

Open heavy-flavour production and elliptic flow in p-Pb collisions at the LHC with ALICE

Henrique Zanolli on behalf of the ALICE Collaboration

University of São Paulo (Brazil) and Utrecht University (Netherlands)



Utrecht University



Why study heavy-quark production in p-Pb?



Constrain Cold Nuclear Matter (CNM) effects

- Modification of nuclear PDFs at low x (shadowing), gluon saturation
- Parton transverse momentum broadening
- Cold nuclear matter parton energy loss

Baseline for Pb-Pb collisions

- b and c quarks: ideal probes to study the QGP

Talks: X. Peng , B. Trzeciak , A. Dubla

Collective effects in p-Pb?

- Collective-like effects (elliptic flow)? Mass dependence?
- Geometry fluctuations? Interaction between final-state particles?

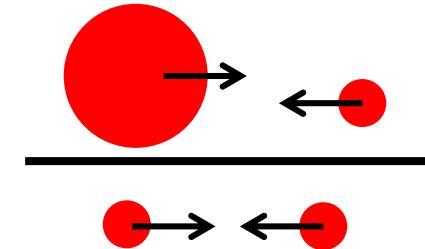
Observables

- Nuclear modification factor:

$$R_{\text{pPb}}(p_T) = \frac{1}{A} \frac{d\sigma_{\text{pPb}}/dp_T}{d\sigma_{\text{pp}}/dp_T}$$

when studied vs centrality :

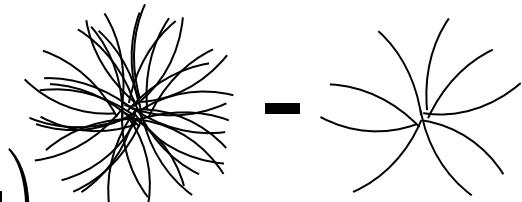
$$Q_{\text{pPb}}^{\text{cent}} = \frac{1}{\langle T_{\text{pPb}}^{\text{cent}} \rangle} \frac{d^2 N_{\text{pPb}}^{\text{cent}} / dp_T}{d\sigma_{\text{pp}}/dp_T} \quad \langle T_{\text{pPb}}^{\text{cent}} \rangle = \frac{\langle N_{\text{coll}} \rangle^{\text{cent}}}{\sigma_{\text{NN}}}$$



Phys. Rev. C 91, 064905 ⚡

- Azimuthal anisotropy (v_2): Jet subtraction using low multiplicity events

$$\left(\frac{1}{N_a} \frac{dN^{\text{ab}}}{d(\Delta\phi)} \right)^{\text{HM}} - \left(\frac{1}{N_a} \frac{dN^{\text{ab}}}{d(\Delta\phi)} \right)^{\text{LM}}_{\text{sub}} = P \left(1 + \sum_{n=1}^{\infty} 2 \times v_n^a v_n^b \times \cos[n\Delta\phi] \right)$$



ALICE detector

Minimum bias (5.02 TeV)

2013
 $\approx 100M$ p-Pb Ev., $\mathcal{L}_{int} = 47.8 \mu b^{-1}$

2016
 $\approx 600M$ p-Pb Ev., $\mathcal{L}_{int} = 292 \mu b^{-1}$

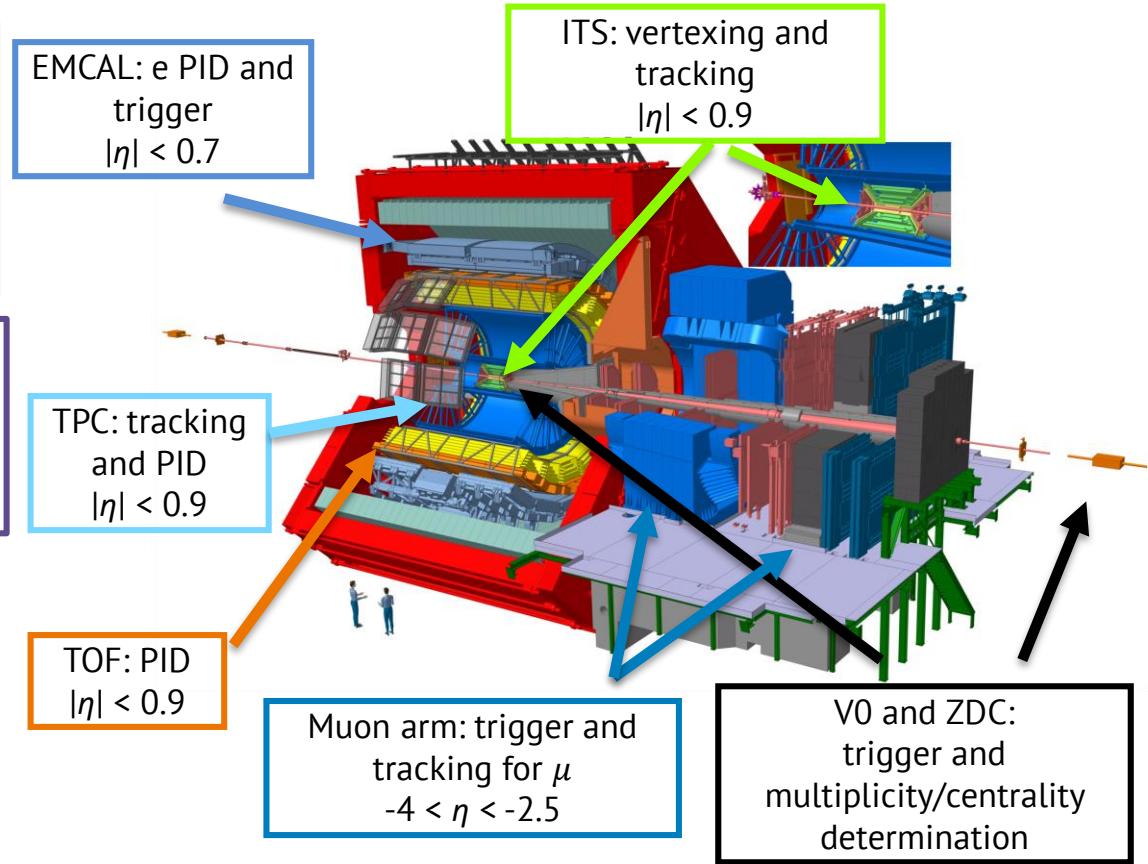
Electrons (2016) (8.16 TeV)

Trig. GA1 ($p_T > 10 \text{ GeV}/c$) $\mathcal{L}_{int} = 599 \mu b^{-1}$
 Trig. GA2 ($p_T > 5 \text{ GeV}/c$) $\mathcal{L}_{int} = 34.6 \mu b^{-1}$
 $\approx 20M$ MB events $\mathcal{L}_{int} = 10.1 \mu b^{-1}$

Muons (2013)

Trigger MSL ($p_T > 0.5 \text{ GeV}/c$)
 $p\text{-Pb } \mathcal{L}_{int} = 196 \mu b^{-1}$
 $Pb\text{-p } \mathcal{L}_{int} = 254 \mu b^{-1}$

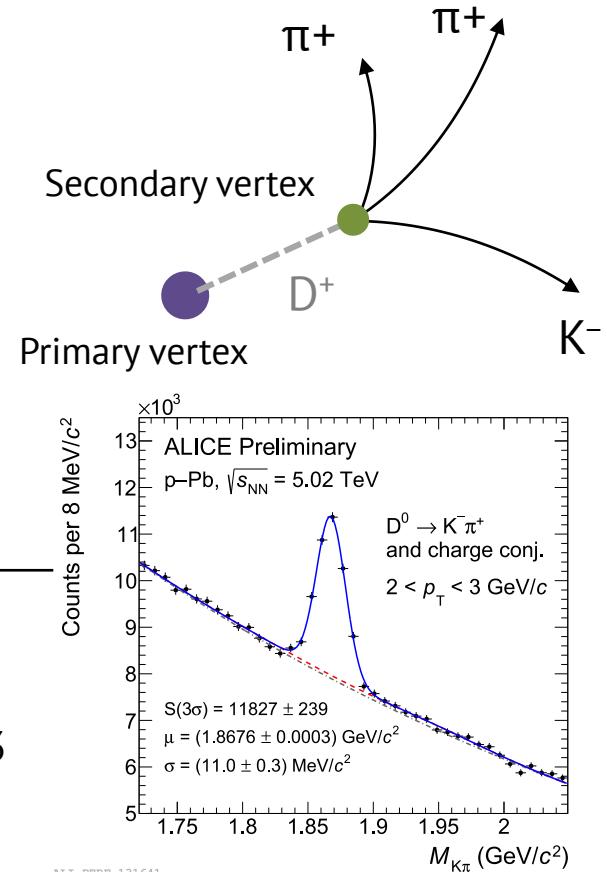
Trigger MSH ($p_T > 4.2 \text{ GeV}/c$)
 $p\text{-Pb } \mathcal{L}_{int} = 4.9 \cdot 10^3 \mu b^{-1}$
 $Pb\text{-p } \mathcal{L}_{int} = 5.8 \cdot 10^3 \mu b^{-1}$



D-meson reconstruction

- Fully reconstructed in hadronic decays
- Topological selection of secondary vertexes and invariant mass analysis
- Analysis with detailed study of combinatorial-background inv. mass shape and without vertex reconstruction for D^0 (best results for $p_T < 1 \text{ GeV}/c$)

	Mass (GeV/c^2)	$c\tau$ (μm)	Decay	BR (%)
D^0	1.865	123	$K^- \pi^+$	3.93
D^+	1.870	312	$K^- \pi^+ \pi^+$	9.46
D^{*+}	2.010	-	$D^0 (K^- \pi^+) \pi^+$	67.7×3.93
D_s^+	1.968	150	$\Phi(K^- K^+) \pi^+$	2.27



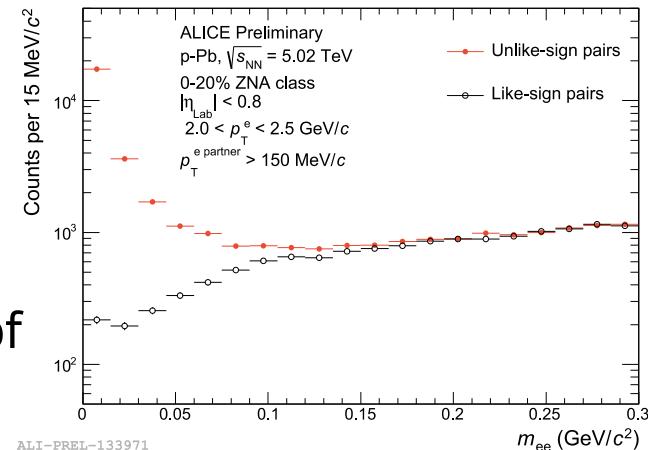
HF decay lepton identification

Muons

- $b, c \rightarrow \mu^\pm X$ (BR $\approx 10\%$)
- μ from π and K are subtracted using simulations tuned with the abundances of pions and kaons measured at mid-rapidity.
- Absorber reduces contamination from other particles
- W-boson contribution subtracted exploiting POWHEG simulations with nPDF

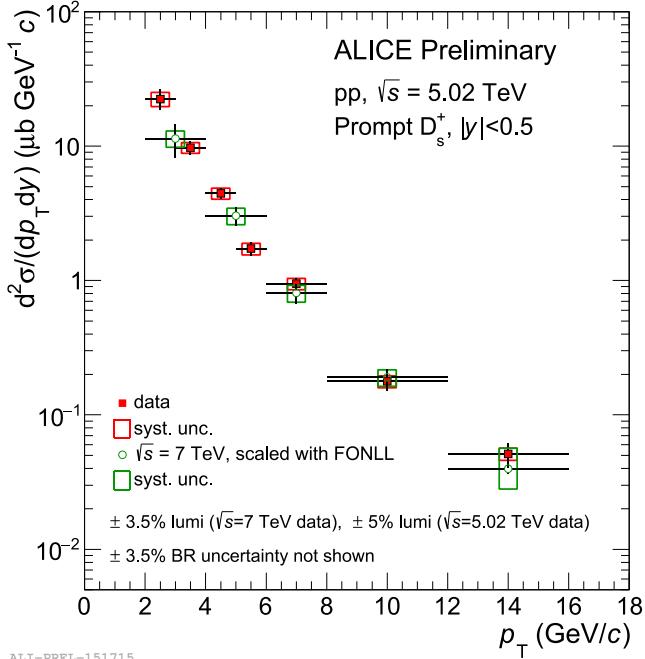
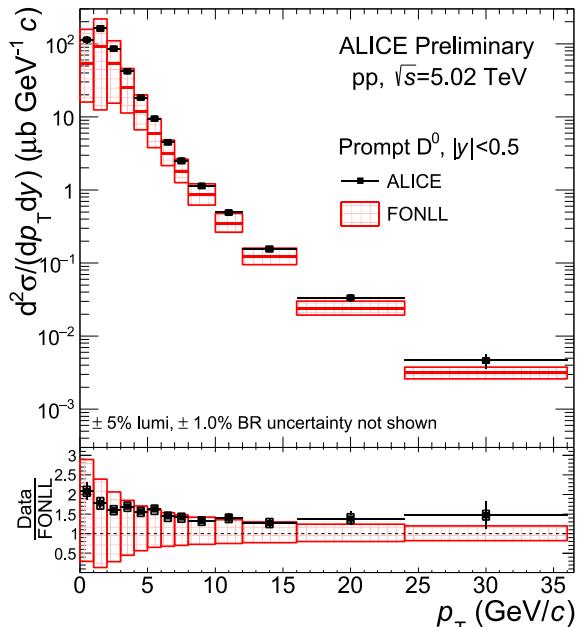
Electrons

- $b, c \rightarrow e^\pm X$ (BR $\approx 10\%$)
- PID: TPC and TOF ($|\eta| < 0.9$), EMCAL ($|\eta| < 0.7$)
- Dalitz decay of neutral mesons and γ conversions identified via invariant mass of electro pairs and subtracted



Integrated centrality results

New reference for D mesons (pp 5.02 TeV)

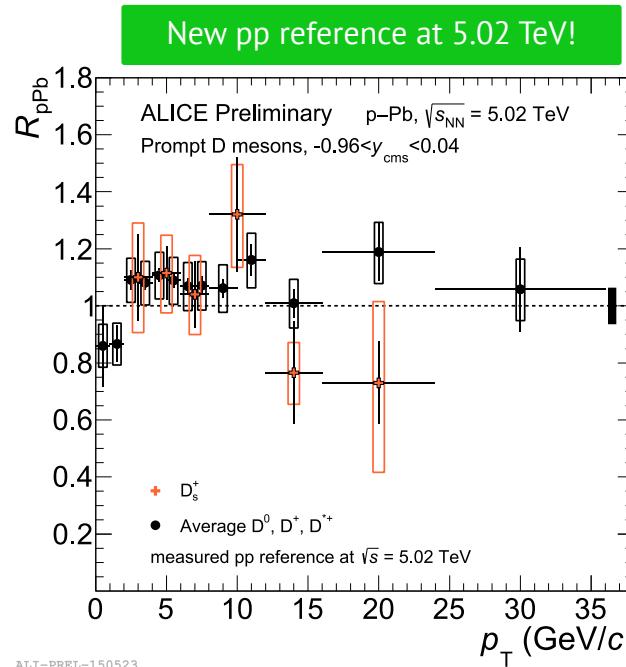
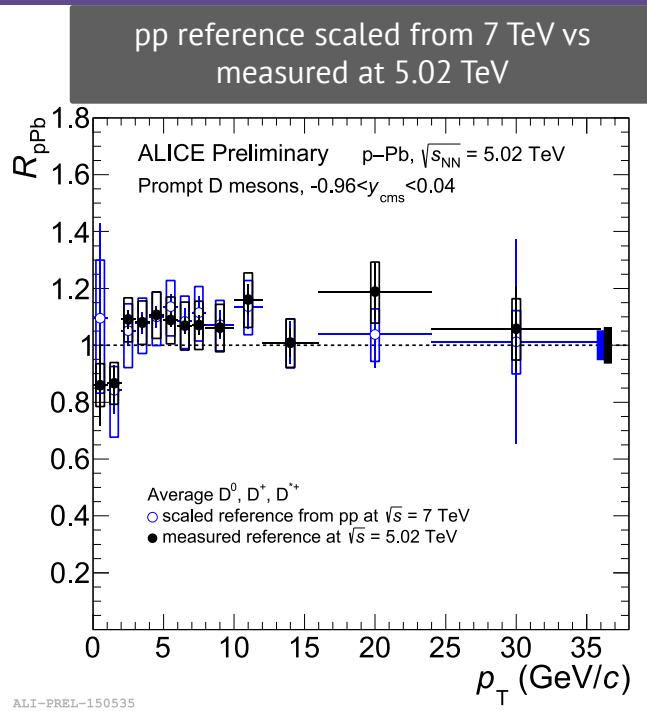


ALICE-
PUBLIC-
2018-006

Posters:
S. Costanza
& N. Valle
A. M Veen
C. Terrevoli

- Significant reduction of uncertainties on the reference thanks to large min. bias data sample in pp $\sqrt{s} = 5.02$ TeV collected in 2017
- Results compatible with scaled references at 7 TeV

D-meson R_{pPb} at 5.02 TeV



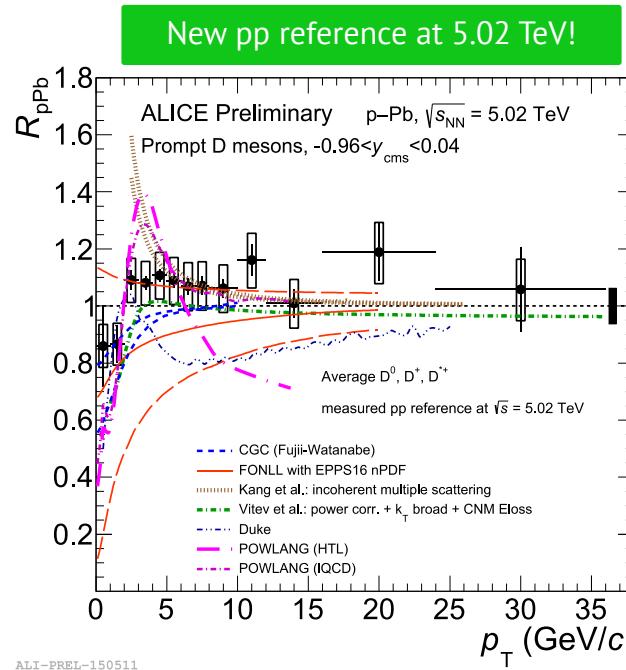
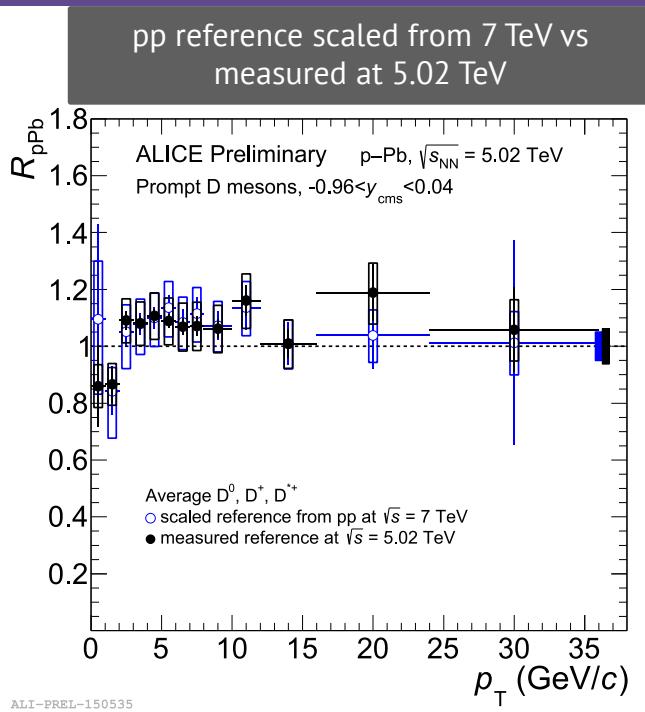
$$R_{\text{pPb}} = \frac{1}{A} \frac{d\sigma_{\text{pPb}}/dp_{\text{T}}}{d\sigma_{\text{pp}}/dp_{\text{T}}}$$

Posters:
R. Bala 
A. M Veen 
C. Terrevoli 

ALICE-
PUBLIC-
2017-008

- New pp ref. significantly reduces the uncertainties for $p_{\text{T}} < 3 \text{ GeV}/c$ and at all p_{T} for D_s^+
- $D_s^+ R_{\text{pPb}}$ compatible with D-meson R_{pPb} . Both compatible with unity.

D-meson R_{pPb} at 5.02 TeV



$$R_{\text{pPb}} = \frac{1}{A} \frac{d\sigma_{\text{pPb}}/dp_{\text{T}}}{d\sigma_{\text{pp}}/dp_{\text{T}}}$$

Posters:
R. Bala 
A. M Veen 
C. Terrevoli 

ALICE-
PUBLIC-
2017-008

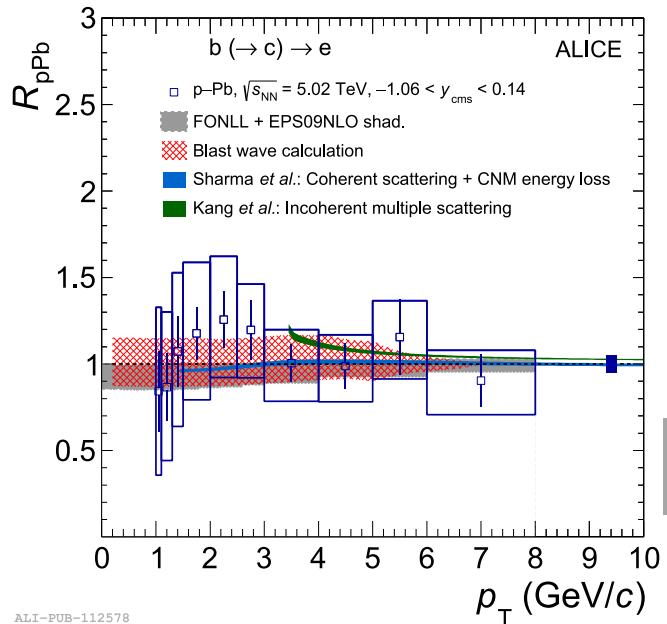
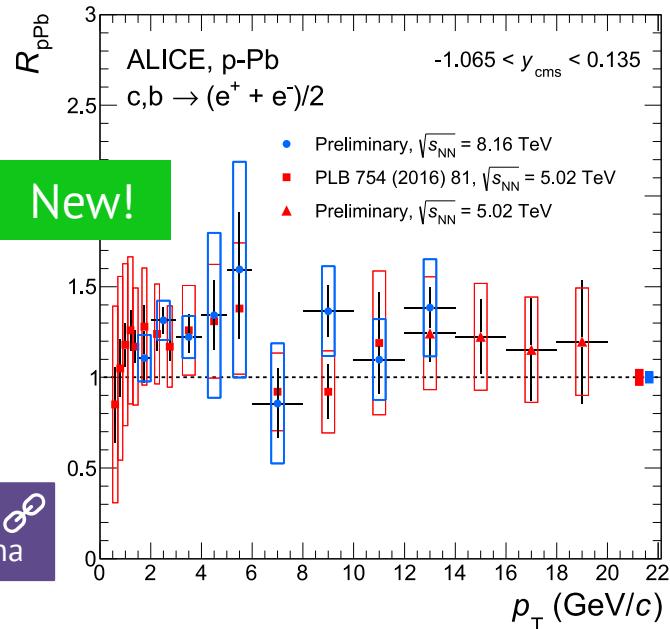
- New pp ref. significantly reduces the uncertainties for $p_{\text{T}} < 3 \text{ GeV}/c$ and at all p_{T} for D_s^+

- $D_s^+ R_{\text{pPb}}$ compatible with D-meson R_{pPb} . Both compatible with unity.
- More stringent constraints to models at low p_{T}

Model Ref.:
check backup

HF electron R_{pPb} at 5.02 and 8.16 TeV

Poster: 
D. Kawana

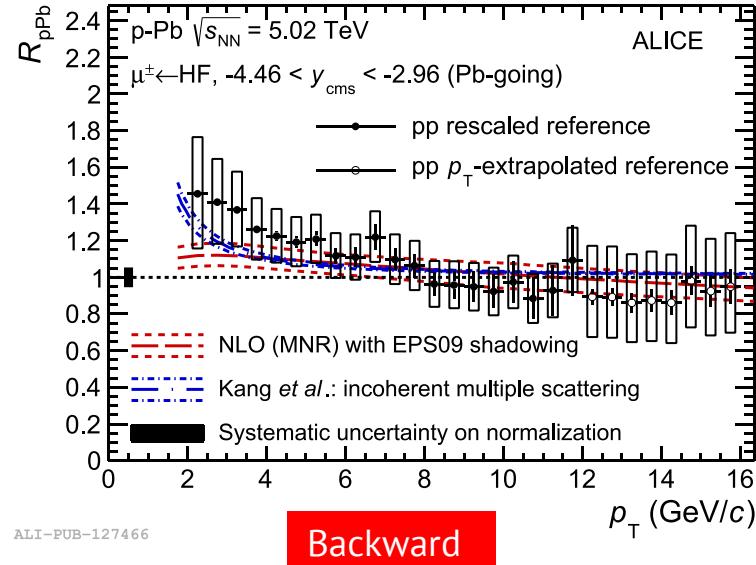
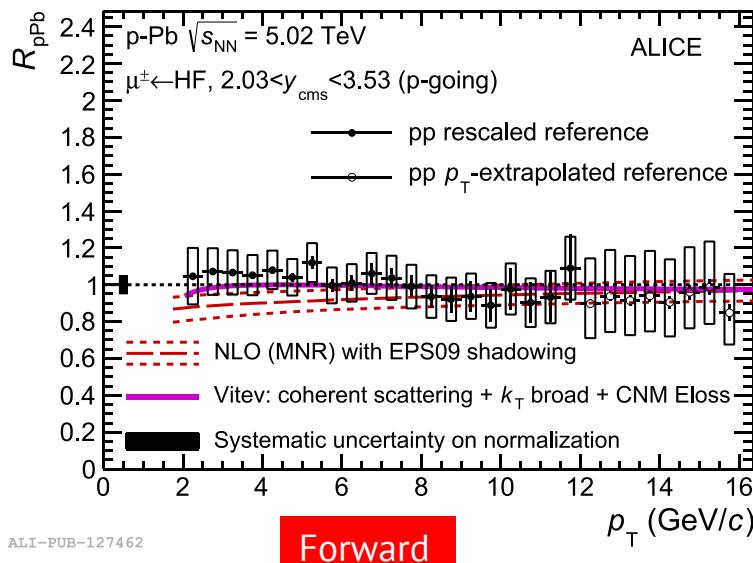


JHEP 07
(2017) 052

Model Ref.:
check backup

- R_{pPb} is compatible with unity in all the p_T intervals
- No energy dependence within uncertainties
- Beauty and beauty+charm electron results are compatible within uncertainties
- Models describe well the R_{pPb}

HF muons R_{pPb} at 5.02 TeV



PLB 770
(2017) 459-472

- Different rapidity ranges allow to access to different x regimes
- Forward rapidity: compatible with unity
- Backward rapidity: above unity by more than 2σ for $2.5 < p_{\text{T}} < 3.5 \text{ GeV}/c$
- Well described by model calculations including cold nuclear matter effects.

Model Ref.:
check backup

Centrality/multiplicity-dependent studies

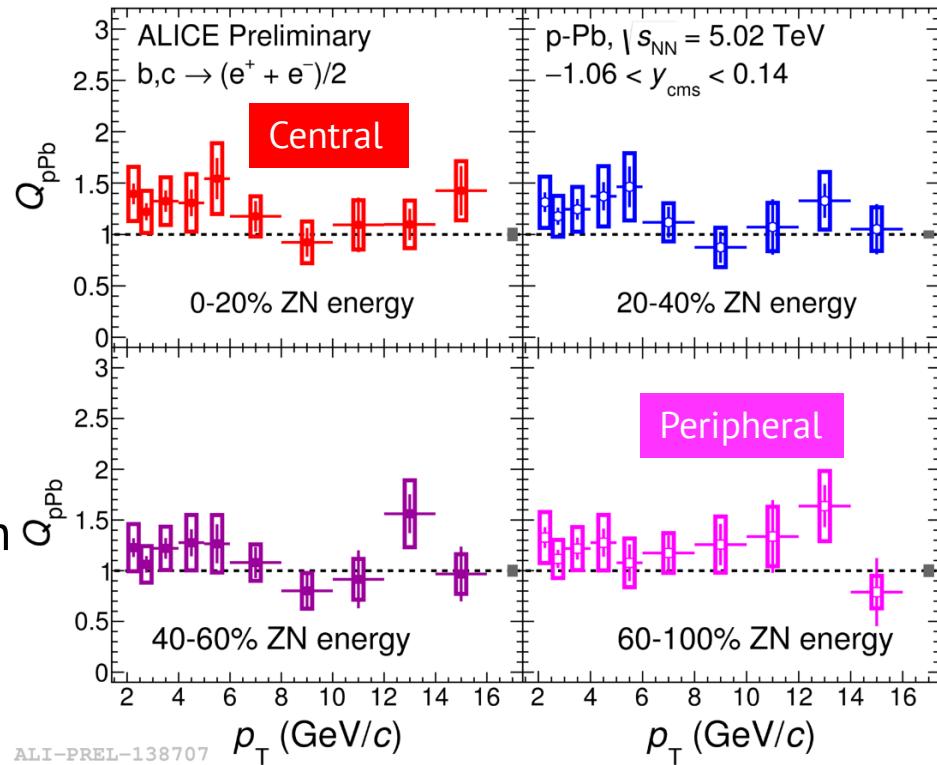
HFe at 5.02 TeV as function of centrality



$$Q_{\text{pPb}}^{\text{cent}} = \frac{1}{\langle T_{\text{pPb}}^{\text{cent}} \rangle} \frac{d^2 N_{\text{pPb}}^{\text{cent}} / dp_T}{d\sigma_{\text{pp}} / dp_T}$$

Phys. Rev. C 91, 064905

- Energy deposited in neutron calorimeter in the Pb-going side used as centrality estimator (ZN)
- HFe Q_{pPb} compatible with unity in σ all the centralities studied. No multiplicity dependence found.

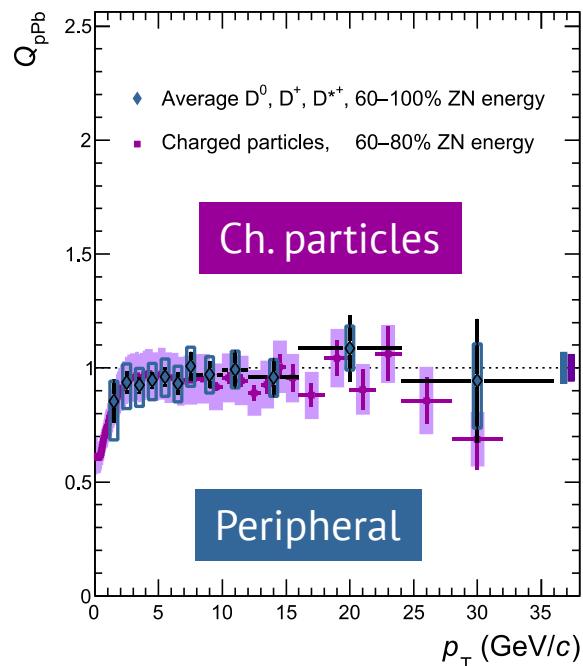
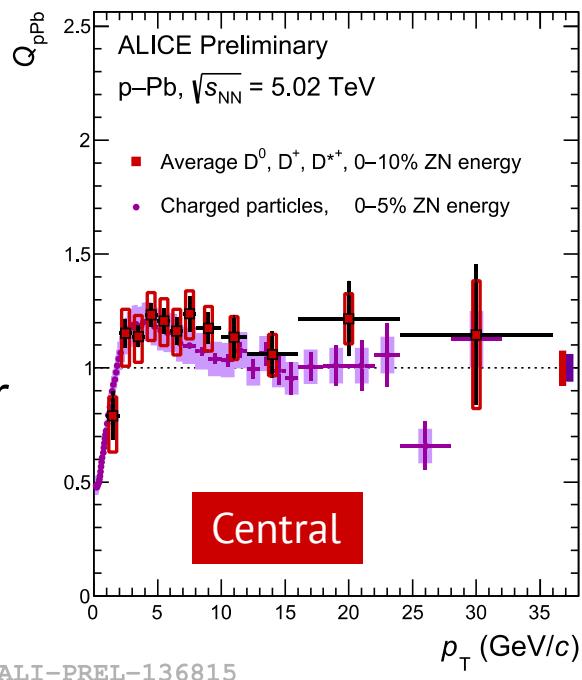


Poster:
S. De

D-meson Q_{pPb} as function of centrality



- Central and peripheral results are compatible within uncertainties and compatible with unity
- D-meson Q_{pPb} similar to charged particles within uncertainties



Using scaled reference from pp collisions at 7 TeV

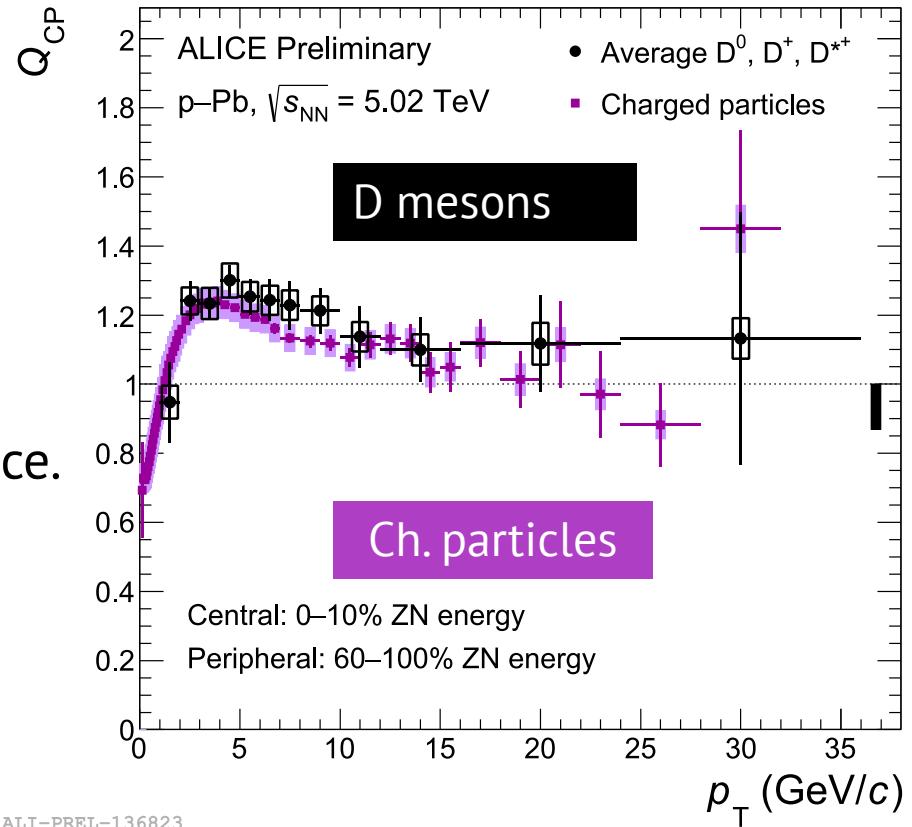
Posters:
C. Bedda
C. Terrevoli

ALI-PREL-136815

D-meson production central/peri.

$$Q_{\text{cp}} = \frac{\frac{d^2 N_{\text{pPb}}^{\text{central}} / dp_T}{\langle T_{\text{pPb}}^{\text{central}} \rangle}}{\frac{d^2 N_{\text{pPb}}^{\text{peri}} / dp_T}{\langle T_{\text{pPb}}^{\text{peri}} \rangle}}$$

- Hint of $Q_{\text{CP}} > 1$ in $3 < p_T < 8 \text{ GeV}/c$ for D mesons with 1.5σ significance.
Initial- or final-state effect?
- D-meson Q_{CP} similar to charged particles



Posters:

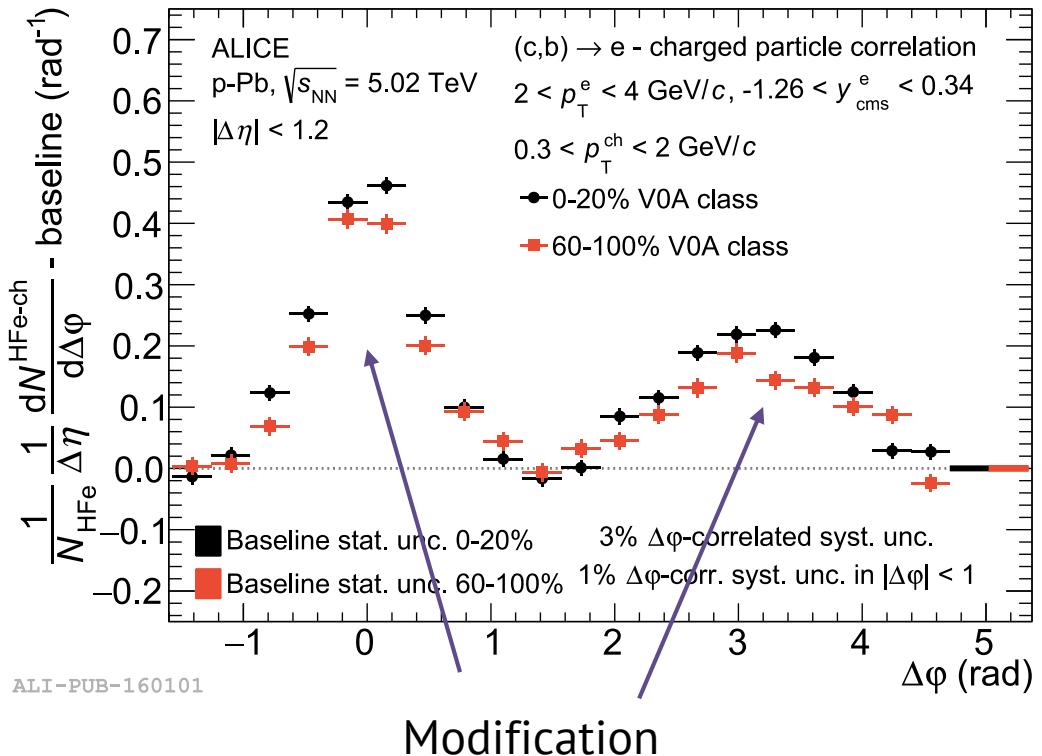
C. Bedda

C. Terrevoli

HFe ν_2 at high multiplicity at 5.02 TeV



- Two-particle correlations of HFe with charged particles in **high multiplicity** and **low multiplicity** events
- Near and away side modification from low multiplicity to high multiplicity

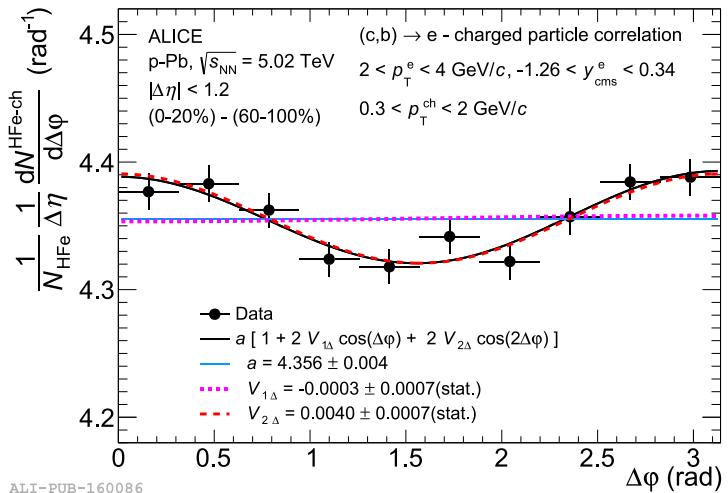


HFe ν_2 at high multiplicity at 5.02 TeV

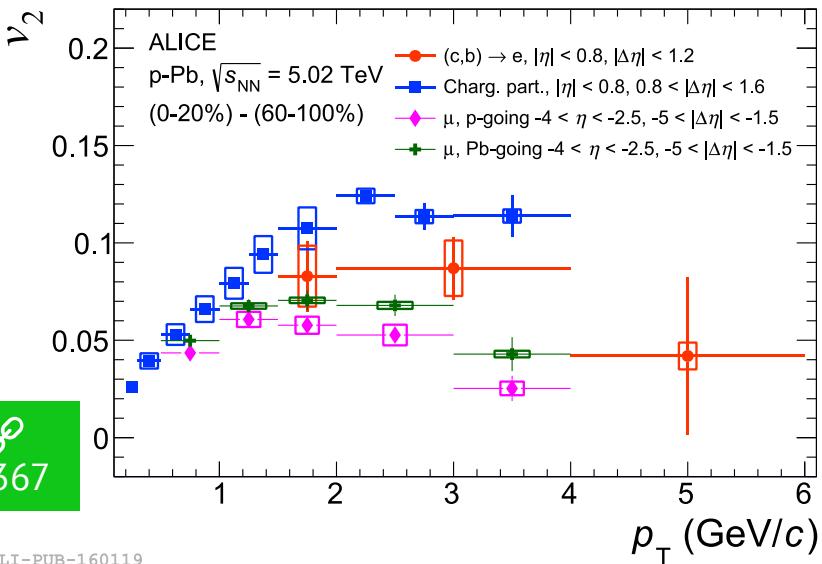


- Jet subtraction: high mult. - low mult.
- Modulation present! Collective effects?
Initial- or final-state effect?

$$C^{\text{HM}} - C_{\text{sub}}^{\text{LM}} = P \left(1 + \sum_{n=1}^2 2 \times V_{n\Delta} \times \cos[n\Delta\varphi] \right)$$



arXiv: 1805.04367



- Significance: **5.1 σ for $1.5 < p_T^e < 4 \text{ GeV}/c$**
- Effect is qualitatively similar to the one observed for light flavours and inclusive muons

More p-Pb results

HF electron production

Integrated Centrality

D. Kawana 

Studies vs Centrality

S. De 

Studies vs Multiplicity

P. Dhankher 

D-meson production

Integrated Centrality

R. Bala 

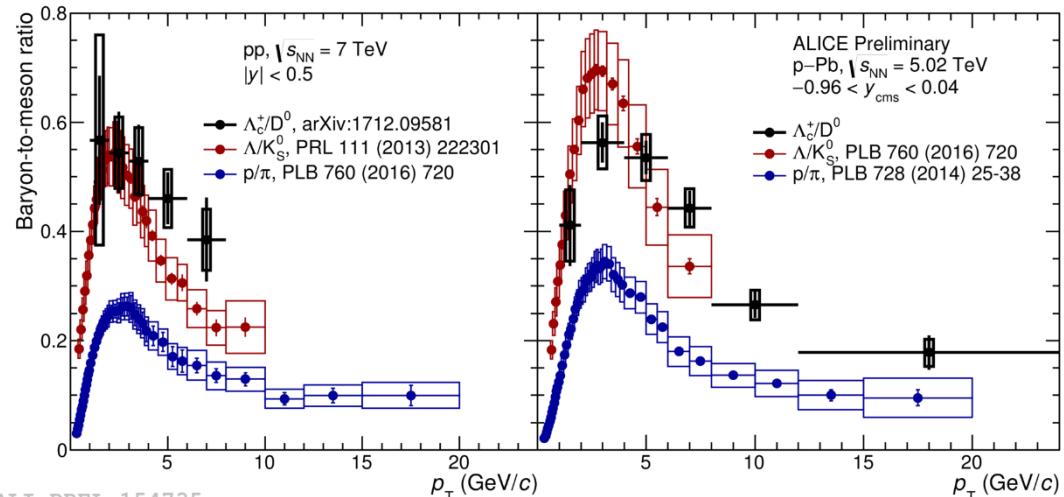
A. M Veen 

C. Terrevoli 

Studies vs Centrality

C. Bedda 

C. Terrevoli 



Check also new results on charmed baryons

D-meson pp ref:
S. Costanza
& N. Valle 
A. M Veen 

Talk
X. Peng 

Posters:
E. Meninno 
C. Hills 
J. Wilkinson 

Summary

- R_{pPb} of D mesons, HF electrons and muons **compatible with unity**. Suppression in Pb-Pb collisions yield is, from a large extension, coming from final-state effects.
- Important reduction of the uncertainties on the R_{pPb} of strange and non-strange D mesons thanks to the new pp reference at 5.02 TeV
- Q_{pPb} compatible with unity for HF electrons and D mesons.
- **Hints of $Q_{cp} > 1$ for D mesons** in $3 < p_T < 8$ GeV/c (1.5σ), possible modification of the production. From initial- or final-state effects?
- **Positive v_2 measured for HF electrons with more than 5σ** significance for $1.5 < p_T^e < 4$ GeV/c. Collective effects? Initial- or final-state effect?

Thank you!

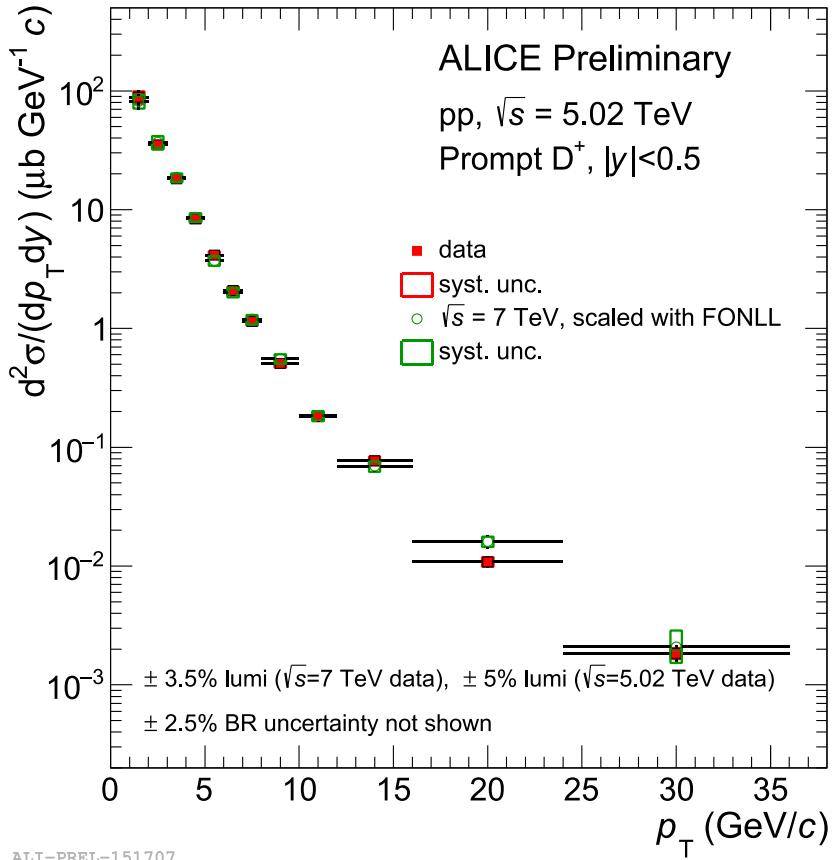
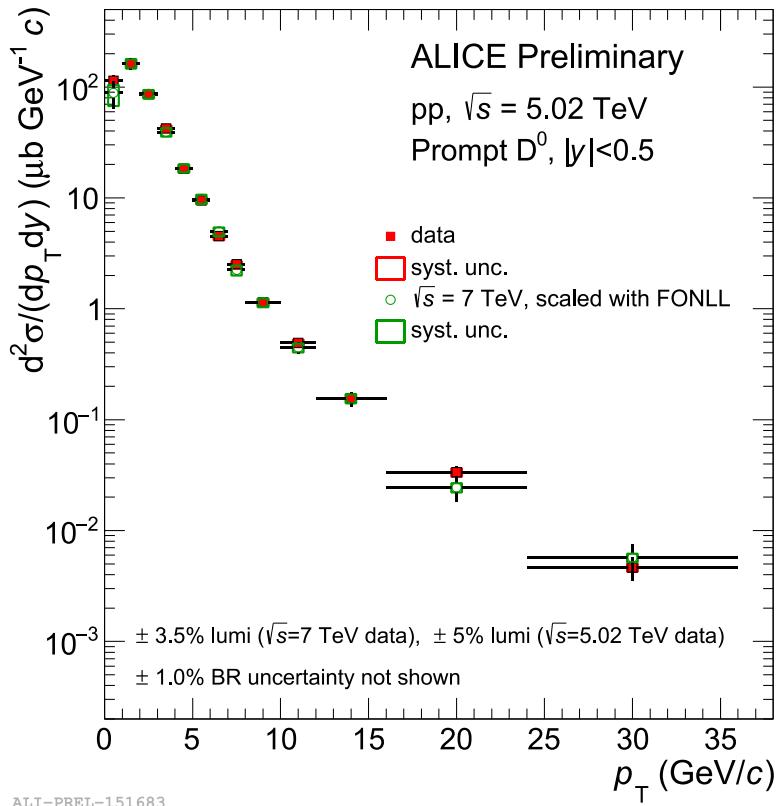
Acknowledgement



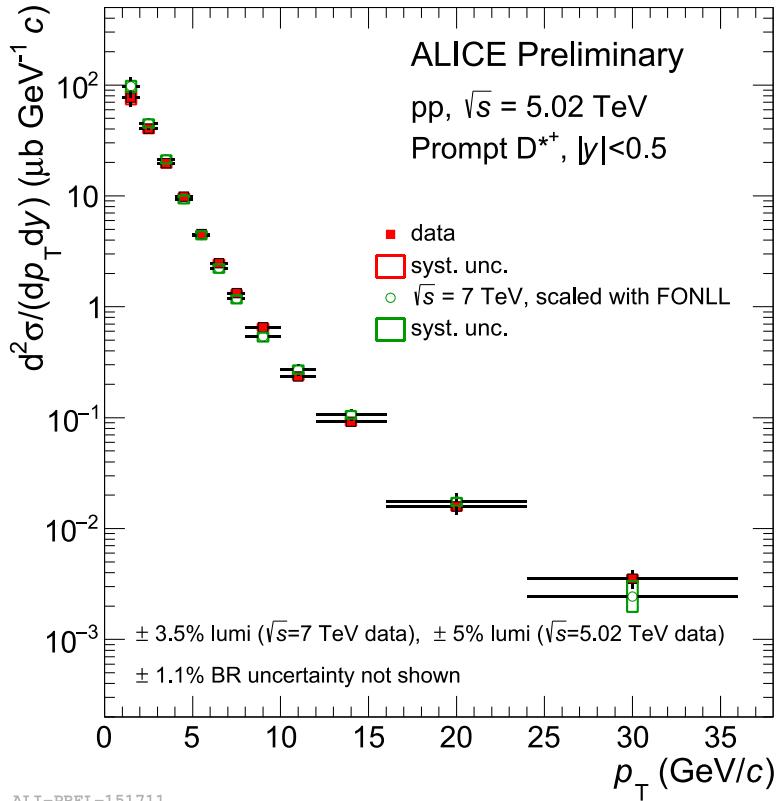
Netherlands Organisation
for Scientific Research

Backup

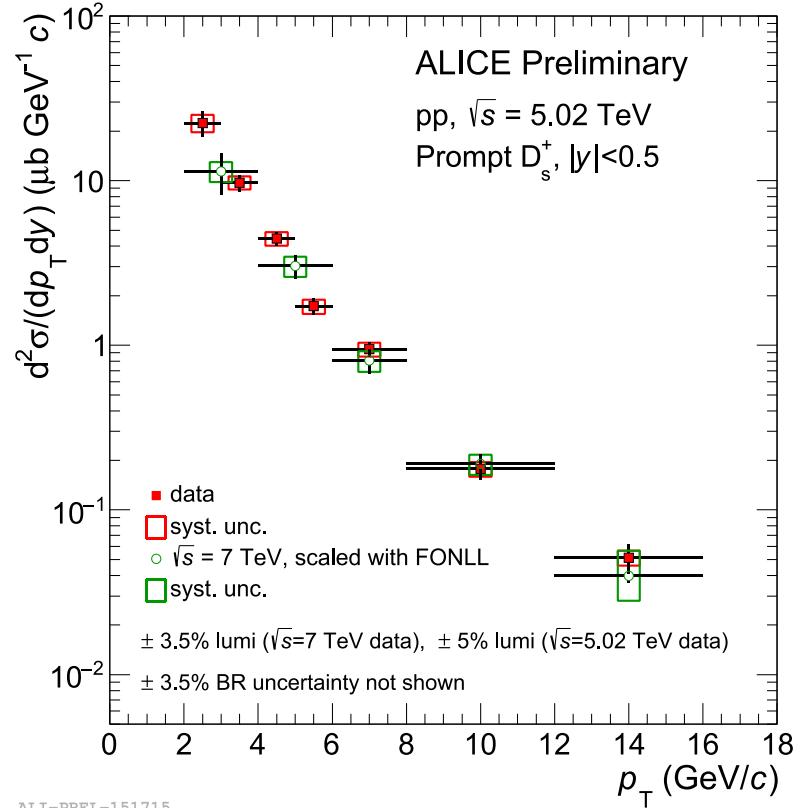
D-meson production in pp



D-meson production in pp

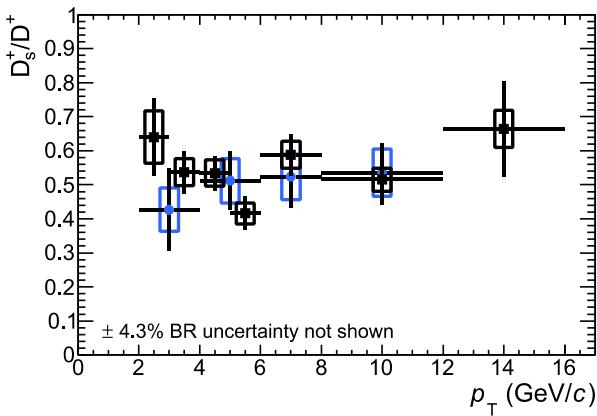
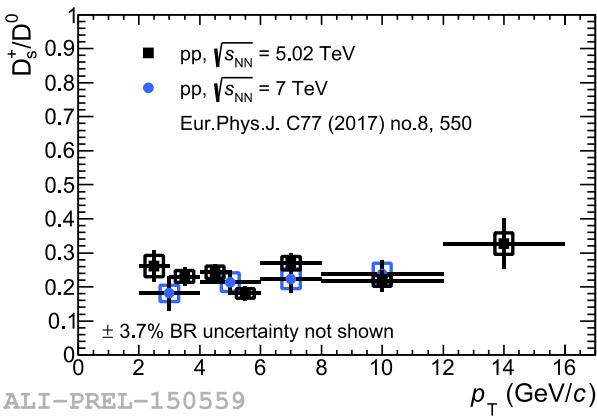
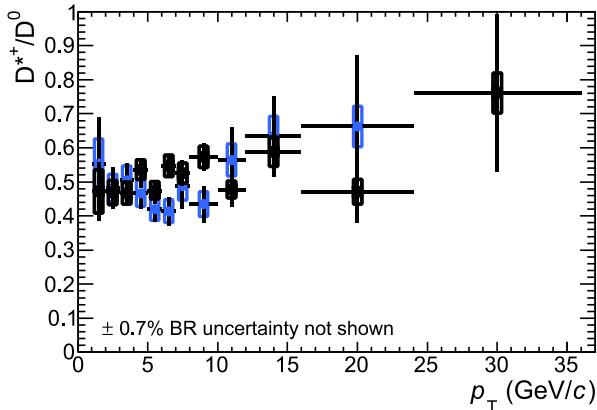
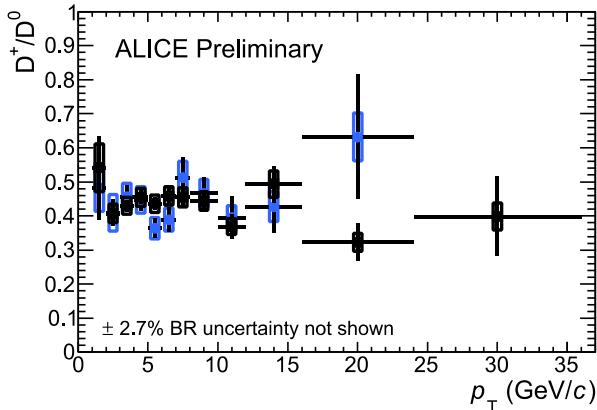


ALI-PREL-151711



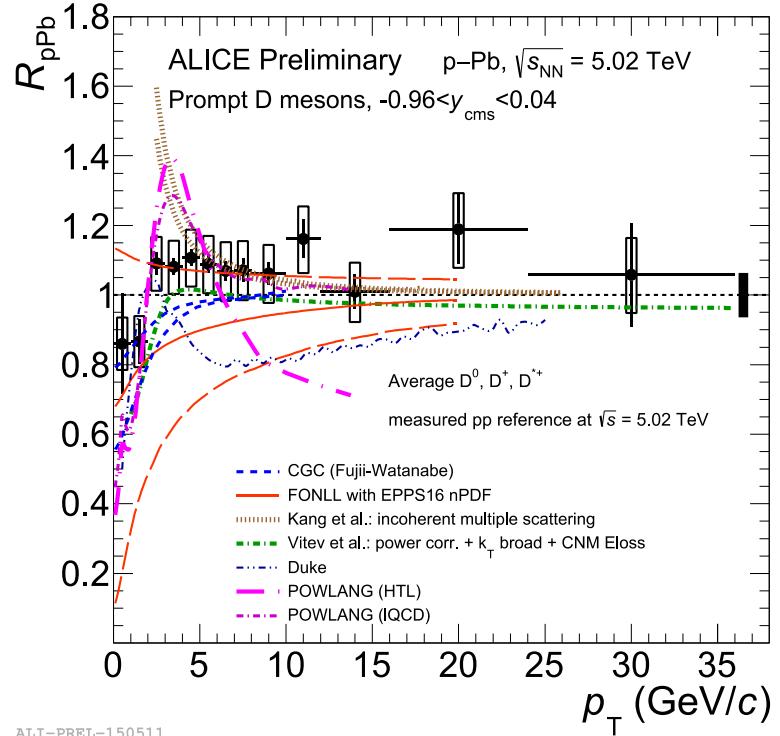
ALI-PREL-151715

D-meson ratios results in pp



Model references for D meson R_{pPb}

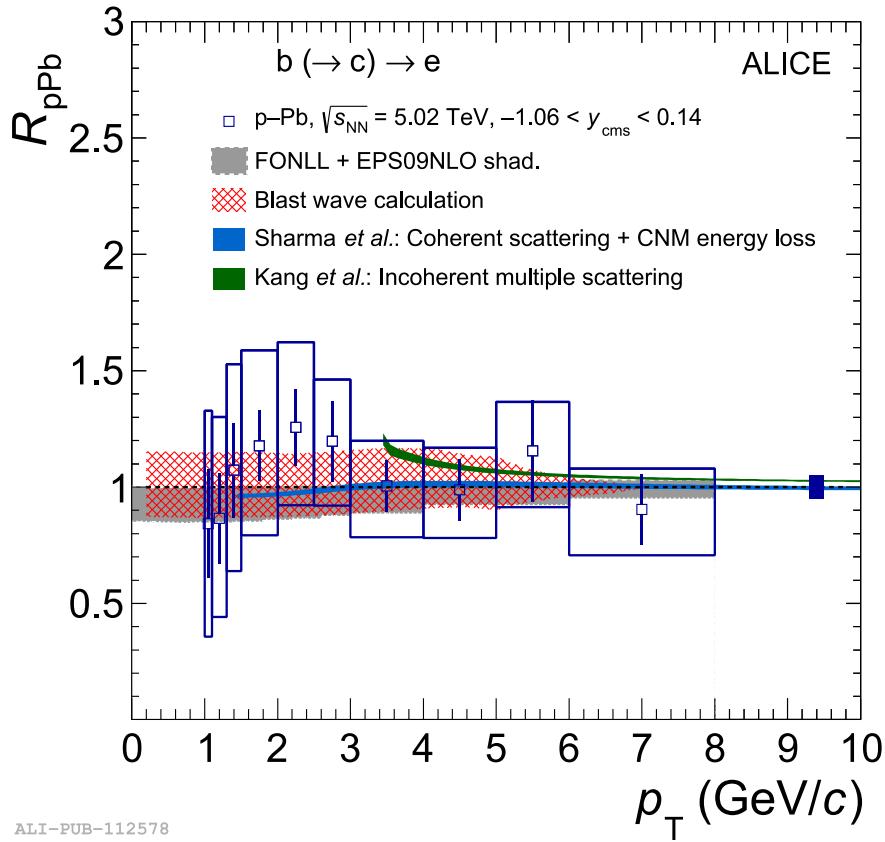
- **CGC**: arXiv:1706.06728
- **FONLL** (JHEP 1210 (2012) 137, arXiv:1205.6344) **with EPPS16 nPDFs** (Eur. Phys.J. C77 no. 3, (2017) 163, arXiv:1612.05741).
- **Vitev et al**: Phys.Rev.C80 (2009) 054902, arXiv:0904.0032.
- **Kang et al.**: Phys. Lett. B740 (2015) 23–29, arXiv:1409.2494.
- **Duke**: Nucl. xPart. Phys. Proc. 276-278 (2016) 225–228, arXiv:1510.07520.
- **POWLANG**: JHEP 03 (2016) 123, arXiv:1512.05186.



Model references for HFe beauty R_{pPb}

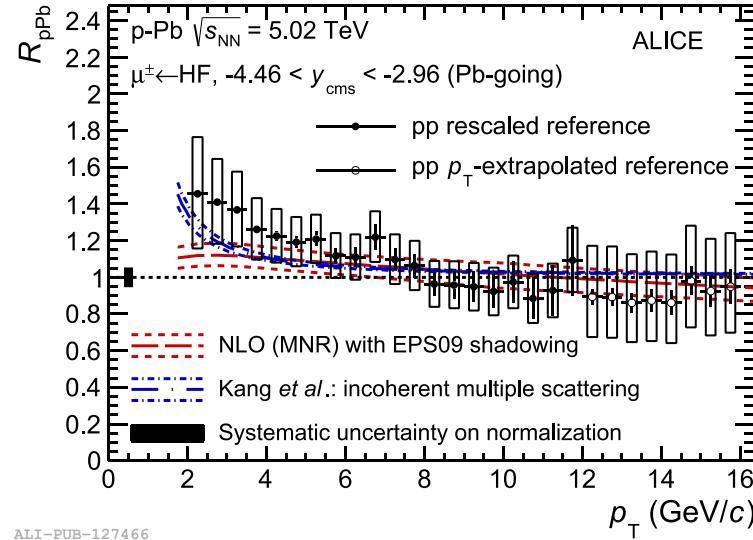
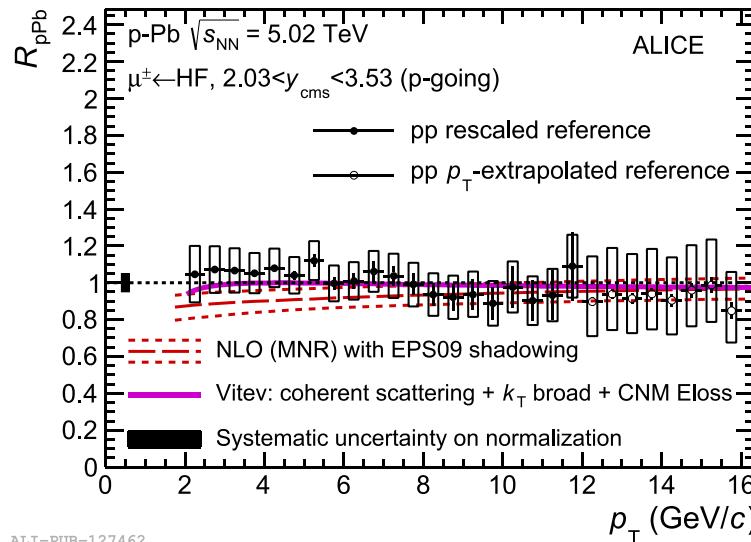


- **FONLL** (JHEP 1210 (2012) 137, arXiv:1205.6344 [hep-ph]) with **EPS09NLO** (JHEP 04 (2009) 065, arXiv:0902.4154)
- **Blast wave calculation:** Phys. Lett. B 728 (2014) 25, arXiv:1307.6796
- **Sharma et al:** Phys. Rev. C 80 (2009) 054902, arXiv:0904.0032
- **Kang et al:** , Phys. Lett. B 740 (2015) 23, arXiv:1409.2494



ALI-PUB-112578

Model references for HF muons R_{pPb}

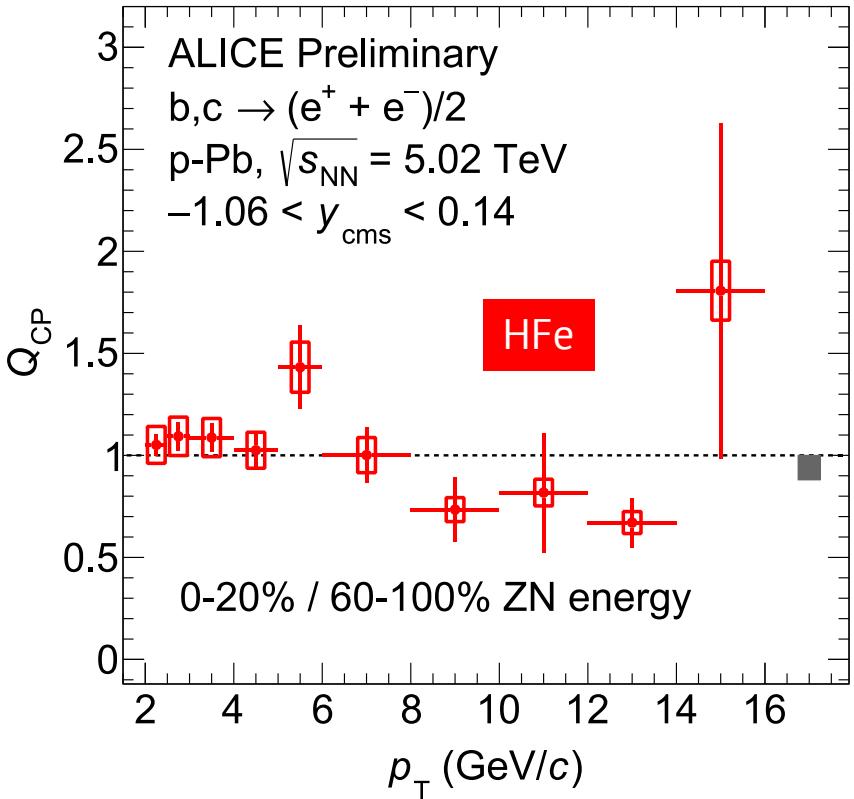


- NLO with EPS09 (Nucl. Phys. B, 373 (1992))
- Vitev: Phys. Rev. C, 80 (2009), Article 054902, arXiv:0904.0032
- Kang et al: Phys. Lett. B, 740 (2015), pp. 23-29, arXiv:1409.2494

HF electron Q_{cp}

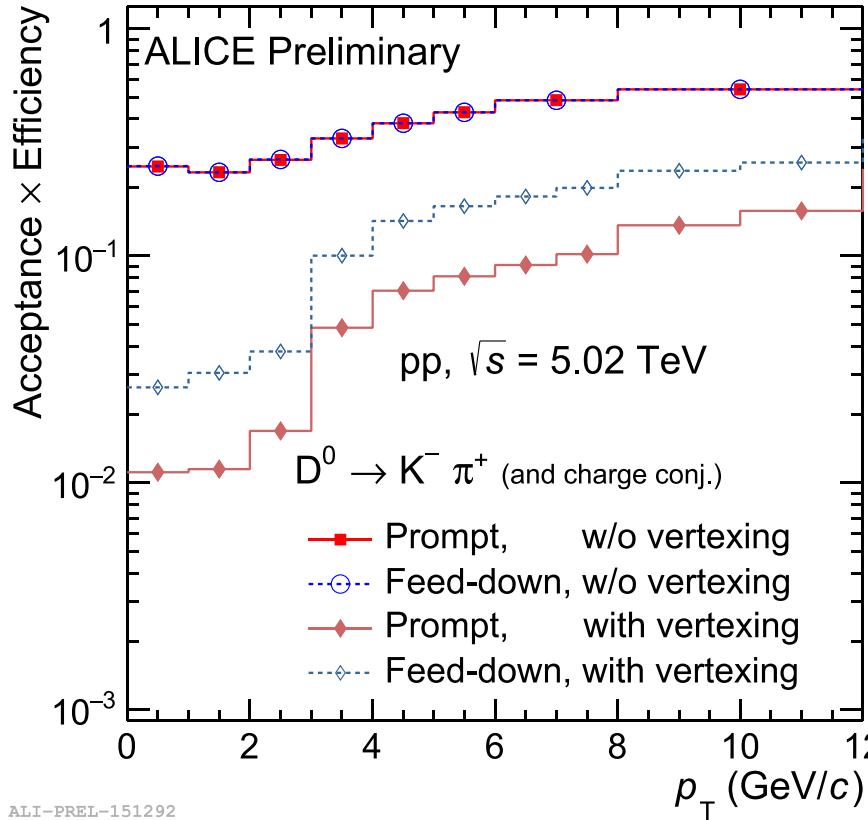


- HFe Q_{CP} compatible with unity within uncertainties
- Decay kinematics do not allow a direct comparison to the D meson one

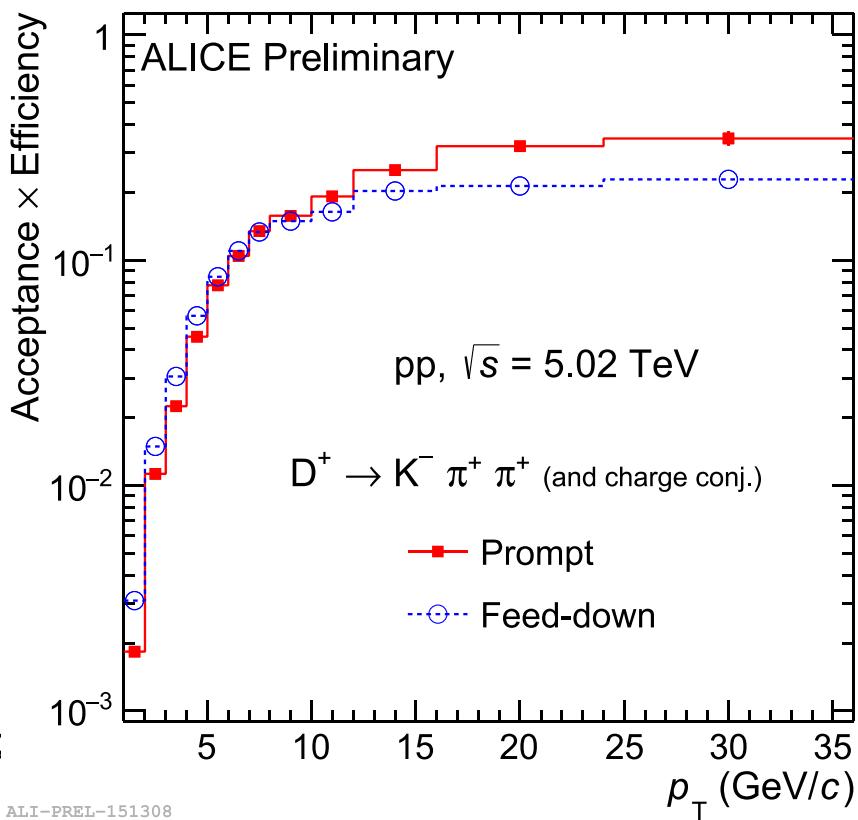


ALI-PREL-138715

D-meson reconstruction efficiency

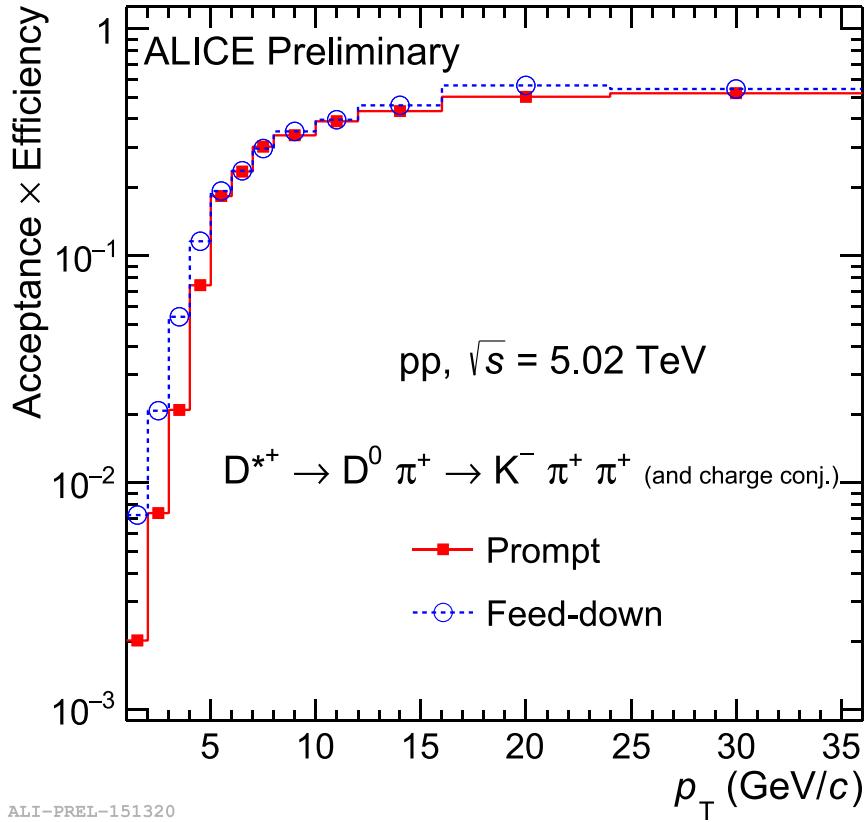
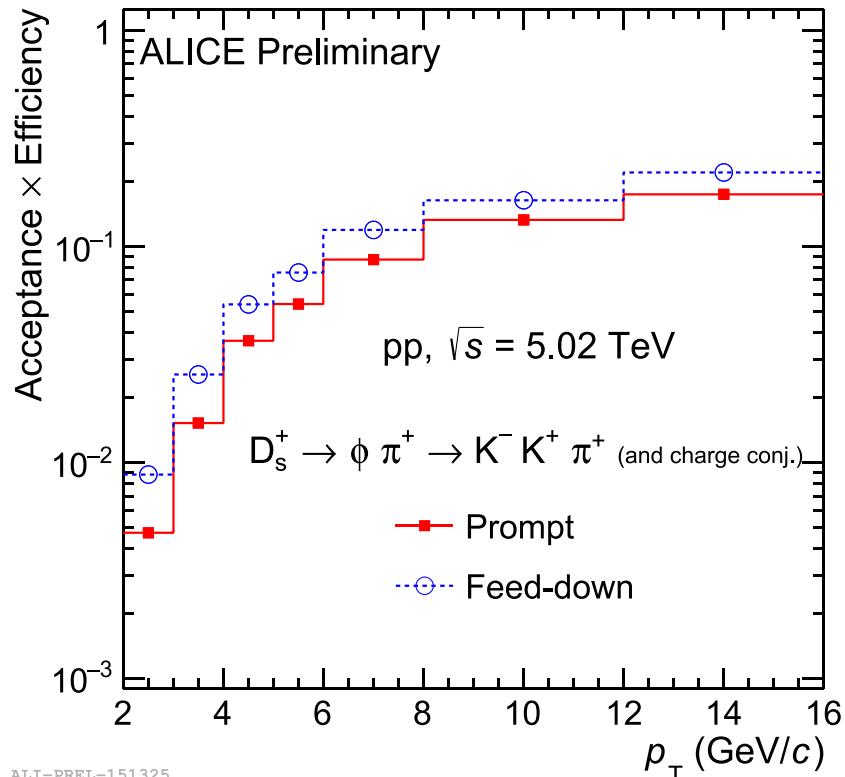


ALI-PREL-151292

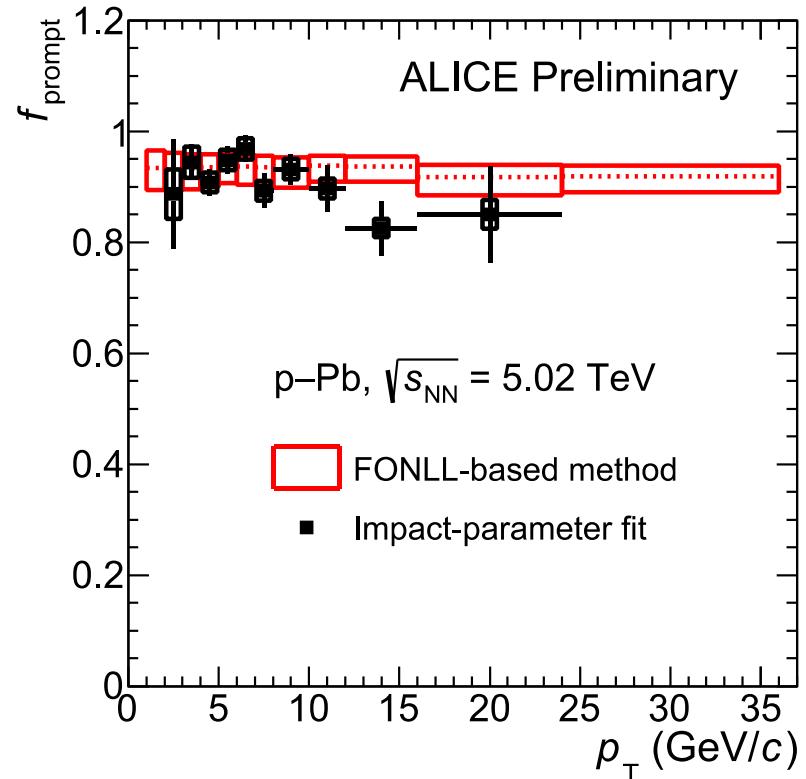
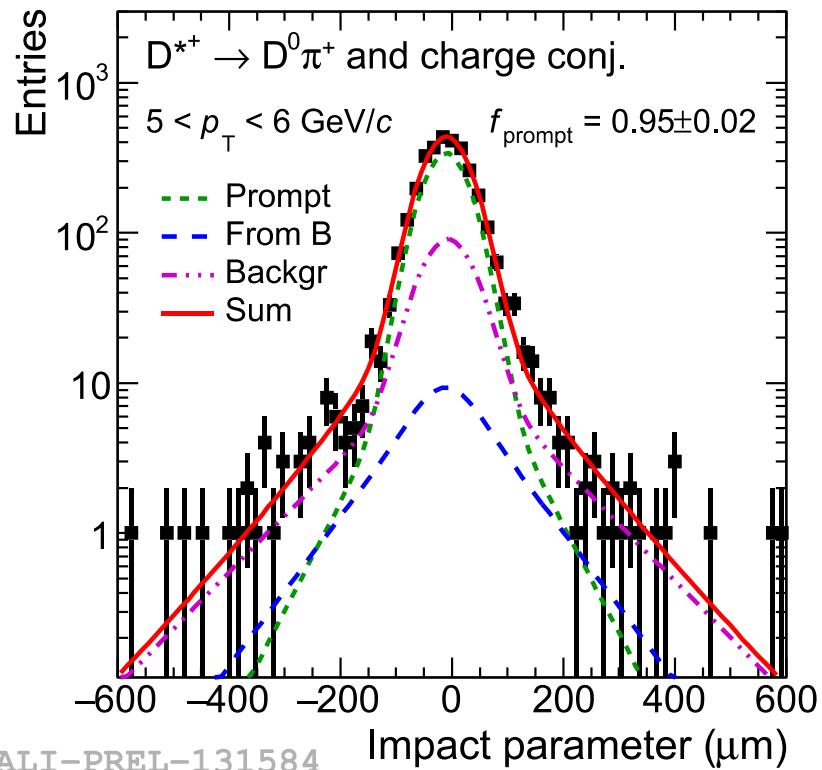


ALI-PREL-151308

D-meson reconstruction efficiency



Feed-down subtraction



HFe reconstruction

