Strangeness production in small collision systems at the LHC

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Introduction
Strangeness production extensively studied in A-A:

- Strangeness enhancement (original idea)
- Canonical suppression in pp
- $\Lambda/K^0_S$ enhancement at intermediate $p_T$
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- Progressive release of canonical suppression
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What about pp?
Detecting strange particles in ALICE
A Large Ion Collider Experiment

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trigger, tracking, vertex, PID (dE/dx)
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Gas-filled ionization detection volume:
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**V0** (2.8<η<5.1 (V0A) & 
-3.7<η<-1.7 (V0C))
Forward arrays of scintillators:
trigger, beam gas rejection, 
multiplicity estimation
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HOW DO WE ESTIMATE MULTIPLICITY:

- Use forward rapidity estimator V0M (sum of amplitudes in V0A & V0C)
- For each V0M multiplicity class we take the average of the distribution of charged tracks in |\(\eta\)|<0.5: \(\langle dN_{ch}/d\eta \rangle\)

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- Forward arrays of scintillators: trigger, beam gas rejection, multiplicity estimation
Results
Spectra get harder for higher multiplicity.

Ratio
$\text{SPEC}_{\text{bin-i}} / \text{SPEC}_{\text{INEL}}$
constant for $p_T \gtrsim 4$ GeV/c for $K^0_S$ and $\Lambda$

Levy-Tsallis fits performed in order to extract yields (low-$p_T$ extrapolation)
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Ratio
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constant for \( p_T > \approx 4 \text{ GeV/c} \) for \( K_S^0 \) and \( \Lambda \)

... and also for \( \Xi \) and \( \Omega \)

Levy-Tsallis fits performed in order to extract yields (low- \( p_T \) extrapolation)
• Momentum range 0.1(0.3)-20 GeV/c for $\pi(p)$, combining PID information from ITS+TPC+TOF
• Low $p_T$: hardening with increasing multiplicity, more pronounced for protons
• Spectral shapes unaltered at high $p_T$
The hardening of the spectra can be quantified looking at the $\langle p_T \rangle$ as a function of multiplicity.

Raising trend of $\langle p_T \rangle$ with the multiplicity for all identified particles (logarithmic fit to guide the eye)
The ratio depends on the event multiplicity in a qualitatively similar way as in p-Pb and Pb-Pb.

The magnitude is smaller in pp with respect to p-Pb and Pb-Pb, but note that for similar percentiles $\langle dN_{ch}/d\eta \rangle$ changes dramatically among the three systems.
$\Lambda/\pi$ ratio as a function of multiplicity in pp:

- Very good agreement with INEL result at low mult.
- Follows the same trend observed in p-Pb
**Λ/π**

**Λ/π** ratio as a function of multiplicity in pp:

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Pythia6 and 8 with several tunes (P-0, P-2011, 4C, Monash) considered: **strong disagreement** with observed trend.

CR does not change the prediction significantly.
Λ/π and Ω/π
$\Xi/\pi$ and $\Omega/\pi$ ratios as a function of multiplicity in pp:

- In very good **agreement with INEL** result at low multiplicity
- **Seated** precisely on top of the $p$-Pb datapoints
- Reaches GC saturation value (THERMUS and GSI-Heidelberg models) in the case of $\Xi$. It stays below in the case of $\Omega$. 
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How fast does the \( h/\pi \) ratio increase for the different species?

We plot \( \frac{[h/\pi]_{\text{system}}}{[h/\pi]_{\text{pp INEL}}} \)

The relative increase with multiplicity is more pronounced for baryons with higher strangeness content.

The increase is \textit{strangeness-related and not baryon-related}, since for protons the ratio remains constant from \( \langle N_{ch}\rangle_{\text{INEL}} \) up to highest \( \langle N_{ch}\rangle \) probed.

Systematics are LARGELY correlated across multiplicity!
Study of strange particle production as a function of the multiplicity in small systems at the LHC with ALICE

Λ/π, Ξ/π and Ω/π ratios:

• increase as a function of \( \langle dN_{\text{ch}}/d\eta \rangle \) with the same trend as observed in p-Pb
• baryons with higher strangeness content exhibit larger increase with multiplicity
• Pythia6 and Pythia8(Monash) do not reproduce the observed trend

Λ/K_S^0 ratio as a function of \( p_T \):

• shows a qualitatively similar trend as the same quantity measured in p-Pb and Pb-Pb
Backup
### Multiplicity classes and \( \langle dN_{\text{ch}}/d\eta \rangle \)

| \( K_S^0 \) and \( \Lambda \) | \( \langle dN_{\text{ch}}/d\eta \rangle |\eta|<0.5 \) | \( \Xi \) | \( \Omega \) | \( \langle dN_{\text{ch}}/d\eta \rangle |\eta|<0.5 \) |
|---|---|---|---|---|
| 0 - 1% | 21.29±0.04±0.64 | 0 - 1% | 21.29±0.04±0.64 | 0 - 5% | 17.47±0.02±0.52 |
| 1 - 5% | 16.51±0.01±0.50 | 1 - 5% | 16.51±0.01±0.50 | 5 - 15% | 12.48±0.01±0.38 |
| 5 - 10% | 13.46±0.01±0.40 | 5 - 10% | 13.46±0.01±0.40 | 15 - 30% | 8.99±0.01±0.27 |
| 10 - 15% | 11.51±0.01±0.35 | 10 - 15% | 11.51±0.01±0.35 | 15 - 30% | 8.99±0.01±0.27 |
| 15 - 20% | 10.08±0.01±0.30 | 15 - 30% | 8.99±0.01±0.27 | 15 - 30% | 8.99±0.01±0.27 |
| 20 - 30% | 8.45±<0.01±0.25 | 30 - 50% | 6.06±<0.01±0.19 | 30 - 50% | 6.06±<0.01±0.19 |
| 30 - 40% | 6.72±<0.01±0.21 | 30 - 50% | 6.06±<0.01±0.19 | 30 - 50% | 6.06±<0.01±0.19 |
| 40 - 50% | 5.40±<0.01±0.17 | 50 - 70% | 3.90±<0.01±0.14 | 50 - 100% | 2.89±<0.01±0.14 |
| 50 - 70% | 3.90±<0.01±0.14 | 50 - 70% | 3.90±<0.01±0.14 | 50 - 100% | 2.89±<0.01±0.14 |
| 70 - 100% | 2.26±<0.01±0.12 | 70 - 100% | 2.26±<0.01±0.12 | 70 - 100% | 2.89±<0.01±0.14 |

\[
\langle dN_{\text{ch}}/d\eta \rangle^{\text{MAX}} \approx 3.5 \ (3) \times \langle dN_{\text{ch}}/d\eta \rangle^{\text{INEL}}
\]
Topological cuts

V0.a

DCA V0 Neg. daughter to Prim. Vtx

V0 b

DCA between V0 daughters

V0 c

Prim. Vtx

DCA V0 to Prim. Vtx

Casc.a

Bachelor : $\pi^-$

DCA Bachelor to Prim. Vtx

Casc.b

DCA between $\Xi^-$ daughters

Casc + V0.d

$R_{max}$

$R_{min}$
Strange particles signal

Several topological cuts tuned in order to optimize S/B

PID performed with TPC for all the 2(3) V0(cascade) decay daughters

Bin-counting technique applied to extract yields
Acceptance \times \text{efficiency correction}

Acceptance \times \text{efficiency (A}\times\varepsilon) \text{ estimated through Pythia-Perugia0 simulation propagated through full ALICE geometry using Geant3.}

\Xi^- \text{ and } \Omega^- \text{ corrections were obtained using a Monte Carlo sample with enriched cascade content}

A\times\varepsilon \text{ verified to be independent of the charged particle multiplicity}
The multiplicity-integrated trend is more similar to the one observed at high multiplicity rather than to the one observed at low multiplicity.
h/π ratio normalized to the ratio at the high multiplicity limit as a function of charged pion multiplicity... 

... together with THERMUS curves for the three species (T=156±10MeV, R=R_c, γ_s=1, μ_B=μ_Q=μ_S=0)

The canonical suppression picture is in qualitative good agreement with the experimental results.