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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

P. González[1], **P. Ladrón de Guevara**[1,a], **E. López Torres**[3], **A. Marín**[2], **E. Serradilla**[1] for the ALICE Collaboration

[1]Department of Technology, CIEMAT, Madrid, Spain
[2]Gesellschaft für Schwerionenforschung mbH, Darmstadt, Germany
[3]CEADEN, Ciudad Habana, Cuba

Abstract We present Monte Carlo preliminary results about the feasibility to detect the χ_c family in p-p collisions at 14 TeV in the ALICE Central Barrel at CERN LHC. The χ_{c1} and χ_{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 γ were reconstructed and identified in the ALICE ITS, TPC and TRD detectors. Separate signals corresponding to γ from χ_{c1} and from χ_{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/Ψ suppression in central heavy ion collisions was observed at SPS [1] and RHIC [2] energies. χ_c is an important source of J/Ψ as a signal of deconfinement for nuclear modification factor studies and p-p collisions should provide the necessary baseline. The experimental study of χ_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_{χ_c} given by equation (1.1) have been presented (PHENIX) at RHIC energies [2]. Predictions of χ_{c1}/Ψ and χ_{c2}/Ψ for Pb-Pb at LHC exist in the context of the Statistical Hadronization Model [6].

$$R_{\chi_c} = \frac{1}{\sigma(J/\Psi)} \sum_{i=1}^{2} \sigma(\chi_{ci}) BR(\chi_{ci} \to J/\Psi + \gamma) \qquad (1.1)$$

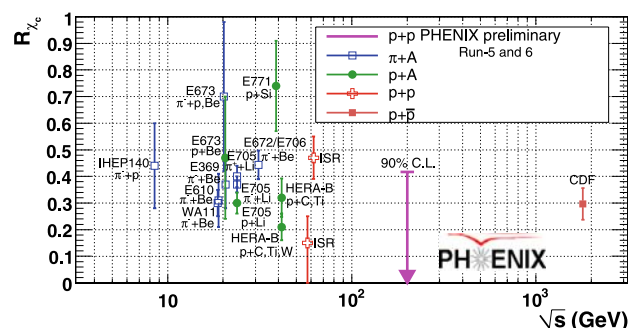[a] e-mail: pedro.ladron@ciemat.es

**Fig. 1.1** Compilation of the experimental data on R_{χ_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 χ_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/π 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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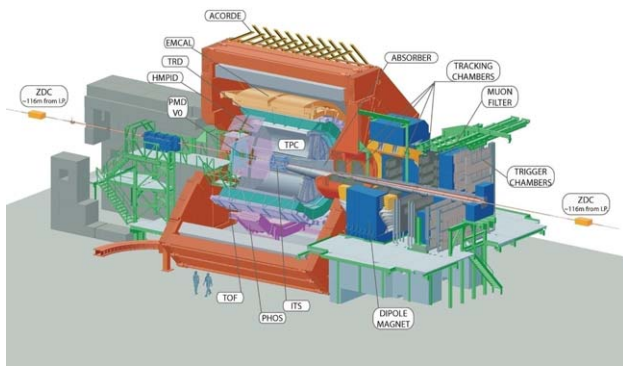
Fig. 2.1 General layout of the ALICE experiment at CERN LHC

3 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:

$$\sigma(\chi_{c1}) = 31.8 \ \mu b \tag{3.1}$$

$$\sigma(\chi_{c2}) = 52.5 \ \mu b \tag{3.2}$$

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 χ_c were assumed to be the same as for J/Ψ, and given by equations (3.3) and (3.4), respectively.

$$f(p_t) = \frac{p_t}{(1 + (\frac{p_t}{4})^2)^{3.6}} \tag{3.3}$$

$$f(y) = \begin{cases} e^{-(|y|-4)^2/2} & \text{if } |y| > 4 \\ 1 & \text{if } |y| < 4 \end{cases} \tag{3.4}$$

– J/Ψ were forced to e^+e^- decay and the pseudorapidity η for the decay products (e^+, e^- and γ) was constrained to $|\eta| < 1.2$. The χ_c acceptance implied by this condition is ∼10%.
– Each χ_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.
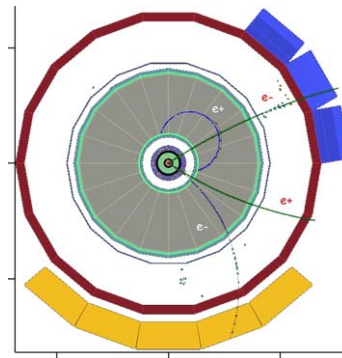

Fig. 3.1 Visualization of a $\chi_c \to J/\Psi + \gamma$ event in the ALICE Central Barrel

4 J/Ψ reconstruction

After selecting tracks coming from the primary vertex within 3 sigmas, and requiring a signal in the central detector ITS, TPC and TRD, electrons were reconstructed and identified with an efficiency of 94.1% and purity of 99.5%. Then, the invariant mass $M(e^+e^-)$ spectrum was computed. Contamination of ∼4% coming from γ converted very near of the origin, from Dalitz pairs in π^0 decay and from other sources was cured cutting out the pairs where angle between e^+ and e^- was lower than 0.05 rad. Final spectrum (see Fig. 4.1) showed the J/Ψ. Note that the tail on the left of the J/Ψ peak is due to bremsstrahlung. The like-sign technique reproduced quite well the combinatorial background (see Fig. 4.1) since open heavy flavour semileptonic decay was not taken into account in the generated events.

The reconstruction efficiency for J/Ψ within $|\eta| < 0.9$ is 37.0% after subtracting the combinatorial background and integrating the peak from 2.8 to 3.6 GeV/c^2 to suppress the bremsstrahlung tail. Including the bremsstrahlung tail the efficiency is 47.6%. The main source of this figure lies on the single electron reconstruction efficiency and acceptance within $|\eta| < 0.9$, 68%. The losses (32%) are mainly coming
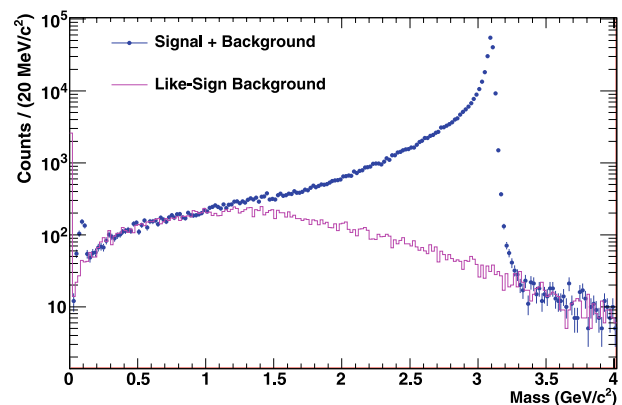
Fig. 4.1 Mass spectrum of J/Ψ (*circles*) and its combinatorial background (*line*)

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 γ reconstruction

In our data, photons originate from the decay of $\chi_c \to J/\Psi + \gamma$ 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 χ_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 γ (upper), and the p_t for the γ from χ_c confirmed by Monte Carlo (lower). Note that γ can be reconstructed down to a p_t of 100 MeV/c.

The reconstruction efficiency of χ_c photons has been computed for two sets (see Fig. 5.3): (a) the reconstructed V^0 tagged as γ after applying the selection cuts and requested to come only from χ_c, and (b) the reconstructed V^0 associated to χ_c photons. Figure 5.3 shows an average total efficiency for γ from χ_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 γ from χ_c.

6 χ_c reconstruction

Once the J/Ψ and the γ's coming from the primary vertex are detected on the central barrel, χ_c can be identified in the invariant mass spectrum of J/Ψ and γ, $M(e^+e^-\gamma)$. 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 γ'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 γ 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 χ_c as 0.9%.

χ_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).
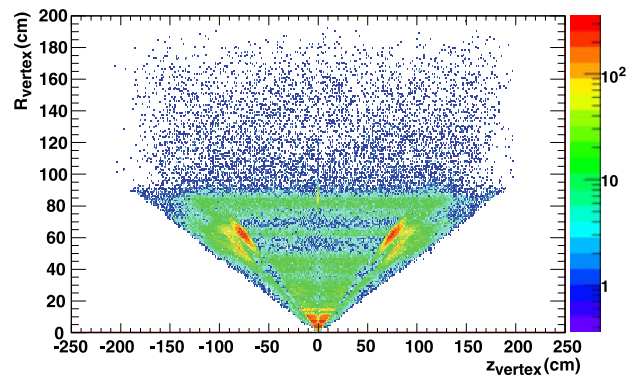

Fig. 5.1 Distribution of reconstructed γ conversion vertices
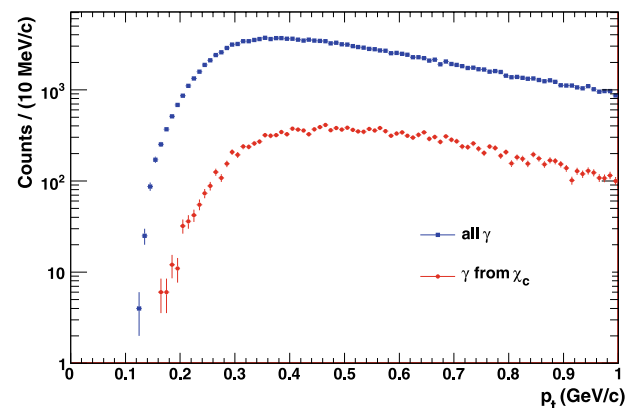

Fig. 5.2 Transverse momentum distribution, p_t, of all γ and of χ_c photons, reconstructed using the conversion method
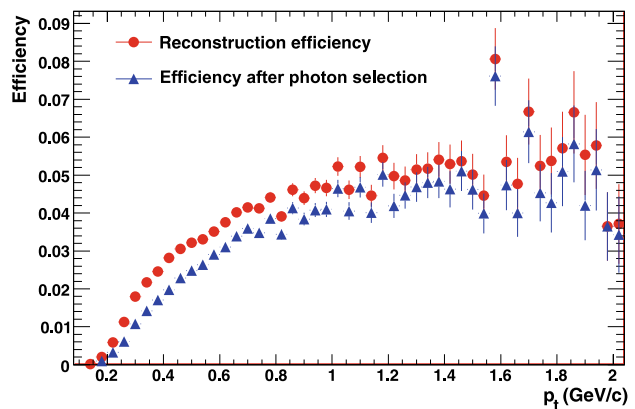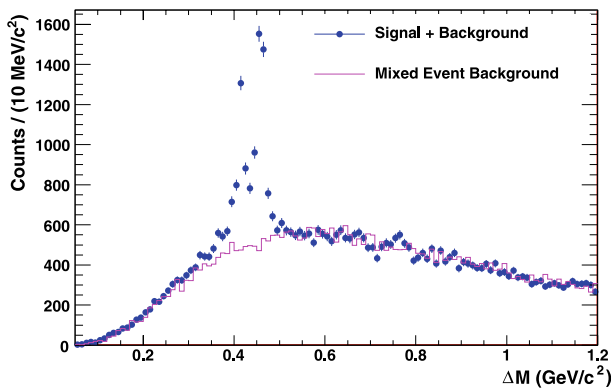

Fig. 5.3 Reconstruction efficiency of χ_c photons. *Circles* are the efficiency, given the conversion probability and the V^0 method, using the MC information to identify the χ_c photons. *Triangles* are the efficiency from reconstruction after applying the cuts and selecting only the photons coming from χ_c

Fig. 6.1 $\Delta M = M(e^+e^-\gamma) - M(e^+e^-)$ spectrum (*circles*) and its combinatorial background (*line*)
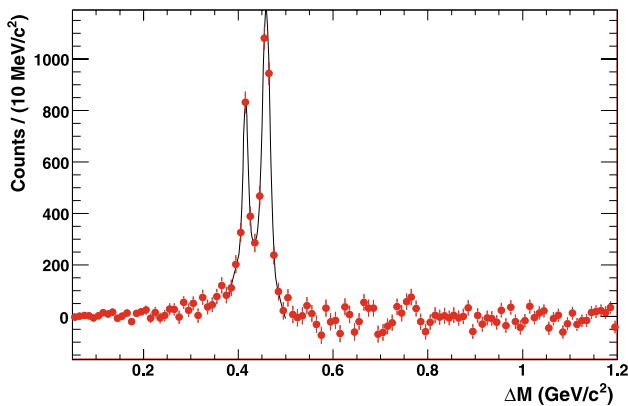
Fig. 6.2 ΔM after background subtraction, showing energy transitions from χ_{c1} and χ_{c2} to J/Ψ in CM reference system. The *continuous line* shows the nominal position and amplitude of the peaks
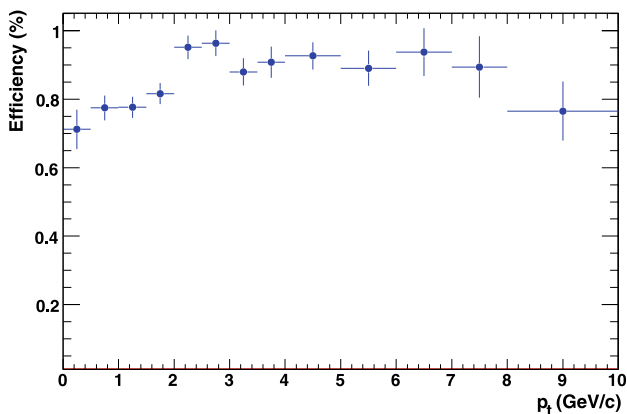
Fig. 6.3 χ_c reconstruction efficiency as a function of p_t

7 χ_c expected rates

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

$$\chi_{c1} \to J/\Psi + \gamma : 35.6\% \tag{7.1}$$

$$\chi_{c2} \to J/\Psi + \gamma : 20.2\% \tag{7.2}$$

$$J/\Psi \to e^+e^- : 5.94\% \tag{7.3}$$

and assuming a luminosity:

$$L = 10^{30} \text{ cm}^{-2} \text{ s}^{-1} \tag{7.4}$$

the rate of $\chi_c \to J/\Psi + \gamma$ production is 1.3 per second. This must be weighted by our acceptance (10%) and our reconstruction efficiency of 0.9% to give 1.2×10^{-3} observable χ_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 χ_c is accordingly ~12,000.

8 Conclusions

The electrons from J/Ψ were reconstructed and identified using the ALICE Central Barrel with an efficiency of 94.1% and purity of 99.5%. The J/Ψ was reconstructed with an efficiency of ~37% after cutting the bremsstrahlung tail, selecting only $M(e^+e^-)$ events from 2.8 GeV/c² to 3.6 GeV/c².

γ were reconstructed via conversions in the Central Barrel with p_t reaching down to 100 MeV/c. The mean reconstruction efficiency was ~3%.

χ_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 χ_c family via $M(e^+e^-\gamma) - M(e^+e^-)$ mass difference, showing transitions from χ_{c1} and χ_{c2} to J/Ψ. The overall efficiency of χ_c reconstruction was ~0.9%.

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

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