Measurement of the inclusive isolated prompt photons cross section in pp collisions at √s = 7 TeV with the ATLAS detector using 4.6 fb-1

Aad, G.; et al., [Unknown]; Aben, R.; Beemster, L.J.; Bentvelsen, S.C.M.; Berge, D.; Berglund, E.; Bobbink, G.J.; Bos, K.; Boterenbrood, H.; Castelli, A.; Colijn, A.P.; de Jong, P.J.; de Nooij, L.; Deluca, C.; Deviveiros, P.O.; Dhaliwal, S.; Ferrari, P.; Gadatsch, S.; Geerts, D.A.A.; Hartjes, F.G.; Hessey, N.P.; Hod, N.; Igonkina, O.; Kayl, M.S.; Kluit, P.M.; Koffeman, E.N.; Lee, H.C.; Lenz, T.; Linde, F.L.; Mahlstedt, J.; Mechnich, J.; Mussche, I.; Ottersbach, J.P.; Pani, P.; Ruckstuhl, N.M.; Salek, D.; Ta, D.; Tsiakiris, M.; Valencic, N.; van der Deijl, P.C.; van der Geer, R.; van der Graaf, H.; van der Leeuw, R.H.L.; van Vulpen, I.B.; Verkerke, W.; Vermeulen, J.C.; Vranjes Milosavljevic, M.; Vreeswijk, M.

Published in:
Physical Review D. Particles, Fields, Gravitation, and Cosmology

DOI:
10.1103/PhysRevD.89.052004

PHYSICAL REVIEW D **89**, 052004 (2014)

Measurement of the inclusive isolated prompt photons cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector using 4.6 fb^{-1}

G. Aad *et al.**
(ATLAS Collaboration)
(Received 7 November 2013; published 24 March 2014)

A measurement of the cross section for the production of isolated prompt photons in pp collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV is presented. The results are based on an integrated luminosity of 4.6 fb^{-1} collected with the ATLAS detector at the LHC. The cross section is measured as a function of photon pseudorapidity η^γ and transverse energy E_T^γ in the kinematic range $100 \leq E_T^\gamma < 1000$ GeV and in the regions $|\eta^\gamma| < 1.37$ and $1.52 \leq |\eta^\gamma| < 2.37$. The results are compared to leading-order parton-shower Monte Carlo models and next-to-leading-order perturbative QCD calculations. Next-to-leading-order perturbative QCD calculations agree well with the measured cross sections as a function of E_T^γ and η^γ.

DOI: 10.1103/PhysRevD.89.052004 PACS numbers: 13.85.Qk, 12.38.Qk

I. INTRODUCTION

Prompt photon production at hadron colliders allows tests of perturbative QCD predictions [1]. The measurement is sensitive to the gluon content of the proton through the $qg \to q\gamma$ process, which dominates the prompt photon production cross section at the LHC, and can be used to constrain parton distribution functions (PDFs) [2–7]. The study of prompt photons is also important for a better understanding of other prompt photon QCD processes (such as quark-antiquark annihilation, $q\bar{q} \to \gamma + g$ and fragmentation). In addition, prompt photon production is a major background for a number of Standard Model processes (such as $H \to \gamma\gamma$) and signatures of physics beyond the Standard Model.

Recent measurements of the production cross section of isolated prompt photons have been performed by ATLAS [8,9] and CMS [10,11] using pp collision data at $\sqrt{s} = 7$ TeV at the LHC. Earlier measurements were made by CDF and D0 using $p\bar{p}$ collisions collected at $\sqrt{s} = 1.8$ TeV and $\sqrt{s} = 1.96$ TeV at the Tevatron collider [12–15]. Also, similar measurements were made at the $Sp\bar{p}S$ collider [16,17].

In this paper, the production cross section of isolated prompt photons is measured in the transverse energy (E_T^γ) range between 100 GeV and 1 TeV, extending the result of the previous ATLAS measurement, which covered the range between 45 and 400 GeV [9]. The differential cross section as a function of E_T^γ is measured in the pseudorapidity [18] range $|\eta^\gamma| < 1.37$ (the barrel region) and $1.52 \leq |\eta^\gamma| < 2.37$ (the end-cap region). Photon reconstruction in these pseudorapidity regions has a high efficiency and a low background rate. The differential cross section is also studied as a function of η^γ for $E_T^\gamma > 100$ GeV. The data sample corresponds to an integrated luminosity of 4.64 ± 0.08 fb^{-1} [19]; thus this analysis uses a data set more than 2 orders of magnitude larger than that used in the previous measurement [9].

In the following, all photons produced in pp collisions and that are not secondaries to hadron decays are considered as "prompt." They include "direct" photons, which originate from the hard processes calculable in perturbative QCD, and "fragmentation" photons, which are the result of the fragmentation of a colored high-p_T parton [6,20]. Photons are considered "isolated" if the transverse energy (E_T^{iso}) within a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ centered around the photon in the pseudorapidity and azimuthal angle (ϕ) is smaller than 7 GeV. In next-to-leading-order (NLO) parton-level theoretical calculations, E_T^{iso} is calculated from all partons within the cone, while in the leading-order (LO) parton-shower Monte Carlo (MC) simulations, E_T^{iso} is calculated from all the generated particles (except muons and neutrinos) inside the cone. Experimentally, E_T^{iso} is calculated from the energy deposited in the calorimeters in a $\Delta R = 0.4$ cone around the photon candidate, corrected for effects associated with the energy of the photon candidate itself, the underlying event, and the additional pp interactions in the same bunch crossing (pileup) [21]. The main background for the prompt photons consists of photons from decays of light neutral mesons such as the π^0 or η.

II. THE ATLAS DETECTOR

ATLAS [22] is a multipurpose detector with a forward-backward symmetric cylindrical geometry and nearly 4π coverage in solid angle. The most relevant subdetectors for the present analysis are the inner tracking detector (ID) and the calorimeters.

* Full author list given at the end of the article.

The ID consists of a silicon pixel detector and a silicon microstrip detector covering the pseudorapidity range $|\eta| < 2.5$, and a straw-tube transition radiation tracker covering $|\eta| < 2.0$. It is immersed in a 2 T magnetic field provided by a superconducting solenoid. The ID allows efficient reconstruction of converted photons if the conversion occurs at a radius of less than 0.80 m.

The electromagnetic calorimeter (ECAL) is a lead/liquid-argon (LAr) sampling calorimeter providing coverage for $|\eta| < 3.2$. It consists of a barrel section ($|\eta| < 1.475$) and two end caps ($1.375 < |\eta| < 3.2$). The central region ($|\eta| < 2.5$) is segmented into three layers in shower depth. The first (inner) layer, covering $|\eta| < 1.4$ in the barrel and $1.5 < |\eta| < 2.4$ in the end caps, has a high η granularity (between 0.003 and 0.006 depending on η), which can be used to provide event-by-event discrimination between single-photon showers and two overlapping showers such as those produced by π^0 decay. The second layer, which collects most of the energy deposited in the calorimeter by the photon shower, has a cell granularity of 0.025×0.025 in $\eta \times \phi$. The third layer is used to correct high-energy showers for leakage. In front of the ECAL a thin presampler layer, covering the pseudorapidity interval $|\eta| < 1.8$, is used to correct for energy loss before the ECAL.

The hadronic calorimeter (HCAL), surrounding the ECAL, consists of an iron/scintillator-tile calorimeter in the range $|\eta| < 1.7$, and two copper/LAr calorimeters spanning $1.5 < |\eta| < 3.2$. The ECAL and HCAL acceptance is extended by two copper/LAr forward calorimeters (using copper and tungsten as absorbers) up to $|\eta| = 4.9$.

A three-level trigger system is used to select events containing photon candidates. The first level (level 1) is implemented in hardware and is based on towers with a coarser granularity (0.1×0.1 in $\eta \times \phi$) than that of the ECAL. They are used to search for electromagnetic deposits in $\eta \times \phi$ regions of 2×1 and 1×2 towers, within a fixed window of size 2×2 and with an E_{T}^{γ} above a programmable threshold. The algorithms of the second and third level triggers (collectively referred to as the *high-level trigger*) are implemented in software. The high-level trigger exploits the full granularity and precision of the calorimeter to refine the level-1 trigger selection, based on improved energy resolution and detailed information on energy deposition in the calorimeter cells.

III. DATA AND SIMULATED SAMPLES

A. Collision data selection

The measurement presented here is based on proton-proton collision data collected at a center-of-mass energy of $\sqrt{s} = 7$ TeV with the ATLAS detector at the LHC in 2011. Only events where both the calorimeter and the ID are fully operational and that have good data quality are used. Events are triggered using a high-level photon trigger, with a nominal E_{T}^{γ} threshold of 80 GeV. The trigger selection criteria for the fraction and profile of the energy measured in the various layers of the calorimeters are looser than the photon identification criteria applied in this analysis and described in Sec. IV C. For 2011, the average number of pp interactions in the same bunch crossing is nine. In order to reduce noncollision backgrounds, events are required to have a reconstructed primary vertex [23] consistent with the average beam-spot position and with at least three associated tracks. The contribution from noncollisional background to the signal photon sample was estimated to be below 0.1% [8] for $E_{\mathrm{T}}^{\gamma} < 100$ GeV. A visual scan of pp collision events for higher transverse momenta of photons did not indicate the presence of noncollisional background at the level which can be important for this measurement.

B. Simulated events

To study the characteristics of signal and background events, MC samples are generated using PYTHIA 6.4 [24], a LO parton-shower MC generator, with the modified LO MRST2007 [4,5,25] PDFs. The event generator parameters are set according to the ATLAS AMBT2 tune [26]. The ATLAS detector response is simulated using the GEANT4 program [27]. In order to have a realistic description of the experimental conditions under which the data are taken, pileup interactions are included in the simulation. These samples are then reconstructed with the same algorithms used for data. More details of the event generation and simulation infrastructure of the ATLAS experiment are provided in Ref. [28].

For the study of systematic uncertainties and for comparisons with the final cross sections, events are generated with the HERWIG 6.5 [29] model using the ATLAS AUET2 tune [30] and the same PDFs as used for the PYTHIA event generation. HERWIG and PYTHIA use different parton-shower and hadronization models.

Signal MC samples include hard-scattering photons from the LO processes $qg \to q\gamma$ and $q\bar{q} \to g\gamma$, and photons from QED radiation from quarks produced in QCD $2 \to 2$ processes.

To study background processes, MC samples enriched in photons from meson decays with an $E_{\mathrm{T}}^{\gamma} > 100$ GeV are used. The samples are generated using all tree-level $2 \to 2$ QCD processes, while events with photons originating from quarks were removed.

IV. PHOTON SELECTION

The reconstruction of photons in the ATLAS detector is described in detail elsewhere [8,31]. The selection of photons is discussed in the following three sections: kinematic preselection, isolation selection, and shape identification.

A. Photon kinematic preselection

As already stated in Sec. III, photon candidates are first required to have passed an 80 GeV trigger. From these, only those with calibrated transverse energies above 100 GeV are retained for the subsequent analysis. The calibration includes an *in situ* technique based on the Z boson mass peak [32]. In order to benefit from the fine segmentation of the first layer of the ECAL for identification of genuine photons, the photon candidates are required to be within the barrel or the end-cap pseudorapidity regions. After the selection, approximately 2.6×10^6 photon candidates remain in the data sample. These candidates include converted photons, i.e. photons that produce electron-positron pairs in the presence of material and are identified by their tracks.

B. Photon isolation selection

Isolation is an important observable for prompt photon studies. The prompt photon signal is expected to be more isolated from hadronic activity than the background. Also, because of the mixture of hard-scattering and fragmentation contributions in the prompt photon signal, it is important to have a well modeled isolation variable that can be linked to the parton-level isolation cut used in NLO QCD computations. A robust isolation prescription helps limit the nonperturbative fragmentation contribution, which is poorly understood in theory, while retaining the signal produced from direct processes.

This study uses the same definition of the cone isolation variable $E_{\mathrm{T}}^{\mathrm{iso}}$ as for the previous ATLAS measurement [9]. It is computed using calorimeter cells from both the ECAL and HCAL, in a cone of radius $\Delta R = 0.4$ around the photon candidate. The contributions from the 5×7 second-layer ECAL cells in the $\eta \times \phi$ space around the photon shower barycenter are not included in the calculation. The expected small value of the leakage from the photon shower into the cone outside this small central region, evaluated as a function of the E_{T}^{γ} in simulated samples of single photons, is then subtracted from the isolation variable. The contribution to the photon isolation energy from the underlying event and pileup is subtracted using the procedure proposed in Refs. [33,34] and implemented as described in Ref. [8]. After these corrections, the transverse isolation energy of simulated prompt photons is independent of E_{T}^{γ}. A residual mild dependence on the amount of in-time pileup (from collisions of protons in the same bunches as the hard pp scattering from which the photon originates) is observed for this isolation variable. This dependence can be traced back to the fact that $E_{\mathrm{T}}^{\mathrm{iso}}$ is calculated from cells without noise suppression whereas the pileup correction is computed from noise-suppressed topological clusters [35]. The pileup dependence of $E_{\mathrm{T}}^{\mathrm{iso}}$ is well modeled in the simulation and found to be robust against systematic uncertainties discussed later.

In the following, all photon candidates having reconstructed isolation energies $E_{\mathrm{T}}^{\mathrm{iso}} \leq 7$ GeV are considered "isolated," while candidates with $E_{\mathrm{T}}^{\mathrm{iso}} > 7$ GeV are considered "nonisolated." These definitions are applied to the data and to the MC calculations at both parton and particle level. An ambient energy algorithm correction, which is used to correct for the activity of the underlying event, is also applied for the particle-level MC isolation. The isolation requirement $E_{\mathrm{T}}^{\mathrm{iso}} \leq 7$ GeV is looser than that used in the previous analysis [9] and is chosen in order to optimize the signal purity and the photon reconstruction efficiency at high E_{T}^{γ}.

C. Photon shower-shape identification

Shape variables computed from the lateral and longitudinal energy profiles of the shower in the ECAL are used to further discriminate the signal from the background. The selection criteria do not depend on the photon candidate's E_{T}^{γ}, but vary as a function of the photon's reconstructed η^{γ} to take into account significant changes in the total thickness of the upstream material and variations in the calorimeter geometry or granularity. Among the shower-shape variables used in the photon selection, a number of variables are computed from the finely segmented first layer of the electromagnetic calorimeter that are fairly uncorrelated with the $E_{\mathrm{T}}^{\mathrm{iso}}$. They are the shower width along η, the asymmetry between the first and second maxima in the energy profile along η and a second significant maximum in the energy deposited in contiguous strips [21]. A background-enhanced sample is provided by requiring the photon candidates to fail the "tight" identification criteria for one of these variables and to satisfy all the other criteria. From now on, such photons are called "nontight" candidates, while the photon candidates satisfying the tight selection are called tight candidates. The cross section measurement is based on the tight photons. The tight selection criteria are optimized independently for unconverted and converted photons to account for the different developments of the showers.

After the photon identification requirements, 1.3×10^6 (6.2×10^5) tight photon candidates remain in the barrel (end-cap) η^{γ} region. The fraction of converted photons is 32% (45%) in the barrel (end-cap) η^{γ} region. There are 19 photon candidates with E_{T}^{γ} between 800 GeV and 1 TeV. The total number of events with more than one good photon candidate contributing to this measurement is 1240.

V. BACKGROUND ESTIMATION AND SIGNAL EXTRACTION

The main background for prompt photons is due to hadronic jets containing π^0 mesons that carry most of the jet energy and that decay to photon pairs. Such background photons are expected to be less isolated than prompt photons due to activity from the other particles in the jet. The isolation energy $E_{\mathrm{T}}^{\mathrm{iso}}$ therefore provides a discrimination between prompt photons and photons from jets and meson decays. To avoid relying on the simulation to accurately model the energy flow inside jets and the fragmentation to π^0 mesons, a data-driven technique is used for the reconstruction of the background isolation distribution.

The residual background contamination in the tight candidates event sample is estimated using the "two-dimensional side bands" method [8]. It is based on the definition of a "tight-isolated" signal region A and three background control regions B, C, D: "tight-nonisolated," "nontight-isolated" and "nontight-nonisolated," respectively. The basic method assumes that the control regions have negligible signal contamination and that the isolation energy distribution of background events is the same for tight and nontight candidates. In that case the signal yield in region A, N_S^A, can be obtained from the number N^k of events observed in data, in each of the four regions $k = A$, B, C, and D, as

$$N_S^A = N^A - N^C \frac{N^B}{N^D}. \qquad (1)$$

The method can easily be extended to account for deviations from the previous hypotheses, requiring only a limited knowledge of the signal and background properties. In that case, the equation to solve is

$$N_S^A = N^A - R_{\mathrm{BKG}} \frac{(N^B - c_B N_S^A)(N^C - c_C N_S^A)}{(N^D - c_D N_S^A)}, \qquad (2)$$

where $c_k = N_S^k / N_S^A$ are the fractions of signal events expected in each of the three control regions, relative to the signal region A, and $R_{\mathrm{BKG}} = N_{\mathrm{BKG}}^A N_{\mathrm{BKG}}^D / N_{\mathrm{BKG}}^B N_{\mathrm{BKG}}^C$ characterizes the correlation between the isolation and identification variables in background events ($R_{\mathrm{BKG}} = 1$ when the correlations are negligible).

Figure 1(a) shows the distribution of $E_{\mathrm{T}}^{\mathrm{iso}}$ for tight and nontight candidates. The latter is normalized to the former in the background-dominated region $E_{\mathrm{T}}^{\mathrm{iso}} > 15$ GeV. The excess of tight candidates over normalized nontight candidates in the region $E_{\mathrm{T}}^{\mathrm{iso}} < 15$ GeV shows a clear peak for signal prompt photons. Figures 1(b) and 1(c) show the isolation profile of photon candidates after subtracting the distribution of nontight candidates [with the same normalization as applied in Fig. 1(a)], for different ranges of the photon candidate transverse energy in the two different η^γ regions. The distributions of these signal-enriched samples are largely independent of the E_{T}^{γ} range, according to the simulation.

In the following, Eq. (2) is used to estimate the prompt photon yield in the selected sample, with R_{BKG} fixed to one as observed (within uncertainties) in simulated background events. Results obtained neglecting signal leakage in the control regions, as in Eq. (1), or with $R_{\mathrm{BKG}} \neq 1$ are used to evaluate systematic uncertainties. In the end-cap region there are too few events in the 500–600 GeV bin; therefore, the signal purity from the preceding bin is used instead.

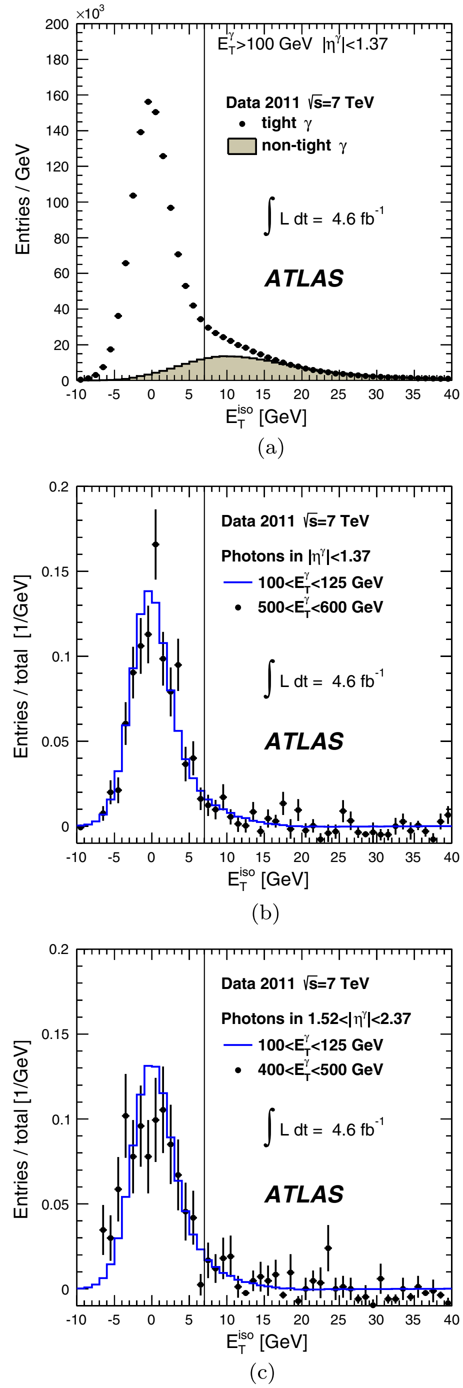

FIG. 1 (color online). (a) Distributions of tight photon transverse energy $E_{\mathrm{T}}^{\mathrm{iso}}$ (dots) and nontight (shaded gray region) photon candidates in data, for photon transverse energy $E_{\mathrm{T}}^{\gamma} >$ 100 GeV in the central η^γ region. The latter is normalized to the former for $E_{\mathrm{T}}^{\mathrm{iso}} > 15$ GeV. Distributions of tight $E_{\mathrm{T}}^{\mathrm{iso}}$ photons in the barrel (b) and end-cap (c) regions after subtracting the normalized nontight distribution. For both (b) and (c) a comparison of two representative E_{T}^{γ} regions with different η^γ is shown. The vertical lines show the requirement of $E_{\mathrm{T}}^{\mathrm{iso}} \leq$ 7 GeV used to define the final cross sections. These distributions are normalized to one.

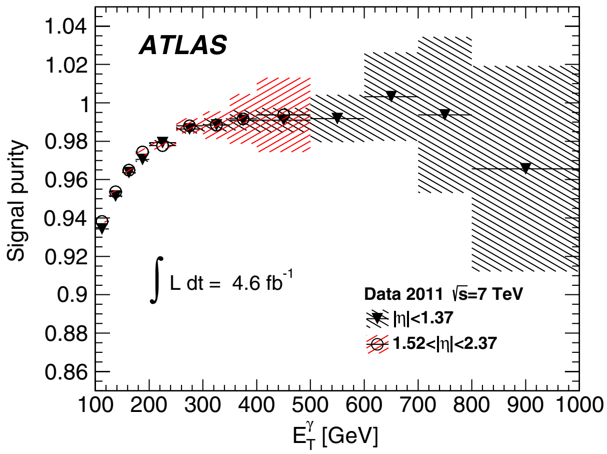

FIG. 2 (color online). The signal purity for the barrel and end-cap η^γ regions as a function of photon transverse energy E_T^γ estimated from the data using the two-dimensional side band approach shown in Eq. (2). The shaded bands indicate statistical uncertainties.

The largest contribution to the impurity arises from background photons that come from the meson decays. Figure 2 shows the signal purity for prompt photons in region A as a function of E_T^γ for the barrel and end-cap regions. The signal purity is estimated from the data using the two-dimensional side band approach shown in Eq. (2). The shaded bands indicate statistical uncertainties. The measured signal purity is larger than 93% and increases with E_T^γ. The purity has also been determined using Eq. (1) and the result agrees with the default method to within 3% and has a similar E_T^γ dependence.

VI. RESIDUAL BACKGROUND

A possible residual background could arise from electrons that fake photons: primarily high-p_T isolated electrons from W or Z boson decays that tend to be misidentified as converted photons. The corresponding misidentification probability is measured by studying the invariant mass spectrum of $e^\pm\gamma$ combinations in the Z boson mass range. It was found that the background from prompt electrons is ≈0.5% for $E_T^\gamma < 400$ GeV [9]. This contribution is subtracted from the signal photon sample. A similar study indicates that the rate of misidentified photons with E_T^γ above 400 GeV originating from electrons is well below 0.5% and the signal yield is not further corrected.

VII. CROSS SECTION MEASUREMENT

The differential cross section for the production of isolated prompt photons in a given phase-space bin i is $N_i/(C_i(\gamma)\cdot\Delta_i\cdot\int\mathcal{L}dt)$, where N_i is the number of photons in a bin i after the background subtraction, $C_i(\gamma)$ is a correction factor, Δ_i is the width of bin i and $\int\mathcal{L}dt$ is the integrated luminosity. The correction factor $C_i(\gamma)$ is evaluated from the bin-by-bin ratio of the number of reconstructed prompt photons to the number of particle-level prompt photons in the signal simulation. The isolation requirement $E_T^{\rm iso} \leq 7$ GeV was applied for both reconstructed and particle-level photons. The photon reconstruction efficiency in the MC simulation was tuned using data-driven techniques [36]. The correction factor $C_i(\gamma)$ accounts for acceptance and smearing effects, photon reconstruction efficiency and selection efficiency, as well as the event selection efficiency. The various components of the correction are discussed.

(i) Acceptance and smearing correction is defined as the efficiency for a particle-level photon, in the acceptance of the differential cross section, to be reconstructed as a photon passing all the selection criteria outlined in Sec. VI. The largest contributing factor to this efficiency is the selection requirement $E_T^{\rm iso} \leq 7$ GeV. The shower-shape corrections for the MC simulation are determined from the comparison of data with the simulation in the control samples of photons selected in the same kinematic regions as used in this measurement. The average value of this efficiency in the barrel region was found to be 95%, while it is 87% in the end-cap region.

(ii) Identification efficiency is defined as the efficiency for reconstructed prompt photons after the isolation requirement to pass the tight photon identification criteria described in Sec. V. This efficiency was estimated by using simulated signal events after correcting the simulated shower shapes in the calorimeter to match those observed in data [8]. This efficiency in the barrel and end-cap region was found to be above 93%.

(iii) Trigger efficiency is defined as the efficiency for an event to be accepted by a photon trigger with an energy threshold of 80 GeV. The trigger efficiency is determined using a data-driven technique based on high-level triggers with low-E_T^γ threshold, and it is estimated to be close to 100% for $E_T^\gamma >$ 100 GeV [37].

In addition to the efficiencies quoted above, the correction factor also accounts for the bin-by-bin migration due to the finite bin sizes. The MC simulations indicate that the rms of the E_T^γ resolution for photons in the range $100 < E_T^\gamma < 600$ GeV is close to 3% in the central region and 4% in the end-cap region. The widths of the bins for the differential cross section measurement are chosen to be substantially larger than the resolution in order to minimize migration between neighboring bins.

The average value of the $C_i(\gamma)$ estimated using PYTHIA is about 94% in the barrel region and 86% in the end-cap region. It increases with E_T^γ by approximately 4% in the range of E_T^γ explored in this measurement. This correction factor is shown in Fig. 3, where the shaded bands represent the systematic and statistical uncertainties discussed in Sec. VIII.

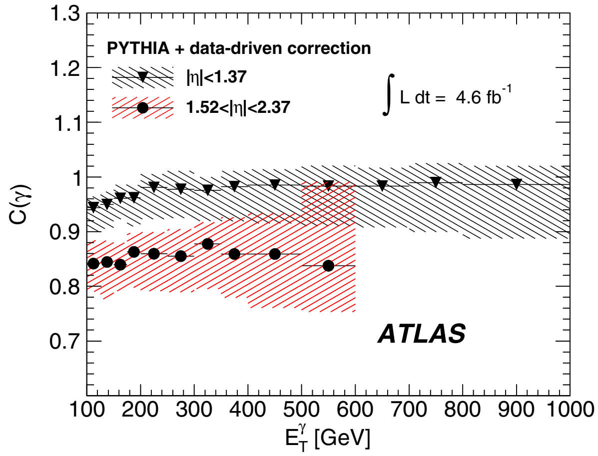

FIG. 3 (color online). The correction factor $C_i(\gamma)$ as a function of photon transverse energy E_T^γ for the barrel and end-cap regions. The correction factor is evaluated from the bin-by-bin ratio, using the PYTHIA simulation, of reconstructed prompt photons to particle-level prompt photons in the signal simulation. The shaded bands indicate statistical and systematic uncertainties discussed in Sec. VIII.

VIII. SYSTEMATIC UNCERTAINTIES

The systematic uncertainties on the measured differential cross sections are determined by repeating the analysis with some of the selection or analysis procedures changed. The systematic variations affect the $C_i(\gamma)$ correction factors and signal purity, thus an overall change in the cross section. The largest uncertainties are described below.

(i) A shift between the true and reconstructed isolation energy in the MC simulation was found to be less than 700 MeV for $E_T^{\text{iso}} \simeq 7$ GeV. This difference does not depend on the E_T^γ, and is similar in PYTHIA and HERWIG signal and background MC samples. This difference is also similar to that observed between the data and MC simulation. In the previous publication [9], this difference estimated using electrons was found to be 500 MeV.
MC samples with an additional amount of material in front of the calorimeter show a small effect on the isolation distribution. For this MC, the shift between the true and reconstructed levels for the isolation is smaller than 700 MeV. The correction factors $C_i(\gamma)$ calculated using such MC showed a negligible effect on the cross section.
The systematic uncertainty on the cross section due to the isolation cut was evaluated by changing the requirement by ±700 MeV in the simulation and recalculating the correction factors $C_i(\gamma)$. This systematic variation leads to a typical uncertainty of less than 1% for all E_T^γ explored in this measurement.

(ii) The uncertainty on the cross section due to insufficient knowledge of the photon identification efficiency is estimated by using different techniques for the photon identification as described in Ref. [36]. Such uncertainties also account for the amount of material upstream of the calorimeter. An effect of 2% or less is observed for all E_T^γ explored in this measurement.

(iii) The uncertainty due to the photon energy measurement is calculated by varying the photon energy scale within the expected uncertainty in the MC simulation. This uncertainty mostly affects the $C_i(\gamma)$ correction factor. The effect of such a variation leads to an uncertainty between 2% at low E_T^γ and 6% at large E_T^γ.

(iv) The systematic uncertainty on the cross section due to the photon energy resolution is calculated by smearing the central value and then varying the reconstructed energy in the MC simulations as described in Ref. [8] and then recomputing the $C_i(\gamma)$ factor. This uncertainty is typically 2% for all E_T^γ explored in this measurement.

(v) The stability on the $C_i(\gamma)$ factors due to the choice of MC generator is computed by considering HERWIG for the bin-by-bin correction instead of PYTHIA. The stability affects photon reconstruction and identification. It also probes the uncertainty on the signal reconstruction due to an alternative fragmentation mechanism. The uncertainty on the cross section due to this contribution ranges from 2% at low E_T^γ to 4% at $E_T^\gamma > 800$ GeV.

(vi) The uncertainty on the background subtraction is estimated using alternative background subtraction techniques discussed in Sec. V. Equation (2) is modified to either neglect signal leakage or include a modified R_{BKG}. The background is subtracted by either neglecting correlations between the signal and background regions or using the central values of the correlations estimated from simulated background events. The uncertainty on the cross section due to the background subtraction technique varies between 2% and 3% for all E_T^γ explored in this measurement.

(vii) The uncertainty arising from the definition of the background control regions is estimated by repeating the measurement using an alternative definition of the nonisolated region. The isolation requirement was increased from 7 to 10 GeV. Such a redefinition affects both the signal purity and the $C_i(\gamma)$ factors. An effect of 1% or less for all E_T^γ explored in this measurement is observed, which is compatible with the statistical uncertainty.

(viii) The systematic uncertainty on the fraction of photons from fragmentation was estimated using the PYTHIA signal sample with 50% fewer photons from fragmentation. Alternatively, weights of events with photons from fragmentation were scaled by a factor of two. The effect from such changes on the final cross sections is compatible with the statistical uncertainty ($< 0.5\%$).

(ix) The relative systematic uncertainty on the cross section due to the uncertainty of the luminosity measurement is 1.8% [19]. It is fully correlated among all E_T and η bins of the differential cross sections.

The sources of systematic uncertainty are assumed uncorrelated and thus the total systematic uncertainty is estimated by summing in quadrature all the contributions. The final systematic uncertainty on the differential and total cross sections in the barrel (end-cap) region is below 6% (7%). This uncertainty is smaller than that for the 2010 cross section [9] due to improvements in evaluation of the photon energy scale uncertainty, the photon identification efficiency, and due to a reduction of the luminosity uncertainty.

As a cross-check, the measurement is repeated using an alternative definition of the photon transverse isolation energy, based on three-dimensional topological clusters [35] of energy deposits in the calorimeters, affecting mostly the photon reconstruction efficiency. The same calorimeter cells are used for both the calculation of the photon isolation and for the subtraction of the contribution from the underlying event and pileup, thus providing a quantity that is less dependent on the amount of pileup. A difference smaller than 3% is found between the alternative and the nominal results. In addition, in order to verify the reliability of the pileup removal technique, differential cross sections were calculated separately for low-pileup and high-pileup runs. A good agreement between these two cross sections was found.

IX. THEORETICAL PREDICTIONS

The expected prompt photon production cross section was estimated using the JETPHOX 1.3 Monte Carlo program [6,20], which implements a full NLO QCD calculation of both the direct and fragmentation contributions to the total cross section. The parton-level isolation, defined as the total E_T from the partons produced with the photon inside a cone of radius $\Delta R = 0.4$ in $\eta \times \phi$ around the photon direction, is required to be smaller than 7 GeV. The fragmentation contribution in the JETPHOX calculation decreases with increasing E_T^γ and becomes negligible for $E_T^\gamma > 500$ GeV. Further details of the JETPHOX calculation can be found in Ref. [38]. The calculation uses the NLO photon fragmentation function of BFG set II [39]. The CT10 [40] and MSTW2008NLO [41] PDFs for the proton are provided by the LHAPDF package [42]. The nominal renormalization (μ_R), factorization (μ_F) and fragmentation (μ_f) scales were set to the photon transverse energy ($\mu_R = \mu_F = \mu_f = E_T^\gamma$). Systematic uncertainties on the QCD cross sections are estimated and listed below.

(1) The scale uncertainty is evaluated by varying the three scales following the constraints and are added in quadrature [38]:
   (i) $\mu_R = \mu_F = \mu_f \in [E_T^\gamma/2, 2E_T^\gamma]$;
   (ii) $\mu_R \in [E_T^\gamma/2, 2E_T^\gamma]$, $\mu_F = \mu_f = E_T^\gamma$;
   (iii) $\mu_F \in [E_T^\gamma/2, 2E_T^\gamma]$, $\mu_R = \mu_f = E_T^\gamma$;
   (iv) $\mu_f \in [E_T^\gamma/2, 2E_T^\gamma]$, $\mu_R = \mu_F = E_T^\gamma$.

This leads to a change of between 12% and 20% in the predicted cross section.

(2) The uncertainty on the differential cross section due to insufficient knowledge of the PDFs was obtained by repeating the JETPHOX calculation for 52 eigenvector sets of the CT10 PDF and applying a scaling factor in order to obtain the uncertainty for the 68% confidence-level (C.L.) interval [38]. The corresponding uncertainty on the cross section increases with E_T^γ and varies between a 5% at $E_T^\gamma \simeq 100$ GeV and 15% at $E_T^\gamma \simeq 900$ GeV.

(3) The effect of the uncertainty on the value of the strong coupling constant, α_s, is evaluated following the recommendation in Ref. [40]. This was done using different CT10 PDF sets with α_s values varied by ± 0.002 around the central value $\alpha_s = 0.118$. Then, a scaling factor was applied in order to obtain the uncertainty for the 68% C.L. interval. The average α_s uncertainty on the cross section is 4.5%, with a small dependence on E_T^γ.

In the following, the total uncertainty includes the three sources above added in quadrature. In addition the uncertainty arising from the scale variations, which is the largest of these three contributions, will be shown separately.

In order to perform a proper comparison with the JETPHOX calculation, the effects of hadronization, pileup and the underlying event have to be understood because the isolation energy is directly sensitive to these effects. The ambient-energy-density correction used for the $E_T^{\rm iso}$ reconstruction reduces the effects from the underlying event and pileup, but this effect may not be completely taken into account. Using PYTHIA and HERWIG with different tunes, the combined effect from hadronization and the underlying event is estimated to be about $\pm 1\%$. This correction is small compared to the full uncertainty from other sources and is not included in the total theoretical uncertainty.

The measured cross sections are also compared to those from the LO parton-shower generators, PYTHIA and HERWIG. These models are described in Sec. III B. Both simulate the fragmentation components through the emission of photons in the parton shower.

X. RESULTS

The differential cross section for the production of isolated prompt photons is obtained from the number of signal events as discussed in Sec. VII. The measured E_T^γ-differential cross sections together with the theoretical predictions are shown in Figs. 4 and 5 for the barrel and end-cap η^γ regions, respectively. Tables I and II list the values of the differential cross sections shown in these figures. Figure 6 and Table III show the cross section as a function of η^γ for $E_T^\gamma > 100$ GeV. The full error bars on the data points represent the combination of statistical and systematic uncertainties. The inner error bars show statistical uncertainties. The shaded bands on the NLO predictions show the theoretical uncertainties as discussed in Sec. IX. The theoretical uncertainties due to the choice of factorization and renormalization scales as well as the fragmentation scale are shown as an inner band.

The NLO calculations agree with the data up to the highest E_T^γ considered. The data are somewhat higher than the central NLO calculation for low E_T^γ but agree within the theoretical uncertainty of the NLO calculation. This trend is also visible throughout η^γ as it is dominated by the low E_T^γ range of the measurement. At low E_T^γ, the observed difference between the NLO predictions based CT10 PDF and MSTW2008NLO PDF are larger than the PDF uncertainty estimated using CT10. The difference between CT10 and MSTW2008NLO predictions is smaller than the CT10 PDF uncertainty for $E_T^\gamma > 600$ GeV.

The predictions of the LO parton-shower MC generators, PYTHIA and HERWIG, are also shown in Figs. 4–6. The PYTHIA model describes the data fairly well, while HERWIG falls below the data by 10%–20%. The shapes of the cross sections are well described by both models.

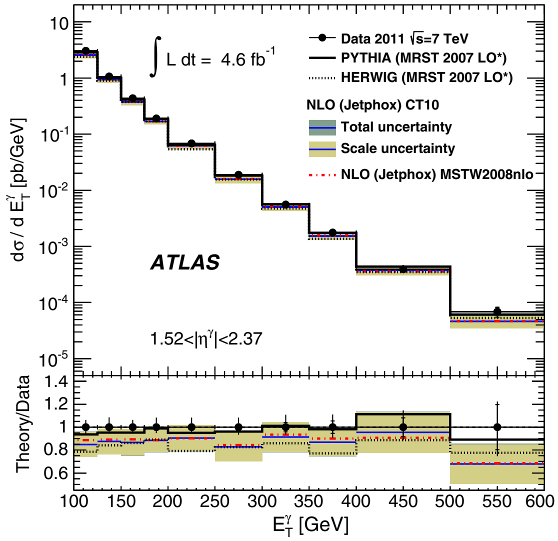

FIG. 5 (color online). Measured (dots with error bars) and expected inclusive prompt photon cross section in the end-cap region. The inner error bars on the data points show statistical uncertainties, while the full error bars show statistical and systematic uncertainties added in quadrature. The NLO theory prediction is shown with the shaded bands that indicate the scale uncertainty (the inner yellow band) and the total uncertainty (the outer green band), which also includes the PDF and α_s uncertainties. The LO parton-shower MC generators are shown as lines.

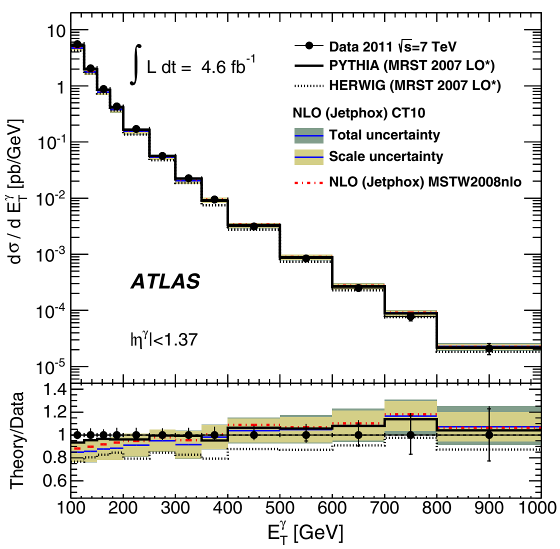

FIG. 4 (color online). Measured (dots with error bars) and expected inclusive prompt photon cross section as a function of the photon transverse energy E_T^γ in the barrel η^γ region. The inner error bars on the data points show statistical uncertainties, while the full error bars show statistical and systematic uncertainties added in quadrature. The NLO theory prediction is shown with the shaded bands that indicate the scale uncertainty (the inner yellow band) and the total uncertainty (the outer green band), which also includes the PDF and α_s uncertainties. The LO parton-shower MC generators are shown as lines. The bottom panel shows the corresponding theory/data ratio, in which the data points are centered at one.

PYTHIA describes the shape of the E_T^γ cross section better than the JETPHOX NLO calculation.

The data are also compared to MC predictions that include only direct photons from $qg \to q\gamma$ and $q\bar{q} \to g\gamma$ processes calculated at LO QCD. Figure 7 shows that these MC generators predict a cross section at low E_T^γ that is 20%

TABLE I. Measured inclusive prompt photon production cross section in the pseudorapidity range $|\eta^\gamma| < 1.37$ as a function of E_T^γ with statistical and systematic uncertainties.

E_T^γ bin [GeV]	$d\sigma/dE_T^\gamma \pm$ (stat) $\pm$ (syst) [pb/GeV]
100–125	$5.55 \pm 0.02^{+0.30}_{-0.21}$
125–150	$2.06 \pm 0.01^{+0.12}_{-0.07}$
150–175	$8.82 \pm 0.07^{+0.44}_{-0.32} \times 10^{-01}$
175–200	$4.28 \pm 0.05^{+0.27}_{-0.14} \times 10^{-01}$
200–250	$1.71 \pm 0.01^{+0.11}_{-0.06} \times 10^{-01}$
250–300	$5.65 \pm 0.07^{+0.32}_{-0.23} \times 10^{-02}$
300–350	$2.25 \pm 0.04^{+0.13}_{-0.08} \times 10^{-02}$
350–400	$9.43 \pm 0.21^{+0.64}_{-0.34} \times 10^{-03}$
400–500	$3.12 \pm 0.08^{+0.24}_{-0.12} \times 10^{-03}$
500–600	$8.44 \pm 0.44^{+0.69}_{-0.38} \times 10^{-04}$
600–700	$2.50 \pm 0.24^{+0.22}_{-0.11} \times 10^{-04}$
700–800	$7.77 \pm 1.30^{+0.73}_{-0.41} \times 10^{-05}$
800–1000	$2.11 \pm 0.48^{+0.22}_{-0.10} \times 10^{-05}$

TABLE II. Measured inclusive prompt photon production cross section in the pseudorapidity range $1.52 \leq |\eta^\gamma| < 2.37$ as a function of E_T^γ with statistical and systematic uncertainties.

E_T^γ bin [GeV]	$d\sigma/dE_T^\gamma \pm$ (stat) $\pm$ (syst) [pb/GeV]
100–125	$3.03 \pm 0.01^{+0.19}_{-0.19}$
125–150	$1.06 \pm 0.01^{+0.09}_{-0.06}$
150–175	$4.34 \pm 0.05^{+0.27}_{-0.24} \times 10^{-01}$
175–200	$1.90 \pm 0.03^{+0.15}_{-0.09} \times 10^{-01}$
200–250	$6.84 \pm 0.08^{+0.57}_{-0.36} \times 10^{-02}$
250–300	$1.89 \pm 0.04^{+0.15}_{-0.12} \times 10^{-02}$
300–350	$5.52 \pm 0.22^{+0.55}_{-0.29} \times 10^{-03}$
350–400	$1.76 \pm 0.10^{+0.17}_{-0.13} \times 10^{-03}$
400–500	$3.93 \pm 0.32^{+0.49}_{-0.33} \times 10^{-04}$
500–600	$6.83 \pm 1.35^{+0.72}_{-1.10} \times 10^{-05}$

TABLE III. Measured inclusive prompt photon production cross section for $E_T^\gamma > 100$ GeV as a function of $|\eta^\gamma|$ with statistical and systematic uncertainties.

$|\eta^\gamma|$ bin	$d\sigma/d|\eta^\gamma| \pm$ (stat) $\pm$ (syst) [pb]
0.0–0.2	$1.72 \pm 0.01^{+0.08}_{-0.08} \times 10^{+02}$
0.2–0.4	$1.71 \pm 0.01^{+0.08}_{-0.08} \times 10^{+02}$
0.4–0.6	$1.75 \pm 0.01^{+0.09}_{-0.07} \times 10^{+02}$
0.6–0.8	$1.77 \pm 0.01^{+0.10}_{-0.06} \times 10^{+02}$
0.8–1.0	$1.73 \pm 0.01^{+0.09}_{-0.07} \times 10^{+02}$
1.0–1.2	$1.75 \pm 0.01^{+0.11}_{-0.06} \times 10^{+02}$
1.2–1.37	$1.76 \pm 0.01^{+0.13}_{-0.06} \times 10^{+02}$
1.52–1.8	$1.68 \pm 0.01^{+0.12}_{-0.11} \times 10^{+02}$
1.8–2.0	$1.46 \pm 0.01^{+0.10}_{-0.08} \times 10^{+02}$
2.0–2.2	$1.41 \pm 0.01^{+0.09}_{-0.07} \times 10^{+02}$
2.2–2.37	$1.17 \pm 0.01^{+0.07}_{-0.07} \times 10^{+02}$

lower than the data which includes all the higher-order fragmentation processes. This difference is reduced at high E_T^γ, where the contribution from photons originating from fragmentation becomes small. This shows that the higher order fragmentation processes contribute significantly to the shape of the predicted E_T^γ cross section.

The total inclusive cross section of direct photons calculated in the kinematic region $E_T^\gamma > 100$ GeV, $|\eta^\gamma| < 1.37$ and $E_T^{\text{iso}} \leq 7$ GeV is

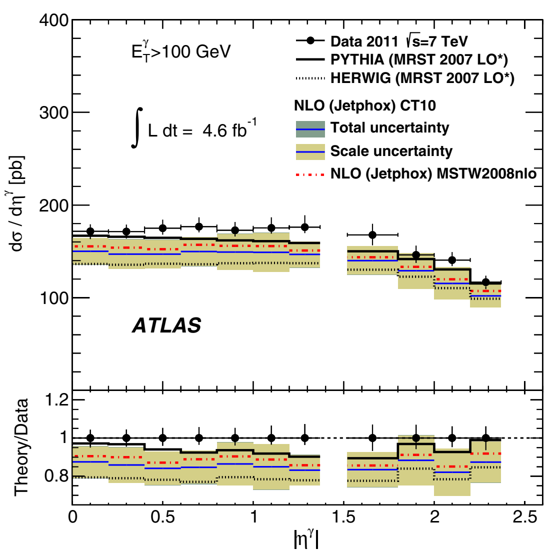

FIG. 6 (color online). Measured and expected inclusive prompt photon cross section as a function of $|\eta^\gamma|$, for photons with transverse energies above 100 GeV excluding $1.37 < |\eta^\gamma| < 1.52$. The data points show full error bars that contain statistical, systematic, and luminosity uncertainties added in quadrature and are negligible. The NLO theory prediction is shown with the shaded bands that indicate the scale uncertainty (the inner yellow band) and the total uncertainty (the outer green band), which also includes the PDF and α_s uncertainties. Predictions from the LO parton-shower MC generators are shown as lines.

$$\sigma(\gamma + X) = 236 \pm 2(\text{stat})^{+13}_{-9}(\text{syst}) \pm 4(\text{lumi}) \text{ pb}.$$

PYTHIA predicts that this cross section is 224 pb while HERWIG predicts 187 pb. The cross section was calculated from the total number of signal events in the given kinematic region. The NLO calculations with the CT10 and MSTW2008NLO PDFs predict 203 ± 25(theory) pb and 212 ± 24(theory) pb, respectively, where the theory uncertainty is symmetrized and includes the scale, PDF and α_s uncertainties.

The total inclusive cross section for direct photons within the kinematic range $E_T^\gamma > 100$ GeV, $1.52 \leq |\eta^\gamma| < 2.37$ and $E_T^{\text{iso}} \leq 7$ GeV is

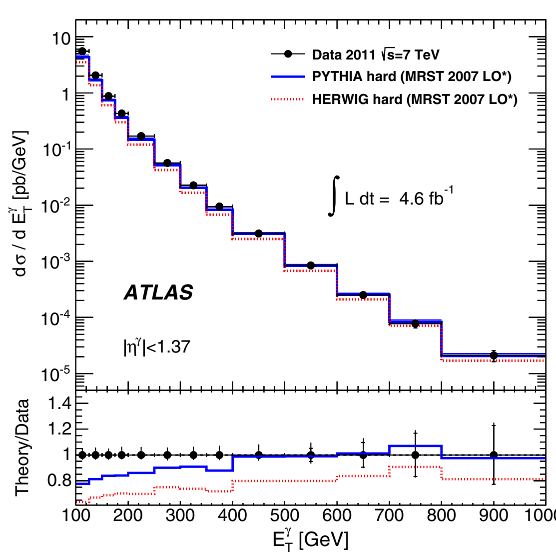

FIG. 7 (color online). The same data as in Fig. 4, but the comparison is made with MC predictions that include only direct photons from the hard processes.

$$\sigma(\gamma + X) = 123 \pm 1(\text{stat})^{+9}_{-7}(\text{syst}) \pm 2(\text{lumi})\ \text{pb},$$

which can be compared to predictions of 118 (PYTHIA) and 99 pb (HERWIG). The NLO calculations based on CT10 and MSTW2008NLO PDFs predict 105 ± 15 (theory) and 109 ± 15(theory) pb, respectively.

XI. CONCLUSION

A measurement of the differential cross sections for the inclusive production of isolated prompt photons in pp collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV was presented using 4.6 fb^{-1} of collision data collected with the ATLAS detector at the LHC. The cross sections were measured as a function of photon transverse energy E_T^γ and pseudorapidity η^γ. The E_T^γ kinematic range of this measurement spans from 100 GeV to 1 TeV, thus significantly extending the measured kinematic range previously published [9] by ATLAS. The measured differential cross section falls by more than 5 orders of magnitude in this kinematic range.

Both PYTHIA and HERWIG describe the shapes of the differential cross sections. The HERWIG generator predicts a smaller cross section compared to PYTHIA and the data. The MC studies presented in this paper indicate that fragmentation contributions are needed for a good description of the data.

The data agree with the NLO predictions based on the CT10 and MSTW2008 PDF up to the highest measured $E_T^\gamma \simeq 1$ TeV. In this kinematic regime, the theoretical uncertainties due to the PDFs of the proton become significant. Thus the presented cross sections have the potential to provide additional constraints on the proton PDFs.

ACKNOWLEDGMENTS

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; EPLANET, ERC and NSRF, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT and NSRF, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; BRF and RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (United Kingdom) and BNL (USA) and in the Tier-2 facilities worldwide.

[1] P. Aurenche, R. Baier, M. Fontannaz, and D. Schiff, Nucl. Phys. **B297**, 661 (1988).
[2] P. Aurenche, R. Baier, M. Fontannaz, J. F. Owens, and M. Werlen, Phys. Rev. D **39**, 3275 (1989).
[3] H. Lai, J. Botts, J. Huston, J. Morfin, J. Owens, J. Qiu, W. Tung, and H. Weerts, Phys. Rev. D **51**, 4763 (1995).
[4] A. D. Martin, R. Roberts, W. J. Stirling, and R. Thorne, Eur. Phys. J. C **4**, 463 (1998).
[5] A. D. Martin, R. Roberts, W. J. Stirling, and R. Thorne, Eur. Phys. J. C **14**, 133 (2000).
[6] P. Aurenche, M. Fontannaz, J.-P. Guillet, E. Pilon, and M. Werlen, Phys. Rev. D **73**, 094007 (2006).
[7] D. d'Enterria and J. Rojo, Nucl. Phys. **B860**, 311 (2012).
[8] ATLAS Collaboration, Phys. Rev. D **83**, 052005 (2011).
[9] ATLAS Collaboration, Phys. Lett. B **706**, 150 (2011).
[10] CMS Collaboration, Phys. Rev. Lett. **106**, 082001 (2011).
[11] CMS Collaboration, Phys. Rev. D **84**, 052011 (2011).
[12] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. D **65**, 112003 (2002).
[13] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. D **70**, 074008 (2004).
[14] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. D **80**, 111106(R) (2009).
[15] V. Abazov *et al.* (D0 Collaboration),Phys. Lett. B **639**, 151 (2006).
[16] C. Albajar *et al.* (UA1 Collaboration), Phys. Lett. B **209**, 385 (1988).
[17] J. Alitti *et al.* (UA2 Collaboration), Phys. Lett. B **263**, 544 (1991).

[18] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector, and the z axis along the beam line. The x axis points from the IP to the center of the LHC ring, and the y axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam line. Observables labeled "transverse" are projected into the x-y plane. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\ \tan(\theta/2)$.
[19] ATLAS Collaboration, Eur. Phys. J. C **73**, 2304 (2013).
[20] S. Catani, M. Fontannaz, J.-P. Guillet, and E. Pilon, J. High Energy Phys. 05 (2002) 028.
[21] ATLAS Collaboration, J. High Energy Phys. 01 (2013) 086.
[22] ATLAS Collaboration, JINST **3**, S08003 (2008).
[23] The leading primary vertex is defined as the vertex with the highest $\Sigma|p_T|^2$ of tracks.
[24] T. Sjöstrand, S. Mrenna, and P. Z. Skands, J. High Energy Phys. 05 (2006) 026.
[25] A. Sherstnev and R. S. Thorne, Eur. Phys. J. C **55**, 553 (2008).
[26] ATLAS Collaboration, Report No. ATL-PHYS-PUB-2011-009, 2011, http://cds.cern.ch/record/1363300/files/ATL-PHYS-PUB-2011-009.pdf.
[27] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[28] ATLAS Collaboration, Eur. Phys. J. C **70**, 823 (2010).
[29] G. Corcella, I. G. Knowles, G. Marchesini, S. Moretti, K. Odagiri, P. Richardson, M. H. Seymour, and B. R. Webber, J. High Energy Phys. 01 (2001) 010.
[30] ATLAS Collaboration, Report No. ATL-PHYS-PUB-2011-008, 2011, http://cds.cern.ch/record/1345343/files/ATL-PHYS-PUB-2011-008.pdf.
[31] ATLAS Collaboration, Report No. CERN-OPEN-2008-020, 2009, http://cds.cern.ch/record/1125884/files/CERN-OPEN-2008-020.pdf.
[32] ATLAS Collaboration, Eur. Phys. J. C **72**, 1909 (2012).
[33] M. Cacciari, G. P. Salam, and G. Soyez, J. High Energy Phys. 04 (2008) 005.
[34] M. Cacciari, G. P. Salam, and S. Sapeta, J. High Energy Phys. 04 (2010) 065.
[35] W. Lampl *et al.*, Report No. ATL-LARG-PUB-2008-002, 2008, http://cds.cern.ch/record/1099735/files/larg-pub-2008-002.pdf.
[36] ATLAS Collaboration, Report No. ATLAS-CONF-2012-123, 2012, http://cds.cern.ch/record/1473426/files/ATLAS-CONF-2012-123.pdf.
[37] ATLAS Collaboration, Report No. ATLAS-CONF-2012-048, 2012, http://cds.cern.ch/record/1450089/files/ATLAS-CONF-2012-048.pdf.
[38] R. Blair *et al.*, Report No. CERN-OPEN-2011-041, 2011, http://cds.cern.ch/record/1379880/files/CERN-OPEN-2011-041.pdf.
[39] L. Bourhis, M. Fontannaz, and J. Guillet, Eur. Phys. J. C **2**, 529 (1998).
[40] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C.-P. Yuan, Phys. Rev. D **82**, 074024 (2010).
[41] A. Martin, W. Stirling, R. Thorne, and G. Watt, Eur. Phys. J. C **63**, 189 (2009).
[42] W. Giele *et al.*, arXiv:hep-ph/0204316.

G. Aad,[48] T. Abajyan,[21] B. Abbott,[112] J. Abdallah,[12] S. Abdel Khalek,[116] A. A. Abdelalim,[49] O. Abdinov,[11] R. Aben,[106] B. Abi,[113] M. Abolins,[89] O. S. AbouZeid,[159] H. Abramowicz,[154] H. Abreu,[137] Y. Abulaiti,[147a,147b] B. S. Acharya,[165a,165b,b] L. Adamczyk,[38a] D. L. Adams,[25] T. N. Addy,[56] J. Adelman,[177] S. Adomeit,[99] T. Adye,[130] S. Aefsky,[23] T. Agatonovic-Jovin,[13b] J. A. Aguilar-Saavedra,[125b,c] M. Agustoni,[17] S. P. Ahlen,[22] F. Ahles,[48] A. Ahmad,[149] M. Ahsan,[41] G. Aielli,[134a,134b] T. P. A. Åkesson,[80] G. Akimoto,[156] A. V. Akimov,[95] M. A. Alam,[76] J. Albert,[170] S. Albrand,[55] M. J. Alconada Verzini,[70] M. Aleksa,[30] I. N. Aleksandrov,[64] F. Alessandria,[90a] C. Alexa,[26a] G. Alexander,[154] G. Alexandre,[49] T. Alexopoulos,[10] M. Alhroob,[165a,165c] M. Aliev,[16] G. Alimonti,[90a] J. Alison,[31] B. M. M. Allbrooke,[18] L. J. Allison,[71] P. P. Allport,[73] S. E. Allwood-Spiers,[53] J. Almond,[83] A. Aloisio,[103a,103b] R. Alon,[173] A. Alonso,[36] F. Alonso,[70] A. Altheimer,[35] B. Alvarez Gonzalez,[89] M. G. Alviggi,[103a,103b] K. Amako,[65] Y. Amaral Coutinho,[24a] C. Amelung,[23] V. V. Ammosov,[129,a] S. P. Amor Dos Santos,[125a] A. Amorim,[125a,d] S. Amoroso,[48] N. Amram,[154] C. Anastopoulos,[30] L. S. Ancu,[17] N. Andari,[30] T. Andeen,[35] C. F. Anders,[58b] G. Anders,[58a] K. J. Anderson,[31] A. Andreazza,[90a,90b] V. Andrei,[58a] X. S. Anduaga,[70] S. Angelidakis,[9] P. Anger,[44] A. Angerami,[35] F. Anghinolfi,[30] A. V. Anisenkov,[108] N. Anjos,[125a] A. Annovi,[47] A. Antonaki,[9] M. Antonelli,[47] A. Antonov,[97] J. Antos,[145b] F. Anulli,[133a] M. Aoki,[102] L. Aperio Bella,[18] R. Apolle,[119,e] G. Arabidze,[89] I. Aracena,[144] Y. Arai,[65] A. T. H. Arce,[45] S. Arfaoui,[149] J-F. Arguin,[94] S. Argyropoulos,[42] E. Arik,[19a,a] M. Arik,[19a] A. J. Armbruster,[88] O. Arnaez,[82] V. Arnal,[81] A. Artamonov,[96] G. Artoni,[23] D. Arutinov,[21] S. Asai,[156] N. Asbah,[94] S. Ask,[28] B. Åsman,[147a,147b] L. Asquith,[6] K. Assamagan,[25] R. Astalos,[145a] A. Astbury,[170] M. Atkinson,[166] B. Auerbach,[6] E. Auge,[116] K. Augsten,[127] M. Aurousseau,[146b] G. Avolio,[30] D. Axen,[169] G. Azuelos,[94,f] Y. Azuma,[156] M. A. Baak,[30] C. Bacci,[135a,135b] A. M. Bach,[15] H. Bachacou,[137] K. Bachas,[155] M. Backes,[49] M. Backhaus,[21] J. Backus Mayes,[144] E. Badescu,[26a] P. Bagiacchi,[133a,133b] P. Bagnaia,[133a,133b] Y. Bai,[33a] D. C. Bailey,[159] T. Bain,[35] J. T. Baines,[130] O. K. Baker,[177] S. Baker,[77] P. Balek,[128] F. Balli,[137] E. Banas,[39] P. Banerjee,[94] Sw. Banerjee,[174] D. Banfi,[30] A. Bangert,[151] V. Bansal,[170] H. S. Bansil,[18] L. Barak,[173] S. P. Baranov,[95] T. Barber,[48] E. L. Barberio,[87] D. Barberis,[50a,50b]

M. Barbero,[84] D. Y. Bardin,[64] T. Barillari,[100] M. Barisonzi,[176] T. Barklow,[144] N. Barlow,[28] B. M. Barnett,[130] R. M. Barnett,[15] A. Baroncelli,[135a] G. Barone,[49] A. J. Barr,[119] F. Barreiro,[81] J. Barreiro Guimarães da Costa,[57] R. Bartoldus,[144] A. E. Barton,[71] V. Bartsch,[150] A. Basye,[166] R. L. Bates,[53] L. Batkova,[145a] J. R. Batley,[28] A. Battaglia,[17] M. Battistin,[30] F. Bauer,[137] H. S. Bawa,[144,g] S. Beale,[99] T. Beau,[79] P. H. Beauchemin,[162] R. Beccherle,[50a] P. Bechtle,[21] H. P. Beck,[17] K. Becker,[176] S. Becker,[99] M. Beckingham,[139] K. H. Becks,[176] A. J. Beddall,[19c] A. Beddall,[19c] S. Bedikian,[177] V. A. Bednyakov,[64] C. P. Bee,[84] L. J. Beemster,[106] T. A. Beermann,[176] M. Begel,[25] C. Belanger-Champagne,[86] P. J. Bell,[49] W. H. Bell,[49] G. Bella,[154] L. Bellagamba,[20a] A. Bellerive,[29] M. Bellomo,[30] A. Belloni,[57] O. L. Beloborodova,[108,h] K. Belotskiy,[97] O. Beltramello,[30] O. Benary,[154] D. Benchekroun,[136a] K. Bendtz,[147a,147b] N. Benekos,[166] Y. Benhammou,[154] E. Benhar Noccioli,[49] J. A. Benitez Garcia,[160b] D. P. Benjamin,[45] J. R. Bensinger,[23] K. Benslama,[131] S. Bentvelsen,[106] D. Berge,[30] E. Bergeaas Kuutmann,[16] N. Berger,[5] F. Berghaus,[170] E. Berglund,[106] J. Beringer,[15] P. Bernat,[77] R. Bernhard,[48] C. Bernius,[78] F. U. Bernlochner,[170] T. Berry,[76] C. Bertella,[84] F. Bertolucci,[123a,123b] M. I. Besana,[90a,90b] G. J. Besjes,[105] N. Besson,[137] S. Bethke,[100] W. Bhimji,[46] R. M. Bianchi,[124] L. Bianchini,[23] M. Bianco,[72a,72b] O. Biebel,[99] S. P. Bieniek,[77] K. Bierwagen,[54] J. Biesiada,[15] M. Biglietti,[135a] H. Bilokon,[47] M. Bindi,[20a,20b] S. Binet,[116] A. Bingul,[19c] C. Bini,[133a,133b] B. Bittner,[100] C. W. Black,[151] J. E. Black,[144] K. M. Black,[22] D. Blackburn,[139] R. E. Blair,[6] J.-B. Blanchard,[137] T. Blazek,[145a] I. Bloch,[42] C. Blocker,[23] J. Blocki,[39] W. Blum,[82] U. Blumenschein,[54] G. J. Bobbink,[106] V. S. Bobrovnikov,[108] S. S. Bocchetta,[80] A. Bocci,[45] C. R. Boddy,[119] M. Boehler,[48] J. Boek,[176] T. T. Boek,[176] N. Boelaert,[36] J. A. Bogaerts,[30] A. G. Bogdanchikov,[108] A. Bogouch,[91,a] C. Bohm,[147a] J. Bohm,[126] V. Boisvert,[76] T. Bold,[38a] V. Boldea,[26a] N. M. Bolnet,[137] M. Bomben,[79] M. Bona,[75] M. Boonekamp,[137] S. Bordoni,[79] C. Borer,[17] A. Borisov,[129] G. Borissov,[71] M. Borri,[83] S. Borroni,[42] J. Bortfeldt,[99] V. Bortolotto,[135a,135b] K. Bos,[106] D. Boscherini,[20a] M. Bosman,[12] H. Boterenbrood,[106] J. Bouchami,[94] J. Boudreau,[124] E. V. Bouhova-Thacker,[71] D. Boumediene,[34] C. Bourdarios,[116] N. Bousson,[84] S. Boutouil,[136d] A. Boveia,[31] J. Boyd,[30] I. R. Boyko,[64] I. Bozovic-Jelisavcic,[13b] J. Bracinik,[18] P. Branchini,[135a] A. Brandt,[8] G. Brandt,[15] O. Brandt,[54] U. Bratzler,[157] B. Brau,[85] J. E. Brau,[115] H. M. Braun,[176,a] S. F. Brazzale,[165a,165c] B. Brelier,[159] J. Bremer,[30] K. Brendlinger,[121] R. Brenner,[167] S. Bressler,[173] T. M. Bristow,[46] D. Britton,[53] F. M. Brochu,[28] I. Brock,[21] R. Brock,[89] F. Broggi,[90a] C. Bromberg,[89] J. Bronner,[100] G. Brooijmans,[35] T. Brooks,[76] W. K. Brooks,[32b] E. Brost,[115] G. Brown,[83] P. A. Bruckman de Renstrom,[39] D. Bruncko,[145b] R. Bruneliere,[48] S. Brunet,[60] A. Bruni,[20a] G. Bruni,[20a] M. Bruschi,[20a] L. Bryngemark,[80] T. Buanes,[14] Q. Buat,[55] F. Bucci,[49] J. Buchanan,[119] P. Buchholz,[142] R. M. Buckingham,[119] A. G. Buckley,[46] S. I. Buda,[26a] I. A. Budagov,[64] B. Budick,[109] L. Bugge,[118] O. Bulekov,[97] A. C. Bundock,[73] M. Bunse,[43] T. Buran,[118,a] H. Burckhart,[30] S. Burdin,[73] T. Burgess,[14] S. Burke,[130] E. Busato,[34] V. Büscher,[82] P. Bussey,[53] C. P. Buszello,[167] B. Butler,[57] J. M. Butler,[22] C. M. Buttar,[53] J. M. Butterworth,[77] W. Buttinger,[28] M. Byszewski,[10] S. Cabrera Urbán,[168] D. Caforio,[20a,20b] O. Cakir,[4a] P. Calafiura,[15] G. Calderini,[79] P. Calfayan,[99] R. Calkins,[107] L. P. Caloba,[24a] R. Caloi,[133a,133b] D. Calvet,[34] S. Calvet,[34] R. Camacho Toro,[49] P. Camarri,[134a,134b] D. Cameron,[118] L. M. Caminada,[15] R. Caminal Armadans,[12] S. Campana,[30] M. Campanelli,[77] V. Canale,[103a,103b] F. Canelli,[31] A. Canepa,[160a] J. Cantero,[81] R. Cantrill,[76] T. Cao,[40] M. D. M. Capeans Garrido,[30] I. Caprini,[26a] M. Caprini,[26a] D. Capriotti,[100] M. Capua,[37a,37b] R. Caputo,[82] R. Cardarelli,[134a] T. Carli,[30] G. Carlino,[103a] L. Carminati,[90a,90b] S. Caron,[105] E. Carquin,[32b] G. D. Carrillo-Montoya,[146c] A. A. Carter,[75] J. R. Carter,[28] J. Carvalho,[125a,i] D. Casadei,[109] M. P. Casado,[12] M. Cascella,[123a,123b] C. Caso,[50a,50b,a] E. Castaneda-Miranda,[174] A. Castelli,[106] V. Castillo Gimenez,[168] N. F. Castro,[125a] G. Cataldi,[72a] P. Catastini,[57] A. Catinaccio,[30] J. R. Catmore,[30] A. Cattai,[30] G. Cattani,[134a,134b] S. Caughron,[89] V. Cavaliere,[166] D. Cavalli,[90a] M. Cavalli-Sforza,[12] V. Cavasinni,[123a,123b] F. Ceradini,[135a,135b] B. Cerio,[45] A. S. Cerqueira,[24b] A. Cerri,[15] L. Cerrito,[75] F. Cerutti,[15] A. Cervelli,[17] S. A. Cetin,[19b] A. Chafaq,[136a] D. Chakraborty,[107] I. Chalupkova,[128] K. Chan,[3] P. Chang,[166] B. Chapleau,[86] J. D. Chapman,[28] J. W. Chapman,[88] D. G. Charlton,[18] V. Chavda,[83] C. A. Chavez Barajas,[30] S. Cheatham,[86] S. Chekanov,[6] S. V. Chekulaev,[160a] G. A. Chelkov,[64] M. A. Chelstowska,[105] C. Chen,[63] H. Chen,[25] S. Chen,[33c] X. Chen,[174] Y. Chen,[35] Y. Cheng,[31] A. Cheplakov,[64] R. Cherkaoui El Moursli,[136e] V. Chernyatin,[25] E. Cheu,[7] S. L. Cheung,[159] L. Chevalier,[137] V. Chiarella,[47] G. Chiefari,[103a,103b] J. T. Childers,[30] A. Chilingarov,[71] G. Chiodini,[72a] A. S. Chisholm,[18] R. T. Chislett,[77] A. Chitan,[26a] M. V. Chizhov,[64] G. Choudalakis,[31] S. Chouridou,[9] B. K. B. Chow,[99] I. A. Christidi,[77] A. Christov,[48] D. Chromek-Burckhart,[30] M. L. Chu,[152] J. Chudoba,[126] G. Ciapetti,[133a,133b] A. K. Ciftci,[4a] R. Ciftci,[4a] D. Cinca,[62] V. Cindro,[74] A. Ciocio,[15] M. Cirilli,[88] P. Cirkovic,[13b] Z. H. Citron,[173] M. Citterio,[90a] M. Ciubancan,[26a] A. Clark,[49] P. J. Clark,[46] R. N. Clarke,[15] J. C. Clemens,[84] B. Clement,[55] C. Clement,[147a,147b] Y. Coadou,[84] M. Cobal,[165a,165c] A. Coccaro,[139] J. Cochran,[63] S. Coelli,[90a] L. Coffey,[23] J. G. Cogan,[144] J. Coggeshall,[166] J. Colas,[5] S. Cole,[107] A. P. Colijn,[106] N. J. Collins,[18] C. Collins-Tooth,[53] J. Collot,[55] T. Colombo,[120a,120b] G. Colon,[85] G. Compostella,[100] P. Conde Muiño,[125a]

E. Coniavitis,[167] M. C. Conidi,[12] S. M. Consonni,[90a,90b] V. Consorti,[48] S. Constantinescu,[26a] C. Conta,[120a,120b] G. Conti,[57] F. Conventi,[103a,j] M. Cooke,[15] B. D. Cooper,[77] A. M. Cooper-Sarkar,[119] N. J. Cooper-Smith,[76] K. Copic,[15] T. Cornelissen,[176] M. Corradi,[20a] F. Corriveau,[86,k] A. Corso-Radu,[164] A. Cortes-Gonzalez,[166] G. Cortiana,[100] G. Costa,[90a] M. J. Costa,[168] D. Costanzo,[140] D. Côté,[30] G. Cottin,[32a] L. Courneyea,[170] G. Cowan,[76] B. E. Cox,[83] K. Cranmer,[109] S. Crépé-Renaudin,[55] F. Crescioli,[79] M. Cristinziani,[21] G. Crosetti,[37a,37b] C.-M. Cuciuc,[26a] C. Cuenca Almenar,[177] T. Cuhadar Donszelmann,[140] J. Cummings,[177] M. Curatolo,[47] C. J. Curtis,[18] C. Cuthbert,[151] H. Czirr,[142] P. Czodrowski,[44] Z. Czyczula,[177] S. D'Auria,[53] M. D'Onofrio,[73] A. D'Orazio,[133a,133b] M. J. Da Cunha Sargedas De Sousa,[125a] C. Da Via,[83] W. Dabrowski,[38a] A. Dafinca,[119] T. Dai,[88] F. Dallaire,[94] C. Dallapiccola,[85] M. Dam,[36] D. S. Damiani,[138] A. C. Daniells,[18] H. O. Danielsson,[30] V. Dao,[105] G. Darbo,[50a] G. L. Darlea,[26c] S. Darmora,[8] J. A. Dassoulas,[42] W. Davey,[21] T. Davidek,[128] E. Davies,[119,e] M. Davies,[94] O. Davignon,[79] A. R. Davison,[77] Y. Davygora,[58a] E. Dawe,[143] I. Dawson,[140] R. K. Daya-Ishmukhametova,[23] K. De,[8] R. de Asmundis,[103a] S. De Castro,[20a,20b] S. De Cecco,[79] J. de Graat,[99] N. De Groot,[105] P. de Jong,[106] C. De La Taille,[116] H. De la Torre,[81] F. De Lorenzi,[63] L. De Nooij,[106] D. De Pedis,[133a] A. De Salvo,[133a] U. De Sanctis,[165a,165c] A. De Santo,[150] J. B. De Vivie De Regie,[116] G. De Zorzi,[133a,133b] W. J. Dearnaley,[71] R. Debbe,[25] C. Debenedetti,[46] B. Dechenaux,[55] D. V. Dedovich,[64] J. Degenhardt,[121] J. Del Peso,[81] T. Del Prete,[123a,123b] T. Delemontex,[55] M. Deliyergiyev,[74] A. Dell'Acqua,[30] L. Dell'Asta,[22] M. Della Pietra,[103a,j] D. della Volpe,[103a,103b] M. Delmastro,[5] P. A. Delsart,[55] C. Deluca,[106] S. Demers,[177] M. Demichev,[64] A. Demilly,[79] B. Demirkoz,[12,l] S. P. Denisov,[129] D. Derendarz,[39] J. E. Derkaoui,[136d] F. Derue,[79] P. Dervan,[73] K. Desch,[21] P. O. Deviveiros,[106] A. Dewhurst,[130] B. DeWilde,[149] S. Dhaliwal,[106] R. Dhullipudi,[78,m] A. Di Ciaccio,[134a,134b] L. Di Ciaccio,[5] C. Di Donato,[103a,103b] A. Di Girolamo,[30] B. Di Girolamo,[30] S. Di Luise,[135a,135b] A. Di Mattia,[153] B. Di Micco,[135a,135b] R. Di Nardo,[47] A. Di Simone,[134a,134b] R. Di Sipio,[20a,20b] M. A. Diaz,[32a] E. B. Diehl,[88] J. Dietrich,[42] T. A. Dietzsch,[58a] S. Diglio,[87] K. Dindar Yagci,[40] J. Dingfelder,[21] F. Dinut,[26a] C. Dionisi,[133a,133b] P. Dita,[26a] S. Dita,[26a] F. Dittus,[30] F. Djama,[84] T. Djobava,[51b] M. A. B. do Vale,[24c] A. Do Valle Wemans,[125a,n] T. K. O. Doan,[5] D. Dobos,[30] E. Dobson,[77] J. Dodd,[35] C. Doglioni,[49] T. Doherty,[53] T. Dohmae,[156] Y. Doi,[65,a] J. Dolejsi,[128] Z. Dolezal,[128] B. A. Dolgoshein,[97,a] M. Donadelli,[24d] J. Donini,[34] J. Dopke,[30] A. Doria,[103a] A. Dos Anjos,[174] A. Dotti,[123a,123b] M. T. Dova,[70] A. T. Doyle,[53] M. Dris,[10] J. Dubbert,[88] S. Dube,[15] E. Dubreuil,[34] E. Duchovni,[173] G. Duckeck,[99] D. Duda,[176] A. Dudarev,[30] F. Dudziak,[63] L. Duflot,[116] M-A. Dufour,[86] L. Duguid,[76] M. Dührssen,[30] M. Dunford,[58a] H. Duran Yildiz,[4a] M. Düren,[52] M. Dwuznik,[38a] J. Ebke,[99] S. Eckweiler,[82] W. Edson,[2] C. A. Edwards,[76] N. C. Edwards,[53] W. Ehrenfeld,[21] T. Eifert,[144] G. Eigen,[14] K. Einsweiler,[15] E. Eisenhandler,[75] T. Ekelof,[167] M. El Kacimi,[136c] M. Ellert,[167] S. Elles,[5] F. Ellinghaus,[82] K. Ellis,[75] N. Ellis,[30] J. Elmsheuser,[99] M. Elsing,[30] D. Emeliyanov,[130] Y. Enari,[156] O. C. Endner,[82] R. Engelmann,[149] A. Engl,[99] J. Erdmann,[177] A. Ereditato,[17] D. Eriksson,[147a] J. Ernst,[2] M. Ernst,[25] J. Ernwein,[137] D. Errede,[166] S. Errede,[166] E. Ertel,[82] M. Escalier,[116] H. Esch,[43] C. Escobar,[124] X. Espinal Curull,[12] B. Esposito,[47] F. Etienne,[84] A. I. Etienvre,[137] E. Etzion,[154] D. Evangelakou,[54] H. Evans,[60] L. Fabbri,[20a,20b] C. Fabre,[30] G. Facini,[30] R. M. Fakhrutdinov,[129] S. Falciano,[133a] Y. Fang,[33a] M. Fanti,[90a,90b] A. Farbin,[8] A. Farilla,[135a] T. Farooque,[159] S. Farrell,[164] S. M. Farrington,[171] P. Farthouat,[30] F. Fassi,[168] P. Fassnacht,[30] D. Fassouliotis,[9] B. Fatholahzadeh,[159] A. Favareto,[90a,90b] L. Fayard,[116] P. Federic,[145a] O. L. Fedin,[122] W. Fedorko,[169] M. Fehling-Kaschek,[48] L. Feligioni,[84] C. Feng,[33d] E. J. Feng,[6] H. Feng,[88] A. B. Fenyuk,[129] J. Ferencei,[145b] W. Fernando,[6] S. Ferrag,[53] J. Ferrando,[53] V. Ferrara,[42] A. Ferrari,[167] P. Ferrari,[106] R. Ferrari,[120a] D. E. Ferreira de Lima,[53] A. Ferrer,[168] D. Ferrere,[49] C. Ferretti,[88] A. Ferretto Parodi,[50a,50b] M. Fiascaris,[31] F. Fiedler,[82] A. Filipčič,[74] F. Filthaut,[105] M. Fincke-Keeler,[170] K. D. Finelli,[45] M. C. N. Fiolhais,[125a,i] L. Fiorini,[168] A. Firan,[40] J. Fischer,[176] M. J. Fisher,[110] E. A. Fitzgerald,[23] M. Flechl,[48] I. Fleck,[142] P. Fleischmann,[175] S. Fleischmann,[176] G. T. Fletcher,[140] G. Fletcher,[75] T. Flick,[176] A. Floderus,[80] L. R. Flores Castillo,[174] A. C. Florez Bustos,[160b] M. J. Flowerdew,[100] T. Fonseca Martin,[17] A. Formica,[137] A. Forti,[83] D. Fortin,[160a] D. Fournier,[116] H. Fox,[71] P. Francavilla,[12] M. Franchini,[20a,20b] S. Franchino,[30] D. Francis,[30] M. Franklin,[57] S. Franz,[30] M. Fraternali,[120a,120b] S. Fratina,[121] S. T. French,[28] C. Friedrich,[42] F. Friedrich,[44] D. Froidevaux,[30] J. A. Frost,[28] C. Fukunaga,[157] E. Fullana Torregrosa,[128] B. G. Fulsom,[144] J. Fuster,[168] C. Gabaldon,[30] O. Gabizon,[173] A. Gabrielli,[20a,20b] A. Gabrielli,[133a,133b] S. Gadatsch,[106] T. Gadfort,[25] S. Gadomski,[49] G. Gagliardi,[50a,50b] P. Gagnon,[60] C. Galea,[99] B. Galhardo,[125a] E. J. Gallas,[119] V. Gallo,[17] B. J. Gallop,[130] P. Gallus,[127] K. K. Gan,[110] R. P. Gandrajula,[62] Y. S. Gao,[144,g] A. Gaponenko,[15] F. M. Garay Walls,[46] F. Garberson,[177] C. García,[168] J. E. García Navarro,[168] M. Garcia-Sciveres,[15] R. W. Gardner,[31] N. Garelli,[144] V. Garonne,[30] C. Gatti,[47] G. Gaudio,[120a] B. Gaur,[142] L. Gauthier,[94] P. Gauzzi,[133a,133b] I. L. Gavrilenko,[95] C. Gay,[169] G. Gaycken,[21] E. N. Gazis,[10] P. Ge,[33d,o] Z. Gecse,[169] C. N. P. Gee,[130] D. A. A. Geerts,[106] Ch. Geich-Gimbel,[21] K. Gellerstedt,[147a,147b] C. Gemme,[50a] A. Gemmell,[53] M. H. Genest,[55] S. Gentile,[133a,133b] M. George,[54] S. George,[76] D. Gerbaudo,[164] A. Gershon,[154]

H. Ghazlane,[136b] N. Ghodbane,[34] B. Giacobbe,[20a] S. Giagu,[133a,133b] V. Giangiobbe,[12] P. Giannetti,[123a,123b] F. Gianotti,[30] B. Gibbard,[25] A. Gibson,[159] S. M. Gibson,[76] M. Gilchriese,[15] T. P. S. Gillam,[28] D. Gillberg,[30] A. R. Gillman,[130] D. M. Gingrich,[3,f] N. Giokaris,[9] M. P. Giordani,[165a,165c] R. Giordano,[103a,103b] F. M. Giorgi,[16] P. Giovannini,[100] P. F. Giraud,[137] D. Giugni,[90a] C. Giuliani,[48] M. Giunta,[94] B. K. Gjelsten,[118] I. Gkialas,[155,p] L. K. Gladilin,[98] C. Glasman,[81] J. Glatzer,[21] A. Glazov,[42] G. L. Glonti,[64] M. Goblirsch-Kolb,[100] J. R. Goddard,[75] J. Godfrey,[143] J. Godlewski,[30] M. Goebel,[42] C. Goeringer,[82] S. Goldfarb,[88] T. Golling,[177] D. Golubkov,[129] A. Gomes,[125a,d] L. S. Gomez Fajardo,[42] R. Gonçalo,[76] J. Goncalves Pinto Firmino Da Costa,[42] L. Gonella,[21] S. González de la Hoz,[168] G. Gonzalez Parra,[12] M. L. Gonzalez Silva,[27] S. Gonzalez-Sevilla,[49] J. J. Goodson,[149] L. Goossens,[30] P. A. Gorbounov,[96] H. A. Gordon,[25] I. Gorelov,[104] G. Gorfine,[176] B. Gorini,[30] E. Gorini,[72a,72b] A. Gorišek,[74] E. Gornicki,[39] A. T. Goshaw,[6] C. Gössling,[43] M. I. Gostkin,[64] I. Gough Eschrich,[164] M. Gouighri,[136a] D. Goujdami,[136c] M. P. Goulette,[49] A. G. Goussiou,[139] C. Goy,[5] S. Gozpinar,[23] L. Graber,[54] I. Grabowska-Bold,[38a] P. Grafström,[20a,20b] K-J. Grahn,[42] E. Gramstad,[118] F. Grancagnolo,[72a] S. Grancagnolo,[16] V. Grassi,[149] V. Gratchev,[122] H. M. Gray,[30] J. A. Gray,[149] E. Graziani,[135a] O. G. Grebenyuk,[122] T. Greenshaw,[73] Z. D. Greenwood,[78,m] K. Gregersen,[36] I. M. Gregor,[42] P. Grenier,[144] J. Griffiths,[8] N. Grigalashvili,[64] A. A. Grillo,[138] K. Grimm,[71] S. Grinstein,[12,q] Ph. Gris,[34] Y. V. Grishkevich,[98] J.-F. Grivaz,[116] J. P. Grohs,[44] A. Grohsjean,[42] E. Gross,[173] J. Grosse-Knetter,[54] J. Groth-Jensen,[173] K. Grybel,[142] F. Guescini,[49] D. Guest,[177] O. Gueta,[154] C. Guicheney,[34] E. Guido,[50a,50b] T. Guillemin,[116] S. Guindon,[2] U. Gul,[53] J. Gunther,[127] J. Guo,[35] P. Gutierrez,[112] N. Guttman,[154] O. Gutzwiller,[174] C. Guyot,[137] C. Gwenlan,[119] C. B. Gwilliam,[73] A. Haas,[109] S. Haas,[30] C. Haber,[15] H. K. Hadavand,[8] P. Haefner,[21] Z. Hajduk,[39] H. Hakobyan,[178] D. Hall,[119] G. Halladjian,[62] K. Hamacher,[176] P. Hamal,[114] K. Hamano,[87] M. Hamer,[54] A. Hamilton,[146a,r] S. Hamilton,[162] L. Han,[33b] K. Hanagaki,[117] K. Hanawa,[161] M. Hance,[15] C. Handel,[82] P. Hanke,[58a] J. R. Hansen,[36] J. B. Hansen,[36] J. D. Hansen,[36] P. H. Hansen,[36] P. Hansson,[144] K. Hara,[161] A. S. Hard,[174] T. Harenberg,[176] S. Harkusha,[91] D. Harper,[88] R. D. Harrington,[46] O. M. Harris,[139] J. Hartert,[48] F. Hartjes,[106] T. Haruyama,[65] A. Harvey,[56] S. Hasegawa,[102] Y. Hasegawa,[141] S. Hassani,[137] S. Haug,[17] M. Hauschild,[30] R. Hauser,[89] M. Havranek,[21] C. M. Hawkes,[18] R. J. Hawkings,[30] A. D. Hawkins,[80] T. Hayakawa,[66] T. Hayashi,[161] D. Hayden,[76] C. P. Hays,[119] H. S. Hayward,[73] S. J. Haywood,[130] S. J. Head,[18] T. Heck,[82] V. Hedberg,[80] L. Heelan,[8] S. Heim,[121] B. Heinemann,[15] S. Heisterkamp,[36] J. Hejbal,[126] L. Helary,[22] C. Heller,[99] M. Heller,[30] S. Hellman,[147a,147b] D. Hellmich,[21] C. Helsens,[30] J. Henderson,[119] R. C. W. Henderson,[71] M. Henke,[58a] A. Henrichs,[177] A. M. Henriques Correia,[30] S. Henrot-Versille,[116] C. Hensel,[54] G. H. Herbert,[16] C. M. Hernandez,[8] Y. Hernández Jiménez,[168] R. Herrberg-Schubert,[16] G. Herten,[48] R. Hertenberger,[99] L. Hervas,[30] G. G. Hesketh,[77] N. P. Hessey,[106] R. Hickling,[75] E. Higón-Rodriguez,[168] J. C. Hill,[28] K. H. Hiller,[42] S. Hillert,[21] S. J. Hillier,[18] I. Hinchliffe,[15] E. Hines,[121] M. Hirose,[117] D. Hirschbuehl,[176] J. Hobbs,[149] N. Hod,[106] M. C. Hodgkinson,[140] P. Hodgson,[140] A. Hoecker,[30] M. R. Hoeferkamp,[104] J. Hoffman,[40] D. Hoffmann,[84] J. I. Hofmann,[58a] M. Hohlfeld,[82] S. O. Holmgren,[147a] J. L. Holzbauer,[89] T. M. Hong,[121] L. Hooft van Huysduynen,[109] J-Y. Hostachy,[55] S. Hou,[152] A. Hoummada,[136a] J. Howard,[119] J. Howarth,[83] M. Hrabovsky,[114] I. Hristova,[16] J. Hrivnac,[116] T. Hryn'ova,[5] P. J. Hsu,[82] S.-C. Hsu,[139] D. Hu,[35] X. Hu,[25] Z. Hubacek,[30] F. Hubaut,[84] F. Huegging,[21] A. Huettmann,[42] T. B. Huffman,[119] E. W. Hughes,[35] G. Hughes,[71] M. Huhtinen,[30] T. A. Hülsing,[82] M. Hurwitz,[15] N. Huseynov,[64,s] J. Huston,[89] J. Huth,[57] G. Iacobucci,[49] G. Iakovidis,[10] I. Ibragimov,[142] L. Iconomidou-Fayard,[116] J. Idarraga,[116] P. Iengo,[103a] O. Igonkina,[106] Y. Ikegami,[65] K. Ikematsu,[142] M. Ikeno,[65] D. Iliadis,[155] N. Ilic,[159] T. Ince,[100] P. Ioannou,[9] M. Iodice,[135a] K. Iordanidou,[9] V. Ippolito,[133a,133b] A. Irles Quiles,[168] C. Isaksson,[167] M. Ishino,[67] M. Ishitsuka,[158] R. Ishmukhametov,[110] C. Issever,[119] S. Istin,[19a] A. V. Ivashin,[129] W. Iwanski,[39] H. Iwasaki,[65] J. M. Izen,[41] V. Izzo,[103a] B. Jackson,[121] J. N. Jackson,[73] P. Jackson,[1] M. R. Jaekel,[30] V. Jain,[2] K. Jakobs,[48] S. Jakobsen,[36] T. Jakoubek,[126] J. Jakubek,[127] D. O. Jamin,[152] D. K. Jana,[112] E. Jansen,[77] H. Jansen,[30] J. Janssen,[21] A. Jantsch,[100] M. Janus,[48] R. C. Jared,[174] G. Jarlskog,[80] L. Jeanty,[57] G.-Y. Jeng,[151] I. Jen-La Plante,[31] D. Jennens,[87] P. Jenni,[30] J. Jentzsch,[43] C. Jeske,[171] S. Jézéquel,[5] M. K. Jha,[20a] H. Ji,[174] W. Ji,[82] J. Jia,[149] Y. Jiang,[33b] M. Jimenez Belenguer,[42] S. Jin,[33a] O. Jinnouchi,[158] M. D. Joergensen,[36] D. Joffe,[40] M. Johansen,[147a,147b] K. E. Johansson,[147a] P. Johansson,[140] S. Johnert,[42] K. A. Johns,[7] K. Jon-And,[147a,147b] G. Jones,[171] R. W. L. Jones,[71] T. J. Jones,[73] P. M. Jorge,[125a] K. D. Joshi,[83] J. Jovicevic,[148] X. Ju,[174] C. A. Jung,[43] R. M. Jungst,[30] P. Jussel,[61] A. Juste Rozas,[12,q] S. Kabana,[17] M. Kaci,[168] A. Kaczmarska,[39] P. Kadlecik,[36] M. Kado,[116] H. Kagan,[110] M. Kagan,[144] E. Kajomovitz,[153] S. Kalinin,[176] S. Kama,[40] N. Kanaya,[156] M. Kaneda,[30] S. Kaneti,[28] T. Kanno,[158] V. A. Kantserov,[97] J. Kanzaki,[65] B. Kaplan,[109] A. Kapliy,[31] D. Kar,[53] K. Karakostas,[10] M. Karnevskiy,[82] V. Kartvelishvili,[71] A. N. Karyukhin,[129] L. Kashif,[174] G. Kasieczka,[58b] R. D. Kass,[110] A. Kastanas,[14] Y. Kataoka,[156] J. Katzy,[42] V. Kaushik,[7] K. Kawagoe,[69] T. Kawamoto,[156] G. Kawamura,[54] S. Kazama,[156] V. F. Kazanin,[108] M. Y. Kazarinov,[64] R. Keeler,[170] P. T. Keener,[121]

R. Kehoe,[40] M. Keil,[54] J. S. Keller,[139] H. Keoshkerian,[5] O. Kepka,[126] B. P. Kerševan,[74] S. Kersten,[176] K. Kessoku,[156] J. Keung,[159] F. Khalil-zada,[11] H. Khandanyan,[147a,147b] A. Khanov,[113] D. Kharchenko,[64] A. Khodinov,[97] A. Khomich,[58a] T. J. Khoo,[28] G. Khoriauli,[21] A. Khoroshilov,[176] V. Khovanskiy,[96] E. Khramov,[64] J. Khubua,[51b] H. Kim,[147a,147b] S. H. Kim,[161] N. Kimura,[172] O. Kind,[16] B. T. King,[73] M. King,[66] R. S. B. King,[119] S. B. King,[169] J. Kirk,[130] A. E. Kiryunin,[100] T. Kishimoto,[66] D. Kisielewska,[38a] T. Kitamura,[66] T. Kittelmann,[124] K. Kiuchi,[161] E. Kladiva,[145b] M. Klein,[73] U. Klein,[73] K. Kleinknecht,[82] M. Klemetti,[86] A. Klier,[173] P. Klimek,[147a,147b] A. Klimentov,[25] R. Klingenberg,[43] J. A. Klinger,[83] E. B. Klinkby,[36] T. Klioutchnikova,[30] P. F. Klok,[105] E.-E. Kluge,[58a] P. Kluit,[106] S. Kluth,[100] E. Kneringer,[61] E. B. F. G. Knoops,[84] A. Knue,[54] B. R. Ko,[45] T. Kobayashi,[156] M. Kobel,[44] M. Kocian,[144] P. Kodys,[128] S. Koenig,[82] F. Koetsveld,[105] P. Koevesarki,[21] T. Koffas,[29] E. Koffeman,[106] L. A. Kogan,[119] S. Kohlmann,[176] F. Kohn,[54] Z. Kohout,[127] T. Kohriki,[65] T. Koi,[144] H. Kolanoski,[16] I. Koletsou,[90a] J. Koll,[89] A. A. Komar,[95] Y. Komori,[156] T. Kondo,[65] K. Köneke,[30] A. C. König,[105] T. Kono,[65,t] A. I. Kononov,[48] R. Konoplich,[109,u] N. Konstantinidis,[77] R. Kopeliansky,[153] S. Koperny,[38a] L. Köpke,[82] A. K. Kopp,[48] K. Korcyl,[39] K. Kordas,[155] A. Korn,[46] A. A. Korol,[108] I. Korolkov,[12] E. V. Korolkova,[140] V. A. Korotkov,[129] O. Kortner,[100] S. Kortner,[100] V. V. Kostyukhin,[21] S. Kotov,[100] V. M. Kotov,[64] A. Kotwal,[45] C. Kourkoumelis,[9] V. Kouskoura,[155] A. Koutsman,[160a] R. Kowalewski,[170] T. Z. Kowalski,[38a] W. Kozanecki,[137] A. S. Kozhin,[129] V. Kral,[127] V. A. Kramarenko,[98] G. Kramberger,[74] M. W. Krasny,[79] A. Krasznahorkay,[109] J. K. Kraus,[21] A. Kravchenko,[25] S. Kreiss,[109] J. Kretzschmar,[73] K. Kreutzfeldt,[52] N. Krieger,[54] P. Krieger,[159] K. Kroeninger,[54] H. Kroha,[100] J. Kroll,[121] J. Kroseberg,[21] J. Krstic,[13a] U. Kruchonak,[64] H. Krüger,[21] T. Kruker,[17] N. Krumnack,[63] Z. V. Krumshteyn,[64] A. Kruse,[174] M. C. Kruse,[45] M. Kruskal,[22] T. Kubota,[87] S. Kuday,[4a] S. Kuehn,[48] A. Kugel,[58c] T. Kuhl,[42] V. Kukhtin,[64] Y. Kulchitsky,[91] S. Kuleshov,[32b] M. Kuna,[79] J. Kunkle,[121] A. Kupco,[126] H. Kurashige,[66] M. Kurata,[161] Y. A. Kurochkin,[91] V. Kus,[126] E. S. Kuwertz,[148] M. Kuze,[158] J. Kvita,[143] R. Kwee,[16] A. La Rosa,[49] L. La Rotonda,[37a,37b] L. Labarga,[81] S. Lablak,[136a] C. Lacasta,[168] F. Lacava,[133a,133b] J. Lacey,[29] H. Lacker,[16] D. Lacour,[79] V. R. Lacuesta,[168] E. Ladygin,[64] R. Lafaye,[5] B. Laforge,[79] T. Lagouri,[177] S. Lai,[48] H. Laier,[58a] E. Laisne,[55] L. Lambourne,[77] C. L. Lampen,[7] W. Lampl,[7] E. Lançon,[137] U. Landgraf,[48] M. P. J. Landon,[75] V. S. Lang,[58a] C. Lange,[42] A. J. Lankford,[164] F. Lanni,[25] K. Lantzsch,[30] A. Lanza,[120a] S. Laplace,[79] C. Lapoire,[21] J. F. Laporte,[137] T. Lari,[90a] A. Larner,[119] M. Lassnig,[30] P. Laurelli,[47] V. Lavorini,[37a,37b] W. Lavrijsen,[15] P. Laycock,[73] O. Le Dortz,[79] E. Le Guirriec,[84] E. Le Menedeu,[12] T. LeCompte,[6] F. Ledroit-Guillon,[55] H. Lee,[106] J. S. H. Lee,[117] S. C. Lee,[152] L. Lee,[177] G. Lefebvre,[79] M. Lefebvre,[170] M. Legendre,[137] F. Legger,[99] C. Leggett,[15] M. Lehmacher,[21] G. Lehmann Miotto,[30] A. G. Leister,[177] M. A. L. Leite,[24d] R. Leitner,[128] D. Lellouch,[173] B. Lemmer,[54] V. Lendermann,[58a] K. J. C. Leney,[146c] T. Lenz,[106] G. Lenzen,[176] B. Lenzi,[30] K. Leonhardt,[44] S. Leontsinis,[10] F. Lepold,[58a] C. Leroy,[94] J-R. Lessard,[170] C. G. Lester,[28] C. M. Lester,[121] J. Levêque,[5] D. Levin,[88] L. J. Levinson,[173] A. Lewis,[119] G. H. Lewis,[109] A. M. Leyko,[21] M. Leyton,[16] B. Li,[33b,v] B. Li,[84] H. Li,[149] H. L. Li,[31] S. Li,[45] X. Li,[88] Z. Liang,[119,w] H. Liao,[34] B. Liberti,[134a] P. Lichard,[30] K. Lie,[166] J. Liebal,[21] W. Liebig,[14] C. Limbach,[21] A. Limosani,[87] M. Limper,[62] S. C. Lin,[152,x] F. Linde,[106] B. E. Lindquist,[149] J. T. Linnemann,[89] E. Lipeles,[121] A. Lipniacka,[14] M. Lisovyi,[42] T. M. Liss,[166] D. Lissauer,[25] A. Lister,[169] A. M. Litke,[138] D. Liu,[152] J. B. Liu,[33b] K. Liu,[33b,y] L. Liu,[88] M. Liu,[45] M. Liu,[33b] Y. Liu,[33b] M. Livan,[120a,120b] S. S. A. Livermore,[119] A. Lleres,[55] J. Llorente Merino,[81] S. L. Lloyd,[75] F. Lo Sterzo,[133a,133b] E. Lobodzinska,[42] P. Loch,[7] W. S. Lockman,[138] T. Loddenkoetter,[21] F. K. Loebinger,[83] A. E. Loevschall-Jensen,[36] A. Loginov,[177] C. W. Loh,[169] T. Lohse,[16] K. Lohwasser,[48] M. Lokajicek,[126] V. P. Lombardo,[5] R. E. Long,[71] L. Lopes,[125a] D. Lopez Mateos,[57] J. Lorenz,[99] N. Lorenzo Martinez,[116] M. Losada,[163] P. Loscutoff,[15] M. J. Losty,[160a,a] X. Lou,[41] A. Lounis,[116] K. F. Loureiro,[163] J. Love,[6] P. A. Love,[71] A. J. Lowe,[144,g] F. Lu,[33a] H. J. Lubatti,[139] C. Luci,[133a,133b] A. Lucotte,[55] D. Ludwig,[42] I. Ludwig,[48] J. Ludwig,[48] F. Luehring,[60] W. Lukas,[61] L. Luminari,[133a] E. Lund,[118] J. Lundberg,[147a,147b] O. Lundberg,[147a,147b] B. Lund-Jensen,[148] J. Lundquist,[36] M. Lungwitz,[82] D. Lynn,[25] R. Lysak,[126] E. Lytken,[80] H. Ma,[25] L. L. Ma,[174] G. Maccarrone,[47] A. Macchiolo,[100] B. Maček,[74] J. Machado Miguens,[125a] D. Macina,[30] R. Mackeprang,[36] R. Madar,[48] R. J. Madaras,[15] H. J. Maddocks,[71] W. F. Mader,[44] A. Madsen,[167] M. Maeno,[5] T. Maeno,[25] L. Magnoni,[164] E. Magradze,[54] K. Mahboubi,[48] J. Mahlstedt,[106] S. Mahmoud,[73] G. Mahout,[18] C. Maiani,[137] C. Maidantchik,[24a] A. Maio,[125a,d] S. Majewski,[115] Y. Makida,[65] N. Makovec,[116] P. Mal,[137,z] B. Malaescu,[79] Pa. Malecki,[39] P. Malecki,[39] V. P. Maleev,[122] F. Malek,[55] U. Mallik,[62] D. Malon,[6] C. Malone,[144] S. Maltezos,[10] V. M. Malyshev,[108] S. Malyukov,[30] J. Mamuzic,[13b] L. Mandelli,[90a] I. Mandić,[74] R. Mandrysch,[62] J. Maneira,[125a] A. Manfredini,[100] L. Manhaes de Andrade Filho,[24b] J. A. Manjarres Ramos,[137] A. Mann,[99] P. M. Manning,[138] A. Manousakis-Katsikakis,[9] B. Mansoulie,[137] R. Mantifel,[86] L. Mapelli,[30] L. March,[168] J. F. Marchand,[29] F. Marchese,[134a,134b] G. Marchiori,[79] M. Marcisovsky,[126] C. P. Marino,[170] C. N. Marques,[125a] F. Marroquim,[24a] Z. Marshall,[121] L. F. Marti,[17] S. Marti-Garcia,[168]

B. Martin,[30] B. Martin,[89] J. P. Martin,[94] T. A. Martin,[171] V. J. Martin,[46] B. Martin dit Latour,[49] H. Martinez,[137] M. Martinez,[12,q] S. Martin-Haugh,[150] A. C. Martyniuk,[170] M. Marx,[83] F. Marzano,[133a] A. Marzin,[112] L. Masetti,[82] T. Mashimo,[156] R. Mashinistov,[95] J. Masik,[83] A. L. Maslennikov,[108] I. Massa,[20a,20b] N. Massol,[5] P. Mastrandrea,[149] A. Mastroberardino,[37a,37b] T. Masubuchi,[156] H. Matsunaga,[156] T. Matsushita,[66] P. Mättig,[176] S. Mättig,[42] C. Mattravers,[119,e] J. Maurer,[84] S. J. Maxfield,[73] D. A. Maximov,[108,h] R. Mazini,[152] M. Mazur,[21] L. Mazzaferro,[134a,134b] M. Mazzanti,[90a] S. P. Mc Kee,[88] A. McCarn,[166] R. L. McCarthy,[149] T. G. McCarthy,[29] N. A. McCubbin,[130] K. W. McFarlane,[56,a] J. A. Mcfayden,[140] G. Mchedlidze,[51b] T. Mclaughlan,[18] S. J. McMahon,[130] R. A. McPherson,[170,k] A. Meade,[85] J. Mechnich,[106] M. Mechtel,[176] M. Medinnis,[42] S. Meehan,[31] R. Meera-Lebbai,[112] T. Meguro,[117] S. Mehlhase,[36] A. Mehta,[73] K. Meier,[58a] C. Meineck,[99] B. Meirose,[80] C. Melachrinos,[31] B. R. Mellado Garcia,[146c] F. Meloni,[90a,90b] L. Mendoza Navas,[163] A. Mengarelli,[20a,20b] S. Menke,[100] E. Meoni,[162] K. M. Mercurio,[57] N. Meric,[137] P. Mermod,[49] L. Merola,[103a,103b] C. Meroni,[90a] F. S. Merritt,[31] H. Merritt,[110] A. Messina,[30,aa] J. Metcalfe,[25] A. S. Mete,[164] C. Meyer,[82] C. Meyer,[31] J-P. Meyer,[137] J. Meyer,[30] J. Meyer,[54] S. Michal,[30] R. P. Middleton,[130] S. Migas,[73] L. Mijović,[137] G. Mikenberg,[173] M. Mikestikova,[126] M. Mikuž,[74] D. W. Miller,[31] W. J. Mills,[169] C. Mills,[57] A. Milov,[173] D. A. Milstead,[147a,147b] D. Milstein,[173] A. A. Minaenko,[129] M. Miñano Moya,[168] I. A. Minashvili,[64] A. I. Mincer,[109] B. Mindur,[38a] M. Mineev,[64] Y. Ming,[174] L. M. Mir,[12] G. Mirabelli,[133a] J. Mitrevski,[138] V. A. Mitsou,[168] S. Mitsui,[65] P. S. Miyagawa,[140] J. U. Mjörnmark,[80] T. Moa,[147a,147b] V. Moeller,[28] S. Mohapatra,[149] W. Mohr,[48] R. Moles-Valls,[168] A. Molfetas,[30] K. Mönig,[42] C. Monini,[55] J. Monk,[36] E. Monnier,[84] J. Montejo Berlingen,[12] F. Monticelli,[70] S. Monzani,[20a,20b] R. W. Moore,[3] C. Mora Herrera,[49] A. Moraes,[53] N. Morange,[62] J. Morel,[54] D. Moreno,[82] M. Moreno Llácer,[168] P. Morettini,[50a] M. Morgenstern,[44] M. Morii,[57] S. Moritz,[82] A. K. Morley,[30] G. Mornacchi,[30] J. D. Morris,[75] L. Morvaj,[102] N. Möser,[21] H. G. Moser,[100] M. Mosidze,[51b] J. Moss,[110] R. Mount,[144] E. Mountricha,[10,bb] S. V. Mouraviev,[95,a] E. J. W. Moyse,[85] R. D. Mudd,[18] F. Mueller,[58a] J. Mueller,[124] K. Mueller,[21] T. Mueller,[28] T. Mueller,[82] D. Muenstermann,[30] Y. Munwes,[154] J. A. Murillo Quijada,[18] W. J. Murray,[130] I. Mussche,[106] E. Musto,[153] A. G. Myagkov,[129,cc] M. Myska,[126] O. Nackenhorst,[54] J. Nadal,[12] K. Nagai,[161] R. Nagai,[158] Y. Nagai,[84] K. Nagano,[65] A. Nagarkar,[110] Y. Nagasaka,[59] M. Nagel,[100] A. M. Nairz,[30] Y. Nakahama,[30] K. Nakamura,[65] T. Nakamura,[156] I. Nakano,[111] H. Namasivayam,[41] G. Nanava,[21] A. Napier,[162] R. Narayan,[58b] M. Nash,[77,e] T. Nattermann,[21] T. Naumann,[42] G. Navarro,[163] H. A. Neal,[88] P. Yu. Nechaeva,[95] T. J. Neep,[83] A. Negri,[120a,120b] G. Negri,[30] M. Negrini,[20a] S. Nektarijevic,[49] A. Nelson,[164] T. K. Nelson,[144] S. Nemecek,[126] P. Nemethy,[109] A. A. Nepomuceno,[24a] M. Nessi,[30,dd] M. S. Neubauer,[166] M. Neumann,[176] A. Neusiedl,[82] R. M. Neves,[109] P. Nevski,[25] F. M. Newcomer,[121] P. R. Newman,[18] D. H. Nguyen,[6] V. Nguyen Thi Hong,[137] R. B. Nickerson,[119] R. Nicolaidou,[137] B. Nicquevert,[30] F. Niedercorn,[116] J. Nielsen,[138] N. Nikiforou,[35] A. Nikiforov,[16] V. Nikolaenko,[129,cc] I. Nikolic-Audit,[79] K. Nikolics,[49] K. Nikolopoulos,[18] P. Nilsson,[8] Y. Ninomiya,[156] A. Nisati,[133a] R. Nisius,[100] T. Nobe,[158] L. Nodulman,[6] M. Nomachi,[117] I. Nomidis,[155] S. Norberg,[112] M. Nordberg,[30] J. Novakova,[128] M. Nozaki,[65] L. Nozka,[114] A.-E. Nuncio-Quiroz,[21] G. Nunes Hanninger,[87] T. Nunnemann,[99] E. Nurse,[77] B. J. O'Brien,[46] D. C. O'Neil,[143] V. O'Shea,[53] L. B. Oakes,[99] F. G. Oakham,[29,f] H. Oberlack,[100] J. Ocariz,[79] A. Ochi,[66] M. I. Ochoa,[77] S. Oda,[69] S. Odaka,[65] J. Odier,[84] H. Ogren,[60] A. Oh,[83] S. H. Oh,[45] C. C. Ohm,[30] T. Ohshima,[102] W. Okamura,[117] H. Okawa,[25] Y. Okumura,[31] T. Okuyama,[156] A. Olariu,[26a] A. G. Olchevski,[64] S. A. Olivares Pino,[46] M. Oliveira,[125a,i] D. Oliveira Damazio,[25] E. Oliver Garcia,[168] D. Olivito,[121] A. Olszewski,[39] J. Olszowska,[39] A. Onofre,[125a,ee] P. U. E. Onyisi,[31,ff] C. J. Oram,[160a] M. J. Oreglia,[31] Y. Oren,[154] D. Orestano,[135a,135b] N. Orlando,[72a,72b] C. Oropeza Barrera,[53] R. S. Orr,[159] B. Osculati,[50a,50b] R. Ospanov,[121] G. Otero y Garzon,[27] J. P. Ottersbach,[106] M. Ouchrif,[136d] E. A. Ouellette,[170] F. Ould-Saada,[118] A. Ouraou,[137] Q. Ouyang,[33a] A. Ovcharova,[15] M. Owen,[83] S. Owen,[140] V. E. Ozcan,[19a] N. Ozturk,[8] K. Pachal,[119] A. Pacheco Pages,[12] C. Padilla Aranda,[12] S. Pagan Griso,[15] E. Paganis,[140] C. Pahl,[100] F. Paige,[25] P. Pais,[85] K. Pajchel,[118] G. Palacino,[160b] C. P. Paleari,[7] S. Palestini,[30] D. Pallin,[34] A. Palma,[125a] J. D. Palmer,[18] Y. B. Pan,[174] E. Panagiotopoulou,[10] J. G. Panduro Vazquez,[76] P. Pani,[106] N. Panikashvili,[88] S. Panitkin,[25] D. Pantea,[26a] A. Papadelis,[147a] Th. D. Papadopoulou,[10] K. Papageorgiou,[155,p] A. Paramonov,[6] D. Paredes Hernandez,[34] W. Park,[25,gg] M. A. Parker,[28] F. Parodi,[50a,50b] J. A. Parsons,[35] U. Parzefall,[48] S. Pashapour,[54] E. Pasqualucci,[133a] S. Passaggio,[50a] A. Passeri,[135a] F. Pastore,[135a,135b,a] Fr. Pastore,[76] G. Pásztor,[49,hh] S. Pataraia,[176] N. D. Patel,[151] J. R. Pater,[83] S. Patricelli,[103a,103b] T. Pauly,[30] J. Pearce,[170] M. Pedersen,[118] S. Pedraza Lopez,[168] M. I. Pedraza Morales,[174] S. V. Peleganchuk,[108] D. Pelikan,[167] H. Peng,[33b] B. Penning,[31] A. Penson,[35] J. Penwell,[60] T. Perez Cavalcanti,[42] E. Perez Codina,[160a] M. T. Pérez García-Estañ,[168] V. Perez Reale,[35] L. Perini,[90a,90b] H. Pernegger,[30] R. Perrino,[72a] P. Perrodo,[5] V. D. Peshekhonov,[64] K. Peters,[30] R. F. Y. Peters,[54,ii] B. A. Petersen,[30] J. Petersen,[30] T. C. Petersen,[36] E. Petit,[5] A. Petridis,[147a,147b] C. Petridou,[155] E. Petrolo,[133a]

F. Petrucci,[135a,135b] D. Petschull,[42] M. Petteni,[143] R. Pezoa,[32b] A. Phan,[87] P. W. Phillips,[130] G. Piacquadio,[144] E. Pianori,[171] A. Picazio,[49] E. Piccaro,[75] M. Piccinini,[20a,20b] S. M. Piec,[42] R. Piegaia,[27] D. T. Pignotti,[110] J. E. Pilcher,[31] A. D. Pilkington,[77] J. Pina,[125a,d] M. Pinamonti,[165a,165c,jj] A. Pinder,[119] J. L. Pinfold,[3] A. Pingel,[36] B. Pinto,[125a] C. Pizio,[90a,90b] M.-A. Pleier,[25] V. Pleskot,[128] E. Plotnikova,[64] P. Plucinski,[147a,147b] S. Poddar,[58a] F. Podlyski,[34] R. Poettgen,[82] L. Poggioli,[116] D. Pohl,[21] M. Pohl,[49] G. Polesello,[120a] A. Policicchio,[37a,37b] R. Polifka,[159] A. Polini,[20a] V. Polychronakos,[25] D. Pomeroy,[23] K. Pommès,[30] L. Pontecorvo,[133a] B. G. Pope,[89] G. A. Popeneciu,[26b] D. S. Popovic,[13a] A. Poppleton,[30] X. Portell Bueso,[12] G. E. Pospelov,[100] S. Pospisil,[127] I. N. Potrap,[64] C. J. Potter,[150] C. T. Potter,[115] G. Poulard,[30] J. Poveda,[60] V. Pozdnyakov,[64] R. Prabhu,[77] P. Pralavorio,[84] A. Pranko,[15] S. Prasad,[30] R. Pravahan,[25] S. Prell,[63] K. Pretzl,[17] D. Price,[60] J. Price,[73] L. E. Price,[6] D. Prieur,[124] M. Primavera,[72a] M. Proissl,[46] K. Prokofiev,[109] F. Prokoshin,[32b] E. Protopapadaki,[137] S. Protopopescu,[25] J. Proudfoot,[6] X. Prudent,[44] M. Przybycien,[38a] H. Przysiezniak,[5] S. Psoroulas,[21] E. Ptacek,[115] E. Pueschel,[85] D. Puldon,[149] M. Purohit,[25,gg] P. Puzo,[116] Y. Pylypchenko,[62] J. Qian,[88] A. Quadt,[54] D. R. Quarrie,[15] W. B. Quayle,[174] D. Quilty,[53] M. Raas,[105] V. Radeka,[25] V. Radescu,[42] P. Radloff,[115] F. Ragusa,[90a,90b] G. Rahal,[179] S. Rajagopalan,[25] M. Rammensee,[48] M. Rammes,[142] A. S. Randle-Conde,[40] K. Randrianarivony,[29] C. Rangel-Smith,[79] K. Rao,[164] F. Rauscher,[99] T. C. Rave,[48] T. Ravenscroft,[53] M. Raymond,[30] A. L. Read,[118] D. M. Rebuzzi,[120a,120b] A. Redelbach,[175] G. Redlinger,[25] R. Reece,[121] K. Reeves,[41] A. Reinsch,[115] I. Reisinger,[43] M. Relich,[164] C. Rembser,[30] Z. L. Ren,[152] A. Renaud,[116] M. Rescigno,[133a] S. Resconi,[90a] B. Resende,[137] P. Reznicek,[99] R. Rezvani,[94] R. Richter,[100] E. Richter-Was,[38b] M. Ridel,[79] P. Rieck,[16] M. Rijssenbeek,[149] A. Rimoldi,[120a,120b] L. Rinaldi,[20a] R. R. Rios,[40] E. Ritsch,[61] I. Riu,[12] G. Rivoltella,[90a,90b] F. Rizatdinova,[113] E. Rizvi,[75] S. H. Robertson,[86,k] A. Robichaud-Veronneau,[119] D. Robinson,[28] J. E. M. Robinson,[83] A. Robson,[53] J. G. Rocha de Lima,[107] C. Roda,[123a,123b] D. Roda Dos Santos,[30] A. Roe,[54] S. Roe,[30] O. Røhne,[118] S. Rolli,[162] A. Romaniouk,[97] M. Romano,[20a,20b] G. Romeo,[27] E. Romero Adam,[168] N. Rompotis,[139] L. Roos,[79] E. Ros,[168] S. Rosati,[133a] K. Rosbach,[49] A. Rose,[150] M. Rose,[76] G. A. Rosenbaum,[159] P. L. Rosendahl,[14] O. Rosenthal,[142] V. Rossetti,[12] E. Rossi,[133a,133b] L. P. Rossi,[50a] M. Rotaru,[26a] I. Roth,[173] J. Rothberg,[139] D. Rousseau,[116] C. R. Royon,[137] A. Rozanov,[84] Y. Rozen,[153] X. Ruan,[146c] F. Rubbo,[12] I. Rubinskiy,[42] N. Ruckstuhl,[106] V. I. Rud,[98] C. Rudolph,[44] M. S. Rudolph,[159] F. Rühr,[7] A. Ruiz-Martinez,[63] L. Rumyantsev,[64] Z. Rurikova,[48] N. A. Rusakovich,[64] A. Ruschke,[99] J. P. Rutherfoord,[7] N. Ruthmann,[48] P. Ruzicka,[126] Y. F. Ryabov,[122] M. Rybar,[128] G. Rybkin,[116] N. C. Ryder,[119] A. F. Saavedra,[151] A. Saddique,[3] I. Sadeh,[154] H. F-W. Sadrozinski,[138] R. Sadykov,[64] F. Safai Tehrani,[133a] H. Sakamoto,[156] G. Salamanna,[75] A. Salamon,[134a] M. Saleem,[112] D. Salek,[30] D. Salihagic,[100] A. Salnikov,[144] J. Salt,[168] B. M. Salvachua Ferrando,[6] D. Salvatore,[37a,37b] F. Salvatore,[150] A. Salvucci,[105] A. Salzburger,[30] D. Sampsonidis,[155] A. Sanchez,[103a,103b] J. Sánchez,[168] V. Sanchez Martinez,[168] H. Sandaker,[14] H. G. Sander,[82] M. P. Sanders,[99] M. Sandhoff,[176] T. Sandoval,[28] C. Sandoval,[163] R. Sandstroem,[100] D. P. C. Sankey,[130] A. Sansoni,[47] C. Santoni,[34] R. Santonico,[134a,134b] H. Santos,[125a] I. Santoyo Castillo,[150] K. Sapp,[124] J. G. Saraiva,[125a] T. Sarangi,[174] E. Sarkisyan-Grinbaum,[8] B. Sarrazin,[21] F. Sarri,[123a,123b] G. Sartisohn,[176] O. Sasaki,[65] Y. Sasaki,[156] N. Sasao,[67] I. Satsounkevitch,[91] G. Sauvage,[5,a] E. Sauvan,[5] J. B. Sauvan,[116] P. Savard,[159,f] V. Savinov,[124] D. O. Savu,[30] C. Sawyer,[119] L. Sawyer,[78,m] D. H. Saxon,[53] J. Saxon,[121] C. Sbarra,[20a] A. Sbrizzi,[3] D. A. Scannicchio,[164] M. Scarcella,[151] J. Schaarschmidt,[116] P. Schacht,[100] D. Schaefer,[121] A. Schaelicke,[46] S. Schaepe,[21] S. Schaetzel,[58b] U. Schäfer,[82] A. C. Schaffer,[116] D. Schaile,[99] R. D. Schamberger,[149] V. Scharf,[58a] V. A. Schegelsky,[122] D. Scheirich,[88] M. Schernau,[164] M. I. Scherzer,[35] C. Schiavi,[50a,50b] J. Schieck,[99] C. Schillo,[48] M. Schioppa,[37a,37b] S. Schlenker,[30] E. Schmidt,[48] K. Schmieden,[30] C. Schmitt,[82] C. Schmitt,[99] S. Schmitt,[58b] B. Schneider,[17] Y. J. Schnellbach,[73] U. Schnoor,[44] L. Schoeffel,[137] A. Schoening,[58b] A. L. S. Schorlemmer,[54] M. Schott,[82] D. Schouten,[160a] J. Schovancova,[126] M. Schram,[86] C. Schroeder,[82] N. Schroer,[58c] M. J. Schultens,[21] H.-C. Schultz-Coulon,[58a] H. Schulz,[16] M. Schumacher,[48] B. A. Schumm,[138] Ph. Schune,[137] A. Schwartzman,[144] Ph. Schwegler,[100] Ph. Schwemling,[137] R. Schwienhorst,[89] J. Schwindling,[137] T. Schwindt,[21] M. Schwoerer,[5] F. G. Sciacca,[17] E. Scifo,[116] G. Sciolla,[23] W. G. Scott,[130] F. Scutti,[21] J. Searcy,[88] G. Sedov,[42] E. Sedykh,[122] S. C. Seidel,[104] A. Seiden,[138] F. Seifert,[44] J. M. Seixas,[24a] G. Sekhniaidze,[103a] S. J. Sekula,[40] K. E. Selbach,[46] D. M. Seliverstov,[122] G. Sellers,[73] M. Seman,[145b] N. Semprini-Cesari,[20a,20b] C. Serfon,[30] L. Serin,[116] L. Serkin,[54] T. Serre,[84] R. Seuster,[160a] H. Severini,[112] A. Sfyrla,[30] E. Shabalina,[54] M. Shamim,[115] L. Y. Shan,[33a] J. T. Shank,[22] Q. T. Shao,[87] M. Shapiro,[15] P. B. Shatalov,[96] K. Shaw,[165a,165c] P. Sherwood,[77] S. Shimizu,[102] M. Shimojima,[101] T. Shin,[56] M. Shiyakova,[64] A. Shmeleva,[95] M. J. Shochet,[31] D. Short,[119] S. Shrestha,[63] E. Shulga,[97] M. A. Shupe,[7] P. Sicho,[126] A. Sidoti,[133a] F. Siegert,[48] Dj. Sijacki,[13a] O. Silbert,[173] J. Silva,[125a] Y. Silver,[154] D. Silverstein,[144] S. B. Silverstein,[147a] V. Simak,[127] O. Simard,[5] Lj. Simic,[13a] S. Simion,[116] E. Simioni,[82] B. Simmons,[77] R. Simoniello,[90a,90b] M. Simonyan,[36] P. Sinervo,[159] N. B. Sinev,[115] V. Sipica,[142]

G. Siragusa,[175] A. Sircar,[78] A. N. Sisakyan,[64,a] S. Yu. Sivoklokov,[98] J. Sjölin,[147a,147b] T. B. Sjursen,[14] L. A. Skinnari,[15] H. P. Skottowe,[57] K. Yu. Skovpen,[108] P. Skubic,[112] M. Slater,[18] T. Slavicek,[127] K. Sliwa,[162] V. Smakhtin,[173] B. H. Smart,[46] L. Smestad,[118] S. Yu. Smirnov,[97] Y. Smirnov,[97] L. N. Smirnova,[98,kk] O. Smirnova,[80] K. M. Smith,[53] M. Smizanska,[71] K. Smolek,[127] A. A. Snesarev,[95] G. Snidero,[75] J. Snow,[112] S. Snyder,[25] R. Sobie,[170,k] J. Sodomka,[127] A. Soffer,[154] D. A. Soh,[152,w] C. A. Solans,[30] M. Solar,[127] J. Solc,[127] E. Yu. Soldatov,[97] U. Soldevila,[168] E. Solfaroli Camillocci,[133a,133b] A. A. Solodkov,[129] O. V. Solovyanov,[129] V. Solovyev,[122] N. Soni,[1] A. Sood,[15] V. Sopko,[127] B. Sopko,[127] M. Sosebee,[8] R. Soualah,[165a,165c] P. Soueid,[94] A. M. Soukharev,[108] D. South,[42] S. Spagnolo,[72a,72b] F. Spanò,[76] R. Spighi,[20a] G. Spigo,[30] R. Spiwoks,[30] M. Spousta,[128,ll] T. Spreitzer,[159] B. Spurlock,[8] R. D. St. Denis,[53] J. Stahlman,[121] R. Stamen,[58a] E. Stanecka,[39] R. W. Stanek,[6] C. Stanescu,[135a] M. Stanescu-Bellu,[42] M. M. Stanitzki,[42] S. Stapnes,[118] E. A. Starchenko,[129] J. Stark,[55] P. Staroba,[126] P. Starovoitov,[42] R. Staszewski,[39] A. Staude,[99] P. Stavina,[145a,a] G. Steele,[53] P. Steinbach,[44] P. Steinberg,[25] I. Stekl,[127] B. Stelzer,[143] H. J. Stelzer,[89] O. Stelzer-Chilton,[160a] H. Stenzel,[52] S. Stern,[100] G. A. Stewart,[30] J. A. Stillings,[21] M. C. Stockton,[86] M. Stoebe,[86] K. Stoerig,[48] G. Stoicea,[26a] S. Stonjek,[100] A. R. Stradling,[8] A. Straessner,[44] J. Strandberg,[148] S. Strandberg,[147a,147b] A. Strandlie,[118] M. Strang,[110] E. Strauss,[144] M. Strauss,[112] P. Strizenec,[145b] R. Ströhmer,[175] D. M. Strom,[115] J. A. Strong,[76,a] R. Stroynowski,[40] B. Stugu,[14] I. Stumer,[25,a] J. Stupak,[149] P. Sturm,[176] N. A. Styles,[42] D. Su,[144] HS. Subramania,[3] R. Subramaniam,[78] A. Succurro,[12] Y. Sugaya,[117] C. Suhr,[107] M. Suk,[127] V. V. Sulin,[95] S. Sultansoy,[4c] T. Sumida,[67] X. Sun,[55] J. E. Sundermann,[48] K. Suruliz,[140] G. Susinno,[37a,37b] M. R. Sutton,[150] Y. Suzuki,[65] Y. Suzuki,[66] M. Svatos,[126] S. Swedish,[169] M. Swiatlowski,[144] I. Sykora,[145a] T. Sykora,[128] D. Ta,[106] K. Tackmann,[42] A. Taffard,[164] R. Tafirout,[160a] N. Taiblum,[154] Y. Takahashi,[102] H. Takai,[25] R. Takashima,[68] H. Takeda,[66] T. Takeshita,[141] Y. Takubo,[65] M. Talby,[84] A. A. Talyshev,[108,h] J. Y. C. Tam,[175] M. C. Tamsett,[78,mm] K. G. Tan,[87] J. Tanaka,[156] R. Tanaka,[116] S. Tanaka,[132] S. Tanaka,[65] A. J. Tanasijczuk,[143] K. Tani,[66] N. Tannoury,[84] S. Tapprogge,[82] S. Tarem,[153] F. Tarrade,[29] G. F. Tartarelli,[90a] P. Tas,[128] M. Tasevsky,[126] T. Tashiro,[67] E. Tassi,[37a,37b] Y. Tayalati,[136d] C. Taylor,[77] F. E. Taylor,[93] G. N. Taylor,[87] W. Taylor,[160b] M. Teinturier,[116] F. A. Teischinger,[30] M. Teixeira Dias Castanheira,[75] P. Teixeira-Dias,[76] K. K. Temming,[48] H. Ten Kate,[30] P. K. Teng,[152] S. Terada,[65] K. Terashi,[156] J. Terron,[81] M. Testa,[47] R. J. Teuscher,[159,k] J. Therhaag,[21] T. Theveneaux-Pelzer,[34] S. Thoma,[48] J. P. Thomas,[18] E. N. Thompson,[35] P. D. Thompson,[18] P. D. Thompson,[159] A. S. Thompson,[53] L. A. Thomsen,[36] E. Thomson,[121] M. Thomson,[28] W. M. Thong,[87] R. P. Thun,[88,a] F. Tian,[35] M. J. Tibbetts,[15] T. Tic,[126] V. O. Tikhomirov,[95,nn] Yu. A. Tikhonov,[108,h] S. Timoshenko,[97] E. Tiouchichine,[84] P. Tipton,[177] S. Tisserant,[84] T. Todorov,[5] S. Todorova-Nova,[162] B. Toggerson,[164] J. Tojo,[69] S. Tokár,[145a] K. Tokushuku,[65] K. Tollefson,[89] L. Tomlinson,[83] M. Tomoto,[102] L. Tompkins,[31] K. Toms,[104] A. Tonoyan,[14] C. Topfel,[17] N. D. Topilin,[64] E. Torrence,[115] H. Torres,[79] E. Torró Pastor,[168] J. Toth,[84,hh] F. Touchard,[84] D. R. Tovey,[140] H. L. Tran,[116] T. Trefzger,[175] L. Tremblet,[30] A. Tricoli,[30] I. M. Trigger,[160a] S. Trincaz-Duvoid,[79] M. F. Tripiana,[70] N. Triplett,[25] W. Trischuk,[159] B. Trocmé,[55] C. Troncon,[90a] M. Trottier-McDonald,[143] M. Trovatelli,[135a,135b] P. True,[89] M. Trzebinski,[39] A. Trzupek,[39] C. Tsarouchas,[30] J. C-L. Tseng,[119] M. Tsiakiris,[106] P. V. Tsiareshka,[91] D. Tsionou,[137] G. Tsipolitis,[10] S. Tsiskaridze,[12] V. Tsiskaridze,[48] E. G. Tskhadadze,[51a] I. I. Tsukerman,[96] V. Tsulaia,[15] J.-W. Tsung,[21] S. Tsuno,[65] D. Tsybychev,[149] A. Tua,[140] A. Tudorache,[26a] V. Tudorache,[26a] J. M. Tuggle,[31] A. N. Tuna,[121] M. Turala,[39] D. Turecek,[127] I. Turk Cakir,[4d] R. Turra,[90a,90b] P. M. Tuts,[35] A. Tykhonov,[74] M. Tylmad,[147a,147b] M. Tyndel,[130] K. Uchida,[21] I. Ueda,[156] R. Ueno,[29] M. Ughetto,[84] M. Ugland,[14] M. Uhlenbrock,[21] F. Ukegawa,[161] G. Unal,[30] A. Undrus,[25] G. Unel,[164] F. C. Ungaro,[48] Y. Unno,[65] D. Urbaniec,[35] P. Urquijo,[21] G. Usai,[8] L. Vacavant,[84] V. Vacek,[127] B. Vachon,[86] S. Vahsen,[15] N. Valencic,[106] S. Valentinetti,[20a,20b] A. Valero,[168] L. Valery,[34] S. Valkar,[128] E. Valladolid Gallego,[168] S. Vallecorsa,[153] J. A. Valls Ferrer,[168] R. Van Berg,[121] P. C. Van Der Deijl,[106] R. van der Geer,[106] H. van der Graaf,[106] R. Van Der Leeuw,[106] D. van der Ster,[30] N. van Eldik,[30] P. van Gemmeren,[6] J. Van Nieuwkoop,[143] I. van Vulpen,[106] M. Vanadia,[100] W. Vandelli,[30] A. Vaniachine,[6] P. Vankov,[42] F. Vannucci,[79] R. Vari,[133a] E. W. Varnes,[7] T. Varol,[85] D. Varouchas,[15] A. Vartapetian,[8] K. E. Varvell,[151] V. I. Vassilakopoulos,[56] F. Vazeille,[34] T. Vazquez Schroeder,[54] F. Veloso,[125a] S. Veneziano,[133a] A. Ventura,[72a,72b] D. Ventura,[85] M. Venturi,[48] N. Venturi,[159] V. Vercesi,[120a] M. Verducci,[139] W. Verkerke,[106] J. C. Vermeulen,[106] A. Vest,[44] M. C. Vetterli,[143,f] I. Vichou,[166] T. Vickey,[146c,oo] O. E. Vickey Boeriu,[146c] G. H. A. Viehhauser,[119] S. Viel,[169] M. Villa,[20a,20b] M. Villaplana Perez,[168] E. Vilucchi,[47] M. G. Vincter,[29] V. B. Vinogradov,[64] J. Virzi,[15] O. Vitells,[173] M. Viti,[42] I. Vivarelli,[48] F. Vives Vaque,[3] S. Vlachos,[10] D. Vladoiu,[99] M. Vlasak,[127] A. Vogel,[21] P. Vokac,[127] G. Volpi,[47] M. Volpi,[87] G. Volpini,[90a] H. von der Schmitt,[100] H. von Radziewski,[48] E. von Toerne,[21] V. Vorobel,[128] M. Vos,[168] R. Voss,[30] J. H. Vossebeld,[73] N. Vranjes,[137] M. Vranjes Milosavljevic,[106] V. Vrba,[126] M. Vreeswijk,[106] T. Vu Anh,[48] R. Vuillermet,[30] I. Vukotic,[31] Z. Vykydal,[127] W. Wagner,[176] P. Wagner,[21] S. Wahrmund,[44] J. Wakabayashi,[102] S. Walch,[88] J. Walder,[71] R. Walker,[99]

W. Walkowiak,[142] R. Wall,[177] P. Waller,[73] B. Walsh,[177] C. Wang,[45] H. Wang,[174] H. Wang,[40] J. Wang,[152] J. Wang,[33a] K. Wang,[86] R. Wang,[104] S. M. Wang,[152] T. Wang,[21] X. Wang,[177] A. Warburton,[86] C. P. Ward,[28] D. R. Wardrope,[77] M. Warsinsky,[48] A. Washbrook,[46] C. Wasicki,[42] I. Watanabe,[66] P. M. Watkins,[18] A. T. Watson,[18] I. J. Watson,[151] M. F. Watson,[18] G. Watts,[139] S. Watts,[83] A. T. Waugh,[151] B. M. Waugh,[77] M. S. Weber,[17] J. S. Webster,[31] A. R. Weidberg,[119] P. Weigell,[100] J. Weingarten,[54] C. Weiser,[48] P. S. Wells,[30] T. Wenaus,[25] D. Wendland,[16] Z. Weng,[152,w] T. Wengler,[30] S. Wenig,[30] N. Wermes,[21] M. Werner,[48] P. Werner,[30] M. Werth,[164] M. Wessels,[58a] J. Wetter,[162] K. Whalen,[29] A. White,[8] M. J. White,[87] R. White,[32b] S. White,[123a,123b] S. R. Whitehead,[119] D. Whiteson,[164] D. Whittington,[60] D. Wicke,[176] F. J. Wickens,[130] W. Wiedenmann,[174] M. Wielers,[80,e] P. Wienemann,[21] C. Wiglesworth,[36] L. A. M. Wiik-Fuchs,[21] P. A. Wijeratne,[77] A. Wildauer,[100] M. A. Wildt,[42,pp] I. Wilhelm,[128] H. G. Wilkens,[30] J. Z. Will,[99] E. Williams,[35] H. H. Williams,[121] S. Williams,[28] W. Willis,[35,a] S. Willocq,[85] J. A. Wilson,[18] A. Wilson,[88] I. Wingerter-Seez,[5] S. Winkelmann,[48] F. Winklmeier,[30] M. Wittgen,[144] T. Wittig,[43] J. Wittkowski,[99] S. J. Wollstadt,[82] M. W. Wolter,[39] H. Wolters,[125a,i] W. C. Wong,[41] G. Wooden,[88] B. K. Wosiek,[39] J. Wotschack,[30] M. J. Woudstra,[83] K. W. Wozniak,[39] K. Wraight,[53] M. Wright,[53] B. Wrona,[73] S. L. Wu,[174] X. Wu,[49] Y. Wu,[88] E. Wulf,[35] B. M. Wynne,[46] S. Xella,[36] M. Xiao,[137] S. Xie,[48] C. Xu,[33b,bb] D. Xu,[33a] L. Xu,[33b,qq] B. Yabsley,[151] S. Yacoob,[146b,rr] M. Yamada,[65] H. Yamaguchi,[156] Y. Yamaguchi,[156] A. Yamamoto,[65] K. Yamamoto,[63] S. Yamamoto,[156] T. Yamamura,[156] T. Yamanaka,[156] K. Yamauchi,[102] T. Yamazaki,[156] Y. Yamazaki,[66] Z. Yan,[22] H. Yang,[33e] H. Yang,[174] U. K. Yang,[83] Y. Yang,[110] Z. Yang,[147a,147b] S. Yanush,[92] L. Yao,[33a] Y. Yasu,[65] E. Yatsenko,[42] K. H. Yau Wong,[21] J. Ye,[40] S. Ye,[25] A. L. Yen,[57] E. Yildirim,[42] M. Yilmaz,[4b] R. Yoosoofmiya,[124] K. Yorita,[172] R. Yoshida,[6] K. Yoshihara,[156] C. Young,[144] C. J. S. Young,[119] S. Youssef,[22] D. Yu,[25] D. R. Yu,[15] J. Yu,[8] J. Yu,[113] L. Yuan,[66] A. Yurkewicz,[107] B. Zabinski,[39] R. Zaidan,[62] A. M. Zaitsev,[129,cc] S. Zambito,[23] L. Zanello,[133a,133b] D. Zanzi,[100] A. Zaytsev,[25] C. Zeitnitz,[176] M. Zeman,[127] A. Zemla,[39] O. Zenin,[129] T. Ženiš,[145a] D. Zerwas,[116] G. Zevi della Porta,[57] D. Zhang,[88] H. Zhang,[89] J. Zhang,[6] L. Zhang,[152] X. Zhang,[33d] Z. Zhang,[116] Z. Zhao,[33b] A. Zhemchugov,[64] J. Zhong,[119] B. Zhou,[88] N. Zhou,[164] Y. Zhou,[152] C. G. Zhu,[33d] H. Zhu,[42] J. Zhu,[88] Y. Zhu,[33b] X. Zhuang,[33a] A. Zibell,[99] D. Zieminska,[60] N. I. Zimin,[64] C. Zimmermann,[82] R. Zimmermann,[21] S. Zimmermann,[21] S. Zimmermann,[48] Z. Zinonos,[123a,123b] M. Ziolkowski,[142] R. Zitoun,[5] L. Živković,[35] V. V. Zmouchko,[129,a] G. Zobernig,[174] A. Zoccoli,[20a,20b] M. zur Nedden,[16] V. Zutshi[107] and L. Zwalinski[30]

(ATLAS Collaboration)

[1]*School of Chemistry and Physics, University of Adelaide, Adelaide, Australia*
[2]*Physics Department, SUNY Albany, Albany New York, USA*
[3]*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
[4a]*Department of Physics, Ankara University, Ankara, Turkey*
[4b]*Department of Physics, Gazi University, Ankara, Turkey*
[4c]*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
[4d]*Turkish Atomic Energy Authority, Ankara, Turkey*
[5]*LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France*
[6]*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
[7]*Department of Physics, University of Arizona, Tucson, Arizona, USA*
[8]*Department of Physics, The University of Texas at Arlington, Arlington, Texas, USA*
[9]*Physics Department, University of Athens, Athens, Greece*
[10]*Physics Department, National Technical University of Athens, Zografou, Greece*
[11]*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[12]*Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain*
[13a]*Institute of Physics, University of Belgrade, Belgrade, Serbia*
[13b]*Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia*
[14]*Department for Physics and Technology, University of Bergen, Bergen, Norway*
[15]*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
[16]*Department of Physics, Humboldt University, Berlin, Germany*
[17]*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[18]*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[19a]*Department of Physics, Bogazici University, Istanbul, Turkey*

[19b]*Department of Physics, Dogus University, Istanbul, Turkey*
[19c]*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
[20a]*INFN Sezione di Bologna, Bologna, Italy*
[20b]*Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*
[21]*Physikalisches Institut, University of Bonn, Bonn, Germany*
[22]*Department of Physics, Boston University, Boston, Massachusetts, USA*
[23]*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
[24a]*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Sao Paulo, Brazil*
[24b]*Federal University of Juiz de Fora (UFJF), Juiz de Fora, Sao Paulo, Brazil*
[24c]*Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei, Sao Paulo, Brazil*
[24d]*Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil*
[25]*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
[26a]*National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[26b]*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca, Romania*
[26c]*University Politehnica Bucharest, Bucharest, Romania*
[26d]*West University in Timisoara, Timisoara, Romania*
[27]*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
[28]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[29]*Department of Physics, Carleton University, Ottawa, Ontario, Canada*
[30]*CERN, Geneva, Switzerland*
[31]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
[32a]*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
[32b]*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[33a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[33b]*Department of Modern Physics, University of Science and Technology of China, Anhui, China*
[33c]*Department of Physics, Nanjing University, Jiangsu, China*
[33d]*School of Physics, Shandong University, Shandong, China*
[33e]*Physics Department, Shanghai Jiao Tong University, Shanghai, China*
[34]*Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France*
[35]*Nevis Laboratory, Columbia University, Irvington, New York, USA*
[36]*Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark*
[37a]*INFN Gruppo Collegato di Cosenza, Rende, Italy*
[37b]*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
[38a]*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
[38b]*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
[39]*The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland*
[40]*Physics Department, Southern Methodist University, Dallas, Texas, USA*
[41]*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
[42]*DESY, Hamburg and Zeuthen, Germany*
[43]*Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
[44]*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
[45]*Department of Physics, Duke University, Durham, North Carolina, USA*
[46]*SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[47]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[48]*Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany*
[49]*Section de Physique, Université de Genève, Geneva, Switzerland*
[50a]*INFN Sezione di Genova, Genova, Italy*
[50b]*Dipartimento di Fisica, Università di Genova, Genova, Italy*
[51a]*E. Andronikashvili Institute of Physics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
[51b]*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
[52]*II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
[53]*SUPA–School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[54]*II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany*
[55]*Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France*
[56]*Department of Physics, Hampton University, Hampton, Virginia, USA*

[57]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA
[58a]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[58b]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[58c]ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
[59]Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
[60]Department of Physics, Indiana University, Bloomington, Indiana, USA
[61]Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
[62]University of Iowa, Iowa City, Iowa, USA
[63]Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA
[64]Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
[65]KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[66]Graduate School of Science, Kobe University, Kobe, Japan
[67]Faculty of Science, Kyoto University, Kyoto, Japan
[68]Kyoto University of Education, Kyoto, Japan
[69]Department of Physics, Kyushu University, Fukuoka, Japan
[70]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[71]Physics Department, Lancaster University, Lancaster, United Kingdom
[72a]INFN Sezione di Lecce, Italy
[72b]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[73]Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[74]Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[75]School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[76]Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[77]Department of Physics and Astronomy, University College London, London, United Kingdom
[78]Louisiana Tech University, Ruston, Louisiana, USA
[79]Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[80]Fysiska institutionen, Lunds universitet, Lund, Sweden
[81]Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[82]Institut für Physik, Universität Mainz, Mainz, Germany
[83]School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[84]CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[85]Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA
[86]Department of Physics, McGill University, Montreal, Quebec, Canada
[87]School of Physics, University of Melbourne, Victoria, Australia
[88]Department of Physics, The University of Michigan, Ann Arbor, Michigan, USA
[89]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA
[90a]INFN Sezione di Milano, Milano, Italy
[90b]Dipartimento di Fisica, Università di Milano, Milano, Italy
[91]B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[92]National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[93]Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[94]Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada
[95]P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
[96]Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[97]Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
[98]D.V.Skobeltsyn Institute of Nuclear Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
[99]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[100]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[101]Nagasaki Institute of Applied Science, Nagasaki, Japan
[102]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
[103a]INFN Sezione di Napoli, Napoli, Italy
[103b]Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
[104]Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA

[105]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[106]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[107]Department of Physics, Northern Illinois University, DeKalb, Illinois, USA
[108]Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
[109]Department of Physics, New York University, New York, New York, USA
[110]Ohio State University, Columbus, Ohio, USA
[111]Faculty of Science, Okayama University, Okayama, Japan
[112]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
[113]Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
[114]Palacký University, RCPTM, Olomouc, Czech Republic
[115]Center for High Energy Physics, University of Oregon, Eugene, OR, USA
[116]LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
[117]Graduate School of Science, Osaka University, Osaka, Japan
[118]Department of Physics, University of Oslo, Oslo, Norway
[119]Department of Physics, Oxford University, Oxford, United Kingdom
[120a]INFN Sezione di Pavia, Italy
[120b]Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[121]Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA
[122]Petersburg Nuclear Physics Institute, Gatchina, Russia
[123a]INFN Sezione di Pisa, Pisa, Italy
[123b]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[124]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
[125a]Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
[125b]Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
[126]Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[127]Czech Technical University in Prague, Praha, Czech Republic
[128]Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[129]State Research Center Institute for High Energy Physics, Protvino, Russia
[130]Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[131]Physics Department, University of Regina, Regina, Saskatchewan, Canada
[132]Ritsumeikan University, Kusatsu, Shiga, Japan
[133a]INFN Sezione di Roma I, Roma, Italy
[133b]Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[134a]INFN Sezione di Roma Tor Vergata, Roma, Italy
[134b]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[135a]INFN Sezione di Roma Tre, Roma, Italy
[135b]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
[136a]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca, Morocco
[136b]Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat, Morocco
[136c]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
[136d]Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco
[136e]Faculté des sciences, Université Mohammed V-Agdal, Rabat, Morocco
[137]DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France
[138]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA
[139]Department of Physics, University of Washington, Seattle, Washington, USA
[140]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[141]Department of Physics, Shinshu University, Nagano, Japan
[142]Fachbereich Physik, Universität Siegen, Siegen, Germany
[143]Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada
[144]SLAC National Accelerator Laboratory, Stanford, California, USA
[145a]Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava, Slovak Republic
[145b]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic

[146a]*Department of Physics, University of Cape Town, Cape Town, South Africa*
[146b]*Department of Physics, University of Johannesburg, Johannesburg, South Africa*
[146c]*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[147a]*Department of Physics, Stockholm University, Sweden*
[147b]*The Oskar Klein Centre, Stockholm, Sweden*
[148]*Physics Department, Royal Institute of Technology, Stockholm, Sweden*
[149]*Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, New York, USA*
[150]*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
[151]*School of Physics, University of Sydney, Sydney, Australia*
[152]*Institute of Physics, Academia Sinica, Taipei, Taiwan*
[153]*Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel*
[154]*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
[155]*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[156]*International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan*
[157]*Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
[158]*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
[159]*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
[160a]*TRIUMF, Vancouver, British Columbia, Canada*
[160b]*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
[161]*Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
[162]*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
[163]*Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia*
[164]*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
[165a]*INFN Gruppo Collegato di Udine, Udine, Italy*
[165b]*ICTP, Trieste, Italy*
[165c]*Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy*
[166]*Department of Physics, University of Illinois, Urbana, Illinois, USA*
[167]*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[168]*Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain*
[169]*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
[170]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
[171]*Department of Physics, University of Warwick, Coventry, United Kingdom*
[172]*Waseda University, Tokyo, Japan*
[173]*Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel*
[174]*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
[175]*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany*
[176]*Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[177]*Department of Physics, Yale University, New Haven, Connecticut, USA*
[178]*Yerevan Physics Institute, Yerevan, Armenia*
[179]*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*

[a]Deceased.
[b]Also at Department of Physics, King's College London, London, United Kingdom.
[c]Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal.
[d]Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal.
[e]Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.
[f]Also at TRIUMF, Vancouver BC, Canada.
[g]Also at Department of Physics, California State University, Fresno CA, USA.
[h]Also at Novosibirsk State University, Novosibirsk, Russia.
[i]Also at Department of Physics, University of Coimbra, Coimbra, Portugal.
[j]Also at Università di Napoli Parthenope, Napoli, Italy.
[k]Also at Institute of Particle Physics (IPP), Canada.
[l]Also at Department of Physics, Middle East Technical University, Ankara, Turkey.

[m]Also at Louisiana Tech University, Ruston LA, USA.
[n]Also at Dep Fisica and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.
[o]Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI, USA.
[p]Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[q]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[r]Also at Department of Physics, University of Cape Town, Cape Town, South Africa.
[s]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[t]Also at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan.
[u]Also at Manhattan College, New York NY, USA.
[v]Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.
[w]Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.
[x]Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
[y]Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France.
[z]Also at School of Physical Sciences, National Institute of Science Education and Research, Bhubaneswar, India.
[aa]Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy.
[bb]Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France.
[cc]Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[dd]Also at Section de Physique, Université de Genève, Geneva, Switzerland.
[ee]Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal.
[ff]Also at Department of Physics, The University of Texas at Austin, Austin TX, USA.
[gg]Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, USA.
[hh]Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[ii]Also at DESY, Hamburg and Zeuthen, Germany.
[jj]Also at International School for Advanced Studies (SISSA), Trieste, Italy.
[kk]Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia.
[ll]Also at Nevis Laboratory, Columbia University, Irvington NY, USA.
[mm]Also at Physics Department, Brookhaven National Laboratory, Upton NY, USA.
[nn]Also at Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia.
[oo]Also at Department of Physics, Oxford University, Oxford, United Kingdom.
[pp]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[qq]Also at Department of Physics, The University of Michigan, Ann Arbor MI, USA.
[rr]Also at Discipline of Physics, University of KwaZulu-Natal, Durban, South Africa.