Study of charm fragmentation with charm meson and baryon angular correlation measurements with ALICE

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PRAGUE

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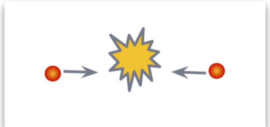
UNIVERSITÀ DEGLI STUDI DI TRIESTE

ALICE

Heavy-flavour hadron production

Charm quark mass ~1.5 GeV/c^2
→ produced in **hard parton-parton scattering** processes in hadronic collisions

- pQCD test
- Hadronisation
- Reference for Pb-Pb



Heavy-flavour hadron production cross section calculated by **factorisation approach**:

$$\frac{d\sigma^{\mathrm{H_c}}}{dp_{\mathrm{T}}}(p_{\mathrm{T}};\mu_{\mathrm{F}},\mu_{\mathrm{R}}) = \mathrm{PDF}(x_1,\mu_{\mathrm{F}}) \otimes \mathrm{PDF}(x_2,\mu_{\mathrm{F}}) \otimes \frac{d\sigma^{\mathrm{c}}}{dp_{\mathrm{T}}^{\mathrm{c}}}(p_{\mathrm{T}};\mu_{\mathrm{F}},\mu_{\mathrm{R}}) \otimes D_{\mathrm{c}\to\mathrm{H_c}}(z = p_{\mathrm{H_c}}/p_{\mathrm{c}},\mu_{\mathrm{F}})$$

Parton Distribution Functions

Hard scattering cross section (pQCD)

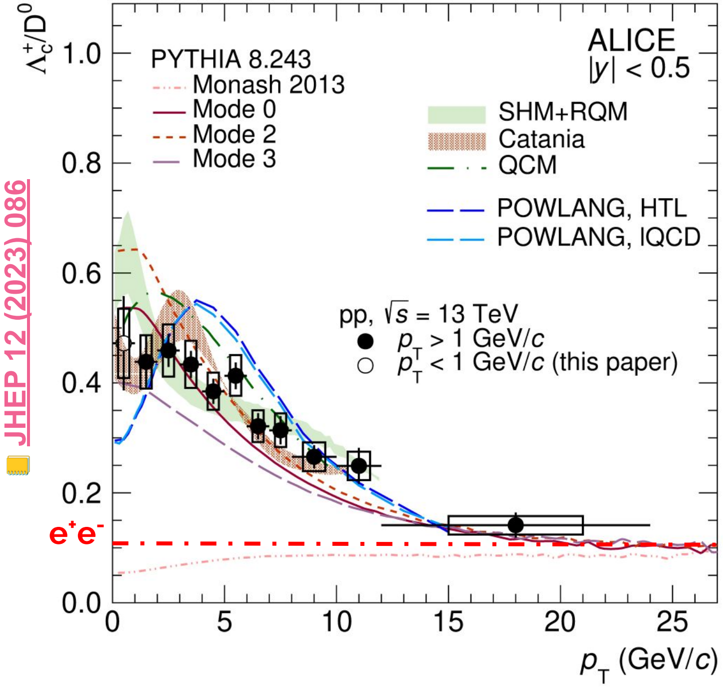
Fragmentation functions (hadronisation)

Assumed **universal** across collision systems (ee,..., AA)

Charm baryon-to-meson enhancement in pp collisions

p_T-dependent enhancement of **Λ_c^+/D^0** ratio in **pp** w.r.t. **e^+e^-**

JHEP 12 (2023) 086



LEP average: (0.113 ± 0.013 ± 0.006) EPJC 75 (2015) 19

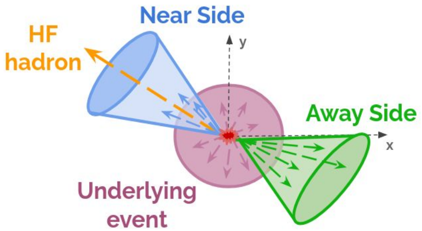
- **PYTHIA 8 Monash** (EPJC (2014) 3024), with FF tuned on e^+e^-, significantly **underestimates** the data
- Different **hadronisation mechanisms proposed**
  - PYTHIA 8 CR-BLC (JHEP 1508 (2015) 003)
  - CATANIA (arXiv:2012.12001) and QCM (EPJC (2018) 78:344)
  - SHM + RQM (PLB 795 (2019) 117-121))
  - POWLANG (arXiv:2306.02152)

Need to better understand HF hadronisation process

- Baryon-to-meson measurement focuses solely on the **charm hadron production**
- **Further studies** can shed light on **charm-quark hadronisation** by considering also the other particles produced in association to the charm hadron

Further characterisation of HF fragmentation

- Additional information from the study of:
  - **Azimuthal correlations** of **HF hadrons** with **charged particles**
    - ➢ multi-differential investigation of fragmentation processes
    - ➢ characterisation of jet shape and its particle composition



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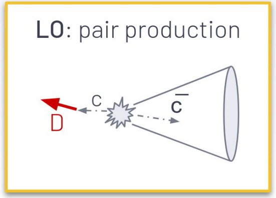
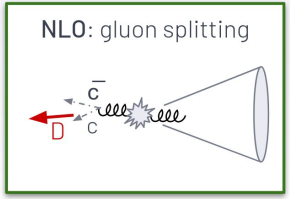
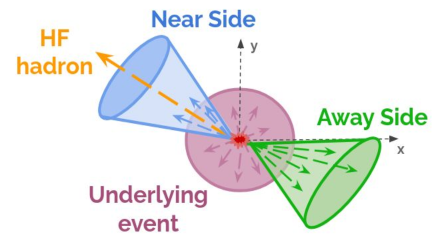
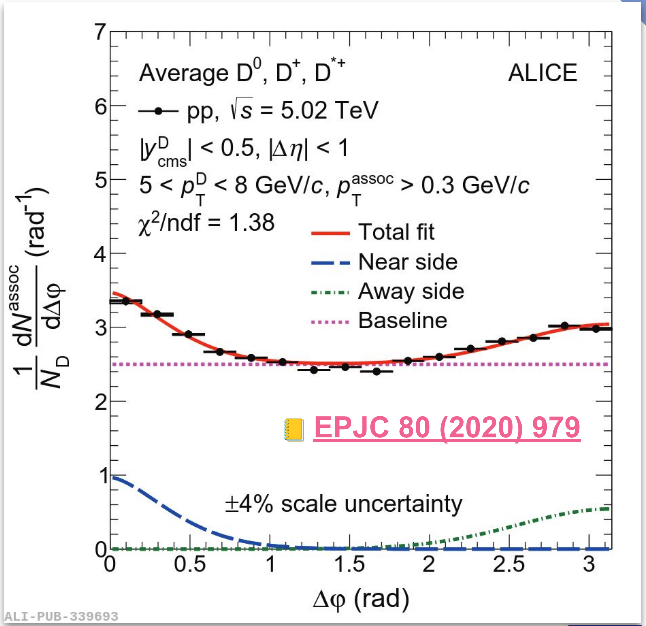




  - At **LO** approximation
    - **Near Side (NS)**: fragmentation of the tagged charm quark
    - **Away Side (AS)**: fragmentation of the recoil charm quark
    - **Baseline**: parametrizes the underlying event activity, assumed to be isotropic
  - **NLO** production mechanisms, relevant at the LHC energies, can alter this topology



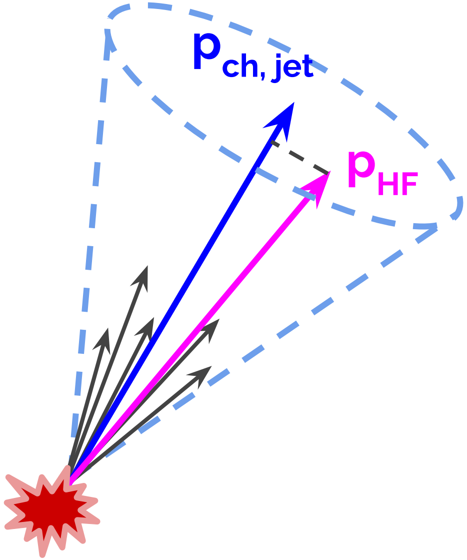


Further characterisation of HF fragmentation

- Additional information from the study of:
  - **Azimuthal correlations** of **HF hadrons** with **charged particles**
    - ➢ multi-differential investigation of fragmentation processes
    - ➢ characterisation of jet shape and its particle composition
  - **HF tagged jets**
    - ➢ access to the original parton kinematics
    - ➢ constrain the HQ fragmentation function

Longitudinal momentum fraction

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

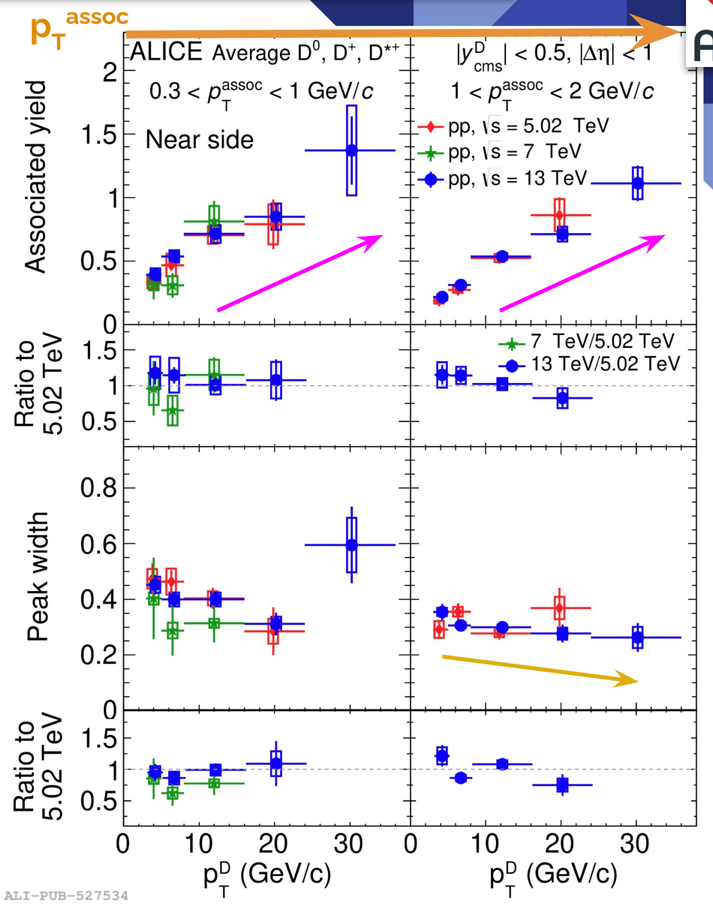


D-h near-side properties

- **Near-Side**: description of charm-jet constituents, their momentum and angular displacement w.r.t. the D meson trigger

- With **increasing p_T^D**:
  - More energetic charm quarks
    - ➢ More phase space to produce other fragments → **Increasing yields**
  - Larger heavy quark boost
    - ➢ More collimated shower → **Sharpening of the peak**

- No centre-of-mass energy dependence



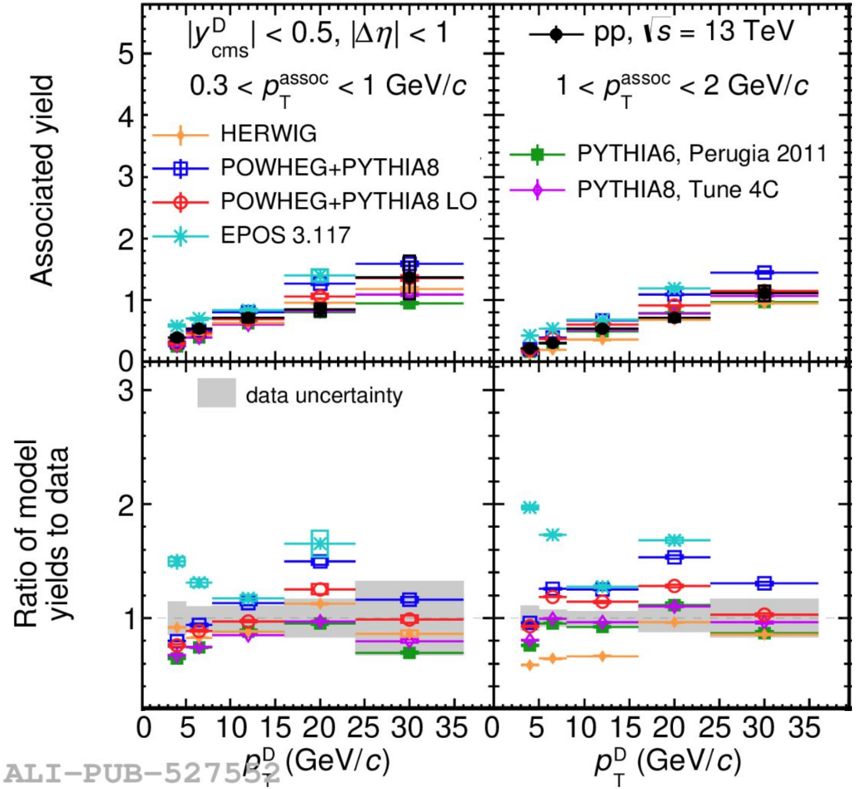
EPJC 82 (2022) 335

D-h comparison to model predictions

- Validation of parton-shower models and Monte Carlo generators

PYTHIA: Eur. Phys. J. C 74, 3024 (2014)
POWHEG: JHEP 06 (2010) 043
EPOS 3: Phys.Rev.C 82(2010)044904
HERWIG: Eur.Phys.J C76 (2016) 196

EPJC 82 (2022) 335

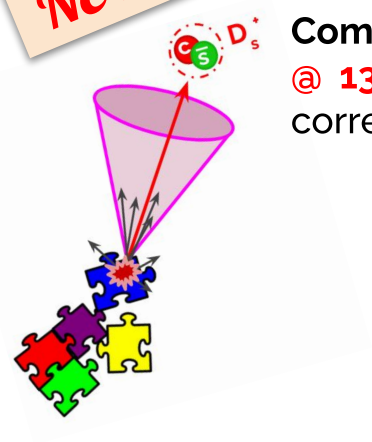


- **NS yield**:
  - Larger values at high-p_{T}^{D} by **POWHEG+PYTHIA 8 NLO** than **PYTHIA 8**
  - About 10% larger yields for **POWHEG+PYTHIA 8 NLO** w.r.t. **POWHEG+PYTHIA 8 LO**
  - **HERWIG** tends to underestimate the data at low p_{T}^{D} and at high p_{T}^{assoc}
  - **EPOS** overestimates the results over the whole p_{T} range

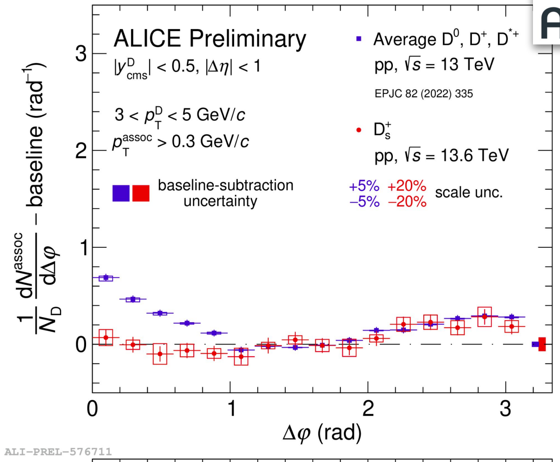
PYTHIA 8 and **POWHEG+PYTHIA 8 LO** provide the best description of the measurement

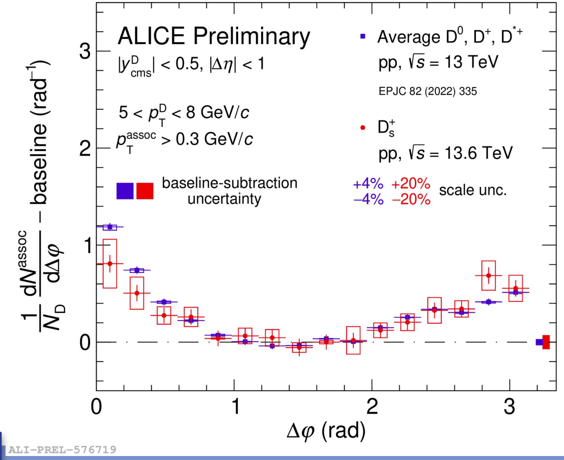
D_s^+-h vs D-h correlation distribution

NEW!



Comparison of the **Δφ shape** between the **D_s^+-h (pp @ 13.6 TeV)** and **non-strange D-h (pp @ 13 TeV)** correlation measurements:

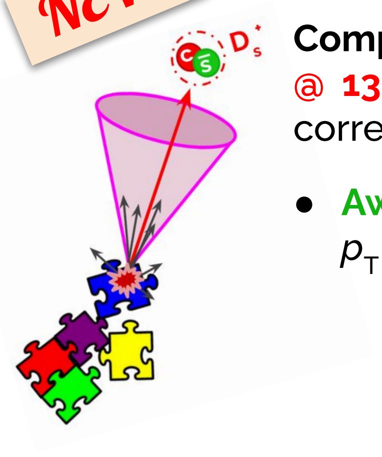




p_T^D

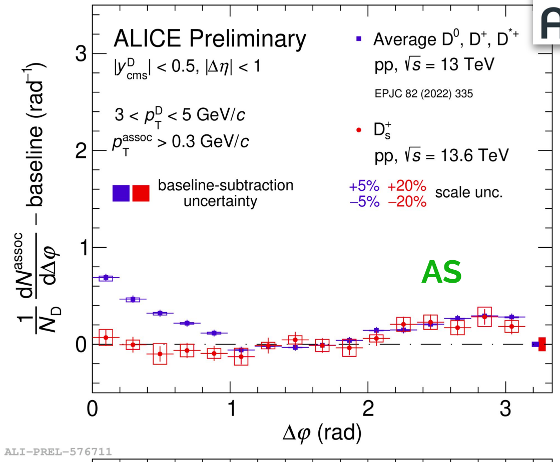
D_s^+-h vs D-h correlation distribution

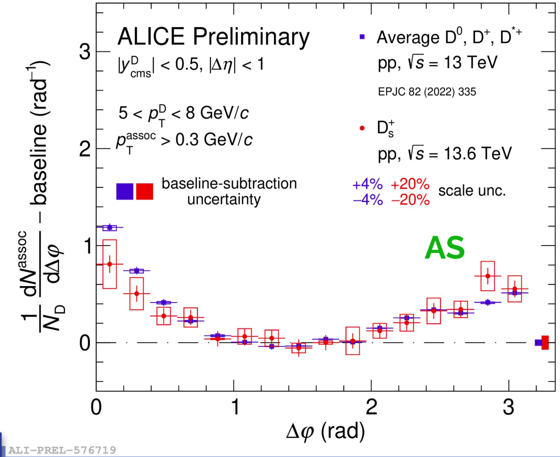
NEW!



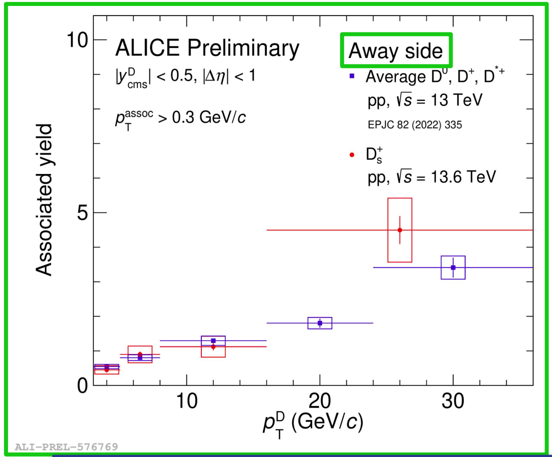
Comparison of the **Δφ shape** between the **D_s^+-h (pp @ 13.6 TeV)** and **non-strange D-h (pp @ 13 TeV)** correlation measurements:

- **Away Side (AS)**: **good agreement** over the whole p_T range



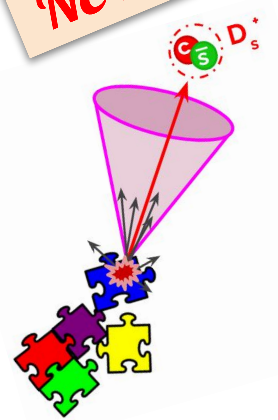


p_T^D



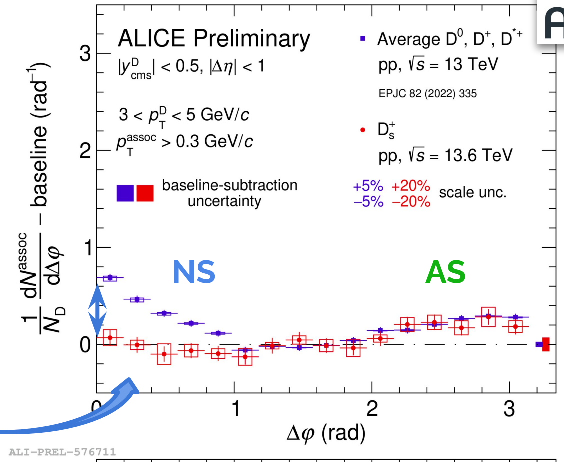
D_s^+-h vs D-h correlation distribution

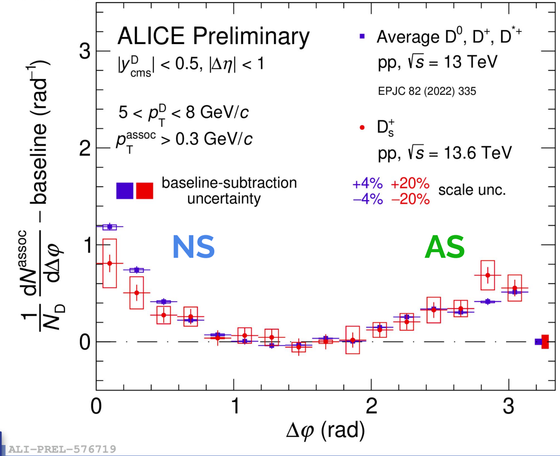
NEW!



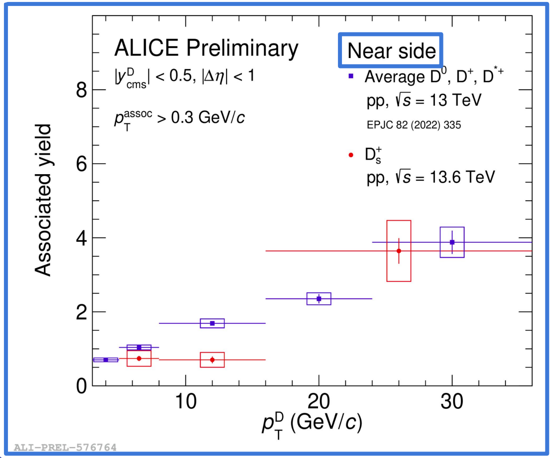
Comparison of the **Δφ shape** between the **D_s^+-h (pp @ 13.6 TeV)** and **non-strange D-h (pp @ 13 TeV)** correlation measurements:

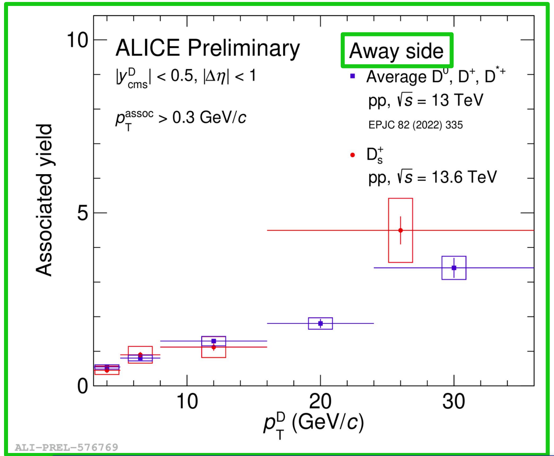
- **Away Side (AS)**: **good agreement** over the whole p_T range
- **Near Side (NS)**: **significant deviation** for low-p_T(D) from non-strange D meson measurement





p_T^D

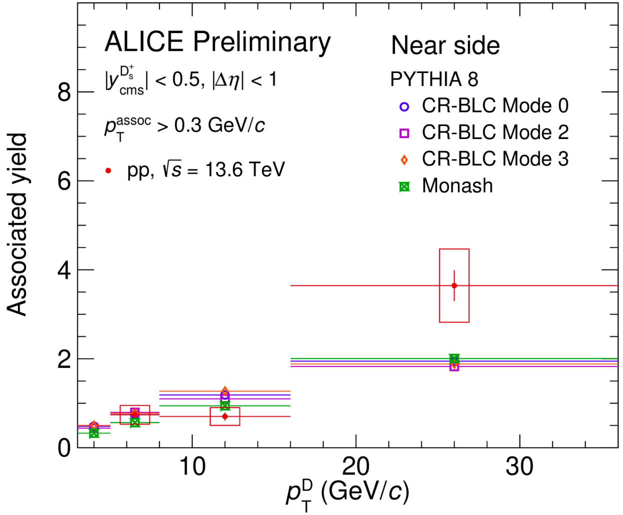


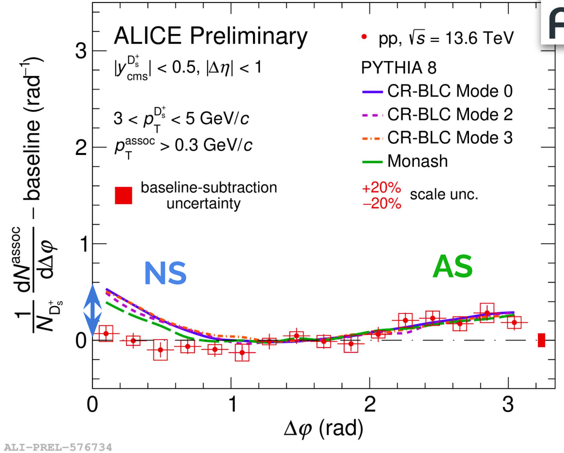


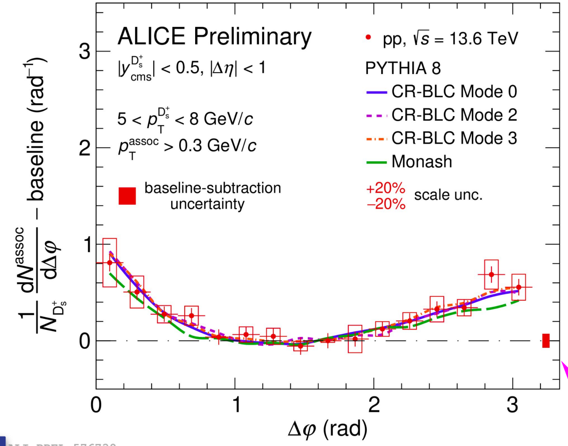
D_s^+-h correlation comparison with models

NEW!

- **PYTHIA 8 CR-BLC Mode 0**, **Mode 2**, **Mode 3** and **Monash** provide a reasonably good description of the **measured shape of the distribution** for $p_T(D_s^+) > 5$ GeV/c
- Anyway, significant deviation of the **near-side** shape from model predictions, in particular for low-$p_T(D_s^+)$

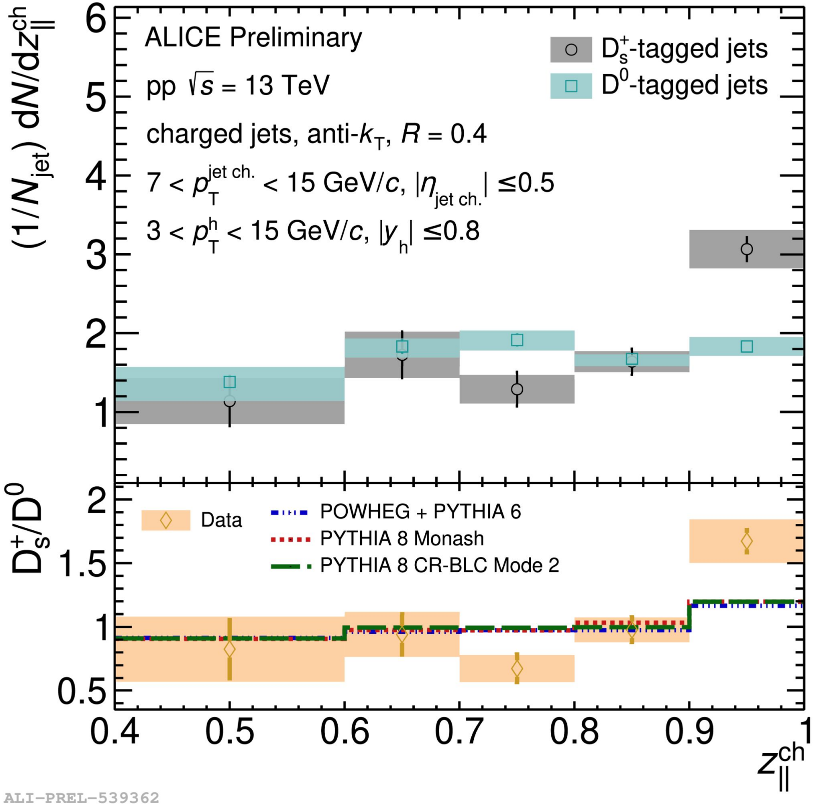






p_T^D

D_s^+ tagged jets



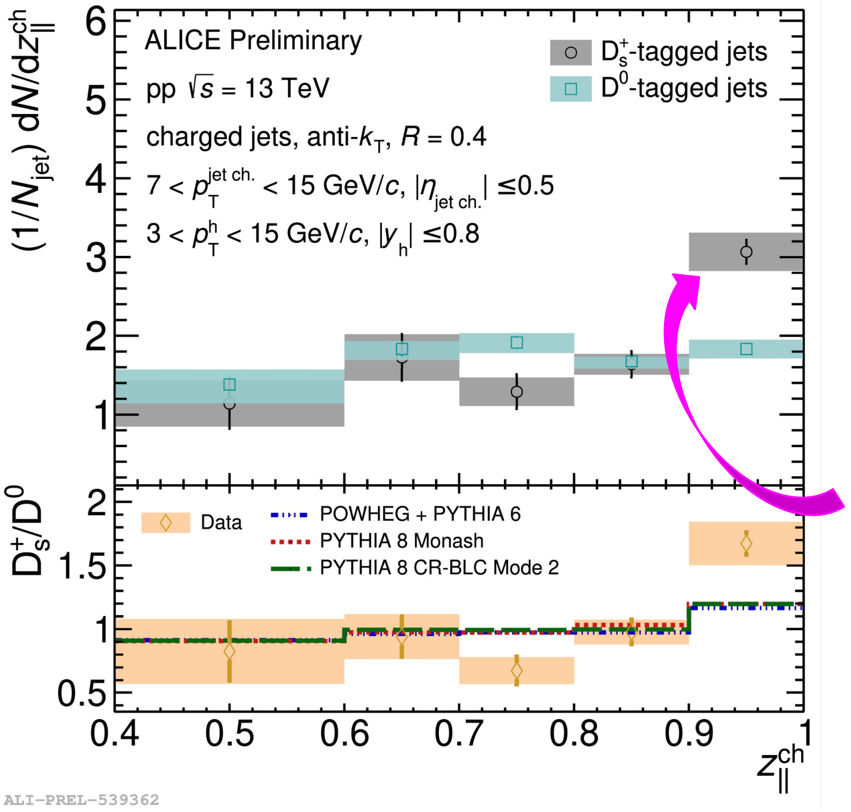
- Alternative way of probing charm fragmentation into D_s^+

D_s^+- tagged jets vs **D⁰-tagged jets** $z_{||}^{ch}$ measurement

Longitudinal momentum fraction

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

D_s^+ tagged jets



- Alternative way of probing charm fragmentation into D_s^+

D_s^+- tagged jets vs **D^0-tagged jets** $z_{||}^{ch}$ measurement

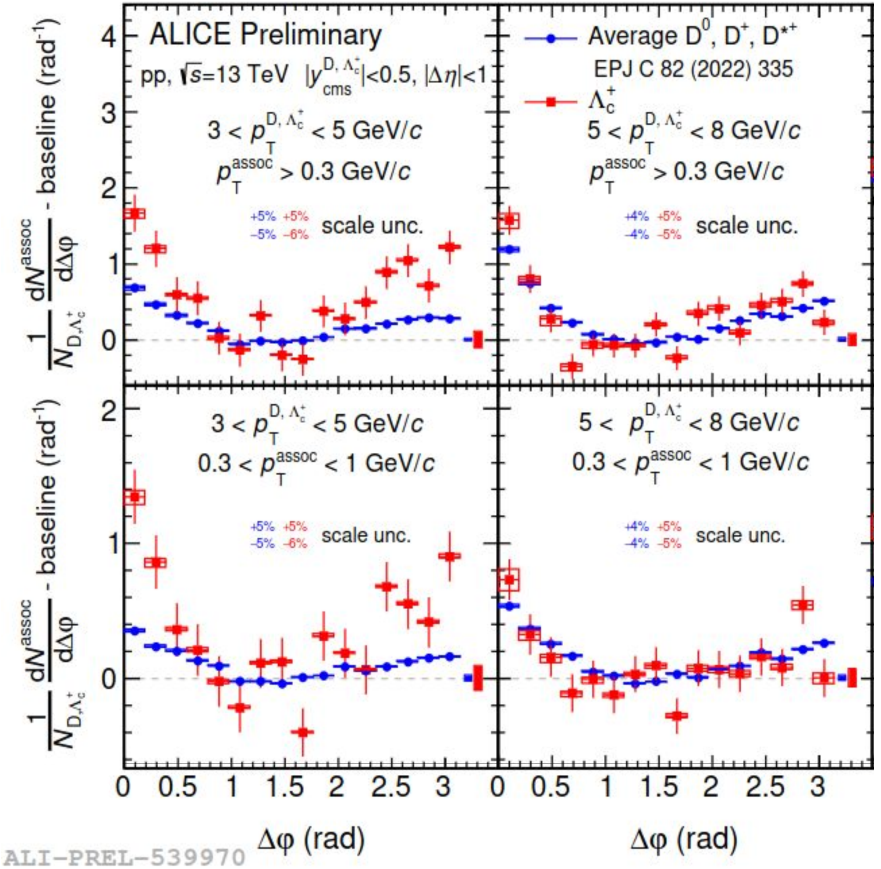
Longitudinal momentum fraction

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

Hint of **harder fragmentation** of charm into **D_s^+** than **D^0** in the studied p_T (ch-jet, D_s^+) range

Could be a possible explanation of the NS observed difference in the D_s^+-h correlation

Λ_c^+-h vs D-h correlation distribution

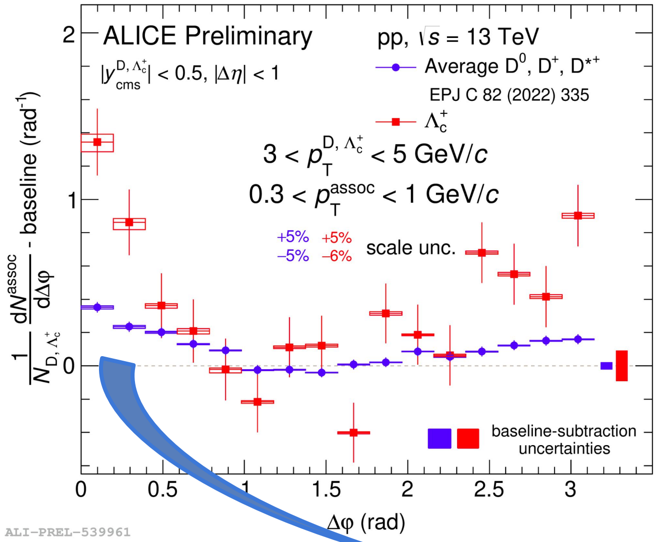


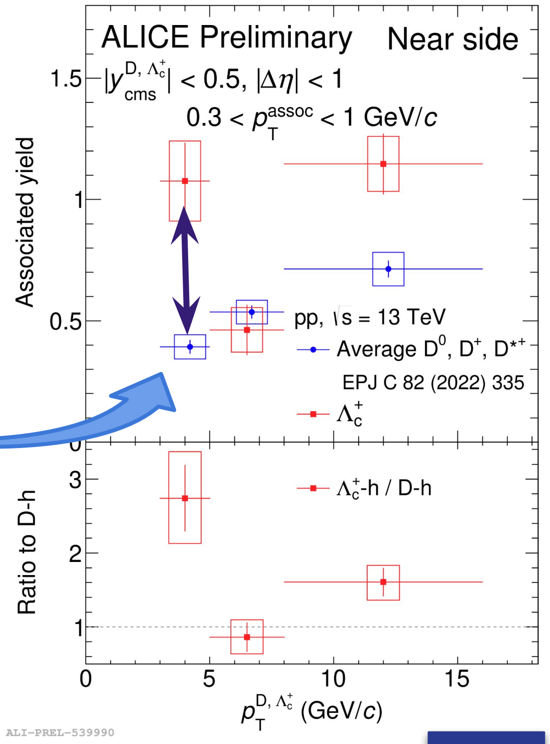
- Address charm fragmentation to baryons
- From the comparison of the Δφ shape:
  - **Good agreement** between the Δφ distributions for p_T(D, Λ_c^+) > 5 GeV/*c*
  - Tendency for an **enhancement of both Λ_c^+-h correlation peaks** at **low-p_T(D, Λ_c^+)** from **D-h measurement**

Characterisation of Λ_c^+-h correlation

Possible motivations of the observed difference:

a) Different energy of the charm quark as a consequence of a **softer Λ_c^+ fragmentation**





b) Decay of higher mass charm states (**SHM+RQM**)

c) Hadronisation by **coalescence** (to be tested with predictions from dedicated models)

Λ_c^+ tagged jets

- Access the charm quark properties if it hadronises to a baryon

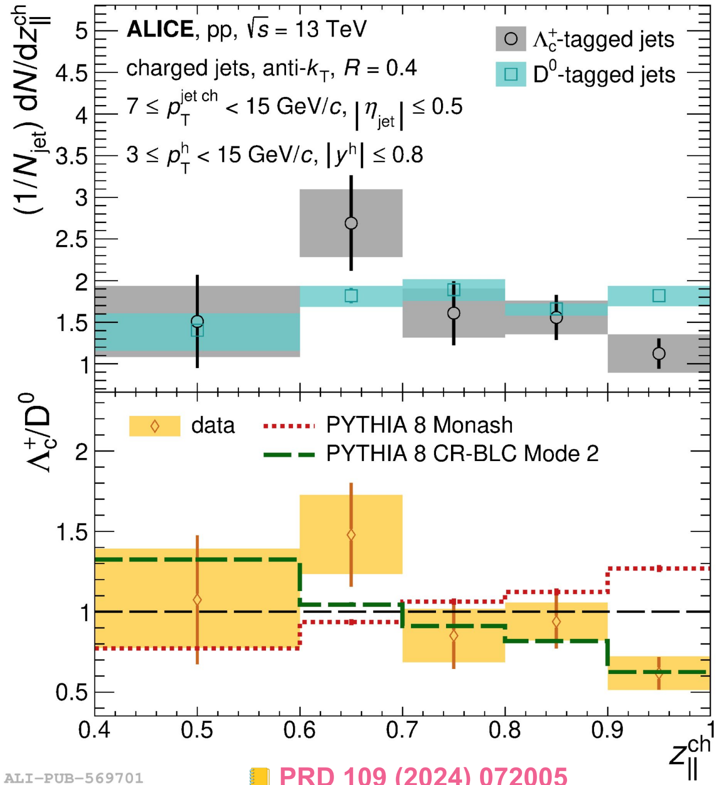
Longitudinal momentum fraction

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

Hint of softer fragmentation of charm into Λ_c^+ than D^0 in the studied p_T (ch-jet, Λ_c^+) range

In agreement with Λ_c^+-h results for $3 < p_T(\Lambda_c^+) < 5$ GeV/c

- PYTHIA 8 CR-BLC Mode 2 in better agreement with data than the PYTHIA 8 Monash tune



PRD 109 (2024) 072005

Summary and outlook

- **ALICE** has carried out a detailed study of the **charm-quark fragmentation** through charm meson and baryon angular correlations and charm meson and baryon tagged jet measurements

- **Non-strange D mesons** with jets and correlations:
  - p_T-differential description of the charm-jet properties
  - fragmentation as in PYTHIA 8 reproduces within uncertainties the measurements

- **First D_s^+-h correlation** measurement accessible with pp data at **$\sqrt{s}$=13.6 TeV**: *NEW!*
  - indications of **harder fragmentation** from both **D_s^+-h** and **D_s^+-jet**
  - observed discrepancy between data and MC generator predictions (PYTHIA 8 CR-BLC)

- **Charm-to-baryon fragmentation** accessible with pp data at **$\sqrt{s}$=13 TeV**:
  - indications of **softer fragmentation** from both **Λ_c^+-h** and **Λ_c^+- jet**

Summary and outlook

- **ALICE** has carried out a detailed study of the **charm-quark fragmentation** through charm meson and baryon angular correlations and charm meson and baryon tagged jet measurements

Further results expected shortly on new Run 3 data samples

➢ Measurement of **Λ_c^+-h correlations** with **more precision**, **higher granularity** and **extended p_T reach**

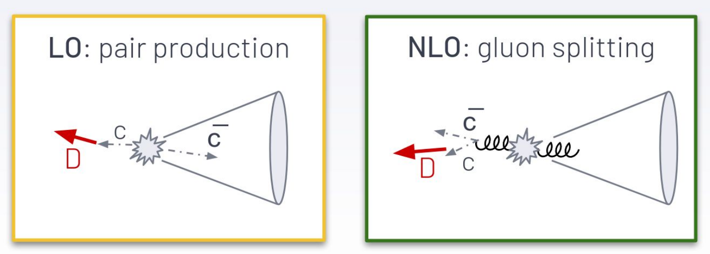
➢ Address **new observables** (e.g. 2D angular correlations, access to beauty sector via non-prompt D)

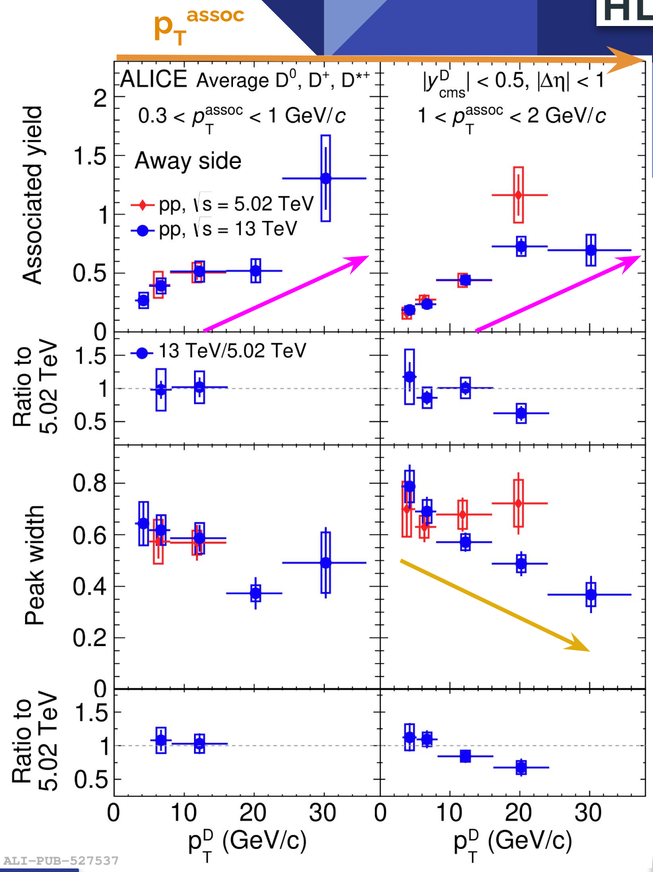
Thanks for your attention!

BACKUP SLIDES

D-h away-side properties comparison with √s

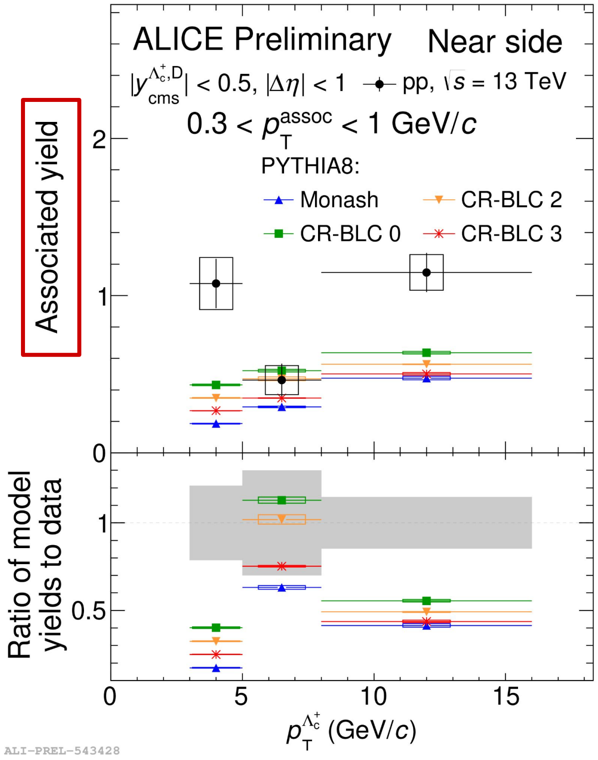
- **Away-Side**: description of the recoil jet, not necessarily developed by a charm quark

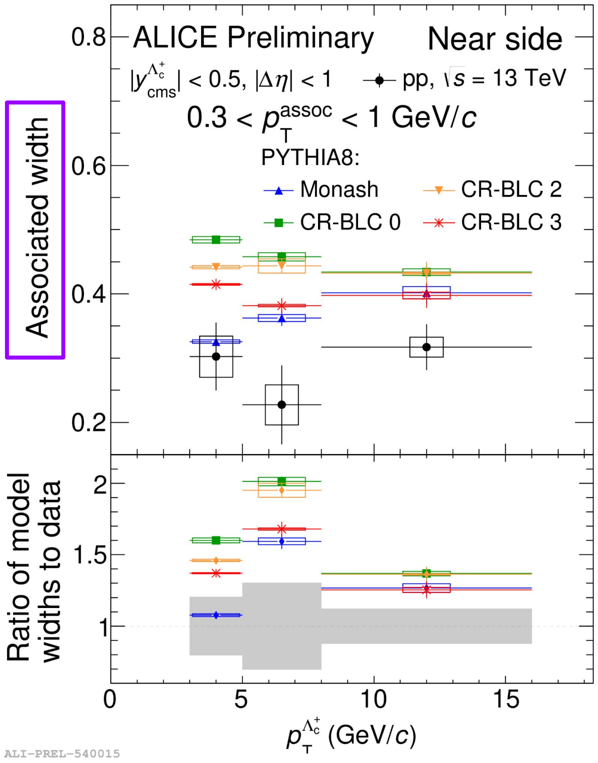




- Similarly as for the NS, with **increasing p_T^D**:
  - More energetic parton:
    - ➢ **Increasing yields**
    - ➢ **Sharpening of the peak**

Λ_c^+-h correlation comparison with models





- **Yields**:
  - tensions with PYTHIA8 predictions
  - low-$p_T(\Lambda_c^+)$ not correctly reproduced
- **Widths**:
  - generally overestimated, though with large uncertainties

PYTHIA 8 CR-BLC modes, despite predicting the Λ_c^+/D^0 p_T-dependence, do not describe the differences in the charm-jet