The $\phi(1020)$-meson production cross section measured with the ATLAS detector at $\sqrt{s}=7$ TeV

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Citation for published version (APA):
de Nooij, L. (2014). The $\phi(1020)$-meson production cross section measured with the ATLAS detector at $\sqrt{s}=7$ TeV. 's-Hertogenbosch: Boxpress.
Summary

In this thesis the $\phi$-meson production cross section in proton-proton interactions at a center-of-mass energy of $\sqrt{s} = 7$ TeV measured with the ATLAS experiment at the LHC is presented. The main aim of the ATLAS detector is to study and explore physics around and above the electroweak symmetry-breaking scale. These processes typically take place at high energy transfers, which separates them from the prevalent processes in $pp$ interactions: namely strong force interactions with low momentum transfers described by non-perturbative quantum chromodynamics (QCD). Monte Carlo event generators are used to simulate these soft processes, but for reliable predictions the models rely on data.

Sources of $\phi$-mesons in $pp$ collisions are direct production from strange sea quarks, gluon fusion or fragmentation processes. This makes the $\phi$ meson a probe of the phenomenology of the hadronization, in contrast to the third generation quarks that are rarely produced in hadronisation. The strange quark mass cannot assumed to be zero in the calculations, unlike the $u$ and $d$ quark mass.

In this thesis the $\phi$ meson is measured through its decay into two kaons. The identification of kaons is based on their energy deposition in the pixel detector. The track reconstruction is provided by the ATLAS inner detector, which comprises the pixel detector, a silicon strip detector and a transition radiation tracker. The energy loss depends on the particle velocity as described by the Bethe–Bloch formula and the mass difference between pion, kaons and protons is used as a discriminating variable, providing discriminating power of momenta below 800 MeV. On the other hand, kaons with momenta below 230 MeV are not reconstructed at all, because they loose all their energy in the construction materials of the pixel detector.

Kaons can thus be reconstructed and identified in a limited momentum range. To avoid model-dependent extrapolations outside this range, the cross section result is presented in a so-called fiducial volume. Being restricted by the requirements on kaon momentum, this volume covers $500 < p_T, \phi < 1200$ MeV and $|y| < 0.8$. Figure S1 shows the invariant mass of all oppositely charged combinations of pairs of tracks that have successfully been identified as kaons. The number of reconstructed $\phi$ mesons is measured by fitting the invariant mass spectrum with a probability density function (p.d.f.) that describes the signal and background contributions separately in each region of phase space.

In order to create the invariant mass spectrum shown in figure S1, both kaons from a $\phi$ decay need to be reconstructed and both tracks need to pass the kaon identification requirements. The tracking efficiency is determined from simulated data as the ratio of the number of generated particles reconstructed as a track to the total number of generated particles. The leading systematic uncertainty in the tracking efficiency determination originates from the simulation of the amount and location of detector material. The kaon identification efficiency is determined using
Figure S1: The invariant mass spectrum is fitted with a probability density function that described signal and background contributions separately to obtain the number of φ-meson candidates.

a data-driven tag-and-probe method. The method counts the number of “tag” instances (with at least one kaon passing the identification requirements) and the number of “probe” (both kaons passing) instances as an independent subset. The tag-and-probe efficiency is then defined as:

\[ \varepsilon_{\text{Tp}} = \frac{N_{\text{probe}}}{N_{\text{tag}}}. \]

This data-driven method is needed, because it was found that the Monte Carlo overestimates the discrimination power between pions and kaons. The tag-and-probe efficiency is observed to be up to a factor of three lower in data. The largest systematic uncertainty in the kaon identification efficiency determination is due to signal extraction in the tag sample.

Both the track reconstruction efficiency and the kaon identification efficiency are determined as a function of kaon momentum. To calculate the number of efficiency-corrected reconstructed φ mesons, each kaon in figure S1 is given a weight to correct for experimental losses. Finally, signal extraction is performed on the corrected invariant mass spectra and the cross section is calculated as the number of efficiency-corrected decays divided by the integrated luminosity. The integrated cross section is found to be

\[ \sigma_{\phi \rightarrow K^+K^-} = 570 \pm 7 \text{ (stat)} \pm 69 \text{ (syst)} \pm 20 \text{ (lumi)} \mu\text{b}, \]

for \(500 < p_T, \phi < 1200 \text{ MeV}, |y_\phi| < 0.8, p_{T,K} > 230 \text{ MeV} \) and \(p_K < 800 \text{ MeV}\).

The φ-meson production cross section is in fair agreement with two of the predictions under examination. Different tunes of the same generator result in significantly different predictions. This measurement can provide useful input for tuning and development of phenomenological models in order to improve Monte Carlo event generators.