Neutral meson production measurements with the ALICE/LHC detector

Paraskevi Ganoti, for the ALICE Collaboration
National and Kapodistrian University of Athens
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Outline

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- Nuclear modification factor, $R_{AA}$
- Summary
Physics motivation

Measurement of $\pi^0$ and $\eta$ mesons in pp collisions

- Cleanly identified via the $\gamma\gamma$ decay.
- At low $p_T$: understand particle production. Compare to phenomenological models.
- At high $p_T$: Test of pQCD cross section predictions.
- At LHC: Constraints on the gluon to pion fragmentation. Access to FF with $s$ quark ($\eta$ meson)
- Reference data for heavy ion collisions.
- Main source of background in the direct-photon measurement and in the heavy-flavour electron measurement.

Measurement of $\pi^0$ and $\eta$ mesons in heavy-ion collisions

- Study energy loss (mainly gluons)/particle suppression.
- Compare to theoretical model predictions.
The ALICE experiment

[Diagram of the ALICE experiment with labels for EMCal, ITS, TPC, PHOS, ACORDE, TRD, HMPID, PMD, V0, T0, TOF, DIPOLE MAGNET, ABSORBER, FMD, T0 & V0, TRIGGER CHAMBERS, MUON FILTER, and ZDC ~116m from IP.]
PHOS calorimeter:
  PbWO4 crystal
  Located at 4.6 m from the ALICE IP.
  \(|\eta|<0.13, 260^\circ<\phi<320^\circ|

\[
\frac{\sigma_{E(GeV)}}{E} = \frac{1.8}{E} + \frac{3.3}{\sqrt{E}} + 1.1\%
\]

EMCal calorimeter:
  77 layers 1.4 mm lead + 1.7 mm scintillator
  Located at 4.4 m from ALICE IP.
  \(|\eta|<0.7, 80^\circ<\phi<180^\circ|

\[
\frac{\sigma_{E(GeV)}}{E} = \frac{5}{E} + \frac{11}{\sqrt{E}} + 1.7\%
\]

PCM (Photon Conversion Method):
  Photon conversion in detector material
  ITS and TPC \(X/X_0=11.4\pm0.5\) sys %
  \(|\eta|<0.9, 0^\circ<\phi<360^\circ|
  \sigma_R < 2\text{cm}, \sigma_Z < 1.5\text{cm}, \sigma_\phi < 7\text{mrad}
  Conversion probability is small (8.5-9%)
  but it is compensated by a wide acceptance.
Analysed data (published or analysis in progress)

**pp collisions at $\sqrt{s} = 0.9$, 2.76 and 7 TeV (PHOS and PCM)**

**Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV (PHOS and PCM, 2010 data)**

**Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV (EMCal and PCM, 2011 data)**
To be published

**pp at $\sqrt{s} = 8$ TeV (EMCal, PCM and PHOS)**
To be published

**p-Pb at $\sqrt{s} = 5.02$ TeV (EMCal, PCM and PHOS)**
To be published

**pp at $\sqrt{s} = 5.02$ TeV and at $\sqrt{s} = 13$ TeV, Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV**
Analyses in progress
\( \pi^0 \) and \( \eta \) are reconstructed via invariant mass analysis

\[
M_{\gamma\gamma} = \sqrt{(2E_{\gamma_1}E_{\gamma_2} - (1 - \cos \theta_{\gamma_1\gamma_2}))}
\]

\( \pi^0 \) in EMCal, pp collisions at \( \sqrt{s}=7 \) TeV

\( \eta \) at EMCal, pp collisions at \( \sqrt{s}=7 \) TeV

\( \pi^0 \) and \( \eta \) in EMCal, Pb-Pb collisions at \( \sqrt{s_{NN}}=2.76 \) TeV

\( \eta \) at EMCal, Pb-Pb collisions at \( \sqrt{s_{NN}}=2.76 \) TeV

Centrality 0-20%
**ALICE performance in neutral mesons, Run I**

- **pp at $\sqrt{s}=2.76$ TeV**
- **Pb-Pb at $\sqrt{s_{NN}}=2.76$ TeV**
- **p-Pb at $\sqrt{s_{NN}}=5.02$ TeV**
ALICE performance in neutral mesons, Run II

**pp at \(\sqrt{s} = 5.02\) TeV**

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

**pp at \(\sqrt{s} = 13\) TeV**

**Pb-Pb at \(\sqrt{s_{NN}} = 13\) TeV**
\( \pi^0 \) and \( \eta \) cross sections in pp collisions

\[ \sqrt{s_{\text{NN}}} = 0.9, 2.76, 7 \text{ and } 8 \text{ TeV} \]

\( \rho_T \) reach:

\( \pi^0 \)'s up to 20 GeV/c and 30 GeV/c for \( \sqrt{s} = 8 \) TeV.

\( \eta \)'s from 0.5 to 10 GeV/c.

Power law dependence at high \( p_T \).

<table>
<thead>
<tr>
<th>( \sqrt{s} ) (TeV)</th>
<th>( n )</th>
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</thead>
<tbody>
<tr>
<td>0.9</td>
<td>7 ± 2</td>
</tr>
<tr>
<td>2.76</td>
<td>6.0 ± 0.5</td>
</tr>
<tr>
<td>7</td>
<td>6.0 ± 0.1</td>
</tr>
<tr>
<td>8</td>
<td>5.9 ± 0.2</td>
</tr>
</tbody>
</table>

NLO pQCD calculations:

Phys. Rev. D91 (2015) 1

Reasonable agreement between data and NLO pQCD for 0.9 and 2.76 TeV but increasing discrepancy with increasing \( p_T \) and \( \sqrt{s} \).

PDF: MSTW

Fragmentation functions: DSS14
0.9 and 2.76 TeV: PCM only
7 TeV: PCM+PHOS

PDF: Cteq6M5
FF: AES

PLB 717 (2012) 162
π⁰ spectra compared to Color Glass Condensate (CGC) calculations (arXiv:1408.2765).

CGC aims at describing strong interacting systems in the high energy limit: non-linear phenomena, gluon recombination.

Model describes our data in the p_T region of 1-10 GeV/c.

Comparisons between the pQCD and the CGC calculations could reveal issues not only on the FF but also on the initial state gluon distributions.
The ALICE measurement of the $\eta/\pi^0$ ratio is consistent with world results in pp collisions at all energies and it is well reproduced by pQCD.

$\eta/\pi^0 \sim 0.4$ for $p_T > 4$ GeV/c.

$\eta$ : PDF:Cteq6M5, FF: AES

$\pi^0$ : PDF:Cteq6M5, FF: DSS
2010 data: $\pi^0$ yields measured in six centrality classes.
$p_T$ reach 0.7-10 GeV/$c$
Clear modification of the spectrum in central collisions.

Low $p_T$: Hydrodynamic flow
High $p_T$: Energy loss of string segments

Dashed lines: Nemchik PRC86, 054904, 2012.
Low $p_T$: Hydrodynamic description
High $p_T$: Color dipole absorption
**R_{AA}**

Measured to quantify nuclear effects in A-A collisions \( R_{AA} \) contains both initial and final state effects.

\( \pi^0 R_{AA} \) measured in three centrality classes. \( p_T \) reach 0.5-10 GeV/c

\[
R_{AA}(p_T) = \frac{(1/N_{evt}) d^2N_{ch}^A / d\eta dp_T}{(1/N_{evt}) d^2N_{ch}^{pp} / d\eta dp_T}
\]

Large \( \pi^0 \) suppression in central Pb – Pb collisions.

Maximum around \( p_T \sim 1\text{-}2 \text{ GeV/c} \) for all centralities.

Increasing suppression as centrality increases

60-80%: \( R_{AA} \sim 0.6 \) for \( p_T \) 6-10 GeV/c

0-5% : \( R_{AA} \sim 0.1 \) for \( p_T \) 6-10 GeV/c

\( \pi^0 R_{AA} \) at LHC lower than at RHIC and at SPS

\( \pi^0 R_{AA} \) decrease due to higher initial energy density dominates over \( \pi^0 R_{AA} \) increase from harder parton \( p_T \) spectrum.

Shape of \( \pi^0 R_{AA}(p_T) \) at \( \sqrt{s_{NN}}=2.76 \text{ TeV} \) similar as at \( \sqrt{s_{NN}} = 200 \text{ GeV} \)

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P. Ganoti

XII Quark Confinement and the Hadron Spectrum, Thessaloniki, Greece 2016

ALICE: EPJC 74 (2014) 10, 3108
PHENIX: PRL 109 (2012) 152301
WA98: PRL 100 (2008) 242301
2011 data with 10 times more statistics, 2 centrality classes, higher $p_T$ reach (20 GeV/c). Measurement by EMCal and PCM.
Comparisons to NLO pQCD pp predictions (Phys. Rev. D91 (2015) 1) scaled by Ncoll
$\eta/\pi^0$ ratio in Pb-Pb collisions

$\eta/\pi^0$ ratio in two centrality classes.

Compared with the charged $K^\pm/\pi^\pm$ (PLB 736 (2014) 186) and the 7 TeV result (PLB 717 (2012) 162).

\( \pi^0 \) and \( \eta \) in p-Pb collisions

Initial state effects can be tested with p-Pb data. \( \pi^0 \) spectrum obtained from PCM, Dalitz, PHOS and EMCal.

\( \eta \) spectrum obtained from PCM and EMCal, \( \sim 100 \text{M events} \).

EPS calculations assuming three different fragmentation functions (JHEP 1207 (2012) 073) and CGC (Phys. Rev D88 (2013) 114020)

\( R_{p-Pb} \) is consistent with the calculations within the errors.
Summary

- $\pi^0$ and $\eta$ invariant cross sections are measured in pp, Pb-Pb and p-Pb collisions over a wide $p_T$ range.

- pp results are compatible with the NLO pQCD calculations at the lower $p_T$ and collision energies, however, there is a growing discrepancy with increasing $p_T$ and $\sqrt{s}$.

- CGC reproduces $\pi^0$ production at $\sqrt{s} = 2.76$ and 7 TeV up to moderate (high) $p_T$.

- $\pi^0$ invariant yield measured in Pb-Pb collisions in 6 centrality classes (2010 data). Comparisons to theoretical models (EPOS and Nemchick et al.) over the complete $p_T$ range are presented.

- The $\eta/\pi^0$ ratio reaches a constant value at $p_T > 4$ GeV/$c$ for all systems, pp, Pb-Pb and p-Pb. In pp collisions, data and pQCD NLO calculations show the same trend.

- In 2011 Pb-Pb collisions, $\pi^0$ and $\eta$ in two centrality classes are measured up to 20 GeV/$c$. Comparisons to NLO pQCD pp predictions (Phys. Rev. D91 (2015) 1) scaled by Ncoll show a suppression in the Pb-Pb data with respect to scaled NLO pQCD.

  - $\pi^0 R_{AA}$ is measured in different centrality classes.
  - $R_{AA} \approx 0.1$ for 0-5% centrality.
  - The measured suppression is stronger than at lower $\sqrt{s_{NN}}$. The shapes of $R_{AA}(p_T)$ at $\sqrt{s_{NN}} = 2.76$ TeV and at $\sqrt{s_{NN}} = 200$ GeV are similar.

- $\pi^0 R_{p-Pb}$ is consistent with unity for $p_T > 2.5$ GeV/$c$. This measurement indicates that the strong suppression of hadron production at high $p_T$ observed in Pb–Pb collisions is not due to an initial-state effect, but is the fingerprint of jet quenching in hot QCD matter.