Results on heavy ion and fixed target collisions at LHCb

Émilie Maurice on behalf of the LHCb collaboration

Hard Probes 2018, Aix-les-Bains, France

October 1st, 2018
LHCb was designed for heavy flavor physics but serves now as a general purpose detector

Fully instrumented in $2 < y < 5$

Excellent performance:

✓ Vertex, IP and decay time resolution
✓ Momentum resolution
✓ Particle identification
  $\epsilon_{K \rightarrow K} \approx 95\%$, $\epsilon_{\pi \rightarrow K} \approx 5\%$
  $\epsilon_{\mu \rightarrow \mu} \approx 97\%$, $\epsilon_{\pi \rightarrow \mu} \approx 1-3\%$
✓ Flexible trigger down to low-$p_T$

Unique forward kinematics in $pPb$, $PbPb$ collisions:

- $1.1 \text{ nb}^{-1}$ $pPb$, $0.5 \text{ nb}^{-1}$ $PbPb$ at $\sqrt{s_{NN}} = 5.02$ TeV (2013)
- $13.6 \text{ nb}^{-1}$ $pPb$, $20.8 \text{ nb}^{-1}$ $PbPb$ at $\sqrt{s_{NN}} = 8.16$ TeV (2016)
- Ion-Ion runs: $10 \mu b^{-1}$ $PbPb$ at $\sqrt{s_{NN}} = 5.02$ TeV (2015) and $0.4 \mu b^{-1}$ $XeXe$ → 2018 $PbPb$ run aiming for a factor 10 more
Unique fixed-target configuration at the LHC
Inject noble gases (He, Ne, Ar, ...) inside the Vertex Locator $\sim 10^{-7}$ mbar

- Installed for beam-gas imaging
- Parasitic to collider data taking
- Fully benefit from LHCb excellent performance
  - $\rightarrow$ New physics opportunities with $p$-nucleus and Pb-nucleus collisions
  - Heavy-ion and cosmic ray related physics
The LHCb fixed-target experiment [JINST 9 (2014) P12005]

Unique fixed-target configuration at the LHC
Inject noble gases (He, Ne, Ar, ...) inside the Vertex Locator $\sim 10^{-7}$ mbar

Installed for beam-gas imaging
Parasitic to collider data taking
Fully benefit from LHCb excellent performance
→ New physics opportunities with $p$-nucleus and Pb-nucleus collisions

Heavy-ion and cosmic ray related physics

Fixed-target kinematic region
$\sqrt{s_{NN}} \in [69, 115]$ GeV
backward rapidity region
LHCb heavy ions recent results

▶ Charm production in fixed-target configuration
LHCb-PAPER-2018-023
→ see Frédéric Fleuret’s talk, Thursday at 9:40

▶ Open charm and beauty production in pPb collisions
$D^0$ LHCb-PAPER-2017-015, JHEP10(2017)090
$\Lambda_c^+$ LHCb-PAPER-2018-021, arXiv:1809.01404
$B^+, B^0, \Lambda_b$ LHCb-CONF-2018-004
→ see Yanxi Zhang’s talk, Thursday at 9:00

▶ Quarkonia production in pPb collisions
$J/\psi$ LHCb-PAPER-2017-014, PLB774(2017)159
$\Upsilon(nS)$ LHCb-PAPER-2018-035 in preparation
→ see Giulia Manca’s talk, Wednesday at 10:00

▶ Exclusive photonuclear $J/\psi$ production in ultra-peripheral PbPb collisions
LHCb-CONF-2018-003
→ see Samuel Belin’s talk, Tuesday at 9:00
Charm production in fixed-target configuration

$p$-nucleus collisions with LHCb fixed-target:

- Baseline for future Pb-nucleus fixed-target studies for quark gluon plasma (QGP)
- Study of nuclear PDF (nPDF), nuclear absorption, ...

LHCb fixed-target collisions: large rapidity coverage at large Bjorken-$x$ in the target

![nPDF anti-shadowing region and charm quark distributions](image)
Charm production in fixed-target configuration

\( p\)-nucleus collisions with LHCb fixed-target:
- Baseline for future Pb-nucleus fixed-target studies for quark gluon plasma (QGP)
- Study of nuclear PDF (nPDF), nuclear absorption, ...

LHCb fixed-target collisions: large rapidity coverage at large Bjorken-\( x \) in the target

Measurement of \( J/\psi \) and \( D^0 \) production using 2 data samples

<table>
<thead>
<tr>
<th>System</th>
<th>( \sqrt{S_{NN}} )</th>
<th>Protons on target</th>
<th>Target A</th>
<th>( L_{\text{int}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p\text{Ar} )</td>
<td>110.4 GeV</td>
<td>( 4.10^{22} )</td>
<td>40</td>
<td>not available</td>
</tr>
<tr>
<td>( p\text{He} )</td>
<td>86.6 GeV</td>
<td>( 5.10^{22} )</td>
<td>4</td>
<td>( 7.58 \pm 0.47 ) nb(^{-1} )</td>
</tr>
</tbody>
</table>
Charm production in fixed-target configuration

LHCb-PAPER-2018-023, in preparation

\[ \sigma_{J/\psi} = 1225.6 \pm 62.0(\text{stat}) \pm 81.6(\text{syst}) \text{ nb/nucleon} \]

\[ \sigma_{D^0} = 156.0 \pm 4.6(\text{stat}) \pm 12.3(\text{syst}) \mu\text{b/nucleon} \]

with fraction \((c \rightarrow D^0) = 0.542 \pm 0.024\)

\[ \sigma_{c\bar{c}} = 287.8 \pm 8.5(\text{stat}) \pm 25.7(\text{syst}) \mu\text{b/nucleon} \]

Cross-section measurements in agreement with previous experimental measurements and with theoretical predictions

→ see Frédéric Fleuret’s talk
Charm production in fixed-target configuration

Cross-sections are compared with

- Phenomenological parametrisations (JHEP 1303 (2013) 122) for $J/\psi$ → Shape in agreement
- HELAC-onia model EPJC 77 (2017) designed and tuned for collider data → Reasonable agreement

No indication of visible valence-like intrinsic charm in rapidity distribution

Starting point for more detailed proton-Neon and future Lead-Neon collisions → see Frédéric Fleuret’s talk
$pPb$, $Pbp$ collisions
$D^0$ measurement in $pPb$ 5.02 TeV

LHCb-PAPER-2017-015, JHEP 10 (2017) 090

Ratio of $J/\psi$/$D^0$ cross sections

Nuclear modification factor

$J/\psi$/$D^0$ cross-sections ratio flat

**Backward rapidity** modification factor close to 1, increasing in most backward rapidity

**Forward rapidity** significant suppression wrt $pp$ yields, good agreement with the theoretical predictions (nuclear PDFs and color glass condensate)

→ see Yanxi Zhang’s talk
**Λ⁺ measurements in pPb 5.02 TeV**


Baryon-to-meson ratio Λ⁺/D⁰ → Sensitive to charm hadronisation mechanism

![Graphs showing R_{Λ⁺/D⁰} as a function of p_T for different rapidity ranges.](image)

- **Forward rapidity**: discrepancies at high-p_T between data and models tuned to pp
- **Backward rapidity**: good agreement between data and model predictions

→ see Yanxi Zhang's talk

Émilie Maurice (LLR, LAL)  
Heavy ion and fixed target collisions at LHCb
$b$–hadrons measurement in $p$Pb 8.16 TeV

**LHCb-CONF-2018-004 in preparation**

$$B^- \rightarrow J/\psi K^-$$

$$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$$

Soon: cross-section measurements at backward and forward rapidity, comparison with $pp$ and baryon / meson ratio

see Yanxi Zhang’s talk
**J/ψ** measurement in pPb 8.16 TeV

**Prompt J/ψ**

- HELAC – Onia with EPS09LO
- HELAC – Onia with nCTEQ15
- FONLL with EPS09NLO
- Energy Loss
- CGC

**J/ψ from b-hadrons**

- HELAC–Onia with EPS09LO
- HELAC–Onia with nCTEQ15
- HELAC–Onia with EPS09NLO
- Energy loss
- CGC

Prompt and non prompt **J/ψ** results compatible with theoretical expectations and lower LHCb energy measurements

→ see Giulia Manca’s talk

Émilie Maurice (LLR, LAL)  Heavy ion and fixed target collisions at LHCb
$\Upsilon(nS)$ measurement in $pPb$ at 8.16 TeV

Study of $\Upsilon(nS)$ production with 20 times more luminosity than in Run 1
ϒ(nS) measurement in pPb at 8.16 TeV

랐

LHCb-PAPER-2018-035 in preparation

ϒ(1S) nuclear modification factor:

▶ Backward rapidity: compatible with unity within uncertainties
▶ Forward rapidity: suppression

ϒ(nS) nuclear modification factors integrated over the phase space:

\[ R(p\text{Pb}/pp)[ϒ(2S)] = 0.86 \pm 0.15 \]
\[ R(p\text{Pb}/pp)[ϒ(3S)] = 0.81 \pm 0.15 \]
\[ R(\text{Pb}p/pp)[ϒ(2S)] = 0.90 \pm 0.21 \]
\[ R(\text{Pb}p/pp)[ϒ(3S)] = 0.44 \pm 0.15 \]

→ Additional suppression of excited states, significant for ϒ(3S) in PbP collisions

→ see Giulia Manca’s talk
PbPb collisions
Centrality of PbPb collisions

LHCb centrality

- Measured by the calorimeter
- Reaches the detector limitation

→ Saturation in the Vertex Locator for the most central PbPb collisions

LHCb current tracking algorithm efficient up to 50% most central collisions

Physics studies limited to 50% less central events
$J/\psi$ in PbPb ultra peripheral collisions

$J/\psi \rightarrow \mu^+\mu^-$ in ultra peripheral collisions (UPC) - LHCb-CONF-2018-003

Interaction between the electromagnetic field of the ions
→ Coherent $J/\psi$ photo-production, sensitive to nPDF, ...

No additional particle production

→ Constraint on model space

2018 PbPb run: expect 10 times more luminosity and include other final states in exclusive $\gamma$-induced reactions

→ see Samuel Belin’s talk
Fixed-target upgrade

Current LHCb fixed-target setup will be upgraded for Run 3

Plan for a storage cell, placed upstream

→ Injection of noble gases but also H$_2$, D$_2$ as references

→ 10–100 times larger instantaneous luminosity per unit length

Other upgrades (crystal target, polarised target, wire target) under discussion
Conclusions

The LHCb detector has unique capabilities for heavy flavor measurements at LHC in collider and fixed-target modes

Recent precision heavy flavour measurements

- Prompt and non-prompt charmonium, open charm ($D^0, \Lambda_c^+$), open beauty ($B^0, B^+, \Lambda_b^+$) and $\Upsilon(nS)$ production measurements in $pPb$ collisions
- Demonstration of capabilities to run in PbPb collisions and exploitation with high-precision ultra-peripheral collisions
- First heavy flavour production measurement in fixed-target mode

More results to come

- 2016 $pPb$ analyses ongoing
- 2018 PbPb collisions to be taken
- 2017 large $pNe$ data sample to analyze and 2018 PbNe collisions to be taken

Rich heavy ion program with LHCb upgrade and the fixed-target upgrade!
$\Lambda_c^+$ invariant mass in $p\mathrm{Pb}$ at 5.02 TeV