Analysis of $\phi$ resonance in $pp$ collisions at 900 GeV with the ALICE detector

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Abstract. ALICE is the LHC experiment mainly dedicated to the study of hot and high energy density nuclear matter created in heavy-ion collisions. ALICE has also developed a detailed proton-proton physics programme, in order to exploit its capabilities to investigate the novel energy regime made available by LHC, which turns out to be quite interesting in itself besides being important as a baseline for the heavy-ion data. Results will be presented of the $\phi$ resonance measurements done with the first data sets taken at LHC between 2009 and 2010, in $pp$ collisions at 900 GeV. $\phi$ transverse momentum spectra and global yields will be shown.

1. Introduction

The study of identified particle production in $pp$ collisions provides a fundamental baseline for properly tuning the QCD-inspired models in order to make predictions at higher energies. In the low-$p_T$ region this helps especially in understanding the nature of the soft part of the underlying event. The ALICE detector [1], thanks to its low operating magnetic field (0.5 T) and to its excellent particle identification (PID) capabilities, is well suited for the study of low-$p_T$ particle production at mid-rapidity. The $\phi$ resonance is of great interest in this respect and has already been widely studied at lower energies (see for example [2]-[5]).

Studying the hadronic resonances in $pp$ collisions provides also a baseline for a better understanding of heavy-ion collisions, where they are useful probes of the hot and dense matter created there [6].

A measurement of the $\phi$ production has been carried out with the first LHC commissioning runs (November-December 2009), consisting in almost 250k events at the center of mass energy of 900 GeV. $dN/dy$ at mid-rapidity and the average transverse momentum were measured. Section 2 will briefly illustrate the most important aspects of the ALICE detector exploited for this study. Section 3 will present the analysis details and section 4 will show the results obtained. Conclusions will be given in section 5.

2. Experimental setup

ALICE [1] is the LHC experiment most specifically devoted to the study of heavy-ion collisions. It is designed to guarantee a very complete reconstruction and identification of the particles produced in those collisions (for details, refer to [1]).

The contribution of several detectors was used in this analysis. Charged particles were tracked by the Time Projection Chamber (TPC) and the Inner Tracking System (ITS). The Silicon
Pixel Detectors (SPD) in the two innermost ITS layers also contributed to the primary vertex reconstruction. The TPC returns a $dE/dx$ measurement with a resolution $\sigma_{TPC} = 6\%$, useful for particle identification (PID). At larger momenta (above $\sim0.7$ GeV/$c$) PID is also supported by the Time of Flight detector (TOF), which reached a time resolution of almost 170 ps. At the trigger level the two VZERO counters helped in rejecting most of the beam-gas interactions.

The first LHC data-taking period consisted essentially in low luminosity ($10^9 p/bunch$) $pp$ beams at $\sqrt{s} = 900$ GeV. The online minimum bias trigger was based on the signals from VZERO counters, the Fast-OR trigger coming from the SPD (see [1] for details) and from the LHC beam pickup signals.

For a better quality of the analysis, events with longitudinal primary vertex position $Z_V \geq 10$ cm were rejected, in order to avoid biases due to the detector acceptance. After the whole set of online and offline selections, the analyzed sample consisted in $\sim250k$ events.

3. Analysis details

3.1. Track selection

The $\phi$ resonance was reconstructed through its $K^+ K^-$ decay channel (branching ratio = 49.2%).

Tracks used for analysis were required to have been reconstructed by both TPC and ITS, with at least 80 clusters in the TPC and a total $\chi^2$ (normalized to the number of TPC points) smaller than 4, in order to ensure a reasonable track quality. Since resonance daughters are indistinguishable from primaries, tracks were also required to have a distance of closest approach to primary vertex smaller than 0.5 cm (3 cm) in the transverse (longitudinal) direction.

A PID request was also made, in the form of a ‘compatibility cut’: a track was accepted if its associated TPC and TOF signals were close to the expected one for a Kaon with the same total momentum, within a fiducial window. The TPC fiducial window was chosen to be $3\sigma_{TPC}$ ($5\sigma_{TPC}$) if the track total momentum at the TPC inner wall was larger (smaller) than 350 MeV/$c$ (see fig. 1 left). The TOF fiducial window on time difference was defined by two hyperbolas, as it is shown in figure 1 (right), to cope with the worsening resolution at small momenta (for $p_T \leq 260$ MeV/$c$ the TOF is never used). Since the TPC-TOF matching efficiency is almost 60%, whenever a TOF signal was absent in the track, the TPC PID cut only was used.

3.2. Signal extraction and correction

The measurement was done in four $p_T$ bins between 0.7 and 3 GeV/$c$ and in a rapidity window $|y| \leq 0.6$, where the efficiency was found to be almost flat. An invariant mass distribution was
Figure 2. (Left) $K^+K^-$ invariant mass spectrum in the $p_T$ bin between 1 and 1.5 GeV/c. The curve is the combined fit of square-root function + Gaussian to the points, and the vertical lines delimit the region where the subtraction is computed. (Right) Efficiency of reconstructed $\phi$ computed in the PYTHIA sample cited in the text, in the four measured $p_T$ bins.

Figure 3. (Left) Corrected $\phi$ spectrum as a function of $p_T$. Shaded boxes represent the sum in quadrature of statistical and systematic errors, and the bars indicate the statistical errors only. The curves are the fit to the functions described in the text. (Right) Comparison of corrected spectrum from data with the corresponding spectrum of $\phi$ generated in a PYTHIA and in a PHOJET sample, normalized to the same integral in the measured $p_T$ range (0.7 to 3 GeV/c).

computed with all unlike-sign charged track pairs (see fig 2, left) and fitted with a square-root function $(A\sqrt{m-m_0})$ plus a Gaussian, to reproduce the peak plus the background. Due to the small size of the measured sample and the consequently large statistical errors in the fit function, the bin counting method was preferred to compute the number of $\phi$. This was then obtained from the subtraction of the background function integral from the total number of entries counted in a fixed invariant mass range. The chosen counting range was $m_\phi \pm 4\sigma$, where $m_\phi$ is the nominal mass of the $\phi$ resonance [7] and $\sigma$ is computed from the full-width at half maximum (FWHM) of a Gaussian, expressed in terms of its $\sigma$ parameter ($\sigma = FWHM/2.35$), and then assuming as FWHM the nominal width $\Gamma_\phi$ [7] of the $\phi$ resonance. This results in a range of $m_\phi \pm 1.7/\Gamma_\phi$.

To correct the measured counts, the $\phi$ reconstruction efficiency was estimated through a PYTHIA simulation made with a realistic implementation of the ALICE detector (see fig. 2, right). Finally, the corrected counts were normalized to the total number of inelastic collisions [8].

Two main sources of systematic error were identified: one was related to the background subtraction, and another is due to TPC-related cuts ($dE/dx$ and number of clusters). They were estimated to range between 3.0 to 7.0% in the first case and from 0.9 to 6% in the second one. Anyway, they are smaller than the statistical error which ranges between 10% and 20% due to the sample size.
Integral & Levy & % & Exponential & % \\
--- & --- & --- & --- & --- \\
0 - 0.7 GeV/c & 0.0090 ± 0.0007 & 45 & 0.009 ± 0.002 & 47 \\
0.7 - 3 GeV/c & 0.0104 ± 0.0007 & 52 & 0.0104 ± 0.0007 & 52 \\
3 - ∞ GeV/c & 0.0006 ± 0.0001 & 3 & 0.0002 ± 0.0001 & 1 \\
Total & 0.020 ± 0.001 & 100 & 0.020 ± 0.002 & 100 \\
⟨p_T⟩ (GeV/c) & 0.98 ± 0.07 & & 0.88 ± 0.06 & \\

Table 1. Computed dN/dy and mean p_T after the spectra fit (see text). First and third line come from function integration, second line comes from measured histogram integral.

4. Results

In order to extract the global integrated yields, the corrected p_T spectrum was fitted with a p_T-dependent exponential and with a Levy function:

\[
\frac{d^2N}{dydp_T} = A \times p_T \times e^{-\frac{p_T}{T}}
\]

\[
\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nT[nT + m(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1 + \frac{mT - m}{nT}\right)^{-n}
\]

where \(m_T = \sqrt{m^2 + p_T^2}\). The full dN/dy distribution was computed by summing the integral fit functions outside the measured range, and the integral of measured bins inside it. In both cases the average transverse momentum was also computed.

Figure 3 (left) shows the measured points and the two used functions, and table 1 reports the computed yields and mean p_T. As expected, the two functions return different values for the latter, due to the very different contribution coming from the high momentum tail. Due to the exiguity of sample size, and the necessity to carry on the measurement on large p_T bins, it was not possible to discriminate between the two functions; then, these difference can give a preliminary estimate of a systematic uncertainty on the value. Figure 3 (right) reports a comparison of the measured points with PYTHIA and PHOJET normalized to the same integral in the measured region (0.7 to 3 GeV/c): while in this range they appear to be quite compatible, both generators give a larger expectation in the extrapolation region at low p_T, which reflects in a smaller mean p_T (0.55 for PHOJET and 0.77 for PYTHIA).

5. Conclusions

Preliminary results have been shown of the measurement of φ resonance in ALICE obtained with the first LHC data at 900 GeV. The p_T spectrum was measured between 0.7 and 3 GeV/c.

These results provide a useful baseline for comparisons with QCD-inspired particle production models and will be a reference for future measurements in heavy-ion collisions at LHC. Moreover, despite the rather low statistics (250 k events), this study demonstrates the excellent capability of ALICE for resonance measurements which will be exploited in pp collisions at higher energies and in heavy-ion collisions.

6. Bibliography

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