ALICE Status Report

Stefania Bufalino (INFN and Politecnico di Torino)
on behalf of the ALICE Collaboration

141st Meeting of the LHCC, February 19th 2020
Outline

• New physics results and papers since last LHCC
  • + a set of preliminary results recently approved
  • Largest number of papers ever in 2019: 47 papers submitted

• ALICE upgrade: goal and commissioning status

• LS2 status and plans

• Summary
Heavy Flavour: charm down to $p_T=0$

- First measurement of Heavy Flavours production in heavy-ion collisions at the LHC down to 0 GeV/c
- ALICE Upgrade is crucial to reduce the background and improve the significance of the measurement

Mass spectrum $D^0 \rightarrow K\pi$

- ALICE Preliminary
- $\sqrt{s_{NN}}=5.02$ TeV
- $D^0 \rightarrow K^-\pi^+$ and charge conjugate
- $0<p_T<1$ GeV/c

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Charm quark: interactions in the QGP

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

ALICE Preliminary

D^0 meson

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

\(|y|<0.5\)

- 0–10%
- 30–50%

± 1.0% BR systematic uncertainty not shown

low \(p_T\): \(R_{AA} > 1\)
→ charm conservation

low \(p_T\): \(R_{AA} < 1\)
→ shadowing

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Charm quark: interactions in the QGP

Prompt $D$ mesons: comparison of $R_{AA}$ and $v_2$ simultaneously

→ Low $p_T$ well described via elastic collisions and/or recombination in expanding hydrodynamic medium
→ Handle on the heavy quark diffusion coefficients

$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{dN^{AA}}{dp_T} / \frac{d\sigma^{pp}}{dp_T}$

low $p_T$: $R_{AA} > 1$ → charm conservation

low $p_T$: $R_{AA} < 1$ → shadowing
Heavy quark hadronization

$\Lambda_c/D$ ratio

- Sensitive to hadronisation mechanism in hadronic collisions
  - Already an enhancement in small systems

- Multiplicity dependence in pp collisions
  - Enhancement over default Pythia
  - Color reconnection models describe data

"$e^+e^-$- like fragm."
Heavy quark hadronization

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- First measurement of the $\Lambda_c$ fragmentation function
  - First step in the direction of a complete understanding of the fragmentation mechanisms of heavy flavour mesons and baryons in pp and Pb-Pb collisions
Jet substructure in pp

The modification of the jet yields and selected hard substructure can constrain dynamical properties of the hot and dense QCD medium.

Data well described by PYTHIA-based generators within the uncertainties.

https://doi.org/10.1016/j.physletb.2020.135227
Jet substructure in Pb-Pb

- Aperture angle dependence of $z_g$ in medium compared to vacuum (smeared) reference
- Suppression of symmetric splittings at large aperture angles in HIC relative to pp

https://doi.org/10.1016/j.physletb.2020.135227
Jet substructure in Pb-Pb

https://doi.org/10.1016/j.physletb.2020.135227

Data shows in Pb-Pb a shift towards smaller number of splittings w.r.t pp collisions which is qualitatively compatible with more quark like fragmentation.

$n_{SD} =$ number of splitting in the declustering process that satisfy $z > z_{cut} = 0.1$ (Soft Drop selection)

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Anisotropic flow

Initial state spatial anisotropies \( \varepsilon_n \) are transferred into final state momentum anisotropies \( v_n \) by pressure gradients, flow of the Quark Gluon Plasma.
Anisotropic flow

Higher harmonic flow $V_n$ ($n \geq 3$)
- Sensitive to the transport properties
- Modeled as the sum of linear and non-linear response to initial anisotropy $\varepsilon_n$

\[ V_n = V_{nNL} + V_{nL} \]

- Corresponds to lower order initial anisotropy coefficient $\varepsilon_2$ and $\varepsilon_3$
- Magnitude of non-linear response in $V_n$

- Expected to correspond to the same order initial anisotropy coefficient $\varepsilon_n$
- Magnitude of linear response in $V_n$

MC event: location of nucleons

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Non-linear mode of identified hadrons

- Mass ordering at low $p_T$
- Momentum increase scales with hadron mass
- Described by hydrodynamic model iEBE-VISHNU

https://arxiv.org/abs/1912.00740

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Non-linear flow mode

- Probes the symmetry plane correlations
- Comparison with calculations from hydrodynamic models
  - different parametrization of shear viscosity ($\eta/s$) and bulk viscosity ($\zeta/s$) over entropy ratios
  - strong constraints on the initial conditions and transport properties of the QGP


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Hypertriton lifetime in Pb-Pb

Hypertriton: lightest known hypernucleus
- bound state of p, n and Λ
- Mass\(^{[1]}\) = 2.992 GeV/c\(^2\)
- Small \(E_{\Lambda}\) (~130 keV) \(\rightarrow\) lifetime expected to be slightly below the free \(\Lambda\)-Lifetime\(^{[2]}\) ~263 ps

- Pb-Pb 2015 dataset published last year
- Results from 2018 Pb-Pb data + Machine Learning methods represent the world best measurement
- Data crucial to constraint models with different hypertriton structure and final state interaction

Two-body decay schema taken from https://doi.org/10.1051/epjconf/201611703003

Hypertriton measurement in pp

Hypertriton: lightest known hypernucleus
- bound state of \( p, n \) and \( \Lambda \)
- Mass\(^1\) = 2.992 GeV/c\(^2\)
- Small \( E_{\text{BA}} \) (~130 keV) \( \rightarrow \) lifetime expected to be slightly below the free \( \Lambda \)-Lifetime\(^2\) ~ 263 ps

- First observation of (anti-)hyper-nuclei production in pp collisions at the LHC
- Extremely rare: dedicated trigger for heavily ionising particles devised in the ALICE Transition Radiation Detector
- Yield measurement in pp will help for a better understanding of the production mechanism

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ALICE LS2 Upgrade Strategy

Goal
- Physics program for LHC Run 3+4: moving to a precision-measurement phase
  - heavy flavour (charm and beauty), low $p_T$ charmonia, hypernuclei, virtual thermal photons
- Luminosity target: (10 +3) nb$^{-1}$ with Pb-Pb collisions ⇒ gain of a factor 100 in statistics over the Run 1+Run 2 programme

How
- Read out all Pb-Pb interactions at a maximum rate of 50 kHz
- Improve vertexing and tracking at low $p_T$
- Improve Muon Performance
- Preserve and strengthen detector specificities: PID, lightweight and precise trackers, low magnetic field
ALICE LS2 Upgrade

Inner Tracking System

Time Projection Chamber

Muon Forward Tracker

Fast Interaction Trigger

Upgraded readout for TOF, TRD, Muon, ZDC, calorimeters

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ALICE LS2 Upgrade

New Inner Tracking System + Muon Forward Tracker

10 m² of CMOS monolithic active pixel sensors
- higher granularity and reduced material budget
- improved resolution for heavy-flavor vertices
- faster readout

TPC Upgrade
Replacement of the MWPC-based readout by detectors employing GEMs to allow TPC operation in continuous mode

Upgraded read-out for many detectors, new integrated Online-Offline, new Fast Interaction Trigger detector
- Record all events at up to 50 kHz in Pb-Pb (1 kHz during Run2)
- Data reduction from 1 TB/s to 85 GB/s via online reconstruction
- Continuous readout of all data into a dedicated computing facility
We have delayed the start of the detector installation sequence by 5 weeks with respect to the Sep. 2019 LHCC in-depth review, which allowed us to carefully address some detector issues and perform extended detector commissioning on the surface.

Installation of TPC: Mar. 23rd 2020
Installation of ITS: Jul. 23rd 2020
Start of global commissioning: Nov. 26th 2020
End of access to the cavern: May 1st 2021
⇒ 155 days of global commissioning = 22 weeks = 5 months
Removal shieldings and opening L3 doors (3-15 Dec, 2018)
Removal of detectors – first 6 LS2 days (3-10 Dec, 2018)

- TPC GEMs: 3 Dec
- ZEM: 3 Dec
- BLM: 4 Dec
- **Compensator magnet**: 4 Dec
- Miniframe beampipe: 5 Dec
- PMD: 7 Dec
- FMD1-V0A and T0A: 10 Dec
- ADA: 10 Dec
- MCH ST2: 10 Dec
TPC PP0, PP1 and PP4 disconnection (5-19 Dec, 2018)
ITS PP0&PP1 disconnection (11-20 Dec, 2018)
Miniframe extraction (10 Jan, 2019)
Move TPC to parking position (11 Feb, 2019)
Remove SPD, FMD3, V0/T0 (20-21 Feb, 2019)
Move TPC to surface (SX2) (4 Mar 2019)
TPC Upgrade commissioning

- Remove Services and FEE (outside cleanroom)
- Uninstall MWPC ROC
- Install GEM ROC
- Install new FEC + test
- Ready for transportation to SX2

- TPC in cleanroom. Cleaning & irradiation tests: 7 Mar
- FC HV infrastructure modification: 25 Apr (A), 13 May (A), 14 Jun (A), 5 Jul (A), 11 Oct (A)
- Survey, shimming, sealing: 16 Aug (C), 25 Aug (C), 25 Oct (C), 16 Sep (C)
- Pre-commissioning with cosmic, Laser, Pulser, Xray: 5 Aug (C), 25 Oct (C), 17 Mar, 20 Mar 2020

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TPC Upgrade commissioning

Laser data for all sector pairs available

Cosmic rays with GEM
ITS Upgrade status

Based on novel MAPS (ALPIDE)

- 10 m² active silicon area (12.5 G-pixels)
- Nr. Layers 7 (6 for old ITS)
- Spatial resolution ~5x5μm² all layers
  (old ITS: 12x100μm² for inner, 20x830μm² for outer)
- X/X₀/layer (first three layers): 0.35% (1.1% first 2 layers of old ITS)

<table>
<thead>
<tr>
<th></th>
<th>On-detector</th>
<th>Spares</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPIDE sensor</td>
<td>~ 27000</td>
<td></td>
<td>✓</td>
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<tr>
<td>IB Staves</td>
<td>48</td>
<td>50</td>
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<tr>
<td>OB HICs</td>
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<td>188</td>
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<tr>
<td>OL Staves</td>
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<td>10</td>
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<tr>
<td>ML Staves</td>
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<td>6</td>
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<tr>
<td>Readout Units</td>
<td>192</td>
<td>30</td>
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<tr>
<td>Power Boards</td>
<td>142</td>
<td>38</td>
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</tr>
<tr>
<td>Large Carbon Structures</td>
<td>24</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
ITS Upgrade: assembly

Half Outer-Barrel Top

Half Inner-Barrel Top

Half Inner-Barrel Bottom

Half Outer-Barrel Bottom
ITS: outer barrel assembly

“old ITS” displayed in the ALICE exhibition area
ITS Upgrade commissioning

Extremely low noise by masking few pixels

Run 001098 (15 x 10^6 events @ 50 kHz, VBB = -3 V, THR = 100 e tuned)

fake-hit rate (per pixel and event)

number of pixel vs hit frequency

- 1: 5853
- 2: 2991
- 3-100: 57
- 101-0.1%: 27
- 0.1%-10%: 13
- 10%-99%: 6
- >99%: 24

number of masked pixels (out of 28 x 10^6)
ITS Upgrade commissioning

Extremely low noise by masking few pixels

- We get around 1 cosmic track per second
- We started analyzing “real” data
- Goal: study track and cluster parameters, alignment

Run 001098 (15 x 10^6 events @ 50 kHz, VBB = -3 V, THR = 100 e^− tuned)
Commissioning status and plans

<table>
<thead>
<tr>
<th>Systems</th>
<th>Installation</th>
<th>Validation</th>
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</thead>
<tbody>
<tr>
<td>FLP</td>
<td>Done</td>
<td>Ongoing</td>
</tr>
<tr>
<td>EPN</td>
<td>Prototype</td>
<td>Feb</td>
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<tr>
<td>PDP</td>
<td>--</td>
<td>Ongoing</td>
</tr>
<tr>
<td>DCS</td>
<td>New nodes in March</td>
<td>Ongoing for Detectors</td>
</tr>
<tr>
<td>CTP</td>
<td>Ongoing</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

- **Global systems**

- **Detectors**

<table>
<thead>
<tr>
<th>Systems</th>
<th>Installation at P2</th>
<th>Commissioning Surf</th>
<th>Commissioning Pit</th>
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<tbody>
<tr>
<td>CPV</td>
<td>FW development</td>
<td></td>
<td>Feb</td>
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<tr>
<td>EMCal/Dcal</td>
<td>FW development</td>
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<td>Dcal ongoing</td>
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<tr>
<td>FDD</td>
<td>Aug/Sept Construction</td>
<td>September</td>
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<tr>
<td>FT0</td>
<td>June/July-Oct October</td>
<td>Construction</td>
<td>July</td>
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<tr>
<td>FV0</td>
<td>Construction</td>
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<td>July</td>
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<td>HMPID</td>
<td>FW development</td>
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<td>ITS</td>
<td>July 23 Cosmics/Noise</td>
<td>August</td>
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<tr>
<td>MCH</td>
<td>Chamber Work</td>
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<td>Ongoing</td>
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<td>MID</td>
<td>Chamber Work</td>
<td></td>
<td>Ongoing</td>
</tr>
<tr>
<td>MFT</td>
<td>June 11 Construction</td>
<td>July</td>
<td></td>
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<tr>
<td>PHOS</td>
<td>FW development</td>
<td></td>
<td>Feb</td>
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<tr>
<td>TOF</td>
<td>FW development</td>
<td></td>
<td>Ongoing</td>
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<tr>
<td>TPC</td>
<td>March 23 Cosmics/Chamber Test</td>
<td>May</td>
<td></td>
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<tr>
<td>TRD</td>
<td>FW development</td>
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<td>Ongoing</td>
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<tr>
<td>ZDC</td>
<td>FW and Maintainance</td>
<td>September</td>
<td></td>
</tr>
</tbody>
</table>

- **ALICE global system and subsystem commissioning progressing well**

- **More and move evolving commissioning activities in 2020**
ALICE O² project

O²/FLP
CR1 First Level Processors
Common readout Units

TPC 3.45 TByte/s
ITS 40 GByte/s
TRD 4GByte/s
Rest 21 Gbyte/s

20 688 fibers

O²/EPN
CR0 Event Processing Nodes

CTP
Central Trigger Processor
Distribution of timing info, heartbeat trigger

Sub-Timeframes
(10-20 ms)

635GByte/s
864 fibers

• First Level Processors (FLPs) to receive detector data (~3TB/s) from detector
• Event Processing Nodes (EPNs) to process sub-timeframe
• Physics and Data Processing (PDP) on grid and EPNs

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Summary

• Many interesting results from Pb-Pb 2018 data
• New published results help to better constraint the properties of the QGP
• Run 3 and Run 4 will be crucial for many measurements
  • shown today: heavy flavour, low $p_T$ charmonia, hypernuclei
Summary

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• New published results help to better constraint the properties of the QGP
• Run 3 and Run 4 will be crucial for many measurements
  • shown today: heavy flavour, low $p_T$ charmonia, hypernuclei

• LS2 activities are progressing on track
• Global system and subsystem commissioning in full swing