Latest LHCb Results from the pA/Ap data

Liang Zhong

Tsinghua University

On behalf of the LHCb collaboration

Strangeness in Quark Matter,
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Outline

- Physics Motivation
- LHCb detector
- Measurement of J/ψ cross section
- Preliminary result from pilot pA run
- Prospect for pA physics
- Summary

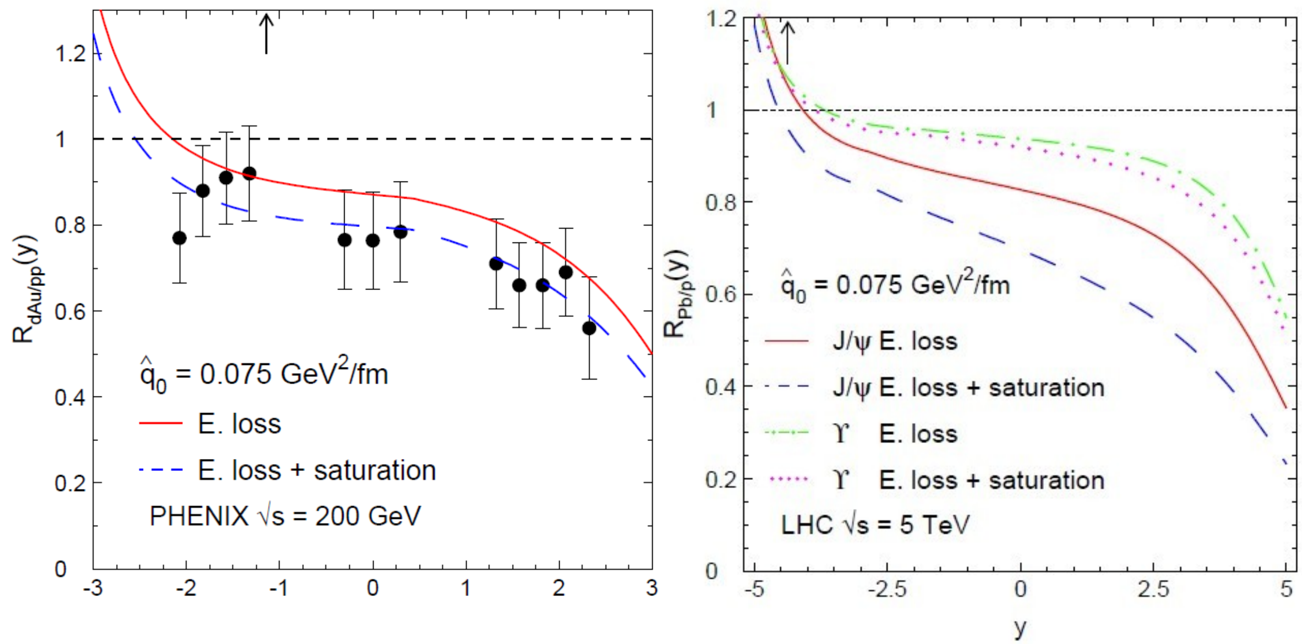
Why pA collision at LHCb?

- pA collision is of considerable interest
  - Decouples the quark gluon plasma effect from cold nuclear matter effect →crucial for the understanding of Heavy Ion Physics
  - Study soft QCD, low-x physics, energy-loss vs. saturation effects
  - Study multi-parton interactions using charged-particle production
- LHCb can play an important role
  - Unique pseudorapidity coverage, not accessible by other LHC experiments

Quarkonium production in pA

- Production of heavy quarkonia at large rapidity suppressed in pA w.r.t pp collisions
- The nuclear modification factor R_{pA} strongly depends on rapidity:

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

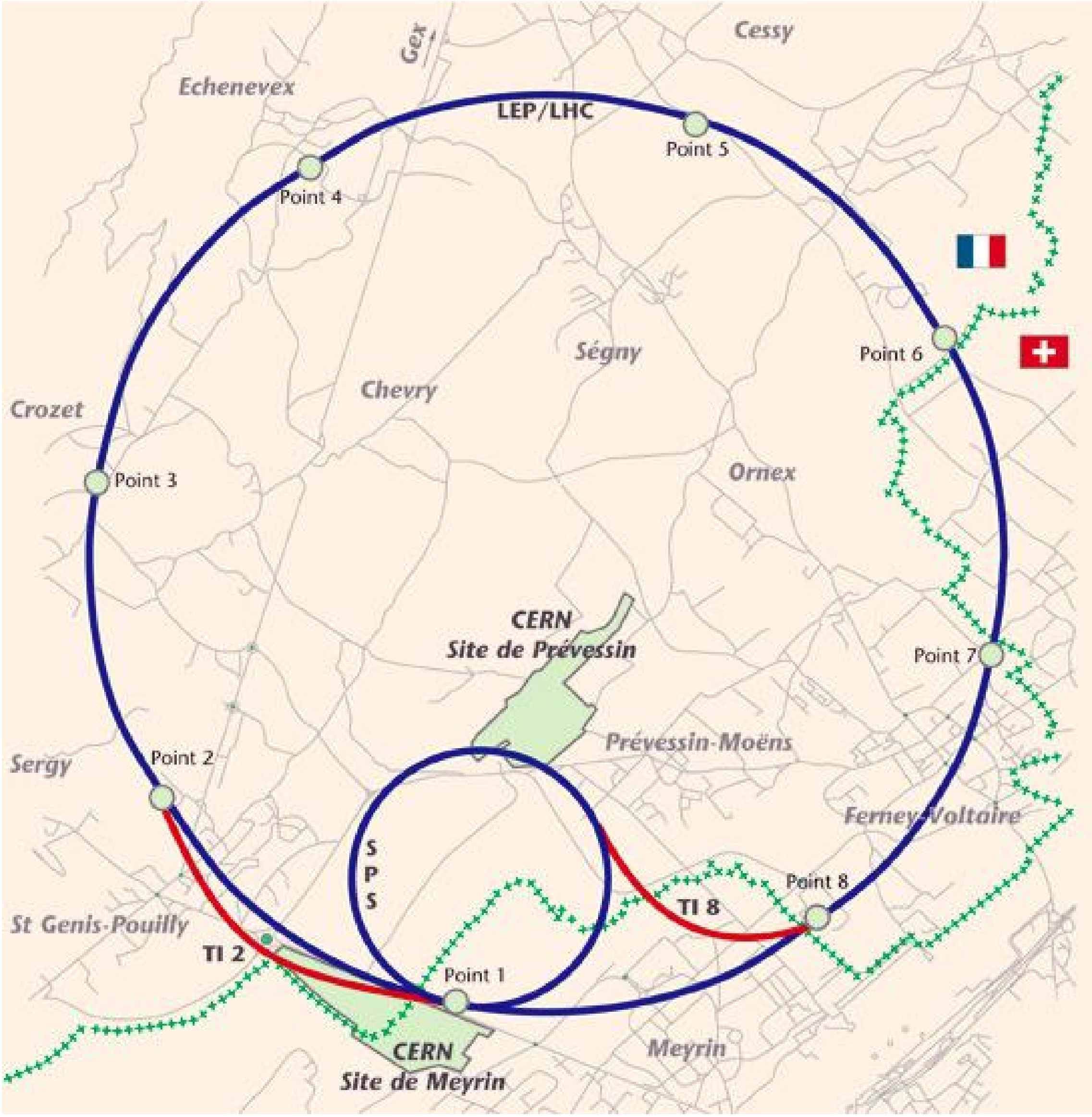


JHEP 1303(2013) 122 [arXiv: 1212.0434]

- Measurement of R_{pA} test models of cold nuclear matter effects.

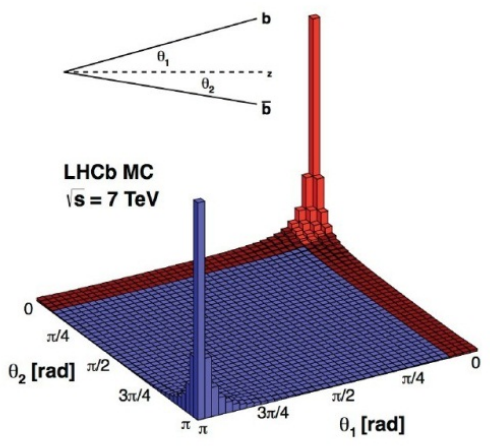
- The forward-backward production ratio can be measured.

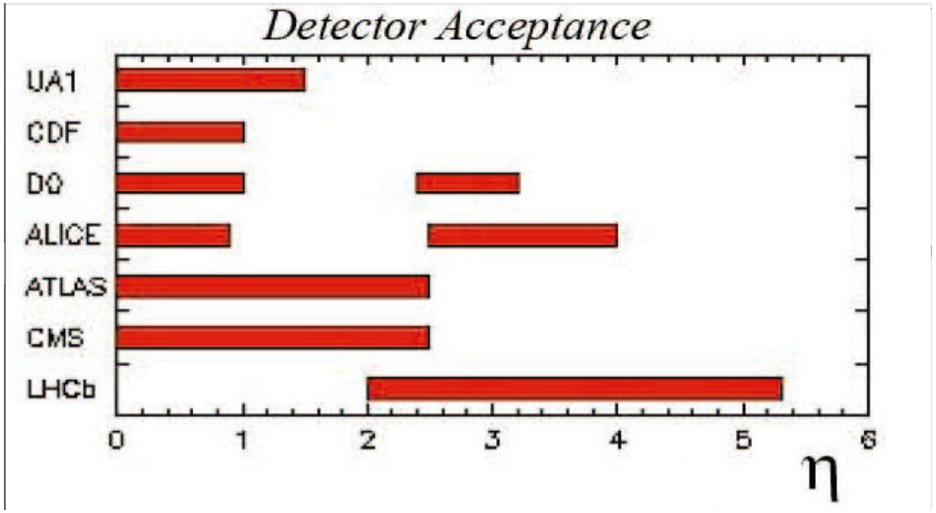
The LHCb detector



The LHCb detector

- Dedicated to heavy flavour physics, but also performs very well for proton-lead collisions
- Forward acceptance (2 < η < 5)
  - Takes advantage of the predominant forward production of heavy flavoured hadrons
  - Unique among LHC detectors, complementary to the General Purpose Detectors.





The LHCb detector

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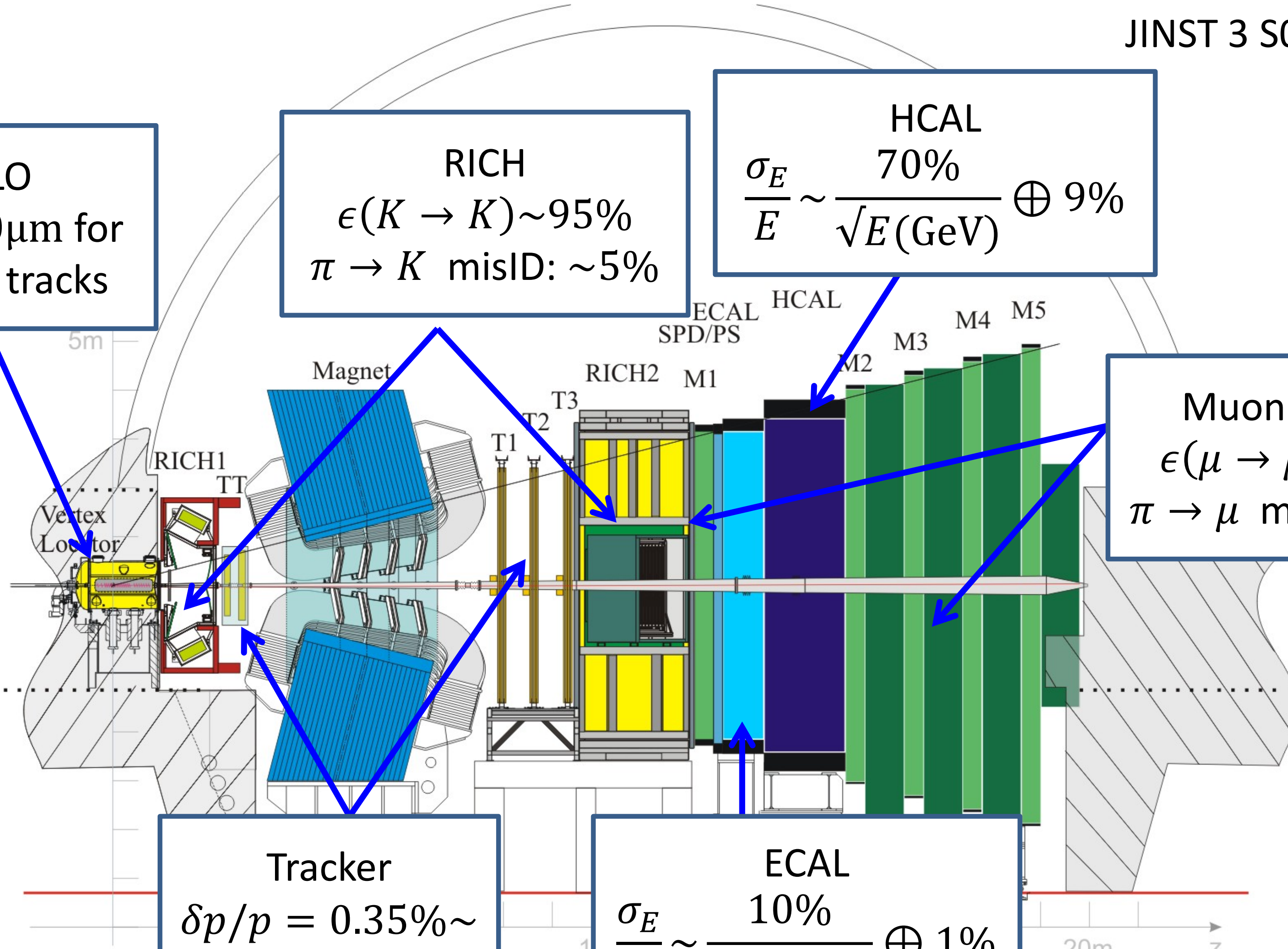


VELO
$\sigma_{IP} \sim 20\mu m$ for high p_T tracks

RICH
$\epsilon(K \to K)\sim95\%$
$\pi \to K$ misID: $\sim5\%$

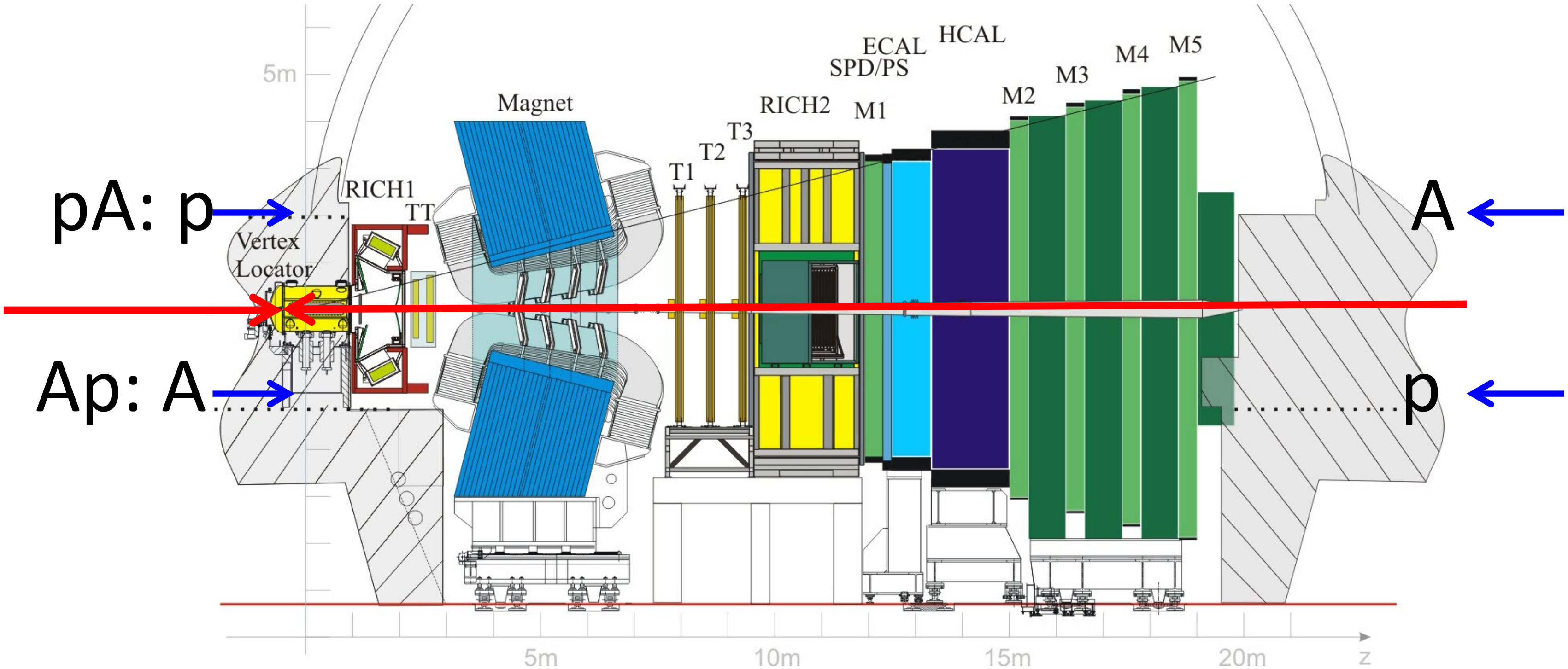
HCAL
$$\frac{\sigma_E}{E} \sim \frac{70\%}{\sqrt{E(\text{GeV})}} \oplus 9\%$$

Muon System
$\epsilon(\mu \to \mu)\sim97\%$
$\pi \to \mu$ misID: $\sim3\%$

Tracker
$\delta p/p = 0.35\%\sim 0.55\%$

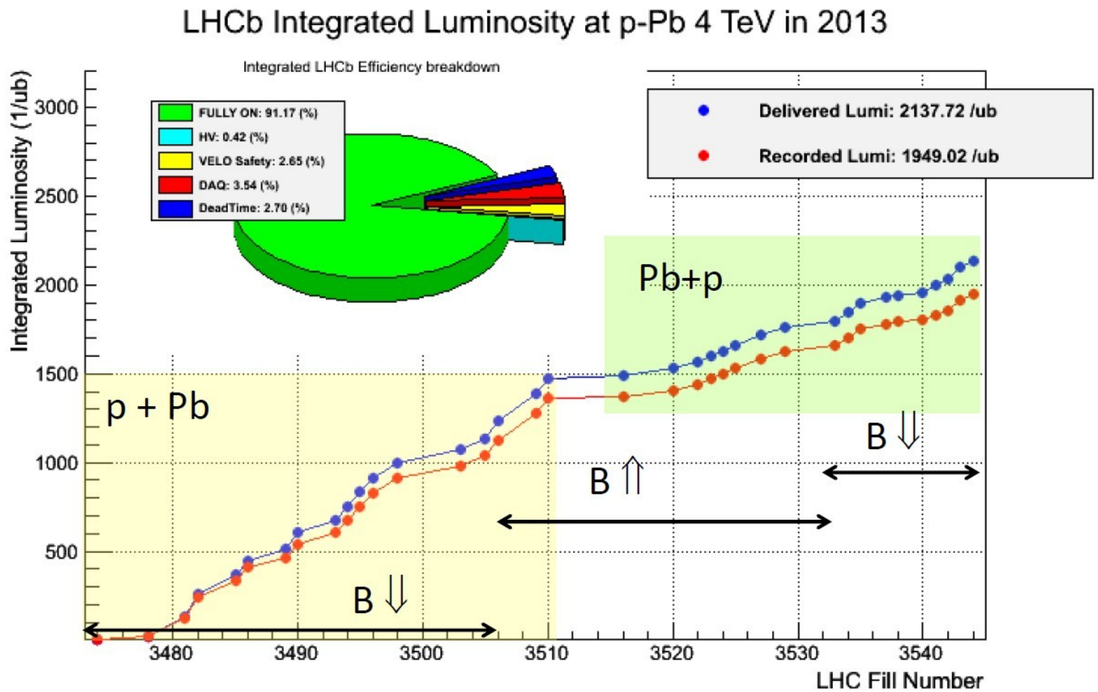
ECAL
$$\frac{\sigma_E}{E} \sim \frac{10\%}{\sqrt{E(\text{GeV})}} \oplus 1\%$$

Beam configurations



- p: $E = 4$ TeV, Pb: E per nucleon $= 1.58$ TeV => $\sqrt{s_{NN}} = 5$ TeV
- Pseudorapidity coverage: pA: $1.5 < \eta < 4.5$ forward production
  (defined in c.m.s) Ap: $-5.5 < \eta < -2.5$ backward production
  (pp: $2 < \eta < 5$)

LHCb pA Data Taking

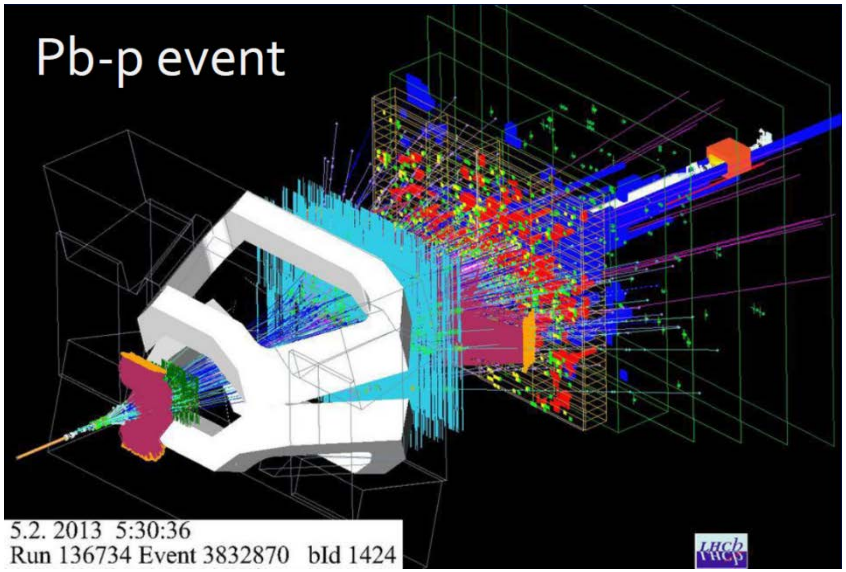


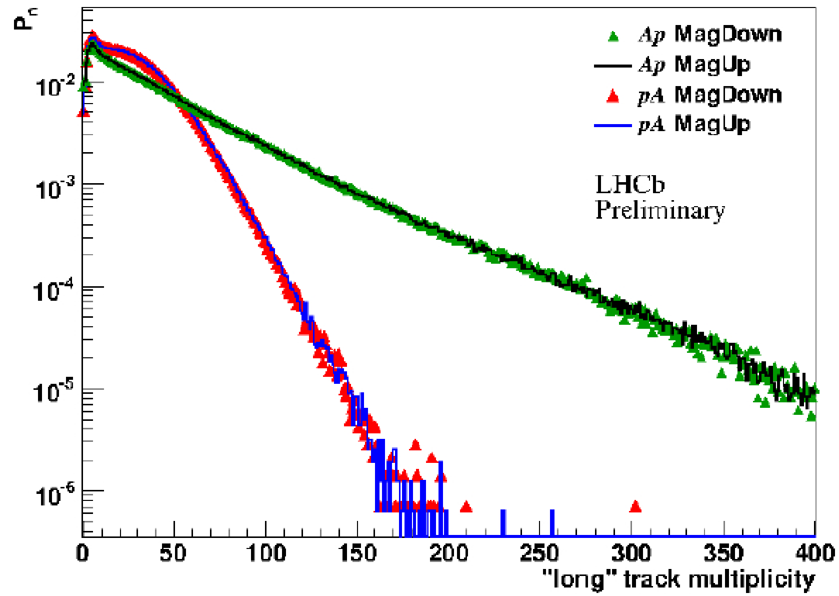
- Low inst. lumi: $\sim 5 \times 10^{27}/\mathrm{cm}^2/\mathrm{s}$ (very low pile-up)
- Integrated lumi. $\sim 1/\mu\mathrm{b}$ in 2012 pilot run, $\sim 2/\mathrm{nb}$ in 2013
- Take data with four different configurations:

  pA / Ap ; magnet up (B ⇑) / down (B⇓)

  The J/ψ results shown here based on 0.75/nb pA and 0.3/nb Ap, B ⇓ of 2013 data

Event properties





- Magnet Up/Down agree with both beam configurations
- Higher track multiplicity in Ap, as expected

J/ψ analysis

[LHCb-CONF-2013-008]

J/ψ production

- Three sources of J/ψ
  - Direct production
  - Feed down from higher states, e.g $\psi(2S), \chi_c$
  - From b hadrons decays

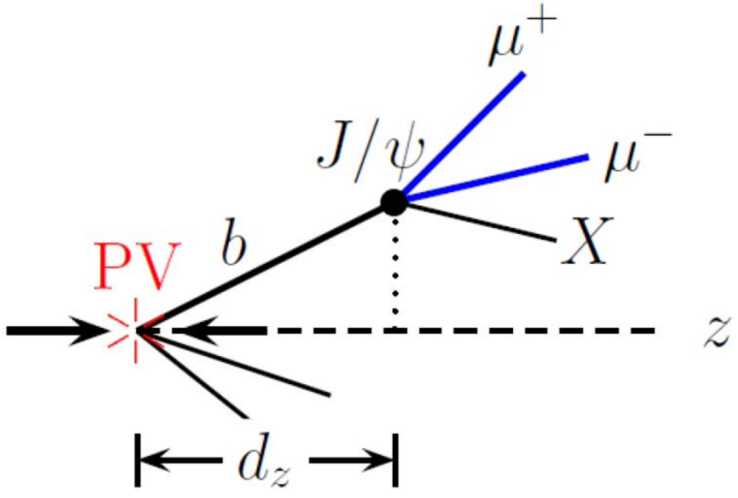
(Direct production and feed down: Prompt J/ψ; from b hadrons decays: J/ψ from b)

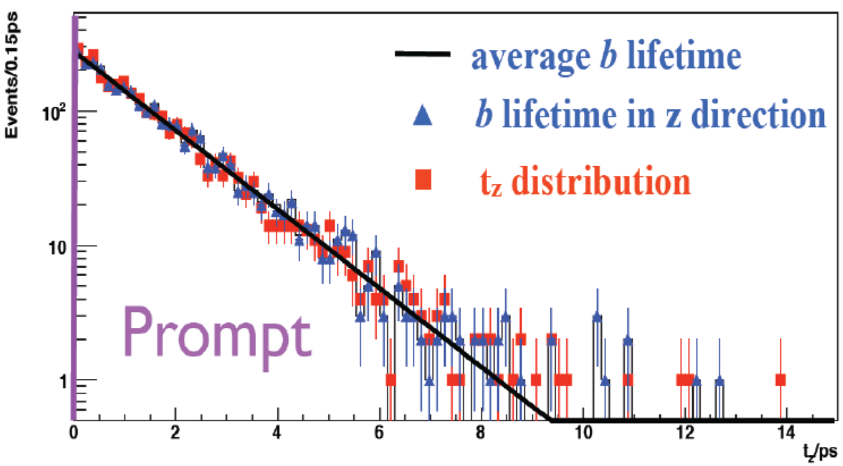
- Analysis strategy
  - Same method as for J/ψ cross section measurement in pp collisions
  - Measure production cross section in bins of y or p_{T} both for prompt J/ψ and J/ψ from b
  - Use pseudo-proper time to separate prompt J/ψ and J/ψ from b (see next slide)

- Pseudo-proper time

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

  – Take advantage of the large lifetime of b hadrons and excellent resolution of LHCb VELO
  – Clear separation between prompt J/ψ and J/ψ from b

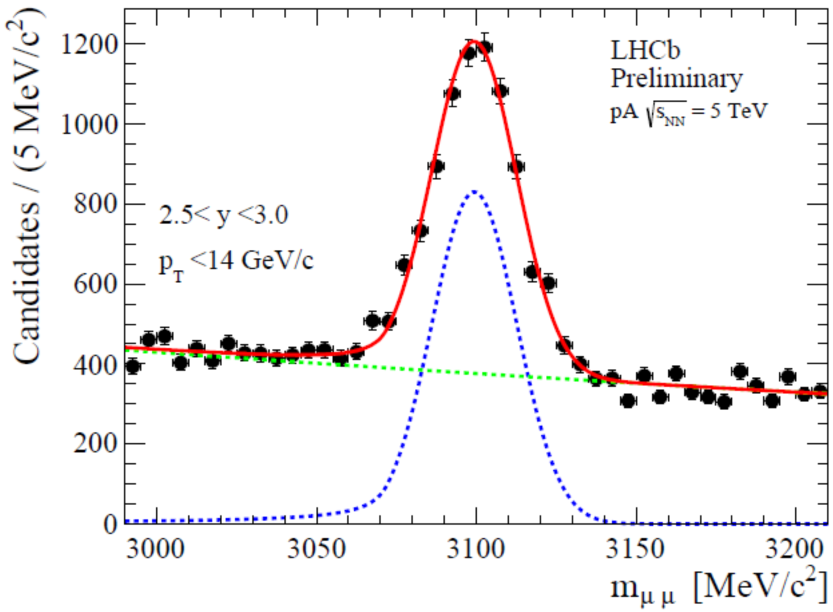


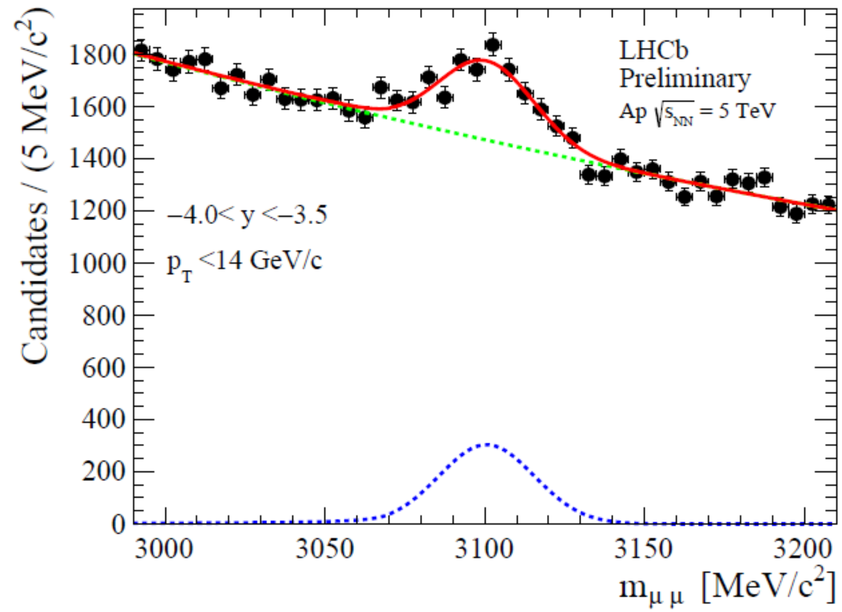


generator level distribution of t_z

Signal Extraction

- Yields in each bin are obtained from simultaneous fit to the dimuon invariant mass and the pseudo-proper time t_z



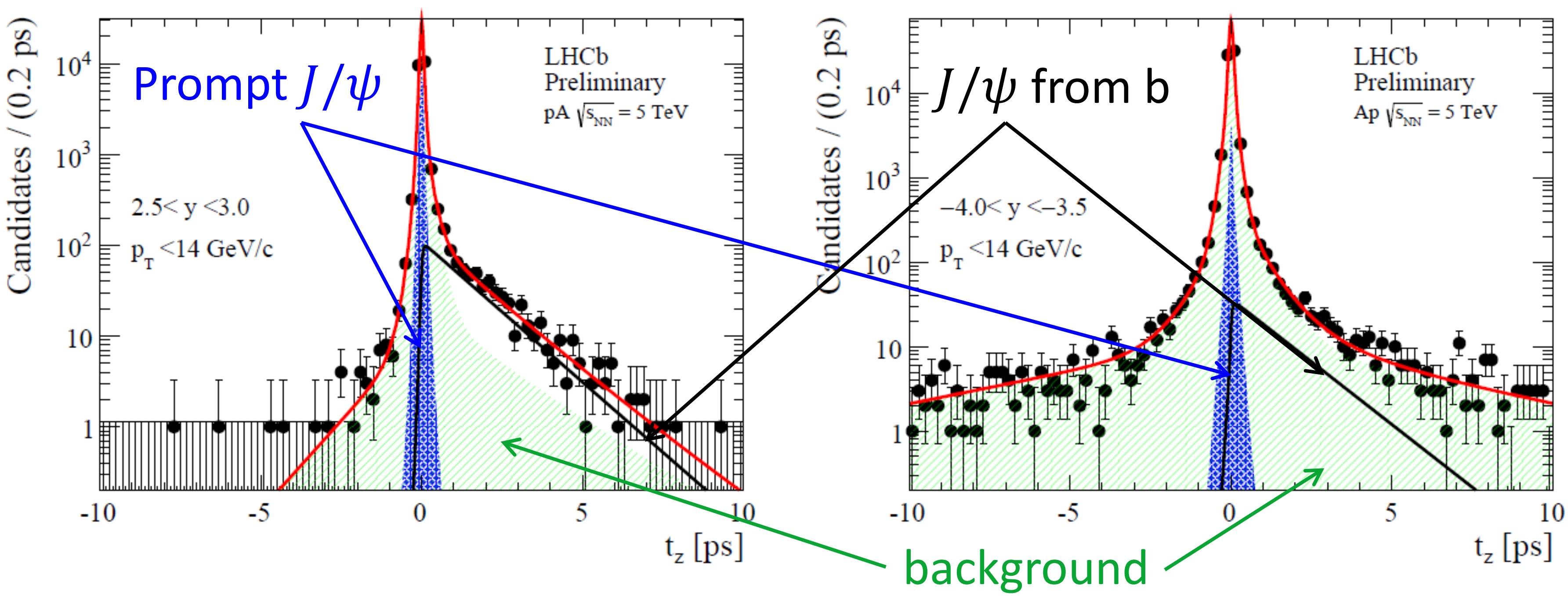


Mass distribution:

- Signal: CB function
- Background : Exponential function

Signal Extraction

- Yields in each bin are obtained from simultaneous fit to the dimuon invariant mass and the pseudo-proper time t_z



t_z distributions:

- Signal : Prompt J/ψ: $\delta(t_z)$ function convolves with gaussian

  J/ψ from b: Exponential function convolves with gaussian
- Background: empirical function from sideband

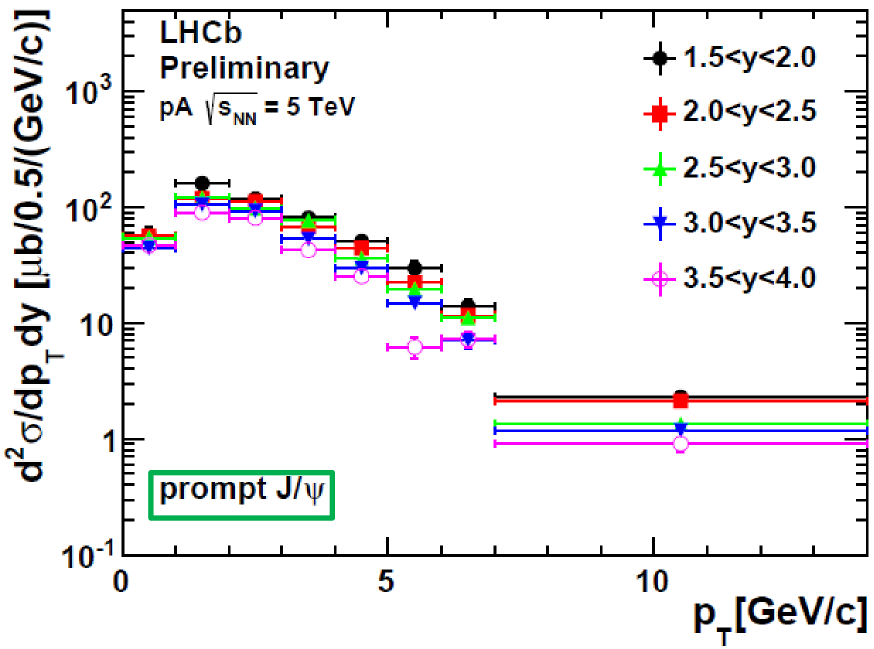
Preliminary study of total J/ψ production

- Total production of prompt J/ψ and J/ψ from b in LHCb
  - pA: $p_T < 14\mathrm{GeV}/c$, $1.5 < y < 4.0$
    - $\sigma_{pA}(\mathrm{prompt}\,J/\psi) = 1028.2 \pm 13.6(\mathrm{stat.}) \pm 88.6(\mathrm{syst.})\mu\mathrm{b}$
    - $\sigma_{pA}(J/\psi\ \mathrm{from}\ b) = 150.1 \pm 4.2(\mathrm{stat.}) \pm 12.6(\mathrm{syst.})\mu\mathrm{b}$
  - Ap: $p_T < 14\mathrm{GeV}/c$, $-5.0 < y < -2.5$
    - $\sigma_{Ap}(\mathrm{prompt}\,J/\psi) = 1141.9 \pm 49.8(\mathrm{stat.}) \pm 98.4(\mathrm{syst.})\mu\mathrm{b}$
    - $\sigma_{Ap}(J/\psi\ \mathrm{from}\ b) = 119.7 \pm 8.3(\mathrm{stat.}) \pm 10.0(\mathrm{syst.})\mu\mathrm{b}$

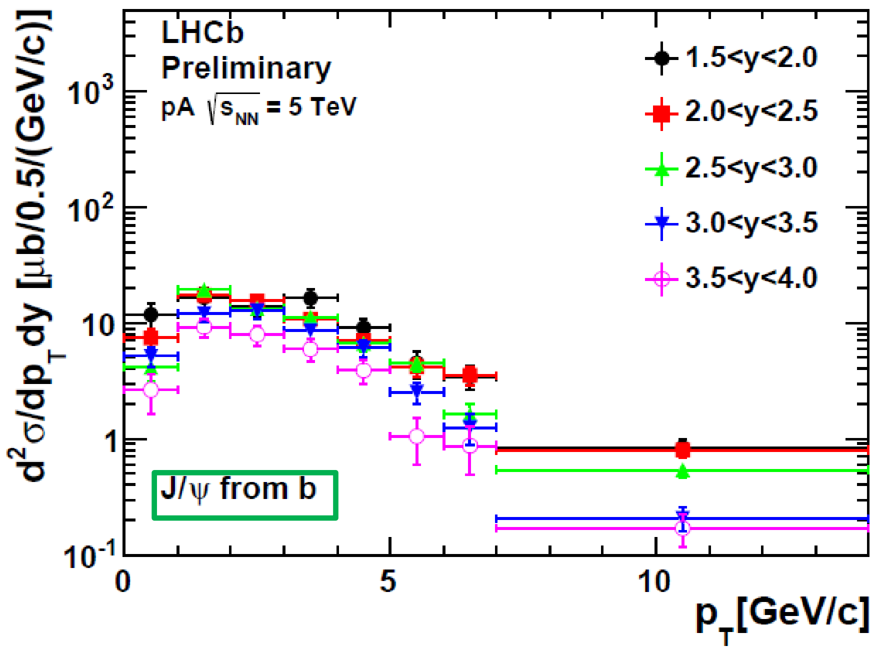
Systematic uncertainties dominated by luminosity, fit model and data-MC discrepancy

Double differential cross section in pA

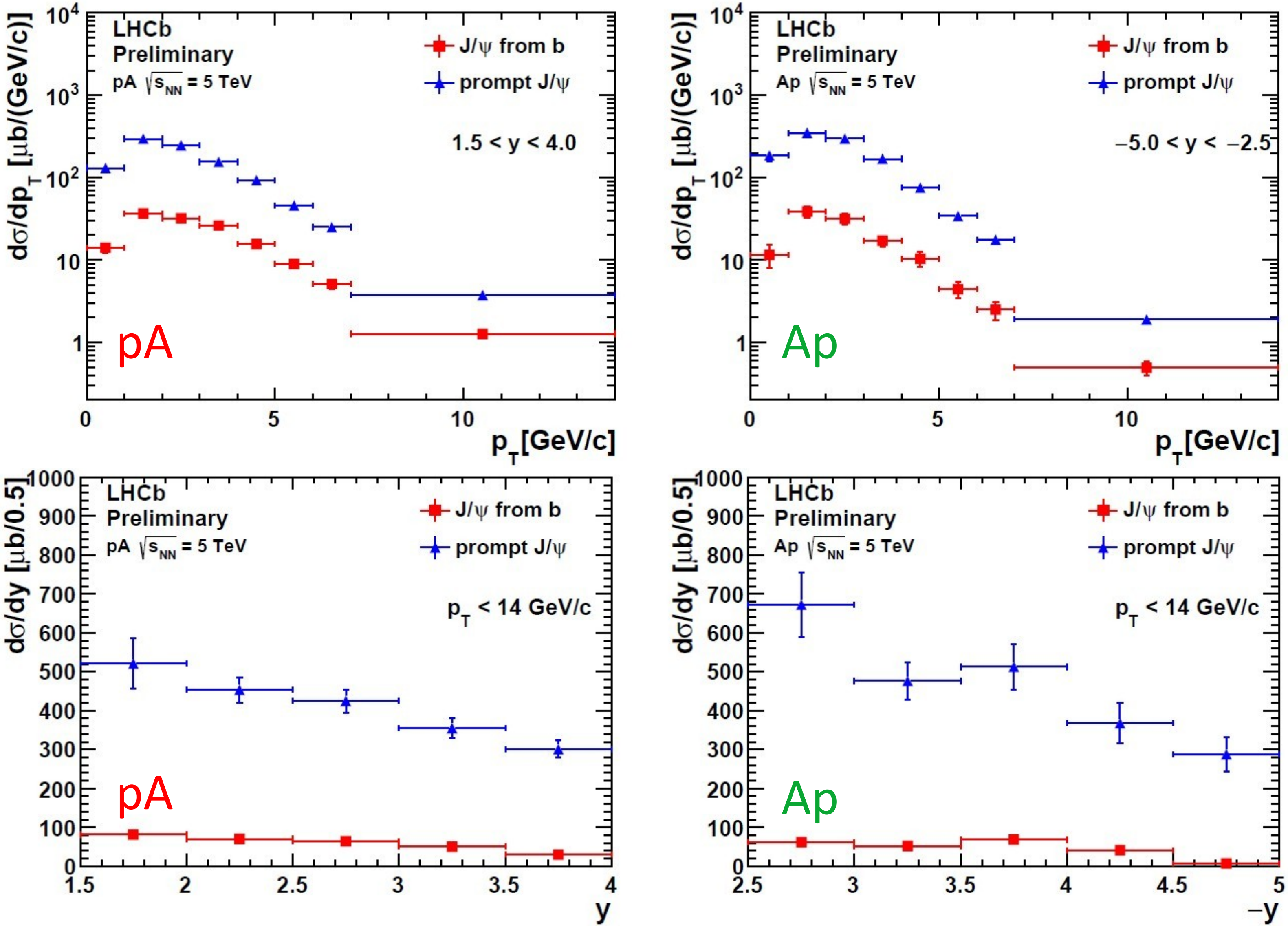
Prompt J/ψ



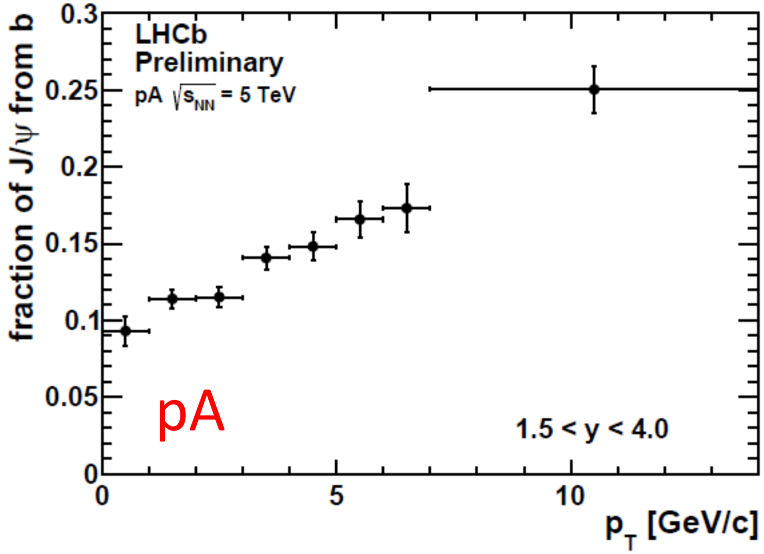
J/ψ from b

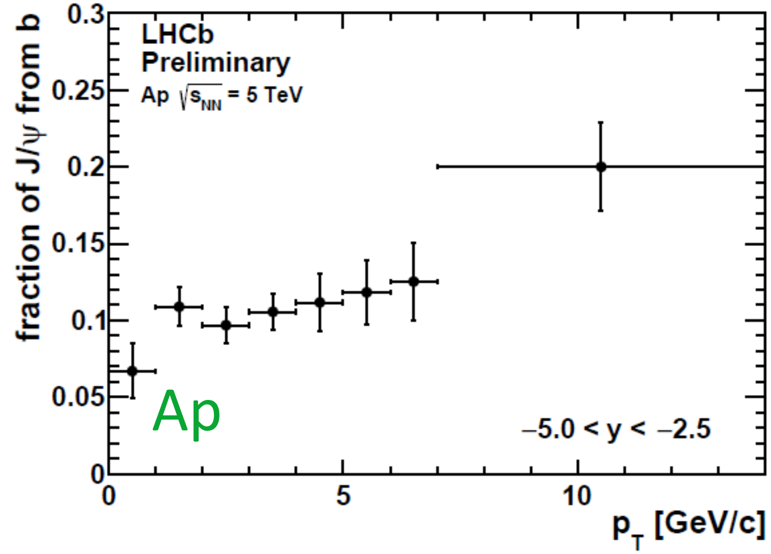


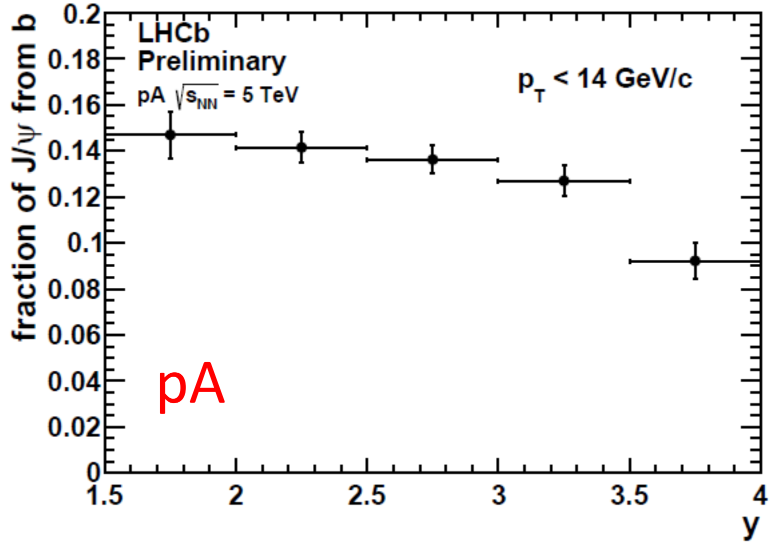
Single differential cross-sections

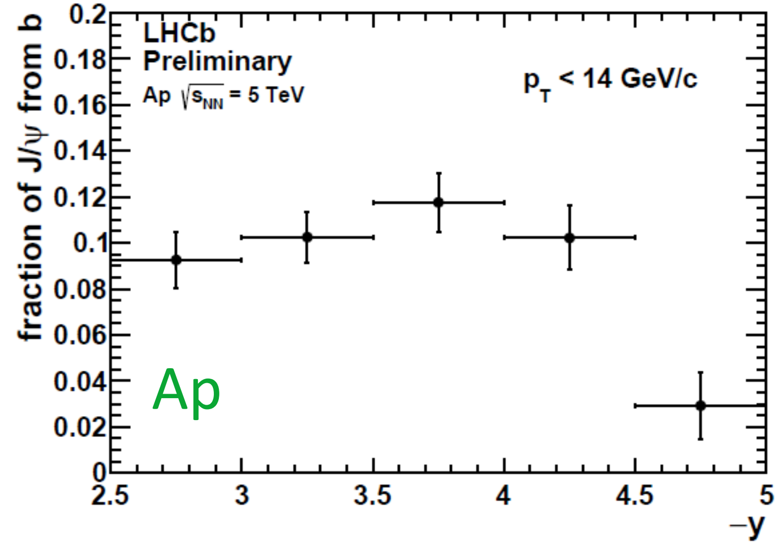


Fraction of J/ψ from b



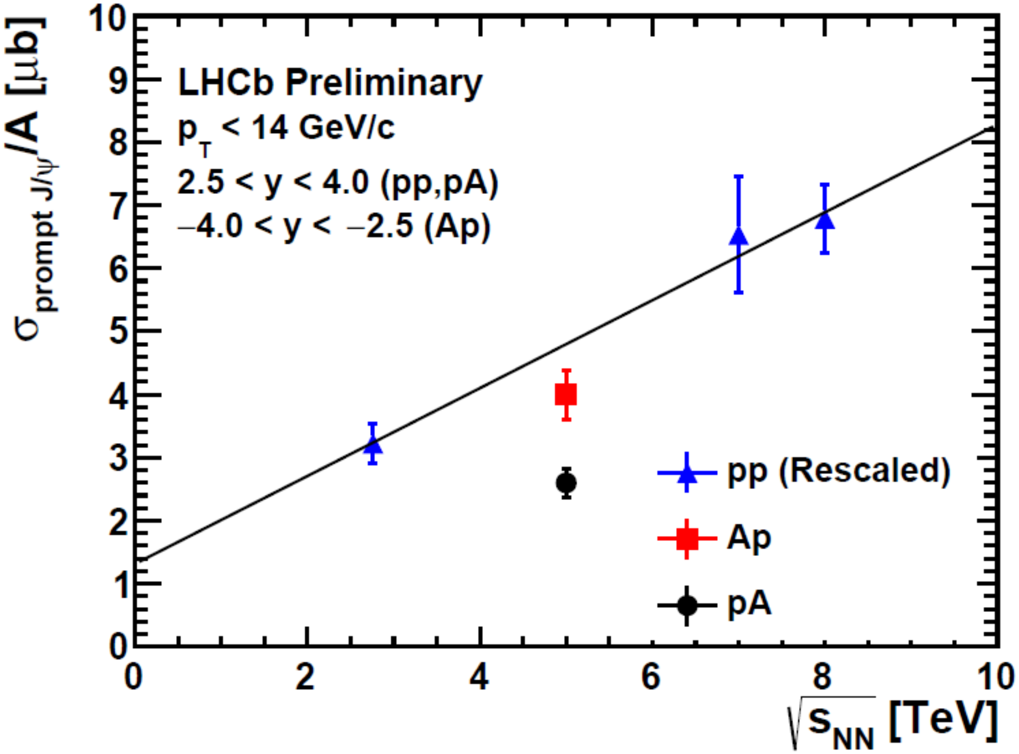






Comparison with other LHCb results

Compare prompt J/ψ only



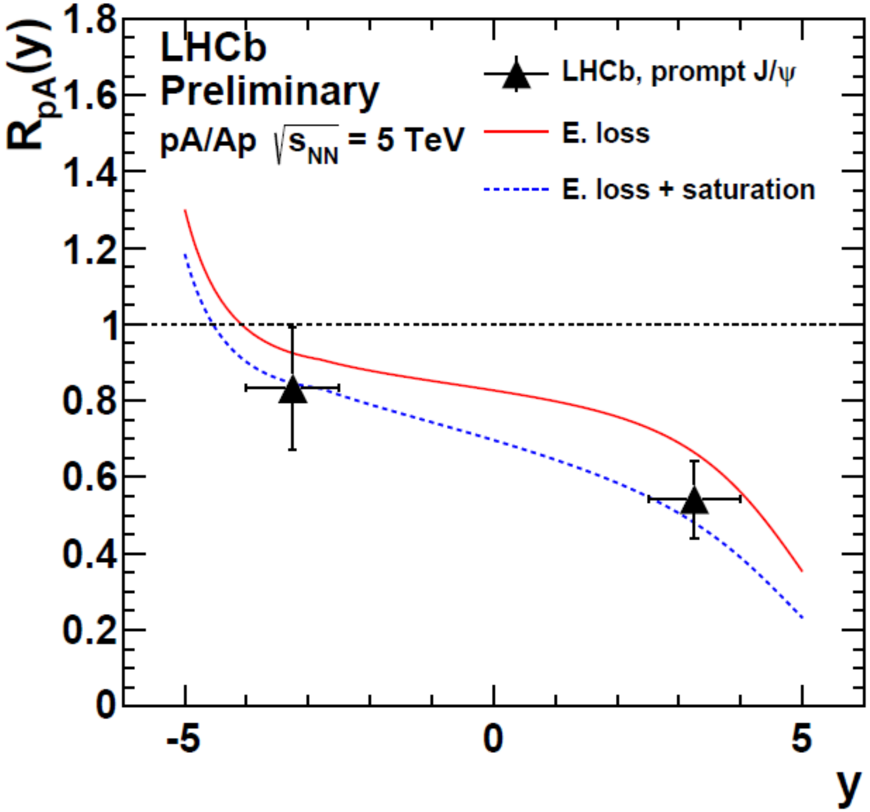
- Rescaled σ_{pp} in common rapidity range: $2.5 < y < 4.0$
- J/ψ cross section scaled by 1/A: A=208 for p-Pb/Pb-p and A=1 for p-p
- Linearly interpolate prompt J/ψ cross section at other energy to obtain $\sigma_{pp}(5\text{TeV})$

Clear suppression in pA, while slight suppression in Ap

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

Comparison with theoretical predictions

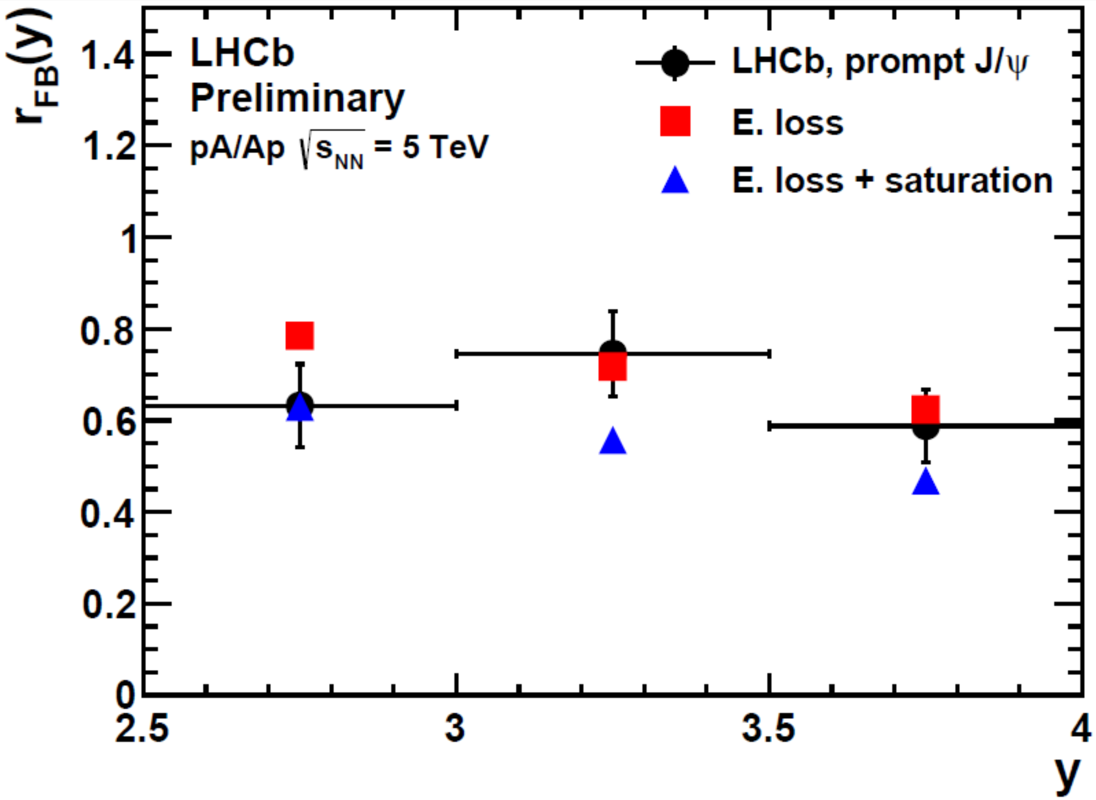
- Nuclear modification factor $R_{pA}(y)$
  - Agree with theoretical predictions
  - With current precision unable to distinguish nuclear effects with or without saturation



JHEP 1303(2013) 122
[arXiv: 1212.0434]

Comparison with theoretical predictions

- Forward-backward production asymmetry $r_{FB}(y)$
  - $r_{FB}(y) = R_{pA}(+|y|)/R_{Ap}(-|y|)$
  - Clear asymmetry between forward-backward production
  - Agree with theoretical predictions



JHEP 1303(2013) 122
[arXiv: 1212.0434]

Pilot run data analysis

[LHCb-CONF-2012-034]

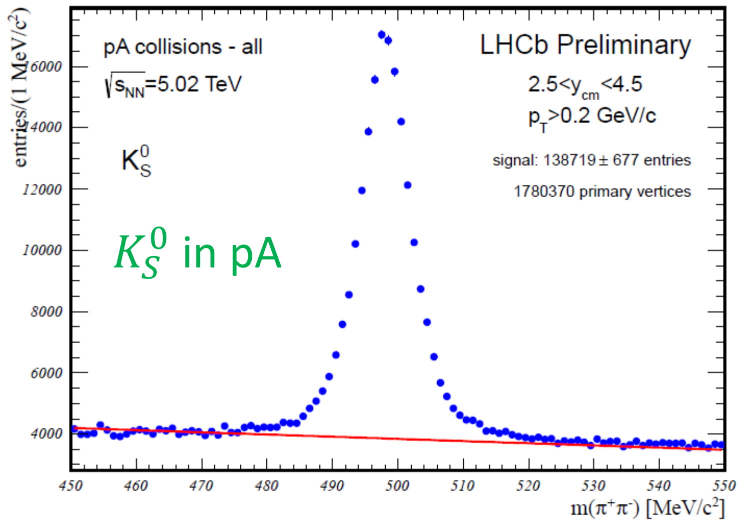
Inelastic pA cross section measurement

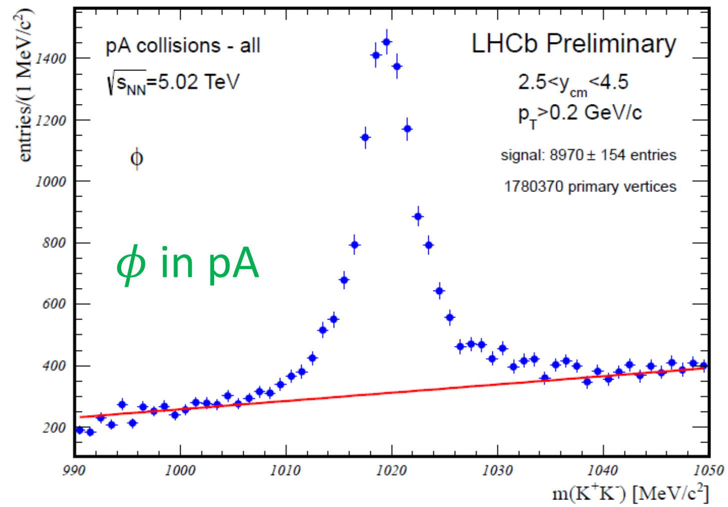
- Inelastic pA cross section $\sigma_{pA} = \frac{N_{pA}}{L \cdot \epsilon}$
  - Event tag: at least one reconstructed track in the detector
    - At least one charged track in $2.5 < y < 4.5$ with $p_T > 0.2\mathrm{GeV}/c$
  - Trigger efficiency $\sim(99 \pm 1)\%$
  - Event count efficiency: $\epsilon_{ev} = (98 \pm 2)\%$
- Measured cross section: $\sigma_{pA} = 2.09 \pm 0.12$ b
  - Agree with expected result: $\sigma_{pp} \times A^{2/3} \sim 2.1$ b

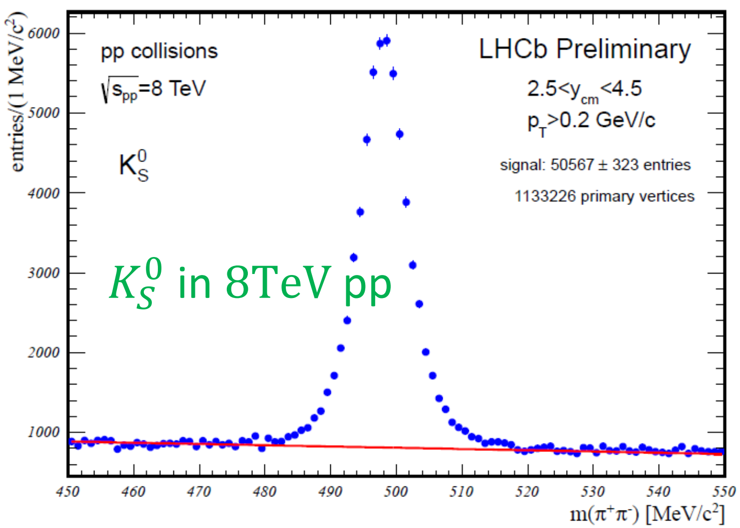
Strange and charm hadron production

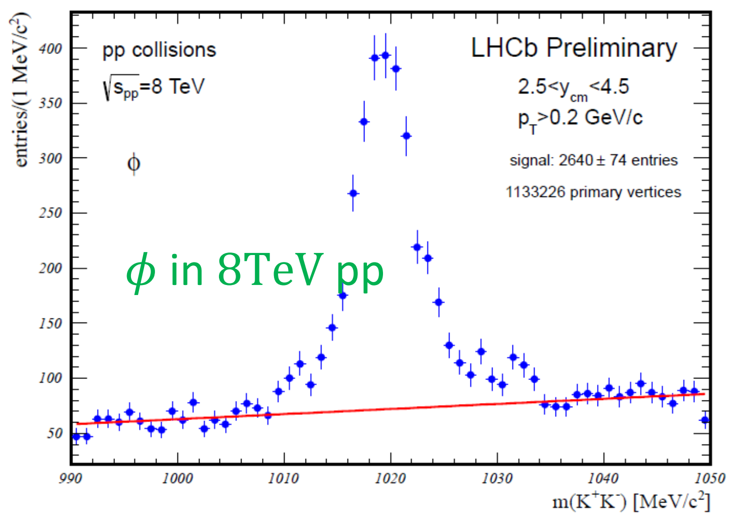
- Compare strange and charm hadron production in pA and pp collisions in the fiducial region $2.5 < y < 4.5$ and $p_T > 0.2\mathrm{GeV}/c$
- Define production ratio R to illustrate the enhancement in particle production when going from pp to pA
  - $R = \frac{N_{pA}/n_{PV,pA}}{N_{pp}/n_{PV,pp}}$
  - Very preliminary result: Uncorrected, should receive a positive correction of 7%-16%
  - Results with the statistical error only

Strangeness production





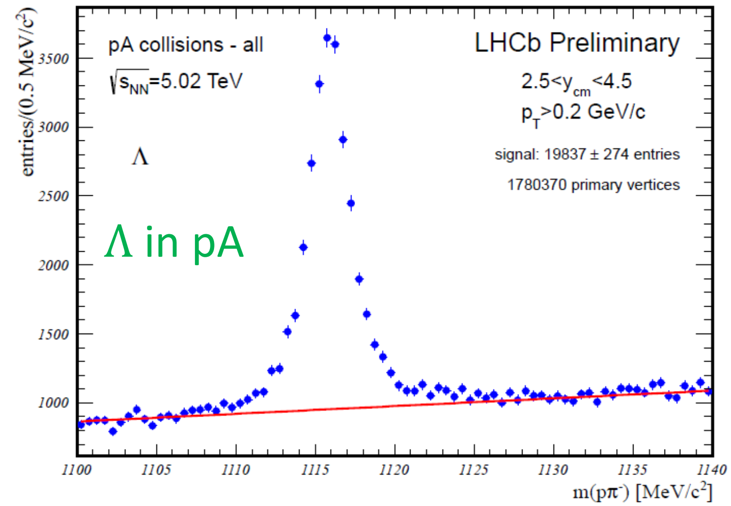


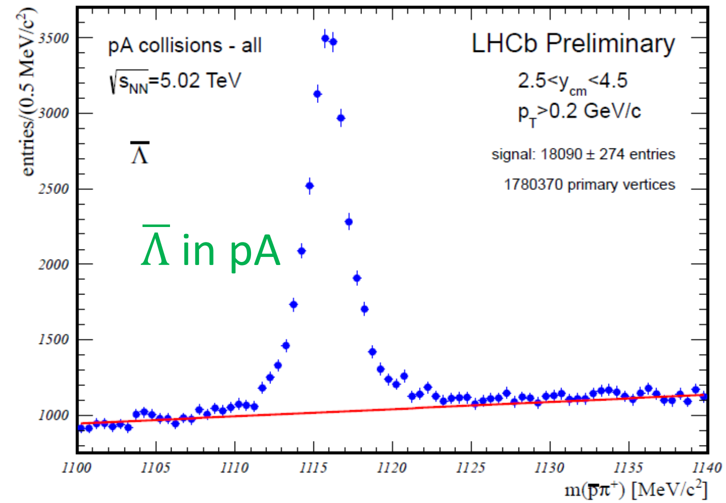


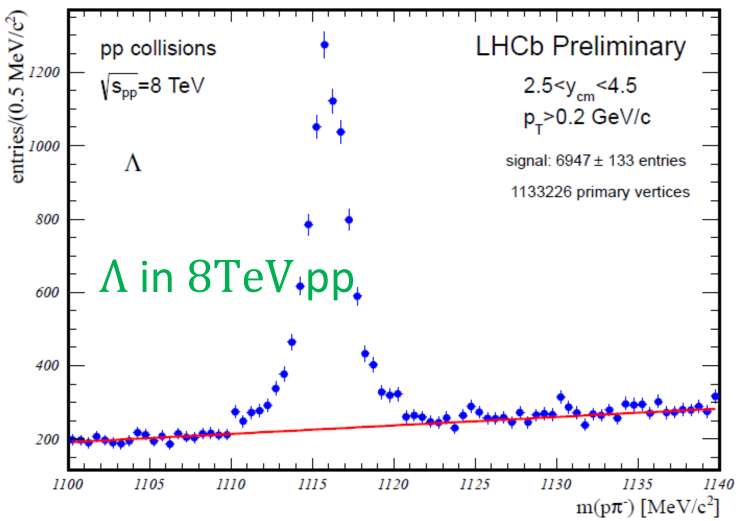
$R(K_S^0) = 1.746 \pm 0.014$

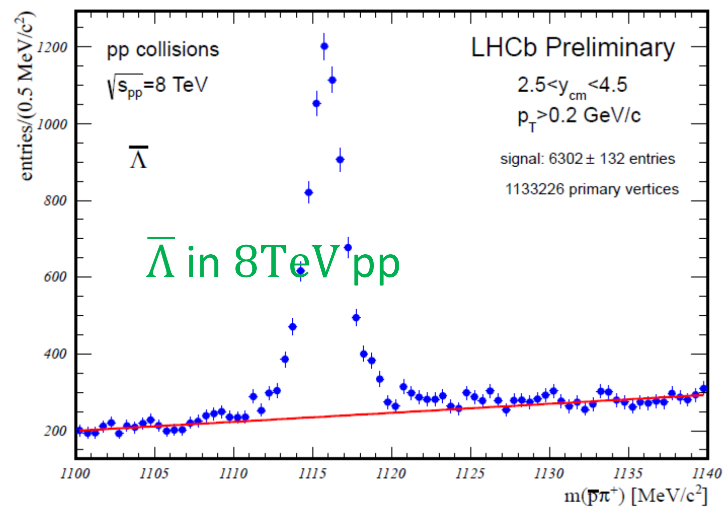
$R(\phi) = 2.163 \pm 0.071$

Strangeness production





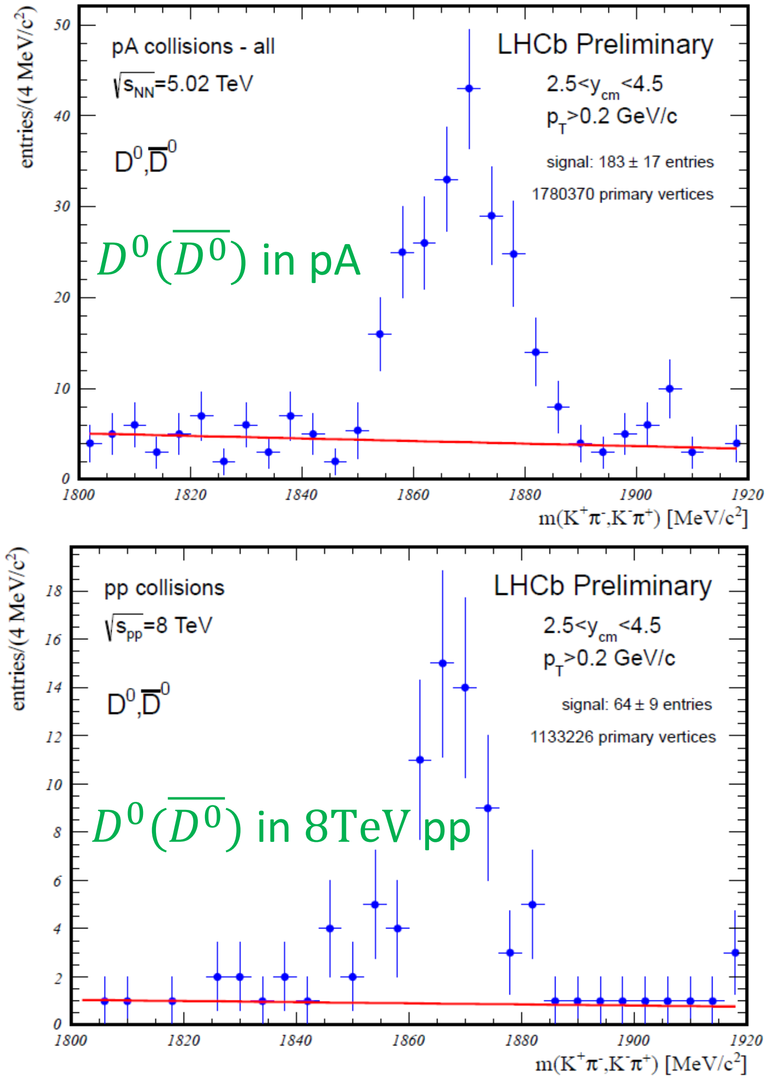




$R(\Lambda) = 1.818 \pm 0.043$

$R(\bar{\Lambda}) = 1.827 \pm 0.047$

Charm hadron production ratio



$$R(D) = 1.832 \pm 0.307$$

Prospects for pA physics at LHCb

- Further analysis planned with the pA data sample
  - Charged particle production
  - Central exclusive production
  - Jet production
  - $\psi(2S)$ and $\Upsilon(nS)$ production
  - Open charm production
  - Drell-Yan processes
  - Particle correlations
  - Low-x physics
  - …

Summary

- ~2/nb of pA/Ap collisions recorded at LHCb
  - Unique opportunities on specific physics measurements
  - Important for the understanding of heavy-ion physics and for probing some particular QCD physics phenomena
- A number of interesting measurements have been performed so far:
  - J/ψ production cross-sections as function of p_T and y
  - Nuclear modification factor R_{pA} and forward-backward production asymmetry r_{FB} as a function of y

  →Clear J/ψ suppression observed, in good agreement with theory
- The pilot run also provides many interesting results.
- More results with larger sample are expected soon!

- Backup

Summary of Systematic Errors

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