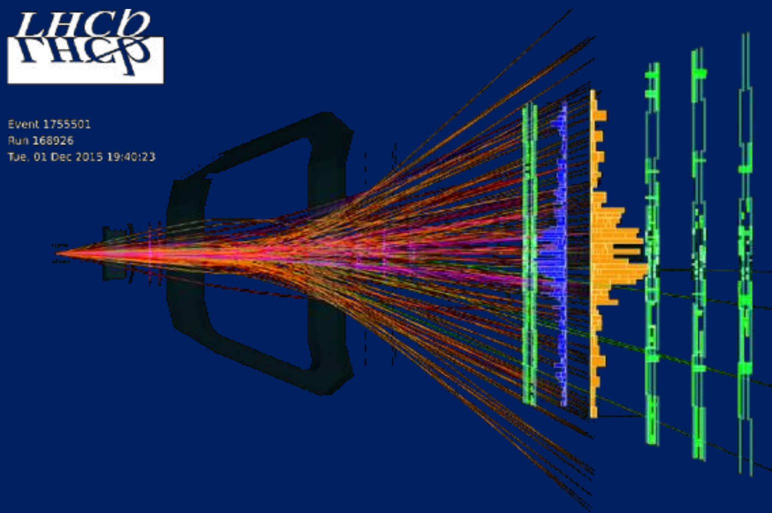
LHCb results and perspectives on heavy-ion physics



QCD @ LHC 2016

22-26August 2016, Zurich

Burkhard Schmidt (CERN), on behalf of the LHCb collaboration

Overview

- Introduction
  - LHCb detector
  - Experimental approach and physics reach
- Results from proton-lead collisions
  - Cold Nuclear Matter (CNM) effects in J/ψ, $\psi(2S)$, Y and D^0 -production
  - Two particle correlations and the near-side ridge
- Perspectives on Heavy Ion Physics
  - First look at PbPb collisions
  - Capabilities for Heavy Ion and Fixed Target physics with LHCb
- Conclusions

LHCb Detector

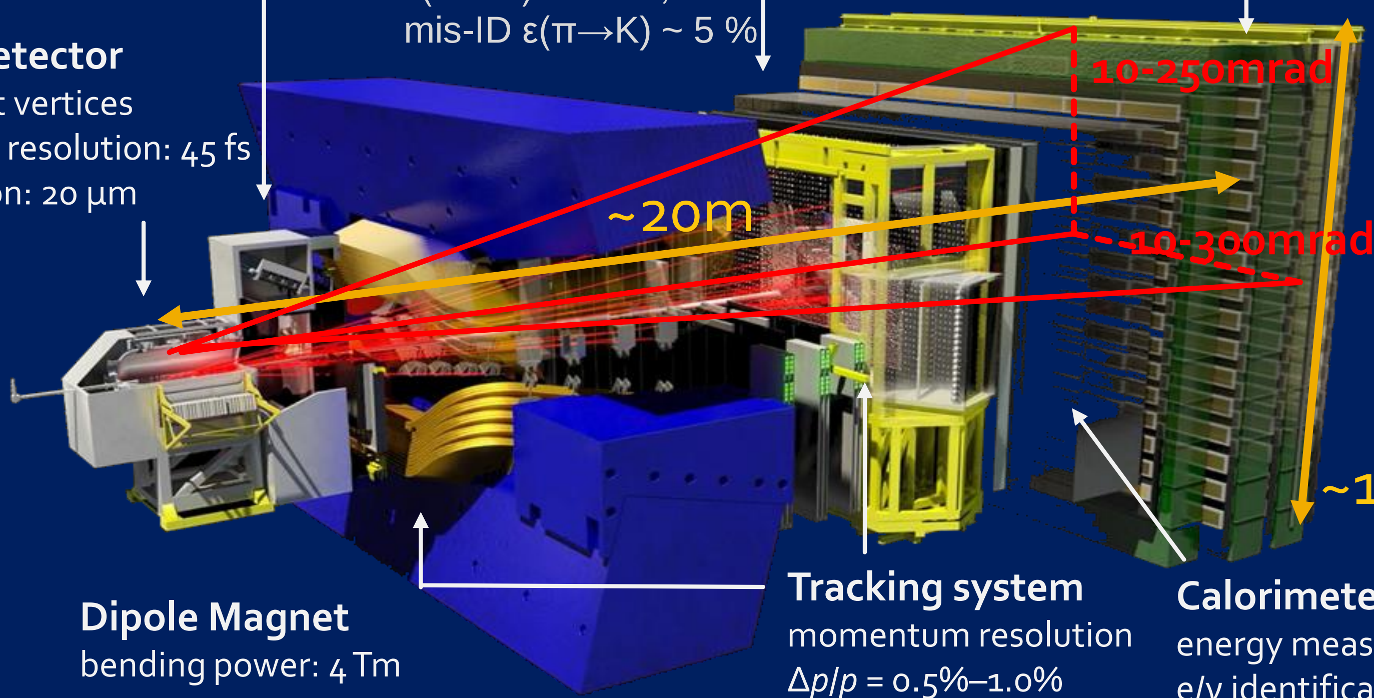
- Single arm spectrometer in the forward direction
  - designed for b-physics – but capable to address many other topics …
  - fully instrumented in its angular acceptance
  - forward and backward coverage for asymmetric beams

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

RICH detectors
K/π/p separation
$\varepsilon(K\rightarrow K) \sim 95\ \%$,
mis-ID $\varepsilon(\pi\rightarrow K) \sim 5\ \%$

Muon system
μ identification $\varepsilon(\mu\rightarrow\mu) \sim 97\ \%$,
mis-ID $\varepsilon(\pi\rightarrow\mu) \sim 1\text{-}3\ \%$

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



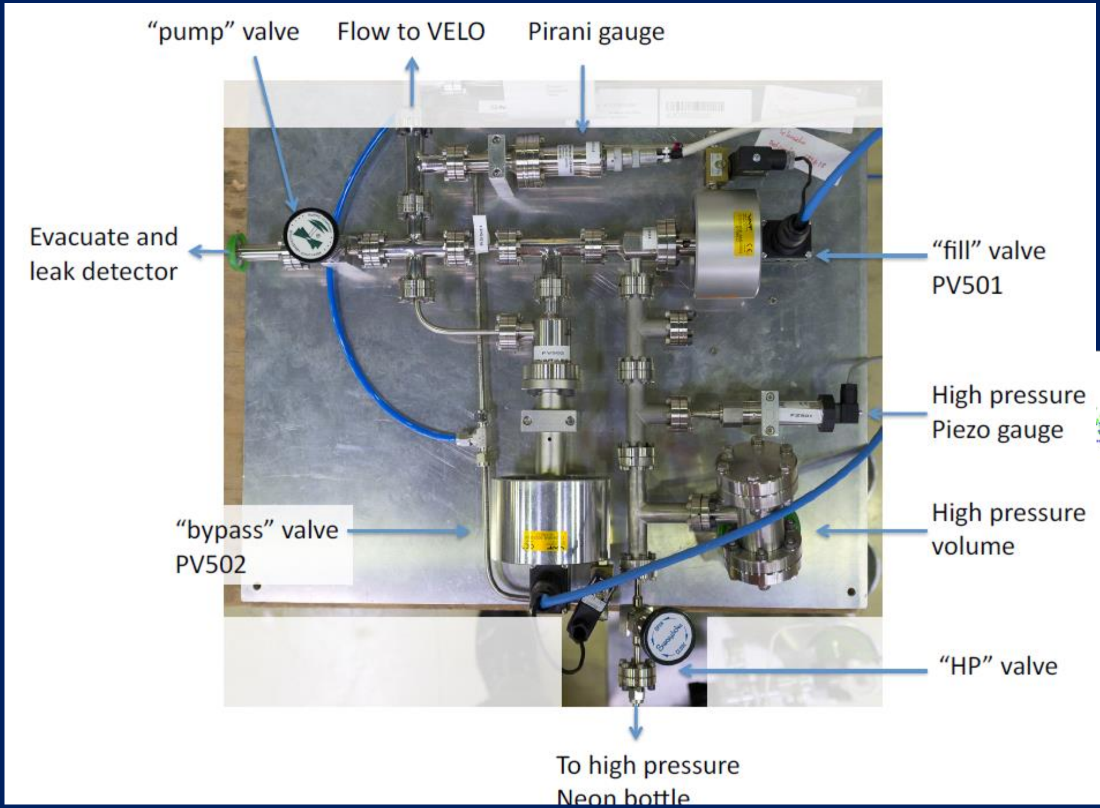
Dipole Magnet
bending power: 4 Tm

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

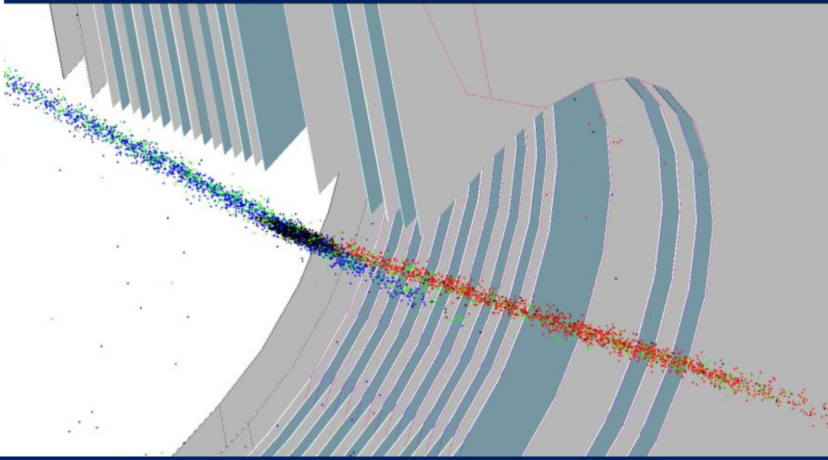
Calorimeters
energy measurement
e/γ identification
$\Delta E/E = 1\ \% \oplus 10\ \%/\sqrt{E}$ (GeV)

Fixed Target Physics with LHCb

SMOG : System for Measuring the Overlap with Gas



- injection of gas into interaction region
- very simple robust system
- used for a precise luminosity determination

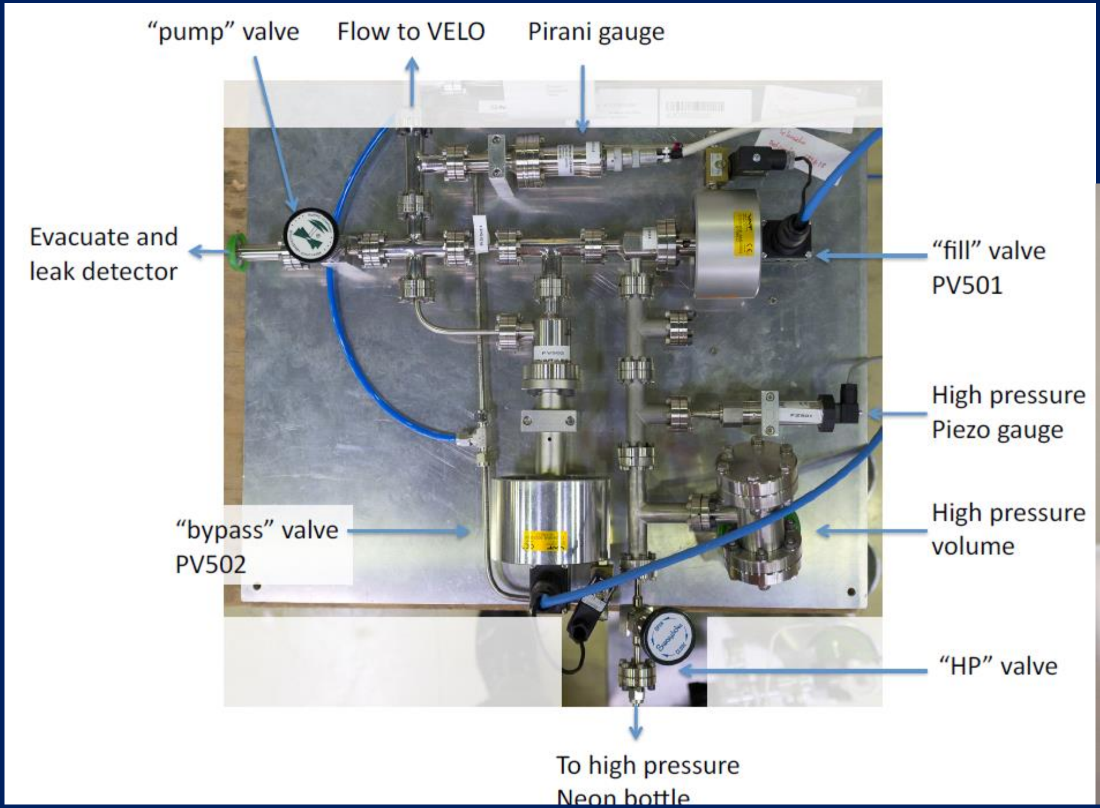


SMOG can be used for fixed target physics:

- Filling scheme and precise vertexing allows to separate beam-beam and beam-gas contributions
- strong acceptance effects as a function of the *z*-position

Fixed Target Physics with LHCb

SMOG : System for Measuring the Overlap with Gas



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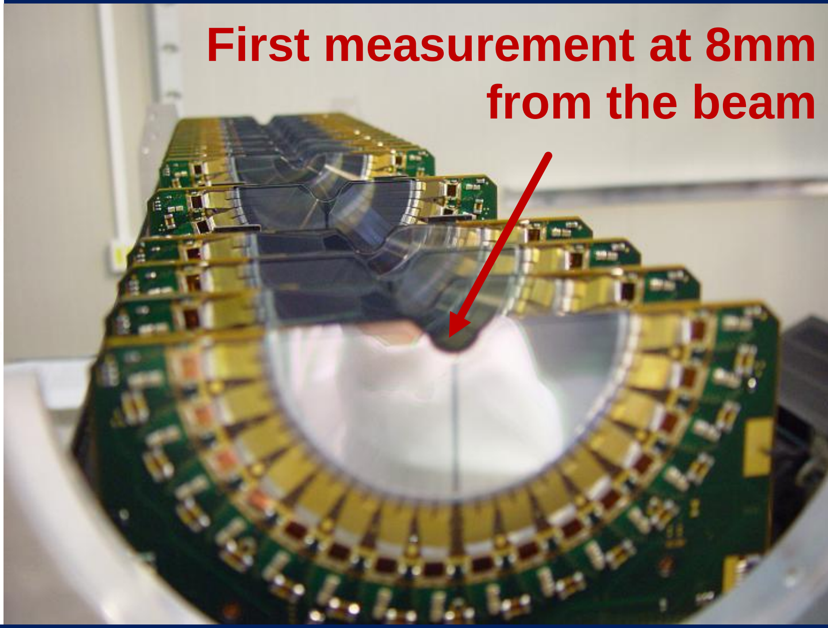


SMOG can be used for fixed target physics:

- Filling scheme and precise vertexing allows to separate beam-beam and beam-gas contributions
- strong acceptance effects as a function of the *z*-position

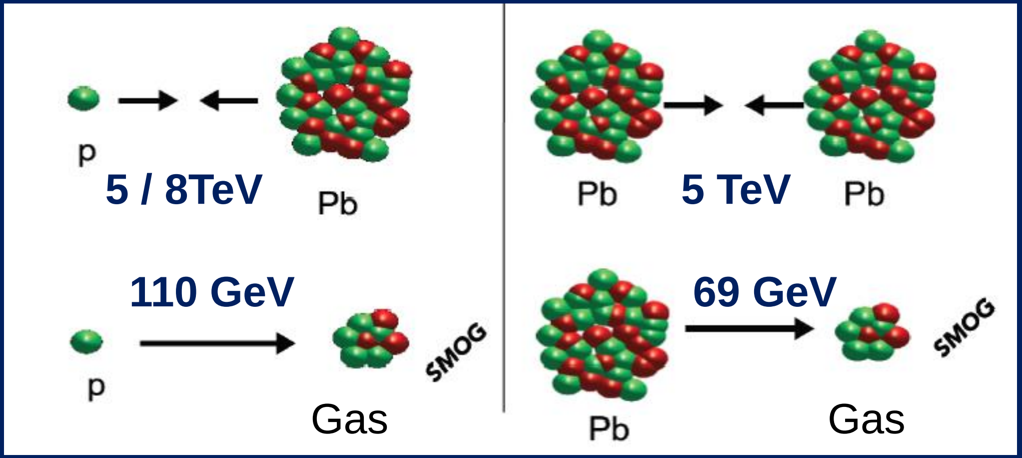
Experimental approach

- 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.

- Experimental approach: **CNM effects** **QGP**

Colliding beam mode

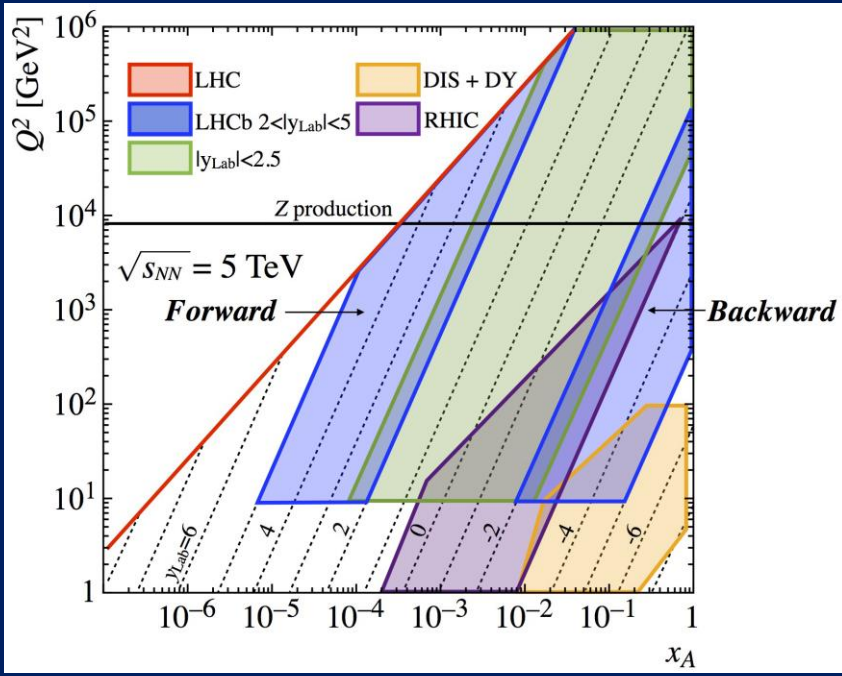
Fixed target mode



➢ In fixed target mode energy densities are achieved which are between those probed at the SPS and RHIC.
➢ **The gap between the SPS and RHIC can be bridged by a single experiment**

Physics Motivation for *p*A studies

- **Study of *p*A collisions important for HI physics**
  - *p*A collisions important as a reference sample for heavy ion collisions, but also interesting by themselves.
  - Examples:



1. Constrain nuclear PDF in e.g. *Z*-boson production in two different x-Q² regions
   - Complementary measurement to ATLAS and CMS
2. Particle correlations to probe collective effects in the dense environment of high energy collisions
   - LHCb can investigate at forward rapidity the long-range correlation (ridge) on the near side, first observed in *pp* (*p*Pb & PbPb) at mid-rapidity
3. Associated Heavy flavour production in *p*Pb to probe Multiple Parton Interactions

Results from proton lead collisions

Setup for Proton-Ion physics

***p*Pb**

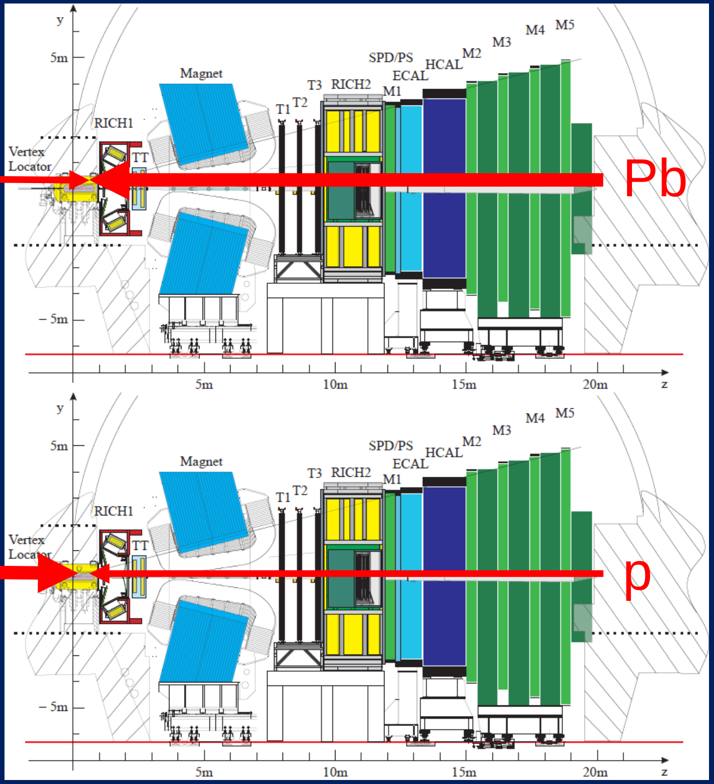
p

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

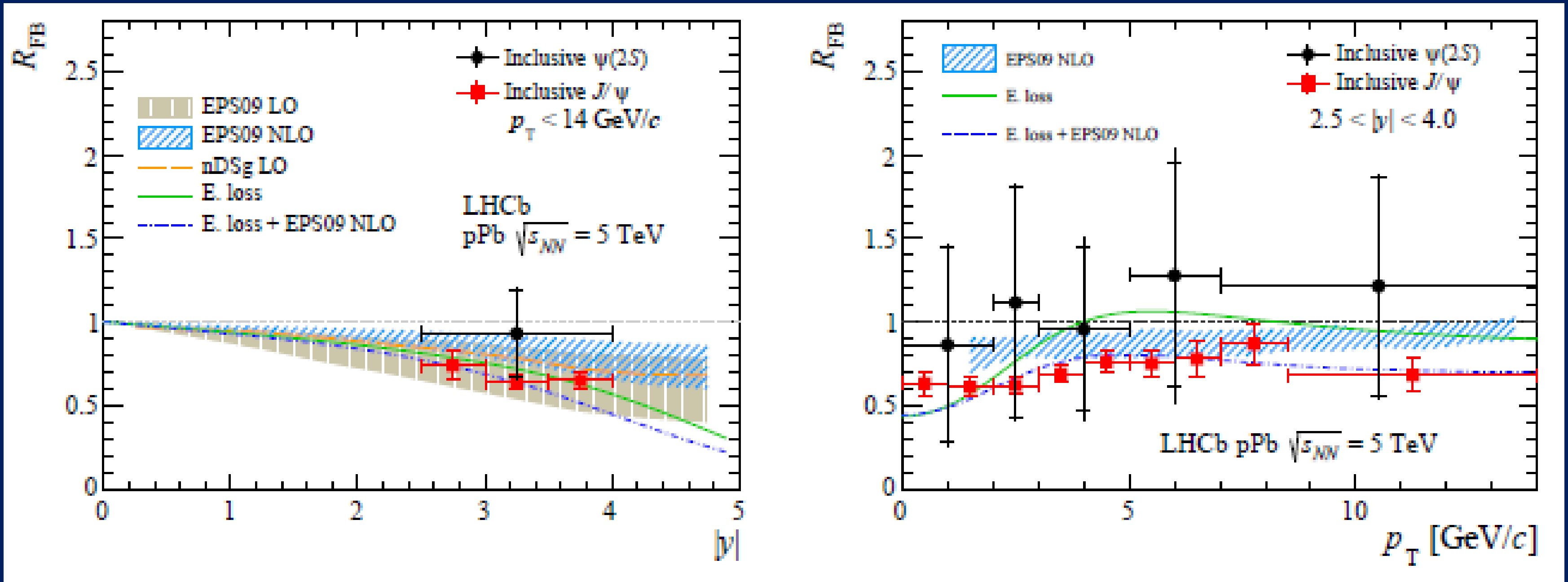
Pb*p*: $-5.5 < y < -2.5$

Data taken in 2013 ~0.5/nb

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

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

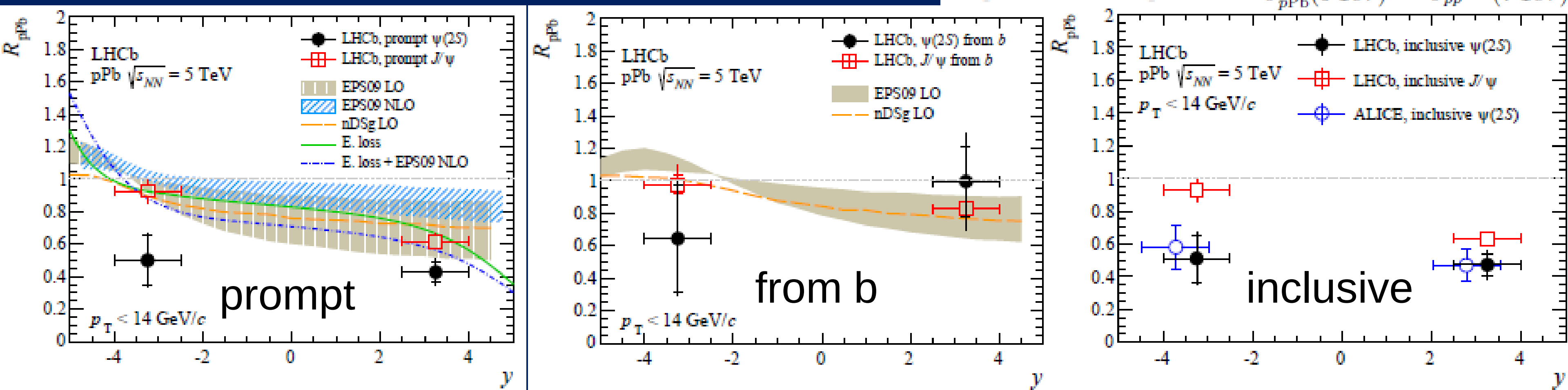
- $$R_{FB}(|y|) = \frac{d\sigma_{pA}/dy}{d\sigma_{Ap}/dy}$$ determined in common range 2.5 < |y| <4.0
- Part of experimental and theoretical uncertainties cancel [JHEP 1603 (2016) 133]



- Large experimental uncertainties
  → more statistics needed to get a trend (R_{FB} of inclusive ψ(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: $R_{pPb}^{\Psi(2S)} \approx R_{pPb}^{J/\Psi} \times \frac{\sigma_{pPb}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{pPb}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(7\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\,\mathrm{TeV})}$

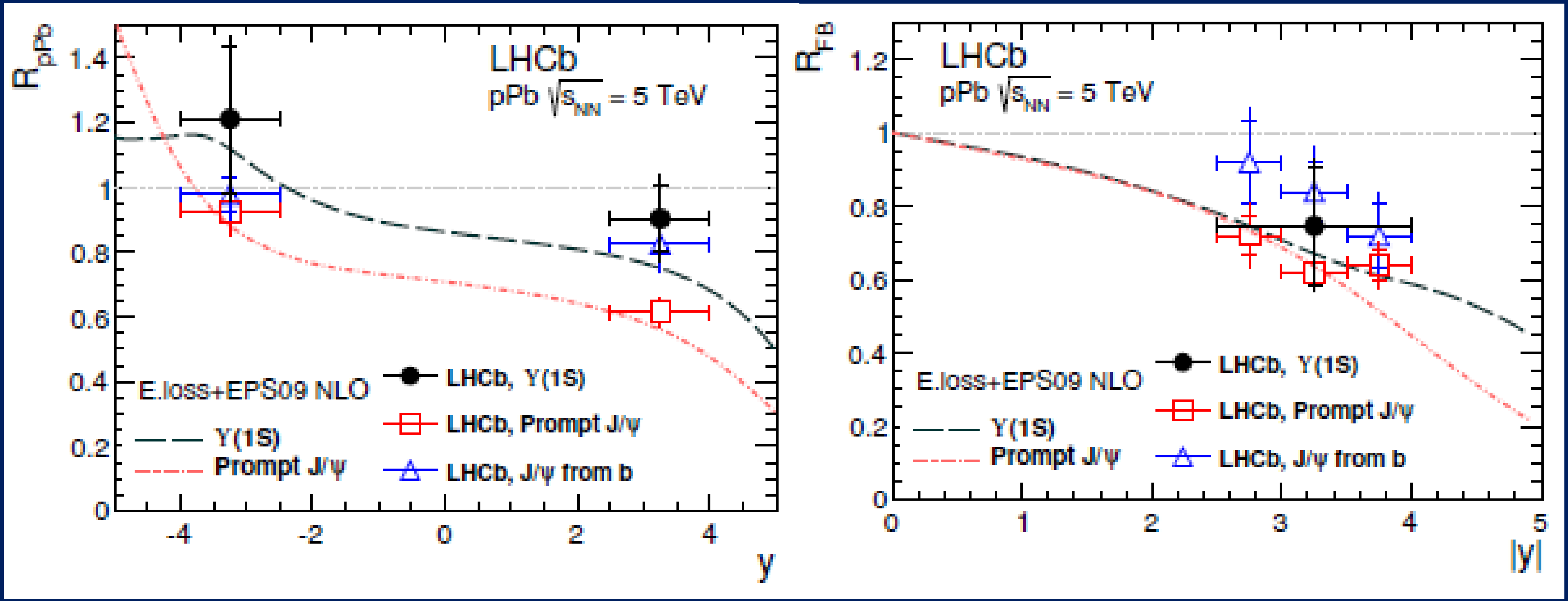


[JHEP 1603 (2016) 133] [ALICE: JHEP 12 (2014) 073]

- 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 mechanism 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

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]

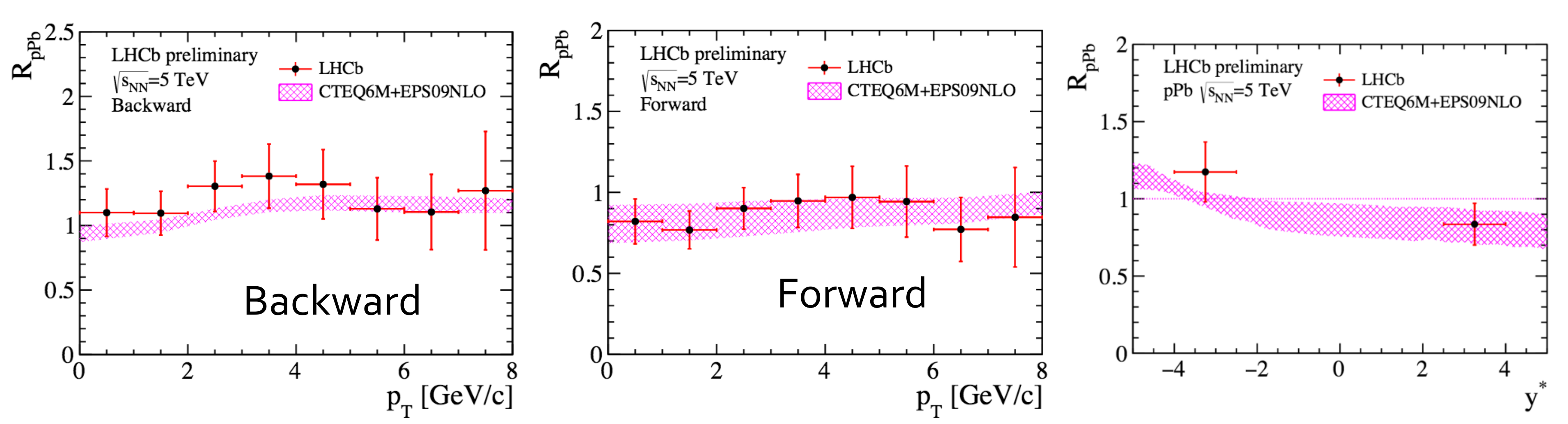


- Cold nuclear effects are also visible with Υ(1S) production
  - Suppression in forward region smaller than for J/Ψ
  - Possible enhancement in backward region due to anti-shadowing
  - Good agreement for prediction with energy loss and shadowing (EPS09 NLO)

Prompt D^0 modification factor

- D^0 cross-section in pp collision at $\sqrt{s}$ = 5 TeV extrapolated using LHCb measurements at 7 and 13 TeV. [Nucl. Phys. B87 (2013), arXiv:1510.01707]
  - pp data at $\sqrt{s}$ = 5 TeV are being analyzed, will be updated soon

LHCb-CONF-2016-003

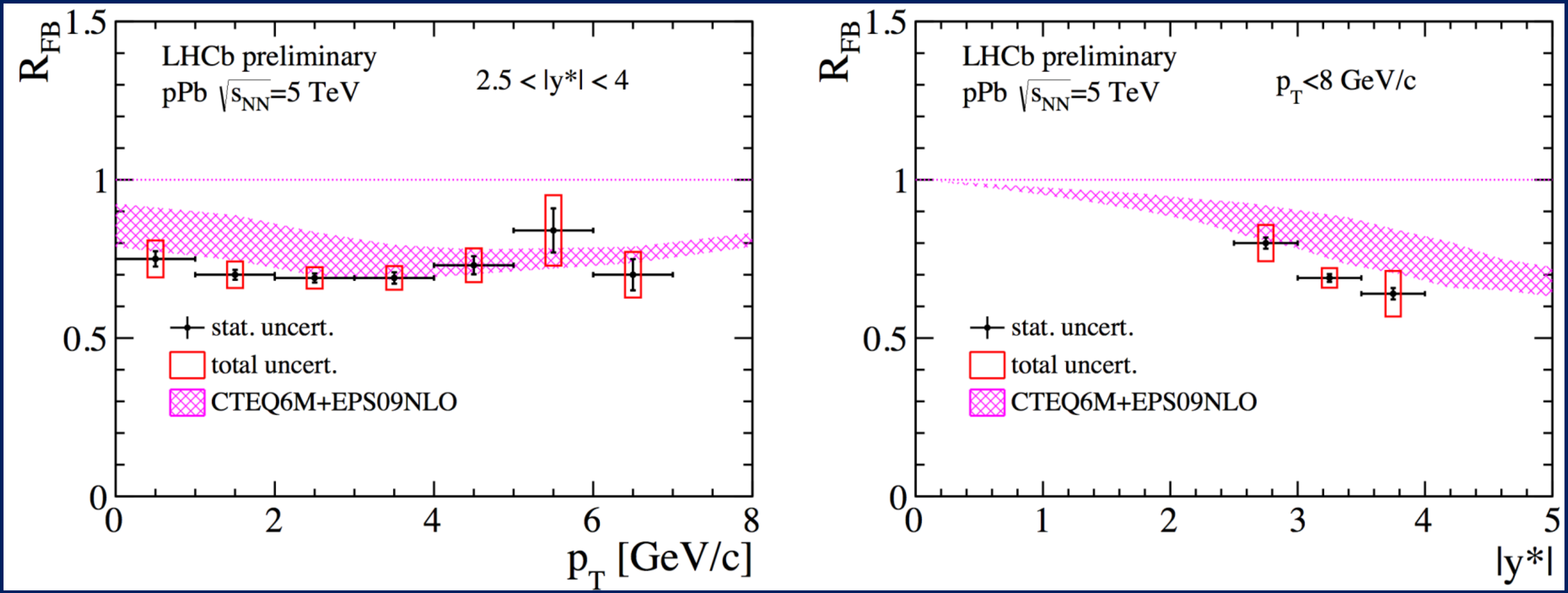


- No strong p_T dependence of the D^0 modification factor R_{pPb}
- Nuclear modification factor smaller in forward region (pos. rapidity)
- Measurements consistent with theoretical predictions from CTEQ6M+EPS09NLO: Nucl. Phys. B373 (1992) 295, JHEP 10 (2003) 046, JHEP 04 (2009) 065

Prompt D^0 forward-backward ratio

- For R_{FB} part of experimental and theoretical uncertainties cancel
- No need of *pp* reference cross section

LHCb-CONF-2016-003



- Significant production asymmetry in forward-backward samples
- No strong p_T dependence of R_{FB}
- Asymmetry more pronounced for larger rapidity
- Measurements consistent with theoretical predictions of CTEQ6M+EPS09NLO:

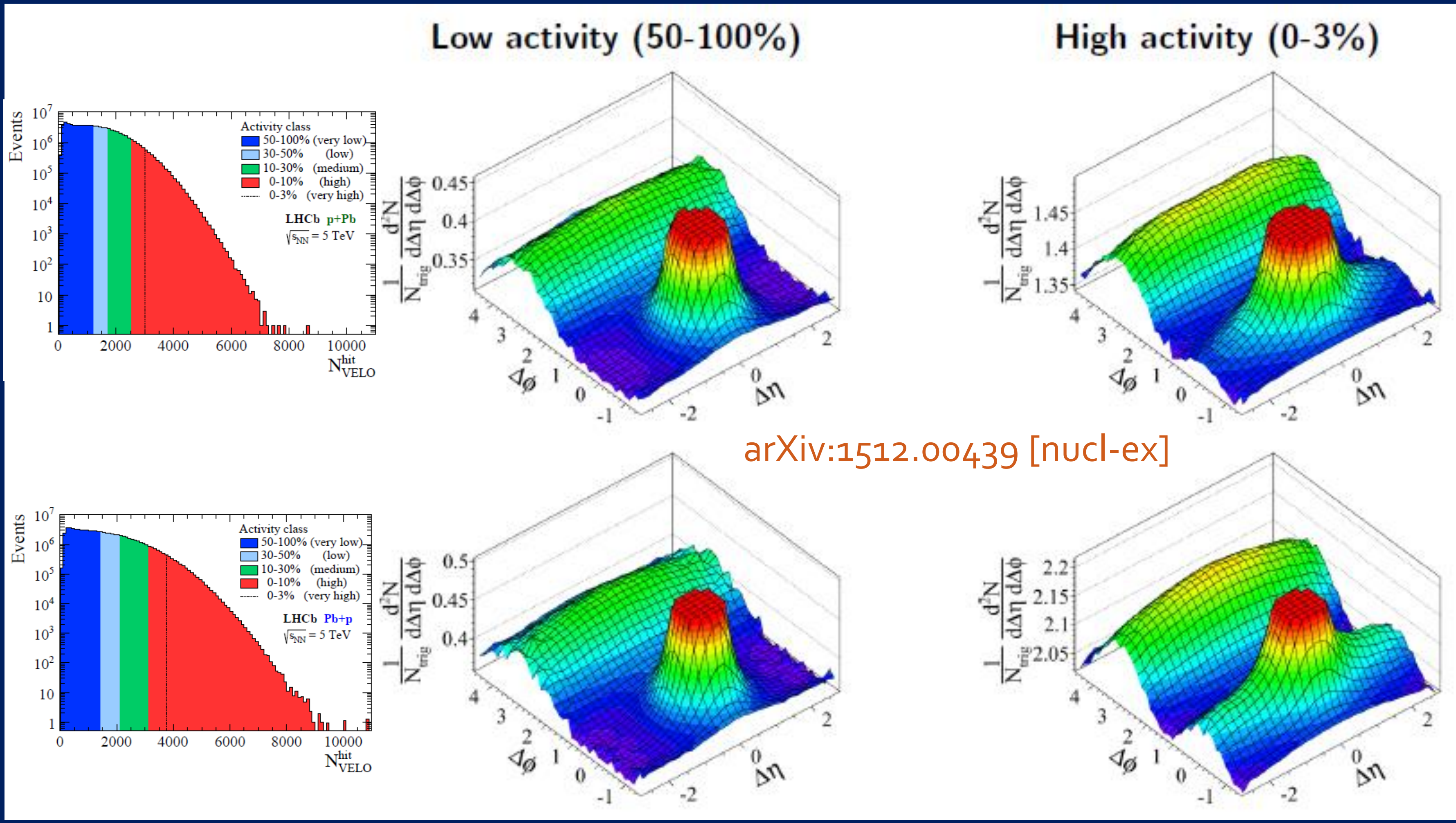
  Nucl. Phys. B373 (1992) 295, JHEP 10 (2003) 046, JHEP 04 (2009) 065

Two particle correlations in *p*Pb and Pb*p*

- Measurement of angular (Δη,Δφ)-correlations of prompt charged particles

pPb configuration (forward)

Pbp configuration (backward)



- In high activity events, the near side ridge (Δφ=0) is clearly visible

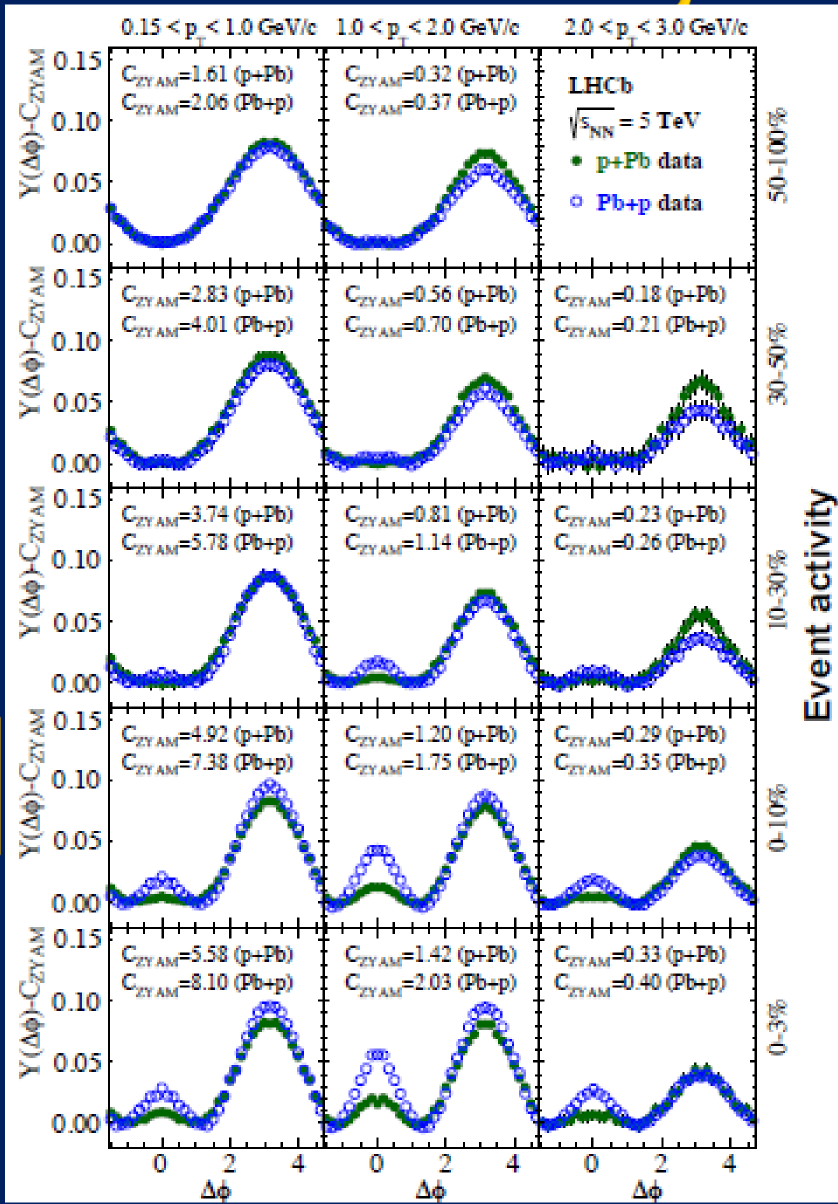
Two particle correlations in the FW region

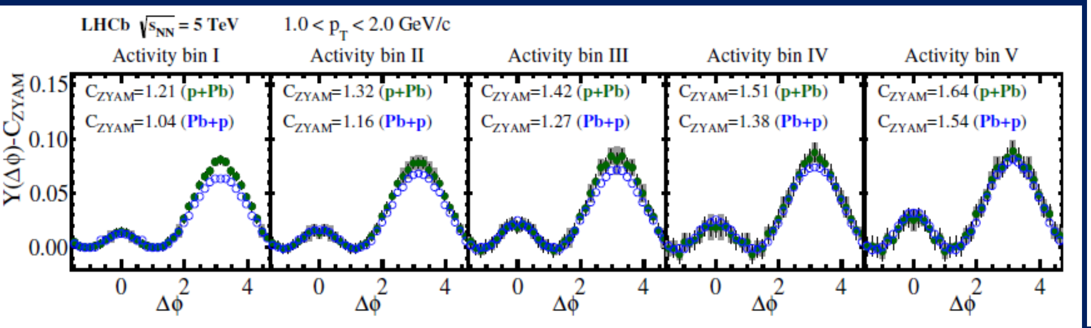
1. Study the **evolution of the long-range correlations** by calculating projection of Δφ in the range $2.0 < \eta < 2.9$ (exclude jet peak)
   - Subtract the zero yield at minimum (ZYAM)

> - Correlation yield increases with event activity
> - On the near side, the second ridge emerges with a maximum in the range $1 < p_T < 2$ GeV/c
> - Near side is more pronounce in Pb*p* than in *p*Pb

2. Compare **absolute activity classes**

> - Near-side ridges in both hemispheres are compatible in strength!



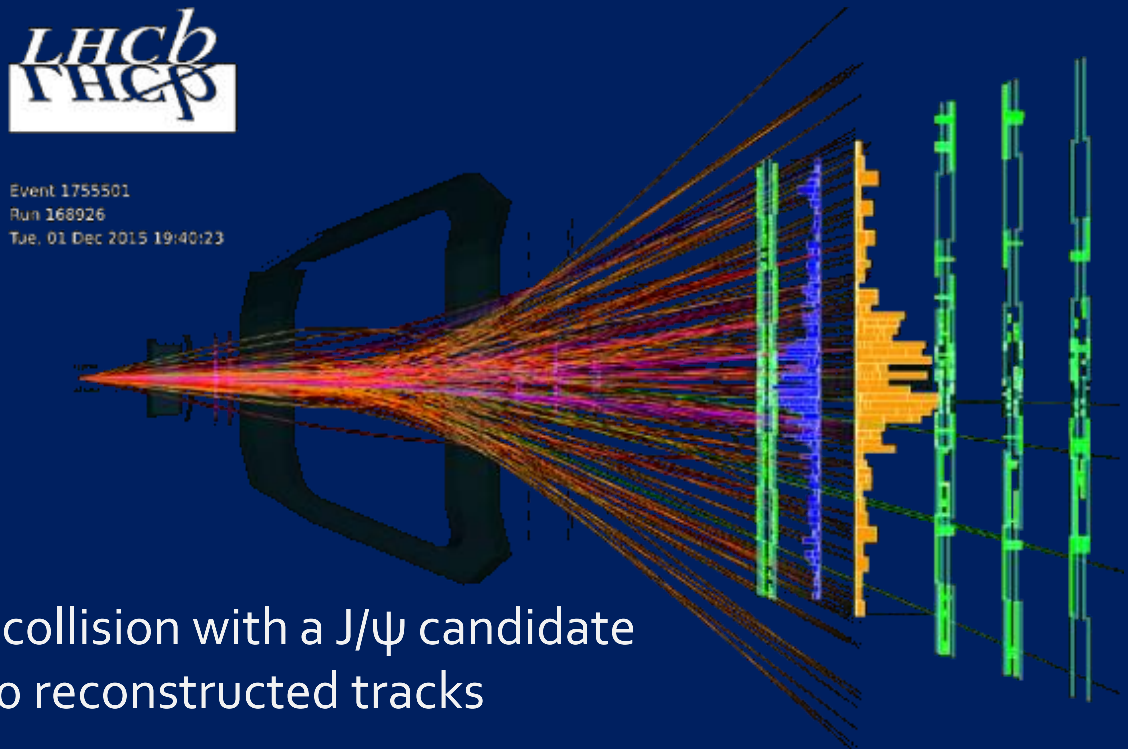


arXiv:1512.00439 [nucl-ex]

Prospects for
Heavy Ion physics with LHCb

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



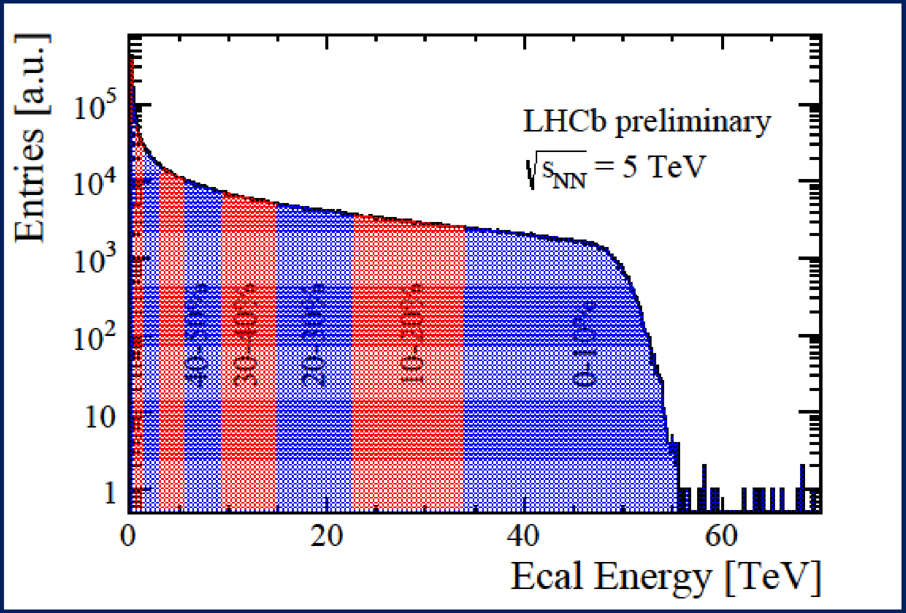
PbPb collision with a J/ψ candidate
in 1130 reconstructed tracks

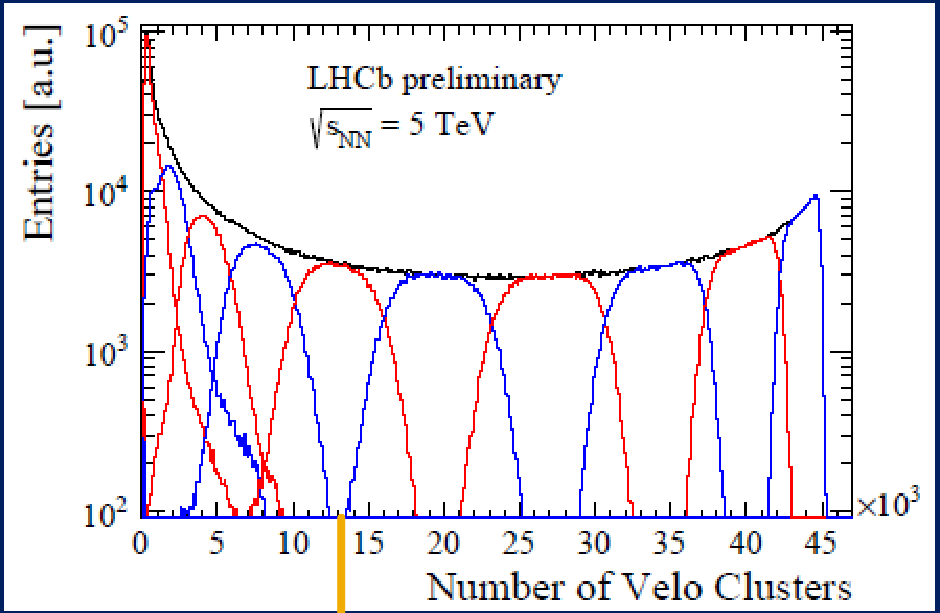
Frist look at centrality determination

- 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





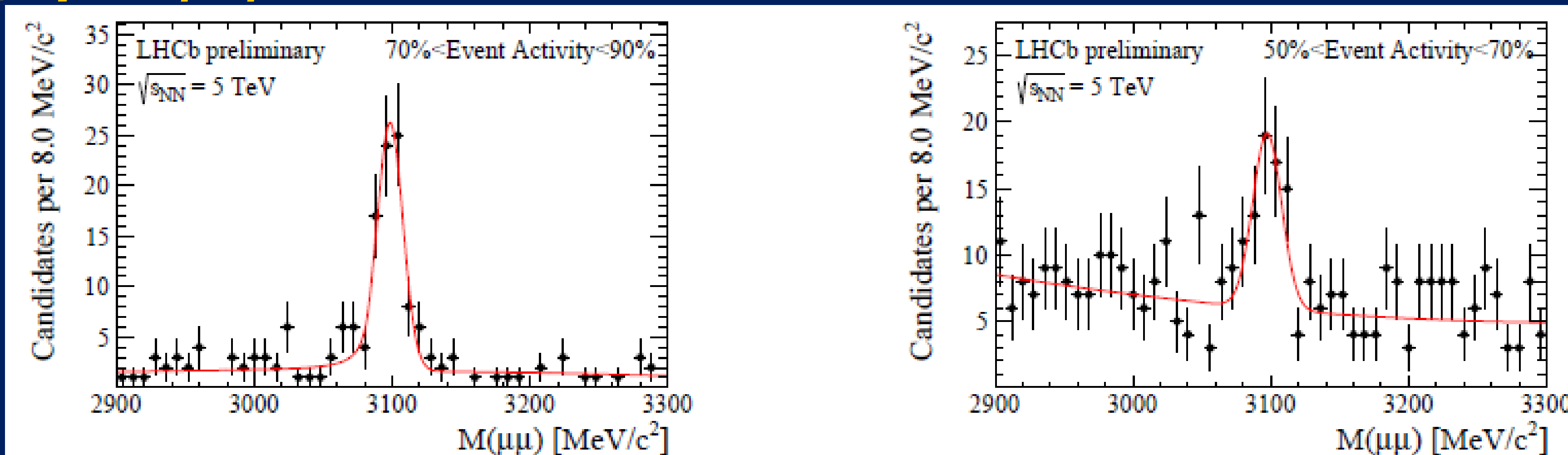
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

50-60%

J/ψ and D^0 in PbPb collisions

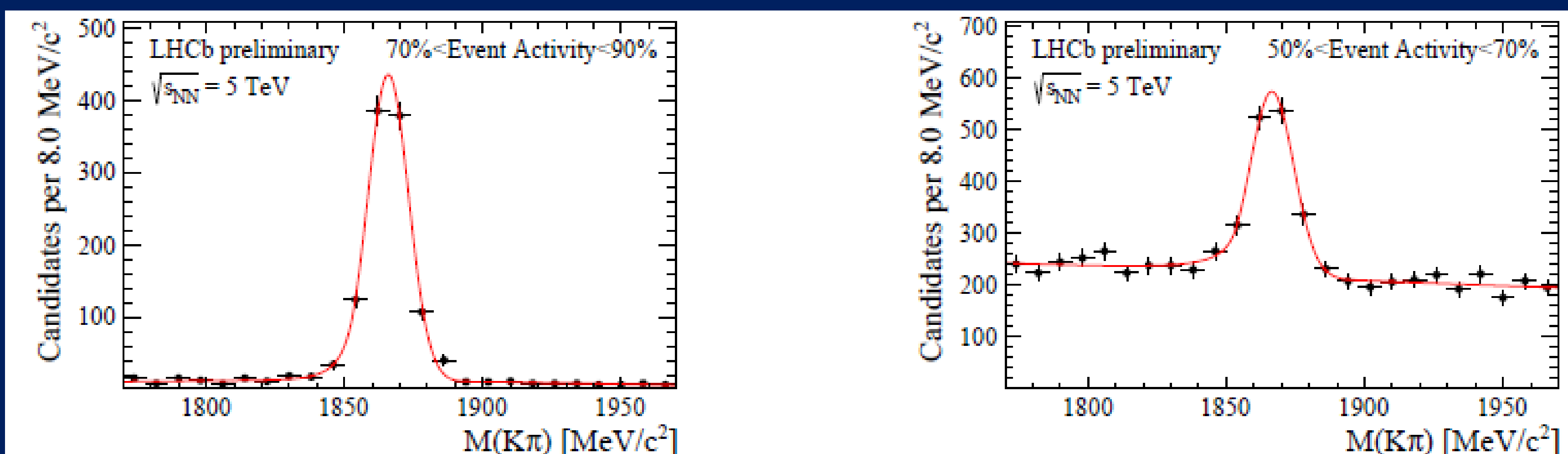
- $J/\psi \rightarrow \mu^+ \mu^-$

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



- $D^0 \rightarrow K^+ \pi^-$

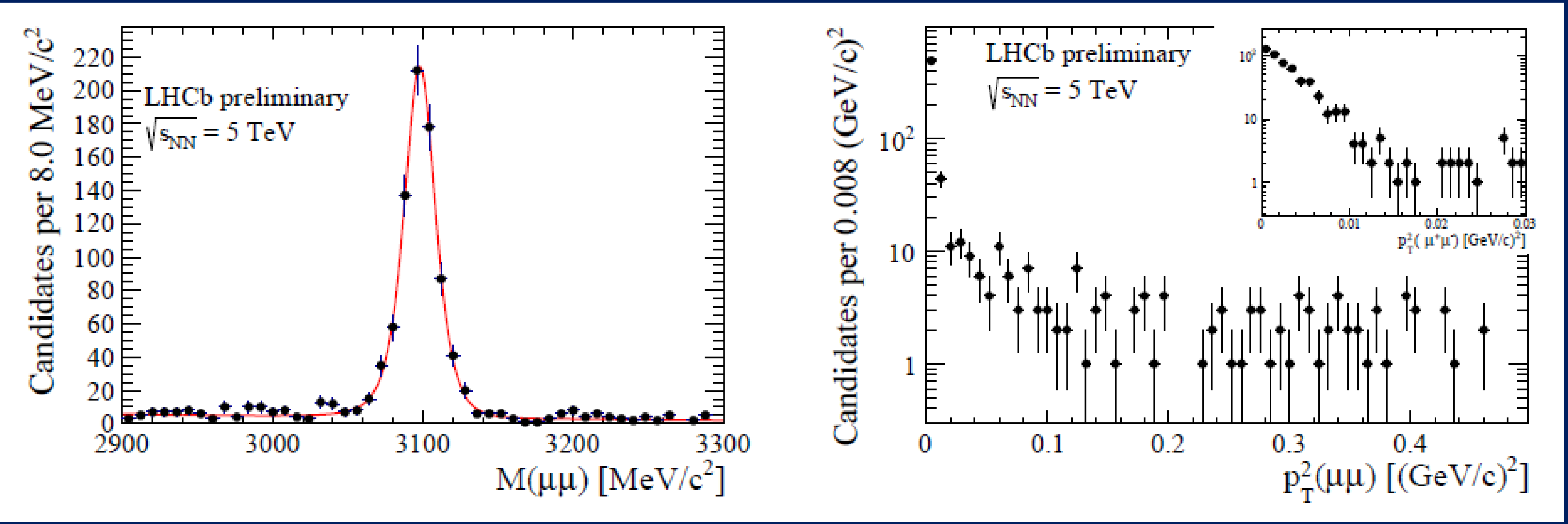
➢ Clear signals also for 50-70% event activity



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

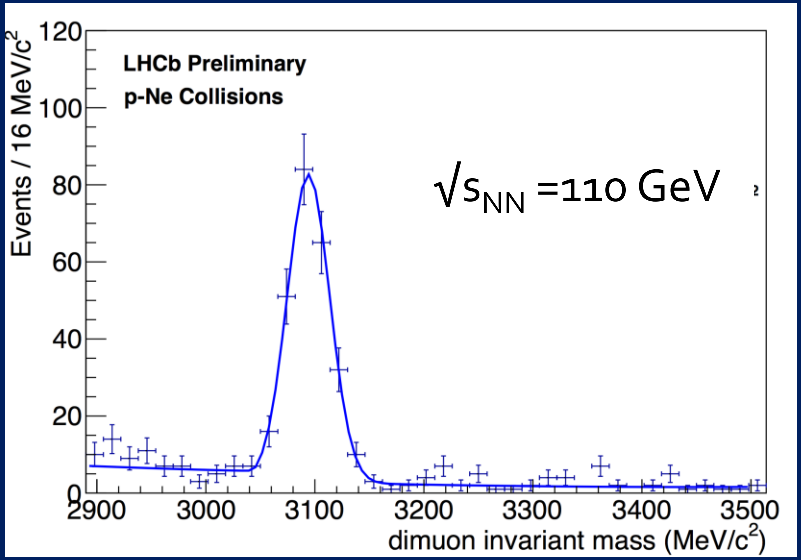


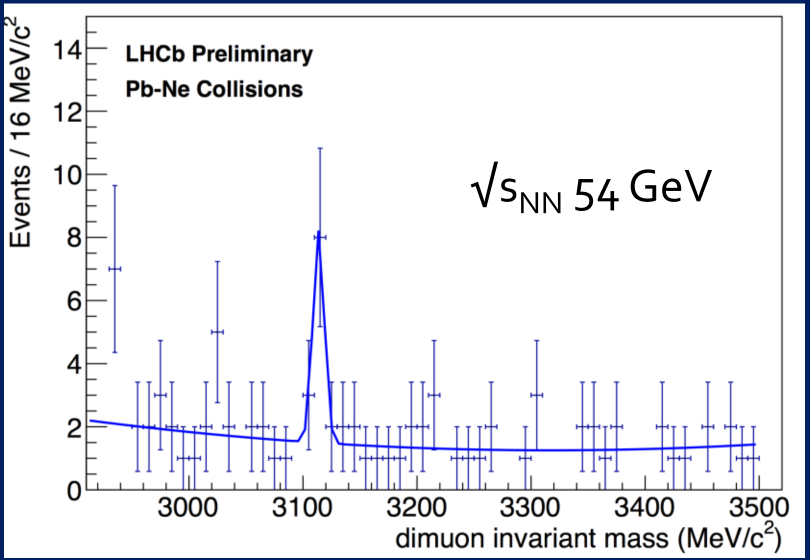
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

- 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

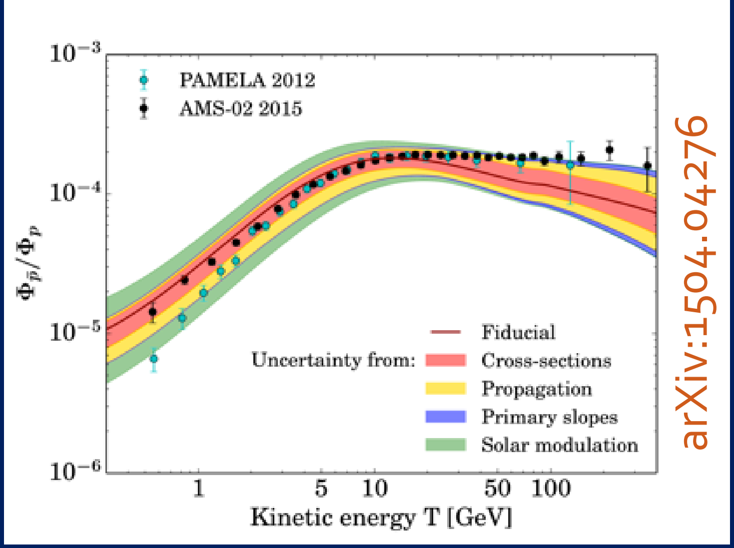
Fixed Target physics with SMOG

- J/ψ production in *p*Ne collisions and in PbNe collisions





- Astrophysical interest:
  - Measure σ (p He → $\bar{p}$ X) to clarify uncertainty on secondary production of $\bar{p}$ in the interstellar medium
  - Many other interesting measurements possible



arXiv:1504.04276

Summary and Conclusions

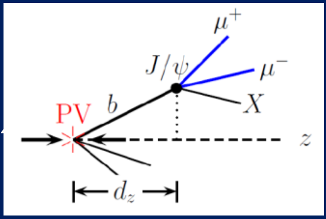
- LHCb participated successfully in proton-lead run in 2013
  - Measurement of J/ψ, $\psi(2s)$, Υ and D^0 and Z-production
    $\rightarrow$ cold nuclear matter effects visible
  - Limited by statistics $\rightarrow$ benefit from larger data samples in Run II
- LHCb physics can cover *pp*, *p*A, and AA interactions
  - Rich program in heavy flavour physics, EW and (soft) QCD
  - We have collected a small sample of PbPb collisions in December 2015
  - We hope to enhance statistics for *p*Pb by a factor 10 this year
- LHCb is in the unique position to do also fixed target physics
  - Exploit the SMOG system with different noble gases
  - Bridge the gap from SPS to LHC physics by a single experiment

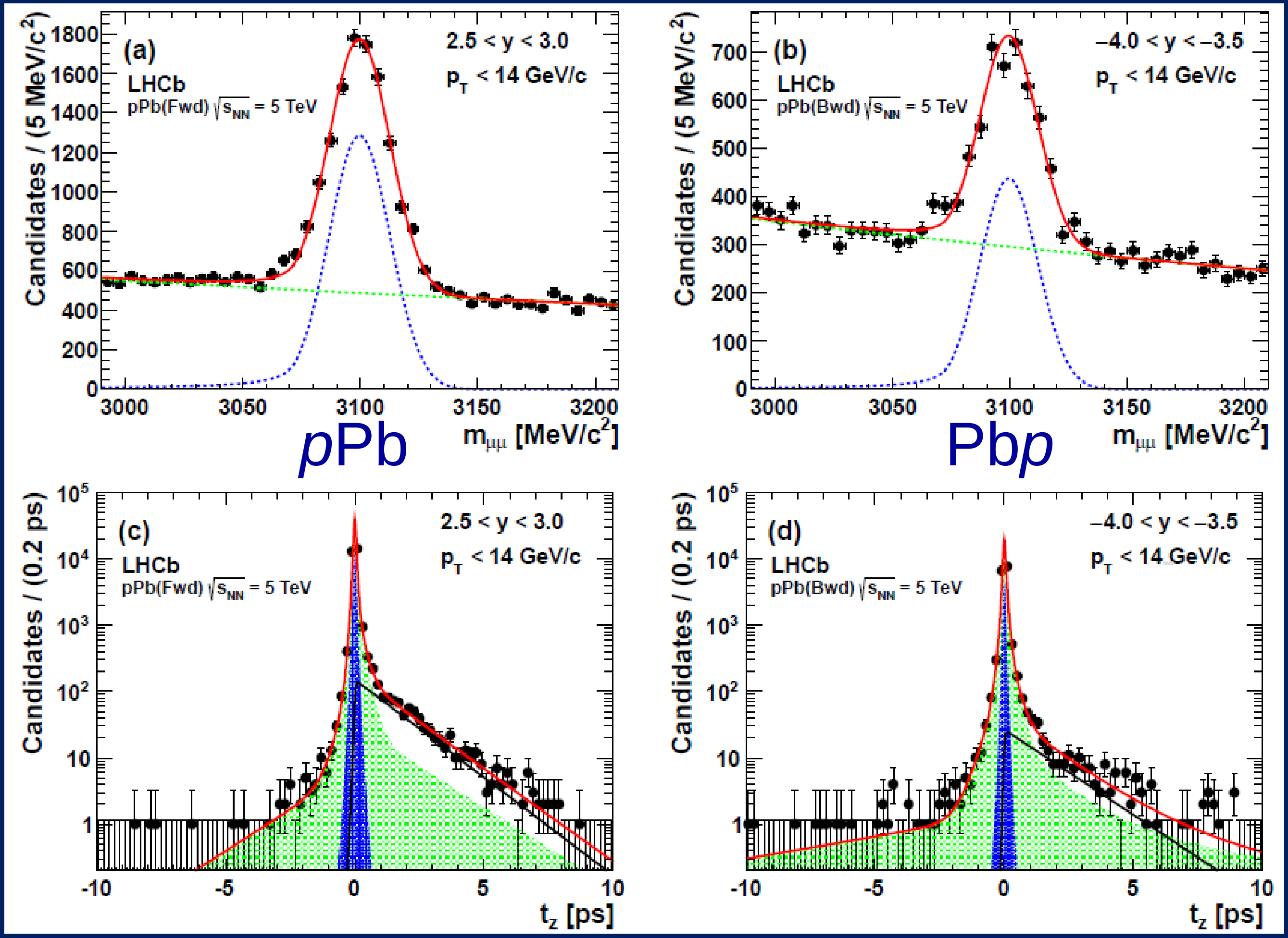
➢ **LHCb is truly a "GPD" in the forward direction**

Backup

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

- Prompt J/ψ and J/ψ from b are extracted by simultaneous fit of mass and pseudo-proper time : $t_z = \left(Z_{J/\psi} - ZPV\right) \times M_{J/\psi} / p$
  [JHEP 02 (2014) 072]





Mass distributions:

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

t_z distributions:

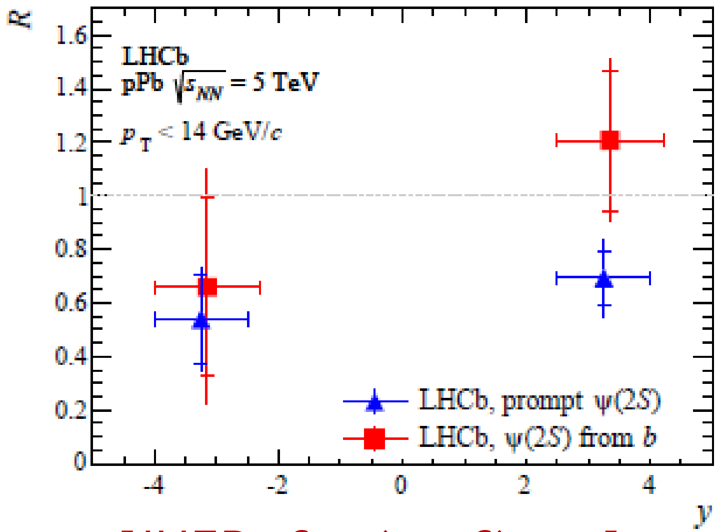
- Signal:
  - $\delta(t_z)$ for prompt J/ψ
    expo. for b-component
- Bkg: empirical function from sideband

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

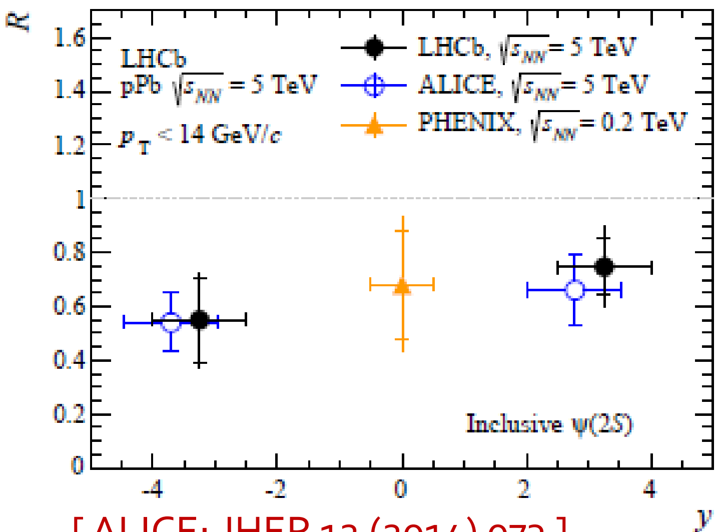
$\psi(2S)$ relative suppression wrt J/ψ

- Relative suppression is calculated as:

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



[JHEP 1603 (2016) 133]

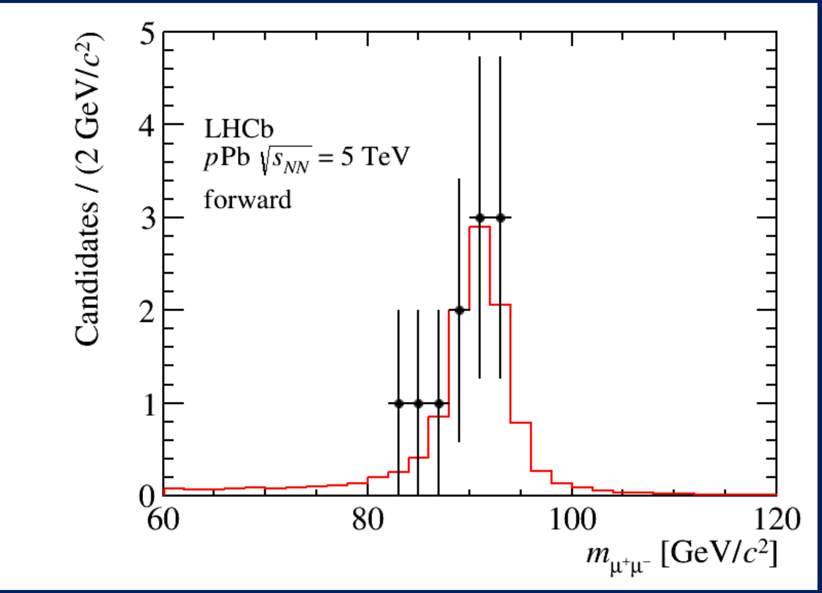


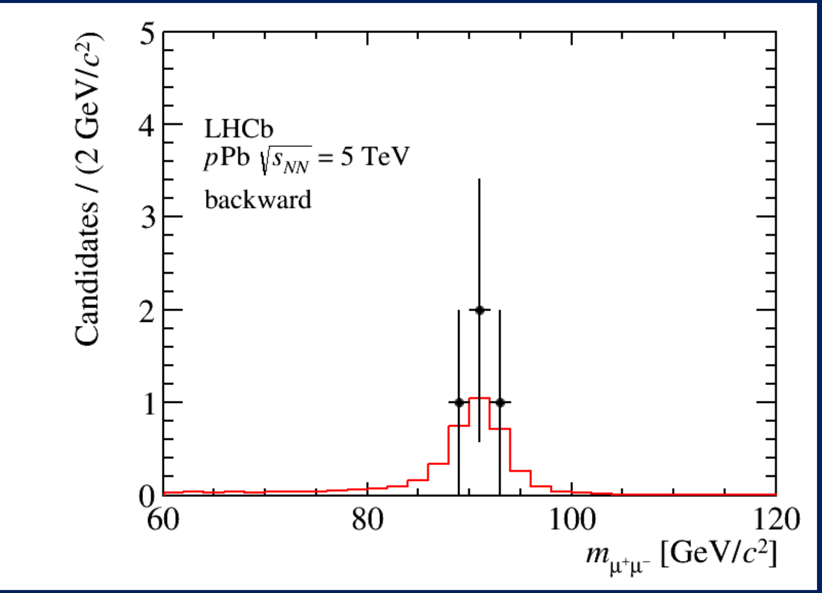
[ALICE: JHEP 12 (2014) 073]
[PHENIX: PRL 111 (2013) 202301]

- 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

Z-production in proton-lead collisions

- muon selection: $p_T > 20$ GeV/c ; $2.0 < y < 4.5$; $60 < M(\mu^+\mu^-) < 120$ GeV/c²
- backgrounds: very small, purity>99% determined from data





[JHEP 09 (2014) 030]

Clean signals: 11 forward-candidates and 4 backward candidates,

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

Looking forward to 10x the statistics in Run II

Prospects for 2016 pPb run

- Plan to do fixed target studies during pPb run at $\sqrt{s_{NN}} = 5$ TeV
- 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 $20\,\mathrm{nb}^{-1}$
$\Upsilon(3S) \to \mu^+\mu^-$	–	300
$\psi(2S) \to \mu^+\mu^-$	500	10000
$Z \to \mu^+\mu^-$	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 Υ(3S)
- Improved precision on Z-production → constrain nPDF
- Associated HF production in pA to study single- and double- parton scattering

J/ψ over Drell-Yan measurement

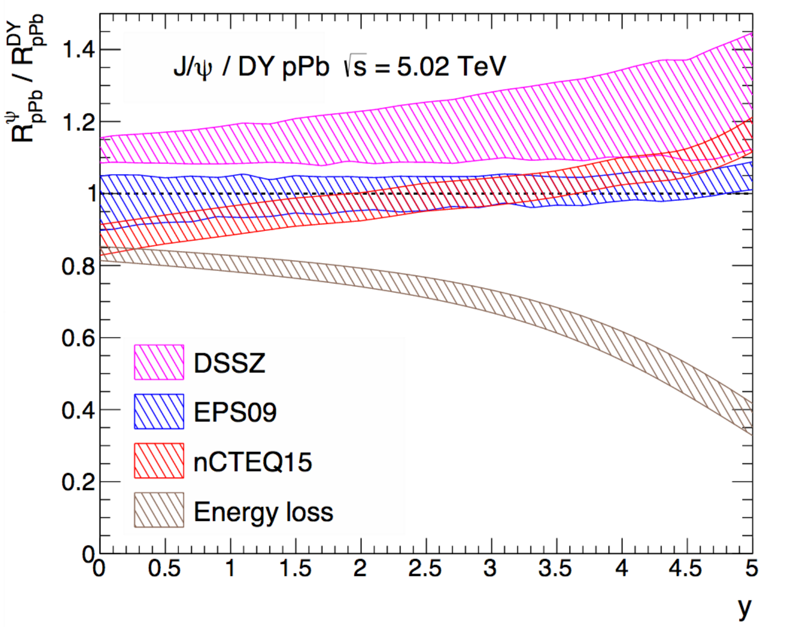


Figure 3: Double ratio $\mathcal{R}_{\mathrm{pPb}}^{\psi/\mathrm{DY}}$ in p–Pb collisions at $\sqrt{s}$ = 5.02 TeV for the various nPDF sets and in the coherent energy loss model.

- Quarkonium production data so far not precise enough to distinguish between various CNM models (shadowing / e-loss)
- 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 *bb* production
- Many systematic effects cancel in the ratio → higher precision
- Projections with 20/nb :
  → 1000 Drell-Yan candidates