Motivation
The LHCb spectrometer
Beam Configurations
Analysis strategy for $J/\Psi$ reconstruction
Measurement of $J/\Psi$ cross sections
Determination of nuclear modification
Calculation of forward-backward asymmetry
Conclusions & Outlook
• study multi-parton interactions
• soft QCD, low-x
• particle yield ratios for testing hadronization models
• study of proton-ion collisions with LHCb accesses unique kinematic region

Focus on:
  • cold-nuclear effects (decouple cold-nuclear matter from quark-gluon plasma effects)
  • soft QCD; energy-loss vs. saturation
  • useful as reference for ion-ion collision analyses
  • $2 < \eta_{lab} < 5$, $P_T < 14$ GeV.
Motivation

Nuclear modification factor:

\[ R_{pA}(y, \sqrt{s}) = \frac{1}{A} \frac{d\sigma_{pA}(y, \sqrt{s})}{dy} \frac{dy}{d\sigma_{pp}(y, \sqrt{s})} \]

From PHENIX data: heavy quarkonia suppressed at large rapidity:
(PRL 107, 2011, 142301)

prediction for LHC energies (5 TeV)
from JHEP 1303(2013) 122

Theoretical calculations by Arleo & Payne
Design luminosity \( (2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}) \)

- good IP measurement: \( \langle \delta \text{IP} \rangle = 20 \mu\text{m} \) for \( p_T > 2 \text{ GeV} \):
  - excellent vertex reconstruction to select \( \text{e.g. } J/\Psi \) mesons
  - separation of prompt from secondary \( J/\Psi \)'s

- \( \mu \) ID efficiency: \( \sim 97\% \) for \( < 3\% \pi \rightarrow \mu \) mis-id probability from \( p = 2 - 100 \text{ GeV} \)
  - reconstruct open charm
  - very useful for particle-yield ratios
  - \( V_0 \) reconstruction
Typical pA collision in LHCb
positive rapidity (protons on lead)

negative rapidity (lead on protons)
LHCb Spectrometer

Event characteristics

Pseudo-rapidity in LHCb for p-Pb collisions

Multiplicity distribution in pA collisions

LHCb-CONF-2012-034
LHCb proton-ion data

- low instantaneous luminosity: \( \mathcal{L} \approx 5 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1} \)
- low pile-up (approx. 1 primary vertex per interaction)
- data-taking efficiency better than 91%.
- results based on 2 beam configurations and 2 magnet configurations.

\[ \text{forward} : \mathcal{L} = 1.1 \text{ nb}^{-1} \quad \text{backward} : \mathcal{L} = 0.5 \text{ nb}^{-1} \]
reconstruct $J/\Psi$ in p-Pb and Pb-p data
separate prompt $J/\Psi$s from secondaries
determine double-differential $J/\Psi$ cross sections
use total prompt $J/\Psi$ cross section for nuclear modification
determine forward-backward asymmetry in prompt $J/\Psi$ production

\[ t_z = \frac{(z_{J/\Psi} - z_{PV}) M_{J/\Psi}}{p_z} \]
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$t_z = \frac{(z_{J/\Psi} - z_{PV}) M_{J/\Psi}}{p_z}$
\( J/\Psi \) production in p-Pb collisions

- determine yields by simultaneous mass & pseudo-proper time fit
- mass model: Crystal-Ball signal and exponential background

Results from arXiv:1308.6729
determine yields by simultaneous mass & pseudo-proper time fit
mass model: Crystal-Ball signal and exponential background
t_z model: exponential for J/Ψ’s from b’s
convoluted with double Gaussian
delta function for signal
empirical function from side-band for background
J/Ψ production in p-Pb collisions
J/Ψ total and double-differential cross sections

- **pA:** $1.5 < y < 4.0$
  - **pA** prompt:
    \[ \sigma_{pA} = 1168 \pm 15 \text{ (stat)} \pm 60 \text{ (sys)} \text{ µb} \]
  - **pA** from b’s:
    \[ \sigma_{pA} = 166 \pm 4.1 \text{ (stat)} \pm 9.2 \text{ (sys)} \text{ µb} \]

- **Ap:** $-5.0 < y < -2.5$
  - **Ap** prompt:
    \[ \sigma_{Ap} = 1293 \pm 49.8 \text{ (stat)} \pm 82 \text{ (sys)} \text{ µb} \]
  - **Ap** from b’s:
    \[ \sigma_{Ap} = 118 \pm 6.8 \text{ (stat)} \pm 12.2 \text{ (sys)} \text{ µb} \]

**Dominated by systematics from luminosity (3%), fit model and data-MC agreement**

Results from arXiv:1308.6729
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Fraction of $J/\Psi$ from b-quarks:

- $p_T < 14 \text{ GeV}/c$
- $1.5 < y < 4.0$
- $-5.0 < y < -2.5$

From: LHCb-CONF-2013-008
Prompt $J/\Psi$ cross sections at LHCb

Comparison of prompt $J/\Psi$ production in p-p, p-Pb and Pb-p:

- re-scale $\sigma_{pp}$ to common rapidity range
- scale $J/\Psi$ cross section by $\frac{1}{A}$
- perform linear interpolation between $\sigma_{pp}$ cross sections
- obtain $\sigma_{pp}@\sqrt{s_{NN}} = 5$ TeV

Total prompt $J/\Psi$ cross section
- clear observation of $J/\Psi$ suppression in pA and Ap
- but Ap cross section only slightly suppressed

From: LHCb-CONF-2013-008
Nuclear modification vs. rapidity for prompt $J/\Psi$'s:

and for $J/\Psi$ from b-quarks:

\[
R_{pA}(y, \sqrt{s}) = \frac{1}{A} \frac{d\sigma_{pA}(y, \sqrt{s})}{dy} \frac{d\sigma_{pp}(y, \sqrt{s})}{dy}
\]

Theory confirmed by data; but more needed to separate saturation from energy loss
Forward-backward asymmetry

\[
r_{FB} \equiv \frac{R_{pA}(y)}{R_{Ap}(-y)}
\]

asymmetry in forward-backward prompt \(J/\Psi\) production:

forward-backward asymmetry for \(J/\Psi\)’s from b-quarks:

Results from arXiv:1308.6729,
Forward-backward asymmetry vs. transverse momentum:

Results from arXiv:1308.6729,
Charm production in proton-ion collisions

Up to now: only pilot data (1 $\mu b^{-1}$) analyzed; proof of principle

- compare charmed hadron production from pp and pA collisions
- single primary vertex
- use RICH’s to differentiate between $\pi^\pm$ and $K^\pm$
- use production ratio to show enhanced particle production in pA collisions

$$R(X) = \frac{N_{pPb}(X)}{N_{pp}(X)} \frac{PV_{pp}}{PV_{pPb}}$$

LHCb Preliminary

$pA$ collisions - all
$\sqrt{s_{NN}}=5.02$ TeV
$2.5<\gamma_{cm}<4.5$
$p_T>0.2$ GeV/c
signal: 183 ± 17 entries
1780370 primary vertices

$pp$ collisions
$\sqrt{s_{NN}}=8$ TeV
$2.5<\gamma_{cm}<4.5$
$p_T>0.2$ GeV/c
signal: 64 ± 9 entries
1133226 primary vertices

$$R(D) = 1.820 \pm 0.307$$

LHCb-CONF-2012-034
Conclusions & Outlook

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- unique kinematic reach complements other experiments
- important for understanding of heavy ion physics
- probe specific QCD phenomena
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- Measurement of (prompt) \(J/\Psi\) cross section in \((y, p_T)\) at \(\sqrt{s_{NN}} = 5\) TeV
- Nuclear modification determined, using interpolated LHCb \(\sigma\)'s to \(\sqrt{s_{NN}} = 5\) TeV
- Nuclear modification in p-Pb collisions in agreement with theoretical predictions
- Forward-backward asymmetry as function of rapidity; agrees with theory
- More data needed to differentiate between energy loss and saturation effects
- Observation of open charm \(D^0\)
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Measurement of (prompt) $J/\Psi$ cross section in $(y, p_T)$ at $\sqrt{s_{NN}} = 5 \text{ TeV}$

Nuclear modification determined, using interpolated LHCb $\sigma$'s to $\sqrt{s_{NN}} = 5 \text{ TeV}$

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Observation of open charm $D^0$

- not all data were analyzed... more to come, with better statistics!
  e.g $\Upsilon$ production in proton-ion collisions