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?

\[ N_{\text{particles}} \sim 10^1 \]  \hspace{2cm}  \[ N_{\text{particles}} \sim 10^2 \]  \hspace{2cm}  \[ N_{\text{particles}} \sim 10^4 \]
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

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**pp**

Jet production
Underlying event studies

**p–Pb**

Cold nuclear matter effects
Multiplicity dependence

**Pb–Pb**

QGP effects
Centrality dependence
Photons in ALICE

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

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

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

\[ \pi^0 \]

\[ \eta \]

Counts

ALICE performance

$\pi^0$: $0.5 \text{ GeV/c} < p_\pi < 0.6 \text{ GeV/c}$

Raw real events

Mixed event BG

Remain. BG

BG subtracted

Fit

ALICE performance

$\eta$: $1.1 \text{ GeV/c} < p_\eta < 1.4 \text{ GeV/c}$

Raw real events

Mixed event BG

Remain. BG

BG subtracted

Fit

Raw real events

Mixed event BG

Remain. BG

BG subtracted

Fit

ALI-PUB-135823

ALI-PUB-135787

Neutral meson reconstruction in ALICE

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![Graphs showing $\pi^0$ and $\eta$ distributions](attachment:image.png)
Neutral meson reconstruction in ALICE

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Data/TCM fit

Neutral mesons in pp collisions

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

![Graphs showing data for $\pi^0$ and $\eta$ mesons](arXiv:1708.08745, Eur. Phys. J. C 78 (2018) 263)
Neutral mesons in pp collisions

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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

**π^0 & η**

Ratio to theory

η/π^0

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

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:

$$Q_{pA} = \frac{dN_{pA}^{dN}}{dT_{pA}} / \langle T_{pA} \rangle \frac{d\sigma_{pp}}{dp_T}$$

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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

**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:**

$$Q_{PA} = \frac{dN_{PA}^{dN}}{dp_T} \frac{<T_{PA}^{dp}d\sigma^{pp}dp_T}{<T_{PP}^{dp}d\sigma^{pp}dp_T}$$

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Neutral mesons in Pb–Pb collisions

\[ \pi^0 \]

**Ratio to theory**

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

**V0A centrality estimation**

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Basis for direct photon background subtraction
Neutral mesons in Pb–Pb collisions

V0A centrality estimation

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Nuclear modification

$$R_{AA} = \frac{dN_{AA}^{/p_T}}{<T_{AA}> d\sigma_{pp}^{/p_T}}$$

- 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 → 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 → 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