ALICE Status Report

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for the ALICE collaboration

LHCC
22.09.15
Run 2 Started

Commissioning Phases

Quiet Beams at 900 GeV

Quiet Beams at 13 TeV

13 TeV LHC Era

Scientists at CERN announce a milestone turning knobs at the #LHC: this one goes to #13TeV econ.st/1dkYzqJ

ALICE back in production!
Detector Status

- Several detectors installed during LS1
  - New calorimeter DCal
  - 4th PHOS module + CPV installed
  - New forward trigger detector AD
  - TRD completed
- All systems integrated in DAQ
- New combined EMCal, PHOS and DCal trigger
- Gas mixture in TPC changed to Ar-CO₂ to better cope with high particle flux
Data Taking

- Isolated bunches: Global OR triggers to enhance diffractive events (V0 | AD | ZDC | SPD)
- Muon data taking at high pileup
- Minimum bias data taking at low $\mu$
- Continuing with 200-300 kHz rate including rare triggers
- Target statistics in 2015
  - 600 M minimum bias low $\mu$
  - 4 pb$^{-1}$ muon triggers
  - 2 pb$^{-1}$ high multiplicity triggers

ALICE Performance, pp $\sqrt{s} = 13$ TeV
- Dimuon triggers: $L = 1.083 \text{ pb}^{-1}$
- V0 HM triggers: $L = 0.198 \text{ pb}^{-1}$
- SPD HM triggers: $L = 0.007 \text{ pb}^{-1}$
High-Multiplicity Trigger

• Aim: collect large high-multiplicity sample to investigate overlapping domain between pp and larger collisions system (p-Pb, Pb-Pb)
  – Collectivity and MPI
• Beam-background and pile-up rejection major challenge (even at low $\mu$ of ~2%)
• Forward and mid-rapidity trigger used
  – Explore selection bias
• In operation since last week
• Target for 2015: 2 pb$^{-1}$
Detector Performance

- New detectors and triggers in operation
- Good stability and running efficiency
- Good momentum and dE/dx resolution with new gas in TPC

ALICE-PUBLIC-2015-004
Publications
(since previous LHCC)

17 New Papers Submitted

Light Flavor
• Precision measurement of the mass difference between light nuclei and anti-nuclei, arXiv:1508.03986, published in Nature Physics

Quarkonia
• Differential studies of inclusive J/ψ and ψ(2S) production at forward rapidity in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.08804, submitted to JHEP
• Centrality dependence of inclusive J/ψ production in p-Pb collisions at √s_{NN} = 5.02 TeV, arXiv:1506.08808, submitted to JHEP

Ultraperipheral & Cosmics
• Coherent ψ(2S) photo-production in ultra-peripheral Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1508.05076, submitted to PLB
• Study of cosmic ray events with high muon multiplicity using the ALICE detector at the CERN Large Hadron Collider, arXiv:1507.07577, submitted to Journal of Astroparticle Physics

Heavy Flavor
• Production of light nuclei and anti-nuclei in pp and Pb-Pb collisions at LHC energies, arXiv:1506.08951, submitted to PRC
• Phi-meson production at forward rapidity in p-Pb collisions at √s_{NN} = 5.02 TeV and in pp collisions at √s = 2.76 TeV, arXiv:1506.09206, submitted to PLB
• H^3_A and H^3_A (bar) production in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.08453, submitted to PLB
• Search for weakly decaying Λn and ΛΛ exotic bound states in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.07499, submitted to PLB
• Centrality dependence of the nuclear modification factor of charged pions, kaons, and protons in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.07287, submitted to PRC

Correlations & Flow
• Centrality dependence of inclusive J/ψ production in p-Pb collisions at √s_{NN} = 5.02 TeV, arXiv:1506.08808, submitted to JHEP
• Centrality dependence of pion freeze-out radii in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1507.06842, submitted to PRC
• Event shape engineering for inclusive spectra and elliptic flow in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1507.06194, submitted to PRC
• One-dimensional pion, kaon, and proton femtoscopy in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.07884, submitted to PRC
• Forward-central two-particle correlations in p-Pb collisions at √s_{NN} = 5.02 TeV, arXiv:1506.08032, submitted to PLB

Jets
• Measurement of jet quenching with semi-inclusive hadron-jet distributions in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.03984, accepted by JHEP
• Elliptic flow of muons from heavy-flavour hadron decays at forward rapidity in Pb-Pb collisions at √s_{NN} = 2.76 TeV”, arXiv:1507.03134, submitted to PLB
• Centrality dependence of high-p_T D meson suppression in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.06604, subm. to JHEP
• Differential studies of inclusive J/ψ and ψ(2S) production at forward rapidity in Pb-Pb collisions at √s_{NN} = 2.76 TeV, arXiv:1506.08804, submitted to JHEP

ALICE Status Report - Jan Fiete Grosse-Oetringhaus
Publications
(since previous LHCC)

8 Papers Published

- Measurement of charged jet production cross sections and nuclear modification in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, arXiv:1503.00681, PLB749(2015)78
- Inclusive, prompt and non-prompt J/$\psi$ production at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, arXiv:1504.07151, JHEP 07(2015) 051
- Elliptic flow of identified hadrons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, arXiv:1405.4632, JHEP 06(2015) 190
- Charged jet cross sections and properties in proton-proton collisions at $\sqrt{s} = 7$ TeV, arXiv:1411.4969, PRD 91(2015) 112012
- Rapidity and transverse-momentum dependence of the inclusive J/$\psi$ nuclear modification factor in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, arXiv:1503.07179, JHEP 06(2015) 055
- Centrality dependence of particle production in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, arXiv:1412.6828, PRC 91(2015) 064905

2 Papers Accepted

- Measurement of charm and beauty production at central rapidity versus charged-particle multiplicity in proton-proton collisions at $\sqrt{s} = 7$ TeV, arXiv:1505.00664, accepted by JHEP
- Coherent $\rho^0$ photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, arXiv:1503.09177, accepted by JHEP

Quark Matter conference (Kobe, Japan) next week

About 30 new results
Cosmic-Ray Muons

- 30.8 days active
- Multiplicity distribution
  - Compatible with mixed-ion primary cosmic-ray composition (CORSIKA 6990 QGSJET II-03)
- High-multiplicity tail
  - Highest multiplicity 276 muons
  - 5 events with >100 muons
  - Consistent with pure ion composition (proton gives 2-3 lower rates)

<table>
<thead>
<tr>
<th>HMM events</th>
<th>CORSIKA 6990 QGSJET II-03</th>
<th>CORSIKA 7350 QGSJET II-04</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>proton</td>
<td>iron</td>
<td>proton</td>
</tr>
<tr>
<td>Period [days per event]</td>
<td>15.5</td>
<td>8.6</td>
<td>11.6</td>
</tr>
<tr>
<td>Rate [×10^{-5} Hz]</td>
<td>0.8</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Uncertainty (%) (syst + stat)</td>
<td>13</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

arXiv:1507.07577
Mass Difference of Nuclei

- Highest precision direct measurement of mass difference in nuclei sector d-\bar{d} and \(^3\)He-\(^3\)He

- TPC+TOF PID

- Calculation of mass difference
  - Uncertainties cancel
  - Relative systematic uncertainties of \(10^{-4}\) (d) and \(10^{-3}\) (\(^3\)He)

Mass Difference of Nuclei (2)

\[ d: \Delta(m/z) = (1.7 \pm 0.9 \text{ (stat)} \pm 2.6 \text{ (syst)}) \cdot 10^{-4} \text{ GeV/c}^2 \]

\[ ^3\text{He}: \Delta(m/z) = (-1.7 \pm 1.2 \text{ (stat)} \pm 1.4 \text{ (syst)}) \cdot 10^{-3} \text{ GeV/c}^2 \]

**Δ(m/z) vs. p/z**

Improvement by 1-2 orders of magnitude re previous limits
• Bound on CPT invariance of strong interaction binding nucleons into nuclei
• Calculate binding energy
\[ \Delta \varepsilon_{A\bar{A}} = Z \Delta m_{pp} + (\Lambda - Z) \Delta m_{nn} - \Delta m_{A\bar{A}} \]
\[ \frac{\Delta \varepsilon}{\varepsilon} = -0.04 \pm 0.05 \text{ (stat.)} \pm 0.12 \text{ (syst.)} \quad d-\bar{d} \]
\[ \frac{\Delta \varepsilon}{\varepsilon} = 0.24 \pm 0.16 \text{ (stat.)} \pm 0.18 \text{ (syst.)} \quad ^3\text{He}-^3\bar{\text{He}} \]
• Improves by factor 2 constraint for deuterons
• First determination for $^3\text{He}$

Hypernuclei weakly bound $\rightarrow$ sensitive to final fireball stages

- First measurement at LHC
  - $\Lambda^3 H \rightarrow ^3\text{He} + \pi^-$ (and c.c.)

- Coalescence or thermal models (long-standing item)
  - Rate consistent with thermal model prediction (same $T$ as for light hadrons)
  - Equilibrium models favored for yield

arXiv:1506.08453
Hypertriton Nuclei (2)

- $p_T$ distribution not compatible with simple coalescence picture
  \[ E_i \frac{d^3 N_i}{(dp_i)^3} = B_A \left( E_p \frac{d^3 N_p}{(dp_p)^3} \right)^A \]

- Lifetime determined from secondary-vertex distribution
  - $c\tau = (5.4^{+1.6}_{-1.2} \pm 1.0 \text{ cm})$
  - Uncertainties competitive for world average
  - Lifetime expected to be similar to free $\Lambda$ (weakly-bound hypernucleus)

arXiv:1506.08453
Hadron-Jet Correlations

- Charged jets with a recoil high $p_T$ trigger particle
- Jet reconstruction with $p_{T,\text{constituents}} > 0.15$ GeV/c for $p_{T,\text{jet}} > 20$ GeV/c
- Novel subtraction technique
  - Compare trigger particle $p_T$ ranges
  - Background jets invariant to trigger particle $p_T$
  - Extract additional jet yield $\Delta_{\text{recoil}}$

Jet yield vs. $p_T$

0-10% Pb-Pb $\sqrt{s}_{\text{NN}} = 2.76$ TeV
Anti-$k_T$ charged jets, $R = 0.2$
$\pi - \Delta_{\phi} < 0.6$

arXiv:1506.03984
Hadron-Jet Correlations (2)

- Comparison of recoil-jet yield to vacuum expectation
  \[ \Delta I_{AA} = \frac{\Delta\text{PbPb}_{\text{recoil}}}{\Delta\text{PYTHIA}_{\text{recoil}}} \]
- Suppression by factor \( \sim 2 \)
- Angular distribution of recoil jets
- No evidence for medium-induced broadening
\[ R_{AA} = \frac{dN_{AA}/dp_T}{\langle T_{AA} \rangle d\sigma_{pp}/dp_T} \]

- Nuclear-modification factor
  \[ R_{AA} = 1 \text{ no modification} \]
  \[ R_{AA} < 1 \text{ suppression} \]

- Centrality dependence of \( D^0, D^\pm, D^{*\pm} \) \( R_{AA} \)
  - \( 5 < p_T < 16 \text{ GeV/c} \)

- Significant suppression at high \( p_T \)
  - Factor 5-6 in most central

- Sign of quark mass dependence
  - \( R_{AA} (B \rightarrow J/\psi) > R_{AA} (D) \approx R_{AA} (\pi) \)
  - Important input for energy-loss models

arXiv:1506.06604
• Forward muons (2.5 < y < 4)
  – 0-40%, 3 < \( p_T \) < 10 GeV/c
  – 2 and 4 particle correlations
• Non HF decay \( \mu \) subtraction
  – Measured \( v_2 \) in |\( \eta \)| < 2.5 (ATLAS)
  – \( v_2 \) of \( \pi \) and K in |\( y \)| < 0.8 (ALICE)
  – Extrapolation, detector simulation
• Significant \( v_2 \) for 3<\( p_T \)<5 GeV/c
  – Compatible with 0 above 5 GeV/c

arXiv:1507.03134
• Forward muons ($2.5 < y < 4$)
  – 0-40%, $3 < p_T < 10$ GeV/c
  – 2 and 4 particle correlations
• Non HF decay $\mu$ subtraction
  – Measured $v_2$ in $|\eta| < 2.5$ (ATLAS)
  – $v_2$ of $\pi$ and $K$ in $|y| < 0.8$ (ALICE)
  – Extrapolation, detector simulation
• Significant $v_2$ for $3 < p_T < 5$ GeV/c
  – Compatible with 0 above 5 GeV/c
• Simultaneous description of $v_2$ and $R_{AA}$ imposes significant model constraints

arXiv:1507.03134
• Novel method exploiting the large event-by-event variation of $v_n$ (PLB719 (2013) 394)
  – Final-state $v_2$ correlated with initial-state eccentricities $\varepsilon_2$ (hydro with small $\eta/s$)
• Define event classes based on $q_2$ (measure of elliptic modulation)
  – Selection works along phase space
  – Bias on $v_2$ independent of $p_T$

$$q_2 = \frac{\sqrt{\left(\sum \cos 2\varphi_i\right)^2 + \left(\sum \sin 2\varphi_i\right)^2}}{\sqrt{M}}$$

arXiv:1507.06194
Event-Shape Engineering (2)

- $p_T$ spectra for $\pi$, $K$, $p$
  - Hardening for large $q_2$
  - Softening for small $q_2$
  - Magnitude depends on mass

- Quantify with Blast-Wave fit
  - Parameterization of hydrodynamic expansion
  - Fixed temperature $T$, allow change of expansion velocity $\beta_T$
  - $\beta_T$ larger than inclusive for large $q_2$
  - $\beta_T$ smaller than inclusive for small $q_2$

- $q_2$ (shape) and $\beta_T$ (expansion) correlated

Significant input for initial state and hydrodynamic expansion models

Ridges in p-Pb Collisions

- Collective nature of ridges in p-Pb collisions established at mid-rapidity (8 particle cumulants, mass ordering)
  - How long range is this effect?
  - Differences of p and Pb side?
- Correlations of hadrons at mid rapidity (tracklets) and forward inclusive muons
  - $\mu$ dominated by $\pi$ and K at low $p_T$, and
  - by heavy flavor decays for $p_T > 2$ GeV/c

p-Pb: $p \rightarrow Pb$
  "p going"

Pb-p: $Pb \rightarrow p$
  "Pb-going"

$\mu$ arm

Particle fraction vs. $p_T$

arXiv:1506.08032
Jet contribution reduced by low-multiplicity subtraction
• Double ridge to $\Delta \eta \sim 5$ and $\eta \sim \pm 4$ ($p$ and Pb-going)
• Quantified by $v_2^\mu = V_{2\Delta}^{\mu-h} / \sqrt{V_{2\Delta}^{h-h}}$
• $p$-going < Pb-going (16%)
• Comparison to AMPT model
  – Microscopic description of partonic and hadronic interactions
• Similar trend for inclusive $\mu$
• For $p_T > 2$ GeV/c, HF > 60%
  – $v_2^{HF}(AMPT) \sim 0$
  – $v_2^{HF}$ (data) > 0? or different particle composition?

arXiv:1506.08032
J/ψ Production in p-Pb

- J/ψ production as a function of event activity
- Compare to $N_{\text{coll}}$ scaled pp ($\rightarrow Q_{\text{pPb}}$)
- Slight enhancement in Pb-going direction
- Suppression at mid-rapidity and in p-going direction

Reproduced within uncertainties by cold nuclear-matter models

arXiv:1506.08808
J/ψ Production in p-Pb (2)

- $\Delta \langle p_T^2 \rangle = \langle p_T^2 \rangle_{pPb} - \langle p_T^2 \rangle_{pp}$

- Harder $p_T$ distribution with increasing event activity

- Larger $\langle p_T^2 \rangle$ in p-going direction than in Pb-going direction

Model comparison suggests influence of initial and final-state rescattering

arXiv:1506.08808
• Exclusive $\psi(2S)$ photo-production in nuclear target
  – $\psi(2S) \rightarrow l^+l^-$
  – $\psi(2S) \rightarrow l^+l^- + \pi^+\pi^-$
  – (separate in $\mu\mu$ and ee channel)

• Model constraints
  – Uncertainties on baseline
  – Strong shadowing disfavored

• Surprising difference of $\sigma(\psi(2S))/\sigma(J/\psi)$ in Pb-Pb and pp
  – Nuclear effects different for 1S than for 2S state?

arXiv:1508.05076
\( \frac{dN_{\text{ch}}}{d\eta} @ 13 \text{ TeV} \)

- Minimum-bias trigger using V0 and AD (new detector)
  - \(-3.7 < \eta < -1.7, 2.8 < \eta < 5.1\)
  - \(-7.0 < \eta < -4.8, 4.9 < \eta < 6.3\)
    - Sensitive to about 96.6\% of inelastic cross section
- Tracklets in two innermost detector layers (SPD, 3.9 cm, 7.6 cm)
- Two event classes
  - Inelastic events
  - At least one charged particle in \( |\eta| < 1 \)
- ALICE and CMS consistent

ALICE-PUBLIC-2015-005
## Summary

### Large number of Run I analyses finalized across all ALICE topics

**Precision Measurements**
- Mass difference of nuclei and antinuclei $\rightarrow$ bound on CPT invariance
- Sign of quark mass dependence in heavy flavor energy loss?

**Novel Techniques**
- Hadron-jet correlations assess charged jets at 20 GeV/c in Pb-Pb
- Event shape engineering maps out initial state and hydrodynamical expansion

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Plus many more, including first results at 13 TeV

ALICE up and running … eagerly waiting for heavy ions