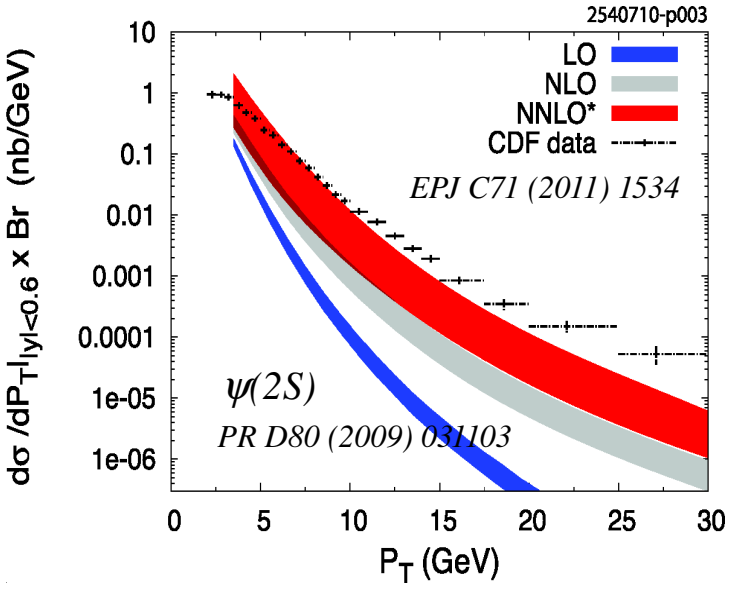
Quarkonia production at LHCb

Alexander Artamonov
IHEP, Protvino, Russia

On behalf of LHCb Collaboration

"16th Lomonosov conference"
MSU, Moscow, Russia, 22-28 August 2013

Physics motivation



- *The study of properties of bound states of heavy quarks plays an important role in our understanding of QCD.*
- *J/ψ and $\psi(2S)$ surplus problem (found by CDF about 20 years ago). Color-singlet model failed to explain the data. Birth of colour-octet model. Renaissance of CSM. So CSM vs (or +) COM.*

- *Ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ is sensitive to CSM vs COM models. Prompt χ_c give substantial feed-down to J/ψ production: crucial for polarization studies of J/ψ.*
- *So far no model can simultaneously explain experimental measurements of quarkonia production and polarization (e.g. dependence on p_T).*

LHCb measurements of heavy quarkonia

- *J/ψ cross-sections at 7 TeV*
  EPJ C71 (2011) 1645, arXiv: 1103.0423
- *J/ψ cross-sections at 2.76 TeV*
  JHEP 02 (2013) 041, arXiv:1212.1045
- *χ_c production at 7 TeV (unconverted γ)*
  PL B714 (2012) 215, arXiv:1202.1080
  PL B718 (2012) 431, arXiv:1204.1463
- *$\psi(2S)$ cross-sections at 7 TeV*
  EPJ C72 (2012) 2100, arXiv:1204.1258
- *$\Upsilon(nS)$ cross-sections at 7 TeV*
  EPJ C72 (2012) 2025, arXiv:1202.6579
- *$\Upsilon(nS)$ from χ_b decay at 7 TeV*
  JHEP 11 (2012) 031, arXiv:1209.0282
- *J/ψ pair production at 7 TeV*
  PL B707 (2012) 52, arXiv:1109.0963
- *J/ψ + open charm production at 7 TeV*
  JHEP 06 (2012) 141, arXiv:1205.0975
- *J/ψ and $\Upsilon(nS)$ production at 8 TeV*
  JHEP 06 (2013) 064, arXiv:1304.6977

LHCb measurements of heavy quarkonia

- *J/ψ cross-sections at 7 TeV*
  EPJ C71 (2011) 1645, arXiv: 1103.0423
- *J/ψ cross-sections at 2.76 TeV*
  JHEP 02 (2013) 041, arXiv:1212.1045
- *χ_c production at 7 TeV (unconverted γ)*
  PL B714 (2012) 215, arXiv:1202.1080
  PL B718 (2012) 431, arXiv:1204.1463
- *$\psi(2S)$ cross-sections at 7 TeV*
  EPJ C72 (2012) 2100, arXiv:1204.1258
- *$\Upsilon(nS)$ cross-sections at 7 TeV*
  EPJ C72 (2012) 2025, arXiv:1202.6579
- *$\Upsilon(nS)$ from χ_b decay at 7 TeV*
  JHEP 11 (2012) 031, arXiv:1209.0282
- *J/ψ pair production at 7 TeV*
  PL B707 (2012) 52, arXiv:1109.0963
- *J/ψ + open charm production at 7 TeV*
  JHEP 06 (2012) 141, arXiv:1205.0975
- *J/ψ and $\Upsilon(nS)$ production at 8 TeV*
  JHEP 06 (2013) 064, arXiv:1304.6977

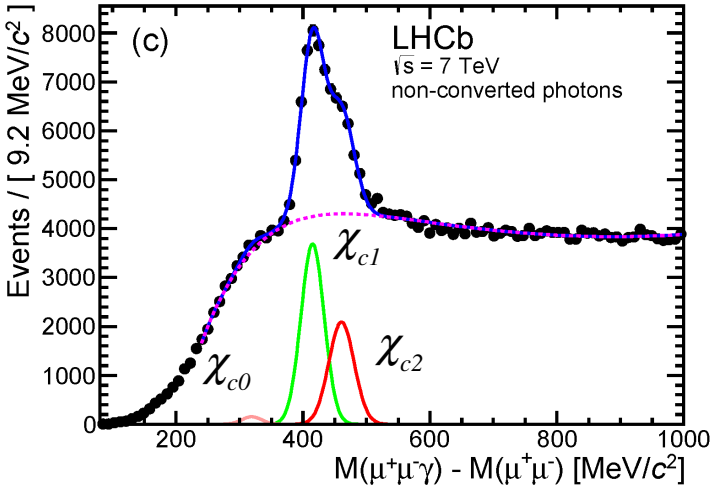
- *χ_c production in pp at 7 TeV (converted γ)*
  arXiv:1307.4285
- *J/ψ polarization in pp at 7 TeV*
  arXiv:1307.6379
- *J/ψ production in pA and Ap collisions*
  LHCb-PAPER-2013-052 (New!)

χ_{cJ} production in pp @ $\sqrt{s}$ = 7 TeV

arXiv:1307.4285

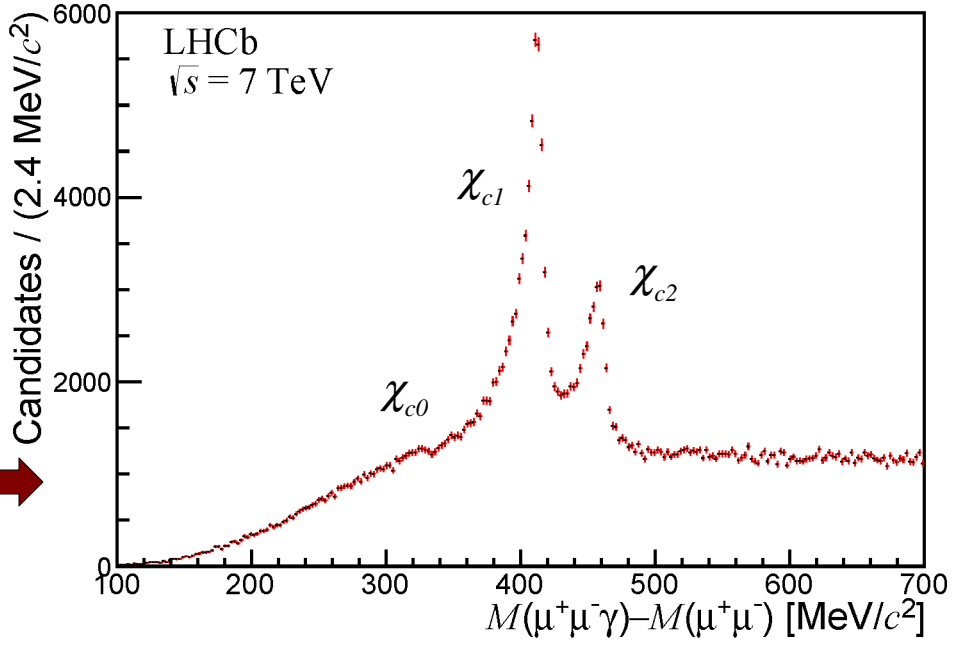
χ_{cJ} production @ $\sqrt{s}$ = 7 TeV

arXiv:1307.4285



- *Previous measurement of χ_{cJ} production by using non-coverted photons: $\mathscr{L}$ = 36 pb^{-1}*
  Phys. Lett. B714 (2012) 215 & arXiv:1204.1462
- *Reconstructed in: $\chi_c \to J/\psi\,\gamma$, where $J/\psi \to \mu^+\mu^-$*

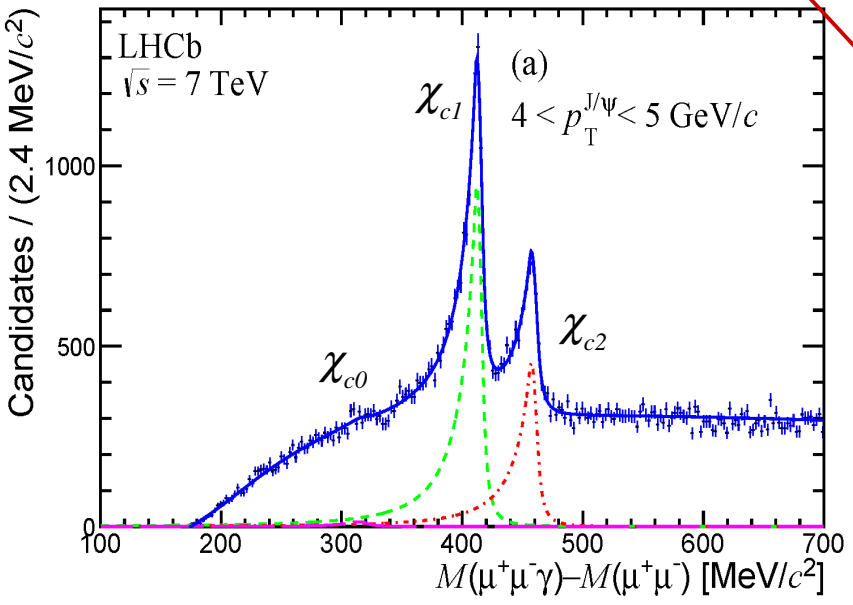
- *New measurement of χ_{cJ} production by using converted photons: $\mathscr{L}$ = 1 fb^{-1}*
  3< $p_T(J/\psi)$ <20 GeV/c, 2 < $y(J/\psi)$ < 4.5
- *Reconstructed in: $\chi_c \to J/\psi\,\gamma$, where $(J/\psi \to \mu^+\mu^-)$ and $(\gamma \to e^+e^-)$*
- *Good mass resolution but low efficiency*

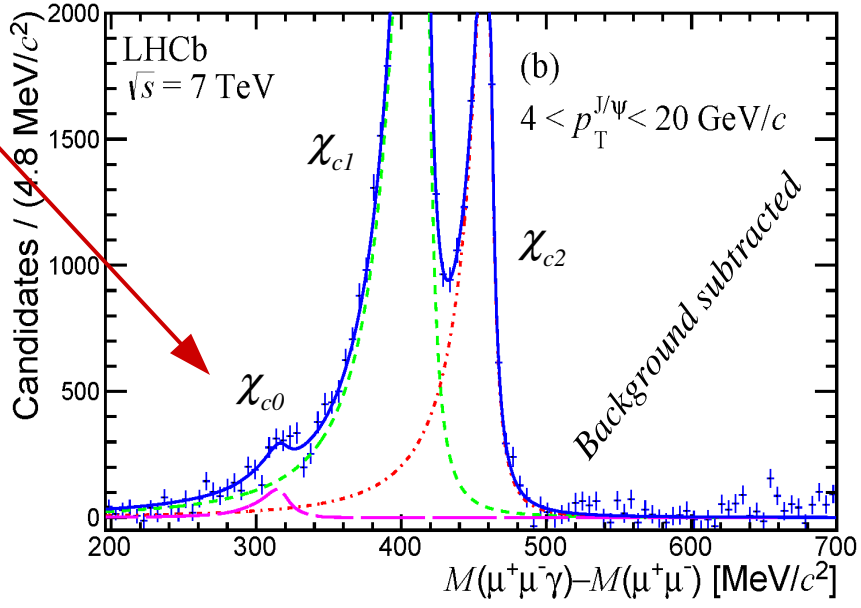


χ_{cJ} production @ $\sqrt{s} = 7$ TeV

arXiv:1307.4285

- *First evidence of χ_{c0} at hadron collider with statistical significance of 4.3σ*
  $N(\chi_{c0}) = 705 \pm 163$
- *Mass resolution: about 4 MeV/c^2*
- *Ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ is sensitive to CS vs CO models*

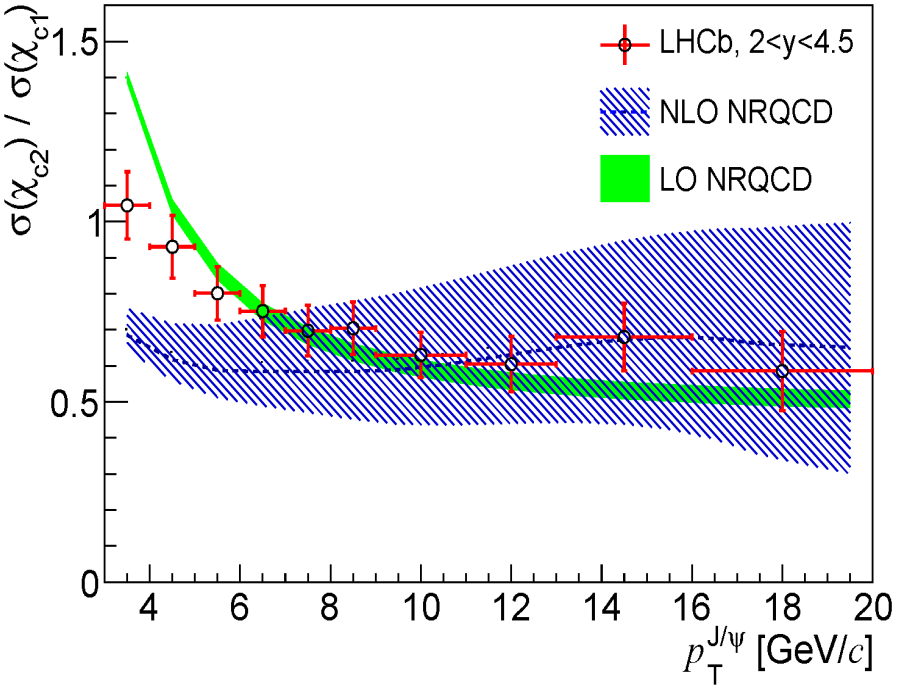




χ_{cJ} production @ $\sqrt{s} = 7$ TeV

arXiv:1307.4285

Ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ and its comparison with theory



Ma, Wang, Chao (2010, 2011)

Likhoded, Luchinsky, Poslavsky (2013)

- *These LHCb results obtained assuming the χ_c mesons are produced unpolarized*
- *Good agreement with the model LO NRQCD. For the model of NLO NRQCD – good agreement at high $p_T(J/\psi)$*

$4 < p_T(J/\psi) < 20$ GeV/c

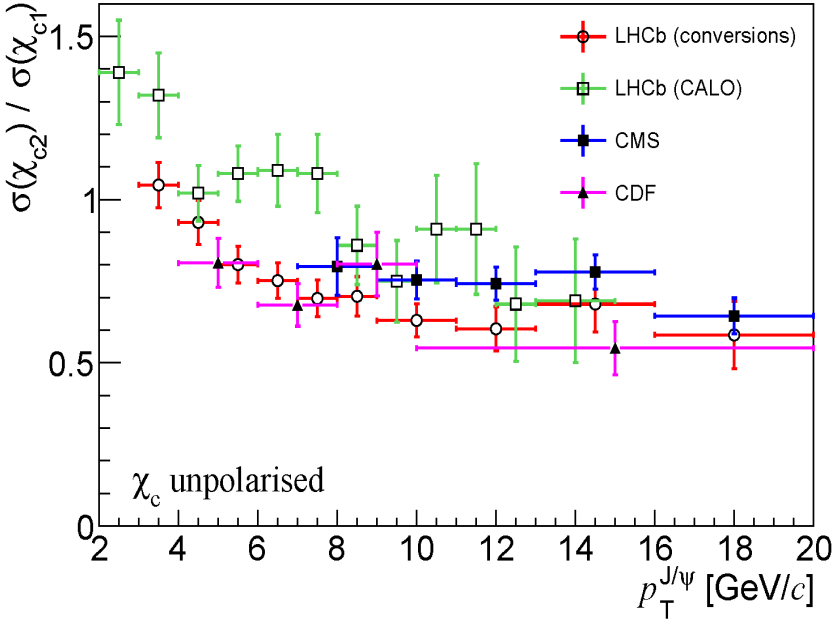
$$\sigma(\chi_{c0})/\sigma(\chi_{c2}) = 1.19 \pm 0.27\,(\text{stat}) \pm 0.29\,(\text{syst}) \pm 0.16\,(p_T\,\text{model}) \pm 0.09\,(\mathcal{B})$$

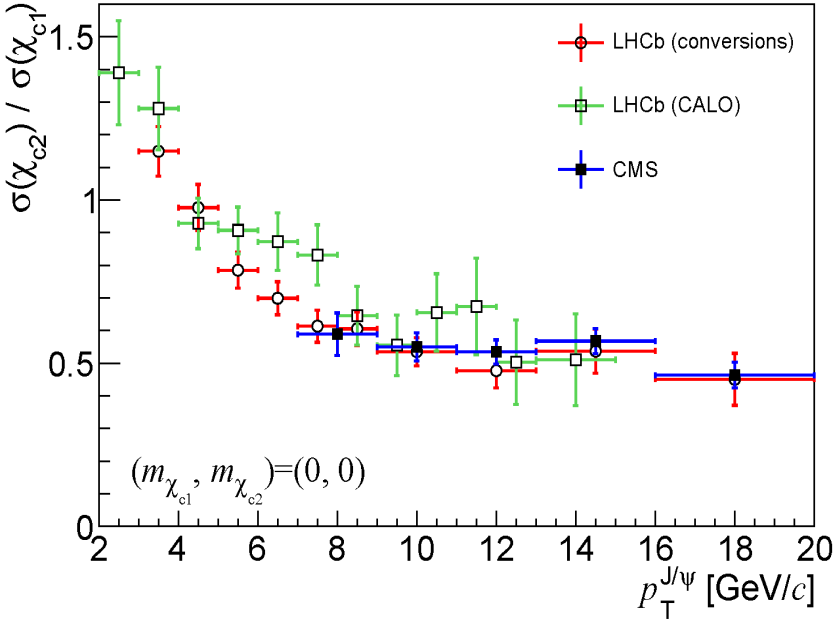
χ_{cJ} production @ $\sqrt{s} = 7$ TeV

arXiv:1307.4285

Comparison of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ obtained by different experiments

- *The results from this analysis (converted photons) compatible with CMS and CDF results*
- *Better agreement achieved when χ_c polarized with $(m(\chi_{c1}), m(\chi_{c2})) = (0,0)$*





J/ψ polarization in pp @ $\sqrt{s} = 7$ TeV

arXiv:1307.6379

J/ψ polarization @ $\sqrt{s} = 7$ TeV

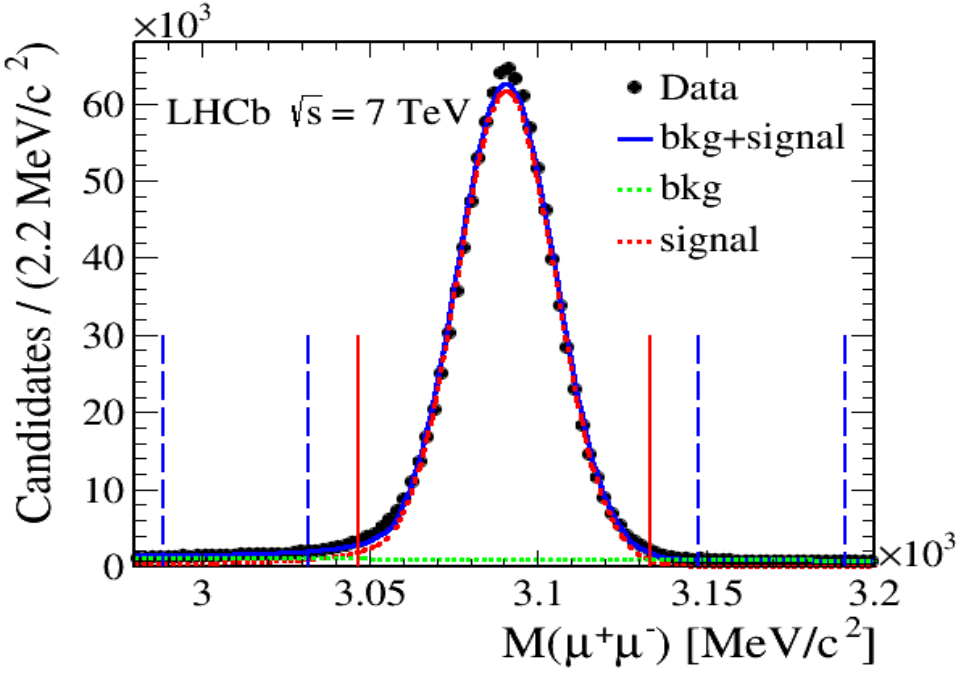
arXiv:1307.6379

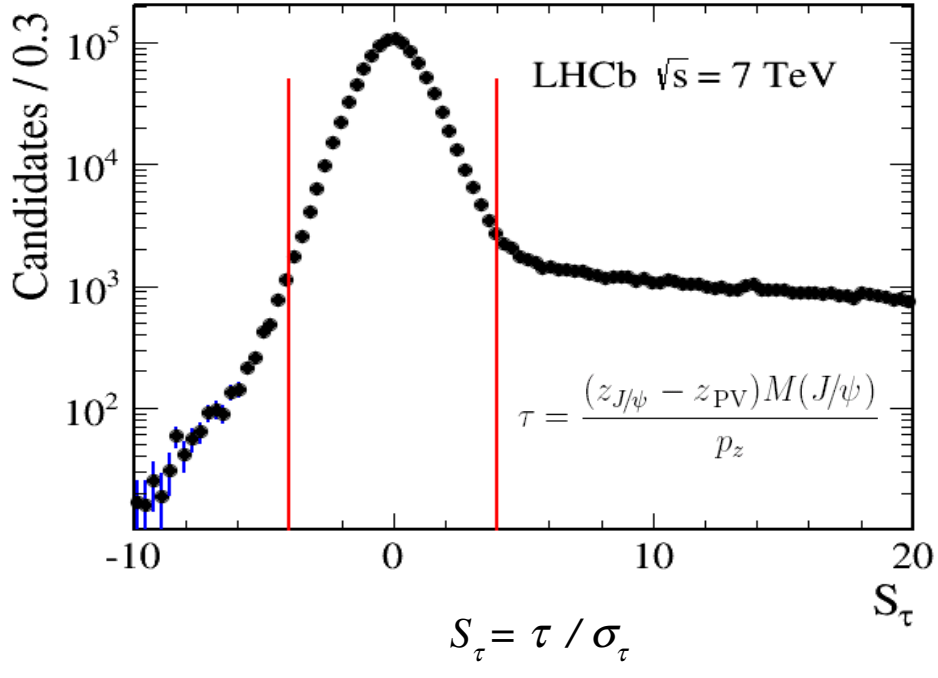
J/ψ polarization: pp collisions @ $\sqrt{s} = 7$ TeV, $\mathscr{L} = 0.37\ fb^{-1}$ (1^{st} half of 2011)

$p_T \in$ [2, 3, 4, 5, 7, 10, 15] GeV/c, $y \in$ [2.0, 2.5, 3.0, 3.5, 4.0, 4.5], only prompt J/ψ candidates

Full angular analysis to determine the polarization parameters ($\lambda_\theta, \lambda_{\theta\phi}, \lambda_\phi$) in HX & CS frames

$$\frac{d^2N}{d\cos\theta\, d\phi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\phi} \sin 2\theta \cos\phi + \lambda_\phi \sin^2\theta \cos 2\phi$$

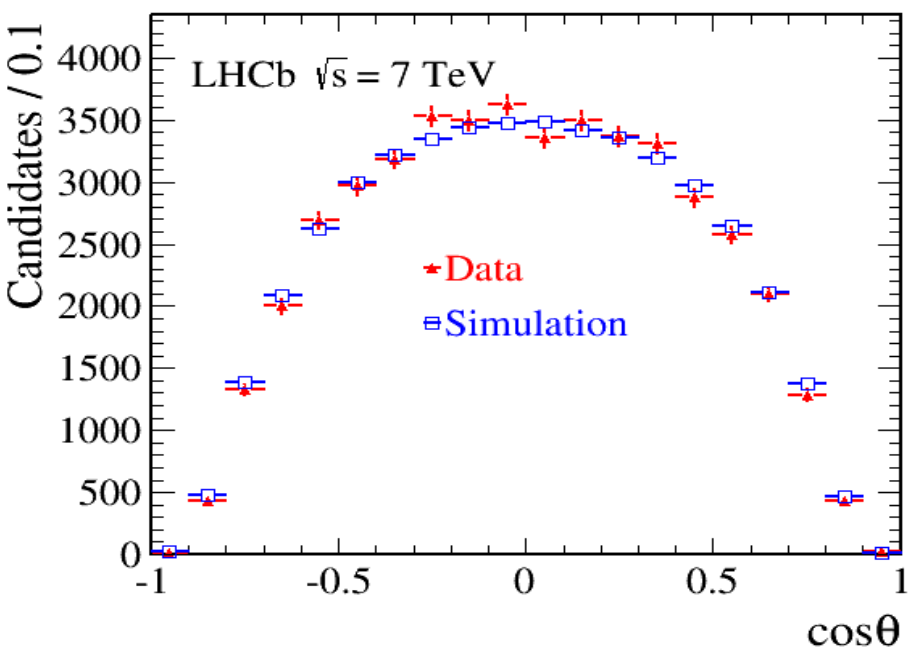


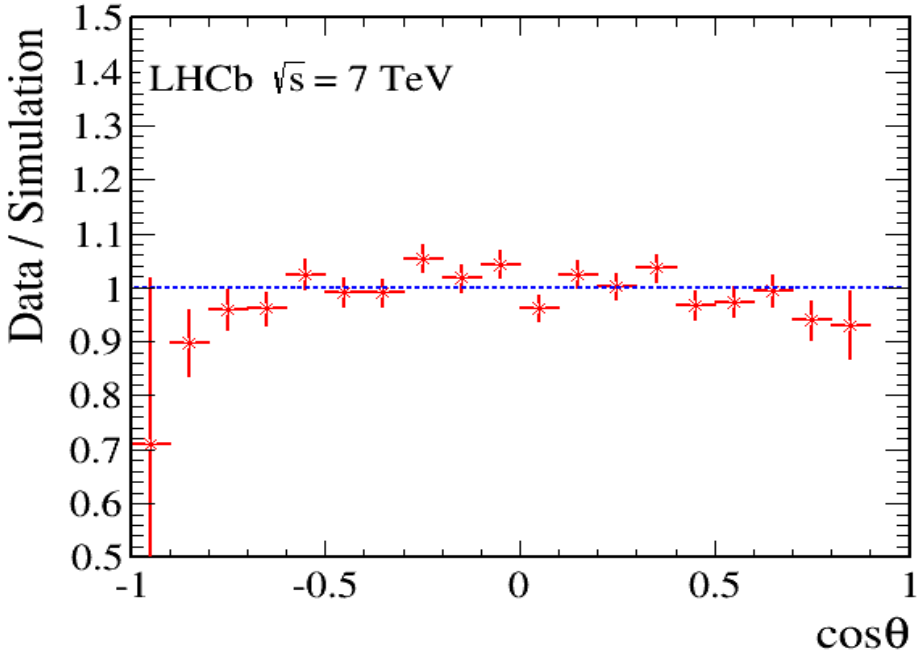


J/ψ polarization @ $\sqrt{s} = 7$ TeV

arXiv:1307.6379

Lots of cross-checks have been done. $B^+ \to J/\psi K^+$ as a control-channel to avoid any artificial polarization. The J/ψ polarization in $B^+ \to J/\psi K^+$ is fixed and known. Weights as function of muon p_T and y obtained from the control-channel $B^+ \to J/\psi K^+$



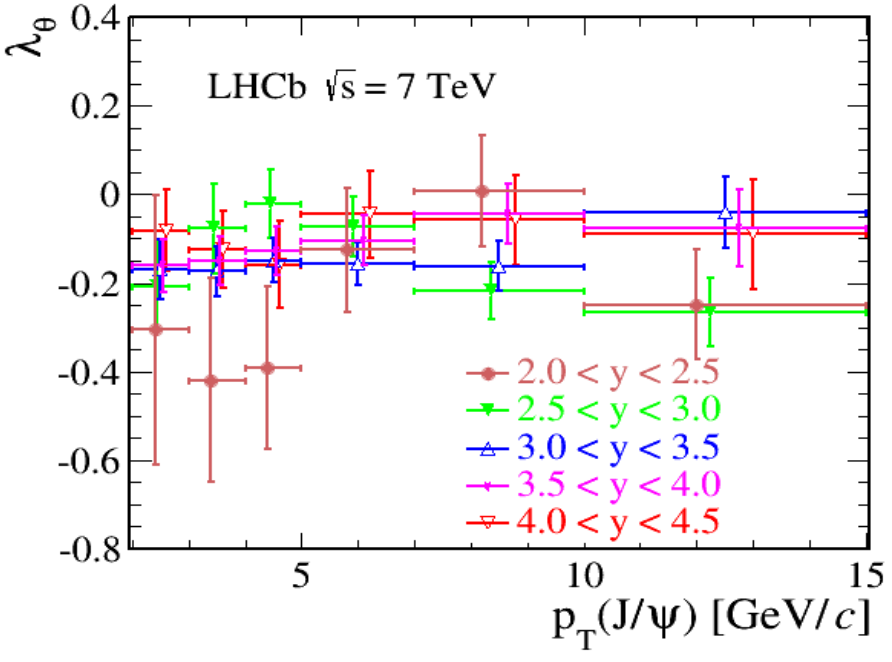


Muon cosθ in HX frame for J/ψ from $B^+ \to J/\psi K^+$ before final reweighting procedure.

J/ψ polarization @ $\sqrt{s} = 7$ TeV

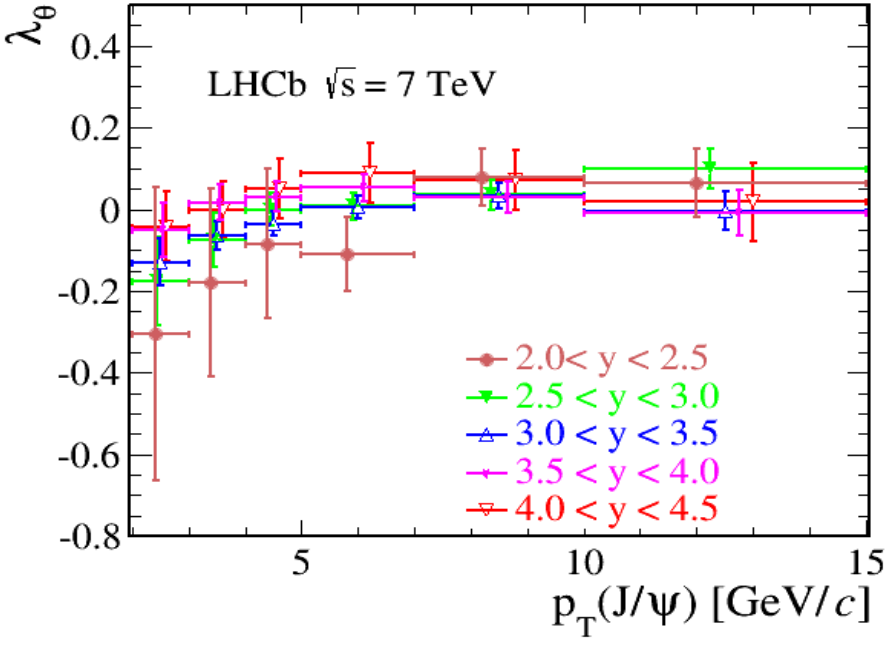
arXiv:1307.6379

Measurements of λ_θ in bins of p_T



helicity frame

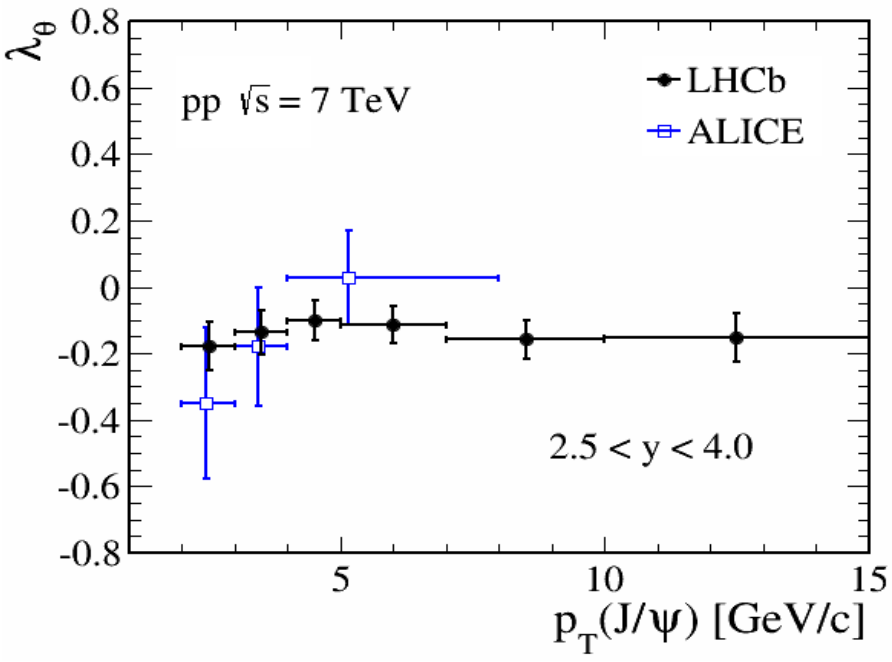
Collins-Soper frame



J/ψ polarization @ $\sqrt{s} = 7$ TeV

arXiv:1307.6379

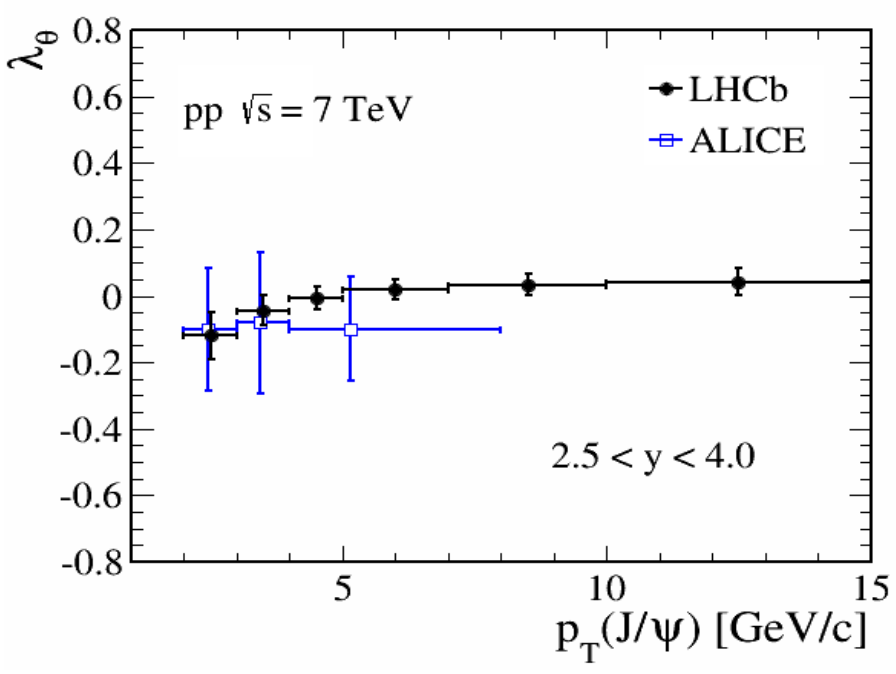
Comparison of LHCb and ALICE results for λ_θ



Collins-Soper frame

Good agreement with ALICE measurements (due to large uncertainties in ALICE results)

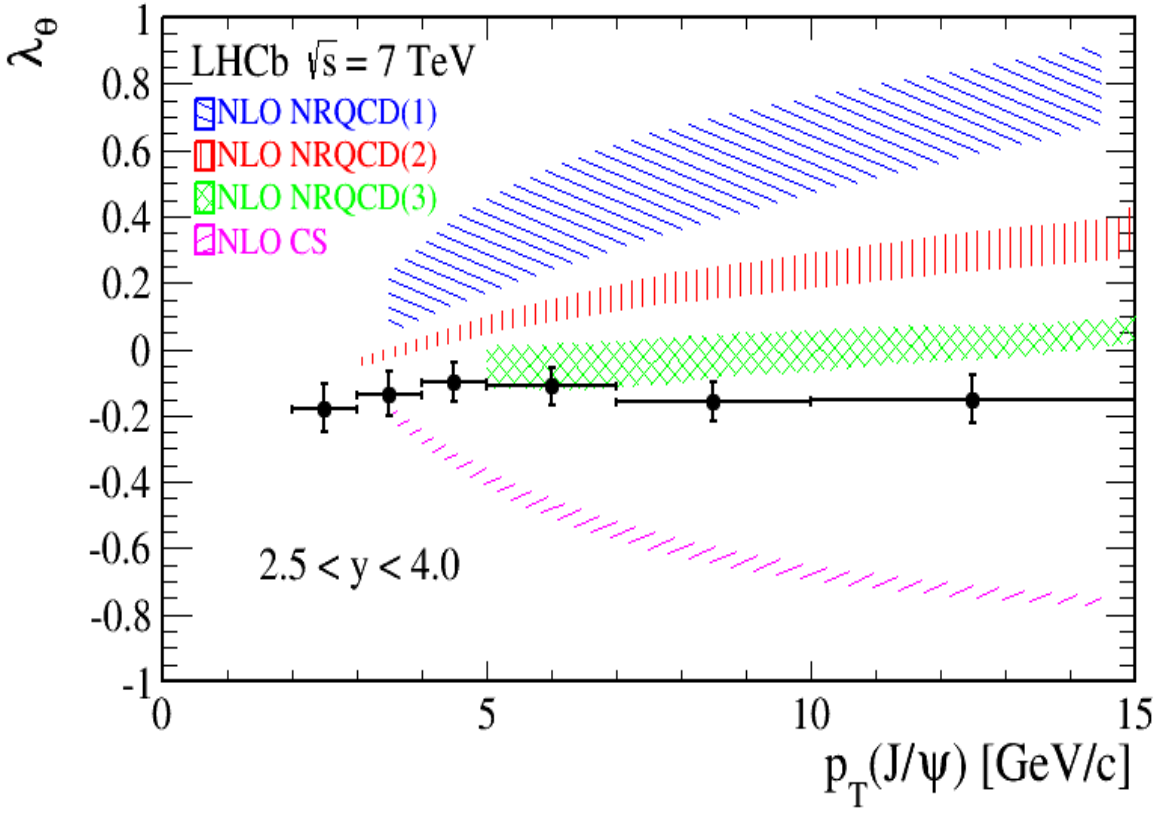
helicity frame



J/ψ polarization @ $\sqrt{s} = 7$ TeV

arXiv:1307.6379

Comparison of LHCb results with theoretical models



NPB 151 (2012) 222-224 (Proc. Suppl.)

PRL 110 (2013) 042002

PRL 108 (2012) 242004

NPB 151 (2012) 222-224 (Proc. Suppl.)

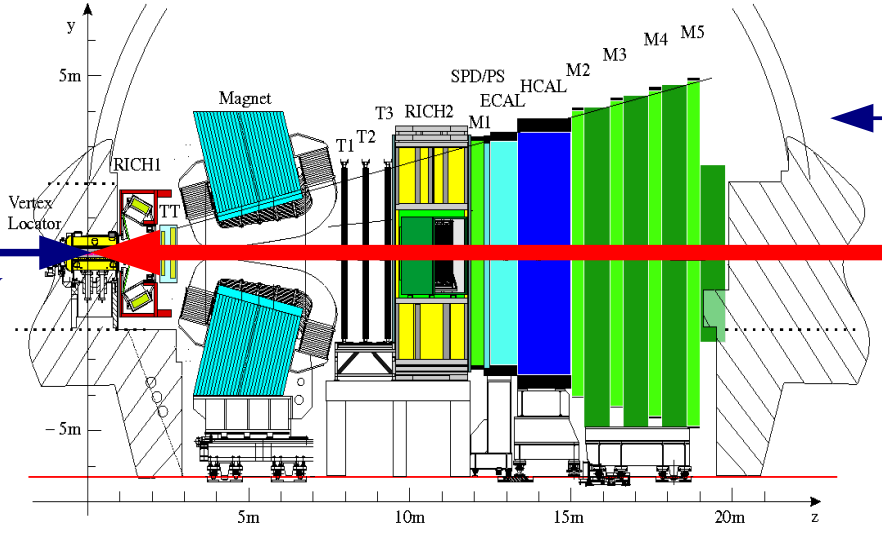
Measured λ_θ agrees with neither theoretical prediction!

J/ψ production in pA & Ap collisions (New!)

LHCb-PAPER-2013-052

J/ψ production in pA & Ap collisions

LHCb-PAPER-2013-052



p beam

E_p = 4 TeV

pA collision (2013)

forward production

$\mathscr{L}$ = 1.1 nb^{-1}

Pb beam

E_N = 1.58 TeV

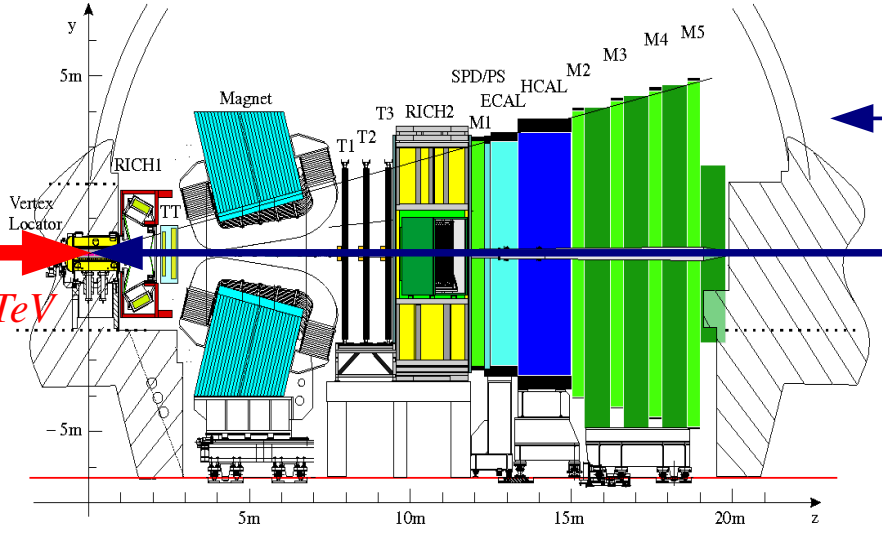
$\sqrt{S_{NN}}$ = 5 TeV

rapidity coverage:

1.5 < y < 4.0 in pA

-5.0 < y < -2.5 in Ap

p_T *coverage*: p_T < 14 GeV/c



Pb beam

E_N = 1.58 TeV

Ap collision (2013)

backward production

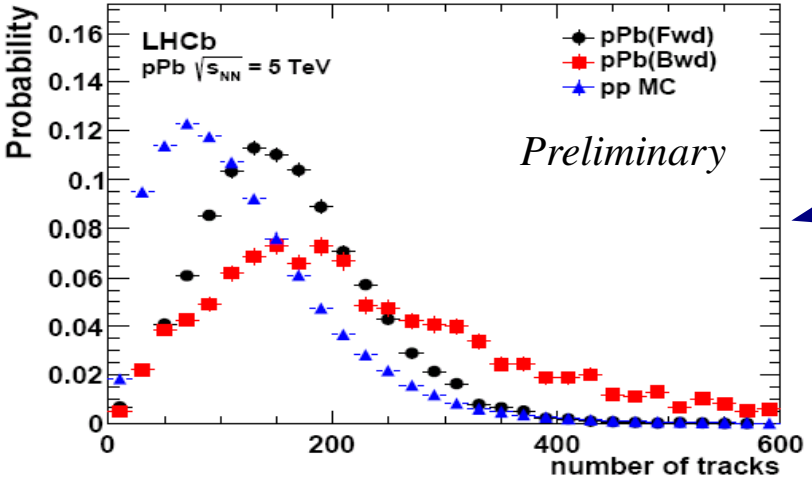
$\mathscr{L}$ = 0.5 nb^{-1}

p beam

E_p = 4 TeV

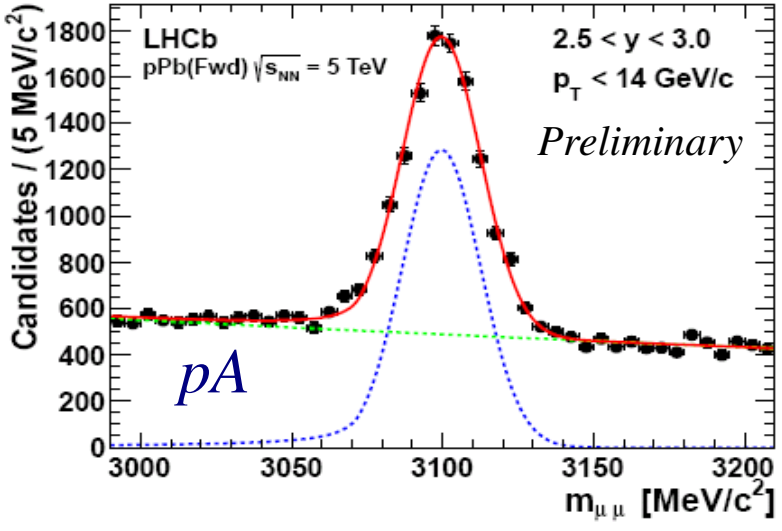
J/ψ production in pA & Ap collisions

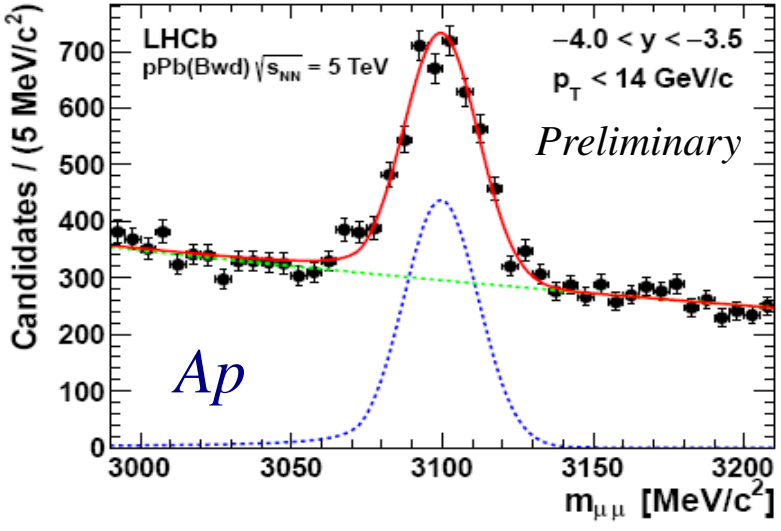
LHCb-PAPER-2013-052



MC data sample is based on pp collision. Comparison of track multiplicity for forward (●), backward (●) and MC data samples (●). MC was reweighted to match the data.

Dimuon mass spectra for pA (left) and Ap (right) collisions



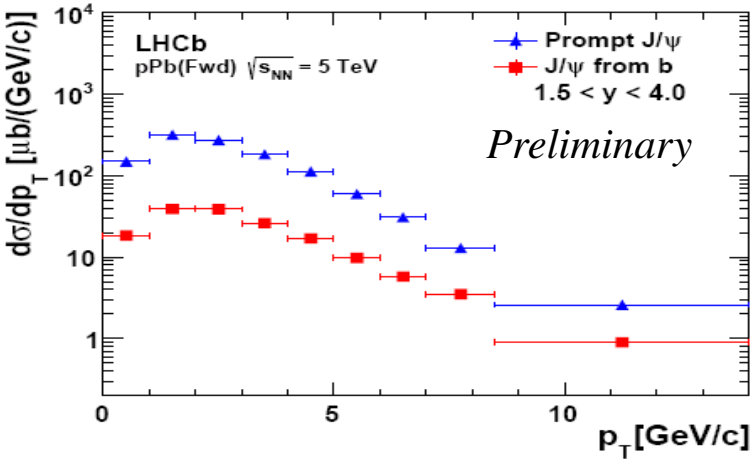


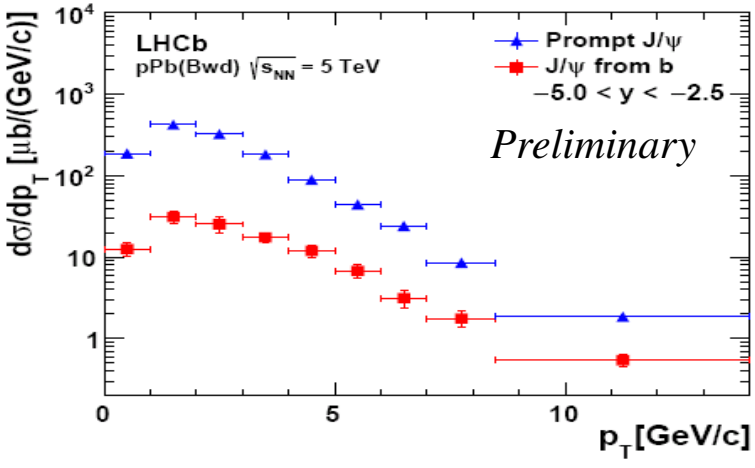
J/ψ production in pA & Ap collisions

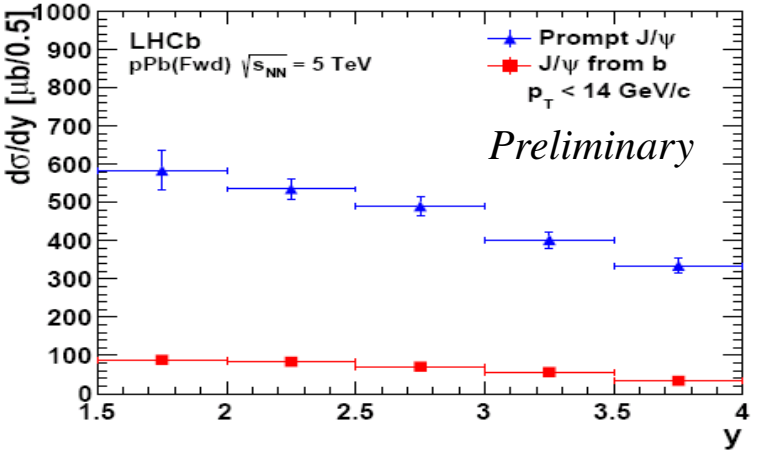
LHCb-PAPER-2013-052

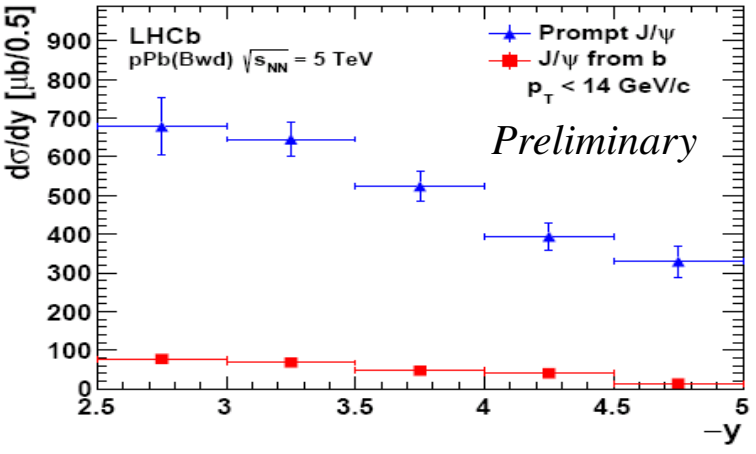
Differential production xsec's for prompt J/ψ and J/ψ from b (For the first time!)

pA







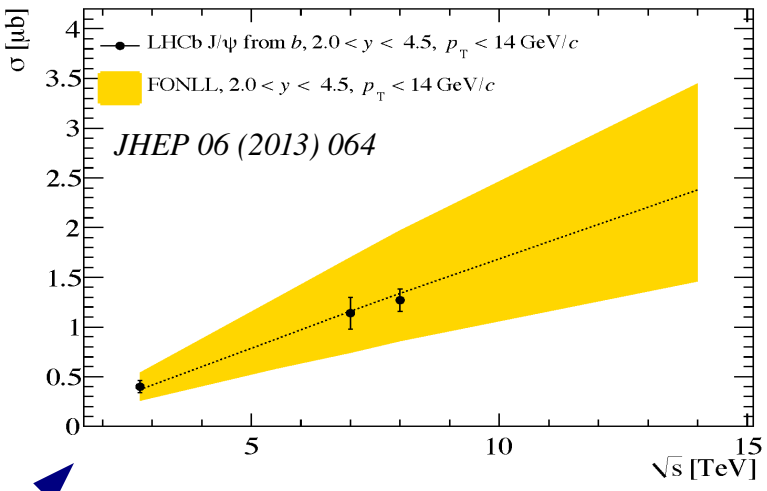


Ap

J/ψ production in pA & Ap collisions

LHCb-PAPER-2013-052

Determination of nuclear modification factor



Cross-sections of J/ψ from b and FONLL predictions in pp collisions for (p_T < 14 GeV) & (2.0 < y < 4.5)

JHEP 02 (2013) 041 [arXiv:1212.1045] J/ψ @ 2.76 TeV
EPJ C71 (2011) 1645 [arXiv:1103.0423] J/ψ @ 7 TeV
JHEP 06 (2013) 064 [arXiv:1304.6977] J/ψ @ 8 TeV

$$R_{\rm pA}(y,\sqrt{s_{\rm NN}}) \equiv \frac{1}{A}\frac{\frac{{\rm d}\sigma_{\rm pA}}{{\rm d}y}(y,\sqrt{s_{\rm NN}})}{\frac{{\rm d}\sigma_{pp}}{{\rm d}y}(y,\sqrt{s_{\rm NN}})}$$

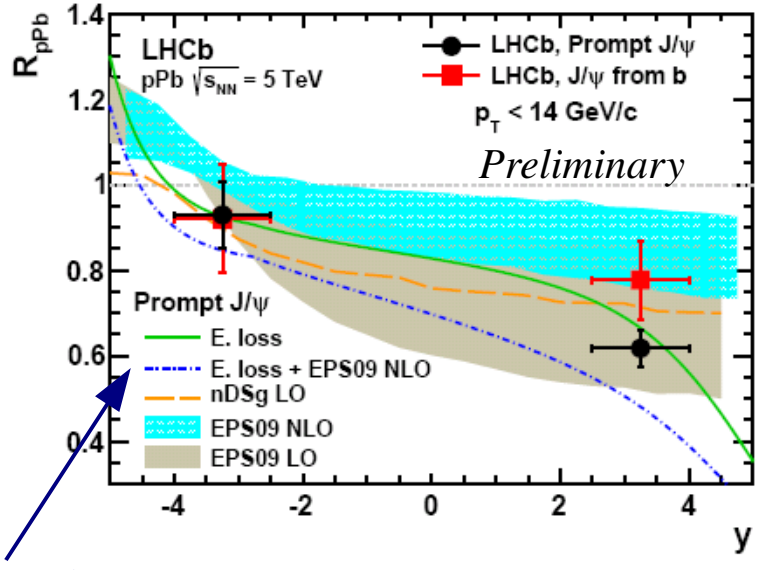
- *Since $\sqrt{s_{NN}}$ = 5 TeV*
- *Previous LHCb measurements of J/ψ production (at $\sqrt{s}$ = 2.76, 7 & 8 TeV) are rescaled to: (p_T < 14 GeV) & (2.5 < y < 4.0)*
- *Power-law interpolation from the previous LHCb measurements to obtain prompt J/ψ (or J/ψ from b) cross-sections in pp collisions at $\sqrt{s_{pp}}$ = 5 TeV*

J/ψ production in pA & Ap collisions

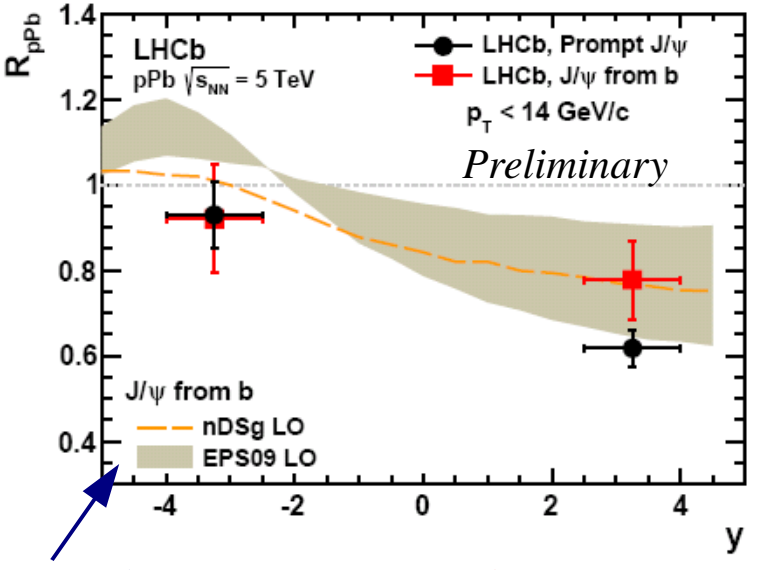
LHCb-PAPER-2013-052

Nuclear modification factor for prompt J/ψ and J/ψ from b (For the first time!)

Suppression of J/ψ at large y is observed. This is less pronounced for J/ψ from b.
It indicates that b hadrons are less affected by cold nuclear matter effects.
Within sizable uncertainties, the measurements agree with most theoretical predictions



predictions for prompt J/ψ



predictions for J/ψ from b

J/ψ production in pA & Ap collisions

LHCb-PAPER-2013-052

Forward-backward production ratio for prompt J/ψ and J/ψ from b (For the first time!)

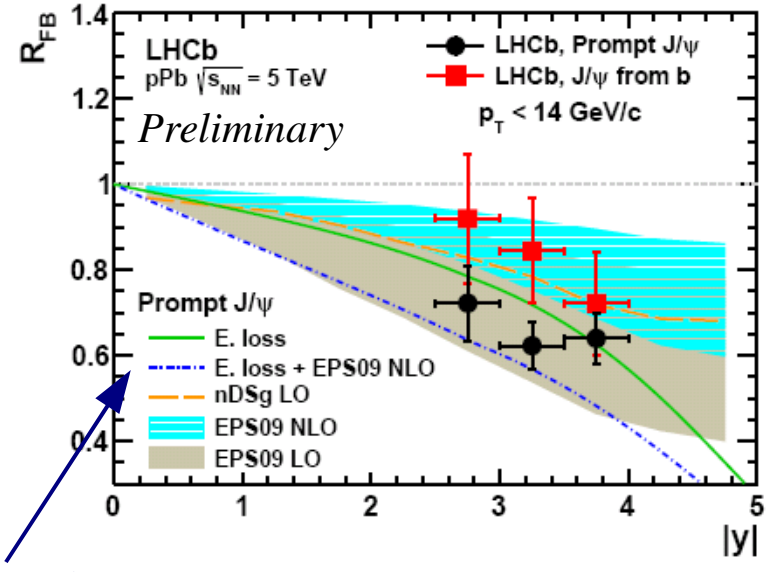
arXiv:1305.4569

JHEP 03 (2013) 122, arXiv:1212.0434

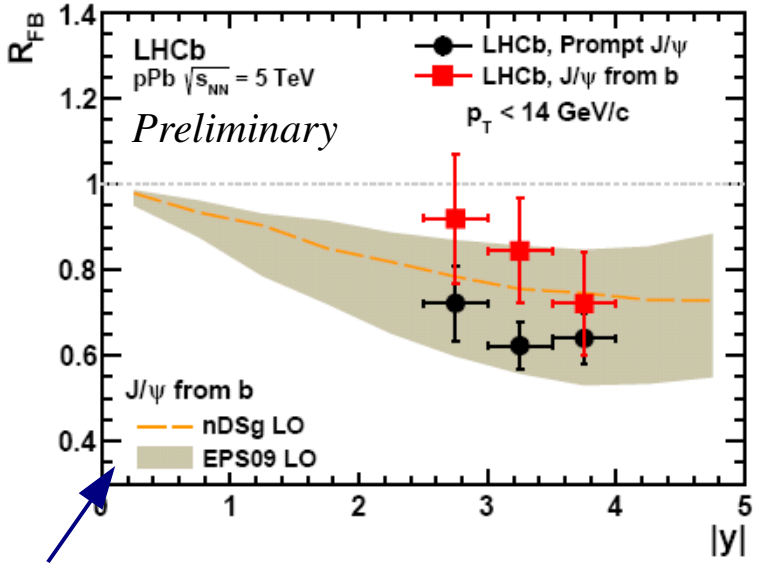
IJMP E22 (2013) 1330007, arXiv:1301.3395

$$R_{\rm FB}(y,\sqrt{s_{\rm NN}}) \equiv R_{p\rm Pb}(+|y|,\sqrt{s_{\rm NN}})/R_{p\rm Pb}(-|y|,\sqrt{s_{\rm NN}})$$

Within sizable uncertainties, the results agree with all theoretical predictions



predictions for prompt J/ψ



predictions for J/ψ from b

Summary

- *By using converted photons, new measurements of ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ has been determined as functions of $p^T(J/\psi)$. The results for $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ are found to be in good agreement with LO NRQCD model.*
- *The full angular analysis for determining the polarization parameters ($\lambda_\theta, \lambda_{\theta\phi}, \lambda_\phi$) of prompt J/ψ produced in pp at $\sqrt{s}$ = 7 TeV has been performed. So far no theoretical model can explain these experimental results.*
- *For the first time, diff. production xsec's of prompt J/ψ and J/ψ from b are measured in pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV. For the first time nuclear modification factor and forward-backward production ratio are determined separately for prompt J/ψ and J/ψ from b in pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV.*
- *Many new ongoing studies are in preparation. Stay tuned!*

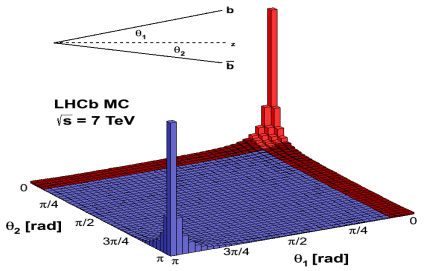
Thank You

Backup

$2 < \eta < 5$
4% of solid angle
40% of heavy quarks

The LHCb detector

is a forward spectrometer designed for precision studies of CP violation and rare decays of b- and c-hadrons



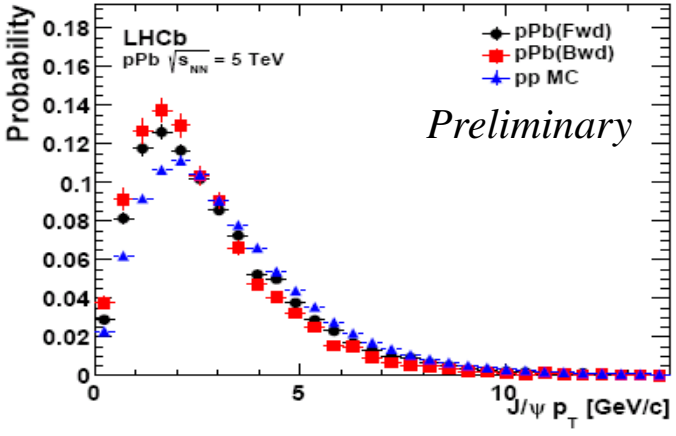
The LHCb Detector
JINST 3 (2008) S08005

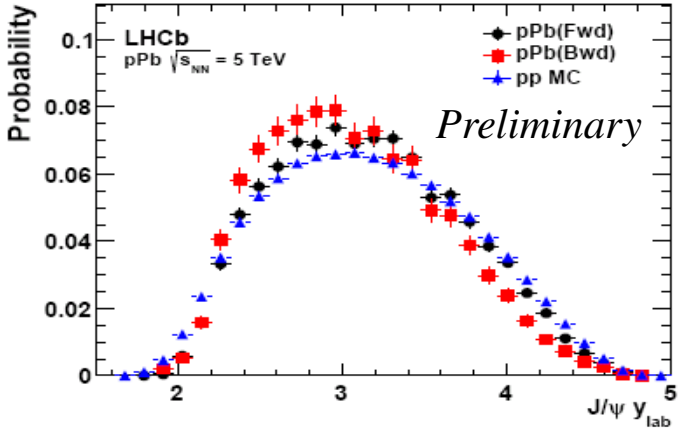
y
5m
– 5m
Vertex Locator
RICH1
TT
Magnet
T1
T2
T3
RICH2
SPD/PS
ECAL
HCAL
M1
M2
M3
M4
M5
5m
10m
15m
20m
z

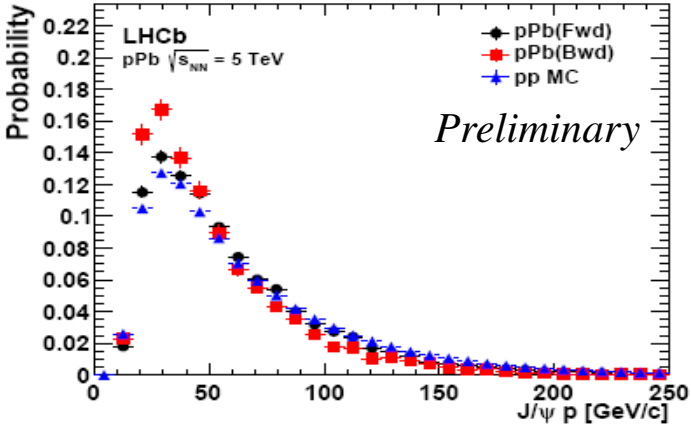
J/ψ production in pA & Ap collisions

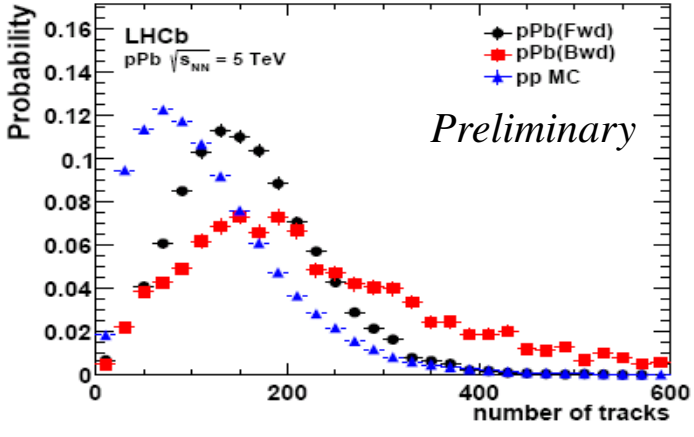
LHCb-PAPER-2013-052

Comparison of MC and data samples. MC is based on pp collisions. Significant difference in track multiplicity distributions. MC was reweighted to match data.









J/ψ production in pA & Ap collisions

LHCb-PAPER-2013-052

Dimuon mass and pseudo proper time spectra