Multiplicity dependence of light flavor hadron production in proton-proton collisions measured with ALICE

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Hyperon-to-pion ratio $pp \to p-Pb \to Pb-Pb$

- Strangeness enhancement is one of the oldest signatures of the QGP formation in HI collisions
  
  (J. Rafelski and B. Muller, PRL 48 (1982) 1066)

- It is described by thermal models

- The ratio for $p-Pb$ increases with multiplicity (arXiv:1512.07227) and makes a bridge between $pp$ and $Pb-Pb$
p_T-dependence of ratio shapes

What do pp ratios look like?

- The multiplicity dependence of baryon to meson ratios in Pb-Pb collisions is a consequence of radial flow
- Similar trends in p-Pb collisions
- What about pp collisions?
Key ALICE sub-detectors for light flavor hadron measurement:

- **Inner Tracking System (ITS)**
  - vertex and track reconstruction
  - PID based on $dE/dx$

- **Time Projection Chamber (TPC)**
  - High-precision tracking
  - Weak decay reconstruction
  - PID based on $dE/dx$

- **Time of Flight (TOF)**
  - PID based on velocity measurement

- **HMPID Ring Imaging Cherenkov detector**
  - PID at high $p_T$

- **V0 scintillators** (2.8 $< \eta <$ 5.1 & -3.7 $< \eta <$ -1.7)
  - Triggering
  - Multiplicity estimation
Direct light flavor identification

Specific ionization energy loss in silicon and gas

**Time-of-Flight**

Range of sub-detectors for the direct identification:

- **ITS** $0.1 < p < 0.5$ GeV/c
- **TPC** $0.25 < p < 0.8$ GeV/c & $3 < p < 20$ GeV/c
- **TOF** $0.5 < p < 3.0$ GeV/c
- **HMPID** $1.5 < p < 5.0$ GeV/c

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Topological selection

Solid lines show the reconstructed charged particle tracks
Multiplicity selection in pp collisions

- Events were classified using the total charge deposited in the V0 scintillators (in $2.8 < \eta < 5.1$ & $-3.7 < \eta < -1.7$). Measurements on light flavor hadrons were carried out at mid-rapidity ($|y|<0.5$).

- This event classification scheme avoids auto-correlation biases.

- Measurements were performed in the $\text{INEL}>0$ class (at least one charged particle with $p_T>0$ and $|\eta|<1$) where $<dN_{ch}/d\eta>_{\text{INEL}>0} \approx 6$ for $|\eta|<0.5$.

- The $\text{INEL}>0$ cross-section was divided into 10 classes according to decreasing value of $<dN_{ch}/d\eta>$: $<dN_{ch}/d\eta>_i=21.3$ ... $<dN_{ch}/d\eta>_x=2.3$. 

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$p_T$-spectra

$\pi^+\pi^-$, $K^+K^-$, $K^0_S$, $K^+\bar{K}^*$

$\pi^+\pi^-$, $K^+K^-$, $p+p\bar{p}$

$K^*_S$, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^-$

$X$ (x 2$^6$)
$IX$ (x 2$^6$)
$VIII$ (x 2$^6$)
$VII$ (x 2$^6$)
$VI$ (x 2$^6$)
$V$ (x 2$^6$)
$IV$ (x 2$^6$)
$III$ (x 2$^6$)
$II$ (x 2$^6$)
$I$ (x 2$^6$)

$K^*+\bar{K}^*$:
$X$ (x 2$^6$)
$IX$ (x 2$^6$)
$VIII$ (x 2$^6$)
$VII$ (x 2$^6$)
$VI$ (x 2$^6$)
$IV+V$ (x 2$^6$)
$III$ (x 2$^6$)
$II$ (x 2$^6$)
$I$ (x 2$^6$)

$\Omega^-+\Omega^-$:
$IX+X$ (x 2$^6$)
$VII+VIII$ (x 2$^6$)
$V+VI$ (x 2$^6$)
$III+IV$ (x 2$^6$)
$I+II$ (x 2$^6$)

ALICE Preliminary
pp at $\sqrt{s}=7$ TeV
V0M Mult. Evt. Classes

ALI-PREL-111017

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Modification of $p_T$-spectra with multiplicity

Ratios of spectra in multiplicity bins over full INEL>0 spectra

- Spectra get harder with increasing multiplicity
- Effect is more pronounced for baryons ($p, \Lambda, \Xi$) than mesons ($\pi, K, K^*$)
Qualitatively the same changes of ratios from low to high multiplicity bins in pp, p-Pb and Pb-Pb collisions but quantitatively different.
Evolution of yield ratios

→ For pp collisions ratios of strange and multi-strange particles increase with multiplicity

→ MC models do not fully describe those trends

→ Results for all systems follow one trend, despite different initial conditions
Integrated baryon to meson ratios

- Baryon to meson ratios do not change significantly with multiplicity => strangeness content, and not mass, drives the observed enhancement
- Not reproduced by MC models
Strength of the enhancement

Strength of the enhancement depends on the number of strange and antistrange quarks

For non-strange particles (protons) enhancement is not observed
Does the relative particle production in pp collisions saturate? Seems to be the case for kaons and protons but not for hyperons.

What is the key factor for the strangeness enhancement in pp collisions: charged particle multiplicity or collision energy?
Summary

- ALICE has observed an enhanced production of strange and multi-strange particles in high-multiplicity pp collisions (arXiv:1606.07424)

- The multiplicity dependence of strangeness production in pp and p-Pb collisions looks similar and approaches the Pb-Pb values

- None of the MC models describe all observed features