Light neutral meson production in the era of precision physics at the LHC

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Big questions in heavy-ion physics

- What are the different particle production mechanisms across different system sizes?
- Can we find the onset of the QGP? → Is there a QGP droplet formed in small systems?

\[
\begin{align*}
\text{pp} & \quad N_{\text{particles}} \sim 10^1 \\
p-\text{Pb} & \quad N_{\text{particles}} \sim 10^2 \\
Pb-Pb & \quad N_{\text{particles}} \sim 10^4
\end{align*}
\]
Why measure neutral mesons?

\[ \pi^0 \to \gamma\gamma, \quad \eta \to \gamma\gamma, \quad \omega \to \pi^0\gamma, \quad ... \]

- Straightforward identification \((M_{\text{inv}})\) → study the particle production mechanisms
- Main background for \(\gamma_{\text{direct}}\) → precise neutral meson measurements lead to precise \(\gamma_{\text{direct}}\) measurements

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ALICE: Photon and event multiplicity measurements

Photon Conversion Method (PCM)

- ITS and TPC
- $|\eta| < 0.9$ and $0^\circ < \varphi < 360^\circ$
- $E_\gamma > 100$ MeV, $E_{\pi^0} > 300$ MeV
- Conversion probability $\sim 8\%$

PHOS calorimeter

- PbWO$_4$ crystals (cell size 2.2 cm x 2.2 cm, at 4.6 m)
- $|\eta| < 0.12$ and $250^\circ < \varphi < 320^\circ$
- $E_\gamma > 200$ MeV, $E_{\pi^0} > 400$ MeV

EMCal calorimeter

- Pb-scintillator towers (cell size 6 cm x 6 cm, at 4.28 m)
- EMCal: $|\eta| < 0.7$, $80^\circ < \varphi < 187^\circ$
- DCal: $0.22 < |\eta| < 0.7$, $260^\circ < \varphi < 320^\circ$
- DCal: $|\eta| < 0.7$, $320^\circ < \varphi < 327^\circ$
- $E_\gamma > 700$ MeV, $E_{\pi^0} > 1.4$ GeV

Centrality estimator V0M

- V0A: $2.8 < \eta < 5.1$, V0C: $-3.7 < \eta < -1.7$
- Measures forward multiplicity in central barrel
Neutral meson reconstruction in ALICE

Analysis strategy:

- **Reconstruct the photons**
- **Obtain the meson raw yield:** integrate $M_{\text{inv}}$ distributions
- **Correct raw yield for efficiency, acceptance, feed-down from secondaries**
- **Combine the different reconstruction methods**
- **More differential studies**
Neutral meson reconstruction in ALICE

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- vs. event multiplicity

- vs. event shape: $0 < S_T < 1$
  - Pencil-like: $S_T \approx 0$
  - Spherical: $S_T \approx 1$

- In-jet production

  - Reconstruct neutral mesons inside charged jets
  - Algorithm: anti-$k_t$, $R = 0.4$, $E > 10$ GeV
Neutral mesons in pp collisions

Main reasons for study:
- Fragmentation
- Contribution underlying event
- Main background for $\gamma_{\text{direct}}$
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More differential studies:
- vs. event multiplicity
- vs. event shape: Sphericity $S_T$

Comparisons to predictions:
- PYTHIA overpredicts $\pi^0$, except for high multiplicity
- PYTHIA overpredicts $\pi^0$ pencil-like events, underpredicts spherical events
- $\eta/\pi^0$ significantly modified for the in-jet production
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Neutral mesons in p–Pb collisions

**π⁰ & η**

![Graph showing π⁰ and η distributions in p–Pb collisions](image1)

**Ratio to theory**

![Graph comparing theory predictions to data](image2)

**η/π⁰**

![Graph showing ratio of η to π⁰](image3)

Minimum Bias production

- Model comparisons show only consistency for limited $p_T$ ranges
- Full Run 1 + Run 2 data will improve the results precision

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Neutral mesons in p–Pb collisions

Multiplicty dependent production

- No significant centrality dependence in the $\eta/\pi^0$ ratio
- $Q_{pA}$ shows significant change of slope at low $p_T$

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Neutral mesons in p–Pb collisions

Nuclear modification factor:

\[ Q_{pA} = \frac{dN_{pA}^{pA}}{dT_{pA}} / \left( T_{pA} \right) \]

\[ \left( \frac{d\sigma^{pp}}{dp_T} \right) \]

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Neutral mesons in Pb–Pb collisions

**Multiplicity dependent production**

- Precise spectra over large momentum range
- Main background for direct photon analysis
- $\eta/\pi^0$ shows significant modification for non-peripheral collisions
- $R_{AA}$ shows strong suppression for central collisions
Neutral mesons in Pb–Pb collisions

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Nuclear modification factor:

\[ R_{AA} = \frac{dN_{AA}}{dp_T} \frac{<T_{AA}>}{d\sigma_{pp}/dp_T} \]

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$$R_{AA} = \frac{dN^{AA}/dp_T}{<T_{AA}> d\sigma^{pp}/dp_T}$$
Neutral mesons spectra measurements provide us with:

- Benchmark for all photon analyses in ALICE
- Information on particle production mechanisms using detailed comparisons to model calculations
- Decay photon background for direct photon measurements
Summary and outlook

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What is next?

1. Build a consistent picture for light neutral meson production
2. Direct photons \( \rightarrow \) **under which conditions do we measure an excess of low \( p_T \) direct photons?**
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Thanks for your attention.
The ALICE detector

- ITS
- TPC
- EMCal
- PHOS