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LHCb Heavy Ion Program

Patrick Robbe, LAL Orsay and CERN, 15 September 2016,

For the LHCb Collaboration

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

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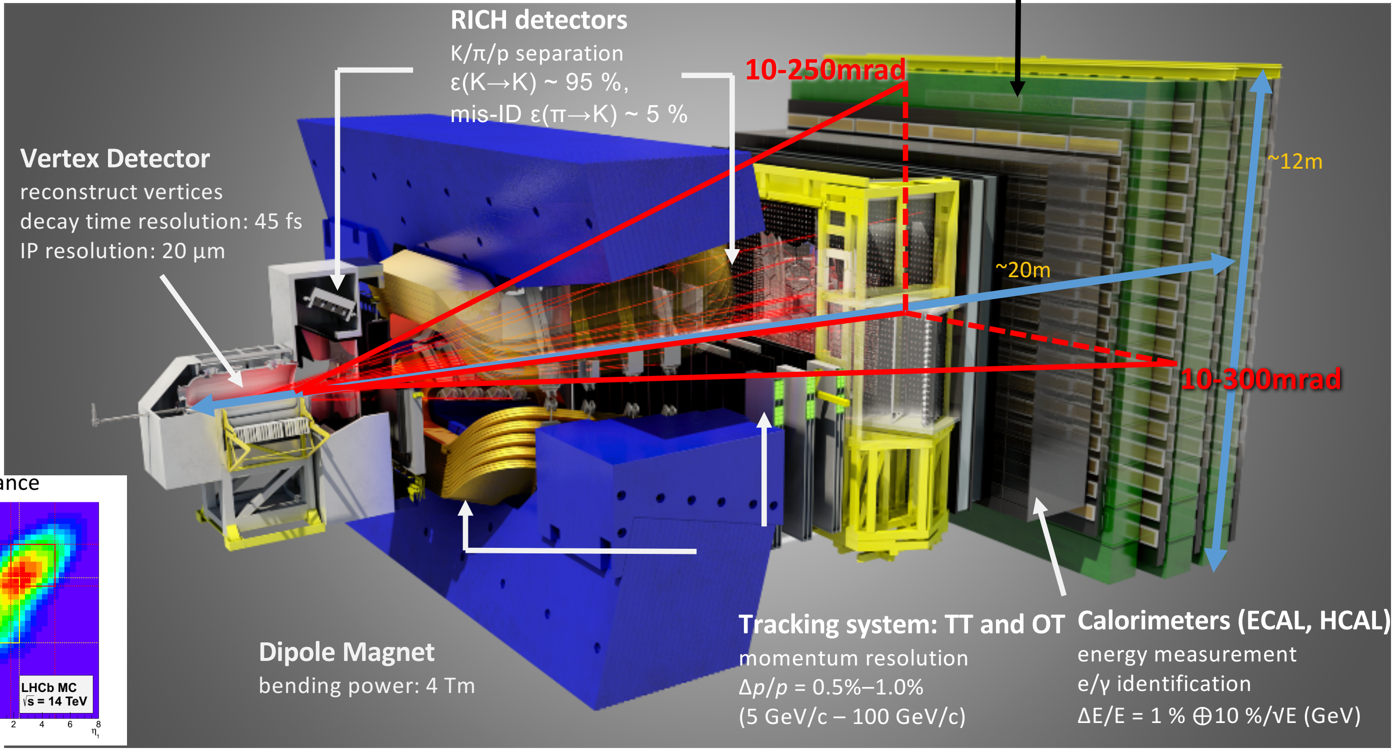
Outline

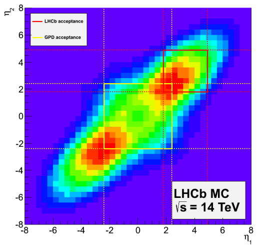
- The LHCb experiment
- Results in *p*Pb and Pb*p* collisions
- Participation in 2015 PbPb run
- Fixed target program

The LHCb experiment

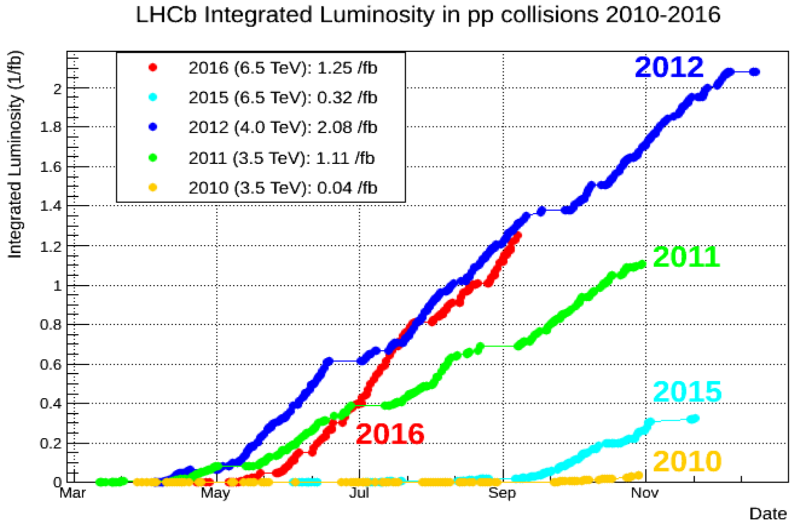
[IJMPA 30 (2015) 1530022]
[JINST 3 (2008) S08005]



bb acceptance



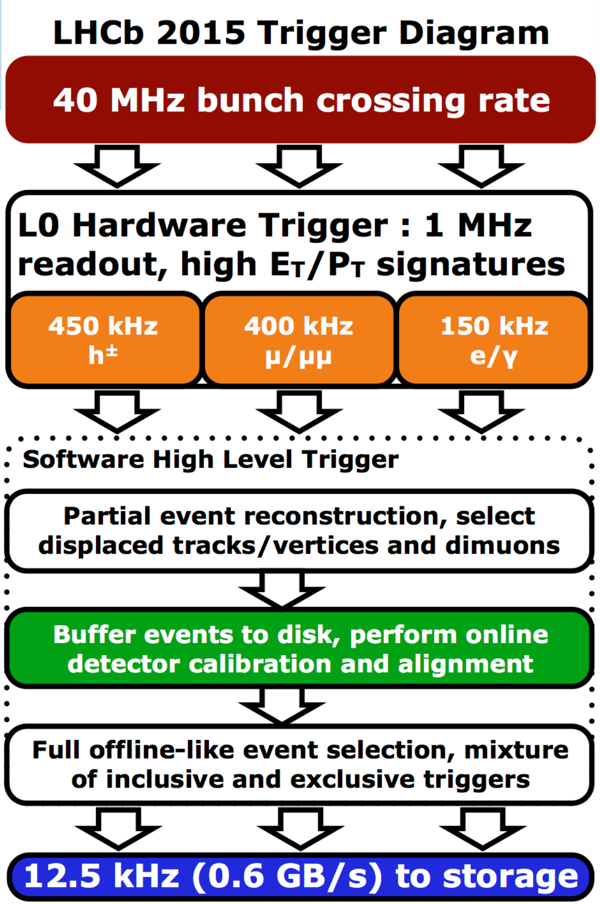
Data Taking



- Core physics program with *pp* collisions, recorded at 7 TeV, 8 TeV and 13 TeV center of mass energy. Smaller data set collected also at 2.76 TeV and 5 TeV.
- Participates also to the heavy ion LHC physics program:
  - *p*Pb and Pb*p* collisions at 5 TeV collected in 2013
  - PbPb collisions at 5 TeV collected in 2015
  - Gas fixed target program since 2013

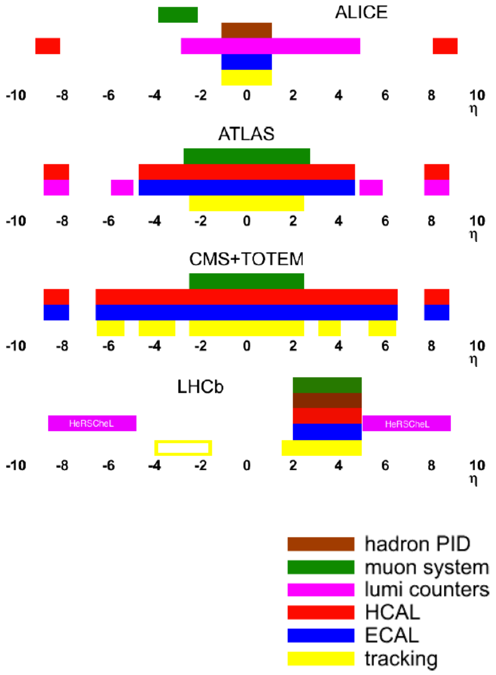
Data Taking

- Two stage trigger system
  - Hardware level based on calorimeters and muon detector
  - Software level running in ~30000 cores
- Output of the trigger is fully aligned and calibrated data, directly usable for the final data analysis.



LHCb and Heavy Ions

- LHCb is specialised in heavy flavour precision physics:
  - Optimised for low pile-up collisions (*ie* low multiplicity):
    - Precise reconstruction and production and decay vertices: time dependent *CP* violation
    - Correlations between particles: flavour tagging
- Some characteristics of the experiment make it attractive for measurements in Heavy ion physics too:
  - Instruments fully the forward region: $2<\eta<5$
  - Precise vertexing: separation of prompt production from *B* decay products
  - Precise tracking: reconstruction down to $p_T=0$
  - Particle identification: reconstruction of hadronic decays



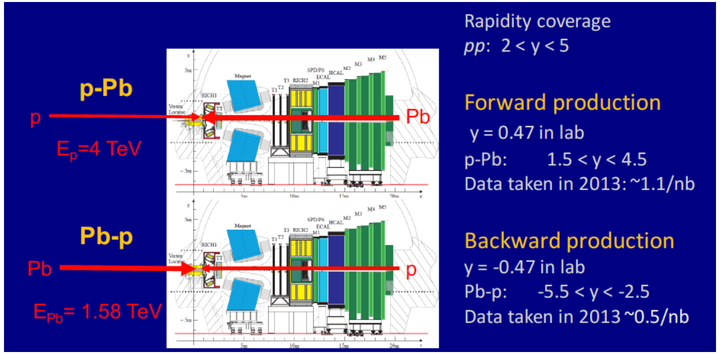
Heavy Flavours and Heavy Ions

- Most of the analyses (for heavy flavour) consist in measuring the ratio of production in *p*Pb collisions to *pp* collisions: $\mathbf{R_{pPb}}$.
- *pp* collisions: **hard process** cross-section
- *p*Pb collisions: hard process + **« cold » nuclear matter effects**
  - Shadowing and anti-shadowing: parton density functions of protons and neutrons are modified when they are in a Pb nucleus compared to a single proton
  - Energy loss: quarks loose energy in the medium of the collision before forming hadrons
- PbPb collisions: hard process + « cold » nuclear matter effects + **« hot » nuclear matter effects** (due to Quark Gluon Plasma, free quarks during a short time after the collision):
  - Recombination: a lot of other heavy quarks are present in the medium and enhance the production of quarkonium (heavy quark bound states)
  - Dissociation: quarkonium melt in the medium
- *p*Pb collisions allow to understand the « background » mechanisms to the ones due to QGP in PbPb collisions, and are also interesting in their own rights.

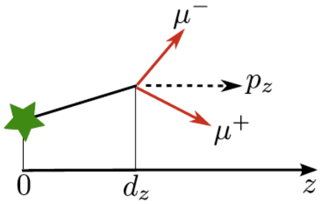
[JHEP 03 (2016) 133]

ψ(2S) production in *p*A collisions

- LHCb took part to the pA LHC run in 2013, with 2 configurations:
  - *p*Pb: 1.1 nb^{-1}
  - Pb*p*: 0.5 nb^{-1}
- Published measurements of J/ψ [JHEP 02 (2014) 72], Υ(1S) [JHEP 07 (2014) 094] and *Z* production [JHEP 09 (2014) 030] , providing input to study of cold nuclear matter effects and constrain nuclear parton density functions (nPDF), at low *x*.
- Measurement of ψ(2S) production cross-section in bins of p_T and *y*
- Separating prompt ψ(2S) from the ones from *b* decay with the pseudo propertime
  - Effects on ψ(2S) from *b* are in fact effects on *b* hadrons.



$$t_z(J/\psi) = \frac{d_z \times M_{J/\psi}}{p_z}$$



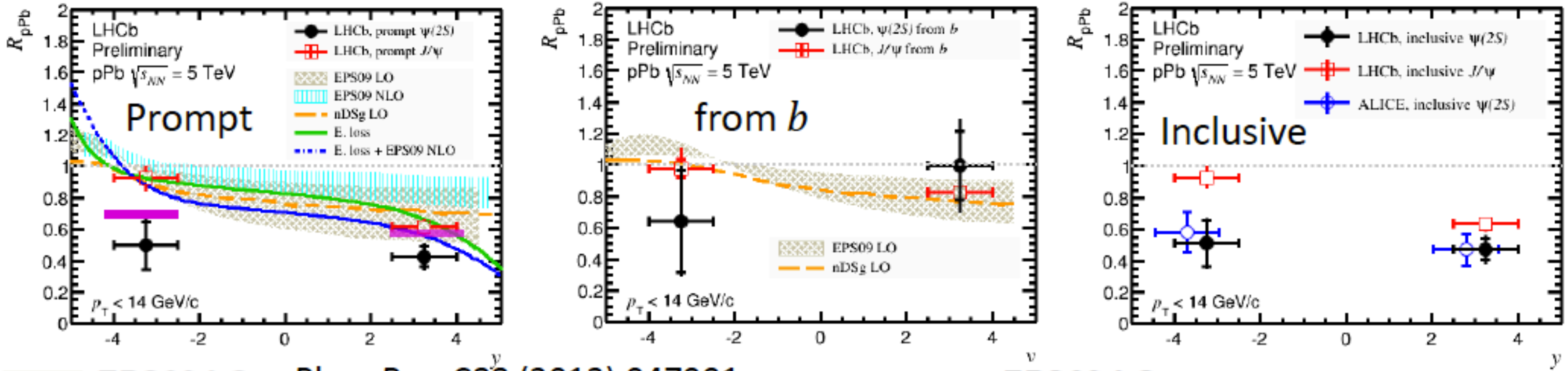
[JHEP 03 (2016) 133]

ψ(2S) production in *p*A collisions

Measurement of nuclear modification factor:

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

Extrapolated from LHCb measurements



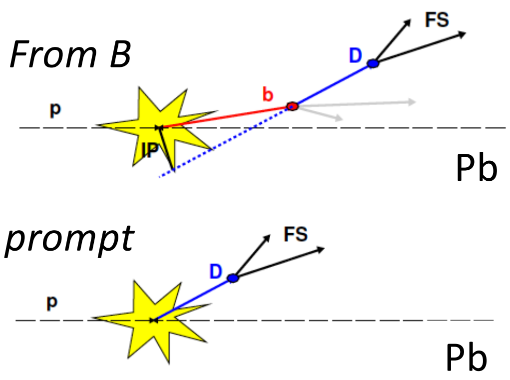
EPS09 LO Phys. Rev. C88 (2013) 047901
EPS09 NLO Int. J. Mod. Phys. E22 (2013) 1330007
nDSg LO Phys. Rev. C88 (2013) 047901
E. loss JHEP 03 (2013) 122
E. loss + EPS09 NLO JHEP 03 (2013) 122

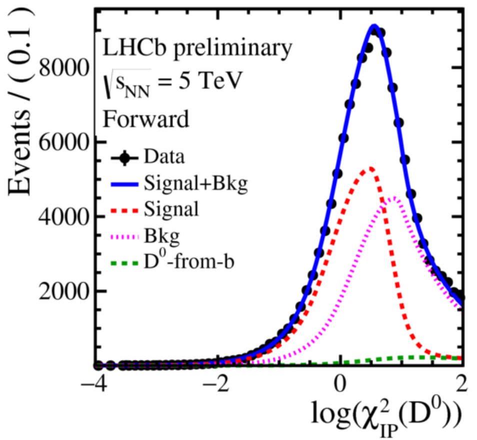
EPS09 LO, **nDSg LO** Nucl.Phys.A926 (2014) 236
Comover Phys. Lett. B749 (2015) 98

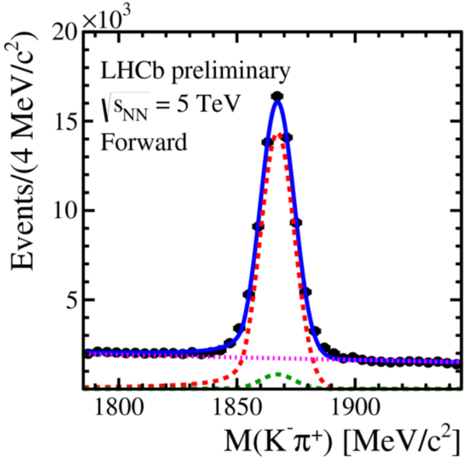
[LHCb-CONF-2016-003]

Prompt D^0 production in pA collisions

- D^0 reconstruction in the hadronic decay mode $D^0 \to K^- \pi^+$ down to p_T=0:
  - Particle identification using the RICH Cerenkov detectors
  - Vertexing information to select displaced vertices
  - Impact parameter to separate prompt production from B decays.





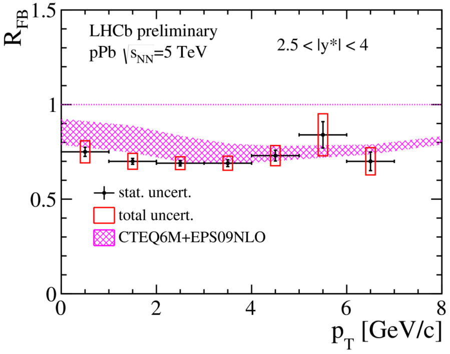


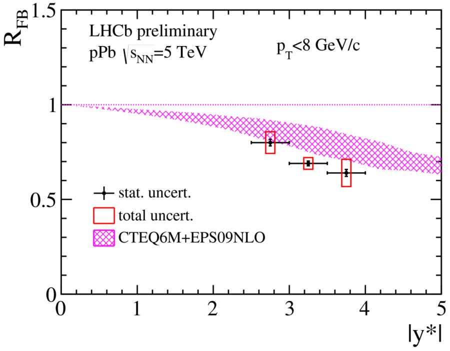
[LHCb-CONF-2016-003]

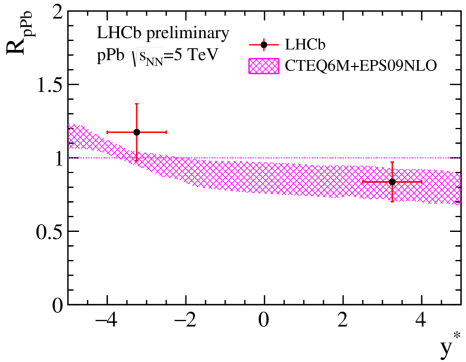
Prompt D^0 production in pA collisions

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

- Another interesting quantity: forward-backward ratio
- In a common rapidity range 2.5 < |y| < 4
- No input from *pp* cross-section and cancelation of experimental systematic uncertainties
- Good agreement with models based on pQCD and nuclear PDF EPS09NLO [Nucl Phys B373 (1992) 295]



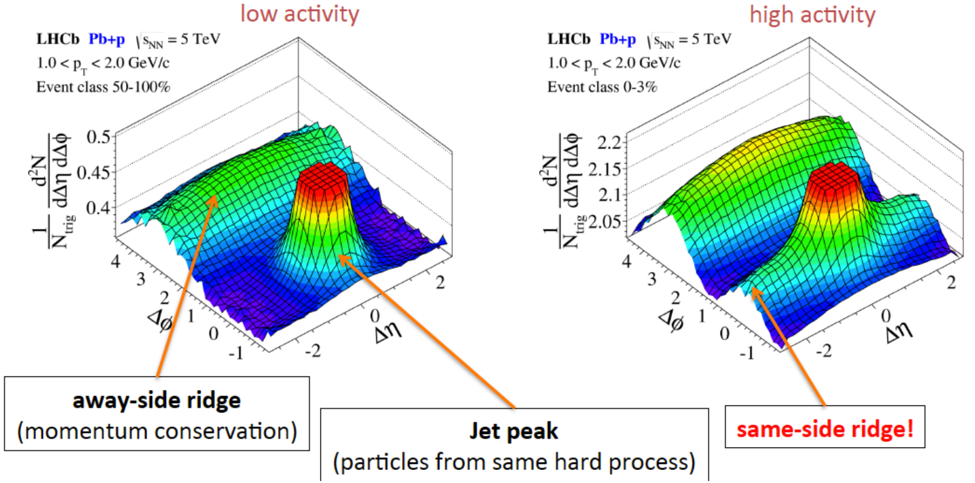


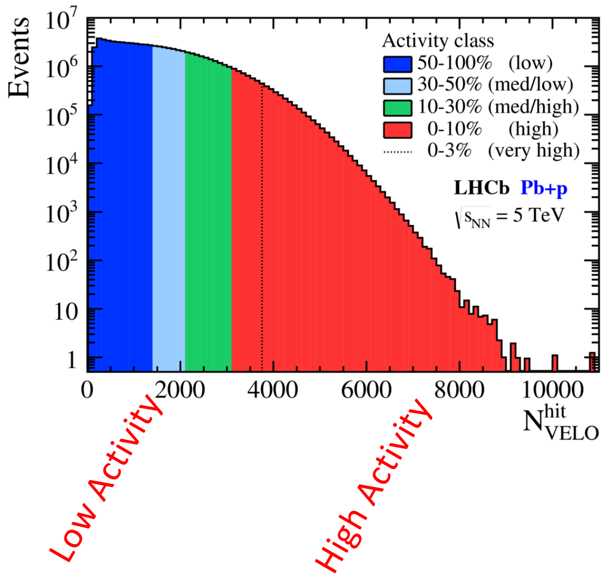


[arXiv:1512.00239]

Two-particle correlations in pA collisions

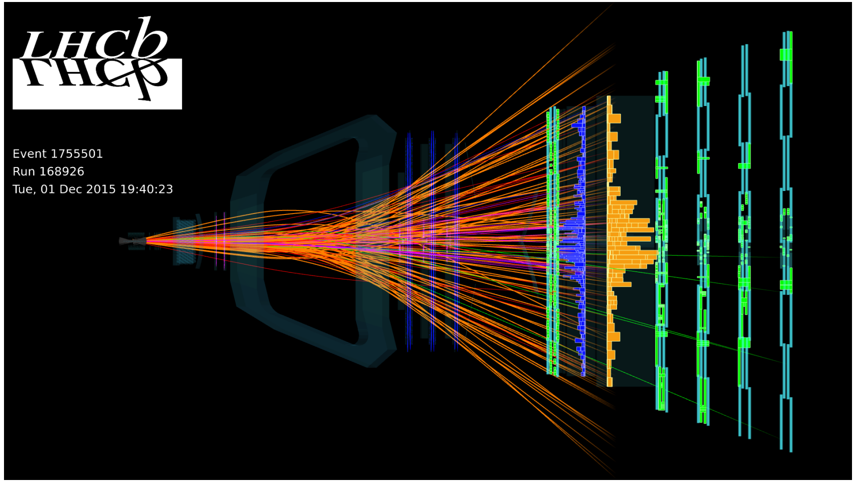
- Measurement in the forward region of two-particle correlations (Δϕ, Δη) , as a function of the event activity (estimated with number of tracks in the VELO)





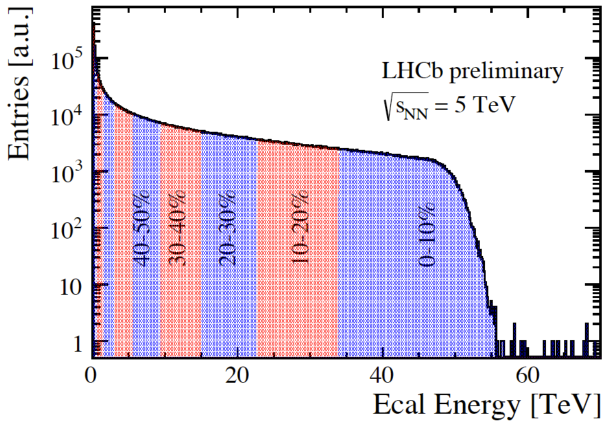
PbPb collisions in LHCb

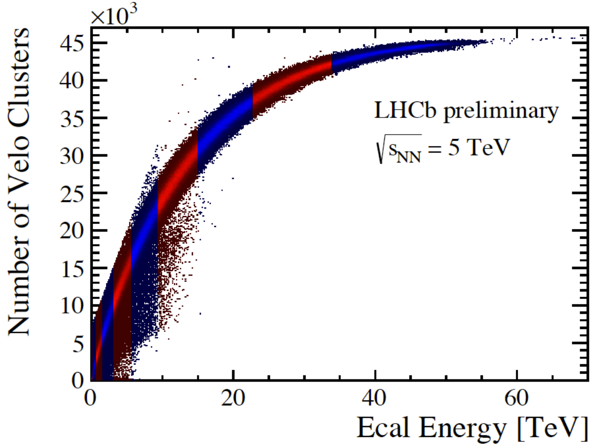
- LHCb took part for the first time to a LHC PbPb run end of 2015, with emphasis on low multiplicity events.
- All sub-detectors were carefully switch on, but in the end were running in nominal configuration
- No operational problem met, all interactions were recorded with a minimum bias trigger, rejecting the large rate of electro-magnetic interactions.
- Up to 54 colliding bunches, *ie* 10% of the luminosity provided to the other LHC experiments, and a total of 3-5 μb^{-1} integrated luminosity



Centrality Reach

- Since LHCb is designed for low multiplicity events, the first question is to know up to which centrality events can be reconstructed.
- Observables to measure event activity: energy deposited in the ECAL and HCAL, which are not saturated even at large multiplicities

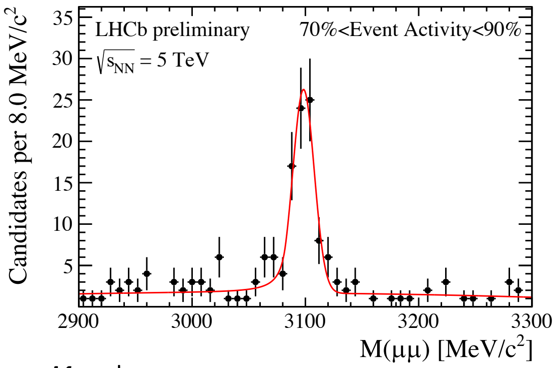


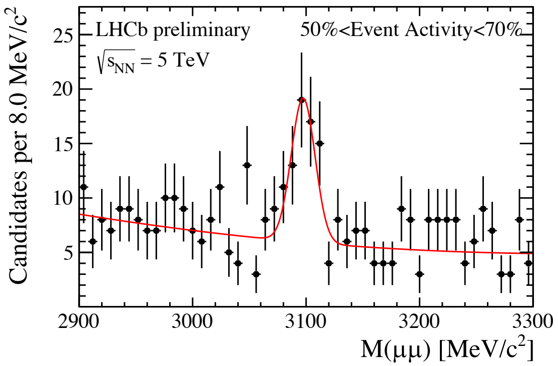


- VELO (tracking) saturates at large multiplicities, and reconstruction is performed only up to 15000 clusters (using standard pp reconstruction algorithms)
- This corresponds to the 50-100% event activity region (based on ECAL energy)

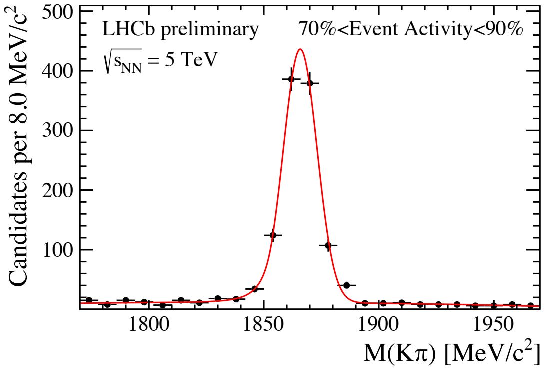
J/ψ and D^0 signals in PbPb collisions

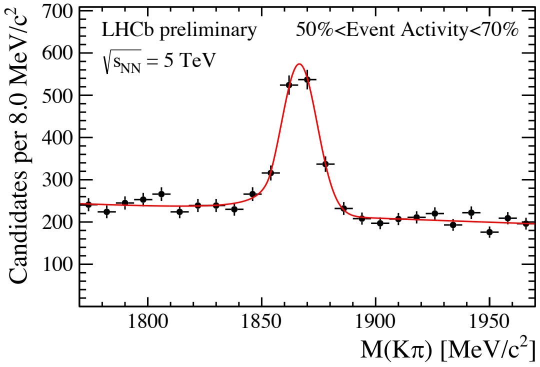
$J/\psi \rightarrow \mu^+ \mu^-$





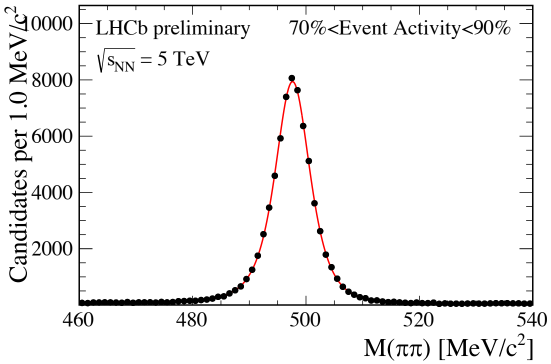
$D^0 \rightarrow K^- \pi^+$

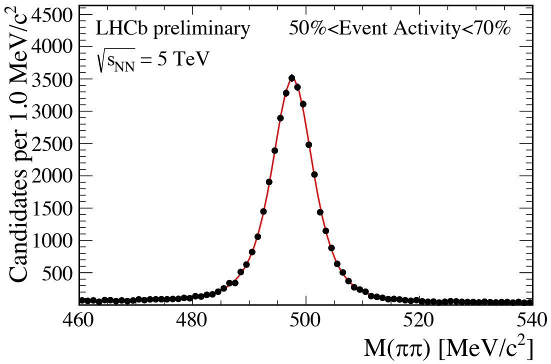




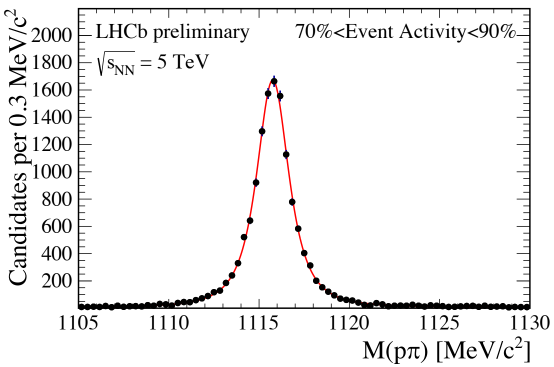
K^0_S and Λ signals in PbPb collisions

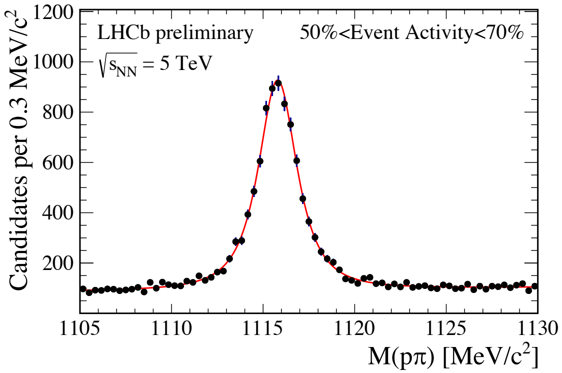
$K^0_S \rightarrow \pi^- \pi^+$





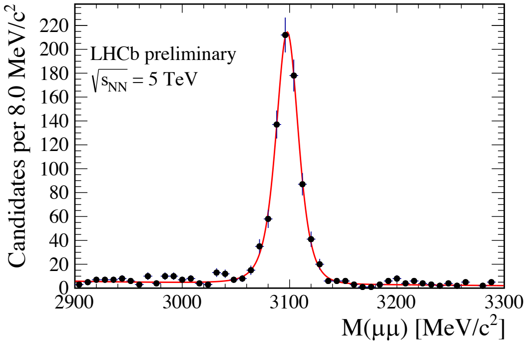
$\Lambda \rightarrow p\ \pi^+$

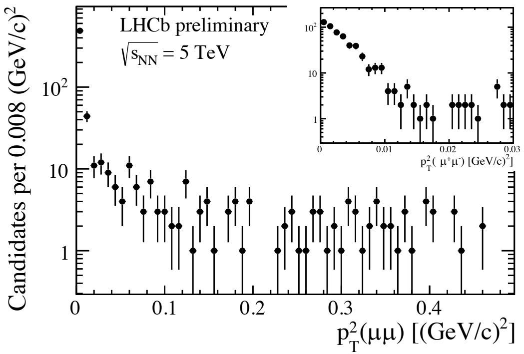




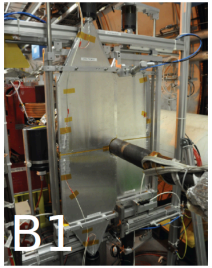
Ultra-peripheral PbPb collisions: J/ψ

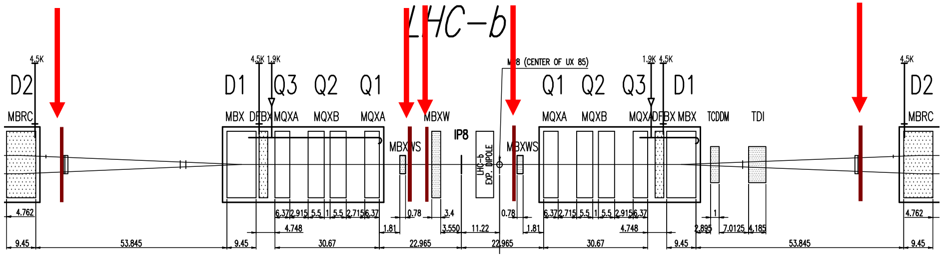
- Low multiplicity events: only two muons in the detector





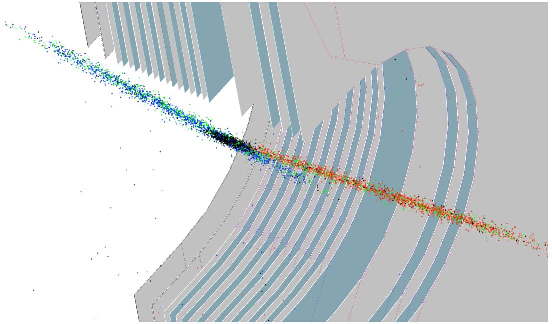
- Extra information about event activity can be obtained from a new detector installed beginning of 2015, HERSCHEL, which was running during the PbPb run: scintillator stations installed forward and backward of the collision point, covering 5 < |η| < 9

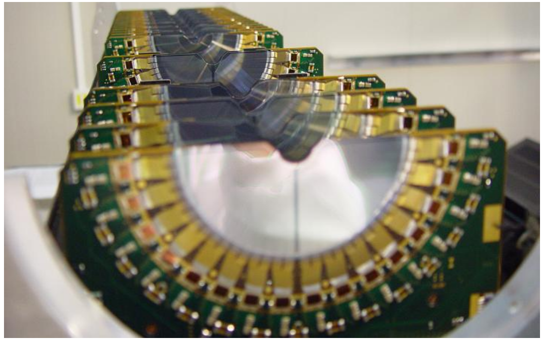




Fixed Target Physics With LHCb

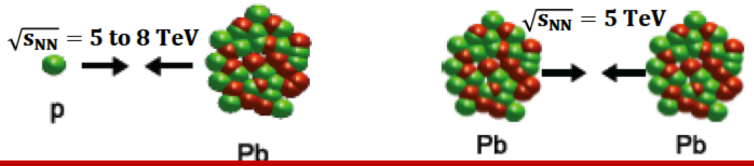
- Gas can be injected inside the LHC vaccuum, in the VELO.
- Used to determine the luminosity but since 2015 is used to collect physics data. [JINST 7 (2012) P01010]
- Originally use Neon gas
- Other non-getterable noble gases can be used: in 2015, we used also **Ar** and **He**
- The pressure in the LHC when the gas is injected is ~2×10^{-7} mbar (instead of 10^{-9} mbar with no injection), between 1 day to 2 weeks.
- Data samples:
  - *p* (6.5 TeV) Ne
  - *p* (6.5 TeV) He
  - *p* (6.5 TeV) Ar
  - *p* (2.5 TeV) Ar
  - Pb (6.37 Z TeV) Ar [In parallel to collision data taking]





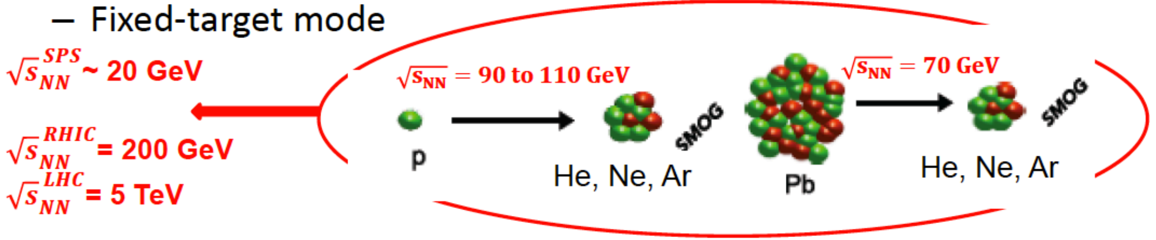
Fixed Target Physics With LHCb

- **LHCb operate in two modes**
  - Collider mode



Unique to LHCb
Unique energies

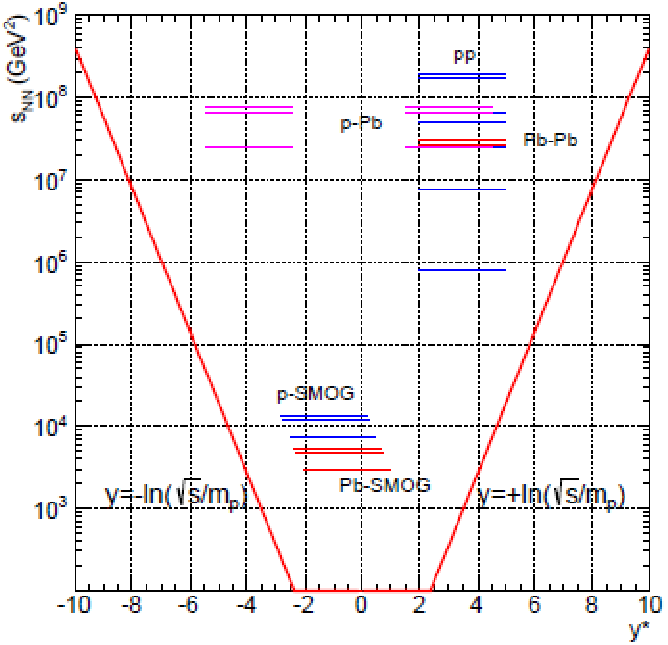
  - Fixed-target mode



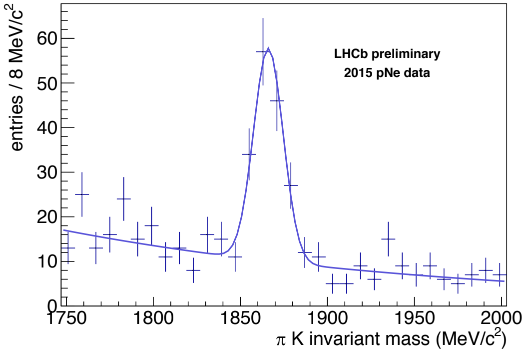
LHCb rapidity 2.5 < yLHCb < 4.5 $\Rightarrow \begin{cases} \text{7 TeV beam:} & -2.3 < y^{*}_{LHCb} < -0.3 \\ \text{2.75 TeV beam:} & -1.8 < y^{*}_{LHCb} < 0.2 \end{cases}$

Fixed Target Physics With LHCb

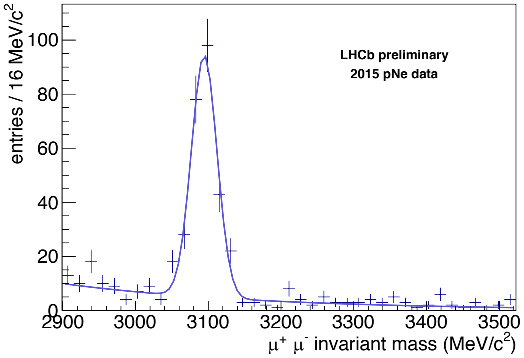
p-Pb
p-p
Pb-Pb
p-GAS
Pb-GAS



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



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



Conclusions

- Several publications obtained with the *p*Pb 2013 dataset: a new *p*Pb run is foreseen end of 2016 where LHCb will collect 10 times more luminosity
- PbPb data available, first results will come soon
- Fixed target feasibility well established during 2015, and is going to provide measurements on heavy flavour production in many different environments:
  - New datasets recorded in 2016 (*p*He)
  - Installation of a new pressure gauge in 2017 to improve the gas pressure measurement precision
- LHCb participates fully in Heavy Ion LHC physics program