Heavy-ion and fixed target physics in LHCb: results and prospects

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CERN seminar
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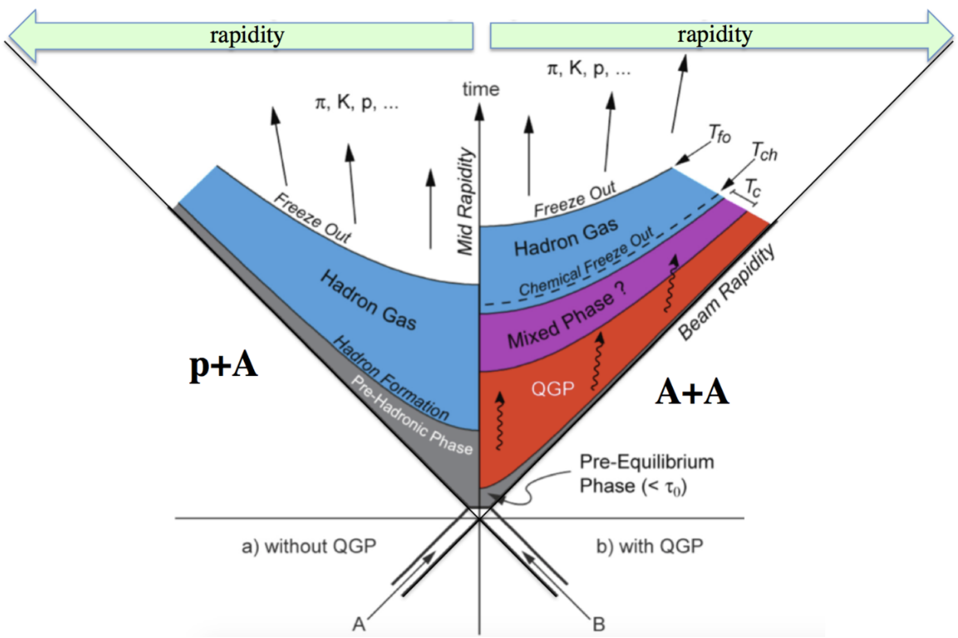
Study the QCD phase diagram with HI collisions

Space-time evolution of the collision



Ultra-relativistic heavy-ion collisions:

- ❑ Explore phase diagram of nuclear matter
- ❑ Study QCD matter under extreme conditions
  - → Formation of **Quark Gluon Plasma** at high T and/or energy density.
- ❑ Many other things to explore in pA/AA: nucleon structure, intrinsic charm, QED at extreme field strengths, diffractive processes…

Experimentally, study hadronic collisions: - as a function of the center-of-mass energy
- for different beam-beam / beam-target configurations

SPS@CERN (fixed target) → RHIC@BNL (collider) → LHC@CERN (collider)

pA, SU, InIn, PbPb… | CuCu, AuAu, dAu | pp, pPb, PbPb

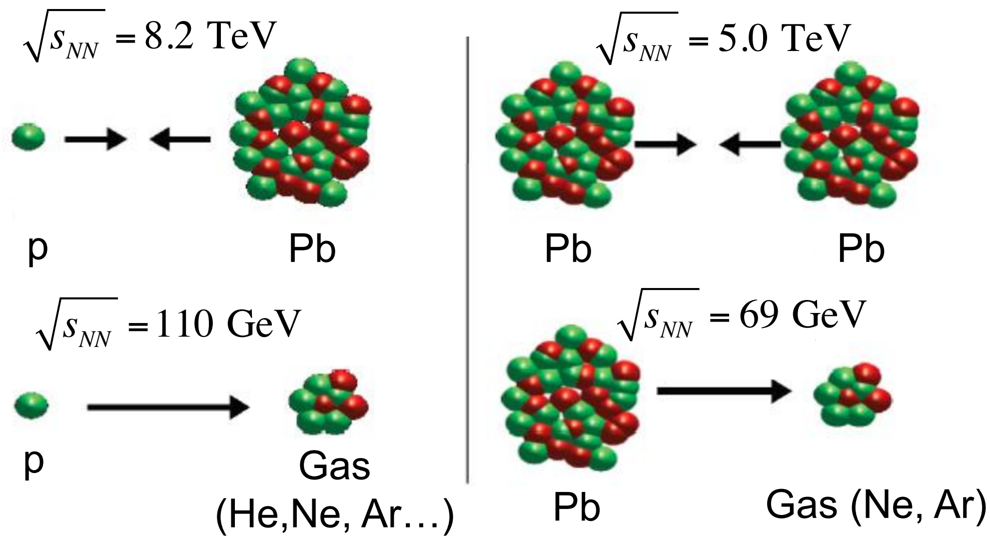
17 | 200 | 5020 → $\sqrt{s_{NN}}$ (GeV)

LHCb running modes and phase space coverage

- LHCb can operate in parralel **collider mode or fixed target mode**

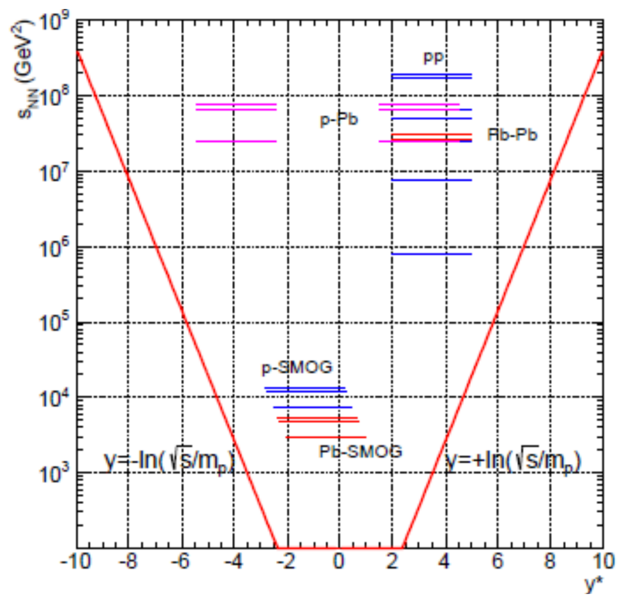
Collider mode

Fixed target mode



- Kinematic acceptance

pp and p-Gas
pPb and Pbp
PbPb and Pb-Gas



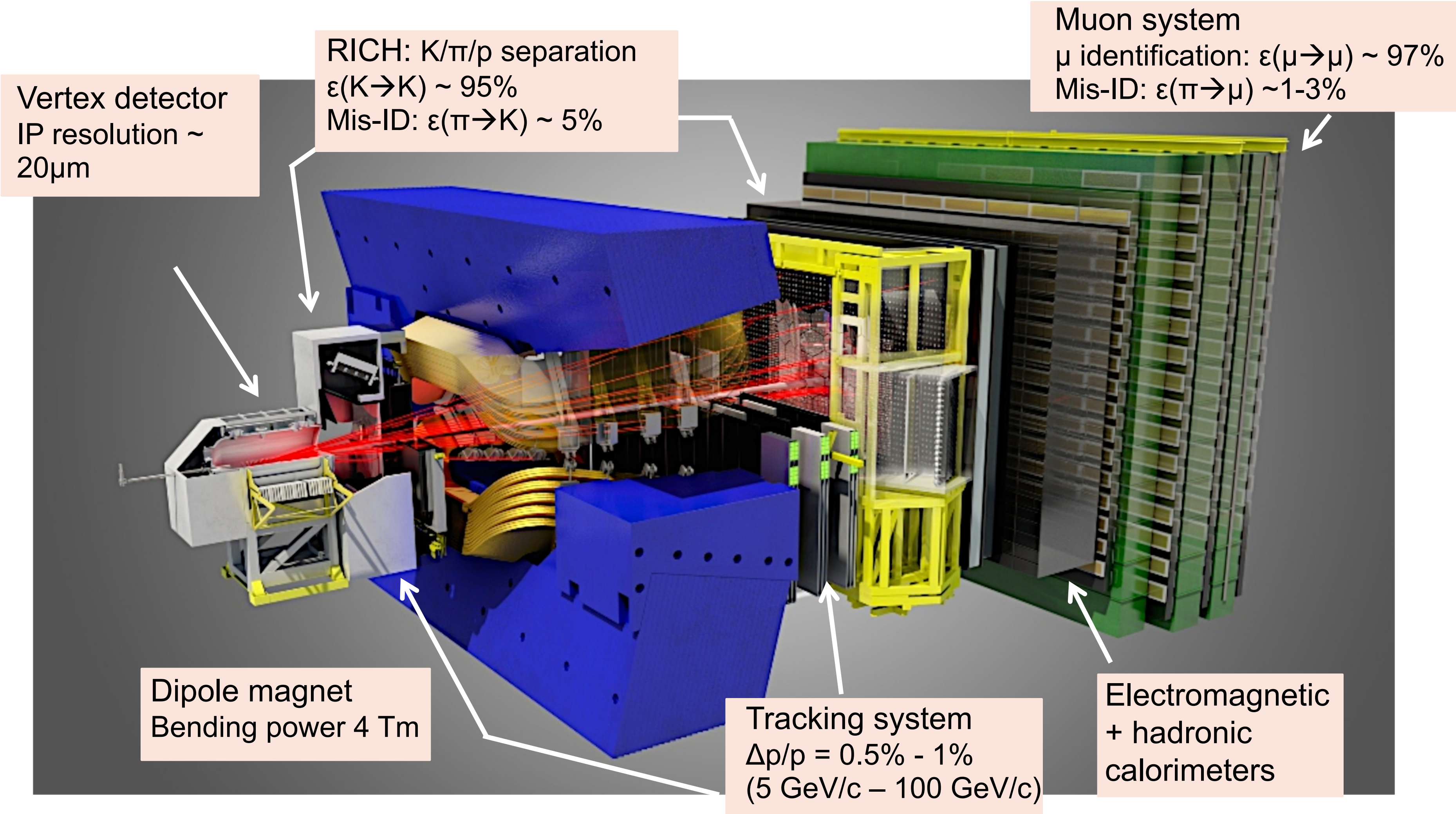
Collider mode: forward/backward coverage
Fixed target mode: Central and backward coverage
Energy between SPS and RHIC

Bridge the gap from SPS to LHC with a single experiment

The LHCb detector

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

- Single arm spectrometer in the forward region
- **Fully instrumented in its angular acceptance (2 < η < 5)**
- VELO also provides backward coverage: -3.5 < η < -1.5
- Designed initially for b-physics but general purpose detector (fixed target, heavy-ion, EW, BSM)



LHCb features

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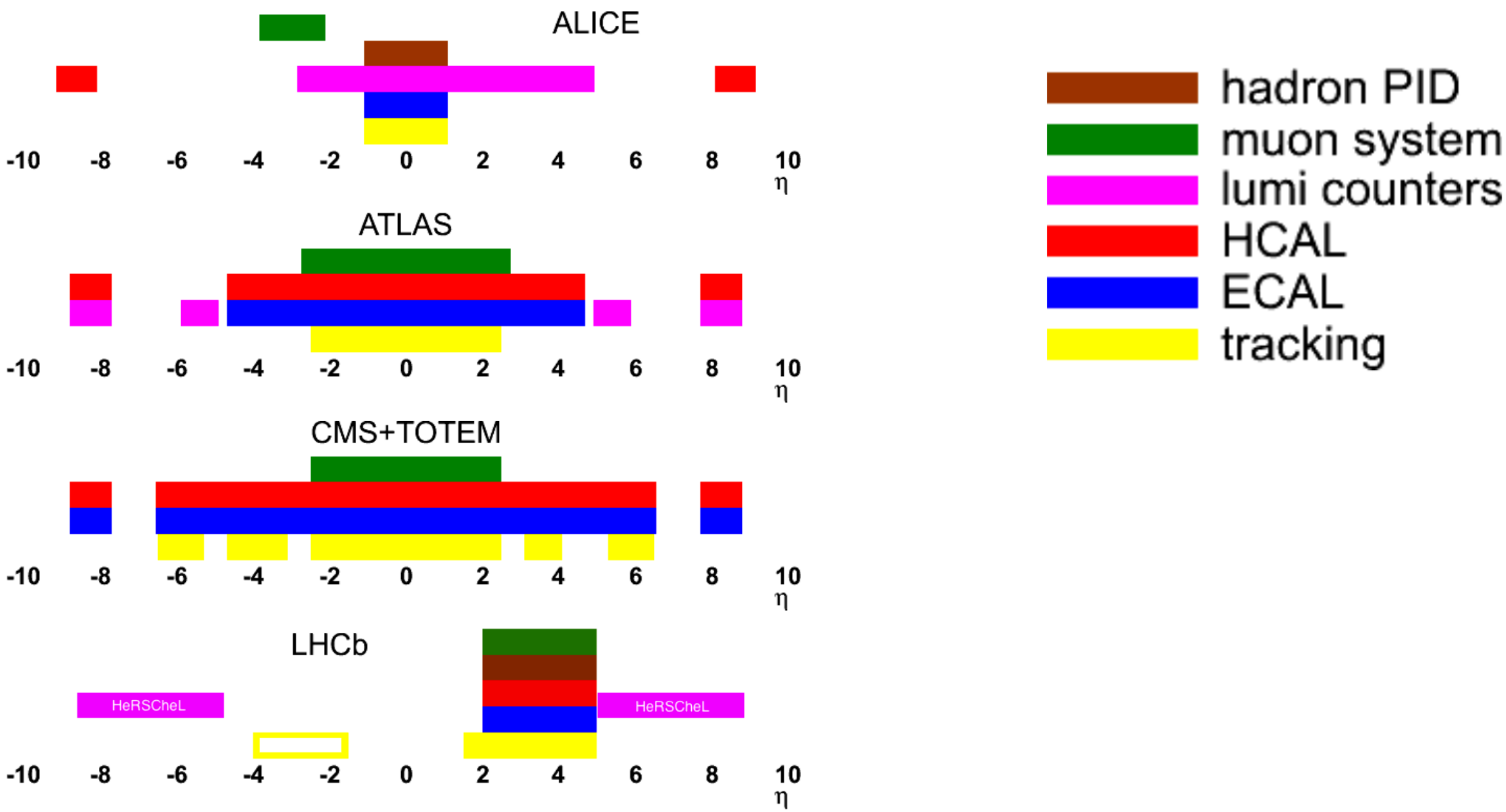
IJMPA 30 (2015) 1530022

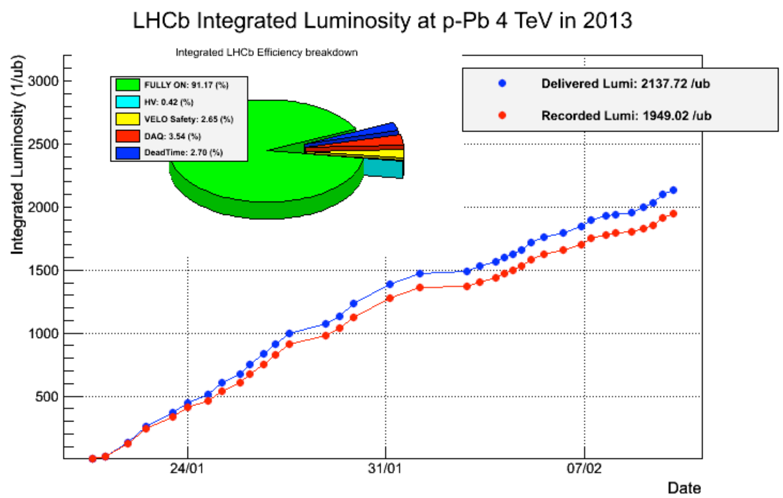


- LHCb is the only detector **fully** instrumented in the forward region
  - → Good complementarity with ALICE apparatus in the forward region (ALICE : Muon detection + Vertex detector after LS2, no calorimeter)
  - → Some measurements currently only possible with LHCb (**good particle identification**)
- Particle detection **down to very low** $\mathbf{p_T}$
- **Good vertexing**, possibility to separate prompt and from-b production

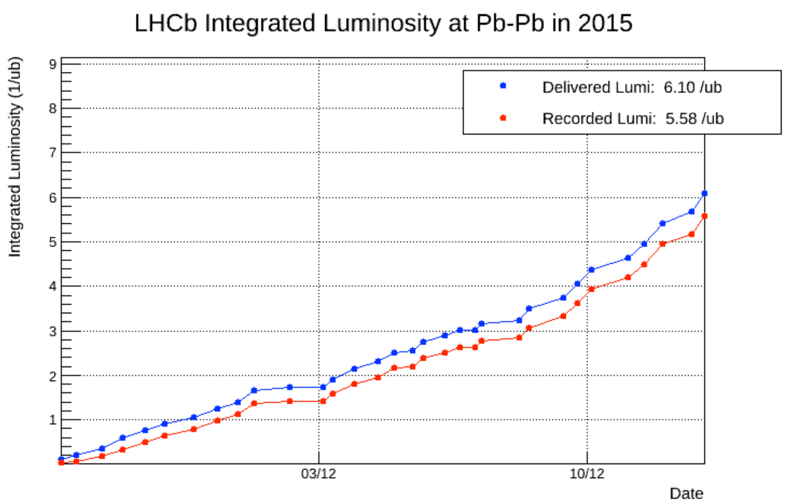
Heavy ion data taking history in LHCb

- **2010 and 2011 Pb-Pb runs**: no participation from LHCb
- **2012 and 2013:** Short (<1h) pilot runs of p-Ne (2012) and Pb-Ne (2013) collisions in fixed target mode thanks to the LHCb SMOG system

- **2013 pPb and Pbp runs** (1 month):
  - First participation of LHCb to the heavy-ion data taking in collider mode
  - Collection of 1.6 nb^{-1} of data (1.1 nb^{-1} in p-Pb / 0.5 nb^{-1} in Pb-p)
  - 5 publications (+1 paper under preparation)



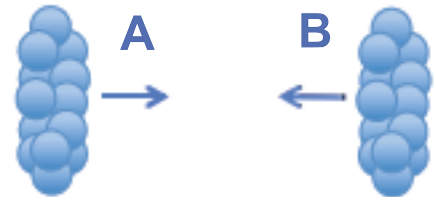
- **2015**
  - Several fixed target data taking periods (p-He, p-Ne, p-Ar, Pb-Ar)
  - First successful participation of LHCb to PbPb data taking!
    → precise luminosity determination still in progress



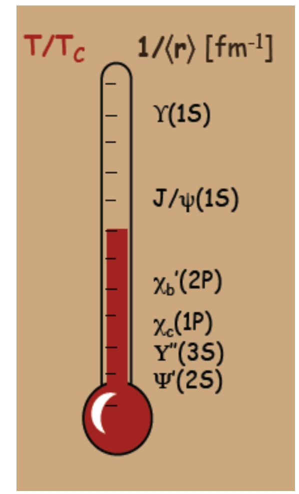
Some physics highlights of the LHCb heavy ion and fixed target program

Heavy flavours studies in AA collisions

Study of Open Heavy flavours and quarkonia are important for the understanding of hot matter created in Heavy-ion collisions



- Heavy quarks produced during initial stages of collisions (hard partonic interactions)
- Experience entire evolution of the system
- **Quarkonium suppression by color screening** in a deconfined medium
- Provide measurement of QGP temperature through sequential melting of states
- Picture more complex for charmonium at high energy (**recombination**). Also interesting effects in very low p_T peripheral events



Courtesy of A. Mocsy

Measure as many states as possible

Measure χ_c with LHCb → Understand J/ψ anomalous suppression measured at SPS

- Open heavy flavours to **study heavy quark energy loss in the QGP**
  - radiative vs collisional energy loss
  - study color-charge and mass dependence of parton energy loss
- Open HF also a reference for quarkonium studies

Open heavy flavours and quarkonia in AA collisions

To confirm and study charmonium color screening and recombination, one must compare charmonium and open charm production in A-A collisions

- Open charm production reflects the original charm quark yield
- QGP phase should not modify the overall heavy quark yields
- QGP phase modify relative heavy quark (hidden/open) yields

In LHCb: - Forward measurement of open/hidden charm production, down to low p_T
- At low and high center of mass energies
- Measurement of many quarkonia states
- Separate measurement of prompt or from-b J/ψ and ψ(2S)

LHCb can study **recombination at the TeV scale** and **color screening at the GeV scale** with charmonia

QGP formation in Pb-Ar at 71 GeV ? Look at expected charged particle mutliplicities

System \ centrality	60 – 100%	50 – 60%	40 – 50%	30 – 40%	20 – 30%	10 – 20 %	0 – 10%
PbNe – 71 GeV	108.6	254.4	392.5	588.0	814.5	1086.0	1494.9
PbAr – 71 GeV	**123,6**	**308,8**	**496,5**	**806,6**	**1228,3**	**1711,9**	**2372,7**
PbKr – 71 GeV	196,9	533,6	919,1	1451,2	2205,5	2986,6	4084,3
PbPb – 17 GeV	**124,2**	**331,6**	**605,9**	**919,6**	**1338,7**	**2035,8**	**2980,5**

EPOS-LHC-v3400

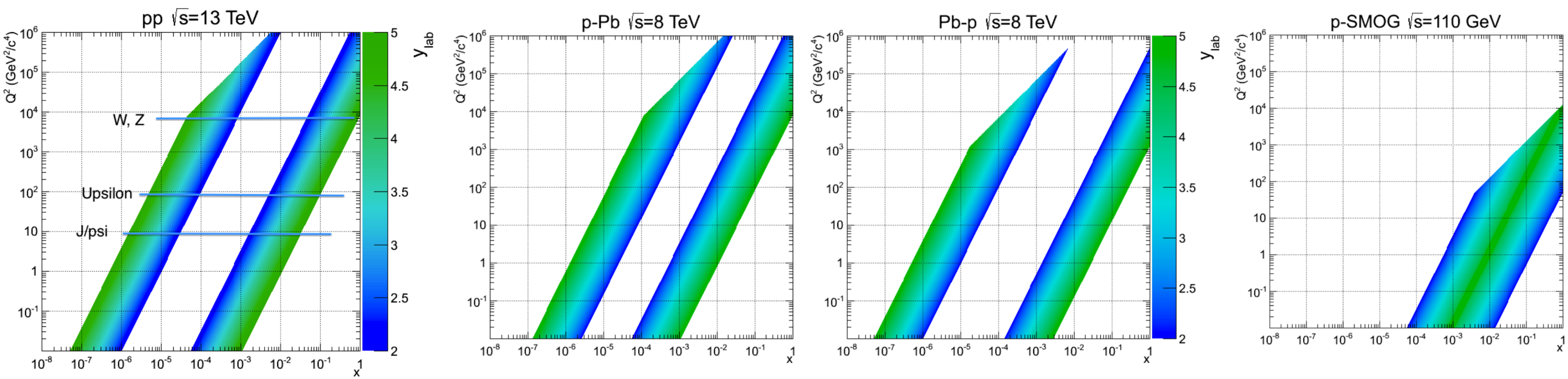
Soft QCD and electroweak measurements

Many open questions in QCD especially in the soft sector which cannot be treated perturbatively

Perform measurements at different √s and in different setups to investigate:

- The nucleon structure of free (pp) versus bound nucleons (pA) inside the nucleus
  - PDFs can be probed via quarkonia, electroweak bosons, Drell Yan measurements
  - Contribution from two x-regions for given Q^2 and y $\left(x_{1,2} = e^{\pm y} \frac{Q}{\sqrt{s}} \right)$
  - Access to **very small x (colliding mode)** and **very large x (fixed target mode)**

Accessible space phase for Ep = 6.5 TeV



- Dynamic of hadronization process
  - Measurement of total cross sections, energy flow measurement, particle multiplicities, Bose-Einstein or Fermi-Dirac correlations….
- Diffractive scattering: accessible with new high rapidity Herschel detector
- QED at extreme conditions
  - Ultraperipheral Collisions: exclusive ρ^0 production, exclusive photoproduction of J/ψ…

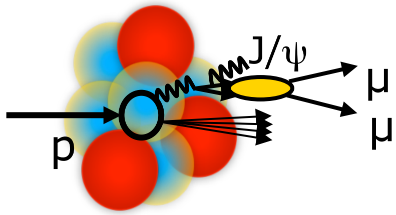
Physics motivation for proton-nucleus studies

➡ Proton-nucleus collisions are interesting by themselves and also provide reference for heavy ion studies

Open Heavy flavours and Quarkonia as tools to study cold nuclear matter effect (CNM)
→ Necessary reference to disentangle QGP effects from CNM effects in AA collisions

Initial state effects

- **Nuclear shadowing = gluon shadowing at LHC [1]**
- **Parton saturation / CGC [2]**
- **Radiative energy loss [3]**
- **Cronin effects [4]**



Final state effects

- **Nuclear absorption [6]:Expected to be small at LHC [7]**
- **Radiative energy loss [8]**
- **Comovers [9]**

Neither initial nor final

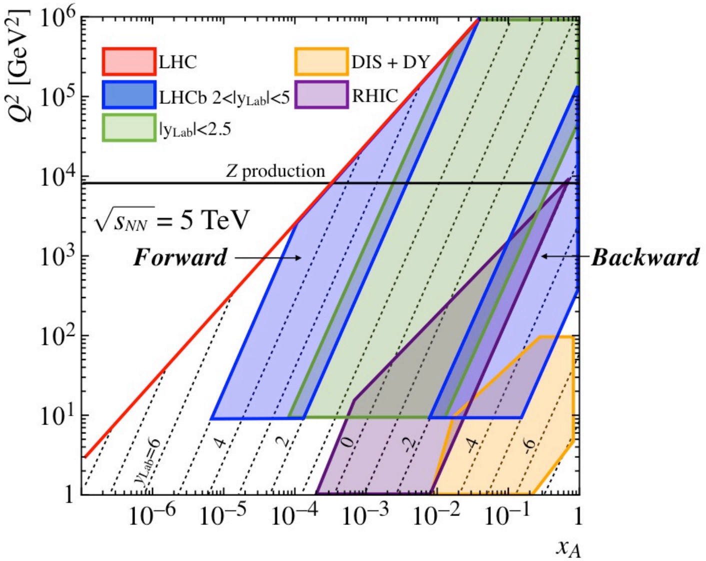
- **Coherent energy loss [5]**

[1] K.J. Eskola et al., JHEP 0904 (2009) 065.
[2] D. Kharzeev et al., Nucl. Phys. A770 (2006) 40.
[3] S. Gavin et al., Phys. Rev. Lett. 68 (1992) 1834.
[4] J. W. Cronin et al., Phys. Rev. D, 11:3105, 1975.
[5] F. Arleo et al., Phys. Rev. Lett. 109 (2012) 122301.
[6] R. Vogt, Nucl. Phys. A700 (2002) 539.
[7] C. Lourenco et al., JHEP 0902.014, 2009.
[8] R. Vogt, Phys. Rev. C61 (2000) 035203
[9] E. Ferreiro, arXiv:1411.0549v2

Physics motivation for proton-nucleus studies

Z boson production to constrain the nuclear parton distribution functions (nPDF)

LHCb in p+Pb and Pb+p probes two different regions in x-Q^2
Complementary measurement to ATLAS/CMS



Sensitivity to nuclear PDF at large x_A (10^{-1}), and low x_A (10^{-4})

Two-particle correlations to probe collective effects in the dense environment of high energy collisions

LHCb can investigate at forward rapidity the long-range correlation on the near side («the ridge») which was observed in pp, pPb (and PbPb) at mid-rapidity $|\eta|< 2.5$

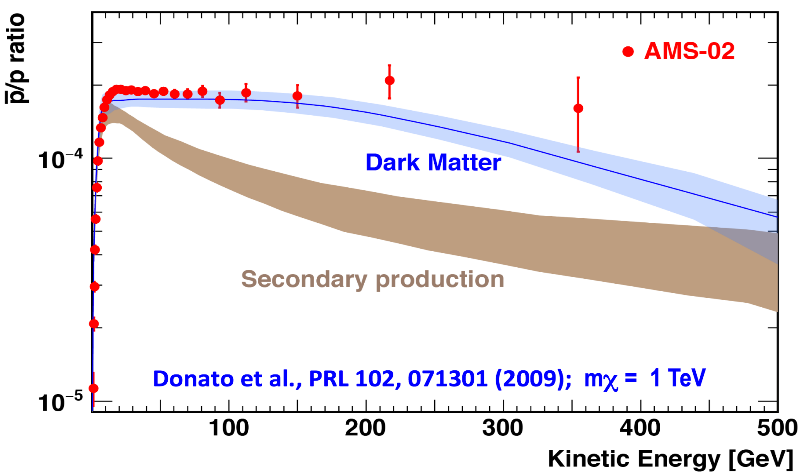
In AA collisions, long range correlations on the near- and away-side interpreted as hydrodynamical flow of the deconfined medium

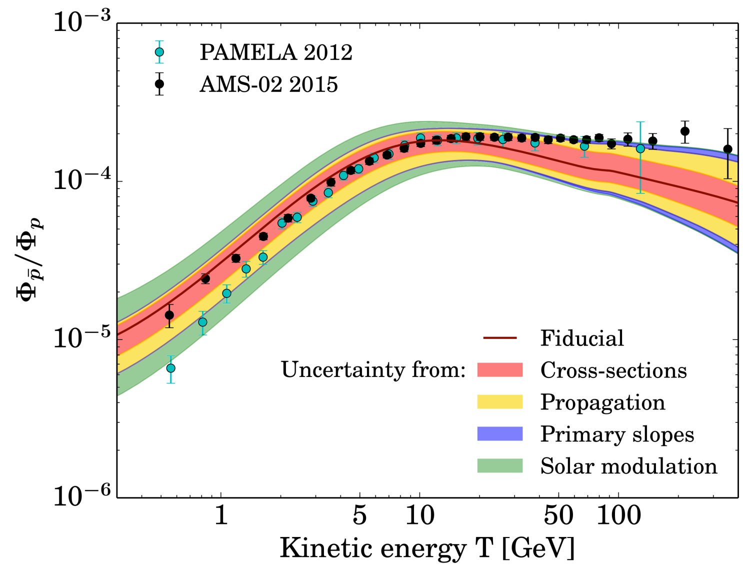
Associated Heavy flavour production in p-Pb to probe Multiple Parton Interaction

Link with other communities: cosmic ray physics

- Recent results from AMS-02 exhibit an antiproton excess with respect to expectations from secondary production (p+p → $\bar{p}$X and p+He → $\bar{p}$X) in the interstellar medium, in the O(100 GeV) region
- Possible evidence for Dark Matter Contribution

AMS Coll., Cern 15.04.2015





arXiv:1504.04276

- More conservative estimates on the related uncertainties show that the results could still fit with secondary production
- Largest uncertainty comes from σ(pHe→ $\bar{p}$X)

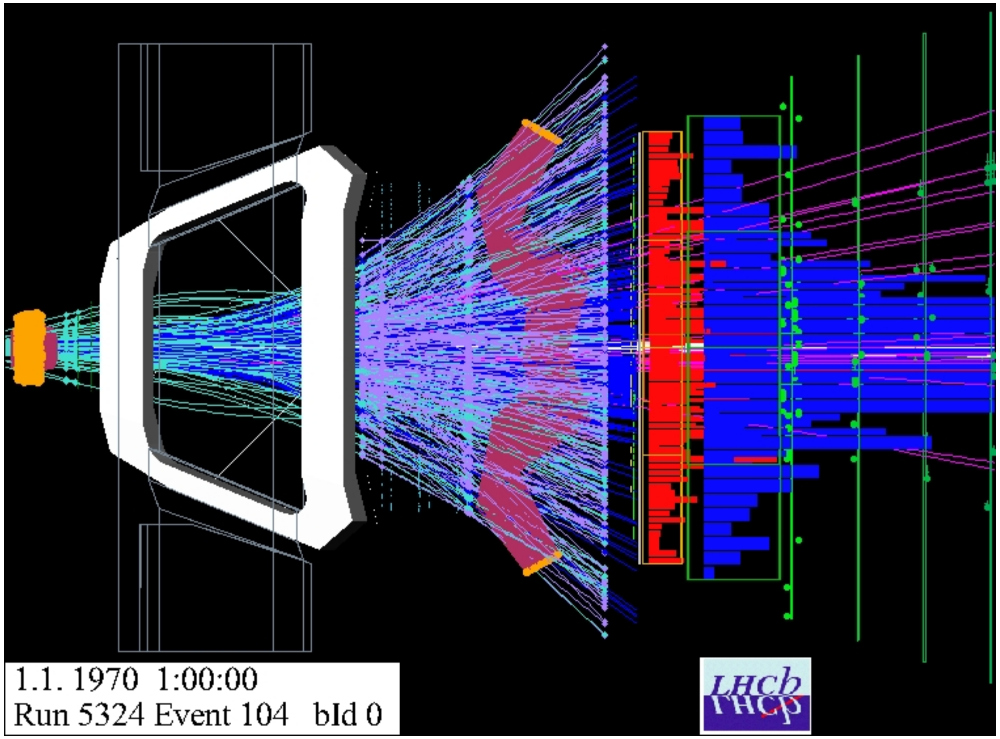
➡ **In fixed target mode, proton beam (6.5 TeV) on He at rest suits well the physics case**

➡ Also possibility to investigate **intrinsic charm at large x**: important for backgrounds in high energy neutrino astrophysics (for IceCube experiment)

For more physics opportunities in fixed target collisions @LHC, see also: **Physics Reports 522 (2013) 239**

Heavy ion studies in fixed target mode

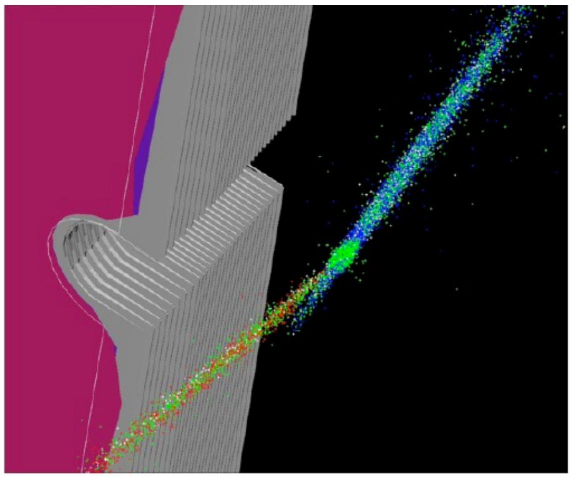
p-Gas and Pb-Gas data taking



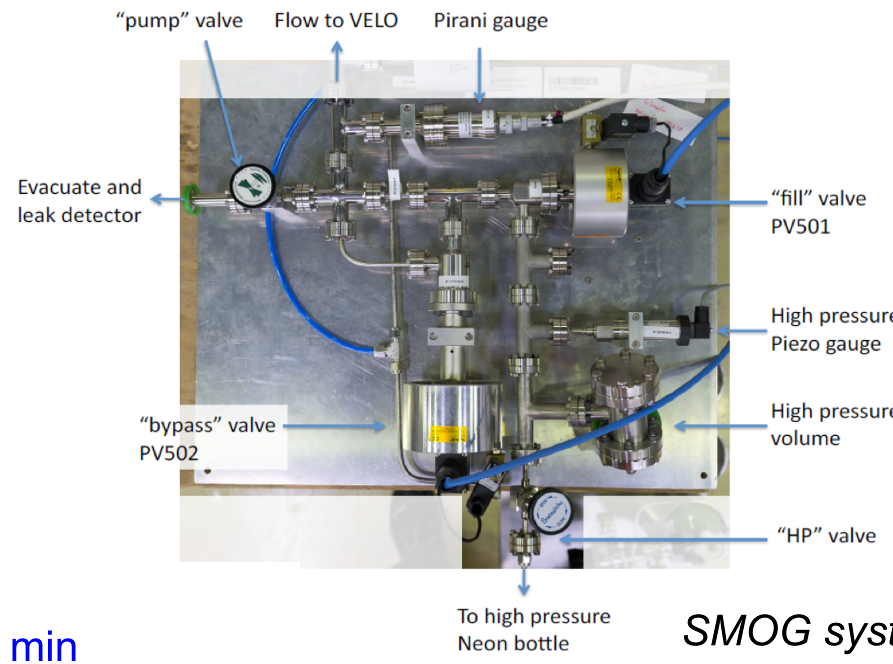
Pb-Ar simulation event display
(full detector simulation with EPOS generator)

The Fixed Target data taking (SMOG)

→ SMOG: System for Measuring Overlap with Gas:
- Main use so far for precise **luminosity determination**
- Low density noble gas injected in the VELO, in the interaction region
- Only local temporary degradation of LHC vacuum



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.



SMOG system

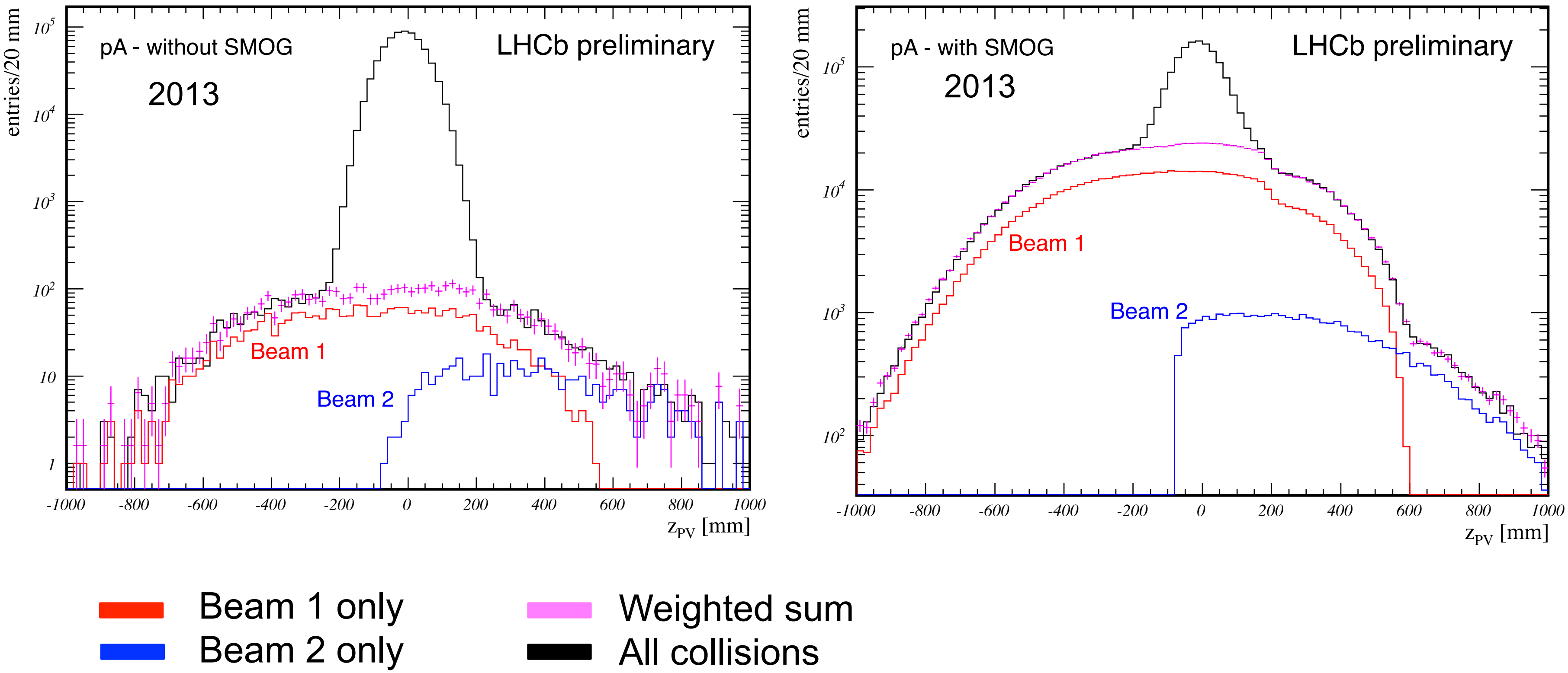
- pNe pilot run at $\sqrt{s_{NN}}$ = 87 GeV (2012) ~ 30 min
- PbNe pilot run at $\sqrt{s_{NN}}$ = 54 GeV (2013) ~ 30min
- pNe run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 12h
- pHe run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 8h
- pAr run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 3 days
- pAr run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ few hours
- PbAr run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ 1.5 week
- pHe run at $\sqrt{s_{NN}}$ = 110 GeV (2016) ~ 2 days

Preferred target Gas

	He	Ne	Ar	Kr	Xe
A	4	20	40	84	131

Fixed Target Interaction Properties

LHCb-CONF-2012-034



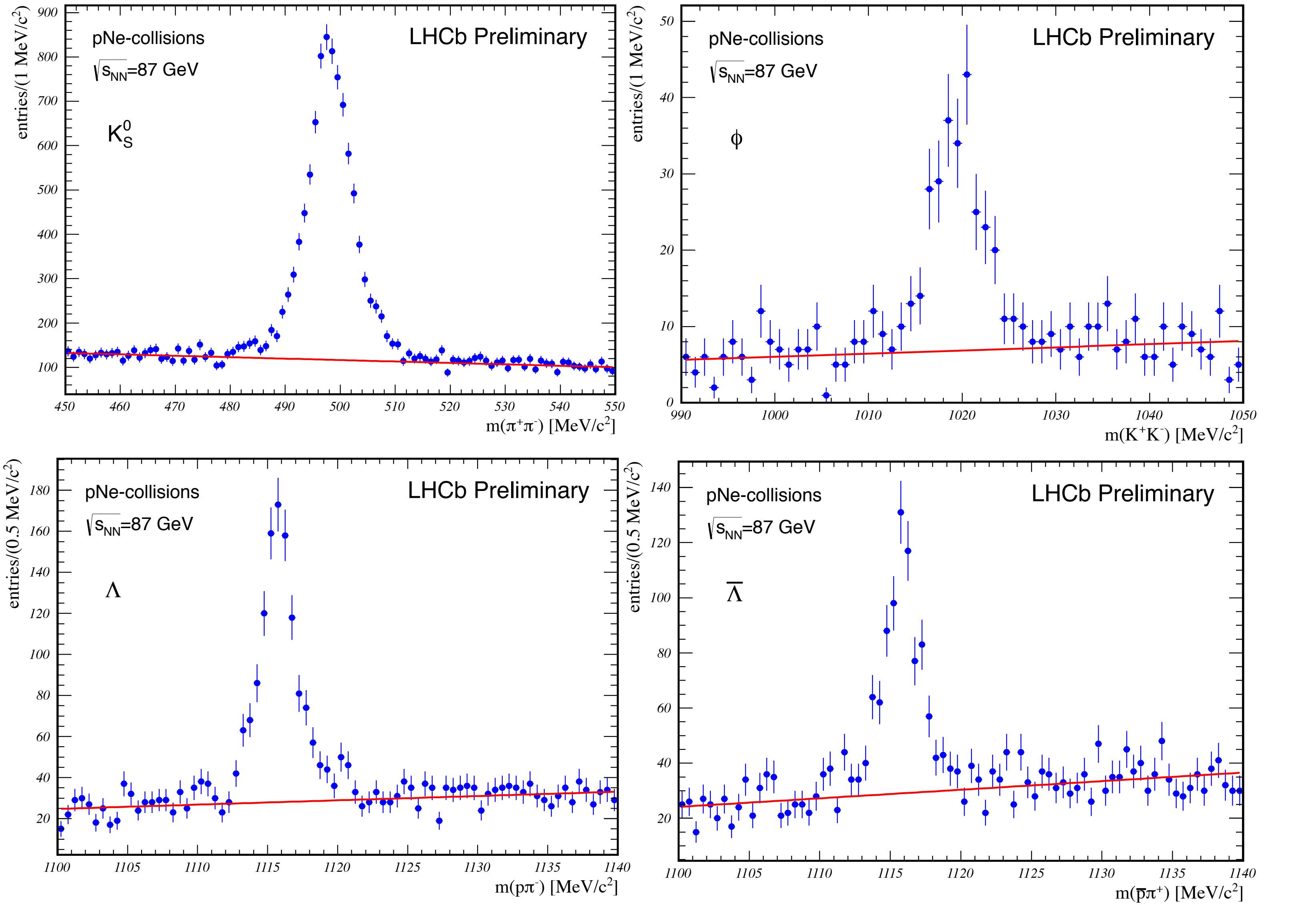
- ❑ Beam-Beam / Beam-Gas interactions can be separated from the filling scheme
  → Fixed target collisions can be isolated from regular collisions in collider mode
  No need for dedicated physics runs!

- ❑ SMOG increases the beam gas rate by two order of magnitudes
  → **Gas pressure (~ 1.5x10^{-7} mbar)** ~ 2 order of magnitude larger than vacuum pressure

Results from p-Ne collisions

- p-Ne collisions at $\sqrt{s_{NN}}$ = 87 GeV, about 30 min of data taking (2012)

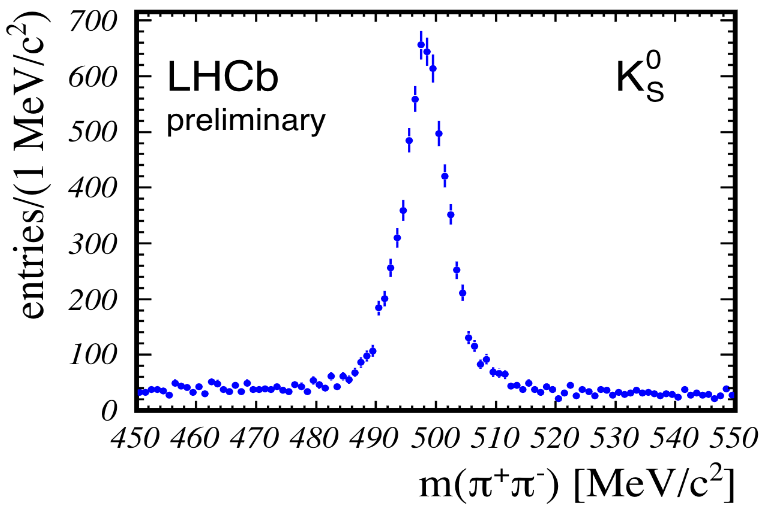
LHCb-CONF-2012-034

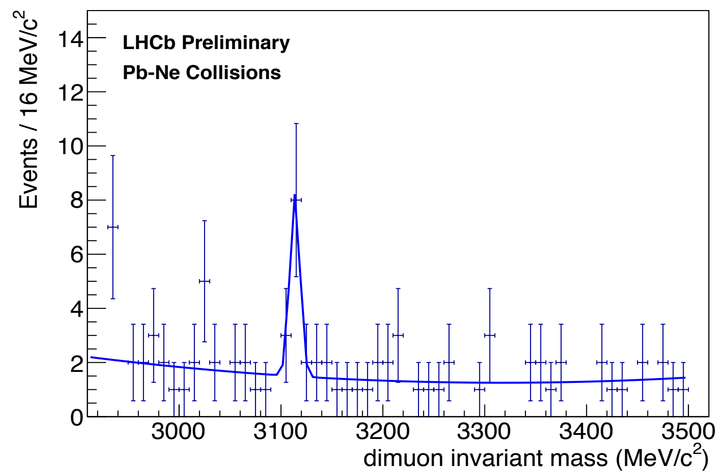


Results from Pb-Ne and p-Ne collisions

- Pb-Ne collisions at $\sqrt{s_{NN}}$ = 54 GeV, about 30 min of data taking (2013)

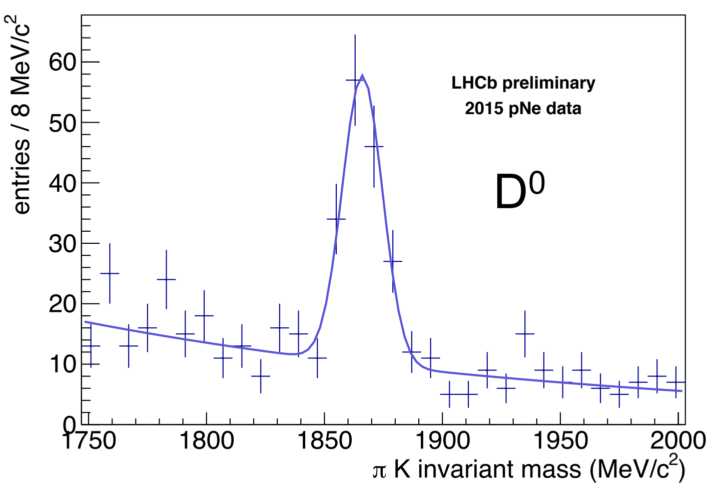
https://twiki.cern.ch/twiki/bin/viewauth/LHCbPhysics/LHCb2015PublicityPlots#SMOG_plots

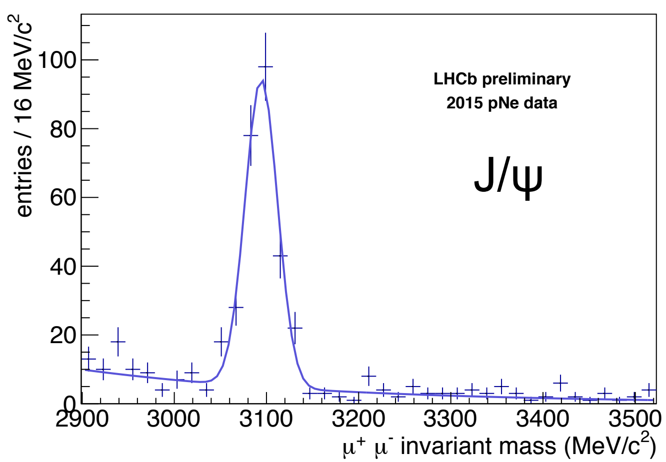




- p-Ne collisions at $\sqrt{s_{NN}}$ = 110 GeV, about 12h of data taking (2015)

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

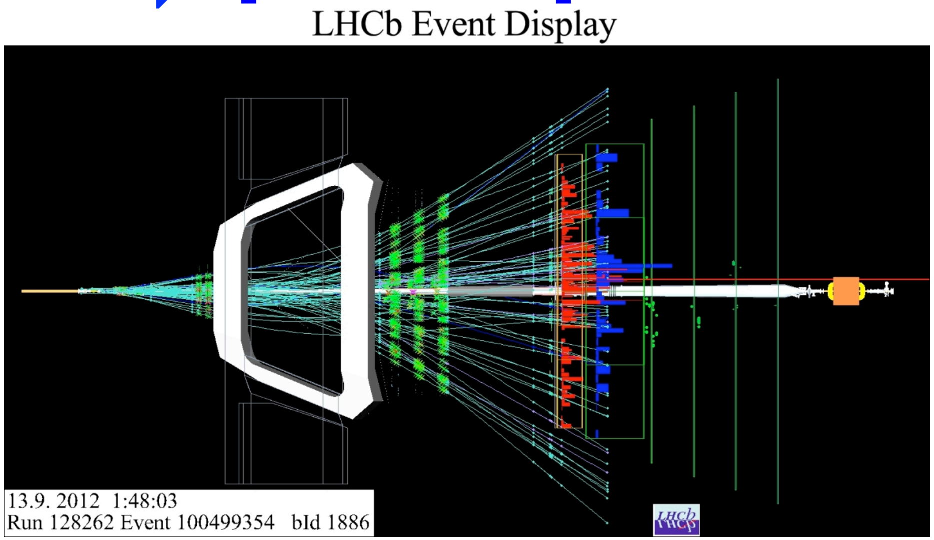




NEW

Heavy ion studies in collider mode

p-Pb/Pb-p data taking



pPb data event display (2012)

Measure observables sensitive to nuclear effects

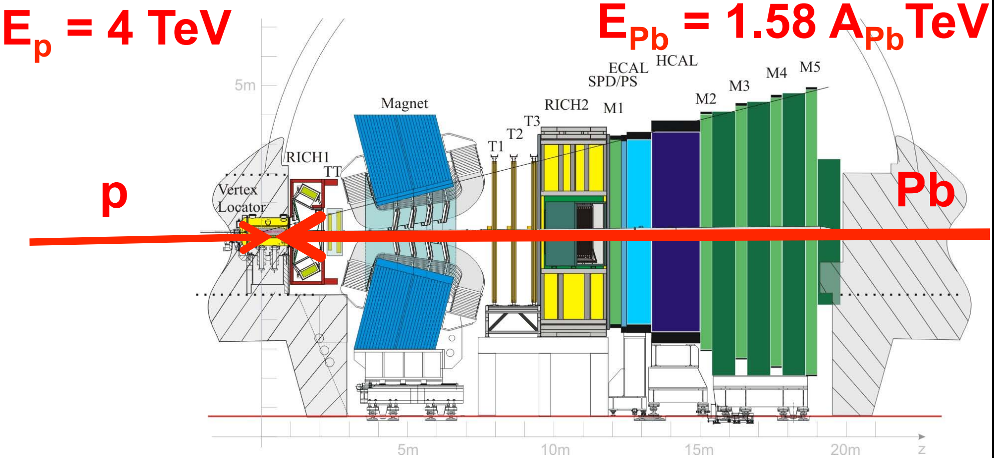
nuclear modification factor: $R_{pA}(y) = \frac{1}{A} \cdot \frac{d\sigma_{pA}/dy}{d\sigma_{pp}/dy}$

forward-backward asymmetry: $R_{FB}(y) = \frac{\sigma_{pA}(+|y|)}{\sigma_{pA}(-|y|)}$

The p-Pb and Pb-p data taking (2013)

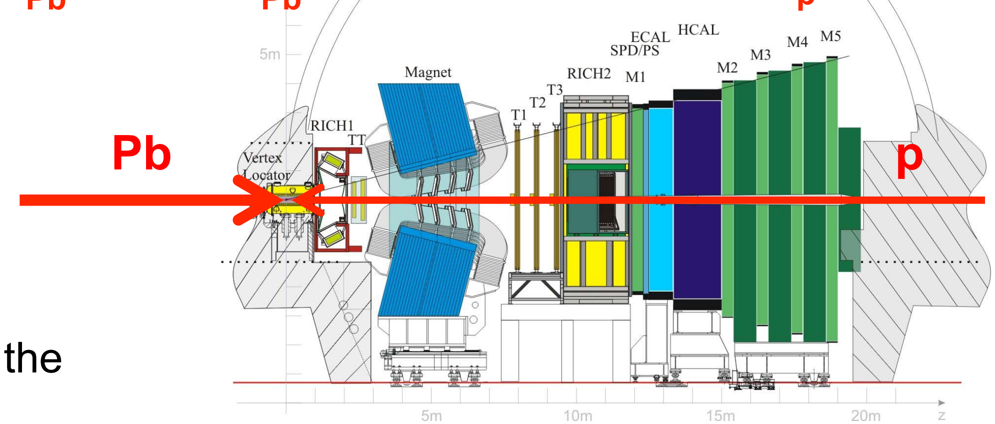
- p-Pb and Pb-p data collected at a nucleon-nucleon center of mass energy $\sqrt{s_{NN}}$ = 5 TeV
- Asymmetric beams: nucleon-nucleon **center-of-mass system shifted by Δy = 0.47** in the direction of the p beam

E_p = 4 TeV E_{Pb} = 1.58 A_{Pb}TeV



p + Pb collisions (forward)
Rapidity coverage: 1.5 < y_{CMS} < 4.5
2013 data sample: L_{int} = 1.1 nb^{-1}
→ Applies to all analyses unless specified

E_{Pb} = 1.58 A_{Pb}TeV E_p = 4 TeV



Pb + p collisions (backward)
Rapidity coverage: -5.5 < y_{CMS} < -2.5
2013 data sample: L_{int} = 0.5 nb^{-1}
→ Applies to all analyses unless specified

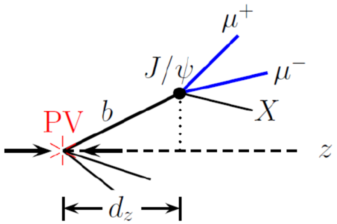
➡ Common rapidity range for most of the analyses below: 2.5 < $|y_{CMS}|$ < 4

J/ψ production in p-Pb and Pb-p

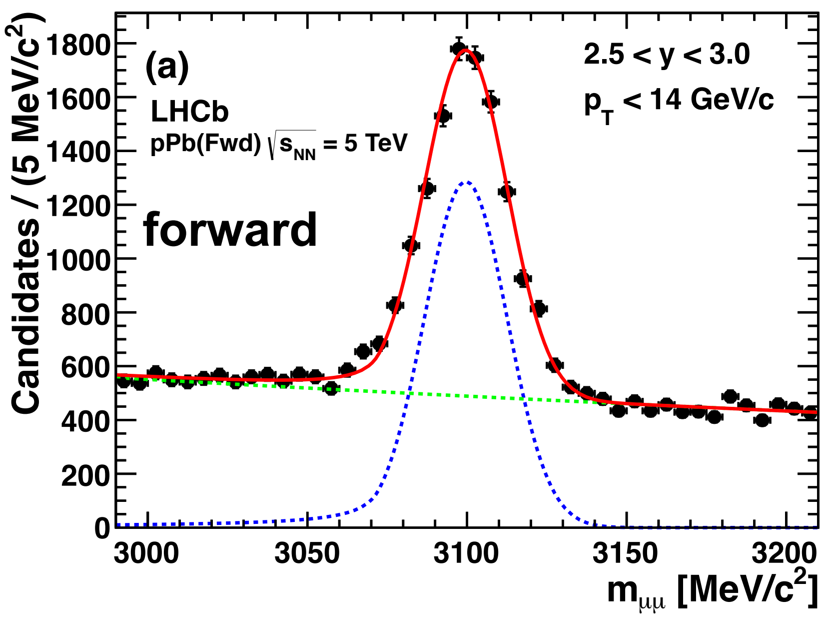
JHEP 02 (2014) 072

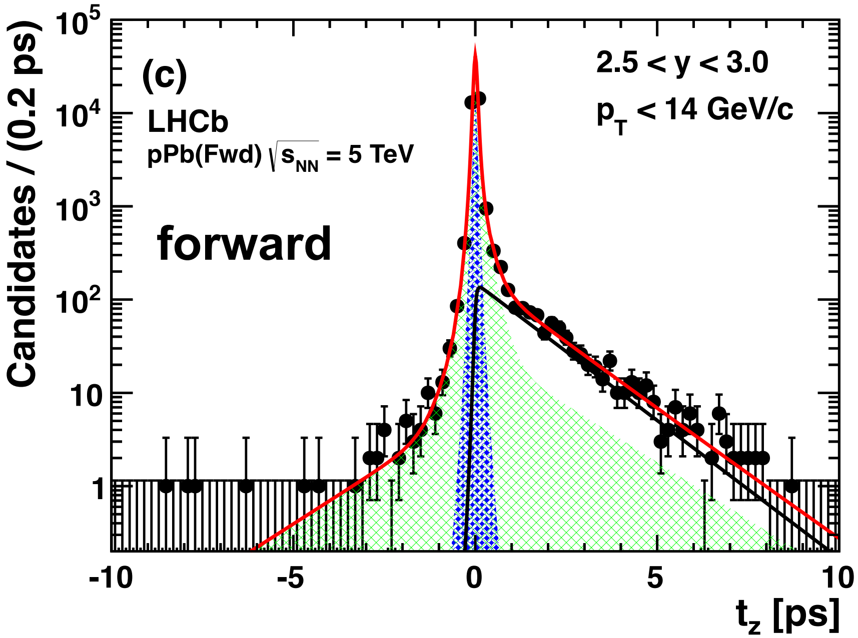
- J/ψ are reconstructed from two well identified muons
- Disentangle prompt J/ψ and J/ψ from b using pseudo-proper time:

$$t_Z = \frac{(Z_{J/\Psi} - Z_{PV}) \times M_{J/\Psi}}{p_z}$$



- Yields of prompt J/ψ and J/ψ from b extracted from simultaneous fit of mass and pseudo-proper time





J/ψ nuclear modification factor (R_{pPb})

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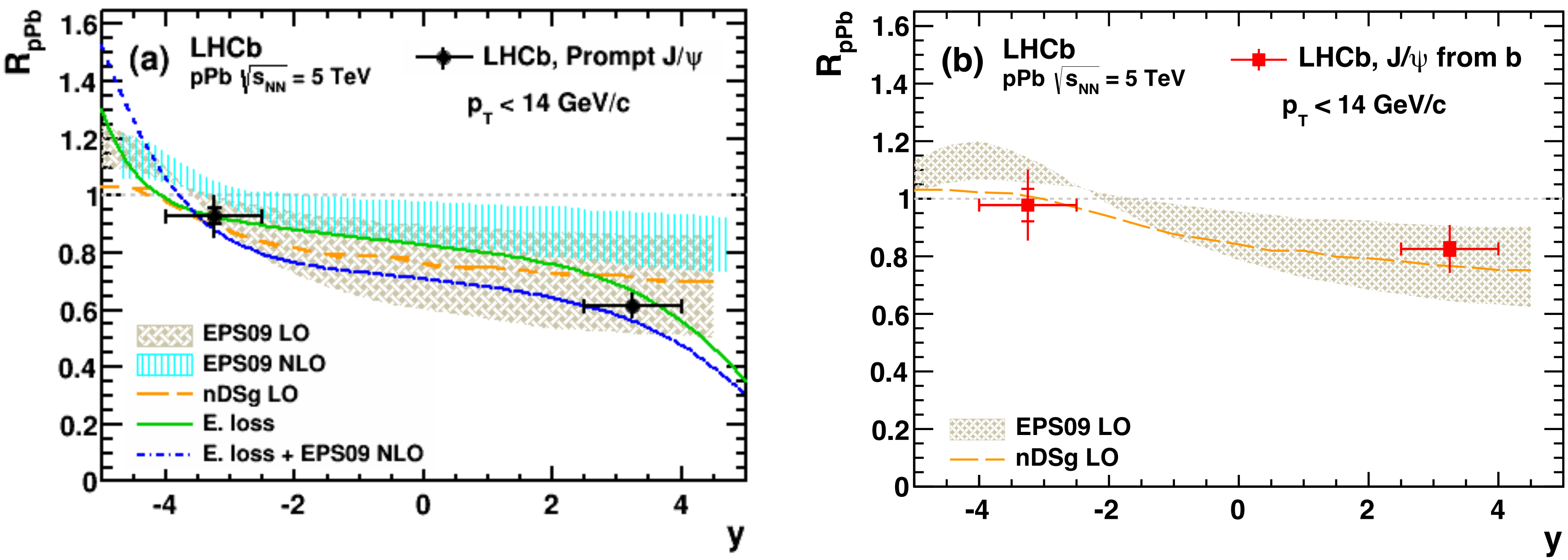
- $R_{pPb}(y) = (1/A) \times (\mathrm{d}\sigma_{\mathrm{pA}}/\mathrm{d}y)/(\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}y)$ in common range 2.5 < $|y_{CMS}|$ < 4.0



Prompt J/ψ: strong suppression at forward y (strong CNM effect)
→ Data well described by coherent E. loss models (w and w/o shadowing)
J/ψ from b: small suppression in the forward region
→ first indication of suppression of b hadron production

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

J/ψ forward to backward ratio (R_{FB})

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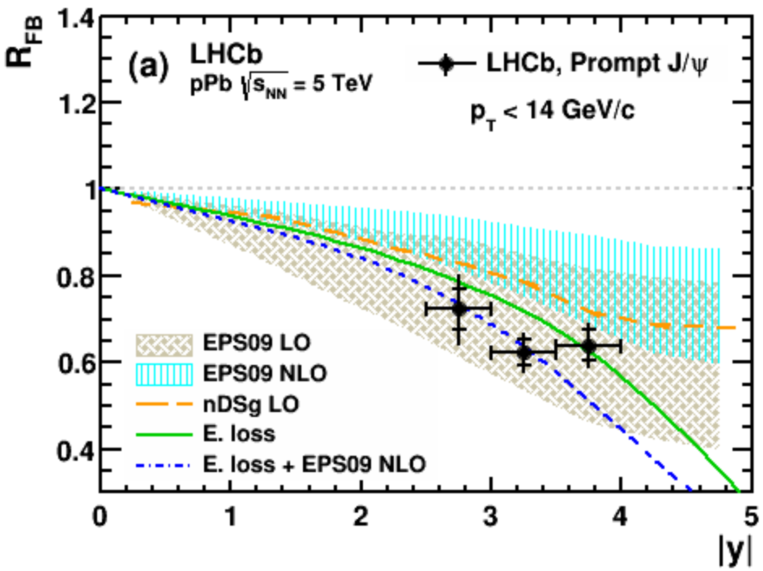
- $R_{FB}(y) = (d\sigma_{pA}/dy)/(d\sigma_{Ap}/dy)$ in common range $2.5 < |y_{CMS}| < 4.0$



Rapidity dependence:

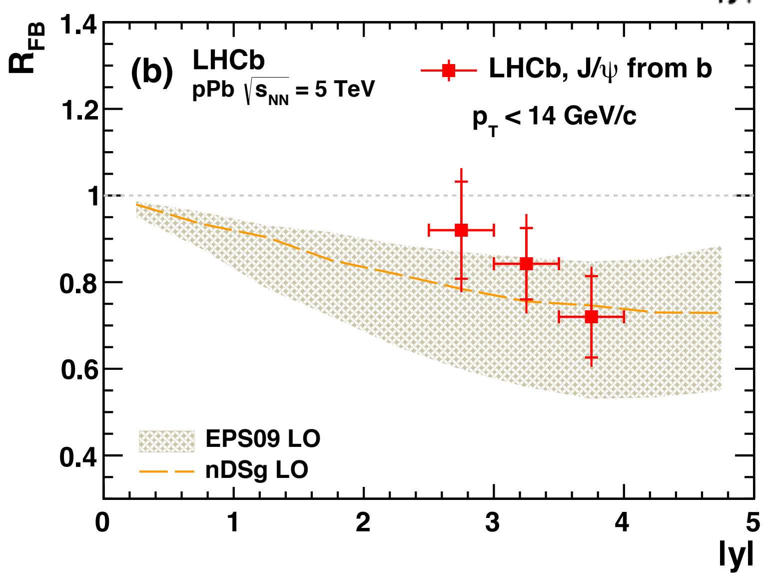
Prompt J/ψ: Clear forward-backward asymmetry

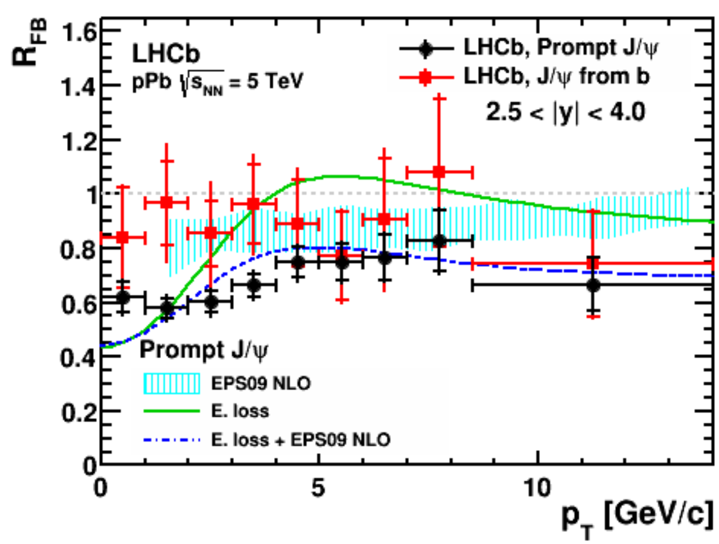
J/ψ from b: Small forward-backward asymmetry

p_T dependence:

Prompt J/ψ : forward backward asymmetry agrees best with E. loss + shadowing (except at low p_T)

J/ψ from b: R_{FB} close to 1

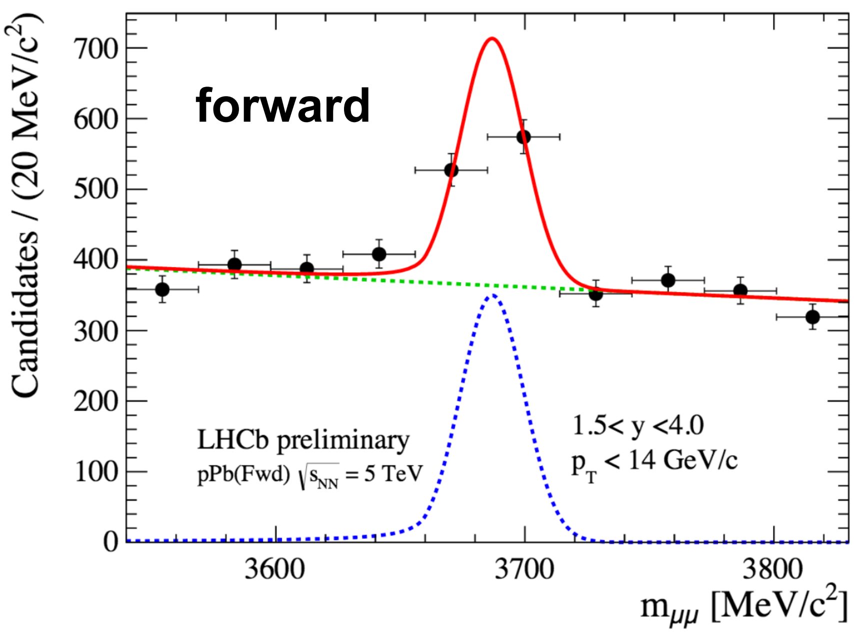


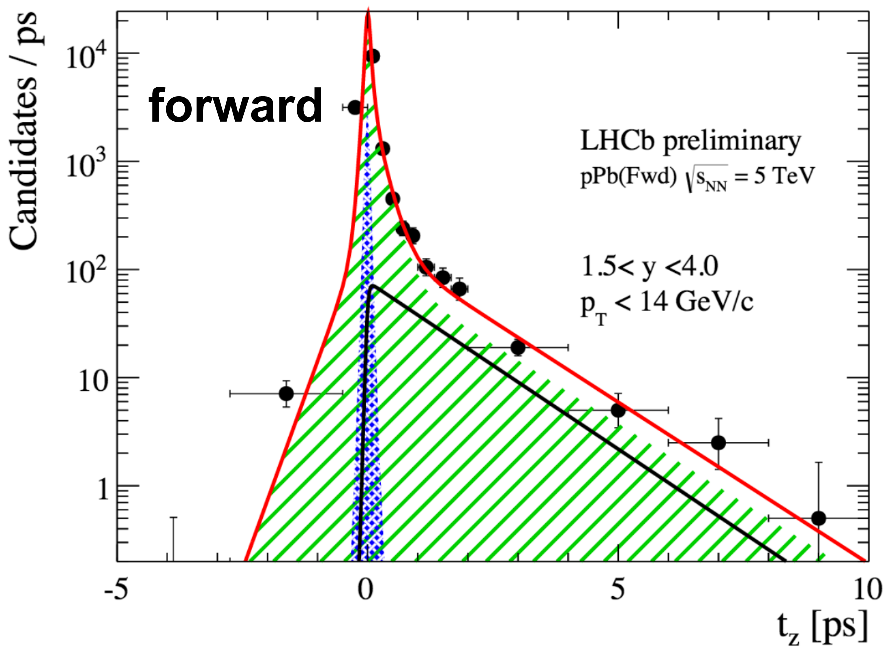


Ψ(2S) production in p-Pb and Pb-p

JHEP 1603 (2016) 133

- Similar analysis strategy as for the J/ψ
- Yields of prompt ψ(2S) and ψ(2S) from b extracted from simultaneous fit of mass and pseudo-proper time

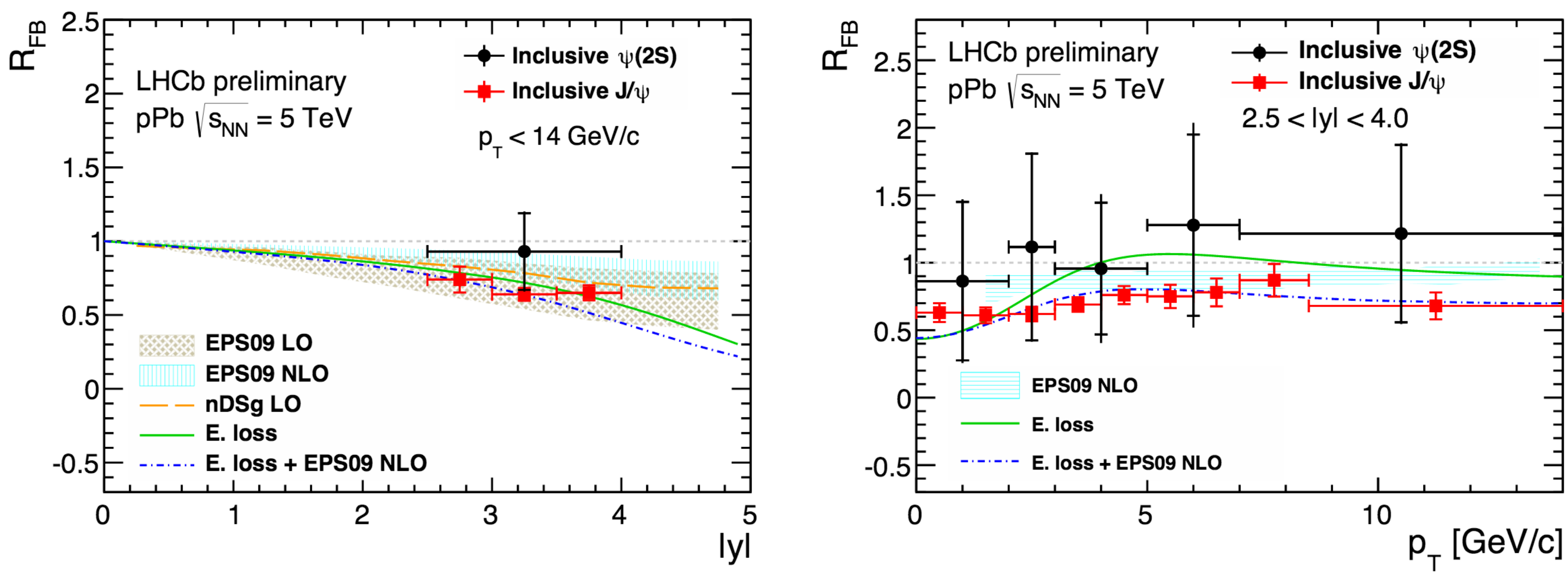




$\Psi(2S)$ forward to backward ratio

JHEP 1603 (2016) 133

- R_{FB} as a function of p_T and rapidity in common range $2.5 < |y_{CMS}| < 4.0$
- No need for pp reference cross section, part of experimental and theoretical uncertainties cancel out



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

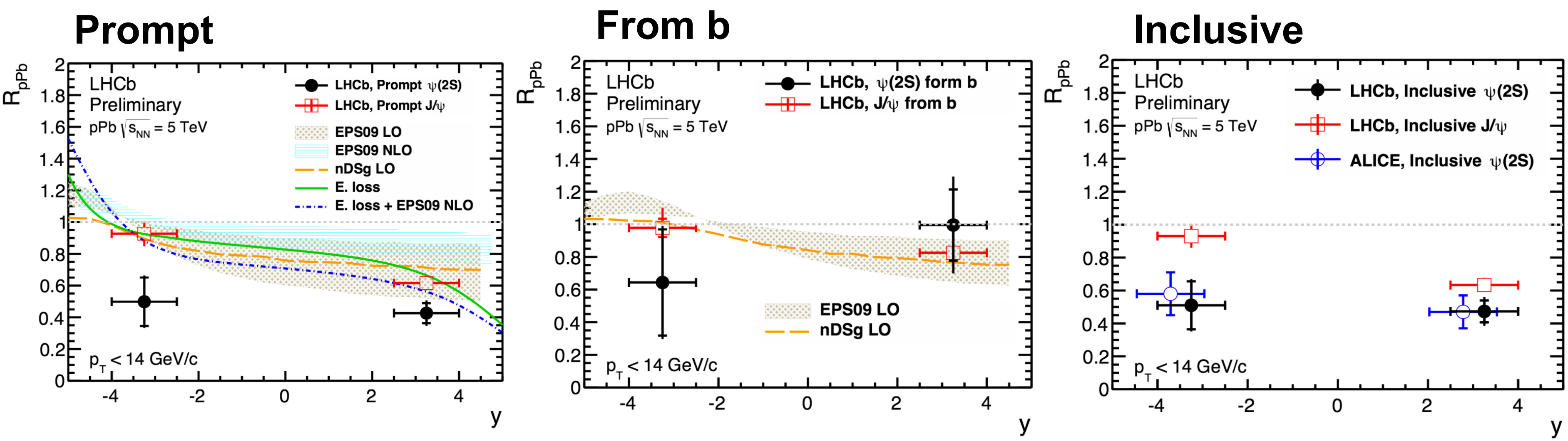
Ψ(2S) nuclear modification factor

JHEP 1603 (2016) 133

- Ψ(2S) nuclear modification factor is calculated from J/Ψ nuclear modification factor

$$\Rightarrow \quad R_{pPb}^{\Psi(2S)} \approx R_{pPb}^{J/\Psi} \times R \qquad \text{with} \qquad R = \frac{R_{pPb}^{\psi(2S)}}{R_{pPb}^{J/\Psi}} = \frac{\sigma_{pPb}^{\psi(2S)}(5\text{TeV})}{\sigma_{pPb}^{J/\Psi}(5\text{ TeV})} \frac{\sigma_{pp}^{J/\Psi}(5\text{ TeV})}{\sigma_{pp}^{\Psi(2S)}(5\text{ TeV})}$$

$$\text{Assuming} \quad \frac{\sigma_{pp}^{J/\Psi}(5\text{ TeV})}{\sigma_{pp}^{\Psi(2S)}(5\text{ TeV})} \approx \frac{\sigma_{pp}^{J/\Psi}(7\text{ TeV})}{\sigma_{pp}^{\Psi(2S)}(7\text{ TeV})}$$



ALICE: JHEP 12 (2014) 073

Prompt ψ(2S) more suppressed than prompt J/ψ
E. loss + shadowing don't explain the ψ(2S) suppression in the backward region
(other mechanism at play? → comovers E. Ferreiro, arXiv:1411.0549v2)
Suppression of ψ(2S) from b consistent with that of J/ψ from b
Suppresion of inclusive ψ(2S) consistent with ALICE results

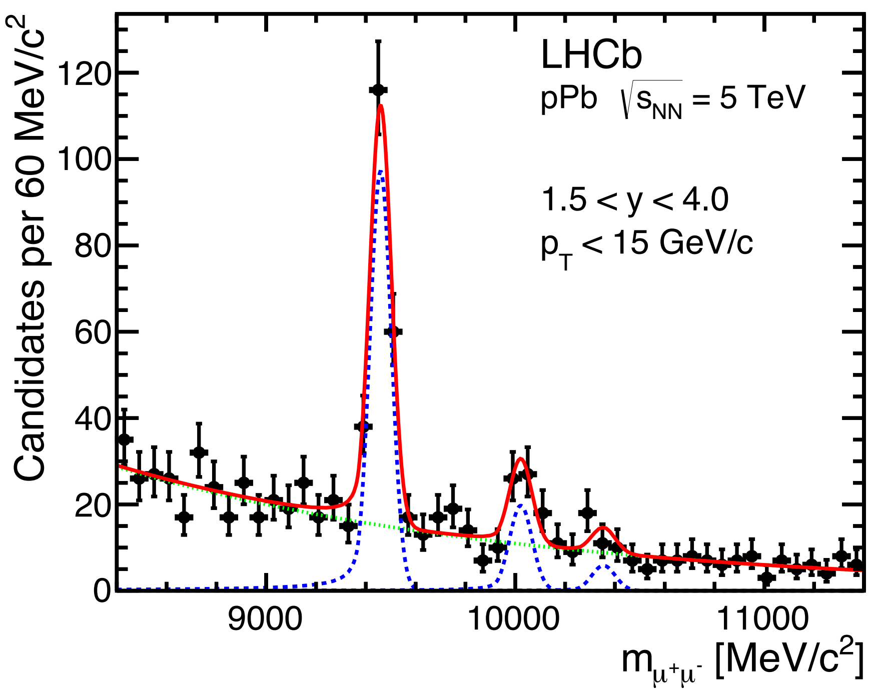
Υ(nS) production in p-Pb and Pb-p

JHEP 07 (2014) 094

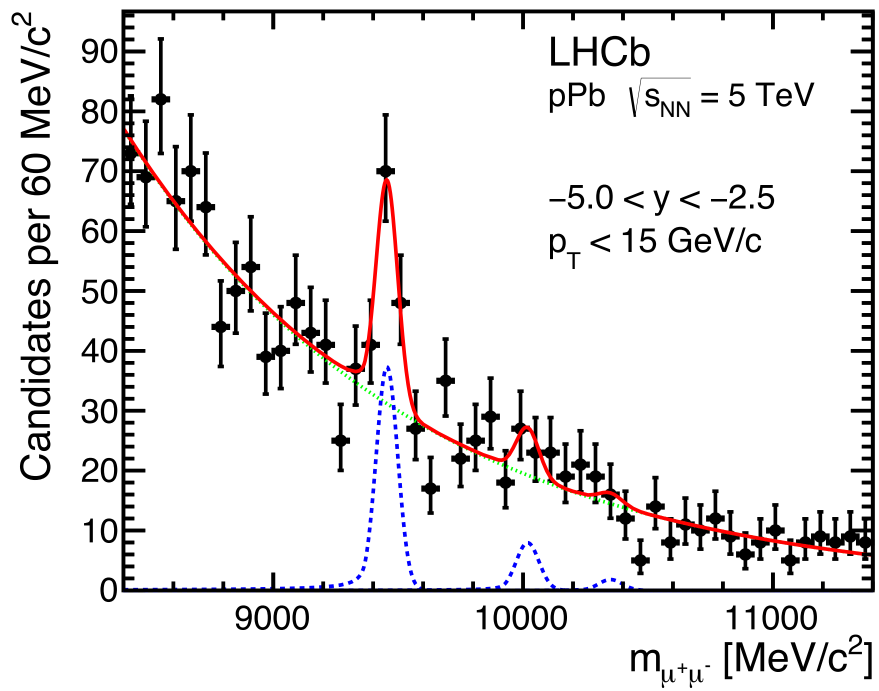
- ϒ states in the dimuon decay channel
- Forward: $1.5 < y_{CMS} < 4.0$, backward: $-5.0 < y_{CMS} < -2.5$; $p_T < 15$ GeV/c

→ Limited statistics do not permit to do a differential measurement

Forward production



Backward production

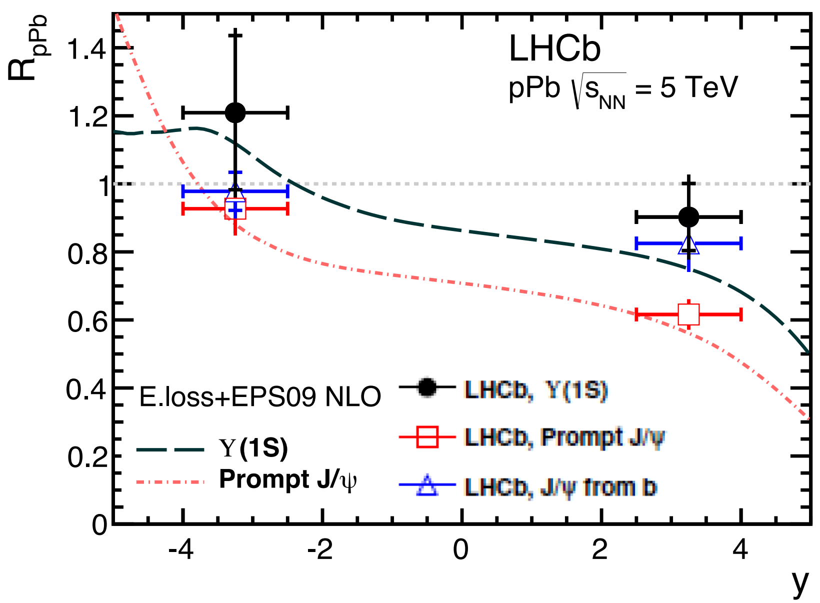


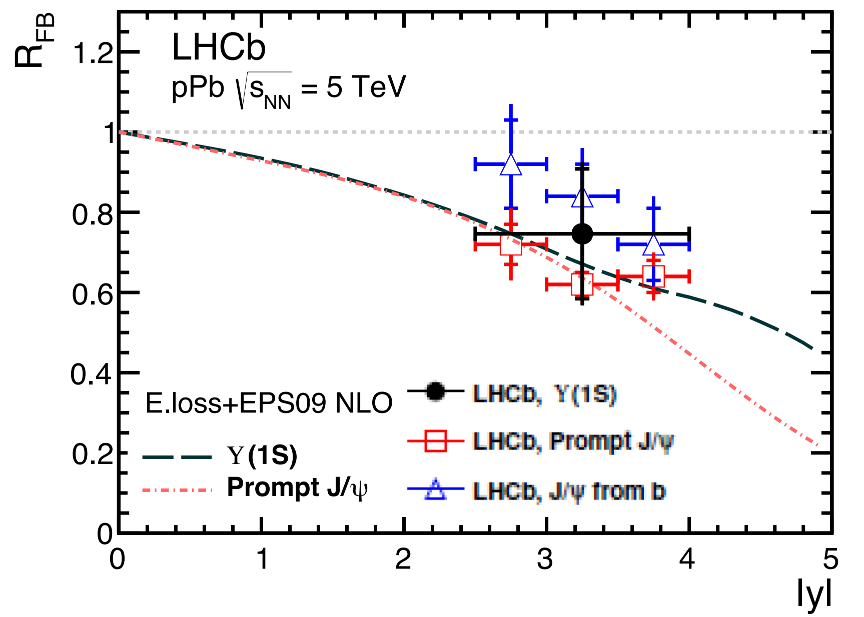
$\Upsilon(1S)$ R_{pA} and R_{FB}

JHEP 07 (2014) 094

- In common rapidity range $2.5 < |y_{CMS}| < 4.0$
- Measurement of $\Upsilon(1S)$ R_{pPb} and R_{FB} is complementary to the one of J/ψ

➡ Probing different x





$\Upsilon(1S)$ is also sensitive to CNM effects

R_{pPb} versus rapidity:

Suppression in forward region is smaller than for J/ψ

Central value in forward region close to that of J/ψ from b → CNM effects on b hadrons

Indication of enhancement in the backward region → could be attributed to anti-shadowing

R_{FB} versus rapidity:

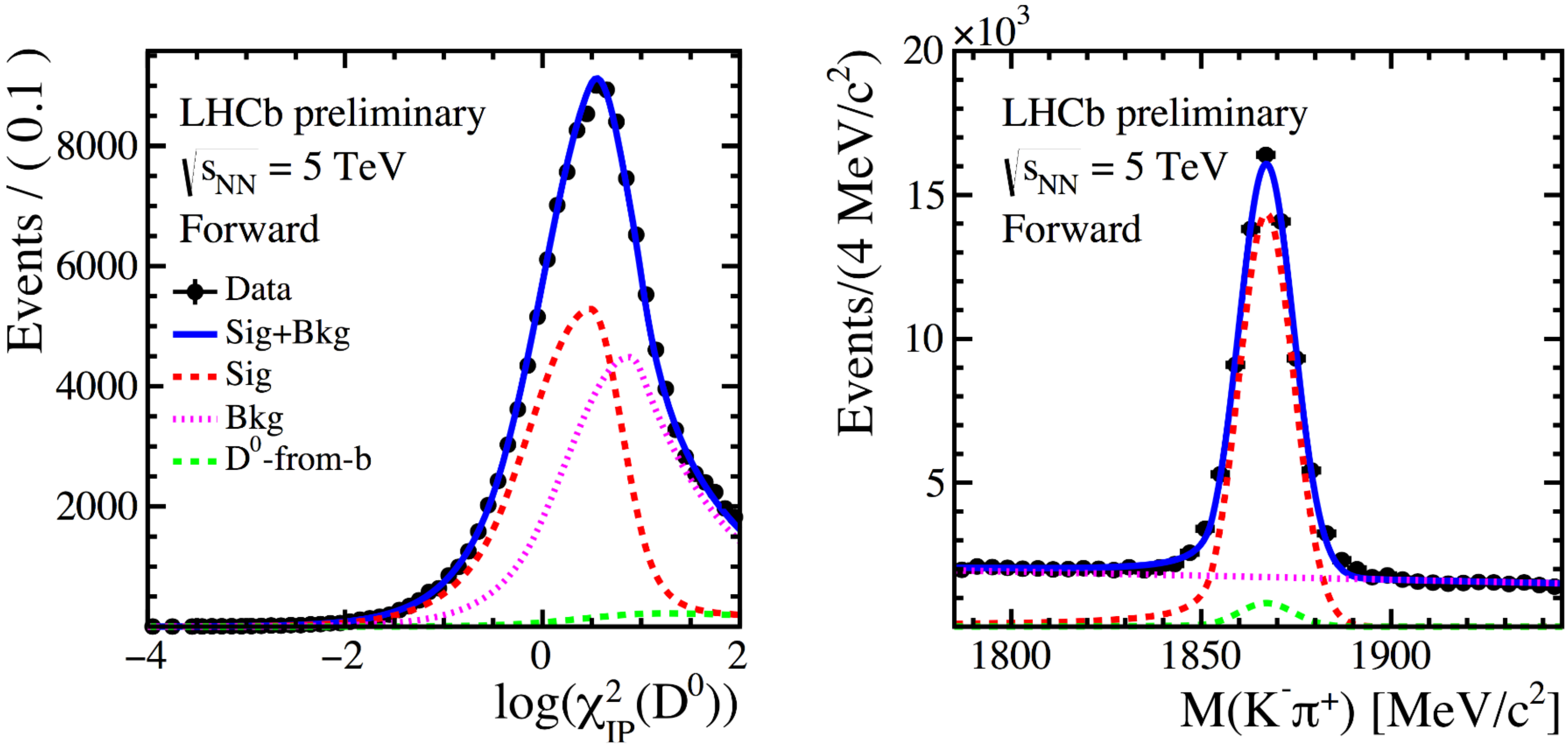
Ratio in agreement with predictions of E. loss + shadowing (EPSO9 NLO)

Prompt D^0 production in p-Pb/Pb-p

LHCB-CONF-2016-003-001

- D^0 reconstructed in $D^0 \to K^- \pi^+$ decay channel
- Lint = 0.11 nb^{-1} (forward), Lint = 0.05 nb^{-1} (backward)
- Prompt D^0 yields obtained from 2D fit of D^0 invariant mass and χ^2 of Impact Parameter

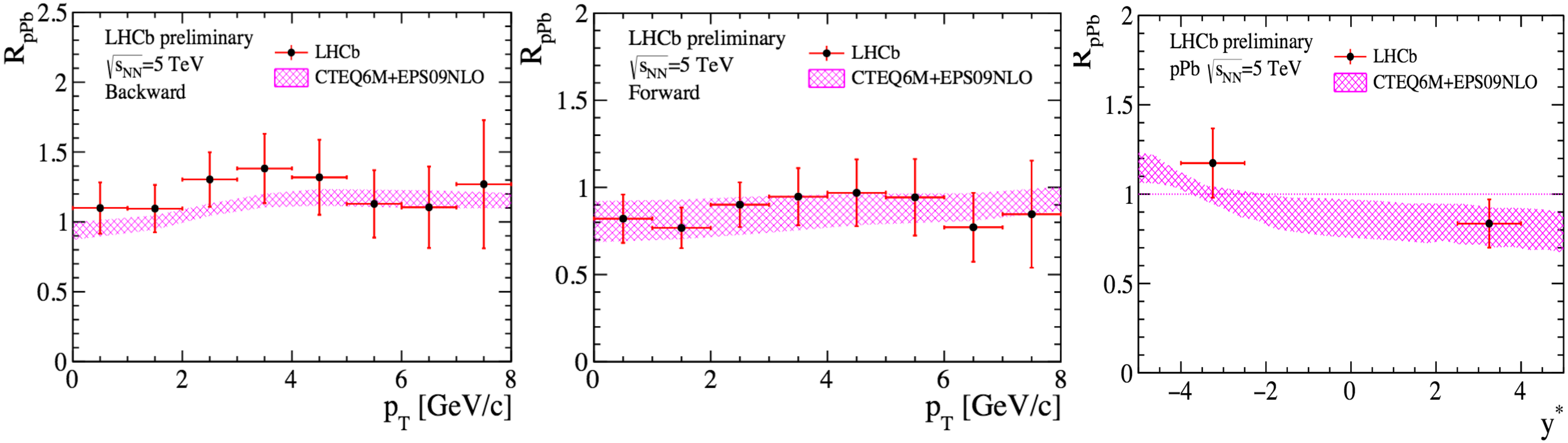
→ LHCb unique to measure prompt D^0 down to zero p_T in the forward region



Prompt D^0 R_{pPb}

LHCB-CONF-2016-003-001

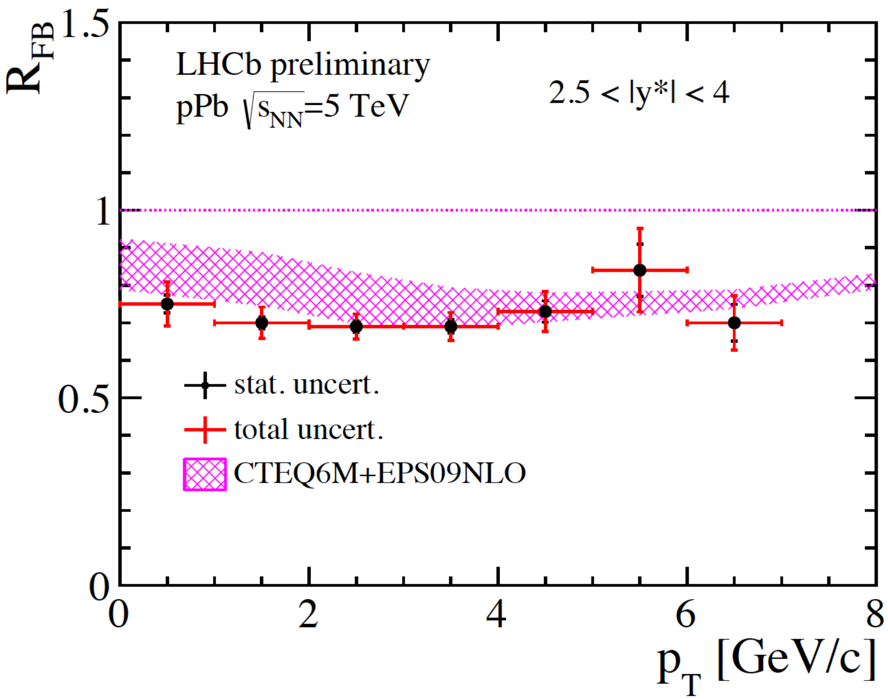
- ❑ D^0 pp reference cross section at √s = 5 TeV obtained from extrapolation of LHCb measurements at √s = 7 TeV and √s = 13 TeV

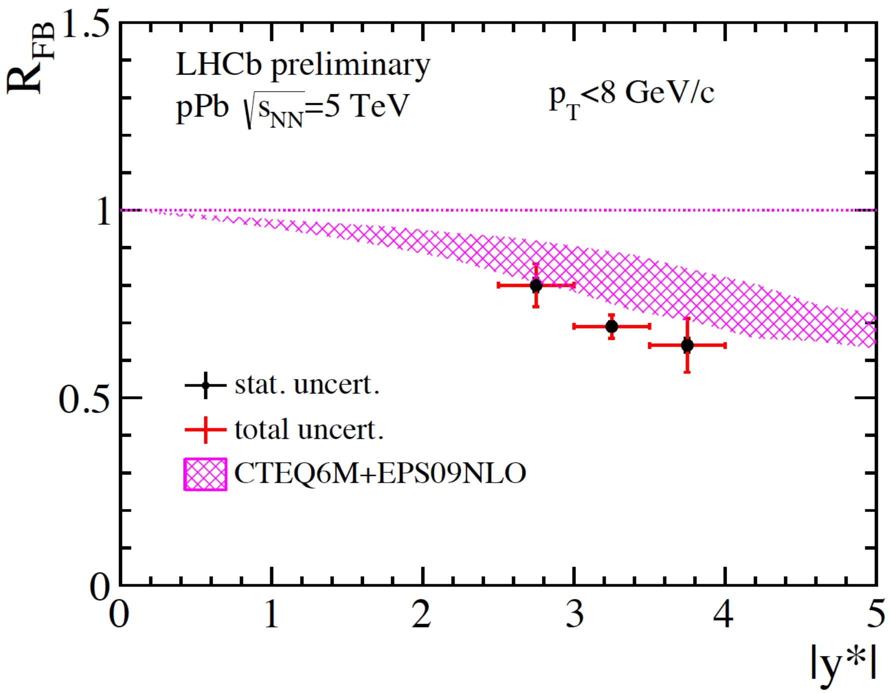


- ❑ No strong p_T dependence of the D^0 R_{pPb} at forward and backward rapidities
- ❑ Nuclear modification factor smaller at forward rapidity
- ❑ Measurement consistent with theoretical predictions from NLO MNR with CTEQ6M + EPS09NLO → Nucl. Phys. B.373 (1992) 295, JHEP 10 (2003) 046, JHEP 04 (2009) 065

Prompt D^0 R_{FB}

- D⁰ forward to backward ratio
- Cancellation of pp reference cross section and of part of the uncertainties





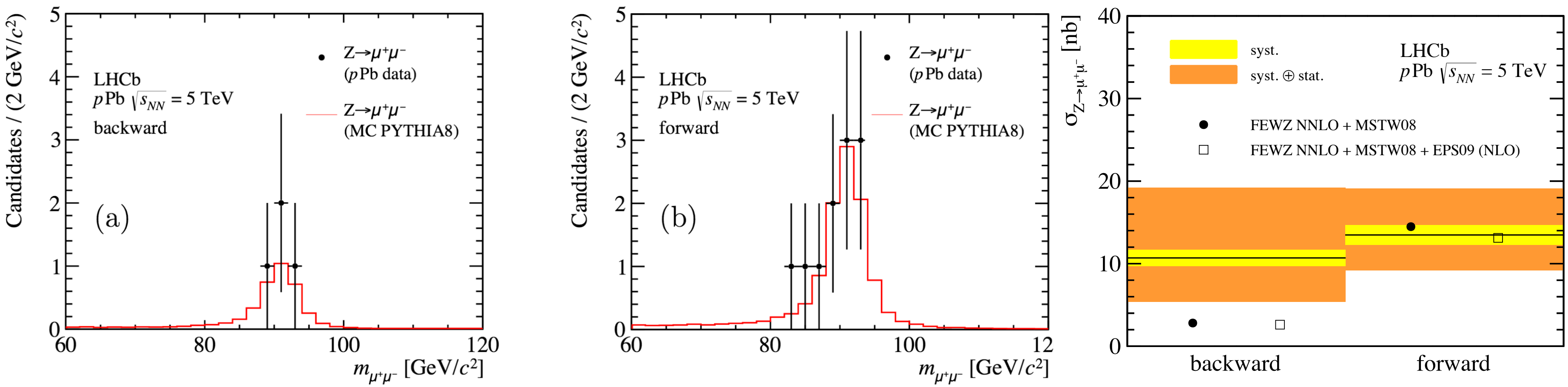
- Clear forward-backward asymmetry → CNM effect
- No strong p_T dependence of the R_{FB}
- Asymmetry more important at larger rapidity
- Measurement consistent with theoretical predictions from NLO MNR with CTEQ6M + EPS09NLO → Nucl. Phys. B.373 (1992) 295, JHEP 10 (2003) 046, JHEP 04 (2009) 065

Z production in p-Pb and Pb-p

JHEP 09 (2014) 030

Muon selection: p_T > 20 GeV/c, 2.0 < η_μ < 4.5, 60 < $M(\mu^+\mu^-)$ < 120 GeV/c^2
Backgrounds: very small, purity > 99% determined from data

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

R_{FB} calculated in the common rapidity range is lower than expectations

→ deviation of 2.2σ from R_{FB} = 1

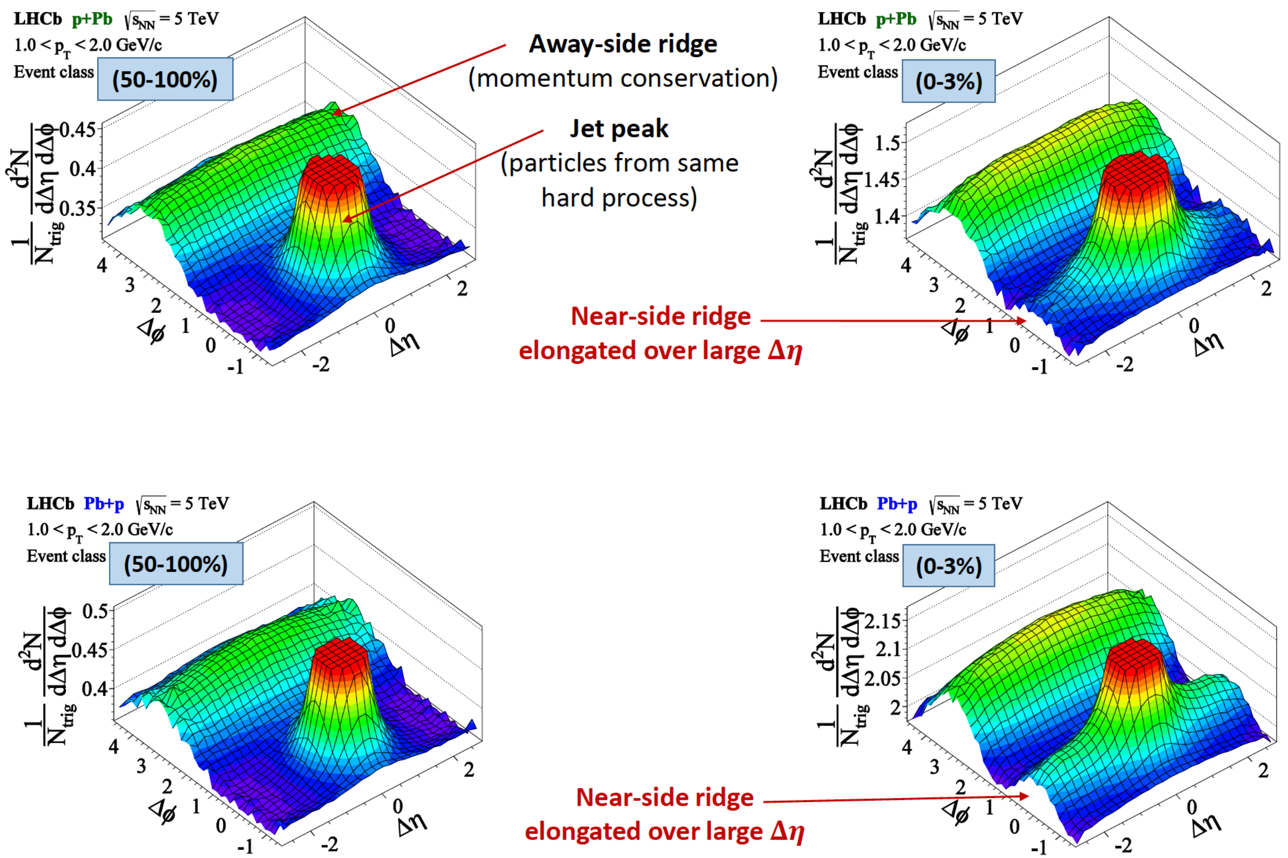
Statistical precision of measured cross sections prevents strong constrain on nPDF

Looking forward to take more data during run II

Two-particle angular correlations in p-Pb/Pb-p

arXiv:1512.00439

- Both beam configurations analyzed separately: L_{int} = 0.46nb^{-1} (p+Pb), L_{int} = 0.30nb^{-1} (Pb-p)
- Rapidity range 1.5 < y_{CMS} < 4.4 (forward), -5.4 < y < -2.5 (backward)
- Correlation function → per-trigger particle associated yield: $\frac{1}{N_{trig}}\frac{d^2N_{pair}}{d\Delta\eta d\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)} \times B(0,0)$
- Event activity classes: fraction of the full distribution of Hits in the VELO (in MB triggered events)



p-Pb configuration
Δϕ=0 near-side ridge clearly visible **in high event activity class** (however not very pronounced)

Pb-p configuration
Δϕ=0 very pronounced near-side ridge in Pb-p in **high activity event class**

Two-particle angular correlations in p-Pb/Pb-p

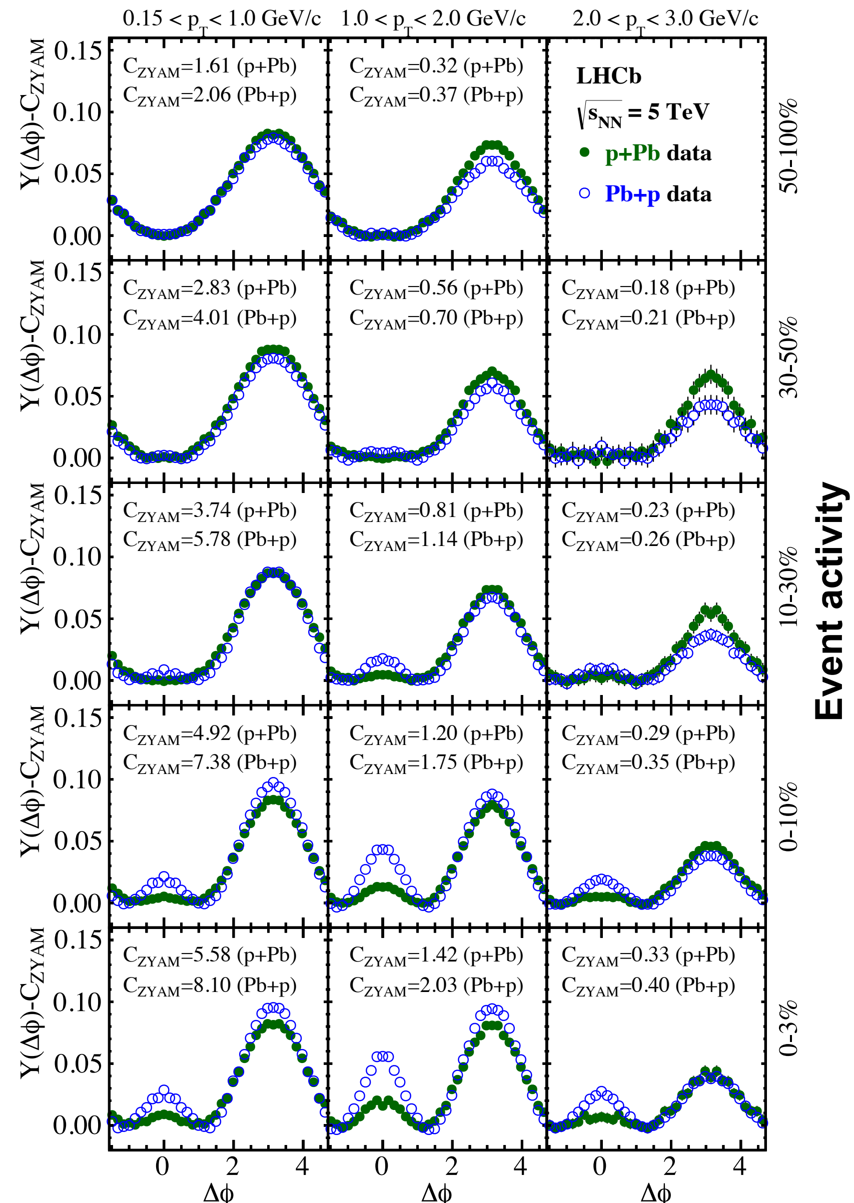
arXiv:1512.00439

- To study the evolution of the long-range correlations on the near and away sides in more details, one-dimensional projections of the correlation function on $\Delta\phi$ are calculated:

$$Y(\Delta\phi) \equiv \frac{1}{N_{trig}} \frac{dN_{pair}}{d\Delta\phi} = \frac{1}{\Delta\eta_b - \Delta\eta_a} \int_{\Delta\eta_a}^{\Delta\eta_b} \frac{1}{N_{trig}} \frac{d^2N_{pair}}{d\Delta\eta d\Delta\phi} d\Delta\eta$$

- 2D-yield averaged in the range $2.0 < \eta < 2.9$ to exclude short range correlations (jet peak)

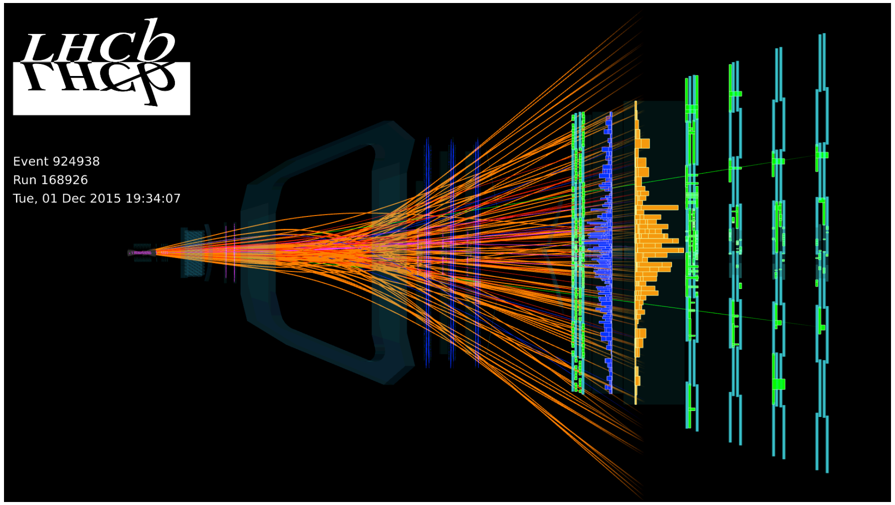
- Subtraction of the zero yield at minimum (ZYAM)

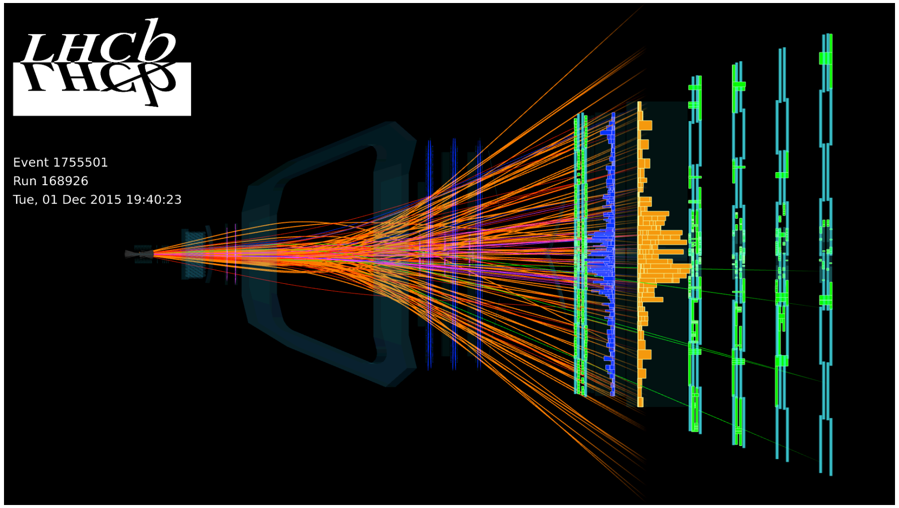


Correlation yield increases with event activity
Away-side ridge decreases towards higher p_T
On the near side the ridge emerges (from 10-30% event activity class in Pb-p, from 0-10% event activity class in p-Pb) with a maximum in $1 < p_T < 2$ GeV/c
Near-side ridge is more pronounce in Pb-p than in p-Pb

Heavy ion studies in collider mode

Pb-Pb data taking





Pb-Pb data event displays (dec 2015)

First LHCb Pb-Pb data taking (2015)

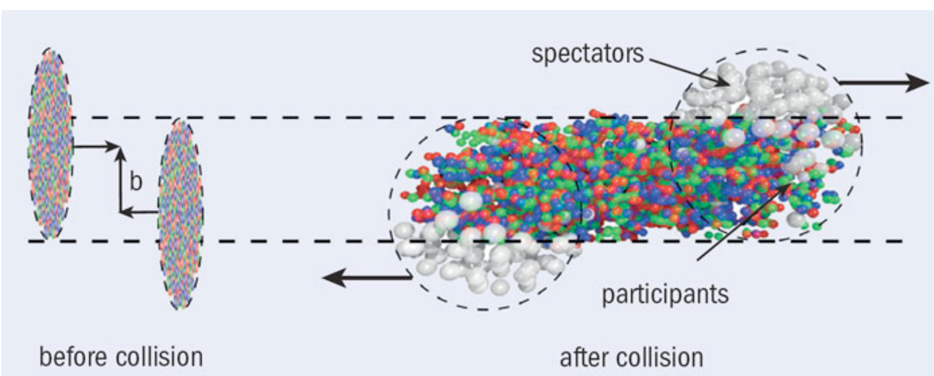
NEW

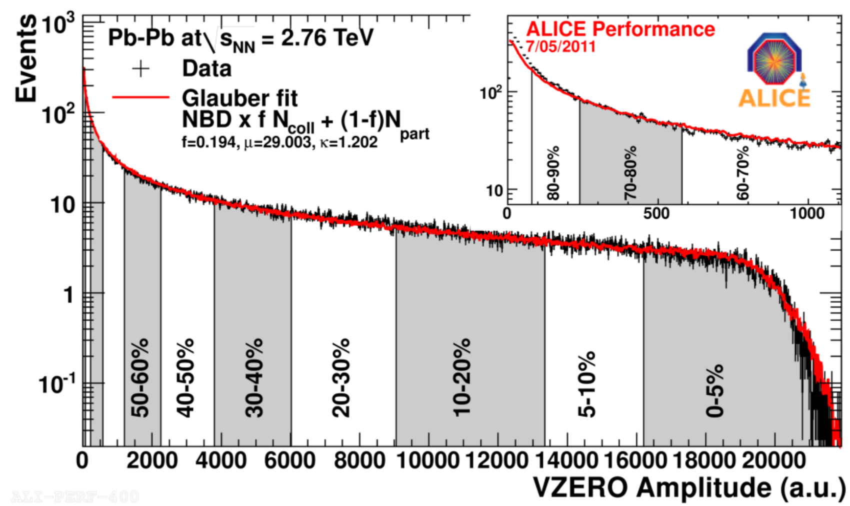
- 24 colliding bunches in LHCb
- Pb-Pb data taken **without any global event cut**
  - → **Important for future determination of the collision centrality**
  - →Track reconstruction performed for events with number of clusters in the Velo up to 15000 (max number of clusters in the Velo ~ 45000)

Centrality is an important quantity in heavy ion collisions

→ Related to the initial overlap region of the colliding nuclei
→ Collision geometry determines the number of nucleons that participate in the collision

Many quantities scale with N_{part}: particle multiplicity, transverse energy





Phys. Rev. C. 88 (2013) 044909

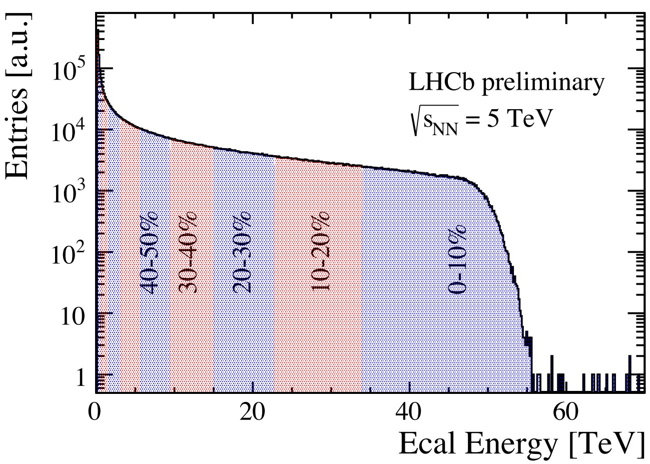
First look at centrality determination in LHCb

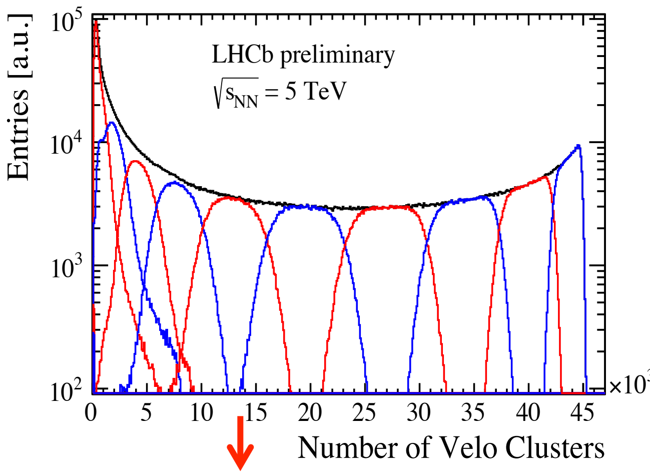
NEW

- ❑ Use quantity which doesn't saturate for centrality measurement
- ❑ Use Minimum Bias triggered events

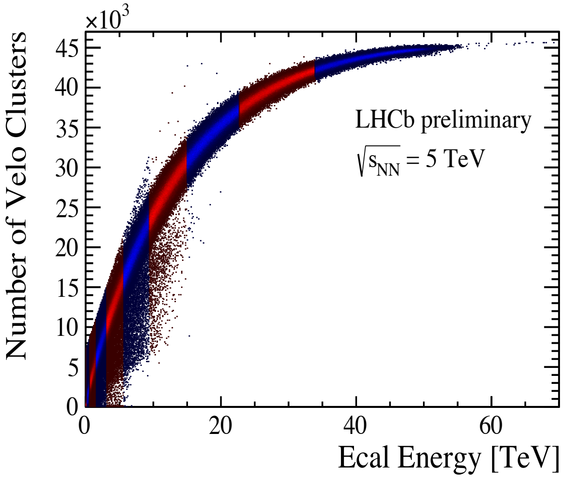
➡ Energy deposition in the electromagnetic (Ecal) / hadronic (Hcal) calorimeters could be a good centrality estimator

Definition of Ecal Event activity classes as a first step towards centrality determination
Events with up to 15000 clusters in Velo → ~ **50-60% Ecal event activity class**





50-60%



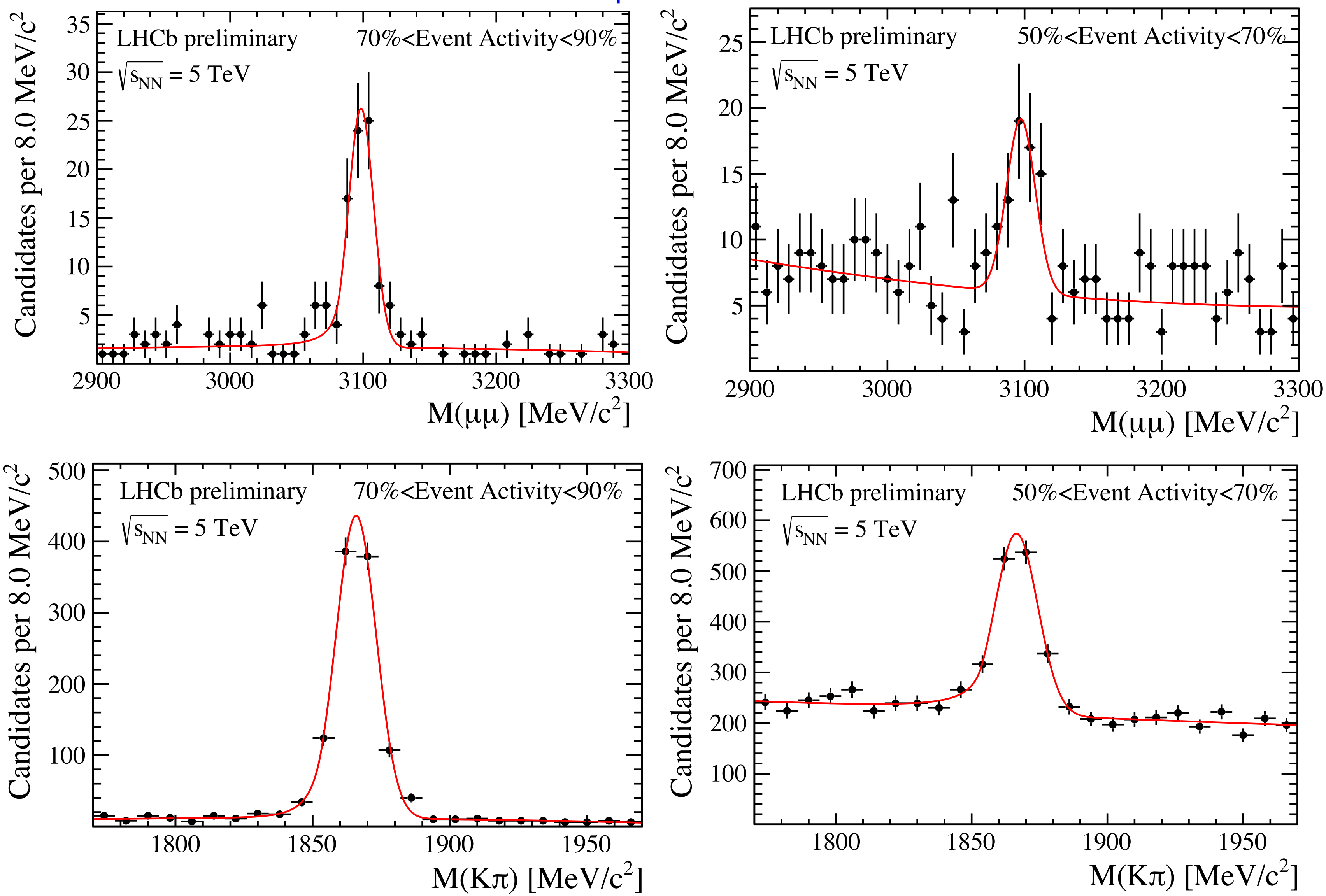
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

First signals in Pb-Pb data taking (2015)

NEW

J/ψ and D^0 signals in bins of Ecal event activity (full statistics)

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

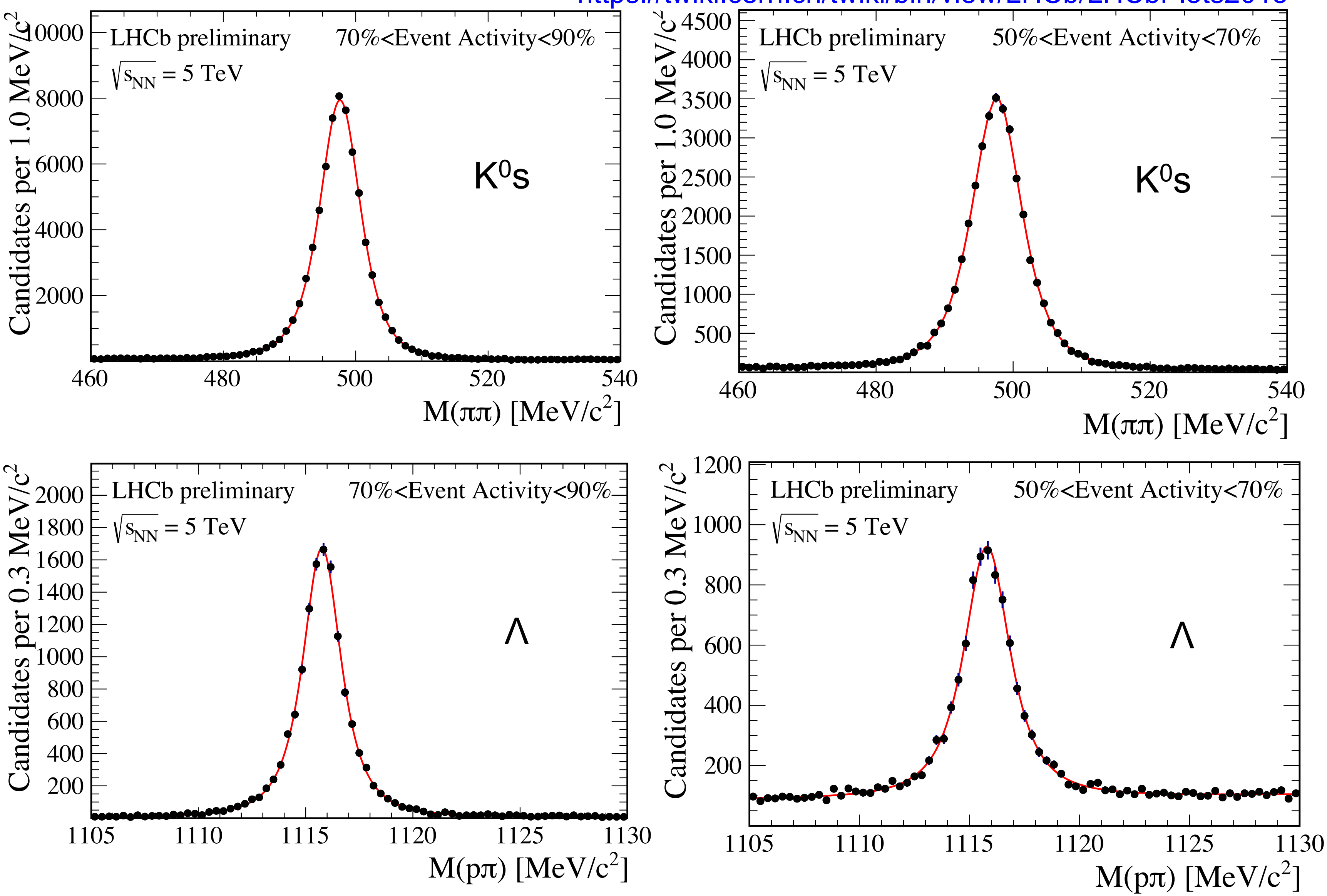


First signals in Pb-Pb data taking (2015)

NEW

K^0s and Λ signals in bins of Ecal event activity (one run)

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

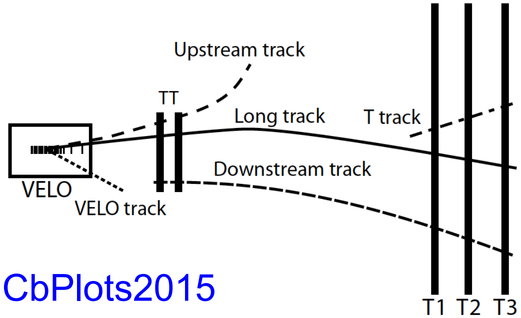


First signals in Pb-Pb data taking (2015)

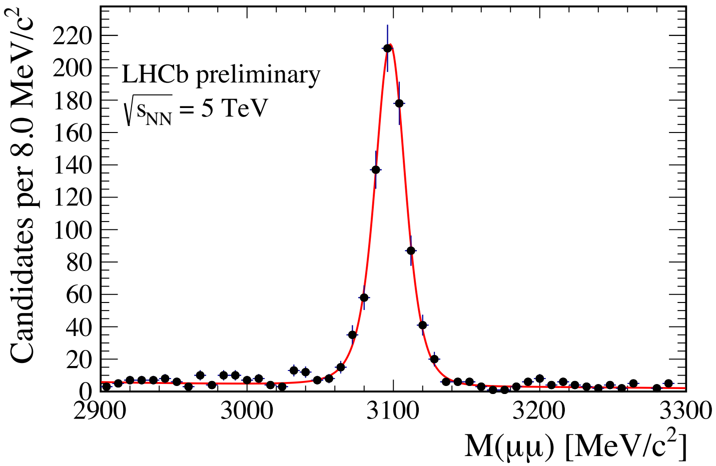
NEW

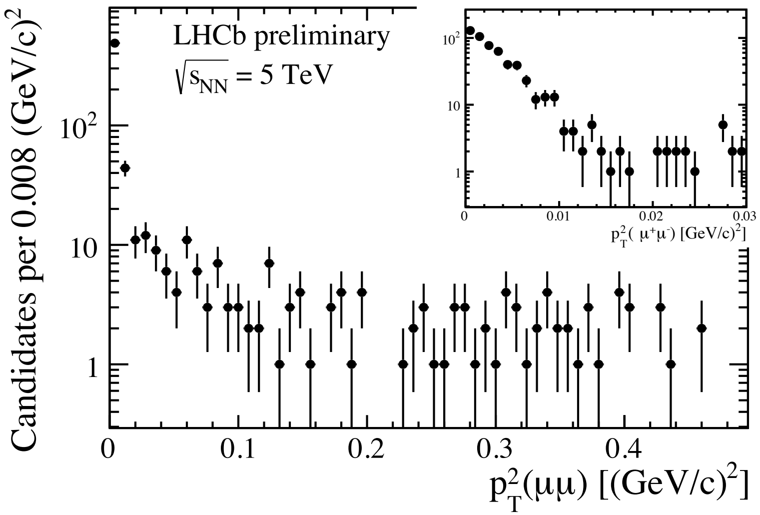
Coherent photoproduction of J/ψ in Pb-Pb UPC

- ✓ Events containing only 2 Long Tracks and only 2 VELO track
- ✓ Number of hits in SPD < 20
- ✓ No Upstream, Downstream and T tracks

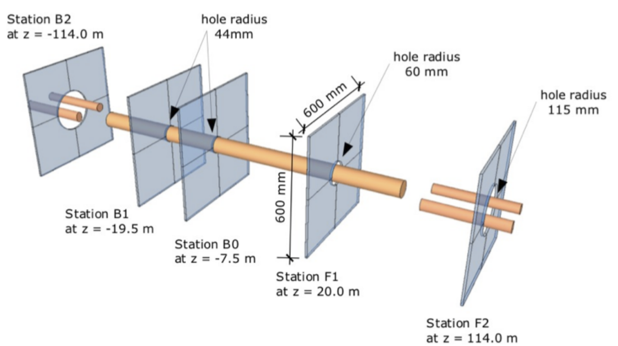


https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015





- ❑ Studies will benefit from new Herschel detector installed in LHCb:
  - High rapidity detector 5 < |η| < 9
  - Possibility to define much larger rapidity gaps
  - Was running from 2015



Conclusions

- **LHCb is in a unique position to do fixed target physics**
  - Exploit the SMOG system with different noble gases (p-Ne, p-He, p-Ar, Pb-Ne, Pb-Ar)
  - Bridge the gap from SPS to LHC physics with a single experiment

- **LHCb succesfully participated in the proton-Pb data taking in 2013**
  - Measurement of J/ψ, ψ(2S), ϒ and prompt D^0 production
    → Cold nuclear matter effects visible on J/ψ, ψ(2S) and ϒ(1S) and prompt D^0 production
  - First observation of forward Z production in proton-nucleus collisions
    → Analysis will benefit from larger statistics data sample in Run II
  - Two-particle angular correlations
    → Near side ridge also observed in the forward region

- **LHCb detector has also collect PbPb data for the first time at the end of 2015**
  - Rich program in heavy flavour physics, EW, (soft) QCD and QGP studied foreseen
  - Results soon to come!

LHCb is a truly general purpose detector in the forward region

& Prospects (2016 run)

- **LHCb will participate in the 2016 pPb data taking ($\sqrt{s_{NN}}$ = 5 and 8.2 TeV)**
  → See next slides

Prospects for 2016 pPb run

- Plan to do fixed target studies during the pPb at $\sqrt{s_{NN}}$ = 5 TeV
  → Only modest increase of the pPb statistics expected wrt 2013

- Asked **L_{int} = 20 nb^{-1}** with equal sharing between pPb/Pbp configurations at $\sqrt{s_{NN}}$ = 8 TeV

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

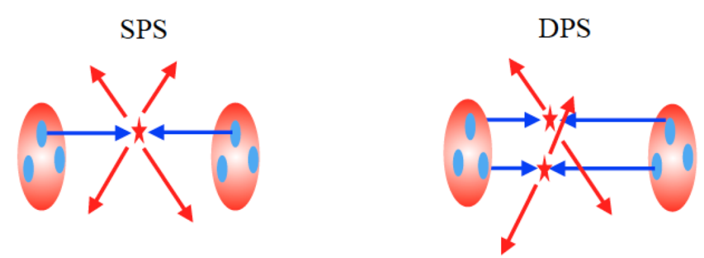
- ❑ Same precision achieved on R_{FB} measurement for ψ(2S) as for J/ψ
- ❑ Improvement in precision for prompt ψ(2S) and from-b ψ(2S) R_{pPb} measurements → better understanding of CNM effects
- ❑ Measurement of nuclear modification factor of all upsilon states (including ϒ(3S))
- ❑ Improvement in precision on Z production measurement → constrains on nPDF
- ❑ Associated heavy flavour production in pA to study Single Parton Scattering and Double Parton Scattering
- ❑ J/ψ over Drell-Yan R_{pPb} ratio to distinguish between shadowing and E. loss models

Highlights: Associated Heavy flavour production

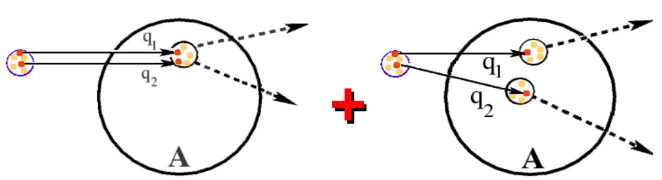
- New and original analyses in pPb to improve understanding of heavy flavour and quarkonia production mechanisms

- Associated heavy flavour production measured by LHCb in pp collisions (D-D *JHEP 06 (2012) 141*, J/ψ-D *JHEP06 (2012) 141*, J/ψ-J/ψ *PLB707(2012) 52*) but never performed in larger systems (pA or AA)

- Associated heavy flavour produced either by Single Parton Scattering (SPS) or Double Parton Scattering (DPS)



- In pPb collisions
  - SPS is enhanced by a factor A = 208 with respect to pp
  - DPS is enhanced by a factor ~ 600 with respect to pp (geometric factor)
    D. D'enterria et al, Nucl. Phys. A 932 (2014) 296
  - Comparison pPb/pp gives information on the relative contribution of SPS and DPS to associated HF production



- Projections with 20 nb^{-1} → **~100 events of associated J/ψ-D^0 production** (assuming no nuclear effects)

Highlights: J/ψ over Drell-Yan measurement

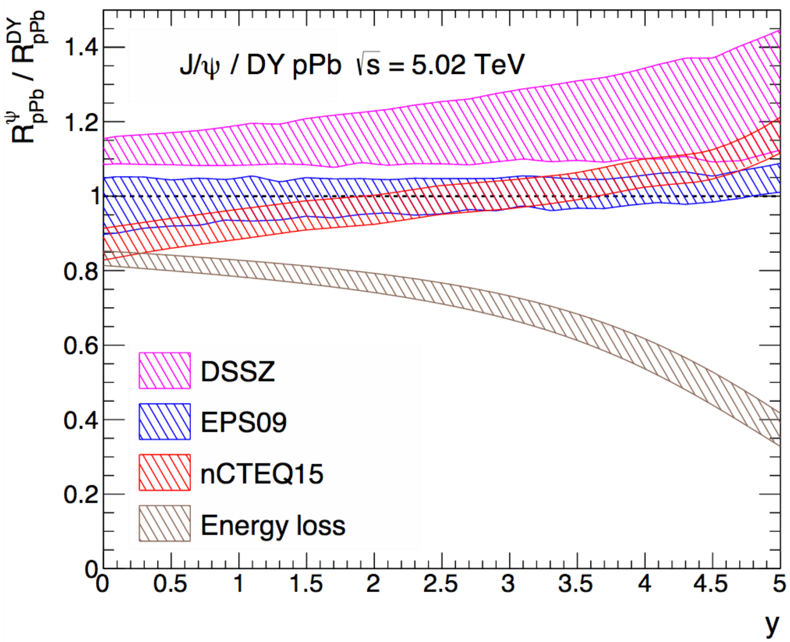


Figure 3: Double ratio $\mathcal{R}^{\psi/\mathrm{DY}}_{\mathrm{pPb}}$ in p–Pb collisions at $\sqrt{s}$ = 5.02 TeV for the various nPDF sets and in the coherent energy loss model.

F. Arléo and S. Peigné, arXiv:1512.01794

- **Up to now, quarkonium production data are not precise enough to be able to distinguish between various CNM models (shadowing / E. loss)**
- Double ratio $R^{J/\Psi}_{pPb} / R^{DY}_{pPb}$ has been proposed as a powerful measurement to disentangle between shadowing and eloss models
- LHCb acceptance is ideal for this measurement
- Velo detector capabilities permit to decrease significantly the background coming from $b\bar{b}$ production
- Many systematic effects cancel in the ratio → higher precision
- Projections with 20 nb^{-1}
  → 1000 Drell-Yan candidates

THANKS FOR YOUR ATTENTION!

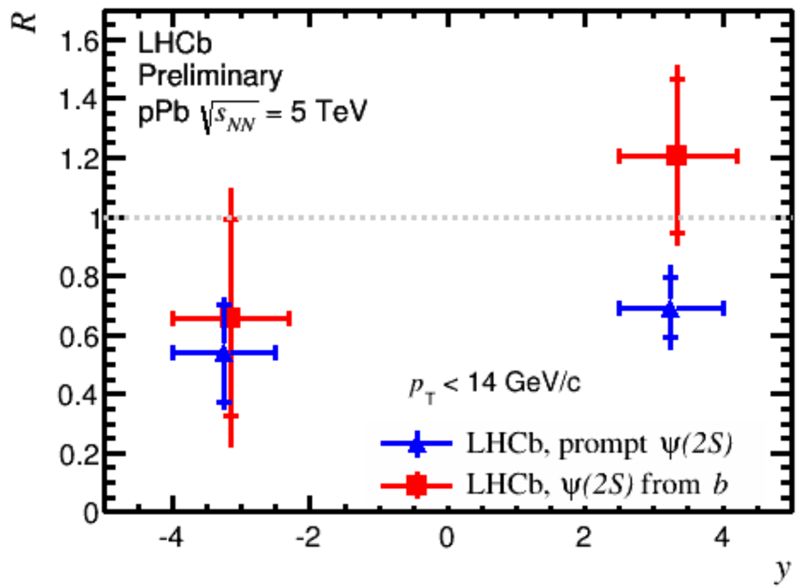
Back up

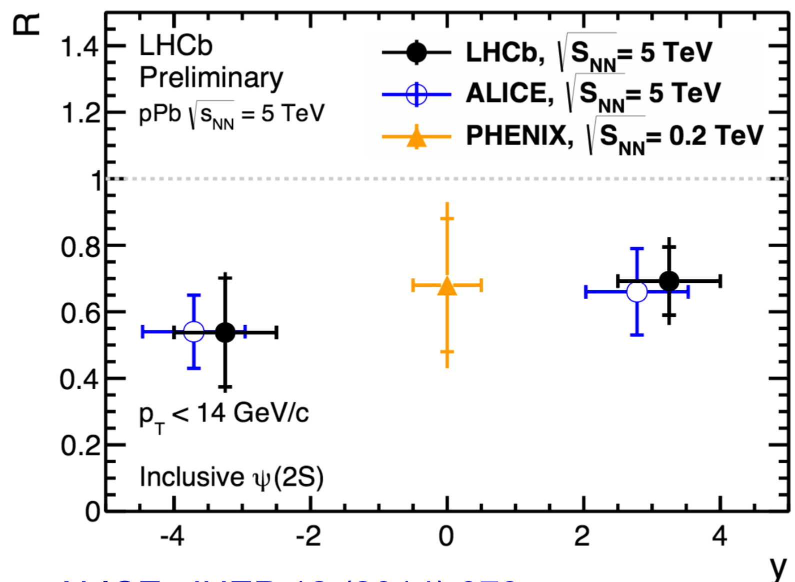
Ψ(2S) relative suppression wrt J/ψ

LHCb-CONF-2015-005

- Relative suppression is calculated as:

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





ALICE: JHEP 12 (2014) 073
PHENIX: Phys. Rev. Lett. 111 (2013), no. 20 (202301)

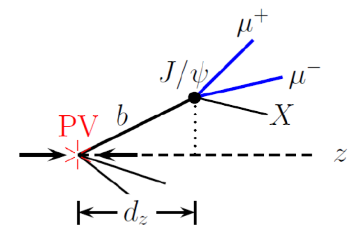
Intriguing stronger suppression of prompt ψ(2S) than that of prompt J/ψ
Similar suppression for ψ(2S) from b and J/ψ from b
→ R compatible with 1 within large uncertainties
Results for inclusive ψ(2S) compatible with ALICE measurement

J/ψ production in p-Pb and Pb-p

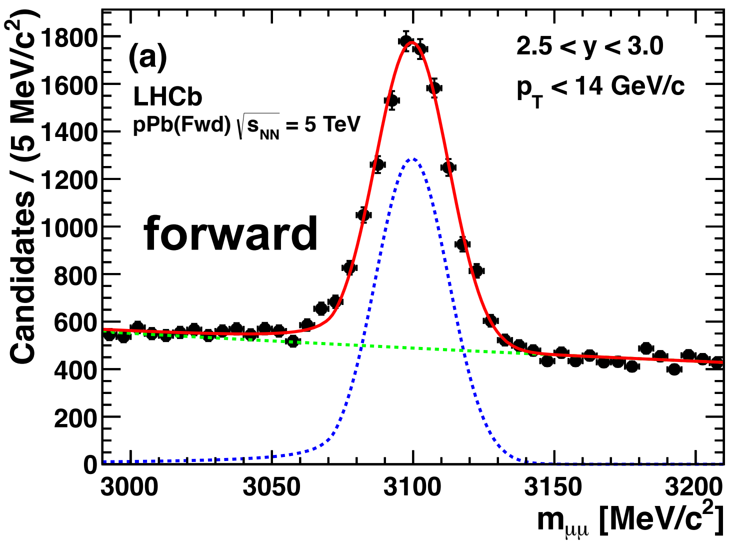
JHEP 02 (2014) 072

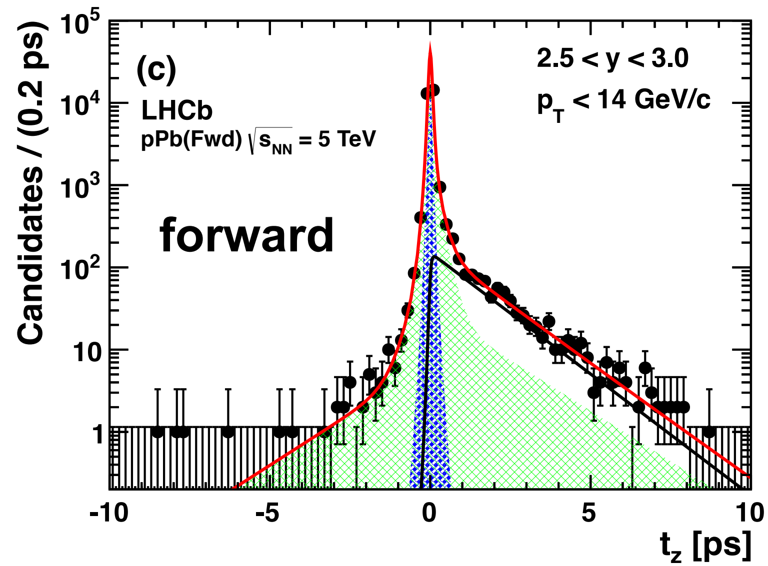
- J/ψ are reconstructed from two well identified muons
- Disentangle prompt J/ψ and J/ψ from b using pseudo-proper time:

$$t_Z = \frac{(Z_{J/\Psi} - Z_{PV}) \times M_{J/\Psi}}{p_z}$$



- Yields of prompt J/ψ and J/ψ from b extracted from simultaneous fit of mass and pseudo-proper time





Mass distribution:

- Signal: Crystal-Ball function
- Background: Exponential

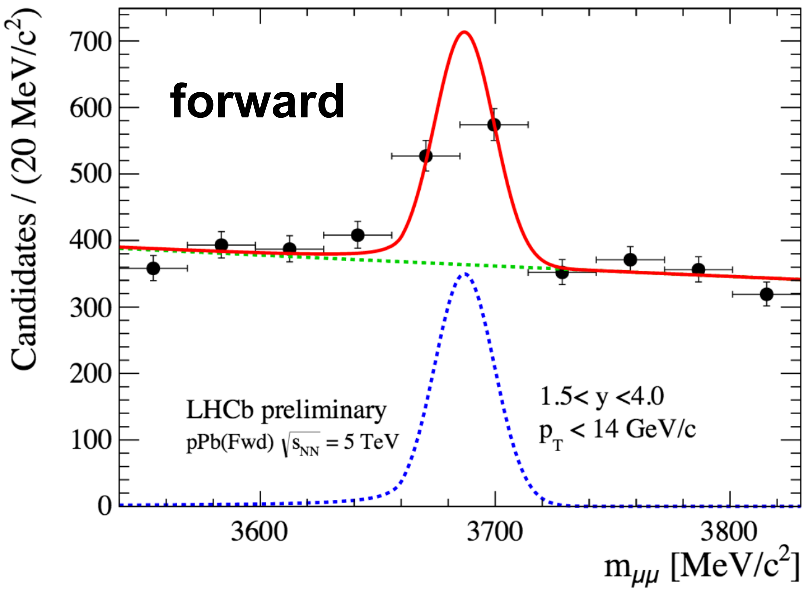
t_Z distribution:

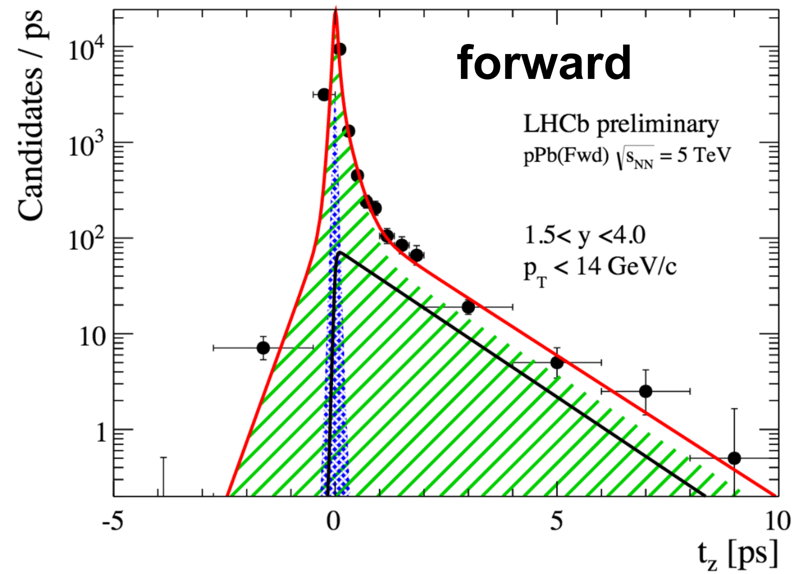
- Signal: - $\delta(t_z)$ for prompts J/ψ (blue curve)
  - Exponential for J/ψ from b (black line)
- Background: Empirical function from sideband (green hatched)

Ψ(2S) production in p-Pb and Pb-p

LHCb-CONF-2015-005

- Similar analysis strategy as for the J/ψ
- Yields of prompt ψ(2S) and ψ(2S) from b extracted from simultaneous fit of mass and pseudo-proper time





Mass distribution:
- Signal: Crystal-Ball function
- Background: Exponential

t_z distribution:
- Signal: - $\delta(t_z)$ for prompts ψ(2S) (blue curve)
  - Exponential for ψ(2S) from b (black line)
- Background: Empirical function from sideband (green hatched)