First measurements of in-jet fragmentation and correlations of charmed mesons and baryons in pp collisions with ALICE

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on behalf of the **ALICE** collaboration

Università & INFN, Bari (IT), CERN

Hard Probes, 26-31 March 2023

Physics Motivations

Charm-hadron **production cross section** calculations in pQCD frameworks are based on:

$$\frac{d\sigma^{H_c}}{dp_T^{H_c}}(p_T;\mu_F,\mu_R) = PDF(x_1,\mu_F) \otimes PDF(x_2,\mu_F) \otimes \frac{d\sigma^{c}}{dp_T^{c}}(p_T;\mu_F,\mu_R) \otimes D_{c\to \mathrm{H}_c}(z = p_{\mathrm{H}_c}/p_c,\mu_F)$$

Talk: Annalena Kalteyer 28/03, 16:50

Talk: Stefano Politanò 29/03, 10:00

Parton distribution functions

Hard scattering cross section (pQCD)

Fragmentation function (hadronization)

About the **fragmentation**, more differential information with respect to single-particle studies is provided by:

→ Charm hadron-tagged jets:

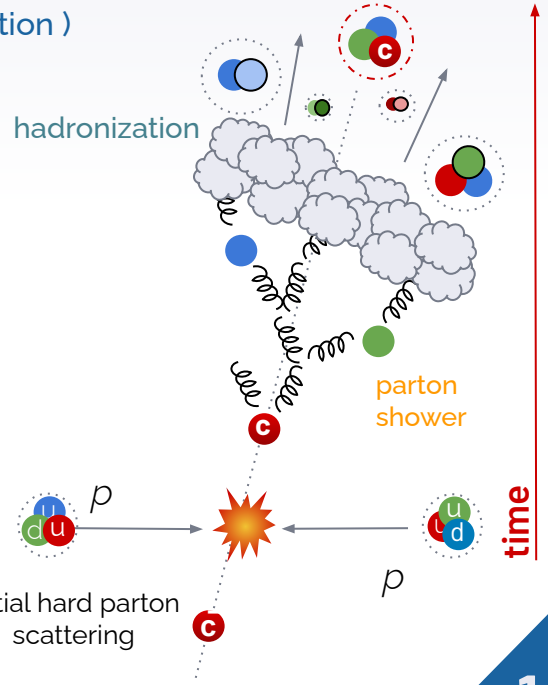
→ access to the original parton kinematics

→ constrain the **fragmentation functions**

→ Azimuthal correlations of charm hadrons with charged particles

→ description of the jet shape and its particle composition

→ sensitivity to production mechanisms



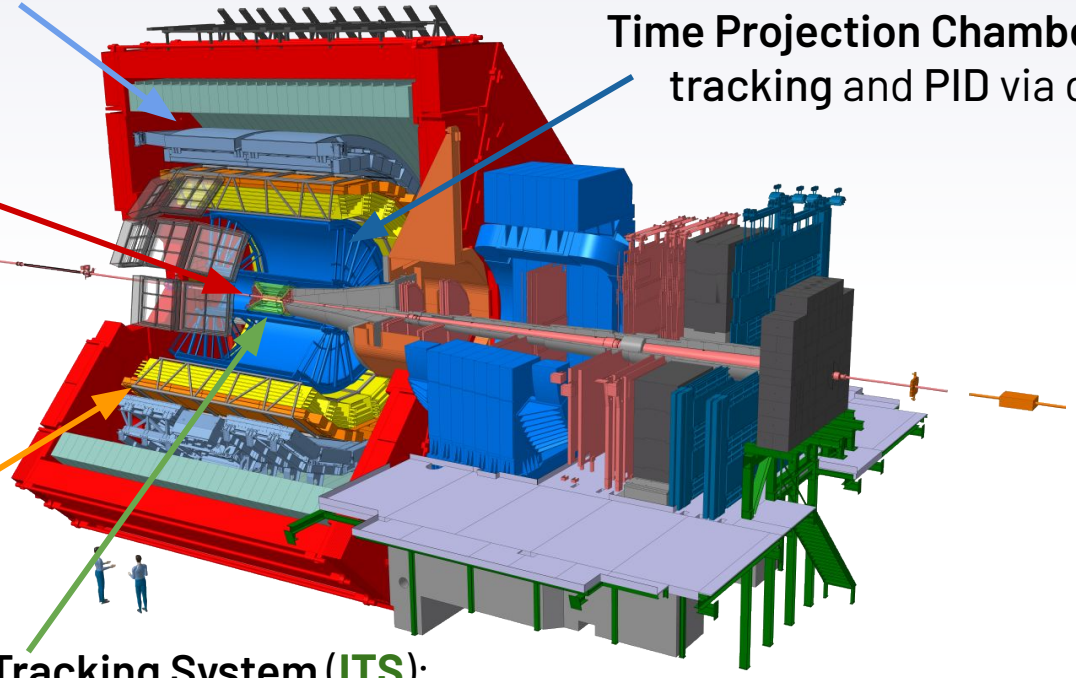
A Large Ion Collider Experiment

Electromagnetic Calorimeter (EMCAL):
e PID and **trigger**

V0:
trigger and **event selection**

Zero Degree Calorimeter (ZDC):
event selection

Time Of Flight (TOF):
PID via time of flight



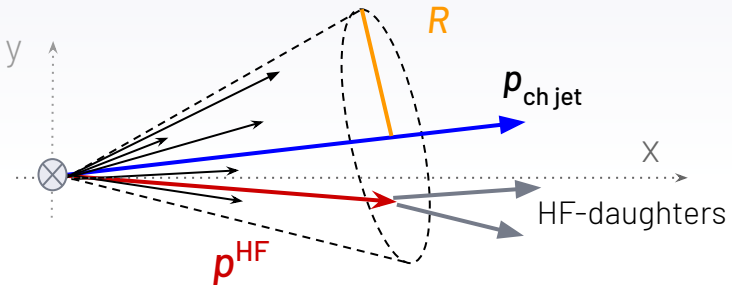
Time Projection Chamber (TPC):
tracking and PID via d*E*/d*x*

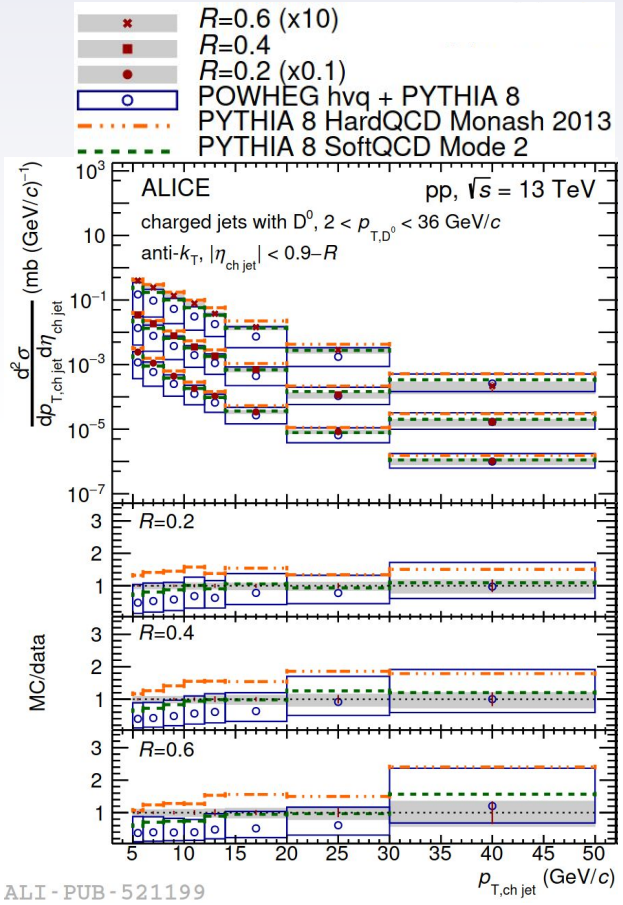
Inner Tracking System (ITS):
tracking, vertexing

D⁰-jets

→ p_T^{jet} is a proxy for the determining the 4-momenta of

the parton (charm) initiating the shower





ALI-PUB-521199

- POWHEG+PYTHIA8 is consistent with data within errors
- PYTHIA8 Soft QCD provides good description of the spectrum

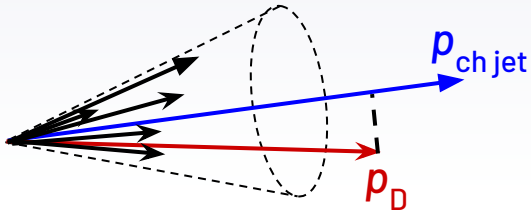
PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

arXiv:2204.10167

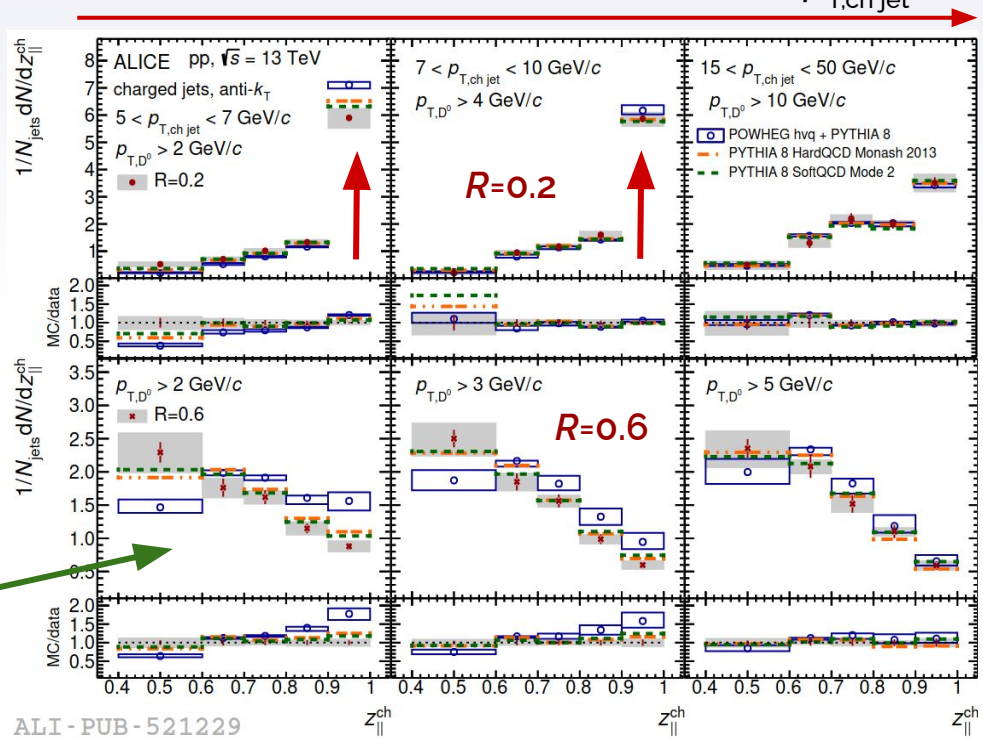
D⁰-jets: longitudinal momentum fraction

Longitudinal momentum fraction

$$z_{||} = \frac{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{HF}}}{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{ch jet}}}$$



- For 5 < pT, ch jet < 10 GeV/c and *R*=0.2 D^0 carries a large fraction of $\vec{p}_{\text{ch jet}}$
- Hint of **softer fragmentation** compared to model predictions



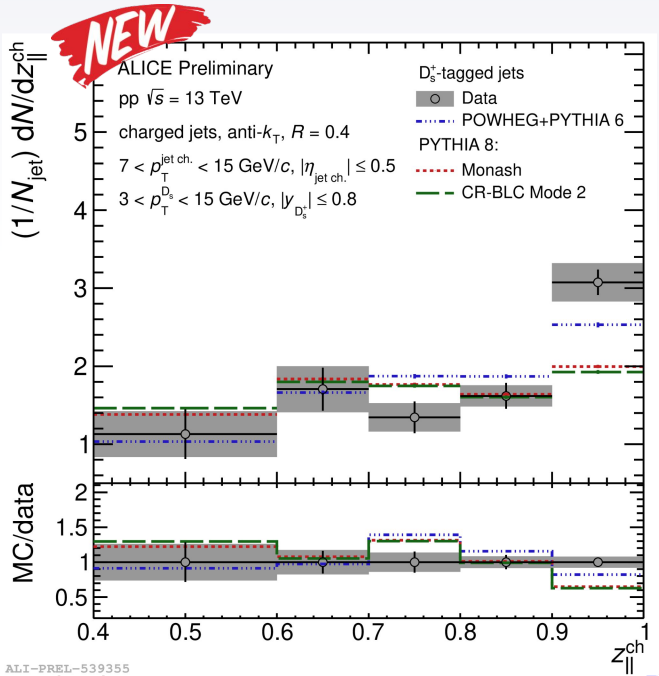
arXiv:2204.10167

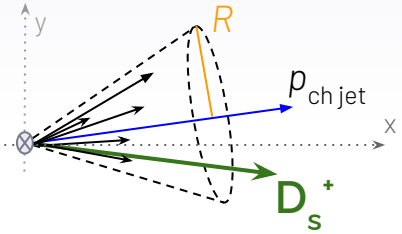
PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

First measurement of D_s^+-jets

Highlight possible differences in the charm fragmentation due to the strange-quark content of the tagged meson

➢ Good compatibility between models and data



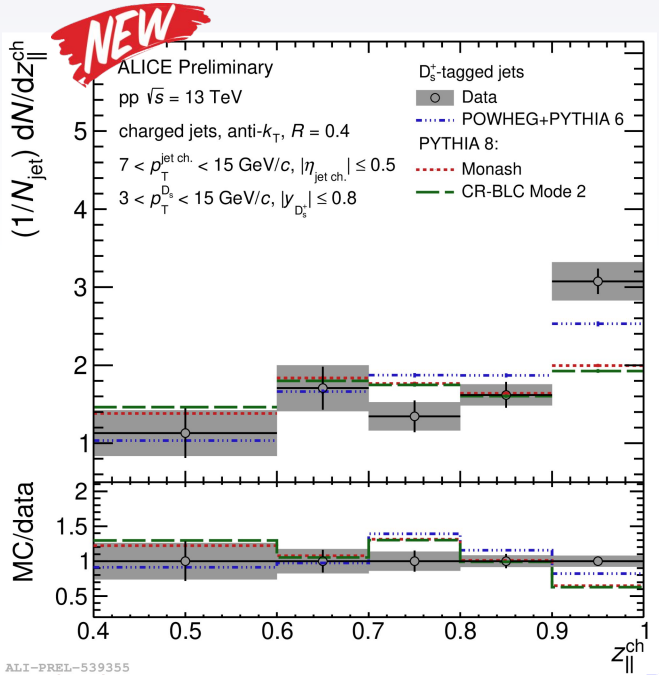


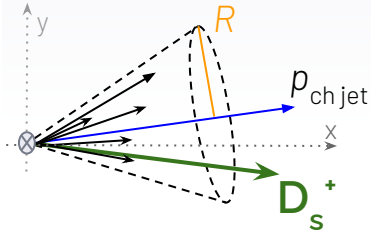
PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

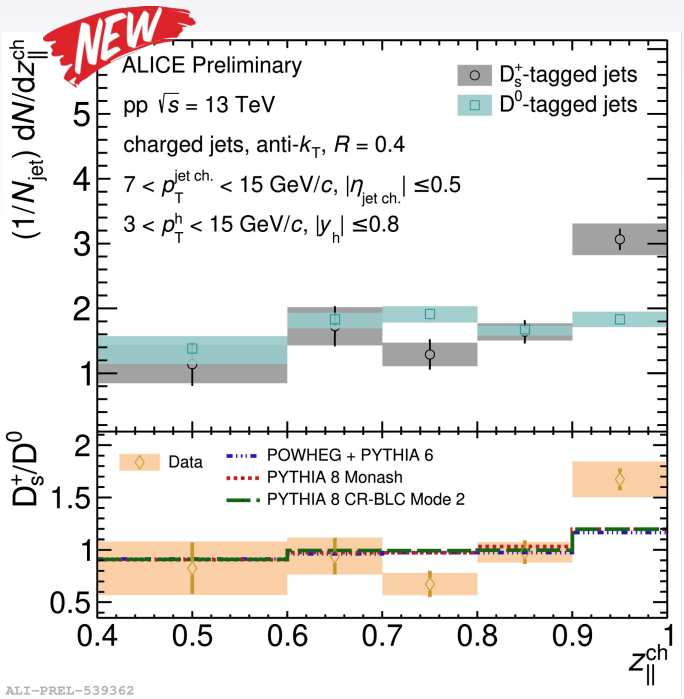
First measurement of D_s^+-jets

Highlight possible differences in the charm fragmentation due to the strange-quark content of the tagged meson

- Good compatibility between models and data
- hint of harder fragmentation with respect to D^0





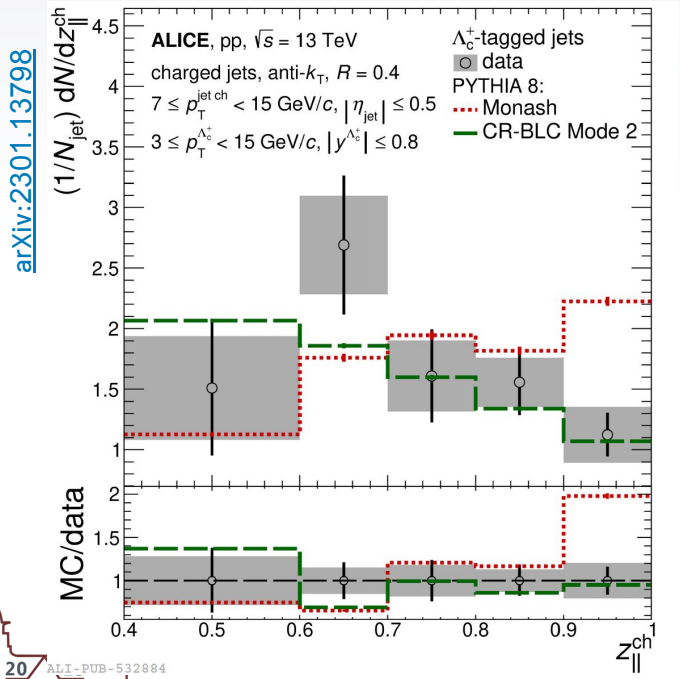


PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

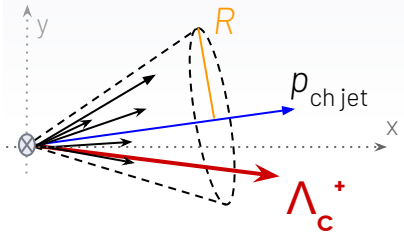
Λ_c^+-jets

→ Probe the fragmentation of charm quarks into charm baryons

- slightly harder fragmentation in PYTHIA8 Monash
- good agreement with PYTHIA8 CR-BLC, mode 2



arXiv:2301.13798



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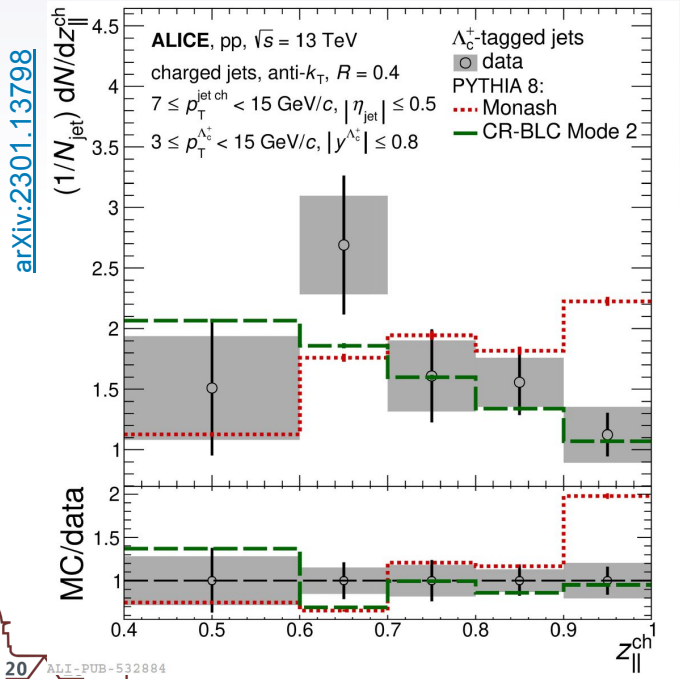
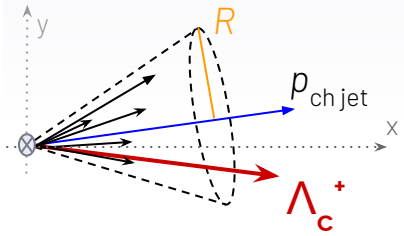
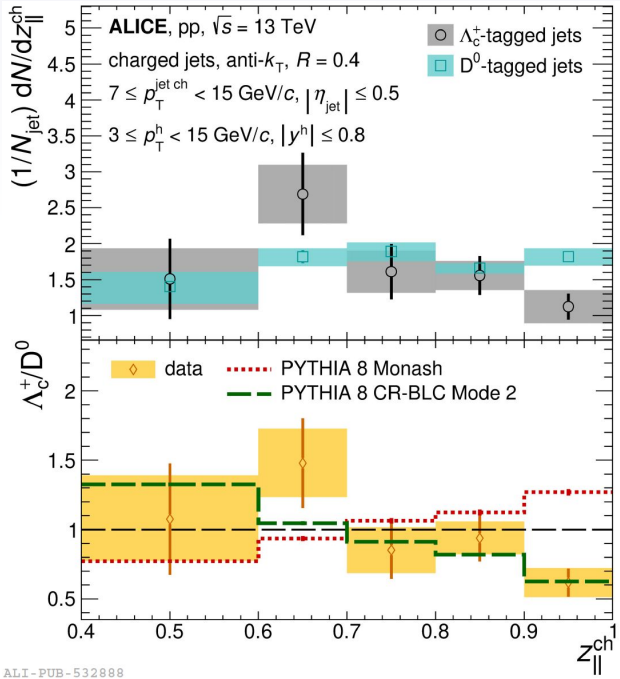




- hint of softer fragmentation into Λ_c^+ than D^0
- Correctly reproduced by PYTHIA8, CR-BLC mode 2

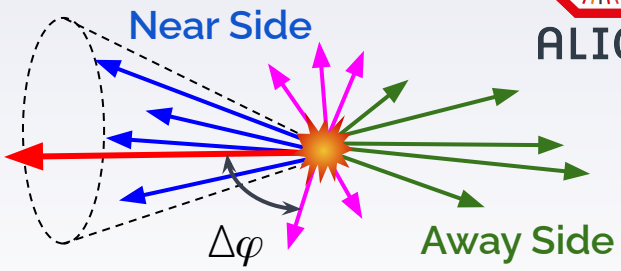


PYTHIA: JHEP 1508 (2015) 003

ALI-PUB-532888

Azimuthal correlations

Final state particles are studied by means of their angular distribution with respect to the direction of the tagged HF particle.



At LO approximation:

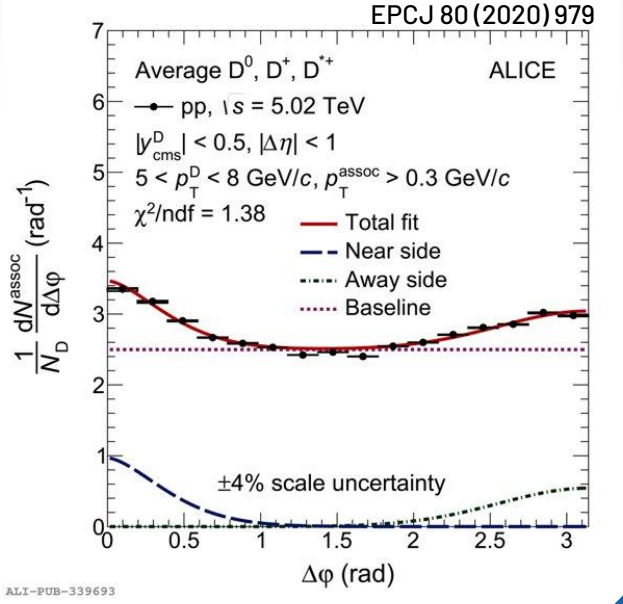
- Near Side (NS): fragmentation of the tagged charm quark;
- Away Side (AS): fragmentation of the other charm quark;
- Transverse Region: information on the underlying event

NLO production mechanisms, relevant at the LHC energies, can alter this topology

Complementary description to HF-tagged jets granting access to:

→ jet shape (angular opening of the jet-cone)

→ jet particle composition (multiplicity and p_T distribution)



First measurement of Λ_c^+-h correlations

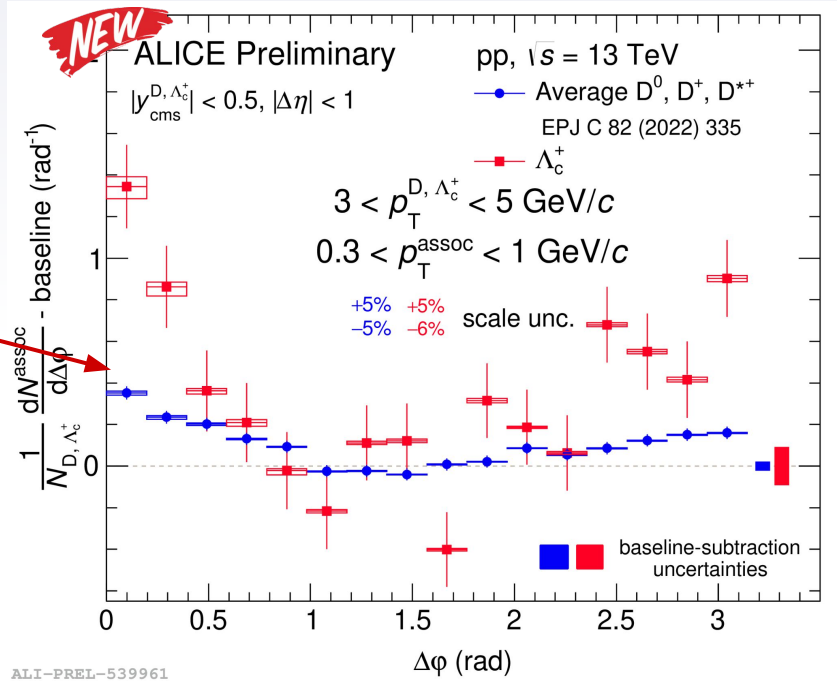
D mesons - h

Λ_c^+ - h

Eur. Phys. J. C 82, 335 (2022)

From the comparison:

→ discrepancy in the low-$p_T(\Lambda_c^+)$ region



* Soft-π contribution removed:

$\Sigma_c^{0,++}(2455) \to \Lambda_c^+ \pi^{\mp}$

$D^{*+} \to D^0 \left(\to K^- \pi^+\right) \pi^+$

First measurement of Λ_c^+-h correlations

D mesons - h

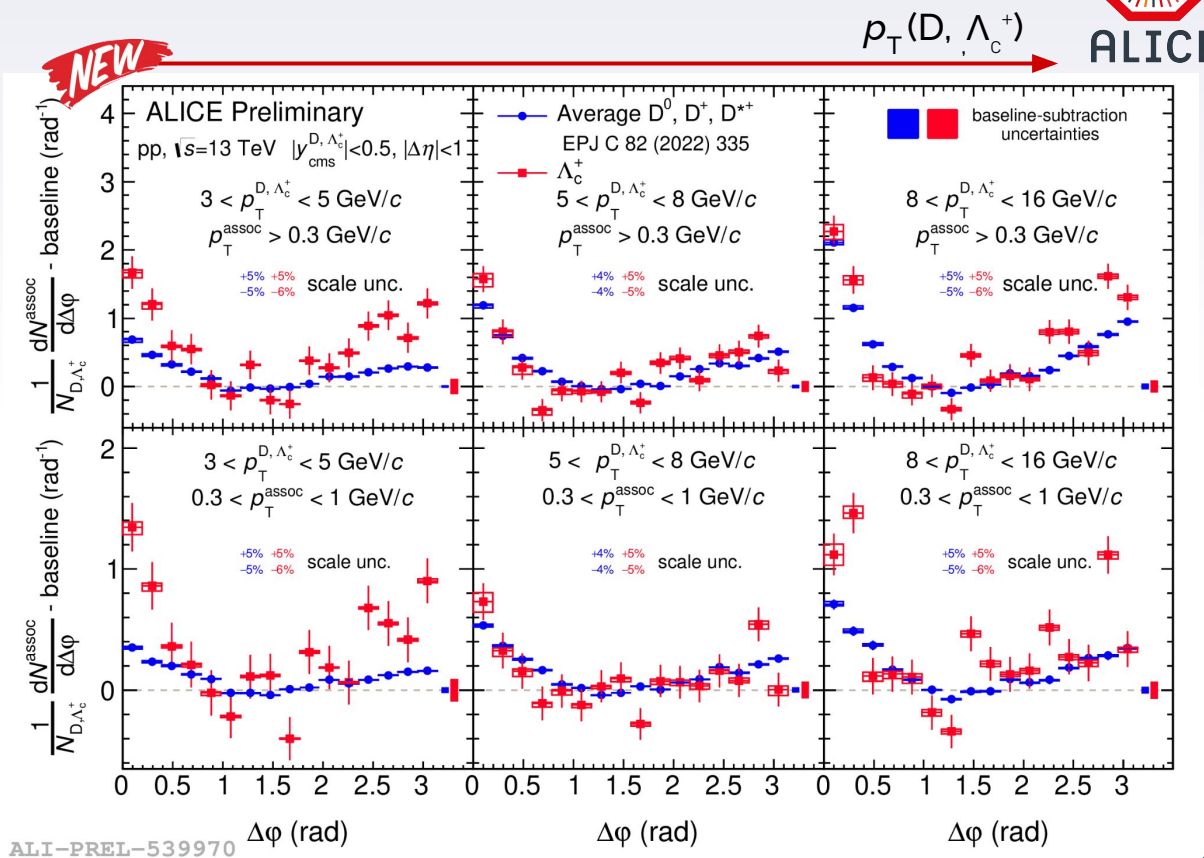
Λ_c^+ - h

Eur. Phys. J. C 82, 335 (2022)

From the comparison:

→ discrepancy in the low-$p_T(\Lambda_c^+)$ region

→ good agreement between the $\Delta\varphi$ distribution in other kinematic ranges



* Soft-π contribution removed:

$\Sigma_c^{0,++}(2455) \to \Lambda_c^+ \pi^{\mp}$

$D^{*+} \to D^0 (\to K^- \pi^+) \pi^+$

Near-Side characterisation

In general, increasing p_T^{HF}:

→ **More energetic parton**

→ **increasing yields**

→ **Larger heavy-quark boost**

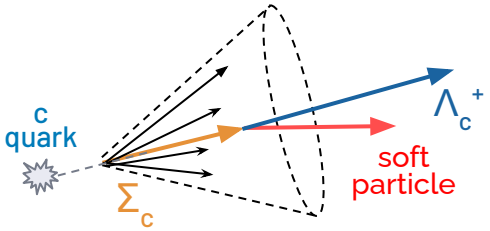
→ more collimated shower

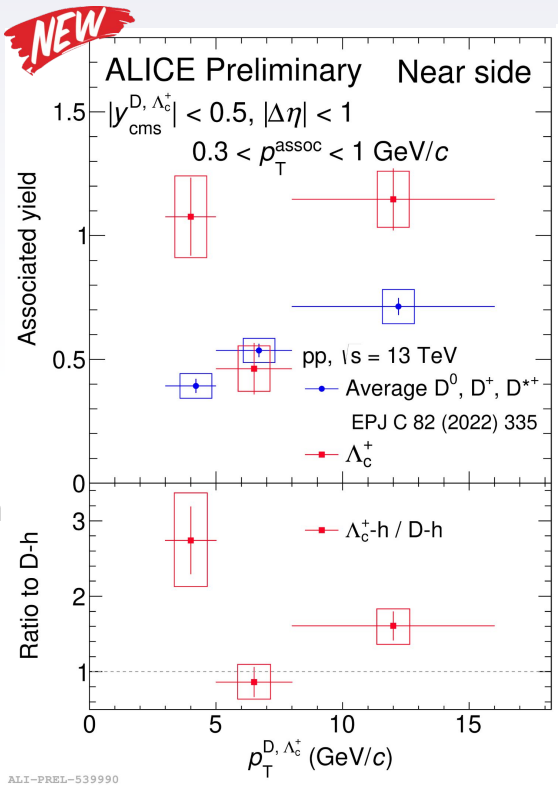
→ **sharpening of the peak**

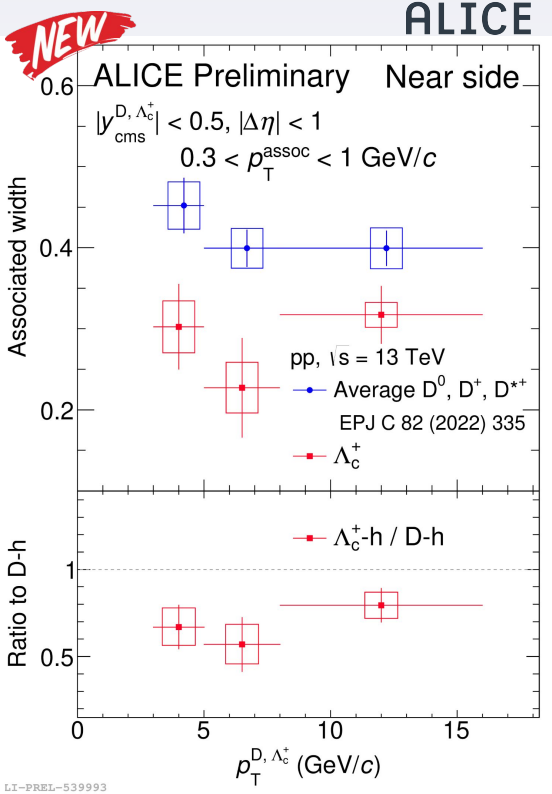
Higher NS yields in Λ_c^+-h than D-h **at low-p_T**:

? **different energy** of the **charm quark** as a consequence of a softer Λ_c^+ fragmentation

? **decay of higher mass charm states**







Comparison with model predictions

Λ_c^+-h:

- ➢ yields:
  - → tensions with PYTHIA8 predictions
    - → low-$p_T(\Lambda_c^+)$ not correctly reproduced
- ➢ widths:
  - → generally overestimated, though with large uncertainties

D-h correlation:

- good description from PYTHIA8 and POWHEG+PYTHIA8

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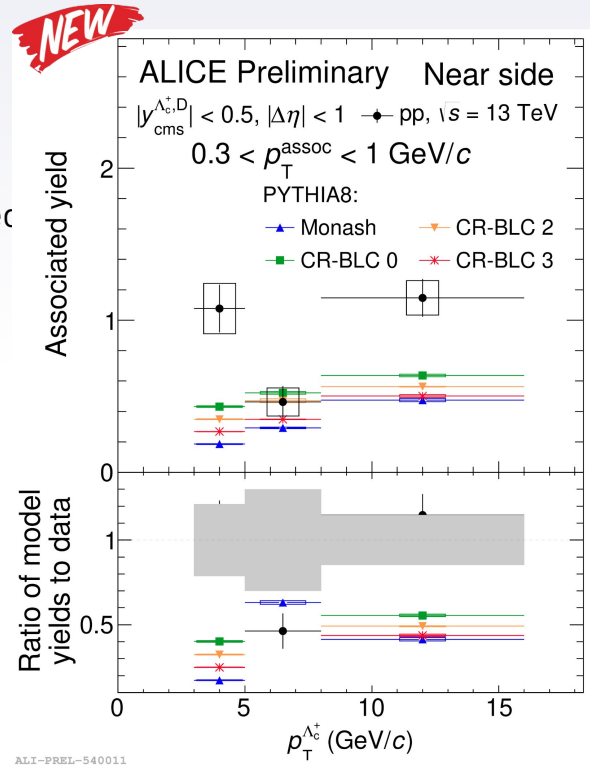
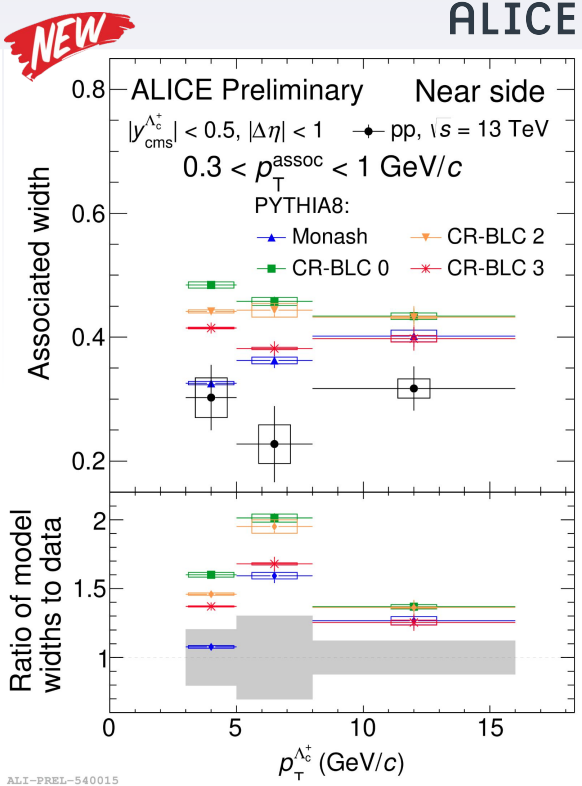


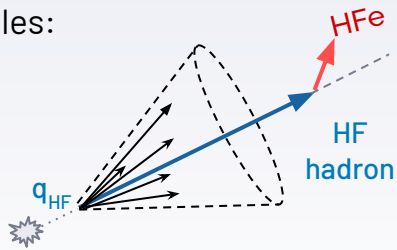


PYTHIA: JHEP 1508 (2015) 003 HERWIG: Eur.Phys.J C76 (2016) 196
POWHEG: JHEP 06 (2010) 043

HFe-h correlations

Correlations between HF semileptonic decay electrons (**HFe**) and charged particles:

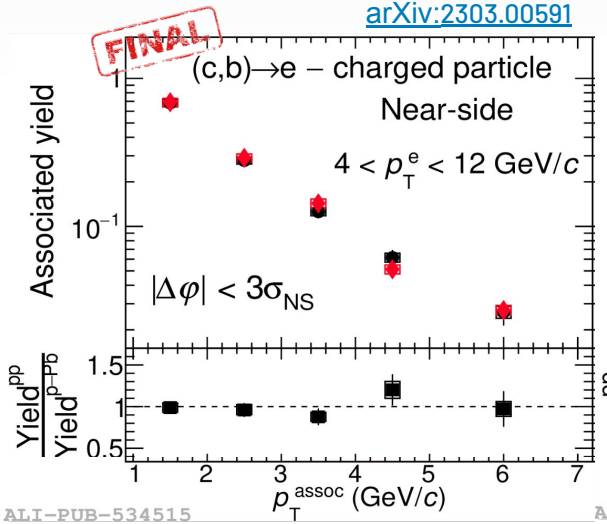
- ✓ large sample of correlation pairs → more differential at high-p_T
- ✓ address charm and beauty fragmentation
- ~ looser connection to HF quark kinematics

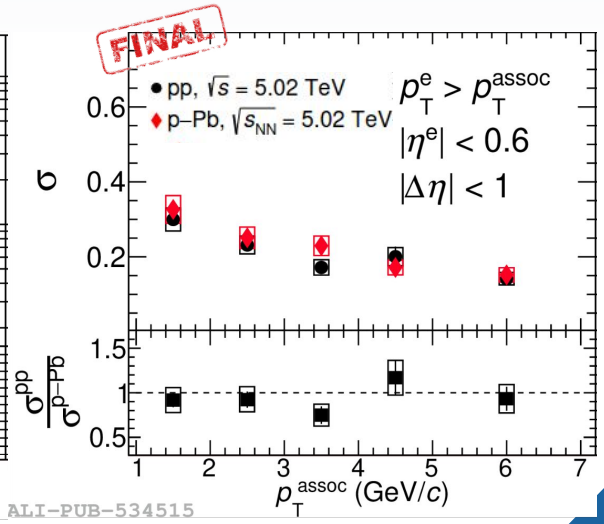


Consistent yields and widths between **pp** and **p–Pb** measurements

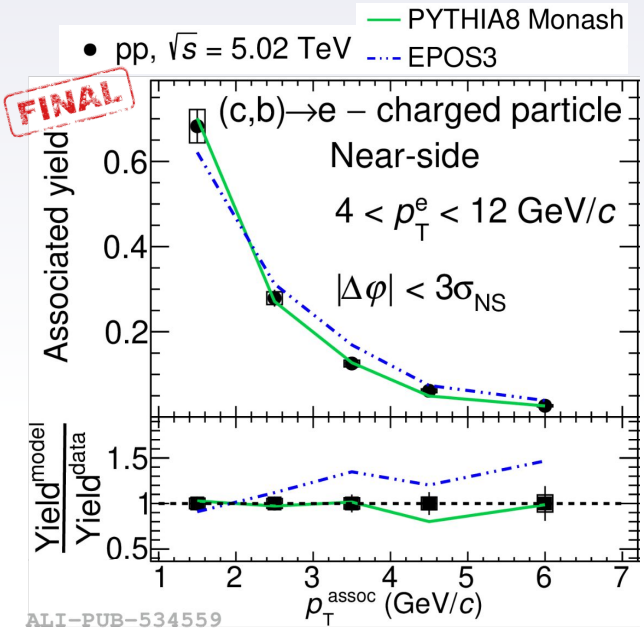
→ no sizeable impact of **CNM** effects

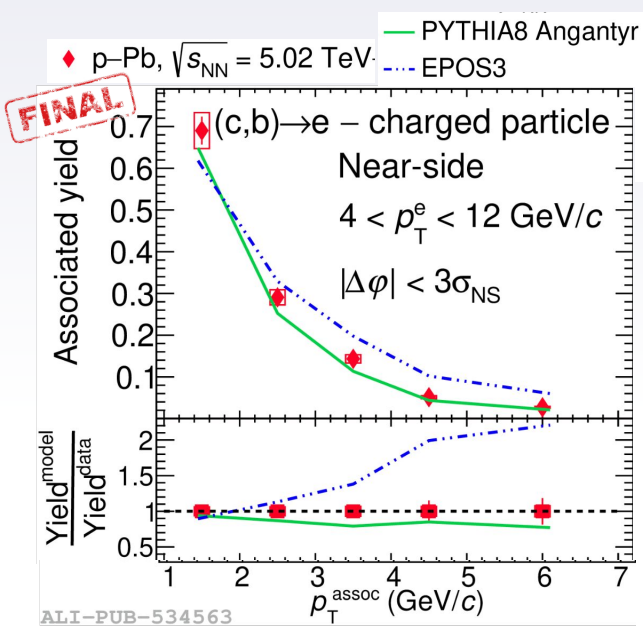
arXiv:2303.00591





HFe-h: comparison with model predictions





$|\eta^e| < 0.6$, $|\Delta\eta| < 1$
$p_T^e > p_T^{assoc}$

arXiv:2303.00591

- EPOS3: small discrepancies in the highest p_T^{assoc} interval.
- PYTHIA8 Monash: good agreement

- EPOS3 slightly overpredicts p–Pb measurements.
- PYTHIA8/Angantyr consistent with data, slightly underestimating the yields

EPOS 3: Phys.Rev.C 82(2010)044904
PYTHIA: JHEP 1508 (2015) 003

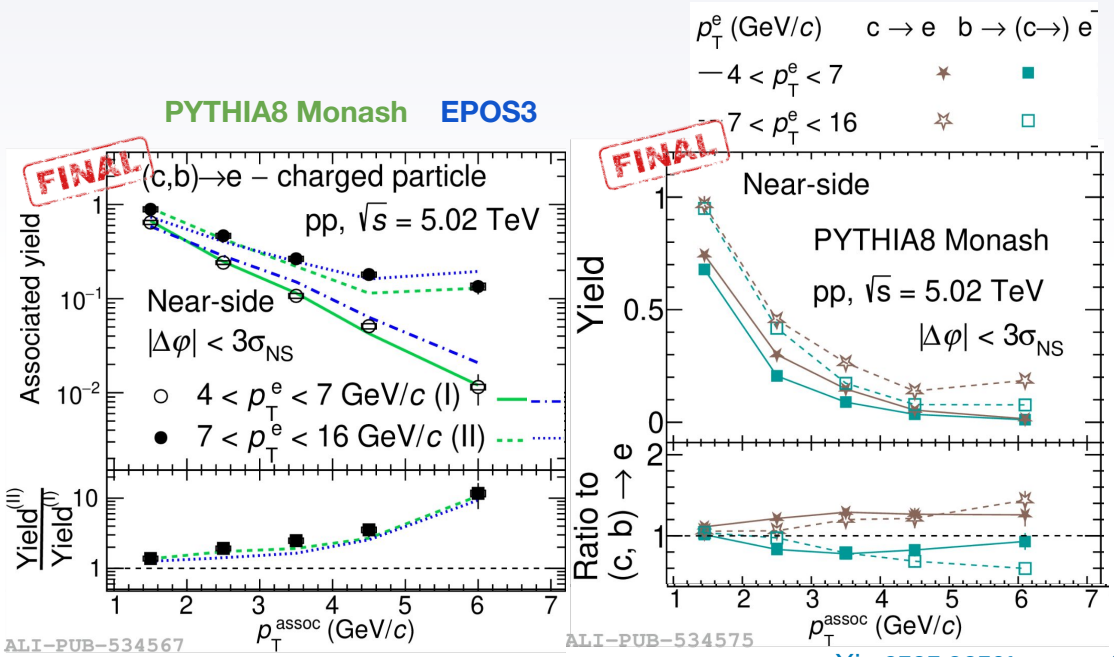
Angantyr: J. High Energ. Phys. (2018)

Beauty contribution to HFe correlations

Strong p_T **dependence** is observed in the fraction b→e/(b+c) → e ([Phys. Lett. B 738(2014) 97](#))
→ for p_T**(HFe)> 7 GeV**, about 60% of e comes from beauty
→ insight into beauty fragmentation

Increase in NS yield at large p_T^{assoc} for high-p_T e
→ higher energy of the heavy quark

Confirmed by PYTHIA8 simulations:
➢ lower yields from b→e than c→e
→ harder fragmentation for b quarks than c



[arXiv:2303.00591](#)

EPOS 3: Phys.Rev.C 82(2010)044904
PYTHIA: JHEP 1508 (2015) 003

Conclusions

The in-jet production and fragmentation of D mesons was investigated:

- ➢ their production, fragmentation and hadronisation are correctly reproduced by models
  - → good theoretical baseline for studies in **p–Pb** and **Pb–Pb** collisions.

Λ_c^+ measurements have shown:

- ➢ softer fragmentation function with respect to D^0 mesons
  - → Soft QCD, CR-BLC correctly reproduce the in-jet production ratio Λ_c^+/D^0
- ➢ discrepancies in Λ_c^+–h correlations can help constraining Monte Carlo predictions.

HFe–h correlations shed further light on HF-quark showers:

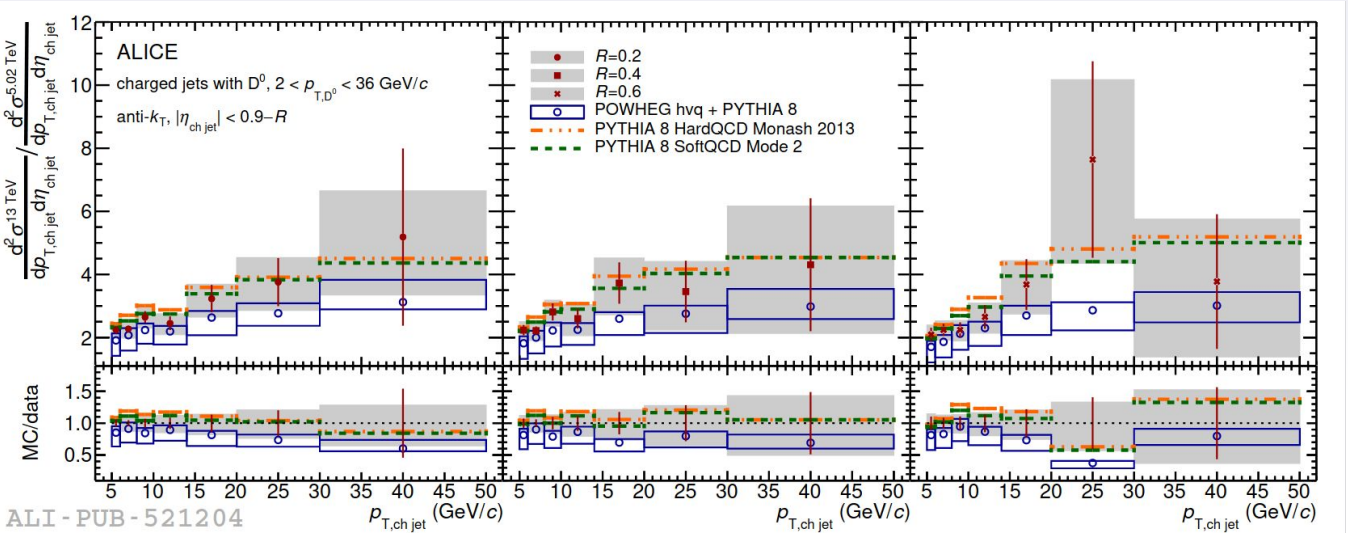
- ➢ addressing charm and beauty effects constraining HFe p_T
- ➢ no sizeable impact of **CNM** effects in p–Pb collisions was observed with current precision.

Thanks for your attention!

Additional Material

D⁰ - jets

arXiv:2204.10167



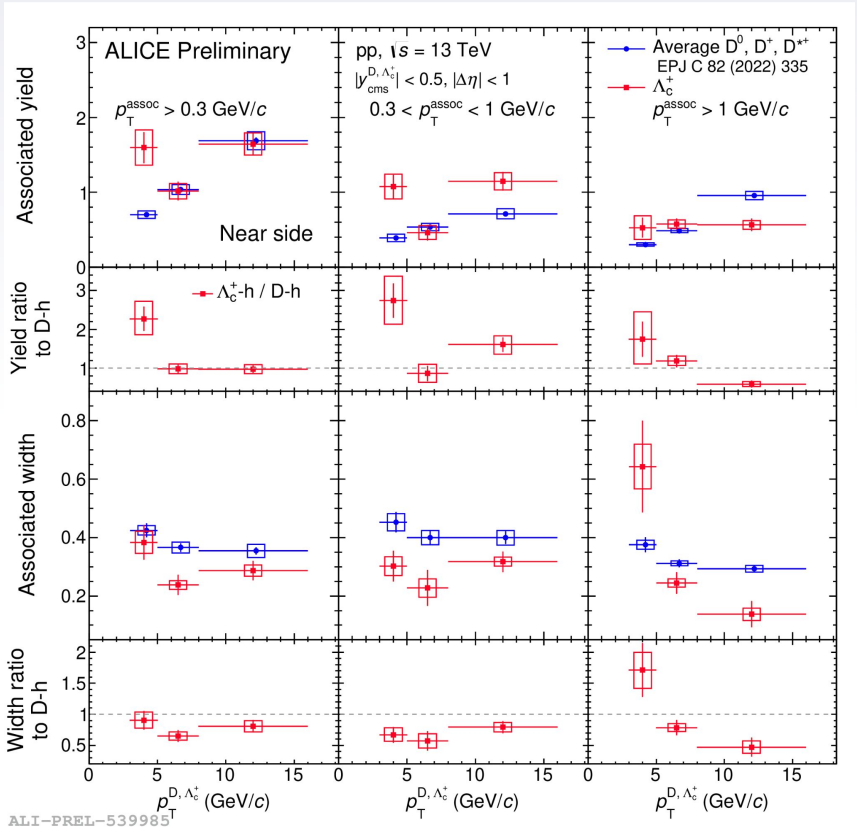
Hardening of the $p_{T,ch\,jet}$ spectra with increasing centre-of-mass energy.

→ PYTHIA SoftQCD correctly reproduce the data

→ POWHEG + PYTHIA 8 simulation tends to underestimate the measured cross section ratios

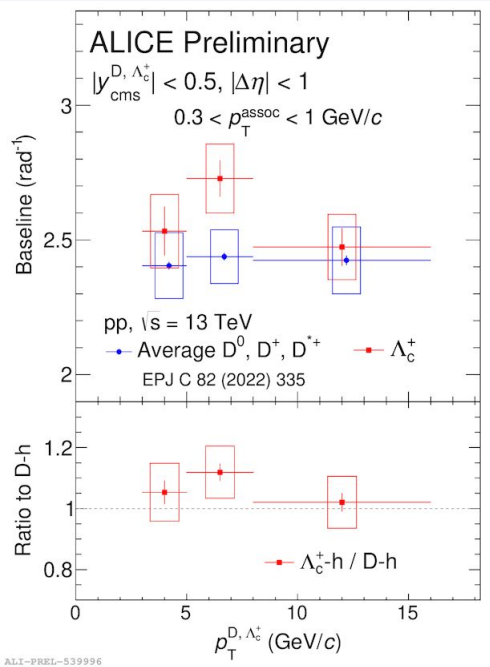
PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

Λ_c^+-h correlations: Near-side and Baseline

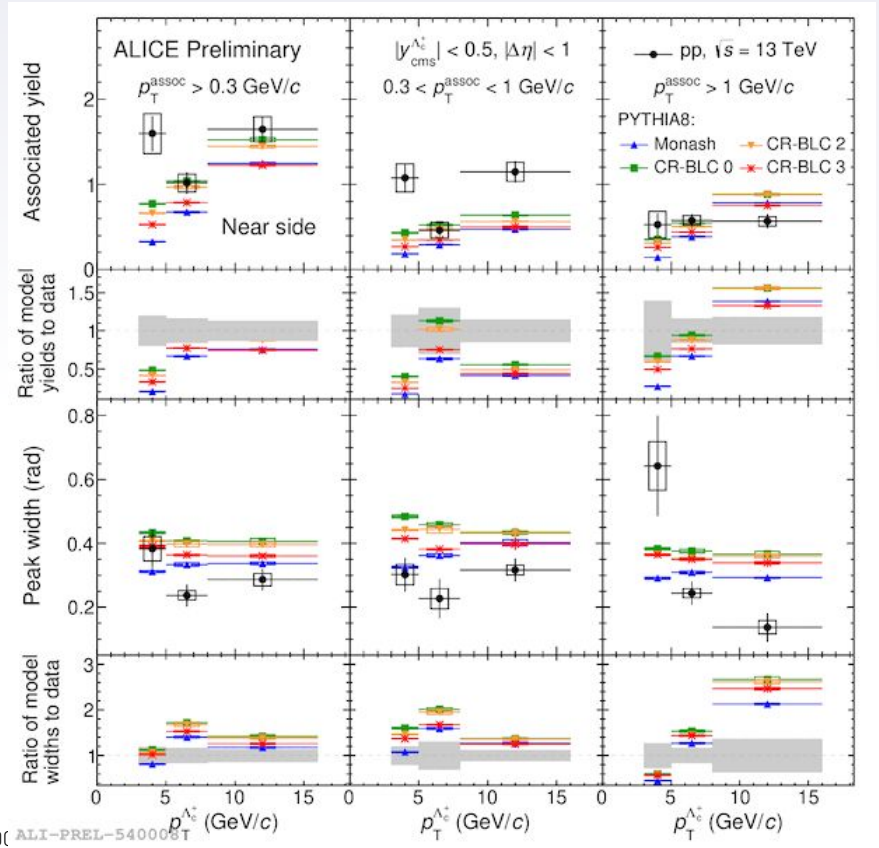


PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

Baseline



Λ_c^+-h correlations: Near-side



PYTHIA: JHEP 1508 (2015) 0(
POWHEG: JHEP 06 (2010) 043

D-h: Near-side comparisons with MC models predictions

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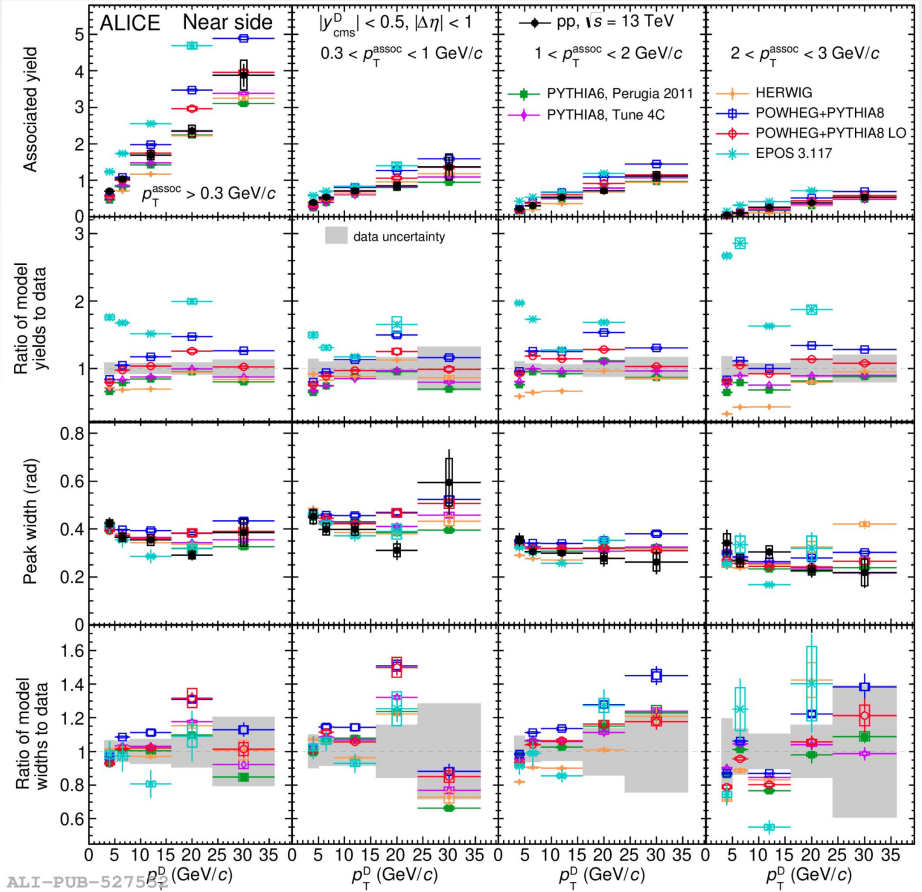
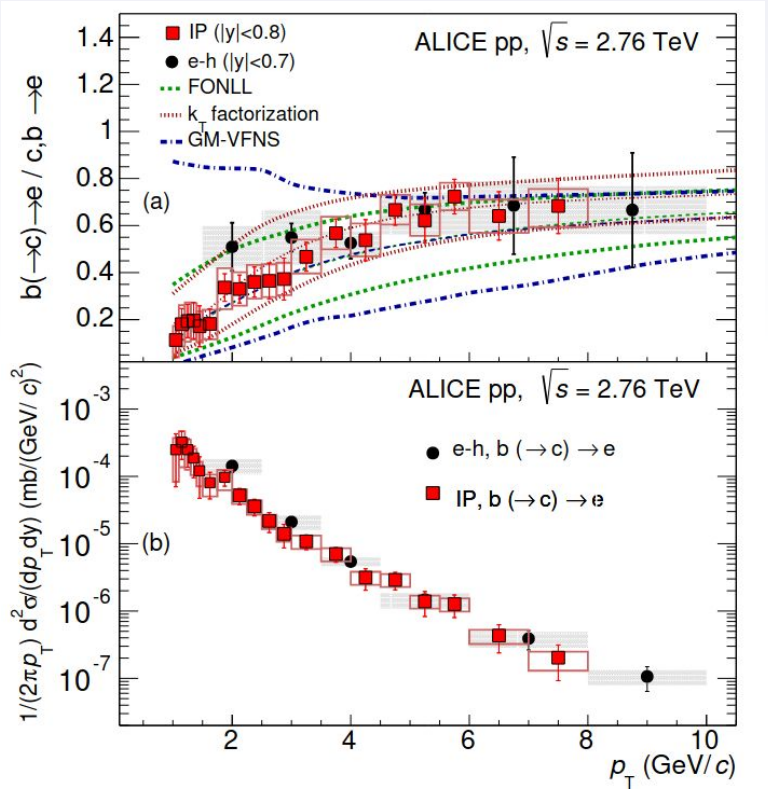


PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043
EPOS 3: Phys.Rev.C 82(2010)044904
HERWIG: Eur.Phys.J C76 (2016) 196

HF-e: beauty electrons

arXiv:2204.10167



PYTHIA: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043