Strangeness production vs multiplicity in pp collisions at $\sqrt{s} = 5.02$ TeV with the ALICE experiment

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Outline

- $K^0_s, \Lambda, \Xi, \Omega$ analysis in pp collisions at $\sqrt{s} = 5.02$ TeV

  ➢ Introduction on QGP and strangeness
  ➢ ALICE experiment
  ➢ Strange hadron identification
  ➢ Overview on results
    ▪ Invariant mass spectra
    ▪ Raw spectra, efficiency and corrected spectra
    ▪ $p_T$-integrated yield and mean $p_T$
  ➢ Summary and next steps
Physics motivation

- At sufficient **high temperature** and **energy density**, nuclear matter undergoes a transition to a phase in which quarks and gluons are not confined: the **Quark Gluon Plasma (QGP)**.

- Such an exotic state is produced in the laboratory in high-energy collisions of **heavy nuclei**. Goal of the **ALICE experiment** is to study the **QGP**.

QGP conditions:

\[ \varepsilon > 1 \text{ GeV/fm}^3 \]

\[ T > 170 \text{ MeV} \]
Physics motivation

- The **strangeness enhancement** observed in heavy-ion collisions was originally proposed as a **signature of QGP formation** in nuclear collisions (Rafelsky, Muller)*
  - Lower Q-value for $s\bar{s}$ relative to $H_sH\bar{s}$ formation
  - Faster equilibration in partonic medium
- More recently the **strangeness enhancement** was also observed in **high-multiplicity pp and p-Pb collisions**
- **Strange hadron production**: key tool for understanding hadronization in different systems

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ALICE at LHC:

- Detectors used for strangeness analysis:

  **ITS** ($|\eta| < 0.9$)
  6 layers of silicon detectors
  - triggering, tracking, (secondary) vertexing, PID (dE/dx)

  **TPC** ($|\eta| < 0.9$)
  Gas-filled detector
  - tracking, vertex, PID (dE/dx)

  **V0A** ($2.8 < \eta < 5.1$) and **V0C** ($-3.7 < \eta < -1.7$)
  Forward-rapidity arrays of scintillators
  - triggering, beam-gas rejection, multiplicity estimator

  **TOF** ($|\eta| < 0.9$)
  Consists of MRPCs
  - PID
  - out of bunch pile-up rejection
Strange hadron identification

- Kinematical and geometrical criteria are applied for the reconstruction

V0s:
- $\Lambda \rightarrow p + \pi^- / \bar{\Lambda} \rightarrow \bar{p} + \pi^+$ (BR= 69.2%)
- $K^0_S \rightarrow \pi^+ + \pi^-$ (BR= 63.9%)

Neutral particles decay into two particles with opposite charge → charge conservation

Cascades:
- $\Xi^- \rightarrow \Lambda + \pi^- / \Xi^+ \rightarrow \bar{\Lambda} + \pi^+$ (BR=99.9%)
- $\Omega^- \rightarrow \Lambda + K^- / \Omega^+ \rightarrow \bar{\Lambda} + K^+$ (BR= 67.8%)

They decay into $\Lambda$ and another particle which is called bachelor

Reconstructed $\Lambda$ candidate associated to a bachelor track to obtain the cascade candidate

$\Lambda$s coming from the decay of $\Xi$ and $\Omega$ have to be subtracted from the «prompt» $\Lambda$ candidates → feed down corrections
V0s and Cascades Analysis

• Results on this topic will be really relevant in order to better understand the strangeness enhancement seen in high multiplicity pp collisions

• With the actual data, the highest multiplicity reached in pp collisions ~15-20 $\langle dN_{ch}/d\eta\rangle_{|\eta|<0.5}$ but thanks to high statistics data from 2017, it is possible to reach higher multiplicity

• Minimum bias data dataset: LHCp17(41 runs)
  Number of events = 1.1 billions

• MC dataset: LHC17l3b
  Number of events = 3 millions

• Studies are performed over multiplicity classes and $p_T$ ranges
  • Multiplicity classes in percentiles

  \( \text{V0s\%} : [0-0.01], [0.01-0.1], [0.1-1], [1-5], [5-10], [10-20], [20-30], [30-40], [40-50], [50-70], [70-90], [90-100]; \)

  \( \Xi\% : [0-0.1], [0.1-1], [1-5], [5-10], [10-15], [15-20], [20-30], [30-40], [40-50], [50-70], [70-100]; \)

  \( \Omega\% : [0-1], [1-5], [5-10], [10-15], [15-30], [30-50], [50-70], [70-100]; \)
**Analysis cuts**

The selection cuts used for both V0s and cascades consist of:
- **Kinematic selections** and **Track quality selections**
- **PID cuts** → energy loss (dE/dx) in the TPC (applied on real data only)
- **Topological selections** → they include a set of “geometrical” requirements in order to identify specific decay topologies

<table>
<thead>
<tr>
<th>Topological variable</th>
<th>$K^0_S$ (Λ)</th>
<th>Ξ(Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCA* Neg. Track to PV**</td>
<td>&gt;0.06 cm</td>
<td>&gt;0.03(0.04)cm</td>
</tr>
<tr>
<td>DCA Pos. Track to PV</td>
<td>&gt;0.06 cm</td>
<td>&gt;0.03(0.04)cm</td>
</tr>
<tr>
<td>DCA Bachelor to PV</td>
<td>-</td>
<td>&gt;0.04 cm</td>
</tr>
<tr>
<td>DCA V0 Daughters</td>
<td>&lt;1σ</td>
<td>&lt;1.5σ</td>
</tr>
<tr>
<td>DCA V0 to PV</td>
<td>-</td>
<td>&gt;0.06 cm</td>
</tr>
<tr>
<td>DCA Bachelor to V0</td>
<td>-</td>
<td>&lt;1.3 cm</td>
</tr>
<tr>
<td>DCA Bachelor to Baryon</td>
<td>-</td>
<td>&gt;0.02 cm</td>
</tr>
<tr>
<td>V0 transverse radius</td>
<td>&gt;0.5</td>
<td>&gt;1.2(1.1)</td>
</tr>
<tr>
<td>V0 Cosine of PA***</td>
<td>&gt;0.97(0.995)</td>
<td>&gt;0.97</td>
</tr>
<tr>
<td>Cascade Cosine of PA</td>
<td>-</td>
<td>&gt; 0.97</td>
</tr>
<tr>
<td>Casc. transverse radius</td>
<td>-</td>
<td>&gt;0.6(0.5)</td>
</tr>
<tr>
<td>V0 inv.mass window</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selection</th>
<th>$K^0_S$ (Λ)</th>
<th>Ξ(Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapidity</td>
<td></td>
<td>y</td>
</tr>
<tr>
<td>Proper Lifetime (mL/p)</td>
<td>&lt;3τ</td>
<td>&lt;3τ</td>
</tr>
<tr>
<td>TPC (dE/dx)</td>
<td>&lt;4σ</td>
<td>&lt;4σ</td>
</tr>
<tr>
<td>Primary selection(MC only)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MC association (MC only)</td>
<td>PDG code</td>
<td>PDG code</td>
</tr>
<tr>
<td>Pseudorapidity</td>
<td></td>
<td>η</td>
</tr>
<tr>
<td>$N_{crossedrows}$</td>
<td>≥70</td>
<td>≥70</td>
</tr>
<tr>
<td>$N_{crossed}/N_{findable}$</td>
<td>≥0.8</td>
<td>-</td>
</tr>
<tr>
<td>ITS refit + TOF flag</td>
<td>TRUE</td>
<td>TRUE</td>
</tr>
</tbody>
</table>

*at least one daughter track hit in TOF or the track is reconstructed with ITS and TPC→ excluding pile-up effect, keep reasonable efficiency

*DCA distance of closet approach
**PV primary vertex
***PA pointing angle
Invariant Mass Spectra and Signal Extraction

Invariant mass distributions for V0s and Cascades reconstructed for selected $p_T$ and multiplicity bins

- The invariant mass spectra are fit by a polynomial (background) + gaussian (peak) function to determine mean and width of the peak

- The signal is extracted by using the bin counting procedure:
  - Integration in peak region
    - V0s→$[\mu-3\sigma_G, \mu+3\sigma_G]$  
    - Cascades→$[\mu-5\sigma_G, \mu+5\sigma_G]$  
  - Background interpolated from the polynomial function under the signal region and subtracted from peak
Raw Spectra : V0s

Then, the extracted signal is normalized to the INEL>0 events to obtain the Raw Spectra.
Raw Spectra : Cascades

Then, the extracted signal is normalized to the INEL>0 events to obtain the Raw Spectra.
Acceptance x Efficiency

- The analysis has been repeated with Monte Carlo using the same criteria applied to the data, in order to produce the acceptance and efficiency corrections.

- The acceptance x efficiency factor ($\varepsilon$) is computed by taking the ratio of reconstructed particles and the corresponding generated ones in each $p_T$ interval.

$$\varepsilon = \frac{N(V0)_{\text{reconstructed}}(p_T)}{N(V0)_{\text{generated}}(p_T)}$$

- The $\text{Acc x eff}$ was obtained for integrated multiplicity, since the $\varepsilon$ factor does not show a dependency from multiplicity.
Corrected Spectra for V0s

Raw spectra are divided by the acceptance times efficiency correction to obtain corrected spectra which are fitted with phenomenological function.
Corrected Spectra: Cascades

- Raw spectra are divided by the acceptance times efficiency correction to obtain corrected spectra.
- For Ξ there are variations between particle and antiparticle that have to be understood.

![Graphs of corrected spectra for Ξ⁻, Ξ⁺ and Ω⁻, Ω⁺](image-url)
**V0s $p_T$-integrated yield and mean $p_T$**

- $p_T$-integrated yields and means $p_T$ are obtained integrating the spectra and the phenomenological function at low and high $p_T$.

![Graph](image1.png)

- For $K_S^0$ the $p_T$-integrated yield is compared with results in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 13$ TeV. Even if it is a preliminary results, it can be seen that the three analyses follow the same trend and no dependency from the initial state energy is observed.

- For $\Lambda$ and $\bar{\Lambda}$, it is necessary to apply the **feed-down corrections** before calculating $p_T$-integrated yields and mean $p_T \rightarrow$ subtraction of (Anti-)Λ coming from the decays of charged and neutral Ξ.
Cascades $p_T$-integrated yield and mean $p_T$

- $p_T$-integrated yields and mean $p_T$ are obtained integrating the spectra and the phenomenological function at low and high $p_T$.

\begin{align*}
\Xi^- + \Xi^+ & \\
\Omega^- + \Omega^+ & \\
\end{align*}

- $p_T$-integrated yields are compared to results in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 13$ TeV. The new results follow the same trend of the two previous ones, showing invariance from the energy of the initial state.
Summary:

- New studies on $K_S^0, \Lambda, \Xi, \Omega$ vs multiplicity in pp collisions @ 5.02 TeV have been presented. In particular:
  - Signal extraction procedure
  - Raw and Corrected Spectra
  - $p_T$-integrated yield and mean $p_T$

Next steps:

- $\Lambda$ feed-down correction $\rightarrow$ subtraction of (Anti-)\Lambda coming from the decays of charged and neutral $\Xi$
- Systematics errors evaluation for V0s and Cascades
- Event and particle loss due to event class selection (INEL>0)
- Paper proposal
Thank you for your attention!
Back up slides
Variables definition:

- **Invariant mass**: \( m_0c^2 = \sqrt{E^2 - (pc)^2} \)
  where \( E \) is the total energy and \( p \) the momentum of the particle and \( c \) the speed of light

- **Pseudorapidity**: \( \eta = -\ln \left( \tan \left( \frac{\theta}{2} \right) \right) \)
  where \( \theta \) is the angle between the momentum of the particle \( \vec{p} \) and the beam

- **Transverse momentum** : \( p_T = \sqrt{p_x^2 + p_y^2} \)
  which is the momentum in the transverse plane perpendicular to z-axis (beam line)

- **Multiplicity**: number of charged particles produced in a defined kinematic region

Multiplicity estimation with V0M detectors:

- The *multiplicity* is obtained by summing up the energy deposited in the two disks of the V0 detector
- This observable scales directly with the number of primary charged particles generated in the collision
- Data sample divided in V0M (V0A & V0C) amplitude classes
- *Multiplicity* is the measurement of the average number of primary charged particles at central rapidity for each V0M amplitude class
Phenomenological function: Levy-Tsallis

- Levy-Tsallis distribution:

\[ h_q(p_T) = C_q \left[ 1 - (1 - q) \frac{p_T}{T} \right]^{\frac{1}{1-q}} \]

- with a normalization constant \( C_q \), a “temperature” \( T \), and a dimensionless non extensivity parameter \( q \) (with \( q > 1 \))