Heavy ion physics with LHCb: an overview

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Etretat, France

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

cnrs dépasser les frontières

P2IO Physique des 2 Infinis et des Origines

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Outline

- **The LHCb detector**
- **LHCb running modes**
- **LHCb phase space coverage**
- **Physics motivations**
- **Heavy ion studies in fixed target mode**
- **Heavy ion studies in collider mode**
  - Results from the pPb and Pbp data taking
  - Prospects for PbPb data taking
- **Conclusions**

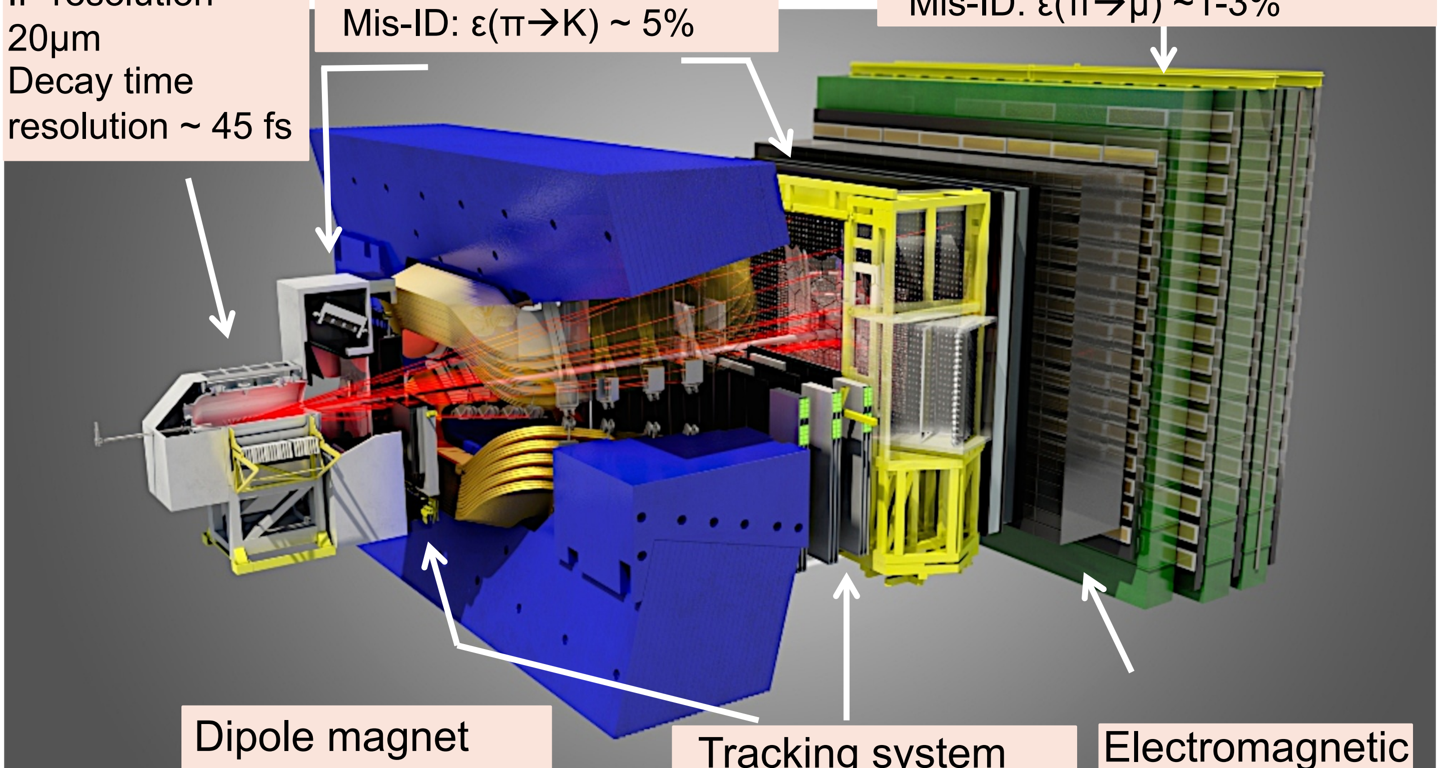
The LHCb detector

- ❑ Single arm spectrometer in the forward region
- ❑ Fully instrumented in its angular acceptance
- ❑ Pseudorapidity coverage $2 < \eta < 5$
- ❑ Designed initially for b-physics but general purpose detector (fixed target collisions, heavy ion physics program…)

Vertex detector
IP resolution ~ 20μm
Decay time resolution ~ 45 fs

RHIC: K/π/p separation
ε(K→K) ~ 95%
Mis-ID: ε(π→K) ~ 5%

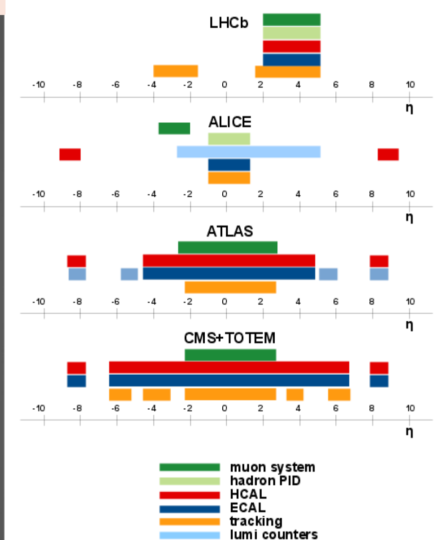
Muon system
μ identification: ε(μ→μ) ~ 97%
Mis-ID: ε(π→μ) ~1-3%



Dipole magnet
Bending power 4 Tm

Tracking system
Δp/p = 0.4% - 0.8%
(5 GeV/c – 100 GeV/c)

Electromagnetic + hadronic calorimeters



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

LHCb running modes

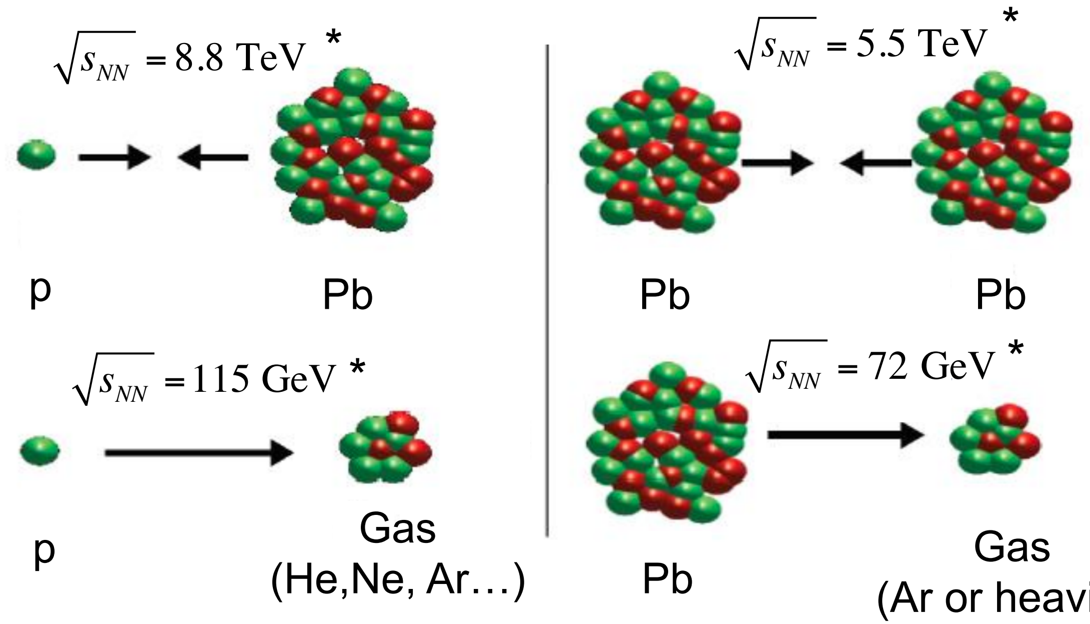
- LHCb can make valuable contributions to the study of pA and AB collisions in the forward region with a **precision not accessible by other experiments**

  → Excellent vertex reconstruction (~20μm), mass resolution (~15 MeV/c²) and PID

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

Collider mode

Fixed target mode

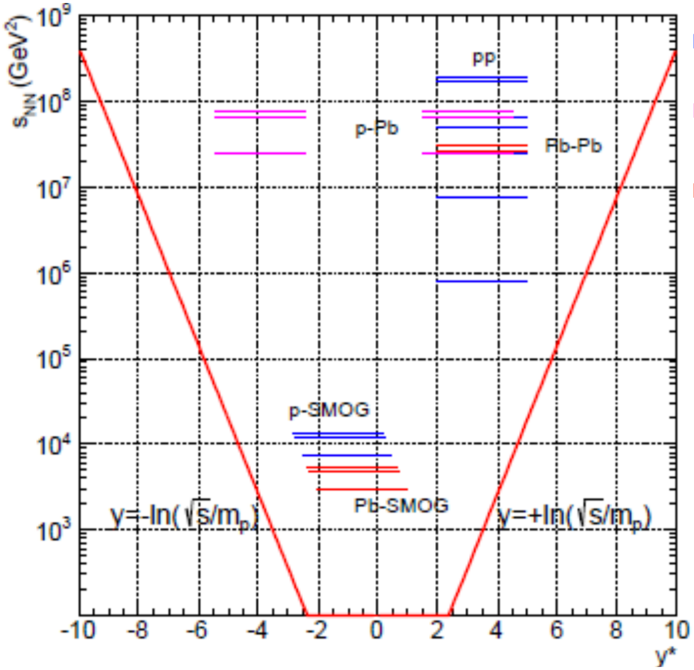


CNM studies (among others) **QGP studies (among others)**

*Highest nucleon-nucleon center of mass energy achievable

LHCb phase space coverage

- Kinematic acceptance and possible beam target configurations



pp and p-Gas

pPb and Pbp

PbPb and Pb-Gas

y*: rapidity in the nucleon-nucleon center-of-mass, with forward direction (positive value) in the direction of the proton beam

Collider mode: forward and backward region covered

Fixed target mode: acceptance is central to backward
Energy density achieved which are between SPS and RHIC ones

Bridge the gap from SPS to LHC with a single experiment

Ebeam (p)	pp	p-Gas	pPb/Pbp	Pb-Gas	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	5.1 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

Already collected

To be collected by the end of 2015

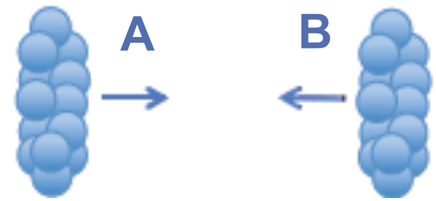
Preferred target Gas

	He	Ne	Ar	Kr	Xe
A	4	20	40	84	131

Heavy quark studies in Nucleus-Nucleus collisions

→ See F. Fleuret talk for more details about open heavy flavour and quarkonium studies in fixed target mode

- ❑ Probe Quark gluon plasma formation
- ❑ Study the phase transition
- ❑ Test lattice QCD calculations



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

→ Quarkonia (J/ψ ,ψ', χ_c) are produced at the early stages of heavy ion collisions
→ They travel trought the medium and can be suppressed by color screening
→ Provide measurement of QGP temperature through sequential melting of states

→ Open charm to study heavy quark energy loss in the QGP/ also a reference for quarkonia studies

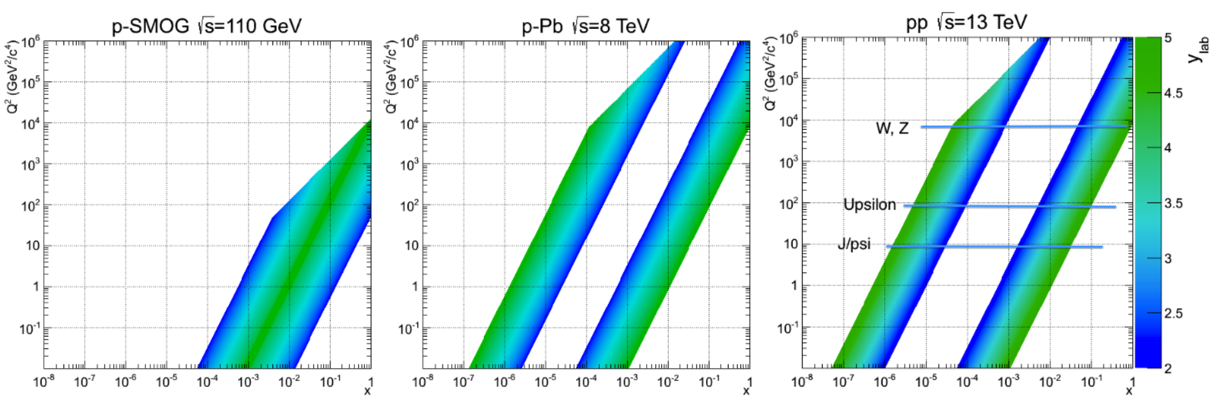
LHCb is the only experiment capable to measure together open and hidden charm production in the forward region in heavy ion collisions
(at low and high center of mass energy)
Offers the possibility to measure all quarkonia states in heavy ion collisions (including χ_c !)
LHCb can measure separately prompt J/ψ, ψ(2S) from J/ψ, ψ(2S) from b

Soft QCD and electroweak measurements

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

- ❑ The possibility to perform measurements at different √s and in different setups will allow to investigate:

→ Nucleon structure of free versus bound nucleons
- PDFs can be probed via quarkonia, electroweak bosons, Drell Yan measurements
- Access to very small x (colliding mode) and very large x (fixed target mode)



→ Dynamic of hadronization process
- Measurement of toal cross sections, energy flow measurement, particle multiplicities, Bose-Einstein or Fermi-Dirac correlations….

→ Diffractive scattering: accessible with new HERSHEL detector

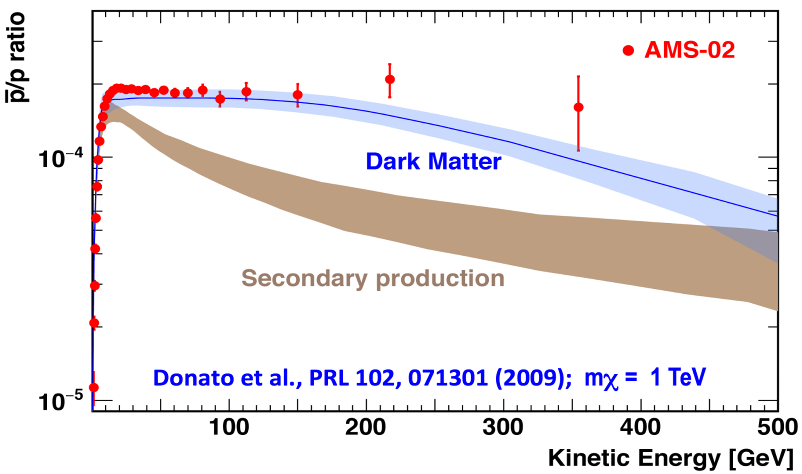
→ Cosmic ray physics (see next slide)

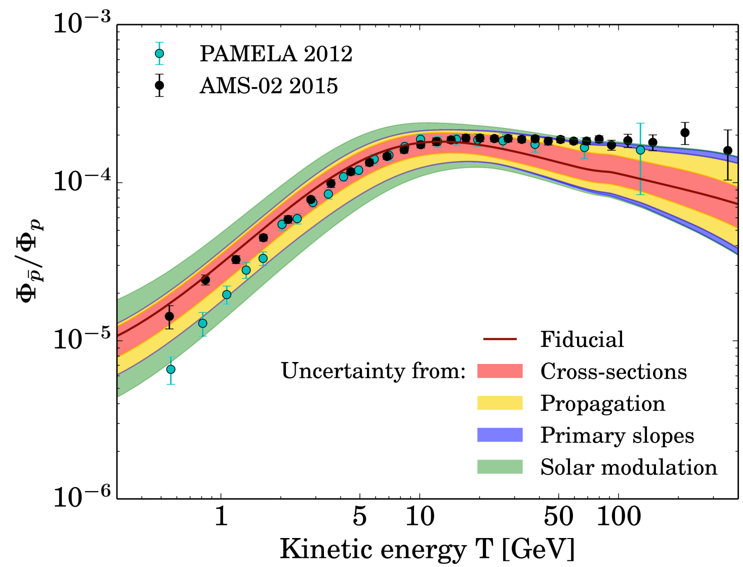
→ QED at extreme conditions and central exclusive production
- Ultraperipheral Collisions: measurement of exclusive ρ^0 production, exclusive J/ψ…

Cosmic rays physics and p-Gas (He) data

- 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

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

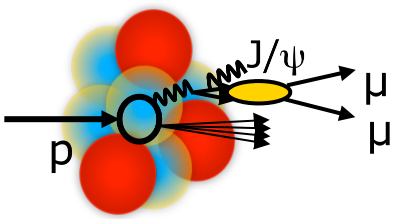
Physics motivation for proton-nucleus studies

→ Proton-nucleus collisions are interesting by themselves but also provide reference for heavy ion studies

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

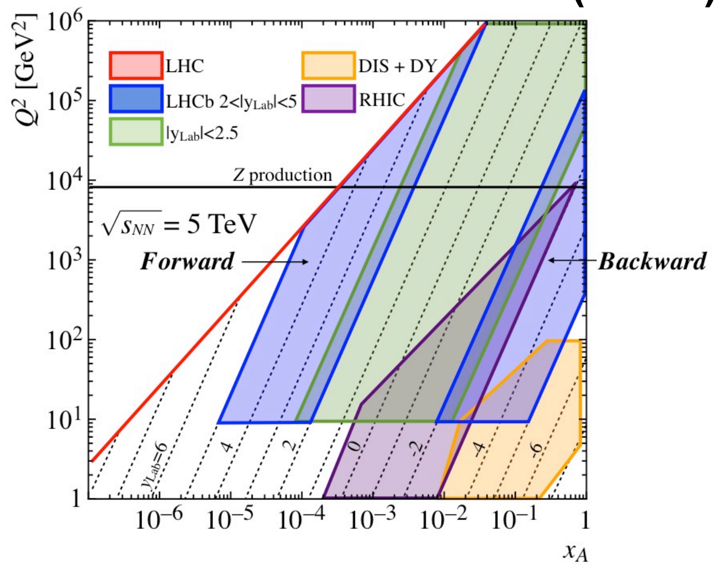
- **Coherent energy loss[5]**

[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

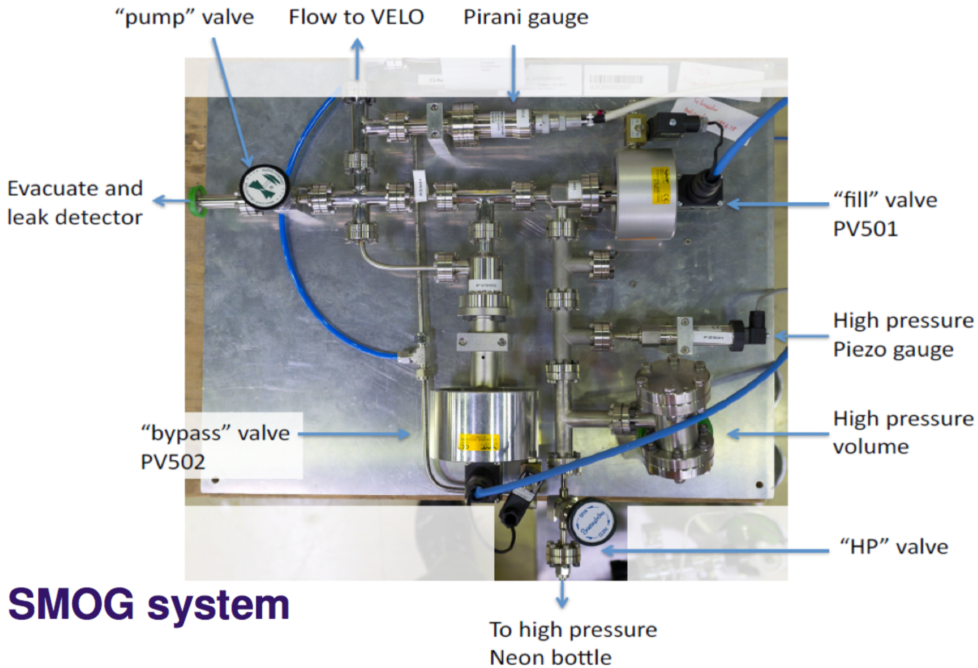
Highest particle density and multiplicities reached in pp and pA at LHC of similar size to that of non central AA collisions

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 $|\eta| < 2.5$

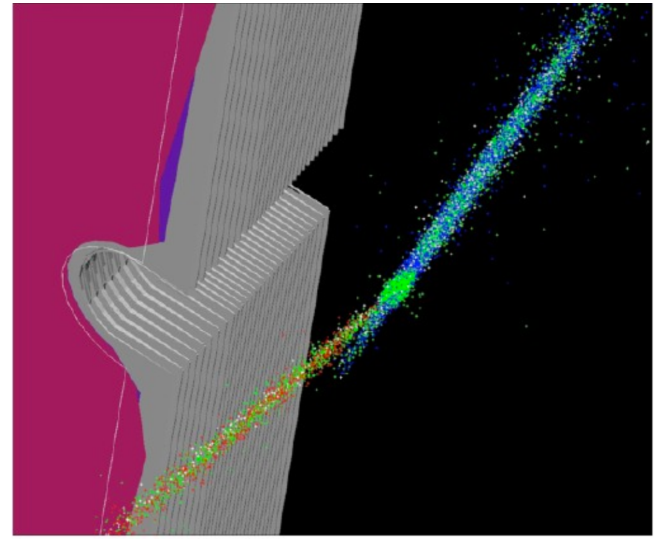
Heavy ion studies in fixed target mode

The SMOG system

→ SMOG: System for Measuring Overlap with Gas



SMOG system



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.

(Possible) Beam target configurations :

- ❑ Proton and Lead beam
- ❑ Hydrogen and noble gases as target : He, Ne, Ar, Kr, Xe

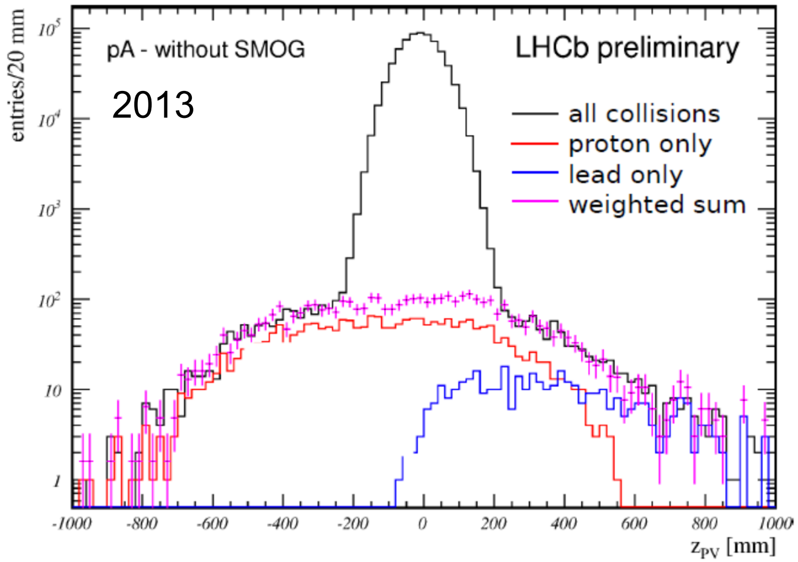
Data taking:

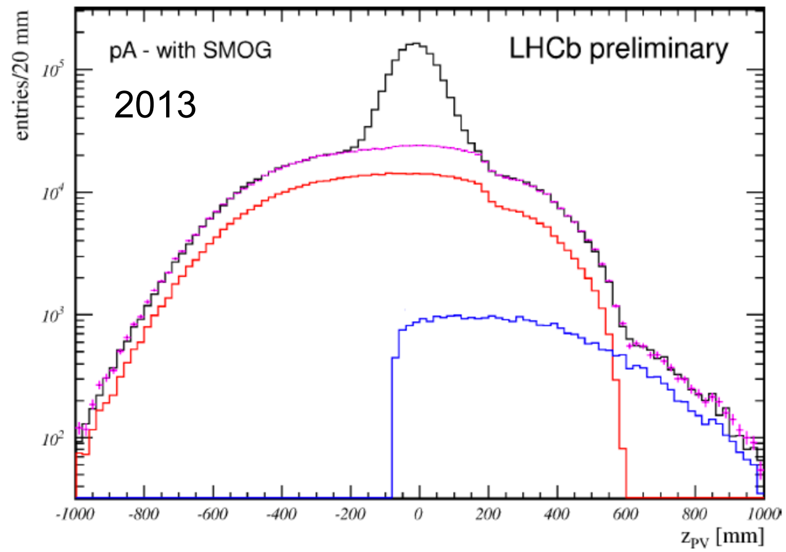
- ❑ pNe pilot run at $\sqrt{s_{NN}}$ = 87 GeV (2012)
- ❑ PbNe pilot run at $\sqrt{s_{NN}}$ = 54 GeV (2013) ~ 30min
- ❑ pNe run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 12h
- ❑ pHe run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 8h
- ❑ pAr run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 3 days (mid-october)
- ❑ PbAr run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ 3 weeks (december)

- ❑ Low density noble gas injected in the VELO of LHCb, in the interaction region
- ❑ Very simple robust system
- ❑ Main use so far for precise luminosity determination
- ❑ Only local temporary degradation of LHC vacuum

Properties of Fixed target interactions

Z distribution of primary verteces in pPb collisions with and without SMOG





LHCb-CONF-2012-034

- Contributions of beam-beam and beam-gas interactions can be separated by knowing the filling scheme
  → Fixed target collisions can be isolated from regular collisions in collider mode
  No need for dedicated physics runs!

- With SMOG increase of the beam gas rate by two order of magnitudes
  → Gas pressure (~ 1.5×10^{-7} mbar) 2 order of magnitude larger than vacuum pressure

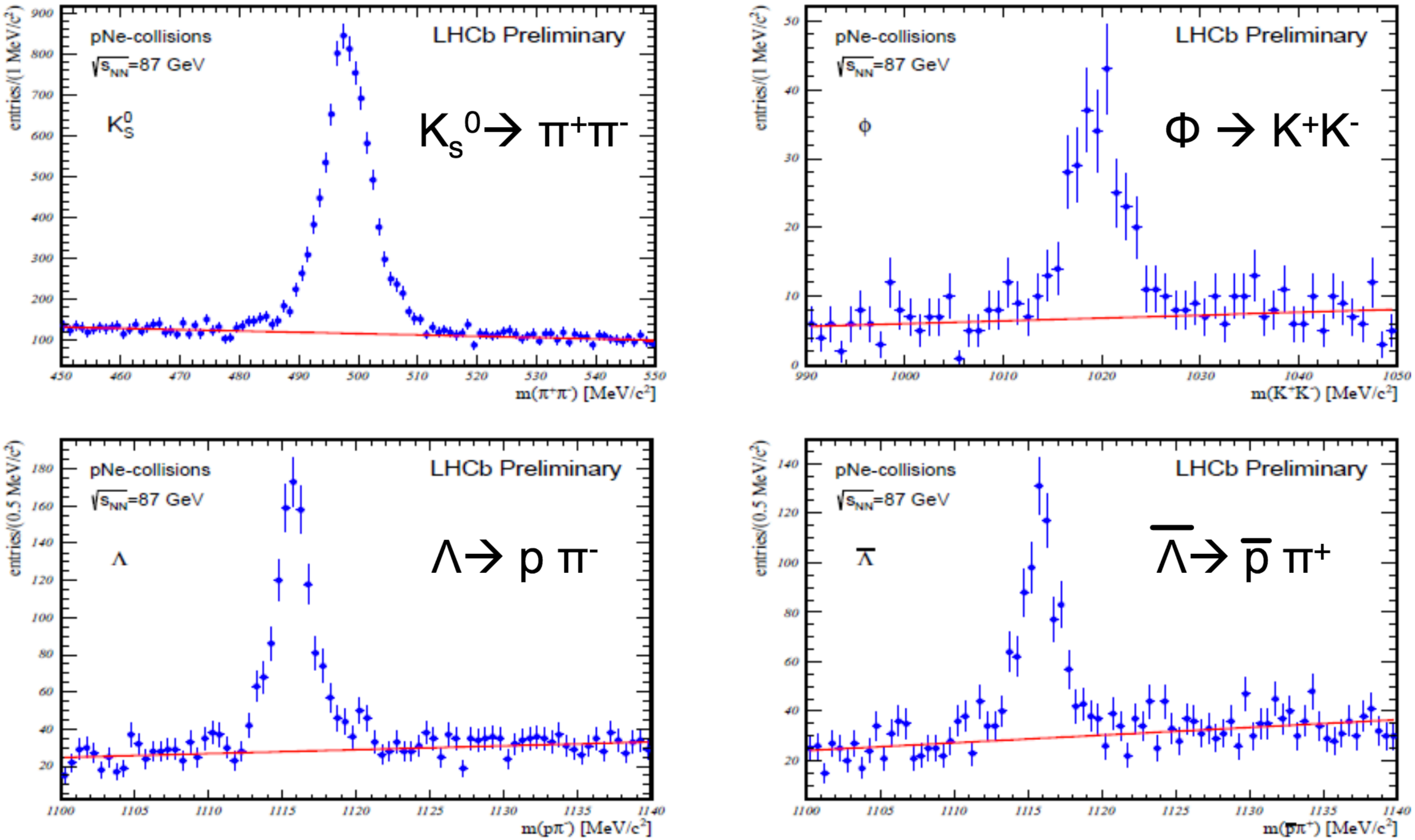
- Strong acceptance effects as a function of Z position

Plan to collect 200M minimum bias events this year per magnet polarity for each beam-gas configuration

Results from p-Ne collisions

- p-Ne collisions at 87 GeV (2012 pilot run)

LHCb-CONF-2012-034



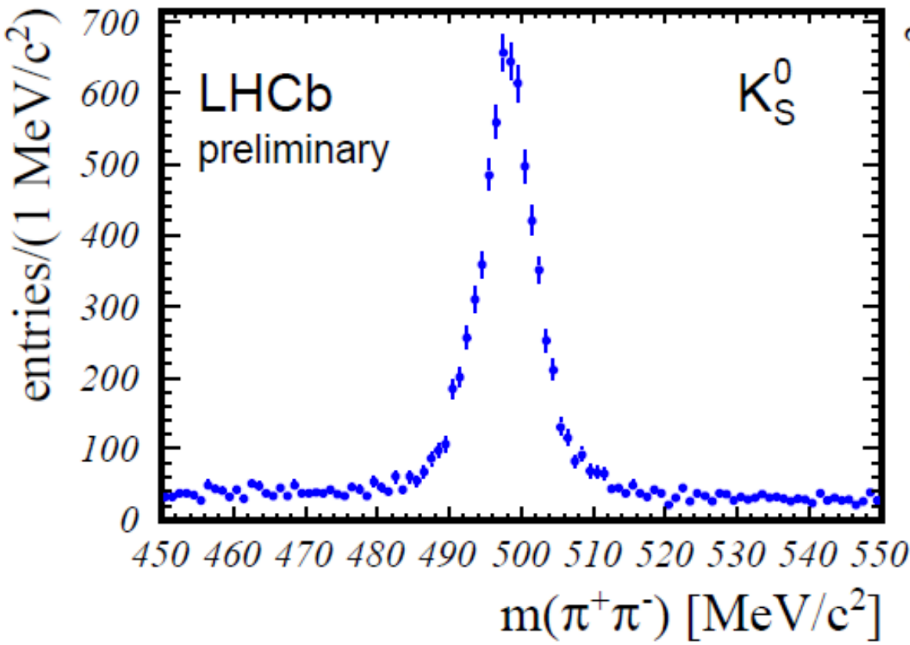
New results from p-Ne collisions at 110 GeV (2015): **about 300 J/ψ collected!**

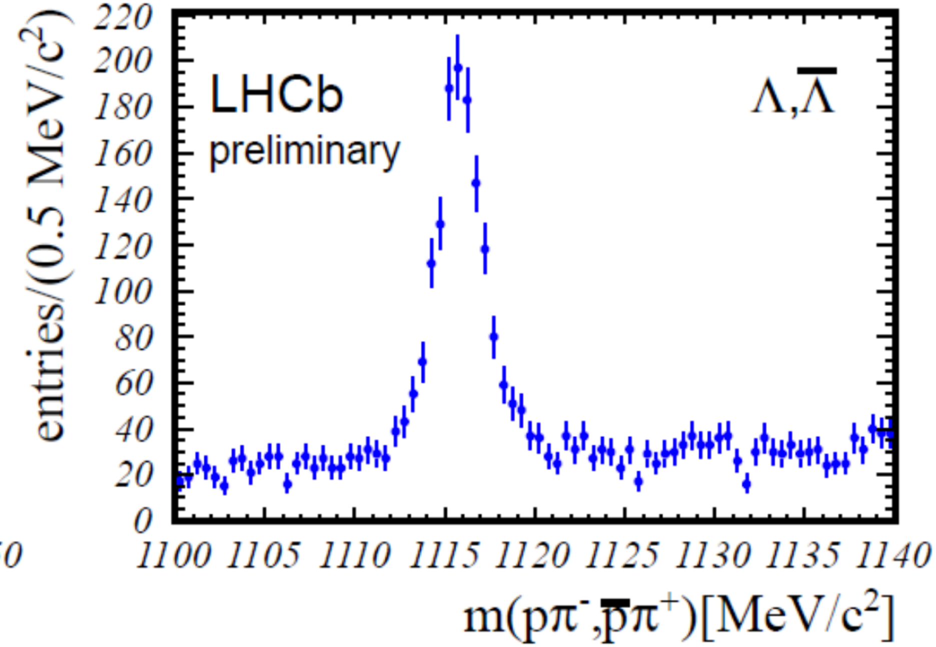
→ **See F. Fleuret talk**

Results for p-He collisions at 110 GeV (2015) to come

Results from Pb-Ne collisions

- ❑ **Pb-Ne collisions at 54 GeV (2013 pilot run)**
- ❑ About 30min of data taking





- ❑ Also first look at J/ψ → about 8 reconstructed

↳ **See F. Fleuret talk**

Looking forward to take more data in Pb-Ar collisions by the end of the year

Heavy ion studies in collider mode

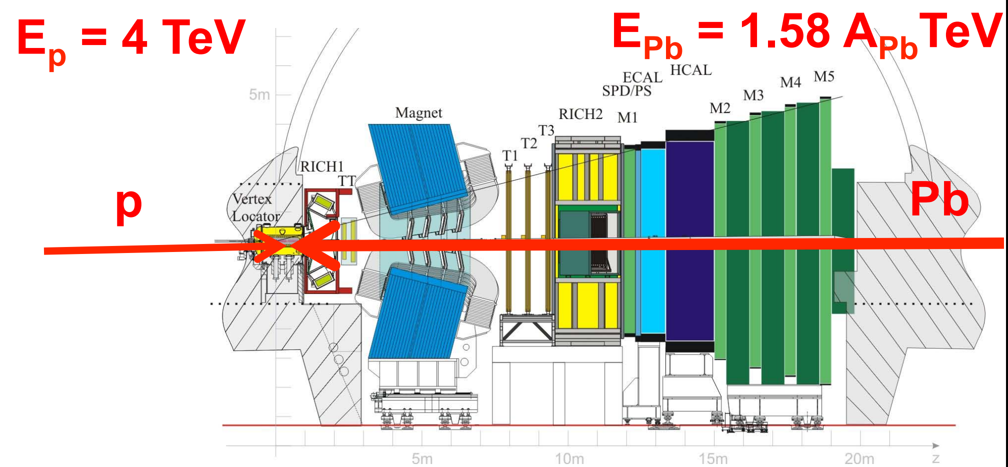
➡ p-Pb and Pb-p collisions

Results from 2013 data taking

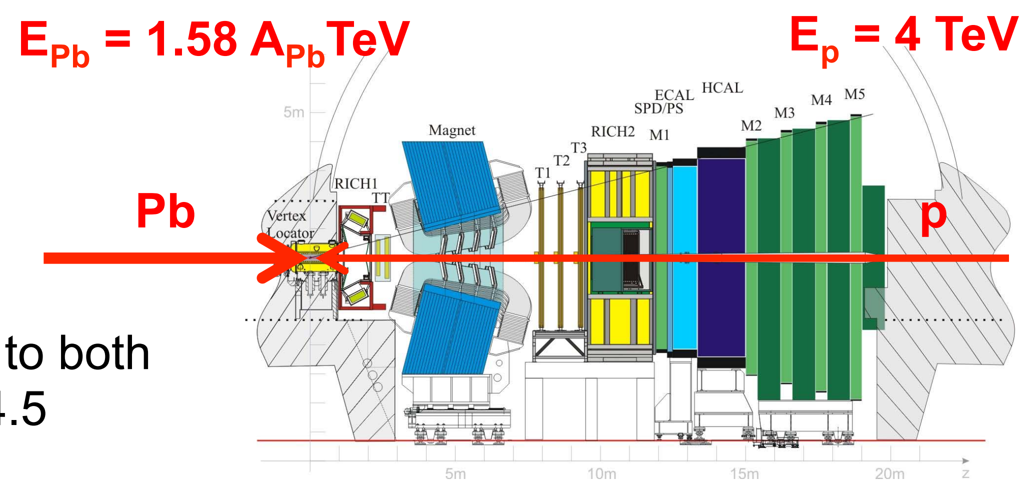
The p-Pb and Pb-p data taking

- 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

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



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



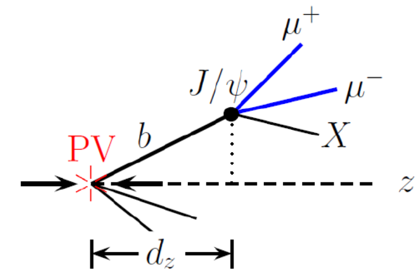
→ Rapidity coverage in common to both configurations: $2.5 < |y_{CMS}| < 4.5$

J/ψ production in p-Pb and Pb-p

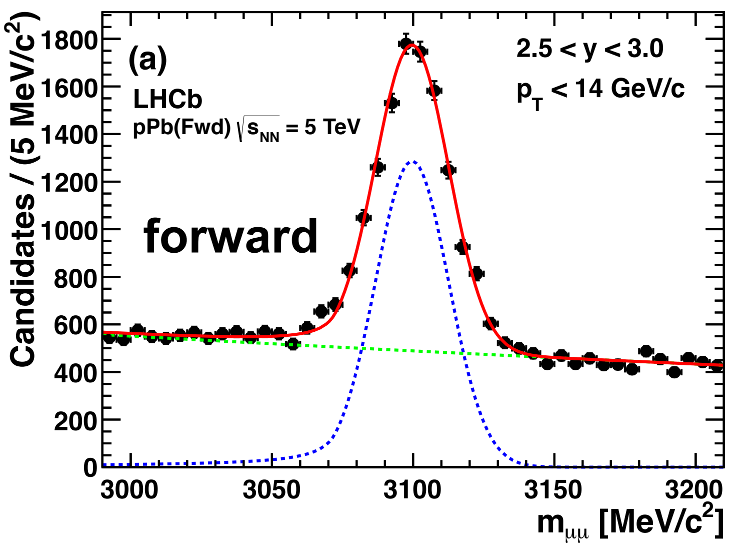
JHEP 02 (2014) 072

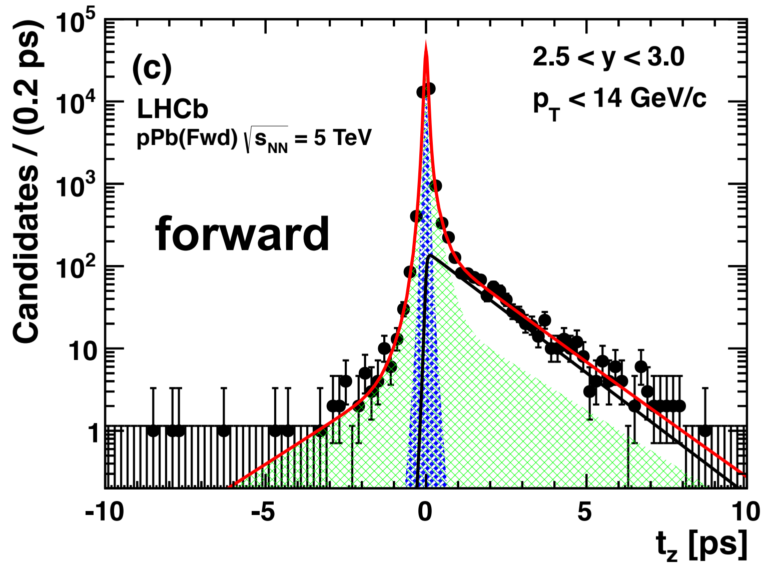
- J/ψ are reconstructed from two well identified muons
- Disentangle prompt J/ψ from J/ψ from b using pseudo-proper time:

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



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



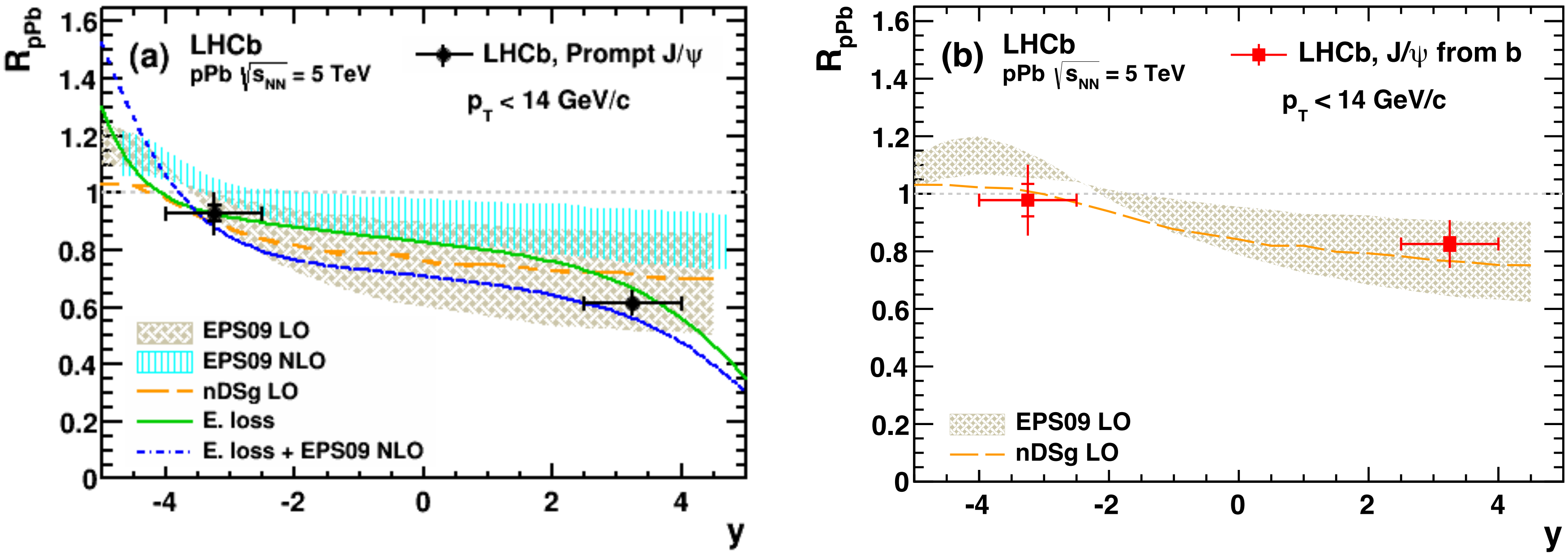


Mass distribution:
- Signal: Crystal-Ball function
- Background: Exponential

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)

J/ψ nuclear modification factor (R_{pPb}) JHEP 02 (2014) 072

- $R_{pPb}(y) = (1/A) \times (d\sigma_{pA}/dy)/(d\sigma_{pp}/dy)$



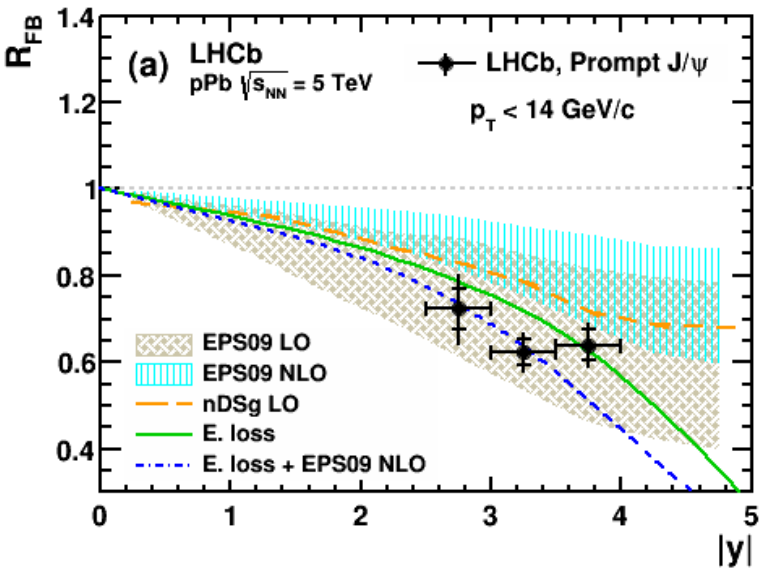
Prompt J/ψ: strong suppression at forward y (strong CNM effect)
→ Data well described by coherent energy loss models (w and w/o shadowing)
J/ψ from b: small suppression in the forward region
→ first indication of suppression of b hadron production

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})

JHEP 02 (2014) 072

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



Rapidity dependence:

Prompt J/ψ: Clear forward-backward asymmetry

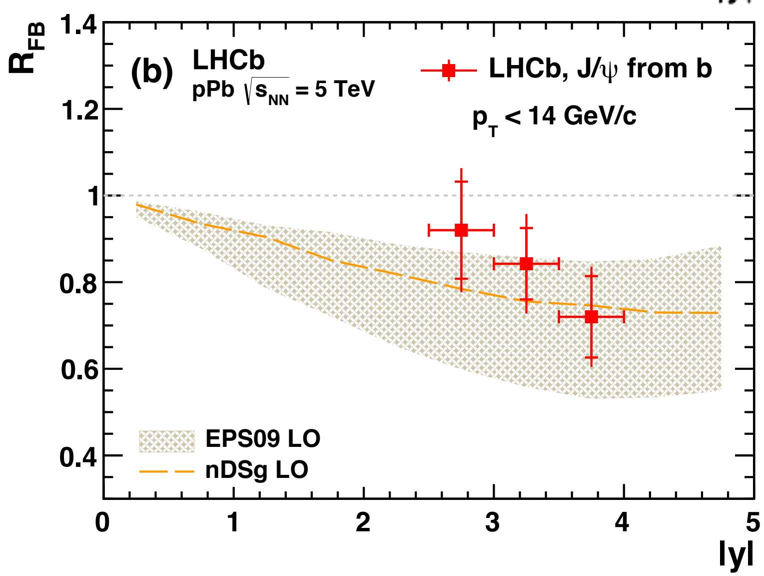
→ More statistics needed to distinguish between models

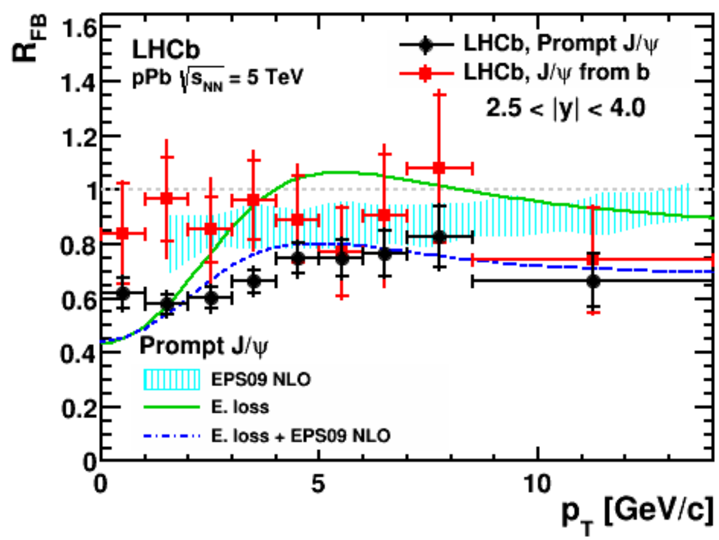
J/ψ from b: Small forward-backward asymmetry

p_T dependence:

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

J/ψ from b: R_{FB} close to 1



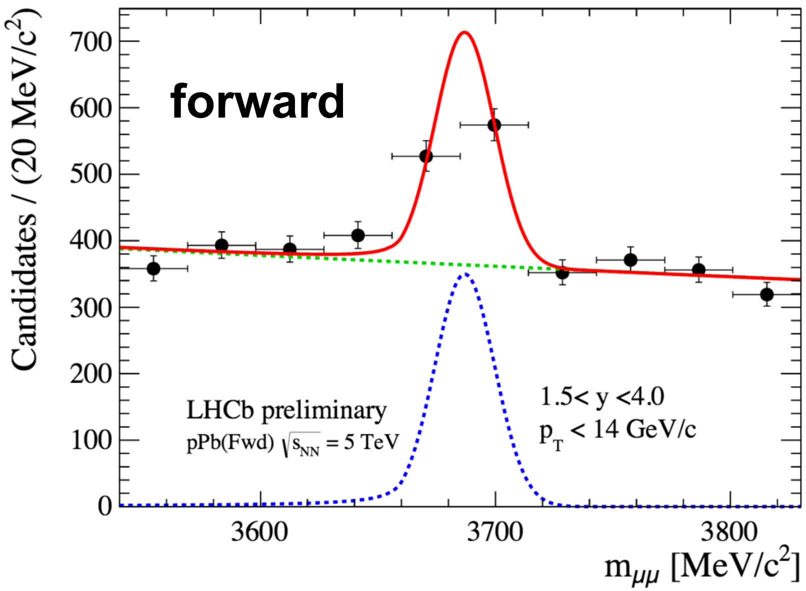


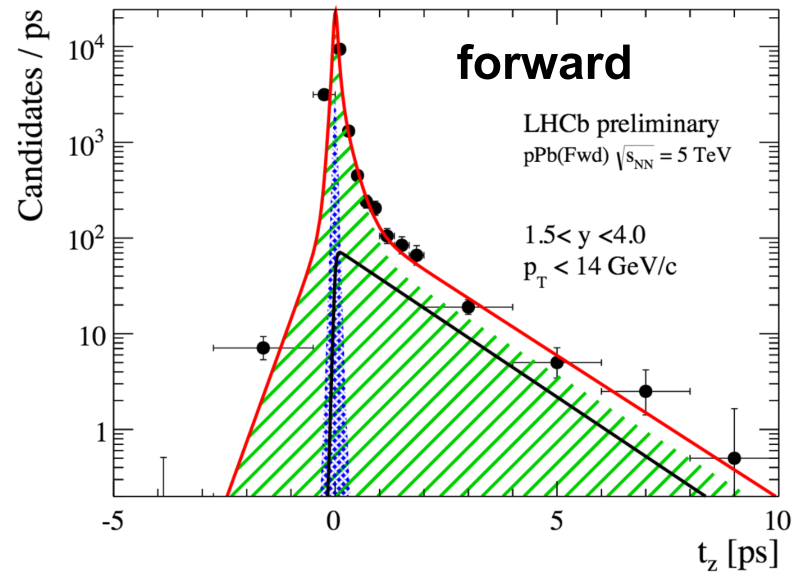
Ψ(2S) production in p-Pb and Pb-p

NEW

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

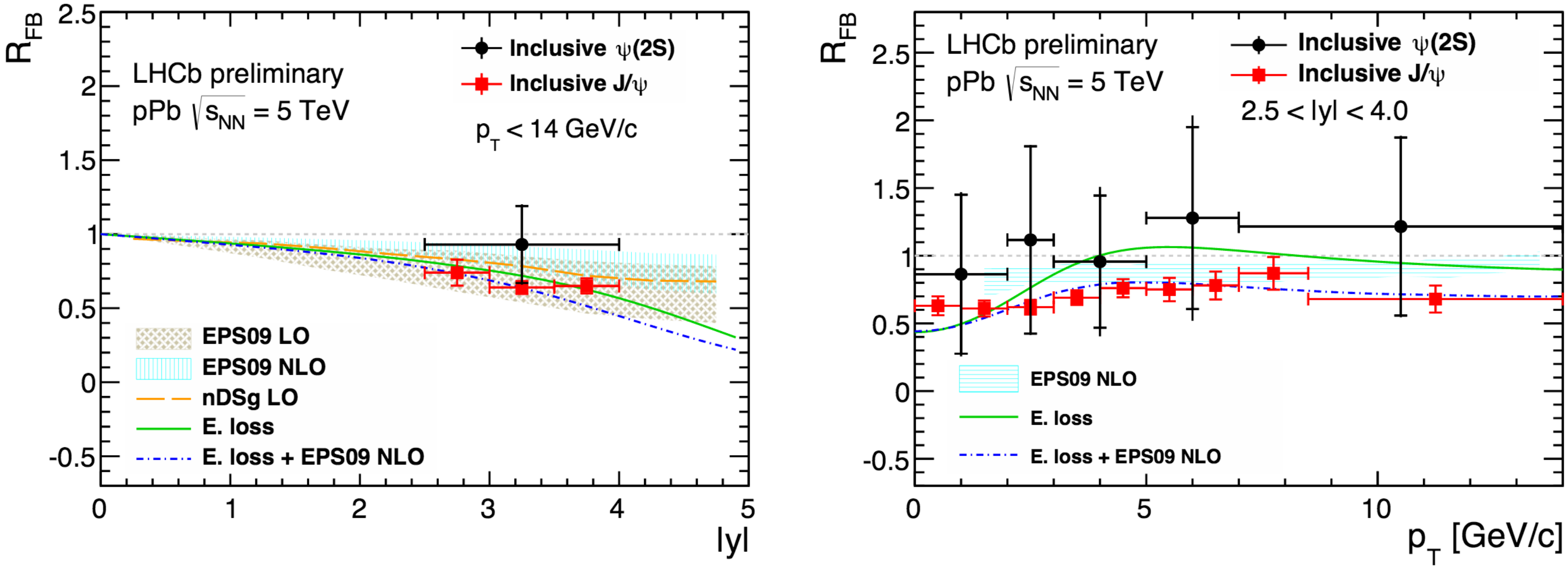
t_z distribution:
- Signal: - $\delta(t_z)$ for prompts ψ(2S) (blue curve)
  - Exponential for ψ(2S) from b (black line)
- Background: Empirical function from sideband (green hatched)

Ψ(2S) forward to backward ratio

NEW

LHCb-CONF-2015-005

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



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)

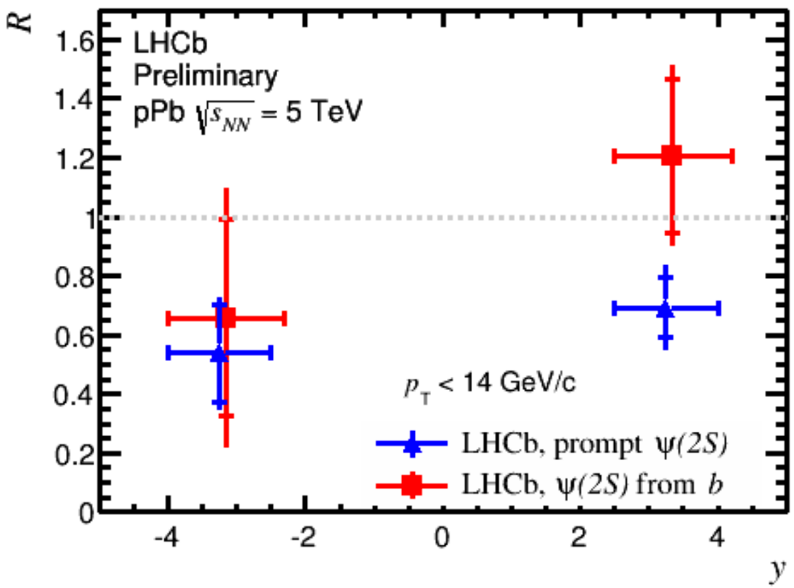
Ψ(2S) relative suppression wrt J/ψ

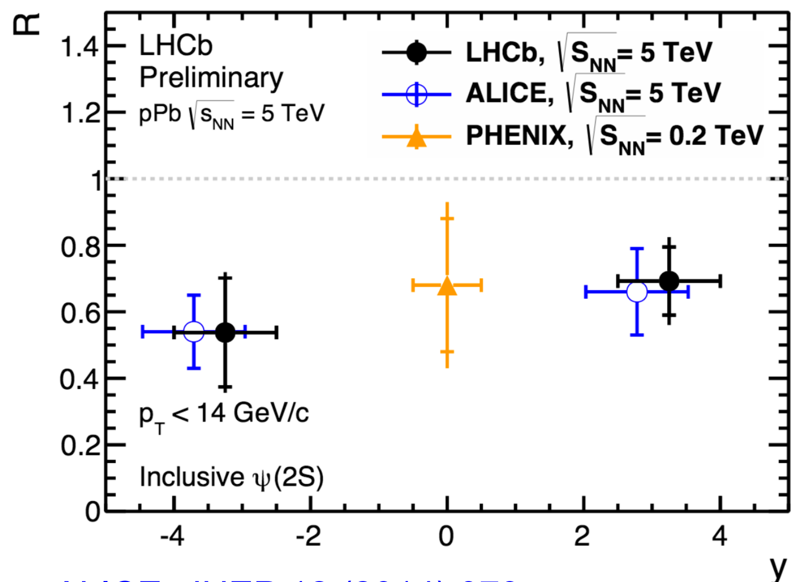
NEW

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

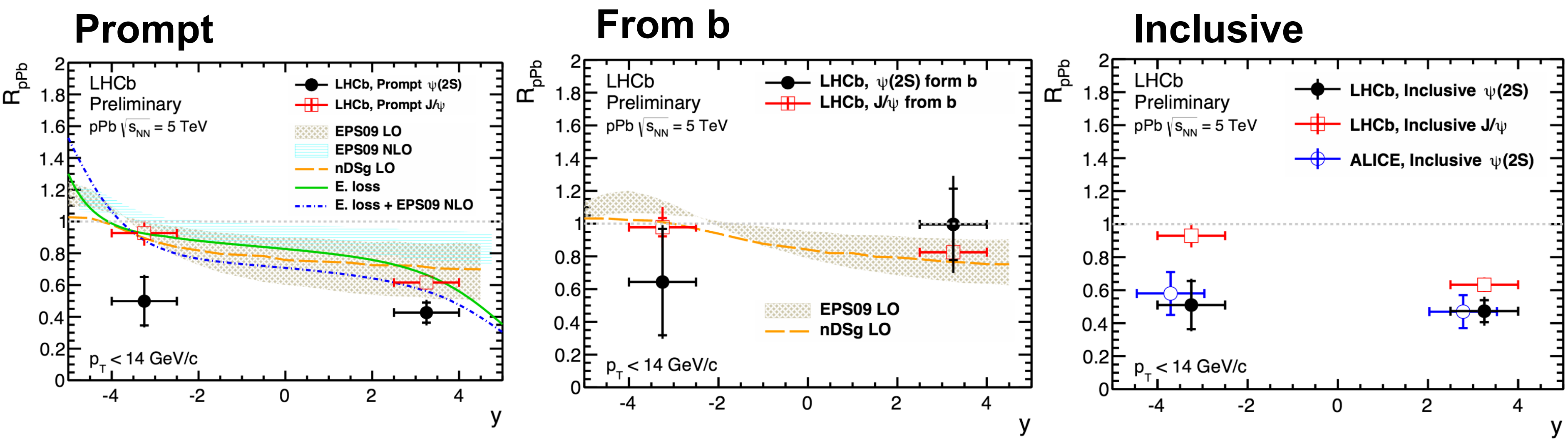
Ψ(2S) nuclear modification factor

NEW

LHCb-CONF-2015-005

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

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



ALICE: JHEP 12 (2014) 073

Prompt ψ(2S) more suppressed than prompt J/ψ
Eloss + shadowing don't explain the ψ(2S) suppression in the backward region (other mechanism at play?)
Suppression of ψ(2S) from b consistent with that of J/ψ from b
Suppresion of inclusive ψ(2S) consistent with ALICE results

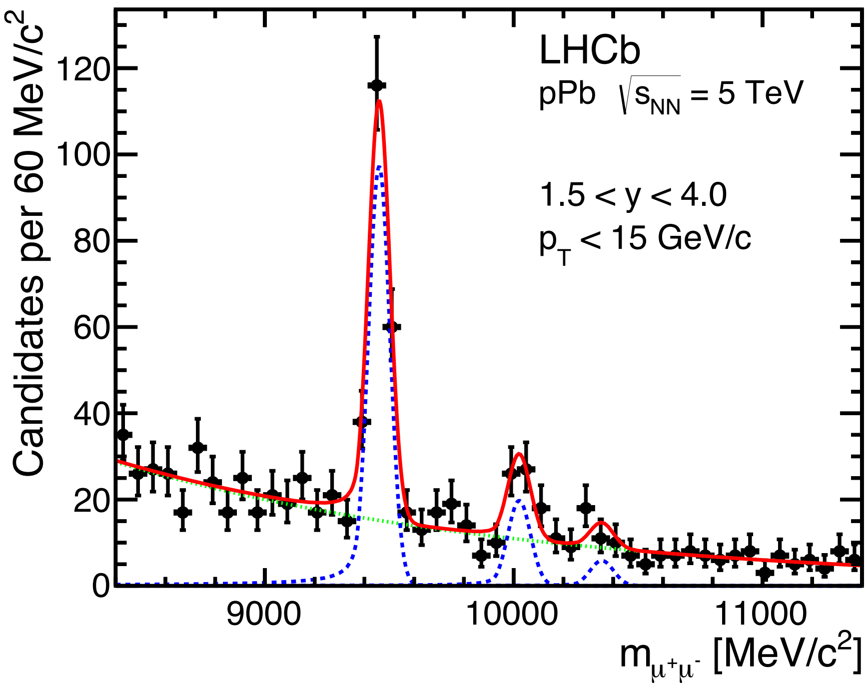
Υ(nS) production in p-Pb and Pb-p

JHEP 07 (2014) 094

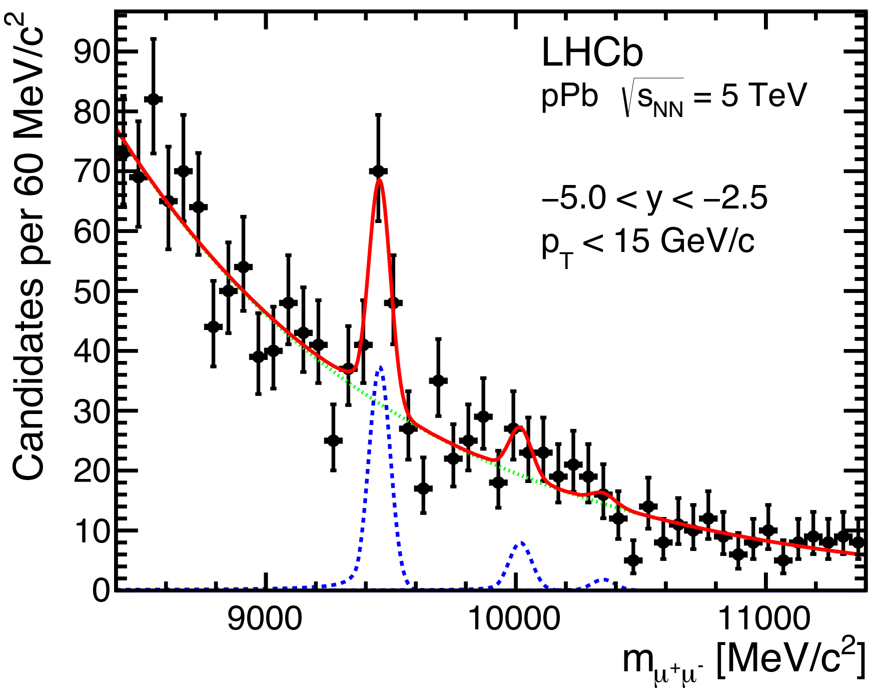
- Υ states in the dimuon decay channel
- Forward: $1.5 < y_{CMS} < 4.0$, backward: $-5.0 < y_{CMS} < -2.5$; $p_T < 15$ GeV/c
- Fit performed with 3 Crystal Balls for signal and an exponential for background

→ Limited statistics do not permit to do a differential measurement

Forward production



Backward production

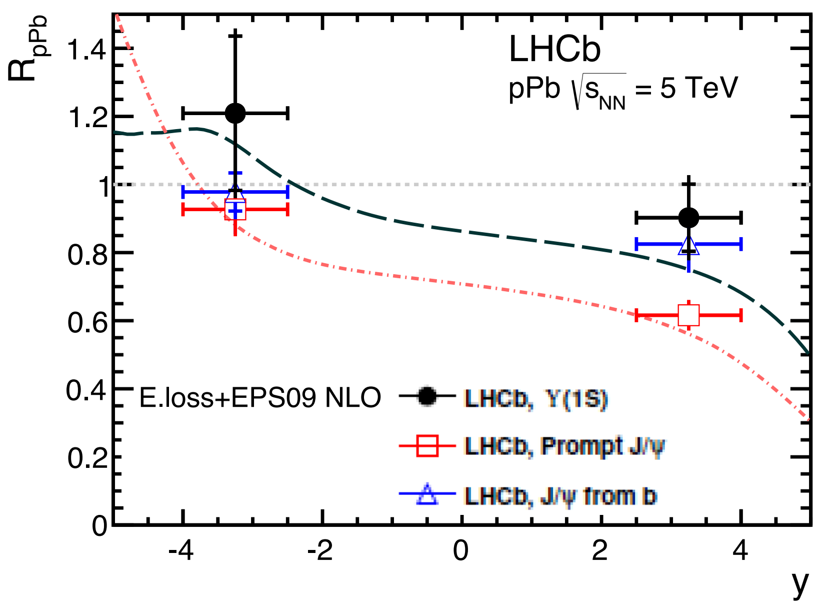


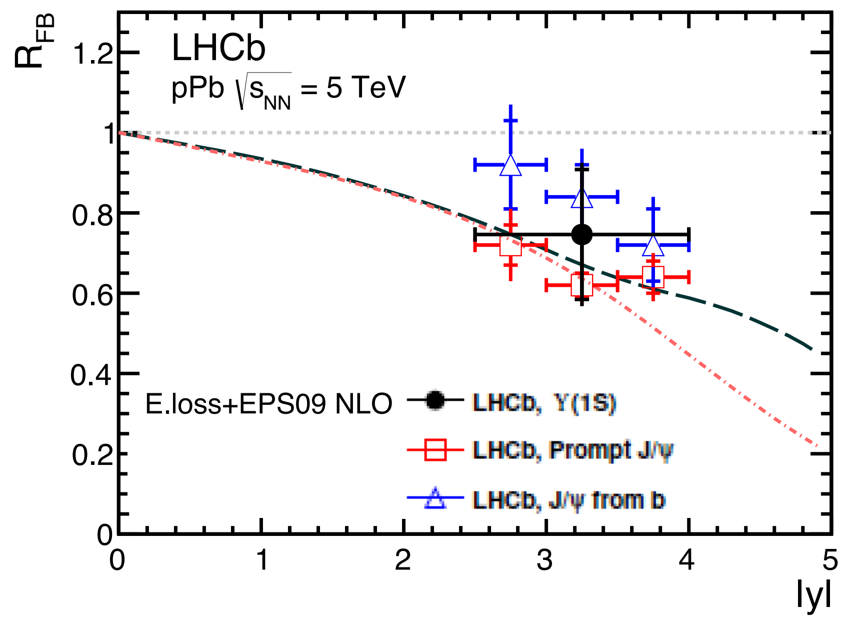
Υ(1S) R_{pA} and R_{FB}

JHEP 07 (2014) 094

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

→ Probing different x_A





Υ(1S) is also sensitive to CNM effets

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 energy loss + shadowing (EPSO9 NLO)

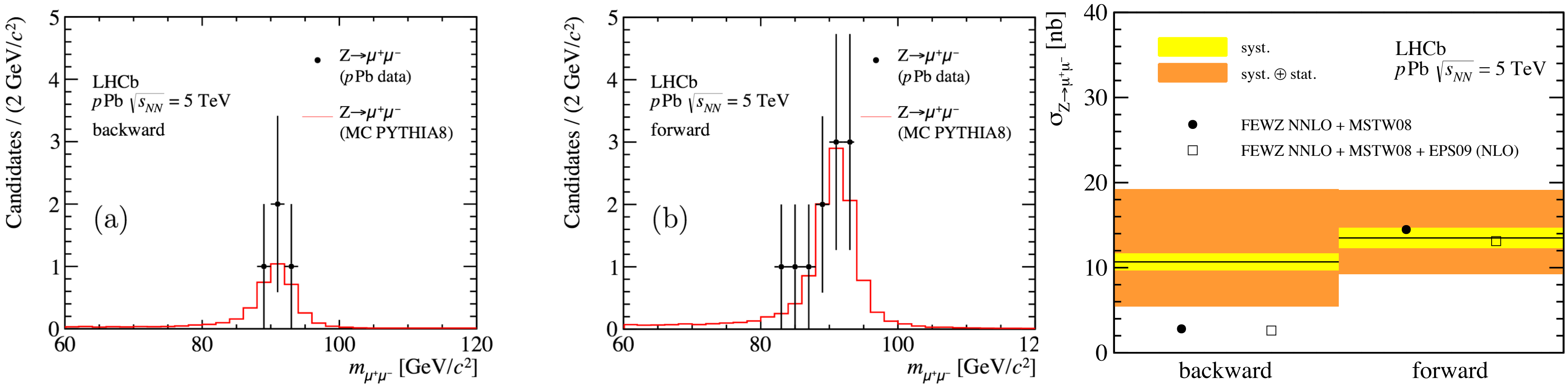
Z production in p-Pb and Pb-p

JHEP 09 (2014) 030

Muon selection: p_T > 20 GeV/c, 2.0 < η < 4.5, 60 < M(μ⁺μ⁻) < 120 GeV/c²

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 conclusions on the presence of CNM

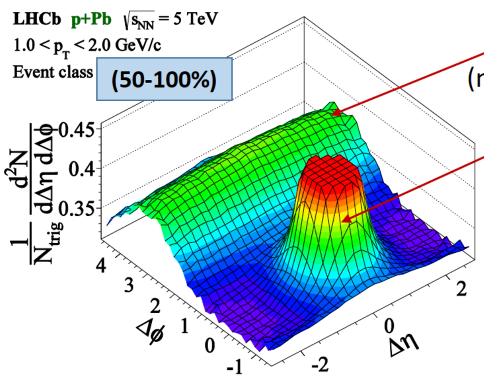
Looking forward to take more data during run II

Two particle correlations in p-Pb and Pb-p

LHCB-CONF-2015-004

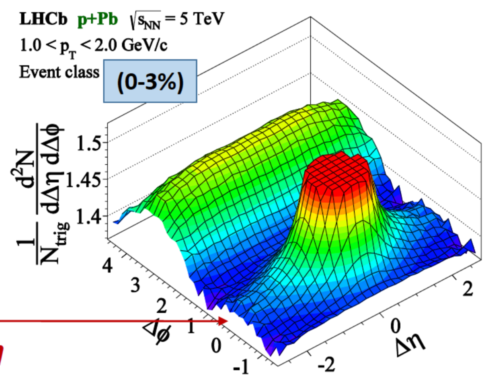
- Measurement of angular (Δη,Δϕ)-correlations of prompt charged particles
- Both beam configurations analyzed separately: L_{int} = 0.46nb^{-1} (p+Pb), L_{int} = 0.30nb^{-1} (Pb-p)
- Rapidity range 1.5 < y_{CMS} < 4.4 (forward), -5.4 < y < -2.5 (backward)
- Correlation function is decribed as a per-trigger particle associated yield:

$$\frac{1}{N_{trig}}\frac{d^2N_{pair}}{d\Delta\eta d\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)} \times B(0,0)$$



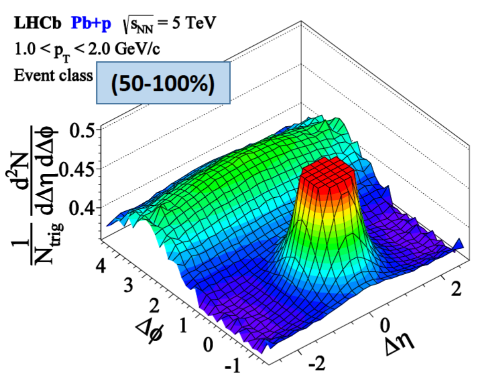
Away-side ridge (momentum conservation)

Jet peak (particles from same hard process)

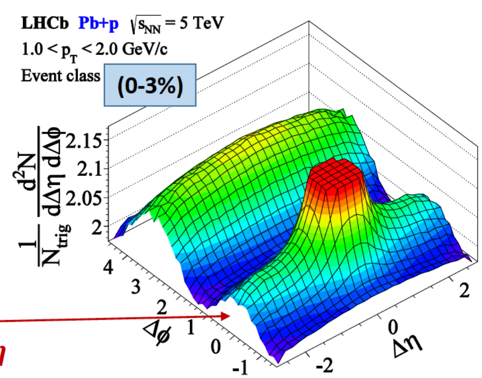


Near-side ridge elongated over large Δη

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



Near-side ridge elongated over large Δη



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

Two particle correlations in p-Pb and Pb-p

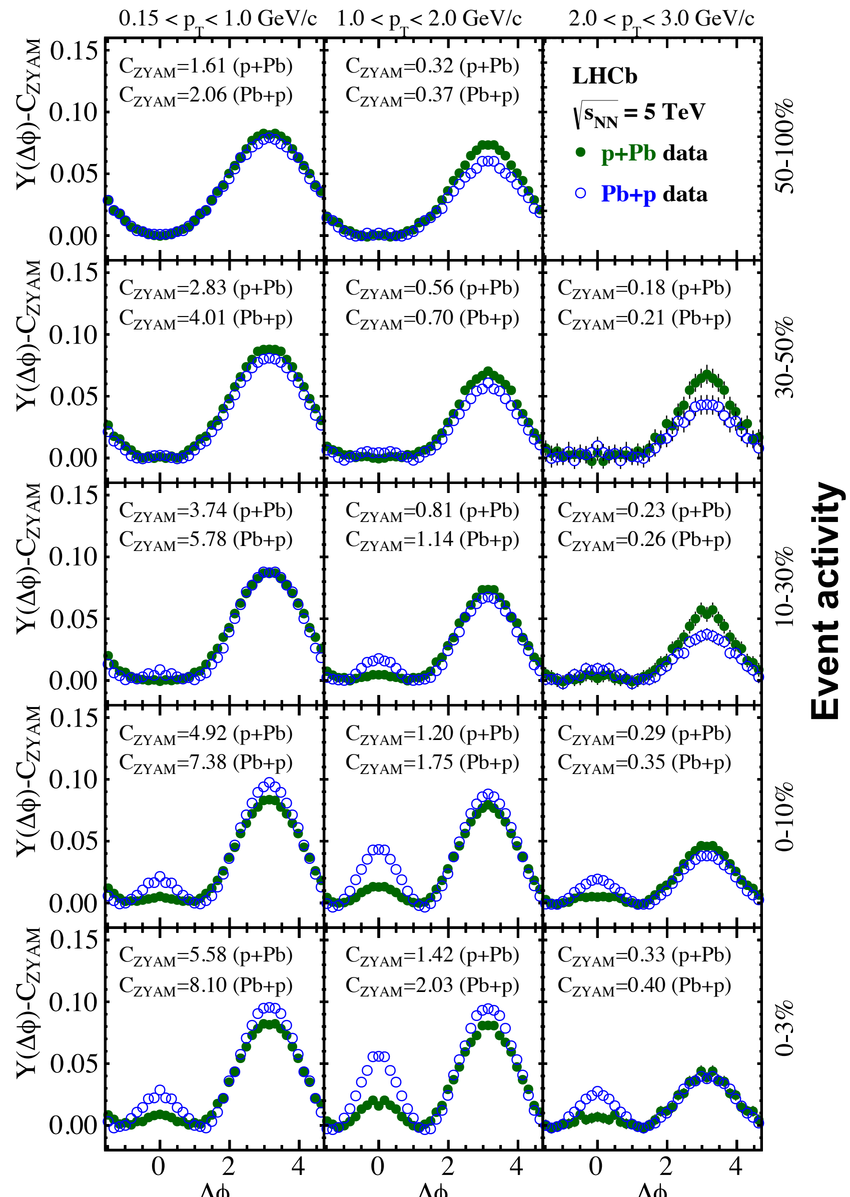
LHCB-CONF-2015-004

- To study the evolution of the long-range correlations on the near and away sides in more details, 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

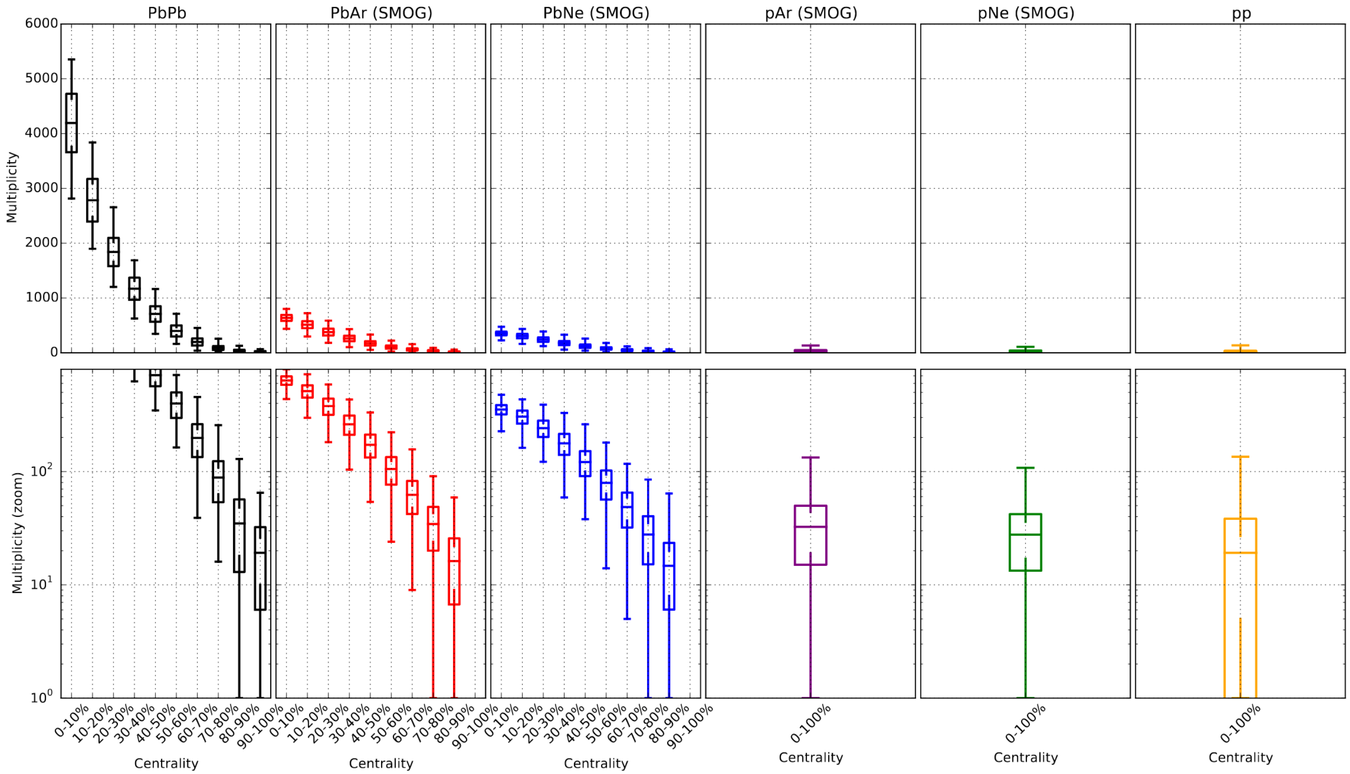
➡ Prospects for Pb-Pb data taking

LHCb will join the Pb-Pb data taking at the end of 2015
Expectations to collect L_{int} ~ 50-70 μb^{-1}

Pb-Pb data taking

- LHCb switch on slowly and carefully during Pb-Pb data taking
- From the LHC point of view, having collisions in LHCb can lead to parasitic collisions near ALICE and degrade the beam lifetime:
  - Default configuration will be with collisions in LHCb
  - A backup filling scheme will be ready in case the default is unstable within LHCb

The recurrent question: can LHCb cope with the multiplicities reached in Pb-Pb collisions?



LHCb-INT-2015-019

Multiplicity in central Pb-Ne collisions ~ Multiplicity in Pb-Pb (centrality 50%)

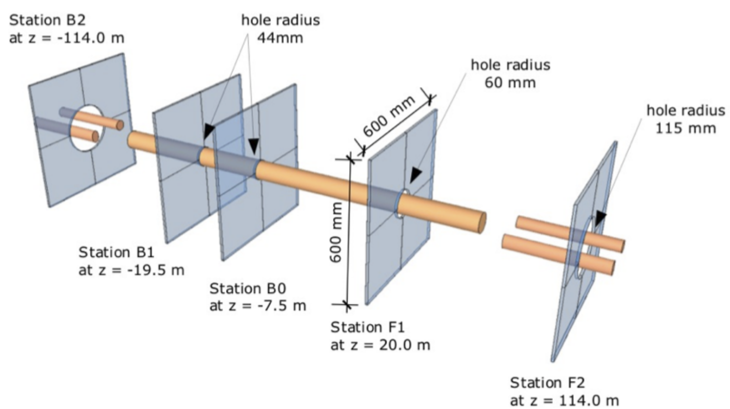
Pb-Ne data already collected in 2013 without probelm

MC studies ongoing to study reconstruction in most central collisions

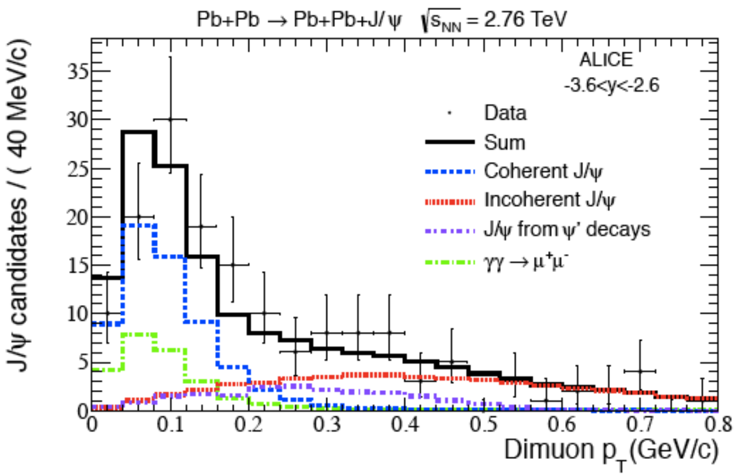
Some first measurement which might be at reach by the end of 2015

→**Focus here on quarkonium**

J/ψ photoproduction in Ultra-Peripheral collisions:
- ALICE measurement performed with L_{int} ~ 55 μb^{-1}
- New HERSHEL detector installed in LHCb:
  - Forward detector $5 < |\eta| < 8$
  - Measure rapidity gaps



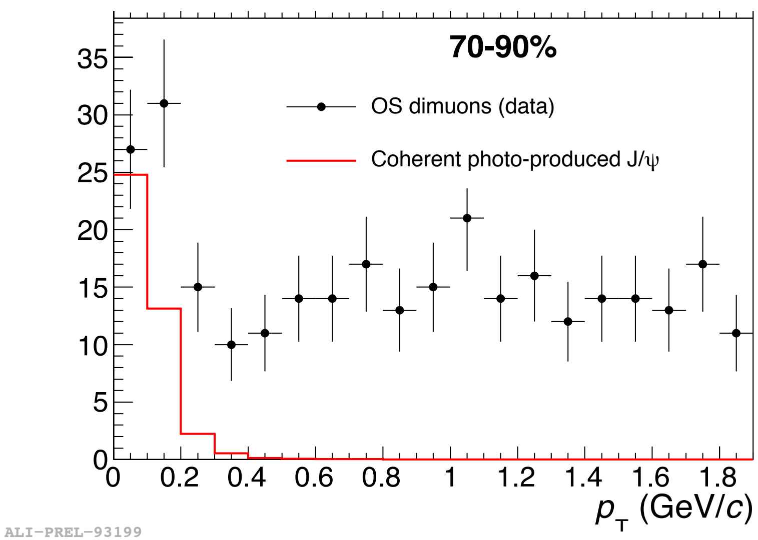
Phys. Lett. B 718 (2013) 1273 - 1283



Low p_T excess in the yield of J/ψ in peripheral Pb-Pb events:
- ALICE measurement performed with L_{int} ~ 70 μb^{-1}

→ Measurement can be extended to ψ(2S) and to χ_c (although challenging experimentally) to test the photoproduction origin

arXiv:1509.08802



See talk of G. Martinez

Conclusions

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

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

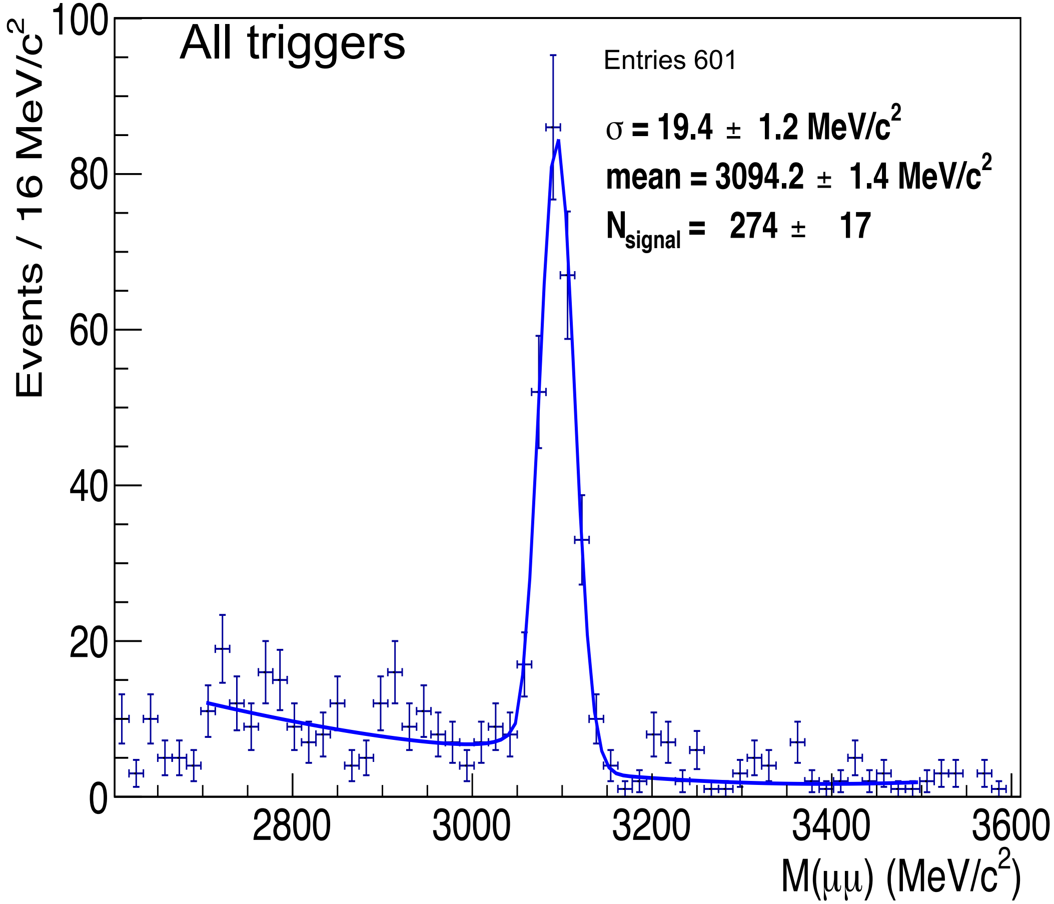
- **LHCb will also collect PbPb data at the end of this year**
  - Rich program in heavy flavour physics, EW, (soft) QCD and QGP studied
  - Expected to collect 50-80 μb^{-1} this year

LHCb is more than a pp heavy flavour experiment
LHCb is a truly general purpose detector in the forward region

Back up

J/ψ signal in p-Ne collisions in 2015 with SMOG

- ❑ $\sqrt{s_{NN}}$ = 110 GeV
- ❑ ~12h of data taking
- ❑ Pressure of the Ne gas ~ 1.5 x 10^{-7} mbar



Physics motivation for proton-nucleus studies

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

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

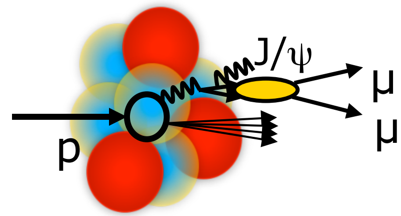
Initial state effects

Nuclear shadowing = gluon shadowing at LHC [1]
Gluon distribution functions are modified by the nuclear environnement. PDF in nuclei ≠ superposition of the individual nucleon PDFs

Parton saturation / CGC [2]
At small x, density of gluons > density of quarks. Saturation of gluon distributions

Radiative energy loss [3]: incoming partons radiate gluons as it traverses the medium

Cronin effects [4]: increase of $<p_T^2>$ from pp to pA . Broadening of the intrinsic p_T distribution → from multiple scattering experienced by the initial gluon from proton as it goes through the nucleus



p-A collisions

coherent energy loss [5]: neither initial nor final state effect. Amount of medium-induced gluon radiation defines strength of J/ψ suppression

Final state effects

Nuclear absorption [6]: break-up of pre-resonant cc pairs due to successives interaction with spectator nucleons
Expected to be small at LHC [7]

Radiative energy loss [8]: outgoing particle radiates energy while traversing the medium

Comovers [9]: interaction of the quarkonium with the produced medium

[1] K.J. Eskola et al., JHEP 0904 (2009) 065.
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[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