Heavy Ion Physics at LHCb

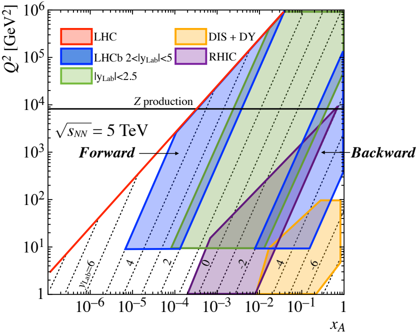
LHCP 2014, New York, June, 2 - 7, 2014

Christian Elsasser [on behalf of the LHCb Collaboration]

Motivation

Proton-lead collisions at $\sqrt{s_{NN}} = 5$ TeV recorded by LHCb $\Rightarrow$ 1.6 nb^{-1}

- Reference for nucleus-nucleus collisions
- Study of QCD in a yet barely explored regime
- Study of cold nuclear matter effects and their disentangling from QGP effects
- Input for the determination of nuclear PDF

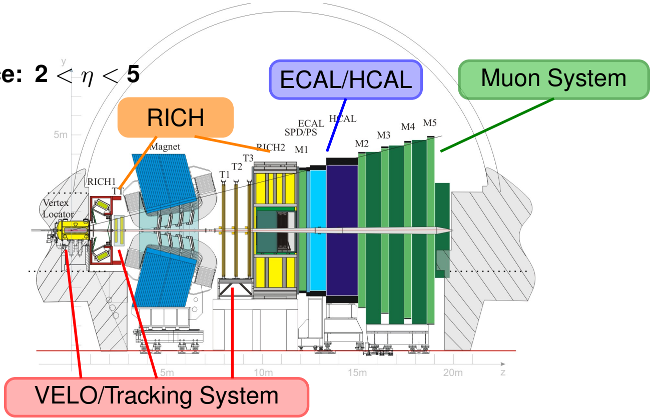


Forward acceptance of LHCb allows to test unique phase space region $\Rightarrow$ sensitivity for very low (*e.g.* $x_A = \mathcal{O}(10^{-4})$ for $Q^2 = M_Z^2$) as well as very high x_A-values

Beam Configuration

Single-arm forward spectrometer $\Rightarrow$ difference in beam configurations

Acceptance: $2 < \eta < 5$



University of Zurich[UZH]

Beam Configuration

Single-arm forward spectrometer $\Rightarrow$ difference in beam configurations

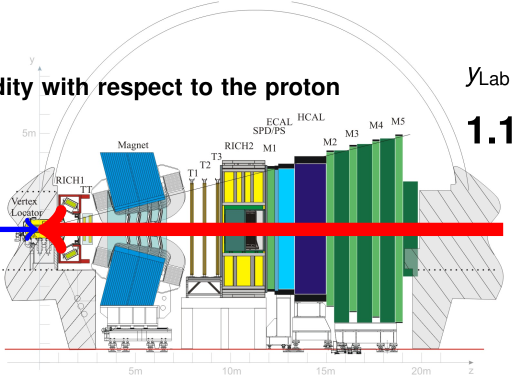
Forward:
positive rapidity with respect to the proton

$y_{\text{Lab}} - y = +0.47$

$\mathbf{1.1\ nb^{-1}}$

p
($E_p = 4$ TeV)

Pb
($E_N = 1.58$ TeV)



Proton beam in the direction of the LHCb detector

Beam Configuration

Single-arm forward spectrometer ⇒ difference in beam configurations

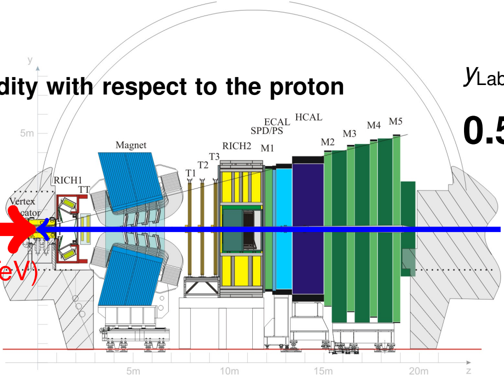
Backward:
negative rapidity with respect to the proton

$y_{\text{Lab}} - y = +0.47$

$0.5\,\text{nb}^{-1}$

Pb
$(E_N = 1.58$ TeV$)$

p
$(E_p = 4$ TeV$)$



Lead beam in the direction of the LHCb detector

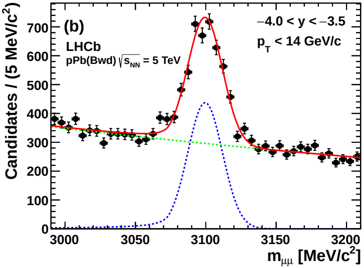
J/ψ Production

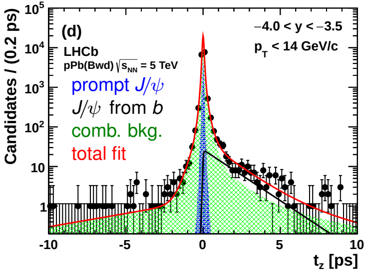
[JHEP 02 (2014) 072]

Measurement in $1.5 < y < 4.0$ (forward) and $-5.0 < y < -2.5$ (backward) as well as $p_T < 14$ GeV$/c$

Simultaneous fit of

- Invariant dimuon mass $m_{\mu^+\mu^-}$
- Pseudo proper time $t_z = (z_{J/\psi,\mathrm{vtx}} - z_{\mathrm{PV}}) \cdot m_{J/\psi}/p_z \Rightarrow$ Discrimination prompt J/ψ/J/ψ from b decays

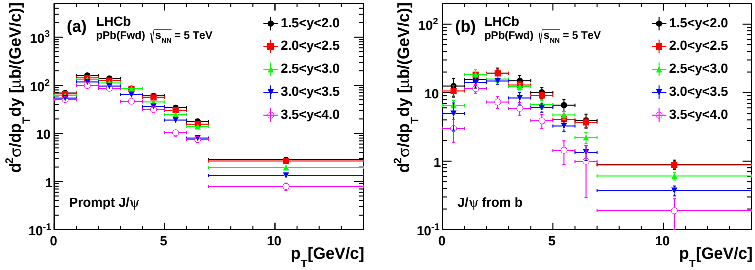




J/ψ Production

[JHEP 02 (2014) 072]

Double differential cross-section $d^2\sigma/dp_T dy$ in the forward direction



Factor ∼10 between prompt J/ψ and J/ψ from $b \Rightarrow$ similar to the values observed in pp collisions at $\sqrt{s} = 2.76$, 7 and 8 TeV

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

J/ψ Production

[JHEP 02 (2014) 072]

Nuclear effects depend on kinematics

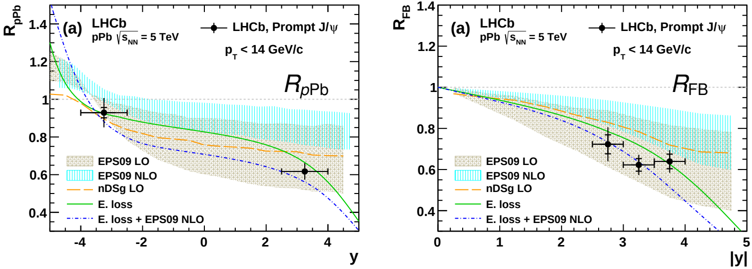
- Nuclear attenuation factor $R_{pA}(y, \sqrt{s_{NN}}) = \frac{1}{A} \frac{\mathrm{d}\sigma_{pA}(y, \sqrt{s_{NN}})/\mathrm{d}y}{\mathrm{d}\sigma_{pp}(y, \sqrt{s_{NN}})/\mathrm{d}y}$
- Forward-backward ratio $R_{\mathrm{FB}}(y, \sqrt{s_{NN}}) = \frac{\mathrm{d}\sigma_{pA}(+|y|, \sqrt{s_{NN}})/\mathrm{d}y}{\mathrm{d}\sigma_{pA}(-|y|, \sqrt{s_{NN}})/\mathrm{d}y}$

Measurement of R_{pA} and R_{FB} in the overlap region of $2.5 < |y| < 4.0$

Reference cross-section $\sigma_{pp}(\sqrt{s} = 5\ \mathrm{TeV})$ for R_{pA} from interpolation of σ_{pp} at $\sqrt{s} = 2.76$, 7 and 8 TeV
[LHCb-CONF-2013-013/ALICE-PUBLIC-2013-002]

J/ψ Production

[JHEP 02 (2014) 072]



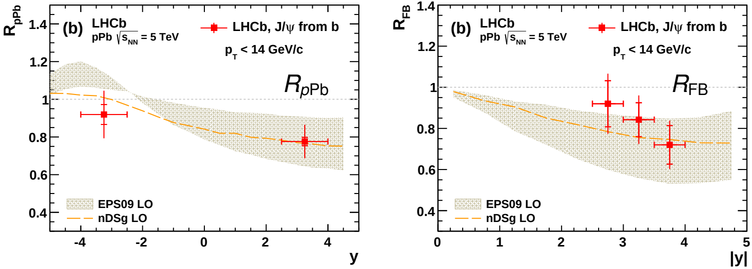
Predictions based on nPDF at NLO sets and energy loss of initial state partons

[JHEP 0904 (2009) 65], [Int. J. Mod. Phys. E Vol. 22 (2013) 1330007], [JHEP 1305 (2013) 155]

⇒ significant sign of cold nuclear matter effects

J/ψ Production

[JHEP 02 (2014) 072]



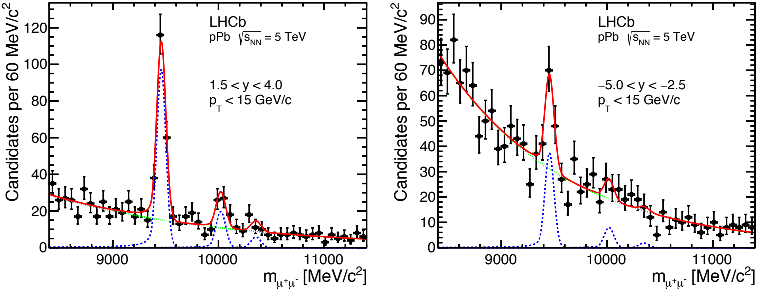
Smaller suppression of J/ψ from b hadrons than on prompt J/ψ

Inclusive J/ψ production: Measurements on inclusive J/ψ production in agreement with those by ALICE
[ALICE-PUBLIC-2013-002/LHCb-CONF-2013-013]

Υ Production

[arXiv:1405.5152]

Cross-section measurements in $1.5 < y < 4.0$ (forward) and $-5.0 < y < -2.5$ (backward) as well as $p_T < 15$ GeV/c



Low statistics prevent differential measurement

Υ Production

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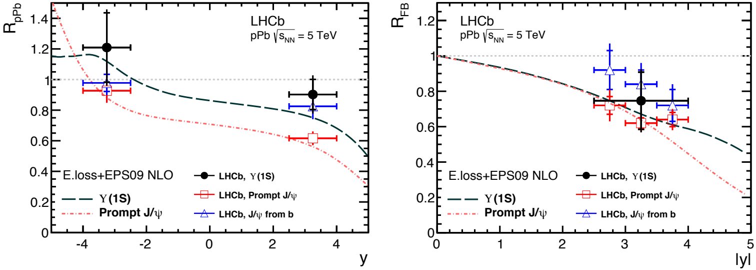
$\sigma(\Upsilon(nS)) \times \mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-)$	**Forward**	**Backward**
$\Upsilon(1S)$	$380 \pm 35_{\text{stat}} \pm 19_{\text{syst}}$ nb	$295 \pm 56_{\text{stat}} \pm 27_{\text{syst}}$ nb
$\Upsilon(2S)$	$75 \pm 19_{\text{stat}} \pm 5_{\text{syst}}$ nb	$81 \pm 39_{\text{stat}} \pm 17_{\text{syst}}$ nb
$\Upsilon(3S)$	$27 \pm 16_{\text{stat}} \pm 4_{\text{syst}}$ nb	$<$ 39 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 @ 90 % C.L.

Υ Production

[arXiv:1405.5152]

Complementary measurement of cold nuclear matter effect with $\Upsilon(1S)$ based on $R_{p\text{Pb}}$ and R_{FB}

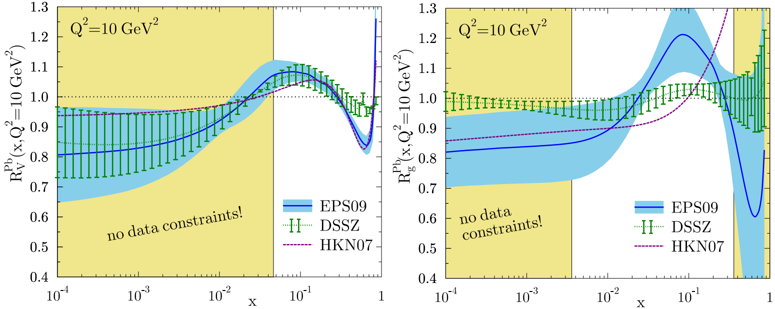


Cold nuclear matter effects also visible in $\Upsilon(1S)$ production

Good agreement with predictions based on EPS09 NLO nPDF set and energy loss model of initial state partons

Z Production

Nuclear PDF sets so far mainly constrained by fixed target data ⇒ no constraints at very low and very high x_A-values



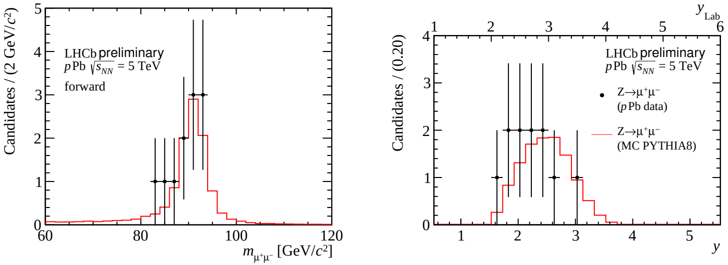
Ratio of PDFs of (left) valence quark and (right) gluons between lead and bare proton (from [H. Paukkunen, arXiv:1401.2345]

LHCb sensitive to x_A range 2×10^{-4}-3×10^{-3} and 0.2-1 at $Q^2 = M_Z^2$.

Z Production

[LHCb-PAPER-2014-022]

Measurement of $Z \to \mu^+\mu^-$ cross-section in fiducial region
$60 < m_{\mu^+\mu^-} < 120$ GeV/c^2, $p_T(\mu) > 20$ GeV/c and $2.0 < \eta(\mu) < 4.5$



11 candidates in the forward direction (*i.e.* p beam into LHCb; 1.1 nb^{-1})

Sample purity estimated to be ~ 99.7 %

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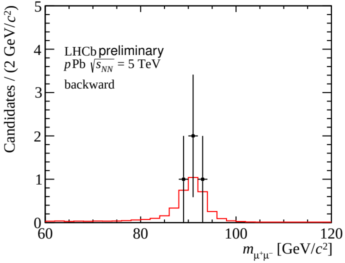
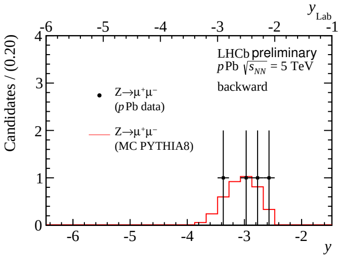




4 candidates in the <u>backward</u> direction (*i.e.* Pb beam into LHCb; 0.5 nb^{-1})

Sample purity estimated to be $\sim$ 99.6 %

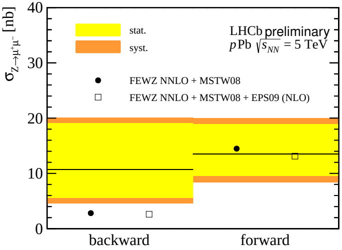
Z Production

[LHCb-PAPER-2014-022]

Measured cross-sections:

Forward $\sigma_{Z\to\mu^+\mu^-} = 13.5^{+5.4}_{-4.0}\,\text{stat} \pm 1.2_{\text{syst}}$ nb

Backward $\sigma_{Z\to\mu^+\mu^-} = 10.7^{+8.4}_{-5.1}\,\text{stat} \pm 1.0_{\text{syst}}$ nb



Predictions from NNLO calculation (FEWZ+MSTW08) with EPS09 NLO:

Forward $\sigma_{Z\to\mu^+\mu^-} = 13.12^{+0.11}_{-0.08}\,\text{theo}\ {}^{+0.27}_{-0.24}\,\text{PDF}\ {}^{+0.03}_{-0.10}\,\text{nPDF}$ nb

Backward $\sigma_{Z\to\mu^+\mu^-} = 2.61^{+0.03}_{-0.03}\,\text{theo}\ {}^{+0.07}_{-0.06}\,\text{PDF}\ {}^{+0.03}_{-0.08}\,\text{nPDF}$ nb

Summary & Outlook

- Successful participation of LHCb in proton-lead data taking
- Measurement of J/ψ and Υ production $\Rightarrow$ cold nuclear matter effects visible in J/ψ and $\Upsilon(1S)$ production
- First observation of Z production in proton-nucleus collisions

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- All presented measurements limited by statistics $\Rightarrow$ benefit from larger data samples after the restart of LHC (anticipation of $10\times$ more data in 2015)

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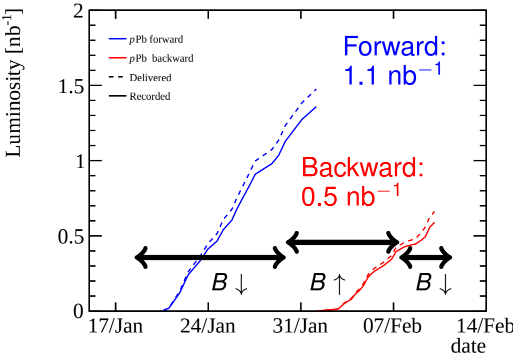
Only a small part of LHCb's potential in proton-lead collisions so far utilised

Back-up

Data Taking

Data in both beam configuration taken with both magnet polarities



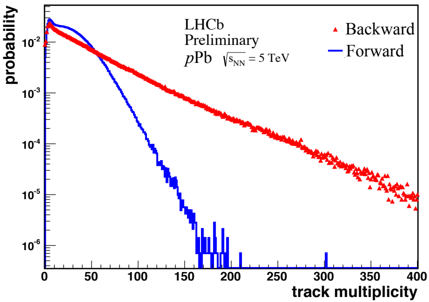
Instant. luminosity: $\mathcal{L} = 5 \times 10^{27}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Low pile-up: 1 primary vertex per (non-empty) bunch crossing

Track Multiplicity

[LHCb-CONF-2013-008]

As expected larger (track) multiplicity in the backward than in the forward sample

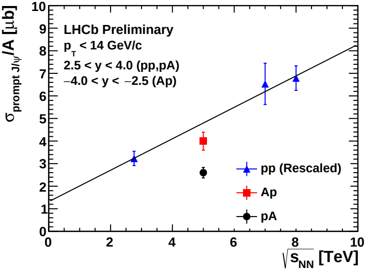


No difference between the magnet polarities

Interpolation of Cross-sections

Interpolation of Onia cross-sections to $\sqrt{s_{NN}} = 5$ TeV tested with

- Linear:
  $\sigma(\sqrt{s}) = a_0 + \sqrt{s}a_1$
  (shown in plot)
- Power-law:
  $(\sqrt{s}/a_0)^\gamma$
- Exponential:
  $a_0 \cdot (1 - \exp(-\sqrt{s}/\lambda)$



Systematic Uncertainties J/ψ Production

Source	Forward [%]	Backward [%]
Muon-ID	1.3	1.3
Trk Eff.	1.5	1.5
Mass fit	2.3	3.4
Luminosity	1.9	2.1
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1.0	1.0
Uncorrelated between bins		
Binning	0.1 – 8.7	0.1 – 6.1
Multiplicity weight	0.1 – 3.0	0.2 – 4.3
t_z fit (J/ψ from b)	0.2 – 12.0	0.2 – 13.0

Systematic Uncertainties Υ Production

Source	Forward [%]			Backward [%]		
	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Muon-ID	1.3	1.3	1.3	1.3	1.3	1.3
Trk Eff.	1.5	1.5	1.5	1.5	1.5	1.5
Mass fit	1.1	4.9	13.0	1.8	19.0	90.0
Luminosity	1.9	1.9	1.9	2.1	2.1	2.1
Trigger	1.9	1.9	1.9	2.1	2.1	2.1
Binning	2.1	2.1	2.1	5.0	5.0	5.0
Reconstruction	1.5	1.5	1.5	1.5	1.5	1.5
Total	5.5	7.3	14.0	9.8	21.0	90.0

Systematic Uncertainties Z Production

Source	Forward [%]	Backward [%]
Muon-ID/Trk/Sel/Rec. Eff.	8.4	8.7
Purity est.	0.5	0.5
GEC[a]	0.0	1.9
Multiplicity weight	1.5	2.0
Luminosity	1.9	2.1
Total	8.7	9.4

[a] Global event cuts

Significance of Z Signal

Given the purity estimated from *pp* collisions reweighted for the different track multiplicity in *p*Pb collisions, the obtained significance is:

Forward	10.4σ (Expected background yield: 0.028)
Backward	6.8σ (Expected background yield: 0.004)