

Transverse-momentum differential radial flow fluctuations across collision systems with CMS

Rohit Kumar Singh
Shandong University

Spicy Gluons, 2026

Oct 18, 2026

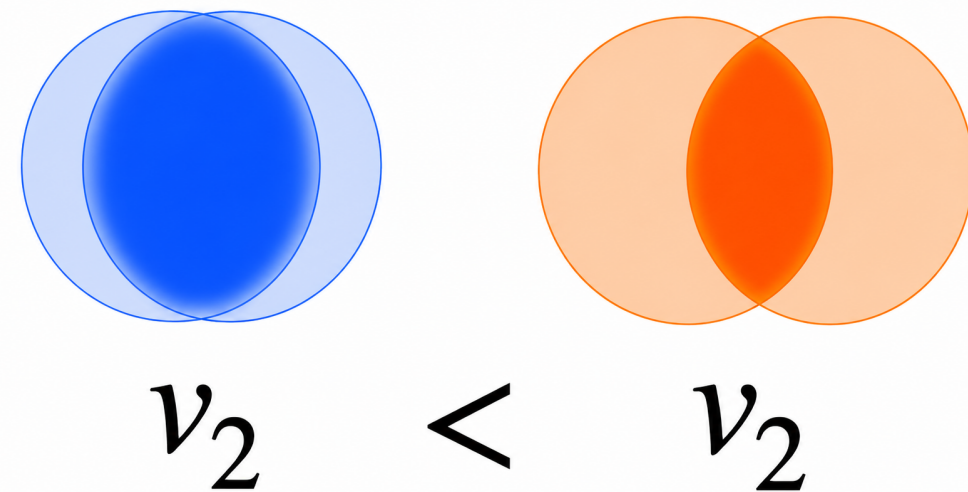


山东大学
SHANDONG UNIVERSITY



Two kinds of transmutation

Shape-flow transmutation



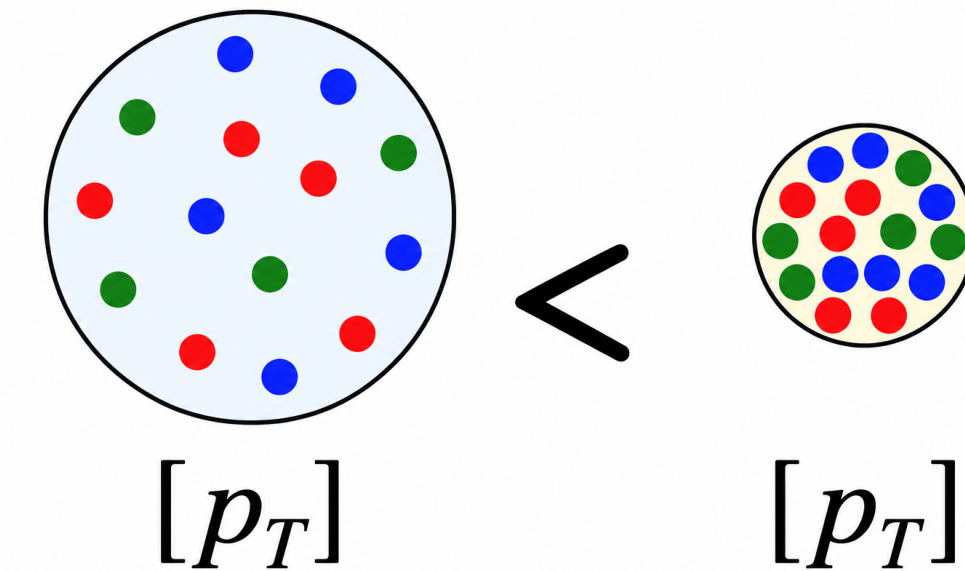
Observables: Anisotropic flow coefficient v_n

p_T differential:
(more informative) $v_n(p_T), n > 0$

Hallmarks of collectivity:

- Long-range nature ($\Delta\eta$ independent)
- Factorization (p_T^{ref} independent)
- Centrality independence of $v_n(p_T)/v_n$
- Consistency b/w higher order cumulants
- Mass ordering, NCQ scaling
- Baryon-Meson splitting, heavy-flavor flow

Size-flow transmutation



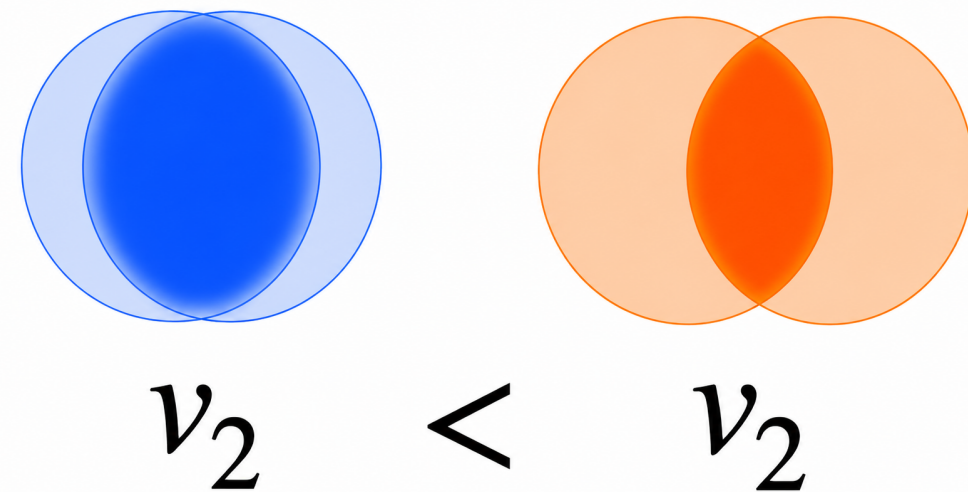
E-by-E $[p_T]$ fluctuations, σ_{p_T}

Not available

**Less realized as a signature
of collectivity**

Two kinds of transmutation

Shape-flow transmutation



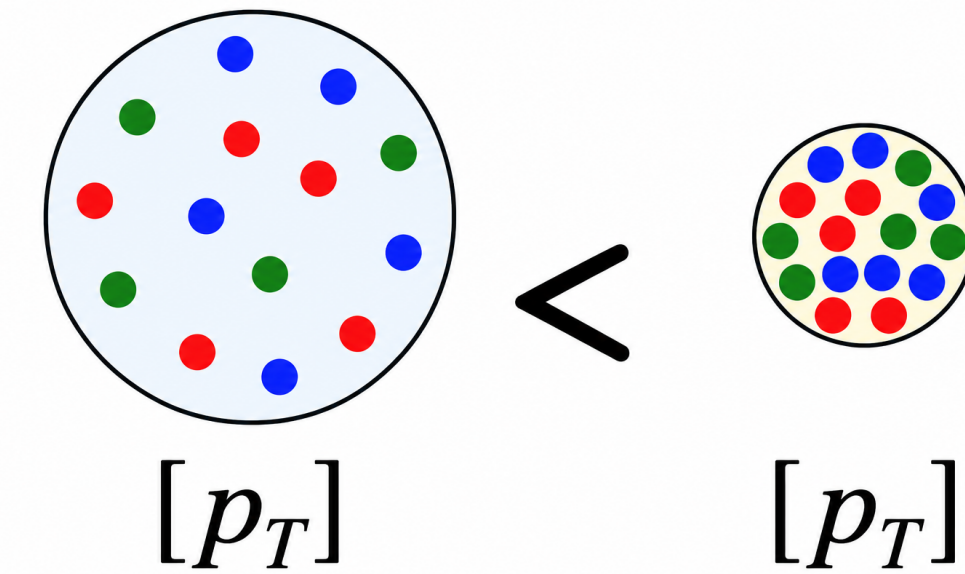
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Size-flow transmutation



E-by-E $[p_T]$ fluctuations, σ_{p_T}

$$v_0(p_T)$$

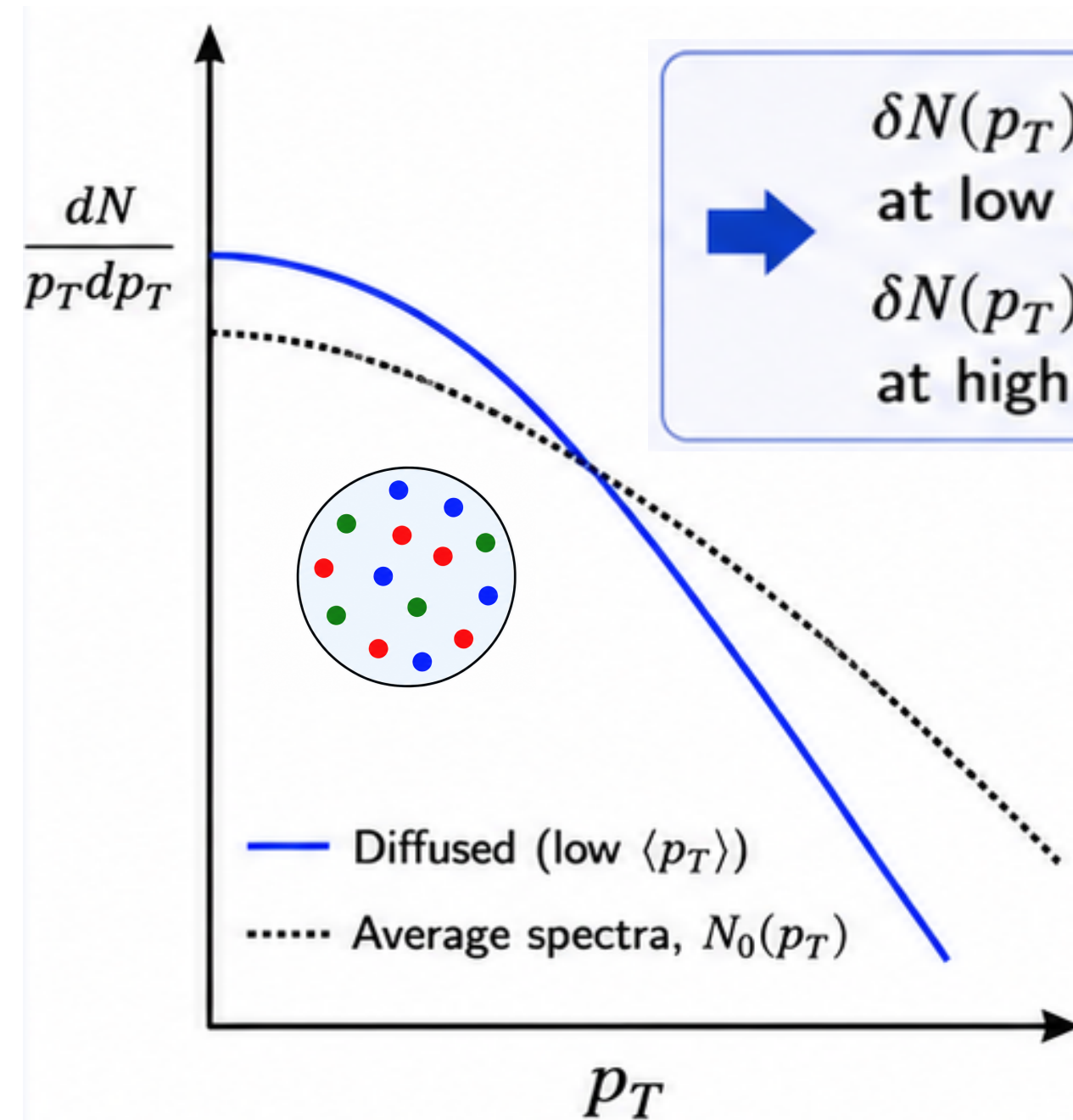
Teaney et.al.: Phys. Rev. C 102, 034905 (2020)

**Do these hallmarks of collectivity
also hold for radial flow?**

Defining the differential radial flow

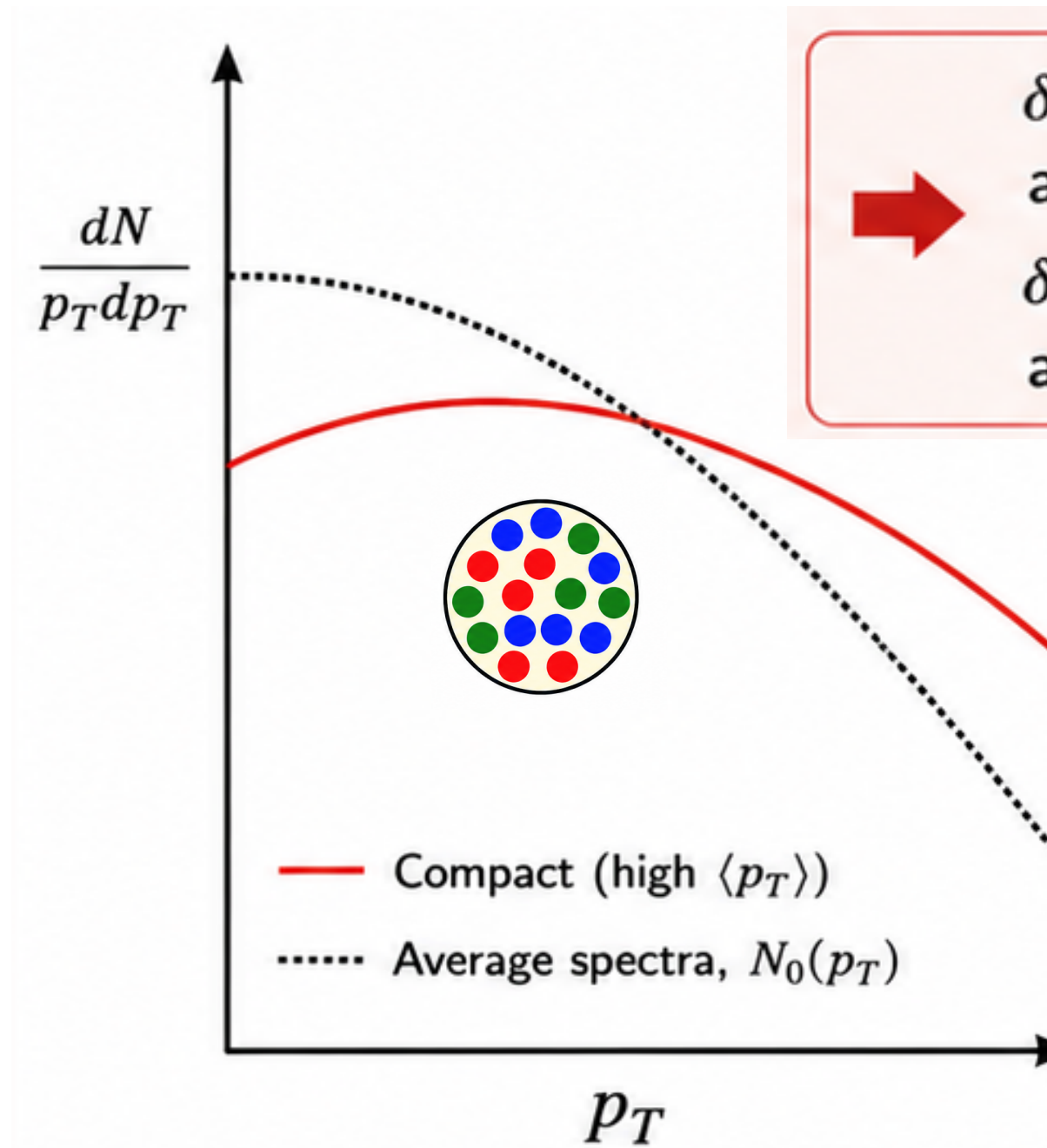
$$v_0(p_T) \sim \langle \delta N(p_T) \delta p_T \rangle$$

Correlation between the fluctuations of local yield ($\delta N(p_T)$) and mean transverse-momentum (δp_T)



$\delta N(p_T) > 0$
at low p_T
 $\delta N(p_T) < 0$
at high p_T

Correlated with
lower $\langle p_T \rangle$
($\delta p_T < 0$)



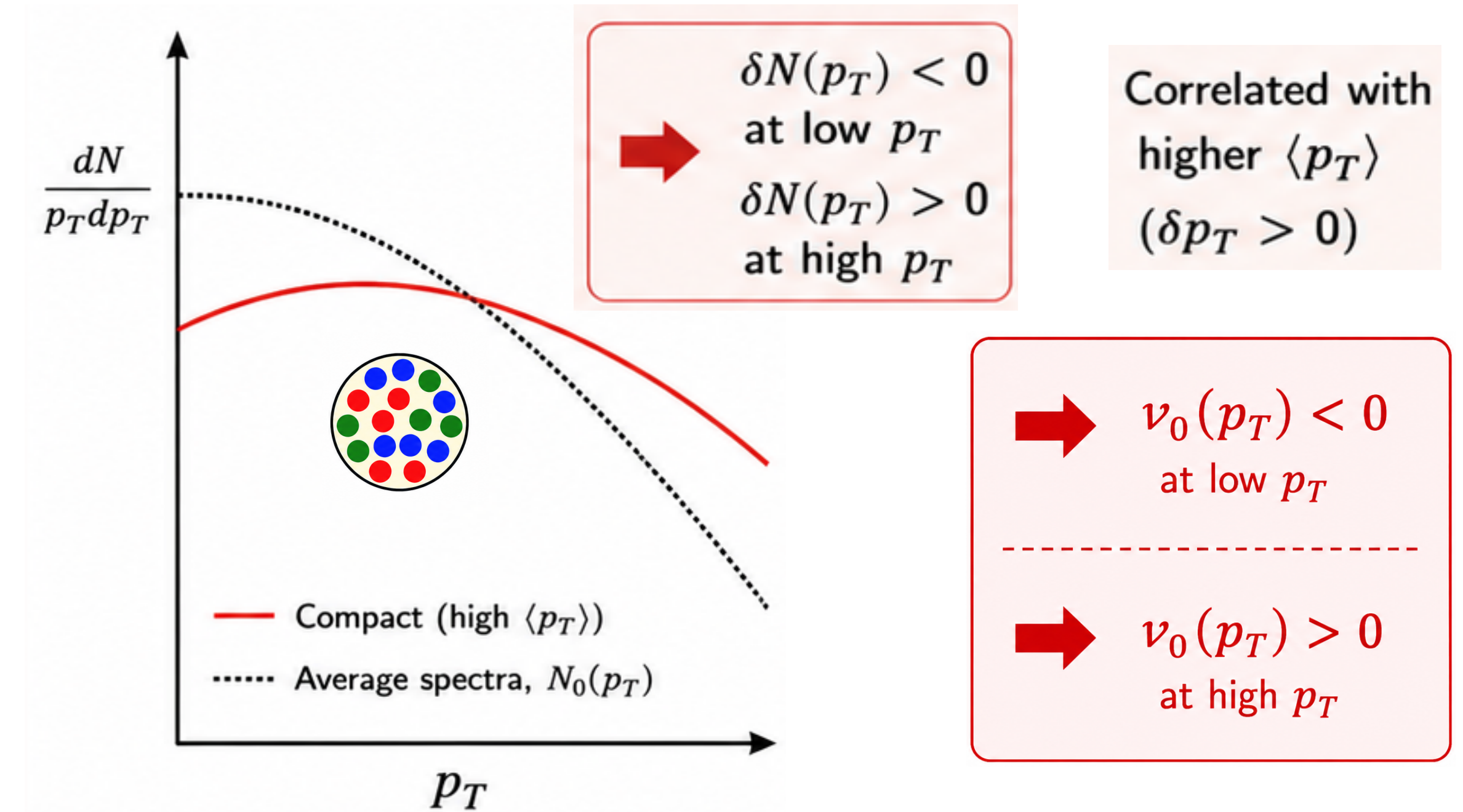
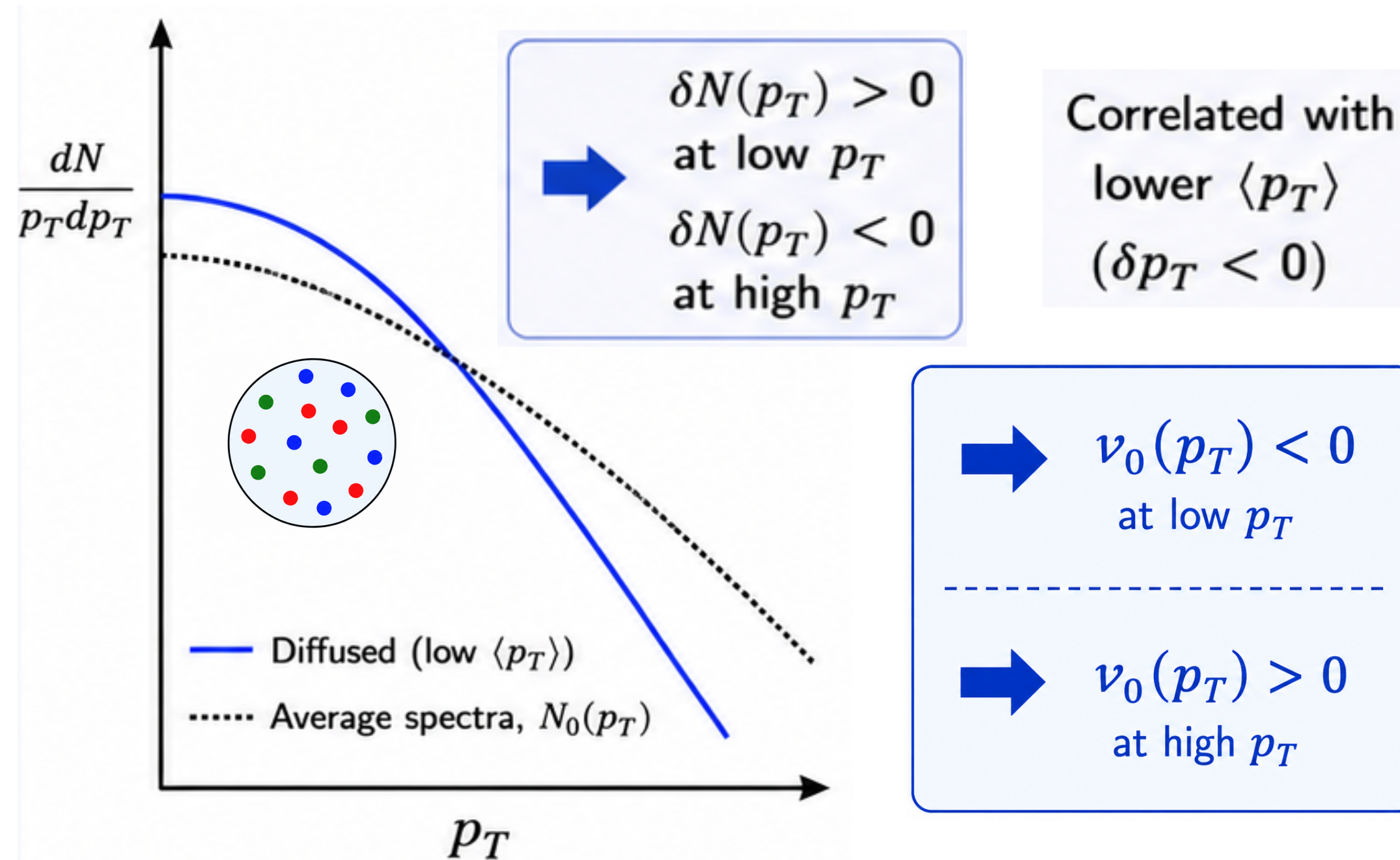
$\delta N(p_T) < 0$
at low p_T
 $\delta N(p_T) > 0$
at high p_T

Correlated with
higher $\langle p_T \rangle$
($\delta p_T > 0$)

Defining the differential radial flow

$$v_0(p_T) \sim \langle \delta N(p_T) \delta p_T \rangle$$

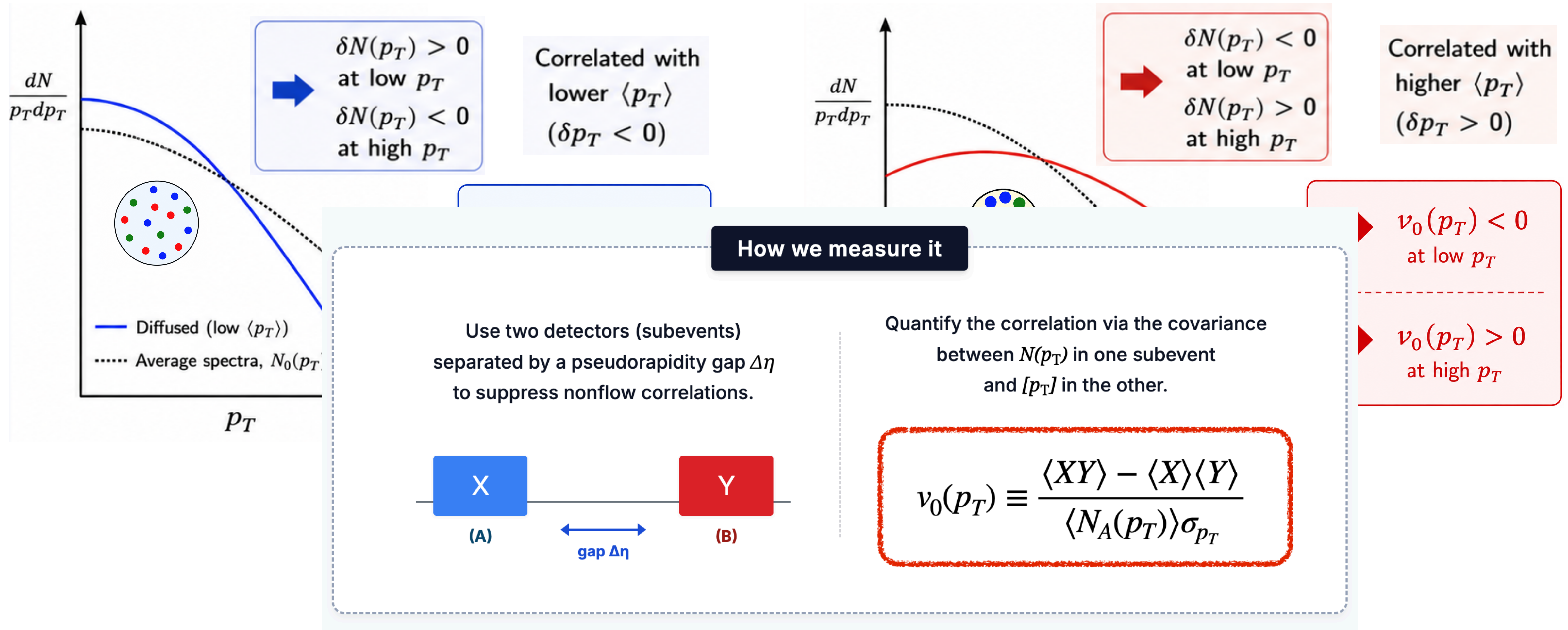
Correlation between the fluctuations of local yield ($\delta N(p_T)$) and mean transverse-momentum (δp_T)



Defining the differential radial flow

$$v_0(p_T) \sim \langle \delta N(p_T) \delta p_T \rangle$$

Correlation between the fluctuations of local yield ($\delta N(p_T)$) and mean transverse-momentum (δp_T)



CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel ($100 \times 150 \mu\text{m}$) $\sim 1\text{m}^2 \sim 66\text{M}$ channels
Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2 \sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying $\sim 18,000\text{A}$

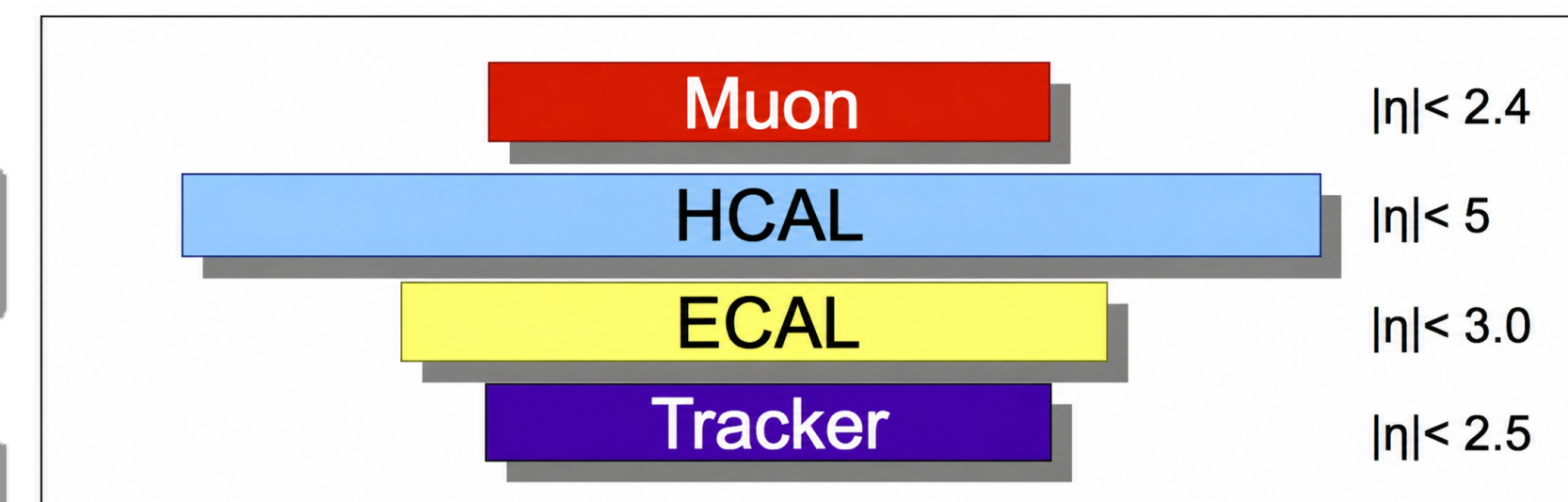
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

PRESHOWER
Silicon strips $\sim 16\text{m}^2 \sim 137,000$ channels

FORWARD CALORIMETER
Steel + Quartz fibres $\sim 2,000$ Channels

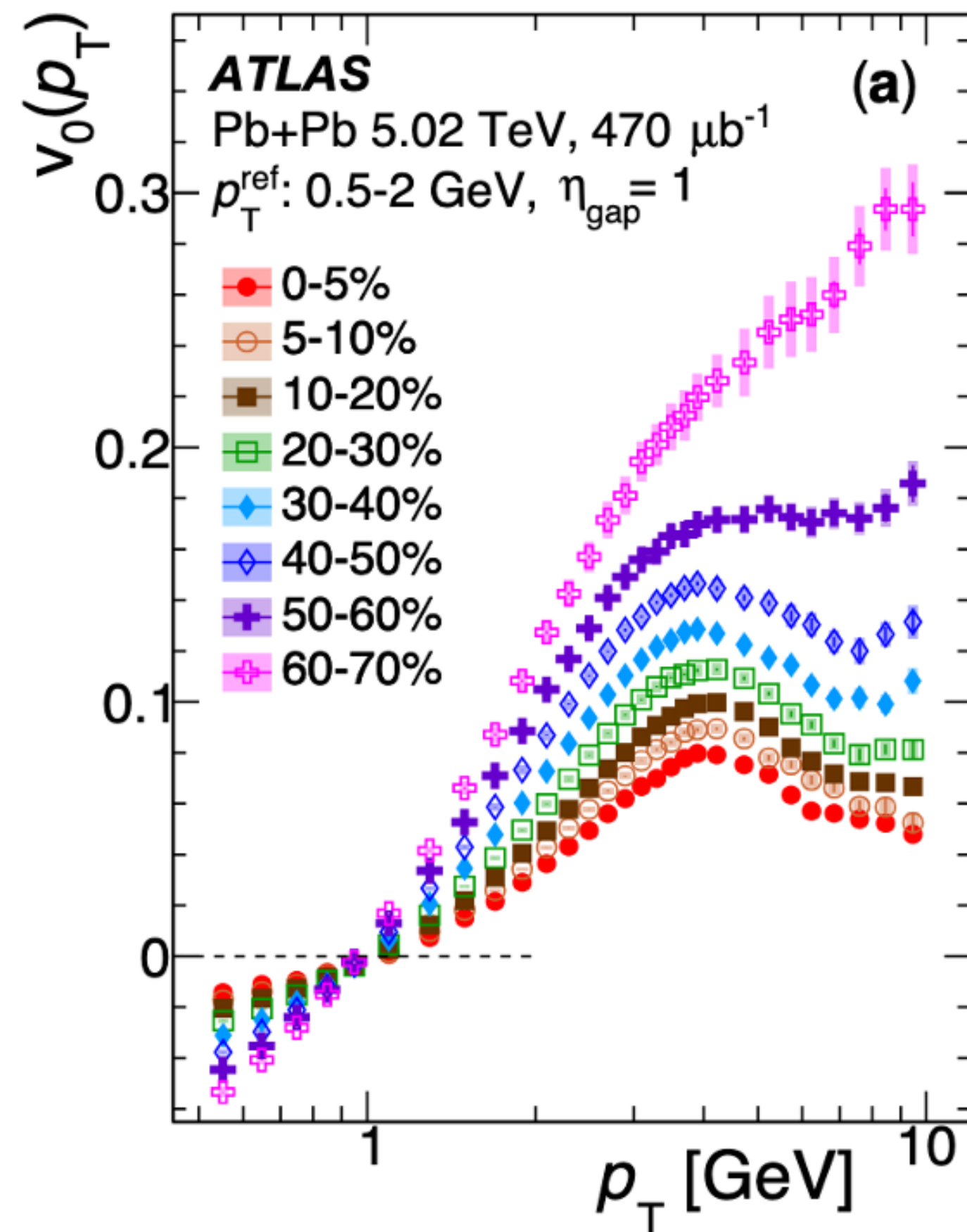
CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO_4 crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator $\sim 7,000$ channels



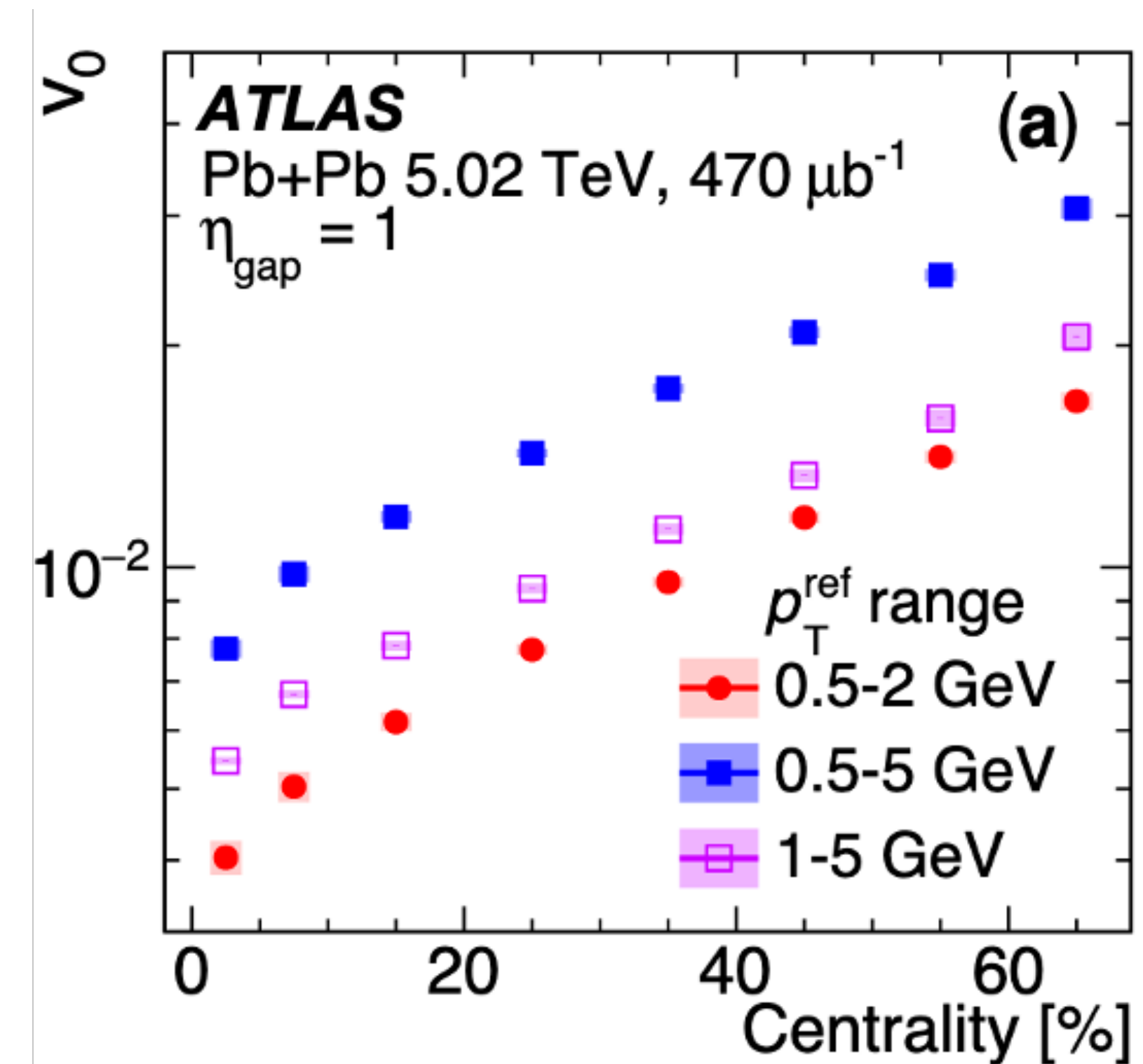
Observations in Large System

Phys. Rev. Lett. 136, 032301



Multiplicity ↓
Fluctuations ↑

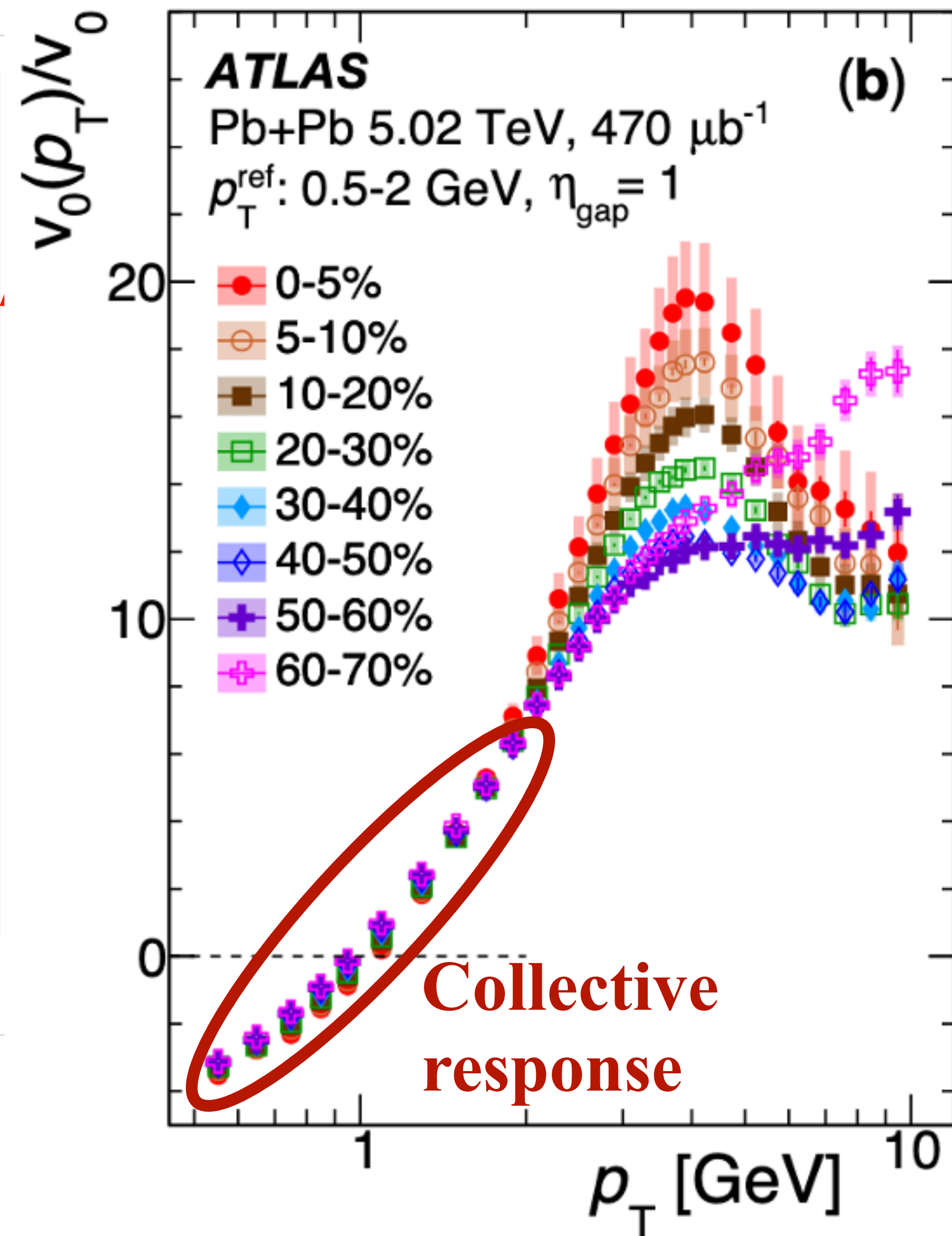
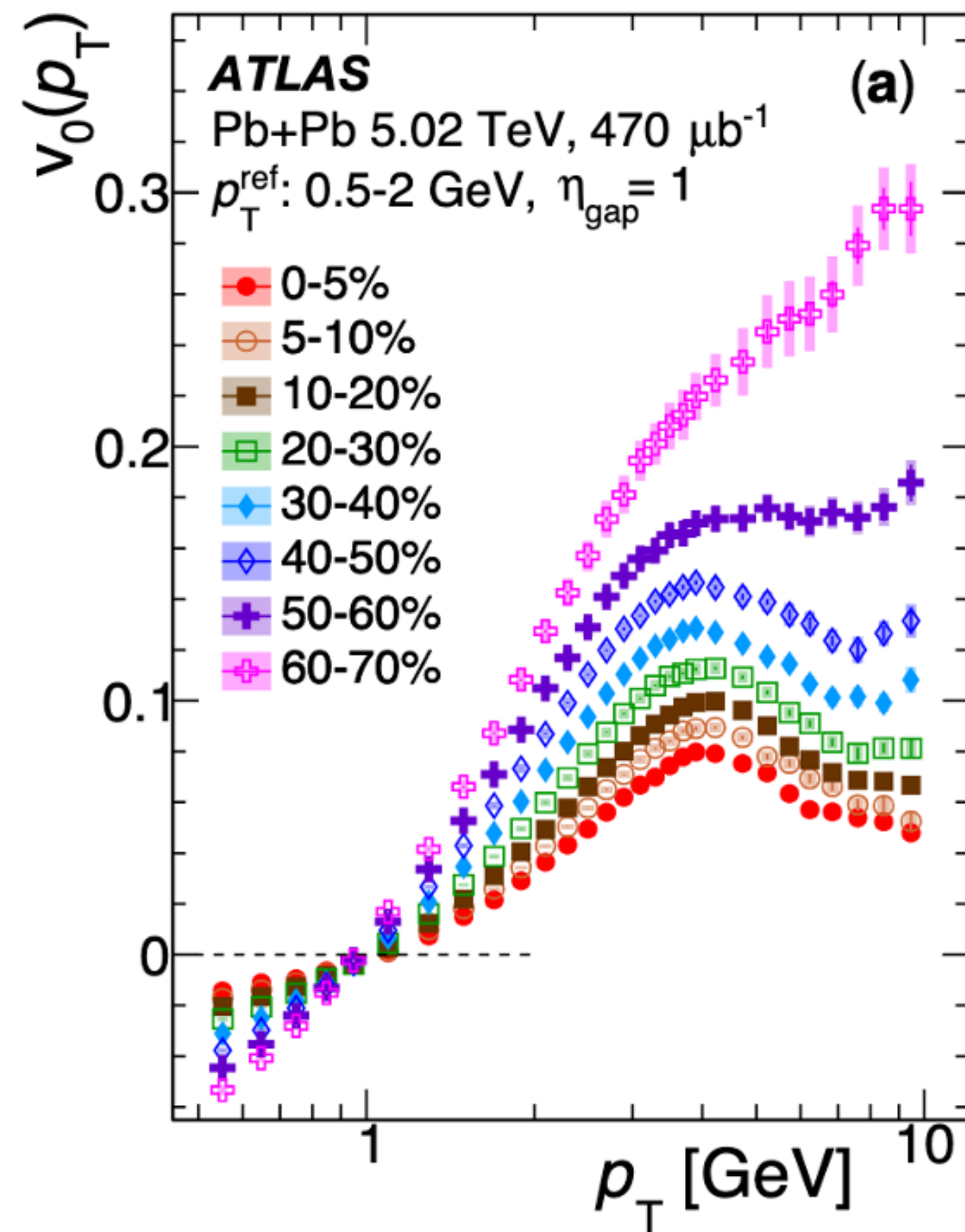
$v_0 \equiv \int v_0(p_T)$ determines the relative size of fluctuations



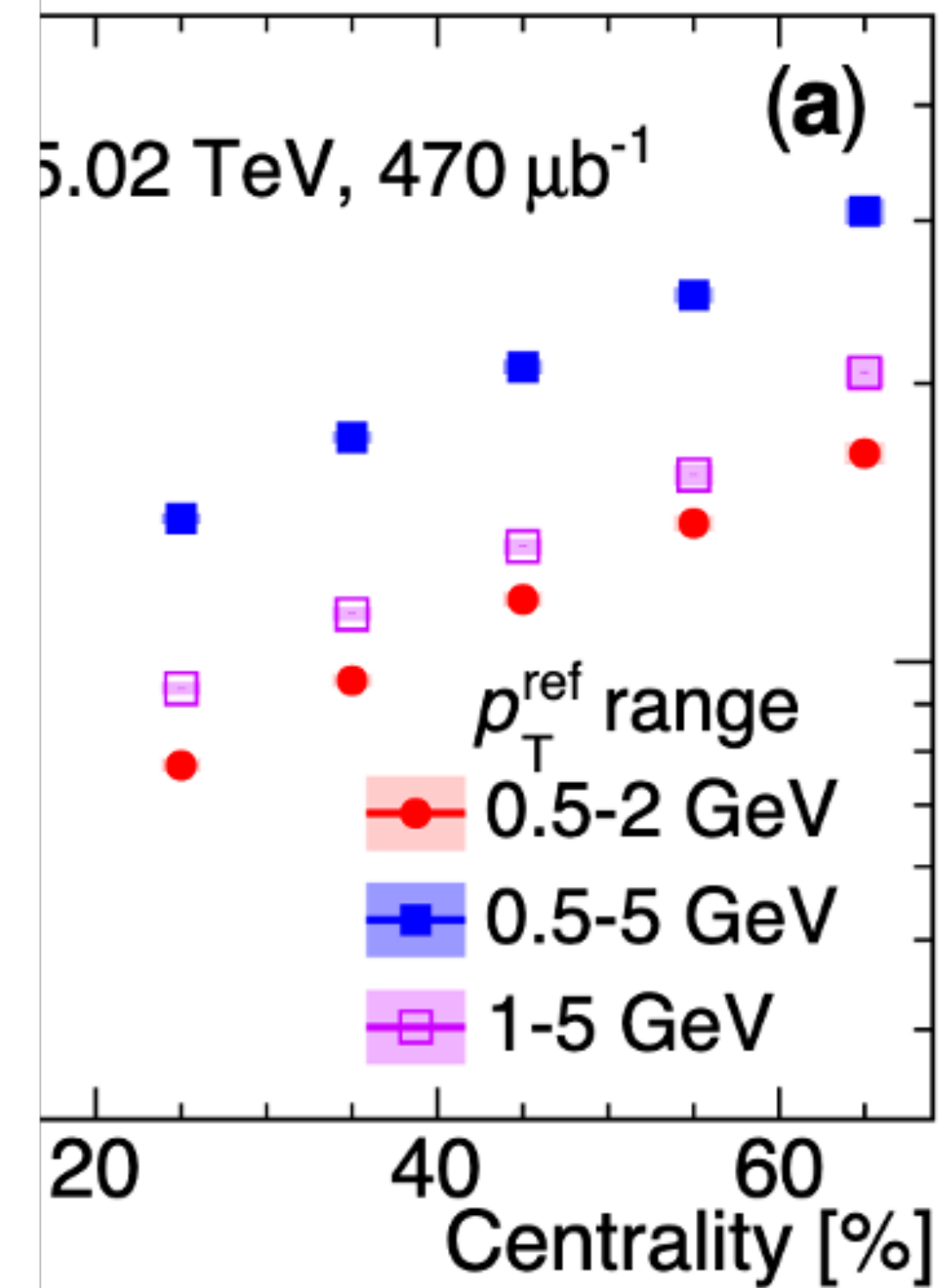
Multiplicity ↓
Fluctuations ↑

Hallmarks of Collectivity

Phys. Rev. Lett. 136, 032301



$v_0(p_T)/v_0$ is independent of size of the fluctuations. Dependence on models of initial conditions is suppressed.

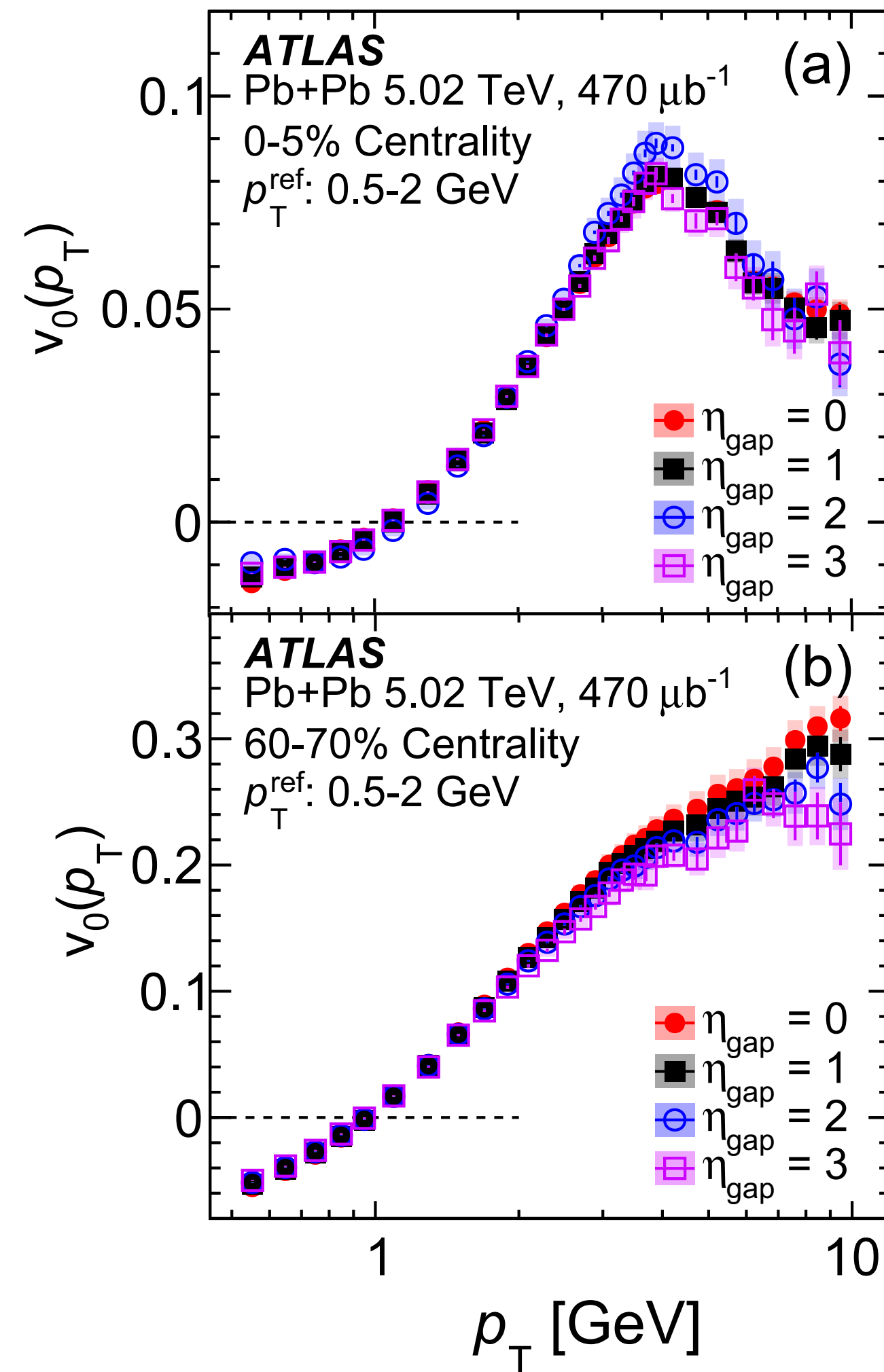


Multiplicity ↓

Fluctuations ↑

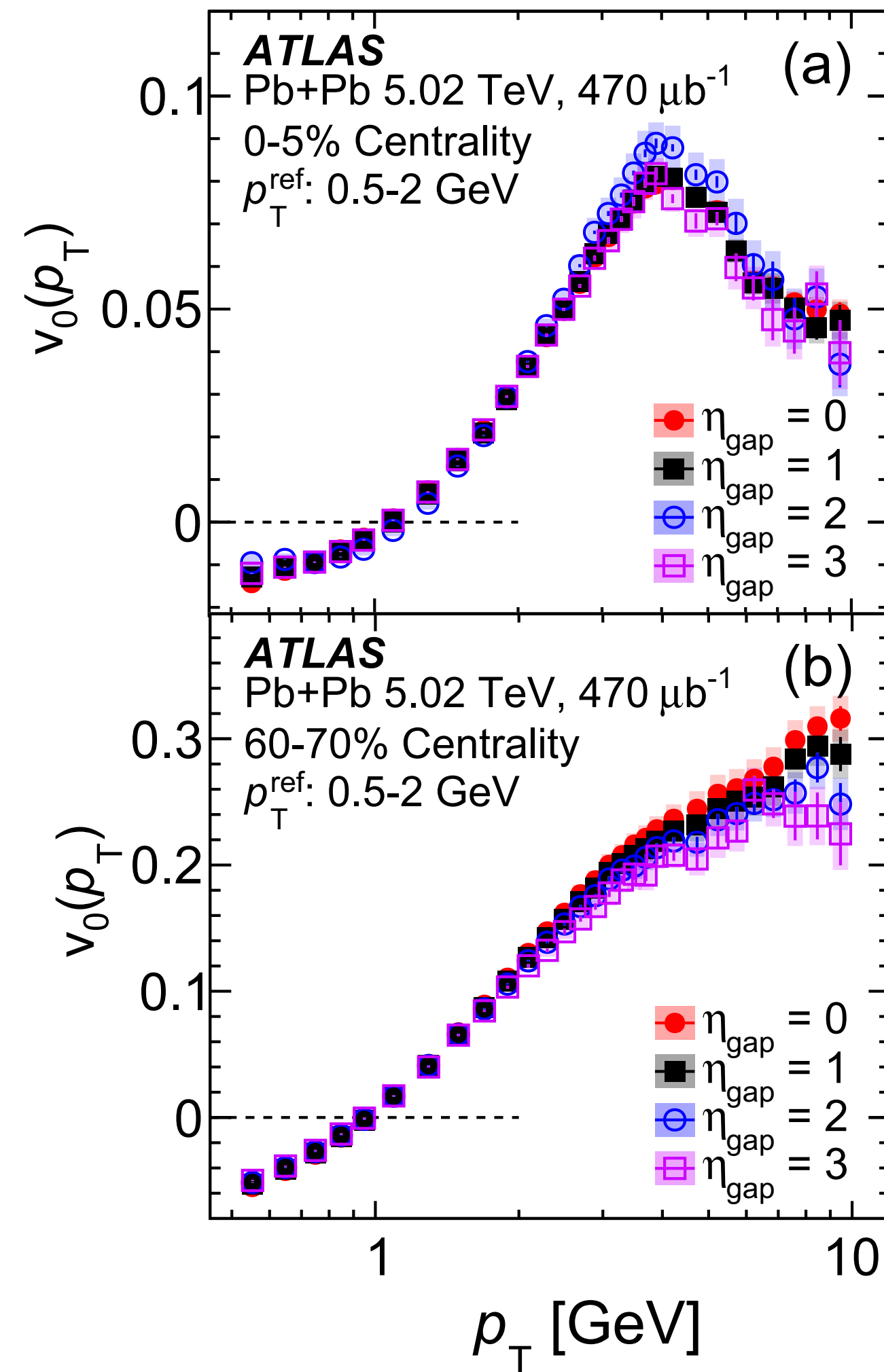
Hallmarks of Collectivity

Long-range nature:
 $\Delta\eta$ independence

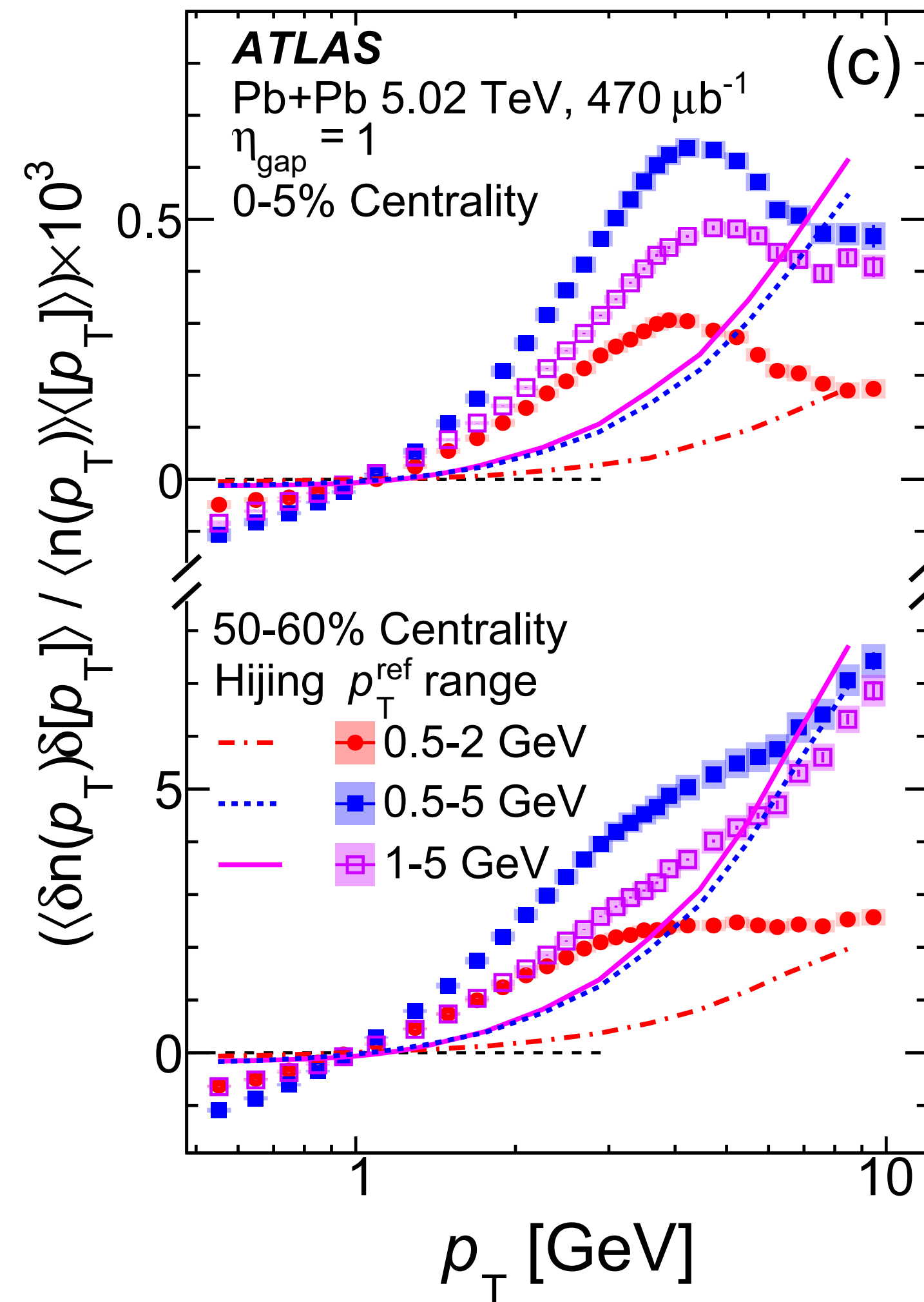


Hallmarks of Collectivity

**Long-range nature:
 $\Delta\eta$ independence**

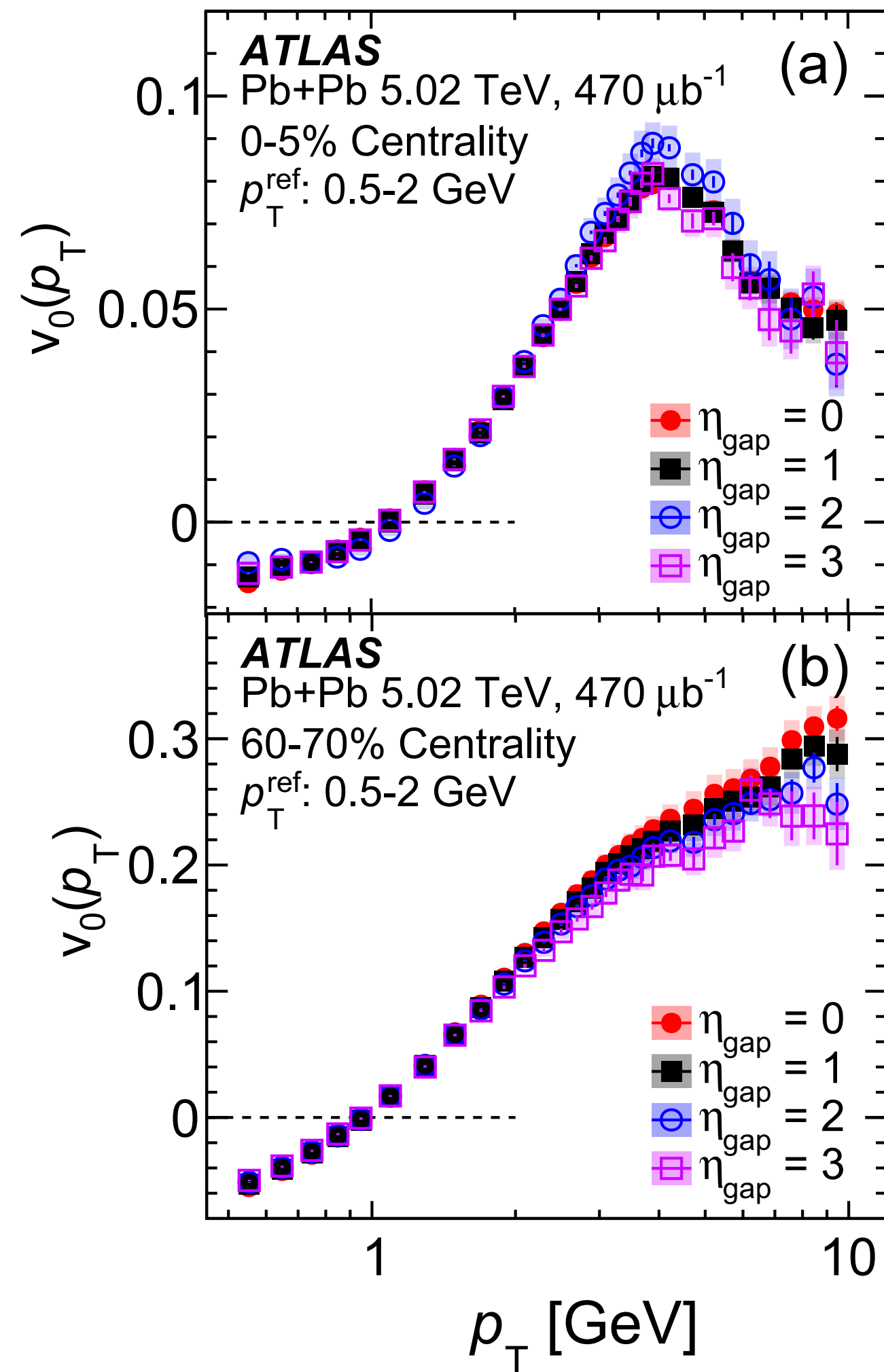


**HIJING underpredicts
strength of correlation**

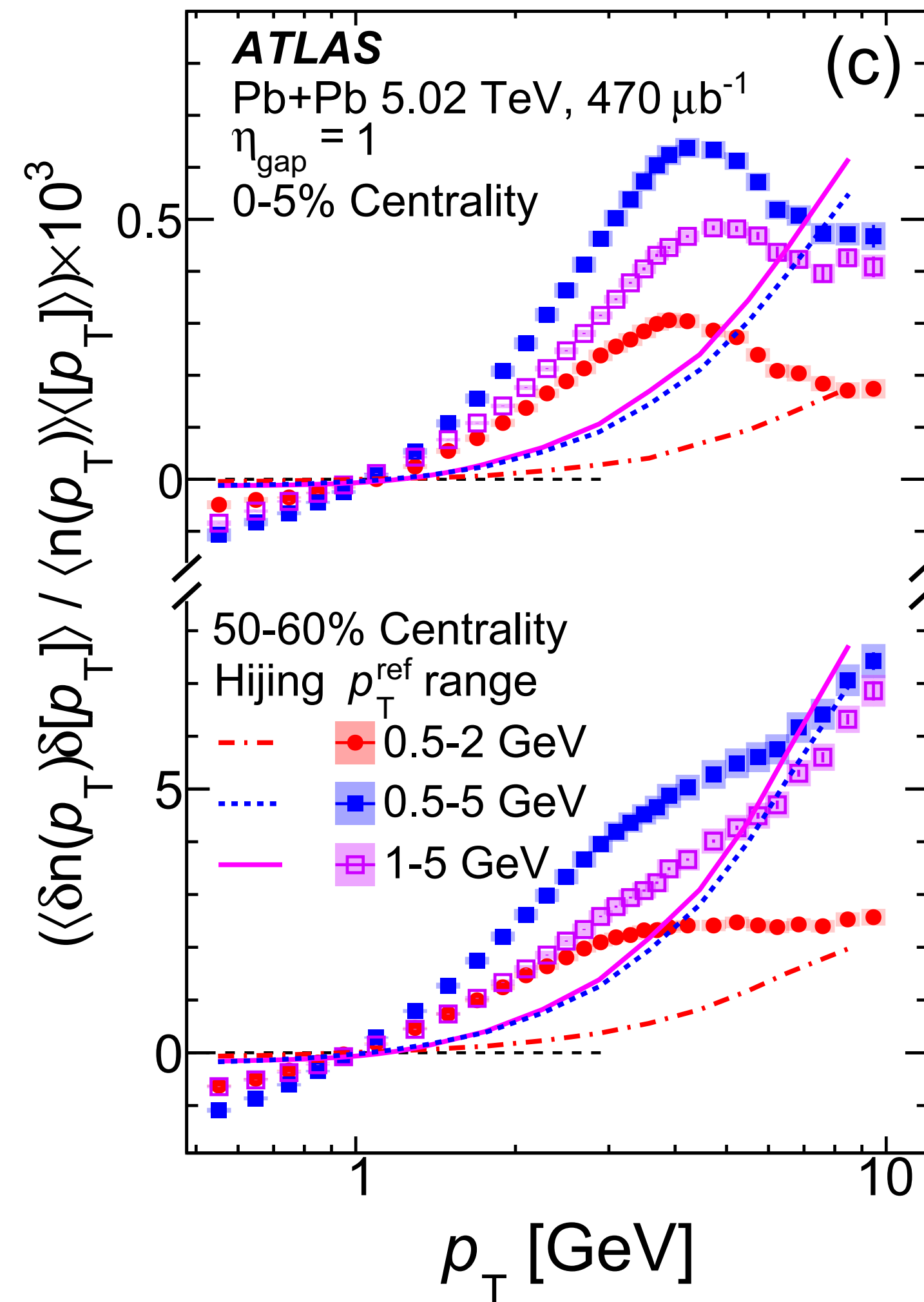


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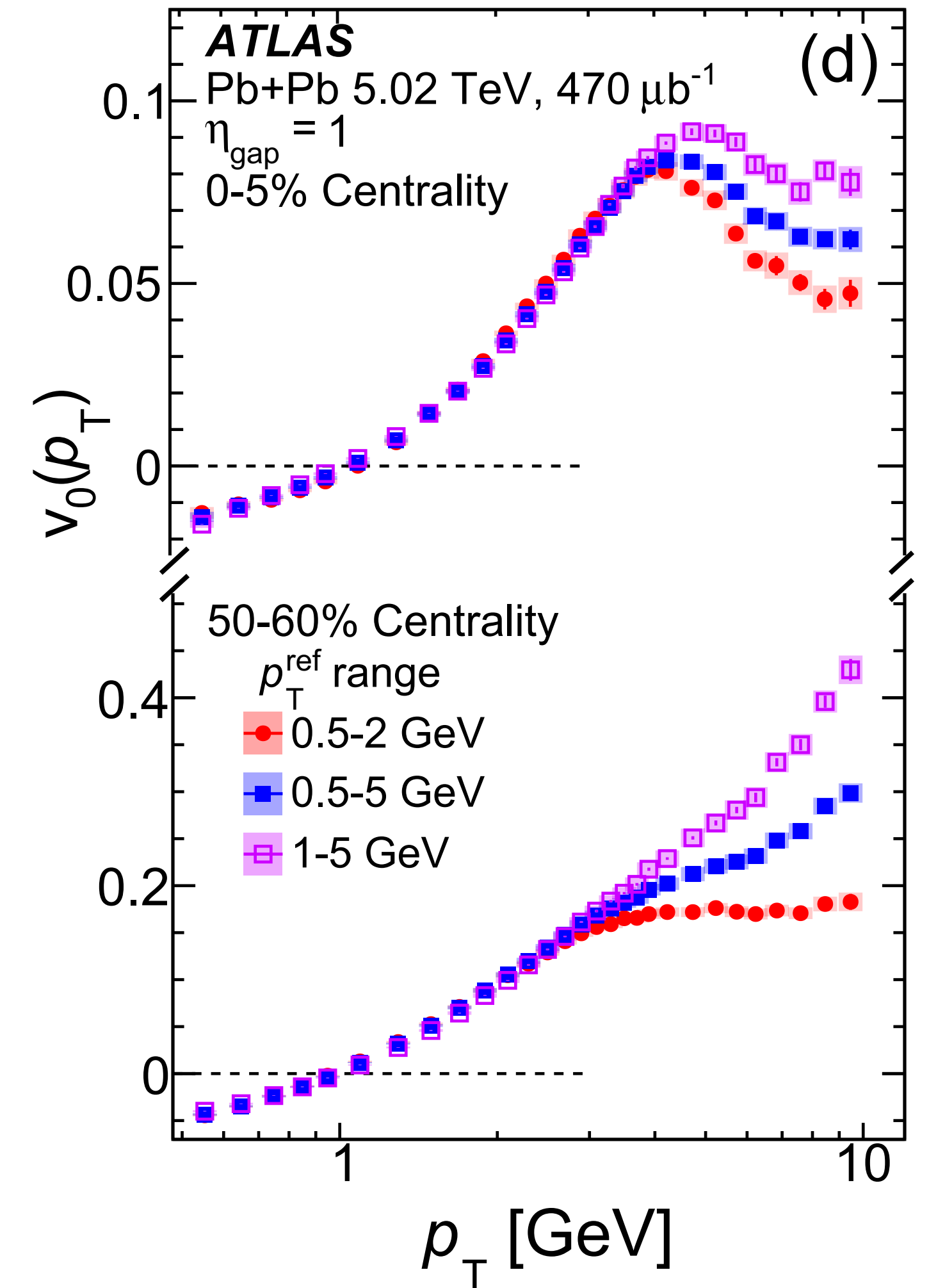
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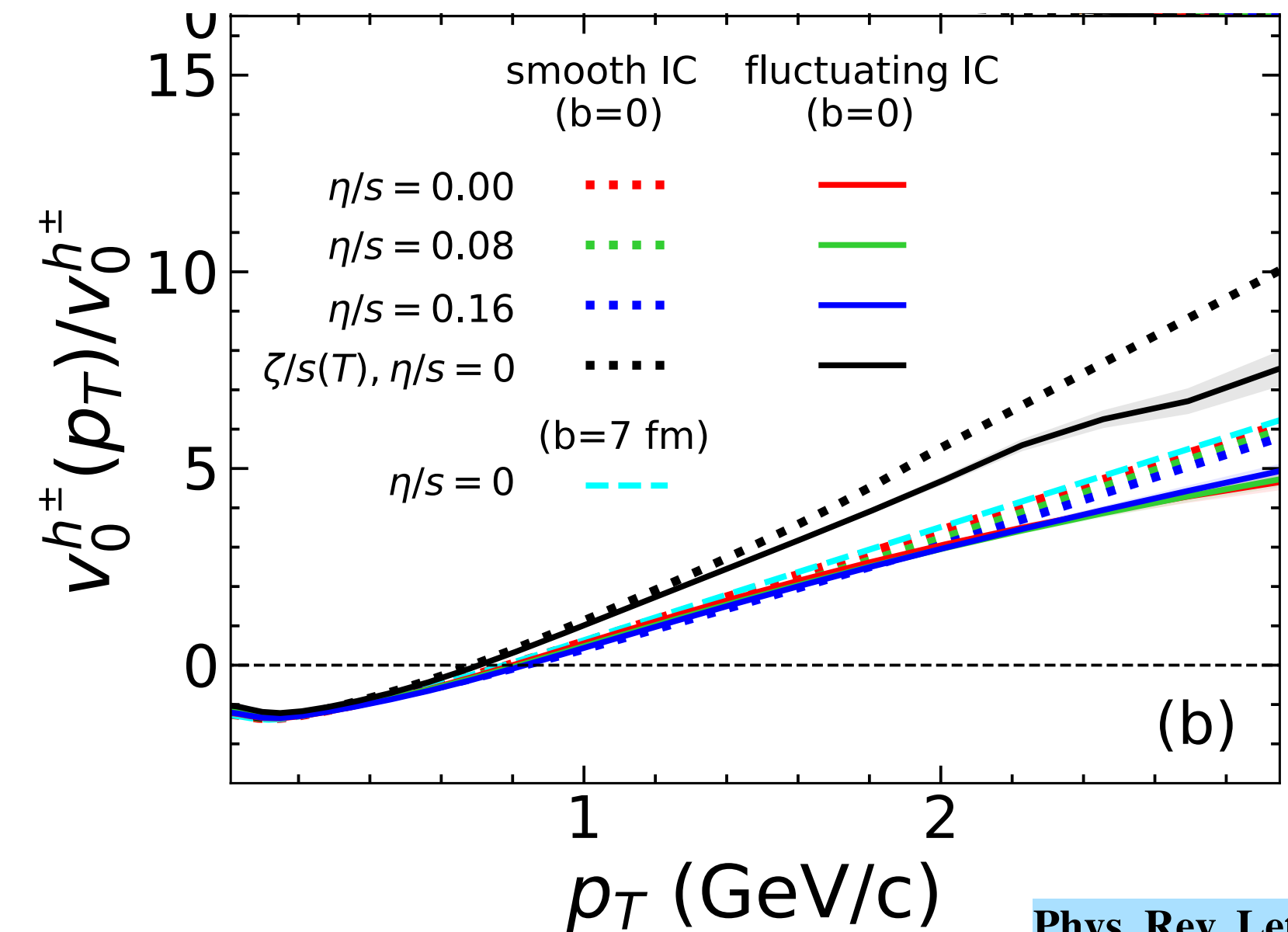
**Factorization holds in
flow dominated regime**



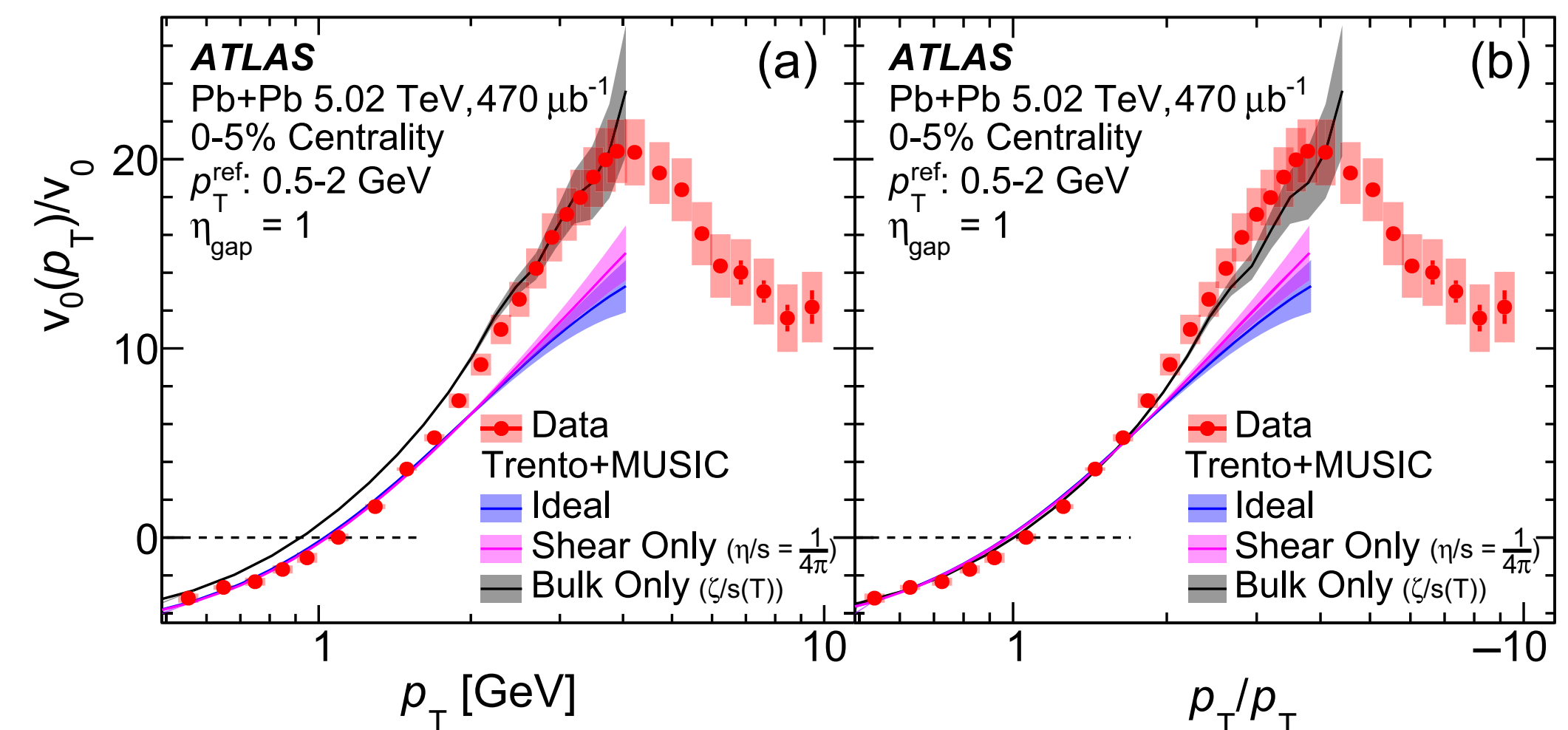
Hydro prediction for large systems

- $v_0(p_T)/v_0$ is independent of the model parameters
- $p_T/\langle p_T \rangle$ reduces the sensitivity to underlying transport coefficients

Ollitrault et.al: [arXiv:2407.17313](https://arxiv.org/abs/2407.17313)



Phys. Rev. Lett. 136, 032301

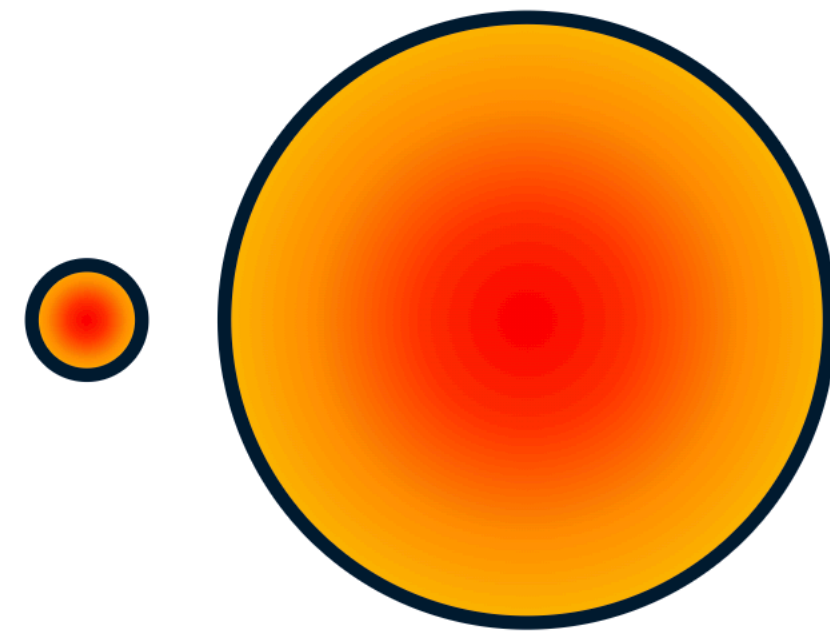


The inevitable question

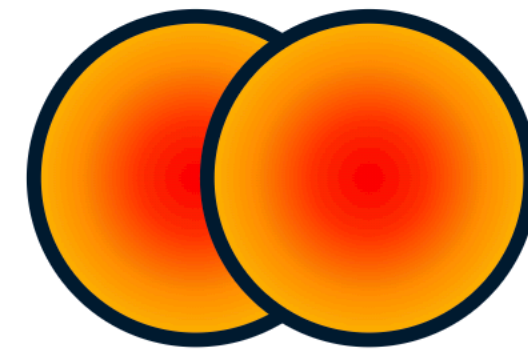
Is radial flow collective in small systems?



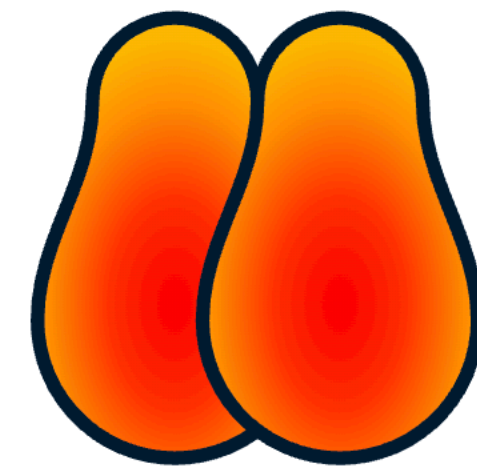
$p+p$



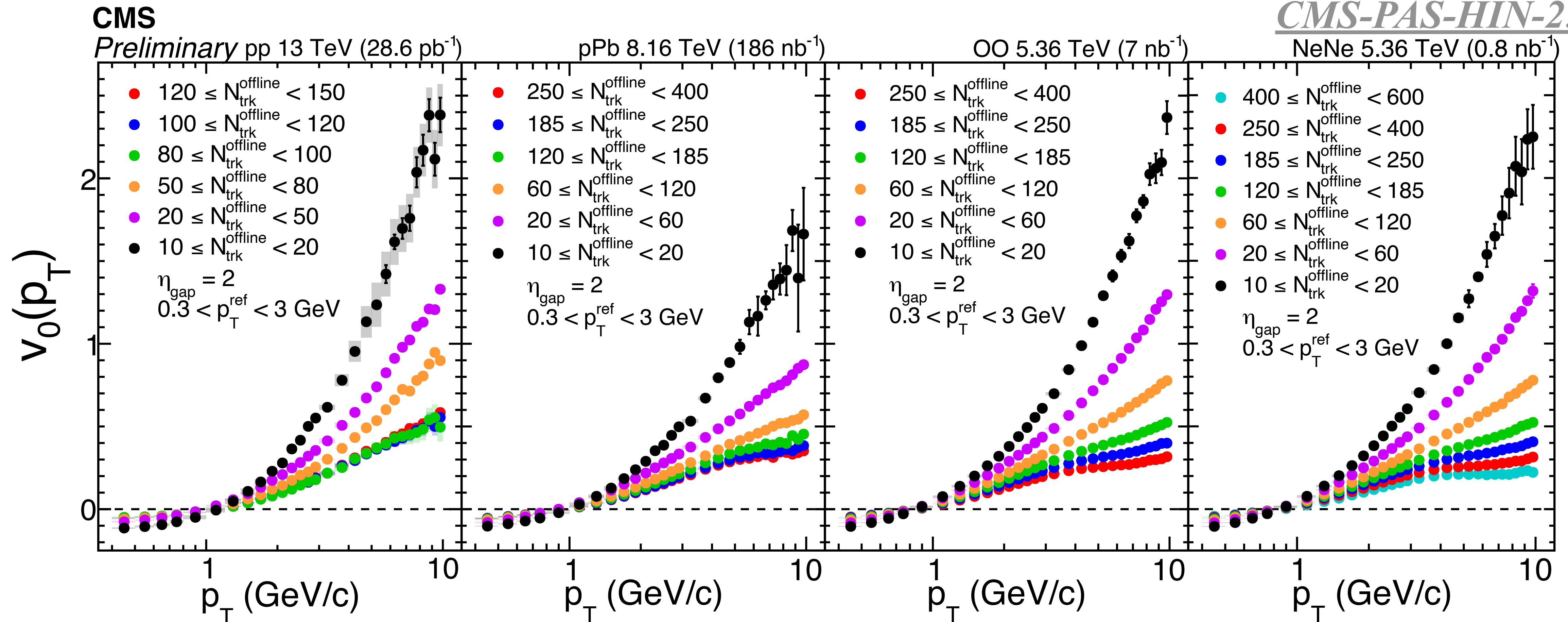
$p+Pb$



$O+O$



$Ne+Ne$

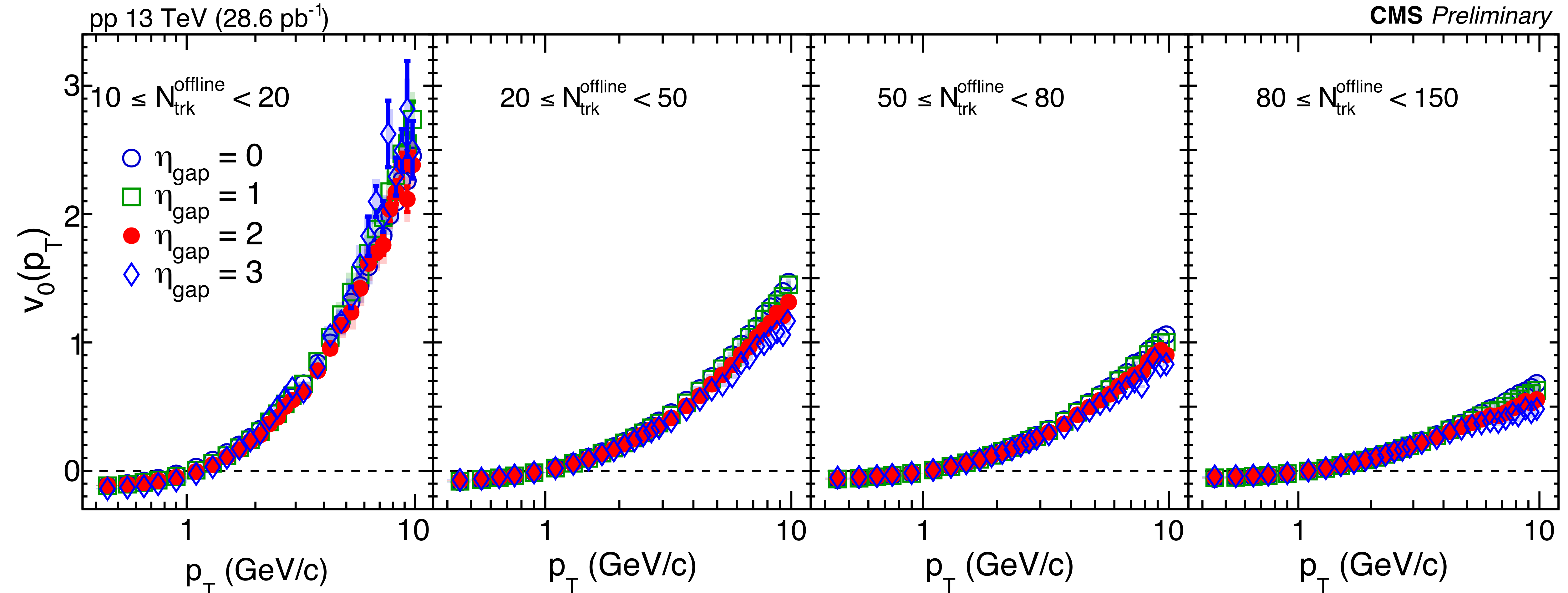


- Increasing magnitude of $v_0(p_T)$ observed with decreasing multiplicity
- Sign change observed at near $\langle p_T \rangle$ of the spectrum
- Splitting more cleaner in OO/NeNe compared to pp/pPb in HM range

Eta gap study: pp collisions

CMS-PAS-HIN-25-016

CMS Preliminary

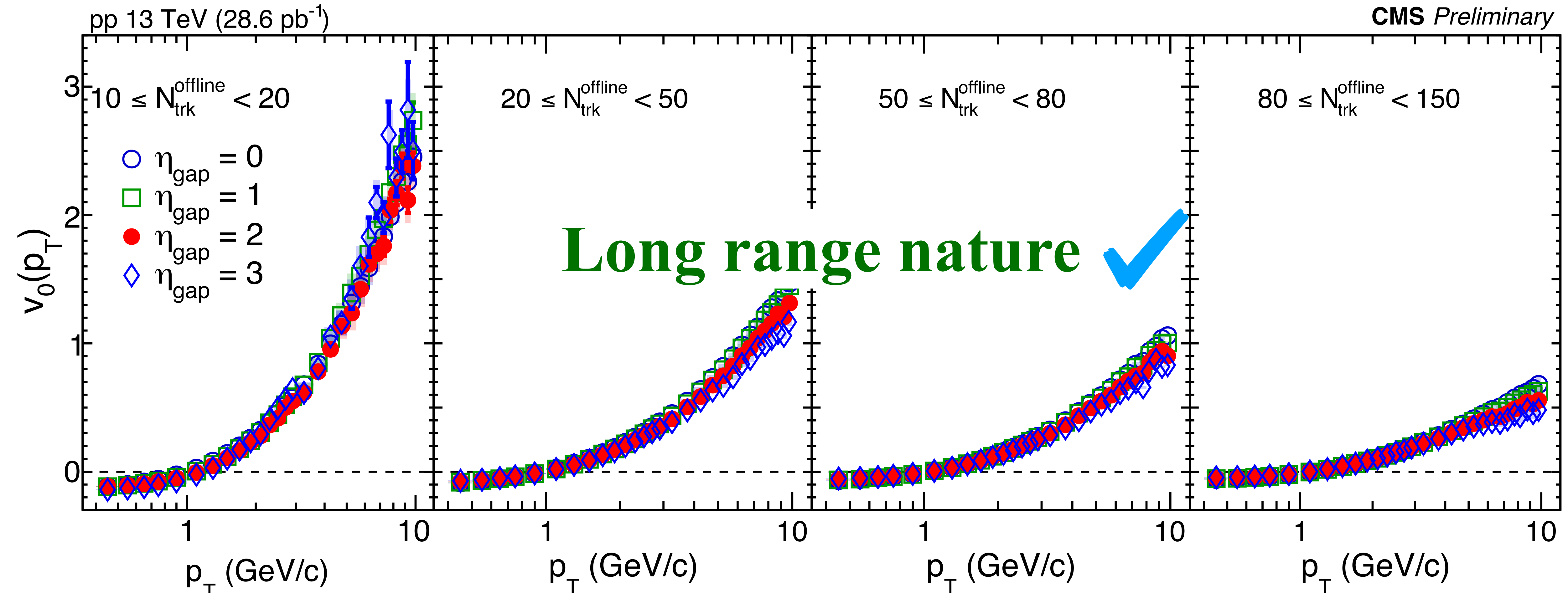


Nearly independent of η gap between subevents at low p_T

Eta gap study: pp collisions

CMS-PAS-HIN-25-016

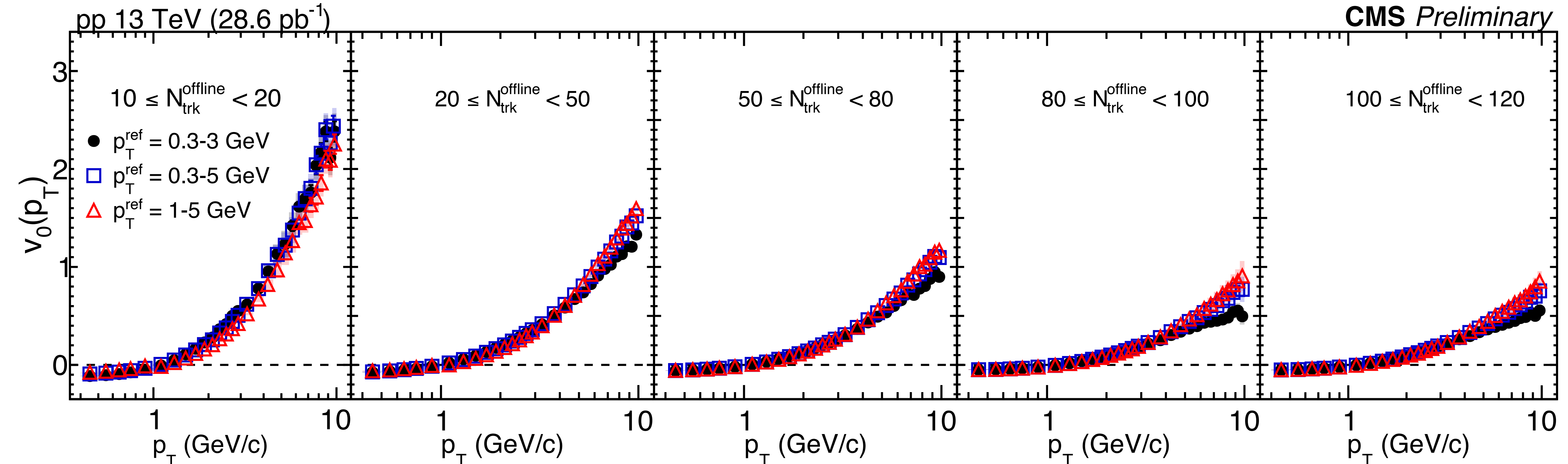
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Dependence on reference p_T range in pp

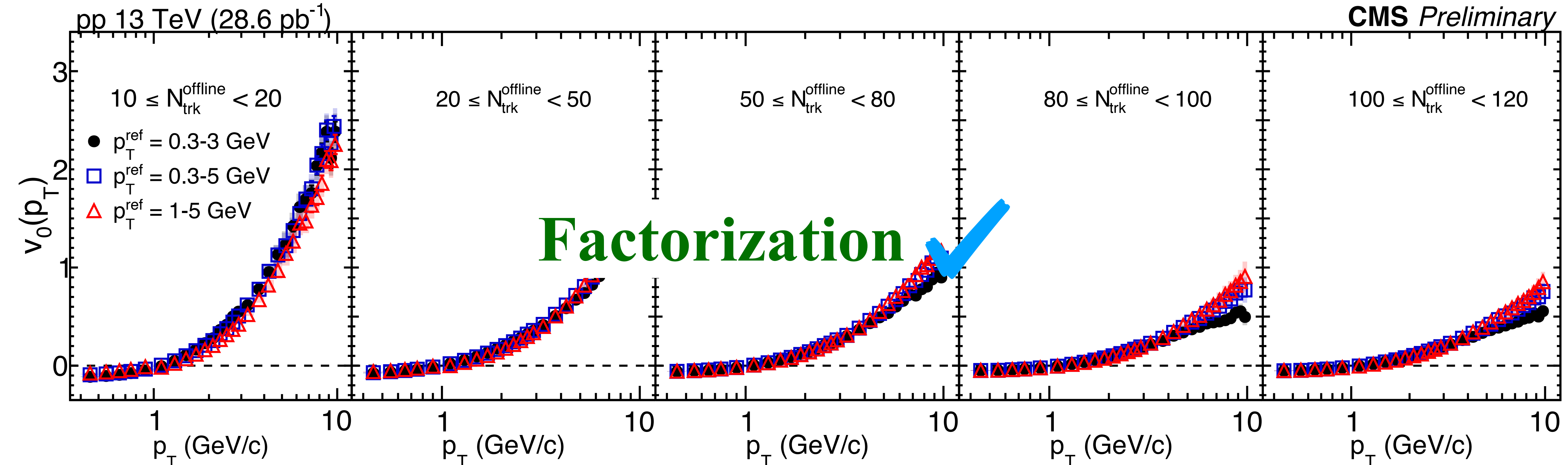
CMS-PAS-HIN-25-016



- $v_0(p_T)$ nearly p_T^{ref} -independent upto ~ 3 GeV for HM pp
- p_T^{ref} of 1-5 GeV deviating in LM pp, opposite trend for 10-20
- p_T^{ref} of 0.3-3 are least affected by nonflow

Dependence on reference p_T range in pp

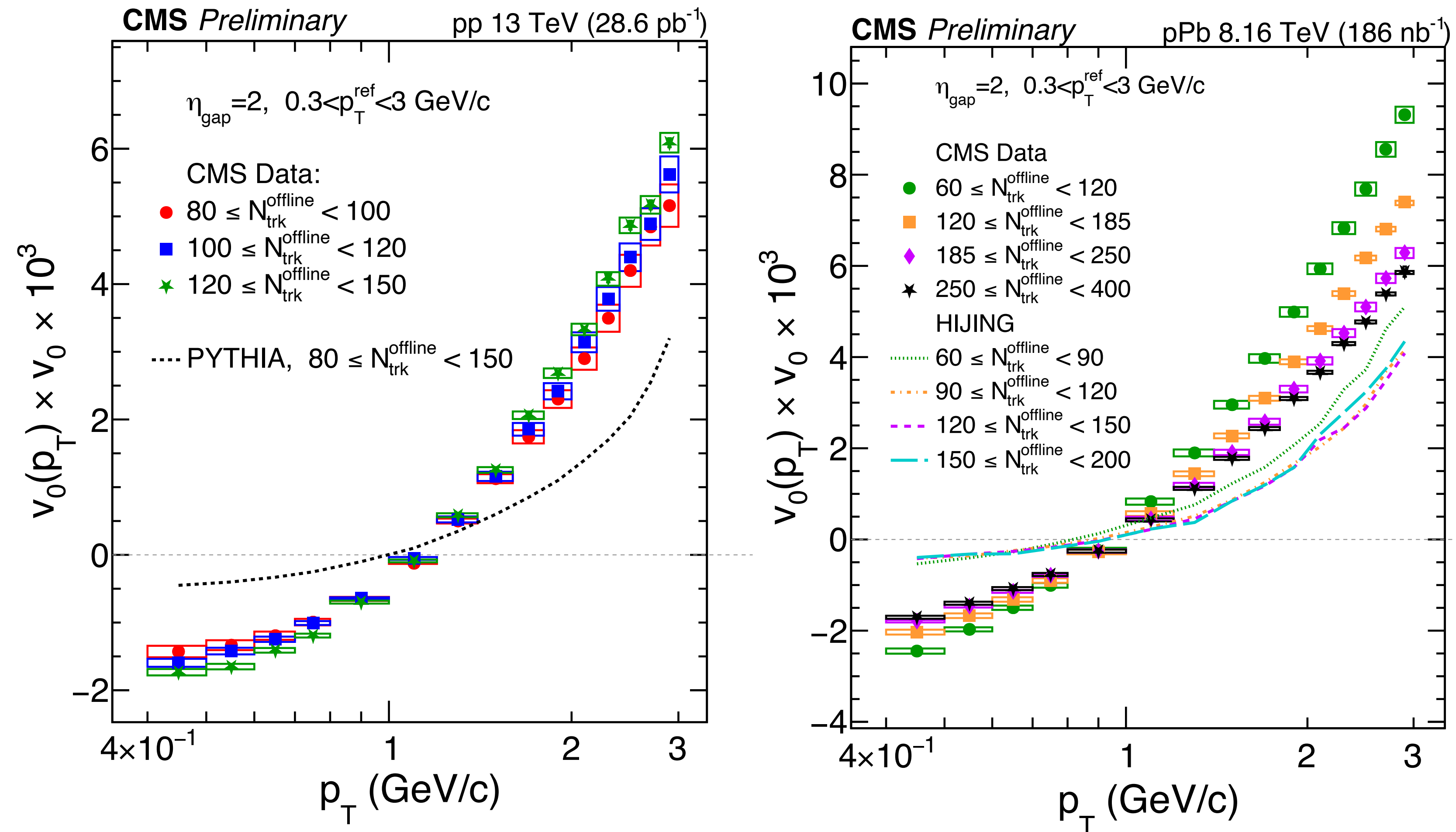
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Studies in non-thermal models

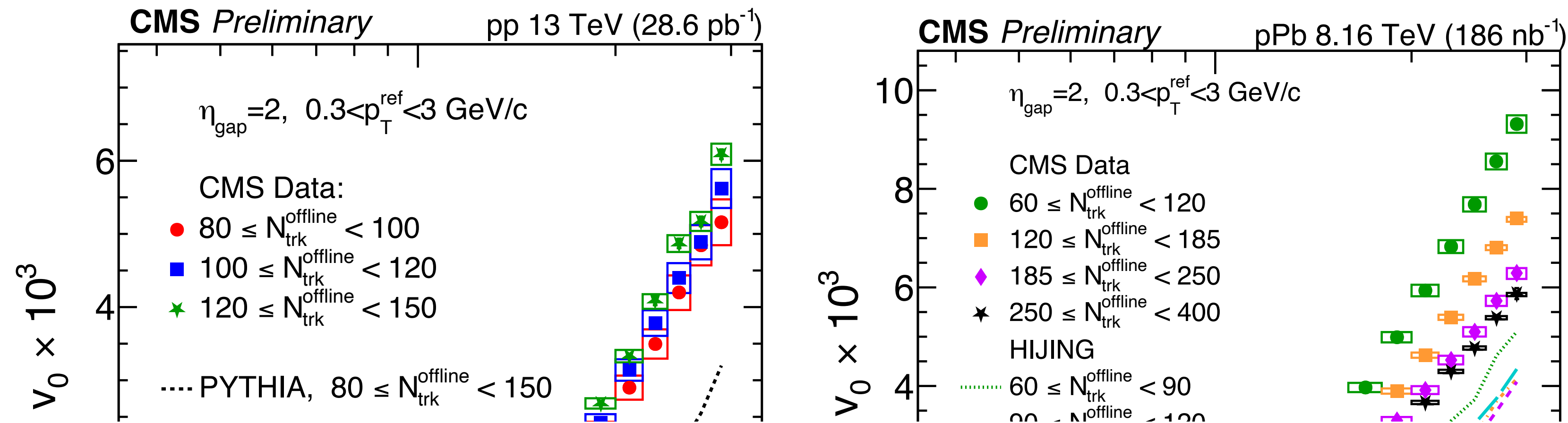
$v_0(p_T) \cdot v_0$ gives the strength of the correlation *CMS-PAS-HIN-25-016*



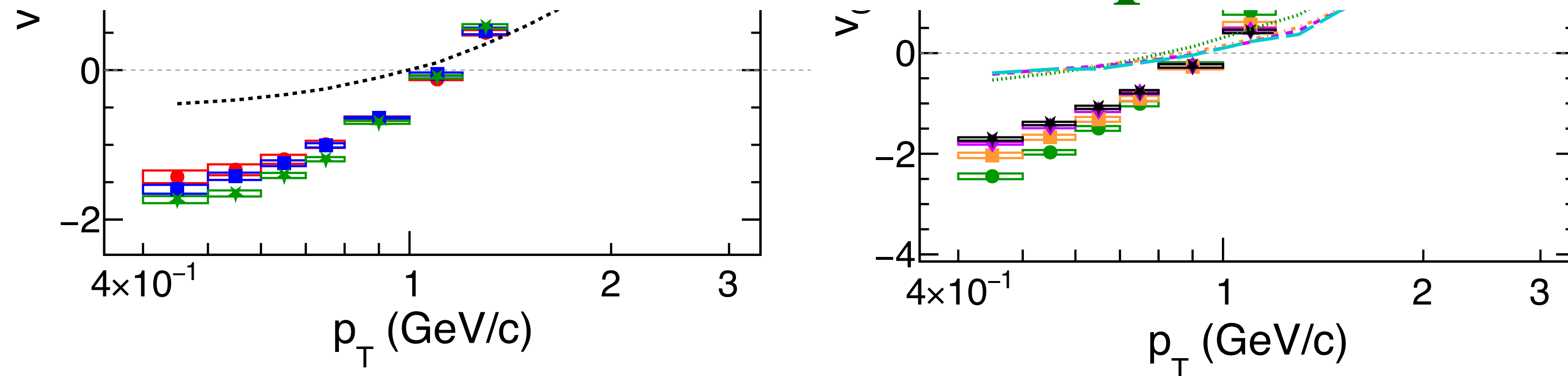
Both PYTHIA in pp and HIJING in pPb qualitatively underpredict the magnitude of $v_0(p_T) \cdot v_0$ measured in data

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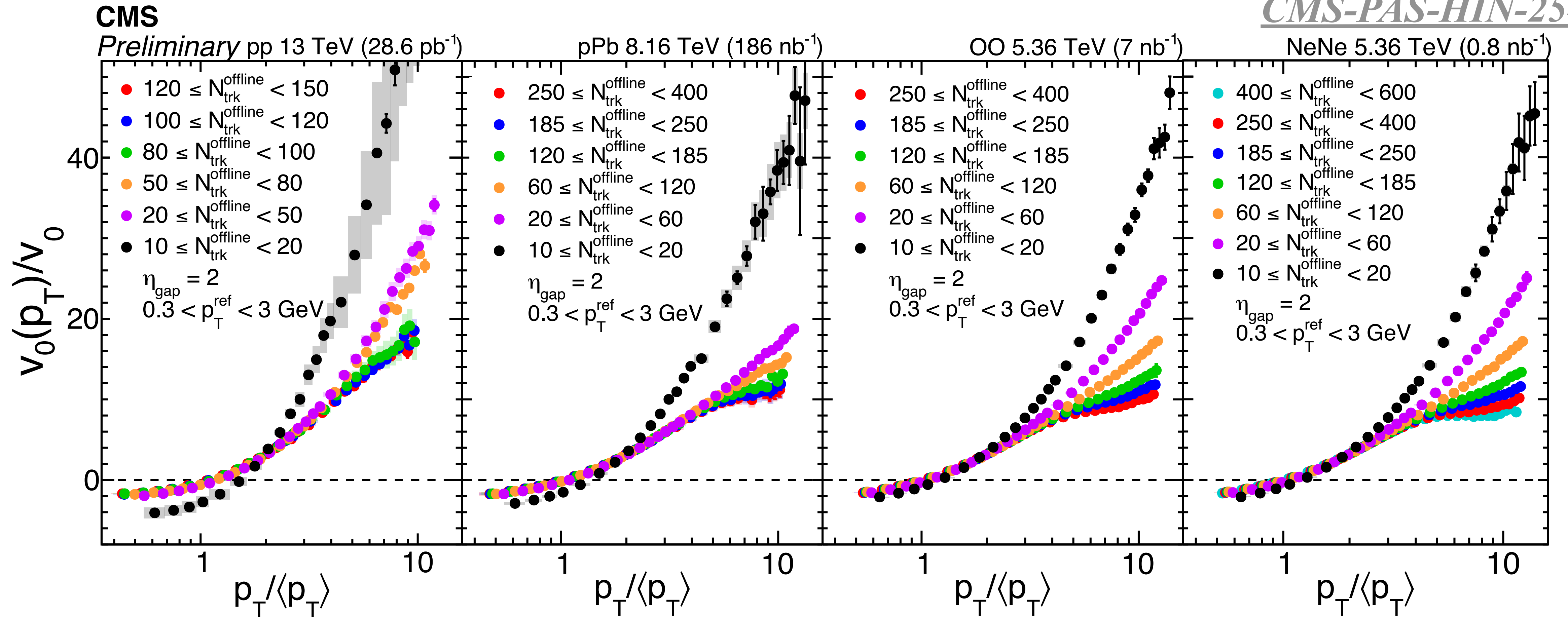
Non-thermal models underpredict data ✓



Both PYTHIA in pp and HIJING in pPb qualitatively underpredict the magnitude of $v_0(p_T) \cdot v_0$ measured in data

$v_0(p_T)$ normalized results

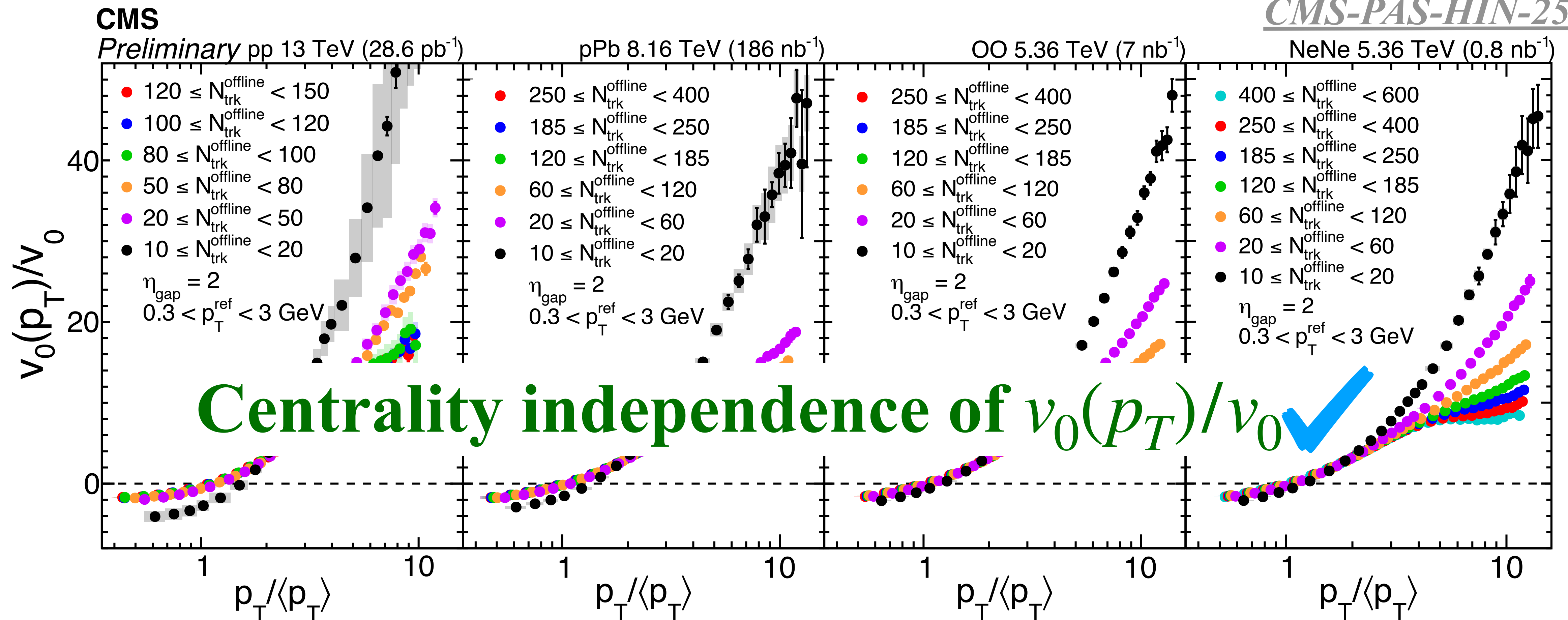
CMS-PAS-HIN-25-016



- Curves for different $N_{\text{trk}}^{\text{offline}}$ bin collapse onto a common shape at low $p_T/\langle p_T \rangle$
- The $10 \leq N_{\text{trk}}^{\text{offline}} < 20$ bin deviates from this common shape
- At high $p_T/\langle p_T \rangle$, no downturn observed

$v_0(p_T)$ normalized results

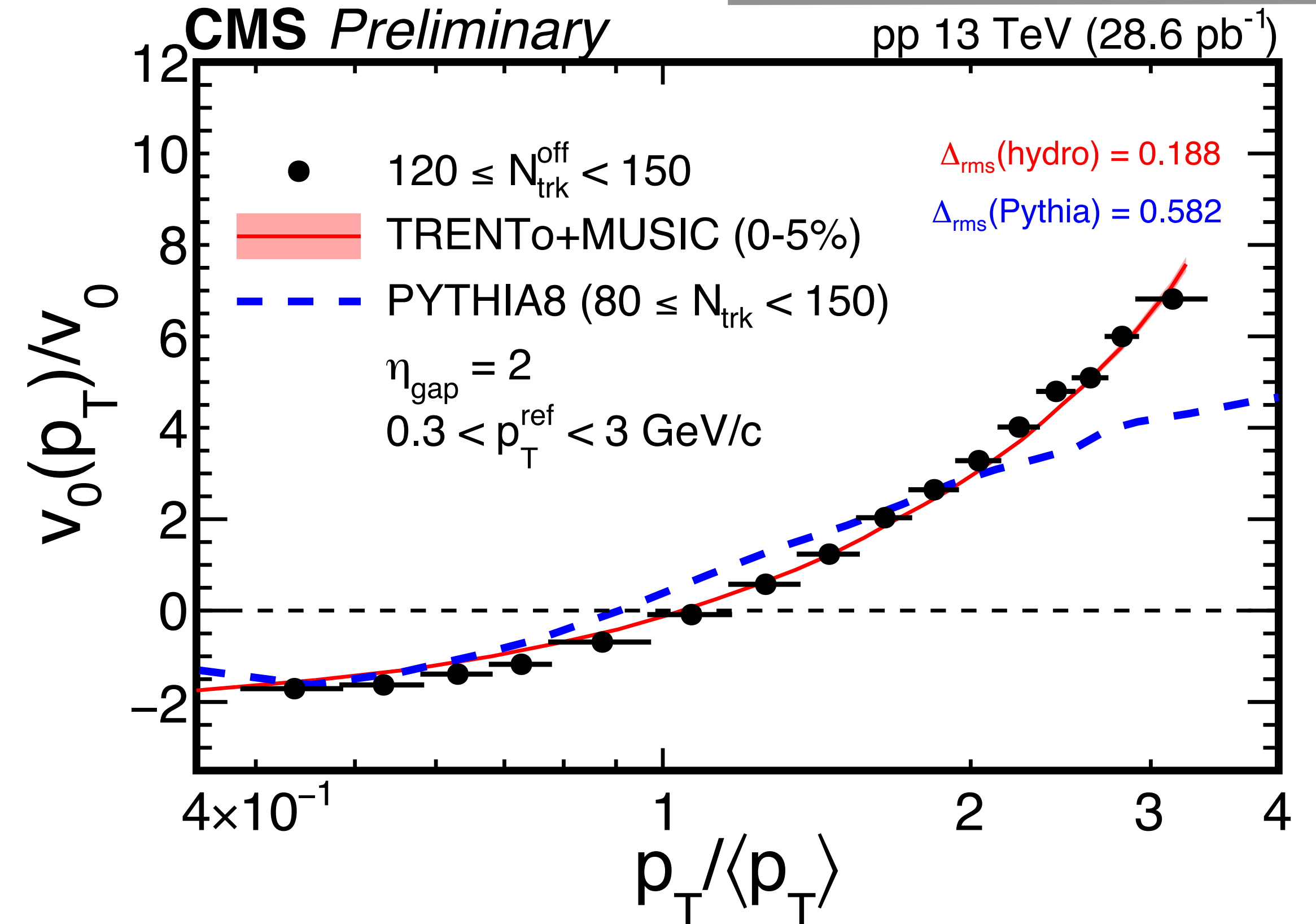
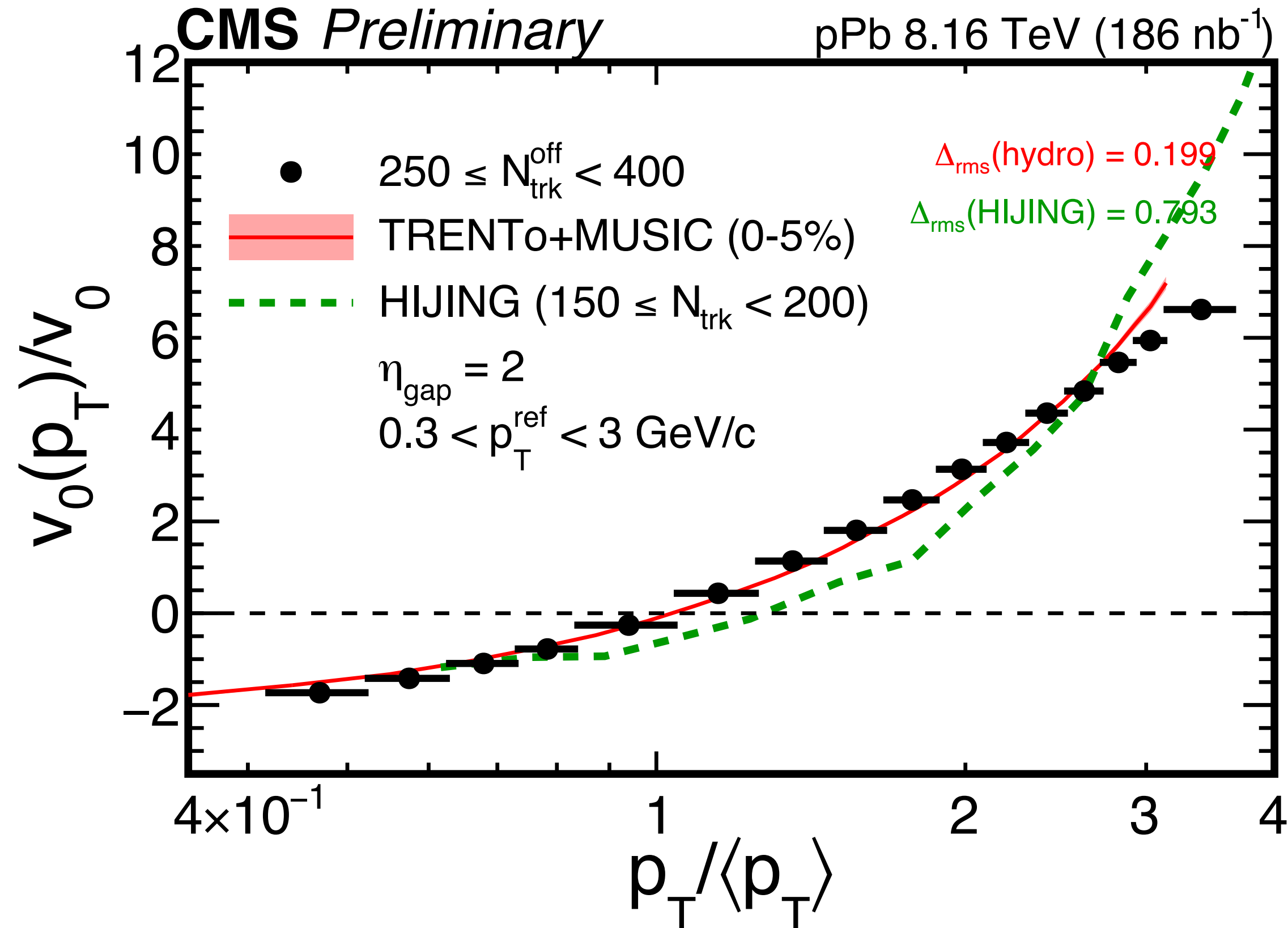
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$v_0(p_T)$ normalized results: Model comparison

CMS-PAS-HIN-25-016

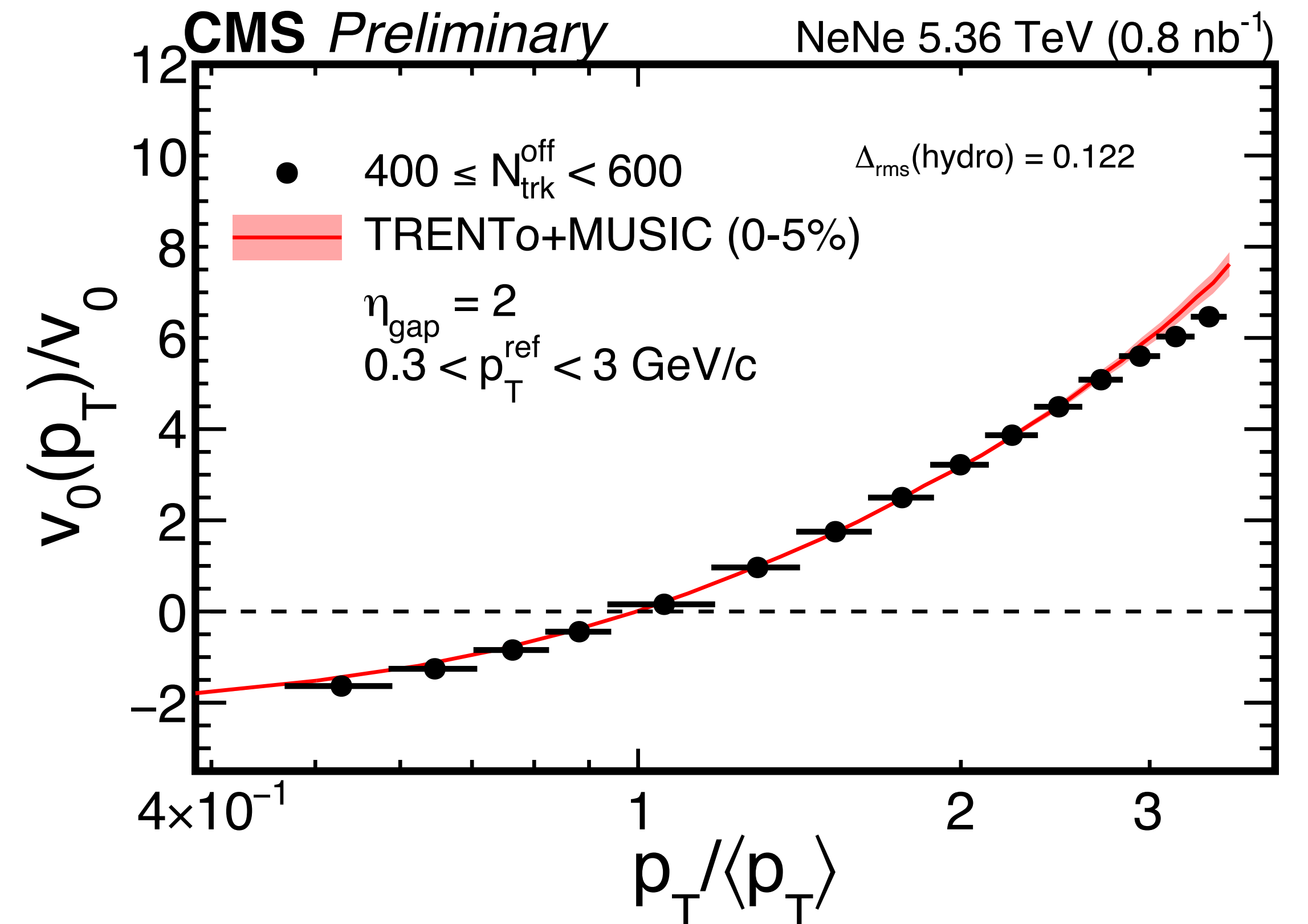
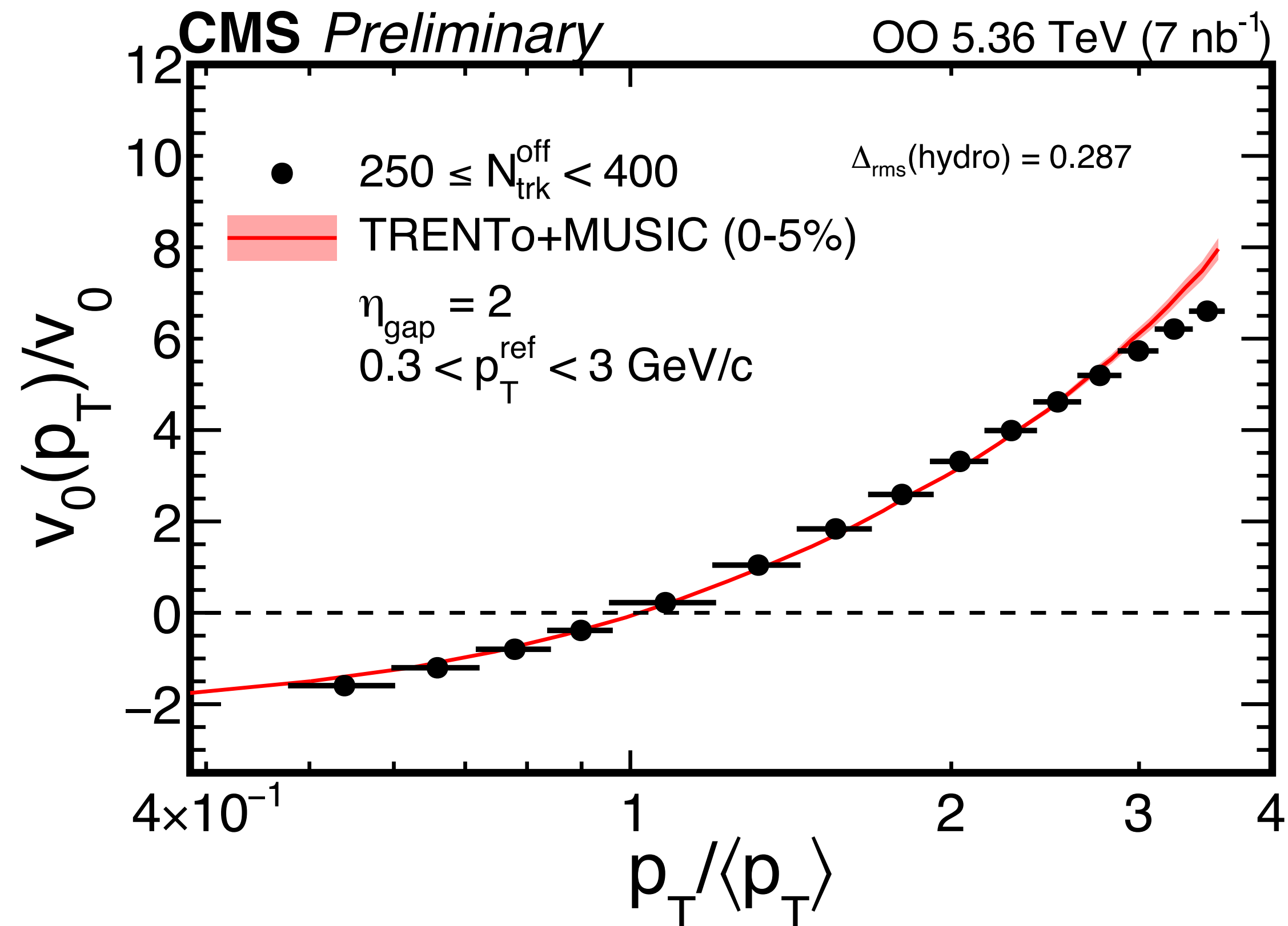


- Comparison with TRENTo + MUSIC (hydro model) in pp and pPb
- Qualitatively good agreement observed between data and hydro model predictions till $\sim 2.5 \text{ GeV}$
- Δ_{rms} value 5-7x larger for non-thermal models than hydro model

$$\Delta_{\text{rms}} = \sqrt{\frac{1}{N} \sum_j \left(\frac{y_j - f_{\text{ref}}(x_j)}{f_{\text{ref}}(x_j)} \right)^2}$$

$v_0(p_T)$ norm results: Model comparisons

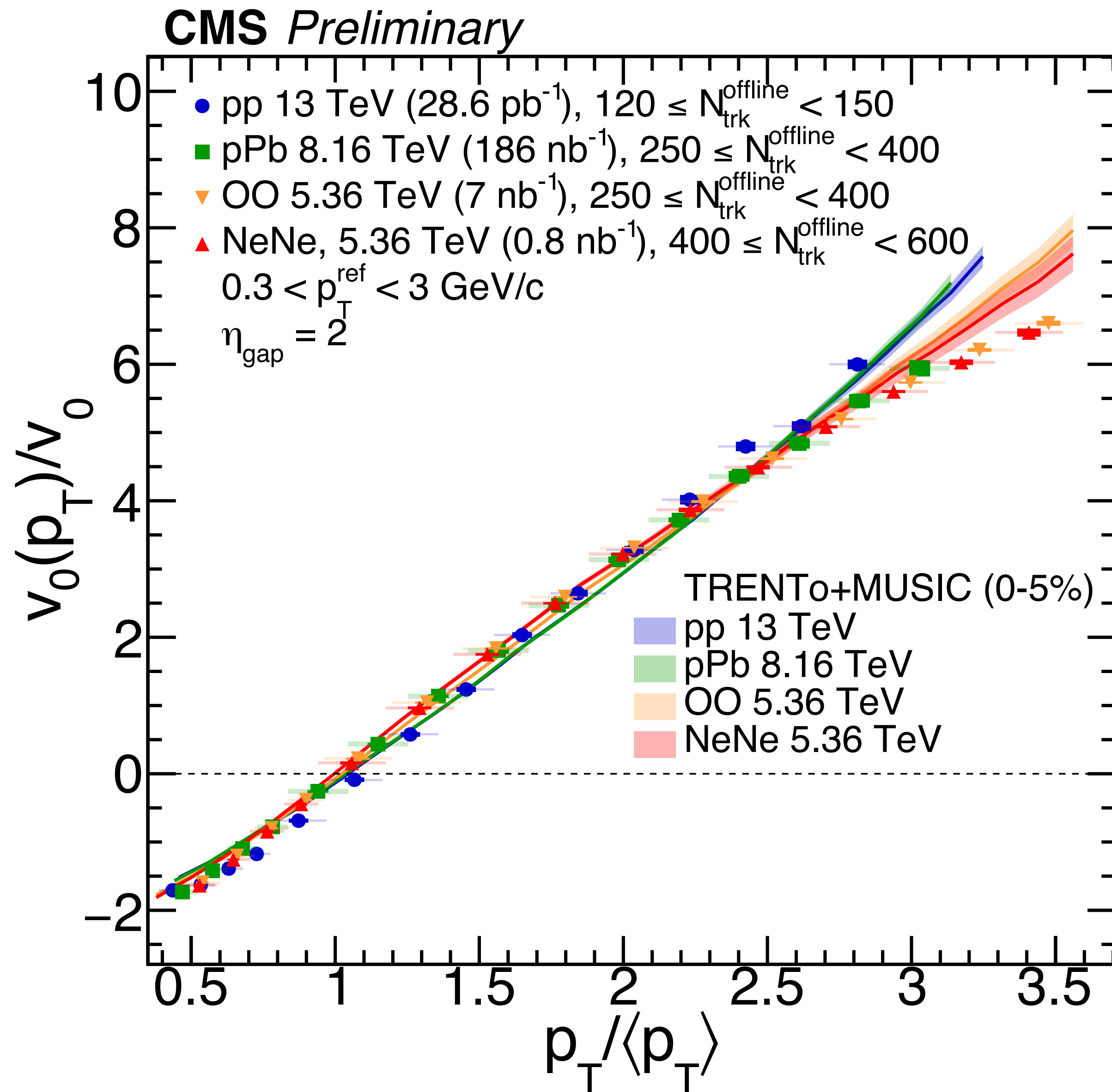
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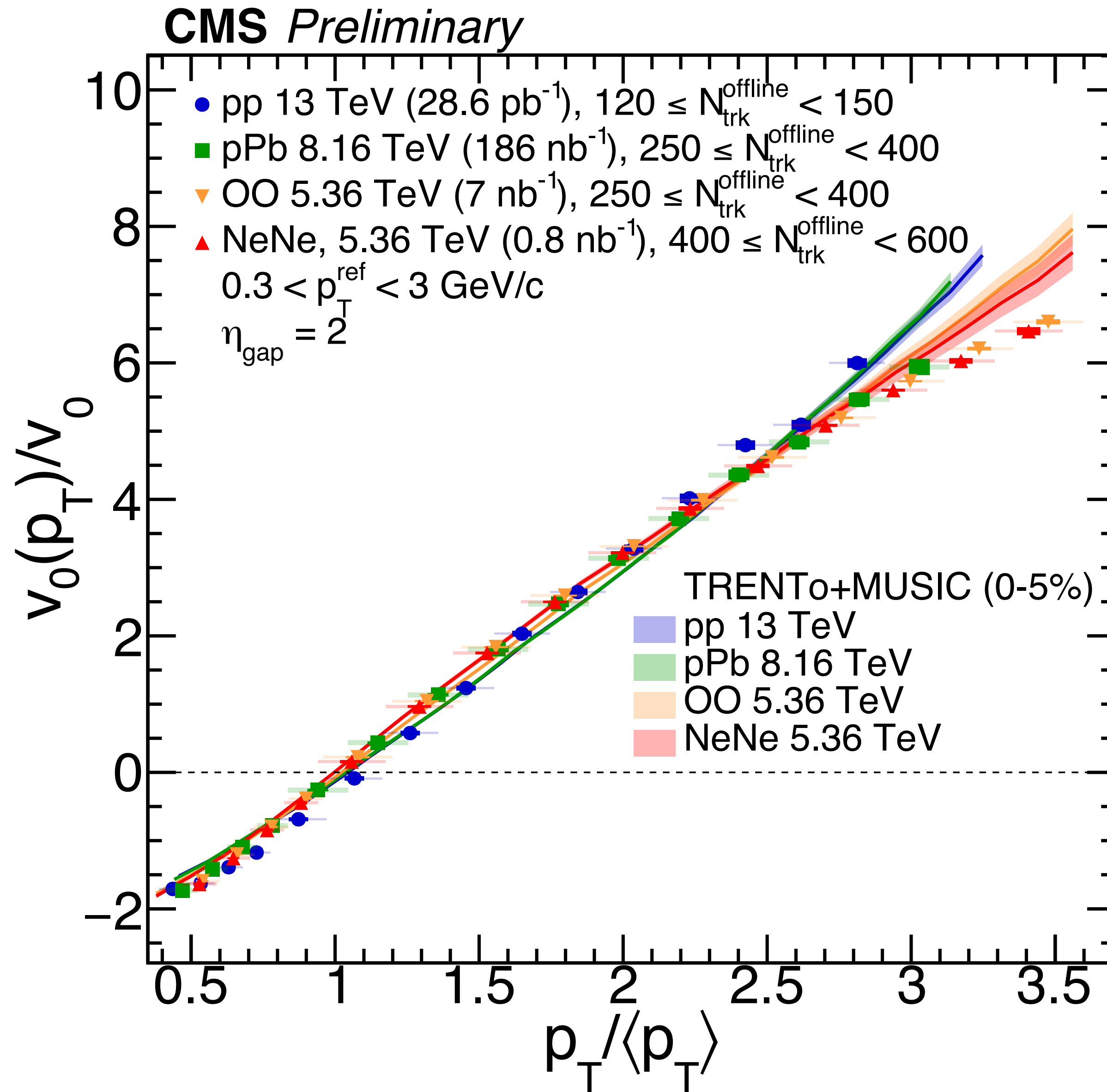
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$v_0(p_T)$ norm results: Cross system comparison



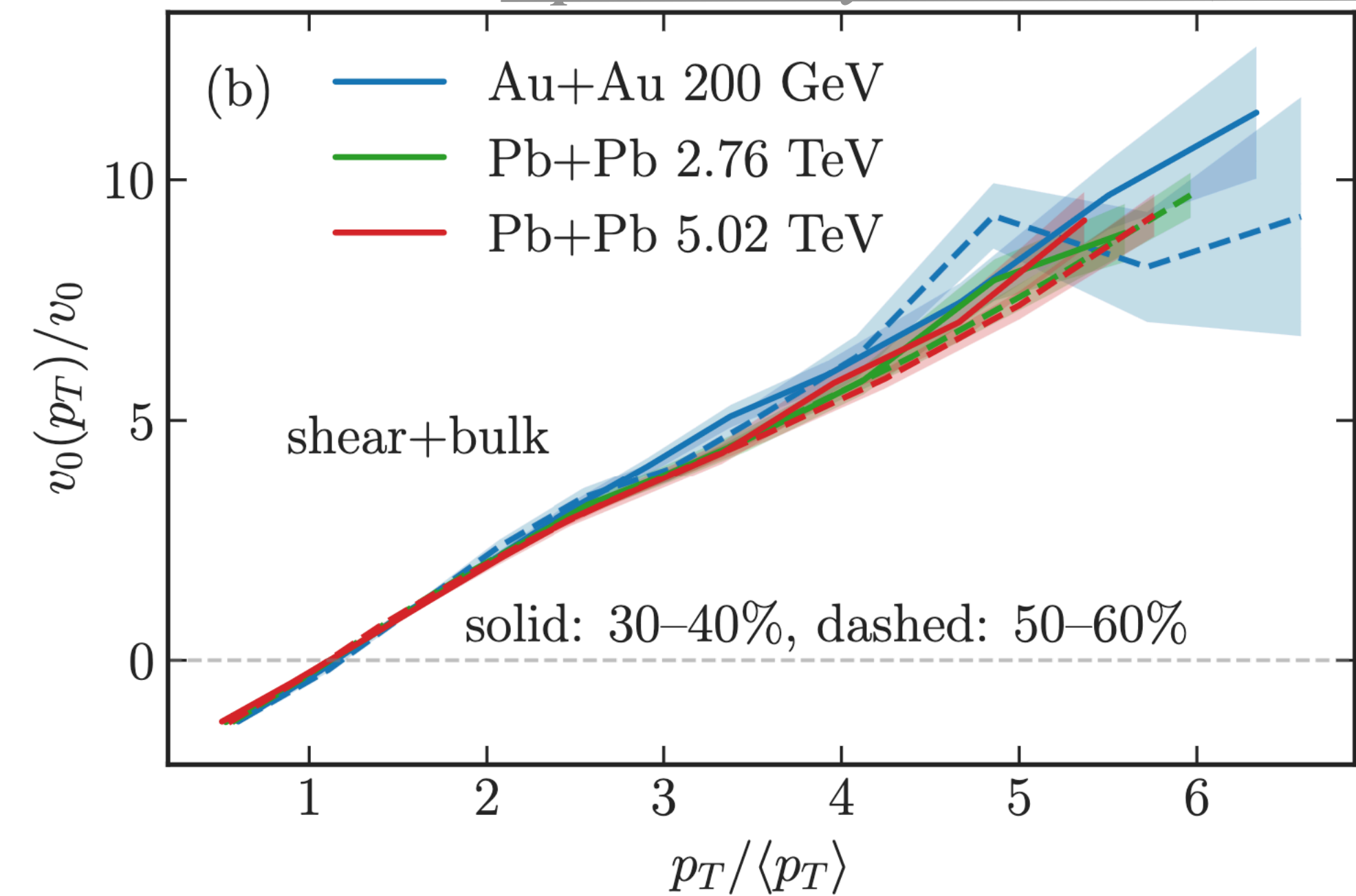
The highest multiplicity bin of all systems following a universal curve as a function of $p_T/\langle p_T \rangle$

$v_0(p_T)$ norm results: Cross system comparison



The highest multiplicity bin of all systems following a universal curve as a function of $p_T / \langle p_T \rangle$

Lipei Du: Phys. Rev. C 113, 014901 (2026)



Summary & Outlook

- First measurement of the p_T differential radial flow fluctuations across different energies and systems
- Many hallmarks of collectivity observed above $N_{trk}^{offline} > 20$ in small systems
- Comparison with hydrodynamic predictions – all agreed well qualitatively
- Do we conclude that **“Radial flow is collective in small systems”**?

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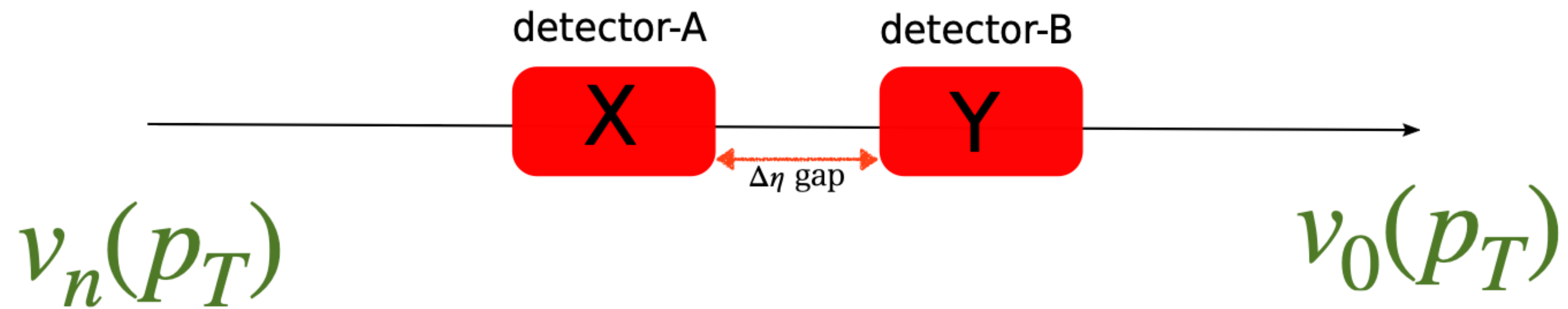
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Stay tuned!!

Backup

Long range momentum correlations



$$X \equiv \sum_{k=1}^{N_A(p_T)} e^{in\phi_k}$$

$$Y \equiv \frac{1}{N_B} \sum_{k=1}^{N_B} e^{-in\phi_k}$$

$$X \equiv N_A(p_T)$$

$$Y \equiv \frac{1}{N_B} \sum_{k=1}^{N_B} (p_T)_k$$

$$v_n(p_T) \equiv \frac{\langle XY \rangle - \cancel{\langle X \rangle} \cancel{\langle Y \rangle}}{\langle N_A(p_T) \rangle v_n\{2\}}$$

$$v_0(p_T) \equiv \frac{\langle XY \rangle - \langle X \rangle \langle Y \rangle}{\langle N_A(p_T) \rangle \sigma_{p_T}}$$

$$v_0 \equiv \frac{\sigma_{p_T}}{\langle p_T \rangle} \equiv \int v_0(p_T)$$

✓ Analysis of $v_0(p_T)$ is very similar to $v_n(p_T)$

✓ η - gap is useful to suppress non-flow.

$$\sigma_{p_T} \equiv \sqrt{\langle XY \rangle - \langle X \rangle \langle Y \rangle}$$

$\downarrow$
 $X = \frac{1}{N_A} \sum_{k=1}^{N_A} p_{T,K}$