Recent LHCb results on charm in the QCD medium

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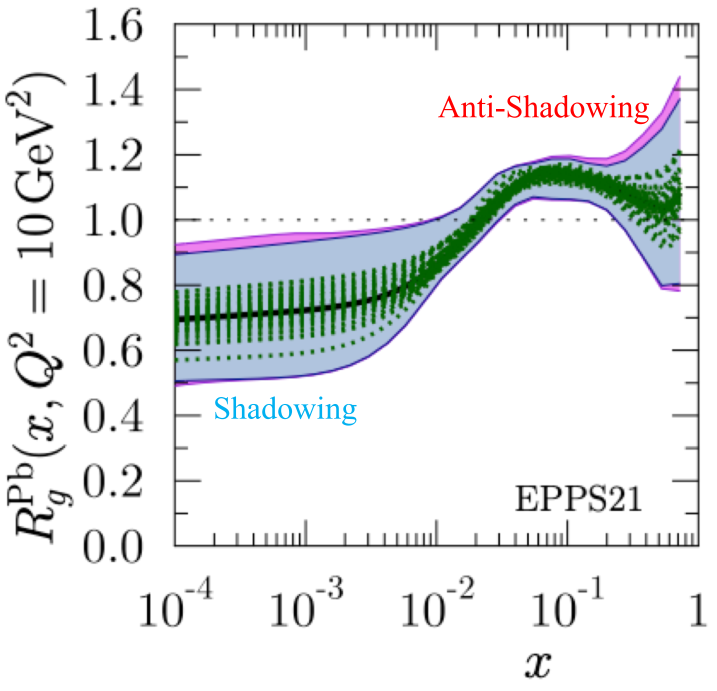
on behalf of the LHCb collaboration

Outline

- Introduction
- LHCb detector and datasets
- Charm results in the QCD medium at LHCb
  - ➢Prompt D^0 meson production in *p*Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV
    LHCb-CONF-2019-004
  - ➢Charm pair production and DPS in *p*Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV
    PHYS. REV. LETT. 125 (2020) 212001
  - ➢Prompt cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in *p*Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV New!
    PHYS. REV. C103 (2021) 064905
- Summary and outlook

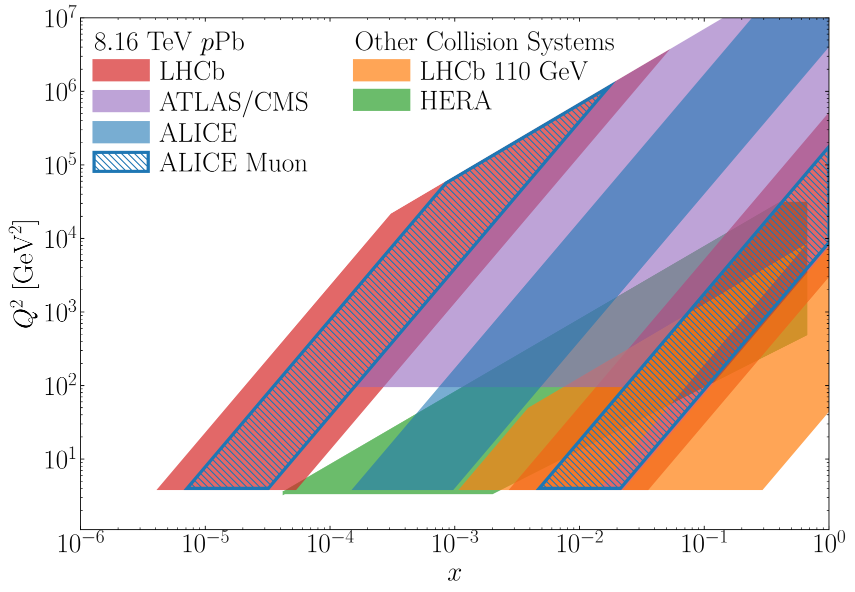
Introduction

- The study of pPb collisions is important to disentangle the effects of cold nuclear matter from effects of quark gluon plasma :
  - Parton distribution functions are modified inside a nucleus.(shadowing and anti-shadowing effects)
  - Charmonium suppression due to interactions with the comoving particles.
- LHCb advantages for such study:
  - Low p_{T} coverage for heavy flavor
  - Forward rapidity coverage
  - Separation of prompt and b decay components
- LHCb pPb collisions constrain the nPDFs.



arXiv:2106.13661

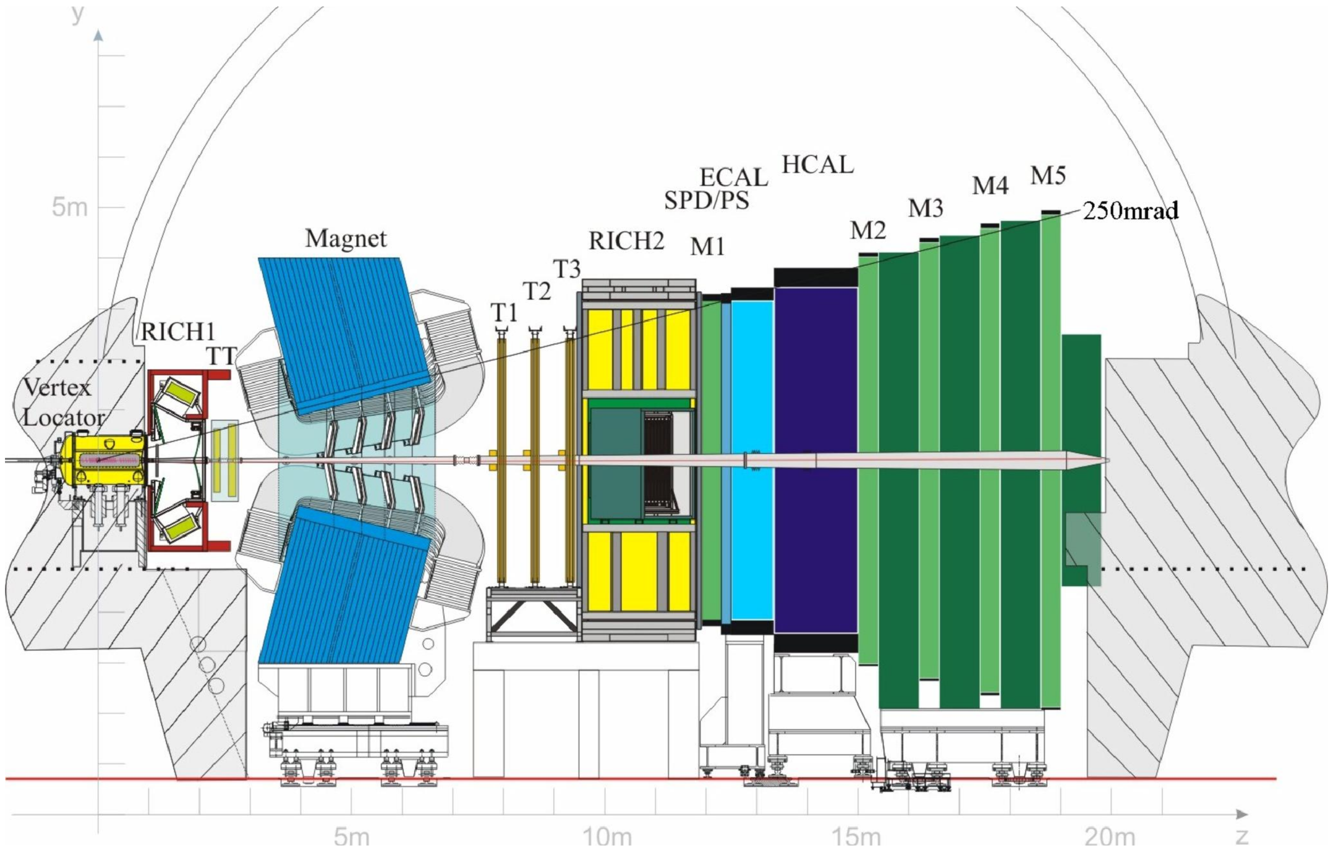
$$R_i(x, Q^2) = f_i^A(x, Q^2)/[A f_i^p(x, Q^2)]$$



Q^2 and x coverage of LHCb acceptance

LHCb detector

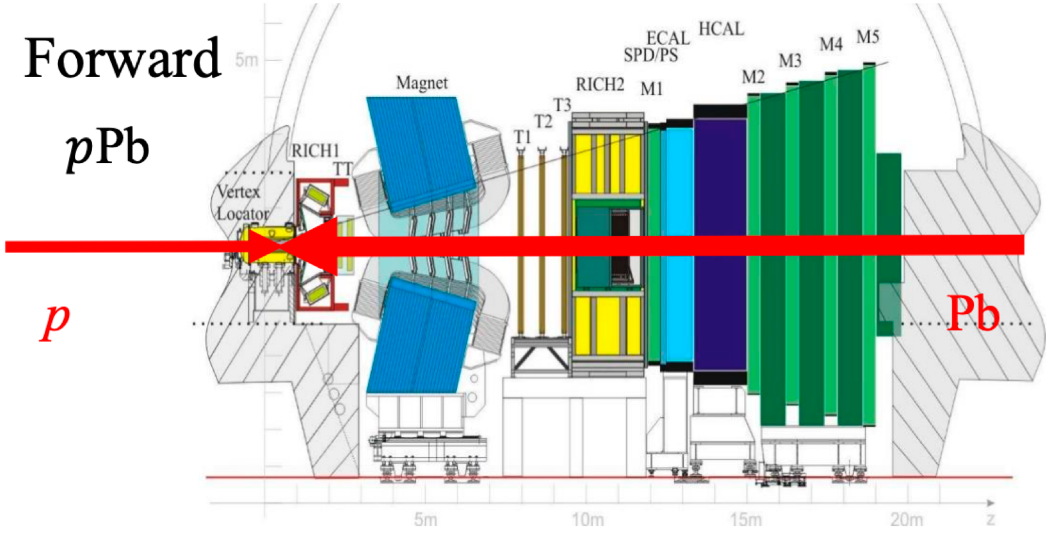
- A single-arm spectrometer in the forward direction
- Acceptance
  - $2 < \eta < 5$
- Charm & beauty factory
  - Vertex Locator
    - 20 μm IP resolution
  - Tracking system
    - $\Delta p/p = 0.5 - 1.0\% (5 - 200 \mathrm{GeV}/c)$
  - RICH: p/K/π separation
    - $\varepsilon(K \to K) \sim 95\%$
    - Mis-ID:$\varepsilon(\pi \to K) \sim 5\%$
  - Muon system
    - $\varepsilon(\mu \to \mu) \sim 97\%$
    - Mis-ID:$\varepsilon(\pi \to \mu) \sim 3\%$
  - Flexible software trigger

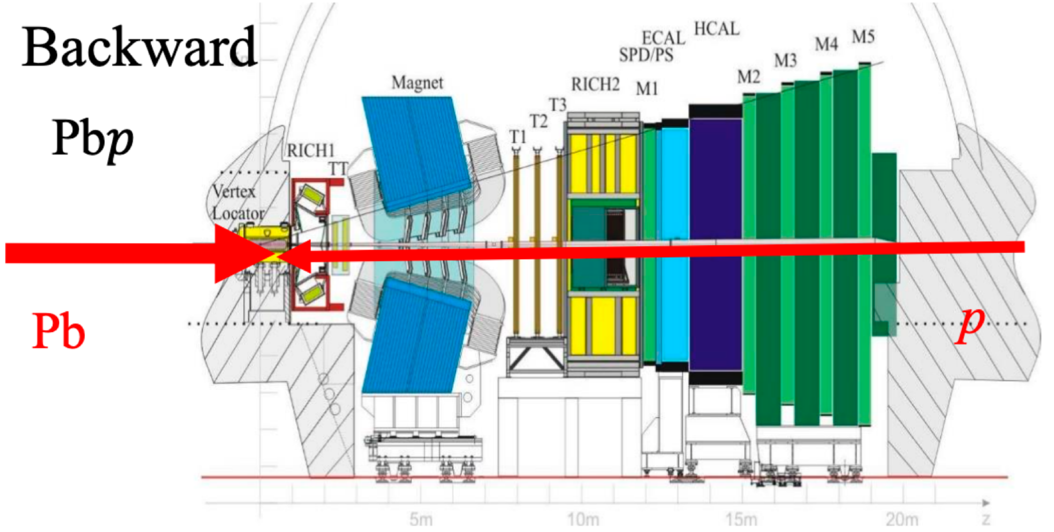


LHCb, JINST 3 (2008) S08005
LHCb, IJMPA 30 (2015) 1530022

Datasets : pPb runs at $\sqrt{s_{NN}} = 8.16$ TeV

- pPb data was taken in 2016 with asymmetric collision configuration.
  - Forward (pPb)
  - Backward (Pbp)
- Beam characteristics
  - 6500 GeV proton beam and 2560 GeV/nucleon Pb beam
  - Center of mass rapidity shift $y^* - y_{\text{lab}} = -0.465$ in direction of proton
  - Luminosity : 13.6 nb^{-1}(pPb) + 20.8 nb^{-1}(Pbp)
- Rapidity acceptance
  - pPb : $1.5 < y^* < 4.0$
  - Pbp : $-5.0 < y^* < -2.5$





Prompt D^0 meson production in pPb at 8.16 TeV

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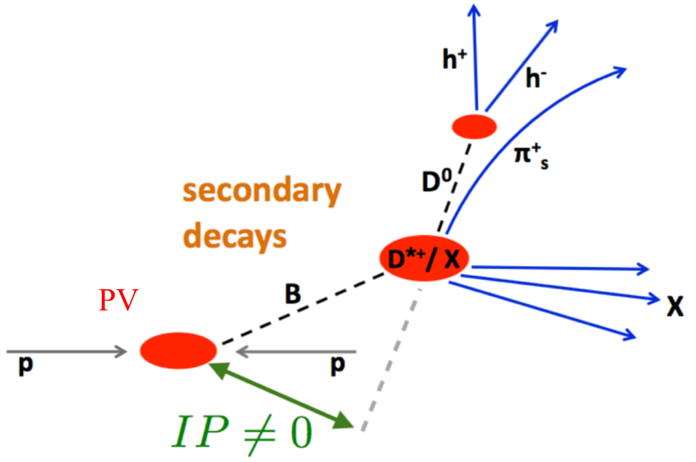
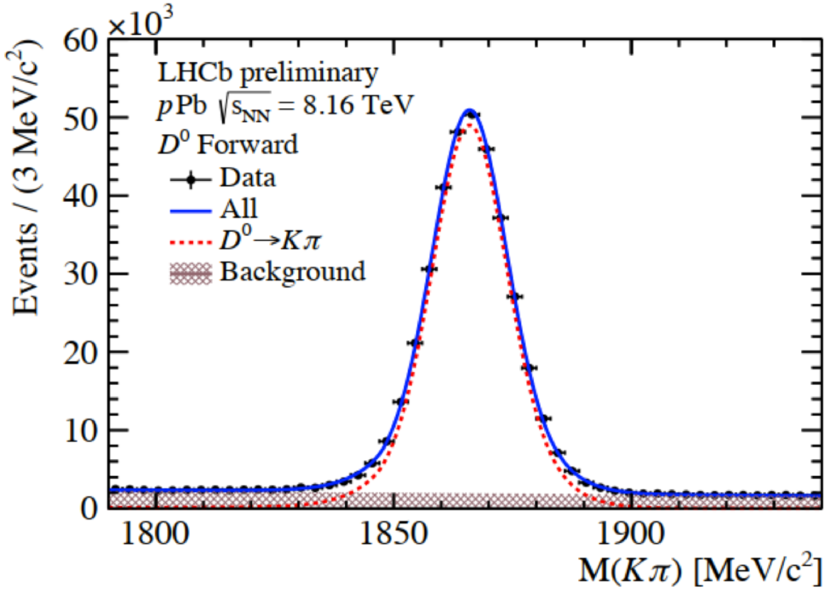
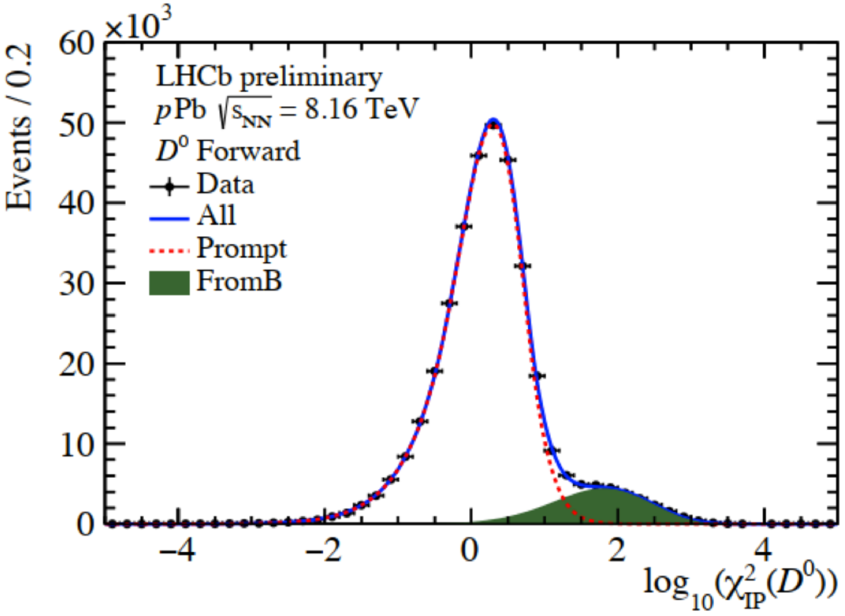
- Decay modes : $D^0 \rightarrow K^-\pi^+$ & c.c
- Inclusive D^0 yield extracted from $K^-\pi^+$ invariant mass fits.
- Impact parameter (IP) is used to seperate the prompt and non-prompt components. The D^0 with smaller impact parameter is more likely to originate from the primary interaction.







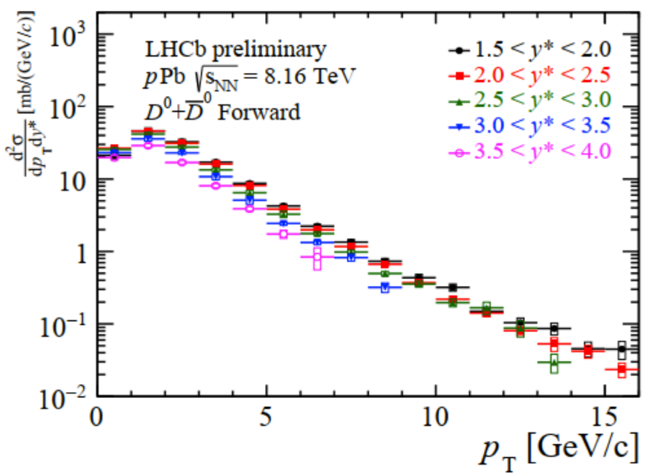
impact parameter : the perpendicular distance from the primary vertex to D^0 path.

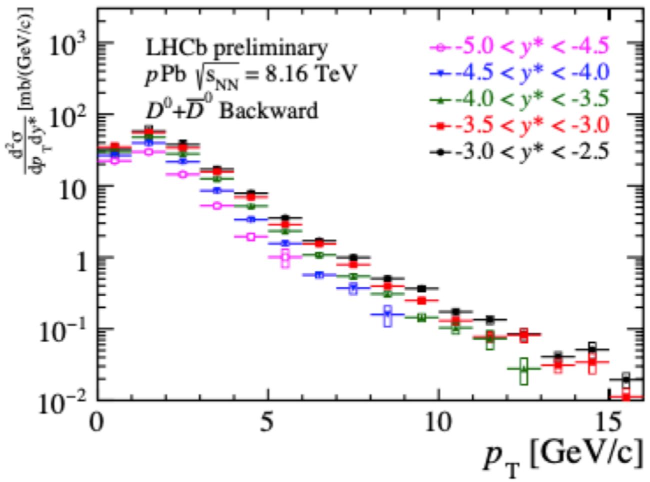
Prompt D^0 meson production in pPb at 8.16 TeV

LHCb-CONF-2019-004

- R_{FB} show a rising trend with p_{T}
  - Consistent with 5.02 TeV results and calculations with nPDFs at low p_{T}.
  - Larger than theoretical predictions at high p_{T}.
- R_{FB} show a slight dependence on y^*
  - Consistent with nPDFs and 5.02 TeV measurement.

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*} = \frac{N(D^0 \to K^{\mp}\pi^{\pm})}{\mathcal{L} \times \epsilon_{\mathrm{tot}} \times \mathcal{B}(D^0 \to K^{\mp}\pi^{\pm}) \times \Delta p_{\mathrm{T}} \times \Delta y^*}$$





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

J.-P. Lansberg and H.-S.Shao, EPJC 77 (2017) S10052. A. Kusina, et al., PRL 121 (2018) 052004.
H.-S. Shao, CPC 184 (2013) 2562-2570.
H.-S. Shao, CPC 198 (2016) 238-259.

error bar : stat
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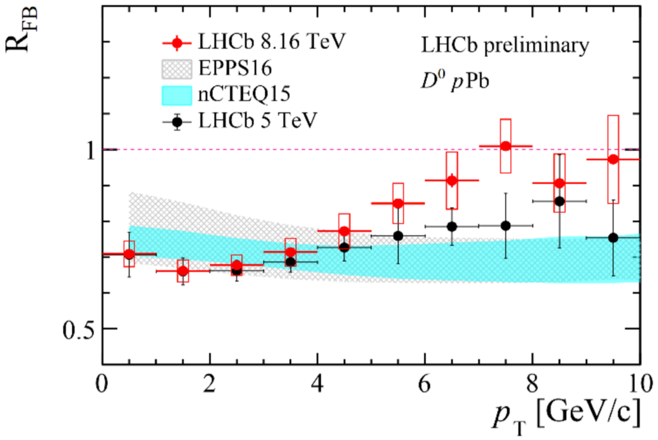
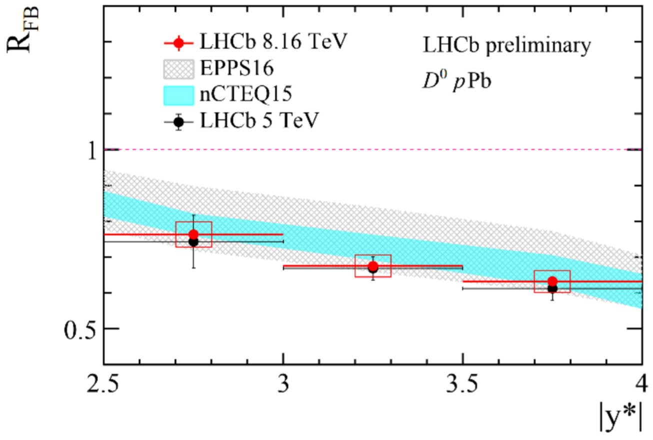




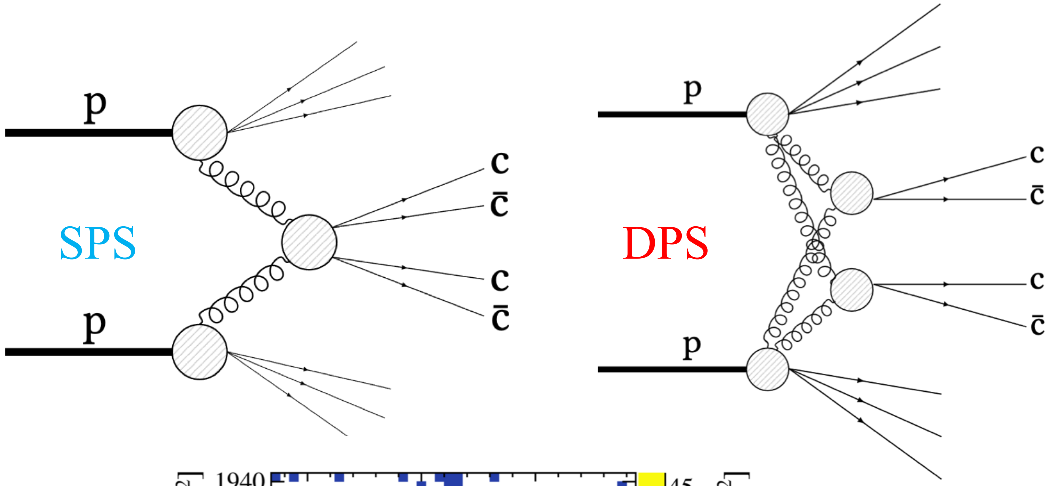
Charm pair production in *p*Pb at 8.16 TeV

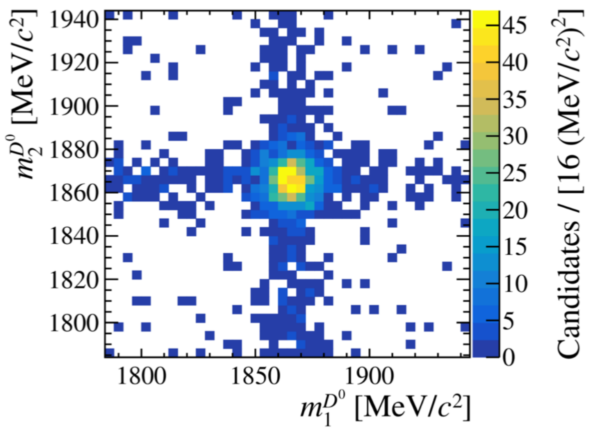
$$\sigma_{\mathrm{DPS}}^{AB} = \frac{1}{1+\delta_{AB}} \frac{\sigma^A \sigma^B}{\sigma_{eff}}$$

1 if A=B else 0

effective cross-section, independent of final state

- First measurement of charm pair production in heavy ion collisions.
  - Double parton scattering (DPS) is predicted to be enhanced in heavy ion collisions.
  - Test universality of σ_{eff} in DPS.
- Single parton scattering
  - Kinematic correlated
  - Cross section is expected to scale with the ion mass number
- Double parton scattering
  - Cross section is enhanced compare to a mass number scaling due to collisions of partons from two different nucleons in the ion
- $D_1 D_2$ and $J/\psi\, D$ pairs are measured($D = D^0, D^+, D_s^+$)
  - Opposite-sign (OS) , e.g.$D^0 \overline{D^0}$ **SPS enrich**
  - Like-sign (LS) , e.g.$D^0\ D^0$ **DPS enrich**





2D invariant-mass distributions of $D^0\ D^0$ pairs

Charm pair correlations in pPb at 8.16 TeV

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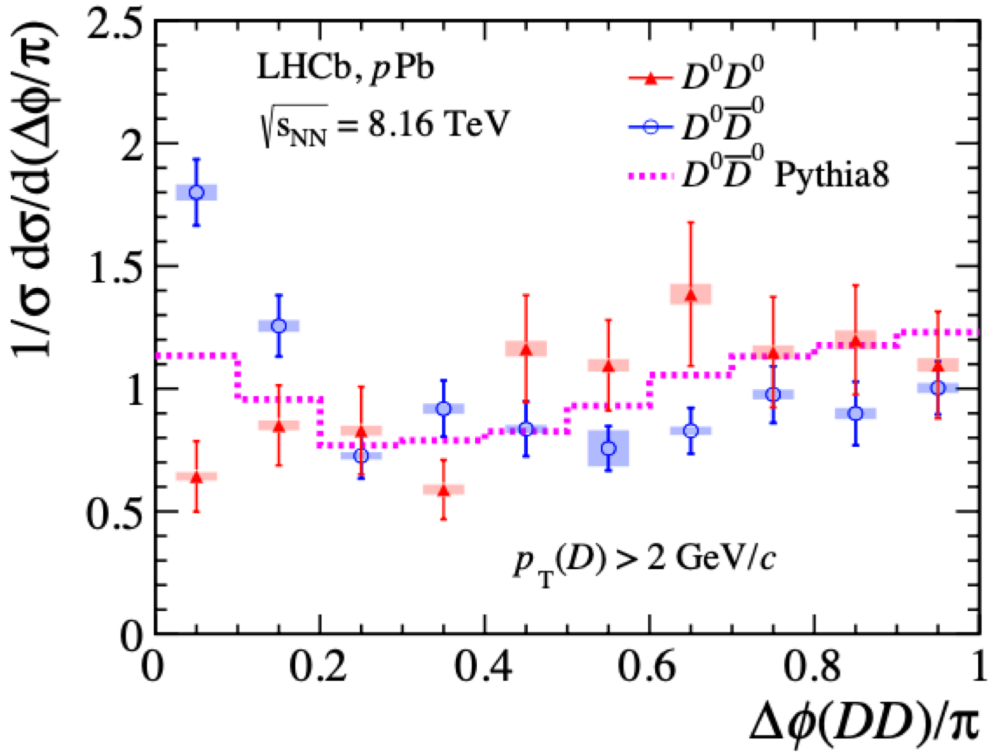
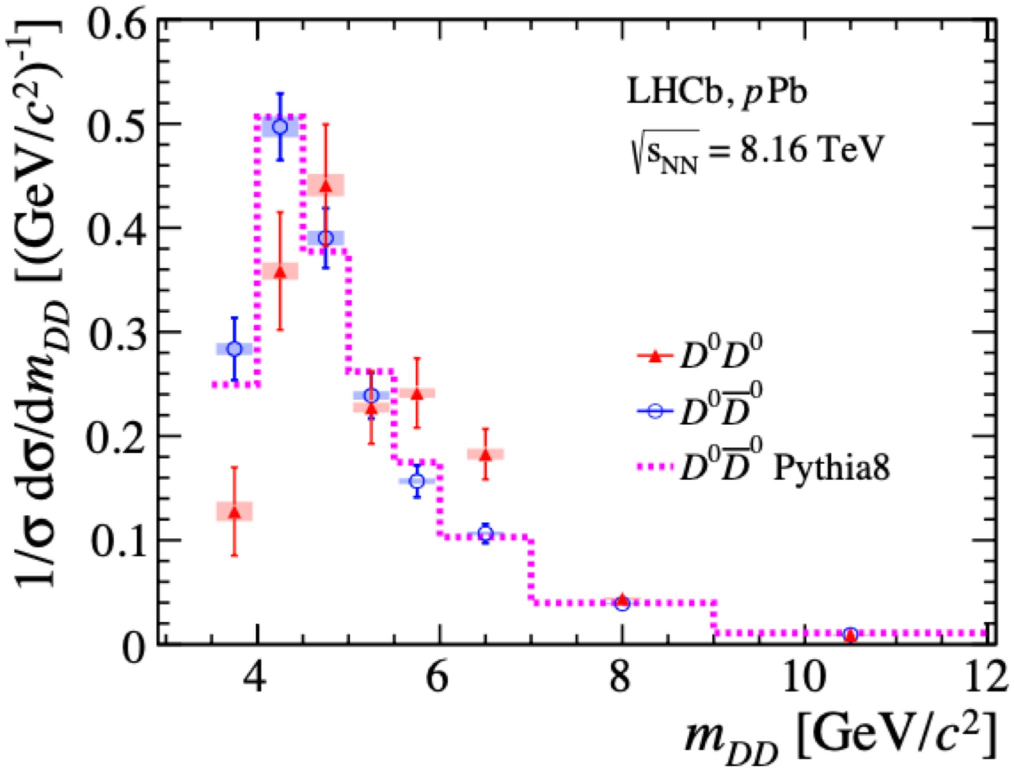
Double charm hadron invariant mass m_{DD}

- Hints of difference between LS and OS pairs
- OS pairs consistent with Pythia8 simulation





Azimuthal angle between the charm hadron pair $\Delta\phi(DD)$

- Difference between LS and OS pairs.
- OS pairs favor values $\Delta\phi \backsim 0$ (near side peak)
- LS pairs consistent with flat distribution (uncorrelated pair).

Charm pair production in pPb at 8.16 TeV

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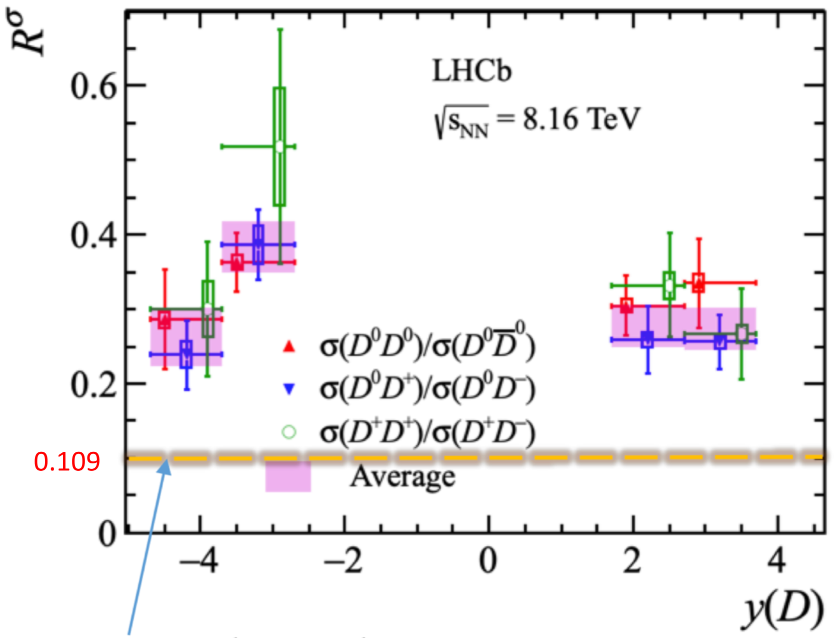
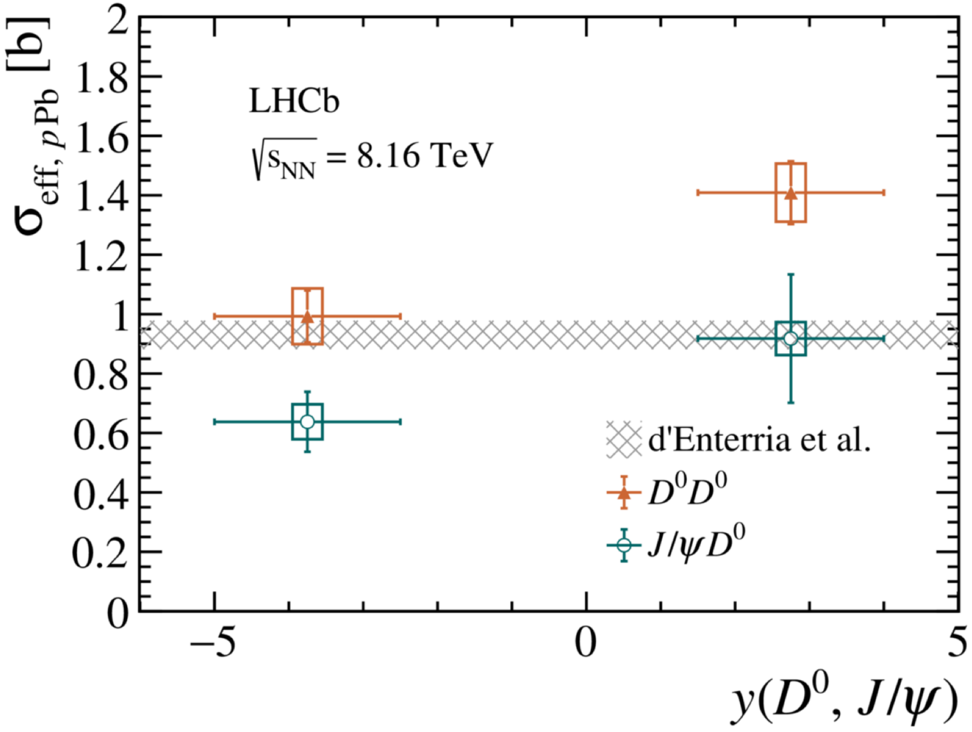
LS/OS ratios are enhanced in pPb compared to pp.

- Suggesting DPS/SPS enhanced by a factor ~3 in pPb compared to pp.



Measured pp values JHEP06,141(2012)



- Effective cross-section σ_{eff} consistent with expected factor ~3 enhancement.
- $\sigma_{\text{eff},p\text{Pb}}^{J/\psi D^0} < \sigma_{\text{eff},p\text{Pb}}^{D^0 D^0}$ possibly due to SPS contamination or DPS enhancement in $J/\psi D^0$ production.
- $\sigma_{\text{eff},p\text{Pb}} > \sigma_{\text{eff,Pb}p}$ suggesting a suppression of DPS in pPb data compared to Pbp.

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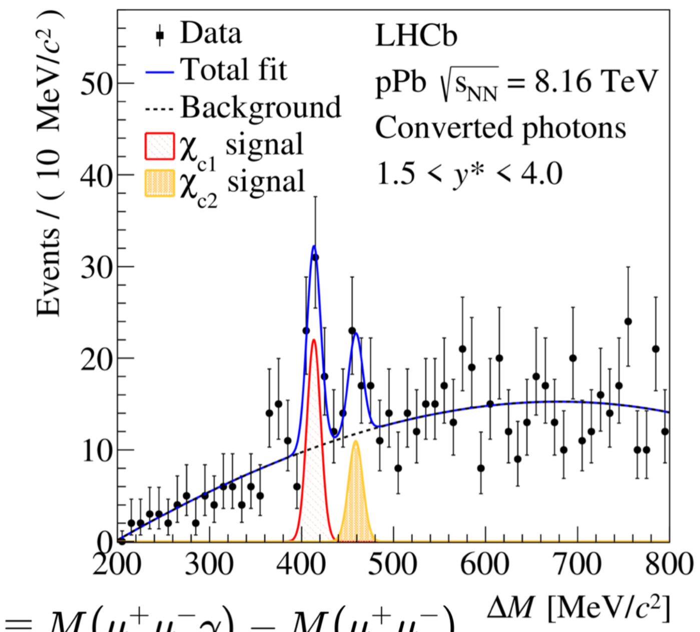
Prompt cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$

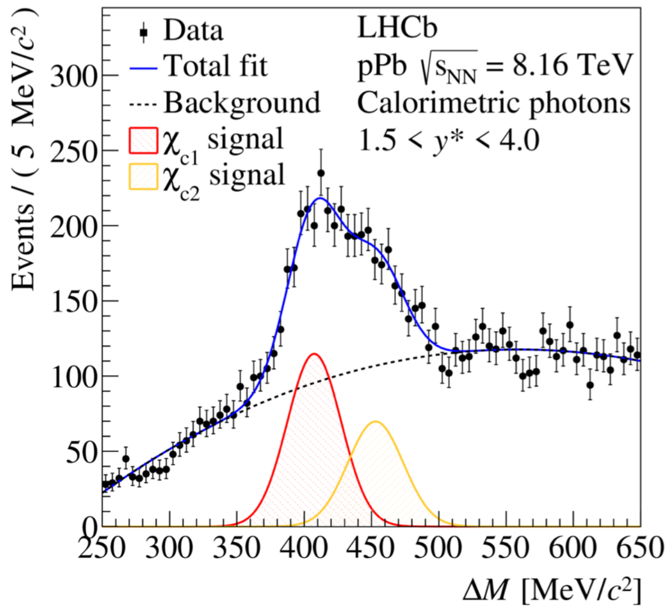
- First measurement of P-wave charmonia in nuclear collisions at LHC.
- χ_{cj} is sensitive to final-state nuclear effects.
- Reconstruction via $\chi_{cj} \to J/\psi\,\gamma$, followed by $J/\psi \to \mu\mu$. Classify the event by photon sources:
    - ➢ Converted photons : e^+e^- reconstructed in the tracking system. (high momentum resolution)
    - ➢ Calorimetric photons : reconstructed in the electromagnetic calorimetric. (larger sample)



$$\Delta M \equiv M(\mu^+\mu^-\gamma) - M(\mu^+\mu^-)$$

$$t_z = \frac{(z_{\text{decay}} - z_{\text{PV}}) \times M_{\chi_{c1}}}{p_z}$$

- Selection of prompt χ_{cj} by pseudodecay time t_z.
- Tracking and particle-identification efficiencies cancel out in the ratio due to similar kinematics of χ_{c1} and χ_{c2} decays.



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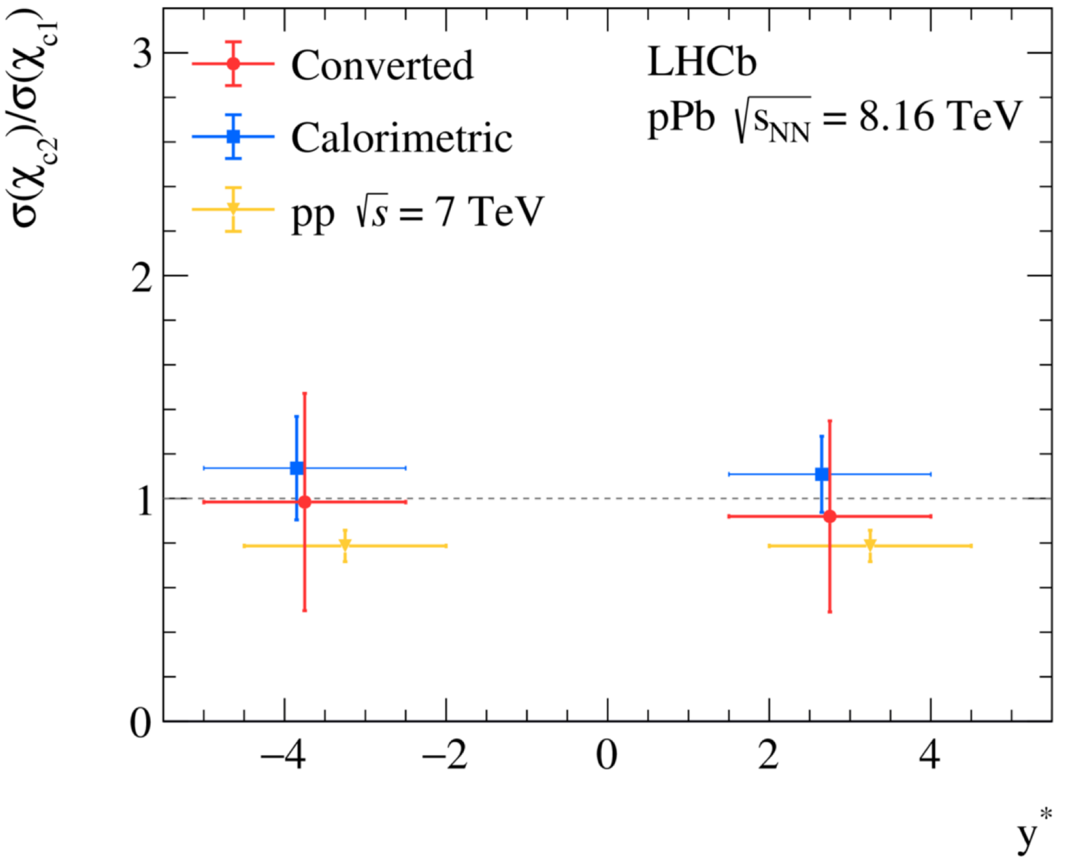
Prompt cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$

- The cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ is consistent with unity at both forward and backward rapidity regions.
- Ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ is larger in *p*Pb than in *pp*, although they are consistent within uncertainty.
- Results suggest that the final-state nuclear effects impact the χ_{c1} and χ_{c2} states similarly within the achieved precision.

$$\mathcal{R} \equiv \frac{\sigma(\chi_{c2})/\sigma(\chi_{c1})|_{p\mathrm{Pb}}}{\sigma(\chi_{c2})/\sigma(\chi_{c1})|_{pp}}$$

Ratio of nuclear-modification factors

$$\mathcal{R}_{\text{forward}} = 1.41 \pm 0.21 \pm 0.18$$
$$\mathcal{R}_{\text{backward}} = 1.44 \pm 0.24 \pm 0.25$$



Summary and outlook

- Prompt D^0 meson production in *p*Pb at 8.16 TeV
  - Hint of R_{FB} increases with increasing p_{T}.
- Charm pair production in *p*Pb at 8.16 TeV
  - Observes 3 times DPS/SPS enhancement in *p*Pb compared to *pp*
  - Observes a suppression of DPS in *p*Pb data compared to Pb*p*.
- Prompt cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in *p*Pb at 8.16 TeV
  - The final-state nuclear effects impact the χ_{c1} and χ_{c2} states similarly within the achieved precision.
- Lots of new results Upcoming:
  - D mesons in *p*Pb
  - Λ_c in PbPb