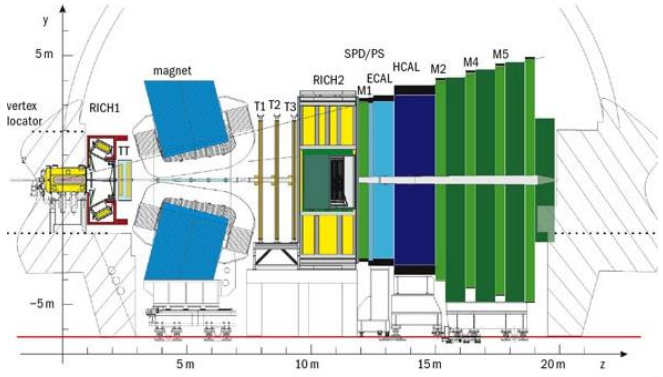
Hard probes with *p*-Pb and Pb-Pb collisions and fixed target results at LHCb



Frédéric FLEURET
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and *Laboratoire de l'Accélérateur Linéaire*, Orsay

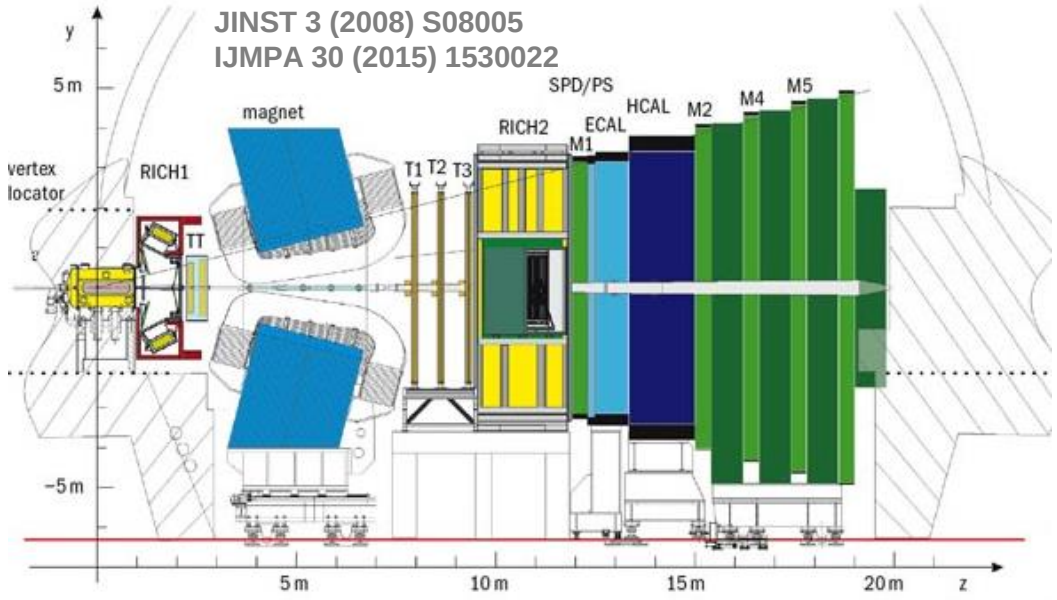
On behalf of the LHCb collaboration

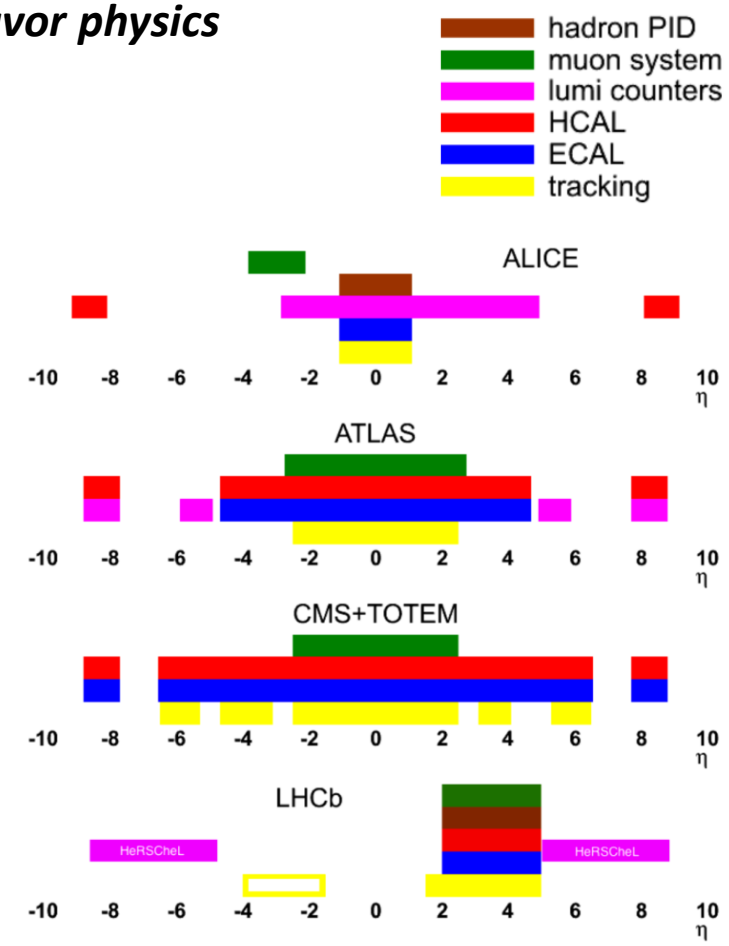
Moriond QCD
La Thuile, 2018

The LHCb detector

Single arm spectrometer, the only LHC experiment fully instrumented in $2 < \eta < 5$

Originally designed for heavy flavor physics





Excellent vertex, IP and decay time resolution

$\sigma(IP) \approx 20\mu m$

Very good momentum resolution

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

Particle identification

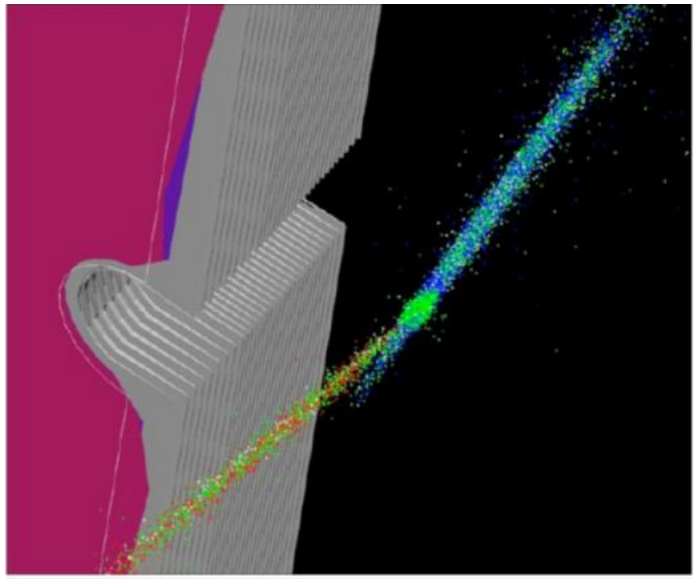
$\varepsilon_{K\to K} \approx 95\%$ for $\varepsilon_{\pi\to K} \approx 5\%$ up to 100 GeV/c

$\varepsilon_{\mu\to\mu} \approx 97\%$ for $\varepsilon_{\pi\to\mu} \approx 1-3\%$

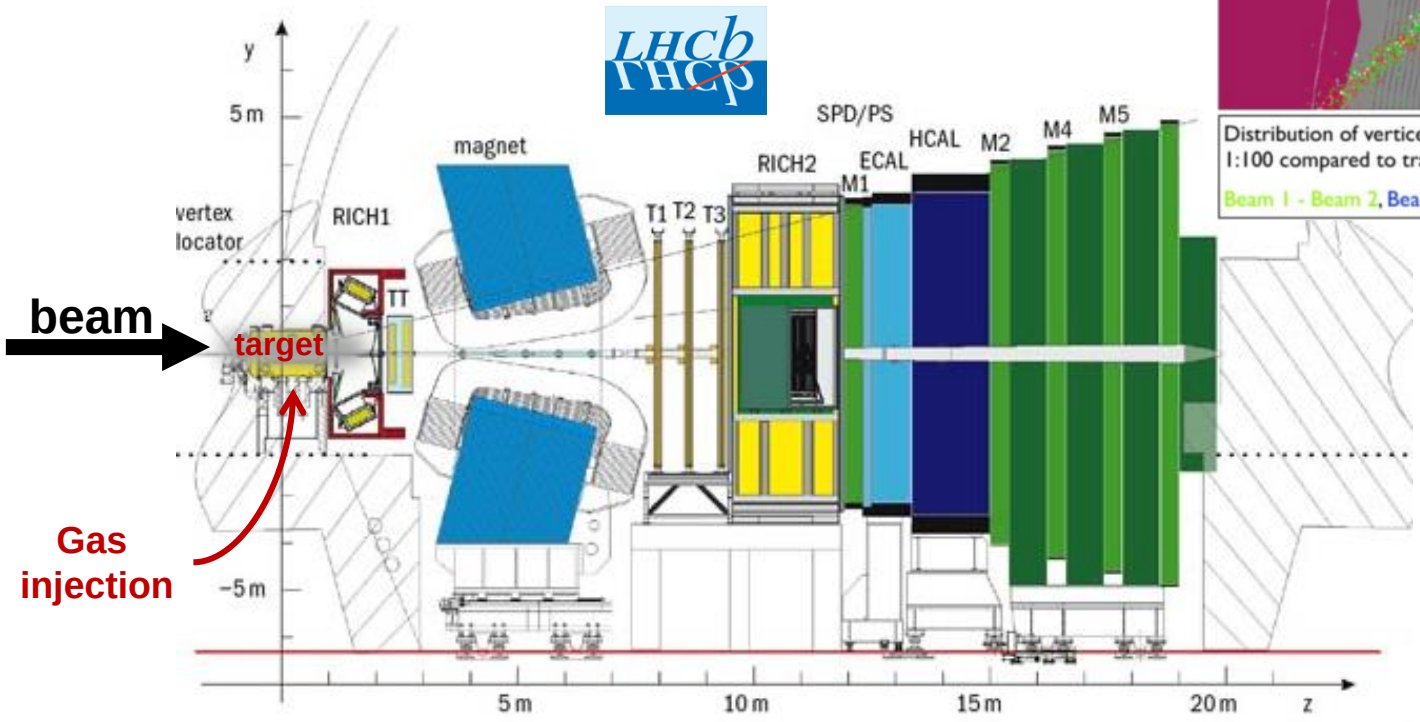
LHCb can operate *p*-Pb and Pb-Pb collisions

The LHCb detector

- **Can also operate in fixed-target mode: unique at LHC**
  - Injecting gas in the LHCb VErtex LOcator (VELO) tank, primarly done to perform luminosity measurement.
  - Can be used as an **internal gas target**
  - Allows measurement of *p*-gas and ion-gas interactions



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.



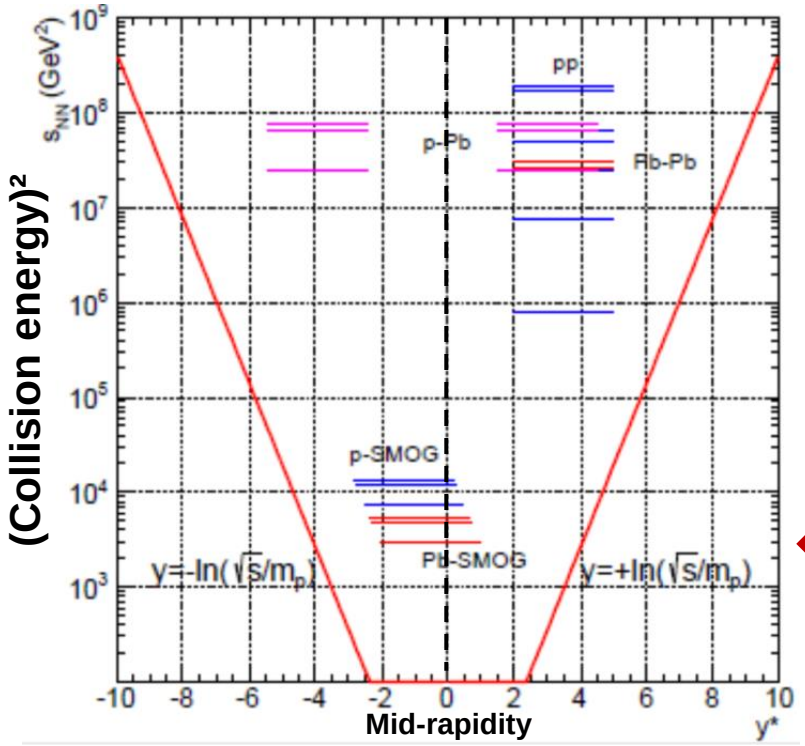
Noble gas only :
(very low chemical reactivity)

He, Ne, Ar, Kr, Xe
A = 4, 20, 40, 84, 131

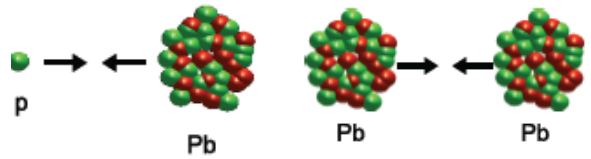
Gas pressure:
10^{-7} to 10^{-6} mbar

LHCb operations for heavy ion physics

LHCb rapidity coverage in the centre-of-mass system

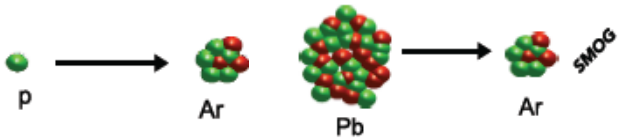


Colliding mode



E_{beam}(p)	pp	p-SMOG	p-Pb/Pb-p	Pb-SMOG	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5. TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.02 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

Fixed-target mode

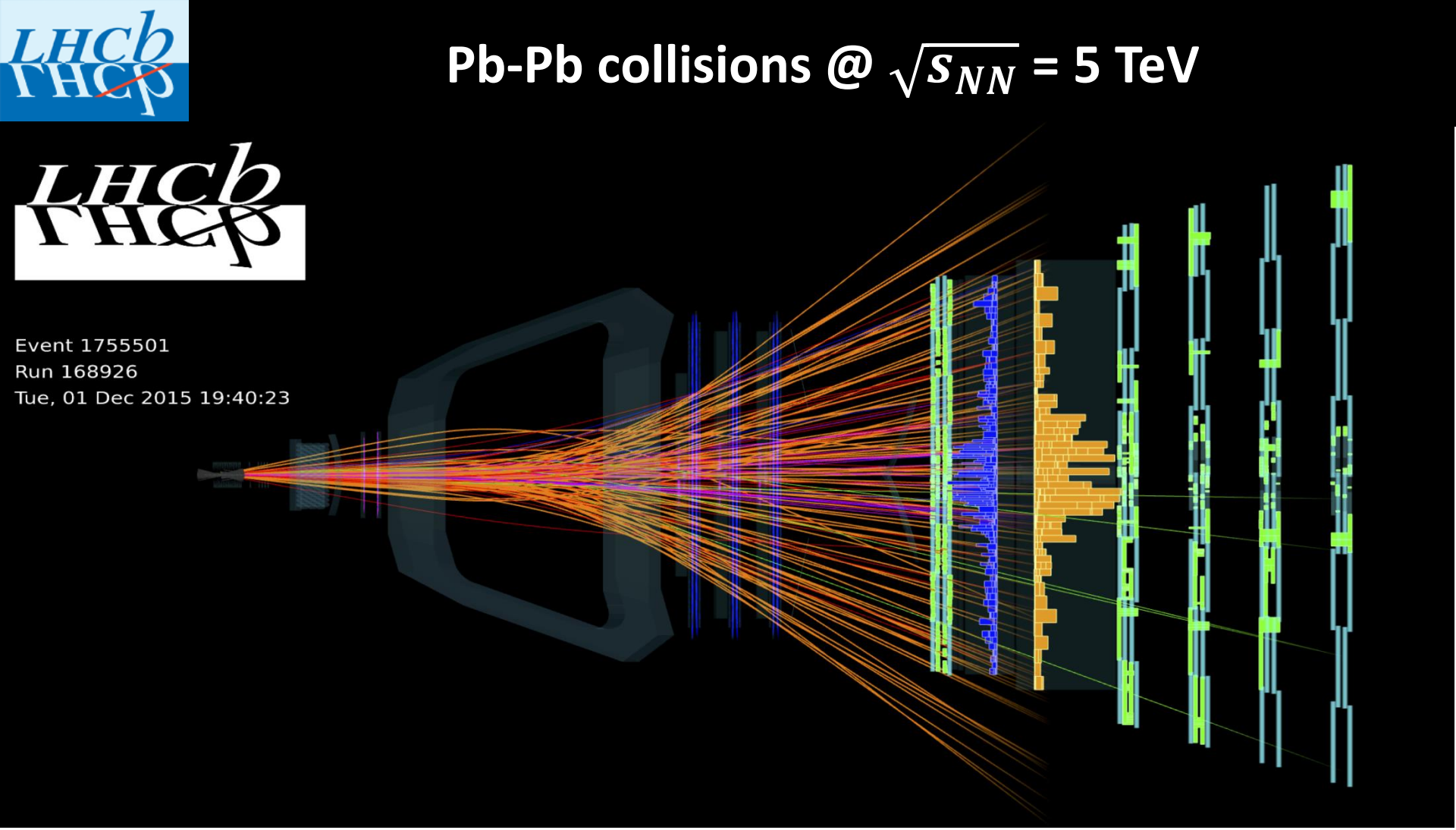


At $\sqrt{s_{NN}} = 110$ GeV $y^* = y_{lab} - 4.77$

In this talk

Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5 TeV,
p-Pb collisions at $\sqrt{s_{NN}}$ = 5 TeV and $\sqrt{s_{NN}}$ = 8 TeV
p-Ar and *p*-He collisions at $\sqrt{s_{NN}}$ = 110 GeV

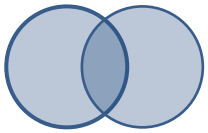
Pb-Pb collisions @ $\sqrt{s_{NN}}$ = 5 TeV



December 2015. First participation of LHCb in Pb-Pb data taking
Only 24 colliding bunches. Very small luminosity ~ 3-5 μb^{-1}
Minimum bias trigger configuration: all inelastic interactions recorded

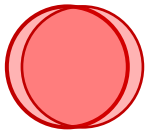
Pb-Pb @ $\sqrt{s_{NN}}$ = 5TeV – collisions centrality

Low Ecal Energy



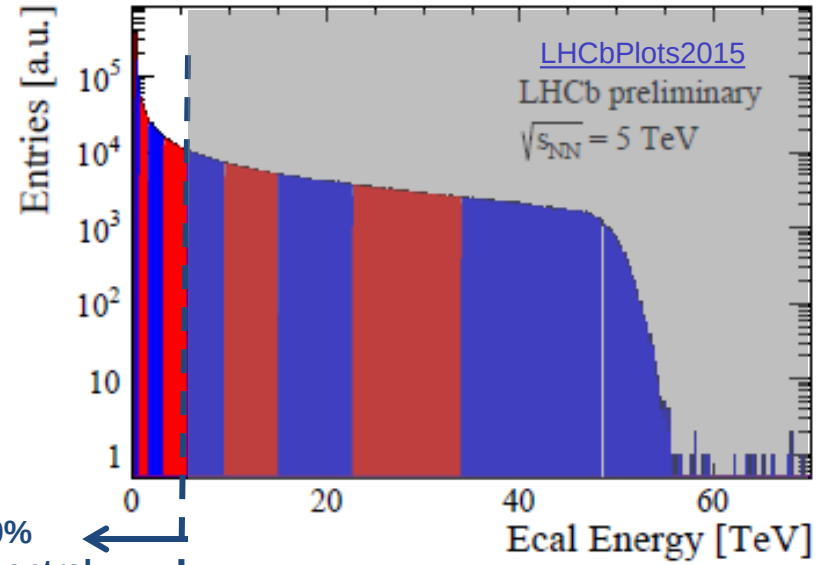
peripheral

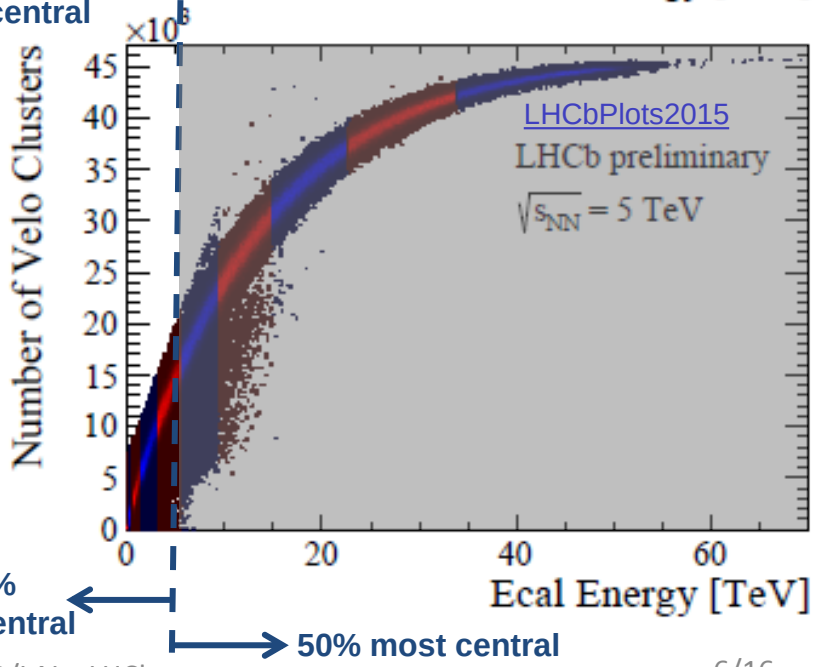
High Ecal Energy



central

- **LHCb centrality reach**
  - Detector limitation due to high occupancy in Pb-Pb collisions
  - No saturation of the calorimeter
  - But, saturation in the Vertex Locator (VELO)
- **LHCb current limitations**
  - Current tracking algorithm efficient up to 50% most central
  - **Physics studies limited to 50% less central events**

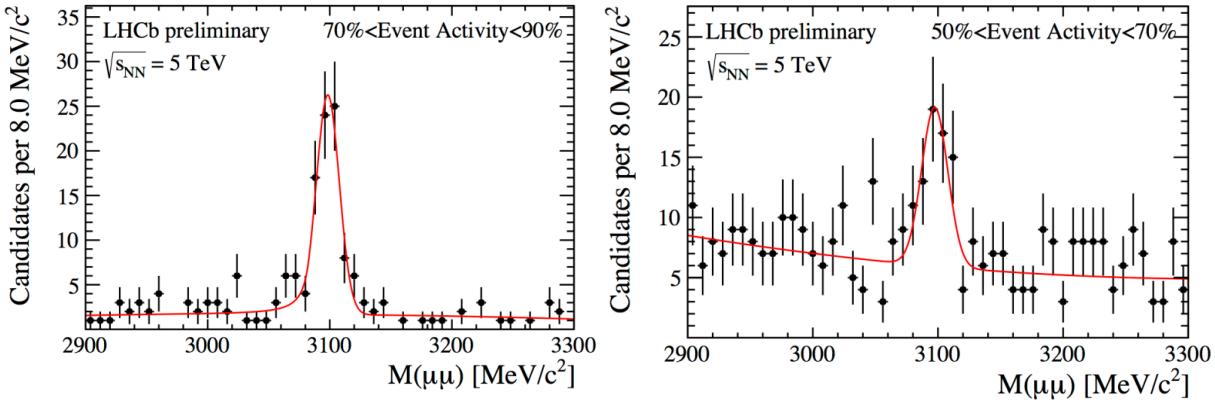




Pb-Pb@ $\sqrt{s_{NN}}$ = 5 TeV – J/ψ signal

- **Hadronic events**

LHCbPlots2015

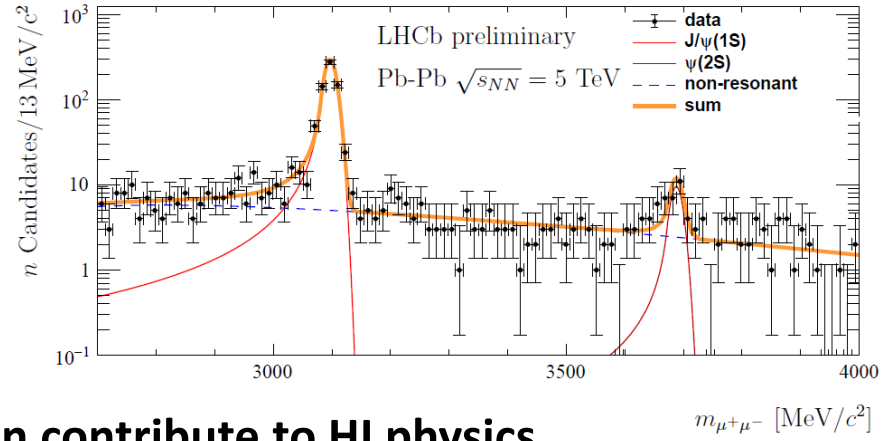


Pb-Pb performance figures "event-activity" corresponds to centrality percentiles.

- **Photon-induced J/ψ in Ultra-Peripheral Collisions (UPC)**

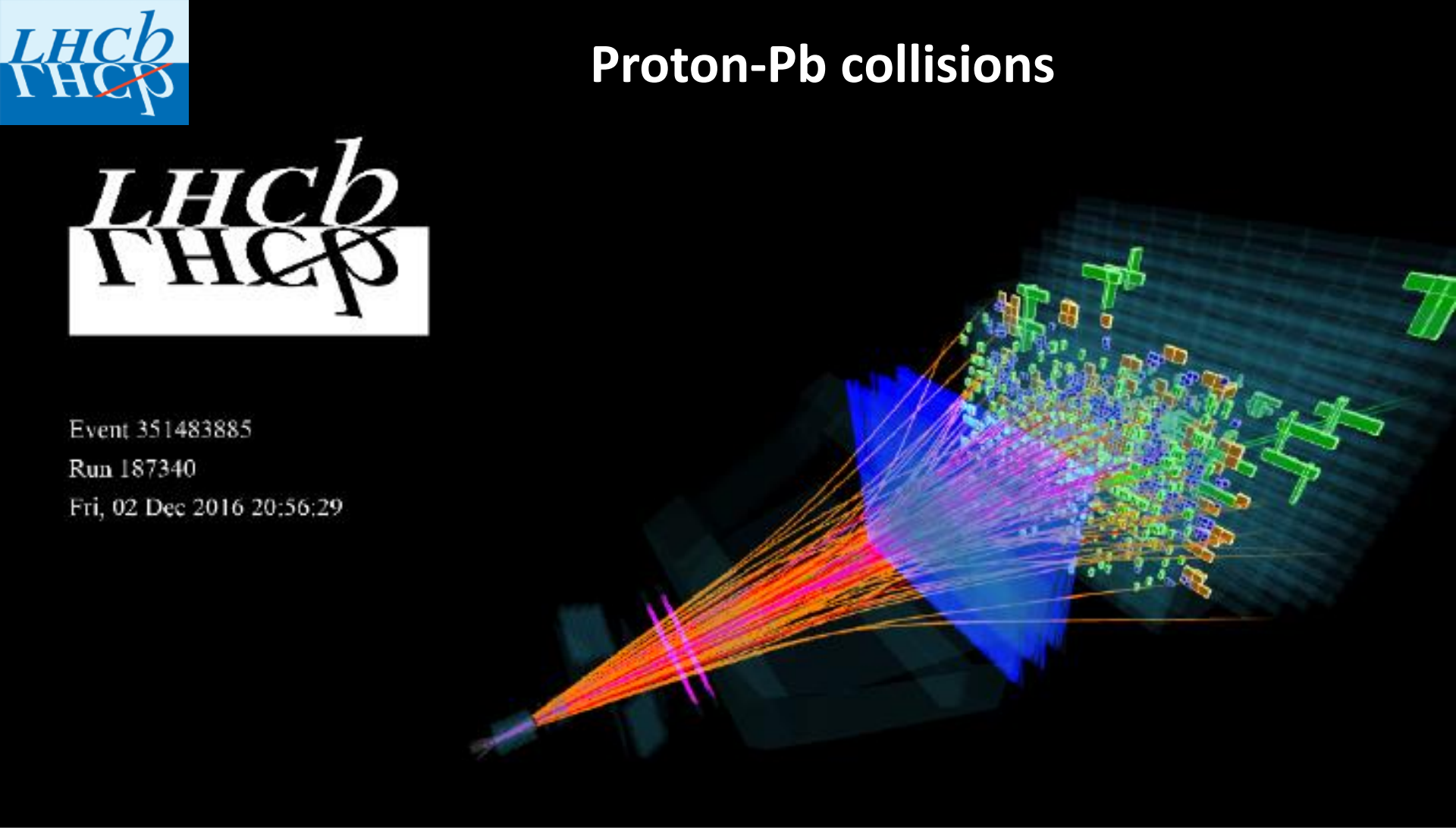
One ion interacts with the electromagnetic field of the other

Nothing in the detector but two tracks



- **Proof of feasibility: done – LHCb can contribute to HI physics**
- **LHCb will participate to the 2018 PbPb run (target ×10 larger lumi than 2015)**

Proton-Pb collisions



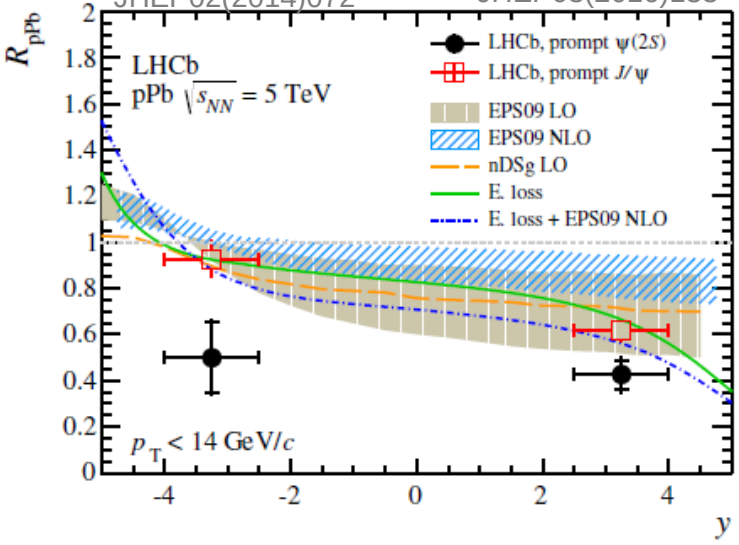
Two data sets presented here:

- $\sqrt{s_{NN}}$ **= 5 TeV proton-Pb interactions recorded in 2013: ~ 1.6 nb^{-1}**
- $\sqrt{s_{NN}}$ **= 8 TeV proton-Pb interactions recorded in 2016: ~ 30 nb^{-1}**

Charm in $\sqrt{s_{NN}}$ = 5 TeV *p*-Pb collisions

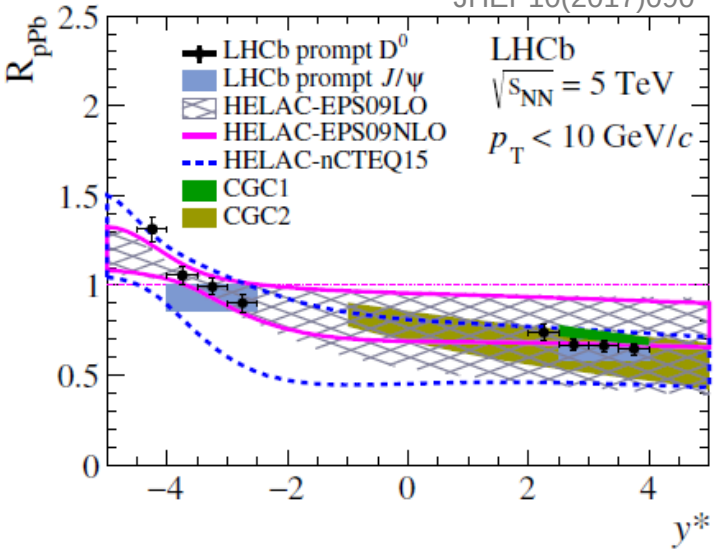
- ***p*-Pb collisions:**
  - Baseline for nucleus-nucleus collisions
  - Study of nuclear PDF (nPDF), coherent energy loss, gluon saturation (CGC), interaction with outcoming hadrons,…

JHEP02(2014)072 JHEP03(2016)133



$$R_{pPb} = \frac{\sigma_{pPb}}{A_{Pb}\sigma_{pp}} = \frac{\sigma_{pPb}}{208.\,\sigma_{pp}}$$

JHEP10(2017)090

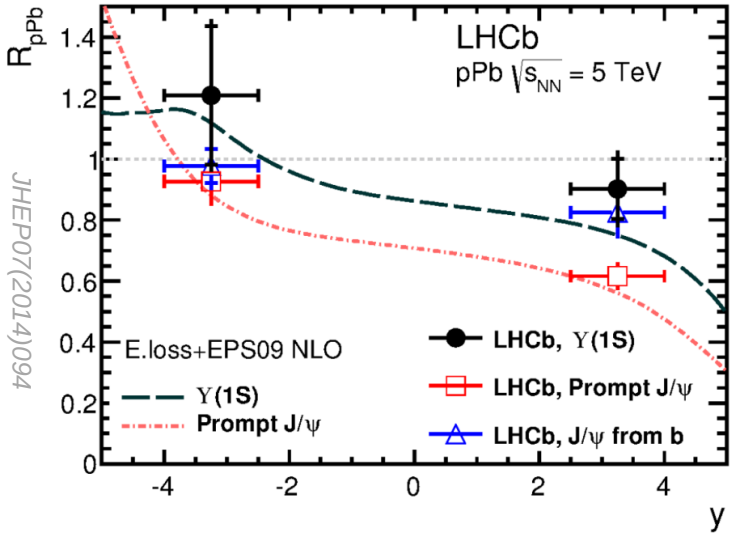


- **Forward rapidity region (y>0) : *p*-Pb collisions**
  - **Significant J/ψ, ψ(2S) and D^0 suppression with respect to p-p yieds**
  - Compatible with nPDF, coherent energy loss mechanism (JHEP 03 (2013) 122) and CGC (PRD 91 (2015) 114005)

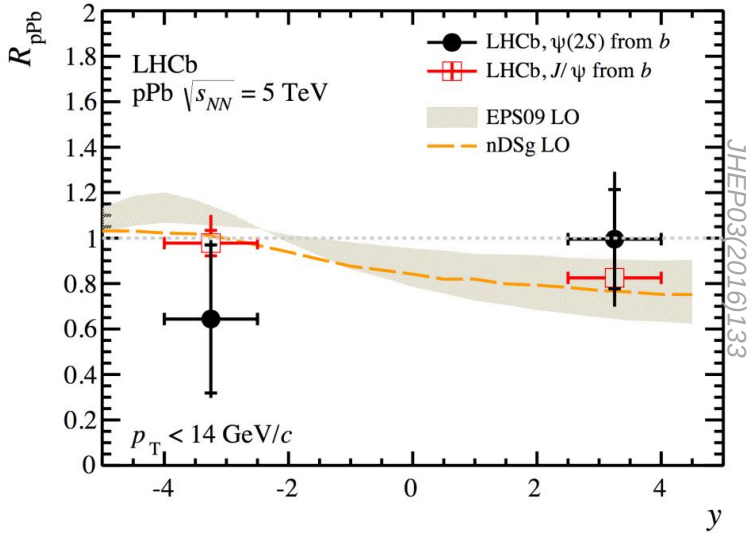
- **Backward rapidity region (y<0) : Pb-*p* collisions**
  - **No significant J/ψ and D^0 modification** (R_{pPb} compatible with unity), compatible with theoretical expectations
  - **Strong ψ(2S) suppression**, not compatible with nPDF and coherent energy loss. Could be due to the interaction of the lightly-bound ψ(2S) with the outcoming hadronic particles. (*Phys. Lett. B 749(2015)98, Nucl.Phys. A943 (2015)*)

Beauty in $\sqrt{s_{NN}}$ = 5 TeV pPb collisions

- ***p*-Pb collisions:**
  - Baseline for nucleus-nucleus collisions
  - Study of nuclear PDF (nPDF), coherent energy loss, gluon saturation (CGC), interaction with outcoming hadrons,…



$$R_{pPb} = \frac{\sigma_{pPb}}{A_{Pb}\sigma_{pp}} = \frac{\sigma_{pPb}}{208.\,\sigma_{pp}}$$

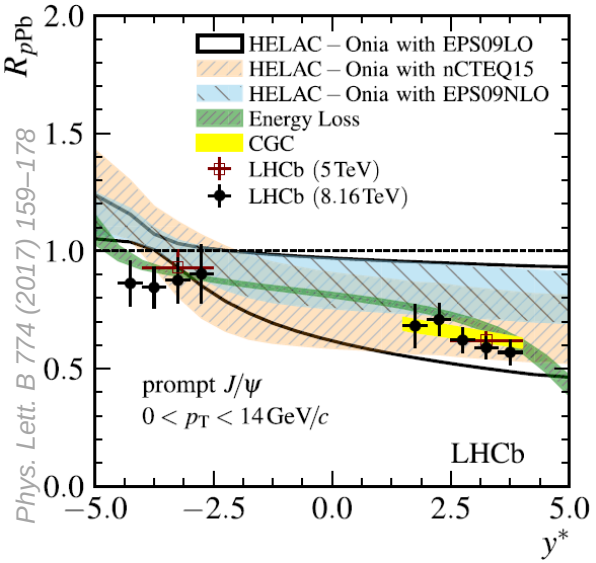


- **Forward rapidity region (y>0) : *p*-Pb collisions**
  - **Little non-prompt J/ψ (J/ψ from b-hadrons) and Υ suppression**
  - compatible with nPDF and coherent energy loss mechanism

- **Backward region (y<0) : Pb-*p* collisions**
  - **No significant non-prompt J/ψ (J/ψ from b) and Υ modification,** compatible with expectations
  - **Possible strong non-prompt ψ(2S) suppression**, not compatible with nPDF and coherent energy loss. If confirmed with 2016 data, would support the scenario of final-state interaction with outcoming hadronic particles.

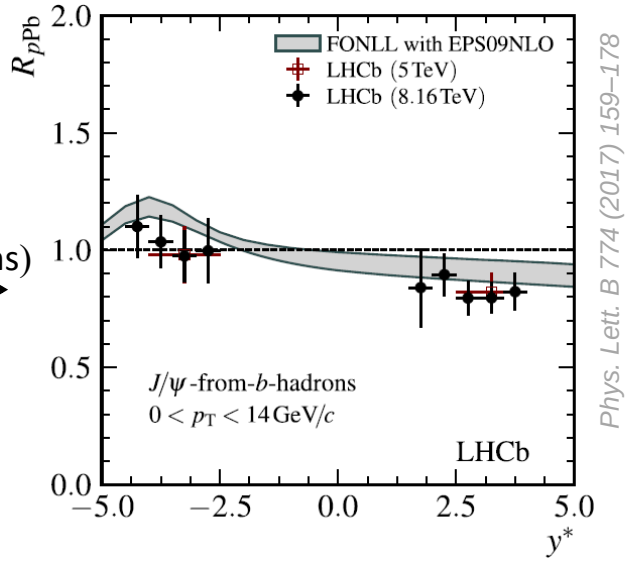
$\sqrt{s_{NN}}$ = 8 TeV (2016) p-Pb collisions

- ***p*-Pb collisions:**
  - Baseline for nucleus-nucleus collisions
  - Study of nuclear PDF (nPDF), coherent energy loss, gluon saturation (CGC), interaction with outcoming hadrons,…



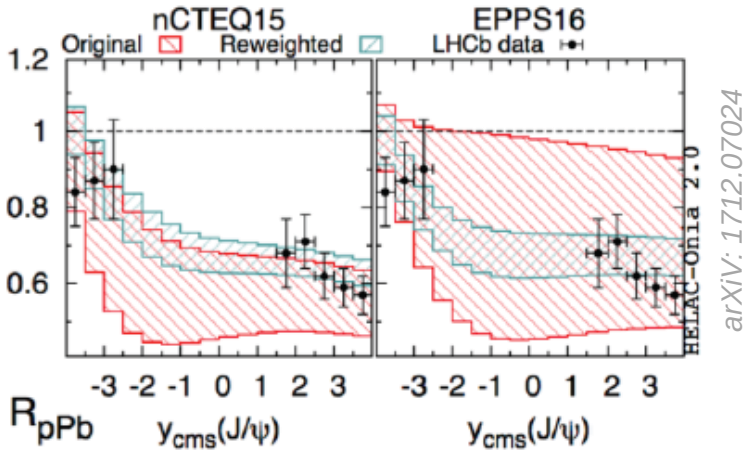
Prompt J/ψ

Non-prompt J/ψ
(J/ψ from b-hadrons)

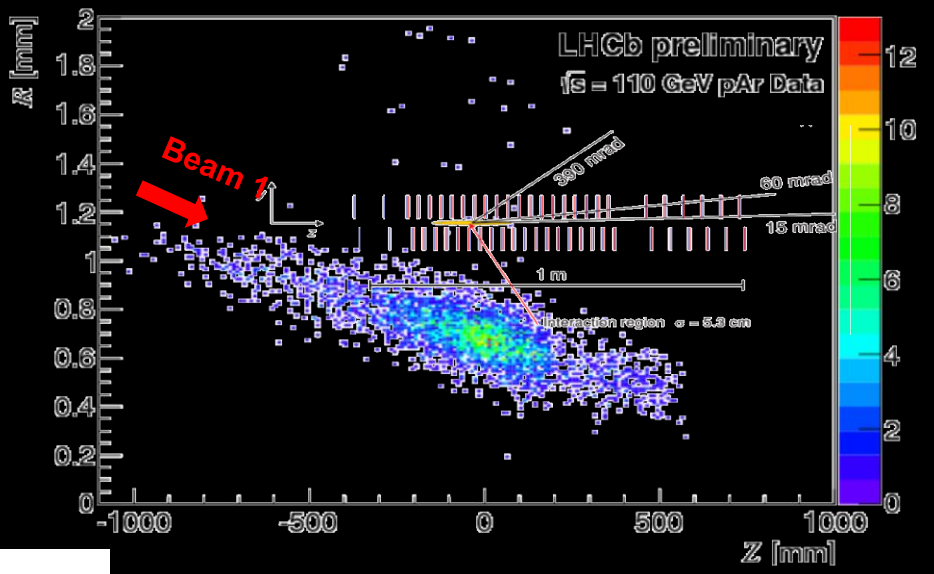


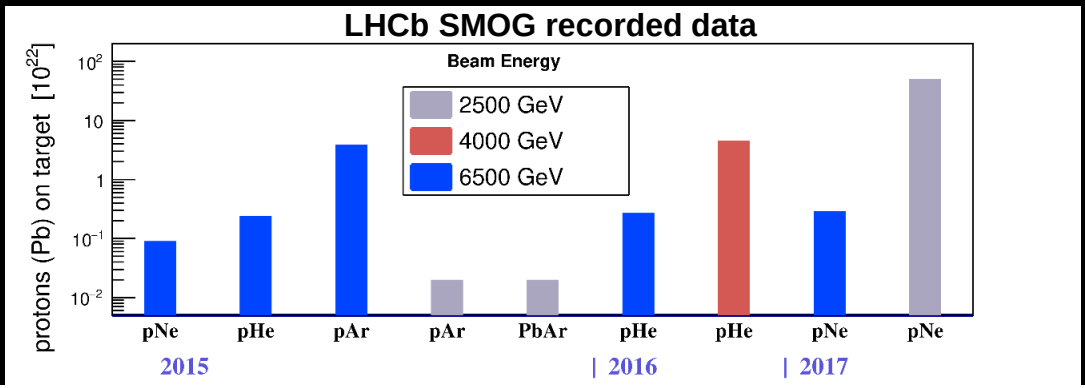
- **Prompt and non-prompt J/ψ results compatible with lower energy data and theoretical expectations**

- ***Put strong constraints on nPDF parametrizations (arXiV: 1712.07024)***



Fixed-target collisions





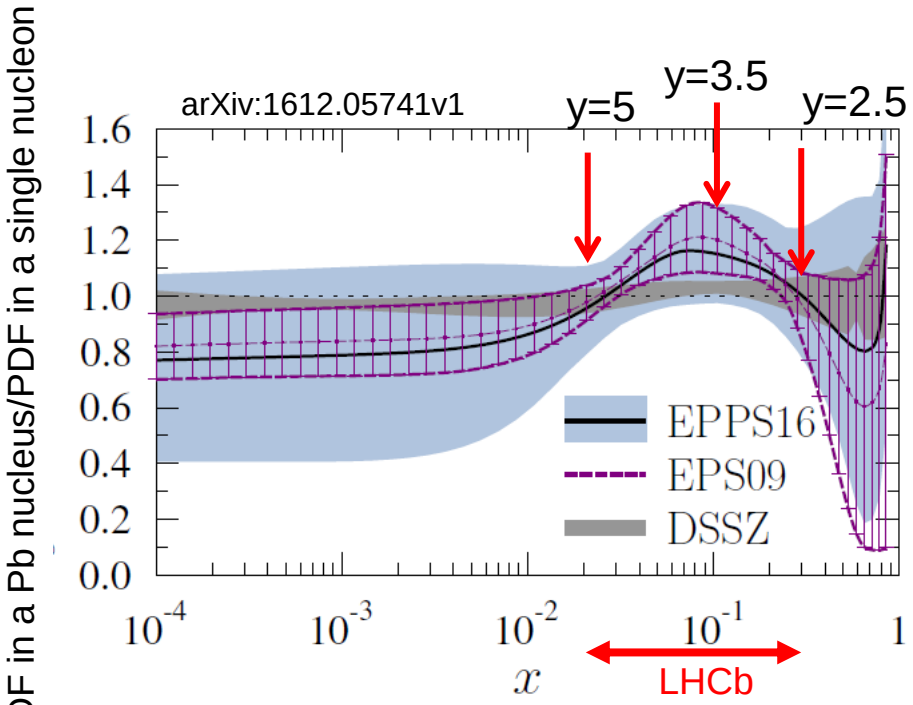
Two data sets presented here:

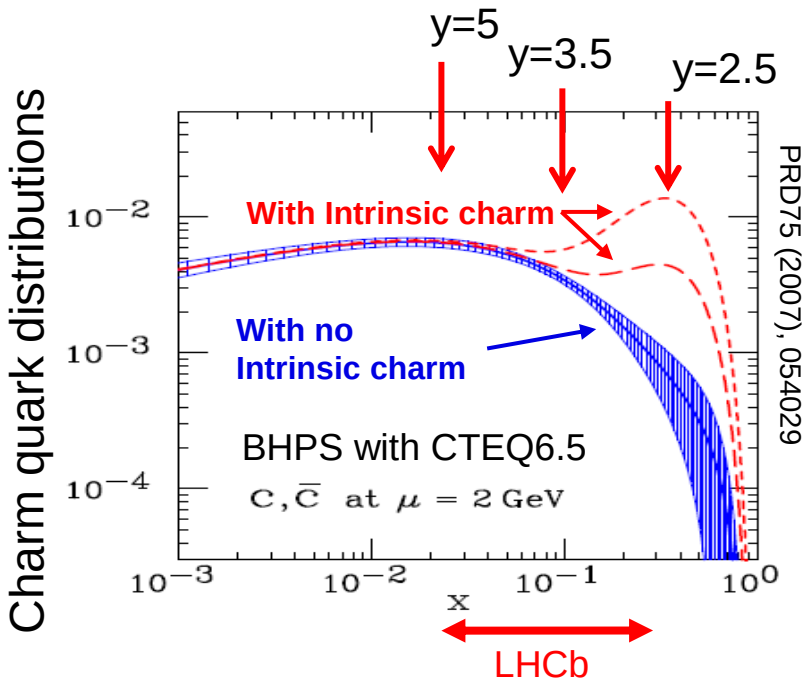
- $\sqrt{s_{NN}}$ = 110 GeV proton-Ar interactions recorded in 2015: ~ 4×10^{22} POTs (17h)
- $\sqrt{s_{NN}}$ = 110 GeV proton-He interactions recorded in 2016: ~ 3×10^{21} POTs (18h)

Charm in Fixed-target $\sqrt{s_{NN}}$ = 110 GeV proton-Ar

- **pAr collisions**
  - Serve as a baseline for nucleus-nucleus collisions
  - Study of nuclear PDF (nPDF), nuclear absorption, …

- **With LHCb-SMOG**, large rapidity coverage (~3 rapidity units) at **large Bjorken-x in the target (x_2)**
  - Give access to **nPDF anti-shadowing** region and **intrinsic charm** content in the nucleon





Bjorken-x = fraction of the nucleon momentum carried by a parton

Charm in Fixed-target $\sqrt{s_{NN}}$ = 110 GeV proton-Ar

(LHCb-CONF-2017-001)

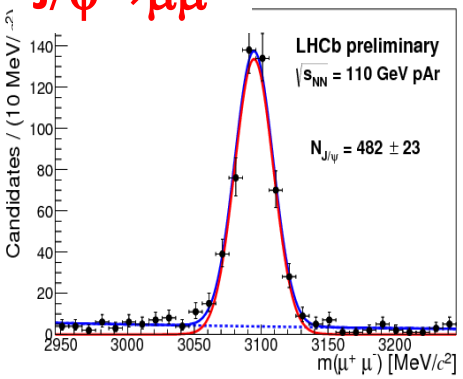
- **$J/\psi \to \mu\mu$ and $D^0 \to K\pi$ signal : ~500 J/ψ and ~6500 D^0 recorded in ~17h**

  - Invariant mass plot

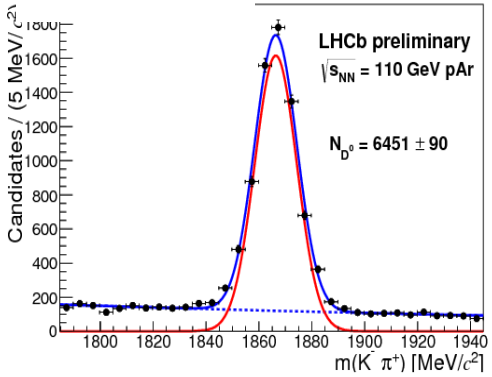
    very clear signal

    very small background

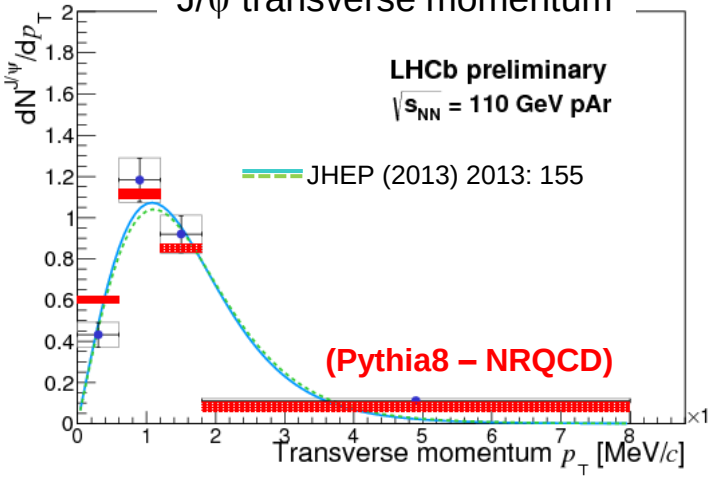
$J/\psi \to \mu\mu$ σ_M ~14 MeV/c²



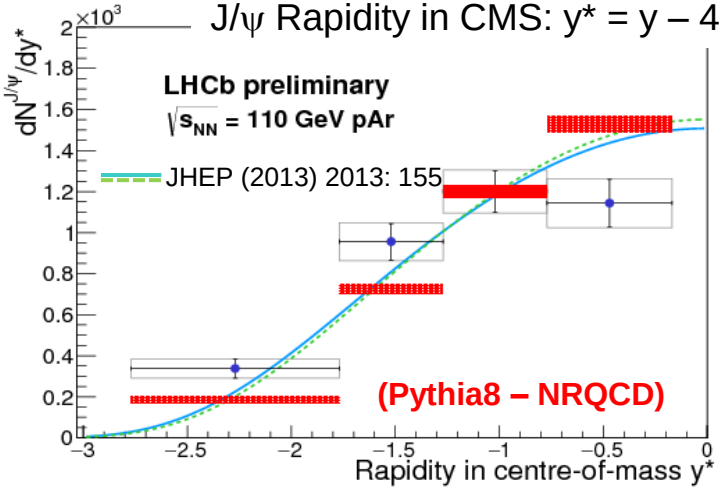
$D^0 \to K\pi$ σ_M ~8 MeV/c²



J/ψ transverse momentum



J/ψ Rapidity in CMS: y* = y – 4.77

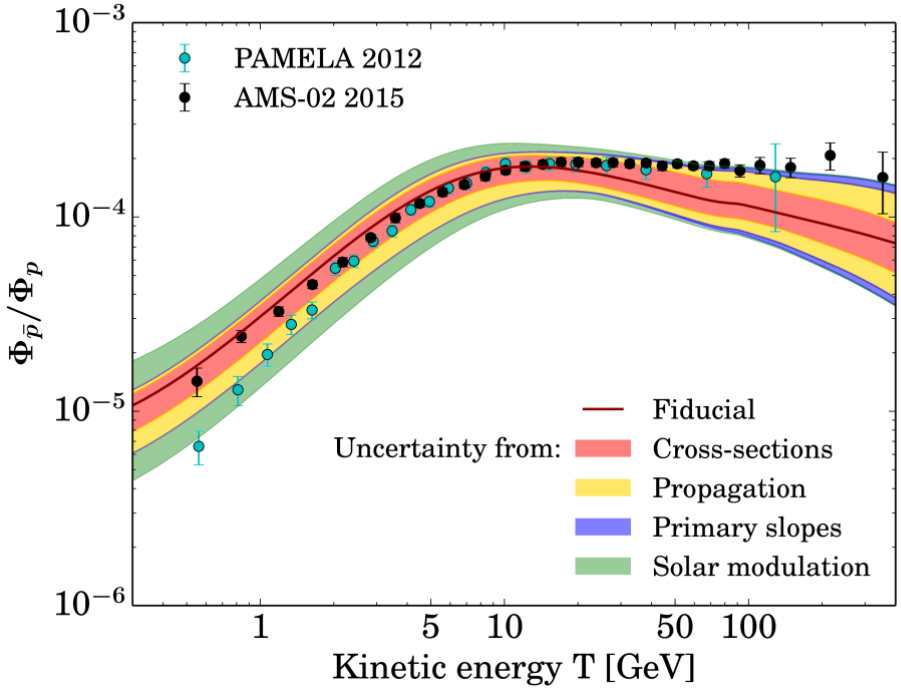


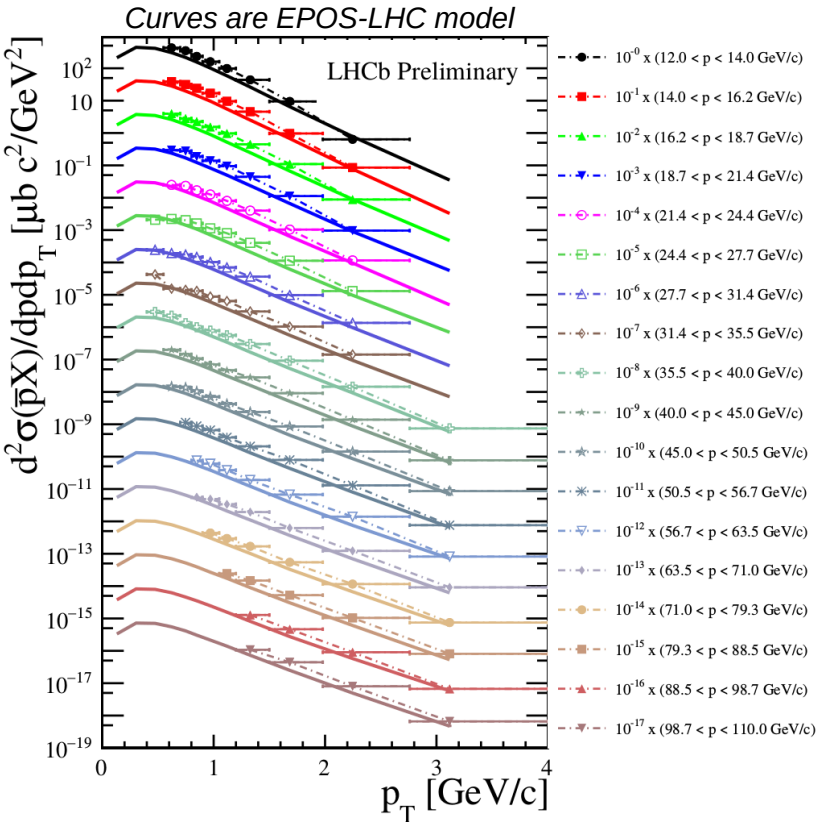
No strong differences observed between data and expectations

Antiproton in fixed-target $\sqrt{s_{NN}}$ = 110 GeV proton-He

(LHCb-CONF-2017-002)

- **Interesting link with cosmic ray physics**
  - The AMS (ISS) experiment measures antiproton production
  - Observed excess may be due to dark-matter candidates annihilation
  - Predictions for $\bar{p}/p$ currently limited by uncertainties on $\bar{p}$ production in p-He collisions
  - LHCb has measured anti-proton cross-section in $\sqrt{s_{NN}}$ = 110 GeV p-He collisions
  - **LHCb measurement permits to constraint MC generators**





Conclusions

- **The LHCb detector**
  - has unique capabilities for heavy flavor measurements at LHC
  - Currently limited to peripheral collisions in Pb-Pb, but **full performances in *p*-Pb collisions**
  - Can operate a **fixed-target program**, unique at LHC

- **Current results**
  - Demonstrate **capabilities to run in Pb-Pb** collisions
  - Performed prompt J/ψ, ψ(2S), D^0 and non-prompt J/ψ and Υ measurements in $\sqrt{s_{NN}}$ **= 5 TeV *p*-Pb** collisions
    - *J/ψ D^0 and Υ measurements compatible with theoretical expectations*
    - *Strong backward-rapidity ψ(2S) suppression, maybe due to interactions with hadronic outcoming particles.*
  - Performed prompt and non-prompt J/ψ measurements in $\sqrt{s_{NN}}$ **= 8 TeV *p*-Pb** collisions
    - *Compatible with lower energy data and theoretical expectations*
  - Performed J/ψ and D^0 measurements in $\sqrt{s_{NN}}$ **= 110 GeV *p*-Ar** collisions
    - *Compatible with expectations*
  - Performed $\bar{p}$ measurements in $\sqrt{s_{NN}}$ **= 110 GeV *p*-He** collisions
    - *Permits to constraint MC generators*

- **Still to come**
  - *p*-Pb at $\sqrt{s_{NN}}$ = 5 TeV : Λ_c , …
  - *p*-Pb at $\sqrt{s_{NN}}$ = 8 TeV : ψ(2S), Υ and B, …
  - *p*-He at $\sqrt{s_{NN}}$ = 87 GeV : J/ψ and D^0 ,…
  - *p*-He at $\sqrt{s_{NN}}$ = 110 GeV : $\bar{p}$ from $\overline{\Lambda^0}$ and $\overline{\Sigma^+}$,…

- **We have only scratched the surface of LHCb capabilities in Ion collisions**