Prompt open charm production in proton-lead collisions with LHCb

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On behalf of the LHCb Collaboration

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Outline

- Introduction
- The LHCb detector
- LHCb pPb data samples
- Prompt D^0 production in 5.02 TeV pPb collisions
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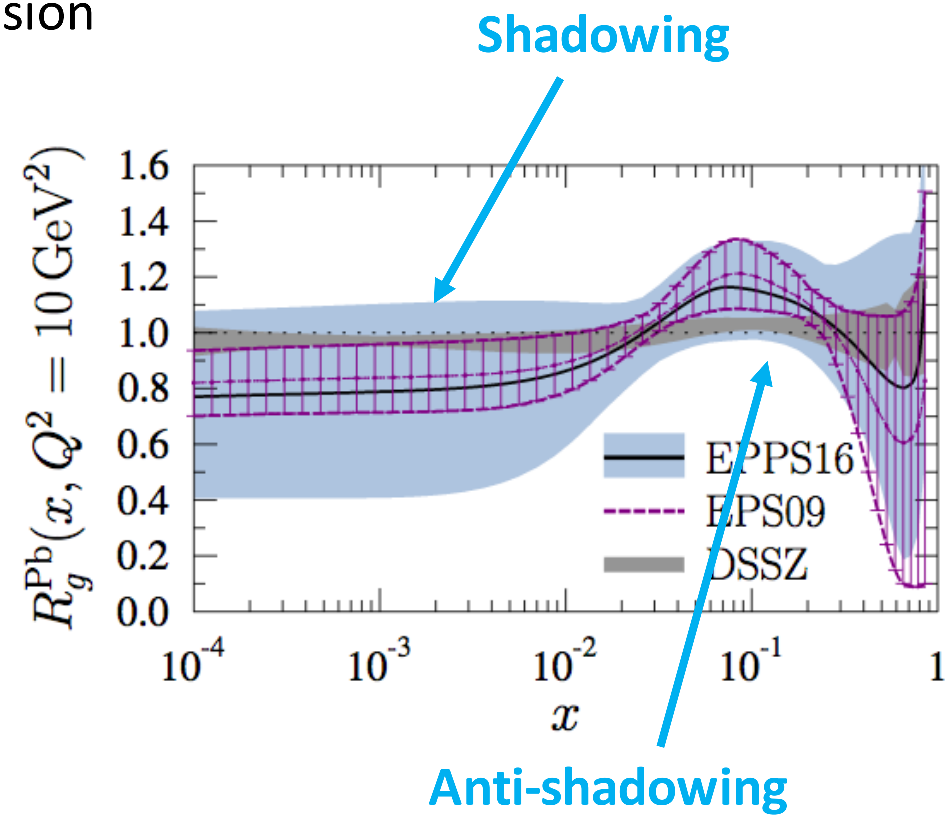
- Summary and outlook

Introduction

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

- Cold nuclear matter effects:
  - Modification of parton distribution functions: nPDF or CGC
  - Energy-loss due to collisions and gluon radiation
  - Interacting with co-moving particles
  - …
- Observables
  - Nuclear modification factor $R_{p\mathrm{Pb}}$
  - Forward-backward ratio R_{FB}
  - Baryon-meson ratio

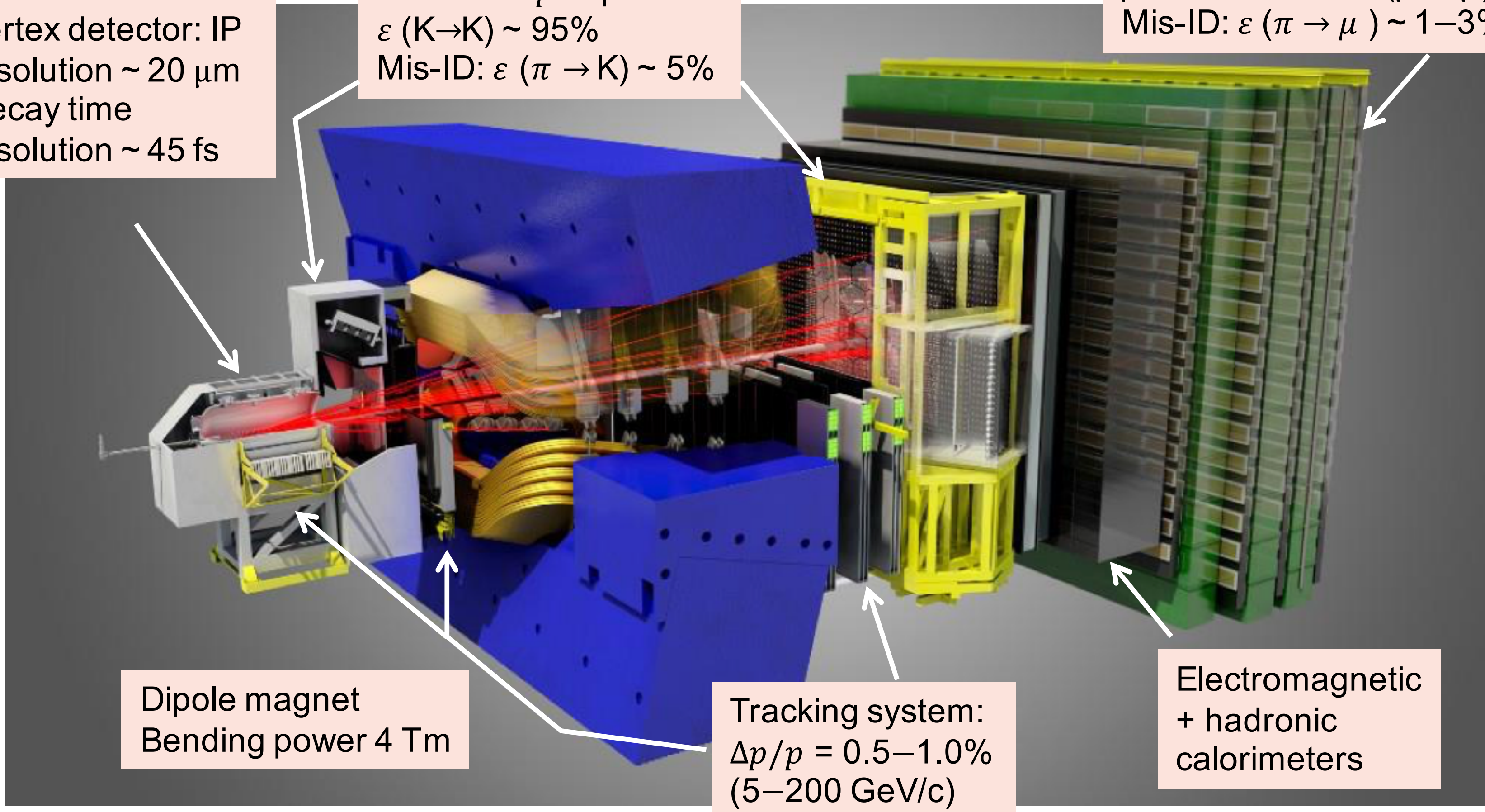


Eur. Phys. J. C (2017) 77:163

The LHCb detector

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

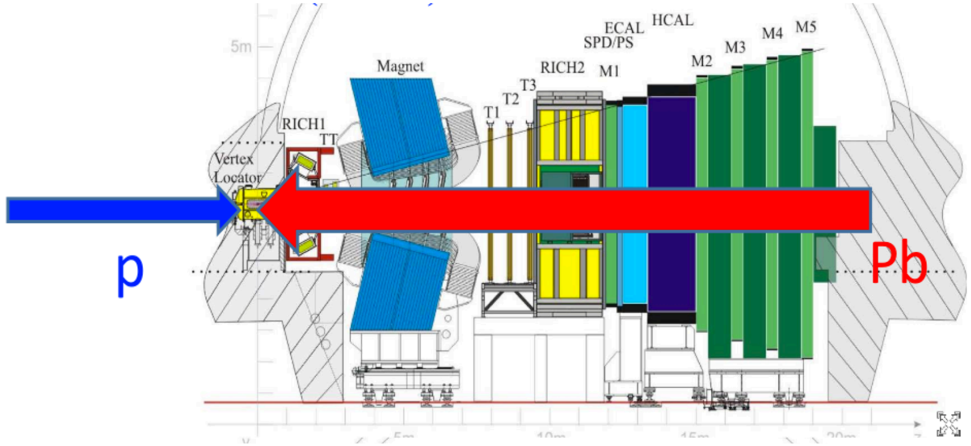
pseudorapidity acceptance $2 < \eta < 5$



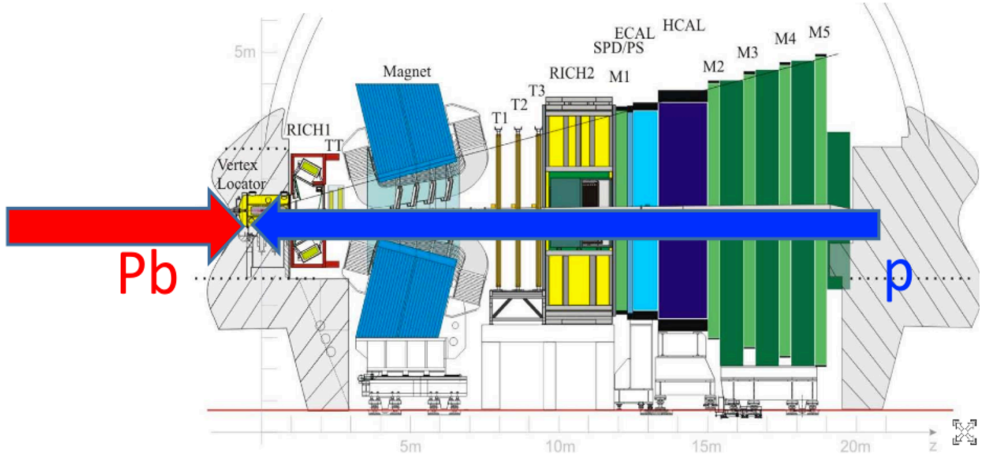
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

LHCb pPb data samples

Forward: pPb

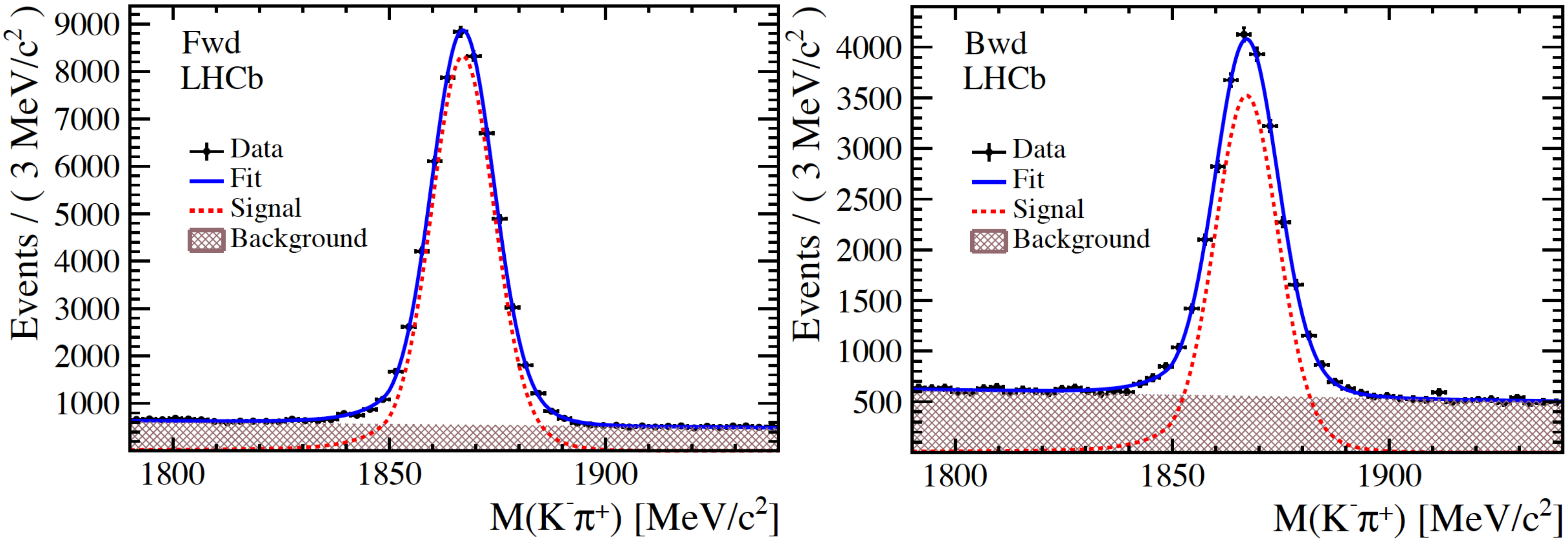


Backward: Pbp



- $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV (2013)
  - ➢ pPb $(1.06\ \mathrm{nb}^{-1})$+ Pb$p(0.52\ \mathrm{nb}^{-1})$
- 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: $2.5 < |y^*| < 4.0$

D^0 producion



- 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, $\mathrm{f} * f_{\mathrm{CB}}(\mu, \sigma, a, n) + (1 - \mathrm{f}) * f_{\mathrm{Gauss}}(\mu, \gamma\sigma)$
  - $a, \gamma,$ f are fixed by MC samples and $n = 1$
  - Background: linear

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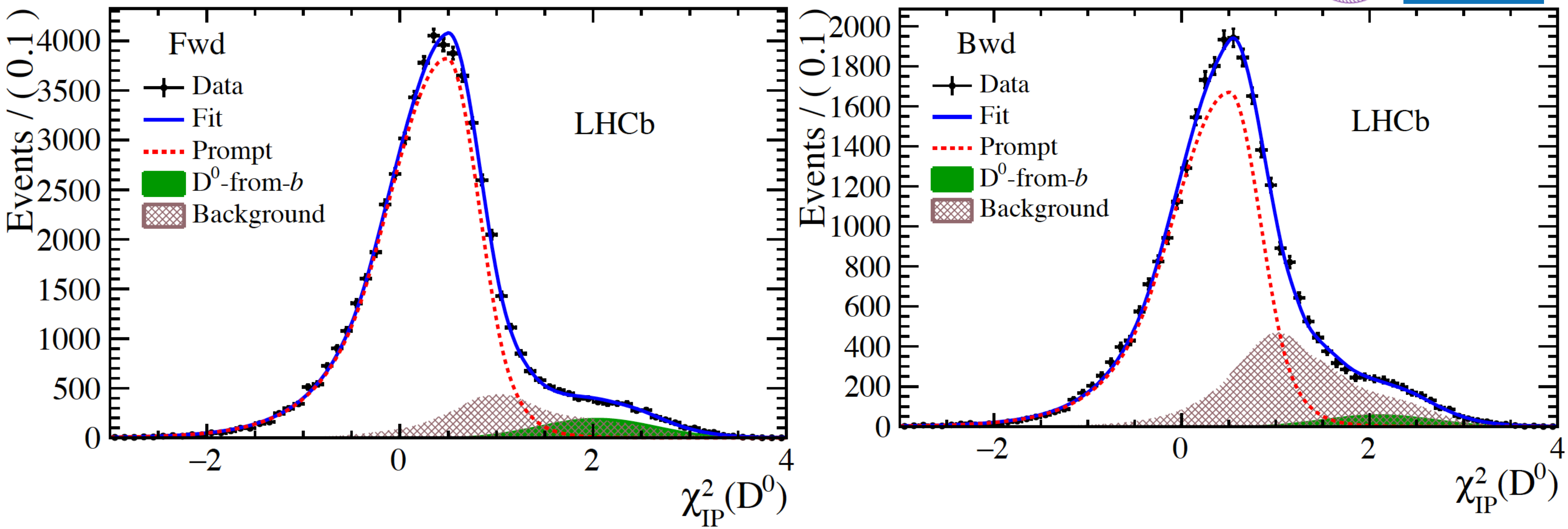
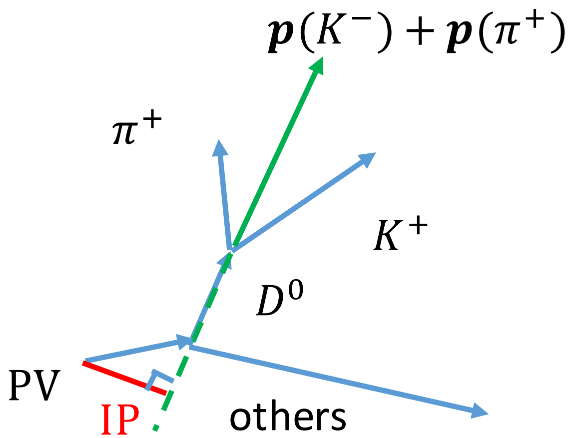
Prompt D^0



- Extract prompt D^0 by fitting χ^2_{IP} distribution
  - ➢Prompt: AGE function, peak position and width are free to float, other parameters are fixed by simulation
  - ➢From b: Gaussian
  - ➢Background: sideband data



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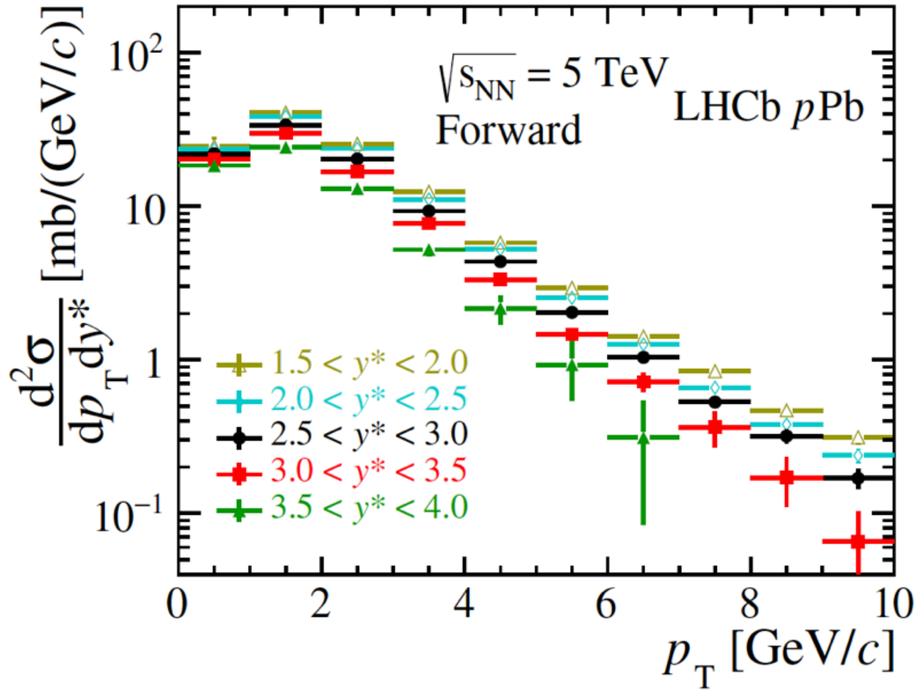
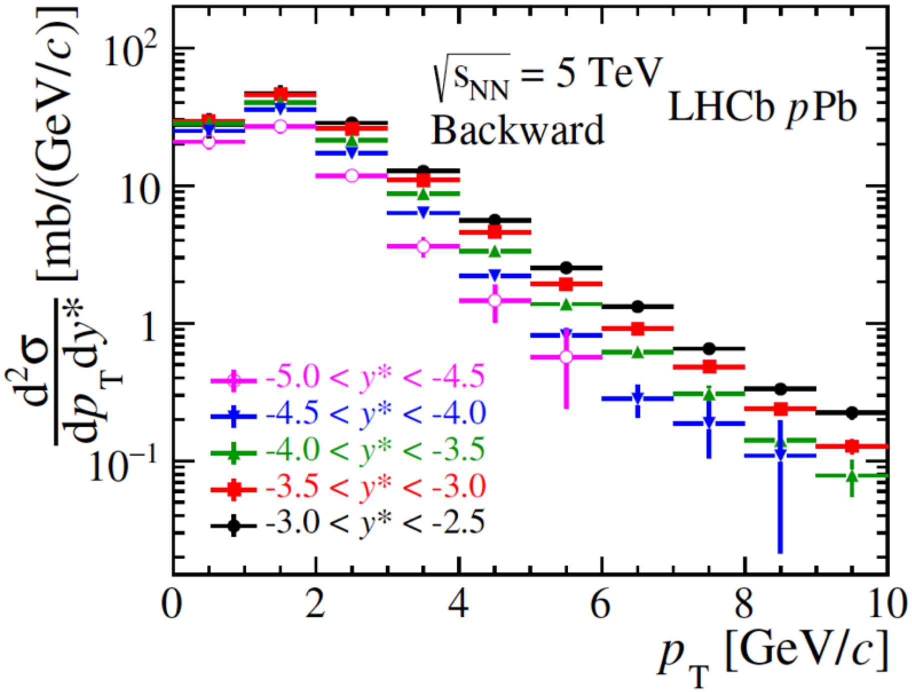
Prompt D^0: cross section





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

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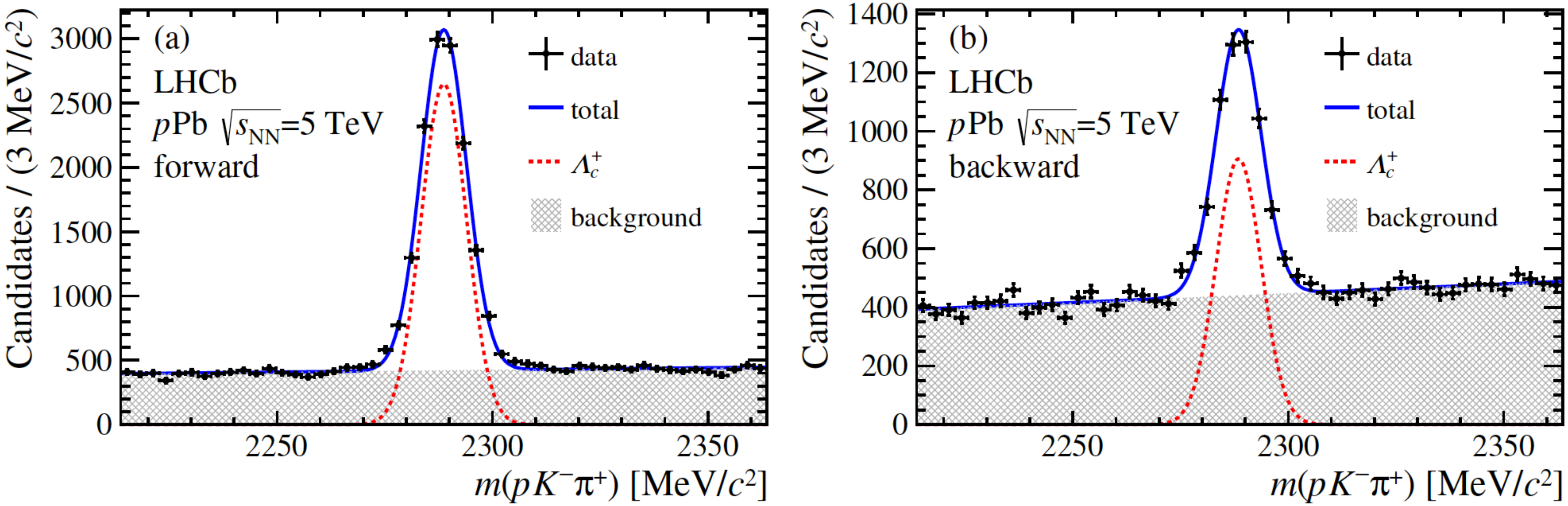
Λ_c^+ production



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

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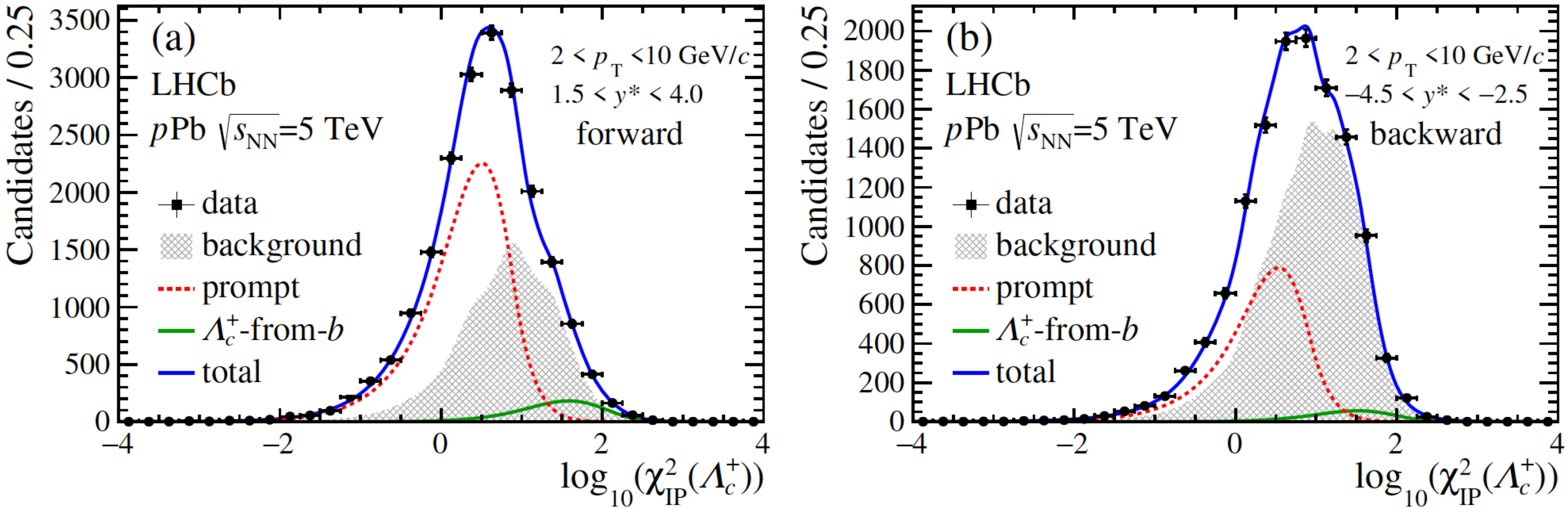
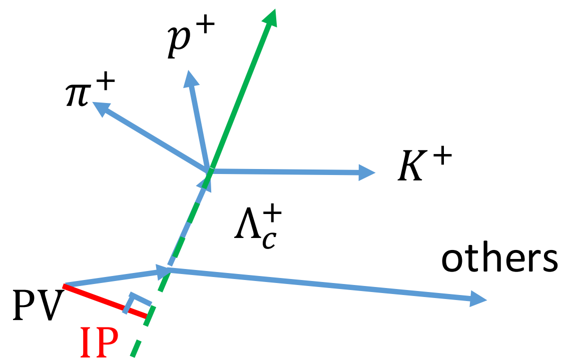
Prompt Λ_c^+



- Extract prompt Λ_c^+ by fitting χ^2_{IP} distribution
  - Prompt: bukin function, peak position is free, other parameters are fixed by simulation
  - From b: bukin function, peak position and width are free, other parameters are fixed by MC
  - Background: sideband data

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



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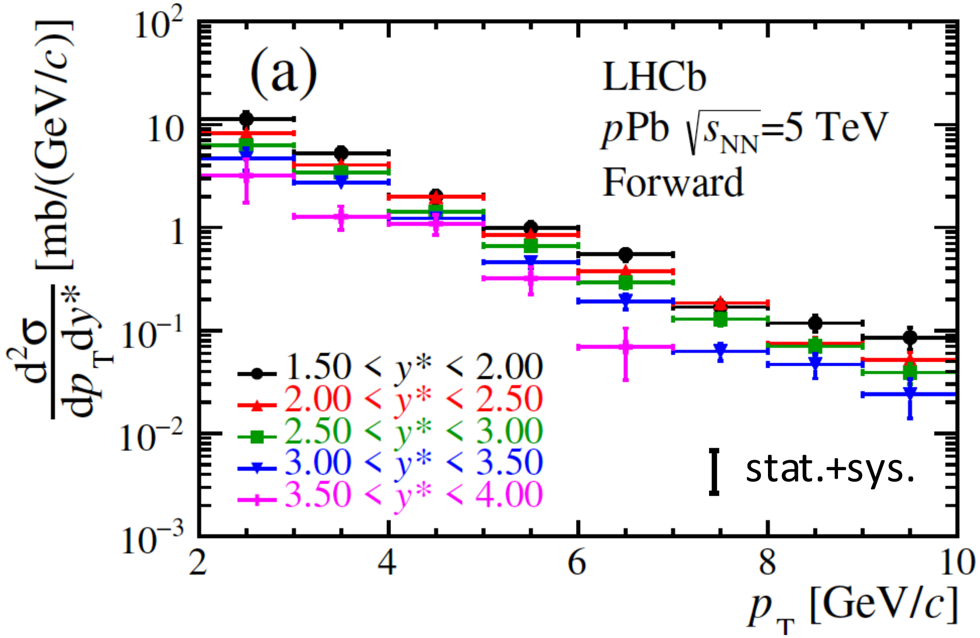
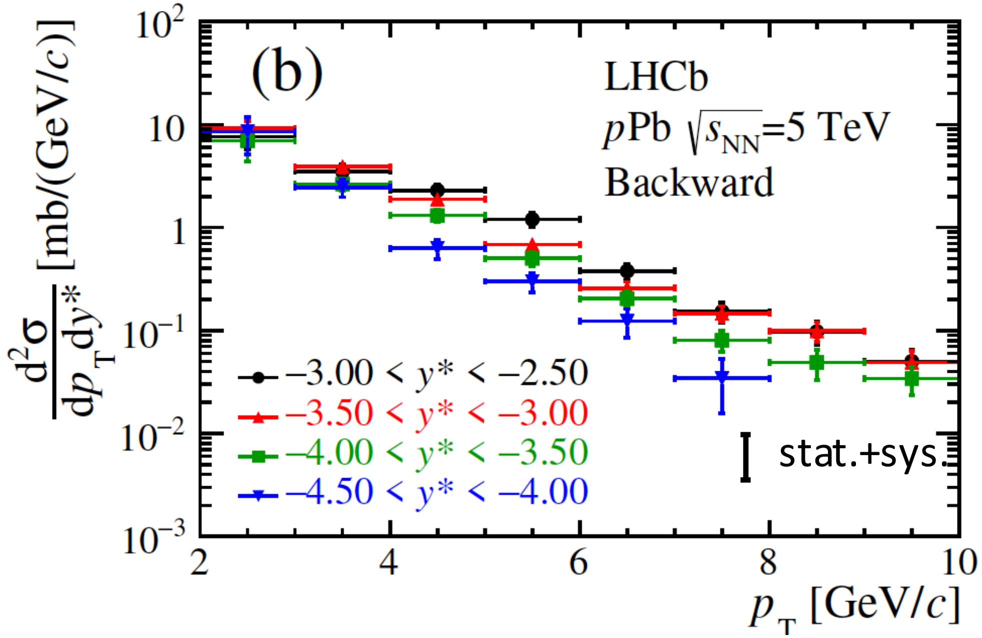
Prompt Λ_c^+: cross section





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

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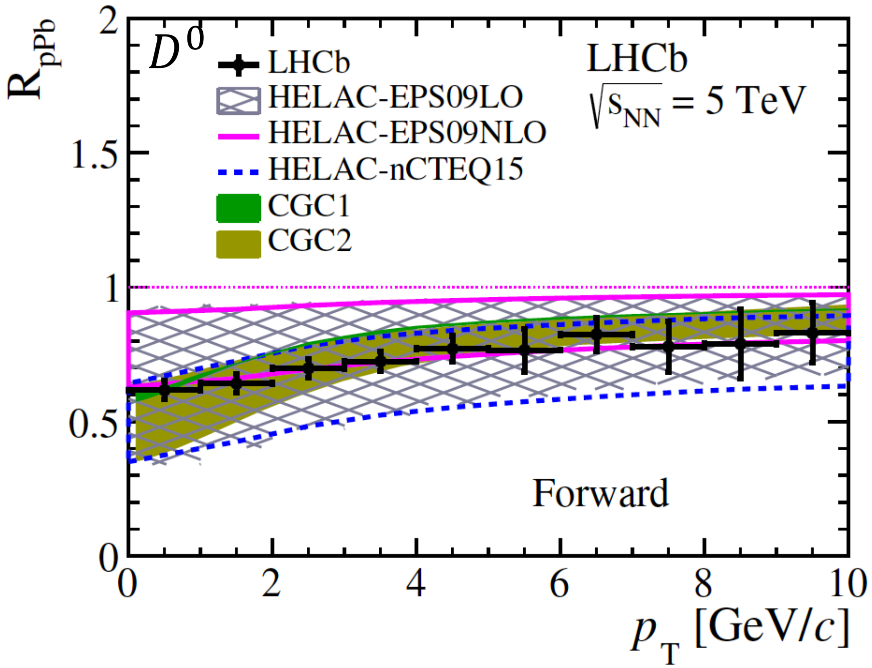
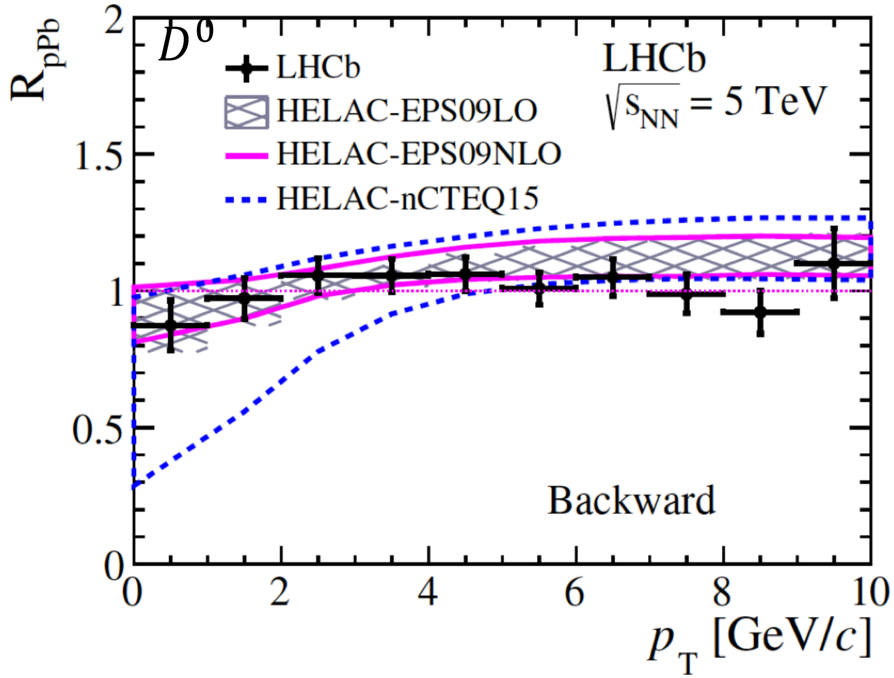
Prompt D^0: nuclear modification factor





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

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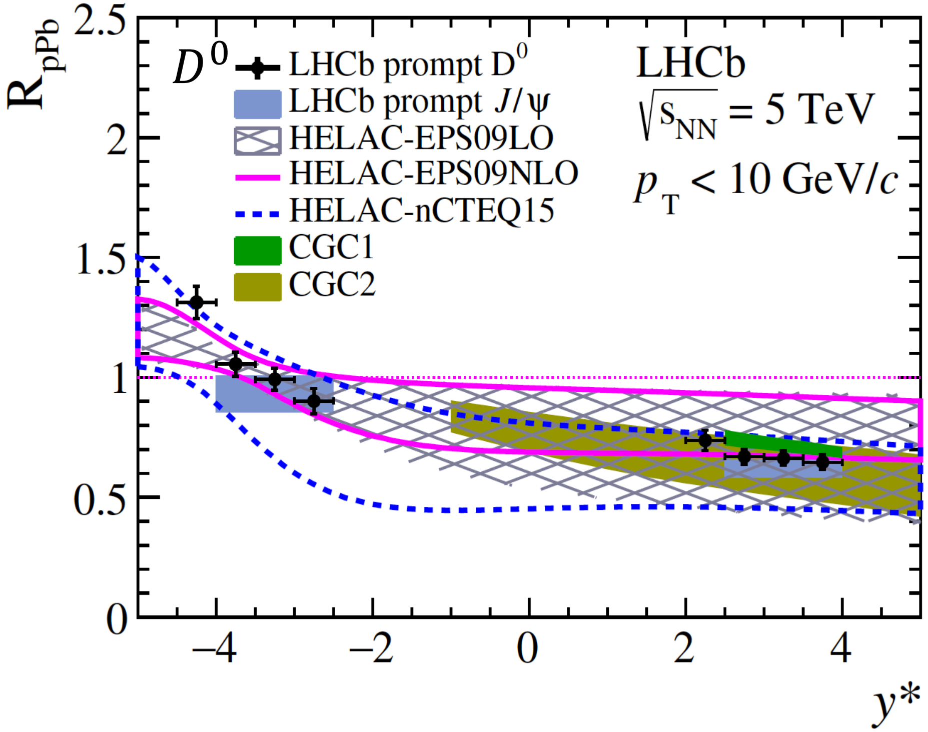
Prompt D^0: nuclear modification factor



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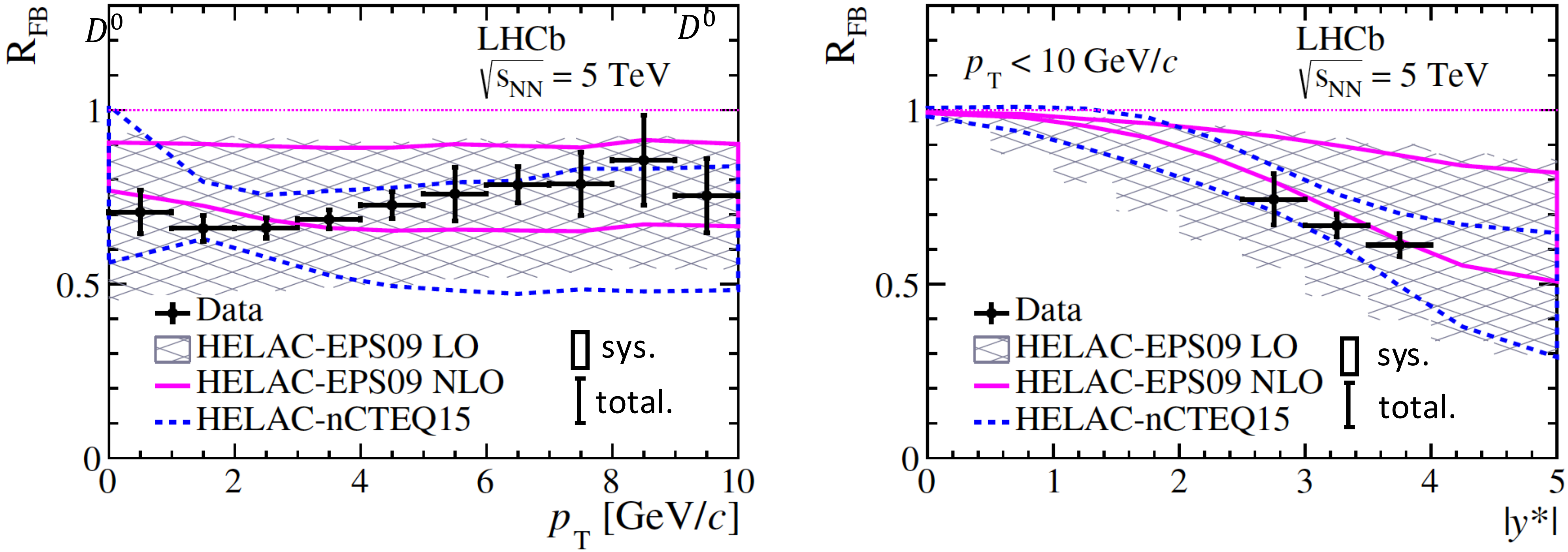
- $R_{p\mathrm{Pb}} = \frac{1}{A} \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*, \sqrt{s_\mathrm{NN}})/\mathrm{d}p_\mathrm{T}(\mathrm{d}y)}{\mathrm{d}\sigma_{pp}(p_\mathrm{T}, y^*, \sqrt{s_\mathrm{NN}})/\mathrm{d}p_\mathrm{T}(\mathrm{d}y)}$, $A = 208$
- pp reference is measured by LHCb
- $R_{p\mathrm{Pb}}$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

Prompt D^0: forward-backward ratio



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

- Data agree with calculations using various nPDF sets
- Data have smaller uncertainties than theory

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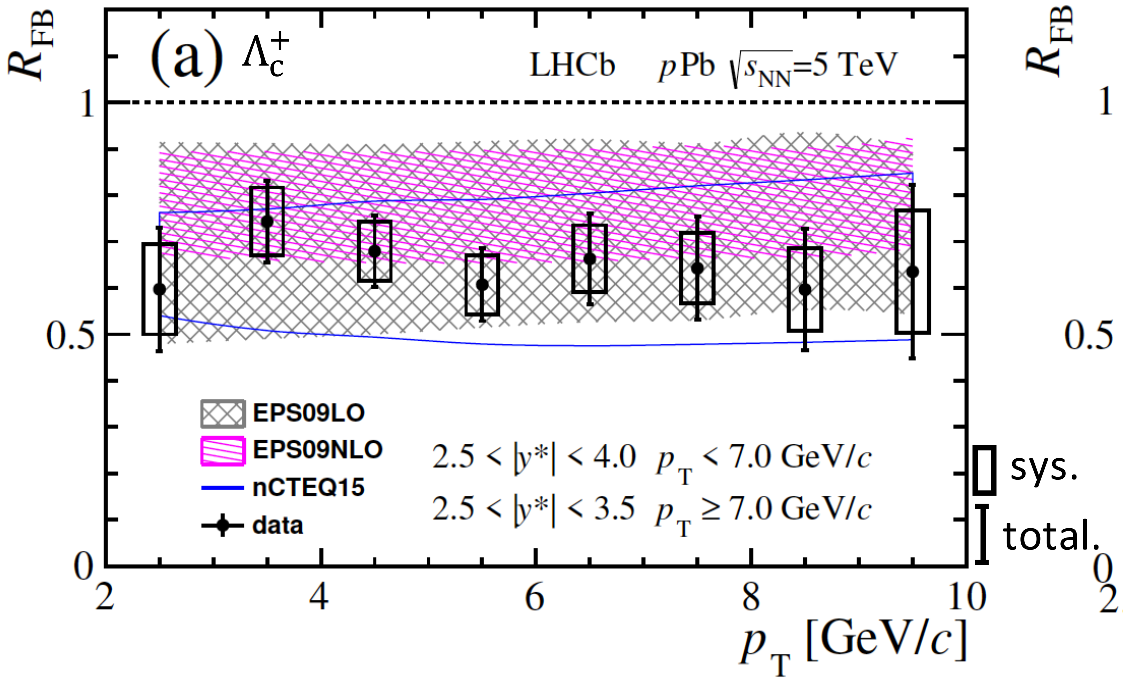
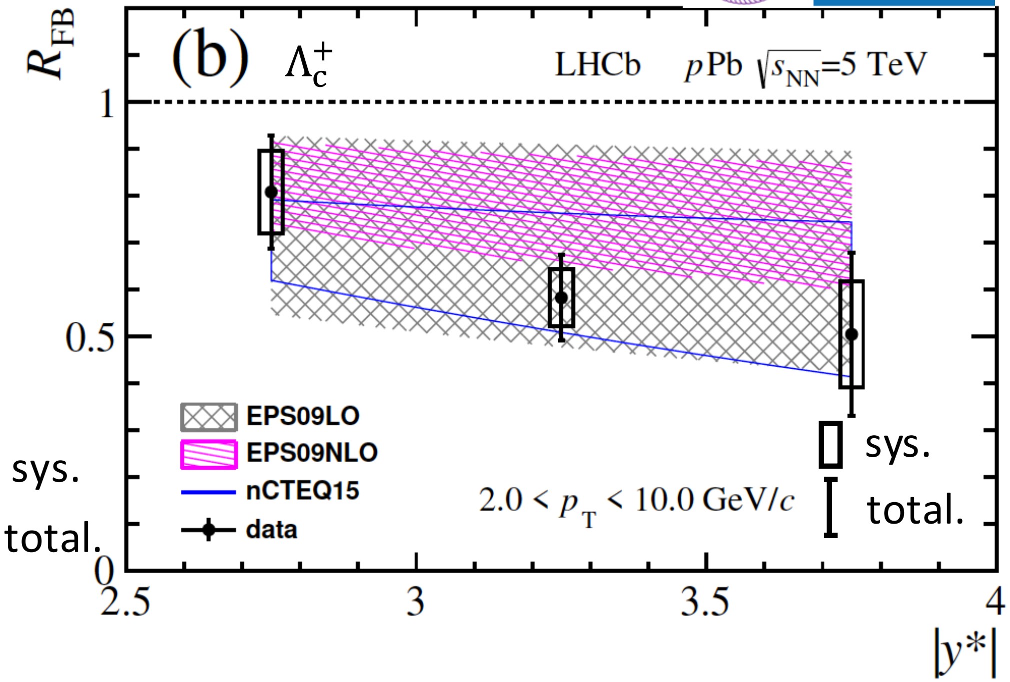
Prompt Λ_c^+: forward-backward ratio





- $R_{\mathrm{FB}} = \dfrac{\mathrm{d}\sigma_{p\mathrm{Pb}}(p_{\mathrm{T}},+|y^*|)/\mathrm{d}p_{\mathrm{T}}(\mathrm{d}y)}{\mathrm{d}\sigma_{\mathrm{Pb}p}(p_{\mathrm{T}},-|y^*|)/\mathrm{d}p_{\mathrm{T}}(\mathrm{d}y)}$
- $R_{\mathrm{FB}} < 1$ and decreases with rapidity
- Data agree with calculations using various nPDF sets

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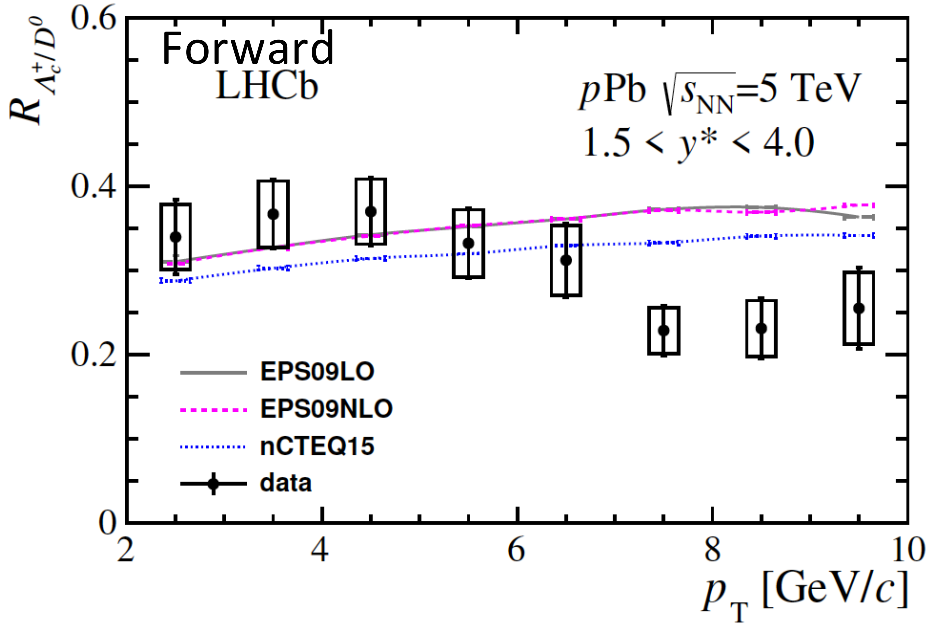
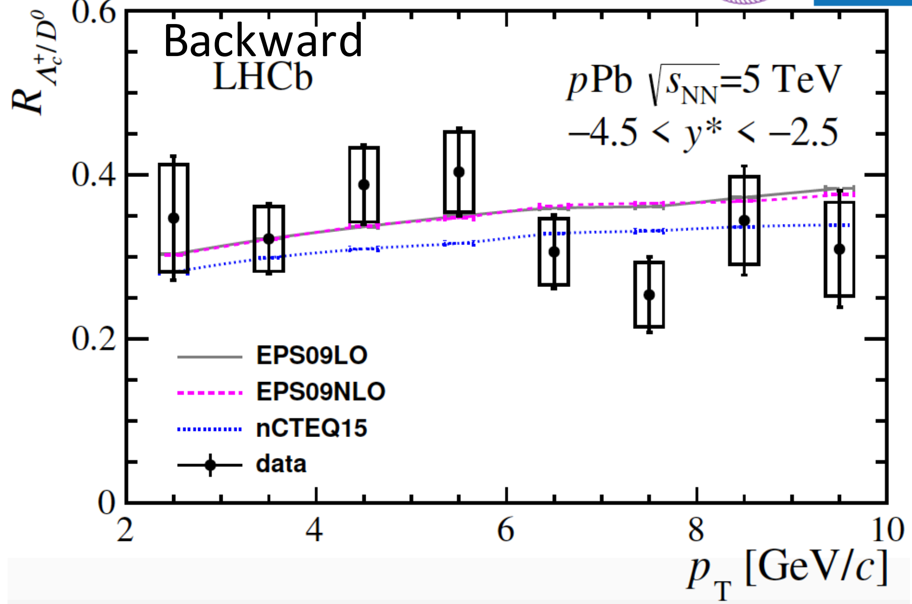
Prompt open charm: baryon/meson ratio





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

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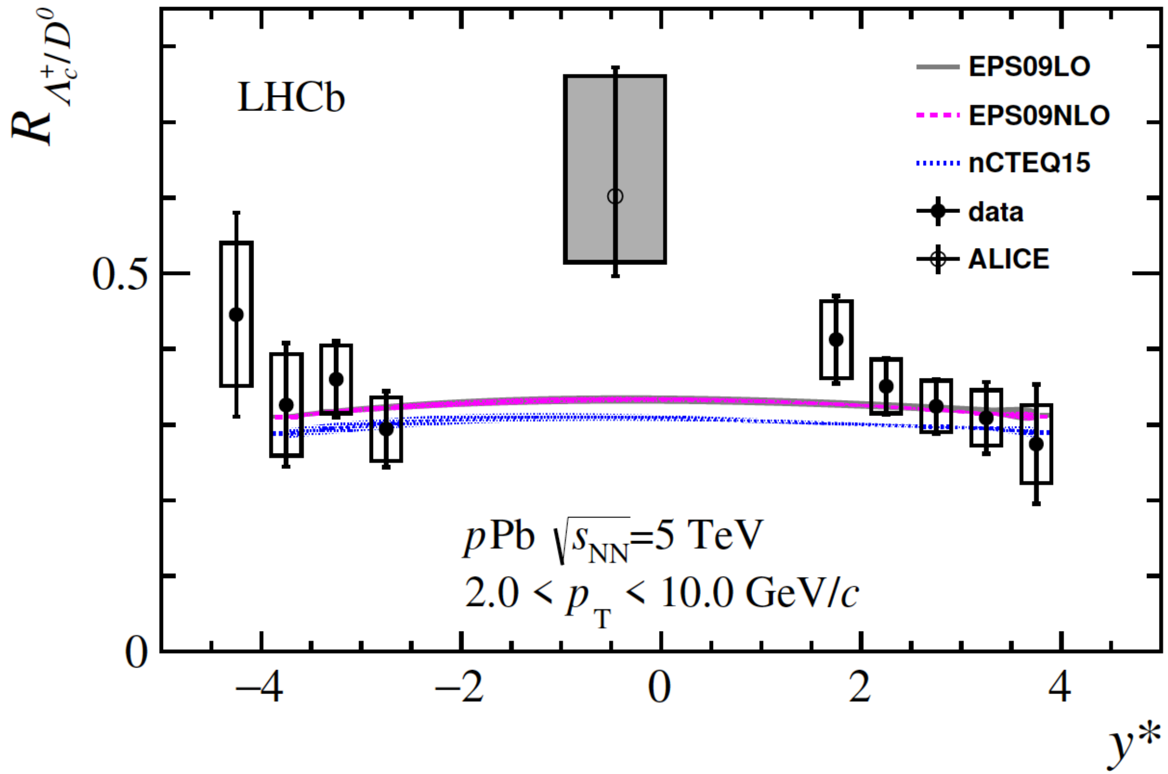
Prompt open charm: baryon/meson ratio



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- $R_{\Lambda_c^+/D^0} = \dfrac{d^2\sigma_{\Lambda_c^+}(p_T, y^*)/dp_T(dy)}{d^2\sigma_{D^0}(p_T, y^*)/dp_T(dy)}$
- Theoretical calculation are based on measured pp results from LHCb
- nPDF uncertainties cancel in baryon/meson ratios
- Data is consistent with theory for all y^*

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 $R_{\mathrm{FB}}^{\Lambda_\mathrm{c}^+}$ agree with nPDF calculations and $R_{\mathrm{FB}}^{D^0}$ has smaller uncertainties than theory
  - $R_{\Lambda_\mathrm{c}^+/D^0}$ agrees with model except in forward high p_T bins
- 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!