Production of identified and unidentified charged hadrons in Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

Nicolò Jacazio on behalf of the ALICE collaboration

University and INFN – Bologna

6-11 February – Quark Matter 2017
- Importance of radial flow and collective evolution in the $p_T$ dependence of particle ratios
- Thermal model is in remarkable agreement with measured particle yields
  - Light-nuclei production is well described
  - Deviations from measured $p$ ($2.5 \sigma$) and $\Xi$ ($2 \sigma$) yields
- Measurements of resonances in central Pb–Pb collisions suggest elastic rescattering in the late hadronic phase

**Posters on resonances by N. Agrawal, F. Bellini, J. Song**
**Poster on nuclei by S. Trogolo**
From Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV...

- Importance of radial flow and collective evolution in the $p_T$ dependence of particle ratios
- Thermal model is in remarkable agreement with measured particle yields
  
  » Light-nuclei production is well described
  
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 Measurements of resonances in central Pb–Pb collisions suggest elastic rescattering in the late hadronic phase

Posters on resonances by N. Agrawal, F. Bellini, J. Song

Poster on nuclei by S. Trogolo
... to Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV

- Measure the effects of the radial flow
  - Does radial flow increase from 2.76 to 5.02 TeV?
- Study the energy dependence of relative particle abundances
- Measure strangeness production in Pb–Pb collisions
- Test the thermal model with measurements
- Study the energy dependence of the nuclear modification factor
- Moderate magnetic field \((B = 0.5 \text{ T})\) in the mid-rapidity region \(|\eta| < 0.9\)
- Tracking down to \(p_T \sim 100 \text{ MeV}/c\)
- High granularity to cope with the high occupancy present in Pb-Pb collisions
- Extensive particle identification (PID) by several techniques

Int. J. Mod. Phys. A 29 (2014) 1430044
Charged particle density measured in central collisions (0-5%) follows trends expected from lower energies.

At $\sqrt{s_{NN}} = 5.02$ TeV, an increase of ~20% with respect to $\sqrt{s_{NN}} = 2.76$ TeV.


Talk 07/02/2017, 12:00
C. Holm Christensen
Unidentified particle spectra

- Measurement of primary unidentified particles in Pb–Pb collisions as a function of centrality
- Significant increase in the precision of the measurement
  » Reduced systematic uncertainties with respect to lower energies
    › Data driven correction for species dependent efficiencies and feed-down
    › Improved detector description
- Comparison to pp measurements scaled by $<T_{AA}>$ values

Posters by J. M. Gronefeld, E. Perez Lezama, P. Huhn

08 Feb 2017
Nicolò Jacazio
Nuclear Modification Factor $R_{AA}$

- Nuclear modification factor of primary charged particles

\[
R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/d\ p_T}{d\sigma_{pp}/d\ p_T}
\]

- Compared with values from Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV (gray markers)

- Reduced systematic uncertainties with respect to lower energies

- No significant evolution with collision energy is found
**Particle identification in ALICE**

**Multiple PID techniques**

- **ITS**
  - $dE/dx$ in silicon
  - Sampling in 4 layers with analogue readout

- **TPC**
  - $dE/dx$ in gas (Ar−CO$_2$)
    - $\sigma_{dE/dx} \sim 5\%$

- **TOF**
  - Time-of-flight measurement
    - $\sigma_{\text{TOF}} \sim 80$ ps

- **HMPID**
  - Cherenkov angle measurement

**Excellent Particle Identification**

- **ITS**
  - ALICE Performance
  - Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV

- **TPC**
  - ALICE Performance
  - Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV

- **TOF**
  - ALICE Performance
  - Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV

- **HMPID**
  - ALICE Performance
  - Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV
Identified particle spectra

- Measured with different analysis techniques: ITS, TPC, TOF, HMPID and topological identification of K from kinks covering different $p_T$ intervals
- Mass dependent hardening of the spectra with increasing centrality
Compared with values from Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV (gray markers)

- **No significant change between the two energies**
Particle ratios: $p/\pi$

- Compared with values from Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV (gray markers)
- Shift of the maximum of $p/\pi$ to higher $p_T$ with respect to lower energies
Blast-Wave model

- Simultaneous fit to the $\pi$, K, p spectra with the Boltzmann–Gibbs Blast-Wave model

- Simplified hydrodynamics model with 3 parameters
  » $\beta_T$ → radial expansion velocity
  » $T_{\text{Kin}}$ → kinetic freeze-out
  » $n$ → velocity profile

\[
E \frac{d^3 N}{d p^3} \propto \int_0^R m_T I_0 \left( \frac{p_T \sinh(\rho)}{T_{\text{Kin}}} \right) K_1 \left( \frac{m_T \cosh(\rho)}{T_{\text{Kin}}} \right) r \, dr
\]

\[
m_T = \sqrt{m^2 + p_T^2} \quad \rho = \tanh^{-1}(\beta_T) \quad \beta_T = \beta_s \left( \frac{r}{R} \right)^n
\]

Schnedermann, Sollfrank and Heinz Phys. Rev. C 48, 2462

Caveats

Values of extracted Blast-Wave parameters depend on the fit range, particle species included in the fit and uncertainties considered

→ Same fitting range as used in Pb–Pb collisions at 2.76 TeV
Blast-Wave fit parameters

- Fit quality at $\sqrt{s_{NN}} = 5.02$ TeV similar to that at 2.76 TeV
- Blast-Wave parameters follow trends obtained at lower energy

Global Blast-Wave fit to π (0.5-1 GeV/c), K (0.2-1.5 GeV/c), p (0.3-3.0 GeV/c)

- ALICE Preliminary, pp, $\sqrt{s} = 7$ TeV
- ALICE, p-Pb, $\sqrt{s} = 5.02$ TeV
- ALICE, Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV
- ALICE Preliminary, Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV

Blast-Wave fit parameters

- Fit quality at $\sqrt{s_{NN}} = 5.02$ TeV similar to that at 2.76 TeV
- Blast-Wave parameters follow trends obtained at lower energy
- Largest expansion velocity for central Pb–Pb collisions
- In Pb–Pb at the two energies parameters are similar at comparable multiplicities.
- Higher $<\beta_T>$ for smaller collision systems at comparable multiplicities.
In Pb–Pb collisions all three species are equally suppressed for all centralities at high $p_T$ ($> 8$ GeV/c).

- (Light-)flavor independent energy loss at high $p_T$ as observed at $\sqrt{s_{NN}} = 2.76$ TeV

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No significant evolution with collision energy is found

Similar observations for \( \pi \) and \( K \)

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proton-proton reference for \( R_{AA} \)

- Significant hardening of the reference spectra with respect to \( \sqrt{s} = 2.76 \text{ TeV} \)
- **No significant energy dependence is observed** for $p/\pi$ and $K/\pi$, as they follow the trends observed at 2.76 TeV

  » Hint of increase in the $K/\pi$ ratio not significant given the present uncertainties

- $K/\pi$ and $p/\pi$ measured in **peripheral Pb–Pb collisions** are consistent with the high-multiplicity pp and $p$–Pb values
Outlook on strangeness production

- Work is ongoing in the analysis of strangeness production
- Reconstruction of strange particle weak-decay topology
Conclusions

- The ALICE collaboration measured the spectra of unidentified particles and of $\pi$, $K$, $p$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
  
  » Improved precision in the measurement of inclusive charged particle production thanks to improved detector performance and analysis techniques

- Significant hardening of particle spectra with centrality
  
  » Blast-Wave model fit result indicates a higher expansion velocity in central collisions at 5.02 TeV than at 2.76 TeV

  → Stronger radial flow at the higher energy

- Nuclear modification factor has no significant evolution with the collision energy

- $p/\pi$ and $K/\pi$ relative abundances exhibit no significant energy dependence

  → Follows the trend with multiplicity established at 2.76 TeV
### Many more results – Posters:

<table>
<thead>
<tr>
<th>Topic</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged particle spectra in Pb-Pb collisions at 5.02 TeV measured with ALICE</td>
<td>J. Maximilian Gronefeld</td>
</tr>
<tr>
<td>Transverse momentum spectra of primary charged particles in pp collisions measured by ALICE at the LHC</td>
<td>E. Perez Lezama</td>
</tr>
<tr>
<td>Data-driven particle composition correction of tracking efficiency for charged particles with ALICE</td>
<td>P. Huhn</td>
</tr>
<tr>
<td>Transverse energy in Pb-Pb collisions with ALICE</td>
<td>P. William Stankus</td>
</tr>
<tr>
<td>Recent results on light nuclei and antinuclei from ALICE at the LHC</td>
<td>S. Trogolo</td>
</tr>
<tr>
<td>Resonances in Pb-Pb, exploring the hadronic phase</td>
<td>F. Bellini</td>
</tr>
<tr>
<td>Suppression of Λ(1520) resonance production in Pb-Pb collisions at the LHC</td>
<td>N. Agrawal</td>
</tr>
<tr>
<td>Production of Σ(1385)⁻ and Ξ(1530)⁰ measured by ALICE in pp, p-Pb and Pb-Pb at the LHC</td>
<td>J. Song</td>
</tr>
<tr>
<td>More results in pp collisions</td>
<td></td>
</tr>
<tr>
<td>φ(1020) production in pp collisions with ALICE at the LHC</td>
<td>S. Tripanty</td>
</tr>
<tr>
<td>Σ⁰ and Σ⁻ baryon production in pp collisions at √s = 7 TeV at the LHC with ALICE</td>
<td>A. Borissov</td>
</tr>
</tbody>
</table>
Backup
$R_{AA}$ model comparison

ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV
charged particles, $|\eta| < 0.8$

$R_{AA}$

ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV
charged particles, $|\eta| < 0.8$

$R_{AA}$

Data 0-10% (±4.5% norm unc.)
Vitev 0-10%

Data 0-5% (±4.5% norm unc.)
Djordjevic 0-5%
Majumder 0-5%
Charged particle spectra in pp at $\sqrt{s} = 5.02$ TeV

Measurement of primary unidentified particles in Minimum Bias pp collisions

Models predict higher values below 1 GeV/c and above 10 GeV/c

Reweighting of the efficiency corrections by the particle composition measured in pp collisions at $\sqrt{s} = 7$ TeV and Pb–Pb at $\sqrt{s}_{NN} = 2.76$ TeV
No significant evolution with the collision energy is found.
Energy dependence of the $R_{AA}$

No significant evolution with the collision energy is found.
Energy dependence of the $R_{AA}$

No significant evolution with the collision energy is found.
- At high $p_T$ the nuclear modification factor is in agreement among different particle species.
At high $p_T$ no significant collision energy dependence in the D meson nuclear modification factor.
ALICE PID capabilities

- $\pi$-K separation and K-p separation for the different detectors

Int. J. Mod. Phys. A29 (2014) 1430044
Kaon identification from Kinks

ALICE Performance

Pb-Pb \( s_{NN} = 5.02 \) TeV

Centrality: 0-90%

0.2 < \( p_T < 6.0 \) GeV/c

\[ K^\pm \rightarrow \pi^\pm + \pi^0 \]

\[ K^\pm \rightarrow \mu^\pm + \nu_\mu \]
Nuclei identification in ALICE

- Identification of light nuclei from specific energy loss in TPC and TOF measurements
Blast-Wave fit – ratio to spectra

Same fitting range as used in Pb–Pb collisions at 2.76 TeV Phys. Rev. C88, (2013) 044910
Blast-Wave fit parameters $T_{\text{kin}} - \langle \beta_T \rangle$.

- Global Blast-Wave fit
  - $\pi$ (0.5-1 GeV/c)
  - $K$ (0.2-1.5 GeV/c)
  - $p$ (0.3-3.0 GeV/c)

\[ T_{\text{kin}} \text{ (GeV/c)} \]

\[ \langle \beta_T \rangle \]

\[ \langle dN_{\text{ch}} / d\eta \rangle_{|\eta|<0.5} \]

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- ALICE Preliminary, pp \( s = 7 \text{ TeV} \)
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- ALICE Preliminary, Pb-Pb \( s_{\text{NN}} = 5.02 \text{ TeV} \)

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Blast-Wave fit parameters $n - \langle \beta_T \rangle$

- $\pi$ (0.5-1 GeV/c)
- $K$ (0.2-1.5 GeV/c)
- $p$ (0.3-3.0 GeV/c)

$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$

- ALICE Preliminary, pp $s = 7$ TeV
- ALICE, p-Pb $s_{NN} = 5.02$ TeV
- ALICE, Pb-Pb $s_{NN} = 2.76$ TeV
- ALICE Preliminary, Pb-Pb $s_{NN} = 5.02$ TeV

$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$

- ALICE Preliminary, pp $s = 7$ TeV
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- ALICE, Pb-Pb $s_{NN} = 2.76$ TeV
- ALICE Preliminary, Pb-Pb $s_{NN} = 5.02$ TeV


## Blast-wave fits in small systems

<table>
<thead>
<tr>
<th>ALICE</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Centrality estimators</strong></td>
<td>Uses forward rapidity estimators V0A: $2.8 &lt; \eta &lt; 5.1$, V0C: $-3.7 &lt; \eta &lt; -1.7$</td>
</tr>
<tr>
<td><strong>Rapidity</strong></td>
<td>$</td>
</tr>
<tr>
<td><strong>Particle species</strong></td>
<td>$\pi^{\pm}, K^{\pm}, p$ (and $K^0_S$, $\Lambda$ in p-Pb)</td>
</tr>
<tr>
<td><strong>Uncertainties on the fitted spectra</strong></td>
<td>Statistical and systematic</td>
</tr>
<tr>
<td><strong>Contours</strong></td>
<td>Uncertainties propagated from the fit</td>
</tr>
</tbody>
</table>

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**Graphs:**
- **Left graph:** Global Blast-Wave fit to $\pi$ (0.5-1 GeV/c), $K$ (0.2-1.5 GeV/c), $p$ (0.3-3.0 GeV/c).
  - ALICE Preliminary, pp, $\sqrt{s} = 7$ TeV
  - ALICE, p-Pb, $\sqrt{s} = 5.02$ TeV
  - ALICE, Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV
  - ALICE Preliminary, Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV

- **Right graph:** CMS Coll., arXiv:1605.06699
  - pp 6.2 pb$^{-1}$ (7 TeV)
  - pPb 35 nb$^{-1}$ (5.02 TeV)
  - PbPb 2.3 $\mu$b$^{-1}$ (2.76 TeV)