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Search for Higgs and Z Boson Decays to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ with the ATLAS Detector

G. Aad *et al.**

(ATLAS Collaboration)

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A search for the decays of the Higgs and Z bosons to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ ($n = 1, 2, 3$) is performed with pp collision data samples corresponding to integrated luminosities of up to 20.3 fb^{-1} collected at $\sqrt{s} = 8 \text{ TeV}$ with the ATLAS detector at the CERN Large Hadron Collider. No significant excess of events is observed above expected backgrounds and 95% C.L. upper limits are placed on the branching fractions. In the $J/\psi\gamma$ final state the limits are 1.5×10^{-3} and 2.6×10^{-6} for the Higgs and Z boson decays, respectively, while in the $\Upsilon(1S, 2S, 3S)\gamma$ final states the limits are $(1.3, 1.9, 1.3) \times 10^{-3}$ and $(3.4, 6.5, 5.4) \times 10^{-6}$, respectively.

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Rare decays of the recently discovered Higgs boson [1,2] to a quarkonium state and a photon may offer unique sensitivity to both the magnitude and sign of the Yukawa couplings of the Higgs boson to quarks [3–6]. These couplings are challenging to access in hadron colliders through the direct $H \rightarrow q\bar{q}$ decays, owing to the overwhelming QCD background [7].

Among the channels proposed as probes of the light quark Yukawa couplings [4,6], those with the heavy quarkonia J/ψ or $\Upsilon(nS)$ ($n = 1, 2, 3$), collectively denoted as Q , in the final state are the most readily accessible, without requirements for dedicated triggers and reconstruction methods beyond those used for identifying the J/ψ or Υ . In particular, the decay $H \rightarrow J/\psi\gamma$ may represent a viable probe of the $Hc\bar{c}$ coupling [4], which is sensitive to physics beyond the Standard Model (SM) [8,9], at the Large Hadron Collider (LHC). The expected SM branching fractions for these decays have been calculated to be $\mathcal{B}(H \rightarrow J/\psi\gamma) = (2.8 \pm 0.2) \times 10^{-6}$, $\mathcal{B}[H \rightarrow \Upsilon(nS)\gamma] = (6.1_{-6.1}^{+17.4}, 2.0_{-1.3}^{+1.9}, 2.4_{-1.3}^{+1.8}) \times 10^{-10}$ [5]. No experimental information on these branching fractions exists. These decays are a source of background and potential control sample for the nonresonant decays $H \rightarrow \mu^+\mu^-\gamma$. These nonresonant decays are sensitive to new physics [10].

Rare decay modes of the Z boson have attracted attention focused on establishing their sensitivity to new physics [11]. Several estimates of the SM branching fraction for the decay $Z \rightarrow J/\psi\gamma$ are available [12–14] with the most recent being $(9.96 \pm 1.86) \times 10^{-8}$ [14]. Measuring these $Z \rightarrow Q\gamma$ branching fractions, benefiting from the larger production cross section relative to the Higgs case, would provide an

important benchmark for the search and eventual observation of $H \rightarrow Q\gamma$ decays. Additionally, experimental access to resonant $Q\gamma$ decay modes would also provide an invaluable tool for the more challenging measurement of inclusive associated $Q\gamma$ production, which has been suggested as a promising probe of the nature of quarkonium production in hadronic collisions [15,16].

The decays $Z \rightarrow Q\gamma$ have not yet been observed, with the only experimental information arising from inclusive measurements, such as $\mathcal{B}(Z \rightarrow J/\psi X) = (3.51_{-0.25}^{+0.23}) \times 10^{-3}$ and the 95% confidence level (C.L.) upper limits $\mathcal{B}[Z \rightarrow \Upsilon(nS)X] < (4.4, 13.9, 9.4) \times 10^{-5}$, from LEP experiments [17–21].

This Letter presents a search for decays of the recently observed Higgs boson and the Z boson to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ final states. The decays $J/\psi \rightarrow \mu^+\mu^-$ and $\Upsilon(nS) \rightarrow \mu^+\mu^-$ are used to reconstruct the quarkonium states. The search is performed with a sample of pp collision data corresponding to an integrated luminosity of 19.2 fb^{-1} (20.3 fb^{-1}) for the $J/\psi\gamma$ [$\Upsilon(nS)\gamma$] analysis, respectively, recorded at a center-of-mass energy $\sqrt{s} = 8 \text{ TeV}$ with the ATLAS detector [22], described in detail in Ref. [23].

Higgs boson production is modeled using the POWHEG-BOX Monte Carlo (MC) event generator [24–28], separately for the gluon fusion (ggF) and vector-boson fusion (VBF) processes calculated in quantum chromodynamics (QCD) up to next-to-leading order in α_s . The Higgs boson transverse momentum (p_T) distribution predicted for the ggF process is reweighted to match the calculations of Refs. [29,30], which include QCD corrections up to next-to-next-to-leading order and QCD soft-gluon resummations up to next-to-next-to-leading logarithms. Quark mass effects in ggF production [31] are also accounted for.

Physics beyond the SM that modifies the charm coupling can also change production dynamics and branching fractions. In this analysis we assume the production rates and dynamics for a SM Higgs boson with $m_H = 125 \text{ GeV}$, obtained from Ref. [32], with an uncertainty on the

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

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dominant ggF production mode of 12%. The VBF signal model is appropriately scaled to account for the production of a Higgs boson in association with a W or Z boson or in association with a $t\bar{t}$ pair, correcting for the relative production rates and experimental acceptances for these channels. Contributions from nonresonant $H \rightarrow (Z^*/\gamma^*)\gamma \rightarrow \mu^+\mu^-\gamma$ decays are expected to be negligible with respect to the present sensitivity [33–35].

The POWHEG-BOX MC event generator is also used to model Z boson production. The total cross section is estimated from Ref. [36], with an uncertainty of 4%.

The Higgs and Z boson decays are simulated as a cascade of two-body decays. Effects of the helicity of the quarkonium states on the dimuon kinematics are accounted for in both cases. For Higgs and Z boson events generated using POWHEG-BOX, PYTHIA8.1 [37,38] is used to simulate showering and hadronization while PHOTOS [39,40] is used to provide QED radiative corrections to the final state. The simulated events are passed through the full GEANT4 simulation of the ATLAS detector [41,42] and processed with the same software used to reconstruct data events.

The data used to perform the search in the $J/\psi\gamma$ channel were collected using a trigger that required at least one muon with $p_T > 18$ GeV. The events used in the $\Upsilon(nS)\gamma$ channel were collected with a trigger requiring an isolated muon with $p_T > 24$ GeV and a dimuon trigger with p_T thresholds of 18 and 8 GeV for each of the muons, respectively. Events are retained for analysis if they were collected under stable LHC beam conditions and the detector components were operating normally.

Muons are reconstructed from inner-detector tracks combined with independent muon spectrometer tracks or track segments [43] and are required to have $p_T^\mu > 3$ GeV and pseudorapidity $|\eta^\mu| < 2.5$. Candidate $\mathcal{Q} \rightarrow \mu^+\mu^-$ decays are reconstructed from pairs of oppositely charged muons consistent with originating from a common vertex. The highest- p_T muon in a pair, called the leading muon in the following, is required to have $p_T^\mu > 20$ GeV. Dimuons with a mass, $m_{\mu\mu}$, within 0.2 GeV of the J/ψ mass [17] are identified as $J/\psi \rightarrow \mu^+\mu^-$ candidates. In case both muons in the pair are within $|\eta^\mu| < 1.05$, the said requirement is tightened to 0.15 GeV. Dimuons with $8.0 < m_{\mu\mu} < 12.0$ GeV are considered as $\Upsilon(nS) \rightarrow \mu^+\mu^-$ candidates. The transverse momentum of each $\mathcal{Q} \rightarrow \mu^+\mu^-$ candidate, $p_T^{\mu\mu}$, is required to exceed 36 GeV.

Selected $\mathcal{Q} \rightarrow \mu^+\mu^-$ candidates are subjected to isolation and vertex quality requirements. The sum of the p_T of the reconstructed inner-detector tracks and calorimeter energy deposits within $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.2$ of the leading muon is required to be less than 10% of the muon's p_T . The transverse momentum of the inner-detector track associated with the leading muon is subtracted from the sum and the subleading muon is also subtracted if it falls within the isolation cone. To reject backgrounds from

b -hadron decays, the measured transverse decay length L_{xy} between the dimuon vertex and the primary pp vertex is required to be less than three times its uncertainty $\sigma_{L_{xy}}$. In this case, the primary pp vertex is defined as the reconstructed vertex with the highest $\sum_i p_{Ti}^2$ of all associated tracks used to form the vertex.

Photon reconstruction is seeded by clusters of energy in the electromagnetic calorimeter. Clusters without matching tracks are classified as unconverted photon candidates. Clusters matched to tracks consistent with the hypothesis of a photon conversion into an e^+e^- pair are classified as converted photon candidates [44]. Reconstructed photon candidates are required to have transverse momentum $p_T^\gamma > 36$ GeV, pseudorapidity $|\eta^\gamma| < 2.37$, excluding the barrel/endcap calorimeter transition region $1.37 < |\eta^\gamma| < 1.52$, and to satisfy the “tight” photon identification criteria [45]. To further suppress the contamination from jets, an isolation requirement is imposed. The sum of the transverse momentum of all tracks and calorimeter energy deposits within $\Delta R = 0.2$ of the photon direction, excluding those associated with the reconstructed photon, is required to be less than 8% of the photon's transverse momentum.

Combinations of a $\mathcal{Q} \rightarrow \mu^+\mu^-$ candidate and a photon, satisfying $\Delta\phi(\mu^+\mu^-, \gamma) > 0.5$, are retained for further analysis. To improve the sensitivity of the search, the events are classified into four exclusive categories, based upon the pseudorapidity of the muons and the photon reconstruction classification. Events where both muons are within the region $|\eta^\mu| < 1.05$ and the photon is (is not) classified as a conversion constitute the “barrel converted” (BC) [“barrel unconverted” (BU)] category. Events where at least one of the muons is outside the region $|\eta^\mu| < 1.05$ and the photon is (is not) classified as a conversion constitute the “endcap converted” (EC) [“endcap unconverted” (EU)] category. The number of candidates observed in each category following the complete event selection is shown in Table I.

The total signal efficiency (kinematic acceptance, trigger, and reconstruction efficiencies) in the $J/\psi\gamma$ final state is 22% and 12% for the Higgs and Z boson decays, respectively. The corresponding efficiencies for the $\Upsilon(nS)\gamma$ final state are 28% and 15%. The $m_{\mu\mu\gamma}$ resolution is similar for both the Higgs and Z boson decays and varies between 1.2% and 1.8%. The $m_{\mu\mu}$ resolution is 1.4% and 2.4% for the barrel and endcap categories, respectively.

The main source of background, referred to as inclusive QCD background, is dominated by inclusive quarkonium production where a jet in the event is reconstructed as a photon. For the $\Upsilon(nS)\gamma$ final state, events containing $Z \rightarrow \mu^+\mu^-$ decays with final-state photon radiation (FSR) constitute a second source of background, a contribution which is found to be negligible in the $J/\psi\gamma$ final state. The normalization of both of these background sources is extracted directly from a fit to data. The modeling of the

TABLE I. The number of observed events in each analysis category. For comparison, the expected background yield is given in parentheses for the two $m_{\mu\mu\gamma}$ ranges of interest. The Higgs and Z boson contributions expected for branching fraction values of 10^{-3} and 10^{-6} , respectively, are also shown. For $\Upsilon(nS)\gamma$, the 1S, 2S, and 3S contributions are summed.

Category	Observed (expected background)				Signal		
	All	Mass range [GeV]		Z	H		
		80–100	115–135			\mathcal{B} [10^{-6}]	\mathcal{B} [10^{-3}]
$J/\psi\gamma$							
BU	30	9	(8.9 ± 1.3)	5	(5.0 ± 0.9)	1.29 ± 0.07	1.96 ± 0.24
BC	29	8	(6.0 ± 0.7)	3	(5.5 ± 0.6)	0.63 ± 0.03	1.06 ± 0.13
EU	35	8	(8.7 ± 1.0)	10	(5.8 ± 0.8)	1.37 ± 0.07	1.47 ± 0.18
EC	23	6	(5.6 ± 0.7)	2	(3.0 ± 0.4)	0.99 ± 0.05	0.93 ± 0.12
$\Upsilon(nS)\gamma$							
BU	93	42	(39 ± 6)	16	(12.9 ± 2.0)	1.67 ± 0.09	2.6 ± 0.3
BC	71	32	(27.7 ± 2.4)	5	(9.7 ± 1.2)	0.79 ± 0.04	1.45 ± 0.18
EU	125	49	(47 ± 6)	16	(17.8 ± 2.4)	2.24 ± 0.12	2.5 ± 0.3
EC	85	31	(31 ± 5)	18	(12.3 ± 1.9)	1.55 ± 0.08	1.60 ± 0.20

inclusive QCD background shape, obtained with a data-driven approach, and of the $Z \rightarrow \mu^+\mu^-$ background shape, obtained from simulation, is described in the following two paragraphs.

The background from inclusive QCD processes is modeled with a nonparametric data-driven approach using templates to describe the kinematic distributions. The approach exploits a sample of loosely selected $\mu^+\mu^-\gamma$ events, around 2400 in the $J/\psi\gamma$ channel and around 3200 in the $\Upsilon(nS)\gamma$ channel. These control samples are formed from events satisfying the nominal $\mathcal{Q}\gamma$ selection, but with relaxed dimuon and photon transverse momenta ($p_T^\gamma > 25$ GeV and $p_T^{\mu\mu} > 25$ GeV) and isolation requirements (separate fractional calorimeter energy and track momentum isolation for the photon and dimuon system of less than 60%). Contamination of this sample from signal events is expected to be negligible. Probability density functions (pdfs) used to model the $p_T^{\mu\mu}$, p_T^γ , $\Delta\eta(\mu^+\mu^-, \gamma)$ and $\Delta\phi(\mu^+\mu^-, \gamma)$ distributions of this control sample, independently for each category, are constructed using Gaussian kernel density estimation [46]. To account for kinematic correlations, the distributions of p_T^γ , $\Delta\eta(\mu^+\mu^-, \gamma)$ and $\Delta\phi(\mu^+\mu^-, \gamma)$ are estimated in eight exclusive regions of $p_T^{\mu\mu}$. In the case of the dimuon and photon isolation variables, correlations are accounted for by using two-dimensional histograms derived in five exclusive regions of $p_T^{\mu\mu}$. The $m_{\mu\mu}$ distributions are modeled using Gaussian pdfs, with parameters derived from a fit to the control sample. In the $\Upsilon(nS)\gamma$ channel, the data control sample is corrected for contamination from $Z \rightarrow \mu^+\mu^-\gamma$ decays. The pdfs of these kinematic and isolation variables are sampled to generate an ensemble of pseudocandidates, each with a complete $\mathcal{Q}\gamma$ four-vector and an associated pair of correlated dimuon and photon isolation values. The nominal selection requirements are imposed on the ensemble and

the surviving pseudocandidates are used to construct templates for the kinematic distributions, notably the inclusive QCD background $m_{\mu\mu\gamma}$ and $p_T^{\mu\mu}$ distributions.

The background from $Z \rightarrow \mu^+\mu^-\gamma$ decays is modeled with templates derived from a sample of simulated Z boson events with $m_{\mu\mu}$ in the $\Upsilon(nS)$ mass region. To validate this background model with data, the sidebands of the $m_{\mu\mu\gamma}$ distribution in several validation regions, defined by relaxed kinematic or isolation requirements, are used to compare the prediction of the background model with the data. Good agreement within the statistical uncertainties is observed.

The composition of the inclusive QCD background and the $Z \rightarrow \mu^+\mu^-\gamma$ decay contribution is investigated with data. The details of the composition do not enter directly the background estimation for this search, but the composition itself is a crucial input in feasibility studies for future searches or measurements, where projections of these backgrounds to different center-of-mass energies or luminosity conditions are needed. To facilitate this study, the selection requirements on $m_{\mu\mu}$ and $|L_{xy}/\sigma_{L_{xy}}|$ are relaxed to include the sideband regions. In the $J/\psi\gamma$ final state, a simultaneous unbinned maximum likelihood fit to the $m_{\mu\mu}$ and $|L_{xy}/\sigma_{L_{xy}}|$ distributions is performed. Once the simultaneous fit is performed, the composition of the subset of events satisfying the nominal $m_{\mu\mu}$ and $|L_{xy}/\sigma_{L_{xy}}|$ requirements is estimated. After the complete event selection, around 56% of the events originate from prompt J/ψ production, 3% from nonprompt J/ψ production (from b -hadron decays) and 41% are combinatoric backgrounds from nonresonant dimuon events.

A separate simultaneous fit to the $m_{\mu\mu\gamma}$ and $m_{\mu\mu}$ distributions of the same sample of candidate J/ψ events finds no significant contribution from $Z \rightarrow \mu^+\mu^-\gamma$ decays, a

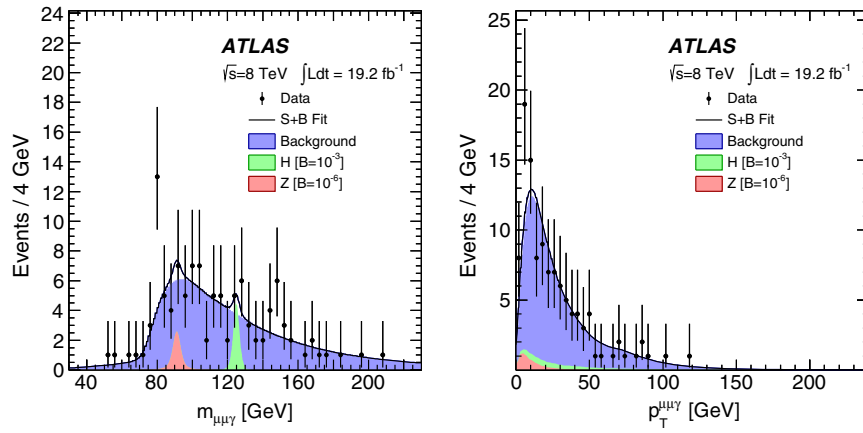


FIG. 1 (color online). The $m_{\mu\gamma}$ and $p_T^{\mu\gamma}$ distributions of the selected $J/\psi\gamma$ candidates, along with the results of the unbinned maximum likelihood fit to the signal and background model ($S + B$ fit). The error bars on the data points correspond to the statistical uncertainties. The Higgs and Z boson contributions as expected for branching fraction values of 10^{-3} and 10^{-6} , respectively, are also shown.

conclusion that is also supported by a study based on simulated $Z \rightarrow \mu^+\mu^-$ events.

For the $\Upsilon(nS)\gamma$ final state a simultaneous fit is performed to the $m_{\mu\mu}$ and $m_{\mu\gamma}$ distributions. After the full event selection, inclusive $\Upsilon(nS)$ production accounts for 7% of events, 27% of the events are produced in $Z \rightarrow \mu^+\mu^-\gamma$ decays, and 66% of the events are associated with combinatoric backgrounds from nonresonant dimuon events. The contribution from $Z \rightarrow \mu^+\mu^-\gamma$ decays is in agreement with the MC expectation.

Trigger efficiencies and efficiencies for muon and photon identification are determined from samples of $Z \rightarrow \ell\ell$, $Z \rightarrow \ell\ell\gamma$ ($\ell = e, \mu$), and $J/\psi \rightarrow \mu^+\mu^-$ decays in data [43,47]. The systematic uncertainty on the expected signal yield associated with the trigger efficiency is estimated to be 1.7%. The photon (both converted and unconverted) and muon reconstruction and identification efficiency uncertainties are estimated to be 0.5% (0.7%) and 0.4% (0.4%) for the Higgs boson (Z boson) signal, respectively. An uncertainty on the integrated luminosity of 2.8% is derived using the method described in Ref. [48]. The photon energy scale uncertainty, determined from $Z \rightarrow e^+e^-$ and validated using $Z \rightarrow \ell\ell\gamma$ decays [49], is propagated through the simulated signal samples as a function of η^γ and p_T^γ . The uncertainty associated with the description of the photon energy scale in the simulation is found to be less than 0.2% of the three-body invariant mass while the uncertainty associated with the photon energy resolution is found to be negligible relative to the overall three-body invariant mass resolution. Similarly, the systematic uncertainty associated with the muon momentum measurement is determined using data samples of $J/\psi \rightarrow \mu^+\mu^-$ and $Z \rightarrow \mu^+\mu^-$ decays and validated using $\Upsilon(nS) \rightarrow \mu^+\mu^-$ decays [43]. For the p_T range relevant to this analysis, the systematic uncertainties associated with the muon momentum scale are negligible.

The uncertainty in the shape of the inclusive QCD background is estimated through the study of variations in the background modeling procedure. The shape of the pdf is allowed to vary around the nominal shape within an envelope associated with shifts in the $p_T^{\mu\mu}$ and p_T^γ distributions. Furthermore, a separate background model, generated without removing the contamination from $Z \rightarrow \mu^+\mu^-\gamma$ decays, provides an upper bound on potential mismodeling associated with this process.

Results are extracted by means of a simultaneous unbinned maximum likelihood fit, performed to the selected events with $30 \text{ GeV} < m_{\mu\mu\gamma} < 230 \text{ GeV}$ separately in each of the analysis categories. In the $J/\psi\gamma$ final state, the fit is performed on the $m_{\mu\mu\gamma}$ and $p_T^{\mu\mu\gamma}$ distributions, while for the $\Upsilon(nS)\gamma$ candidates a similar fit is performed using the $m_{\mu\mu\gamma}$, $p_T^{\mu\mu\gamma}$, and $m_{\mu\mu}$ distributions. The latter distribution provides discrimination between the three $\Upsilon(nS)$ states and constrains the $Z \rightarrow \mu^+\mu^-\gamma$ background normalization. No significant $Z \rightarrow Q\gamma$ or $H \rightarrow Q\gamma$ signals are observed, as shown in Figs. 1 and 2.

Upper limits on the branching fractions for the Higgs and Z boson decays to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ are set using the CL_s modified frequentist formalism [50] with the profile likelihood ratio test statistic [51]. The expected SM production cross sections are assumed for the Higgs and Z bosons. The results are summarized in Table II.

The 95% C.L. upper limit on the branching fraction for $H \rightarrow J/\psi\gamma$ decays corresponds to about 540 times the expected SM branching fraction. The upper limits on the $Z \rightarrow J/\psi\gamma$ and $Z \rightarrow \Upsilon(nS)\gamma$ branching fractions significantly constrain the allowed range of values obtained from theoretical calculations [12–14]. Upper limits are also set on the combined branching fractions $\mathcal{B}[H \rightarrow \Upsilon(nS)\gamma] < 2.0 \times 10^{-3}$ and $\mathcal{B}[Z \rightarrow \Upsilon(nS)\gamma] < 7.9 \times 10^{-6}$, where the relative contribution of each final state to the potential

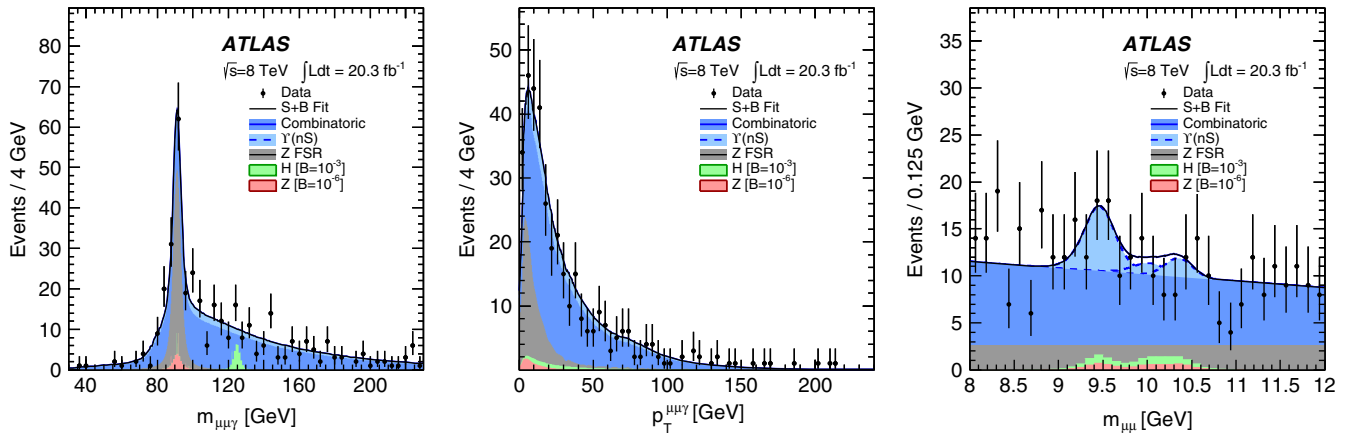


FIG. 2 (color online). The $m_{\mu\mu\gamma}$, $p_T^{\mu\mu\gamma}$, and $m_{\mu\mu}$ distributions of the selected $\Upsilon(nS)\gamma$ candidates, along with the results of the unbinned maximum likelihood fit to the signal and background model ($S + B$ fit). The error bars on the data points correspond to the statistical uncertainties. The Higgs and Z boson contributions as expected for branching fraction values of 10^{-3} and 10^{-6} , respectively, for each of the $\Upsilon(nS)$ are also shown.

signal is profiled (allowed to float to the values that maximize the likelihood) during the fit.

In conclusion, the first search for the decays of the SM Higgs and Z bosons to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ ($n = 1, 2, 3$) has been performed with $\sqrt{s} = 8$ TeV pp collision data samples corresponding to integrated luminosities of up to 20.3 fb^{-1} collected with the ATLAS detector at the LHC. No significant excess of events is observed above the background. In the $J/\psi\gamma$ final state, the 95% C.L. upper limits on the relevant branching fractions for the SM Higgs and Z bosons are 1.5×10^{-3} and 2.6×10^{-6} , respectively. The corresponding upper limits in the $\Upsilon(1S, 2S, 3S)\gamma$ channels are $(1.3, 1.9, 1.3) \times 10^{-3}$ and $(3.4, 6.5, 5.4) \times 10^{-6}$, for the SM Higgs and Z bosons, respectively. These are the first experimental bounds on exclusive Higgs and Z boson decays to final states involving quarkonia.

TABLE II. Expected and observed branching fraction limits at 95% C.L. for $\sqrt{s} = 8$ TeV. The $\pm 1\sigma$ fluctuations of the expected limits are also given. For the Higgs decay search, limits are also set on the cross section times branching fraction $\sigma(pp \rightarrow H) \times \mathcal{B}(H \rightarrow Q\gamma)$.

	95% C.L. upper limits				
	J/ψ	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\sum_n \Upsilon(nS)$
		$\mathcal{B}(Z \rightarrow Q\gamma) [10^{-6}]$			
Expected	$2.0^{+1.0}_{-0.6}$	$4.9^{+2.5}_{-1.4}$	$6.2^{+3.2}_{-1.8}$	$5.4^{+2.7}_{-1.5}$	$8.8^{+4.7}_{-2.5}$
Observed	2.6	3.4	6.5	5.4	7.9
		$\mathcal{B}(H \rightarrow Q\gamma) [10^{-3}]$			
Expected	$1.2^{+0.6}_{-0.3}$	$1.8^{+0.9}_{-0.5}$	$2.1^{+1.1}_{-0.6}$	$1.8^{+0.9}_{-0.5}$	$2.5^{+1.3}_{-0.7}$
Observed	1.5	1.3	1.9	1.3	2.0
		$\sigma(pp \rightarrow H) \times \mathcal{B}(H \rightarrow Q\gamma) [\text{fb}]$			
Expected	26^{+12}_{-7}	38^{+19}_{-11}	45^{+24}_{-13}	38^{+19}_{-11}	54^{+27}_{-15}
Observed	33	29	41	28	44

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G. Aad,⁸⁵ B. Abbott,¹¹³ J. Abdallah,¹⁵² S. Abdel Khalek,¹¹⁷ O. Abdinov,¹¹ R. Aben,¹⁰⁷ B. Abi,¹¹⁴ M. Abolins,⁹⁰
 O. S. AbouZeid,¹⁵⁹ H. Abramowicz,¹⁵⁴ H. Abreu,¹⁵³ R. Abreu,³⁰ Y. Abulaiti,^{147a,147b} B. S. Acharya,^{165a,165b,b}
 L. Adamczyk,^{38a} D. L. Adams,²⁵ J. Adelman,¹⁰⁸ S. Adomeit,¹⁰⁰ T. Adye,¹³¹ T. Agatonovic-Jovin,¹³
 J. A. Aguilar-Saavedra,^{126a,126f} M. Agustoni,¹⁷ S. P. Ahlen,²² F. Ahmadov,^{65,c} G. Aielli,^{134a,134b} H. Akerstedt,^{147a,147b}
 T. P. A. Åkesson,⁸¹ G. Akimoto,¹⁵⁶ A. V. Akimov,⁹⁶ G. L. Alberghi,^{20a,20b} J. Albert,¹⁷⁰ S. Albrand,⁵⁵
 M. J. Alconada Verzini,⁷¹ M. Aleksa,³⁰ I. N. Aleksandrov,⁶⁵ C. Alexa,^{26a} G. Alexander,¹⁵⁴ G. Alexandre,⁴⁹ T. Alexopoulos,¹⁰
 M. Alhroob,¹¹³ G. Alimonti,^{91a} L. Alio,⁸⁵ J. Alison,³¹ B. M. M. Allbrooke,¹⁸ L. J. Allison,⁷² P. P. Allport,⁷⁴
 A. Aloisio,^{104a,104b} A. Alonso,³⁶ F. Alonso,⁷¹ C. Alpigiani,⁷⁶ A. Altheimer,³⁵ B. Alvarez Gonzalez,⁹⁰ M. G. Alviggi,^{104a,104b}
 K. Amako,⁶⁶ Y. Amaral Coutinho,^{24a} C. Amelung,²³ D. Amidei,⁸⁹ S. P. Amor Dos Santos,^{126a,126c} A. Amorim,^{126a,126b}
 S. Amoroso,⁴⁸ N. Amram,¹⁵⁴ G. Amundsen,²³ C. Anastopoulos,¹⁴⁰ L. S. Ancu,⁴⁹ N. Andari,³⁰ T. Andeen,³⁵ C. F. Anders,^{58b}

G. Anders,³⁰ K. J. Anderson,³¹ A. Andreazza,^{91a,91b} V. Andrei,^{58a} X. S. Anduaga,⁷¹ S. Angelidakis,⁹ I. Angelozzi,¹⁰⁷ P. Anger,⁴⁴ A. Angerami,³⁵ F. Anghinolfi,³⁰ A. V. Anisenkov,^{109,d} N. Anjos,¹² A. Annovi,^{124a,124b} M. Antonelli,⁴⁷ A. Antonov,⁹⁸ J. Antos,^{145b} F. Anulli,^{133a} M. Aoki,⁶⁶ L. Aperio Bella,¹⁸ G. Arabidze,⁹⁰ Y. Arai,⁶⁶ J. P. Araque,^{126a} A. T. H. Arce,⁴⁵ F. A. Arduh,⁷¹ J-F. Arguin,⁹⁵ S. Argyropoulos,⁴² M. Arik,^{19a} A. J. Armbruster,³⁰ O. Arnaez,³⁰ V. Arnal,⁸² H. Arnold,⁴⁸ M. Arratia,²⁸ O. Arslan,²¹ A. Artamonov,⁹⁷ G. Artoni,²³ S. Asai,¹⁵⁶ N. Asbah,⁴² A. Ashkenazi,¹⁵⁴ B. Åsman,^{147a,147b} L. Asquith,¹⁵⁰ K. Assamagan,²⁵ R. Astalos,^{145a} M. Atkinson,¹⁶⁶ N. B. Atlay,¹⁴² B. Auerbach,⁶ K. Augsten,¹²⁸ M. Aurousseau,^{146b} G. Avolio,³⁰ B. Axen,¹⁵ M. K. Ayoub,¹¹⁷ G. Azuelos,^{95,e} M. A. Baak,³⁰ A. E. Baas,^{58a} C. Bacci,^{135a,135b} H. Bachacou,¹³⁷ K. Bachas,¹⁵⁵ M. Backes,³⁰ M. Backhaus,³⁰ P. Bagiacci,^{133a,133b} P. Bagnaia,^{133a,133b} Y. Bai,^{33a} T. Bain,³⁵ J. T. Baines,¹³¹ O. K. Baker,¹⁷⁷ P. Balek,¹²⁹ T. Balestri,¹⁴⁹ F. Balli,⁸⁴ E. Banas,³⁹ Sw. Banerjee,¹⁷⁴ A. A. E. Bannoura,¹⁷⁶ H. S. Bansil,¹⁸ L. Barak,¹⁷³ S. P. Baranov,⁹⁶ E. L. Barberio,⁸⁸ D. Barberis,^{50a,50b} M. Barbero,⁸⁵ T. Barillari,¹⁰¹ M. Barisonzi,^{165a,165b} T. Barklow,¹⁴⁴ N. Barlow,²⁸ S. L. Barnes,⁸⁴ B. M. Barnett,¹³¹ R. M. Barnett,¹⁵ Z. Barnovska,⁵ A. Baroncelli,^{135a} G. Barone,⁴⁹ A. J. Barr,¹²⁰ F. Barreiro,⁸² J. Barreiro Guimarães da Costa,⁵⁷ R. Bartoldus,¹⁴⁴ A. E. Barton,⁷² P. Bartos,^{145a} A. Bassalat,¹¹⁷ A. Basye,¹⁶⁶ R. L. Bates,⁵³ S. J. Batista,¹⁵⁹ J. R. Batley,²⁸ M. Battaglia,¹³⁸ M. Bause,^{133a,133b} F. Bauer,¹³⁷ H. S. Bawa,^{144,f} J. B. Beacham,¹¹¹ M. D. Beattie,⁷² T. Beau,⁸⁰ P. H. Beauchemin,¹⁶² R. Beccherle,^{124a,124b} P. Bechtle,²¹ H. P. Beck,^{17,g} K. Becker,¹²⁰ S. Becker,¹⁰⁰ M. Beckingham,¹⁷¹ C. Becot,¹¹⁷ A. J. Beddall,^{19c} A. Beddall,^{19c} V. A. Bednyakov,⁶⁵ C. P. Bee,¹⁴⁹ L. J. Beemster,¹⁰⁷ T. A. Beermann,¹⁷⁶ M. Begel,²⁵ K. Behr,¹²⁰ C. 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Bingul,^{19c} C. Bini,^{133a,133b} C. W. Black,¹⁵¹ J. E. Black,¹⁴⁴ K. M. Black,²² D. Blackburn,¹³⁹ R. E. Blair,⁶ J.-B. Blanchard,¹³⁷ J. E. Blanco,⁷⁷ T. Blazek,^{145a} I. Bloch,⁴² C. Blocker,²³ W. Blum,^{83,a} U. Blumenschein,⁵⁴ G. J. Bobbink,¹⁰⁷ V. S. Bobrovnikov,^{109,d} S. S. Bocchetta,⁸¹ A. Bocci,⁴⁵ C. Bock,¹⁰⁰ C. R. Boddy,¹²⁰ M. Boehler,⁴⁸ J. A. Bogaerts,³⁰ A. G. Bogdanchikov,¹⁰⁹ C. Bohm,^{147a} V. Boisvert,⁷⁷ T. Bold,^{38a} V. Boldea,^{26a} A. S. Boldyrev,⁹⁹ M. Bomben,⁸⁰ M. Bona,⁷⁶ M. Boonekamp,¹³⁷ A. Borisov,¹³⁰ G. Borissov,⁷² S. Borroni,⁴² J. Bortfeldt,¹⁰⁰ V. Bortolotto,^{60a} K. Bos,¹⁰⁷ D. Boscherini,^{20a} M. Bosman,¹² J. Boudreau,¹²⁵ J. Bouffard,² E. V. Bouhova-Thacker,⁷² D. Boumediene,³⁴ C. Bourdarios,¹¹⁷ N. Bousson,¹¹⁴ S. Boutouil,^{136d} A. Boveia,³⁰ J. Boyd,³⁰ I. R. Boyko,⁶⁵ I. Bozic,¹³ J. Bracinek,¹⁸ A. Brandt,⁸ G. Brandt,¹⁵ O. Brandt,^{58a} U. Bratzler,¹⁵⁷ B. Brau,⁸⁶ J. E. Brau,¹¹⁶ H. M. Braun,^{176,a} S. F. Brazzale,^{165a,165c} K. Brendlinger,¹²² A. J. Brennan,⁸⁸ L. Brenner,¹⁰⁷ R. Brenner,¹⁶⁷ S. Bressler,¹⁷³ K. Bristow,^{146c} T. M. Bristow,⁴⁶ D. Britton,⁵³ F. M. Brochu,²⁸ I. Brock,²¹ R. Brock,⁹⁰ J. Bronner,¹⁰¹ G. Brooijmans,³⁵ T. Brooks,⁷⁷ W. K. Brooks,^{32b} J. Brosamer,¹⁵ E. Brost,¹¹⁶ J. Brown,⁵⁵ P. A. Bruckman de Renstrom,³⁹ D. Bruncko,^{145b} R. Bruneliere,⁴⁸ A. Bruni,^{20a} G. Bruni,^{20a} M. Bruschi,^{20a} L. Bryngemark,⁸¹ T. Buanes,¹⁴ Q. Buat,¹⁴³ F. Bucci,⁴⁹ P. Buchholz,¹⁴² A. G. Buckley,⁵³ S. I. Buda,^{26a} I. A. Budagov,⁶⁵ F. Buehrer,⁴⁸ L. Bugge,¹¹⁹ M. K. Bugge,¹¹⁹ O. Bulekov,⁹⁸ H. Burckhart,³⁰ S. Burdin,⁷⁴ B. Burghgrave,¹⁰⁸ S. Burke,¹³¹ I. Burmeister,⁴³ E. Busato,³⁴ D. Büscher,⁴⁸ V. Büscher,⁸³ P. Bussey,⁵³ C. P. Buszello,¹⁶⁷ J. M. Butler,²² A. I. Butt,³ C. M. Buttar,⁵³ J. M. Butterworth,⁷⁸ P. Butti,¹⁰⁷ W. Buttinger,²⁵ A. Buzatu,⁵³ S. Cabrera Urbán,¹⁶⁸ D. Caforio,¹²⁸ O. Cakir,^{4a} P. Calafiura,¹⁵ A. Calandri,¹³⁷ G. Calderini,⁸⁰ P. Calfayan,¹⁰⁰ L. P. Caloba,^{24a} D. Calvet,³⁴ S. Calvet,³⁴ R. Camacho Toro,⁴⁹ S. Camarda,⁴² D. Cameron,¹¹⁹ L. M. Caminada,¹⁵ R. Caminal Armadans,¹² S. Campana,³⁰ M. Campanelli,⁷⁸ A. Campoverde,¹⁴⁹ V. Canale,^{104a,104b} A. Canepa,^{160a} M. Cano Bret,⁷⁶ J. Cantero,⁸² R. Cantrill,^{126a} T. Cao,⁴⁰ M. D. M. Capeans Garrido,³⁰ I. Caprini,^{26a} M. Caprini,^{26a} M. Capua,^{37a,37b} R. Caputo,⁸³ R. Cardarelli,^{134a} T. Carli,³⁰ G. Carlino,^{104a} L. Carminati,^{91a,91b} S. Caron,¹⁰⁶ E. Carquin,^{32a} G. D. Carrillo-Montoya,^{146c} J. R. Carter,²⁸ J. Carvalho,^{126a,126c} D. Casadei,⁷⁸ M. P. Casado,¹² M. Casolino,¹² E. Castaneda-Miranda,^{146b} A. Castelli,¹⁰⁷ V. Castillo Gimenez,¹⁶⁸ N. F. Castro,^{126a} P. Catastini,⁵⁷ A. Catinaccio,³⁰ J. R. Catmore,¹¹⁹ A. Cattai,³⁰ G. Cattani,^{134a,134b} J. Caudron,⁸³ V. Cavaliere,¹⁶⁶ D. Cavalli,^{91a} M. Cavalli-Sforza,¹² V. Cavasinni,^{124a,124b} F. Ceradini,^{135a,135b} B. C. Cerio,⁴⁵ K. Cerny,¹²⁹ A. S. Cerqueira,^{24b} A. Cerri,¹⁵⁰ L. Cerrito,⁷⁶ F. Cerutti,¹⁵ M. Cerv,³⁰ A. Cervelli,¹⁷ S. A. Cetin,^{19b} A. Chafaq,^{136a} D. Chakraborty,¹⁰⁸ I. Chalupkova,¹²⁹ P. Chang,¹⁶⁶ B. Chapleau,⁸⁷ J. D. Chapman,²⁸ D. Charfeddine,¹¹⁷ D. G. Charlton,¹⁸

C. C. Chau,¹⁵⁹ C. A. Chavez Barajas,¹⁵⁰ S. Cheatham,¹⁵³ A. Chegwidden,⁹⁰ S. Chekanov,⁶ S. V. Chekulaev,^{160a}
 G. A. Chelkov,^{65,h} M. A. Chelstowska,⁸⁹ C. Chen,⁶⁴ H. Chen,²⁵ K. Chen,¹⁴⁹ L. Chen,^{33d,i} S. Chen,^{33c} X. Chen,^{33f} Y. Chen,⁶⁷
 H. C. Cheng,⁸⁹ Y. Cheng,³¹ A. Cheplakov,⁶⁵ E. Cheremushkina,¹³⁰ R. Cherkaoui El Moursli,^{136e} V. Chernyatin,^{25,a} E. Cheu,⁷
 L. Chevalier,¹³⁷ V. Chiarella,⁴⁷ J. T. Childers,⁶ A. Chilingarov,⁷² G. Chiodini,^{73a} A. S. Chisholm,¹⁸ R. T. Chislett,⁷⁸
 A. Chitan,^{26a} M. V. Chizhov,⁶⁵ S. Chouridou,⁹ B. K. B. Chow,¹⁰⁰ D. Chromek-Burckhart,³⁰ M. L. Chu,¹⁵² J. Chudoba,¹²⁷
 J. J. Chwastowski,³⁹ L. Chytka,¹¹⁵ G. Ciapetti,^{133a,133b} A. K. Ciftci,^{4a} D. Cinca,⁵³ V. Cindro,⁷⁵ A. Ciocio,¹⁵ Z. H. Citron,¹⁷³
 M. Citterio,^{91a} M. Ciubancan,^{26a} A. Clark,⁴⁹ P. J. Clark,⁴⁶ R. N. Clarke,¹⁵ W. Cleland,¹²⁵ C. Clement,^{147a,147b} Y. Coadou,⁸⁵
 M. Cobal,^{165a,165c} A. Coccaro,¹³⁹ J. Cochran,⁶⁴ L. Coffey,²³ J. G. Cogan,¹⁴⁴ B. Cole,³⁵ S. Cole,¹⁰⁸ A. P. Colijn,¹⁰⁷ J. Collot,⁵⁵
 T. Colombo,^{58c} G. Compostella,¹⁰¹ P. Conde Muiño,^{126a,126b} E. Coniavitis,⁴⁸ S. H. Connell,^{146b} I. A. Connelly,⁷⁷
 S. M. Consonni,^{91a,91b} V. Consorti,⁴⁸ S. Constantinescu,^{26a} C. Conta,^{121a,121b} G. Conti,³⁰ F. Conventi,^{104aj} M. Cooke,¹⁵
 B. D. Cooper,⁷⁸ A. M. Cooper-Sarkar,¹²⁰ K. Copic,¹⁵ T. Cornelissen,¹⁷⁶ M. Corradi,^{20a} F. Corriveau,^{87,k} A. Corso-Radu,¹⁶⁴
 A. Cortes-Gonzalez,¹² G. Cortiana,¹⁰¹ M. J. Costa,¹⁶⁸ D. Costanzo,¹⁴⁰ D. Côté,⁸ G. Cottin,²⁸ G. Cowan,⁷⁷ B. E. Cox,⁸⁴
 K. Cranmer,¹¹⁰ G. Cree,²⁹ S. Crépe-Renaudin,⁵⁵ F. Crescioli,⁸⁰ W. A. Cribbs,^{147a,147b} M. Crispin Ortuzar,¹²⁰
 M. Cristinziani,²¹ V. Croft,¹⁰⁶ G. Crosetti,^{37a,37b} T. Cuhadar Donszelmann,¹⁴⁰ J. Cummings,¹⁷⁷ M. Curatolo,⁴⁷ C. Cuthbert,¹⁵¹
 H. Czirr,¹⁴² P. Czodrowski,³ S. D'Auria,⁵³ M. D'Onofrio,⁷⁴ M. J. Da Cunha Sargedas De Sousa,^{126a,126b} C. Da Via,⁸⁴
 W. Dabrowski,^{38a} A. Dafinca,¹²⁰ T. Dai,⁸⁹ O. Dale,¹⁴ F. Dallaire,⁹⁵ C. Dallapiccola,⁸⁶ M. Dam,³⁶ J. R. Dandoy,³¹
 A. C. Daniells,¹⁸ M. Danninger,¹⁶⁹ M. Dano Hoffmann,¹³⁷ V. Dao,⁴⁸ G. Darbo,^{50a} S. Darmora,⁸ J. Dassoulas,³
 A. Dattagupta,⁶¹ W. Davey,²¹ C. David,¹⁷⁰ T. Davidek,¹²⁹ E. Davies,^{120,l} M. Davies,¹⁵⁴ O. Davignon,⁸⁰ P. Davison,⁷⁸
 Y. Davygora,^{58a} E. Dawe,¹⁴³ I. Dawson,¹⁴⁰ R. K. Daya-Ishmukhametova,⁸⁶ K. De,⁸ R. de Asmundis,^{104a} S. De Castro,^{20a,20b}
 S. De Cecco,⁸⁰ N. De Groot,¹⁰⁶ P. de Jong,¹⁰⁷ H. De la Torre,⁸² F. De Lorenzi,⁶⁴ L. De Nooij,¹⁰⁷ D. De Pedis,^{133a}
 A. De Salvo,^{133a} U. De Sanctis,¹⁵⁰ A. De Santo,¹⁵⁰ J. B. De Vivie De Regie,¹¹⁷ W. J. Dearnaley,⁷² R. Debbé,²⁵
 C. Debenedetti,¹³⁸ D. V. Dedovich,⁶⁵ I. Deigaard,¹⁰⁷ J. Del Peso,⁸² T. Del Prete,^{124a,124b} D. Delgove,¹¹⁷ F. Deliot,¹³⁷
 C. M. Delitzsch,⁴⁹ M. Deliyergiyev,⁷⁵ A. Dell'Acqua,³⁰ L. Dell'Asta,²² M. Dell'Orso,^{124a,124b} M. Della Pietra,^{104aj}
 D. della Volpe,⁴⁹ M. Delmastro,⁵ P. A. Delsart,⁵⁵ C. Deluca,¹⁰⁷ D. A. DeMarco,¹⁵⁹ S. Demers,¹⁷⁷ M. Demichev,⁶⁵
 A. Demilly,⁸⁰ S. P. Denisov,¹³⁰ D. Derendarz,³⁹ J. E. Derkaoui,^{136d} F. Derue,⁸⁰ P. Dervan,⁷⁴ K. Desch,²¹ C. Deterre,⁴²
 P. O. Deviveiros,³⁰ A. Dewhurst,¹³¹ S. Dhaliwal,¹⁰⁷ A. Di Ciaccio,^{134a,134b} L. Di Ciaccio,⁵ A. Di Domenico,^{133a,133b}
 C. Di Donato,^{104a,104b} A. Di Girolamo,³⁰ B. Di Girolamo,³⁰ A. Di Mattia,¹⁵³ B. Di Micco,^{135a,135b} R. Di Nardo,⁴⁷
 A. Di Simone,⁴⁸ R. Di Sipio,^{20a,20b} D. Di Valentino,²⁹ C. Diaconu,⁸⁵ M. Diamond,¹⁵⁹ F. A. Dias,⁴⁶ M. A. Diaz,^{32a}
 E. B. Diehl,⁸⁹ J. Dietrich,¹⁶ T. A. Dietzsch,^{58a} S. Diglio,⁸⁵ A. Dimitrievska,¹³ J. Dingfelder,²¹ F. Dittus,³⁰ F. Djama,⁸⁵
 T. Djobava,^{51b} J. I. Djuvsland,^{58a} M. A. B. do Vale,^{24c} D. Dobos,³⁰ M. Dobre,^{26a} C. Doglioni,⁴⁹ T. Doherty,⁵³ T. Dohmae,¹⁵⁶
 J. Dolejsi,¹²⁹ Z. Dolezal,¹²⁹ B. A. Dolgoshein,^{98,a} M. Donadelli,^{24d} S. Donati,^{124a,124b} P. Dondero,^{121a,121b} J. Donini,³⁴
 J. Dopke,¹³¹ A. Doria,^{104a} M. T. Dova,⁷¹ A. T. Doyle,⁵³ M. Dris,¹⁰ E. Dubreuil,³⁴ E. Duchovni,¹⁷³ G. Duckeck,¹⁰⁰
 O. A. Ducu,^{26a} D. Duda,¹⁷⁶ A. Dudarev,³⁰ L. Duflot,¹¹⁷ L. Duguid,⁷⁷ M. Dührssen,³⁰ M. Dunford,^{58a} H. Duran Yildiz,^{4a}
 M. Düren,⁵² A. Durglishvili,^{51b} D. Duschinger,⁴⁴ M. Dwuznik,^{38a} M. Dyndal,^{38a} W. Edson,² N. C. Edwards,⁴⁶
 W. Ehrenfeld,²¹ T. Eifert,³⁰ G. Eigen,¹⁴ K. Einsweiler,¹⁵ T. Ekelof,¹⁶⁷ M. El Kacimi,^{136c} M. Ellert,¹⁶⁷ S. Elles,⁵
 F. Ellinghaus,⁸³ A. A. Elliot,¹⁷⁰ N. Ellis,³⁰ J. Elmsheuser,¹⁰⁰ M. Elsing,³⁰ D. Emelianov,¹³¹ Y. Enari,¹⁵⁶ O. C. Endner,⁸³
 M. Endo,¹¹⁸ R. Engelmann,¹⁴⁹ J. Erdmann,⁴³ A. Ereditato,¹⁷ D. Eriksson,^{147a} G. Ernis,¹⁷⁶ J. Ernst,² M. Ernst,²⁵ S. Errede,¹⁶⁶
 E. Ertel,⁸³ M. Escalier,¹¹⁷ H. Esch,⁴³ C. Escobar,¹²⁵ B. Esposito,⁴⁷ A. I. Etiennevire,¹³⁷ E. Etzion,¹⁵⁴ H. Evans,⁶¹ A. Ezhilov,¹²³
 L. Fabbri,^{20a,20b} G. Facini,³¹ R. M. Fakhruddinov,¹³⁰ S. Falciano,^{133a} R. J. Falla,⁷⁸ J. Faltova,¹²⁹ Y. Fang,^{33a} M. Fanti,^{91a,91b}
 A. Farbin,⁸ A. Farilla,^{135a} T. Farooque,¹² S. Farrell,¹⁵ S. M. Farrington,¹⁷¹ P. Farthouat,³⁰ F. Fassi,^{136e} P. Fassnacht,³⁰
 D. Fassouliotis,⁹ A. Favareto,^{50a,50b} L. Fayard,¹¹⁷ P. Federic,^{145a} O. L. Fedin,^{123,m} W. Fedorko,¹⁶⁹ S. Feigl,³⁰ L. Feligioni,⁸⁵
 C. Feng,^{33d} E. J. Feng,⁶ H. Feng,⁸⁹ A. B. Fenyuk,¹³⁰ P. Fernandez Martinez,¹⁶⁸ S. Fernandez Perez,³⁰ S. Ferrag,⁵³
 J. Ferrando,⁵³ A. Ferrari,¹⁶⁷ P. Ferrari,¹⁰⁷ R. Ferrari,^{121a} D. E. Ferreira de Lima,⁵³ A. Ferrer,¹⁶⁸ D. Ferrere,⁴⁹ C. Ferretti,⁸⁹
 A. Ferretto Parodi,^{50a,50b} M. Fiascaris,³¹ F. Fiedler,⁸³ A. Filipčič,⁷⁵ M. Filipuzzi,⁴² F. Filthaut,¹⁰⁶ M. Fincke-Keeler,¹⁷⁰
 K. D. Finelli,¹⁵¹ M. C. N. Fiolhais,^{126a,126c} L. Fiorini,¹⁶⁸ A. Firan,⁴⁰ A. Fischer,² C. Fischer,¹² J. Fischer,¹⁷⁶ W. C. Fisher,⁹⁰
 E. A. Fitzgerald,²³ M. Flechl,⁴⁸ I. Fleck,¹⁴² P. Fleischmann,⁸⁹ S. Fleischmann,¹⁷⁶ G. T. Fletcher,¹⁴⁰ G. Fletcher,⁷⁶ T. Flick,¹⁷⁶
 A. Floderus,⁸¹ L. R. Flores Castillo,^{60a} M. J. Flowerdew,¹⁰¹ A. Formica,¹³⁷ A. Forti,⁸⁴ D. Fournier,¹¹⁷ H. Fox,⁷² S. Fracchia,¹²
 P. Francavilla,⁸⁰ M. Franchini,^{20a,20b} D. Francis,³⁰ L. Franconi,¹¹⁹ M. Franklin,⁵⁷ M. Fraternali,^{121a,121b} D. Freeborn,⁷⁸
 S. T. French,²⁸ F. Friedrich,⁴⁴ D. Froidevaux,³⁰ J. A. Frost,¹²⁰ C. Fukunaga,¹⁵⁷ E. Fullana Torregrosa,⁸³ B. G. Fulsom,¹⁴⁴

J. Fuster,¹⁶⁸ C. Gabaldon,⁵⁵ O. Gabizon,¹⁷⁶ A. Gabrielli,^{20a,20b} A. Gabrielli,^{133a,133b} S. Gadatsch,¹⁰⁷ S. Gadomski,⁴⁹ G. Gagliardi,^{50a,50b} P. Gagnon,⁶¹ C. Galea,¹⁰⁶ B. Galhardo,^{126a,126c} E. J. Gallas,¹²⁰ B. J. Gallop,¹³¹ P. Gallus,¹²⁸ G. Galster,³⁶ K. K. Gan,¹¹¹ J. Gao,^{33b,85} Y. S. Gao,^{144,f} 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,^{121a} B. Gaur,¹⁴² L. Gauthier,⁹⁵ P. Gauzzi,^{133a,133b} I. L. Gavrilenko,⁹⁶ C. Gay,¹⁶⁹ G. Gaycken,²¹ E. N. Gazis,¹⁰ P. Ge,^{33d} Z. Gecse,¹⁶⁹ C. N. P. Gee,¹³¹ D. A. A. Geerts,¹⁰⁷ Ch. Geich-Gimbel,²¹ C. Gemme,^{50a} M. H. Genest,⁵⁵ S. Gentile,^{133a,133b} M. George,⁵⁴ S. George,⁷⁷ D. Gerbaudo,¹⁶⁴ A. Gershon,¹⁵⁴ H. Ghazlane,^{136b} N. Ghodbane,³⁴ B. Giacobbe,^{20a} S. Giagu,^{133a,133b} V. Giangiobbe,¹² P. Giannetti,^{124a,124b} F. Gianotti,³⁰ B. Gibbard,²⁵ S. M. Gibson,⁷⁷ M. Gilchriese,¹⁵ T. P. S. Gillam,²⁸ D. Gillberg,³⁰ G. Gilles,³⁴ D. M. Gingrich,^{3,e} N. Giokaris,⁹ M. P. Giordani,^{165a,165c} F. M. Giorgi,^{20a} F. M. Giorgi,¹⁶ P. F. Giraud,¹³⁷ D. Giugni,^{91a} C. Giuliani,⁴⁸ M. Giulini,^{58b} B. K. Gjelsten,¹¹⁹ S. Gkaitatzis,¹⁵⁵ I. Gkialas,¹⁵⁵ E. L. Gkougkousis,¹¹⁷ L. K. Gladilin,⁹⁹ C. Glasman,⁸² J. Glatzer,³⁰ P. C. F. Glaysher,⁴⁶ A. Glazov,⁴² M. Goblirsch-Kolb,¹⁰¹ J. R. Goddard,⁷⁶ J. Godlewski,³⁹ S. Goldfarb,⁸⁹ T. Golling,⁴⁹ D. Golubkov,¹³⁰ A. Gomes,^{126a,126b,126d} R. Gonçalo,^{126a} J. Goncalves Pinto Firmino Da Costa,¹³⁷ L. Gonella,²¹ S. González de la Hoz,¹⁶⁸ G. Gonzalez Parra,¹² S. Gonzalez-Sevilla,⁴⁹ L. Goossens,³⁰ P. A. Gorbounov,⁹⁷ H. A. Gordon,²⁵ I. Gorelov,¹⁰⁵ B. Gorini,³⁰ E. Gorini,^{73a,73b} A. Gorišek,⁷⁵ E. Gornicki,³⁹ A. T. Goshaw,⁴⁵ C. Gössling,⁴³ M. I. Gostkin,⁶⁵ M. Gouighri,^{136a} D. Goujdami,^{136c} A. G. Goussiou,¹³⁹ H. M. X. Grabas,¹³⁸ L. Graber,⁵⁴ I. Grabowska-Bold,^{38a} P. Grafström,^{20a,20b} K.-J. Grahn,⁴² J. Gramling,⁴⁹ E. Gramstad,¹¹⁹ S. Grancagnolo,¹⁶ V. Grassi,¹⁴⁹ V. Gratchev,¹²³ H. M. Gray,³⁰ E. Graziani,^{135a} Z. D. Greenwood,^{79,n} K. Gregersen,⁷⁸ I. M. Gregor,⁴² P. Grenier,¹⁴⁴ J. Griffiths,⁸ A. A. Grillo,¹³⁸ K. Grimm,⁷² S. Grinstein,^{12,o} Ph. Gris,³⁴ Y. V. Grishkevich,⁹⁹ J.-F. Grivaz,¹¹⁷ J. P. Grohs,⁴⁴ A. Grohsjean,⁴² E. Gross,¹⁷³ J. Grosse-Knetter,⁵⁴ G. C. Grossi,^{134a,134b} Z. J. Grout,¹⁵⁰ L. Guan,^{33b} J. Guenther,¹²⁸ F. Guescini,⁴⁹ D. Guest,¹⁷⁷ O. Gueta,¹⁵⁴ E. Guido,^{50a,50b} T. Guillemin,¹¹⁷ S. Guindon,² U. Gul,⁵³ C. Gumpert,⁴⁴ J. Guo,^{33e} S. Gupta,¹²⁰ P. Gutierrez,¹¹³ N. G. Gutierrez Ortiz,⁵³ C. Gutsche,⁴⁴ N. Guttman,¹⁵⁴ C. Guyot,¹³⁷ C. Gwenlan,¹²⁰ C. B. Gwilliam,⁷⁴ A. Haas,¹¹⁰ C. Haber,¹⁵ H. K. Hadavand,⁸ N. Haddad,^{136e} P. Haefner,²¹ S. Hageböck,²¹ Z. Hajduk,³⁹ H. Hakobyan,¹⁷⁸ M. Haleem,⁴² J. Haley,¹¹⁴ D. Hall,¹²⁰ G. Halladjian,⁹⁰ G. D. Hallewell,⁸⁵ K. Hamacher,¹⁷⁶ P. Hamal,¹¹⁵ K. Hamano,¹⁷⁰ M. Hamer,⁵⁴ A. Hamilton,^{146a} S. Hamilton,¹⁶² G. N. Hamity,^{146c} P. G. Hamnett,⁴² L. Han,^{33b} K. Hanagaki,¹¹⁸ K. Hanawa,¹⁵⁶ M. Hance,¹⁵ P. Hanke,^{58a} R. Hanna,¹³⁷ J. B. Hansen,³⁶ J. D. Hansen,³⁶ P. H. Hansen,³⁶ K. Hara,¹⁶¹ A. S. Hard,¹⁷⁴ T. Harenberg,¹⁷⁶ F. Hariri,¹¹⁷ S. Harkusha,⁹² R. D. Harrington,⁴⁶ P. F. Harrison,¹⁷¹ F. Hartjes,¹⁰⁷ M. Hasegawa,⁶⁷ S. Hasegawa,¹⁰³ Y. Hasegawa,¹⁴¹ A. Hasib,¹¹³ S. Hassani,¹³⁷ S. Haug,¹⁷ R. Hauser,⁹⁰ L. Hauswald,⁴⁴ M. Havranek,¹²⁷ C. M. Hawkes,¹⁸ R. J. Hawkins,³⁰ A. D. Hawkins,⁸¹ T. Hayashi,¹⁶¹ D. Hayden,⁹⁰ C. P. Hays,¹²⁰ J. M. Hays,⁷⁶ H. S. Hayward,⁷⁴ S. J. Haywood,¹³¹ S. J. Head,¹⁸ T. Heck,⁸³ V. Hedberg,⁸¹ L. Heelan,⁸ S. Heim,¹²² T. Heim,¹⁷⁶ B. Heinemann,¹⁵ L. Heinrich,¹¹⁰ J. Hejbal,¹²⁷ L. Helary,²² M. Heller,³⁰ S. Hellman,^{147a,147b} D. Hellmich,²¹ C. Helsens,³⁰ J. Henderson,¹²⁰ R. C. W. Henderson,⁷² Y. Heng,¹⁷⁴ C. Hengler,⁴² A. Henrichs,¹⁷⁷ A. M. Henriques Correia,³⁰ S. Henrot-Versille,¹¹⁷ G. H. Herbert,¹⁶ Y. Hernández Jiménez,¹⁶⁸ R. Herrberg-Schubert,¹⁶ G. Herten,⁴⁸ R. Hertenberger,¹⁰⁰ L. Hervas,³⁰ G. G. Hesketh,⁷⁸ N. P. Hessey,¹⁰⁷ R. Hickling,⁷⁶ E. Higón-Rodríguez,¹⁶⁸ E. Hill,¹⁷⁰ J. C. Hill,²⁸ K. H. Hiller,⁴² S. J. Hillier,¹⁸ I. Hinchliffe,¹⁵ E. Hines,¹²² R. R. Hinman,¹⁵ M. Hirose,¹⁵⁸ D. Hirschbuehl,¹⁷⁶ J. Hobbs,¹⁴⁹ N. Hod,¹⁰⁷ M. C. Hodgkinson,¹⁴⁰ P. Hodgson,¹⁴⁰ A. Hoecker,³⁰ M. R. Hoferkamp,¹⁰⁵ F. Hoenig,¹⁰⁰ M. Hohlfeld,⁸³ T. R. Holmes,¹⁵ T. M. Hong,¹²² L. Hooft van Huysduynen,¹¹⁰ W. H. Hopkins,¹¹⁶ Y. Horii,¹⁰³ A. J. Horton,¹⁴³ J.-Y. Hostachy,⁵⁵ S. Hou,¹⁵² A. Hoummada,^{136a} J. Howard,¹²⁰ J. Howarth,⁴² M. Hrabovsky,¹¹⁵ I. Hristova,¹⁶ J. Hrivnac,¹¹⁷ T. Hryn'ova,⁵ A. Hrynevich,⁹³ C. Hsu,^{146c} P. J. Hsu,^{152,p} S.-C. Hsu,¹³⁹ D. Hu,³⁵ Q. Hu,^{33b} X. Hu,⁸⁹ Y. Huang,⁴² Z. Hubacek,³⁰ F. Hubaut,⁸⁵ F. Huegging,²¹ T. B. Huffman,¹²⁰ E. W. Hughes,³⁵ G. Hughes,⁷² M. Huhtinen,³⁰ T. A. Hülsing,⁸³ N. Huseynov,^{65,c} J. Huston,⁹⁰ J. Huth,⁵⁷ G. Iacobucci,⁴⁹ G. Iakovidis,²⁵ I. Ibragimov,¹⁴² L. Iconomidou-Fayard,¹¹⁷ E. Ideal,¹⁷⁷ Z. Idrissi,^{136e} P. Iengo,^{104a} O. Igonkina,¹⁰⁷ T. Izawa,¹⁷² Y. Ikegami,⁶⁶ K. Ikematsu,¹⁴² M. Ikeno,⁶⁶ Y. Ilchenko,^{31,q} D. Iliadis,¹⁵⁵ N. Ilic,¹⁵⁹ Y. Inamaru,⁶⁷ T. Ince,¹⁰¹ P. Ioannou,⁹ M. Iodice,^{135a} K. Iordanidou,⁹ V. Ippolito,⁵⁷ A. Irls Quiles,¹⁶⁸ C. Isaksson,¹⁶⁷ M. Ishino,⁶⁸ M. Ishitsuka,¹⁵⁸ R. Ishmukhametov,¹¹¹ C. Issever,¹²⁰ S. Istin,^{19a} J. M. Iturbe Ponce,⁸⁴ R. Iuppa,^{134a,134b} J. Ivarsson,⁸¹ W. Iwanski,³⁹ H. Iwasaki,⁶⁶ J. M. Izen,⁴¹ V. Izzo,^{104a} B. Jackson,¹²² M. Jackson,⁷⁴ P. Jackson,¹ M. R. Jaekel,³⁰ V. Jain,² K. Jakobs,⁴⁸ S. Jakobsen,³⁰ T. Jakoubek,¹²⁷ J. Jakubek,¹²⁸ D. O. Jamin,¹⁵² D. K. Jana,⁷⁹ E. Jansen,⁷⁸ R. W. Jansky,⁶² J. Janssen,²¹ M. Janus,¹⁷¹ G. Jarlskog,⁸¹ N. Javadov,^{65,c} T. Javůrek,⁴⁸ L. Jeanty,¹⁵ J. Jejelava,^{51a,r} G.-Y. Jeng,¹⁵¹ D. Jennens,⁸⁸ P. Jenni,^{48,s} J. Jentsch,⁴³ C. Jeske,¹⁷¹ S. Jézéquel,⁵ H. Ji,¹⁷⁴ J. Jia,¹⁴⁹ Y. Jiang,^{33b} J. Jimenez Pena,¹⁶⁸ S. Jin,^{33a} A. Jinaru,^{26a} O. Jinnouchi,¹⁵⁸ M. D. Joergensen,³⁶ P. Johansson,¹⁴⁰ K. A. Johns,⁷ K. Jon-And,^{147a,147b} G. Jones,¹⁷¹ R. W. L. Jones,⁷² T. J. Jones,⁷⁴ J. Jongmanns,^{58a} P. M. Jorge,^{126a,126b} K. D. Joshi,⁸⁴ J. Jovicevic,¹⁴⁸ X. Ju,¹⁷⁴ C. A. Jung,⁴³ P. Jussel,⁶²

A. Juste Rozas,^{12,o} M. Kaci,¹⁶⁸ A. Kaczmarzka,³⁹ M. Kado,¹¹⁷ H. Kagan,¹¹¹ M. Kagan,¹⁴⁴ S. J. Kahn,⁸⁵ E. Kajomovitz,⁴⁵
C. W. Kalderon,¹²⁰ S. Kama,⁴⁰ A. Kamenshchikov,¹³⁰ N. Kanaya,¹⁵⁶ M. Kaneda,³⁰ S. Kaneti,²⁸ V. A. Kantserov,⁹⁸
J. Kanzaki,⁶⁶ B. Kaplan,¹¹⁰ A. Kapliy,³¹ D. Kar,⁵³ K. Karakostas,¹⁰ A. Karamaoun,³ N. Karastathis,^{10,107} M. J. Kareem,⁵⁴
M. Karnevskiy,⁸³ S. N. Karpov,⁶⁵ Z. M. Karpova,⁶⁵ K. Karthik,¹¹⁰ V. Kartvelishvili,⁷² A. N. Karyukhin,¹³⁰ L. Kashif,¹⁷⁴
R. D. Kass,¹¹¹ A. Kastanas,¹⁴ Y. Kataoka,¹⁵⁶ A. Katre,⁴⁹ J. Katzy,⁴² K. Kawagoe,⁷⁰ T. Kawamoto,¹⁵⁶ G. Kawamura,⁵⁴
S. Kazama,¹⁵⁶ V. F. Kazanin,¹⁰⁹ M. Y. Kazarinov,⁶⁵ R. Keeler,¹⁷⁰ R. Kehoe,⁴⁰ M. Keil,⁵⁴ J. S. Keller,⁴² J. J. Kempster,⁷⁷
H. Keoshkerian,⁸⁴ O. Kepka,¹²⁷ B. P. Kerševan,⁷⁵ S. Kersten,¹⁷⁶ R. A. Keyes,⁸⁷ F. Khalil-zada,¹¹ H. Khandanyan,^{147a,147b}
A. Khanov,¹¹⁴ A. Kharlamov,¹⁰⁹ A. Khodinov,⁹⁸ A. Khomich,^{58a} T. J. Khoo,²⁸ G. Khoriauli,²¹ V. Khovanskiy,⁹⁷
E. Khramov,⁶⁵ J. Khubua,^{51b,t} H. Y. Kim,⁸ H. Kim,^{147a,147b} S. H. Kim,¹⁶¹ N. Kimura,¹⁵⁵ O. Kind,¹⁶ B. T. King,⁷⁴ M. King,¹⁶⁸
R. S. B. King,¹²⁰ S. B. King,¹⁶⁹ J. Kirk,¹³¹ A. E. Kiryunin,¹⁰¹ T. Kishimoto,⁶⁷ D. Kisielewska,^{38a} F. Kiss,⁴⁸ K. Kiuchi,¹⁶¹
E. Kladiva,^{145b} M. H. Klein,³⁵ M. Klein,⁷⁴ U. Klein,⁷⁴ K. Kleinknecht,⁸³ P. Klimek,^{147a,147b} A. Klimentov,²⁵
R. Klingenberg,⁴³ J. A. Klinger,⁸⁴ T. Klioutchnikova,³⁰ P. F. Klok,¹⁰⁶ E.-E. Kluge,^{58a} P. Kluit,¹⁰⁷ S. Kluth,¹⁰¹ E. Kneringer,⁶²
E. B. F. G. Knoop,⁸⁵ A. Knue,⁵³ D. Kobayashi,¹⁵⁸ T. Kobayashi,¹⁵⁶ M. Kobel,⁴⁴ M. Kocian,¹⁴⁴ P. Kodys,¹²⁹ T. Koffas,²⁹
E. Koffeman,¹⁰⁷ L. A. Kogan,¹²⁰ S. Kohlmann,¹⁷⁶ Z. Kohout,¹²⁸ T. Kohriki,⁶⁶ T. Koi,¹⁴⁴ H. Kolanoski,¹⁶ I. Koletsou,⁵
A. A. Komar,^{96a} Y. Komori,¹⁵⁶ T. Kondo,⁶⁶ N. Kondrashova,⁴² K. Köneke,⁴⁸ A. C. König,¹⁰⁶ S. König,⁸³ T. Kono,^{66,u}
R. Konoplich,^{110,v} N. Konstantinidis,⁷⁸ R. Kopeliansky,¹⁵³ S. Koperny,^{38a} L. Köpke,⁸³ A. K. Kopp,⁴⁸ K. Korcyl,³⁹
K. Kordas,¹⁵⁵ A. Korn,⁷⁸ A. A. Korol,^{109,d} I. Korolkov,¹² E. V. Korolkova,¹⁴⁰ O. Kortner,¹⁰¹ S. Kortner,¹⁰¹ T. Kosek,¹²⁹
V. V. Kostyukhin,²¹ V. M. Kotov,⁶⁵ A. Kotwal,⁴⁵ A. Kourkoumeli-Charalampidi,¹⁵⁵ C. Kourkoumelis,⁹ V. Kouskoura,²⁵
A. Koutsman,^{160a} R. Kowalewski,¹⁷⁰ T. Z. Kowalski,^{38a} W. Kozanecki,¹³⁷ A. S. Kozhin,¹³⁰ V. A. Kramarenko,⁹⁹
G. Kramberger,⁷⁵ D. Krasnopevtsev,⁹⁸ M. W. Krasny,⁸⁰ A. Krasznahorkay,³⁰ J. K. Kraus,²¹ A. Kravchenko,²⁵ S. Kreiss,¹¹⁰
M. Kretz,^{58c} J. Kretzschmar,⁷⁴ K. Kreutzfeldt,⁵² P. Krieger,¹⁵⁹ K. Krizka,³¹ K. Kroeninger,⁴³ H. Kroha,¹⁰¹ J. Kroll,¹²²
J. Kroseberg,²¹ J. Krstic,¹³ U. Kruchonak,⁶⁵ H. Krüger,²¹ N. Krumnack,⁶⁴ Z. V. Krumshateyn,⁶⁵ A. Kruse,¹⁷⁴ M. C. Kruse,⁴⁵
M. Kruskal,²² T. Kubota,⁸⁸ H. Kucuk,⁷⁸ S. Kuday,^{4b} S. Kuehn,⁴⁸ A. Kugel,^{58c} F. Kuger,¹⁷⁵ A. Kuhl,¹³⁸ T. Kuhl,⁴²
V. Kukhtin,⁶⁵ Y. Kulchitsky,⁹² S. Kuleshov,^{32b} M. Kuna,^{133a,133b} T. Kunigo,⁶⁸ A. Kupco,¹²⁷ H. Kurashige,⁶⁷
Y. A. Kurochkin,⁹² R. Kurumida,⁶⁷ V. Kus,¹²⁷ E. S. Kuwertz,¹⁴⁸ M. Kuze,¹⁵⁸ J. Kvita,¹¹⁵ T. Kwan,¹⁷⁰ D. Kyriazopoulos,¹⁴⁰
A. La Rosa,⁴⁹ J. L. La Rosa Navarro,^{24d} L. La Rotonda,^{37a,37b} C. Lacasta,¹⁶⁸ F. Lacava,^{133a,133b} J. Lacey,²⁹ H. Lacker,¹⁶
D. Lacour,⁸⁰ V. R. Lacuesta,¹⁶⁸ E. Ladygin,⁶⁵ R. Lafaye,⁵ B. Laforge,⁸⁰ T. Lagouri,¹⁷⁷ S. Lai,⁴⁸ L. Lambourne,⁷⁸
S. Lammers,⁶¹ C. L. Lampen,⁷ W. Lampl,⁷ E. Lançon,¹³⁷ U. Landgraf,⁴⁸ M. P. J. Landon,⁷⁶ V. S. Lang,^{58a} A. J. Lankford,¹⁶⁴
F. Lanni,²⁵ K. Lantzsck,³⁰ S. Laplace,⁸⁰ C. Lapoire,³⁰ J. F. Laporte,¹³⁷ T. Lari,^{91a} F. Lasagni Manghi,^{20a,20b} M. Lassnig,³⁰
P. Laurelli,⁴⁷ W. Lavrijsen,¹⁵ A. T. Law,¹³⁸ P. Laycock,⁷⁴ O. Le Dortz,⁸⁰ E. Le Guirriec,⁸⁵ E. Le Menedeu,¹² T. LeCompte,⁶
F. Ledroit-Guillon,⁵⁵ C. A. Lee,^{146b} S. C. Lee,¹⁵² L. Lee,¹ G. Lefebvre,⁸⁰ M. Lefebvre,¹⁷⁰ F. Legger,¹⁰⁰ C. Leggett,¹⁵
A. Lehan,⁷⁴ G. Lehmann Miotto,³⁰ X. Lei,⁷ W. A. Leight,²⁹ A. Leisos,¹⁵⁵ A. G. Leister,¹⁷⁷ M. A. L. Leite,^{24d} R. Leitner,¹²⁹
D. Lellouch,¹⁷³ B. Lemmer,⁵⁴ K. J. C. Leney,⁷⁸ T. Lenz,²¹ G. Lenzen,¹⁷⁶ B. Lenzi,³⁰ R. Leone,⁷ S. Leone,^{124a,124b}
C. Leonidopoulos,⁴⁶ S. Leontsinis,¹⁰ C. Leroy,⁹⁵ C. G. Lester,²⁸ M. Levchenko,¹²³ J. Levêque,⁵ D. Levin,⁸⁹
L. J. Levinson,¹⁷³ M. Levy,¹⁸ A. Lewis,¹²⁰ A. M. Leyko,²¹ M. Leyton,⁴¹ B. Li,^{33b,w} B. Li,⁸⁵ H. Li,¹⁴⁹ H. L. Li,³¹ L. Li,⁴⁵
L. Li,^{33e} S. Li,⁴⁵ Y. Li,^{33c,x} Z. Liang,¹³⁸ H. Liao,³⁴ B. Liberti,^{134a} P. Lichard,³⁰ K. Lie,¹⁶⁶ J. Liebal,²¹ W. Liebig,¹⁴
C. Limbach,²¹ A. Limosani,¹⁵¹ S. C. Lin,^{152,y} T. H. Lin,⁸³ F. Linde,¹⁰⁷ B. E. Lindquist,¹⁴⁹ J. T. Linnemann,⁹⁰ E. Lipeles,¹²²
A. Lipniacka,¹⁴ M. Lisovyi,⁴² T. M. Liss,¹⁶⁶ D. Lissauer,²⁵ A. Lister,¹⁶⁹ A. M. Litke,¹³⁸ B. Liu,¹⁵² D. Liu,¹⁵² J. Liu,⁸⁵
J. B. Liu,^{33b} K. Liu,^{33b,z} L. Liu,⁸⁹ M. Liu,⁴⁵ M. Liu,^{33b} Y. Liu,^{33b} M. Livan,^{121a,121b} A. Lleres,⁵⁵ J. Llorente Merino,⁸²
S. L. Lloyd,⁷⁶ F. Lo Sterzo,¹⁵² E. Lobodzinska,⁴² P. Loch,⁷ W. S. Lockman,¹³⁸ F. K. Loebinger,⁸⁴ A. E. Loevschall-Jensen,³⁶
A. Loginov,¹⁷⁷ T. Lohse,¹⁶ K. Lohwasser,⁴² M. Lokajicek,¹²⁷ B. A. Long,²² J. D. Long,⁸⁹ R. E. Long,⁷² K. A. Looper,¹¹¹
L. Lopes,^{126a} D. Lopez Mateos,⁵⁷ B. Lopez Paredes,¹⁴⁰ I. Lopez Paz,¹² J. Lorenz,¹⁰⁰ N. Lorenzo Martinez,⁶¹ M. Losada,¹⁶³
P. Loscutoff,¹⁵ P. J. Lösel,¹⁰⁰ X. Lou,^{33a} A. Lounis,¹¹⁷ J. Love,⁶ P. A. Love,⁷² F. Lu,^{33a} N. Lu,⁸⁹ H. J. Lubatti,¹³⁹
C. Luci,^{133a,133b} A. Lucotte,⁵⁵ F. Luehring,⁶¹ W. Lukas,⁶² L. Luminari,^{133a} O. Lundberg,^{147a,147b} B. Lund-Jensen,¹⁴⁸
M. Lungwitz,⁸³ D. Lynn,²⁵ R. Lysak,¹²⁷ E. Lytken,⁸¹ H. Ma,²⁵ L. L. Ma,^{33d} G. Maccarrone,⁴⁷ A. Macchiolo,¹⁰¹
J. Machado Miguens,^{126a,126b} D. Macina,³⁰ D. Madaffari,⁸⁵ R. Madar,³⁴ H. J. Maddocks,⁷² W. F. Mader,⁴⁴ A. Madsen,¹⁶⁷
T. Maeno,²⁵ A. Maevskiy,⁹⁹ E. Magradze,⁵⁴ K. Mahboubi,⁴⁸ J. Mahlstedt,¹⁰⁷ S. Mahmoud,⁷⁴ C. Maiani,¹³⁷
C. Maidantchik,^{24a} A. A. Maier,¹⁰¹ T. Maier,¹⁰⁰ A. Maio,^{126a,126b,126d} S. Majewski,¹¹⁶ Y. Makida,⁶⁶ N. Makovec,¹¹⁷
B. Malaescu,⁸⁰ Pa. Malecki,³⁹ V. P. Maleev,¹²³ F. Malek,⁵⁵ U. Mallik,⁶³ D. Malon,⁶ C. Malone,¹⁴⁴ S. Maltezos,¹⁰

V. M. Malyshev,¹⁰⁹ S. Malyukov,³⁰ J. Mamuzic,⁴² B. Mandelli,³⁰ L. Mandelli,^{91a} I. Mandić,⁷⁵ R. Mandrysch,⁶³
 J. Maneira,^{126a,126b} A. Manfredini,¹⁰¹ L. Manhaes de Andrade Filho,^{24b} J. Manjarres Ramos,^{160b} A. Mann,¹⁰⁰
 P. M. Manning,¹³⁸ A. Manousakis-Katsikakis,⁹ B. Mansoulie,¹³⁷ R. Mantifel,⁸⁷ M. Mantoani,⁵⁴ L. Mapelli,³⁰ L. March,^{146c}
 G. Marchiori,⁸⁰ M. Marcisovsky,¹²⁷ C. P. Marino,¹⁷⁰ M. Marjanovic,¹³ F. Marroquim,^{24a} S. P. Marsden,⁸⁴ Z. Marshall,¹⁵
 L. F. Marti,¹⁷ S. Marti-Garcia,¹⁶⁸ B. Martin,⁹⁰ T. A. Martin,¹⁷¹ V. J. Martin,⁴⁶ B. Martin dit Latour,¹⁴ H. Martinez,¹³⁷
 M. Martinez,^{12o} S. Martin-Haugh,¹³¹ A. C. Martyniuk,⁷⁸ M. Marx,¹³⁹ F. Marzano,^{133a} A. Marzin,³⁰ L. Masetti,⁸³
 T. Mashimo,¹⁵⁶ R. Mashinistov,⁹⁶ J. Masik,⁸⁴ A. L. Maslennikov,^{109,d} I. Massa,^{20a,20b} L. Massa,^{20a,20b} N. Massol,⁵
 P. Mastrandrea,¹⁴⁹ A. Mastroberardino,^{37a,37b} T. Masubuchi,¹⁵⁶ P. Mättig,¹⁷⁶ J. Mattmann,⁸³ J. Maurer,^{26a} S. J. Maxfield,⁷⁴
 D. A. Maximov,^{109,d} R. Mazini,¹⁵² S. M. Mazza,^{91a,91b} L. Mazzaferro,^{134a,134b} G. Mc Goldrick,¹⁵⁹ S. P. Mc Kee,⁸⁹
 A. McCann,⁸⁹ R. L. McCarthy,¹⁴⁹ T. G. McCarthy,²⁹ N. A. McCubbin,¹³¹ K. W. McFarlane,^{56a} J. A. Mcfayden,⁷⁸
 G. Mchedlidze,⁵⁴ S. J. McMahon,¹³¹ R. A. McPherson,^{170,k} J. Mechnich,¹⁰⁷ M. Medinnis,⁴² S. Meehan,^{146a} S. Mehlhase,¹⁰⁰
 A. Mehta,⁷⁴ K. Meier,^{58a} C. Meineck,¹⁰⁰ B. Meirose,⁴¹ C. Melachrinou,³¹ B. R. Mellado Garcia,^{146c} F. Meloni,¹⁷
 A. Mengarelli,^{20a,20b} S. Menke,¹⁰¹ E. Meoni,¹⁶² K. M. Mercurio,⁵⁷ S. Mergelmeyer,²¹ N. Meric,¹³⁷ P. Mermod,⁴⁹
 L. Merola,^{104a,104b} C. Meroni,^{91a} F. S. Merritt,³¹ H. Merritt,¹¹¹ A. Messina,^{30,aa} J. Metcalfe,²⁵ A. S. Mete,¹⁶⁴ C. Meyer,⁸³
 C. Meyer,¹²² J-P. Meyer,¹³⁷ J. Meyer,¹⁰⁷ R. P. Middleton,¹³¹ S. Migas,⁷⁴ S. Miglioranza,^{165a,165c} L. Mijović,²¹
 G. Mikenberg,¹⁷³ M. Mikestikova,¹²⁷ M. Mikuž,⁷⁵ A. Milic,³⁰ D. W. Miller,³¹ C. Mills,⁴⁶ A. Milov,¹⁷³ D. A. Milstead,^{147a,147b}
 A. A. Minaenko,¹³⁰ Y. Minami,¹⁵⁶ I. A. Minashvili,⁶⁵ A. I. Mincer,¹¹⁰ B. Mindur,^{38a} M. Mineev,⁶⁵ Y. Ming,¹⁷⁴ L. M. Mir,¹²
 G. Mirabelli,^{133a} T. Mitani,¹⁷² J. Mitrevski,¹⁰⁰ V. A. Mitsou,¹⁶⁸ A. Miucci,⁴⁹ P. S. Miyagawa,¹⁴⁰ J. U. Mjörnmark,⁸¹
 T. Moa,^{147a,147b} K. Mochizuki,⁸⁵ S. Mohapatra,³⁵ W. Mohr,⁴⁸ S. Molander,^{147a,147b} R. Moles-Valls,¹⁶⁸ K. Mönig,⁴²
 C. Monini,⁵⁵ J. Monk,³⁶ E. Monnier,⁸⁵ J. Montejo Berlingen,¹² F. Monticelli,⁷¹ S. Monzani,^{133a,133b} R. W. Moore,³
 N. Morange,¹¹⁷ D. Moreno,¹⁶³ M. Moreno Llácer,⁵⁴ P. Morettini,^{50a} M. Morgenstern,⁴⁴ M. Morii,⁵⁷ V. Morisbak,¹¹⁹
 S. Moritz,⁸³ A. K. Morley,¹⁴⁸ G. Mornacchi,³⁰ J. D. Morris,⁷⁶ A. Morton,⁵³ L. Morvaj,¹⁰³ H. G. Moser,¹⁰¹ M. Mosidze,^{51b}
 J. Moss,¹¹¹ K. Motohashi,¹⁵⁸ R. Mount,¹⁴⁴ E. Mountricha,²⁵ S. V. Mouraviev,^{96,a} E. J. W. Moyses,⁸⁶ S. Muanza,⁸⁵
 R. D. Mudd,¹⁸ F. Mueller,¹⁰¹ J. Mueller,¹²⁵ K. Mueller,²¹ R. S. P. Mueller,¹⁰⁰ T. Mueller,²⁸ D. Muenstermann,⁴⁹ P. Mullen,⁵³
 Y. Munwes,¹⁵⁴ J. A. Murillo Quijada,¹⁸ W. J. Murray,^{171,131} H. Musheghyan,⁵⁴ E. Musto,¹⁵³ A. G. Myagkov,^{130,bb}
 M. Myska,¹²⁸ O. Nackenhurst,⁵⁴ J. Nadal,⁵⁴ K. Nagai,¹²⁰ R. Nagai,¹⁵⁸ Y. Nagai,⁸⁵ K. Nagano,⁶⁶ A. Nagarkar,¹¹¹
 Y. Nagasaka,⁵⁹ K. Nagata,¹⁶¹ M. Nagel,¹⁰¹ E. Nagy,⁸⁵ A. M. Nairz,³⁰ Y. Nakahama,³⁰ K. Nakamura,⁶⁶ T. Nakamura,¹⁵⁶
 I. Nakano,¹¹² H. Namasivayam,⁴¹ G. Nanava,²¹ R. F. Naranjo Garcia,⁴² R. Narayan,^{58b} T. Nattermann,²¹ T. Naumann,⁴²
 G. Navarro,¹⁶³ R. Nayyar,⁷ H. A. Neal,⁸⁹ P. Yu. Nechaeva,⁹⁶ T. J. Neep,⁸⁴ P. D. Nef,¹⁴⁴ A. Negri,^{121a,121b} M. Negrini,^{20a}
 S. Nektarijevic,¹⁰⁶ C. Nellist,¹¹⁷ A. Nelson,¹⁶⁴ S. Nemecek,¹²⁷ P. Nemethy,¹¹⁰ A. A. Nepomuceno,^{24a} M. Nessi,^{30,cc}
 M. S. Neubauer,¹⁶⁶ M. Neumann,¹⁷⁶ R. M. Neves,¹¹⁰ P. Nevski,²⁵ P. R. Newman,¹⁸ D. H. Nguyen,⁶ R. B. Nickerson,¹²⁰
 R. Nicolaidou,¹³⁷ B. Nicquevert,³⁰ J. Nielsen,¹³⁸ N. Nikiforou,³⁵ A. Nikiforov,¹⁶ V. Nikolaenko,^{130,bb} I. Nikolic-Audit,⁸⁰
 K. Nikolopoulos,¹⁸ P. Nilsson,²⁵ Y. Ninomiya,¹⁵⁶ A. Nisati,^{133a} R. Nisius,¹⁰¹ T. Nobe,¹⁵⁸ M. Nomachi,¹¹⁸ I. Nomidis,²⁹
 T. Nooney,⁷⁶ S. Norberg,¹¹³ M. Nordberg,³⁰ O. Novgorodova,⁴⁴ S. Nowak,¹⁰¹ M. Nozaki,⁶⁶ L. Nozka,¹¹⁵ K. Ntekas,¹⁰
 G. Nunes Hanninger,⁸⁸ T. Nunnemann,¹⁰⁰ E. Nurse,⁷⁸ F. Nuti,⁸⁸ B. J. O'Brien,⁴⁶ F. O'grady,⁷ D. C. O'Neil,¹⁴³ V. O'Shea,⁵³
 F. G. Oakham,^{29,e} H. Oberlack,¹⁰¹ T. Obermann,²¹ J. Ocariz,⁸⁰ A. Ochi,⁶⁷ I. Ochoa,⁷⁸ S. Oda,⁷⁰ S. Odaka,⁶⁶ H. Ogren,⁶¹
 A. Oh,⁸⁴ S. H. Oh,⁴⁵ C. C. Ohm,¹⁵ H. Ohman,¹⁶⁷ H. Oide,³⁰ W. Okamura,¹¹⁸ H. Okawa,¹⁶¹ Y. Okumura,³¹ T. Okuyama,¹⁵⁶
 A. Olariu,^{26a} A. G. Olchevski,⁶⁵ S. A. Olivares Pino,⁴⁶ D. Oliveira Damazio,²⁵ E. Oliver Garcia,¹⁶⁸ A. Olszewski,³⁹
 J. Olszowska,³⁹ A. Onofre,^{126a,126e} P. U. E. Onyisi,^{31,q} C. J. Oram,^{160a} M. J. Oreglia,³¹ Y. Oren,¹⁵⁴ D. Orestano,^{135a,135b}
 N. Orlando,¹⁵⁵ C. Oropeza Barrera,⁵³ R. S. Orr,¹⁵⁹ B. Osculati,^{50a,50b} R. Ospanov,⁸⁴ G. Otero y Garzon,²⁷ H. Otono,⁷⁰
 M. Ouchrif,^{136d} E. A. Ouellette,¹⁷⁰ F. Ould-Saada,¹¹⁹ A. Ouraou,¹³⁷ K. P. Oussoren,¹⁰⁷ Q. Ouyang,^{33a} A. Ovcharova,¹⁵
 M. Owen,⁵³ V. E. Ozcan,^{19a} N. Ozturk,⁸ K. Pachal,¹²⁰ A. Pacheco Pages,¹² C. Padilla Aranda,¹² M. Pagáčová,⁴⁸
 S. Pagan Griso,¹⁵ E. Paganis,¹⁴⁰ C. Pahl,¹⁰¹ F. Paige,²⁵ P. Pais,⁸⁶ K. Pajchel,¹¹⁹ G. Palacino,^{160b} S. Palestini,³⁰ M. Palka,^{38b}
 D. Pallin,³⁴ A. Palma,^{126a,126b} Y. B. Pan,¹⁷⁴ E. Panagiotopoulou,¹⁰ C. E. Pandini,⁸⁰ J. G. Panduro Vazquez,⁷⁷ P. Pani,^{147a,147b}
 N. Panikashvili,⁸⁹ S. Panitkin,²⁵ L. Paolozzi,^{134a,134b} Th. D. Papadopoulou,¹⁰ K. Papageorgiou,¹⁵⁵ A. Paramonov,⁶
 D. Paredes Hernandez,¹⁵⁵ M. A. Parker,²⁸ K. A. Parker,¹⁴⁰ F. Parodi,^{50a,50b} J. A. Parsons,³⁵ U. Parzefall,⁴⁸ E. Pasqualucci,^{133a}
 S. Passaggio,^{50a} F. Pastore,^{135a,135b,a} Fr. Pastore,⁷⁷ G. Pásztor,²⁹ S. Patariaia,¹⁷⁶ N. D. Patel,¹⁵¹ J. R. Pater,⁸⁴ T. Pauly,³⁰
 J. Pearce,¹⁷⁰ L. E. Pedersen,³⁶ M. Pedersen,¹¹⁹ S. Pedraza Lopez,¹⁶⁸ R. Pedro,^{126a,126b} S. V. Peleganchuk,¹⁰⁹ D. Pelikan,¹⁶⁷
 H. Peng,^{33b} B. Penning,³¹ J. Penwell,⁶¹ D. V. Perepelitsa,²⁵ E. Perez Codina,^{160a} M. T. Pérez García-Estañ,¹⁶⁸ L. Perini,^{91a,91b}

H. Pernegger,³⁰ S. Perrella,^{104a,104b} R. Peschke,⁴² V. D. Peshekhonov,⁶⁵ K. Peters,³⁰ R. F. Y. Peters,⁸⁴ B. A. Petersen,³⁰ T. C. Petersen,³⁶ E. Petit,⁴² A. Petridis,^{147a,147b} C. Petridou,¹⁵⁵ E. Petrolo,^{133a} F. Petrucci,^{135a,135b} N. E. Pettersson,¹⁵⁸ R. Pezoa,^{32b} P. W. Phillips,¹³¹ G. Piacquadio,¹⁴⁴ E. Pianori,¹⁷¹ A. Picazio,⁴⁹ E. Piccaro,⁷⁶ M. Piccinini,^{20a,20b} M. A. Pickering,¹²⁰ R. Piegai,²⁷ D. T. Pignotti,¹¹¹ J. E. Pilcher,³¹ A. D. Pilkington,⁷⁸ J. Pina,^{126a,126b,126d} M. Pinamonti,^{165a,165c,dd} J. L. Pinfold,³ A. Pingel,³⁶ B. Pinto,^{126a} S. Pires,⁸⁰ M. Pitt,¹⁷³ C. Pizio,^{91a,91b} L. Plazak,^{145a} M.-A. Pleier,²⁵ V. Pleskot,¹²⁹ E. Plotnikova,⁶⁵ P. Plucinski,^{147a,147b} D. Pluth,⁶⁴ R. Poettgen,⁸³ L. Poggioli,¹¹⁷ D. Pohl,²¹ G. Polesello,^{121a} A. Policicchio,^{37a,37b} R. Polifka,¹⁵⁹ A. Polini,^{20a} C. S. Pollard,⁵³ V. Polychronakos,²⁵ K. Pommès,³⁰ L. Pontecorvo,^{133a} B. G. Pope,⁹⁰ G. A. Popeneciu,^{26b} D. S. Popovic,¹³ A. Poppleton,³⁰ S. Pospisil,¹²⁸ K. Potamianos,¹⁵ I. N. Potrap,⁶⁵ C. J. Potter,¹⁵⁰ C. T. Potter,¹¹⁶ G. Poulard,³⁰ J. Poveda,³⁰ V. Pozdnyakov,⁶⁵ P. Pralavorio,⁸⁵ A. Pranko,¹⁵ S. Prasad,³⁰ S. Prell,⁶⁴ D. Price,⁸⁴ J. Price,⁷⁴ L. E. Price,⁶ M. Primavera,^{73a} S. Prince,⁸⁷ M. Proissl,⁴⁶ K. Prokofiev,^{60c} F. Prokoshin,^{32b} E. Protopapadaki,¹³⁷ S. Protopopescu,²⁵ J. Proudfoot,⁶ M. Przybycien,^{38a} E. Ptacek,¹¹⁶ D. Puddu,^{135a,135b} E. Pueschel,⁸⁶ D. Puldon,¹⁴⁹ M. Purohit,^{25,ee} P. Puzo,¹¹⁷ J. Qian,⁸⁹ G. Qin,⁵³ Y. Qin,⁸⁴ A. Quadt,⁵⁴ D. R. Quarrie,¹⁵ W. B. Quayle,^{165a,165b} M. Queitsch-Maitland,⁸⁴ D. Quilty,⁵³ A. Qureshi,^{160b} V. Radeka,²⁵ V. Radescu,⁴² S. K. Radhakrishnan,¹⁴⁹ P. Radloff,¹¹⁶ P. Rados,⁸⁸ F. Ragusa,^{91a,91b} G. Rahal,¹⁷⁹ S. Rajagopalan,²⁵ M. Rammensee,³⁰ C. Rangel-Smith,¹⁶⁷ F. Rauscher,¹⁰⁰ S. Rave,⁸³ T. C. Rave,⁴⁸ T. Ravenscroft,⁵³ M. Raymond,³⁰ A. L. Read,¹¹⁹ N. P. Readioff,⁷⁴ D. M. Rebuffi,^{121a,121b} A. Redelbach,¹⁷⁵ G. Redlinger,²⁵ R. Reece,¹³⁸ K. Reeves,⁴¹ L. Rehnisch,¹⁶ H. Reisin,²⁷ M. Relich,¹⁶⁴ C. Rembser,³⁰ H. Ren,^{33a} A. Renaud,¹¹⁷ M. Rescigno,^{133a} S. Resconi,^{91a} O. L. Rezanova,^{109,d} P. Reznicek,¹²⁹ R. Rezvani,⁹⁵ R. Richter,¹⁰¹ E. Richter-Was,^{38b} M. Ridel,⁸⁰ P. Rieck,¹⁶ C. J. Riegel,¹⁷⁶ J. Rieger,⁵⁴ M. Rijssenbeek,¹⁴⁹ A. Rimoldi,^{121a,121b} L. Rinaldi,^{20a} E. Ritsch,⁶² I. Riu,¹² F. Rizatdinova,¹¹⁴ E. Rizvi,⁷⁶ S. H. Robertson,^{87,k} A. Robichaud-Veronneau,⁸⁷ D. Robinson,²⁸ J. E. M. Robinson,⁸⁴ A. Robson,⁵³ C. Roda,^{124a,124b} L. Rodrigues,³⁰ S. Roe,³⁰ O. Røhne,¹¹⁹ S. Rolli,¹⁶² A. Romaniouk,⁹⁸ M. Romano,^{20a,20b} S. M. Romano Saez,³⁴ E. Romero Adam,¹⁶⁸ N. Rompotis,¹³⁹ M. Ronzani,⁴⁸ L. Roos,⁸⁰ E. Ros,¹⁶⁸ S. Rosati,^{133a} K. Rosbach,⁴⁸ P. Rose,¹³⁸ P. L. Rosendahl,¹⁴ O. Rosenthal,¹⁴² V. Rossetti,^{147a,147b} E. Rossi,^{104a,104b} L. P. Rossi,^{50a} R. Rosten,¹³⁹ M. Rotaru,^{26a} I. Roth,¹⁷³ J. Rothberg,¹³⁹ D. Rousseau,¹¹⁷ C. R. Royon,¹³⁷ A. Rozanov,⁸⁵ Y. Rozen,¹⁵³ X. Ruan,^{146c} F. Rubbo,¹⁴⁴ I. Rubinskiy,⁴² V. I. Rud,⁹⁹ C. Rudolph,⁴⁴ M. S. Rudolph,¹⁵⁹ F. Rühr,⁴⁸ A. Ruiz-Martinez,³⁰ Z. Rurikova,⁴⁸ N. A. Rusakovich,⁶⁵ A. Ruschke,¹⁰⁰ H. L. Russell,¹³⁹ J. P. Rutherford,⁷ N. Ruthmann,⁴⁸ Y. F. Ryabov,¹²³ M. Rybar,¹²⁹ G. Rybkin,¹¹⁷ N. C. Ryder,¹²⁰ A. F. Saavedra,¹⁵¹ G. Sabato,¹⁰⁷ S. Sacerdoti,²⁷ A. Saddique,³ H. F. W. Sadrozinski,¹³⁸ R. Sadykov,⁶⁵ F. Safai Tehrani,^{133a} M. Saimpert,¹³⁷ H. Sakamoto,¹⁵⁶ Y. Sakurai,¹⁷² G. Salamanna,^{135a,135b} A. Salamon,^{134a} M. Saleem,¹¹³ D. Salek,¹⁰⁷ P. H. Sales De Bruin,¹³⁹ D. Salihagic,¹⁰¹ A. Salnikov,¹⁴⁴ J. Salt,¹⁶⁸ D. Salvatore,^{37a,37b} F. Salvatore,¹⁵⁰ A. Salvucci,¹⁰⁶ A. Salzburger,³⁰ D. Sampsonidis,¹⁵⁵ A. Sanchez,^{104a,104b} J. Sánchez,¹⁶⁸ V. Sanchez Martinez,¹⁶⁸ H. Sandaker,¹⁴ R. L. Sandbach,⁷⁶ H. G. Sander,⁸³ M. P. Sanders,¹⁰⁰ M. Sandhoff,¹⁷⁶ C. Sandoval,¹⁶³ R. Sandstroem,¹⁰¹ D. P. C. Sankey,¹³¹ A. Sansoni,⁴⁷ C. Santoni,³⁴ R. Santonico,^{134a,134b} H. Santos,^{126a} I. Santoyo Castillo,¹⁵⁰ K. Sapp,¹²⁵ A. Sapronov,⁶⁵ J. G. Saraiva,^{126a,126d} B. Sarrazin,²¹ O. Sasaki,⁶⁶ Y. Sasaki,¹⁵⁶ K. Sato,¹⁶¹ G. Sauvage,^{5a} E. Sauvan,⁵ G. Savage,⁷⁷ P. Savard,^{159,e} C. Sawyer,¹²⁰ L. Sawyer,^{79,n} D. H. Saxon,⁵³ J. Saxon,³¹ C. Sbarra,^{20a} A. Sbrizzi,^{20a,20b} T. Scanlon,⁷⁸ D. A. Scannicchio,¹⁶⁴ M. Scarcella,¹⁵¹ V. Scarfone,^{37a,37b} J. Schaarschmidt,¹⁷³ P. Schacht,¹⁰¹ D. Schaefer,³⁰ R. Schaefer,⁴² J. Schaeffer,⁸³ S. Schaepe,²¹ S. Schaezel,^{58b} U. Schäfer,⁸³ A. C. Schaffer,¹¹⁷ D. Schaile,¹⁰⁰ R. D. Schamberger,¹⁴⁹ V. Scharf,^{58a} V. A. Schegelsky,¹²³ D. Scheirich,¹²⁹ M. Schernau,¹⁶⁴ C. Schiavi,^{50a,50b} J. Schieck,¹⁰⁰ C. Schillo,⁴⁸ M. Schioppa,^{37a,37b} S. Schlenker,³⁰ E. Schmidt,⁴⁸ K. Schmieden,³⁰ C. Schmitt,⁸³ S. Schmitt,^{58b} B. Schneider,^{160a} Y. J. Schnellbach,⁷⁴ U. Schnoor,⁴⁴ L. Schoeffel,¹³⁷ A. Schoening,^{58b} B. D. Schoenrock,⁹⁰ A. L. S. Schorlemmer,⁵⁴ M. Schott,⁸³ D. Schouten,^{160a} J. Schovancova,⁸ S. Schramm,¹⁵⁹ M. Schreyer,¹⁷⁵ C. Schroeder,⁸³ N. Schuh,⁸³ M. J. Schultens,²¹ H.-C. Schultz-Coulon,^{58a} H. Schulz,¹⁶ M. Schumacher,⁴⁸ B. A. Schumm,¹³⁸ Ph. Schune,¹³⁷ C. Schwanenberger,⁸⁴ A. Schwartzman,¹⁴⁴ T. A. Schwarz,⁸⁹ Ph. Schwegler,¹⁰¹ Ph. Schwemling,¹³⁷ R. Schwienhorst,⁹⁰ J. Schwindling,¹³⁷ T. Schwindt,²¹ M. Schwoerer,⁵ F. G. Sciaccia,¹⁷ E. Scifo,¹¹⁷ G. Sciolla,²³ F. Scuri,^{124a,124b} F. Scutti,²¹ J. Searcy,⁸⁹ G. Sedov,⁴² E. Sedykh,¹²³ P. Seema,²¹ S. C. Seidel,¹⁰⁵ A. Seiden,¹³⁸ F. Seifert,¹²⁸ J. M. Seixas,^{24a} G. Sekhniaidze,^{104a} S. J. Sekula,⁴⁰ K. E. Selbach,⁴⁶ D. M. Seliverstov,^{123,a} N. Semprini-Cesari,^{20a,20b} C. Serfon,³⁰ L. Serin,¹¹⁷ L. Serkin,⁵⁴ T. Serre,⁸⁵ R. Seuster,^{160a} H. Severini,¹¹³ T. Sfiligoj,⁷⁵ F. Sforza,¹⁰¹ A. Sfyrta,³⁰ E. Shabalina,⁵⁴ M. Shamim,¹¹⁶ L. Y. Shan,^{33a} R. Shang,¹⁶⁶ J. T. Shank,²² M. Shapiro,¹⁵ P. B. Shatalov,⁹⁷ K. Shaw,^{165a,165b} A. Shcherbakova,^{147a,147b} C. Y. Shehu,¹⁵⁰ P. Sherwood,⁷⁸ L. Shi,^{152,ff} S. Shimizu,⁶⁷ C. O. Shimmin,¹⁶⁴ M. Shimojima,¹⁰² M. Shiyakova,⁶⁵ A. Shmeleva,⁹⁶ D. Shoaleh Saadi,⁹⁵ M. J. Shochet,³¹ S. Shojaii,^{91a,91b} S. Shrestha,¹¹¹ E. Shulga,⁹⁸ M. A. Shupe,⁷ S. Shushkevich,⁴² P. Sicho,¹²⁷

O. Sidiropoulou,¹⁷⁵ D. Sidorov,¹¹⁴ A. Sidoti,^{20a,20b} F. Siegert,⁴⁴ Dj. Sijacki,¹³ J. Silva,^{126a,126d} Y. Silver,¹⁵⁴ D. Silverstein,¹⁴⁴ S. B. Silverstein,^{147a} V. Simak,¹²⁸ O. Simard,⁵ Lj. Simic,¹³ S. Simion,¹¹⁷ E. Simioni,⁸³ B. Simmons,⁷⁸ D. Simon,³⁴ R. Simoniello,^{91a,91b} P. Sinervo,¹⁵⁹ N. B. Sinev,¹¹⁶ G. Siragusa,¹⁷⁵ A. Sircar,⁷⁹ A. N. Sisakyan,^{65,a} S. Yu. Sivoklokov,⁹⁹ J. Sjölin,^{147a,147b} T. B. Sjursen,¹⁴ M. B. Skinner,⁷² H. P. Skottowe,⁵⁷ P. Skubic,¹¹³ M. Slater,¹⁸ T. Slavicek,¹²⁸ M. Slawinska,¹⁰⁷ K. Sliwa,¹⁶² V. Smakhtin,¹⁷³ B. H. Smart,⁴⁶ L. Smestad,¹⁴ S. Yu. Smirnov,⁹⁸ Y. Smirnov,⁹⁸ L. N. Smirnova,^{99,gg} O. Smirnova,⁸¹ K. M. Smith,⁵³ M. Smith,³⁵ M. Smizanska,⁷² K. Smolek,¹²⁸ A. A. Snesarev,⁹⁶ G. Snidero,⁷⁶ S. Snyder,²⁵ R. Sobie,^{170,k} F. Socher,⁴⁴ A. Soffer,¹⁵⁴ D. A. Soh,^{152,ff} C. A. Solans,³⁰ M. Solar,¹²⁸ J. Solc,¹²⁸ E. Yu. Soldatov,⁹⁸ U. Soldevila,¹⁶⁸ A. A. Solodkov,¹³⁰ A. Soloshenko,⁶⁵ O. V. Solovyanov,¹³⁰ V. Solovyev,¹²³ P. Sommer,⁴⁸ H. Y. Song,^{33b} N. Soni,¹ A. Sood,¹⁵ A. Sopczak,¹²⁸ B. Sopko,¹²⁸ V. Sopko,¹²⁸ V. Sorin,¹² D. Sosa,^{58b} M. Sosebee,⁸ C. L. Sotiropoulou,¹⁵⁵ R. Soualah,^{165a,165c} P. Soueid,⁹⁵ A. M. Soukharev,^{109,d} D. South,⁴² S. Spagnolo,^{73a,73b} F. Spanò,⁷⁷ W. R. Spearman,⁵⁷ F. Spettel,¹⁰¹ R. Spighi,^{20a} G. Spigo,³⁰ L. A. Spiller,⁸⁸ M. Spusta,¹²⁹ T. Spreitzer,¹⁵⁹ R. D. St. Denis,^{53,a} S. Staerz,⁴⁴ J. Stahlman,¹²² R. Stamen,^{58a} S. Stamm,¹⁶ E. Stanecka,³⁹ C. Stanescu,^{135a} M. Stanescu-Bellu,⁴² M. M. Stanitzki,⁴² S. Stapnes,¹¹⁹ E. A. Starchenko,¹³⁰ J. Stark,⁵⁵ P. Staroba,¹²⁷ P. Starovoitov,⁴² R. Staszewski,³⁹ P. Stavina,^{145a,a} P. Steinberg,²⁵ B. Stelzer,¹⁴³ H. J. Stelzer,³⁰ O. Stelzer-Chilton,^{160a} H. Stenzel,⁵² S. Stern,¹⁰¹ G. A. Stewart,⁵³ J. A. Stillings,²¹ M. C. Stockton,⁸⁷ M. Stoebe,⁸⁷ G. Stoicea,^{26a} P. Stolte,⁵⁴ S. Stonjek,¹⁰¹ A. R. Stradling,⁸ A. Straessner,⁴⁴ M. E. Stramaglia,¹⁷ J. Strandberg,¹⁴⁸ S. Strandberg,^{147a,147b} A. Strandlie,¹¹⁹ E. Strauss,¹⁴⁴ M. Strauss,¹¹³ P. Strizenec,^{145b} R. Ströhmer,¹⁷⁵ D. M. Strom,¹¹⁶ R. Stroynowski,⁴⁰ A. Strubig,¹⁰⁶ S. A. Stucci,¹⁷ B. Stugu,¹⁴ N. A. Styles,⁴² D. Su,¹⁴⁴ J. Su,¹²⁵ R. Subramaniam,⁷⁹ A. Succurro,¹² Y. Sugaya,¹¹⁸ C. Suhr,¹⁰⁸ M. Suk,¹²⁸ V. V. Sulin,⁹⁶ S. Sultansoy,^{4c} T. Sumida,⁶⁸ S. Sun,⁵⁷ X. Sun,^{33a} J. E. Sundermann,⁴⁸ K. Suruliz,¹⁵⁰ G. Susinno,^{37a,37b} M. R. Sutton,¹⁵⁰ Y. Suzuki,⁶⁶ M. Svatos,¹²⁷ S. Swedish,¹⁶⁹ M. Swiatlowski,¹⁴⁴ I. Sykora,^{145a} T. Sykora,¹²⁹ D. Ta,⁹⁰ C. Taccini,^{135a,135b} K. Tackmann,⁴² J. Taenzer,¹⁵⁹ A. Taffard,¹⁶⁴ R. Tafirout,^{160a} N. Taiblum,¹⁵⁴ H. Takai,²⁵ R. Takashima,⁶⁹ H. Takeda,⁶⁷ T. Takeshita,¹⁴¹ Y. Takubo,⁶⁶ M. Talby,⁸⁵ A. A. Talyshev,^{109,d} J. Y. C. Tam,¹⁷⁵ K. G. Tan,⁸⁸ J. Tanaka,¹⁵⁶ R. Tanaka,¹¹⁷ S. Tanaka,¹³² S. Tanaka,⁶⁶ A. J. Tanasijczuk,¹⁴³ B. B. Tannenwald,¹¹¹ N. Tannoury,²¹ S. Tapprogge,⁸³ S. Tarem,¹⁵³ F. Tarrade,²⁹ G. F. Tartarelli,^{91a} P. Tas,¹²⁹ M. Tasevsky,¹²⁷ T. Tashiro,⁶⁸ E. Tassi,^{37a,37b} A. Tavares Delgado,^{126a,126b} Y. Tayalati,^{136d} F. E. Taylor,⁹⁴ G. N. Taylor,⁸⁸ W. Taylor,^{160b} F. A. Teischinger,³⁰ M. Teixeira Dias Castanheira,⁷⁶ P. Teixeira-Dias,⁷⁷ K. K. Temming,⁴⁸ H. Ten Kate,³⁰ P. K. Teng,¹⁵² J. J. Teoh,¹¹⁸ F. Tepel,¹⁷⁶ S. Terada,⁶⁶ K. Terashi,¹⁵⁶ J. Terron,⁸² S. Terzo,¹⁰¹ M. Testa,⁴⁷ R. J. Teuscher,^{159,k} J. Therhaag,²¹ T. Theveneaux-Pelzer,³⁴ J. P. Thomas,¹⁸ J. Thomas-Wilsker,⁷⁷ E. N. Thompson,³⁵ P. D. Thompson,¹⁸ R. J. Thompson,⁸⁴ A. S. Thompson,⁵³ L. A. Thomsen,³⁶ E. Thomson,¹²² M. Thomson,²⁸ W. M. Thong,⁸⁸ R. P. Thun,^{89,a} F. Tian,³⁵ M. J. Tibbetts,¹⁵ R. E. Ticse Torres,⁸⁵ V. O. Tikhomirov,^{96,hh} Yu. A. Tikhonov,^{109,d} S. Timoshenko,⁹⁸ E. Tiouchichine,⁸⁵ P. Tipton,¹⁷⁷ S. Tisserant,⁸⁵ T. Todorov,^{5,a} S. Todorova-Nova,¹²⁹ J. Tojo,⁷⁰ S. Tokár,^{145a} K. Tokushuku,⁶⁶ K. Tollefson,⁹⁰ E. Tolley,⁵⁷ L. Tomlinson,⁸⁴ M. Tomoto,¹⁰³ L. Tompkins,^{144,ii} K. Toms,¹⁰⁵ N. D. Topilin,⁶⁵ E. Torrence,¹¹⁶ H. Torres,¹⁴³ E. Torró Pastor,¹⁶⁸ J. Toth,^{85,ij} F. Touchard,⁸⁵ D. R. Tovey,¹⁴⁰ H. L. Tran,¹¹⁷ T. Trefzger,¹⁷⁵ L. Tremblet,³⁰ A. Tricoli,³⁰ I. M. Trigger,^{160a} S. Trincaz-Duvoid,⁸⁰ M. F. Tripiana,¹² W. Trischuk,¹⁵⁹ B. Trocmé,⁵⁵ C. Troncon,^{91a} M. Trotter-McDonald,¹⁵ M. Trovatelli,^{135a,135b} P. True,⁹⁰ M. Trzebinski,³⁹ A. Trzupek,³⁹ C. Tsarouchas,³⁰ J. C.-L. Tseng,¹²⁰ P. V. Tsiarshka,⁹² D. Tsionou,¹³⁷ G. Tsiapolitis,¹⁰ N. Tsirintanis,⁹ S. Tsiskaridze,¹² V. Tsiskaridze,⁴⁸ E. G. Tskhadadze,^{51a} I. I. Tsukerman,⁹⁷ V. Tsulaia,¹⁵ S. Tsuno,⁶⁶ D. Tsybychev,¹⁴⁹ A. Tudorache,^{26a} V. Tudorache,^{26a} A. N. Tuna,¹²² S. A. Tupputi,^{20a,20b} S. Turchikhin,^{99,gg} D. Turecek,¹²⁸ I. Turk Cakir,^{4b} R. Turra,^{91a,91b} A. J. Turvey,⁴⁰ P. M. Tuts,³⁵ A. Tykhonov,⁴⁹ M. Tylmad,^{147a,147b} M. Tyndel,¹³¹ I. Ueda,¹⁵⁶ R. Ueno,²⁹ M. Ughetto,⁸⁵ M. Ugland,¹⁴ M. Uhlenbrock,²¹ F. Ukegawa,¹⁶¹ G. Unal,³⁰ A. Undrus,²⁵ G. Unel,¹⁶⁴ F. C. Ungaro,⁴⁸ Y. Unno,⁶⁶ C. Unverdorben,¹⁰⁰ J. Urban,^{145b} P. Urquijo,⁸⁸ P. Urrejola,⁸³ G. Usai,⁸ A. Usanova,⁶² L. Vacavant,⁸⁵ V. Vacek,¹²⁸ B. Vachon,⁸⁷ N. Valencic,¹⁰⁷ S. Valentinetti,^{20a,20b} A. Valero,¹⁶⁸ L. Valery,¹² S. Valkar,¹²⁹ E. Valladolid Gallego,¹⁶⁸ S. Vallecorsa,⁴⁹ J. A. Valls Ferrer,¹⁶⁸ W. Van Den Wollenberg,¹⁰⁷ P. C. Van Der Deijl,¹⁰⁷ R. van der Geer,¹⁰⁷ H. van der Graaf,¹⁰⁷ R. Van Der Leeuw,¹⁰⁷ N. van Eldik,³⁰ P. van Gemmeren,⁶ J. Van Nieuwkoop,¹⁴³ I. van Vulpen,¹⁰⁷ M. C. van Woerden,³⁰ M. Vanadia,^{133a,133b} W. Vandelli,³⁰ R. Vanguri,¹²² A. Vaniachine,⁶ F. Vannucci,⁸⁰ G. Vardanyan,¹⁷⁸ R. Vari,^{133a} E. W. Varnes,⁷ T. Varol,⁴⁰ D. Varouchas,⁸⁰ A. Vartapetian,⁸ K. E. Varvell,¹⁵¹ F. Vazeille,³⁴ T. Vazquez Schroeder,⁵⁴ J. Veatch,⁷ F. Veloso,^{126a,126c} T. Velz,²¹ S. Veneziano,^{133a} A. Ventura,^{73a,73b} D. Ventura,⁸⁶ M. Venturi,¹⁷⁰ N. Venturi,¹⁵⁹ A. Venturini,²³ V. Vercesi,^{121a} M. Verducci,^{133a,133b} W. Verkerke,¹⁰⁷ J. C. Vermeulen,¹⁰⁷ A. Vest,⁴⁴ M. C. Vetterli,^{143,e} O. Viazlo,⁸¹ I. Vichou,¹⁶⁶ T. Vickey,^{146c,kk} O. E. Vickey Boeriu,^{146c} G. H. A. Viehhauser,¹²⁰ S. Viel,¹⁵ R. Vigne,³⁰ M. Villa,^{20a,20b} M. Villaplana Perez,^{91a,91b} E. Vilucchi,⁴⁷ M. G. Vinciter,²⁹ V. B. Vinogradov,⁶⁵ J. Virzi,¹⁵ I. Vivarelli,¹⁵⁰ F. Vives Vaque,³

S. Vlachos,¹⁰ D. Vladoiu,¹⁰⁰ M. Vlasak,¹²⁸ M. Vogel,^{32a} P. Vokac,¹²⁸ G. Volpi,^{124a,124b} M. Volpi,⁸⁸ H. von der Schmitt,¹⁰¹ H. von Radziewski,⁴⁸ E. von Toerne,²¹ V. Vorobel,¹²⁹ K. Vorobev,⁹⁸ M. Vos,¹⁶⁸ R. Voss,³⁰ J. H. Vosseveld,⁷⁴ N. Vranjes,¹³ M. Vranjes Milosavljevic,¹³ V. Vrba,¹²⁷ M. Vreeswijk,¹⁰⁷ R. Vuillermet,³⁰ I. Vukotic,³¹ Z. Vykydal,¹²⁸ P. Wagner,²¹ W. Wagner,¹⁷⁶ H. Wahlberg,⁷¹ S. Wahrmund,⁴⁴ J. Wakabayashi,¹⁰³ J. Walder,⁷² R. Walker,¹⁰⁰ W. Walkowiak,¹⁴² C. Wang,^{33c} F. Wang,¹⁷⁴ H. Wang,¹⁵ H. Wang,⁴⁰ J. Wang,⁴² J. Wang,^{33a} K. Wang,⁸⁷ R. Wang,¹⁰⁵ S. M. Wang,¹⁵² T. Wang,²¹ X. Wang,¹⁷⁷ C. Wanotayaroj,¹¹⁶ A. Warburton,⁸⁷ C. P. Ward,²⁸ D. R. Wardrope,⁷⁸ M. Warsinsky,⁴⁸ A. Washbrook,⁴⁶ C. Wasicki,⁴² P. M. Watkins,¹⁸ A. T. Watson,¹⁸ I. J. Watson,¹⁵¹ M. F. Watson,¹⁸ G. Watts,¹³⁹ S. Watts,⁸⁴ B. M. Waugh,⁷⁸ S. Webb,⁸⁴ M. S. Weber,¹⁷ S. W. Weber,¹⁷⁵ J. S. Webster,³¹ A. R. Weidberg,¹²⁰ B. Weinert,⁶¹ J. Weingarten,⁵⁴ C. Weiser,⁴⁸ H. Weits,¹⁰⁷ P. S. Wells,³⁰ T. Wenaus,²⁵ D. Wendland,¹⁶ T. Wengler,³⁰ S. Wenig,³⁰ N. Wermes,²¹ M. Werner,⁴⁸ P. Werner,³⁰ M. Wessels,^{58a} J. Wetter,¹⁶² K. Whalen,²⁹ A. M. Wharton,⁷² A. White,⁸ M. J. White,¹ R. White,^{32b} S. White,^{124a,124b} D. Whiteson,¹⁶⁴ D. Wicke,¹⁷⁶ F. J. Wickens,¹³¹ W. Wiedenmann,¹⁷⁴ M. Wielers,¹³¹ P. Wienemann,²¹ C. Wiglesworth,³⁶ L. A. M. Wiik-Fuchs,²¹ A. Wildauer,¹⁰¹ H. G. Wilkens,³⁰ H. H. Williams,¹²² S. Williams,¹⁰⁷ C. Willis,⁹⁰ S. Willocq,⁸⁶ A. Wilson,⁸⁹ J. A. Wilson,¹⁸ I. Wingerter-Seez,⁵ F. Winklmeier,¹¹⁶ B. T. Winter,²¹ M. Wittgen,¹⁴⁴ J. Wittkowski,¹⁰⁰ S. J. Wollstadt,⁸³ M. W. Wolter,³⁹ H. Wolters,^{126a,126c} B. K. Wosiek,³⁹ J. Wotschack,³⁰ M. J. Woudstra,⁸⁴ K. W. Wozniak,³⁹ M. Wu,⁵⁵ S. L. Wu,¹⁷⁴ X. Wu,⁴⁹ Y. Wu,⁸⁹ T. R. Wyatt,⁸⁴ B. M. Wynne,⁴⁶ S. Xella,³⁶ D. Xu,^{33a} L. Xu,^{33b,11} B. Yabsley,¹⁵¹ S. Yacoub,^{146b,mm} R. Yakabe,⁶⁷ M. Yamada,⁶⁶ Y. Yamaguchi,¹¹⁸ A. Yamamoto,⁶⁶ S. Yamamoto,¹⁵⁶ T. Yamanaka,¹⁵⁶ K. Yamauchi,¹⁰³ Y. Yamazaki,⁶⁷ Z. Yan,²² H. Yang,^{33e} H. Yang,¹⁷⁴ Y. Yang,¹⁵² S. Yanush,⁹³ L. Yao,^{33a} W.-M. Yao,¹⁵ Y. Yasu,⁶⁶ E. Yatsenko,⁴² K. H. Yau Wong,²¹ J. Ye,⁴⁰ S. Ye,²⁵ I. Yeletsikh,⁶⁵ A. L. Yen,⁵⁷ E. Yildirim,⁴² K. Yorita,¹⁷² R. Yoshida,⁶ K. Yoshihara,¹²² C. Young,¹⁴⁴ C. J. S. Young,³⁰ S. Youssef,²² D. R. Yu,¹⁵ J. Yu,⁸ J. M. Yu,⁸⁹ J. Yu,¹¹⁴ L. Yuan,⁶⁷ A. Yurkewicz,¹⁰⁸ I. Yusuff,^{28,nn} B. Zabinski,³⁹ R. Zaidan,⁶³ A. M. Zaitsev,^{130,bb} A. Zaman,¹⁴⁹ S. Zambito,²³ L. Zanello,^{133a,133b} D. Zanzi,⁸⁸ C. Zeitnitz,¹⁷⁶ M. Zeman,¹²⁸ A. Zemla,^{38a} K. Zengel,²³ O. Zenin,¹³⁰ T. Ženiš,^{145a} D. Zerwas,¹¹⁷ D. Zhang,⁸⁹ F. Zhang,¹⁷⁴ J. Zhang,⁶ L. Zhang,¹⁵² R. Zhang,^{33b} X. Zhang,^{33d} Z. Zhang,¹¹⁷ X. Zhao,⁴⁰ Y. Zhao,^{33d,117} Z. Zhao,^{33b} A. Zhemchugov,⁶⁵ J. Zhong,¹²⁰ B. Zhou,⁸⁹ C. Zhou,⁴⁵ L. Zhou,³⁵ L. Zhou,⁴⁰ N. Zhou,¹⁶⁴ C. G. Zhu,^{33d} H. Zhu,^{33a} J. Zhu,⁸⁹ Y. Zhu,^{33b} X. Zhuang,^{33a} K. Zhukov,⁹⁶ A. Zibell,¹⁷⁵ D. Zieminska,⁶¹ N. I. Zimine,⁶⁵ C. Zimmermann,⁸³ R. Zimmermann,²¹ S. Zimmermann,⁴⁸ Z. Zinonos,⁵⁴ M. Ziolkowski,¹⁴² L. Živković,¹³ G. Zobernig,¹⁷⁴ A. Zoccoli,^{20a,20b} M. zur Nedden,¹⁶ G. Zurzolo,^{104a,104b} and L. Zwalinski³⁰

(ATLAS Collaboration)

¹*Department of Physics, University of Adelaide, Adelaide, Australia*²*Physics Department, SUNY Albany, Albany NY, United States of America*³*Department of Physics, University of Alberta, Edmonton AB, Canada*^{4a}*Department of Physics, Ankara University, Ankara, Turkey*^{4b}*Istanbul Aydin University, Istanbul, Turkey*^{4c}*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*⁵*LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France*⁶*High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States of America*⁷*Department of Physics, University of Arizona, Tucson, AZ, United States of America*⁸*Department of Physics, The University of Texas at Arlington, Arlington, TX, United States of America*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*¹³*Institute of Physics, 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, CA, United States of America*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, Italy*^{20b}*Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*

- ²¹Physikalisches Institut, University of Bonn, Bonn, Germany
- ²²Department of Physics, Boston University, Boston, MA, United States of America
- ²³Department of Physics, Brandeis University, Waltham, MA, United States of America
- ^{24a}Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil
- ^{24b}Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora, Brazil
- ^{24c}Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei, Brazil
- ^{24d}Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
- ²⁵Physics Department, Brookhaven National Laboratory, Upton, NY, United States of America
- ^{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
- ²⁷Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- ²⁸Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- ²⁹Department of Physics, Carleton University, Ottawa, ON, Canada
- ³⁰CERN, Geneva, Switzerland
- ³¹Enrico Fermi Institute, University of Chicago, Chicago, IL, United States of America
- ^{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}Department of Physics and Astronomy, Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai, China
- ^{33f}Physics Department, Tsinghua University, Beijing 100084, China
- ³⁴Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France
- ³⁵Nevis Laboratory, Columbia University, Irvington, NY, United States of America
- ³⁶Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
- ^{37a}INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, 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
- ³⁹The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- ⁴⁰Physics Department, Southern Methodist University, Dallas, TX, United States of America
- ⁴¹Physics Department, University of Texas at Dallas, Richardson, TX, United States of America
- ⁴²DESY, Hamburg and Zeuthen, Germany
- ⁴³Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- ⁴⁴Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
- ⁴⁵Department of Physics, Duke University, Durham NC, United States of America
- ⁴⁶SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- ⁴⁷INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ⁴⁸Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany
- ⁴⁹Section de Physique, Université de Genève, Geneva, Switzerland
- ^{50a}INFN Sezione di Genova, Italy
- ^{50b}Dipartimento di Fisica, Università di Genova, Genova, Italy
- ^{51a}E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi, Georgia
- ^{51b}High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- ⁵²II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- ⁵³SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- ⁵⁴II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- ⁵⁵Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
- ⁵⁶Department of Physics, Hampton University, Hampton, VA, United States of America
- ⁵⁷Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States of America
- ^{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
- ⁵⁹Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan

- ^{60a}*Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
- ^{60b}*Department of Physics, The University of Hong Kong, Hong Kong, China*
- ^{60c}*Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- ⁶¹*Department of Physics, Indiana University, Bloomington, IN, United States of America*
- ⁶²*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
- ⁶³*University of Iowa, Iowa City, IA, United States of America*
- ⁶⁴*Department of Physics and Astronomy, Iowa State University, Ames, IA, United States of America*
- ⁶⁵*Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia*
- ⁶⁶*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
- ⁶⁷*Graduate School of Science, Kobe University, Kobe, Japan*
- ⁶⁸*Faculty of Science, Kyoto University, Kyoto, Japan*
- ⁶⁹*Kyoto University of Education, Kyoto, Japan*
- ⁷⁰*Department of Physics, Kyushu University, Fukuoka, Japan*
- ⁷¹*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
- ⁷²*Physics Department, Lancaster University, Lancaster, United Kingdom*
- ^{73a}*INFN Sezione di Lecce, Italy*
- ^{73b}*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
- ⁷⁴*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
- ⁷⁵*Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia*
- ⁷⁶*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
- ⁷⁷*Department of Physics, Royal Holloway University of London, Surrey, United Kingdom*
- ⁷⁸*Department of Physics and Astronomy, University College London, London, United Kingdom*
- ⁷⁹*Louisiana Tech University, Ruston, LA, United States of America*
- ⁸⁰*Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France*
- ⁸¹*Fysiska institutionen, Lunds universitet, Lund, Sweden*
- ⁸²*Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain*
- ⁸³*Institut für Physik, Universität Mainz, Mainz, Germany*
- ⁸⁴*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
- ⁸⁵*CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France*
- ⁸⁶*Department of Physics, University of Massachusetts, Amherst, MA, United States of America*
- ⁸⁷*Department of Physics, McGill University, Montreal QC, Canada*
- ⁸⁸*School of Physics, University of Melbourne, Victoria, Australia*
- ⁸⁹*Department of Physics, The University of Michigan, Ann Arbor, MI, United States of America*
- ⁹⁰*Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States of America*
- ^{91a}*INFN Sezione di Milano, Milano, Italy*
- ^{91b}*Dipartimento di Fisica, Università di Milano, Milano, Italy*
- ⁹²*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus*
- ⁹³*National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus*
- ⁹⁴*Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States of America*
- ⁹⁵*Group of Particle Physics, University of Montreal, Montreal, QC, Canada*
- ⁹⁶*P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia*
- ⁹⁷*Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia*
- ⁹⁸*National Research Nuclear University MEPhI, Moscow, Russia*
- ⁹⁹*D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
- ¹⁰⁰*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
- ¹⁰¹*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
- ¹⁰²*Nagasaki Institute of Applied Science, Nagasaki, Japan*
- ¹⁰³*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
- ^{104a}*INFN Sezione di Napoli, Napoli, Italy*
- ^{104b}*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
- ¹⁰⁵*Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States of America*
- ¹⁰⁶*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
- ¹⁰⁷*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
- ¹⁰⁸*Department of Physics, Northern Illinois University, DeKalb, IL, United States of America*
- ¹⁰⁹*Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia*
- ¹¹⁰*Department of Physics, New York University, New York, NY, United States of America*
- ¹¹¹*Ohio State University, Columbus, OH, United States of America*
- ¹¹²*Faculty of Science, Okayama University, Okayama, Japan*
- ¹¹³*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States of America*
- ¹¹⁴*Department of Physics, Oklahoma State University, Stillwater, OK, United States of America*

- ¹¹⁵Palacký University, RCPTM, Olomouc, Czech Republic
- ¹¹⁶Center for High Energy Physics, University of Oregon, Eugene, OR, United States of America
- ¹¹⁷LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
- ¹¹⁸Graduate School of Science, Osaka University, Osaka, Japan
- ¹¹⁹Department of Physics, University of Oslo, Oslo, Norway
- ¹²⁰Department of Physics, Oxford University, Oxford, United Kingdom
- ^{121a}INFN Sezione di Pavia, Pavia, Italy
- ^{121b}Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- ¹²²Department of Physics, University of Pennsylvania, Philadelphia, PA, United States of America
- ¹²³Petersburg Nuclear Physics Institute, Gatchina, Russia
- ^{124a}INFN Sezione di Pisa, Pisa, Italy
- ^{124b}Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- ¹²⁵Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States of America
- ^{126a}Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
- ^{126b}Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
- ^{126c}Department of Physics, University of Coimbra, Coimbra, Portugal
- ^{126d}Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
- ^{126e}Departamento de Física, Universidade do Minho, Braga, Portugal
- ^{126f}Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada (Spain), Portugal
- ^{126g}Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
- ¹²⁷Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
- ¹²⁸Czech Technical University in Prague, Praha, Czech Republic
- ¹²⁹Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
- ¹³⁰State Research Center Institute for High Energy Physics, Protvino, Russia
- ¹³¹Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ¹³²Ritsumeikan University, Kusatsu, Shiga, Japan
- ^{133a}INFN Sezione di Roma, Roma, Italy
- ^{133b}Dipartimento di Fisica, Sapienza Università di Roma, 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
- ¹³⁷DSM/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
- ¹³⁸Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States of America
- ¹³⁹Department of Physics, University of Washington, Seattle, WA, United States of America
- ¹⁴⁰Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ¹⁴¹Department of Physics, Shinshu University, Nagano, Japan
- ¹⁴²Fachbereich Physik, Universität Siegen, Siegen, Germany
- ¹⁴³Department of Physics, Simon Fraser University, Burnaby, BC, Canada
- ¹⁴⁴SLAC National Accelerator Laboratory, Stanford, CA, United States of America
- ^{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
- ¹⁴⁸Physics Department, Royal Institute of Technology, Stockholm, Sweden
- ¹⁴⁹Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, NY, United States of America
- ¹⁵⁰Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- ¹⁵¹School of Physics, University of Sydney, Sydney, Australia
- ¹⁵²Institute of Physics, Academia Sinica, Taipei, Taiwan
- ¹⁵³Department 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, ON, Canada*
- ^{160a}*TRIUMF, Vancouver, BC, Canada*
- ^{160b}*Department of Physics and Astronomy, York University, Toronto, ON, Canada*
- ¹⁶¹*Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
- ¹⁶²*Department of Physics and Astronomy, Tufts University, Medford, MA, United States of America*
- ¹⁶³*Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia*
- ¹⁶⁴*Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States of America*
- ^{165a}*INFN Gruppo Collegato di Udine, Sezione di Trieste, 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, IL, United States of America*
- 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, BC, Canada*
- ¹⁷⁰*Department of Physics and Astronomy, University of Victoria, Victoria, BC, 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, WI, United States of America*
- 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, CT, United States of America*
- 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*
- ^aDeceased.
- ^bAlso at Department of Physics, King's College London, London, United Kingdom.
- ^cAlso at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
- ^dAlso at Novosibirsk State University, Novosibirsk, Russia.
- ^eAlso at TRIUMF, Vancouver, BC, Canada.
- ^fAlso at Department of Physics, California State University, Fresno CA, United States of America.
- ^gAlso at Department of Physics, University of Fribourg, Fribourg, Switzerland.
- ^hAlso at Tomsk State University, Tomsk, Russia.
- ⁱAlso at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.
- ^jAlso at Università di Napoli Parthenope, Napoli, Italy.
- ^kAlso at Institute of Particle Physics (IPP), Canada.
- ^lAlso at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ^mAlso at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
- ⁿAlso at Louisiana Tech University, Ruston LA, United States of America.
- ^oAlso at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
- ^pAlso at Department of Physics, National Tsing Hua University, Taiwan.
- ^qAlso at Department of Physics, The University of Texas at Austin, Austin TX, United States of America.
- ^rAlso at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
- ^sAlso at CERN, Geneva, Switzerland.
- ^tAlso at Georgian Technical University (GTU), Tbilisi, Georgia.
- ^uAlso at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan.
- ^vAlso at Manhattan College, New York, NY, United States of America.
- ^wAlso at Institute of Physics, Academia Sinica, Taipei, Taiwan.
- ^xAlso at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France.
- ^yAlso at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
- ^zAlso at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France.
- ^{aa}Also at Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy.

- ^{bb} Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
- ^{cc} Also at Section de Physique, Université de Genève, Geneva, Switzerland.
- ^{dd} Also at International School for Advanced Studies (SISSA), Trieste, Italy.
- ^{ee} Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America.
- ^{ff} Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China.
- ^{gg} Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia.
- ^{hh} Also at National Research Nuclear University MEPhI, Moscow, Russia.
- ⁱⁱ Also at Department of Physics, Stanford University, Stanford CA, United States of America.
- ^{jj} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
- ^{kk} Also at Department of Physics, Oxford University, Oxford, United Kingdom.
- ^{ll} Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America.
- ^{mm} Also at Discipline of Physics, University of KwaZulu-Natal, Durban, South Africa.
- ⁿⁿ Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia.