Multi-strange baryon production in Pb-Pb and pp collisions with ALICE

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on behalf of the ALICE Collaboration
Measuring multi-strange baryons with ALICE
- Physics motivation
- Multi-strange baryon detection

Results
- Spectra in Pb-Pb and pp collisions
- Strangeness enhancement
- Nuclear modification factor ($R_{AA}$)

Summary
Measuring multi-strange baryons

Physics motivation

Why measure (multi-)strange hyperons

✓ no net strangeness content in the colliding system
✓ small hadronic cross-section → information on the early stages of the system evolution in Pb-Pb collisions
✓ measurements in pp:
  o baseline to understand Pb-Pb
  o insight into different production mechanisms at play
Measuring multi-strange baryons

Physics motivation

Why measure (multi-)strange hyperons

✓ no net strangeness content in the colliding system
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✓ measurements in pp:
  o baseline to understand Pb-Pb
  o insight into different production mechanisms at play

What can be inferred

✓ constraints on QCD-inspired models in pp collisions (e.g. PYTHIA)
✓ constraints on hydro-dynamical models in Pb-Pb collisions (e.g. EPOS, Kraków, VISH2+1 and HKM)
✓ origin of observed “strangeness enhancement” in Pb-Pb wrt pp collisions
✓ behavior of nuclear modification factor ($R_{AA}$)
Multi-strange baryons in ALICE are reconstructed via their weak (cascade) decay topology:

1. charged tracks reconstructed in the tracking system [ITS + TPC]
2. specific ionization (in the TPC) used to identify daughters
3. cascade candidates obtained by combining reconstructed tracks and applying cuts on geometry and kinematics

\[
\begin{align*}
\Xi^- (dss) & \rightarrow \Lambda \pi^- \rightarrow p\pi^-\pi^- \quad (B.R. \ 63.9\%) \\
\Xi^+ (dss) & \rightarrow \bar{\Lambda}\pi^+ \rightarrow \bar{p}\pi^+\pi^+ \quad (B.R. \ 63.9\%) \\
\Omega^- (sss) & \rightarrow \Lambda K^- \rightarrow p\pi^-K^- \quad (B.R. \ 43.3\%) \\
\Omega^+ (sss) & \rightarrow \bar{\Lambda}K^+ \rightarrow \bar{p}\pi^+K^+ \quad (B.R. \ 43.3\%)
\end{align*}
\]
Multi-strange baryons in ALICE are reconstructed via their weak [cascade] decay topology:

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Measuring multi-strange baryons
Multi-strange baryon detection

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

$\Omega^-$

0-20% centrality
$2.8 < p_T < 3.2$ GeV/c

Multi-strange baryons in ALICE are reconstructed via their weak [cascade] decay topology:

1. charged tracks reconstructed in the tracking system [ITS + TPC]
2. specific ionization (in the TPC) used to identify daughters
3. cascade candidates obtained by combining reconstructed tracks and applying cuts on geometry and kinematics

$\Xi^- (dss) \rightarrow \Lambda \pi^- \rightarrow p \pi^- \pi^- \ (B.R. \ 63.9\%)
\Xi^+ (dss) \rightarrow \Lambda \pi^+ \rightarrow p \pi^+ \pi^+ \ (B.R. \ 63.9\%)
\Omega^- (sss) \rightarrow \Lambda K^- \rightarrow p \pi^- K^- \ (B.R. \ 43.3\%)
\Omega^+ (sss) \rightarrow \Lambda K^+ \rightarrow p \pi^+ K^+ \ (B.R. \ 43.3\%)

Signal = Summed bin count – Integral of background fit function
Results
Spectra in pp collisions

- Analysis on a data sample of about 80M minimum bias events pp at $\sqrt{s} = 2.76$ TeV taken in 2011
- $p_T$ reach of 6 (Ξ) and 5 GeV/c (Ω)
- Particle and anti-particle spectra identical within uncertainties

$N_{\text{in}}$ = Number of Inelastic collisions
Results

Spectra in pp collisions

- Comparison with PYTHIA Perugia-2011\cite{1}:
  - tuned with measured multiplicity at 7 TeV,
  - Deviations in the low $p_T$ region (increasing with strangeness)

\cite{1} Phys. Rev. D 82, 074018 (2010)
Results

Spectra in pp collisions

- Comparison with PYTHIA Perugia-2011\(^1\):
  - tuned with measured multiplicity at 7 TeV,
- Deviations in the low $p_T$ region (increasing with strangeness)
- Same results at the two energies $\sqrt{s} = 7$ TeV\(^2\) and 2.76 TeV
- Hint of agreement above 7 GeV/c for $\Xi$

\(^1\) Phys. Rev. D 82, 074018 (2010)
Results

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

- Analysis on a data sample of about 20M minimum bias events Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV taken in 2010
- 5 centrality bins
- $p_T$ reach: 8 (Ξ) and 7 GeV/c (Ω) in 10% most central Pb-Pb collisions
- Particle and anti-particle spectra identical within uncertainties

arXiv:1307.5543
Results

Spectra in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV

- **Models**
  - VISH2+1$^{[1]}$: viscous hydrodynamic model
  - HKM$^{[2]}$: ideal hydro model, with hadron cascade (UrQMD)
  - Kraków$^{[3]}$: non-equilibrium corrections due to bulk viscosity in transition from hydrodynamics to particles
  - EPOS$^{[4]}$: incorporates hydrodynamics and models the interaction between high $p_T$ hadrons and expanding fluid, also use UrQMD as hadronic cascade model

**Results**

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

- **Models**
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  - EPOS\(^4\): incorporates hydrodynamics and models the interaction between high $p_T$ hadrons and expanding fluid, also use UrQMD as hadronic cascade model

- **Results**
  - Kraków model provides a good description for both yields and shapes ($p_T < 3$ GeV/c)
  - EPOS gives the most successful description of spectra shape in a wider $p_T$ range

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\(^1\) Phys. Rev. C 84, 044903 (2011)
Results

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

arXiv:1307.5543

![Diagram showing spectra in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV]

Results

Strangeness enhancement

\[ E = \frac{Y_{\text{PbPb}}}{< N_{\text{part}} >} \]
\[ = \frac{Y_{\text{PbPb}}}{Y_{\text{pp}} / 2} \]

- Found to qualitatively match predictions at SPS and RHIC
  - Increasing with strangeness content
  - Decreasing with centre-of-mass energy
Results

Strangeness enhancement

\[ E = \frac{Yield_{\text{PbPb}}}{2} \frac{\langle N_{\text{part}} \rangle}{Yield_{\text{pp}}} \]

- Found to qualitatively match predictions at SPS and RHIC
  - Increasing with strangeness content
  - Decreasing with centre-of-mass energy

- Reference for enhancements at LHC
  - Interpolate 7 TeV and lower energies pp yields using excitation function from PYTHIA Perugia-2011\(^1\)
  - Checked with preliminary measurement in pp collision at \(\sqrt{s} = 2.76\) TeV

\(^1\) Phys. Rev. D 82, 074018 (2010)
Results

Strangeness enhancement

\[ E = \frac{Yield_{PbPb}/ < N_{part}>}{Yield_{pp}/ 2} \]

Hierarchical based on strangeness content

\[ Pb-Pb \text{ at } \sqrt{s_{NN}} = 2.76 \text{ TeV} \]

arXiv:1307.5543

D. Colella (INFN Bari, Italy)
Results
Strangeness enhancement

\[ E = \frac{\text{Yield}_{\text{PbPb}}}{<N_{\text{part}}>} \left( \frac{\text{Yield}_{\text{pp}}}{2} \right) \]

- Hierarchy based on strangeness content
- Decreasing trend with energy as observed at SPS energies and from SPS to RHIC

\[ Y_{\text{yield}} / \langle N_{\text{part}} \rangle \text{ relative to pp/p-Be} \]

Graphs showing yield relative to pp/p-Be for Pb-Pb at different energies.

\[ \Xi^- \]
\[ \Xi^+ \]
\[ \Omega^- + \bar{\Omega}^+ \]

References:
Results

Strangeness enhancement

\[ E = \frac{\text{Yield}_{\text{PbPb}} / <N_{\text{part}}>}{\text{Yield}_{\text{pp}} / 2} \]

- Hierarchy based on strangeness content
- Decreasing trend with energy as observed at SPS energies and from SPS to RHIC
- Hyperon to pion ratios:
  - enhancement almost half of that in the left hand plot
  - found to match predictions from thermal models (grand canonical approach) with \( T = 164 \text{ MeV} \)\[1\] [full lines]

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2. ALICE pp at 7 TeV
3. ALICE pp at 900 GeV
4. STAR Au-Au, pp at 200 GeV
5. ALICE Pb-Pb at 2.76 TeV
6. ALICE pp at 7 TeV
7. STAR Au-Au, pp at 200 GeV

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Results

Nuclear modification factor

\[ R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{(d^2N/dydp_T)_{A-A}}{(d^2\sigma_{INEL}/dydp_T)_{pp}} \]

Compared with \( \pi, k, p \) and \( \phi \)
Results

Nuclear modification factor

\[ R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{(d^2 N / dy dp_T)_{A-A}}{(d^2 \sigma_{INEL} / dy dp_T)_{pp}} \]

- Compared with π, k, p and φ
- At high \( p_T \) \( R_{AA} \) does not depend on the mass of the particle
- Mass ordering at mid-\( p_T \)

\( R_{AA} \) vs. \( p_T \) for different particles and mass intervals.
Results

Nuclear modification factor

\[ R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{(d^2 N / dy dp_T)_{A-A}}{(d^2 \sigma_{INEL} / dy dp_T)_{pp}} \]

- Compared with \( \pi, k, p \) and \( \phi \)
- At high \( p_T \), \( R_{AA} \) does not depend on the mass of the particle
- Mass ordering at mid-\( p_T \)
- Effect of strangeness enhancement on the \( \Omega \) (and \( \Xi \))
- Shaded points for Xi and Omega obtained with extrapolated pp ref.
Results

Nuclear modification factor

\[ R_{AA} = \frac{1}{\langle T_{AA} \rangle} \left( \frac{d^2N}{dydp_T} \right)_{A-A} \left( \frac{d^2\sigma_{INEL}}{dydp_T} \right)_{pp} \]

- Compared with \( \pi, k, p \) and \( \phi \)
- At high \( p_T \) \( R_{AA} \) does not depend on the mass of the particle
- Mass ordering at mid-\( p_T \)
- Effect of strangeness enhancement on the \( \Omega \) (and \( \Xi \))
- \( R_{AA} \) vs centrality: follows trend similar to other particles
Summary

- **pp collisions**
  - Preliminary multi-strange $p_T$ spectra: $p_T$ ranges [0.6, 6.0] GeV/c for $\Xi$ and [1.0, 5.0] GeV/c for $\Omega$.
  - PYTHIA Perugia2011 tune underestimates the multi-strange spectra, both at $\sqrt{s} = 7$ and 2.76 TeV.

- **Pb-Pb collisions**
  - Multi-strange $p_T$ spectra in 5 centrality classes: $p_T$ ranges [0.6-8.0] GeV/c for $\Xi$ and [1.2, 7.0] GeV/c for $\Omega$ in the most central class (0-10%).
  - Reasonably good agreement with the Krakow and EPOS hydrodynamical models.

- Strangeness enhancement weaker at LHC than at RHIC, mainly due to the behavior of strangeness production in pp.

- $\Xi$ nuclear modification factor: behavior at high $p_T$ similar to the other particles.
  - $\Omega R_{AA}$ strongly affected by strangeness enhancement.
Backup
### Topological cuts in Pb-Pb and pp analysis

**Cuts for cascades**

<table>
<thead>
<tr>
<th>Cut</th>
<th>PbPb $\Xi$ ($\Omega$)</th>
<th><a href="mailto:pp@2.76TeV">pp@2.76TeV</a> $\Xi$ ($\Omega$)</th>
<th>pp@7TeV $\Xi$ ($\Omega$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Allowed VO ip (cm)</td>
<td>0.1</td>
<td>0.05(0.01)</td>
<td>0.07</td>
</tr>
<tr>
<td>Window around the $\Lambda$ mass (MeV/c²)</td>
<td>0.005</td>
<td>0.006(0.008)</td>
<td>1.110 - 1.122</td>
</tr>
<tr>
<td>Min allowed bachelor ip (cm)</td>
<td>0.03</td>
<td>0.03(0.01)</td>
<td>0.05</td>
</tr>
<tr>
<td>Max allowed DCA cascade daughter (cm)</td>
<td>0.3</td>
<td>1.5(0.5)</td>
<td>1.6 (1.0)</td>
</tr>
<tr>
<td>Min allowed cos of cascade PA</td>
<td>0.9992</td>
<td>0.985(0.990)</td>
<td>0.97 (re-set)</td>
</tr>
<tr>
<td>Min radius of the fid. vol. (cm)</td>
<td>1.5(1.0)</td>
<td>0.4(0.4)</td>
<td>0.8 (0.6)</td>
</tr>
<tr>
<td>Proper length cascade (cm)</td>
<td>15(8)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Cuts for VO**

<table>
<thead>
<tr>
<th>Cut</th>
<th>PbPb $\Xi$ ($\Omega$)</th>
<th><a href="mailto:pp@2.76TeV">pp@2.76TeV</a> $\Xi$ ($\Omega$)</th>
<th>pp@7TeV $\Xi$ ($\Omega$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min allowed ip for 1° daughter (cm)</td>
<td>0.1</td>
<td>0.05(0.05)</td>
<td>0.04 (0.03)</td>
</tr>
<tr>
<td>Min allowed ip for 2° daughter (cm)</td>
<td>0.1</td>
<td>0.05(0.05)</td>
<td>0.04 (0.03)</td>
</tr>
<tr>
<td>Max allowed DCA between daughter tracks (cm)</td>
<td>0.8</td>
<td>1.5(1.5)</td>
<td>1.6 stan. dev.</td>
</tr>
<tr>
<td>Min allowed cosine of VO’s PA</td>
<td>0.998</td>
<td>pt dependent</td>
<td>0.97</td>
</tr>
<tr>
<td>Min radius of fiducial volume (cm)</td>
<td>3.0</td>
<td>0.2(0.2)</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Backup

Acceptance-efficiency correction vs $p_T$

$\Omega^-$

$\Xi^-$

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

Centrality:
- 0-10%
- 60-80%

Acceptance x Efficiency

$0-10\% \times 0.75$

$60-80\% \times 0.75$

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ALI−PUB−57292

D. Colella (INFN Bari, Italy)  SQM 2013 - Birmingham (U.K.)  July 22-27, 2013  27
To measure the yields in the full $p_T$ range the following parametrization have been used in Pb-Pb and pp analysis:

- **Blast-wave** [1]: hydrodynamically inspired model which assumes a thermalized, transverse expanding source.
  - Three fit parameters: kinetic freeze-out temperature, transverse velocity and exponential power ($T, \beta_T$ and $n$)
  - Gives the best fit to individual particles
  - From PHOBOS evidence that this parametrization gives a good description to very low $p_T$

- **Lévy-Tsallis** [2]: the function is grounded in Tsallis statistics and approximates an exponential component (represented by $T$ parameter) as well as a power-law dependence for high-$p_T$ tail.

\[
\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nT[nT + m_0(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1 + \frac{m_T - m_0}{nT}\right)^{-n}
\]

- where $T$, $n$ and $dN/dy$ (this representing the particle yield per unit rapidity) are fit parameters, $m_T = \sqrt{m_0^2 + p_T^2}$ and $m_0$ denotes the particle mass.

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$p_T$ spectra in pp collision at $\sqrt{s} = 2.76$ TeV with omega particle and anti-particle separated
Reference for enhancements at LHC

- Interpolate 0.9 \cite{1} and 7 \cite{2} TeV pp data for $\Xi$
- Interpolate 200 \cite{3} GeV (STAR) and 7 \cite{2} TeV pp data for $\Omega$
- Use excitation function from PYTHIA Perugia-2011 \cite{4}: $s^{0.25}$ [$s^{0.22}$ for charged multiplicity]
- Checked to match the preliminary measurement in pp collision at $\sqrt{s} = 2.76$ TeV

### Yield $\Xi$

<table>
<thead>
<tr>
<th>Interpolated</th>
<th>Measured</th>
</tr>
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<tbody>
<tr>
<td>$(\Xi^-) 0.0068\pm0.0023$</td>
<td>$(\Xi^-) 0.0060\pm0.0001$</td>
</tr>
<tr>
<td>$(\Xi^+) 0.0066\pm0.0022$</td>
<td>$(\Xi^+) 0.0060\pm0.0001$</td>
</tr>
</tbody>
</table>

### Yield $\Omega$

<table>
<thead>
<tr>
<th>Interpolated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(\Omega^-+\Omega^+) 0.00107\pm0.00050$</td>
<td>$(\Omega^-+\Omega^+) 0.00092\pm0.00007$</td>
</tr>
</tbody>
</table>

\[\text{pp@2.76 TeV} \quad \text{Yield } \Xi \quad \text{Yield } \Omega\]

\[\text{Interpolated} \quad (\Xi^-) 0.0068\pm0.0023 \quad (\Xi^+) 0.0066\pm0.0022 \quad (\Omega^-+\Omega^+) 0.00107\pm0.00050\]

\[\text{Measured} \quad (\Xi^-) 0.0059\pm0.0001^{+0.0007}_{-0.0007} \quad (\Omega^-+\Omega^+) 0.00092\pm0.00007^{+0.00017}_{-0.00017}\]

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