Electron identification with the electromagnetic calorimeter and its application for charmonia studies in the experiment ALICE3 at the LHC

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The ALICE3 Upgrade

ALICE3 is a next-generation heavy-ion detector [1] at the Large Hadron Collider and is a successor to the present ALICE experiment. The plan is to start the ALICE3 operation in the LHC Run 5 and beyond (2035+).

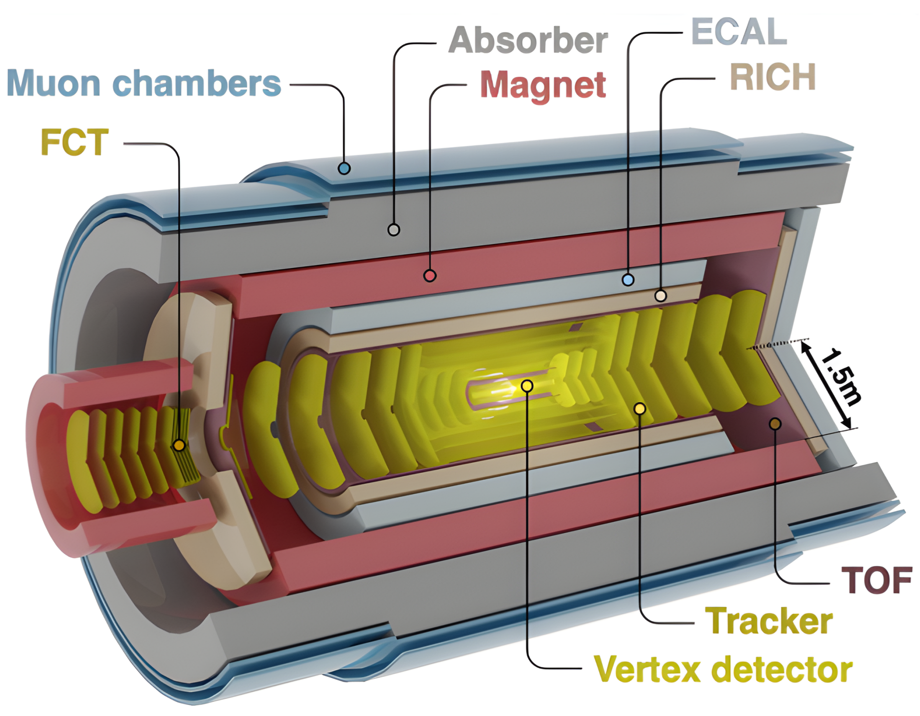

Figure 1. The ALICE3 setup [1] ©CERN

One of the physics tasks of ALICE3 is precision measurements of quarkonia production in S- and P-states in pp and AA collisions [2].

The Scope of the Research

The goal of the studies is to simulate the **ALICE3 electromagnetic calorimeter** within the ALICE fast Monte Carlo framework **DelphesO2** [3]. The event generator **PYTHIA8** is used: pp collisions at $\sqrt{s} = 14$ TeV, process **Onia:all**.

The key detectors for electron identification and charmonium reconstruction are as follows:

- **The tracker (ITS)** for reconstruction of $e^{\pm}$ tracks from the J/ψ dilepton decay
- **The electromagnetic calorimeter (ECAL)** for $e^{\pm}$ identification and photon reconstruction from the $\chi_{cJ} \to J/\psi + \gamma$ decay

Detector response, reconstruction and particle identification is implemented in DelphesO2:

1. **Detection of charged particles** in ECAL based on simplistic model of hadron interaction and minimum-ionizing particles;
2. **Electron Identification** algorithm comparing track deposited energy in ECAL with its momenta reconstructed in ITS;
3. **Track Matching** algorithm comparing ECAL signal coordinates with track's propagated projection on the ECAL surface.

For analysis we use ALICE O2 software suite [4].

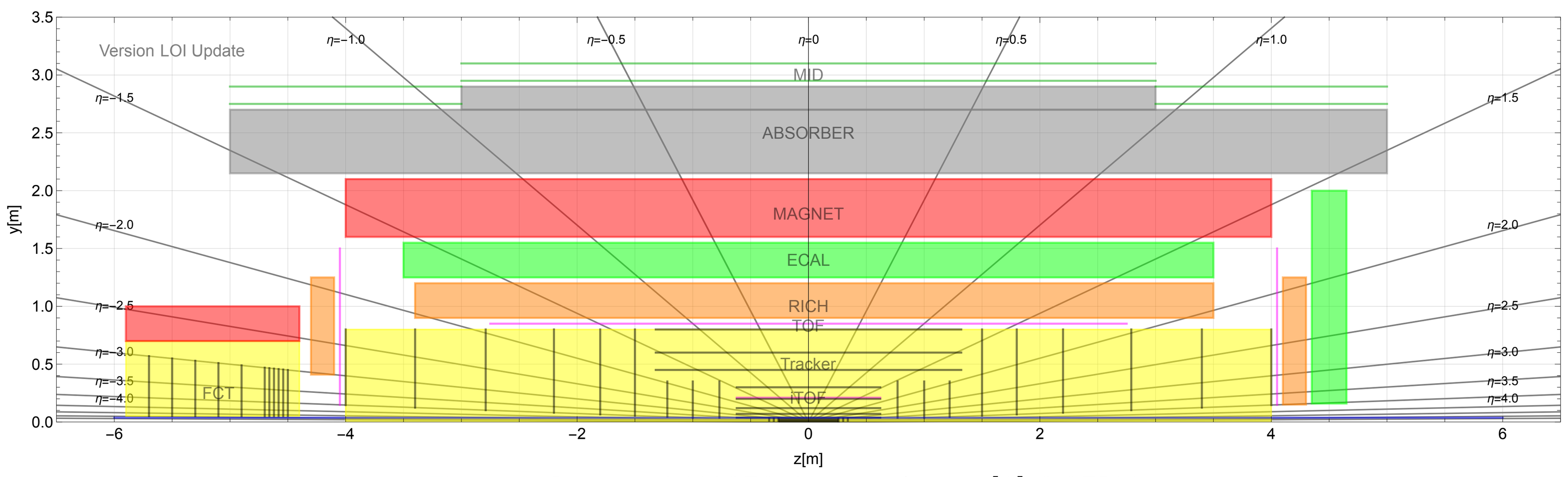

Figure 2. Proposed ALICE3 detector layout [1] ©CERN

The ALICE3 ECAL barrel is divided into two segments:

	Technology used:
High-Resolution segment situated between $\|\eta\| < 0.53$	PbWO$_4$ crystals
Coarse segment situated between $0.53 < \|\eta\| < 1.6$	Pb + organic sci

Electron Identification

ECAL response to different particle species is implemented in DelphesO2:

- Electrons and photons deposit their full energy in the ECAL cells;
- Muons deposit MIPs - randomized ionization loss energy with a Landau distribution;
- Hadron response is 50% MIP and 50% hadronic strong interaction.

Eventually all deposited energies get smeared with a Gauss function according to finite photostatistics.

Electron identification is based on equality of energy E deposited in ECal and momentum p measured in ITS. Simulation confirm $E/p \approx 1$ for electrons (Figure 3) and $E/p < 1$ for other tracks.

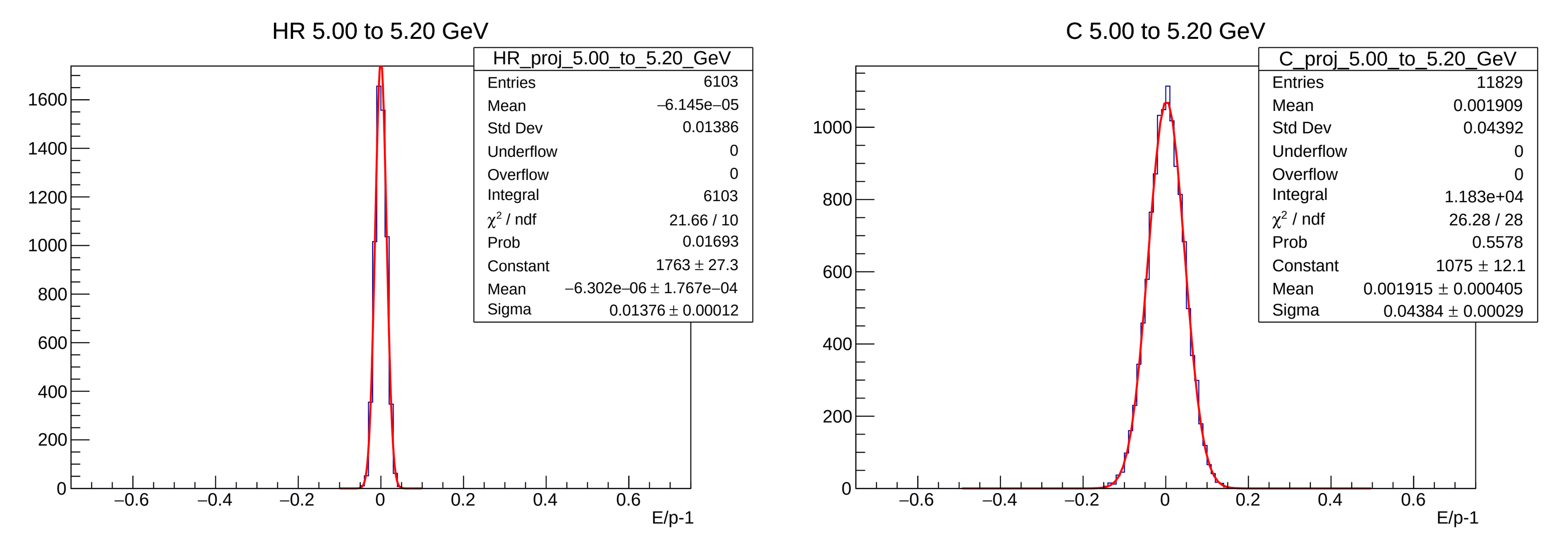

Figure 3. Example of fitting the $E/p - 1$ distribution for the electrons with Gauss distribution function at $E = [5.0, 5.2]$ GeV for the different calorimeter segments (High-Resolution segment on the left, Coarse segment on the right)

Resulting Gaussian fits give us the standard deviations σ for the distributions which defines criteria for electron candidate selection $|E/p - 1| < 2\sigma$.

Track Matching

Another pre-requisite for electron identification is track propagation matching with reconstructed point in ECAL. Track propagation to ECAL surface is smeared due to multiple scattering and tracking resolutions, and ECAL reconstructed point is smeared according to shower development in ECAL medium. Track matching residuals in φ and in Z are shown in figure 4. Electron is identified when $|Z| < 2\sigma_Z$, $|\Delta\varphi| < 2\sigma_\varphi$.

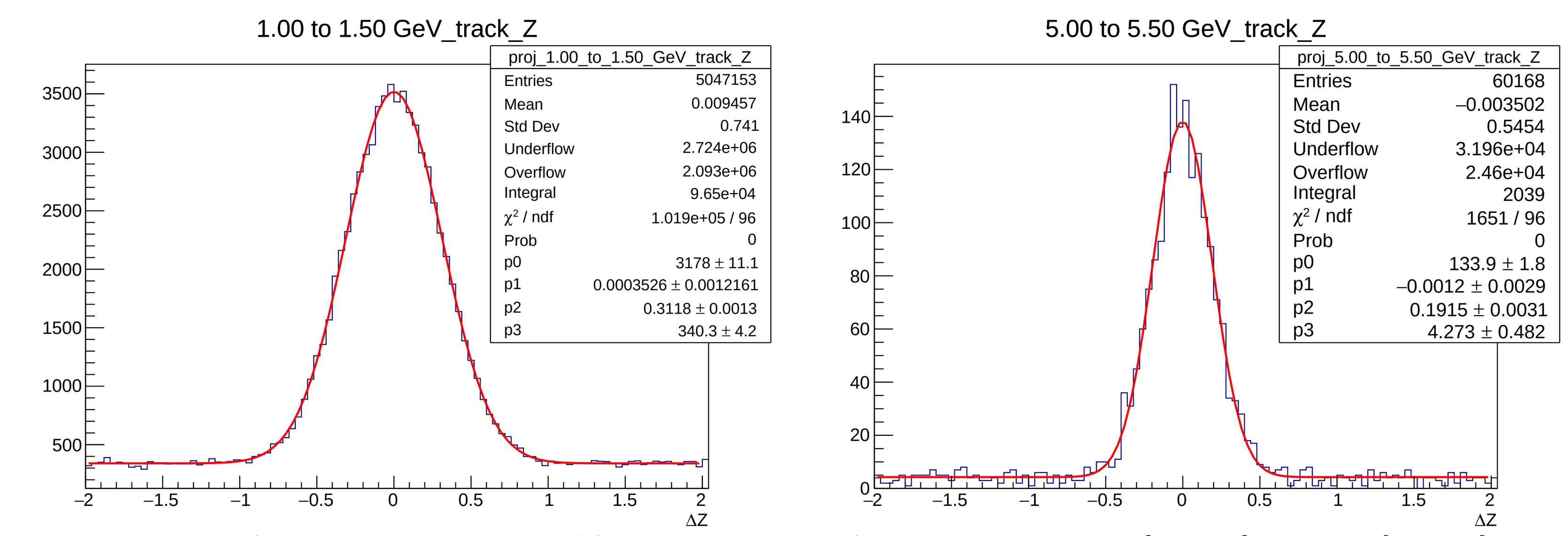

Figure 4. Examples of fitting the for variable ΔZ with Gauss plus a constant at $E = [1.0, 1.5]$ and $E = [5.0, 5.5]$ GeV

- If we do not see a track within a signal's vicinity, we consider the signal to be left by a photon.
- If the signal data is within the acceptance corridor, we use the "E/p method" to identify which of the signals best represents an electron.

Combined Algorithm Efficiency

To measure the efficiency of our algorithm we save the momenta of the identified particles and compare them with electrons deducted from MC data.

We analyzed 100 thousand pp collision events in PYTHIA8 with the **SoftQCD:inelastic** and **Onia:all** process options to comparing them with electrons deducted from MC data (figure 5).

Onia:all processes force at least one type of χ_c meson in every collision event.

SoftQCD processes have very low amounts of electrons compared to hadrons; a big factor in the Coarse calorimeter's higher relative contamination.

Results

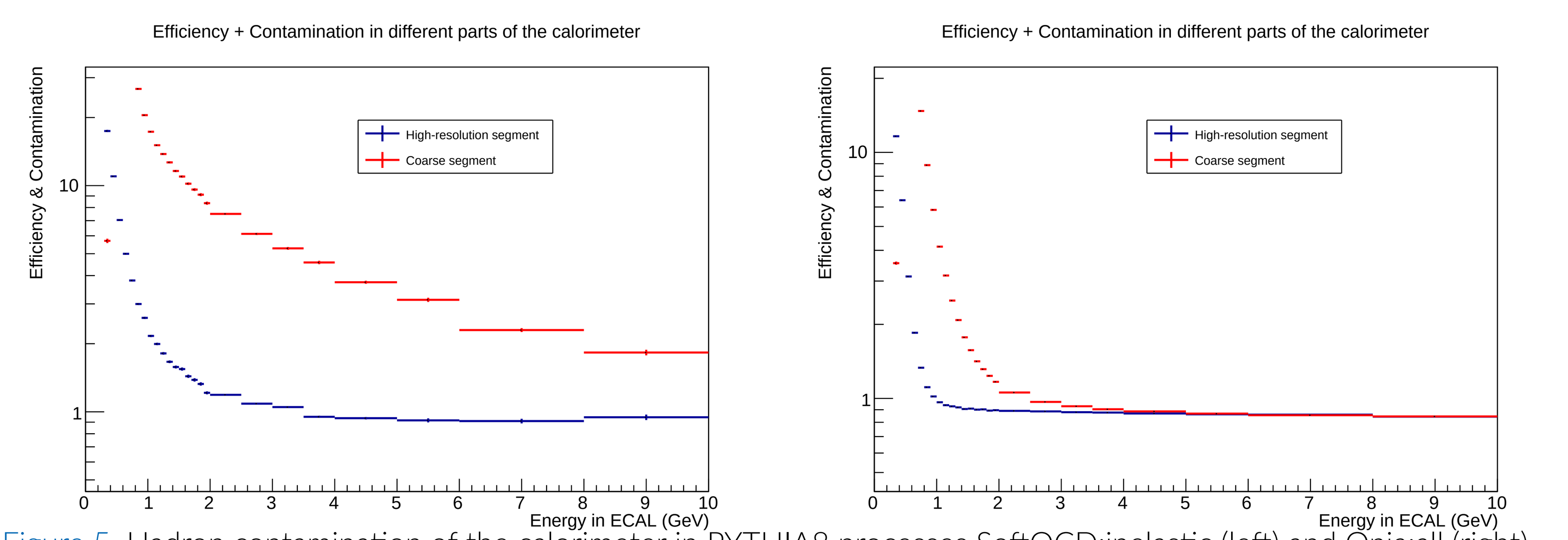

Figure 5. Hadron contamination of the calorimeter in PYTHIA8 processes SoftQCD:inelastic (left) and Onia:all (right) (High-resolution segment drawn in blue, Coarse segment drawn in red)

Charmonia reconstruction

The J/ψ is reconstructed via invariant-mass spectra of electron-positron candidate pairs. Electrons and positrons can hit one of the two ECAL segment, or different segments ("Mixed").

Furthermore, we can reconstruct the χ_{c1} and χ_{c2} peaks in *Onia:all* processes. We also weigh the processes with their branching ratios.

To construct the χ_c spectra we add a candidate photon to a candidate electron-positron pair.

$$\chi_c \to J/\psi\gamma \to e^+e^-\gamma \quad (1)$$

The χ_{c1} and χ_{c2} peaks can only be seen when the *photon* candidates are from the *High-Resolution* segment (figure 6). χ_{c0} is heavily suppressed by it's branching ratio.

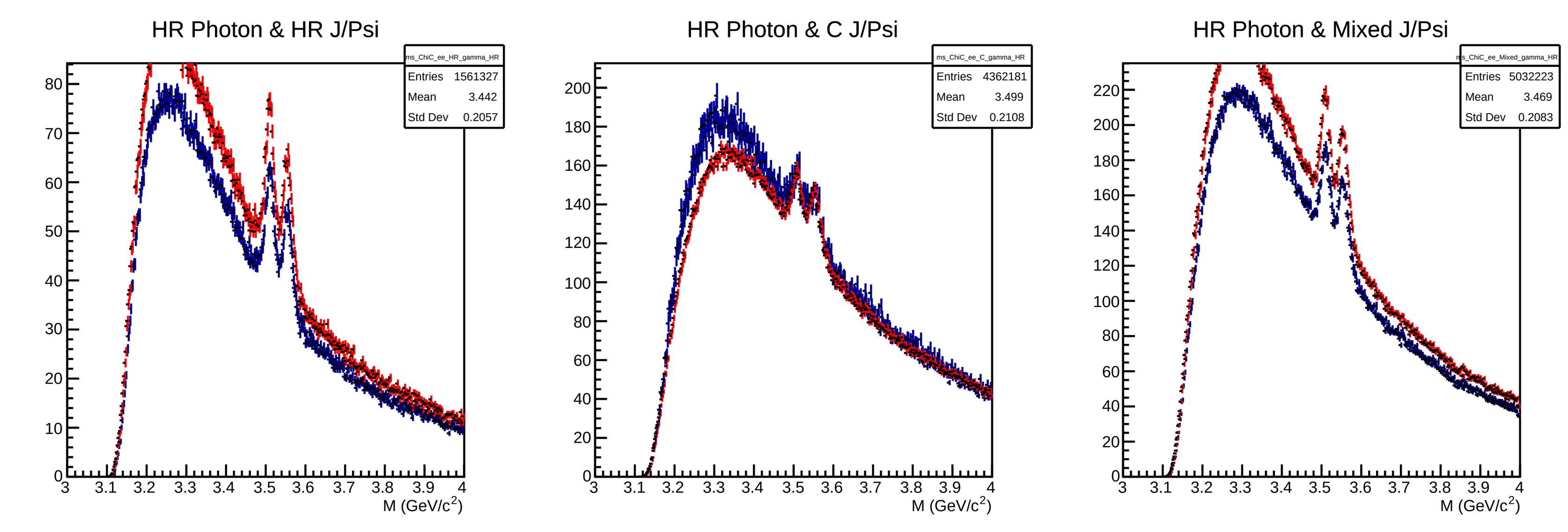

Figure 6. $e^+e^-\gamma$ spectra in different scenarios (histograms in red shows reconstruction using MC data, blue histograms show reconstruction from derived candidates for particles)

Developed electron identification indicates that χ_{c1}, χ_{c2} detection is feasible in pp collisions in ALICE3.

References

[1] [ALICE], "Letter of intent for ALICE 3: A next-generation heavy-ion experiment at the LHC," [arXiv:2211.02491 [physics.ins-det]].

[2] Y. Kharlov, Y. Hambardzumyan and A. Varlamov, "Probing the Hot QCD Matter via Quarkonia at the Next-Generation Heavy-Ion Experiment at LHC," Particles **6** (2023) no.2, 546-555

[3] ALICE fast simulation DelphesO2, `https://github.com/AliceO2Group/DelphesO2`

[4] ALICE analysis framework `https://aliceo2group.github.io/analysis-framework/`

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