Open charm and beauty states production in proton-lead collisions with LHCb

Di Yang (Tsinghua University)

On behalf of the LHCb Collaboration

JUNE 11th 2019

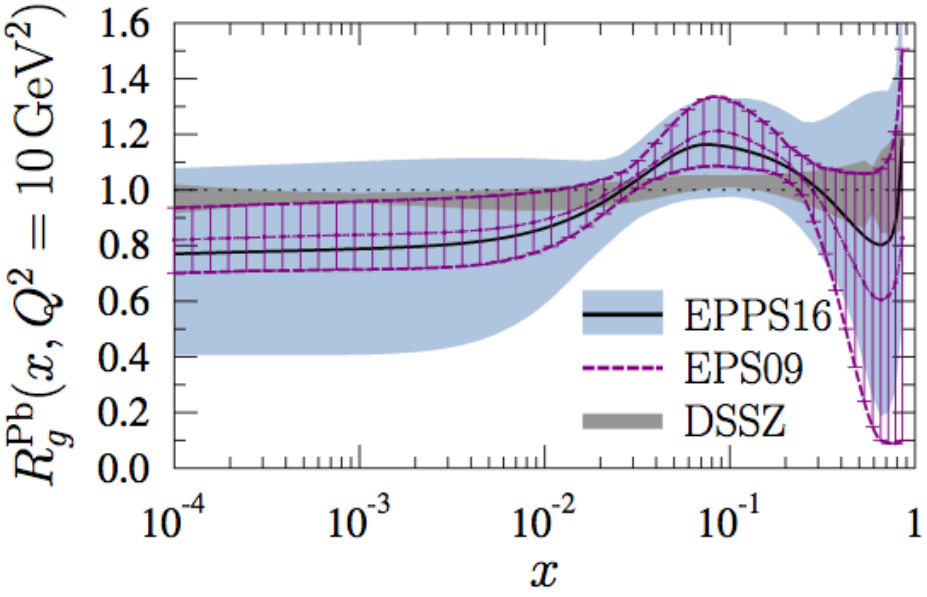
Outline

- Introduction
- The LHCb detector
- LHCb pPb data samples
- Prompt open charm production in 5.02 TeV pPb collisions
  JHEP 10 (2017) 090
  JHEP 02 (2019) 102
- Open beauty production in 8.16 TeV pPb collisions
  Phys. Rev. D99 052011 (2019)
- Summary and outlook

Introduction

- Heavy flavour states are good probes in heavy-ion collisions
  - $m_Q \gg \Lambda_{\mathrm{QCD}}$: allows perturbative calculations
  - Experience whole time evolution of collision

- Cold nuclear matter effects:
  - Modification of parton distribution functions: nPDF or CGC
  - Energy-loss with (in) coherent small-angle gluon radiation
  - Interacting with co-moving particles
  - …
- Observables
  - Nuclear modification factor $R_{p\mathrm{Pb}}$
  - Forward-backward ratio R_{FB}
  - Particle ratios

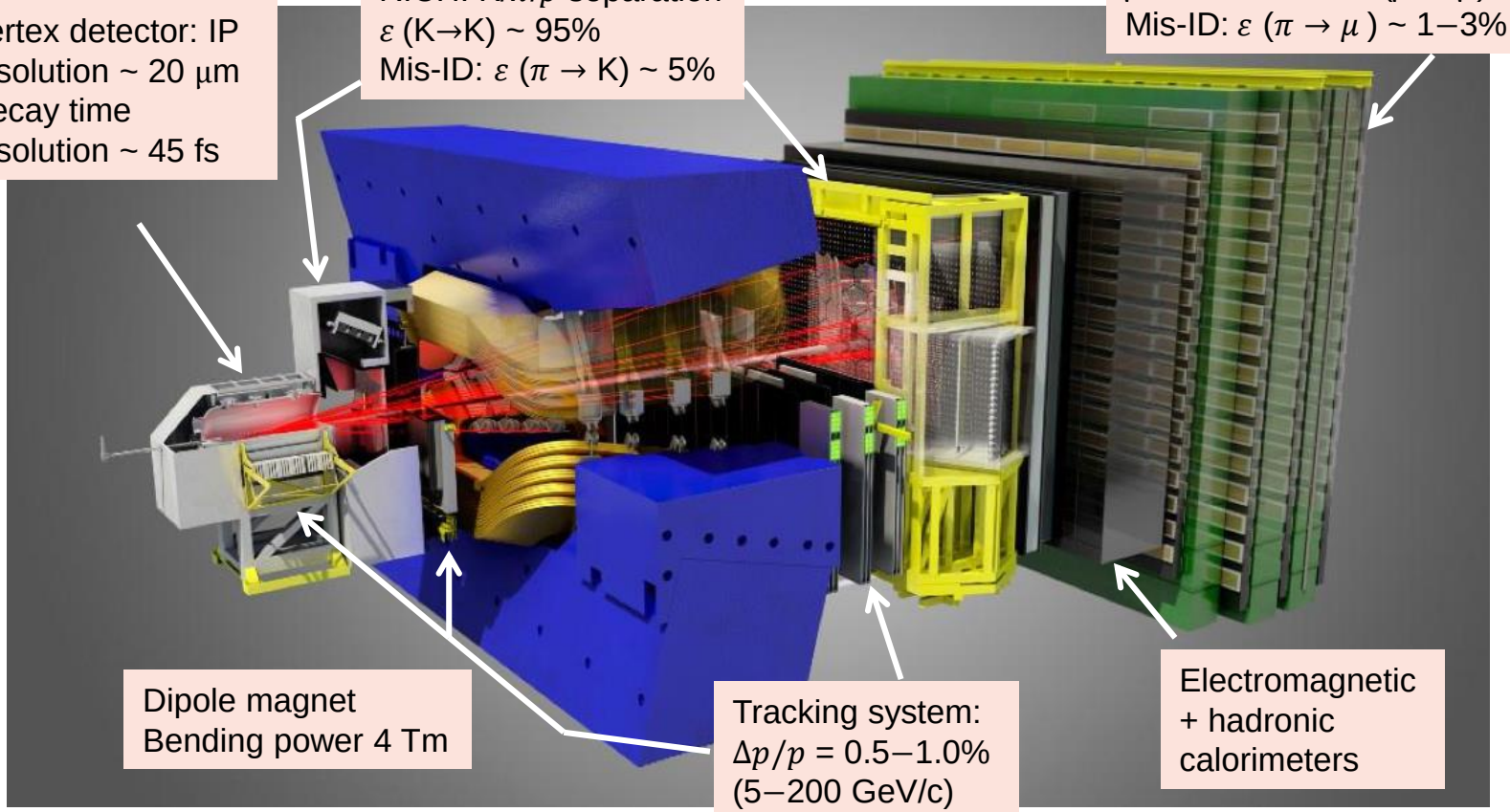


Eur. Phys. J. C (2017) 77:163

The LHCb detector

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

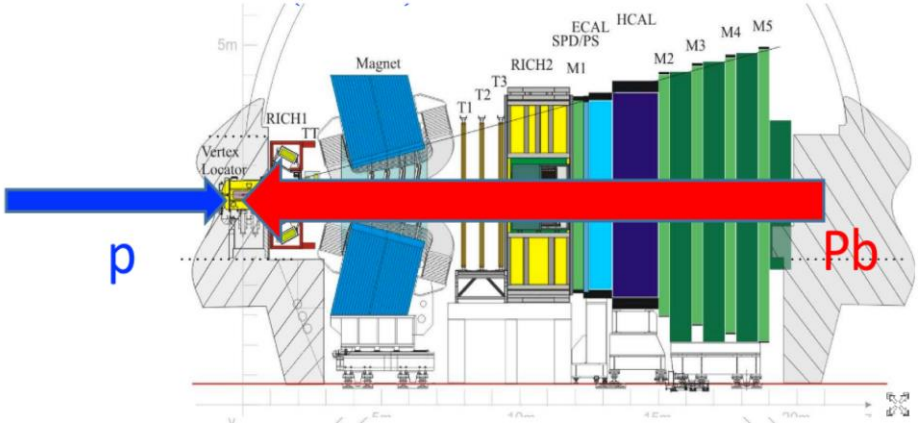
pseudorapidity acceptance $2 < \eta < 5$



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

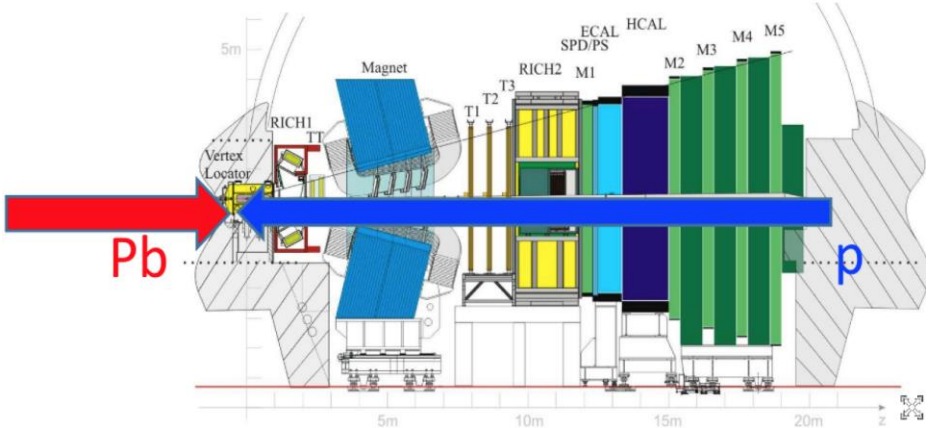
LHCb pPb data samples

Forward: pPb



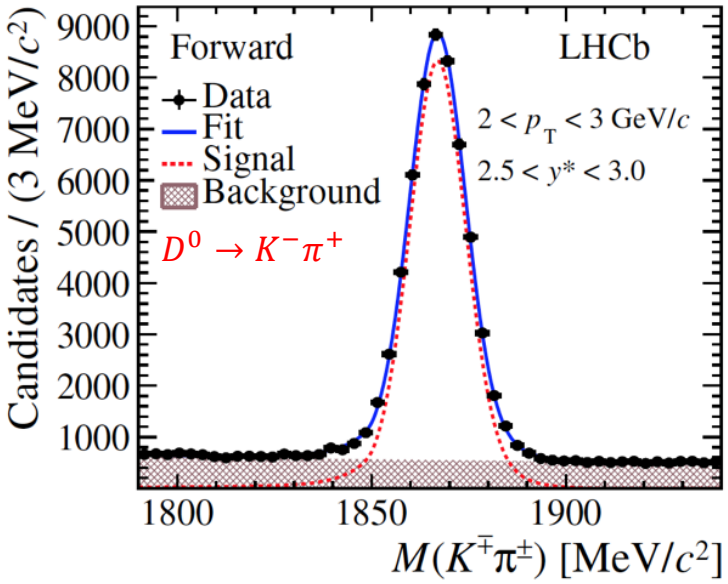
- $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV (2013)
  - pPb $(1.06\ \mathrm{nb}^{-1})$+ Pb$p$$(0.52\ \mathrm{nb}^{-1})$
- $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV (2016)
  - pPb $(13.6\ \mathrm{nb}^{-1})$+ Pb$p$$(21.8\ \mathrm{nb}^{-1})$

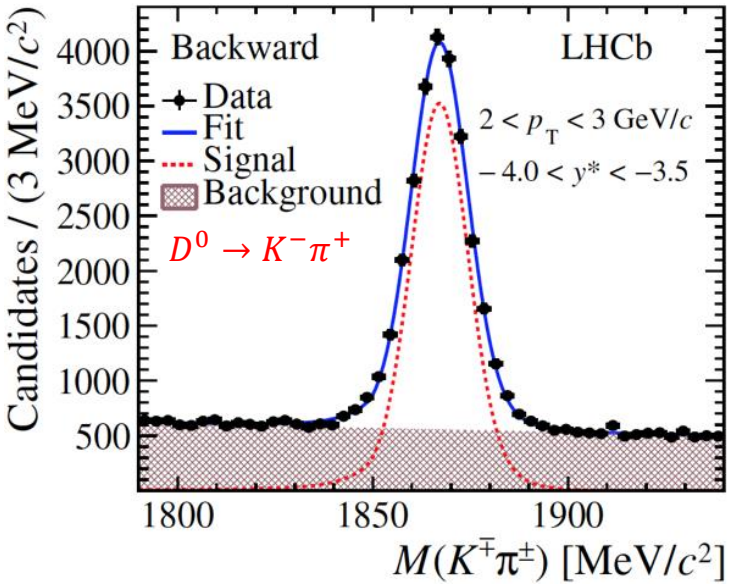
Backward: Pbp



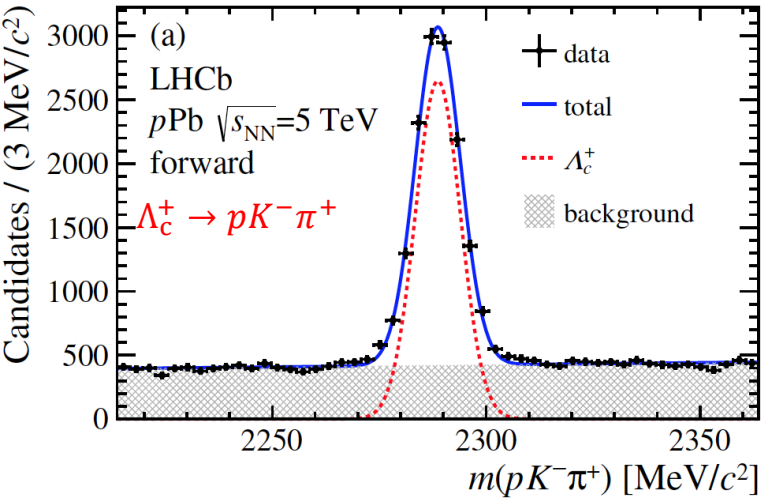
- Rapidity coverage
  - $y^* = y_{\mathrm{lab}} - y_{\mathrm{cms}}$
    rapidity in nucleon-nucleon cms
  - $\Delta y = \pm 0.465$
  - Forward (pPb): $1.5 < y^* < 4.0$
  - Backward (Pbp): $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$

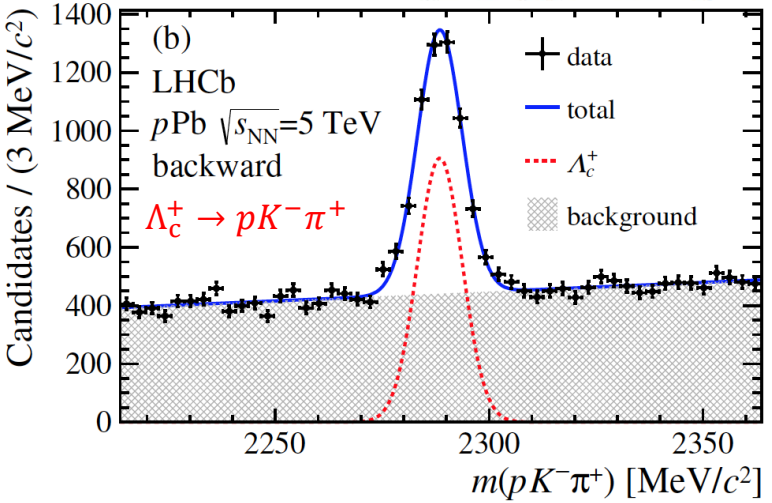
Prompt open charm: signals





Reconstructed through decay channels:
$D^0 \to K^-\pi^+$,
$\Lambda_c^+ \to pK^-\pi^+$





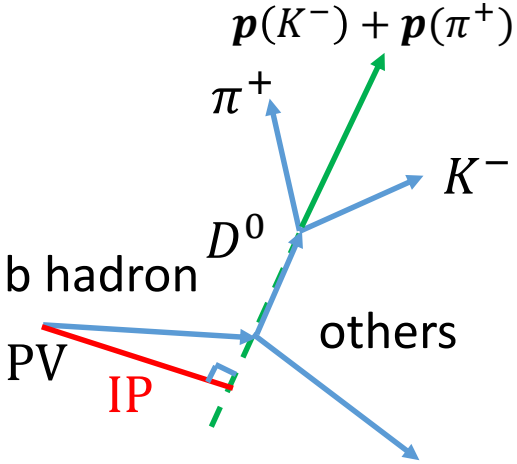
JHEP 10 (2017) 090
JHEP 02 (2019) 102

Gaussian signal + linear background

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

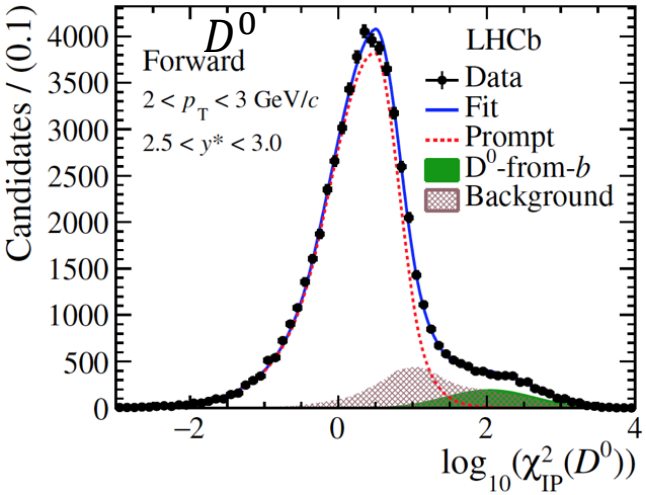
Prompt and non-prompt charm

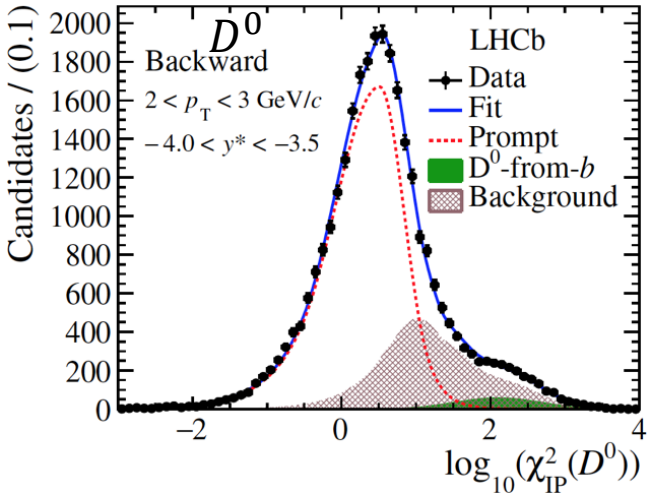
Distinguish prompt and non-prompt by fitting impact parameter (IP) distribution

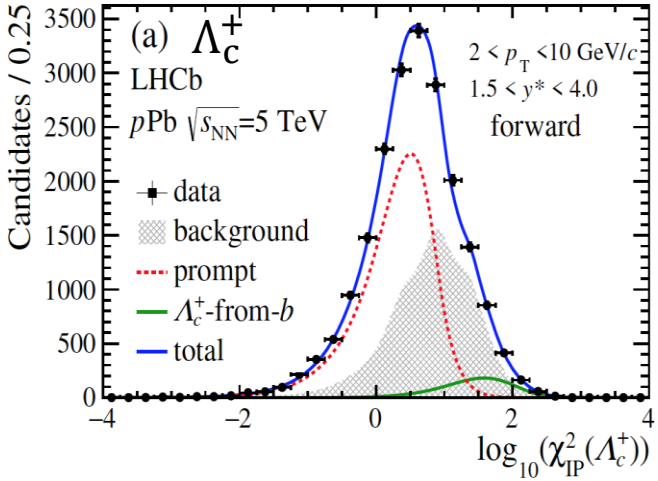


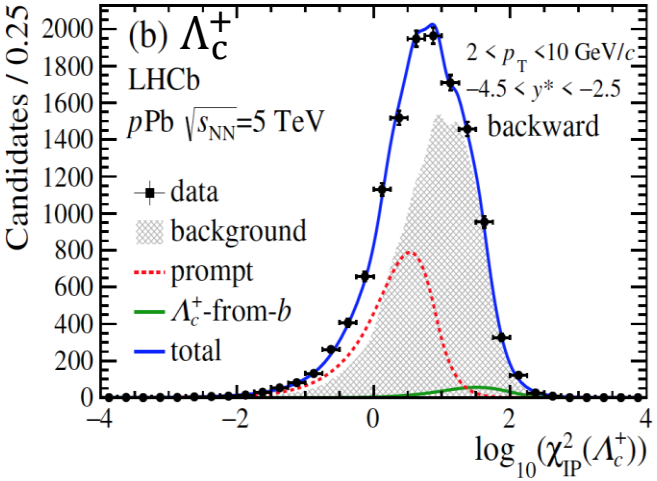
Non-prompt: charm produced from b decay (IP>0)

Prompt : charm produced directly in collision (IP=0)







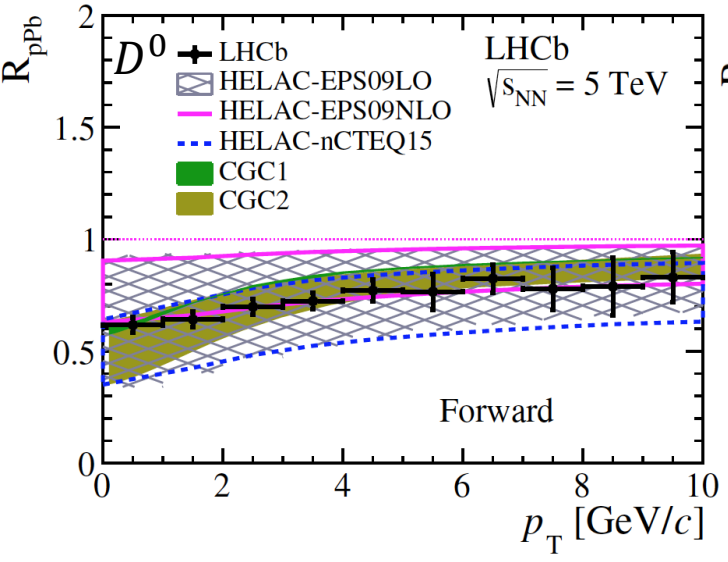


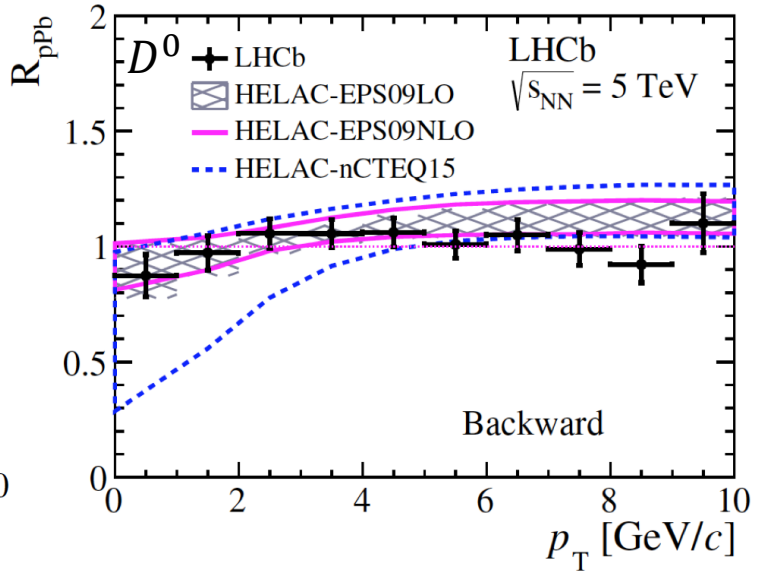
Prompt, from b and background are all described by bukin

Prompt charm yields can be extracted

JHEP 10 (2017) 090
JHEP 02 (2019) 102

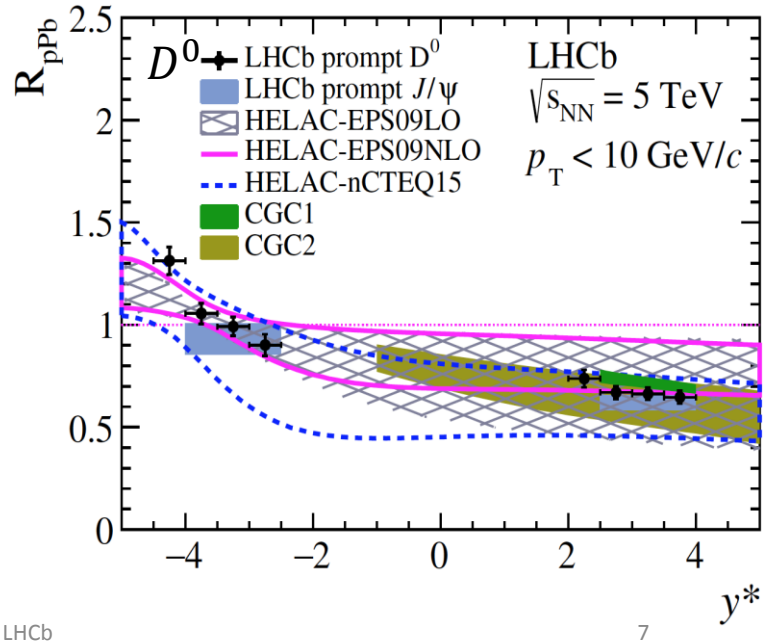
Prompt open charm: nuclear modification factor



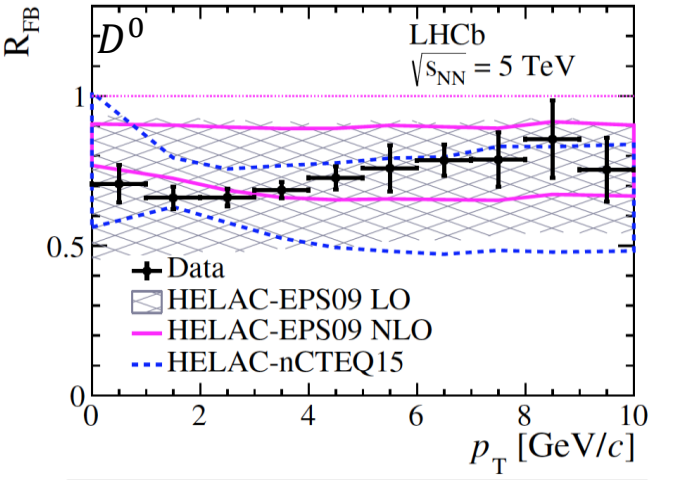


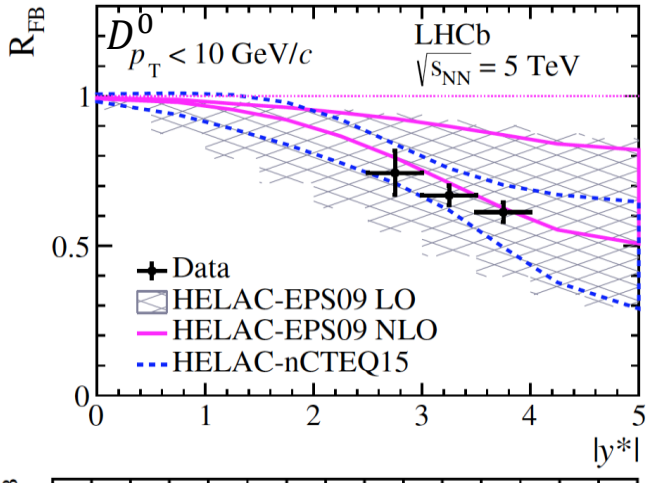
JHEP 10 (2017) 090

- $R_{p\mathrm{Pb}} = \frac{1}{A}\frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(p_\mathrm{T},y^*,\sqrt{s_\mathrm{NN}})/\mathrm{d}p_\mathrm{T}(\mathrm{d}y)}{\mathrm{d}\sigma_{pp}(p_\mathrm{T},y^*,\sqrt{s_\mathrm{NN}})/\mathrm{d}p_\mathrm{T}(\mathrm{d}y)}$, $A = 208$
- pp reference is measured by LHCb
- $R_{p\mathrm{Pb}}$ suppressed at forward rapidity
  - ➢Slight increase with increasing p_T
- $R_{p\mathrm{Pb}}$ close to 1 at backward rapidity
- Data are consistent with models with nPDF, CGC
- **Data have smaller uncertainties than theory**

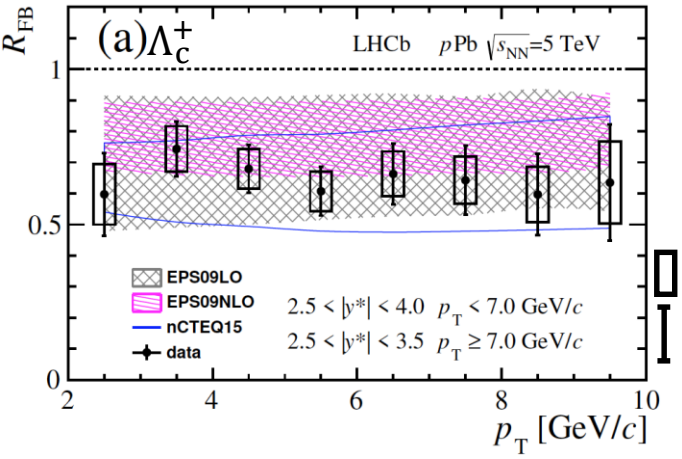


Prompt open charm: forward-backward ratio



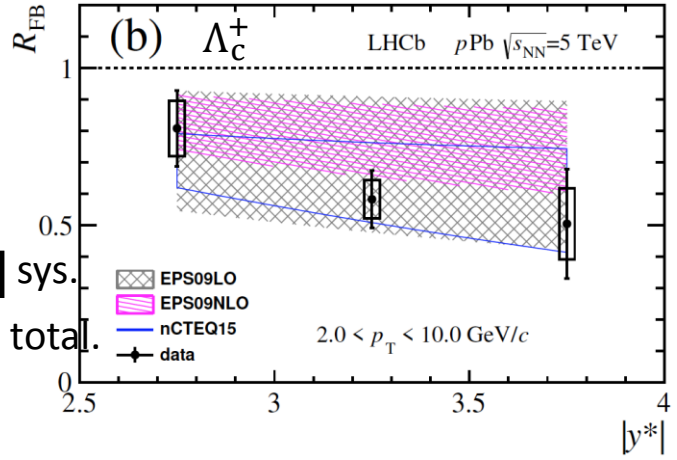


- $R_{\mathrm{FB}} = \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(p_{\mathrm{T}},+|y^*|)/\mathrm{d}p_{\mathrm{T}}(\mathrm{d}y)}{\mathrm{d}\sigma_{\mathrm{Pb}p}(p_{\mathrm{T}},-|y^*|)/\mathrm{d}p_{\mathrm{T}}(\mathrm{d}y)}$ $R_{\mathrm{FB}} < 1$ and decreases with rapidity



sys.

total.



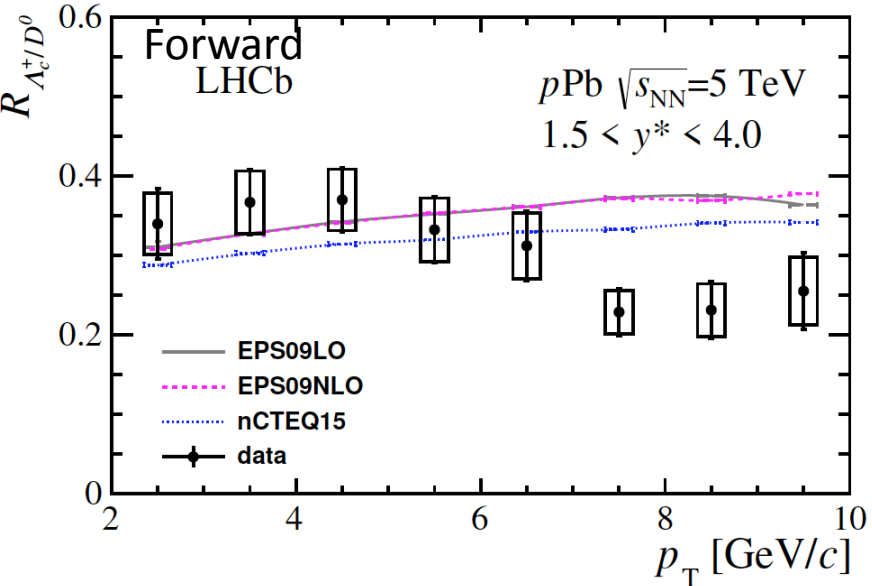
sys.

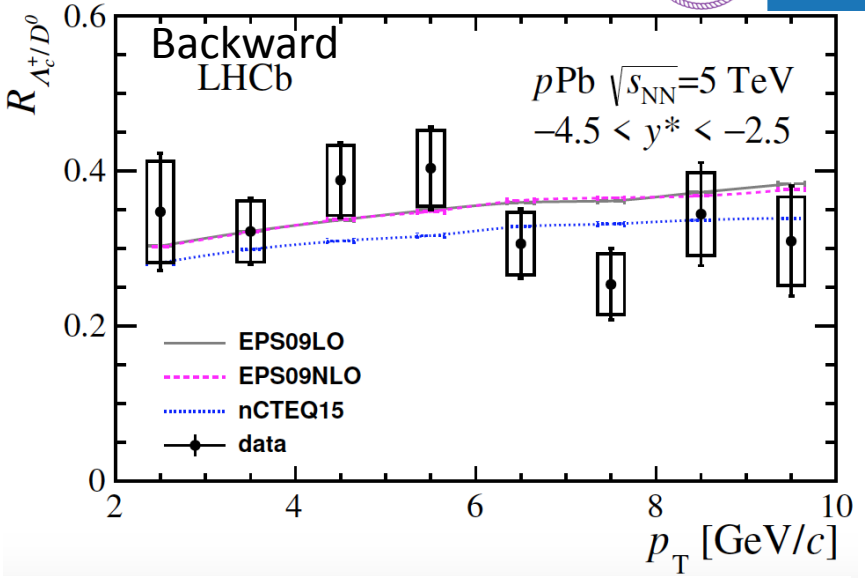
total.

- Data agree with calculations using various nPDF sets
- D^0 data have smaller uncertainties than theory

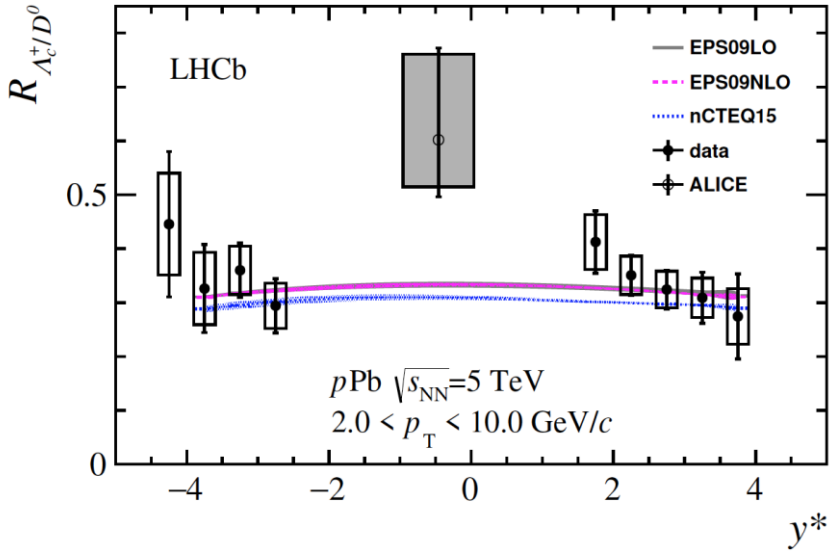
JHEP 10 (2017) 090
JHEP 02 (2019) 102

Prompt open charm: particle ratio



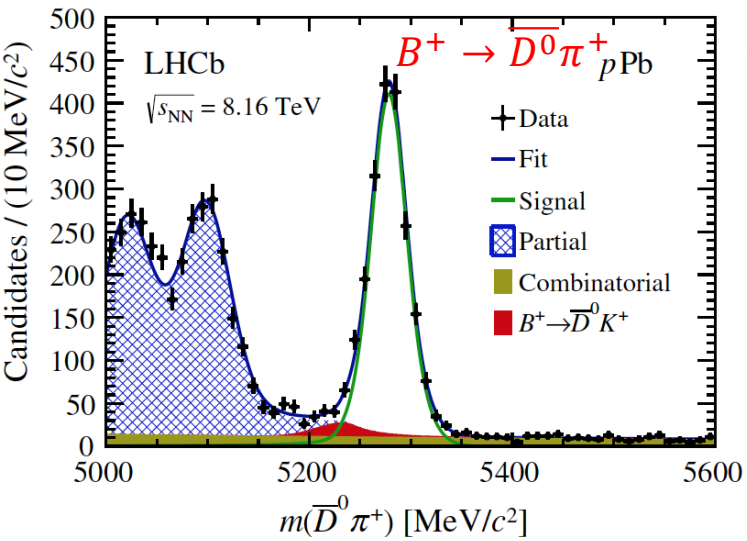


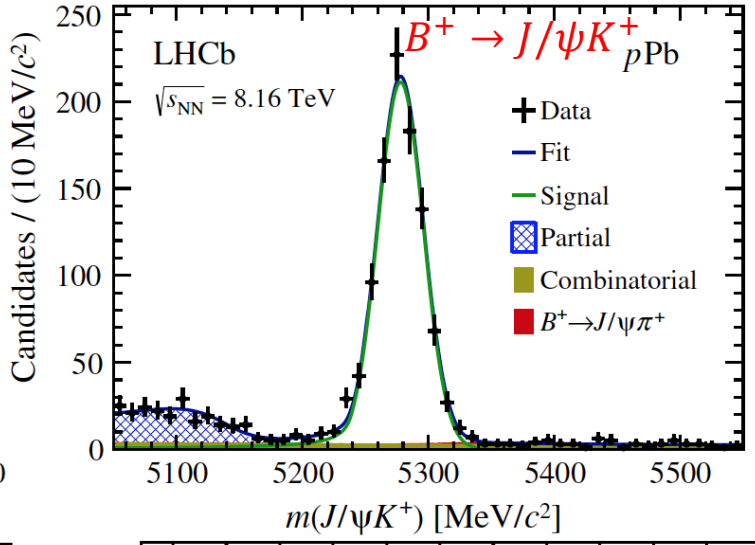
- $R_{\Lambda_c^+/D^0} = \dfrac{\mathrm{d}^2\sigma_{\Lambda_c^+}(p_T,y^*)/\mathrm{d}p_T(\mathrm{d}y)}{\mathrm{d}^2\sigma_{D^0}(p_T,y^*)/\mathrm{d}p_T(\mathrm{d}y)}$
- Theoretical calculation are based on measured pp results from LHCb
- nPDF uncertainties cancel in baryon/mes ratios
- Forward: consistent with theory in lower and below theory in higher p_T
- Backward: consistent with theory for all p_T and y^*

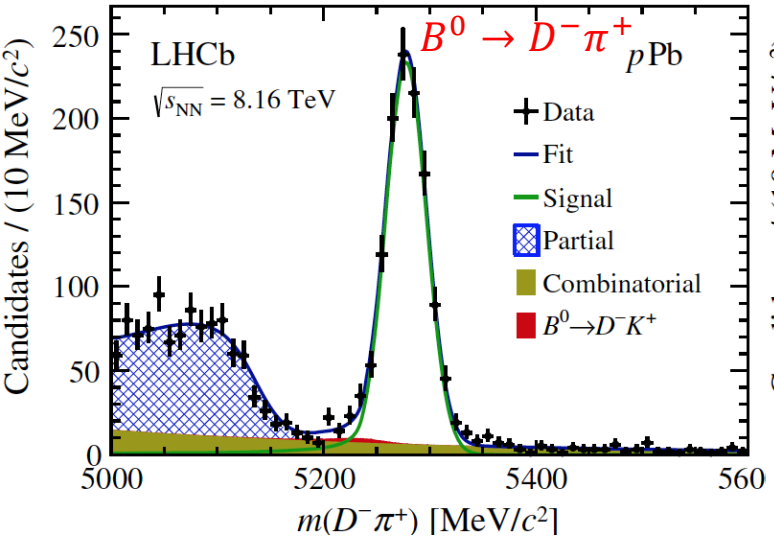


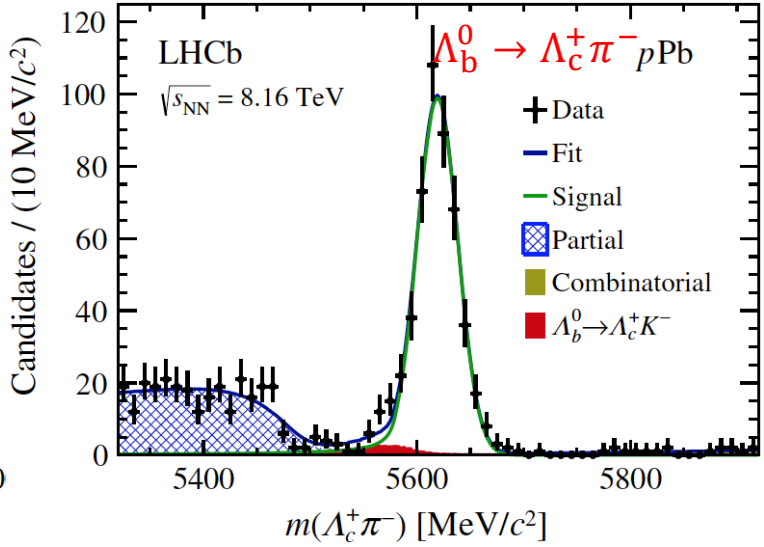
JHEP 02 (2019) 102

Open beauty: signals









- Reconstructed through decay channels:

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

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

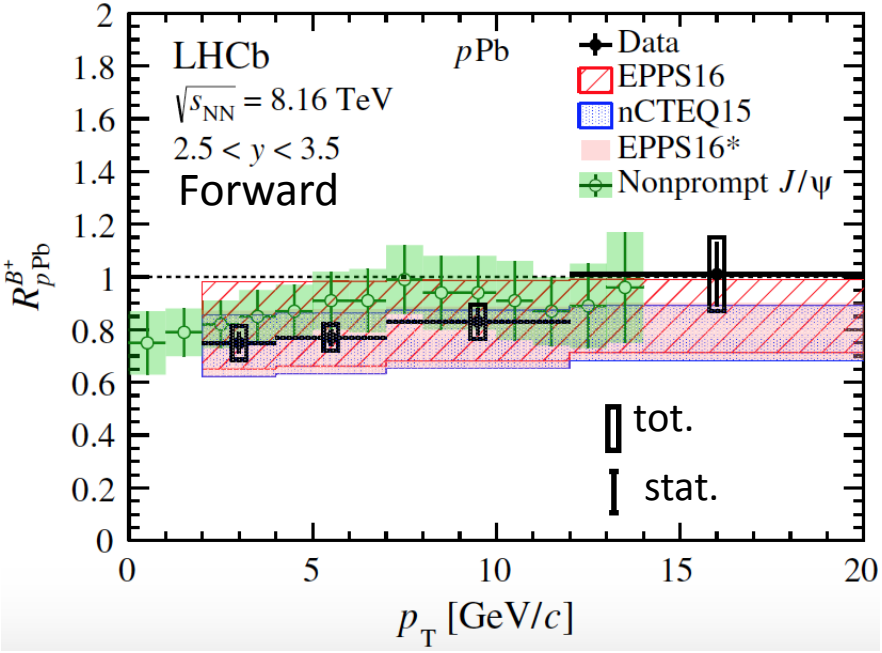
$B^0 \to D^-\pi^+$;

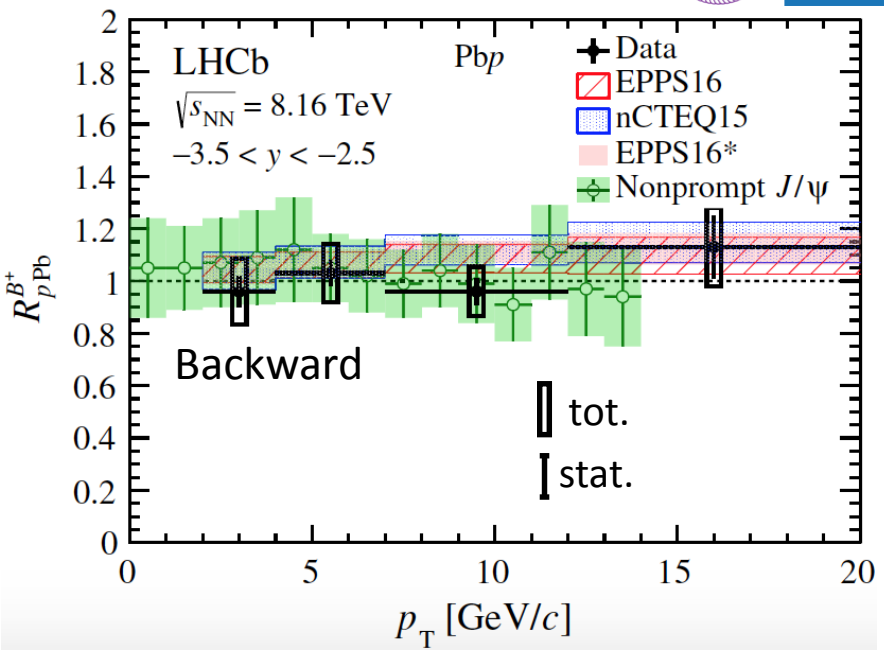
$\Lambda_b^0 \to \Lambda_c^+\pi^-$

Phys. Rev. D99 052011 (2019)

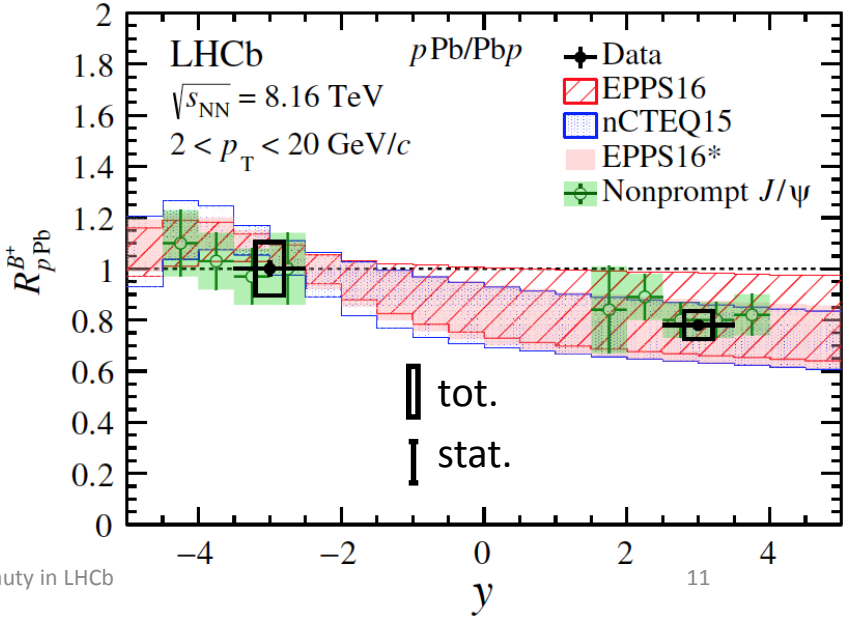
Extract yields by fitting invariant mass distribution and obtain cross section σ as a function of p_T and y

Open beauty: nuclear modification factor



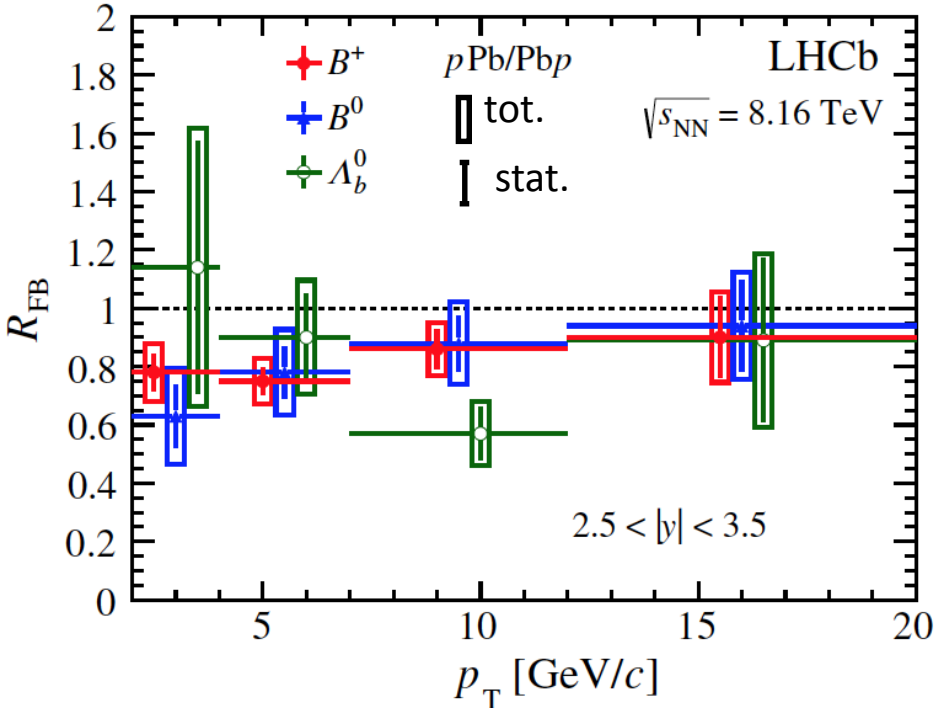


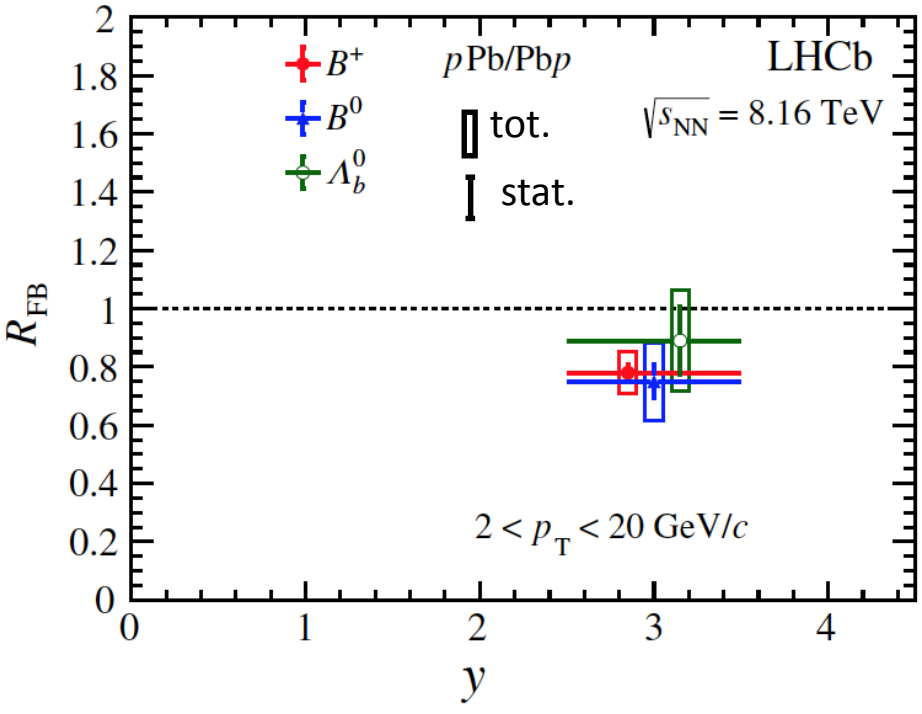
- Forward: suppressed, $R_{p\mathrm{Pb}}$ increases with p_{T}
- Backward: ≈ 1
- Data are consistent with nPDF calculations and J/ψ from b decay
- Beauty suppression is comparable to charm



Phys. Rev. D99 052011 (2019)

Open beauty: forward-backward ratio

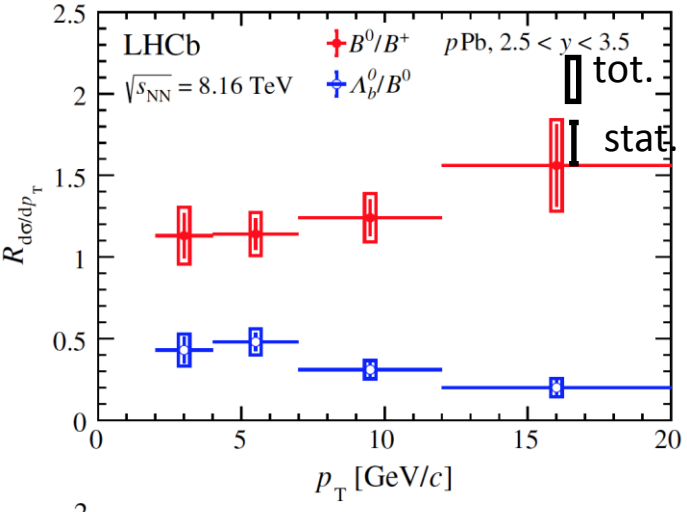


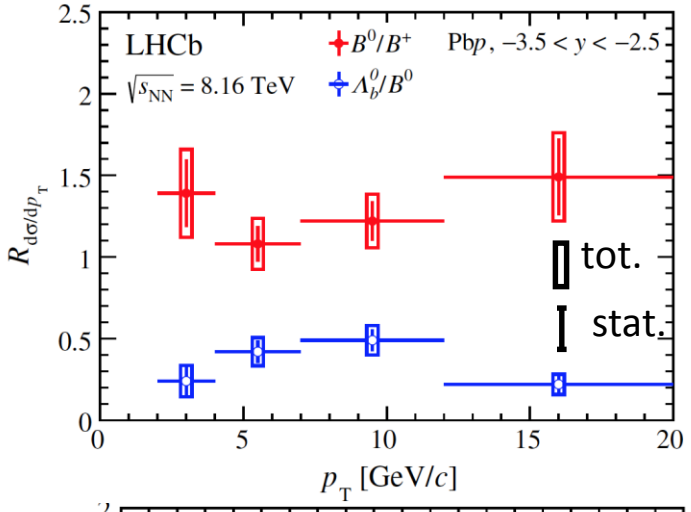


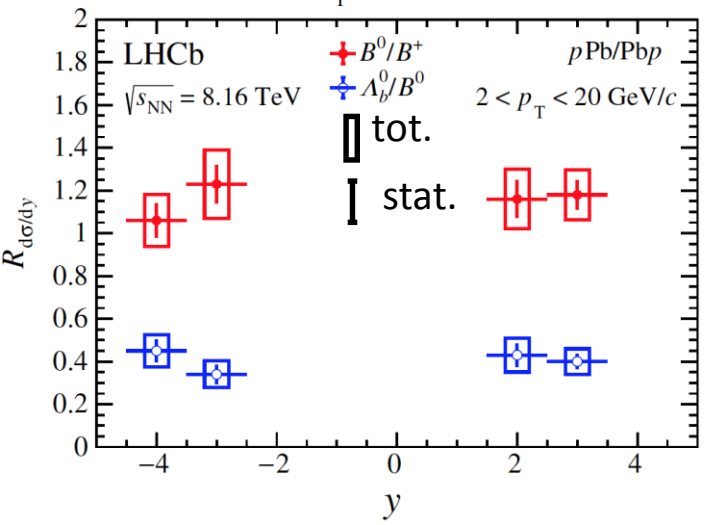
- R_{FB} for B mesons < 1
  - ➢No strong dependence with p_{T} is observed
  - ➢Consistent with nPDF calculations
- R_{FB} for B^0 and B^+ are similar
- R_{FB} for Λ_{b}^0 suffers larger statistical uncertainty

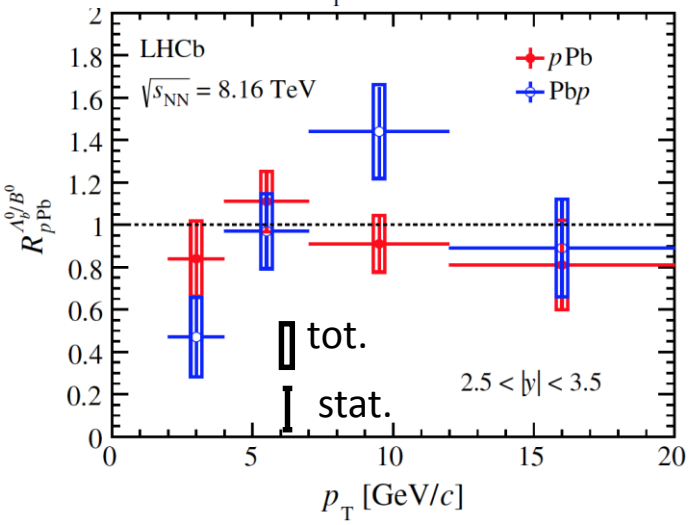
Phys. Rev. D99 052011 (2019)

Open beauty: particle ratio









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

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

- 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

Phys. Rev. D99 052011 (2019)

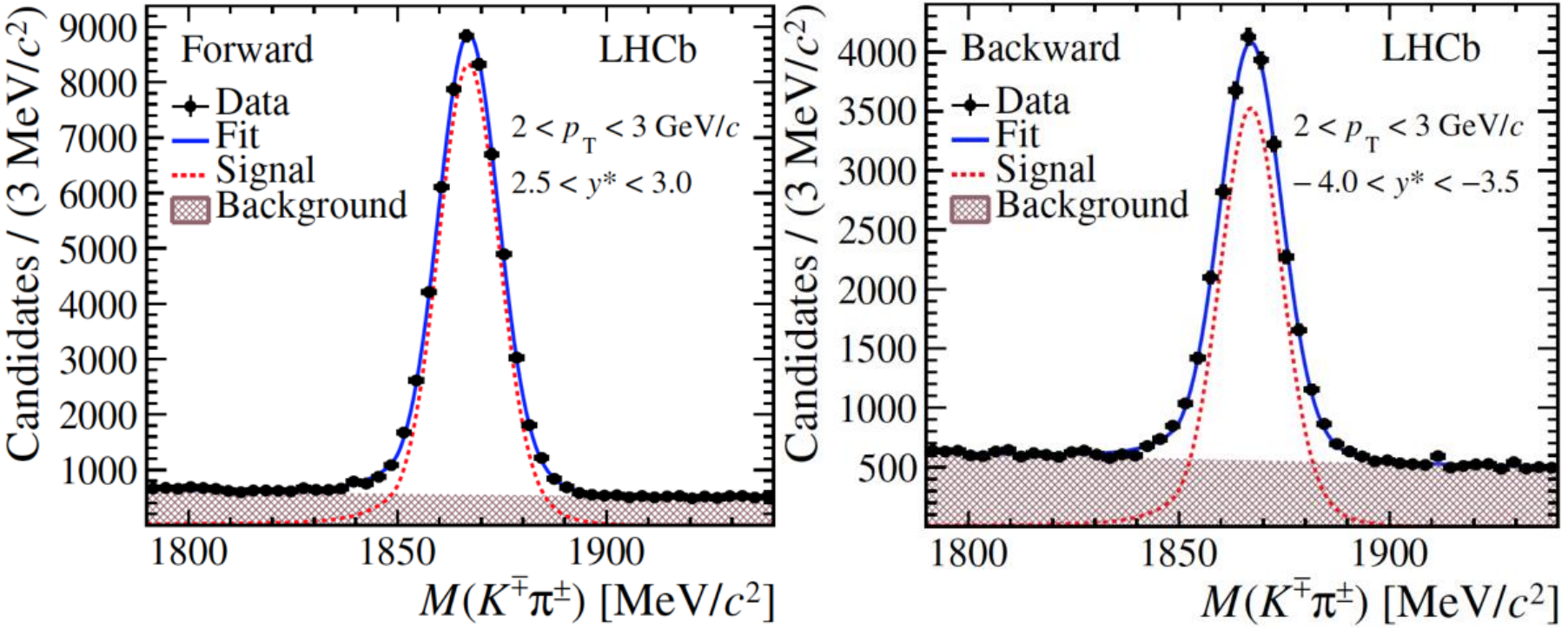
Summary and outlook

- LHCb has excellent capabilities to study heavy flavour in heavy ion studies
- Production of D^0 and Λ_c^+ are measured in 5.02 TeV pPb collisions by LHCb
  - $R_{p\mathrm{Pb}}^{D^0}$ is significantly suppressed in the forward and more precise than theory so that can be used to constrain model
  - $R_{\mathrm{FB}}^{D^0}$ and $R_{\mathrm{FB}}^{\Lambda_c^+}$ agree with nPDF calculations and $R_{\mathrm{FB}}^{D^0}$ has smaller uncertainties than theory
  - $R_{\Lambda_c^+/D^0}$ agrees with model except in forward high p_{T} bins
- Production of B^+, B^0 and Λ_b^0 are measured in 8.16 TeV pPb collisions by LHCb (Λ_b^0 first measured in heavy ion collisions using exclusive hadronic states)
  - $R_{p\mathrm{Pb}}^{B^+}$ agrees with nPDF calculations theory and J/ψ from b decay
  - $R_{p\mathrm{Pb}}^{\Lambda_b^0}/R_{p\mathrm{Pb}}^{B^0} \approx 1$ at forward rapidity
- Production of open charm in 8.16 TeV and more species such as D_s^+, D^* in 5.02 TeV pPb collisions are under study
  - Multiplicity dependence


Thank you!

Back up slides

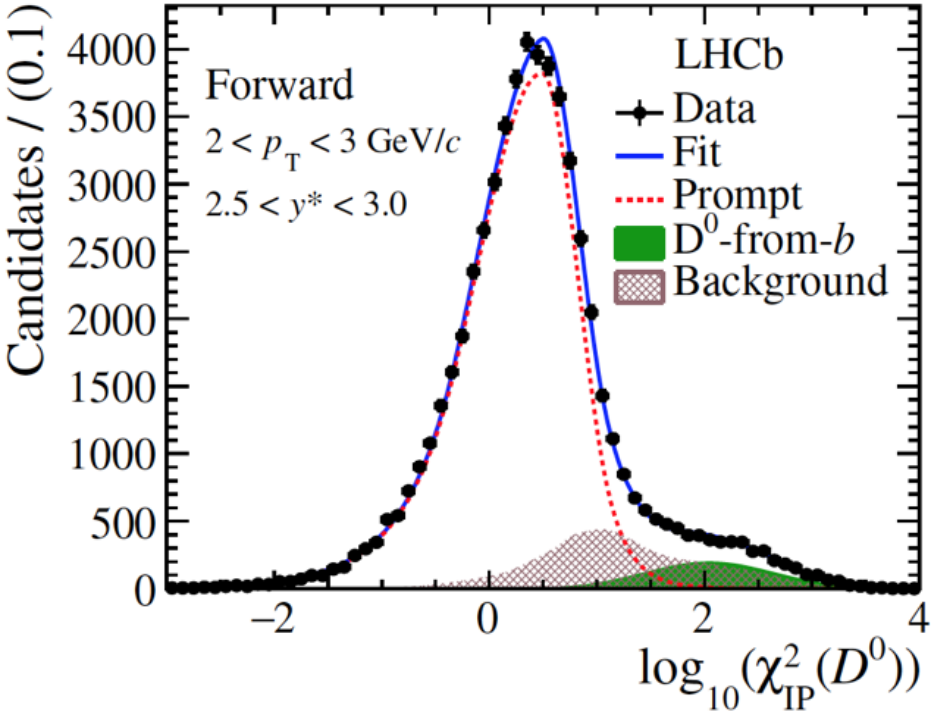
Open charm production: prompt D^0

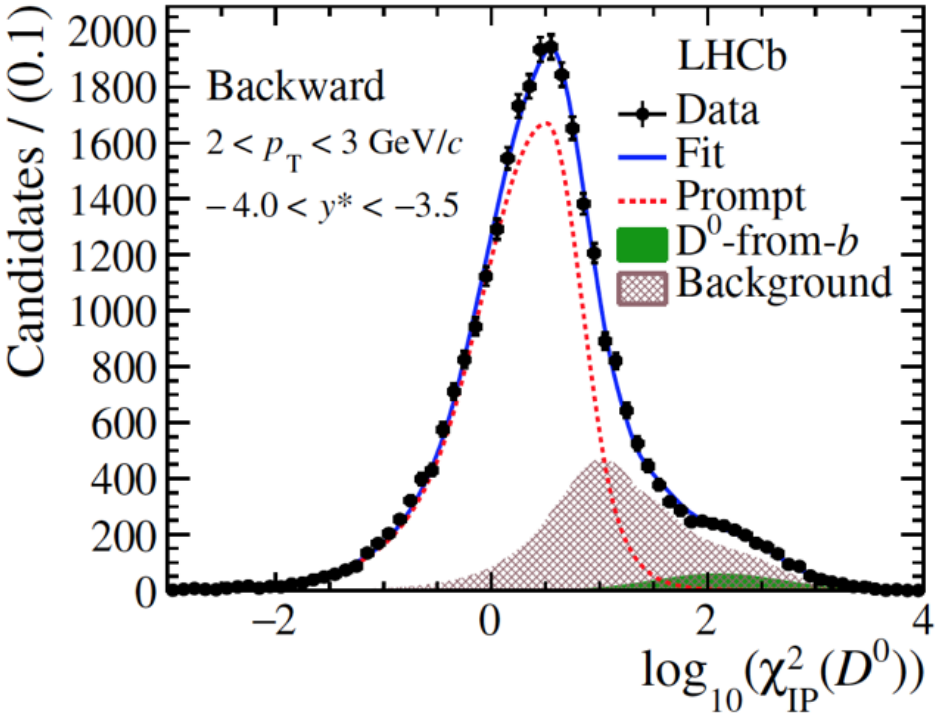


- Reconstructed through decay channel: $D^0 \to K^-\pi^+$
- Obtain D^0 yields $N(D^0 \to K^-\pi^+)$ by fitting invariant mass distribution:
  - Signal: Crystal Ball + Gaussian
  - Background: linear

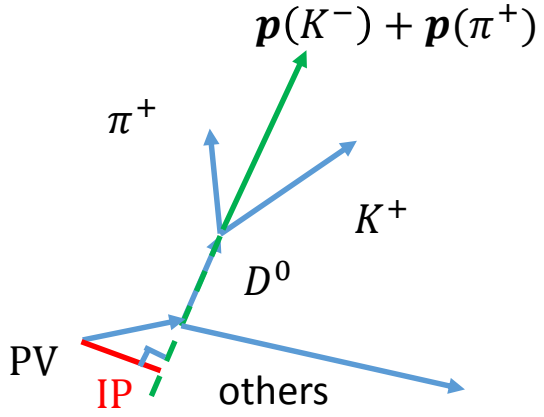
JHEP 10 (2017) 090

Open charm production: prompt D^0



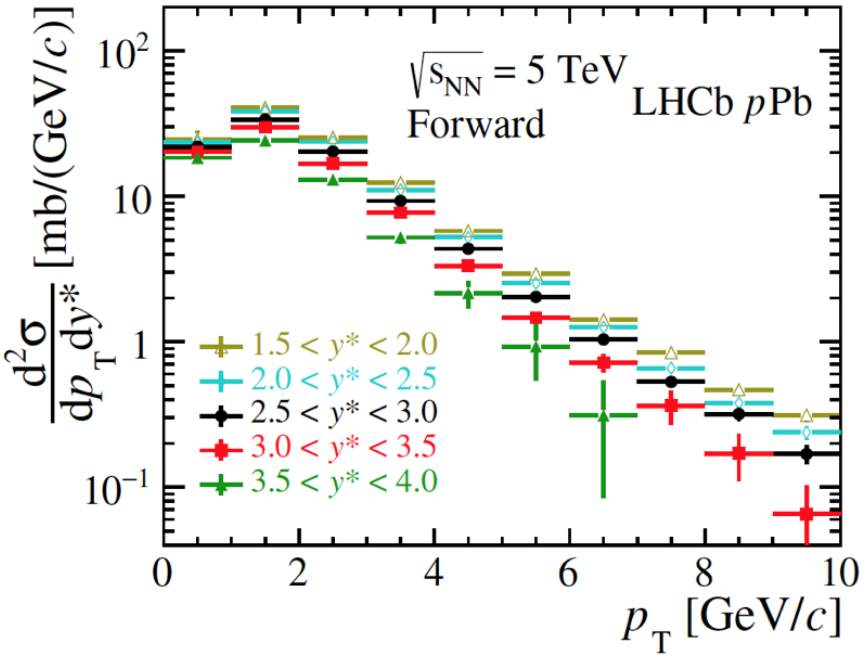


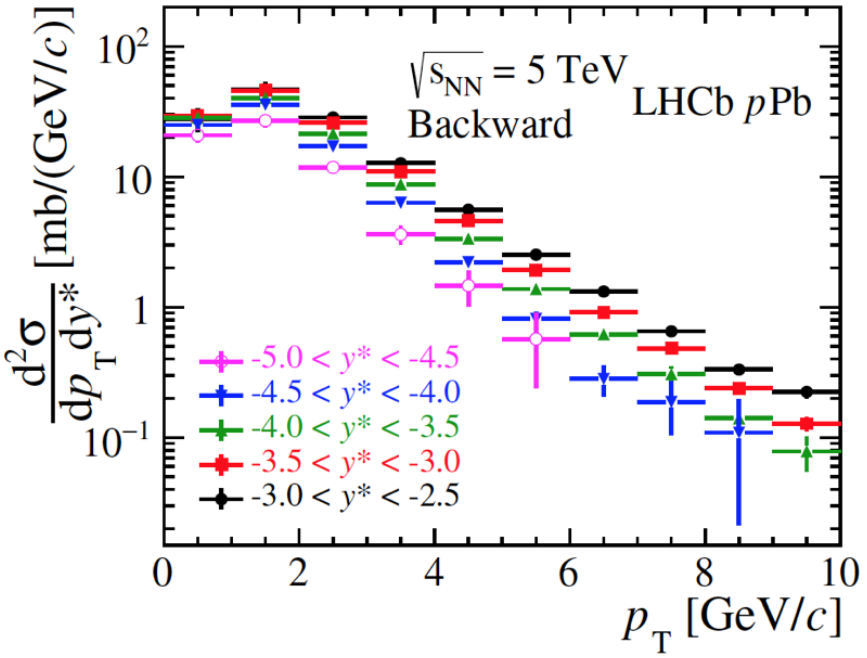
- Extract prompt D^0 by fitting χ^2_{IP} distribution
  - Prompt: simulation
  - from b: simulation
  - Background: sideband in data



JHEP 10 (2017) 090

Prompt D^0: cross section

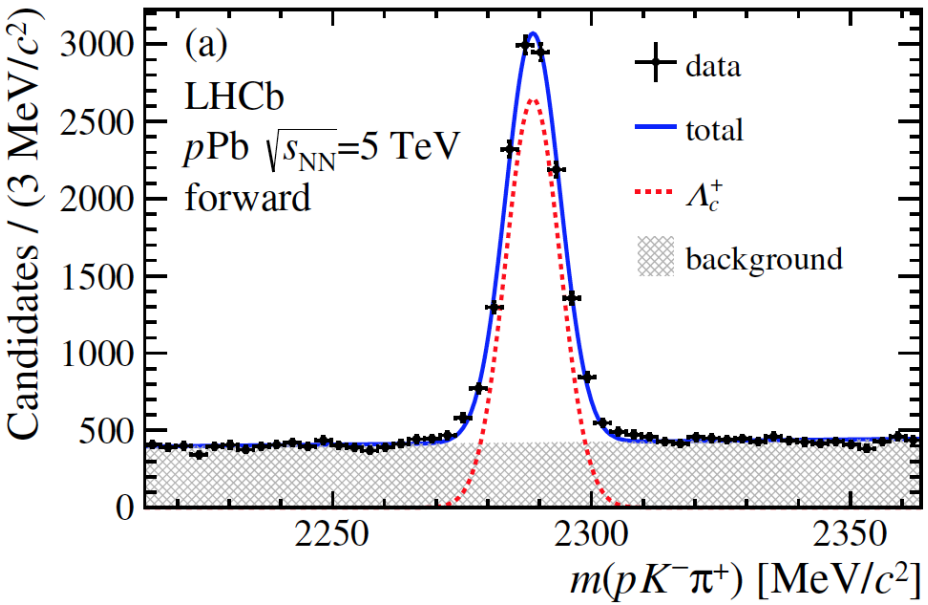


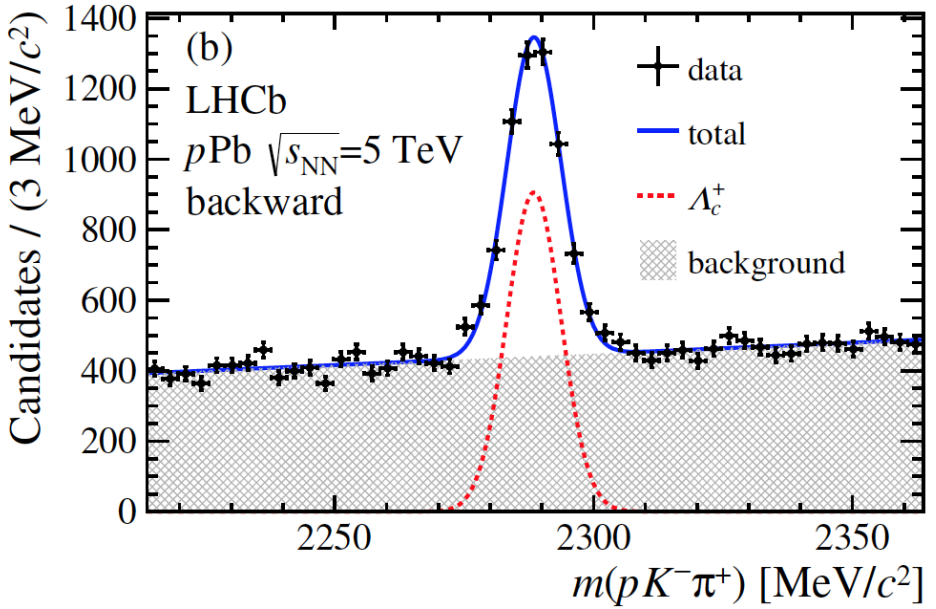


- Double-differential Cross section: $\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} = \frac{N(D^0 \to K^-\pi^+; p_T, y)}{\mathcal{L} \times \varepsilon(p_\mathrm{T}, y) \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) \times \Delta y \times \Delta p_\mathrm{T}}$
- The uncertainty is the quadratic sum of the statistical and systematic components
- $\varepsilon(p_\mathrm{T}, y)$: effeciency estimated from simulation sample
- $\sigma(p_\mathrm{T} < 10\ \mathrm{GeV}/c\ ,\ 1.5 < y^* < 4.0) = 230.6 \pm 0.5(\mathrm{stat}) \pm 13.0(\mathrm{sys})$ mb
- $\sigma(p_\mathrm{T} < 10\ \mathrm{GeV}/c\ ,\ -5.0 < y^* < -2.5) = 252.7 \pm 1.0(\mathrm{stat}) \pm 20(\mathrm{sys})$ mb

JHEP 10 (2017) 090

Open charm production: prompt Λ_c^+

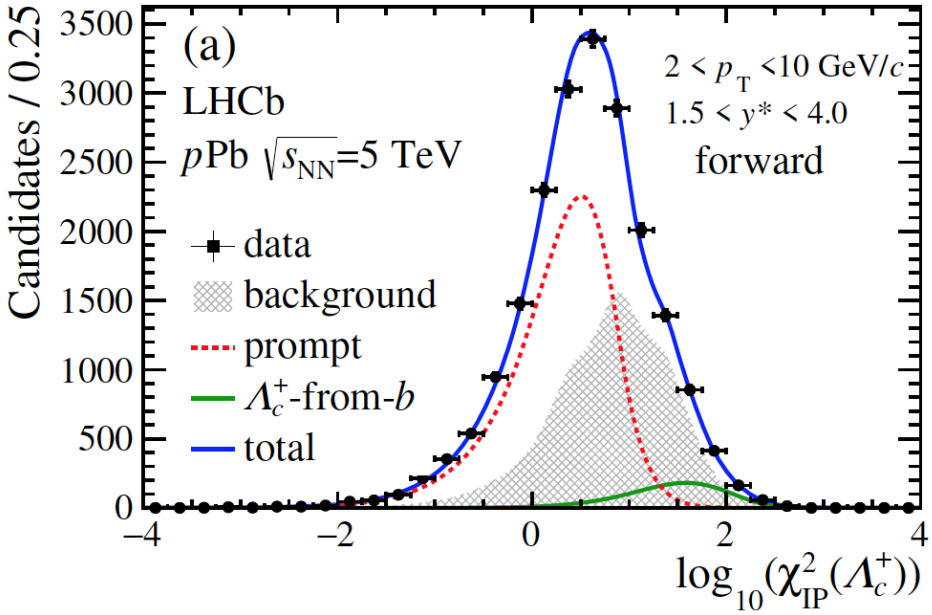


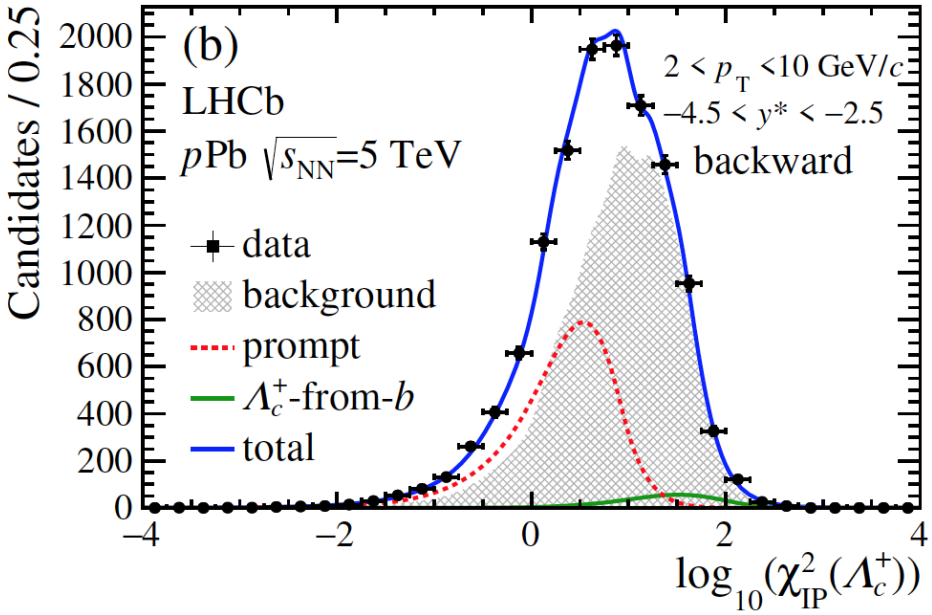


- Reconstructed throught decay channel:$\Lambda_c^+ \to pK^-\pi^+$
- Obtain Λ_c^+ yields $N(\Lambda_c^+ \to pK^-\pi^+)$ by fitting invariant mass distribution:
  - Signal: Gaussian
  - Background: linear

JHEP 02 (2019) 102

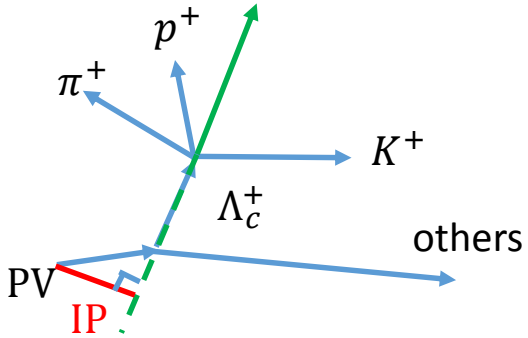
Open charm production: prompt Λ_c^+





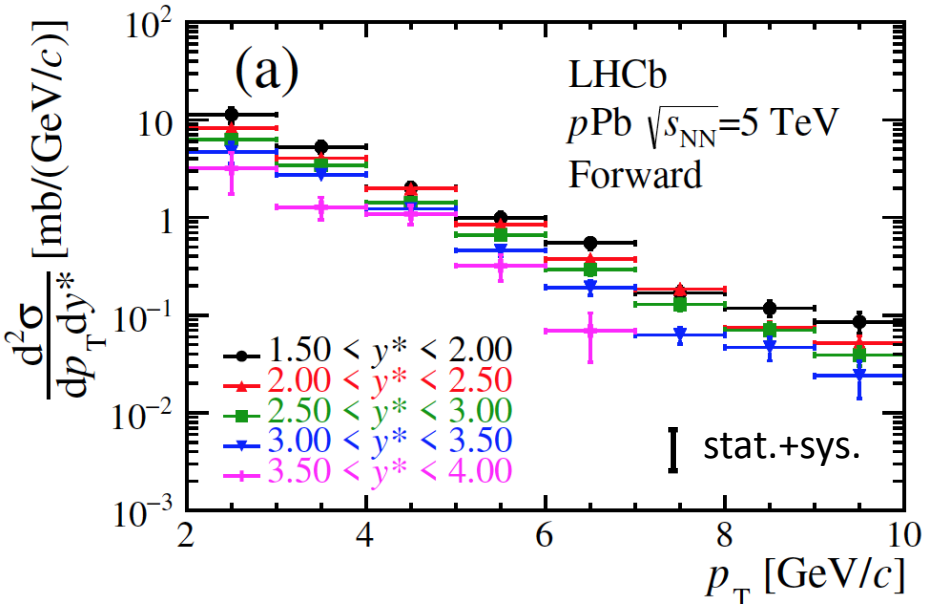
- Extract prompt Λ_c^+ by fitting χ^2_{IP} distribution
  - ➢Prompt: simulation
  - ➢from b: simulation
  - ➢Background: sideband in data

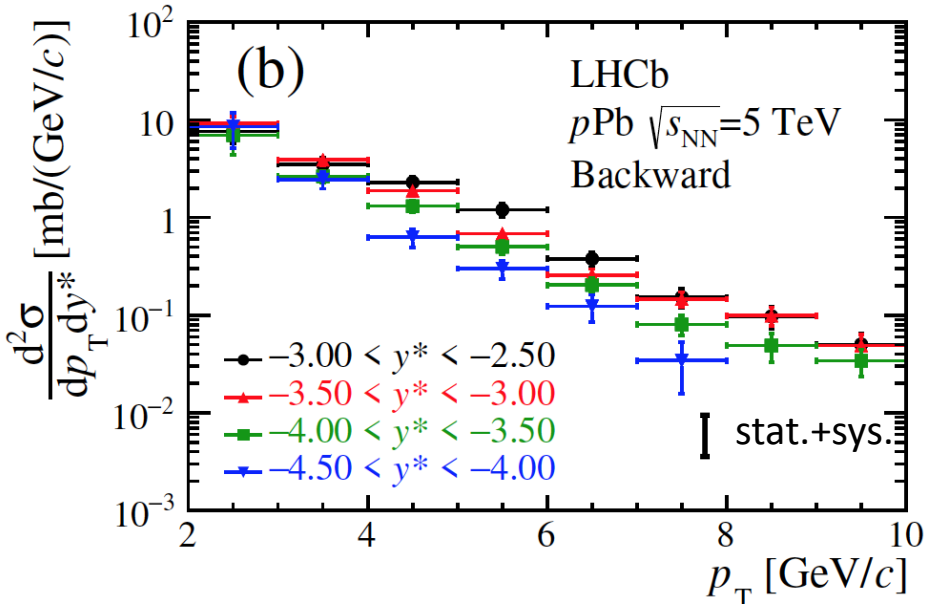
$$\boldsymbol{p}(K^-) + \boldsymbol{p}(\pi^+) + \boldsymbol{p}(p^+)$$



JHEP 02 (2019) 102

Prompt Λ_c^+: cross section

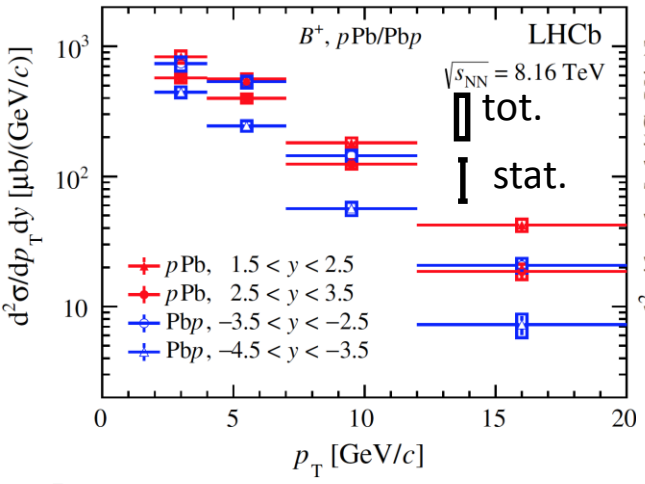


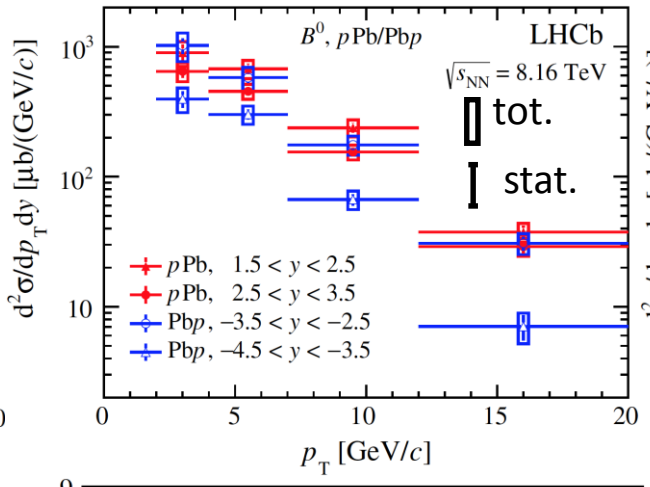


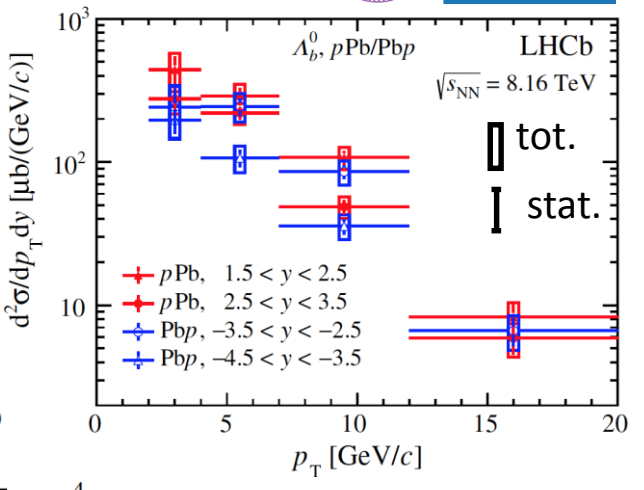
- Double-differential Cross section: $\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} = \frac{N(\Lambda_c^+ \to pK^-\pi^+; p_T, y)}{\mathcal{L} \times \varepsilon(p_\mathrm{T}, y) \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) \times \Delta y \times \Delta p_\mathrm{T}}$
- $\varepsilon(p_\mathrm{T}, y)$: effeciency estimated from simulation sample
- $\sigma(2 < p_\mathrm{T} < 10\ \mathrm{GeV}/c\,,\ 1.5 < y^* < 4.0) = 32.1 \pm 1.1(\mathrm{stat}) \pm 3.2(\mathrm{sys})$ mb
- $\sigma(2 < p_\mathrm{T} < 10\ \mathrm{GeV}/c\,,\ -5.0 < y^* < -2.5) = 27.7 \pm 1.8(\mathrm{stat}) \pm 3.8(\mathrm{sys})$ mb

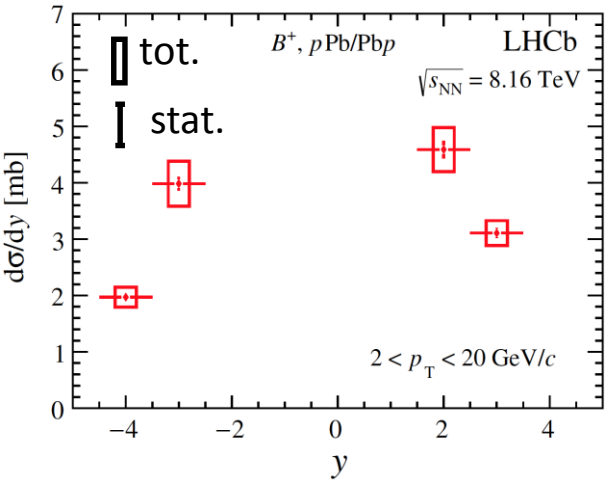
JHEP 02 (2019) 102

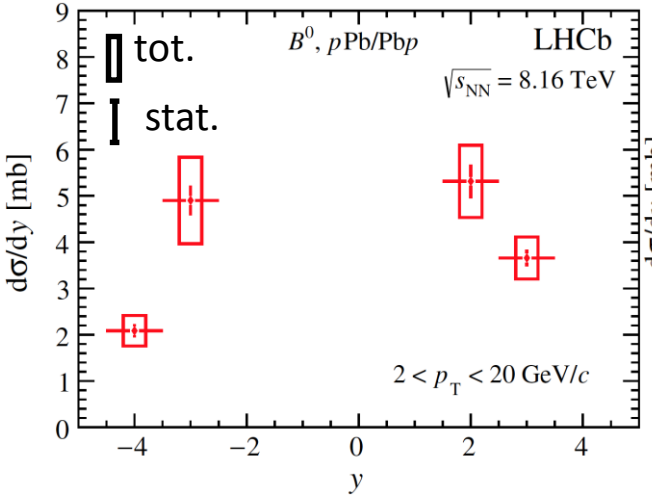
Beauty production: cross section

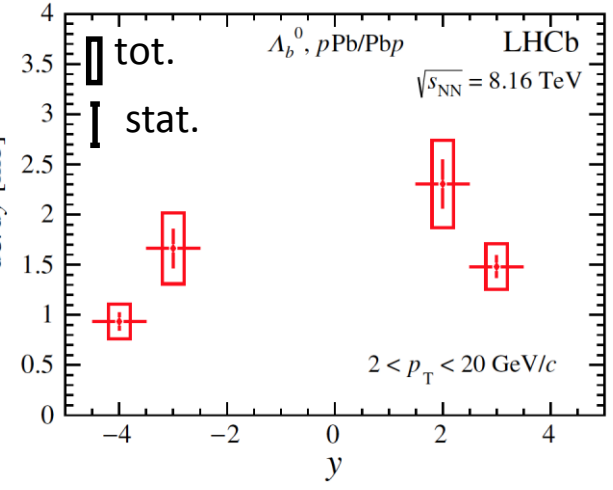












p_{T} and y distribution for Λ_{b}^0, B^+ and B^0 are similar

Phys. Rev. D99 052011 (2019)