Charm jet and correlation measurements with ALICE in pp and p–Pb collisions at the LHC

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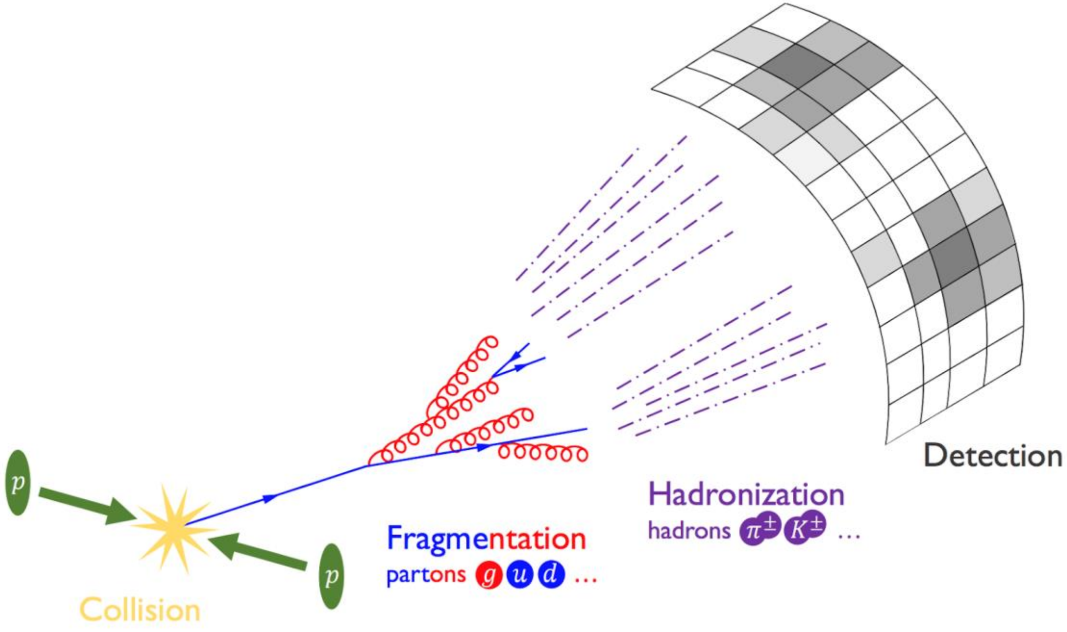
Physics Outline

The study of Heavy-Flavour (HF) quarks in small system provides the reference for the understanding of their interaction with the Quark Gluon Plasma (QGP).

In pp collisions, they are useful to:

- test pQCD calculation;
- constrain and validate fragmentation and hadronization models;
- provide a reference for larger systems, such as p-Pb and Pb-Pb.

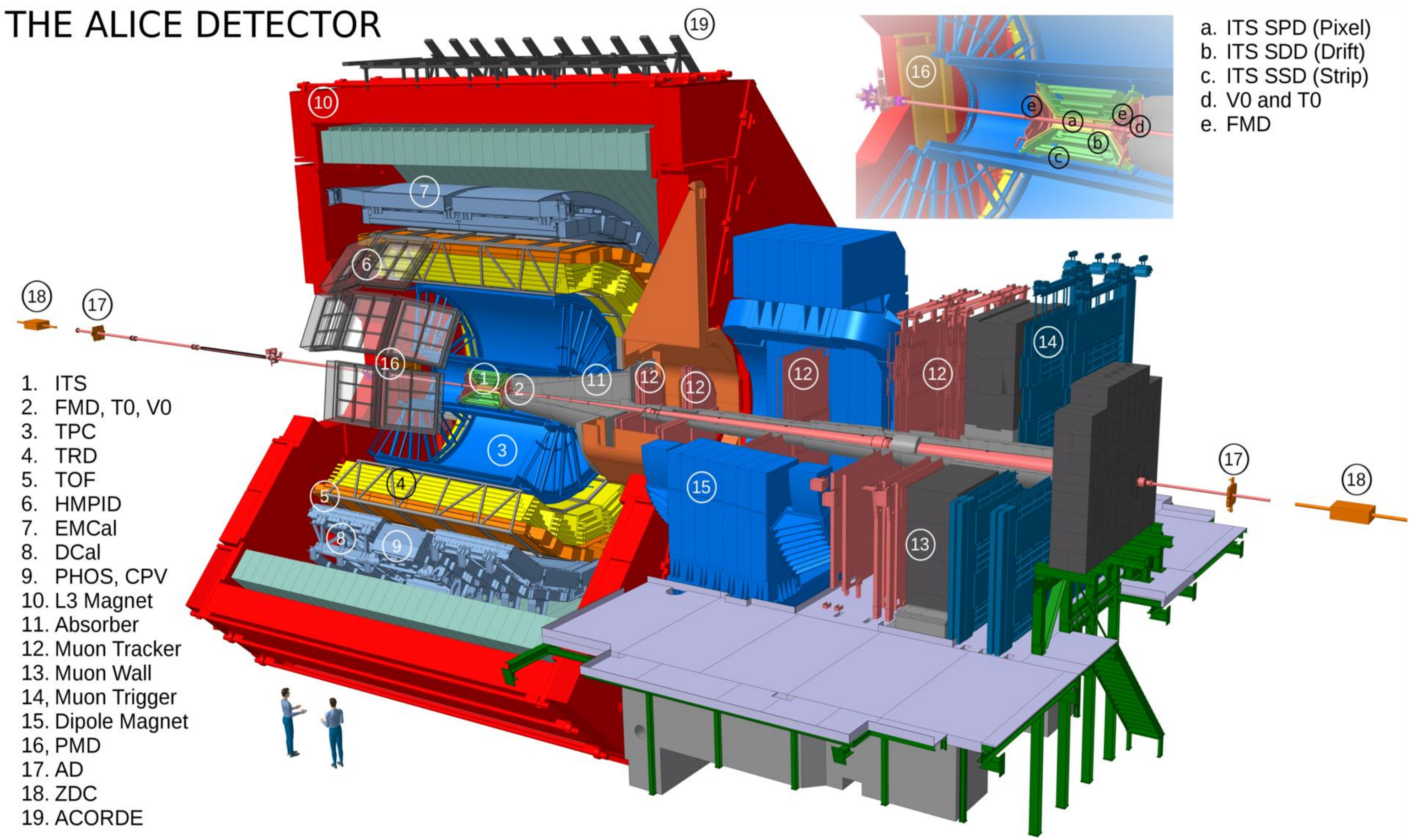


In p-Pb:

- their production and kinematic properties can be modified by cold nuclear matter (CNM) effects like shadowing or energy loss-mechanisms.

Differential studies as HF-jets and HF-correlations can give a more direct access to the parton dynamics, providing more information than single particle studies.

ALICE: A Large Ion Collider Experiment



ITS: tracking + vertexing ($|\eta| < 0.9$)

TPC: tracking + PID ($|\eta| < 0.9$)

TOF: PID ($|\eta| < 0.9$)

EMCAL: high-pT trigger + electron ID ($|\eta| < 0.7$)

V0: trigger + centrality/multiplicity estimation ($-3.7 < \eta < -1.7$, $2.8 < \eta < 5.1$)

ZDC: centrality estimation ($4.8 < \eta < 5.7$)

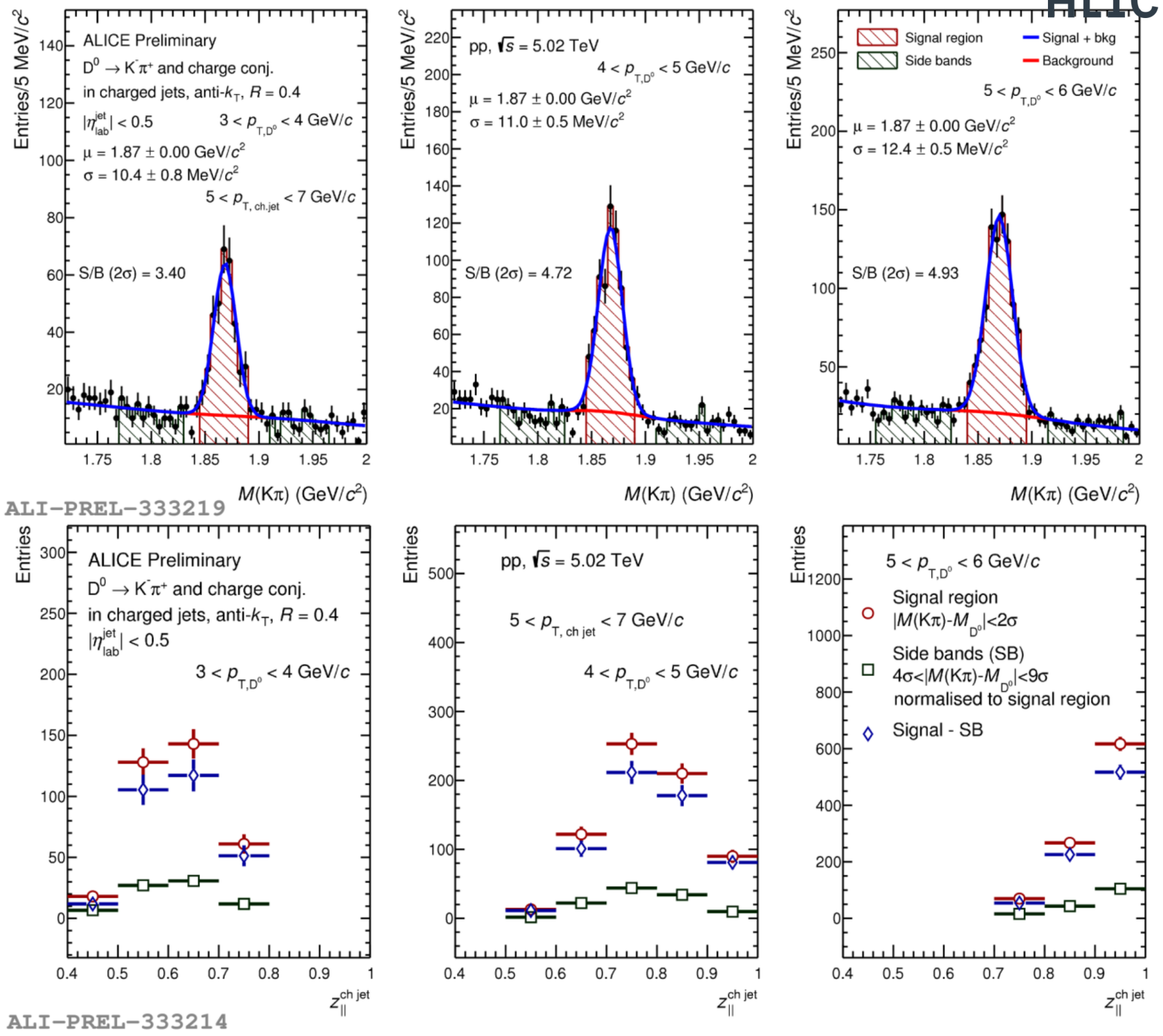
D^0- and Λ_C- tagged jets

Analysis strategy: charm-tagged jets

- Topological reconstruction of the charm candidates

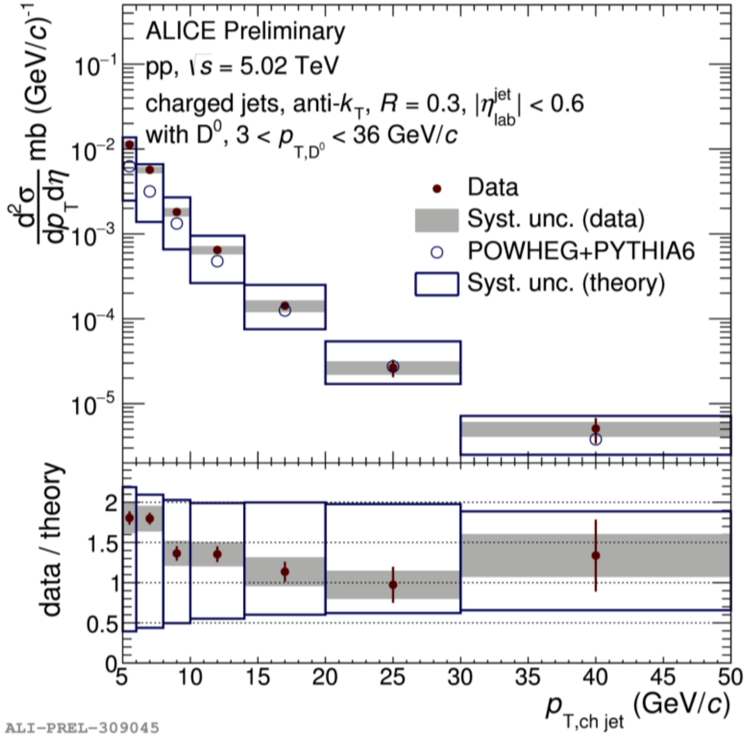
$$D^0 \rightarrow K^-\pi^+ + \text{conj. (B.R. 3.89\%)}$$
$$\Lambda_C^+ \rightarrow pK_S^0 + \text{conj. (B.R. 1.59\%)}$$

- For every candidate, the jet-finder algorithm on charged particles is run (Fastjet, anti-kT).
- Extraction of the jet raw yield through Invariant Mass analysis → Sideband subtraction performed
- Corrections for Jet Efficiency and Beauty Feed-Down
- 2D unfolding for detector effects in order to simultaneously correct the measured $p_{\mathrm{T,\,ch\,jet}}$ and distributions to particle level.

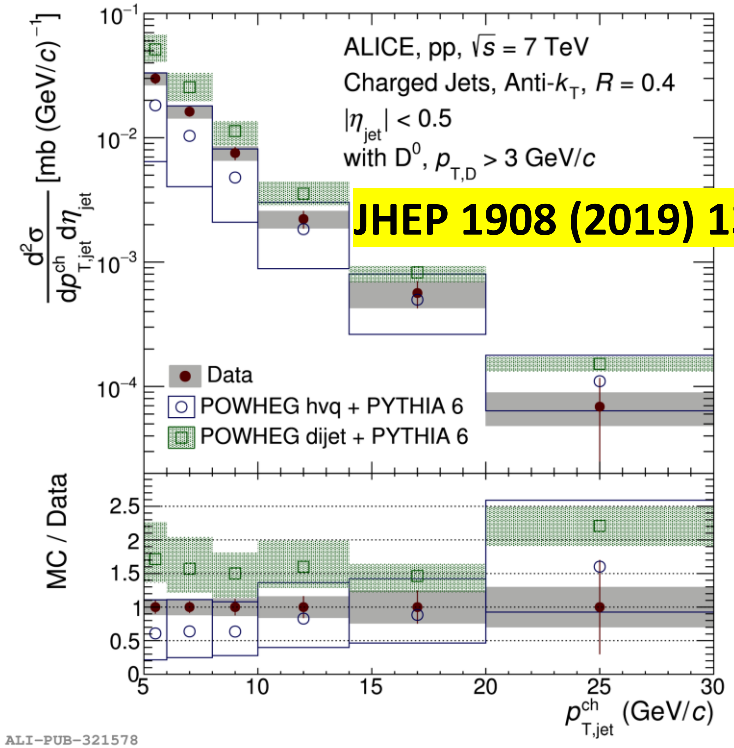


D^0-tagged jets production cross-section

pp at $\sqrt{s}$= 5.02 TeV



pp at $\sqrt{s}$= 7 TeV



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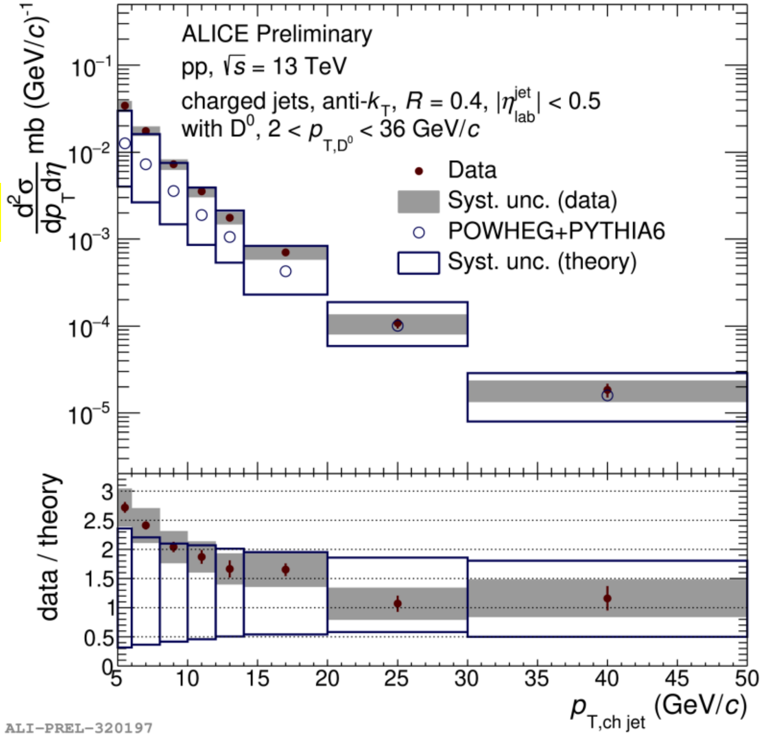
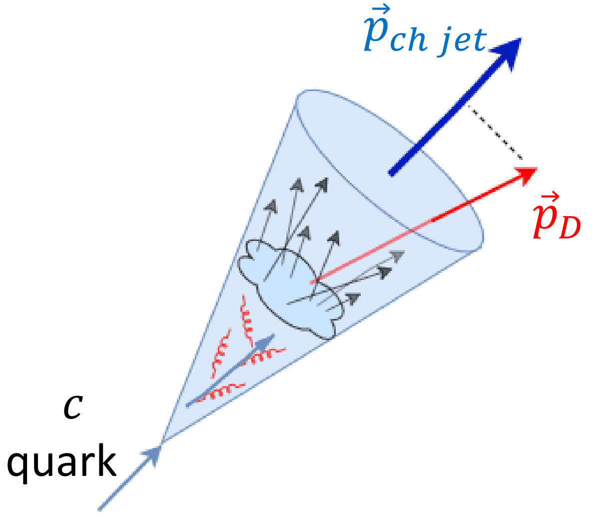
pp at $\sqrt{s}$= 13 TeV



A similar dependence of the D^0-tagged jet cross-section is observed with increasing $p_{\mathrm{T,\ ch\ jet}}$ between the collision energies

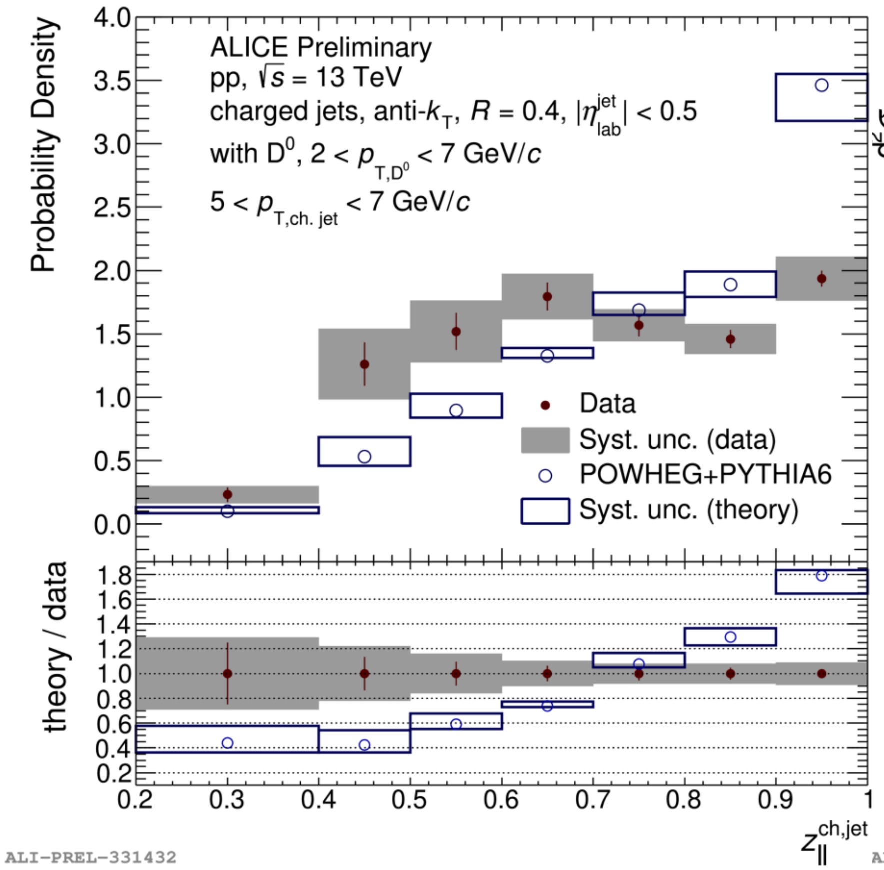
- POWHEG hvq CT10NLO + PYTHIA6 well reproduces the data points, with increasing compatibility with $p_{\mathrm{T,\ ch\ jet}}$
- POWHEG dijet + PYTHIA 6 data above points and different trend wrt POWHEG hvq CT10NLO + PYTHIA6

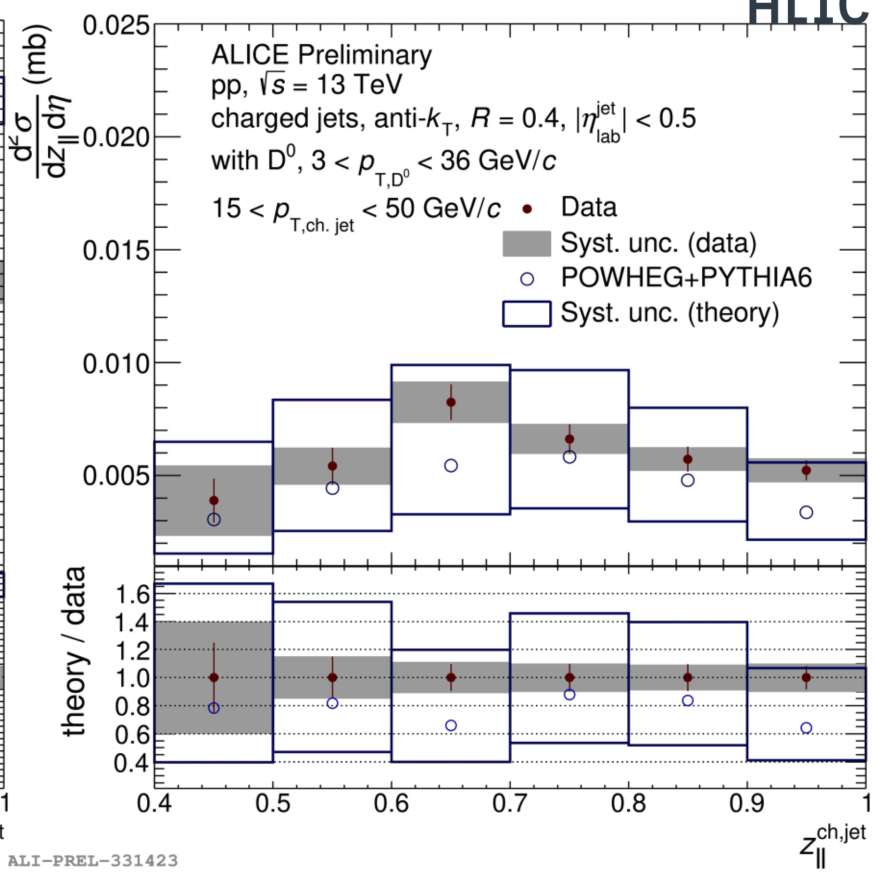
D^0-tagged jets: parallel momentum fraction



Parallel momentum fraction carried by the reconstructed D^0

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





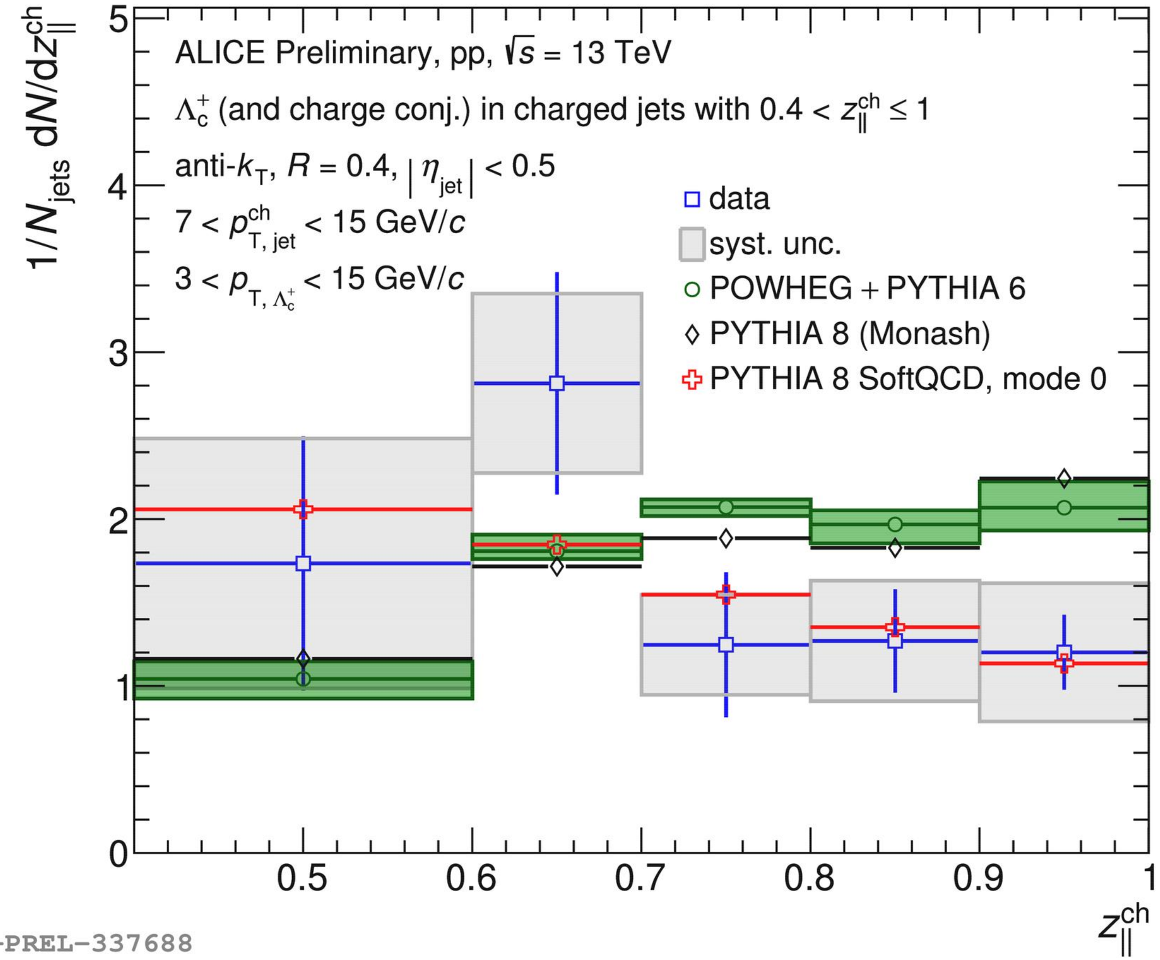
- A softer fragmentation wrt model is observed for small $z_{||}$ at small p_{T}^{D} and in the low- $p_{\text{T, ch jet}}$ range.
- At large $p_{\text{T, ch jet}}$ POWHEG hvq CT10NLO + PYTHIA6 provides results compatible within the syst. uncertainties.

Λ_C -tagged jets: parallel momentum fraction

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

First measurements of $z_{||}^{ch}$ probability density in Λ_C -tagged jets

→ large statistical uncertainties measured.



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Comparisons to models:

- POWHEG hvq CT10NLO + PYTHIA6 and PYTHIA8 (Monash) :

  → softer fragmentation observed in data

- PYTHIA8 SoftQCD

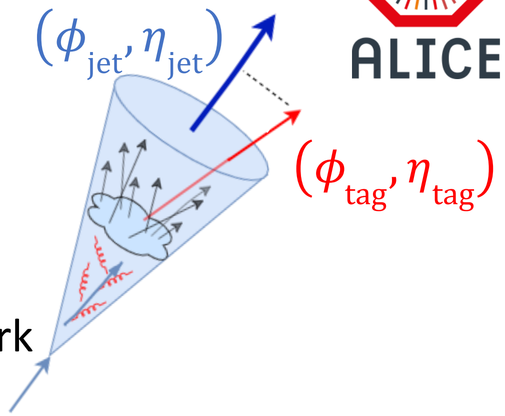
  → predictions show a better agreement with data

D^0 - and Λ_C -tagged jets: Radial Displacement

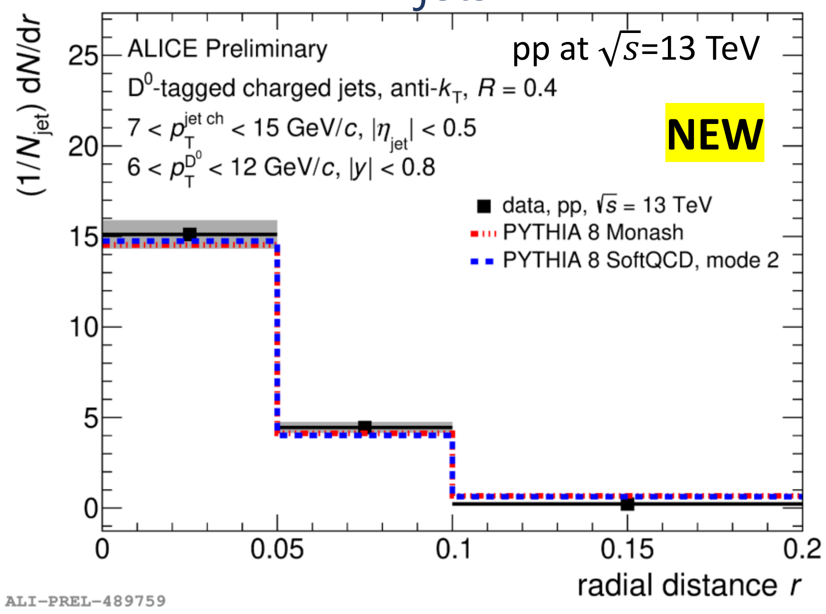
Understanding the impact of hadronization mechanisms on the radial shape of the hf- tagged jets.

A “radial distance” can be defined between the jet direction and the identified hf-particle as:

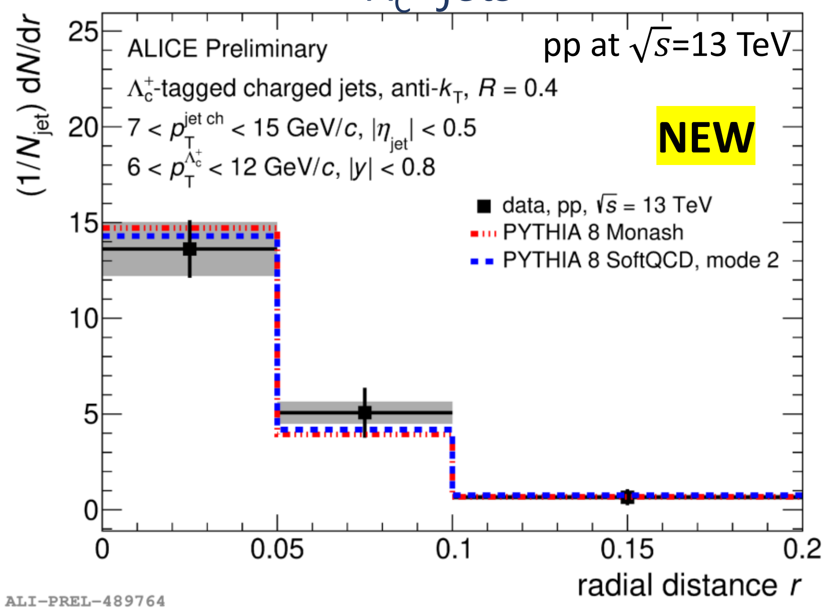
$$r = \sqrt{(\phi_{jet} - \phi_{tag})^2 + (\eta_{jet} - \eta_{tag})^2}$$

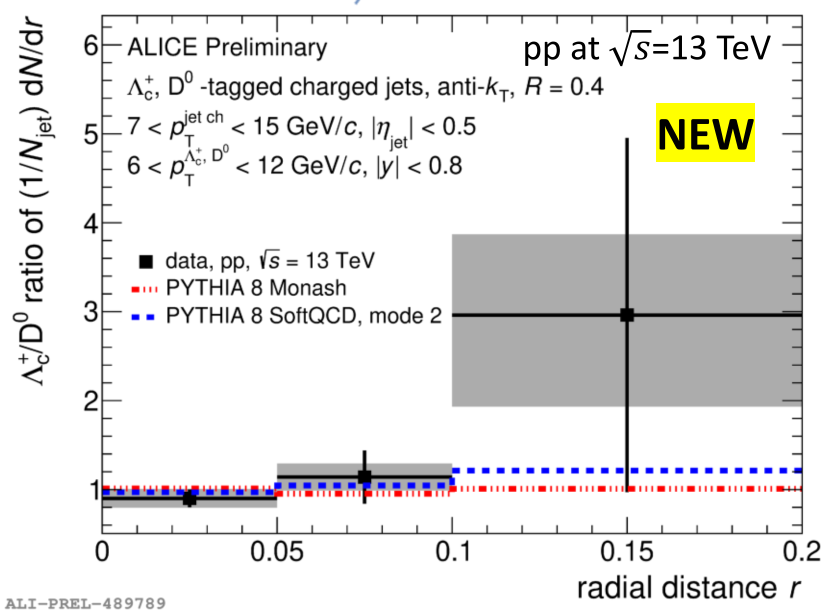


D^0-jets



Λ_C -jets

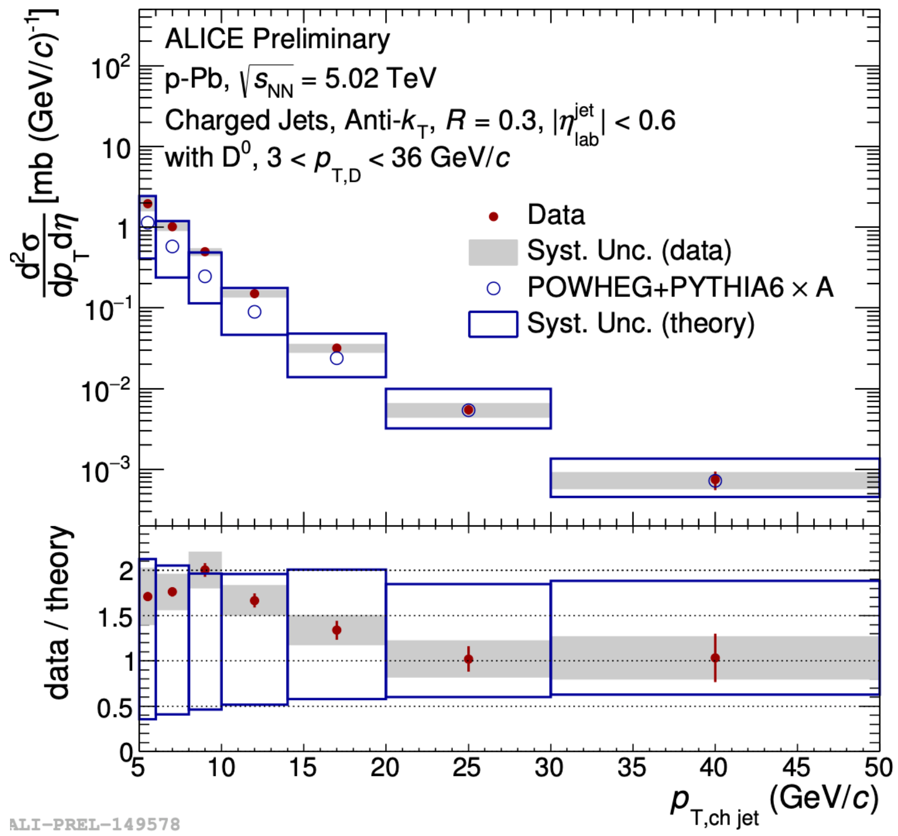


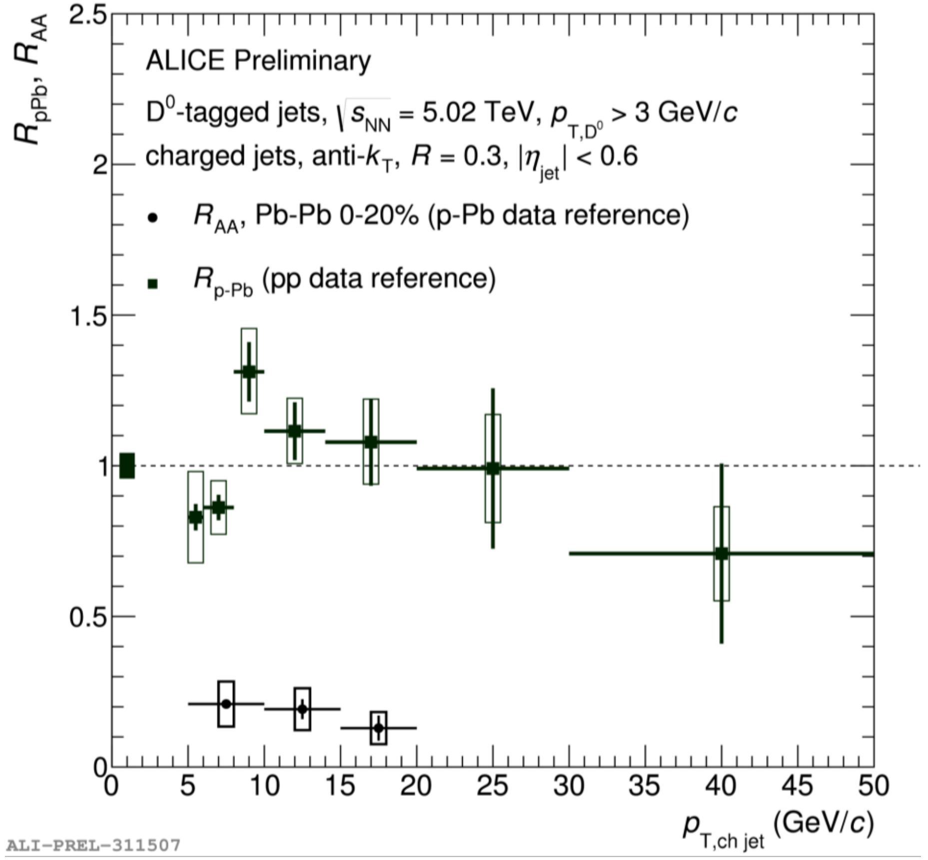


- Hint of a trend in the ratio Λ_C / D^0 as function of the radial distance

  → Possible Λ_C less collimated with the direction of the hf-jet than the D^0

D^0 -tagged jets in p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV





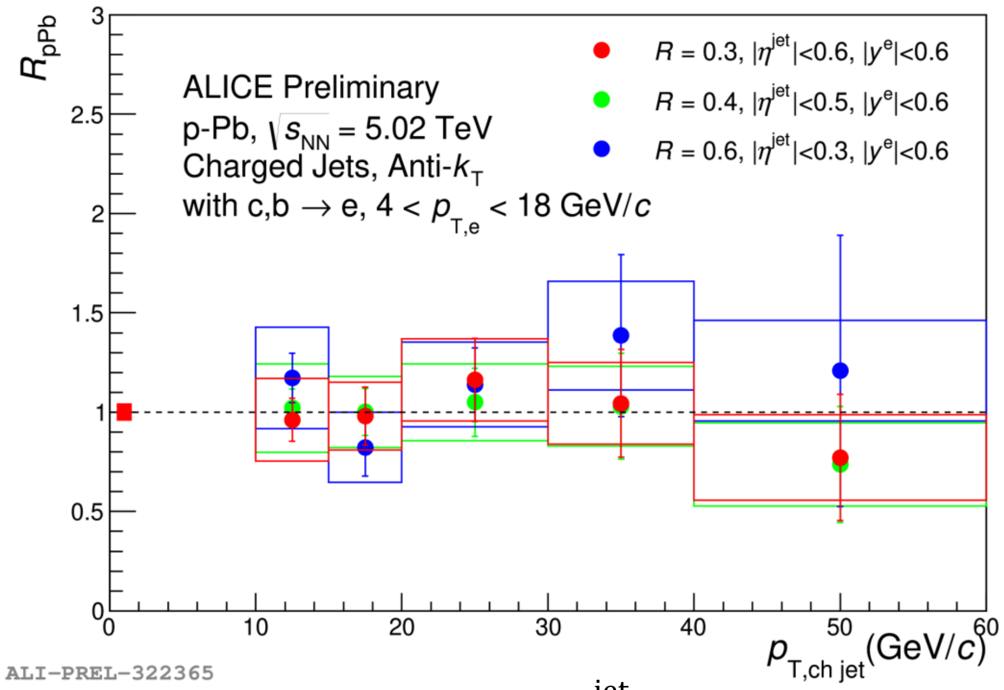
- A good agreement between data and POWHEG + PYTHIA6 predictions in p-Pb.
- The differential pp cross section (scaled by A_{Pb} = 208) is compatible within statistical uncertainties with the p-Pb data.
- The nuclear modification factor $R_{pPb} \approx$ 1 over the $p_T^{ch,jet}$ interval.

HF-electron jets in p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

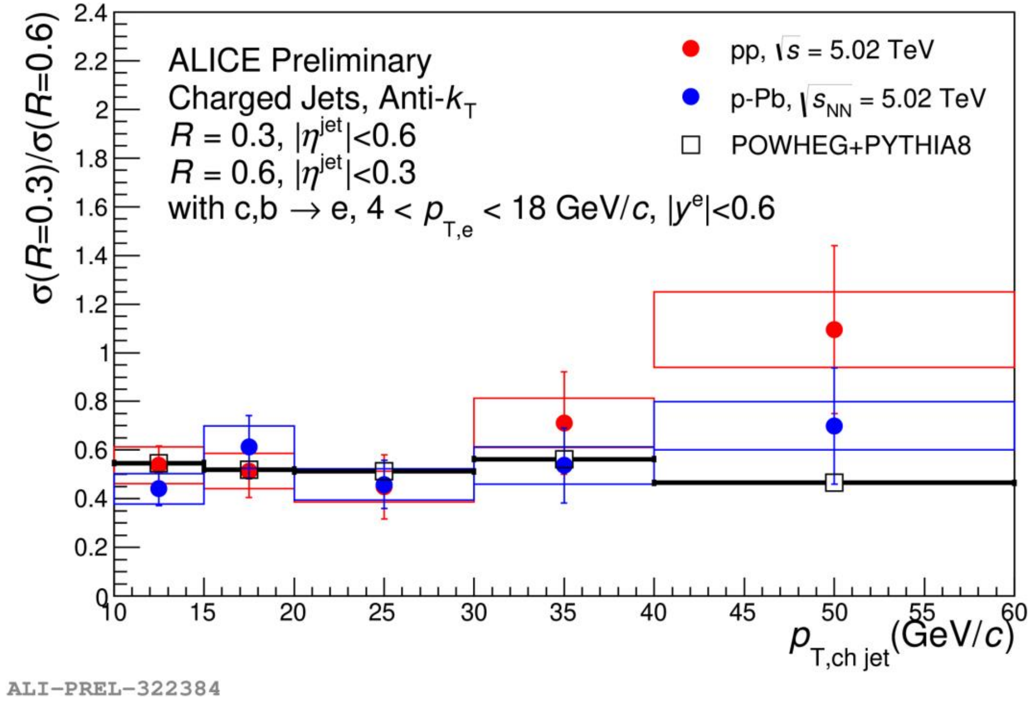
Jets containing electrons from a HF-hadron semileptonic decay are measured both in pp and p-Pb.

In p-Pb, modifications to the jet-shape or spectrum, are evidences of final states effects (QGP):

- *jet broadening*: dependence on R (jet cone size);
- *jet suppression*: modification to the p_T^{jet} spectrum .



R_{pPb} not dependent on jet R: p_T^{jet} spectrum not modified



Jet shape unmodified in pp and p-Pb collisions

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In p-Pb, modifications to the jet-shape or spectrum, are evidences of final states effects (QGP):

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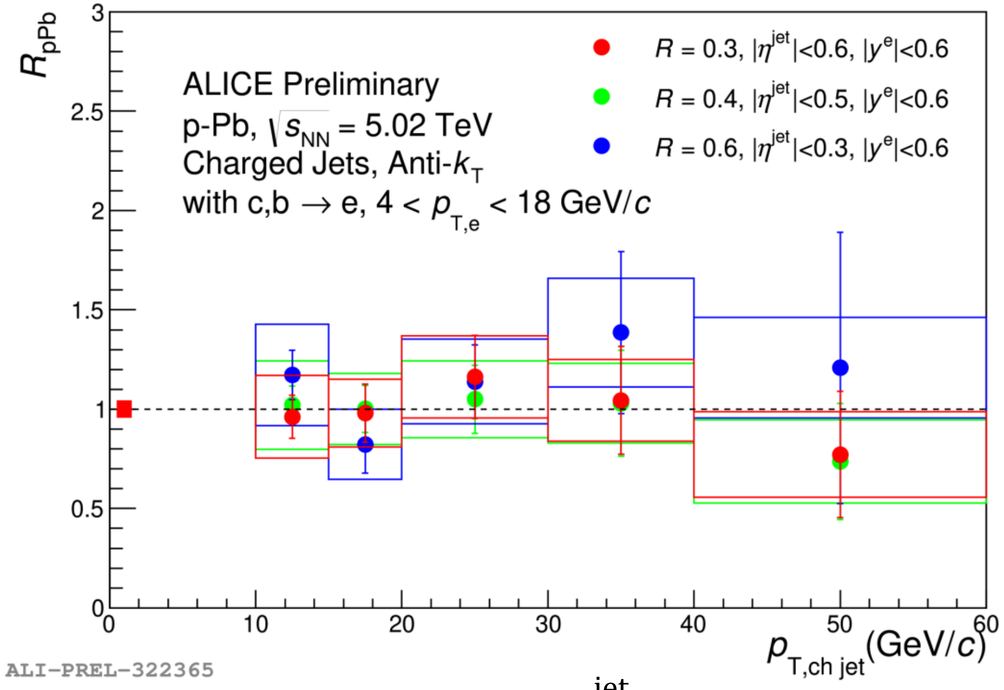
- *jet suppression*: modification to the p_T^{jet} spectrum .

No evidences of modification of the jet in small system



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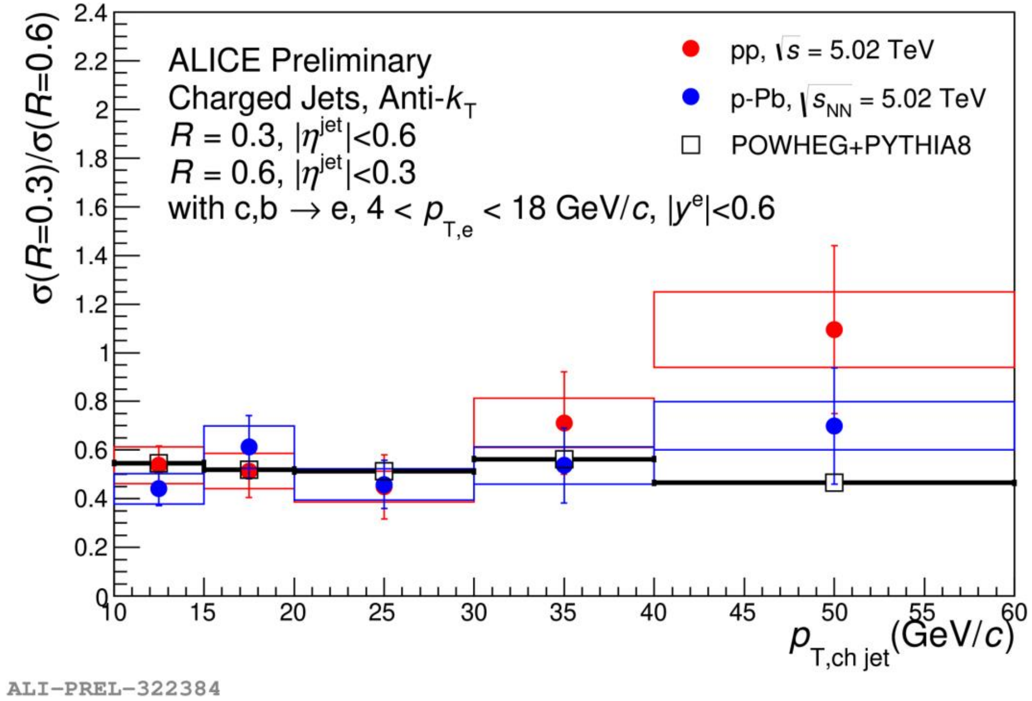


Jet shape unmodified in pp and p-Pb collisions

D - charged particles azimuthal correlations

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

- Sensitive to the production mechanisms

  Pair Creation (LO): c quarks are produced back-to-back

  - "Near Side" peak at $\Delta\varphi = 0$: populated by particles from the showering of the D-meson parent c quark;
  - "Away side" peak at $\Delta\varphi = \pi$: "*recoiling jet*" particles;

  Hard gluon radiation (NLO): smearing of both peaks;

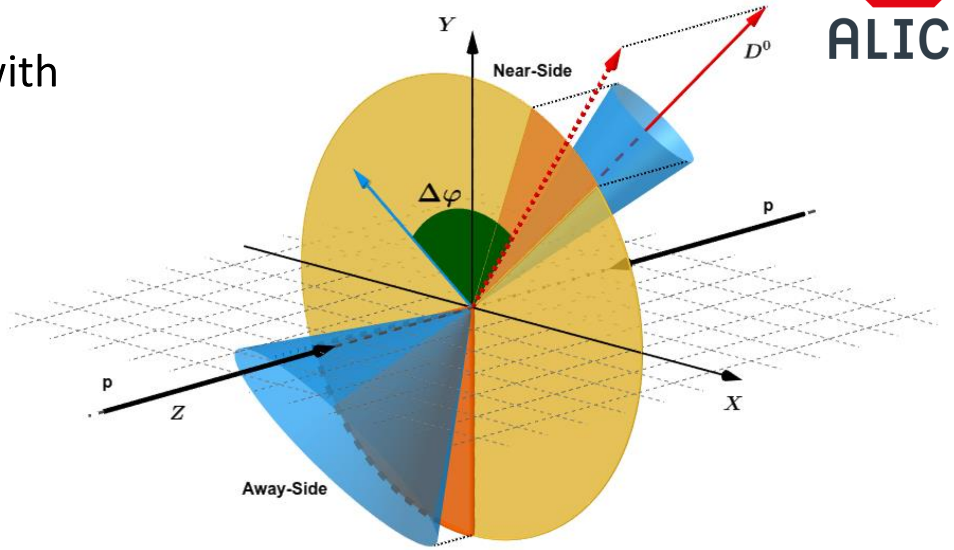
  Gluon splitting (NLO): c-$\bar{c}$ produced closely, so showering products are collimated the direction of the tagged D meson

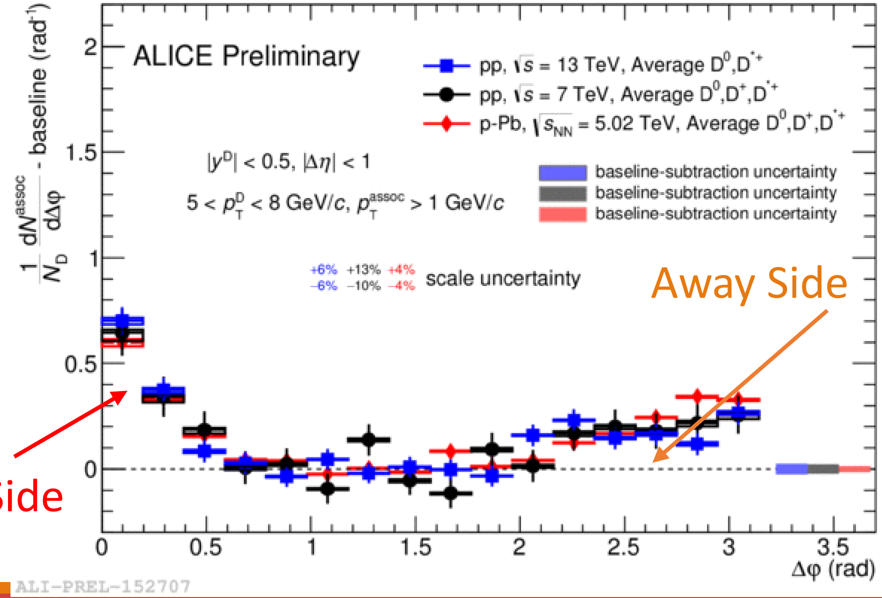
  Flavour excitation (NLO): flat contribution with $\Delta\varphi$.

- Differential description of the peaks shape with $p_{\mathrm{T}}^{\mathrm{assoc}}$

  Characterization of the charm fragmentation products.

In p-Pb, find modifications to the correlation shape induced by CNM effects.





Near Side

D - charged particles azimuthal correlations

1) Evaluation of the 2D Correlation Distributions$(\Delta\varphi, \Delta\eta)$:

- Topological reconstruction of D meson candidates

$$D^0 \rightarrow K^-\pi^+ + \text{conj.} \qquad (\text{B.R. } 3.89\%)$$
$$D^+ \rightarrow K^-\pi^+\pi^+ + \text{conj.} \qquad (\text{B.R. } 9.38\%)$$
$$D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+ + \text{conj.} \quad (\text{B.R. } 2.67\%)$$

- Identification of associated (charged) particles;
- Sideband subtraction and event-mixing technique;
- Corrections for efficiency, acceptance;
- Integration over $|\Delta\eta| < 1$;
- Corrections for contamination and feed-down.

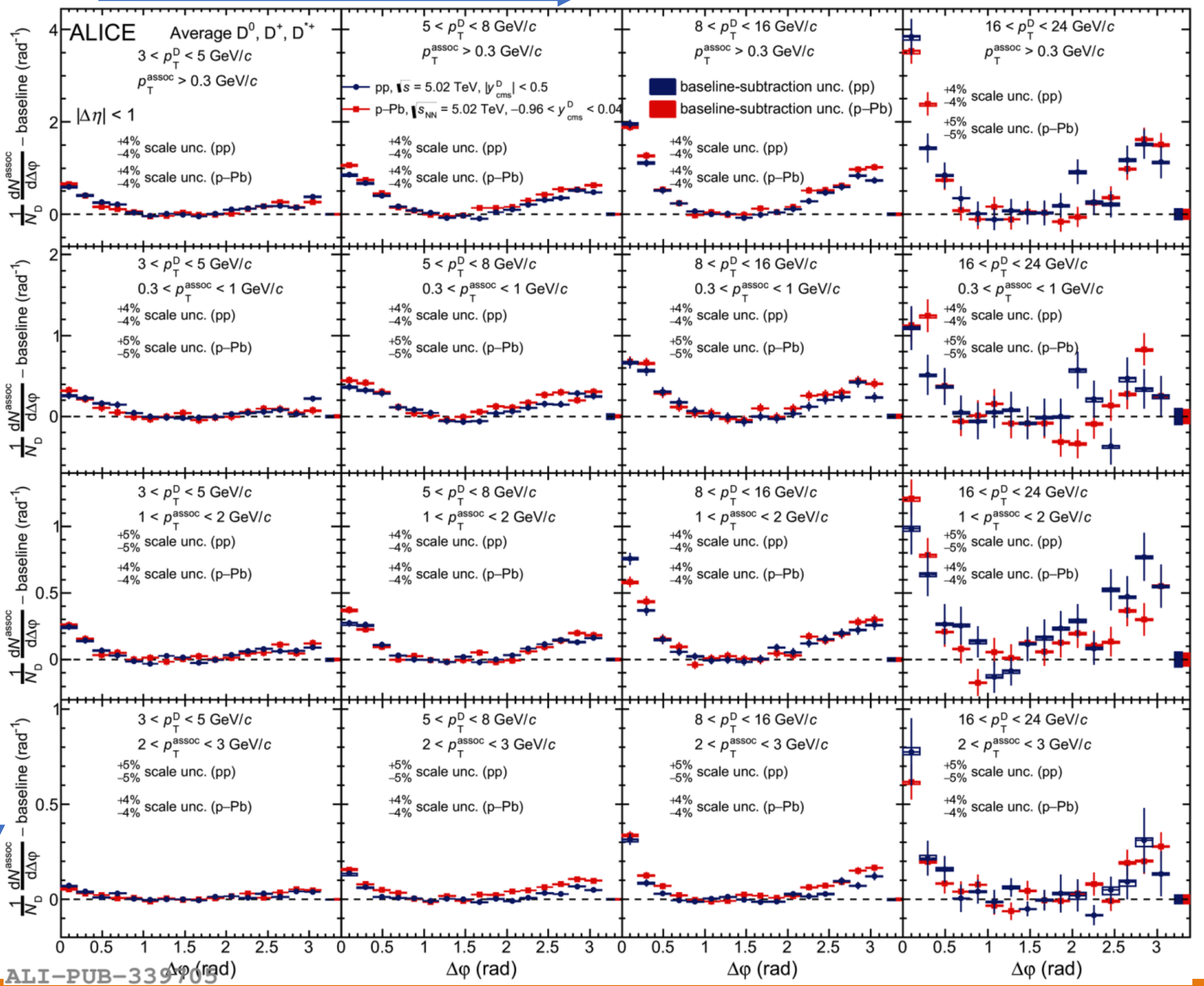
2) Fit procedure:

- Generalized Gaussian (NS) + Gaussian (AS) + constant term (Baseline)

Preliminary results are also available for pp collision at $\sqrt{s}$= 13 TeV

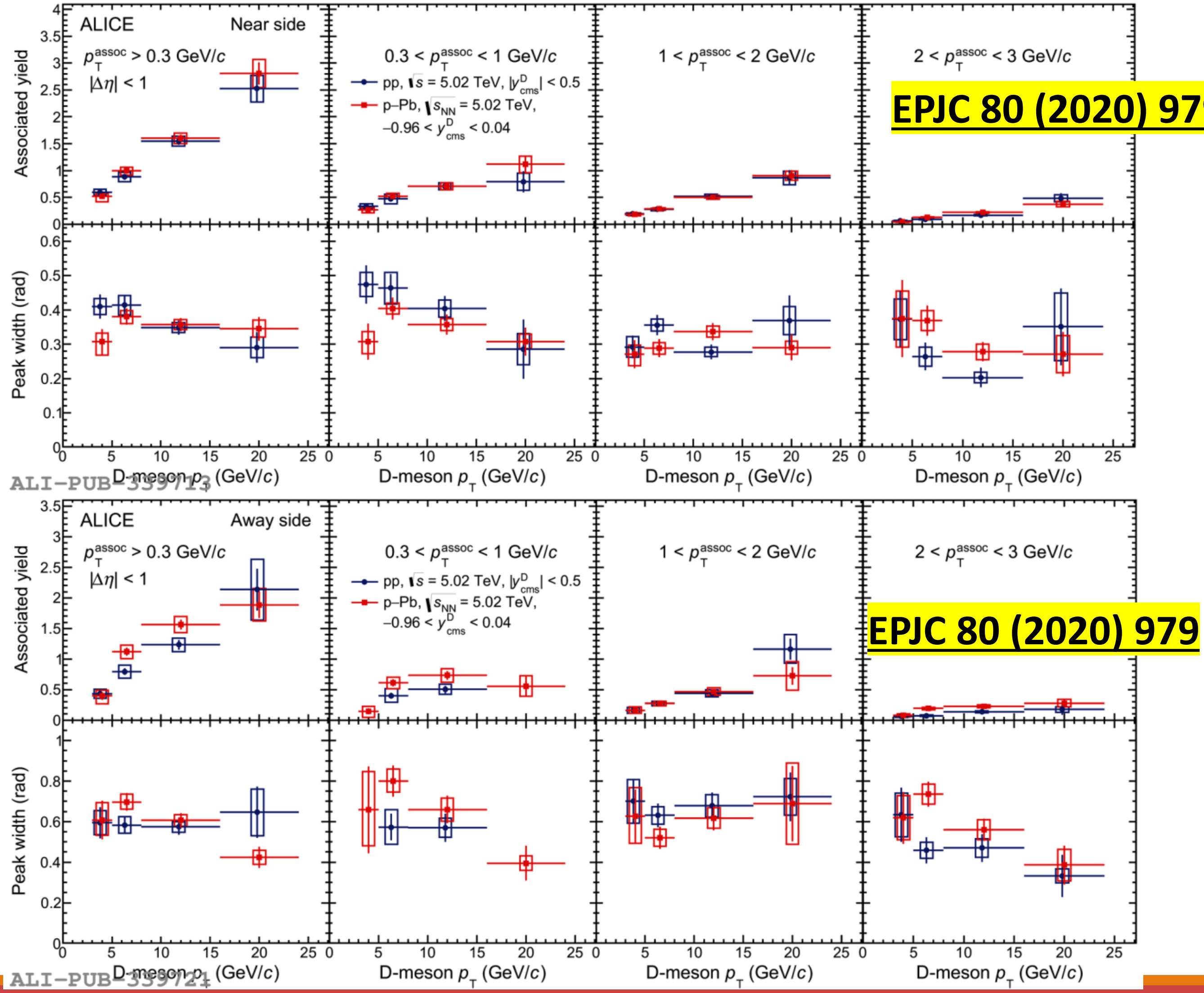
p_T^D(GeV/c) pp and p-Pb at $\sqrt{s}$= 5.02 TeV

p_T^{assoc}(GeV/c)



D - charged particles azimuthal correlations

pp and p-Pb at $\sqrt{s}$= 5.02 TeV p_{T}^{assoc} (GeV/c)



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- Corrections for contamination and feed-down.

2) Fit procedure:

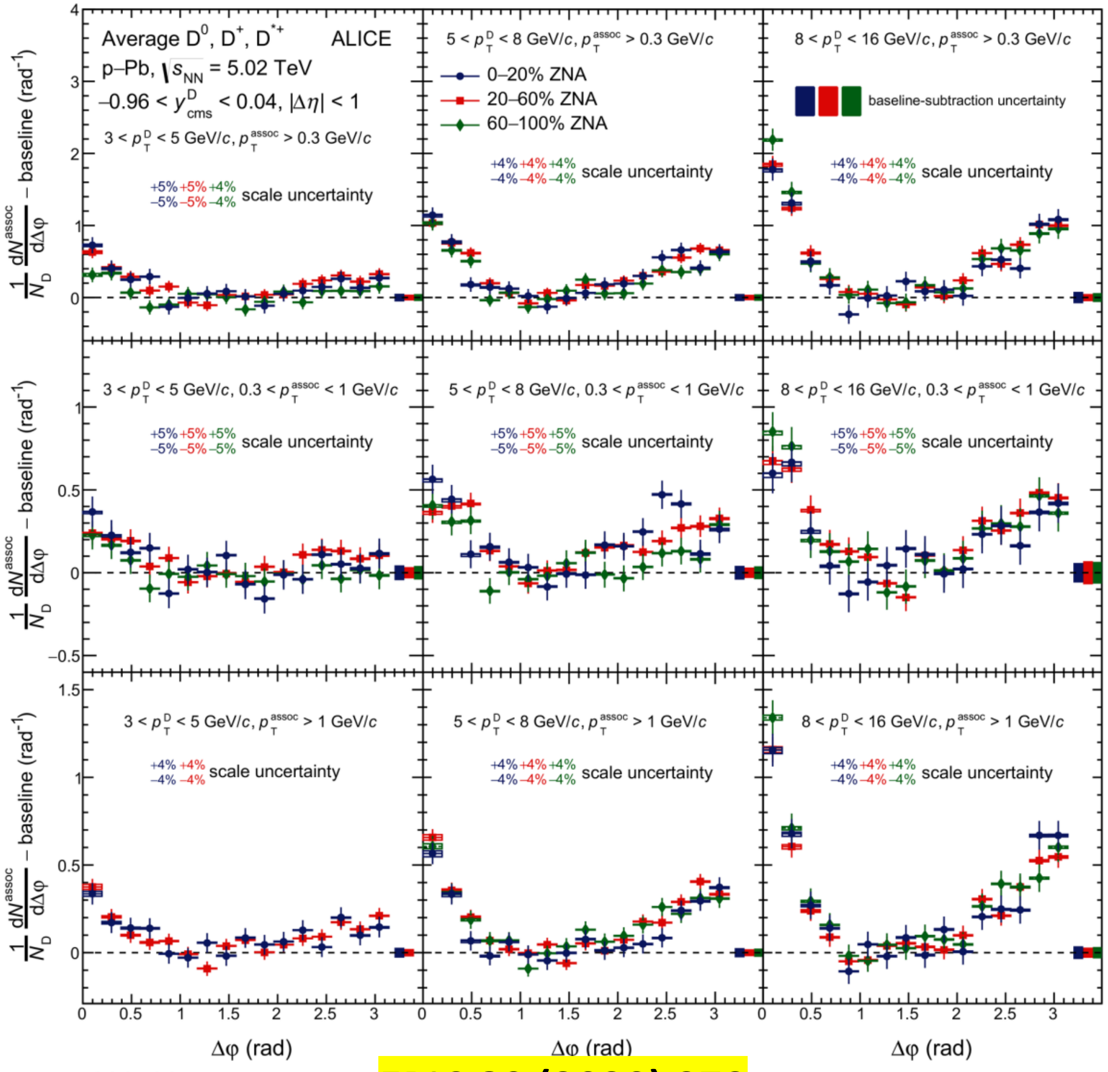
- Generalized Gaussian (NS) + Gaussian (AS) + constant term (Baseline)

Consistent values of the fit observables in pp and p-Pb collisions are observed in all kinematic ranges.

→ no significant impact from cold-nuclear-matter effects on the c fragmentation arises with current statistics.

D - charged particles azimuthal correlations

p-Pb at $\sqrt{s}$= 5.02 TeV



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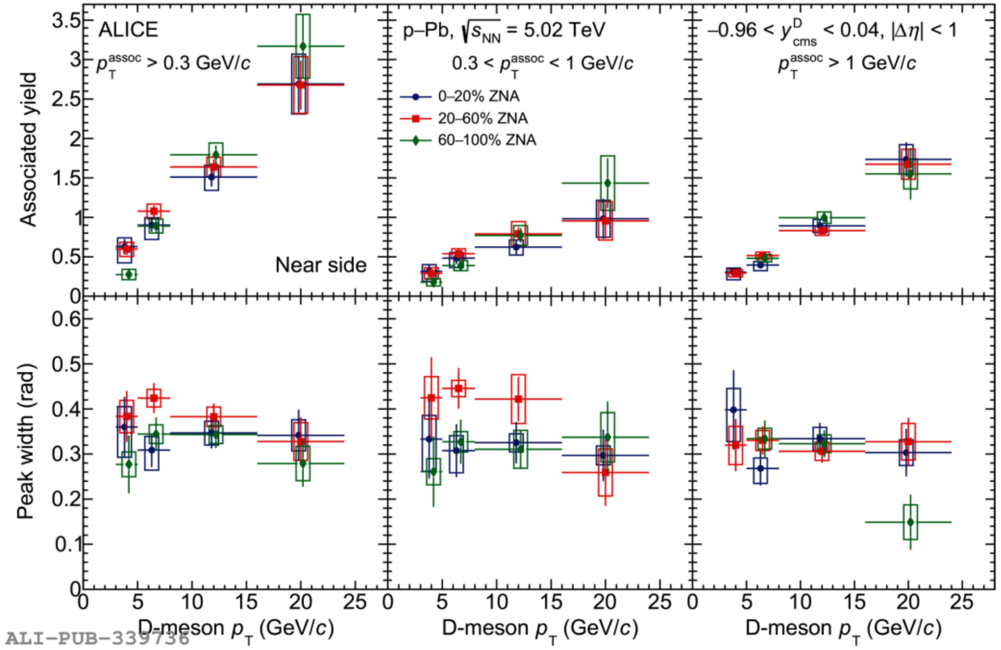


Azimuthal correlation distributions in p-Pb are studied also as function of the collision centrality to better address possible modifications to the fragmentation of the c quark.

- p-Pb distribution shapes are compatible within statistical uncertainties. The fit observables do not show a dependence on the collision centrality.

HFe-charged particles azimuthal correlation distributions

HF-electron sources are:

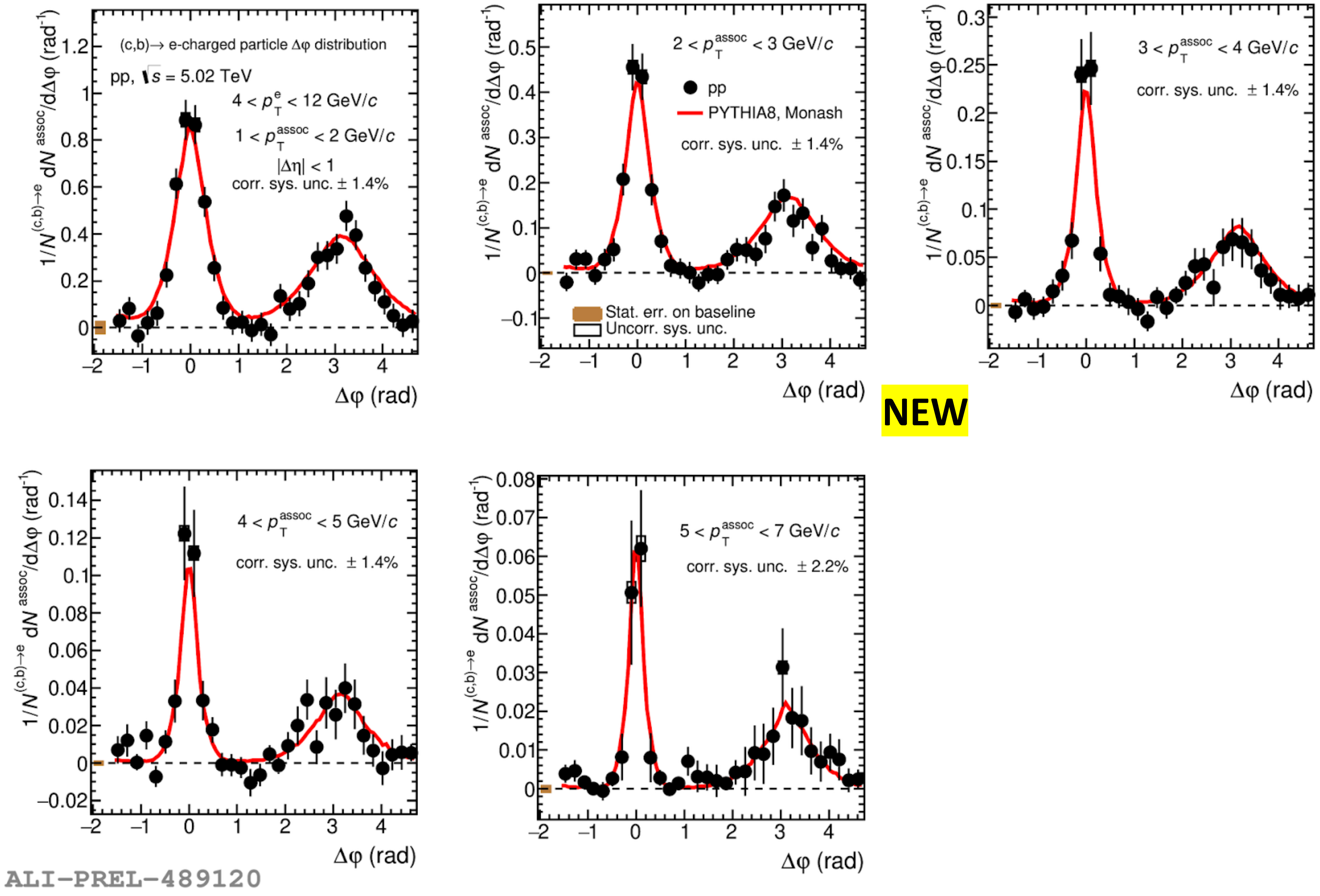
- semi-leptonic decays of heavy-flavour hadrons.

Main background contributions come from:

- Dalitz decays of light neutral mesons,
- photon conversion in the detector material.

The azimuthal correlation distribution undergoes a correction procedure similar to that of the D meson distribution.

Fitting procedure:
Two generalized gaussian are considered for the peaks.



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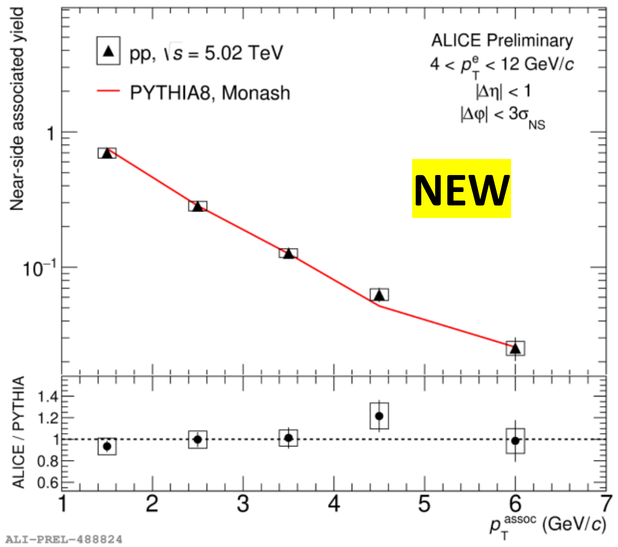
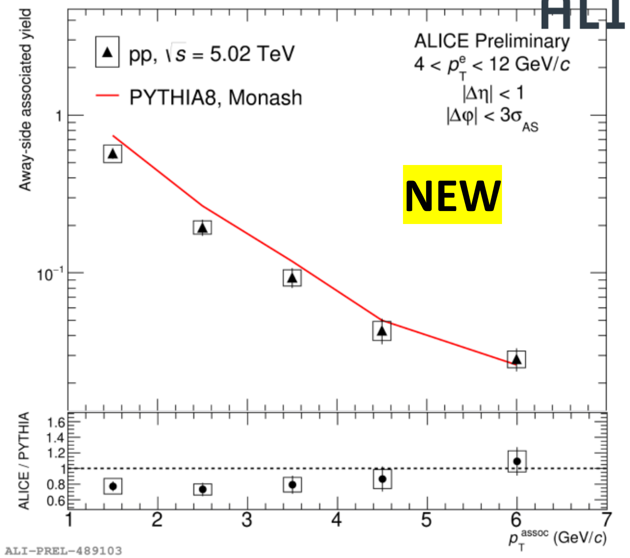
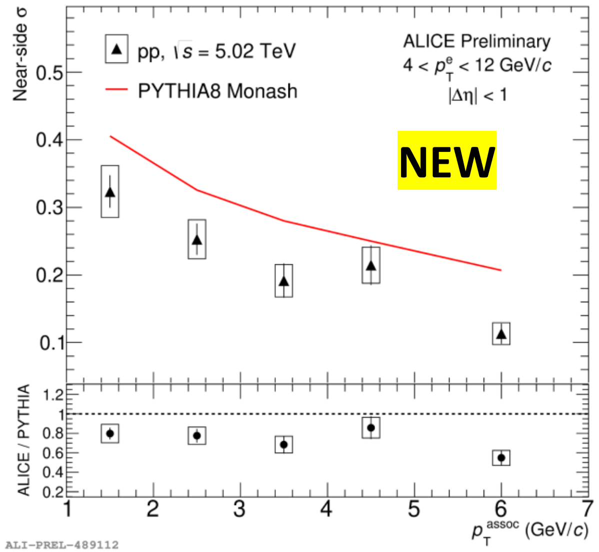
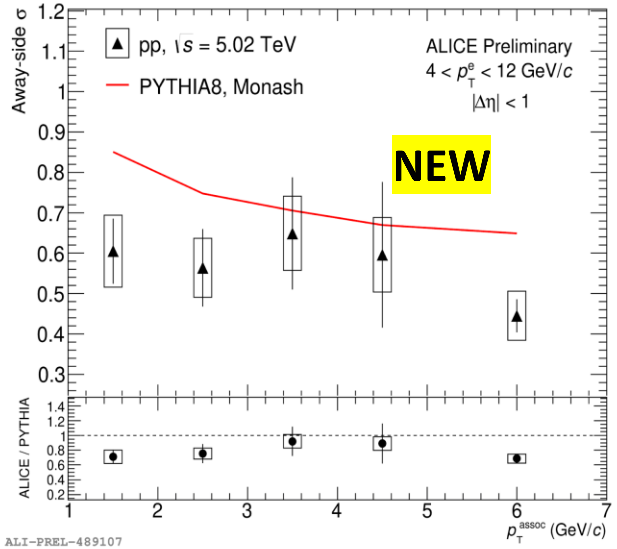
The azimuthal correlation distribution undergoes a correction procedure similar to that of the D meson distribution.

Fitting procedure:
Two generalized Gaussian are considered for the peaks:
- NS yield is very well reproduced by the PYTHIA8;
- both the widths are underestimated by the PYTHIA8 predictions.

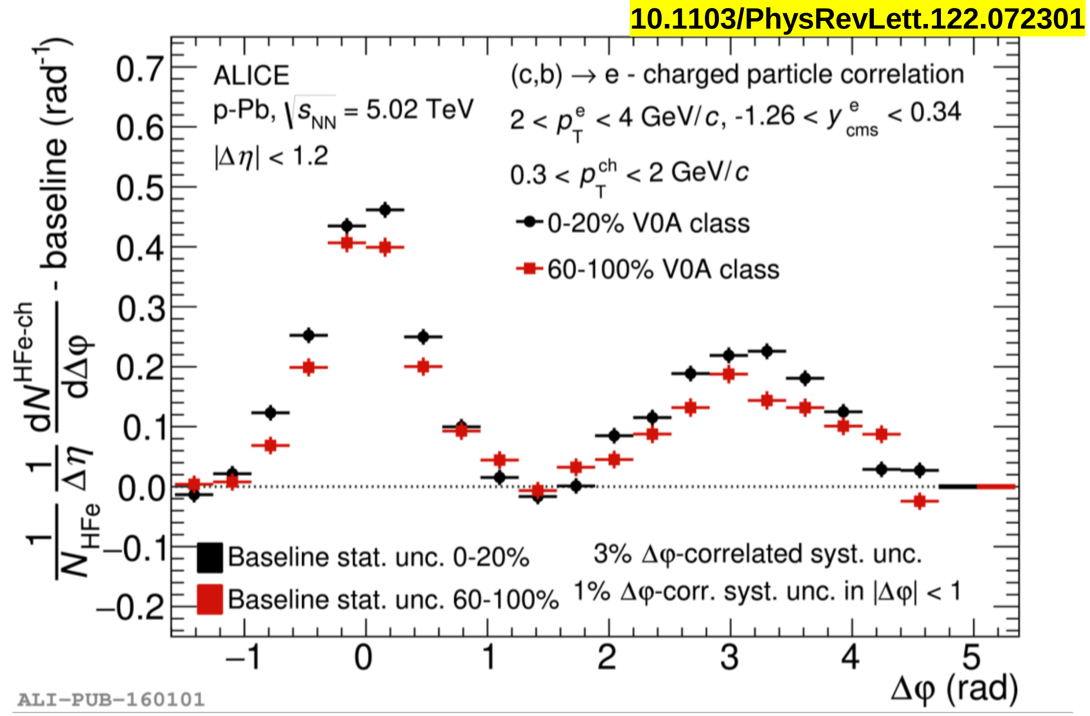


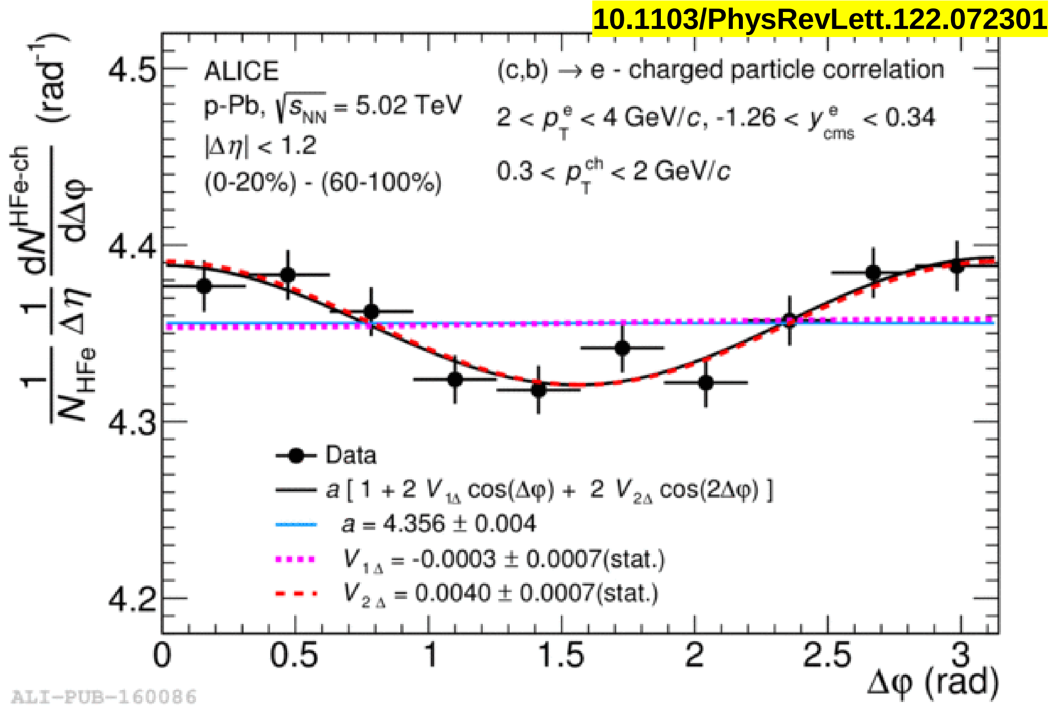






HFe-charged particles azimuthal correlation distributions





Azimuthal correlations between heavy-flavour decay electrons with charged particles are computed in two multiplicity classes considering p-Pb collisions:

- HM (high multiplicity, 0-20%)
- LM (low multiplicity, 60-100%)

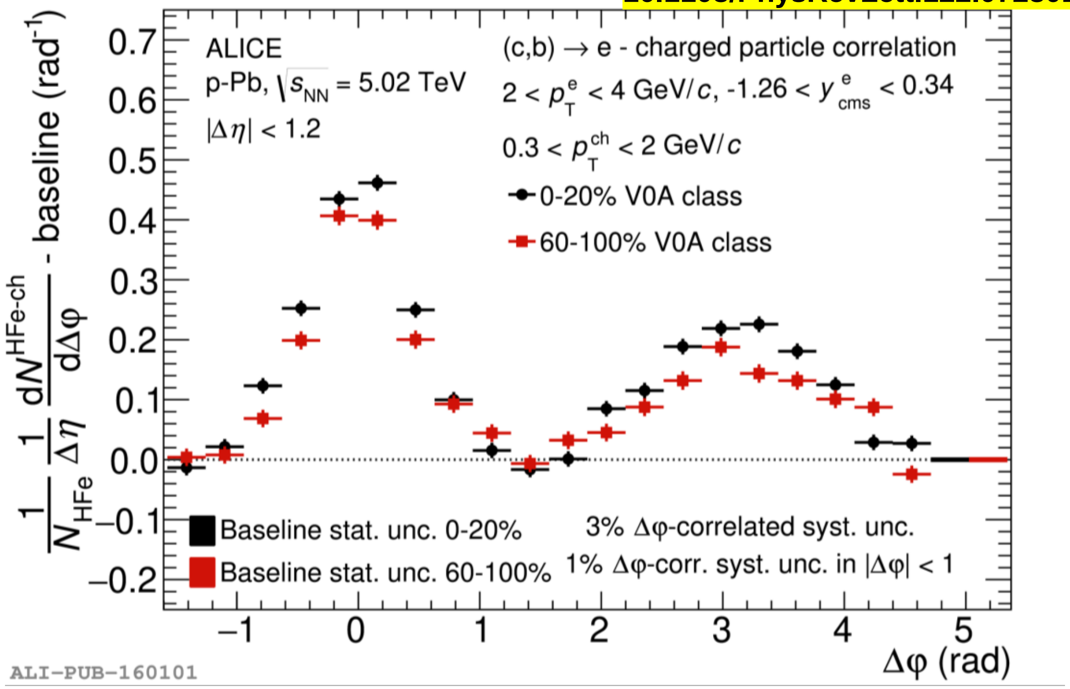
The jet-induced correlations peaks are removed by subtracting the LM from the HM distribution and fitting the resulting distribution with a Fourier decomposition.

Azimuthal Anysotropy is found:

$$v_{2\Delta} = 0.0040 \pm 0.0007 \text{ (stat)}$$

HFe-charged particles azimuthal correlation distributions

10.1103/PhysRevLett.122.072301



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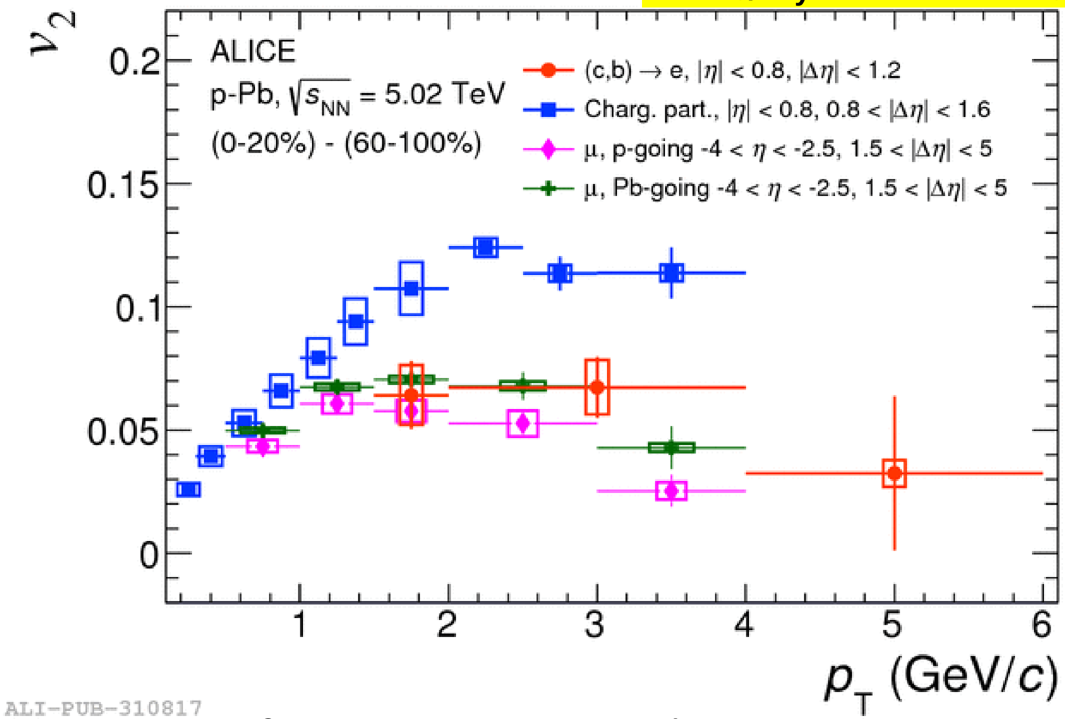

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- HM (high multiplicity, 0-20%)
- LM (low multiplicity, 60-100%)

From factorization approach:

- HFe v_2 is larger than zero
  (about 5σ significance in $1.5 < p_T^e < 4$ GeV/c)

→ Comparable with charged particles and muons

Can this be interpreted as a final state effects ?

Summary

- HF - tagged jets:
  - ✓ theoretical predictions successfully describe the experimental cross-section;
  - ✓ softer fragmentation at low $p_{\mathrm{T,\,ch\,jet}}$ is observed by looking at the fragmentation function;
  - ✓ first measurements of the radial displacement;
  - ✓ nuclear modification factor in D-meson tagged jets;

- HFe – tagged jets
  - ✓ final state effects excluded by studying the dependence of the jet shape on the jet-radius.

- D-h azimuthal correlation distribution:
  - ✓ differential study with $p_{\mathrm{T}}^{\mathrm{D}}$ and $p_{\mathrm{T}}^{\mathrm{assoc}}$;
  - ✓ comparison between measurements in p-Pb and pp;
  - ✓ centrality-dependent study;

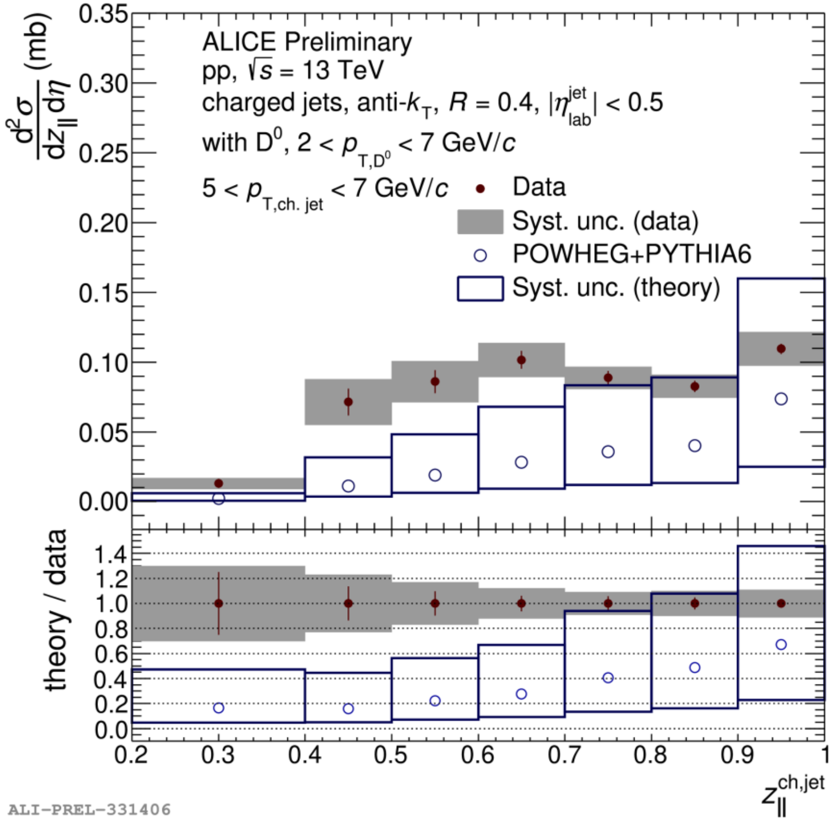
- HFe – charged particle azimuthal correlation distributions
  - ✓ first measurements in pp at $\sqrt{s}$=5.02 TeV;
  - ✓ measurements of positive v_2 in p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV;

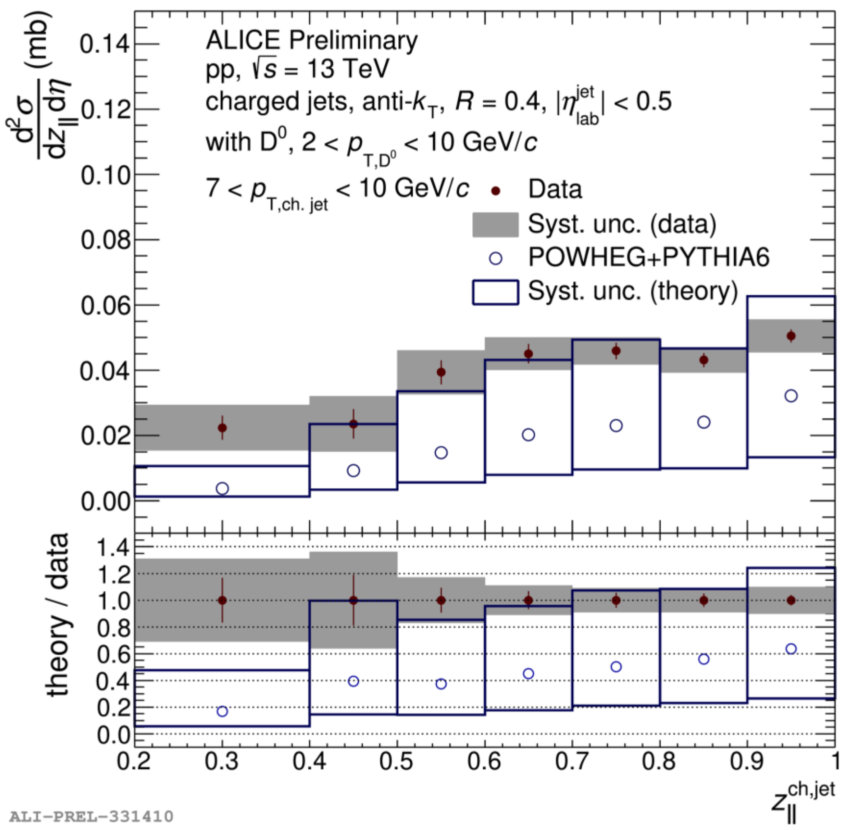
Thanks
for your attention

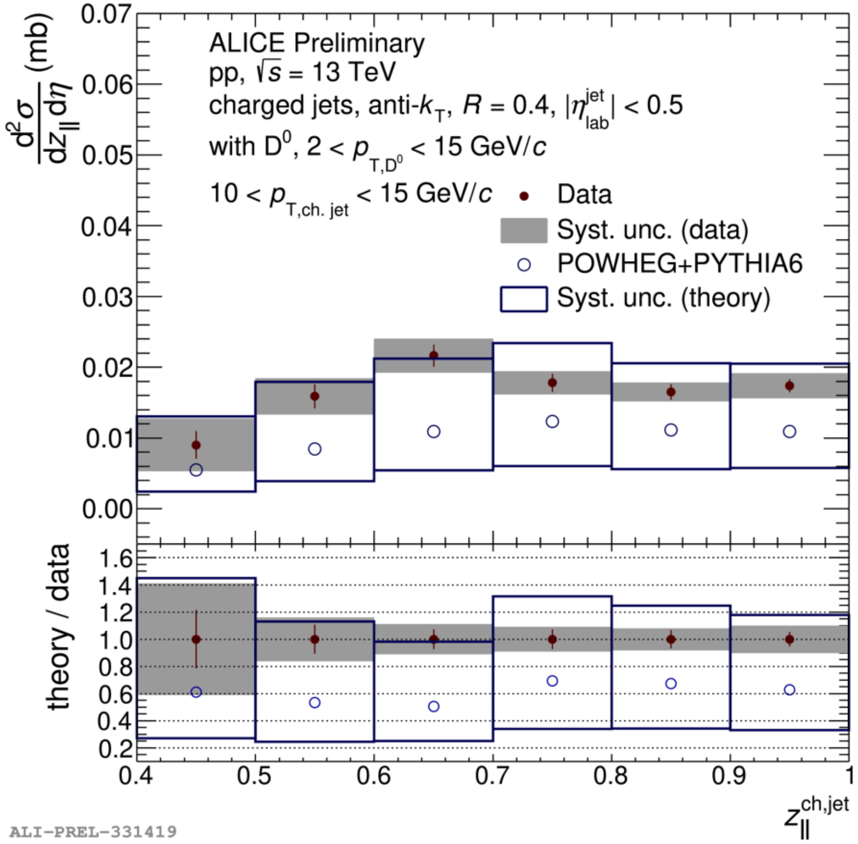
D^0-tagged jets: parallel momentum fraction

$$z_{||}^{\mathrm{ch}} = \frac{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{D}}}{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{ch\ jet}}}$$

pp at $\sqrt{s}$ = 13 TeV







D^0-tagged jets: parallel momentum fraction

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

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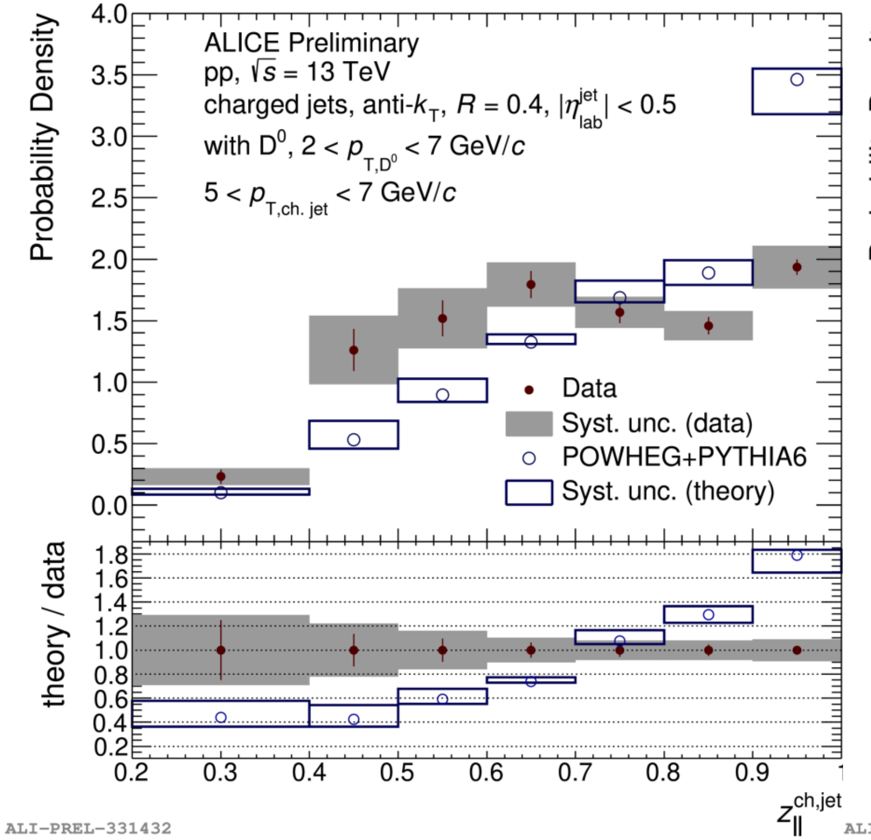
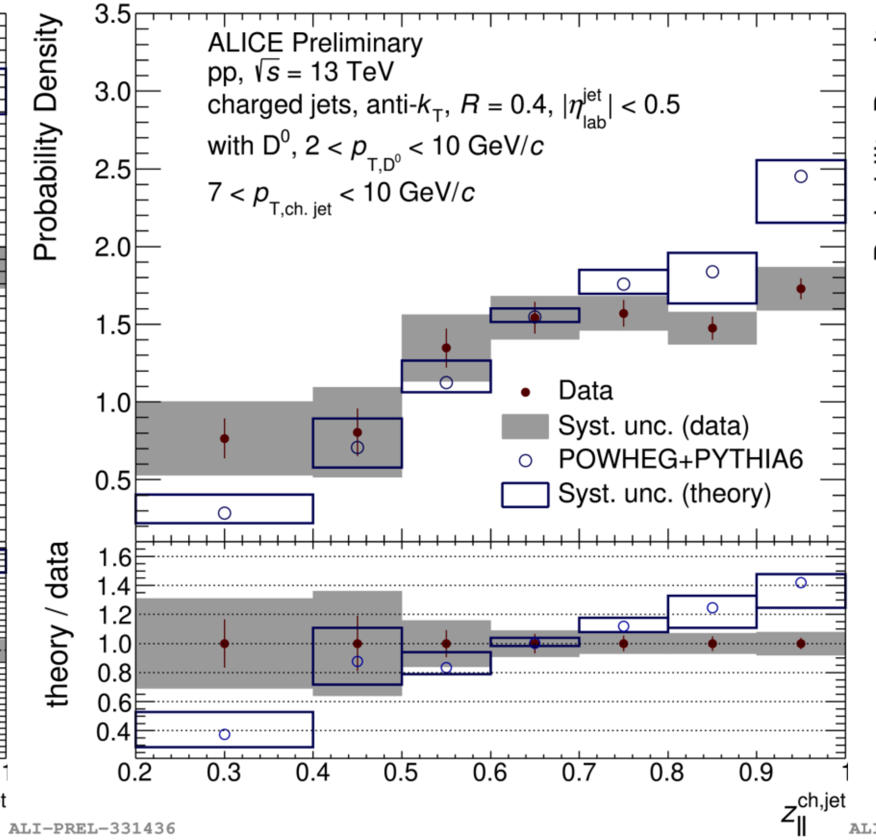
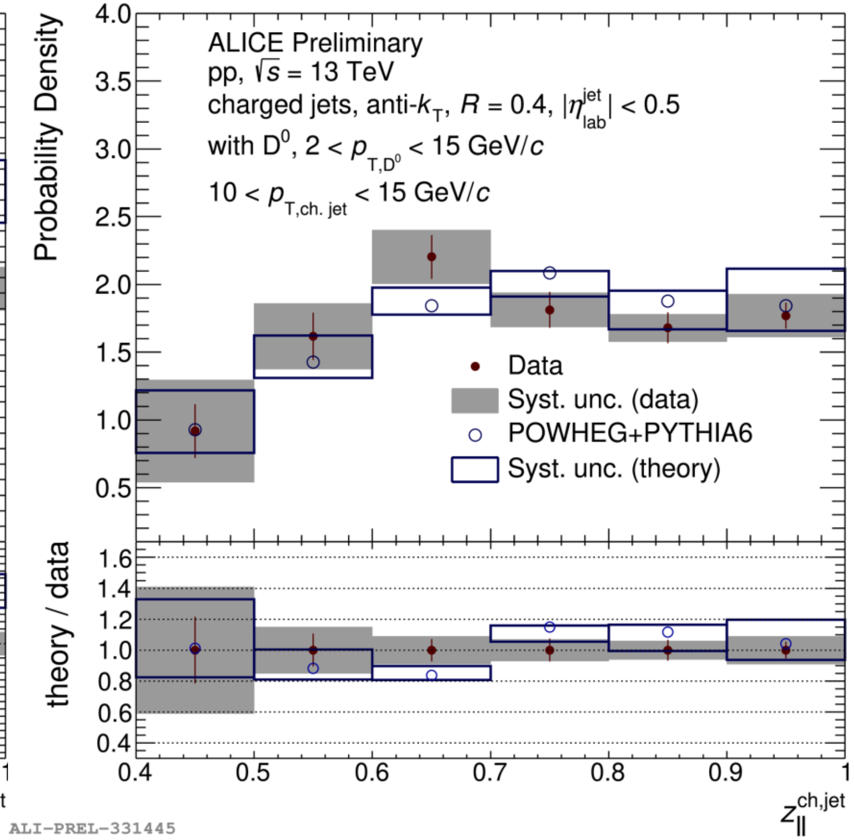
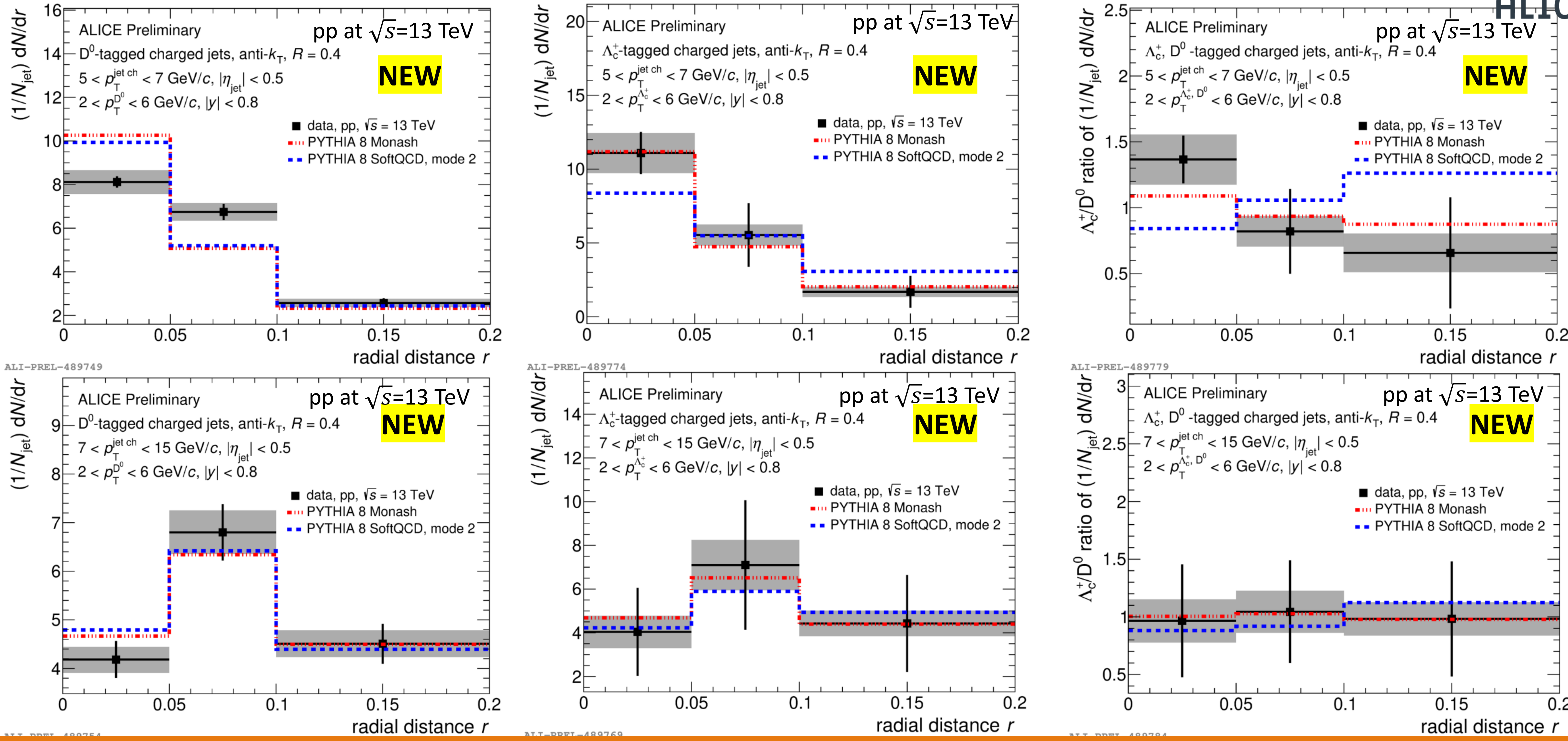






D^0 - and Λ_C –tagged jets: Radial Displacement

$r = \sqrt{\Delta\phi^2 + \Delta\eta^2}$



D - charged particles azimuthal correlations

Fit procedure (Periodic function)

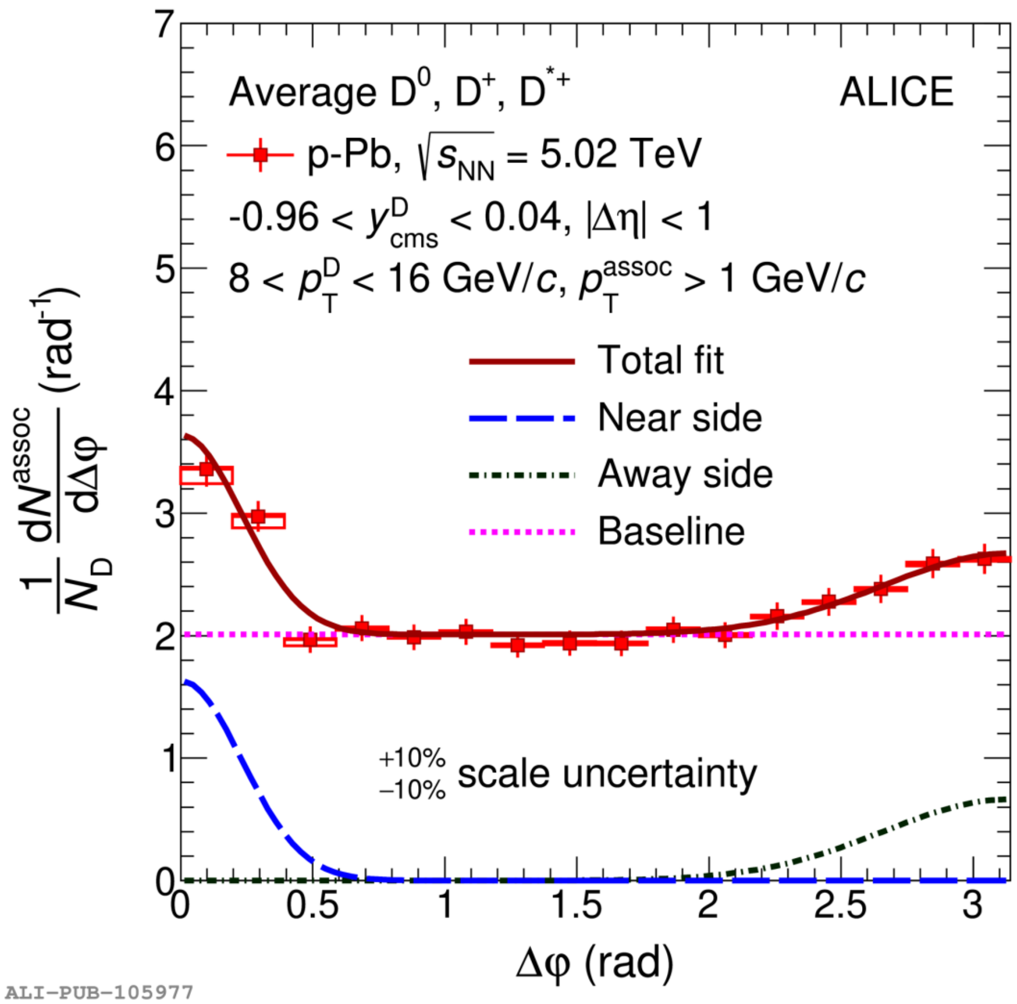
- Generalized Gaussian (NS) + Gaussian (AS) + constant term (Baseline)

$$f(\Delta\varphi) = C + \frac{Y_{\mathrm{NS}}\,\beta}{2\alpha\Gamma(1/\beta)}\exp\left(-\frac{(\Delta\varphi)^{\beta}}{\alpha^{\beta}}\right) + \frac{Y_{\mathrm{AS}}}{\sqrt{2\pi\sigma_{\mathrm{AS}}^{2}}}\exp\left(-\frac{(\Delta\varphi-\pi)^{2}}{2\sigma_{\mathrm{AS}}^{2}}\right)$$

Y_{NS} *and* Y_{AS} *:* yields (integrals under the curves)
σ_{NS} *and* σ_{AS} *:* widths of the two distributions

$\sigma_{NS} = \alpha^2\Gamma(3/\beta)/\Gamma(1/\beta)$

Example of fit of the D-charged particles azimuthal correlation distributions



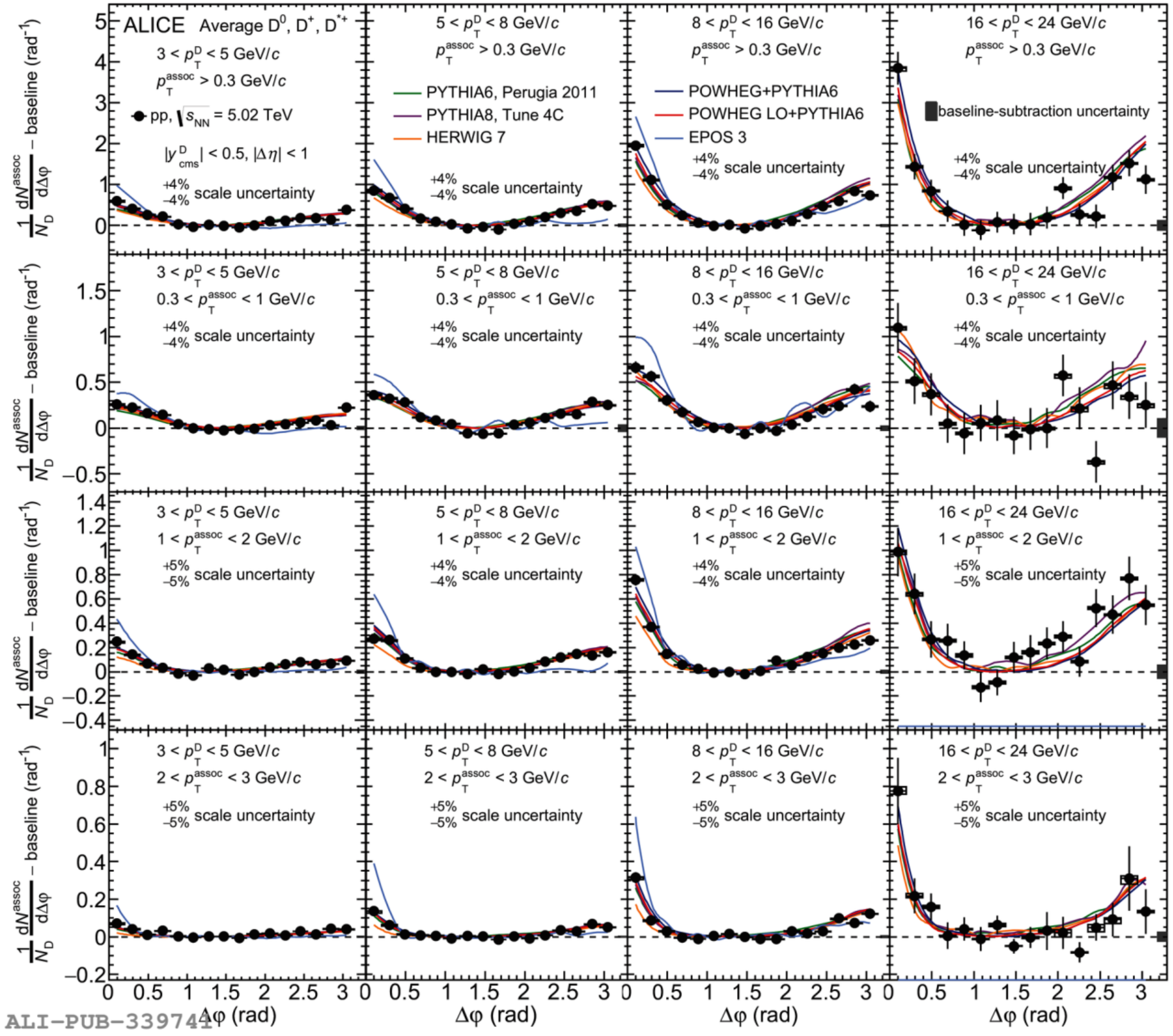
D - charged particles azimuthal correlations

Comparisons with MonteCarlo models:

- PYTHIA (2→ 2 matrix at LO), NLO contributions in the showering, Lund string model for the hadronization stage:
  - PYTHIA6, Perugia 2011: first tune considering the data in pp collisions at $\sqrt{s}$ =7 TeV at LHC.
  - PYTHIA8: improved Multi Parton Interactions (MPI) and color reconnection mechanisms (CR);
- POWHEG (NLO pQCD generator): coupled with PYTHIA for the parton showering and the hadronization:
  - POWHEG LO + PYTHIA6: hard scattering matrix elements computation stopped at LO;
- HERWIG (NLO): showering processes are angularly ordered, cluster hadronization model;
- EPOS3: based on Gribov–Regge theory, hadronization through string fragmentation

p_T^D(GeV/c) pp at $\sqrt{s}$= 5.02 TeV

p_T^{assoc}(GeV/c)



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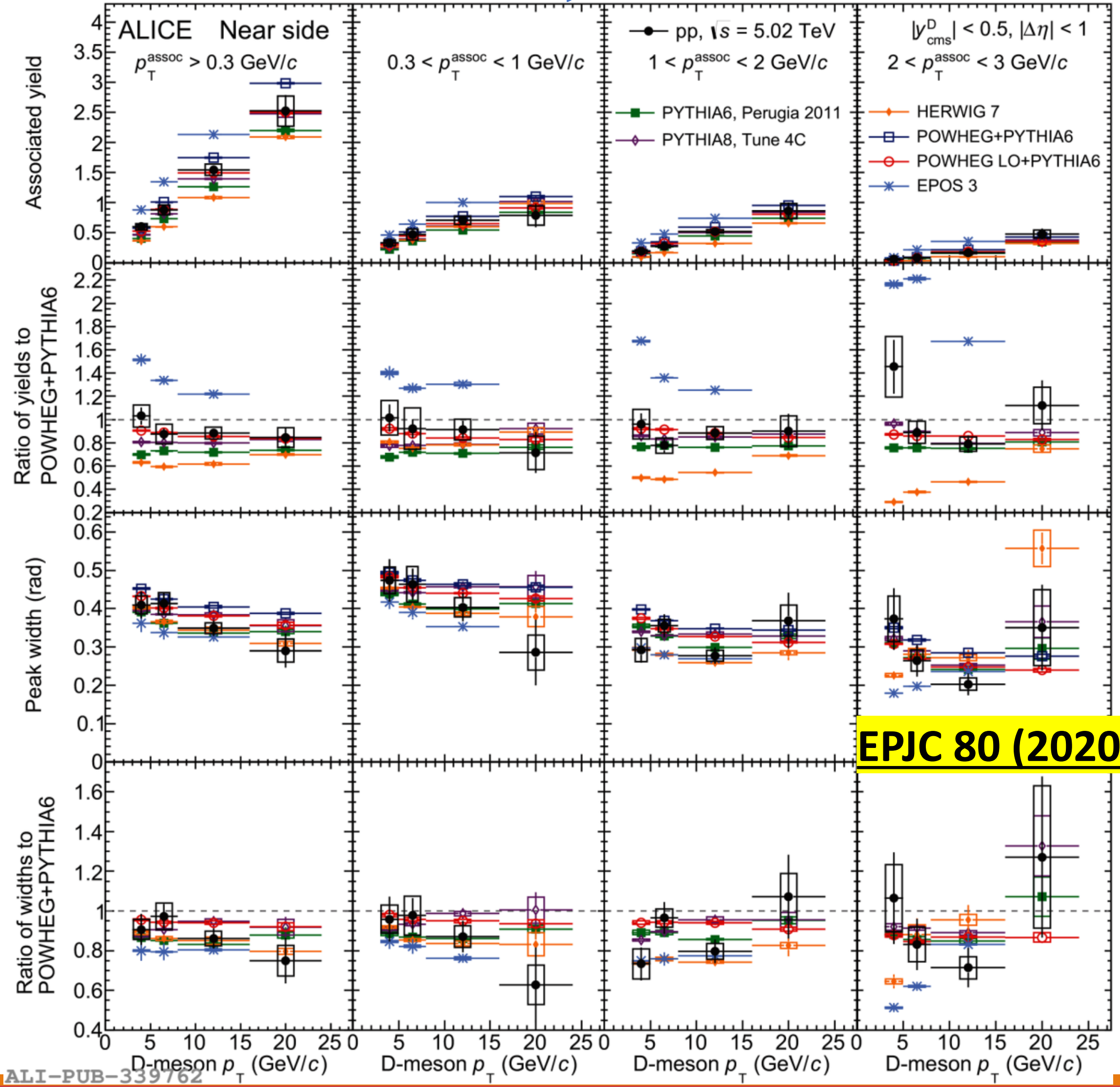
$p_{\mathrm{T}}^{\mathrm{assoc}}$ (GeV/c) NS observables



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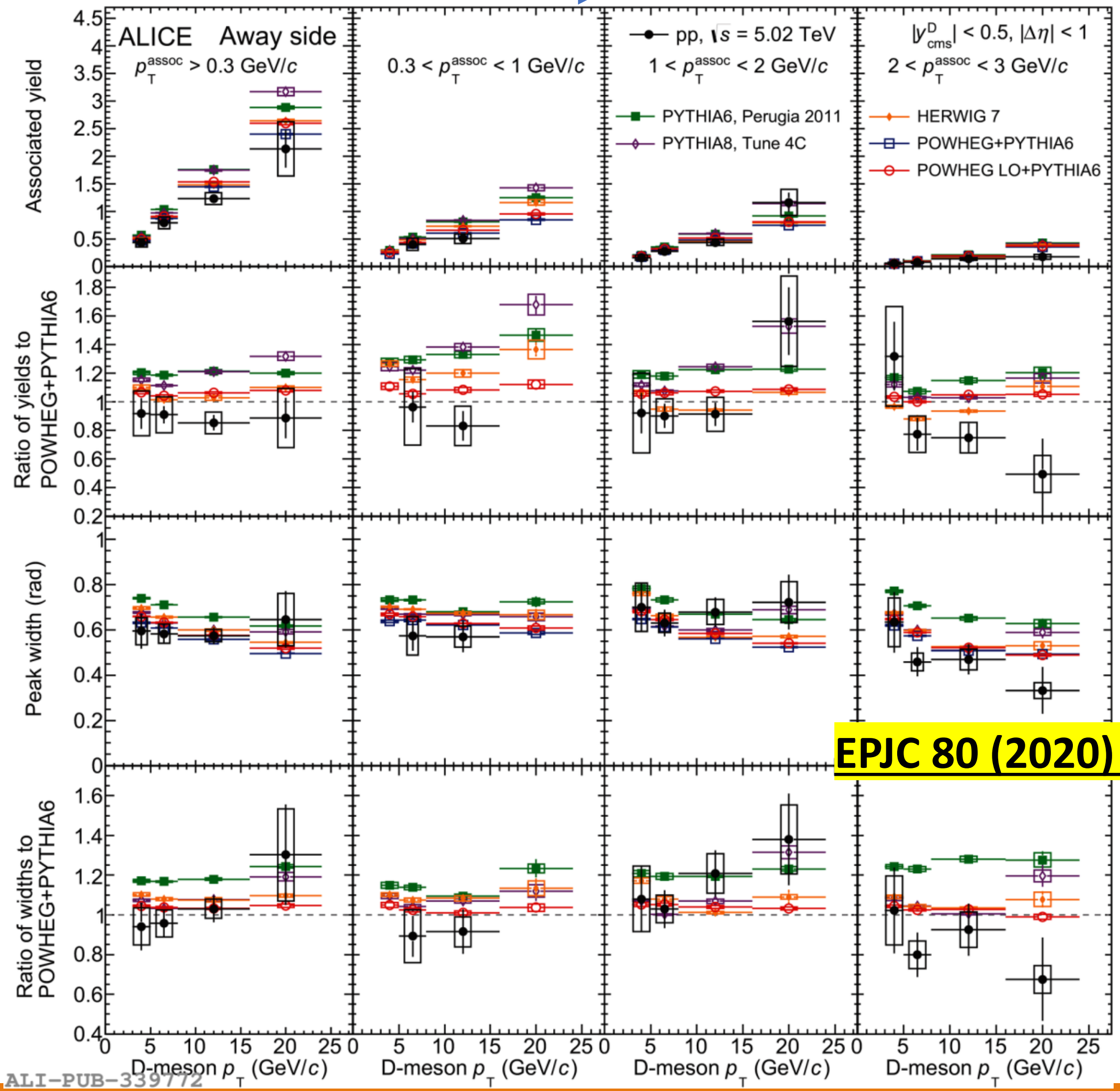
$p_{\mathrm{T}}^{\mathrm{assoc}}$ (GeV/c) AS observables



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