Highlights from the LHCb experiment

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On behalf of the LHCb collaboration
The LHCb experiment [JINST 3 (2008) S08005]

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 fixed-target configuration
  [JINST 9 (2014) P12005]

Emilie Maurice (LLR) – Highlights from the LHCb experiment
LHCb heavy ions program

LHCb has unique capabilities to do high-precision measurements and search for exotic signatures in the forward region

Large and complementary phase space coverage

But saturation in PbPb collisions (up to 60% centrality)

In addition to pp collisions, large variety of p-nucleus and nucleus-nucleus collisions to study:
QCD precision measurements, ultra-peripheral and peripheral PbPb collisions physics, cosmics physics, and much more!
Quark Matter program

8 Talks
First performance results from upgraded LHCb and SMOG II, **Saverio Mariani**, April 6th, 11:30, T15: Future facilities and new instrumentation
Measurements of collectivity in the forward region at LHCb, **Cheuk Ping Wong**, April 7th, 9:00, T07: Correlations and fluctuations (II)
Quarkonia production in Ultraperipheral PbPb collisions at LHCb, **Samuel Belin**, April 7th, 9:40, T09: Ultra-peripheral collisions (I)
Production of exotic hadrons in high multiplicity pp and pPb collisions at LHCb, **Eliane Eppel**, April 7th, 10:00, T11: Heavy flavors, quarkonia
Studies of low-x phenomena with the LHCb detector, **Oscar Boente Garcia**, April 7th, 11:10, T09: Ultra-peripheral collisions (II)
Probing the valence quark region of nucleons with Z bosons at LHCb, **Tianqi Li**, April 7th, 16:50, T13: Electroweak probes (II)
Heavy flavour production at LHCb, **Benjamin Audurier**, April 7th, 15:00, T11: Heavy flavors, quarkonia, and strangeness production (IV)
New measurements in fixed-target collisions at LHCb, **Jiayin Sun**, April 7th, 15:20, T11: Heavy flavors, quarkonia, and strangeness production (IV)

7 Posters
Searching for the gluon saturation scale at x ~10^{-5} with the LHCb detector using direct photons, **Cesar Luiz Da Silva**, April 6th, Session 2 T07_2
Study of charmonium photoproduction in ultra-peripheral lead-lead collisions at LHCb, **Xiaolin Wang**, April 6th, Session 2 T08 / T09
Prompt open charm production in 5.02 TeV pPb collisions with LHCb, **Yiheng Luo**, April 8th, Session 3 T11_5
Prompt D^+ and D^+_s production in 8.16 TeV pPb collisions at LHCb, **Chenxi Gu**, April 8th, Session 3 T11_5
Prompt Λ^+_c production and Λ^+_c/D^0 ratio in pPb collisions at 8.16 TeV by LHCb, **Di Yang**, April 8th, Session 3 T11_5
Studies on charm-strange baryon Xi_c+ in 8.16 TeV pPb collisions with LHCb, **Roman Litvinov**, April 8th, Session 3 T11_5
Fragmentation functions of identified charmed mesons, **Sara Sellam**, April 8th, Session 3 T11_5

Emilie Maurice (LLR) – Highlights from the LHCb experiment
First LHCb measurements of prompt charged particles in pPb and pp collisions

Measurements in the forward and backward regions at $\sqrt{s} = 5$ TeV [arXiv:2108.13115]

- Differential production cross-sections in $p_T$ and $\eta$ intervals
- Nuclear modification factor

$$R_{\text{pPb}}(\eta, p_T) = \frac{1}{A} \frac{d^2\sigma_{\text{pPb}}(\eta, p_T)}{dp_T d\eta}$$

Complementary measurements in backward and forward $\eta$ regions

In the forward region: a suppression is observed, especially for low $p_T$
In the backward region: significant enhancement for high $p_T$

- Clear pseudorapidity dependence, that nPDFs alone cannot described
- Differences with CGC calculations at the lowest $p_T$
- Multiple scattering calculations fail to describe the backward region

Stringent constraints on non-perturbative QCD models

Emilie Maurice (LLR) – Highlights from the LHCb experiment
Measurement of $\pi^0$ production in pPb collisions at the LHC

First measurements in the forward and backward regions at $\sqrt{s} = 8.16$ TeV [LHCb-PAPER-2021-053]

- Differential production cross-sections in $p_T$ and $\eta$ intervals

- Nuclear modification factor
  \[ R_{ppb}^{\pi^0} = \frac{1}{208} \frac{d\sigma_{ppb}^{\pi^0}}{dp_T} / \frac{d\sigma_{pp}^{\pi^0}}{dp_T} \]
  using pp interpolation between 5 and 13 TeV results

Forward region

- Suppression consistent with nPDF predictions, but larger than CGC calculations
- Consistent with charged-particle $R_{pPb}$ at 5.02 TeV

Backward region

- Enhancement larger than nPDF predictions, but smaller than charged particle $R_{pPb}$ (baryon enhancement ?)

Precise and independent measurements ($\pi^0$ and charged particles) constraining nPDFs and saturation models in low-x region
LHCb has demonstrated excellent capabilities to discover new particles, such as $T^+_{cc}$ tetraquark [arXiv:2109.01056]

**Investigation of $\chi_{c1}(3872)$ state**
- Nature: tetraquark, molecule?
- Probe of QCD medium?

**Measurement of relative $\chi_{c1}(3872)$ production with $\psi(2S)$, via their decays into $J/\psi \, \pi^+ \pi^-$**
- In pp collisions at 8 TeV, with 2 fb$^{-1}$ [Phys. Rev. Lett. 126 (2021) 092001]
- In pPb collisions, at 8.16 TeV, with 12.5 nb$^{-1}$ [LHCb-CONF-2022-001]
Production of $\chi_c(3872) / \psi(2S)$ in pp and pPb collisions

First measurement of $\chi_c(3872) / \psi(2S)$ ratio in pp collisions versus multiplicity

- Prompt ratio is suppressed with multiplicity in pp collisions
- Consistent with a compact tetraquark modelisation
- Dominated by comover breakup (PRD 103 (2021) 7, EPJC 81 (2021) 669)

First measurement of a tetraquark production, $\chi_c(3872)$, in pPb collisions:
- Increase medium temperature and also the multiplicity

- $\chi_c(3872)$ seems to behave quite differently than $\psi(2S)$
- Current uncertainties preclude drawing firm conclusions
- $\psi(2S)$ is suppressed in pPb and PbPb
- $\chi_c(3872)$ production may also be enhanced

$\chi_c(3872)$: a new QCD probe

Emilie Maurice (LLR) – Highlights from the LHCb experiment
Probing QCD with $Z^0$ bosons in pp collisions

Measurement of $Z^0$ boson production cross-section is particularly sensitive to parton distribution functions (PDFs):

- First measurements of the angular coefficients of Drell-Yan $\mu^+\mu^-$ pairs in the forward rapidity region [arXiv:2203.01602]

- Differential and total cross-section measurement at 13 TeV [arXiv:2112.07458]

- The most precise measurement to date of the $Z^0$ boson production cross-section in the forward region

- Test NNLO perturbative QCD with similar precision

- First measurement of the fraction of $Z^0$-boson + jet events containing a charm jet [arXiv:2109.08084]

  Ratio in intervals of $Z^0$ rapidity and compared to NLO calculations in pp collisions at 13 TeV

- Sizable enhancement at forward $Z^0$ rapidities, consistent with a proton wave function containing $|uuudcc\bar{c}\bar{c}>$ component (Intrinsic charm) predicted by LFQCD
Probing QCD with $Z^0$ bosons in pPb collisions

Measurement of $Z^0$ boson production in pPb collisions [LHCb-PAPER-2022-009]

- $Z^0$ production fiducial cross-section
- Forward-backward ratio
- Nuclear Modification factor

All are measured inclusively and differentially

Results are globally compatible with

→ Theoretical predictions from EPPS16 and nCTEQ16 nPDFs
→ Previous results at 5.02 TeV from various experiments

$Z^0$ measurements show strong constraining power for modeling the nPDFs

Emilie Maurice (LLR) – Highlights from the LHCb experiment
J/ψ production measurements in pp collisions at 5 TeV

Measurements with an integrated luminosity of 9.18 fb⁻¹

- J/ψ differential cross-sections, as functions of $p_T$ and $y$
- Separately for prompt and non-prompt J/ψ
- Ratios between J/ψ production cross-section between
  - 8 TeV and 5 TeV
  - 13 TeV and 5 TeV

Prompt J/ψ measurements show:

→ A good agreement with NLO NRQCD calculations in the high-$p_T$ region
→ A small tension in the low-$p_T$ region for NRQCD and CGC calculations

FONLL calculations describe well the non-prompt J/ψ measurements

The J/ψ nuclear modification factor $R_{pPb}$ at 5 TeV is also updated
**D^0** production in pPb collisions at 8.16 TeV

Most precise measurement of the prompt D^0 production in pPb collisions from the LHC to date

- The nuclear modification factors and forward-backward production ratios
  - Large asymmetry between forward and backward production
  - Higher $R_{FB}$ than the predictions of nPDFs calculations for the high $p_T$ region

- A suppression of high $p_T$ D^0 production in the backward rapidity is observed

![Graph showing the comparison between LHCb 8.16 TeV and 5 TeV in terms of $R_{pPb}$ for different rapidity regions.](image)

The measurement of $R_{pPb}$ provides a stringent test of nPDF down to small x regions
Modification of b hadronization in high multiplicity pp collisions

Bridges the gap between production in vacuum and dense hadronic environment by studying $B^0_s/B^0$ production versus multiplicity

Test strangeness production enhancement with multiplicity and possible b-hadronization via quark coalescence especially at low $p_T$ where the bulk of particles is produced

$$\frac{\sigma(B^0_s)}{\sigma(B^0)} \cdot B^0_s \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)\pi^+\pi^- \quad pp : \sqrt{s} = 13 \text{ TeV} \ (5.5 \text{ fb}^{-1})$$

→ $B^0_s/B^0$ production at low-multiplicity consistent with previous $e^+e^-$ measurements

→ At low $p_T$, increasing trend versus multiplicity
Centrality determination in nucleus-nucleus collisions

Procedure to classify the data into geometric quantities from the Glauber MC model [arXiv:2111.01607] accepted by JINST

- Exploit the measured energy deposits in the electromagnetic calorimeter to map the real data

PbPb collisions at 5 TeV

PbNe collisions at 68.5 GeV

First centrality measurements at LHCb, and first measurements for fixed-target collisions at the LHC

Emilie Maurice (LLR) – Highlights from the LHCb experiment
**J/ψ photo-production in PbPb collisions at 5 TeV**


**First LHCb measurements using PbPb peripheral collisions (up to 60%)** [arXiv:2108.02681]

Photo-produced J/ψ disentangled from hadronically through dimuon \( p_T \) spectrum fit

Photo-produced J/ψ differential yields study as a function of \( p_T \), \( y \) and \( N_{\text{part}} \)

Measured yields of the photo-produced J/ψ

→ Higher at low rapidity than high rapidity
→ Consistent with being constant with respect to \( N_{\text{part}} \)

**Confirmation of photo-produced J/ψ in PbPb peripheral hadronic collisions**

Shape of the results are qualitatively described by the theoretical predictions (normalisation discrepancy)
First measurements $\Lambda^+_{c}/D^0$ production ratio in peripheral PbPb collisions

$$R = \frac{\sigma(\Lambda^+_{c} \rightarrow pK^+\pi^-)}{\sigma(D^0 \rightarrow K^-\pi^+)}$$

$\Lambda^+_{c}/D^0$ differential ratio study as a function of $p_T$, $y$ and $N_{\text{part}}$ [LHCb-PAPER-2021-046] in preparation

$\rightarrow$ All are consistent with a constant trend around $R(\Lambda^+_{c}/D^0) \sim 0.27$

$\rightarrow$ Consistent with previous LHCb measurements in pPb collisions

$\rightarrow$ Compatible within 2σ with PYTHIA 8 prediction in pp collisions at 5.02 TeV including the color recombination mechanism

$\rightarrow$ Systematic discrepancy versus $p_T$ is observed with the statistical hadronization model prediction

$\rightarrow$ Lower $\Lambda^+_{c}/D^0$ ratio in LHCb compared to ALICE experiment due to different rapidity range?

Emilie Maurice (LLR) – Highlights from the LHCb experiment
Fixed target - astrophysics

Space-born experiments (AMS-02) are searching for DM decays by comparing the antiproton abundance in cosmic rays

- Interpretation limited by models of antiproton production in cosmic rays collisions with the interstellar medium (H, He)

Dedicated measurements using pHe collisions:

- First LHCb result only dealing with prompt processes [Phys. Rev. Lett. 121 (2018) 222001]
- Dedicated measurement to the component from anti-hyperon decays in pHe collisions [LHCb-PAPER-2022-006] in preparation

→ Theoretical models largely underestimate the anti-hyperon contributions to the total antiproton yield
→ Ratios depend on the antiproton kinematics, usually neglected by theoretical models

LHCb fixed-target configuration is also a privileged place for charm production studies

Jiayin Sun, 7 Apr 2022, 15:20

Emilie Maurice (LLR) – Highlights from the LHCb experiment
LHCb upgrade

LHCb is currently facing a major upgrade:
- Most of the detectors replaced
- Fully-software detector read-out and data processing

→ LHCb is a brand-new general purpose experiment

Study of central PbPb collisions during Run 3?
Simulation studies show that no saturation effects up to 30% centrality

Next upgrades
- ~2025: New tracking station inside the magnet
- ~2030: Mighty tracker, no more centrality limitation
The LHCb fixed target upgrade

From 2022, 20-cm-long gas storage cell (SMOG2) upstream of the LHCb nominal IP

- Gas pressure up to x100 with the same flow as Run2
- Studies ongoing to also inject heavy noble (Kr, Xe) and non-noble (H₂, D₂, O₂) gases
- Opportunity to operate simultaneously in collider and fixed-target modes

- Dedicated reconstruction and trigger studies, with no-showstopper found
- First data-driven method for particle identification performance using fixed-target data only [LHCb-DP-2021-007]

Separation of the interaction region wrt beam-beam

With the LHCb fixed target upgrade
unique opportunities to extend heavy-ion, QCD and astrophysics program
Conclusions

LHCb has an expanding physics program

From QCD precise results: demonstration with LHCb run 1 & 2 data
- Many precise results from large pp/pPb/PbPb datasets
- UPC and PC measurement in LHCb PbPb pioneering samples
- Unique results with the fixed-target program at LHC

Toward QGP characterization and stringent QCD constraints: run 3 and beyond!
- New detector from 2022
- Improvement of the tracking performances
- Ambitious fixed-target program

Many new exciting opportunities ahead!