NEW RESULTS RELATED TO QGP IN SMALL SYSTEMS WITH ALICE

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Introduction and Motivation
Motivation

- pA and AA: qualitatively same features in several observables of bulk particle production

- AA:
  - Strangeness enhancement/canonical suppression in small systems
  - Baryon/meson ratio enhancement

- pA:
  - Progressive release of canonical suppression with increasing system size/strangeness enhancement
  - Baryon/meson ratio qualitatively similar to AA

PID & Multiplicity estimation

Detectors used for PID:

- **Inner Tracking System (ITS)**
  - also: trigger, tracking, vertex

- **Time Projection Chamber (TPC)**
  - also: tracking

- **Time-Of-Flight (TOF)**

Multiplicity estimation:

- **V0M** – multiplicity estimator at forward rapidities
  - Two plastic scintillators:
    - V0A \( \, 2.8 < \eta < 5.1 \) 
    - V0C \( \, -3.7 < \eta < -1.7 \) 
  - \( \text{V0M} = \text{V0A} + \text{V0C} \)
  - Used in order to minimize the auto-correlation biases
RESULTS
\( p_T \)-differential spectra – pp at \( \sqrt{s} = 7 \) TeV

Measure a comprehensive set of light-flavoured particles in a wide \( p_T \) range, interested in radial flow and chemical composition of events

- Hardening with increasing multiplicity
- Flattening at high \( p_T \)
$p_T$-differential spectra – pp at $\sqrt{s} = 7$ TeV

Similar effects for strange-hadron spectra
$p_T$-differential spectra – pp at $\sqrt{s} = 7$ TeV

And multi-strange hadrons

\begin{align*}
\langle dN_{ch}/d\eta \rangle &= 21.3 \\
\langle dN_{ch}/d\eta \rangle &= 17.5 \\
\langle dN_{ch}/d\eta \rangle &= 2.3 \\
\langle dN_{ch}/d\eta \rangle &= 2.9
\end{align*}
$p_T$-differential ratios vs. multiplicity

Baryon/meson ratios:

- Qualitatively similar trends in all systems
- Depletion at low $p_T$, enhancement at intermediate
- Different magnitudes, but also different multiplicity densities

![Graphs showing differential ratios for p-Pb and Pb-Pb collisions.](image-url)
$p_T$-differential ratios vs. multiplicity

- Enhancement in Pb-Pb explained by coalescence/radial flow, but also seen in p-Pb and pp
- Mass ordering in Pb-Pb is described by hydrodynamical evolution of the system, which may require a fireball in local thermal (kinetic) equilibrium
$\rho_T$-integrated yield ratios vs. multiplicity

Integrated yield ratios: comparison between systems

- Both $K/\pi$ and $p/\pi$ ratios consistent between different colliding systems for similar $dN_{ch}/d\eta$
$p_T$-integrated yield ratios vs. multiplicity

Integrated yield ratios: comparison between systems

- Both $K/\pi$ and $p/\pi$ ratios consistent between different colliding systems for similar $dN_{\text{ch}}/d\eta$
- Similar behaviour for multi-strange baryons
- Particle composition seems to be driven by $dN_{\text{ch}}/d\eta$
Baryon-to-meson ratios: pp & p-Pb comparison

pp and pA ratios normalized to multiplicity-integrated ratios:

- Protons: consistent with unity
  - Enhancement not related to baryon number
- Slope increases with strangeness content

Strangeness-related increase of ratio vs. multiplicity
Comparison to Thermal Model calculations

Another look into pp and pA

- $\Lambda/\pi$, $\Xi/\pi$, $\Omega/\pi$ approaching grand canonical saturation in same predicted way

- Consider strange hadron to $\pi$ ratio at high multiplicity limit

- Trend for $\Lambda/\pi$, $\Xi/\pi$, $\Omega/\pi$ roughly described by THERMUS

- Reminder: Trends not reproduced by existing Pythia tunes
Nuclear Modification Factor

Pb-Pb:
- Mass-ordered suppression of soft hadrons
- Species-independent suppression of hard particles

p-Pb
- No suppression above $p_T \approx 2 \text{ GeV}/c$
- Consistent with unity for all species above $p_T \approx 6 \text{ GeV}/c$
- Cronin peak/mass ordering?
Summary
Summary

The production of identified hadrons as a function of event multiplicity in pp collisions at $\sqrt{s} = 7$ TeV has been measured and reported

- Measured $p_T$-differential hadron spectra harden with multiplicity
- Ratios of $p_T$-differential spectra to minimum bias flatten out at high $p_T$
- $p_T$-differential baryon-to-meson ratios show significant evolution from low to high multiplicity; same qualitative behaviour observed in p-Pb and Pb-Pb collisions
- Strange-hadron to pion ratios:
  - Qualitatively similar among pp and p-Pb
  - Enhanced strange particle production with multiplicity observed
- Suppression of high $p_T$ hadrons present in Pb-Pb, not in p-Pb
Backup
The ridge

- Also, double-ridge (but not in this talk)
\(<p_T>\) vs. multiplicity

The hardening of spectra can be quantified by looking at the \(<p_T>\) as a function of multiplicity

- Rising trend of \(<p_T>\) with multiplicity for all identified particles
- Mass ordered
- Logarithmic fit to guide the eye
ITS, TPC and TOF performance in $\sqrt{s} = 7$ TeV pp collisions

ITS:
- $\pi$: [0.1 – 0.6] GeV/c
- K: [0.2 – 0.6] GeV/c
- p: [0.3 – 0.6] GeV/c

TPC:
- $\pi$: [0.2 – 0.5] GeV/c
- K: [0.25 – 0.6] GeV/c
- p: [0.4 – 0.8] GeV/c
  + relativistic rise

TOF:
- $\pi$: [0.5 – ~3] GeV/c
- K: [0.6 – ~3] GeV/c
- p: [0.8 – ~4] GeV/c

Topological PID

- Topological PID of weakly decaying strange baryons:
  \( \Lambda = |uds\rangle \)
  \( \Xi = |dss\rangle \)
  \( \Omega = |sss\rangle \)
$\langle dN_{\text{ch}}/d\eta \rangle$ in V0M bins

<table>
<thead>
<tr>
<th>V0M (%)</th>
<th>$\langle dN_{\text{ch}}/d\eta \rangle$</th>
<th>V0M (%)</th>
<th>$\langle dN_{\text{ch}}/d\eta \rangle$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.1</td>
<td>25.3 ± 0.8</td>
<td>0.1 - 1</td>
<td>20.8 ± 0.6</td>
</tr>
<tr>
<td>1 - 5</td>
<td>16.5 ± 0.5</td>
<td>5 - 10</td>
<td>13.5 ± 0.4</td>
</tr>
<tr>
<td>10 - 15</td>
<td>11.5 ± 0.3</td>
<td>15 - 20</td>
<td>10.1 ± 0.3</td>
</tr>
<tr>
<td>20 - 30</td>
<td>8.4 ± 0.3</td>
<td>30 - 40</td>
<td>6.7 ± 0.2</td>
</tr>
<tr>
<td>40 - 50</td>
<td>5.4 ± 0.2</td>
<td>50 - 70</td>
<td>3.9 ± 0.1</td>
</tr>
<tr>
<td>70 - 100</td>
<td>2.3 ± 0.1</td>
<td>0 - 100</td>
<td>6.0 ± 0.2</td>
</tr>
</tbody>
</table>
$p_T$-differential ratios vs. multiplicity

$K/\pi$, $p/\pi$ ratios:

- $p/\pi$ shows much stronger variation with multiplicity than $K/\pi$
  - Mass ordering

![Graphs showing $K/\pi$ and $p/\pi$ ratios vs. $p_T$]
Integrated yield ratios vs. multiplicity

Integrated yield ratios: comparison between systems

- Levy-Tsallis fits to $p_T$-differential spectra (serves as extrapolation to $p_T = 0$; negligible contribution from $p_T \to \infty$ extrapolation)

- Both $K/\pi$ and $p/\pi$ ratios consistent between different colliding systems for the similar $dN_{ch}/d\eta$

***Multiplicity uncorrelated errors are not shown here, but will be included in the forthcoming publication
Comparison to MC event generators

Integrated yield ratios:

- 4 different Pythia tunes were used
- Color reconnection has similar effect in all tunes
- None of the tunes can describe both $K/\pi$ and $p/\pi$ ratios quantitatively. This holds for tunes with and without color reconnection
Comparison to MC event generators

Ratios vs. multiplicity in pp:

- Smooth trend pp → pA → AA with multiplicity
- Λ/π and Ξ/π reach predicted GC saturation values
- Ω/π stays below
- Pythia 6 & 8 do not describe the data
- Color reconnection has little impact on predicted multiplicity dependence of strangeness production