Study of J/ψ production and cold nuclear matter effects in p-Pb collisions

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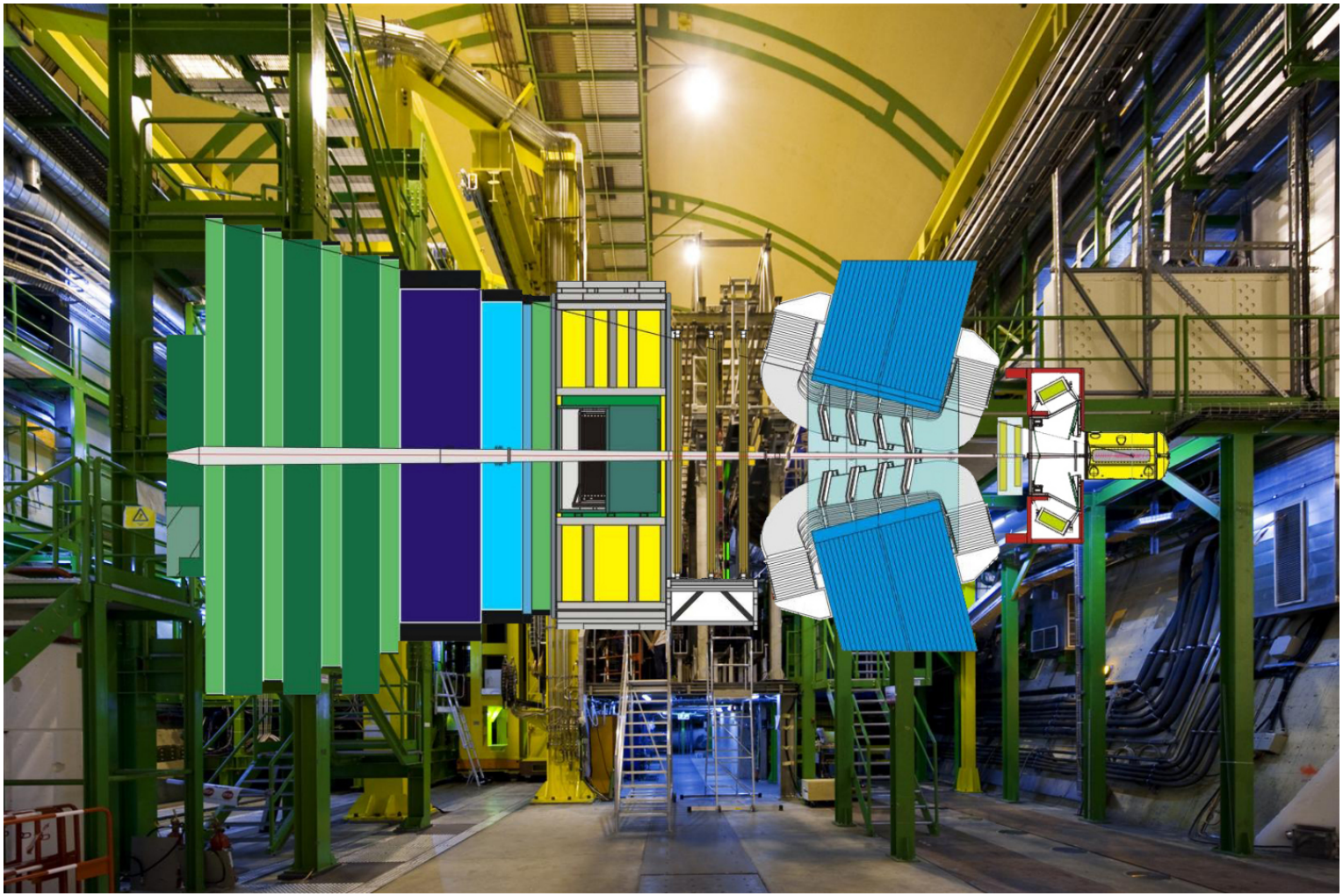
Outline

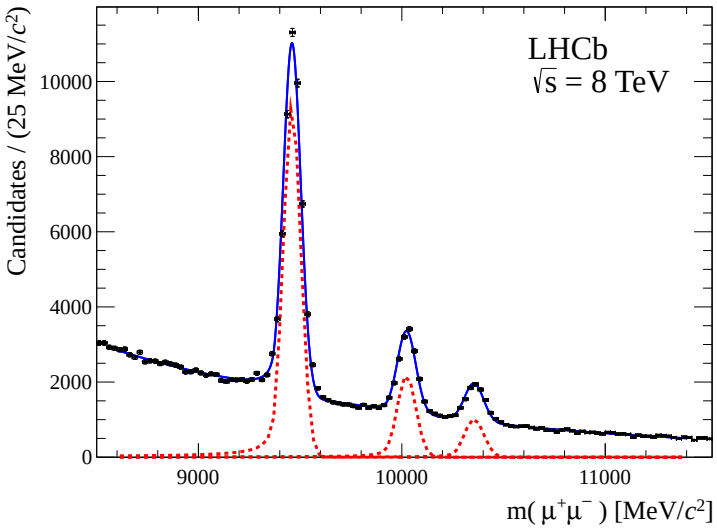
LHCb Detector

Covers only 4% of the solid angle, but captures $\sim$ 25% of the heavy quark cross-section in pp collisions.

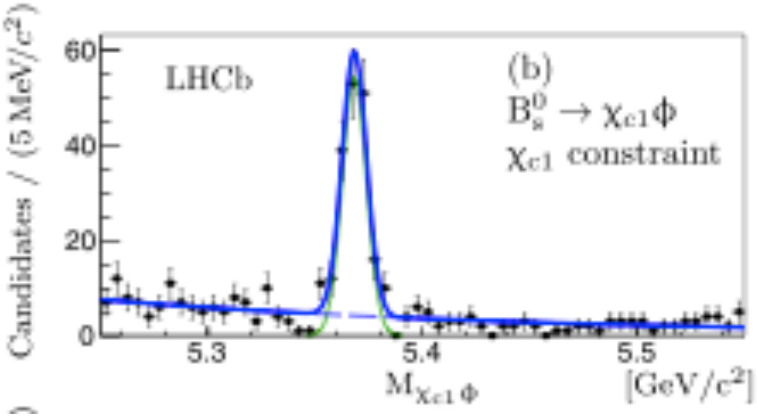


LHCb in a nutshell

Impact parameter resolution:	$20\ \mu\mathrm{m}$
Proper time resolution:	$\Delta\tau = 45\,\mathrm{fs}$ for $B_s^0 \to J/\psi\,\Phi$ and $B_s^0 \to D_s^+\pi$
Momentum resolution:	$\Delta p/p = 0.4\% - 0.6\%$ (5 GeV/c- 100 GeV/c)
Mass resolution:	$\Delta m = 8\ \mathrm{MeV}/c^2$ for $B \to J/\psi\,X$ constrained J/ψ mass.
RICH π-K 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 $\epsilon(\pi \to \mu) \sim 1 - 3\%$
E.m. energy resolution:	$\Delta E/E = 1\% \oplus 10\%/\sqrt{E(\mathrm{GeV})}$

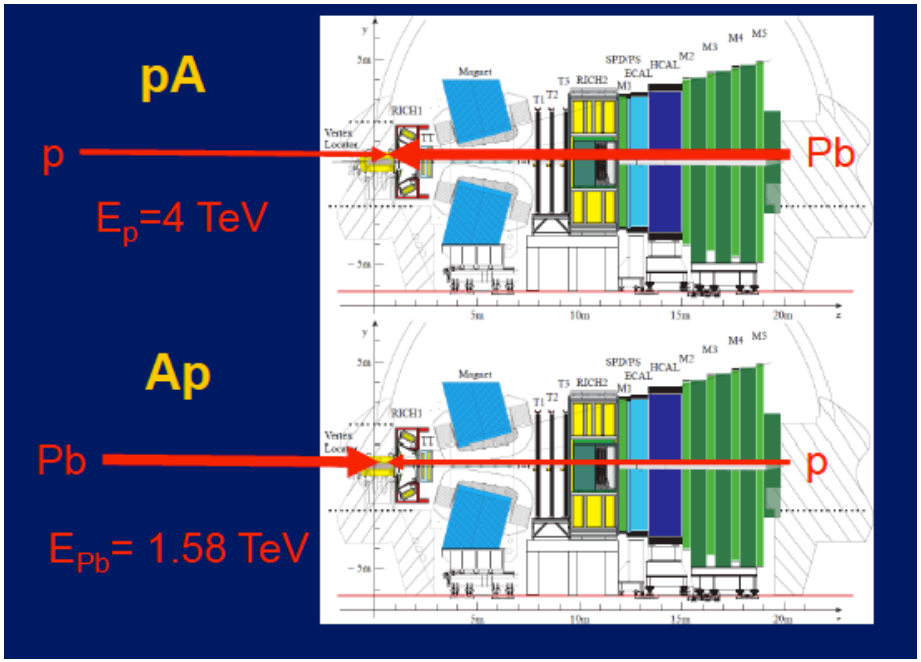


J. High Energy Phys. 06 (2013) 064



Nucl. Phys. B 874 (2013) 663-678

Beam configurations

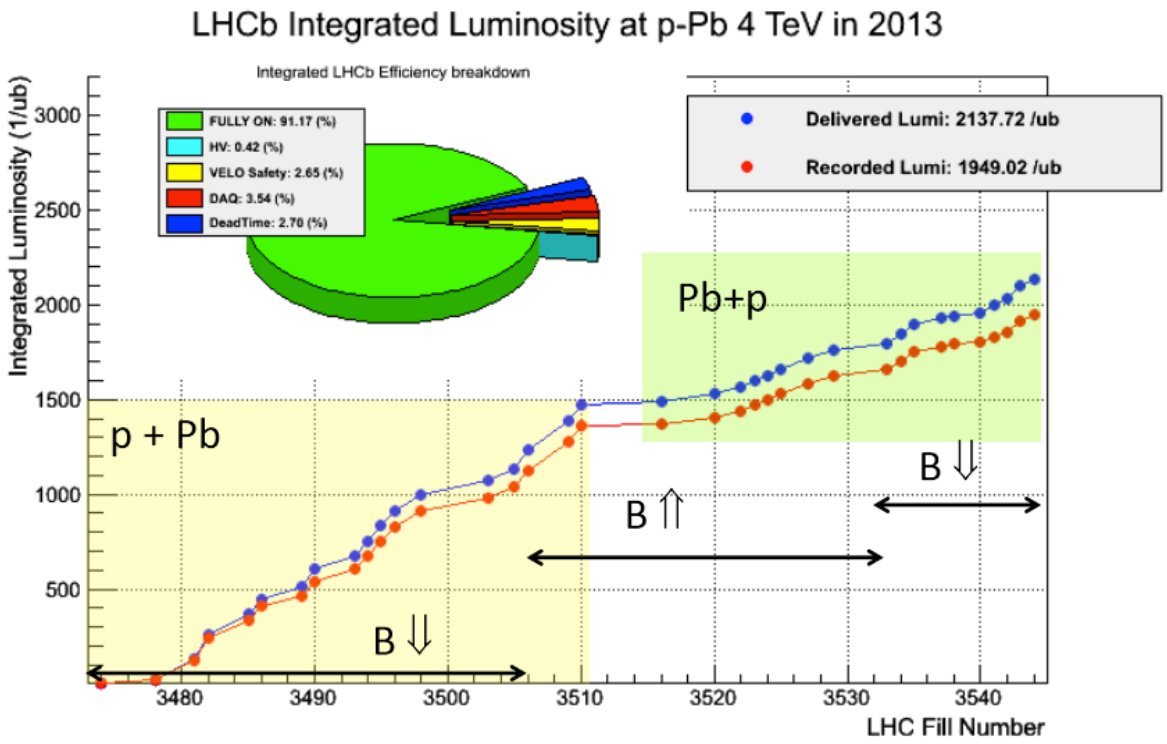


Rapidity coverage:

- Forward direction (p-Pb):
  - $y = +0.47$
  - pA: $1.5 < y < 4.5$
- Backward direction (Pb-p):
  - $y = -0.47$
  - pA: $-5.5 < y < -2.5$

- Common frame for the measurements: $2.5 < |y| < 4.0$
- Center-of-mass energy: $\sqrt{s} = 5\,\mathrm{TeV}$

2013 p-Pb data taking



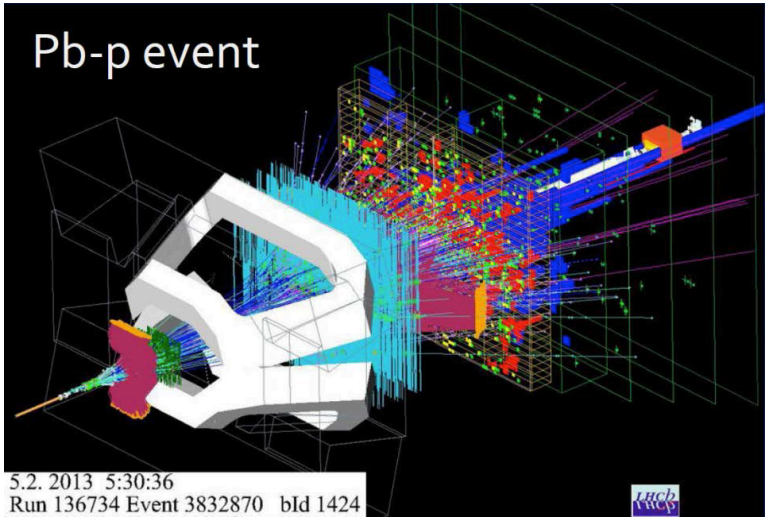
Integrated luminosity after data qualitiy:

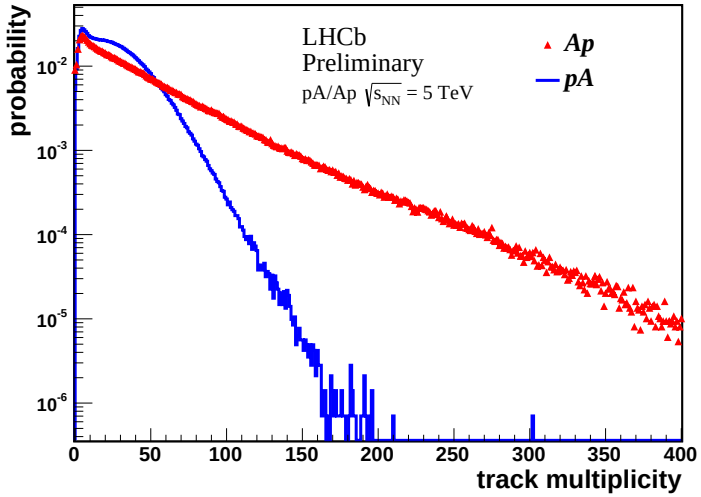
p-Pb $\sim 1.1\,\mathrm{nb}^{-1}$

Pb-p $\sim 0.5\,\mathrm{nb}^{-1}$

- Four different data taking periods: p-Pb / Pb-p, magnet up, magnet down
- Instantaneous luminosity: $45 \times 10^{27}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- Low pile-up: $\sim$1 primary interaction per event.

p-Pb events at LHCb





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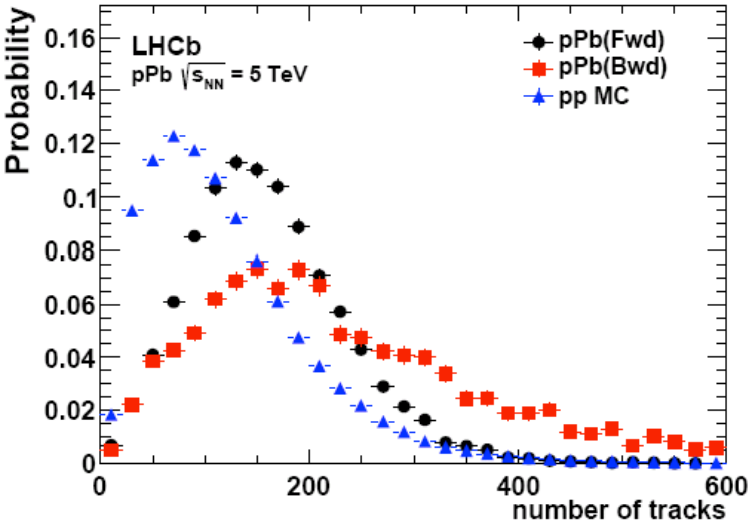
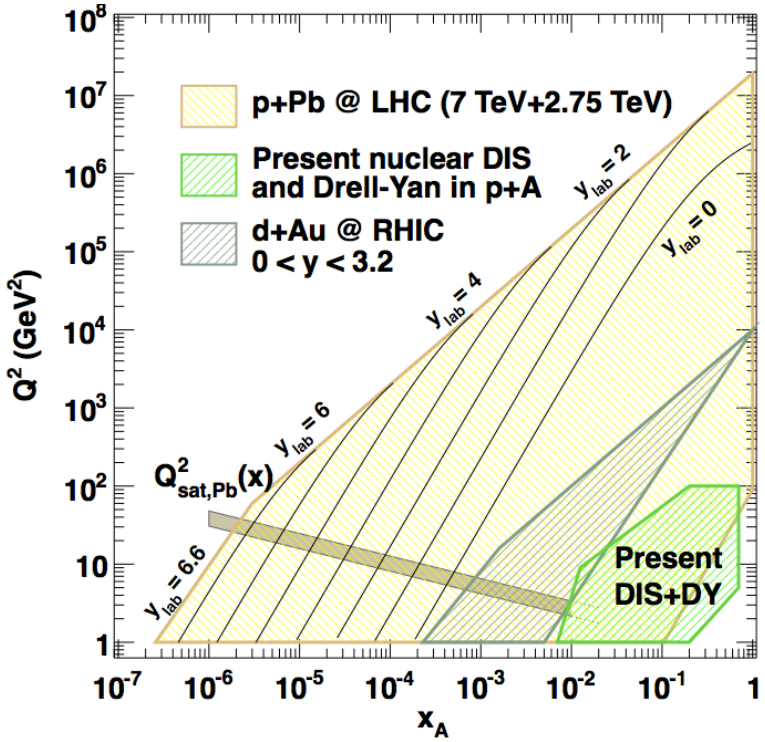


- Higher track multiplicity in Pb-p as expected.
- Magnet polarities agree for both beam configurations.
- All plots unless stated from J. High Energy Phys. 02 (2014) 072

Why pA physics at LHCb?

- pA collisions interesting both in itself and in understanding heavy ion collisions.
- Allows factorizing the QGP effects from Cold Nuclear Matter effects.
- Insight into yet unexplored region of QCD.

- LHCb with its unique rapidity coverage can play an important role.
- Measurements can constrain PDF at low x, Q^2.

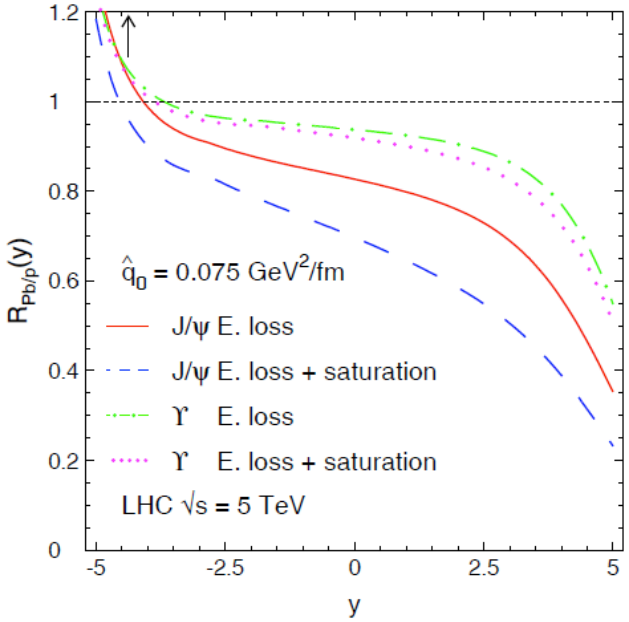


Quarkonium production in pA

Heavy flavour and quarkonium important probes of the QGP energy loss mechanisms, medium transport properties, quark deconfinement, and temperature

Cold Nuclear Matter (CNM) effects

- Production of heavy quarkonia suppressed at large rapidity in pA collisions.



arXiv:1212.0434

Nuclear Modification Factor

- $N_{coll} = A$ in pA collisions.

Forward-Backward asymmetry:

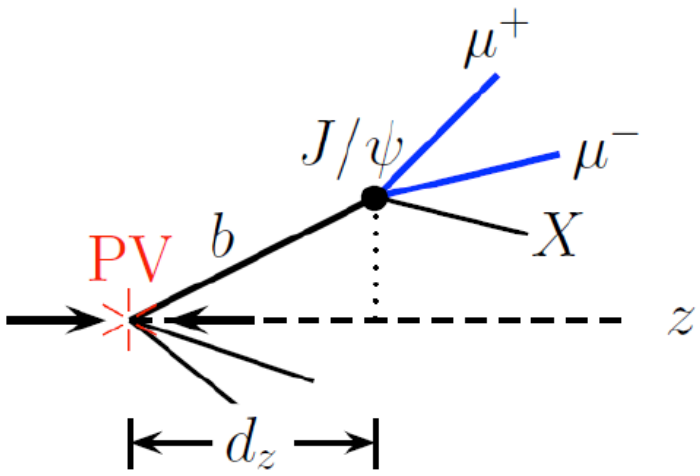
- pp J/ψ cross section uncertainties cancel out.

$$R_{pA}(y, \sqrt{s_{NN}}) = \frac{1}{N_{coll}} \frac{d\sigma_{pA}(y, \sqrt{s_{NN}})/dy}{d\sigma_{pp}(y, \sqrt{s_{NN}})/dy}$$

$$R_{FB}(y, \sqrt{s_{NN}}) = \frac{R_{pPb}(+|y|, \sqrt{s_{NN}})}{R_{pPb}(-|y|, \sqrt{s_{NN}})}$$

J/ψ production in pA

- Three sources of J/ψ prompt and non prompt:
  - Direct production
  - Feed down from heavier $c\bar{c}$ states: $\psi(2S)$, χ_{c0}, χ_{c1}...
  - From b hadrons decays.
- Analysis strategy same as for pp collisions:
  - Reconstruct J/ψ from 2 muons.
  - Measure separately the production cross section in bins of transverse momentum and rapidity for prompt and non-prompt J/ψ.
  - Separate prompt and non-prompt using pseudo propertime:



$$\sigma = \frac{N(J/\psi \to \mu^+\mu^-)}{\mathcal{L} \times \epsilon \times \mathcal{B}(J/\psi \to \mu^+\mu^-)}$$

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

J/ψ signal extraction

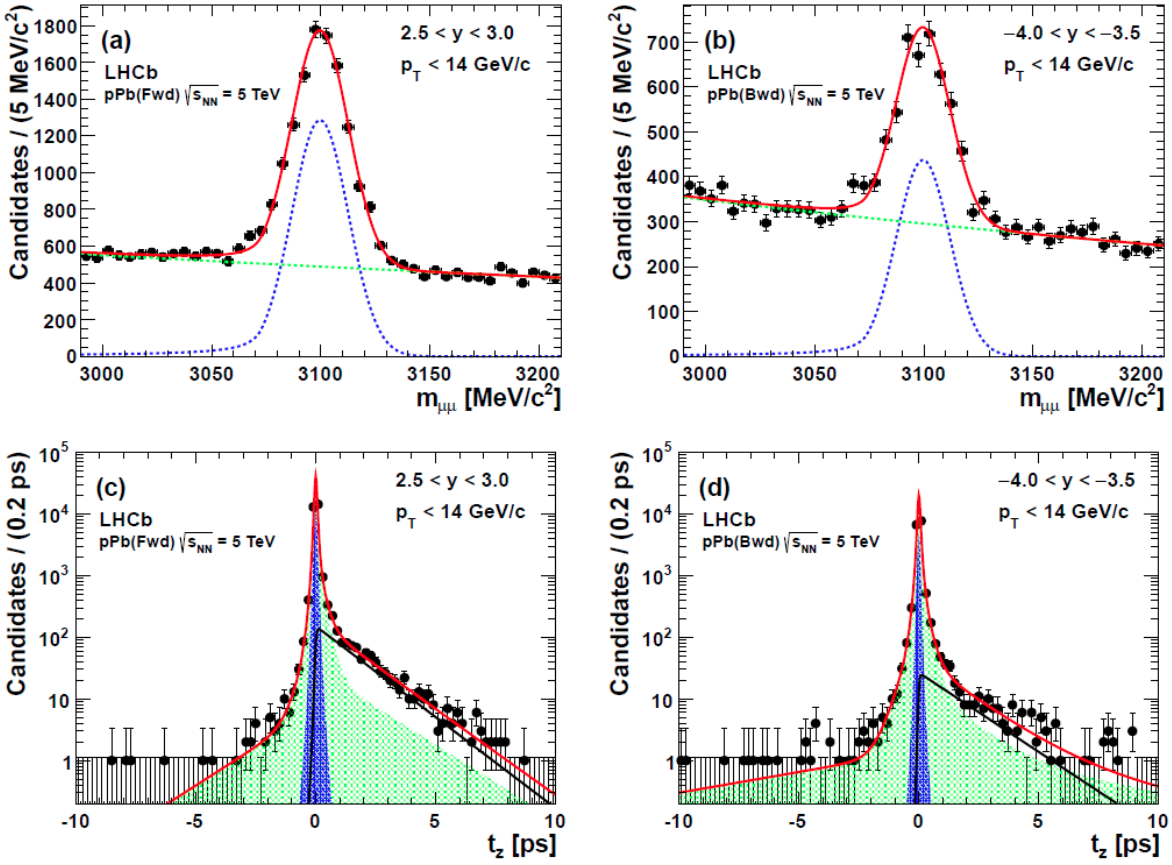
Yields of prompt J/ψ and J/ψ from b extracted from simultaneous fit of mass and pseudo propertime $t_z = \left(z_{J/\psi} - z_{PV}\right) \times \frac{M_{J/\psi}}{p_z}$

Mass fits

- Signal by Crystal Ball
- background by exponential

Propertime fit:

- Prompt signal by $\delta-$function
- Non-prompt signal by exponential
- Background by empirical function from sidebands.



pA (forward) Ap (backward)

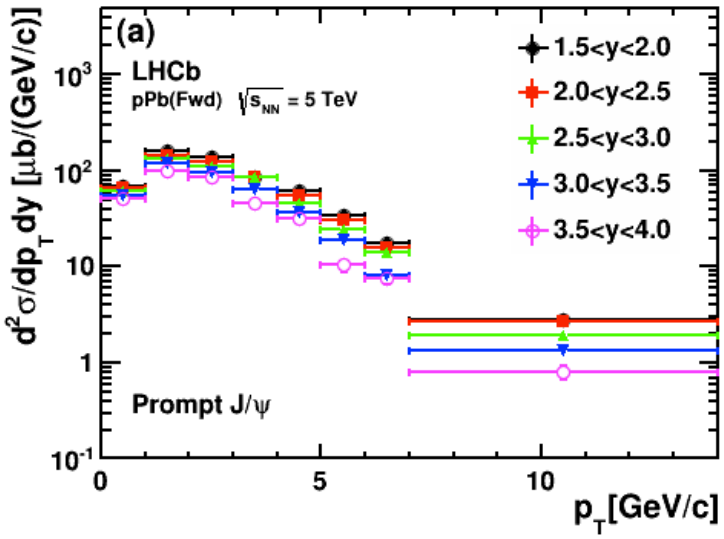
Double differential J/ψ cross sections

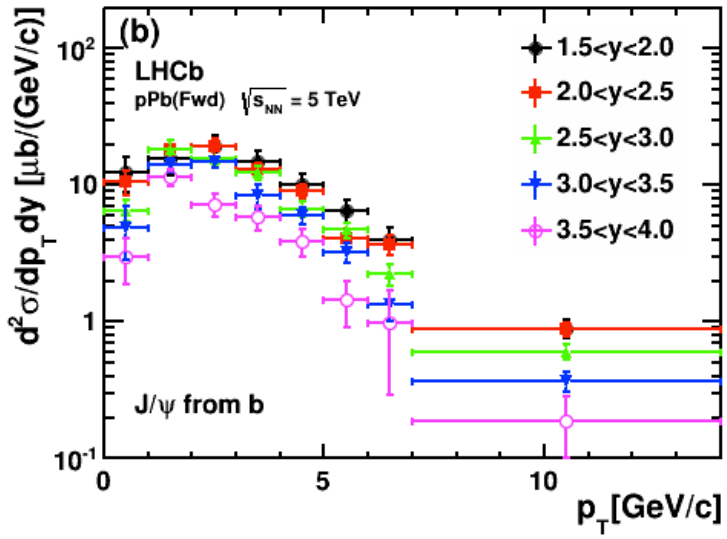
$$\frac{d\sigma}{dp_T dy} = \frac{N(J/\psi \to \mu^+\mu^-)}{\mathcal{L} \times \epsilon \times \mathcal{B}(\mathrm{J}/\psi \to \mu^+\mu^-) \times \acute{}p_T \times \acute{}\mathrm{y}}$$

$\epsilon_{\mathrm{tot}} = \epsilon_{\mathrm{acc}} \times \epsilon_{\mathrm{rec}} \times \epsilon_{\mathrm{trg}} \sim 45\%$

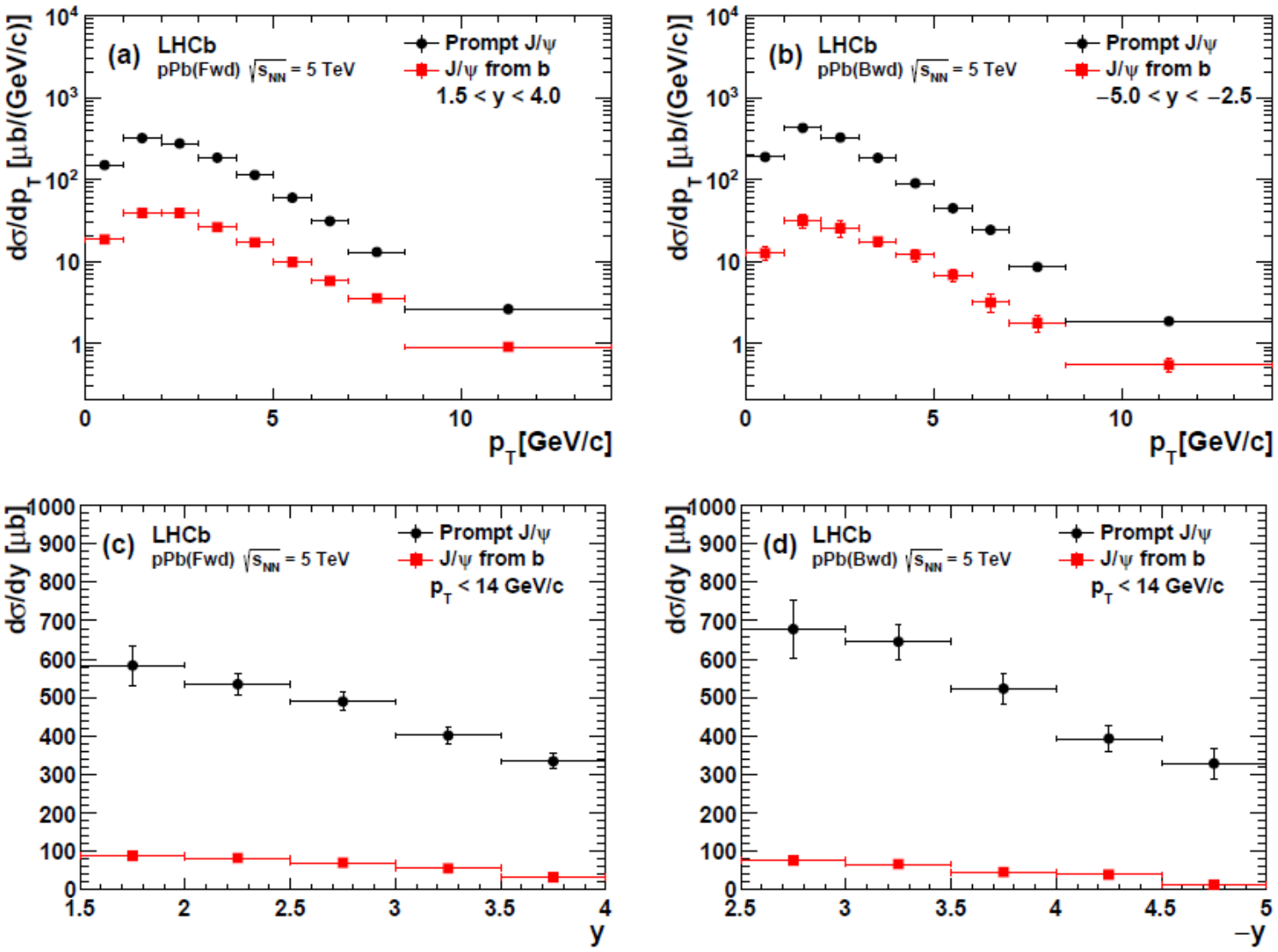
- $\epsilon_{\mathrm{acc}} \times \epsilon_{\mathrm{rec}}$ including detection, reconstruction and selection estimated from simulation.
- ϵ_{trg} obtained from the minimum-bias sample collected in the data.
- In the efficiency estimation no polarization for the J/ψ is assumed.

Double differential cross section in pA:





Single differential J/ψ cross sections



Summary of systematic uncertainties

Correlated between bins:

Source of the uncertainty	Forward %	Backward %
Mass fit from checking dimuon mass with double Crystal Ball	2.3	3.4
Radiative tail with dimuon mass below signal region	1.0	1.0
Muon identification from “tag and probe”	1.3	1.3
Track reconstruction efficiency from pp/pA multiplicity difference	1.5	1.5
Luminosity calibration	1.9	2.1
Branching ratio from PDG	1.0	1.0

Uncorrelated between bins:

Source of the uncertainty	Forward %	Backward %
y-p_T binning	0.1-8.7	0.1-6.1
Reweighting of track multiplicity in simulation comp. to no reweighting	0.1-3.0	0.2-4.3
t_Z fit on non-prompt J/ψ by extraction with $s - Plot$	0.2-12.0	0.2-13.0

- Systematics dominated by fit model, luminosity and agreement between data and simulation
- No uncertainty assigned to unknown J/ψ polarization but effect measured to be small.

Reference J/ψ pp cross section at $E_{CM} = 5$ TeV

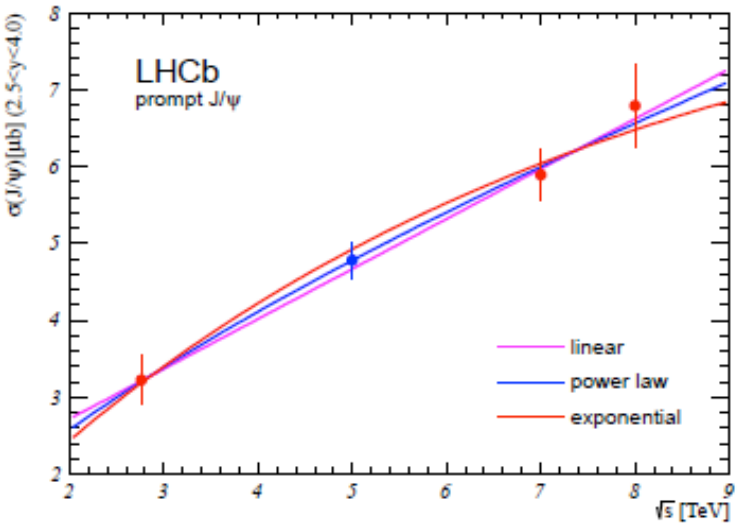
Input to the determination of the nuclear modification factor.

- Interpolation from measurements at 2.76 TeV, 7 TeV and 8 TeV.
- Rescaling from $2.0 < y < 4.5$ to the common rapidity range $2.5 < y < 4.0$ (∼60%).
- Three different functions used to interpolate.

$$(\sqrt{s}/p0)^{p_1}$$

$$p_0 + \sqrt{s}p_1$$

$$p_0\left(1 - exp\left(\sqrt{s}p_1\right)\right)$$



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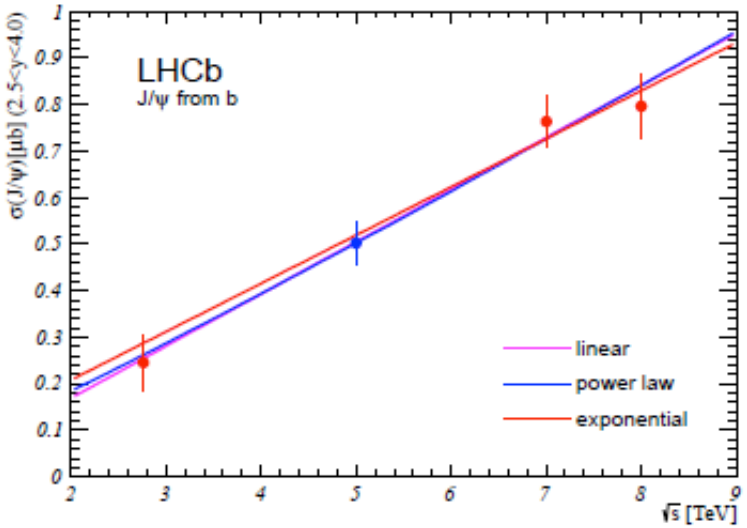

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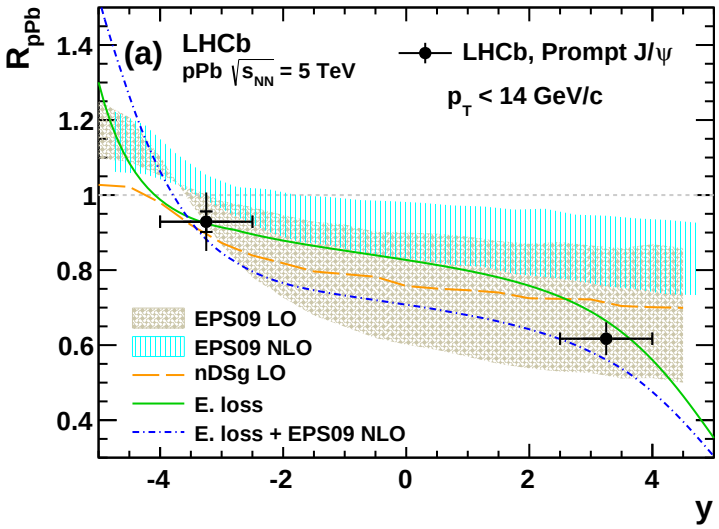
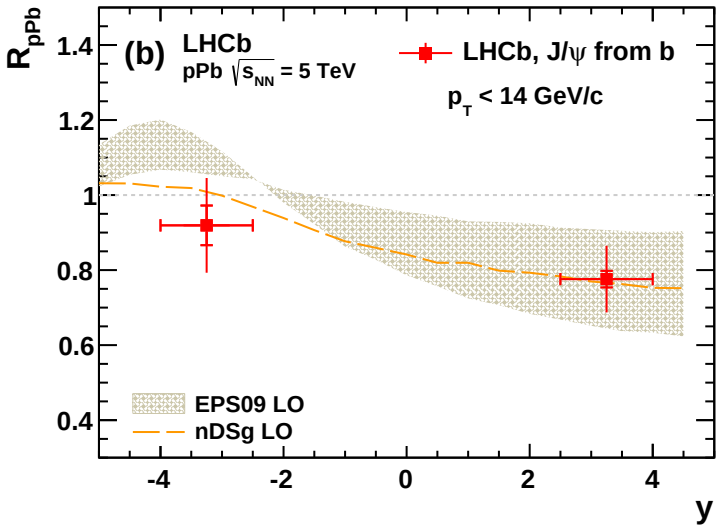
- Power law extrapolations used.
- Functions checked against predictions from LO-CEM and FONLL.

Nuclear Modification Factor

- Strong dependence on rapidity.
- Non prompt less affected than prompt J/ψ.
- B hadrons less affected by cold nuclear effects $\Rightarrow$ dependance on mass $\Rightarrow$ Measure for upsilon.
- Agreement with theoretical predictions, even though these are affected by large uncertainty.
- Precision insufficient to distinguish nuclear effects with/out saturation.

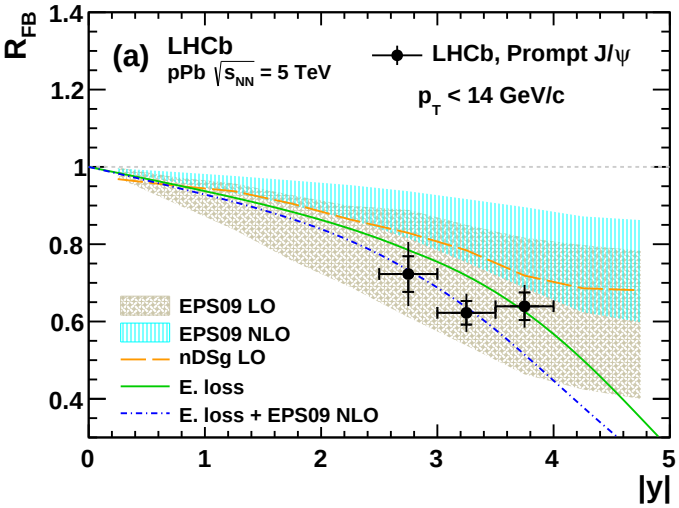


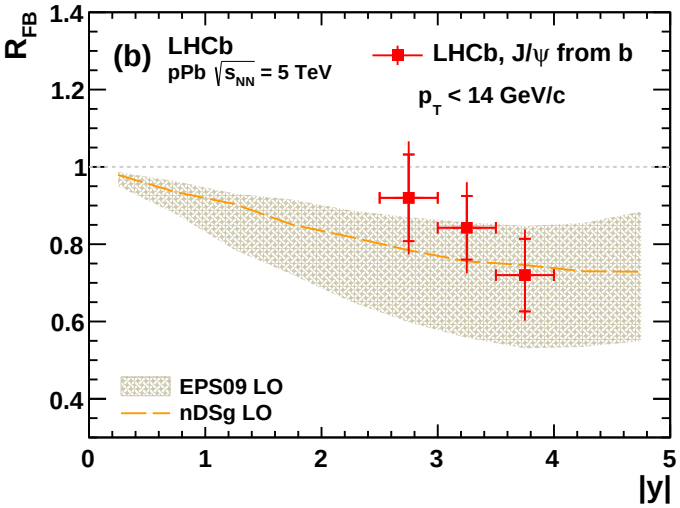


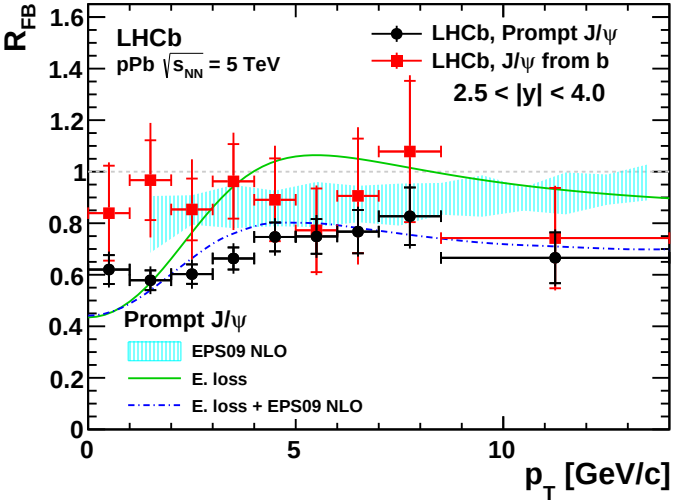
Theoretical predictions from: JHEP 03 (2013) 122, JHEP 05 (2013) 155

Forward-Backward asymmetry

- Uncertainties from proton-proton cross section cancel out.
- Clear difference between prompt J/ψ and J/ψ from b.







Conclusions

- Study of pA collisions is important to better understand Cold Nuclear Matter effects and for probing some yet unexplored QCD physics phenomena.
- LHCb has recorded $\sim 1.8\,\mathrm{nb}^{-1}$ p-Pb collisions in a unique kinematic range.
- J/ψ production cross section measured as function of p_T and y.
- Nuclear Modification Factor and Forward-Backward production asymmetry also measured as function of p_T and y.
- Clear J/ψ suppression observed in agreement with theory.
- Further analyses planned with the pA sample
- Looking forward to a $10\times$ increase in luminosity in Run II.