Quarkonia and heavy flavor in pPb at LHCb

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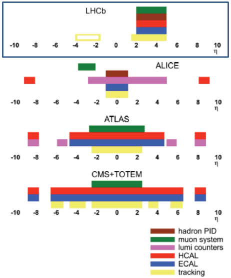
International Conference on the Initial Stages in High-Energy Nuclear Collisions,
Illa da Toxa, Galicia, Spain

Outline

- Motivation
- The LHCb spectrometer
- Beam Configurations
- Analysis strategy for J/Ψ reconstruction
- Measurement of J/Ψ cross sections
- Determination of nuclear modification
- Calculation of forward-backward asymmetry
- Conclusions $\&$ Outlook

Motivation

- 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:

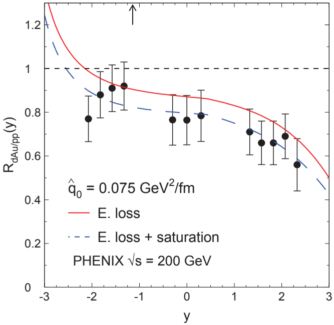
- cold-nuclear effects (decouple cold-nuclear matter from quark-gluon plasma effects)
- soft QCD; energy-loss *vs.* saturation
- useful as reference for ion-ion collision analyses
- $2 < \eta_{\text{lab}} < 5$, $P_T < 14$ GeV.

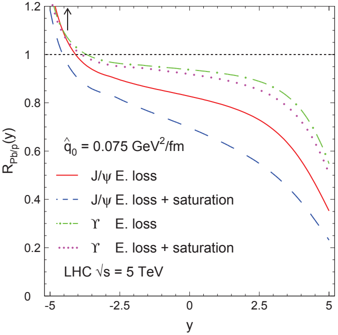
Nuclear modification factor:

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

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

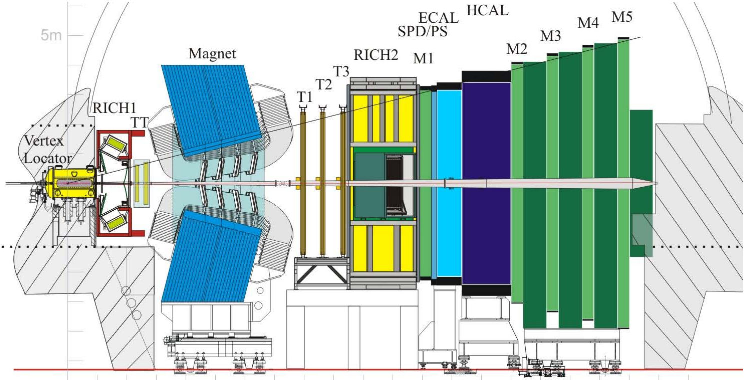
prediction for LHC energies (5 TeV) from JHEP 1303(2013) 122



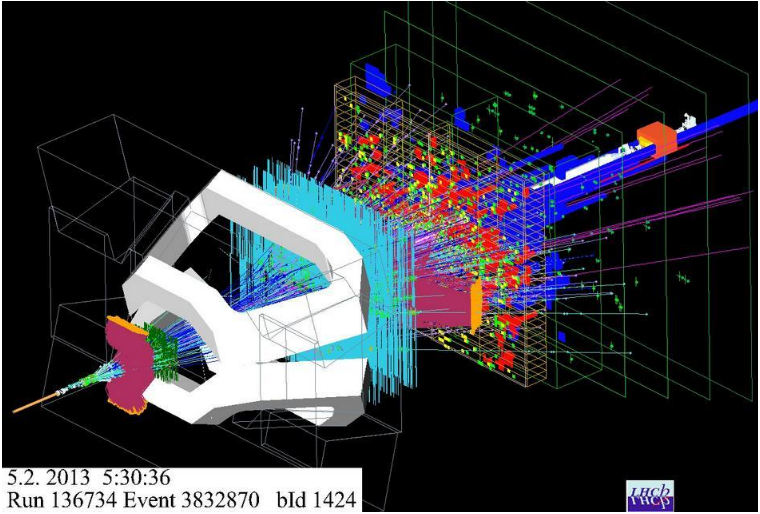


Theoretical calculations by Arleo & Peyne

LHCb Spectrometer



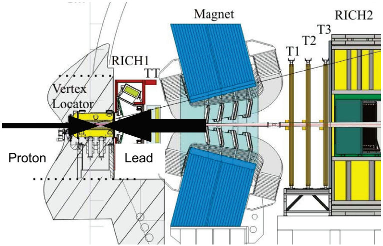
- Design luminosity $(2 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1})$
- good IP measurement: $\langle \delta \mathrm{IP} \rangle = 20\mu\mathrm{m}$ for $p_\mathrm{T} > 2$ GeV:
  - excellent vertex reconstruction to select *e.g.* J/Ψ mesons
  - separation of prompt from secondary J/Ψ's
- μ ID efficiency: $\sim 97\ \%$ for $< 3\ \%\ \pi \ \rightarrow\ \mu$ mis-id probability from $p = 2 - 100$ GeV
  - reconstruct open charm
  - very useful for particle-yield ratios
  - V_0 reconstruction



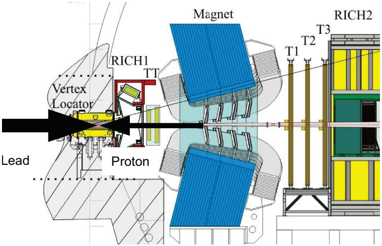
Typical pA collision in LHCb

LHCb Spectrometer

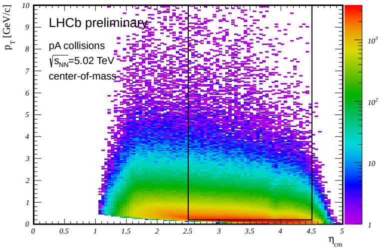
Event characteristics



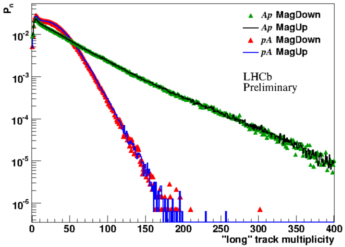
positive rapidity (protons on lead)



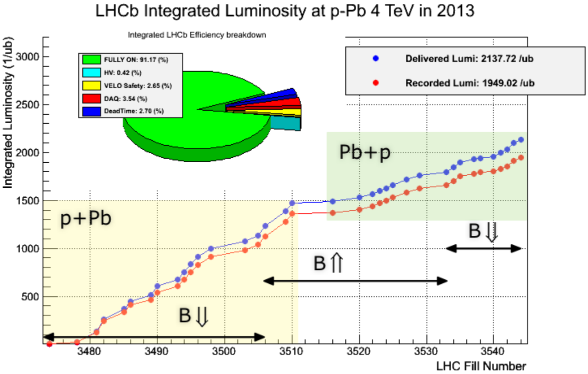
negative rapidity (lead on protons)



Pseudo-rapidity in LHCb for p-Pb collisions



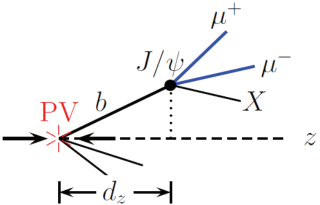
Multiplicity distribution in pA collisions



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

$$\text{forward} : \mathcal{L} = 1.1\ \mathrm{nb}^{-1} \qquad \text{backward} : \mathcal{L} = 0.5\ \mathrm{nb}^{-1}$$

- reconstruct J/Ψ in p-Pb and Pb-p data
- separate prompt J/Ψs from secondaries
- determine double-differential J/Ψ cross sections
- use total prompt J/Ψ cross section for nuclear modification
- determine forward-backward asymmetry in prompt J/Ψ production



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

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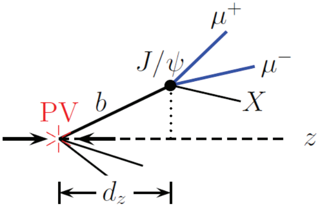

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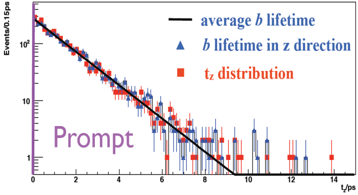
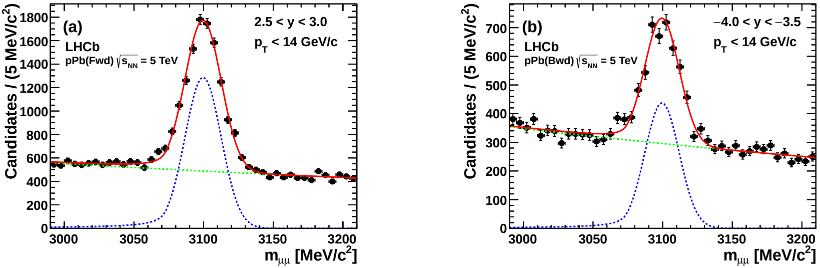


generator level distribution of t_z

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

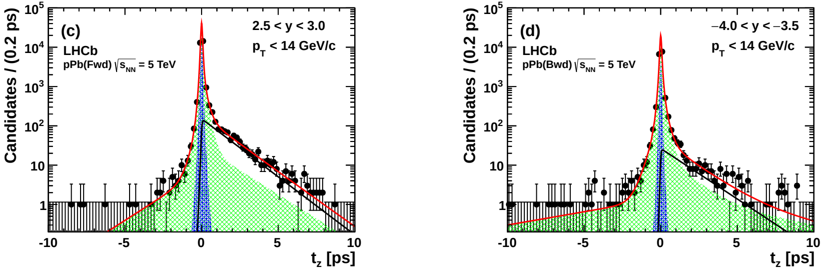


Results from arXiv:1308.6729

J/Ψ production in p-Pb collisions

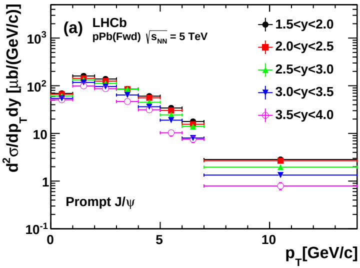
Mass- and pseudo-proper time fit

- 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

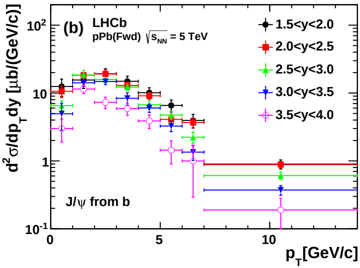


Results from arXiv:1308.6729

- pA: $1.5 < y < 4.0$
  - pA prompt:
    $\sigma_{\mathrm{pA}} = 1168 \pm 15\ (\mathrm{stat}) \pm 60\ (\mathrm{sys})\ \mu\mathrm{b}$
  - pA from b's:
    $\sigma_{\mathrm{pA}} = 166 \pm 4.1\ (\mathrm{stat}) \pm 9.2\ (\mathrm{sys})\ \mu\mathrm{b}$
- Ap: $-5.0 < y < -2.5$
  - Ap prompt:
    $\sigma_{\mathrm{Ap}} = 1293 \pm 49.8\ (\mathrm{stat}) \pm 82\ (\mathrm{sys})\ \mu\mathrm{b}$
  - Ap from b's:
    $\sigma_{\mathrm{Ap}} = 118 \pm 6.8\ (\mathrm{stat}) \pm 12.2\ (\mathrm{sys})\ \mu\mathrm{b}$



Prompt J/Ψ

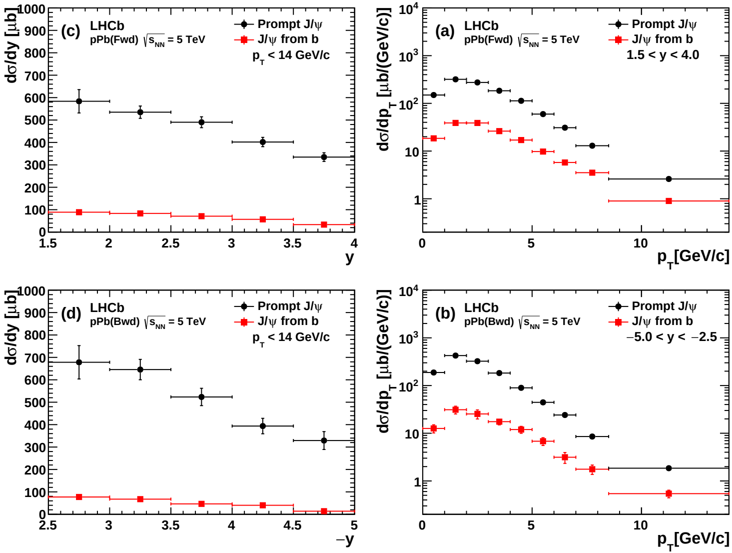


J/Ψ from b's

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

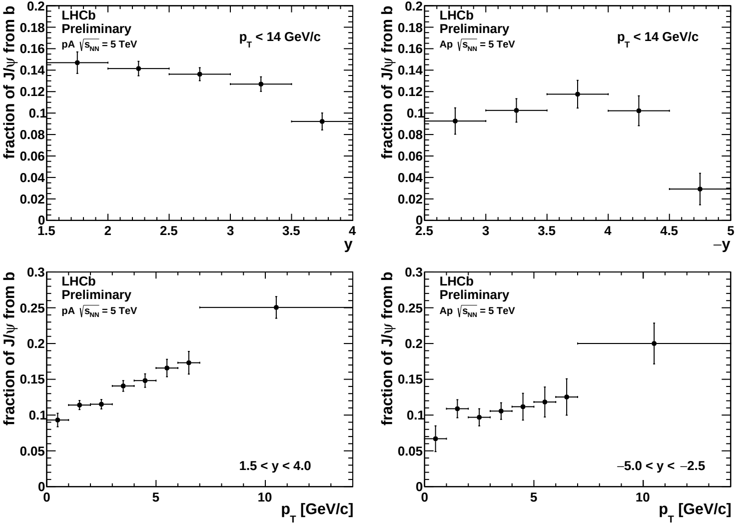
J/Ψ production in p-Pb collisions

J/Ψ single-differential cross sections



Results from `arXiv:1308.6729`

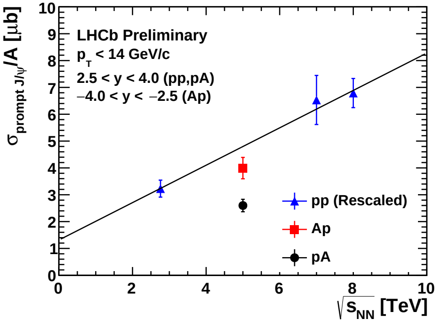
Fraction of J/Ψ from b-quarks:



From: LHCb-CONF-2013-008

Prompt J/Ψ cross sections at LHCb

Comparison of prompt J/Ψ production in p-p, p-Pb and Pb-p:



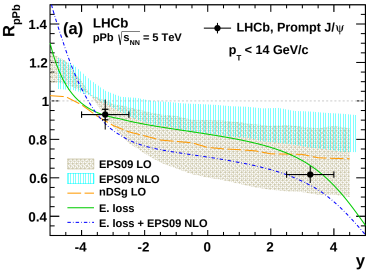
Total prompt J/Ψ cross section

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

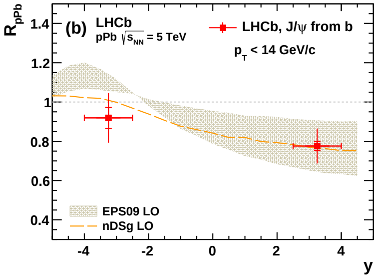
- clear observation of J/Ψ suppression in pA and Ap
- but Ap cross section only slightly suppressed

From: LHCb-CONF-2013-008

Nuclear modification *vs.* rapidity for prompt J/Ψ's:



and for J/Ψ from b-quarks:



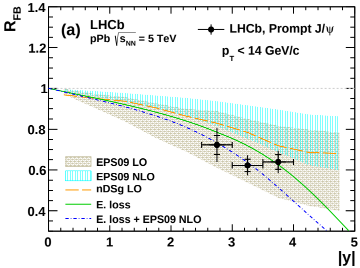
$$R_{pA}(y,\sqrt{s}) = \frac{1}{A}\frac{\frac{d\sigma_{pA}(y,\sqrt{s})}{dy}}{\frac{d\sigma_{pp}(y,\sqrt{s})}{dy}}$$

Theory confirmed by data; but more needed to separate saturation from energy loss

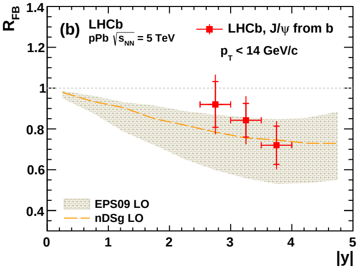
Results from `arXiv:1308.6729`,
predictions from `arXiv:1305.4569`, IJM Phys E22 (2013) 1330007, JHEP 03 (2013) 122

$$r_{\mathrm{FB}} \equiv \frac{R_{\mathrm{pA}}(y)}{R_{\mathrm{Ap}}(-y)}$$

asymmetry in forward-backward prompt J/Ψ production:



forward-backward asymmetry for J/Ψ's from b-quarks:



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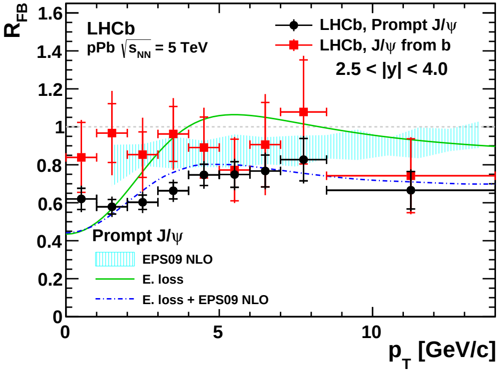
Forward-backward asymmetry *vs.* transverse momentum:



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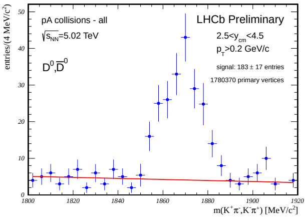
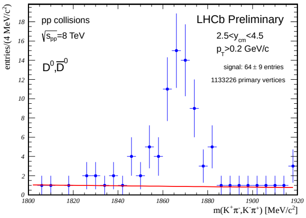
Charm production in proton-ion collisions

Up to now: only pilot data ($1\ \mu\mathrm{b}^{-1}$) 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 $\mathrm{K}^{\pm}$
- use production ratio to show enhanced particle production in pA collisions

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





$$R(\mathrm{D}) = 1.820 \pm 0.307$$

LHCb-CONF-2012-034

Conclusions & Outlook

- $\sim 1.7\ \mathrm{nb}^{-1}$ recorded by LHCb in 2013 p-Pb & Pb-p runs
- 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/Ψ cross section in (y, p_T) at $\sqrt{s_\mathrm{NN}} = 5\ \mathrm{TeV}$
- Nuclear modification determined, using interpolated LHCb σ's to $\sqrt{s_\mathrm{NN}} = 5\ \mathrm{TeV}$
- 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
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- not all data were analyzed... more to come, with better statistics!
  e.g Υ production in proton-ion collisions