Measurement of χ_c in CMS

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Abstract

The principles of χ_c–meson reconstruction in CMS are presented. Monte Carlo events, simulated with PYTHIA 8 event generator, are used to illustrate different stages of such an analysis.

1 Introduction

Quarkonium states (charmonia, bound states of charm and anti-charm quarks, and bottomonia, bound states of beauty and anti-beauty quarks) were suggested many years ago to be "golden probes" for the creation of a deconfined medium of quarks and gluons, the quark gluon plasma (QGP), in ultrarelativistic heavy-ion collisions (e.g. AuAu, or PbPb collisions). Because of their different sizes and binding energies, they are expected to be destroyed in a sequential order, dependent on the medium temperature: the tightest bound will be affected last, at the highest temperatures, while the loosest ones will be affect first, at lower temperatures. As such, quarkonia can be used as a thermometer of the QGP, an example of which is shown in Fig. 1.

However, the ground states, $\Upsilon(1S)$ and $\psi(1S)$ (J/ψ), the easiest to measure experimentally, have big contributions from the decay of other excited states, as can be seen in Fig. 2 for the charmonium ground state. These so called "feed-down" contributions, have also a strong p_T dependence. So in order to assess whether a certain disappearance of the yield of J/ψ measured in PbPb collisions at the LHC is really due to the J/ψ destruction itself, or only due to the destruction of the excited states, one has to be able to measure the excited states in PbPb collisions. While the $\psi(2S)$ and $\Upsilon(2S, 3S)$ have been measured already at the LHC in PbPb collisions by CMS, the χ_x states have never been measured, in any heavy–ion collisions.

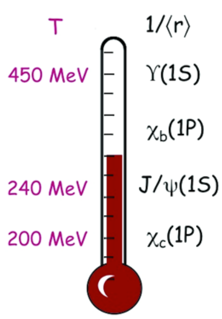


Figure 1: Example of a "quarkonia" thermometer, from A. Mocsy, Eur. Phys. J C61, 2009.

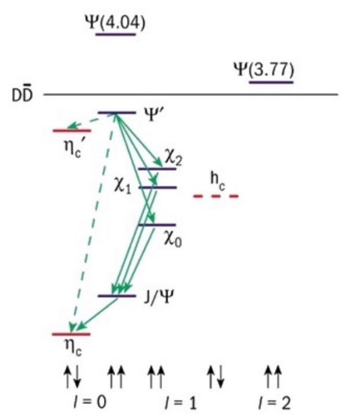


Figure 2: Diagram to show the contribution from the excited charmonium states (e.g. $\psi(2S), \chi_c(1, 2,))$ to the ground state, J/ψ.

2 My summer work

As I am rather new to CMS and the CMS software, the main goal for my summer spent in CERN was to understand the basic steps of an analysis, how one goes from a real (or simulated) collision to a measurement.

The χ_c was the particle taken as a working example. The long-term goal is to follow–up, back at my home institution, this analysis with real data, in pp collisions at 5TeV, and then PbPb and pPb collisions at 5TeV.

Experimentally in CMS, the χ_c–mesons can be identified via their radiative decay into J/ψ–mesons and photons. The J/ψ can be identified via its decay into a muon pair, while the emitted photon can be measured directly (at high transverse momentum, p_T, where the reconstruction in the CMS electromagnetic calorimeter is good), or through their conversion in the detector material into e^+e^- pairs. This last method, shown in Fig. 3 has the advantage that it can be used at all p_T–s, but the disadvantage that, with a much lower efficiency for conversions, it requires a much higher amount of data in order to perform a precise measurement.

In the following I will briefly describe the CMS detector, the reconstruction of muons and photons in CMS (objects needed for the χ_c reconstruction), show the flow–chart of going from a χ_c event (MC events in this case) to a reconstructed χ_c, and in the end, how all the objects of the analysis appear in the detector, using FireWorks, the CMS event display tool.

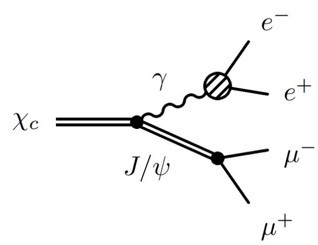


Figure 3: Diagram showing the decay-chain a χ_c (or it's direct decay products) suffers in the detector: $\chi_c \to \gamma(e^+e^-) + J/\psi(\mu^+\mu^-)$.

3 CMS detector and reconstruction

The central feature of the CMS apparatus (Fig. 4) is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 4 T. Within the superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass/scintillator hadron calorimeter (HCAL). Muons are measured in gas–ionization detectors embedded in the steel flux-return yoke outside the solenoid. In addition to the barrel and endcap detectors, the CMS has an extensive forward calorimetry. Muons are measured in the pseudorapidity range $|\eta\mu| < 2.4$, where $|\eta| = -\ln[\tan(\theta/2)]$, and θ is the polar angle measured from the beam axis. The ECAL, used for photon identification, is made up of a barrel section and two endcaps, forming a layer between the tracker and the HCAL. The cylindrical barrel consists of 61200 crystals formed into 36 supermodules, each weighing around three tonnes and containing 1700 crystals. The flat ECAL endcaps seal off the barrel at either end and are made up of almost 15000 further crystals. For extra spatial precision, the ECAL also contains Preshower detectors that sit in front of the endcaps. These allow CMS to distinguish between single high–energy photons (often signs of exciting physics) and the less interesting close pairs of low-energy photons.

3.1 Muon reconstruction

The CMS muon reconstruction procedure identifies 3 types of muons: standalone muons (STA), tracker muons (TRK), and global muons (GLB). In the offline reconstruction, the segments reconstructed only with information from the muon chambers are used to generate "seeds" consisting of position and direction vectors and an estimate of the muon transverse momentum. These initial estimates are used as seeds for the track fits in the muon system, which are performed using segments and hits from DTs, CSCs and RPCs and are based on the Kalman filter technique. The result is a collection of reco::Track objects reconstructed in the muon spectrometer, which are referred to as "standalone muons". For each standalone muon track, a search for tracks matching it among those reconstructed in the inner tracking system (referred to as "tracker tracks", "inner tracks" or "silicon tracks") is performed, and the best–matching tracker track is selected. For each "tracker track" — "standalone muon" pair, the track fit using all hits in both tracks is performed, again based on the Kalman filter technique. The result is a collection of "reco::Track" objects referred to as "global muons". An approach complementary to the global–muon reconstruction consists in considering all tracker tracks to be potential muon candidates and in checking this hypothesis by looking for compatible signatures in the calorimeters and in the muon system. Tracker tracks identified as muons by this method are referred to as "tracker muons".

For the results obtained in this work for χ_c, global muons are used.

3.2 Conversion photon reconstruction

Photons traversing the CMS tracker have a sizeable probability of converting into electron positron pairs. Although converted photons are fully clustered in the ECAL, and identified with good approximation, additional useful information is gained by reconstructing the associated e^+e^- track pairs. The low–energy photons produced in the χ_c radiative decays that convert into electrons and positrons often produce tracks that are rather asymmetric, with one of the two tracks carrying a small fraction of the photon energy. Given that these tracks rarely reach the calorimeter, they are reconstructed exclusively using information from the silicon tracker.

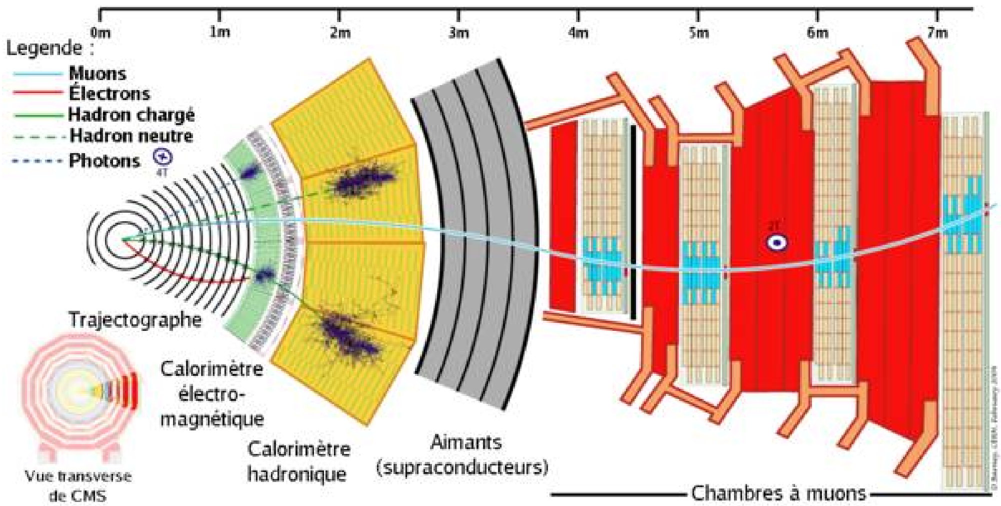
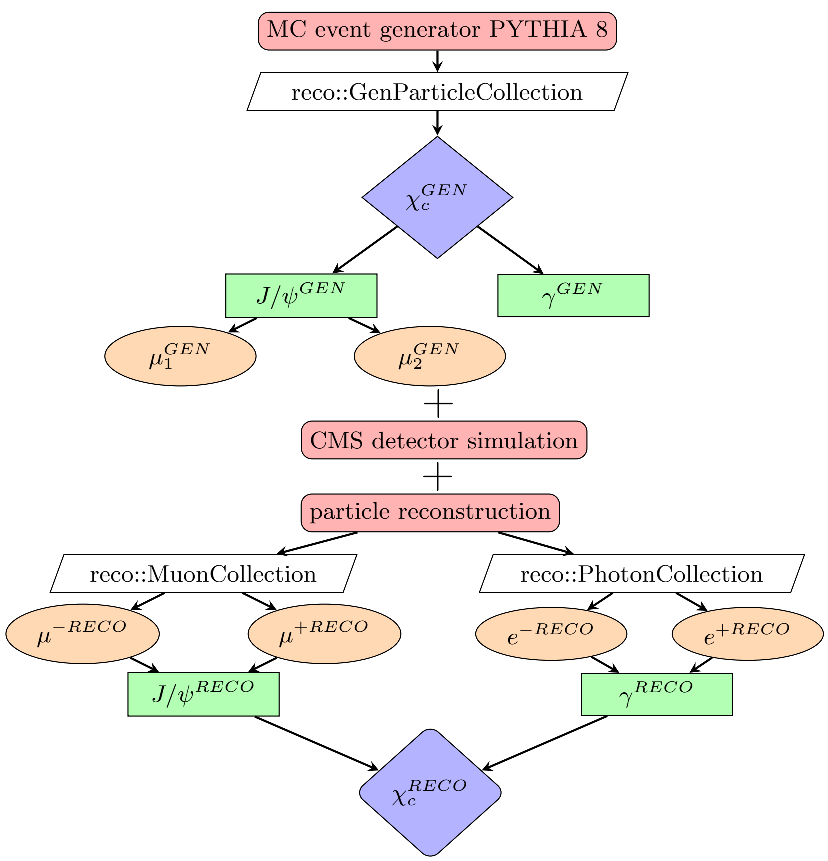


Figure 4: A transverse slice through CMS detector, with different colors for different particles and the detectors in which they are measured shown in different colors.

4 Analysis flow–chart



5 Results

Figures 5 and 6 show the invariant mass distribution and the transverse momentum distribution (p_T) of χ_c–mesons, as they are generated by PYTHIA 8, before they decay in J/ψ and a photon.

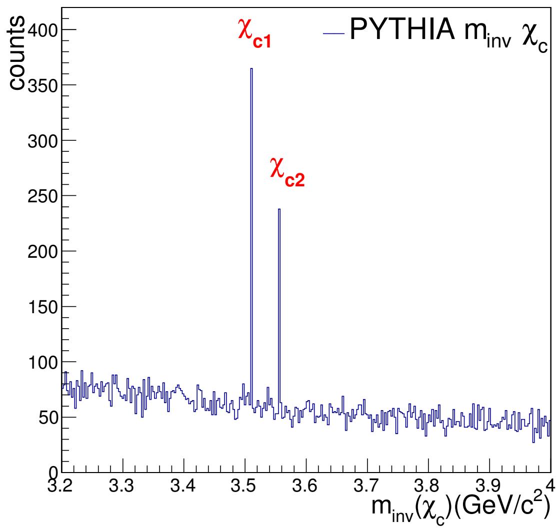


Figure 5: Invariant mass distribution of generated by PYTHIA 8 χ_c–mesons.

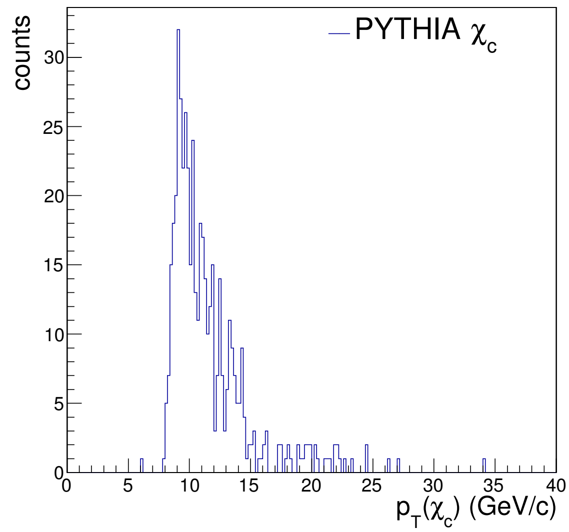


Figure 6: p_T–distribution of generated by PYTHIA 8 χ_c–mesons.

Figure 7 shows the invariant mass distribution of J/ψ–mesons, as they are generated by PYTHIA 8 (left panel of the figure) and as they are reconstructed from the decay muons reconstructed as global muons by the CMS software. The transverse momentum distribution of the same particle is shown in Fig. 8.

Figure 9 shows a CMS event display with an event corresponding to the diagram in Fig. 3. One can see the generated χ_c–meson with its decay products, J/ψ and the photon. In addition, at the generator level, J/ψ is decayed by PYTHIA in 2 muons, which after their whole passage through the CMS detector is simulated with GEANT (a simulator for the passage and interaction of particles with detector material), are reconstructed from hits and segments as global muons. The photon is not decayed by PYTHIA, but GEANT shows how the photon converts in the tracker material into an electron and positron pair. Combining the 2 electrons into a photon objects, an invariant mass distribution using the reconstructed J/ψ can be made, which will show the reconstructed χ_c peak. For this last step though, in order to have enough events to see a good peak, a huge amount of MC events needs to be simulated (because of the small conversion rate in the CMS detector). Currently I run additional PYTHIA 8 events, and plan to accumulate enough statistics in a near future.

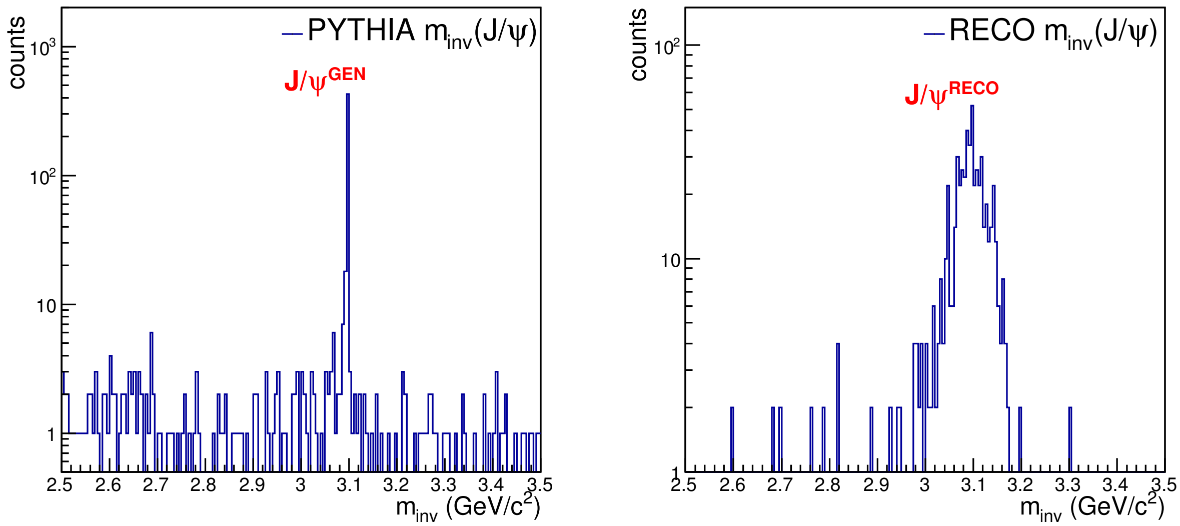


Figure 7: Invariant mass distribution of generated by PYTHIA 8 and reconstructed from reco collection χ_c–mesons.

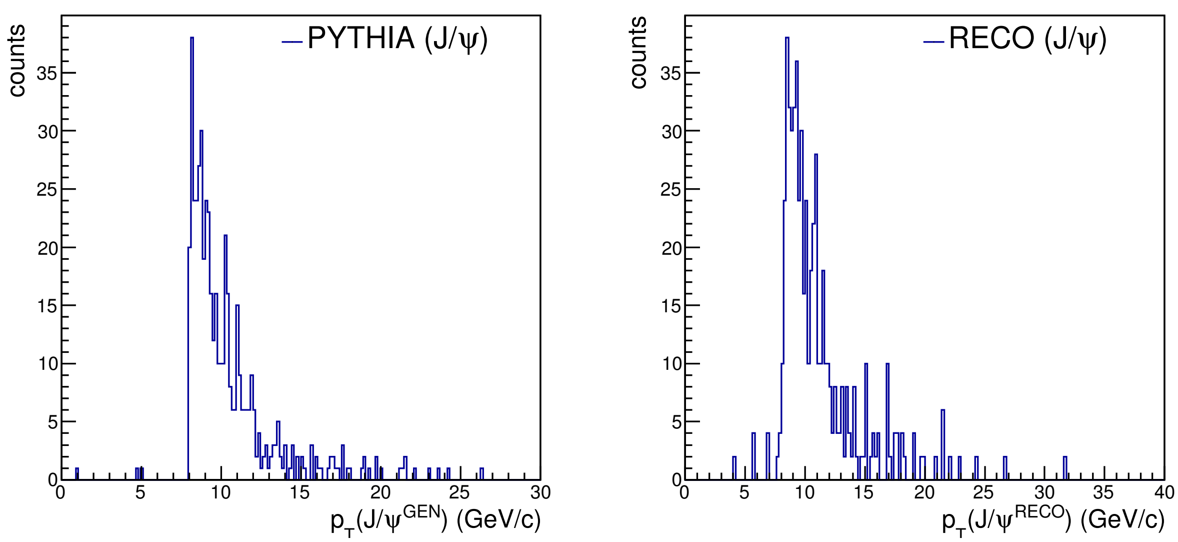


Figure 8: p_T–distribution of generated by PYTHIA 8 and reconstructed from reco collection J/ψ–mesons.

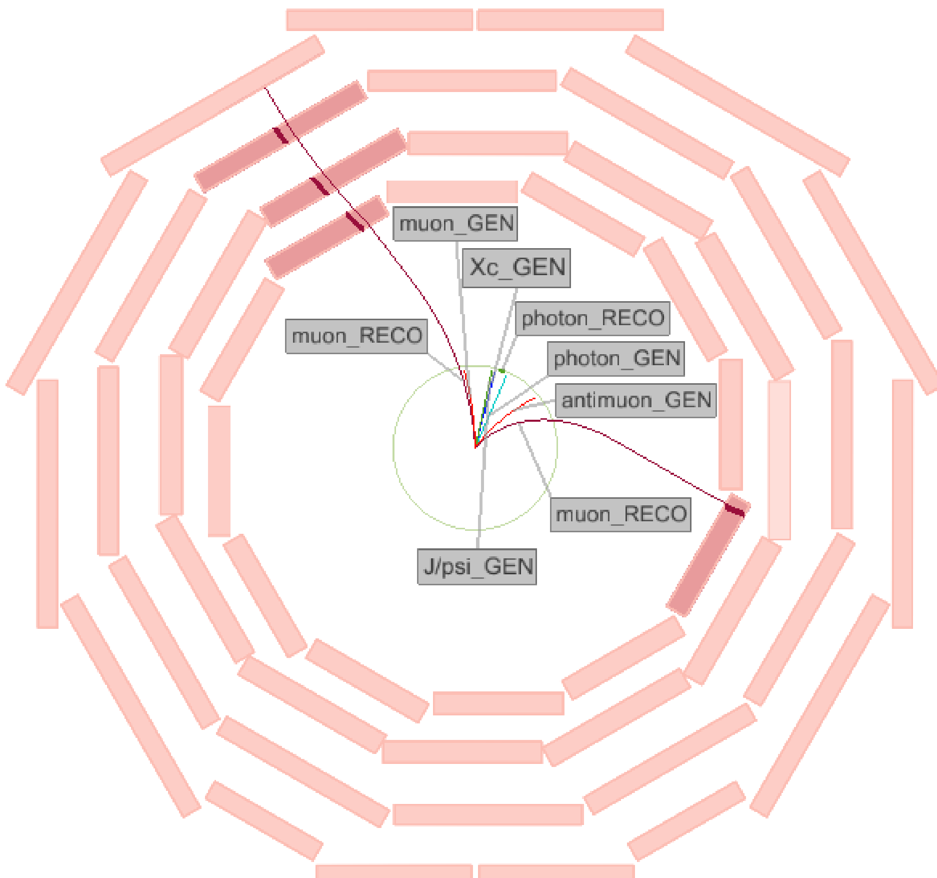


Figure 9: CMS event display.