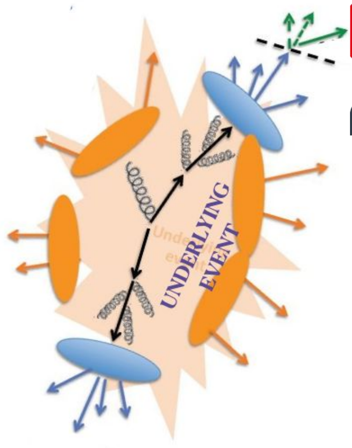
Investigating heavy-flavour jet properties via heavy-flavour particle correlations with ALICE

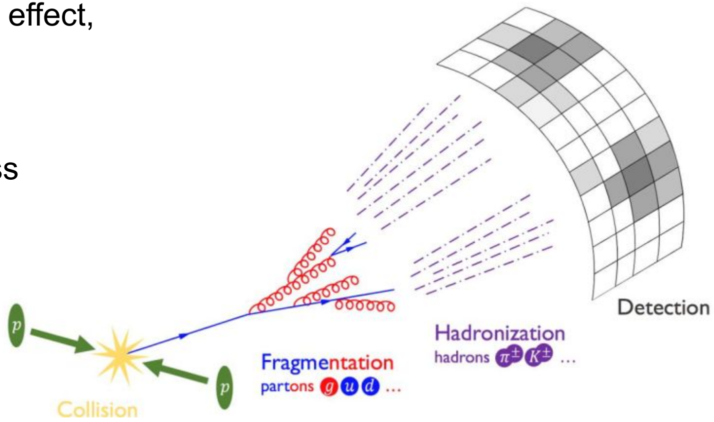
Ravindra Singh on behalf of the ALICE Collaboration
Indian Institute of Technology Indore (IN)

DIS2022 Spain, 2-6 May 2022

Motivation: heavy-flavour jets



- Heavy-Flavours
  - Heavy-flavour jets minimize dependence on hadronization process due to including all particles from parton shower.
- pp collisions
  - Test for pQCD calculations
  - Investigate fragmentation and hadronization models
  - Flavour and mass dependence
  - Quark (HF) vs gluon (other) jet difference
- p—Pb Collisions
  - Modification due to (Cold Nuclear Matter) CNM effects, gluon saturation effect, and energy loss-mechanisms.
- Pb—Pb collisions
  - Modification due to (Quark Gluon Plasma) QGP medium and energy loss mechanisms.



How the jets can help?

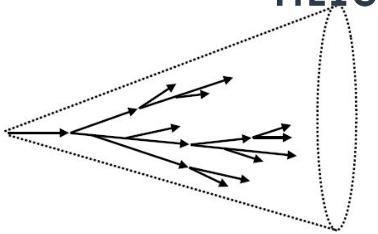
- Smaller dependence on the hadronization models allow better comparison to QCD.
  - Gluon initiated jets – broader fragmentation
  - Quark initiated jets – more collimated

- Inclusive jets
  - Powerful probes of QCD
  - Well constrained at high p_T, low p_T experimentally challenging.
  - Mostly gluon initiated.

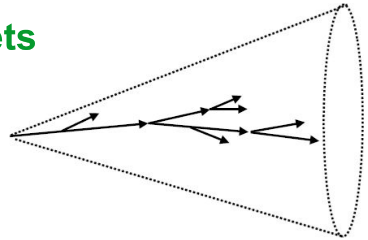
- Heavy-flavour jets:
  - HF conserved through the parton shower
  - Quark initiated

- Inclusive vs heavy-flavour jets at low p_T
  - Effect of Casimir factors and dead cone

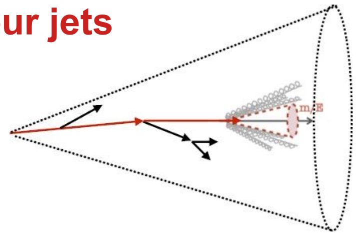
Gluon initiated jets



Inclusive jets

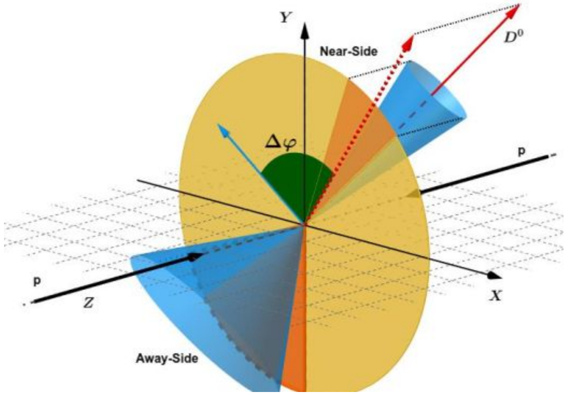


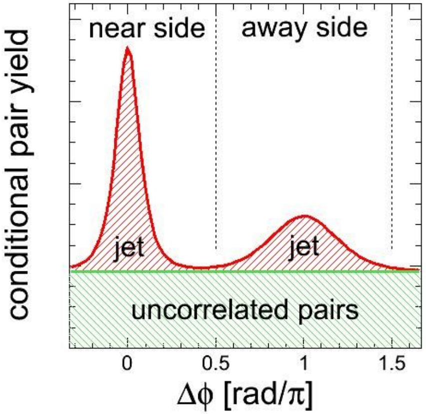
Heavy-flavour jets



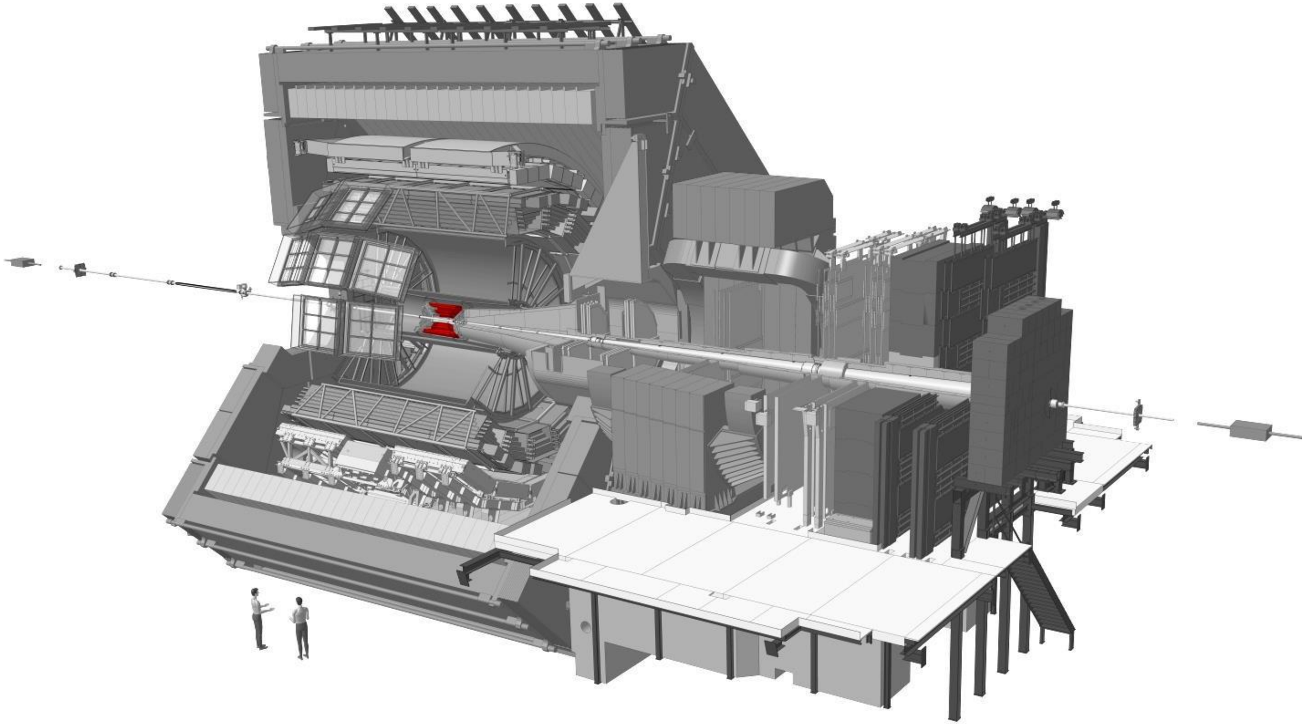
Motivation: heavy-flavour correlation

- Jet-like correlations is the alternative way to study the jets.
- Low p_T jets study can be possible.
- Give access to the production mechanisms
  - Pair Creation (LO):
    - quarks are produced back-to-back
    - “Near Side” peak at $\Delta\varphi$ = 0: Produced by the particle associated with high pT trigger particle.
    - “Away side” peak at $\Delta\varphi$ = π: Produced by the particles associated with the recoiled jet.
  - Hard gluon radiation (NLO):
    - Broadening of both peaks
  - Gluon splitting (NLO):
    - Heavy-flavours are produced closely, so showering products are collimated in the direction of the trigger.
  - Flavour excitation (NLO):
    - flat $\Delta\varphi$ contribution.



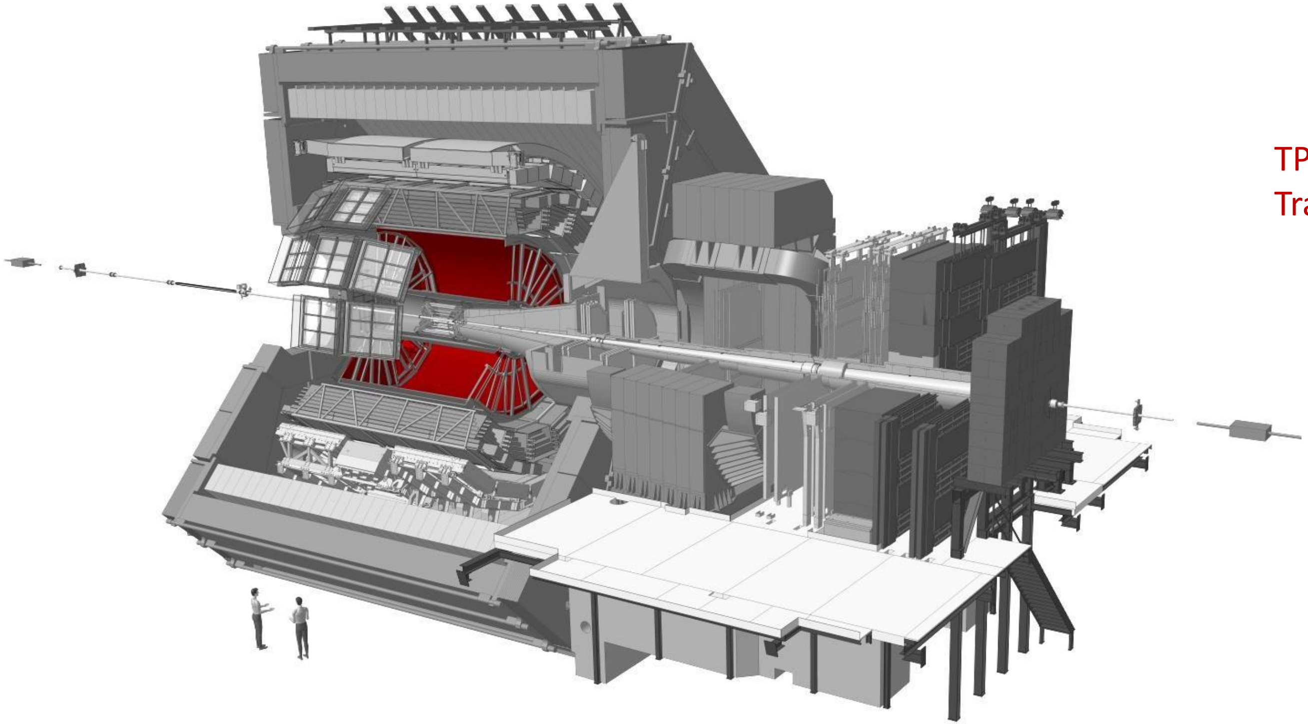


The ALICE Detector – Inner Tracking System



<u>Detectors</u>
ITS $|\eta| < 0.9$
Vertexing and tracking

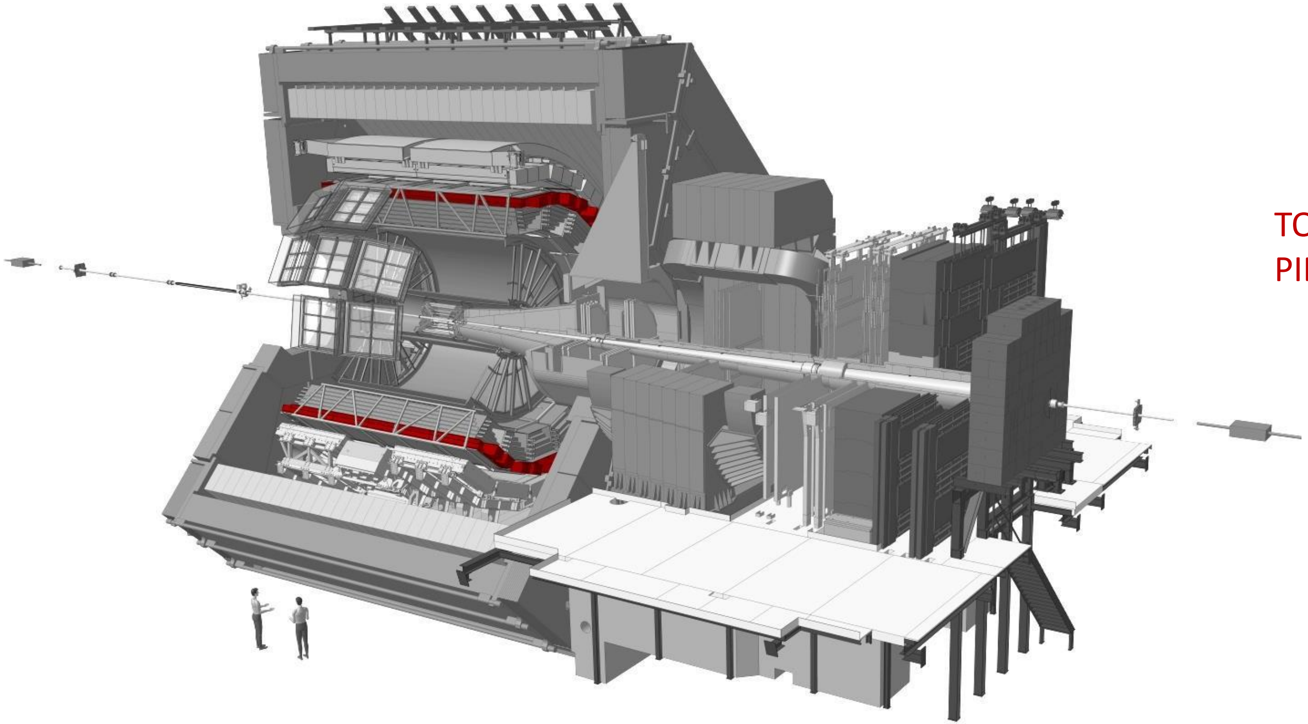
The ALICE Detector (Time Projection Chamber)



TPC $|\eta| < 0.9$

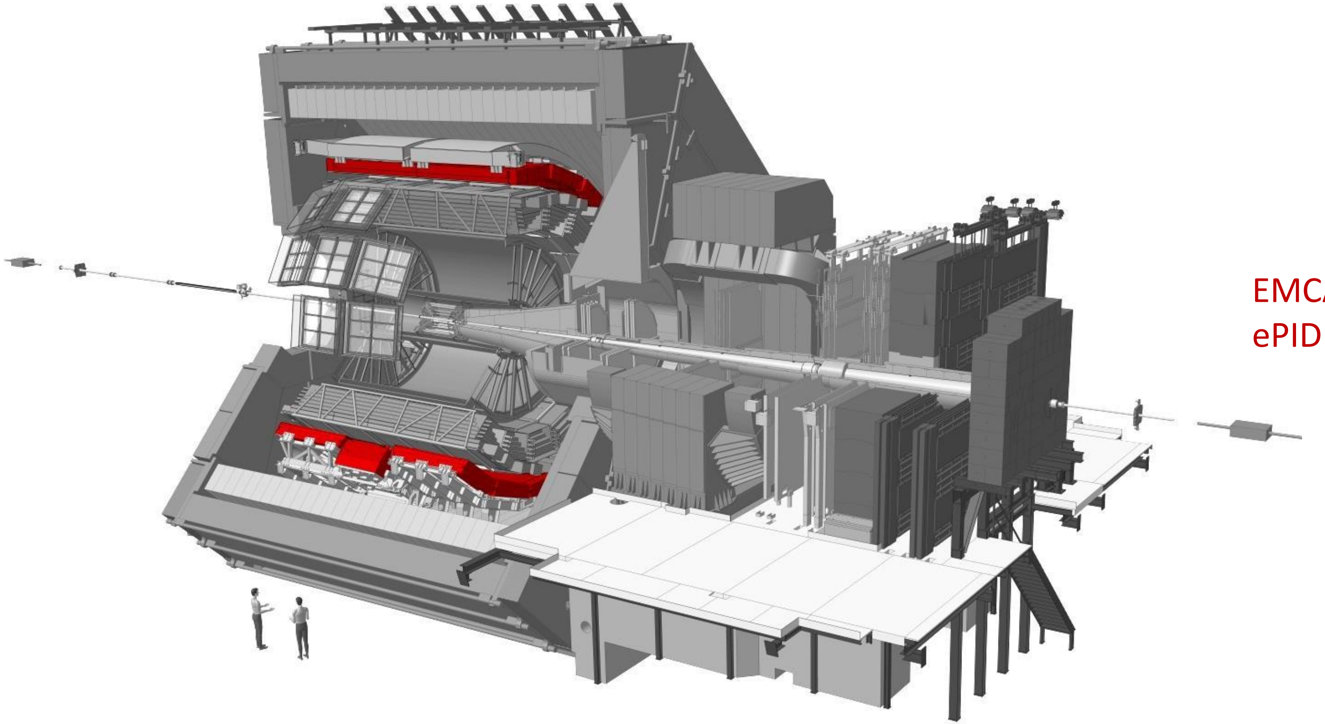
Tracking and PID

The ALICE Detector – Time of Flight



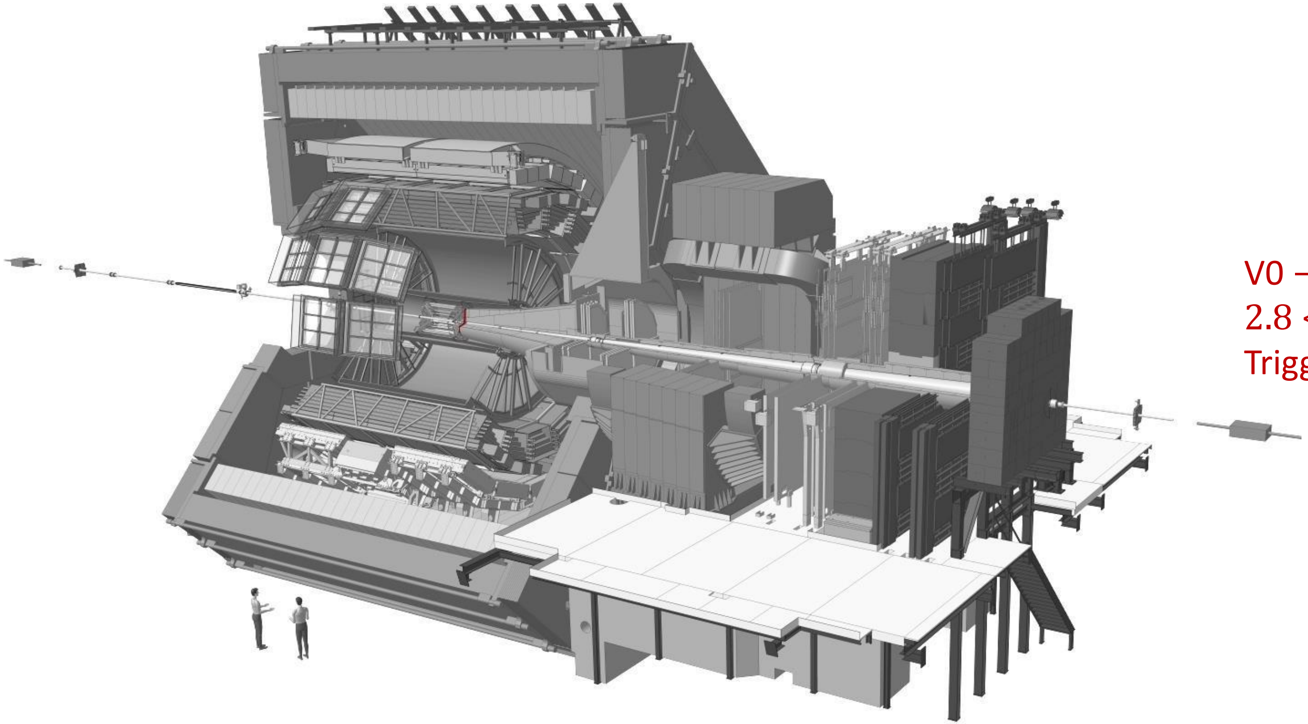
TOF $|\eta| < 0.9$
PID

The ALICE Detector – Calorimeters



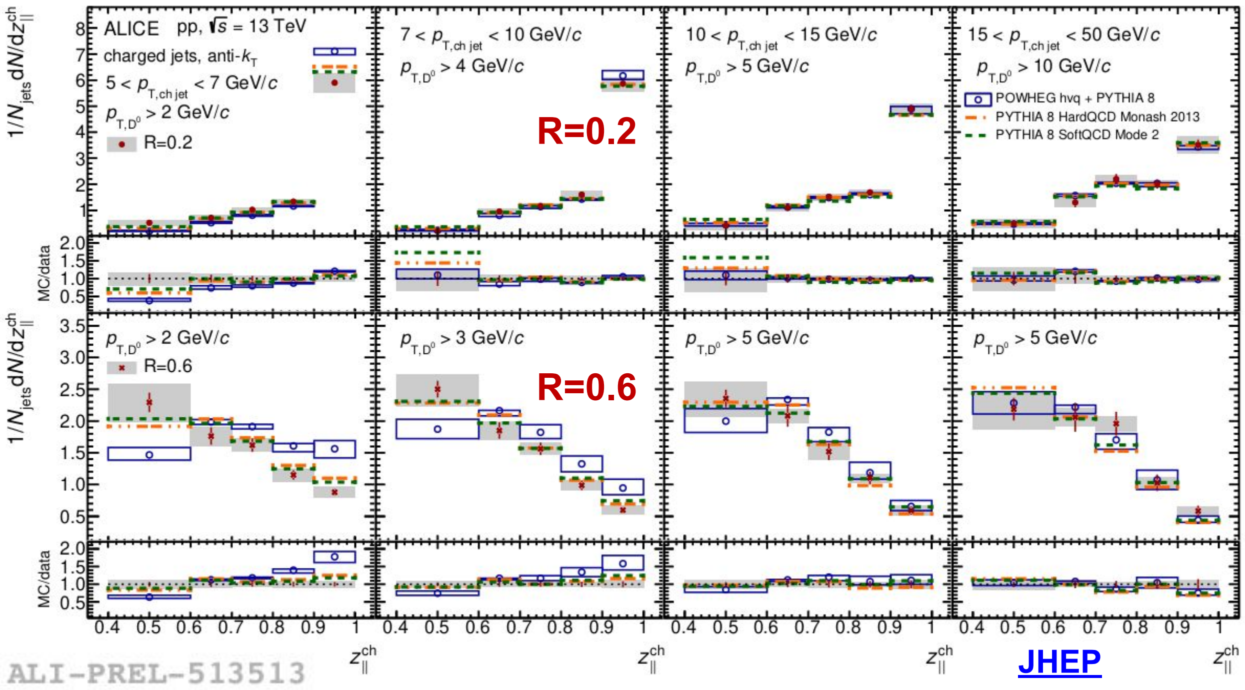
EMCAL/PHOS $|\eta| < 0.7$
ePID and trigger

The ALICE Detector – V0



V0 $-3.7 < \eta - 1.7$
$2.8 < \eta - 5.1$
Trigger and background rejection

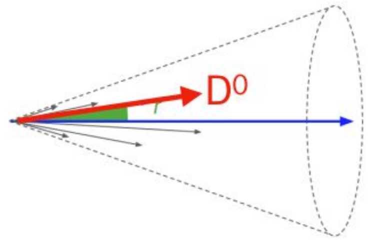
HF jets to look into fragmentation



JHEP

HF-tagged jets provide a handle on the evolution of quarks hadrons

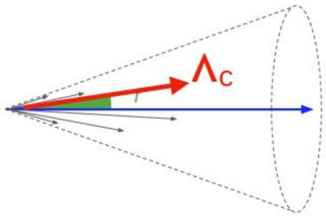
$$Z_{\parallel}^{ch} = \frac{\vec{p}_{ch\,jet} \cdot \vec{p}_{HF}}{\vec{p}_{ch\,jet} \cdot \vec{p}_{ch\,jet}}$$



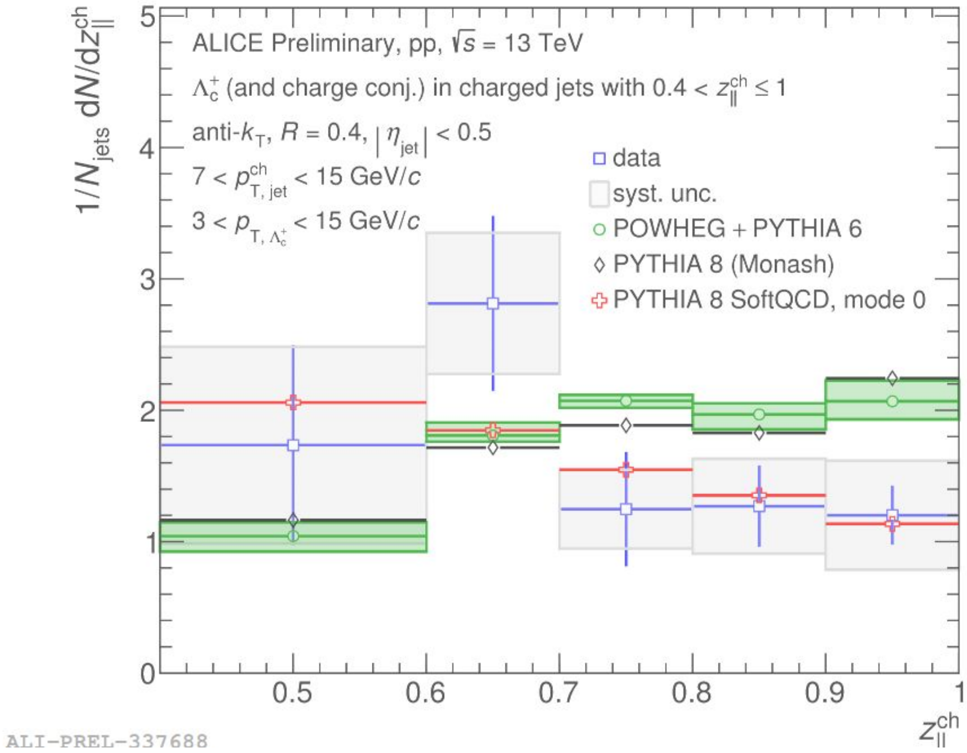
- Hint of a softer fragmentation in data wrt model predictions (especially NLO) for low $p_{T,ch\,jet}$ and larger R
- The core of the jet (R=0.2) is dominated by the HF hadron, as expected from the suppression of small angle emissions.
- At large angle (R>0.2) the charm quark emissions are recovered

HF jets to look into fragmentation

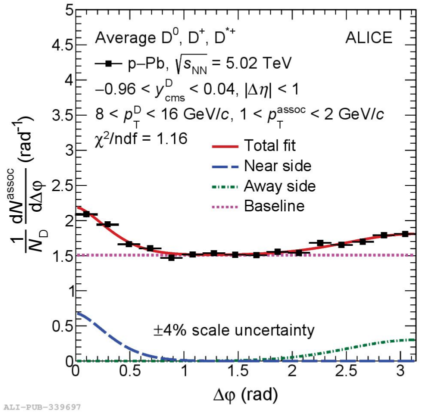
HF-tagged jets provide a handle on the evolution of quarks into hadrons

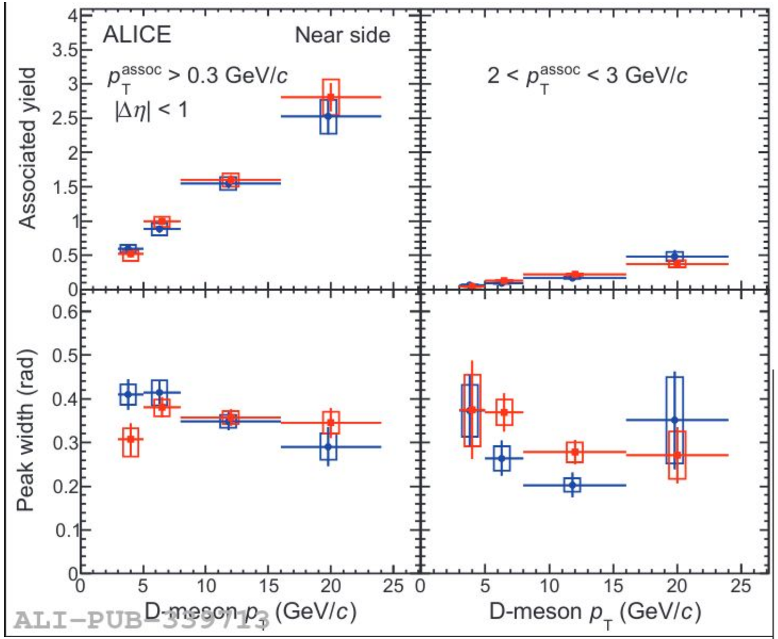


- Data point toward a softer fragmentation w.r.t. classic in vacuum fragmentation models in the low $p_{T,ch\text{-}jet}$ range (beyond Leading Color fragmentation needed)

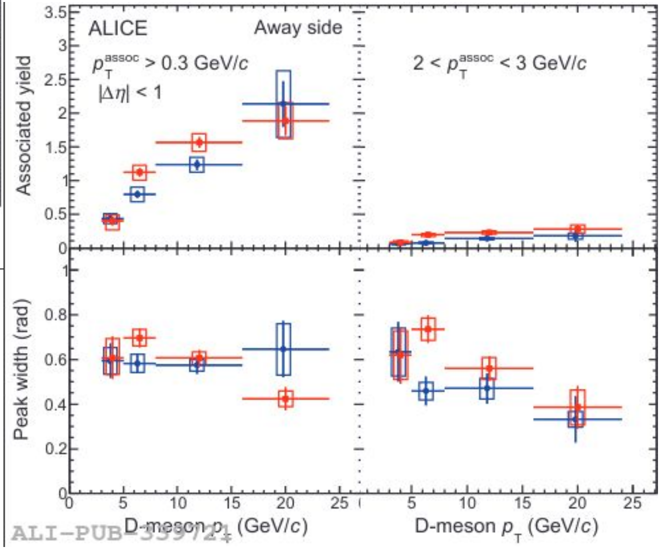


D-meson and charged particle azimuthal correlation in pp and p–Pb at 5.02 TeV





- 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 charm fragmentation arises with current statistics.



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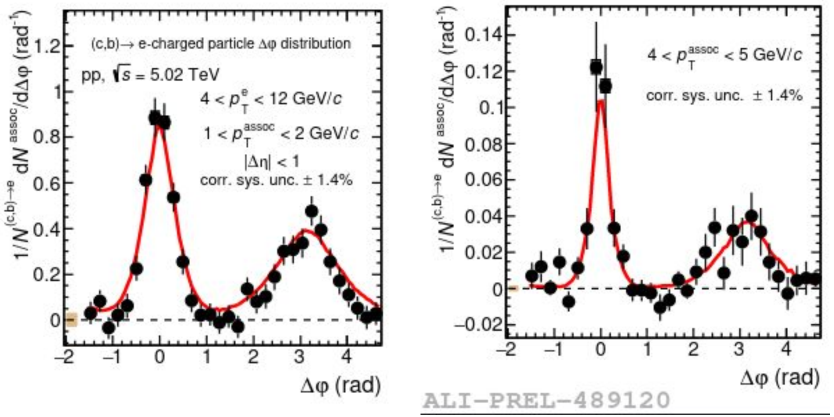
Fitting procedure:

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

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

HFe-charged particles azimuthal correlation distributions



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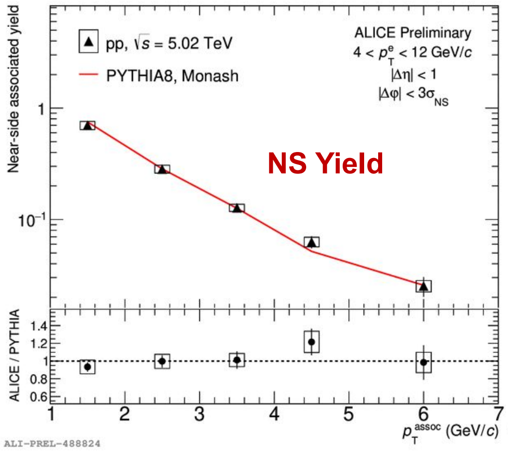
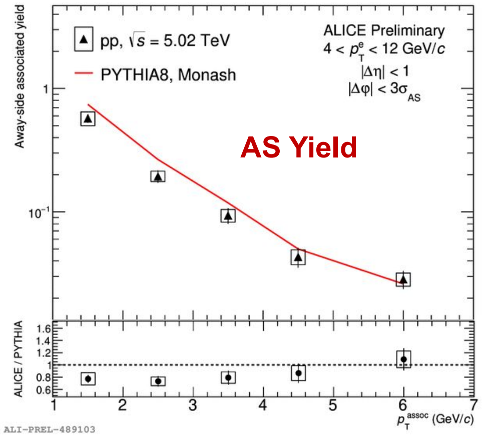
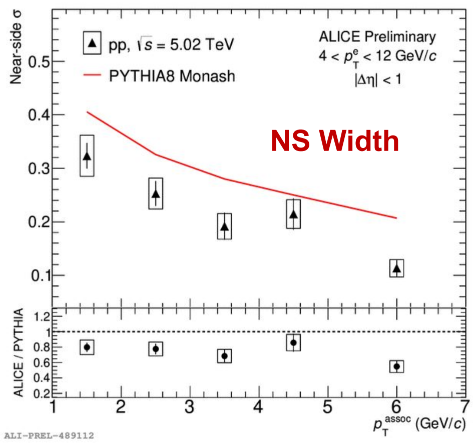
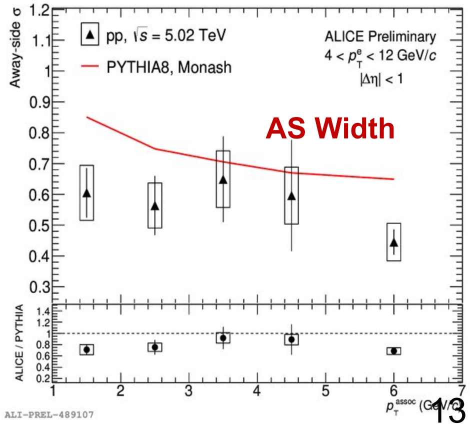


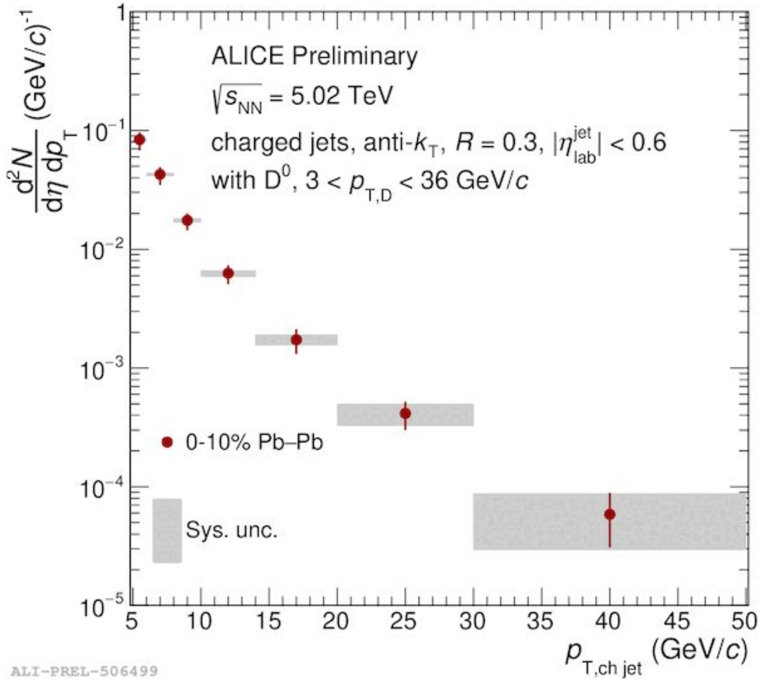


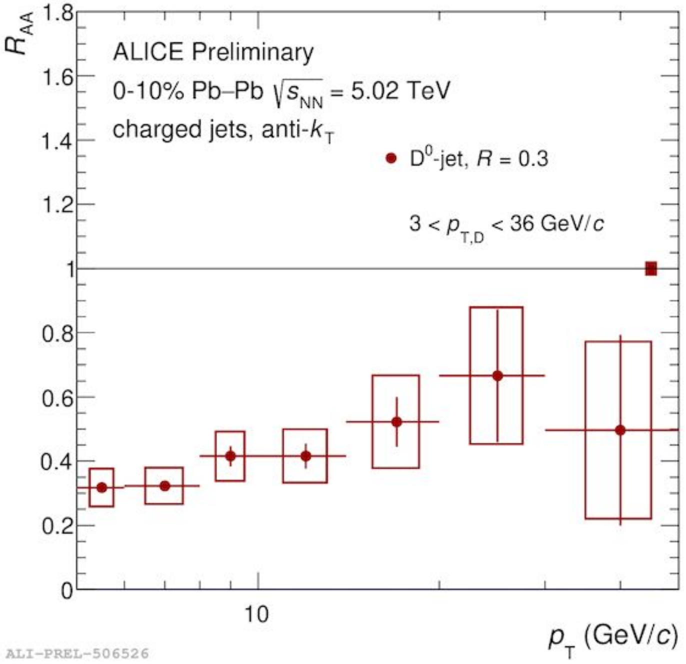




- NS yield is very well reproduced by the PYTHIA8.
- Both the widths are underestimated by the PYTHIA8 predictions.

Medium effects: D^0-jets in 0-10% Pb-Pb





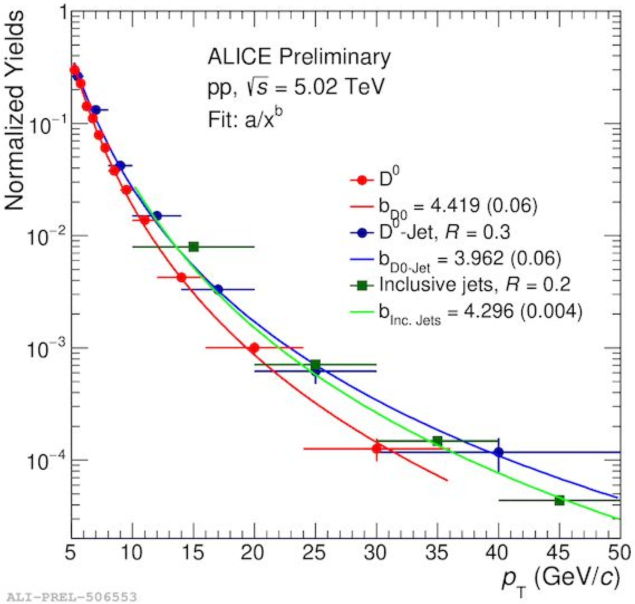
p_T-differential cross section in Pb-Pb central collisions

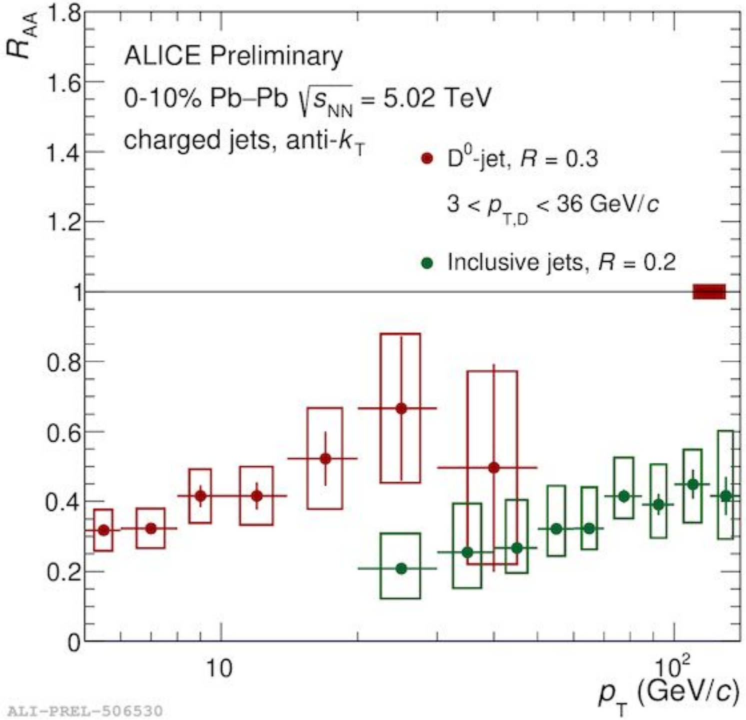
Baseline: D^0-jet p_T differential cross section in pp at 5.02 TeV with same jet reconstruction

Suppression of D^0-jets in central Pb—Pb collisions

Medium effects: D^0-jets in 0-10% Pb-Pb

- Higher R_{AA} of D^0-jet compared to inclusive jets in Pb–Pb?
  - Comparison is sensitive to difference between quarks and gluon energy loss (Casimir colour effect)
  - Comparison could also be sensitive to mass effects (dead-cone effect).





ALICE 3 Detector

- ALICE 3: a next-generation heavy-ion experiment for LHC Run 5.
- Compact all-silicon tracker with high-resolution vertex detector.

Heavy-flavour hadrons
($p_T \rightarrow 0$, wide η range)
– vertexing, tracking, hadron ID

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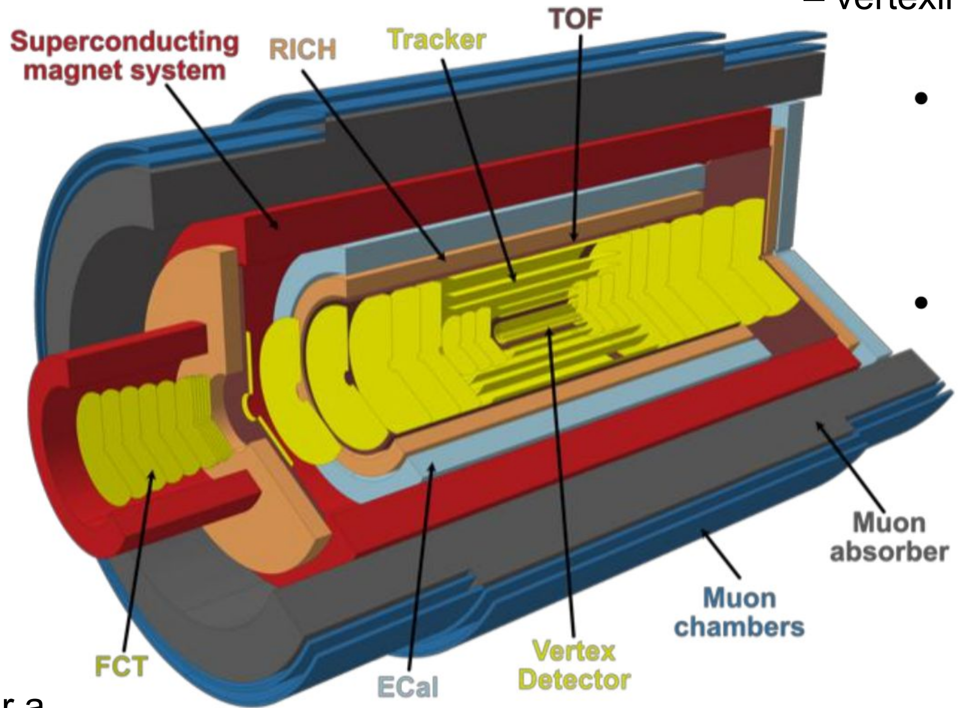
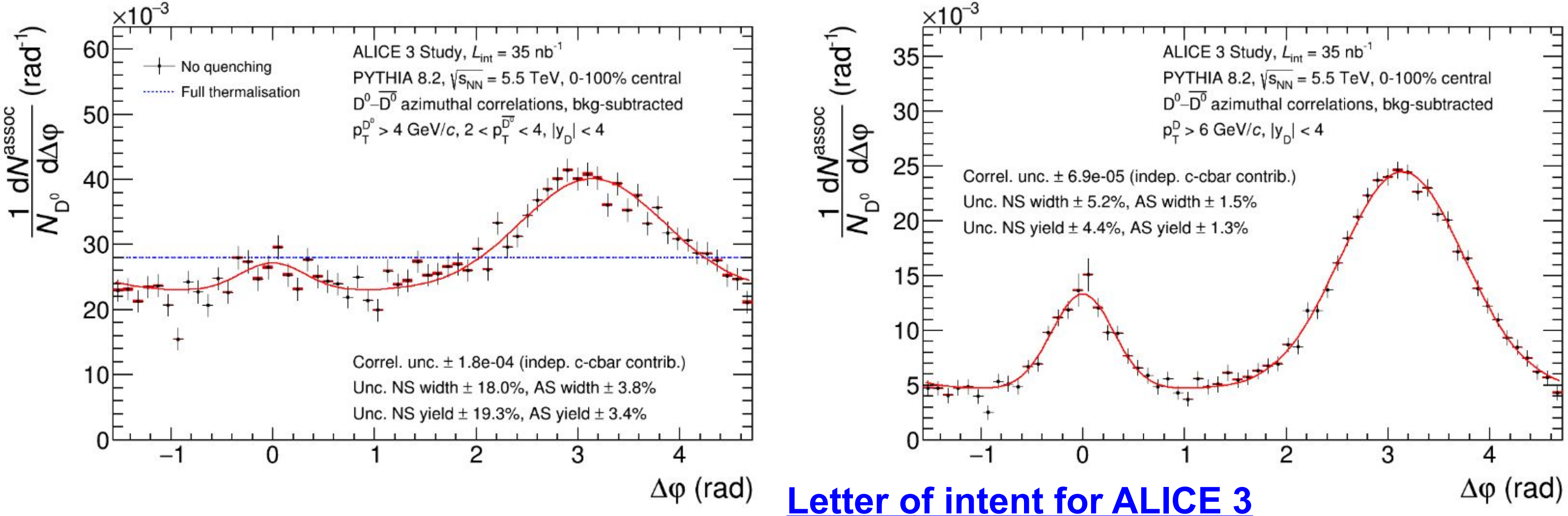


Particle identification over a large acceptance.

[Letter of intent for ALICE 3]

Expected performance of azimuthal correlation in Pb-Pb collisions

- Calculation of estimated D^0 -D^0 pairs in Pb-Pb collisions for 35 nb^{-1} luminosity.
- Includes background subtraction and weights to account for D^0-D^0 reconstruction and selection efficiencies. Normalization to the number of trigger D^0 mesons.
- Correlation patterns in Pb-Pb collisions will be detailed enough to assess the effects of transport broadening and thermalisation, using pp collisions as a reference.



[Letter of intent for ALICE 3]

- Expected performance for azimuthal correlation distributions of D^0 and D^0 in $|\eta|$<4, in 0-100% Pb–Pb collisions, for L_{int} = 35 nb^{-1}.

Summary:

- HF - tagged jets:

✓ Theoretical predictions successfully describe the experimental cross-section.
✓ Softer fragmentation at low $p_{T,\text{ch jet}}$ is observed by looking at the fragmentation function.
✓ Nuclear modification factor in D-meson tagged jets shows suppression up to 70%.

- D-h azimuthal correlation distribution:

✓ Comparison between pp and p-Pb measurements showing consistency with each other.
✓ No major effect observed due to CNM effect.

- HFe – charged particle azimuthal correlation distributions

✓ Near-side yield is consistent with PYTHIA8 predictions while PYTHIA8 overestimate away-side yield at lower p_T.

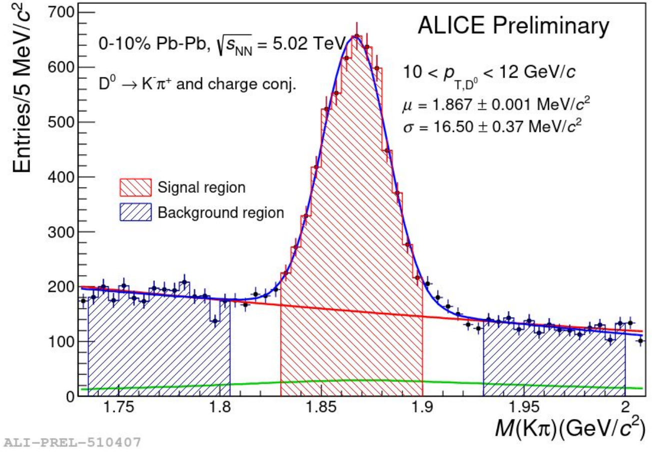
- ALICE3 Detector

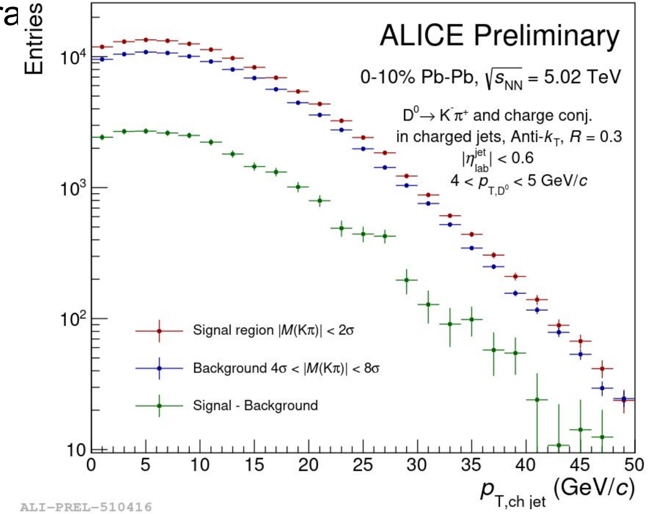
✓ Wide η range
✓ Correlation patterns in Pb-Pb collisions will be detailed enough to assess the effects of transport broadening and thermalisation.

Thank You

Medium effects: D^0-jets in 0-10% Pb-Pb

- Invariant mass was used to extract D^0-jet raw signal spectrum with side-band subtraction.
- Correction for the D^0-jet efficiency and D^0-reflections.
- Subtraction of feed-down D^0-jet component.
- POWHEG predictions convoluted with measured non-prompt D^0 R_{AA}
- Jet-p_T spectra corrected for detector effects and background fluctuations
- Unfolding using an itera

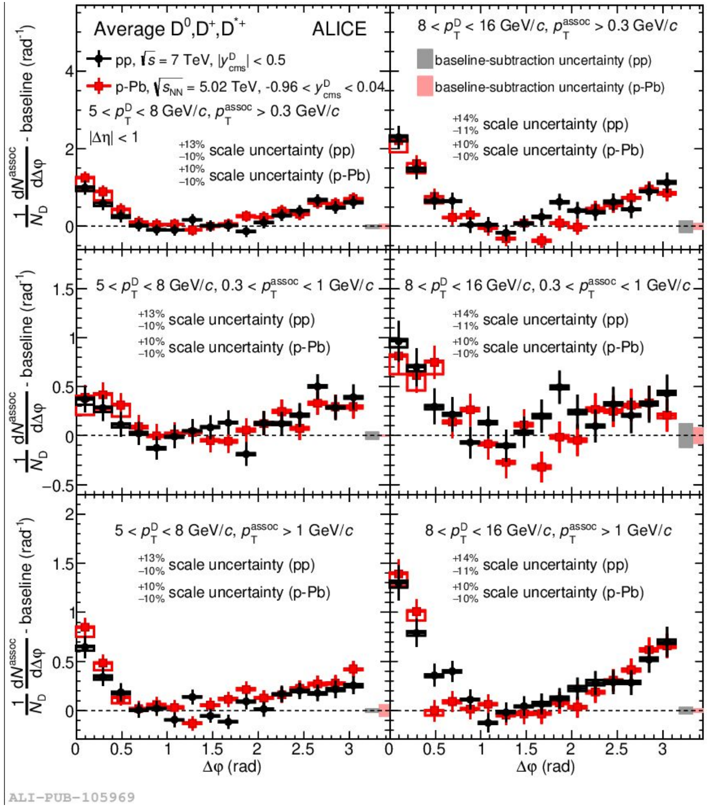


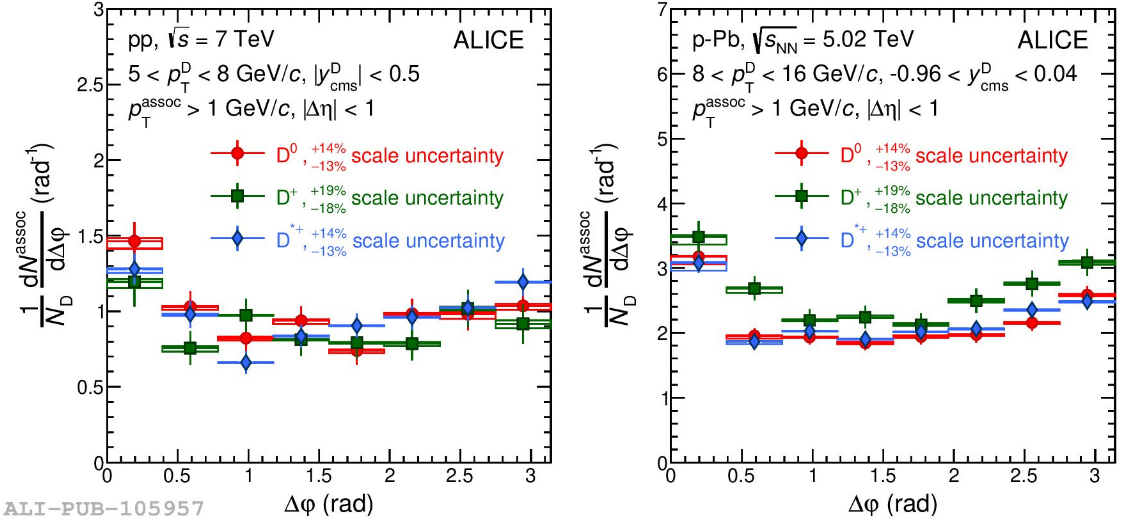


Raw jet spectrum corrected for D^0-jet efficiency

- D^0 -meson $3 < p_T < 36$ GeV/c
- Charged jets, anti-k_T algorithm with R = 0.3
- Jet $5 < p_T < 50$ GeV/c

Comparison of correlation distributions in pp and p–Pb collisions





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Near-side yield and widths in p–Pb collisions at 5.02 TeV

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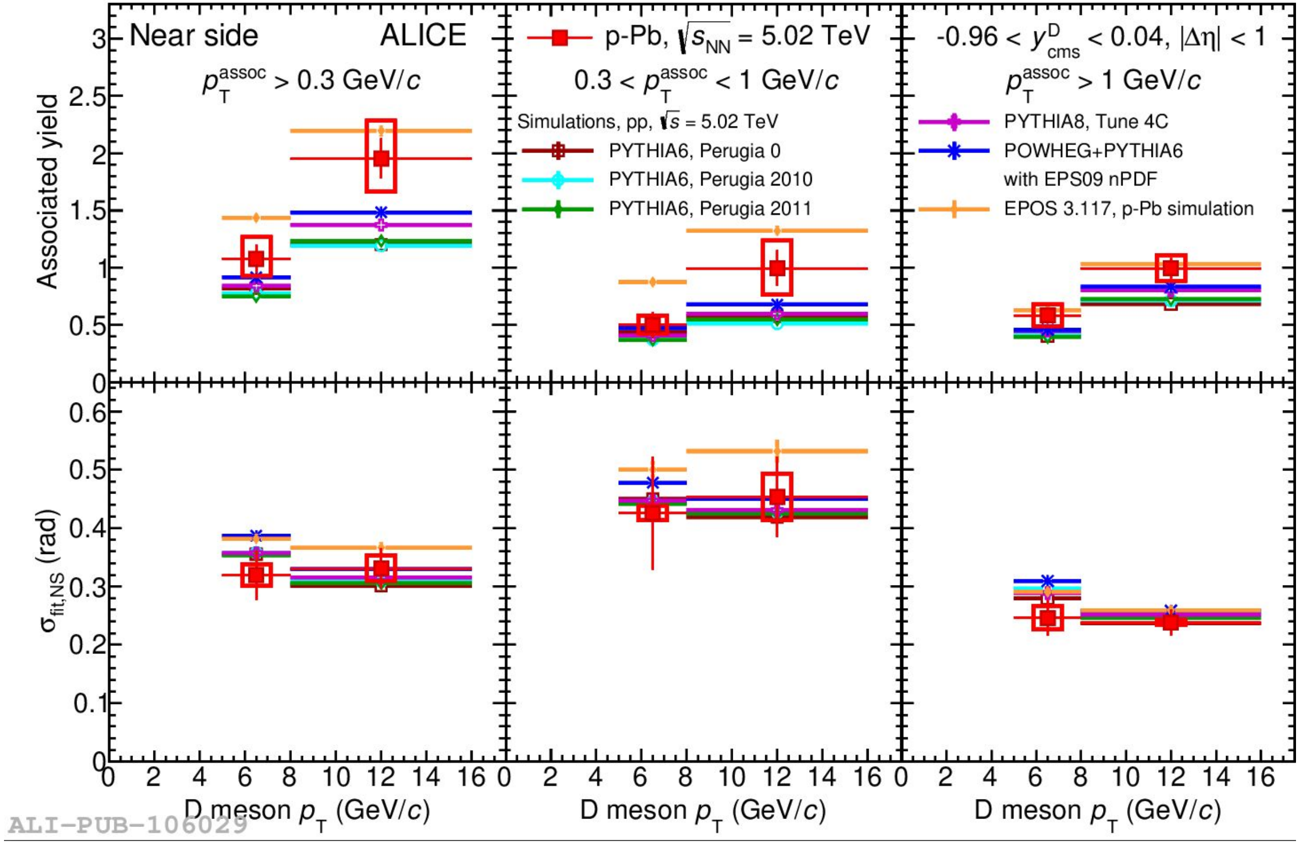
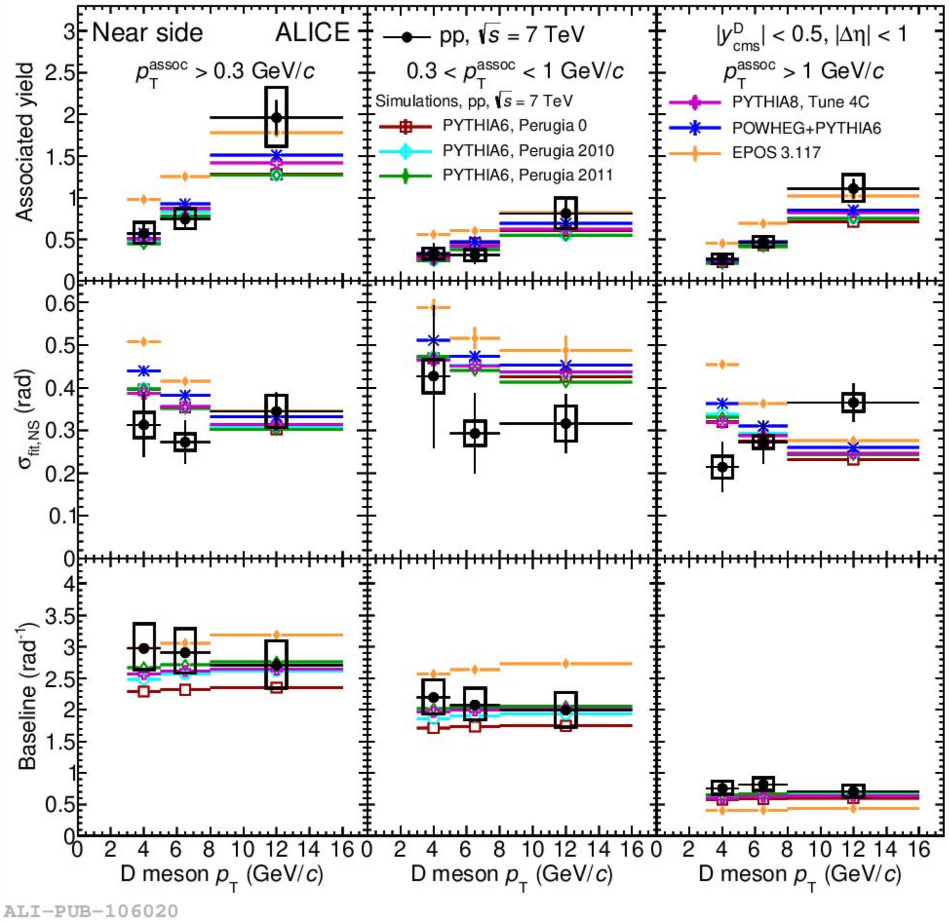


Near-side observables and baseline in pp collisions at 7 TeV



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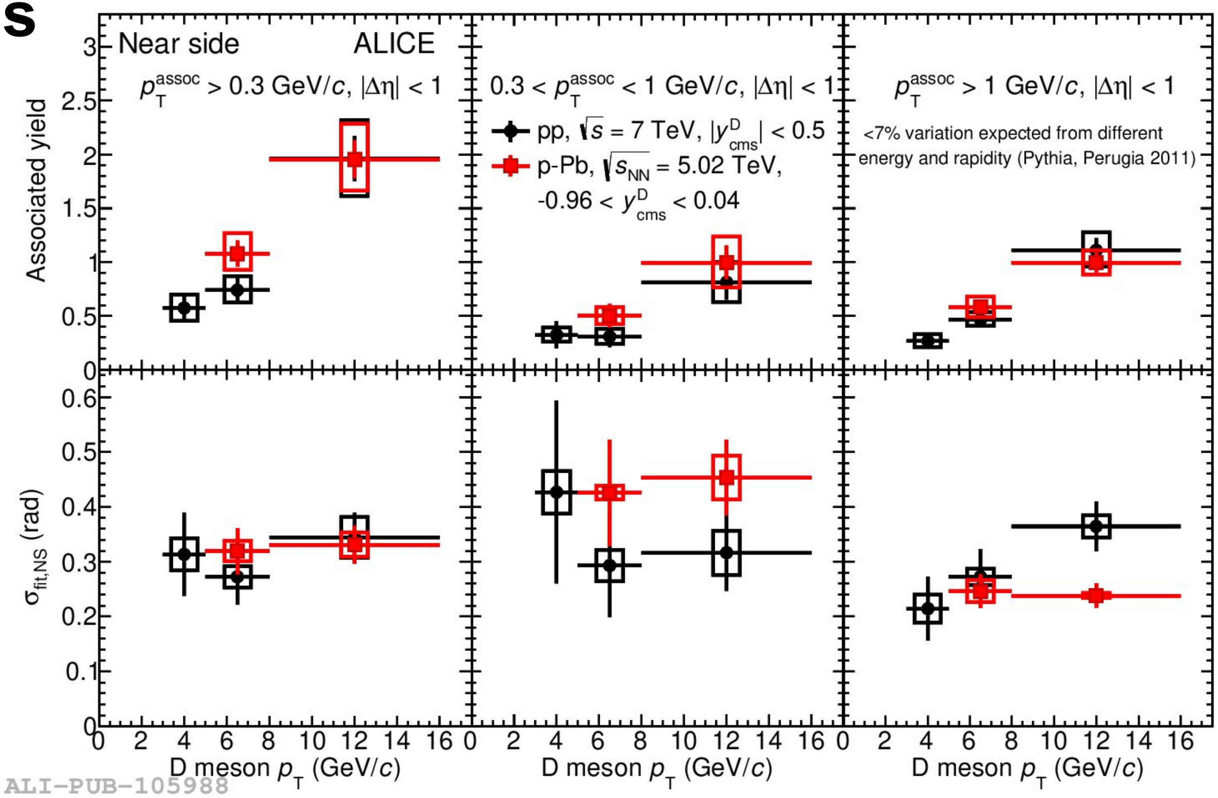
Comparison of near-side observables in pp and p–Pb collisions



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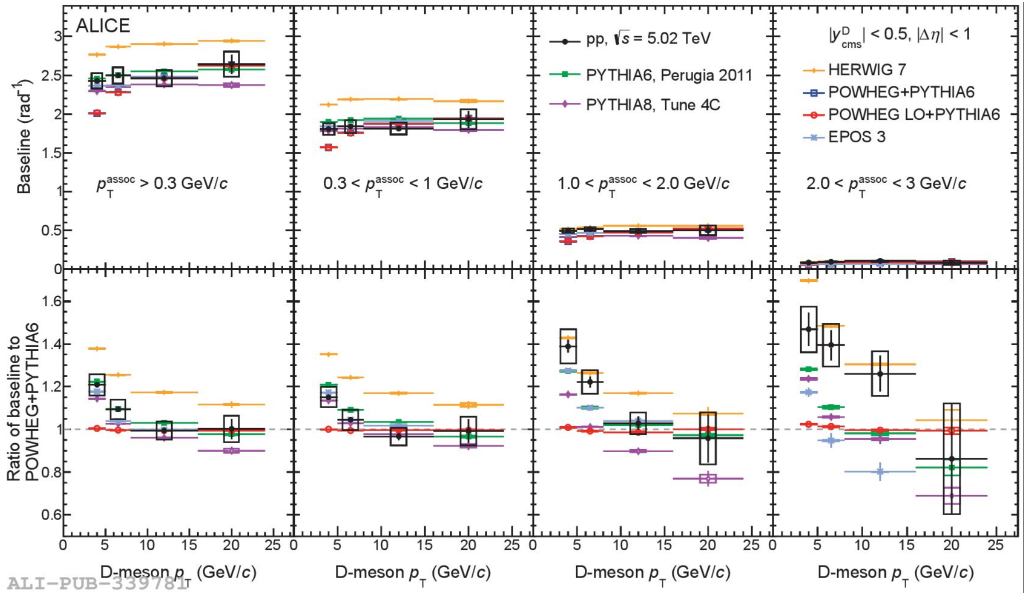
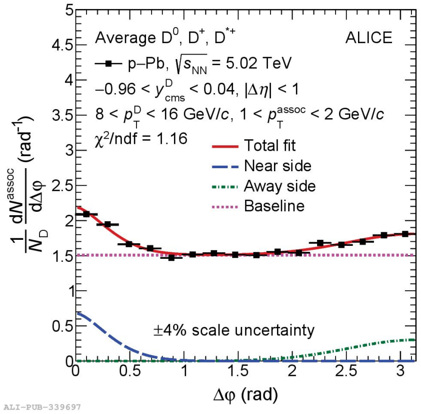
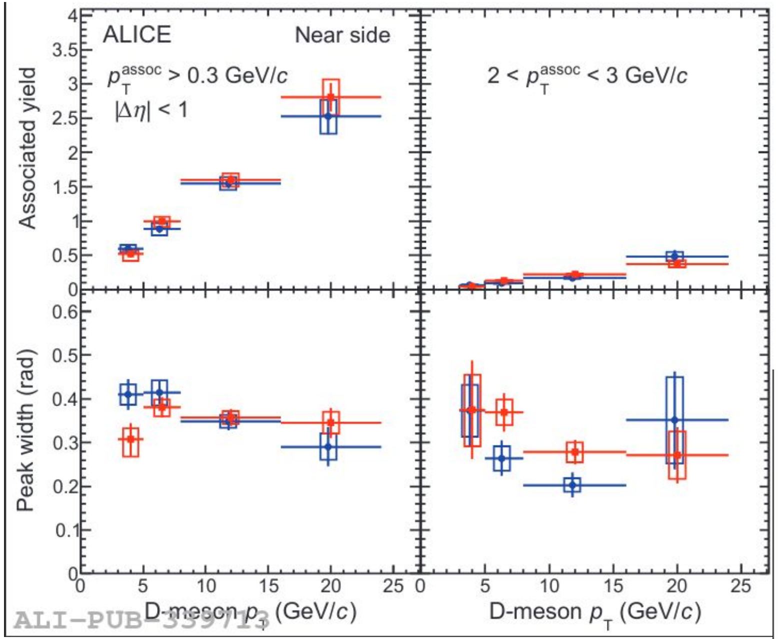
D-meson Baseline comparison with models in pp at 5.02 TeV



[EPJC 80 (2020) 979](https://doi.org/10.1140/epjc/s10052-020-8118-z)

D-meson and charged particle azimuthal correlation in pp and p–Pb at 5.02 TeV





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

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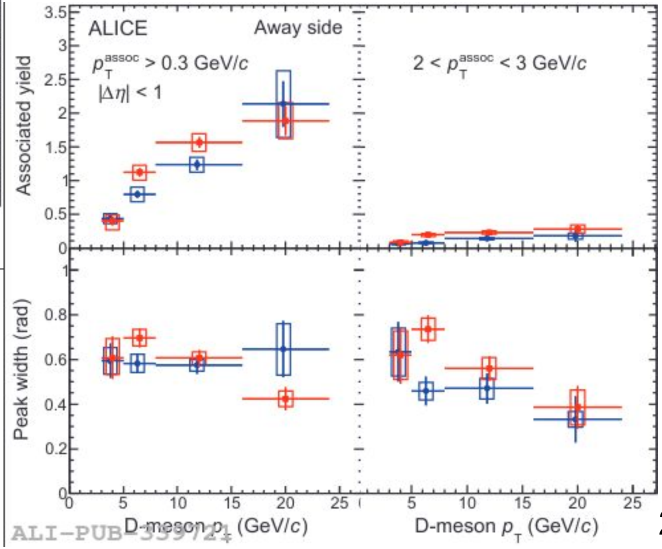
Identification of associated (charged) particles;

- Sideband subtraction and event-mixing technique;
- Corrections for efficiency, acceptance;
- Integration over $\Delta\eta < 1$;
- Corrections for contamination and feed-down.

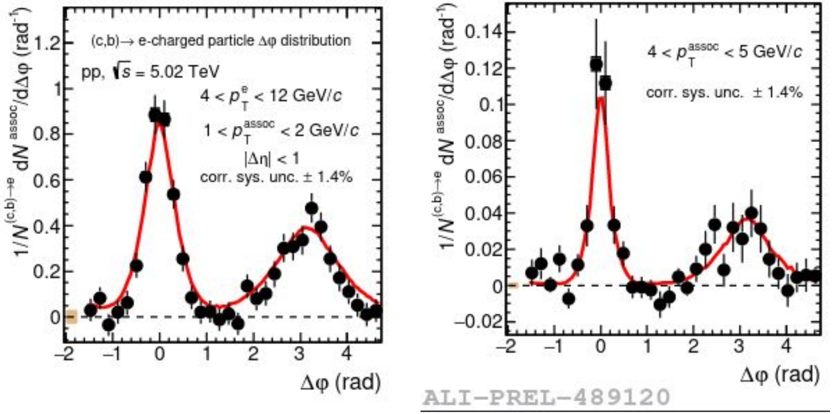
2) Fit procedure:

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

- 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 charm fragmentation arises with current statistics.



HFe-charged particles azimuthal correlation distributions



HF-electron sources are:

- semi-electronic 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.
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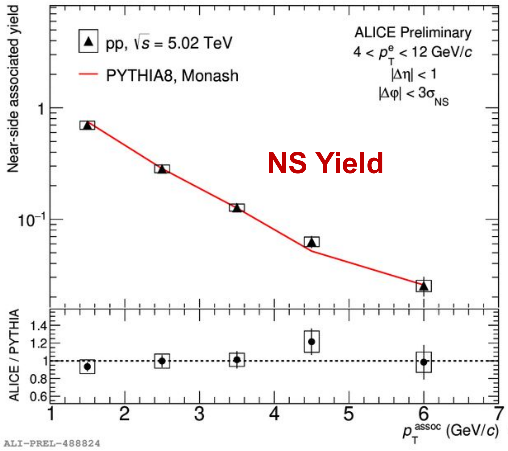
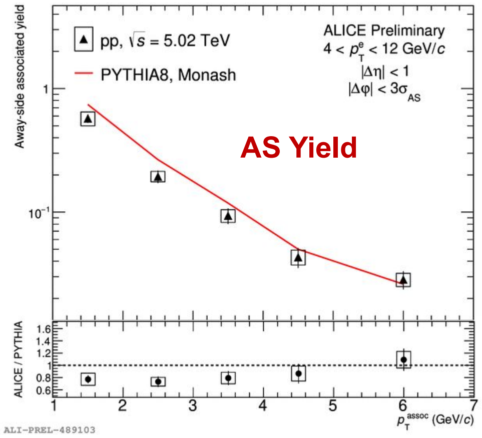
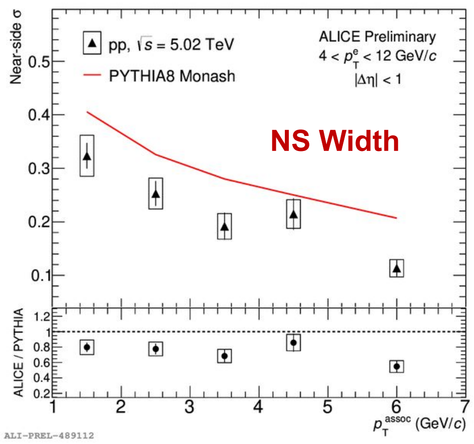
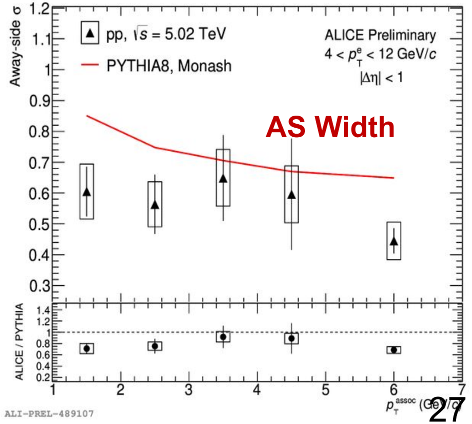
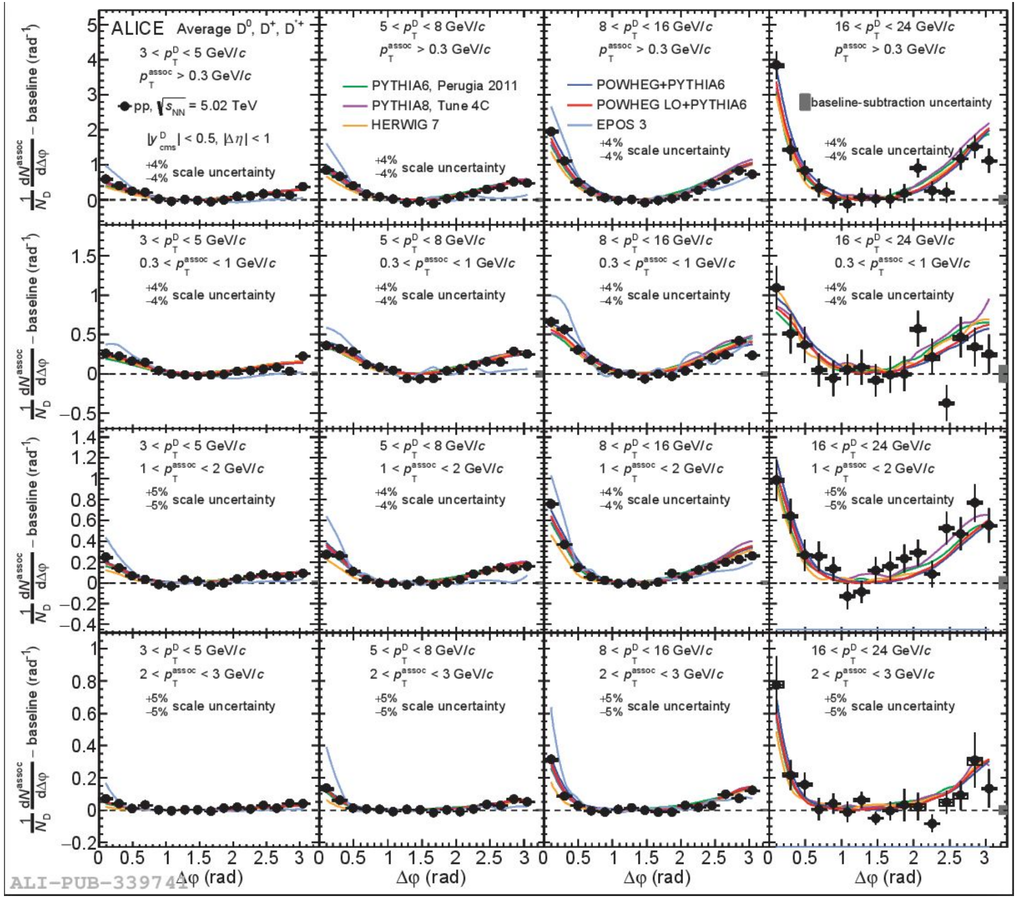


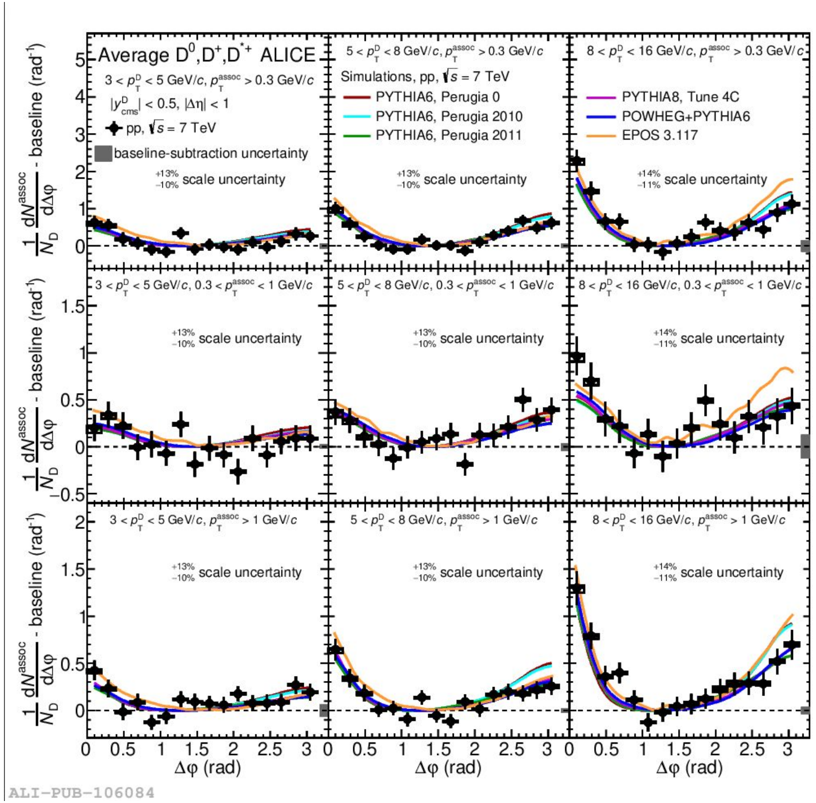






Model comparisons of D-charged particle correlation distribution in at 5.02 and 7 TeV





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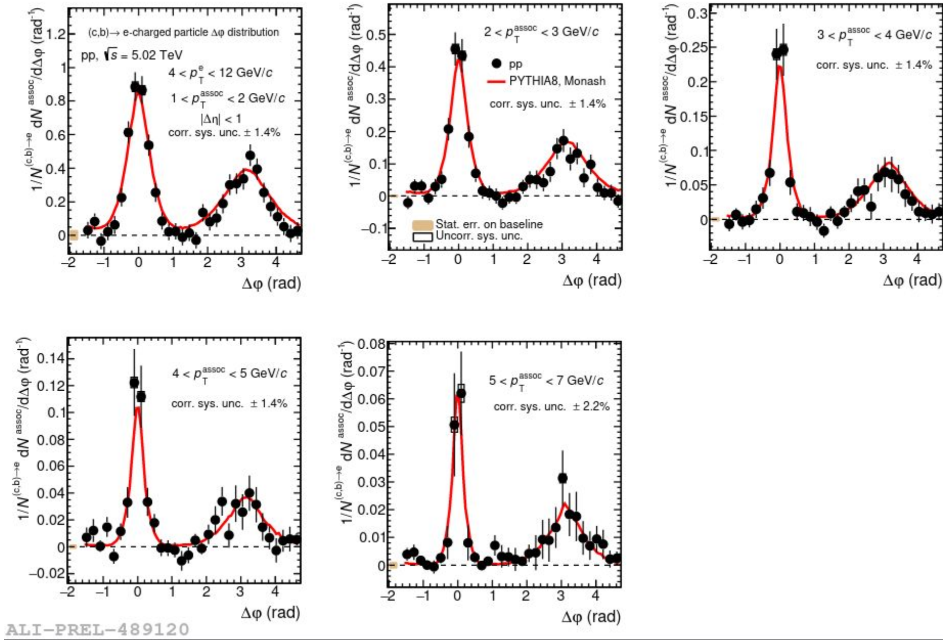
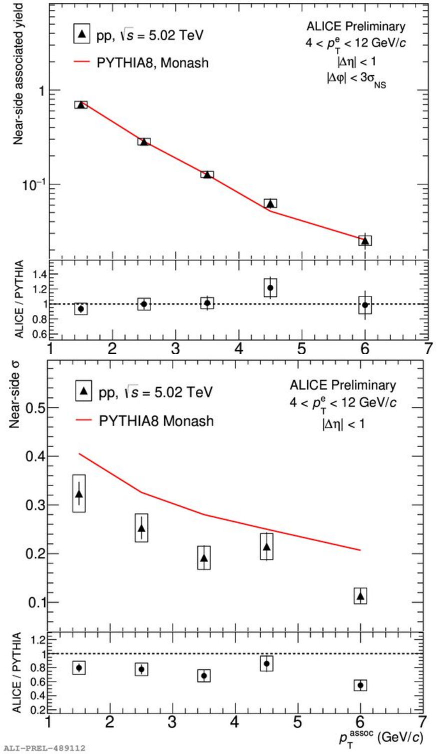
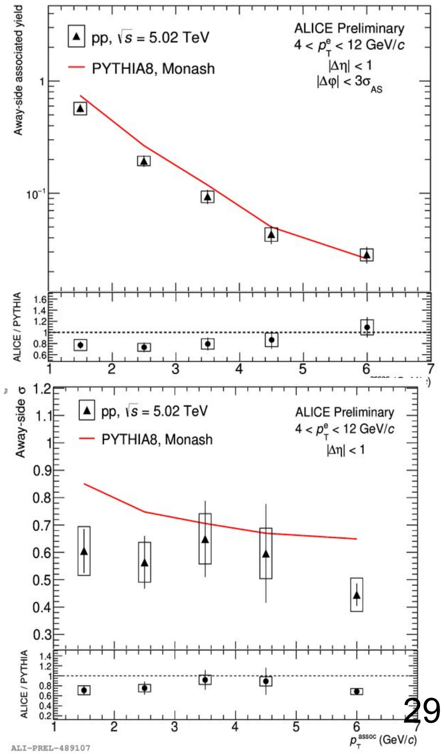
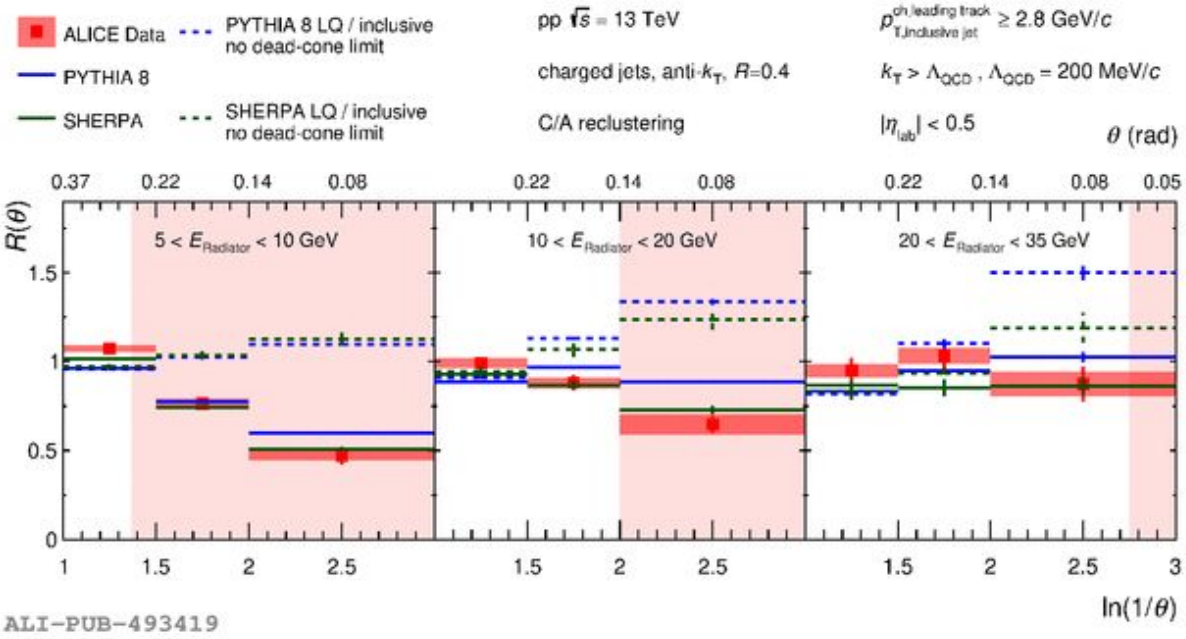
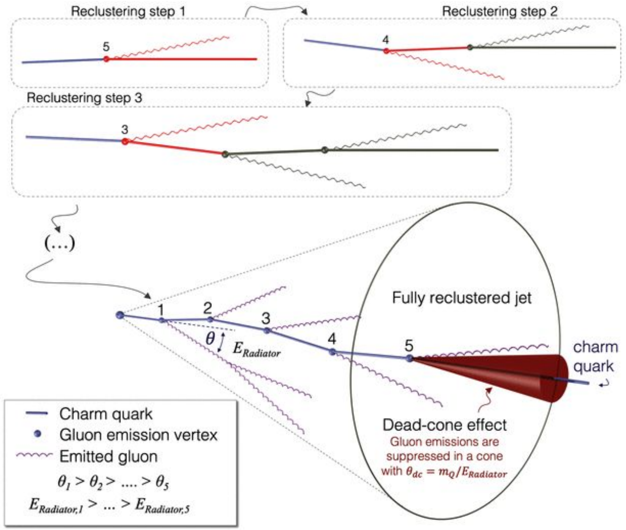






Direct experimental access to the dead-cone





arXiv:2106.05713

- Ratio of emission angle distributions for charm quarks and inclusive partons reveals the dead-cone effect.
- Significant suppression of small-θ emissions
- Dead cone narrows with increasing charm-quark energy

The dead cone is a well-known effect in gauge theories, where radiation from a charged particle of mass m and energy E is suppressed within an angular size of m/E.