Medium-induced modification of jet-like azimuthal correlations with heavy-flavor triggers

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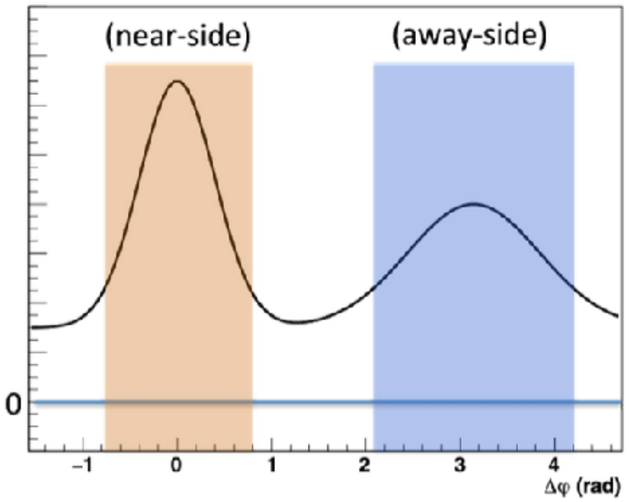
Introduction

- Two-particle angular correlations with a high p_{T} trigger —> complementary method to jet reconstruction to characterize jets and their properties, especially at low p_{T}.

- Heavy quarks are produced in hard scattering process with high Q^2
  - Emit gluon radiation generating a parton shower and hadronize —> heavy quark jet

- Angular correlations with a heavy-flavor particle trigger allows study of heavy-flavor jet properties.



$$\Delta\varphi(\mathrm{HF}-\mathrm{h}) = \varphi^{\mathrm{HF}}_{\mathrm{trig}} - \varphi^{\mathrm{h}}_{\mathrm{asso}}$$

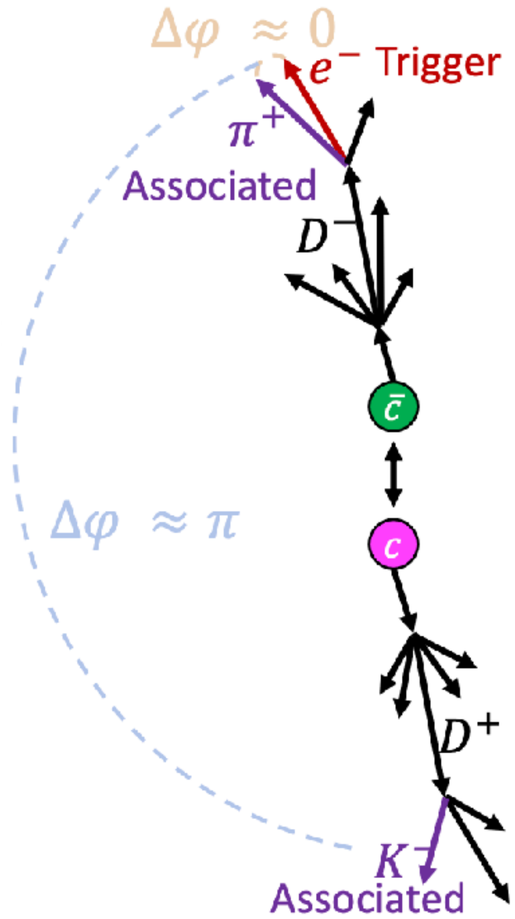
Typical structure at LO:

Near-side: $\Delta\varphi \approx 0$

- Associated particles from same jet as trigger

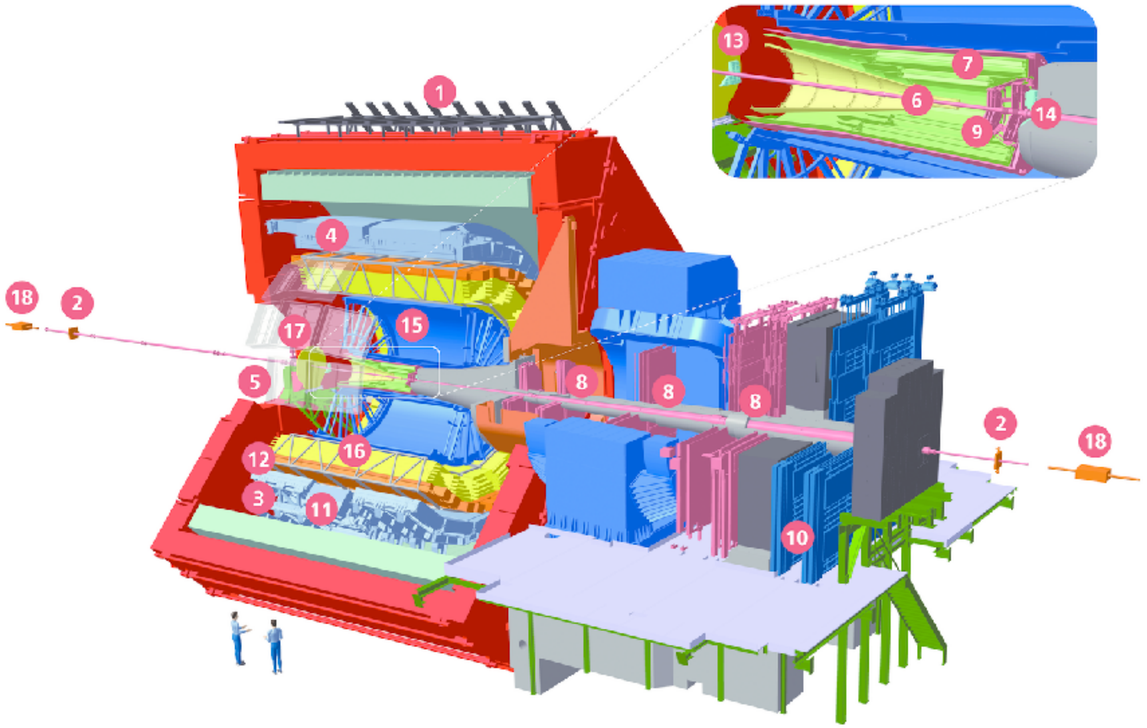
Away-side: $\Delta\varphi \approx \pi$

- Associated particles from the recoil jet



ALICE detector

Run 2 -> Run 3: several upgraded detectors



Relevant upgrades:

New Inner Tracker System (ITS2)

- Full pixels; closer to interaction point (39 mm -> 23 mm); Improved impact parameter resolution (factor of 2); Faster readout

New Time Projection Chamber (TPC) readout

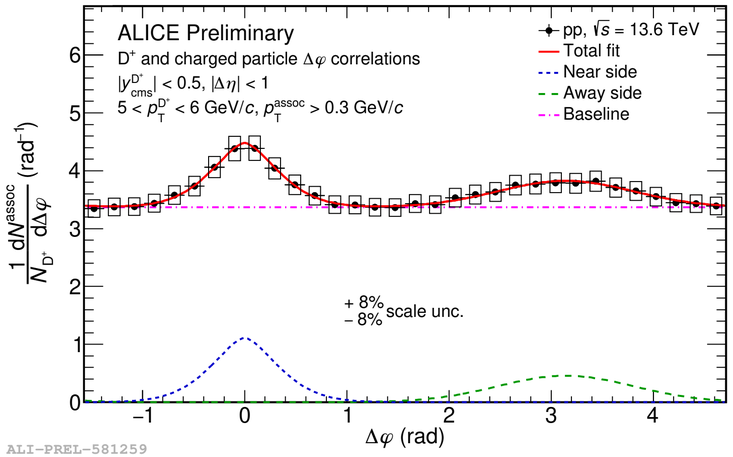
- Continuous readout -> large statistics at higher interaction rates

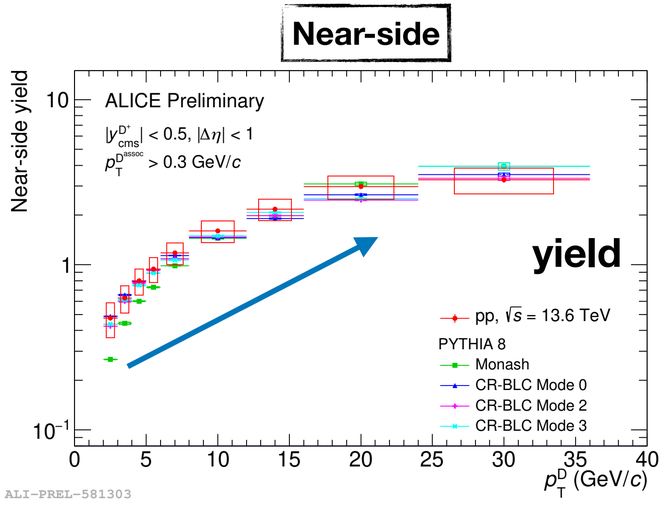
Well suitable for new and differential HF measurements

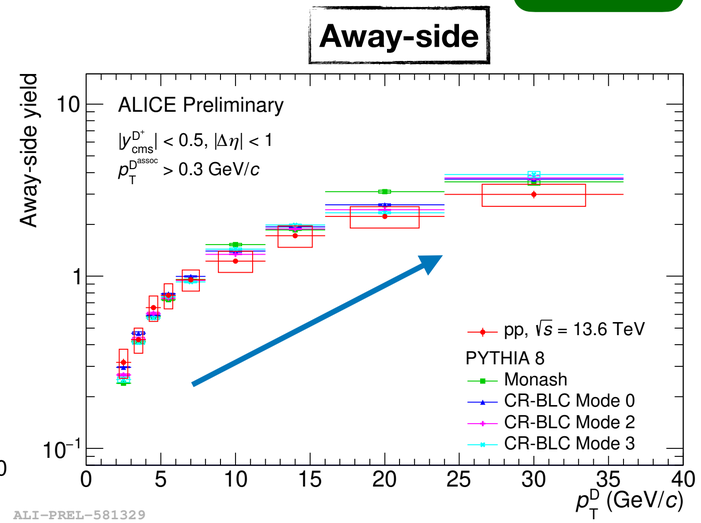
HF-h correlations in pp

Run 3

$\Delta\varphi(\mathrm{D}^+ - \mathrm{h})$ correlations in pp collisions





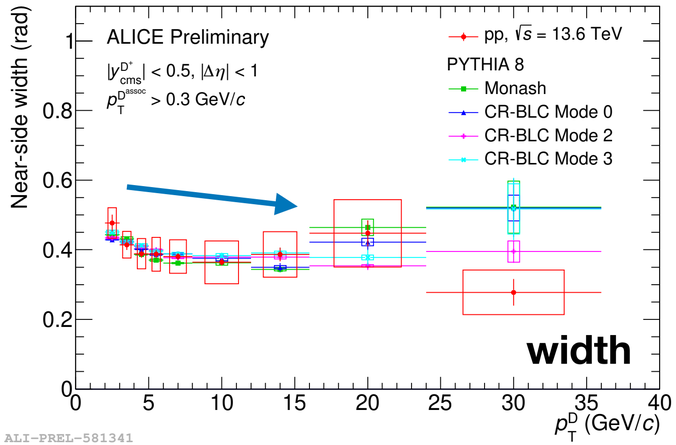


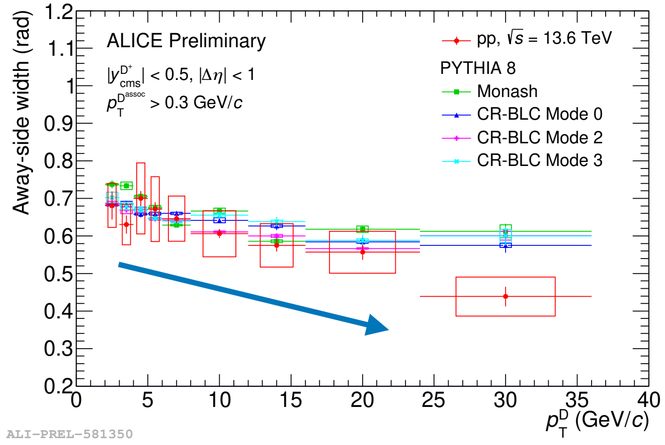
HF-h correlations characterizes:

- Angular profile : fit with Generalized Gaussian or von Mises to describe the near-side and away-side peaks
- Associated particle multiplicity
- Momentum distribution vs $p_{\mathrm{T}}^{\mathrm{trigger}}$ and $p_{\mathrm{T}}^{\mathrm{asso}}$

❖ With increasing $p_{\mathrm{T}}^{\mathrm{trigger}}$

- higher associated yield from more energetic HF parton —> more phase phase for fragmentation
- larger heavy quark boost —> more collimated peaks

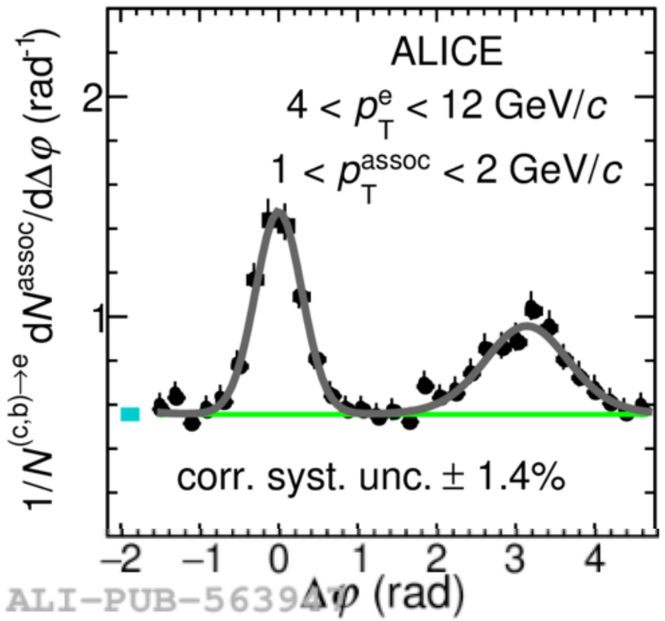


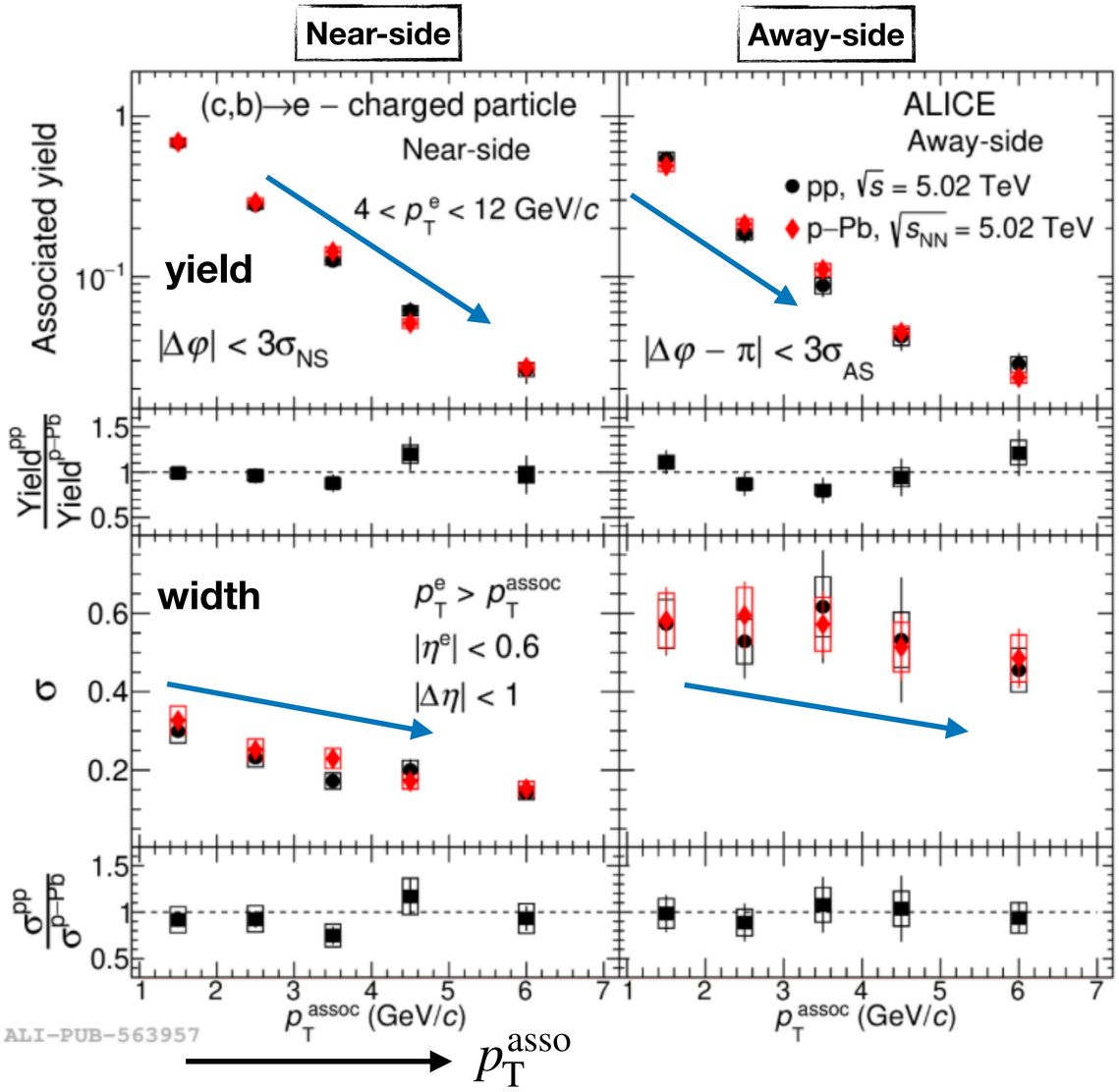


$p_{\mathrm{T}}^{\mathrm{D}}$

HF-h correlations in pp

$\Delta\varphi(\mathrm{c,b} -> \mathrm{e} - \mathrm{h})$ **correlations in pp collisions**





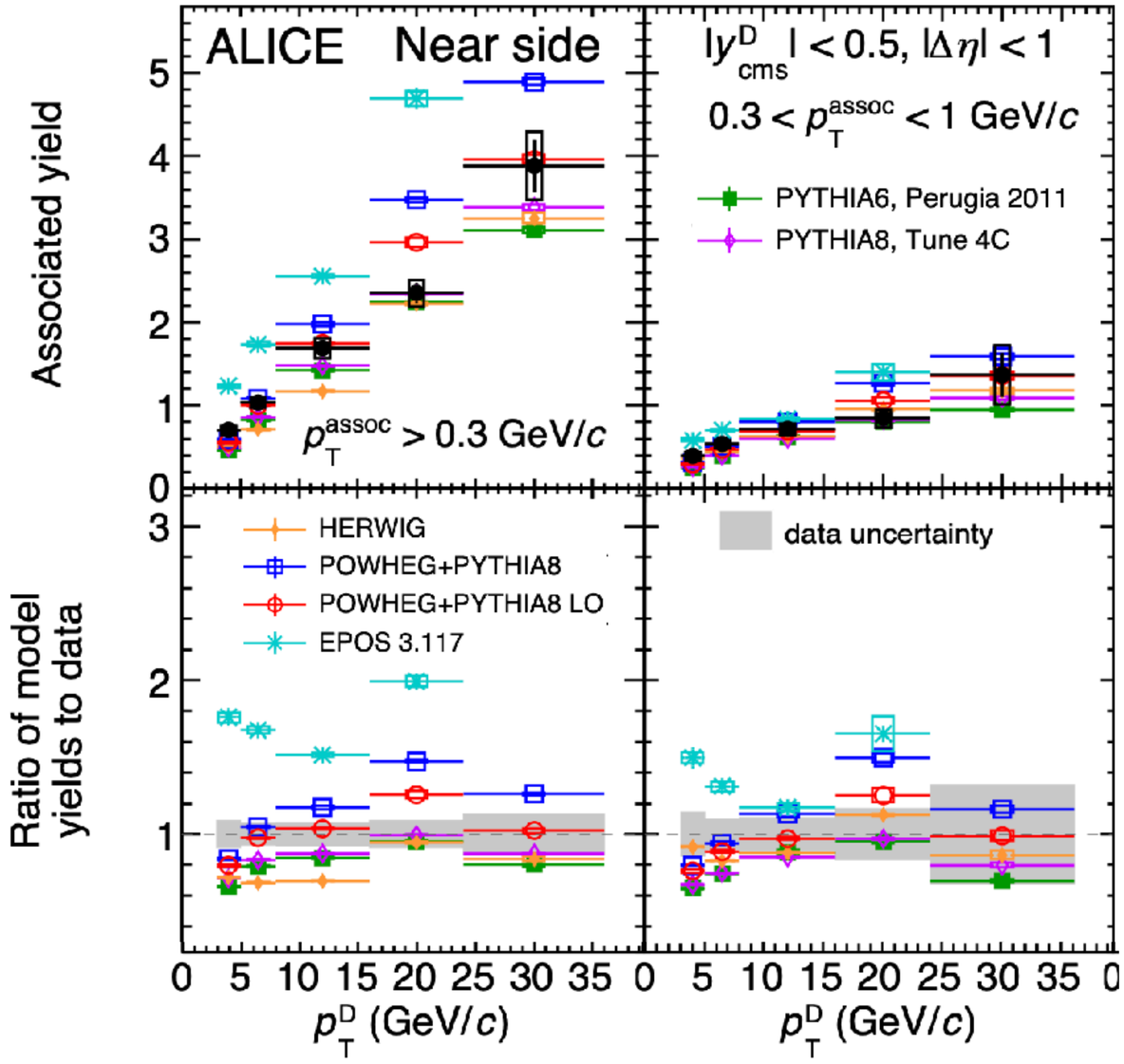
- With increasing p_T^{asso}
  - decreasing associated yield due harder fragmentation of heavy quarks —> less energy remaining for higher p_T associated particles
  - more collimated peaks on NS
- **Correlation distributions in p-Pb collisions consistent with pp collisions.**

Comparison with MC models

Validation of parton-shower and Monte Carlo generators

PYTHIA6 Perugia 2011
PYTHIA8, Tune 4C
HERWIG
POWHEG+PYTHIA8
POWHEG+PYTHIA8 LO
EPOS 3.117

- Overall $p_{\mathrm{T}}^{\mathrm{trigger}}$ and $p_{\mathrm{T}}^{\mathrm{asso}}$ dependent trends described by PYTHIA, POWHEG and HERWIG models.
- EPOS tends to overestimate the NS results.
- **PYTHIA 8 and POWHEG+PYTHIA8 gives the best description overall.**



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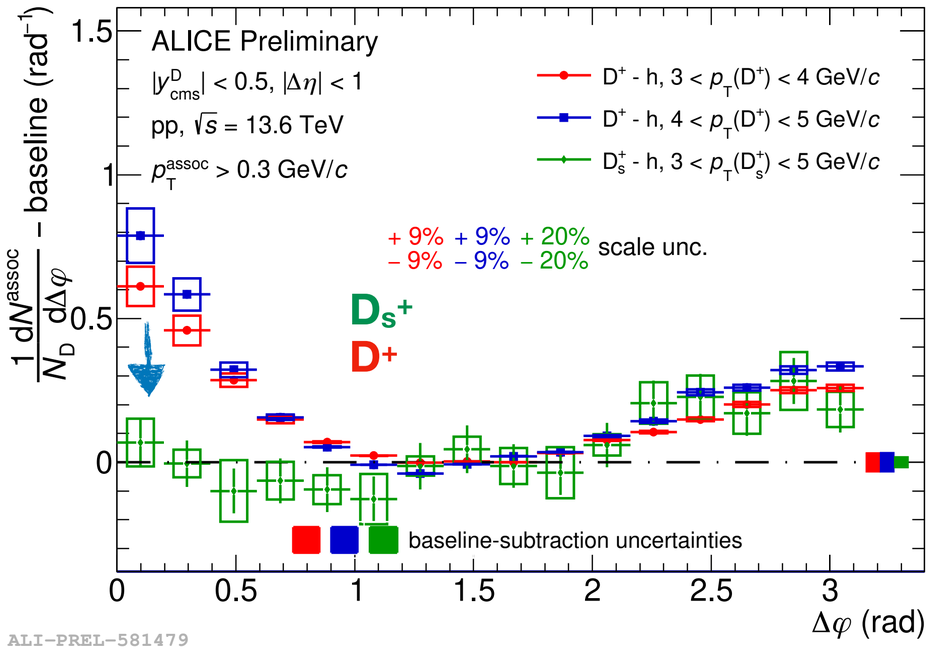
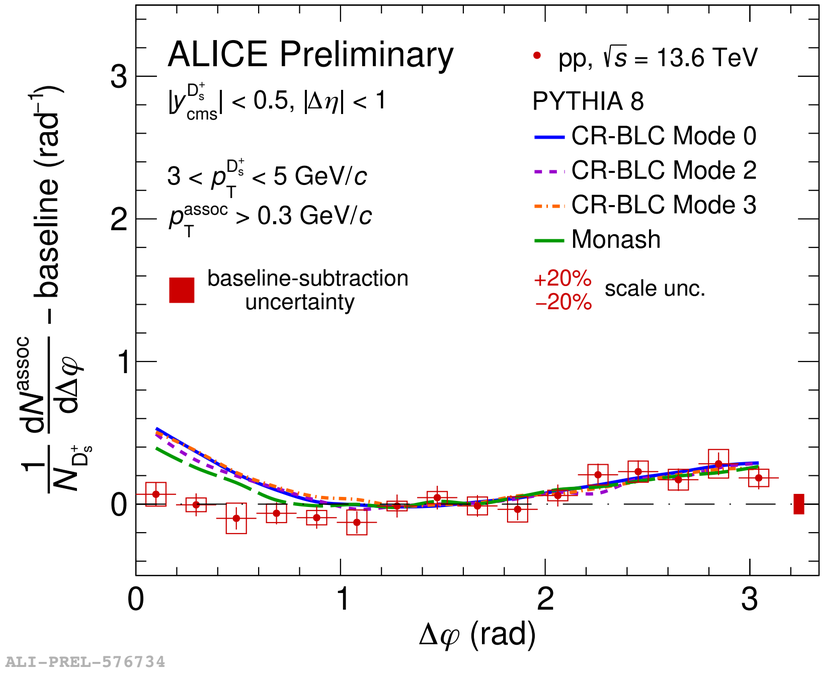
Strange HF hadron correlations in pp

$\Delta\varphi(\mathrm{D_s}^+ - \mathrm{h})$ correlations in pp collisions: study fragmentation mechanism

Run 3





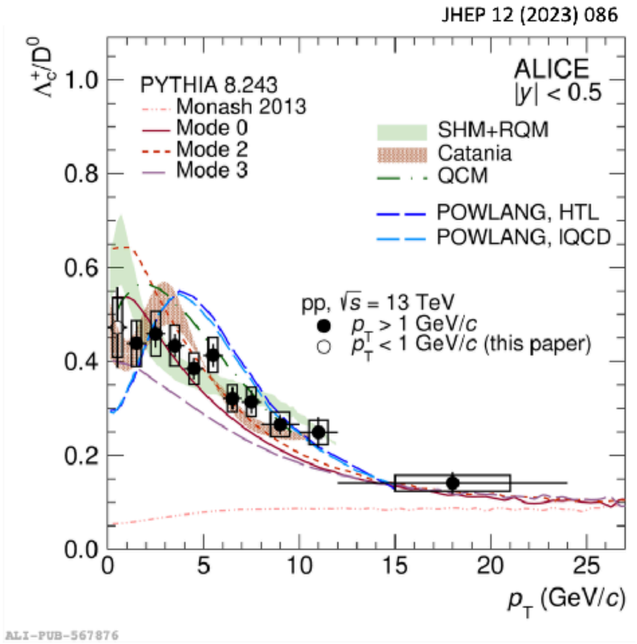
* High $p_T^{trigger}$ data in backup

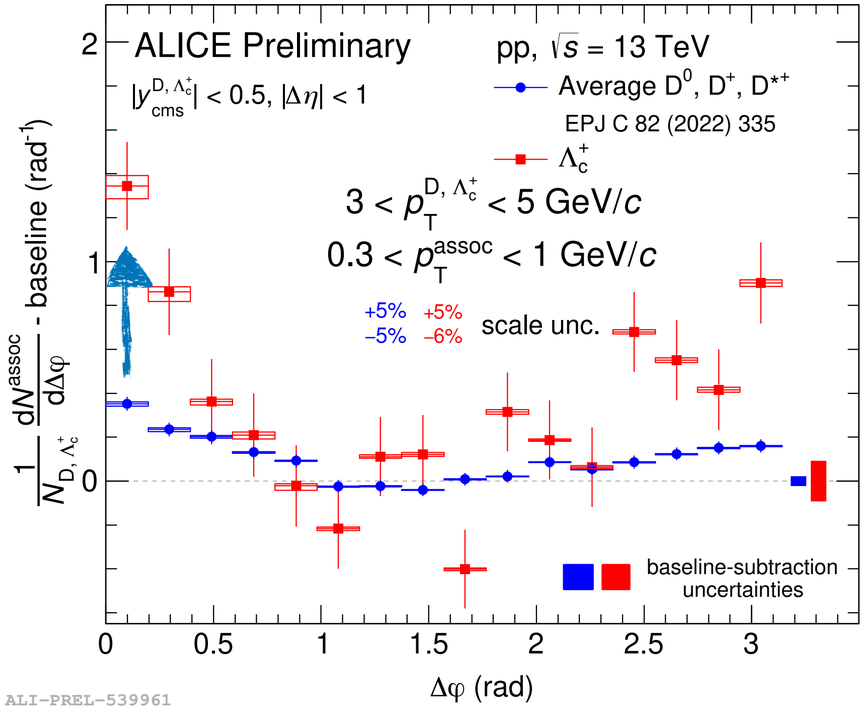
- Larger sample collected in Run 3 allows correlations with D_s^+ trigger (not accessible in Run 2).
- **Near-side: significantly lower associated yield for D_s^+ compared to D^+ at low $p_T^{trigger}$**; Consistent at higher $p_T^{trigger}$.
- Away side: similar distributions for D_s^+ and D^+ triggered correlations in the full p_T range measured.

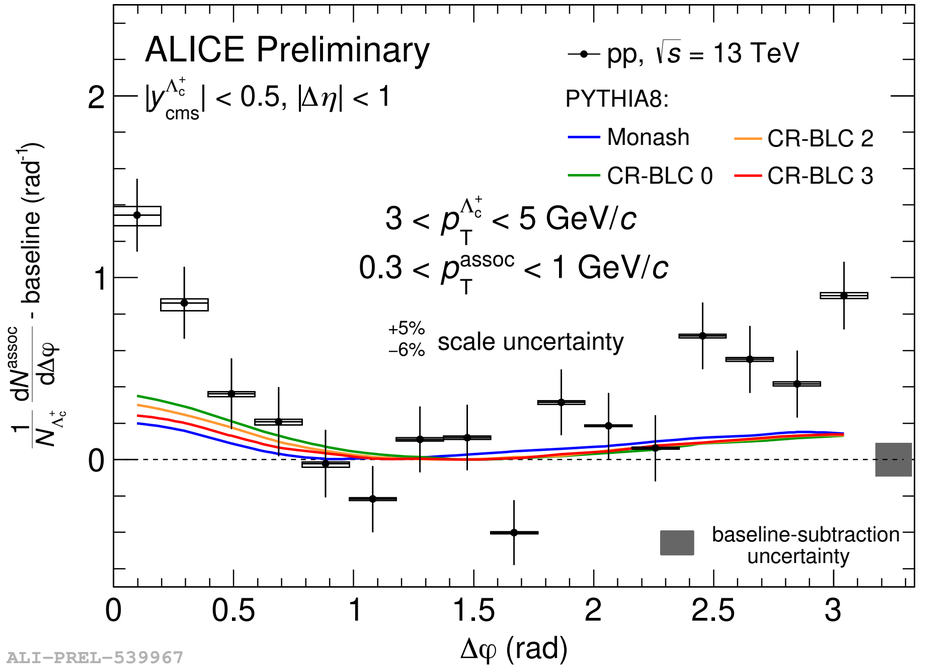
- **Different tunes of PYTHIA overestimate the near-side peak at low $p_T^{D_s^+}$**; describe the away-side peak, and the full distribution for $p_T^{D_s^+} > 5$ GeV/c
- **Possible explanation for the difference: harder fragmentation of charm quark into D_s^+ than non-strange D mesons** (consistent with $z_{||}$ measurement)

HF baryon correlations in pp

$\Delta\varphi(\Lambda_c^+ - \mathrm{h})$ correlations in pp collisions: study baryon hadronization mechanism







- Larger Λ_c^+/D^0 ratio measured in pp compared to e+e- at low and intermediate p_T.
- PYTHIA with CR-BLC modes, and models with coalescence describes the data within uncertainty.

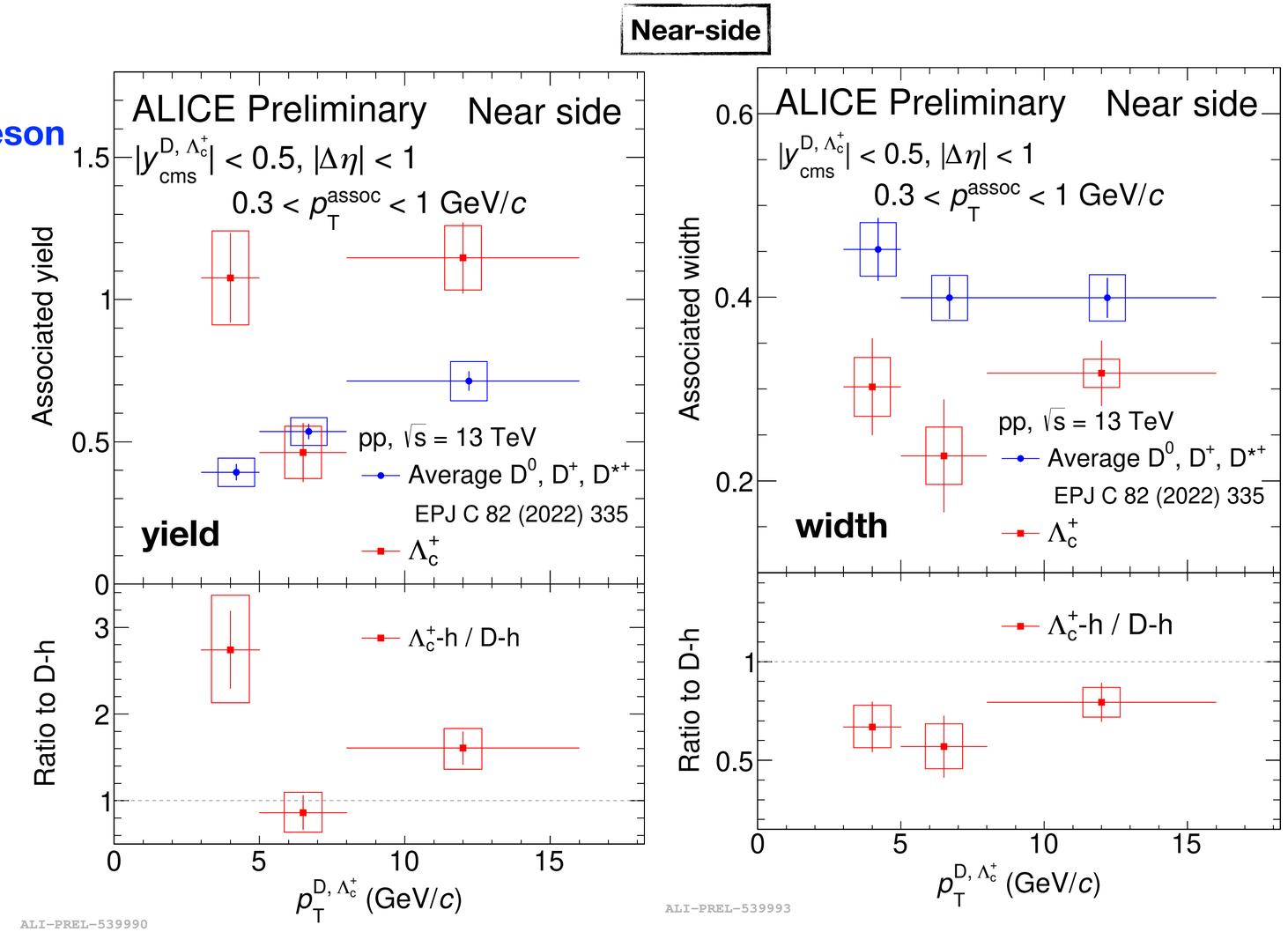
- Λ_c^+ triggered correlations compared to D-meson.
- **Trend of enhanced correlation peaks at low $p_\mathrm{T}^{\Lambda_c^+}$ and $p_\mathrm{T}^{\mathrm{asso}}$.**
- **Different tunes of PYTHIA underestimate the peaks at low $p_\mathrm{T}^{\Lambda_c^+}$**; describe the data at higher $p_\mathrm{T}^{\Lambda_c^+}$

HF baryon correlations in pp

- Peak yields and widths extracted for near- and away-side.
- Higher yield for Λ_c^+ at low $p_{\mathrm{T}}^{\mathrm{trigger}}$.
- Peak widths lower for Λ_c^+ compared to D-mesons.

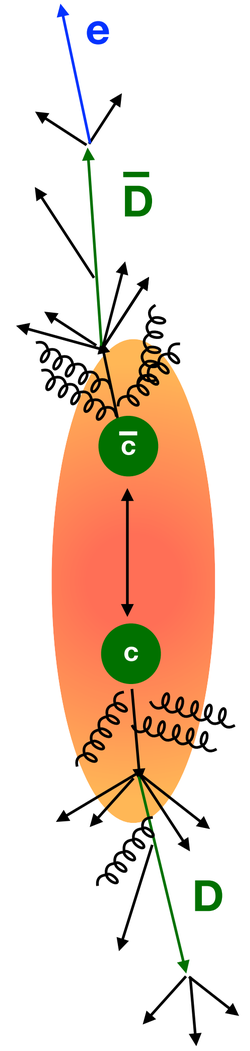
Possible explanations:

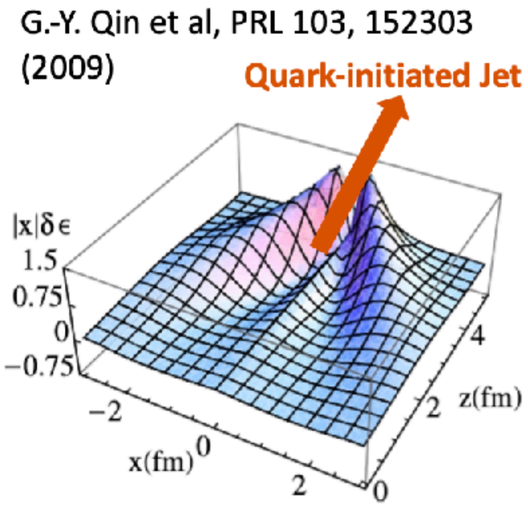
- **softer fragmentation of charm quark into Λ_c^+ than D mesons** (consistent with $z_{\parallel}$ measurement)
- Decay of higher mass charm states (SHM+RQM)
- Hadronization by coalescence impacting the mean p_{T} and associated particle multiplicity
  -> exploring with models



HF correlations in Pb-Pb

- Heavy quarks traverse the QGP medium and undergo energy loss via elastic collisions and gluon radiation.
  - Energy available for parton shower can be different from in-vacuum fragmentation changing the fragmentation function
  - High-momentum partons propagating through the medium lead to modifications in the QGP due to injection of energy and momentum lost by the jet into the plasma
  - Correlation between the bulk dynamics of the medium and the jet





- Angular correlations of HF trigger particle and charged hadrons provide insights into these effects.

- The per-trigger nuclear modification factor (I_{AA}) of peak yields can be used to study the effect of the QGP medium

$$I_{\mathrm{AA}} = \frac{Y_{\Delta\varphi}^{\mathrm{Pb-Pb}}}{Y_{\Delta\varphi}^{\mathrm{pp}}}$$

HF-h correlations in Pb-Pb

- Azimuthal correlations of c,b -> e and charged hadrons in 0—10% and 30—50% Pb—Pb collisions

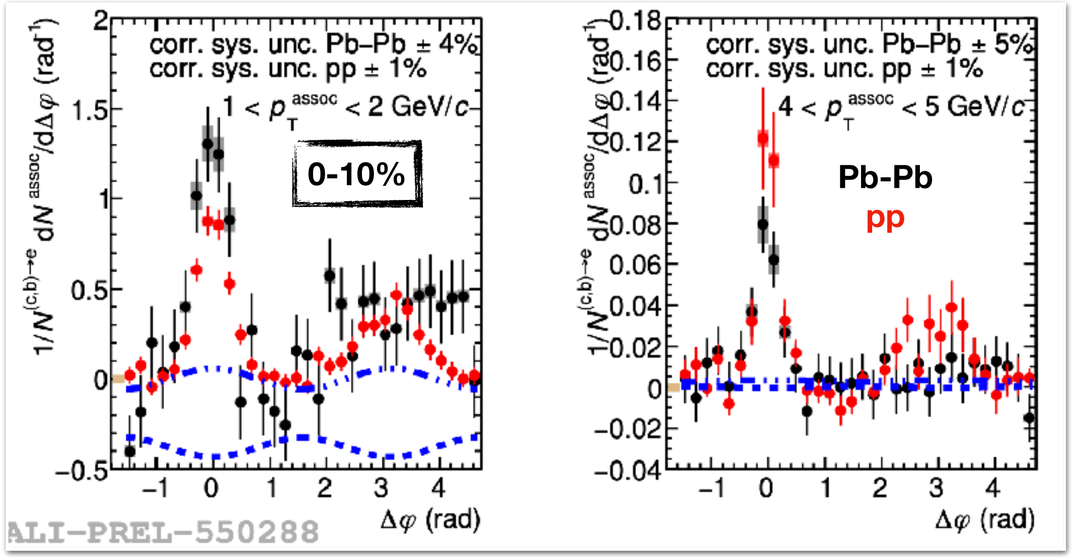
- Uncorrelated background subtracted by fitting a baseline function to the transverse region, including elliptic flow modulation:

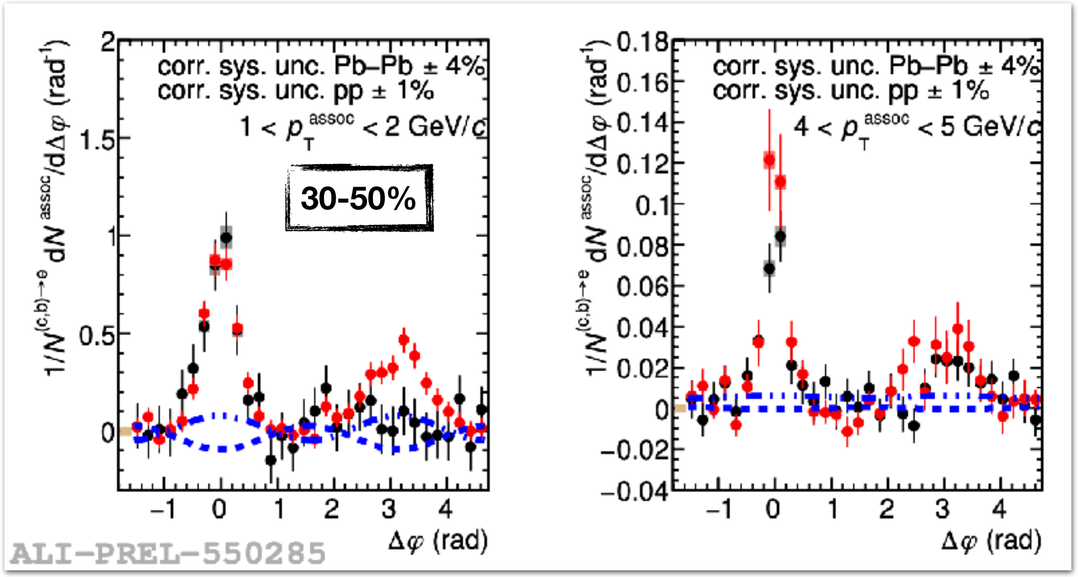
$$B(\Delta\varphi) = b[1 + 2v_2^{\mathrm{c,b->e}} v_2^{\mathrm{ch}} \cos(2\Delta\varphi)]$$

- 0 – 10% centrality:
  - Near-side peak slightly higher in Pb—Pb compared to pp at low $p_{\mathrm{T}}^{\mathrm{asso}}$
  - Away-side peak shape differs significantly as $p_{\mathrm{T}}^{\mathrm{asso}}$ increases
    - higher and broader peak for $p_{\mathrm{T}}^{\mathrm{asso}} < 2$ GeV/c
    - peak quenched for $p_{\mathrm{T}}^{\mathrm{asso}} > 4$ GeV/c

- 30 – 50% centrality:
  - Near side peak similar in pp and Pb—Pb
  - Away-side peak lower in Pb—Pb compared to pp

ALICE Preliminary
(c,b)→e – charged particle
$4 < p_{\mathrm{T}}^{\mathrm{e}} < 12$ GeV/c
$p_{\mathrm{T}}^{\mathrm{e}} > p_{\mathrm{T}}^{\mathrm{assoc}}$
$\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
$|y^{\mathrm{e}}| < 0.6$, $|\Delta\eta| < 1$

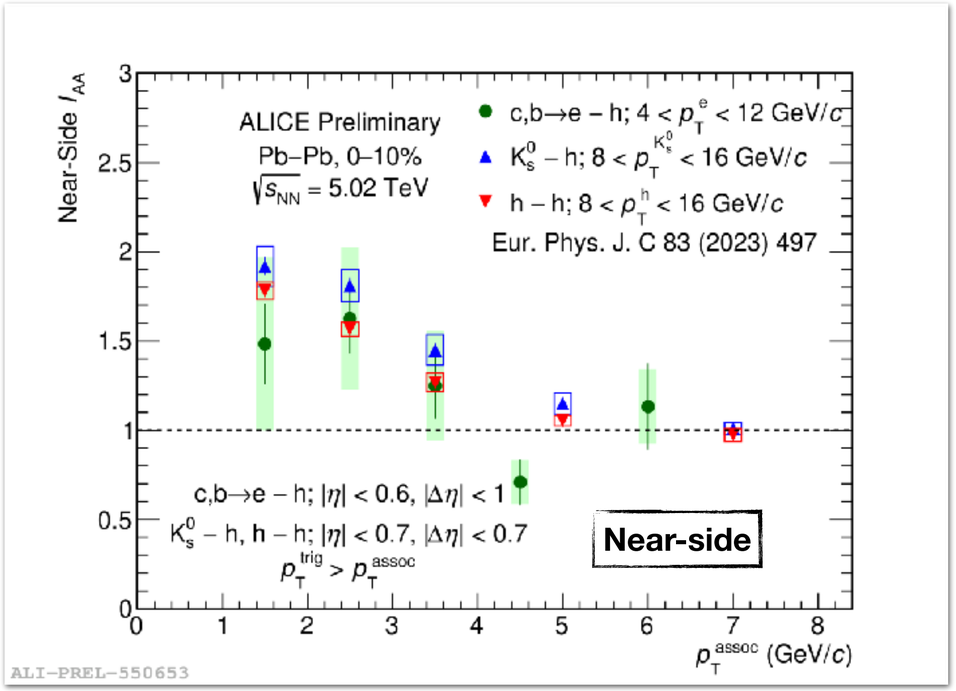


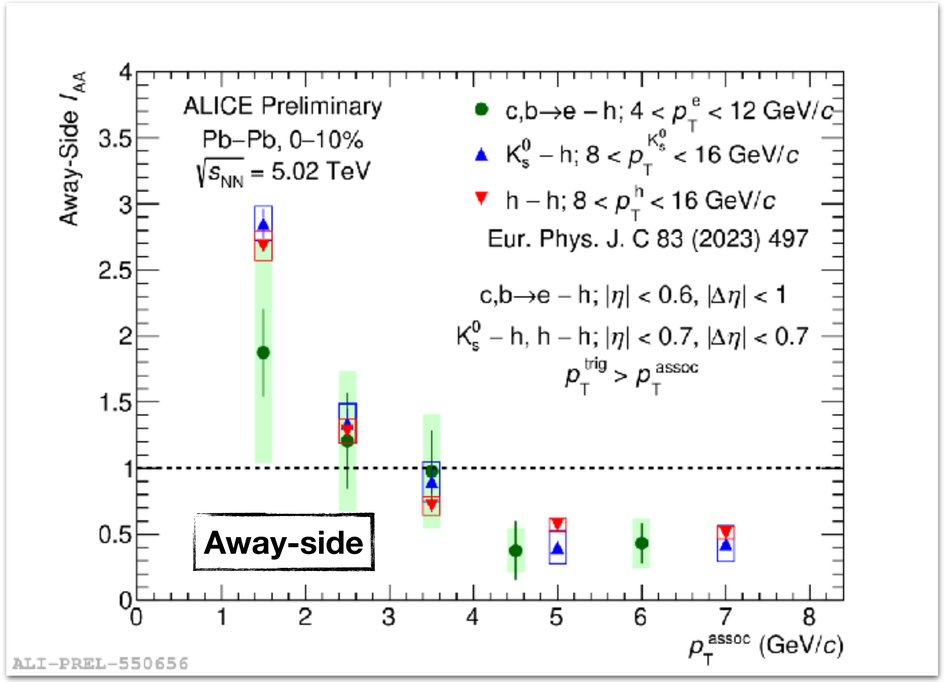


Near- and away-side IAA

The per-trigger nuclear modification factor (I_{AA}) in 0—10% Pb-Pb

$$I_{\mathrm{AA}} = \frac{Y_{\Delta\varphi}^{\mathrm{Pb-Pb}}}{Y_{\Delta\varphi}^{\mathrm{pp}}}$$





c, b→e — h
K^0_s — h
h — h

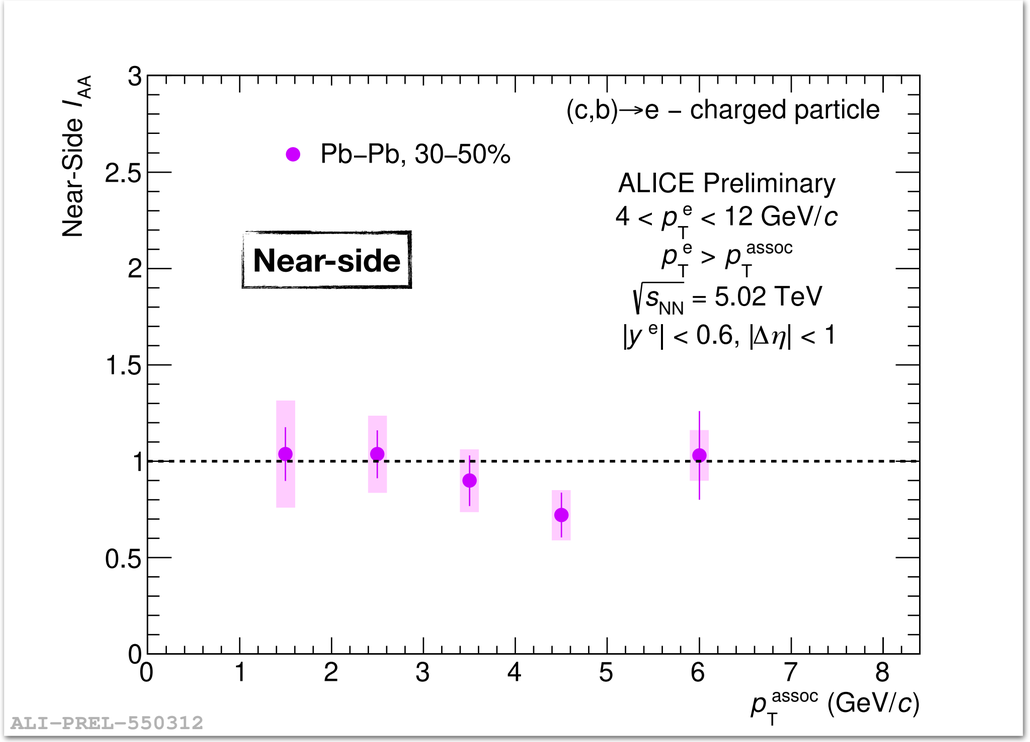
- I_{AA} for **c,b -> e** compared to **K_s^0-hadron** and di-hadron correlations
  - Similar trends for LF and HF triggers
  - Caveats for comparing LF and HF: different hadron-to-parton p_{T} scale; additional decay kinematics for c,b -> e

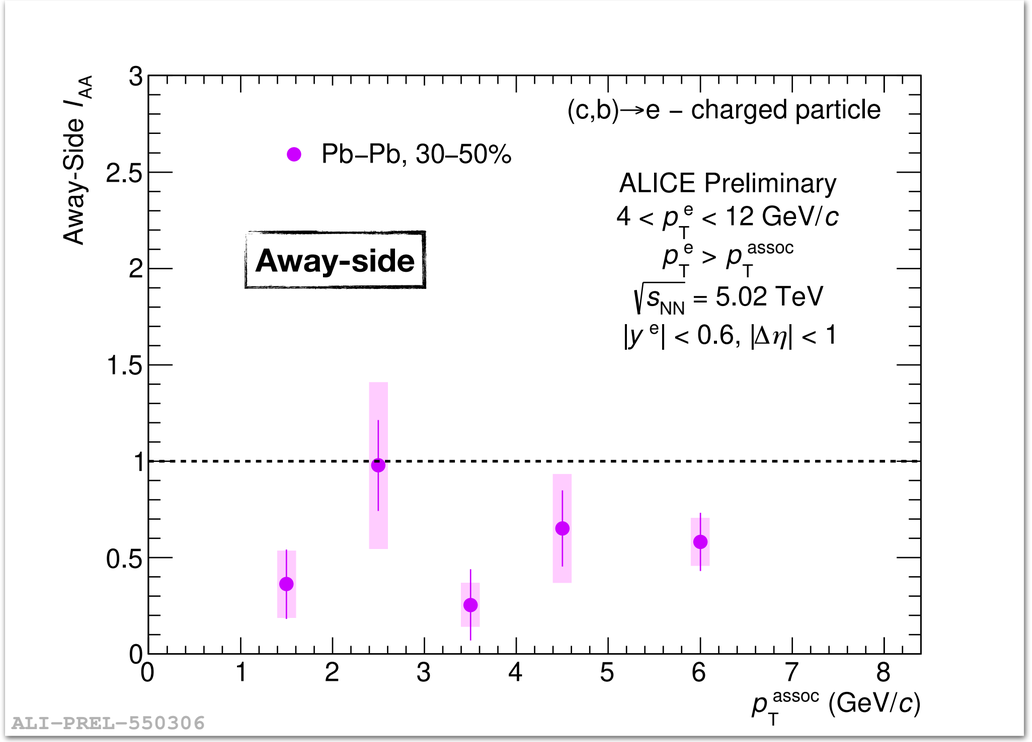
- Near-side:
  - I_{AA} trends above unity (1.3 σ) at low $p_{\mathrm{T}}^{\mathrm{asso}}$; I_{AA} ~ 1 at high $p_{\mathrm{T}}^{\mathrm{asso}}$
- Away-side:
  - hint of suppression (2.5 σ) for $p_{\mathrm{T}}^{\mathrm{asso}} > 4$ GeV/c

Near- and away-side IAA

The per-trigger nuclear modification factor (I_{AA}) in 30—50% Pb-Pb

$$I_{\mathrm{AA}} = \frac{Y_{\Delta\varphi}^{\mathrm{Pb-Pb}}}{Y_{\Delta\varphi}^{\mathrm{pp}}}$$





- Near-side:
  - I_{AA} consistent with unity
- Away-side:
  - hint of suppression for $p_{\mathrm{T}}^{\mathrm{asso}} > 3$ GeV/c

Summary

- **Azimuthal angular correlations of heavy-flavor trigger and charged hadrons -> study and characterize heavy-flavor jet fragmentation and its modification in the presence of a QGP medium.**

- pp collisions:
  - Non-strange charm meson correlations well described by PYTHIA 8 MC simulations.
  - Different correlation peak distributions observed for D_s^+ and charm baryons —> not described by MC
    - possible effects from different fragmentation.

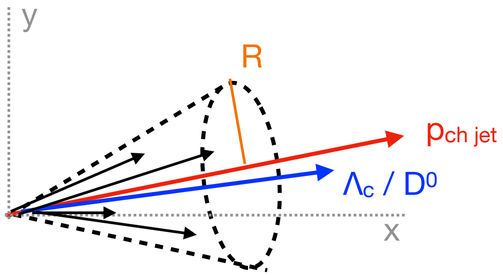
- Pb—Pb collisions:
  - Presence of QGP affects the angular correlation distributions.
  - Trends of higher associated particle yield at low $p_{\mathrm{T}}^{\mathrm{asso}}$ on the near-side correlations in central Pb-Pb collisions.
  - Hint of suppression of associated particle yield at low $p_{\mathrm{T}}^{\mathrm{asso}}$ on the away-side.
  - I_{AA} for heavy-flavor triggered correlations similar to light-flavor triggers.

- **Run 3:**
  - Improve precision and granularity of current measurements with higher statistics extending the p_{T} reach.
  - Access to beauty sector.
  - New observables such as 2D correlations, HF— HF correlations.

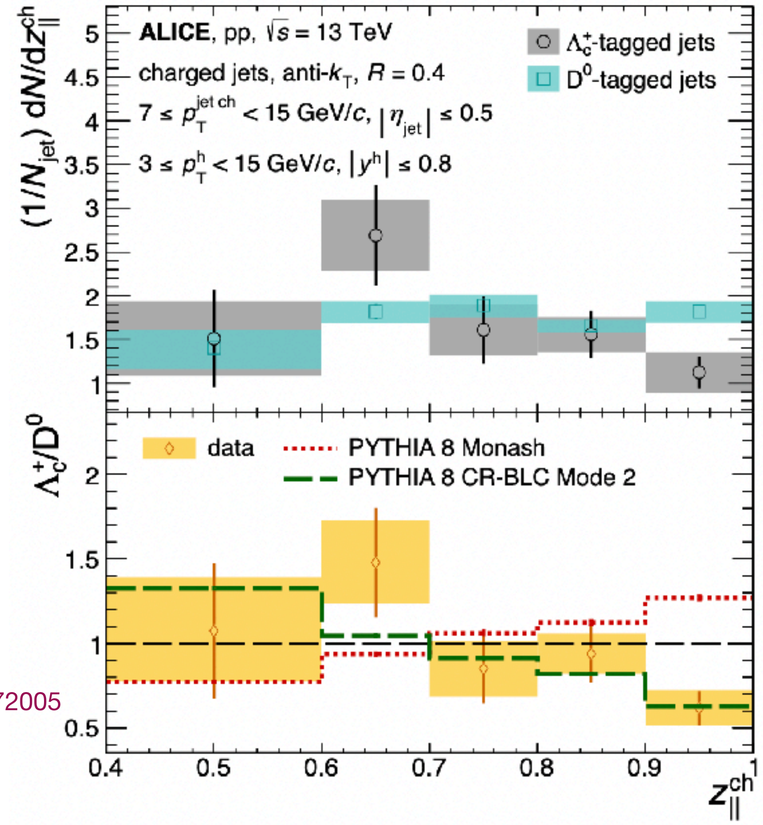
BACK UP

Fragmentation Function

Study charm jet fragmentation functions



$$z_{||}^{ch} = \frac{p_{jet} \cdot p_{HF}}{p_{jet} \cdot p_{jet}}$$



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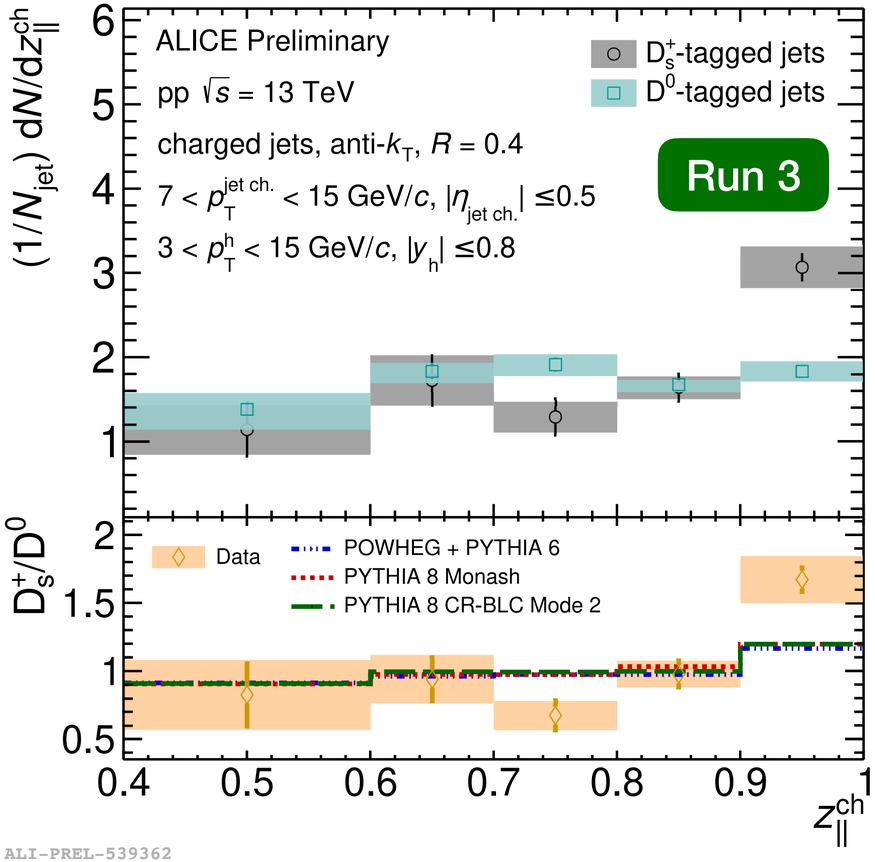


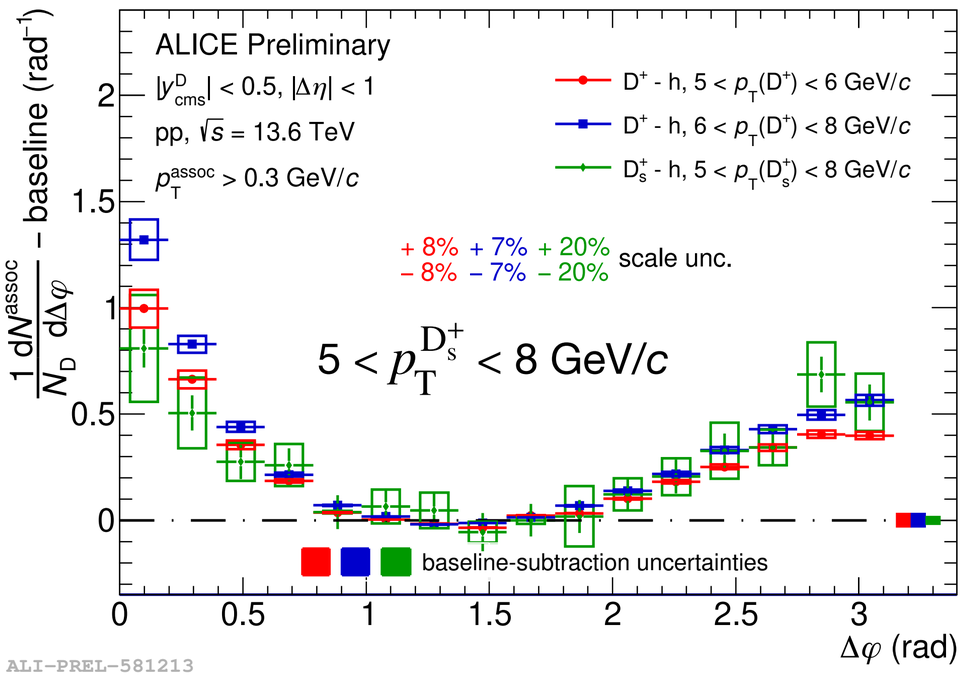
ALI-PREL-539362

- Hint of softer fragmentation of charm quarks to Λ_c compared to D^0 mesons.
- PYTHIA 8 with CR describes the data

- Hint of harder fragmentation of charm quarks to D_s^+ compared to D^0 mesons.
- MC does not describe large $Z_{||}^{ch}$

Strange HF hadron correlations in pp

Run 3



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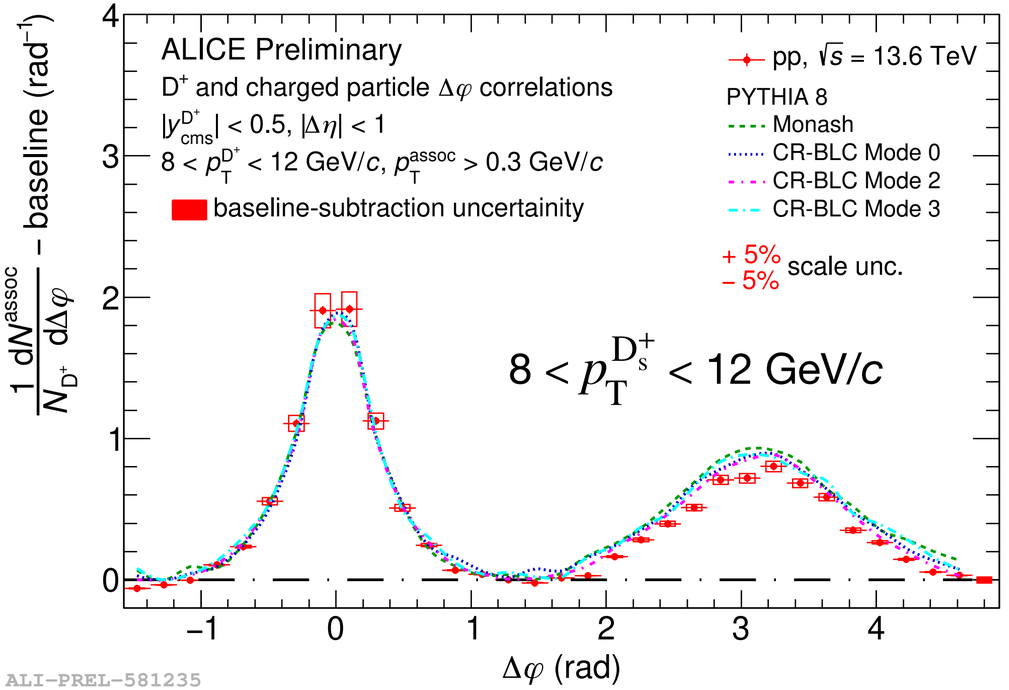

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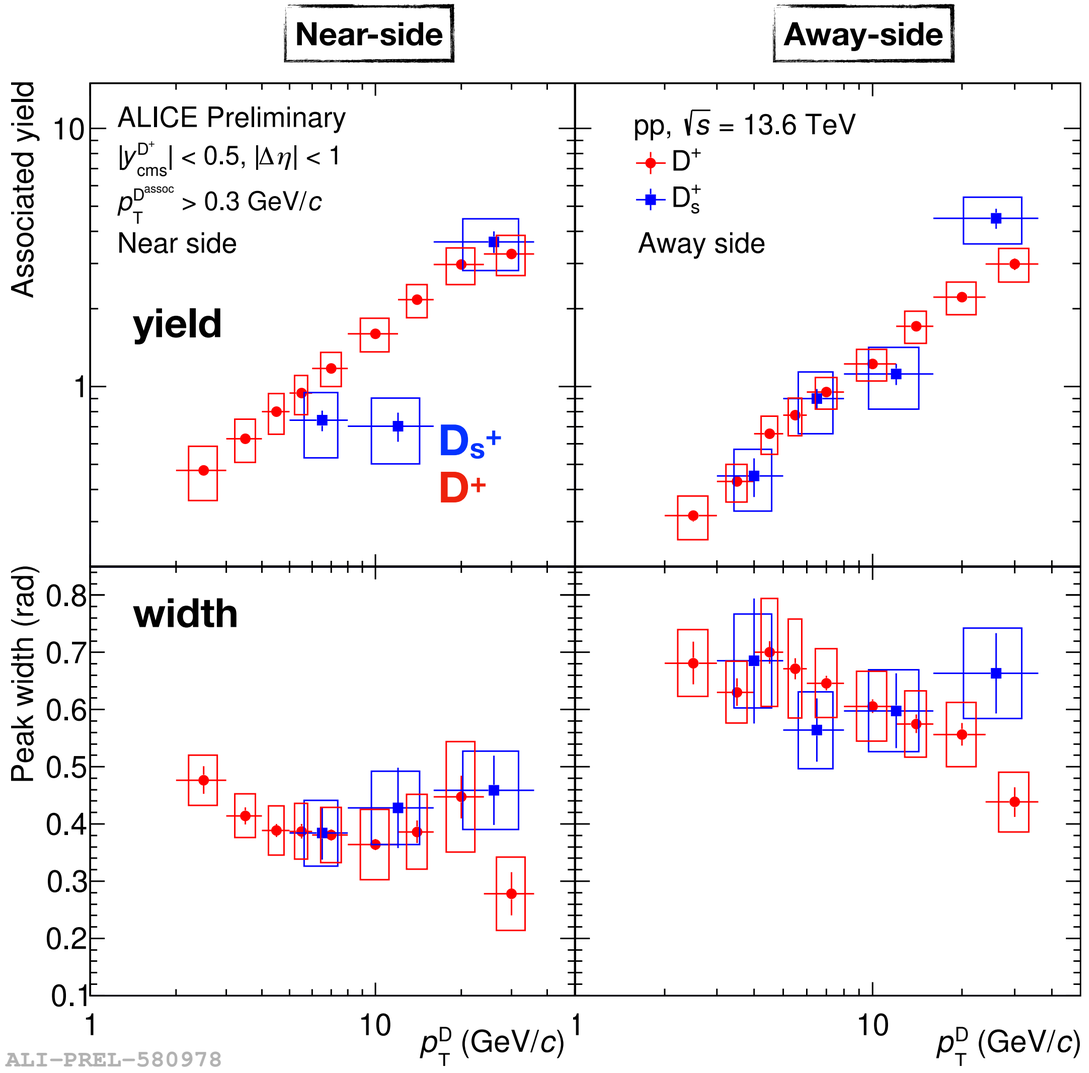
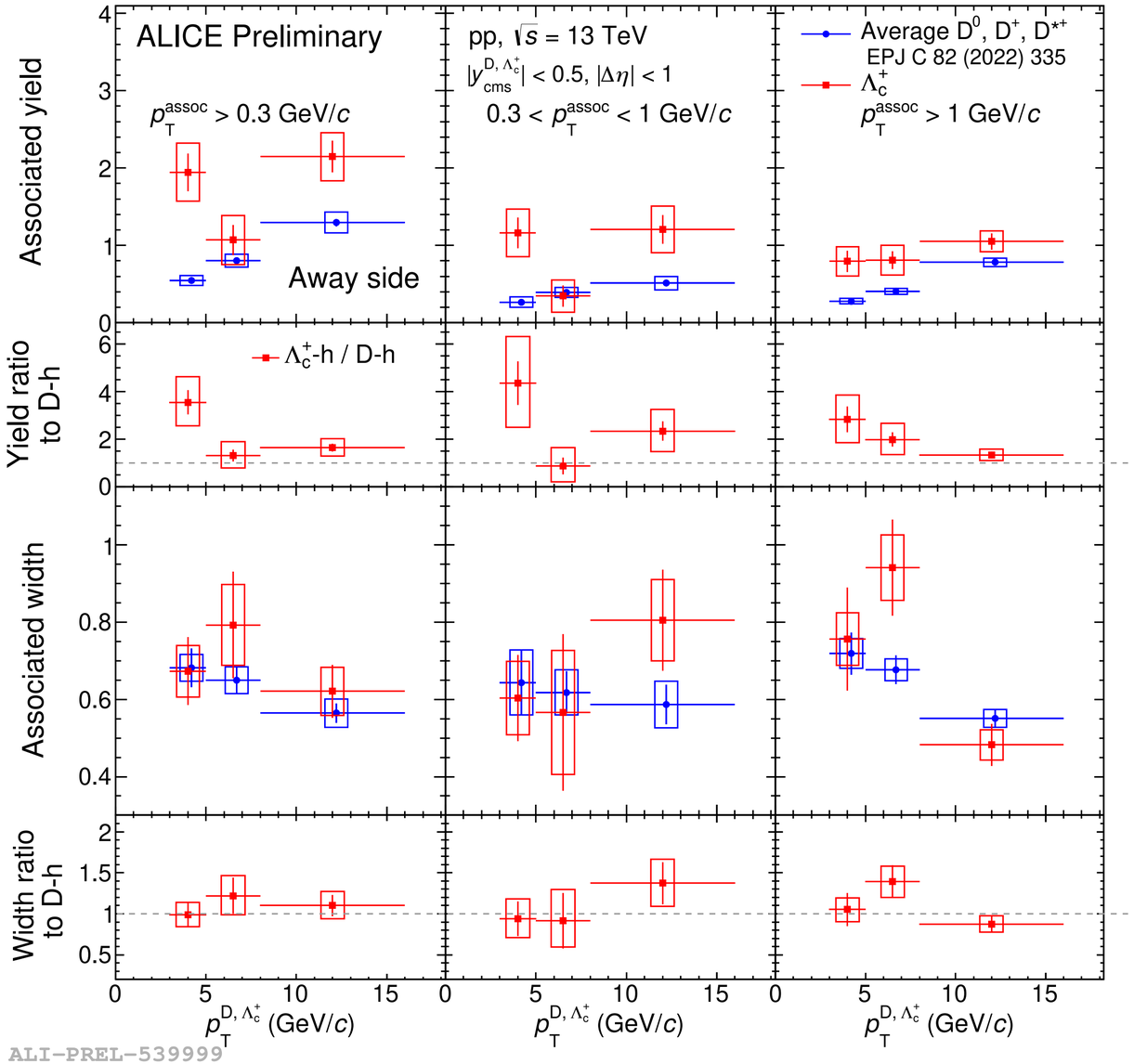
Strange HF hadron correlations in pp

$\Delta\varphi(\mathrm{D_s}^+ - \mathrm{h})$ correlations in pp collisions

Run 3



HF baryon correlations in pp



Away-side