LHCb results from proton-lead collisions

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on behalf of the LHCb collaboration

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Outline

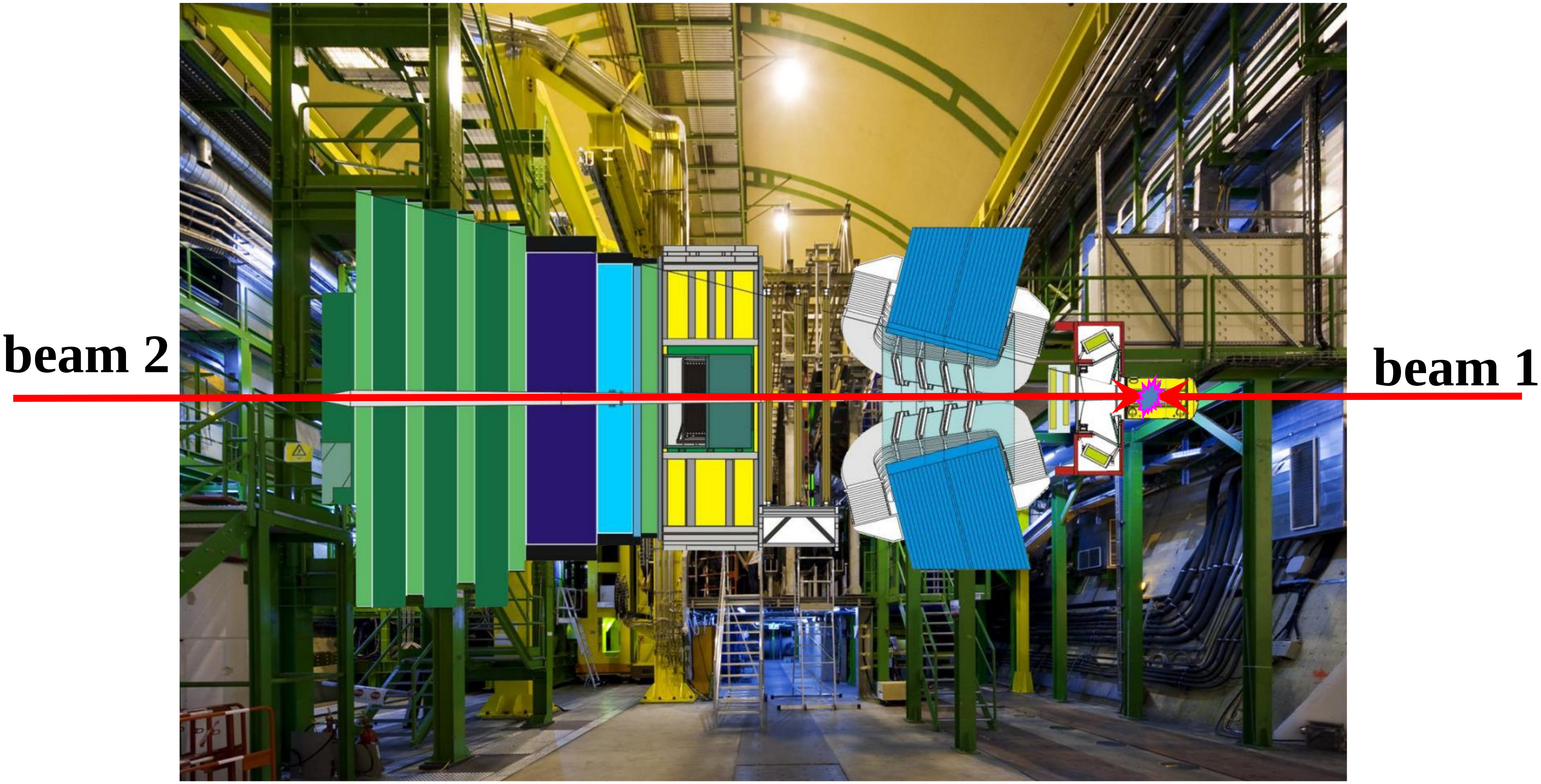
- The LHCb detector and pPb data taking
- Physics motivation
- $\psi(2S)$ production and cold nuclear matter effects in pPb collisions at 5 TeV **NEW!**
- J/ψ and Υ production in pPb collisions at 5 TeV
- Summary

LHCb detector

JINST 3 (2008) S08005

Dedicated to beauty and charm physics

Pseudorapidity acceptance
$2 < \eta < 5$

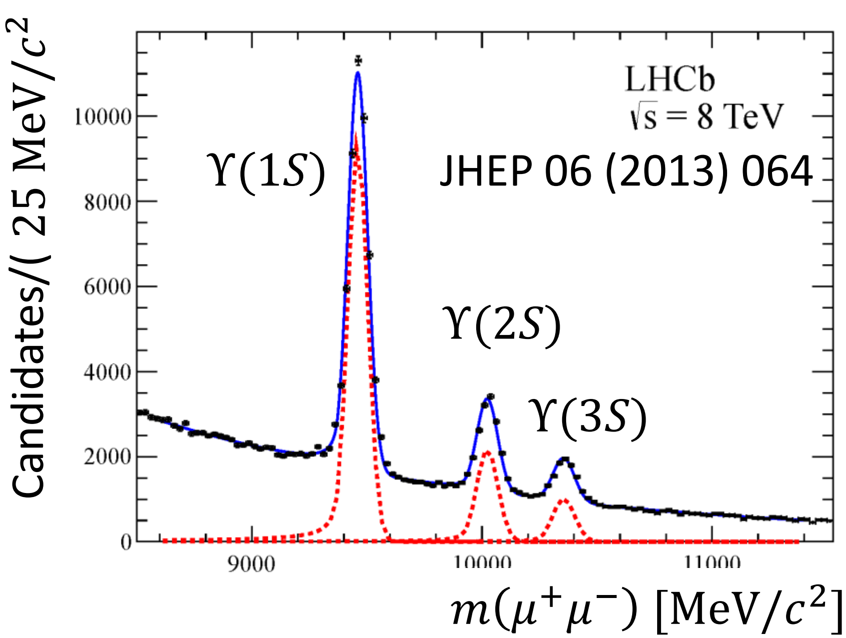


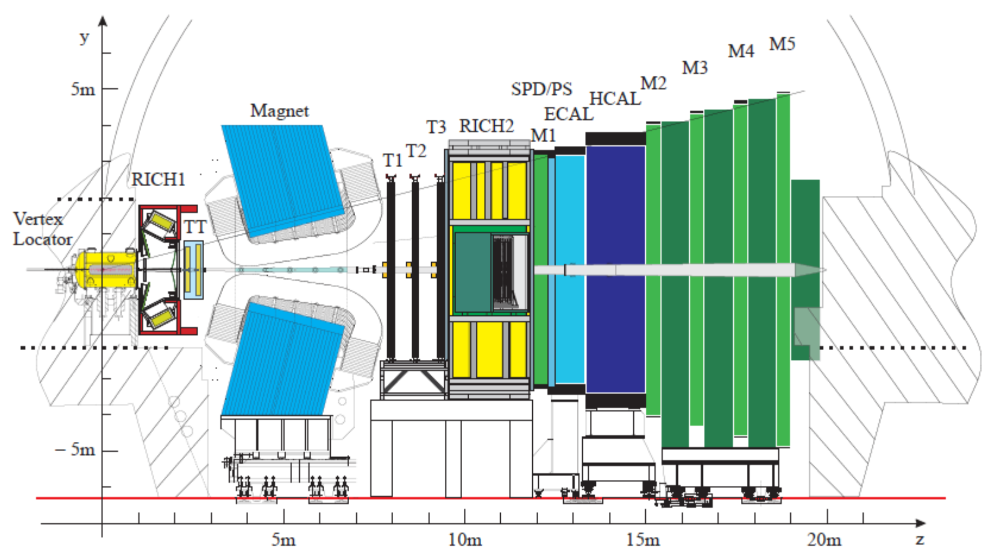
can also contribute to heavy-ion physics …

LHCb in a nutshell

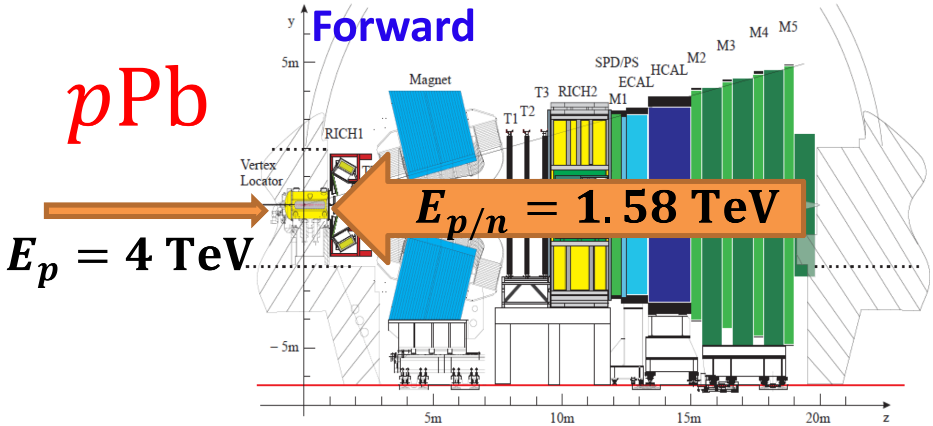
Int.J.Mod.Phys. A30 (2015) 1530022

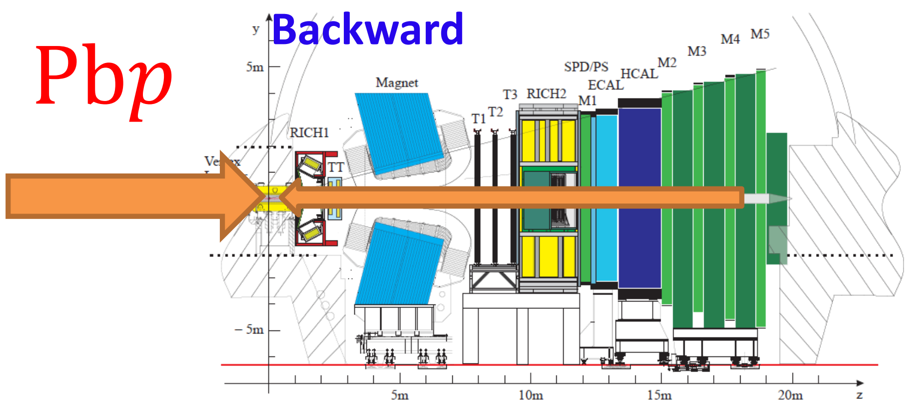
Impact parameter:	$\sigma_{IP} = 20\ \mu\text{m}$
Proper time:	$\sigma_\tau = 45$ fs for $B_s^0 \to J/\psi\phi$ or $D_s^+\pi^-$
Momentum:	$\Delta p/p = 0.5 \sim 0.8\%\ (5 – 100\ \text{GeV}/c)$
Mass :	$\sigma_m = 8\ \text{MeV}/c^2$ for $B \to J/\psi X$ (constrained $\text{m}_{J/\psi}$)
RICH $K-\pi$ separation:	$\epsilon(K \to K) \sim 95\%$ mis-ID $\epsilon(\pi \to K) \sim 5\%$
Muon ID:	$\epsilon(\mu \to \mu) \sim 97\%$ mis-ID $\epsilon(\pi \to \mu) \sim 1-3\%$
ECAL:	$\Delta E/E = 1 \oplus 10\%/\sqrt{E(\text{GeV})}$





Beam configuration





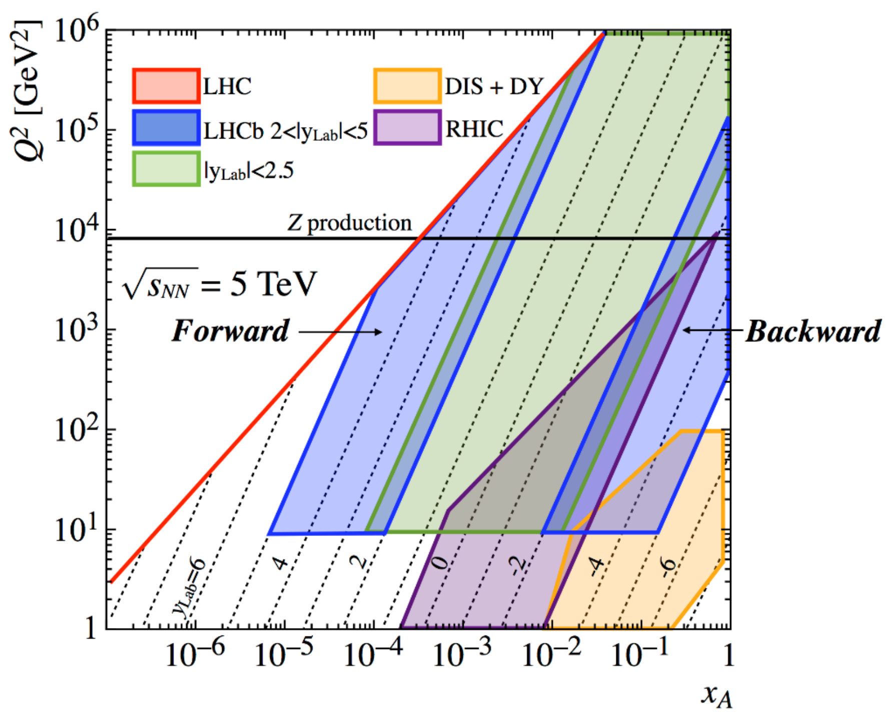
- Asymmetric beam energy
  - ✓ $E_p = 4$ TeV
  - ✓ $E_N = 1.58$ TeV for lead beam
  - ✓ $\sqrt{s_{NN}} = 5$ TeV
  - ✓ rapidity shift $\Delta y = \pm 0.465$
- Rapidity coverage (in nucleon-nucleon cms frame)
  - ✓ **Forward direction (pPb)**
    $1.5 < y < 4.0$
  - ✓ **Backward direction (Pbp)**
    $-5.0 < y < -2.5$
- Common coverage
  - ✓ $2.5 < |y| < 4.0$

Integrated luminosity after data quality:
Forward (pPb) : $1.1\ \mathrm{nb}^{-1}$
Backward (Pbp): $0.5\ \mathrm{nb}^{-1}$

Physics motivation

- pA collisions are important to study cold nuclear matter effects
- Cold nuclear matter effects are of great interest by themselves, in addition to QGP studies
- Insight to unexplored region of QCD phenomena
- Constrain nuclear Parton Density Function (nPDF) at low x over wide Q^2

- LHCb can play an important role
- Unique rapidity coverage with full particle identification



$\psi(2S)$ production and cold nuclear matter effects in $p\mathrm{Pb}$ collisions at $\sqrt{s_{NN}} = 5\ \mathrm{TeV}$

[LHCb-CONF-2015-005]

NEW!

Analysis strategy

- Reconstructed using $\psi(2S) \to \mu^+\mu^-$ decay channel
- Measurement performed in bins of p_T and y

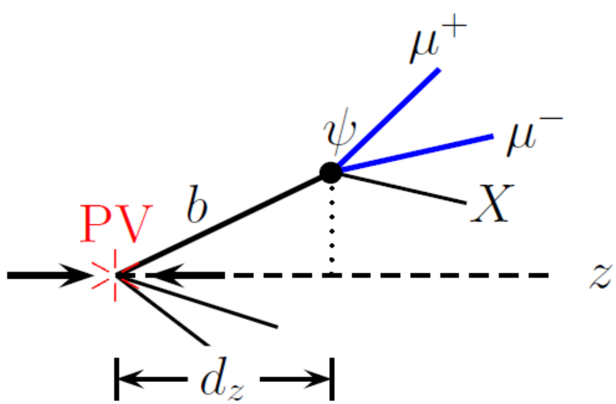
$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_\mathrm{T}(\mathrm{d}y)} = \frac{N^{\mathrm{corr}}\left(\psi(2S)\to\mu^+\mu^-\right) \text{ in } p_\mathrm{T}\ (y) \text{ bins}}{\mathcal{L} \times \mathcal{B}(\psi(2S)\to\mu^+\mu^-) \times \Delta p_\mathrm{T}(\Delta y)}$$

- $\mathcal{B}(\psi(2S) \to e^+e^-) = (7.89 \pm 0.17) \times 10^{-3}$ used instead of

  $\mathcal{B}(\psi(2S) \to \mu^+\mu^-) = (7.9 \pm 0.9) \times 10^{-3}$ assuming lepton universality

- Prompt $\psi(2S)$ and $\boldsymbol{\psi(2S)}$ **from $\boldsymbol{b}$** separated by pseudo proper time $t_z = (z_\psi - z_\mathrm{PV}) \times \frac{M_\psi}{p_z^\psi}$

Note:
Cold nuclear matter effects on $\boldsymbol{\psi(2S)}$ **from $\boldsymbol{b}$** reflect those on ***b* hadrons**!

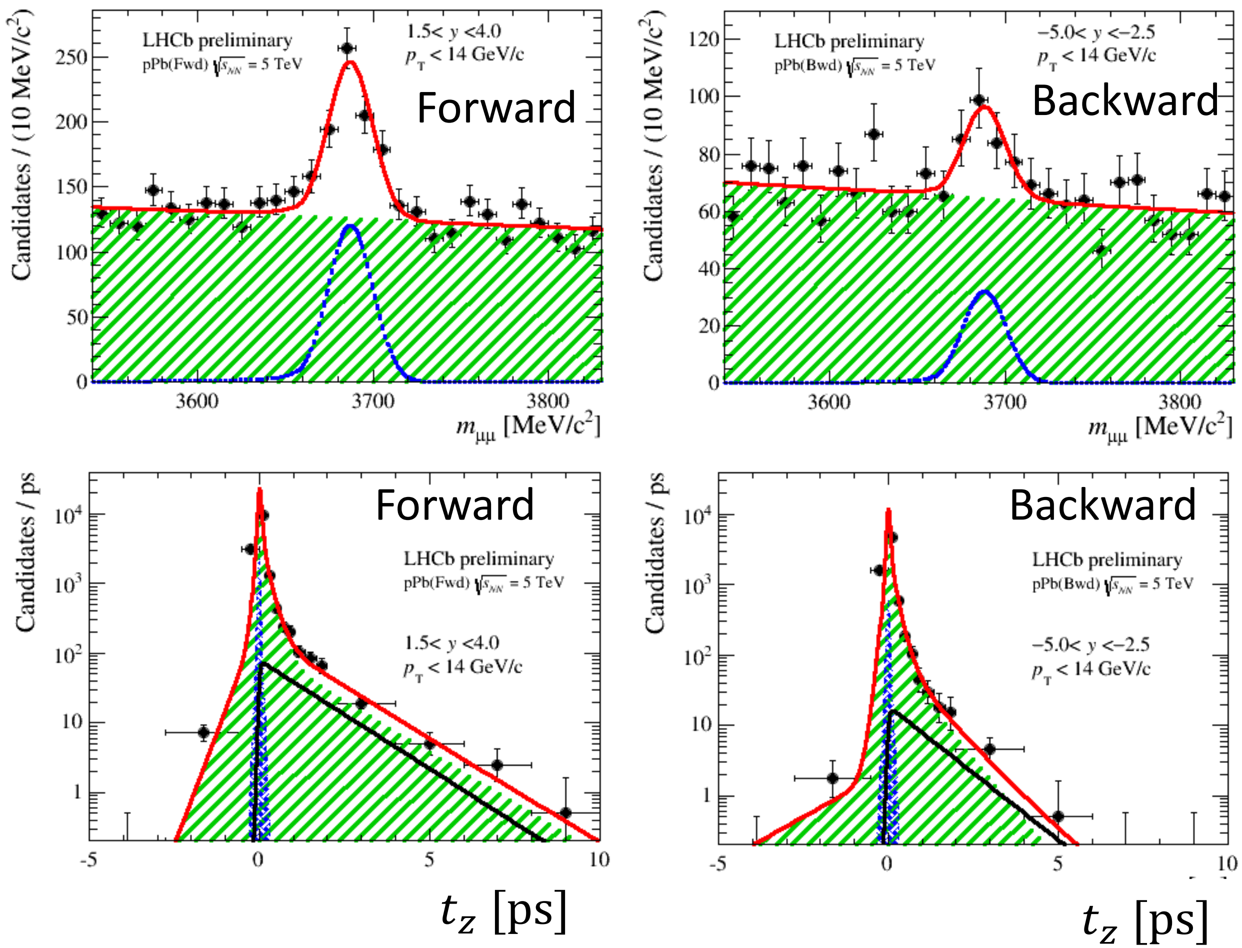


$\psi(2S)$ signal extraction

LHCb-CONF-2015-005

- Yields of prompt $\psi(2S)$ and $\boldsymbol{\psi(2S)}$ **from** $\boldsymbol{b}$ in each bin extracted from simultaneous fit to mass and pseudo proper time t_z

- Mass distribution
  - ✓ Signal: Crystal Ball
  - ✓ Background: exponential
- t_z distribution
  - ✓ Prompt signal $\boldsymbol{\delta}$**-function** $\otimes \boldsymbol{f}_{\mathbf{res}}$
  - ✓ **non-prompt signal exponential** $\otimes \boldsymbol{f_{res}}$
  - ✓ background empirical functions from sidebands



Total $\psi(2S)$ cross-sections in pPb

LHCb-CONF-2015-005

$\sigma_{\mathrm{F}}(\text{prompt}, +1.5 < y < +4.0) = 138 \pm 17 \pm 8\ \mu\mathrm{b}$

$\sigma_{\mathrm{B}}(\text{prompt}, -5.0 < y < -2.5) = 93 \pm 25 \pm 10\ \mu\mathrm{b}$

$\sigma_{\mathrm{F}}(\textbf{from } \boldsymbol{b}, +1.5 < y < +4.0) = 54 \pm 8 \pm 4\ \mu\mathrm{b}$

$\sigma_{\mathrm{B}}(\textbf{from } \boldsymbol{b}, -5.0 < y < -2.5) = 20 \pm 8 \pm 4\ \mu\mathrm{b}$

($p_{\mathrm{T}} < 14\ \mathrm{GeV}/c$)

Systematics dominated by mass fit and t_z fit model

Source	Forward			Backward		
	prompt	from b	inclusive	prompt	from b	inclusive
Correlated between bins						
Tracking	1.5	1.5	1.5	1.5	1.5	1.5
Muon identification	1.3	1.3	1.3	1.3	1.3	1.3
Trigger	1.9	1.9	1.9	1.9	1.9	1.9
Luminosity	1.9	1.9	1.9	2.1	2.1	2.1
Branching fraction	2.2	2.2	2.2	2.2	2.2	2.2
Track quality *et al.*	1.5	1.5	1.5	1.5	1.5	1.5
Mass fit	3.8 – 6.9	0.3 – 3.9	3.2 – 8.2	9.2 – 10	16 – 20	3.0 – 5.4
Uncorrelated between bins						
Multiplicity weight	0.7	0.7	0.7	1.7	1.7	1.7
MC kinematics	0.6 – 10	0.4 – 10	0.2 – 9.8	1.4	2.4	0.7 – 23
t_z fit	1.6 – 12	0.3 – 92	0.1 – 18	1.4 – 7.8	8.5 – 29	0.1 – 17

Differential cross-sections of $\psi(2S)$

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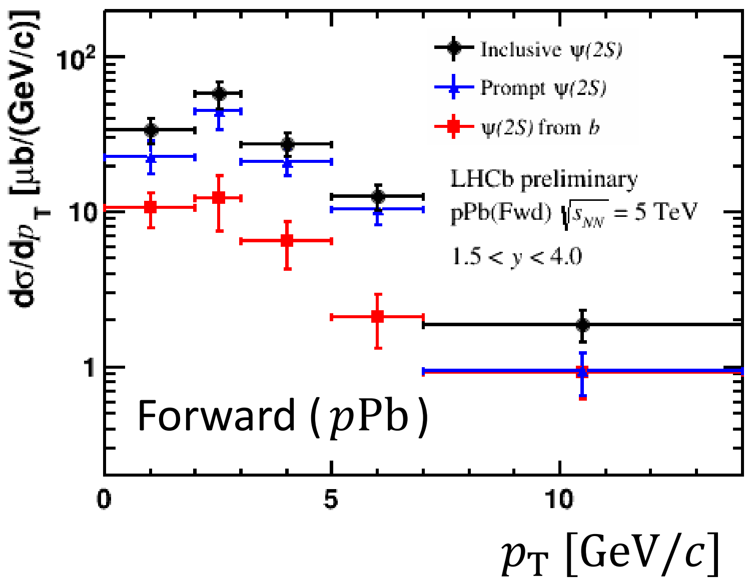
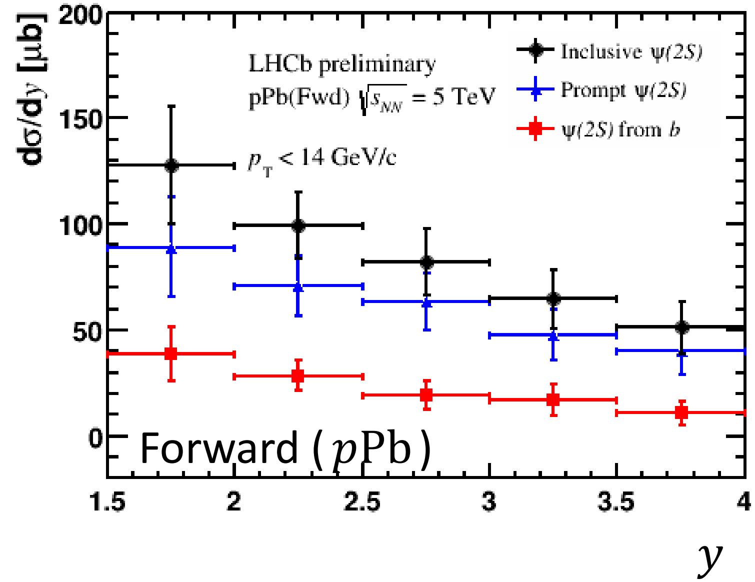
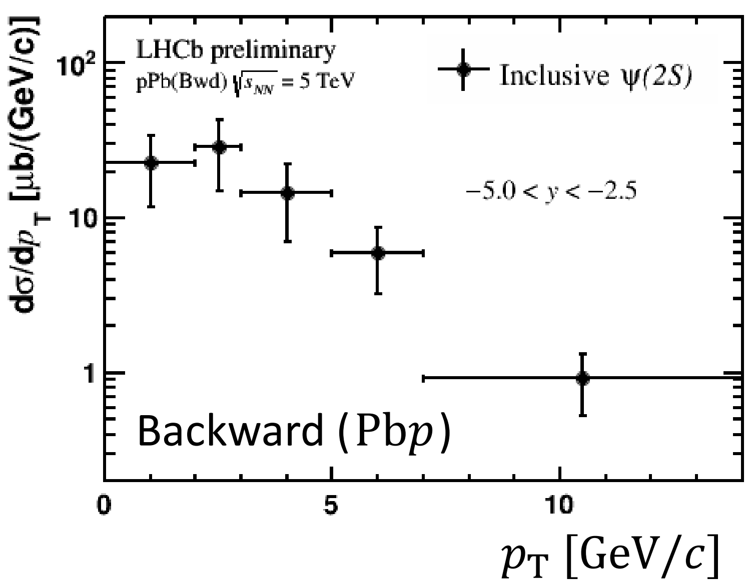
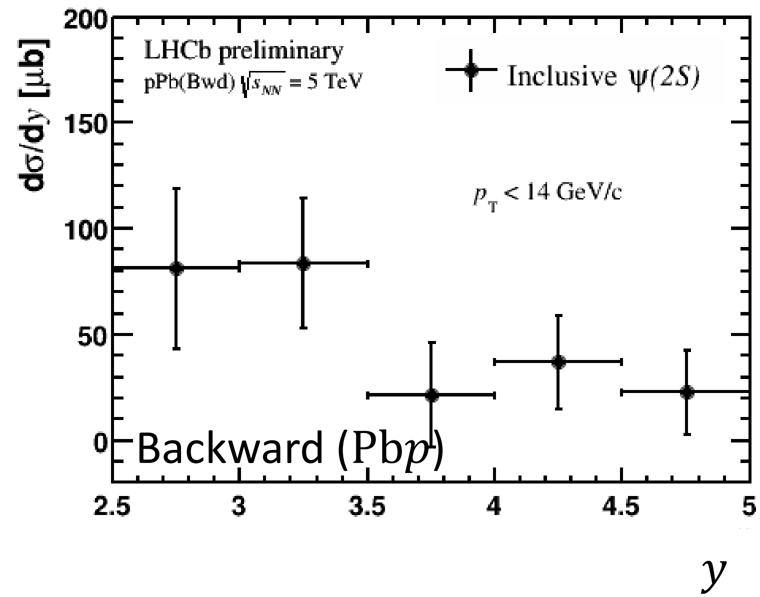




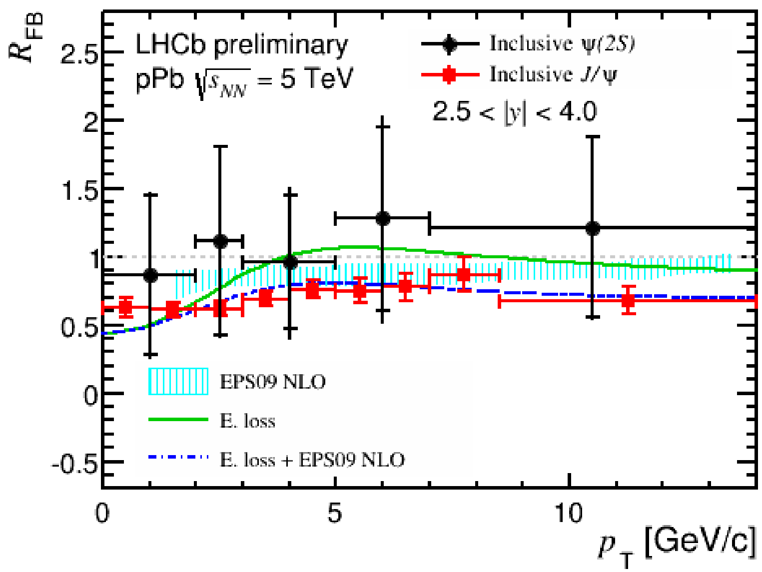


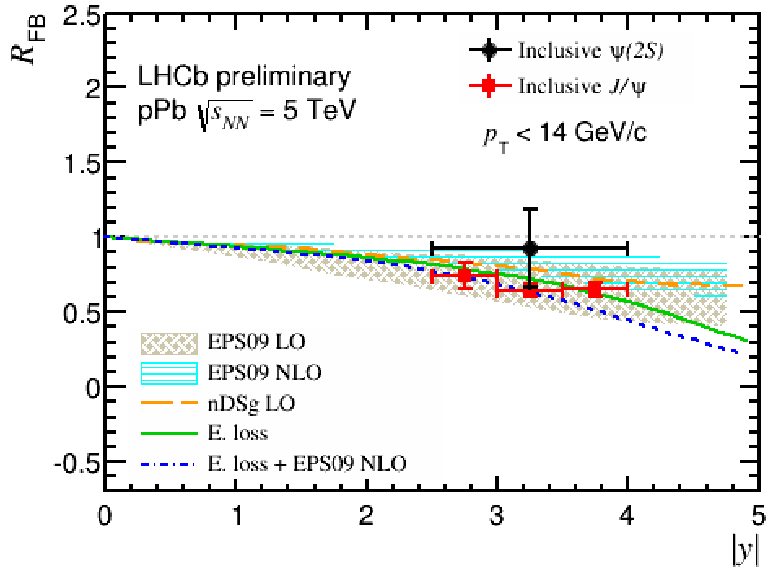


Forward-backward production ratio R_{FB}

LHCb-CONF-2015-005
JHEP 02 (2014) 072

- Independent of pp cross-sections
- Part of experimental and theoretical uncertainties cancel
- Consistent with theoretical calculations





EPS09 LO	Phys. Rev. C88 (2013) 047901
EPS09 NLO	Int. J. Mod. Phys. E22 (2013) 1330007
nDSg LO	Phys. Rev. C88 (2013) 047901
E. loss	JHEP 03 (2013) 122
E. loss + EPS09 NLO	JHEP 03 (2013) 122

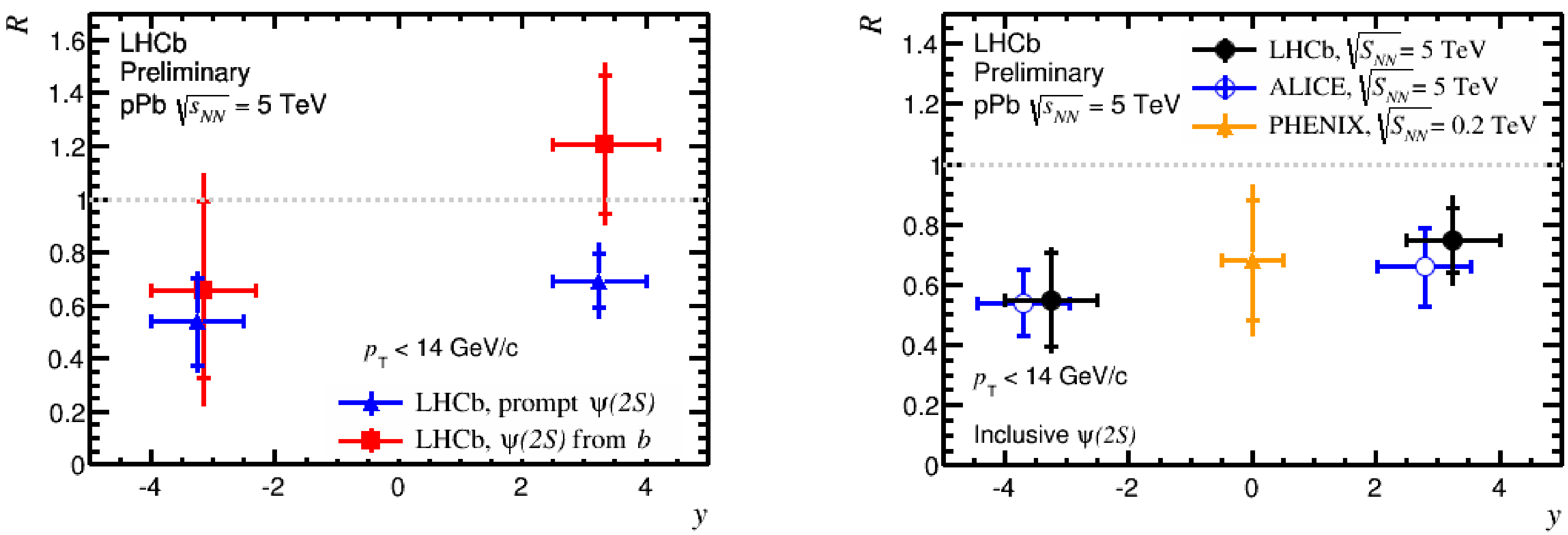
Relative suppression

LHCb-CONF-2015-005

- Suppression relative to J/ψ

$$R \equiv \frac{R_{p\mathrm{Pb}}^{\psi(2S)}}{R_{p\mathrm{Pb}}^{J/\psi}} = \frac{\sigma_{p\mathrm{Pb}}^{\psi(2S)}(5\ \mathrm{TeV})}{\sigma_{p\mathrm{Pb}}^{J/\psi}(5\ \mathrm{TeV})}\frac{\sigma_{pp}^{J/\psi}(5\ \mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(5\ \mathrm{TeV})} \simeq \frac{\sigma_{p\mathrm{Pb}}^{\psi(2S)}(5\ \mathrm{TeV})}{\sigma_{p\mathrm{Pb}}^{J/\psi}(5\ \mathrm{TeV})}\frac{\sigma_{pp}^{J/\psi}(7\ \mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\ \mathrm{TeV})}$$

- Suppression of prompt $\psi(2S)$ stronger than that of prompt J/ψ
- Same suppression expected for $\psi(2S)$ from b and J/ψ from b
- Results for inclusive $\psi(2S)$ consistent with ALICE

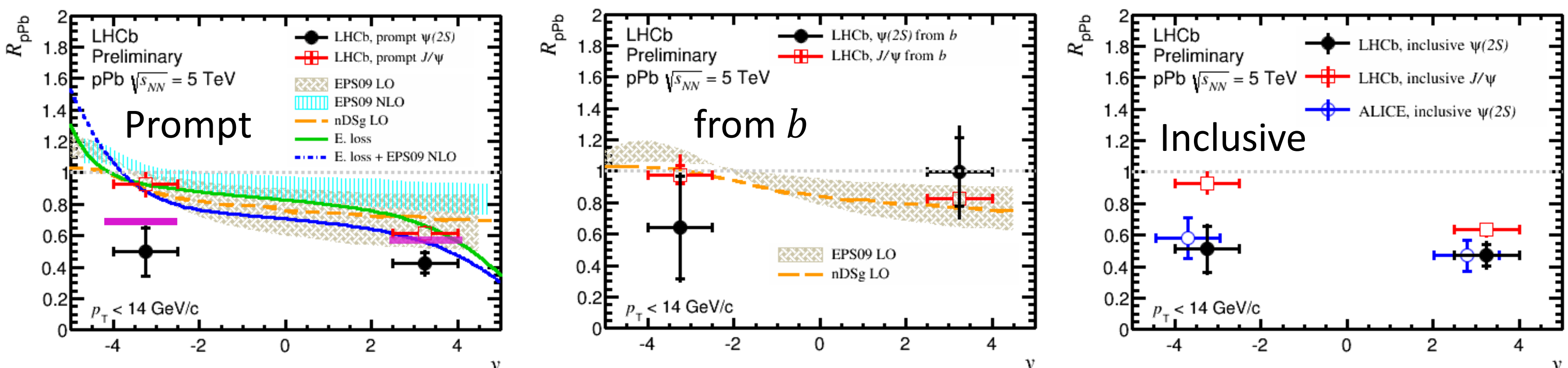


Nuclear modification factor $R_{p\mathrm{Pb}}$ for $\psi(2S)$

LHCb-CONF-2015-005

JHEP 02 (2014) 072

- Assuming $\frac{\sigma_{pp}^{J/\psi}(5\ \mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(5\ \mathrm{TeV})} \simeq \frac{\sigma_{pp}^{J/\psi}(7\ \mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\ \mathrm{TeV})} \Rightarrow R_{p\mathrm{Pb}}^{\psi(2S)} \simeq R_{p\mathrm{Pb}}^{J/\psi} \times R$
- **Prompt $\boldsymbol{\psi(2S)}$** more suppressed than prompt J/ψ
- Suppression of **$\boldsymbol{\psi(2S)}$ from $\boldsymbol{b}$** consistent with that of J/ψ from b
- Suppression of inclusive $\psi(2S)$ consistent with ALICE
- Theoretical calculations underestimate prompt $\psi(2S)$ suppression



EPS09 LO	Phys. Rev. C88 (2013) 047901	
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nDSg LO	Phys. Rev. C88 (2013) 047901	
E. loss	JHEP 03 (2013) 122	
E. loss + EPS09 NLO	JHEP 03 (2013) 122	

EPS09 LO, nDSg LO: Nucl.Phys.A926 (2014) 236

Comover Phys. Lett. B749 (2015) 98

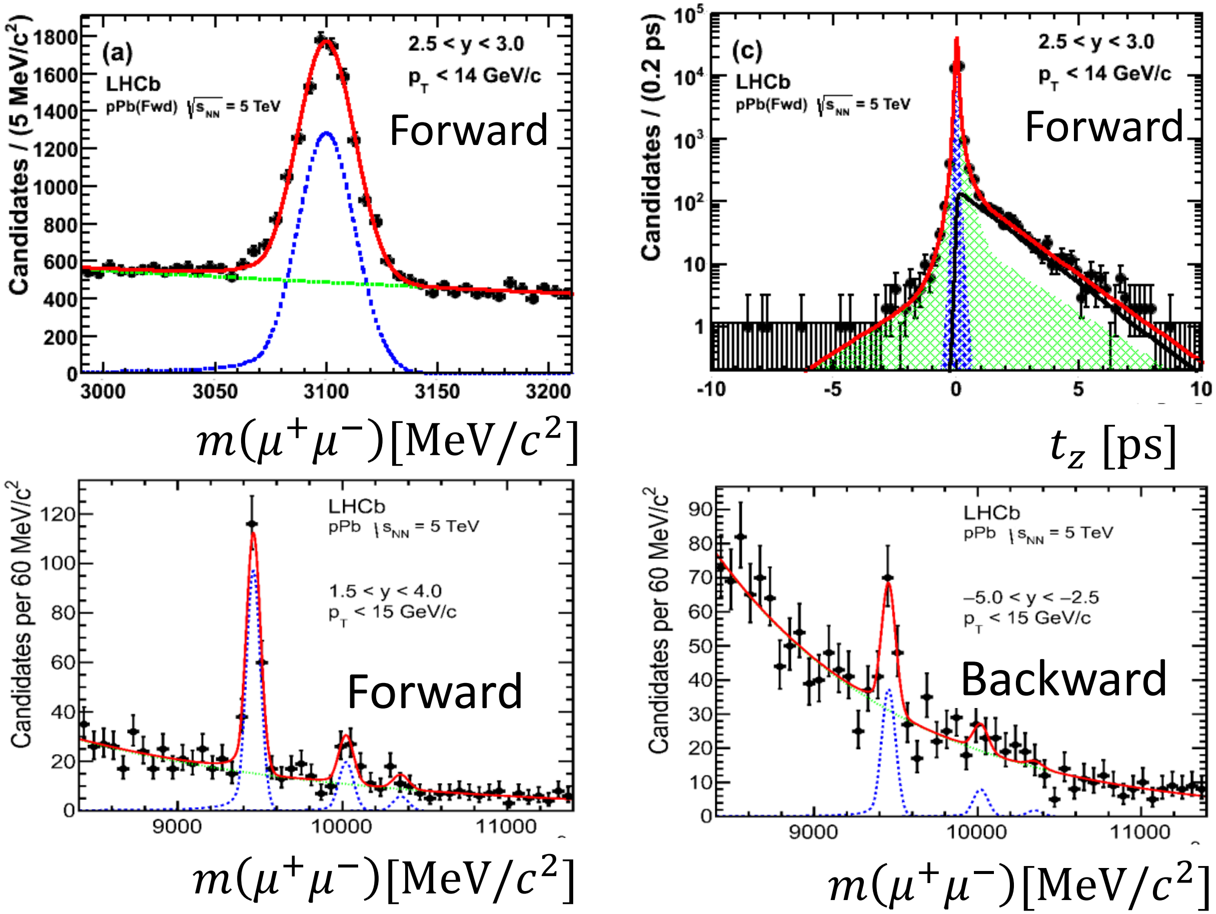
J/ψ and Υ production and cold nuclear matter effects in $p\mathrm{Pb}$ collisions at $\sqrt{s_{NN}} = 5\ \mathrm{TeV}$

[JHEP 02 (2014) 072, JHEP 07 (2014) 094]

Signal extraction

JHEP 02 (2014) 072
JHEP 07 (2014) 094

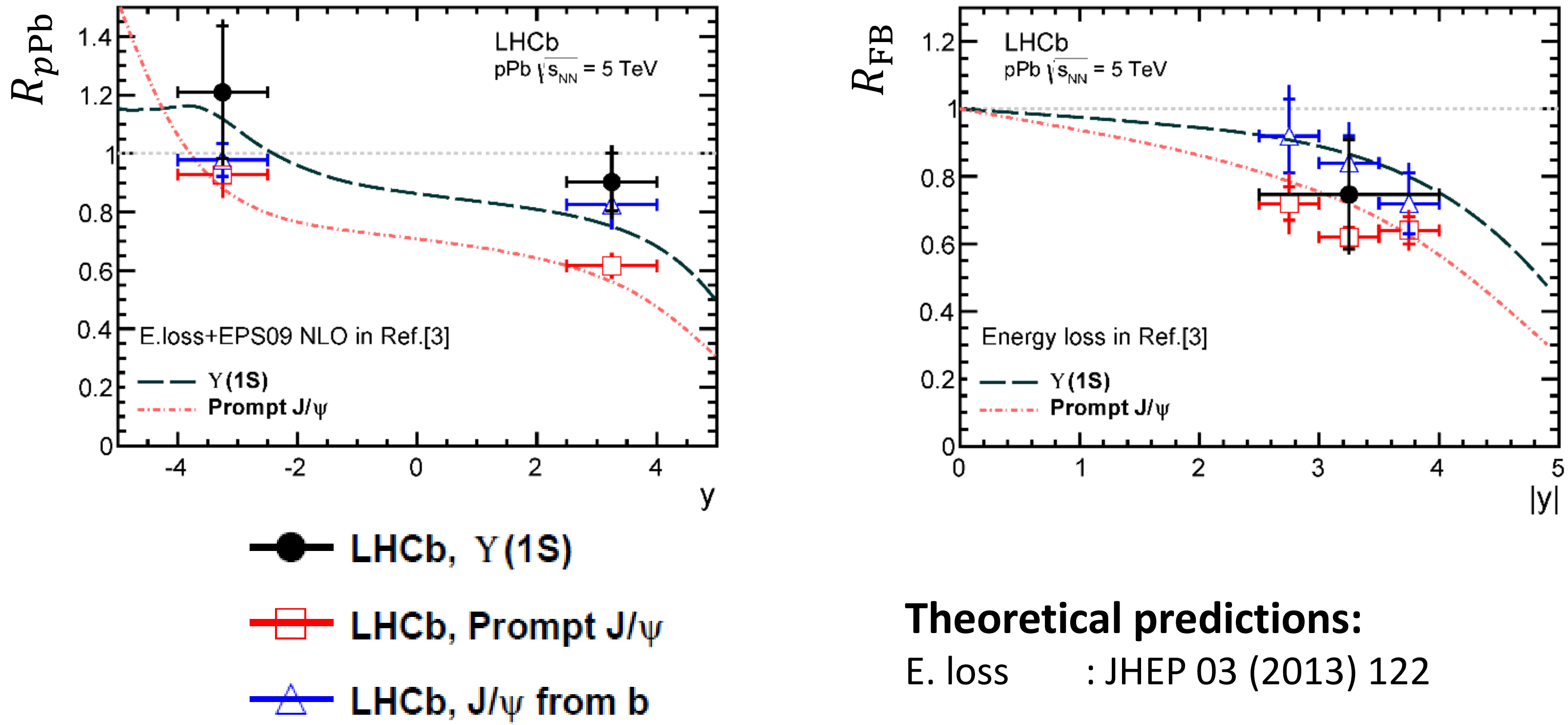
- Reconstructed using dimuon final states
- **Prompt J/ψ** and **J/ψ from b** separated by fits to mass and t_z distributions



Nuclear modification factor for J/ψ and $\Upsilon(1S)$

JHEP 02 (2014) 072
JHEP 07 (2014) 094

- Significant suppression for prompt J/ψ in forward
- Compatible suppression between $\boldsymbol{\Upsilon(1S)}$ and b hadrons
- Possible enhancement of $\boldsymbol{\Upsilon(1S)}$ in backward consistent with antishadowing effect
- Consistent with theoretical calculations considering energy loss



Theoretical predictions:
E. loss : JHEP 03 (2013) 122

Summary

- LHCb recorded about $1.6\ \mathrm{nb}^{-1}$ $p\mathrm{Pb}$ data in a unique kinematic range with full particle identification
- Production cross-sections measured for J/ψ, $\psi(2S)$, $\Upsilon(nS)$
  - Prompt J/ψ ($\psi(2S)$) and J/ψ ($\psi(2S)$) from b separated
- Nuclear modification factor $R_{p\mathrm{Pb}}$ and forward-backward production ratio R_{FB} determined for prompt J/ψ, prompt $\psi(2S)$, b hadrons (via $\psi^{(\prime)}$ from b), and $\Upsilon(1S)$
  - Suppression of prompt $\psi(2S)$ stronger relative to prompt J/ψ
  - $\psi(2S)$ from b, J/ψ from b and $\Upsilon(1S)$ show consistent results
- Looking forward to more heavy-ion results using RUN II data
  - $p + \mathrm{A}$ and $\mathrm{Pb} + \mathrm{A}$ fixed-target data ($\mathrm{A} = \mathrm{Ne}, \mathrm{Ar}, \mathrm{et\ al}$)
  - $p\mathrm{Pb}$ collisions with more statistics
  - PbPb collisions


Thank you!

Backup slides

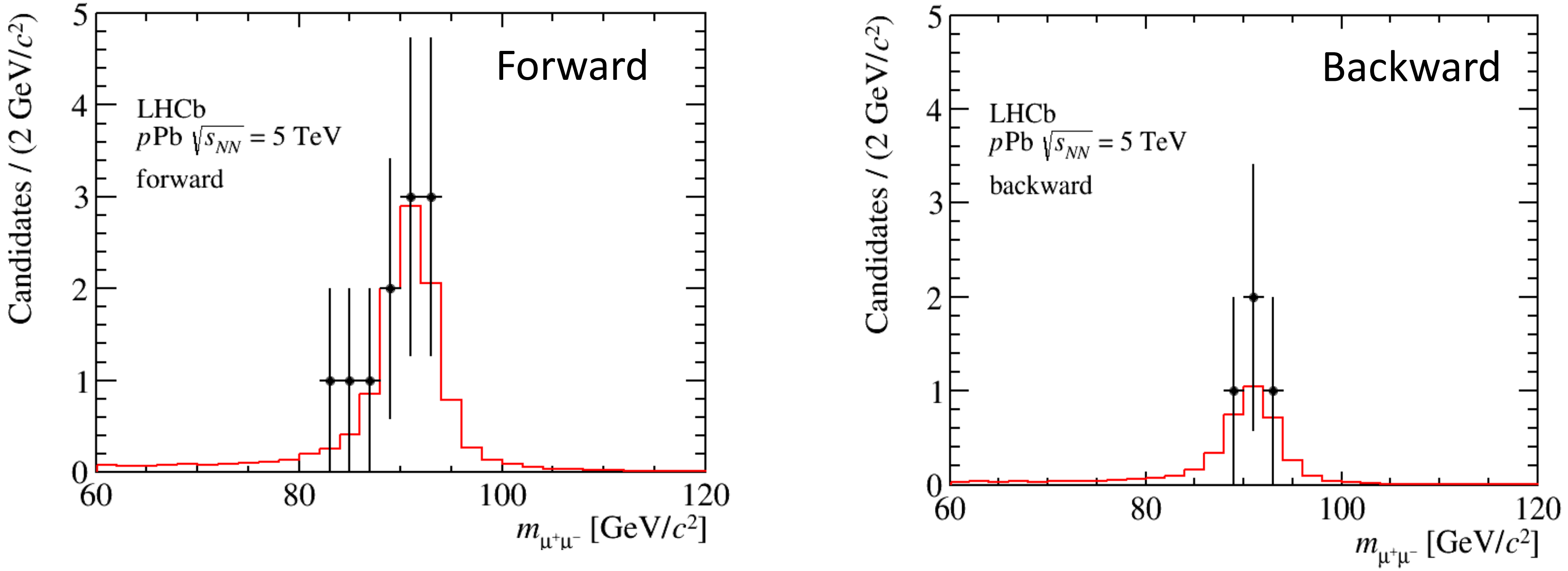
Z production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}} = 5\ \mathrm{TeV}$

[JHEP 09 (2014) 030]

Z production in $p\mathrm{Pb}$ collisions

JHEP 09 (2014) 030

- First observation of Z boson production in $p\mathrm{Pb}$ collisions at $\sqrt{s_{NN}} = 5\ \mathrm{TeV}$
- Z reconstructed using $Z \to \mu^+\mu^-$ decays
- Kinematic region:
  $p_{\mathrm{T}}(\mu^{\pm}) > 20\ \mathrm{GeV}/c,\ 2.0 < \eta(\mu^{\pm}) < 4.5,\ 60 < m(\mu^+\mu^-) < 120\ \mathrm{GeV}/c^2$
- Clean signals: 11 candidate in forward, 4 candidates in backward
  Purity > 99% determined in data



Z production in pPb collisions (cont.)

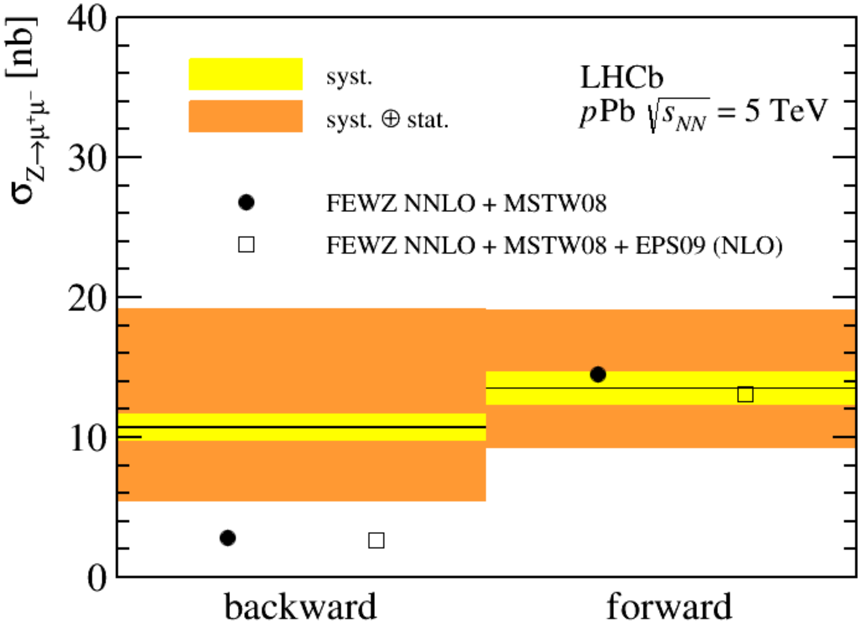
JHEP 09 (2014) 030

- Cross-sections:

$$\sigma^{\text{fwd}}_{Z\to\mu^+\mu^-} = 13.5^{+5.4}_{-4.0}(\text{stat.}) \pm 1.2(\text{syst.})\ \text{nb}$$
$$\sigma^{\text{bwd}}_{Z\to\mu^+\mu^-} = 10.7^{+8.4}_{-5.1}(\text{stat.}) \pm 1.0(\text{syst.})\ \text{nb}$$

- Forward-backward production ratio

$$R_{\text{FB}}(2.5 < |y| < 4.0) = 0.094^{+0.104}_{-0.062}(\text{stat.})^{+0.004}_{-0.007}(\text{syst.})$$



FEWZ NNLO + MSTW08:
Comput.Phys. Commun. 182 (2011) 2388
Phys. Rev. D86 (2012) 094034
Eur. Phys. J. C63 (2009) 189