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Prompt K^0_S production in pp collisions at $\sqrt{s} = 0.9$ TeV ☆,☆☆

LHCb Collaboration

A R T I C L E I N F O

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Dedicated to the memory of Werner Ruckstuhl, Peter Schlein and Tom Ypsilantis, who each played a fundamental role in the design of the experiment

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A B S T R A C T

The production of K^0_S mesons in pp collisions at a centre-of-mass energy of 0.9 TeV is studied with the LHCb detector at the Large Hadron Collider. The luminosity of the analysed sample is determined using a novel technique, involving measurements of the beam currents, sizes and positions, and is found to be $6.8 \pm 1.0\ \mu b^{-1}$. The differential prompt K^0_S production cross-section is measured as a function of the K^0_S transverse momentum and rapidity in the region $0 < p_T < 1.6$ GeV/c and $2.5 < y < 4.0$. The data are found to be in reasonable agreement with previous measurements and generator expectations.

1. Introduction

Strangeness production studies provide sensitive tests of soft hadronic interactions, as the mass of the strange quark is of the order of Λ_{QCD}. Strange-hadron production is suppressed, as a consequence, but still occurs in the non-perturbative regime. The hadronic production of K^0_S mesons has been studied by several experiments at a range of different centre-of-mass energies, both in pp and $p\bar{p}$ collisions (see for example [1–7]). The most recent measurements of K^0_S production at the Tevatron have shown deviations with respect to the expectations of hadronization models [6]. Strangeness production is also a topic of great interest in heavy ion physics, and measurements of this process in pp and $p\bar{p}$ collisions serve as reference point [7].

In this Letter measurements of prompt K^0_S production are presented using data collected with the LHCb detector in pp collisions at $\sqrt{s} = 0.9$ TeV, during the 2009 pilot run of the Large Hadron Collider (LHC). A K^0_S is defined to be prompt if it is directly produced in the pp collision, or if it appears in the decay chain of a non-weakly-decaying resonance (such as K^*) directly produced in the pp collision. The measurements are made in the rapidity interval $2.5 < y < 4.0$ and down to below 0.2 GeV/c transverse momentum with respect to the beam line. This is a region not explored at this energy by any previous experiment, and is complementary to the coverage of other LHC experiments. The determination of the prompt K^0_S production cross-section is normalized using an absolute measurement of the luminosity that relies on knowledge of the beam profiles.

The Letter is organized as follows. Section 2 gives a brief description of the LHCb detector and the configuration used to record data in December 2009 during the LHC pilot run. Section 3 gives an overview of the analysis strategy, the details of which are presented in the three following sections. Section 4 is dedicated to an explanation of the luminosity measurement, Section 5 presents the K^0_S candidate selection and Section 6 the determination of the K^0_S trigger and reconstruction efficiencies. The final results are discussed in Section 7 and compared with model expectations, before concluding in Section 8.

2. LHCb detector and 2009 data sample

The LHCb detector is a single-arm magnetic dipole spectrometer with a polar angular coverage with respect to the beam line of approximately 15 to 300 mrad in the horizontal bending plane, and 15 to 250 mrad in the vertical non-bending plane. The detector is described in detail elsewhere [8]. All subdetectors were fully operational and in a stable condition for the data that are analysed. For the measurements presented in this Letter the tracking detectors and trigger strategy are of particular importance.

A right-handed coordinate system is defined with its origin at the nominal pp interaction point, the z axis along the beam

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line and pointing towards the magnet, and the y axis pointing upwards. Beam-1 (beam-2) travels in the direction of positive (negative) z.

The LHCb tracking system consists of the Vertex Locator (VELO) surrounding the pp interaction region, a tracking station (TT) upstream of the dipole magnet, and three tracking stations (T1–T3) downstream of the magnet. Particles traversing from the interaction region to the downstream tracking stations experience a bending-field integral of 3.7 Tm on average.

The VELO consists of silicon microstrip modules, providing a measure of the radial and azimuthal coordinates, r and ϕ, distributed in 23 stations arranged along the beam direction. The first two stations at the most upstream z positions are instrumented to provide information on the number of visible interactions in the detector at the first level of the trigger ('pile-up detector'). The VELO is constructed in two halves (left and right), movable in the x and y directions so that it can be centred on the beam. During stable beam conditions the two halves are located at their nominal closed position, with active silicon at 8 mm from the beams, providing full azimuthal coverage. During injection and beam adjustments the two halves are moved apart horizontally to a retracted position away from the beams.

The TT station also uses silicon microstrip technology. The downstream tracking stations T1–T3 have silicon microstrips in the region close to the beam pipe (Inner Tracker, IT), whereas straw tubes are employed in the outer region (Outer Tracker, OT).

During the 2009 run, low intensity beams collided in LHCb at the LHC injection energy, corresponding to a total energy of 0.9 TeV. Due to the dipole magnetic field the beams have a crossing angle that results in the pp centre-of-mass frame moving with velocity $0.0021c$ in the $-x$ direction. Both the beam sizes and crossing angle were larger than those designed for high-energy collisions. In order not to risk the safety of the VELO, the 2009 data were recorded with the two VELO halves positioned 15 mm away from their nominal data-taking position (VELO partially open), resulting in a reduced azimuthal coverage. For this run, the magnetic dipole field was pointing downwards.

The bulk of the data presented here were collected in a series of LHC fills with the following two sets of beam conditions. The first configuration contained four bunches per beam, spaced by more than 8 µs, with two colliding and two non-colliding bunches, and a total peak beam intensity of about 1.8×10^{10} protons per bunch. The second configuration contained 16 bunches per beam, spaced by more than 2 µs, with eight colliding and eight non-colliding bunches, and a total peak beam intensity of about 1.3×10^{10} protons per bunch. The nominal LHC injection optical function at the interaction point was used ($\beta^* = 10$ m).

A trigger strategy was deployed to provide high efficiency for pp inelastic interactions and for beam collisions with the residual gas in the vacuum chamber. The latter class of events is a necessary ingredient for the luminosity analysis. Events were collected for three bunch-crossing types: two colliding bunches (bb), beam-1 bunch with no beam-2 bunch ($b1$), and beam-2 bunch with no beam-1 bunch ($b2$). The first two categories of crossings, which produce particles in the forward ($+z$) direction, were triggered using calorimeter information: a 2×2 cluster with more than 240 MeV of transverse energy in the Hadron Calorimeter (HCAL) and at least three hits in the 6016 cells of the Scintillator Pad Detector (SPD) at the entrance to the calorimeter were required. Events containing a track in the muon system with transverse momentum above 480 MeV/c were also triggered. Crossings of the type $b2$, which produce particles in the backward direction only, were triggered by demanding a hit multiplicity of more than seven in the pile-up detector.

The visible collision rate for a single bunch pair was about 10 Hz and the acquired $b1$ ($b2$) rate for a single bunch was approximately 0.015 Hz (0.002 Hz), in agreement with the measured residual pressure and VELO acceptance. A sample of 424 193 events triggered in bb crossings is used in the K^0_S analysis.

3. Analysis strategy

All K^0_S candidates are reconstructed in the $\pi^+\pi^-$ decay mode, using only events triggered by the calorimeter. Contributions from secondary interactions in the detector material or from the decay of long-lived particles are suppressed by requiring the K^0_S candidates to point back to the pp-collision point. No attempt is made to separate the contributions from K^0_S mesons produced in diffractive and non-diffractive processes.

Due to the long K^0_S lifetime and partially open VELO position, only a small fraction of the K^0_S daughter tracks traversing the spectrometer leave a signal in the VELO. Therefore, two paths are followed for the K^0_S reconstruction and selection:

a) Downstream-track selection:
Tracks reconstructed only with hits in the TT and T1–T3 stations (called downstream tracks) are combined, without using the VELO. The origin of the K^0_S is taken as the point on the z axis that is closest to the reconstructed flight vector of the K^0_S candidate. This point is taken as an estimate of the primary vertex (PV), and is referred to as the 'pseudo-PV'.

b) Long-track selection:
K^0_S candidates are formed with tracks leaving hits in the VELO and in the T stations (called long tracks). If available, measurements in the TT are added to the tracks. The PV is reconstructed from tracks seen in the detector, using VELO information whenever available.

The analysis is performed in bins of K^0_S phase space. The kinematic variables used are the K^0_S transverse momentum $p_T = \sqrt{p_x^2 + p_y^2}$ and the rapidity $y = \frac{1}{2}\ln((E + p_z)/(E - p_z))$, where $(E, \vec{p})$ is the K^0_S four-momentum in the pp centre-of-mass system. For a given bin i in p_T and y, the prompt K^0_S production cross-section is calculated as

$$\sigma_i = \frac{N_i^{\mathrm{obs}}}{\epsilon_i^{\mathrm{trig/sel}} \epsilon_i^{\mathrm{sel}} L_{\mathrm{int}}}, \tag{1}$$

where N_i^{obs} is the number of observed $K^0_S \to \pi^+\pi^-$ signal decays with reconstructed p_T and y in bin i, $\epsilon_i^{\mathrm{sel}}$ the reconstruction and selection efficiency, $\epsilon_i^{\mathrm{trig/sel}}$ the trigger efficiency on selected events, and L_{int} the integrated luminosity. The number of signal events N_i^{obs} is obtained from the mass distributions of the K^0_S candidates.

The reconstruction and selection efficiency is estimated from a fully-simulated Monte Carlo (MC) sample of single pp collisions as

$$\epsilon_i^{\mathrm{sel}} = \frac{N_i^{\mathrm{sel}}}{N_i^{\mathrm{prompt}}}, \tag{2}$$

where N_i^{sel} is the number of $K^0_S \to \pi^+\pi^-$ signal decays selected in the untriggered MC sample with reconstructed p_T and y in bin i (extracted using the same procedure as in the data), and where N_i^{prompt} is the number of generated prompt K^0_S mesons with generated p_T and y in bin i. This efficiency includes the geometrical acceptance, as well as the reconstruction and selection efficiencies. It also incorporates all corrections related to the following effects: secondary interactions of K^0_S in the material, $K^0_S \to \pi^+\pi^-$ branching fraction, decay in flight and secondary interaction of the decay