Rescattering effects on resonances production in small systems with ALICE at the LHC

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Hadronic resonances → ideal probes to characterize heavy-ion collisions

• Short lived resonances: comparable to hadronic phase lifetime (~ 1-10 fm/c) → sensitive to rescattering and regeneration

• Small collision systems (pp and p–Pb):
  ➢ Used as a baseline for heavy-ion collisions
  ➢ Recent results show some typical phenomena of heavy-ion collisions
Particle yield ratios in small systems

Resonance yields compared to ground-state hadrons with similar quark content (such as K*0/K and ρ0/π)

- Goal in heavy ion collisions: characterize the properties of the hadronic phase
- Same study in pp and p–Pb collisions → smooth trend across multiplicity
- Long-lived resonances (like φ) → no evidence of multiplicity evolution
- K*0 and ρ0 → hint of decreasing trend
- Some QCD-inspired event generators, like PYTHIA 8 [1] and EPOS-LHC [2] can reproduce the suppression without a hadronic phase → colour reconnection and core/corona effects

The ALICE detector: Main sub-detectors for resonance reconstruction

THE ALICE DETECTOR

1. ITS
2. FMD, T0, VO
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCAL
8. PHOS CPV
9. MAGNET
10. ACROR
11. ABSORBER
12. MUON TRACKING
13. MUON WALL
14. MUON TRIGGER
15. DIPOLE
16. PMD
17. ZDC

Inner Tracking System (ITS)
- 6 layers of silicon detectors
- Trigger, tracking, vertex, PID (dE/dx)
The ALICE detector:
Main sub-detectors for resonance reconstruction

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The ALICE detector's Time Projection Chamber (TPC)
- Gas-filled ionization detector
- Tracking, vertex, PID (dE/dx)
The ALICE detector:
Main sub-detectors for resonance reconstruction

Time Of Flight (TOF)
- Multi-gap Resistive Plate Chamber
- PID through particle time of flight
The ALICE detector:
Main sub-detectors for resonance reconstruction

V0A and V0C
- 2 arrays of plastic scintillator hodoscopes
- Trigger, centrality/multiplicity estimator
**Signal extraction**

- **Resonance yield extraction** from invariant mass distribution of the decay daughters identified with TPC/TOF and topological selection criteria

- Uncorrelated background calculated via event mixing technique or like-sign pair method

- Remaining distribution fitted with a Breit-Wigner (signal) + polynomial (residual background)
$p_T$ distributions versus event multiplicity: $K^*(892)^\pm$

- Good agreement between $K^{*\pm}$ and $K^{*0}$ results (isospin symmetry)
- Hardening of $p_T$ spectra and maximum shifts with increasing multiplicity $\rightarrow$ flow-like effects

LOWE PANEL
- Mean $p_T$ increasing with multiplicity
- The process causing spectra variation is dominant at low $p_T$
$p_T$ distributions versus event multiplicity: $\Lambda(1520)$

$\Lambda(1520)$: same trend as $K^{*\pm}$

- The spectral shape changes with multiplicity class
- $p_T$ distributions get harder with increasing event multiplicity

Sonali Padhan, Poster Session: Resonances and Hyper-nuclei
Integrated yield versus event multiplicity: Λ(1520)

- dN/dy spectra exhibit a linear increase with increasing \( \langle dN_{ch}/d\eta \rangle \)

As observed for other hadron species, resonance production rate does not depend on collision energy → it is driven by the event multiplicity

Sonali Padhan, Poster Session: Resonances and Hyper-nuclei

pp at \( \sqrt{s} = 5.02 \) and 13 TeV
K*(892)±/K⁰_s ratio versus event multiplicity

- Suppression of K*±/K⁰_s with increasing multiplicity in pp and Pb–Pb collisions
- K*± analysis in pp @ 13 TeV confirms, with lower systematic uncertainties, suppression observed for K*⁰ [3]
- EPOS-LHC: same treatment for pp, p–A, and A–A systems → two regions: core (high density) and corona (low density)
- Core can form in pp collisions: critical density reached because of partons multiple scattering

Model predictions are computed for K*⁰ measurements

\[ \tau(K^{\pm}) \sim 4 \text{ fm/c} \]

\[ \langle \frac{dN}{d\eta} \rangle^{1/3} \]

**K^{*\pm}/K^0_s ratio for low and high multiplicity classes**

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

- Important K^{*\pm}/K^0_s **suppression** for \( p_T < 2.5 \) GeV/c (low \( p_T \))
- Results consistent with those obtained for K^{*0}
- Stronger suppression at low \( p_T \) interpreted in A–A collisions as a signature for rescattering effects:
  - **hint** of a (short-lived) **hadronic phase** in pp collisions?

**Antonina Rosano, Poster Session: Resonances and Hyper-nuclei**
No suppression for $\Lambda^*/\Lambda$ in pp and p–Pb collisions

Suppression of $\Lambda^*/\Lambda$ in most central Pb–Pb collisions with respect to smaller systems and peripheral Pb–Pb

$\Lambda^*/\Lambda$ is more suppressed w.r.t $K^*/K$ although $\tau(\Lambda^*) > \tau(K^*)$

$\tau(\Lambda^*) \sim 13 \text{ fm}/c$
Transverse spherocity: $K^*(892)^\pm$ in pp at $\sqrt{s} = 13$ TeV

Suman Deb, Poster Session: Resonances and Hyper-nuclei

ALICE Preliminary
pp, $\sqrt{s} = 13$ TeV
(I - III) VOM Mult. class
$(K^*^+ + K^*)/2$, $|y| < 0.5$

- Dominance of isotropic events seems to decrease with increasing $p_T$, where jetty events take over.

- $K^{\pm}/K^{\pm}$ ratio: hint of spherocity dependence at low $p_T$.

$K^*(892)^\pm$ in pp at $\sqrt{s} = 13$ TeV

$\left(1/N_{_{\text{ev}}}\right) \frac{d^2N}{dp_T^2 dy}$ (GeV/c)$^2$

$p_T$ spectra for several spherocity classes measured for high multiplicity events.
Measurement of $\phi$ meson pair in pp at $\sqrt{s} = 7$ TeV

Strangeness enhancement in small systems: study of double $\phi$ production in pp at $\sqrt{s} = 7$ TeV

- Inclusive $\phi$ meson production: $\langle Y_\phi \rangle$

In terms of statistical properties:

- Average yield of produced $\phi$ meson: $\mu = \langle Y_\phi \rangle$

- Variance of produced $\phi$ mesons: $\sigma^2 = \langle Y_{\phi}^2 \rangle - \langle Y_\phi \rangle^2$

- $\langle Y_\phi \rangle$ directly measured, $\langle Y_{\phi}^2 \rangle$ can be obtained through the $\phi$ meson pair production: $\langle Y_{\phi\phi} \rangle$

\[
\langle Y_{\phi} \rangle = 2\langle Y_{\phi\phi} \rangle + \langle Y_\phi \rangle \quad \sigma^2 = \left( 2\langle Y_{\phi\phi} \rangle + \langle Y_\phi \rangle \right) - \langle Y_\phi \rangle^2
\]
New way to characterise production:

\[ \gamma_\Phi = \frac{\sigma^2}{\mu} - 1 = \frac{2\langle Y_{\Phi\Phi} \rangle}{\langle Y_\Phi \rangle} - \langle Y_\Phi \rangle \]

- \( \gamma_\Phi \) describes the accordance with a poissonian behaviour of the production statistics:
  - If \( \gamma_\Phi = 0 \), purely statistical with a Poissonian distribution
  - If \( \gamma_\Phi \neq 0 \), production enhanced or suppressed

- Results:
  - \( \gamma_\Phi > 0 \) : non-statistical and enhanced
  - PYTHIA models underestimate \( \langle Y_\Phi \rangle \), \( \langle Y_{\Phi\Phi} \rangle \) while \( \gamma_\Phi \) is described quantitatively

Strangeness enhancement in small systems:
study of double \( \phi \) production in pp at \( \sqrt{s} = 7 \text{ TeV} \)
Summary

- **Small collision systems**: from benchmark measurements to results with a trend similar to Pb–Pb collisions

- **New measurements of K*(892)^±** consistent with the result obtained for K*(892)^0
  - K*±/K^0_S ratio suppressed in high multiplicity pp collisions → rescattering effects or mini-plasma formation (core) in small systems too?
  - Ratio of K*±/K± p_T spectra: hint of spherocity dependence

- **New measurements of Λ(1520)**
  - Λ(1520)/Λ ratio suppressed in central Pb–Pb collisions. No suppression in pp and p–Pb collisions

- **φ meson pair production**
  - Strangeness production in pp collisions: deviations from a Poissonian distribution
Thank you for your attention
Backup
Introduction

- Hadronic resonances are the perfect probes to characterize the system formed in heavy-ion collisions at ultrarelativistic energies.

- If the critical condition of temperature and energy density are satisfied ($T_C \sim 170$ MeV and $\varepsilon_C \sim 1$ GeV/fm$^3$), system evolves following several stages: Pre-equilibrium $\rightarrow$ QGP $\rightarrow$ Hadronization $\rightarrow$ Chemical freeze-out $\rightarrow$ Kinetic freeze-out.

- In particular, the phase between chemical and kinetic freeze-out is known as hadronic phase.

- Small collision systems (pp and p–Pb):
  - Used as a baseline for heavy-ion collisions.
  - Recent results on resonance production show the onset of phenomena typical of heavy-ion collisions, like collective behaviour and suppression of the yield ratios of resonances to stable particles.
Resonances with a lifetime comparable to the one of the hadronic phase are particularly interesting because they may be sensitive to the competing **regeneration** and **rescattering** effects.

**Regeneration**: a given resonance can be regenerated as a consequence of pseudo-elastic collisions of the particles medium → signal gain: yield enhancement.

**Re-scattering**: resonance decay daughters interact with other particles of the hadronic medium → signal loss: yield suppression.

Long-lived resonances, like $\Xi(1530)$ and $\phi(1020)$, decaying outside the hadronic medium do not undergo any such processes.
Yields at kinetic freeze-out depend on:

- Resonance and hadronic phase lifetime
- Yields at the chemical freeze-out
- Scattering cross sections of decay products

Resonance yields encode the effects of interaction during the hadronic phase!

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$\rho(770)^0$</th>
<th>$K^*(892)^\pm$</th>
<th>$K^*(892)^0$</th>
<th>$f_0(990)$</th>
<th>$\Sigma(1385)^\pm$</th>
<th>$\Xi(1820)^\pm$</th>
<th>$\Lambda(1520)$</th>
<th>$\Xi(1530)^0$</th>
<th>$\phi(1020)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark composition</td>
<td>$u\bar{u} + d\bar{d}$ $\sqrt{2}$</td>
<td>$u\bar{s}$, $\bar{u}s$</td>
<td>$d\bar{s}$, $\bar{d}s$</td>
<td>unknown</td>
<td>$uus$, $dds$</td>
<td>$dss$</td>
<td>$uds$</td>
<td>$uss$</td>
<td>$s\bar{s}$</td>
</tr>
<tr>
<td>$\tau$ (fm/c)</td>
<td>1.3</td>
<td>3.6</td>
<td>4.2</td>
<td>large unc.</td>
<td>5-5.5</td>
<td>8.1</td>
<td>12.6</td>
<td>21.7</td>
<td>46.4</td>
</tr>
<tr>
<td>Decay</td>
<td>$\pi \pi$</td>
<td>$K^0_s \pi$</td>
<td>$K \pi$</td>
<td>$\pi^+ \pi^-$</td>
<td>$\Lambda \pi$</td>
<td>$\Lambda K$</td>
<td>$p K$</td>
<td>$\Xi \pi$</td>
<td>$K K$</td>
</tr>
<tr>
<td>B.R. (%)</td>
<td>100</td>
<td>33.3</td>
<td>66.6</td>
<td>46</td>
<td>87</td>
<td>unknown</td>
<td>22.5</td>
<td>66.7</td>
<td>48.9</td>
</tr>
</tbody>
</table>

Fireball lifetime: $\tau \sim 10$ fm/c at LHC energies
The ALICE detector

Data collected from:

<table>
<thead>
<tr>
<th>Collision System</th>
<th>$\sqrt{s_{NN}}$ (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp</td>
<td>0.9, 2.76, 5.02, 7, 8, 13</td>
</tr>
<tr>
<td>p–Pb</td>
<td>5.02, 8.16</td>
</tr>
<tr>
<td>Xe–Xe</td>
<td>5.44</td>
</tr>
<tr>
<td>Pb–Pb</td>
<td>2.76, 5.02</td>
</tr>
</tbody>
</table>
Overview on resonance production

Small collision systems (pp, p–Pb):  
- $\phi/ K$, $\Sigma^{*\pm}/\Lambda$, $\Lambda(1520)/\Lambda$, and $\Xi^{*0}/\Xi$ ratios are independent on charged particle multiplicity  
- $\rho^0/\pi$, $K^{*0}/K$ $\to$ hint of suppression (possible re-scattering effect)

Heavy-ion collision systems (Pb–Pb, Xe–Xe):  
- $\rho^0/\pi$, $K^{*0}/K$, $\Sigma^{*\pm}/\Lambda$, and $\Lambda(1520)/\Lambda$ ratios are suppressed with respect to pp, p–Pb and peripheral Pb–Pb: dominance of re-scattering compared to regeneration  
- $\phi/K$, and $\Xi^{*0}/\Xi$ no suppression: larger lifetime $\to$ decay outside the medium

New results for $K^*(892)^\pm$, $\Lambda(1520)$, and $\phi(1020)$ will be shown here