LHCb results in proton-nucleus collisions at the LHC

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Outline

- Motivation
- LHCb Detector
- Beam configurations
- Measurements
 - J/Ψ production
 - Y production
 - Z boson production
- Outlook
- Conclusions

Motivation

LHCb fully instrumented in the forward region

→ study proton-ion collisions in a unique kinematic region

pA collisions interesting by itself and as a reference sample for heavy ion collisions

pA data should allow factorizing the QGP effects from Cold Nuclear Matter effects

Sensitive probes of properties of nuclear matter

- Nuclear parton distribution function (nPDF)
- Nuclear attenuation factors
- Tests phenomenological models

Heavy flavour and quarkonium probe

- energy loss mechanisms
- medium transport properties
- quark deconfinement

Electroweak bosons:

- probe nuclear PDFs which are poorly constraint
- LHCb sensitive to x_A range $2 \times 10^{-4} - 3 \times 10^{-3}$ and 0.2–1 at mass of Z

Fully instrumented in the forward region ($2 < \eta < 5$)
 some detection capability in backward region ($-3.5 < \eta < -1.5$)

- Tracking: $\sigma_p/p \sim 0.4-0.6\%$
- Vertex resolution:
 $\sigma_{xy} \sim 15\mu\text{m}, \sigma_z \sim 80\mu\text{m}$
- Muon ID $\epsilon=97\%$; mis-id: 0.7%
- Kaon ID $\epsilon=90\%$; π mis-id < 5%

• Analyses based on

- 2013 proton-lead runs @ 5 TeV
- single arm spectrometer → two different beam configurations

Beam Configurations

Forward:

- proton-lead collisions at 5 TeV
- luminosity: 1.1 nb^{-1} recorded by LHCb
- proton beam in the direction of the LHCb detector
- positive rapidity with respect to the proton
- shift in rapidity: $\Delta y = y_{\text{lab}} - y = 0.47$, acceptance $1.5 < y < 4.0$

Beam Configurations

Backward:

- proton-lead collisions at 5 TeV
- luminosity: 0.5 nb^{-1} recorded by LHCb
- proton beam in the direction of the LHCb detector
- negative rapidity with respect to the proton
- shift in rapidity: $\Delta y = y_{\text{lab}} - y = 0.47$, acceptance $-5.0 < y < -2.5$

Pb: $E_N = 1.58 \text{ TeV}$

p: $E = 4 \text{ TeV}$

LHCb Integrated Luminosity at p-Pb 4 TeV in 2013

- low instantaneous luminosity: $L \approx 5 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1}$
- low pile-up (approx. 1 primary vertex per beam crossing)
- data-taking efficiency better than 91%.
- results based on 2 beam configurations and 2 magnet configurations.
- p+Pb : $L = 1.1 \text{ nb}^{-1}$
- Pb+p : $L = 0.5 \text{ nb}^{-1}$

J/Ψ production in p-Pb collisions

- reconstruct J/Ψ in di-muon channel
- forward: $1.5 < y < 4.0$ and backward: $-5.0 < y < -2.5$
- $p_T < 14$ GeV
- separate prompt J/Ψs from secondaries: pseudo-proper time

$$t_z = \frac{(z_{J/\psi} - z_{PV}) \cdot M_{J/\psi}}{p_z}$$

Results:

- differential J/Ψ cross sections
- nuclear modification factor
- forward-backward asymmetry

Yields: simultaneous fit to mass & pseudo-proper time

Mass model: **Crystal-Ball signal** and **exponential background**

Yields: simultaneous fit to mass & pseudo-proper time

Mass model: Crystal-Ball signal and exponential background

t_z model: exponential for J/ Ψ 's from b's convoluted with double Gaussian

δ function for prompt J/ Ψ 's convoluted with double Gaussian

empirical function (sPlot) from side-band for background

Acceptance and efficiency corrections from pp simulation
pp simulation reweighted to describe track multiplicity

pA: $1.5 < y < 4.0$

prompt: $\sigma = 1168 \pm 15 \text{ (stat)} \pm 60 \text{ (sys)} \mu\text{b}$

from b's: $\sigma = 166 \pm 4.1 \text{ (stat)} \pm 9.2 \text{ (sys)} \mu\text{b}$

Ap: $-5.0 < y < -2.5$

prompt: $\sigma = 1293 \pm 49.8 \text{ (stat)} \pm 82 \text{ (sys)} \mu\text{b}$

from b's: $\sigma = 118 \pm 6.8 \text{ (stat)} \pm 12.2 \text{ (sys)} \mu\text{b}$

Prompt J/ ψ cross section about 10 times higher than J/ ψ from b
 $\Rightarrow$ similar to the values observed in pp collisions at 2.76, 7 and 8 TeV
[JHEP 02 (2013) 041], [EPJC (2011) 71 1645], [JHEP 06 (2013) 064]

Largest systematic uncertainties:

mass model: 2.3-3.4%

difference of pT and y distribution between simulation and data: 0.1-8.7%

multiplicity reweighting: 0.1-4.3%

tZ fit (only for J/ ψ from b) 0.2-12%

forward

backward

forward: double differential cross sections

prompt J/ψ

J/ψ from b

Quantified with measurement of

- Nuclear modification factor

$$R_{pPb} = 1/A (d\sigma_{pA}/dy) / (d\sigma_{pp}/dy) \text{ in overlap region } 2.5 < |y| < 4.0$$

=1 if pA collision is superposition of A pp collisions

<1 in case of suppression due to medium

- Forward backward production ratio

$$R_{FB} = (d\sigma_{pA}/dy) / (d\sigma_{Ap}/dy) \text{ in overlap region } 2.5 < |y| < 4.0$$

→ many uncertainties cancel

Reference pp cross section at 5 TeV not measured directly:

interpolation of σ_{pp} at $\sqrt{s}=2.76, 7$ and 8 TeV

JHEP 02(2013)041, EPJC (2011) 71 1645, JHEP 06 (2013) 064

$R_{pPb} = 1/A (d\sigma_{pA}/dy) / (d\sigma_{pp}/dy)$ in overlap region $2.5 < |y| < 4.0$

Prompt J/ψ : significant sign of cold nuclear matter effects: 40% measurements agree with most of the predictions

J/ψ from b: modest suppression wrt pp first indication of suppression of b hadron production in Pb agreement with predictions in forward region

Predictions:

LO CSM with EPS09 or nDSg parametrisation for modification of PDFs

Energy loss effects of initial and final state partons with or without modification

EPS09: JHEP 0904 (2009) 65, nDSG: Phys. Rev. D69(2004) 074028

Energy loss: JHEP 03(2013) 122, LO: Nucl. Phys. B127 (1980) 425, Phys. Lett. B102, (1981) 364

NLO: Phys. Rev. D17 (1978) 2324

$$R_{FB} = (d\sigma_{pA}/dy)/(d\sigma_{Ap}/dy) \text{ in three bins in } |y|$$

Prompt J/ψ: significant forward-backward asymmetry

J/ψ from b: R_{FB} closer to one

EPS09(NLO) predicts smaller asymmetry for prompt J/ψ

Predictions:

LO CSM with EPS09 or nDSg parametrisation for modification of PDFs

Energy loss effects of initial and final state partons with or without modification

R_{FB} in bins of p_T , integrated over y

Predictions for prompt J/ψ only

EPS09(NLO) plus energy loss agrees with data

Comparison to ALICE

Sum of prompt J/ψ and J/ψ from b
in good agreement with ALICE
JHEP 02(2014) 073

- reconstruct Y in di-muon channel
- forward $1.5 < y < 4.0$ and backward $-5.0 < y < -2.5$
- $p_T < 15$ GeV

low statistics $\rightarrow$ no differential measurement

Yields: fit to mass

Mass model: **three Crystal-Balls for signal** and **exponential background**

forward

backward

Cross-section times branching fraction, integrated over p_T and y

$\sigma(\Upsilon(nS)) \times \mathcal{B}(\Upsilon(nS) \rightarrow \mu^+ \mu^-)$		
	Forward	Backward
$\Upsilon(1S)$	$380 \pm 35_{\text{stat}} \pm 19_{\text{syst}} \text{ nb}$	$295 \pm 56_{\text{stat}} \pm 27_{\text{syst}} \text{ nb}$
$\Upsilon(2S)$	$75 \pm 19_{\text{stat}} \pm 5_{\text{syst}} \text{ nb}$	$81 \pm 39_{\text{stat}} \pm 17_{\text{syst}} \text{ nb}$
$\Upsilon(3S)$	$27 \pm 16_{\text{stat}} \pm 4_{\text{syst}} \text{ nb}$	$< 39 \text{ nb @ 90 \% C.L.}$
Relative suppression factor $R^{nS/1S}$		
	Forward	Backward
$R^{2S/1S}$	$0.20 \pm 0.05_{\text{stat}} \pm 0.01_{\text{syst}}$	$0.28 \pm 0.14_{\text{stat}} \pm 0.05_{\text{syst}}$
$R^{3S/1S}$	$0.07 \pm 0.04_{\text{stat}} \pm 0.01_{\text{syst}}$	$< 0.13 \text{ @ 90 \% C.L.}$

Statistical uncertainty is dominating

Dominant systematic uncertainties:

p_T and y dependence of signal 4%(forward) 7%(backward)

or trigger efficiency : 2%(forward) 5%(backward)

Y production: cold nuclear effects

Measurement of R_{pPb} and R_{FB} with $Y(1S)$ complementary to J/ψ (probing different x_A)

- Cold nuclear effects are also visible with $Y(1S)$ production
- Suppression in forward region smaller than for J/ψ
- Possible enhancement in backward region due to anti-shadowing
- Agreement with prediction EPS09(NLO) for nPDF and with and without energy loss

Z production

LHCb probes two distinct regions in x - Q^2 : $x_{1,2} = (Q/\sqrt{s}) e^{\pm y}$

Forward kinematics:

@ first order, collision of a sea and a valence quark

Complementary to ATLAS/CMS

LHCb phase space:

→ sensitivity to nuclear PDF at large x_A and low x_B

Z production in pA

Ratio of nuclear PDF for Pb to bare proton PDF [arXiv:1401.2345]

gluon

valence quarks

Nuclear PDF (nPDF) poorly constrained at high and low x_A , where measurements at LHCb have a good sensitivity.

LHCb sensitivity: 2×10^{-4} – 3×10^{-3} and 0.2 – 1 at $Q^2 = M_Z^2$

Forward: pA collisions

Luminosity: $1.099 \pm 0.021 \text{ nb}^{-1}$

Selection:

muons: $p_T > 20 \text{ GeV}$, $2 < \eta < 4.5$

mass: $60 < M_{\mu\mu} < 120 \text{ GeV}^2$

Purity:

from data: about 99.7%

11 candidates

Backward: Ap collisions

Luminosity: $0.521 \pm 0.011 \text{ nb}^{-1}$

Selection:

muons: $p_T > 20 \text{ GeV}$, $2 < \eta < 4.5$

mass: $60 < M_{\mu\mu} < 120 \text{ GeV}^2$

Purity:

from data: about 99.6%

4 candidates

Z production in proton-lead

arXiv:1406.2885

Efficiencies, purity from data

Cross sections:

forward:

$$\sigma_{Z(\rightarrow\mu^+\mu^-)} = 13.5^{+5.4}_{-4.0} \text{ (stat.)} \pm 1.2 \text{ (syst.) nb}$$

backward:

$$\sigma_{Z(\rightarrow\mu^+\mu^-)} = 10.7^{+8.4}_{-5.1} \text{ (stat.)} \pm 1.0 \text{ (syst.) nb}$$

Theoretical predictions:

NNLO calculations (FEWZ)

nuclear modification: EPS09(NLO)

future higher statistics measurements
will provide important information
on nuclear PDFs

FEWZ: Y. Li and F. Petriello, Phys. Rev. D86 (2012) 094034, arXiv:1208.5967.

EPS09: K. Eskola, H. Paukkunen, and C. Salgado, JHEP 04 (2009) 065, arXiv:0902.4154.

Fiducial volume

muons: $p_T > 20 \text{ GeV}$, $2 < \eta < 4.5$

mass: $60 < M(\mu\mu) < 120 \text{ GeV}^2$

Results from pilot run: 0.9 μb

Inject Ne gas, measure beam-gas pNe (or PbNe) interaction at $s=87$ GeV

Summary and Outlook

- LHCb successfully participated in proton-lead runs
- Measurement of J/ψ and Y production
 - cold nuclear matter effects visible in J/ψ and Y ($1S$) production
- First observation of Z production in proton-nucleus collisions
- Many more measurements ongoing
- Measurements limited by statistics
 - benefit from larger data samples after the restart of LHC
- In addition, we have sample of pNe and PbNe data
- Only a small part of LHCb's potential so far used

Backup slides

SMOG: System for Measuring Overlap with Gas