Event-shape engineering for the D-meson elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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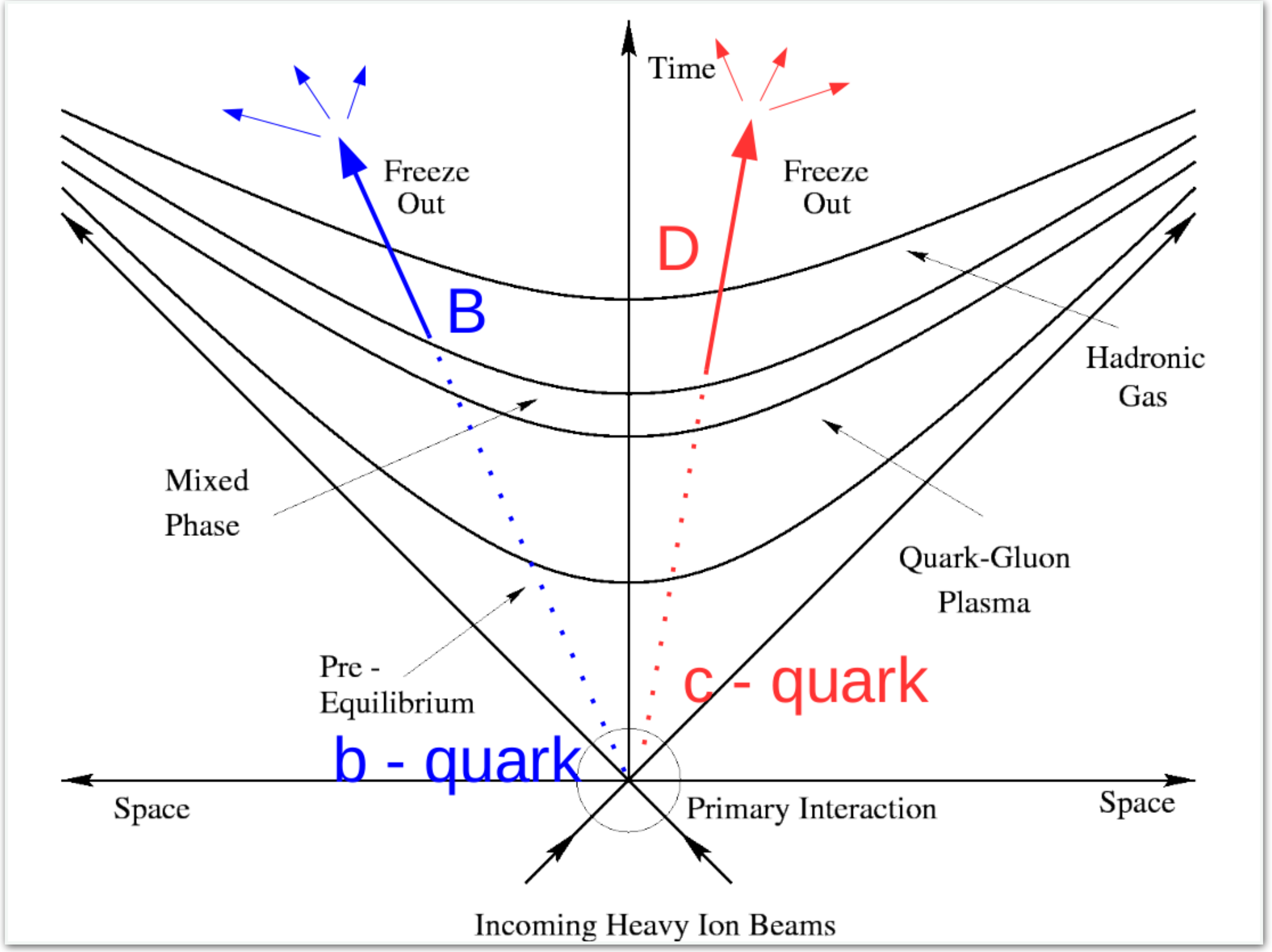
Outline

- Physics motivation: heavy flavours as probe of the QGP and event-shape engineering technique
- The ALICE detector
- D-meson reconstruction strategy in ALICE
- D-meson elliptic flow measurement in ALICE
- D^0, D^+, D^{*+}, D_s^+ unbiased elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
- Event-shape engineering for the D-meson elliptic flow
- Conclusions and outlook

Heavy flavours as a probe of the Quark-Gluon Plasma



- Heavy flavours (i.e. c and b quarks) in heavy-ion collisions are produced mainly in hard-scattering processes

  HF production $t_{\mathrm{prod}} \lesssim \hbar/m_{\mathrm{c,b}} \sim 0.1(0.04)\ \mathrm{fm}/c$

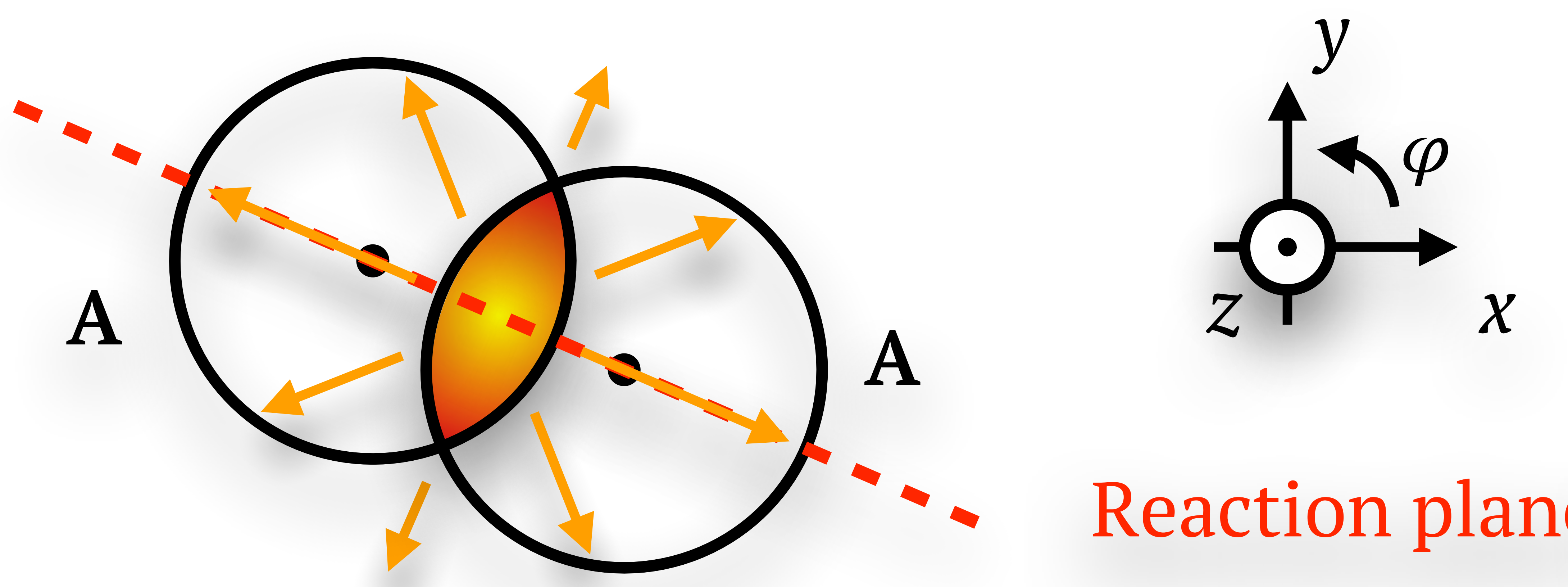
  QGP formation $t_{\mathrm{QGP}} \sim 0.3\ \mathrm{fm}/c$ (LHC)

- Heavy flavours experience the whole system evolution interacting with the medium constituents

  → powerful probe for the characterisation of the Quark-Gluon Plasma

[1] F. M. Liu, S. X. Liu, Phys. Rev. C 89, 034906 (2014)

Azimuthal anisotropy

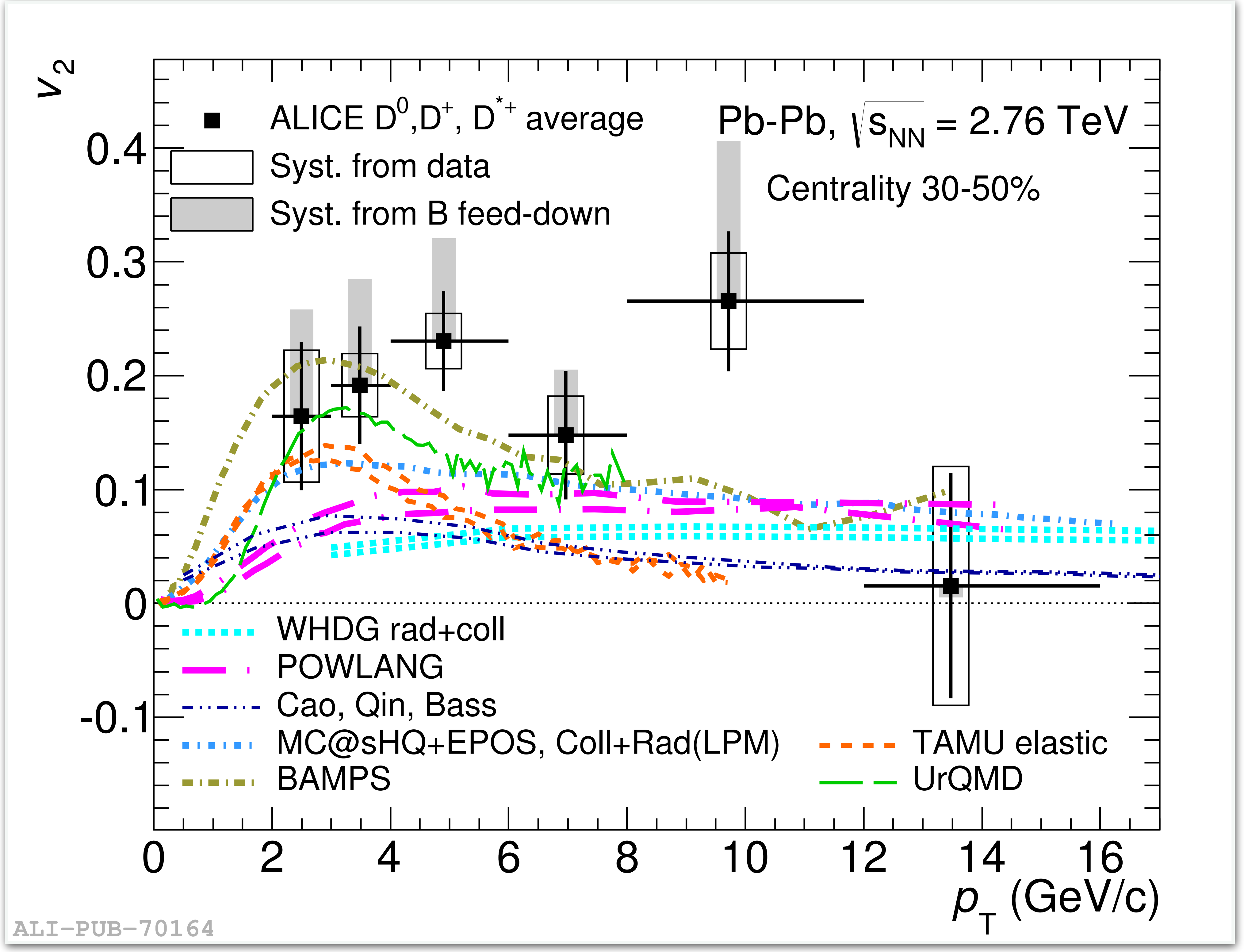


Reaction plane Ψ_{RP}

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})]\right\}$$

$$v_2 = \langle \cos[2(\varphi - \Psi_{RP})] \rangle$$

second harmonic coefficient, Elliptic Flow



PRC 90, 034904 (2014)

- At low p_T: participation in the collective motion and thermalisation of heavy quarks in the medium [1]
- At high p_T: path-length dependence of energy loss [2]

[1] S. Batsouli, S. Kelly, M. Gyulassy, J. L. Nagle, Phys. Lett. B 557, 26 (2003)
[2] M. Gyulassy, I. Vitev, X. N. Wang, Phys. Rev. Lett. 86, 2537 (2001)

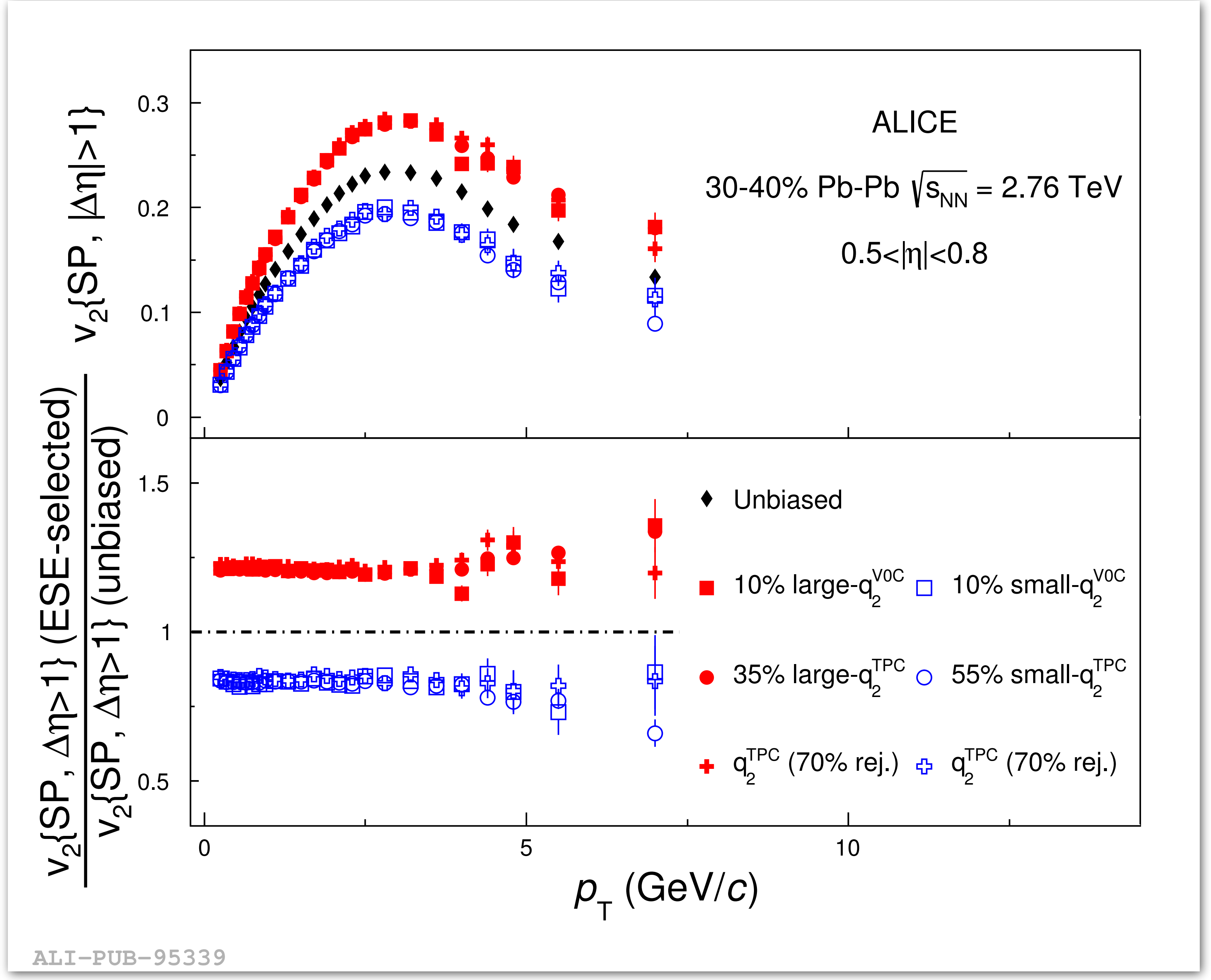
Event-shape engineering

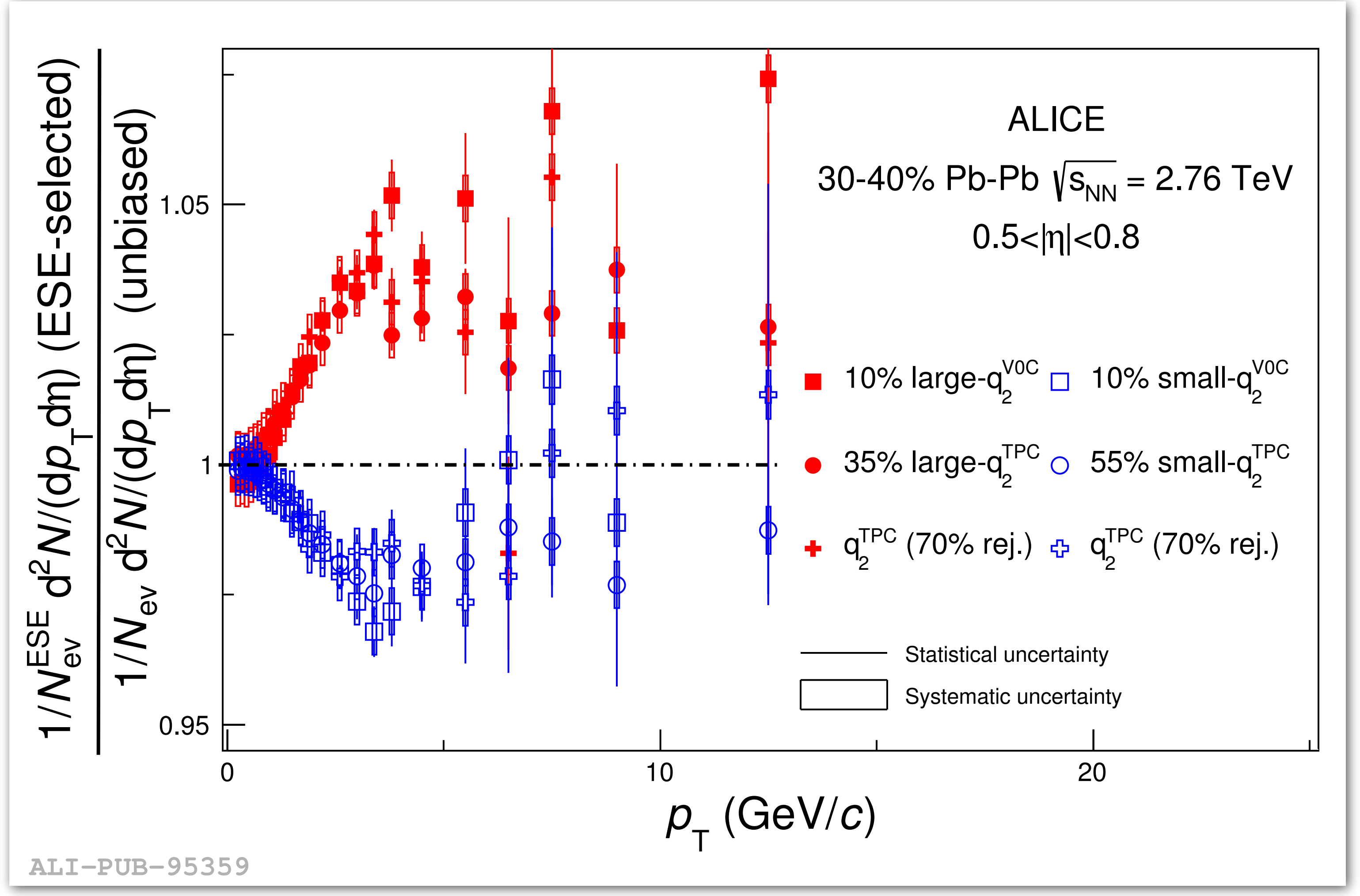
- The Event-shape engineering (ESE) technique allows us to study different observables in classes of events corresponding to the same centrality, but different eccentricity:

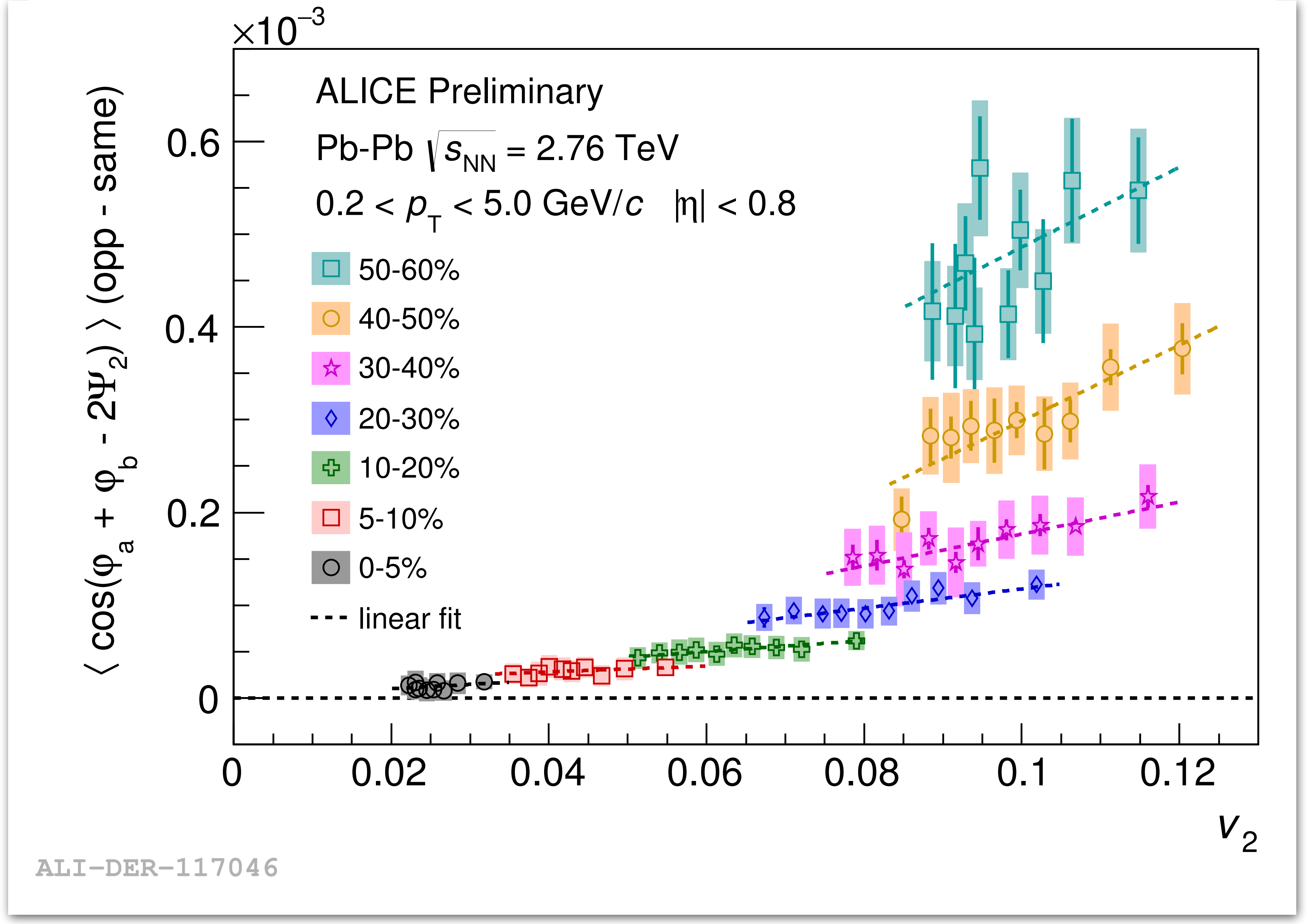
(i) Event-by-event fluctuations of elliptic flow

(ii) Coupling between radial and elliptic flow

(iii) Search of the Chiral Magnetic Effect



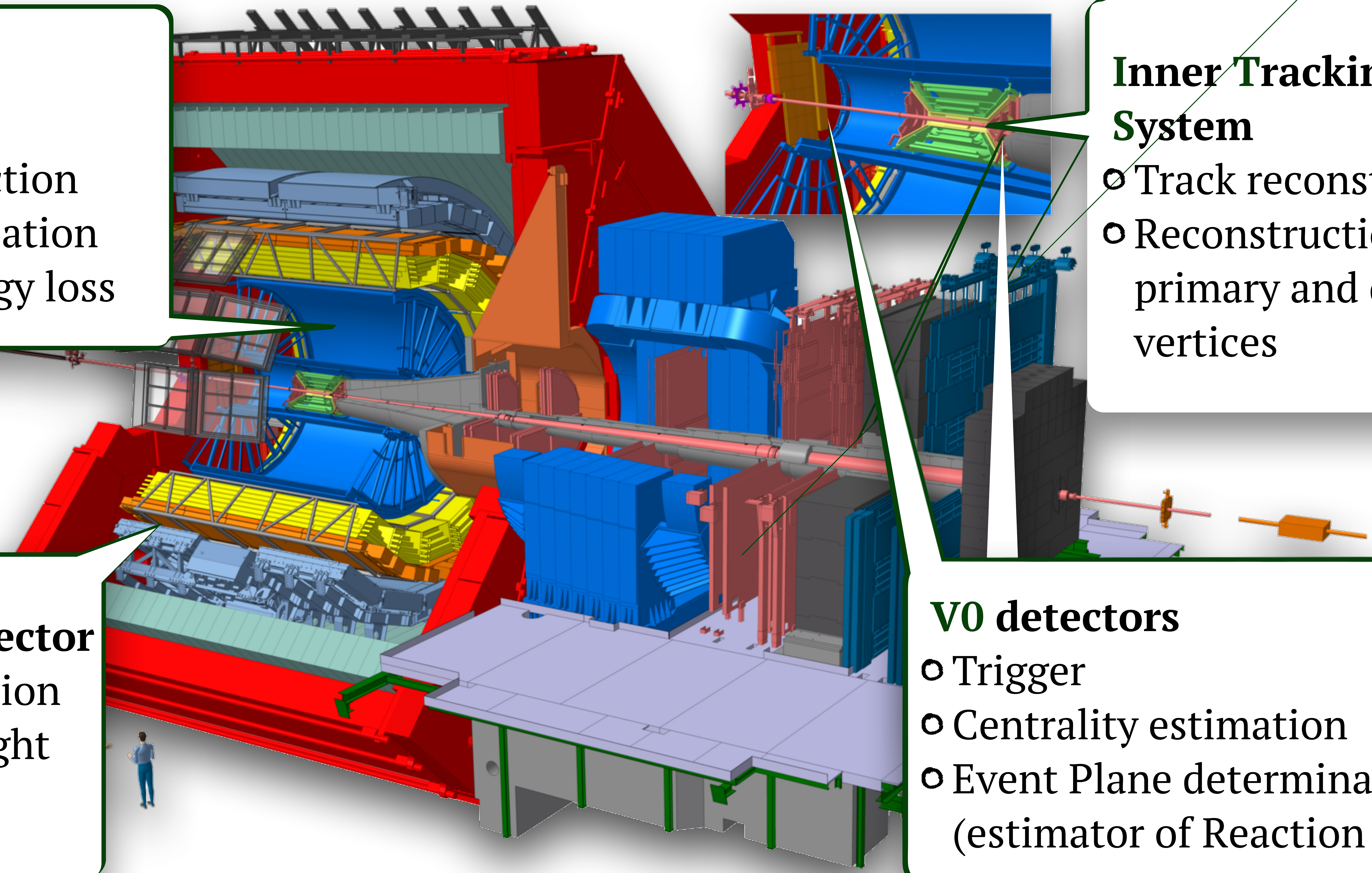




Phys. Rev. C 93, 034916

arXiv:1709.04723

The ALICE detector



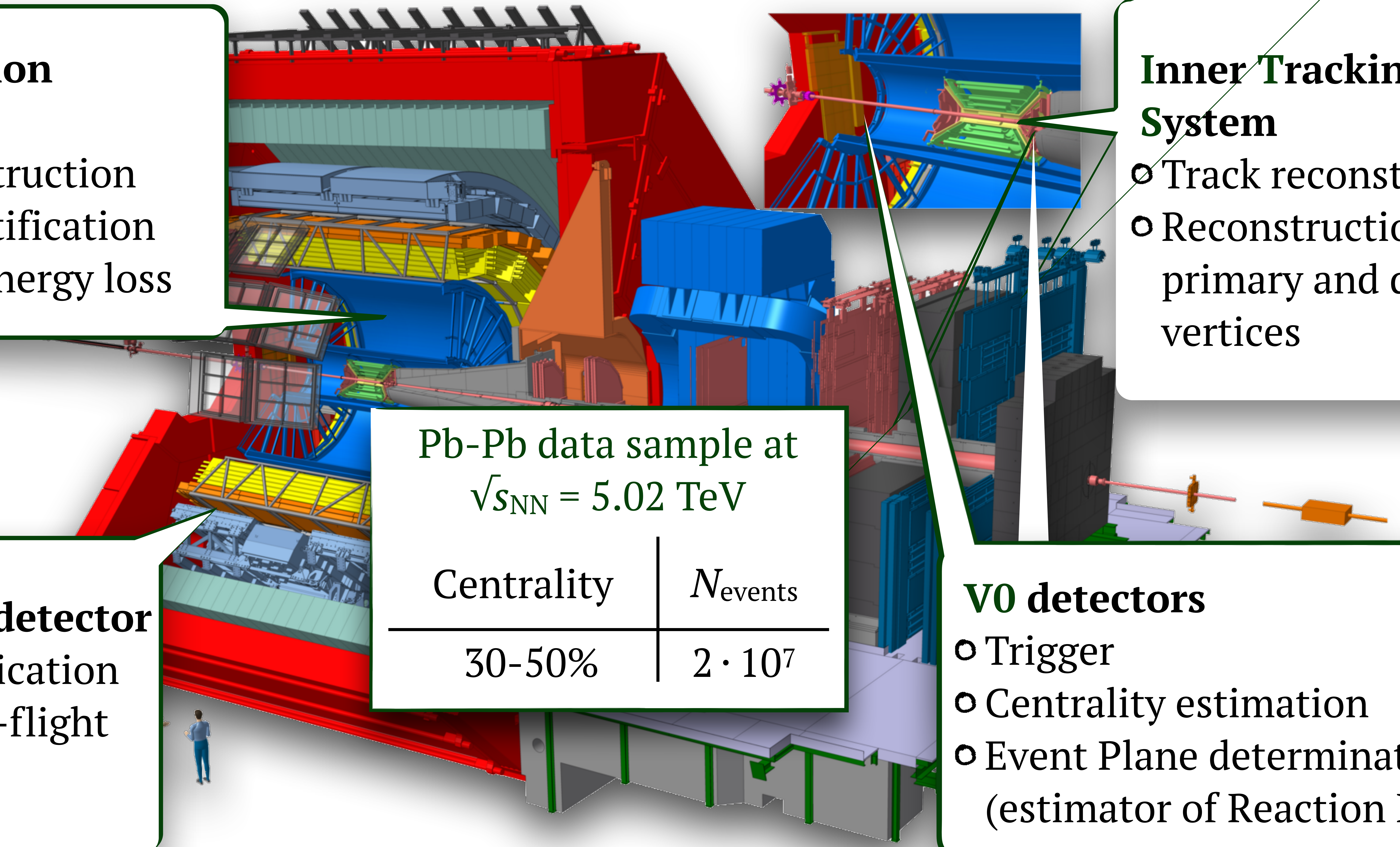
Time Projection Chamber
- Track reconstruction
- Particle identification via specific energy loss

Inner Tracking System
- Track reconstruction
- Reconstruction of primary and decay vertices

Time of Flight detector
- Particle identification via the time-of-flight measurement

V0 detectors
- Trigger
- Centrality estimation
- Event Plane determination (estimator of Reaction Plane)

The ALICE detector



Time Projection Chamber
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Inner Tracking System
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Pb-Pb data sample at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

Centrality	N_{events}
30-50%	$2 \cdot 10^{7}$

Time of Flight detector
- Particle identification via the time-of-flight measurement

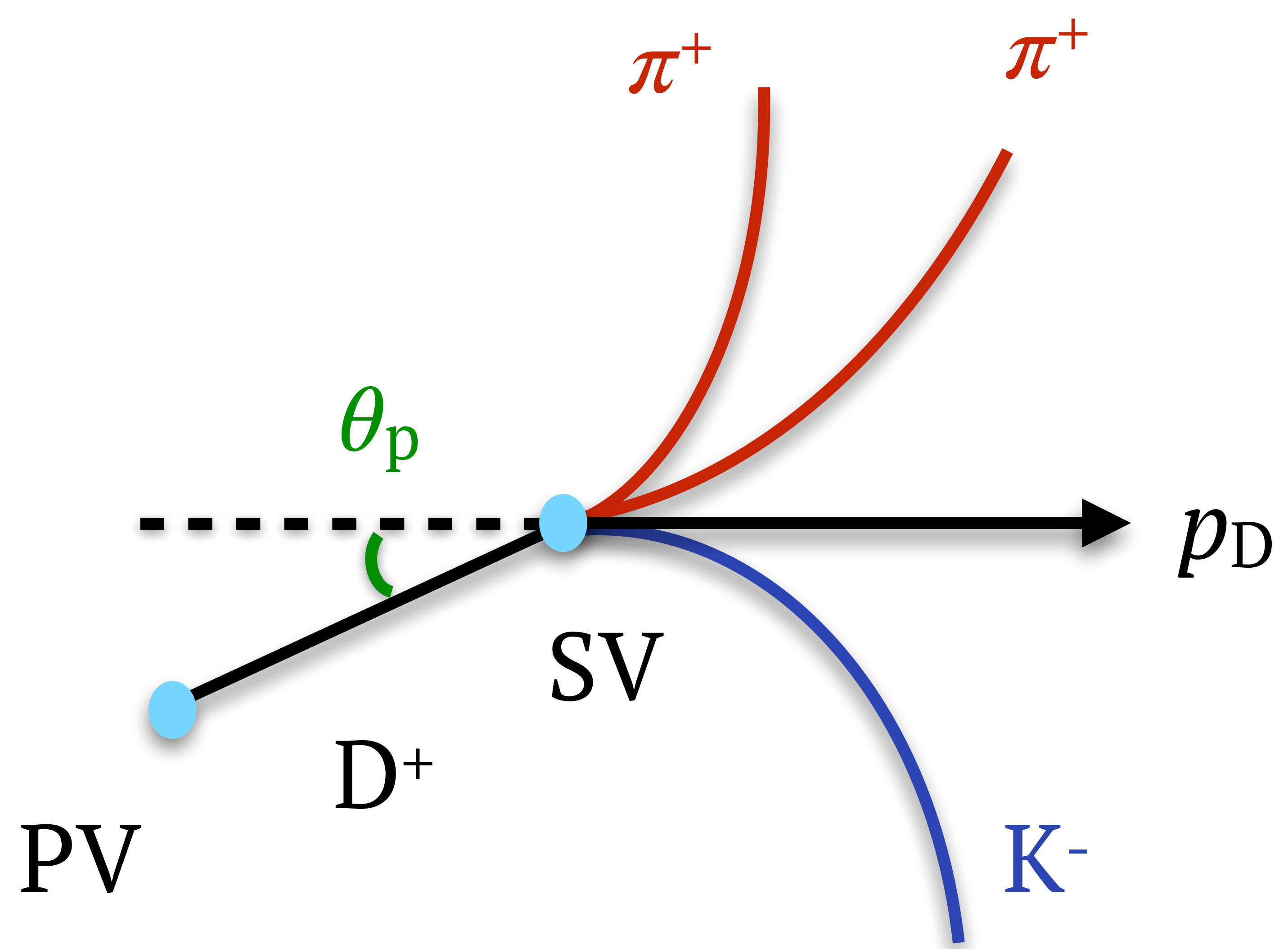
V0 detectors
- Trigger
- Centrality estimation
- Event Plane determination (estimator of Reaction Plane)

Reconstruction of D mesons in ALICE

- D mesons are reconstructed in the mid-rapidity region via their hadronic decays

[1]

Meson	Mass (GeV/c^2)	decay channel	$c\tau$ (μm)	BR (%)
D^0 ($c\bar{u}$)	1.865	$K^-\pi^+$	123	3.93
D^+ ($c\bar{d}$)	1.870	$K^-\pi^+\pi^+$	312	9.46
D^{*+} ($c\bar{d}$)	2.010	D^0 ($\rightarrow K^-\pi^+$) π^+	strong decay	67.7 (x 3.93)
D_s^+ ($c\bar{s}$)	1.968	ϕ ($\rightarrow K^-K^+$) π^+	150	2.27

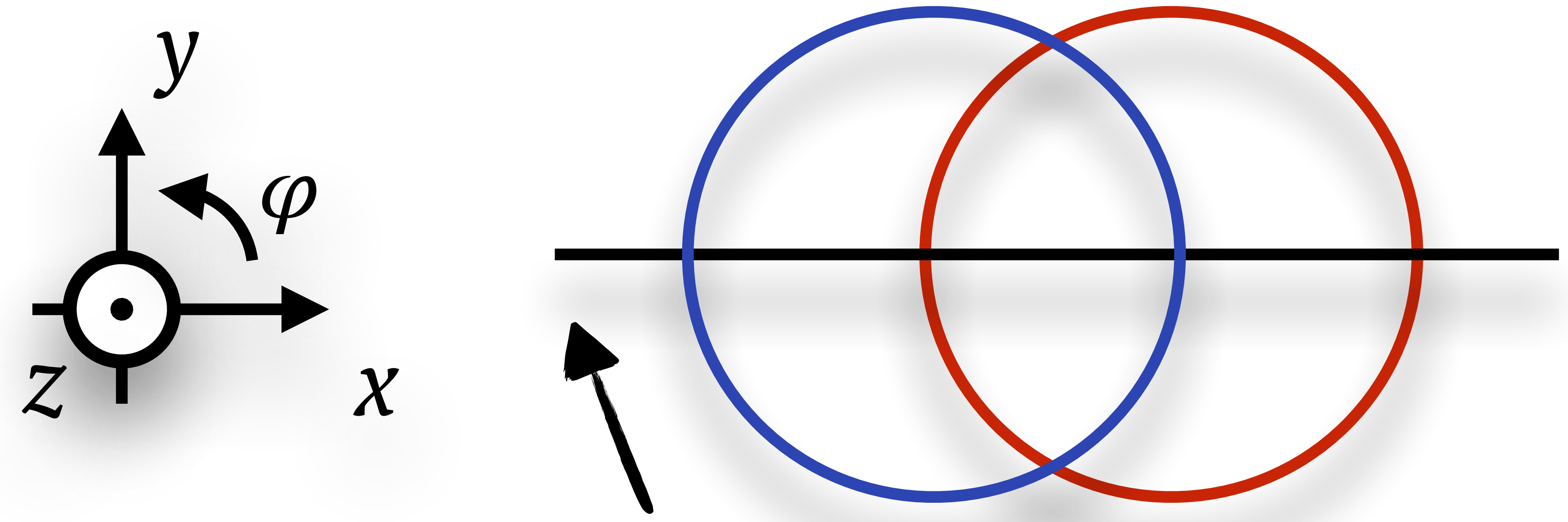


- Full reconstruction of decay topologies displaced few hundred microns from the interaction vertex
- Reduction of the combinatorial background achieved applying:
  (i) geometrical selection of displaced decay-vertex topology
  (ii)particle identification (PID) of decay tracks
- Signal extracted from invariant-mass analysis
- Feed-down from b-hadrons subtracted with a FONLL-based method [2]

[1] PDG, Chin. Phys. C40 (2016) 100001 [2] M. Cacciari, M. Greco, P. Nason, JHEP 9805, 007 (1998)

D-meson v_2 measurement with the EP method

- D-meson v_2 measured at mid-rapidity ($|y| < 0.8$) using the Event-plane method



Reaction plane

- Event-plane angle:

$$\psi_2 = \frac{1}{2} \tan \frac{Q_{2,\mathrm{y}}}{Q_{2,\mathrm{x}}} \quad \text{where} \quad \begin{cases} Q_{2,\mathrm{x}} = \sum_{i=1}^{M} \cos(2\varphi_i) \\ Q_{2,\mathrm{y}} = \sum_{i=1}^{M} \sin(2\varphi_i) \end{cases}$$

estimator for the Reaction plane angle, measured with the V0 detectors ($-3.7 < \eta < -1.7$ U $2.8 < \eta < 5.1$)

D-meson v_2 measurement with the EP method

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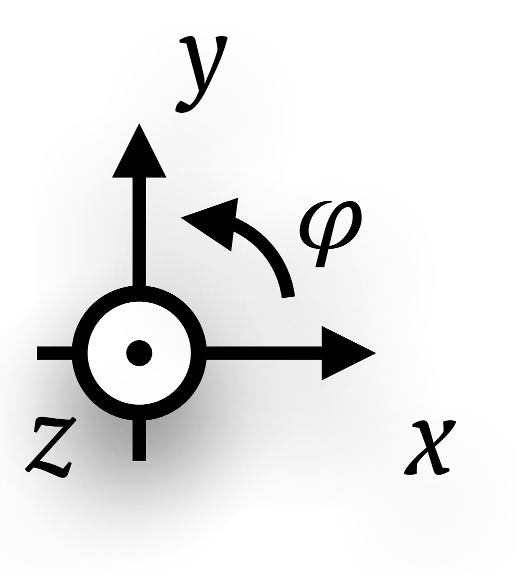
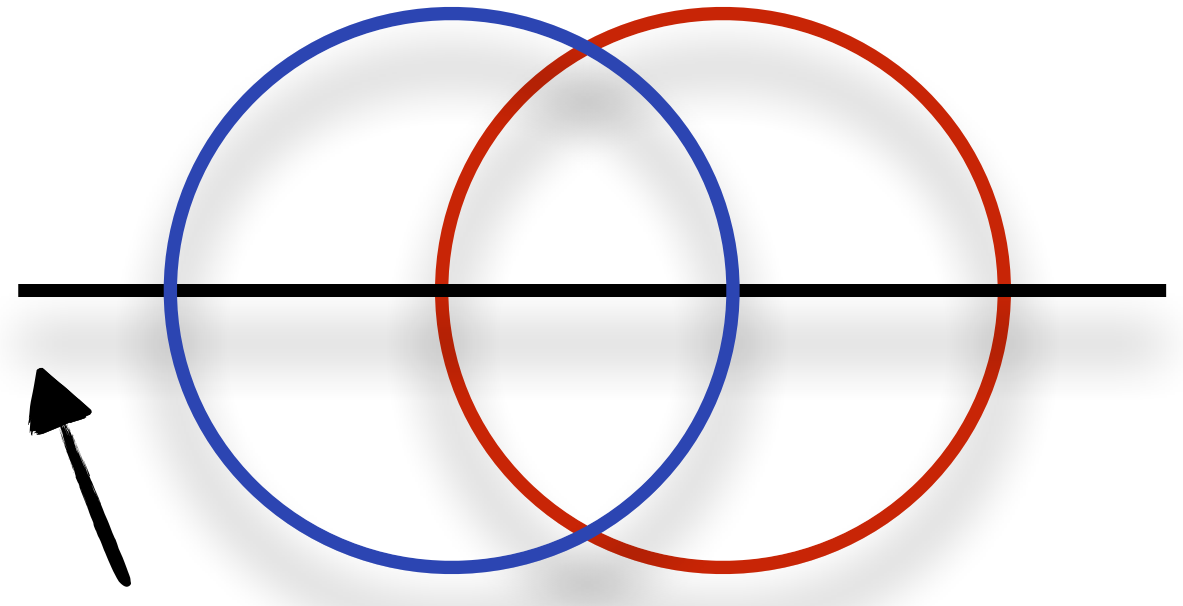
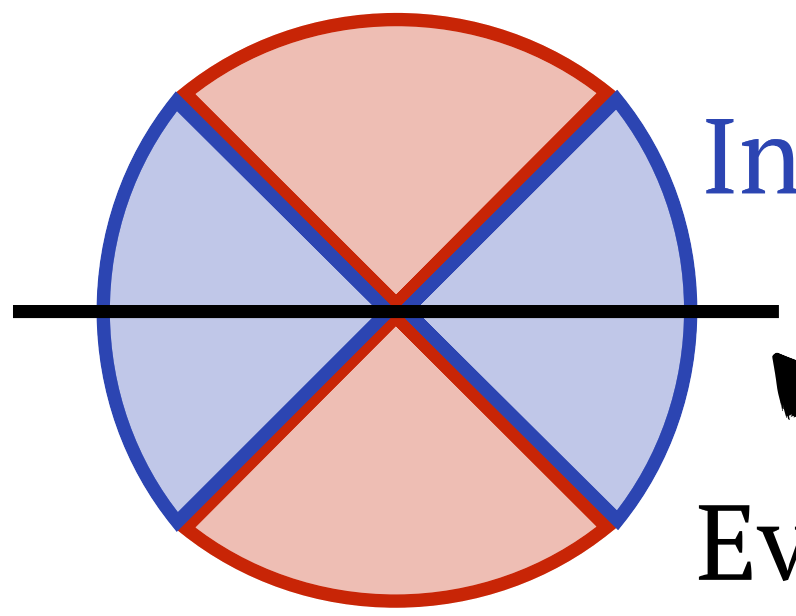


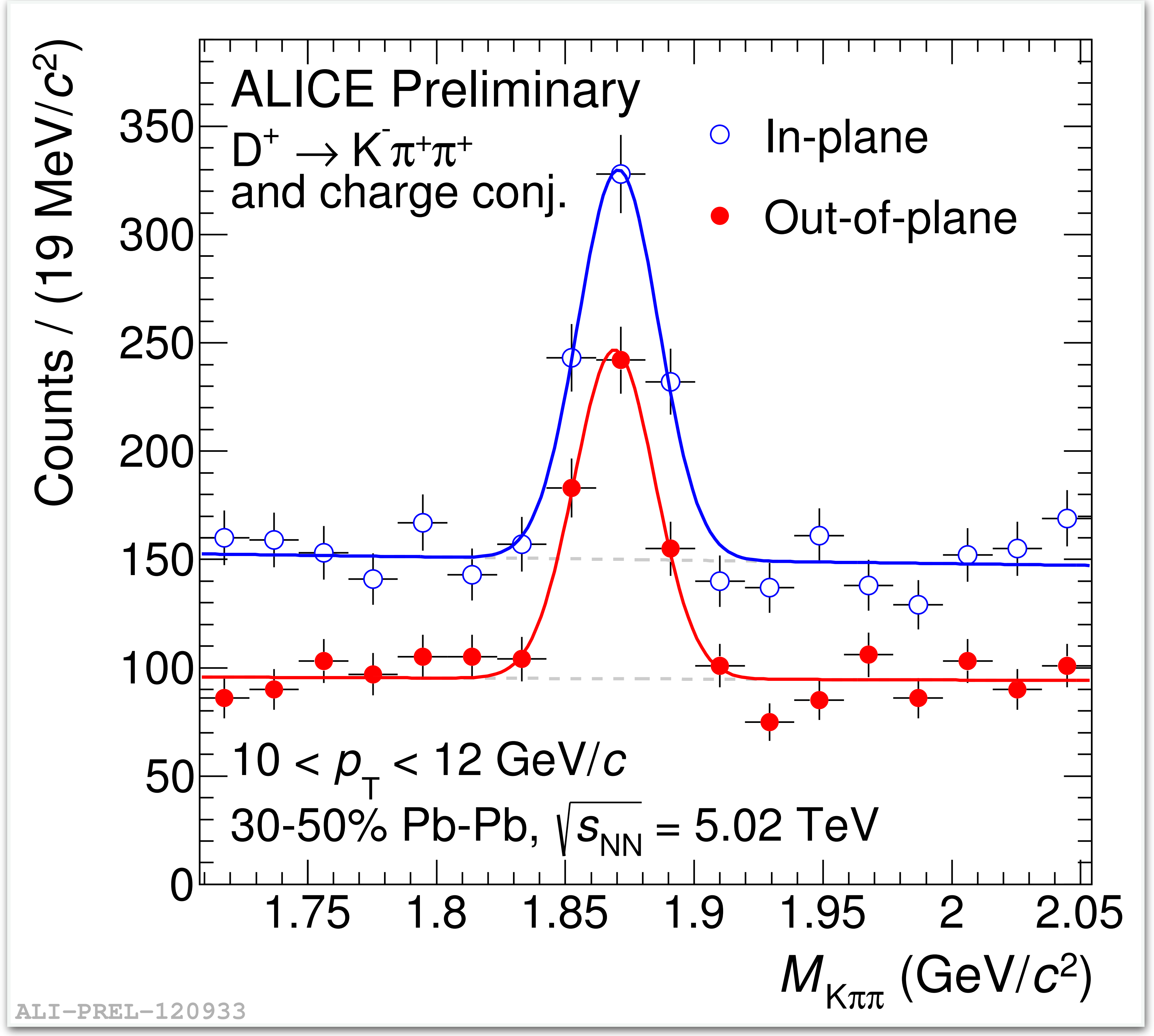


- Event-plane angle: estimator for the Reaction plane angle, measured with the V0 detectors ($-3.7 < \eta < -1.7$ U $2.8 < \eta < 5.1$)

- D-meson candidates divided in two samples:
  - In-plane
  - Out-of-plane

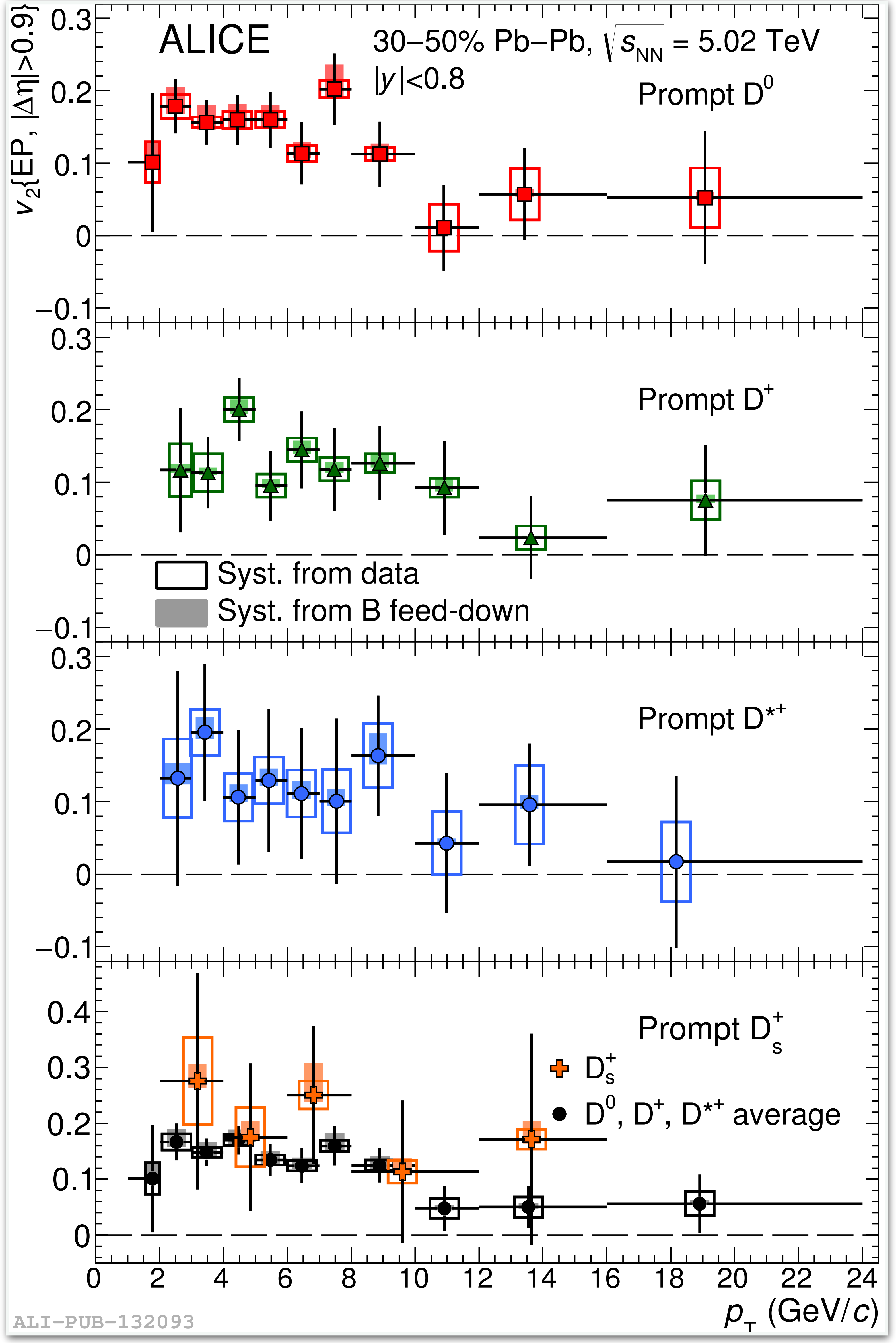


$$v_2\{\mathrm{EP}\} = \frac{1}{R_2}\frac{4}{\pi}\frac{N_{\text{in-plane}} - N_{\text{out-of-plane}}}{N_{\text{in-plane}} + N_{\text{out-of-plane}}}$$



- R_2 is the Event-Plane resolution

D-meson v_2 in mid-central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



- D^0, D^+, D^{*+} v_2 compatible within uncertainties in the whole p_T coverage of the measurement

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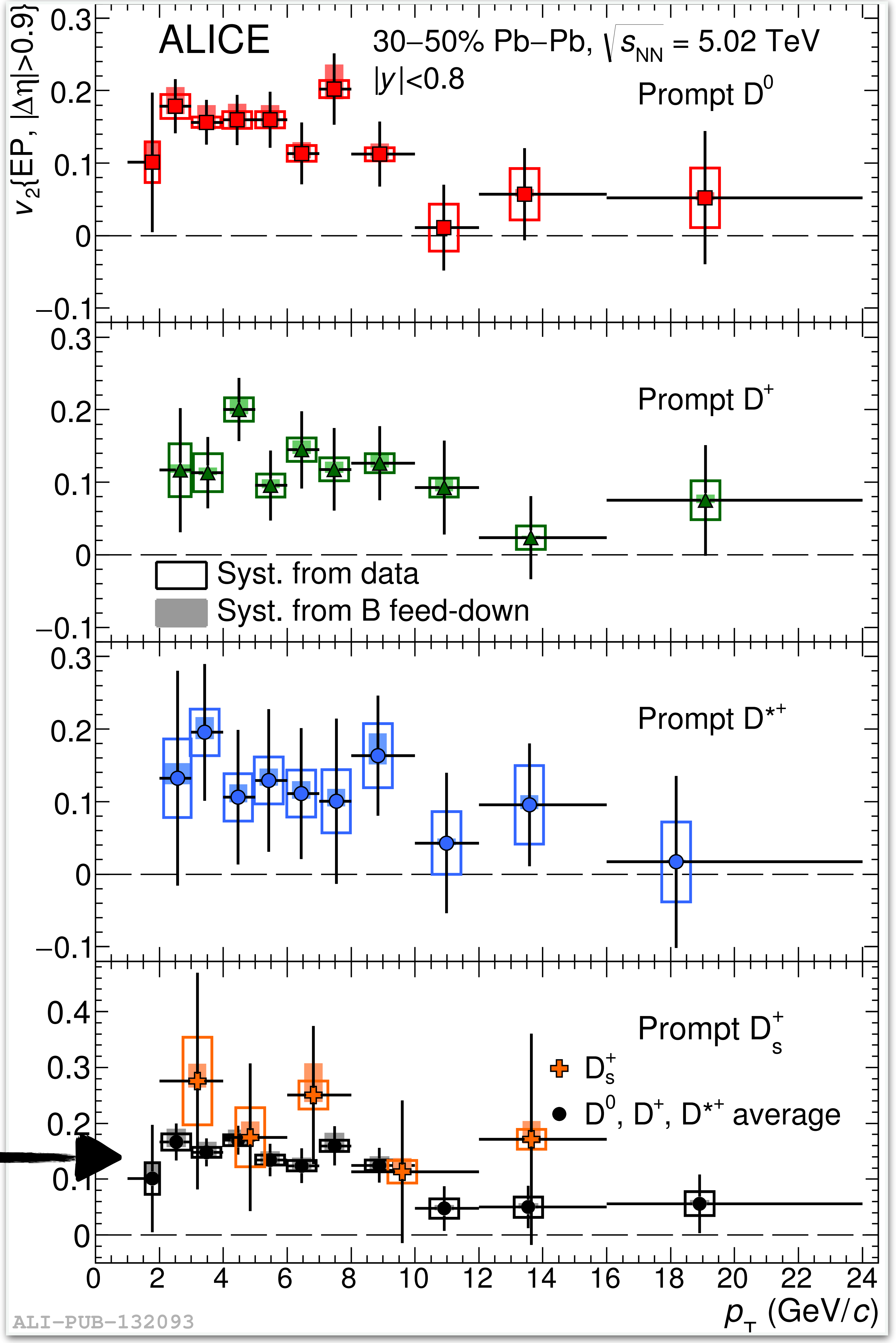
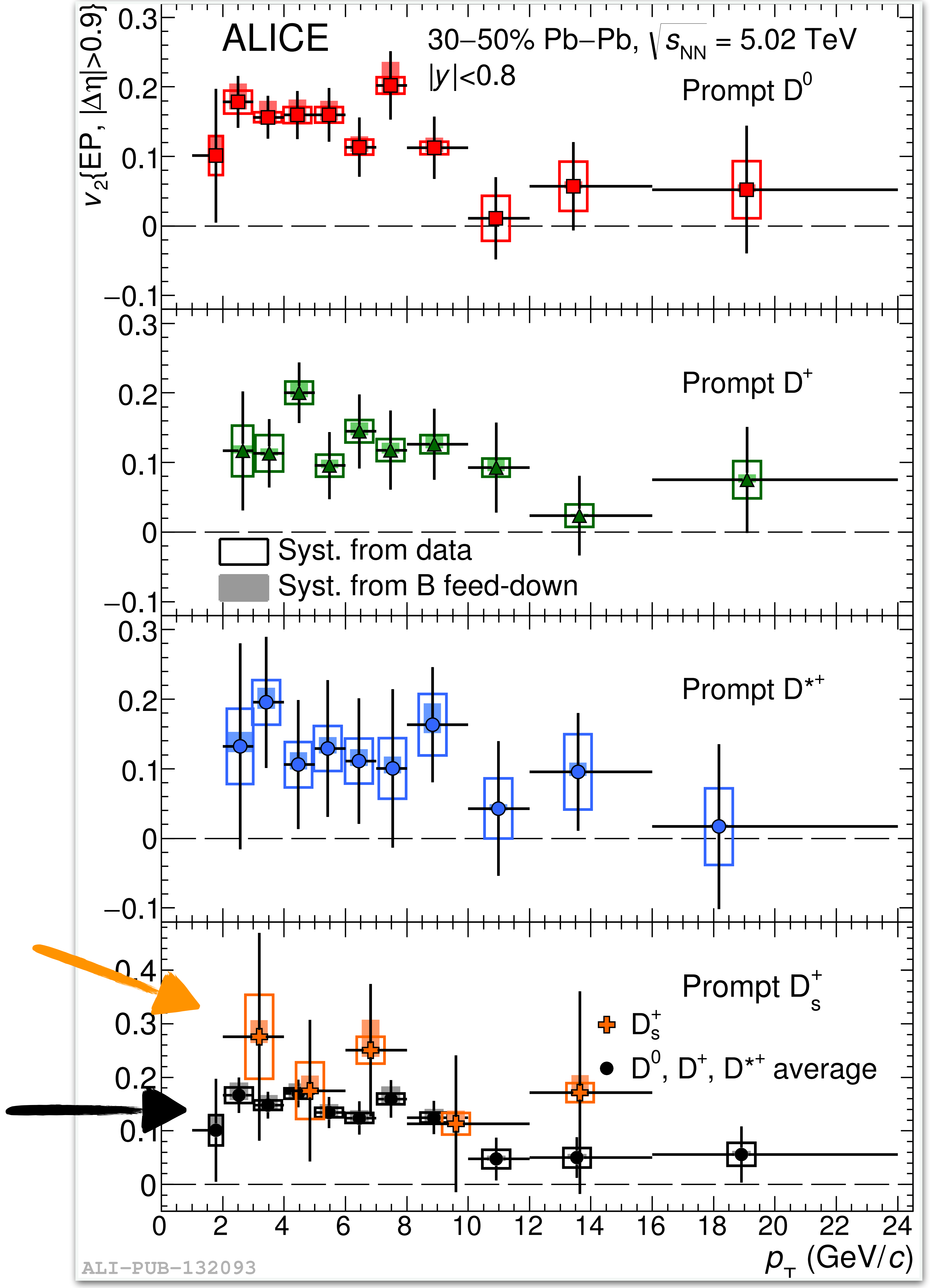


- D^0, D$^+$, D^{*+} v_2 compatible within uncertainties in the whole p_T coverage of the measurement
- Average non-strange D-meson v_2 larger than zero in $2 < p_T < 10$ GeV/c

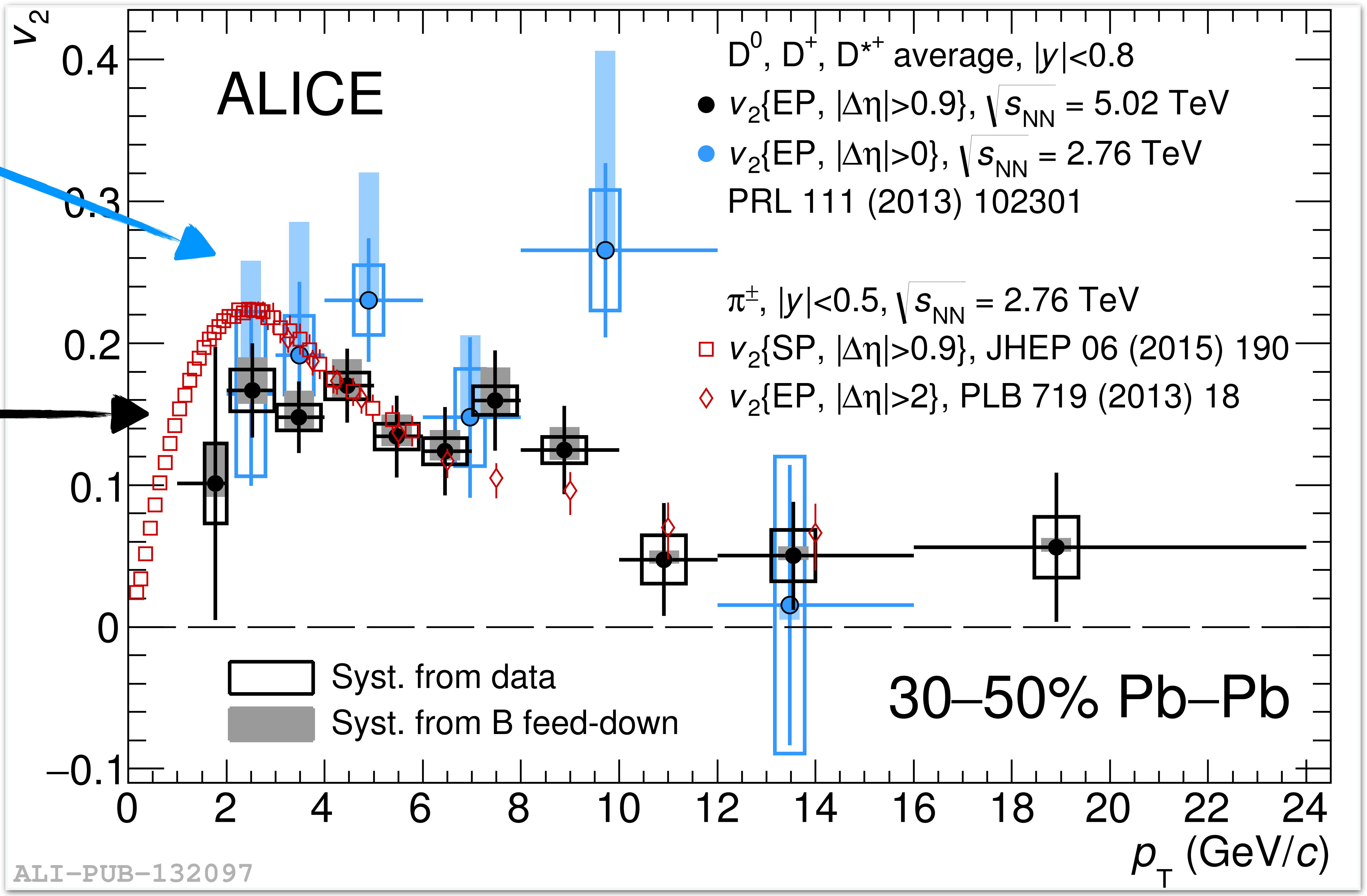
D-meson v_2 in mid-central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



- D^0, D$^+$, D^{*+} v_2 compatible within uncertainties in the whole p_T coverage of the measurement
- Average non-strange D-meson v_2 larger than zero in $2 < p_T < 10$ GeV/c
- D$_s^+$ v_2 measured for the first time at the LHC is found to be compatible to that of non-strange D mesons and positive in $2 < p_T < 8$ GeV/c with a significance of about 2.6σ

D-meson v_2 in mid-central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

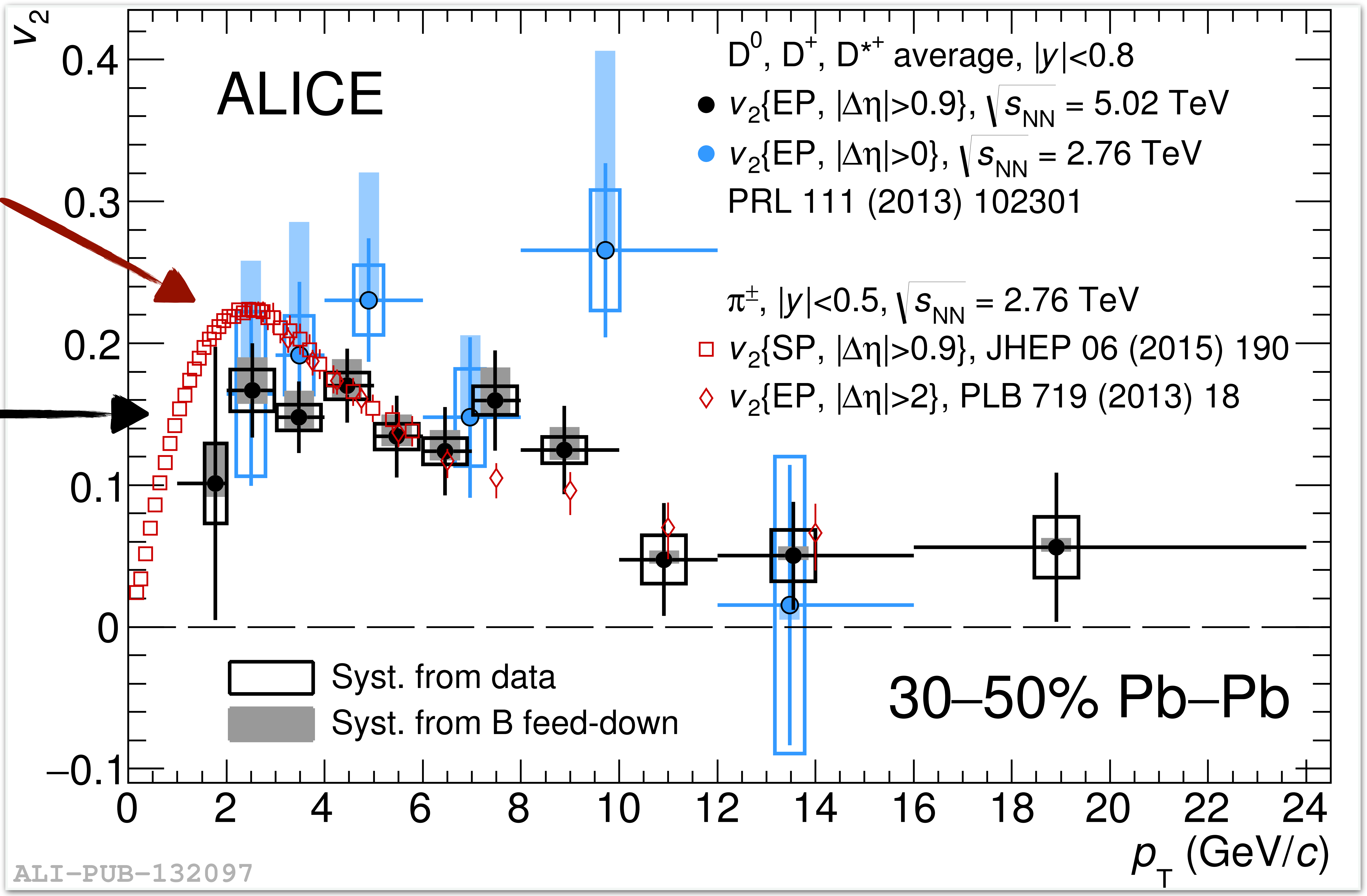
- Non-strange D-meson v_2 compatible at $\sqrt{s_{NN}}$ = 5.02 TeV and $\sqrt{s_{NN}}$ = 2.76 TeV



Phys. Rev. Lett. 120, 102301

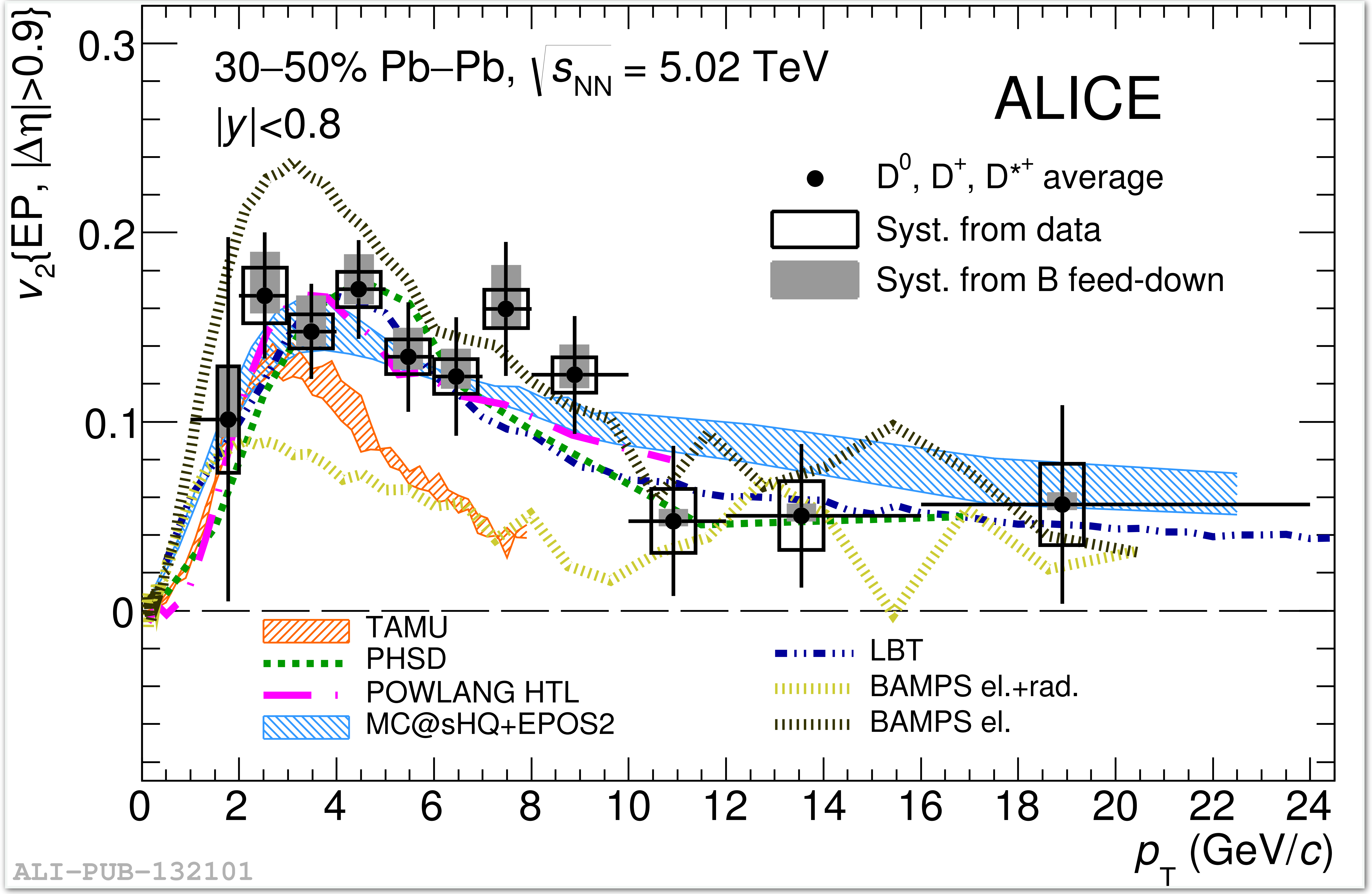
D-meson v_2 in mid-central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- Non-strange D-meson v_2 compatible at $\sqrt{s_{NN}}$ = 5.02 TeV and $\sqrt{s_{NN}}$ = 2.76 TeV
- Non-strange D-meson v_2 similar to that of $\pi^{\pm}$
  - → hint of difference for p_T < 4 GeV/c
  - → more statistics needed to quantify it



Phys. Rev. Lett. 120, 102301

D-meson v_2 compared to models



Phys. Rev. Lett. 120, 102301

- Improved precision of the measurement can constrain model parameters, e.g. the heavy-flavour spatial diffusion coefficient

$$D_s = (T/m_Q)\tau_Q$$

→ For models describing the data with χ^2/ndf < 1:

$$1.5 < 2\pi T_c D_s < 7$$

$$\rightarrow \tau_{\text{charm}} = 3 - 14 \text{ fm}/c$$

TAMU: PLB 735, 445-450 (2014)
PHSD: PRC 92, 014910 (2015)
POWLANG: EPJC 75, 121 (2015)
MC@sHQ+EPOS: PRC 89, 014905 (2014)
LBT: Phys. Lett. B777 (2018) 255-259
BAMPS: JPG 42, 115106 (2015)

ESE for the D-meson v_2 - q_2 selection

- The magnitude of the second-harmonic reduced flow vector

$$q_2 = |\boldsymbol{Q}_2|/\sqrt{M}$$

can be used to quantify the eccentricity (average v_2) of the events

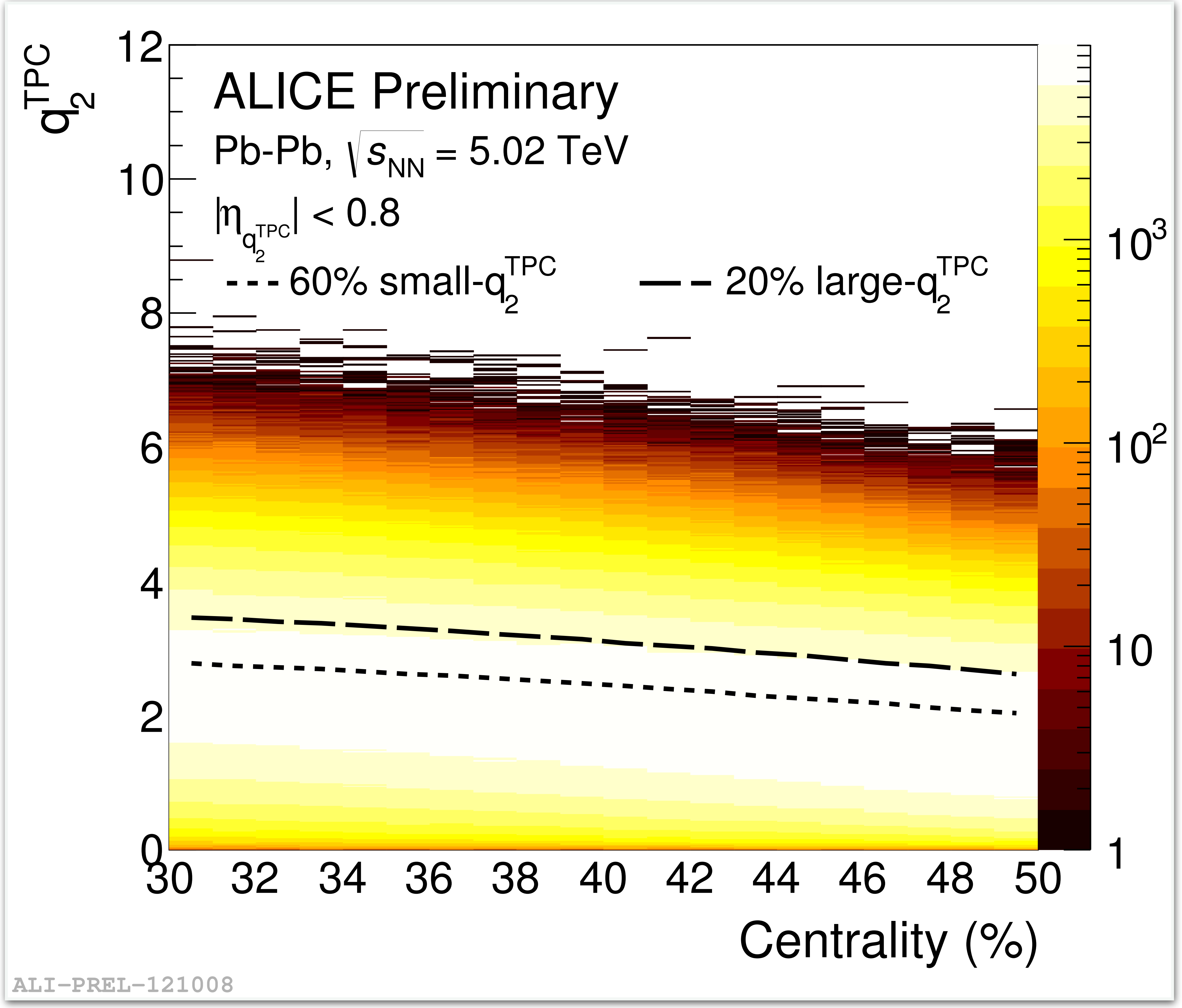
$$\langle q_2^2 \rangle \simeq 1 + \langle (M-1) \rangle \langle (v_2^2 + \delta_2) \rangle \quad [1]$$

multiplicity

elliptic flow

non-flow effects

→ computed using tracks at mid-rapidity $|\eta| < 0.8$, since the selectivity of q_2 depends on the multiplicity and the φ resolution of the detector



[1] S. A. Voloshin, A. M. Poskanzer, and R. Snellings, Relativistic Heavy Ion Physics,Vol. 1/23 (Springer- Verlag, 2010), pp. 5–54

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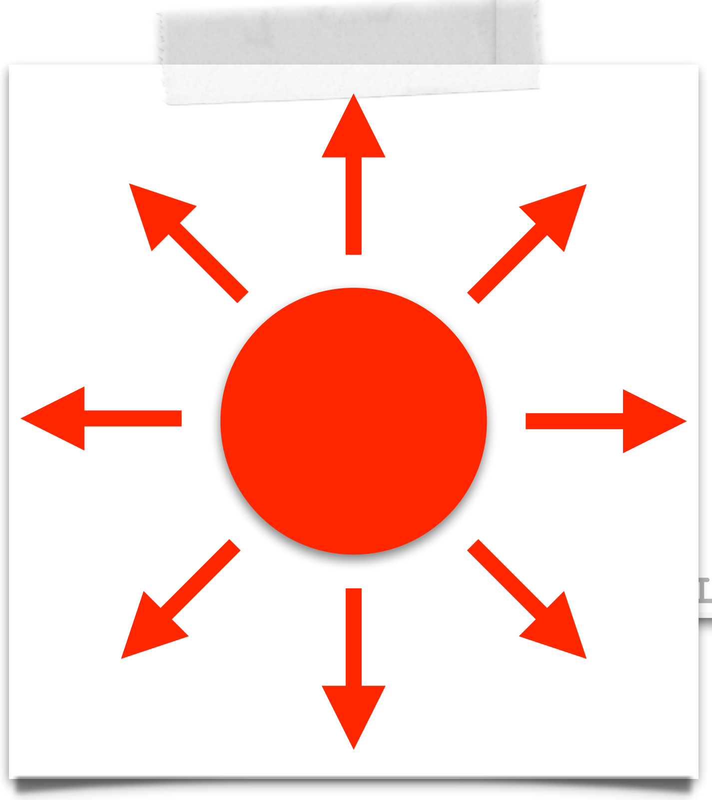

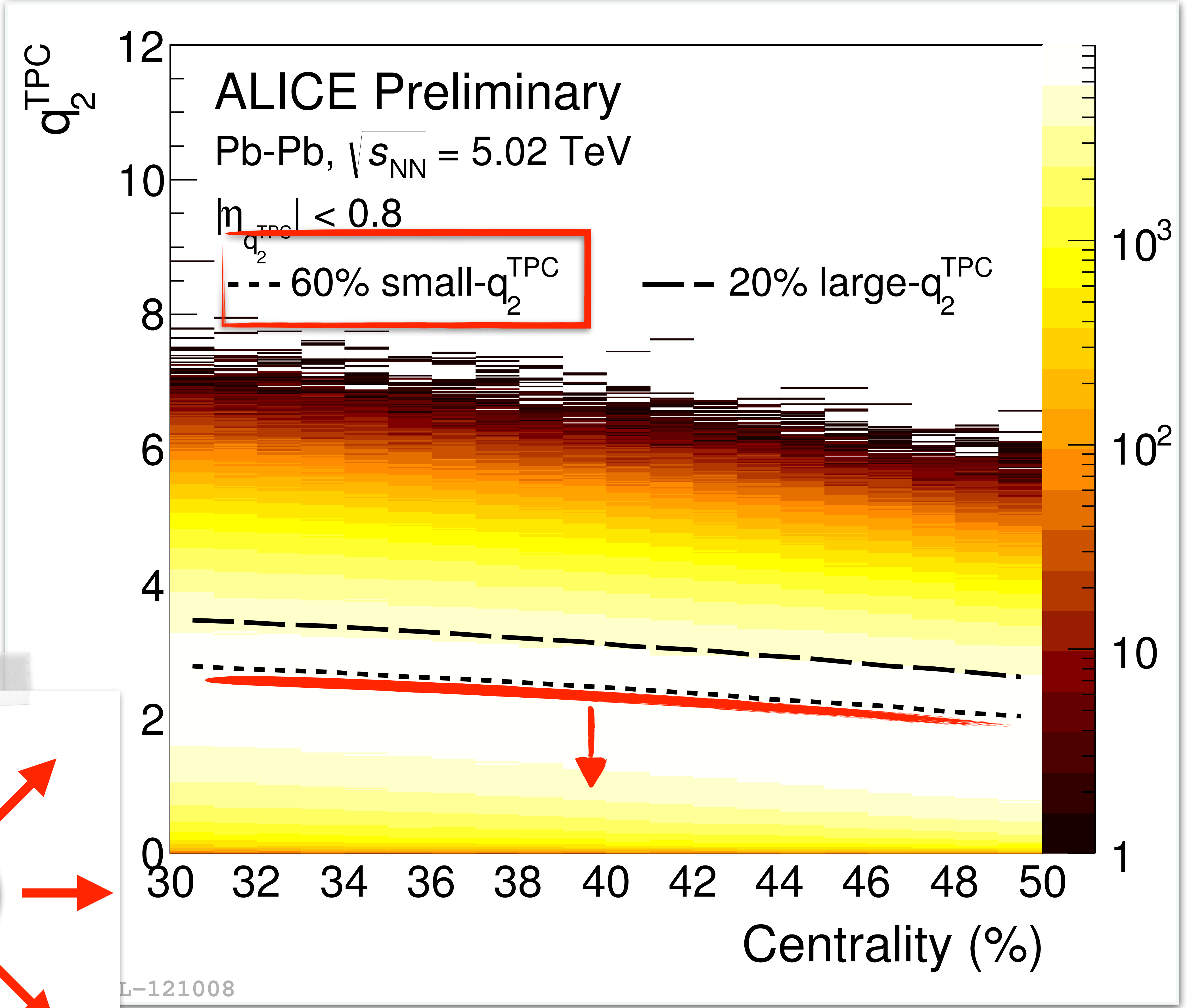

- Events divided in two classes:

(i) 60% with smallest q_2

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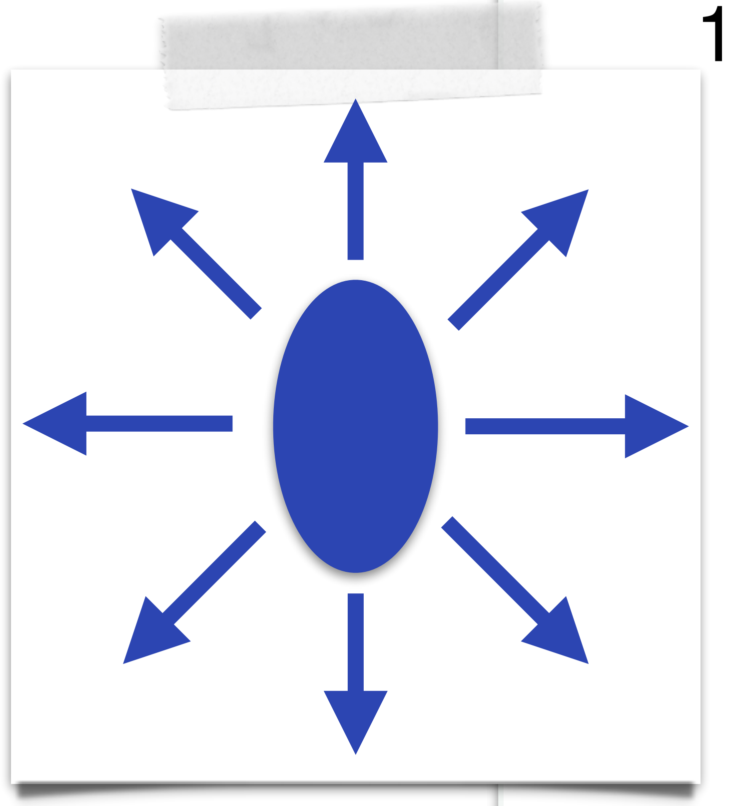
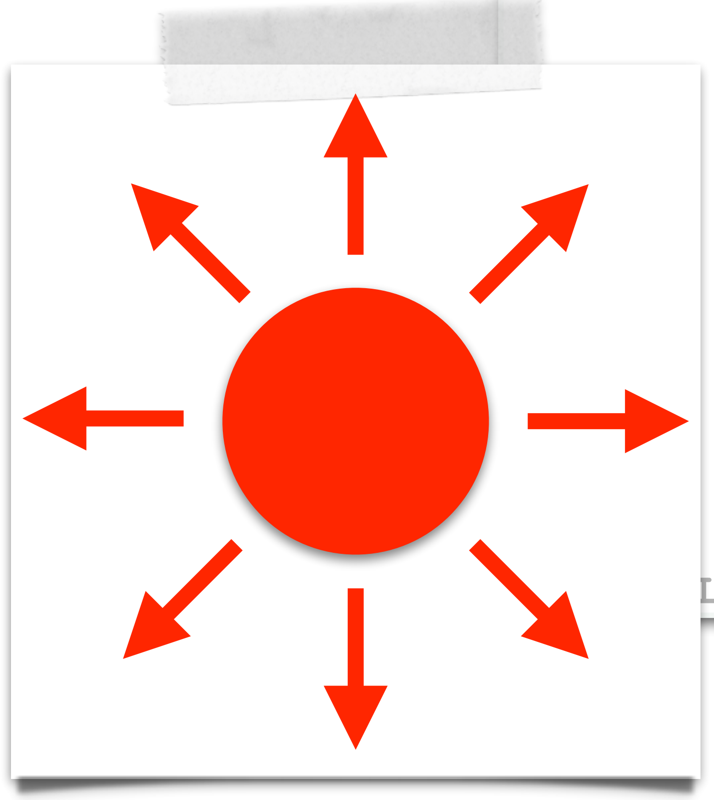
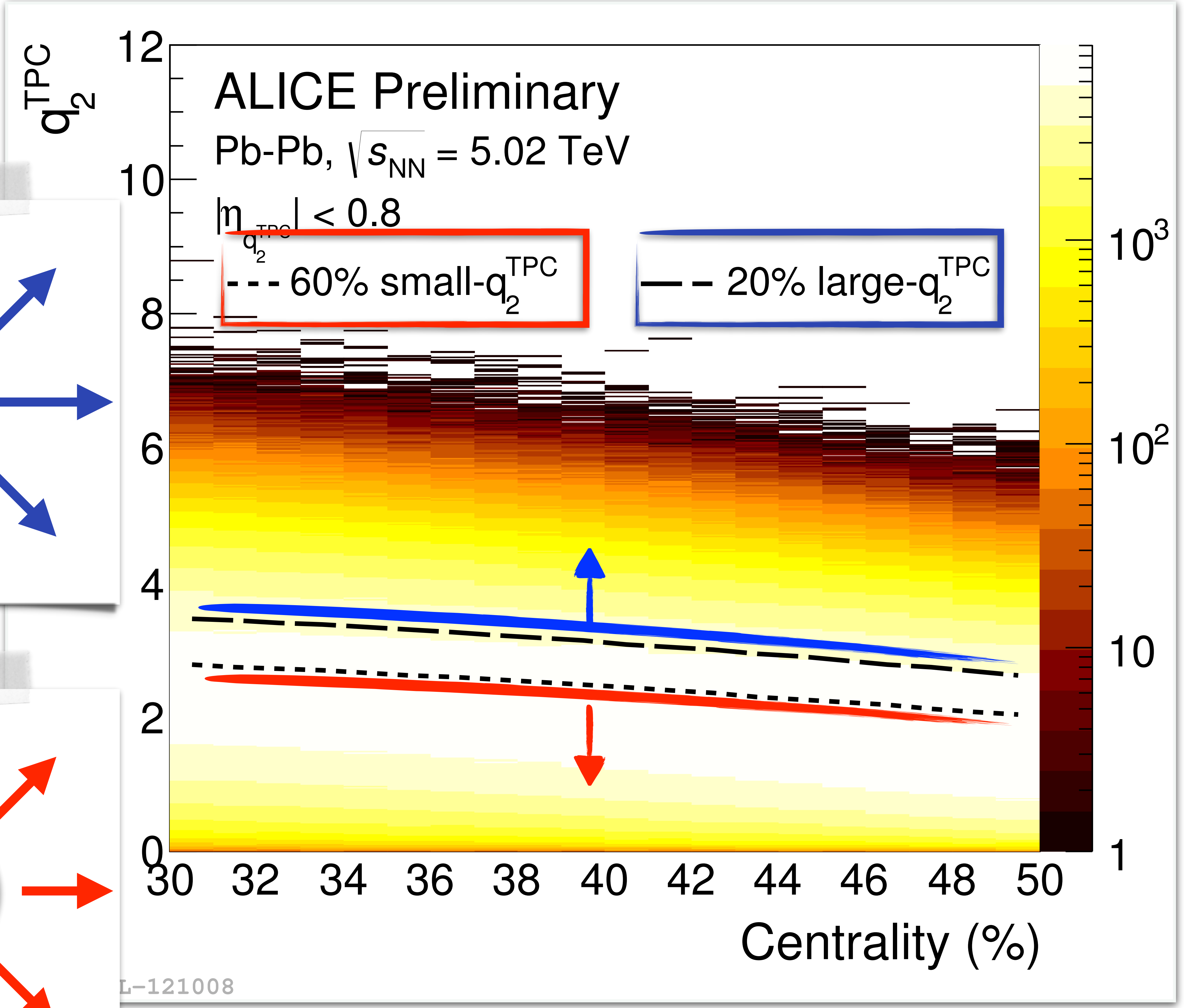


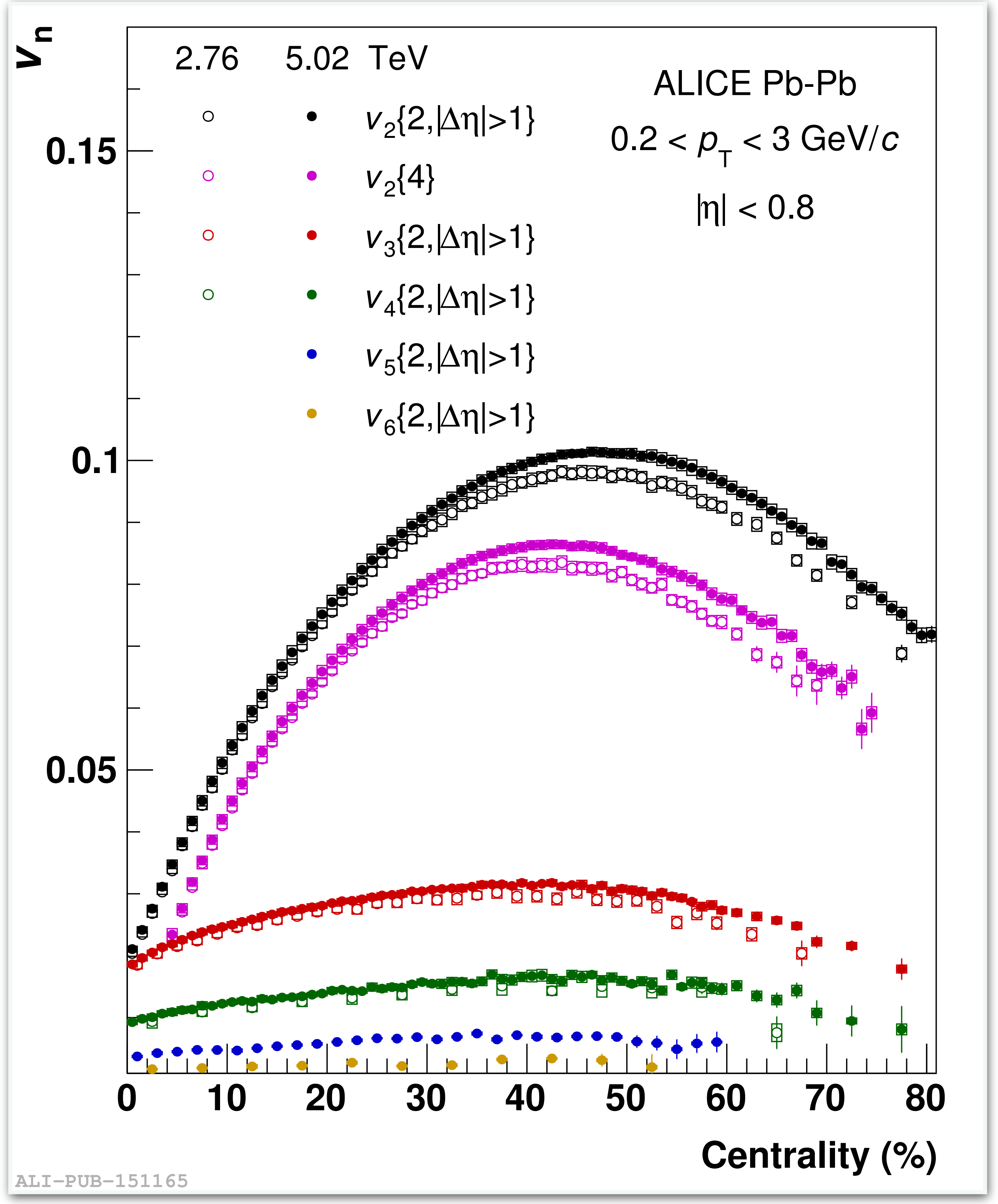




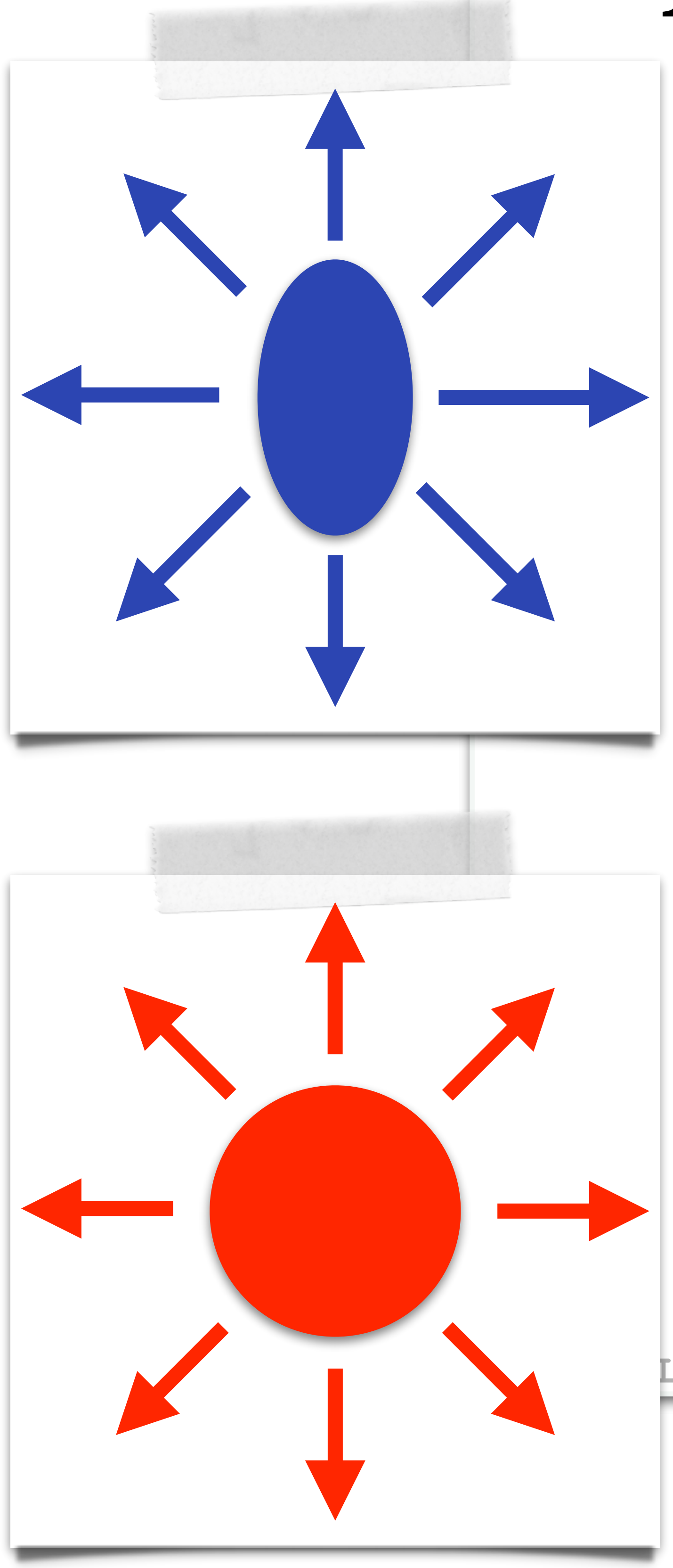
- Events divided in two classes:
  (i) 60% with smallest q_2
  (ii) 20% with largest q_2

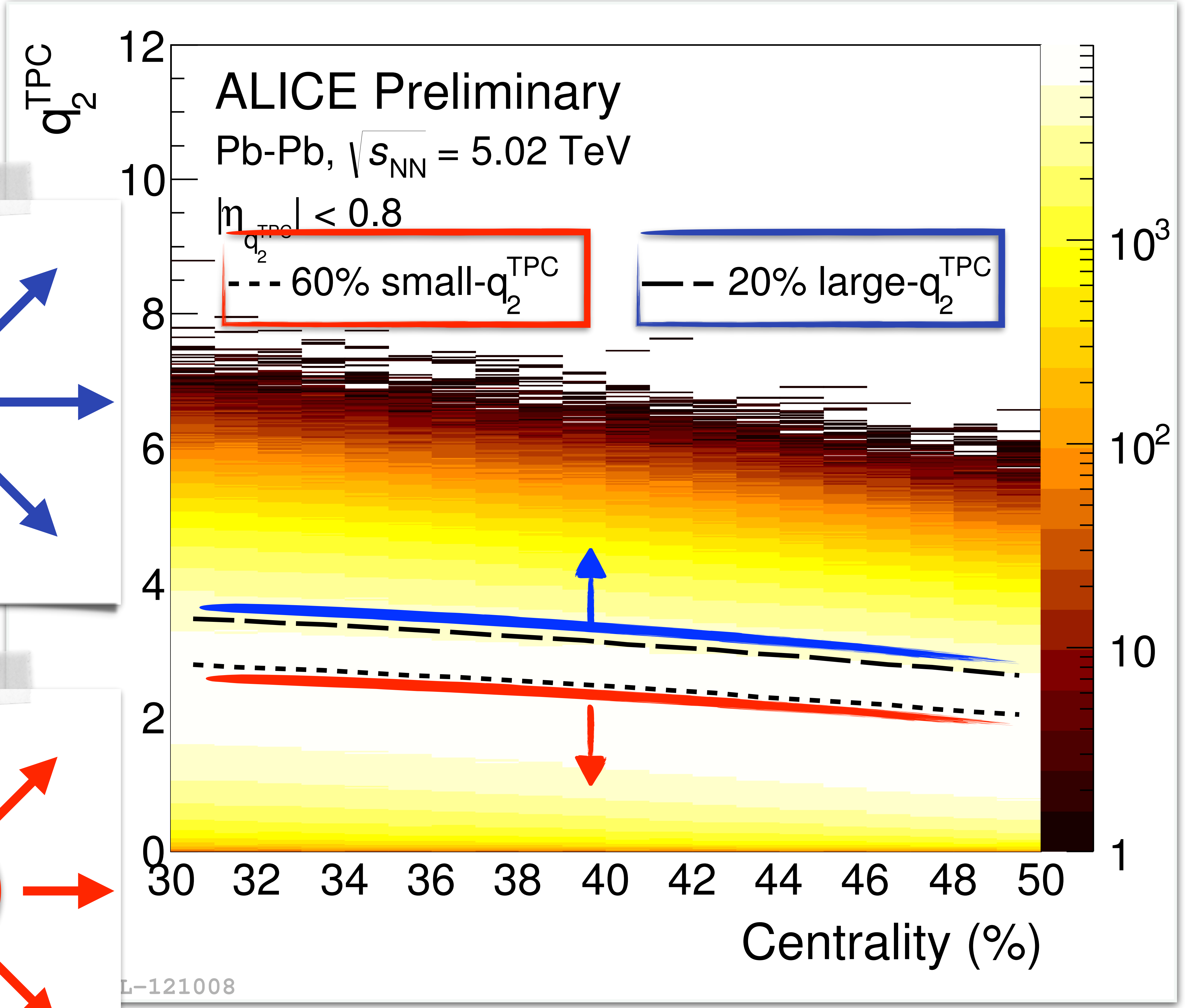
ESE for the D-meson v_2 - q_2 selection

- q_2 selection performed in 1% - wide centrality intervals, because of the centrality dependence of the q_2 (v_2)



otherwise unbalance centrality distribution and spoil ESE selection





- Events divided in two classes:
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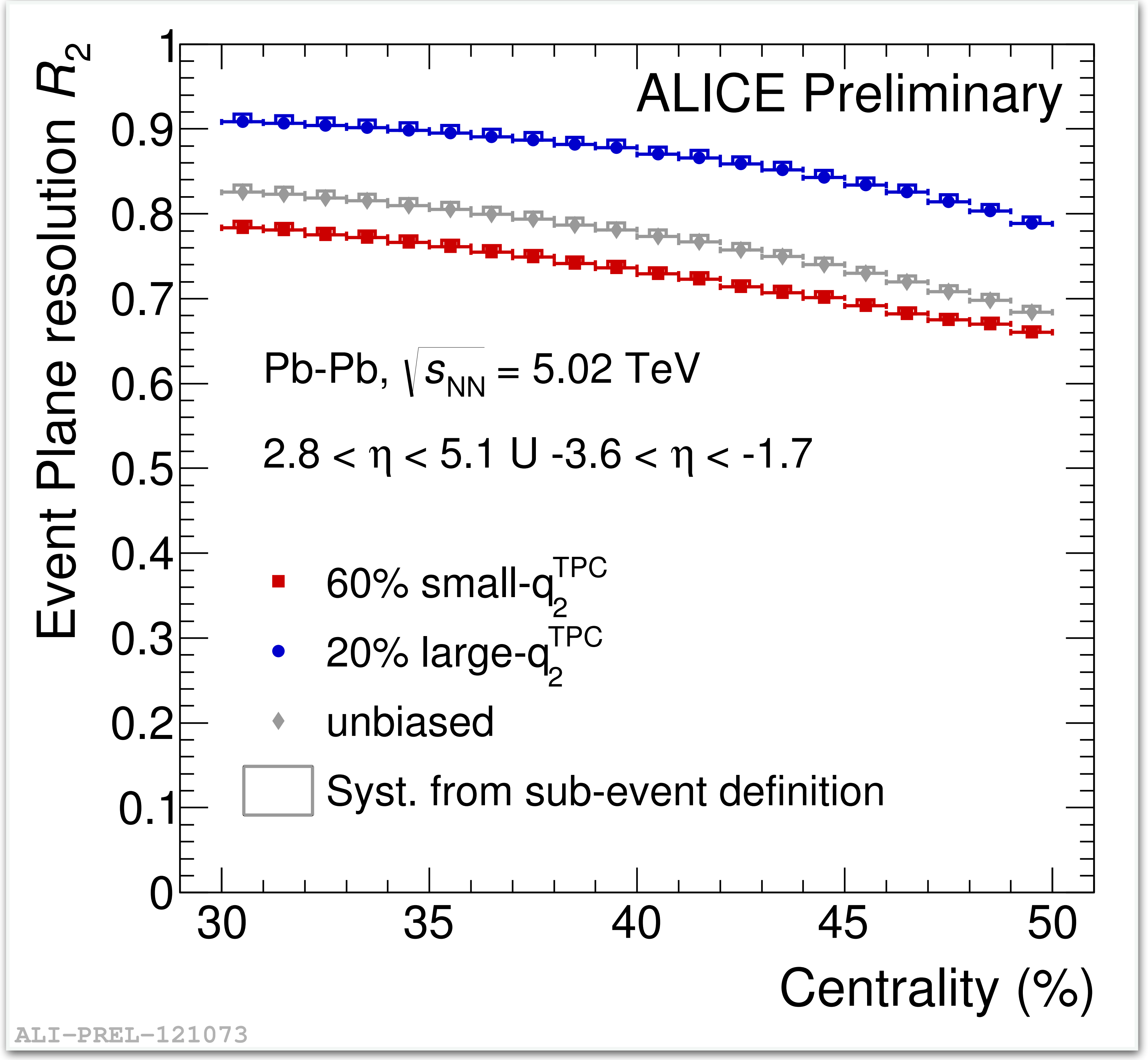
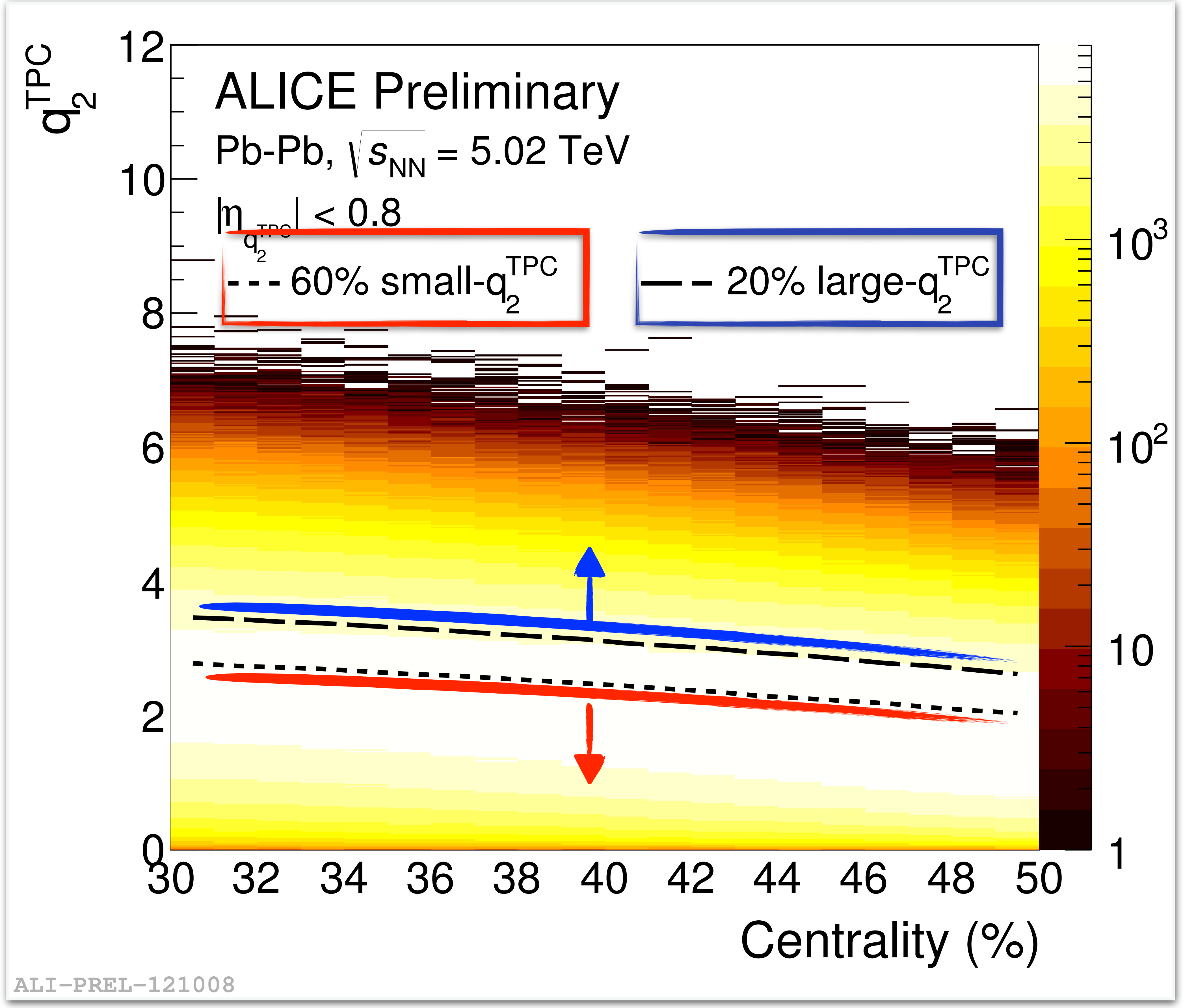
ESE for the D-meson v_2 - R_2 resolution

- Event-plane resolution computed independently for each ESE-selected sample



$$R_2 \propto v_2\sqrt{M} \quad [1]$$

larger in events with large q_2 (large v_2) and lower in events with small q_2 (small v_2)



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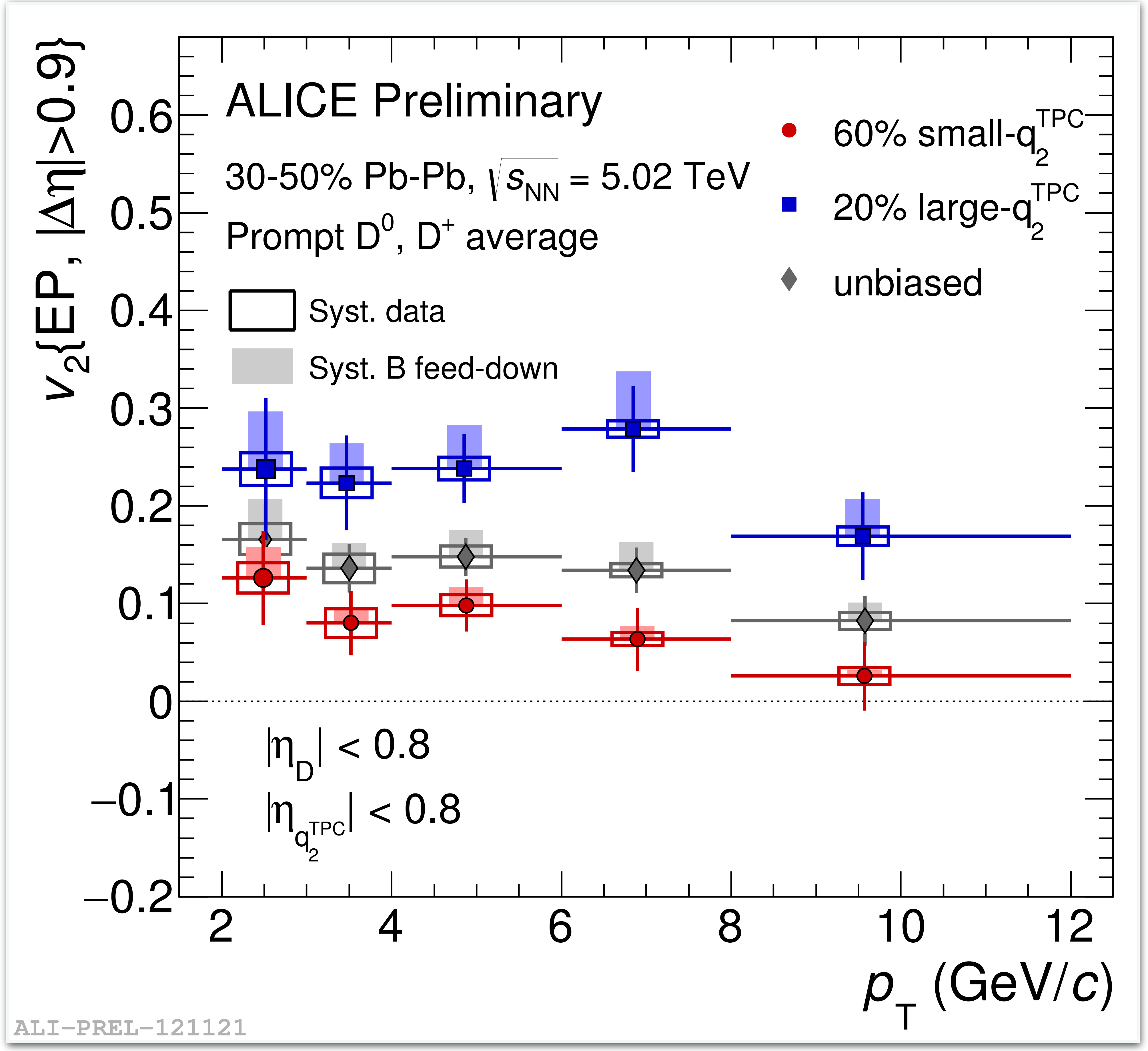
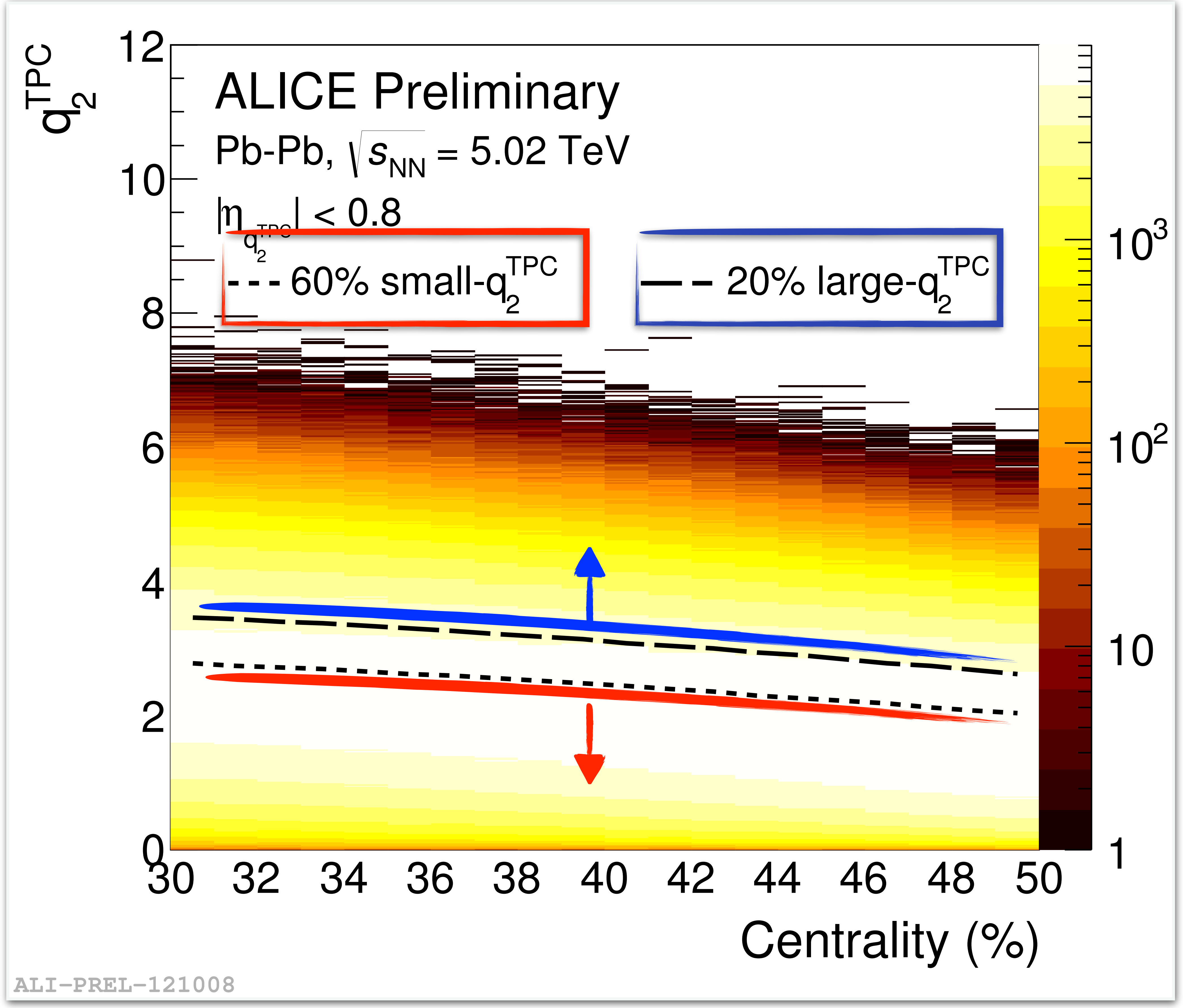
[1] Phys. Rev. C 58, 1671

ESE for the D-meson v_2

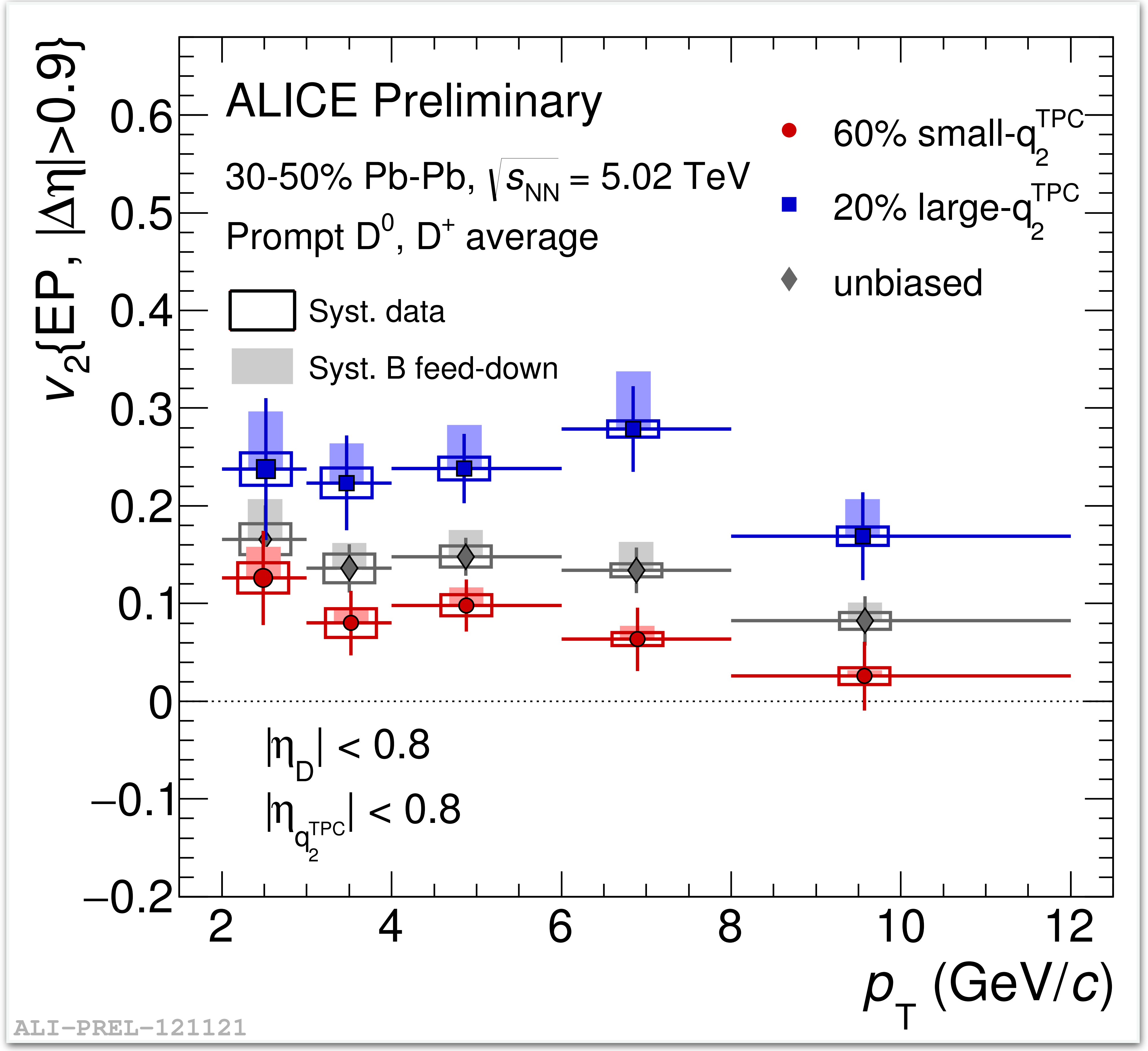


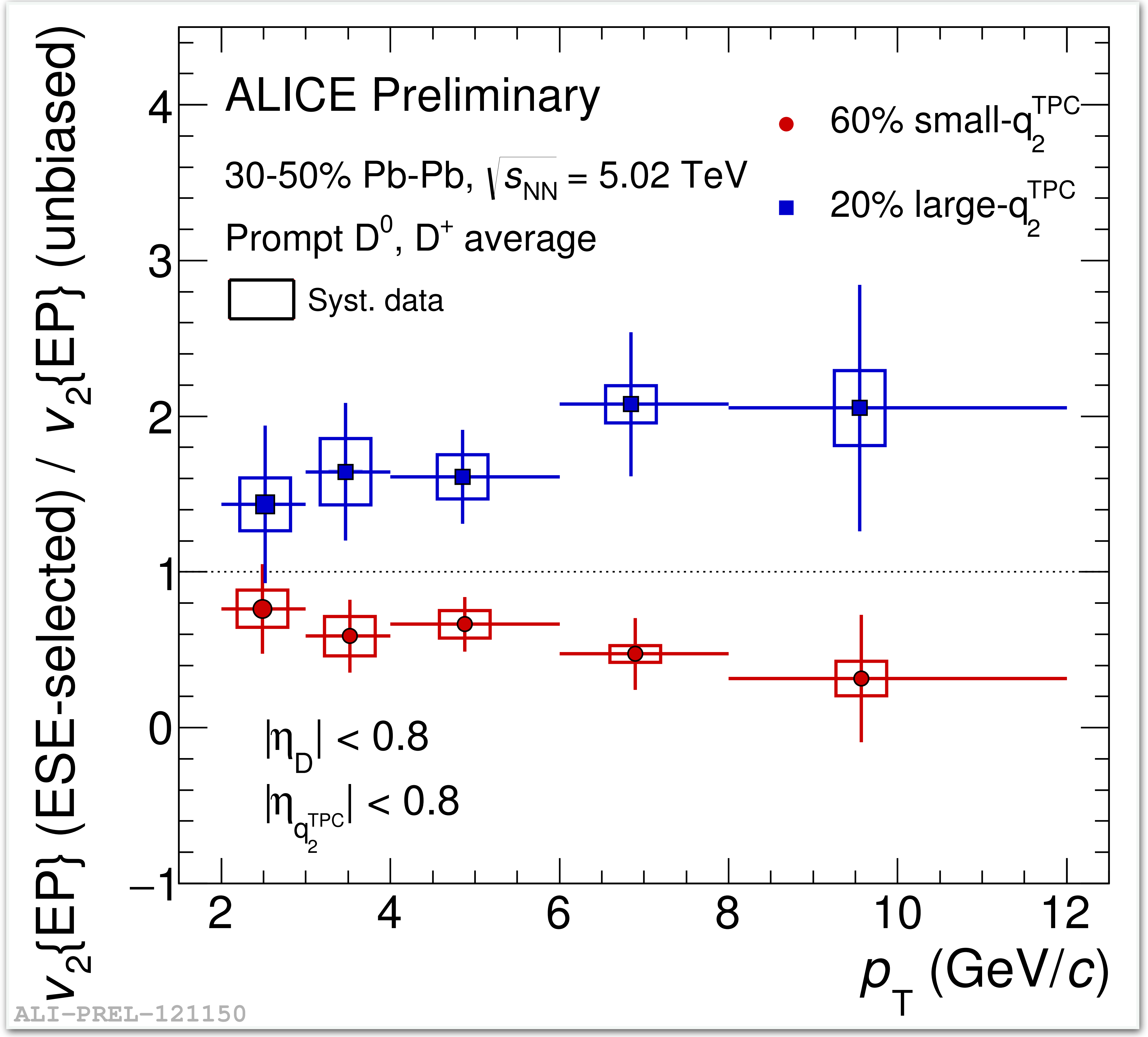


- Larger(smaller) D-meson v_2 in the large(small)-q_2 sample indicates a positive correlation between D-meson v_2 and the collective expansion of the bulk matter

- Events divided in two classes:
  - (i) 60% with smallest q_2
  - (ii) 20% with largest q_2

ESE for the D-meson v_2

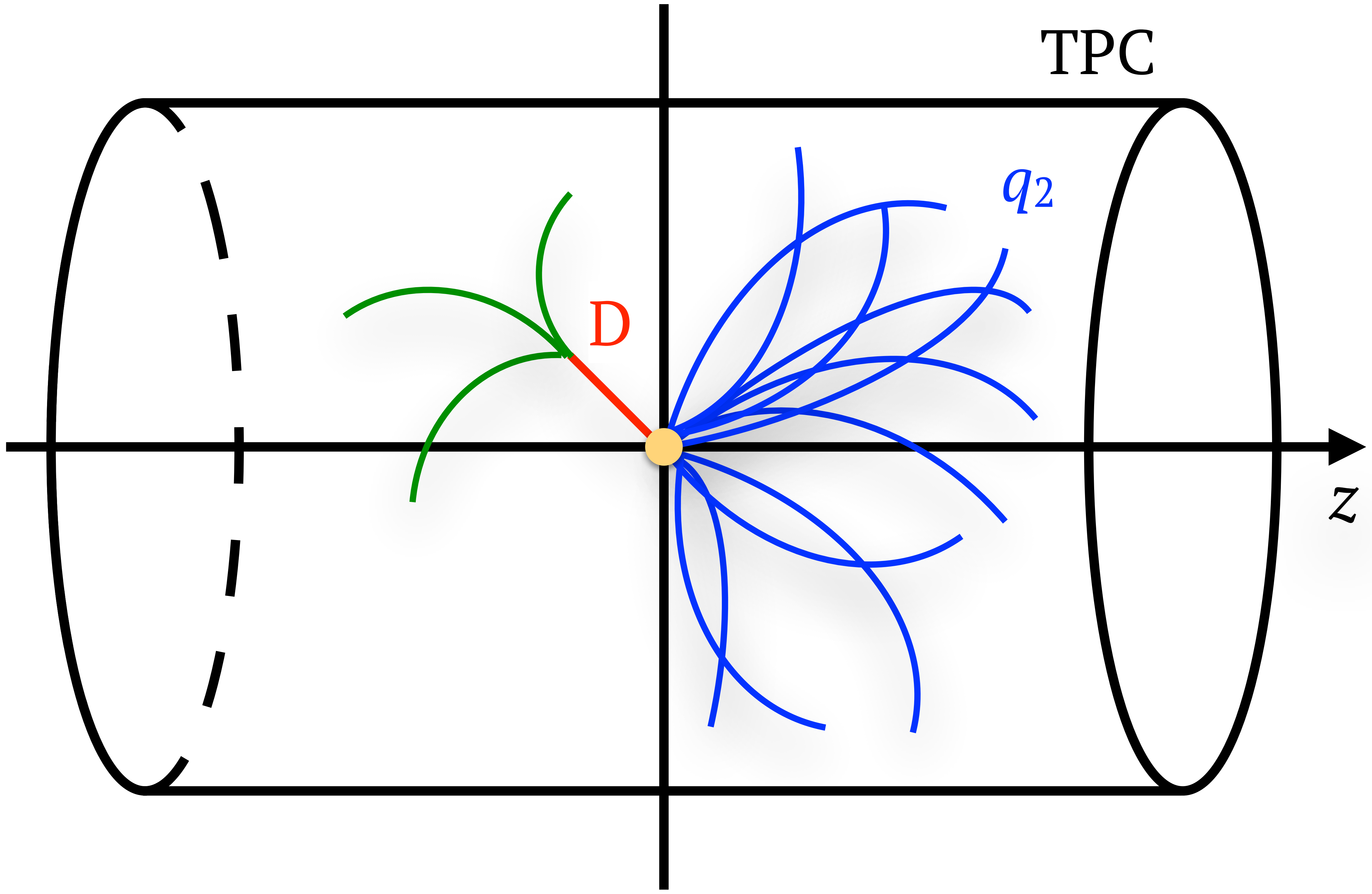


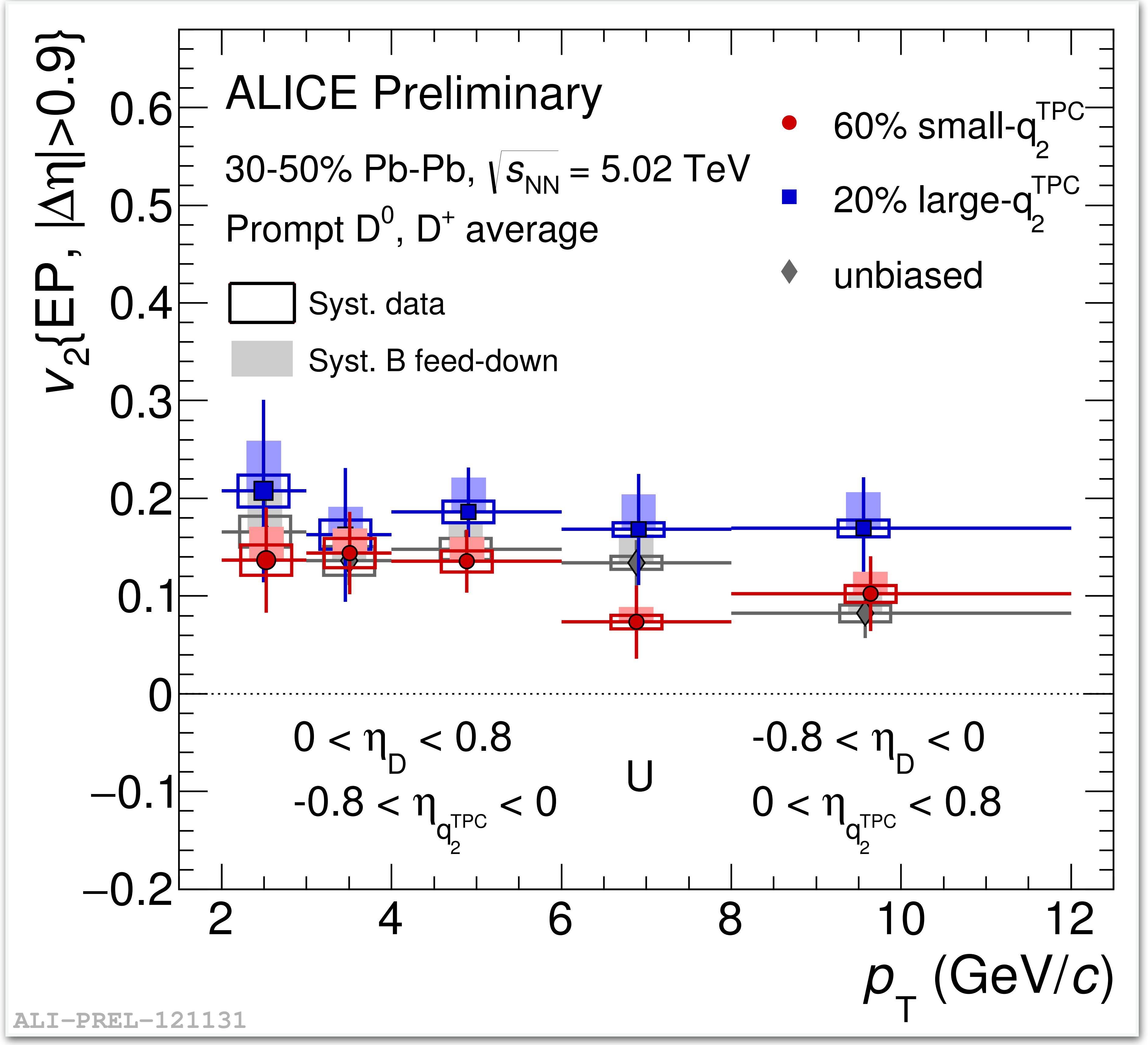


- D-meson v_2 about 50%(30%) larger than the unbiased one in the large(small)-q_2 sample
- Same pseudorapidity interval for D mesons and q_2 could lead to an increase of the effect due to autocorrelations and non-flow contributions

Autocorrelations and non-flow contributions

- To study non-flow contaminations and autocorrelations measurement repeated correlating
  (i) D-meson v_2 in one half of the TPC ($0 < \eta < 0.8$ or $-0.8 < \eta < 0$)
  (ii) q_2 in the other half of the TPC ($-0.8 < \eta < 0.8$ or $0 < \eta < 0.8$)





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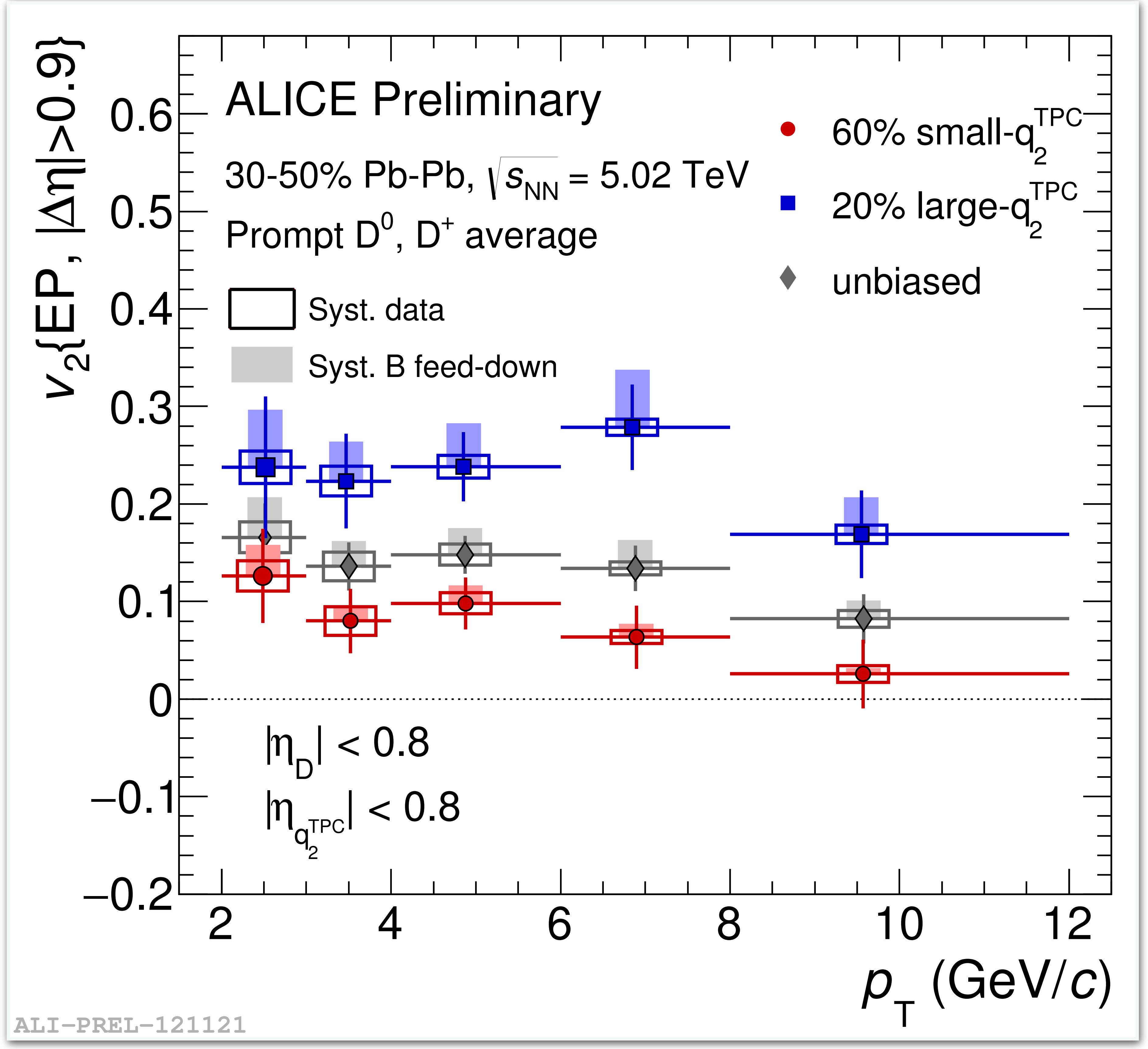
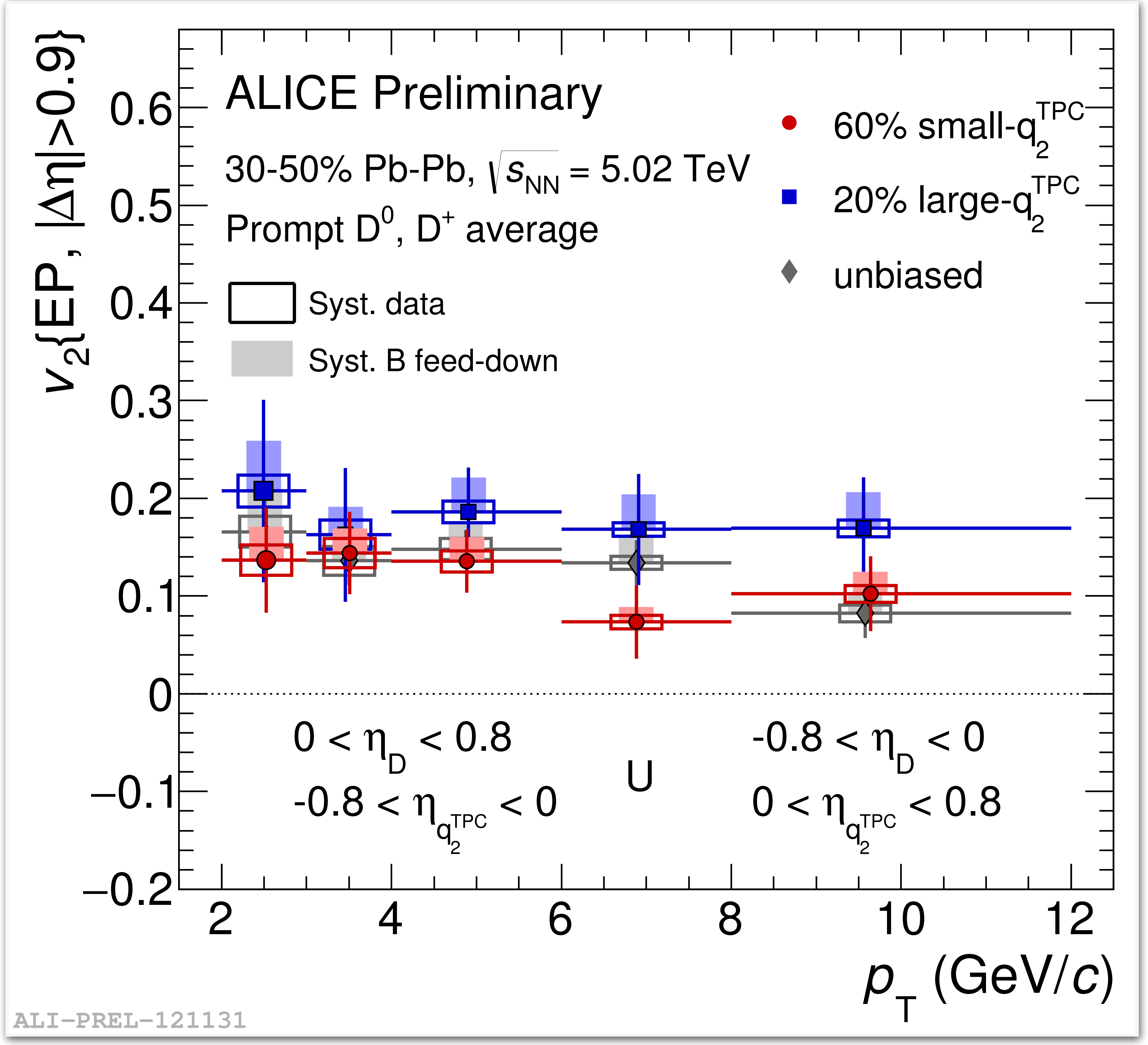
- Effect still present, but reduced

↓

Is it only due to autocorrelations and non-flow contributions?

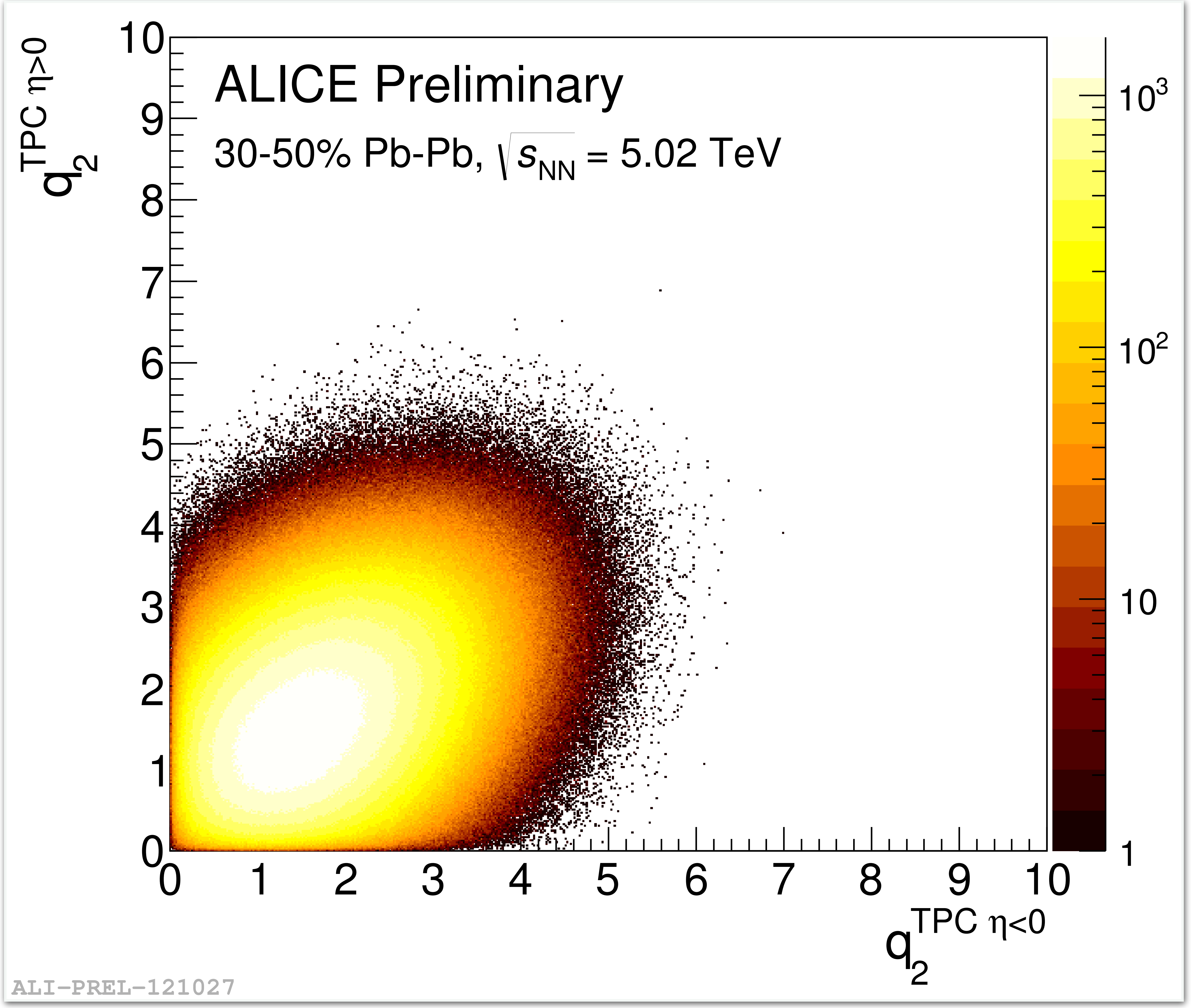




Spoil of the q_2 selectivity

- The reduction of the separation between the ESE-selected v_2 observed by performing the measurement with $|\Delta\eta| > 0$ between the D-meson v_2 and the q_2 is a superposition of two effects:
  (i) removal of non-flow contributions and autocorrelations
  (ii) spoil of the q_2 selectivity due to the reduction of the number of tracks used to compute q_2

→ reflected in a broad correlation between $q_2(0 < \eta < 0.8)$ and $q_2(-0.8 < \eta < 0)$



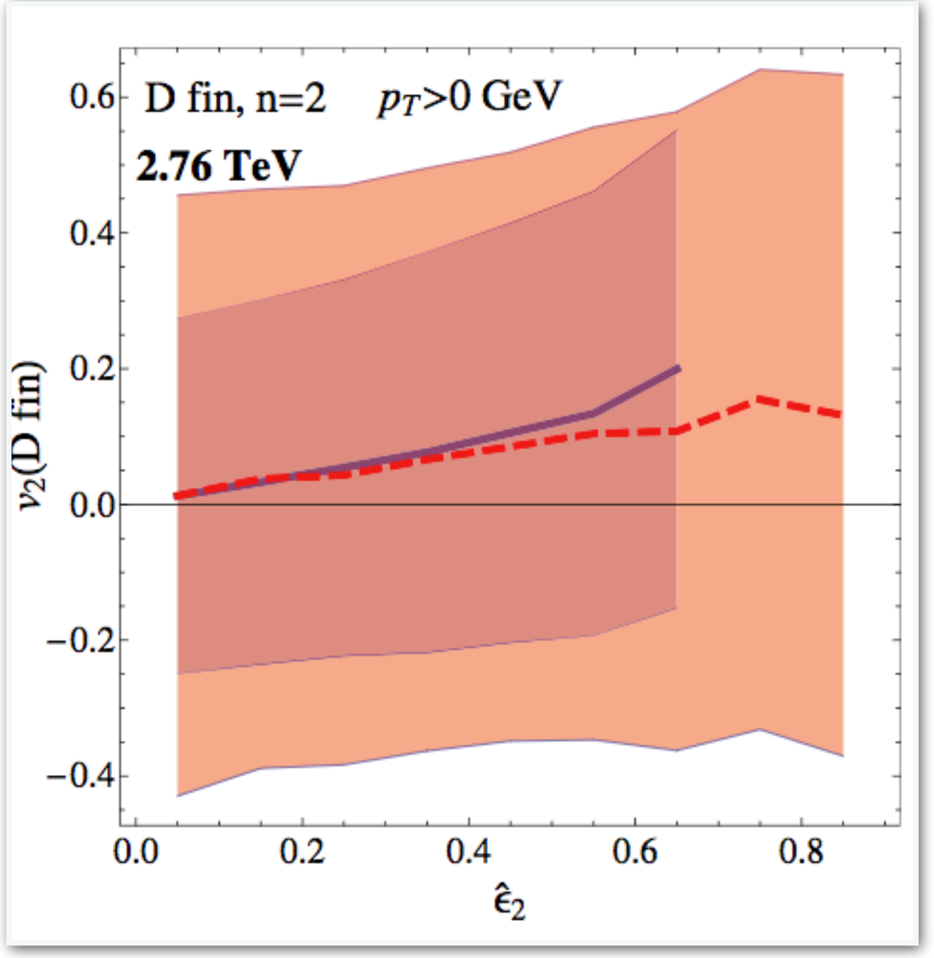
Conclusions and outlook

- D^0, D^+, D^{*+}, D_s^+ unbiased v_2 in mid-central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - (i) Non-strange D-meson elliptic flow larger than zero in and similar to that of pions
  - (ii) D_s^+ v_2 compatible to that of non-strange D mesons and positive with 2.6σ significance

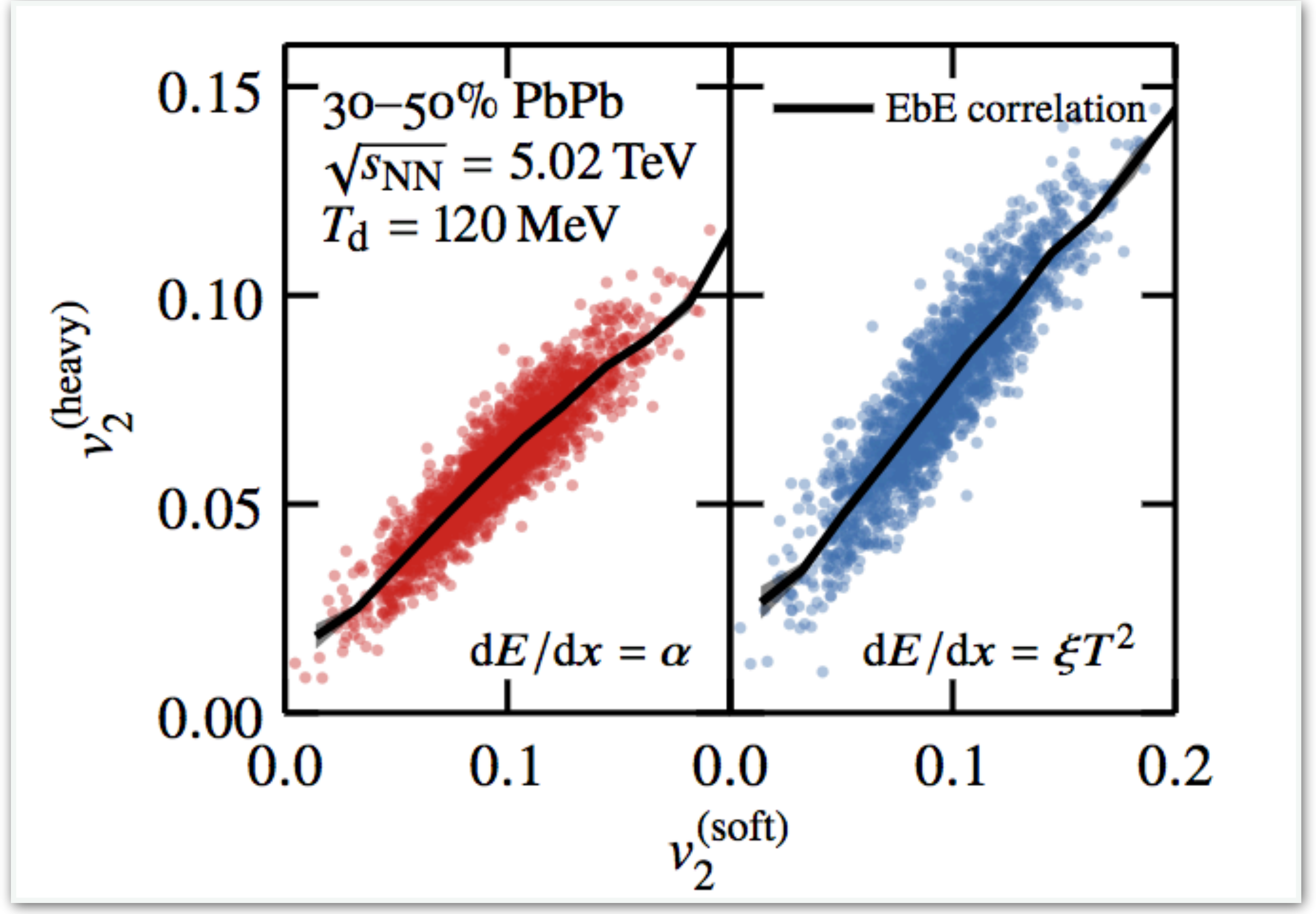
- Event-shape engineering for the D-meson v_2
  - (i) Suggests a correlation between the D-meson v_2 and light hadrons v_2
  - (ii) Next step: comparison to models

  → can we learn something more about the coupling of the charm quark with the medium?

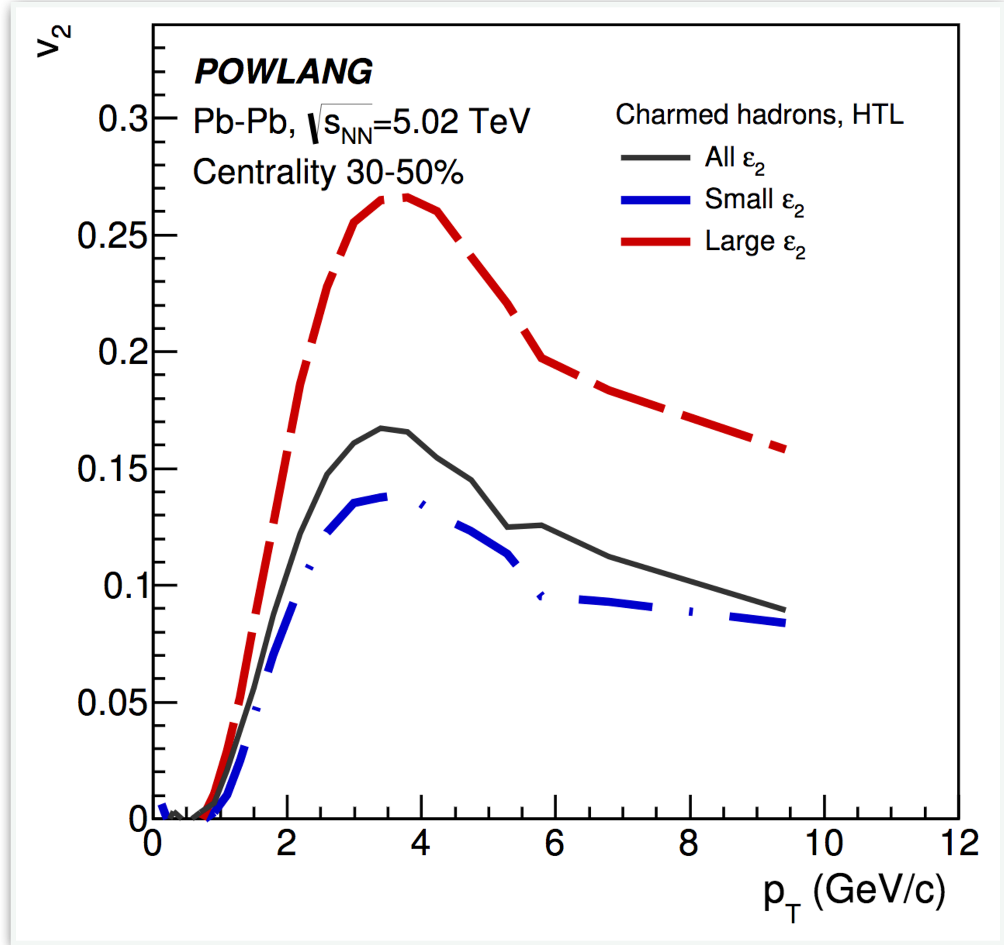
[1]



[2]



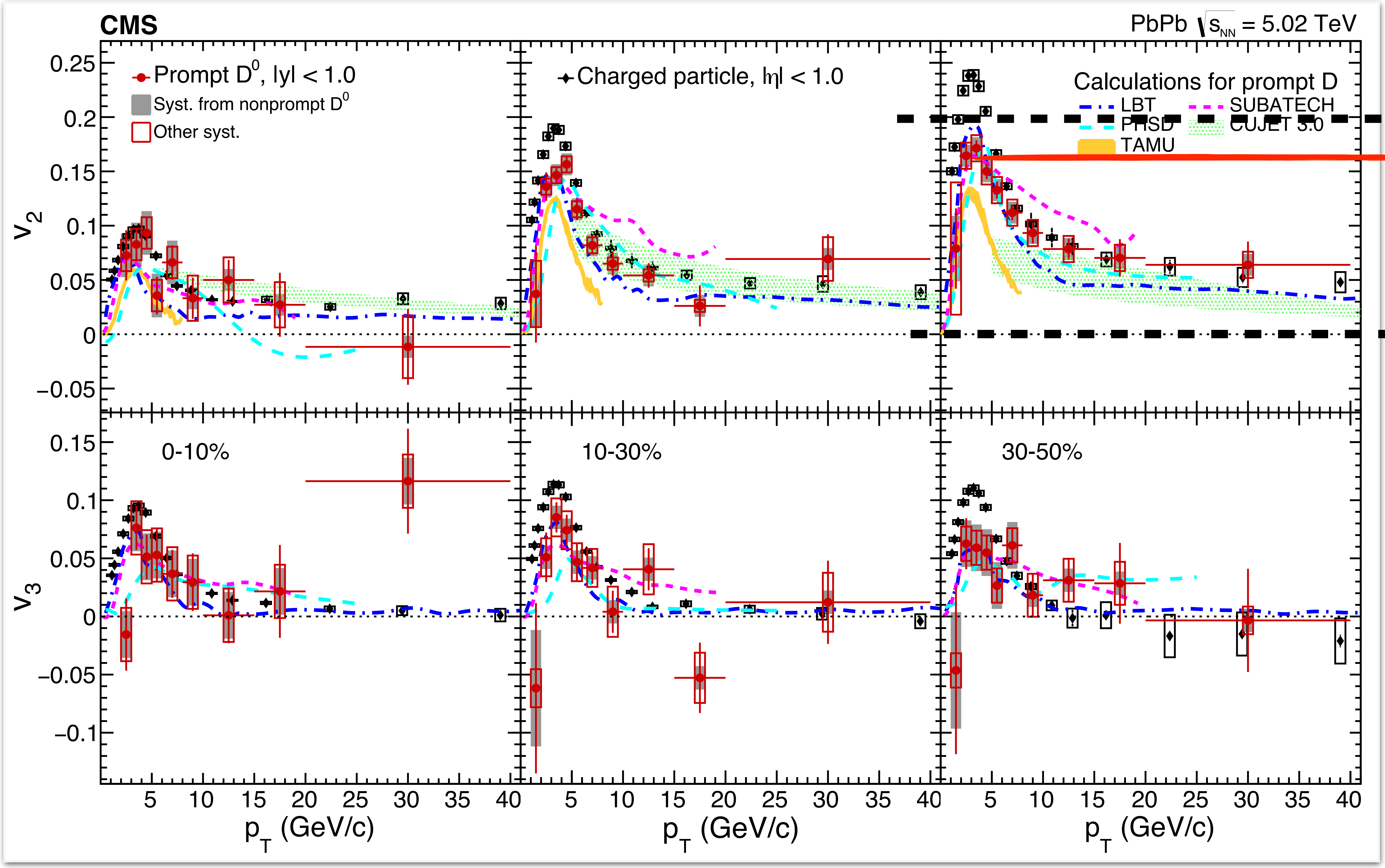
[3]

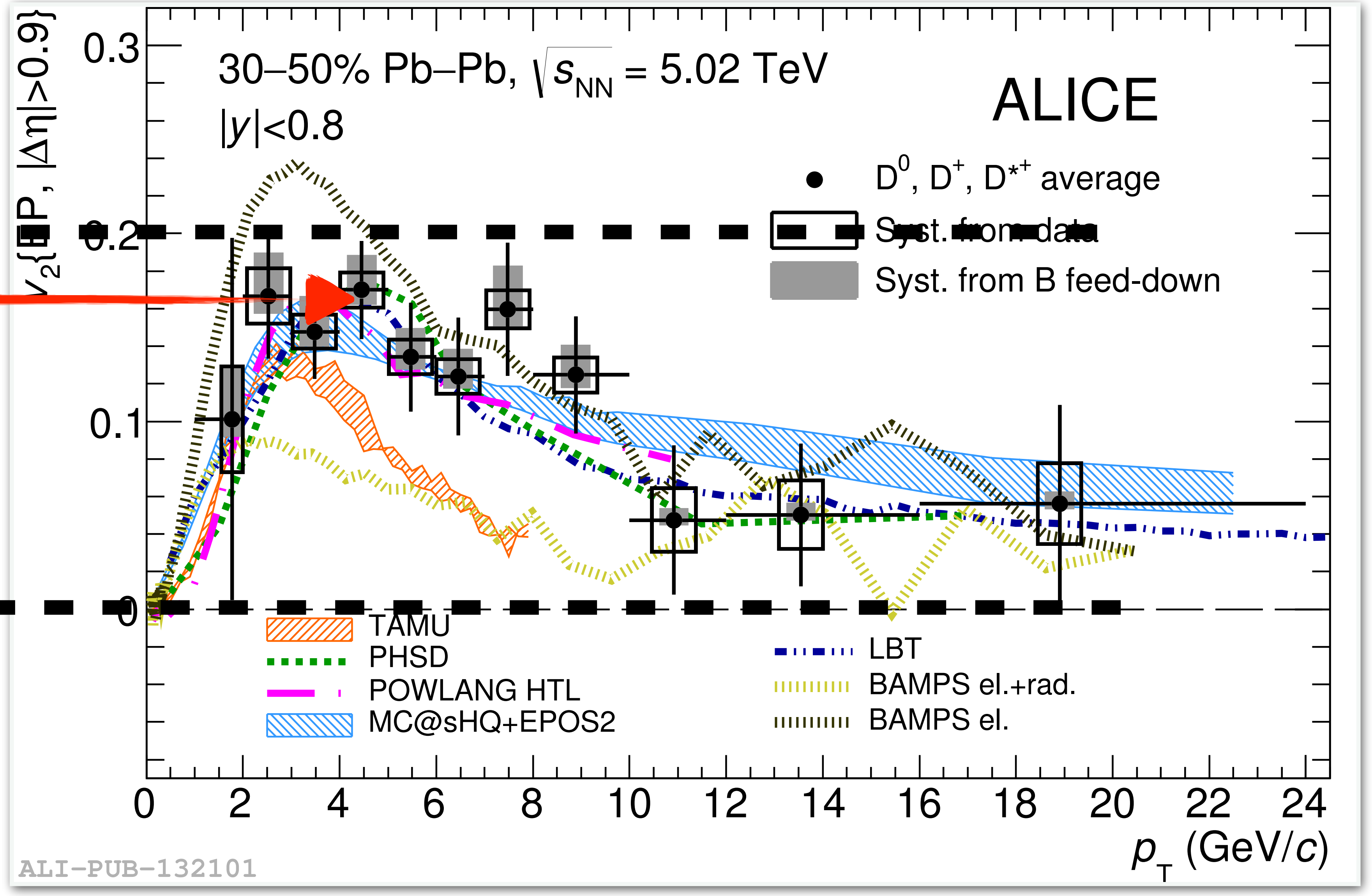


[1] Gossiaux SQM17
[2] Prado et all., Nucl. Phys. A 967 (2017) 664-667
[3] Beraudo QM18

BACKUP SLIDES

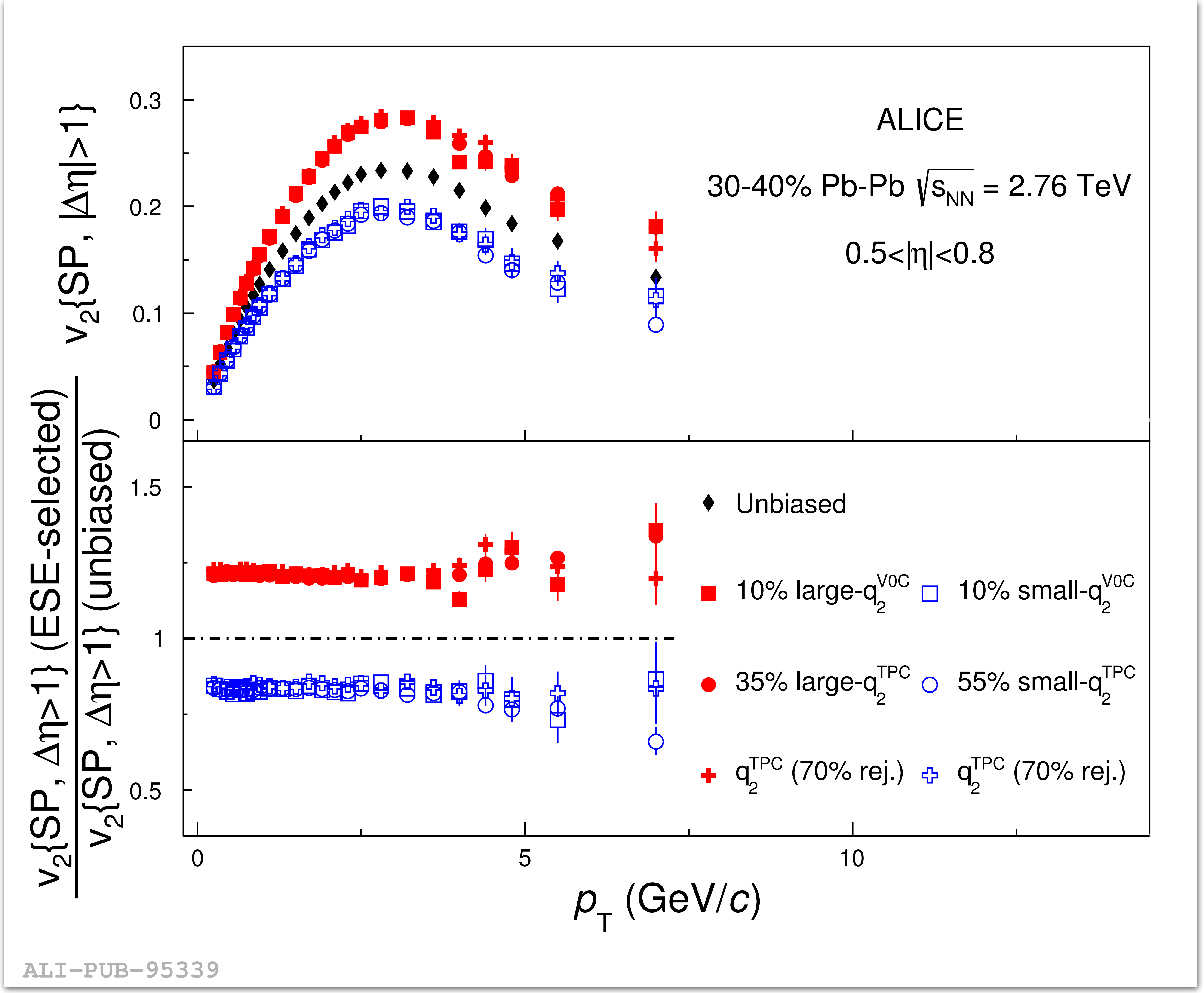
D-meson v_2 ALICE - CMS comparison





- Similar D-meson v_2 measured with EP method by ALICE and SP method by CMS

Different q_2 selectivity - charged particles



- The effect observed considering the 10% events with largest(smallest) q_2 computed using the V0C can be obtained using TPC:
  (i) releasing the selection on q_2 (35% for the large-q_2 sample and 55% for the small-q_2 sample)
  (ii) decreasing artificially the number of tracks used to compute q_2 of 70%

Coupling between radial and elliptic flow - identified particles