Recent results from LHCb

Yanxi ZHANG
Peking university

On behalf of the LHCb collaboration

13/June/2022
LHCb contributions

Talks

Prospect of collectivity measurement, Quarkonia in UPC and peripheral PbPb collisions, Low-\(x\) phenomena, \(Z^0\) production, Heavy flavor with strangeness, Imanol Corredoira, Tue. Weison Duan, Wed. Thomas Boettcher, Wed. Hengne Li, Wed. Chenxi Gu, Wed.

Posters

Fixed-target results, Heavy flavor and exotic, Quarkonia production in jets, Sara Sellam Krista Lizbeth Smith Naomi Cooke
LHCb experiment

- General purpose detector, covering $p_T \geq 0$ and forward $2 < \eta < 5$

**Vertex reconstruction**
- $\sigma_{IP} \approx 20 \mu m$
- $\sigma_{\tau} \approx 45$ fs w.r.t. $\tau_B \approx 1.5$ ps

**Muon identification**
- $\epsilon(\mu \rightarrow \mu) \approx 97\%$
- MisID rate ($\pi \rightarrow \mu) \approx 1 - 3\%$

**Track reconstruction**
- $\epsilon$(Tracking) $\approx 96\%$
- $\delta p/p \approx 0.5\%-1\%$ (5-200 GeV)
- $\epsilon(m_{J/\psi}) \approx 15$ MeV

**Hadron identification**
- $\epsilon(K \rightarrow K), \epsilon(p \rightarrow p) > 90\%$
- MisID rate ($\pi \rightarrow K/p) < 5\%$
LHCb heavy-ion program

• High-precision measurements in low and high-\(x\)
  ➢ Operated at low occupancy, up to 60% for PbPb

• Unique fixed-target collisions

• Analyses: heavy flavor and soft probes, exotic signatures, cosmic ray physics and so on

  LHCb results

• Heavy ion data on disk

Colliding modes

<table>
<thead>
<tr>
<th>Colliding modes</th>
<th>recorded luminosity [nb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sqrt{s_{NN}} = 5.02) TeV</td>
<td>10^5</td>
</tr>
<tr>
<td>(\sqrt{s_{NN}} = 8.16) TeV</td>
<td>10^7</td>
</tr>
</tbody>
</table>

Fixed-target

<table>
<thead>
<tr>
<th>Fixed-target</th>
<th>probes (Pb) on target [10^3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sqrt{s_{NN}} = 110) GeV</td>
<td>10^-2</td>
</tr>
<tr>
<td>(\sqrt{s_{NN}} = 69) GeV</td>
<td>10^-2</td>
</tr>
</tbody>
</table>

2015
<table>
<thead>
<tr>
<th>pPb</th>
<th>pPb</th>
<th>pPb</th>
<th>pPb</th>
<th>pPb</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>2015</td>
<td>2016</td>
<td>2018</td>
<td></td>
</tr>
</tbody>
</table>

2015
<table>
<thead>
<tr>
<th>pNe</th>
<th>pHe</th>
<th>pAr</th>
<th>PbAr</th>
<th>pHe</th>
<th>pHe</th>
<th>pNe</th>
<th>pNe</th>
<th>pNe</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>2016</td>
<td>2017</td>
<td>2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Charged hadron production in $p$Pb

- $d^2\sigma/dp_T dy$ and $R_{pPb}(p_T, \eta)$ for not-identified $h^\pm$ up to $p_T < 8$ GeV
- **Forward**
  - Strong suppression with $R_{pPb} < 1$
  - $R_{pPb}$ increases from low to high $p_T$
  - Consistent with CGC, nPDF+DSS

- **Backward**
  - Cronin peak, $R_{pPb}$ reaches 1.4
  - $R_{pPb}$ inconsistent with nPDF or pQCD+multiple scattering, both contribute?

LHCb:PRL128(2022)142004

LHCb $\sqrt{s_{NN}}=5$ TeV

<table>
<thead>
<tr>
<th>Forward</th>
<th>Backward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt charged particles</td>
<td>Data</td>
</tr>
<tr>
<td>$2.0&lt;\eta&lt;2.5$</td>
<td>$3.5&lt;\eta&lt;4.0$</td>
</tr>
<tr>
<td>$2.5&lt;\eta&lt;3.0$</td>
<td>$4.0&lt;\eta&lt;4.3$</td>
</tr>
<tr>
<td>$3.0&lt;\eta&lt;3.5$</td>
<td></td>
</tr>
<tr>
<td>$3.5&lt;\eta&lt;4.0$</td>
<td></td>
</tr>
<tr>
<td>$4.0&lt;\eta&lt;4.3$</td>
<td></td>
</tr>
</tbody>
</table>

EPPS16+DDS

CGC

pQCD+MS

\( \pi^0 \) production in \( pPb \)

- \( \frac{d\sigma}{dp_T} \) and \( R_{pPb}(p_T) \) for \( 1.5 < p_T < 10 \) GeV, forward and backward

- **Backward**
  - \( R_{pPb} \) larger than nPDF predictions, but smaller than that of not-identified charged tracks

- **Forward**
  - Strong suppression, \( R_{pPb} \) data consistent with charged tracks and nPDF, CGC predictions

LHCb:arXiv:2204.10608
$D^0$ production

- Open heavy flavor: initial conditions, in-medium energy loss, coalescence…
- New precise measurement for $D^0$ production in $p$Pb at $\sqrt{s_{\text{NN}}} = 8.16$ TeV
- $R_{FB}$
  - Consistent with $D^0$ production in 5 TeV $p$Pb data
  - Inconsistent with coherent energy loss at low $p_T$
  - Inconsistent nPDF calculations at $p_T > 5$ GeV

LHCb:arXiv:2205.03936
Stringent constraint on models

- $R_{p\text{Pb}}$ of $D^0$ production in $p\text{Pb}$ at $\sqrt{s_{\text{NN}}} = 8.16$ TeV
  - **Forward**: $R_{p\text{Pb}} < 1$, consistent with nPDF and CGC
  - **Backward**: flat at high $p_T$, underestimated by nPDF

LHCb:arXiv:2205.03936

Heavy flavor and exotic production
Krista Smith, poster
\(Z^0\): ideal probe of initial stage

- EW production sensitive to PDFs, final state effects negligible
- \(\sigma_{Z^0+c\text{ jet}}\) in \(pp\) collisions
  - Enhancement at most-forward \(Z^0\) rapidities, indicative of intrinsic-charm component
- \(Z^0\) production in \(p\text{Pb}\) collisions at \(\sqrt{s_{NN}} = 8.16\) TeV
  - Compatible with EPPS16, nCTEQ15 with current precision

LHCb: PRL128(2022)082001

Hengne Li, Wed.

LHCb: arXiv:2205.10213
$b$ hadronization in high multiplicity $pp$ data

- Strangeness enhancement tested with $\frac{\sigma_{B_0}}{\sigma_{B^0}}$ in $pp$ collisions

**Low $p_T$**
- Agrees with $e^+e^-$ at low multiplicity
- Increases with multiplicity

**High $p_T$**
- Agrees with $e^+e^-$
- No obvious multiplicity dependence

- Compatible with coalescence; new insight into heavy quark hadronization

Heavy flavor strangeness
Chenxi Gu, Wed.
$c$ hadronization in peripheral PbPb data

- $\sigma_{\Lambda_c^+}/\sigma_{D^0}$ measured in 90 $\rightarrow$ 60% centrality of PbPb collisions
  - No strong dependence on $p_T$ and $y$, and centrality class
  - Compatible with LHCb $p$Pb and Pythia8 tune, no hint of $\Lambda_c^+$ enhancement
  - Inconsistent Statistical Hadronization Model prediction
  - Generally below ALICE in $p$Pb $\rightarrow \Lambda_c^+$ enhancement more pronounced at mid rapidity?

---

**LHCb-PAPER-2021-046**

---

RQM+Frag: JHEP08(2015)003
PYTHIA8+color reconnection (CR): PRL124(2020)042301
Exotic state production

- $\sigma_{\chi_c(3872)}$ studied in $pp$ and $pPb$ data
  - In $pp$ data: $\sigma_{\chi_c(3872)} / \sigma_{\psi(2S)}$ in prompt production decreases with multiplicity
  - In $pPb$ data: $\chi_c(3872)$ first evidence
  - Hint of $\sigma_{\chi_c(3872)} / \sigma_{\psi(2S)}$ increases with system size from $pp \to pPb \to PbPb$
  - Dissociation vs Recombination

Heavy flavor and exotic production
Krista Smith, poster

Heavy quarkonium probes

- Coherent production of quarkonium in UPC PbPb collisions sensitive to production models and gluon PDF
  - $\sigma_{J/\psi}^{\text{coh}}, \sigma_{\psi(2S)}^{\text{coh}}$ measured in PbPb at $\sqrt{s_{\text{NN}}} = 5$ TeV
    - Compared with pQCD and CGC+color dipole in various models
    - Provide strong constrains on model calculations

$LHCb$-PAPER-2022-012 New!

---

Low $p_T$ quarkonia
Weisong Duan, Wed
Fixed target program: strangeness production

• Production of $\bar{p}$ from antihyperon decays
  $$p \rightarrow \text{He at } \sqrt{s_{NN}}=110 \text{ GeV}$$

• Cross-section ratio over prompt production: $R_H$
  ➢ Non-prompt production dominated (80%) by $\Lambda \rightarrow \bar{p}\pi^+$
  ➢ Models underestimate data

Inclusive: $H = \Lambda, \Sigma, \Xi, \Omega \ldots$

Exclusive: $H = \bar{\Lambda}$

• Input to understand secondary $\bar{p}$ cosmic flux and tune event generators

New fixed-target results
Sara Sellam, poster

LHCb:arxiv:2205.09009
Fixed target program: nuclear matter

- Charmonium production in $p \to \text{Ne}$ data at $\sqrt{s_{NN}} = 68.5$ GeV LHCb-PAPER-2022-006

$$\frac{d\sigma}{dp_T} \text{ for } J/\psi \text{ consistent with model}$$

\[\text{[PRC103 (2021) 035204]}\]

- $J/\psi$ and $D^0$ production in $\text{Pb} \to \text{Ne}$ data at $\sqrt{s_{NN}} = 68.5$ GeV LHCb-PAPER-2022-011

- Full centrality region
- $\sigma_{J/\psi}/\sigma_{D^0}$ as a function of binary nucleon-nucleon collisions $N_{\text{coll}}$:

$$\sigma_{J/\psi}/\sigma_{D^0} = \langle N_{\text{coll}} \rangle^{\alpha' - 1}, \quad \alpha' \text{ agrees with } pA \text{ data by NA50 [PLB410(1997)337]}$$

$\alpha' \neq 1$ suggests $J/\psi$ production may be affected by additional nuclear effect compared to $D^0$
LHCb upgrade for Run3

- Average granularity of tracking system increased by $\times 5$
- Full software trigger

Faster, more efficient and flexible

- Colliding mode:
  Tracking functional up to 30% PbPb centrality

- SMOG2: new dedicated gas cell upstream of interaction point

More options for gas target, higher gas density, simultaneous running with collider mode

Performance of colliding mode not degraded when SMOG2 switched on
Conclusion

• LHCb expanding program in heavy ion physics
  ➢ Soft particle production
  ➢ Heavy flavor production and hadronization
  ➢ Exotic hadron production
  ➢ Heavy quarkonium measurements in UPC and peripheral PbPb collisions
  ➢ EW boson production
  ➢ Unique results with the fixed-target program

• Run3: toward central PbPb collisions, new and more precise measurements
  ➢ New detector allowing reconstructing higher multiplicity
  ➢ New SMOG2 system
  ➢ Full software trigger

Talks

Prospect of collectivity measurement, Imanol Corredoira, Tue.
Quarkonia in UPC and peripheral PbPb collisions, Weison Duan, Wed.
Low-\(x\) phenomena, Thomas Boettcher, Wed.
\(Z^0\) production, Hengne Li, Wed.
Heavy flavor with strangeness, Chenxi Gu, Wed.

Posters

Fixed-target results, Sara Sellam
Heavy flavor and exotic, Krista Lizbeth Smith
Quarkonia production in jets, Naomi Cooke
Backup slides
$R_{pPb}(y)$ of $D^0$ at $\sqrt{s_{NN}} = 8.16$ TeV

- Tension with nPDF at high $p_T$
- Difference w.r.t 5 TeV due to different $x$-region?

[Graph showing $R_{pPb}$ vs. $y^*$ with different data sets and theories at 8.16 and 5.02 TeV.]
$R_{pPb}(y)$ of $D^0$ at $\sqrt{s_{NN}} = 8.16$ TeV

- Energy loss alone not enough; nPDF undershoots at high $p_T$ for backward
\( Z^0 \) at \( \sqrt{s_{NN}} = 8.16 \) TeV
\( \sigma(\Lambda_c^+)/\sigma(D^0) \) ratio compared with ALICE

- Similar decreasing trend at \( p_T > 4 \) GeV
- Magnitude similar to \( pp \) but below \( pPb \) and central \( PbPb \) data by ALICE at mid rapidity
  - \( \Lambda_c^+ \) enhancement strong rapidity dependence from mid to forward rapidity?
- Lower values than ALICE at mid rapidity
Exotic state production

- Prompt production in $pp$ decreases multiplicity, dissociation larger for $\chi_{c1}(3872)$ than $\psi(2S)$
  - Geometric comover model: $\chi_{c1}(3872)$ is compact
  - Constituent comover model: $\chi_{c1}(3872)$ loosely bound hadron molecule

LHCb: PRL126(2020)092001

[EPJC81(2021)669]

[PRD103(2021)071901]
UPC $J/\psi$

- Extraction of coherent signals using STARLight templates of $p_T$ distribution
J/ψ photo-production in peripheral PbPb data

- Coherent production for nuclear overlap, a special probe of heavy ion collisions
- Signal confirmed in LHCb PbPb data at $\sqrt{S_{NN}} = 5$ TeV

Yield as functions of centrality class and kinematics consistent with predictions, but measurement larger by about 50%

Calculations: PRC99(2019)061901

LHCb: PRC105(2022)L032201
Quarkonia production in jets

• Probing heavy quarkonium production mechanism
• Smaller fraction of jet $p_T$ carried by $J/\psi$, indicative of production in shower

$z(J/\psi) \equiv p_T(J/\psi)/p_T(\text{jet})$

• $J/\psi$ transversely polarized in jets?