D-meson and hadron correlations in the ALICE experiment and in simulations

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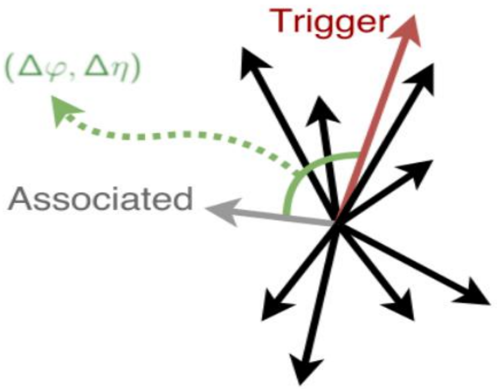
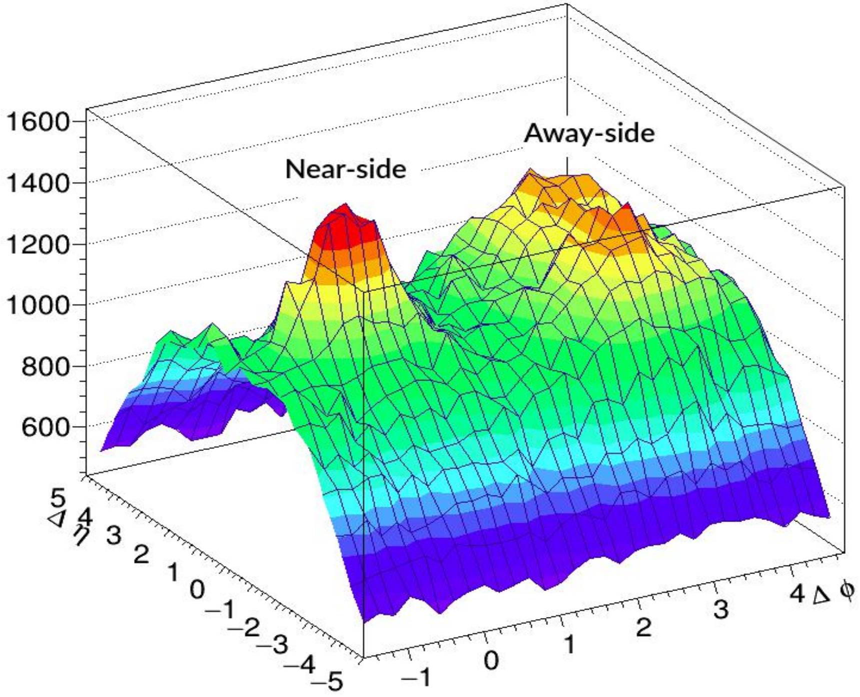
Physics motivation



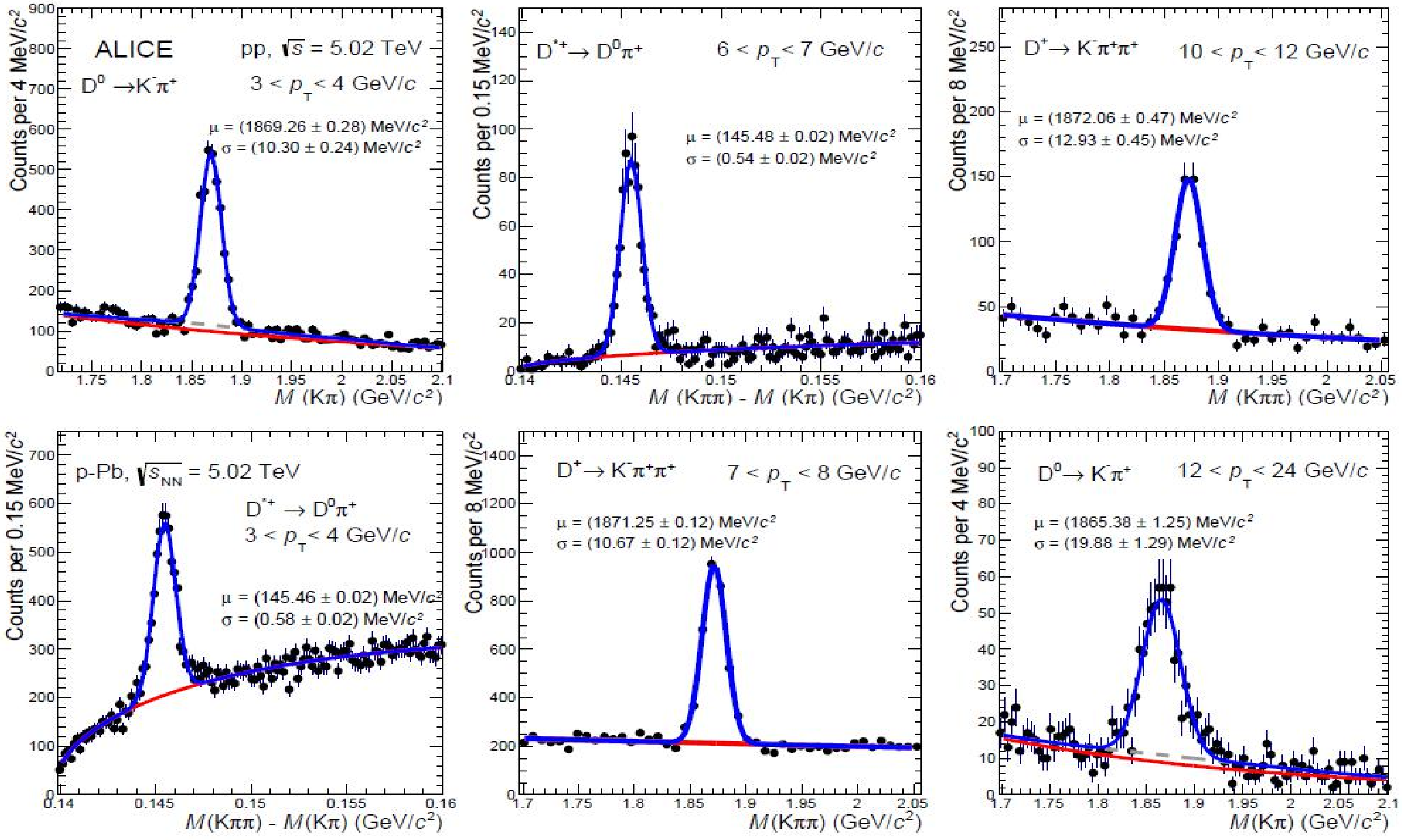
- The direction of the produced particles are correlated
- Associated charged particles and trigger D meson
  - sensitive to the charm-quark production, fragmentation, and hadronisation processes in proton-proton collisions
- Pseudorapidity(η) and azimuth angle(φ)
- Calculating the Δη and Δφ differences
- Associated yield per trigger

$$\frac{1}{N_{trigger}} \frac{d^2 N_{assoc}}{\Delta\varphi d\Delta\eta}$$



Reconstruction of D mesons in ALICE

- pp and p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV
- charged hadron tracks reconstructed in the ITS and TPC
- topological cuts based on angles, secondary vertex
- D^0 and D^+ raw yields extracted from invariant mass fits in several p_T ranges
- D^{*+} yields from invariant mass difference ΔM = M(Kππ)-M(Kπ)



D meson reconstruction:

$$D^+ \rightarrow K^-\pi^+\pi^+$$
$$D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$$
$$D^0 \rightarrow K^-\pi^+$$

Evaluation of the correlation

- The two-dimensional correlation distributions are affected by
  - the limited detector acceptance (mixed event technique)l
  - reconstruction efficiency of the associated tracks ($A^{assoc}\ \varepsilon^{assoc}$)
  - the variation of those values for prompt D mesons ($A^{trig}\ \varepsilon^{trig}$)
- In order to correct for these effects
  - a weight equal to $1/(A^{assoc}\ \varepsilon^{assoc})$ and $1/(A^{trig}\ \varepsilon^{trig})$ was assigned to each correlation pair and a weight of $1/(A^{trig}\ \varepsilon^{trig})$ was applied also to the entries in the D-meson invariant-mass distributions

- The per-trigger angular-correlation distribution was obtained by subtracting the sideband-region correlation distribution from the peak-region one:

$$\tilde{C}_{\rm inclusive}(\Delta\varphi,\Delta\eta) = \frac{p_{\rm prim}(\Delta\varphi)}{S_{\rm peak}}\left(\left.\frac{C(\Delta\varphi,\Delta\eta)}{{\rm ME}(\Delta\varphi,\Delta\eta)}\right|_{\rm peak} - \frac{B_{\rm peak}}{B_{\rm sidebands}}\left.\frac{C(\Delta\varphi,\Delta\eta)}{{\rm ME}(\Delta\varphi,\Delta\eta)}\right|_{\rm sidebands}\right)$$

- Bring the contribution of the feed-down contamination back to an unbiased value:

$$\tilde{C}^{\rm corr}_{\rm inclusive}(\Delta\varphi) = \tilde{C}_{\rm inclusive}(\Delta\varphi)\left[\frac{A^{\rm prompt}_{\rm NS}(\Delta\varphi)}{A^{\rm total}_{\rm NS}(\Delta\varphi)}\cdot f_{\rm prompt} + \frac{A^{\rm feed-down}_{\rm NS}(\Delta\varphi)}{A^{\rm total}_{\rm NS}(\Delta\varphi)}\cdot(1-f_{\rm prompt})\cdot c_{\rm FD-bias}(\Delta\varphi)\right]$$

D-h correlation peak fits

Average of D^0, D^+, D^{*+} contributions
The fit function:

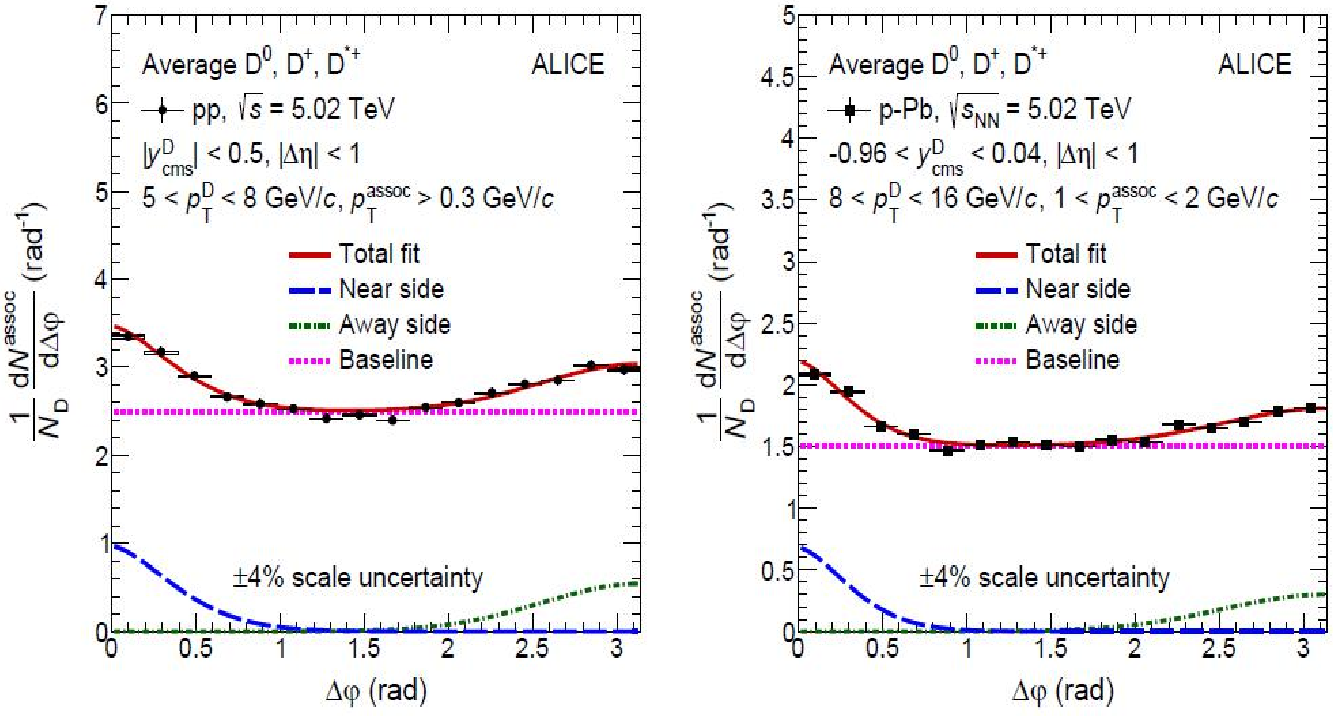
- a constant term b describing the flat contribution below the correlation peaks,
- a generalised Gaussian term describing the near-side peak,
- a Gaussian reproducing the away-side peak.

α : is related to the variance of the function, hence to its width
β : drives the shape of the peak (the Gaussian function is obtained for β = 2)

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

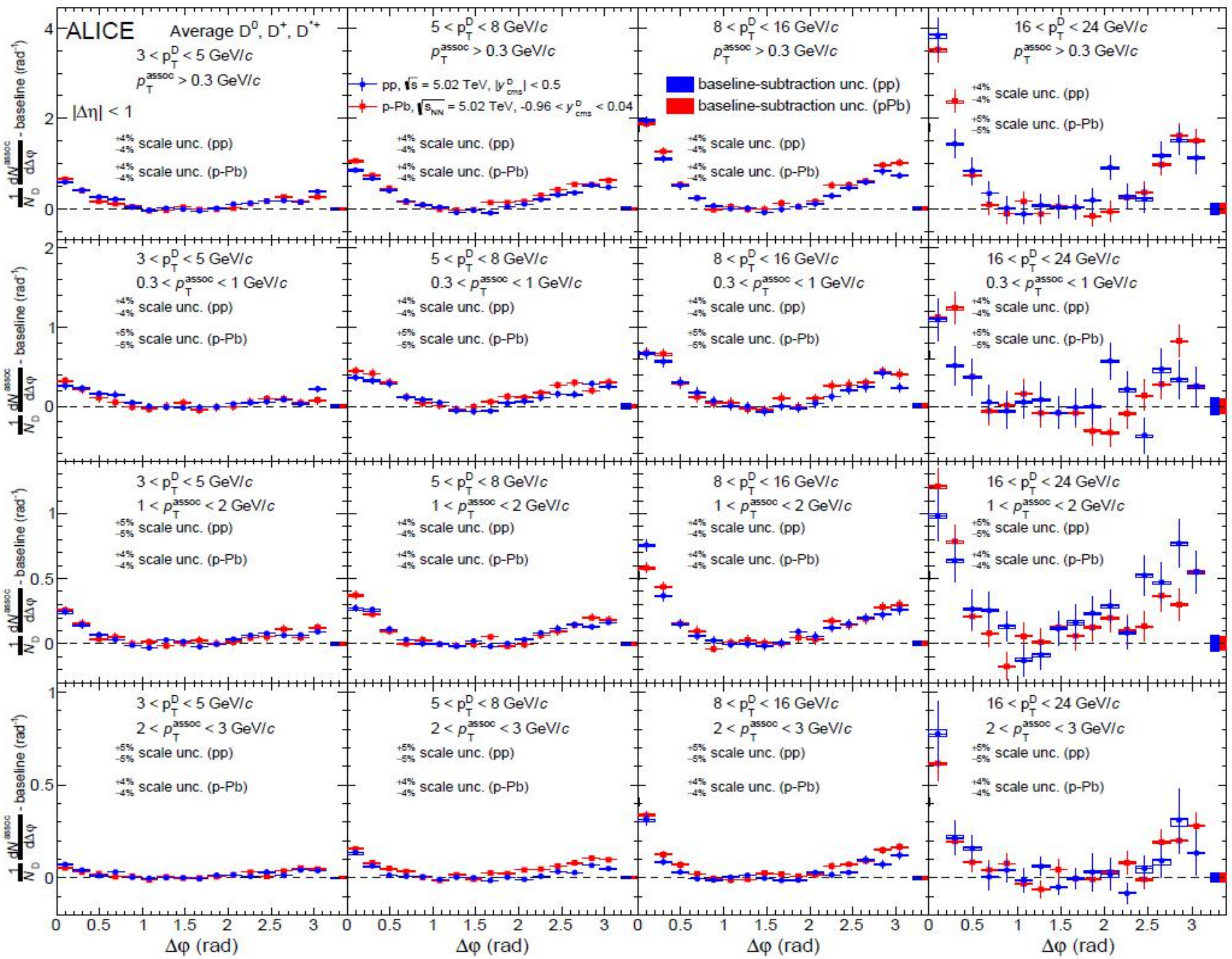
near-side widths of the correlation peaks are described by the square root of the variance:

$$\alpha\sqrt{\Gamma(3/\beta)/\Gamma(1/\beta)}$$

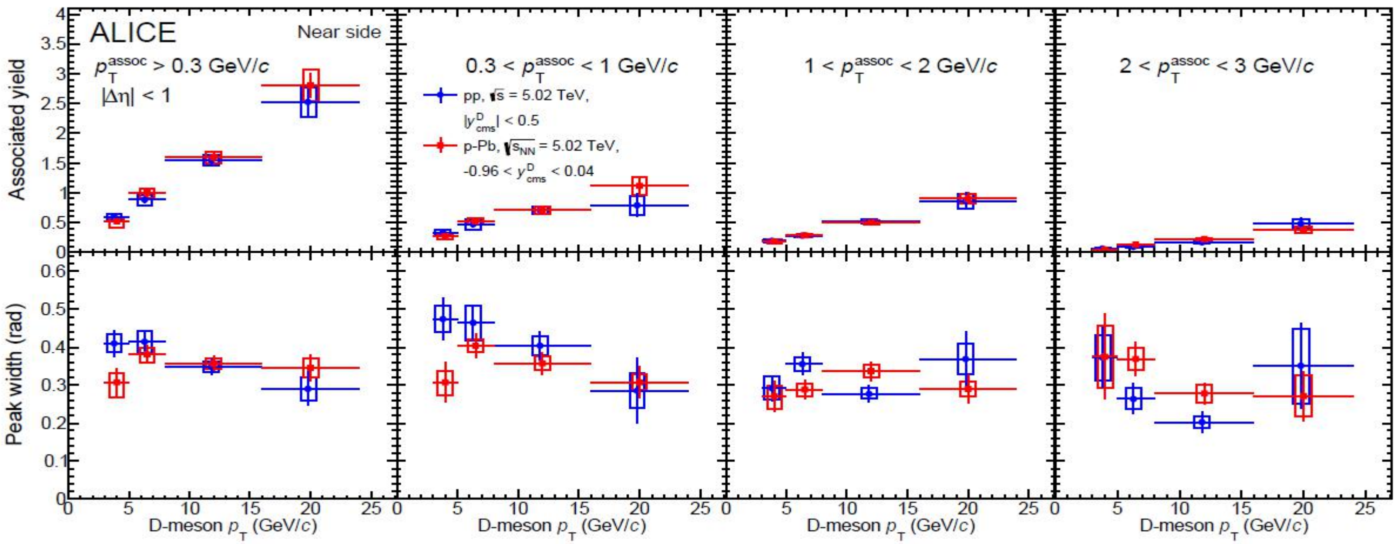


Comparison of results in pp and p–Pb collisions

- The height of the near-side correlation peak is increasing for increasing values of the D-meson p_T.
  - This reflects the production of a higher number of particles in the jet accompanying the fragmenting charm quark, when the energy of the latter increases.
- A similar, though milder, effect can be observed also for the away-side peak.



Comparison of results in pp and p–Pb collisions



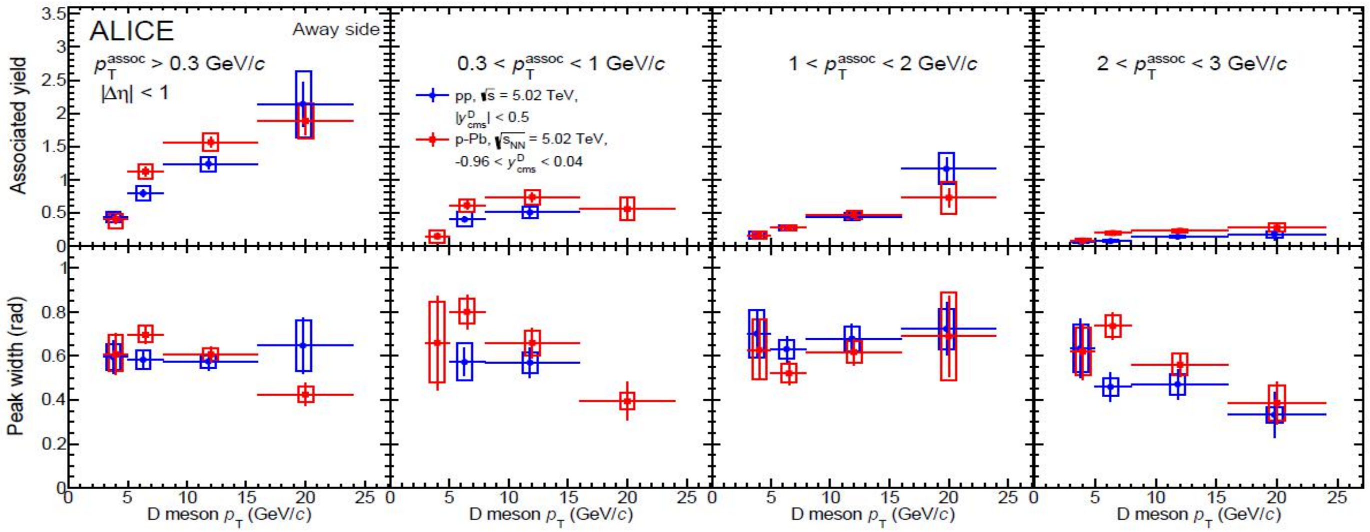
Near-side peak

- A tendency for a narrowing of the near-side peak with increasing p_T^D, signalled by a decrease of the peak width, is also observed.

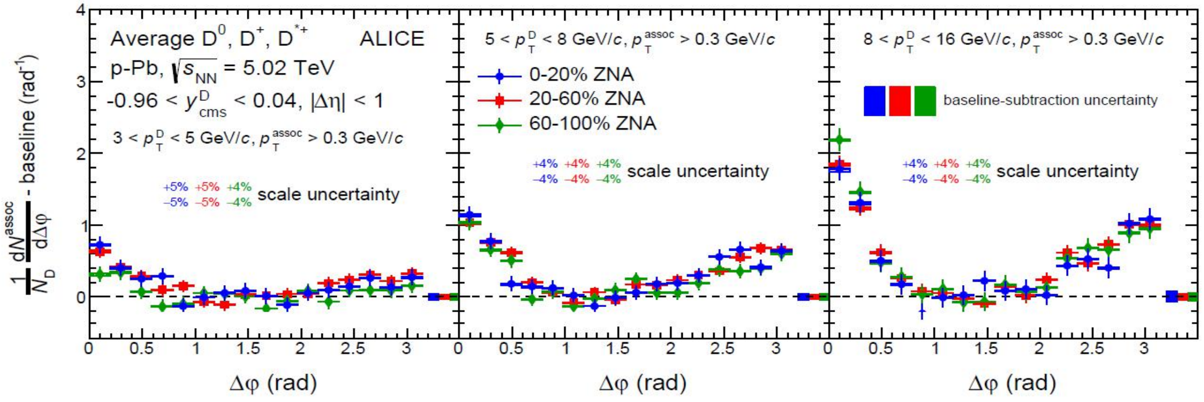
Away-side peak

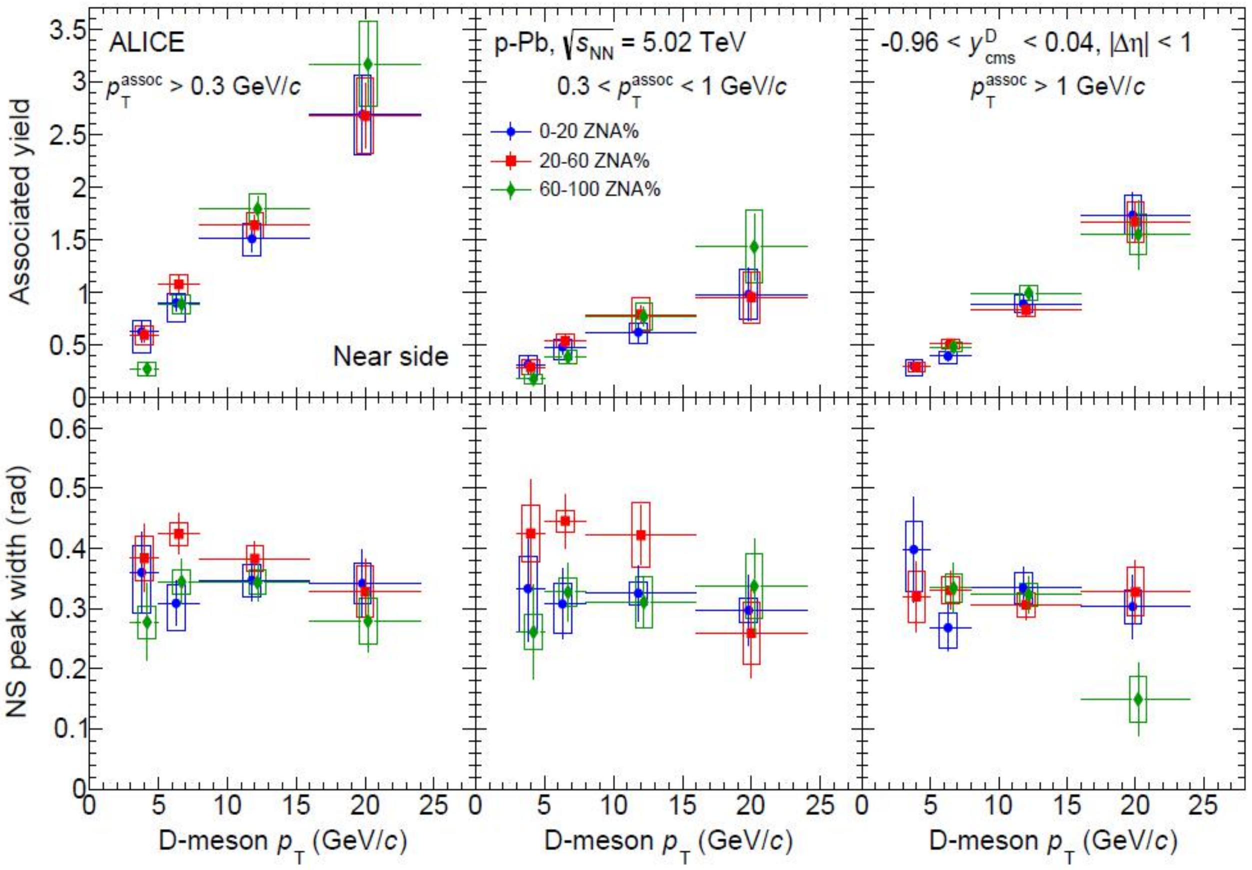
- The away-side yields show an increasing trend with p_T^D values in the two collision systems.
- The away-side peak widths show compatible values in pp and p–Pb collisions in all kinematic ranges.

No significant impact from cold-nuclear-matter effects on the fragmentation of charm quarks within the current precision.



Results in p–Pb collisions as a function of the event centrality





No strong centrality dependence on the correlation peaks, which could have possibly been induced by nuclear-matter effects or multiplicity-dependent vacuum-QCD effects.

Comparsion to Monte Carlo simulations (near- side)

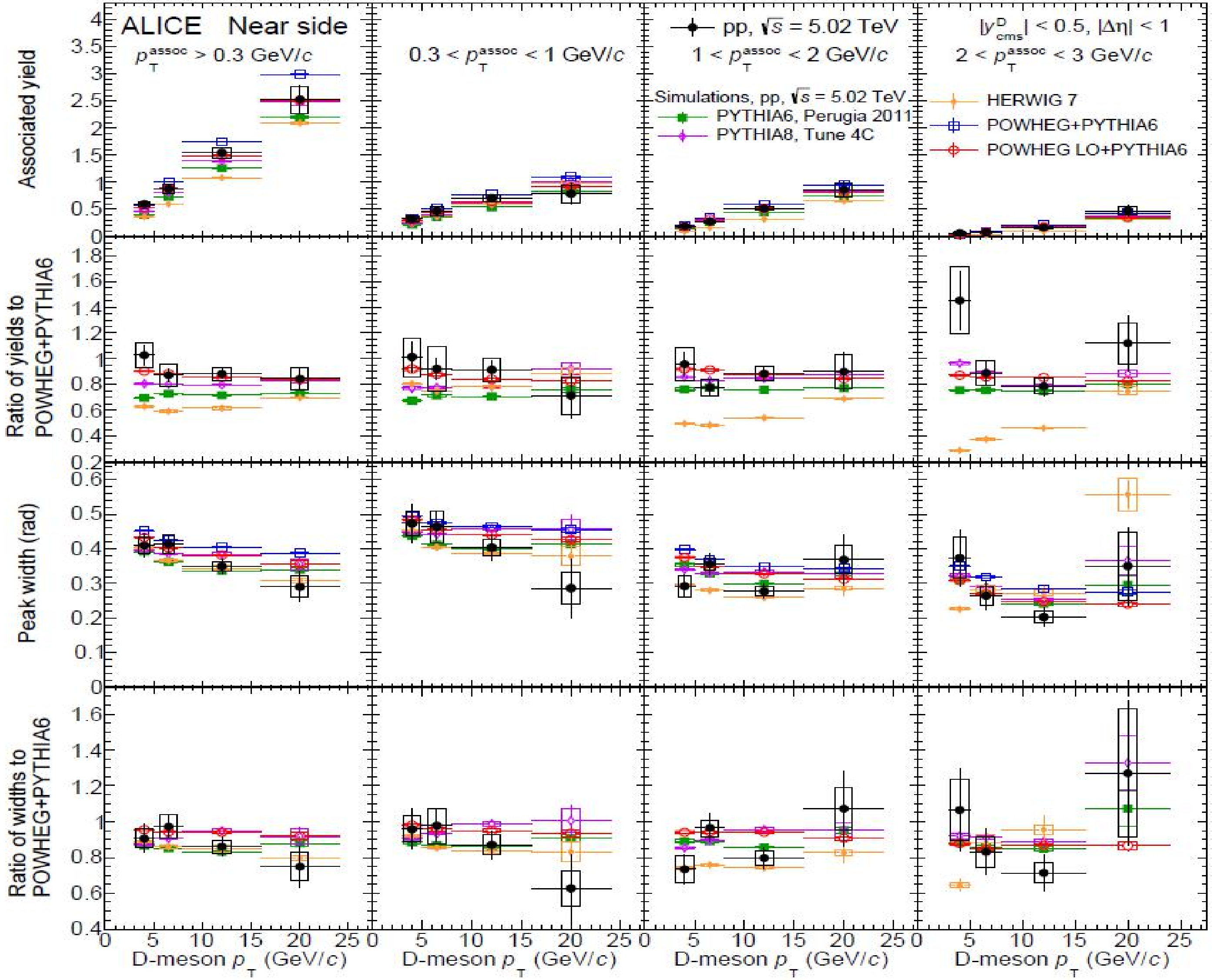
PYTHIA6: LO generator with initial and final state parton shower, Lund string fragmentation.

PYTHIA8: also includes multiple-parton interactions.

HERWIG: NLO including heavy flavor, cluster hadronisation model

POWHEG+PYTHIA: NLO calculation of hard processes, followed by Lund fragmentation

POWHEG LO+PYTHIA: hard process stopped at the LO level, Lund fragmentation



Sensitivity to fragmentation and parton shower

- Best description by POWHEG+PYTHIA6 and POWHEG LO+PYTHIA6
- Yields typically underestimated by HERWIG
- NLO models predict slightly broader peaks

Comparsion to Monte Carlo simulations (away- side)

PYTHIA6: LO generator with initial and final state parton shower, Lund string fragmentation.

PYTHIA8: also includes multiple-parton interactions.

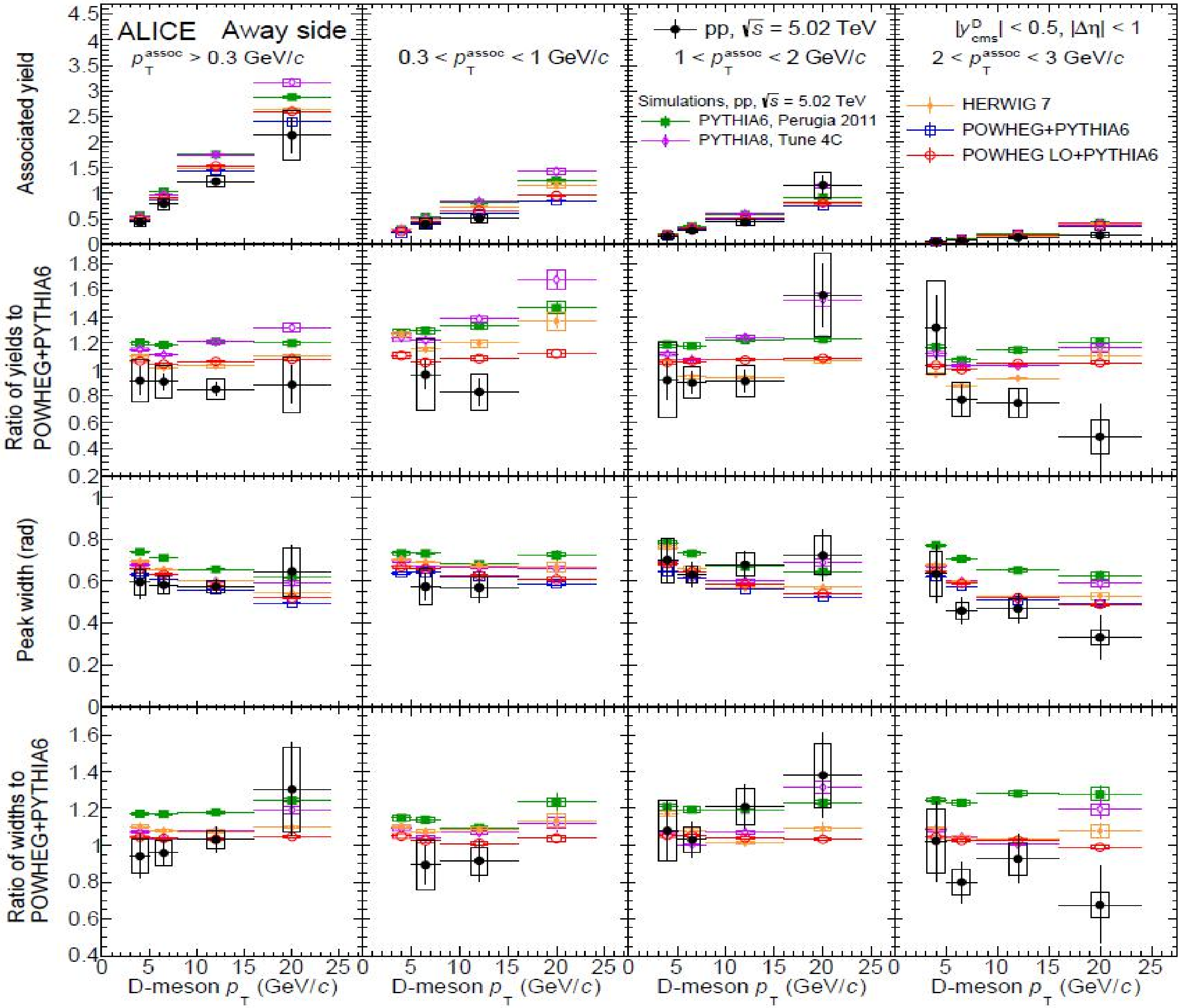
HERWIG: NLO including heavy flavor, cluster hadronisation model

POWHEG+PYTHIA: NLO calculation of hard processes, followed by Lund fragmentation

POWHEG LO+PYTHIA: hard process stopped at the LO level, Lund fragmentation

Sensitivity to parton shower and fragmentation

- Best description by POWHEG+PYTHIA6 and POWHEG LO+PYTHIA6
- PYTHIA6 (Perugia11) overpredicts both the yields and widths
- PYTHIA8 (4C) overpredicts low-p_T yields and widths



Comparsion to Monte Carlo simulations (baseline)

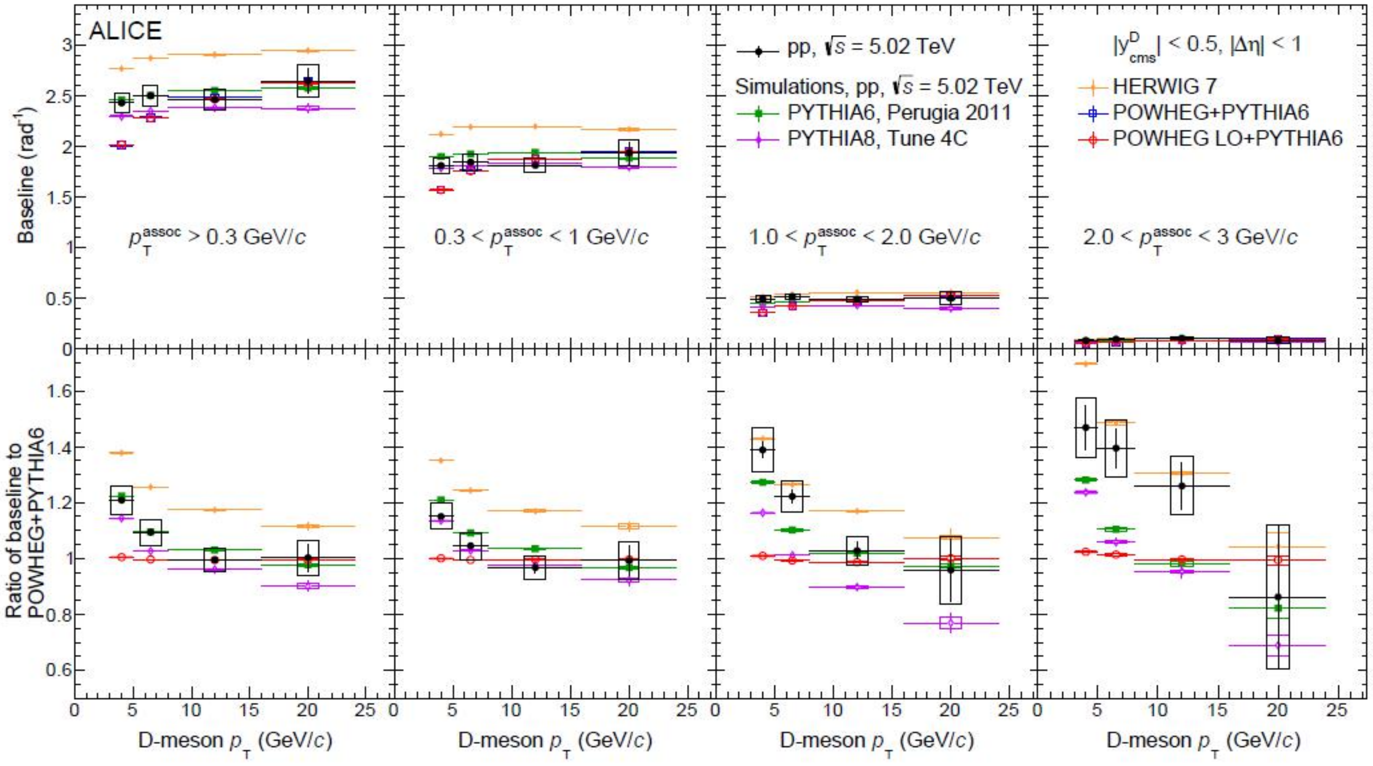
PYTHIA6: LO generator with initial and final state parton shower, Lund string fragmentation.

PYTHIA8: also includes multiple-parton interactions.

HERWIG: NLO including heavy flavor, cluster hadronisation model

POWHEG+PYTHIA: NLO calculation of hard processes, followed by Lund fragmentation

POWHEG LO+PYTHIA: hard process stopped at the LO level, Lund fragmentation

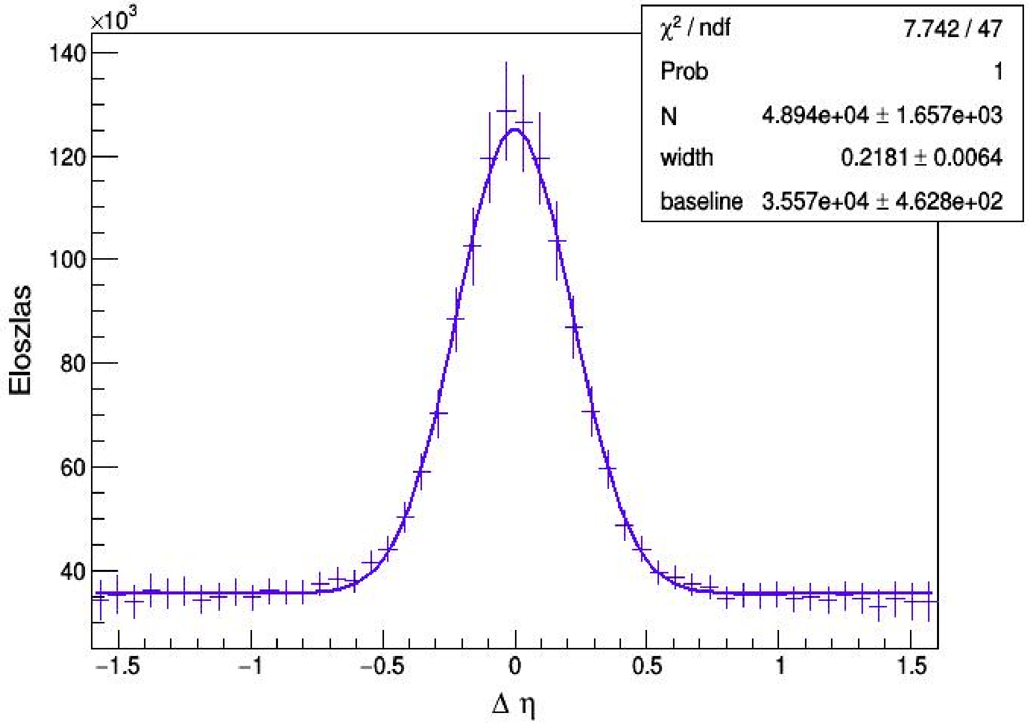


Sensitive to the underlying event

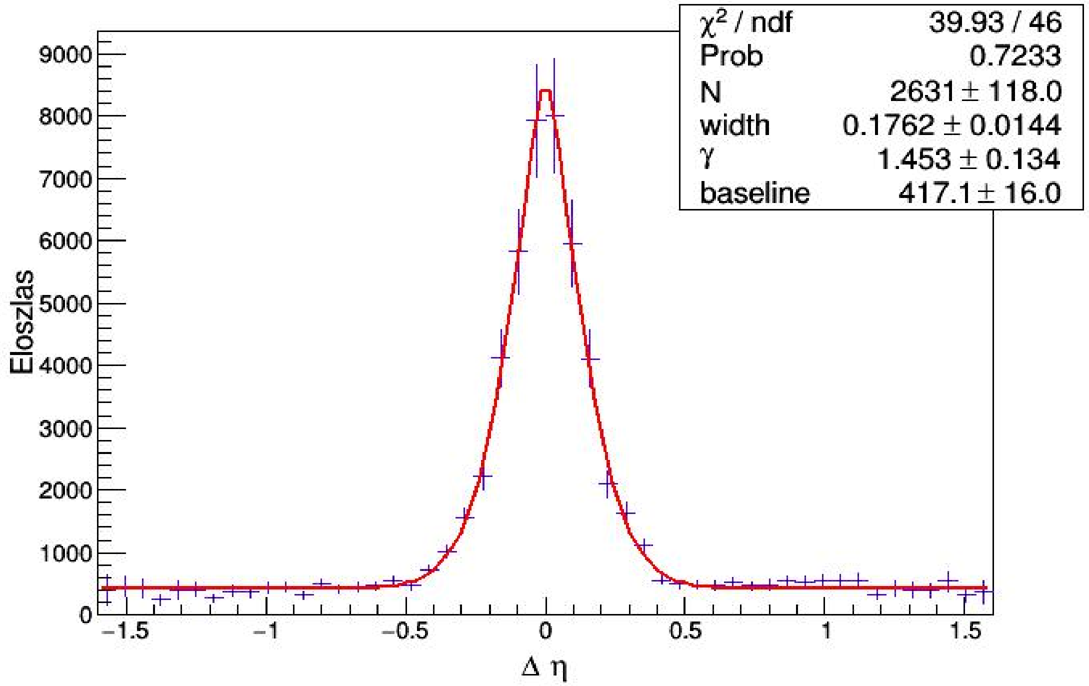
- Decrease toward higher pTassoc (expected)
- p_T^{assoc}<1 GeV: best description by PYTHIA
- p_T^{assoc}>1 GeV: best description by HERWIG
- POWHEG NLO and LO are the same in all ranges (not trivial since influence from NLO charm contributions would be expected)

Further investigations using PYTHIA

Simulations without detector effects



D meson and hadron correlation at 5 TeV
$5 < p_T^{trigger} < 8$
$1 < p_T^{assoc} < 2$



Pion,proton, kaon and hadron correlation at 5 TeV
$5 < p_T^{trigger} < 8$
$3 < p_T^{assoc} < 5$

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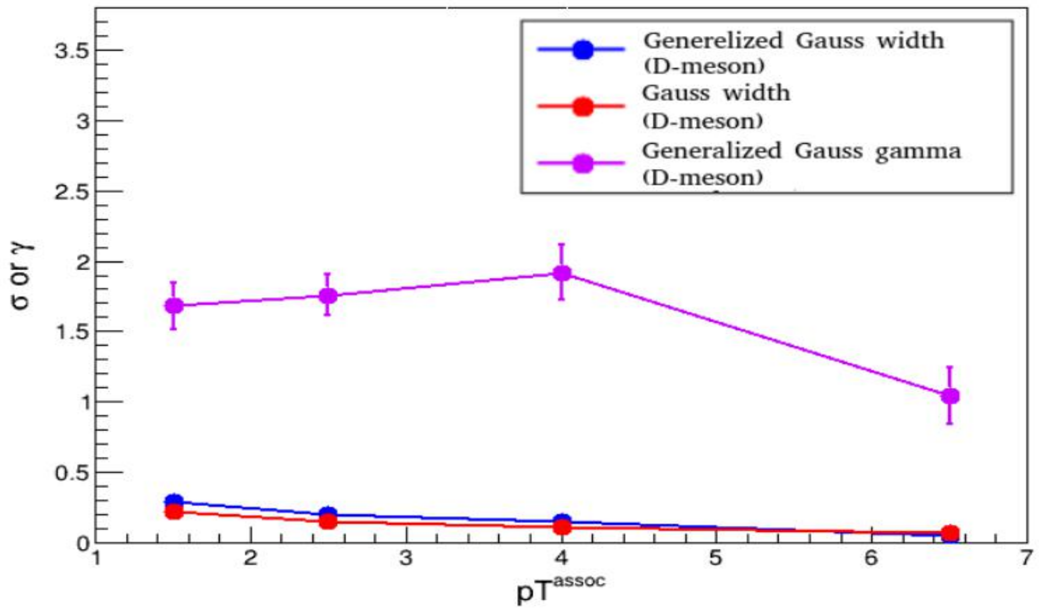
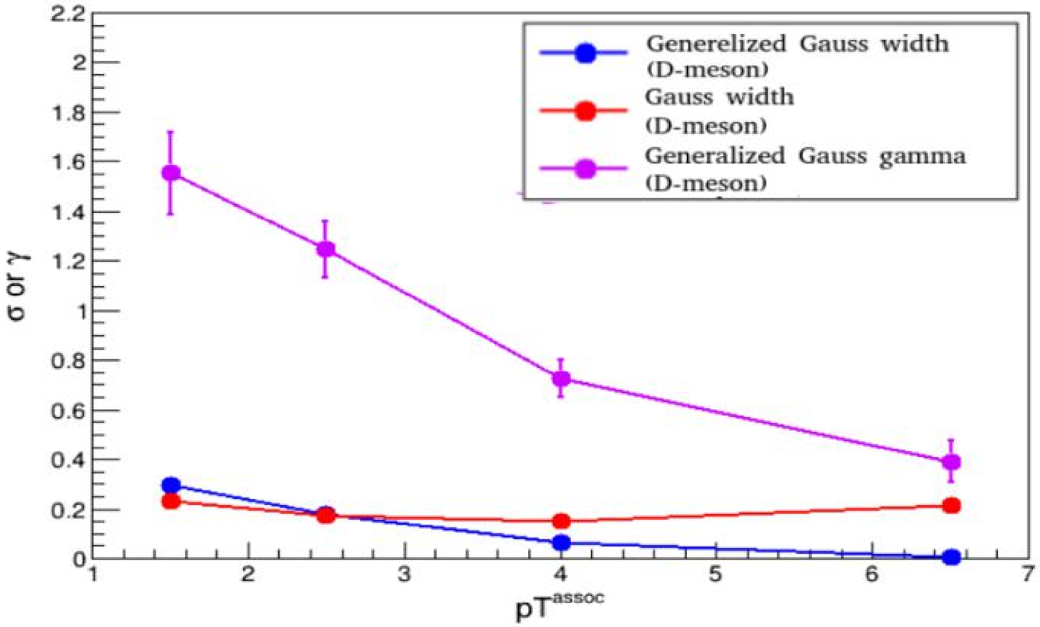
Prompt and late D meson separation

D meson from c quark



Peaks are consistent with Gaussian.

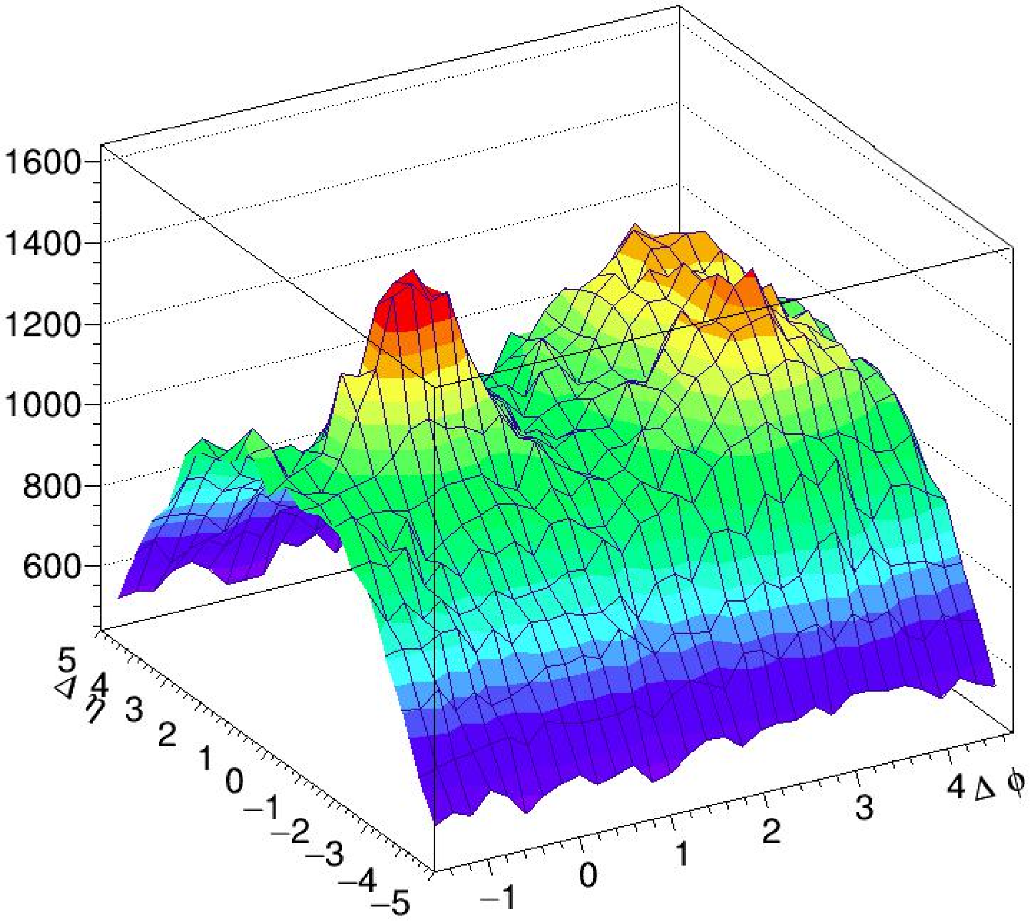
D meson from the decay of B meson

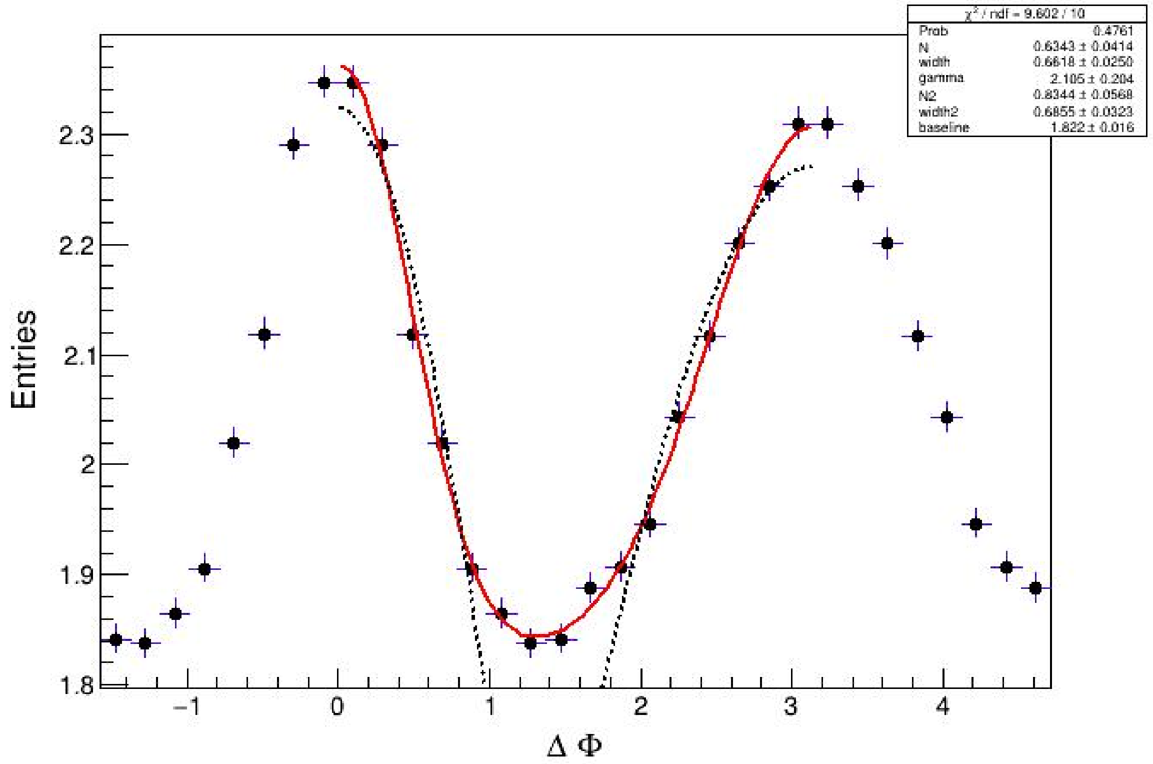


GenGauss parameter decreases with p_T, together with σ. (Peaks are getting both narrower and "peakier" towards high p_T).

Prompt and non-prompt contributions can be separated based on correlation shapes.

Full detector simulation in the ALICE framework





D meson and hadron correlation at 5 TeV

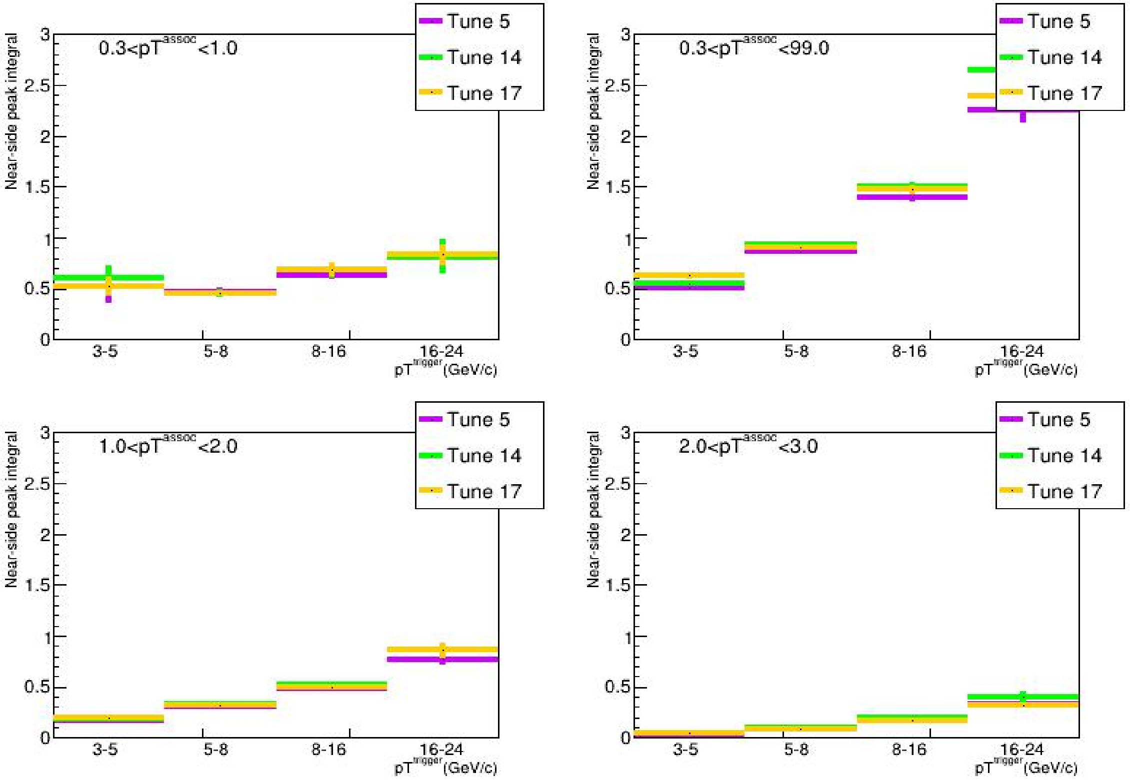
$8 < p_T^{assoc} < 16$

$0.3 < p_T^{trigger} < 1.0$

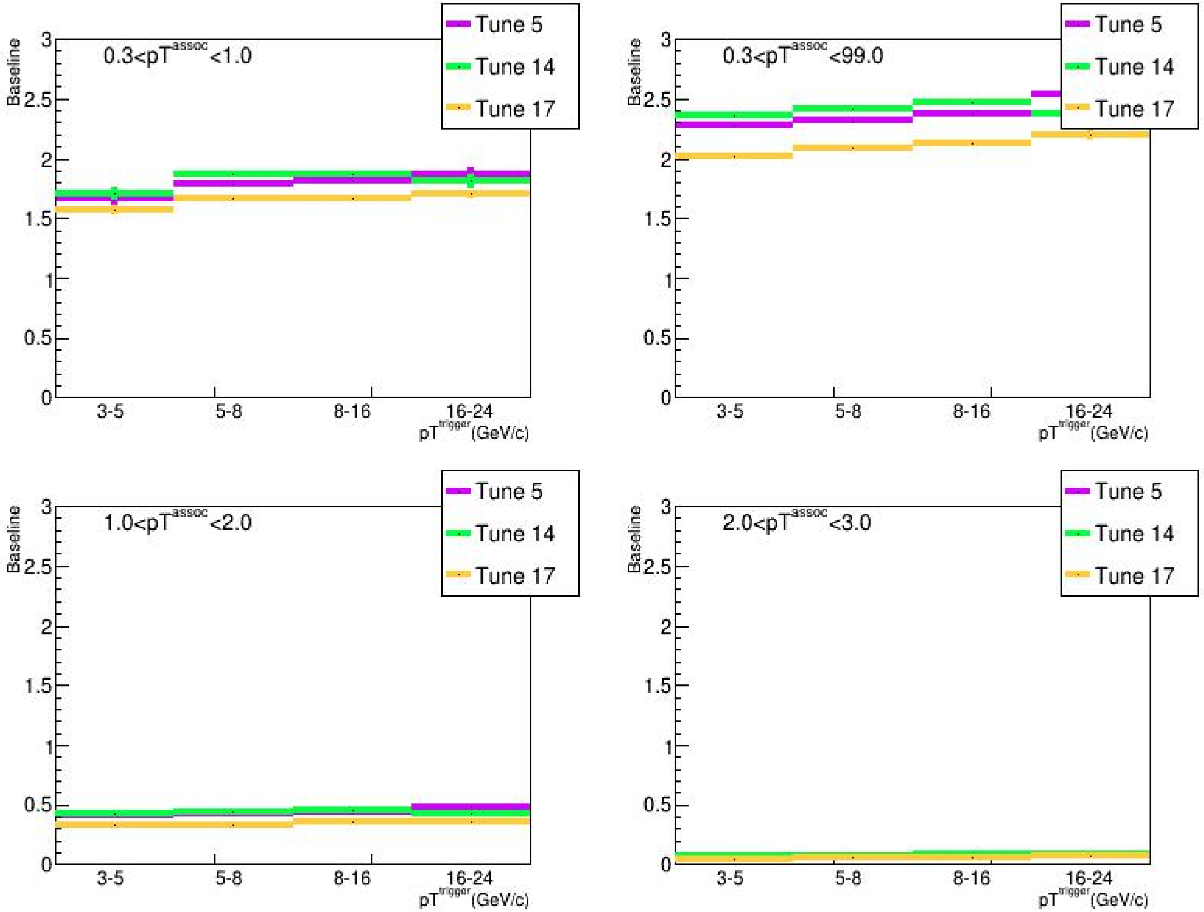
Different tunes

- 4C (Tune 5)
- Monash (Tune 14)
- MonashStar (Tune 17)

Near-side peak yield



Baseline



- Peaks are predicted similarly
- Significantly lower baseline for MonashStar (~20% at max)
- Different underlying events

Different colour reconnection modes

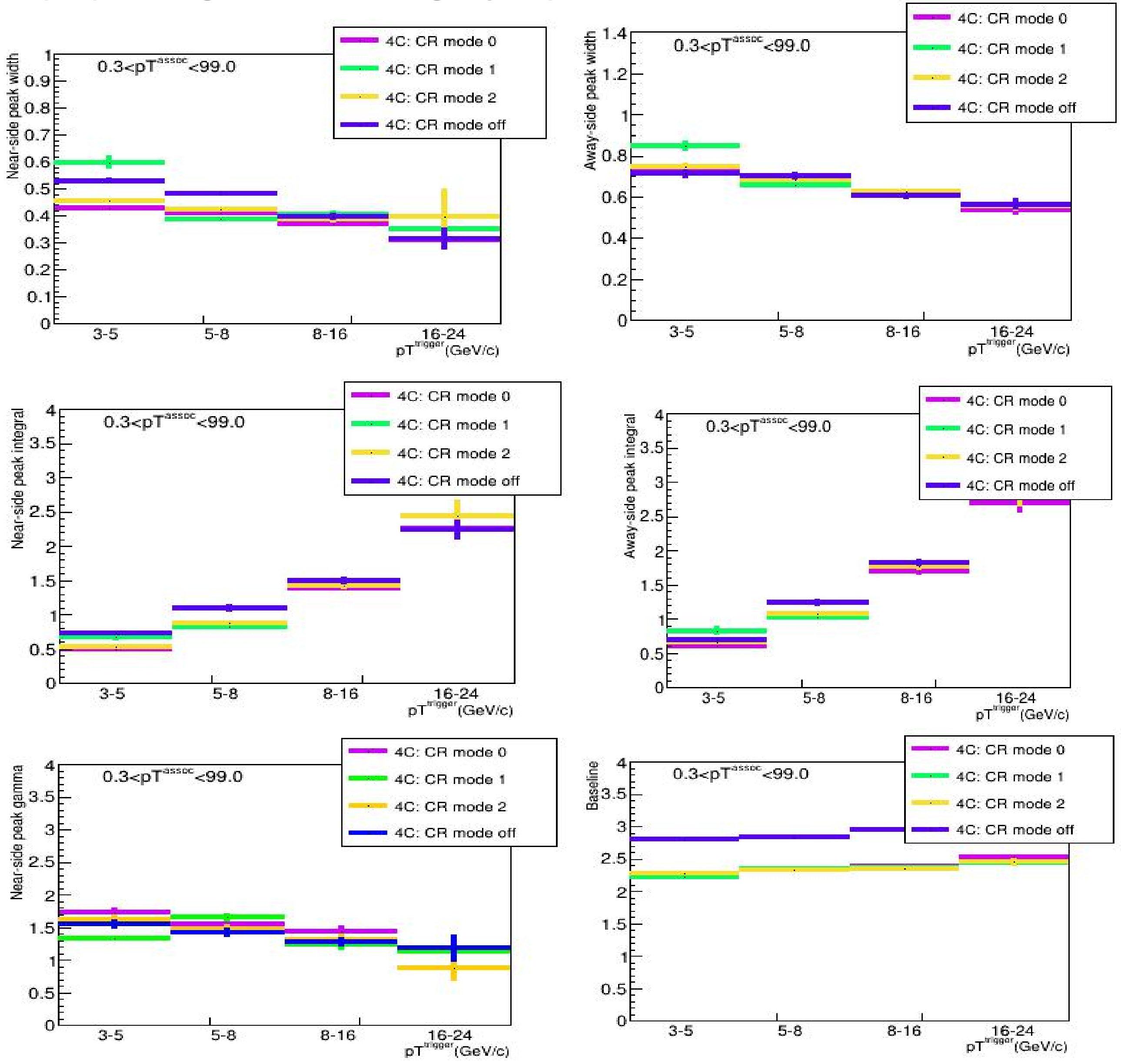
- Mode 0 : The MPI-based original Pythia 8 scheme.
- Mode 1 : The new QCD based scheme.
- Mode 2 : The new gluon-move model.
- Reconnection off.

A tendency for a narrowing of the near-side and away-side peak with increasing p_T^D.

An increasing trend of the near-side and away-side yield with increasing p_T^D.

Baseline is significantly higher in CR off. Expected since CR=off corresponds to higher average multiplicities.

Note: Other parameters are mostly the same => difference only in underlying event.



Different parton levels

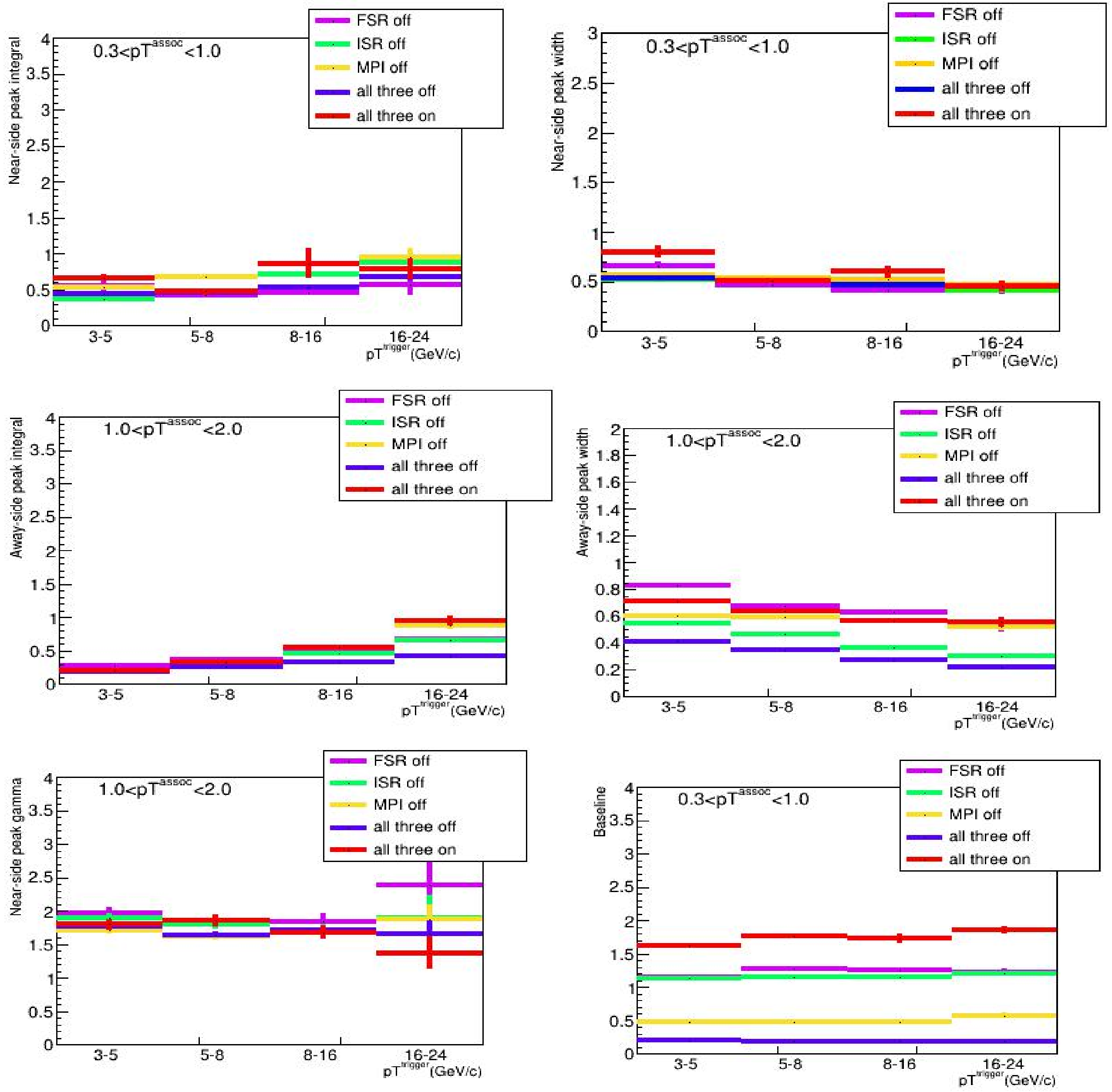
Near-side yield: significant contribution of FSR at higher trigger $p_T^{trigger}$.

Near-side width and shape: no change, maybe it is driven by fragmentation/hadronic state.

Away-side yield: Significant contribution from MPI.

Away-side width: Contributions of parton-level effects make it wider as expected (especially ISR). FSR=off overshoots all=ON.

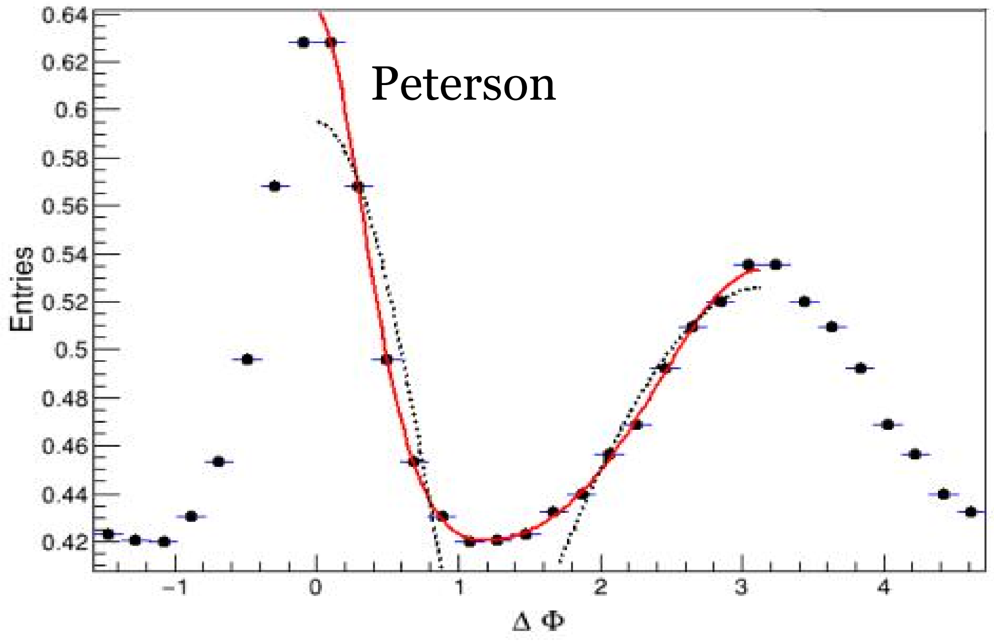
Baseline: Contributions of parton-level effects to underlying event as expected. Weak p_T-leading dependence.

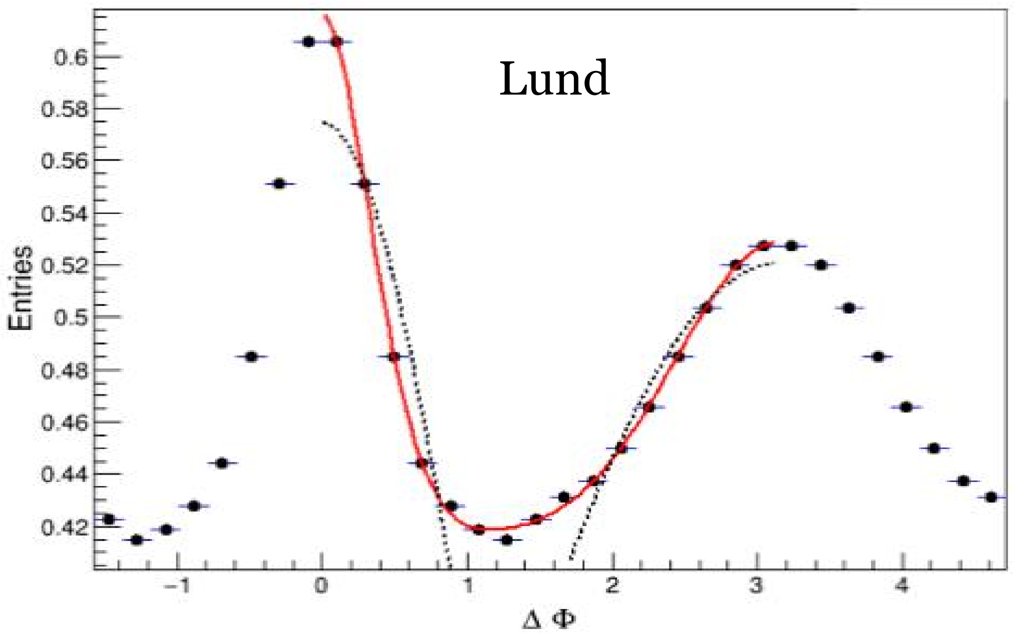


Heavy-flavour fragmentation (Lund vs. Peterson model)

Peterson formula is a fragmentation function for heavy quarks. We use this instead of the Lund formula. For fits to experimental data, better agreement can be obtained.

$$f(z) = \frac{1}{z(1 - \frac{1}{z} - \frac{\epsilon}{1-z})^2}$$





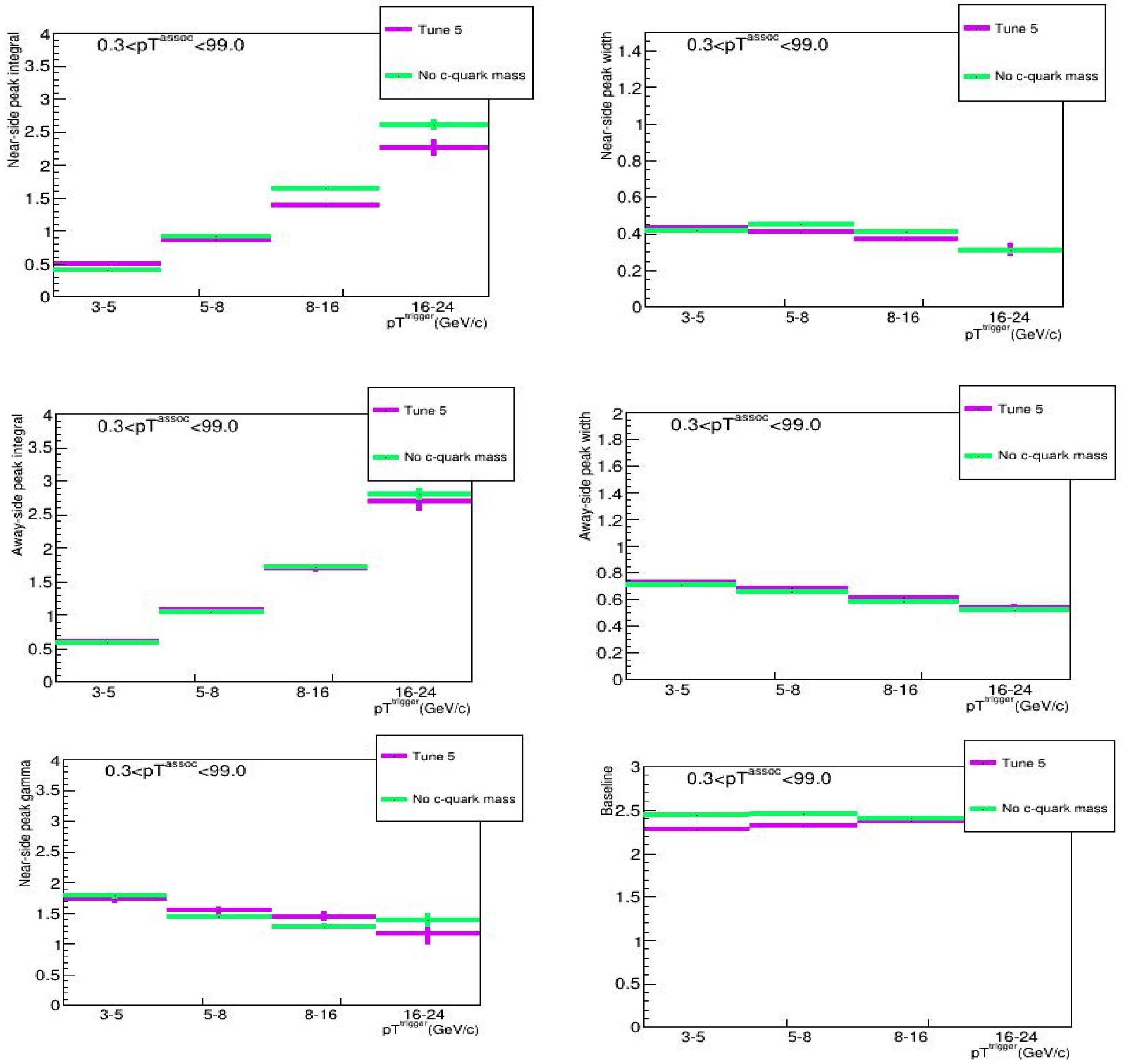
No significant difference between the two model.

No c-quark mass

Disable the charm quark mass in order to sort the mass cone effect and the color charge effect.

Slight differences at near-side width and yield.

Baseline: Slight difference in underlying event at low p_T.



Summary

ALICE measurements of azimuthal-correlation distributions of D^0, D^{*+}, and D^+ mesons with charged particles in pp and p–Pb collisions at 5.02 TeV

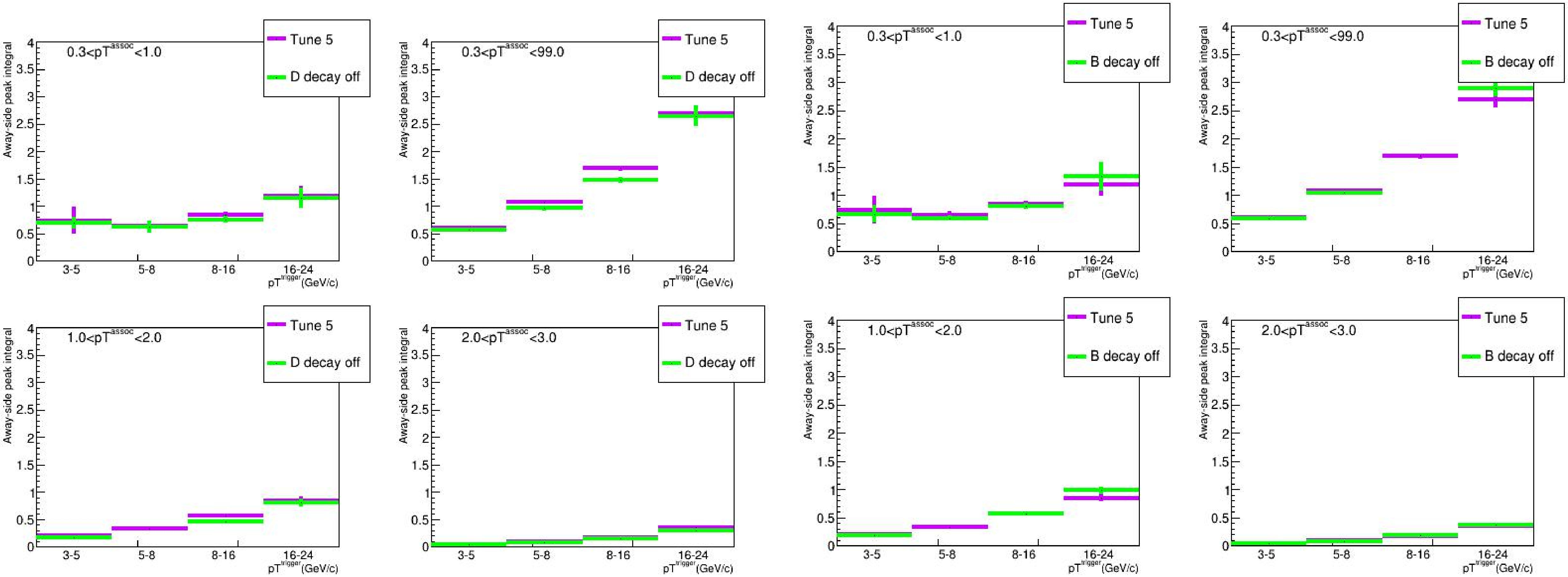
- No strong dependence on system (pp vs. pPb) or on event multiplicity.
- The fragmentation and hadronisation of charm quarks is **not strongly influenced by cold-nuclear-matter effects.**
- Best description by POWHEG+PYTHIA: importance of NLO processes in correlations.
- HERWIG underestimates near-side yields and baseline at low p_T: shortcomings of cluster fragmentation model.

Investigation of correlations using simulation components

- Correlations: a tool to statistically separate prompt and non-prompt contributions.
- Different PYTHIA tunes: importance of underlying event contribution to background.
- Important role of color reconnection, but no significant difference between colour reconnection models.
- Contribution of parton-level effects (ISR,FSR and MPI) to underlying event and away-side peak
- No significant difference depending on Lund vs. Peterson fragmentation model.
- Slight differences when setting the c-quark mass to 0: role of dead cone effect in fragmentation.

Thanks for your attention!

Prompt and late D meson separation



Monte Carlo simulations

PYTHIA

- Allows for the generation of ultra-relativistic collisions of leptons and/or hadrons.
- It employs 2 to 2 QCD matrix elements evaluated perturbatively with leading-order precision.
- The parton showering follows a leading-logarithmic p_T ordering, with soft-gluon emission divergences.
- The hadronisation is handled with the Lund string-fragmentation model.

HERWIG

- Allows one to perform Monte Carlo simulations at NLO accuracy for most of the Standard Model processes, including heavy-quark production.
- The parton showering is performed with an angular ordering of the fragments, which correctly takes the coherence effects for soft-gluon emissions into account.
- Hadronisation is handled via the cluster hadronisation model.

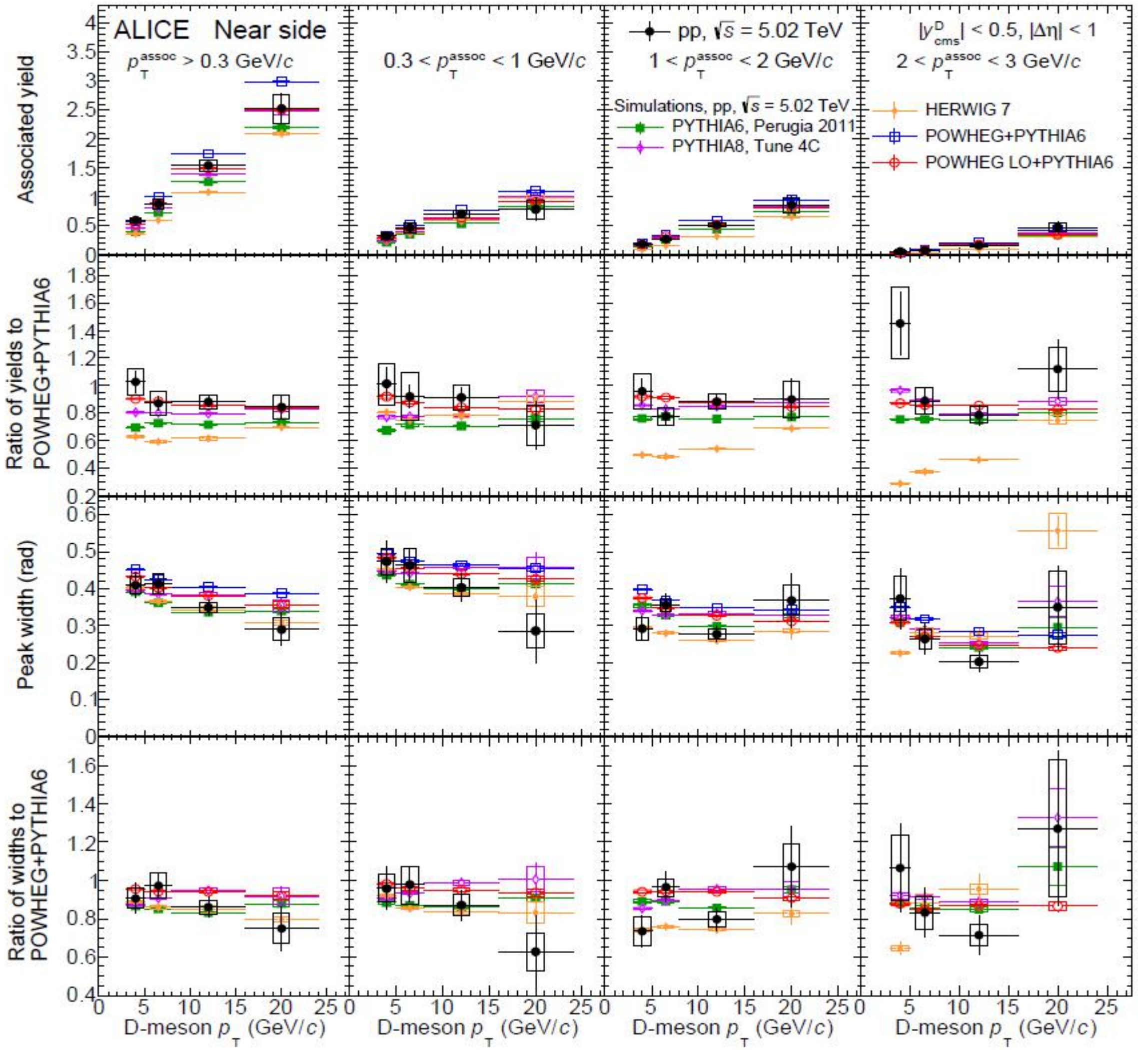
POWHEG

- A pQCD generator capable of calculating hard-scattering matrix elements with NLO accuracy, which can be coupled to Monte Carlo generators, like PYTHIA or HERWIG for the parton showering and hadronisation of the produced partons.

POWHEG+PYTHIA

- Stopping the computation of the hard-scattering matrix elements at leading-order accuracy, before passing the generated partons to PYTHIA for the showering and hadronisation.

Comparison to Monte Carlo simulations (near-side)



Near-side yield

- POWHEG+PYTHIA6 predicts the largest values of the near-side yields, while POWHEG LO+PYTHIA6 shows about 10% lower yields.
  - This difference could be explained by a different relative contribution of the NLO production mechanisms, in particular the gluon splitting, present already at the level of the hard scattering for POWHEG+PYTHIA6.
- PYTHIA8 provides near-side yield values comparable to those of POWHEG LO+PYTHIA6, while PYTHIA6 yields are slightly lower.
- HERWIG predictions for near-side yields are the lowest, except for the 0.3 < p_T^{assoc} < 1 GeV/c range, where they are comparable to PYTHIA8 expectations.
- The closest description of data is provided by POWHEG+PYTHIA6 and POWHEG LO+PYTHIA6, with data points lying between the two predictions.

Near-side width

- POWHEG+PYTHIA6 give the broadest peaks, followed by POWHEG LO+PYTHIA6, with increasing difference between the two model predictions with increasing p_T^{assoc} .
- PYTHIA8 gives similar widths as POWHEG LO+PYTHIA6, while PYTHIA6 widths are generally lower.
- HERWIG predictions are consistent with PYTHIA6 for p_T^{assoc} < 1 GeV/c, and are generally lower for p_T^{assoc}> 1 GeV/c.
- POWHEG+PYTHIA6 provides systematically larger widths than what is observed in the data, though in general they are compatible within the total uncertainties, point-by-point.

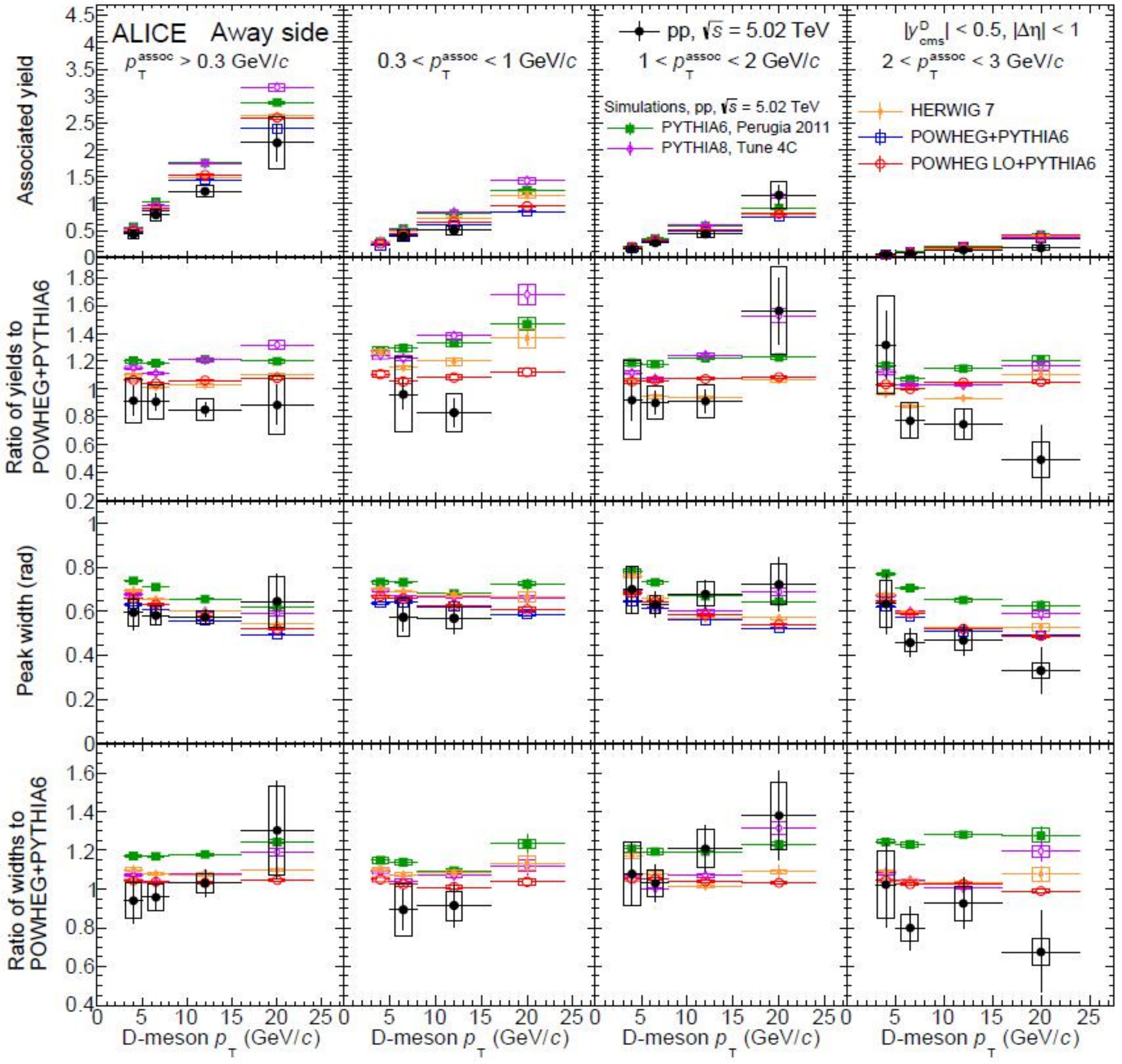
Comparison to Monte Carlo simulations (away-side)

Away-side yield

- POWHEG+PYTHIA6 predicts the smallest away-side yields, with about 5%-10% smaller values, than POWHEG LO+PYTHIA6 expectations
- HERWIG predicts similar yields as POWHEG LO+PYTHIA6 for the integrated p_T^{assoc} range (with larger values for $0.3 < p_T^{assoc} < 1$ GeV/c and smaller values for $p_T^{assoc} > 1$).
- PYTHIA8 and PYTHIA6 predictions tend to overpredict away-side yields.
- The best description of the away-side yields is provided by POWHEG+PYTHIA6 and POWHEG LO+PYTHIA6 over the full kinematic range, as well as by HERWIG for $p_T^{assoc} > 1$ GeV/c, as in the near-side peak case.

Away-side width

- The largest values of the away-side peak width are given by PYTHIA6 event generator, in particular for large values of p_T^{assoc}.
- The expectations from all the other models are very similar, with POWHEG+PYTHIA6 being in general the lowest of them.
- All the models are in agreement with the results, except for PYTHIA6, which tends to systematically overpredict the data points.



Comparison to Monte Carlo simulations (baseline)

Expected:

- baseline values decrease with increasing p_T^{assoc}
- mild increasing trend with p_T^D : POWHEG+PYTHIA6 and POWHEG LO+PYTHIA6 predict a larger increase than HERWIG and PYTHIA

Not trivial:

- POWHEG+PYTHIA6 and POWHEG LO+PYTHIA6: same baseline values for all the kinematic ranges
  - different treatment of next-to leading order contributions to charm production

Best description of the results,

- for low p_T^{assoc} values is provided by PYTHIA, while HERWIG overestimates the values by ~15% and POWHEG+PYTHIA6 underpredicts them by 20%
- for $p_T^{assoc} > 1$ GeV/c is provided by HERWIG, while PYTHIA and POWHEG+PYTHIA6 tend to underpredict data values