Feasibility Studies of Charmonia Measurements at the ALICE Experiment at LHC

7th International Conference on Particle Physics and Astrophysics

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October 2024

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ALICE 3

- ALICE 3 is a planned heavy-ion detector at the LHC.
- Is a successor to the present ALICE experiment.
- Will start operating in the LHC Run 5 (2035+).

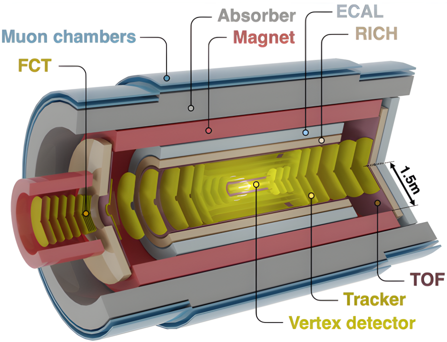

Figure: The ALICE 3 setup

Charmonia in ALICE 3

- One of the main tasks of ALICE 3 is measuring quarkonia production in S- and P-states in pp, pPb and PbPb collisions.
- Heavy quarks are produced at the beginning of the collision $\rightarrow$ they probe the entire evolution of the quark–gluon medium
- Due to different binding energies, systematic precision measurements of all charmonia states in one experiment would allow for discrimination of models of quark-gluon medium properties.
  - $\chi_{cJ} \rightarrow J/\psi\gamma$ $(J = 0, 1, 2)$
  - $J/\psi \rightarrow l^+l^-$, $l^\pm = \mu^\pm$ or $e^\pm$, in our studies we focus on J/ψ detection via dielectron decay channel

Charmonia reconstruction

Previously, we were able to reconstruct χ_{c1} and χ_{c2} in fast simulations.

- ALICE 3 detectors used in analysis:
  - Central tracker for $e^{\pm}$ momentum measurement
  - Electromagnetic calorimeter (ECAL) for $e^{\pm}$ identification and for photon measurement
- Electron identification in ALICE 3:
  - Matching tracks reconstructed in the central tracker, with clusters reconstructed in ECAL
  - Equality of track momentum p and cluster energy E: $E/p \approx 1$, fiducial range of E/p is a subject of optimization and depends on momentum and energy resolutions.

ALICE 3 Previous Results

We were able to distinctly see χ_{c1} and χ_{c2} peaks when photons were detected in the high-resolution segment of the ALICE 3 ECAL.

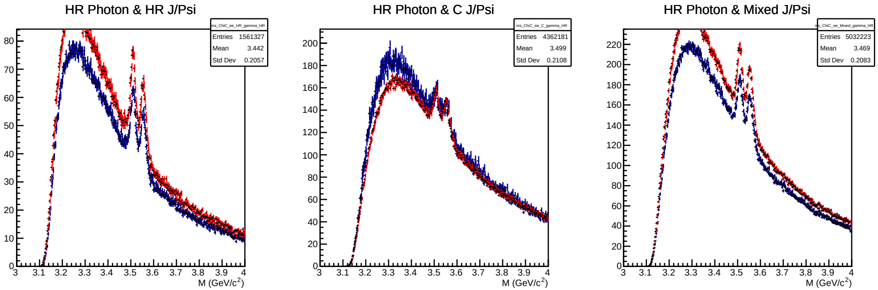

Figure: $e^+e^-\gamma$ spectra in different scenarios (histograms in red shows reconstruction using MC data, blue histograms show reconstruction from derived candidates for particles). HR and C are short for High-Resolution and Coarse segment detection in the calorimeter.

Validation of electron ID on ALICE data

Methods of electron identification developed for ALICE 3 in simulations, were tested on ALICE data recorded in LHC Run 3. Detectors used for analysis:

- Central tracking system (ITS+TPC): $|\eta| < 0.8$, $\Delta\varphi = 2\pi$
- Particle identification (TPC+TOF): $|\eta| < 0.8$, $\Delta\varphi = 2\pi$
- Photon Spectrometer (PHOS): $|\eta| < 0.12$, $\Delta\varphi = 0.38\pi$

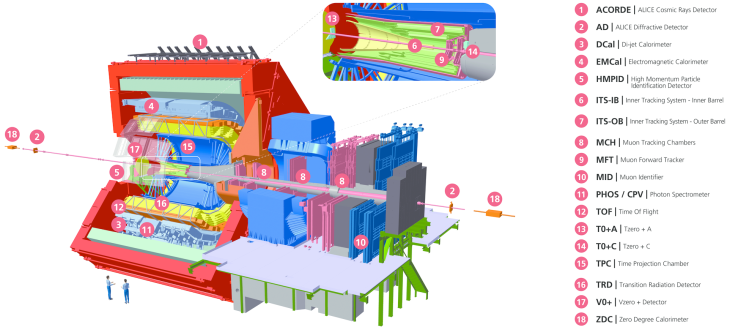

Figure: ALICE detector

Electron reconstruction and identification in ALICE

- Conventional method of electron reconstruction and identification in ALICE is measuring specific ionization loss of a charged track in TPC and time-of-flight of a track from the interaction point to the TOF detector.
- Complimentary method of electron ID is based on combining tracks and electromagnetic clusters in the ALICE calorimeter PHOS:
  - Select tracks matching with clusters in PHOS. Matching range is energy-dependent and should be optimized
  - Pick out matched clusters with a shape of an electromagnetic shower. This enhances samples of electron candidate clusters
  - Apply energy cut on clusters to further suppress the hadronic background
  - Optionally apply electron ID on charged tracks using dE/dx from TPC to increase electron track purity
  - Request $E/p \approx 1$ for cluster-track matching.

Track Selection Criteria

We take a standard/predefined cut to get primary and well reconstructed tracks:

- Collision vertex $|Z| < 10\ cm$
- $|DCA_{XY}| < 3\ cm$, $|DCA_Z| < 3\ cm$
- Number of clusters in ITS $\in [4.5, 7]$ with $\chi^2_{ITS}/cl < 5$
- Number of clusters in TPC $\in [90, 170]$ with $\chi^2_{TPC}/cl < 4$
- Crossed Rows in TPC $\in [80, 161]$

For our analysis we also set

- $p_T \in [0.8, 20]\ GeV/c$, $|\eta| < 0.8$

Track Matching

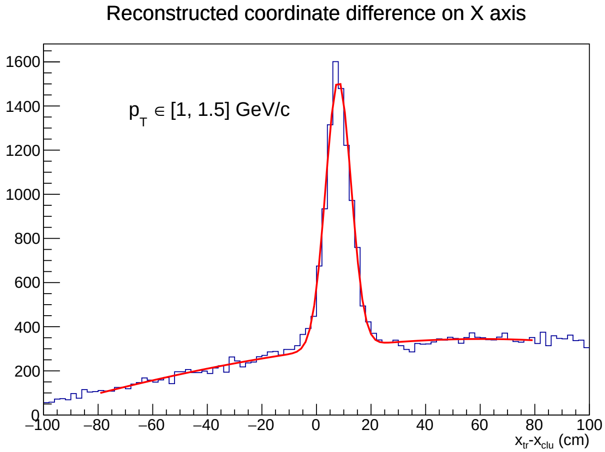

Figure: Example for negative tracks; difference between X coordinate for all tracks and all clusters in an event. Fitted with Gaussian function + polynomial of 2nd order. 3σ corridor is set as an acceptance range in the analysis.

PID Criteria

We use TPC and TOF detectors to identify electrons

TPC/TOF electron inclusion

$N\sigma^{e}_{TPC} \in [-3, 2]$
$N\sigma^{e}_{TOF} \in [-3, 3]$

TPC rejection
($\pi^{\pm}, K^{\pm}, p^{\pm}$ exclusion)

$N\sigma^{\pi}_{TPC} \in [-3, 3.5]$
$N\sigma^{K}_{TPC} \in [-3, 4]$
$N\sigma^{p}_{TPC} \in [-3, 4]$

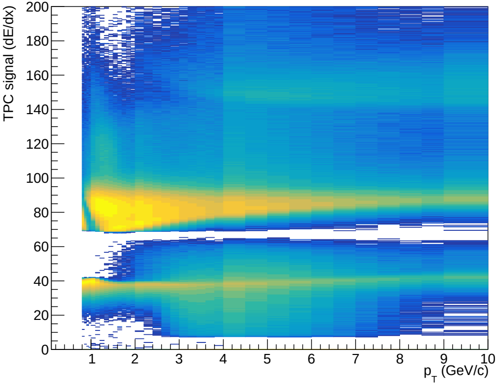

Figure: TPC dE/dx signal after PID cuts

E/p Ratio for Matching EM clusters

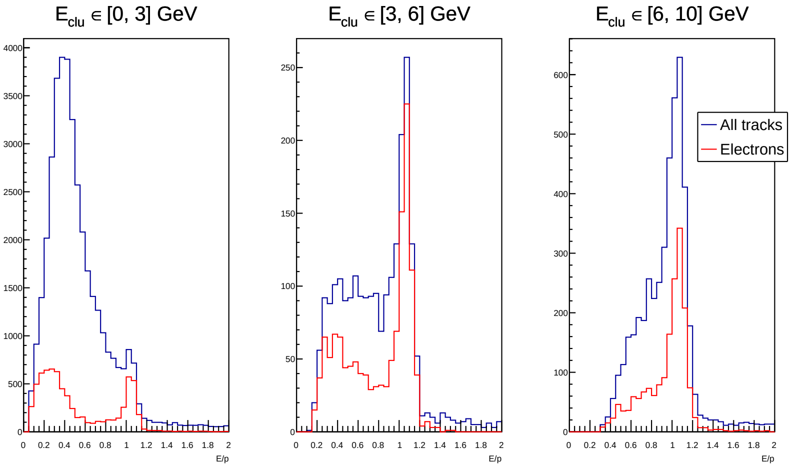

Figure: E/p at different cluster energies, projections within (left to right): 0 to 3 GeV, 3 to 6 GeV, 6 to 10 GeV. Blue lines signify all tracks, red lines signify identified electrons via TPC and TOF. Restricted shape: cluster must be caused by an electromagnetic shower.

e^+e^- Mass Spectra

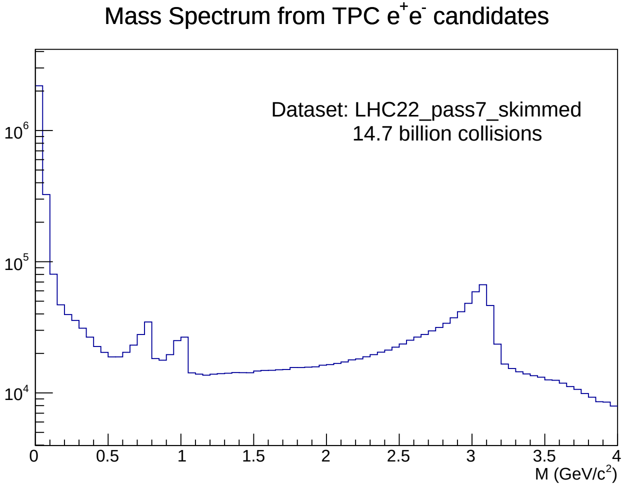

Figure: Mass spectrum of TPC identified electron positron pair. Meson peaks can be seen - $\rho(770)$ combined with $\omega(782)$, $\phi(1020)$ and $J/\psi(1S)$.

Conclusion

Results show that:

- Electron identification is attainable with PHOS.
- Set track selection and PID criteria allow J/ψ to be reconstructed from dielectron decay channel using TPC+TOF.

Next steps:

- Measure PHOS electron identification efficiency.
- Try to reconstruct J/ψ and χ_{cJ} mesons using PHOS.
- Reapply used methods in Run 3 PbPb collisions.

"This work is supported by RSF grant 22-42-04405"

References and Links

- [ALICE], "Letter of intent for ALICE 3: A next-generation heavy-ion experiment at the LHC," [arXiv:2211.02491 [physics.ins-det]].
- 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
- Hambardzumyan, Y., Kharlov, Y. Electron Identification with the Electromagnetic Calorimeter and Its Application for Charmonia Studies in the Experiment ALICE3 at the LHC. Phys. Part. Nuclei Lett. 21, 642–645 (2024).
- ALICE fast simulation DelphesO2 `https://github.com/AliceO2Group/DelphesO2`
- ALICE analysis framework `https://aliceo2group.github.io/analysis-framework/`

[Backup] Energy Spectra After Skimming

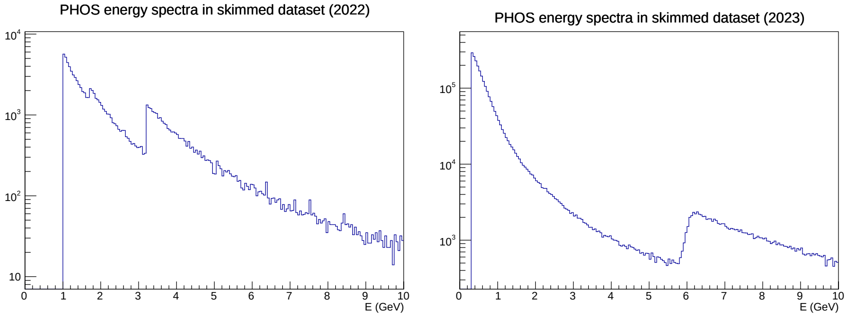

Figure: Skimmed energy spectra of 2022 and 2023 data

[Backup] E/p ratio (thinned 2023 data)

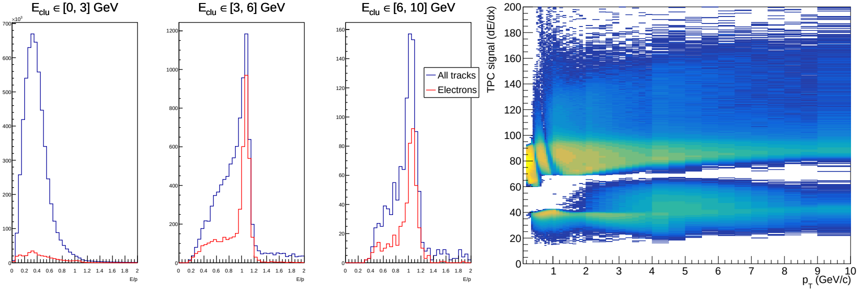

Figure: Analysis of thinned 2023 data. E/p ratio at different energies and TPC signal after cuts

[Backup] e^+e^- Mass Spectra (2023 data)

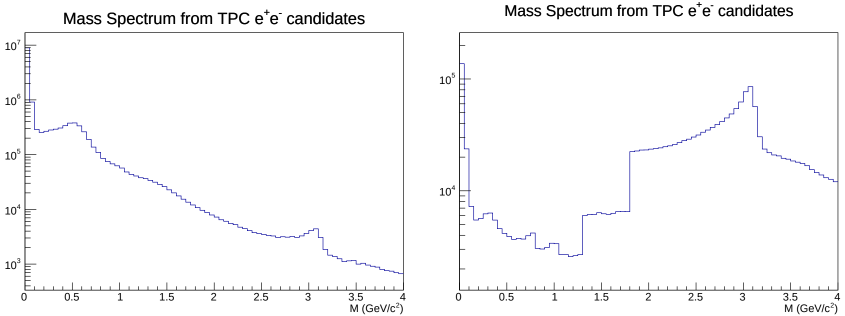

Figure: Mass spectra e^+e^- of thinned and skimmed 2023 data