

Results and plans with heavy ion collisions at the LHCb experiment

Francesco Bossù
on behalf of the LHCb collaboration

Laboratoire de l'Accélérateur Linéaire, Orsay

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- 1 Introduction
- 2 p-Pb results
- 3 First look at PbPb collisions
- 4 Fixed-target physics
- 5 Summary

1 Introduction

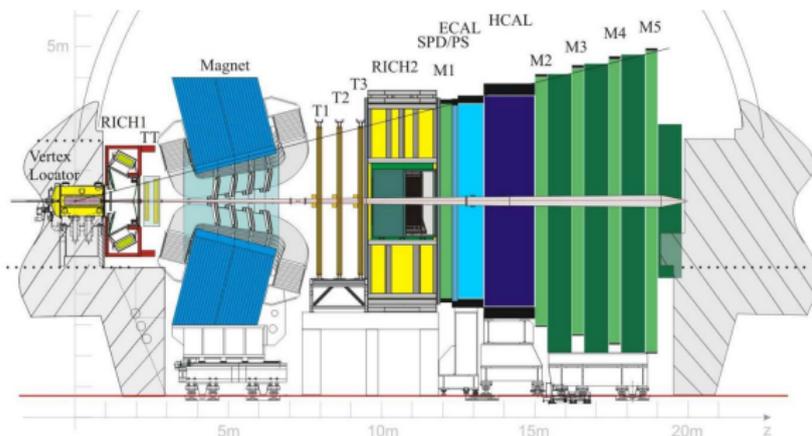
2 p-Pb results

3 First look at PbPb collisions

4 Fixed-target physics

5 Summary

- Single arm spectrometer, fully instrumented in $2 < y < 5$
- Designed for heavy flavor physics, it is becoming a **general purpose detector**



Excellent vertex, IP and decay time resolution

- $\sigma(IP) \approx 20\mu m$ for high- p_T tracks
- $\sigma(\tau) \approx 45fs$ for $B_s^0 \rightarrow J/\psi\phi$ decays

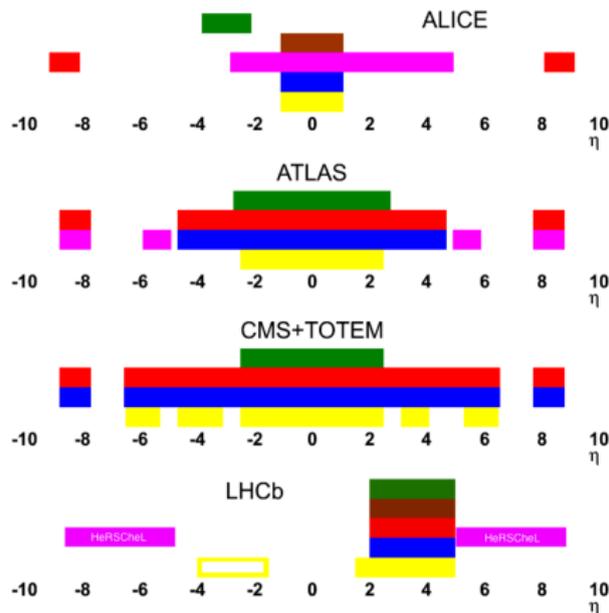
Very good momentum resolution

- $\delta p/p \approx 0.5 - 1\%$ for $0 < p < 200$ GeV/c

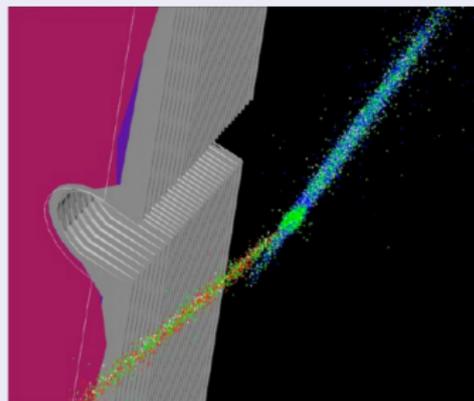
Particle identification

- $\epsilon_{K \rightarrow K} \approx 95\%$ for $\epsilon_{\pi \rightarrow K} \approx 5\%$ up to 100 GeV/c
- $\epsilon_{\mu \rightarrow \mu} \approx 97\%$ for $\epsilon_{\pi \rightarrow \mu} \approx 1 - 3\%$

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



LHCb as Fixed Target experiment



Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.

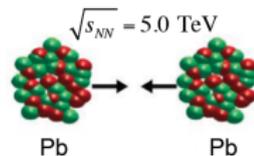
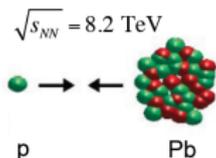
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

- LHCb fully instrumented in $2 < y < 5$
- Collider mode: **Complementary to other LHC experiments**
- Data taking in fixed target mode: **unique feature!**

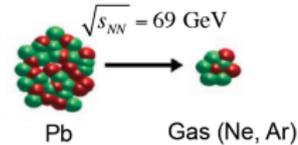
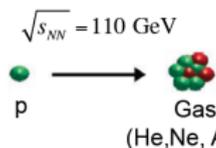
- SMOG: System for Measuring Overlap with Gas
- Noble gases injected in the interaction region
- Designed and used for luminosity measurements
- Allows measurement of p- or Pb-Gas collisions

LHCb running modes

Collider mode



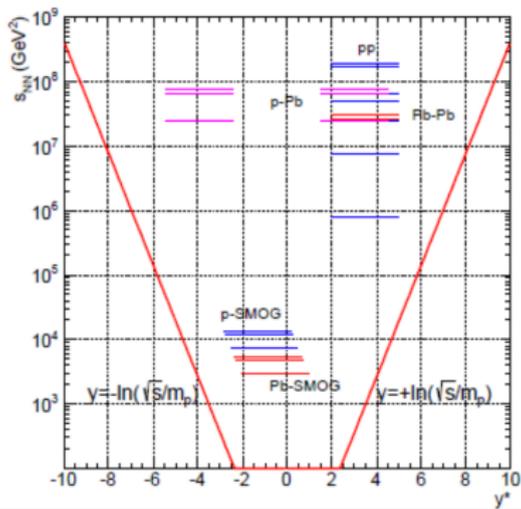
Fixed target mode



Kinematic coverage in rest frame

- Collider: forward/backward rapidities
- Fixed target: mid and backward rapidities, energies between SPS and RHIC

LHCb bridges the gap from SPS to LHC in a single experiment



y^* : rapidity in the centre of mass frame

① Introduction

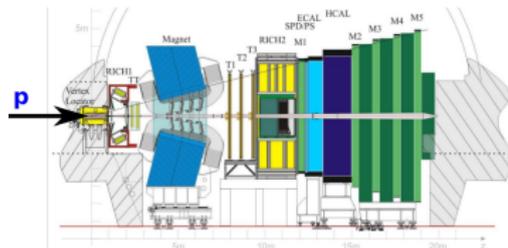
② p-Pb results

③ First look at PbPb collisions

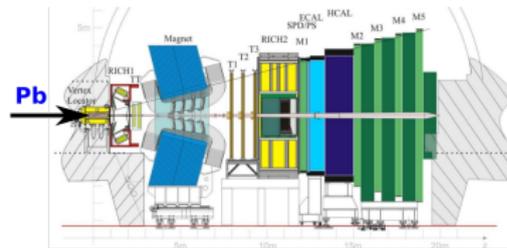
④ Fixed-target physics

⑤ Summary

- **Goal:** study nuclear matter effects
- Two-particle angular correlations
 - Long range correlation measurements in Pb-Pb collisions interpreted as hydrodynamical flow of deconfined medium
 - Mid-rapidity measurements showed “the ridge” in p-Pb collisions. LHCb forward rapidity coverage is unique.
- Open and hidden heavy-flavours:
 - Produced in initial hard scatterings
 - Essential tools to study cold nuclear matter effects (CNM)
 - p-Pb measurements essential to disentangle QGP from CNM effects in AA collisions
- 1.6 nb^{-1} collected in 2013.
- p and Pb beams reversal allows to study backward and forward rapidity regions
- Asymmetry in beam energies: rapidity coverage shifted by $\Delta y \sim 0.47$



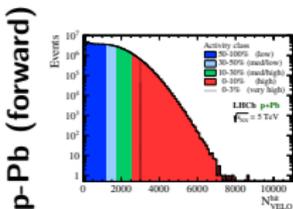
$$1.5 < y^* < 4.5$$



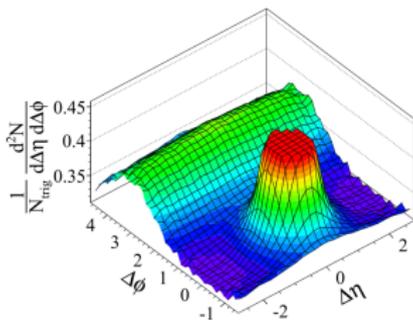
$$-5.5 < y^* < -2.5$$

p-Pb - Two particle angular correlations

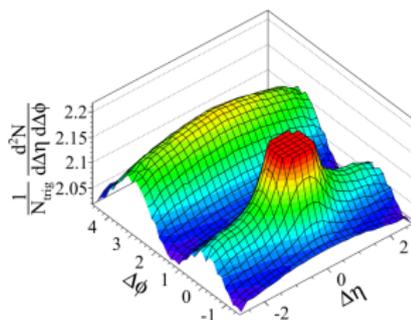
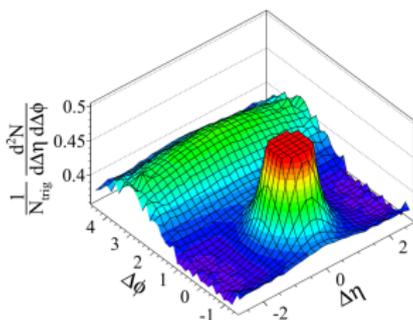
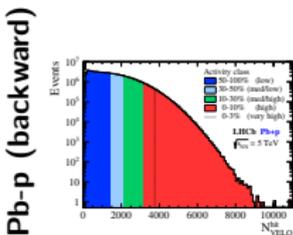
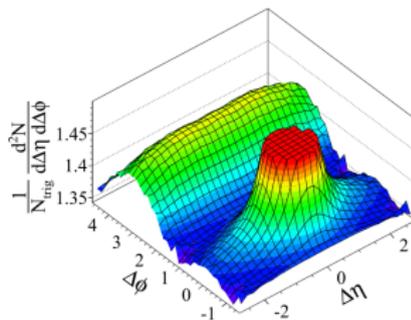
Measurement of angular ($\Delta\phi, \Delta\eta$)-correlations of prompt charged particles



Low activity (50-100%)



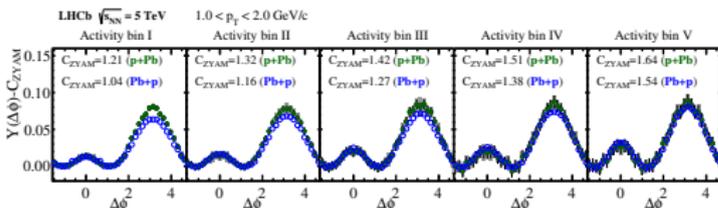
High activity (0-3%)



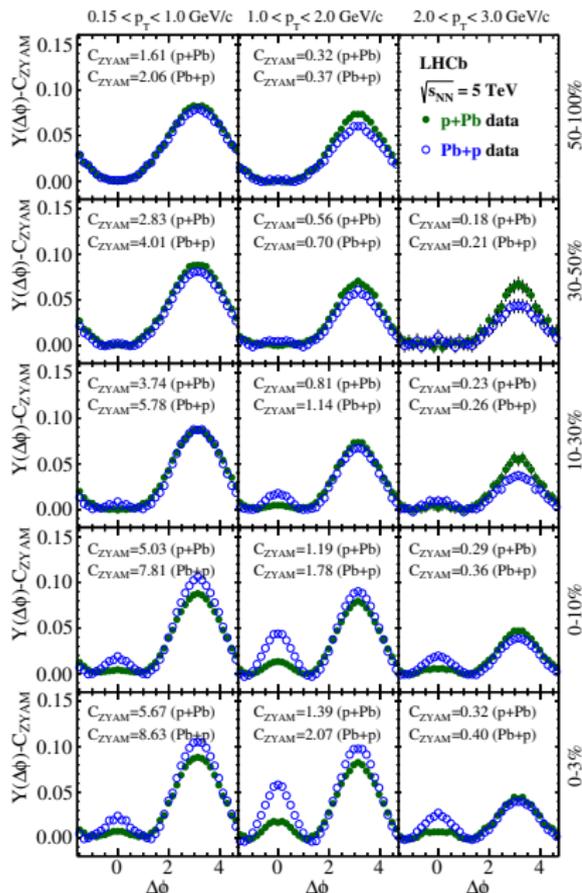
In high activity events, near side ridge ($\Delta\phi = 0$) visible

p-Pb - Two particle angular correlations

- $\Delta\phi$ projections away from the jet peak ($2 < |\Delta\phi| < 2.9$)
- Subtraction of the Zero Yield At Minimum (ZYAM)
- Near side correlation increases with the event activity
- More evident in Pb-p collisions (backward)
- Absolute event activity classes
- Backward and forward near-side correlations of compatible strength



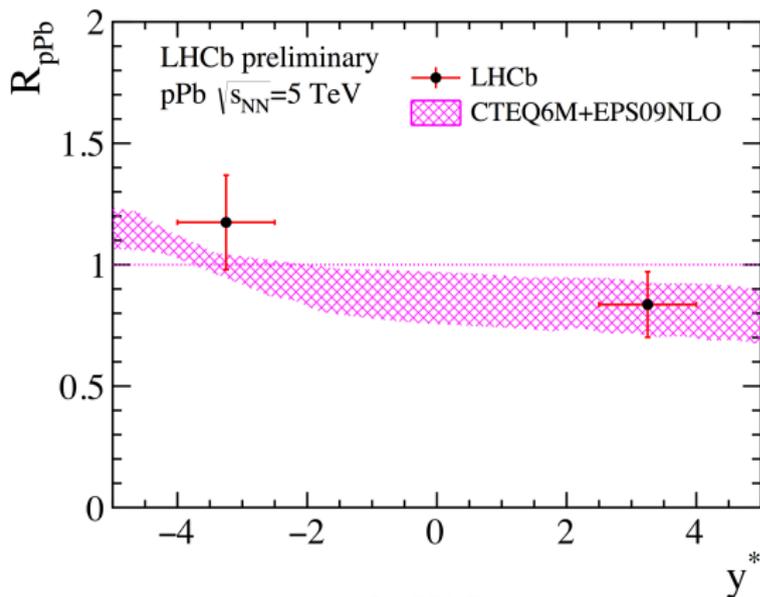
arXiv:1512.00439



p-Pb - Prompt D^0 nuclear modification factor

- D^0 fully reconstructed in the decay $D^0 \rightarrow K^- \pi^+$, **down to $p_T = 0$**
- Minimum bias selections, particle identification and vertex displacement
- Prompt yields: 2D fit to D^0 mass and impact parameter

$$R_{pPb}(p_T, y^*) = \frac{1}{A} \cdot \frac{\sigma_{pPb}(p_T, y^*)}{\sigma_{pp}(p_T, y^*)}$$

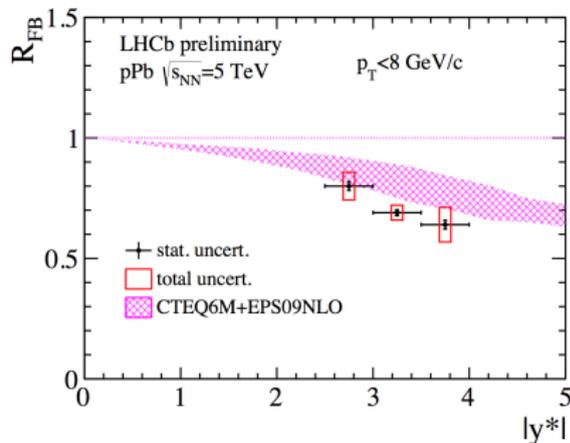
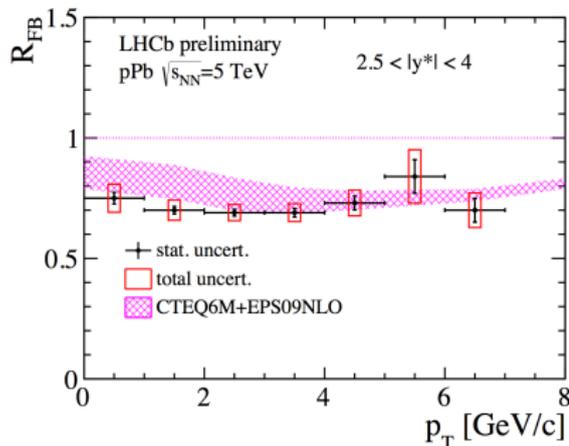


LHCb-CONF-2016-003

- $\sigma_{pp}(\sqrt{s} = 5\text{TeV})$: extrapolation using LHCb measurements at 7 and 13 TeV
- Analysis of the pp@5TeV reference run ongoing
- R_{pPb} less than unity at forward rapidities
- pQCD calculations that uses EPS09 nuclear PDF parametrization reproduce the data

$$R_{FB}(p_T, |y^*|) = \frac{\sigma_{pPb}(p_T, y^*)}{\sigma_{Pbp}(p_T, y^*)}$$

- Systematics uncertainties largely cancel
- Common rapidity range $2.5 < |y^*| < 4$

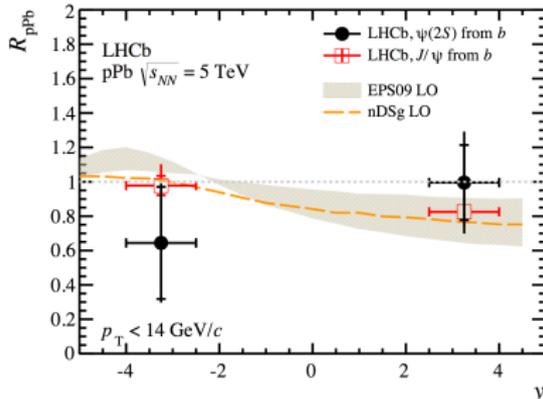
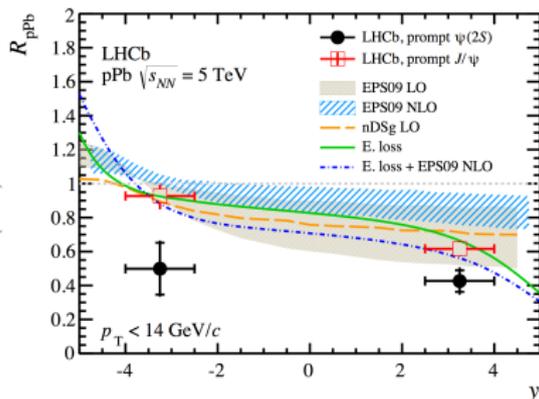


- Clear asymmetry forward/backward
- No p_T dependence
- Asymmetry more important at larger y^*
- Within uncertainties, data are reproduced by pQCD calculations with EPS09 nPDF

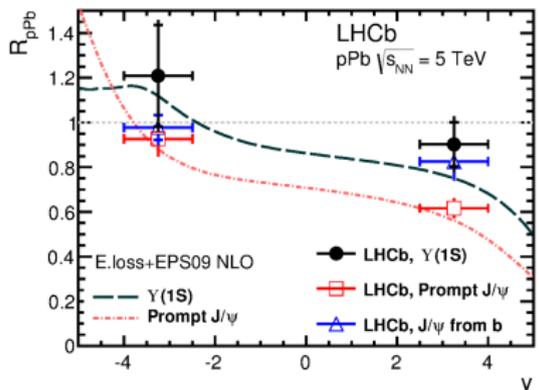
p-Pb - J/ψ , $\psi(2S)$ and $\Upsilon(1S)$

- Candidates fully reconstructed from well identified muons
- Prompt J/ψ , $\psi(2S)$ and those from b decays separated using pseudo-proper decay time

JHEP 1402 (2014) 072
JHEP 1603 (2016) 133



JHEP 07 (2014) 094



Forward rapidity

- Significant suppression for J/ψ , even larger for $\psi(2S)$
- Modest suppression for non-prompt J/ψ , similar to $\Upsilon(1S)$

Backward rapidity

- No suppression for J/ψ and $\Upsilon(1S)$
- Unexpected large suppression for $\psi(2S)$, not described by E.loss and shadowing

J/ψ and $\Upsilon(1S)$ results reproduced by models

① Introduction

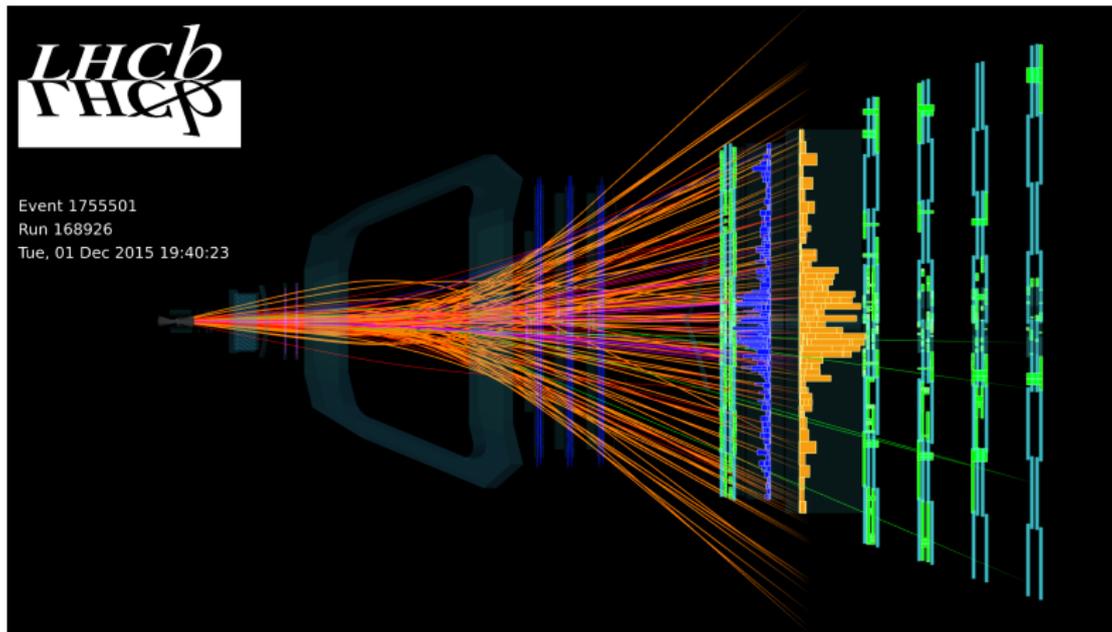
② p-Pb results

③ **First look at PbPb collisions**

④ Fixed-target physics

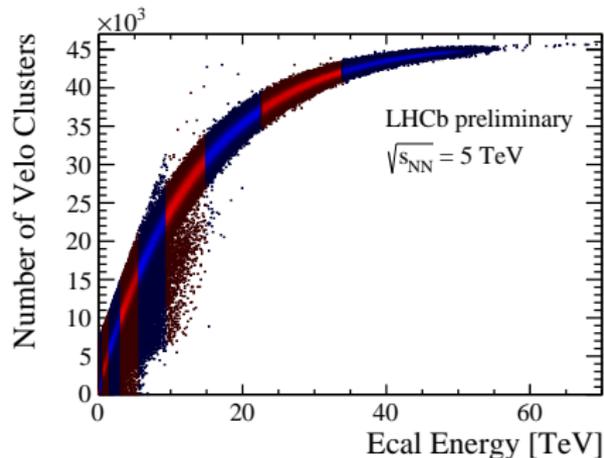
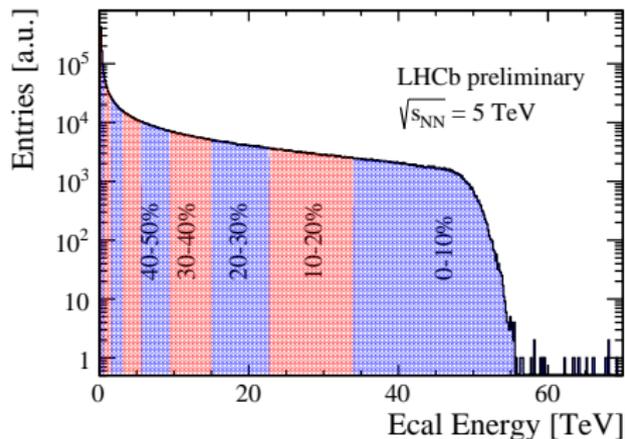
⑤ Summary

- December 2015. First time of LHCb participation in Pb-Pb data taking
- Only 24 colliding bunches. Luminosity $\approx 3\text{-}5 \mu\text{b}^{-1}$
- Minimum bias trigger configuration: all inelastic interactions recorded on tape



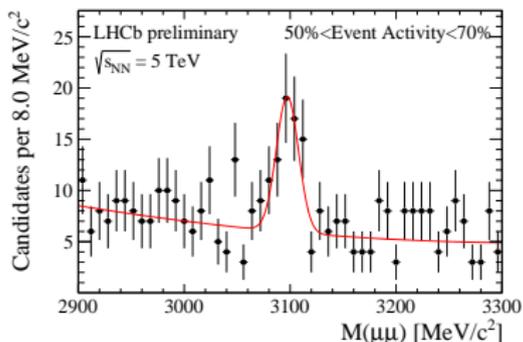
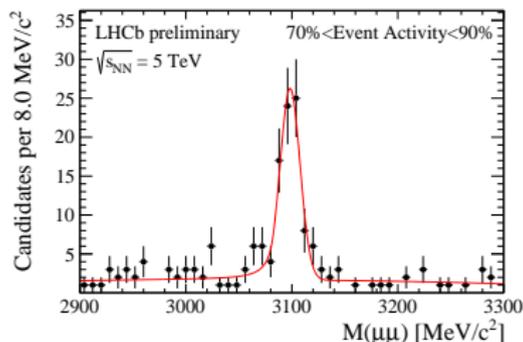
Example of one PbPb event with more than 1000 charged tracks and a J/ψ candidate

- Experimental observables: total energy in the calorimeters, EM (Ecal) or hadronic (Hcal)
- No saturation of calorimeter signals even for most central collisions

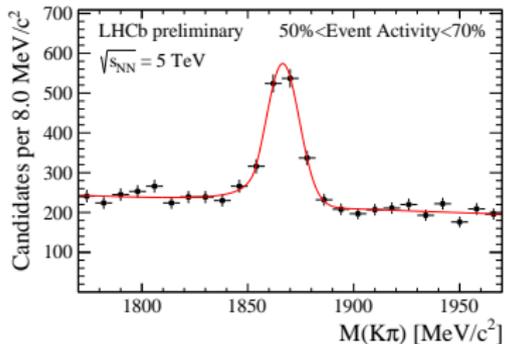
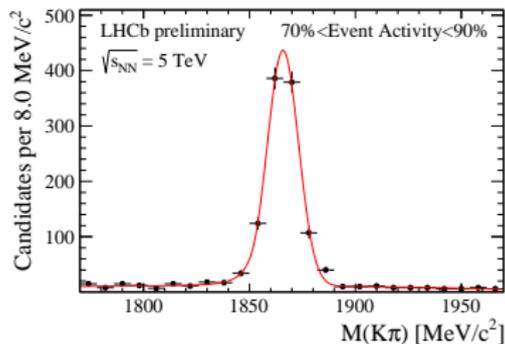


- Event classification in terms of Ecal activity
- Saturation in Vertex Locator (VELO) clearly visible. Track reconstruction was performed up to ~ 15 k clusters
- Corresponding range: 50-100% event activity

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

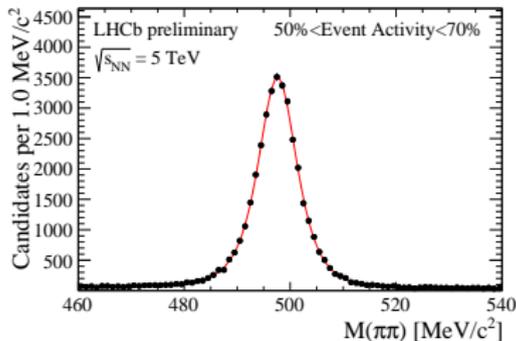
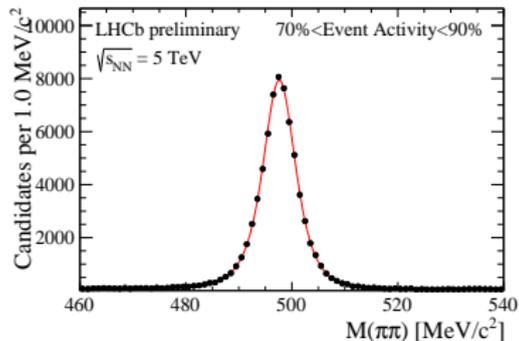


$$D^0 \rightarrow K^- \pi^+$$

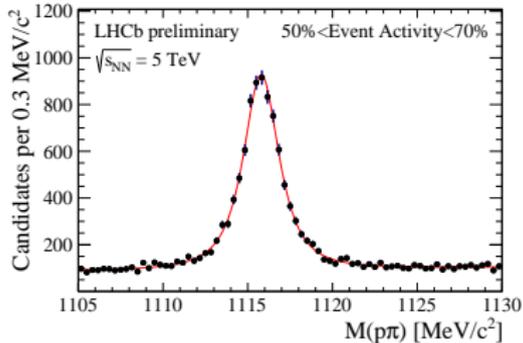
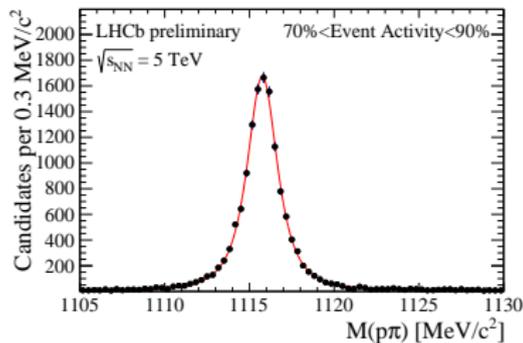


Clear signals also in 50-70% event activity bin

$$K_S^0 \rightarrow \pi^+ \pi^-$$

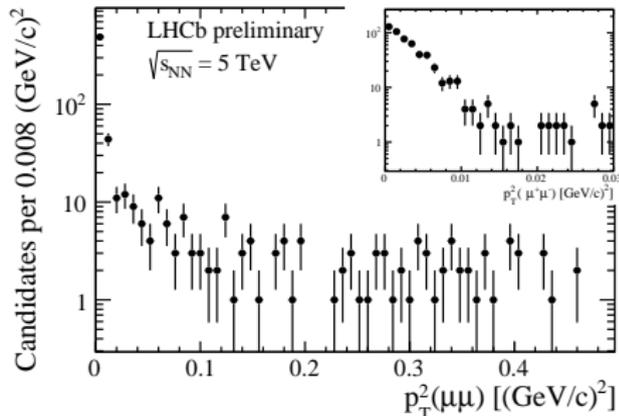
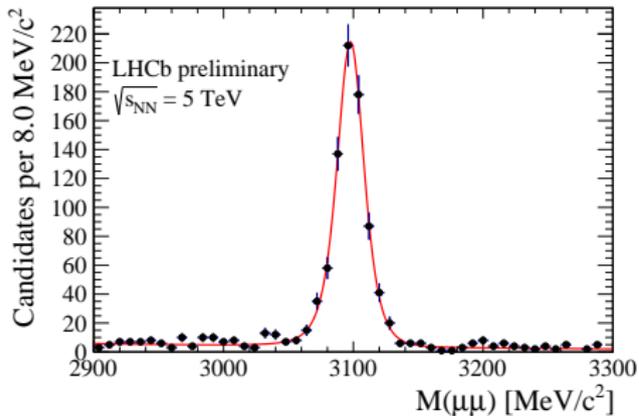


$$\Lambda \rightarrow p\pi^+$$

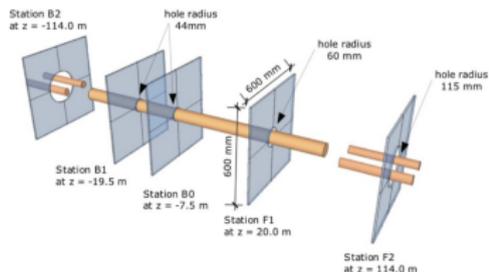


PbPb - J/ψ in ultra-peripheral collisions

Selection: nothing in the detector but two muon tracks



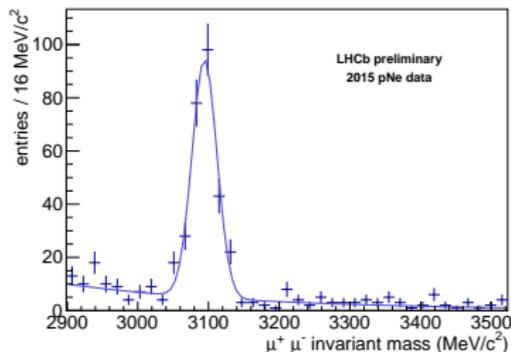
- Candidates of coherent photo-produced J/ψ in PbPb ultra peripheral collisions
- These studies will benefit of the new Herschel detector
 - Possibility to define large rapidity gaps: $5 < |y| < 9$
 - Herschel was taking data in 2015



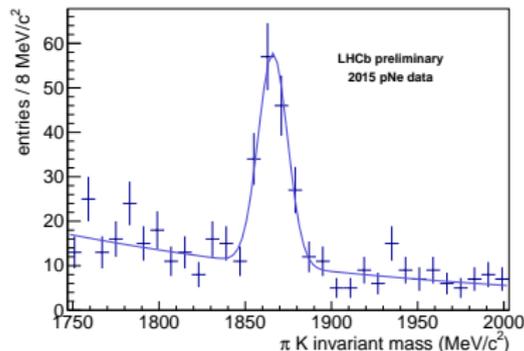
- ① Introduction
- ② p-Pb results
- ③ First look at PbPb collisions
- ④ **Fixed-target physics**
- ⑤ Summary

- Data collected with different beams/targets and at different energies
- Example of an ongoing analysis:
 J/ψ and open charm production in p-Ne at $\sqrt{s_{NN}} = 110$ GeV

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



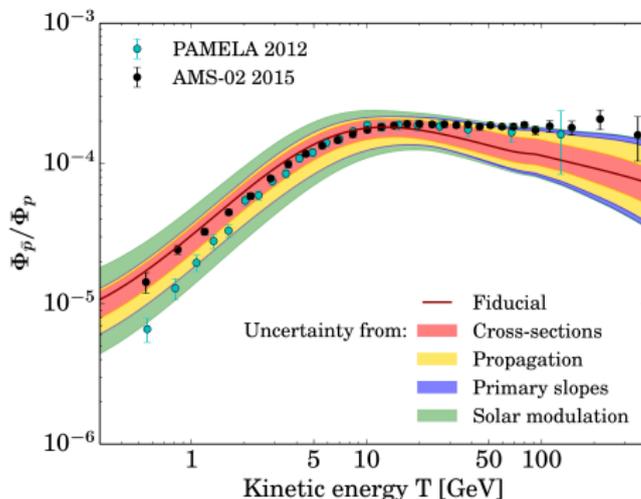
$$D^0 \rightarrow K^- \pi^+$$



- Clear signals
- Luminosity determination is challenging: based on pe^- elastic scattering
- Analysis ongoing on pHe, pNe, pAr and PbAr data sets

Fixed-target - Link with cosmic ray physics

- AMS-02 results show a possible excess of antiprotons with respect to secondary production in the interstellar medium ($pp \rightarrow \bar{p}X$ and $pHe \rightarrow \bar{p}X$)
- Possible evidence for Dark Matter contribution



JCAP 1509 (2015) no.09, 023

- Largest uncertainty: $\sigma(pHe \rightarrow \bar{p}X)$
- LHC proton beam on He at rest, good energy range for cross section measurements
- High energy neutrino physics: backgrounds from charm production.
- Possibility to study with LHCb intrinsic charm at large x

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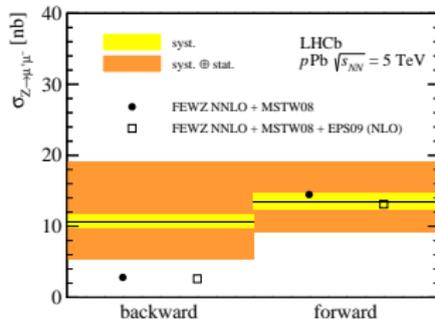
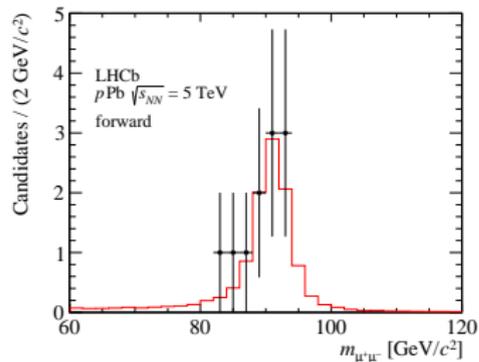
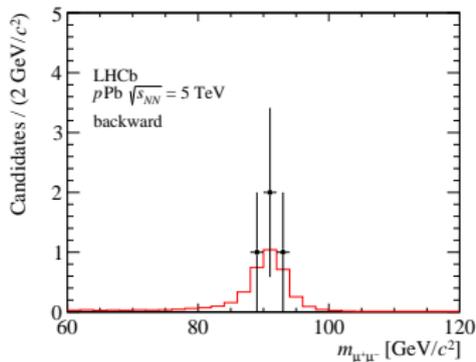
- LHCb demonstrated that it can play an important role in heavy ion physics
- Successful data taking in pPb collisions at $\sqrt{s_{NN}} = 5$ TeV in 2013
 - Two-particle angular correlations: similar behaviour backward-forward rapidities in absolute event activity classes
 - Cold nuclear matter effects visible in heavy quarkonia and open charm measurements
- PbPb collisions collected in 2015
 - For the moment, measurements will be carried out for peripheral and ultra-peripheral collisions
 - Clear physics signals, analysis ongoing
- Fixed-target physics
 - Unique feature!!
 - Exploiting colliding system of different sizes and energies

More to come:

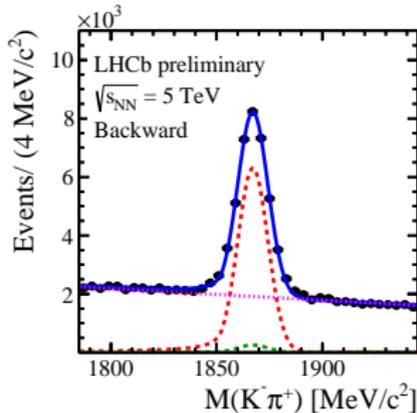
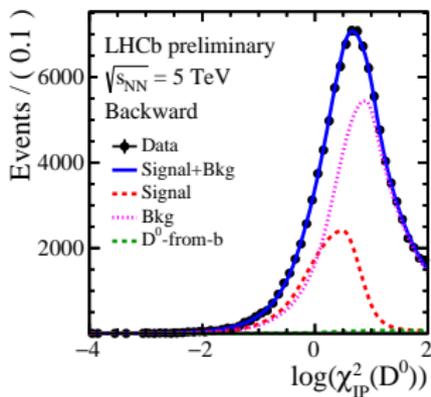
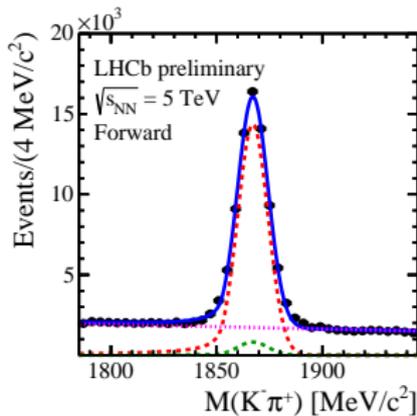
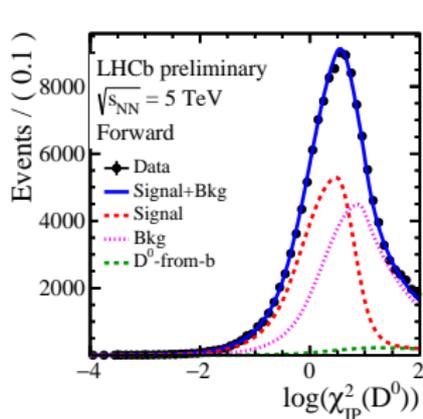
- Looking forward to collecting pPb collisions at $\sqrt{s_{NN}} = 5$ and 8 TeV in 2016
- At 8 TeV, 10x more statistics with respect to previous pPb run
- Possibility to study more observables ($\Upsilon(3S)$, Drell-Yan, associated $J/\psi - D^0$, W boson ...)
- In the meanwhile, additional fixed target campaigns are foreseen.

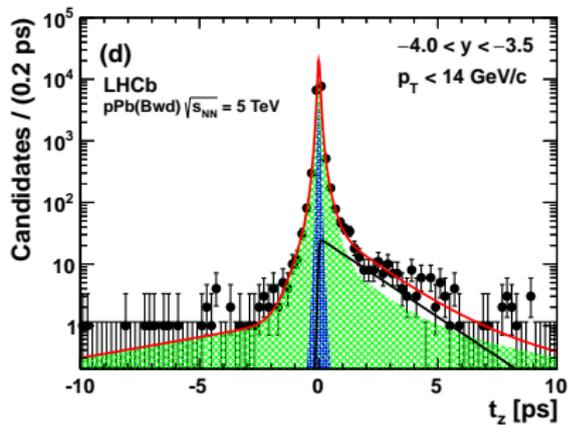
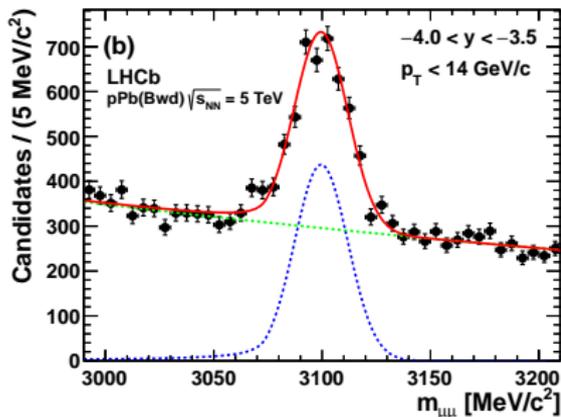
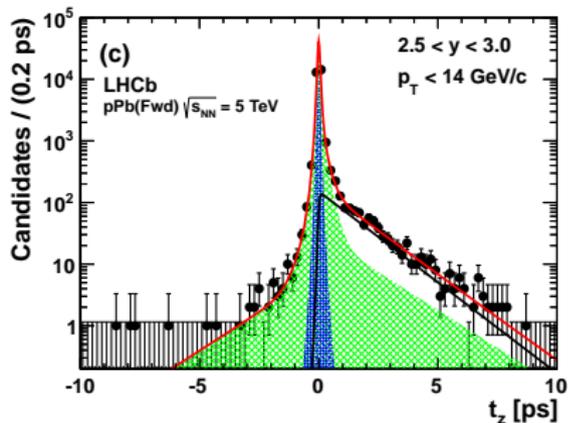
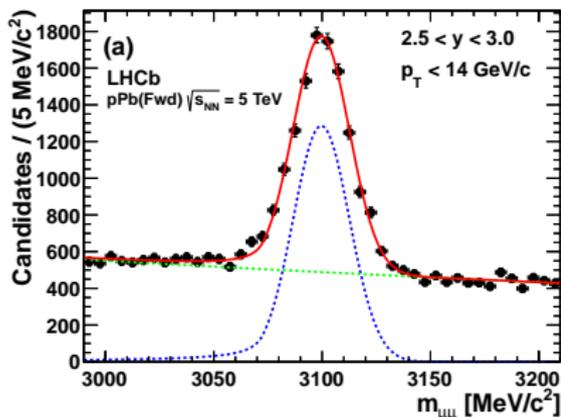
Stay tuned!

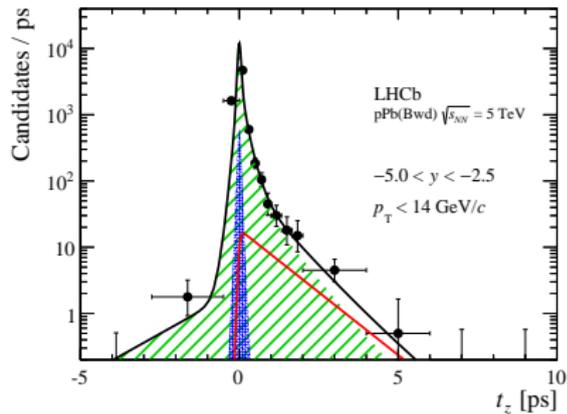
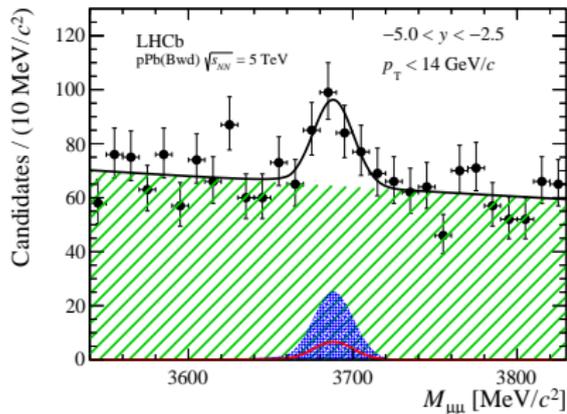
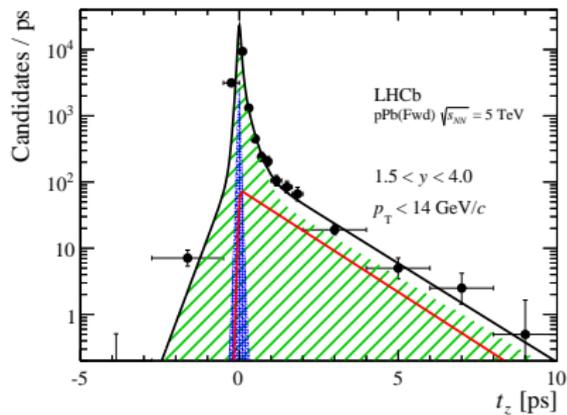
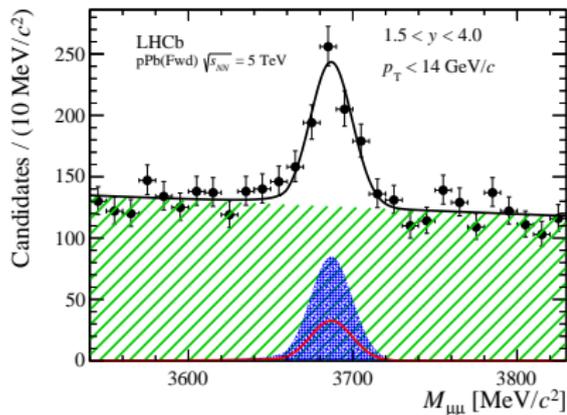
backups



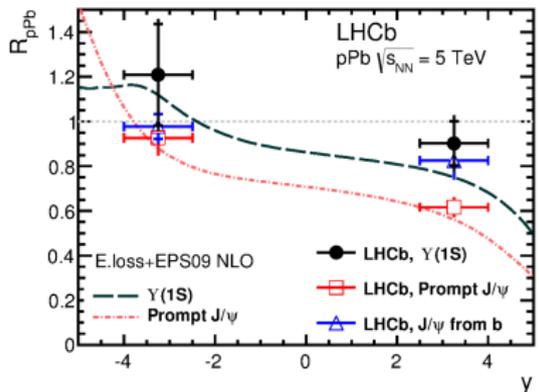
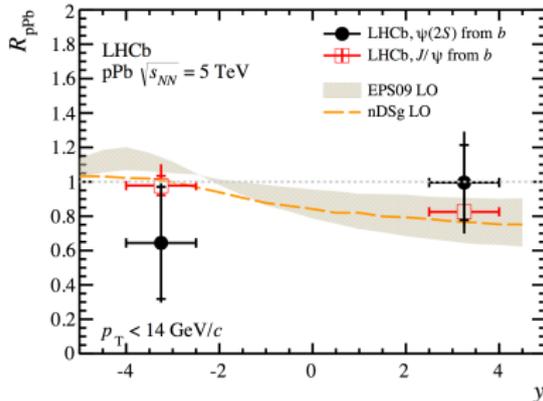
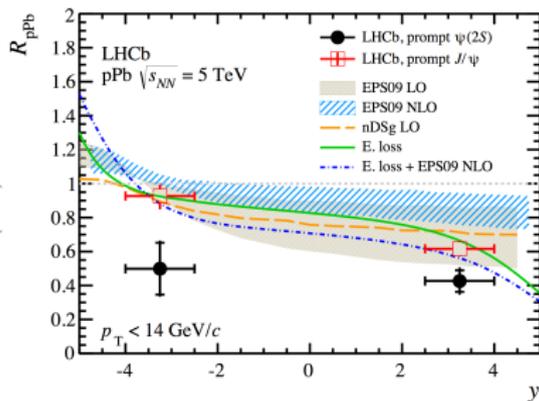
- Clean signal: 11 forward candidates, 4 backward candidates
- Cross sections in agreement with predictions, although the production of Z in the backward region appears slightly higher than prediction







- Candidates fully reconstructed from well identified muons
- Prompt J/ψ , $\psi(2S)$ and those from b decays separated using pseudo-proper decay time



Models

- EPS09LO (CSM): PRC88 (2013) 047901; NPA 926 (2014) 236
- EPS09LNO (shadowing + CEM): IJMP E22 (2013) 1330007
- Energy Loss: JHEP 03 (2013) 122; JHEP 05 (2013) 155
- nDSg LO: PRC88 (2013) 047901