Quarkonium Production in pPb and PbPb collisions with LHCb

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on behalf of the LHCb collaboration

Overview

- Introduction
  - LHCb detector and physics motivation
- Quarkonium Production in pPb collisions
  - Cold Nuclear Matter effects in J/ψ, $\psi(2S)$ and Υ-production
- First look at quarkonium production in PbPb collisions
  - Centrality determination and first look at J/ψ-production
- Prospects for the pPb run in November 2016
- Conclusions

LHCb Detector

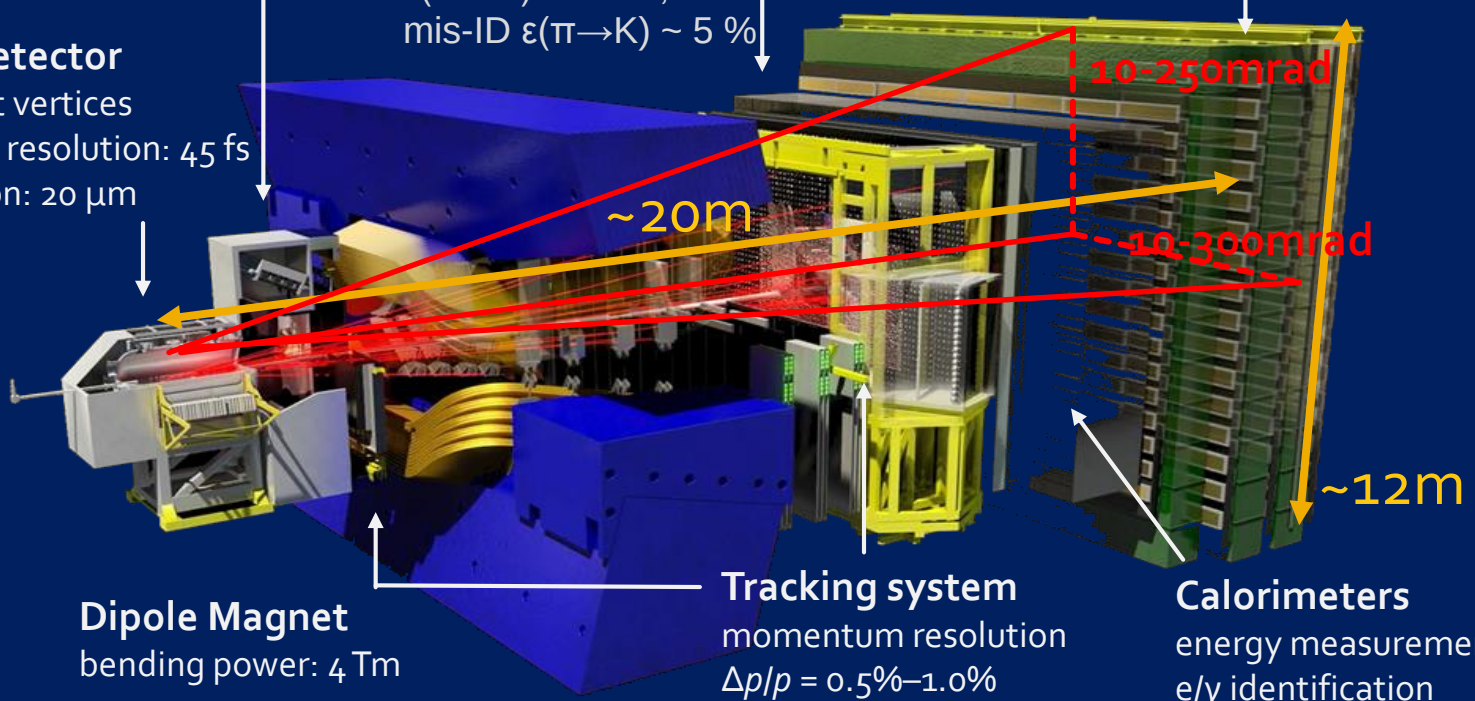
- Single arm spectrometer in the forward direction
  - designed for b-physics – but capable to address many other topics …
  - fully instrumented in its angular acceptance
  - forward and backward coverage for asymmetric beams

[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]

RICH detectors
K/π/p separation
ε(K→K) ~ 95 %,
mis-ID ε(π→K) ~ 5 %

Muon system
μ identification ε(μ→μ) ~ 97 %,
mis-ID ε(π→μ) ~ 1-3 %

Vertex Detector
reconstruct vertices
decay time resolution: 45 fs
IP resolution: 20 μm



Dipole Magnet
bending power: 4 Tm

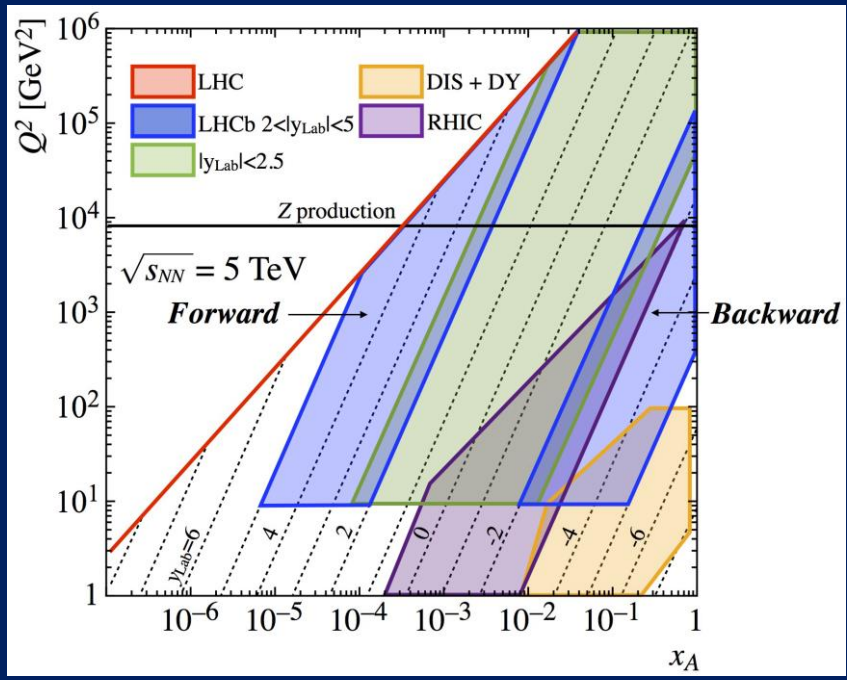
Tracking system
momentum resolution
$\Delta p/p$ = 0.5%–1.0%
(5 GeV/c – 100 GeV/c)

Calorimeters
energy measurement
e/γ identification
$\Delta E/E = 1\,\% \oplus 10\,\%/\sqrt{E\,(\mathrm{GeV})}$

Experimental approach

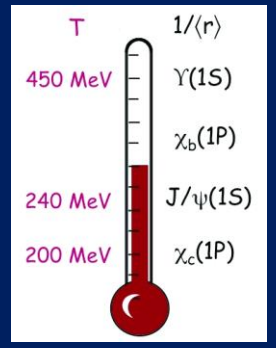
- LHCb can make valuable contributions to the study of proton – nucleus and nucleus-nucleus collisions in the forward region with a precision not accessible to other experiments:
  - Good vertexing with possibility to separate prompt and from *B* decay products
  - Precise tracking down to very low p_T and excellent particle identification, including hadronic decays

- Example:
  - PDFs can be probed via quarkonia, EW and Drell-Yan measurements
  - Contribution from two x-regions for Q^2 and y ($x_{1,2} = e^{\pm y}\ Q / 2\sqrt{s}$)
  - ➢ Complementary measurement to ATLAS and CMS



Motivation for Heavy Flavour studies

- Heavy flavour / quarkonium production are an important probe
  - to disentangle QGP effects from Cold-Nuclear-Matter (CNM) effects
  - to understand energy-loss and medium-transport mechanisms in nucleus collisions and sequential melting for quarkonia.



- Different kinds of CNM effects can be considered:

1. Initial state:
   - **Nuclear shadowing** (= Gluon shadowing at the LHC) [K.J. Escola, JHEP 0904 065]
   - **Gluon saturation** (described in CGC model) [D. Kharzeev ,Nucl. Phys A77 (2006) 40]
   - **Radiative energy loss** [S. Gavin et al. Phys.Rev.Lett 68 (1992) 1834]
   - **Cronin effects** [J.W. Cronin et al. Phys. Rev. D 11 (1975) 3105]
2. Final state:
   - **Nuclear absorption** (small at the LHC) [R. Vogt, Nucl. Phys. A700 (2002) 539]
   - **Radiative Energy Loss** [R. Vogt, Phys. Rev C 61 (2000) 035203]
   - **Comovers** [E. Ferreiro, Phys. Lett B749 (2015) 98]
3. Coherent parton energy-loss:
   - **Multiple elastic scatterings** [F. Arleo et al. Phys. Rev Lett 109 (2012) 122301]

Quarkonium production in proton-lead collisions

Setup for Proton-Ion physics

***p*Pb**

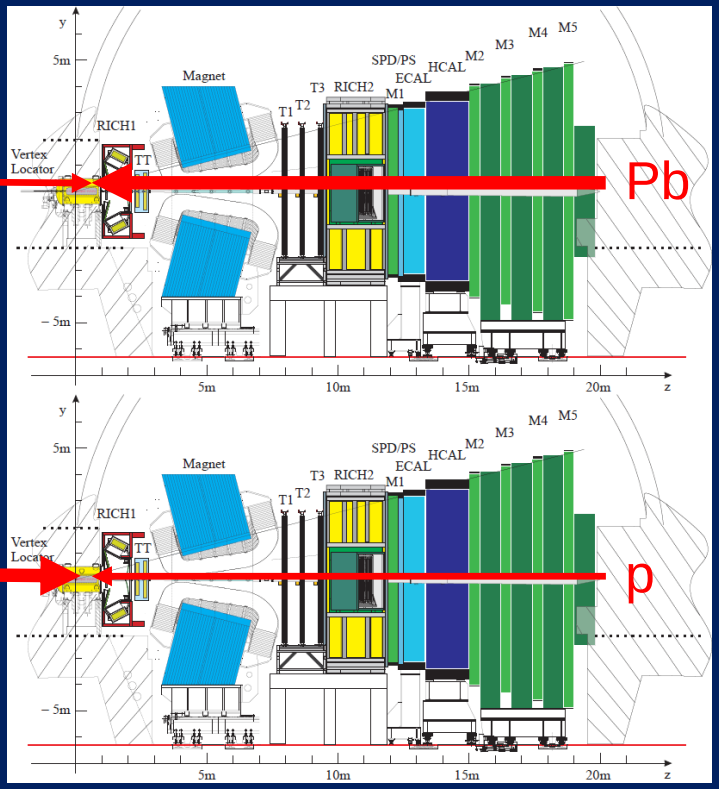
p

E_p=4 TeV

Pb*p*

Pb

E_{Pb}= 1.58 TeV



Rapidity coverage

pp: 2 < y < 5

Forward production

y = 0.47 in lab

*p*Pb: 1.5 < y < 4.5

Data taken in 2013: ~1.1/nb

Backward production

y = -0.47 in lab

Pb*p*: -5.5 < y < -2.5

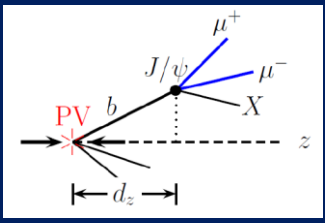
Data taken in 2013 ~0.5/nb

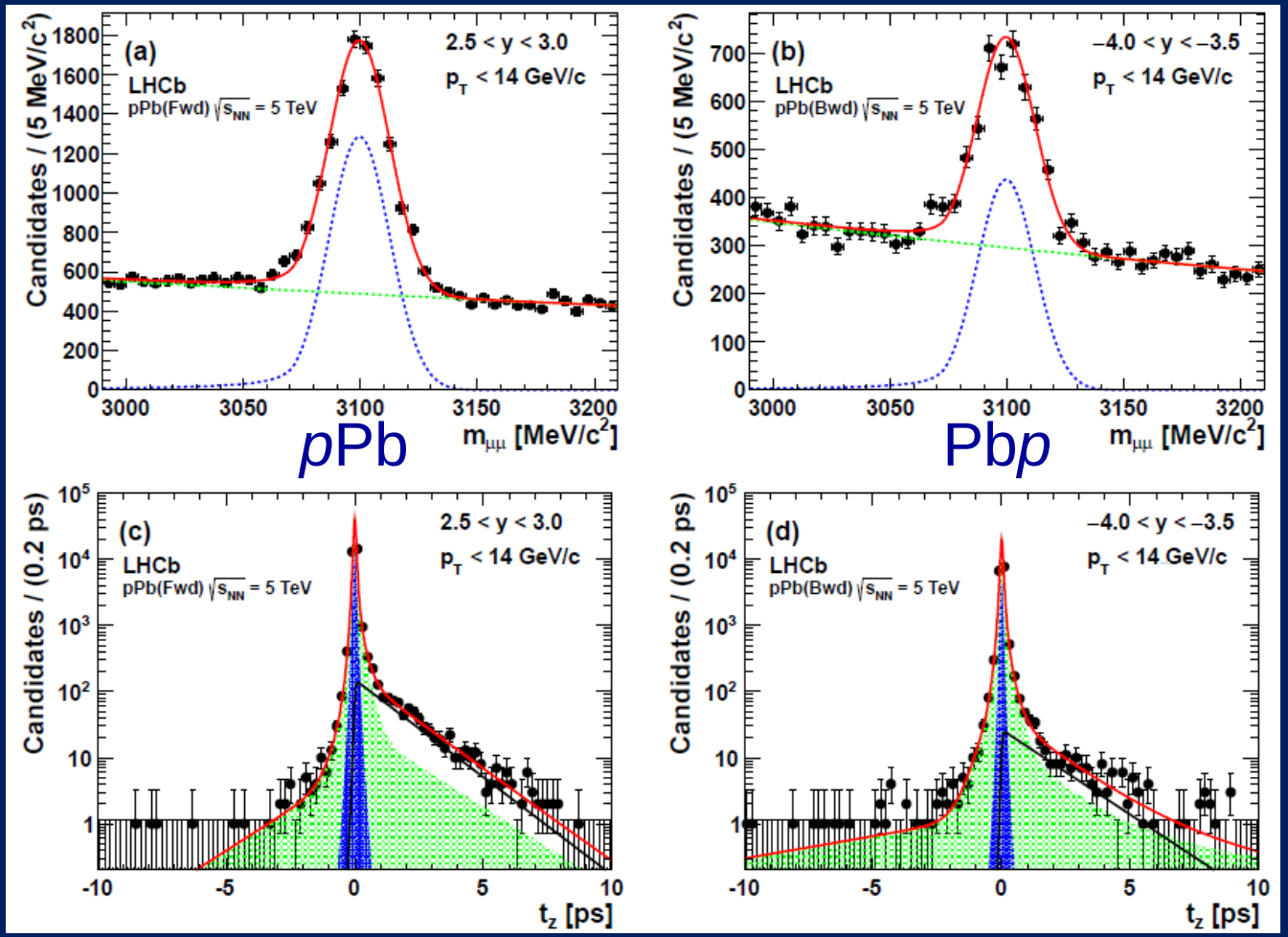
- Common range for measurements: 2.5 < |y| < 4
- Center-of-mass energy : $\sqrt{s_{NN}} \approx 5$TeV

J/ψ & $\psi(2S)$ production in pPb collisions

- Prompt J/ψ and J/ψ from b are extracted by simultaneous fit of mass and pseudo-proper time : $t_z = (Z_{J/\psi} - ZPV) \times M_{J/\psi} / p_Z$

  [JHEP 02 (2014) 072]





Mass distributions:

- Signal : Crystal-Ball fct.
- Bkg : exponential
- red line: sum of all contr.

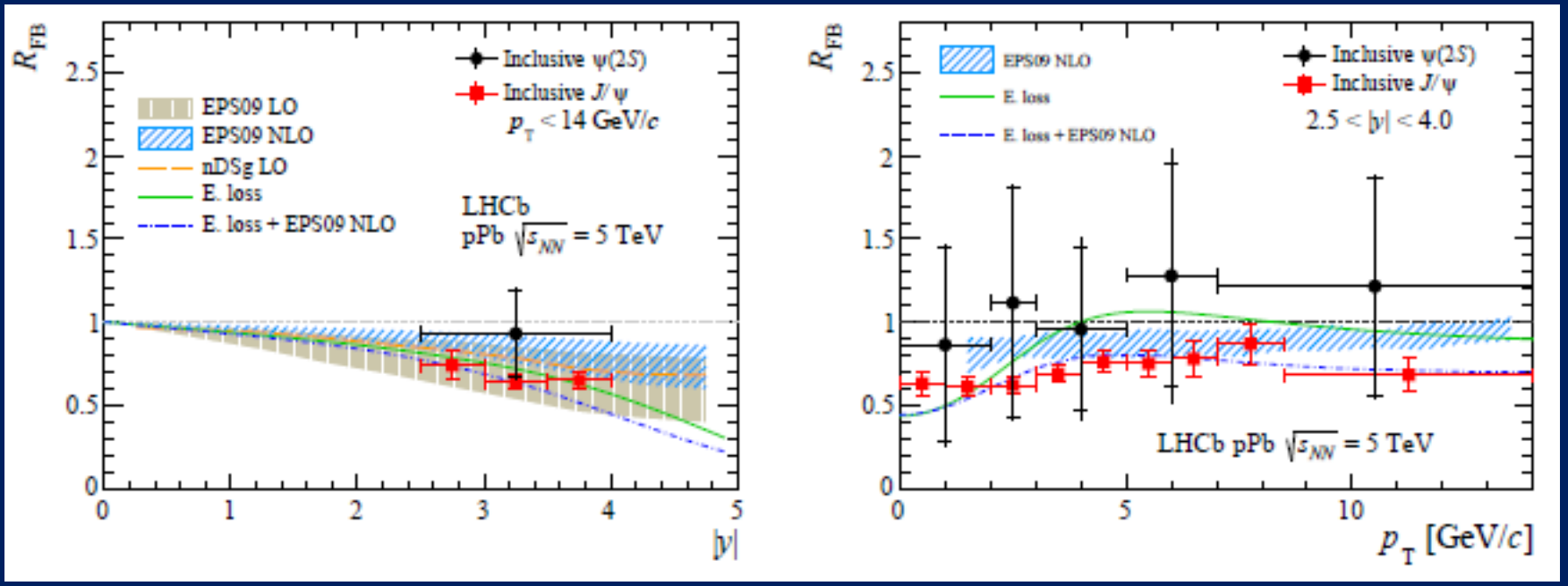
t_z distributions:

- Signal:
  - $\delta(t_z)$ for prompt J/ψ
    expo. for b-component
- Bkg: empirical function from sideband

blue line: prompt J/ψ
black line: J/ψ from b
Green hatched: comb. bkg
red line: sum of all contr.

J/ψ and $\psi(2S)$ forward-backward ratio

- $R_{FB}(|y|) = \frac{d\sigma_{pA}/dy}{d\sigma_{Ap}/dy}$ determined in common range $2.5 < |y| < 4.0$
- Part of experimental and theoretical uncertainties cancel [JHEP 1603 (2016) 133]

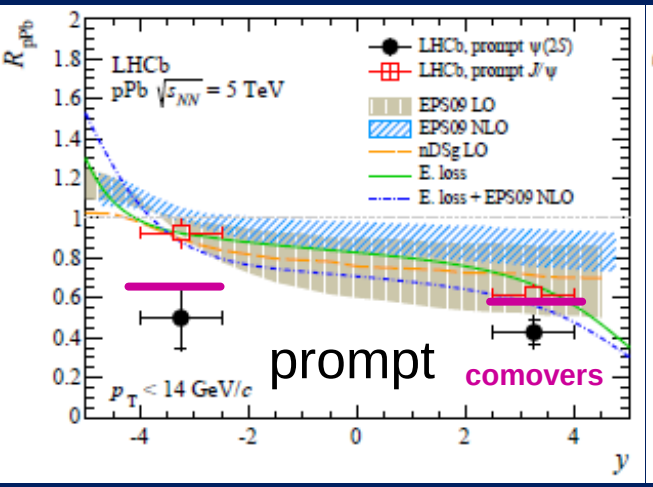


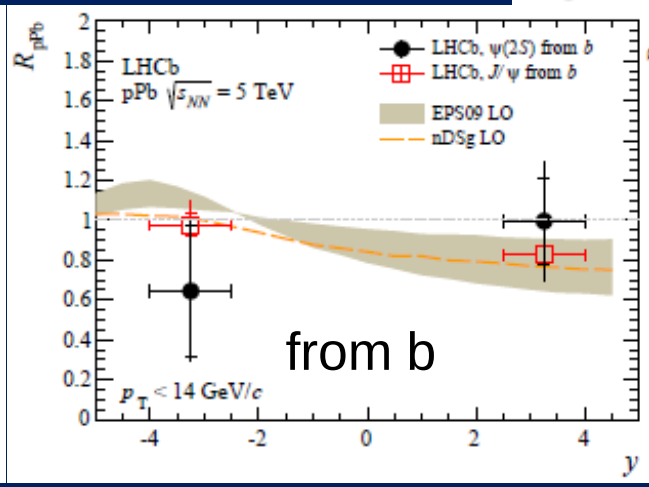
- Large experimental uncertainties for $\psi(2S)$
  → more statistics needed to get a trend (R_{FB} of inclusive $\psi(2S)$ compatible both with unity and with suppression of inclusive J/ψ)

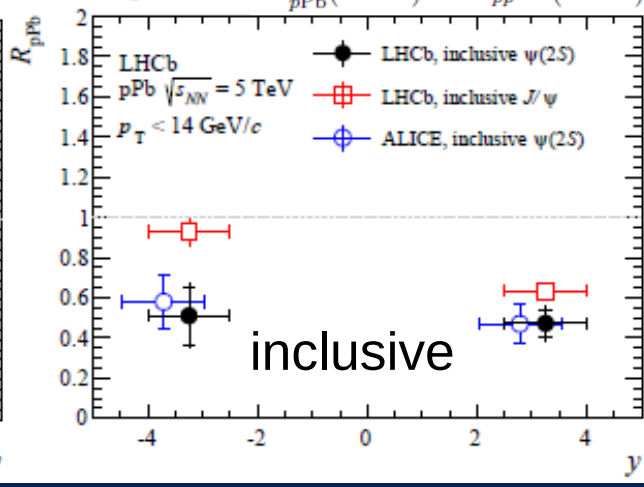
J/ψ and $\psi(2S)$ modification factor

- $$R_{pA}(y) = \frac{1}{A}\frac{d\sigma_{pA}/dy}{d\sigma_{pp}/dy}$$
  - determined in overlap region $2.5 < |y| < 4.0$
  - J/ψ cross-section in pp collisions at 5 TeV from interpolation of measurements at 2.76, 7 and 8 TeV
  - R_{pPb} for $\psi(2S)$ is calculated from using:

$$R_{pPb}^{\Psi(2S)} \approx R_{pPb}^{J/\Psi} \times \frac{\sigma_{pPb}^{\psi(2S)}(5\ \mathrm{TeV})}{\sigma_{pPb}^{J/\psi}(5\ \mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(7\ \mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\ \mathrm{TeV})}$$







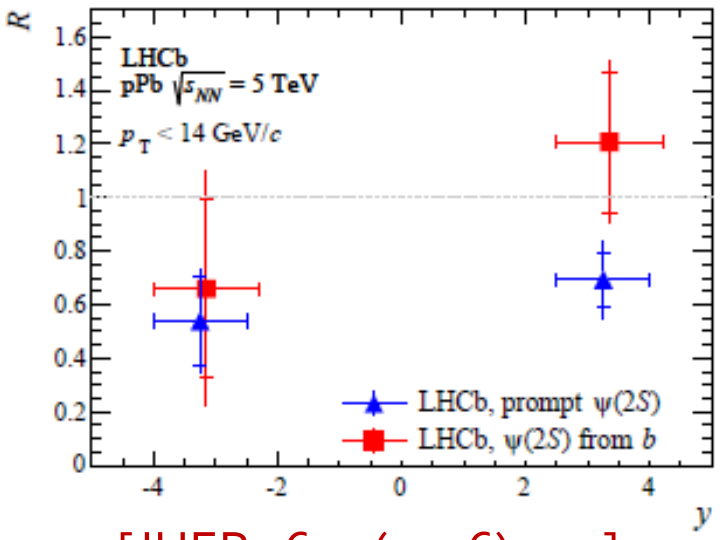
[JHEP 1603 (2016) 133] [ALICE: JHEP 12 (2014) 073]

- Prompt ψ(2S) more suppressed than prompt J/ψ
- Energy loss + shadowing don't explain the ψ(2S) suppression in the backward region. Do other mechanisms like comovers play a role ?
- Suppression of ψ(2S) from *b* consistent with that of J/ψ from *b*
- Suppression of inclusive ψ(2S) consistent with ALICE results

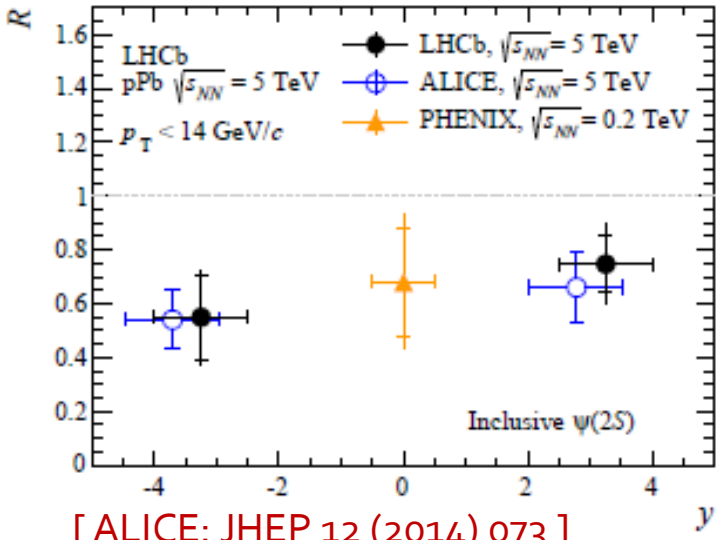
$\psi(2S)$ relative suppression wrt J/ψ

- Relative suppression is calculated as:

$$R \equiv \frac{R_{p\mathrm{Pb}}^{\psi(2S)}}{R_{p\mathrm{Pb}}^{J/\psi}} = \frac{\sigma_{p\mathrm{Pb}}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{p\mathrm{Pb}}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(5\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(5\,\mathrm{TeV})} = \frac{\sigma_{p\mathrm{Pb}}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{p\mathrm{Pb}}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(7\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\,\mathrm{TeV})}$$



[JHEP 1603 (2016) 133]



[ALICE: JHEP 12 (2014) 073]
[PHENIX: PRL 111 (2013) 202301]

- Intriguing stronger suppression of prompt ψ(2S) than that of prompt J/ψ
- Expect similar suppression for ψ(2S) from *b* and J/ψ from *b*
  → R compatible with 1 within large uncertainties
- Results for inclusive ψ(2S) compatible with ALICE measurement

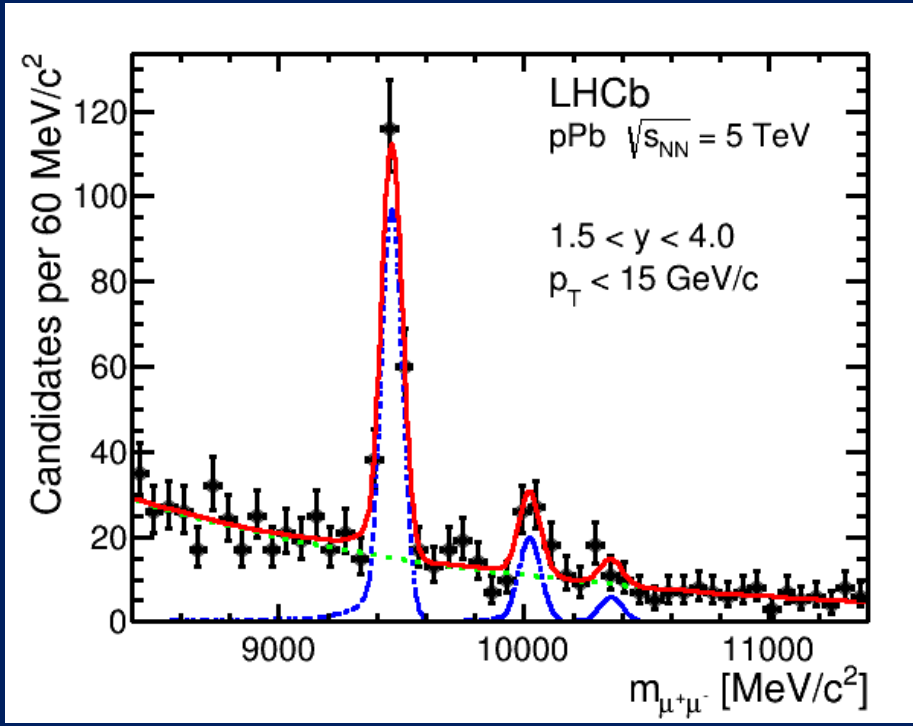
Υ(nS) - production in *p*Pb collisions

reconstruct Υ-states in di-muon channel

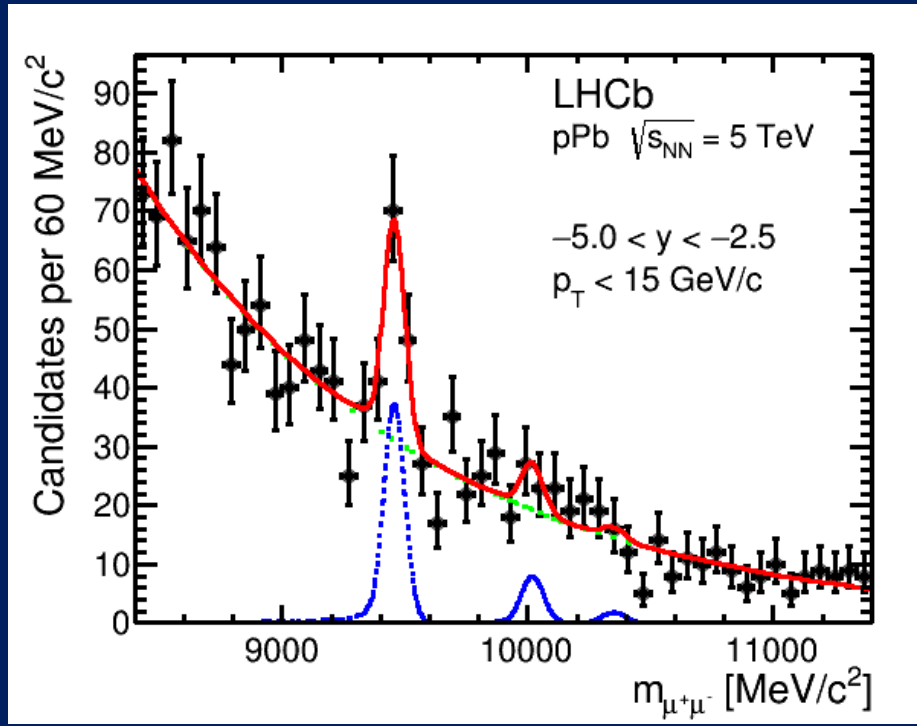
- forward $1.5 < y < 4.0$ and backward $-5.0 < y < -2.5$; $p_T < 15$ GeV/c
- Mass model: three Crystal-Balls for signal and exponential background
- low statistics → no differential measurement

[JHEP 07 (2014) 094]

- Forward production

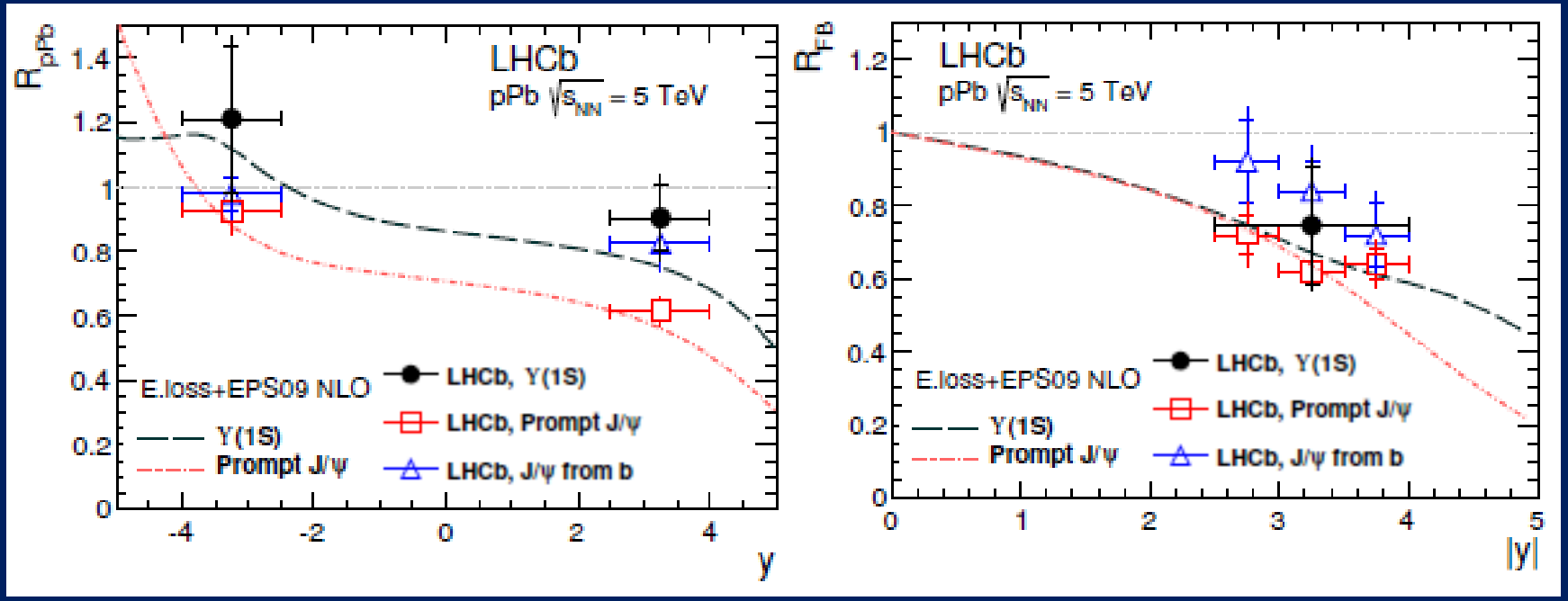


- Backward production



Υ(1S) – production: CNM effects

- Measurement of R_{pPb} and R_{FB} with Υ(1S) complementary to J/Ψ (probing different x_A) [JHEP 07 (2014) 094]

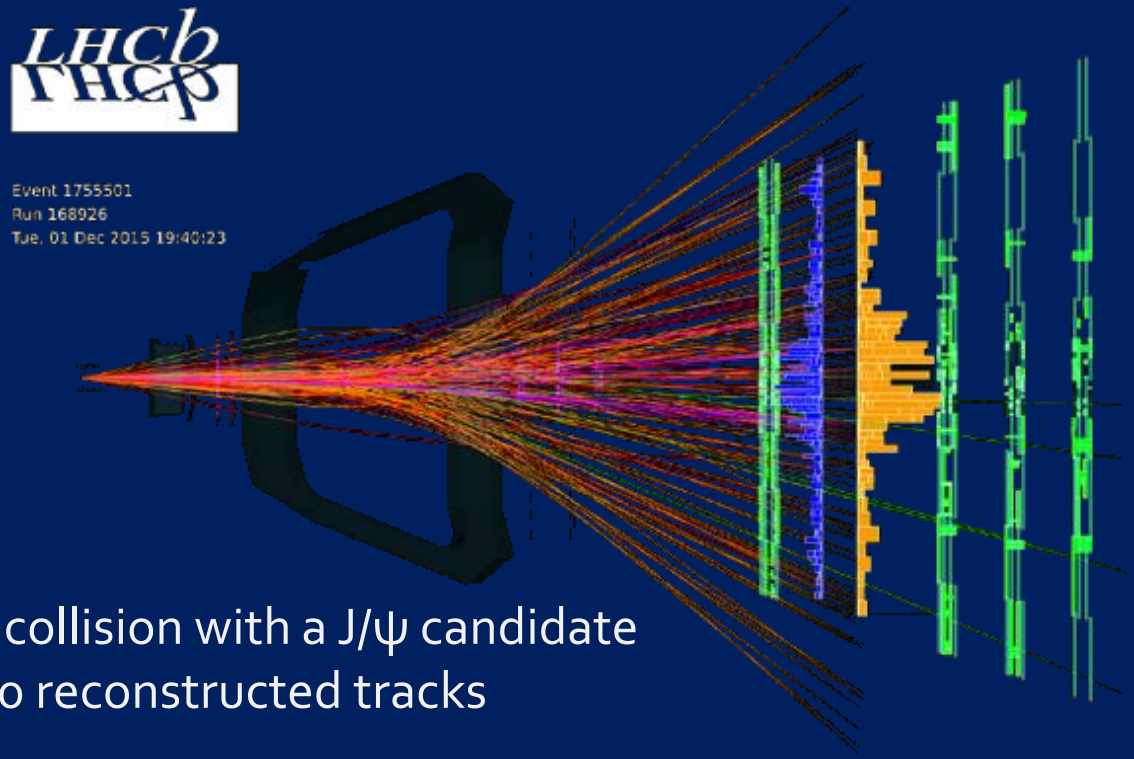


- Cold nuclear effects are also visible with Υ(1S) production
  - Suppression in forward region smaller than for J/Ψ
  - Possible enhancement in backward region due to anti-shadowing
  - Good agreement for prediction with energy loss and shadowing (EPS09 NLO)

First Look at Quarkonium production in lead-lead collisions

Lead-lead collisions in LHCb

- First participation in PbPb running in Nov/Dec 2015
  - 24 colliding bunches; integrated luminosity ~5 / μb
  - all inelastic interactions recorded with minimum-bias trigger, no global event cut → important for centrality determination



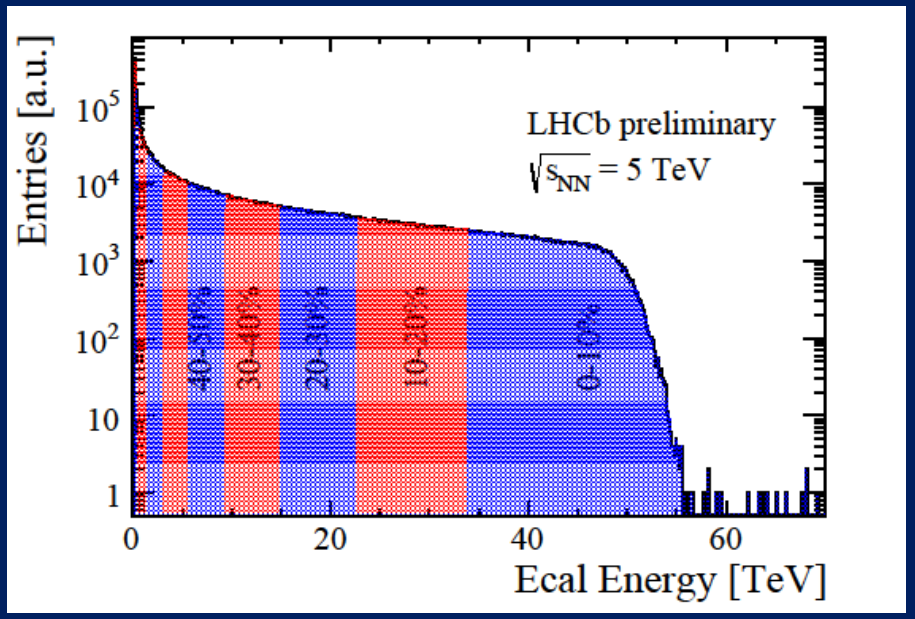
PbPb collision with a J/ψ candidate in 1130 reconstructed tracks

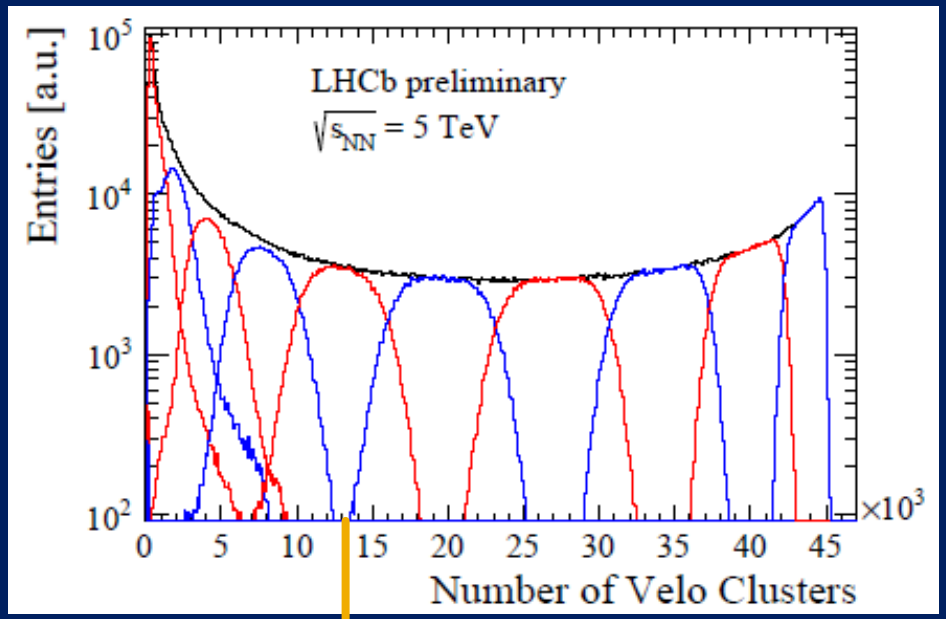
Centrality determination

- Use quantity which doesn't saturate for centrality measurement
  - Energy deposition in the electromagnetic (ECAL) / hadronic (HCAL) calorimeters seems to be a good centrality estimator
  - First step: Event classification in terms of ECAL activity classes

    Tracking may be possible up to 15'000 clusters in VELO

    →~ 50-60% ECAL event activity class



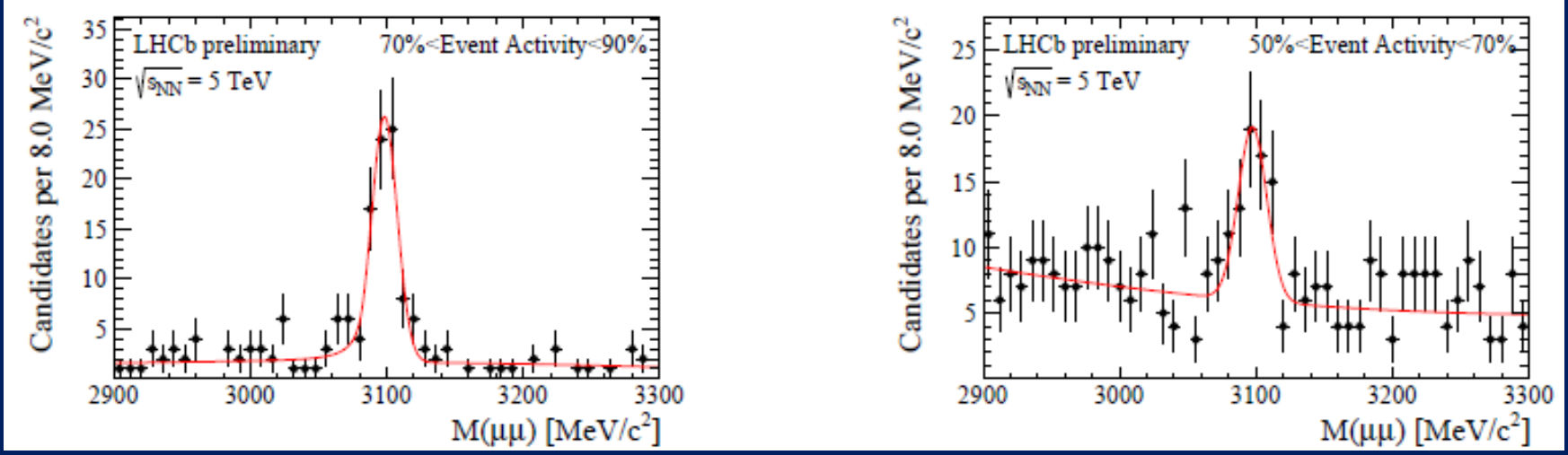


https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

J/ψ production in PbPb collisions

- J/ψ carries information about the system created in PbPb collision
  - a probe for QGP formation
  - plan to measure R_{AA}, using the result in pp at $\sqrt{s}$=5 TeV
- Analysis status:
  - tracking efficiency difficult to estimate due to low statistics & high occupancy
  - plan to use data driven methods to determine tracking and PID efficiency
- $J/\psi \rightarrow \mu^+ \mu^-$

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

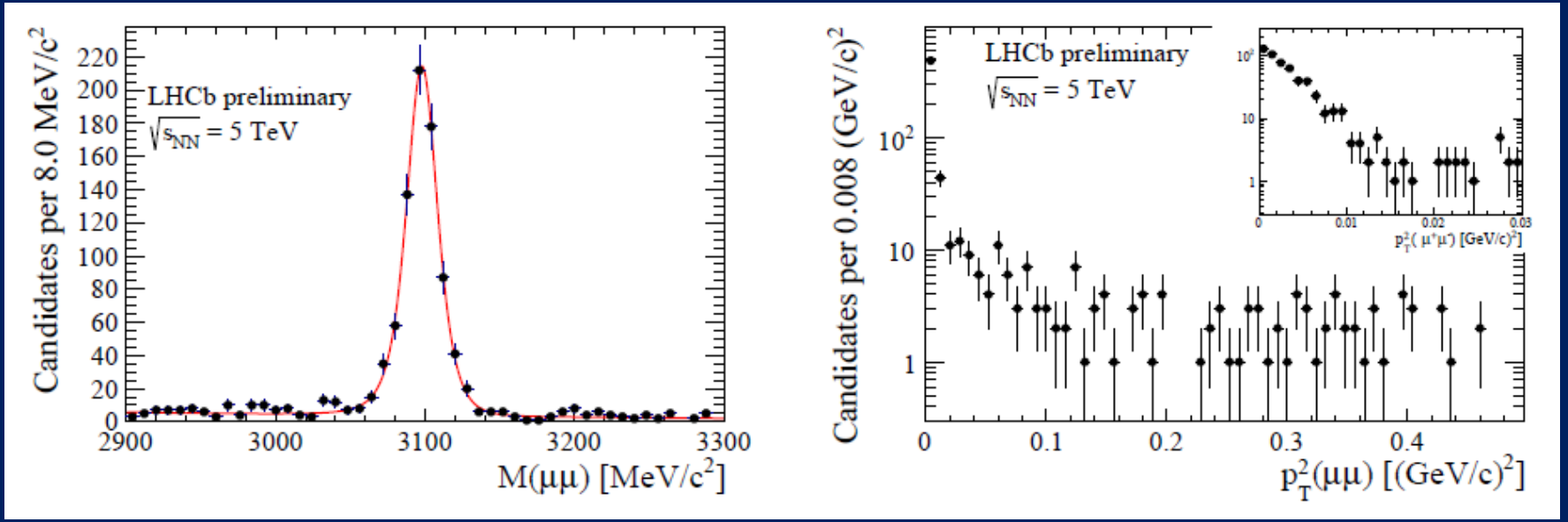


- Clear signals also for 50-70% event activity

Coherent photoproduction of J/ψ in PbPb

- Also ultra peripheral collisions are of great interest
  - ➢ QED with extreme field-strength and large cross-sections

Events containing **only 2 long tracks** in the spectrometer



https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

- Very clean signature with very soft transverse momentum spectrum
- Ongoing studies will benefit from new high rapidity HERSCHEL detector
  - ➢ rapidity coverage $5 < \eta < 9$
  - ➢ Possibility to define large rapidity gaps

Prospects for the proton-lead run in November 2016

Prospects for 2016 pPb run

- Intend to do fixed target studies during pPb run at $\sqrt{s_{NN}} = 5$ TeV
  - Measure σ (p He $\rightarrow \bar{p}$ X) to clarify uncertainty on secondary production of $\bar{p}$ in the interstellar medium (astrophysical interest)
- Requested L_{int} of 20/nb at $\sqrt{s_{NN}} \sim 8$ TeV
  - shared between both beam configurations pPb & Pbp

Channel	2013 yields	Yields expected in 2016 with $20\,\mathrm{nb}^{-1}$
$\Upsilon(3S) \rightarrow \mu^+\mu^-$	–	300
$\psi(2S) \rightarrow \mu^+\mu^-$	500	10000
$Z \rightarrow \mu^+\mu^-$	12	250
Associated $J/\psi - D^0$ production	–	100
Drell Yan	–	1000

  - Statistic would allow to achieve same precision on R_{FB} in ψ(2S) as for J/ψ
  - Measurement of R_{pPb} for all upsilon states, including Y(3S)
  - Improved precision on Z-production → constrain nPDF
  - Associated HF production in pPb to study single- and double- parton scattering

J/ψ over Drell-Yan measurement

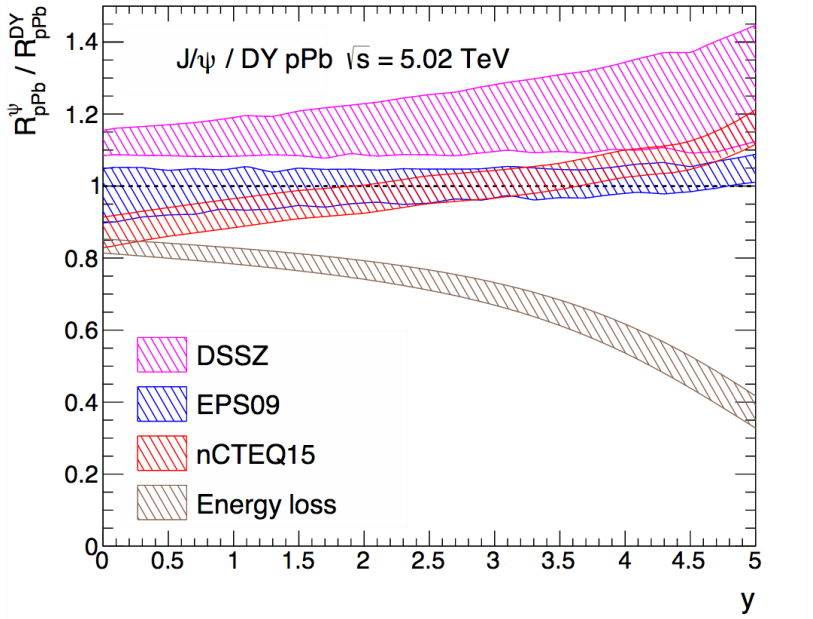


Figure 3: Double ratio $\mathcal{R}^{\psi/\mathrm{DY}}_{\mathrm{pPb}}$ in p–Pb collisions at $\sqrt{s} = 5.02$ TeV for the various nPDF sets and in the coherent energy loss model.

[F. Arleo, S. Peigné arXiv:1512.01794]

- Quarkonium production data so far not precise enough to distinguish between various CNM models
- Double ratio has been proposed as a powerful measurement to disentangle between shadowing and e-loss models
- LHCb is ideal for this measurement:
  - Optimal acceptance
  - VELO detector capabilities permit to decrease significantly the background from $b\bar{b}$ production
- Many systematic effects cancel in the ratio → higher precision
- Projections with 20/nb :
  → 1000 Drell-Yan candidates

Summary and Conclusions

- LHCb participated successfully in pPb run in 2013
  - Measurement of J/ψ, $\psi(2s)$, Υ-production (also D^0 and Z-production)
    $\rightarrow$ cold nuclear matter effects visible
  - Limited by statistics $\rightarrow$ benefit from larger data samples in Run II
- LHCb participated for the first time in 2015 in the PbPb run
  - We have collected a sample of ~5/ub of PbPb collisions
  - Analysis of J/ψ-production in collisions with up to 50% centrality ongoing
- LHCb is looking forward to the pPb run this year
  - We hope to enhance statistics for *p*Pb by a factor 10
  - LHCb should be able to shed further light on various CNM models
    … and maybe distinguish between them