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UNIVERSITY OF THE
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JOHANNESBURG

Measurement of azimuthal correlations of D mesons with charged particles in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE at the LHC

(On behalf of the ALICE Collaboration)

ALICE

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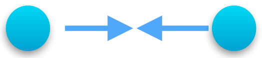
Outline

- **Introduction**
  - ✓ Physics motivation
  - ✓ ALICE detector
- **Methodology**
  - ✓ D-meson signal extraction
  - ✓ D-meson charged-particle angular correlations in pp collisions
- **Results**
- **Summary and outlook**

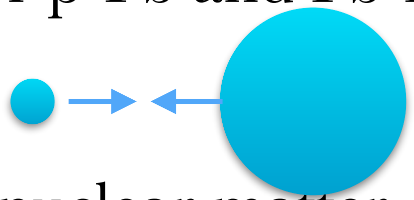
Physics Motivation

pp collisions:



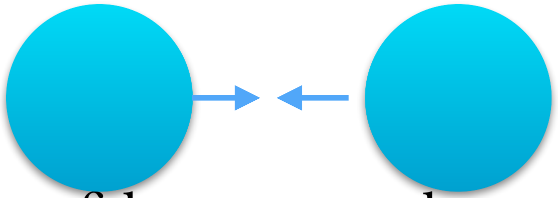
- Study the production mechanisms, (c → D) fragmentation and hadronization of charm quarks and test pQCD calculations
- Act as a reference for p-Pb and Pb-Pb systems

p—Pb collisions:

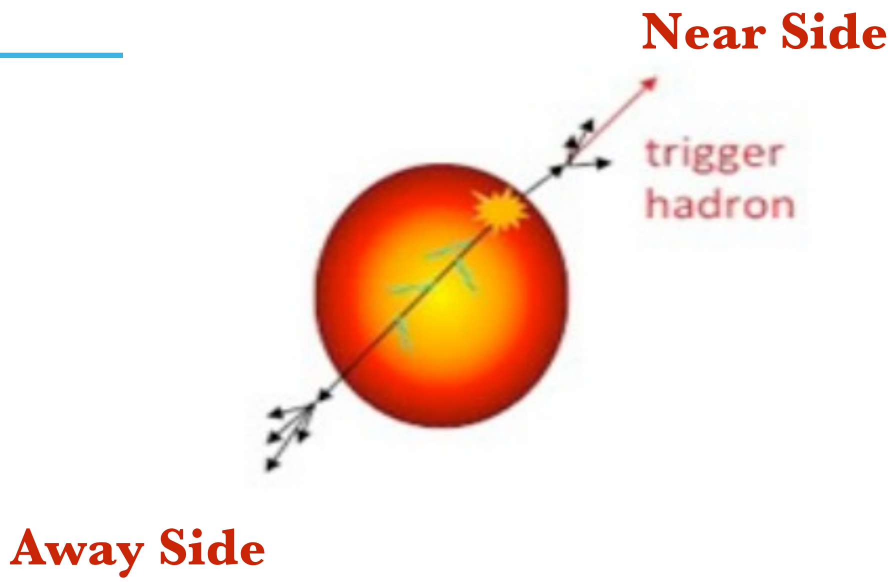


- Investigate the cold nuclear matter effects on the charm jets
- Search for long-range ridge-like structure in near-side and away-side regions (“double ridge”) as observed in h-h correlations.

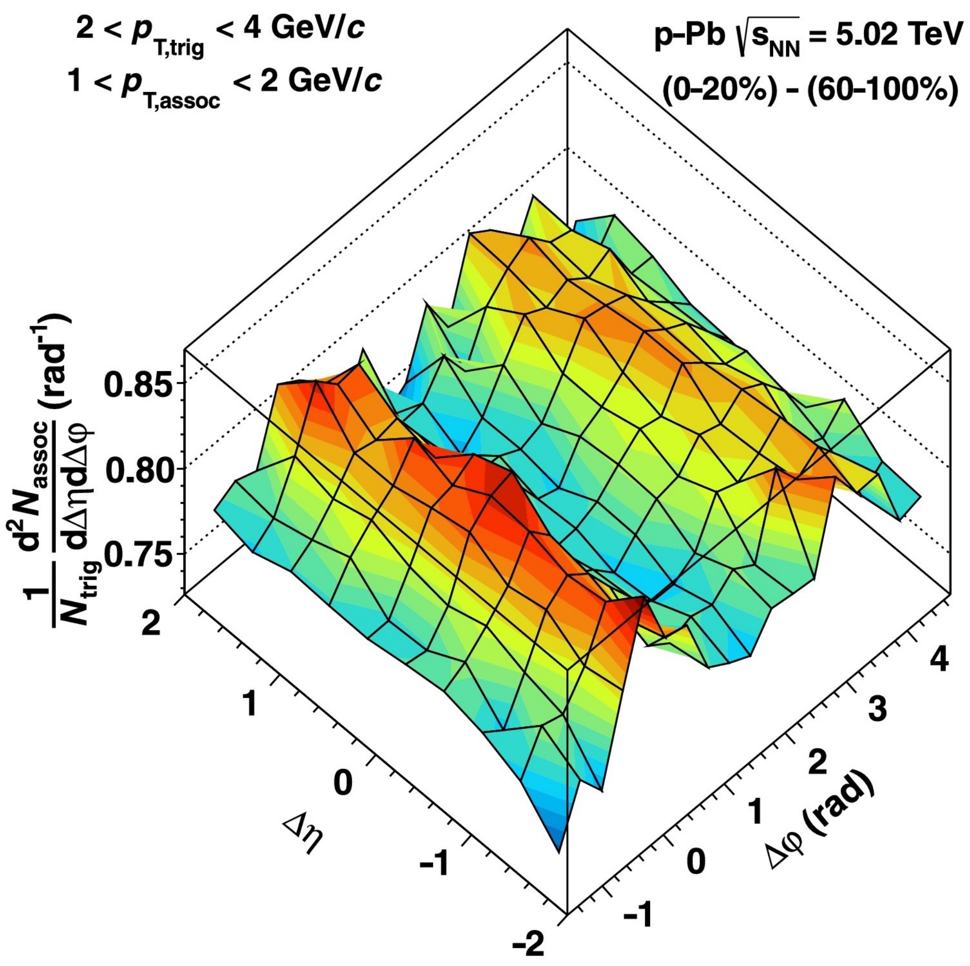
Pb—Pb collisions (LHC Run 3):



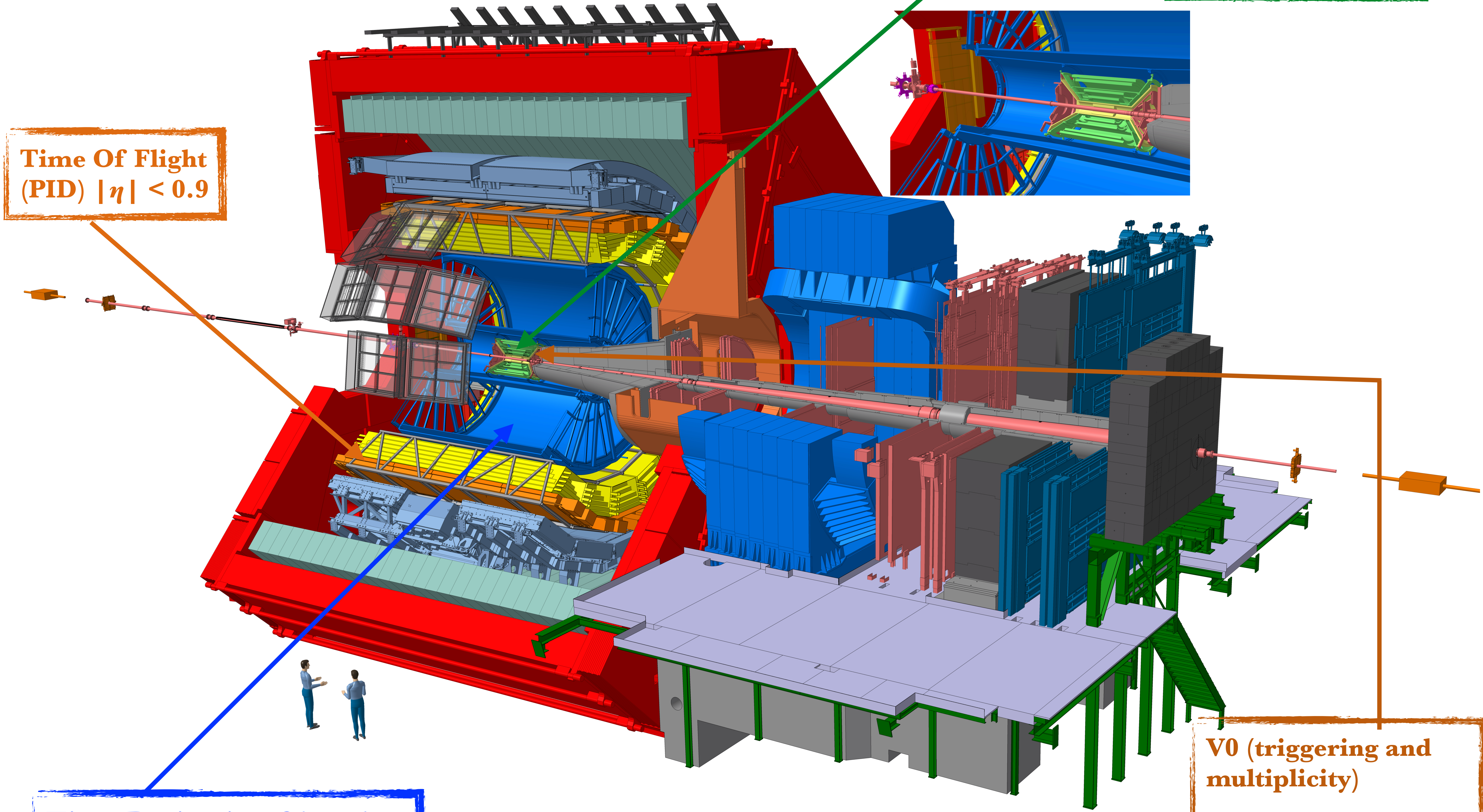
- Study the path length dependence of heavy-quark energy loss
- Probe QGP effects on the heavy quarks by studying how correlation distributions of heavy-flavour particles are modified w.r.t to pp collisions



ALICE Collaboration, *Phys.Lett.B 719 (2013) 29-41*



ALICE Detector



Inner Tracking system (tracking, vertexing, PID)
$|\eta| < 0.9$

Time Of Flight (PID) $|\eta| < 0.9$

Time Projection Chamber (tracking and PID)
$|\eta| < 0.9$

V0 (triggering and multiplicity)

V0A : $2.8 < \eta < 5.1$

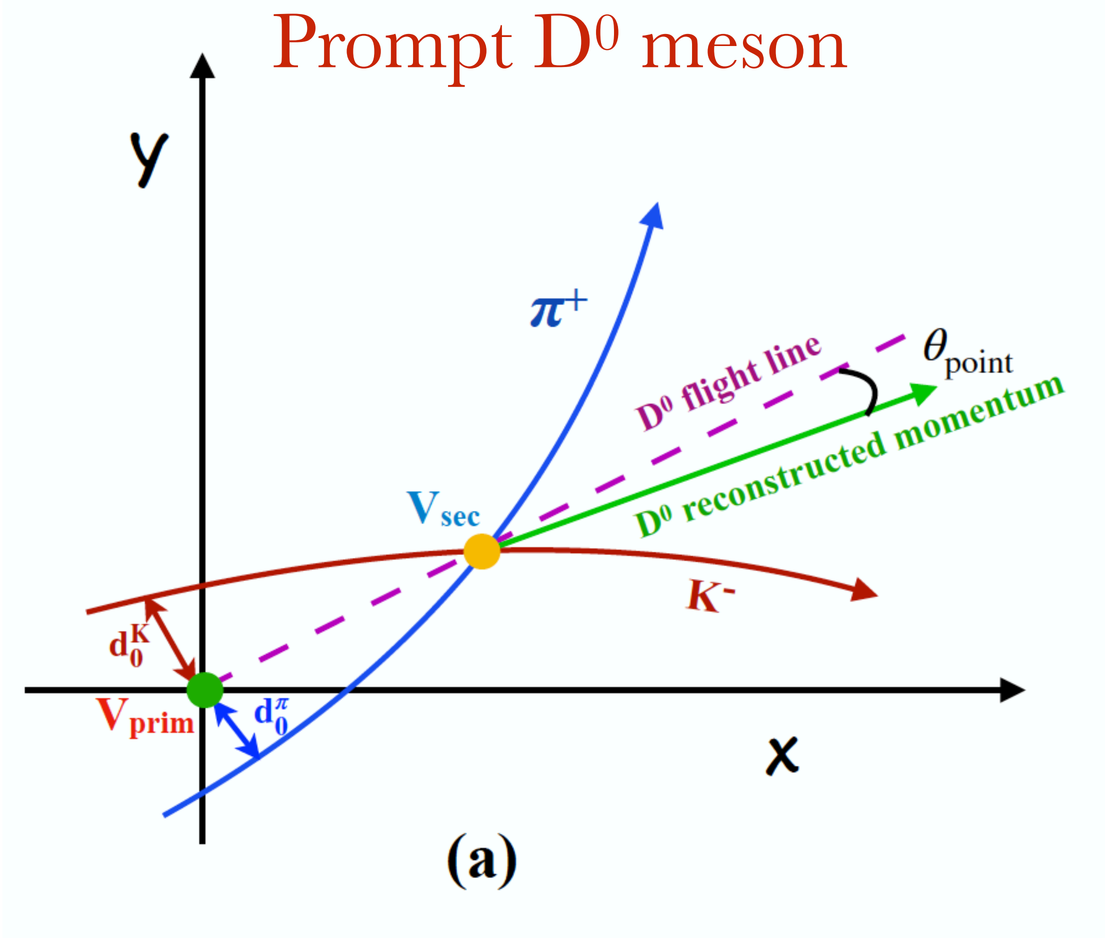
V0C : $-3.7 < \eta < -1.7$

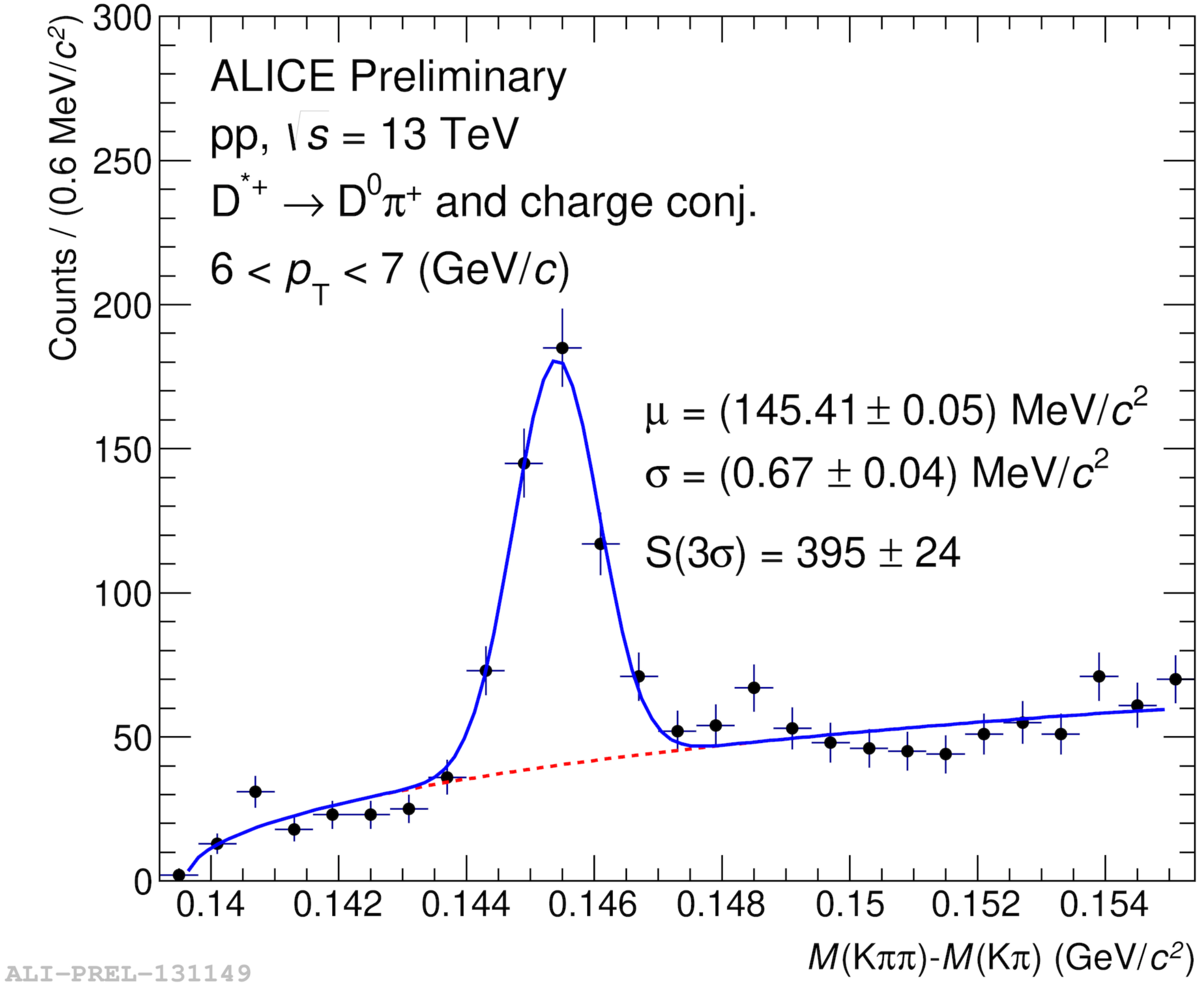
Methodology

$D^0(c\bar{u}) \rightarrow K^-\pi^+$, BR : 3.89 ± 0.04 %

$D^+(c\bar{d}) \rightarrow K^-\pi^+\pi^+$, BR : 8.98 ± 0.28 %

$D^{*+}(c\bar{d}) \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$, BR : 67.7 ± 0.5 %


Prompt D^0 meson



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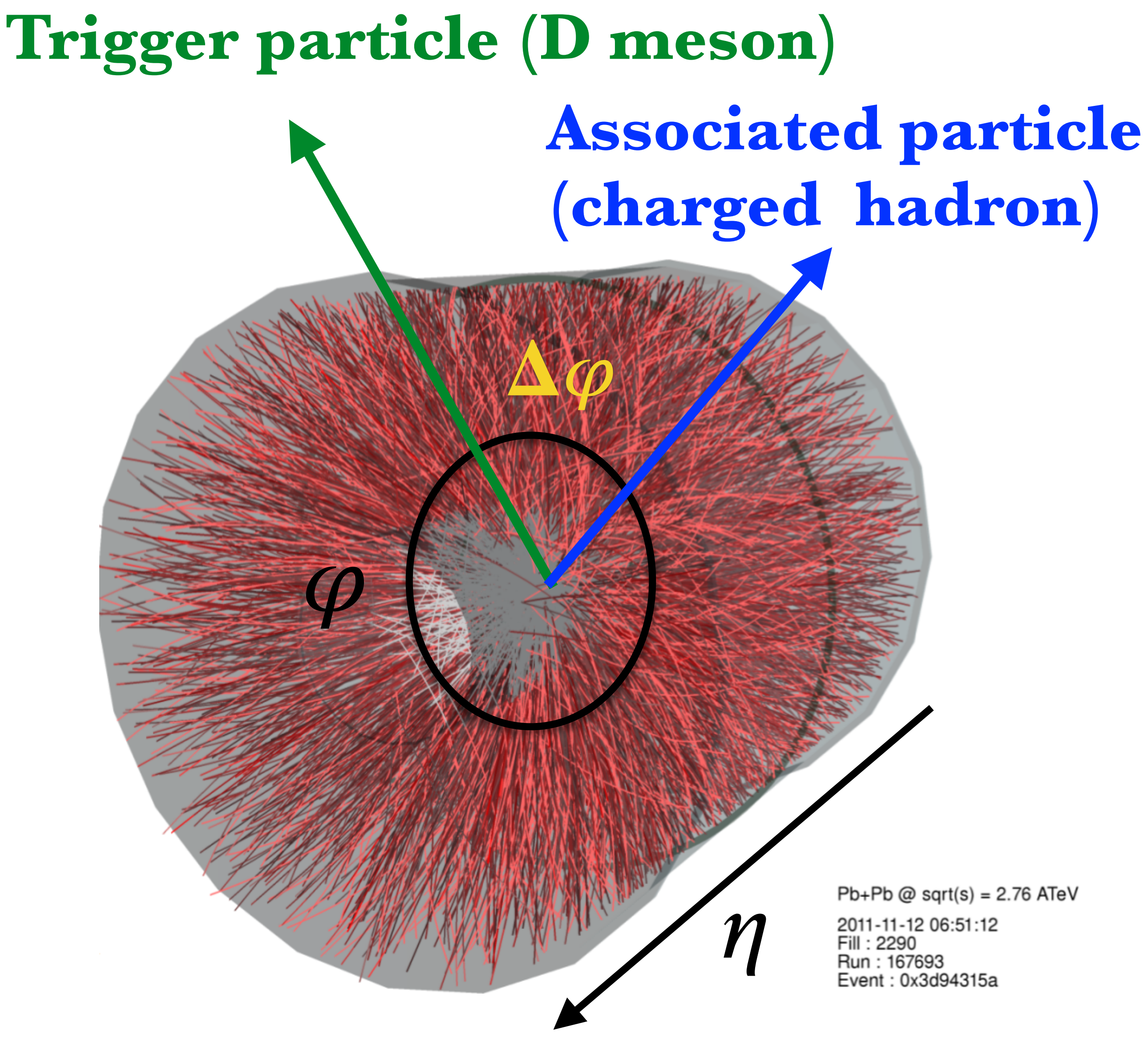
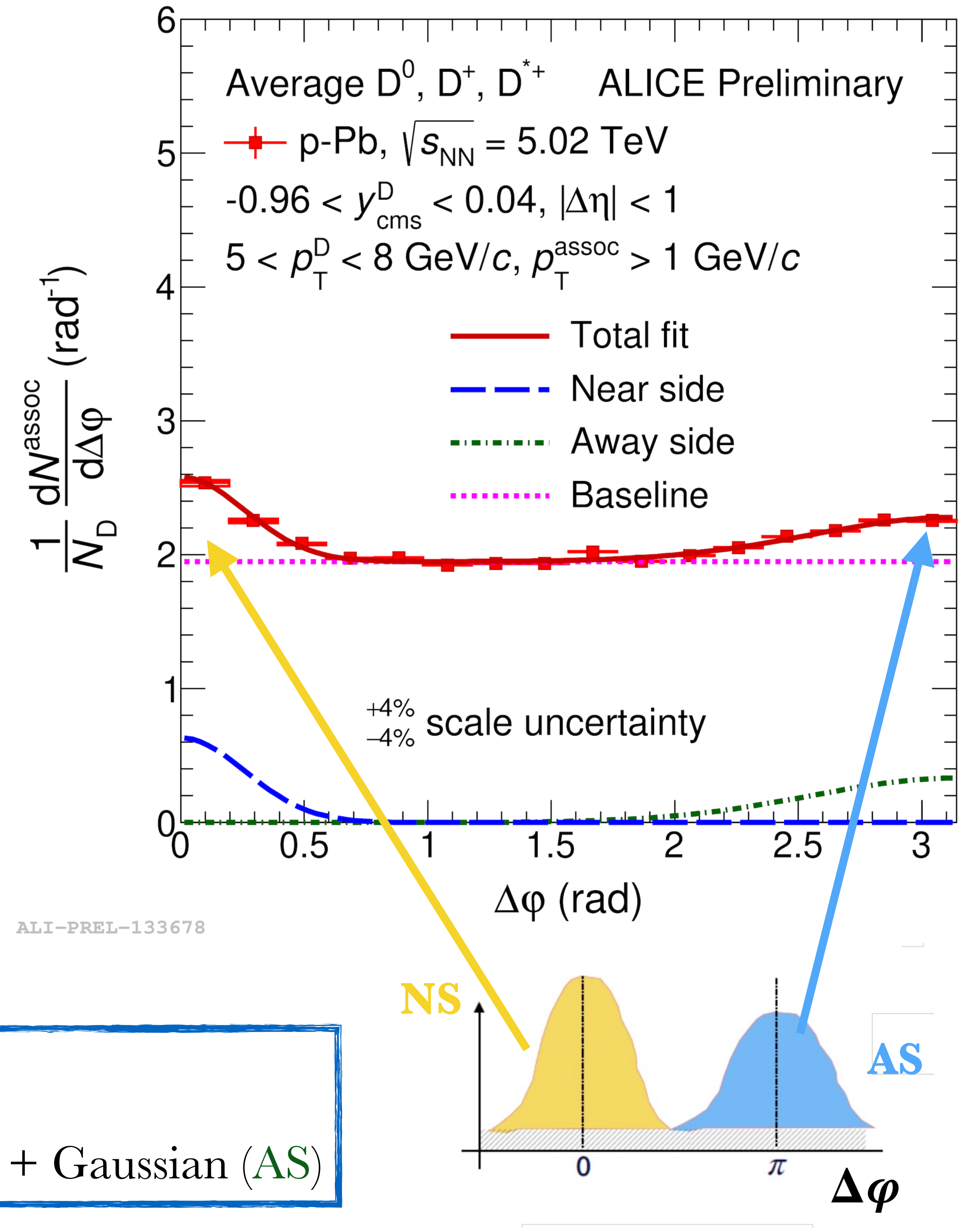
- D-meson raw yields are extracted by fitting the invariant-mass distribution of the candidates

Methodology



Trigger particle (D meson)

Associated particle (charged hadron)

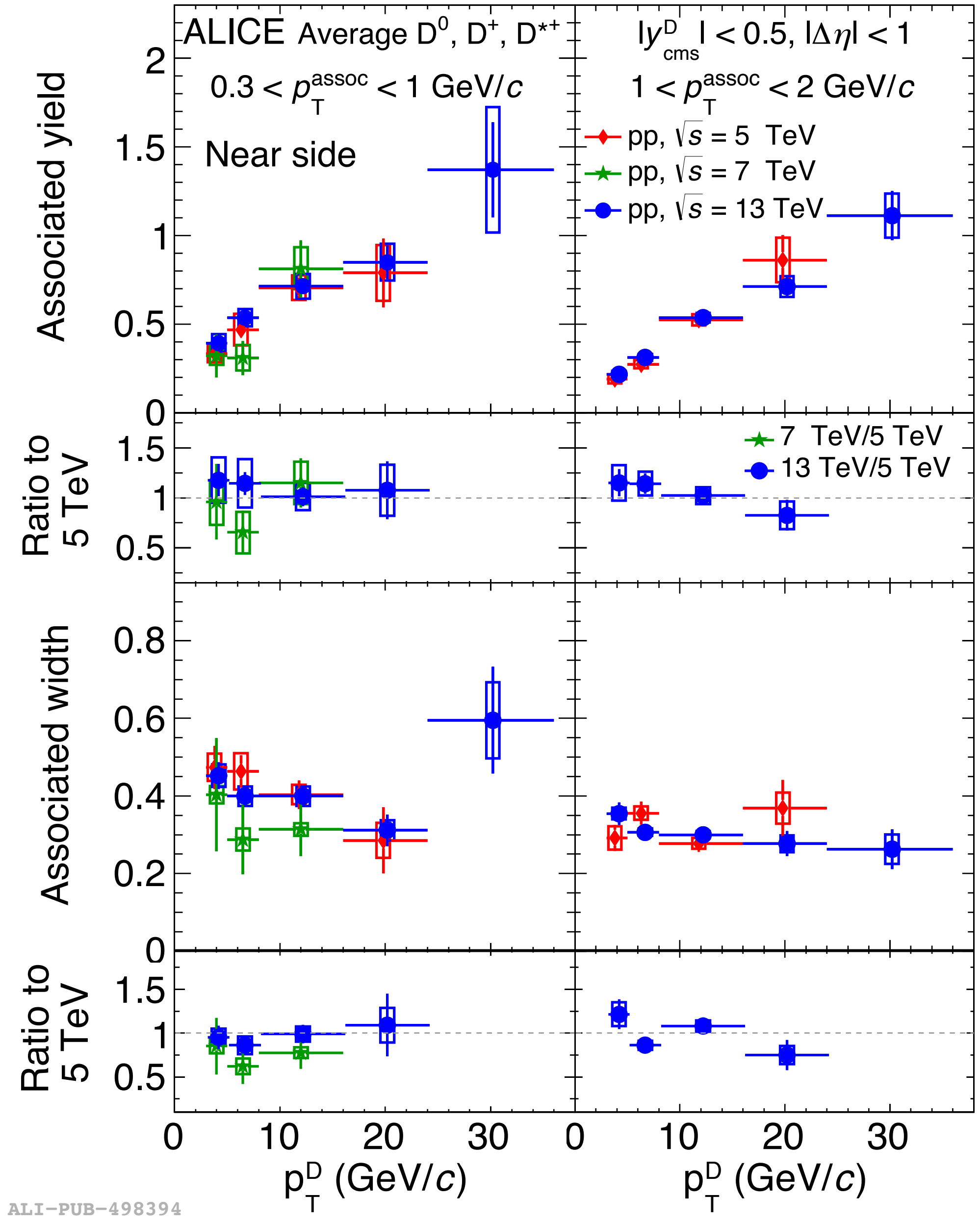


Fitting function:

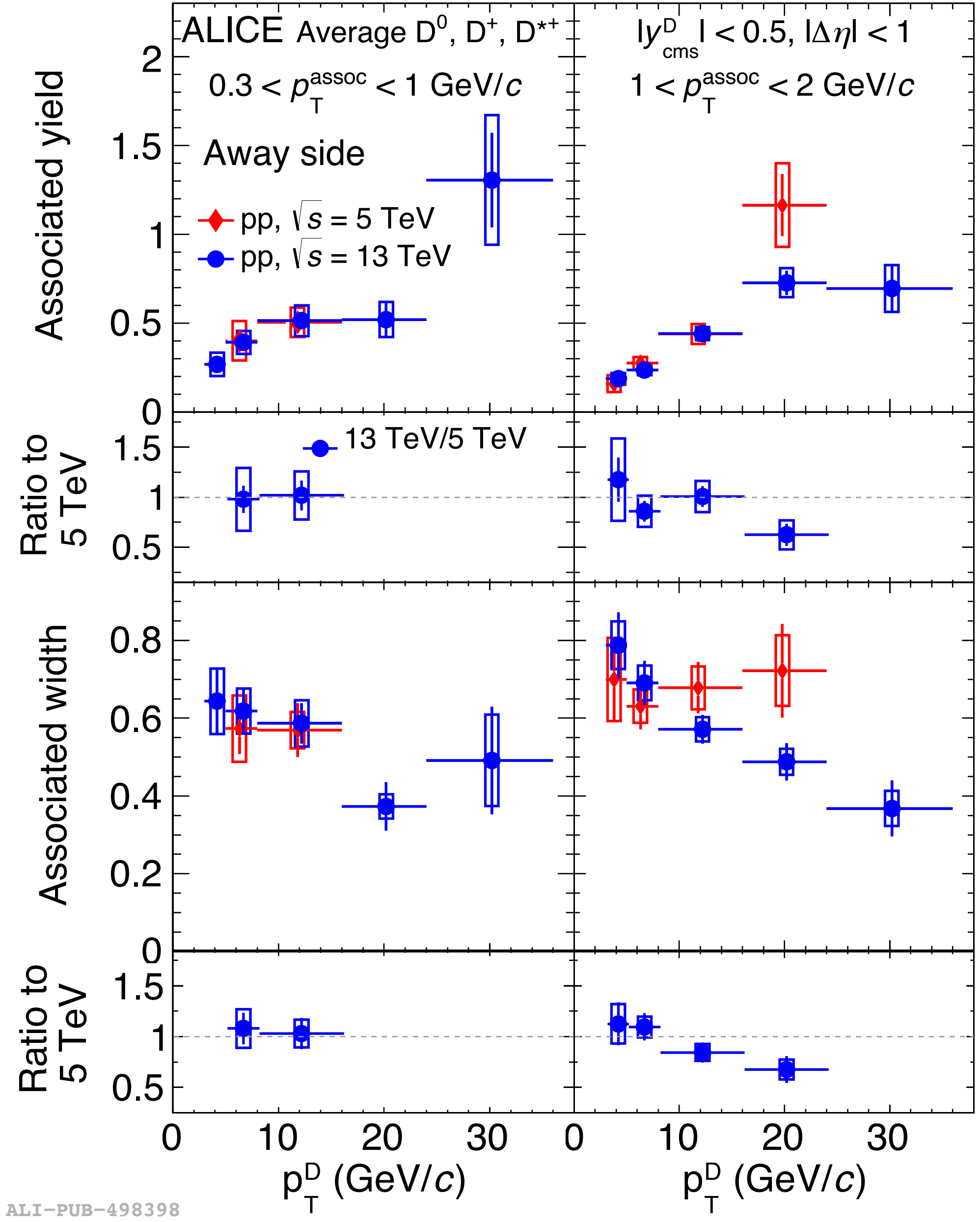
Constant term (Baseline) + Gaussian (NS) + Gaussian (AS)

D-meson azimuthal correlations with charged particles in pp collisions

Near-side



Away-side



ALICE Collaboration,

Eur. Phys. J. C 77 (2017) 245

EPJC 80 (2020) 979

arXiv:2110.10043

- The NS and AS yields increase for increasing values of the D-meson p_T.
- The narrowing of the peak is seen in both NS and AS. It may be explained with:
  - I. more collimated angular pattern of the partons fragmented from charm quark,
  - II. an increased collinearity of charm and anti-charm quarks produced from gluon-splitting mechanism
- No sizeable energy dependence within total uncertainties

Near-side (NS) peak yields in pp compared with event generators

ALICE Collaboration,
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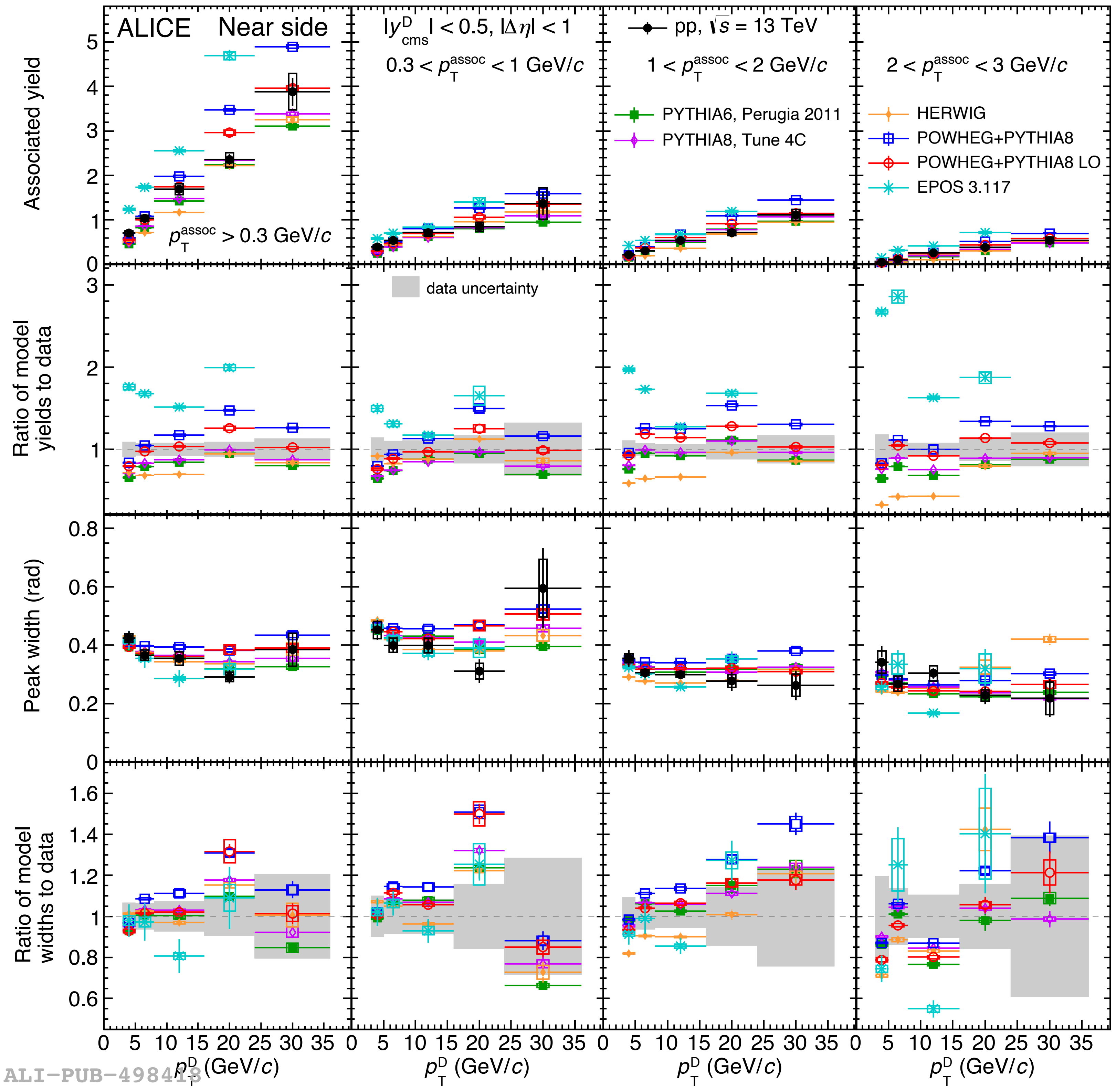
EPJC 80 (2020) 979
arXiv:2110.10043

$p_T^{assoc} > 0.3$ GeV/c $0.3 < p_T^{assoc} < 1.0$ GeV/c $1 < p_T^{assoc} < 2$ GeV/c $2 < p_T^{assoc} < 3$ GeV/c



NS yields:

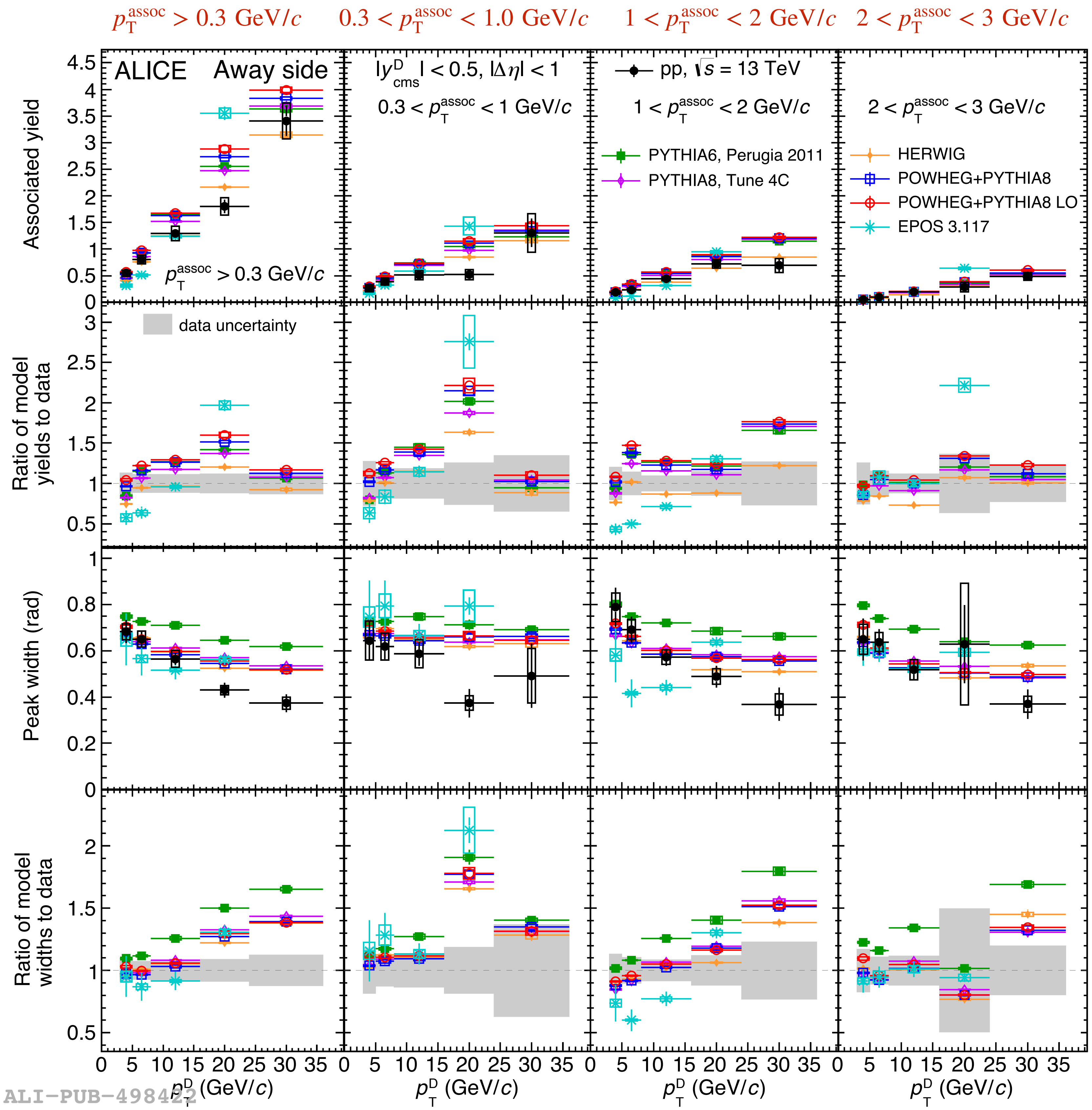
- PYTHIA8 and POWHEG+PYTHIA8 closer to the data
- About 10% larger yields for POWHEG+NLO w.r.t to LO ⟶ more collinear production via gluon splittings
- HERWIG underestimated the yields in low p_T^D ($p_T^D < 8$ GeV/c) and at high p_T^{assocc} ($p_T^{assocc} > 1.0$ GeV/c)
- EPOS overestimates the yield in whole p_T ranges

NS widths:

- All models reproduce the measured width within the uncertainties

Away-side (AS) peak yields in pp compared with event generators

ALICE Collaboration,
Eur. Phys. J. C 77 (2017) 245
EPJC 80 (2020) 979
arXiv:2110.10043



AS yields:

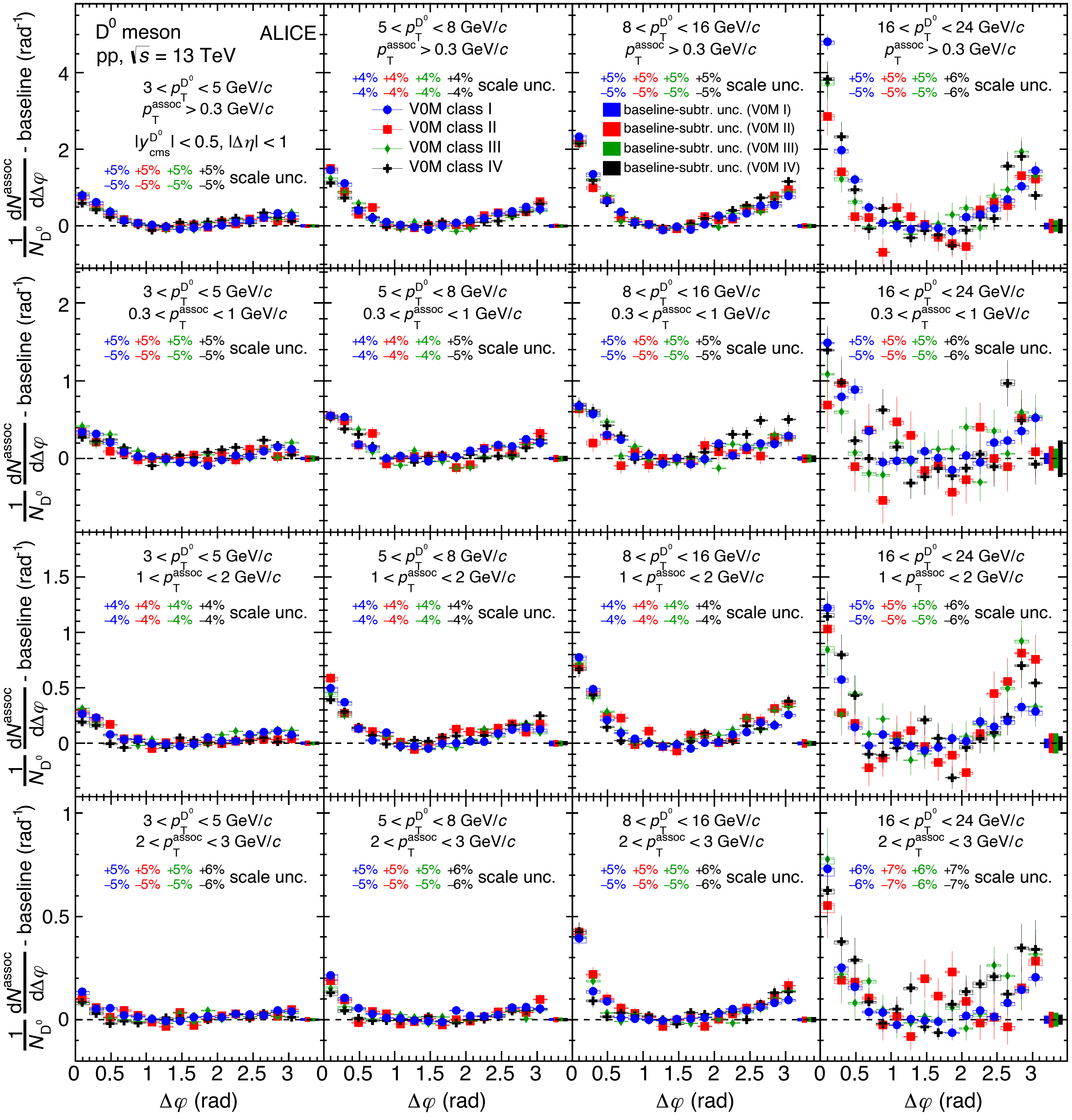
- PYTHIA6, PYTHIA8 and HERWIG give best measurement.
- POWHEG+NLO and LO provide the highest away-side yields.
- LO gives 5% larger values than NLO may be due to an increased amount of back-to-back production process.
- EPOS underestimates the yield for $p_T^D <$ 5 GeV/c, while, for $16 < p_T^D < 24$ GeV/c, it gives higher value.

AS widths:

- The narrowing of AS peak is predicted by all the models with increasing p_T^D except for $0.3 < p_T^{assoc} < 1.0$ GeV/c region

D-meson azimuthal correlations with charged particles vs multiplicity

$3 < p_T^D < 5$ GeV/c $5 < p_T^D < 8$ GeV/c $8 < p_T^D < 16$ GeV/c $16 < p_T^D < 24$ GeV/c



ALI-PUB-498402

ALICE Collaboration, *arXiv:2110.10043*

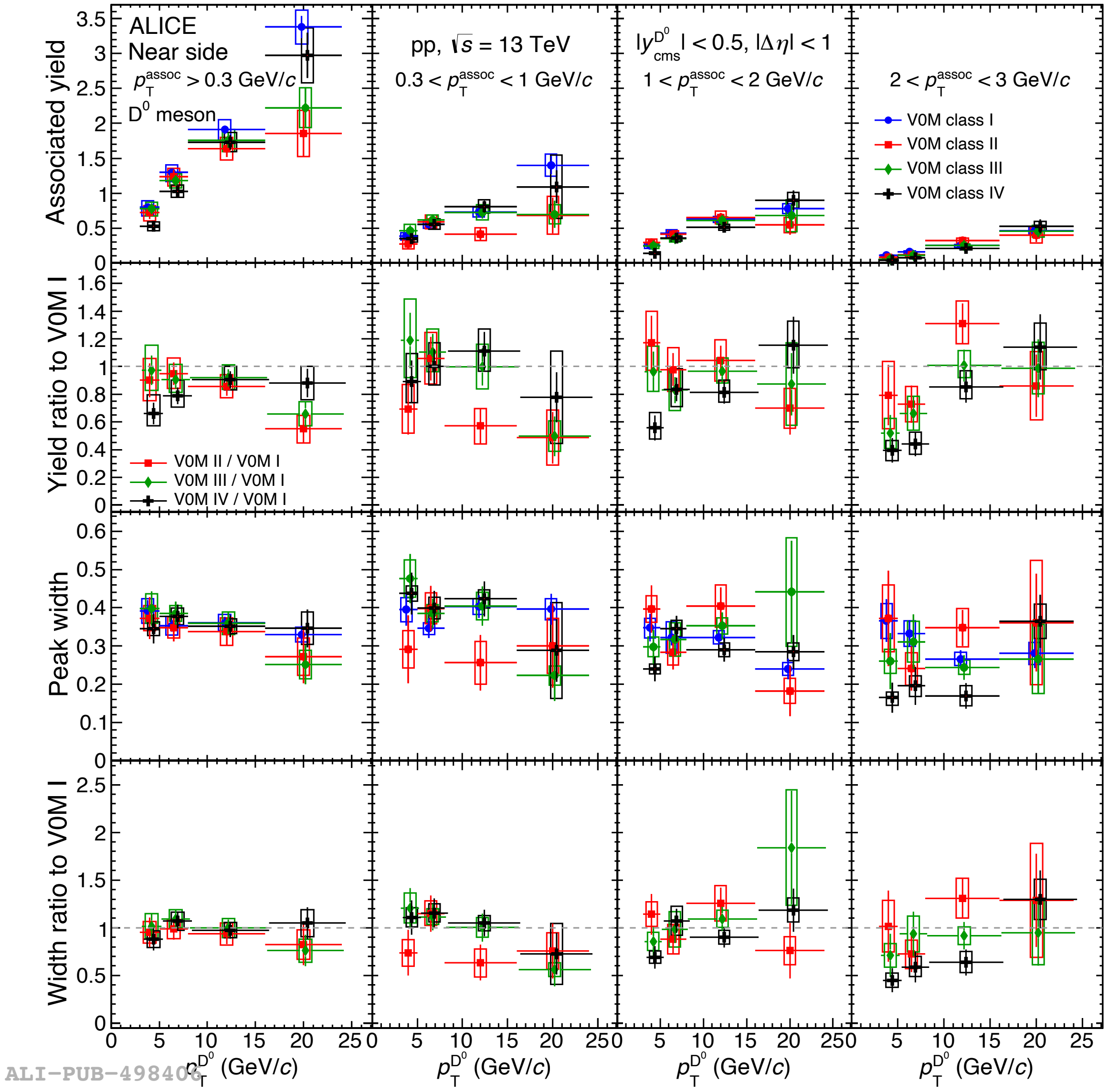
V0M Multiplicity classes	**I**	**II**	**III**	**IV**
$\langle dN_{ch}/d\eta \rangle$	**31.15 ± 0.40**	**18.39 ± 0.23**	**11.46 ± 0.15**	**4.41 ± 0.06**

$\langle dN_{ch}/d\eta \rangle$ = average number of charged particles

- The height the NS peak increases for increasing values of the D-meson p_T.
- The correlation distributions don't show any multiplicity dependence.

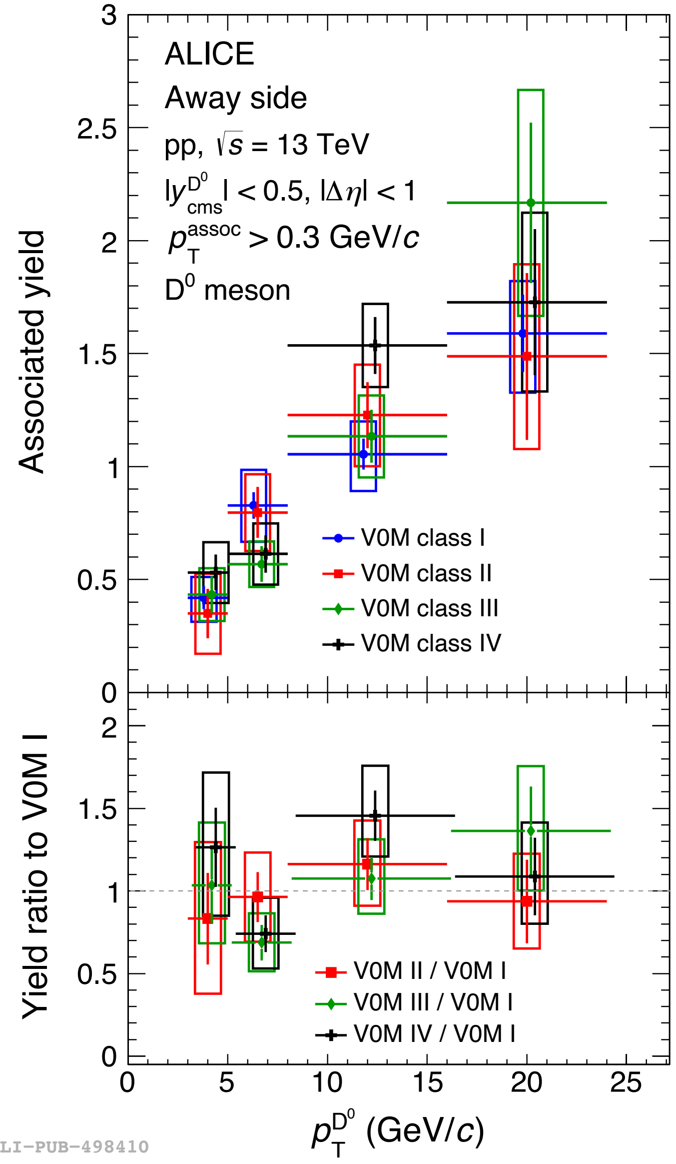
NS and AS properties vs multiplicity

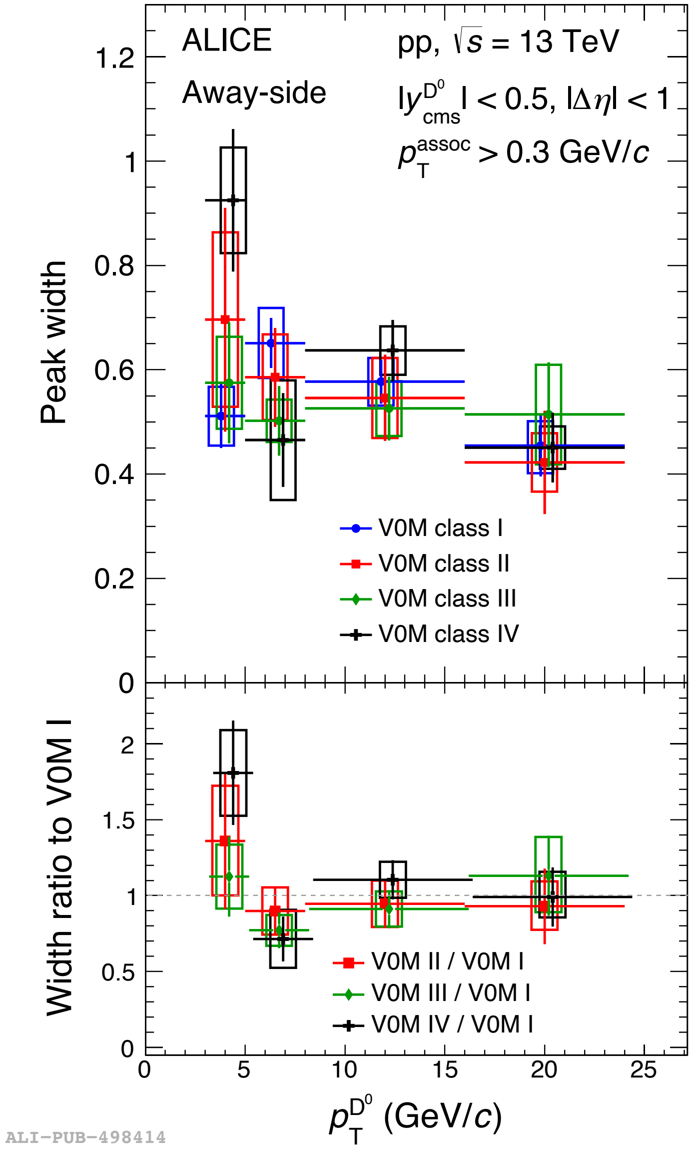
Near-side



Away-side

ALICE Collaboration, ***arXiv:2110.10043***

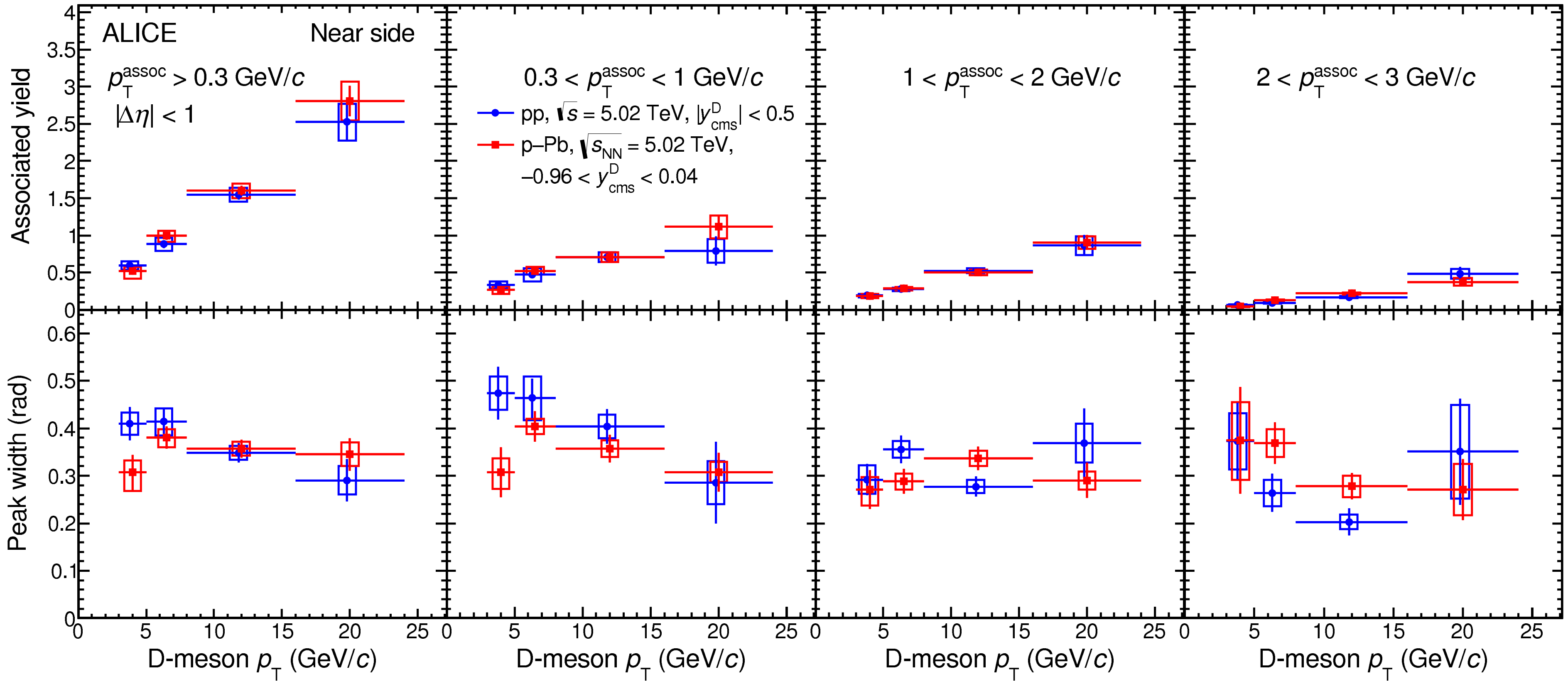


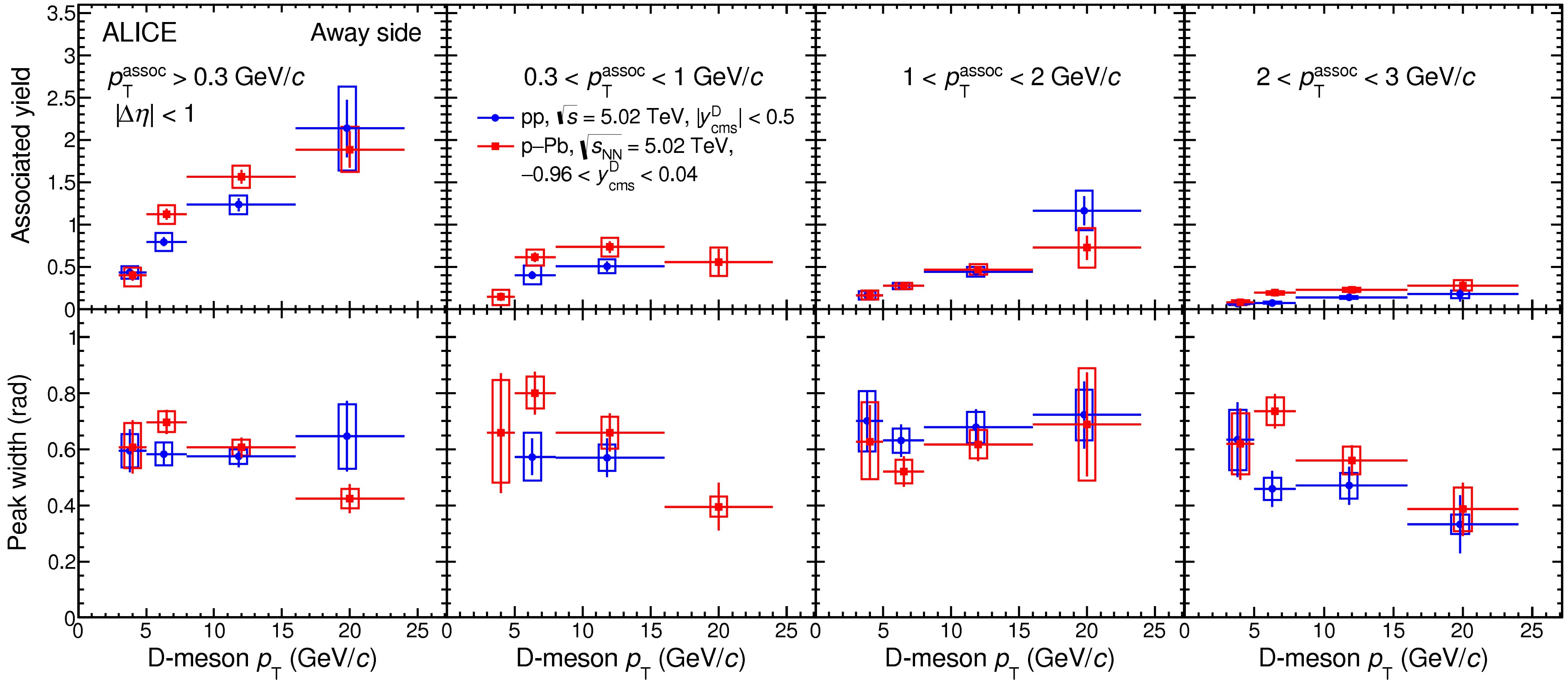


- NS yields and widths are consistent within uncertainties in different multiplicity classes
- No significant modification of the charm fragmentation and hadronisation in collisions of different multiplicity

- The AS yield and width values are fully consistent within the uncertainties among all the multiplicity intervals.

pp and p–Pb comparison





ALICE Collaboration,
EPJC 80 (2020) 979

- NS and AS yields and widths are consistent within uncertainties in the two collision systems.
- No significant impact of CNM effects on the fragmentation and hadronisation of charm quark appears within the current precision of the measurements.

Summary and Outlook

- The results of the azimuthal correlation measurements between D mesons and charged particles in pp collisions, extracted in different p_{T} intervals of trigger and associated charged particles, are presented.

- The measured distributions, as well as the properties of the correlation peaks, are described qualitatively well by simulations performed with PYTHIA8 and POWHEG+PYTHIA8.

- The overall compatibility of the correlation-peak features for different multiplicity indicates that the charm-quark fragmentation and hadronisation processes are not particularly sensitive to the event multiplicity.

- With LHC Run 3 data we will study the correlation in Pb-Pb and these measurements in pp and p-Pb will be fundamental as references.

- With LHC Run 3 we will also look for $\mathrm{D}-\bar{\mathrm{D}}$ correlations (as it should not differ much from the angular distribution of $\mathrm{c\bar{c}}$ quarks) in pp and Pb-Pb collision systems.

Thanks for listening

Experimental probes to study QGP

Basic terminology:

Transverse momentum $(p_{\mathrm{T}}) = \sqrt{p_x^2 + p_y^2}$

Pseudo-rapidity $(\eta) = -ln[tan(\theta/2)]$

Polar angle (θ)

Azimuthal angle (φ)

Two-particle correlation :

$$\Delta\varphi = \varphi_{trig} - \varphi_{assoc}$$

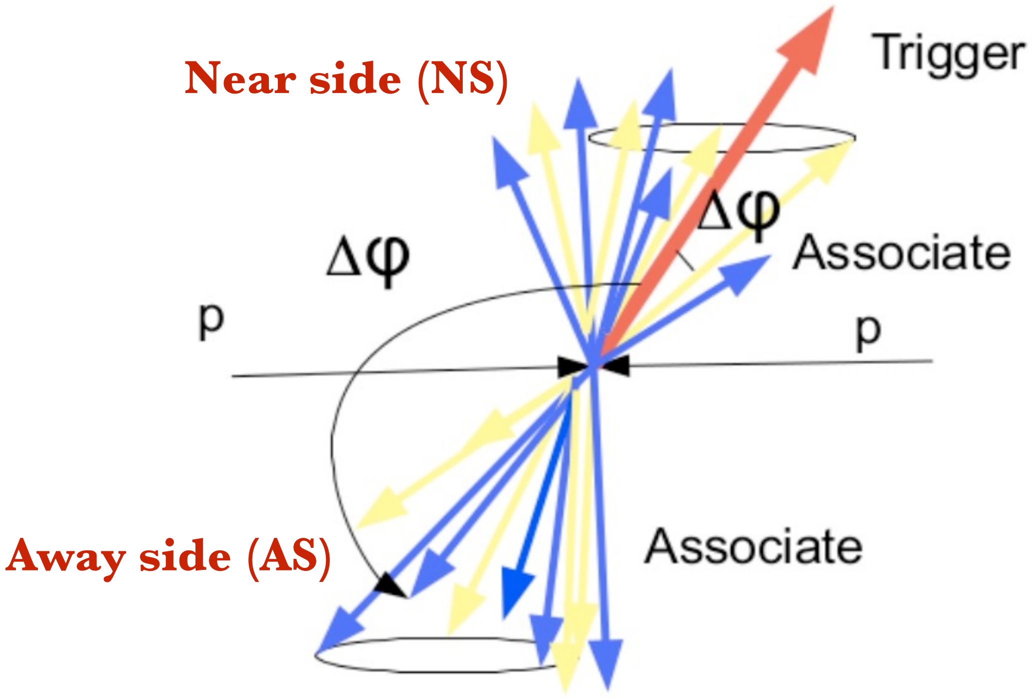
$$\Delta\eta = \eta_{trig} - \eta_{assoc}$$

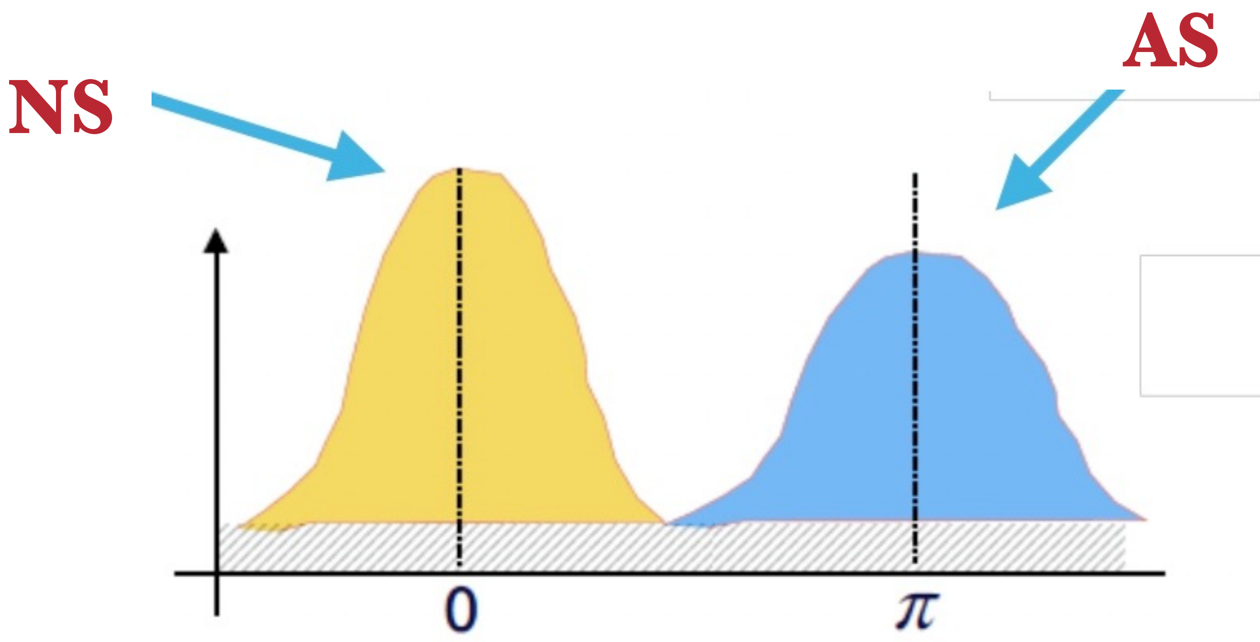
Near side (NS):

Both particles come from same jet

Away side (AS):

The associated particle comes from the opposite side jet w.r.t. the trigger particle





$$\Delta\varphi = \varphi_D - \varphi_{assoc}$$

Physics Motivation

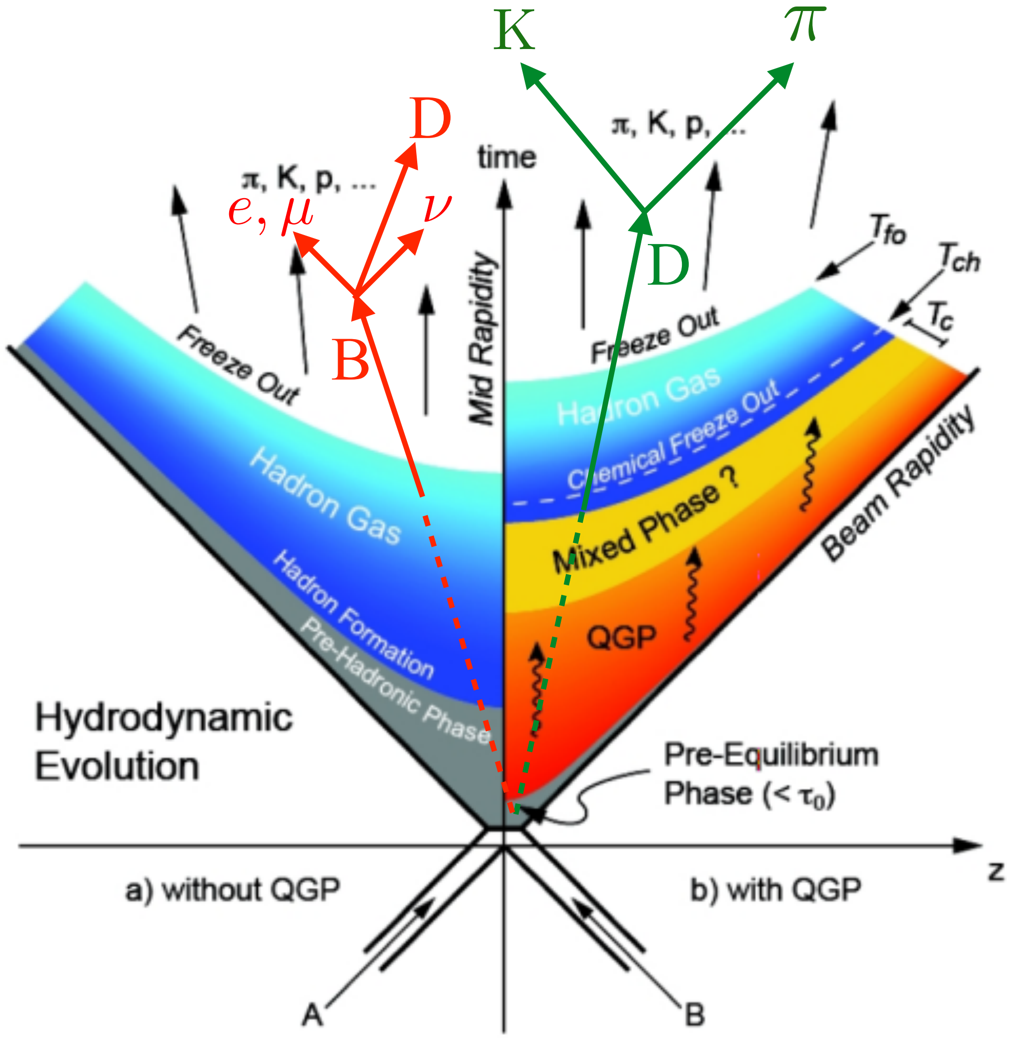
- Heavy quarks (charm (c) and beauty (b)), having a large mass, are produced in hard-parton scatterings in the early stages of the collision.

$$t_{c,b} \sim \frac{1}{2m_{c,b}} < 0.1\ fm << t_{QGP} \sim 5-10\ fm$$

- They experience the whole evolution of the quark-gluon plasma (QGP), representing an important tool for its characterization.
- Heavy quarks can interact with the medium via elastic collisions with the constituents and medium-induced gluon radiation.
- Energy loss of heavy quarks are different from light quarks and gluons.

$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

Dokshitzer and Kharzeev, PLB 519 (2001) 199



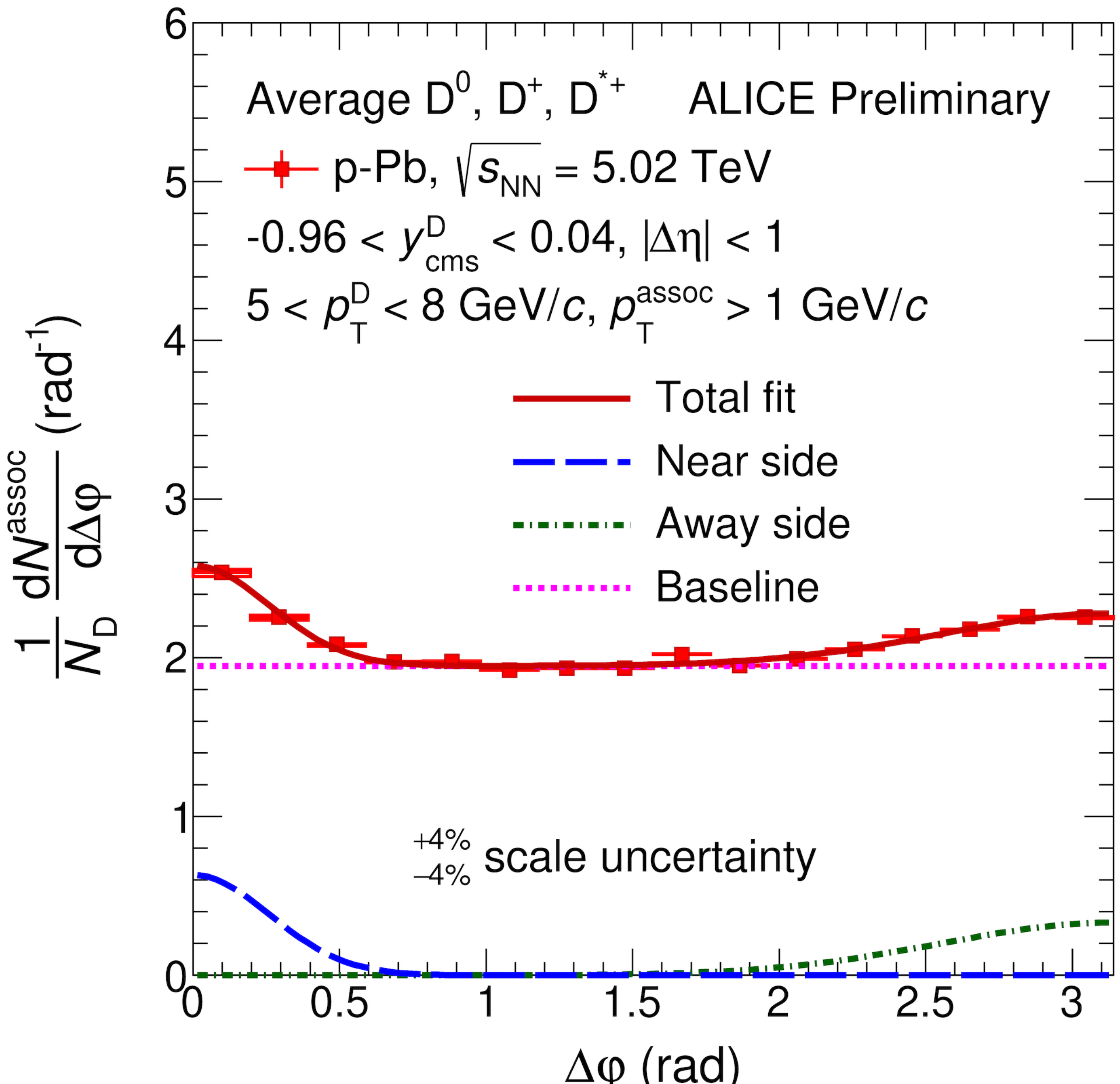
Methodology

Azimuthal Correlations:

- ✓ Each selected D meson is correlated with charged tracks produced in the collision with $|\eta| < 0.8$ (excluding the daughter particles) both under the signal peak and in two sideband regions, to build $(\Delta\eta, \Delta\varphi)$ correlation distributions.

Corrections:

- ✓ event-mixing
- ✓ Side-band subtraction
- ✓ D-meson efficiency and track efficiency
- ✓ Secondary particle contamination
- ✓ Feed-down correction



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Two Gaussian

Const. Baseline

Fitting function: $$f(\Delta\varphi) = c + \frac{Y_{NS}}{\sqrt{2\pi}\sigma_{NS}} e^{-\frac{(\Delta\varphi-\mu_{NS})^2}{2\sigma_{NS}^2}} + \frac{Y_{AS}}{\sqrt{2\pi}\sigma_{AS}} e^{-\frac{(\Delta\varphi-\mu_{AS})^2}{2\sigma_{AS}^2}}$$