Light neutral mesons production at the LHC measured by ALICE

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High-energy heavy-ion collisions

- A new state of matter, called “quark-gluon plasma”, where quarks and gluons are deconfined from hadrons.
- Particle physics under the extremely hot and dense condition.
- ALICE is one of the LHC experiments which focuses on high-energy heavy-ion collisions.
Physics Motivation of neutral mesons

• In pp collisions:
  - constrain fragmentation function and parton distribution function.
  - baseline for pA and AA collisions.

• In pA collisions:
  - study cold nuclear matter effects.
  - baseline for AA collisions.

• In AA collisions:
  - partonic interactions in the quark-gluon plasma.
  - powerful probes for studying suppression of hadrons at high transverse momentum ($p_T$).

• Inputs to background estimation for electromagnetic probes in all collision systems.
ALICE apparatus at the LHC

THE ALICE DETECTOR

PHOS
A homogeneous electromagnetic calorimeter

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

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Photon reconstructions in ALICE

- **EMCal/DCal**: sampling calorimeter 77 layers of lead + scintillator
  
  $|\eta| < 0.7$, $80^\circ < \phi < 187^\circ$, 4.28 m from IP,
  
  $0.22 < |\eta| < 0.7$ and $260^\circ < \phi < 320^\circ$
  
  $|\eta| < 0.7$ and $320^\circ < \phi < 327^\circ$ 4.28 m from IP

- **PCM**: external conversion ($\gamma \rightarrow e^+e^-$) in detector materials (ITS + TPC)
  
  $|\eta| < 0.9$, $0^\circ < \phi < 360^\circ$

- **PHOS**: fine-segmented homogeneous calorimeter with PWO crystals
  
  $|\eta| < 0.12$, $250^\circ < \phi < 320^\circ$, 4.6 m from IP
## Run1/2 data sets and neutral meson spectra results

<table>
<thead>
<tr>
<th>Collision system</th>
<th>$\sqrt{s_{NN}}$ (TeV)</th>
<th>Luminosity (nb$^{-1}$)</th>
<th>Published papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp</td>
<td>0.9</td>
<td>0.14 (MB)</td>
<td>Phys. Lett. B 717 (2012) 162-172</td>
</tr>
<tr>
<td>p-Pb/Pb-p</td>
<td>5.02</td>
<td>0.05 (MB)</td>
<td>Eur. Phys. J. C (2018) 78:624</td>
</tr>
</tbody>
</table>
| Pb-Pb            | 2.76                 | 0.10 (HM) 2.3 x 10^{-3} (MB) | Phys. Rev. C 98, 044901 (2018)  
| pp               | 5.02                 | 20 (MB) + 1000 (Calo)  | In progress |
| pp               | 13                   | 98 (MB) + 16 x 10^{3} (Calo) | In progress |
| p-Pb             | 5.02                 | 0.33 (MB)              | In progress |
| p-Pb/Pb-p        | 8.16                 | 0.06 (MB) + 12 (Calo)  | In progress |
| Pb-Pb            | 5.02                 | 12 x 10^{-3} (MB)      | In progress |
| Xe-Xe            | 5.44                 | 0.19 x 10^{-3} (MB)    | In progress |

Triggers  
MB : Minimum Bias  
Calo : Calorimeters  
HM : High Multiplicity
Invariant mass distributions with 2 photons

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Performance of calorimeter triggers

- Significant enhancement with EM/DCal and PHOS triggers.
  - rejection factor $\sim O(10^3)$.
  - extend $p_T$ range up to higher $p_T$.
  - especially, helps to extract $\eta$ mesons signal.
Neutral mesons in pp collisions at different energies

- \( p_T \) spectra of neutral mesons have been measured in pp collisions at different energies.

- Pythia8 reproduces their \( p_T \) spectra at all energies.

- NLO pQCD calculations over-predict their cross sections by \( \sim 30\% \).

- Results in pp collisions at \( \sqrt{s} = 7 \) TeV contributes FF : DSS14.
Neutral mesons in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- Neutral mesons in 5 multiplicity classes determined by Zero Degree Calorimeter at forward rapidity.
  - $\pi^0 : 0.4 < p_T < 40$ GeV/$c$
  - $\eta : 0.7 < p_T < 25$ GeV/$c$
$\eta/\pi^0$ ratio and $m_T$ scaling

$m_T \equiv \sqrt{p_T^2 + m^2}$, \[ \frac{1}{m_T} \frac{d^2N}{dm_T dy} = \frac{1}{p_T} \frac{d^2N}{dp_T dy}, \]

- $m_T$ scaling: experimental scaling behavior for hadrons.
  - used for hadronic cocktails to measure EM probes.

- Violation of $m_T$ scaling at $p_T < 3$ GeV/c.
- No multiplicity dependence in p-Pb collisions.
Q\textsubscript{pA} of neutral mesons in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

\begin{equation}
Q_{pA}(p_T) = \frac{1}{\langle N_{\text{coll}} \rangle} \frac{dN_{pA}/dp_T}{dN_{pp}/dp_T}
\end{equation}

$N_{\text{coll}}$ : the number of binary collisions of nucleon

- Similar $Q_{pA}$ for $\pi^0$ and $\eta$.
- D mesons (consisting of a charm and a light quark) show same trend as light hadrons.
- A bump around $p_T = 3$ GeV/c for inclusive charged hadrons ($h^\pm$) because of Cronin effect on protons.
$R_{AA}$ of $\pi^0$ in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV

- Strong multiplicity dependence.

- Similar suppression level at 2 collision energies.

$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$

If $R_{AA} = 1$: consistent with expectation from pp data.

If $R_{AA} < 1$: medium effect, especially parton energy-loss in QGP.
Comparison of $R_{AA}$ with theoretical models

- Both theoretical models can describe amount of suppression as a function of $p_T$ and multiplicity.


  - Phys. Rev. D 93, 074030 (2016)
Comparison of $R_{AA}$ among different hadrons

- $R_{AA}^{D} > R_{AA}^{\pi} \sim R_{AA}^{h_{\pm}}$ at $p_T < 10$ GeV/c.
  - Several things to consider: different energy loss mechanisms, e.g.,
    collisional energy loss for heavy flavors,
    dead-cone effects in radiative energy loss for heavy flavors.

- Similar suppression in a whole $p_T$ range for all hadron species in peripheral collisions.
Summary

• In pp collisions:
  - Constrain FF and PDF.
  - Reference for pA and AA collisions.

• In p-Pb collisions:
  - Neutral meson yields have been measured in difference multiplicity classes.
  - $Q_{pA}$ of neutral mesons are consistent with those of inclusive charged particles and D mesons for all multiplicity classes.

• In Pb-Pb collisions:
  - $R_{AA}$ at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV are similar for all multiplicity classes.
  - $R_{AA}^D \sim R_{AA}^{\pi} \sim R_{AA}^{h\pm}$ at $p_T > 10$ GeV/c.
  - $R_{AA}^D > R_{AA}^{\pi} \sim R_{AA}^{h\pm}$ at $p_T < 10$ GeV/c, related to different energy-loss mechanisms.
backup
Statistics in pp at 13 TeV