LHCb results on J/ψ production and prospects for p-Pb physics

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On behalf of the LHCb collaboration

Workshop on proton-nucleus collisions at the LHC
ECT* Trento
6-10 May 2013

Outline

- LHCb experiment
- 2013 p-Pb data taking
- J/ψ production results
- Prospects for p-Pb physics
- Summary

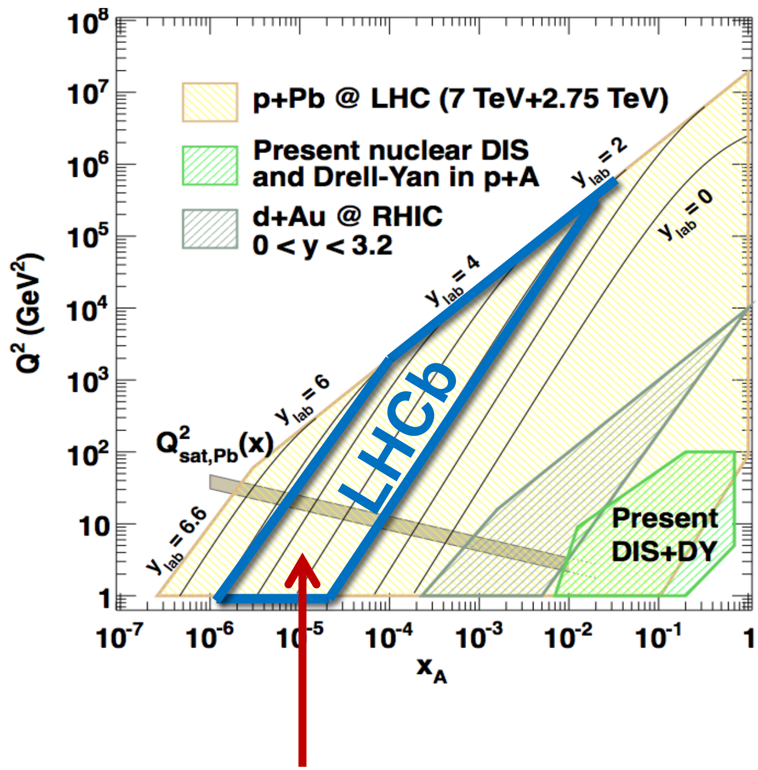
Physics motivation

➢ Study of p-Pb collisions can provide:

- Important input for understanding ion-ion collisions
- Insights into unexplored region of QCD

➢ The LHCb detector can play a unique role:

- It can study physics processes involving particles at very small angles, which are not accessible by other detectors



✓ Rather informative to DY measurements and to constrain saturation physics

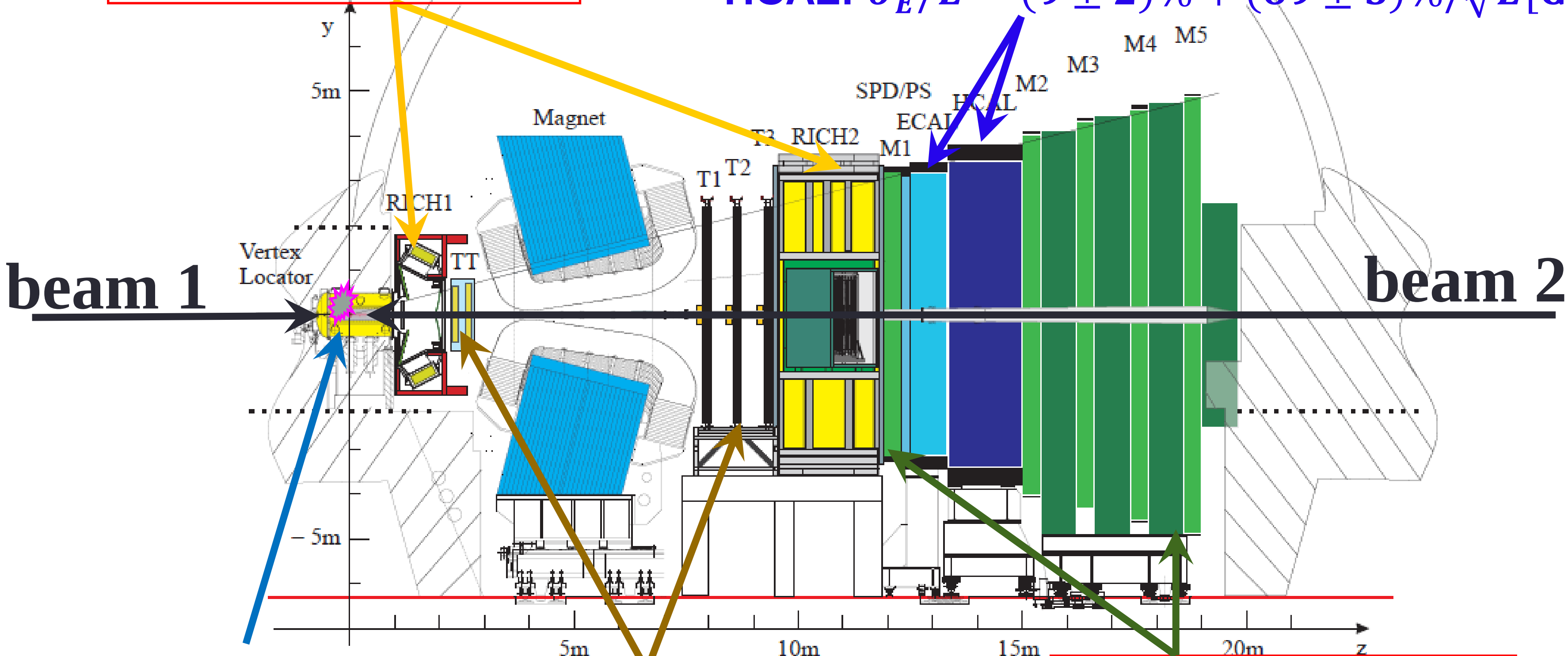
http://cds.cern.ch/journal/CERNBulletin/2013/08/News%20Articles/1514560?ln=en

LHCb detector

Forward Spectrometer
Pseudorapidity acceptance
$2 < \eta < 5$

RICH1 & RICH2
$\epsilon(K \to K) \sim 95\%$
$\pi \to K$ mis-id: $\sim 5\%$

ECAL: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\mathrm{GeV}]}$
HCAL: $\sigma_E/E \sim (9 \pm 2)\% + (69 \pm 5)\%/\sqrt{E[\mathrm{GeV}]}$



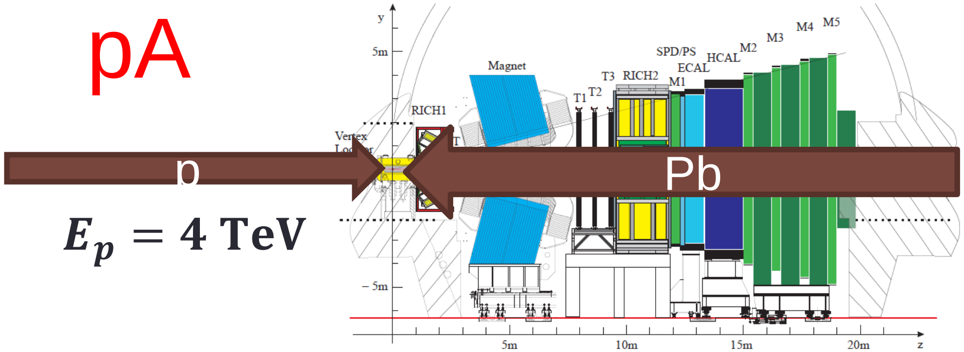
VELO
$\sigma_{\mathrm{IP}} \sim 20\ \mu\mathrm{m}$
for high-p_T tracks

Tracking System
$\Delta p/p = 0.4\%@5\ \mathrm{GeV}/c$
to $0.6\%@100\ \mathrm{GeV}/c$

Muon System
$\epsilon(\mu \to \mu) \sim 97\%$
$\pi \to \mu$ mis-id: $1 \sim 3\%$

pA and Ap configurations

pA



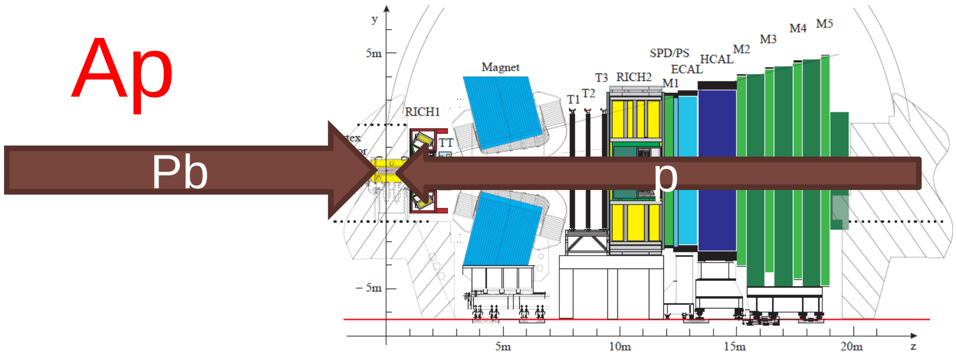
$E_p = 4$ TeV

$E_{p/n} = 1.58$ TeV

➔ Forward production

y > 0

Ap



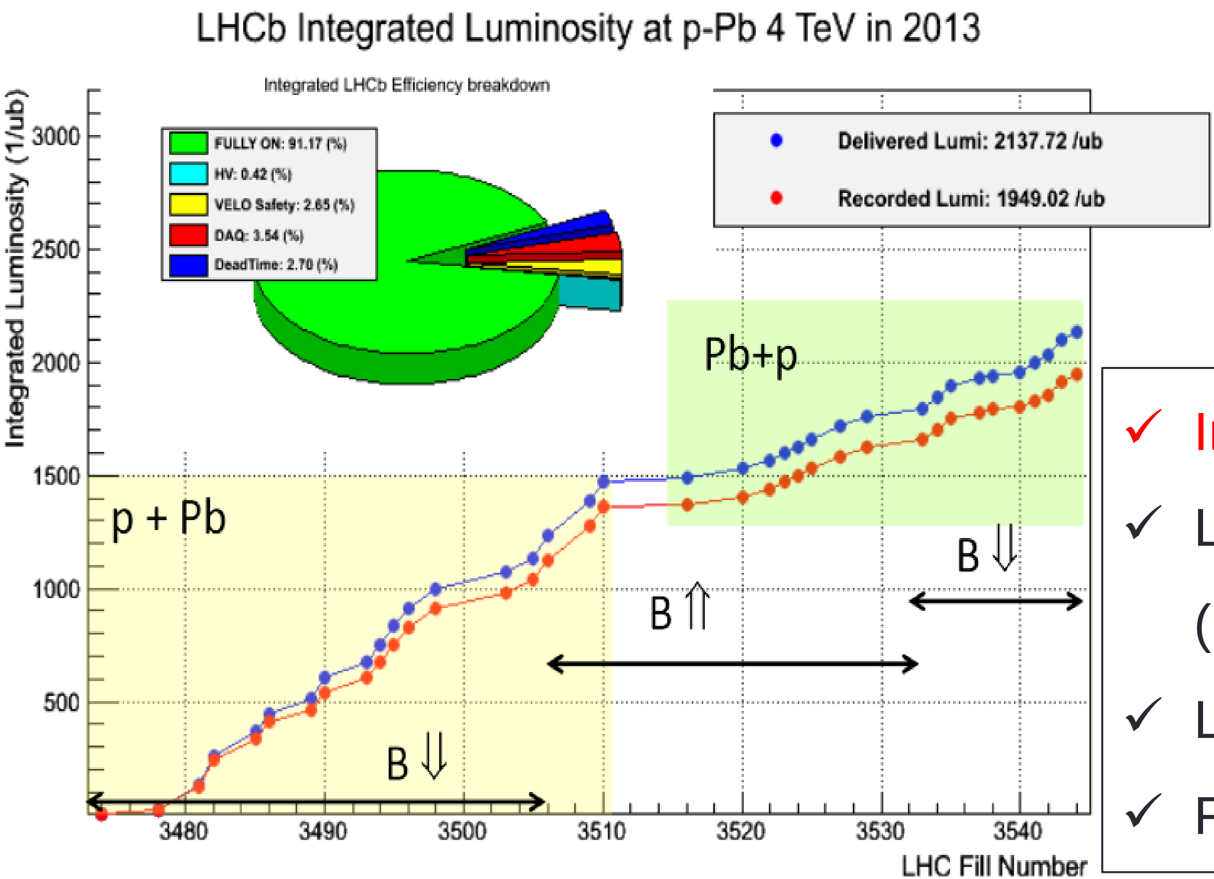
➔ Backward production

y < 0

- ✓ $\sqrt{s_{NN}} = 5$ TeV
- ✓ Different rapidity (in c.m.s) coverage
  - pp : $2.0 < \eta < 5.0$
  - pA: $1.5 < \eta < 4.5$
  - Ap: $-5.5 < \eta < -2.5$

- Rapidity is always defined w.r.t. to the proton direction

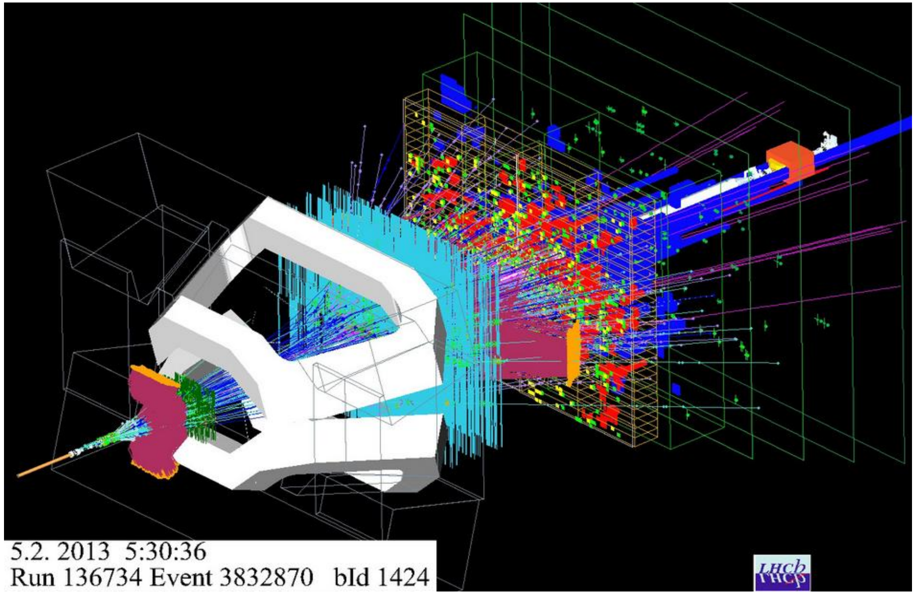
2013 p-Pb data taking

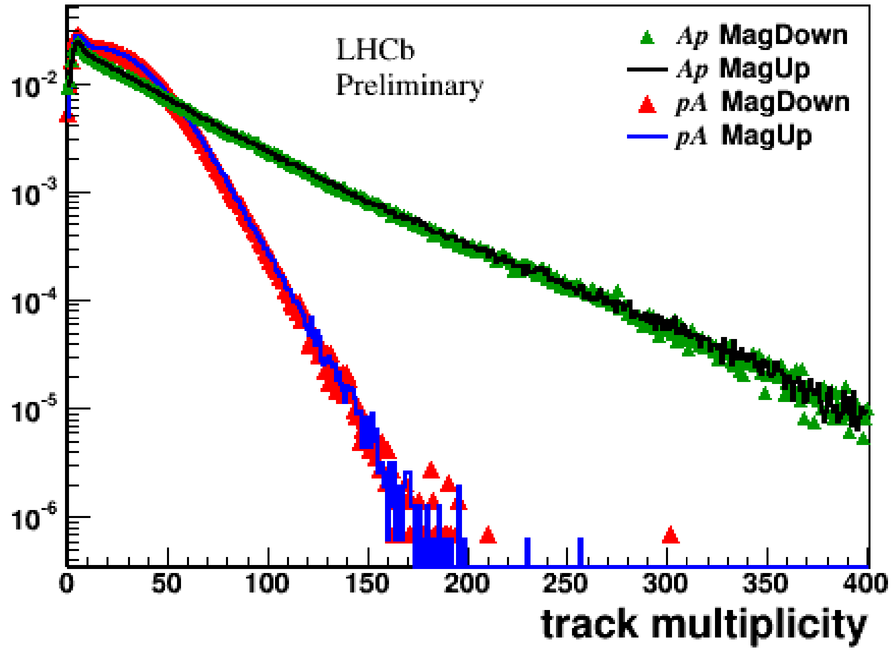


20 Jan. - 10 Feb.

- ✓ Integrated lumi. ~ 2 nb^{-1}
- ✓ Low instantaneous lumi. ($\sim 5 \times 10^{27}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$)
- ✓ Low pile-up
- ✓ Four configurations

Event display and track multiplicity





- ✓ Mag up/down agree for both pA and Ap
- ✓ Higher multiplicities in Ap as expected

J/ψ production

[LHCb-CONF-2013-008]

Introduction to J/ψ production cross-section

- Sensitive probe of properties of nuclear matter in heavy quarkonium production:
  - nuclear attenuation factors
  - nuclear parton distribution function (nPDF)
  - ……

- J/ψ production measurement: a major goal for LHCb p-Pb run
  - wide rapidity coverage
  - coverage for low p_T
  - can be compared with LHCb measurements in pp collisions at 2.76, 7 and 8 TeV to study heavy quarkonium suppression

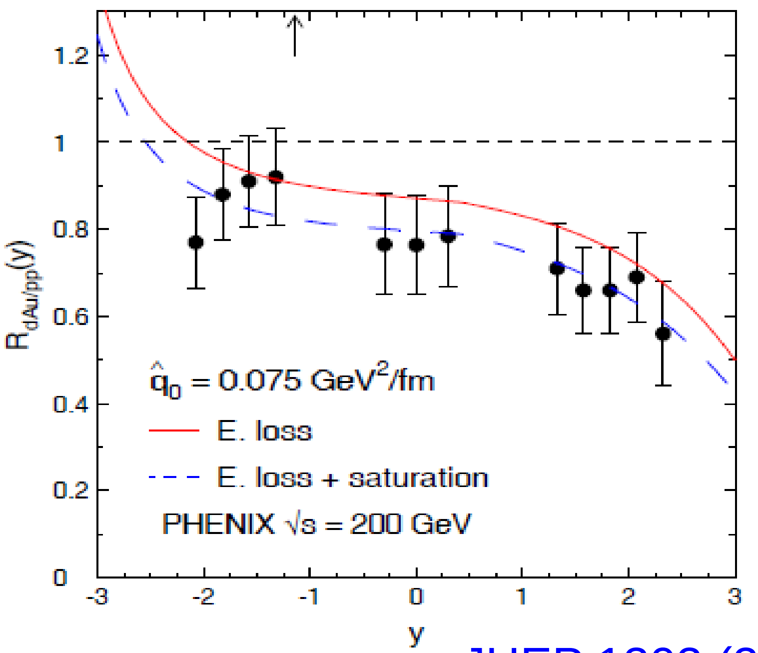
JHEP 02 (2013) 041 [arXiv:1212.1045]
Eur. Phys. J. C71 (2011) 1645 [arXiv:1103.0423]
LHCb-PAPER-2013-016 [arXiv:1304.6977]

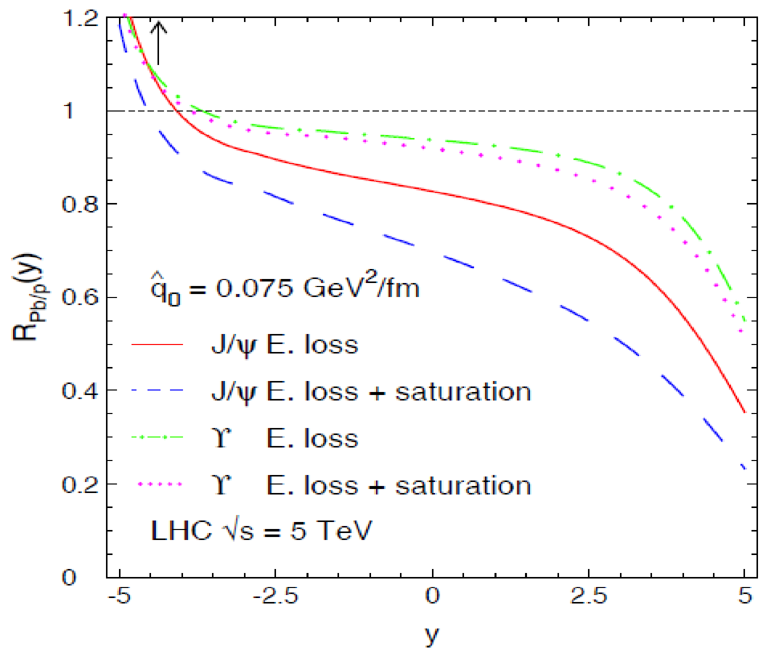
Heavy quarkonia suppression

- Production of heavy quarkonia at large rapidity strongly suppressed in p-Pb collisions

Nuclear attenuation factor:

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





JHEP 1303 (2013) 122 [arXiv:1212.0434]

Prompt J/ψ and J/ψ from b

- **Three main sources of J/ψ :**
  - direct production in p-Pb collisions
  - feed down from heavier charmonium states ($\psi(2S)$, χ_c,…)
  - J/ψ from b-hadron decay chains

Prompt J/ψ (direct production and feed down)

J/ψ from b (from b-hadron decay chains)

- **Results** (based on 0.75 nb^{-1} pA data and 0.30 nb^{-1} Ap data)**:**
  - Differential cross-section of prompt J/ψ and J/ψ from b
  - Fraction of $J/\psi\ from\ b$ as a function of y and $\mathrm{p_T}$
  - $r_{FB}(y) \equiv \frac{d\sigma_{pA}}{dy}(y) / \frac{d\sigma_{Ap}}{dy}(-y)$ measured directly

    Reflect forward-backward production asymmetry
  - $R_{pA}(\mathrm{y})$ $\sigma_{pp}(5\ \mathrm{TeV})$ needed

    Nuclear attenuation factor

Prompt J/ψ in common y bins (r_{FB} and R_{pA})

Analysis strategy

- The measurement of the production cross section both for **prompt J/ψ** and for J/ψ **from b**, namely:

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

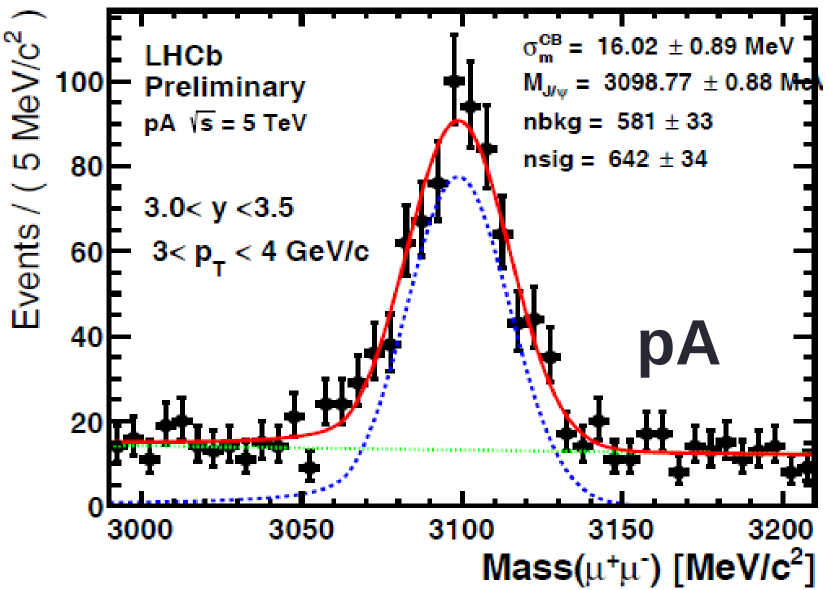
- Measurements restricted to:
  - pA: 1.5< y <4.0 Ap: -5.0< y < -2.5 (y in c.m.s. of proton-nucleon)
  - p_T<14 GeV/c

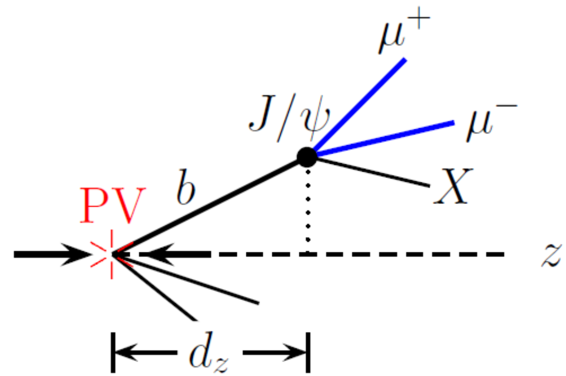
- Use pseudo-proper time to separate prompt J/ψ and J/ψ from b

J/ψ signal extraction

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

Mass spectrum of incl. J/ψ





Mass model:

Sig : Crystal Ball

Bkg : exponential

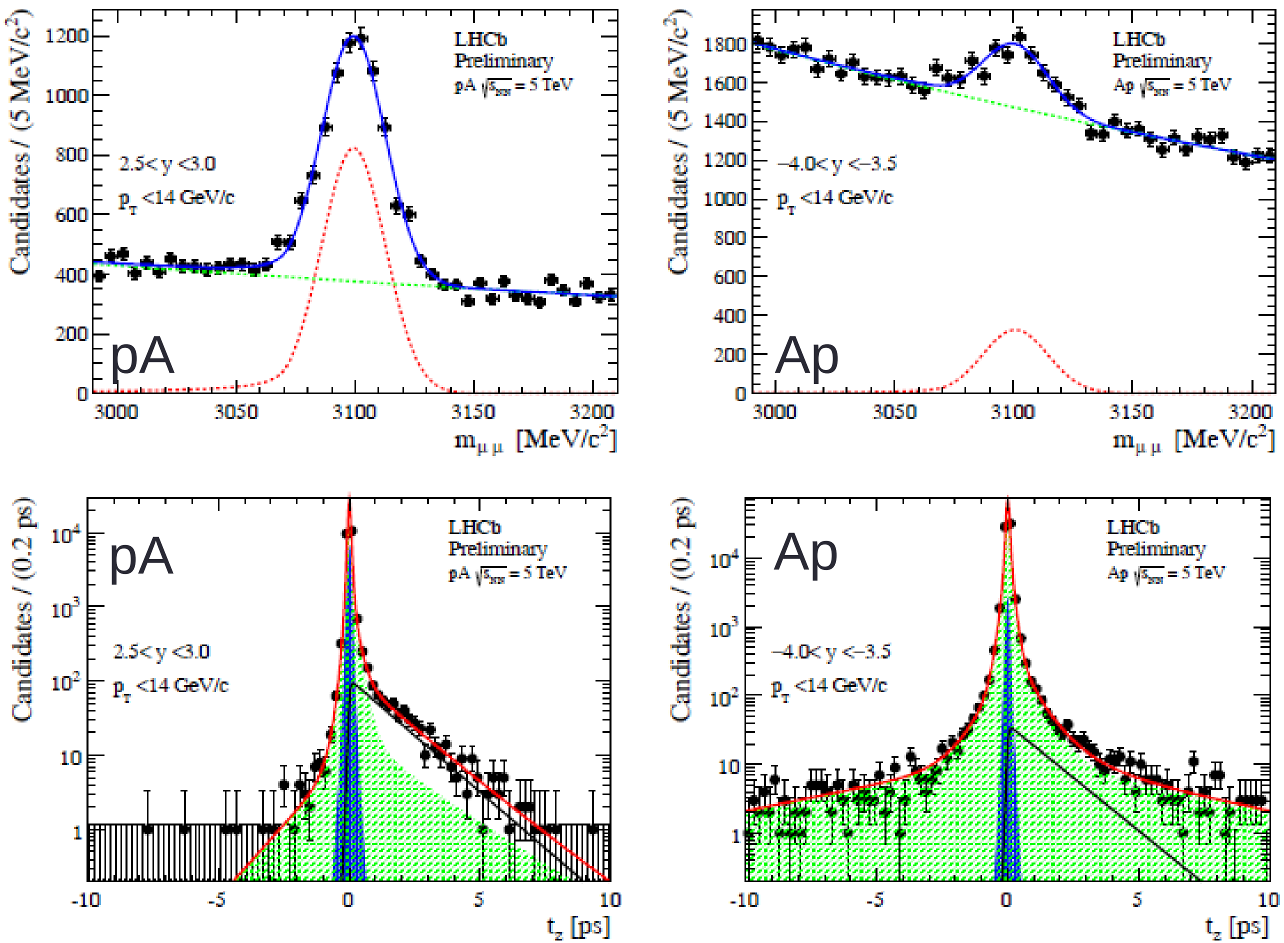
t_z model:

Sig :

- $\delta(t_z)$ for prompt J/ψ
- exponential for b-component
- both convoluted with double gaussian resolution function

Bkg: empirical function from sideband

Fit projections



Blue line : prompt J/ψ **Solid black:** J/ψ from b

Green hatched : combinatorial Background

Efficiency

- $\boldsymbol{\epsilon}_{\mathbf{tot}} = \boldsymbol{\epsilon}_{\mathbf{acc}} \times \boldsymbol{\epsilon}_{\mathbf{rec}} \times \boldsymbol{\epsilon}_{\mathbf{tri}}$ (~ 45%)
  - ϵ_{acc} and ϵ_{rec}(including detecting, reconstruction and selection efficiency): estimated from simulation.
  - ϵ_{tri} : obtained directly from the minimum-bias sample collected in the data (~ 95%)

N.B.: For efficiency estimation no polarization of J/ψ production is assumed.

Preliminary Results

Total cross-sections

- Total production of prompt J/ψ and J/ψ from b in LHCb in the fiducial region:

pA: $p_T < 14\ \mathrm{GeV/c}\,,\ \mathbf{1.5 < y < 4.0}$

$$\sigma_{pA}(prompt\ J/\psi) = \mathbf{1028.2 \pm 13.6\ (stat.) \pm 88.6 (syst.)\ \mu b}$$

$$\sigma_{pA}(J/\psi\ from\ b) = \mathbf{150.1 \pm 4.2\ (stat.) \pm 12.6 (syst.)\ \mu b}$$

Ap: $p_T < 14\ \mathrm{GeV/c}\,,\ \mathbf{-5 < y < -2.5}$

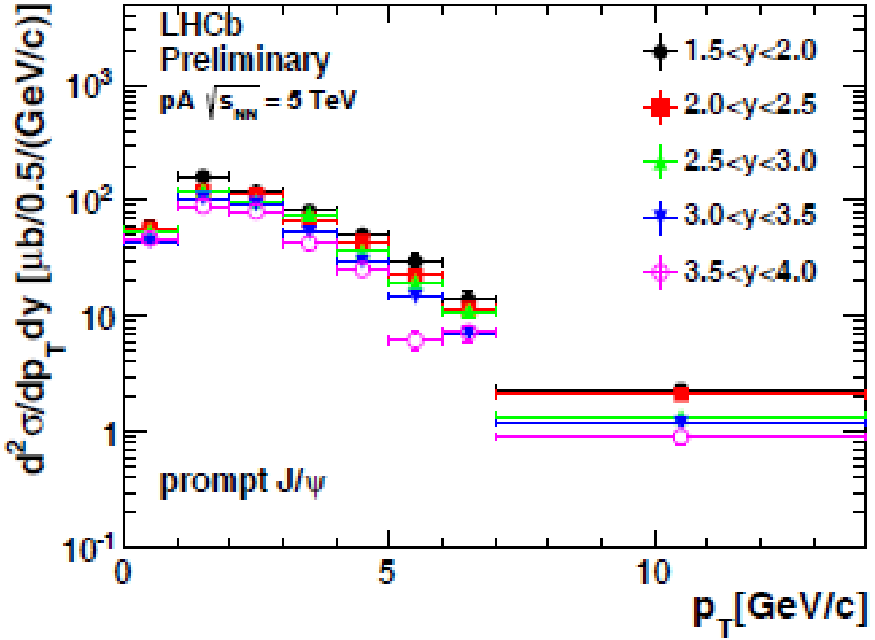
$$\sigma_{Ap}(prompt\ J/\psi) = \mathbf{1141.9 \pm 49.8\ (stat.) \pm 98.4 (syst.)\ \mu b}$$

$$\sigma_{Ap}(J/\psi\ from\ b) = \mathbf{119.7 \pm 8.3\ (stat.) \pm 10.0 (syst.)\ \mu b}$$

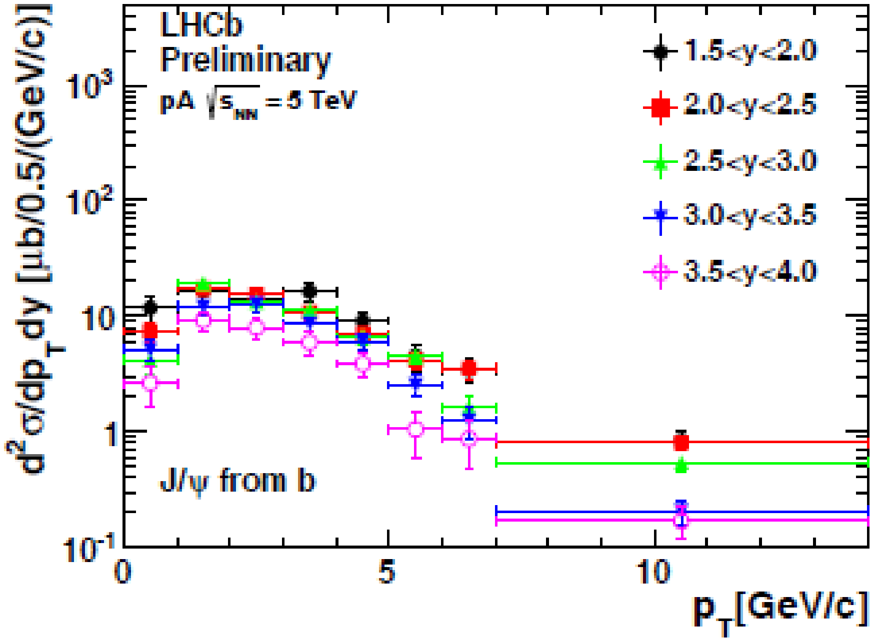
Systematics dominated by luminosity, fit model and data-MC discrepancy.

Double differential cross-section in pA

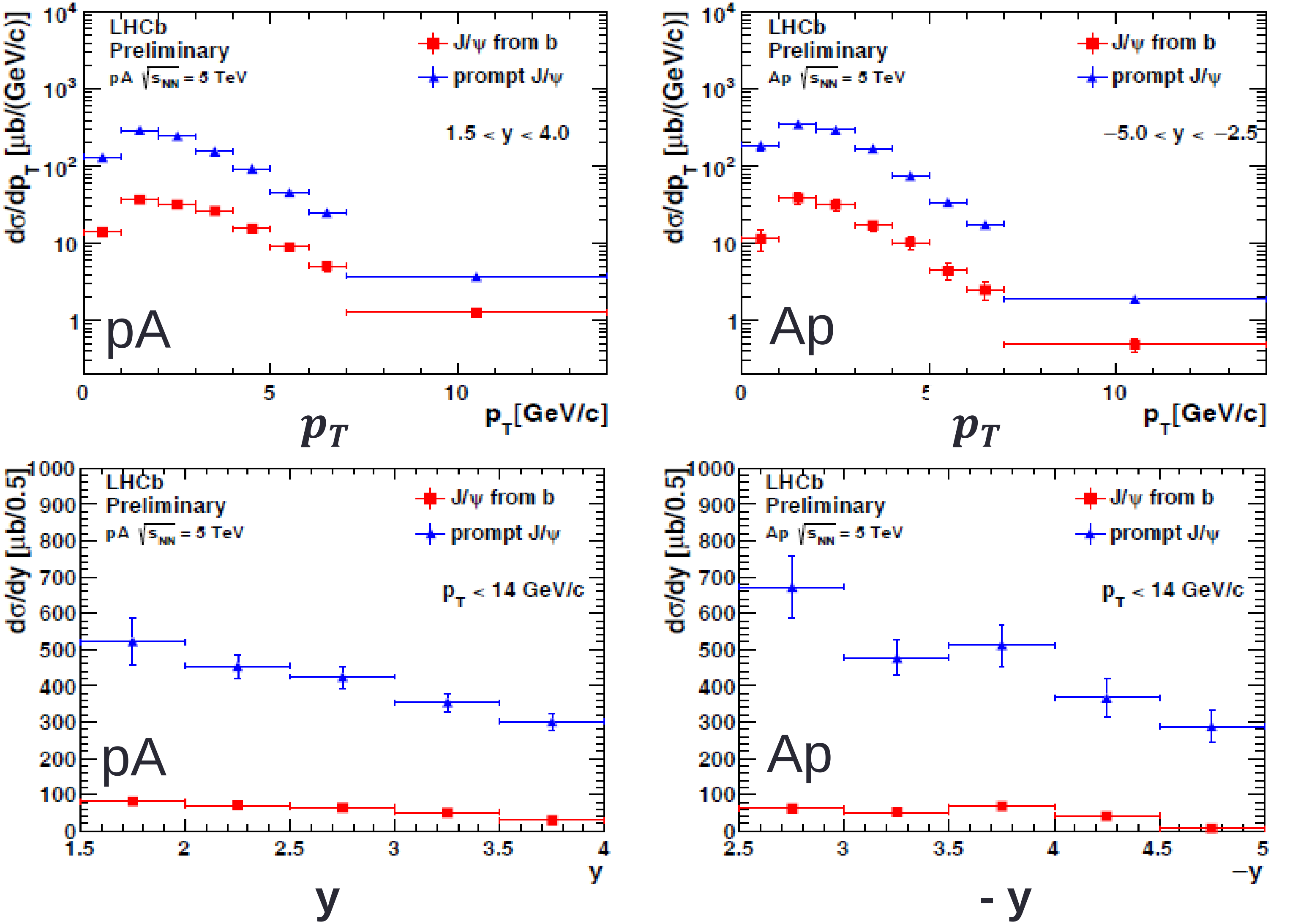
Prompt J/ψ



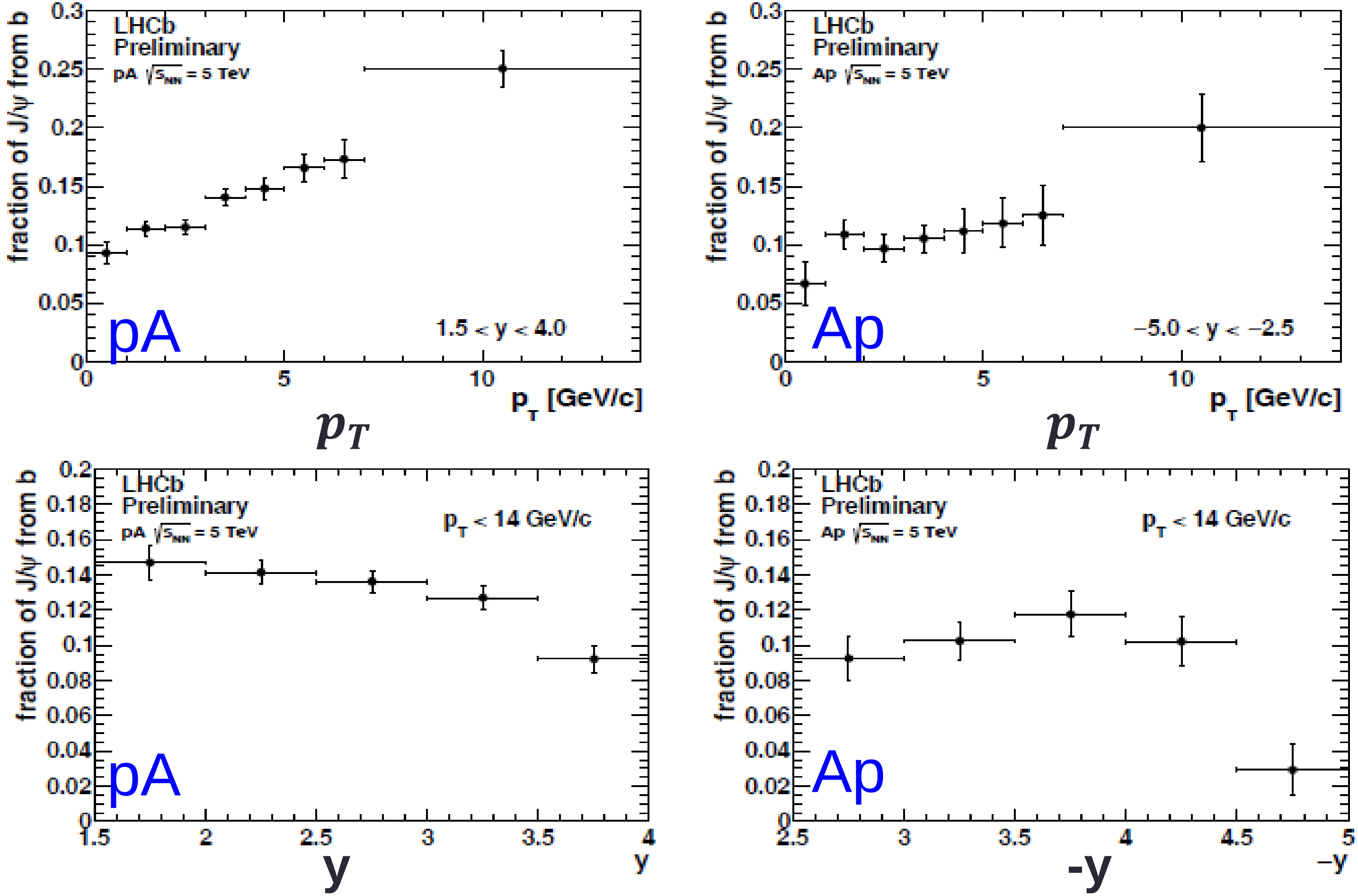
J/ψ from b



Single differential cross-sections

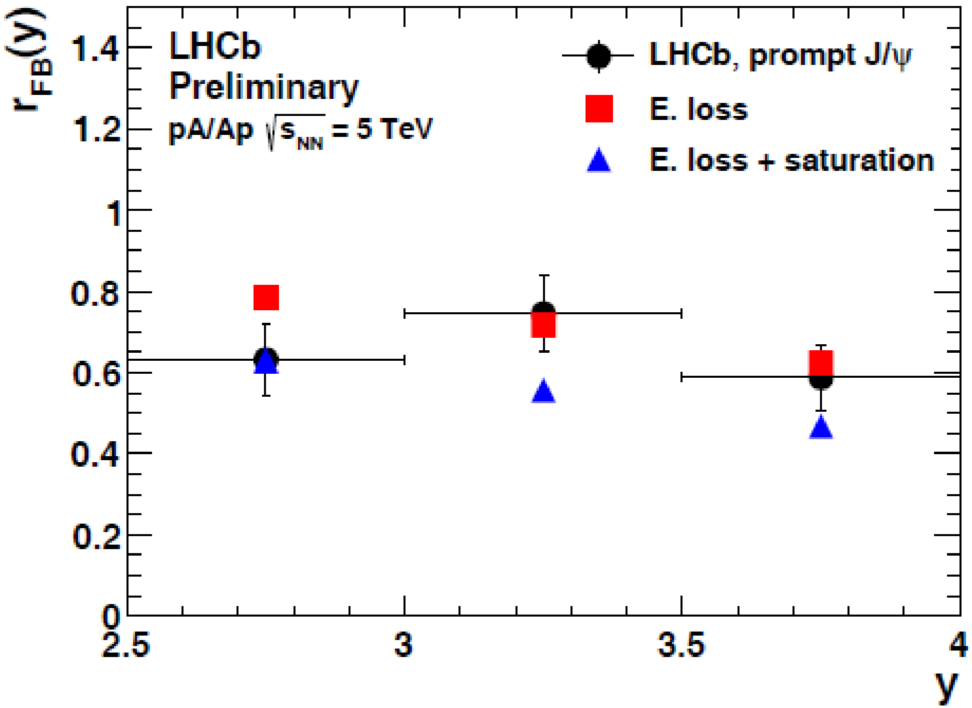


Fraction of J/ψ from b v.s. $p_T(y)$



- ✓ Fraction of J/ψ from b increases with transverse momentum
- ✓ Larger fraction of J/ψ from b in pA than Ap.

Forward-backward production asymmetry r_{FB}

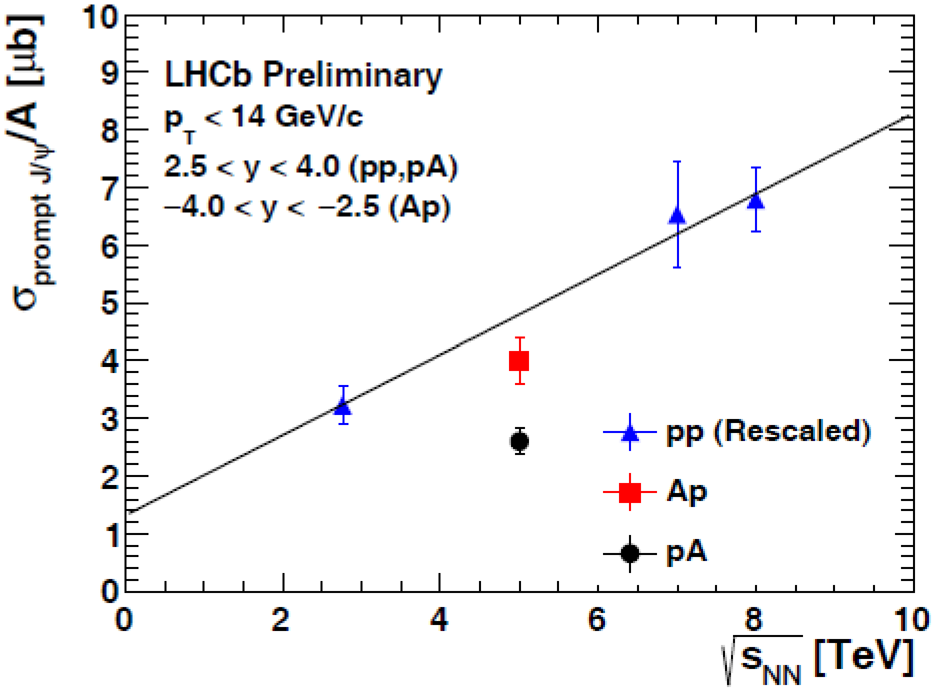


Theoretical predictions:
JHEP 1303 (2013) 122
[arXiv:1212.0434]

- ✓ Clear forward-backward production asymmetry
- ✓ Agreement with theoretical predictions
- ✓ Current precision insufficient to distinguish nuclear effects with or without saturation

Comparison with σ_{pp} at 5 TeV

Prompt J/ψ



A = 208 for pA and Ap, A =1 for pp

- ✓ Rescaled σ_{pp} in common rapidity range: 2.5<y<4.0
- ✓ Linear interpolation to obtain $\sigma_{pp}(5\ \mathrm{TeV})$ from prompt J/ψ cross-section in pp collisions
- ✓ Clear suppression in pA, while slight suppression in Ap.

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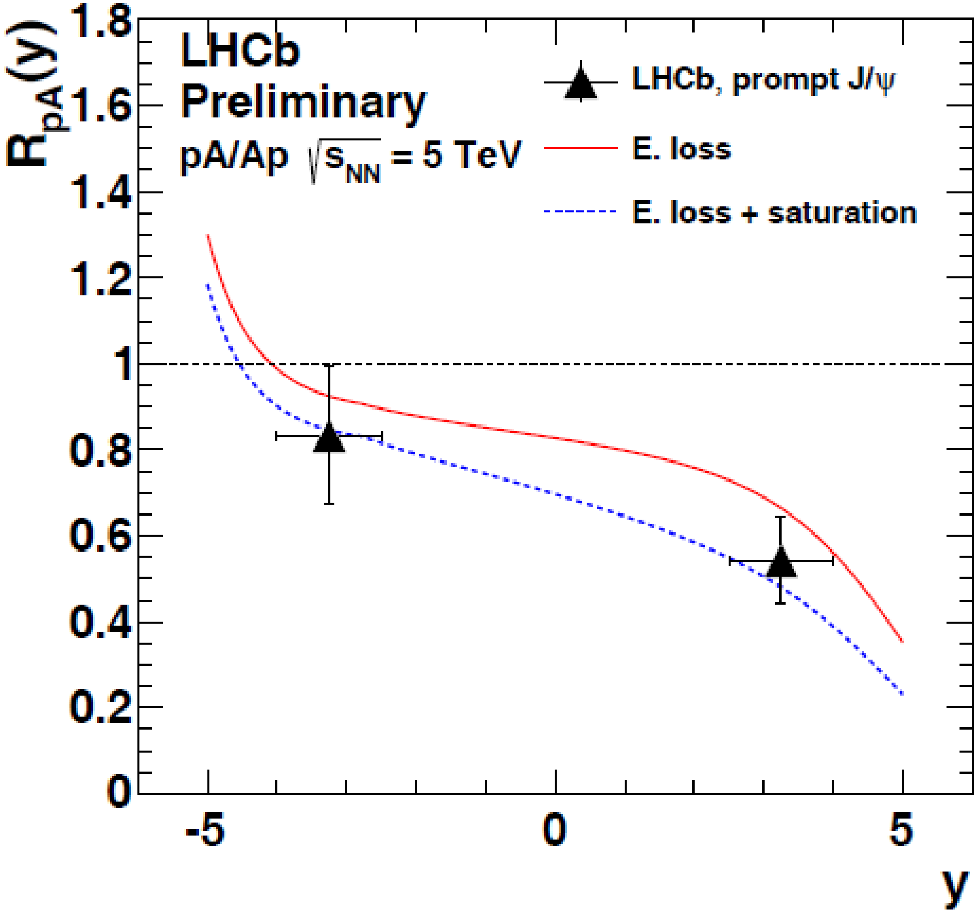
LHCb-PAPER-2013-016 [arXiv:1304.6977]

Nuclear attenuation factor $R_{pA}(y)$

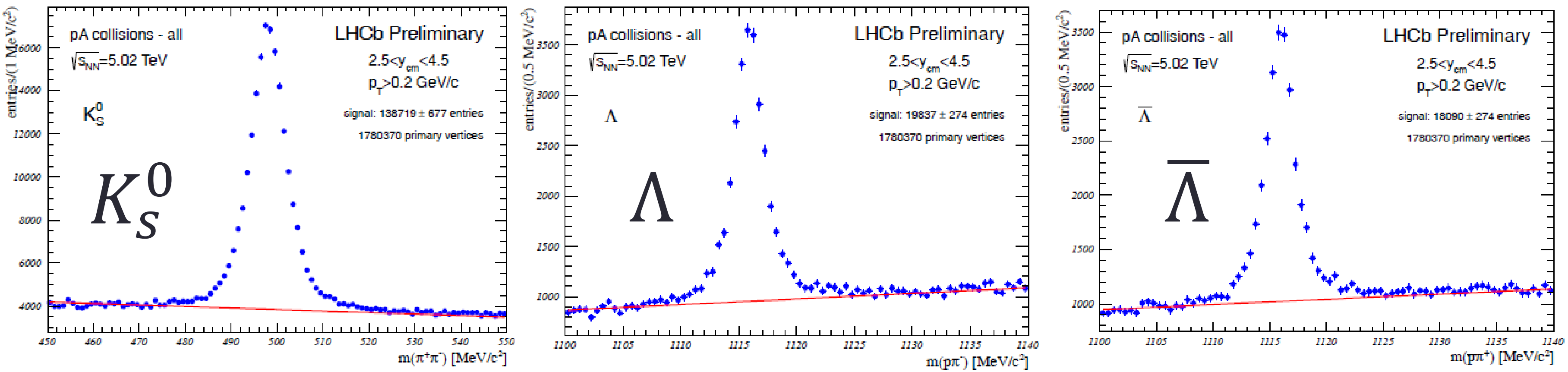


Theoretical predictions:
JHEP 1303 (2013) 122
[arXiv:1212.0434]

✓ Good agreement with theoretical predictions

Prospects

➢ Lots of opportunities offered by p-Pb collisions at LHCb. The unique angular coverage will enable us to study strangeness, charm and also beauty production in regions not accessible to the other experiments.



[LHCb-CONF-2012-034]

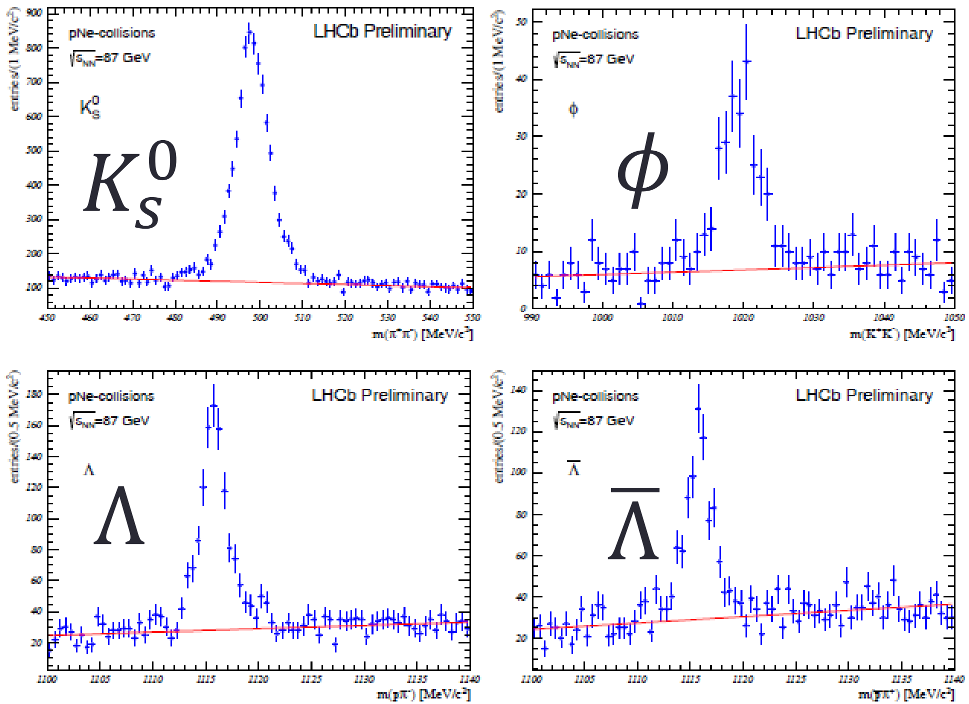
- From pA pilot run:
  - $R(K^0_S) = (K^0_S$/pA-vertex)/(K^0_S/pp-vertex) = $1.745 \pm 0.014_{stat}$
  - $R(\Lambda) = (\Lambda$/pA-vertex)/(Λ/pp-vertex) = $1.818 \pm 0.043_{stat}$
  - $R(\bar{\Lambda}) = (\bar{\Lambda}$/pA-vertex)/($\bar{\Lambda}$/pp-vertex) = $1.827 \pm 0.047_{stat}$

- Preliminary study of V^0 production ratios in p-Pb very promising.

Prospects

- **More interesting analyses**
  - Central exclusive production
  - Jet production
  - $\psi(2S)$ and $\Upsilon(nS)$ production
  - Open-charm production
  - DIS and Drell-Yan
  - Particle correlations
  - Low-x physics
  - pNe, PbNe(fixed-target) physics
  - ……

pNe collisions



[LHCb-CONF-2012-034]

Summary

- ~ 2 nb^{-1} recorded at LHCb provides unique opportunities on specific physics measurements interesting for understanding ion−ion collisions and probing some particular QCD physics phenomena.

- J/ψ production cross-section as a function of p_{T} and y measured in p-Pb collisions at $\sqrt{s_{NN}} = 5\ \mathrm{TeV}$
- Nuclear attenuation factor R_{pA} measured with $\sigma_{pp}(5\ \mathrm{TeV})$ interpolated from previous measurements
- The forward-backward production asymmetry ratio r_{FB} measured as a function of rapidity
- Clear J/ψ suppression and good agreement with theory

- More analyses on-going …

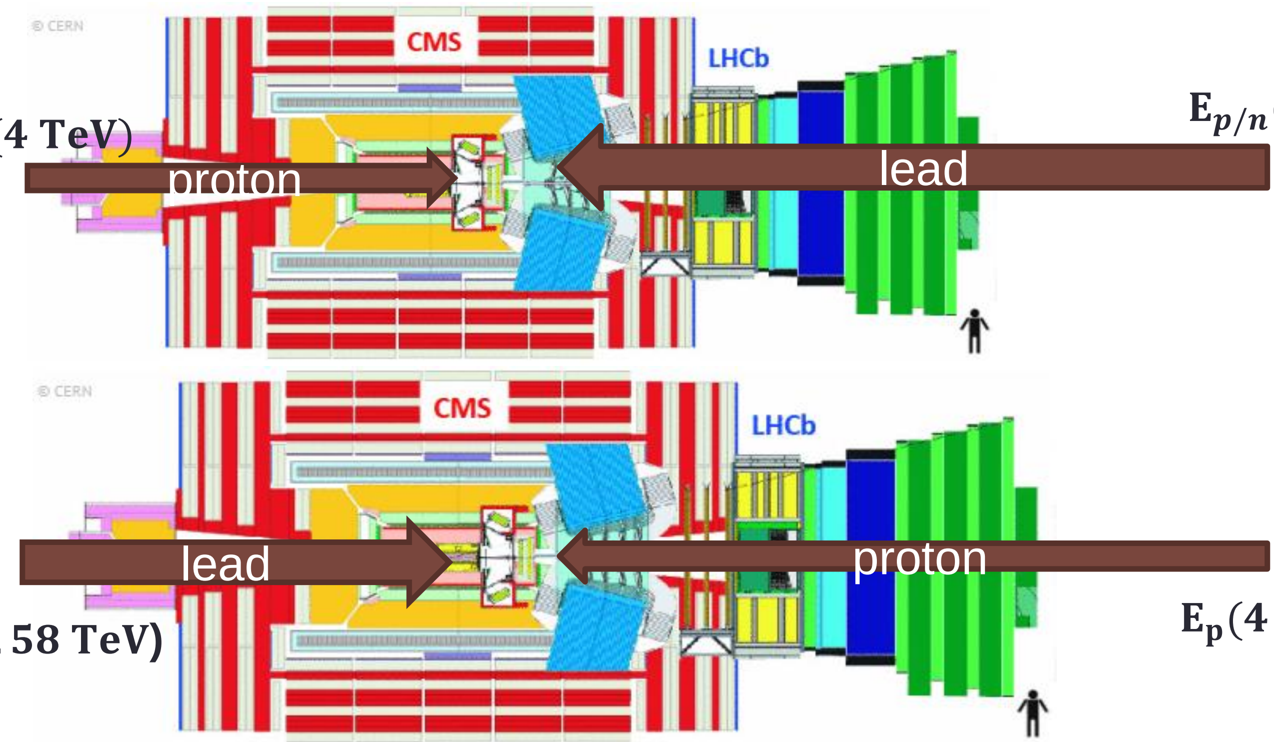
Thank you!

BACKUP

pA and Ap configurations

pA

$\mathbf{E_p(4\ TeV)}$ $\mathbf{E_{p/n}(1.58\ TeV)}$



Ap

$\mathbf{E_{p/n}(1.58\ TeV)}$ $\mathbf{E_p(4\ TeV)}$

Main features:

- center-of-mass energy $\sqrt{s_{pN}} = 5\ \mathrm{TeV}$
- Rapidity of proton-nucleon system in lab:
  $y_0(pA) = 0.47, \qquad y_0(Ap) = -0.47$
- Rapidity coverage in proton-nucleon system:
  1.5<y<4.5 (for pA) -5.0<y<-2.5 (for Ap)

y always indicates rapidity in proton-nucleon cms system

Triggers

- Loose trigger used for p-Pb run
  due to very low instantaneous luminosity ($\sim 5 \times 10^{27}\ \mathrm{cm^{-2}s^{-1}}$)

- Only Hlt1 used, L0 and Hlt2 in pass through mode

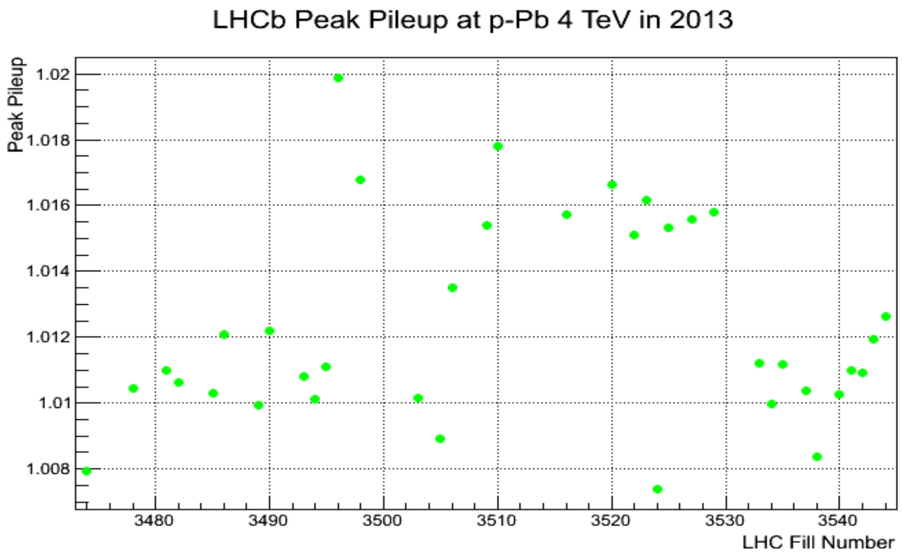
- Hlt1SingleMuonNoIP line used

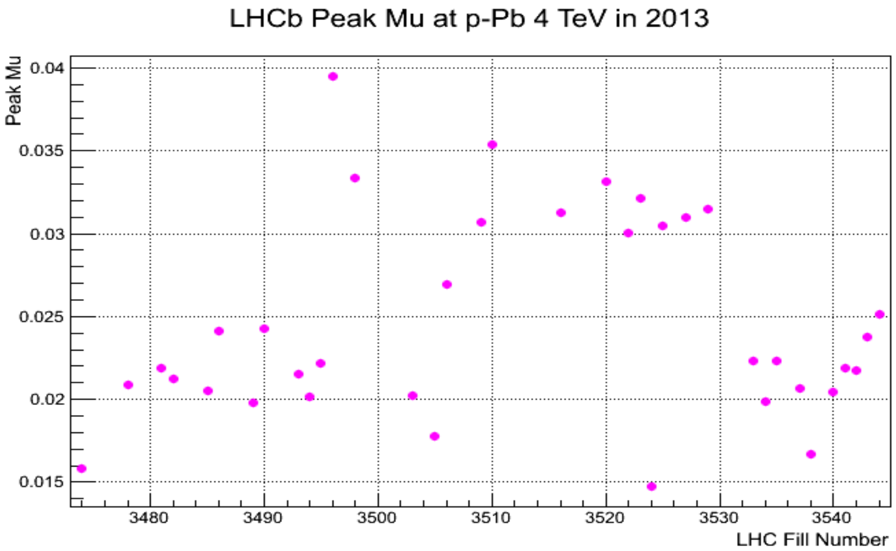
  $p_T(\mu) > 0.6\ \mathrm{GeV}/c$ ($1.3\ \mathrm{GeV}/c$ in 2011/12)

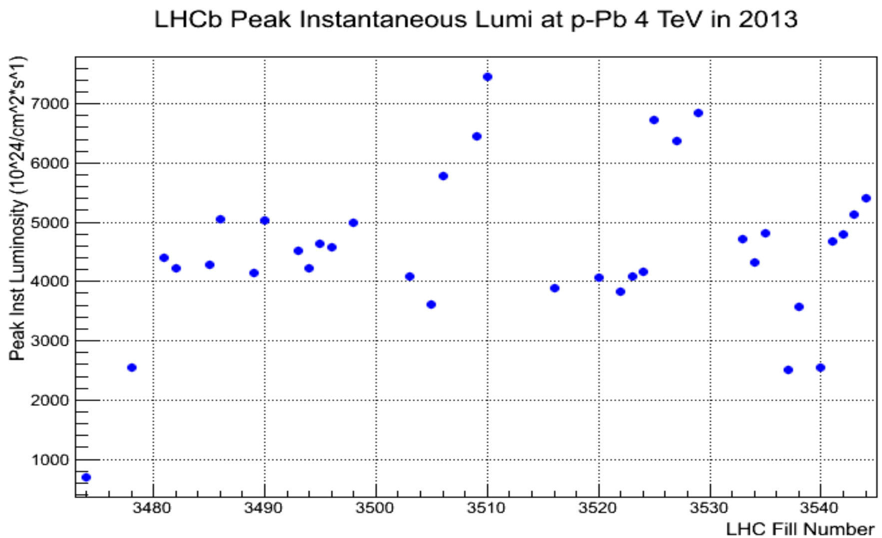
  $p(\mu) > 1.0\ \mathrm{GeV}/c$ ($6.0\ \mathrm{GeV}/c$ in 2011/12)

➔ High trigger efficiency expected

Instantaneous luminosity

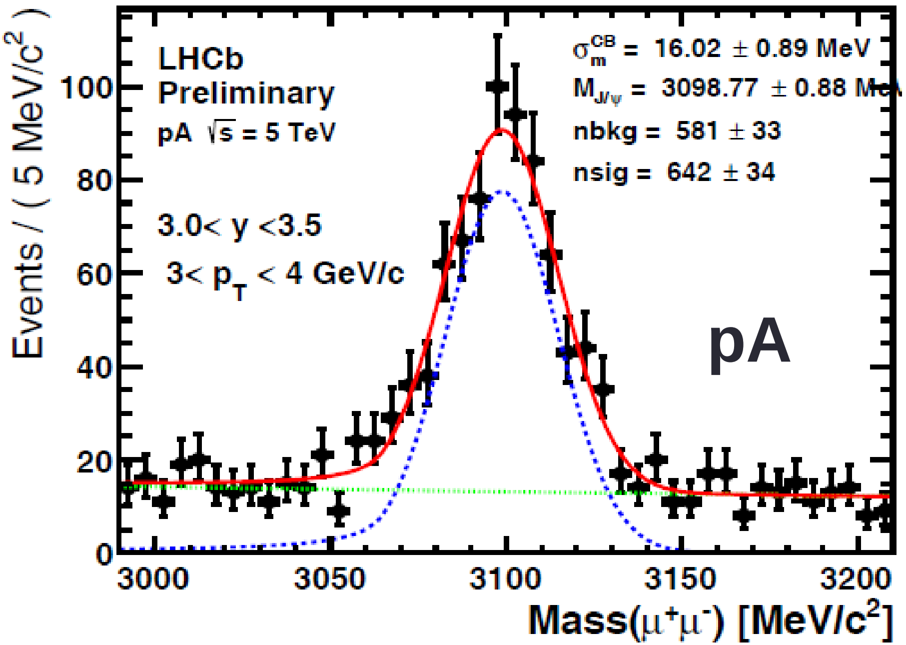






J/ψ mass spectrum

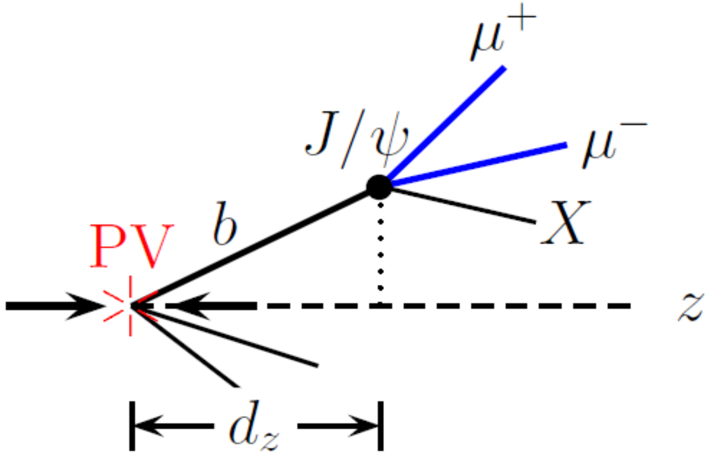
$$f_{CB}(x; M, \sigma, \alpha, n) = \begin{cases} \dfrac{\left(\frac{n}{|\alpha|}\right)^n e^{-\frac{1}{2}\alpha^2}}{\left(\frac{n}{|\alpha|} - |\alpha| - \frac{x-M}{\sigma}\right)^n} & \dfrac{x-M}{\sigma} < -|\alpha| \\ exp\left(-\dfrac{1}{2}\left(\dfrac{x-M}{\sigma}\right)^2\right) & \dfrac{x-M}{\sigma} > -|\alpha|. \end{cases}$$

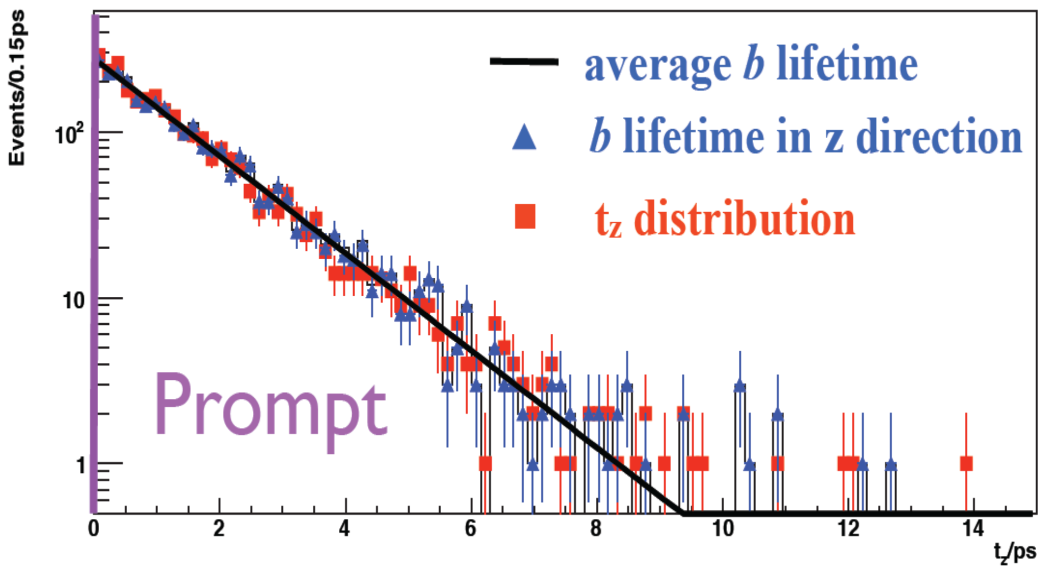


sig : Crystal Ball bkg : exponential

pseudo-proper time t_z

$$t_z = \frac{d_z \times M_{J/\psi}}{p_z^{J/\psi}}$$





generator level distribution of t_z

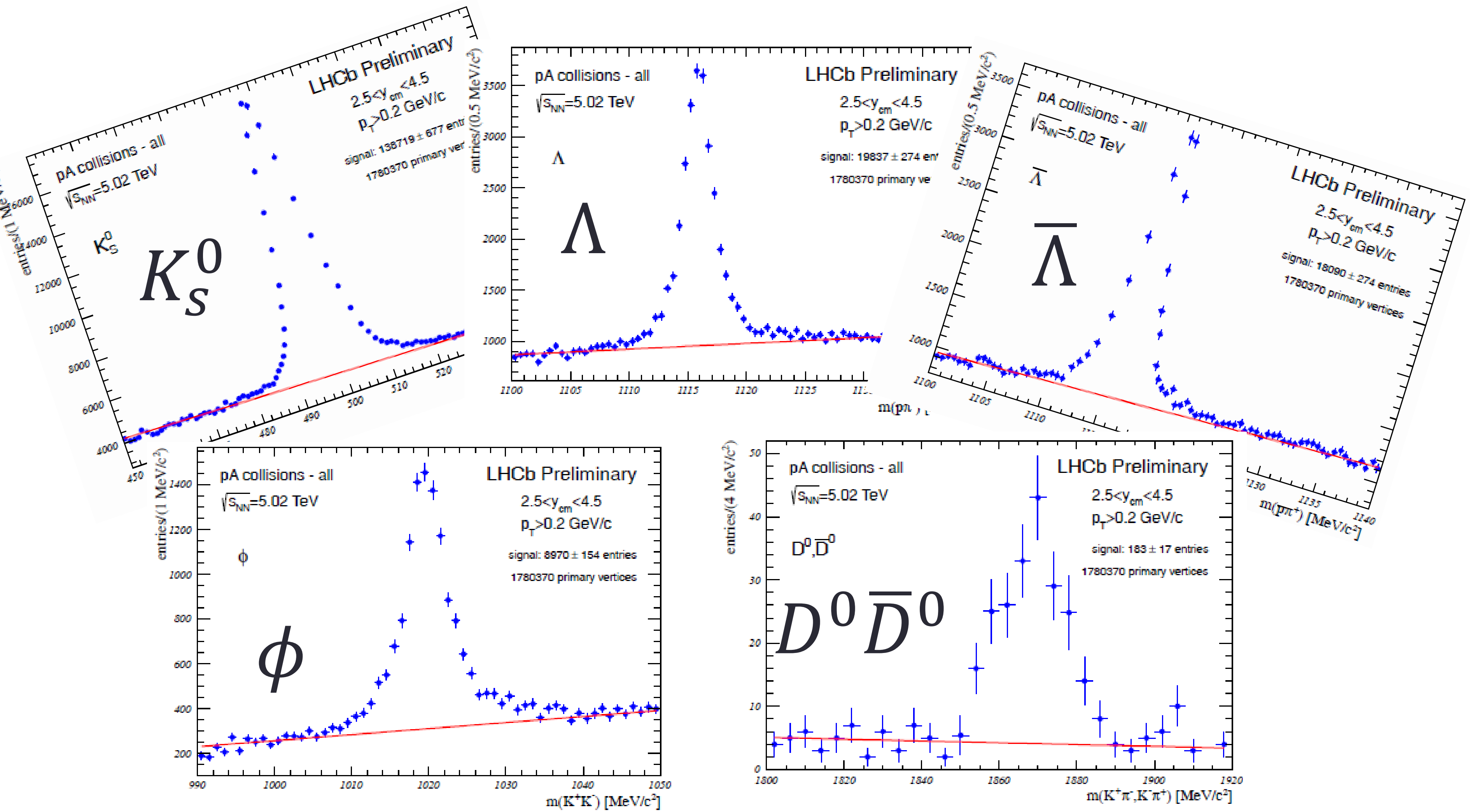
(for J/ψ from b)

- good approximation of average b lifetime
- well described by exponential distribution

Summary of systematic uncertainties

Source	Systematic uncertainty (%)
Correlated between bins	
Mass fits	1.8
Tracking efficiency	1.5
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1.0
Luminosity	5.0
t_z fit (*only for* J/ψ *from* b)	5.0
Vertexing, track quality, etc.	3.5
Uncorrelated between bins	
Binning	0.1 to 14

Prospects



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