Harmonic decomposition of two particle angular correlations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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for the
ALICE Collaboration

7th Workshop on
Particle Correlations
and Femtoscopy
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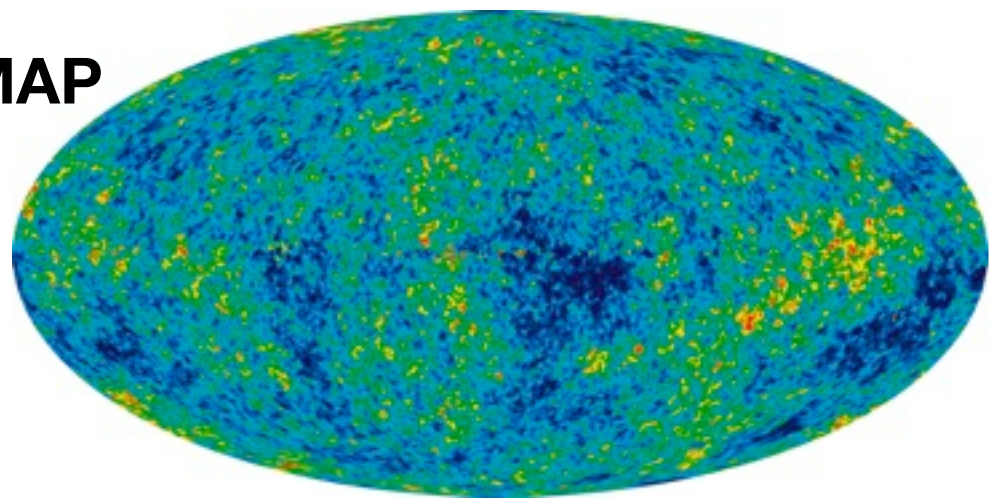
Based on arXiv:1109.2501
(Submitted 12 Sep 2011)

Harmonics of Big and Little Bangs

Temperature anisotropy from CMB radiation

Power spectra hold a wealth of info from early epochs

WMAP



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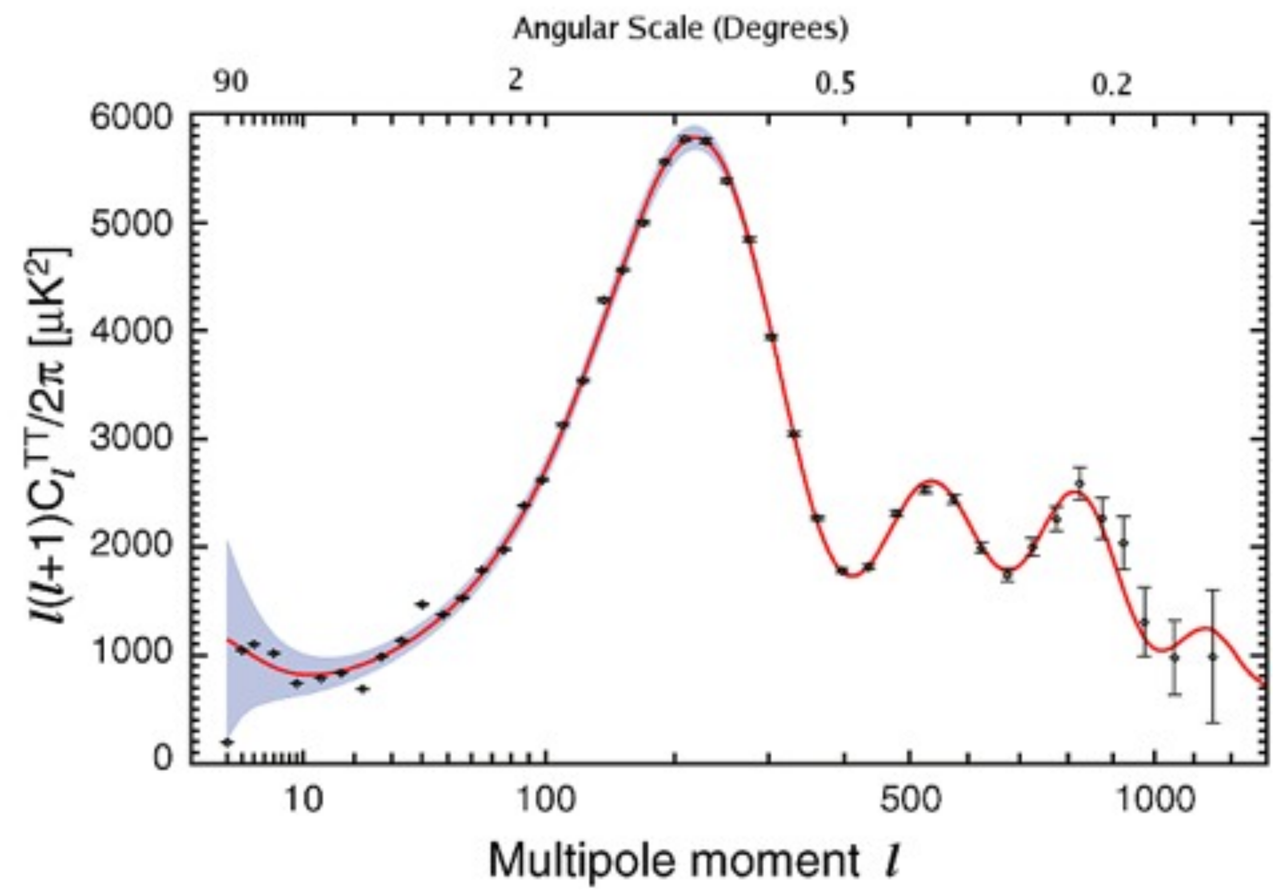
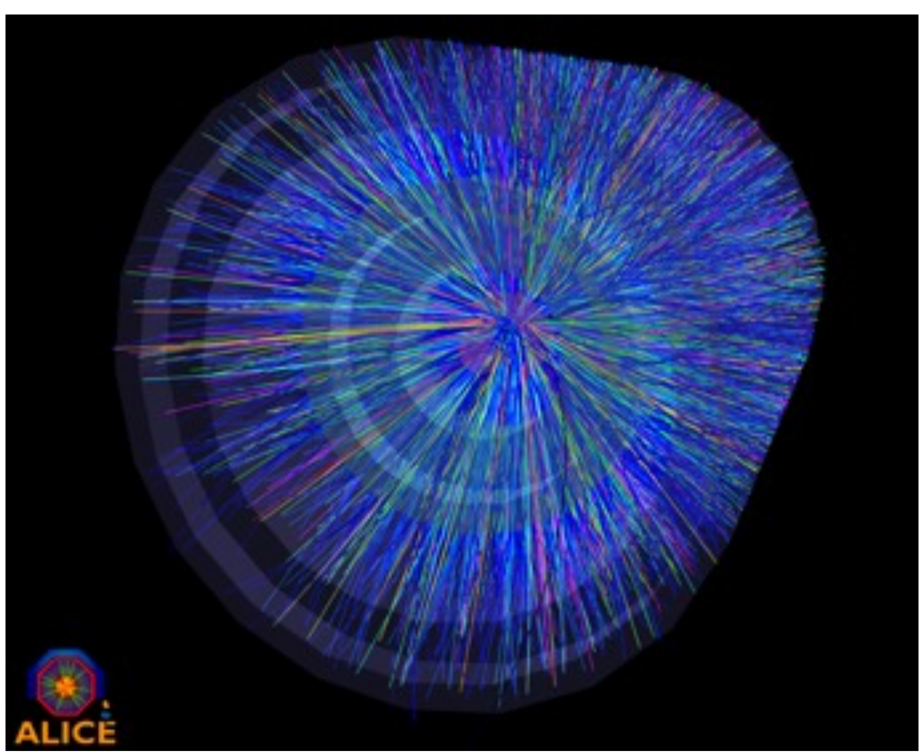


TeV-scale Pb-Pb collisions



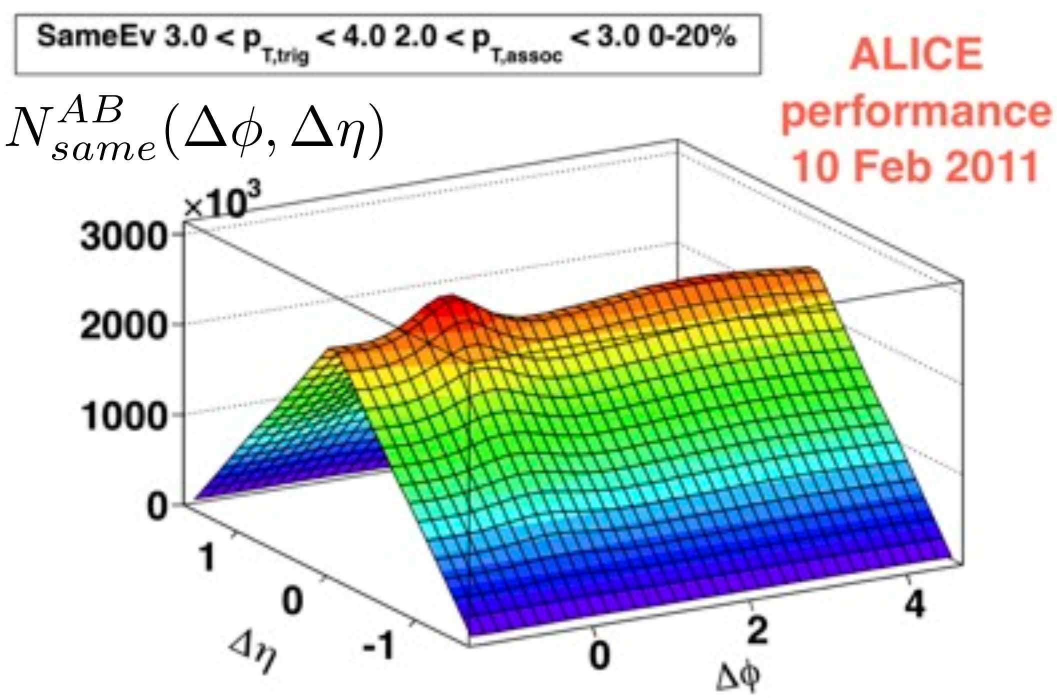
Can we similarly make "power spectra" from A+A collisions?

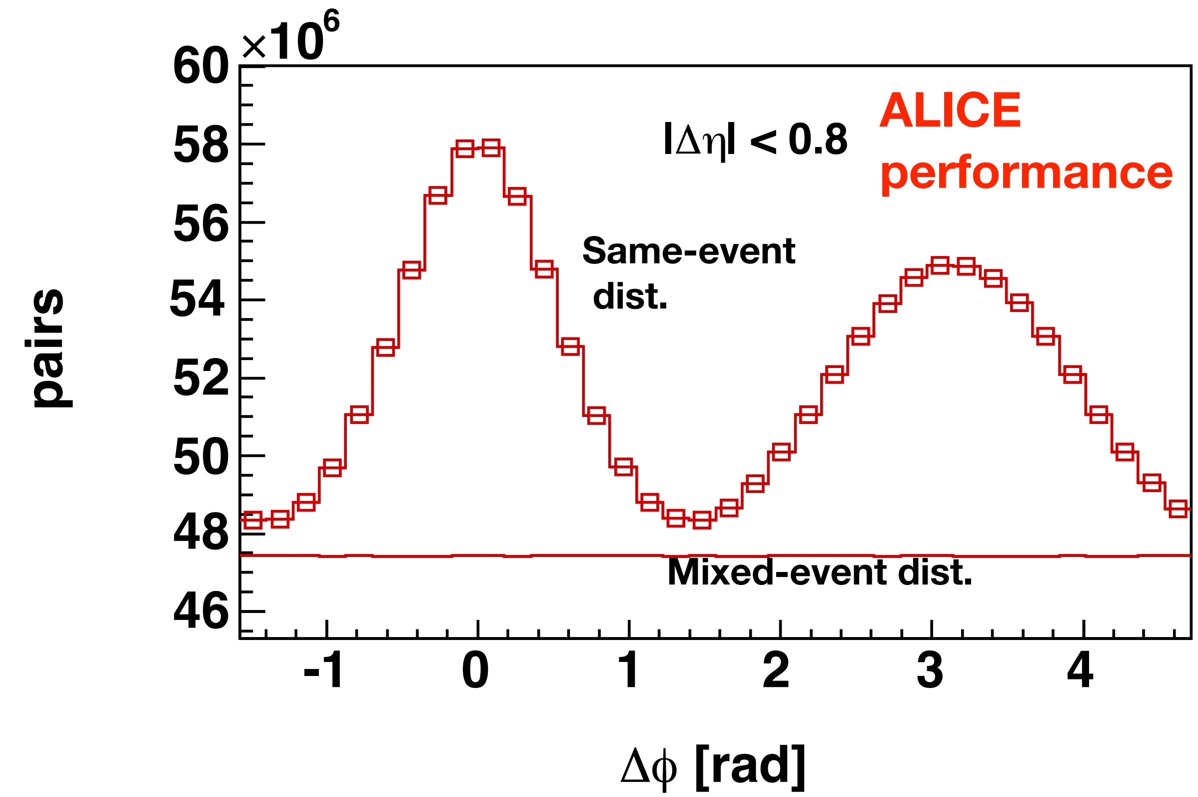
What can be learned?

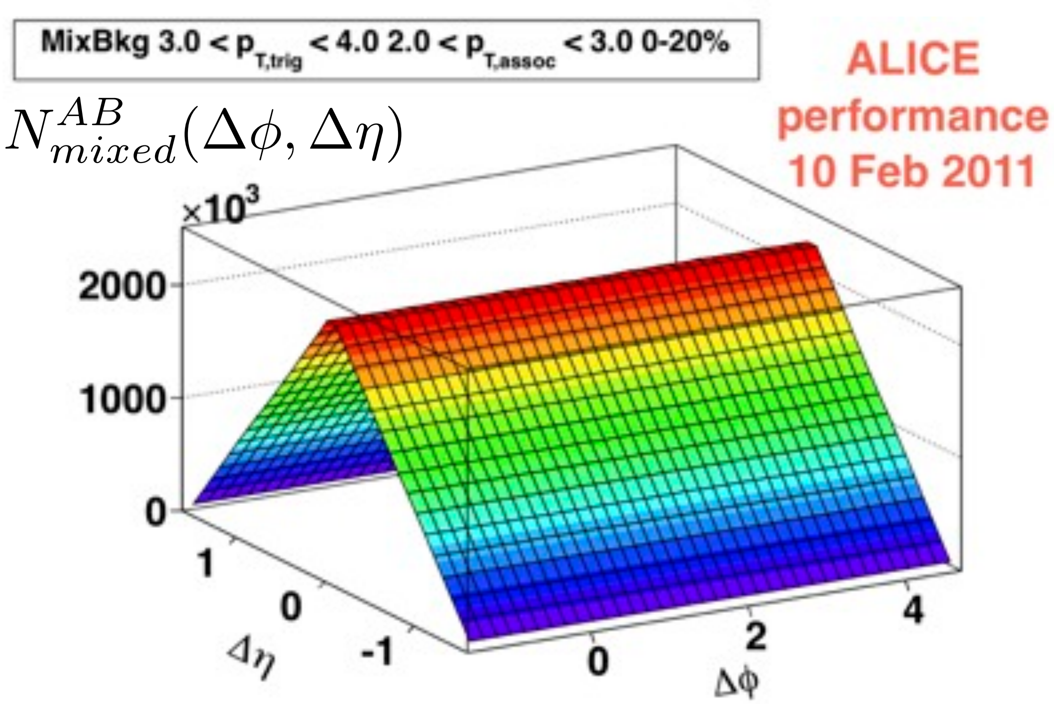
Two-particle correlations

Same and mixed event pair distributions

$$\Delta\phi = \phi_A - \phi_B \qquad \Delta\eta = \eta_A - \eta_B$$







Azimuthal correlation function:

$$C(\Delta\phi) \equiv \frac{N^{AB}_{mixed}}{N^{AB}_{same}} \cdot \frac{dN^{AB}_{same}/d\Delta\phi}{dN^{AB}_{mixed}/d\Delta\phi}$$

Analysis and dataset

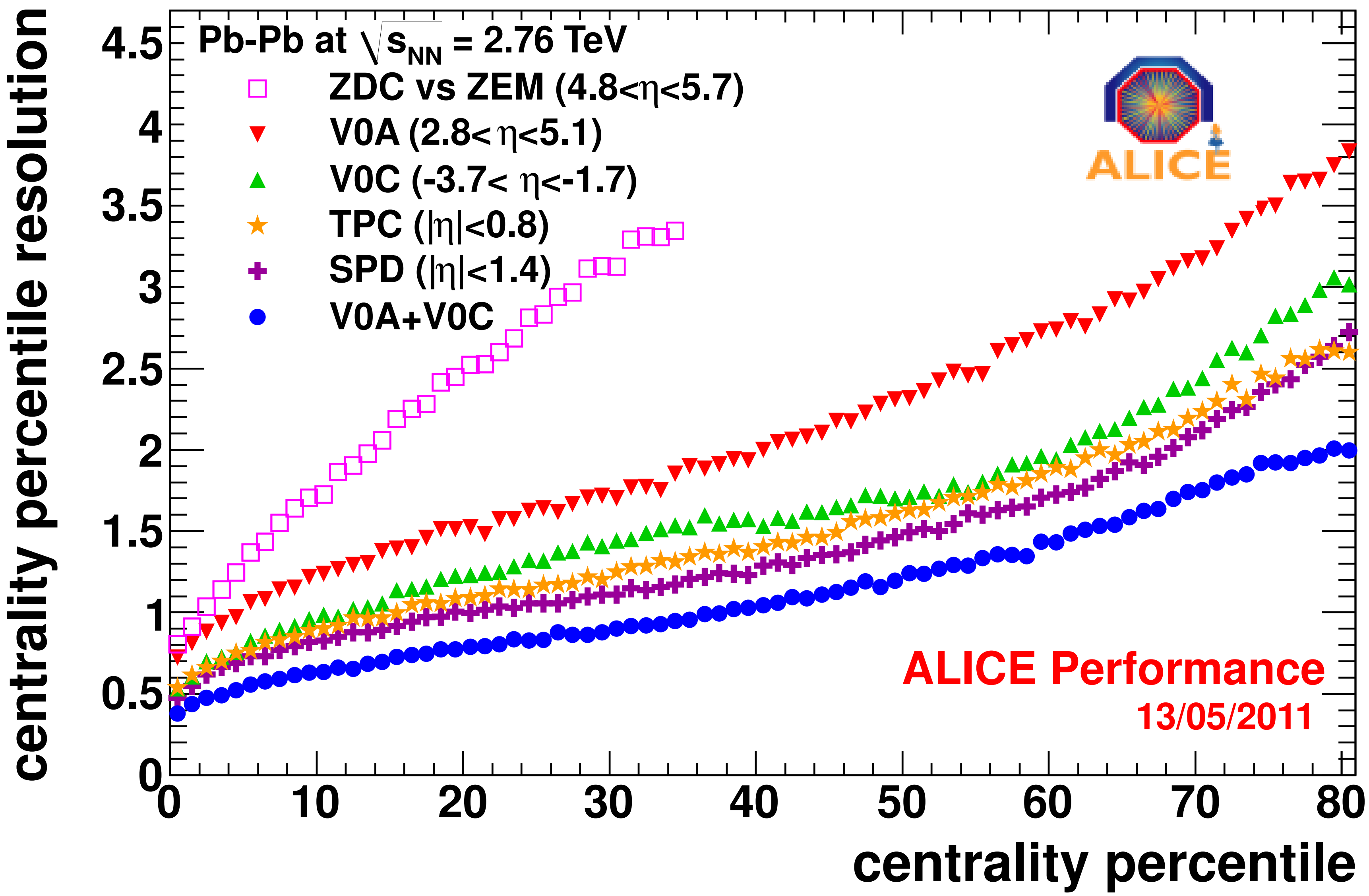
Pb-Pb at 2.76 TeV

13.5 M events in 0-90% after event selection

Centrality

VZERO detectors

resolution < 1%



Tracking

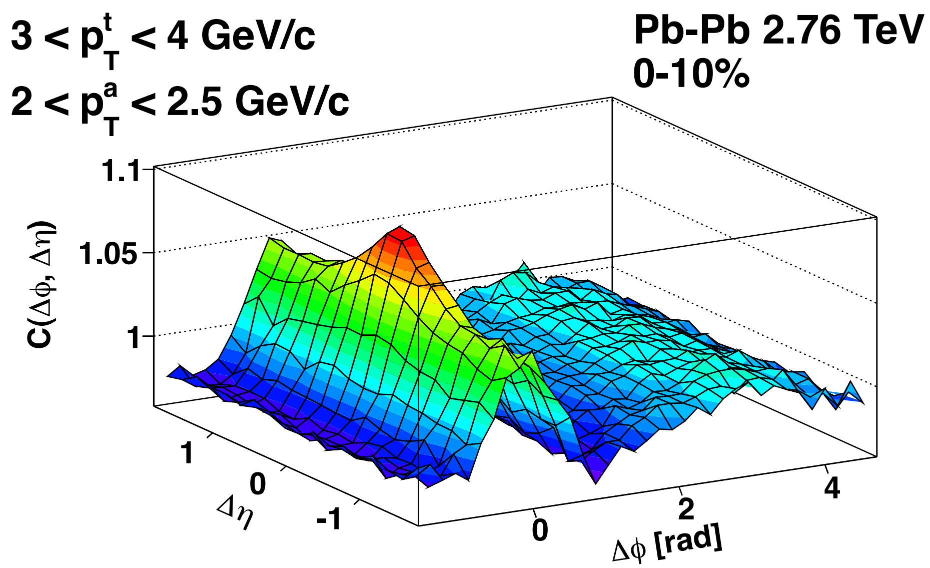
TPC points + ITS vertex

optimum acceptance + precision for correlations

Event structure and shape evolution

In central and low-p_T “bulk-dominated” long-range correlations

- A near side ridge is observed
- A very broad away side is observed, even doubly-peaked for 0-2% central



In high-p_T “jet-dominated” correlations

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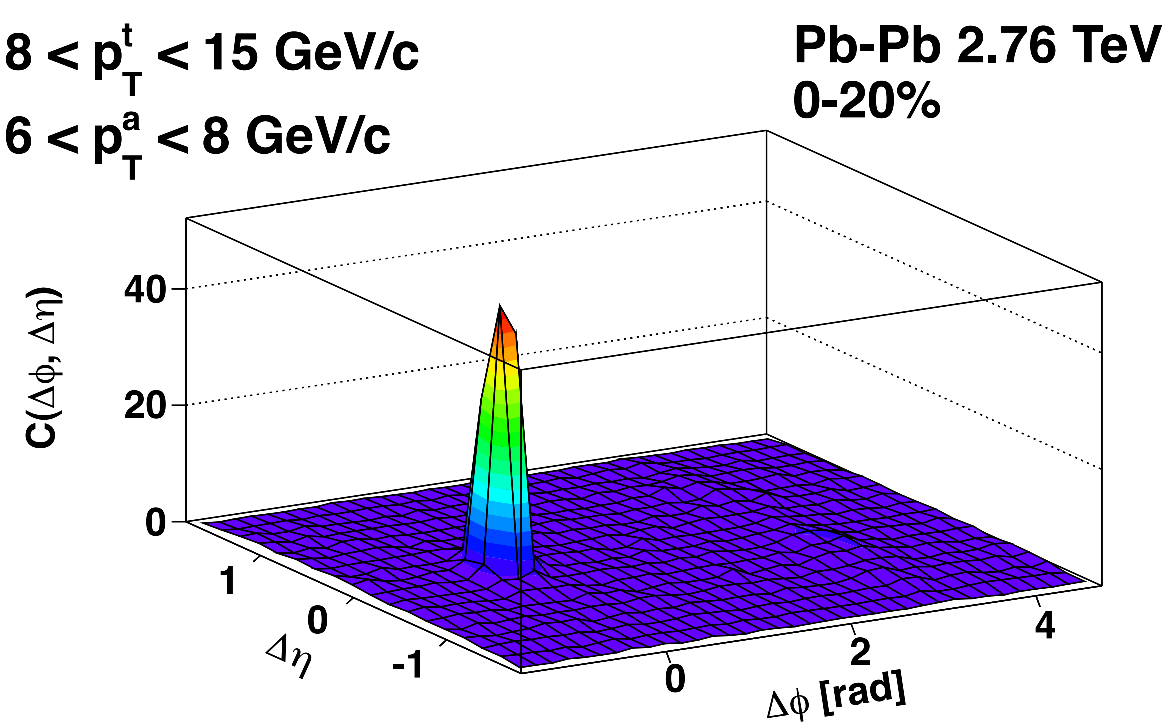
- The away-side jet is very strong; sharp like proton-proton case



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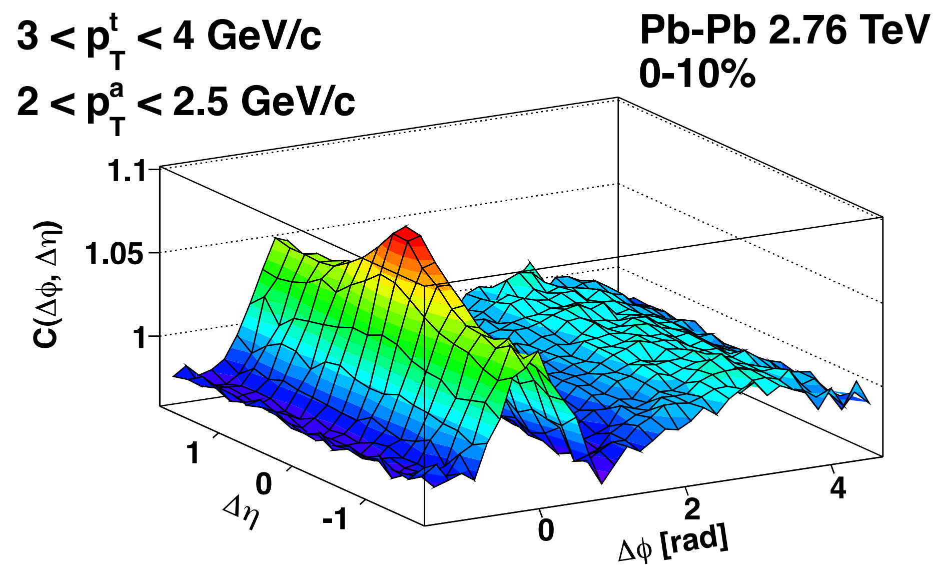

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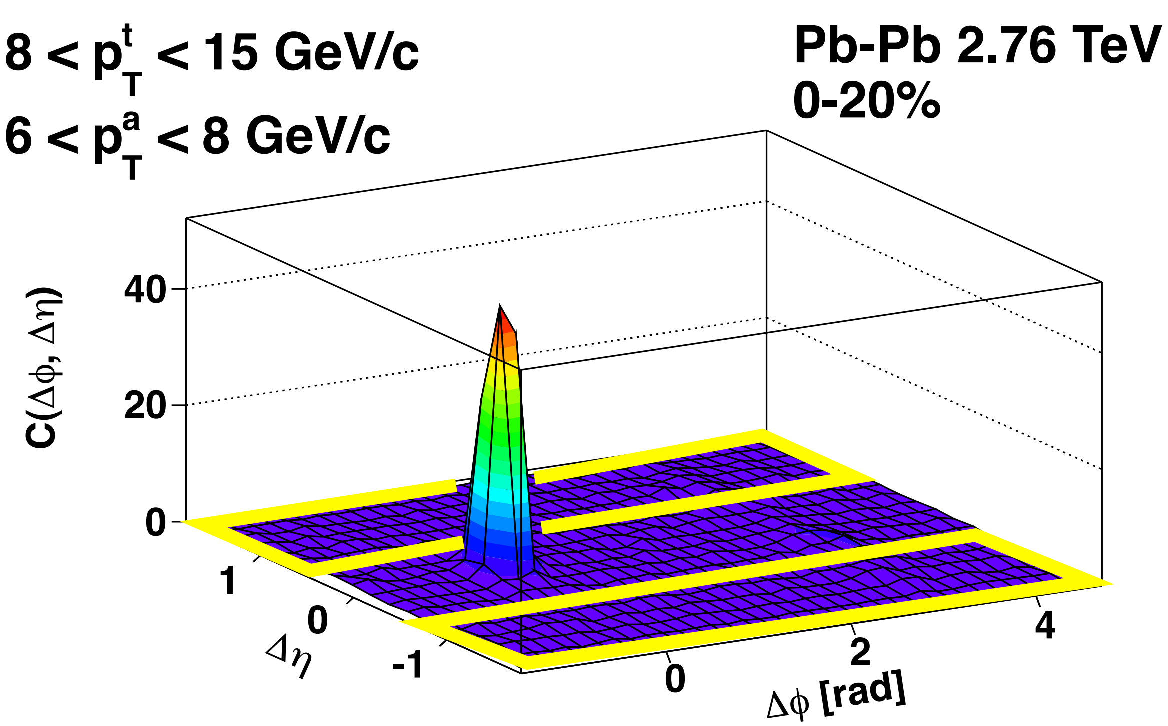

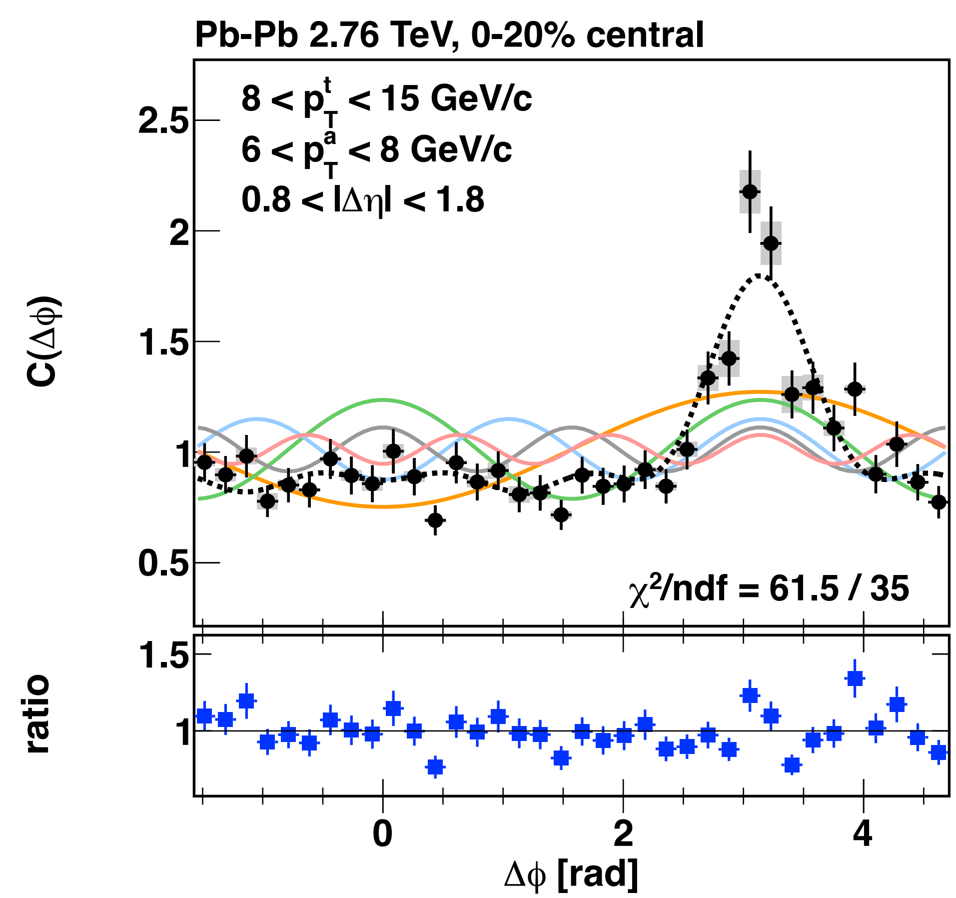

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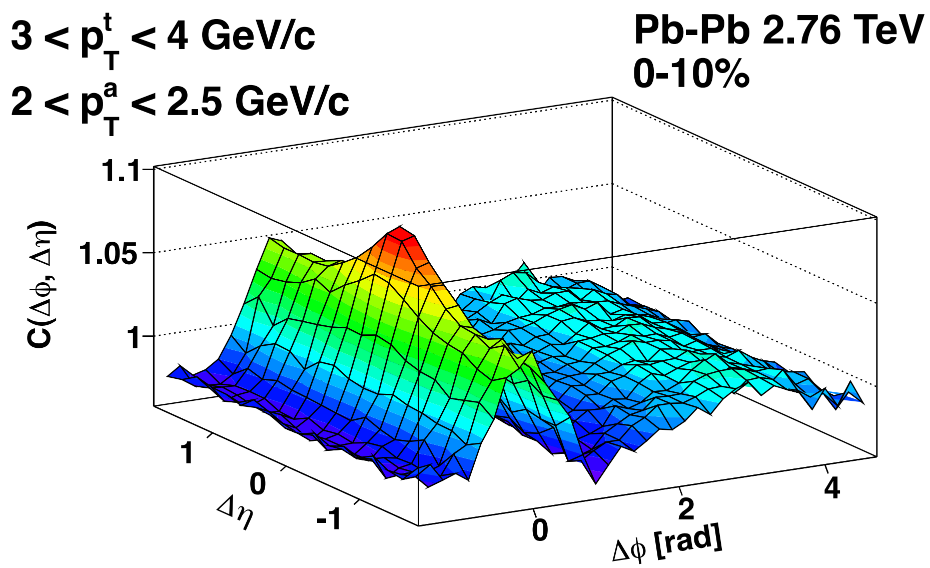

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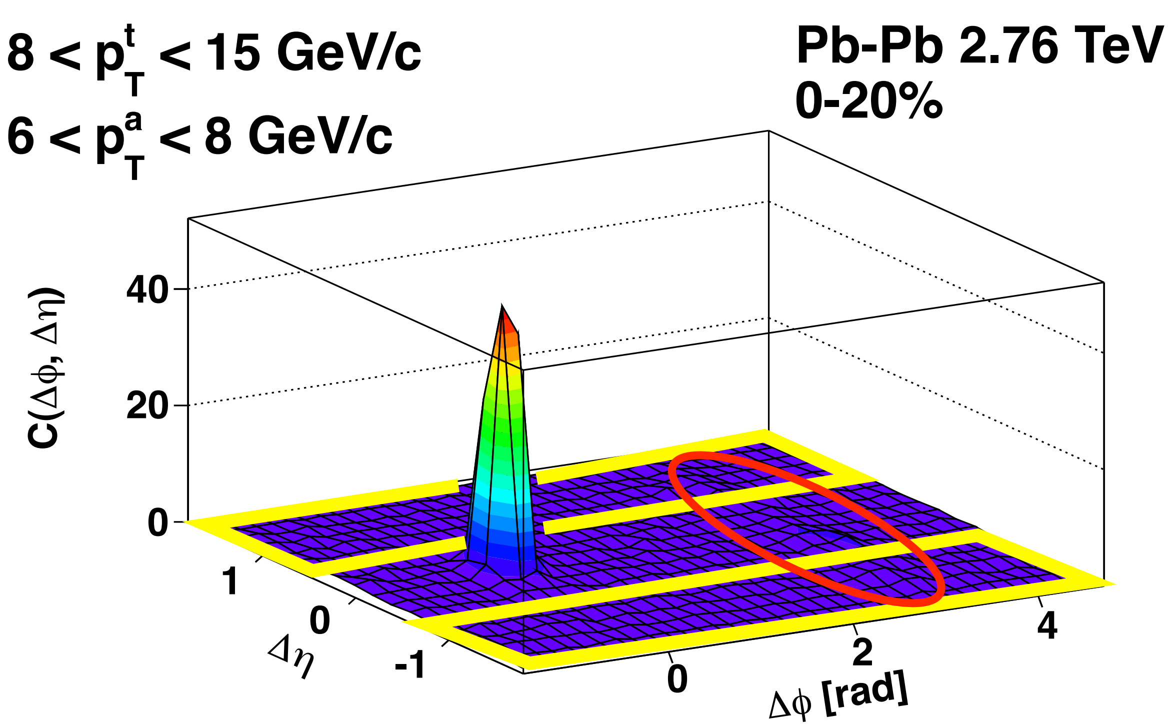
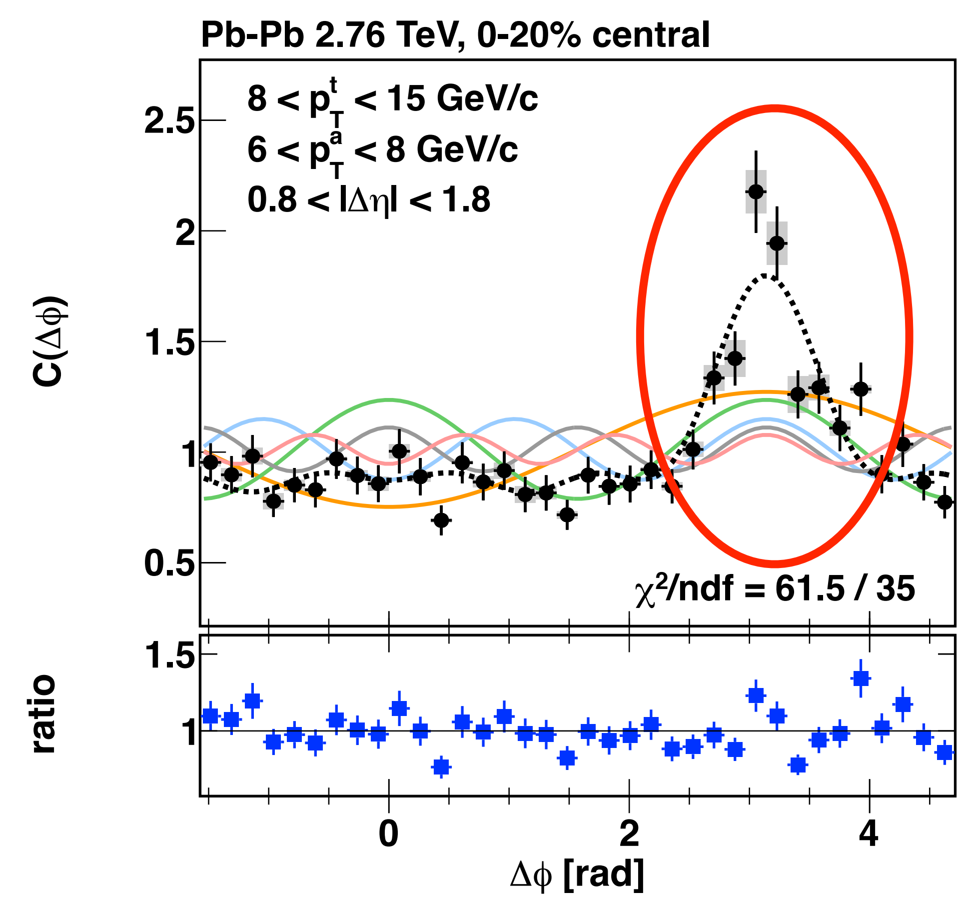


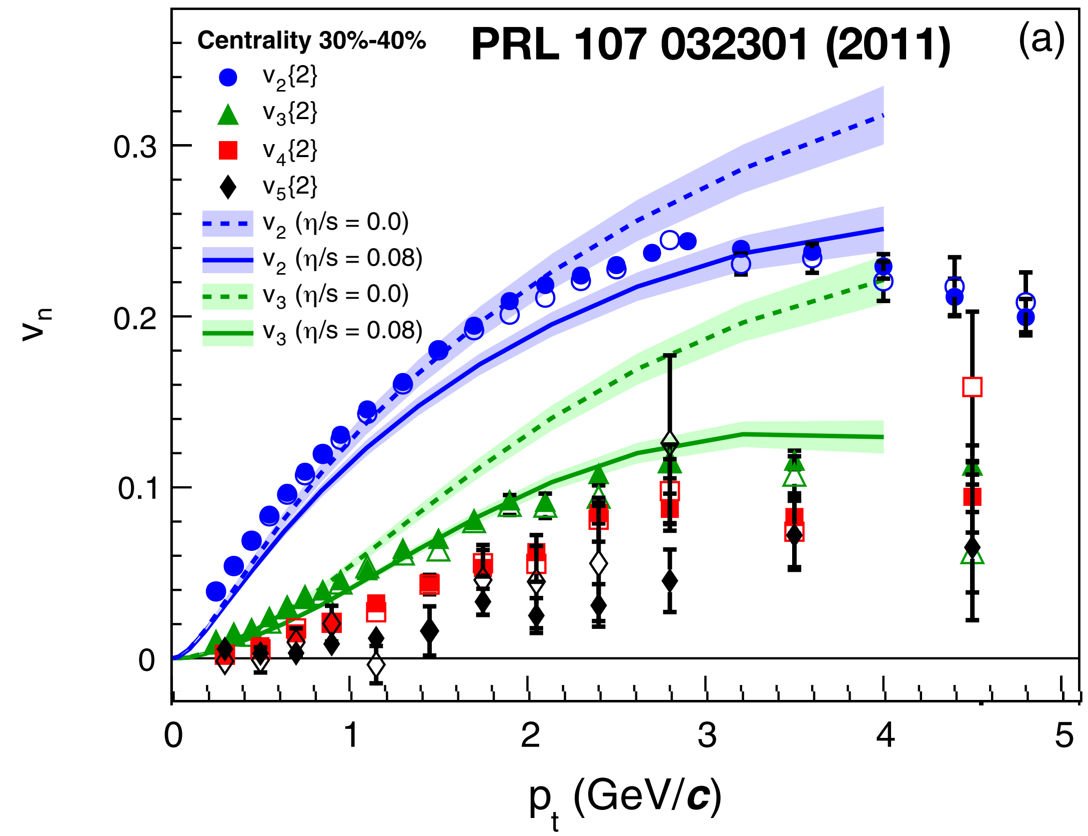


Single vs. pair Fourier decomposition

Single-particle anisotropy

(the familiar v_n coefficients)

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n(p_T)\cos\left(n(\phi - \Psi_n)\right)$$



Pair anisotropy

Similar form, but indep. of Ψ_n

$$\frac{dN^{\text{pairs}}}{d\Delta\phi} \propto 1 + \sum_{n=1}^{\infty} 2V_{n\Delta}(p_T^t, p_T^a)\cos\left(n\Delta\phi\right)$$

Extract directly from 2-particle azimuthal correlations!

$$V_{n\Delta} \equiv \langle\cos\left(n\Delta\phi\right)\rangle = \sum_i C_i \cos(n\Delta\phi_i) \bigg/ \sum_i C_i\,.$$

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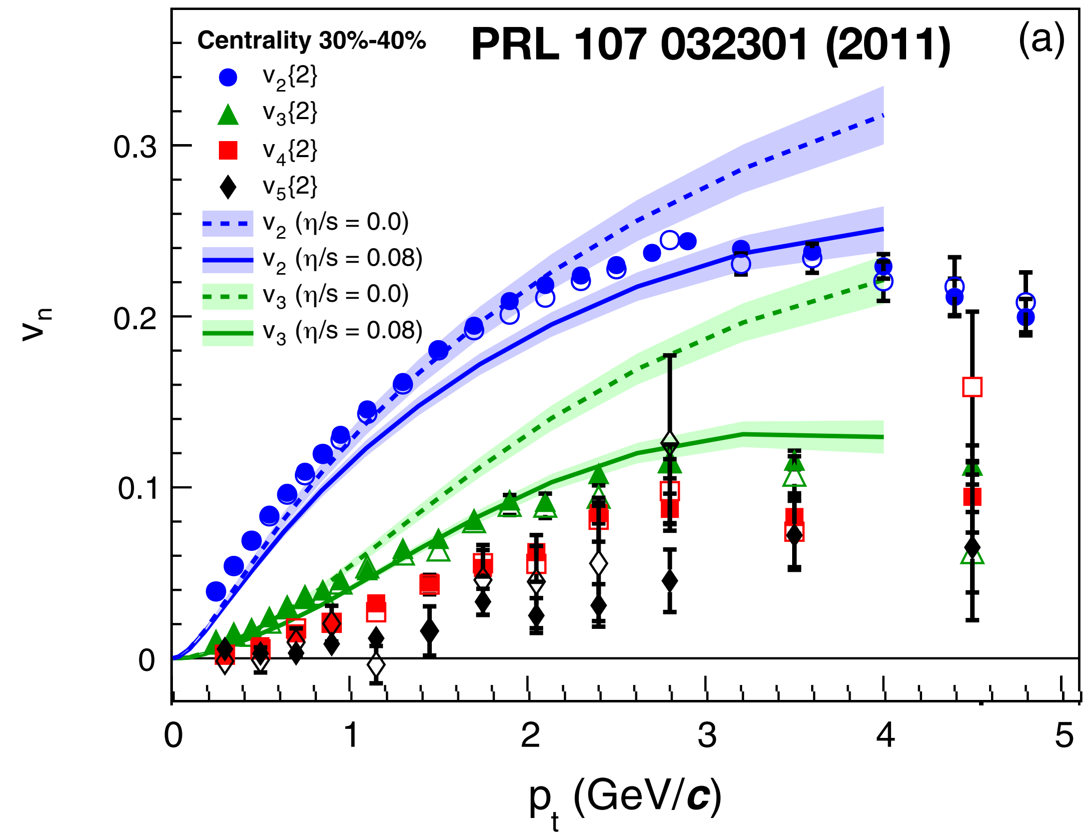

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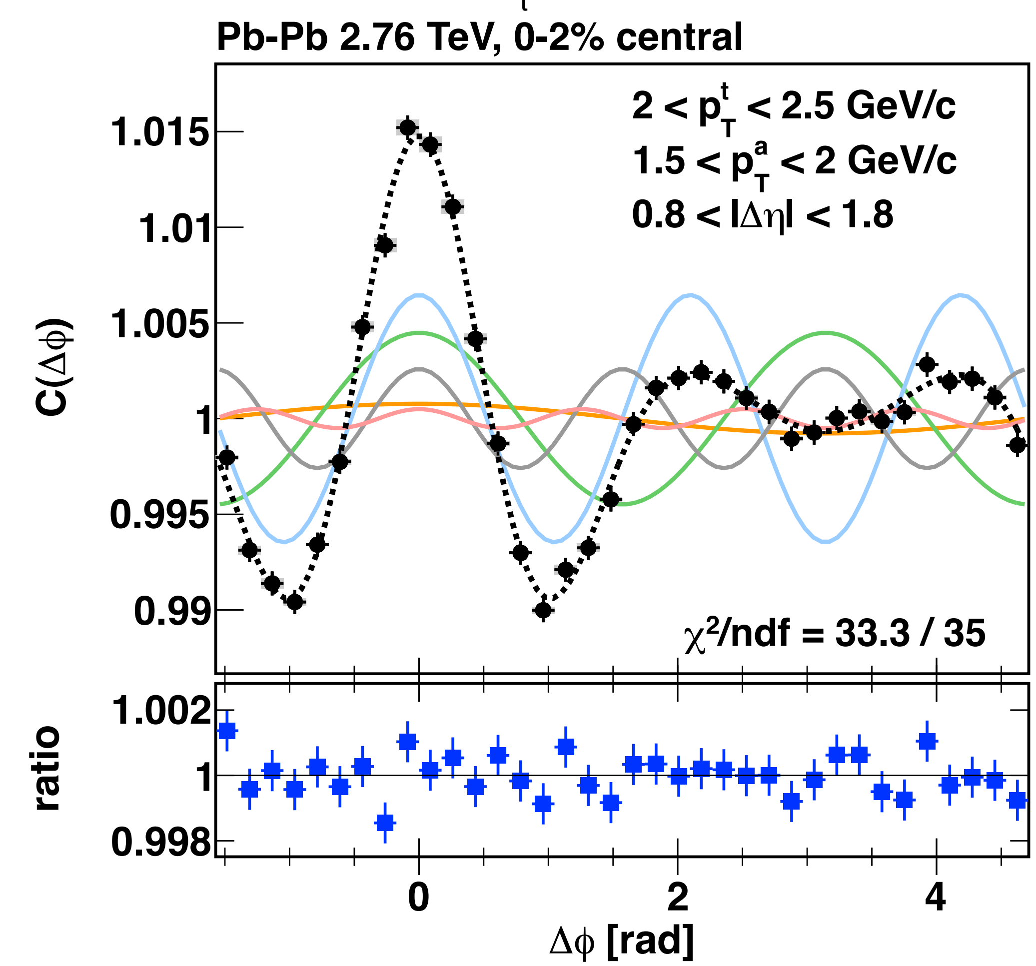

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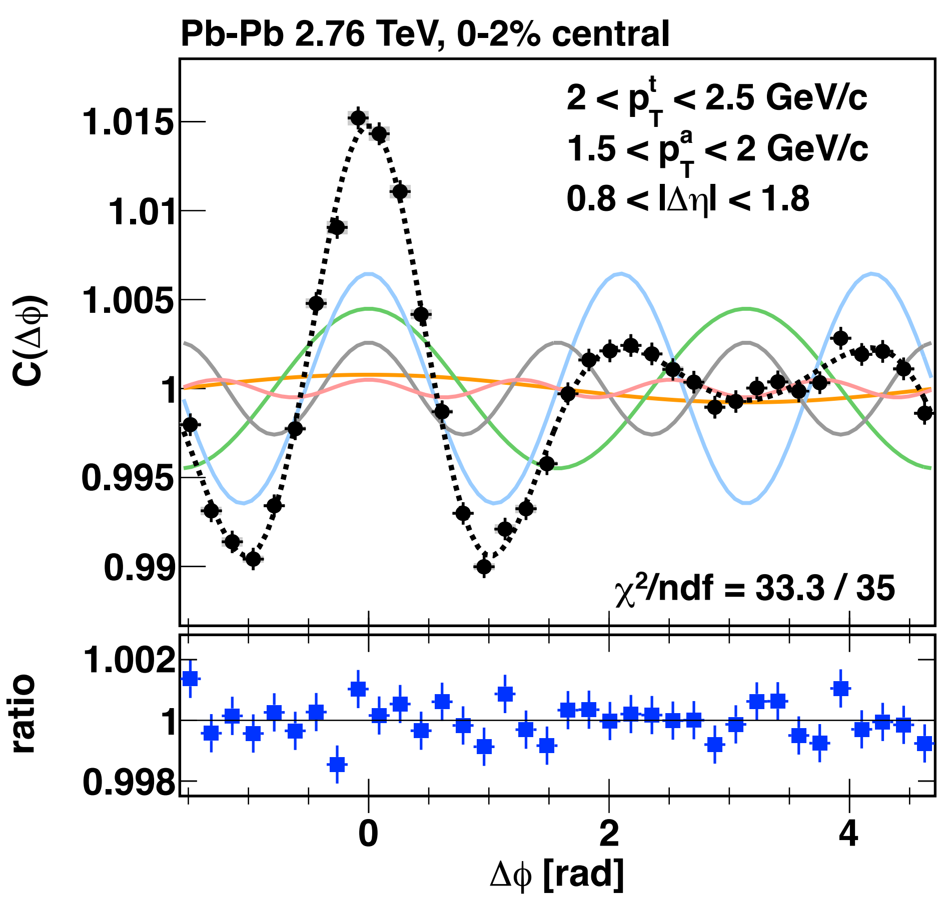
Decomposition in bulk region

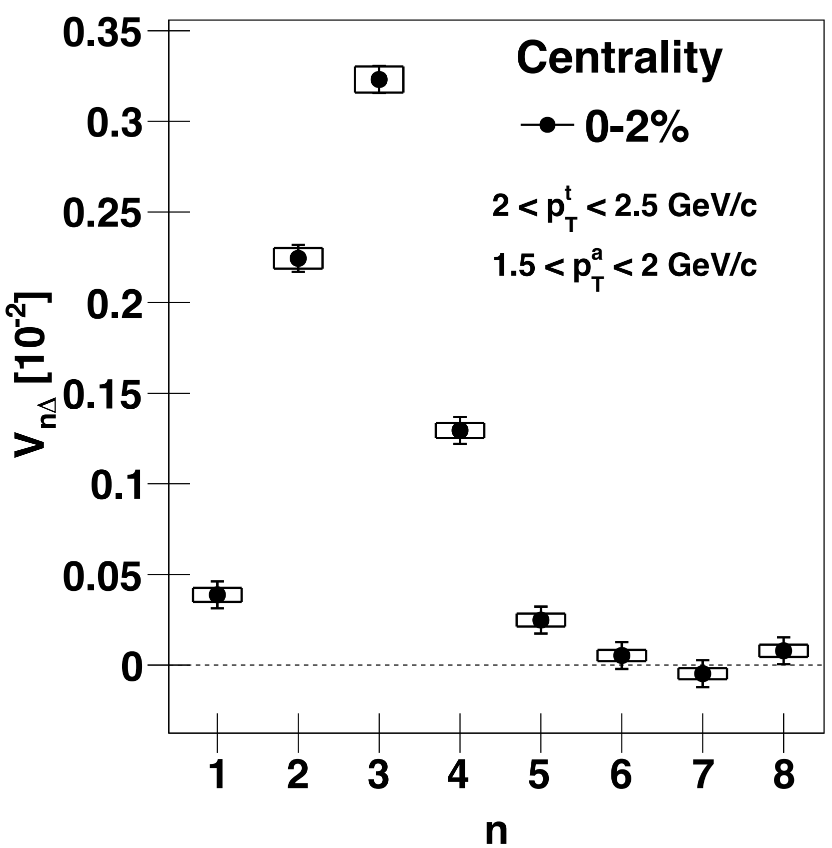
“Power spectrum” of pair Fourier components $V_{n\Delta}$

For ultra-central collisions, n = 3 dominates.

In bulk-dominated correlations, the n > 5 harmonics are weak.

(But not necessarily zero...work in progress.)





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Collision geometry, rather than fluctuations, becomes primary effect

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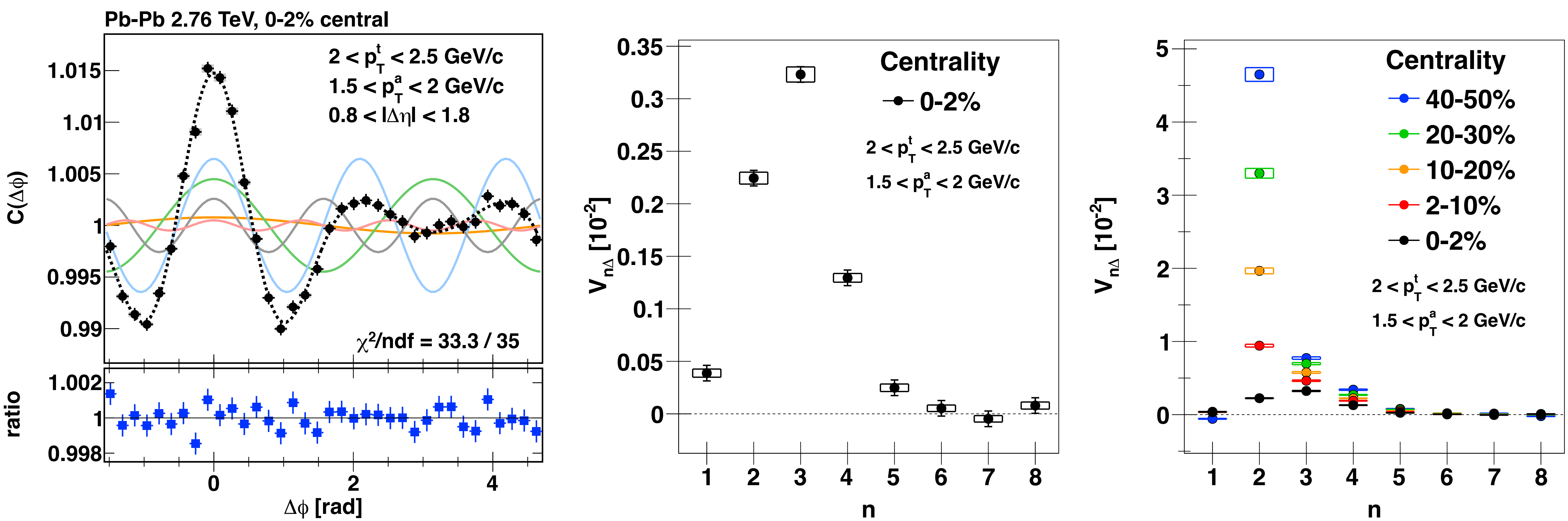

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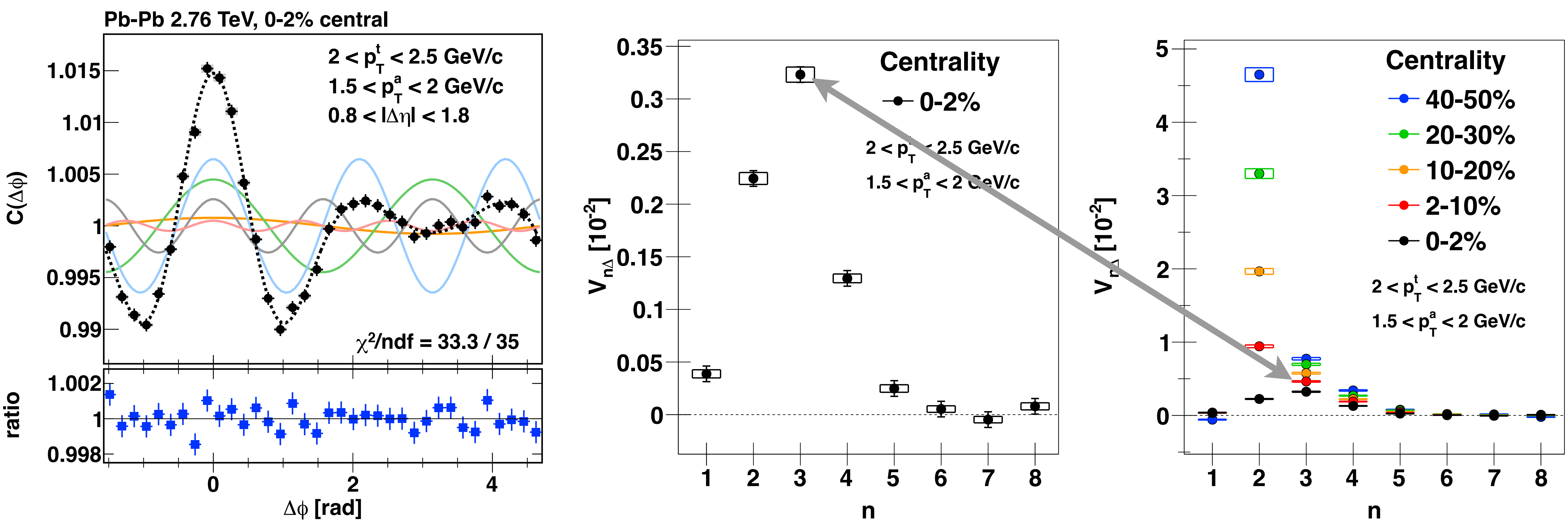

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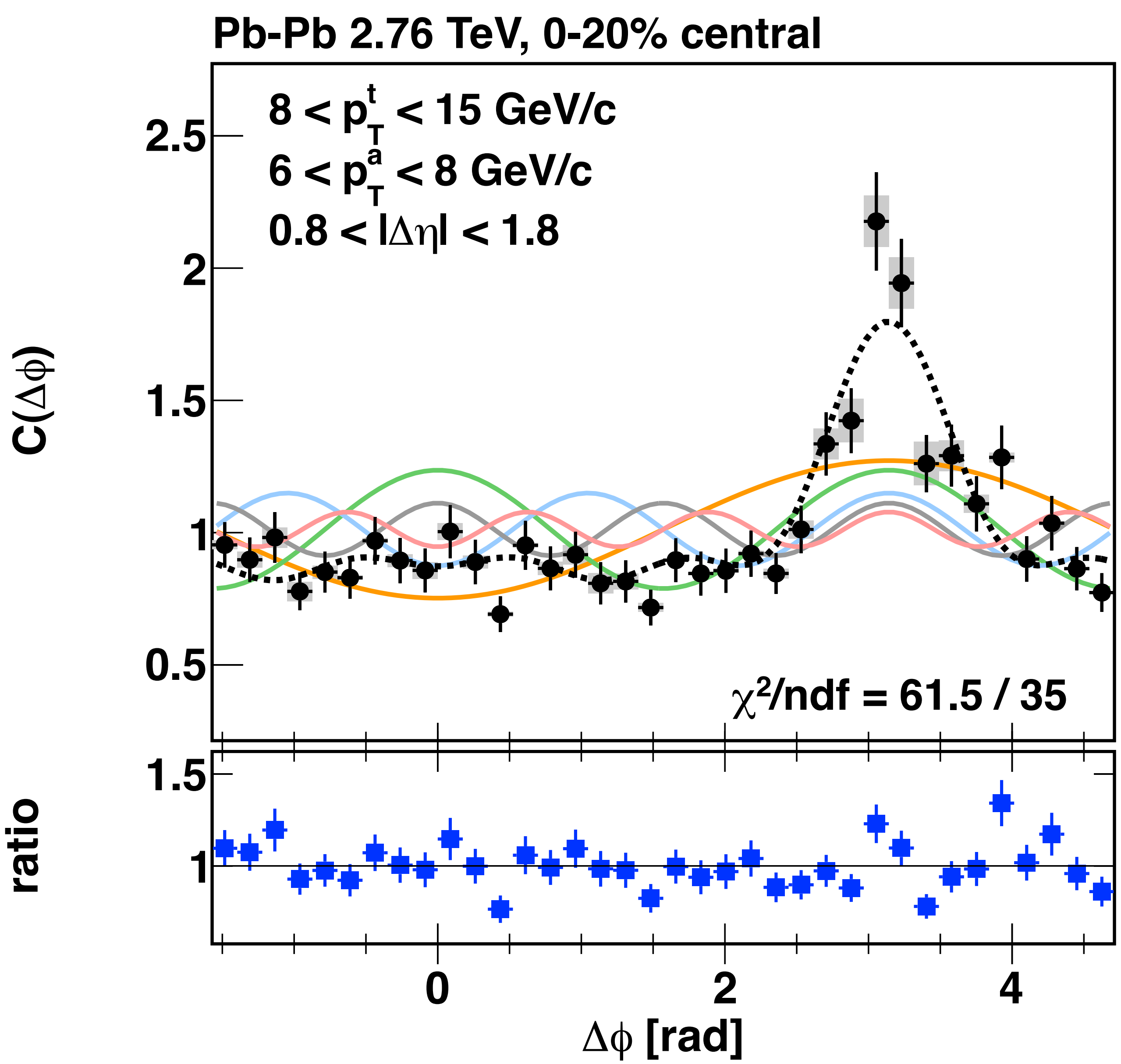
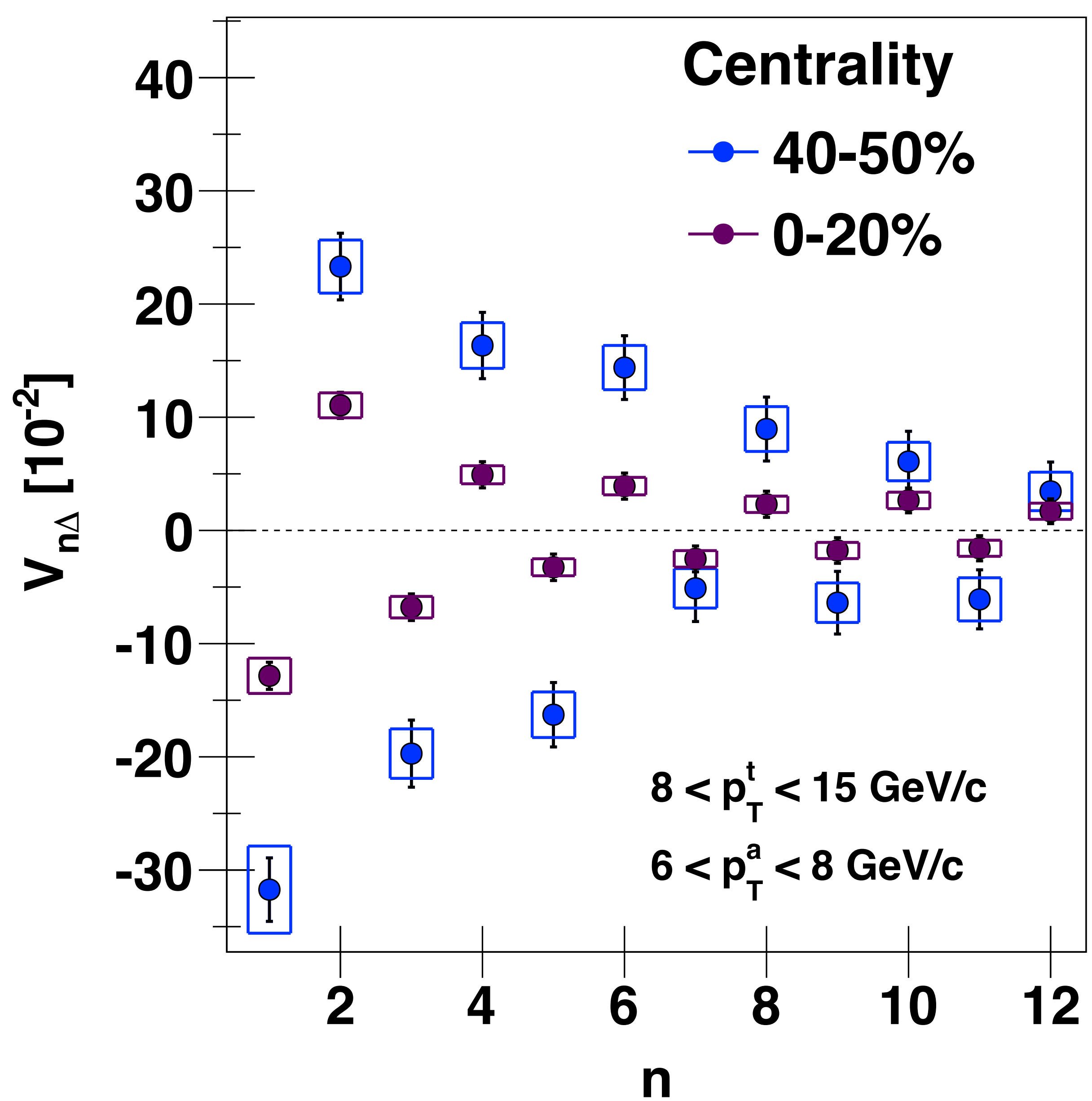
Di-jet Fourier components $V_{n\Delta}$

Very different spectral signature than bulk correlations!

- All odd harmonics < 0, and finite to large n





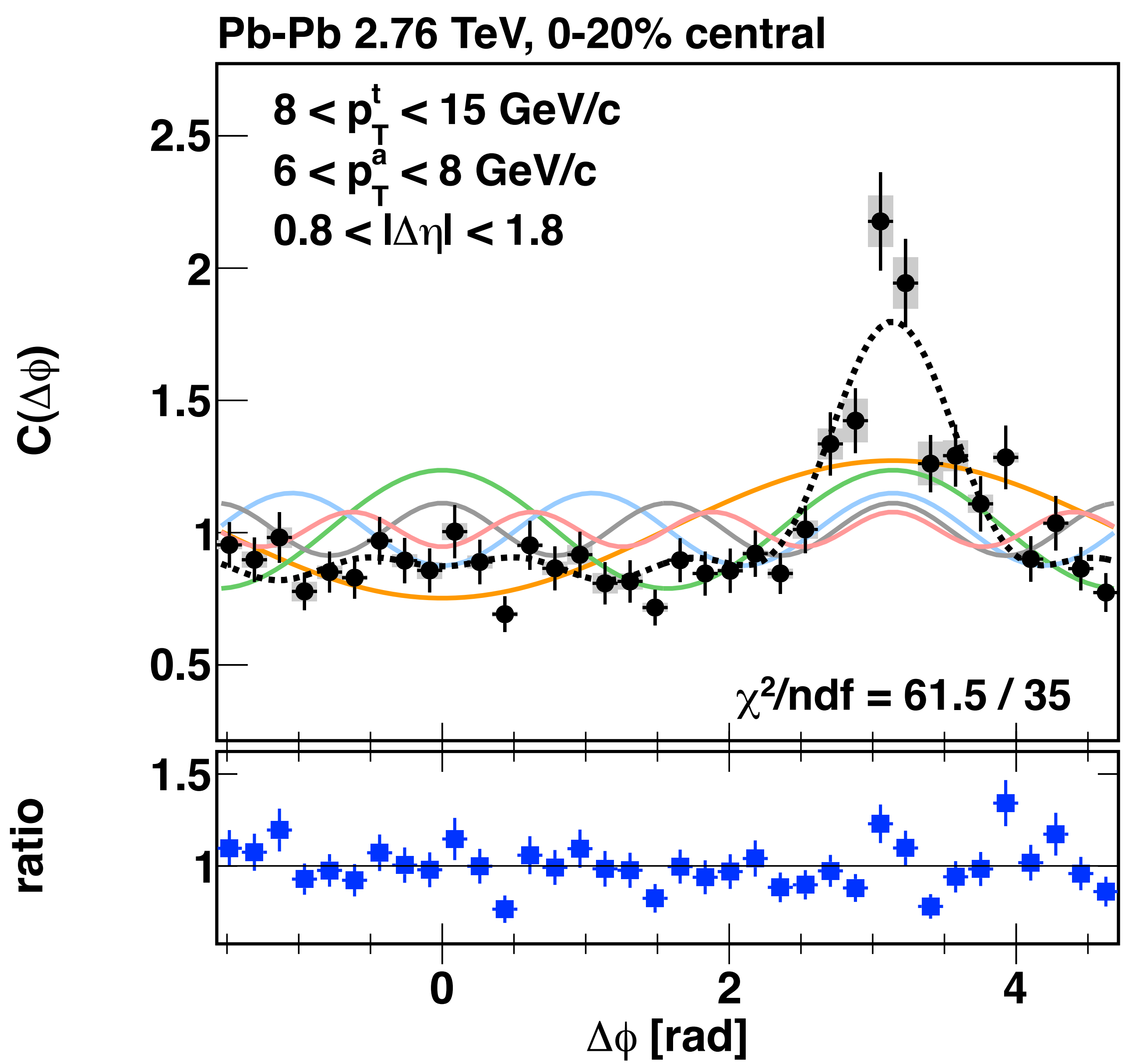
A. Adare (ALICE)

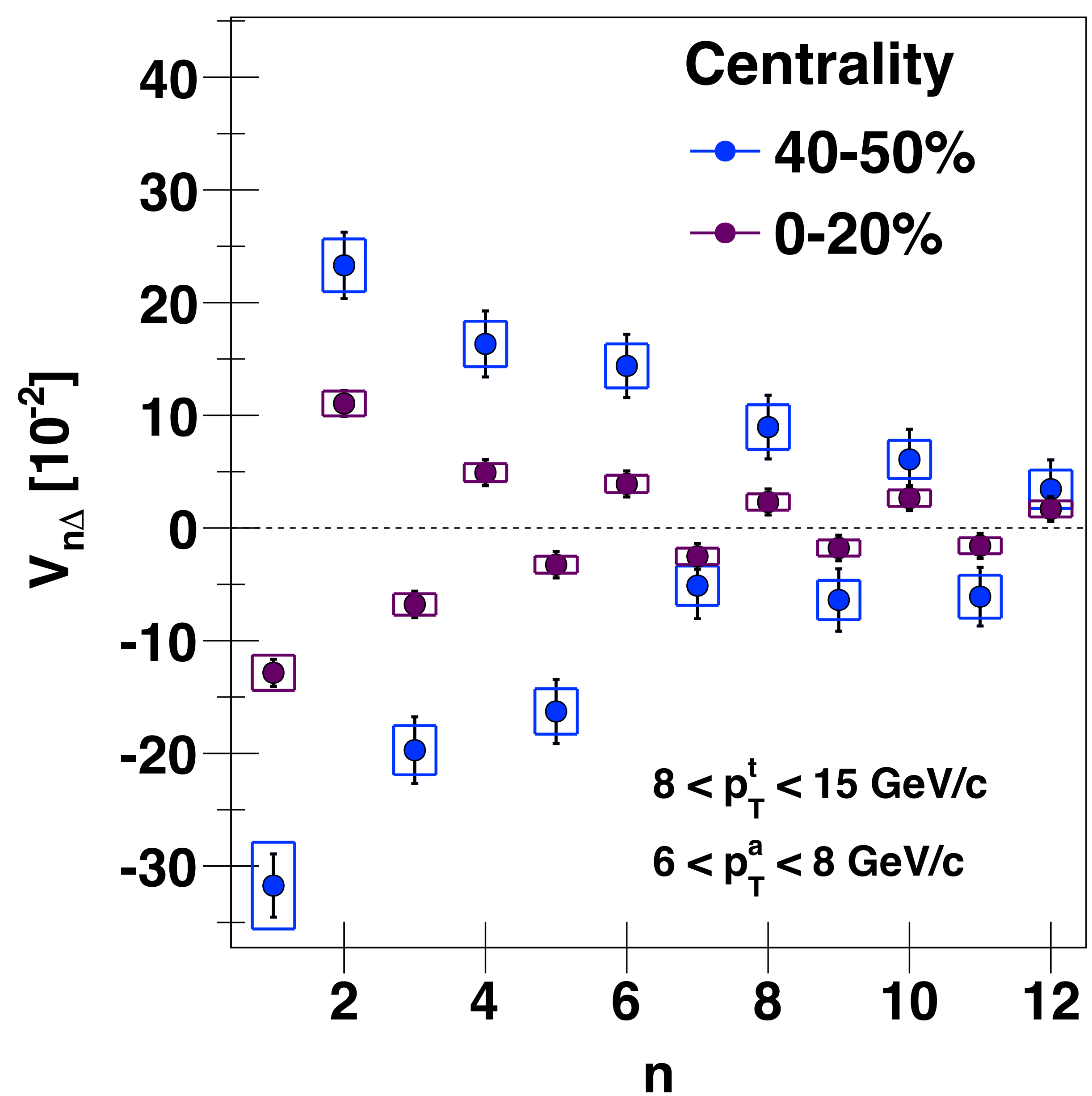
Aside: Gaussian Fourier transform

Away-side peak is (sort of) Gaussian:

The F.T. of a Gaussian($\mu=\pi$, $\sigma_{\Delta\varphi}$) is ±Gaussian($\mu=0$, $\sigma_n = 1/\sigma_{\Delta\varphi}$).

Fit demonstration: when $\mu=\pi$, odd $V_{n\Delta}$ coefficients are negative.





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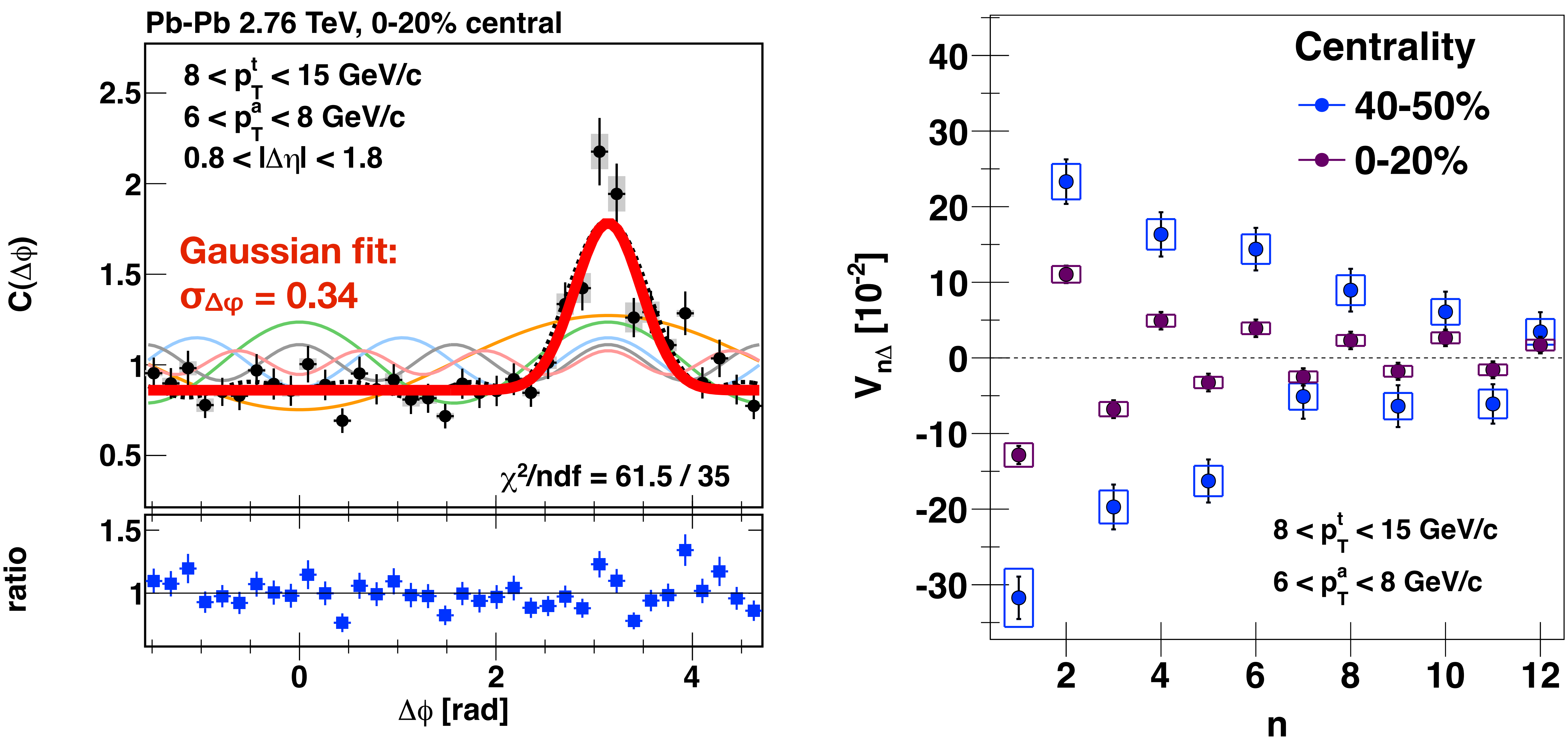

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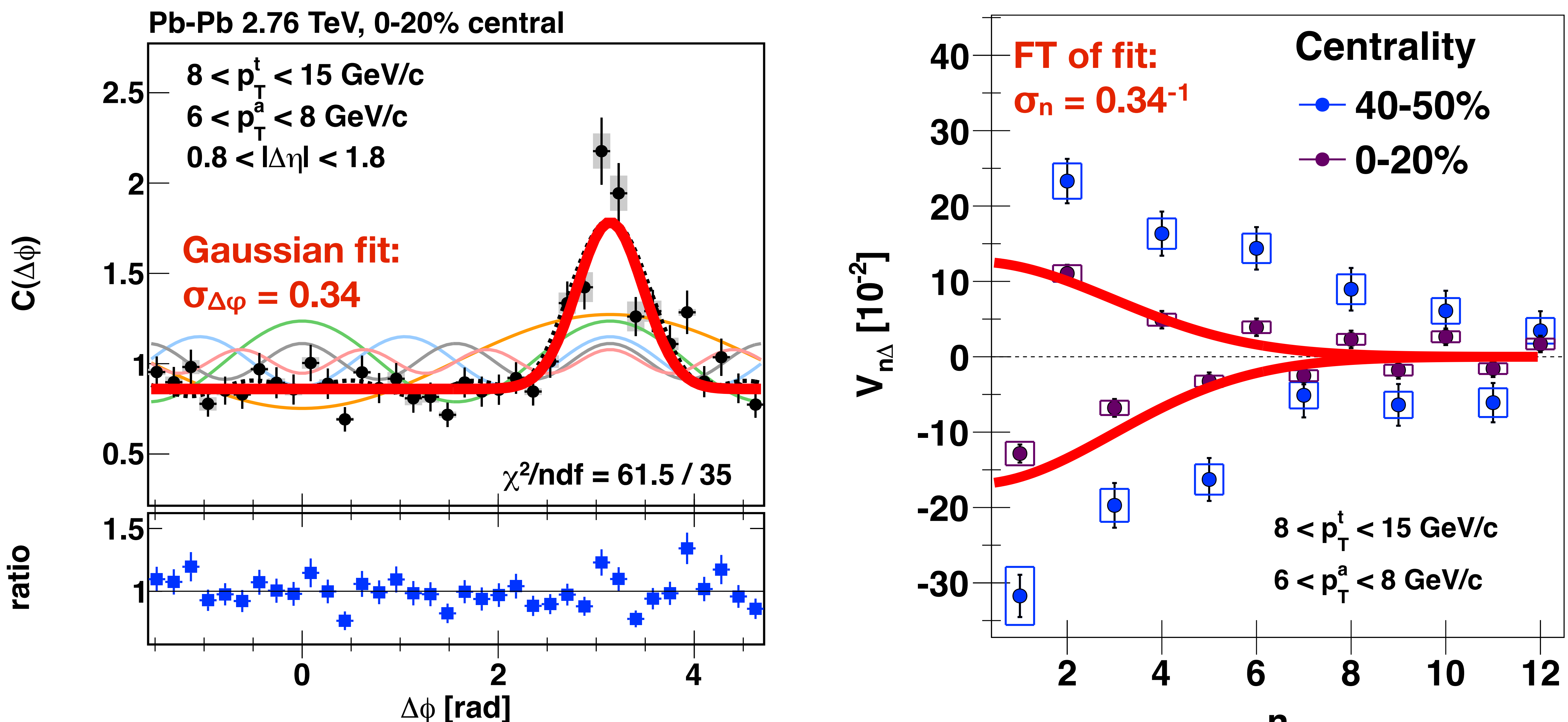
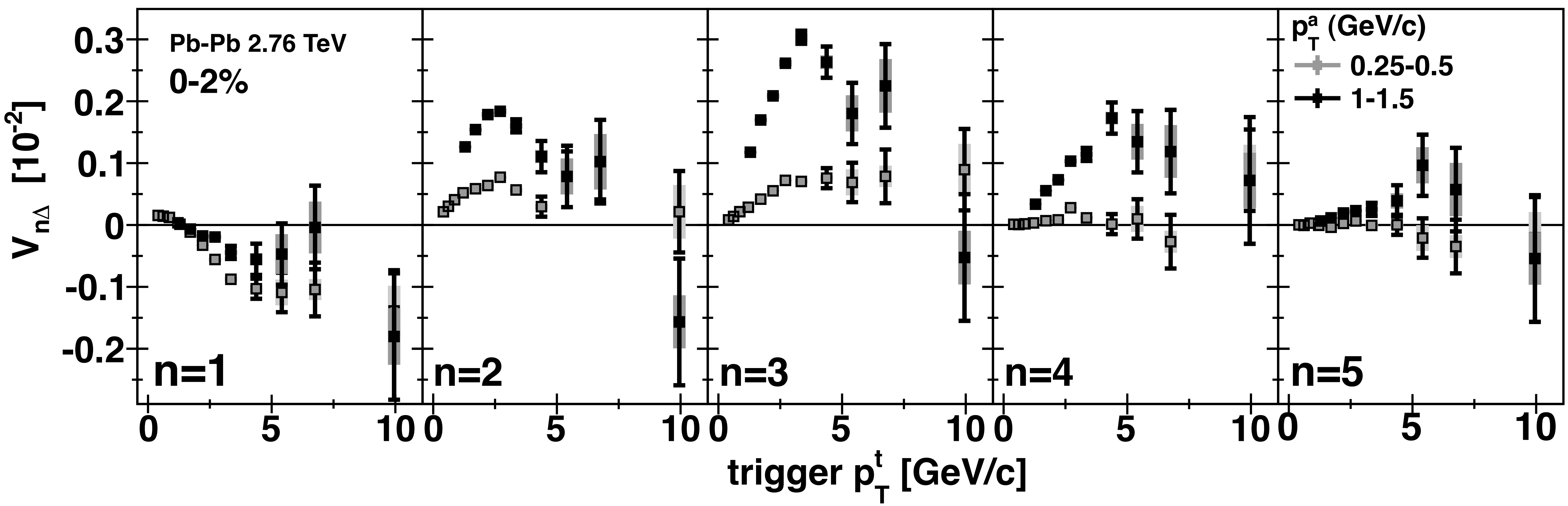


Trigger p_T^t dependence of $V_{n\Delta}$

Similar trends as for v_n

Rises with p_T^t to maximum near 3-4 GeV, then declines



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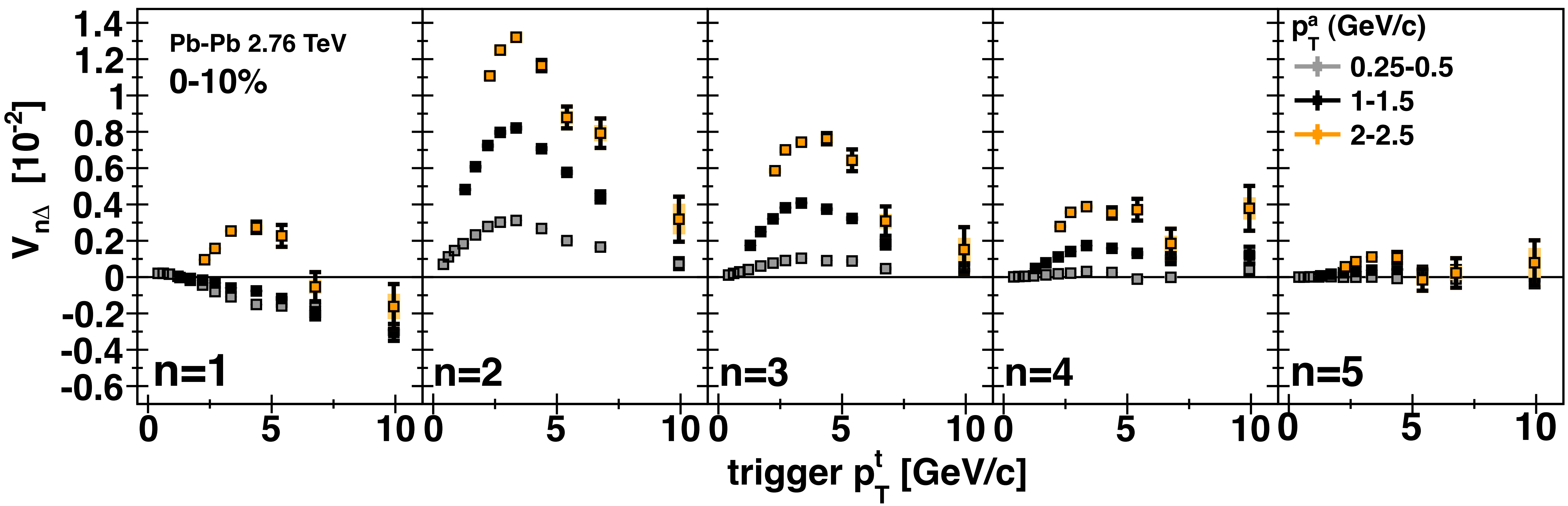

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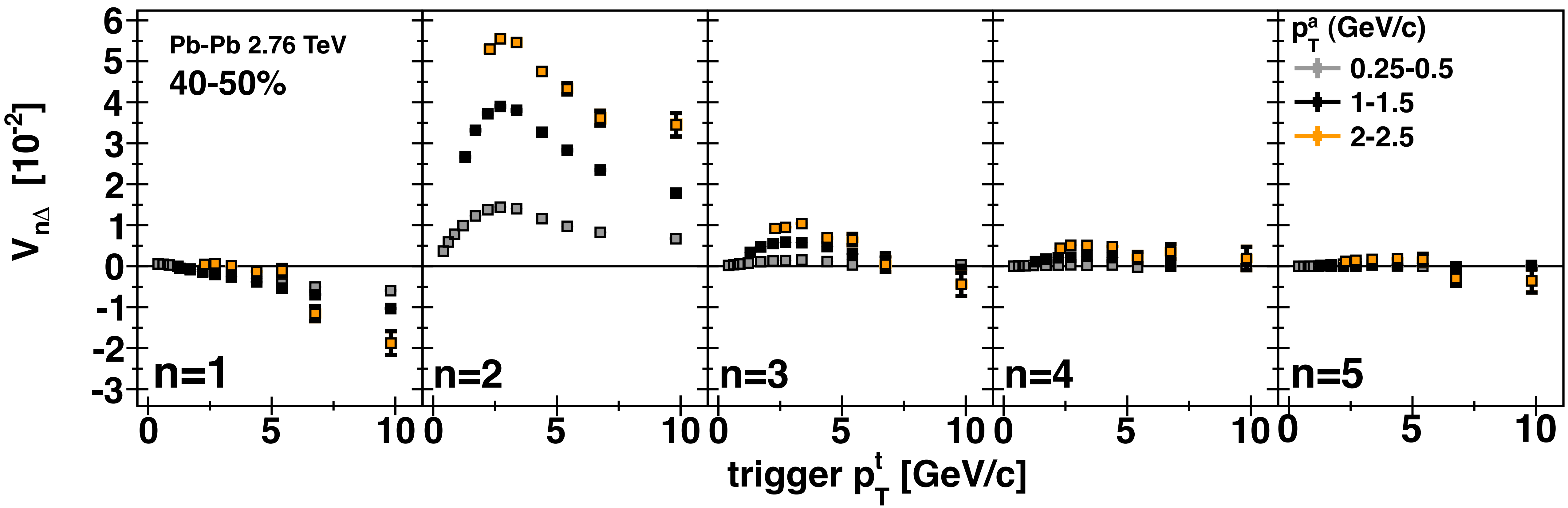

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The factorization hypothesis

Factorization of two-particle anisotropy

For pairs correlated to one another through a common symmetry plane Ψ_n, their correlation is dictated by bulk anisotropy:

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V_{n\Delta}(p_T^t, p_T^a) &= \langle\langle e^{in(\phi_a - \phi_t)}\rangle\rangle \\
&= \langle\langle e^{in(\phi_a - \Psi_n)}\rangle\rangle\langle\langle e^{-in(\phi_t - \Psi_n)}\rangle\rangle \\
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\end{aligned}
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$V_{n\Delta}$ would be generated from one $v_n(p_T)$ curve, evaluated at p_T^t and p_T^a.

Factorization expected:

✔ **For correlations from collective flow.**

Flow is global and affects all particles in the event.

✘ **Not for pairs from fragmenting di-jets.**

Di-jet shapes are “local”, not strongly connected to Ψ_n.

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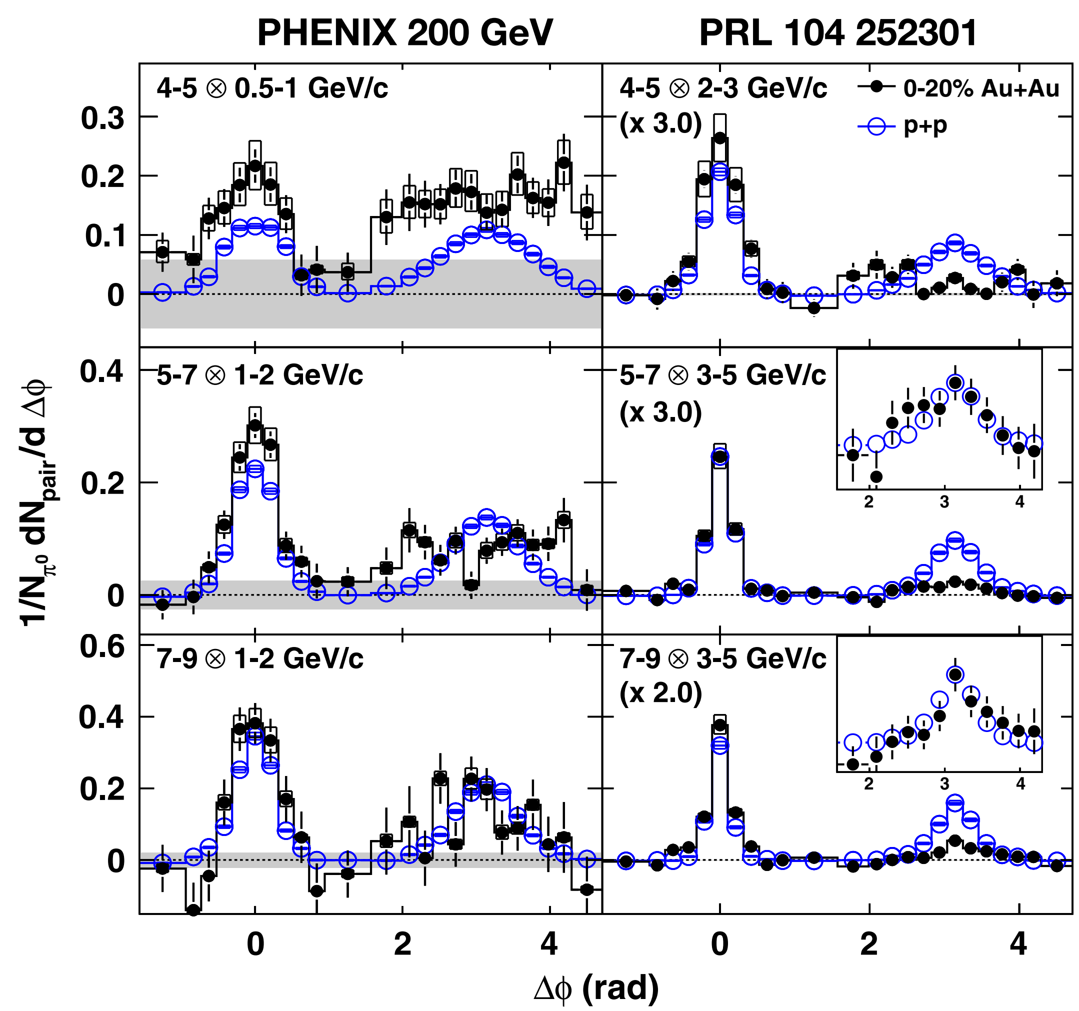

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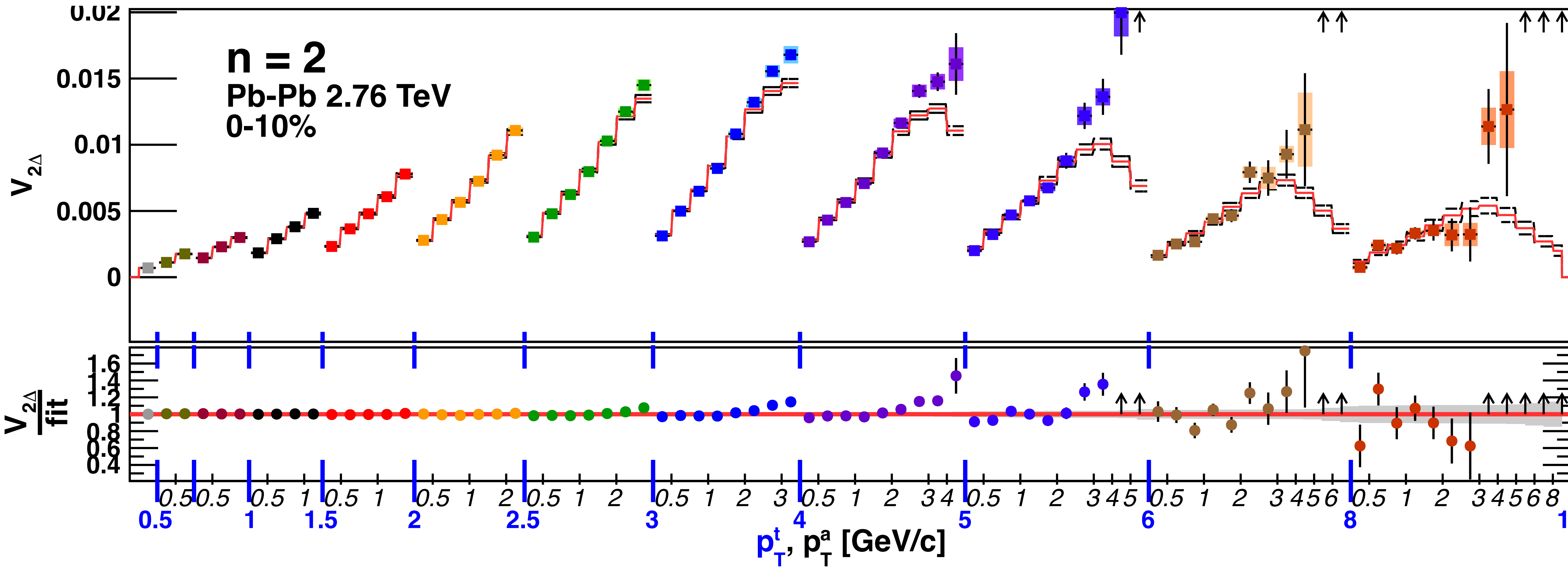
Testing factorization with a global fit

Improving on $V_{n\Delta} = v_n(p_T)^2$ with triggered correlations...

12 p_T^t bins, 12 p_T^a bins; $p_T^t \geq p_T^a$ ⇒ 78 $V_{n\Delta}$ points.

Fit all simultaneously to find $v_n(p_T)$ curve with best-fit $v_n(p_T^t)$ x $v_n(p_T^a)$ product.



At each n:

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⇒ suggests flow correlations.

- **Fit deviates from data in jet-dominated high p_T^a region**

⇒ collective description less appropriate. A. Adare (ALICE)

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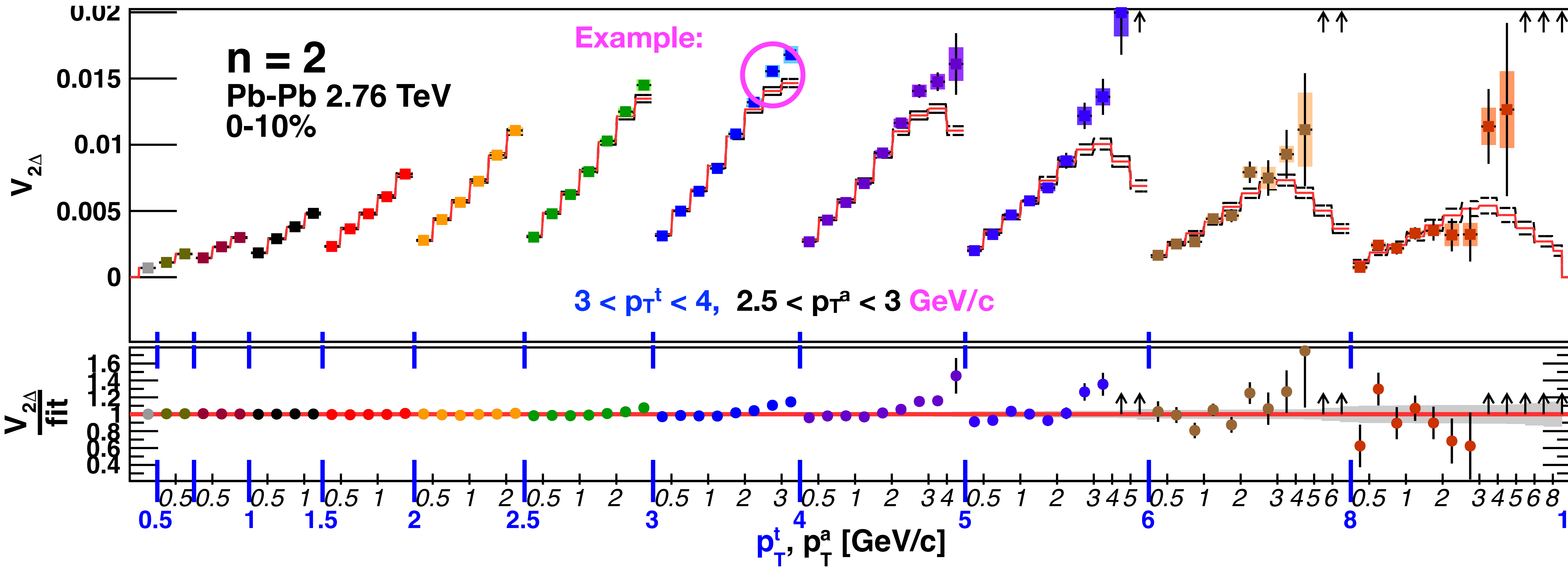

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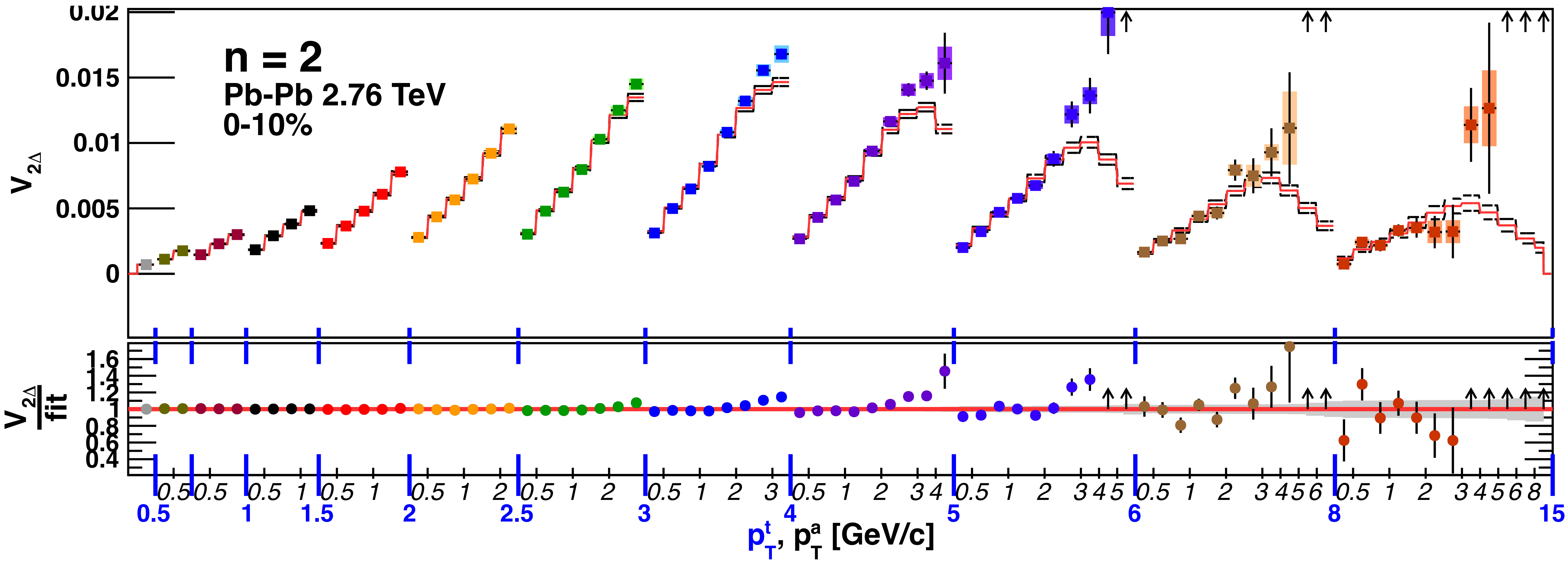

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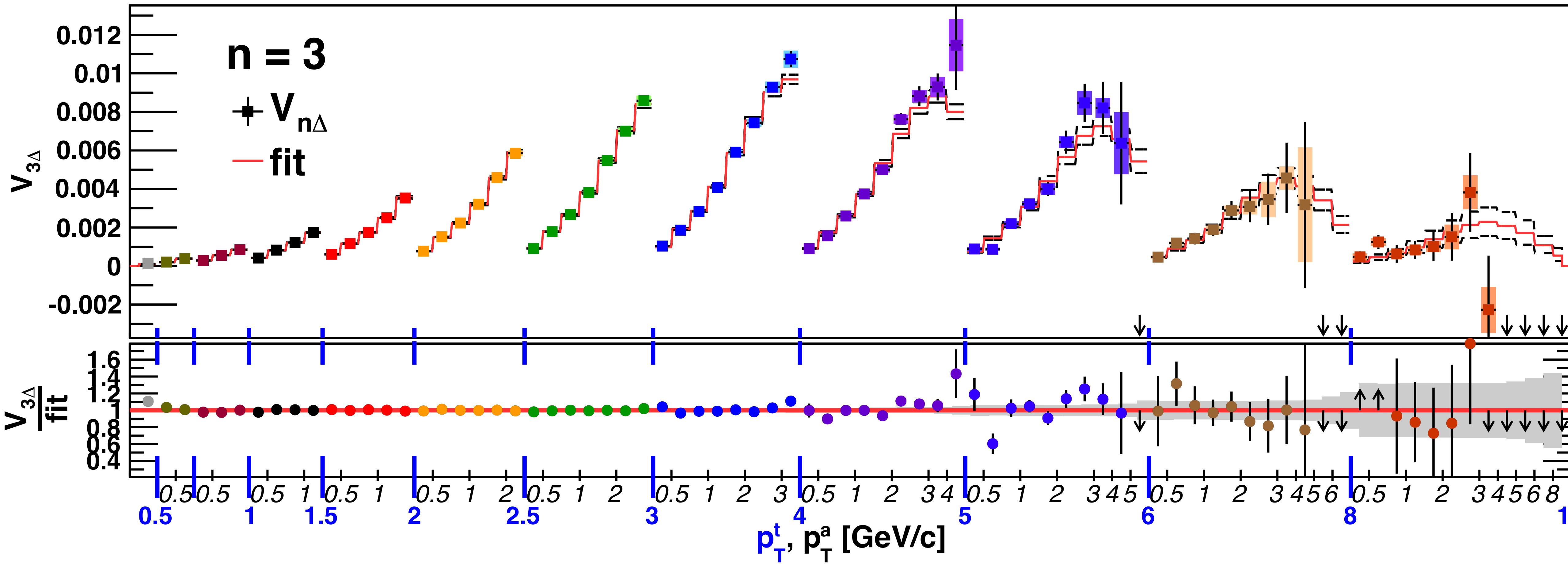

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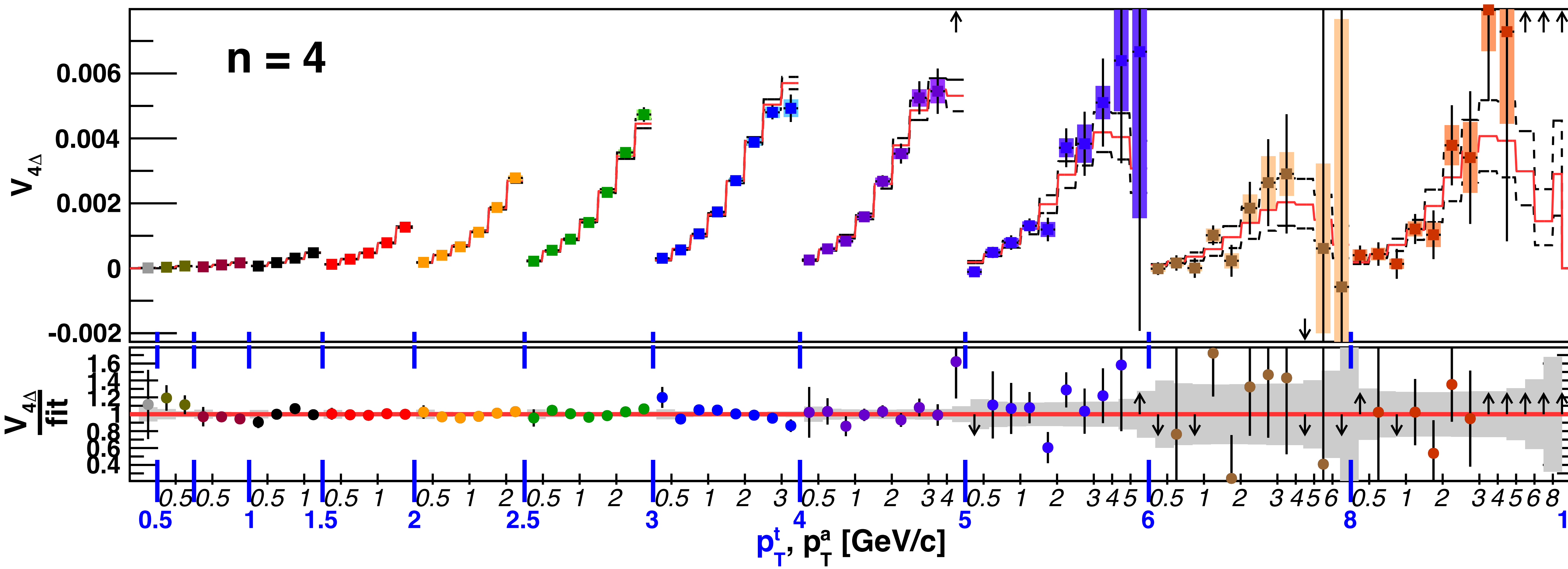

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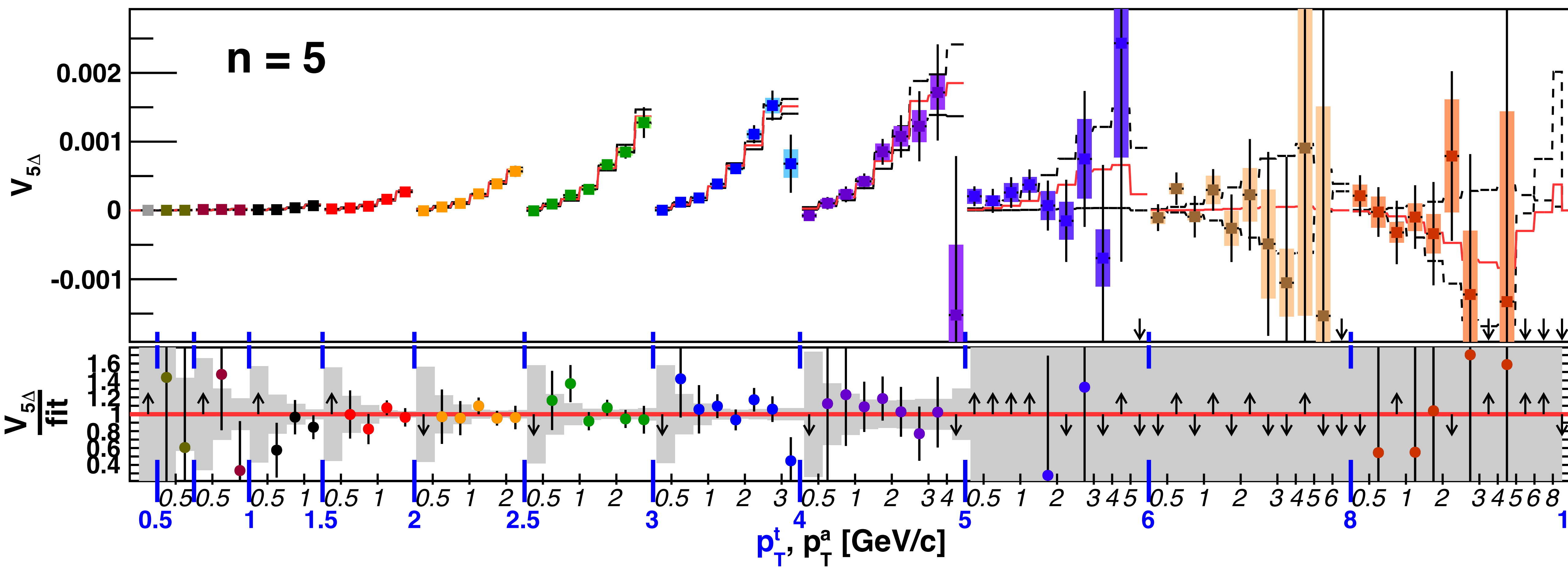

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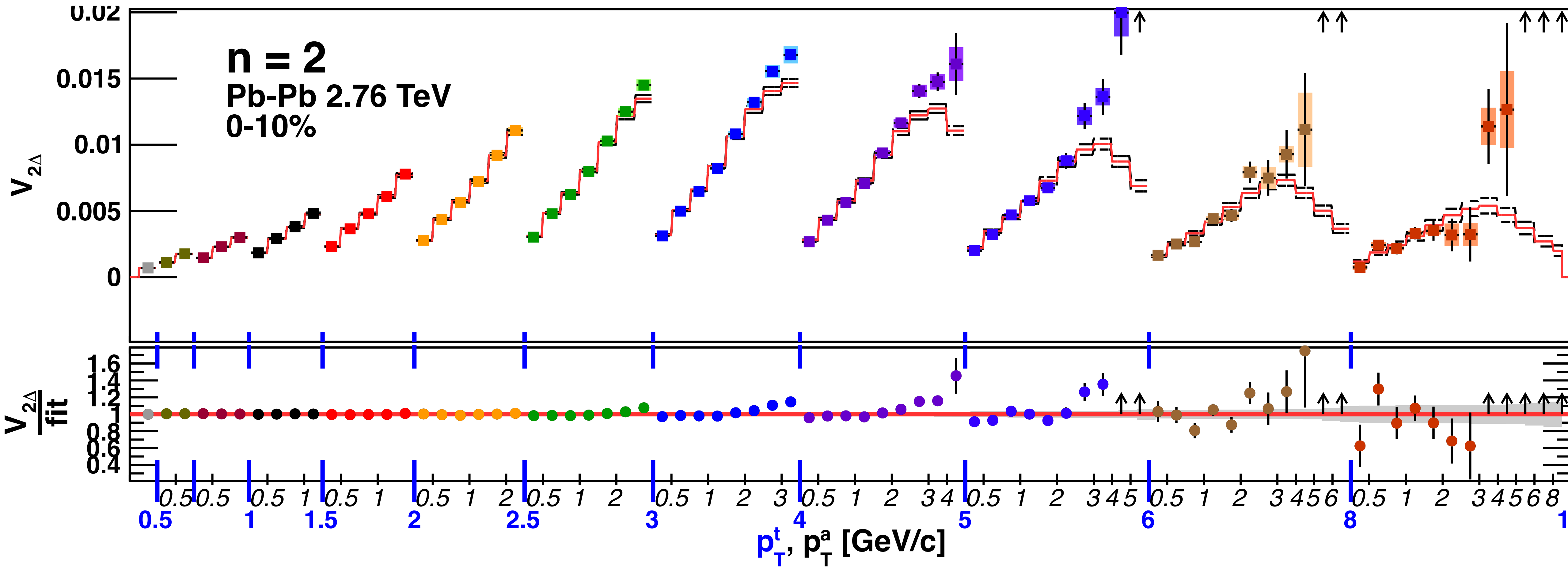

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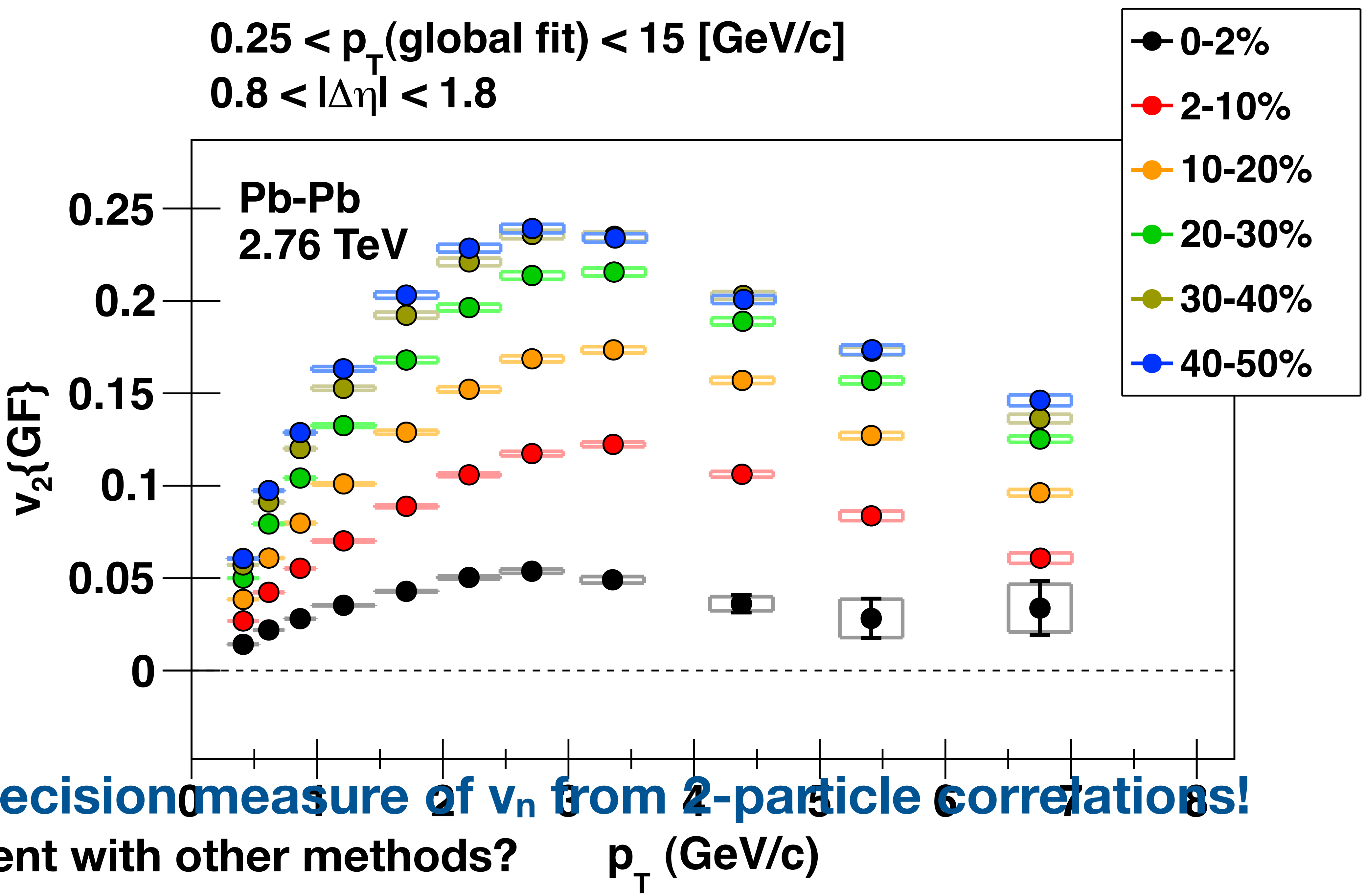
Global fit parameters are v_n coefficients

$2 \leq n \leq 5$ shown here (n=1 later)



High-precision measure of v_n from 2-particle correlations!

Agreement with other methods?

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Global fit parameters are v_n coefficients

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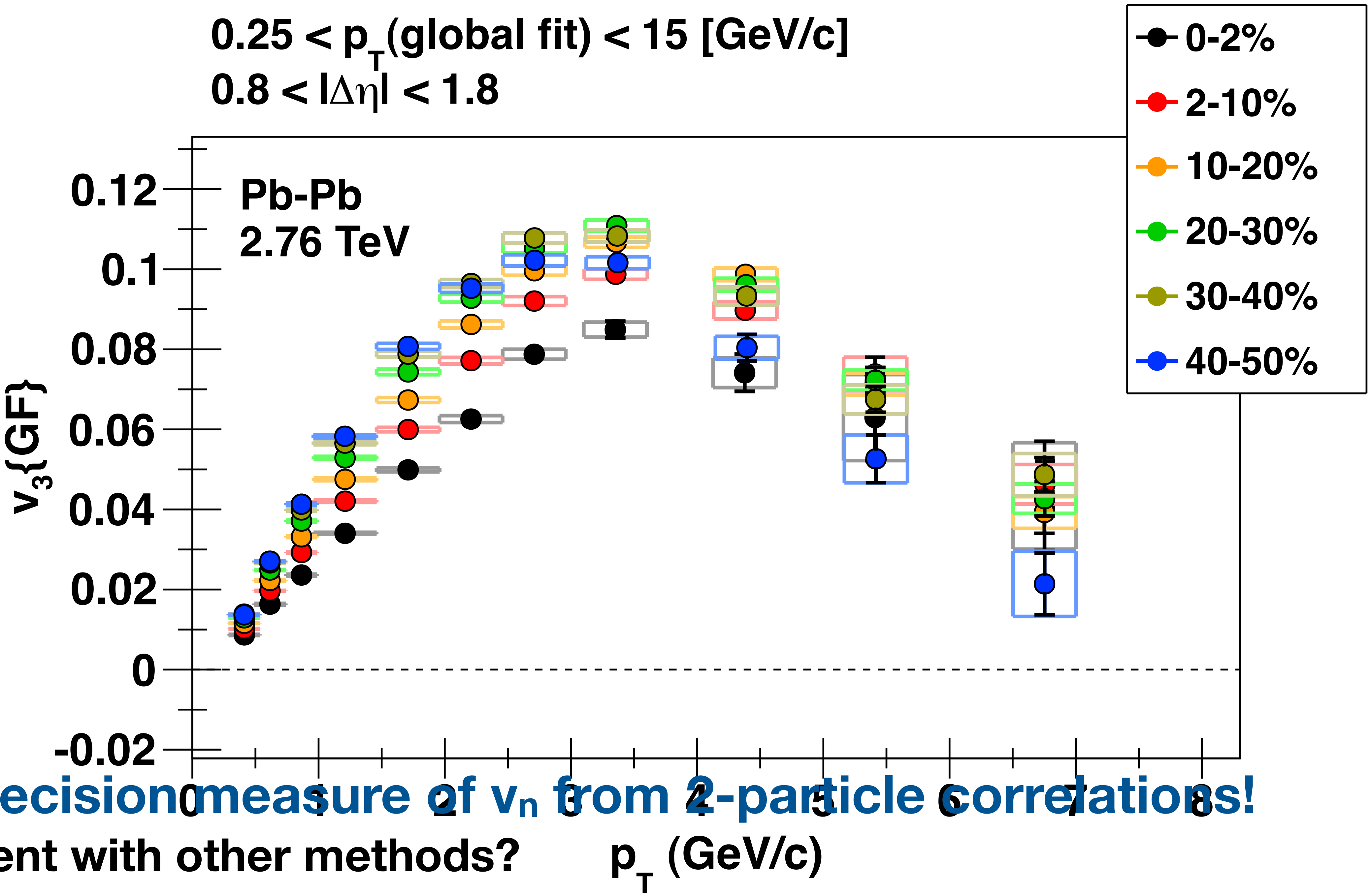

High-precision measure of v_n from 2-particle correlations!

Agreement with other methods?

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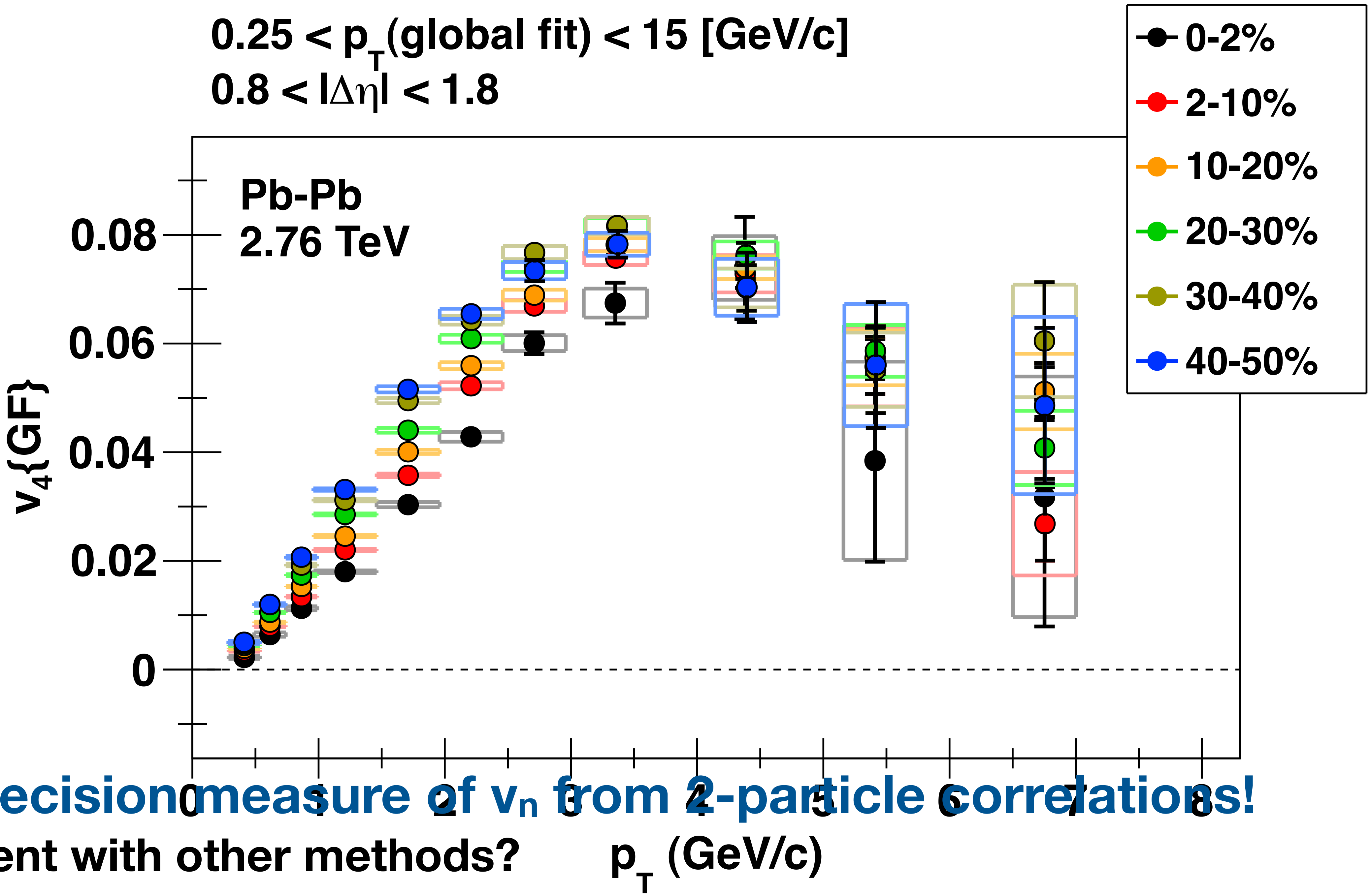

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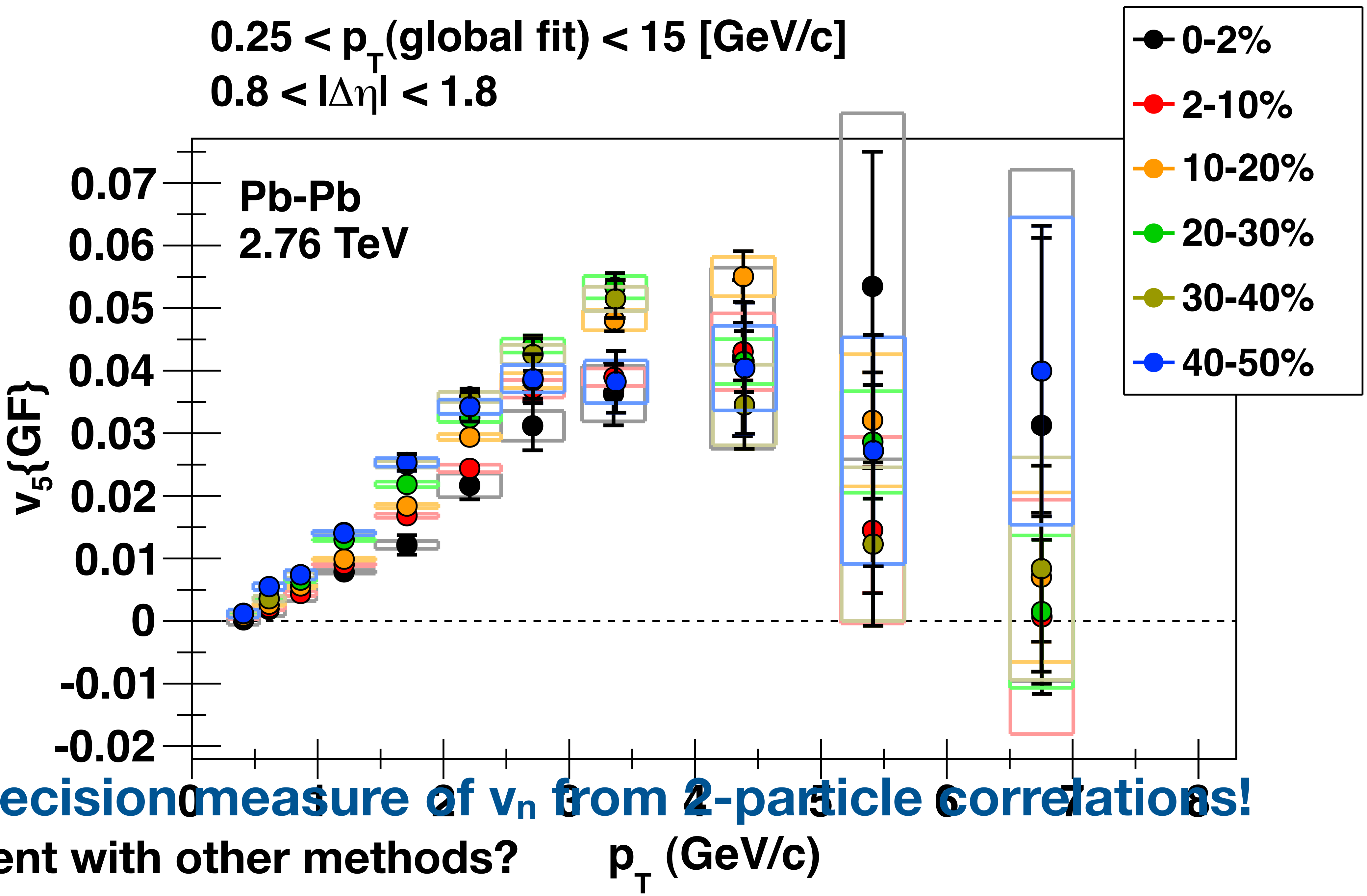

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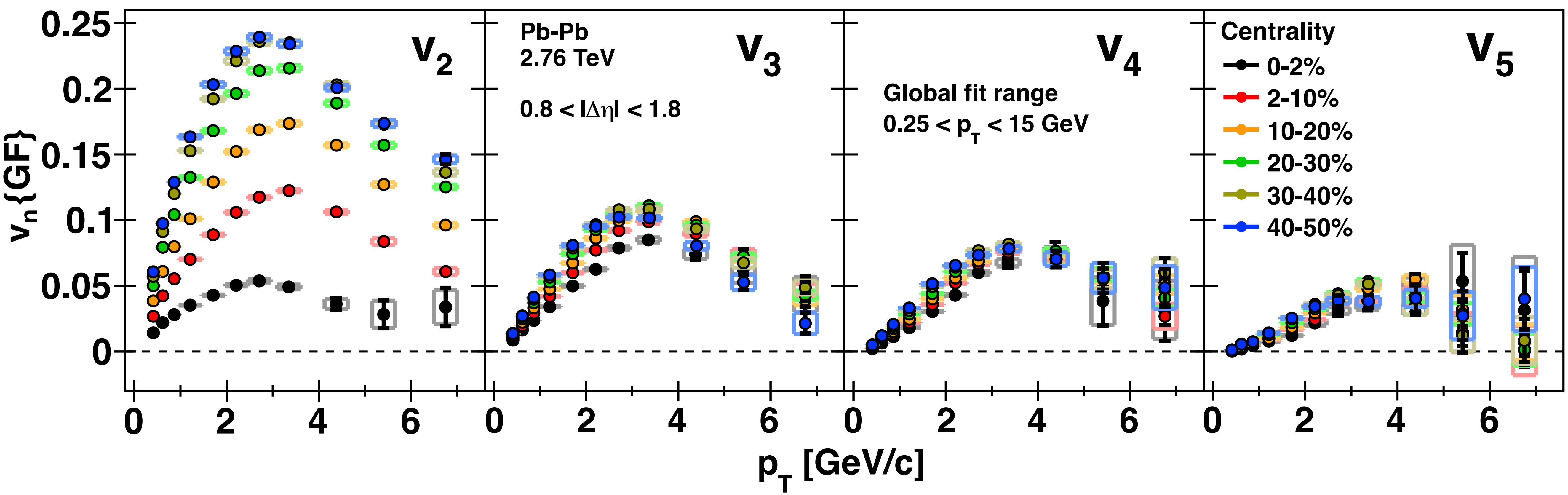

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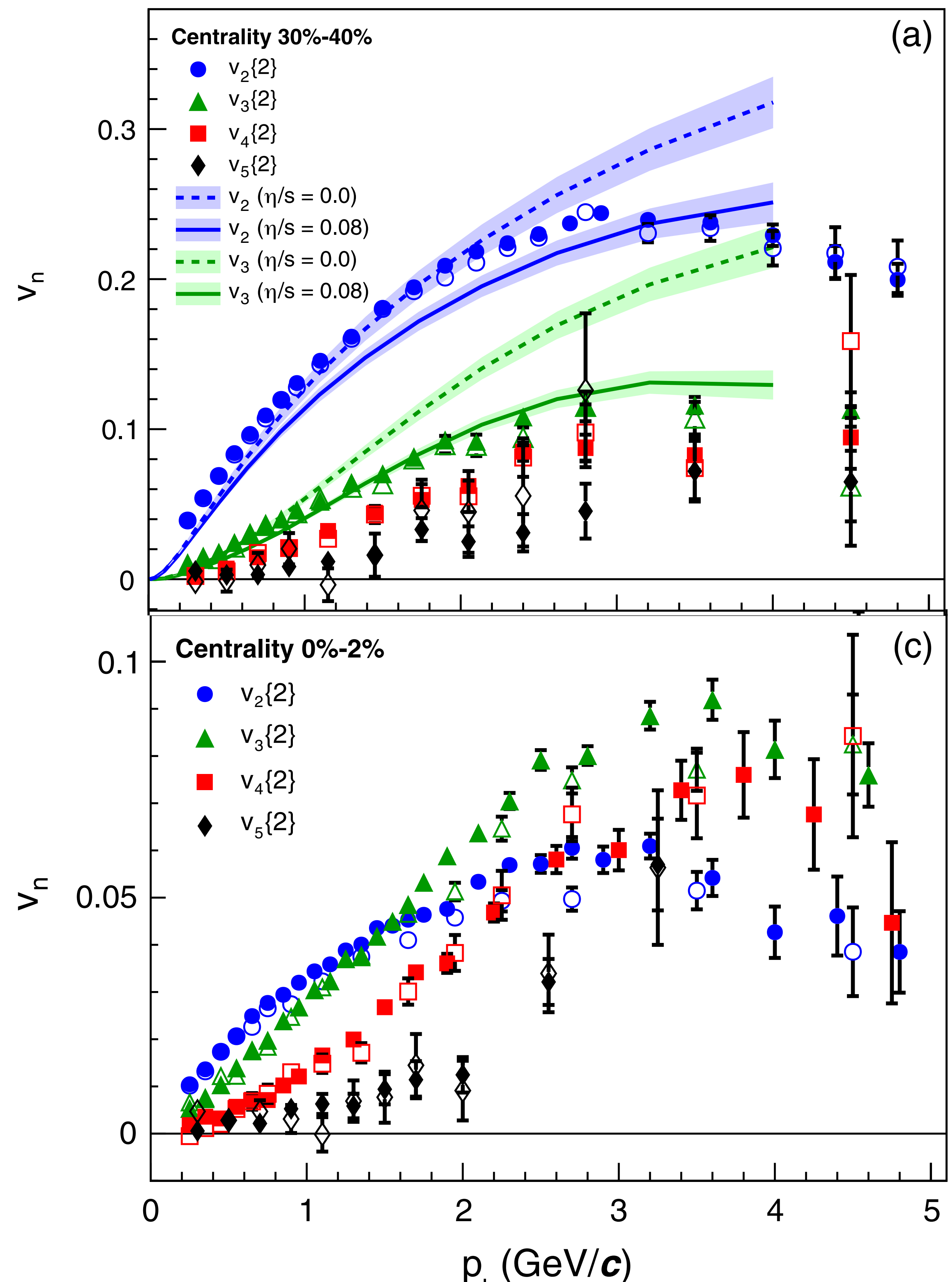
Comparison with ALICE $v_n\{2\}$

Published ALICE $v_n\{2\}$

PRL 107 032301 (2011)

Scalar-product (SP) method

$|\Delta\eta| > 1.0$



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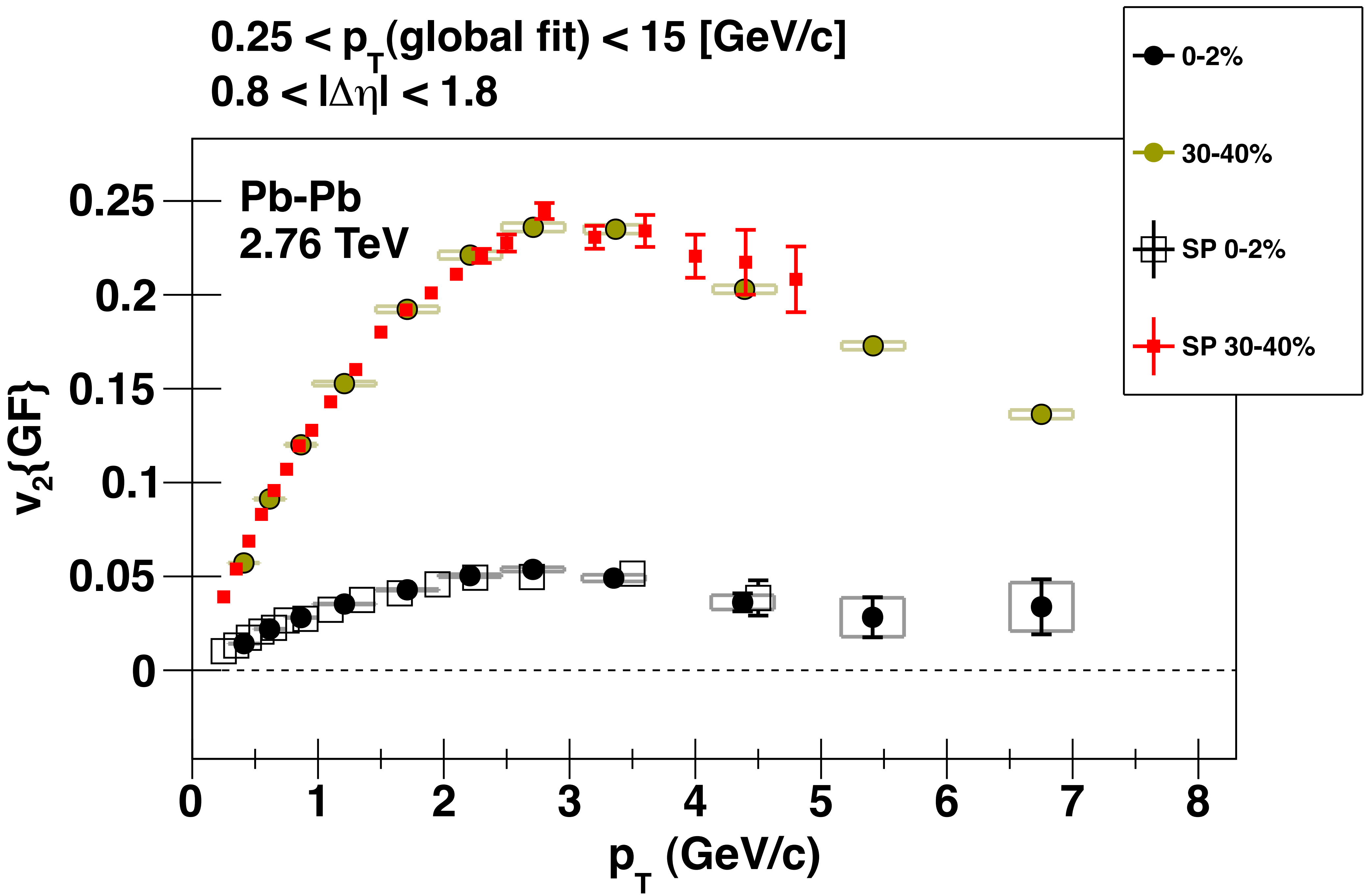
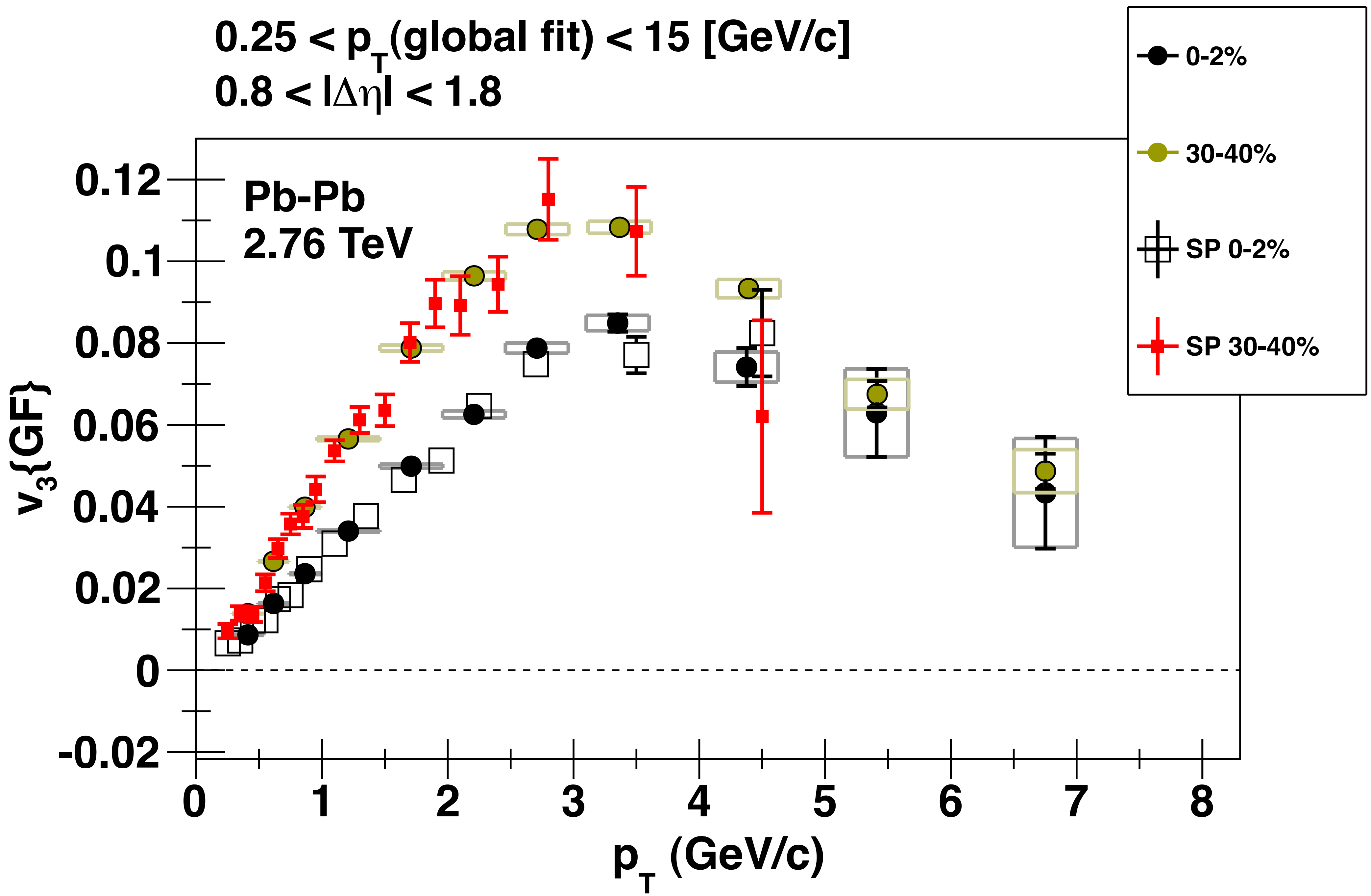


A. Adare (ALICE)

Comparison with ALICE $v_n\{2\}$



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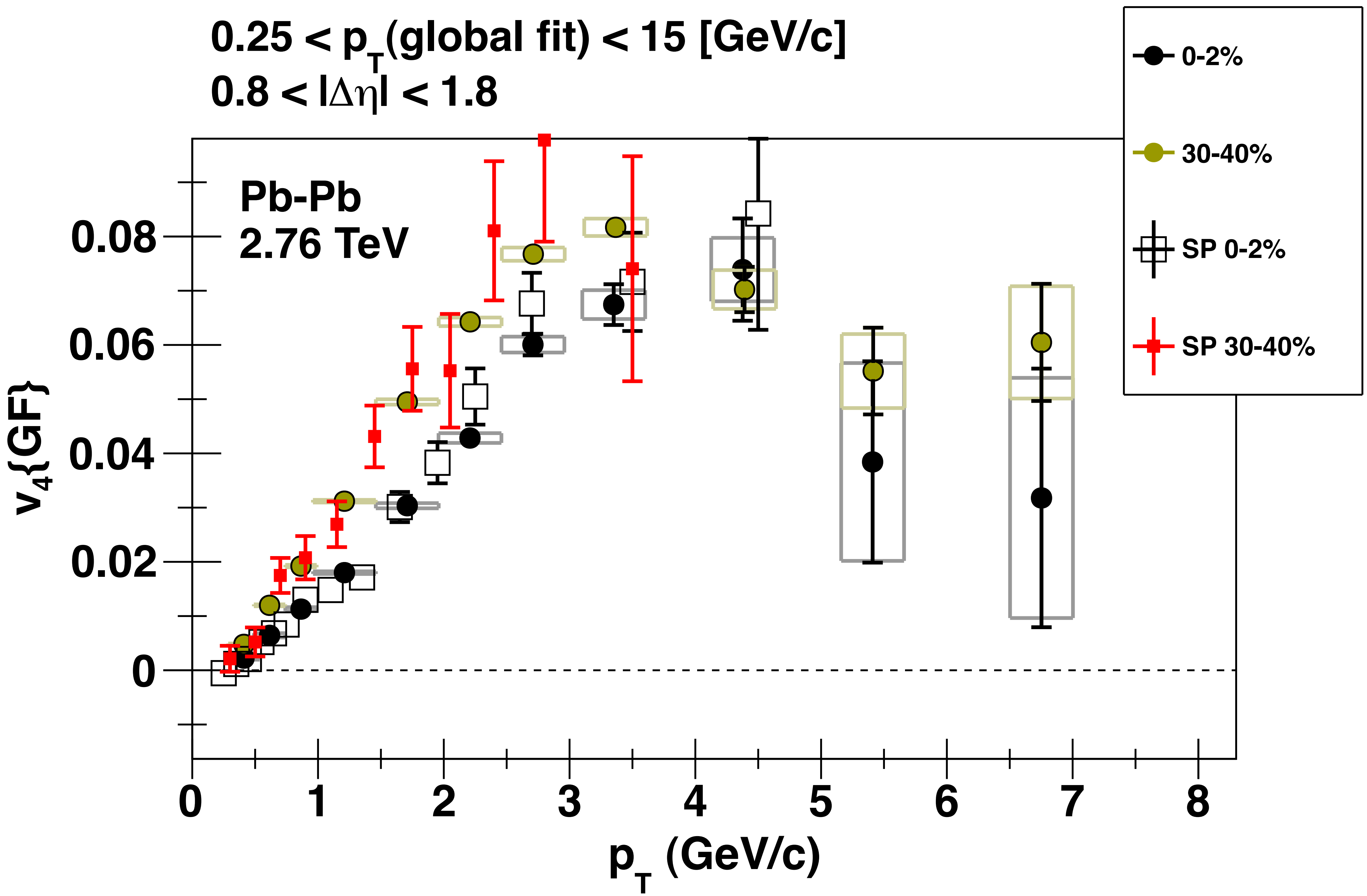

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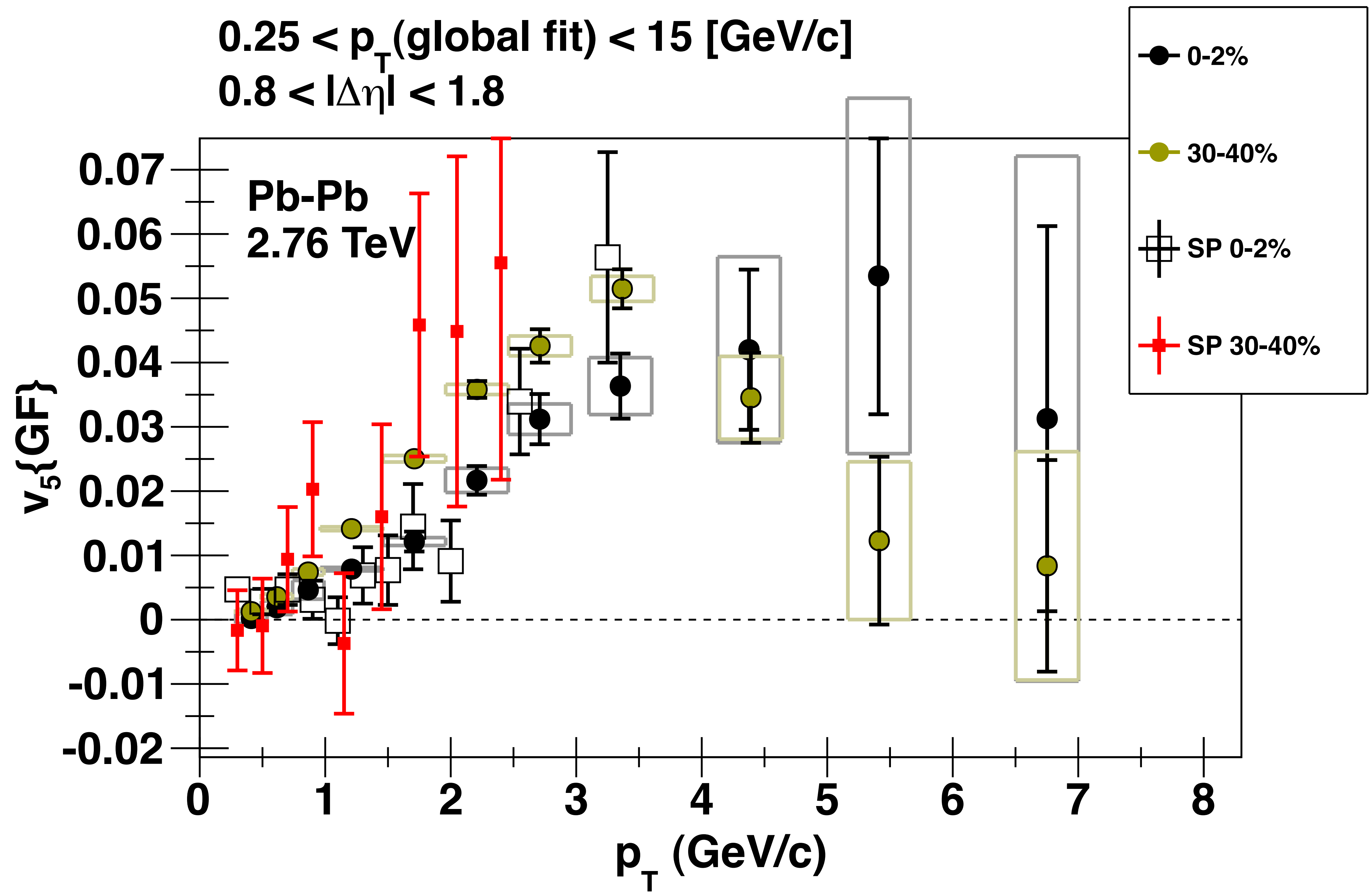

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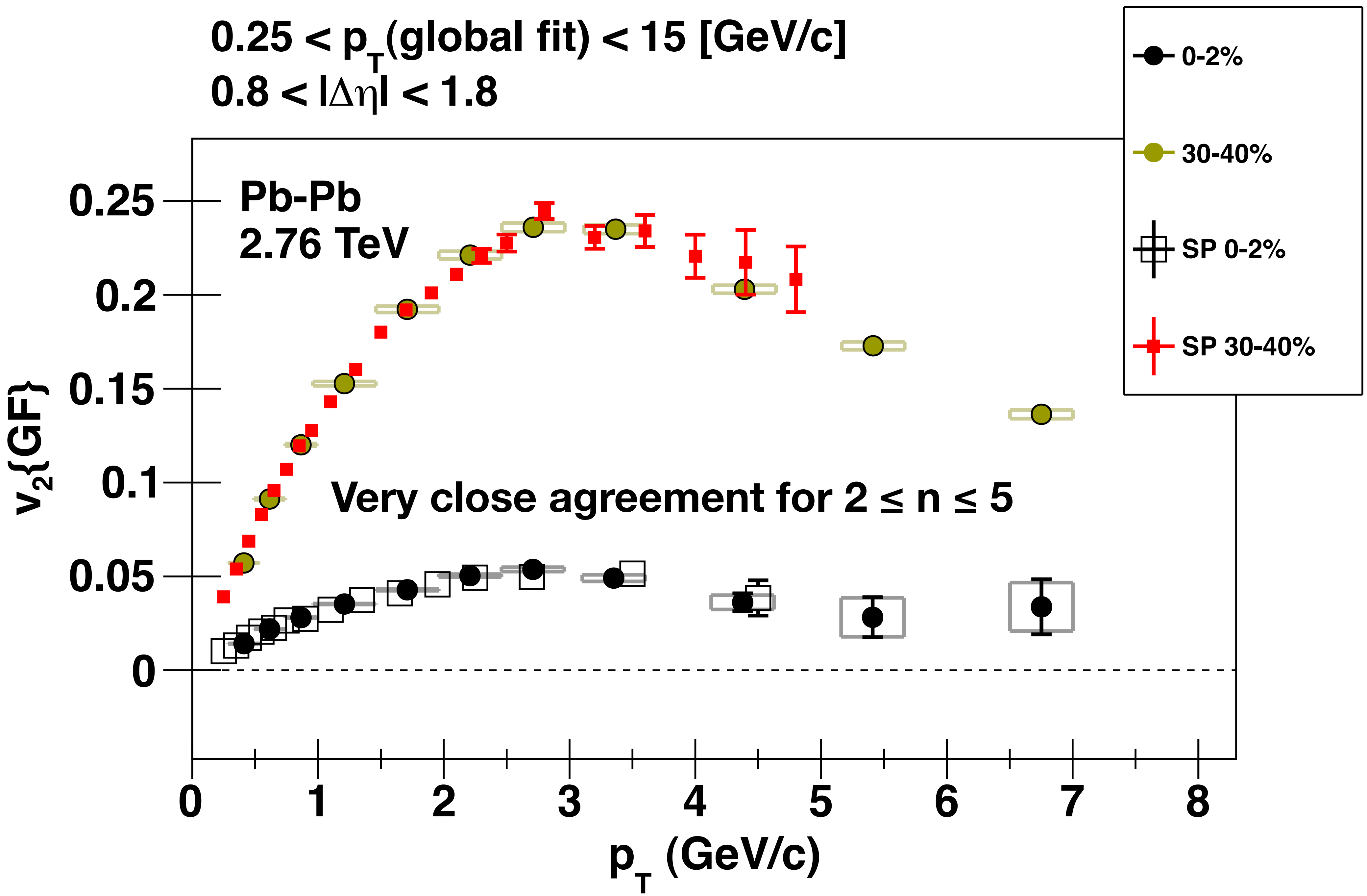
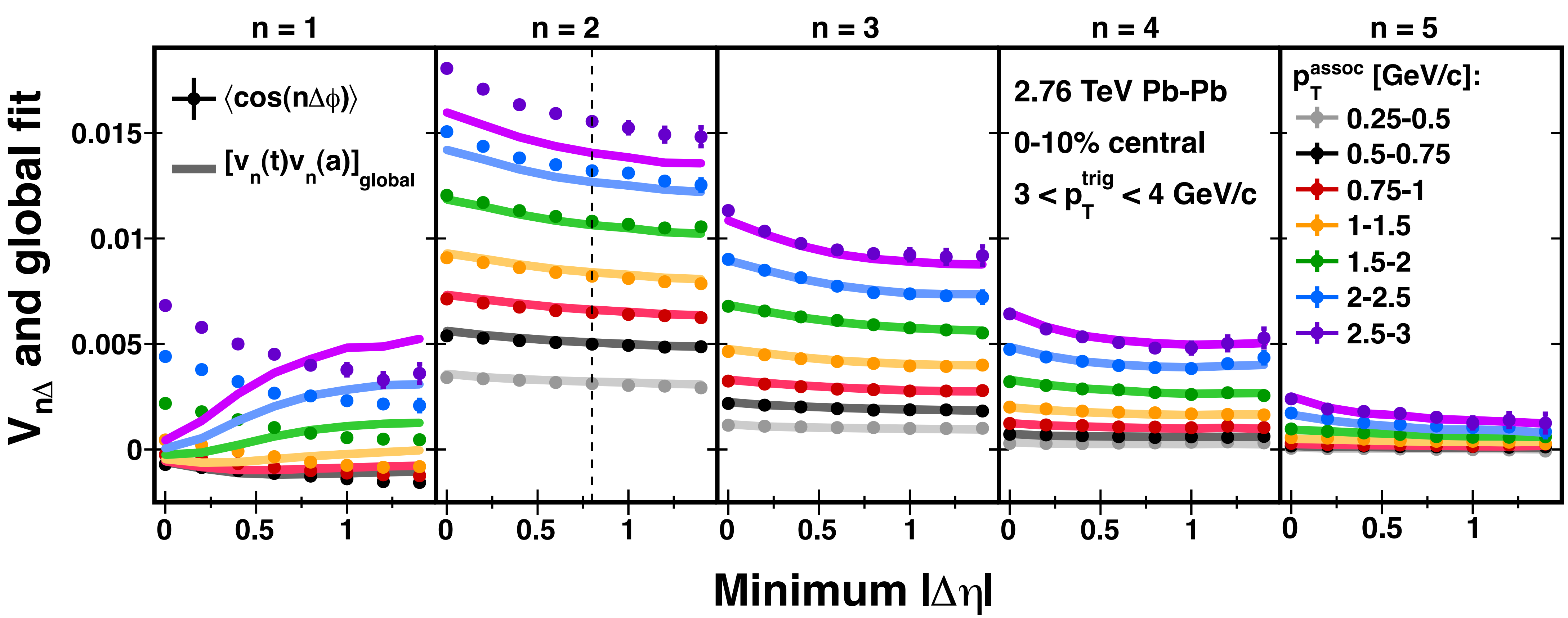


$V_{1\Delta}$ behaves exceptionally...

The n=1 harmonic doesn't factorize

Including the near-side peak enhances disagreement.



$V_{1\Delta}$ behaves exceptionally…

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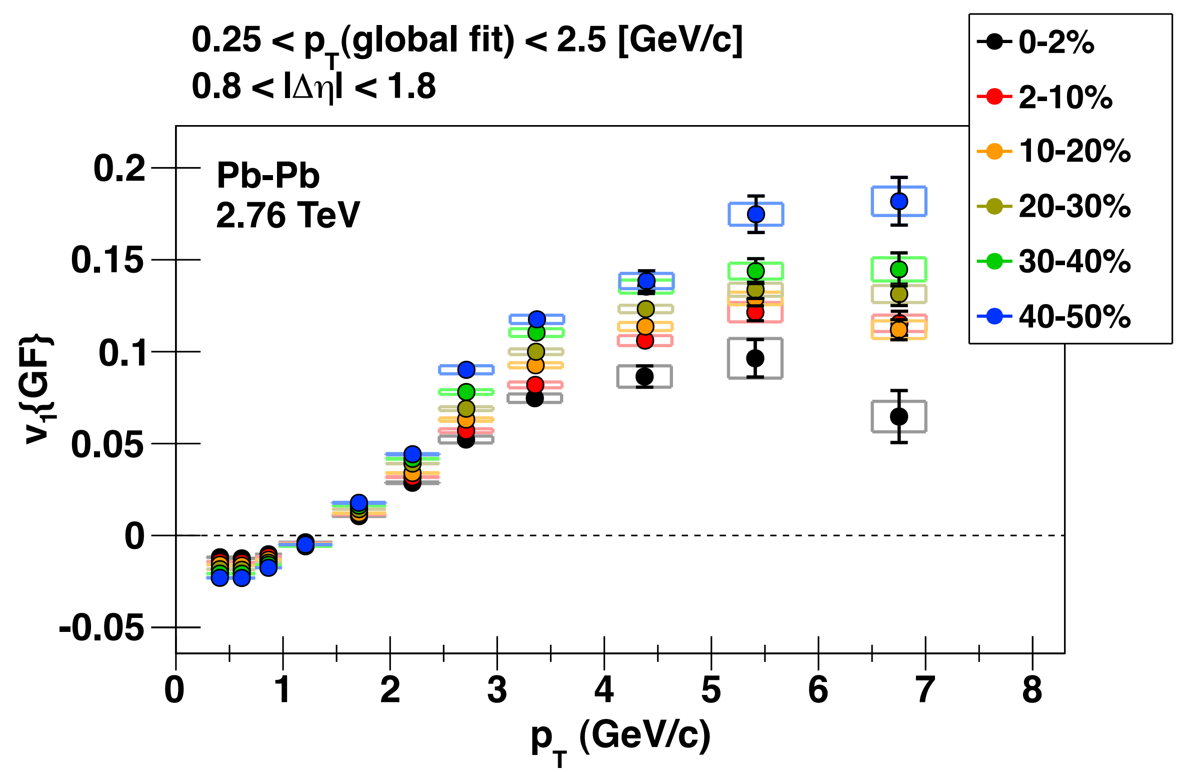
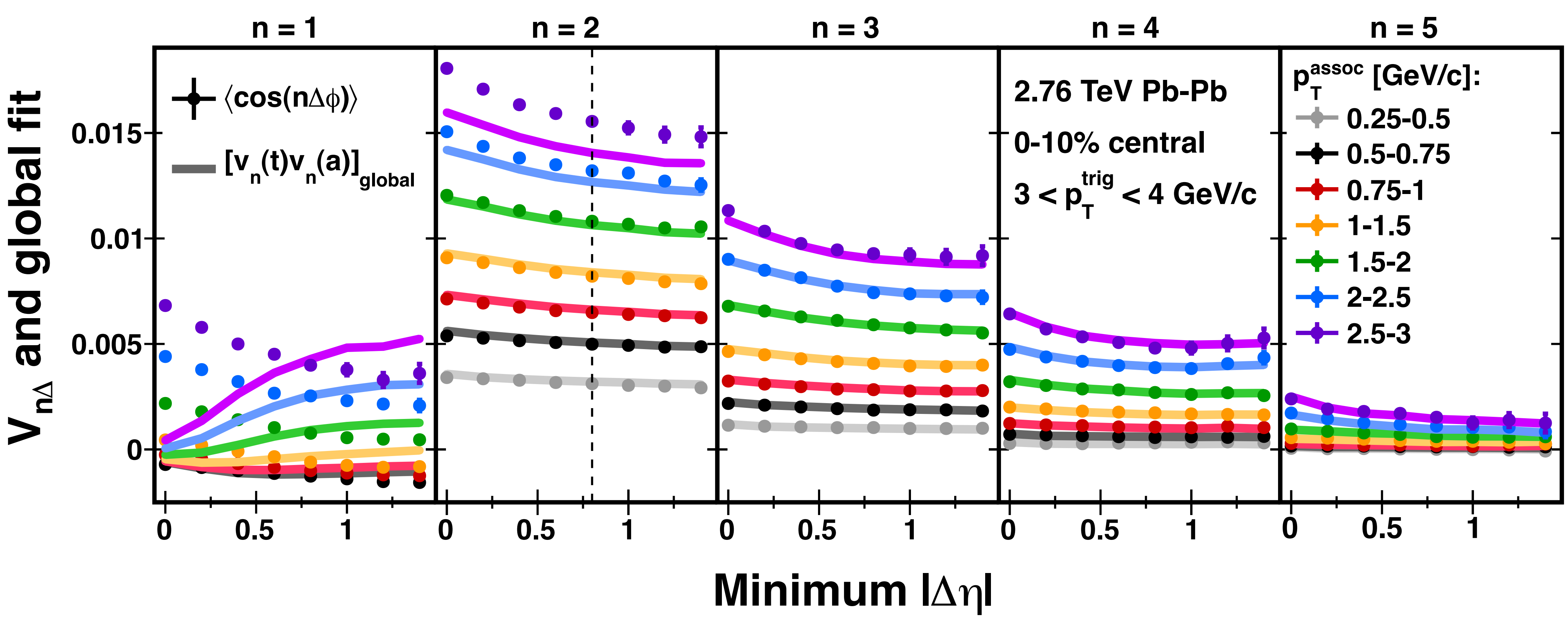
No good global fit over all momenta

However, $v_1\{GF\}$ is qualitatively similar to viscous hydro predictions…under investigation.





Summary

Factorization hypothesis and global fit:

Collective behavior (flow) describes bulk anisotropy (ridge, double-hump)

- No need to invoke Mach cone explanations.

Global fit coefficients (v_n{GF}) consistent with other measurements.

- Another method to measure flow coefficients

Bulk anisotropy factorizes, jet anisotropy does not.

- Bulk correlations related to global symmetries...
- But no such indication for shape of di-jet correlations.

Outlook:

Tackling open questions:

- Higher harmonics?
- Origin of $V_{1\Delta}$? Relation to v_1?

Second-year Pb-Pb data taking is just around the corner!

The end

High trigger, low associated p_T

High-p_T triggers from jet fragmentation

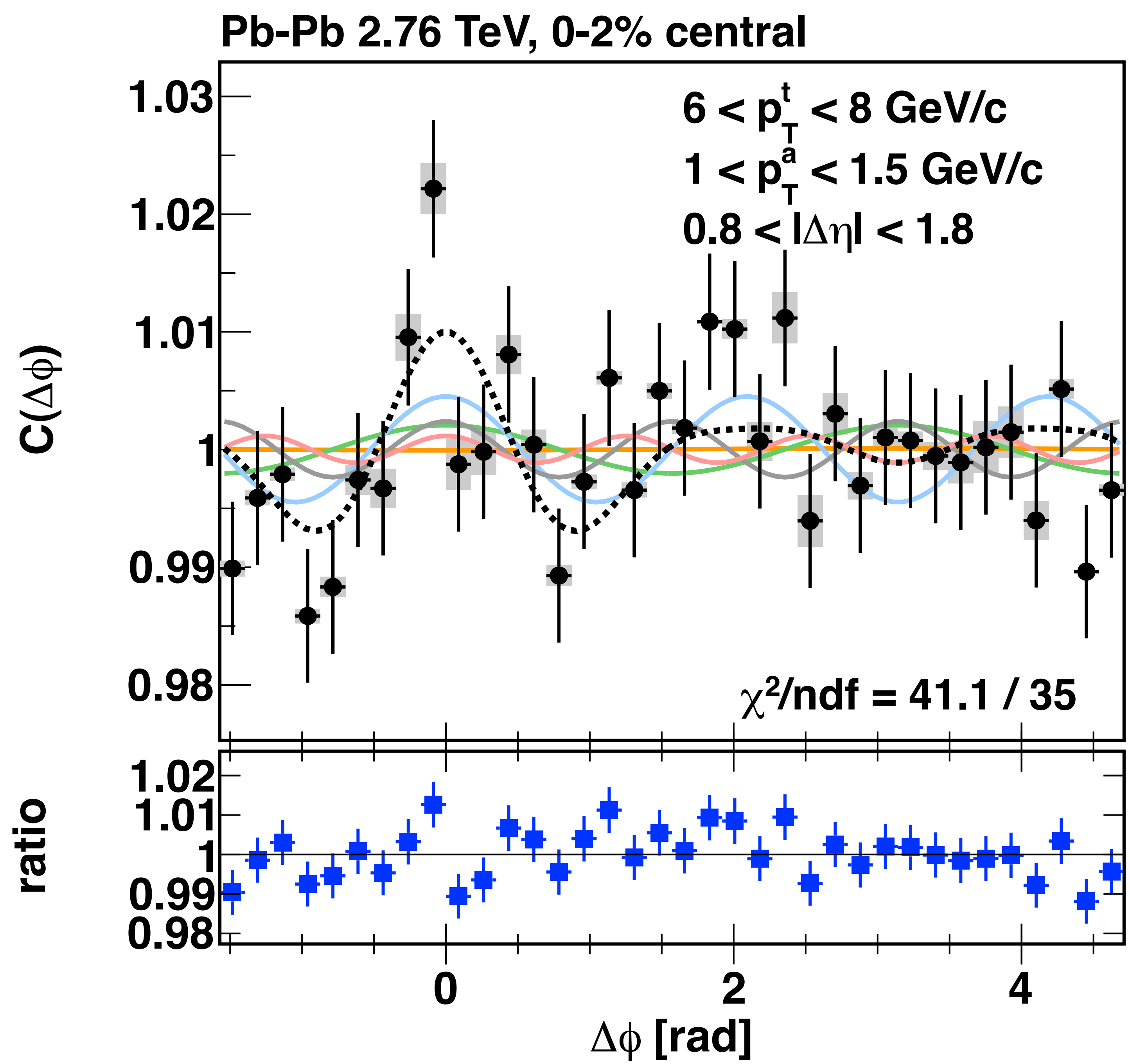
Expect anisotropy from pathlength-dependent quenching (PLDQ).

Low-p_T partners from bulk

Expect anisotropy from flow

Do correlations factorize for this case?

Yes, but not as cleanly as for low p_T^t, low p_T^a correlations.



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