Production and modification of hadronic resonances measured with ALICE

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Outline

• Hadronic phase
• Resonances in ALICE
• Mean $p_T$ & integrated yield
• Particle yield ratios
• Reconstruction of $\Xi(1820)$
Hadronic Phase

**Inelastic Collisions**
- hadron momenta and yields change

**(Pseudo-)elastic Collisions**
- hadron momenta change, but most yields fixed

**Regeneration:** pseudo-elastic scattering through resonance state
- increase in resonance yield

**Re-scattering:**
- elastic scattering smears out mass peak
  - reduces resonance yield

- pseudo-elastic scattering through a different resonance state
  - reduces yield of original resonance

**Yields of long-lived hadrons** fixed

- Free Hadrons

- Resonances have different short lifetimes
  - allow to study properties of hadronic phase in terms of re-scattering and regeneration effects

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Resonances in ALICE

- Inner Tracking System (ITS)
  - Silicon detectors
  - Trigger, tracking, vertex, PID (dE/dx)

- Time Projection Chamber (TPC)
  - Gas-filled ionization detector
  - Tracking, vertex, PID (dE/dx)

- Time Of Flight (TOF)
  - PID through particle time of flight

- V0A and V0C
  - Trigger, centrality/multiplicity estimator

### Resonance Table

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$\tau$ (fm/c)</th>
<th>Decay</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho(770)^0$</td>
<td>1.3</td>
<td>$\pi\pi$</td>
<td>100</td>
</tr>
<tr>
<td>$K^*(892)^0$</td>
<td>4.2</td>
<td>$K\pi$</td>
<td>66.6</td>
</tr>
<tr>
<td>$\Sigma(1385)$</td>
<td>5.5</td>
<td>$\Lambda\pi$</td>
<td>87</td>
</tr>
<tr>
<td>$\Xi(1820)$</td>
<td>8.1</td>
<td>$\Lambda\kappa$</td>
<td>unknown</td>
</tr>
<tr>
<td>$\Lambda(1520)$</td>
<td>12.6</td>
<td>$p\kappa$</td>
<td>22.5</td>
</tr>
<tr>
<td>$\Xi(1530)^0$</td>
<td>21.7</td>
<td>$\Xi\pi$</td>
<td>66.7</td>
</tr>
<tr>
<td>$\phi(1020)$</td>
<td>46.4</td>
<td>KK</td>
<td>49.2</td>
</tr>
</tbody>
</table>

### Year and √s NN [TeV]

<table>
<thead>
<tr>
<th>Year</th>
<th>Pb-Pb</th>
<th>Xe-Xe</th>
<th>p-Pb</th>
<th>pp</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-2011</td>
<td></td>
<td></td>
<td>2017</td>
<td>2009-2013</td>
</tr>
<tr>
<td>2015,2018</td>
<td></td>
<td></td>
<td>2016</td>
<td>2015-2018</td>
</tr>
<tr>
<td>√s NN, [TeV]</td>
<td>2.76</td>
<td>5.02</td>
<td>5.44</td>
<td>0.9, 2.76, 7, 8, 5.02, 13</td>
</tr>
</tbody>
</table>
$p_T$-spectra in Pb-Pb collisions

$\rho(770)^0$

$\Lambda(1520)$

$\Xi(1530)^0$

Lifetime ($fm/c$): $\rho(1.3) < \Lambda^*(4.2) < \Sigma^*(5.5) < \Lambda^*(12.6) < \Xi^*(21.7) < \phi(46.2)$
$p_T$-spectra in Pb-Pb collisions

Lifetime(fm/c): $\rho(1.3) < K^*(4.2) < \Sigma^*(5.5) < \Lambda^*(12.6) < \Xi^*(21.7) < \phi(46.2)$
$p_T$-spectra in Xe-Xe collisions

Lifetime (fm/$c$): $\rho(1.3) < K^*(4.2) < \Sigma^*(5.5) < \Lambda^*(12.6) < \Xi^*(21.7) < \phi(46.2)$
• In central Pb-Pb collisions
  - similar $\langle p_T \rangle$ for $p$, $K^*$ and $\phi$ have been observed
  - expected from hydrodynamics as they have similar masses

• In small collision systems
  - $\langle p_T \rangle$ increases steeper and similarity of $p$, $K^*$ and $\phi$ is broken

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mean $\langle p_T \rangle$

- $\langle p_T \rangle$ obtained from Pb-Pb and Xe-Xe collision are in agreement with each other
- Integrated yield normalized to $\langle dN_{ch}/d\eta \rangle$ for $K^{*0}$ and $\phi$
  - independent of collision energy and systems for pp and p-Pb collisions
Particle yield ratios

• Suppression of $K^*/K$ in central heavy-ion collisions w.r.t. peripheral Pb-Pb(Xe-Xe), p-Pb, pp collisions
  - suggests $K^*$ re-scattering is dominant over regeneration

• Hint of suppression in small systems at high multiplicity
  - hadronic phase also in small systems?

• No suppression $\phi/K$
  - due to larger $\phi$ lifetime

Lifetime(fm/$c$): $\rho(1.3) < K^*(4.2) < \Sigma^*(5.5) < \Lambda^*(12.6) < \Xi^*(21.7) < \phi(46.2)$
Resonance to long-lived particle ratios

\( \rho^0/\pi, K^{*0}/K \) and \( \Lambda^*/\Lambda \) in Pb-Pb: suppression in central Pb-Pb collisions indicates dominance of re-scattering over regeneration for short lived resonances.

\( \Sigma^*/\Lambda \) and \( \Lambda^*/\Lambda \): flat in small systems and no energy dependence from RHIC to LHC.

\( \Xi^*/\Xi \) and \( \phi/K \): no significant centrality dependence across the different collision systems.

In most cases EPOS3 with UrQMD describes the trend qualitatively.

Lifetime (fm/c): \( \rho(1.3) < K^*(4.2) < \Sigma^*(5.5) < \Lambda^*(12.6) < \Xi^*(21.7) < \phi(46.2) \)

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Energy dependence: $\phi/K$

- Flat behavior in wide range of energy ($\sim 10-10^4$ GeV)

- Increase for low energies due to canonical suppression
  - reproduced by statistical model calculation with strangeness correlation radius parameter $R_c = 2.2$ fm

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Reconstruction of $\Xi(1820)$

- First measurement of $\Xi(1820)$ from collider experiment

- Calculation from FASTSUM Collaboration shows potential parity doubling
  - signature of chiral symmetry restoration in heavy-ion collisions
  - expected signal: mass shift, width broadening or change in yield ratio between $\Xi(1820)$ and $\Xi(1530)$

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Conclusion & outlook

- **ALICE** has measured comprehensive set of resonance particles

- **mean $p_T$**
  - steeper increase in small system and similar $\langle p_T \rangle$ for $p$, $K^0$ and $\phi$ in central Pb-Pb collisions

- **Normalized integrated yield**
  - independent of collision energy and systems for pp and p-Pb collisions

- **particle yield ratios**
  - suppression of short-lived resonances, $\rho^0$, $K^*0$, $\Lambda^*$, has been observed in most central collisions w.r.t. small collision systems
  - no suppression observed for the longer-lived resonances, $\phi$

- **Reconstruction of $\Xi(1820)$**
  - first measurement and clear signal
  - results will be compared to $\Xi(1530)$