Hadronic Resonance Production with ALICE at the LHC

Serpil Yalcin Kuzu*, Ayben Karasu Uysal
(for the ALICE Collaboration)
*KTO Karatay University

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    • \( \phi \) in pp, Pb-Pb at \( \sqrt{s_{\text{NN}}} = 2.76 \) TeV and Xe-Xe at \( \sqrt{s_{\text{NN}}} = 5.44 \) TeV
    • Mean \( p_T \)
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• Conclusions and Outlook
Introduction: Motivation

- Resonances are extremely short lived particles. ($\tau_{\text{resonance}} \sim \tau_{\text{fireball}}$)
- Due to this short lifetime they may decay between chemical and kinetic freeze-outs.

The medium may modify their properties as mass, yield and width.

- During the phase transition between partonic state to hadronic state resonances may
  - decay,
  - re-scatter,
  - regenerate.
Introduction: Resonances

- Decay between chemical and kinetic freeze-outs
  → information on hadronization.
- Particle ratios, modification of yield and mean $p_T$
  → hint of rescattering and regeneration in the hadronic phase.
- Nuclear modification factors
  → information about energy loss mechanism in the medium.
- Study on the mass and width
  → interactions of the resonances with the medium.
- Comparison of resonance production in different systems like pp, p-Pb and Pb-Pb
  → provide evidences for in-medium effects.
ALICE: A Large Ion Collider Experiment
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41 countries, 178 institutes, approx. 1800 members
**ALICE: A Large Ion Collider Experiment**

<table>
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<th>Year</th>
<th>System</th>
<th>Energy</th>
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<tr>
<td>2009</td>
<td>p-p</td>
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<tr>
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<td>p-p</td>
<td>7 TeV</td>
</tr>
<tr>
<td>2010</td>
<td>Pb-Pb</td>
<td>2.76 TeV</td>
</tr>
<tr>
<td>2011</td>
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<td>2.76 TeV</td>
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<tr>
<td>2011</td>
<td>Pb-Pb</td>
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<tr>
<td>2013</td>
<td>p-Pb</td>
<td>5.02 TeV</td>
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<tr>
<td>2015</td>
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<tr>
<td>2017</td>
<td>Xe-Xe</td>
<td>5.44 TeV</td>
</tr>
<tr>
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<td>p-p</td>
<td>13 TeV</td>
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</table>
ALICE

- 10000 tons
- 16 m long
- 16 m high
- 16 m wide
ALICE

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**Time Projection Chamber (TPC)**
- primary vertex
- global tracking
- Particle identification via dE/dx in gas
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Time Of Flight (TOF)
- PID via time of flight measurement

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VZERO Scintillator Detectors (V0)
- Centrality definition in Pb-Pb (V0A and V0C)
- Multiplicity event class in p-Pb (V0A, V0C)

Time Of Flight (TOF)
- PID via time of flight measurement

Time Projection Chamber (TPC)
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TOF
V0A
V0C
TPC
Resonance Reconstruction in ALICE

- Decay products as $\pi$, $K$, $p$ identified via PID detectors (TOF, TPC).
Resonance Reconstruction in ALICE

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- Resonances are reconstructed by calculation of the invariant mass spectrum via the identified decay products.

\[ m_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2} \]

- Combinatorial background is identified by various techniques:
  - Like sign technique,
  - Mixed event technique.
Resonance Reconstruction in ALICE

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- Combinatorial background is identified by various techniques:
  - Like sign technique,
  - Mixed event technique.

- Mass, width and yield values are extracted from the background subtracted spectrum.

Reconstruction Example: $K^* \rightarrow K^\pm + \pi^\pm$
Resonance Results in ALICE: $K^*\!\!\!^0$

- Production of $K^*(892)^0$ in pp and Pb-Pb collisions.

$K^*\!\!\!^0 \to K^\pm + \pi^\mp$

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Resonance Results in ALICE: $K^{*0}$

- Production of $K^*(892)^0$ in pp, Pb-Pb and Xe-Xe collisions.

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**pp at $\sqrt{s} = 2.76$ TeV**

**Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV**

**Xe-Xe at $\sqrt{s_{NN}} = 5.44$ TeV**
Resonance Results in ALICE: $\phi$

- Production of $\phi(1020)$ in pp and Pb-Pb collisions.

\[ \phi \rightarrow K^+ + K^- \]

**pp at $\sqrt{s} = 2.76$ TeV**

**Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV**

(Images of plots showing data and fits for the production of $\phi$ in pp and Pb-Pb collisions.)
Resonance Results in ALICE: $\phi$

- Production of $\phi(1020)$ in pp, Pb-Pb and Xe-Xe collisions.

pp at $\sqrt{s} = 2.76$ TeV

Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV

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Resonance Results in ALICE: Mean $p_T$

$pp$ at $\sqrt{s} = 7$ TeV

- increase from lowest to highest multiplicity event class.

PRC 91, 024609 (2015)
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Resonance Results in ALICE: Mean $\langle p_T \rangle$

**pp at $\sqrt{s} = 7$ TeV**

- Increase from lowest to highest multiplicity event class.

- Similar behavior with pp.

**p-Pb at $s_{NN} = 5.02$ TeV**

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Resonance Results in ALICE: Mean $p_T$

- Increase from lowest to highest multiplicity event class.

- Similar behavior with pp.

- Central: Mass ordering of $K^{*0}$, $p$ and $\phi$.

- Peripheral: Split of $\langle p_T \rangle$ for proton and $\phi$.

For small systems the violation of mass ordering of $\langle p_T \rangle$ may indicate different behavior for baryons vs. mesons.
Resonance Results in ALICE: Mean $p_T$

- Increase from lowest to highest multiplicity event class.

- Similar behavior with pp.

- Similar results with Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV.

- Split of $\langle p_T \rangle$ for proton and $\phi$ at low multiplicity.

For small systems the violation of mass ordering of $\langle p_T \rangle$ may indicate different behavior for baryons vs. mesons.
Baryon/meson and meson/meson ratios have similar trend in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

- $p/\phi$ ratio is flat in central Pb-Pb as a function of $p_T$ for $p_T < 3-4$ GeV/c.
- Slope of the $p/\phi$ ratio changes from flat (central) to strong decrease (peripheral collisions, p-Pb and pp).
• Baryon/meson and meson/meson ratios have similar trend in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

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• Slope of the $p/\phi$ ratio changes from flat (central) to strong decrease (peripheral collisions, p-Pb and pp).

• From low to high multiplicity $\phi/\pi$ ratio shows similar trend in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and 5.02 TeV and Xe-Xe at $\sqrt{s_{NN}} = 5.44$ TeV.
Resonance Results in ALICE: Particle Ratios of $K^{*0}/K$ and $\phi/K$

**$K^{*0}/K$**
- Significant suppression going from p-Pb and peripheral Xe–Xe/Pb–Pb collisions to most central Xe–Xe/Pb–Pb collisions.
- Suppression in central Xe–Xe/Pb–Pb collisions interpreted as due to rescattering of $K^{*0}$ daughters.

**$\phi/K$**
- No significant system-size dependence.
- Due to its long lifetime $\phi$ yield is not affected as $K^{*0}$.

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Resonance Results in ALICE: $R_{AA}$ and $Q_{pPb}$

For $R_{AA}$

- No significant energy dependence of $K^{*0} R_{AA}$ in Xe–Xe and Pb–Pb collisions (consistent within uncertainties).
- At high $p_T$ for resonances as well as stable hadrons a strong suppression is observed in most central Pb-Pb collisions.
Resonance Results in ALICE: \( R_{AA} \) and \( Q_{pPb} \)

For \( R_{AA} \):
- No significant energy dependence of \( K^*0 \) \( R_{AA} \) in Xe–Xe and Pb–Pb collisions (consistent within uncertainties).
- At high \( p_T \) for resonances as well as stable hadrons a strong suppression is observed in most central Pb-Pb collisions.

For \( Q_{pPb} \):
- At high \( p_T \) no suppression is observed in p-Pb at \( \sqrt{s_{NN}} = 5.02 \) TeV.
Conclusions and Outlook

Resonances are measured for different collision systems with ALICE at the LHC for large $p_T$ intervals and as a function of multiplicity and centrality.

**pp** spectra are compared with MC models for $K^*0$ and $\phi$:
- low $p_T$ (<2 GeV/c): all models do not describe data well.
- intermediate $p_T$: PHOJET is in good agreement with $K^*0$ data and D6T and ATLAS-CSC tunes of PYTHIA are in good agreement with $\phi$ data.
- high $p_T$ (>8 GeV/c): all models agree with the data.

A relative increase of $<p_T>$ with multiplicity and mass ordering in central/high multiplicity class of Pb-Pb and Xe-Xe.

$p/\phi$: Different than pp and p-Pb, the ratio is flat in central Pb-Pb.

$K^*0/K$: Suppression going from p-Pb and peripheral Xe–Xe/Pb–Pb collisions to most central Xe–Xe/Pb–Pb collisions, which is a hint of re-scattering effects.

$R_{AA}$: In central Pb-Pb collisions resonances are strongly suppressed at high $p_T$ and central Xe-Xe results show similar behavior.

$Q_{pPb}$: No suppression is observed at high $p_T$ in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

More resonances have been studied to probe the properties of the hadronic phase.
Thank you!

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