Probing small systems with heavy quarks with ALICE at the LHC

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Outline

- Why study small systems with heavy quarks?
- Physical observables
- ALICE detector
- Results
  - D-meson production as function of multiplicity
  - D mesons in Jets
  - D mesons - hadron correlations
  - Heavy-flavour electron - hadron correlations
- Conclusion

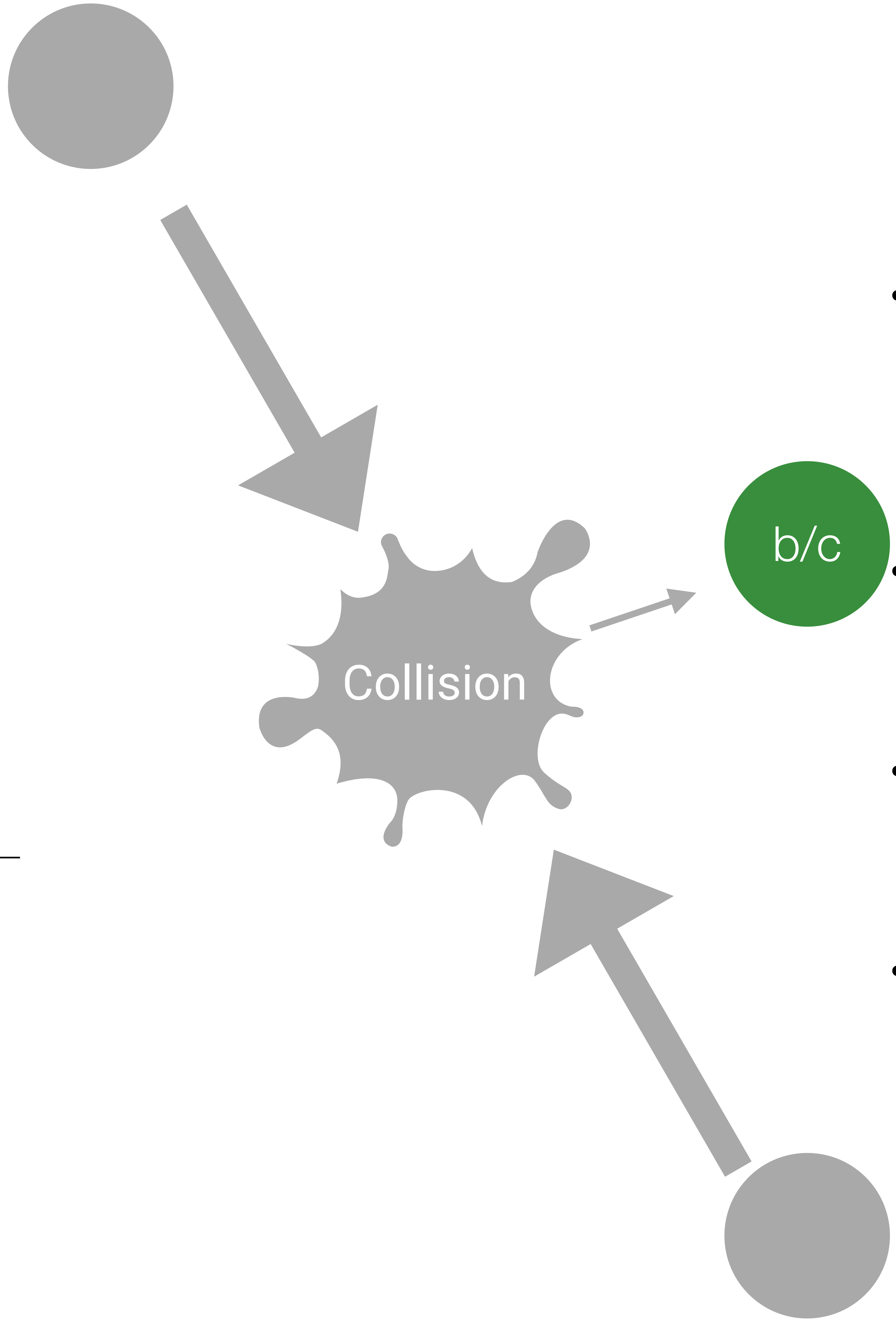
Why study small systems with heavy quarks?

Baseline for Pb-Pb collisions

- b and c quarks: ideal probes to study the QGP formed in Pb-Pb collisions

Constrain Cold Nuclear Matter (CNM) effects

- Shadowing or gluon saturation
- Parton transverse momentum broadening and cold nuclear matter parton energy loss



Additional information accessed with correlations and jets

- Jet production (and suppression) and jet properties
- Heavy-quark fragmentation in different collision systems
- Heavy-quarks production mechanism
- Elliptic flow and collective-like effects?

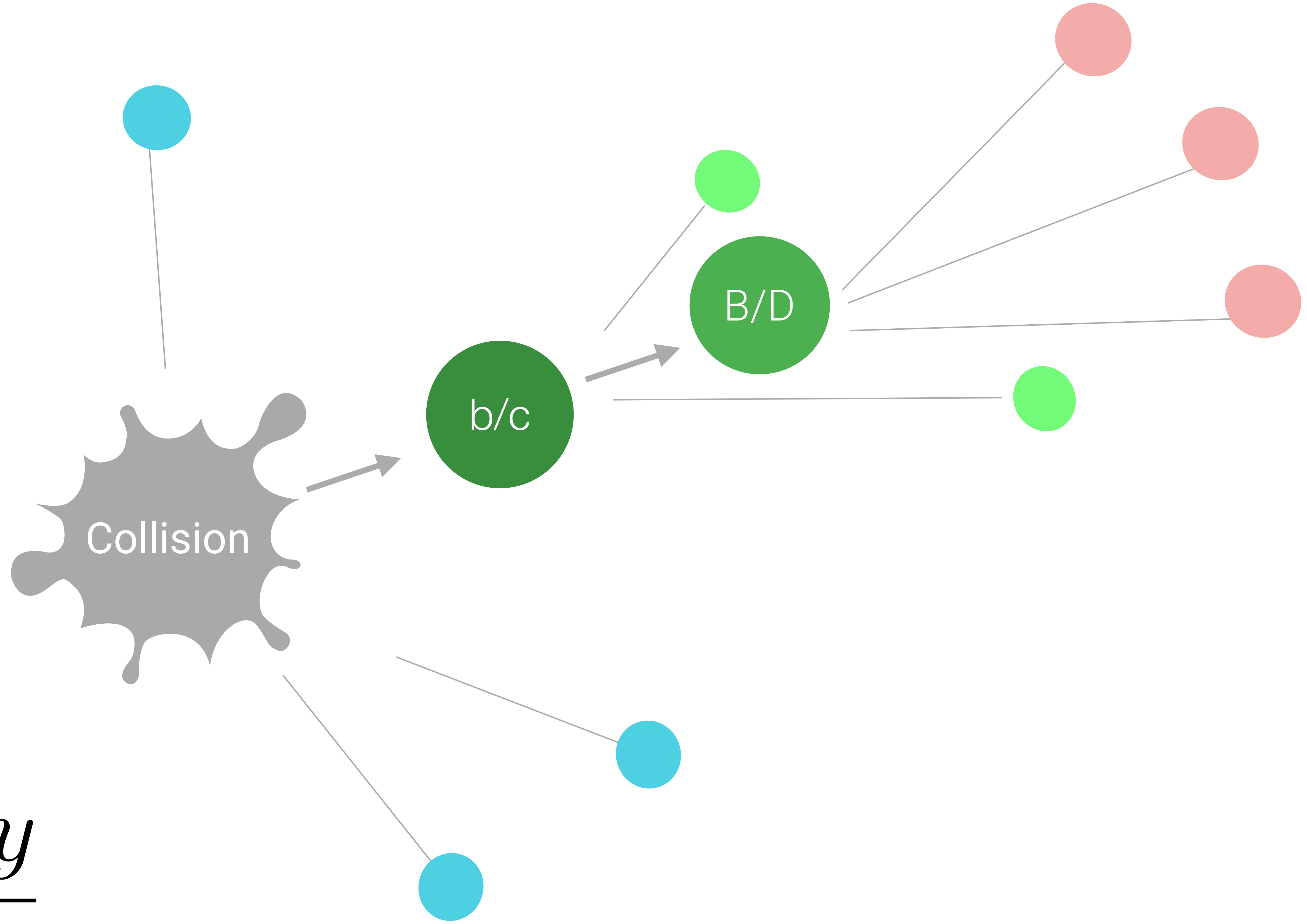
Physical observables

- **Nuclear modification factor** of fully reconstructed D mesons and of leptons from heavy-flavour decays

Modification in p-Pb with respect to pp collisions

Compare the production as function of multiplicity

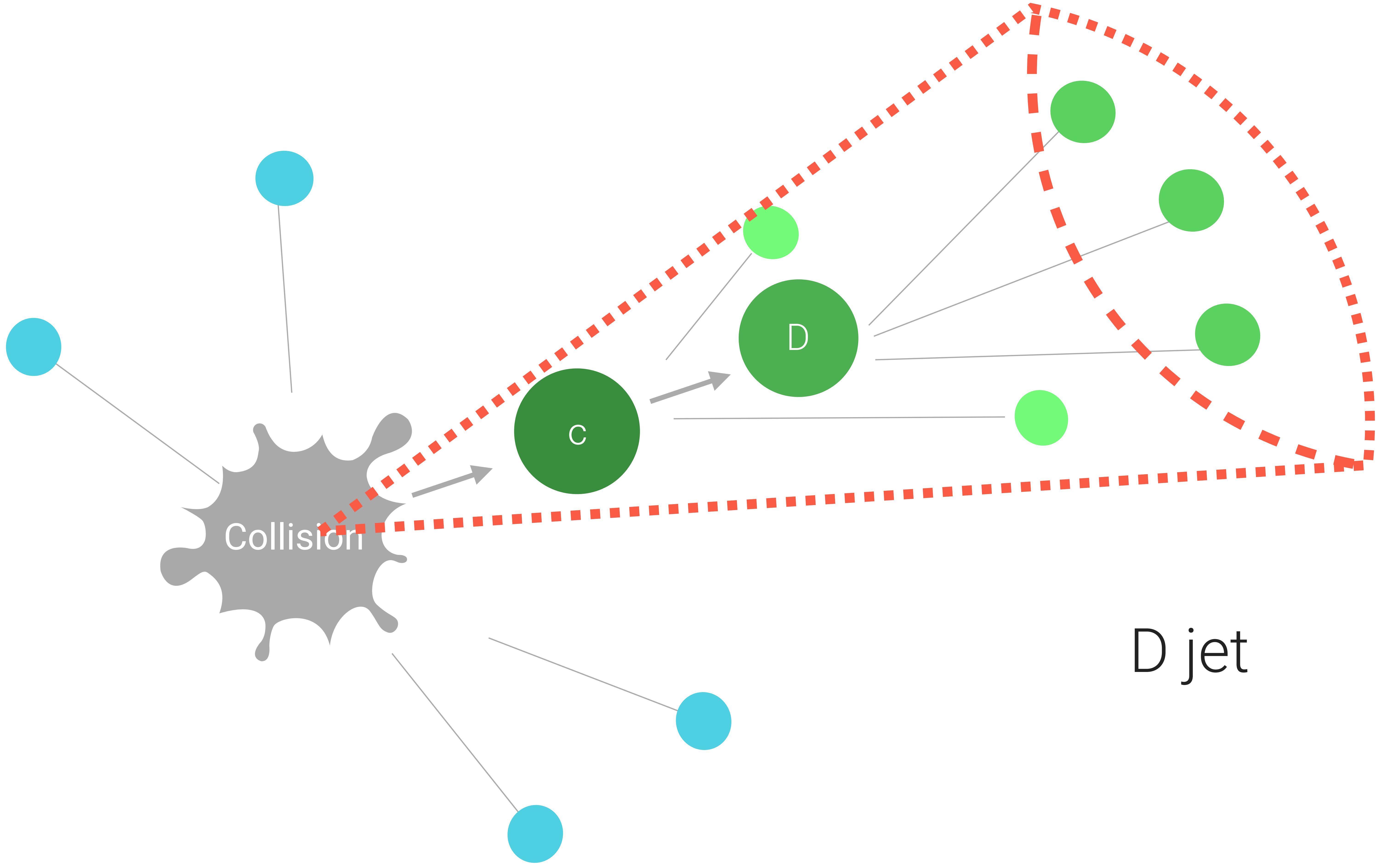
$$R_{pPb} = \frac{1}{A}\frac{\mathrm{d}^2\sigma_{pPb}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{\mathrm{d}^2\sigma_{pp}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}$$



Physical observables

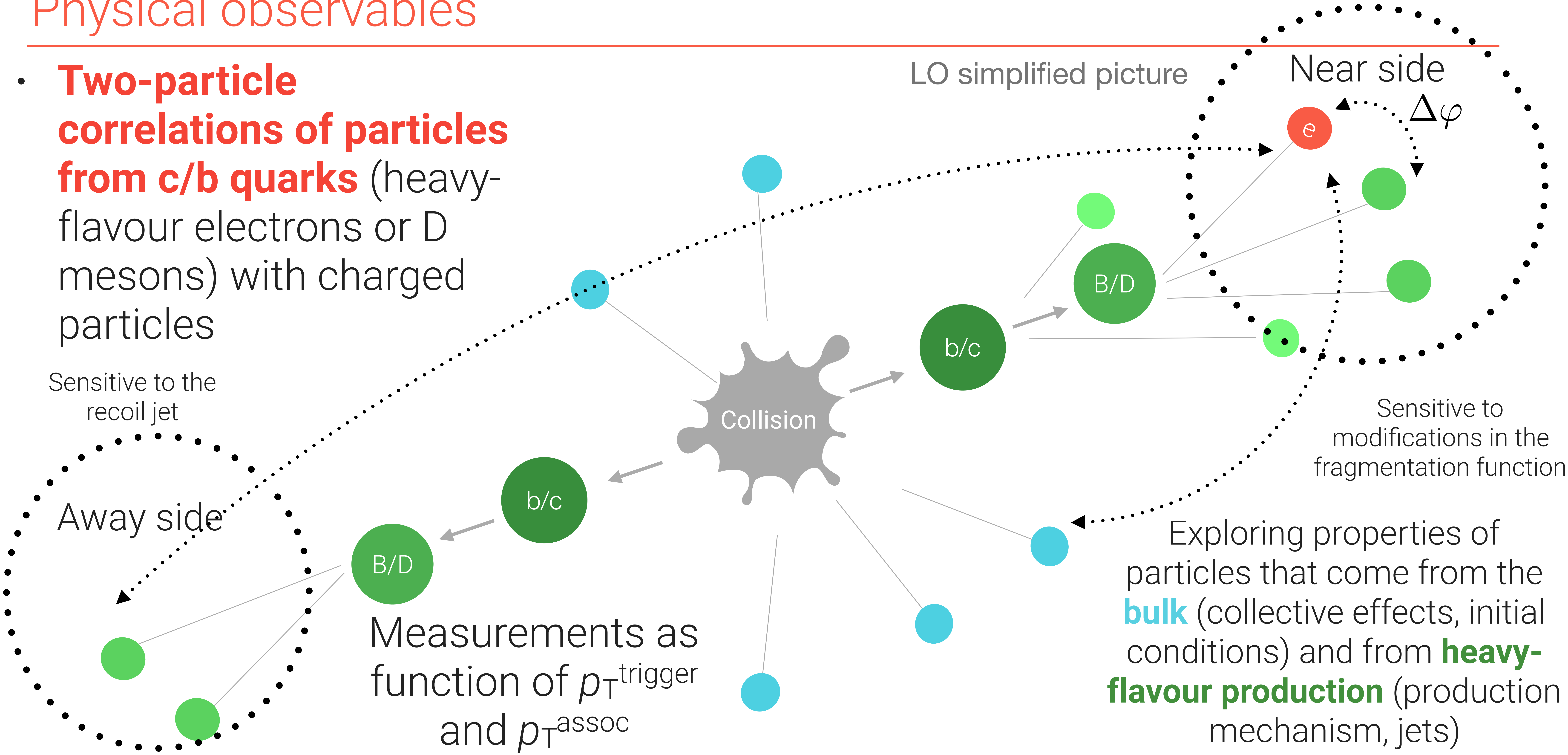
- **Heavy-flavour jets** : charged jets tagged by fully reconstructed D mesons

Access to heavy-quark fragmentation



Physical observables

- **Two-particle correlations of particles from c/b quarks** (heavy-flavour electrons or D mesons) with charged particles



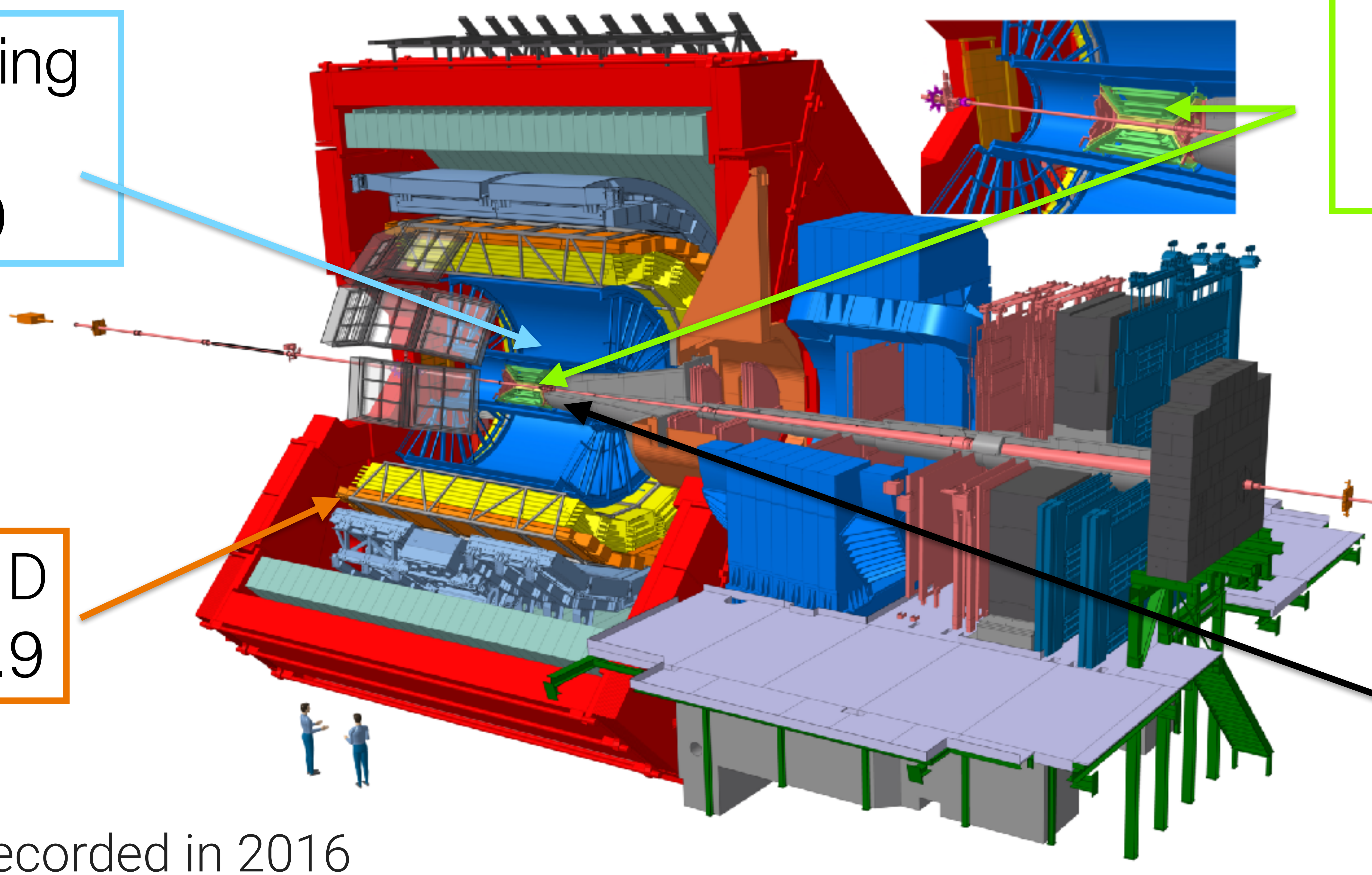
Measurements as function of $p_{\mathrm{T}}^{\mathrm{trigger}}$ and $p_{\mathrm{T}}^{\mathrm{assoc}}$

Exploring properties of particles that come from the **bulk** (collective effects, initial conditions) and from **heavy-flavour production** (production mechanism, jets)

ALICE detector

TPC: tracking and PID
$|\eta| < 0.9$

ITS: vertexing and tracking
$|\eta| < 0.9$



TOF: PID
$|\eta| < 0.9$

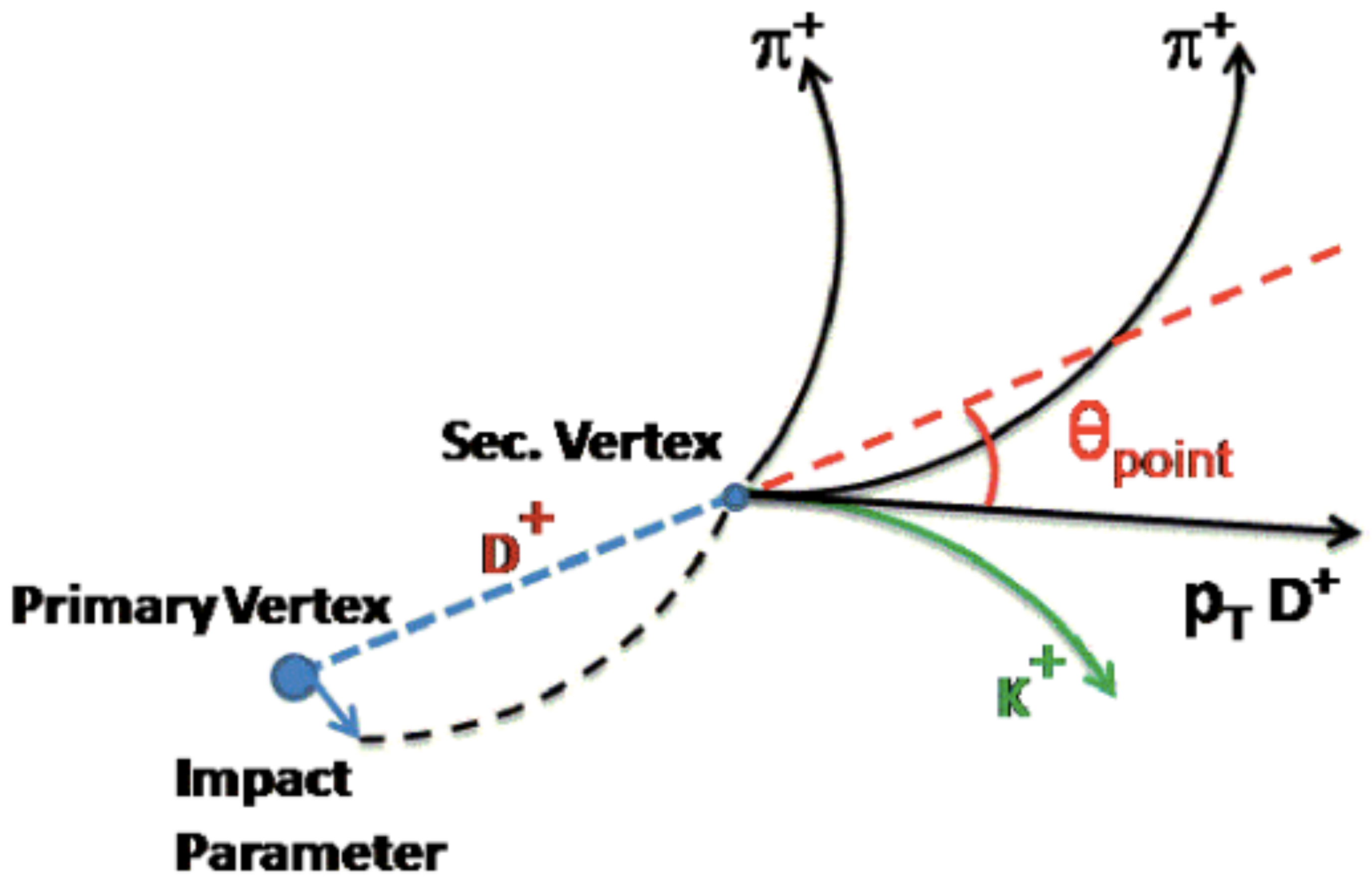
V0s and ZDCs: trigger and multiplicity/ centrality determination

Dataset:
p-Pb 5.02 TeV recorded in 2016
~ 600M MB events (x6 more events than Run 1)
Lint= ~290 μb^{-1}

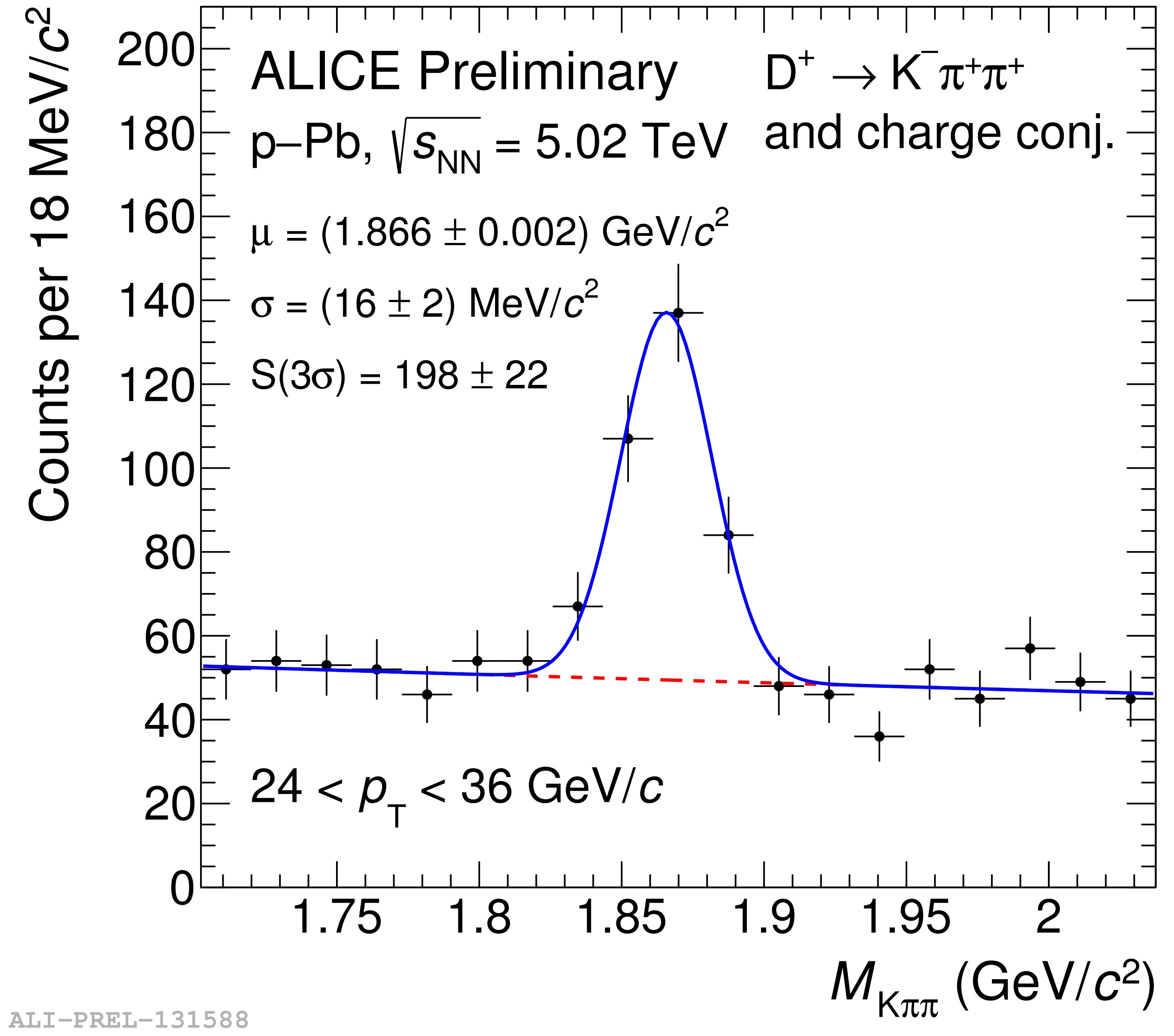
D-meson reconstruction

- ALICE can identify D mesons using fully reconstructed hadronic decay

meson	M (GeV/c^2)	$c\tau$ (μm)	decay	BR (%)
D^0 ($c\bar{u}$)	1.865	123	$K^-\pi^+$	3.93
D^+ ($c\bar{d}$)	1.870	312	$K^-\pi^+\pi^+$	9.46
D^{*+} ($c\bar{d}$)	2.010	Γ = 83.3 KeV	$D^0(K^-\pi^+)\pi^+$	67.7 x 3.93
D^+_s ($c\bar{s}$)	1.968	150	$\Phi(K^-K^+)\pi^+$	2.27



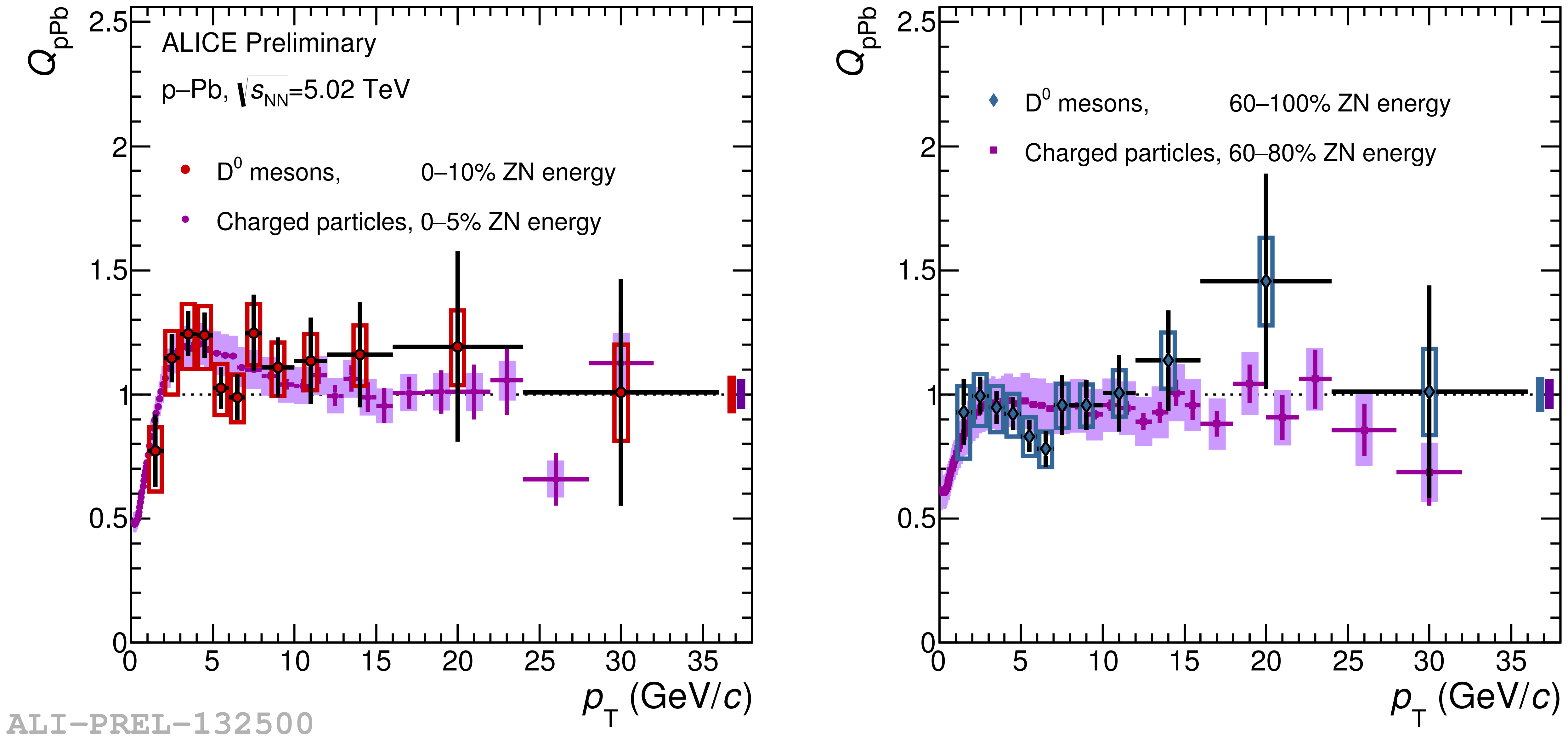
- The signal is extracted from invariant-mass distributions
  - Secondary vertices are few hundred μm displaced with respect to the primary vertex
  - Topological selections and PID are performed in order to reduce background



D-meson production as function of centrality

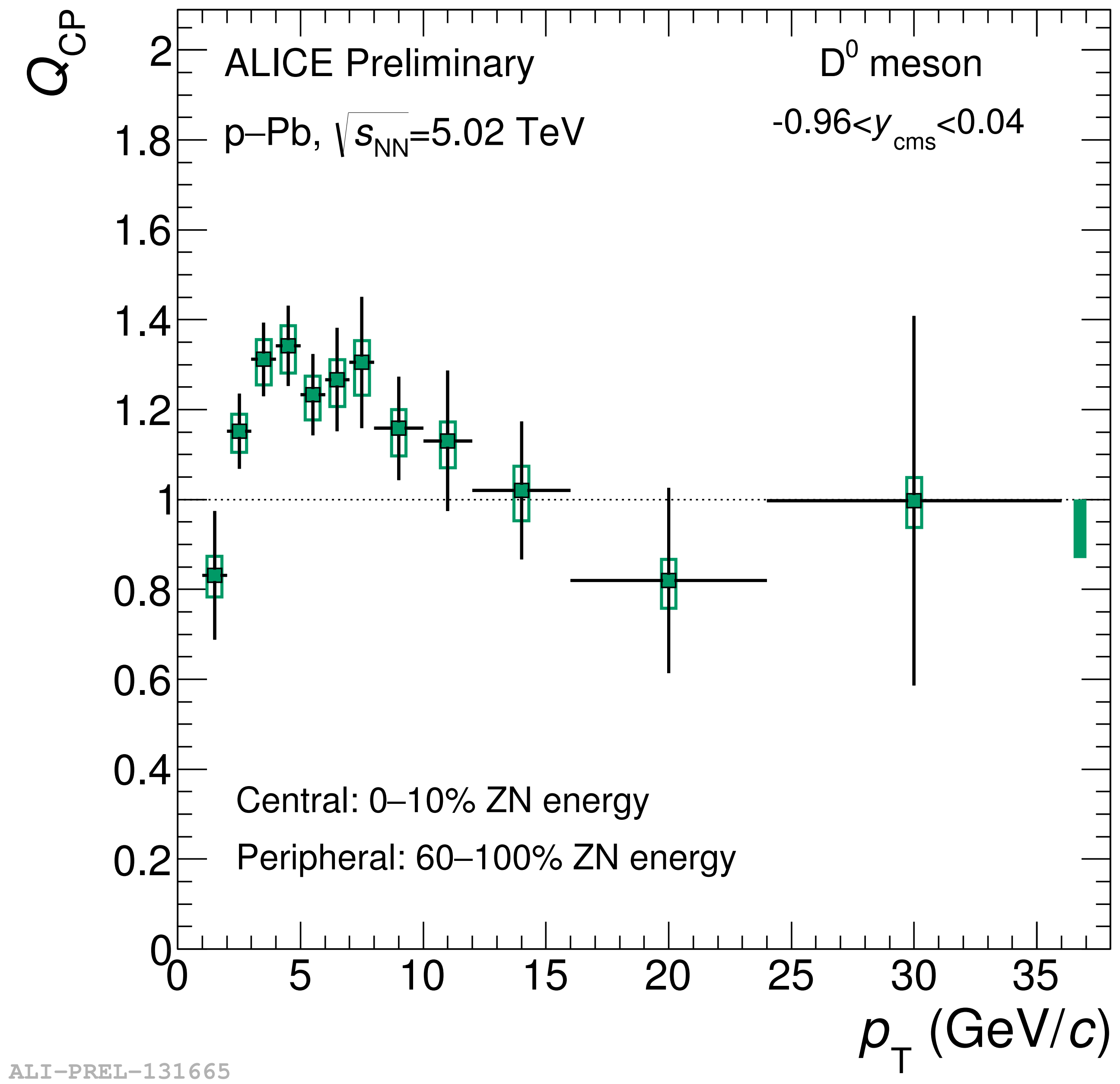
$$Q_{\mathrm{pPb}}^{\mathrm{cent}} = \frac{(\mathrm{d}^2 N^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)^{\mathrm{cent}}_{\mathrm{pPb}}}{\langle T_{\mathrm{pPb}}\rangle^{\mathrm{cent}} \times (\mathrm{d}^2\sigma^{\mathrm{prompt\,D}}_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)}$$

$$Q_{\mathrm{CP}} = \frac{(\mathrm{d}^2 N^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)^{0-10}_{\mathrm{pPb}}/\langle T_{\mathrm{pPb}}\rangle^{0-10}}{(\mathrm{d}^2 N^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)^{60-100}_{\mathrm{pPb}}/\langle T_{\mathrm{pPb}}\rangle^{60-100}}$$



D^0 Q_{pPb} agrees with charge-particles Q_{pPb}

Slightly different centrality ranges

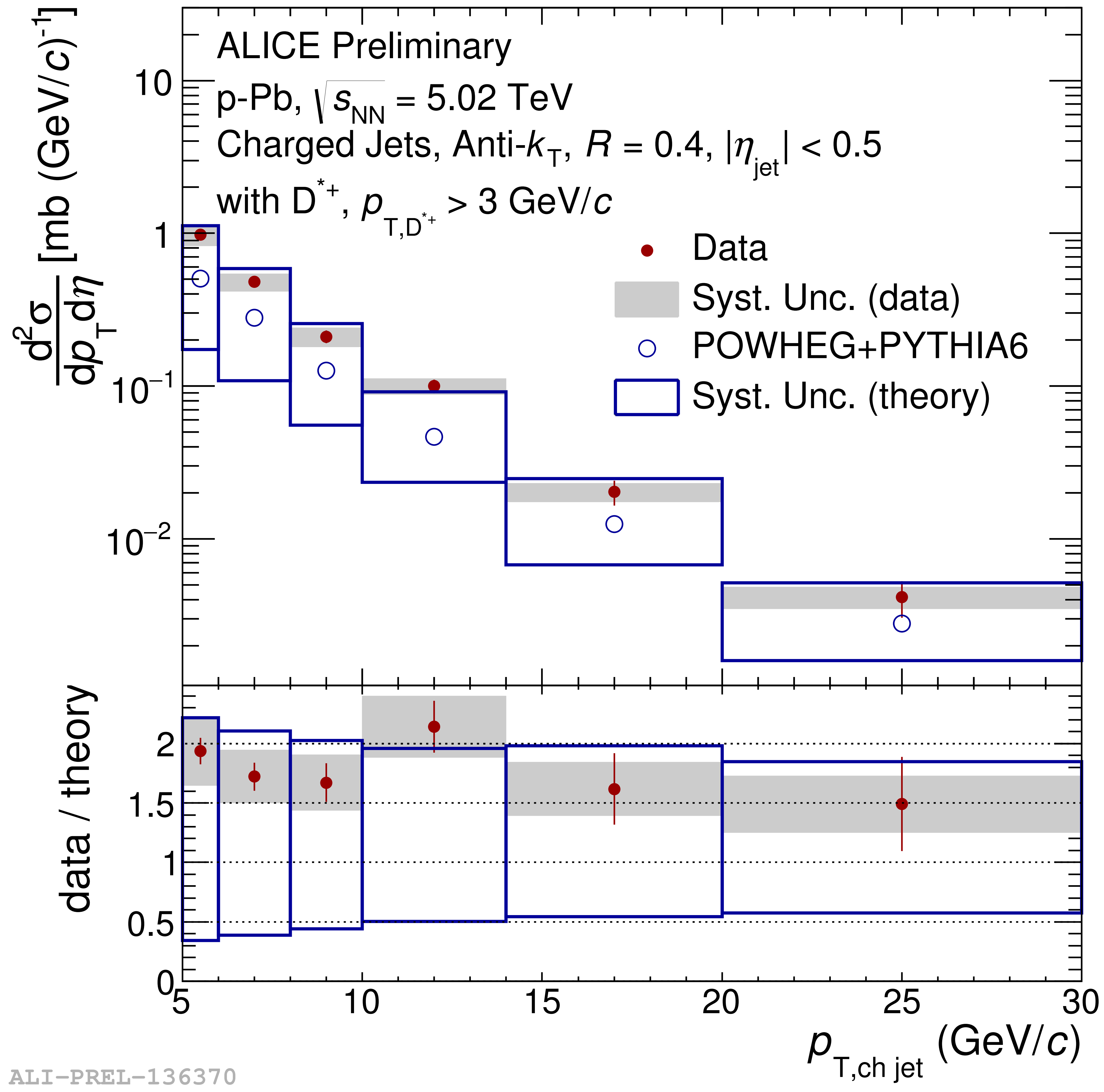


Hint of Q_{CP} >1 in 3-8 GeV/c with 1.7σ

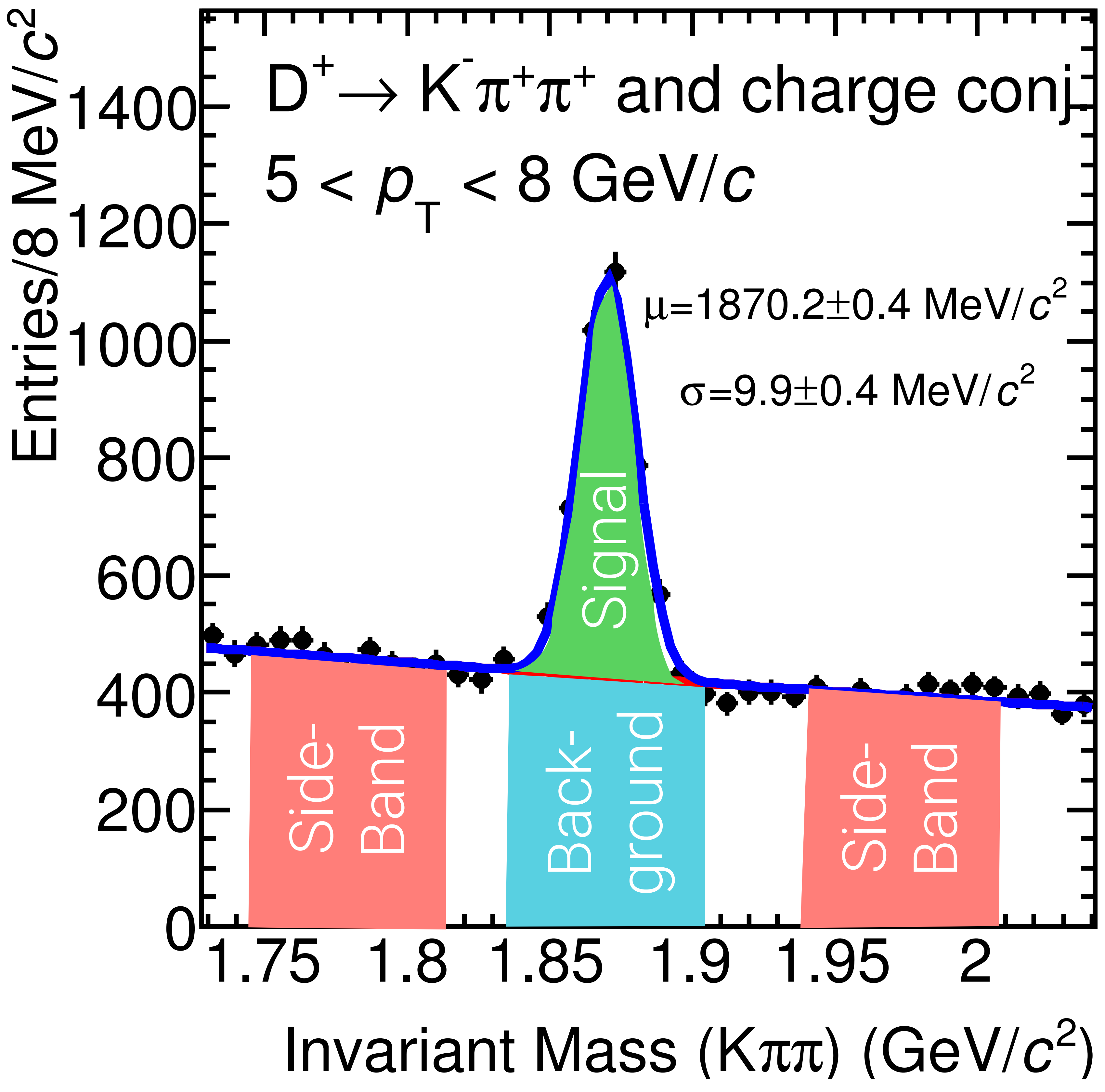
- Is it an Initial or a final state effect?
- Possible influence of radial flow on heavy-flavour hadrons in p-Pb collisions

D mesons in jets

- Charged jets reconstructed with FastJet (anti-k_T)
- D meson required to be one of the jet constituents
- Down to jet p_T = 5 GeV/c
- Data is reproduced by POWHEG+PYTHIA 6 within uncertainties



D meson - hadron correlations: method



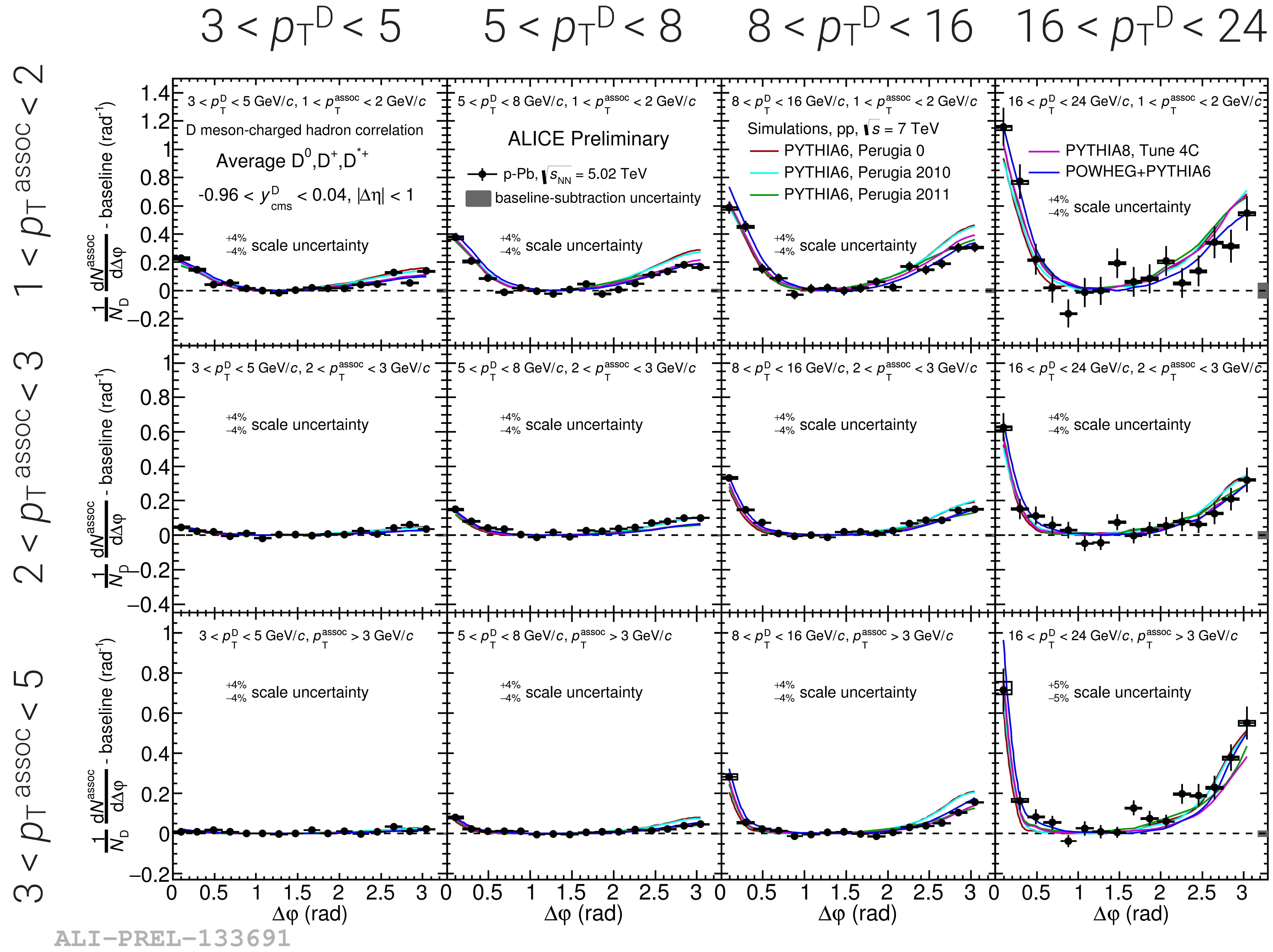
Run 1 Results: Eur. Phys. J. C 77 (2017) 245

- **Sideband region correlation** is normalized to the **background contribution** under the signal. Then they are subtracted from **signal region** + **background contribution** correlations

- Event mixing (limited acceptance and inhomogeneity effects)
- Corrected by reconstruction efficiency (D and hadron)
- B →D feed down subtracted using fit templates

D mesons - hadron correlations in p-Pb

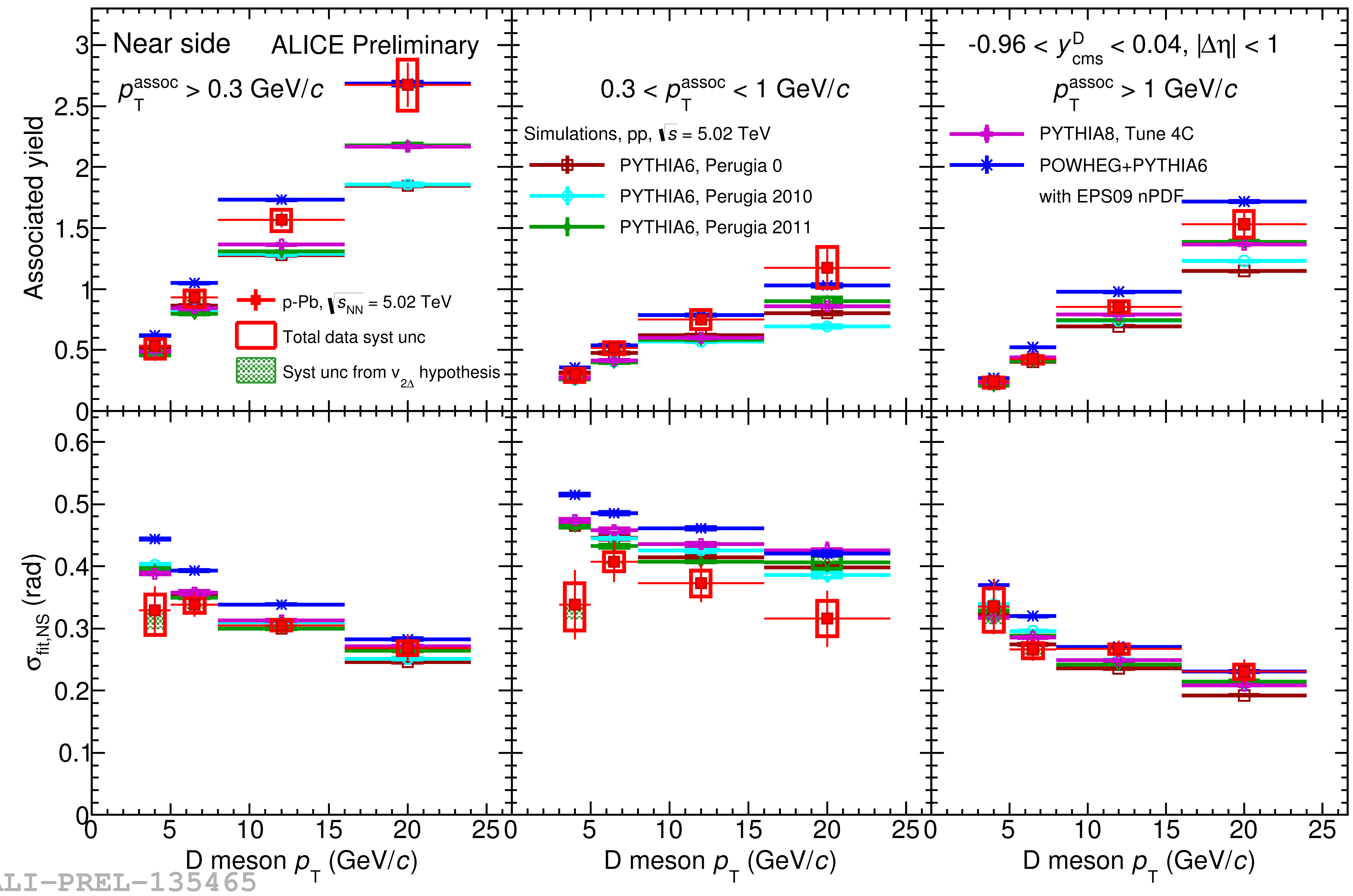
- Results in different D meson (trigger) and hadron (associate) p_T ranges
- New p-Pb data sample offers better precision when compared to Run 1(~ 6x more statistics).
  - Higher $p_T{}^D$ and $p_T{}^{assoc}$ accessible
  - First quantitative access to away side
- The correlation function of D-h in p-Pb collisions is described by PYTHIA tunes and POWHEG + PYTHIA within uncertainties



D mesons - hadron correlations: Near side yields

- Near side yields (obtained using gaussian fits) described by models within uncertainties.
- Similar trend with angular distributions and momentum ordering of NS associated particles in data and simulations.

$p_T^{assoc} > 0.3$ GeV/c $\quad 0.3 < p_T^{assoc} < 1$ GeV/c $\quad p_T^{assoc} > 1$ GeV/c



Heavy-flavour electron identification

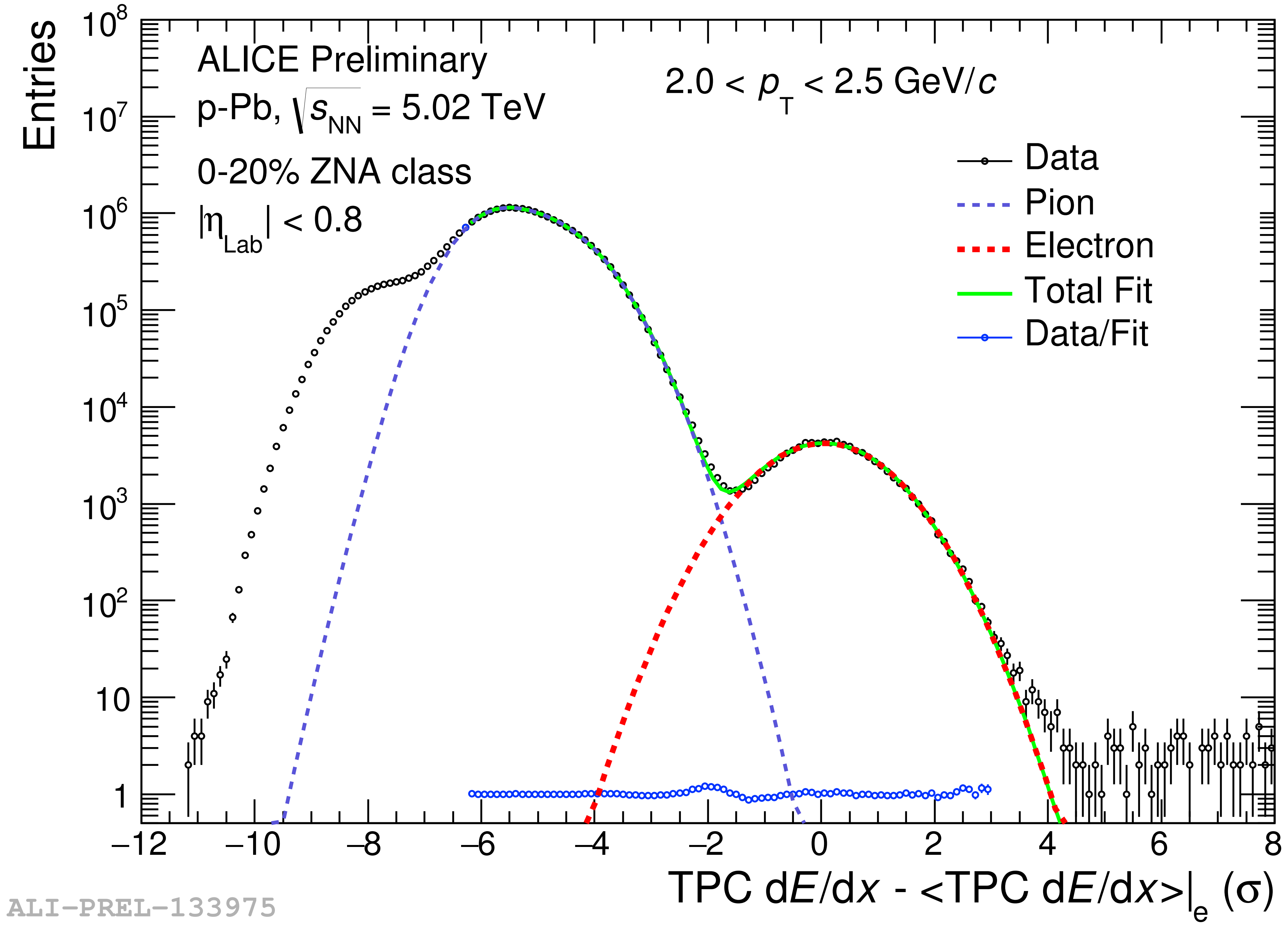
- Heavy-flavour hadrons (B and D) semi-leptonic decays channels (B.R. ~10%)

$$\mathrm{D} \to e\ \mathrm{X}$$

$$\mathrm{B} \to e\ \mathrm{X}$$

- Electrons are identified using the energy loss in the TPC and Time Of Flight (TOF)

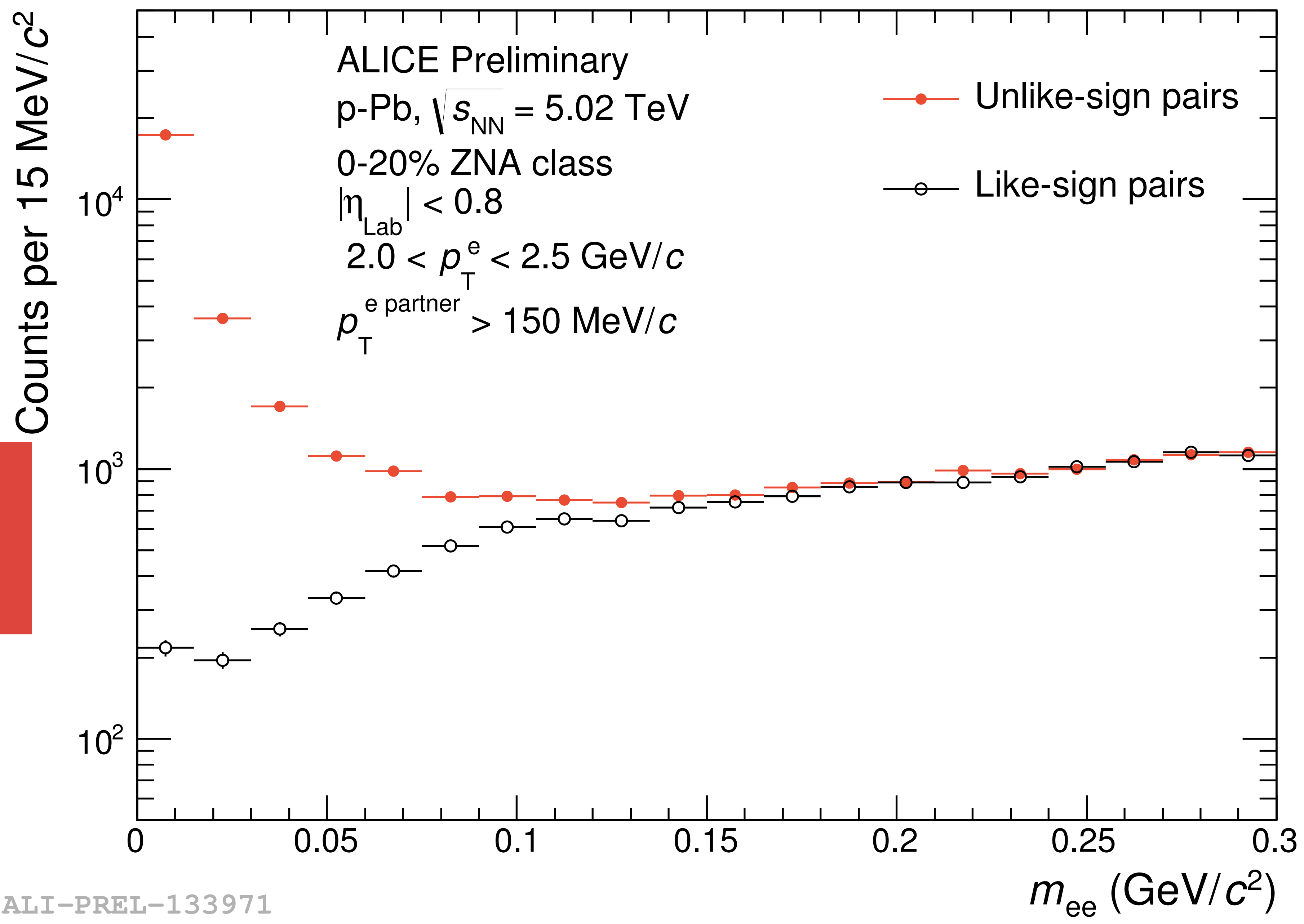
- Electrons from the other main sources are subtracted

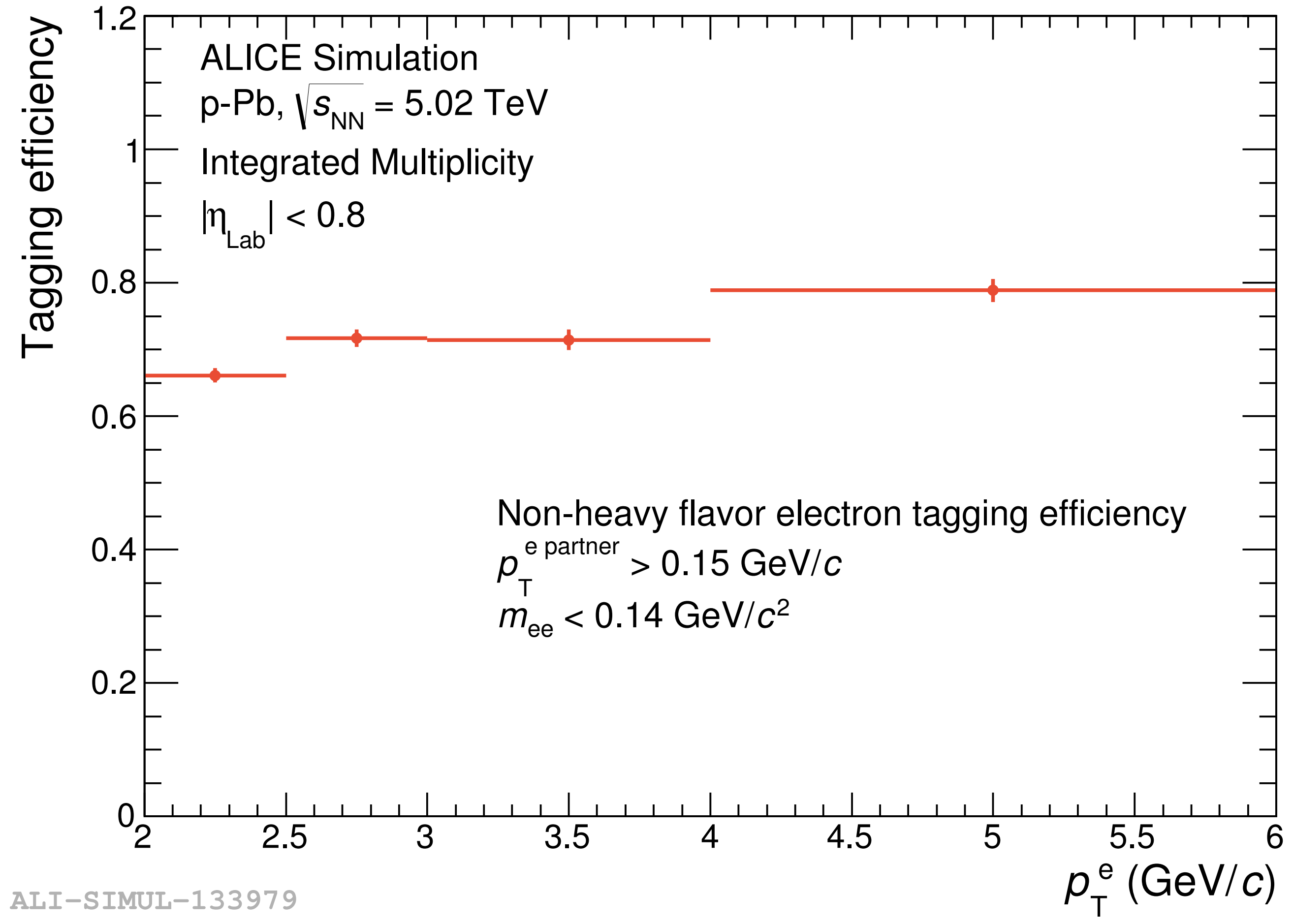


Non heavy-flavour electrons subtraction

- Correlation function is obtained by subtracting the background electrons from the inclusive one

Inclusive e-h	-	e from π^0, η, γ (photonic): Background e-h	=	e from B and D: HFe-h





- **Photonic-electron tagging method:** Unlike sign - Like sign pairs with $m(e^+,e^-) < 140\ \mathrm{MeV}/c^2$ are identified as background

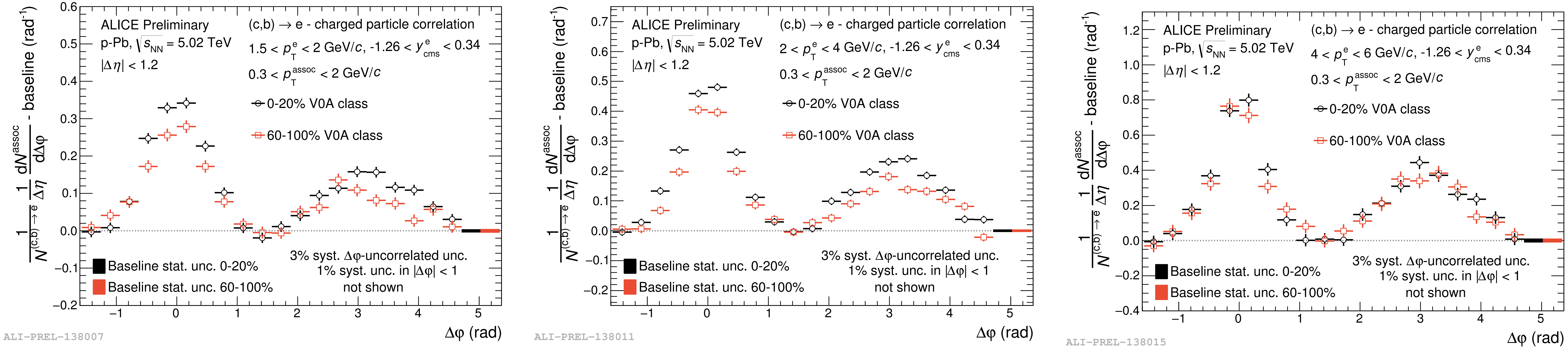
Main background

$$\pi^0(\rightarrow \gamma\gamma) \rightarrow e^+e^-\gamma$$

$$\eta(\rightarrow \gamma\gamma) \rightarrow e^+e^-\gamma$$

HFe - hadron correlations in p-Pb as function of multiplicity

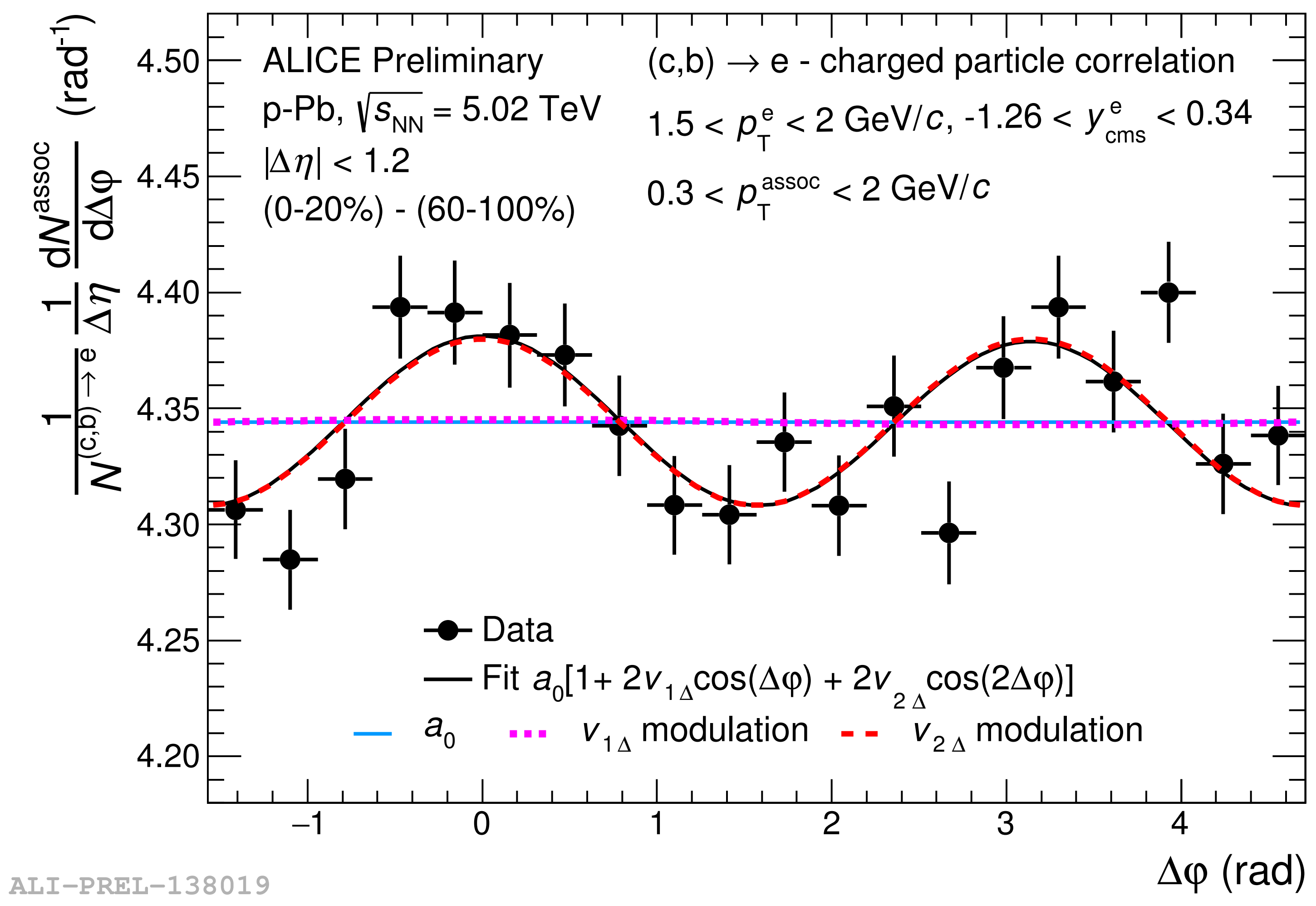
- Looking for multiplicity dependence and possible double-ridge effect (v_2 like) in the heavy-flavor sector in p-Pb collisions.



- Near and Away side modification from Low Multiplicity to High Multiplicity

HFe - hadron correlations in p-Pb as function of multiplicity

- High multiplicity correlation functions are subtracted by the low multiplicity ones to remove the jet component. Assumption: jet correlation function is not modified from low to high multiplicity collisions



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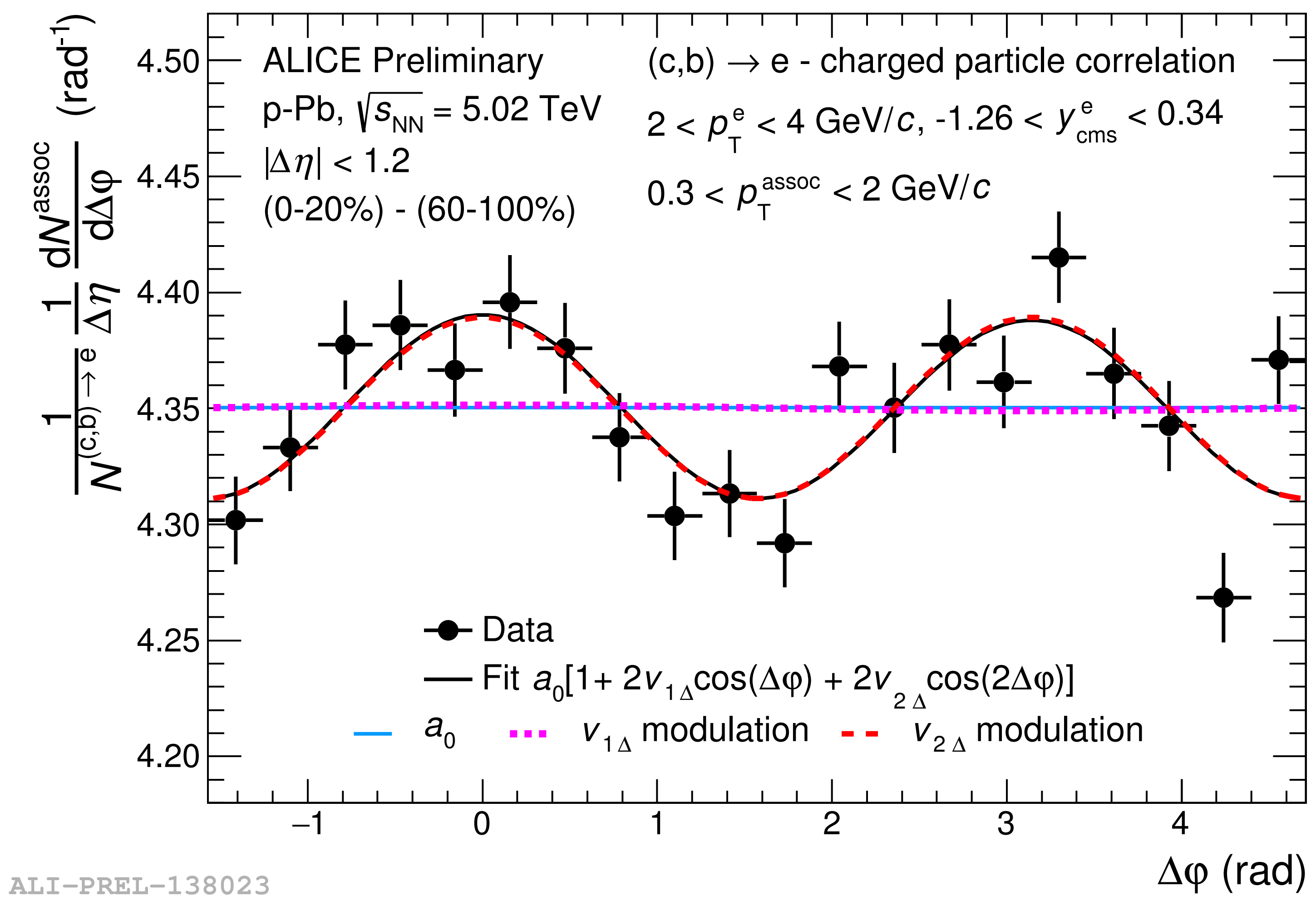

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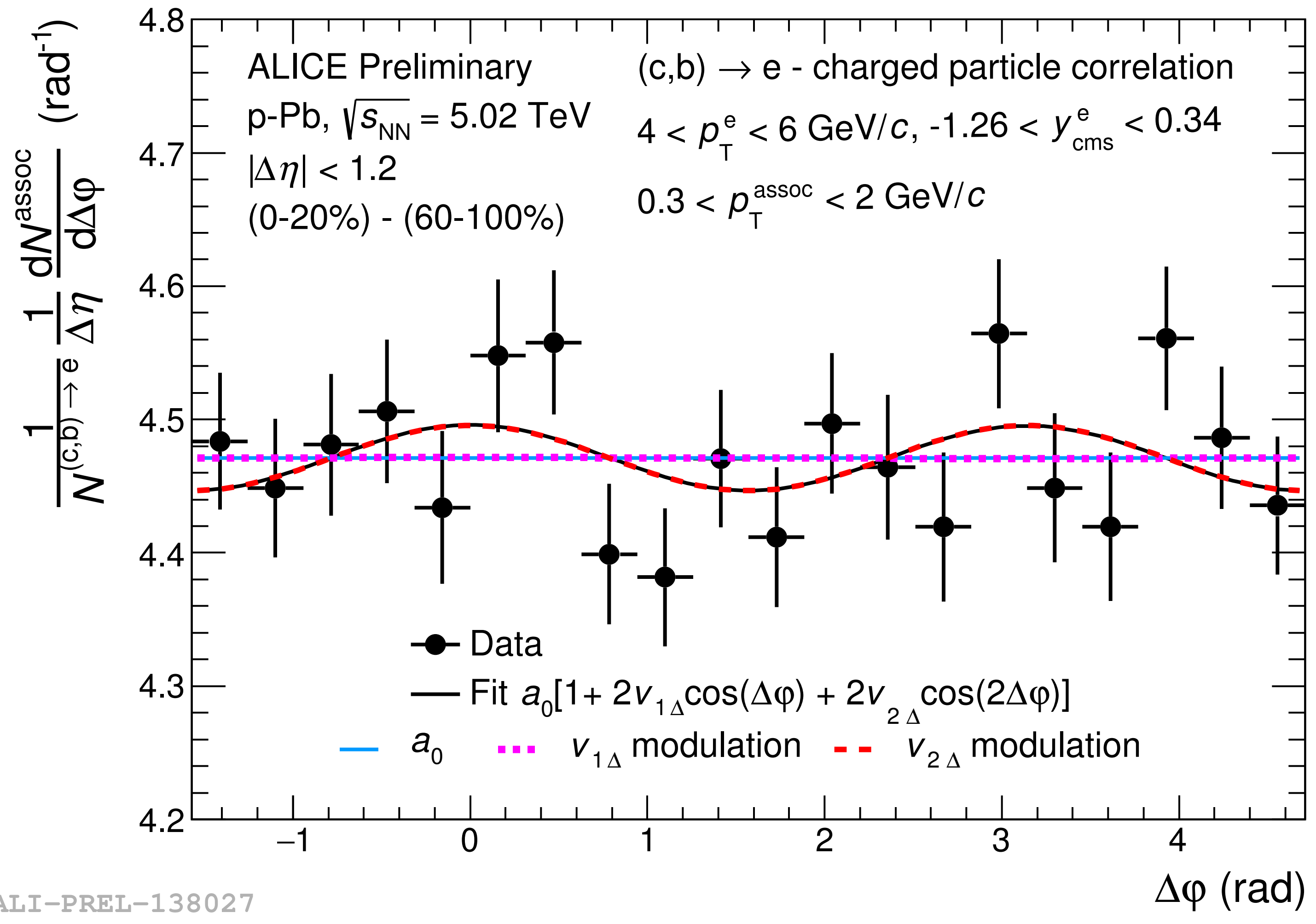
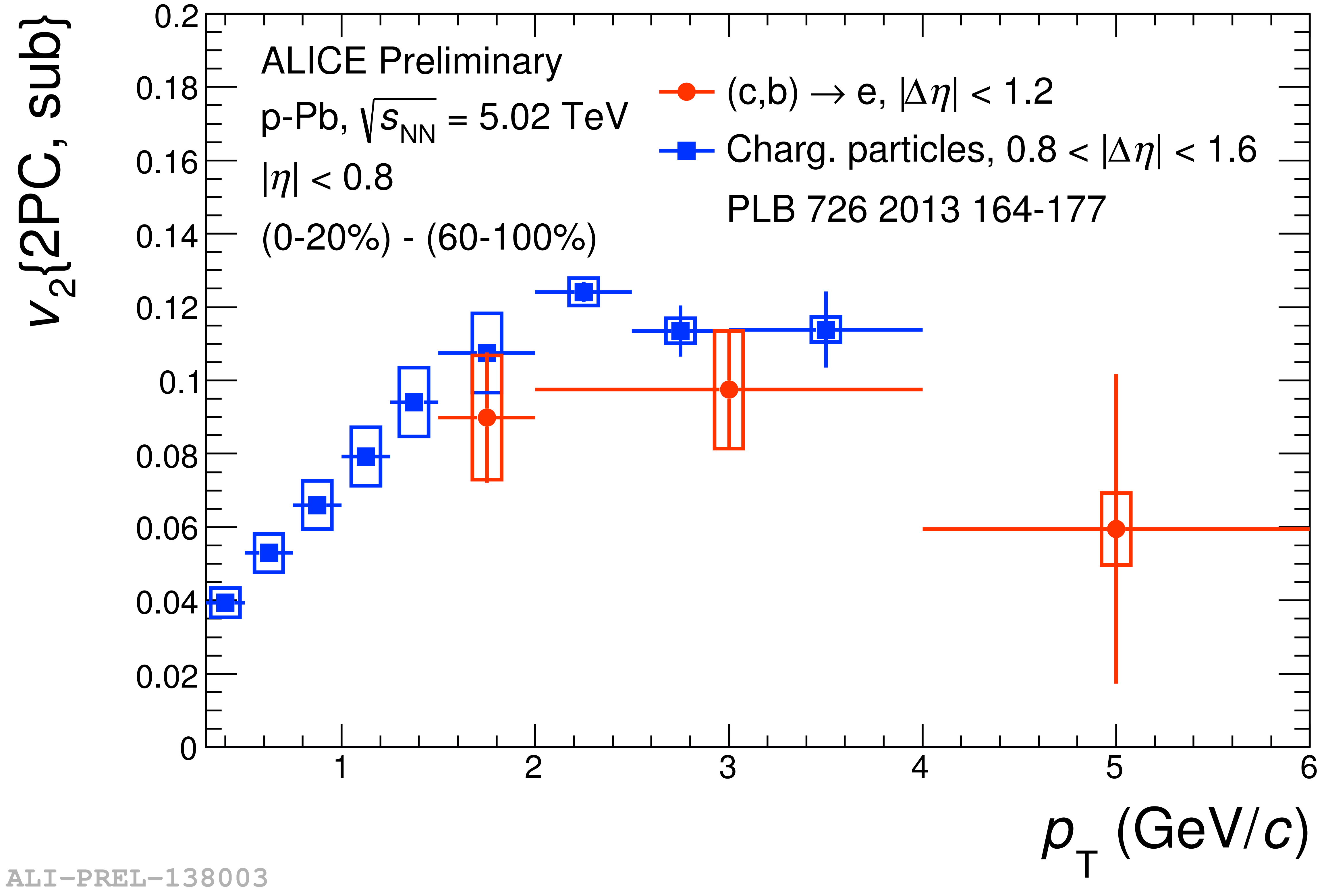


ALI-PREL-138027

v_2^{HFe} {2PC, sub} in p-Pb

- First measurement of heavy-flavour electron v_2^{HFe} {2PC, sub} in p-Pb collisions
- Effect is qualitatively similar to the one observed in the light flavor sector
- Results show a positive v_2^{HFe} (2PC,sub) for electrons with $1.5 < p_T < 4$ GeV/c
- Significance of 3.7σ for $1.5 < p_T < 2$ GeV/c and 4.3σ for $2 < p_T < 4$ GeV/c



Conclusions

- D-meson production: D^0 Q_{CP} shows a hint of enhancement and the D^0 Q_{pPb} in different centrality bins is in qualitative agreement with the charged particle Q_{pPb}.
- D-meson in jets: measurements of jets that contain a D-meson cross section down to 5 GeV/c. The results are compatible with POWHEG+PYTHIA 6.
- D meson - charged particles correlations: new and more precise measurements compared to Run 1. Near side and away side yields are qualitatively described by PYTHIA and POWHEG+PYTHIA expectation
- **Evidence of positive v_2^{HFe} in high-multiplicity p-Pb collisions from the analysis of azimuthal correlations of heavy-flavour decay electrons with charged particles**

Thank you!

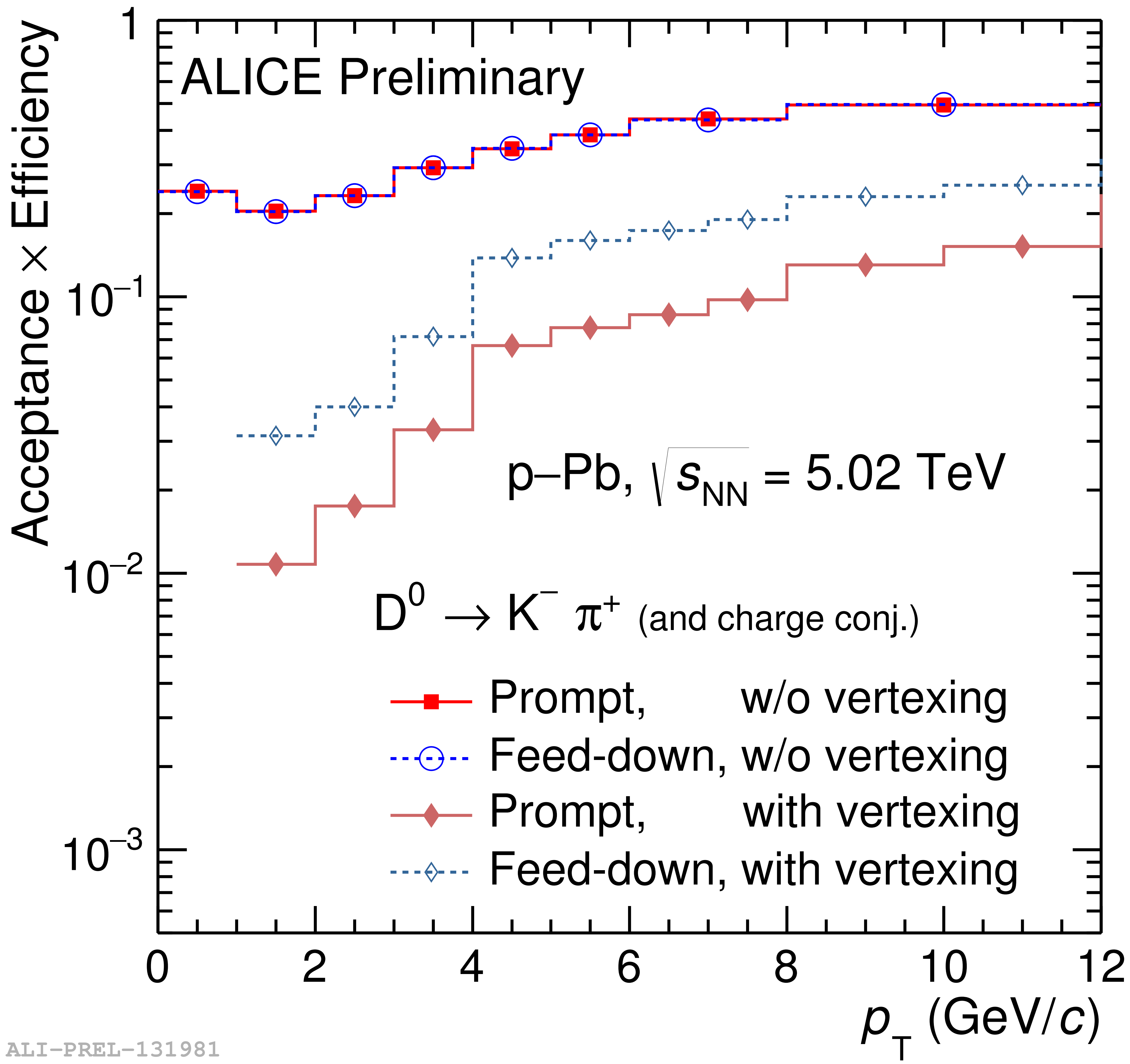
Acknowledgement

FAPESP

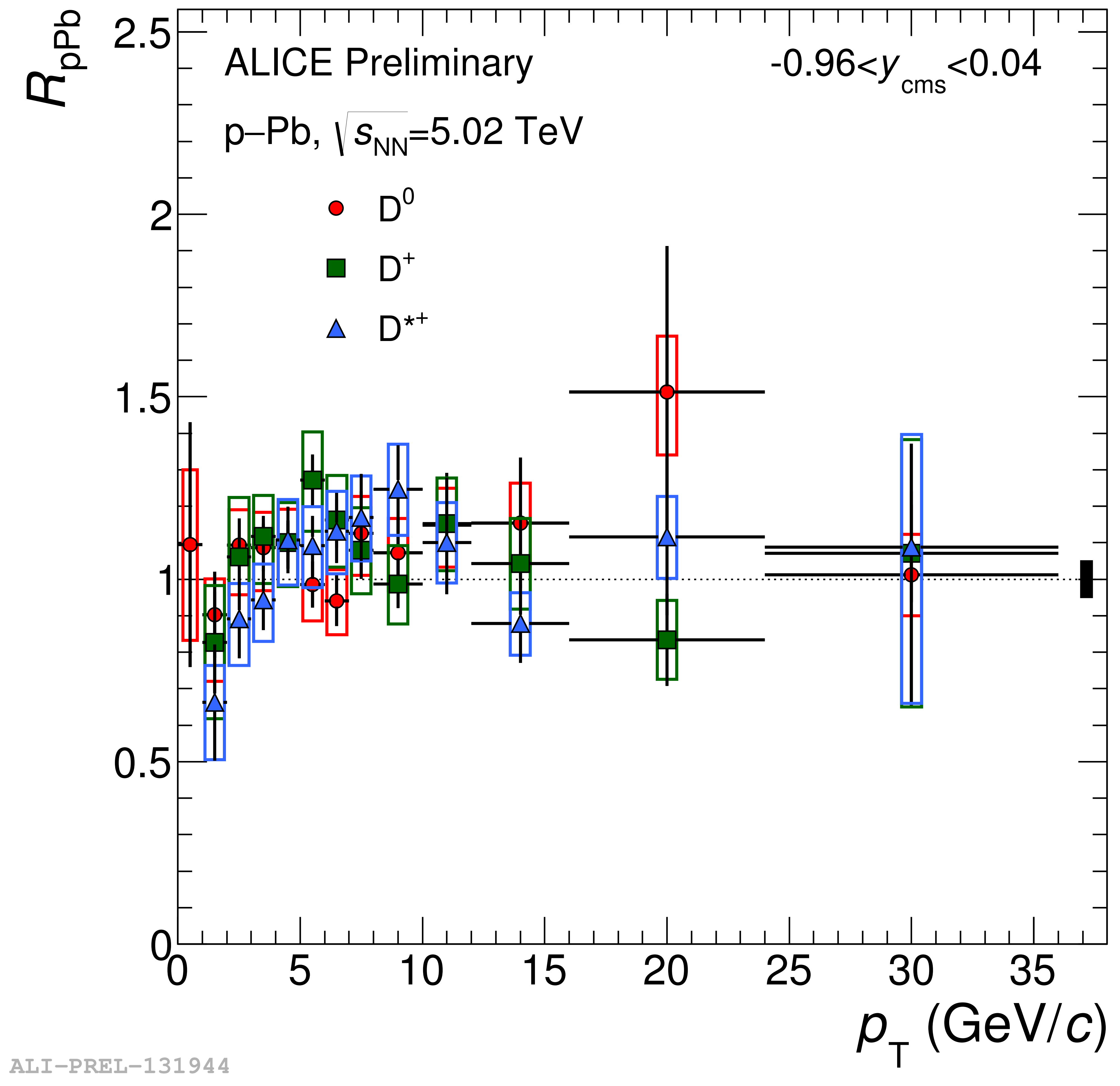
NWO Netherlands Organisation for Scientific Research

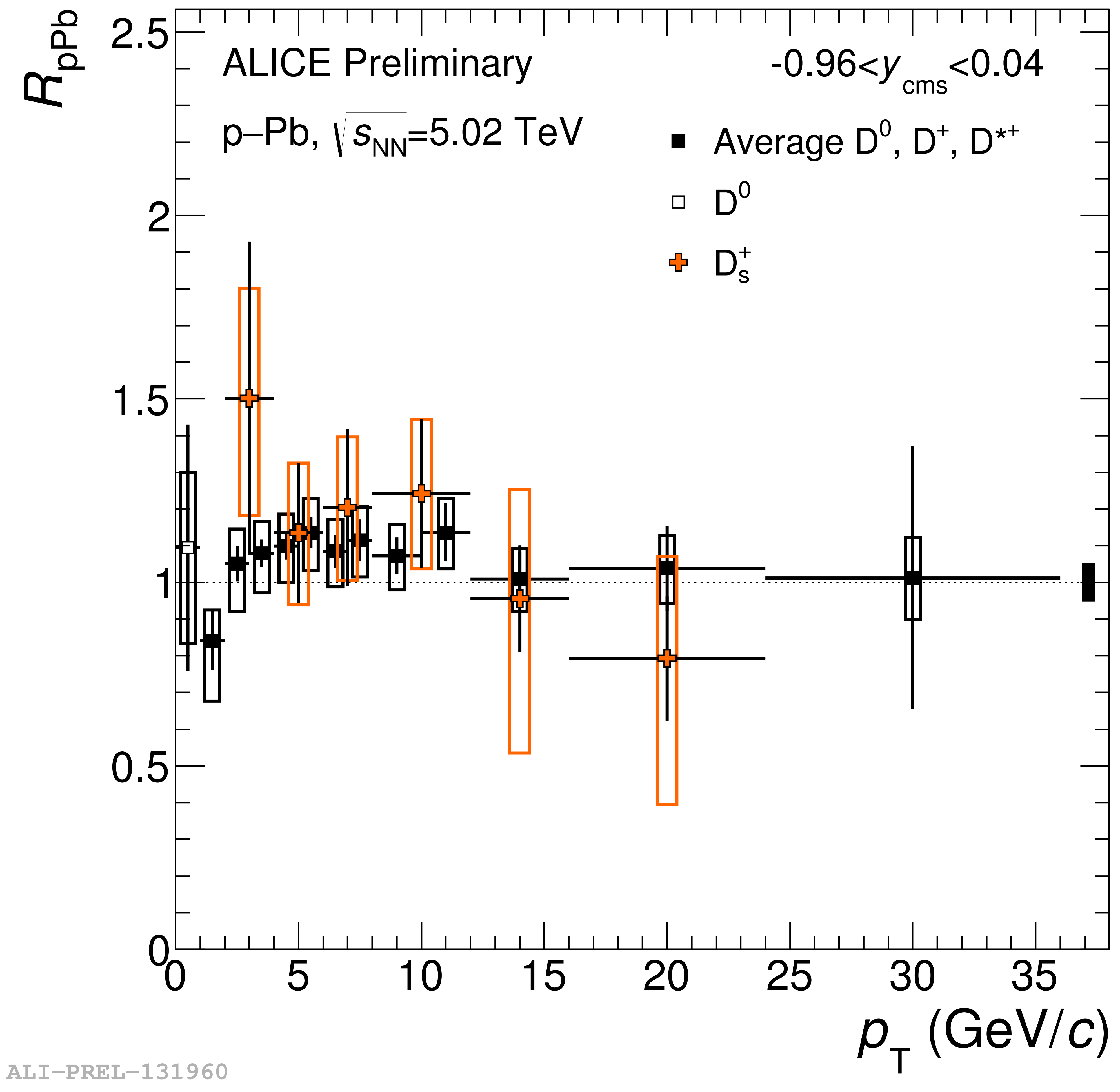
Backup

D-meson reconstruction



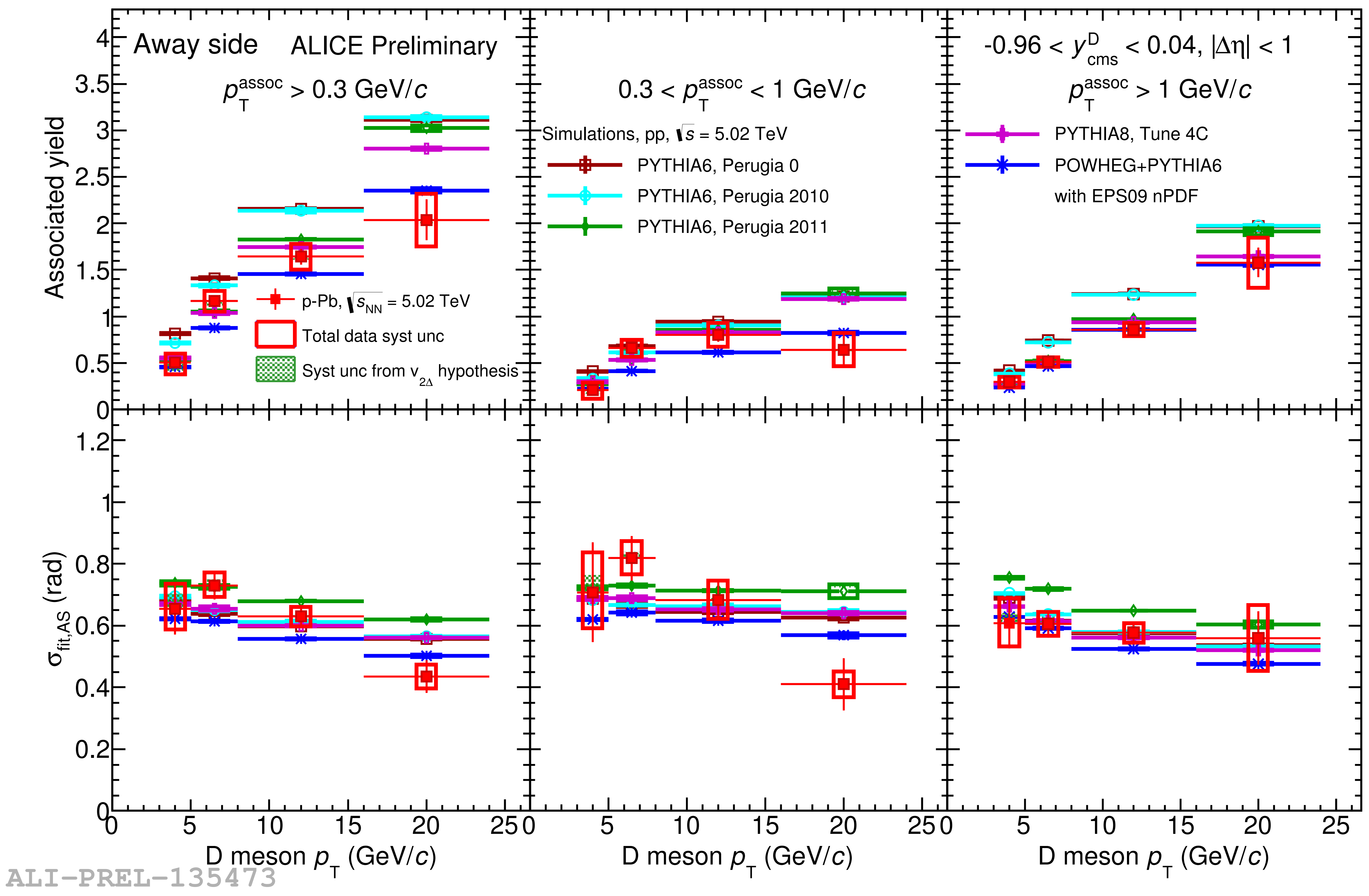
D-meson R_{pPb}


ALICE Preliminary
-0.96<y cms<0.04
p–Pb, √sNN=5.02 TeV
D0
D+
D*+
RpPb
pT (GeV/c)
ALI-PREL-131944

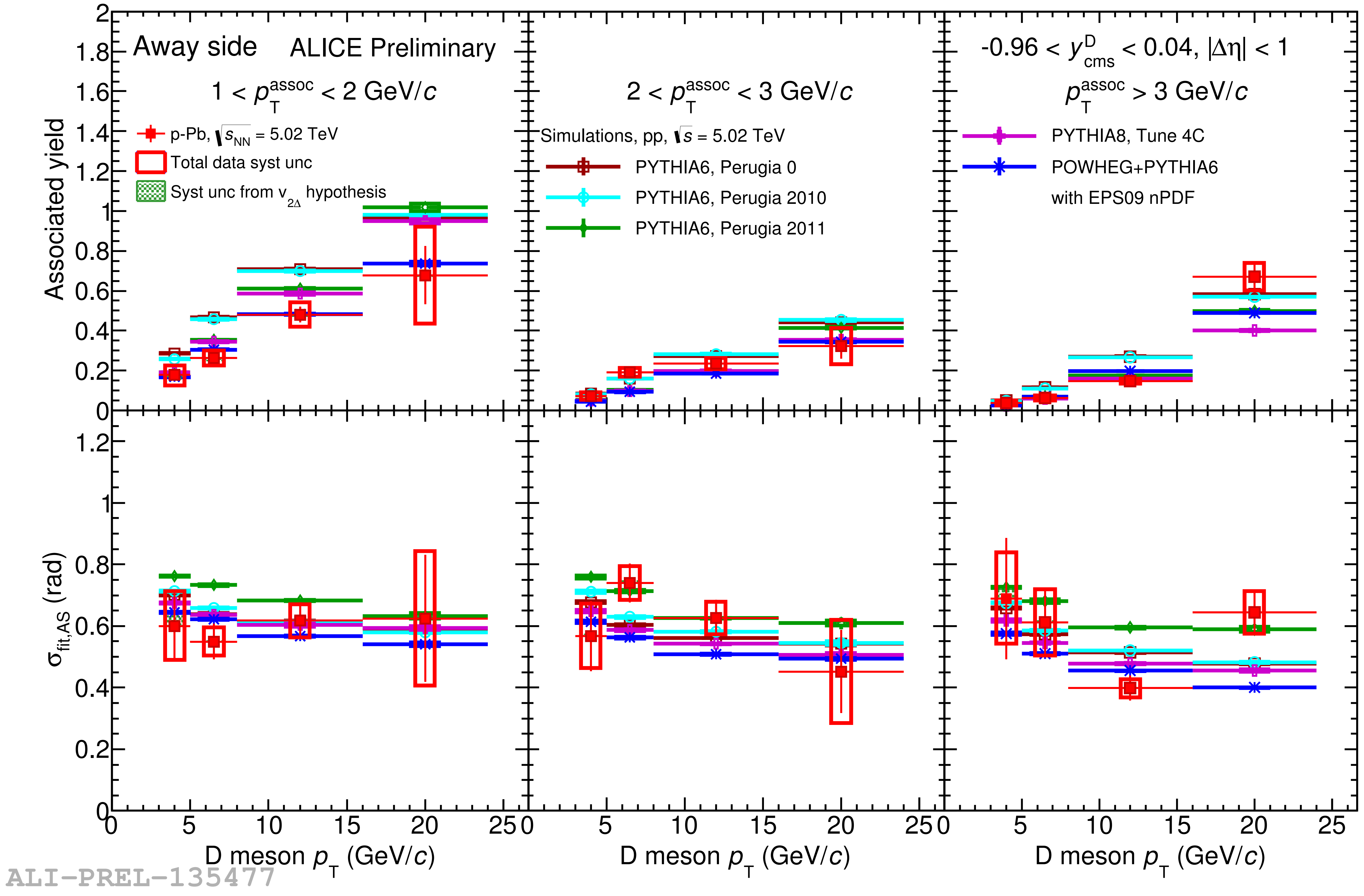

ALICE Preliminary
-0.96<y cms<0.04
p–Pb, √sNN=5.02 TeV
Average D0, D+, D*+
D0
Ds+
RpPb
pT (GeV/c)
ALI-PREL-131960

D-h away side

Lower p_T

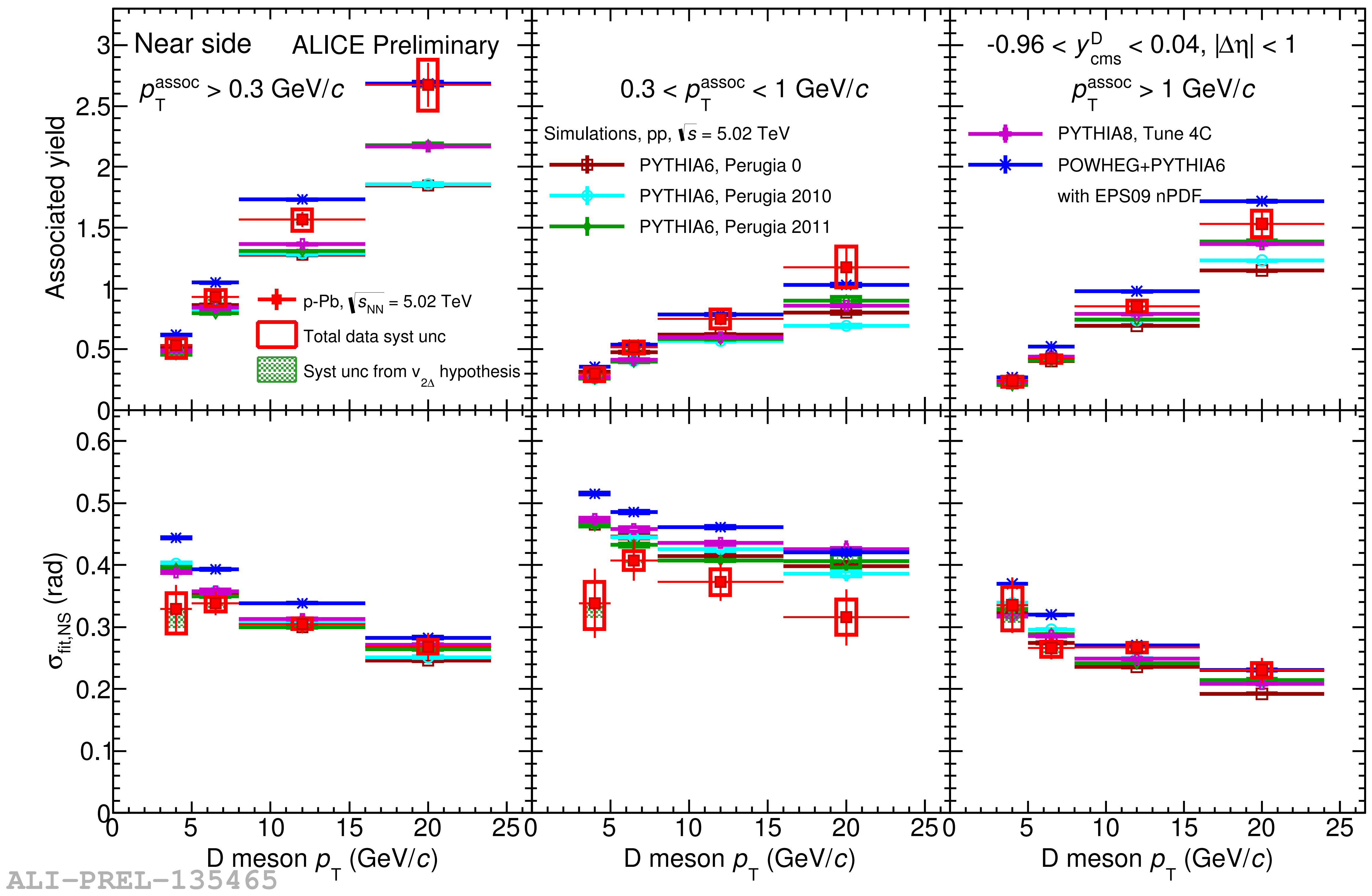


Higher p_T



D-h near side

Lower p_T



Higher p_T