热烈祝贺华南师范大学量子物质研究院成立！

Heavy-ion physics with LHCb

朱相雷（清华大学）

On behalf of the LHCb Collaboration

QCD and Quark Matter Physics

11-13 November 2018

Guangzhou, China

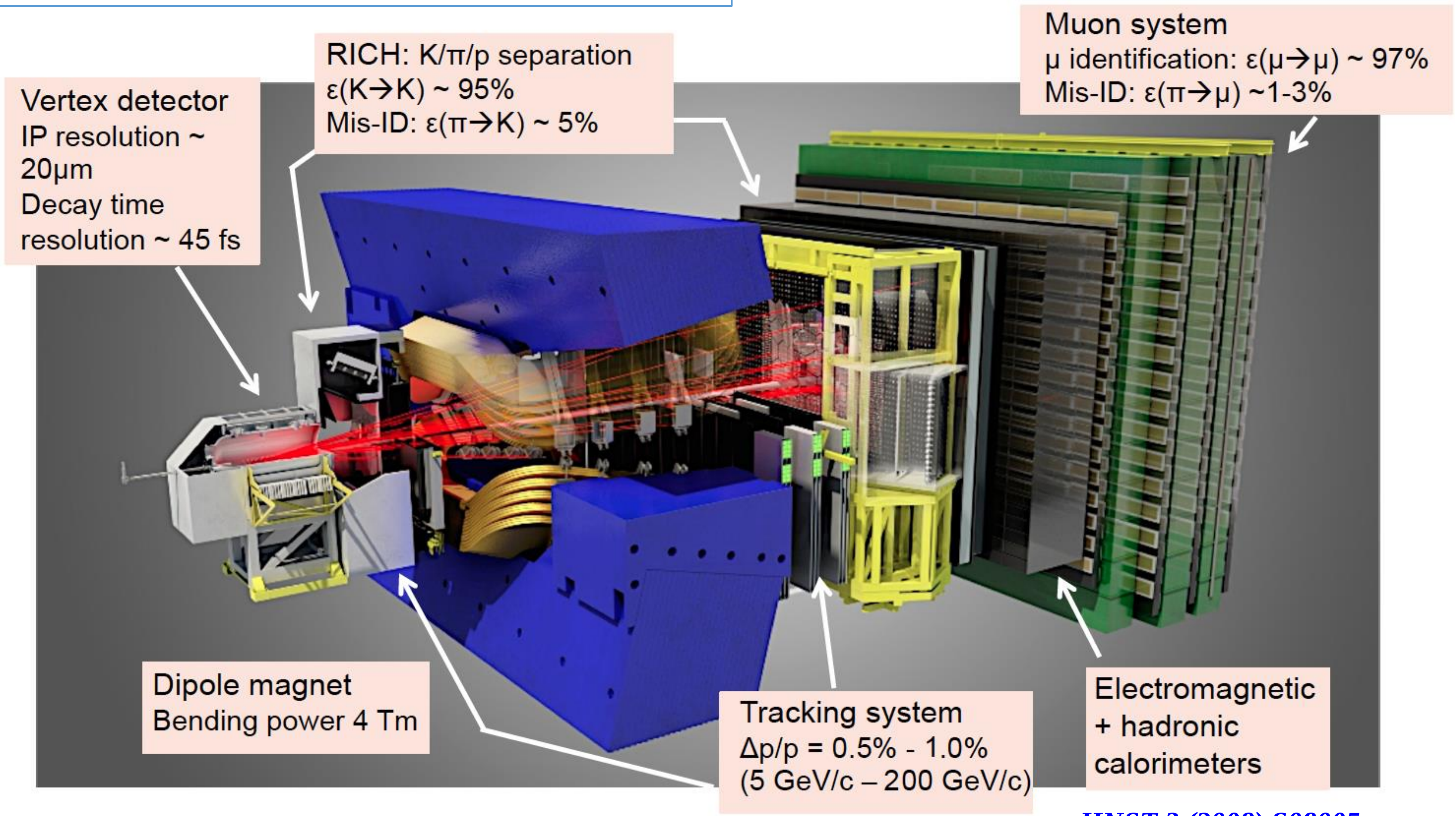
Outline

- The LHCb detector
- Heavy quarkonium production in pPb
- Open heavy flavor production in pPb
- Fixed-target experiments
- PbPb collisions
- Summary

The LHCb detector

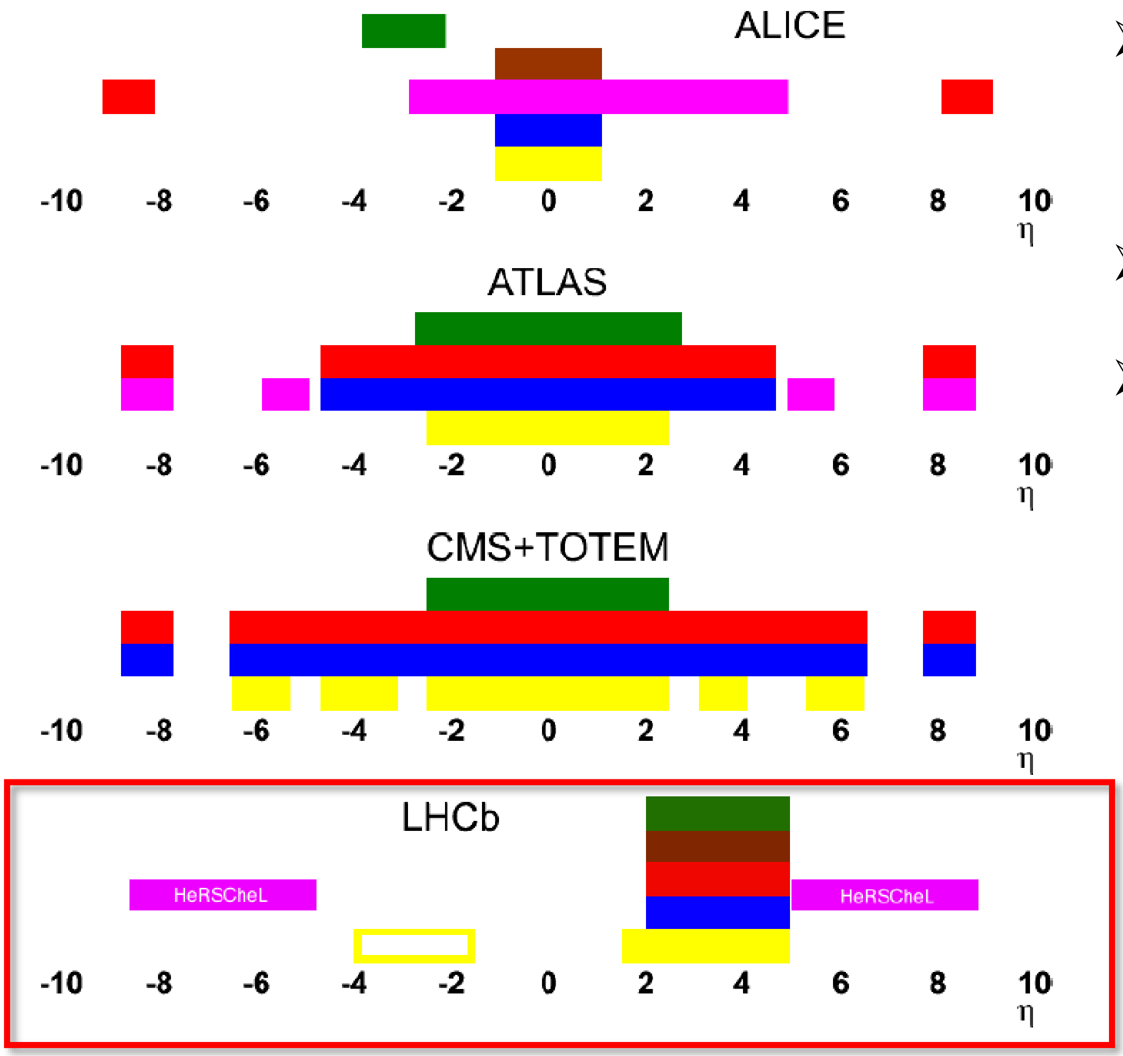
A single arm **general purpose detector** at **forward** rapidity !

pseudorapidity acceptance $2 < \eta < 5$

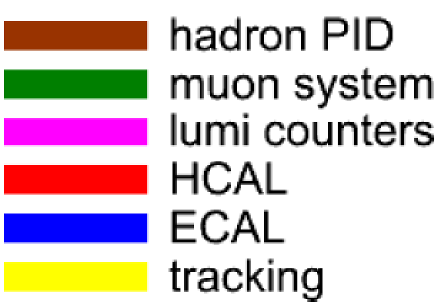


JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

The LHCb detector



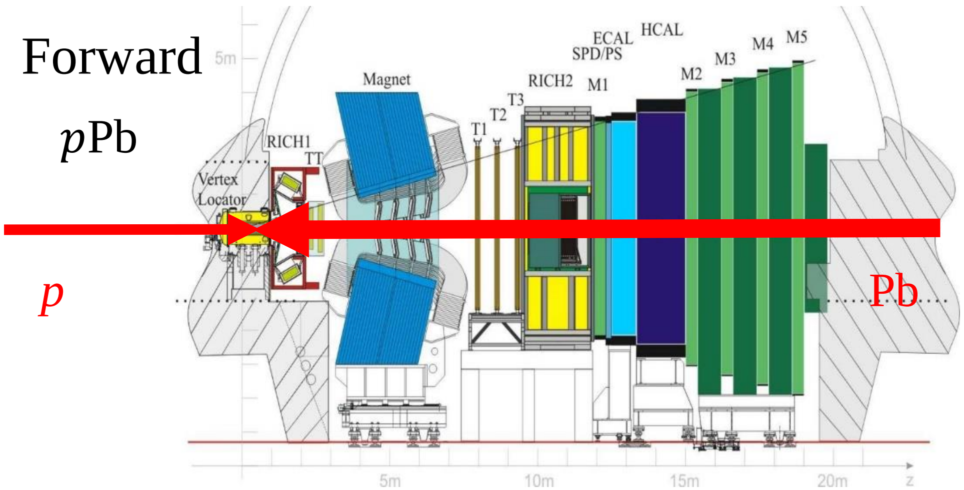
- ALICE
  - central
  - forward coverage for muon only
- ATLAS & CMS
  - central detectors
- LHCb
  - forward detector
  - tracking, particle-ID and calorimetry in full acceptance !



LHCb *p*Pb datasets

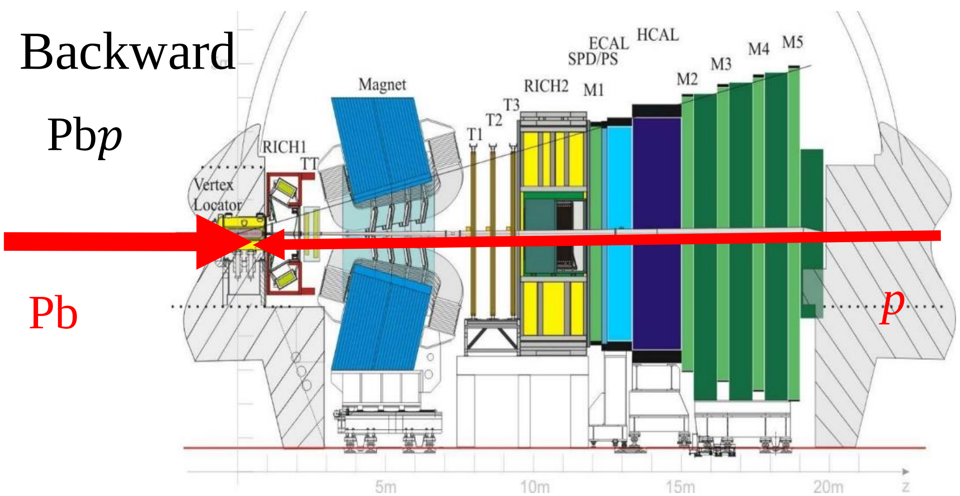
Forward

*p*Pb



Backward

Pb*p*

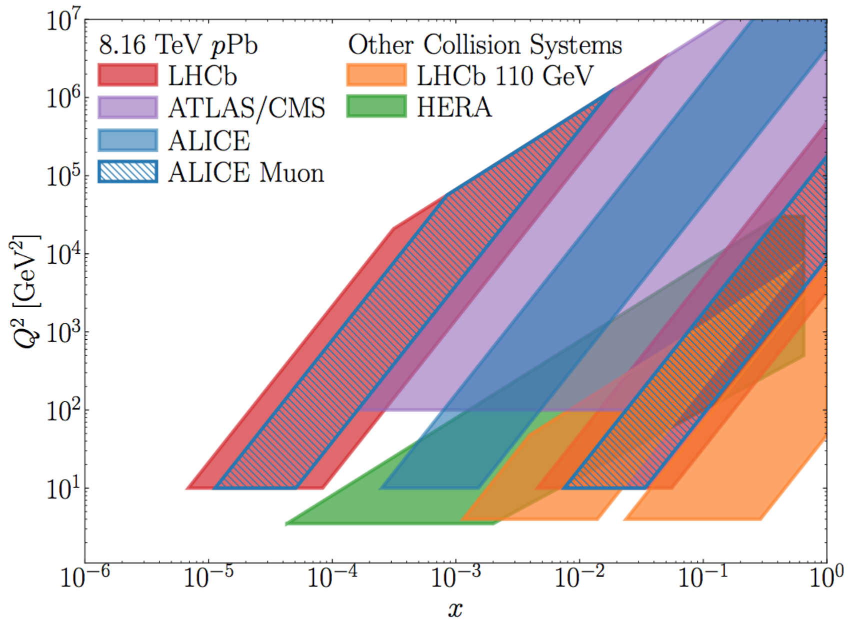


- Rapidity Coverage
  - y^*: rapidity in nucleon-nucleon cms
  - $y_{\text{cms}} = \pm 0.465$
  - Forward: $1.5 < y^* < 4.0$
  - Backward: $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$

- $\sqrt{s_{NN}} = 5.02$ TeV (2013, Run I)
  - *p*Pb (1.06 nb^{-1}) + Pb*p* (0.52 nb^{-1})

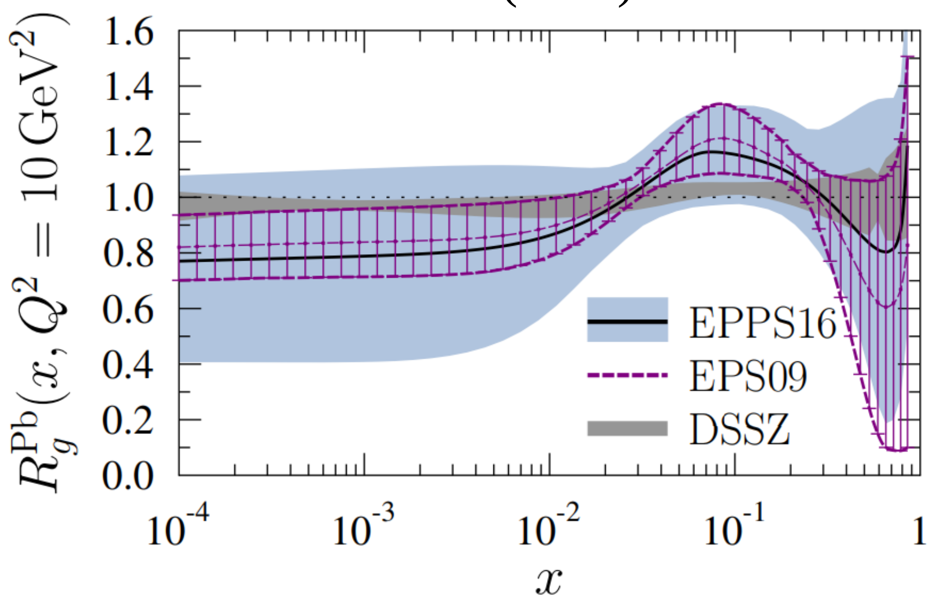
- $\sqrt{s_{NN}} = 8.16$ TeV (2016, Run II)
  - *p*Pb (13.6 nb^{-1}) + Pb*p* (21.8 nb^{-1})

LHCb: frontier experiment in phase space



Graphic by T. Boettcher

EPJ C10 (2017) 1140



Thanks to boost, resolution, low-p_T reach and fast read-out

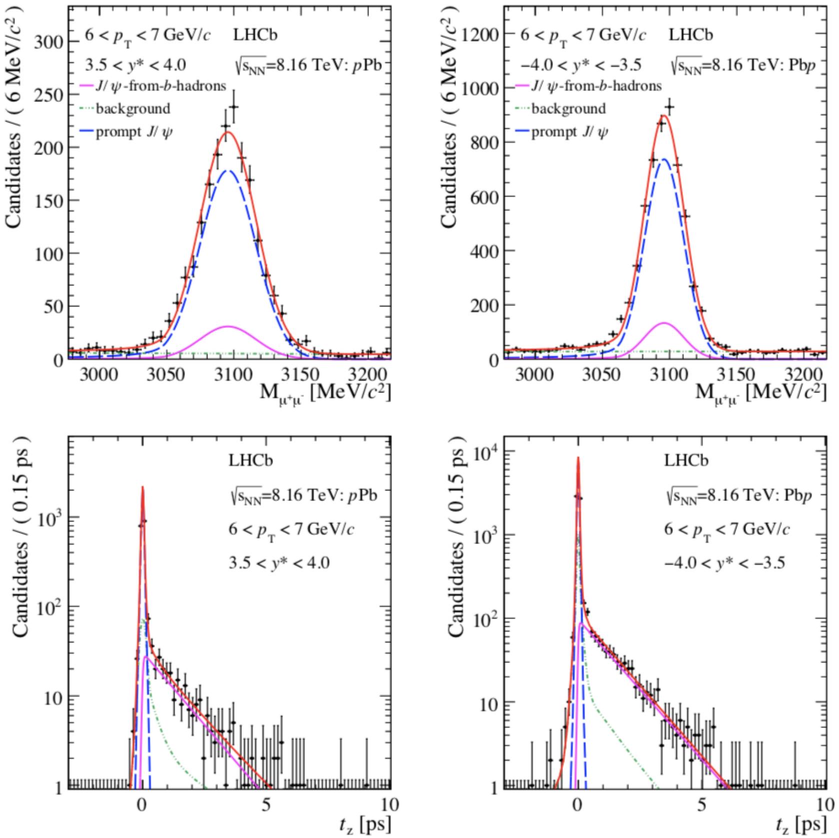
- disentangle initial state from other phenomena
- constrain initial state
- sensitive to physics of the saturation scale

Heavy quarkonium production in pPb collisions

Separation of prompt J/ψ and J/ψ-from-b

- 2016 pPb collision data, 8.16 TeV
- Prompt J/ψ and J/ψ-from-b are extracted by simultaneous fit of mass and pseudo-proper time: $t_Z = (Z_{J/\psi}\text{ -}Z_{PV}) \times M_{J/\psi}/p_Z$

Forward　　　　　　Backward



Mass distribution:
Signal: Crystal Ball
Background: exponential

t_Z distribution:
Signal: δ (t_Z) for prompt J/ψ;
Exponential for J/ψ-from-b.
Background: empirical function from sideband

Total yields:

	prompt	from-b
Forward:	$\sim 3.8 \times 10^5$;	$\sim 6.7 \times 10^4$
Backward:	$\sim 5.6 \times 10^5$;	$\sim 7.1 \times 10^4$

[PLB 774(2017) 159-178]

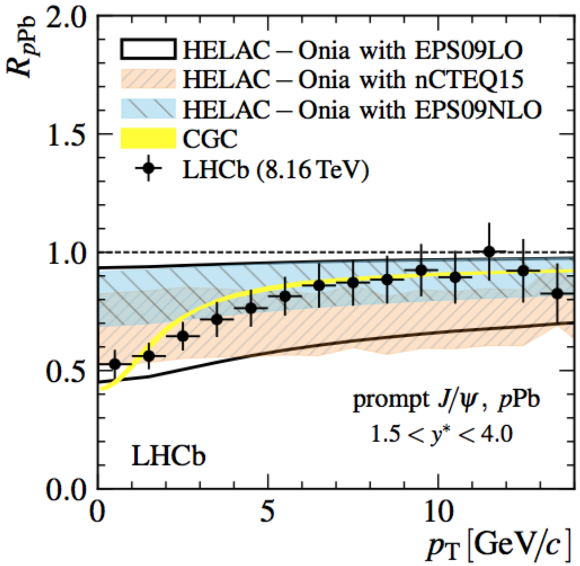
Prompt J/ψ R_{pPb} in pPb at 8.16 TeV

Nuclear modification factor is defined as:

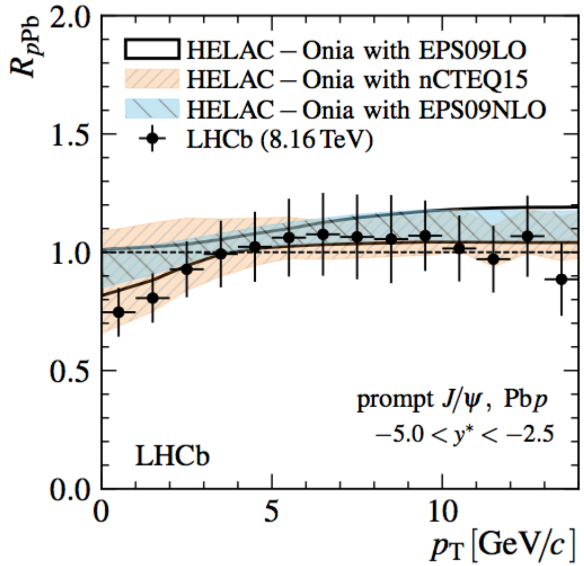
$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) \equiv \frac{1}{A}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}, A = 208$$

- In Fwd: suppression at low p_T up to 50%, converging to unity at high p_T
- In Bwd: R_{pPb} closer to unity. Intriguing low values in Bwd at low p_T
- Overall agreement with theoretical models. Compatible with pPb 5 TeV results.

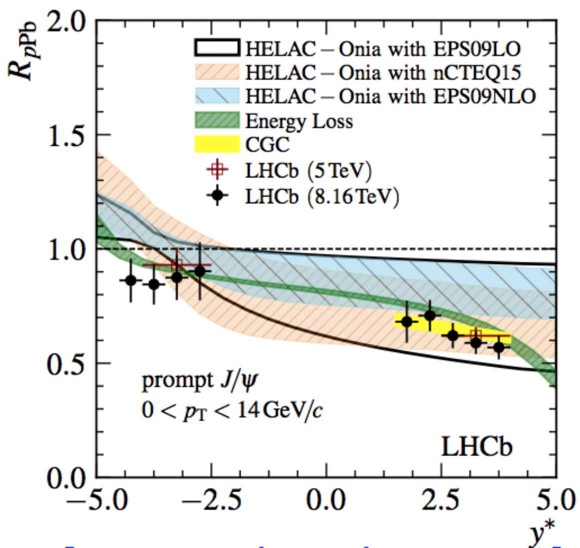
R_{pPb} vs. p_T, Forward



R_{pPb} vs. p_T, Backward



R_{pPb} vs. y^*



[PLB 774(2017) 159-178]

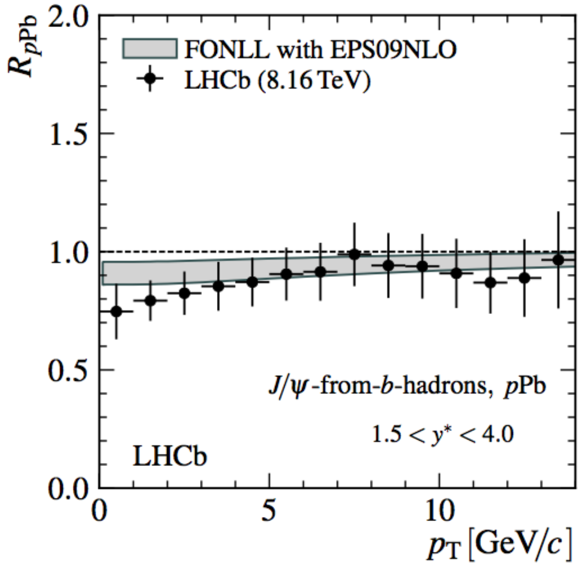
J/ψ-from-b R_{pPb} in pPb at 8.16 TeV

Nuclear modification factor is defined as:

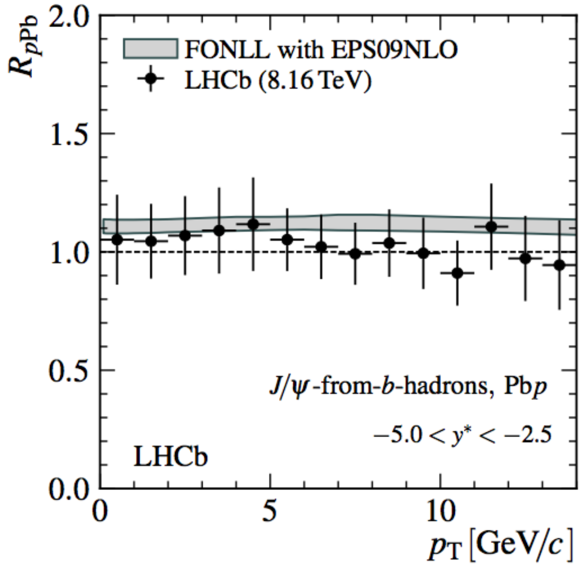
$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) \equiv \frac{1}{A}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}, A = 208$$

- In Fwd: suppression at low p_T up to 30%, converging to unity at high p_T
- In Bwd: R_{pPb} slightly above unity
- Overall agreement with theoretical model. Compatible with pPb 5 TeV results.

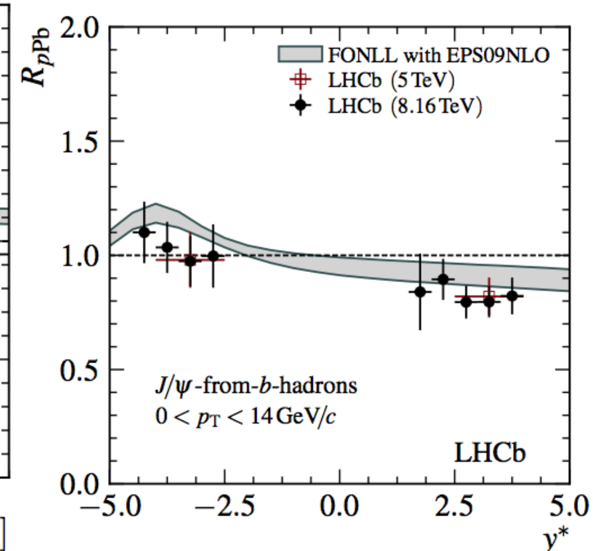
R_{pPb} vs. p_T, Forward



R_{pPb} vs. p_T, Backward



R_{pPb} vs. y^*



[PLB 774(2017) 159-178]

$J/\psi\ R_{FB}$ in pPb at 8.16 TeV

Forward-backward production ratio is defined as:

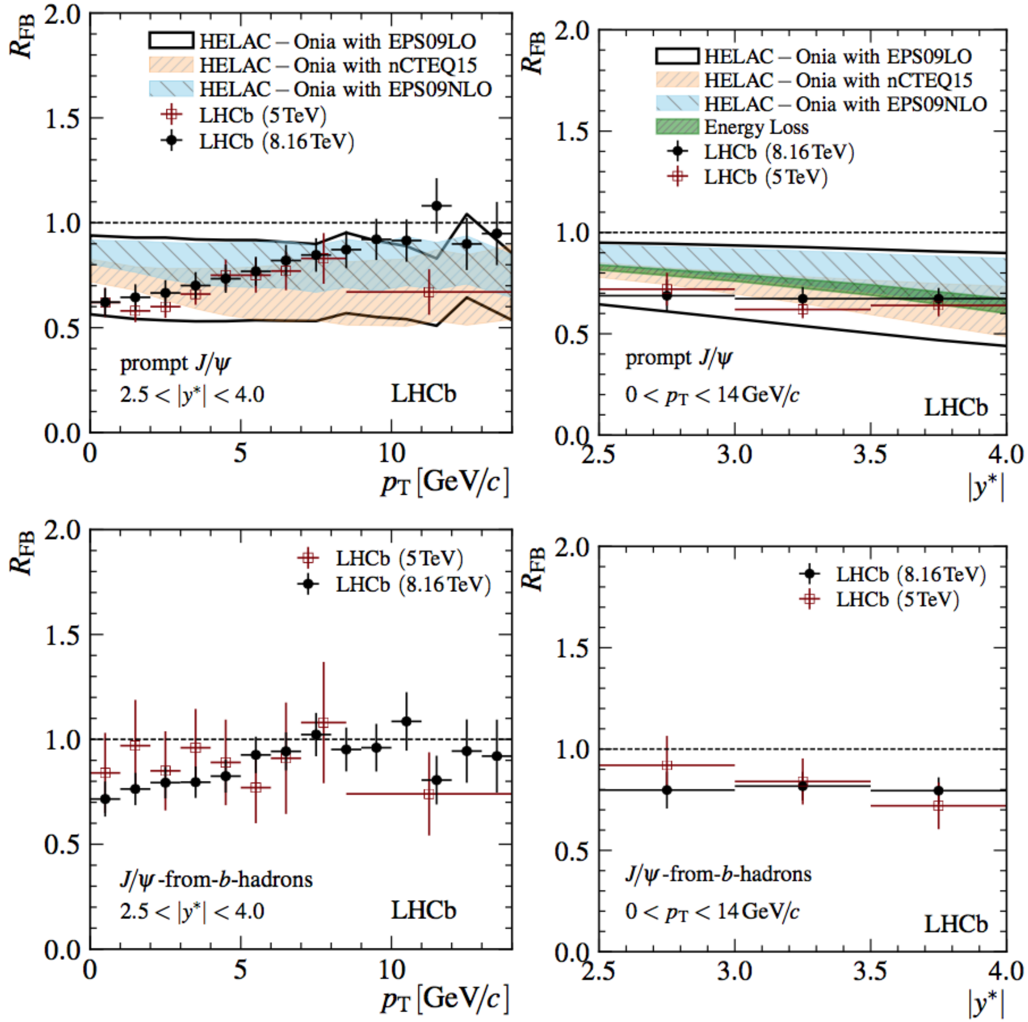
$$R_{\rm FB}(p_{\rm T}, y^*) \equiv \frac{\frac{{\rm d}^2\sigma_{p{\rm Pb}}(p_{\rm T}, +|y^*|)}{{\rm d}p_{\rm T}{\rm d}y^*}}{\frac{{\rm d}^2\sigma_{{\rm Pb}p}(p_{\rm T}, -|y^*|)}{{\rm d}p_{\rm T}{\rm d}y^*}}$$

- Clear forward-backward asymmetry for prompt J/ψ, in particular at low p_T
- For J/ψ-from-b: R_{FB} is closer to unity
- Agreement with pPb 5 TeV data within uncertainties

R_{FB} vs. p_T $\quad$ R_{FB} vs. $y*$

Prompt

From-b



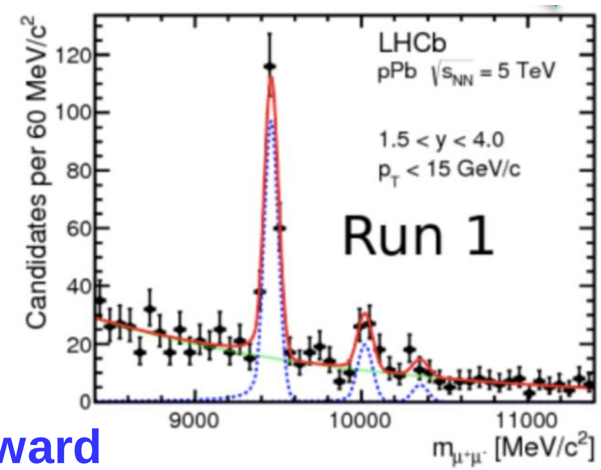
[PLB 774(2017) 159-178]

Υ(nS) signals in pPb at 8.16 TeV

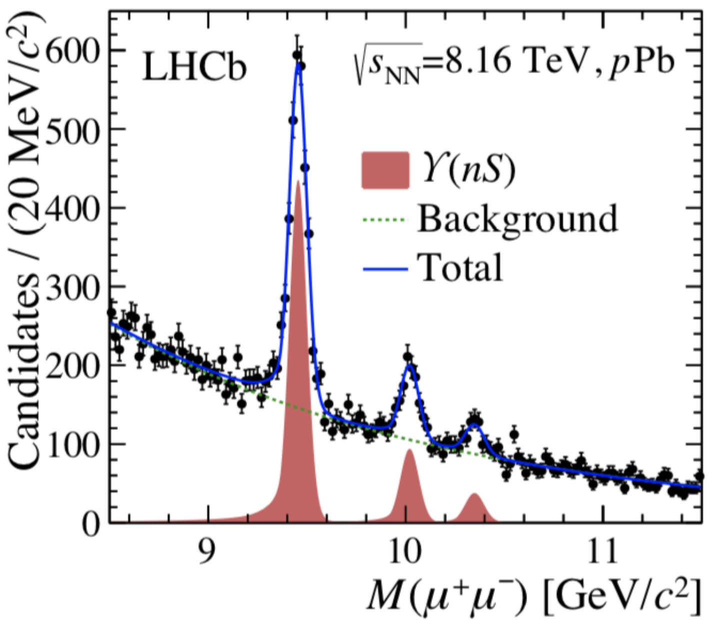
- Run II pPb sample ~20xdata w.r.t. Run I
- Cross-section, R_{pPb}, R_{FB} measured for all Υ states

Samples	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\mathcal{L}$
pPb	2705 ± 87	584 ± 49	262 ± 44	12.5 nb^{-1}
Pbp	3072 ± 82	679 ± 54	159 ± 39	19.3 nb^{-1}

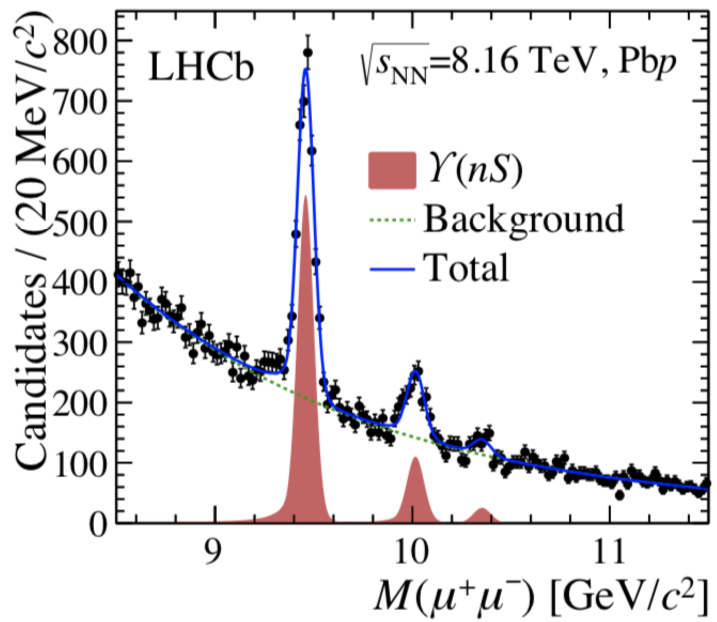
JHEP1407 (2014) 094



Forward



Backward

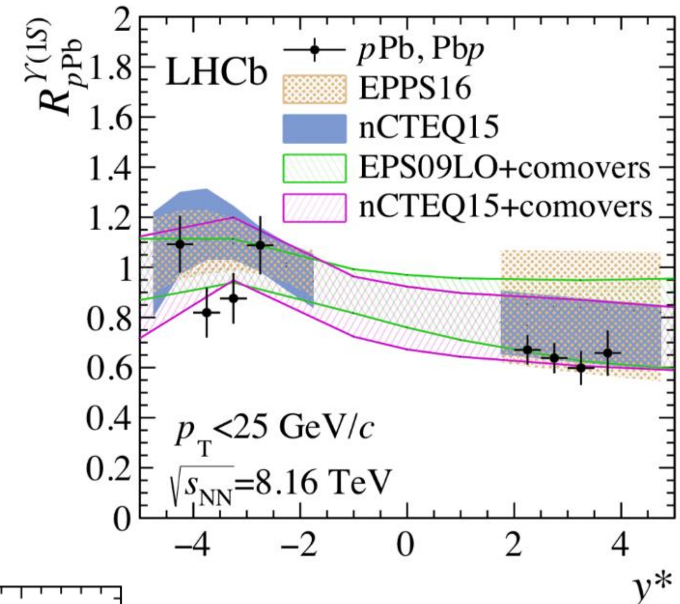


arXiv: 1810.07655

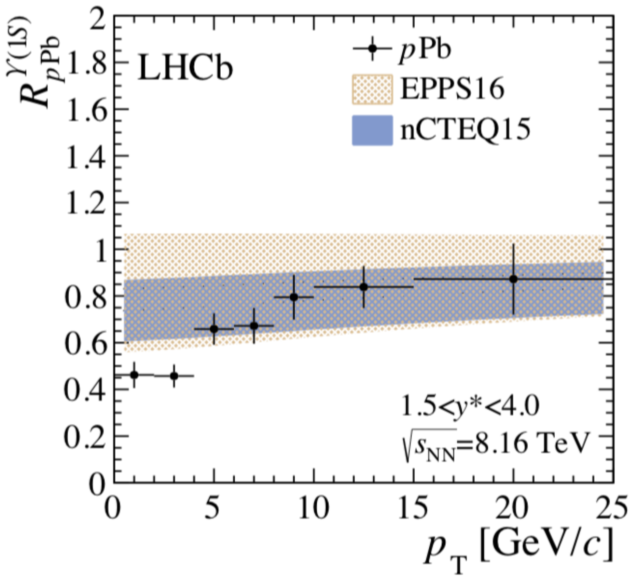
$\Upsilon(1S)\ R_{pPb}$ in pPb at 8.16 TeV

$$R_{p\mathrm{Pb}}(p_{\mathrm{T}},y^*)=\frac{1}{208}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_{\mathrm{T}},y^*)/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_{\mathrm{T}},y^*)/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*}$$

- Suppression in the forward pPb region confirmed



Forward



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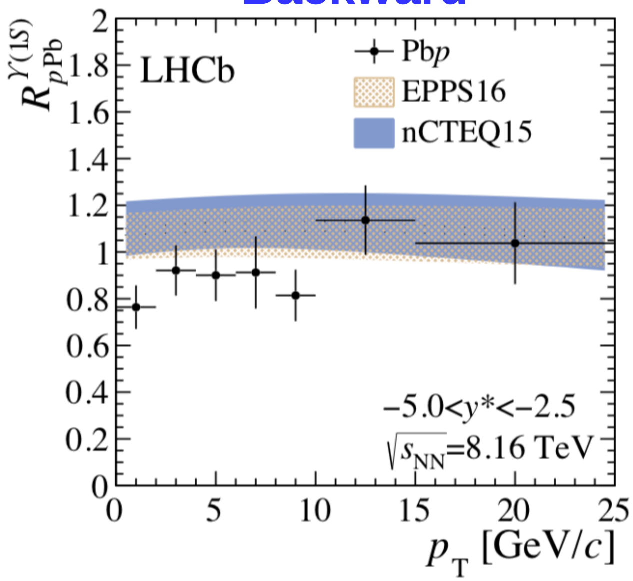
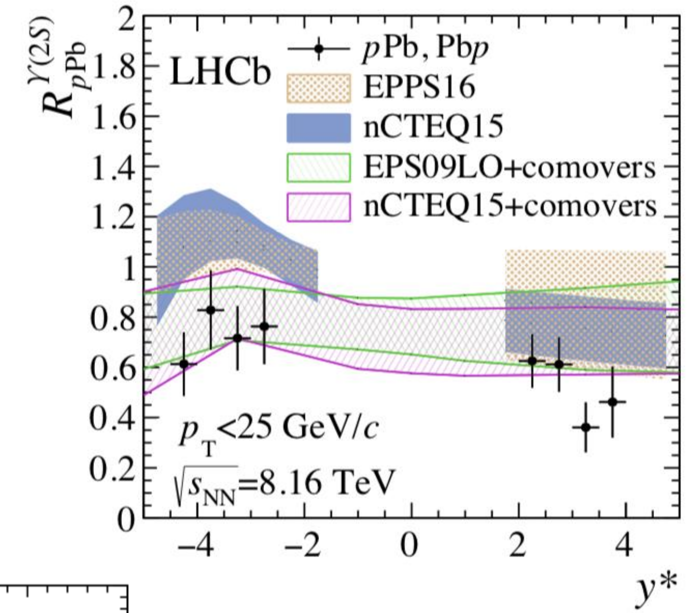


arXiv: 1810.07655

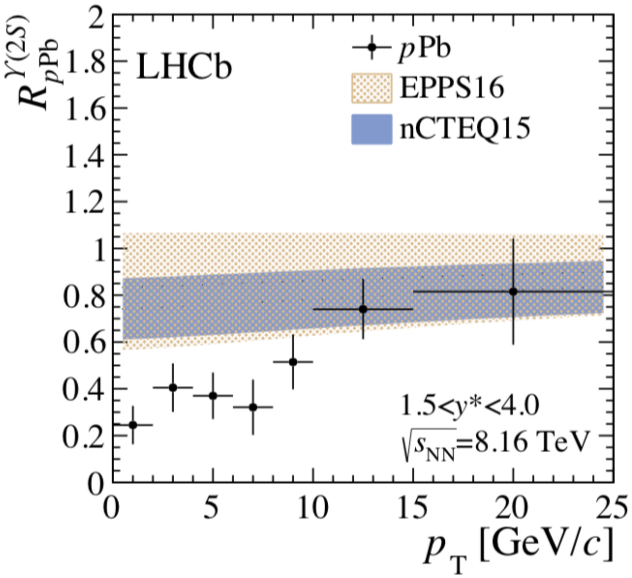
$\Upsilon(2S)\ R_{pPb}$ in pPb at 8.16 TeV

$$R_{p\mathrm{Pb}}(p_{\mathrm{T}}, y^*) = \frac{1}{208}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_{\mathrm{T}}, y^*)/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_{\mathrm{T}}, y^*)/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*}$$

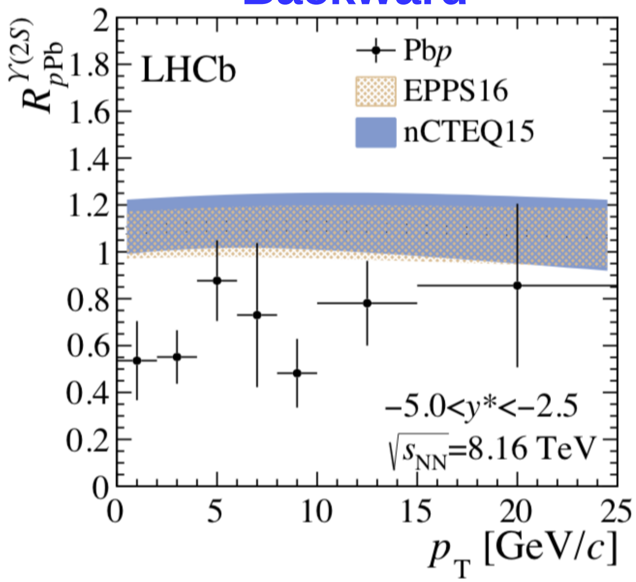
- More suppression in the forward pPb region



Forward



Backward

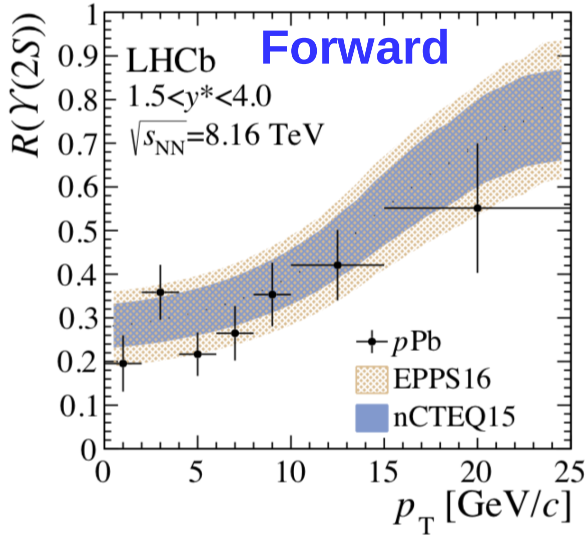


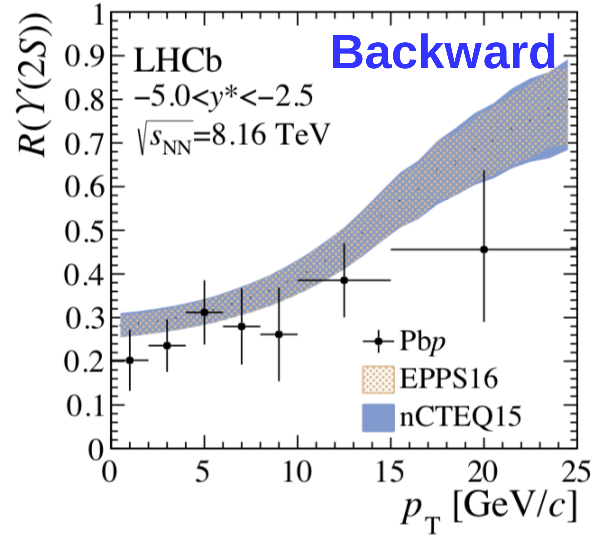
arXiv: 1810.07655

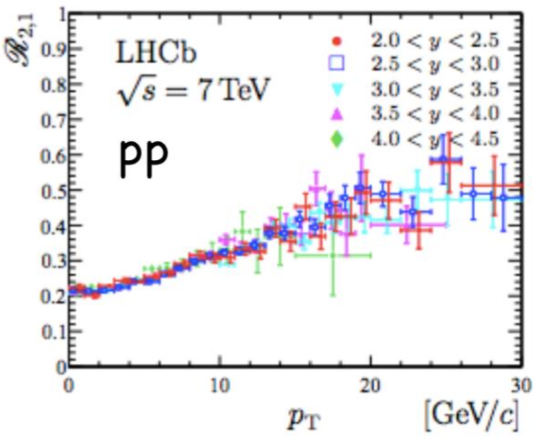
Υ(nS) to Υ(1S) ratios in pPb at 8.16 TeV

$$R(\Upsilon(nS)) = \frac{[\mathrm{d}^2\sigma/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*]\,(\Upsilon(nS))}{[\mathrm{d}^2\sigma/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*]\,(\Upsilon(1S))}$$

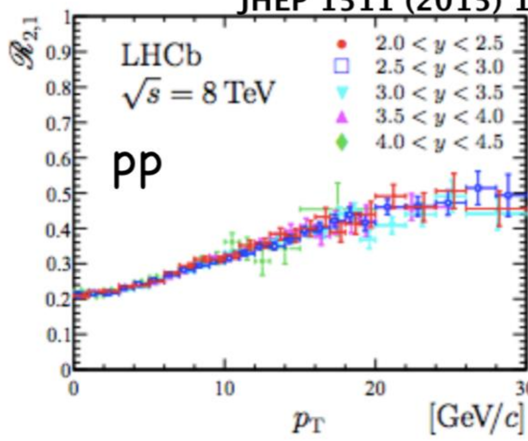
arXiv: 1810.07655

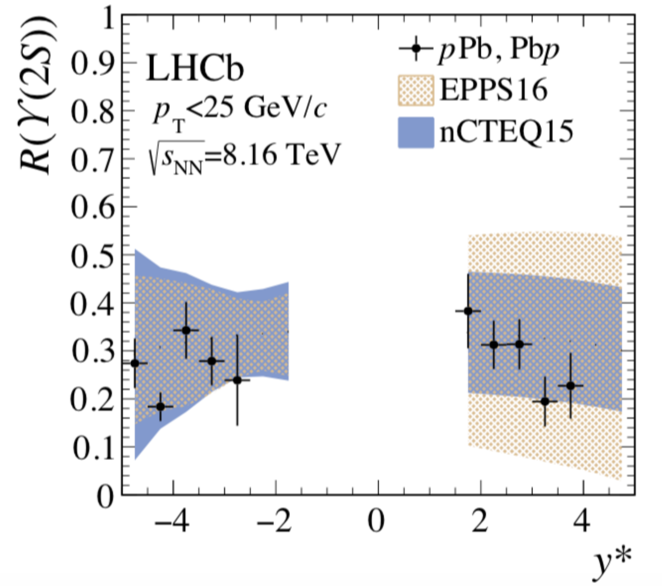






JHEP 1511 (2015) 103



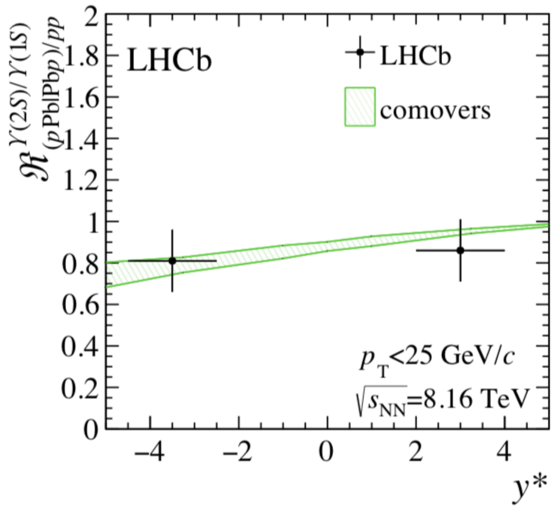


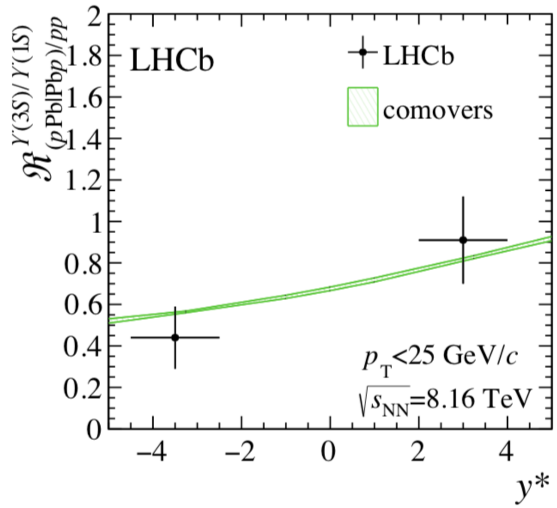
Υ(nS) double ratios in pPb at 8.16 TeV

arXiv: 1810.07655

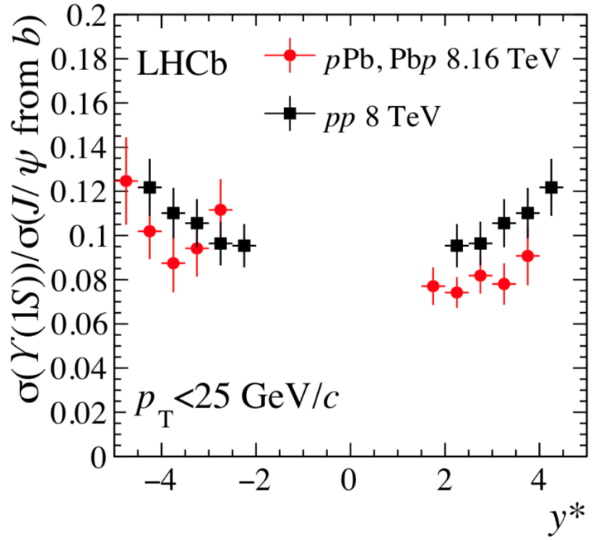
$$\mathfrak{R}^{\Upsilon(nS)/\Upsilon(1S)}_{(p\text{Pb}|\text{Pb}p)/pp} = \frac{R(\Upsilon(nS))_{p\text{Pb}|\text{Pb}p}}{R(\Upsilon(nS))_{pp}}$$

$$\mathfrak{R}^{\Upsilon(2S)/\Upsilon(1S)}_{p\text{Pb}/pp} = 0.86 \pm 0.15,$$
$$\mathfrak{R}^{\Upsilon(3S)/\Upsilon(1S)}_{p\text{Pb}/pp} = 0.81 \pm 0.15,$$
$$\mathfrak{R}^{\Upsilon(2S)/\Upsilon(1S)}_{\text{Pb}p/pp} = 0.91 \pm 0.21,$$
$$\mathfrak{R}^{\Upsilon(3S)/\Upsilon(1S)}_{\text{Pb}p/pp} = 0.44 \pm 0.15.$$



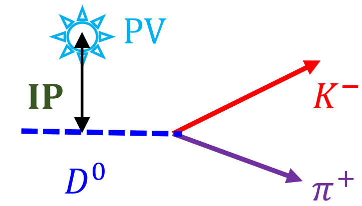


Ratio of $\Upsilon(1S)$ over non-prompt J/ψ

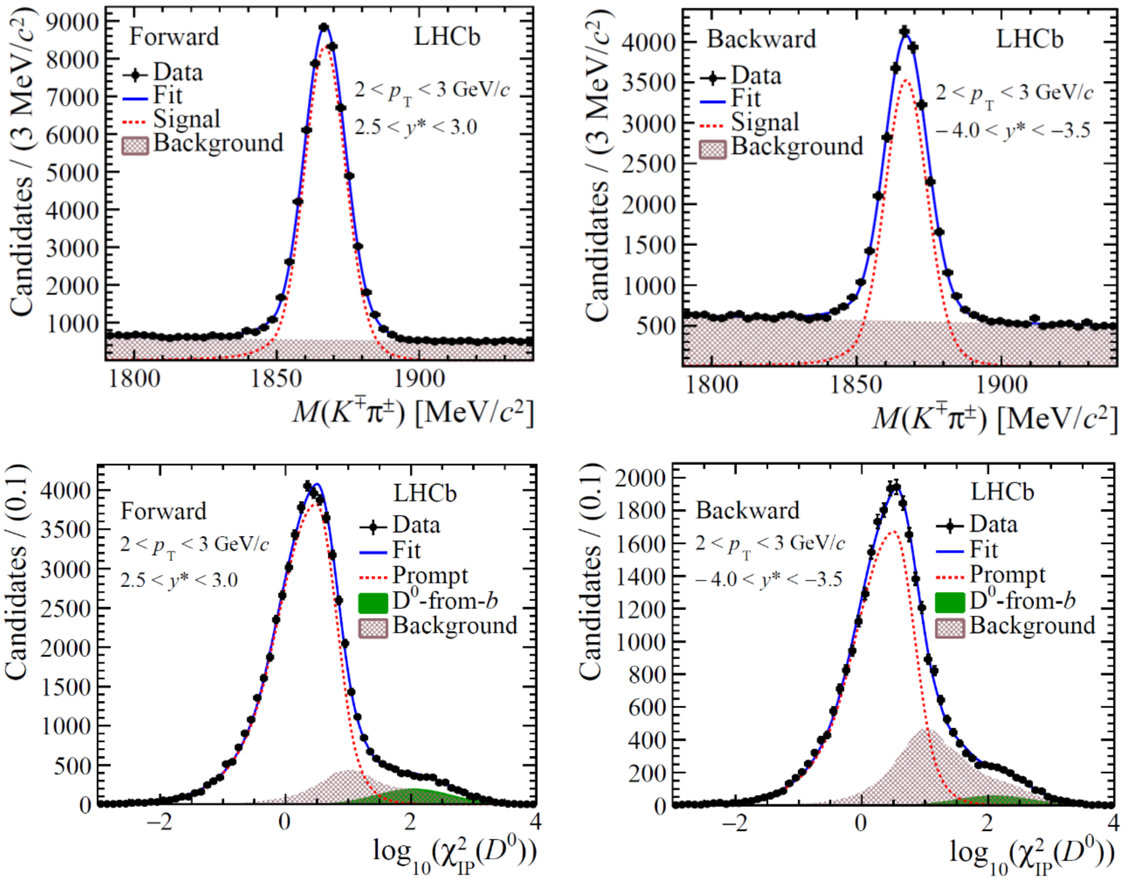


Open heavy flavor production in pPb collisions

Prompt D^0 measurement in pPb at 5 TeV



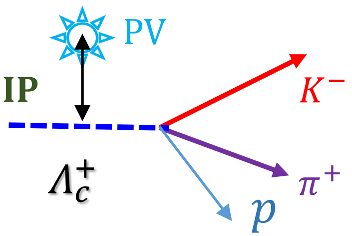
Forward ↓ Backward ↓



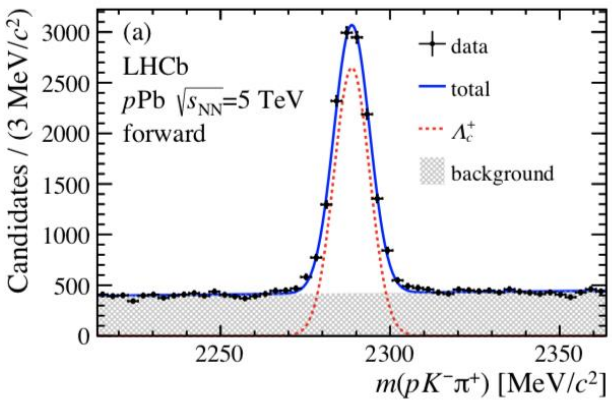
JHEP 10 (2017) 090

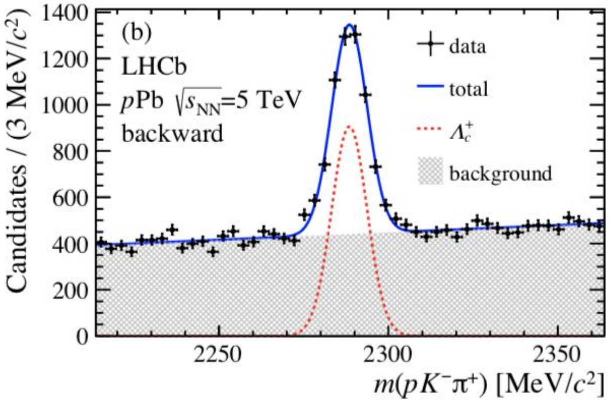
- Reconstructed through decay channel:
  $D^0 \to K^-\pi^+$
- Inclusive D^0 mesons from fitting invariant mass dist.:
  - Signal: Crystal Ball+Gaussian
  - Background: linear
- Prompt D^0 fraction extracted from fitting impact parameter dist.:
  - Prompt: simulation
  - D^0-from-b: simulation
  - Background: sideband in data

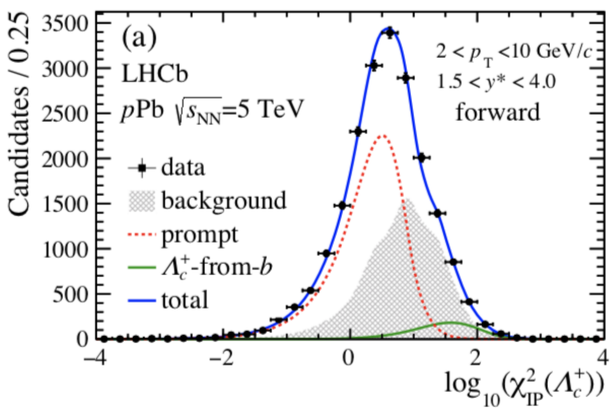
Prompt Λ_c^+ measurement in pPb at 5 TeV

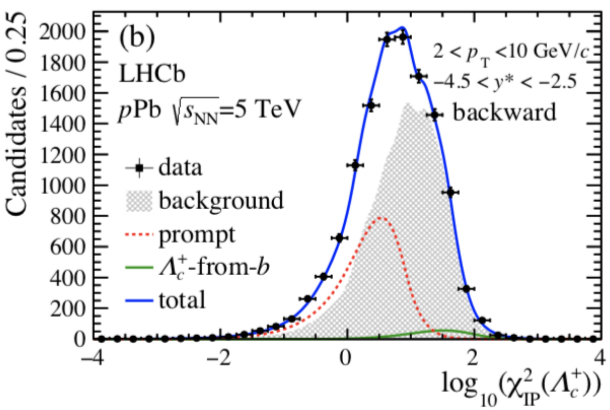


Forward ↓ Backward ↓





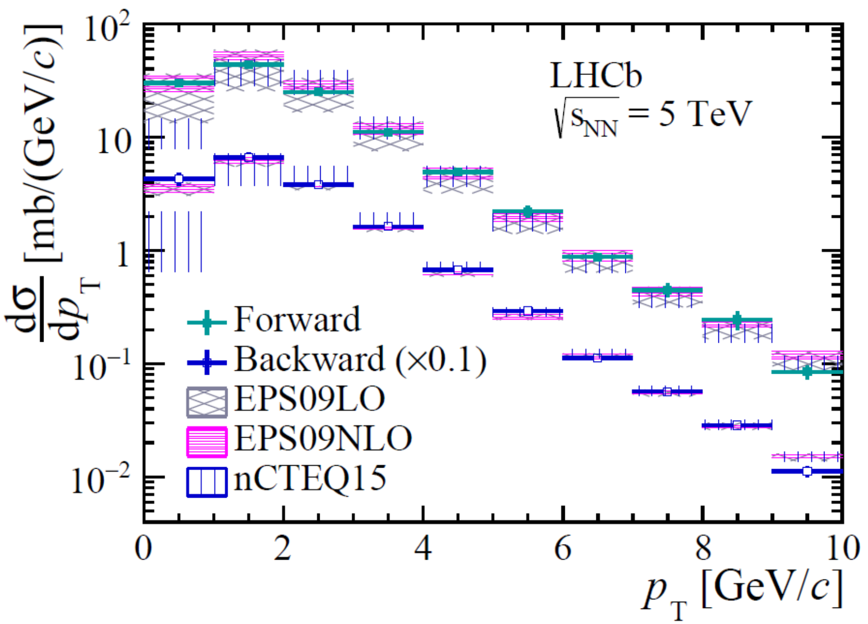


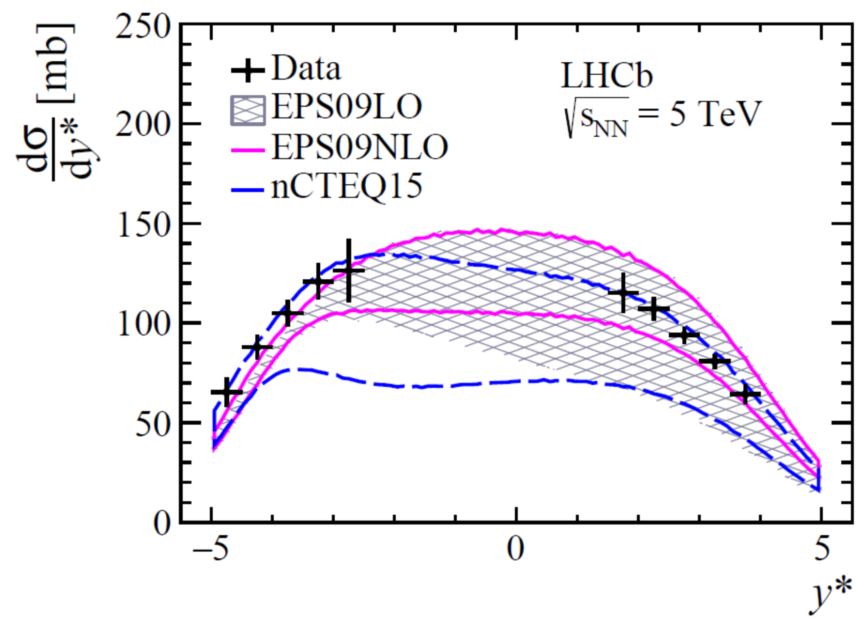


arXiv: 1809.01404

- Reconstructed through decay channel
  $\Lambda_c^+ \to pK^-\pi^+$
- Inclusive Λ_c^+ baryons from fitting invariant mass dist.:
  - Signal: Gaussian
  - Background: linear
- Prompt Λ_c^+ fraction extracted from fitting impact parameter dist.:
  - Prompt: simulation
  - Λ_c^+-from-b: simulation
  - Background: sideband in data

Prompt D^0 differential cross-section in pPb





- Data consistent with nPDF predictions
- Theoretical calculation with Helac-Onia:
  - Fit to existing LHC *pp* cross-section measurement
  - Incorporate nPDF
- nCTEQ15 under predicts cross-section at lowest p_T
- **Data more precise than nPDFs**

JHEP 10 (2017) 090

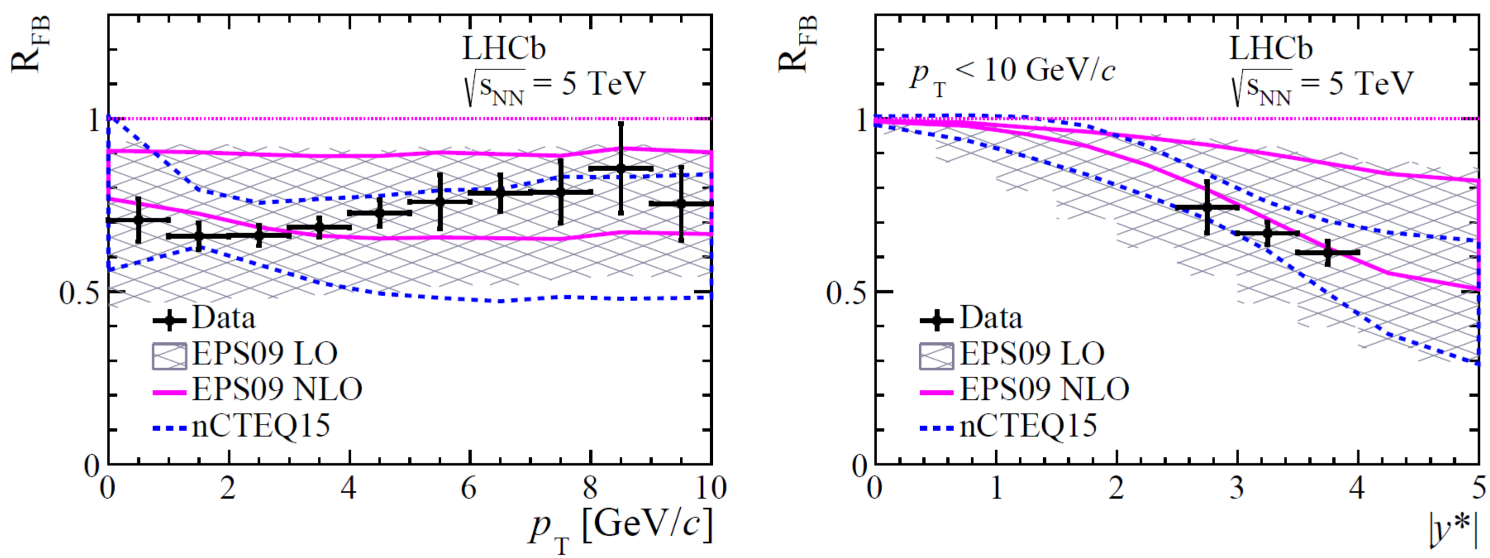
Eur. Phys. J. C77 (2017) 1
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

Prompt D^0 at 5 TeV forward-backward production ratio

$$R_{\mathrm{FB}} = \frac{\sigma(+|y^*|, p_{\mathrm{T}})}{\sigma(-|y^*|, p_{\mathrm{T}})}$$

- R_{FB} does not need results from *pp* collisions.
- Compared to Helac-Onia calculations incorporating different nPDFs
  - Model parameterisation constrained by existing LHC *pp* cross-section measurements
- Consistent with nPDF predictions within uncertainty
- **Data show smaller uncertainties than nPDF calculations**

JHEP 10 (2017) 090



Eur. Phys. J. C77 (2017) 1

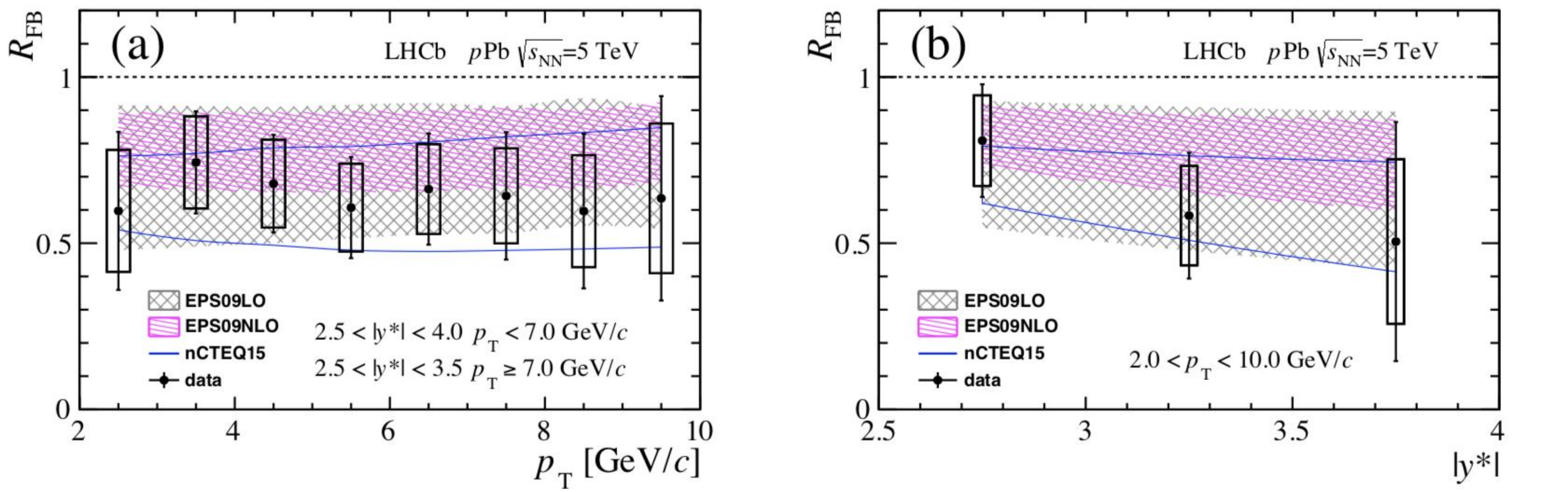
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

Prompt Λ_c^+ at 5 TeV forward-backward production ratio

$$R_{\mathrm{FB}} = \frac{\sigma(+|y^*|, p_{\mathrm{T}})}{\sigma(-|y^*|, p_{\mathrm{T}})}$$

- R_{FB} does not need results from *pp* collisions.
- Compared to Helac-Onia calculations incorporating different nPDFs
  - Model parameterisation constrained by LHC *pp* cross-section measurements
- Consistent with nPDF predictions within uncertainty
- **Data uncertainties comparable to nPDF calculations**

arXiv: 1809.01404



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Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

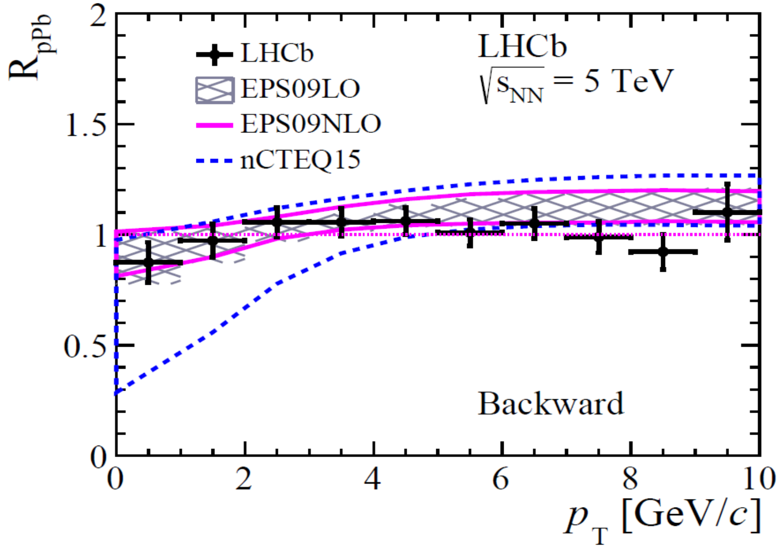
Prompt D^0 at 5 TeV nuclear modification factor in pPb

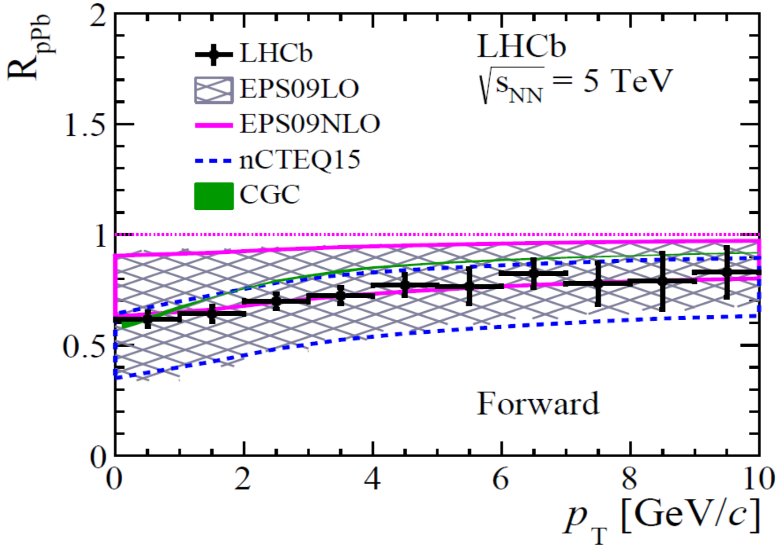
JHEP 10 (2003) 046
Eur. Phys. J. C77 (2017) 1
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

$$R_{p\text{Pb}}(y^*, p_\text{T}) = \frac{1}{A} \times \frac{\text{d}\sigma_{p\text{Pb}}(y^*, p_\text{T}, \sqrt{s_\text{NN}})/\text{d}x}{\text{d}\sigma_{pp}(y^*, p_\text{T}, \sqrt{s_\text{NN}})/\text{d}x}, \quad A=208$$

- *pp* reference directly measured by LHCb
- $R_{p\text{Pb}}$ suppressed at forward rapidity
  - slight increase with increasing p_T
- $R_{p\text{Pb}}$ closer to 1 at backward rapidity

- Measurements consistent with models with nPDF, CGC
- **Data has smaller uncertainties than theory**





JHEP 10 (2017) 090

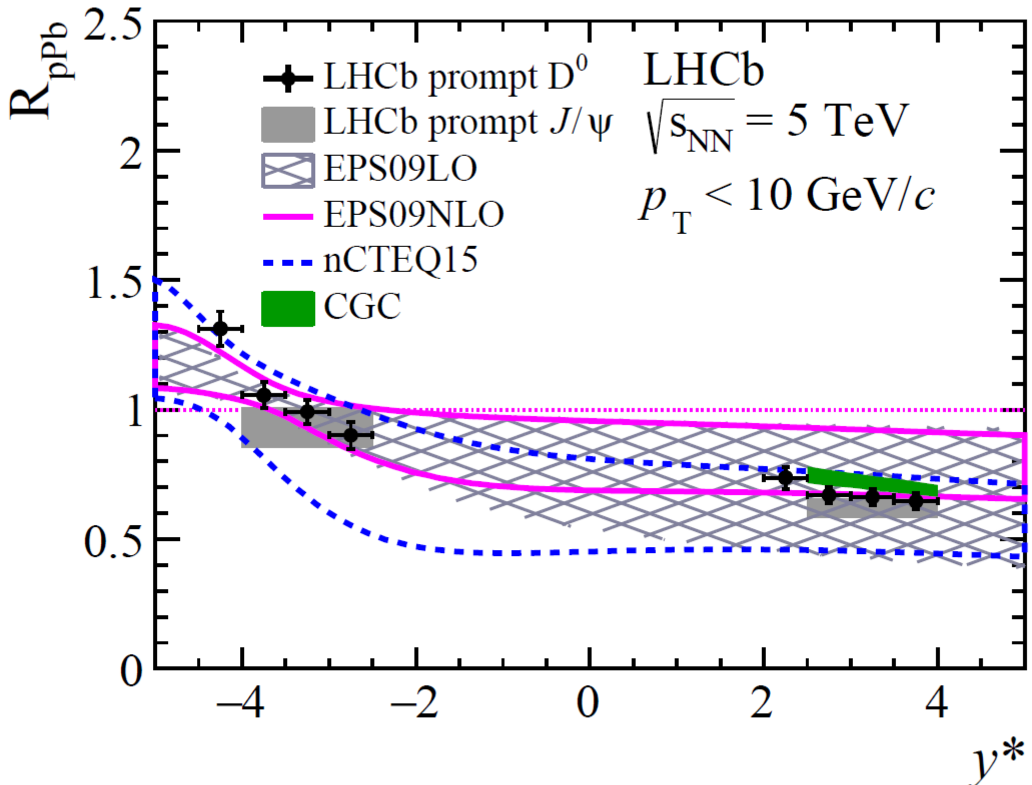
Prompt D^0 at 5 TeV nuclear modification factor in pPb

JHEP 10 (2003) 046
Eur. Phys. J. C77 (2017) 1
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

$$R_{p\mathrm{Pb}}(y^*, p_\mathrm{T}) = \frac{1}{A} \times \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/\mathrm{d}x}{\mathrm{d}\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/\mathrm{d}x}, \ A = 208$$

- *pp* reference directly measured by LHCb
- forward
  - significant suppression
- backward
  - closer to 1
  - hint of enhancement at large rapidity

- Measurements consistent with models with nPDF, CGC
- **Data has smaller uncertainties than theory**



JHEP 10 (2017) 090

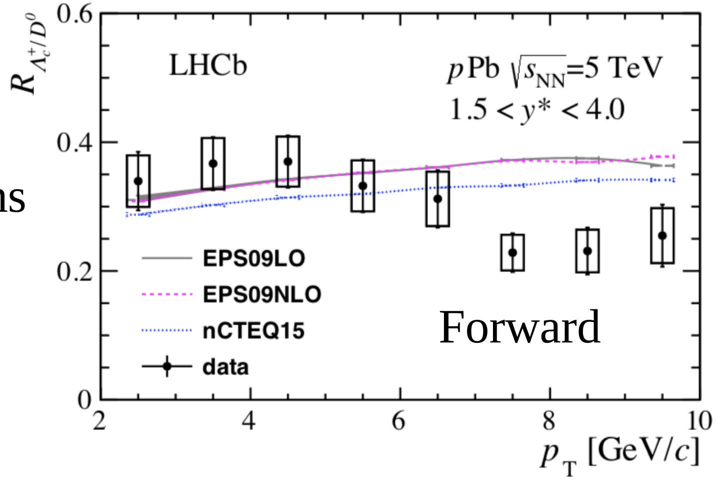
Charmed baryon/meson production ratio $R_{\Lambda_c^+/D^0}$ at 5 TeV

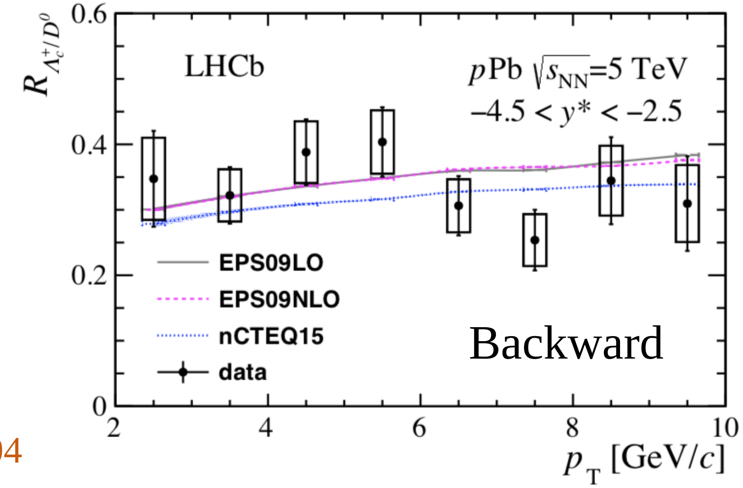
Eur. Phys. J. C77 (2017) 1
Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_{\mathrm{T}})}{\sigma_{D^0}(y^*, p_{\mathrm{T}})}$$

- Sensitive to charm hadronisation mechanisms
- Model based on measured *pp* cross-section
- nPDF effects mostly cancel
  - EPS09LO & EPS09NLO similar
  - nCTEQ15 slightly lower.
- Slight increase with increasing p_{T}

- **Forward:**
  - **Consistent at lower p_{T}**
  - **Below theories at higher p_{T}**
- **Backward:**
  - **Consistent for all p_{T}**





arXiv: 1809.01404

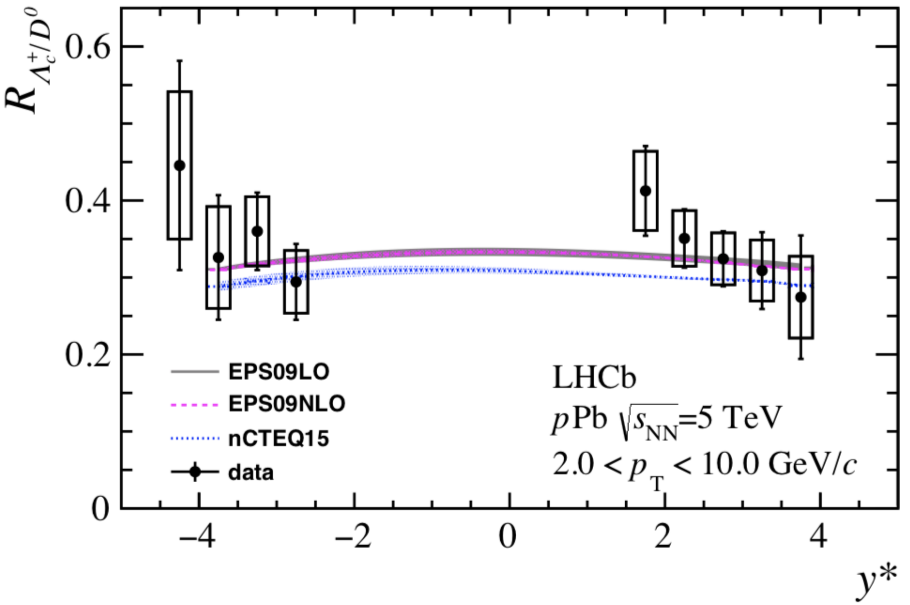
Charmed baryon/meson production ratio $R_{\Lambda_c^+/D^0}$ at 5 TeV

$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_T)}{\sigma_{D^0}(y^*, p_T)}$$

- Sensitive to charm hadronisation mechanisms
- Model based on measured *pp* cross-section
- nPDF effects mostly cancel
    - EPS09LO & EPS09NLO similar
    - nCTEQ15 slightly lower
- Flat across y^*

- **Consistent with theories for all y^***

arXiv: 1809.01404

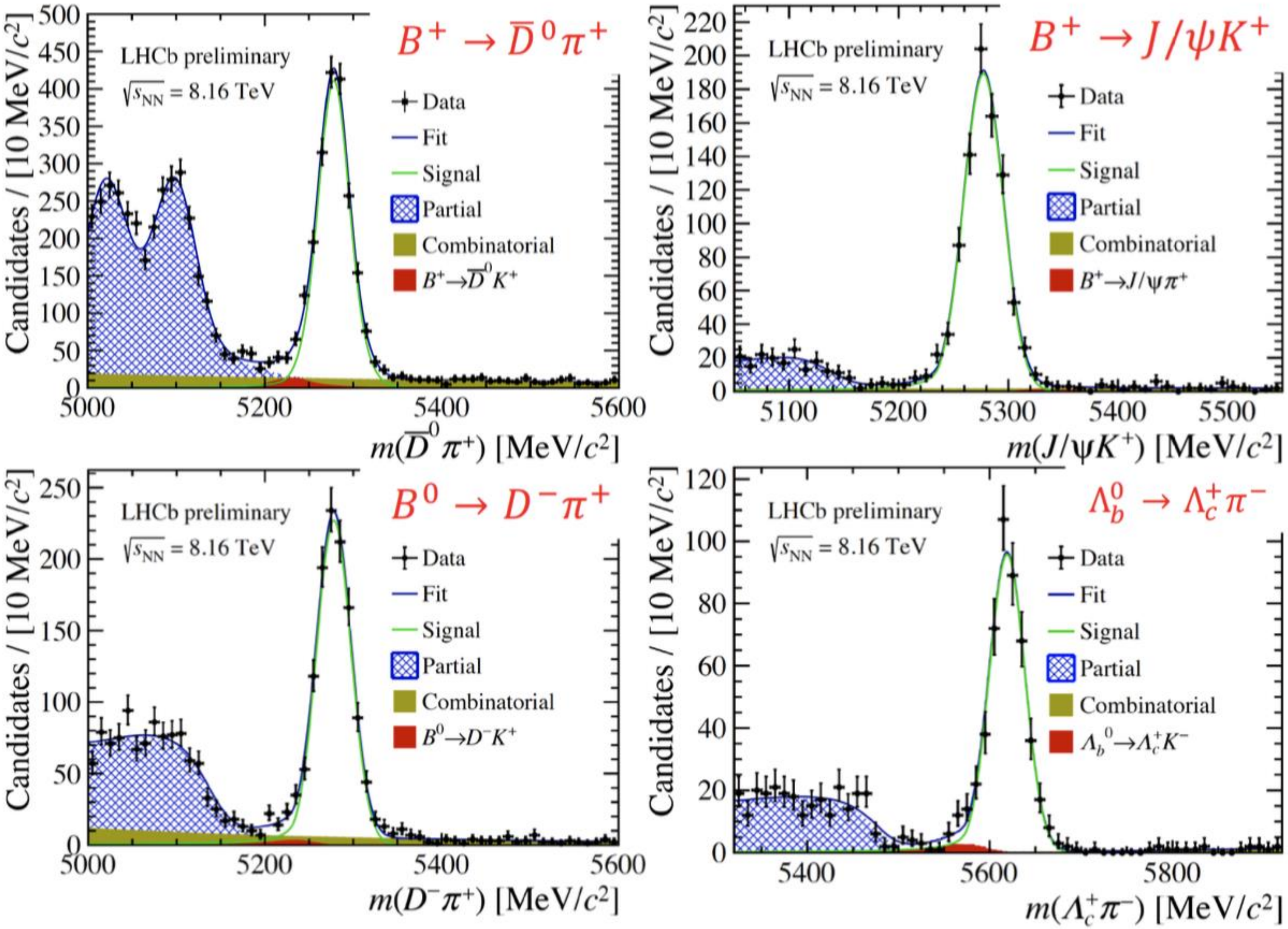


Eur. Phys. J. C77 (2017) 1

Comput. Phys. Commun. 184 (2013) 2562

Comput. Phys. Commun. 198 (2016) 238

Open beauty signals at 8.16 TeV



- Reconstructed through decay channels:

$B^+ \to J/\psi K^+$,

$B^+ \to \overline{D^0}\pi^+$;

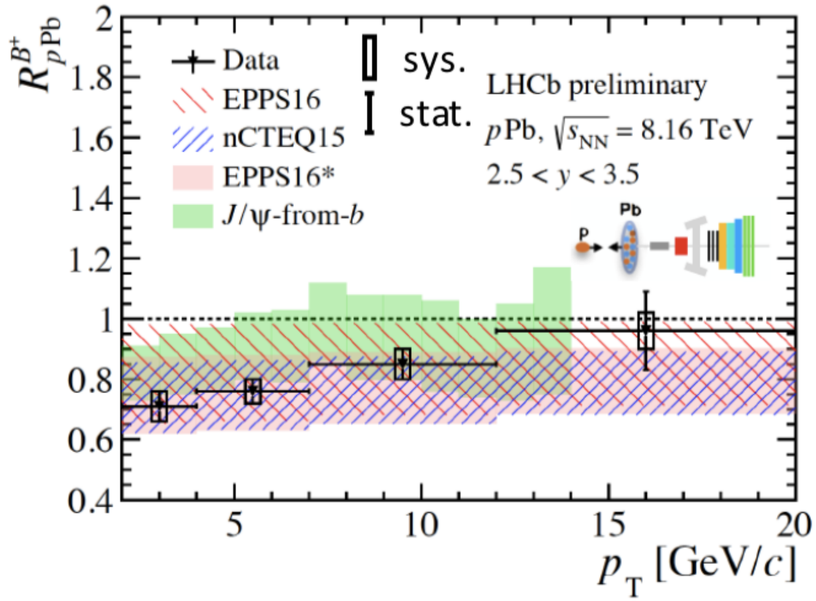
$B^0 \to D^-\pi^+$;

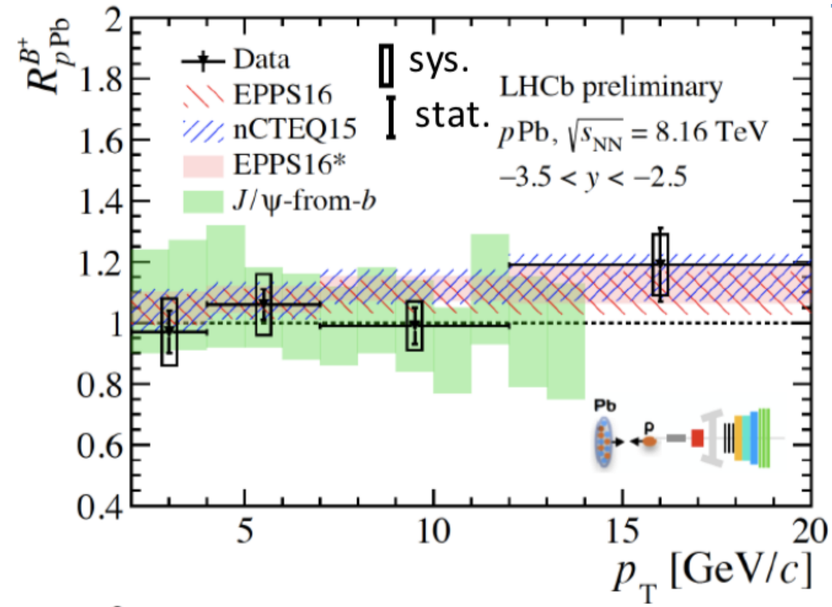
$\Lambda_b^0 \to \Lambda_c^+\pi^-$

LHCb-CONF-2018-004

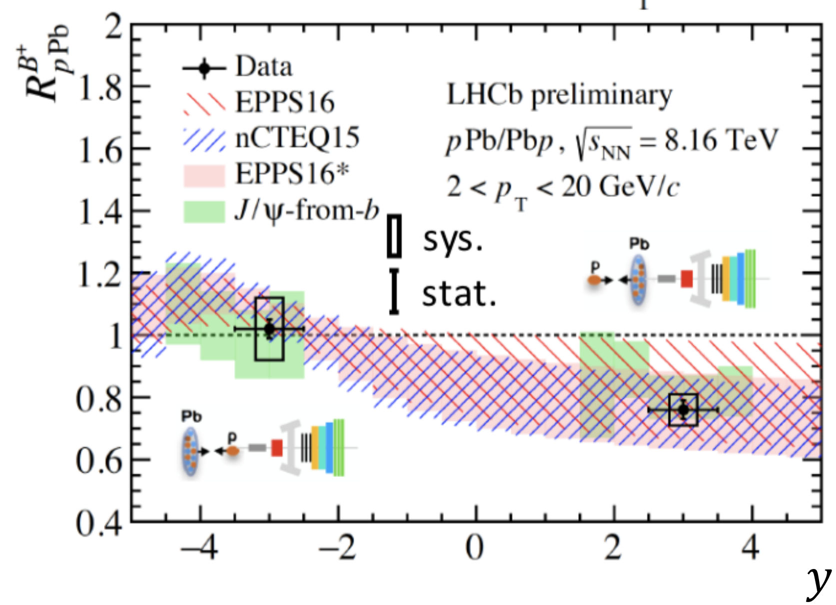
Extract yields by fitting invariant mass distribution and obtain cross section σ as a function of p_T and y

Open beauty R_{pPb} at 8.16 TeV



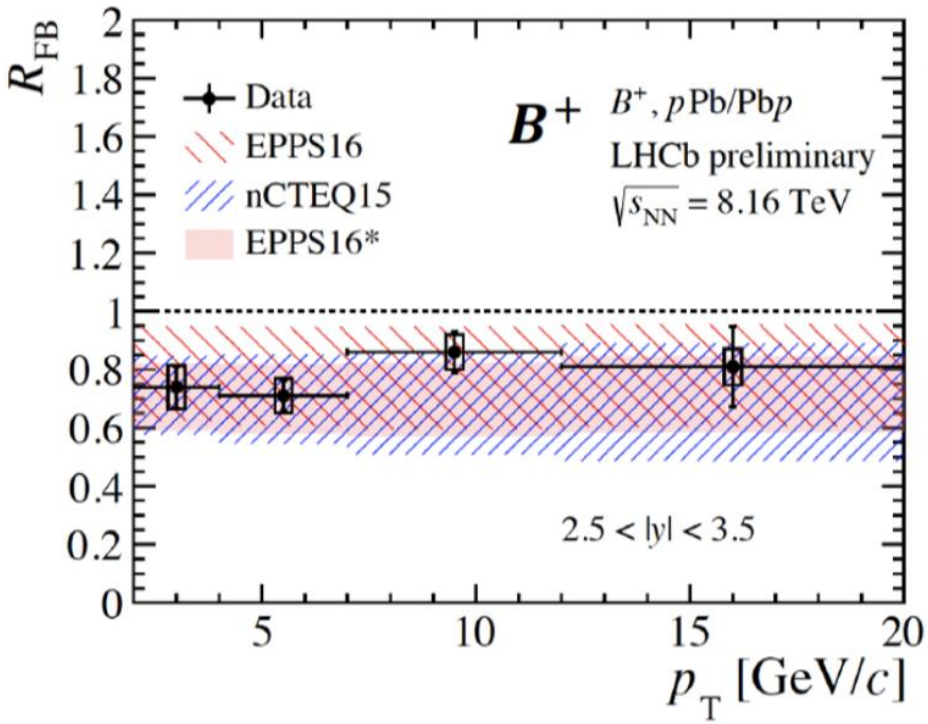


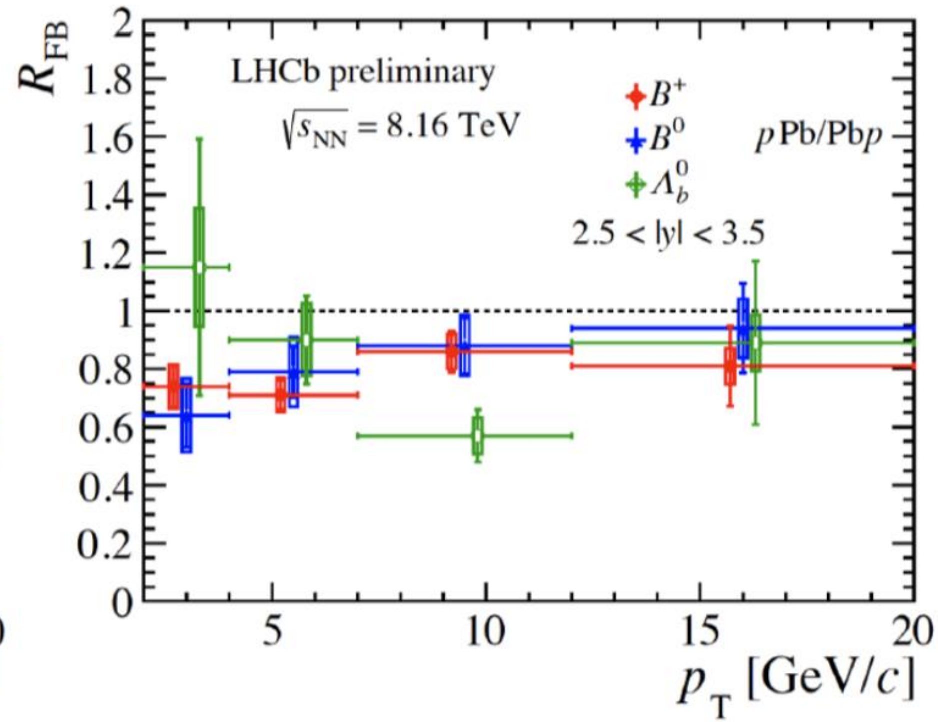
- Forward: suppressed, increases with p_{T}
- Backward: ≈ 1
- Data are consistent with nPDF calculations and J/ψ from b decay
- Beauty suppression is comparable to charm



LHCb-CONF-2018-004

Open beauty forward-backward ratio at 8.16 TeV

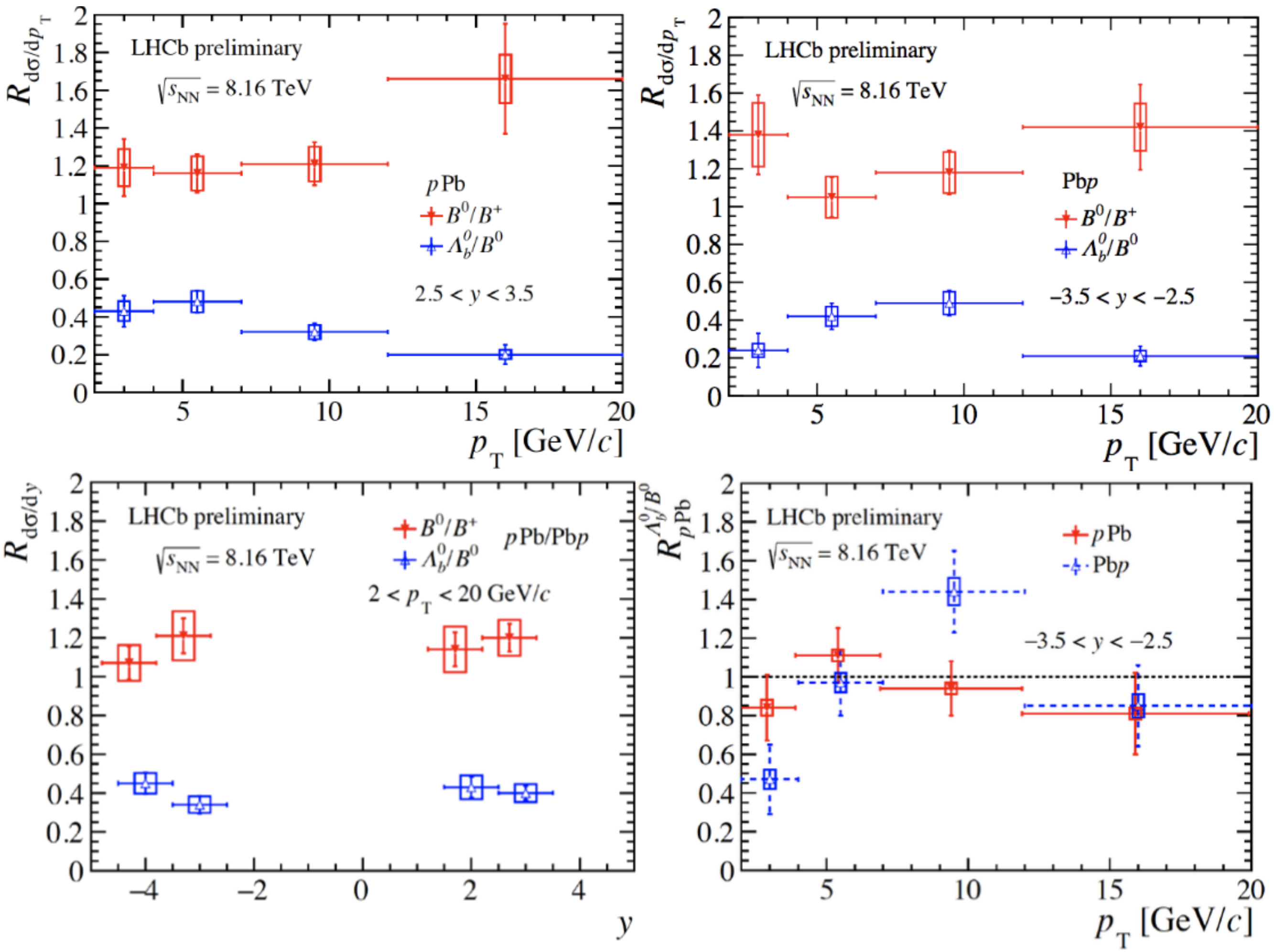




- R_{FB} for B mesons < 1
  - ➢No strong dependence on p_T is observed
  - ➢Consistent with nPDF calculations
- R_{FB} for B^0 and B^+ are similar
- R_{FB} for Λ_b^0 suffers larger statistical uncertainty

LHCb-CONF-2018-004

Open beauty particle ratios at 8.16 TeV



$$\frac{d\sigma_{B^0}/dy(dp_T)}{d\sigma_{B^+}/dy(dp_T)}$$

$$\frac{d\sigma_{\Lambda_b^0}/dy(dp_T)}{d\sigma_{B^0}/dy(dp_T)}$$

- B^0/B^+ about 1-σ from 1, explained by systematic uncertainties
- $\Lambda_b^0/B^0 \approx 0.4$, decreases at high p_T, and is compatible to Λ_c^+/D^0 in the same region, similar to LHCb pp data [JHEP 08 (2014) 143]

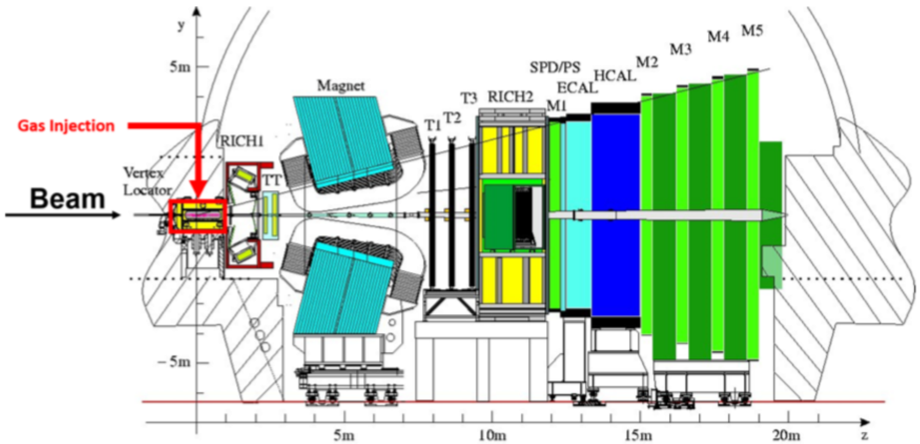
- $R_{pPb}^{\Lambda_b^0/B^0} \equiv R_{pPb}^{\Lambda_b^0}/R_{pPb}^{B^0} \approx 1$ and is independent of p_T at forward rapidity, suffers larger fluctuations due to higher level of background at backward rapidity

The LHCb fixed-target experiment

JINST 9 (2014) P12005

Unique fixed-target configuration at the LHC

Inject noble gases (He, Ne, Ar, ...) inside the Vertex Locator $\sim 10^{-7}$ mbar



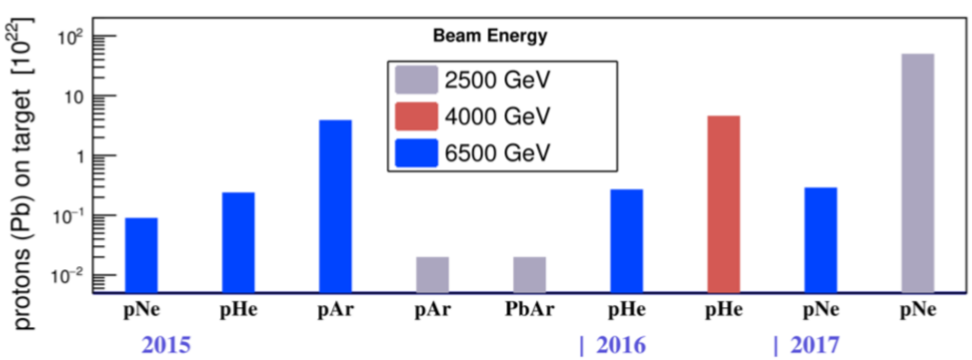
Installed for beam-gas imaging

Parasitic to collider data taking

Fully benefit from LHCb excellent performance

→ **New physics opportunities with *p*-nucleus and Pb-nucleus collisions**

Heavy-ion and cosmic ray related physics



Fixed-target kinematic region

$\sqrt{s_{NN}} \in [69, 115]$ GeV

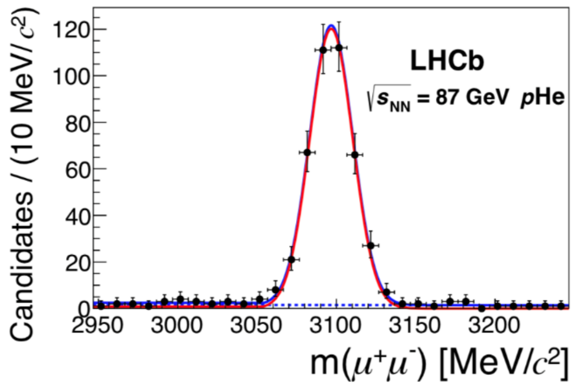
backward rapidity region

Charm production in fixed target pHe collisions

- **$J/\psi \to \mu^+\mu^-$ and $D^0 \to K^{\mp}\pi^{\pm}$ inclusive cross sections in *p*He @86.6 GeV**

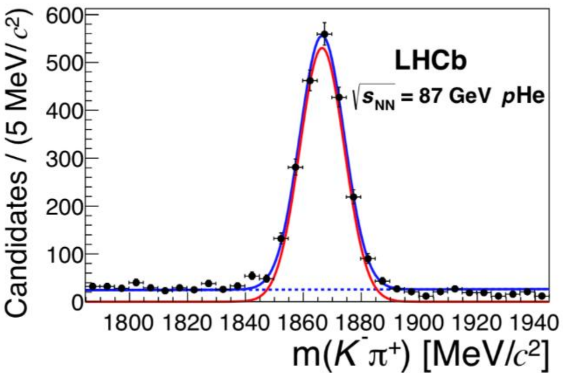
LHCb-PAPER-2018-023

arXiv:1810.07907



J/ψ

D^0

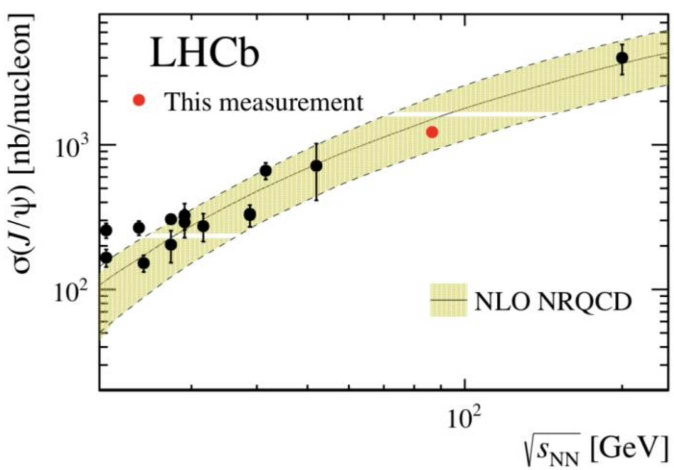


$$\sigma_{J/\psi} = 1225.6 \pm 100.7\,\mathrm{nb/nucleon}$$

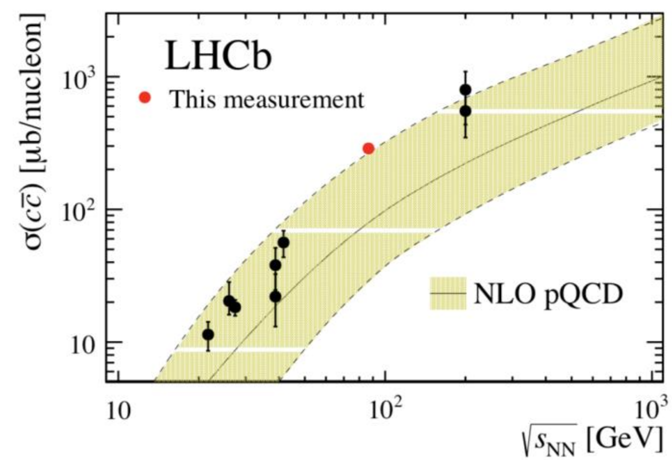
$$\sigma_{D^0} = 156.0 \pm 13.1\,\mu\mathrm{b/nucleon}$$

with fraction ($c \to D^0$) = 0.542±0.024

$$\sigma_{c\bar{c}} = 288 \pm 24.2 \pm 6.9\,\mu\mathrm{b/nucleon}$$



LHCb result in good agreement with NRQCD fit and other measurements



LHCb result in reasonable agreement with NLO pQCD (MNR) predictions and other measurements

PbPb collisions with LHCb

Ion-Ion runs: 10 μb^{-1} PbPb at 5.02 TeV (2015) and 0.4 μb^{-1} XeXe

→ 2018 PbPb run aiming for a factor 10 more

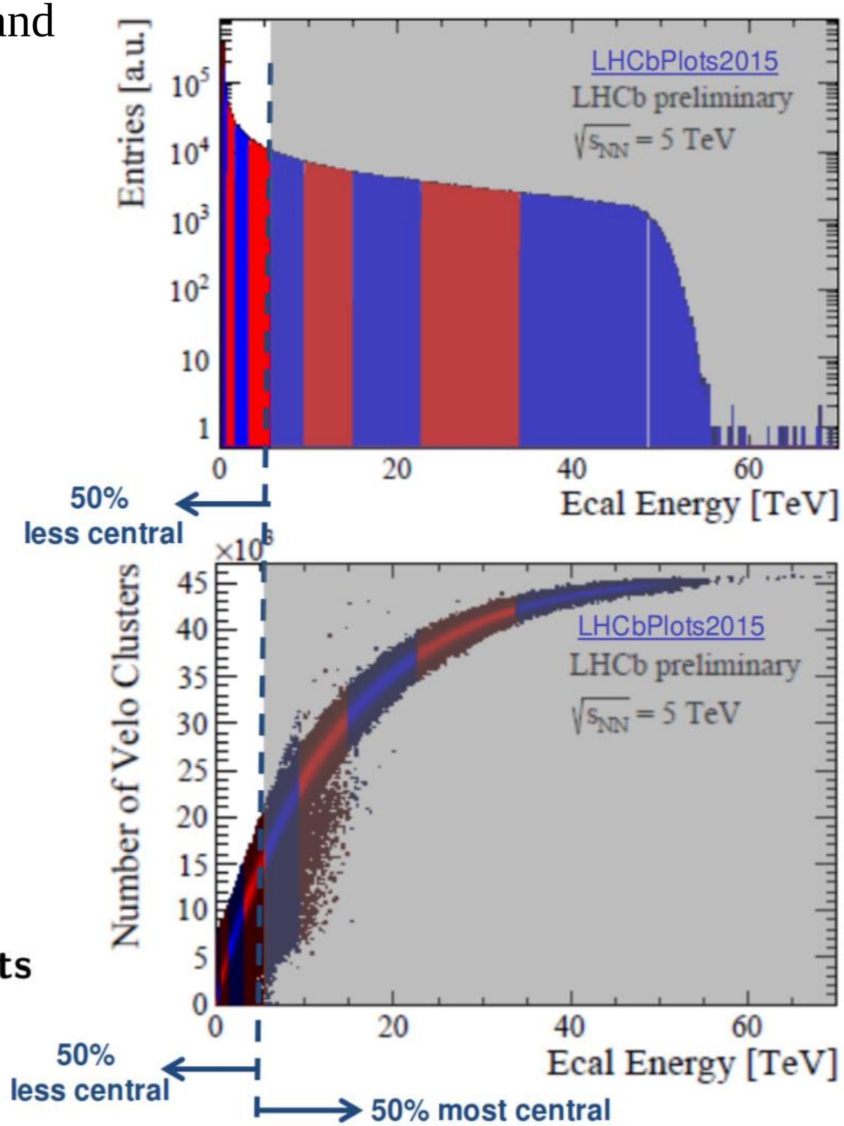
LHCb centrality

- Measured by the calorimeter
- Reaches the detector limitation

→ Saturation in the Vertex Locator for the most central PbPb collisions

LHCb current tracking algorithm efficient up to 50% most central collisions

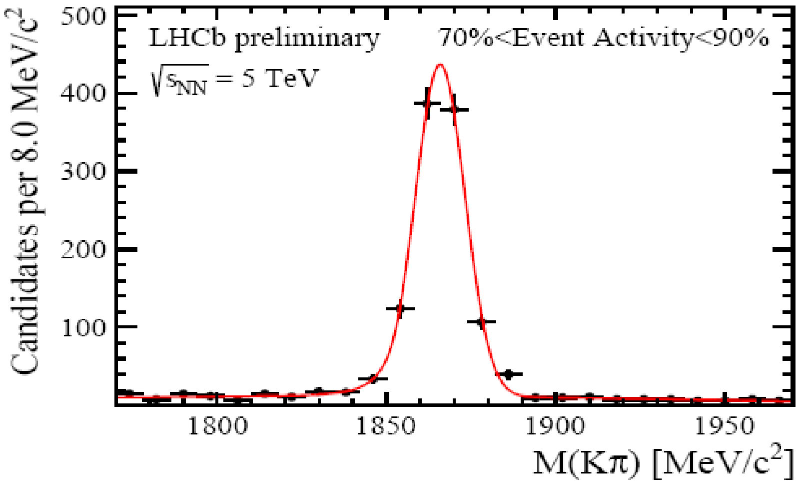
Physics studies limited to 50% less central events

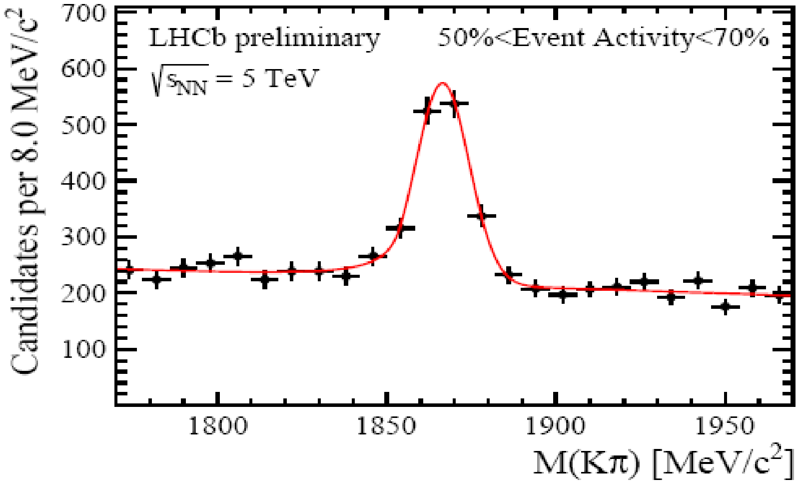


https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

D^0 in PbPb (a first look)

Reconstructed through $D^0 \to K^-\pi^+ + CC$ decays





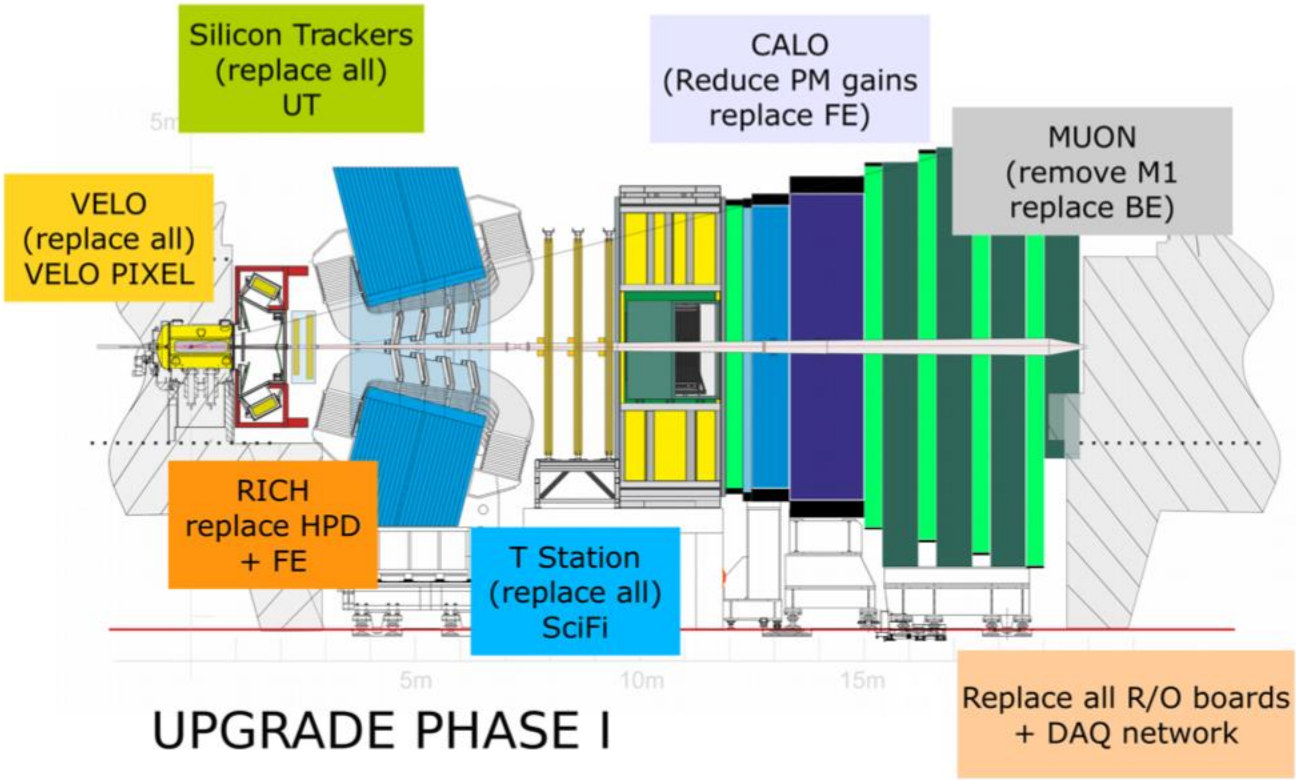
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

Summary

- The current heavy flavor measurements in pPb collisions and fixed-target collisions provide precise and unique constraints on nuclear modifications in proton-nucleus collisions at low-x & high-x
- More measurements with the current dataset, especially with the high statistics $\sqrt{s_{NN}} = 8.16$ TeV pPb data are still yet to come…

backup

LHCb detector upgrades phase I (2021-)

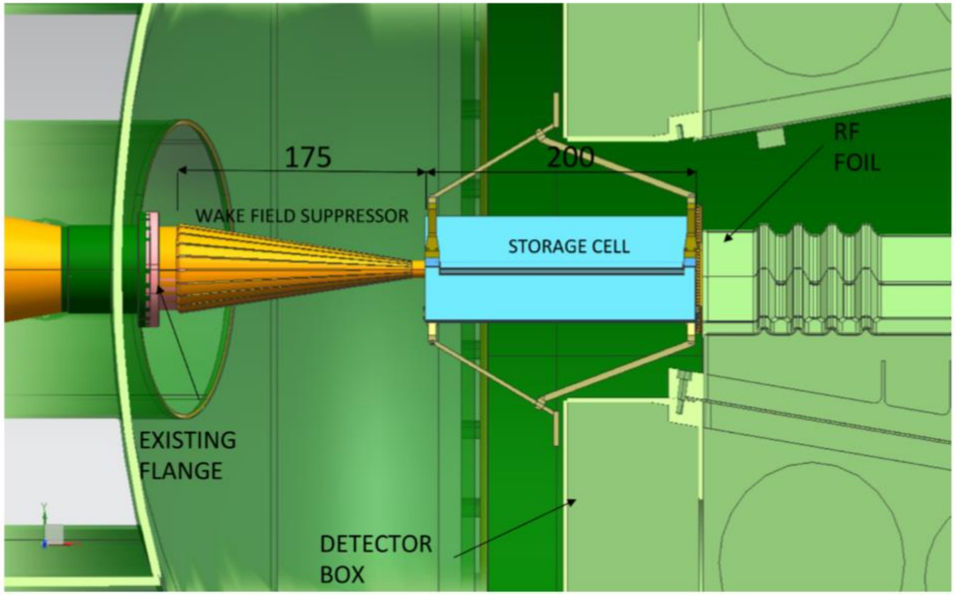


- replace full tracker for 5 times higher pile-up in *pp*
- inspect 30 MHz rate in software trigger in *pp*
- magnet stations for low-p_T tracks & TOF for low momentum PID in consideration for Phase I consolidation or Phase II

Fixed-target upgrade

Current LHCb fixed-target setup will be upgraded for Run 3

Plan for a storage cell, placed upstream

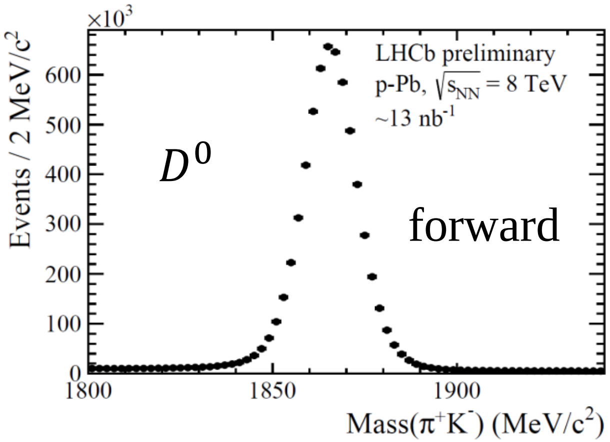


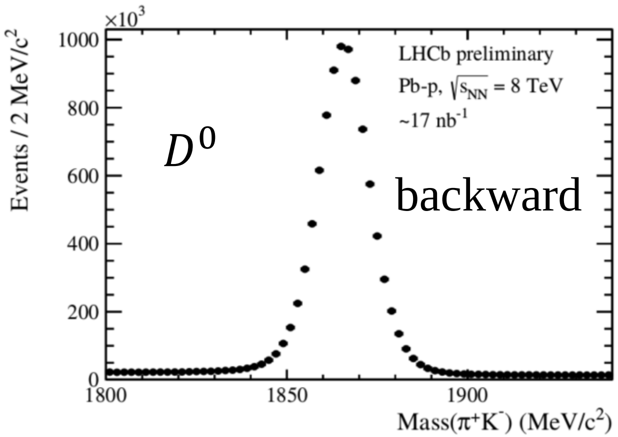
→ Injection of noble gases but also H_2, D_2 as references

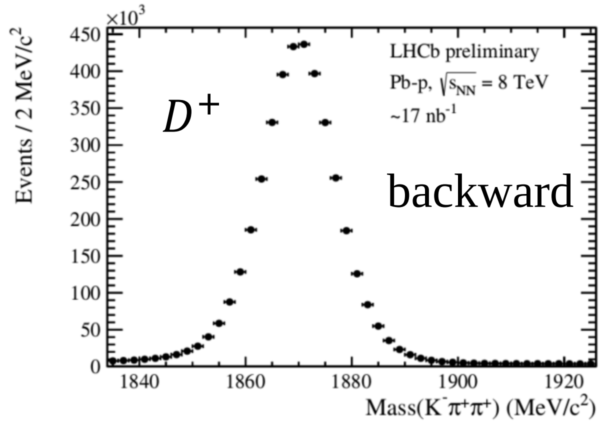
→ **10−100 times larger instantaneous luminosity per unit length**

Other upgrades (crystal target, polarised target, wire target) under discussion

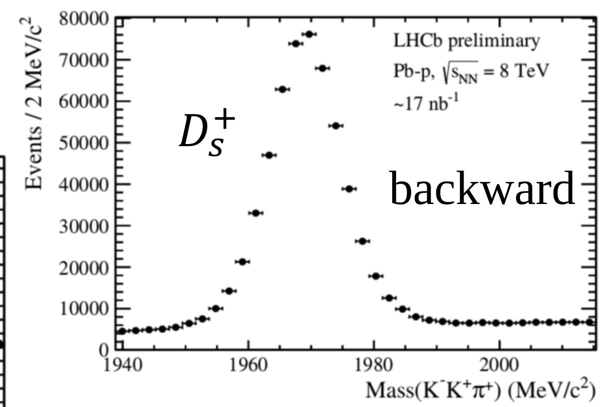
Open charm measurements in *p*Pb 8 TeV

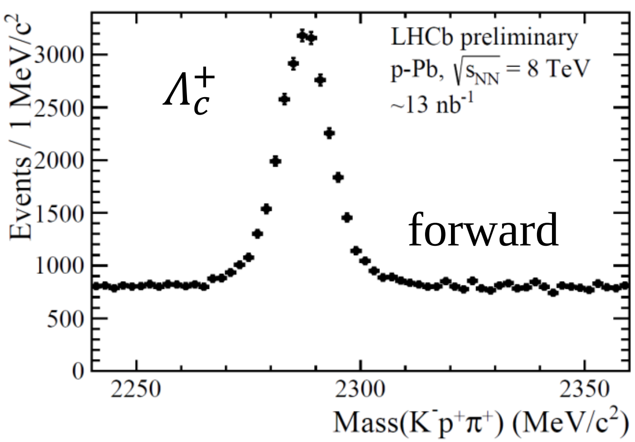


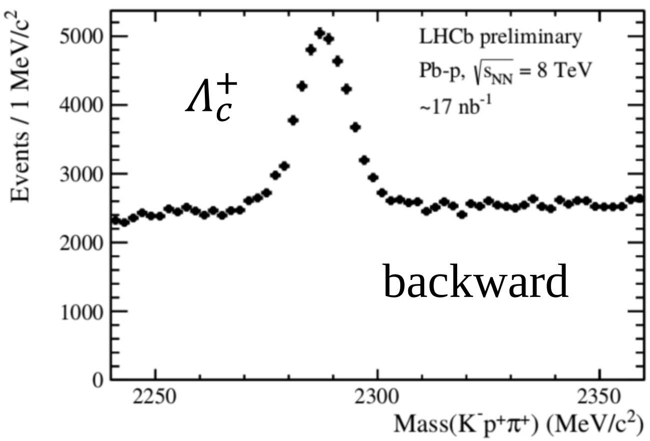




- Precision measurements of charmed hadrons in *p*Pb
- Accuracy improvement in $R_{\Lambda_c^+/D^0}$
- Measurements as functions of multiplicity
- Analyses ongoing



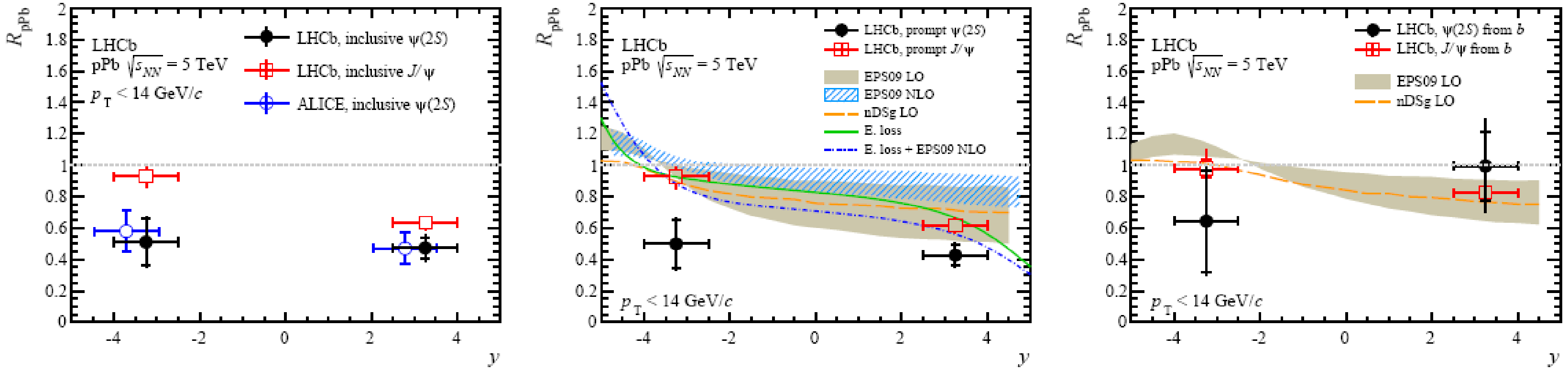




J/ψ and $\psi(2S)$ R_{pPb} in pPb at 5 TeV

→ *nuclear modification factor*

inclusive | prompt | delayed



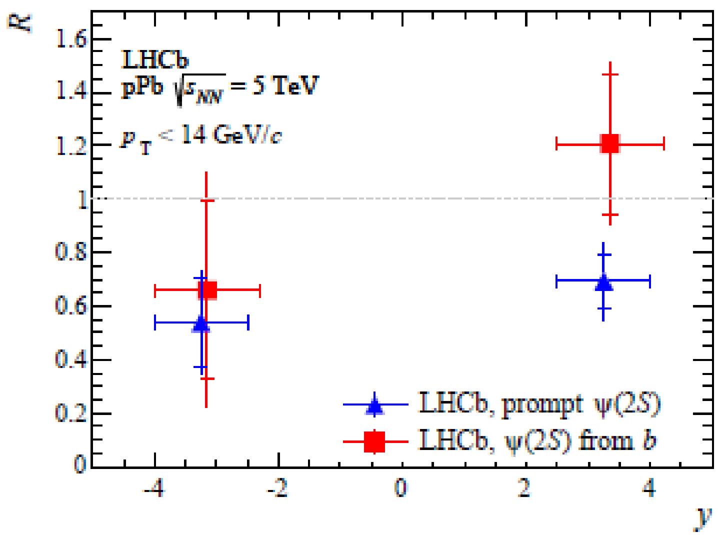
LHCb: JHEP 03 (2016) 033

- results require interpolation of pp cross-section to $\sqrt{s} = 5$ TeV
- $R_{pPb} \neq 1$: the nucleus is not a loose collection of independent nucleons
- tighter bound B-mesons less affected than prompt J/ψ
- energy loss and shadowing are about equally important
- J/ψ data agree with “energy loss + NLO shadowing”
- consistent results from ALICE and LHCb for stronger $\psi(2S)$ suppression
- more data needed to confirm differences between J/ψ and $\psi(2S)$

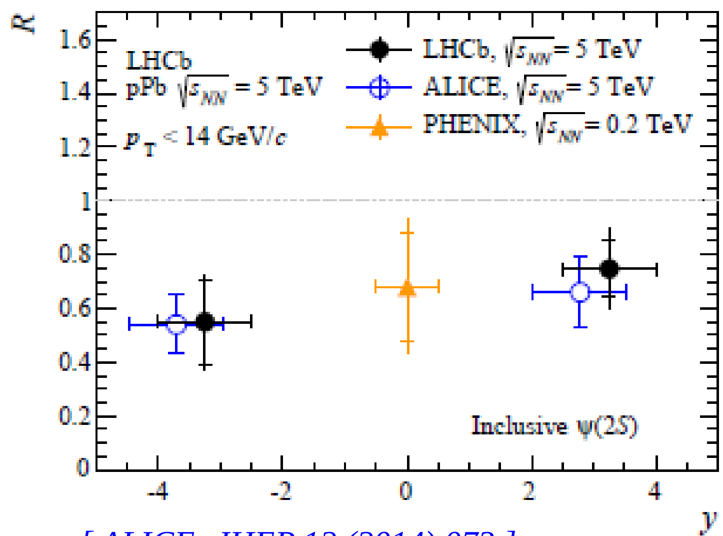
ψ(2S) relative suppression wrt J/ψ

- Relative suppression is calculated as:

$$R \equiv \frac{R_{pPb}^{\psi(2S)}}{R_{pPb}^{J/\psi}} = \frac{\sigma_{pPb}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{pPb}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(5\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(5\,\mathrm{TeV})} = \frac{\sigma_{pPb}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{pPb}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(7\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\,\mathrm{TeV})}$$



[LHCb: JHEP 1603 (2016) 133]



[ALICE: JHEP 12 (2014) 073]

[PHENIX: PRL 111 (2013) 202301]

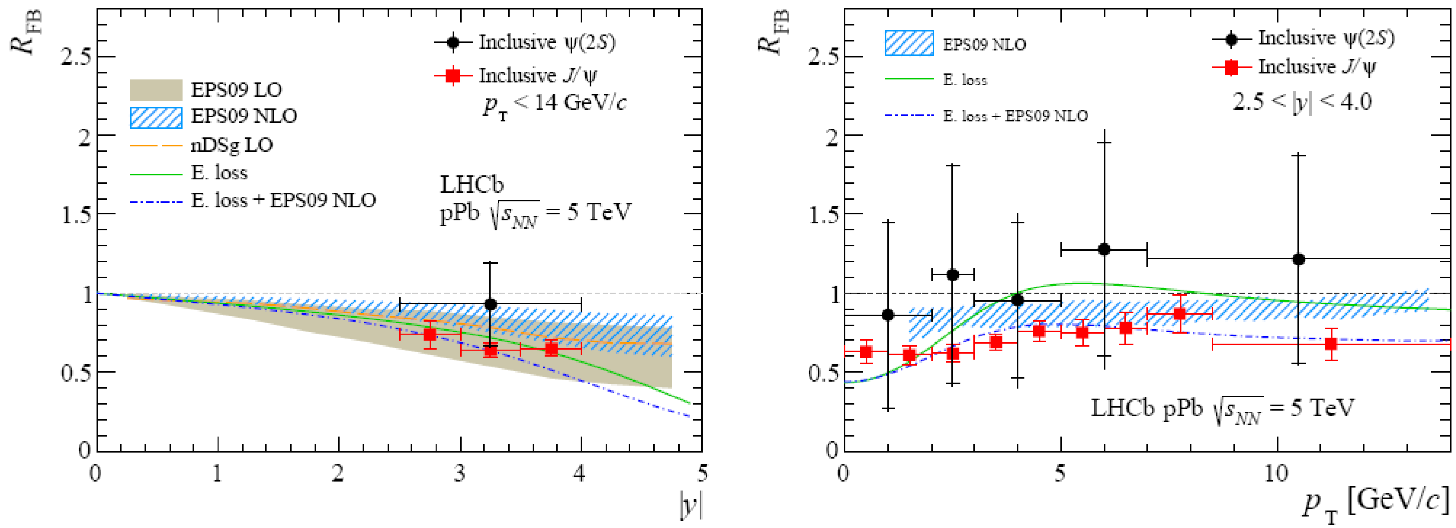
- Intriguing stronger suppression of prompt ψ(2S) than that of prompt J/ψ
- Expect similar suppression for ψ(2S) from *b* and J/ψ from *b*

  → R compatible with 1 within large uncertainties
- Results for inclusive ψ(2S) compatible with ALICE measurement

J/ψ and $\psi(2S)$ R_{FB} in pPb at 5 TeV

→ *forward-backward asymmetry*

LHCb: JHEP 03 (2016) 033



- cross-section interpolation NOT required
- many systematic uncertainties cancel
- J/ψ and $\psi(2S)$ consistent within uncertainties
- trend towards smaller asymmetry for $\psi(2S)$
- expect to resolve with 2016 pPb data

Ferreiro et al. PRC88(2013)04791

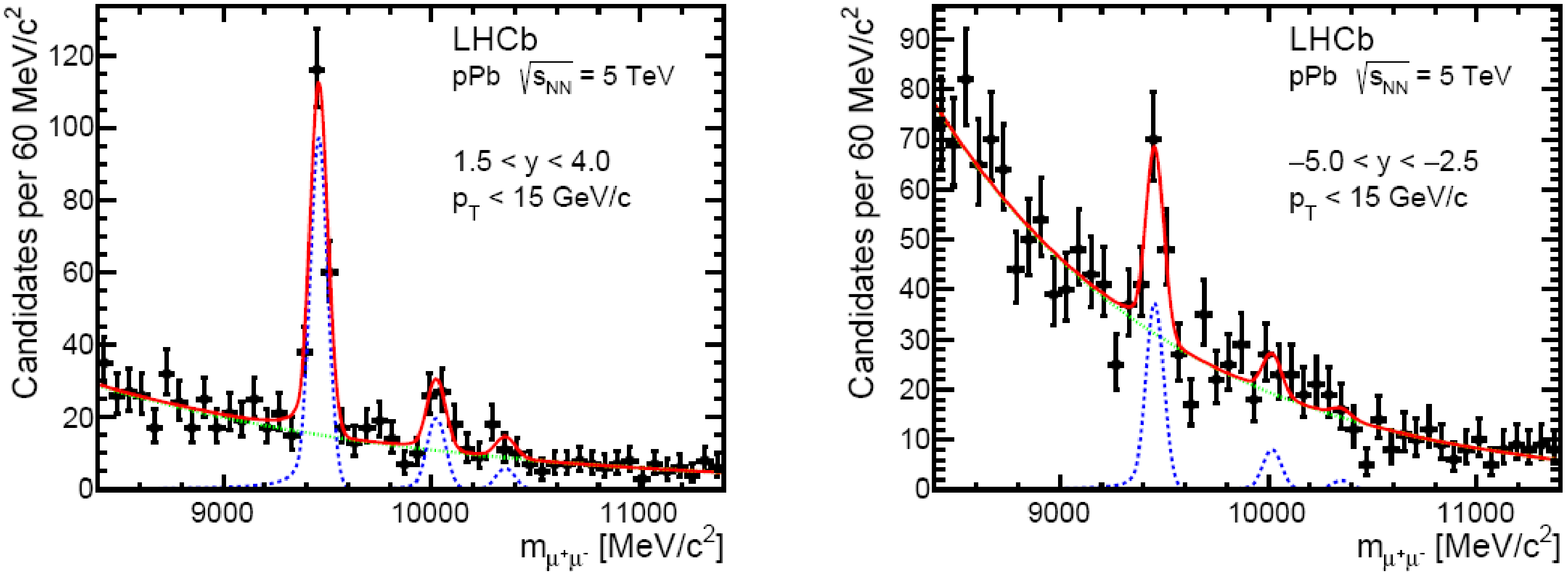
Arleo, Peigne JHEP03(2013)122

Albacete et al. IJMPE22(2013)133007

Υ production in pPb at 5TeV

- Low statistics due to low production rate

LHCb: JHEP 07 (2014) 094

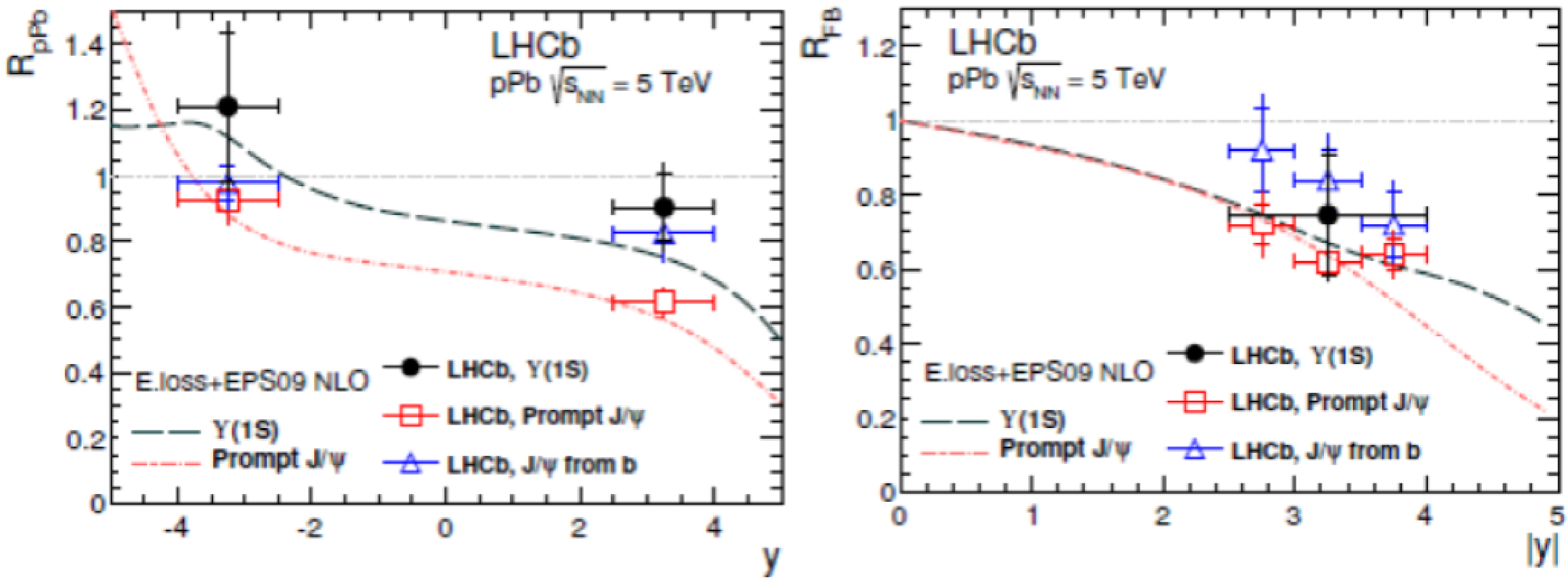


- no differential measurements possible
- kinematic range: $p_T < 15\,\text{GeV}/c$, $1.5 < y < 4.0$ and $-5.0 < y < -2.5$
- study nuclear effects in common rapidity range $2.5 < |y| < 4.0$
- evidence for strong suppression of $\Upsilon(2S)$ and $\Upsilon(3S)$
- 2016 data expected to allow measurements for all states

→ focus on $\Upsilon(1S)$

ϒ production in pPb at 5TeV

→ ϒ(1S) *nuclear modification factor and fwd/bwd asymmetry*



LHCb: JHEP 07 (2014) 094

- large uncertainties
- less suppression for Upsilon than for prompt J/ψ production
- backward data consistent with expectations of anti-shadowing
- Upsilon consistent with J/ψ from b

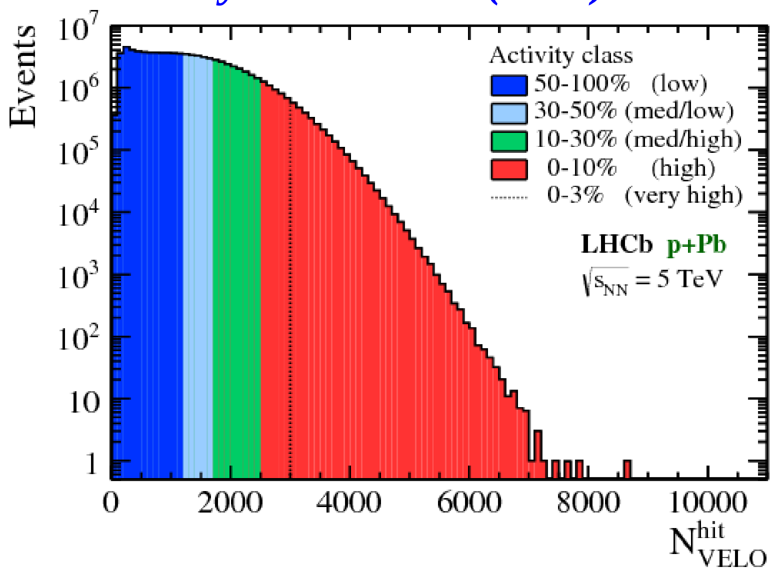
❖ more data needed for firm conclusions

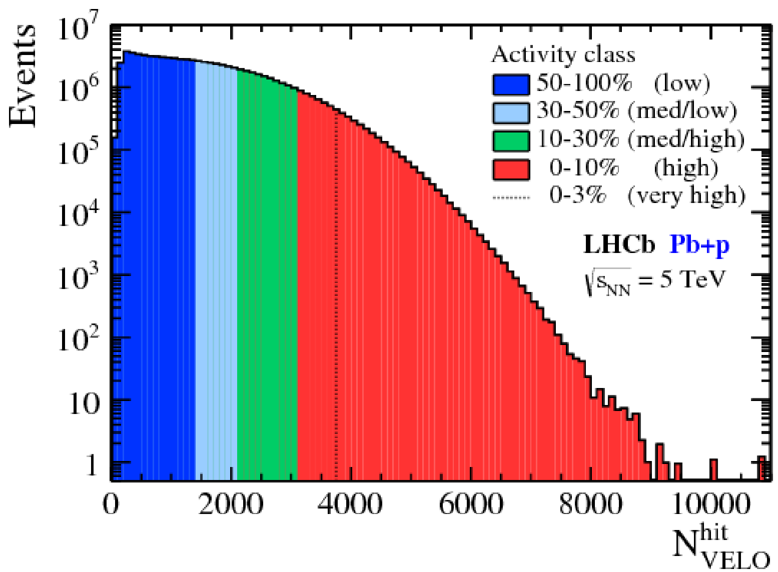
Two particle correlations in pPb collisions

Definition of event activity

Phys. Lett. B762 (2016) 473

- **Data sample used in analysis:**
  - Minimum-bias events: 1.1×10^8 for ***p*+Pb** and **Pb+*p*** each.
  - High-multiplicity events: events with VELO hits larger than 2200, 1.1×10^8 for ***p*+Pb** and 1.3×10^8 for **Pb+*p***.
- Use VELO-hit multiplicity to measure the event activity
  - proportional to number of charged particles
- Hit-multiplicity in **Pb+*p*** greater than ***p*+Pb**
- **Relative activity classes**
  - from low (50-100%) to very high (0-3%) event activity
- **Common absolute activity classes** for **Pb+*p*** and ***p*+Pb**
  - 5 bins in $2200 < \mathcal{N}_{VELO}^{hits} < 3500$

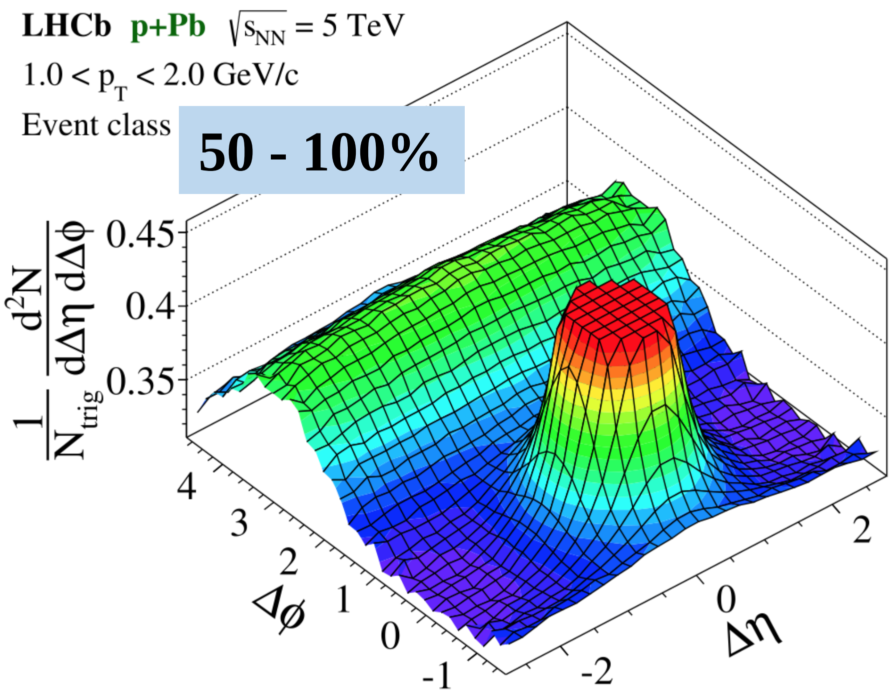


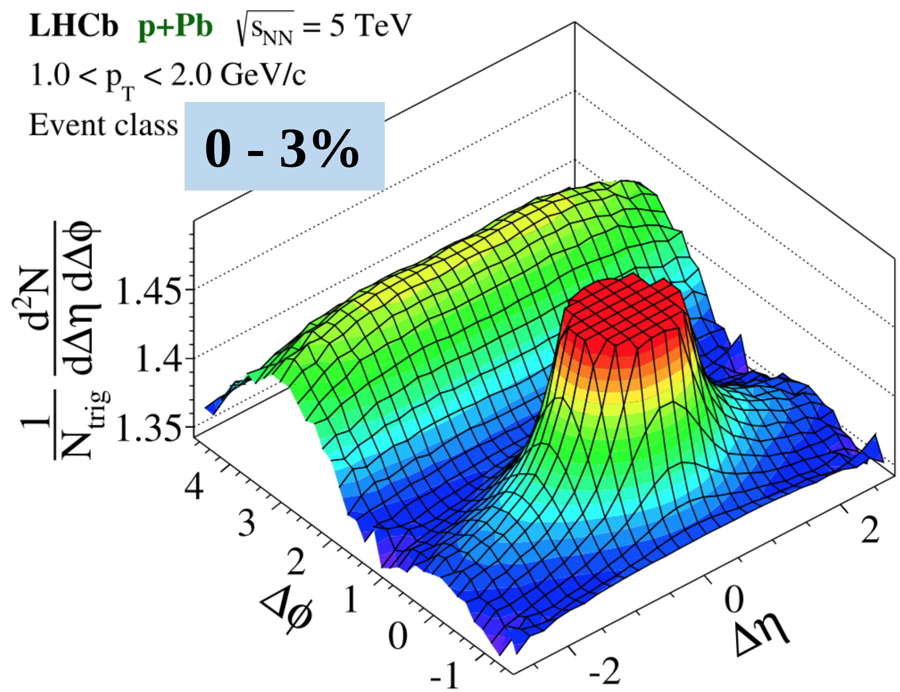


The ridge in *p*+Pb collisions

p_T range : 1.0 - 2.0 GeV/c

Phys. Lett. B762 (2016) 473





At low event activity (50-100%)

- $\Delta\phi = \pi$: away side ridge present
- $\Delta\phi = 0$: No sign of near-side ridge

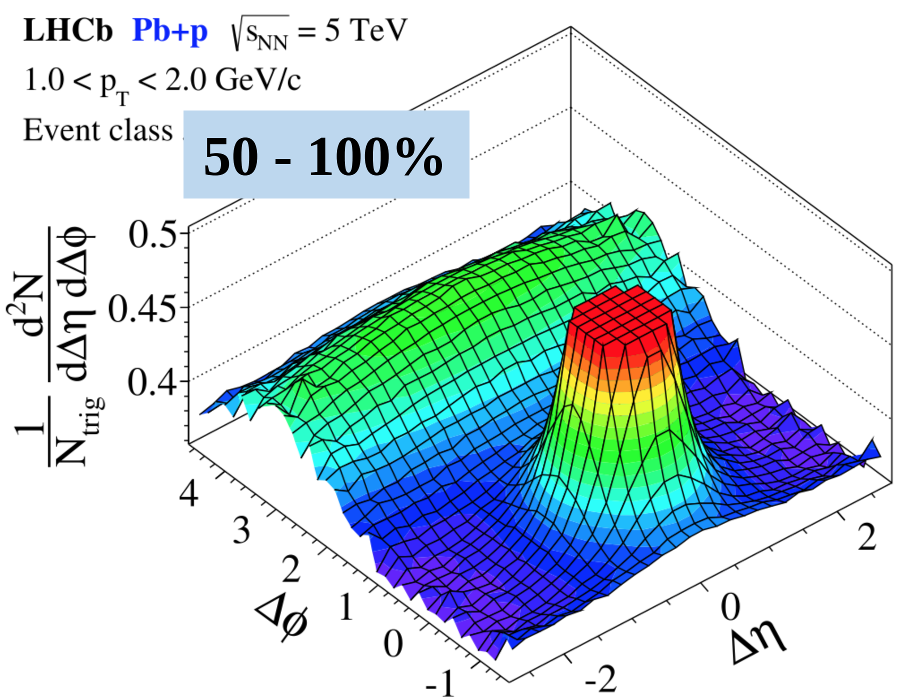
At high event activity (0-3%)

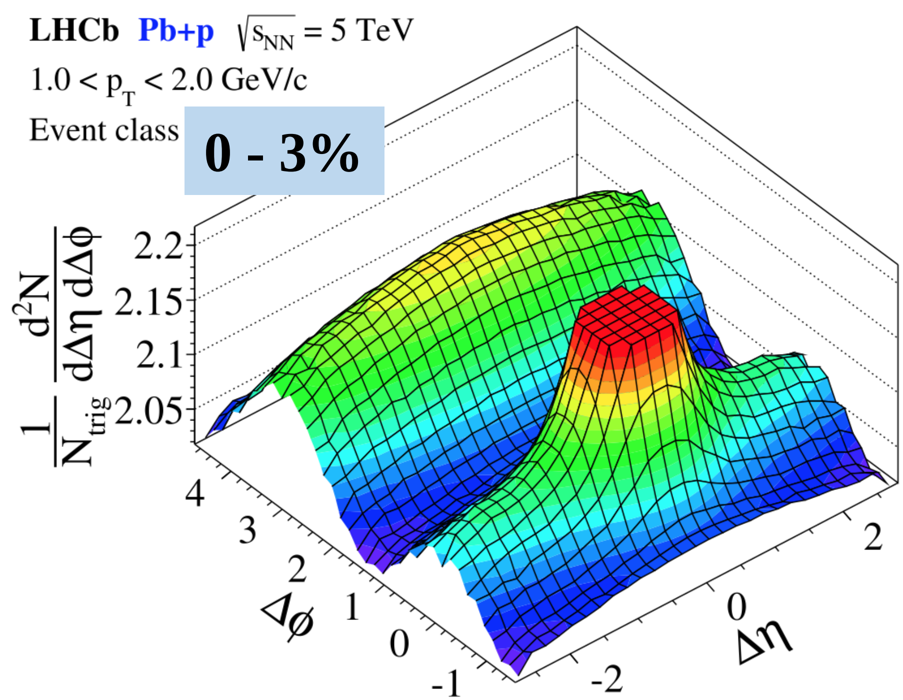
- $\Delta\phi = \pi$: away side ridge present
- **$\Delta\phi = 0$: near-side ridge is evolving and clearly visible!**

The ridge in Pb+p collisions

p_T range : 1.0 - 2.0 GeV/c

Phys. Lett. B762 (2016) 473





At low event activity (50-100%)

- $\Delta\phi = \pi$: away side ridge present
- $\Delta\phi = 0$: No sign of near-side ridge

At high event activity (0-3%)

- $\Delta\phi = \pi$: away side ridge present
- **$\Delta\phi = 0$: near-side ridge elongated over large $\Delta\eta$!**

The ridge evolution

Phys. Lett. B762 (2016) 473

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

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

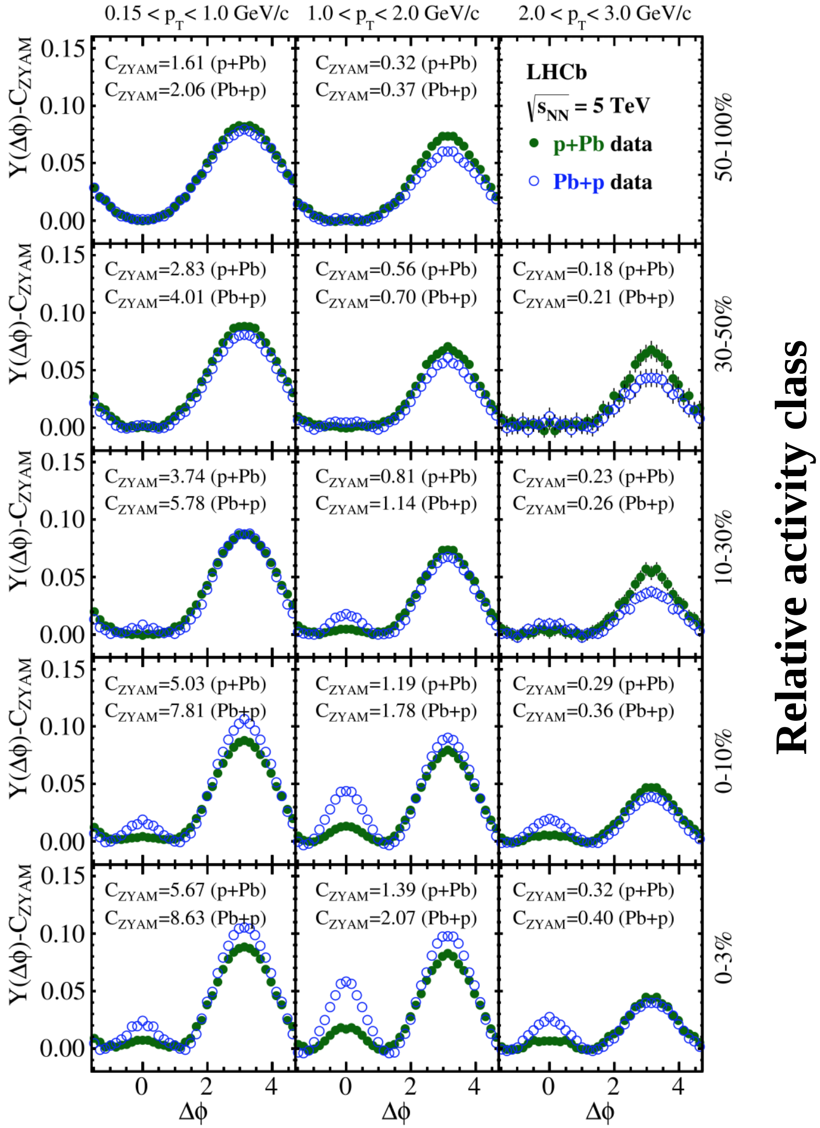
- Subtract the zero-yield-at-minimum (ZYAM)

➢The correlation yield increases with event activity.

➢The away-side ridge decreases towards higher p_T.

➢On the near side, the second ridge emerges with a maximum in the range $1 < p_T < 2$ GeV/c.

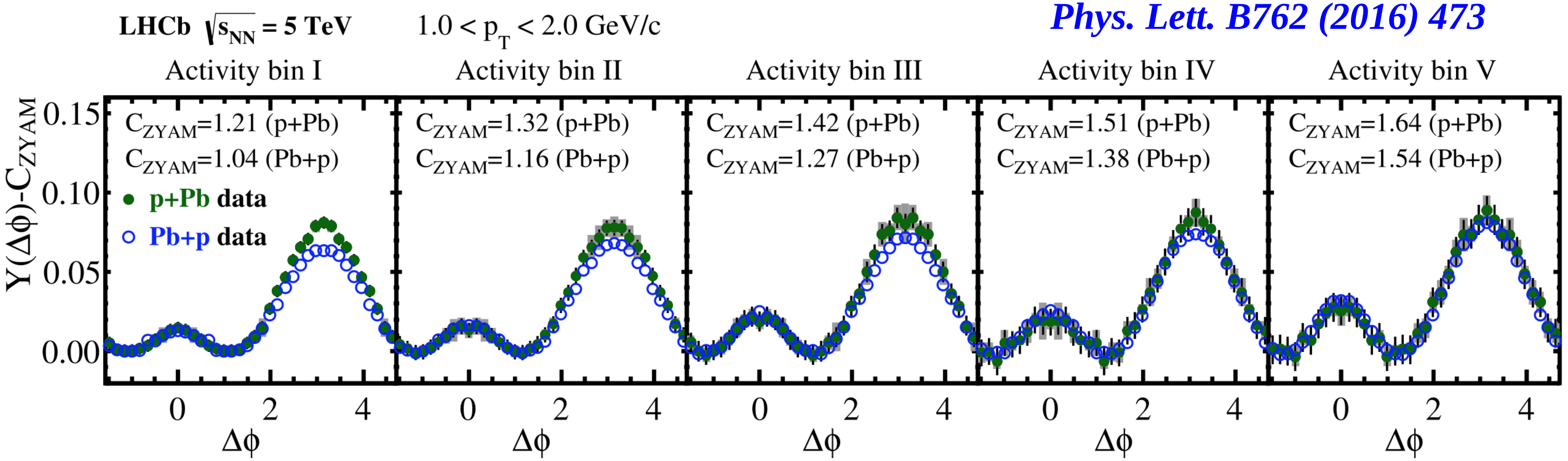
➢Near side is more pronounced in **Pb+*p*** than in ***p*+Pb**.



The ridge evolution

- Compare both hemispheres (Pb or p direction) in **common absolute activity ranges**.
- Five identical activity ranges for the ***p*+Pb** and **Pb+*p*** configurations ($2200 < \mathcal{N}_{VELO}^{hits} < 3500$), the same particle production in $2.0 < \eta < 4.9$.

Phys. Lett. B762 (2016) 473



- Strength of **near-side ridges in both hemispheres are compatible with each other!**
- Different probed rapidity ranges in both beam configurations show no sizable effect. ***p*+Pb: $1.5 < y < 4.4$;** **Pb+*p*: $-5.4 < y < -2.5$**

LHCb heavy-ion collider mode: a wealth of data

	year	$\sqrt{s_{NN}}$		
pPb/Pbp	2013	5.02 TeV	1.6 nb^{-1}	
PbPb	2015	5.02 TeV	10 μb^{-1}	
pPb/Pbp	2016	8.16 TeV	34 nb^{-1}	21 $\times$2013
XeXe	2017	5.44 TeV	0.4 μb^{-1}	
PbPb	*2018*	*5.02 TeV*		$\approx$ 10 $\times$2015

- fast detector
  full inelastic luminosity in PbPb and XeXe
  full rate in pPb/Pbp in HLT
- tracking 50-100 % centrality in PbPb
- data full of peaks and phenomena to explore