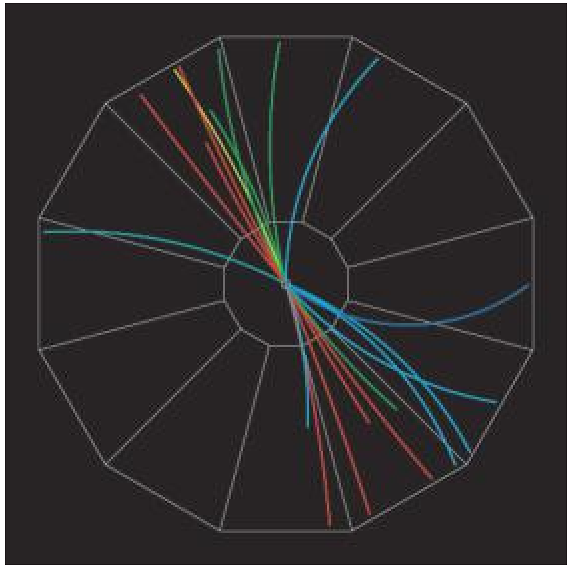
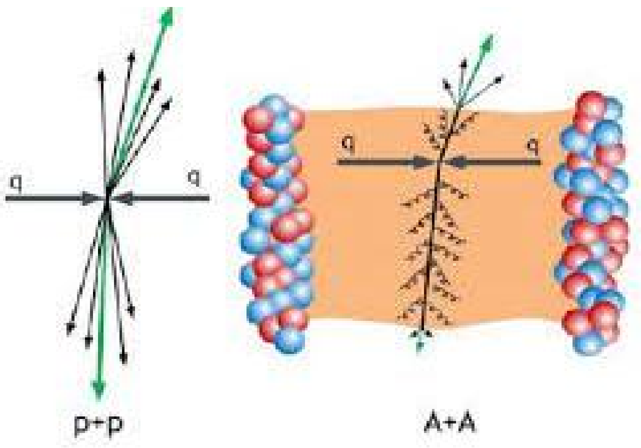
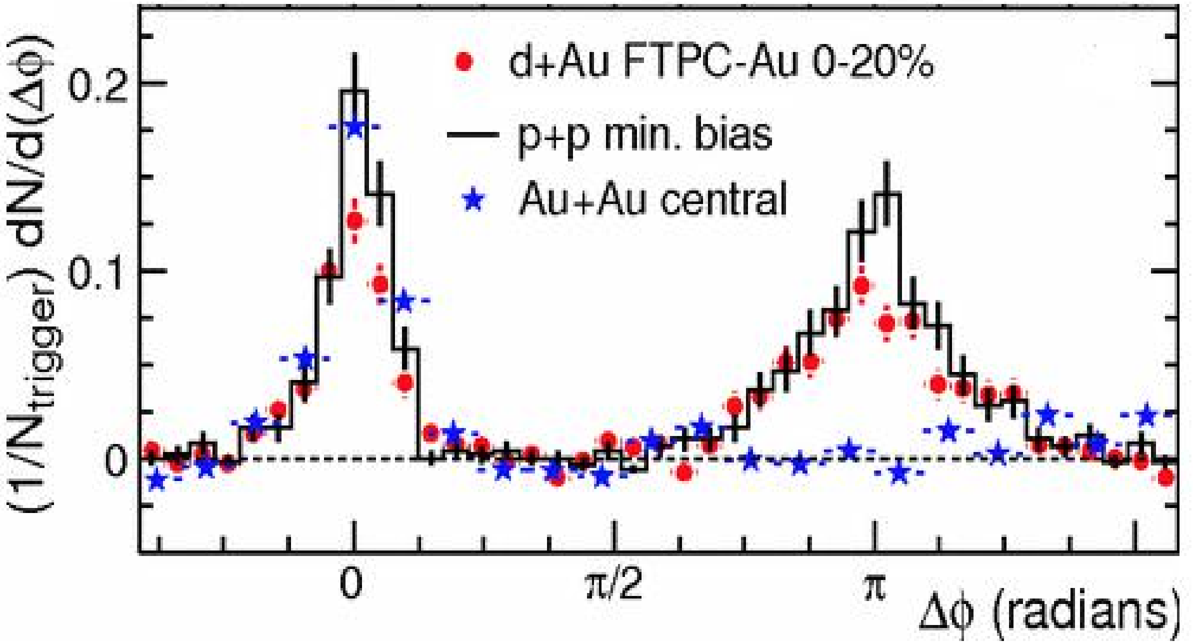
Azimuthal correlations of D mesons with charged particles with the ALICE experiment at the LHC

Frajna Eszter

Physics motivation







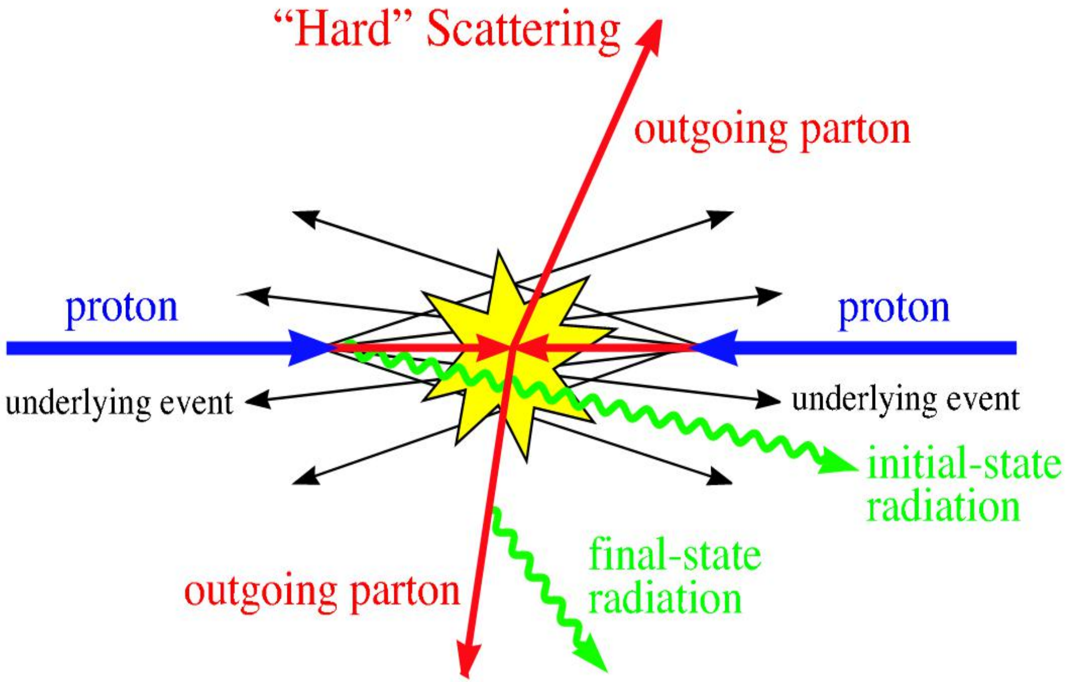
PRL 91 (2003) 072304

- High-energy nucleus-nucleus collisions make it possible to study the properties of the QGP medium through the observed changes in the jet fragmentation.
- In p(d) + A collisions, CNM effects can be studied.

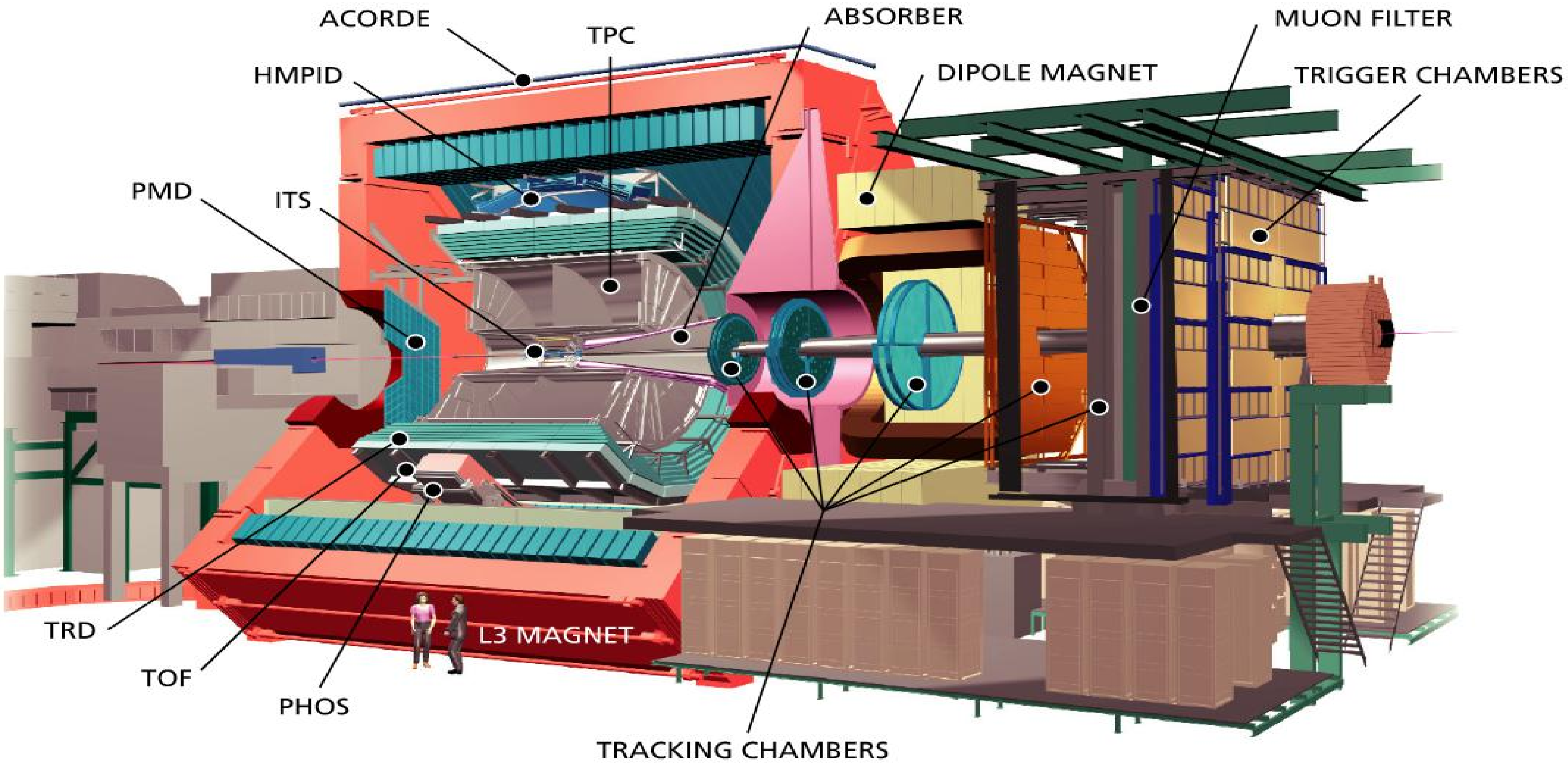
- The suppression of the away-side jets was observed in angular correlation measurements at RHIC.
- This was one of the first evidences of the strongly interacting Quark Gluon Plasma.

Heavy-flavour correlations in pp collisions

- Understanding jet structure with angular correlations
  - Full jet reconstruction is problematic at low momenta because of the high background. Solution: measuring the angular correlation of final-state hadrons.
  - Near-side correlation peak is sensitive to fragmentation
  - Away-side is sensitive to hard QCD production
  - Both sensitive to multi-parton interactions (MPI), initial and final-state radiations (ISR,FSR)
- Correlations with heavy quarks
  - Sensitivity to the charm and beauty quark production, flavor-dependent fragmentation, dead cone effect and hadronisation processes
  - Sensitivity to QCD production mechanisms (eg. LO flavor pair creation, NLO gluon splitting/Flavor excitation)



The ALICE detector

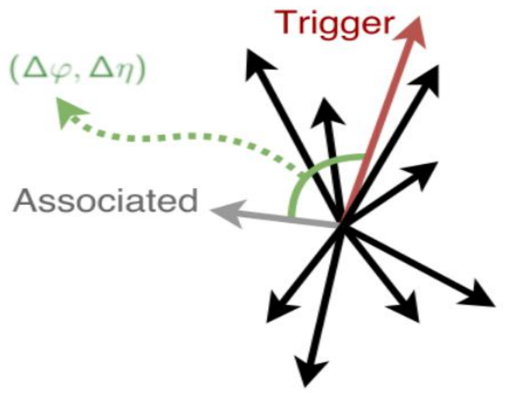


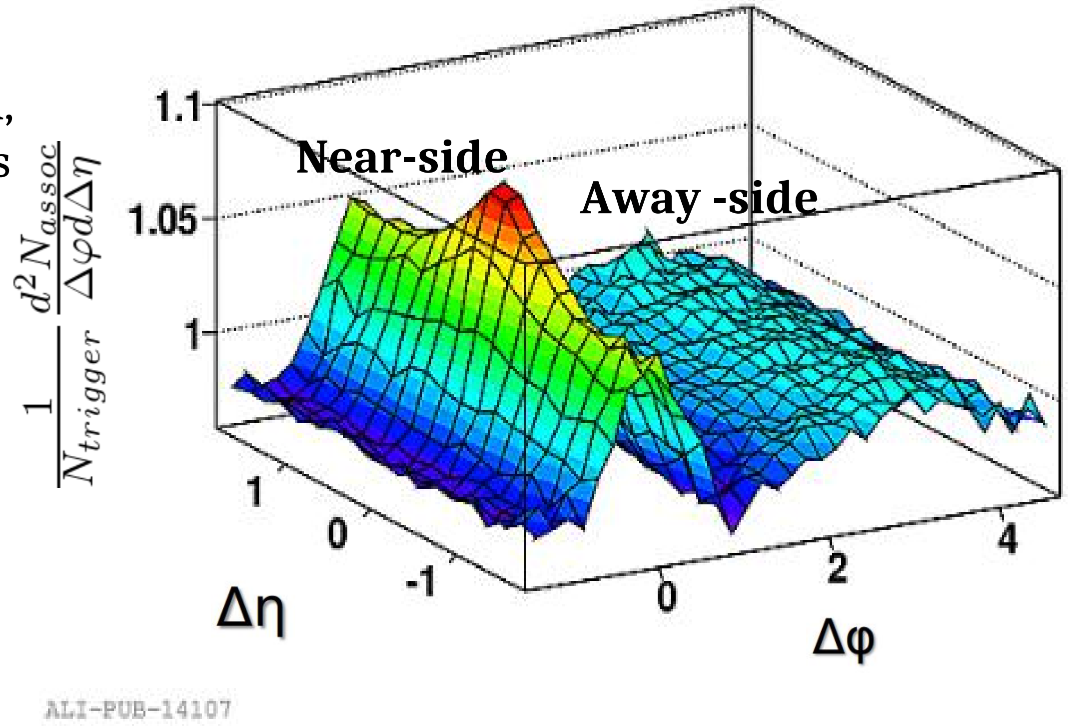
- Excellent particle identification capabilities down to low momenta with the TPC
- Heavy-flavor identification is aided by secondary vertex reconstruction in the ITS

Analysis strategy

- In both soft and hard processes, the direction of the produced particles are correlated
- Associated charged particles with D mesons as the trigger
  - 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

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

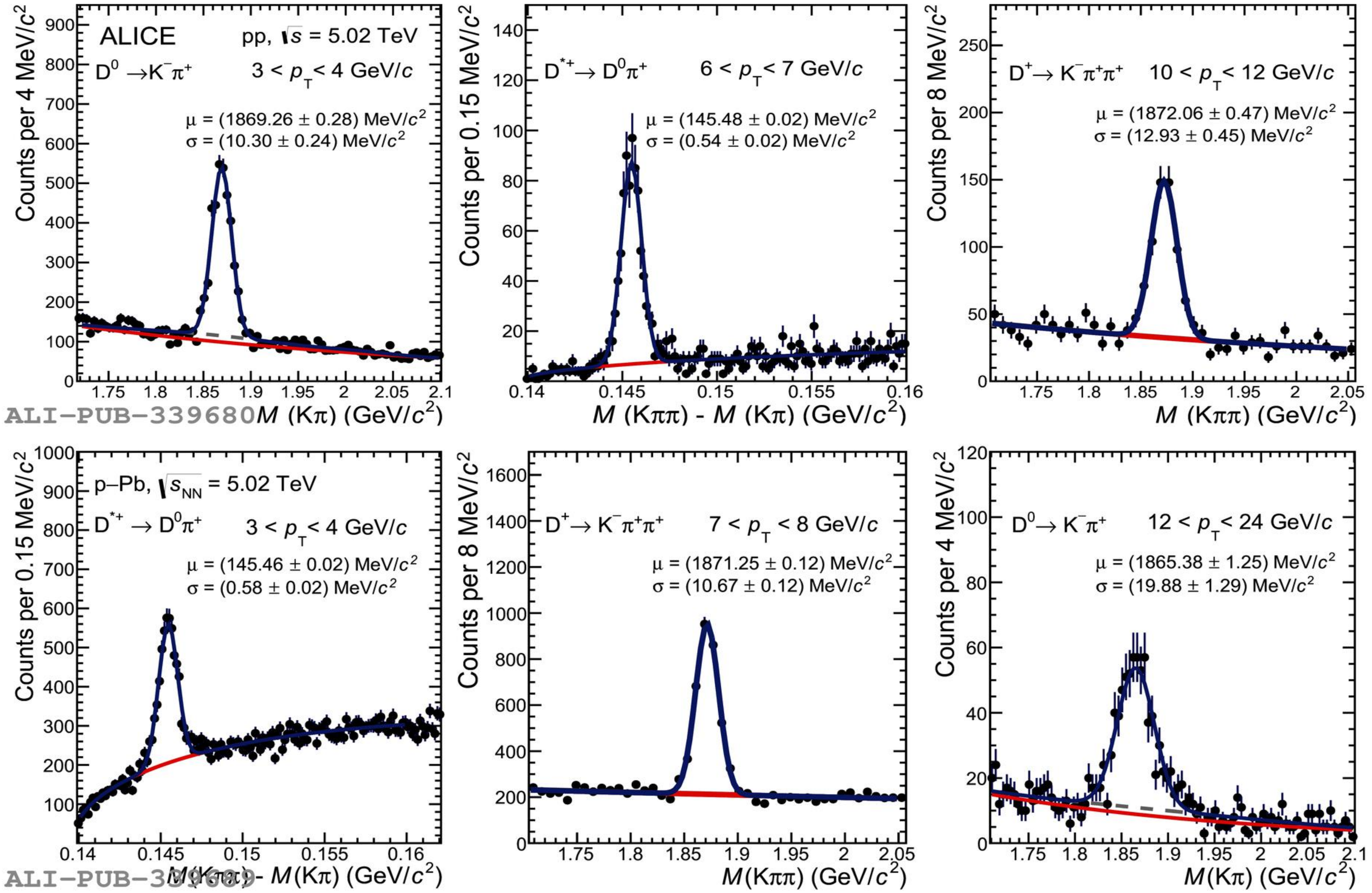




(illustration: h-h correlations in Pb-Pb at sqrt{s}=2.76 TeV)

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 reconstruction of secondary vertexes
- D-meson raw yields extracted from invariant mass fits in several p_T intervals



D-meson reconstruction:

- $D^+ \rightarrow K^- \pi^+ \pi^+$ BR~ 9.5%
- $D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+$ BR ~ 2.6%
- $D^0 \rightarrow K^- \pi^+$ BR ~ 3.9%

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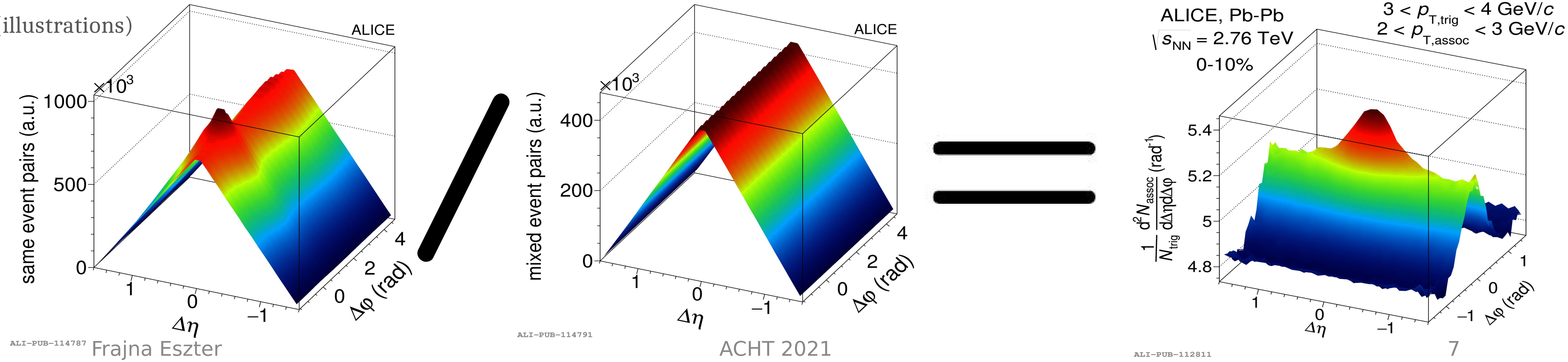
Evaluation and correction of the azimuthal-correlation functions

- D-meson candidates are selected from the +/- 2σ peak region
- Correlation distribution C(Δφ,Δη) evaluated in several p_T^D and p_T^{assoc} intervals
- Acceptance corrections based on mixed event technique, and reconstruction efficiency corrections are applied for both the trigger and associated particles
- The combinatorial background, properly normalized from the sideband, is subtracted from the peak-region correlation:

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

(illustrations)



D-h correlation peak fits

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

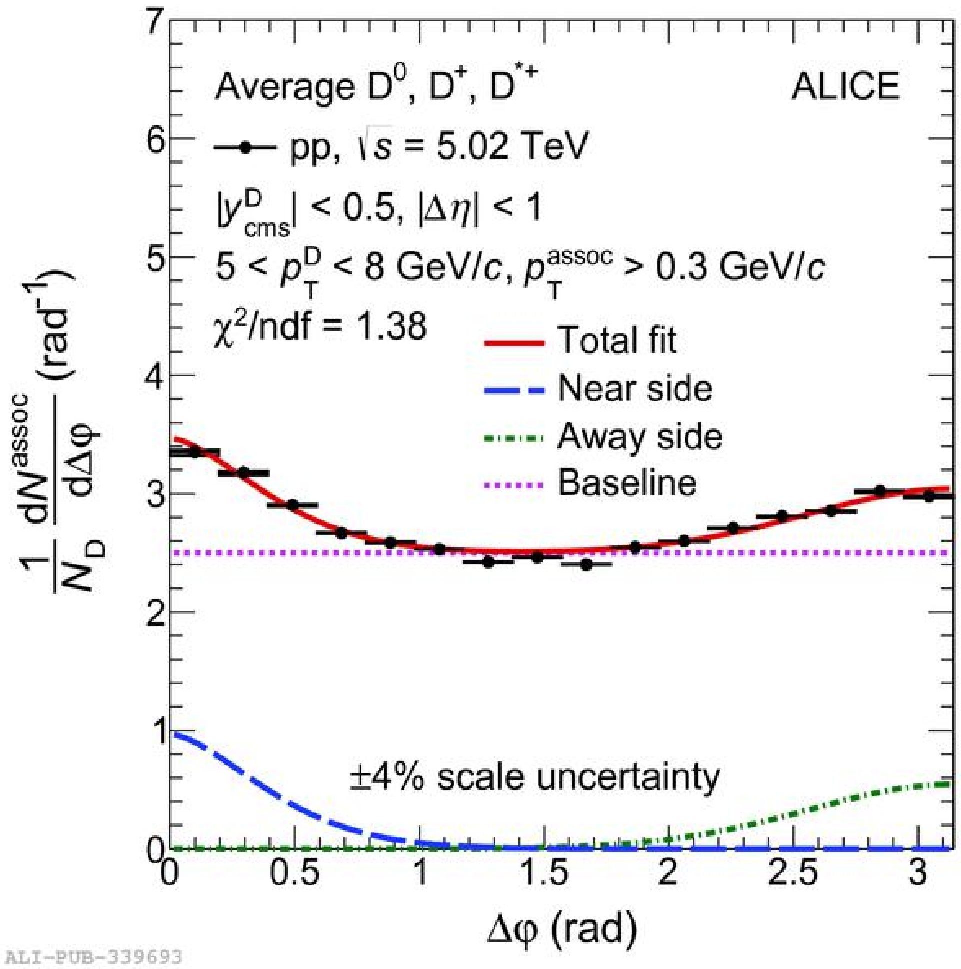
- a constant term b describing the flat contribution below the correlation peaks,
- a generalised Gaussian term describing the near-side peak,
- a Gaussian reproducing the away-side peak.

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)

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

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

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



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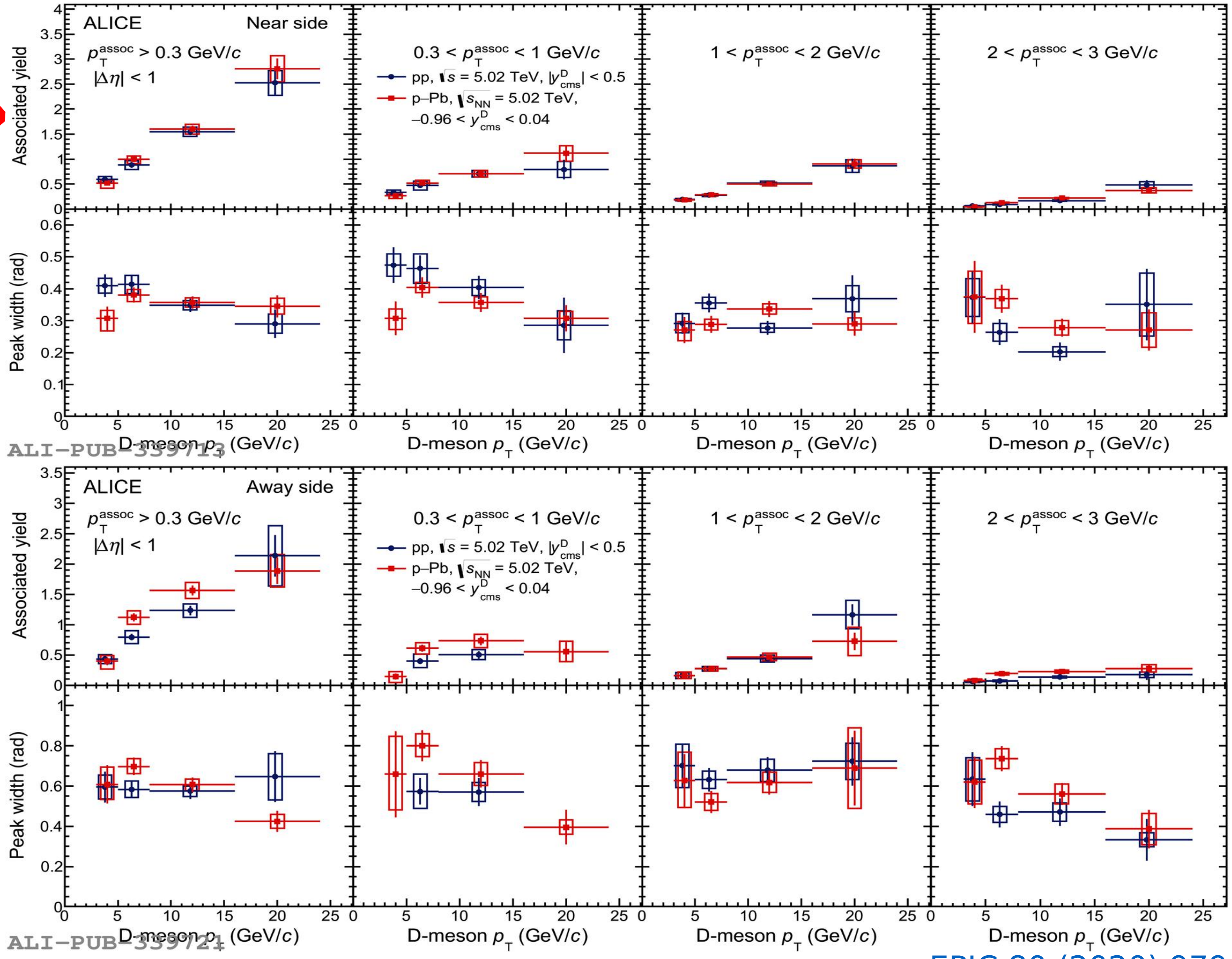
Comparison of results in pp and p–Pb collisions

increasing p_T^D



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.

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.

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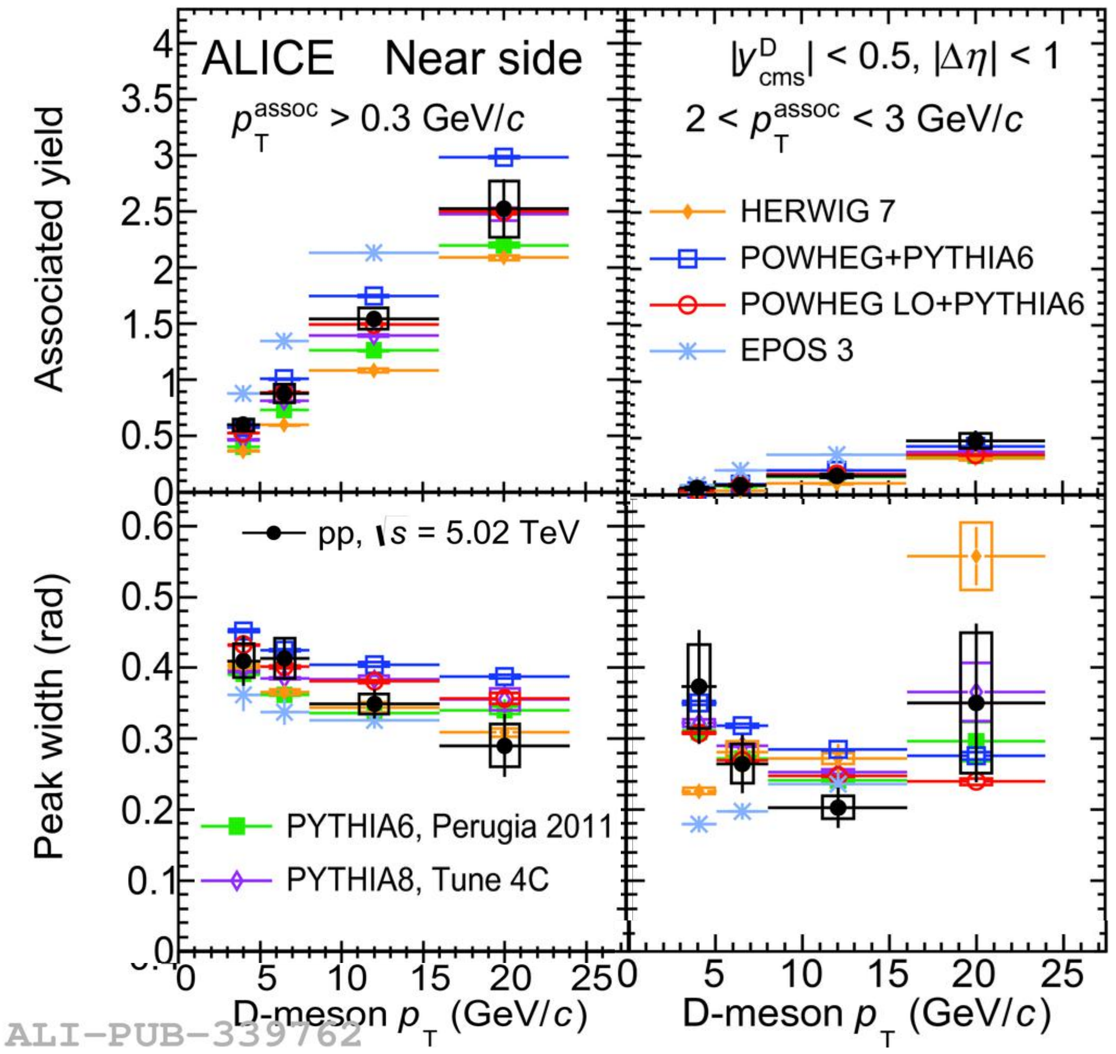
Comparsion to Monte Carlo simulations (near-side)

Near-side and away-side: sensitivity to fragmentation and parton shower

- Best description by **POWHEG+PYTHIA6**, **POWHEG LO+PYTHIA6** and **PYTHIA8** & Yields typically underestimated by **HERWIG 7** & NLO models predict slightly broader peaks & **EPOS3** typically overpredicts the yields



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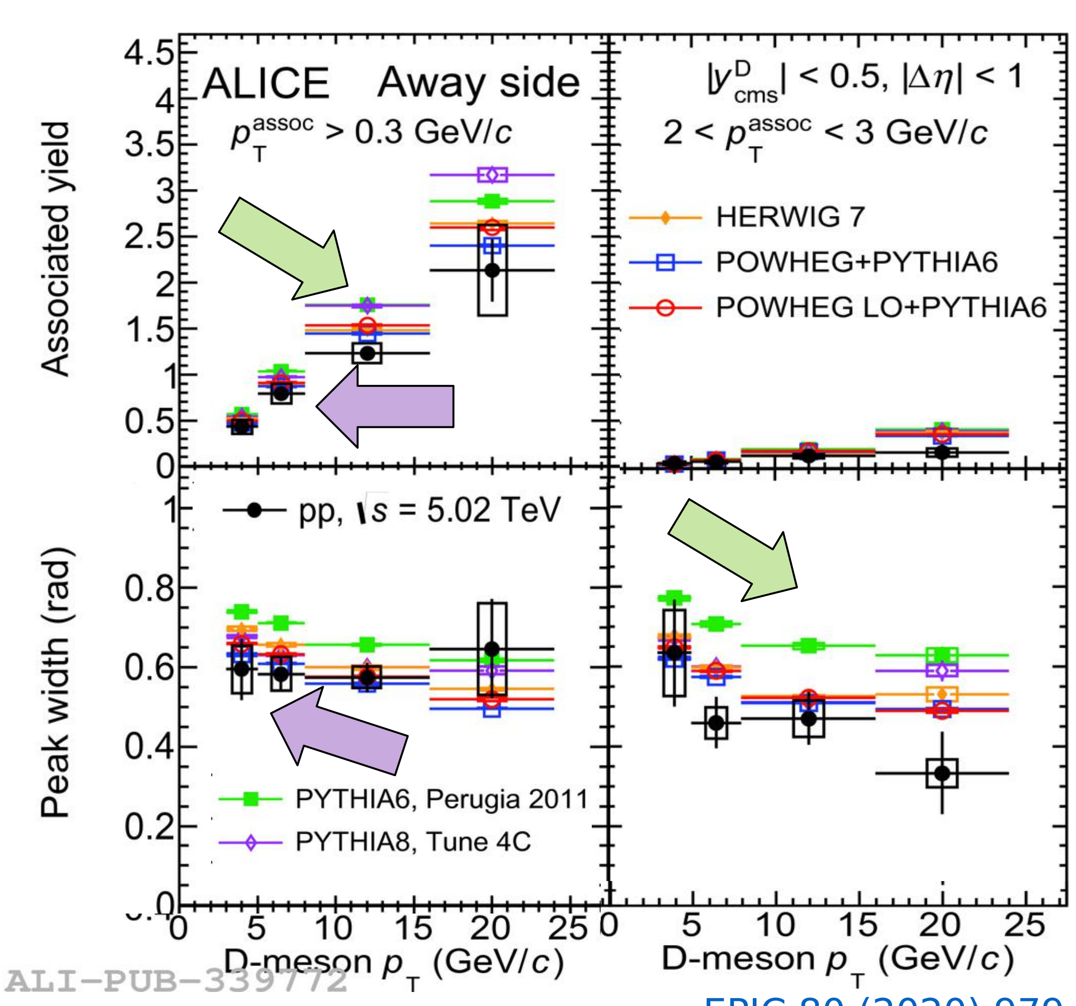
Comparsion to Monte Carlo simulations (away-side)

Near-side and away-side: sensitivity to fragmentation and parton shower

- Best description by **POWHEG+PYTHIA6**, **POWHEG LO+PYTHIA6** and **PYTHIA8** & Yields typically underestimated by **HERWIG 7** & NLO models predict slightly broader peaks & **EPOS3** typically overpredicts the yields

- **PYTHIA6** (Perugia11) overpredicts both the yields and widths & **PYTHIA8** (4C) overpredicts low-p_T yields and widths



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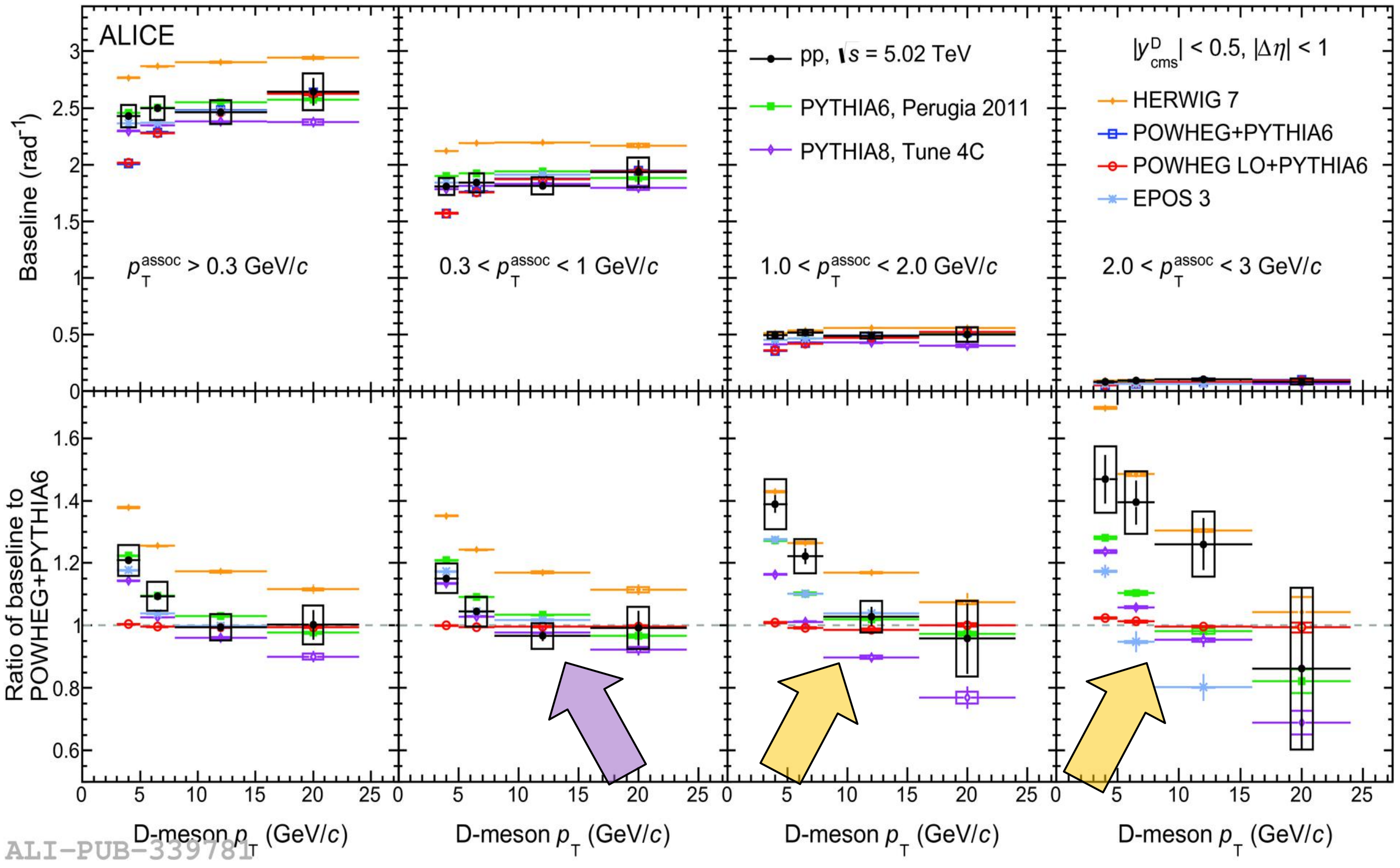
Comparsion to Monte Carlo simulations (baseline)

Near-side and away-side: sensitivity to fragmentation and parton shower

- Best description by **POWHEG+PYTHIA6**, **POWHEG LO+PYTHIA6** and **PYTHIA8** & Yields typically underestimated by **HERWIG 7** & NLO models predict slightly broader peaks & **EPOS3** typically overpredicts the yields
- **PYTHIA6** (Perugia11) overpredicts both the yields and widths & **PYTHIA8** (4C) overpredicts low-p_T yields and widths

Baseline: Sensitive to the underlying event

- p_T^{assoc}<1 GeV: best description by **PYTHIA**
- p_T^{assoc}>1 GeV: best description by **HERWIG 7**
- POWHEG NLO and LO are the same in all ranges (not trivial since influence expected from NLO charm contributions)



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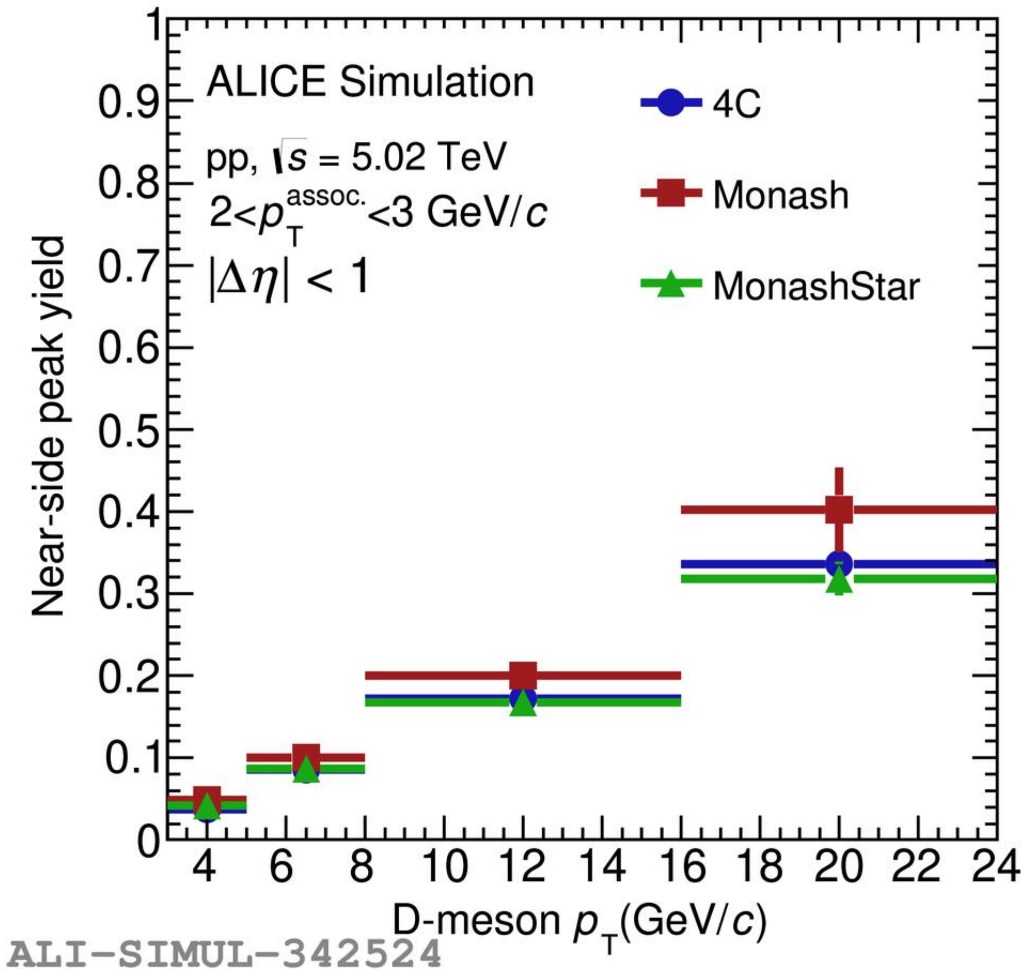
INVESTIGATION OF CORRELATIONS USING PYTHIA 8

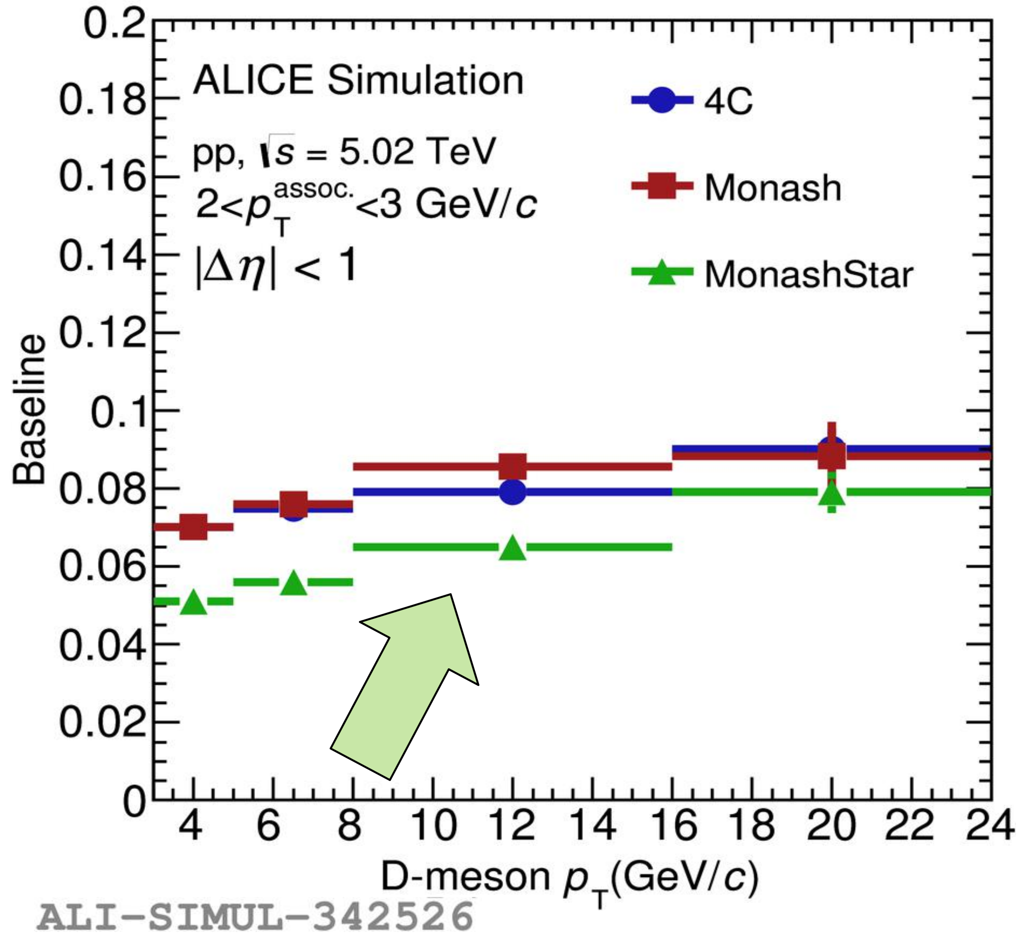
Different tunes

Monash: EPJC 74 (2014) 8, 3024
MonashStar: EPJC 76 (2016) 3, 155
4C: JHEP 1103 (2011) 032

Near-side peak yield



Baseline



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

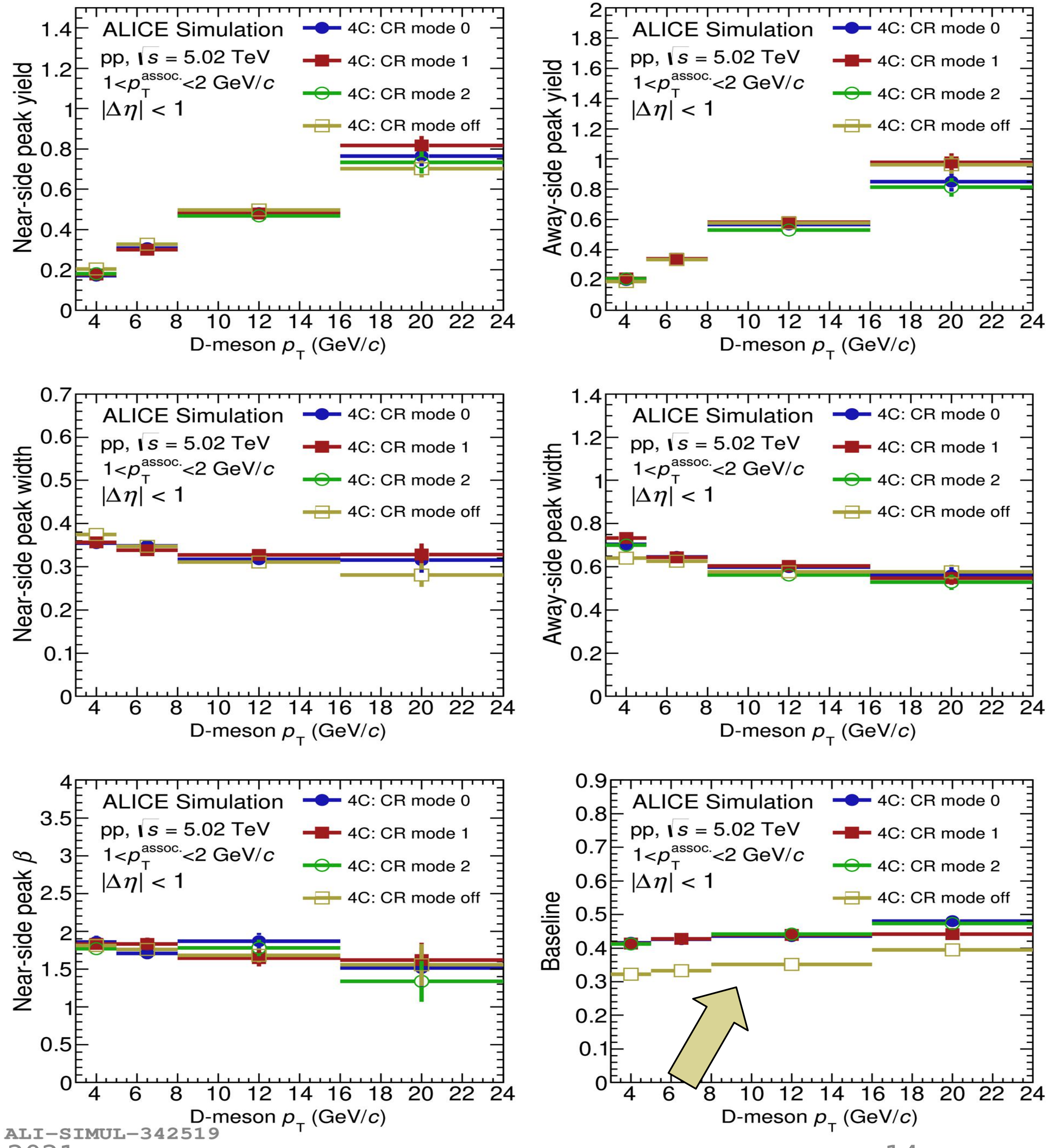
Different colour reconnection models

- 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: Other parameters than CR off are mostly the same => difference only in underlying event.

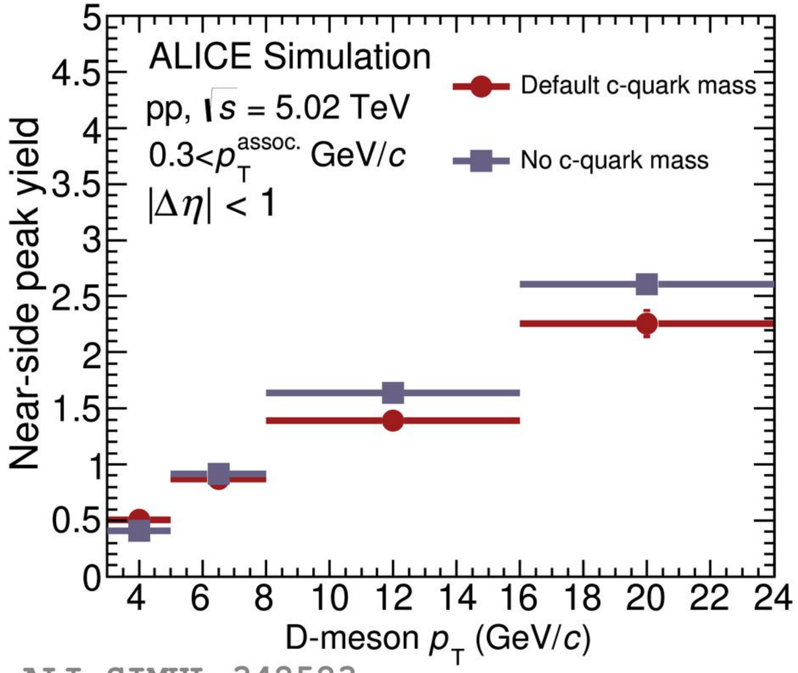


Dead-cone effect

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

Slight differences in the near-side width and yield.

Baseline: Slight difference in underlying event at low p_T.



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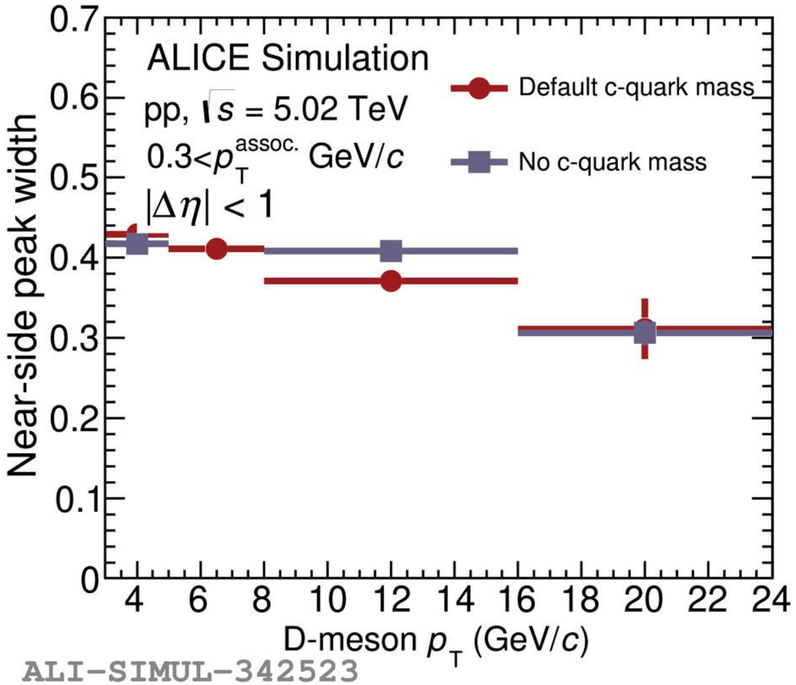

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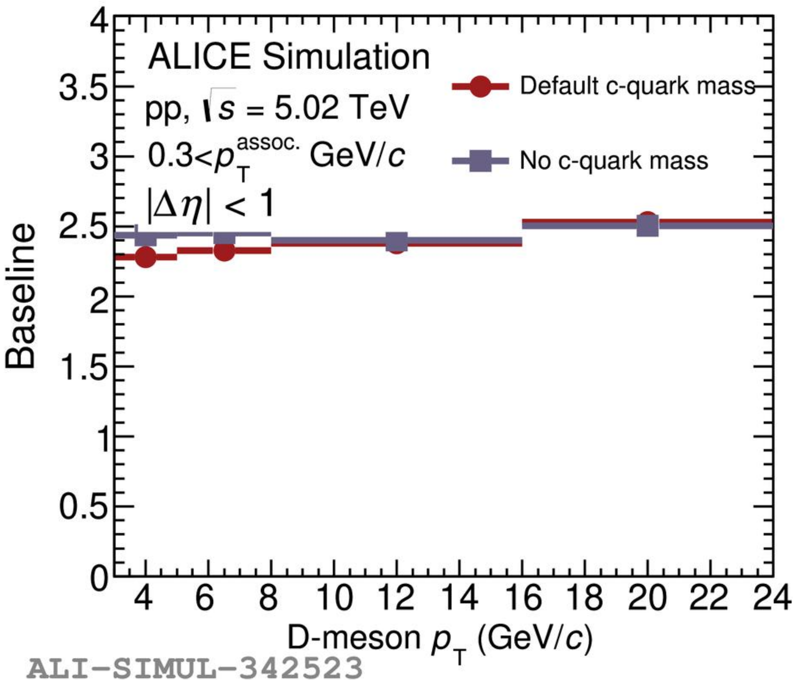

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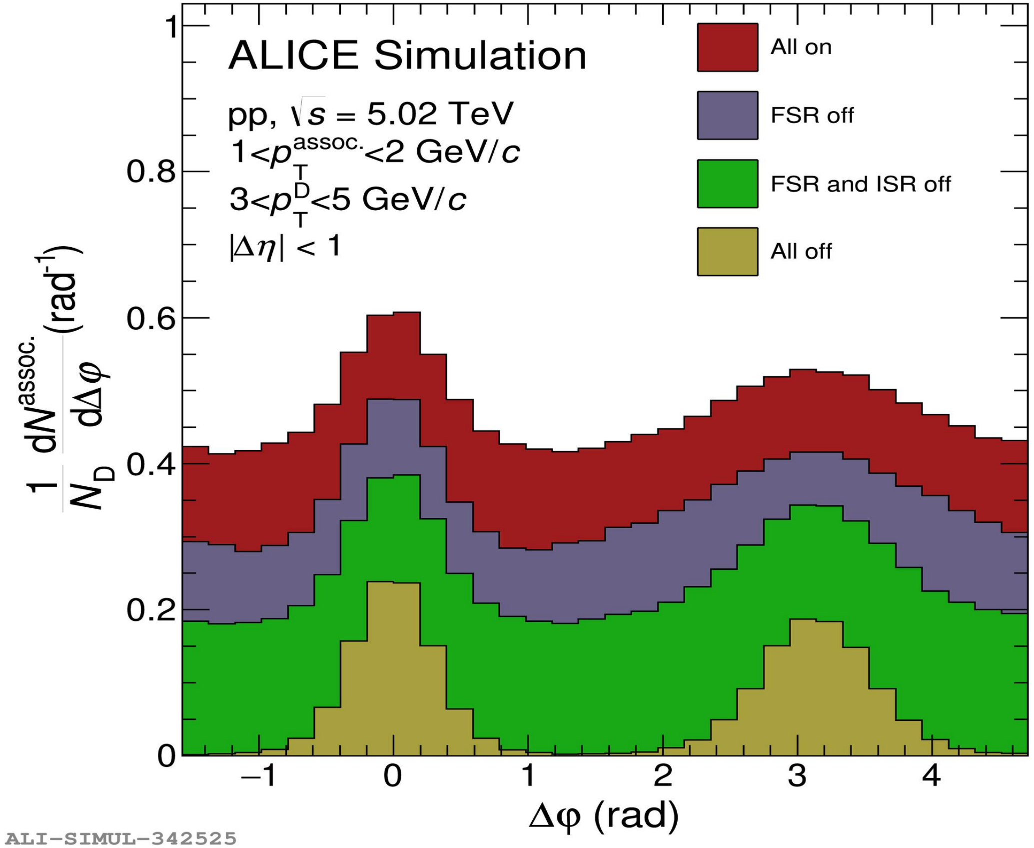
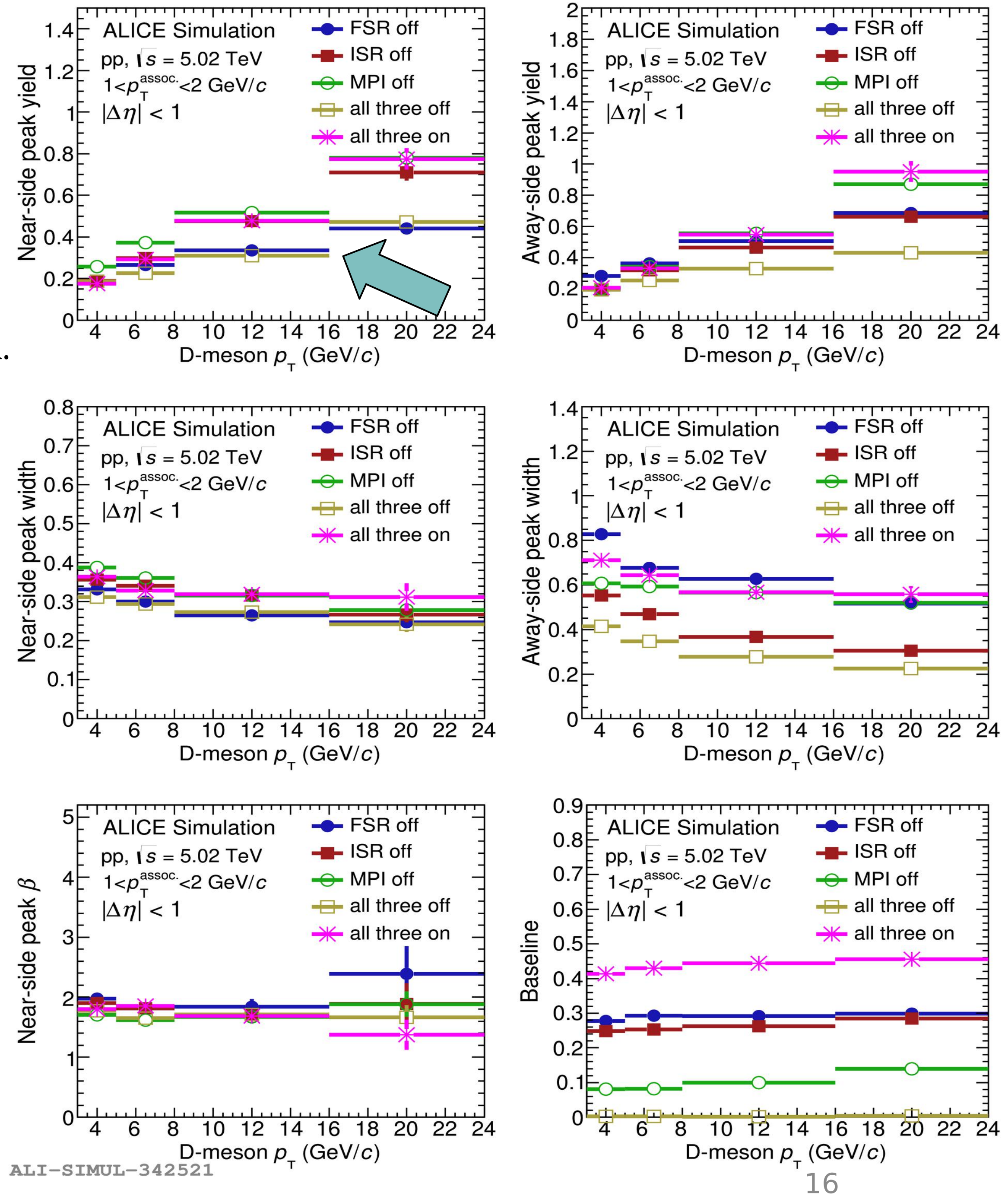
Different parton level contributions

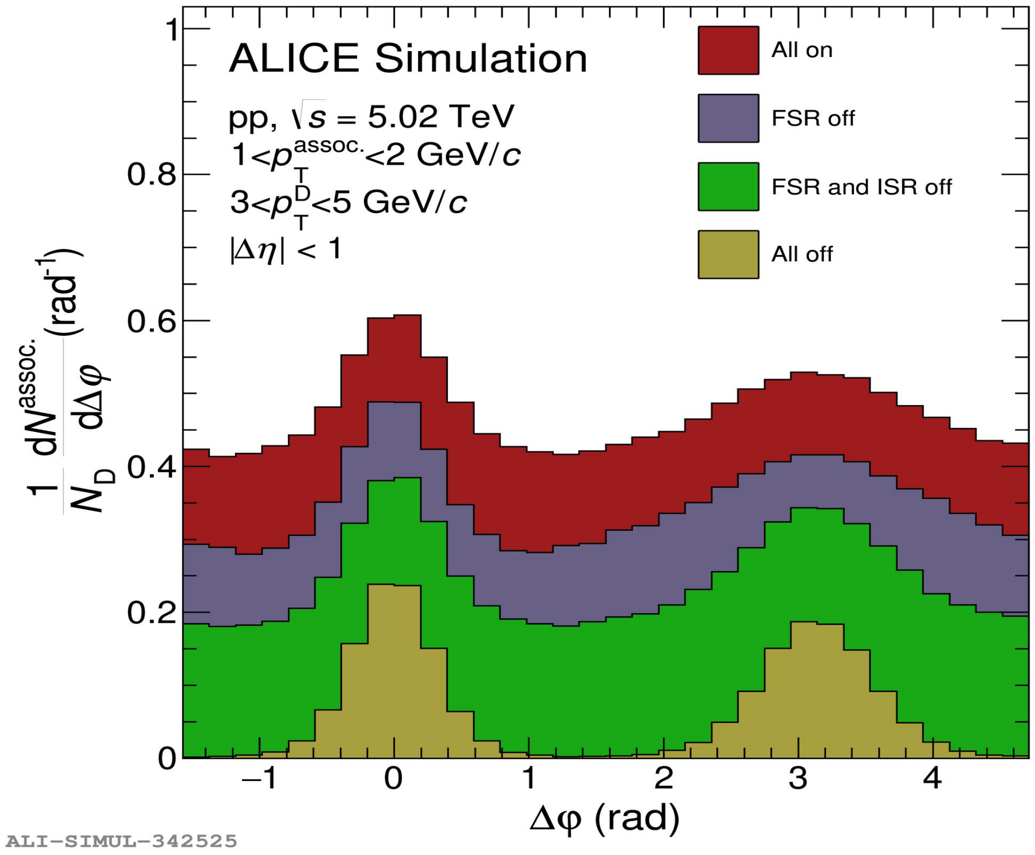
Near-side yield: significant contribution of FSR at higher trigger $p_T^{trigger}$.
Near-side width and shape: Not affected by partonic processes. This suggests that the near-side peak is primarily determined by fragmentation.

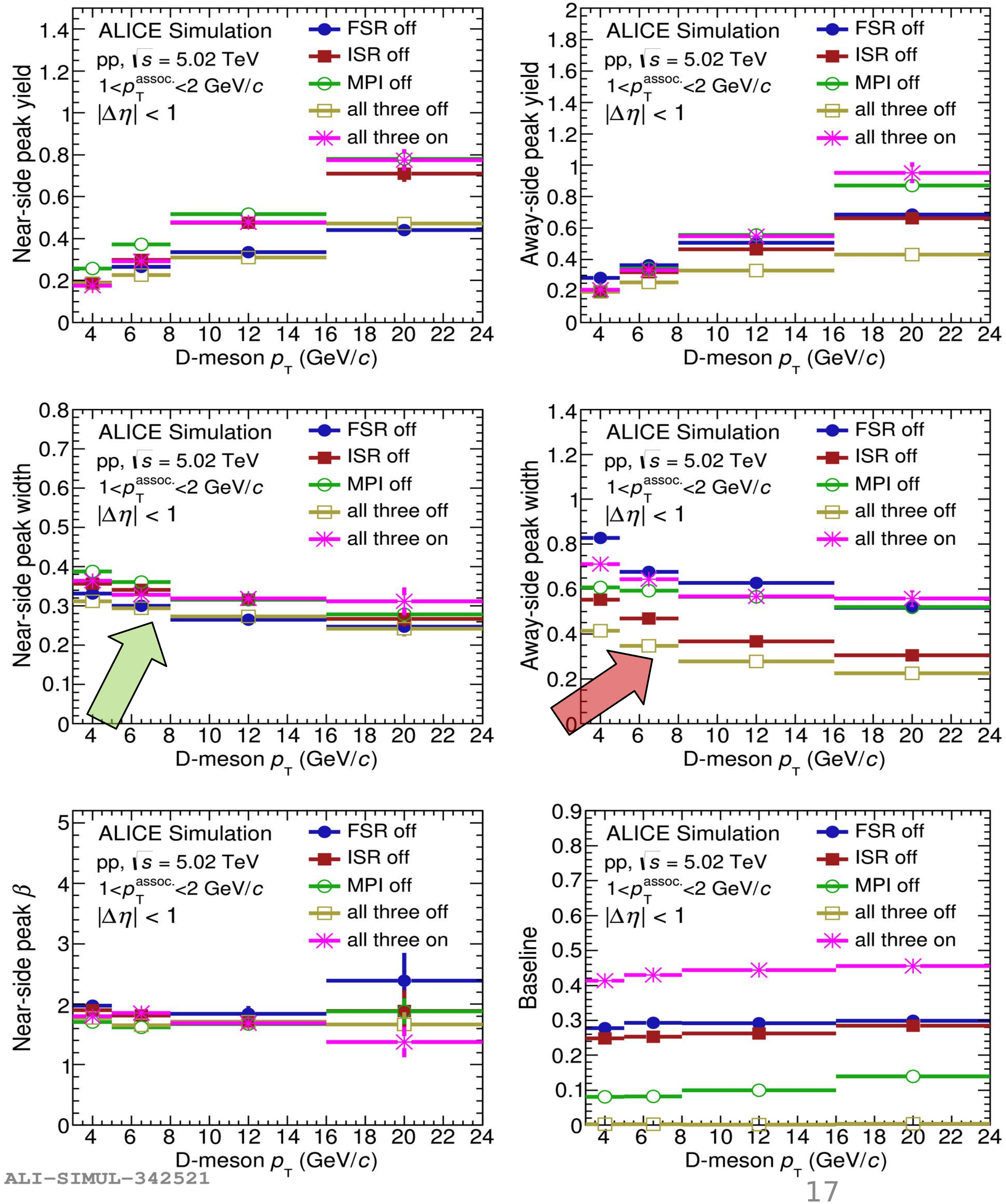




Different parton level contributions

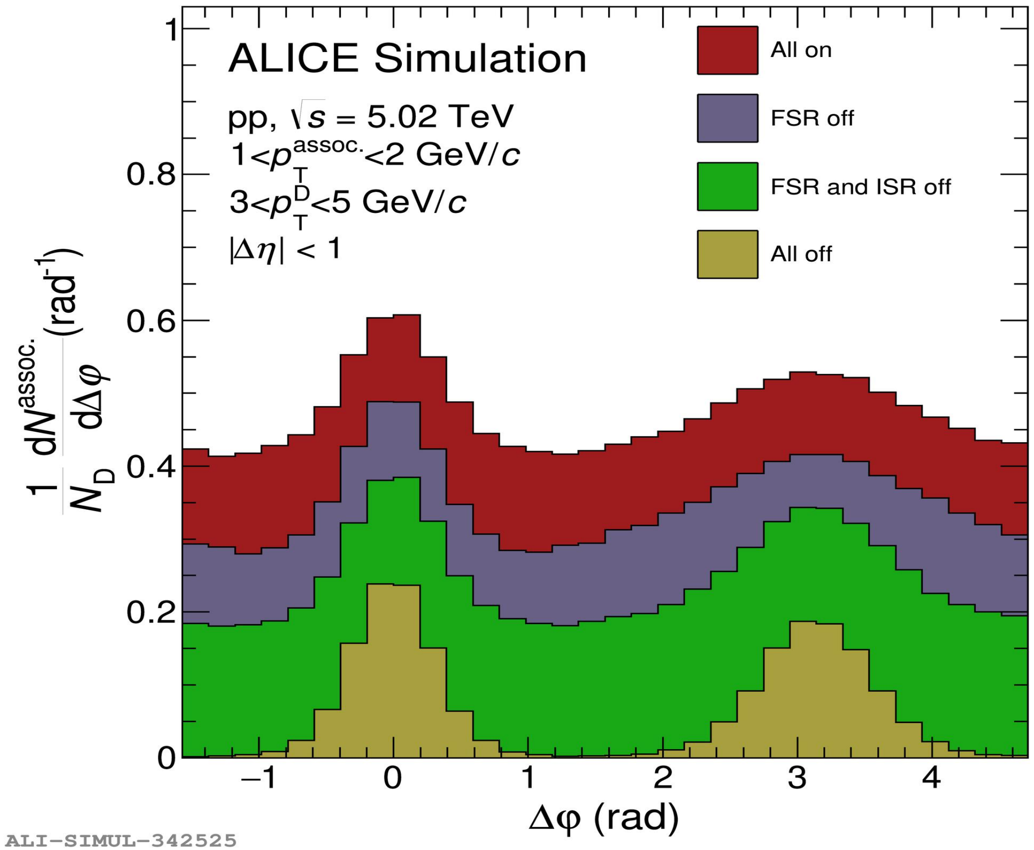
Away-side yield: Significant contribution from MPI.
Away-side width: Contributions of parton-level effects make it wider as expected (especially ISR). FSR=off overshoots all=ON.





Different parton level contributions

Baseline: Mostly affected by MPI (which generates the underlying event). Also influenced by initial- and final state radiations Weak p_T-leading dependence.



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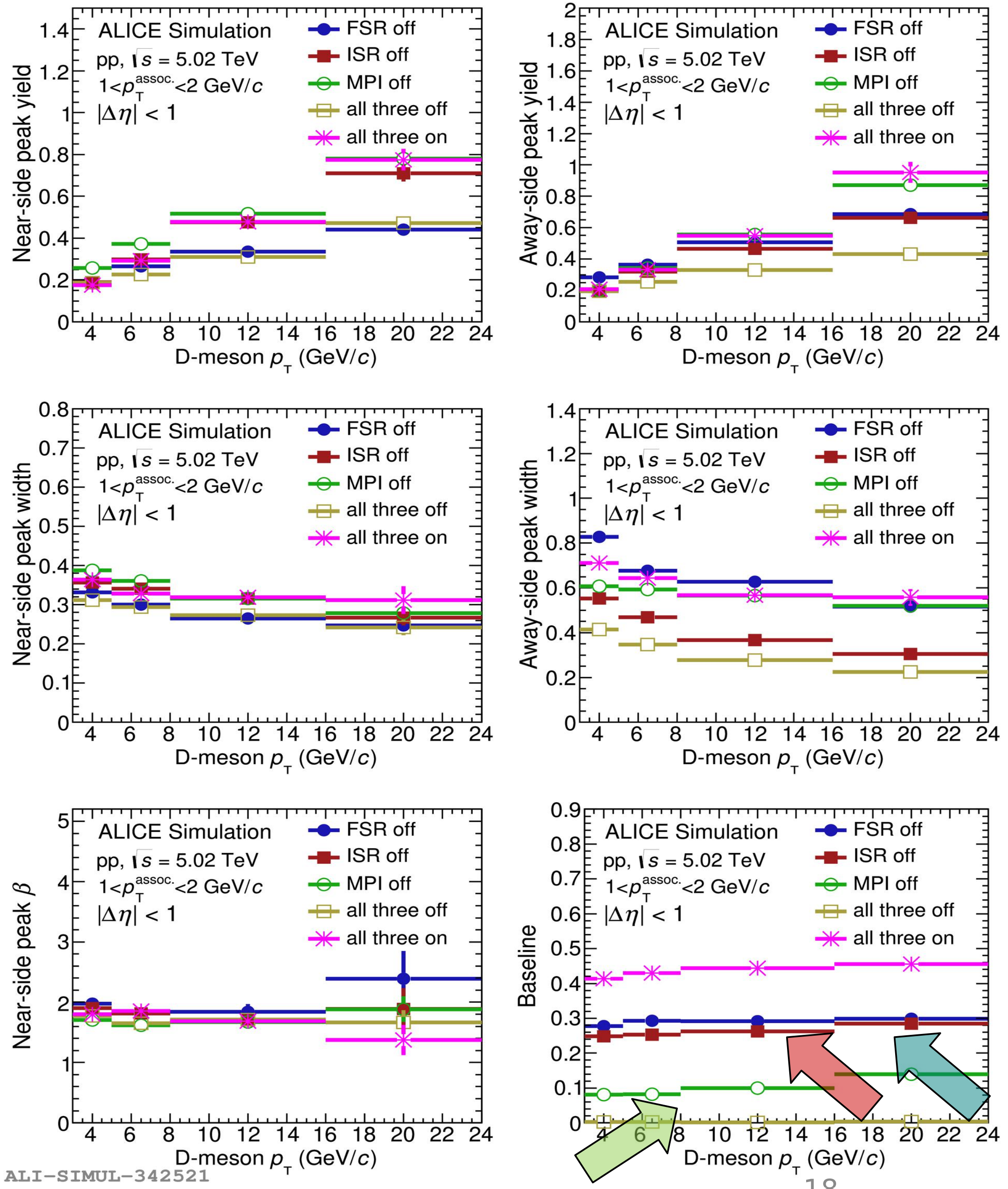

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Heavy-flavour fragmentation (Lund vs. Peterson models)

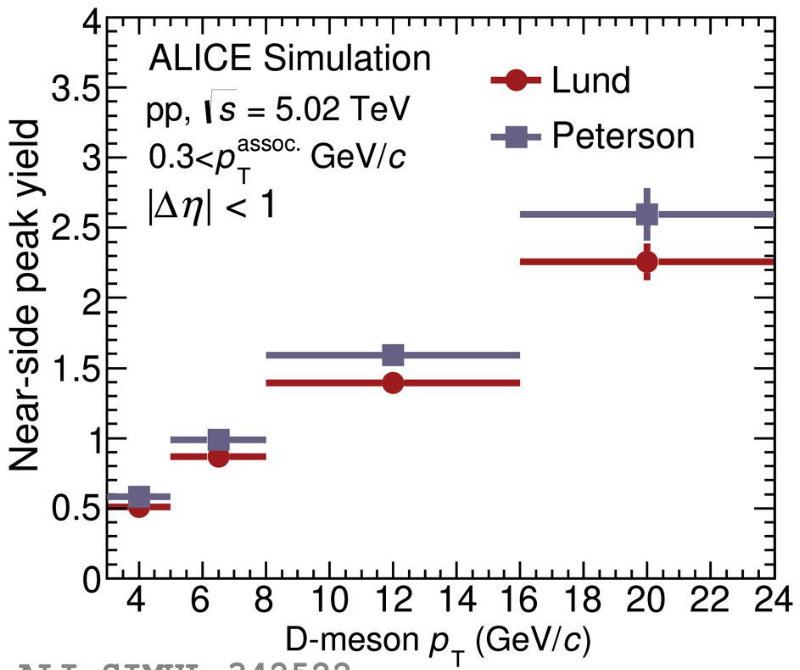
By default, the Lund fragmentation formula is used in PYTHIA:

$$f(z) = \frac{(1-z)^a}{z}\exp\left(-\frac{bm_{\perp h}^2}{z}\right)$$

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.

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

Hint of different trends, but
no significant difference between the two model.



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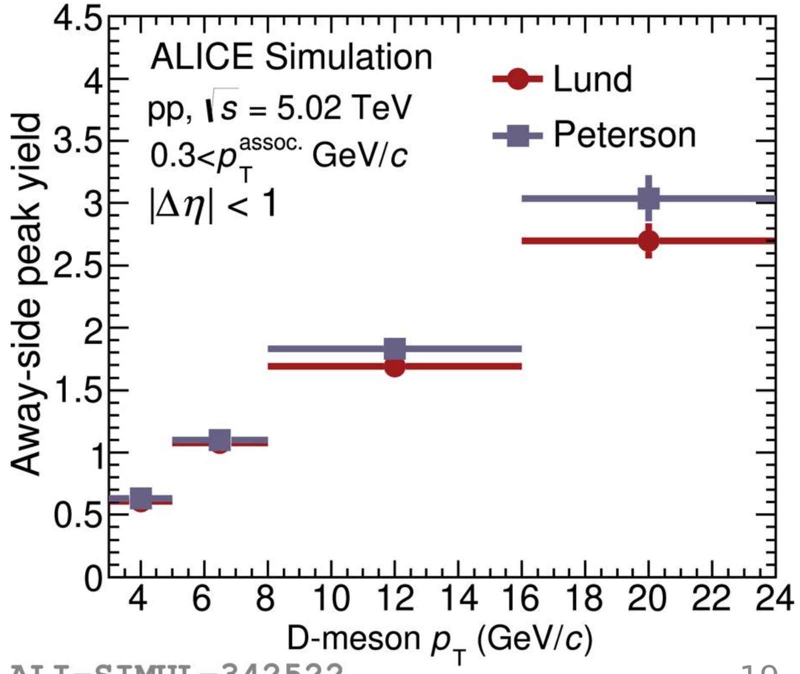
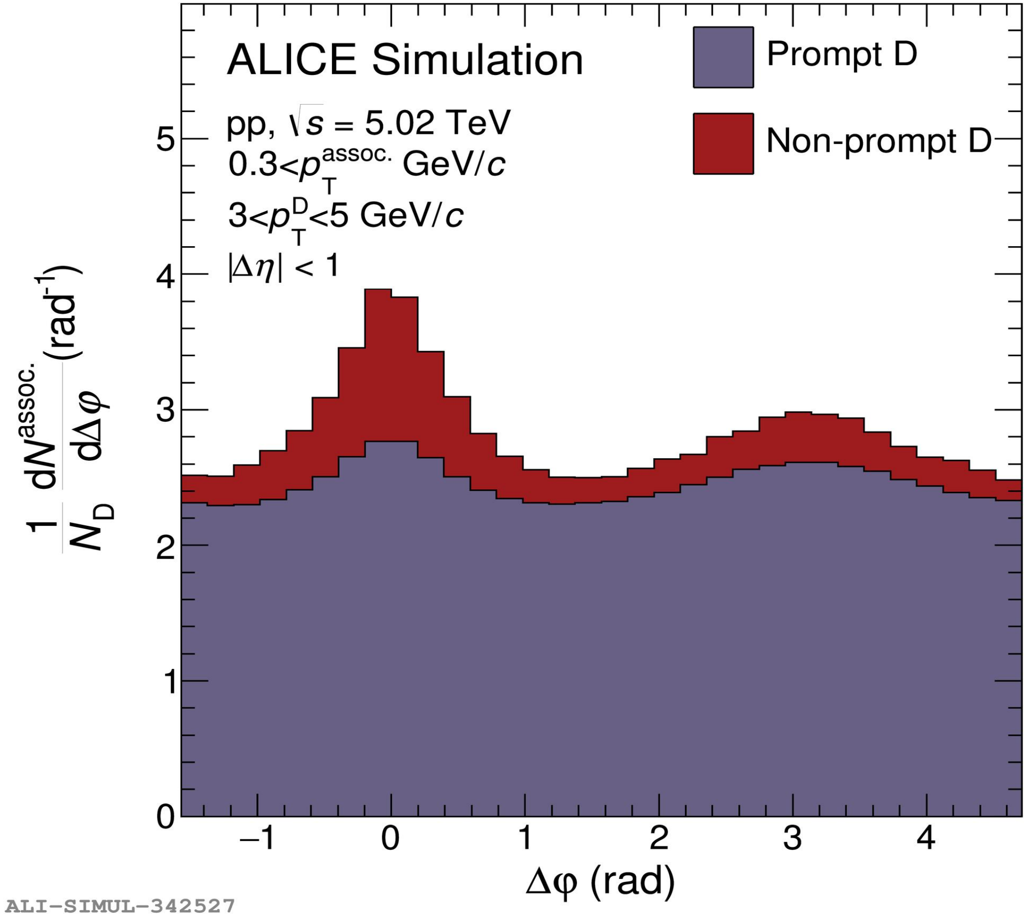


ALI-SIMUL-342522

Prompt and non-prompt D-meson separation

Near-side yield and away-side yield: non-prompt D meson is significantly higher. (~50% max)



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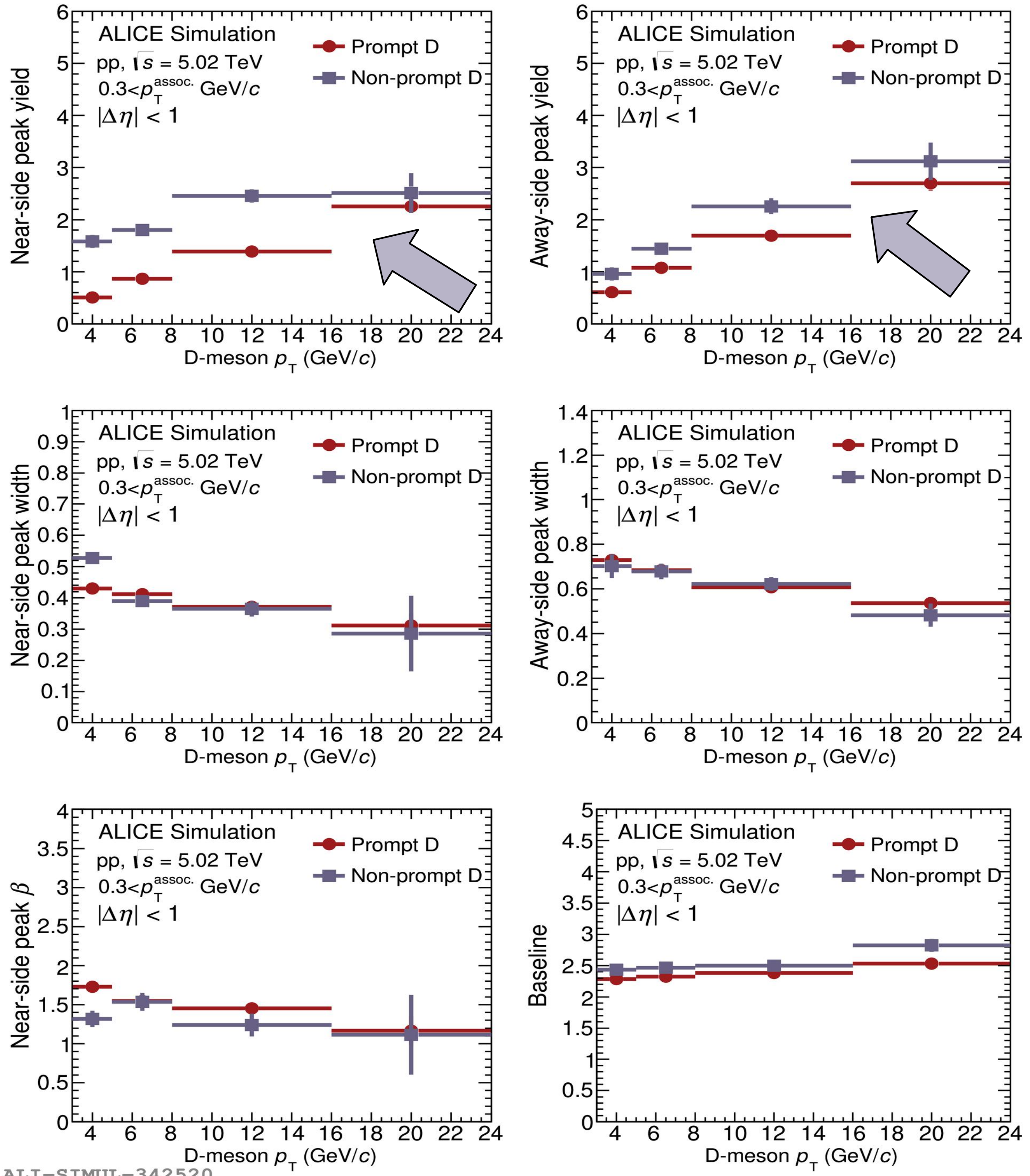
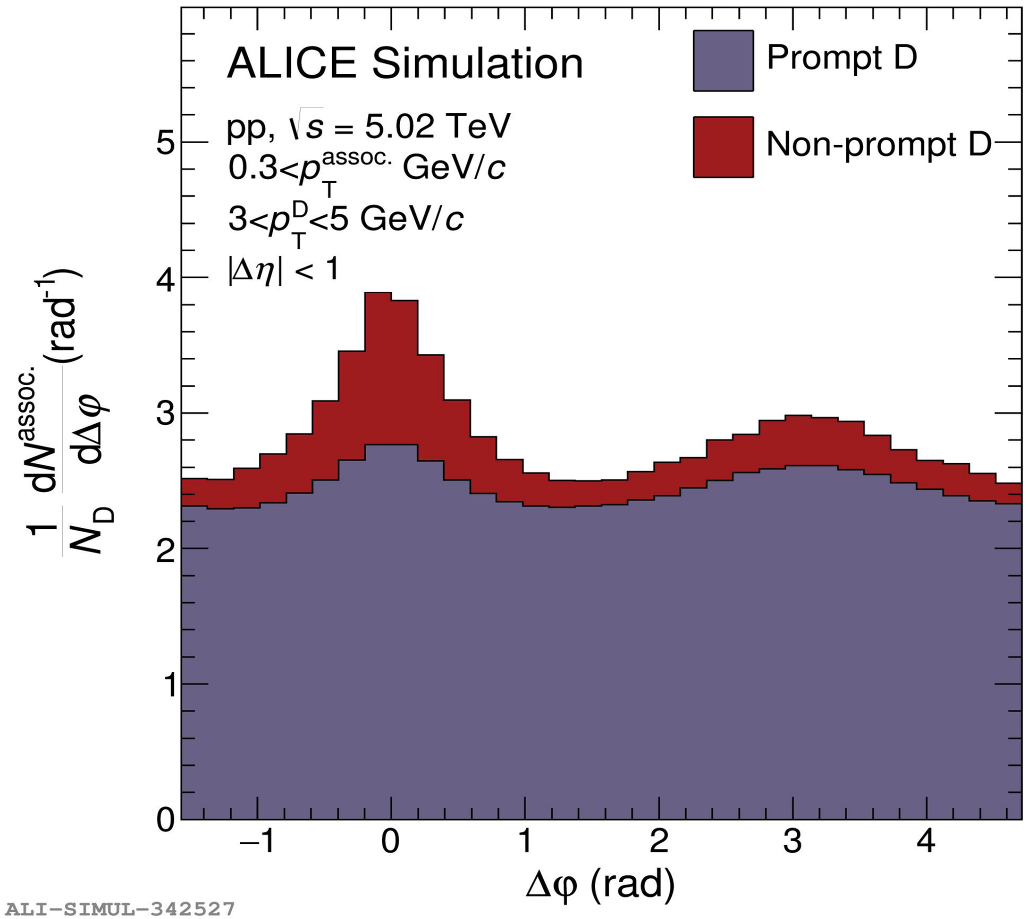


ALI-SIMUL-342520

Prompt and non-prompt D-meson separation

Near-side and away-side width and shape: significantly different near-side shape at low p_T.



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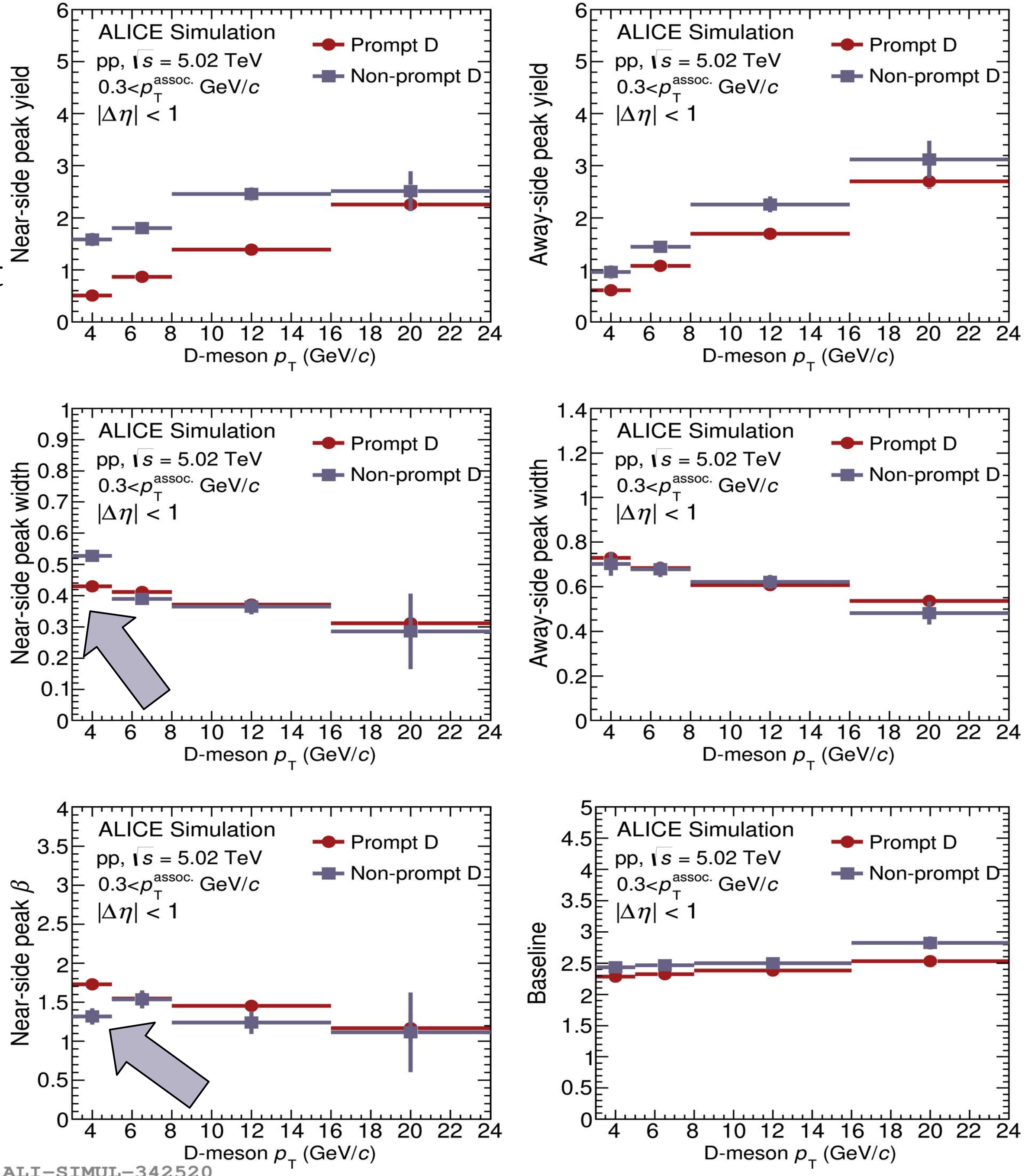
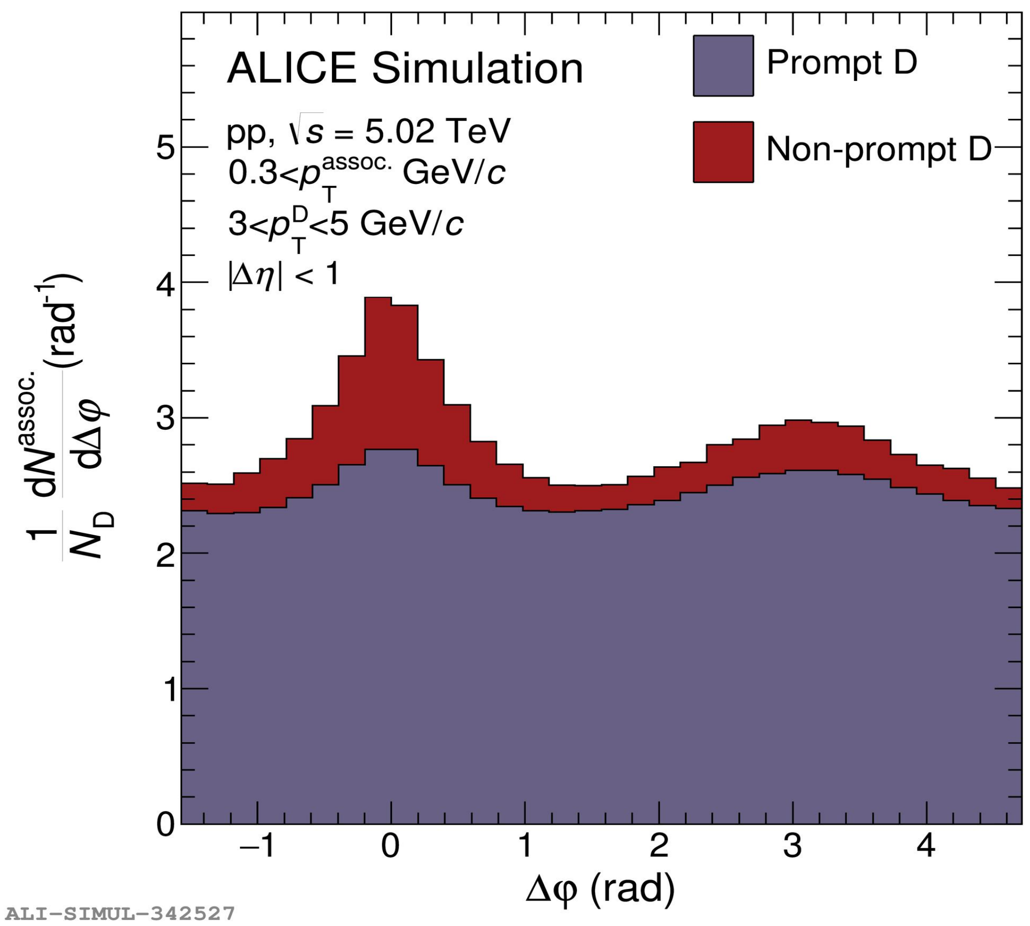
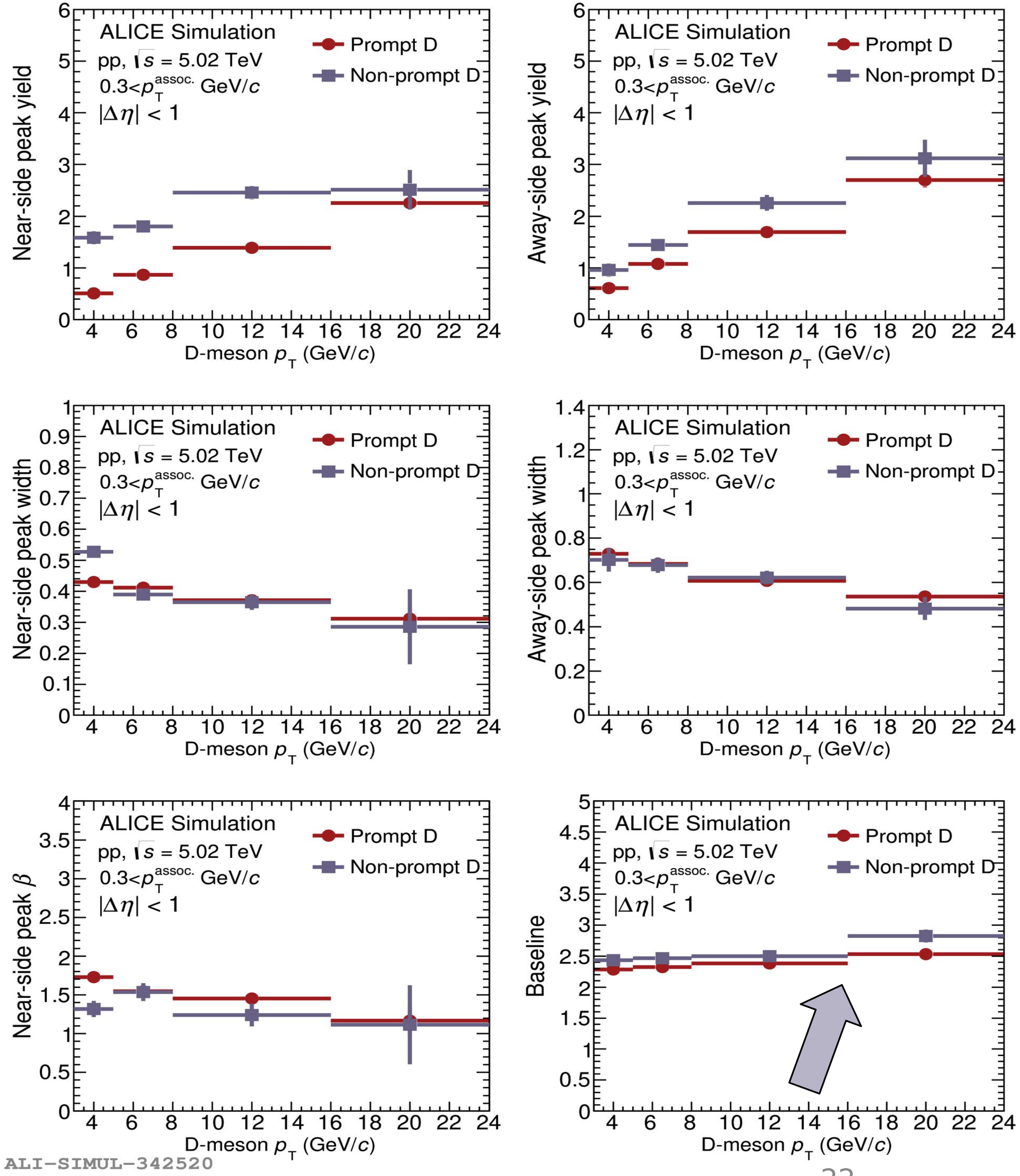


ALI-SIMUL-342520

Prompt and non-prompt D-meson separation

Baseline:Significantly higher baseline for non-prompt D meson (~10% at max)





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): 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

- ***Different PYTHIA tunes***: importance of underlying event contribution to background.
- Important role of ***colour 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.
- Correlations: a tool to statistically separate ***prompt and non-prompt contributions***.

Thanks for your attention!

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