



Azimuthal correlations of D mesons with charged particles in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE at the LHC

Shyam Kumar for the ALICE Collaboration

email: shyam.kumar@cern.ch

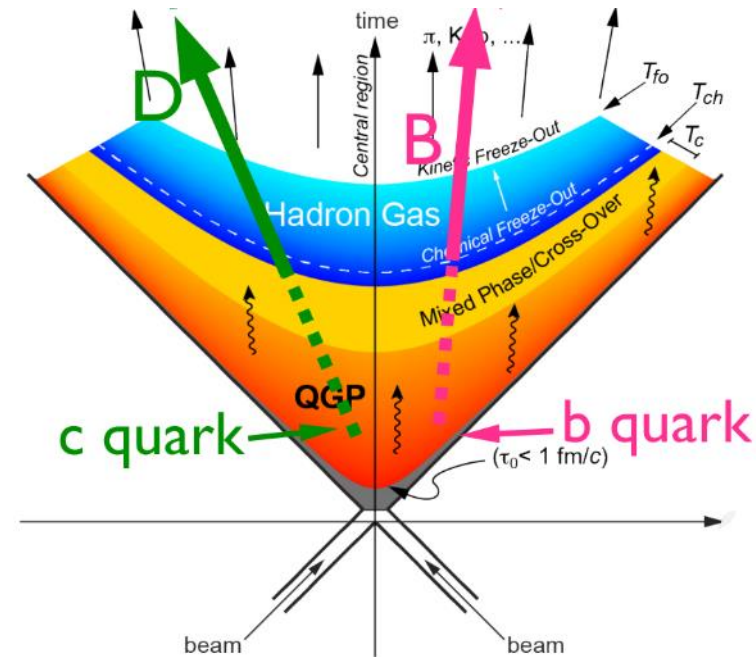
3rd Heavy flavour meet-2019
IIT Indore, India



Outline

- Physics Motivations
- ALICE Detector
- Analysis Strategy
- Main Observables
- Results
- Summary

- ❖ Heavy quarks (charm and beauty) are produced through hard parton scatterings in the initial stage of the collisions
- ❖ Production time scale $\Delta t \sim 1/2m_{c,b}$
 - Charm: $\sim 0.07 \text{ fm}/c$
 - Beauty: $\sim 0.02 \text{ fm}/c$
- ❖ QGP formation time
 - t_0 : $0.1 - 1.0 \text{ fm}/c$
- ❖ Heavy quarks are witness of the whole evolution of the medium produced in ultra-relativistic heavy-ion collisions
- ❖ Ideal probe to study the medium properties
- ❖ Two types of heavy-flavour particles
 - Open heavy flavour: particles with non-zero net charm or beauty quantum number e.g. D and B mesons
 - Hidden (closed) heavy flavour: bound states of $Q\bar{Q}$ pairs i.e. J/psi, Upsilon
- ❖ Initial-state effects [in p-A collisions at Low p_T]:
 - Anti-shadowing, Shadowing, k_T broadening (Cronin effect), and Color-Glass-Condensate (CGC)
- ❖ Final-state Effects (due to medium) [in AA collision at High p_T]:
 - Energy loss by gluon radiation, in-medium hadronization (Recombination vs Fragmentation)



Ref: Cristina Bedda, Measurement of D-meson production in p-Pb and Pb-Pb collisions with the ALICE detector at the LHC, ICNF 2017.

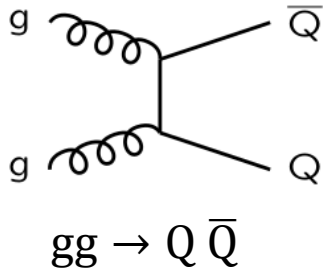
Ref: Panagiota Foka, Małgorzata Anna Janik. <https://doi.org/10.1016/j.revip.2016.11.001>.

Heavy-flavour production mechanisms

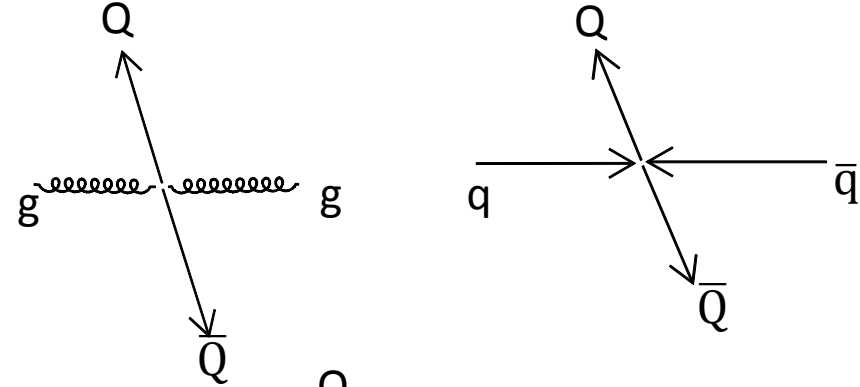
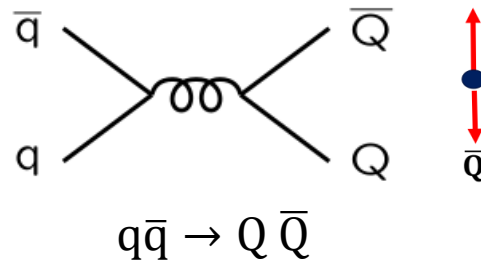
1. Pair Production [Leading Order (LO)] $O(\alpha_s^2)$

1. Q and \bar{Q} symmetric in p_T back to back
2. Nearly equal near-and away-side peaks

Gluon fusion

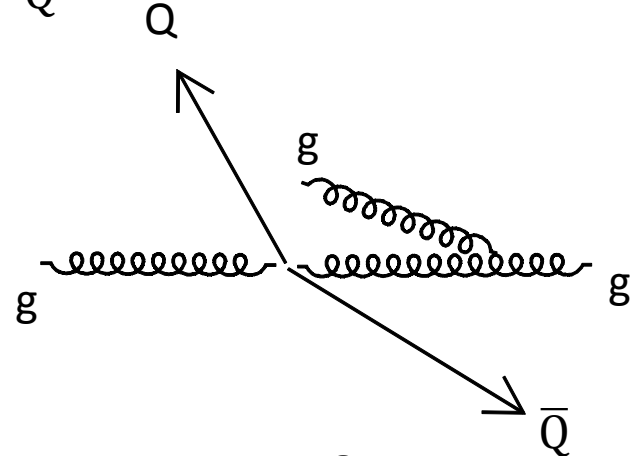
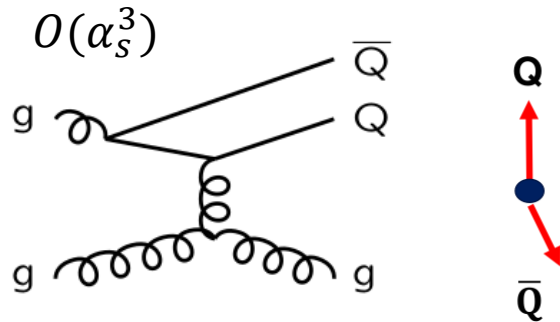


Quark Annihilation



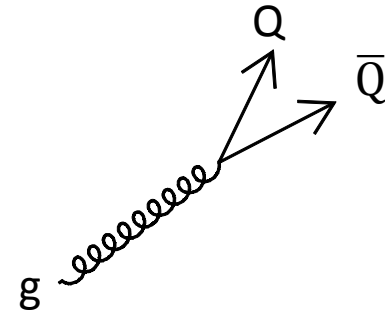
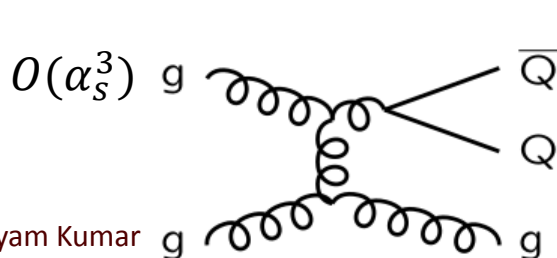
2. Flavour Excitation [Next to Leading Order (NLO)] $O(\alpha_s^3)$

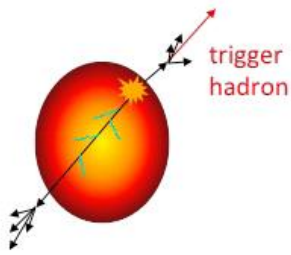
1. Q and \bar{Q} asymmetric in p_T with broad opening angle
2. Away side peak broadening



3. Gluon Splitting [Next to Leading Order (NLO)] $O(\alpha_s^3)$

1. Q and \bar{Q} asymmetric in p_T with small opening angle
2. Increasing near side peak





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

$$\Delta\phi = \phi_{\text{trig}} - \phi_{\text{assoc}}$$

High- p_T D meson \Rightarrow Trigger Hadron

D-hadron correlations:

❖ pp collisions:

- Characterization of fragmentation of charm quarks into jets
- Test and constrain perturbative QCD inspired models
- Reference for p-Pb and Pb-Pb collisions

❖ p-Pb collisions:

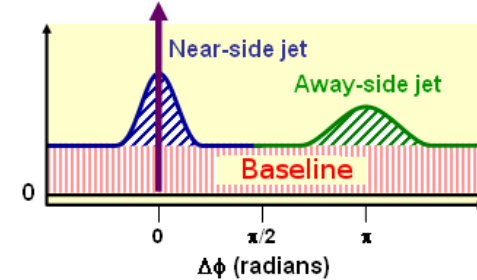
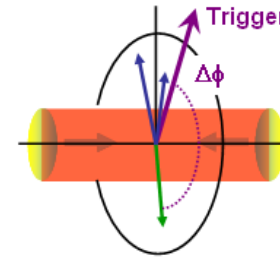
- Cold Nuclear Matter (CNM) effects, Initial State effects
- Double-ridge structure in centrality dependent analysis
- Disentangle final-state QGP-induced modifications from CNM effects

❖ Pb-Pb collisions:

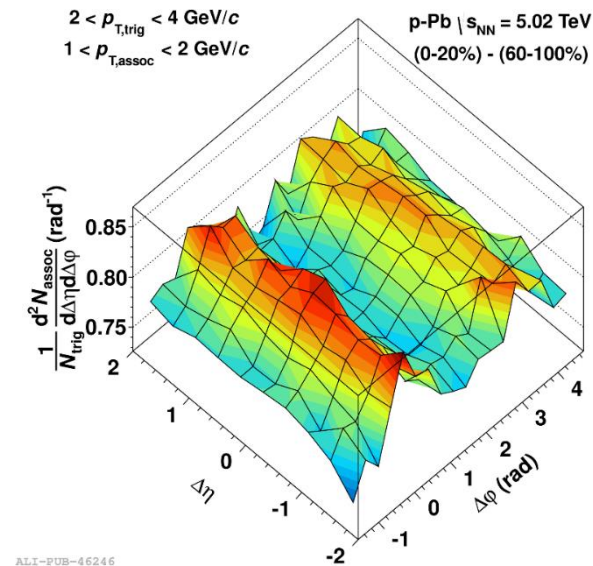
- Study of in-medium partonic energy loss and its path-length dependence
- Interaction of heavy quarks with the medium
- Characterization of medium-induced modification of charm-quark fragmentation and hadronization

Expected energy loss: $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$

Overall correlation distribution
Near Side (NS) and Away Side (AS) peaks



Ref: STAR collaboration. Jets in nuclear collisions, the STAR experiment at RHIC, BNL, 2006



Ref: Phys.Lett.B 719 (2013) 29-41

Ref: Dokshitzer & Kharzeev, PLB 519 (2001) 199

$$D^+ \rightarrow K^- \pi^+ \pi^+ (9.13 \pm 0.19 \%)$$

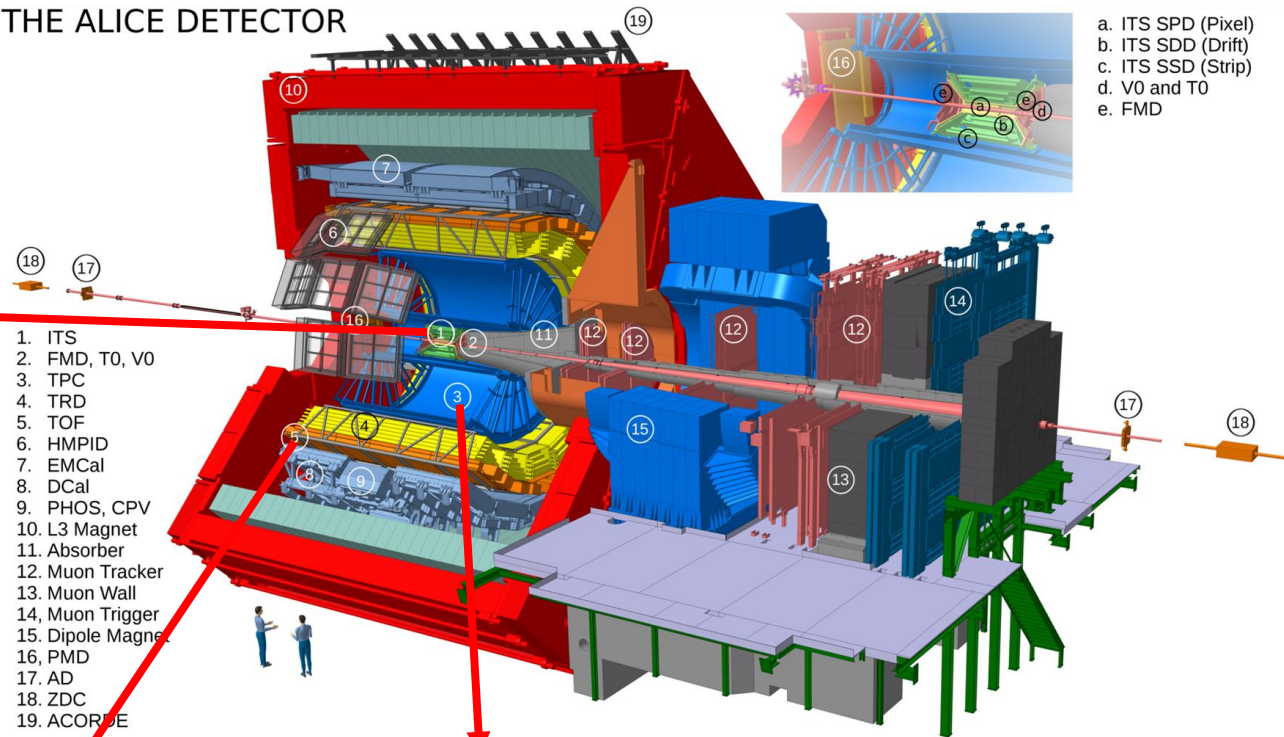
$$D^0 \rightarrow K^- \pi^+ (3.88 \pm 0.05 \%)$$

$$D^{*+} \rightarrow D^0 \pi^+ (67.7 \pm 0.50 \%)$$

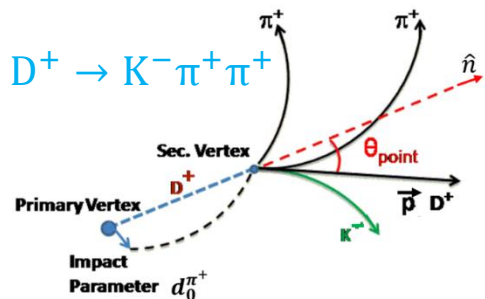
ALICE Detector



THE ALICE DETECTOR



ITS: Inner Tracking System



TOF: Time Of Flight

TPC: Time Projection Chamber

❖ Data Sample:

- p-Pb 2016 data with $\sqrt{s_{NN}} = 5.02$ TeV
Events: 625M
- pp 2017 data with $\sqrt{s} = 5.02$ TeV,
Events: 985 M

Ref: J.Phys.G39(2000)123001

$$SF = \frac{\text{Background}}{\text{LSB} + \text{RSB}}$$

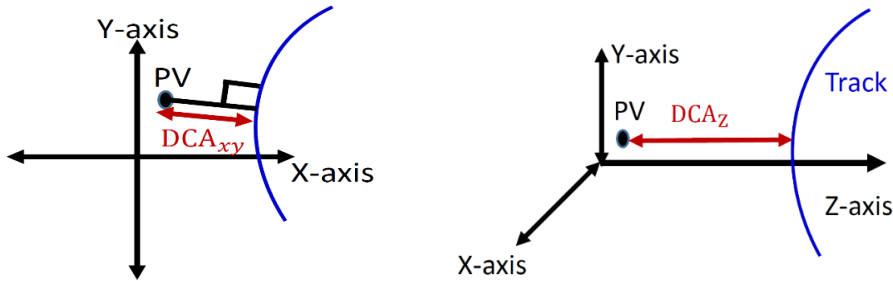
- ❖ D^+ , D^0 and D^* signal extraction from invariant mass plots
- ❖ Correlation of D mesons **with primary charged particles (e, μ , π , K and p)** with removing D-meson daughters

➤ **Correlation of D meson = correlation in [S+B] region – (correlation in [LSB+RSB] region)*SF**

- ❖ Mixed Event [ME] correction: for **limited and inhomogeneities detector acceptance** (events with same z-vtx and multiplicity are mixed)

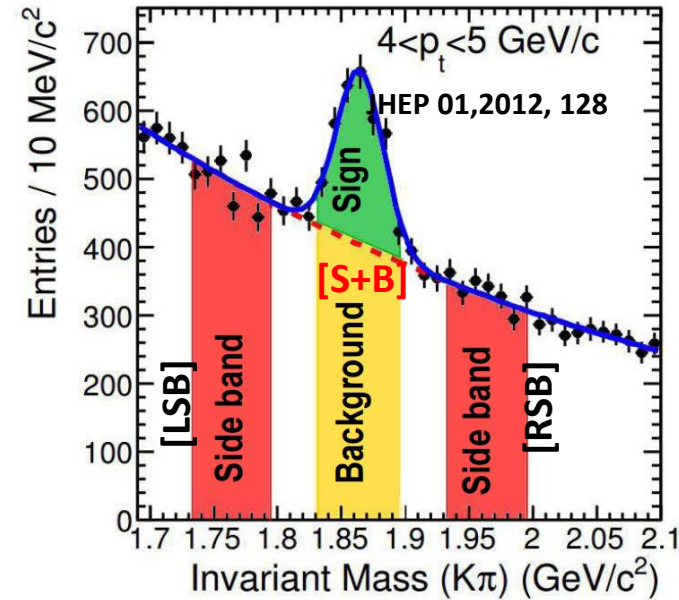
$$\frac{d^2 N^{\text{MECorr}}(\Delta\phi, \Delta\eta)}{d\phi d\eta} = \frac{\frac{d^2 N^{\text{SE}}(\Delta\phi, \Delta\eta)}{d\phi d\eta}}{\frac{d^2 N^{\text{ME}}(\Delta\phi, \Delta\eta)}{d\phi d\eta}} \frac{d^2 N^{\text{ME}}(0,0)}{d\phi d\eta} \quad [\text{SE}]: \text{ Same Event}$$

- ❖ Correction for the **contamination of secondary particles** from strangeness decays and conversion inside detector



- ❖ Correction for **D-meson efficiency and associated track efficiency**
- ❖ Correction for feed-down of D mesons from B-hadron decays

Method of Signal Extraction



- ❖ **Projection onto $\Delta\varphi$ axis** and weighted average of the three D-meson species
- ❖ Fitting of correlations distributions NS-peak and AS-peak and extraction of main observables
- ❖ **NS yield, NS sigma, AS yield and AS sigma**

Correlation of Trigger D meson with primary charged particles

Trigger p_T ranges [GeV/c]
3-5
5-8
8-16
16-24

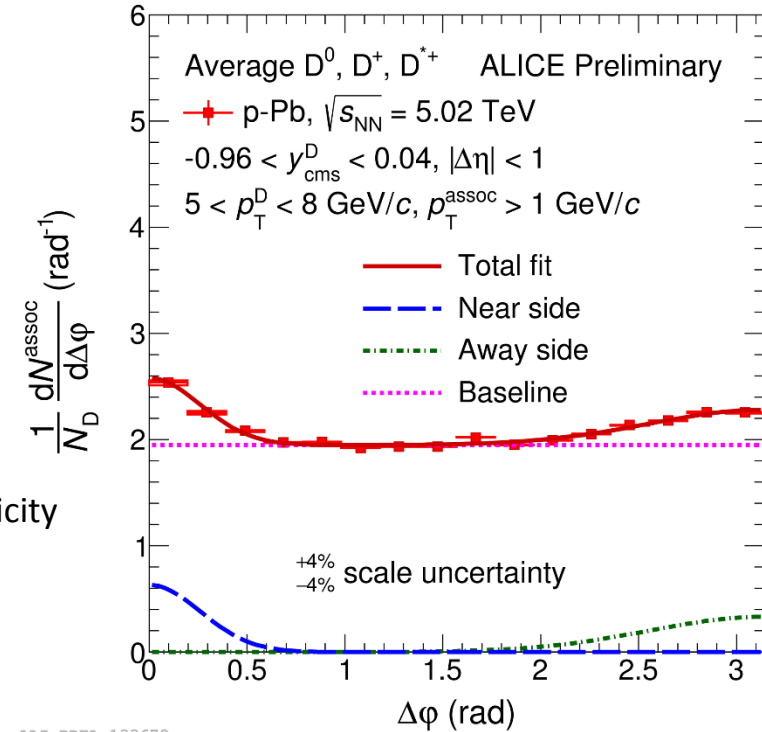


Associated track p_T ranges [GeV/c]
0.3-99.0
1.0-99.0
0.3-1.0
1.0-2.0
2.0-3.0
3.0-99.0

❖ Fitting of correlation distribution

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

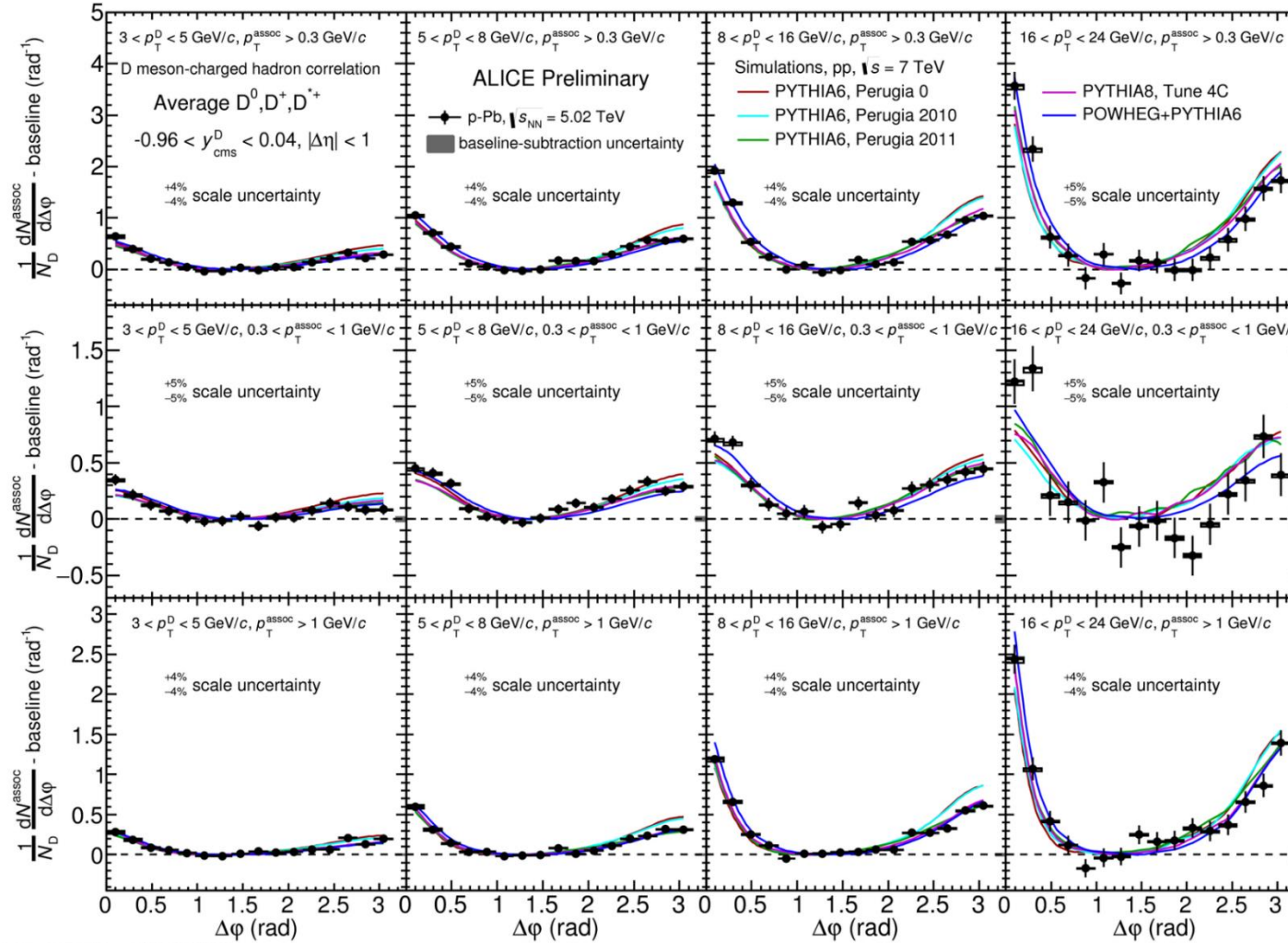
- c : baseline for the underlying tracks => estimator of the event multiplicity
- NS yield (Y_{NS}): number of tracks per D-meson in NS jet
- AS yield (Y_{AS}): number of tracks per D-meson in AS jet
- NS sigma (σ_{NS}): angular distribution of tracks in NS jet
- AS sigma (σ_{AS}): angular distribution of tracks in AS jet



D-hadron correlation describes the feature of NS and AS jet created from the fragmentation of charm quarks

Comparison of correlation distributions in data and predictions:

Good agreement between data and expectations from **PYTHIA** and **POWHEG**



p-Pb data $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$

D-meson p_T ranges:

3-5, 5-8, 8-16, and 16-24

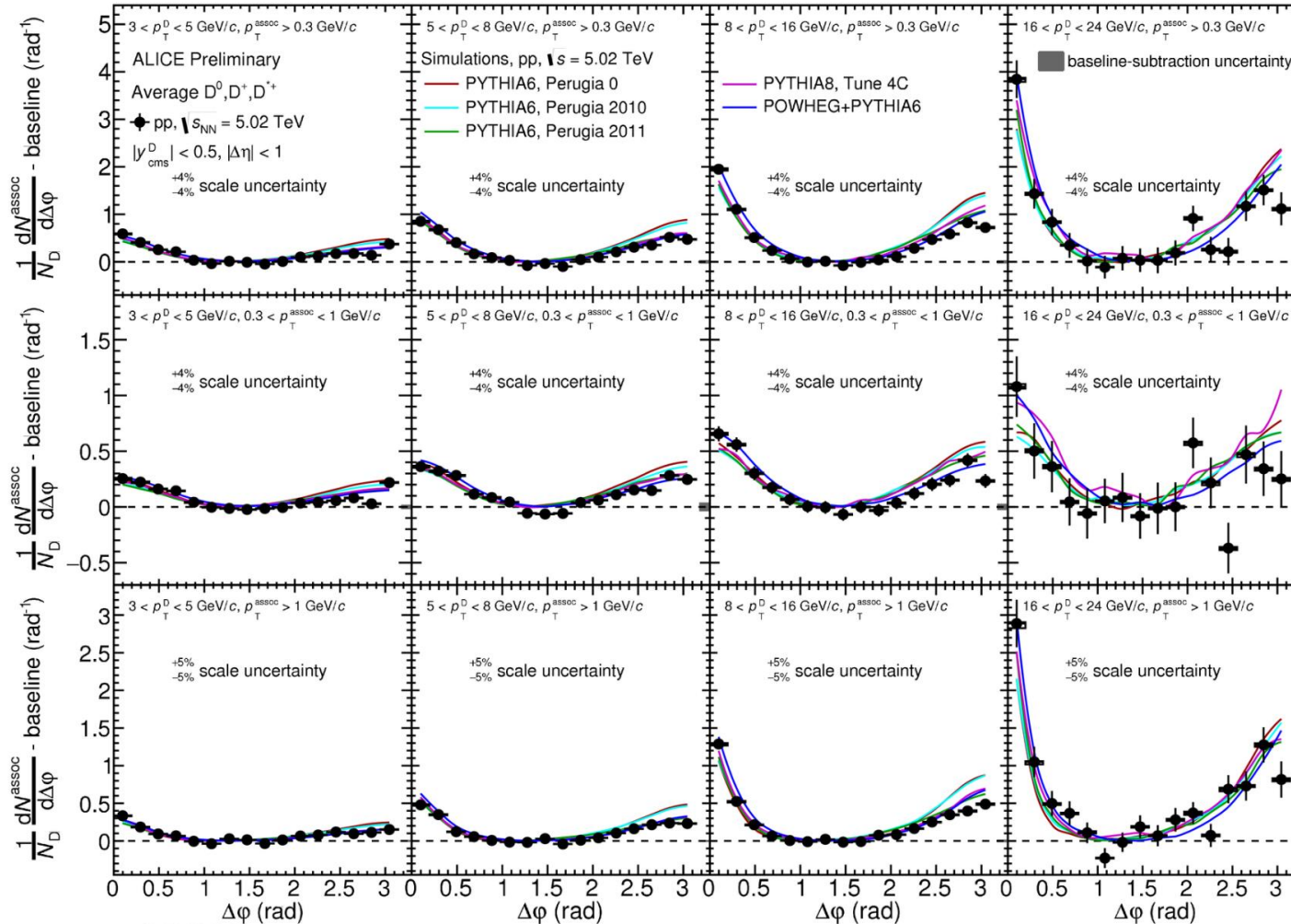
GeV/c

Associated track p_T ranges:

> 0.3, > 1.0 and 0.3-1.0

GeV/c

- ❖ **Comparison of correlation distributions in data and predictions:**
- **Good agreement between data and expectations from **PYTHIA** and **POWHEG****



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

D-meson p_T ranges:

3-5, 5-8, 8-16, and 16-24

GeV/c

Associated track p_T ranges:

> 0.3, > 1.0 and 0.3-1.0

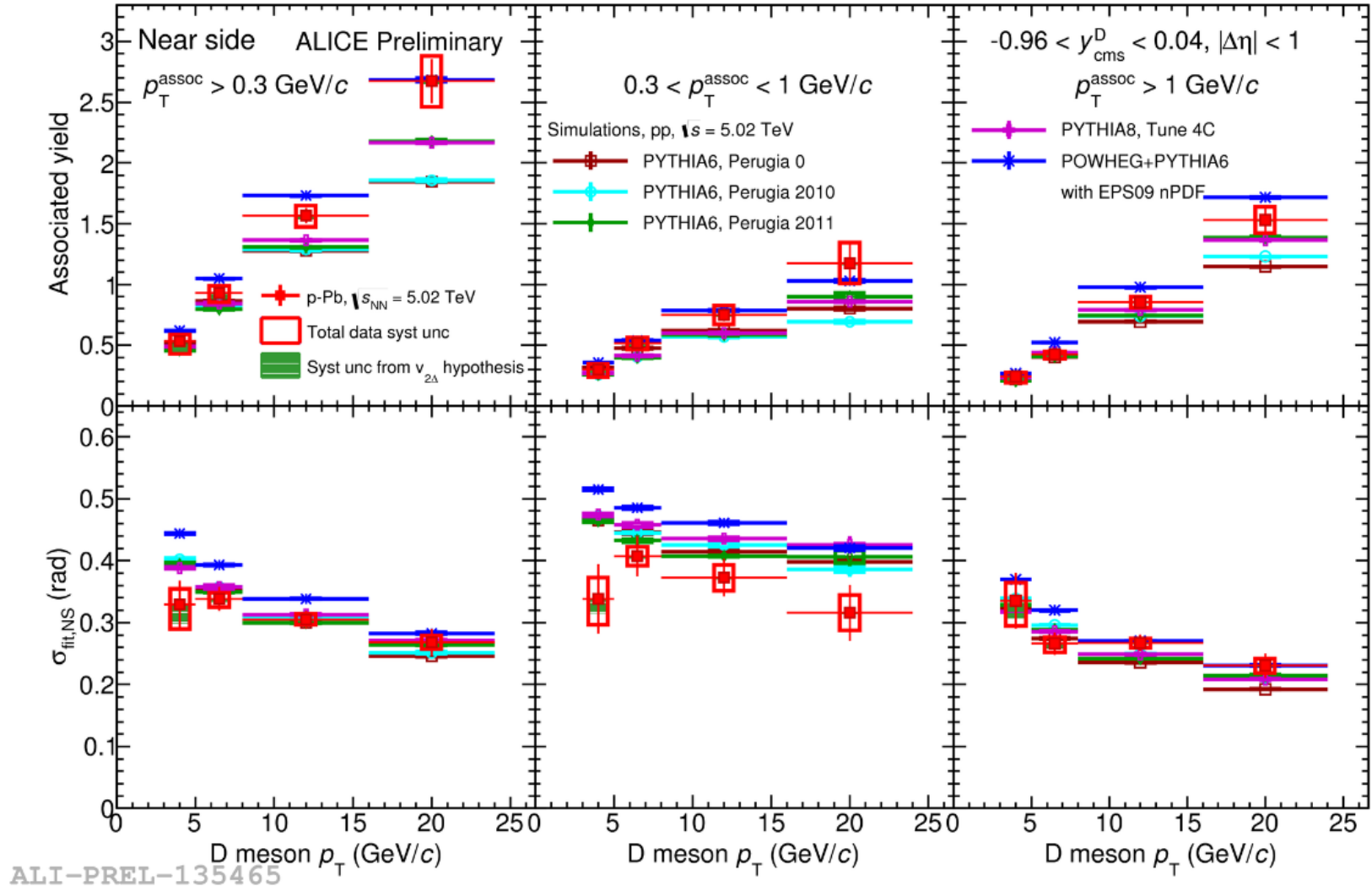
GeV/c

ALI-PREL-307299

Comparison of NS yields and sigmas with MC simulations

p-Pb data $\sqrt{s_{NN}} = 5.02$ TeV

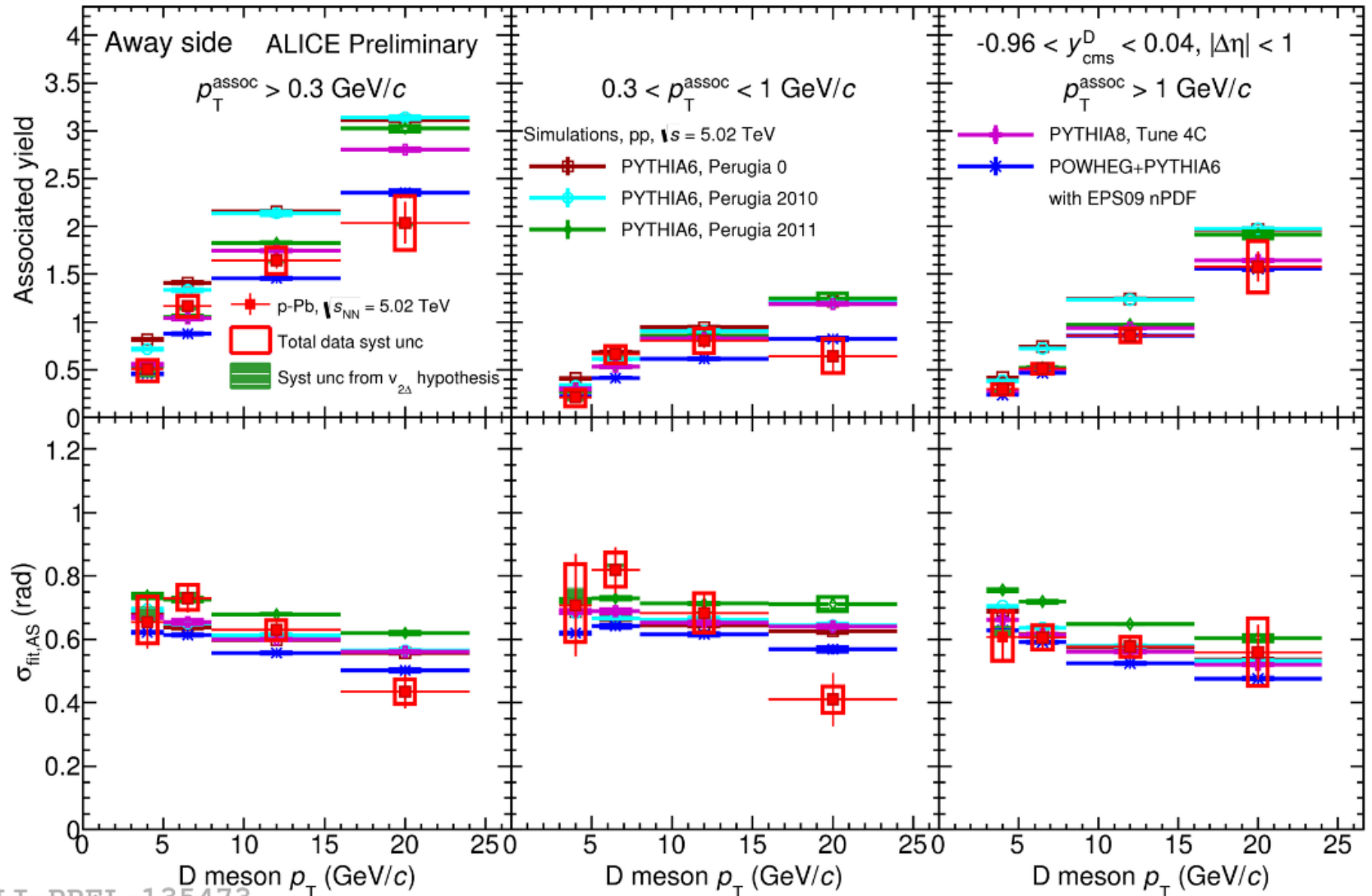
Near Side p_T : $> 0.3, > 1.0$ and $0.3-1.0$ GeV/c



Comparison of **AS yields and sigmas** with MC simulations

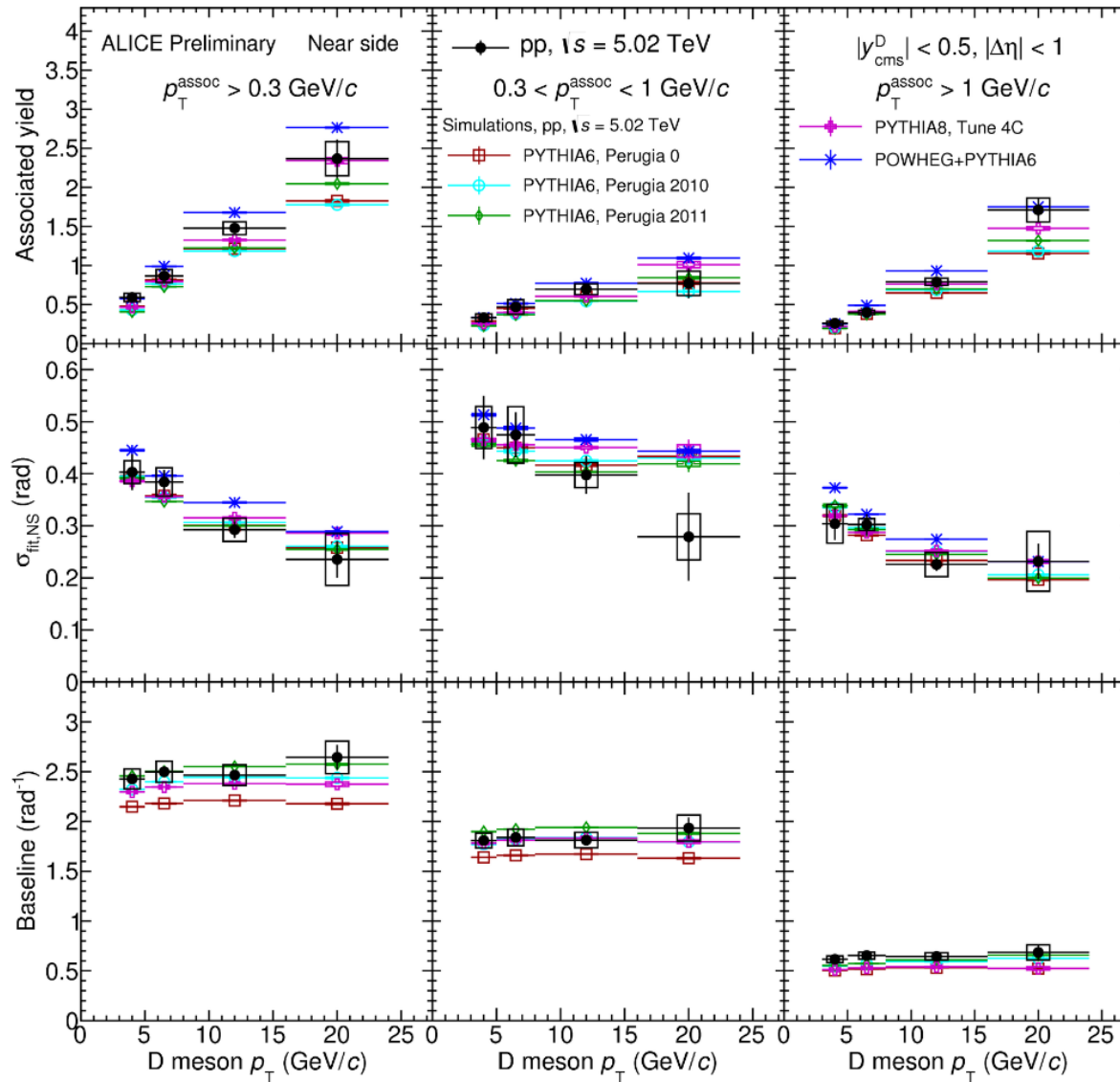
p-Pb data $\sqrt{s_{NN}} = 5.02$ TeV

Away Side p_T : $> 0.3, > 1.0$ and $0.3-1.0$ GeV/c



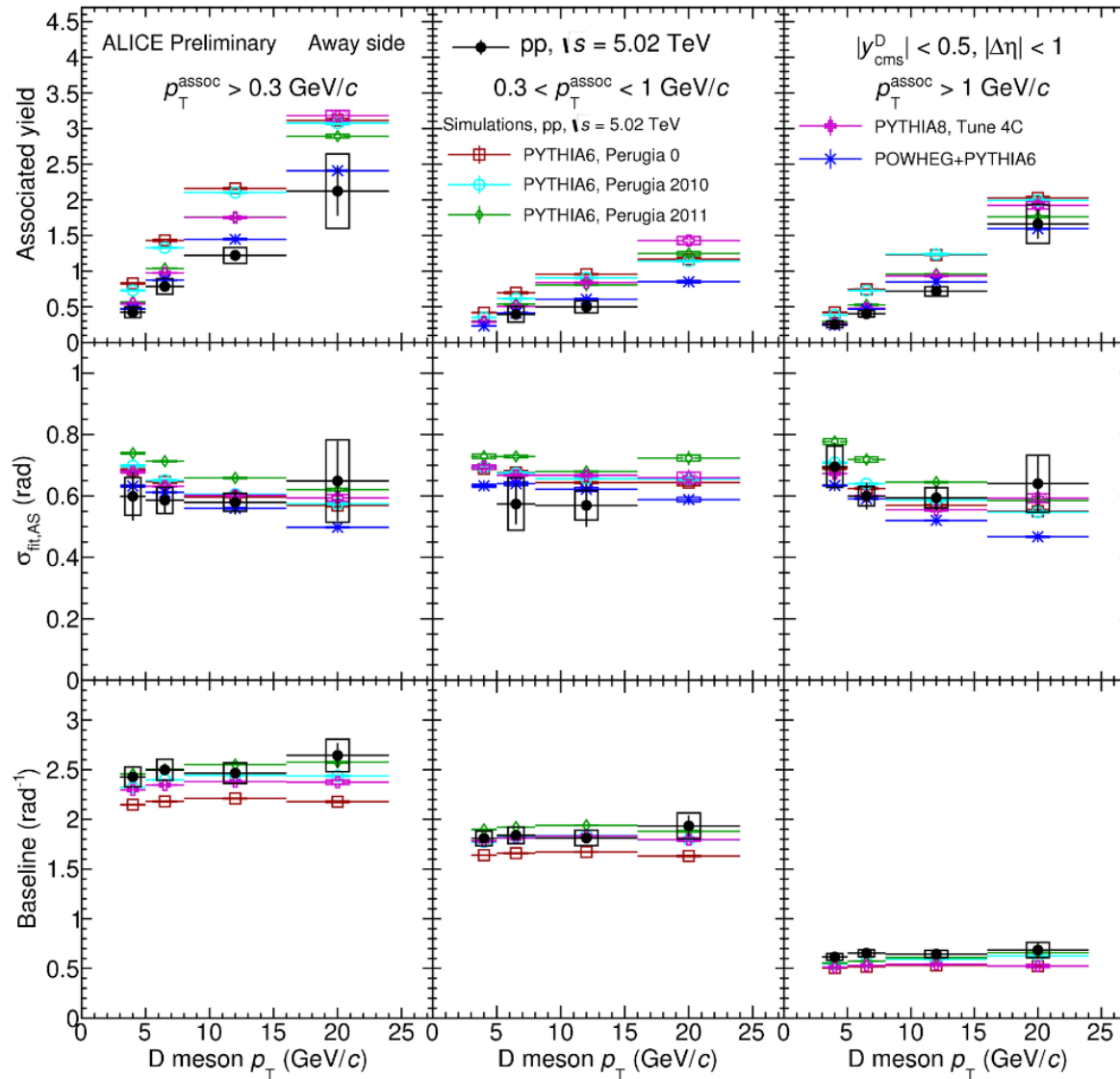
ALI-PREL-135473

Good agreement between data and expectations from **PYTHIA and POWHEG**



ALI-PREL-307362

Good agreement between data and expectations from **PYTHIA** and **POWHEG**



**Away Side p_T : $> 0.3, > 1.0$
and $0.3-1.0$ GeV/c**

ALI-PREL-307380

Good agreement between data and expectations from **PYTHIA and **POWHEG****

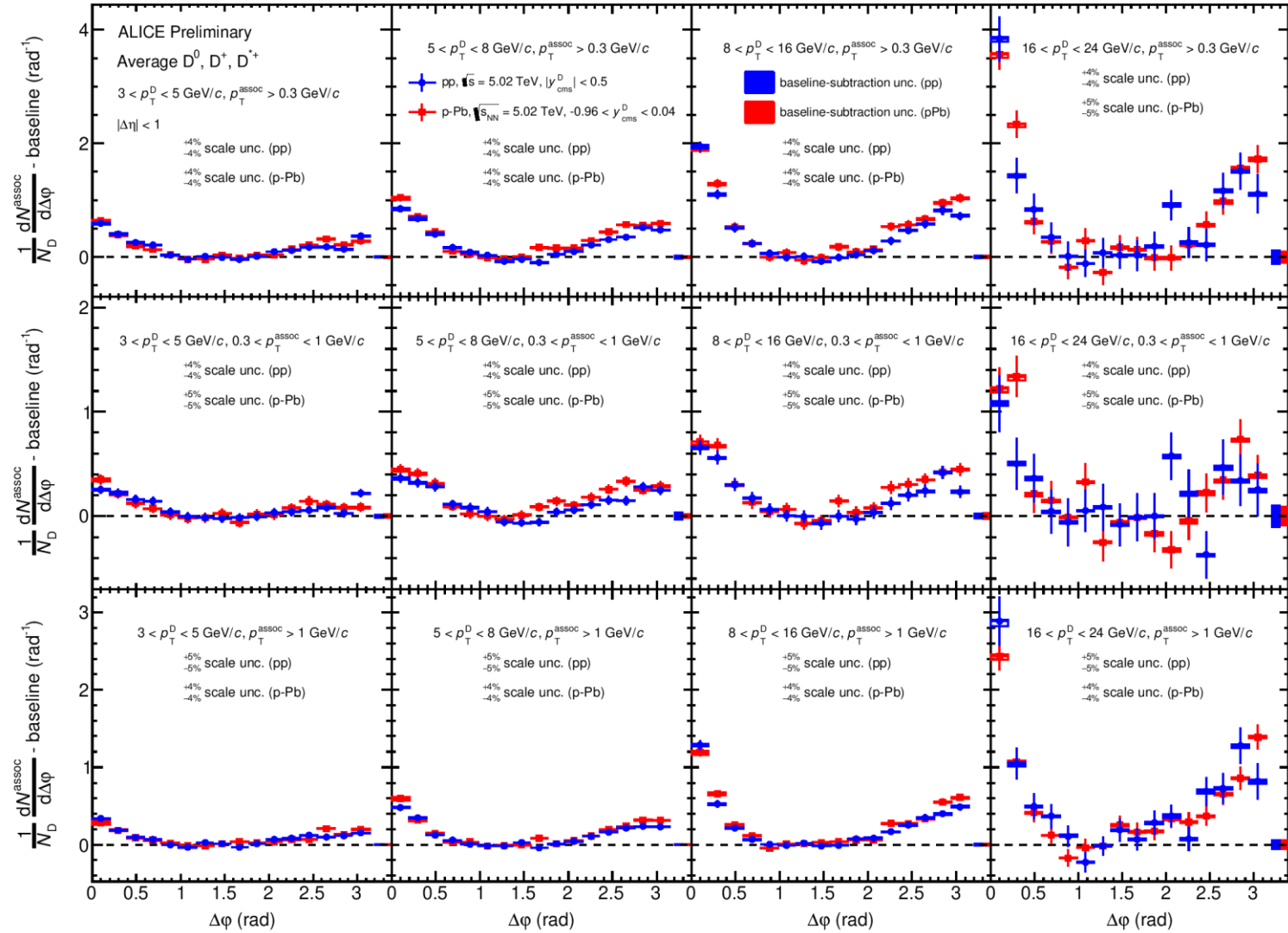
Comparison between pp and p-Pb data correlation



ALICE

D-meson p_T ranges: 3-5, 5-8, 8-16, and 16-24 GeV/c

Associated track p_T ranges: > 0.3 , > 1.0 and $0.3-1.0$ GeV/c



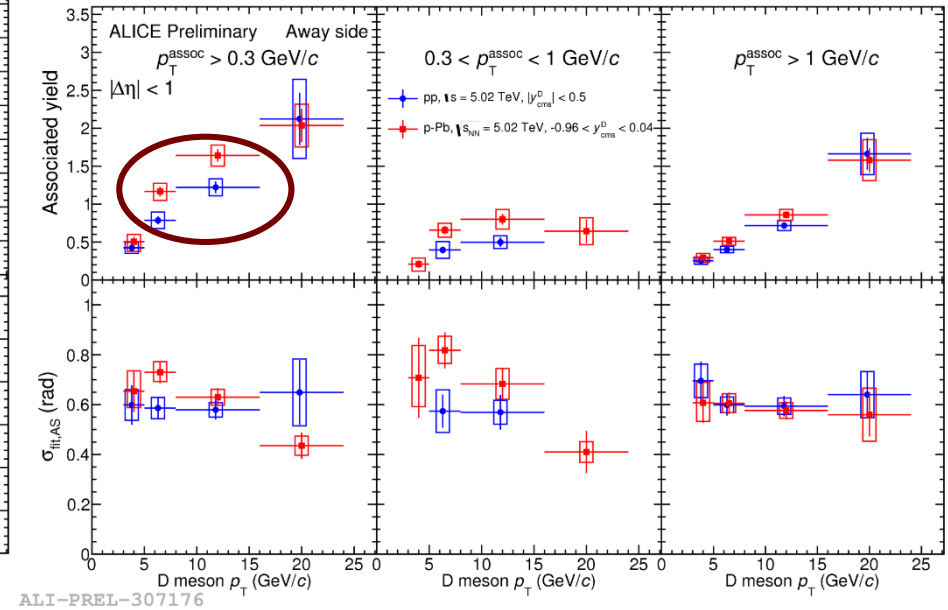
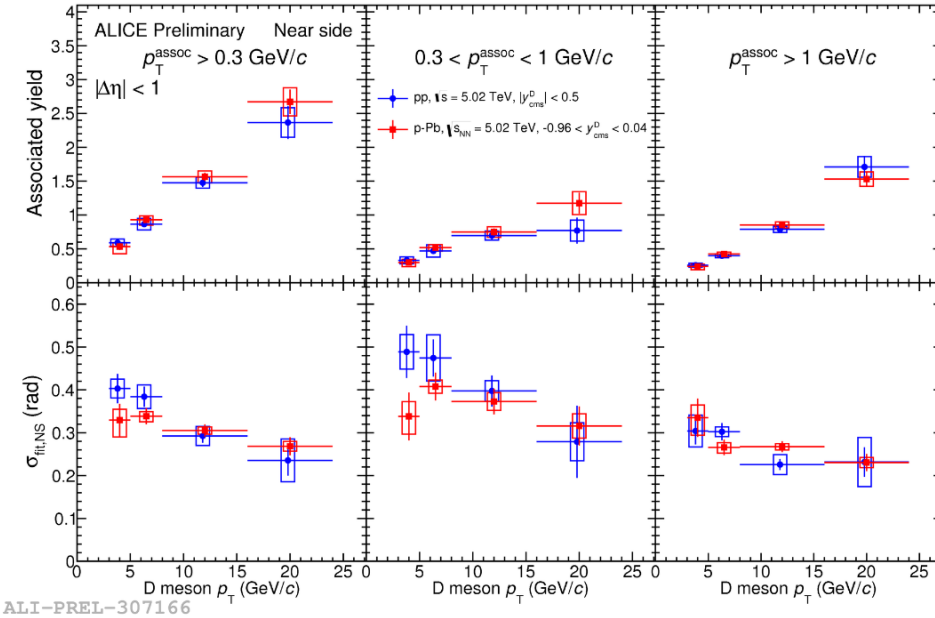
ALI-PREL-307309

Correlation distributions show a **good agreement for the NS** while for the **AS** there is an **enhancement for p-Pb data**

Comparison of NS, AS yield and sigma for pp and p-Pb data

Near Side p_T : > 0.3 , > 1.0 and $0.3-1.0$ GeV/c

Away Side p_T : > 0.3 , > 1.0 and $0.3-1.0$ GeV/c



Hints for cold nuclear matter effects \Rightarrow Enhancement of yield in AS for p-Pb data at intermediate p_T

❖ Centrality-dependent Analysis in p-Pb data

Centrality estimator: ZNA (Zero degree neutron calorimeter Anticlockwise)

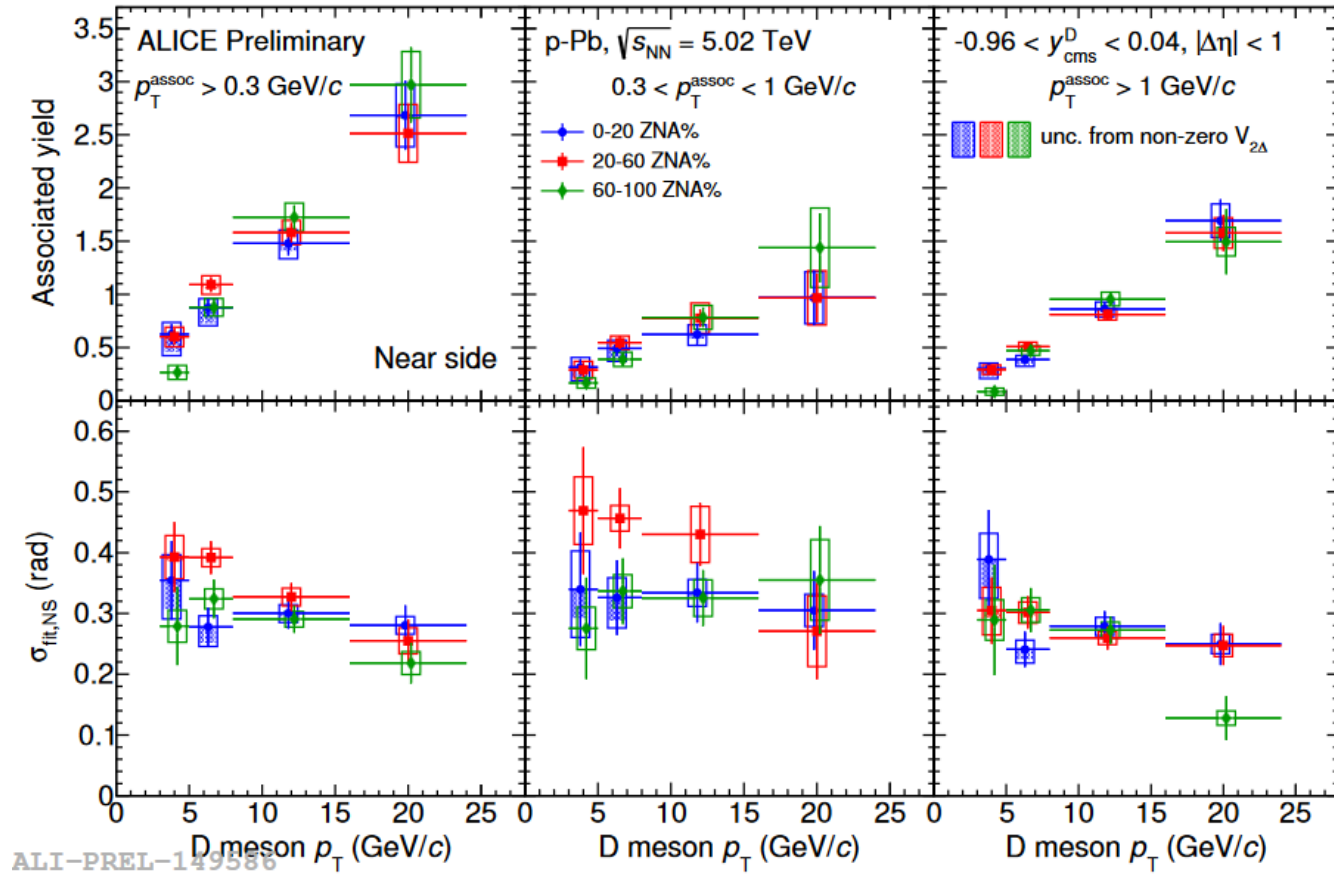
0-20% centrality \Rightarrow High Multiplicity (HM) \Rightarrow Jet contributions+ Medium effects

60-100% centrality \Rightarrow Low Multiplicity (LM) \Rightarrow Jet contributions

HM – LM \Rightarrow Medium effects \Rightarrow signature: a nonzero v_2 coefficient (elliptic flow)

Near Side p_T : $> 0.3, > 1.0$ and

$0.3-1.0$ GeV/c



Limited statistics: v_2 coefficient cannot be extracted

The results are compatible within uncertainties

- NS and AS yields and sigmas are compared with model predictions
- Charm jets are well described by PYTHIA and POWHEG within uncertainties
- pp and p-Pb data results are compared and present **some hints for cold nuclear matter effects**
- Centrality differential analysis also completed but due to **statistics limitations the v_2 coefficient cannot be extracted**
- Results obtained in different centrality classes are compatible within uncertainties

Thank You !!!

Why Sideband subtraction working?

Let assume Sign= S & Background = B_0

$$\text{Sign} = S = (S + B_0) - (B_L + B_R) * SF$$

$$SF = \frac{B_0}{B_L + B_R}$$

For correlation:

Let's assume that in an event, there are 2 D-meson (Sign), 4 D-meson (B_0) and also there are primary particles (e, mu, pi, K and p)

Assuming no detector effects

$$\text{Signal correlation} = 2 \times 1000 = 2000 = \left(\frac{dN}{d\phi}\right)_{\text{Sign}=S}$$

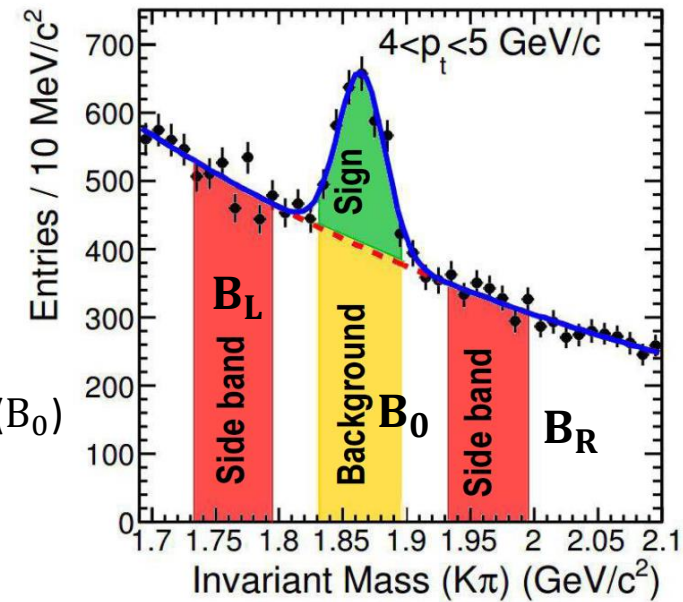
$$\left(\frac{dN}{d\phi}\right)_{S+B_0} = (4 + 2) \times 1000 = 6000$$

$$\left(\frac{dN}{d\phi}\right)_{B_L} = B_L \times 1000 \text{ and } \left(\frac{dN}{d\phi}\right)_{B_R} = B_R \times 1000$$

$$\left(\frac{dN}{d\phi}\right)_{S+B_0} - SF * \left[\left(\frac{dN}{d\phi}\right)_{B_L} + \left(\frac{dN}{d\phi}\right)_{B_R} \right] = 6000 - \frac{4}{(B_L+B_R)} * (B_L + B_R) * 1000 = 2000 = \left(\frac{dN}{d\phi}\right)_{\text{Sign}}$$

Background subtraction under the peak B_0 using the side band subtraction method will not change the result

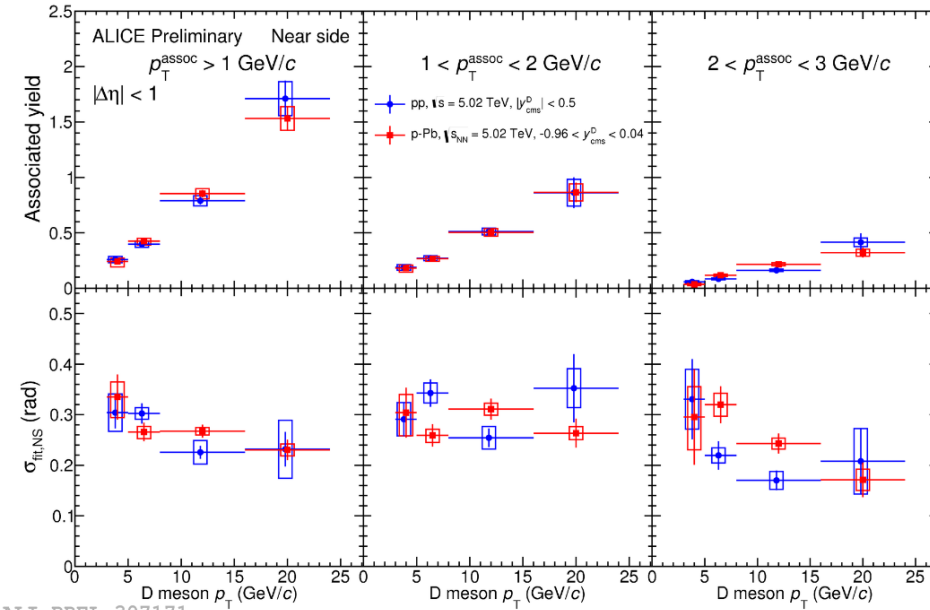
Method of Signal Extraction



$$SF = \frac{B_0}{B_L + B_R}$$

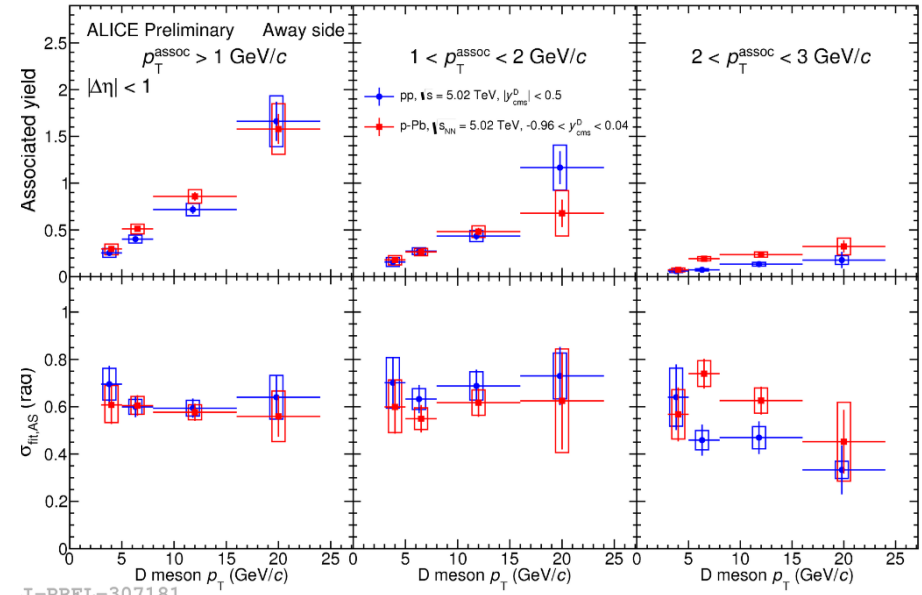
Comparison of NS, AS yield and sigma for pp and p-Pb data

Near Side p_T : > 1.0, 1.0-2.0 and 2.0-3.0 GeV/c



ALI-PREL-307171

Away Side p_T : > 1.0, 1.0-2.0 and 2.0-3.0 GeV/c



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Hints for the cold nuclear matter effect \Rightarrow Enhancement of yield in AS for p-Pb data at intermediate p_T