Production of open charm and beauty states in *p*Pb collisions with LHCb

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On behalf of the LHCb Collaboration

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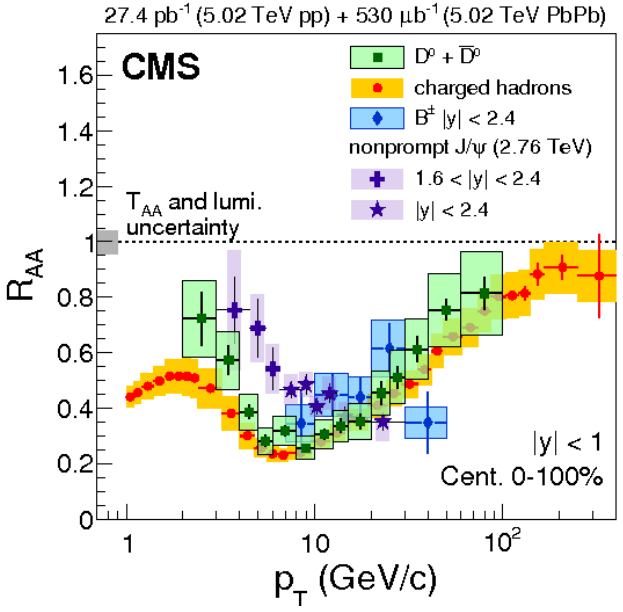
Outline

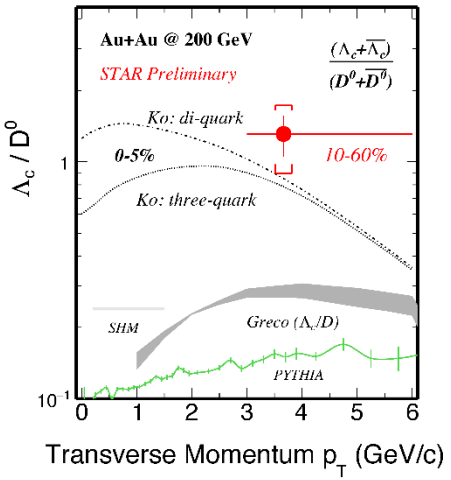
- Open heavy flavor measurements in pPb collisions
- The LHCb detector
- LHCb pPb datasets
- Prompt $D^0$and Λ_c^+ production in pPb collisions at 5 TeV
- Upcoming open beauty and charm measurements
- Conclusion

Open heavy flavor in PbPb collisions

- Heavy flavor states are sensitive probes to study the properties of the QGP created in AA collision.
  - Produced in the early stage of the collisions
  - Significant D^0 quenching at higher p_T observed in central PbPb collisions
  - Large Λ_c^+/D^0 ratio measured in mid-central AuAu collisions
  - *b*-hadron measurements becoming available at LHC
- Open heavy flavor in *p*A collisions provides baseline measurements to disentangle cold nuclear matter effects from effects of hot and dense medium.

arXiv:1708.04962

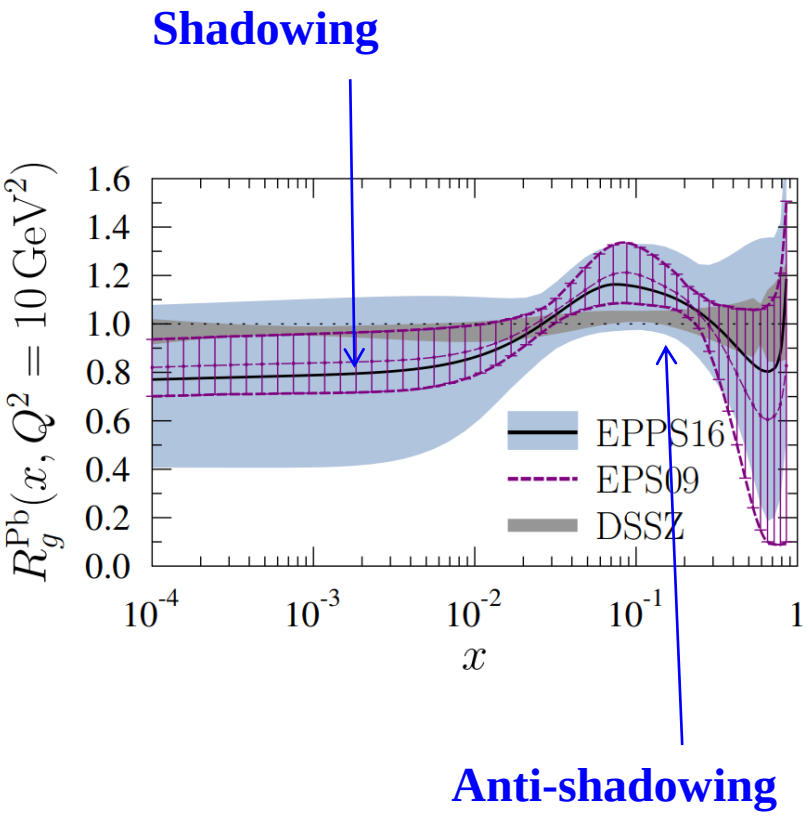




arXiv:1704.04353

Open heavy flavor in pPb collisions

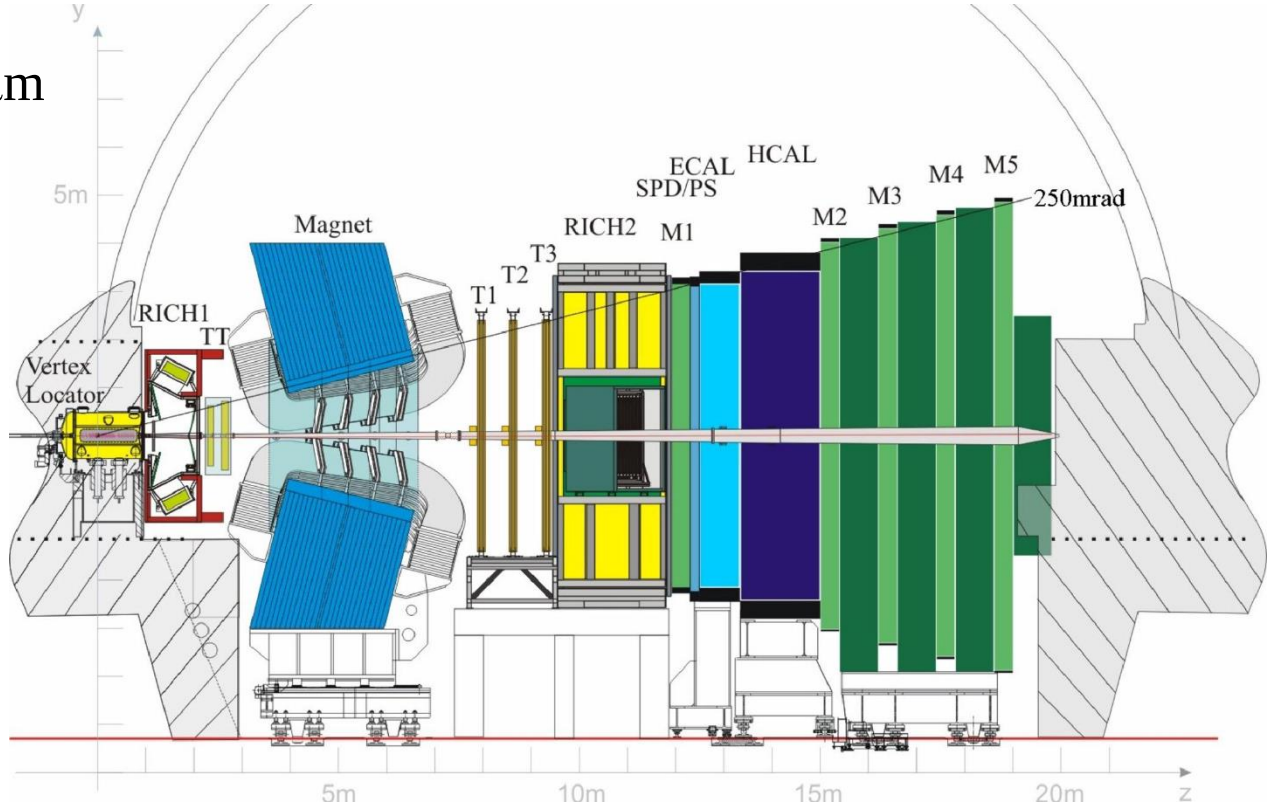
- LHCb well suited to pPb measurements:
  - Heavy flavor measurement down to $p_T = 0$
  - Separation of prompt and b-decay components
- Cold Nuclear Matter effects
  - Initial state:
    - Modification of nuclear PDF
    - Color Glass Condensate
  - Multiple scattering or radiation of partons crossing the nucleus
  - Final state



arXiv:1802.05927

LHCb detector

- A single arm forward spectrometer designed for the study of particles containing *c* or *b* quark
- Acceptance: $2 < \eta < 5$
- Vertex detector
  - IP resolution ~ 20 μm
- Tracking system
  - $\frac{\Delta p}{p} = 0.5\% - 1\%$ (5-200 GeV/*c*)
- RICH
  - K/π/p separation
- Electromagnetic + hadronic Calorimeters
- Muon systems

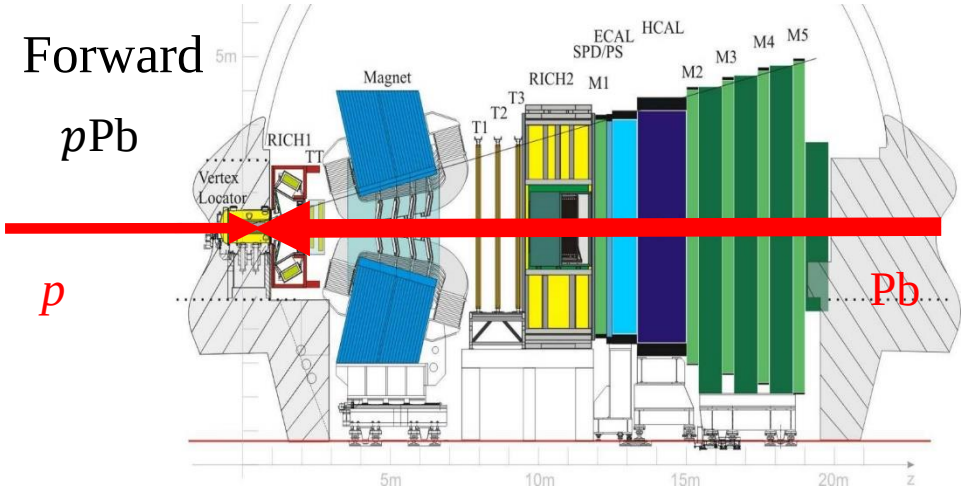


JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

LHCb pPb datasets

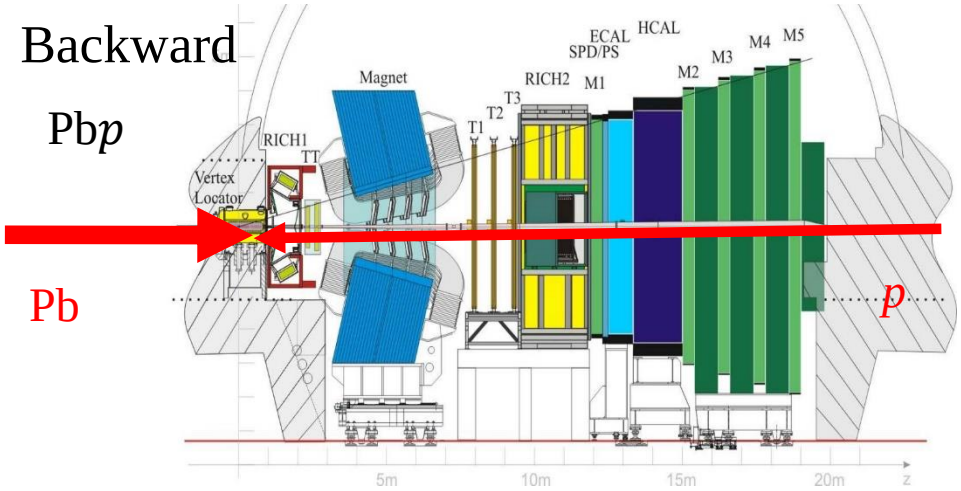
Forward

pPb



Backward

Pbp

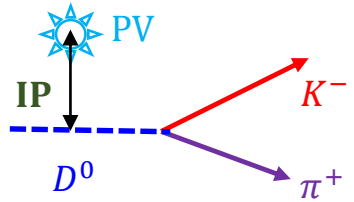


- Rapidity Coverage
  - y^*: rapidity in nucleon-nucleon cms
  - $y_{\mathrm{cms}} = \pm 0.465$
  - Forward: $1.5 < y^* < 4.0$
  - Backward: $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$

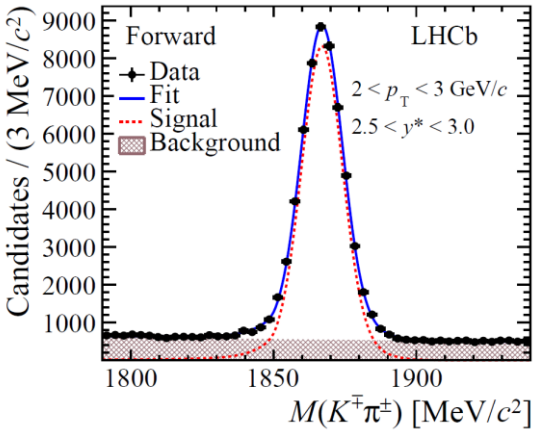
- $\sqrt{s_{NN}} = 5.02$ TeV (2013)
  - pPb (1.06 nb^{-1}) + Pbp (0.52 nb^{-1})

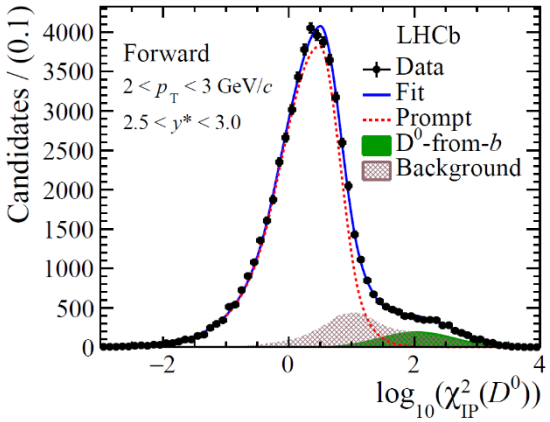
- $\sqrt{s_{NN}} = 8.16$ TeV (2016)
  - pPb (13.6 nb^{-1}) + Pbp (21.8 nb^{-1})

Prompt D^0 measurement in pPb at 5 TeV



Forward ↓





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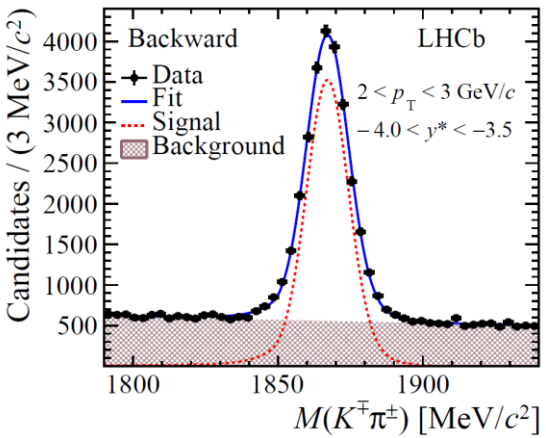

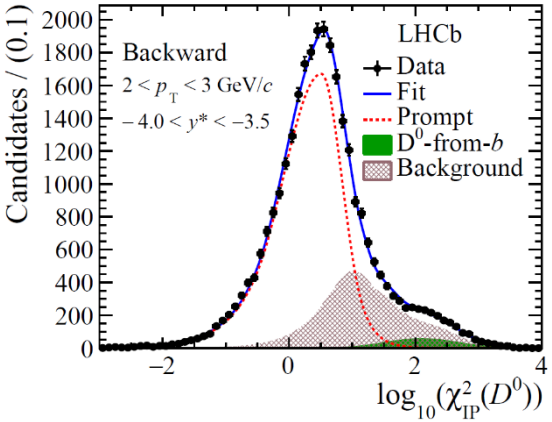

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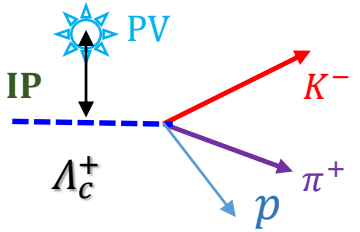
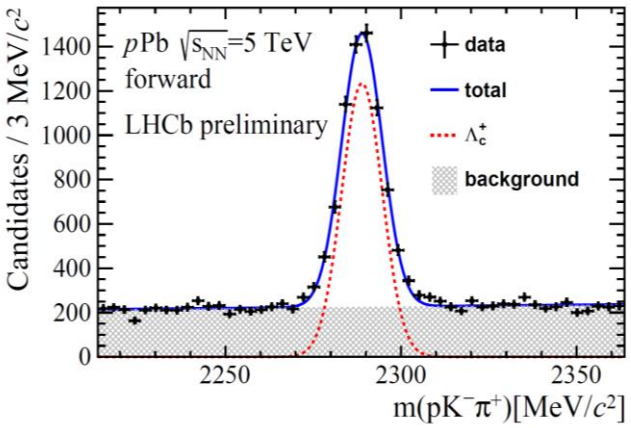
- Reconstructed through decay channel:
  $D^0 \to K^-\pi^+$
- Inclusive D^0 mesons from fitting invariant mass dist.:
  - Signal:
    Crystal Ball+Gaussian
  - Background: linear
- Prompt D^0 fraction extracted from fitting impact parameter dist.:
  - Prompt: simulation
  - D^0-from-b: simulation
  -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

Prompt Λ_c^+ measurement in pPb at 5 TeV



Forward ↓



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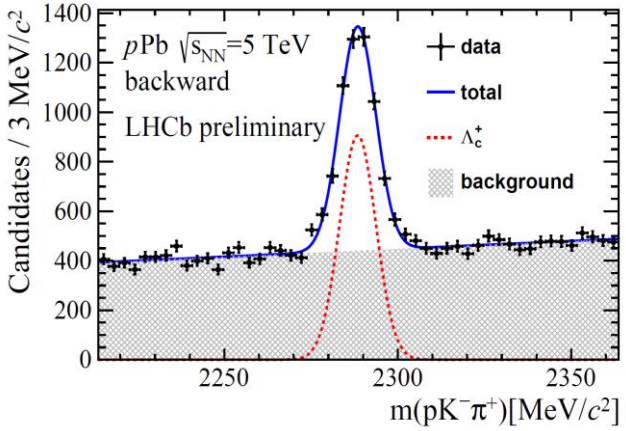

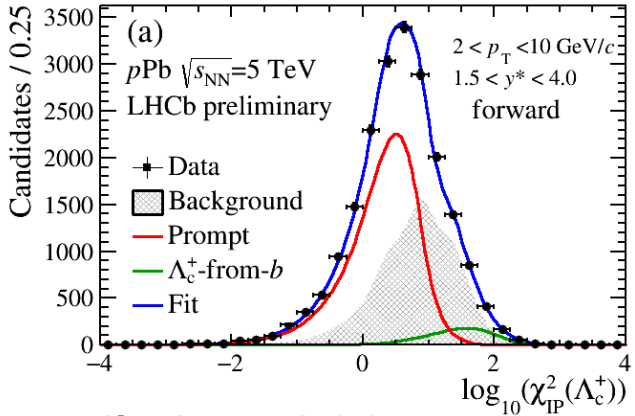

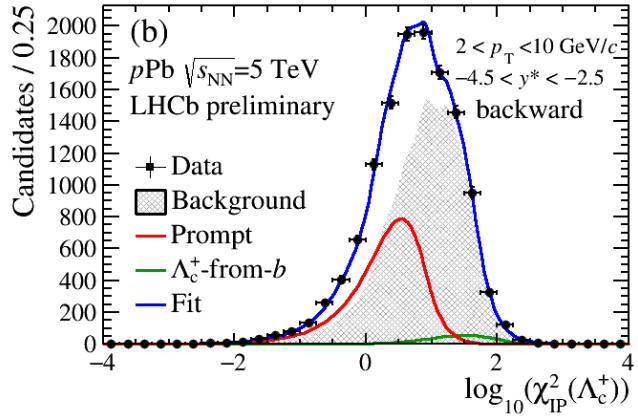

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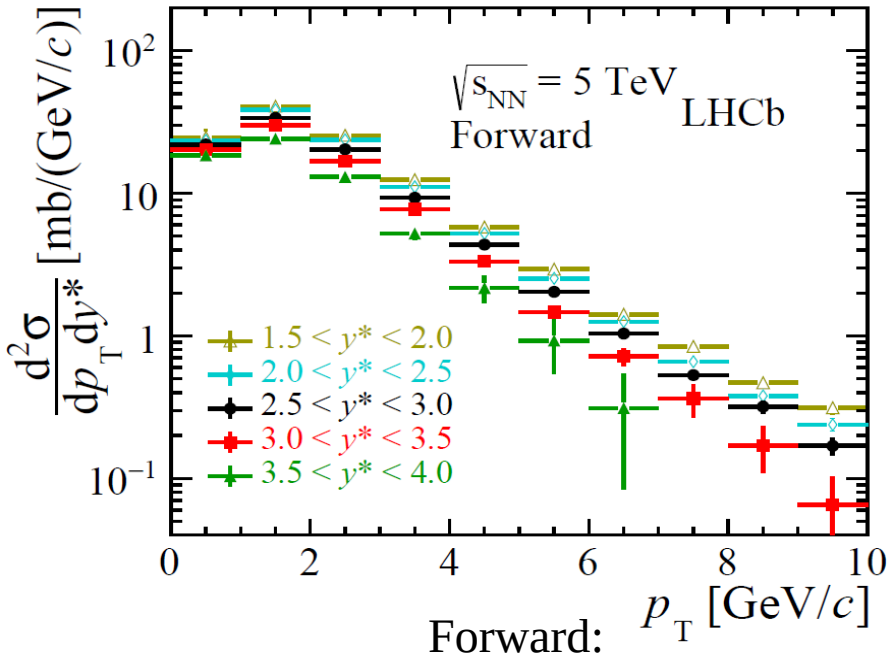
- Reconstructed through decay channel
  $\Lambda_c^+ \to pK^-\pi^+$
- Inclusive Λ_c^+ baryons from fitting invariant mass dist.:
  - Signal: Gaussian
  - Background: linear

Prompt Λ_c^+ fraction extracted from fitting impact parameter dist.:

- Prompt: simulation
- Λ_c^+-from-b: simulation
- Background: sideband in data

Prompt D^0 double-differential cross-section in pPb

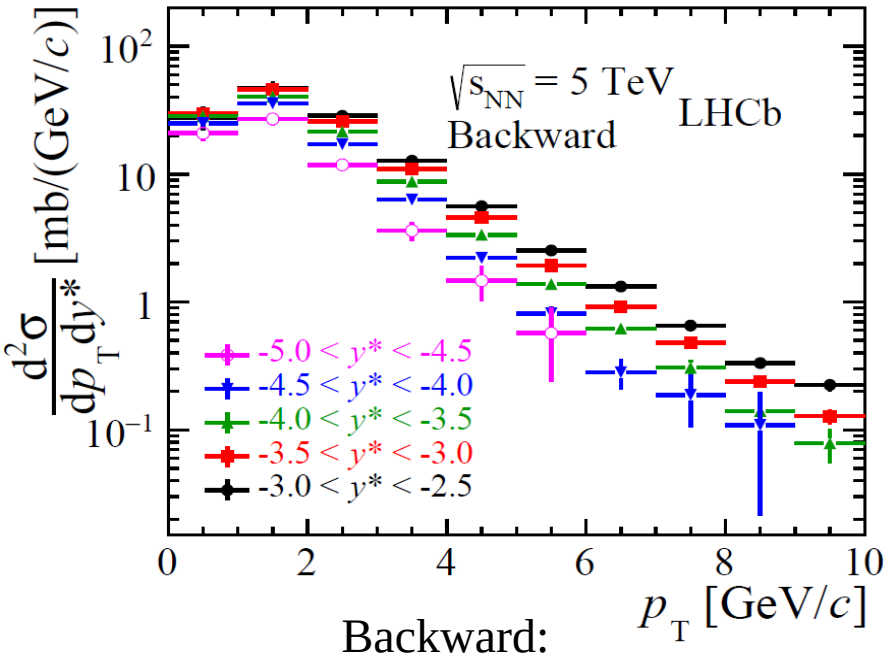


Forward:

$0 < p_T < 10$ GeV/c

$1.5 < y^* < 4.0$

$\sigma_{forward} = 230.6 \pm 0.5 \pm 13.0$ mb



Backward:

$0 < p_T < 10$ GeV/c

$-5.0 < y^* < -2.5$

$\sigma_{backward} = 252.7 \pm 1.0 \pm 20.0$ mb

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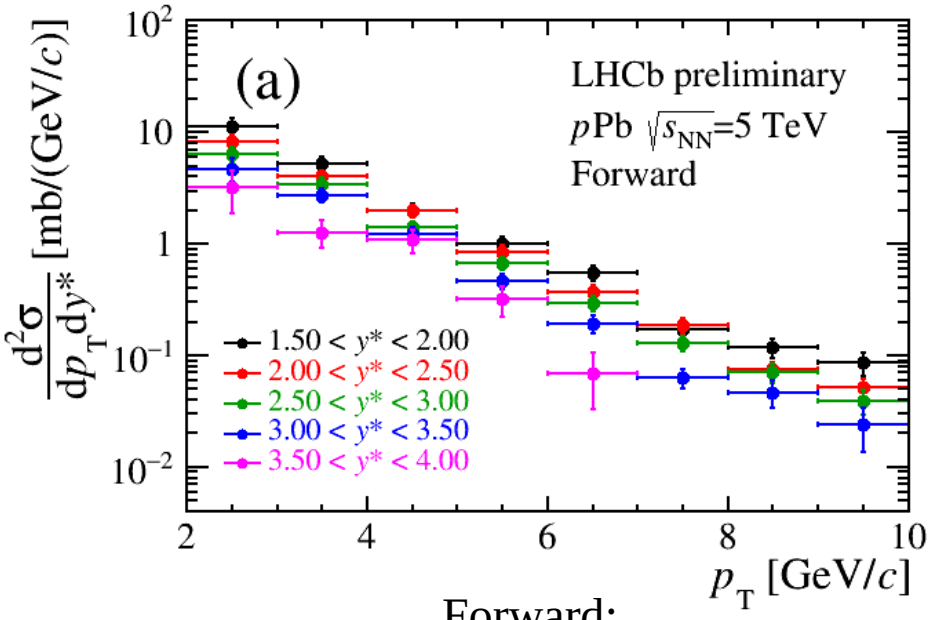
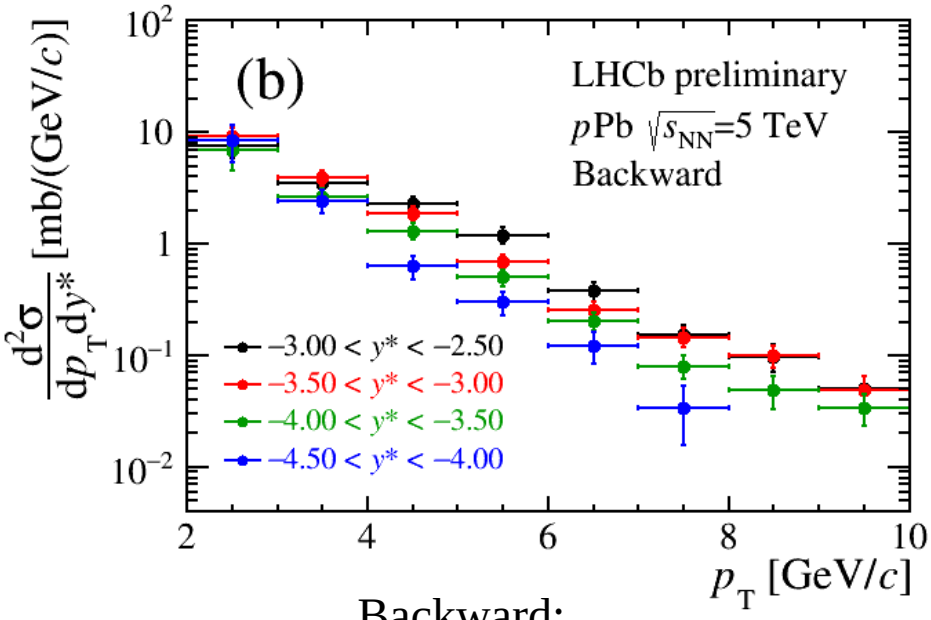
Prompt Λ_c^+ double-differential cross-section in pPb





Forward:
$2 < p_T < 10$ GeV/c
$1.5 < y^* < 4.0$

$\sigma_{forward} = 32.1 \pm 1.0 \pm 4.1$ mb

Backward:
$2 < p_T < 10$ GeV/c
$-4.5 < y^* < -2.5$

$\sigma_{backward} = 27.7 \pm 1.5 \pm 4.5$ mb

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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**

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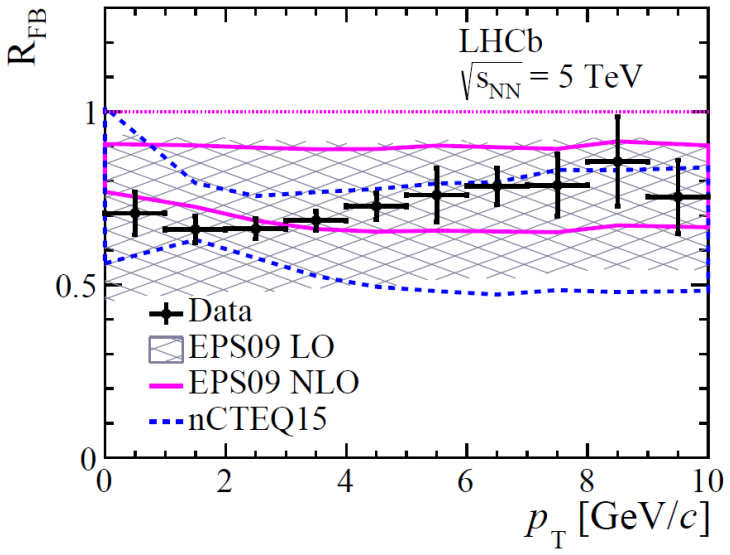

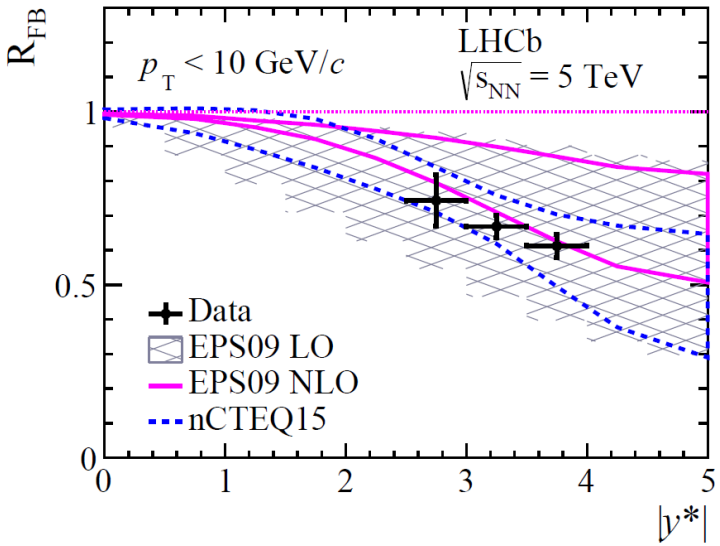

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Comput. Phys. Commun. 184 (2013) 2562
Comput. Phys. Commun. 198 (2016) 238

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

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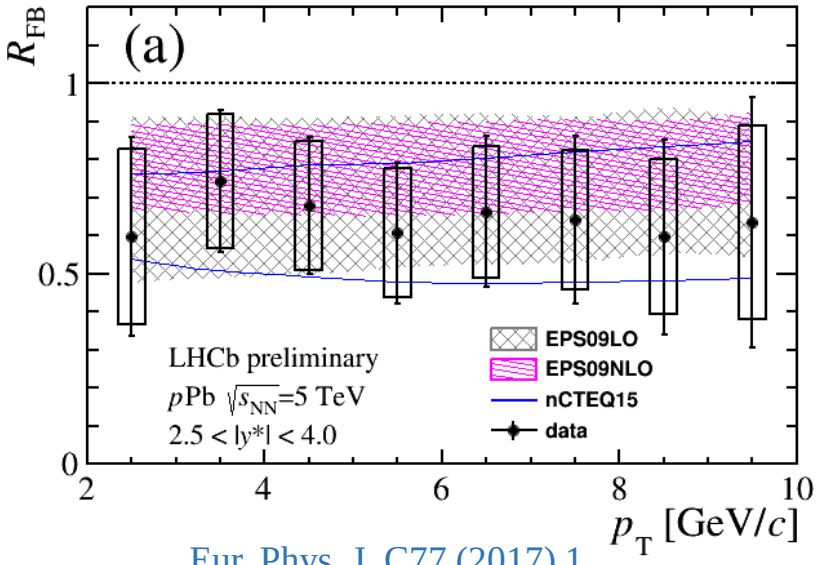
- R_{FB} does not need results from pp collisions.
- Compared to Helac-Onia calculations incorporating different nPDFs
  - Model parameterisation constrained by LHC pp cross-section measurements
- Consistent with nPDF predictions within uncertainty
- **Data uncertainties comparable to nPDF calculations**



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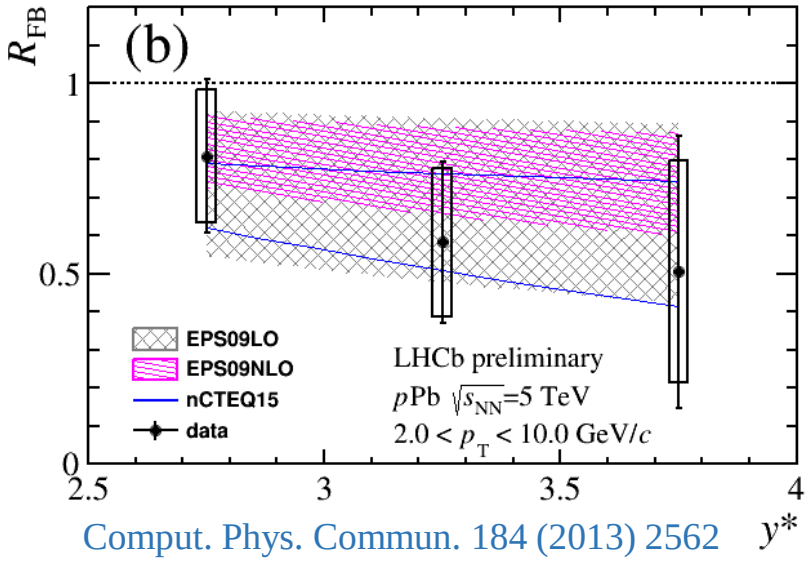

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Prompt D^0 at 5 TeV nuclear modification factor in pPb

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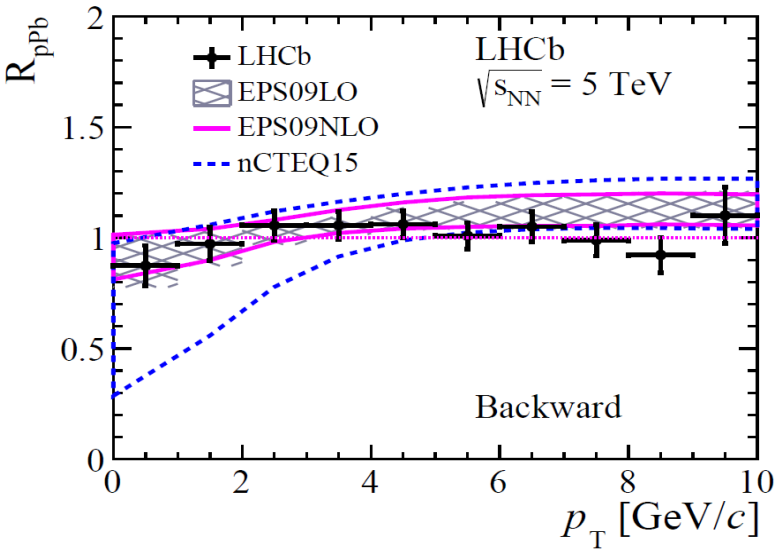
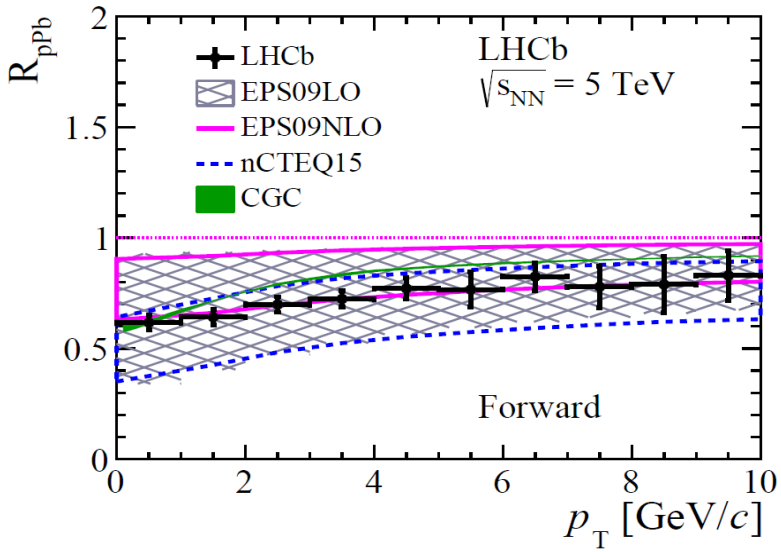
$$R_{p\mathrm{Pb}}(y^*, p_\mathrm{T}) = \frac{1}{A} \times \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/\mathrm{d}x}{\mathrm{d}\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/\mathrm{d}x}, \quad A{=}208$$

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

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





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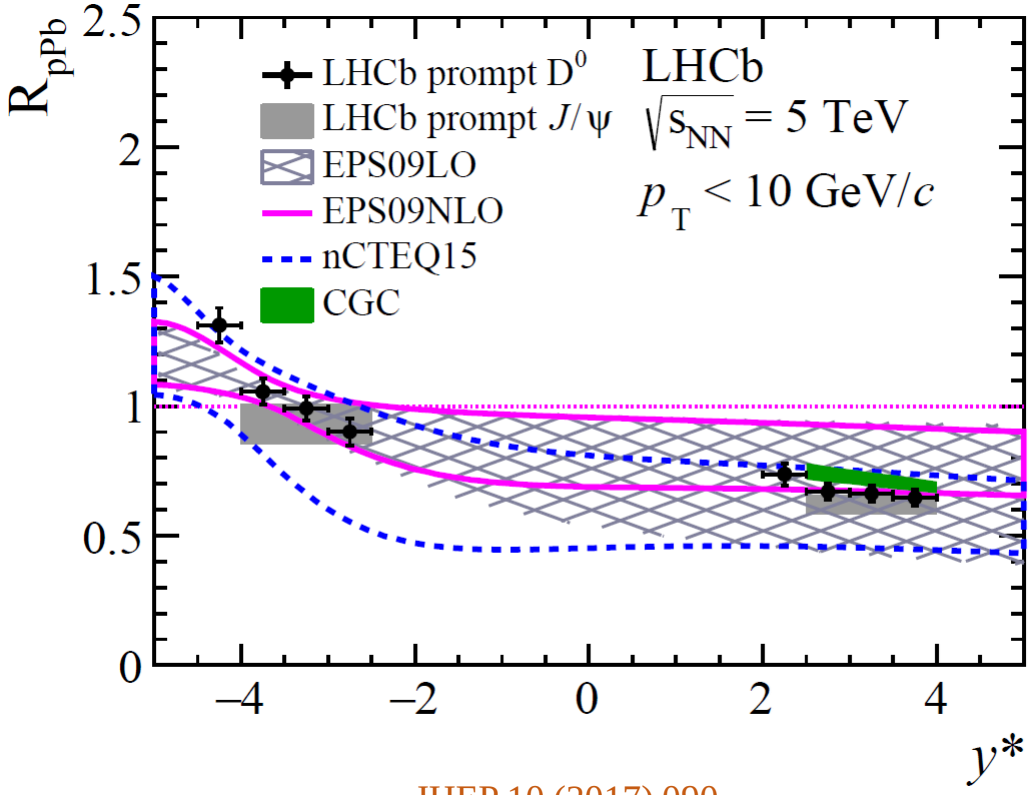
$$R_{p\mathrm{Pb}}(y^*, p_\mathrm{T}) = \frac{1}{A} \times \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/\mathrm{d}x}{\mathrm{d}\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/\mathrm{d}x}, \quad A{=}208$$

- *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**



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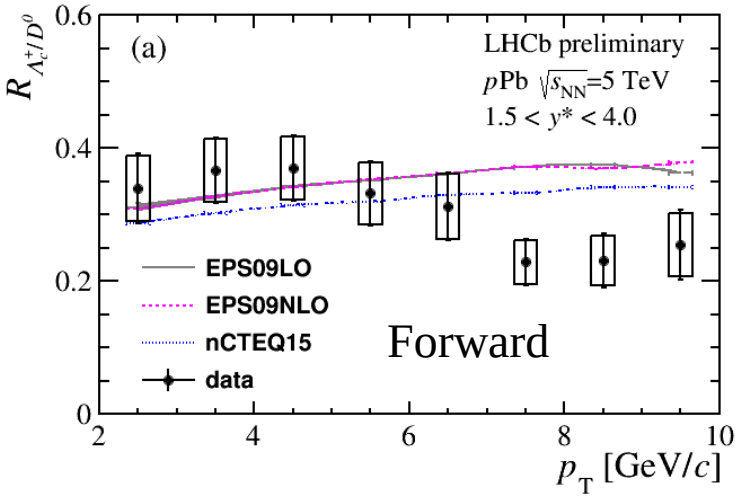
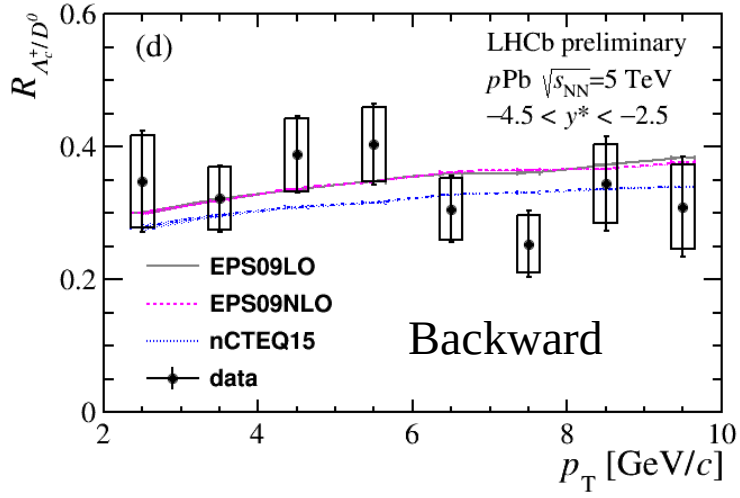
$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_T)}{\sigma_{D^0}(y^*, p_T)}$$

- Sensitive to charm hadronisation mechanisms
- Model based on measured *pp* cross-section
- nPDF effects mostly cancel
  - EPS09LO & EPS09NLO similar
  - nCTEQ15 slightly lower.
- Slight increase with increasing p_T
- **Forward:**
  - **Consistent at lower p_T**
  - **Below theories at higher p_T**
- **Backward:**
  - **Consistent for all p_T**





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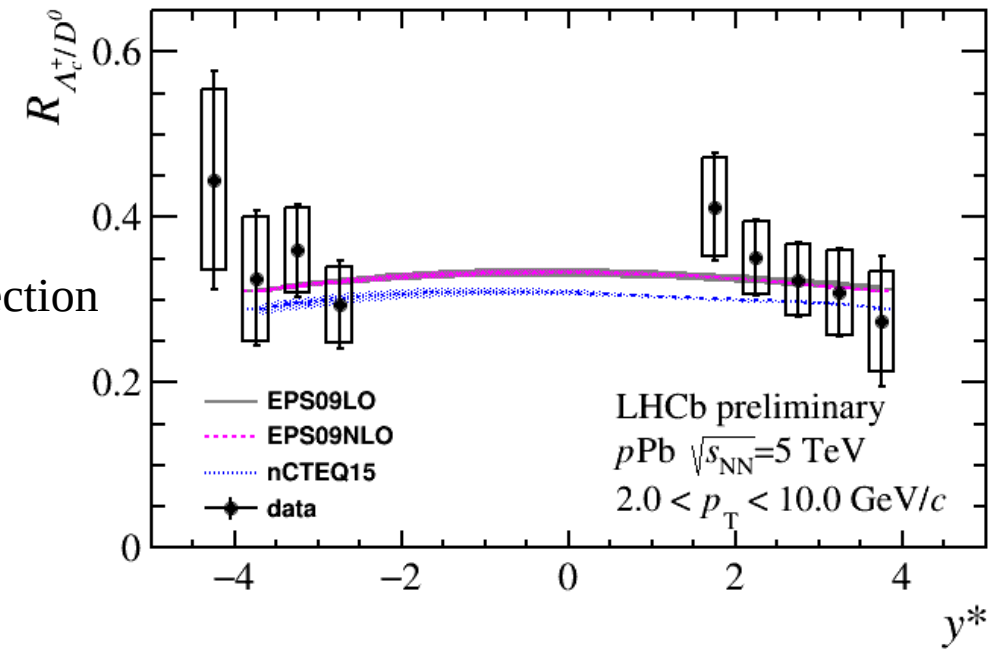
$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_{\mathrm{T}})}{\sigma_{D^0}(y^*, p_{\mathrm{T}})}$$

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

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



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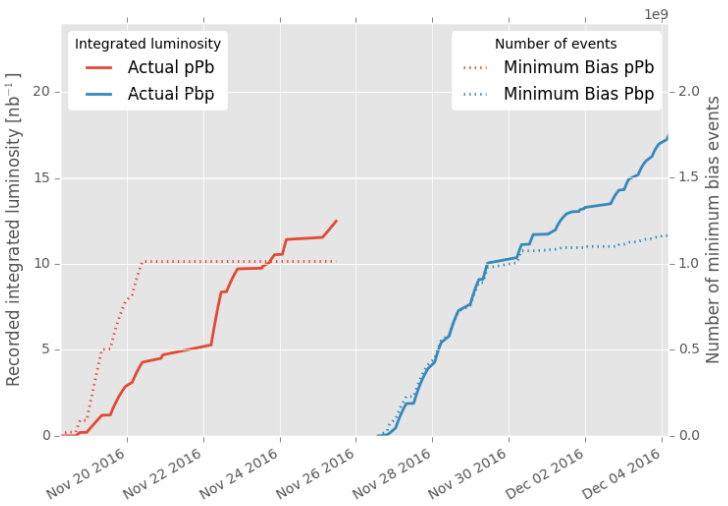
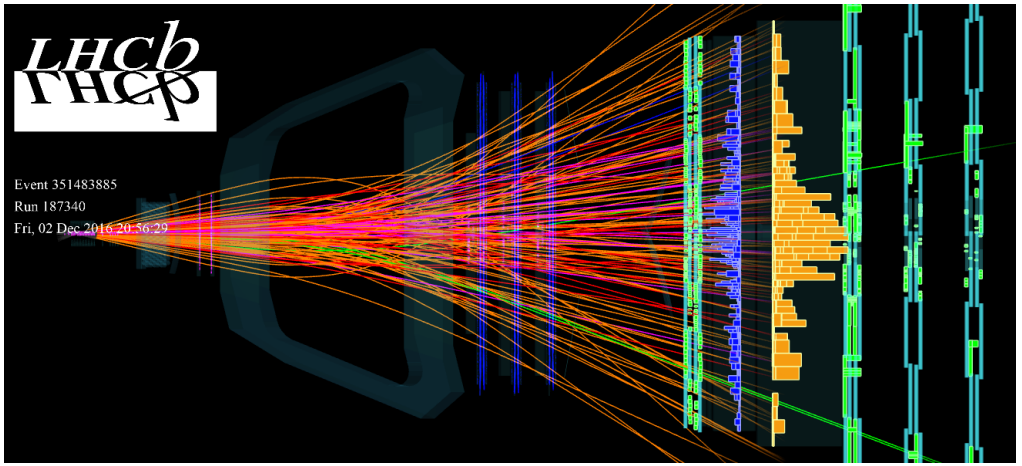
Ongoing open heavy flavor measurements at LHCb

- LHCb participated in the 8 TeV pPb data taking during 2016.
- Recorded luminosity in total $\sim 31 nb^{-1}$(20 times more than 2013)
- Increased charm & beauty cross-sections at higher energy
- Measurements of beauty hadrons in pPb (upcoming)
- Precision measurements of charmed hadrons in pPb (ongoing)

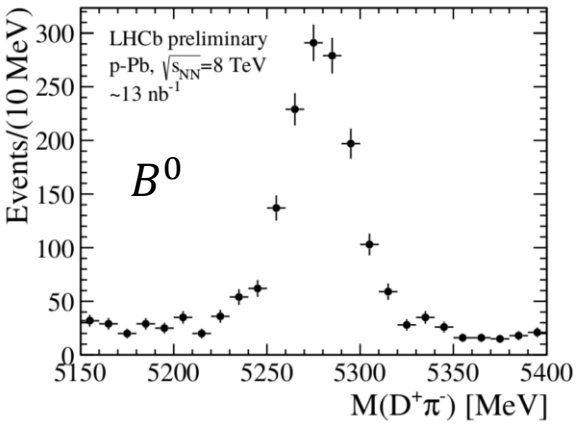


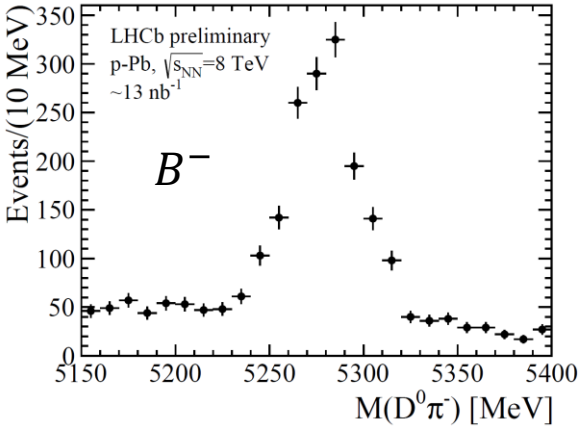


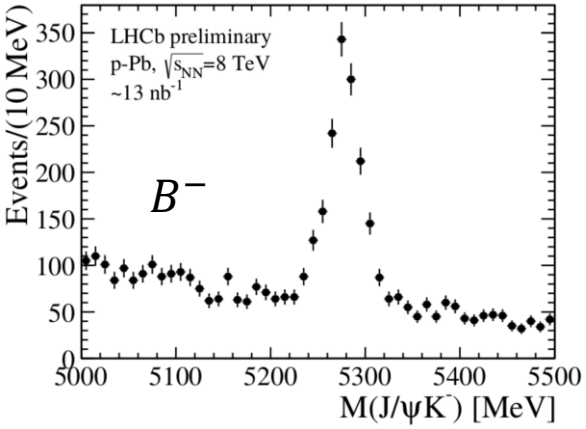
A high multiplicity pPb event seen by LHCb in 2016

http://lhcb-public.web.cern.ch/lhcb-public/

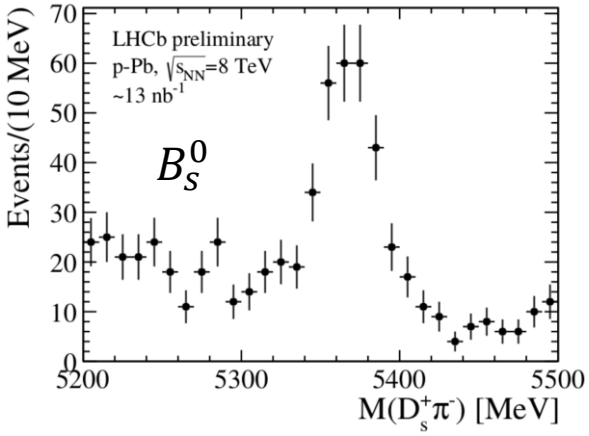
Open beauty measurements in *p*Pb 8 TeV

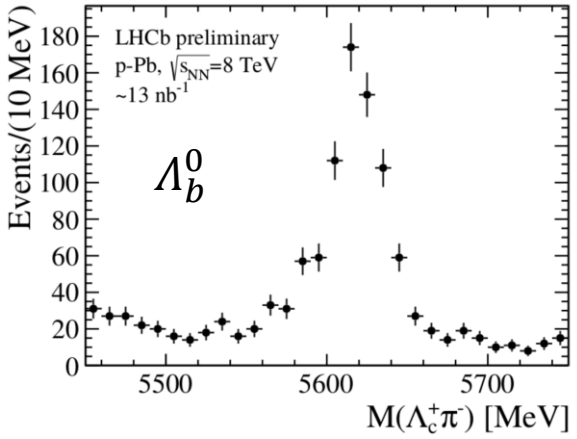




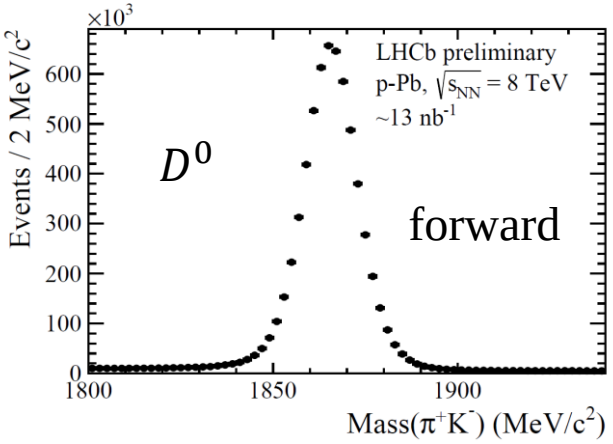


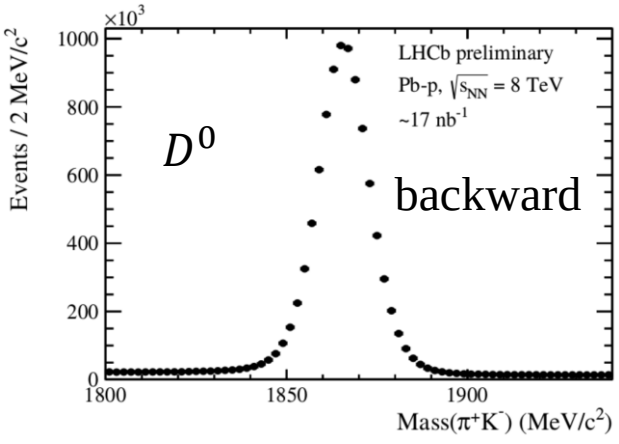
- Upcoming results on fully reconstructed *b* hadrons:
  - B^+, Λ_b^0 cross-sections in *p*Pb
  - R_{FB} for B^+, Λ_b^0
  - baryon-meson ratio $R_{\Lambda_b^0/B^+}$
  - $R_{p\mathrm{Pb}}$ for B^+, Λ_b^0

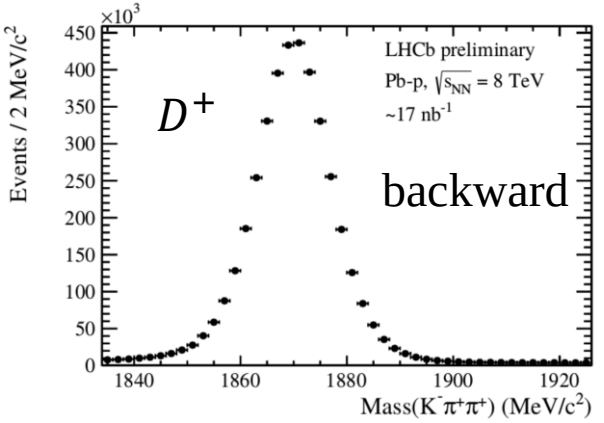




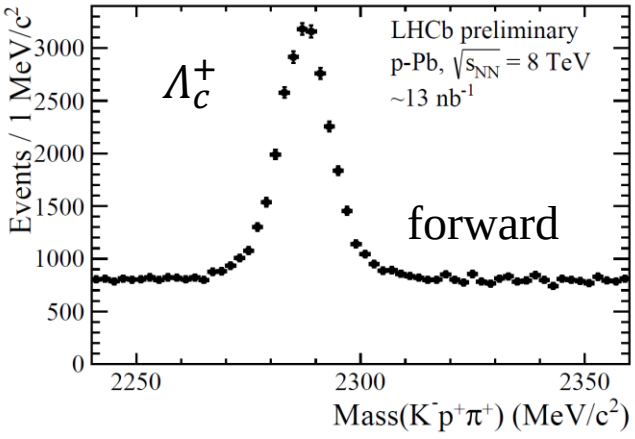
Open charm measurements in *p*Pb 8 TeV

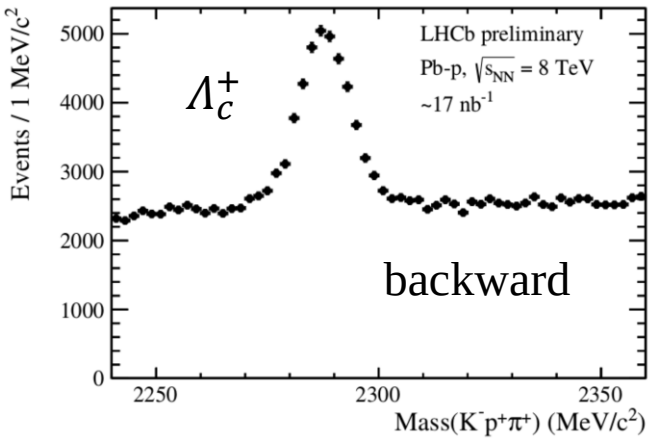


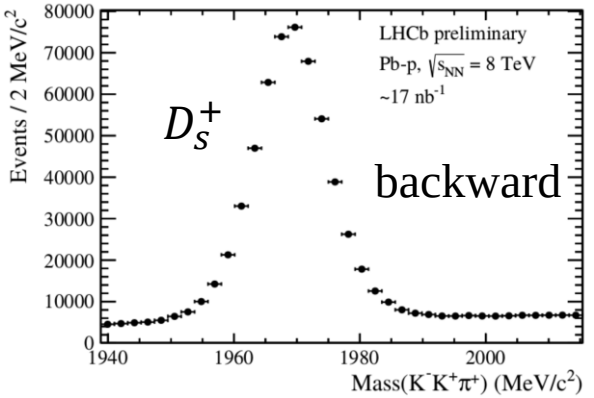




- Precision measurements of charmed hadrons in *p*Pb
- Accuracy improvement in $R_{\Lambda_c^+/D^0}$
- Measurements as functions of multiplicity
- Analyses ongoing







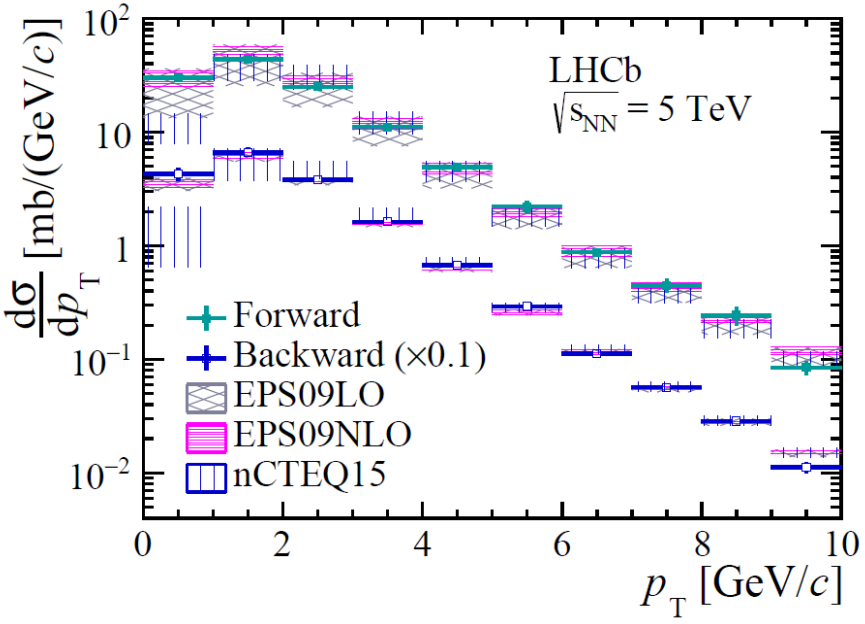
Conclusions

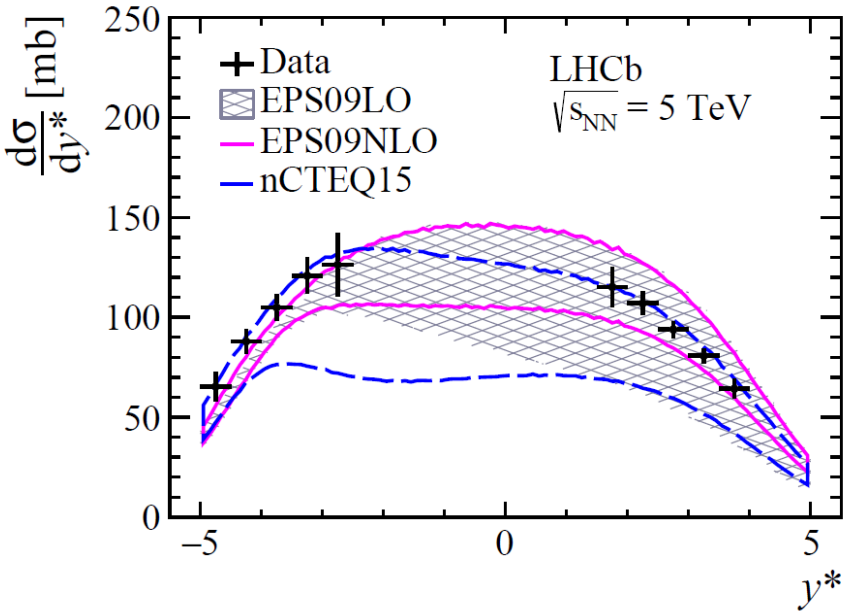
- Cross-sections of prompt D^0 and Λ_c^+ in pPb collisions at 5 TeV measured by LHCb
  - Nuclear modification factor of D^0 in pPb collisions directly measured
    - Significant D^0 suppression in the forward rapidity
    - more precise than theory
  - R_{FB} measured for D^0 and Λ_c^+, results consistent with theoretical calculations
    - D^0 more precise than theory
    - Λ_c^+ uncertainties comparable to nPDF
  - Charmed baryon-to-meson ratio $R_{\Lambda_c^+/D^0}$ measured
    - Consistent with model except high p_{T} in forward rapidity

- 8 TeV pPb data with high statistics enable exciting new measurements of open heavy flavor in cold nuclear matter
  - Upcoming results on open beauty states
  - Precision measurements of charmed hadrons ongoing

backup

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**

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