Simulation study of $\chi_c \to J/\psi + \gamma$ detection with $J/\psi \to e^+e^-$ in pp collisions in the ALICE experiment at LHC

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Abstract We present Monte Carlo preliminary results about the feasibility to detect the $\chi_c$ family in p-p collisions at 14 TeV in the ALICE Central Barrel at CERN LHC. The $\chi_{c1}$ and $\chi_{c2}$ were forced to decay in the radiative channel $J/\psi + \gamma \to e^+e^- + \gamma$ and were merged with a proton-proton non-biased collision. After Monte Carlo transport and simulation of the detector response, the $e^+$, $e^-$ and converted $\gamma$ were reconstructed and identified in the ALICE ITS, TPC and TRD detectors. Separate signals corresponding to $\gamma$ from $\chi_{c1}$ and from $\chi_{c2}$ were observed. The position and relative weight of the fit to gaussians agreed with the input values within the statistical limits.

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1 Introduction

Heavy-flavour bound states constitute a valuable probe of the hot/dense strongly interacting matter formed in relativistic collisions of heavy nuclei. $J/\psi$ suppression in central heavy ion collisions was observed at SPS [1] and RHIC [2] energies. $\chi_c$ is an important source of $J/\psi$ as a signal of deconfinement for nuclear modification factor studies and p-p collisions should provide the necessary baseline. The experimental study of $\chi_c$ family has been done in the last 10 years in HERA [3], CDF [4] and L3 [5] experiments among others (see Fig. 1.1). Recently, preliminary measurements of $R_{\chi_c}$ given by equation (1.1) have been presented (PHENIX) at RHIC energies [2]. Predictions of $\chi_{c1}/\psi$ and $\chi_{c2}/\psi$ for Pb-Pb at LHC exist in the context of the Statistical Hadronization Model [6].

$$R_{\chi_c} = \frac{1}{\sigma(J/\psi)} \sum_{i=1}^{2} \sigma(\chi_{ci}) BR(\chi_{ci} \to J/\psi + \gamma)$$

Fig. 1.1 Compilation of the experimental data on $R_{\chi_c}$ [8]

2 ALICE experiment at CERN LHC

ALICE [7] is a general purpose heavy ion experiment designed to study the physics of strongly interacting matter and the Quark Gluon Plasma (QGP) in nucleus-nucleus collisions at the LHC.

The following ALICE subsystems were used for the identification and reconstruction of the $\chi_c$ (see Fig. 2.1):

- ITS (Inner Tracking System): measures the position of the primary and secondary vertices of short lived particles.
- TPC (Time Projection Chamber): performs the tracking of the charged particles and the particle identification through $dE/dx$.
- TRD (Transition Radiation Detector): allows $e/\pi$ separation and improves momentum resolution.

Momentum for electrons from primary vertex was measured with the three detectors. For some reconstructed photons, part of the ITS or the complete ITS maybe missing depending where the conversion occurs.

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Monte Carlo generation

The $\chi_c \to J/\Psi + \gamma$ events were generated with AliRoot v4-11-Rev-02 \([9]\) under the following conditions:

- Cross sections for p-p collisions at 14 TeV:
  \[
  \sigma(\chi_{c1}) = 31.8 \text{ µb} \quad (3.1) \\
  \sigma(\chi_{c2}) = 52.5 \text{ µb} \quad (3.2)
  \]

  They were computed in \([10]\) from Color Evaporation Model at Next Leading Order using known parametrizations of the nuclear modifications of parton densities to model shadowing effects. The constraints were set from measured quarkonia cross sections.

- Transverse momentum $p_t$ and rapidity $y$ for $\chi_c$ were assumed to be the same as for $J/\Psi$, and given by equations (3.3) and (3.4), respectively.

  \[
  f(p_t) = \frac{p_t}{(1 + (\frac{p_t}{2})^2)^{3.6}} \quad (3.3)
  \\
  f(y) = \begin{cases} 
  e^{-(|y|-4)^2/2} & \text{if } |y| > 4 \\
  1 & \text{if } |y| < 4 
  \end{cases} \quad (3.4)
  \]

- $J/\Psi$ were forced to $e^+e^-$ decay and the pseudorapidity $\eta$ for the decay products ($e^+$, $e^-$ and $\gamma$) was constrained to $|\eta| < 1.2$. The $\chi_c$ acceptance implied by this condition is $\sim 10\%$.

- Each $\chi_c$ event was merged into a non-biased proton-proton collision at 14 TeV generated by PYTHIA v6.214 \([11]\).

The transport of the interaction products through the detector and its response were simulated by GEANT v1-9 \([12]\), and the data produced were reconstructed using the AliRoot software.

$10^6$ of these events were generated and reconstructed using the ALICE GRID \([13]\). The reconstruction of one of these events is shown in Fig. 3.1, where non-electron tracks, mainly generated in the proton-proton non-biased collisions, have been removed for clarity.
from the request of joint fit of the track in the central barrel detectors (ITS + TPC + TRD). At least 3% is due to the fact that the TRD has a non-equipped region in order to allow photons to reach the PHOS detector.

5 $\gamma$ reconstruction

In our data, photons originate from the decay of $\chi_c \rightarrow J/\Psi + \gamma$ and from the decay of neutral mesons from the simulated non-biased p-p collisions. Part of these photons convert on the detector material, mainly in the material prior to the TPC (see Fig. 5.1), which allows a good lever arm to reconstruct the by products. The conversion probability in the $\chi_c$ acceptance is of 8.3%.

The reconstruction of the photons from the positive and negative tracks was done by the “conversion method”, based on the finding of the opposite sign tracks associated to a $V^0$ and on cuts on the angle ($<0.1$ rad) and on the mass ($<0.175$ GeV/c$^2$) of the positive and negative tracks.

The Fig. 5.2 shows the $p_t$ for all the reconstructed $\gamma$ (upper), and the $p_t$ for the $\gamma$ from $\chi_c$ confirmed by Monte Carlo (lower). Note that $\gamma$ can be reconstructed down to a $p_t$ of 100 MeV/c.

The reconstruction efficiency of $\chi_c$ photons has been computed for two sets (see Fig. 5.3): (a) the reconstructed $V^0$ tagged as $\gamma$ after applying the selection cuts and requested to come only from $\chi_c$, and (b) the reconstructed $V^0$ associated to $\chi_c$ photons. Figure 5.3 shows an average total efficiency for $\gamma$ from $\chi_c$ decay (that lie in the low $p_t$ region) of 3.0%. Work is in progress to improve efficiency. It also shows that the set of cuts selects quite well the $\gamma$ from $\chi_c$.

6 $\chi_c$ reconstruction

Once the $J/\Psi$ and the $\gamma$‘s coming from the primary vertex are detected on the central barrel, $\chi_c$ can be identified in the invariant mass spectrum of $J/\Psi$ and $\gamma$, $M(e^+e^-\gamma)$. However, the invariant mass difference $\Delta M = M(e^+e^-\gamma) - M(e^+e^-)$ provides better resolution than $M(e^+e^-\gamma)$ because of the cancellation of systematic errors. Some $\gamma$‘s come in fact from electron bremsstrahlung conversions near the primary vertex. To cure this contamination we requested the angle between the electron and the reconstructed $\gamma$ to be greater than 0.05 rad. The combinatorial background was computed with the event mixing technique (see Fig. 6.1).

Figure 6.2 shows the spectrum after subtraction of the background. Integration from 0.3 to 0.5 GeV/c allows to compute the mean reconstruction efficiency within the Central Barrel acceptance for $\chi_c$ as 0.9%.

$\chi_c$ reconstruction efficiency for different intervals of $p_t$ ranges from 0.7% to 1.0% within the small statistics of this study (see Fig. 6.3).
\[ \Delta M = M(e^+e^-\gamma) - M(e^+e^-) \text{ spectrum (circles) and its combinatorial background (line)} \]

\[ \Delta M \text{ after background subtraction, showing energy transitions from } \chi_{c1} \text{ and } \chi_{c2} \text{ to } J/\Psi \text{ in CM reference system. The continuous line shows the nominal position and amplitude of the peaks} \]

\[ \chi_{c1} \rightarrow J/\Psi + \gamma : 35.6\% \]  
\[ J/\Psi \rightarrow e^+e^- : 5.94\% \]

Taking into account the cross-sections given in (3.1) and (3.2), the decay rates [14]:

\[ \chi_{c1} \rightarrow J/\Psi + \gamma : 20.2\% \]  
\[ J/\Psi \rightarrow e^+e^- : 5.94\% \]

and assuming a luminosity:

\[ L = 10^{30} \text{ cm}^{-2} \text{ s}^{-1} \]

the rate of \( \chi_c \rightarrow J/\Psi + \gamma \) production is 1.3 per second. This must be weighted by our acceptance (10\%) and our reconstruction efficiency of 0.9\% to give \( 1.2 \times 10^{-3} \) observable \( \chi_c \) per second, assuming a 100\% trigger efficiency. The trigger strategy is in discussion, so this figure is a maximum, and assuming a nominal pp run of \( 10^7 \) s, the total maximum expected \( \chi_c \) is accordingly \( \sim 12,000 \).

8 Conclusions

The electrons from \( J/\Psi \) were reconstructed and identified using the ALICE Central Barrel with an efficiency of 94.1\% and purity of 99.5\%. The \( J/\Psi \) was reconstructed with an efficiency of \( \sim 37\% \) after cutting the bremsstrahlung tail, selecting only \( M(e^+e^-) \) events from 2.8 GeV/c^2 to 3.6 GeV/c^2.

\( \gamma \) were reconstructed via conversions in the Central Barrel with \( p_t \) reaching down to 100 MeV/c. The mean reconstruction efficiency was \( \sim 3\% \).

\( \chi_c \) can be detected in the ALICE Central Barrel down to a \( p_t \) of 0.250 GeV/c. ALICE TPC resolution allows for observing a defined structure of \( \chi_c \) family via \( M(e^+e^-\gamma) - M(e^+e^-) \) mass difference, showing transitions from \( \chi_{c1} \) and \( \chi_{c2} \) to \( J/\Psi \). The overall efficiency of \( \chi_c \) reconstruction was \( \sim 0.9\% \).

Assuming a luminosity of \( 10^{30} \text{ cm}^{-2} \text{ s}^{-1} \) the rate of observable \( \chi_c \)’s is expected to be \( 1.2 \times 10^{-3} \) per second. With an ideal \( \chi_c \) trigger, the number of reconstructed \( \chi_c \) in one \( p + p \) nominal run in the ALICE interaction point would be 12,000.

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