Strangeness and hadronic resonance production in pp, p-Pb and Pb-Pb collisions measured by ALICE at the LHC

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Outline

- Physics motivation
- **ALICE** detector
- Multiplicity-dependent *strangeness* production
- Measurement of mesonic and baryonic *resonances*
- Summary
Strangeness enhancement

- Enhanced production of strangeness particles in AA w.r.t. pp

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<th>Mass [GeV/c^2]</th>
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Hyperon-to-pion ratio

- (c) \( \Xi/\pi \)
- \( \Omega/\pi \)

- ALICE Pb-Pb at 2.76 TeV
- ALICE pp at 7 TeV
- ALICE pp at 900 GeV
- STAR Au-Au, pp at 200 GeV

C. ALICE Pb-Pb at 2.76 TeV

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Strangeness enhancement

- Enhanced production of strangeness particles in AA w.r.t. pp

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What are the latest results on strangeness production in different colliding systems at the top LHC energy?
Strangeness enhancement

- Enhanced production of strangeness particles in AA w.r.t. pp

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What are the latest results on strangeness production in different colliding systems at the top LHC energy?

What causes the enhancement?
Probing the 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

**Resonances**
- Different short lifetimes
  - Allow to study properties of hadronic phase in terms of **re-scattering and regeneration** effects

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<th>Resonance</th>
<th>Lifetime [fm/c]</th>
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<tr>
<td>( \rho )</td>
<td>1.3</td>
</tr>
<tr>
<td>( K^{*0} )</td>
<td>4.2</td>
</tr>
<tr>
<td>( \Lambda^{*} )</td>
<td>12.6</td>
</tr>
<tr>
<td>( \Xi^{*0} )</td>
<td>21.7</td>
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<tr>
<td>( \phi )</td>
<td>46.2</td>
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The ALICE detector

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<th>System</th>
<th>Year(s)</th>
<th>√s [TeV]</th>
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<tbody>
<tr>
<td>Pb-Pb</td>
<td>2010-2011</td>
<td>2.76</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>5.02</td>
</tr>
<tr>
<td>Xe-Xe</td>
<td>2017</td>
<td>5.44</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>5.02</td>
</tr>
<tr>
<td>p-Pb</td>
<td>2016</td>
<td>5.02, 8.16</td>
</tr>
<tr>
<td></td>
<td>2009-2013</td>
<td>0.9, 2.76, 7, 8</td>
</tr>
<tr>
<td>pp</td>
<td>2015, 2017</td>
<td>5.02, 13</td>
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The ALICE detector

- **Inner Tracking System (ITS)**
  - SPD, SDD, SSD
  - Trigger, tracking, vertex, PID ($dE/dx$)
The ALICE detector

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

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

- V0A and V0C
  - Trigger, centrality/multiplicity estimator
Strangeness particle $p_T$-spectra in Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

**$K^0$**

Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV

$|y| < 0.5$

**$\Lambda$**

Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV

$|y| < 0.5$

**$\Xi^-\Omega^-$**

Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV

$|y| < 0.5$

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ICHEP2018
Yields to $\pi$ ratio as a function of multiplicity

- Smooth evolution from $pp$ to $Pb-Pb$ collisions
- At similar multiplicity, no dependence with system nor energy is observed
Relative strangeness production

- Enhancement for small systems, saturation for large system
  - strangeness enhancement increases with **strange-quark** content

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Relative strangeness production

- Enhancement for small systems, saturation for large system
  - strangeness enhancement increases with strange-quark content

Open question!
Does $\phi$ behave as a non-strange or double strange particle?

Nature Physics 13 (2017) 535-539
Hidden & Open strangeness

\[ \phi/\pi: (|S|=0)/(|S|=0) \]

- **Ratio** \( \phi/\pi \)
  - large systems: described by thermal model
  - small systems: increase with multiplicity
• Ratio $\phi/\pi$
  - large systems: described by thermal model
  - small systems: increase with multiplicity

• Ratios $\phi/K$ and $\Xi/\phi$ fairly flat across wide multiplicity range
  - The $\phi$ has “effective strangeness” of 1-2 units
Resonances $p_T$-spectra in Pb-Pb

Lifetime(fm/c): $\tau_{\rho}(1.3) < \tau_{K^*}(4.2) < \tau_{\Lambda^*}(12.6) < \tau_{\Xi^*}(21.7) < \tau_{\Phi}(46.2)$

Resonances $p_T$-spectra in Pb-Pb

Lifetime(fm/c): $T_\rho(1.3) < T_{K^*}(4.2) < T_{\Lambda^*}(12.6) < T_{\Xi^*}(21.7) < T_\Phi(46.2)$

https://arxiv.org/abs/1805.04361

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Resonance to long-lived particle ratio

- Suppression of $\rho^0/\pi$ and $K^{*0}/K$ ratios in central Pb-Pb w.r.t. smaller system such as peripheral Pb-Pb, p-Pb and pp
  - Suggests re-scattering is dominant over regeneration for short-lived resonances
- No suppression $\phi/K$ due to larger lifetime

\[ \text{Lifetime(fm/c): } T_\rho(1.3) < T_{K^*}(4.2) < T_{\Lambda^*}(12.6) < T_{\Xi^*}(21.7) < T_\Phi(46.2) \]
Resonance to long-lived particle ratio

- Suppression of $\Lambda^*/\Lambda$ in most central Pb-Pb (0-20\%) wrt. pp, p-Pb (d-Au), peripheral Pb-Pb (Au-Au)
- Thermal models overestimate the data in Pb-Pb
- Qualitatively described by EPOS with UrQMD - overestimates the ratio

Lifetime (fm/c): $T_\rho(1.3) < T_{K^*}(4.2) < T_{\Lambda^*}(12.6) < T_{\Xi^*}(21.7) < T_{\Phi}(46.2)$
Resonance to long-lived particle ratio

- $\Xi^*0/\Xi$ in $pp$ and $p$-$Pb$
  - No clear multiplicity dependence
  - Higher than pQCD-inspired models

- In $Pb$-$Pb$
  - No significant centrality dependence
  - Lower in (semi-)central $Pb$-$Pb$ than $pp$ and $p$-$Pb$
  - Lower than thermal model predictions
  - Possible weak suppression

Lifetime (fm/$c$): $T_\rho(1.3) < T_{K^*}(4.2) < T_{\Lambda^*}(12.6) < T_{\Xi^*}(21.7) < T_{\Phi}(46.2)$
• **ALICE** has measured comprehensive set of identified particles

• We presented latest results on **multiplicity-dependent strangeness** production in all the available colliding systems at the top LHC energy
  - *smooth enhancement* has been observed with multiplicity
  - the enhancement increases with *strangeness content*
  - at similar multiplicity, no dependence with system nor energy is observed
  - $\phi$ has *effective strangeness of 1-2 units*

• Measurements of mesonic and baryonic **resonances** were presented
  - *suppression of short-lived resonances*, $\rho^0$, $K^{*0}$, $\Lambda^{*0}$, has been observed in most central collisions w.r.t. small collision systems
  - *re-scattering is dominant over regeneration*
  - there is **no suppression of long-lived resonances**, $\phi$