ALICE Status Report

127th LHCC Meeting
21 September 2016
C. Zampolli(*) for the ALICE Collaboration

(*) CERN and INFN, Bologna
ALICE Status Report

Outline
- ALICE data (taking, processing)
- Latest Results
- Upgrade
ALICE 2016 data taking

- **Very stable operations**: high operational efficiency >92%
  - central barrel: Minimum Bias, High Multiplicity, Calorimeter, Diffractive triggers
  - muon arm: Muon triggers

ALICE Performance 2016, pp $\sqrt{s} = 13$ TeV

2016-09-09 23:19:53

Minimum bias: 731M
High multiplicity: 400M

ALICE Performance 2016, pp $\sqrt{s} = 13$ TeV

2016-09-09 23:19:53

Dimuon and single muon high-$p_T$: 8.3 pb$^{-1}$
Single muon low-$p_T$: 0.47 pb$^{-1}$
High multiplicity: 3.5 pb$^{-1}$
CALO high threshold: 3.5 pb$^{-1}$
CALO low threshold: 0.36 pb$^{-1}$
PHOS $\gamma$: 2.3 pb$^{-1}$
Double gap: 0.29 pb$^{-1}$
Minimum bias: 0.011 pb$^{-1}$
ALICE 2016 data taking

- **Very stable operations**: high operational efficiency >92%
  - central barrel: Minimum Bias, High Multiplicity, Calorimeter, Diffractive triggers
  - muon arm: Muon triggers

**Example: TPC currents stability**

- Trigger rate to TPC: 200 – 300 Hz in this run
- Laser calibration intervals
- Average currents in the 36 TPC MWPC readout chambers

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**ALICE 2016 data taking**

- **Very stable operations:** high operational efficiency >92%
  - central barrel: Minimum Bias, High Multiplicity, Calorimeter, Diffractive triggers
  - muon arm: Muon triggers

2016 “Fast-track” reconstruction

3e9 events

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ALICE TPC: RCU2

- New Readout Control Unit (RCU2) for **better radiation tolerance** and **faster readout** (factor 2 for central Pb-Pb)

- Experience: **very stable**
  - 1 issue every ~50h of running time
  - Automatic error recovery during data taking (PAUSE AND RESET)

Faster optical readout link: DDL2 @ 3.125 Gb/s

Increased bus granularity (x2) ➔ highly parallelized readout

Flash-based FPGA: MicroSemi SmartFusion2

2016

Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec

Installation | Operation | Operation, firmware upgrades | Operation | pPb running

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Larger than expected Space Point distortions in the TPC seen in Run2 via tracking observables (Distance of Closest Approach to primary vertex shown here)

- ~ proportional to interaction rate
- due to drifting columns of ions
  - charge originating from edges of 6 IROC chambers (and possibly two further chambers)

Before calibration
TPC Space Point Distortions

- Larger than expected Space Point distortions in the TPC seen in Run2 via tracking observables (Distance of Closest Approach to primary vertex shown here)

- \( \sim \) proportional to interaction rate
- due to drifting columns of ions
  - charge originating from edges of 6 IROC chambers (and possibly two further chambers)

- Time dependent calibration procedure to correct the distortions as foreseen for Run3
  - Use inner (ITS) and outer (TRD, TOF) detectors
  - 3D distortion vector for each TPC voxel
  - Smooth parameterization used in reconstruction
TPC Space Point Distortions

• Larger than expected Space Point distortions in the TPC seen in Run 2 via tracking observables (Distance of Closest Approach to primary vertex shown there)

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• ~ proportional to interaction rate
• due "space charge columns" – charge originating from edges of IROC chambers (and possibly between two pairs of sectors) drifting to central electrode

• Time dependent calibration procedure to correct the distortions as foreseen for Run 3
  – Use inner (ITS) and outer (TRD, TOF) detectors
  – 3D distortion vector for each TPC voxel
  – Smooth parameterization used in reconstruction

Pb-Pb @ 5.02 TeV, IR = 7.5 kHz

Before calibration

After calibration
TPC SP Distortions Calibration - performance

DCArφ vs TPC sector

Impact parameter resolution

Pb-Pb 2015, IR = 4.7kHz

TPC tracks, $p_T > 2$ GeV/c

before / after correction

$\Delta$CArφ (cm)

TPC sector

Low IR

High IR

ITS-TPC tracks

$d_0$ resolution (μm)

$\sqrt{p_T}$ (GeV/c)
From data... 

...to results
J/ψ suppression in Pb-Pb

- Nuclear modification factor for hard probes allows the direct comparison of particle production in pp and Pb-Pb collisions (binary scaling)

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

\[ R_{AA} = 1 \] if no nuclear effects in AA collisions; 
\[ ! = 1 \] in case of hot/cold matter effects

- Suppression with almost no centrality dependence
- Larger \( R_{AA} \) (15%) than at lower energy (recombination?), but within uncertainties
- Ratio of \( R_{AA} \) at the two energies \( \rightarrow \) reduced uncertainties on \( R_{AA} \) and models
- Data compatible with models within uncertainties
**J/ψ suppression in Pb-Pb**

- Nuclear modification factor for hard probes allows the direct comparison of particle production in pp and Pb-Pb collisions (binary scaling)

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- Suppression with almost no centrality dependence
- Larger \( R_{AA} \) (15\%) than at lower energy (recombination?), but within uncertainties

\[ R_{AA} \text{ as a function of } p_T \text{ to study regeneration at low } p_T \]
- Higher \( R_{AA} \) at 5 TeV in \( 2 < p_T < 6 \text{ GeV/c} \)?
**$R_{AA}$ of heavy flavour decay muons**

- First measurement of open heavy flavour at forward rapidity in Pb-Pb collisions at 5.02 TeV

- Similar suppression at 5.02 TeV compared to 2.76 TeV

- Increase of suppression (~2.7x) from *peripheral* to *central* and at intermediate $p_T$

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**$R_{AA}$**

- Centrality 0-10%, Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV
- Centrality 0-10%, Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV
- Syst. uncertainty

**$R_{AA}$**

- Centrality 0-10%
- Centrality 20-40%
- Centrality 60-80%
- Syst. uncertainty

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*ALICE Preliminary*
**$R_{\text{CP}}$ of heavy flavour decay muons**

- First measurement of open heavy flavour at forward rapidity in Pb-Pb collisions at 5.02 TeV

$$R_{\text{CP}}(p_T) = \frac{\langle T_{\text{AA}} \rangle_p \frac{d\sigma^C}{dp_T}}{\langle T_{\text{AA}} \rangle_c \frac{d\sigma^P}{dp_T}}$$

$R_{\text{CP}} \rightarrow$ to compare central and peripheral production

- Increase of suppression from peripheral to central

![Graph showing $R_{\text{CP}}$ as a function of $p_T$ for different centralities and momenta.](image)
$R_{AA}$ and $R_{pA}$ for electrons from beauty decays

- Compare beauty, charm, light quarks: mass dependence of energy loss
- $R_{pA}$ (defined analogously to $R_{AA}$) used to study initial state effects in CNM
- Results from p-Pb data at 5.02 TeV and Pb-Pb data at 2.76 TeV

Impact parameter distribution used to
  - enhance the sample of electrons from beauty (p-Pb), then cleaned using a cocktail technique
  - extract the electrons from beauty decays using Monte Carlo templates to the various background sources (Pb-Pb)
**R\(_{AA}\) and R\(_{pA}\) for electrons from beauty decays**

- Compare beauty, charm, light quarks: mass dependence of energy loss
- R\(_{pA}\) (defined analogously to R\(_{AA}\)) used to study initial state effects in CNM
- Results from p-Pb data at 5.02 TeV and Pb-Pb data at 2.76 TeV

![Graph showing nuclear modification factor vs. \(p_T\) for beauty and charm decays](image)

- **R\(_{pA}\)** consistent with 1 (within uncertainties)
- **R\(_{AA}\)** is a 3σ effect at high \(p_T\)
- Dominant beauty contribution

**Charm/beauty ordering**

-charm 
- beauty

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$R_{AA}$ of charged particles

- $R_{AA}$ of charged hadrons at 2.76 TeV showed centrality dependence (the more central events, the stronger suppression)
  - 5.02 TeV: larger particle density may lead to a hotter/denser medium
- Use pp reference data at 5.02 TeV measured by ALICE, and Pb-Pb data taken at low IR (small TPC Space point distortions)
- No significant difference so far between $R_{AA}$ at 2.76 TeV and 5.02 TeV
  - Waiting for more data
Charged hadrons vs multiplicity in pp:

Strangeness

- Compare the behaviour as a function of multiplicity of pp to p-Pb and Pb-Pb

  - Strangeness enhancement with multiplicity
    - Increasing with strangeness content
  - Challenge for models: microscopic description of particle production
    - Similarities between small systems (pp, p-Pb)
      → Collectivity? Radial flow?
  - In pp at 7 TeV, ten V0 multiplicity classes from I to X defined as multiples (from 3.5 to 0.4) of \(<dN_{ch}/d\eta>_{\mathrm{INEL}}^0 (~6)\)
    - \(\pi, K, K^0_S, K^*, p, \Xi, \Lambda, \Omega\) studied

\[ \text{Ratio of yields to } (\pi^+ + \pi^-) \]

\[ \begin{align*}
  \text{ALICE} & \quad \text{pp, } \sqrt{s_N} = 7 \text{ TeV} \\
  \text{p-Pb, } \sqrt{s_{NN}} = 5.02 \text{ TeV} & \quad \text{Pb-Pb, } \sqrt{s_{NN}} = 2.76 \text{ TeV}
\end{align*} \]

\[ \text{PYTHIA8} \quad \text{DIPSY} \quad \text{EPOS LHC} \]

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

\[ \text{Ratio to pions} \]

\[ \text{ALICE Preliminary} \quad \text{pp } \sqrt{s_N} = 7 \text{ TeV} \quad \text{p-Pb } \sqrt{s_{NN}} = 5.02 \text{ TeV} \quad \text{Pb-Pb } \sqrt{s_{NN}} = 2.76 \text{ TeV} \]

arXiv:1606.07424

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Charged hadrons vs multiplicity in pp: \( p_T \) Spectra

- Compare the behaviour as a function of multiplicity of pp to p-Pb and Pb-Pb

- Spectra become harder with increasing multiplicity
- Baryons exhibit the effect more than mesons (mass ordering)
Charged hadrons vs multiplicity in pp: Baryon to Meson ratio

- Compare the behaviour as a function of multiplicity of pp to p-Pb and Pb-Pb

High mult
Low mult

- Baryon to meson ratios: qualitative similar behaviour
Charged hadrons vs multiplicity in pp: Baryon to Meson ratio

- Compare the behaviour as a function of multiplicity of pp to p-Pb and Pb-Pb

- Baryon to meson ratios: qualitative similar behaviour

- Similar behaviour between pp and p-Pb in terms of $<\beta_T>$ vs $T_{\text{kin}}$ (from Blast-Wave fits)
Anisotropic flow in Pb-Pb collisions

- Anisotropic distribution of matter in the overlap region leads to anisotropies in the observed final particle momentum
  - Sensitive to the initial conditions, EOS, transport properties
  - Studied through a Fourier decomposition of the azimuth distribution

\[ E \frac{d^3N}{dp^3} = \frac{1}{2\pi} \frac{d^2N}{p_T dp_T d\eta} \left\{ 1 + 2 \sum_{n=1}^{\infty} v_n(p_T, \eta) \cos[n(\varphi - \Psi_n)] \right\} \]

- Increase in \( v_2, v_3, v_4 \) of 3%, 4%, 10% respectively
- No significant centrality dependence
- Agreement with theoretical predictions
Dielectrons in Pb-Pb

- Dielectrons are penetrating probes that are emitted continuously during the evolution of the system without being affected by it
  - Study of the different phases of the collision
  - First measurement in Pb-Pb (low mass: $m_{ee} < 700 \text{ MeV}/c^2$)

- No enhancement of dielectron production observed
Dielectrons in Pb-Pb

- Dielectrons are penetrating probes that are emitted continuously during the evolution of the system without being affected by it
  - Study of the different phases of the collision
  - First measurement in Pb-Pb (low mass: $m_{ee} < 700$ MeV/$c^2$)
  - Virtual photons contribution “r” extracted in $100 < m_{ee} < 300$ MeV/$c^2$

Perspectives from the ALICE upgrade: benefit from new ITS (suppression of background) and TPC continuous readout (increased event rate)
The ALICE upgrade

**Motivation:** Focus on high-precision measurements of rare probes at low $p_T$
- can not be selected with hardware trigger
- need to record large sample of events

**Target:** Pb-Pb recorded luminosity: $\geq 10 \text{ nb}^{-1}$
- gain in statistics: factor 100 for selected probes!
- plus pp and pA data

**Strategy:**
- read out all Pb-Pb interactions at a maximum rate of 50 kHz with a minimum-bias trigger or continuously (TPC)
- perform online data reduction
ALPIDE sensor

- **Monolithic** (detection and readout) active pixel sensor (MAPS)
- Main parameters of **final prototype**
  - Dimensions: 30 mm x 15 mm
  - Pixel Matrix: 1024 cols x 512 rows
  - Pixel pitch: 29 µm x 27 µm
  - Includes all final functionalities
  - 8 sectors with different pixels

**Used for Upgraded ITS and MFT**

**Final APLIDE chip, very promising preliminary results**
More news from ALICE upgrade

- **TPC**: pre-production (final design) of GEM readout chambers started
  - OROC chamber will be installed in the ALICE cavern for the p-Pb run and beyond

- **SAMPA** (common TPC, MUON readout ASIC): MPW2 (Multi-Project Wafer) under test
  - First (promising!) results show that the noise within specifications
    - N.B. digital readout must be active during signal sampling in continuous readout
  - Gain, signal shaping, linearity, and X-talk according to specifications
## ALICE new publications

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<thead>
<tr>
<th>Status</th>
<th>System</th>
<th>Energy</th>
<th>Title</th>
<th>Reference</th>
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<tr>
<td>Submitted</td>
<td>PbPb</td>
<td>2.76 TeV</td>
<td>Higher harmonic flow coefficients of identified hadrons in Pb-Pb collisions at ( \sqrt{s_{NN}} = 2.76 ) TeV</td>
<td>arXiv:1606.06057 JHEP</td>
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<td>5.02 TeV</td>
<td><strong>J/ψ</strong> suppression at forward rapidity in Pb-Pb collisions at ( \sqrt{s_{NN}} = 5.02 ) TeV</td>
<td>arXiv:1606.08197 PLB</td>
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<td>PbPb, pp</td>
<td>5.02 TeV</td>
<td>Measurement of electrons from beauty hadron decays in p-Pb collisions at ( \sqrt{s_{NN}} = 5.02 ) TeV and Pb-Pb collisions at ( \sqrt{s_{NN}} = 2.76 ) TeV</td>
<td>arXiv:1609.03898 JHEP</td>
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<td><strong>Jet-like correlations</strong> with neutral pion triggers in pp and central Pb-Pb collisions at 2.76 TeV</td>
<td>arXiv:1608.07201 PLB</td>
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<td>pp</td>
<td>7 TeV</td>
<td>Multiplicity-dependent enhancement of strange and multi-strange hadron production in proton-proton collisions at ( \sqrt{s} = 7 ) TeV</td>
<td>arXiv:1606.07424 PRL</td>
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<td>Accepted</td>
<td>PbPb</td>
<td>2.76 TeV</td>
<td>Correlated event-by-event fluctuations of flow harmonics in Pb-Pb collisions at ( \sqrt{s_{NN}} = 2.76 ) TeV</td>
<td>arXiv:1604.07663 PRL</td>
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<td>pPb, pp</td>
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<td>D-meson production in p-Pb collisions at ( \sqrt{s_{NN}} = 5.02 ) TeV and in pp collisions at ( \sqrt{s} = 7 ) TeV</td>
<td>arXiv:1605.07569 JHEP</td>
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# ALICE new publications

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<tr>
<td>Published</td>
<td>PbPb</td>
<td>2.76 TeV</td>
<td>Pseudorapidity dependence of the <strong>anisotropic flow</strong> of charged particles in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV</td>
<td>In press</td>
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<td>Differential studies of inclusive $J/\psi$ and $\psi(2S)$ production at forward rapidity in Pb-Pb collisions at $\sqrt{s_{N_N}} = 2.76$ TeV</td>
<td>JHEP 05 (2016) 179</td>
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<td>Measurement of <strong>transverse energy</strong> at midrapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV</td>
<td>Phys. Rev. C 94, 034903</td>
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<td><strong>Elliptic flow of electrons</strong> from heavy-flavour hadron decays at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV</td>
<td>JHEP 09 (2016) 028</td>
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<td>5.02 TeV</td>
<td>Centrality dependence of the <strong>charged-particle multiplicity</strong> density at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV</td>
<td>Phys. Rev. Lett. 116 (2016) 222302</td>
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<td>Centrality dependence of $\psi(2S)$ suppression in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV</td>
<td>JHEP 06 (2016) 50</td>
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<td>Published</td>
<td>pPb</td>
<td>5.02 TeV</td>
<td>Measurement of <strong>D-meson</strong> production versus multiplicity in p-Pb collisions at ( \sqrt{s_{NN}} = 5.02 ) TeV</td>
<td>JHEP 8 (2016) 1-44</td>
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<td>Multiplicity dependence of charged <strong>pion, kaon, and (anti)proton</strong> production at large transverse momentum in p-Pb collisions at ( \sqrt{s_{NN}} = 5.02 ) TeV</td>
<td>Phys. Lett. B 760 (2016) 720</td>
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More results coming...

...and more...

...presented also at...

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Summary and conclusions

• ALICE is smoothly taking data which are being successfully calibrated and reconstructed
  – Offline calibration procedure developed to correct for the TPC space point distortions seen in Run2 based on interpolation of the interpolation of the ITS (inner), TRD and TOF (outer) tracks to the TPC
• Continuing study properties of the hot nuclear matter on Pb-Pb data
  – High-statistics Run2 data samples
  – Data at different energies don’t show for the moment significant differences (except, possibly, for the J/ψ)
• The analyses of pp and p-Pb data as a function of multiplicity continue to produce intriguing results about collective phenomena in small systems
• ALICE upgrade activity in full swing: characterising final components

More results are coming, stay tuned!
BACK-UP
Charged hadron vs multiplicity in pp

- Compare the behaviour as a function of multiplicity of pp to p-Pb and Pb-Pb

- In pp at 7 TeV, ten V0 multiplicity classes from I to X defined as multiples (from 3.5 to 0.4) of \(<dN_{ch}/d\eta>^{_{INEL}>0}(\sim6)"

- \(\pi, K, K^0_S, K^*, p, \Xi, \Lambda, \Omega\) studied

See also F. Bellini, 124th LHCC