LHC Run 3 and Run 4 prospects for heavy-ion physics with LHCb

Samuel Belin, on behalf of the LHCb collaboration

Outline

1. LHCb run 2
2. LHCb Upgrade
3. Prospects
   - Fixed Target Studies
   - Heavy Ion Studies

Grant funded by the ExploringMatter ERC Consolidator grant number 647 390.
The LHCb detector

Single arm spectrometer fully instrumented in pseudorapidity range $2 < \eta < 5$

- Unique in this range
- Excellent resolution down to $p_T=0$.
- Excellent particle identification.
- Excellent primary vertex determination.

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The LHCb detector

- pp/Pbp/PbPb and fixed target mode

- Injection of noble gas (He, Ne, Ar) in the VErtex LOcator tank
- Gas pressure: $10^{-7}$ to $10^{-6}$ mbar

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Available samples in Run 2

Fixed Target mode samples:

Collider mode samples:

Due to detector saturation, limited to 40% most peripheral
LHCb Upgrades
(to the best of our knowledge at present)
Plan originally made in 2019, it will most likely be shifted...

### Possible schedule and future samples

This table does not include the fixed target program

<table>
<thead>
<tr>
<th>Year</th>
<th>Systems, $\sqrt{s_{NN}}$</th>
<th>Time</th>
<th>$L_{int}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>Pb–Pb 5.5 TeV, pp 5.5 TeV</td>
<td>3 weeks</td>
<td>2.3 nb$^{-1}$ (ALICE), 300 pb$^{-1}$ (ATLAS, CMS), 25 pb$^{-1}$ (LHCb)</td>
</tr>
<tr>
<td>2022</td>
<td>Pb–Pb 5.5 TeV, O–O, p–O</td>
<td>5 weeks</td>
<td>3.9 nb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 week</td>
<td>500 $\mu$b$^{-1}$ and 200 $\mu$b$^{-1}$</td>
</tr>
<tr>
<td>2023</td>
<td>p–Pb 8.8 TeV, pp 8.8 TeV</td>
<td>3 weeks</td>
<td>0.6 pb$^{-1}$ (ATLAS, CMS), 0.3 pb$^{-1}$ (ALICE, LHCb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>few days</td>
<td>1.5 pb$^{-1}$ (ALICE), 100 pb$^{-1}$ (ATLAS, CMS, LHCb)</td>
</tr>
<tr>
<td>2027</td>
<td>Pb–Pb 5.5 TeV, pp 5.5 TeV</td>
<td>5 weeks</td>
<td>3.8 nb$^{-1}$ (ALICE), 300 pb$^{-1}$ (ATLAS, CMS), 25 pb$^{-1}$ (LHCb)</td>
</tr>
<tr>
<td>2028</td>
<td>p–Pb 8.8 TeV, pp 8.8 TeV</td>
<td>3 weeks</td>
<td>0.6 pb$^{-1}$ (ATLAS, CMS), 0.3 pb$^{-1}$ (ALICE, LHCb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>few days</td>
<td>1.5 pb$^{-1}$ (ALICE), 100 pb$^{-1}$ (ATLAS, CMS, LHCb)</td>
</tr>
<tr>
<td>2029</td>
<td>Pb–Pb 5.5 TeV</td>
<td>4 weeks</td>
<td>3 nb$^{-1}$</td>
</tr>
<tr>
<td>Run-5</td>
<td>Intermediate AA</td>
<td>11 weeks</td>
<td>e.g. Ar–Ar 3–9 pb$^{-1}$ (optimal species to be defined)</td>
</tr>
<tr>
<td></td>
<td>pp reference</td>
<td>1 week</td>
<td></td>
</tr>
</tbody>
</table>

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LHCb upgrade run 3

New tracking system:
- Silicon upstream detector (UT)
- Scintillating tracking fiber (SciFi)

New Pixel VELO

New SMOG2 cell

New RICH optics and photodetectors

Upgrade for pp requirement
- 40 MHz collision rate
- Pile Up factor \( \sim 5 \)

Full software trigger
- Remove L0 triggers.
- Read out full detector at 40 MHz.

Heavy ion program will profit from this upgrade!

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Fixed Target: SMOG 2

- Higher density of the gas (up to 100 higher luminosity)
- Better control of the gas density (better luminosity determination)
- New gas H₂, D₂, O₂ in addition to all noble gases

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The goal is to record SMOG collisions in parallel to the pp data-taking.

First preliminary studies show minimal or no disturbance to the pp acquisition.

Reconstruction efficiency is independent from the primary vertex position.

Example SMOG2 pAr at 115 GeV for one year

<table>
<thead>
<tr>
<th>Int. Lumi.</th>
<th>80 pb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sys. error of $J/\Psi$ xsection</td>
<td>~3%</td>
</tr>
<tr>
<td>$J/\Psi$ yield</td>
<td>28 M</td>
</tr>
<tr>
<td>$D^0$ yield</td>
<td>280 M</td>
</tr>
<tr>
<td>$\Lambda_c$ yield</td>
<td>2.8 M</td>
</tr>
<tr>
<td>$\Psi'$ yield</td>
<td>280 k</td>
</tr>
<tr>
<td>$Y(1S)$ yield</td>
<td>24 k</td>
</tr>
<tr>
<td>$DY \mu^+\mu^-$ yield</td>
<td>24 k</td>
</tr>
</tbody>
</table>

Potentially high statistics for the fixed target program!
Fixed Target studies

- Access to large x-Bjorken and low scale $Q^2$.
- Possibility to reduce the uncertainty on the (n)PDFs, crucial input for HI physics as well as for other HEP measurements (BSM, Cosmic Ray physics...)

Estimation with 10 fb$^{-1}$

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Fixed Target studies

- Energy and rapidity scan possible with the variety of gas.
- Exploration of the phase diagram of hadronic matter (reach larger $\mu_B$)!
- Complementary to the RHIC BES results

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Performances Run 3 PbPb

PbPb collisions

- No significant saturation for 70% most peripheral collisions (simulation for higher centralities are being produced), expect almost no saturation for Run4 (90% most peripheral) and no saturation for Run5.
- Semi-central PbPb collisions soon available : QGP studies for LHCb in run 3 !
- Increased statistics: improvement of UPC studies.

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Heavy Ion Studies

- Access to a low, medium and high region of x with PbP and pPb samples
- Possibility to observe gluon saturation by studying the Drell-Yan process.
- The addition of a Magnet Tracking Station in Run4 will allow to reach even lower x region (~10^{-6}).

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Drell-Yan

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Heavy Ions Studies

- Charm and beauty pair correlations measurement both in pp and pPb collisions, the intrinsic transverse momentum $k_T$, carried by the incoming partons, may be sensitive to the saturation scale.

Projection with arbitrary normalisation

At $\Delta \phi = 0$ the NLO production via gluon splitting becomes dominant

Recently measured by LHCb, see Jianqiao’s talk [LINK]
B\(^+\) meson production, nPDF modifications are supposed to be the dominant source of nuclear modifications. Beauty hadron production exhibits smaller uncertainty than charm mesons. Better input for constraining nPDFs.

Precise measurements of nuclear modification in the beauty sector will potentially enable disentangling whether these effects are due to PDF modifications or other effects such as coherent energy loss.
Conclusions

- LHCb has a solid and complete Heavy Ion physics program, with unique capabilities.
- The Fixed Target program unlocks unexplored energies and kinematic conditions.
- The LHCb detector will soon be able to perform Quark Gluon Plasma studies with the improvements of the detector in high occupancy.
Backup