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 a QGP droplet formed in small systems?

$N_{\text{particles}} \sim 10^1$

$N_{\text{particles}} \sim 10^2$

$N_{\text{particles}} \sim 10^4$
Why measure neutral mesons?

\[ \pi^0 \rightarrow \gamma\gamma, \quad \eta \rightarrow \gamma\gamma, \quad \omega \rightarrow \pi^0\gamma, \quad \ldots \]

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

| pp       | p–Pb       | Pb–Pb       |
|----------|------------|-------------|
| Jet production  | Cold nuclear matter effects   | QGP effects   |
| Underlying event studies | Multiplicity dependence | Centrality dependence |

Photons in ALICE

Photon Conversion Method (PCM)

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

PHOS calorimeter

- \(\text{PbWO}_4\) crystals (2.2 cm x 2.2 cm, at 4.6 m)
- \(|\eta| < 0.12 \text{ and } 260^\circ < \varphi < 320^\circ\)
- \(E_{\gamma} > 200 \text{ MeV}, E_{\pi^0} > 400 \text{ MeV}\)

EMCal calorimeter

- Pb-scintillator towers (6 cm x 6 cm, at 4.28 m)
- \(|\eta| < 0.7 \text{ and } 80^\circ < \varphi < 180^\circ\)
- \(E_{\gamma} > 700 \text{ MeV}, E_{\pi^0} > 1.4 \text{ GeV}\)

Centrality estimators

- V0M (V0A & V0C), measures forward multiplicity in central barrel
- ZDC (ZNA & ZNC), measures forward neutrons at large distance
Analysis strategy:

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

Analysis strategy:

- Reconstruct the photons
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\[
\begin{align*}
\pi^0 & \Rightarrow \gamma\gamma \\
\eta & \Rightarrow \gamma\gamma
\end{align*}
\]
Neutral meson reconstruction in ALICE

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![Graphs showing the analysis strategy for reconstructing neutral mesons in ALICE.](image)

arXiv:1708.08745, Eur. Phys. J. C 78 (2018) 263
Neutral mesons in pp collisions

Main reasons for study:
- Fragmentation & in-jet production
- Contribution underlying event
- Main background for $\gamma_{\text{direct}}$

arXiv:1708.08745, Eur. Phys. J. C 78 (2018) 263
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$\pi^0$ model comparisons:
- PYTHIA and NLO overpredict the production
- More differential studies can disentangle the jet and UE components
Neutral mesons in p–Pb collisions

π⁰ & η

Ratio to theory

η/π⁰

Minimum Bias production

- Model comparisons show only consistency for limited $p_T$ ranges
- Full Run 1 + Run 2 result promises to provide very detailed studies

arXiv:1801.07051, Eur. Phys. J. C (2018) 78: 624
Neutral mesons in p–Pb collisions

V0A centrality estimation
- Significant change of slope at low $p_T$
- No significant centrality dependence in the $\eta/\pi^0$ ratio
Neutral mesons in p–Pb collisions

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Nuclear modification factor:

$$Q_{pA} = \frac{dN_{pA}^{dA}}{<T_{pA}> d\sigma^{pp}/dp_T}$$

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Neutral mesons in p–Pb collisions

\[ Q_{PA} = \frac{dN_{PA}^{A}}{dp_{T}} / \langle \frac{d\sigma_{PP}}{dp_{T}} \rangle \]

V0A centrality estimation
- Significant change of slope at low \( p_{T} \)
- No significant centrality dependence in the \( \eta/\pi^{0} \) ratio

ZNA centrality estimation
- Zero-degree calorimeter on A (Pb) side
- Measures energy of spectator nucleons, 114 m from interaction point
- Less centrality dependence observed wrt. V0A centrality estimation

Nuclear modification factor:
Neutral mesons in Pb–Pb collisions

Neutral mesons in Pb–Pb collisions

\[ \pi^0 \]

ALICE Preliminary

\[ \frac{1}{2\pi N_p} \frac{d^3N}{dp_T^2 dy} \]

Pb–Pb at \( \sqrt{s_{NN}} = 5.02 \) TeV

- 0-10% × 2^2
- 20-40% × 2^2
- 60-80% × 2^2

--- TCM fits to Pb–Pb

\[ (\text{GeV}/c)^2 \]

\[ \text{SHM (V. Begun et al.)} \]

- NEQ : 0-10% × 2^2
- EQ : 0-10% × 2^2
- NEQ : 20-40% × 2^2
- EQ : 20-40% × 2^2
- NEQ : 60-80% × 2^2
- EQ : 60-80% × 2^2

Ratio to theory

ALICE Preliminary

Fit

Theory, Data

\[ : 0-10\% \]

\[ \pi \]

NEQ SHM (V. Begun et al.)

EQ SHM (V. Begun et al.)

V0A centrality estimation

- Model comparisons show consistency for limited \( p_T \) ranges
- Basis for direct photon background subtraction

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Neutral mesons in ALICE, EPS-HEP 2019

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Neutral mesons in Pb–Pb collisions

Model comparisons show consistency for limited $p_T$ ranges

Basis for direct photon background subtraction

Nuclear modification

$$R_{AA} = \frac{dN^{AA}/dp_T}{\langle T_{AA} \rangle d\sigma^{pp}/dp_T}$$

Strong suppression for central collisions

Full Run 2 result promises to provide detailed studies
Summary and outlook

Neutral mesons spectra measurements provide us with information on:

- Particle production mechanisms, by comparing to model calculations
- Decay photon background for direct photon measurements
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Where do the next opportunities lie?
1. Overall reducing the uncertainties in the measurements, by:
   - Using full Run 1+2 statistics $\rightarrow$ factor $\sim 2 - 6$ increase
   - Combine all neutral meson reconstruction methods

2. additional differential studies:
   - Vs. multiplicity
   - Vs. event shapes ($S_T$, $S_O$)
   - In-jet production

3. 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