LHCb results in proton-nucleus collisions at the LHC

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on behalf of the LHCb collaboration

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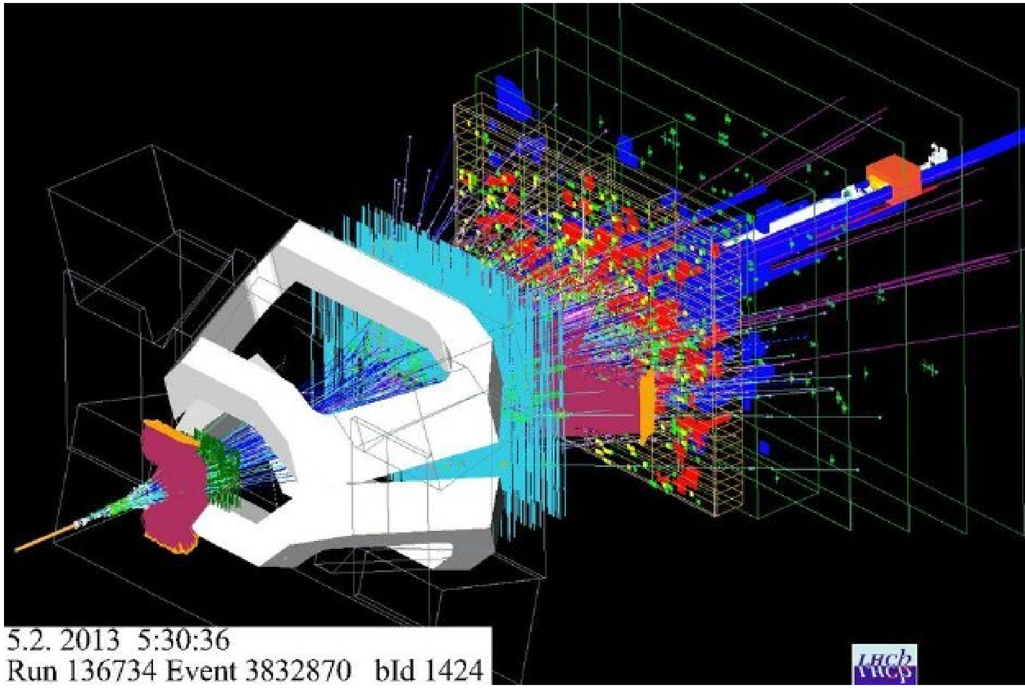
Outline

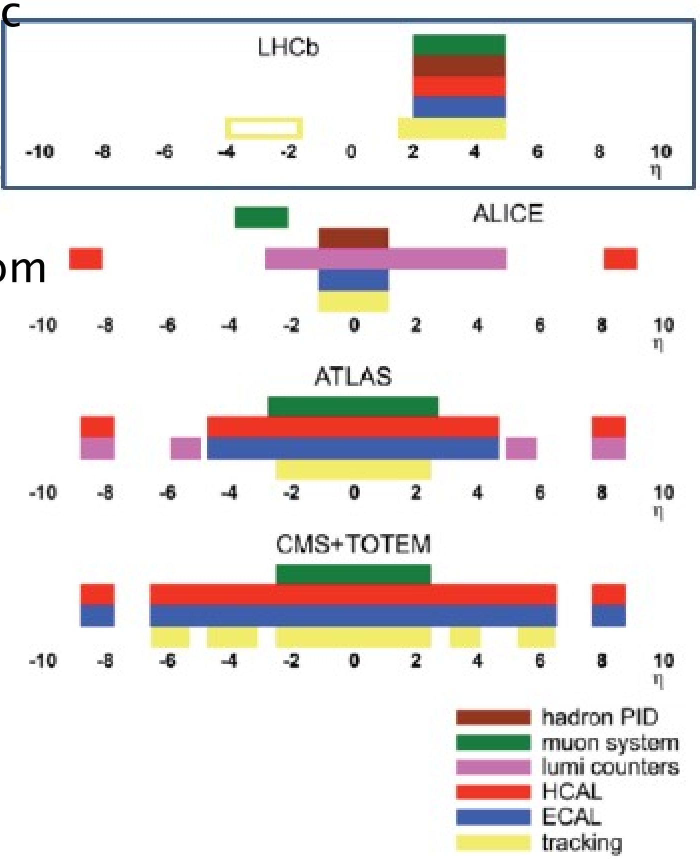
- Motivation
- LHCb Detector
- Beam configurations
- Measurements
  - J/Ψ production
  - Υ production
  - Z boson production
- Outlook
- Conclusions



Motivation

LHCb fully instrumented in the forward region
→ study proton-ion collisions in a unique kinematic region

pA collisions interesting by itself and as a reference sample for heavy ion collisions
pA data should allow factorizing the QGP effects from Cold Nuclear Matter effects



Sensitive probes of properties of nuclear matter
- Nuclear parton distribution function (nPDF)
- Nuclear attenuation factors
  → Tests phenomenological models

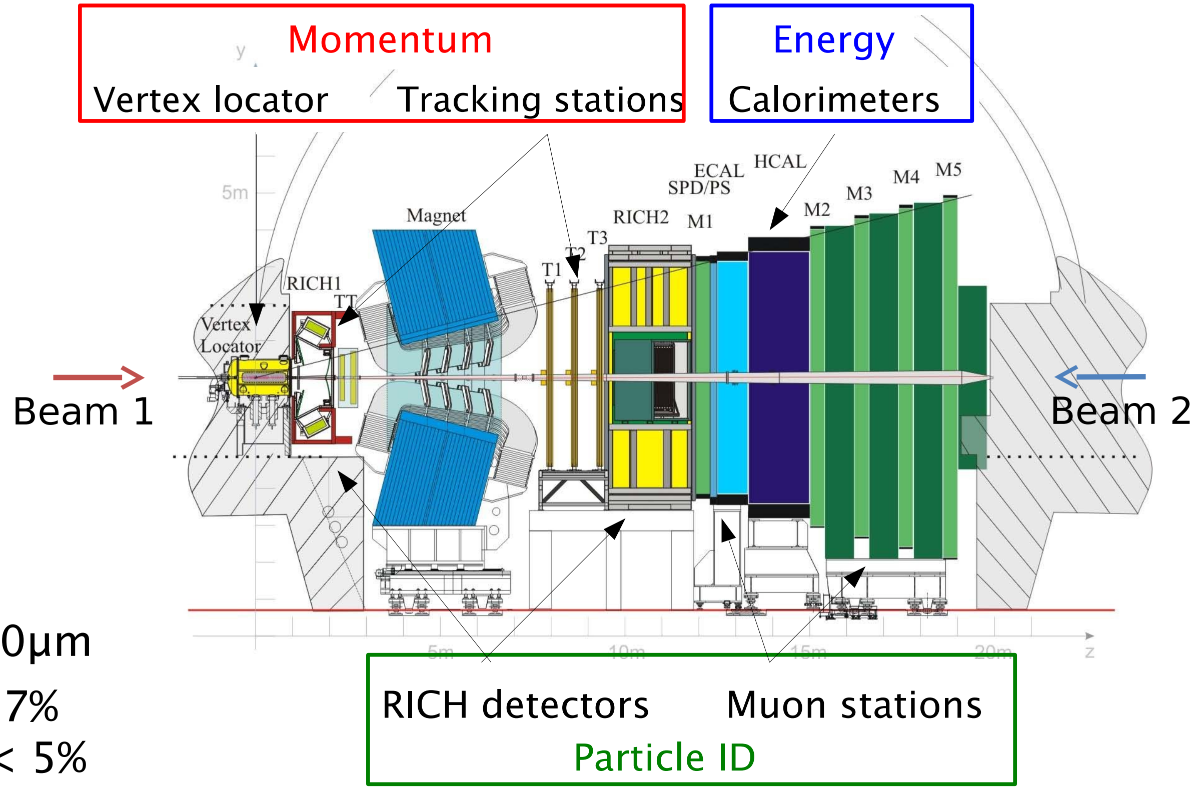
Heavy flavour and quarkonium probe
- energy loss mechanisms
- medium transport properties
- quark deconfinement

Electroweak bosons:
- probe nuclear PDFs which are poorly constraint
→ LHCb sensitive to x_A range $2x10^{-4}$ – $3x10^{-3}$
  and 0.2-1 at mass of Z

LHCb Detector

JINST3 (2008) S08005

Fully instrumented in the forward region ($2 < \eta < 5$)
some detection capability in backward region ($-3.5 < \eta < -1.5$)



- Tracking: $\sigma_p/p \sim 0.4-0.6\%$
- Vertex resolution:
  $\sigma_{xy} \sim 15\mu m$, $\sigma_z \sim 80\mu m$
- Muon ID $\epsilon=97\%$; mis-id: 0.7%
- Kaon ID $\epsilon=90\%$; π mis-id< 5%

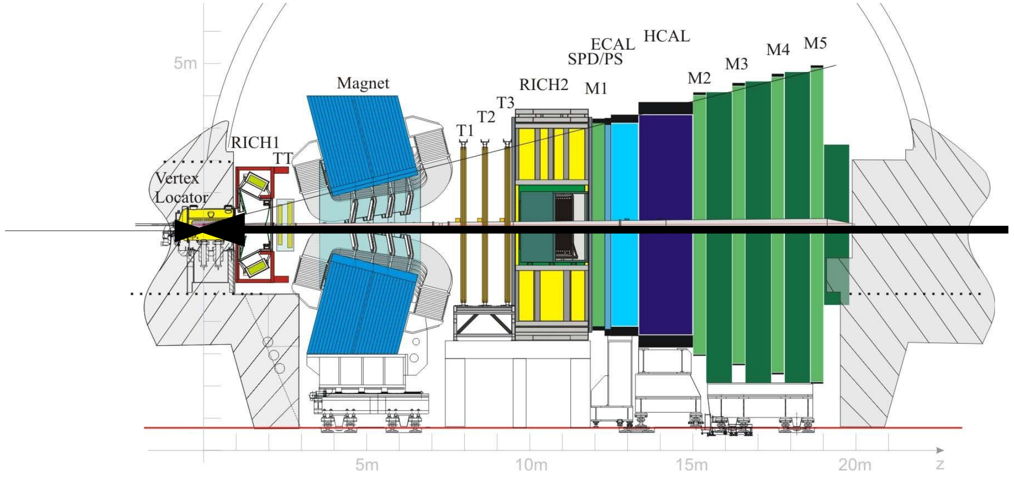
- Analyses based on
  - 2013 proton-lead runs @ 5 TeV
  - single arm spectrometer → two different beam configurations

Beam Configurations

Forward:

- proton-lead collisions at 5 TeV
- luminosity: 1.1 nb^{-1} recorded by LHCb
- proton beam in the direction of the LHCb detector
- positive rapidity with respect to the proton
- shift in rapidity: $\Delta y = y_{lab} - y = 0.47$, acceptance $1.5 < y < 4.0$

p: E 4 TeV



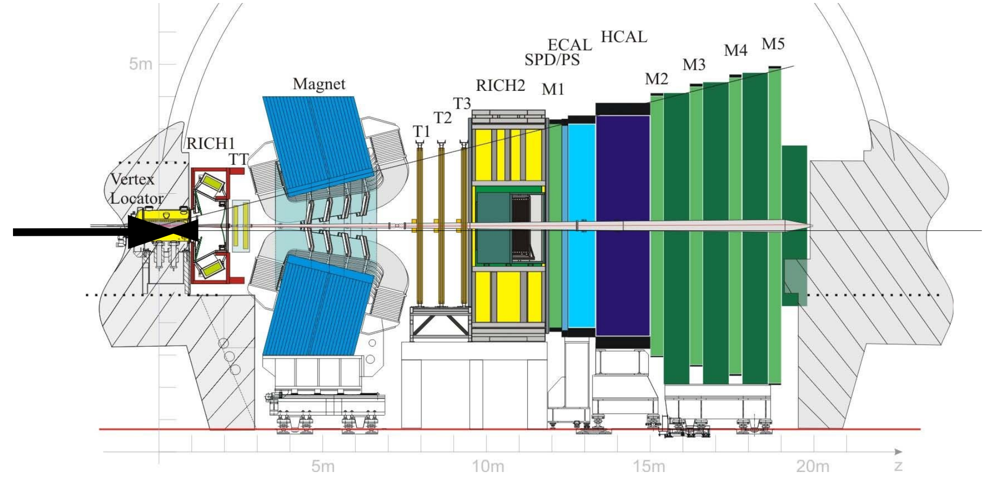
Pb: E_N=1.58 TeV

Beam Configurations

Backward:

- proton-lead collisions at 5 TeV
- luminosity: 0.5 nb^{-1}recorded by LHCb
- proton beam in the direction of the LHCb detector
- negative rapidity with respect to the proton
- shift in rapidity: $\Delta y = y_{lab} - y = 0.47$, acceptance $-5.0 < y < -2.5$

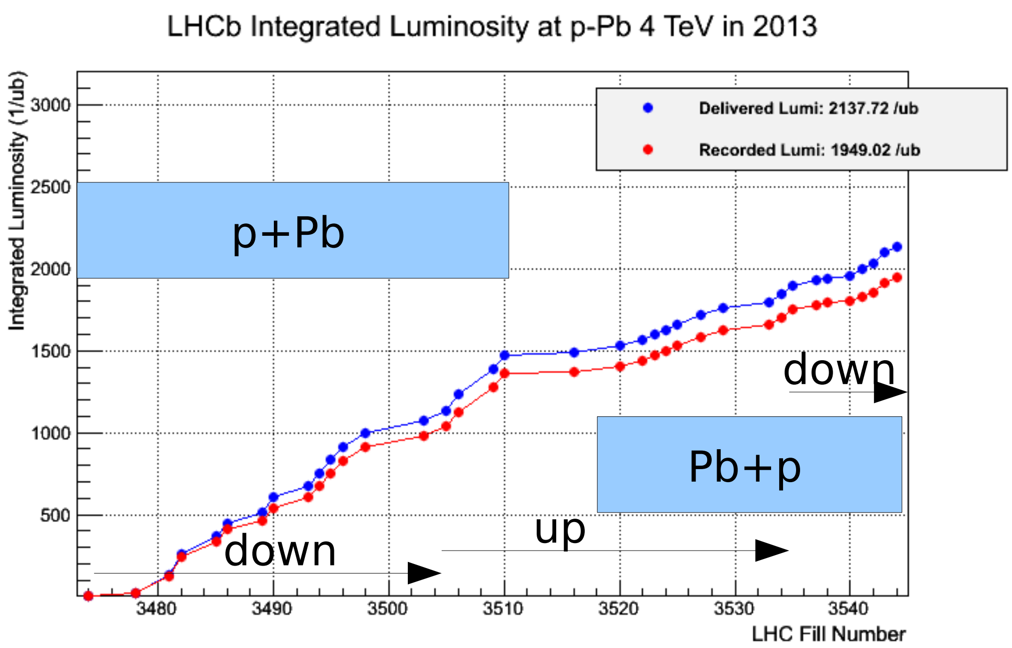
Pb: E_N=1.58 TeV

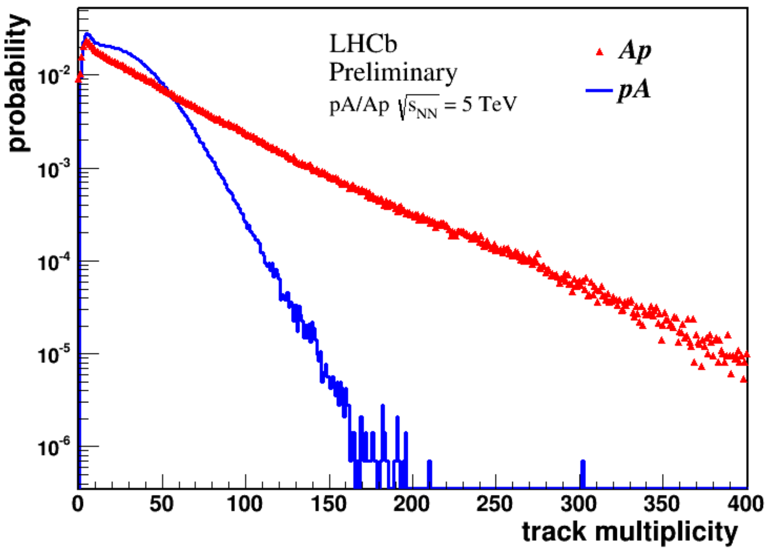


p: E = 4 TeV

LHCb Detector

LHCb-CONF-2013-008



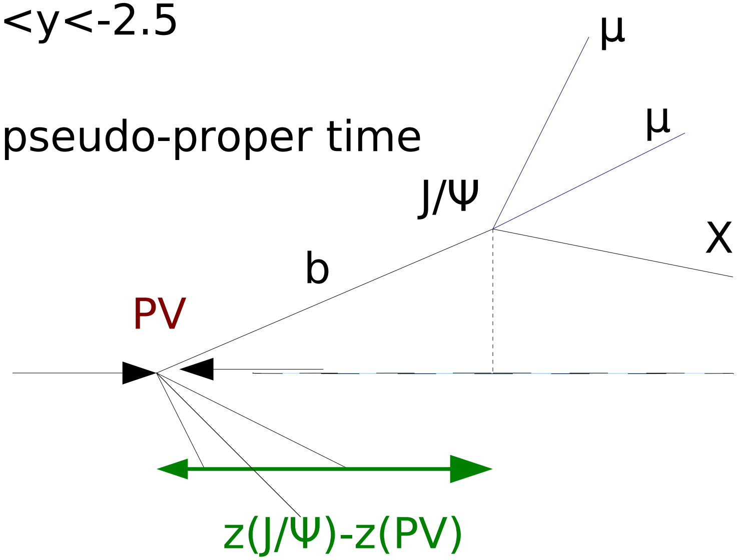


- low instantaneous luminosity: $L \approx 5 \times 10^{27}$ $cm^{-2}s^{-1}$
- low pile-up (approx. 1 primary vertex per beam crossing)
- data-taking efficiency better than 91%.
- results based on 2 beam configurations and 2 magnet configurations.
- p+Pb : $L = 1.1$ nb^{-1}
- Pb+p : $L = 0.5$ nb^{-1}

J/Ψ production in p-Pb collisions

- reconstruct J/Ψ in di-muon channel
- forward: 1.5<y<4.0 and backward: -5.0<y<-2.5
- p_T < 14 GeV
- separate prompt J/Ψs from secondaries: pseudo-proper time

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

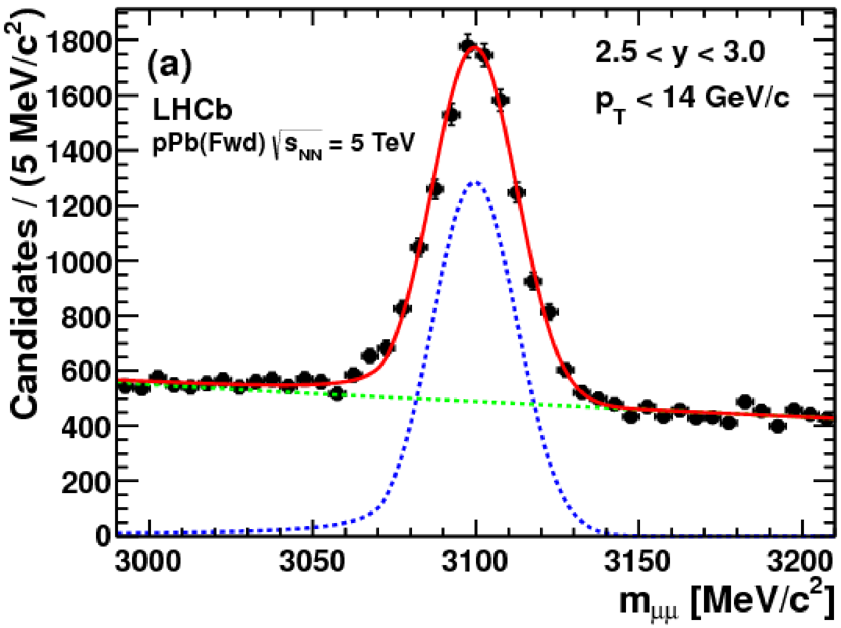


Results:
- differential J/Ψ cross sections
- nuclear modification factor
- forward-backward asymmetry

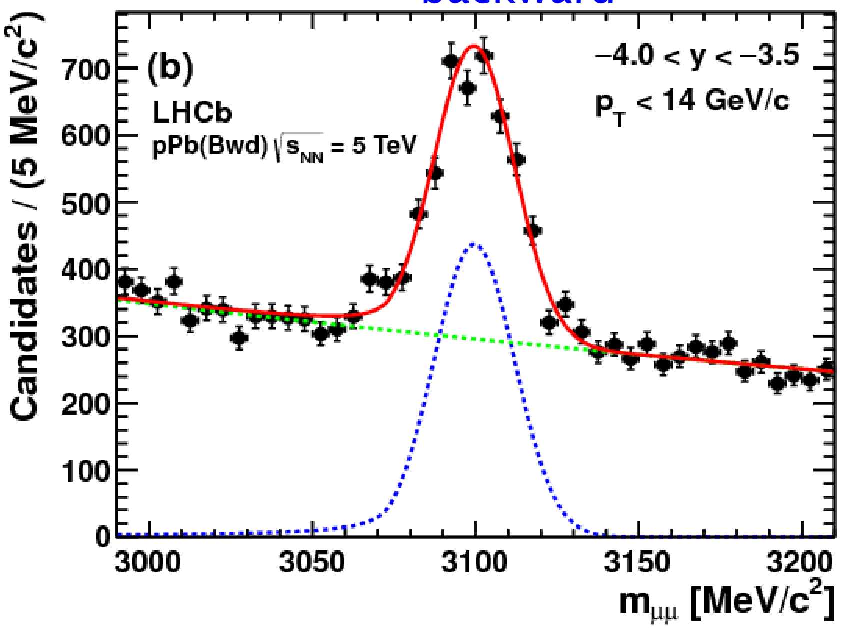
J/Ψ production in p-Pb collisions

Yields: simultaneous fit to mass & pseudo-proper time
Mass model: Crystal-Ball signal and exponential background

forward



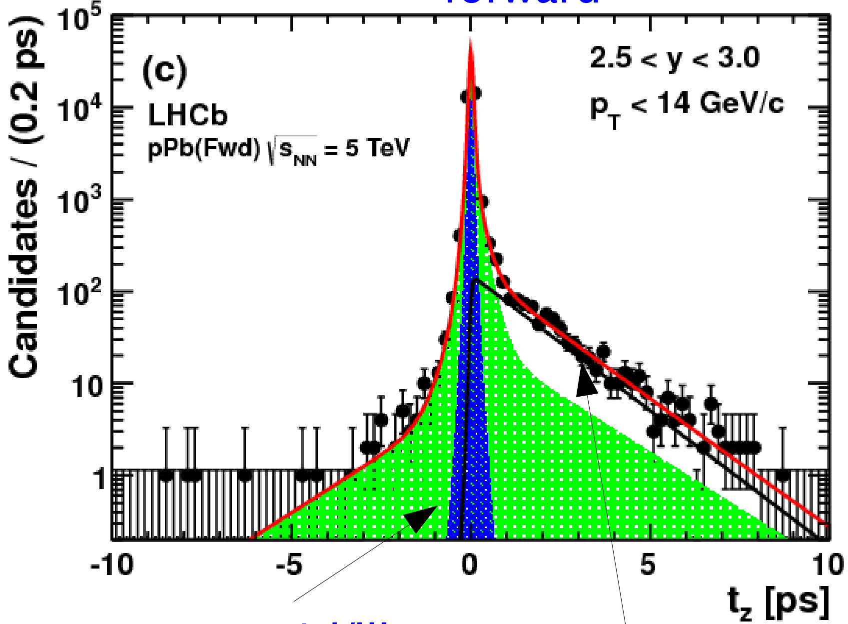
backward



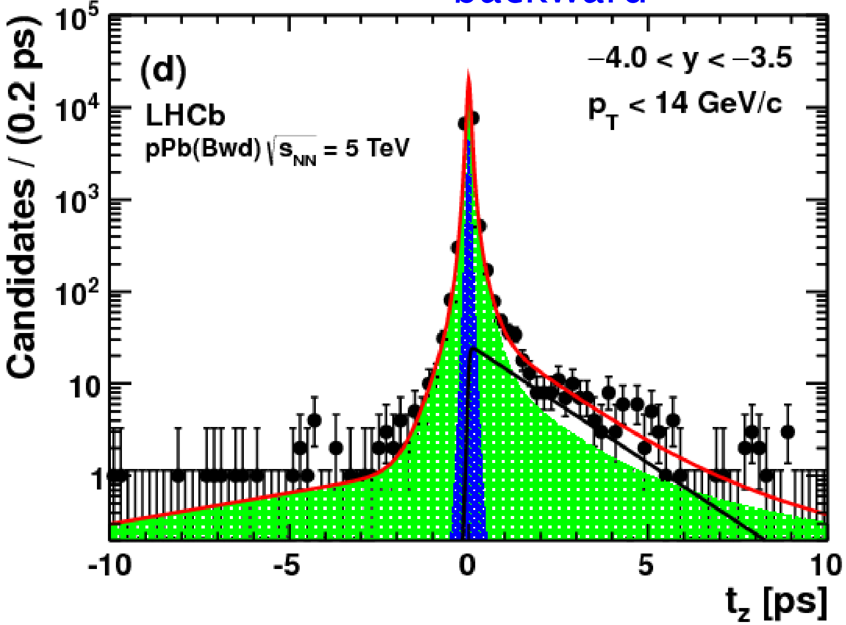
J/Ψ production in p-Pb collisions

Yields: simultaneous fit to mass & pseudo-proper time
Mass model: Crystal-Ball signal and exponential background
t_z model: exponential for J/Ψ's from b's convoluted with double Gaussian
δ function for prompt J/Ψ's convoluted with double Gaussian
empirical function (sPlot) from side-band for background

forward

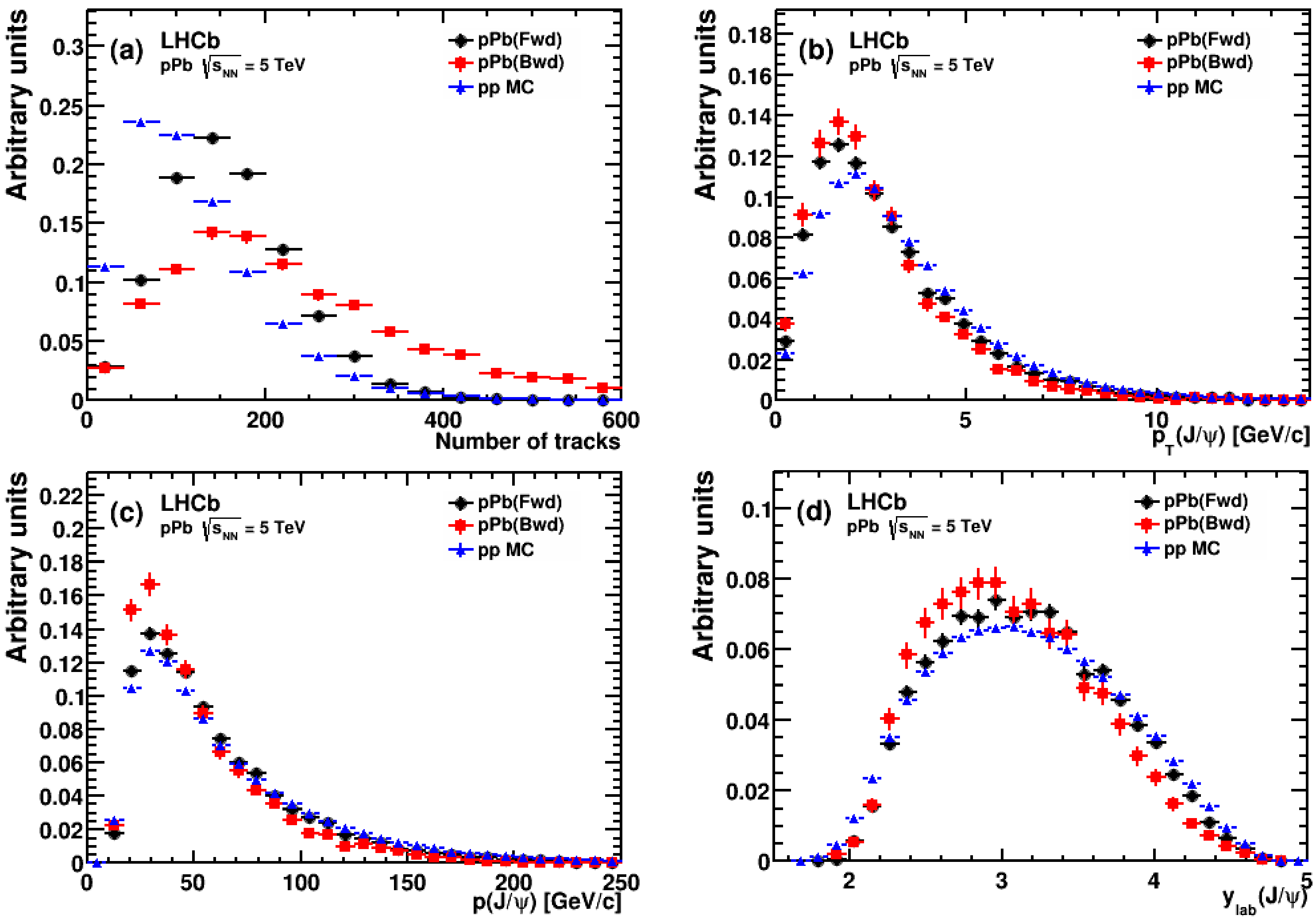


backward



J/Ψ production in p-Pb collisions

JHEP 02(2014) 072



Acceptance and efficiency corrections from pp simulation
pp simulation reweighted to describe track multiplicity

J/Ψ production cross-sections

pA: $1.5 < y < 4.0$

prompt: $\sigma = 1168 \pm 15\ (stat) \pm 60\ (sys)\ \mu b$

from b's: $\sigma = 166 \pm 4.1\ (stat) \pm 9.2\ (sys)\ \mu b$

Ap: $-5.0 < y < -2.5$

prompt: $\sigma = 1293 \pm 49.8\ (stat) \pm 82\ (sys)\ \mu b$

from b's: $\sigma = 118 \pm 6.8\ (stat) \pm 12.2\ (sys)\ \mu b$

Prompt J/ψ cross section about 10 times higher than J/ψ from b

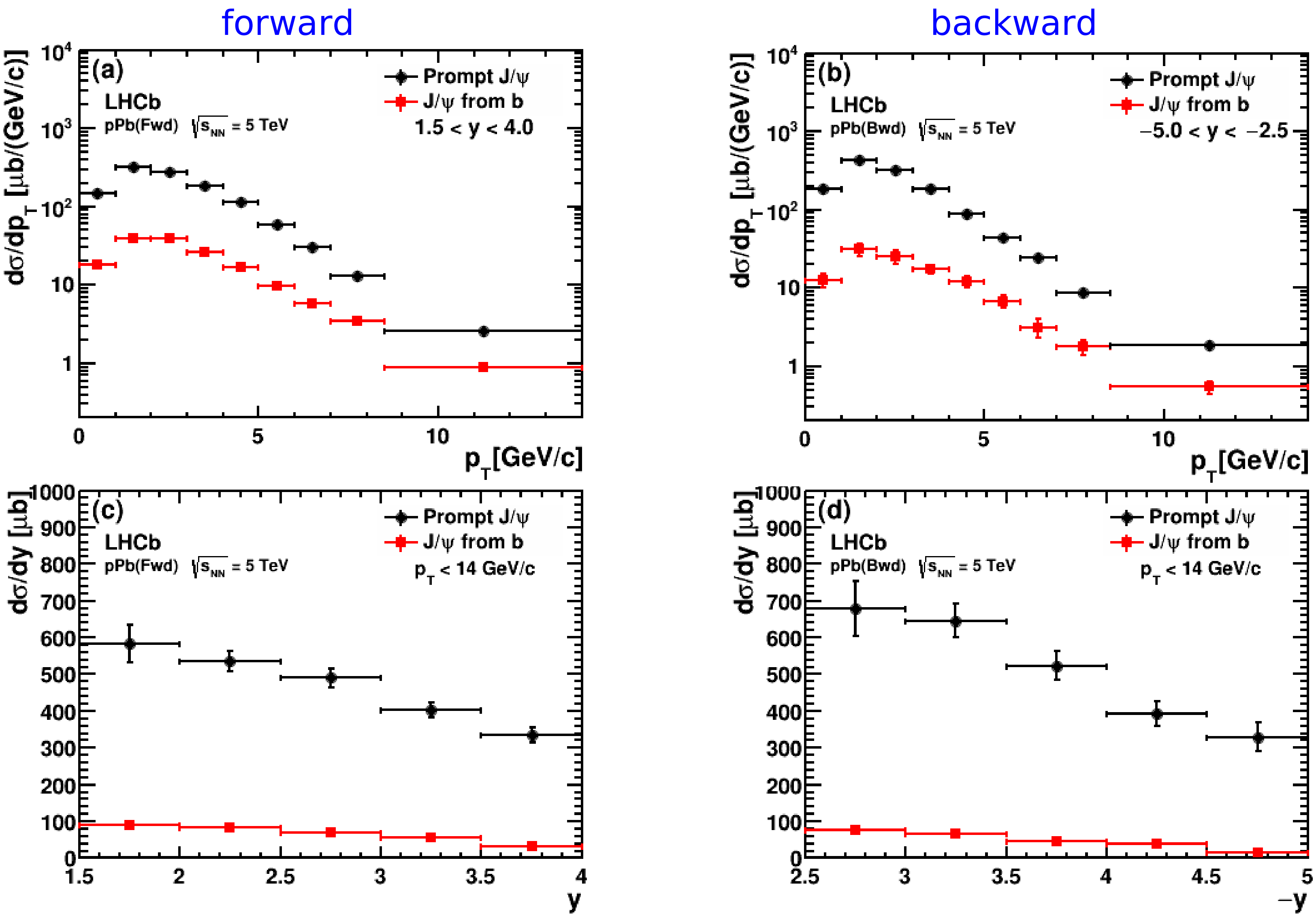
⇒ similar to the values observed in pp collisions at 2.76, 7 and 8 TeV

[JHEP 02 (2013) 041], [EPJC (2011) 71 1645], [JHEP 06 (2013) 064]

Largest systematic uncertainties:

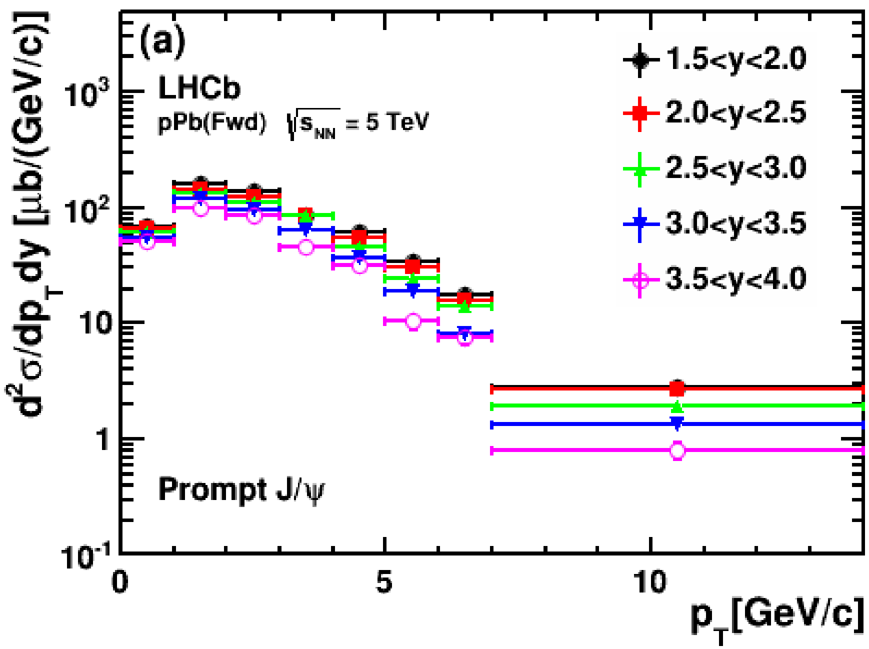
- mass model: 2.3-3.4%
- difference of pT and y distribution between simulation and data: 0.1-8.7%
- multiplicity reweighting: 0.1-4.3%
- tZ fit (only for J/ψ from b) 0.2-12%

Differential J/Ψ production cross-sections

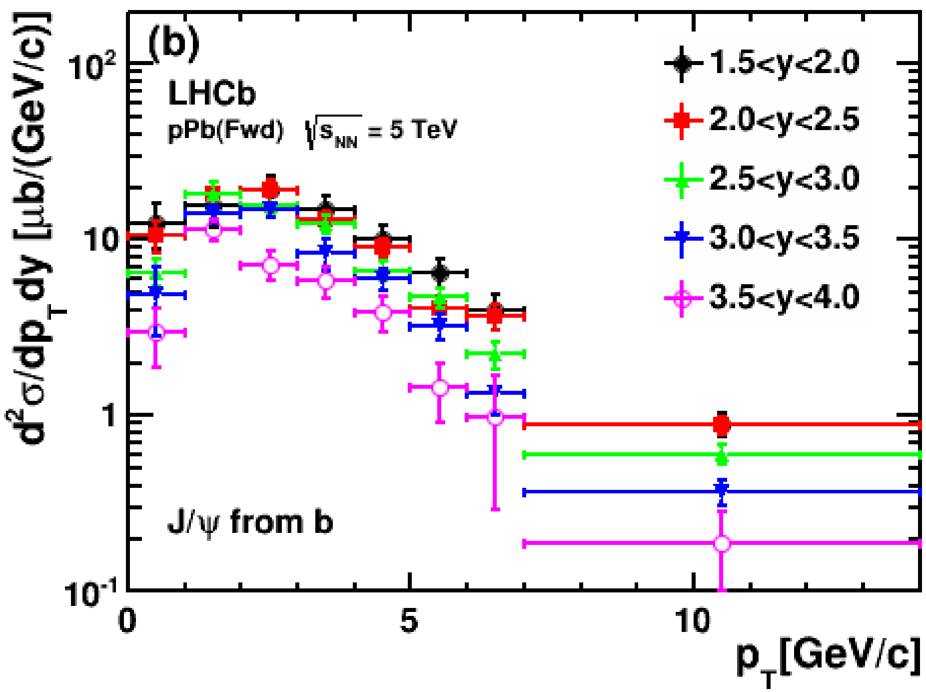


forward: double differential cross sections

prompt J/Ψ



J/Ψ from b



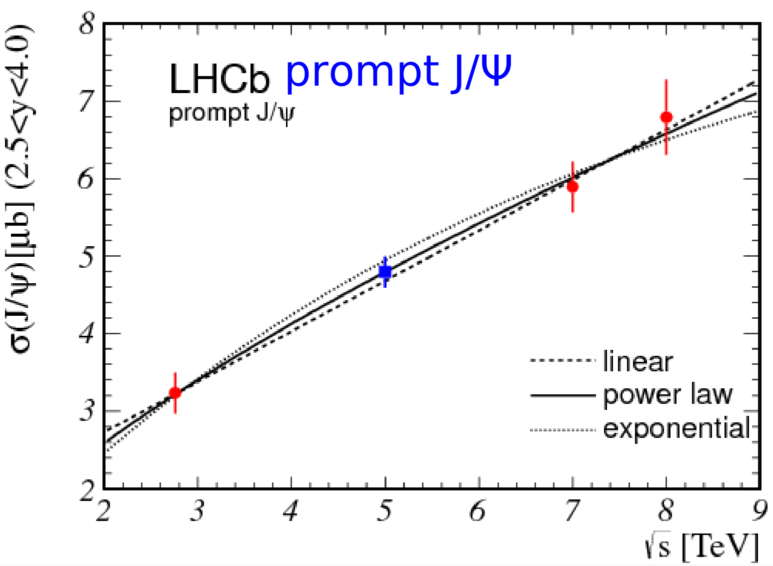
Cold nuclear effects

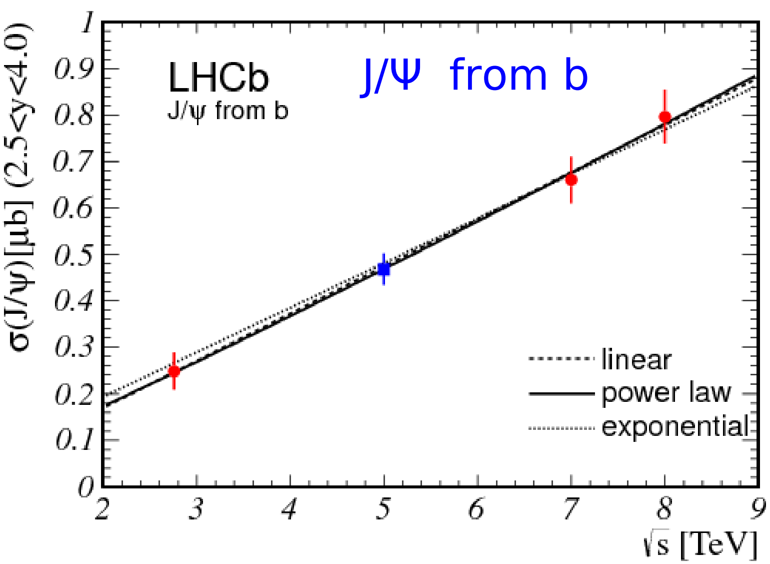
Quantified with measurement of

- Nuclear modification factor
  R_{pPb} =1/A ($d\sigma_{pA}$/dy) /($d\sigma_{pp}$/dy) in overlap region 2.5 < |y | < 4.0
  =1 if pA collision is superposition of A pp collisions
  <1 in case of suppression due to medium
- Forward backward production ratio
  R_{FB} = ($d\sigma_{pA}$/dy)/($d\sigma_{Ap}$/dy) in overlap region 2.5 < |y | < 4.0
  → many uncertainties cancel

Reference pp cross section at 5 TeV not measured directly:
interpolation of σ_{pp} at √s=2.76, 7 and 8 TeV

JHEP 02(2013)041, EPJC (2011) 71 1645, JHEP 06 (2013) 064

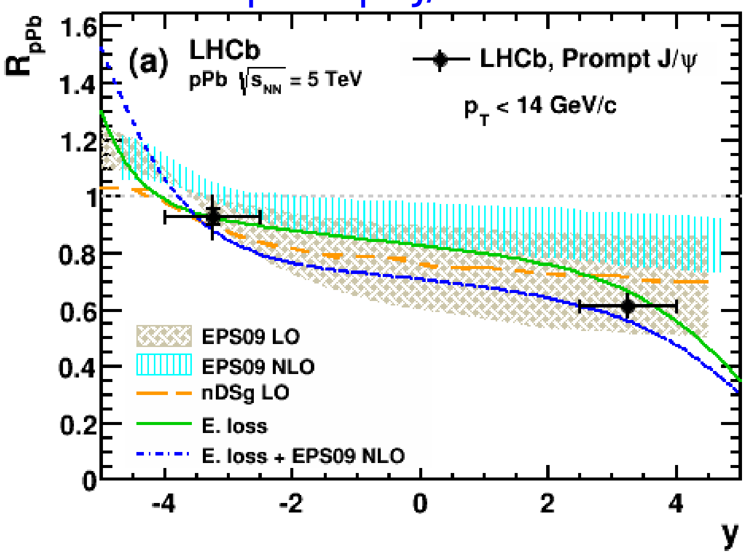




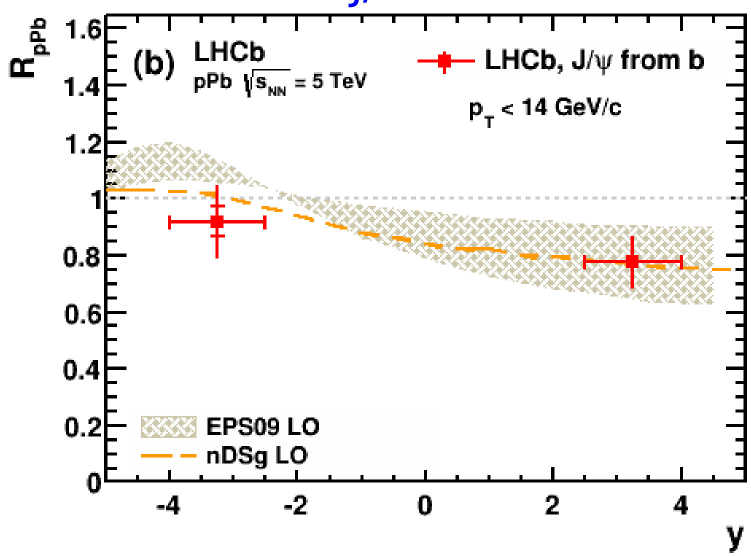
Nuclear modification factor R_{pPb}

$R_{pPb} = 1/A\ (d\sigma_{pA}/dy)\ /(d\sigma_{pp}/dy)$ in overlap region $2.5 < |y| < 4.0$

prompt J/Ψ



J/Ψ from b



Prompt J/Ψ: significant sign of cold nuclear matter effects: 40%
measurements agree with most of the predictions

J/Ψ from b: modest supression wrt pp
first indication of suppression of b hadron production in Pb
agreement with predictions in forward region

Predictions:

LO CSM with EPS09 or nDSg parametrisation for modification of PDFs

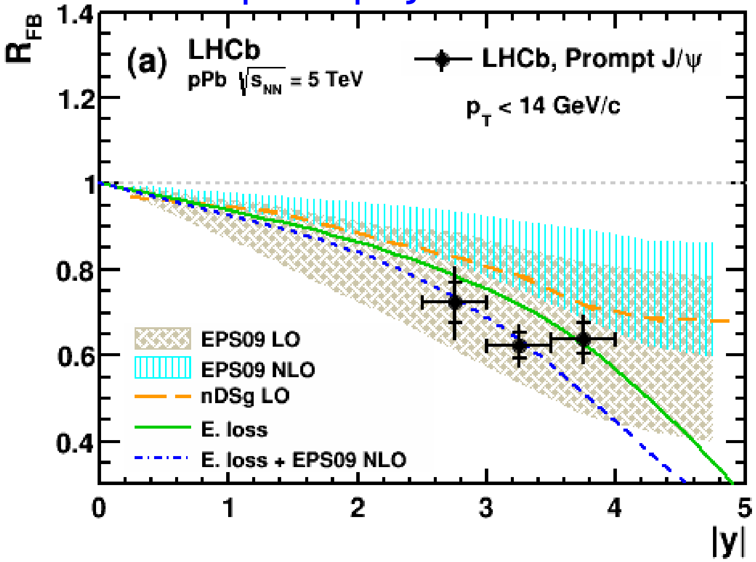
Energy loss effects of initial and final state partons with or without modification

EPS09:JHEP 0904 (2009) 65, nDSG:Phys. Rev.D69(2004) 074028
Energy loss: JHEP 03(2013) 122, LO: Nucl. Phys. B127 (1980) 425, Phys. Lett. B102, (1981) 364
NLO: Phys. Rev. D17 (1978) 2324

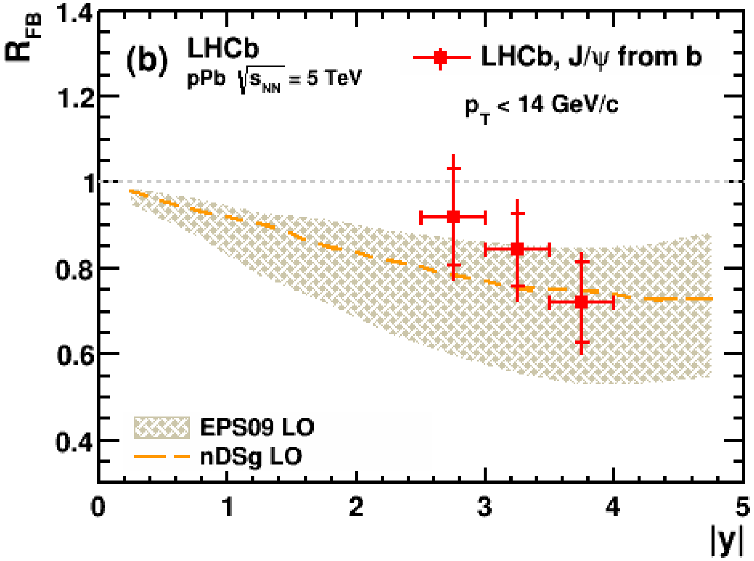
Forward-backward production ratio R_{FB}

$R_{FB} = (d\sigma_{pA}/dy)/(d\sigma_{Ap}/dy)$ in three bins in |y |

prompt J/Ψ



J/Ψ from b



Prompt J/Ψ: significant forward-backward asymmetry
J/Ψ from b: R_{FB} closer to one

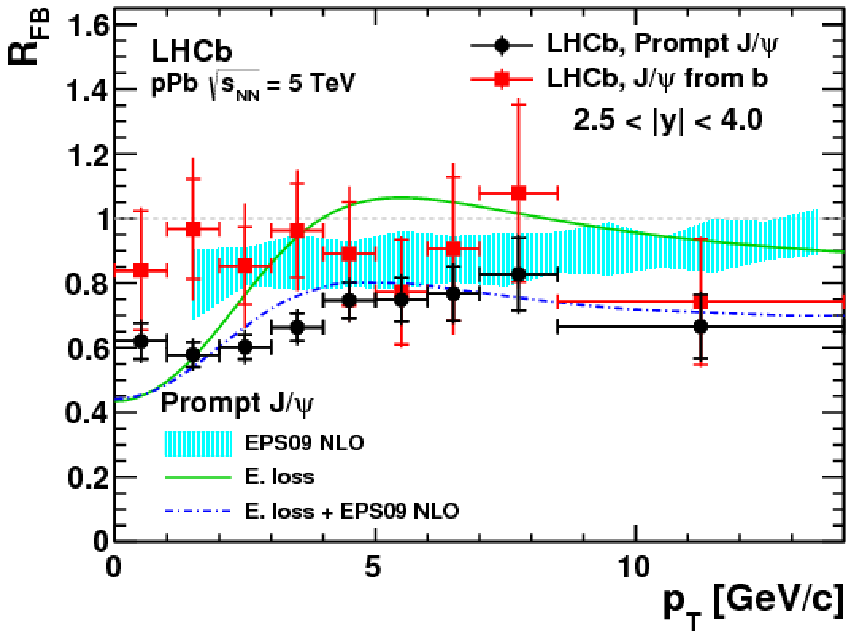
EPS09(NLO) predicts smaller asymmetry for prompt J/Ψ

Predictions:
LO CSM with EPS09 or nDSg parametrisation for modification of PDFs
Energy loss effects of initial and final state partons with or without modification

R_{FB} vs transverse momentum

JHEP 02(2014) 072

R_{FB} in bins of p_T, integrated over y

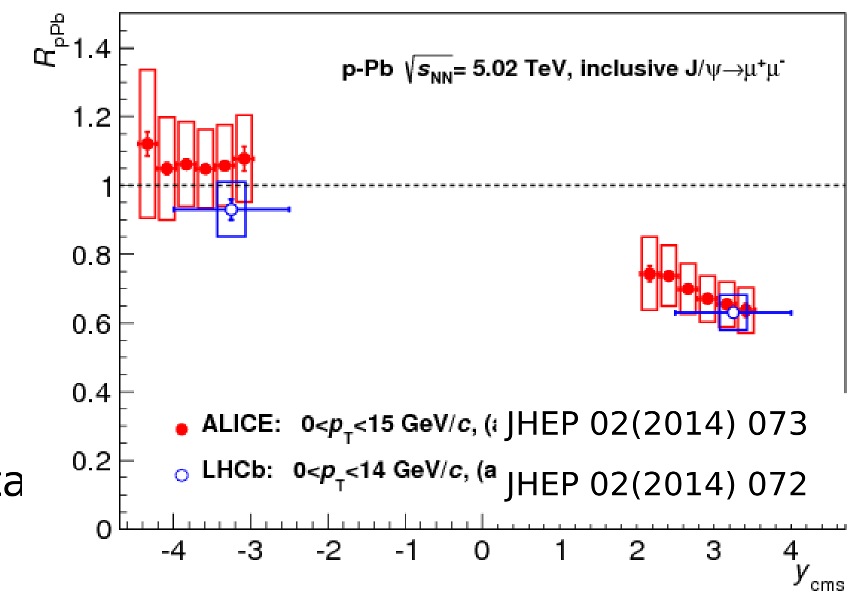


Predictions for prompt J/Ψ only

EPS09(NLO) plus energy loss agrees with data

Comparison to ALICE

Sum of prompt J/Ψ and J/Ψ from b in good agreement with ALICE JHEP 02(2014) 073



Υ production in p-Pb collisions

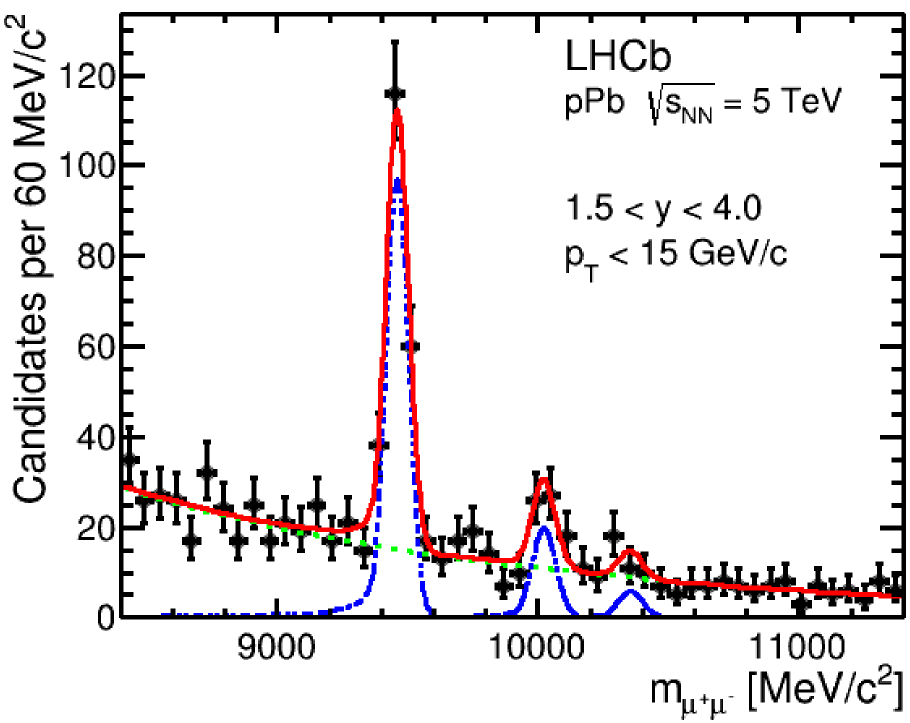
arXiv:1405.5152

- reconstruct Υ in di-muon channel
- forward 1.5<y<4.0 and backward -5.0<y<-2.5
- p_T < 15 GeV

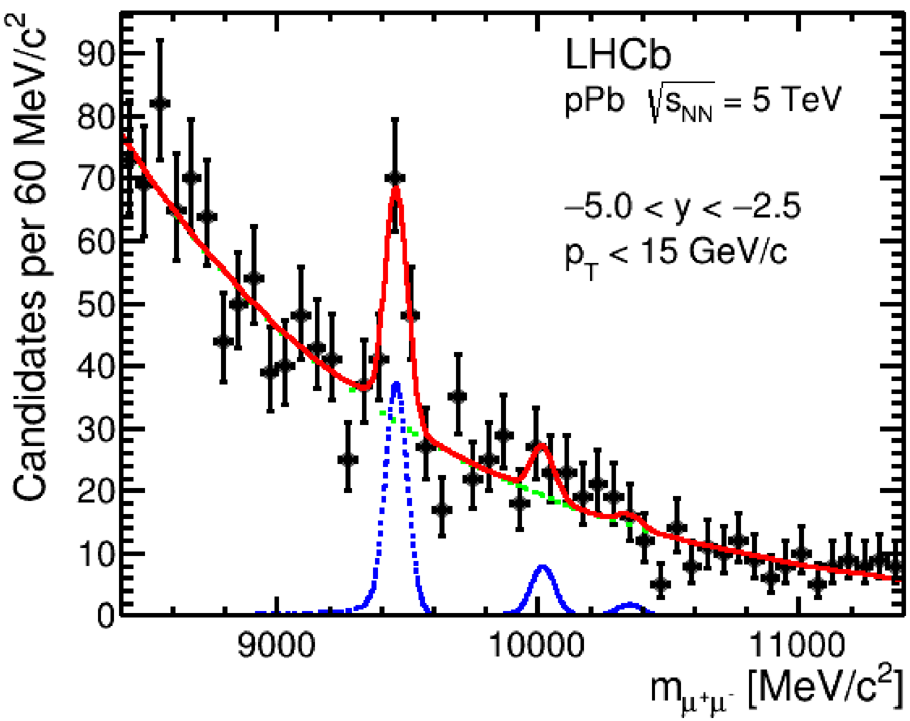
low statistics → no differential measurement

Yields: fit to mass
Mass model: three Crystal-Balls for signal and exponential background

forward



backward



Υ production in p-Pb collisions

arXiv:1405.5152

Cross-section times branching fraction, integrated over p_T and y

$\sigma(\Upsilon(nS)) \times \mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-)$	**Forward**	**Backward**
$\Upsilon(1S)$	$380 \pm 35_{\rm stat} \pm 19_{\rm syst}$ nb	$295 \pm 56_{\rm stat} \pm 27_{\rm syst}$ nb
$\Upsilon(2S)$	$75 \pm 19_{\rm stat} \pm 5_{\rm syst}$ nb	$81 \pm 39_{\rm stat} \pm 17_{\rm syst}$ nb
$\Upsilon(3S)$	$27 \pm 16_{\rm stat} \pm 4_{\rm syst}$ nb	$<$ 39 nb @ 90 % C.L.

Relative suppression factor $R^{nS/1S}$	**Forward**	**Backward**
$R^{2S/1S}$	$0.20 \pm 0.05_{\rm stat} \pm 0.01_{\rm syst}$	$0.28 \pm 0.14_{\rm stat} \pm 0.05_{\rm syst}$
$R^{3S/1S}$	$0.07 \pm 0.04_{\rm stat} \pm 0.01_{\rm syst}$	$<$0.13 @ 90 % C.L.

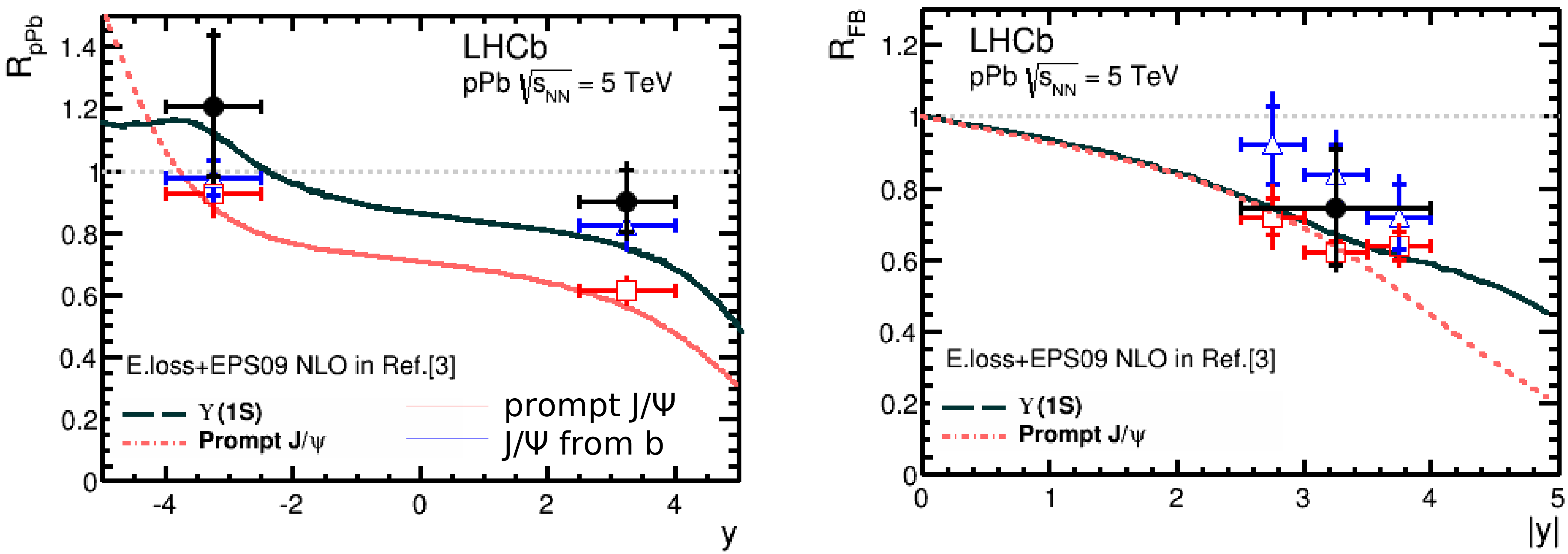
Statistical uncertainty is dominating
Dominant systematic uncertainties:

p_T and y dependence of signal 4%(forward) 7%(backward)

or trigger efficiency : 2%(forward) 5%(backward)

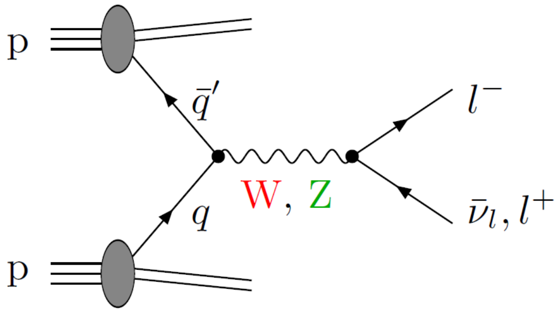
Υ production: cold nuclear effects

Measurement of R_{pPb} and R_{FB} with Υ(1S) complementary to J/Ψ (probing different x_A)



- Cold nuclear effects are also visible with Υ(1S) production
- Suppression in forward region smaller than for J/Ψ
- Possible enhancement in backward region due to anti-shadowing
- Agreement with prediction EPS09(NLO) for nPDF and with and without energy loss

Z production



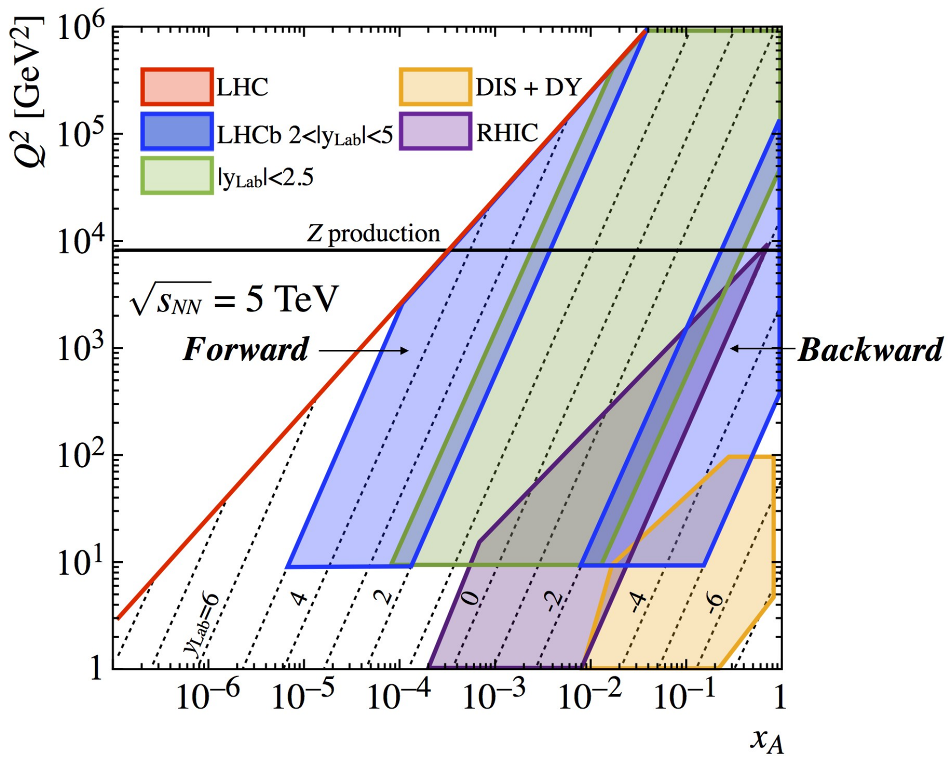
LHCb probes two distinct regions in

x–Q^2: $x_{1,2}=(Q/\sqrt{s})\, e^{\pm y}$

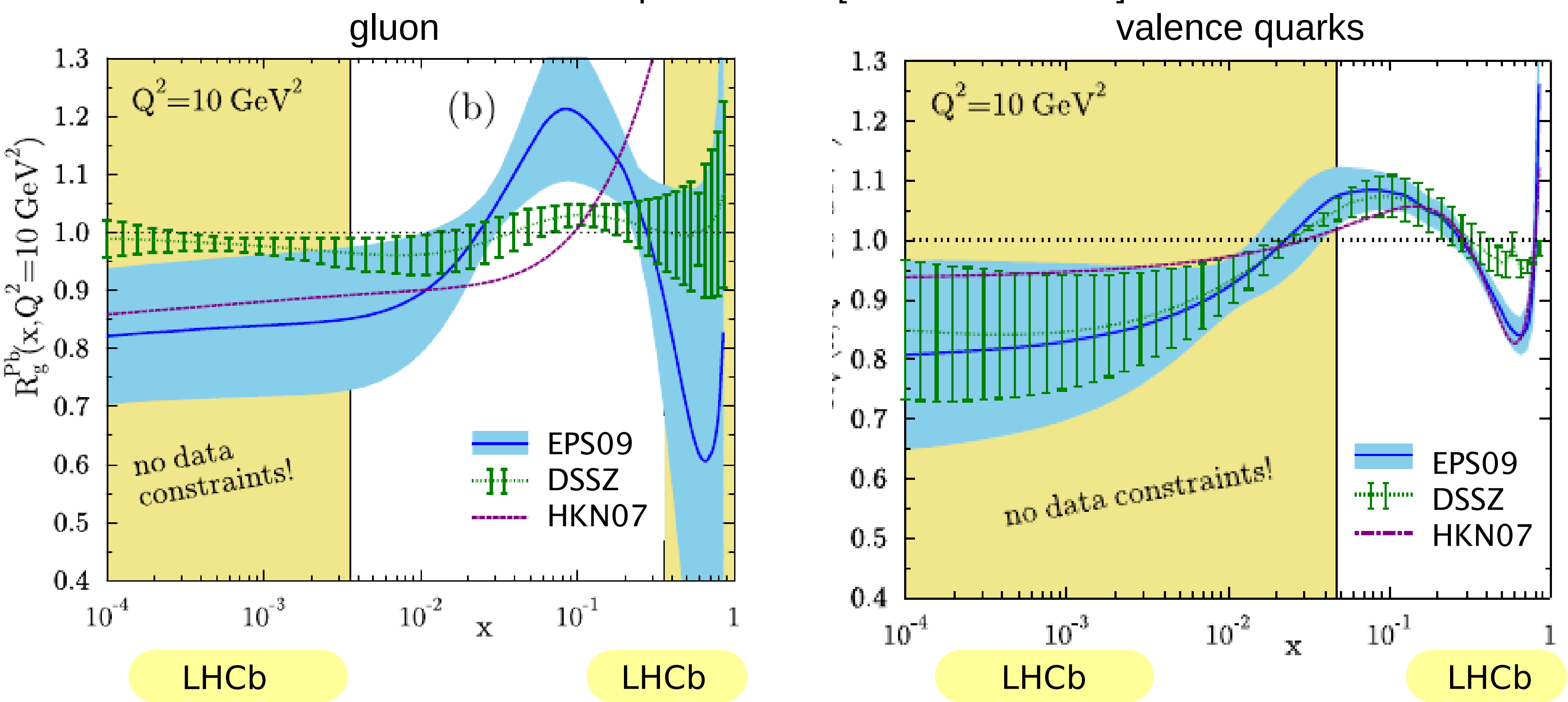
Forward kinematics:
@ first order, collision of a sea and a valence quark

Complementary to ATLAS/CMS

LHCb phase space:
→ sensitivity to nuclear PDF at large x_A and low x_A



Ratio of nuclear PDF for Pb to bare proton PDF [arXiv:1401.2345]

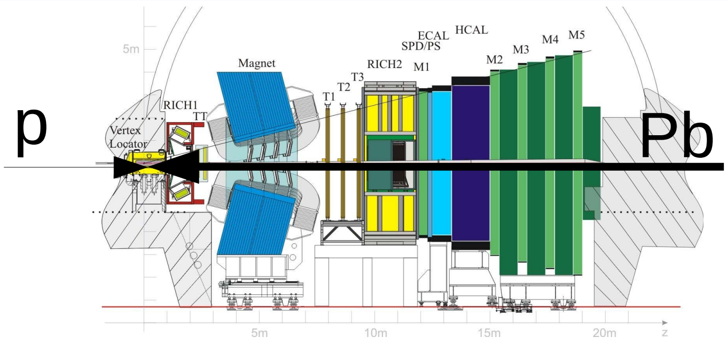


Nuclear PDF (nPDF) poorly constrained at high and low x_A, where measurements at LHCb have a good sensitivity.

LHCb sensitivity: 2×10^{-4}–3×10^{-3} and 0.2–1 at $Q^2 = M_Z^2$

EPS09: JHEP 04 (2009) 065, DSSZ : Phys. Rev. D 85 (2012),HKN07: Phys. Rev. C 76 (2007) 065207

Z production in proton–lead



Forward: pA collisions

Luminosity: 1.099 ± 0.021 nb^{-1}

Selection:

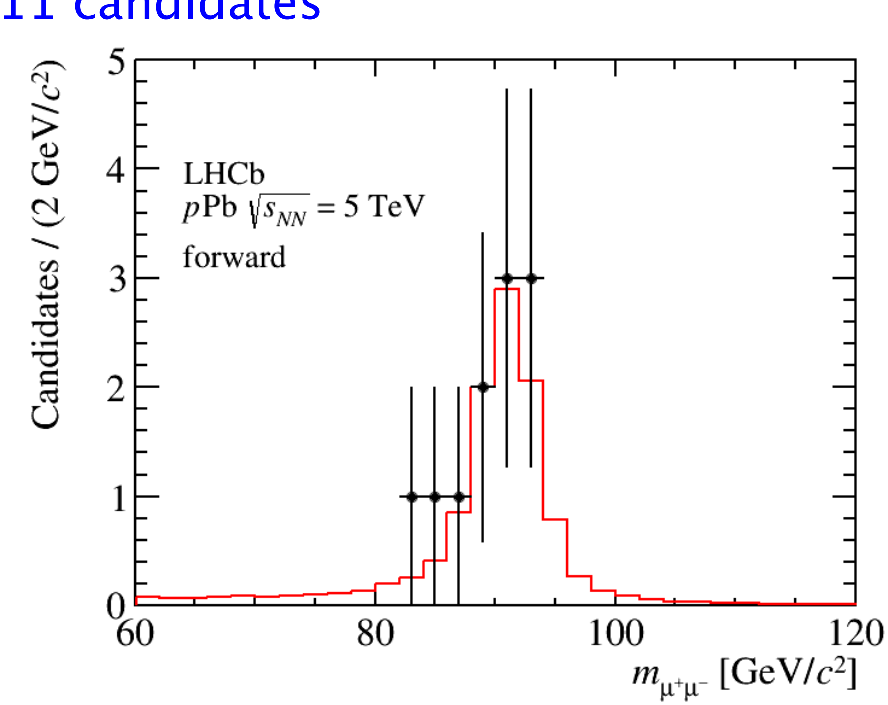
muons: $p_T > 20$ GeV, $2 < \eta < 4.5$

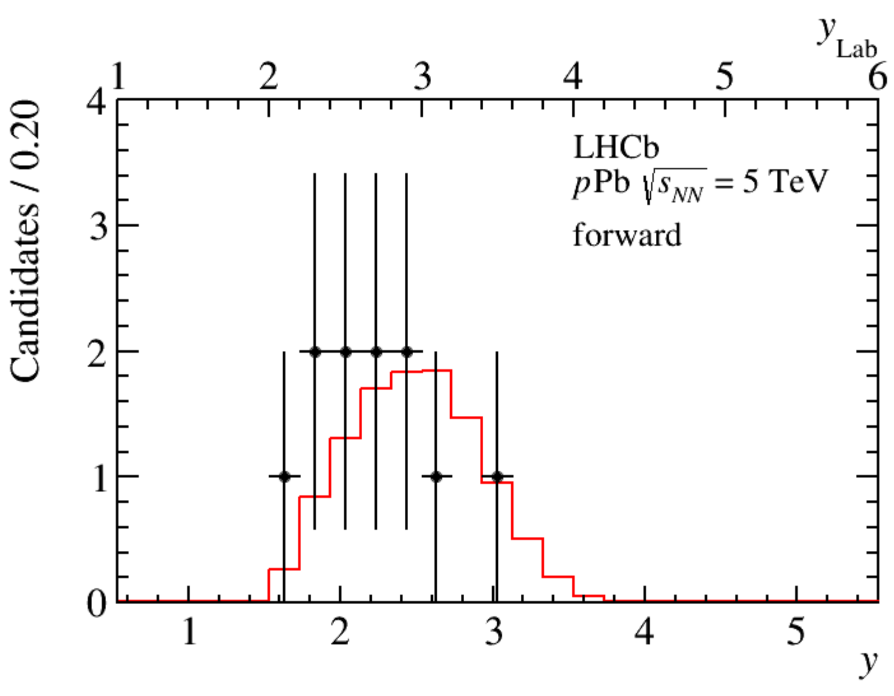
mass: $60 < M_{\mu\mu} < 120$ GeV^2

Purity:

from data: about 99.7%

11 candidates

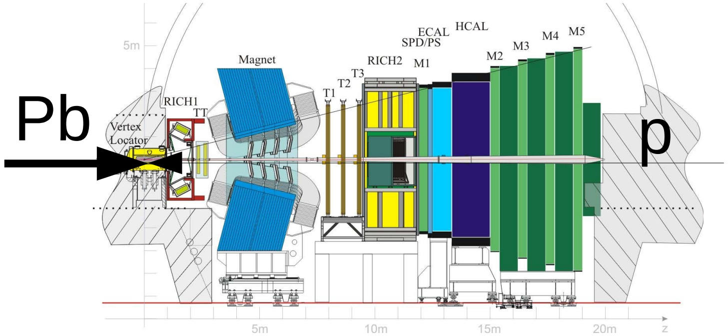




Z production in proton–lead

Backward: Ap collisions

Luminosity: $0.521 \pm 0.011\ \text{nb}^{-1}$



Selection:

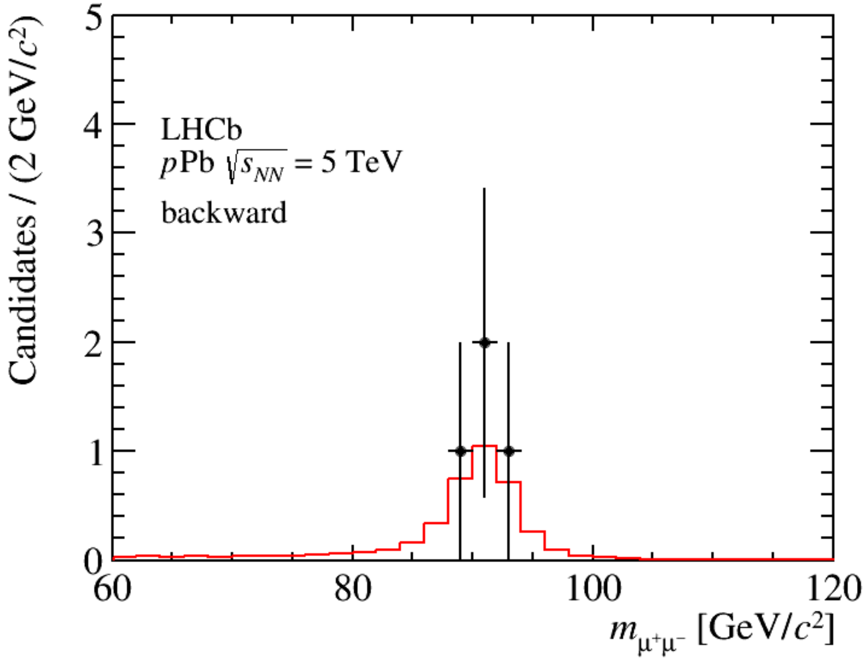
muons: $p_T > 20$ GeV, $2 < \eta < 4.5$

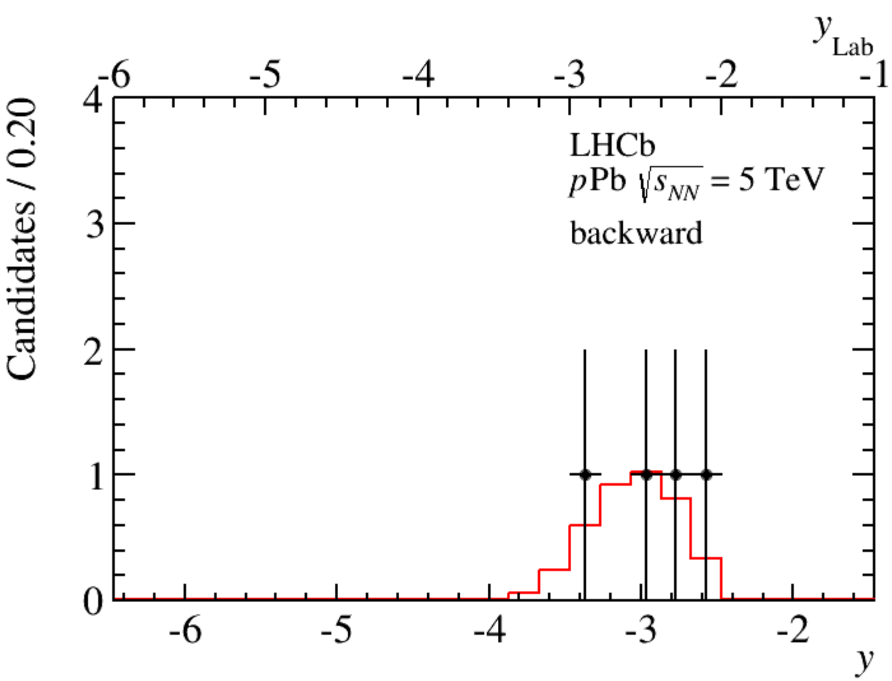
mass: $60 < M_{\mu\mu} < 120$ GeV^2

Purity:

from data: about 99.6%

4 candidates



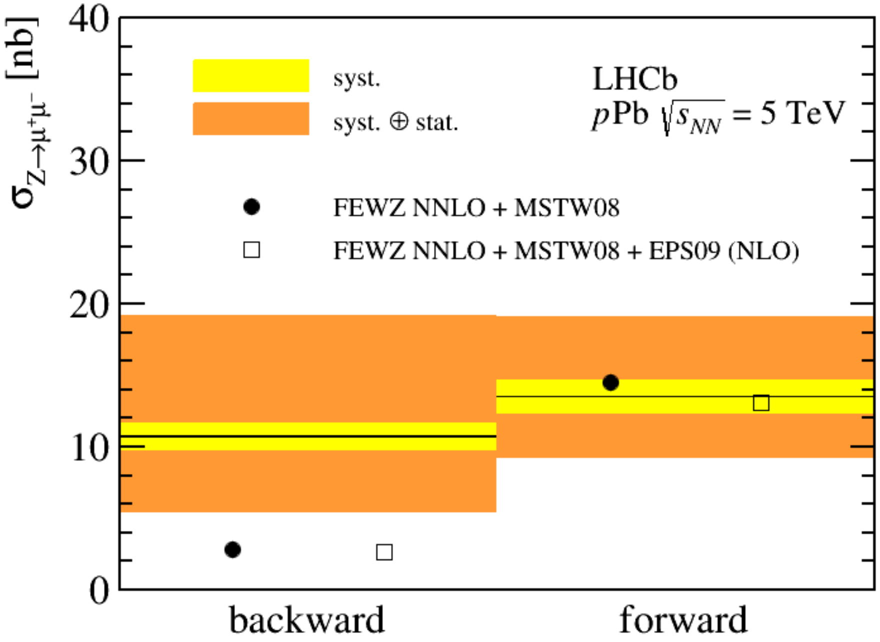


Z production in proton–lead

Efficiencies, purity from data
Cross sections:

forward:
$\sigma_{Z(\rightarrow\mu+\ \mu-)} = 13.5^{+5.4}_{-4.0}$ (stat.) ± 1.2(syst.) nb
backward:
$\sigma_{Z(\rightarrow\mu+\mu-)} = 10.7^{+8.4}_{-5.1}$ (stat.) ± 1.0(syst.) nb

Theoretical predictions:
NNLO calculations (FEWZ)
nuclear modification: EPS09(NLO)



future higher statistics measurements
will provide important information
on nuclear PDFs

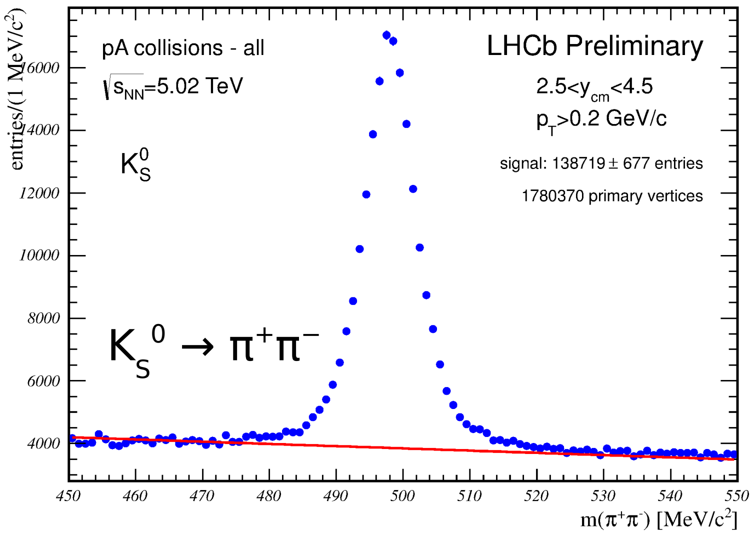
FEWZ: Y. Li and F. Petriello, Phys. Rev. D86 (2012) 094034, arXiv:1208.5967.

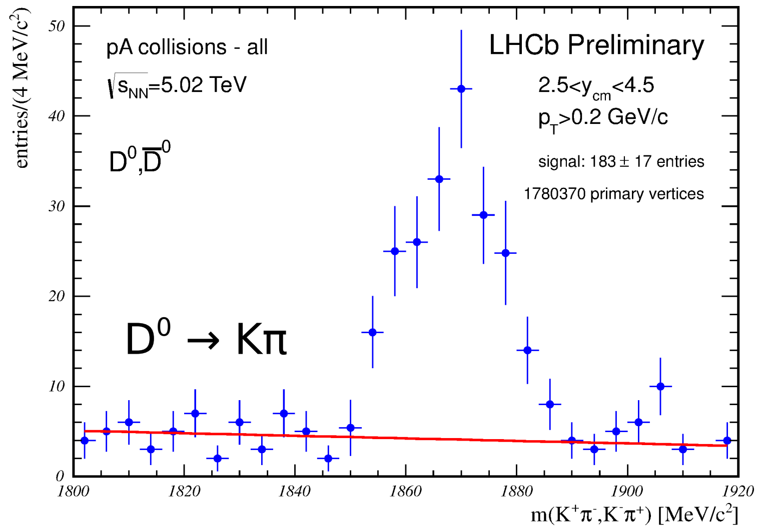
EPS09: K. Eskola, H. Paukkunen, and C. Salgado, JHEP 04 (2009) 065, arXiv:0902.4154.

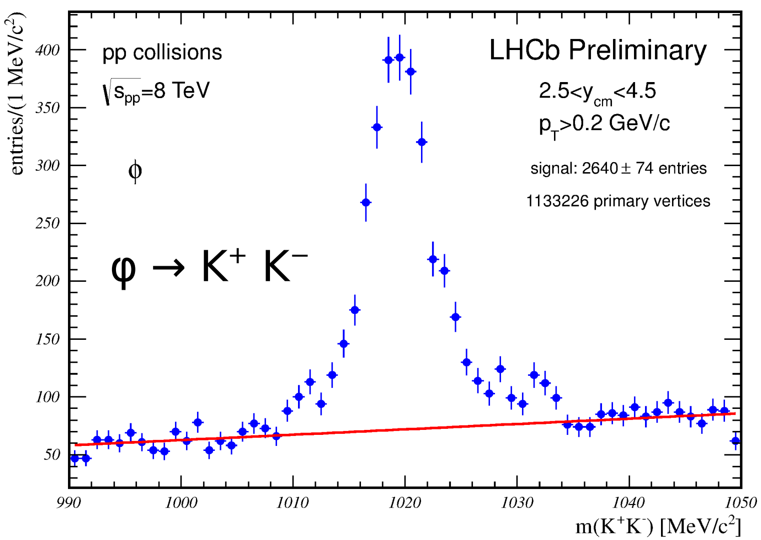
Fiducial volume
muons: p_T>20 GeV, 2<η<4.5
mass: 60<M(μμ)<120 GeV^2

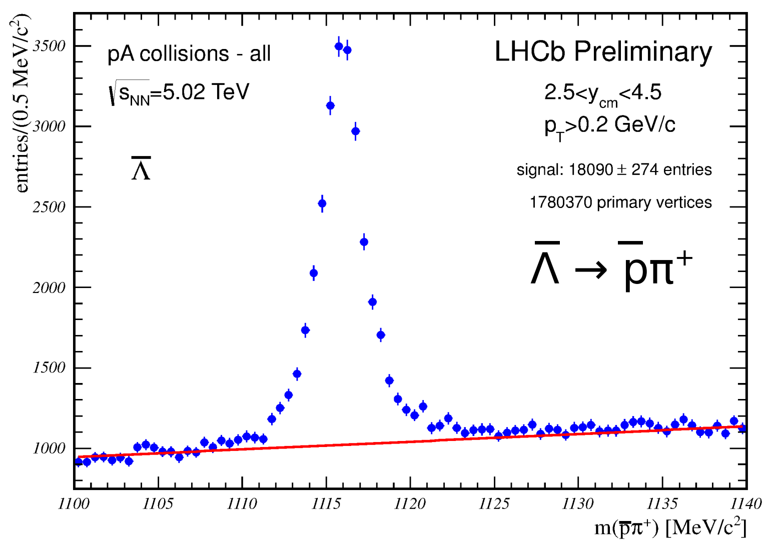
Outlook: Strangeness & Charm production

Results from pilot run: 0.9 μb





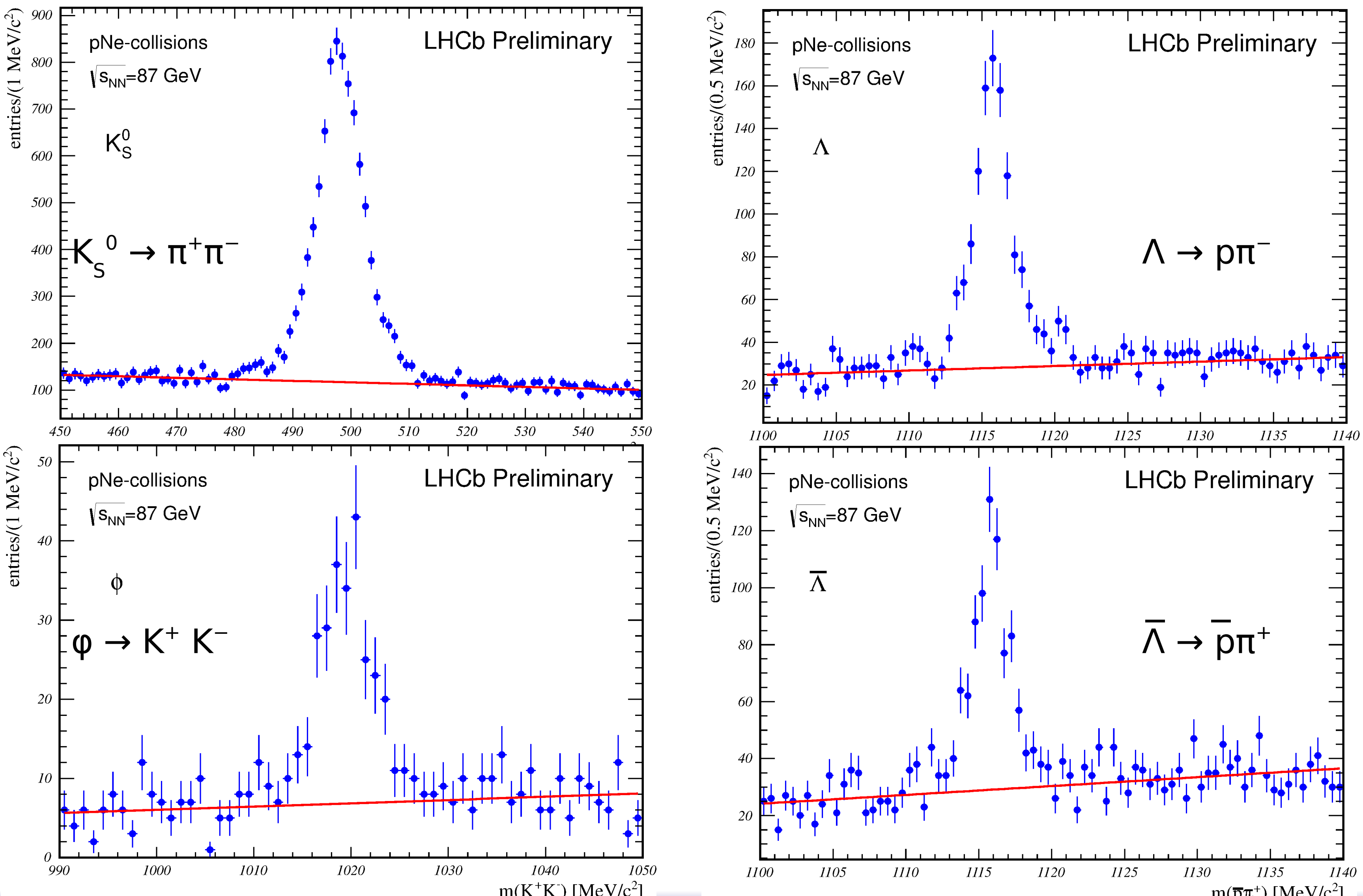




Outlook: Fixed target physics at LHCb

LHCb-CONF-2012-034

Inject Ne gas, measure beam-gas pNe (or PbNe) interaction at s=87 GeV



Summary and Outlook

- LHCb successfully participated in proton-lead runs
- Measurement of J/ψ and Υ production
  → cold nuclear matter effects visible in J/ψ and Υ (1S) production
- First observation of Z production in proton-nucleus collisions
- Many more measurements ongoing
- Measurements limited by statistics
  → benefit from larger data samples after the restart of LHC
- In addition, we have sample of pNe and PbNe data
- Only a small part of LHCbs potential so far used

Backup slides

SMOG: System for Measuring Overlap with Gas