Future measurements from ALICE Run 3 and Run 4

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• Introduction
• ALICE LS2 upgrade
• Preparations for Run 3
• Physics for Run 3 and Run 4
• Future upgrade in LS3
• Summary and Outlook
## LHC Schedule and ALICE Plans

### ALICE LS2 upgrade
- New silicon tracker (ITS2 & MFT)
- TPC Readout planes using GEM
- New Fast Interaction Trigger (FIT)
- New Online/Offline system (O2)
- Upgrade readout of all other detectors

### Global Commissioning (July – Nov)
LHC pilot beam tests (18.10 – 31.10)

### ALICE LS3 upgrade
- New silicon tracker (ITS3)
- Forward Calorimeter (FoCAL)

### LHC Run 3
- Long Shutdown 2 (LS2)
- Run 3
- Long Shutdown 3 (LS3)

### LHC Run 4
- Run 4
- LS4

### ALICE Run3 + Run4
- 13 nb\(^{-1}\) (0.5T, 0.2T) Pb-Pb collisions
- Heavy flavor meson and baryon measurements down to very low \(p_T\)
- Thermal direct radiation via dielectrons
- Quarkonia
- Light nuceli, hyper-nuclei, dibayons
- Forward direct photons

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ALICE upgrade Performance:
ALICE LS2 Upgrade

- New silicon tracker (ITS & MFT)
- TPC Readout planes using GEM
- New Fast Interaction Trigger (FIT)
- New Online/Offline system (O2)
- Upgrade readout of all other detectors

Runs 1 and 2: 1 nb$^{-1}$ of Pb-Pb collisions
- Interaction rate ~8 kHz
- readout rate ≈ 1 kHz

ALICE strategy for Run 3 + Run 4:
- 50 kHz Pb-Pb interaction rate
- Collect L$_{\text{Pb-Pb}}$ = 13 nb$^{-1}$

- Continuous readout and online reconstruction
  → Inspect all MB Pb-Pb collisions at 50 kHz
- x50 statistics increase for many observables
- Improve tracking performance down to low p$_T$
**Inner Tracking System upgrade (ITS2)**
- 7 layers of Si pixel detectors
- Closer to the IP: first layer at $\approx 22$ mm

**Muon Forward Tracker (MFT)**
- New forward vertex detector upstream muon absorber
- 5 layers of Si pixel disks

**Improved tracking efficiency at low $p_T$, improved pointing resolution (x3)**

**ALPIDE (ALICE Pixel Detector)**
- Thinner: for innermost layers $\sim 0.30\% X_0$
- Smaller pixels: $27 \times 29 \, \mu m^2$
- Readout rate: 100 kHz
- 130 000 pixels/cm$^2$
- Max. particle rate: $\sim 100 \, MHz/cm^2$
- Spatial resolution: $\sim 5 \, \mu m$
- Thickness: 50 $\mu m$ for the inner layers
- Fake-hit rate: $< 10^{-9}$ per pixel per event
TPC upgrade

Operate TPC at 50 kHz Pb-Pb collisions
→ no gating grid (GG). ALICE maximum GG operation ~ 3 kHz
→ 4 GEMs to achieve good IBF and continuous readout

- Diameter: 5 m, length: 5 m
- Gas: Ne-CO$_2$-N$_2$, Ar-CO$_2$
- Max. drift time: ~100 μs
- 18 sectors on each side
- Inner and outer read out chambers: IROC, OROC
- Previous detector (Run 1, Run 2):
  - 72 MWPCs, ~550 000 readout pads
  - Wire gating grid (GG) to minimize Ion Back-Flow (IBF)
  - Rate limitation: few kHz
Online – Offline (O2)

Continuous readout

- Readout of detectors and raw data processing (e.g., TPC baseline corrections)

Data compression
- 3.5 TB/s → 600 GB/s

200 First Level Processors (FLP) in CR1

- Synchronous processing
  - Event/time frame building
  - Online reconstruction and calibration (GPU)

250 Event Processing Nodes (EPN) with 2000 GPUs

- Asynchronous reprocessing
  - Final calibration and full reconstruction
Reinstall TPC in ALICE Cavern

Reinstall Miniframe

Install cage and central beampipe

Install MFT and FIT-C

Install FIT-A

Global commissioning

LS2 ends

Jul-Aug '20

Aug-Sep '20

Oct-Nov

Dec-Jan'21

Feb-June

July

Feb? 22
Global Commissioning

TPC: Continuous readout with cosmics, x-rays, and laser

Cosmics

Xrays

ITS: Cosmic ray

~1.5 GeV/c

Tracks with Magnet ON

MFT: TED shots (proton beams on beam dumper)

Global cosmic runs with upgraded detectors and online processing
LHC provided collisions at injection energy during pilot beam test campaigne (18.10 – 31.10)

Pilot beams fully useful for commissioning ALICE
✓ Successful ALICE test campaign with LHC pilot Run
✓ Largely upgraded detector system (several detectors, new readout)
✓ New O2 system for continuous readout, online reconstruction and data reduction

PID by the dE/dx in the TPC from online reconstruction

reconstructed Primary Z-vertex by the ITS

<table>
<thead>
<tr>
<th>Entry</th>
<th>152797</th>
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<tbody>
<tr>
<td>Mean</td>
<td>0.2218</td>
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<tr>
<td>Std Dev</td>
<td>5.598</td>
</tr>
<tr>
<td>Constant</td>
<td>2897 ± 9.1</td>
</tr>
<tr>
<td>Mean</td>
<td>0.2227 ± 0.0144</td>
</tr>
<tr>
<td>Sigma</td>
<td>5.812 ± 0.019</td>
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</table>
Physics topics for Run 3 and Run 4

ALICE Run 3 + Run 4
- 13 nb⁻¹ (0.5T, 0.2T) Pb-Pb collisions
- Heavy flavor meson and baryon measurements down to very low p_T
- Thermal direct radiation via dielectrons
- Quarkonia
- Light nuclei, hyper-nuclei, dibayons
- Forward direct photons

Characterizing the macroscopic long-wavelength QGP properties (transport properties, temperature, new phenomena related to strong EM fields)

Accessing the microscopic parton dynamics underlying QGP properties

Developing a unified picture of particle production from small (pp) to larger (p–A and A–A) systems

Probing parton densities in nuclei at small x and searching for the possible onset of parton saturation.
Dielectrons

Run 2

ALICE Preliminary

Run 3 + 4 with ITS2 (3 nb$^{-1}$ at 0.2 T)

Improvement of dielectron mass spectrum expected in Run 3 + Run 4.
Background yields from know hadronic + HF decays can be subtracted precisely.
Modification of spectral function of $\rho$ meson visible.

Clear contributions from thermal direct radiation visible in IMR.

Medium temperature not affected by blue shift can be extracted. Expected uncertainties: $+10 – 20\%$

**Yields at IMR after HF rejection = thermal radiation from partonic stage**

**LHC expectation**

$T_{\text{slope}} \sim 300$ MeV

$T_{\text{init}} \sim 600$ MeV

**Dielectron excess spectrum**

$\frac{dN}{dM} \approx M^{3/2} \exp(-M/T_S)$
Heavy-quark $R_{AA}$ and $v_2$ give insight into the interactions with the light quarks of the medium and reveal transport properties of the medium.

Precise measurements of charm hadron $v_2$

The first precise measurements of B meson elliptic flow at the LHC
Charm and Beauty $R_{AA}$ and $v_2$

ALICE upgrade foresees a combination of beauty measurements at mid- and forward-rapidity, down to very small $p_T$.

the diffusion coefficient around $T_C$ could be constrained with an uncertainty of about 30–50% of current data.
Enhanced production of charmed/beauty baryons relative to mesons

Insight into the hadronization mechanisms of heavy quarks in QGP and
the existence of [ud] diquarks in the QGP

$\Lambda_c / D^0$ ratio

$\Lambda_b / B^+$ ratio

Oh et al., PRC79 (2009) 044905
Ghosh et al., PRD 90 (2014) 054018
He, Rapp et al. arXiv:1905.9216
Precise comparison of charmonium and bottomonium states: mass/\textit{flavor} dependence of color screening, medium interaction of \textit{qqbar} system, dynamics of charm quark regeneration
ITS3: Truly cylindrical, wafer-size sensors for inner barrel homogeneous inner tracker with ultra-low material budget

- Bent MAPS operated in various test beams (DESY + SPS in July)

<table>
<thead>
<tr>
<th></th>
<th>ITS1</th>
<th>ITS2</th>
<th>ITS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X/X_0$</td>
<td>1.14%</td>
<td>0.38%</td>
<td>0.05%</td>
</tr>
<tr>
<td>innermost radius</td>
<td>39 mm</td>
<td>22 mm</td>
<td>18 mm</td>
</tr>
<tr>
<td>pixel size</td>
<td>50x425 µm²</td>
<td>30x30 µm²</td>
<td>O(15x15 µm²)</td>
</tr>
</tbody>
</table>

- Better pointing angle resolution by x2
- Low $p_T$ (<100 MeV/c) tracking efficiency improves by x1.2-2

LoI: CERN-LHCC-2019-018
**D_{s}B_{s} production and flow**

- Hadronisation of charm and beauty quarks via recombination + enhanced strange-quark production in the QGP.

**Charm and beauty baryons**

- Enhanced production of HF baryons in Pb-Pb collision and probes of diquark correlation and heavy-quark hadronisation and baryon formation.

**Expected improvement of statistical significance by a factor of 2-4 with ITS3**

sensitivity to discriminate azimuthal anisotropy for prompt and non-prompt D_{s}^{+} (charm vs. beauty).
**Low mass dielectrons**

- Less material: fewer conversions
- Better pointing angle resolution: rejection of HF background
- Better tracking at low pT: conversion rejection

**ITS3 improves systematic uncertainties on T by a factor of 2**
FOCAL: forward electromagnetic and hadronic calorimeters

- **FoCal-E**: high-granularity Si-W sampling calorimeter for the measurement of direct $\gamma$ and $\pi^0$
- **FoCal-H**: Pb-Sc sampling calorimeter for photon isolation and jets

Measure isolated $\gamma$ forward

- at LO more than 70% from Compton
- direct sensitivity to gluon density
• The ALICE experiment completed the upgraded detector installation and is about to complete the global commissioning.

• **LHC pilot beams at the end of October key for successful commissioning of ALICE with beam collisions**
  • Upgraded detectors and systems were fully tested with collisions

• Run 3 + Run 4 will allow to study the detailed properties of the QGP with high-luminosity Pb-Pb collisions and with upgraded ALICE detectors.

• Rich physics programs will be conducted in Run 3 + Run 4
  • Thermal radiation via dielectrons
  • Transport properties by charm and bottom hadron measurements down to very low $p_T$
  • Hadronization, dissociation and recombination mechanisms of heavy quarks in the medium
  • and more...

ALICE upgrade performance:
backup
**Online – Offline (O2)**

**O2/FLP**
CRI – First Level Processors
Receive detector data and processing on PCIe-based FPGA board (CRU)

**Continuous Unmodified Raw data**
TPC 3.3 TB/s
ITS2 40 GB/s
Rest 25 GB/s

Sub-Timeframes (10-20ms)

**O2/EPN**
CR0 - Event Processing Nodes
~2000 GPU & CPU

Compressed Timeframes (CTF)
Calibration data

60 PB
Disk storage, 360 GB/s

2/3 CTF
Tier0 archival

1/3 CTF
Tier1 archival

**O2/PDP**
Physics and Data Processing on EPN
- Synchronous reconstruction
- Calibration & asynchronous reconstruction (and event selection only for pp)
- Utilize ~2000 GPU and HPC

TPC 570 GB/s
ITS 40 GB/s
Rest 5 GB/s
ALICE Detectors in Run2

Central Barrel ($|\eta|<0.8$)
(ITS, TPC, TRD, TOF, HMP, EMC, PHOS)
- Tracking
- PID
- EM Calorimeters

Forward Detectors
(V0, T0, FMD, PMD, ZDC)
- Luminosity
- Centrality
- Multiplicities

Forward Spectrometer
-4$<\eta<-2.5$
- MUON Tracking
<table>
<thead>
<tr>
<th>System</th>
<th>Year(s)</th>
<th>$\sqrt{s_{NN}}$ (TeV)</th>
<th>Recorded $L_{int}$ (for muon triggers)</th>
</tr>
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<tbody>
<tr>
<td>Pb–Pb</td>
<td>2010, 2011</td>
<td>2.76</td>
<td>~75 µb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>5.02</td>
<td>~0.25 nb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td>5.02</td>
<td>~0.79 nb$^{-1}$</td>
</tr>
<tr>
<td>Xe–Xe</td>
<td>2017</td>
<td>5.44</td>
<td>~0.3 µb$^{-1}$</td>
</tr>
<tr>
<td>p–Pb</td>
<td>2013</td>
<td>5.02</td>
<td>~15 nb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>2016</td>
<td>5.02, 8.16</td>
<td>~3 nb$^{-1}$; ~25 nb$^{-1}$</td>
</tr>
<tr>
<td>pp</td>
<td>2009–2013</td>
<td>0.9, 2.76, 7, 8</td>
<td>~200 µb$^{-1}$; ~100 nb$^{-1}$; ~1.5 pb$^{-1}$; ~2.5 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>2015, 2017</td>
<td>5.02</td>
<td>~1.3 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>2015–2018</td>
<td>13</td>
<td>~36 pb$^{-1}$</td>
</tr>
</tbody>
</table>

ALICE inspected ~ 1 nb$^{-1}$ Pb-Pb collisions in Run1 + Run2
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- Closer to the IP: first layer at ∼22 mm

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- Spatial resolution: ∼5 μm
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**Improved tracking efficiency at low $p_T$**, improved pointing resolution (x3)
Muon Forward Tracker (MFT)
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