Elliptic Anisotropy at High p_T in pPb Collisions using Subevent Cumulants at CMS

CMS NEW Prelim 24'Fall

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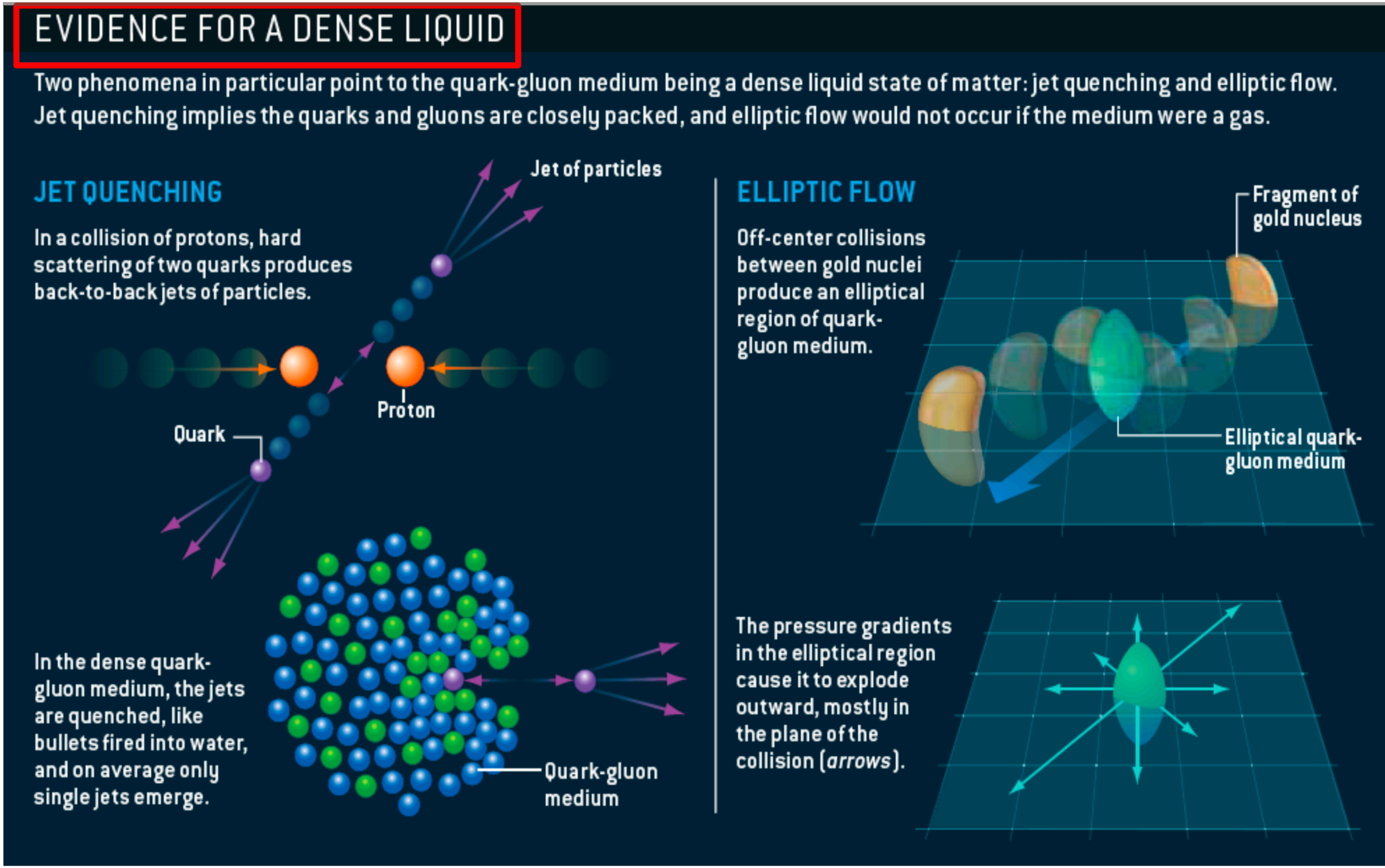
HP2024 NAGASAKI

Date: Sept 23, 2024

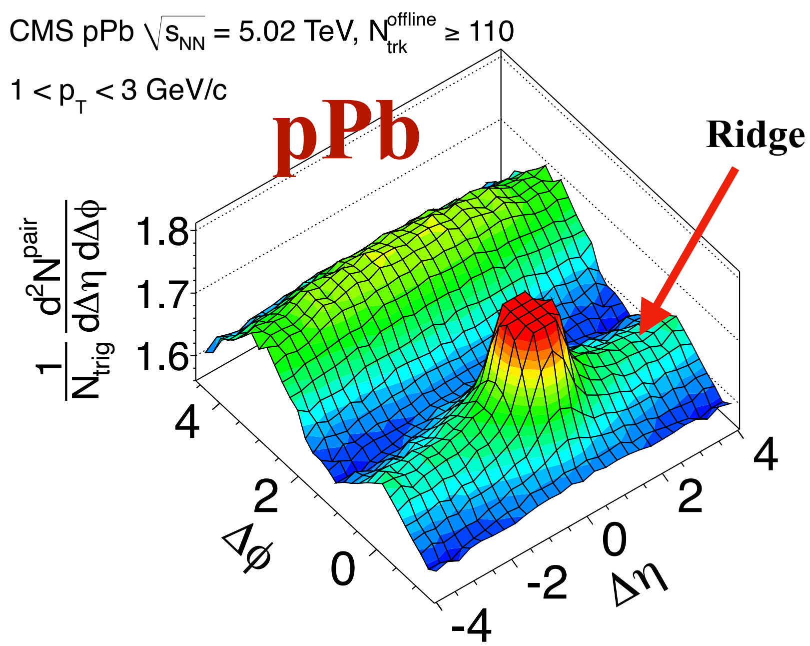
QGP discovery at RHIC: 2005 - 2006



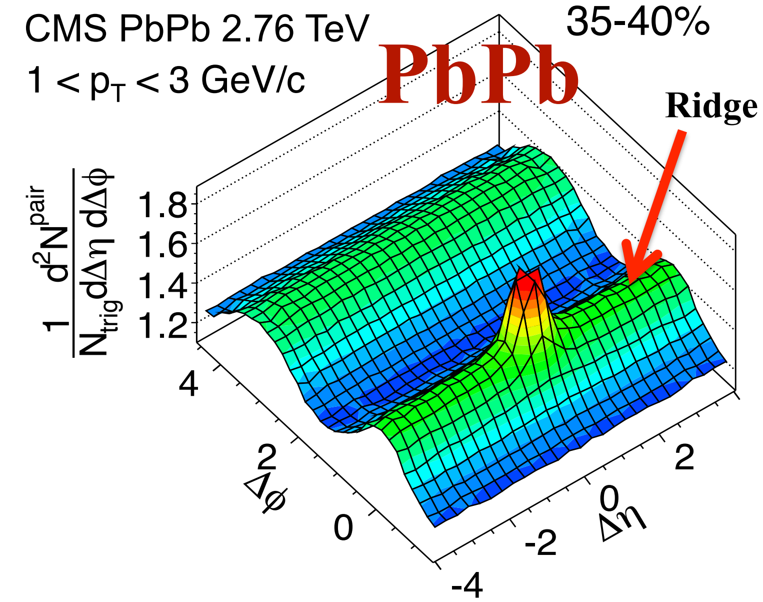
M. Roirdan and W. Zajc
Scientific American, May 2006

Azimuthal Anisotropy at Low p_T

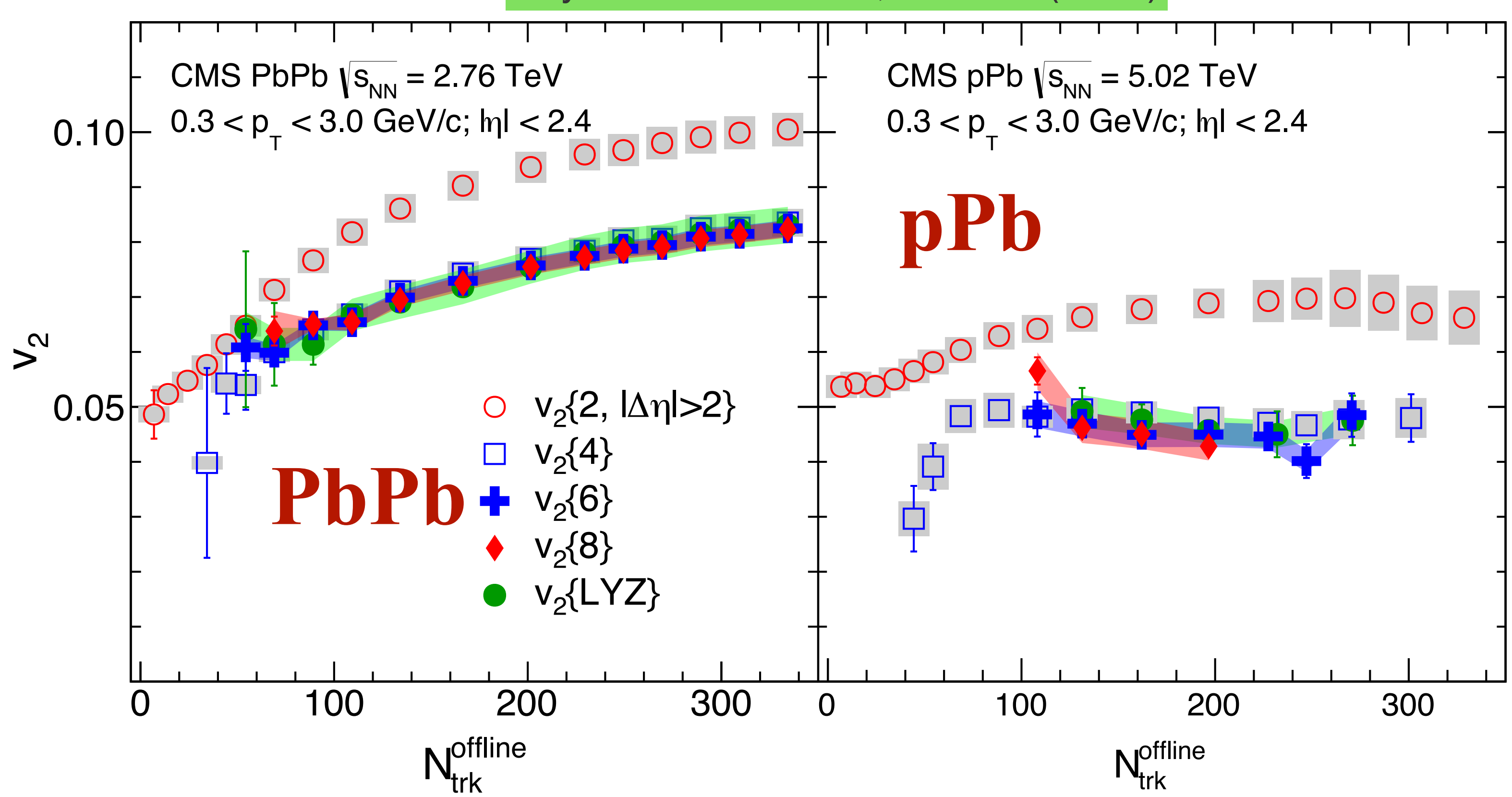
Phys. Lett. B 718, 795 (2013)



JHEP 07 (2011) 076



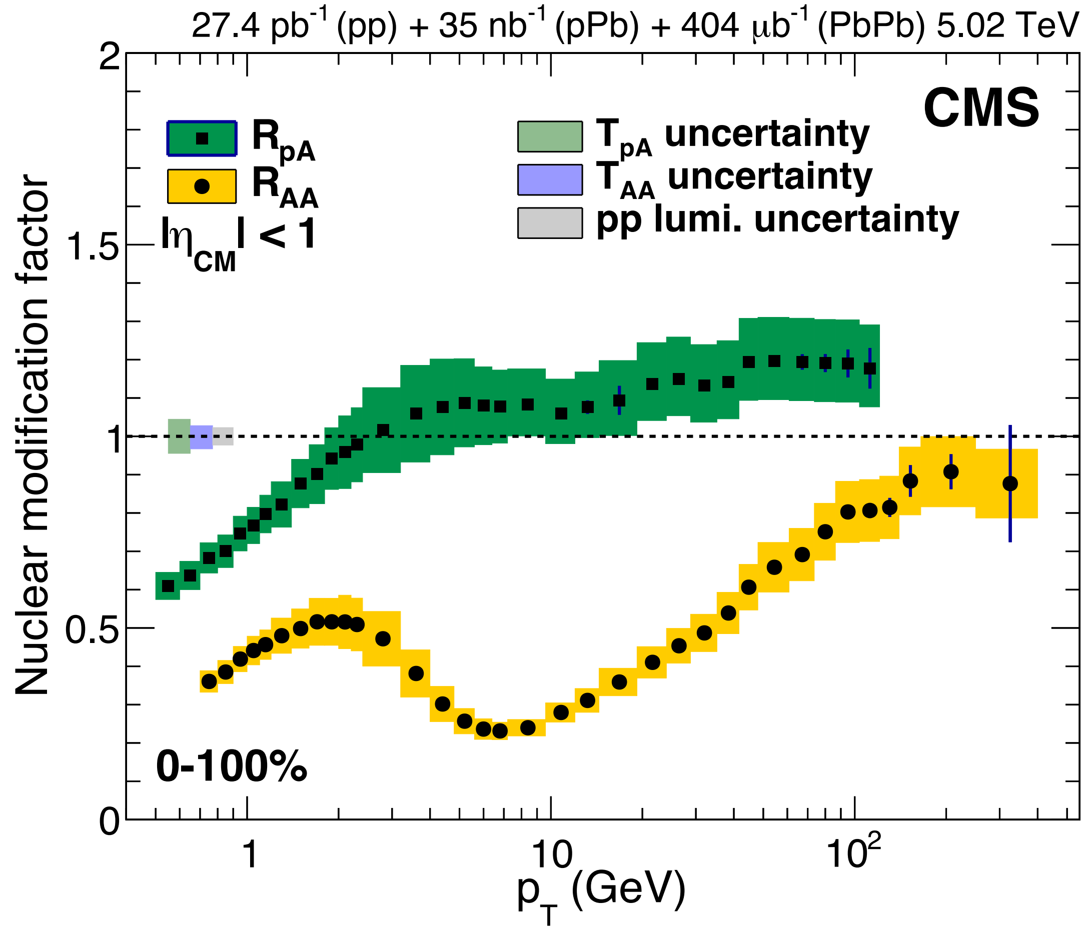
Phys. Rev. Lett. 115, 012301 (2015)

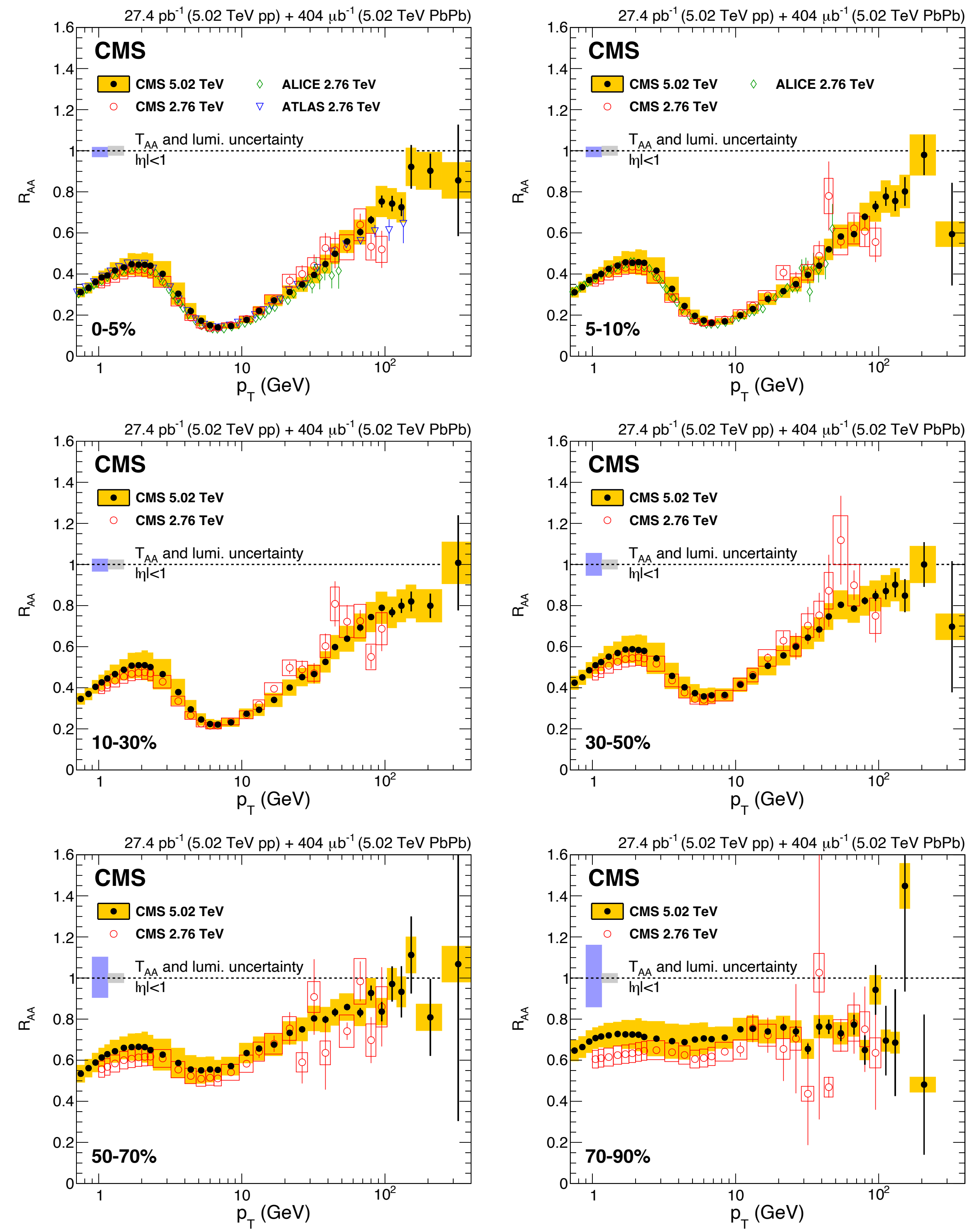


- **Azimuthal Anisotropy (v_n) at low p_T (< 3 GeV/c)**
  - **Discovery of "Ridge" in pPb => sign of collectivity**
  - **Geometry + Fluctuations**
  - **Well described by hydrodynamics**
  - $v_2\{4\} \sim v_2\{6\} \sim v_2\{8\}$ **from cumulant studies**

Nuclear Modification Factor in pPb and PbPb

JHEP 04 (2017) 039





$$R_{AA} = \frac{N^{A+A}_{particles}}{N^{p+p}_{particles} \times N_{coll}}$$

- ❖ R_{AA} shows max suppression in central bins in PbPb
- ❖ Weakening of both magnitude and p_T dependence in peripheral bins
- ❖ No suppression in 2-10 GeV region in minimum bias pPb
- ❖ Weak p_T dependence for $p_T > 10$ GeV
- ❖ pPb: similar system size as peripheral PbPb but no suppression (Caution: Complications from centrality bias factors in pPb)

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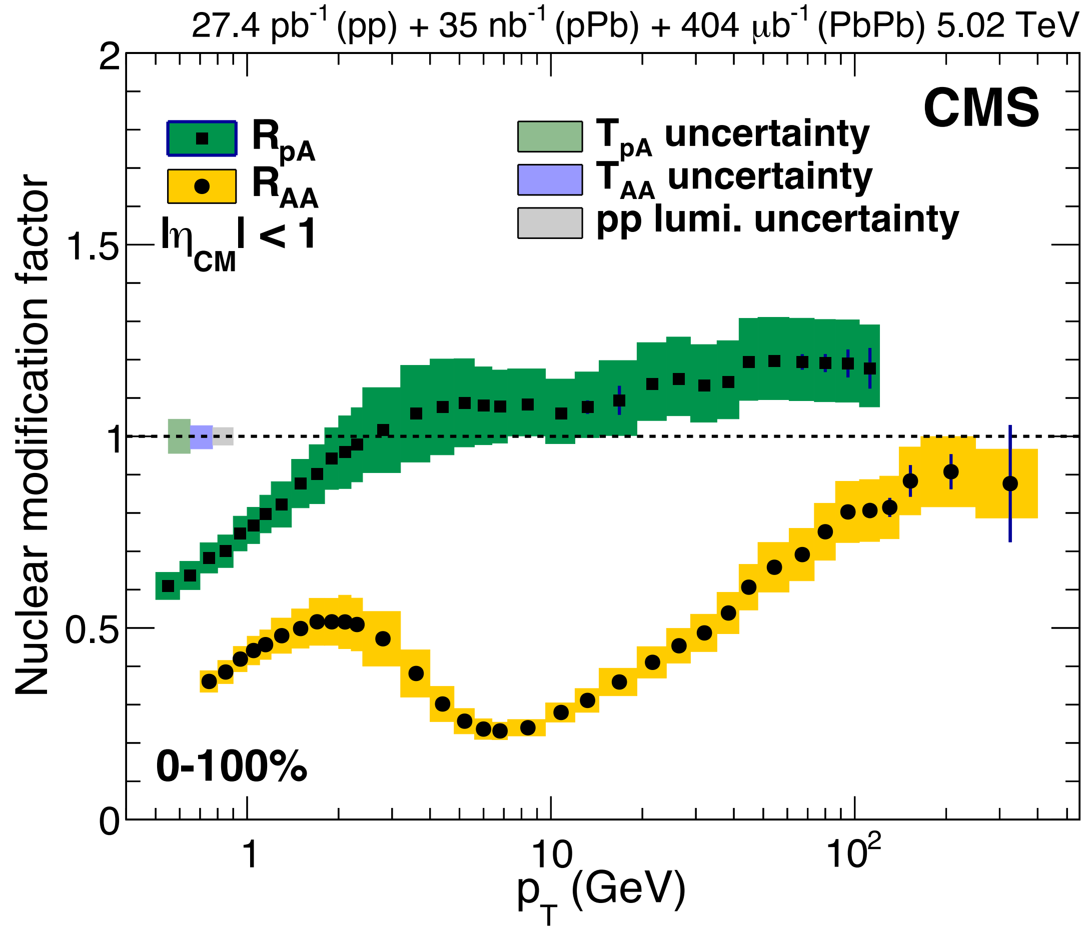

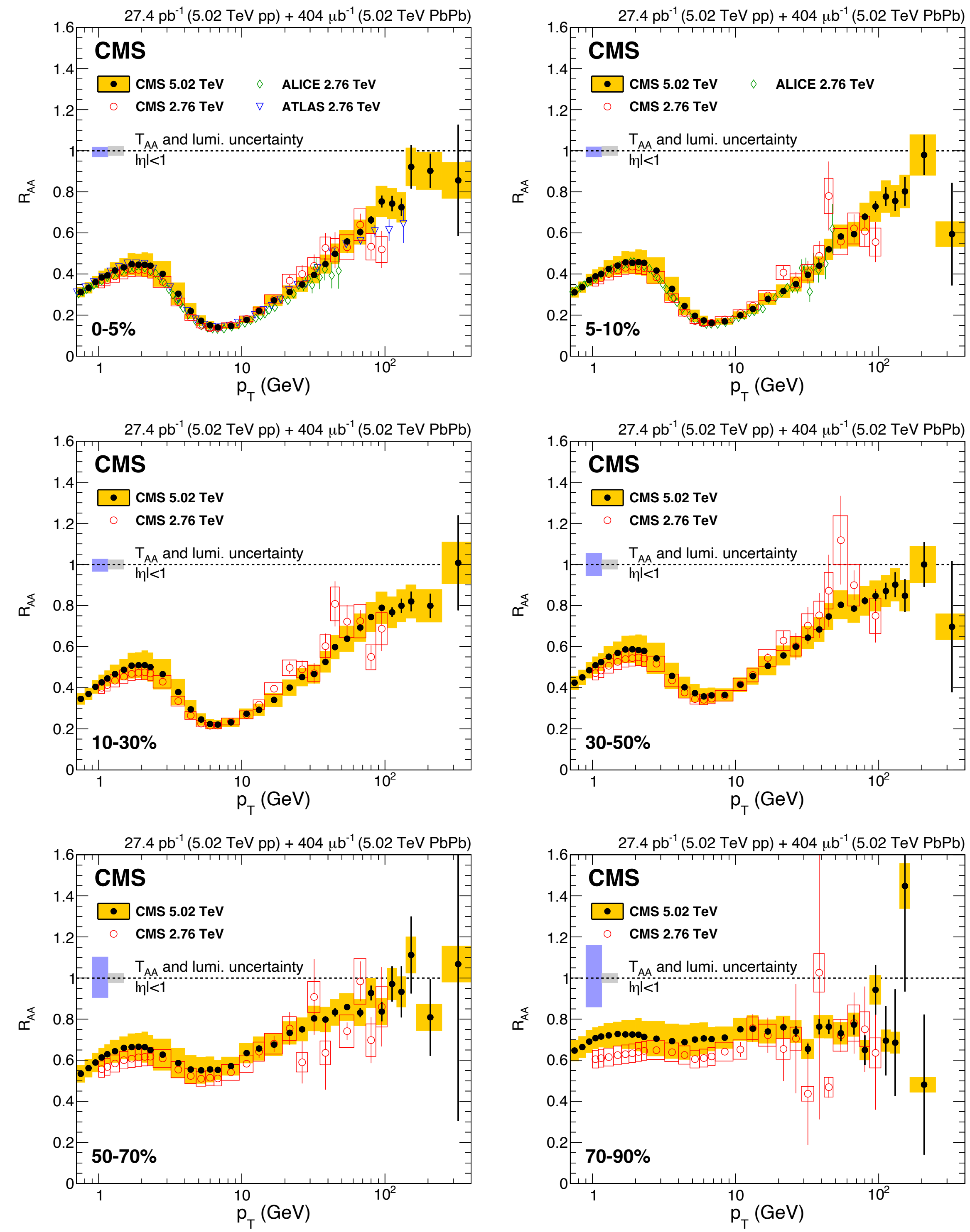

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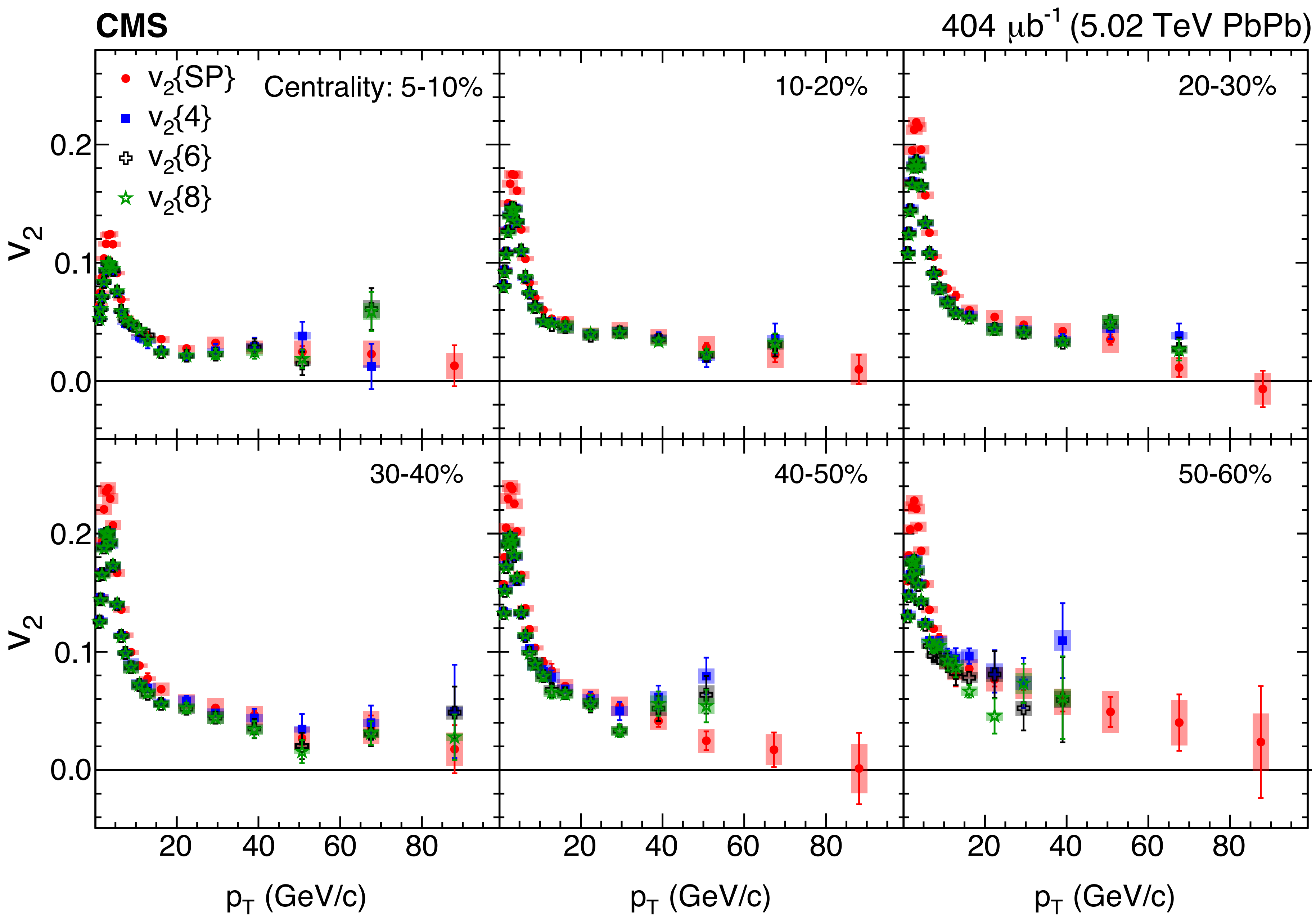
See Dener's talk on Jet Quenching in pPb

Azimuthal Anisotropy at High p_T in AA

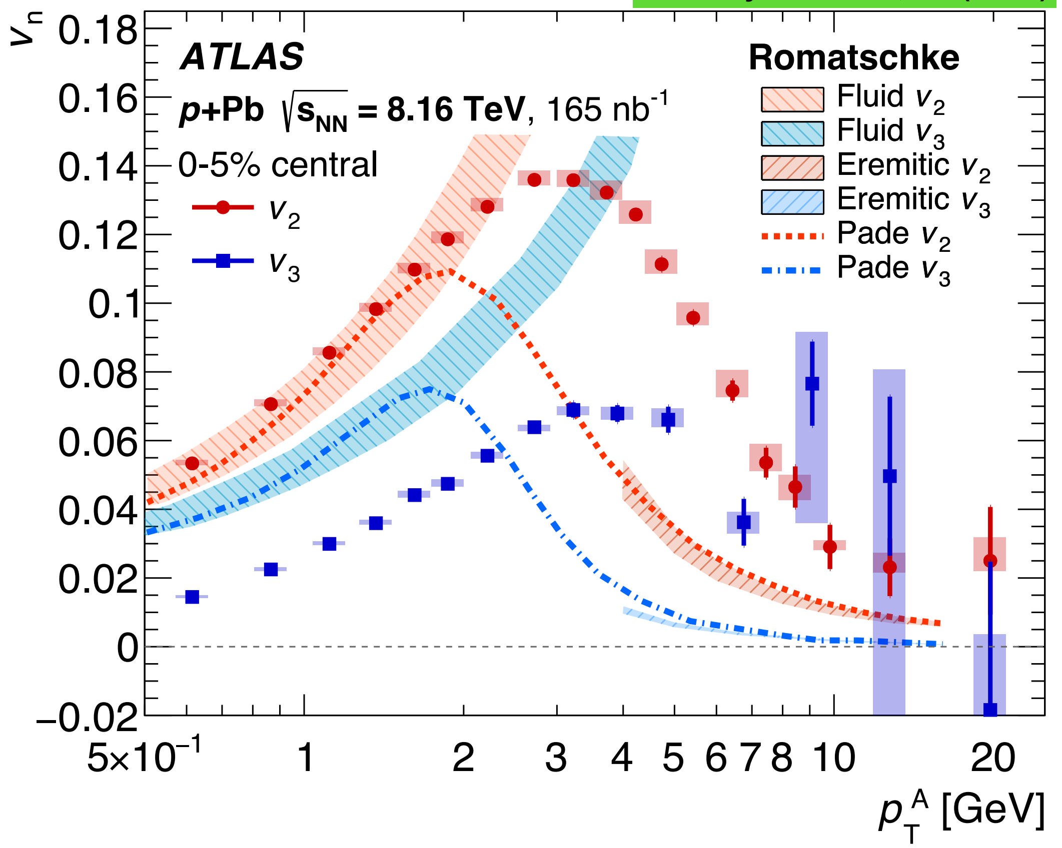
Phys. Lett. B 776 (2017) 195



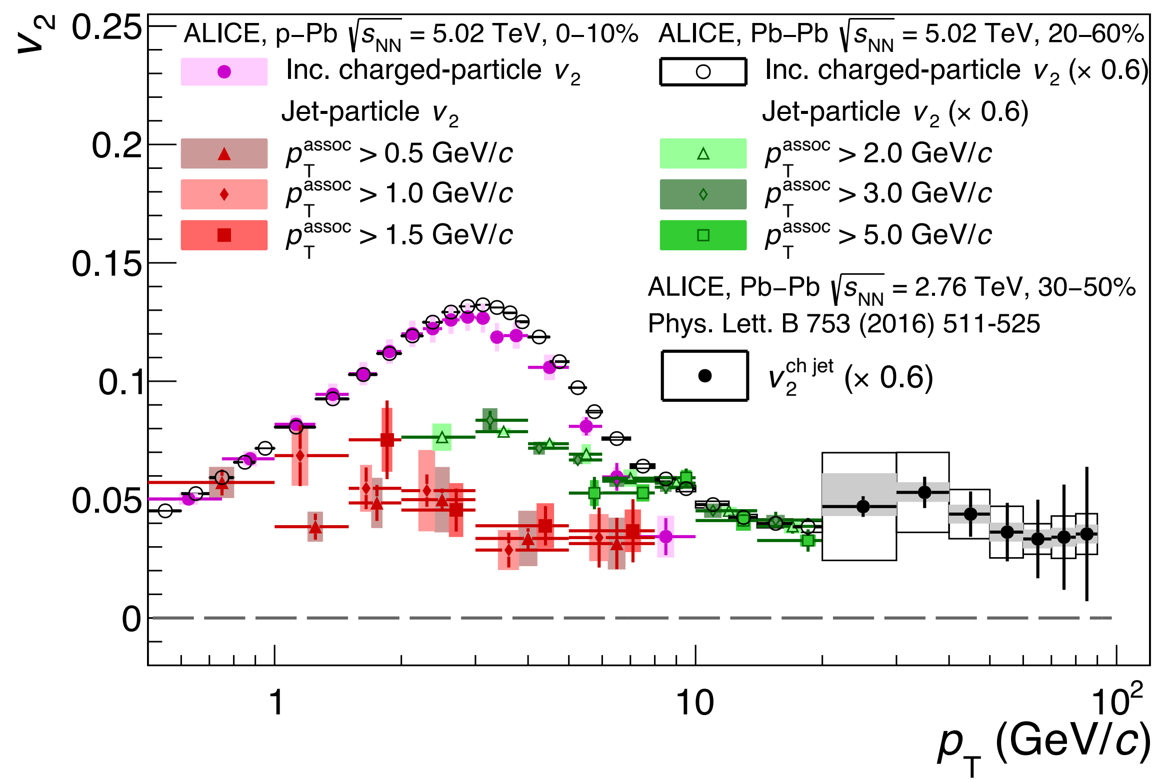
- **Azimuthal Anisotropy (v_n) at high p_T (> 10 GeV/c) in AA:**
  - **Energy loss + Fluctuations, no hydrodynamics**
  - **Sensitive to the path length of high p_T parton in QGP medium (Jet Quenching)**

Previous Measurements of v_n in pPb at High p_T

Eur. Phys. J. C 80, 73 (2020)



arXiv:2212.12609



- ❖ **2-particle correlation technique (nonflow contamination)**
- ❖ **Template fit method for nonflow subtraction**
- ❖ **Based on strong assumptions**

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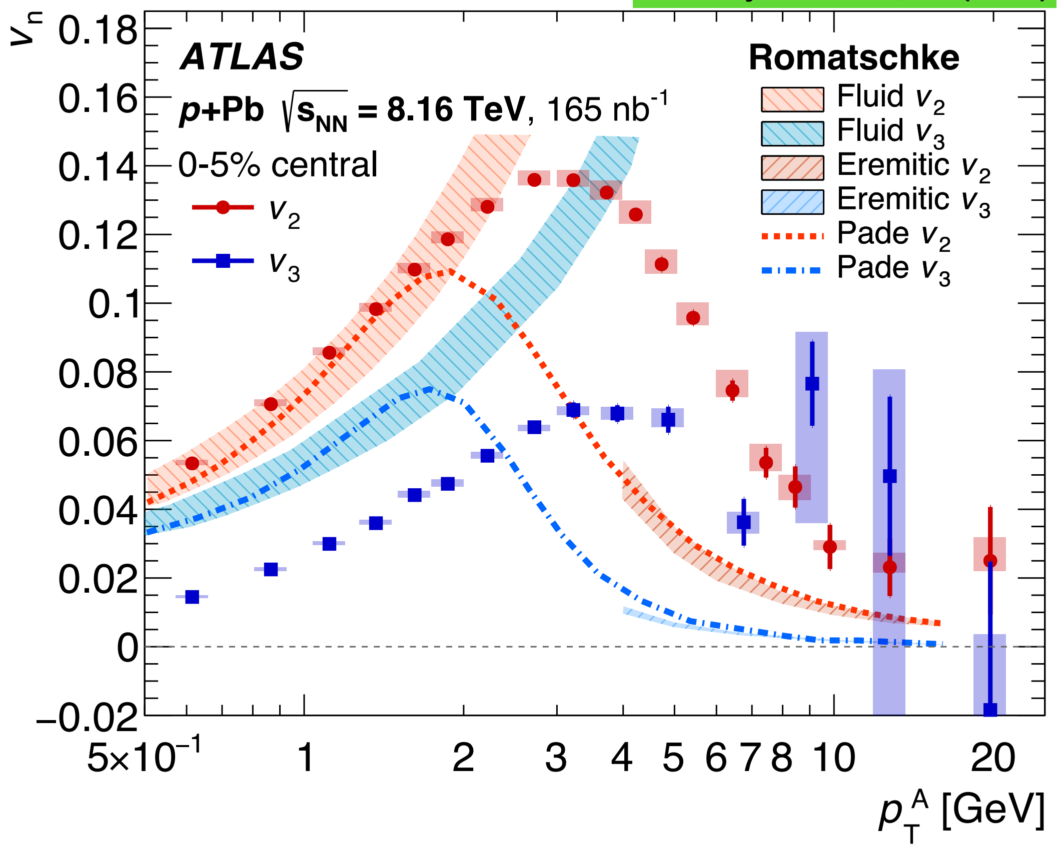

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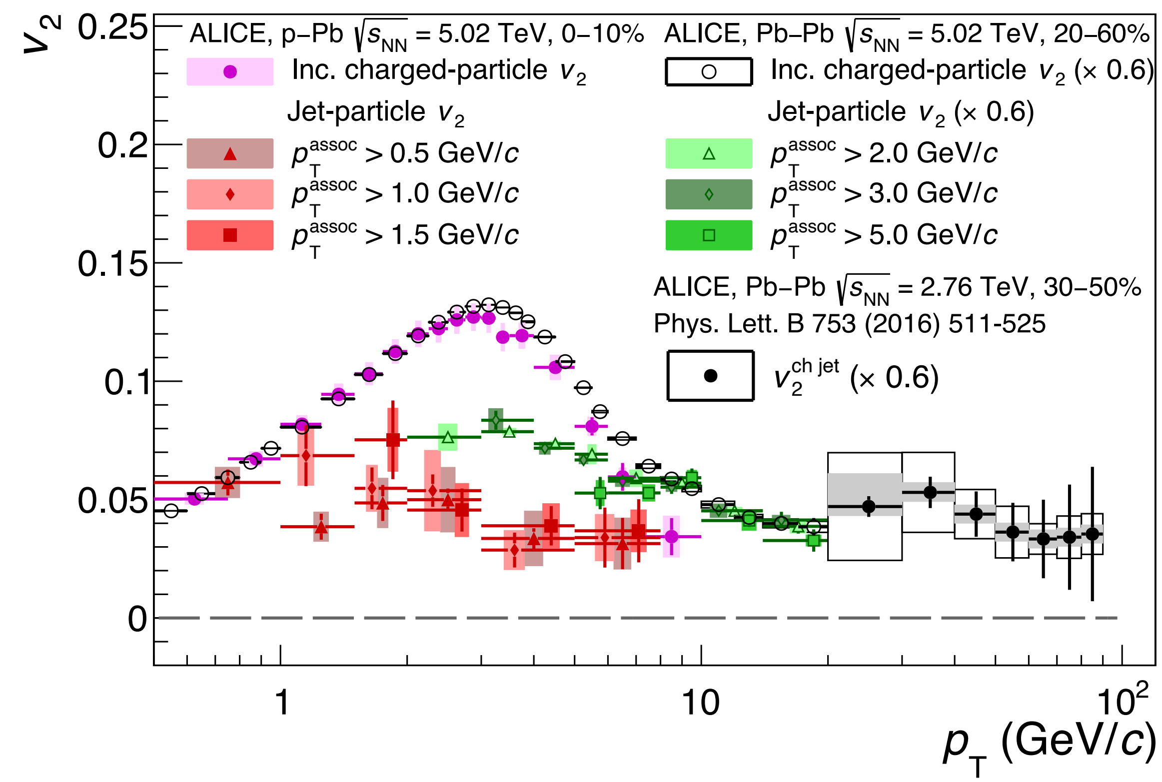

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❋ Open questions:

- ❖ **What could be the source of observed anisotropy at high p_T in pPb?**
- ❖ **How can there be a hydro medium that modifies the distribution of final-state hadrons yet has no impact on high p_T particle distribution?**

Previous Measurements of v_n in pPb at High p_T

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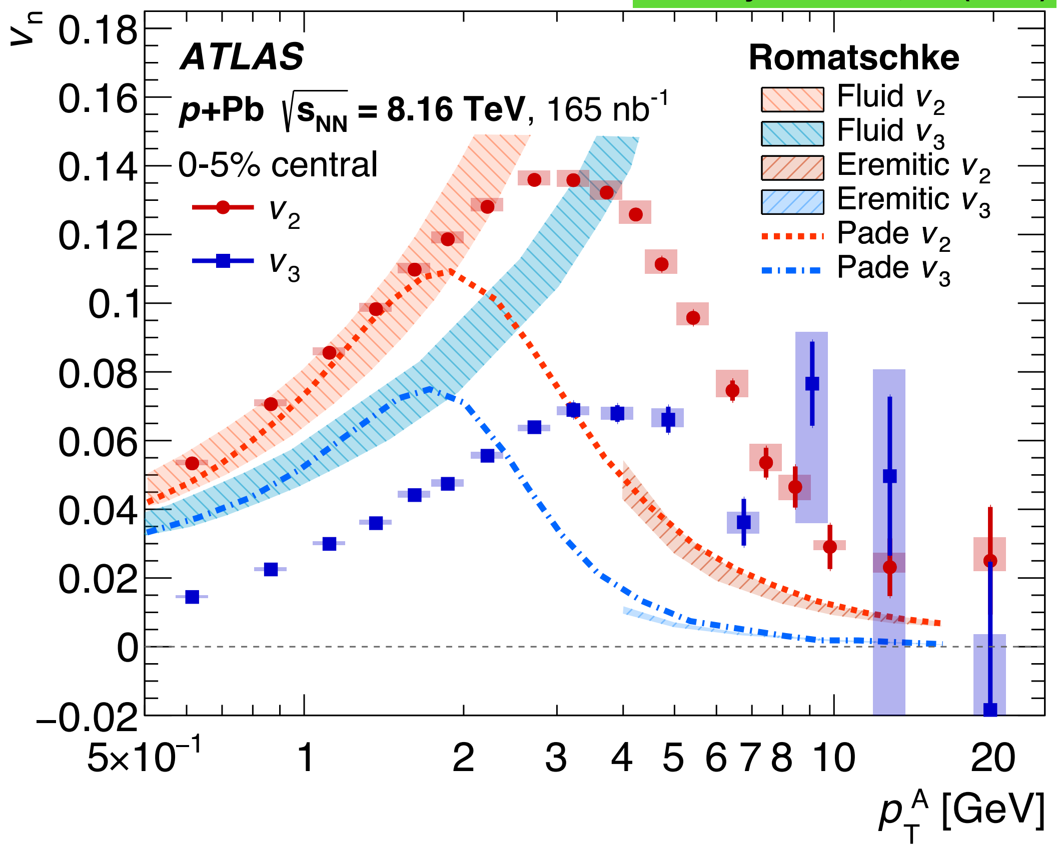

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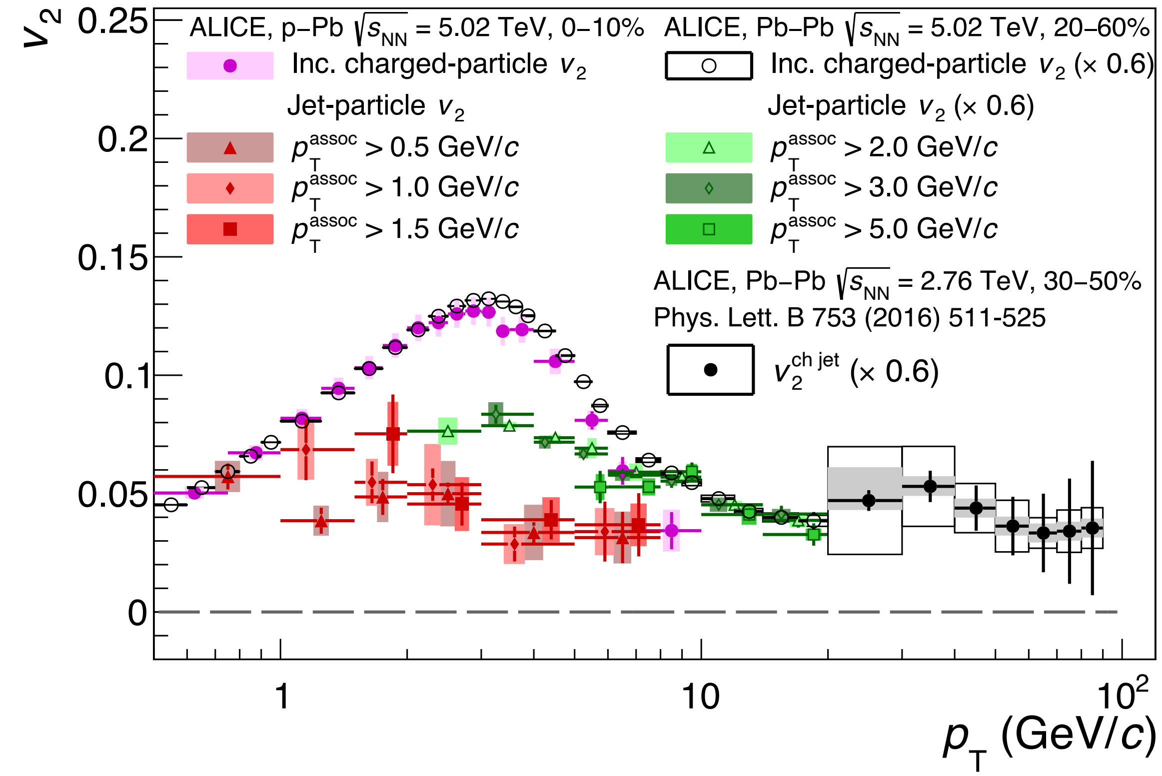

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- What could be the source of observed anisotropy at high p_T in pPb?
- How can there be a hydro medium that modifies the distribution of final-state hadrons yet has no impact on high p_T particle distribution?

Further study using Cumulants:

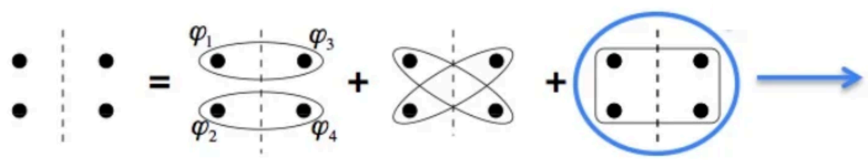
- Known to better mitigate nonflow
- First measurement of v_n using subevent cumulant at high p_T in high multiplicity pPb

Analysis Method

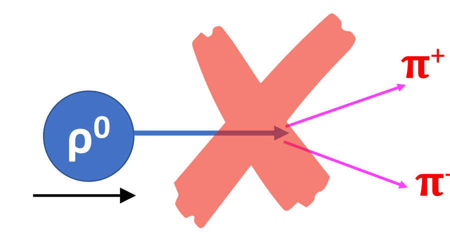
❋ Cumulant method:

- ❖ **Multiparticle correlation technique**
- ❖ **Non-flow suppression in a data-driven way**

Phys.Rev.C83:044913,2011



$$c_n\{4\} = \langle\langle 4\rangle\rangle - 2\cdot\langle\langle 2\rangle\rangle\langle\langle 2\rangle\rangle$$



❋ Q-cumulant:

❖ Q-vector: $Q_n \equiv \sum_{i=1}^{M} e^{in\phi_i}$

$$\langle\langle 2\rangle\rangle = \langle\langle e^{in(\phi_1-\phi_2)}\rangle\rangle, \quad \text{and} \quad \langle\langle 4\rangle\rangle = \langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)}\rangle\rangle$$

Phys. Rev. C 89, 064904 (2014)

=> Cumulants : • $c_n\{2\} = \langle\langle 2\rangle\rangle$ • $c_n\{4\} = \langle\langle 4\rangle\rangle - 2\langle\langle 2\rangle\rangle\cdot\langle\langle 2\rangle\rangle$

=> Flow : • $v_n\{2\} = \sqrt{c_n\{2\}}$ • $v_n\{4\} = \sqrt[4]{-c_n\{4\}}$

=> Differential cumulant : $d_n\{4\} = \langle\langle 4'\rangle\rangle - 2\langle\langle 2'\rangle\rangle\cdot\langle\langle 2\rangle\rangle$

1 POI **3 RFPs**

=> Differential Flow : $v'_n\{4\} = -\dfrac{d_n\{4\}}{(-c_n\{4\})^{3/4}}$

Cumulant method:

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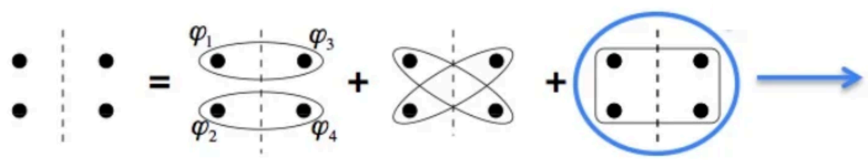
- Non-flow suppression in a data-driven way

Phys.Rev.C83:044913,2011



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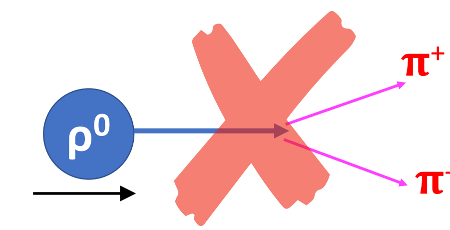

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=> **Flow :**

- $v_n\{2\} = \sqrt{c_n\{2\}}$
- $v_n\{4\} = \sqrt[4]{-c_n\{4\}}$

=> **Differential cumulant :** $d_n\{4\} = \langle\langle 4'\rangle\rangle - 2\langle\langle 2'\rangle\rangle\cdot\langle\langle 2\rangle\rangle$

1 POI **3 RFPs**

=> **Differential Flow :**

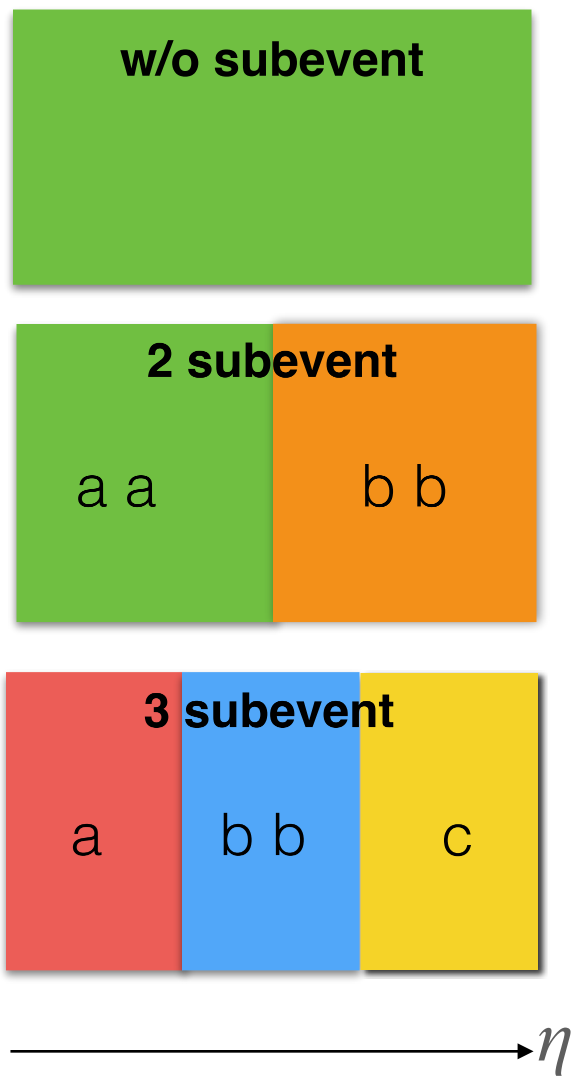
$$v'_n\{4\} = -\frac{d_n\{4\}}{(-c_n\{4\})^{3/4}}$$

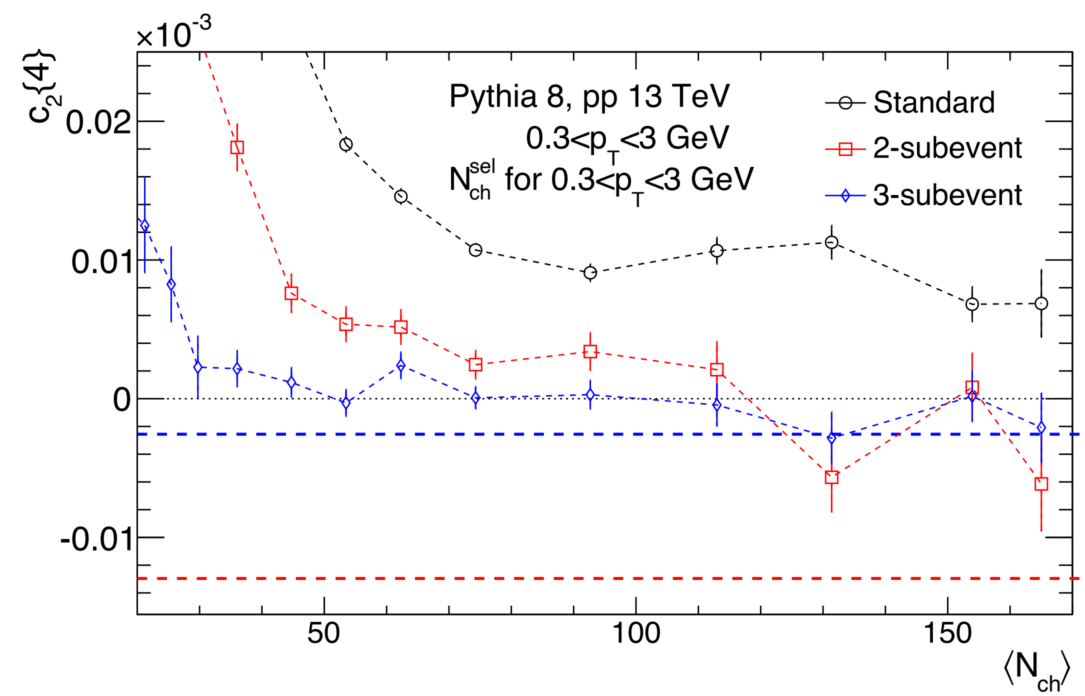
Final observable

Subevent technique:

In order to further suppress few-particle correlations and to explore possible collective correlation signals, we are using subevent cumulant techniques to require rapidity gaps among the particles

- **2 subevent can reduce non-flow contribution from within the Jets**
- **3 and 4 subevents can remove back to back contribution**





Phys. Rev. C 96, 034906 (2017)

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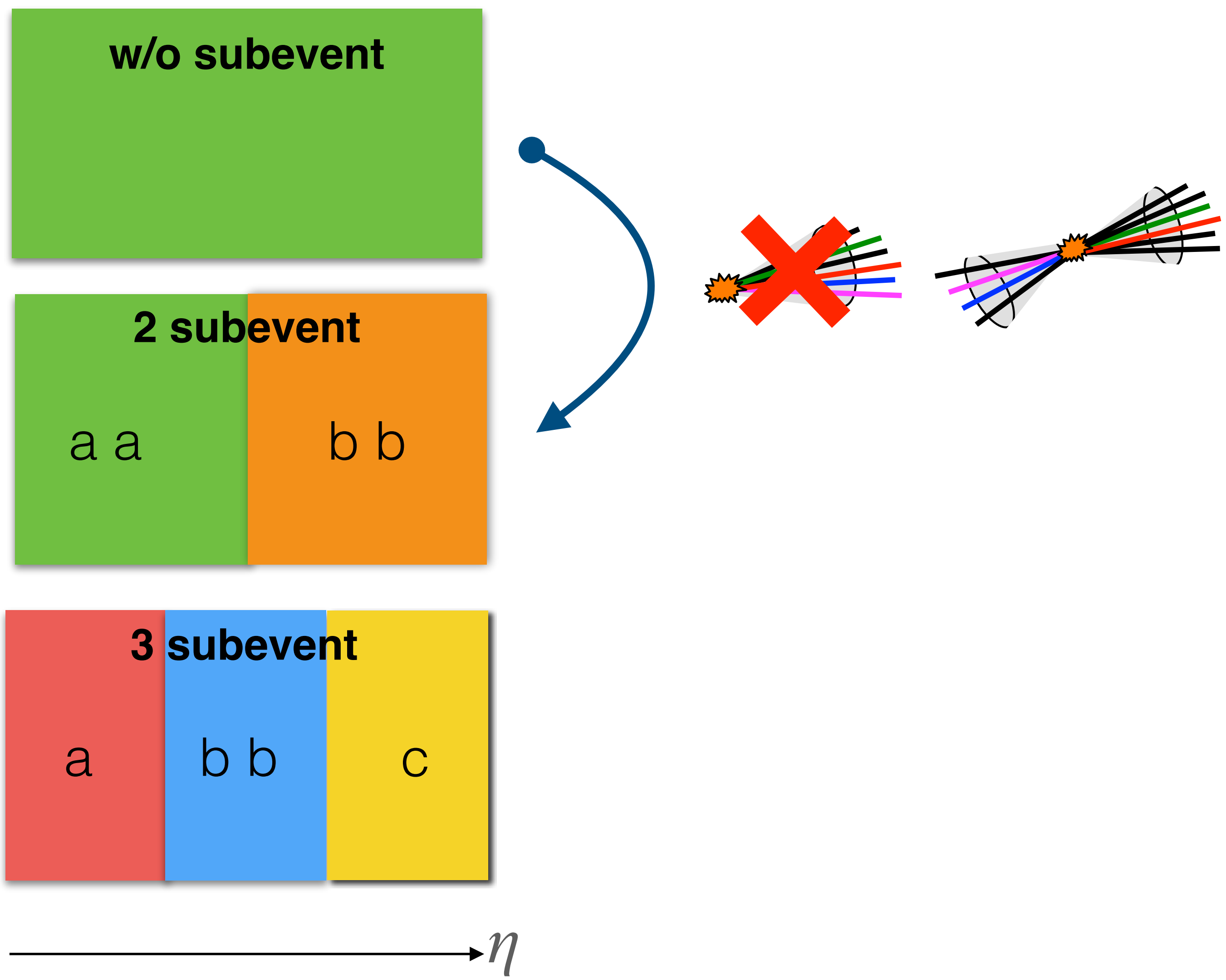

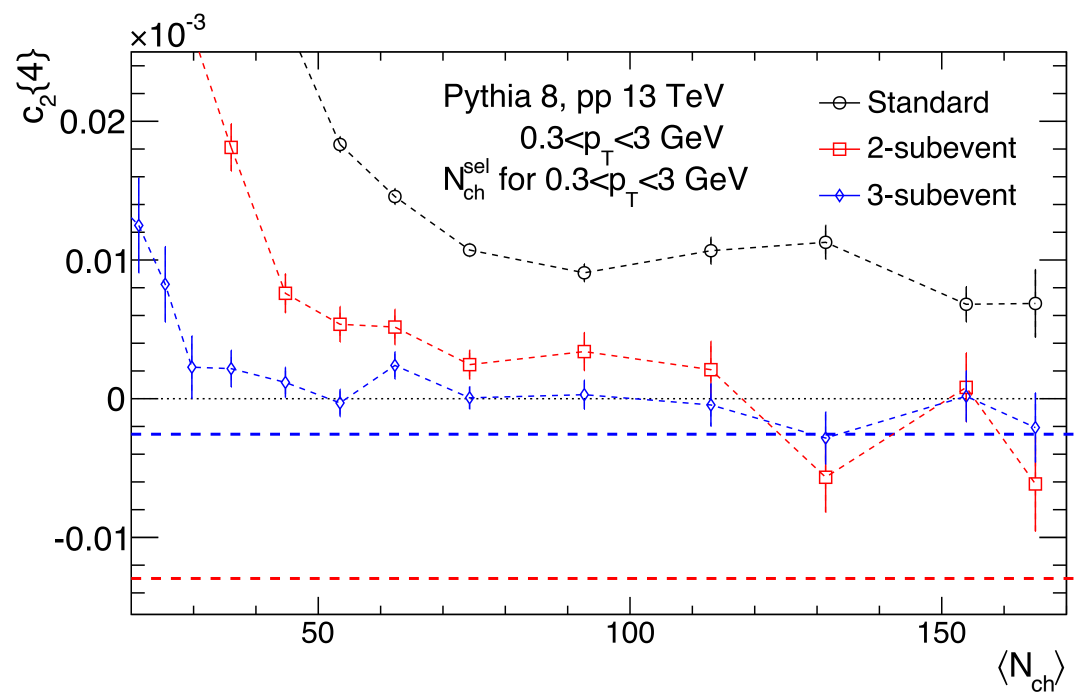

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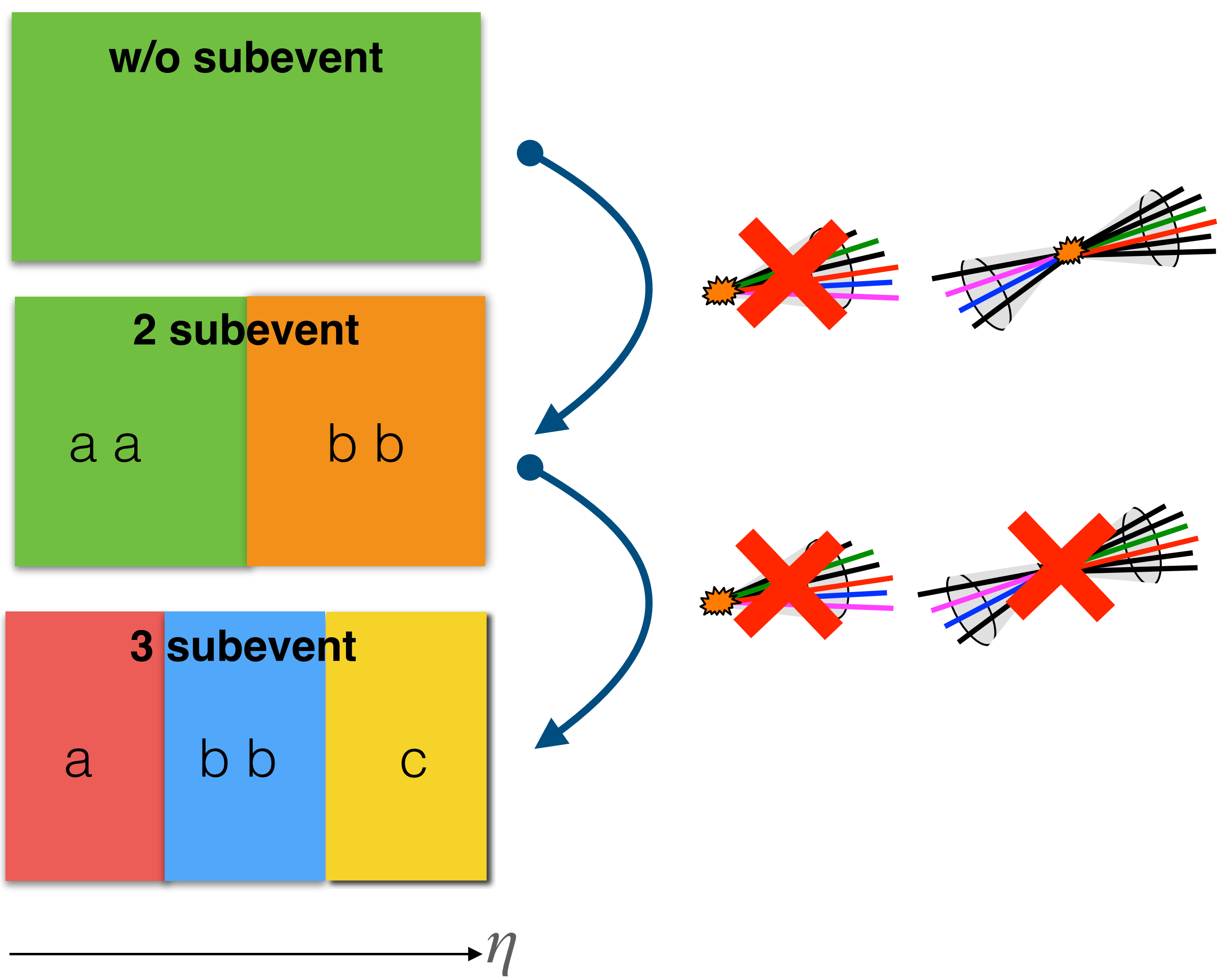

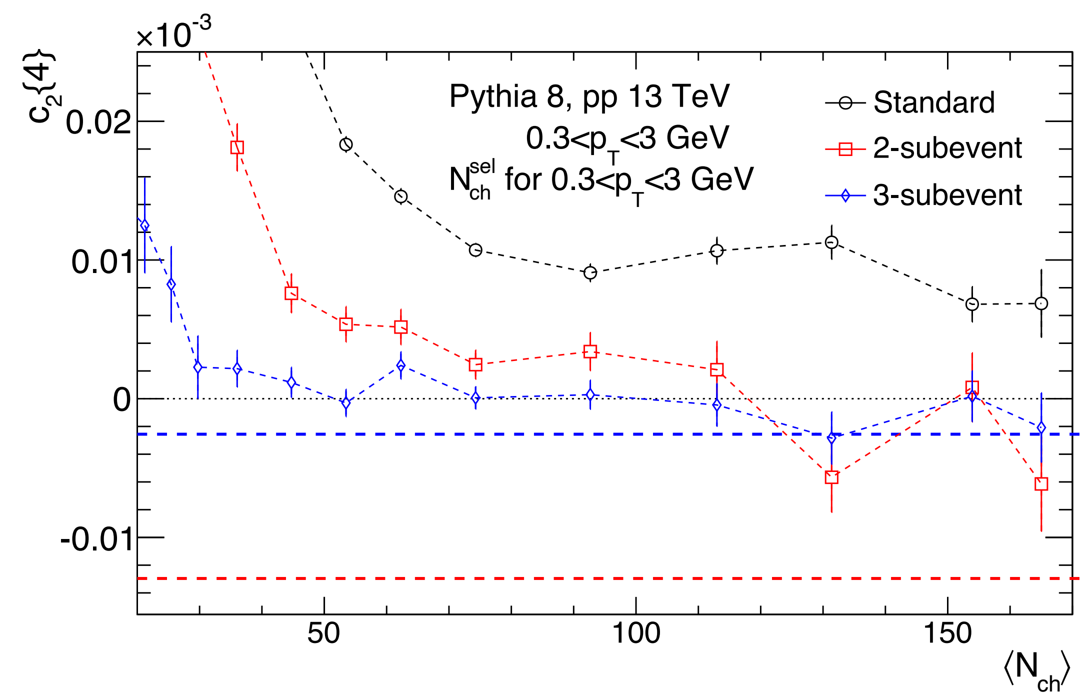

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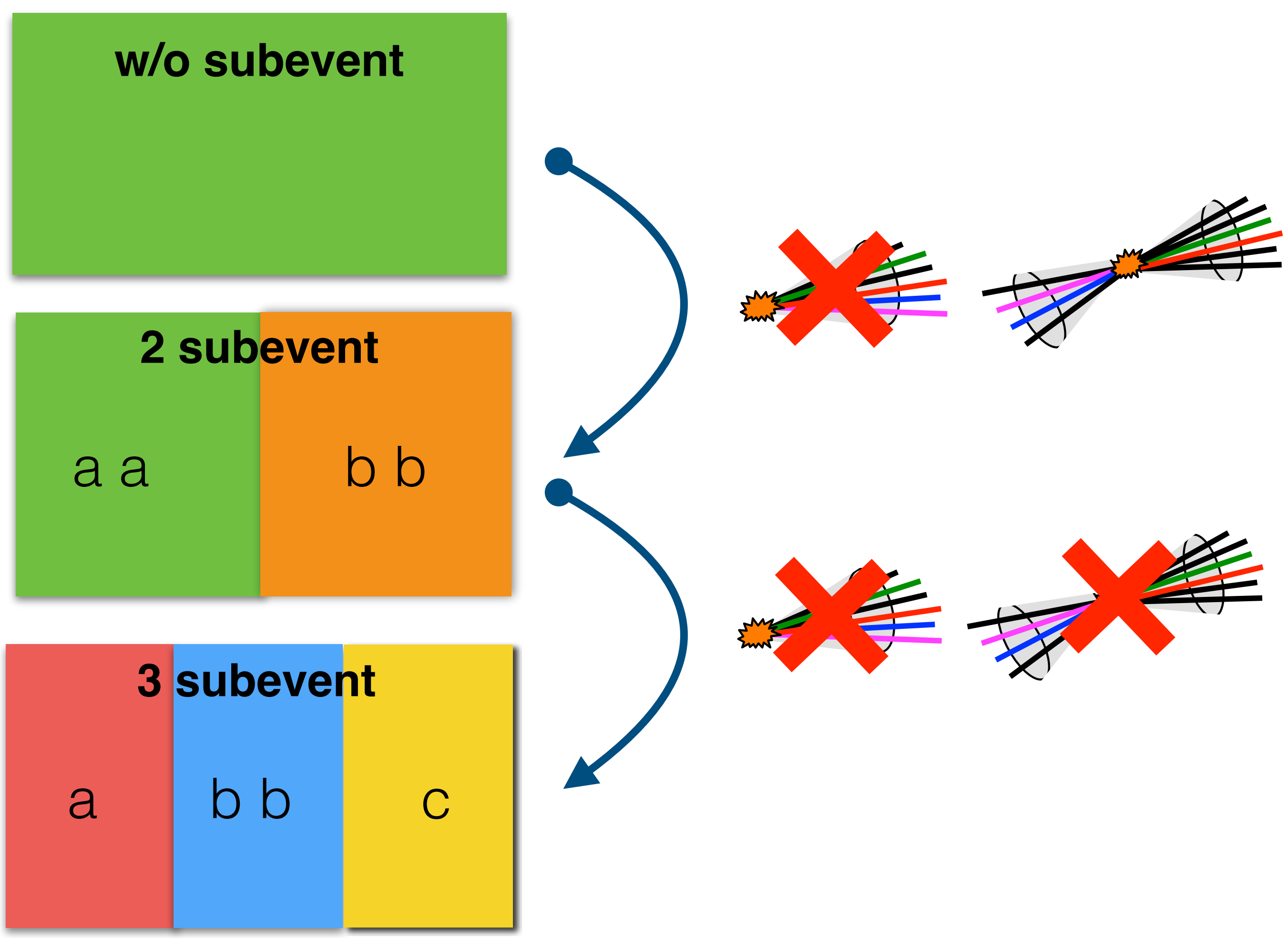

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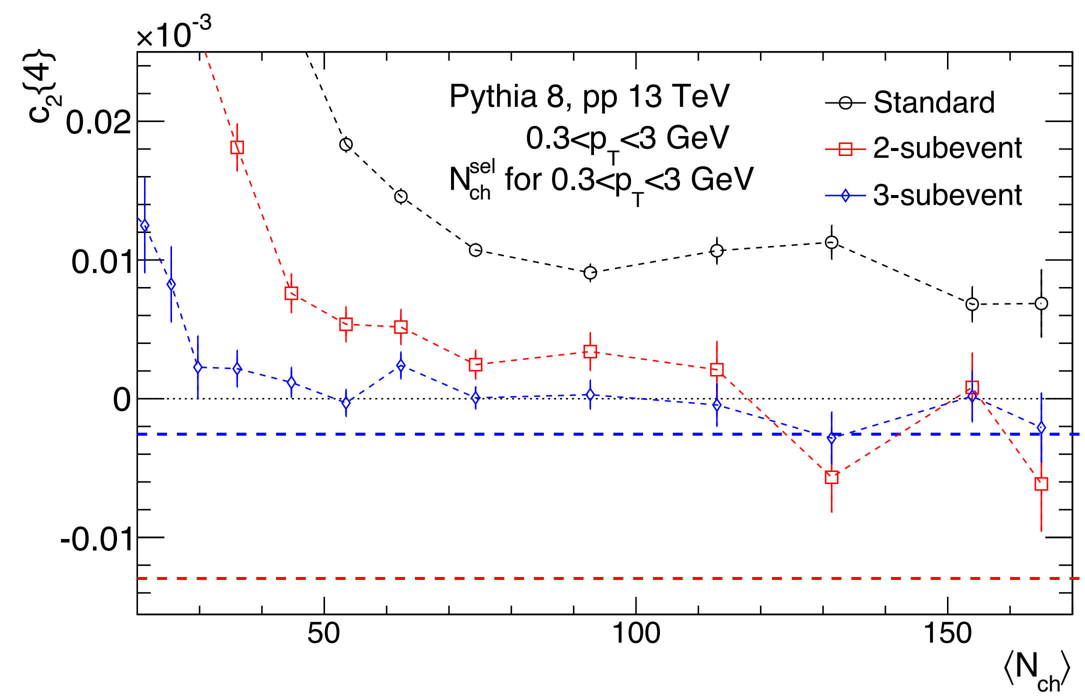
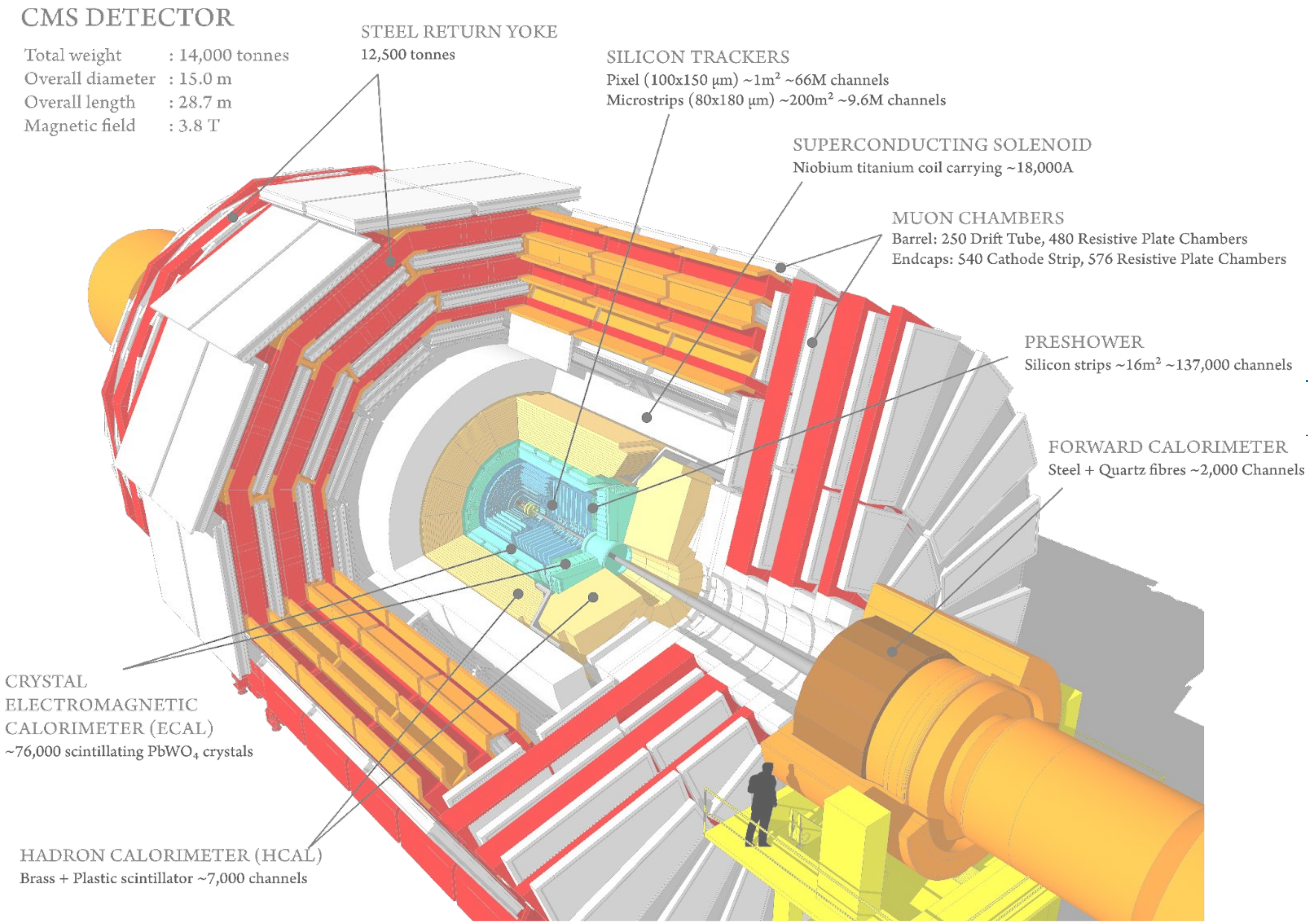


Phys. Rev. C 96, 034906 (2017)

Large η coverage of CMS: enough statistics


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 (100x150 μm) ~1m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Results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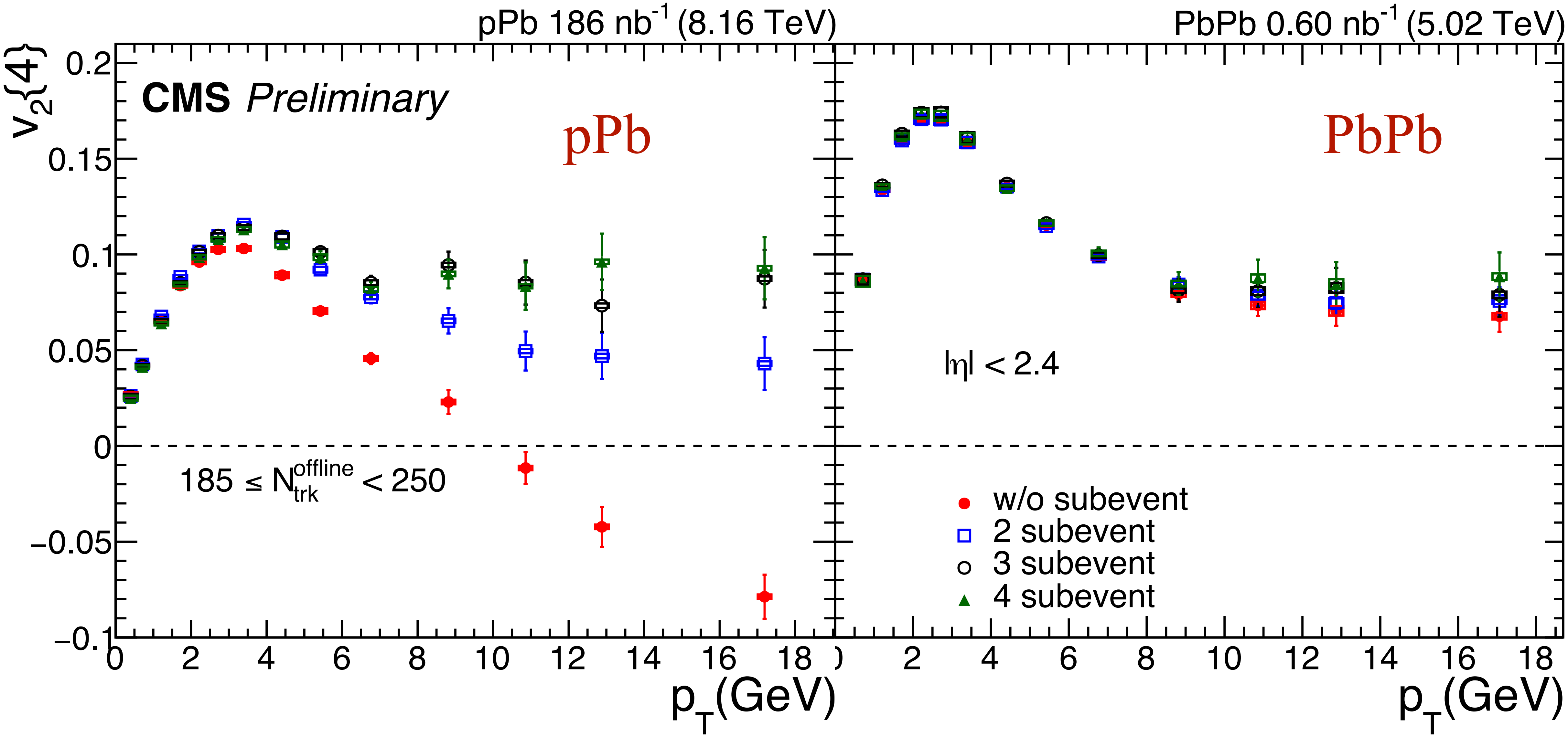
Results

- $v_2\{4\}$ in $185 \leq N_{trk}^{offline} < 250$ as a function of p_T

CMS-PAS-HIN-23-002



- **At low p_T, PbPb has larger $v_2\{4\}$ than pPb**
- **At high p_T, similar magnitude and similar trend of subevent $v_2\{4\}$**

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❋ $v_2\{4\}$ **in** $185 \leq N_{trk}^{offline} < 250$ **as a function of** p_T

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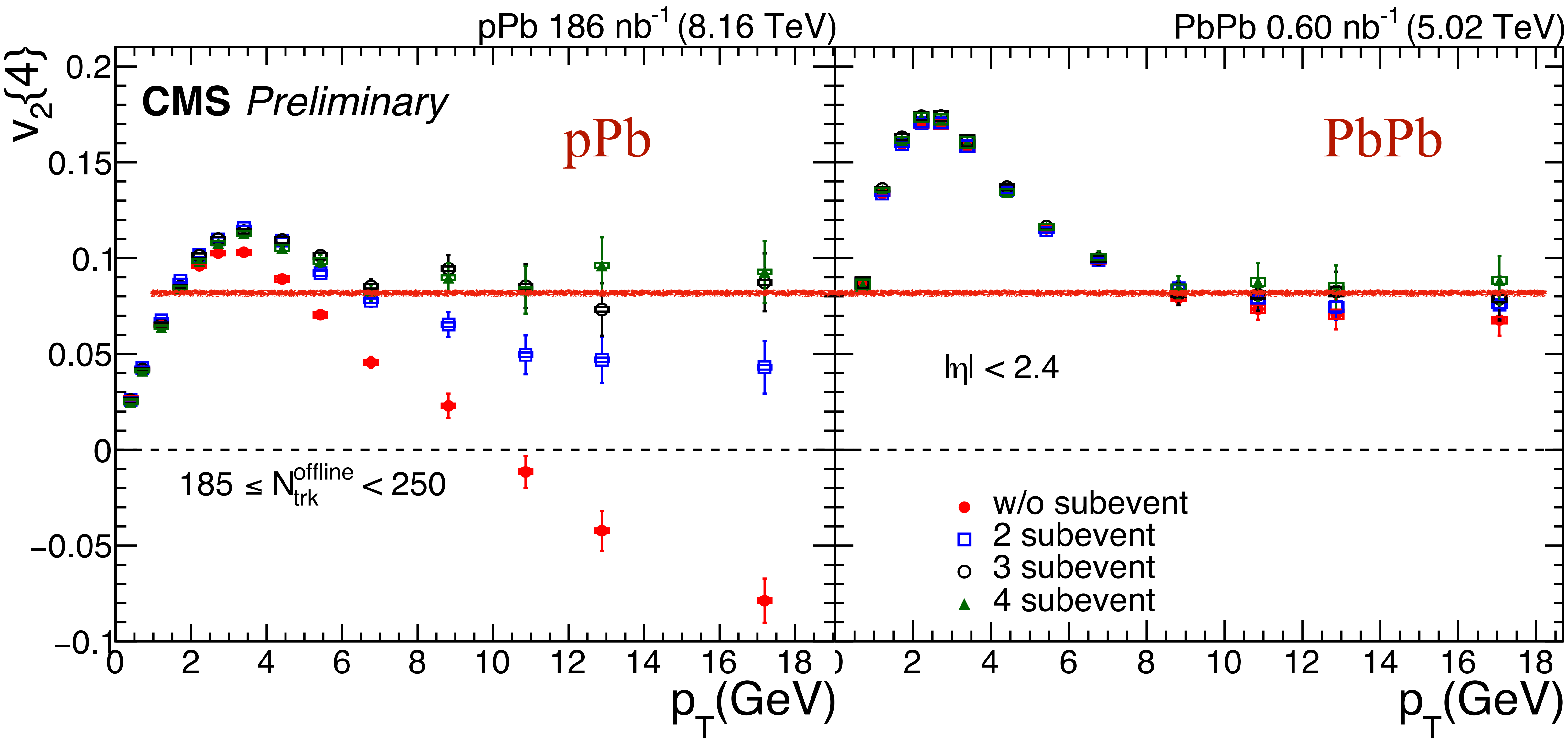
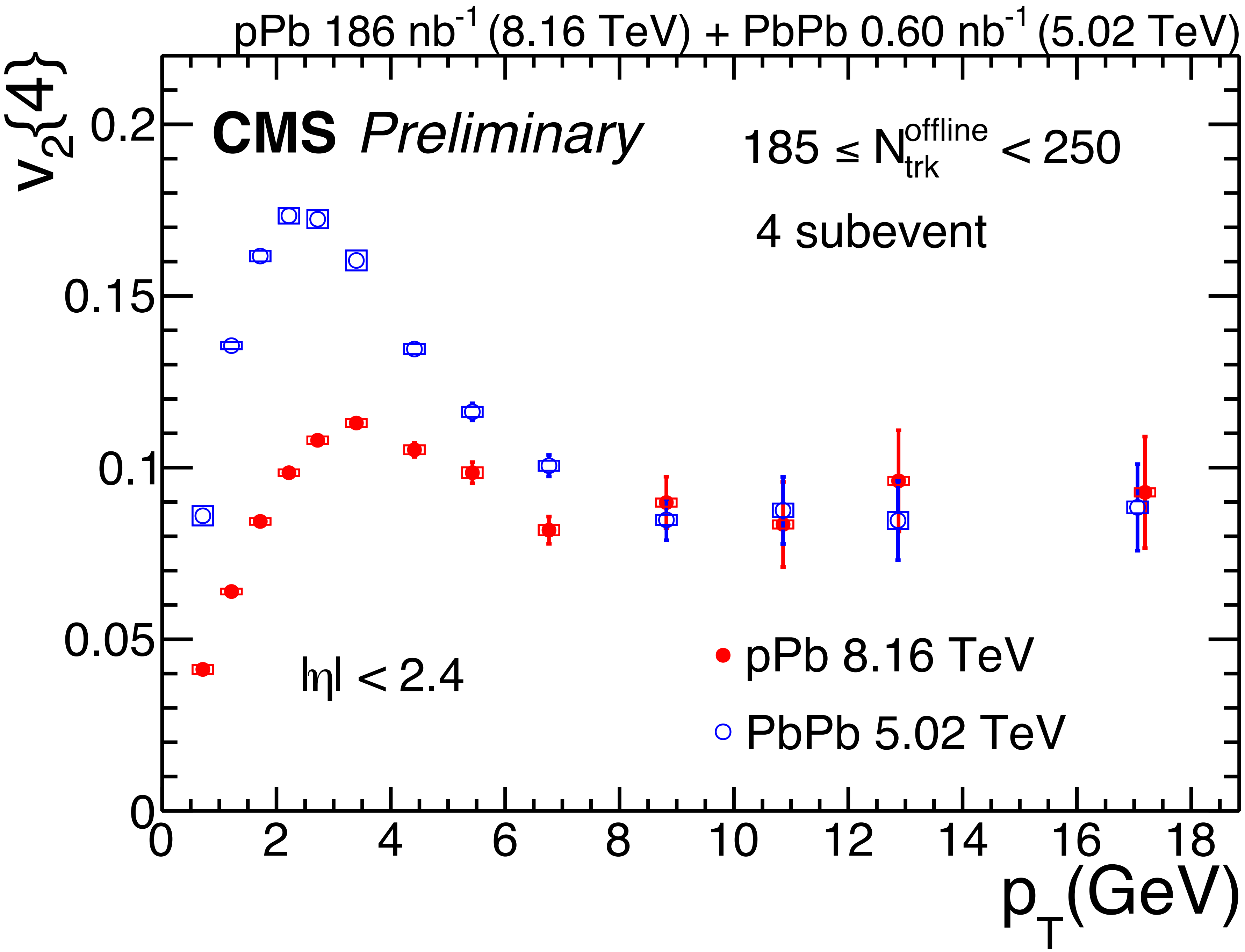


- **At low** p_T**, PbPb has larger** $v_2\{4\}$ **than pPb**
- **At high** p_T**, similar magnitude and similar trend of subevent** $v_2\{4\}$

Results

- **4 subevent $v_2\{4\}$ in $185 \leq (N_{trk}^{offline}) < 250$**

CMS-PAS-HIN-23-002



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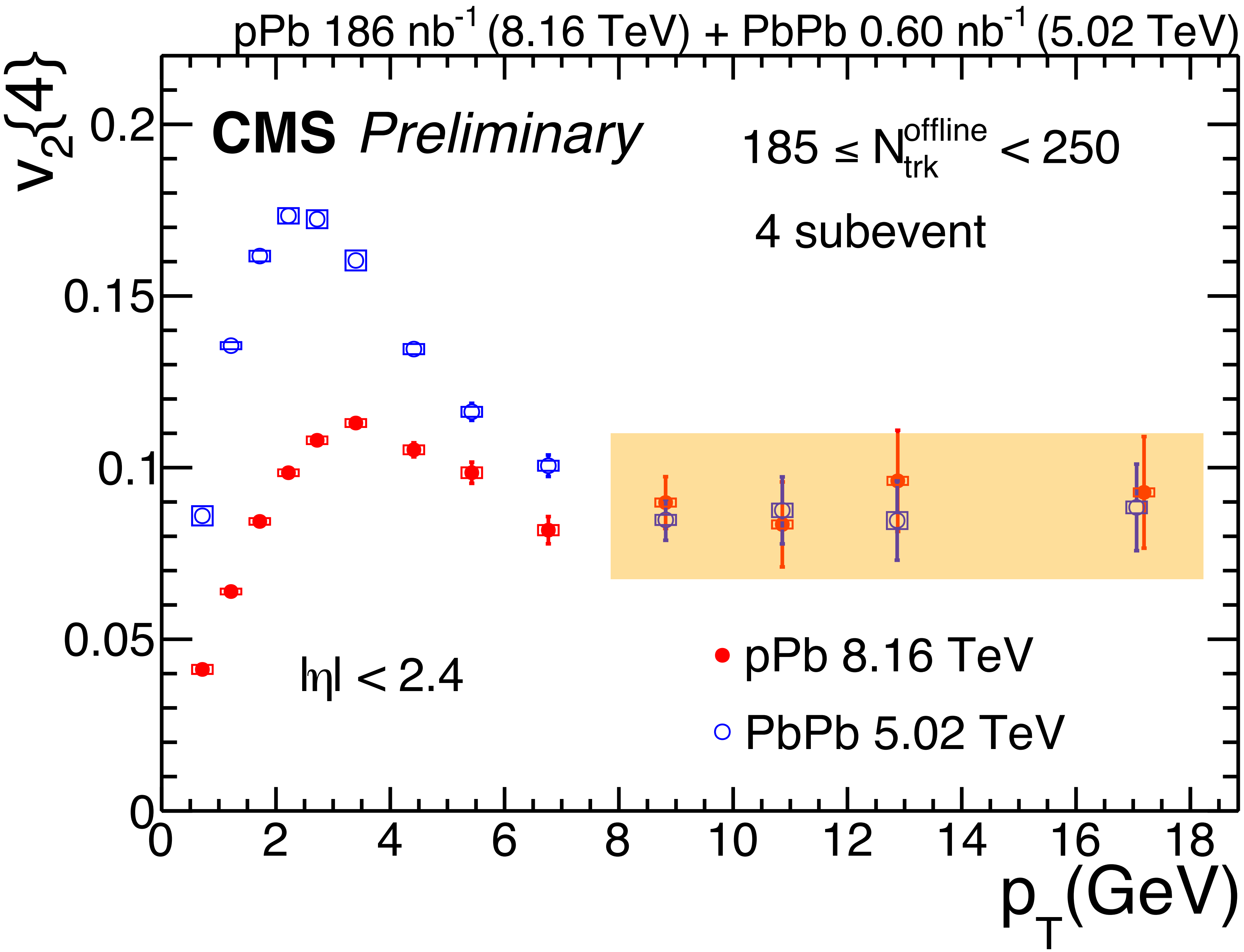
CMS-PAS-HIN-23-002



- **At low p_T, PbPb has larger $v_2\{4\}$ than pPb**
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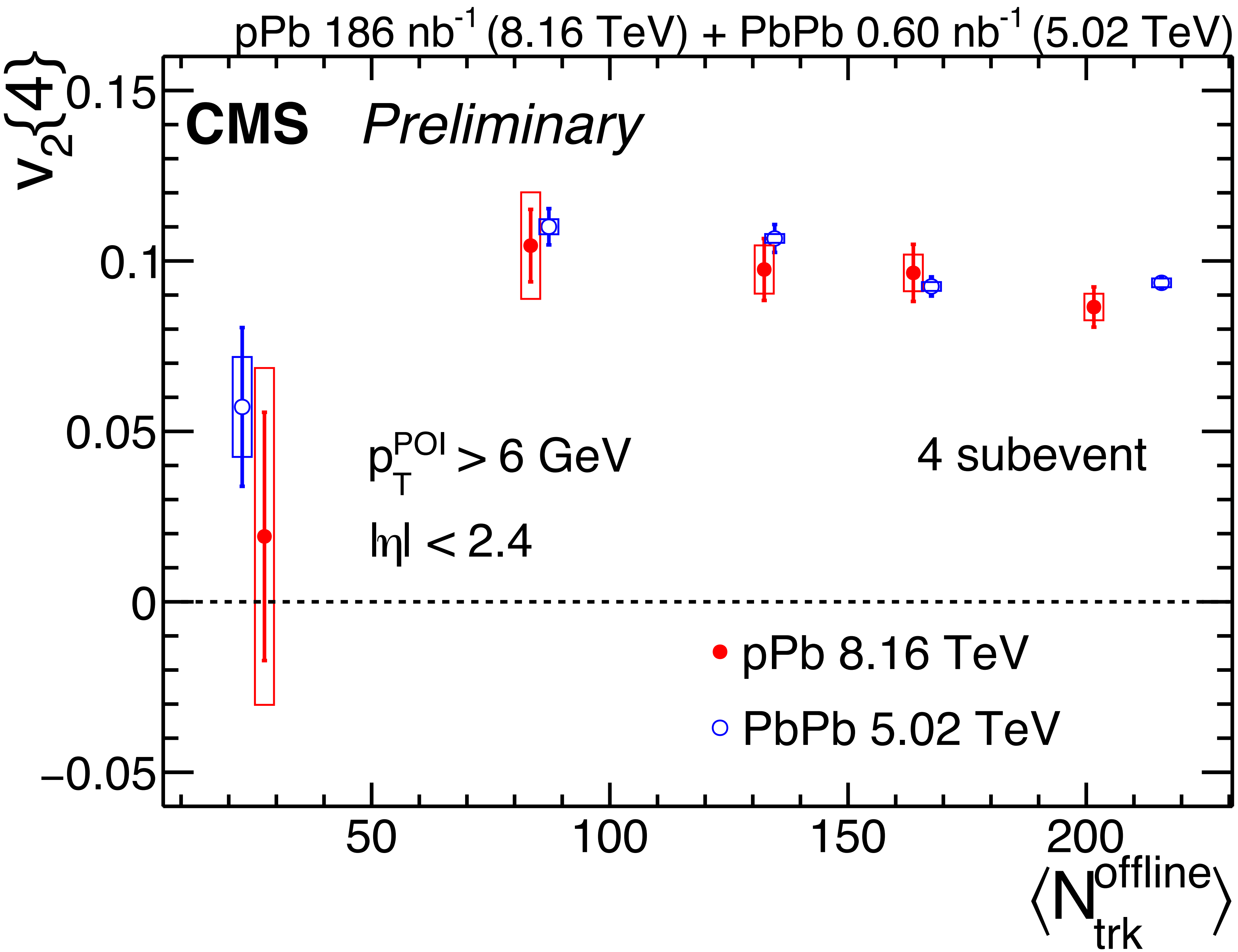
Results

- $v_2\{4\}$ in different $N_{trk}^{offline}$ bins with $p_T^{POI} > 6$ GeV

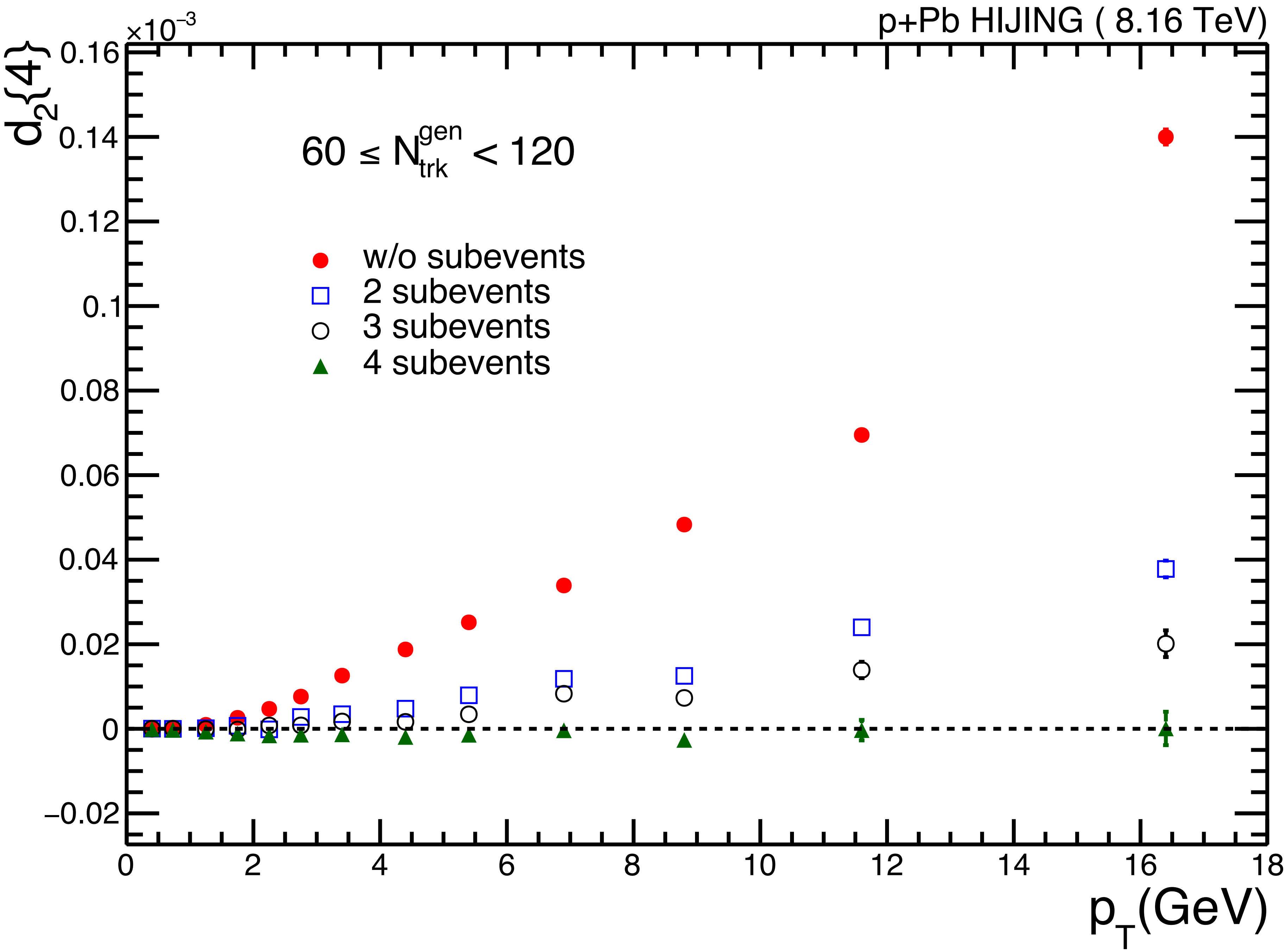
CMS-PAS-HIN-23-002



- **Similar magnitude and trend for both PbPb and pPb when $p_T^{POI} > 6$ GeV across all multiplicity bins**

Cross-check

- $d_2\{4\}$ **in HIJING in** $60 \leq (N_{trk}^{gen}) < 120$



- **HIJING lacks collectivity => used to cross check non-flow subtraction of subevent cumulant**

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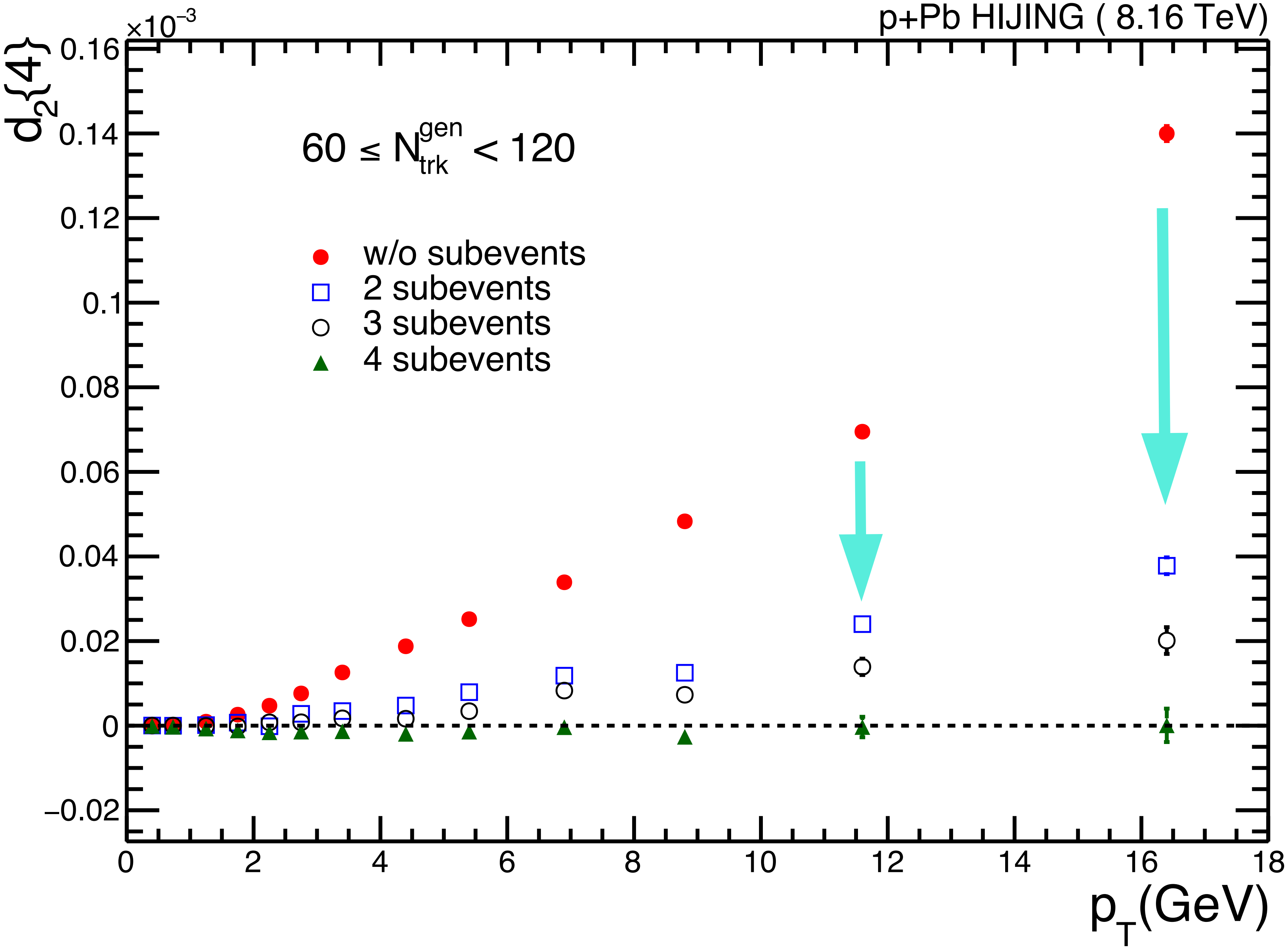

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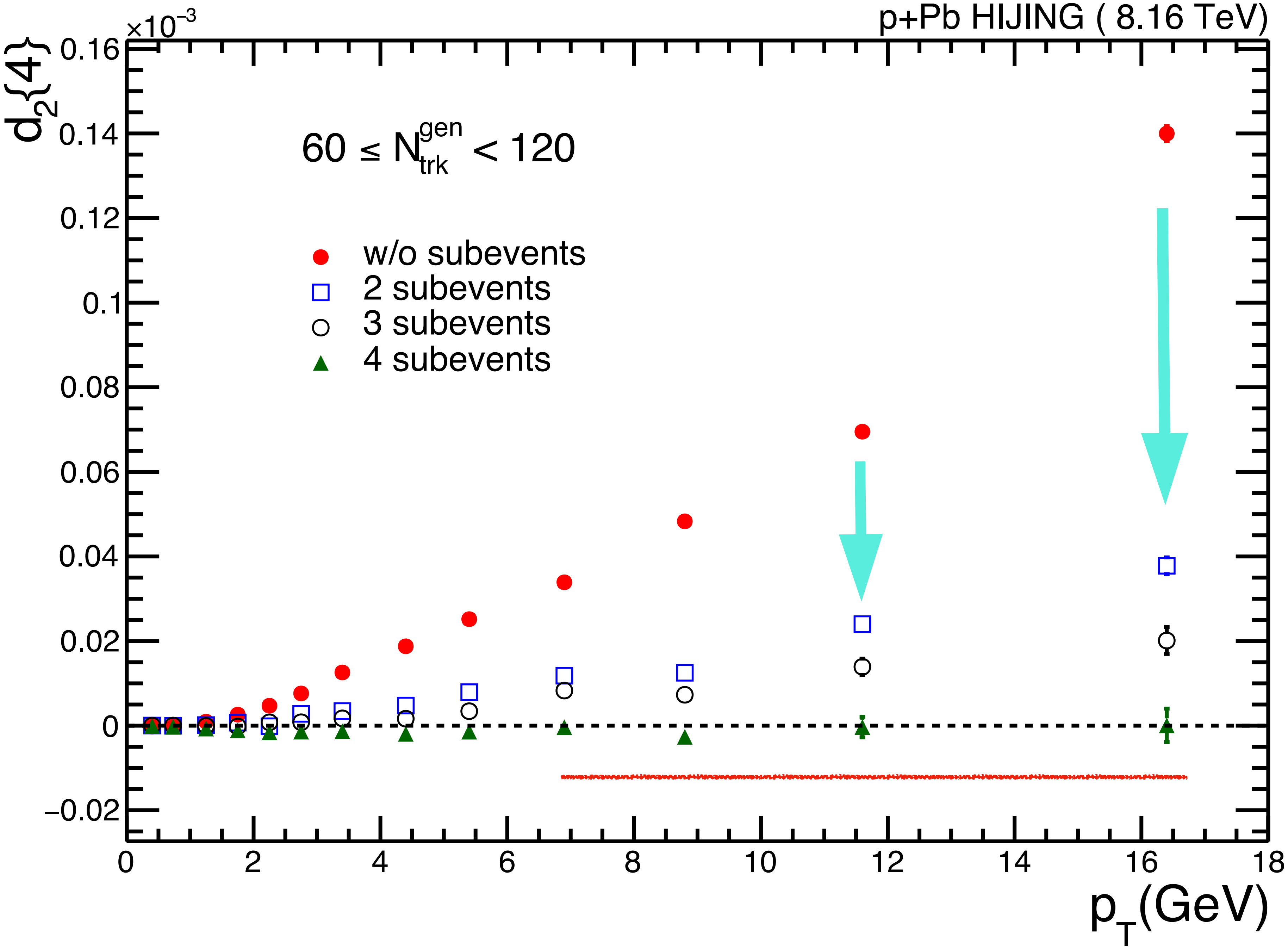

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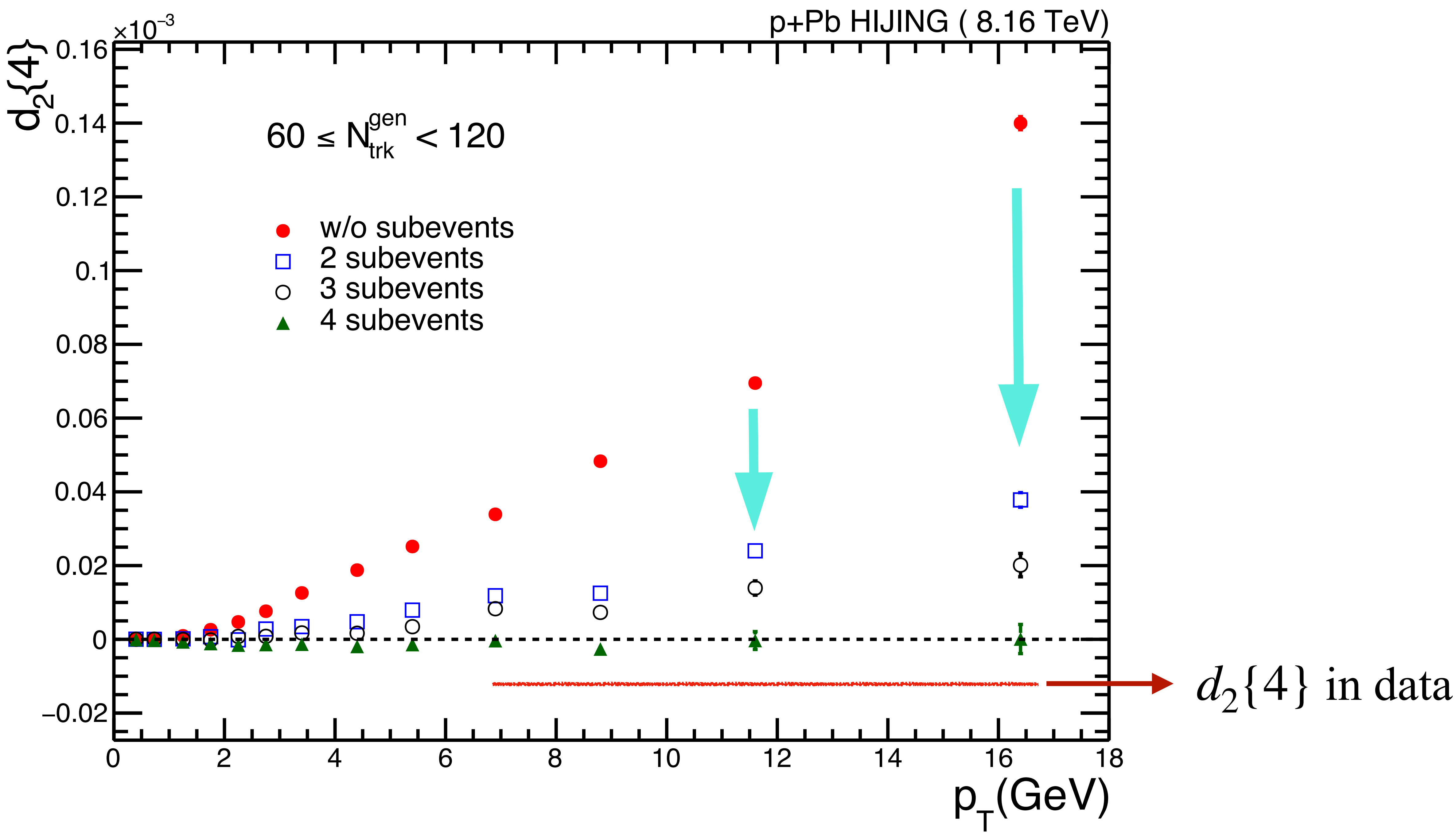

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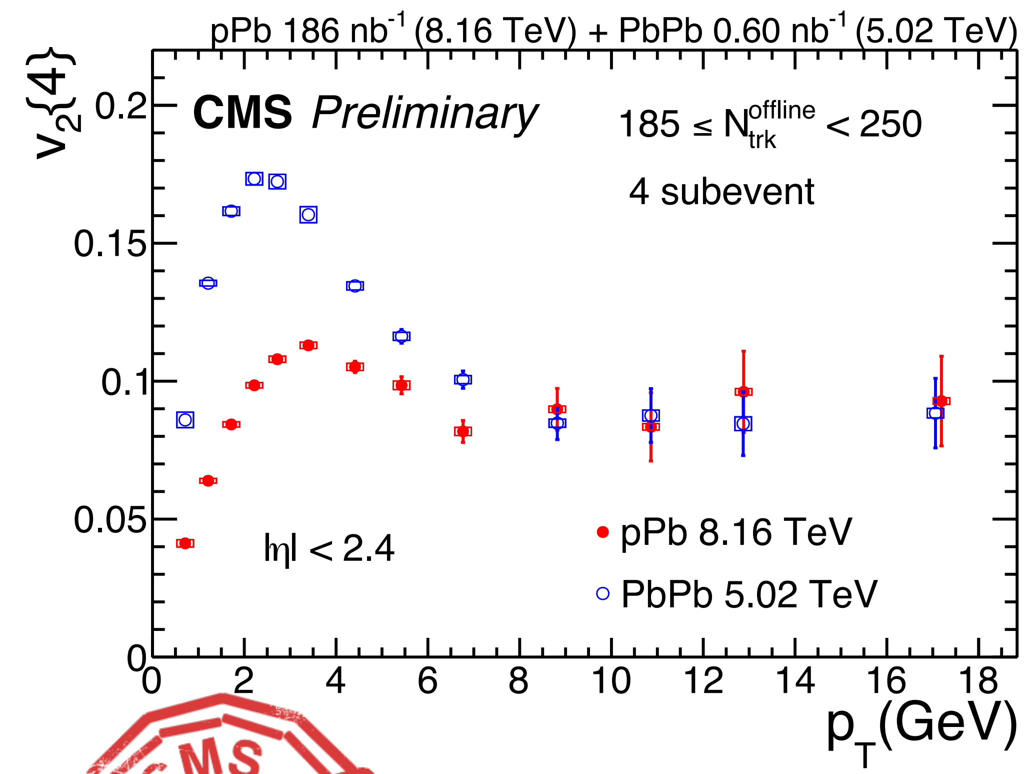
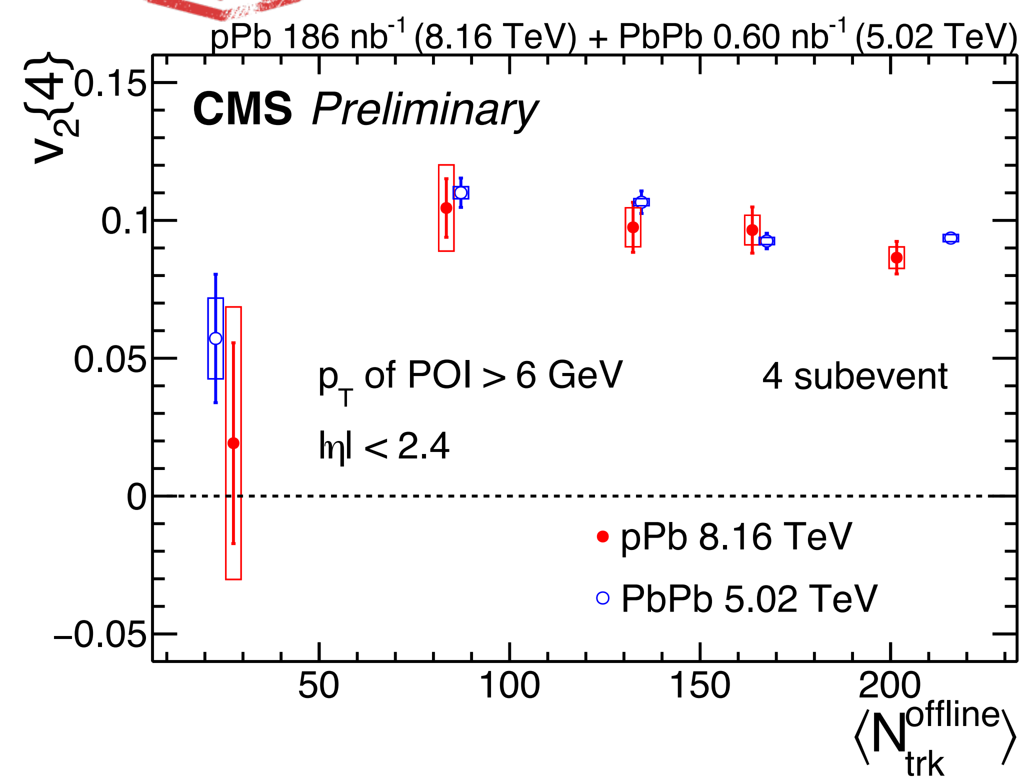
Summary

- The results of $v_2\{4\}$ with subevents for pPb & PbPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV & $\sqrt{s_{NN}}$ = 5.02 TeV, resp.
- After using subevent to remove nonflow, we have obtained a significant positive value for $v_2\{4\}$ at high p_T in pPb
- A striking and surprising similarity in high multiplicity pPb and peripheral PbPb collisions
- These results provide new information on the interaction of high-p_T partons with the medium in small system collisions



CMS-PAS-HIN-23-002



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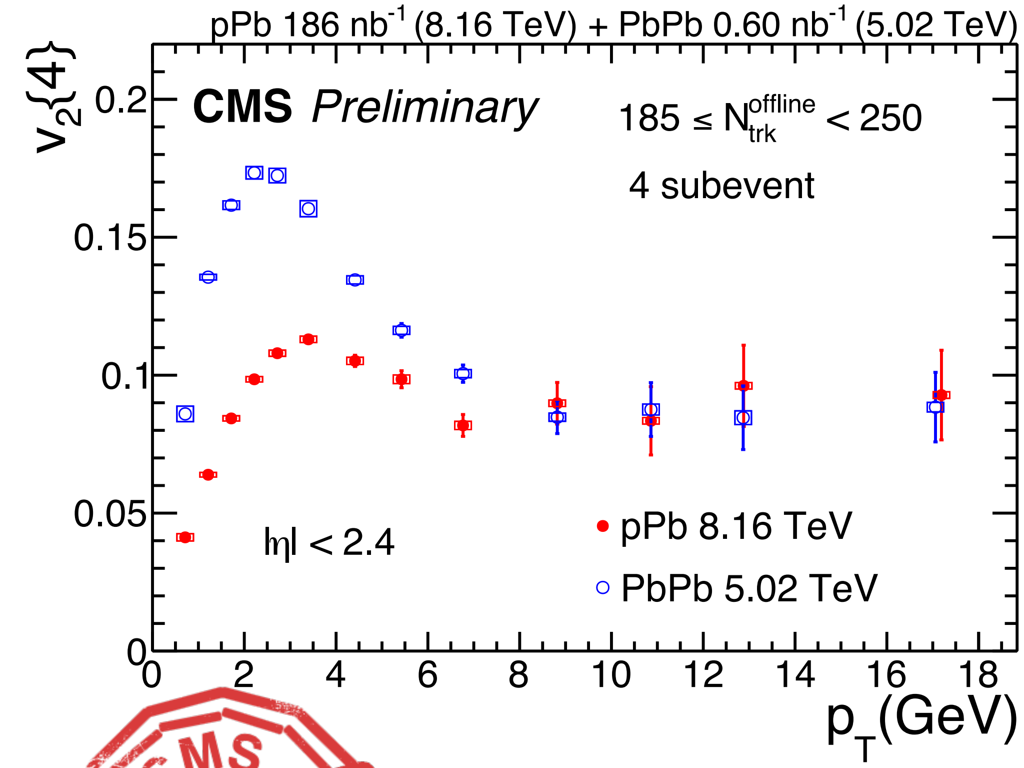
ありがとう

(Arigatō)



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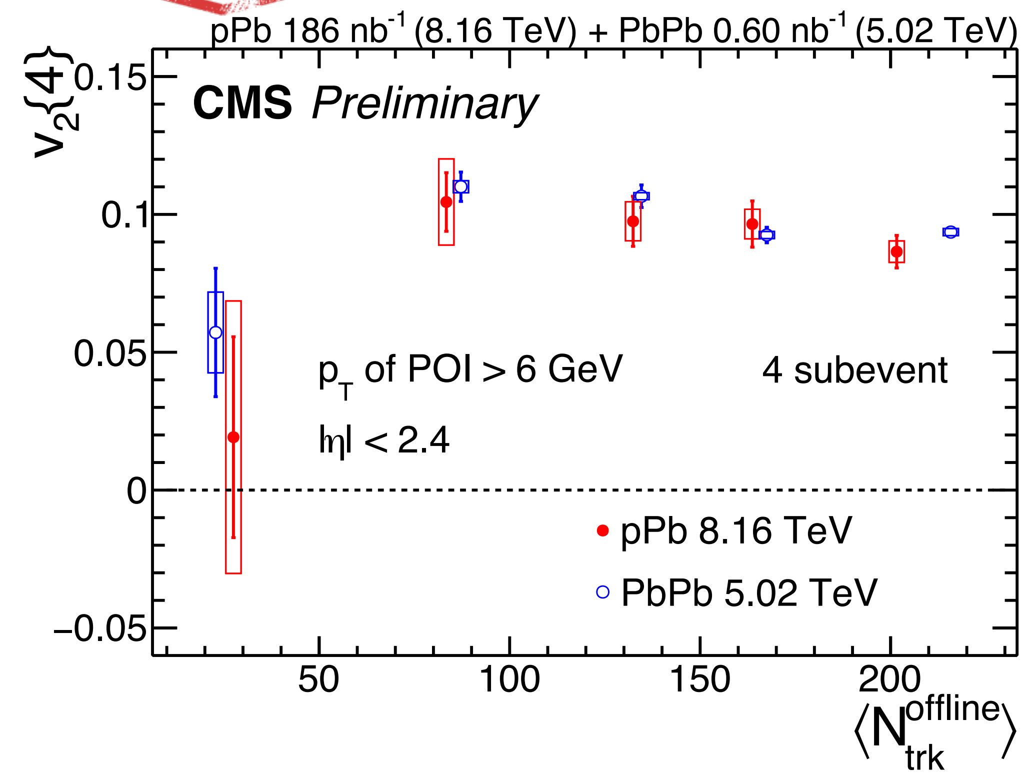
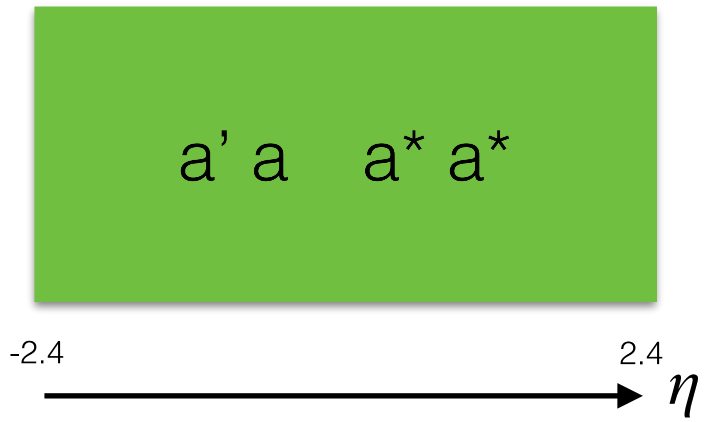


BACK-UP

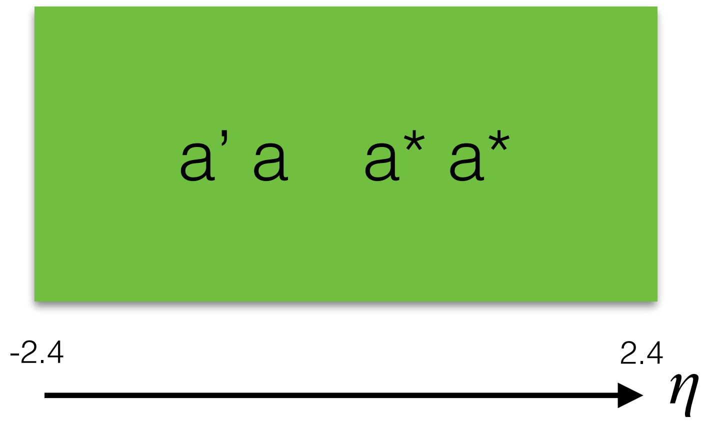
Analysis Method

- **Differential cumulant $d_2\{4\}$ calculation in standard and 2 subevent method**
  - **Standard (w/o subevent)**



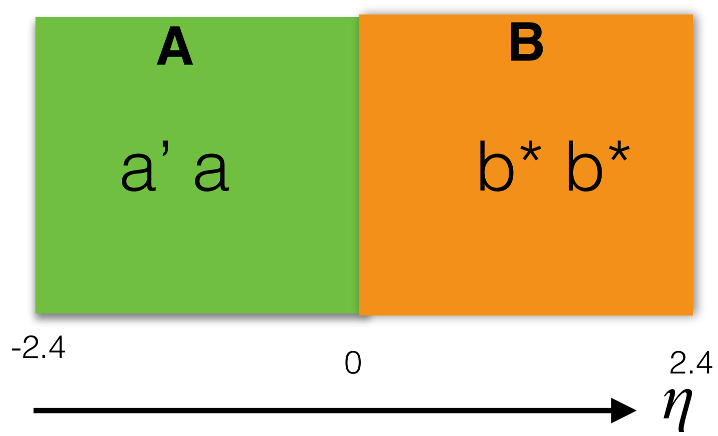
$$d_n\{4\} = \langle\langle 4' \rangle\rangle - 2\langle\langle 2' \rangle\rangle \cdot \langle\langle 2 \rangle\rangle$$

- **Differential cumulant $d_2\{4\}$ calculation in standard and 2 subevent method**
  - **Standard (w/o subevent)**

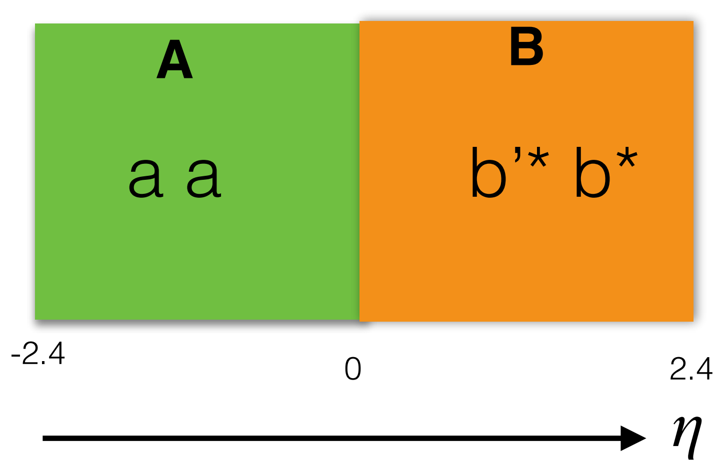


$$d_n\{4\} = \langle\langle 4' \rangle\rangle - 2\langle\langle 2' \rangle\rangle \cdot \langle\langle 2 \rangle\rangle$$

  - **2 subevent**



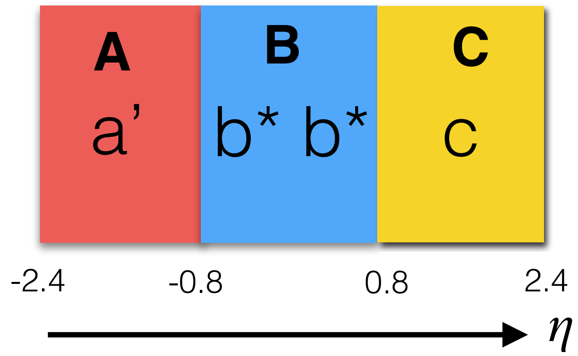
$$d_n\{4\}_{2sub} = \langle\langle 4 \rangle^{a'a|bb} \rangle - 2\langle\langle 2 \rangle^{a'|b} \rangle \cdot \langle\langle 2 \rangle^{a|b} \rangle$$



$$d_n\{4\}_{2sub} = \langle\langle 4 \rangle^{aa|b'b} \rangle - 2\langle\langle 2 \rangle^{a|b'} \rangle \cdot \langle\langle 2 \rangle^{a|b} \rangle$$

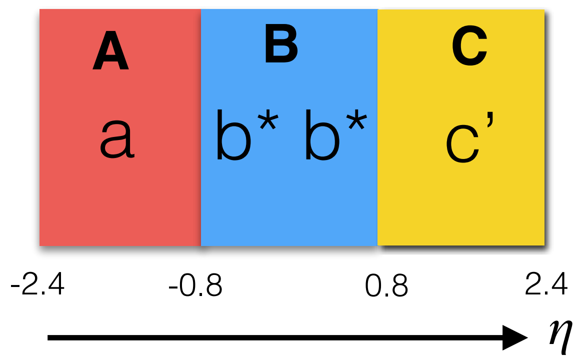
Differential cumulant $d_2\{4\}$ calculation in 3 & 4 subevent method

❖ 3 subevent



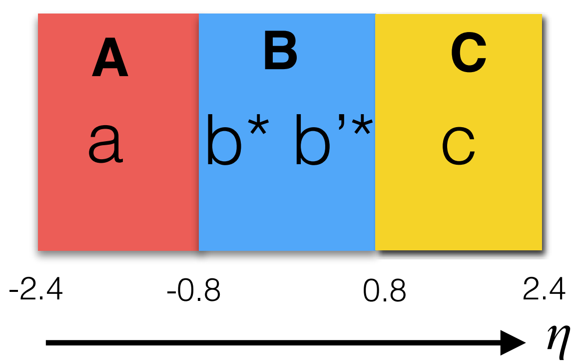
POI : (-2.4<η<0.8)

- $d_n\{4\}_{3sub} = \langle\langle 4\rangle^{a'|bb|c}\rangle - 2\langle\langle 2\rangle^{a'|b}\rangle \cdot \langle\langle 2\rangle^{b|c}\rangle$



POI : (0.8<η<2.4)

- $d_n\{4\}_{3sub} = \langle\langle 4\rangle^{a|bb|c'}\rangle - 2\langle\langle 2\rangle^{a|b}\rangle \cdot \langle\langle 2\rangle^{b|c'}\rangle$



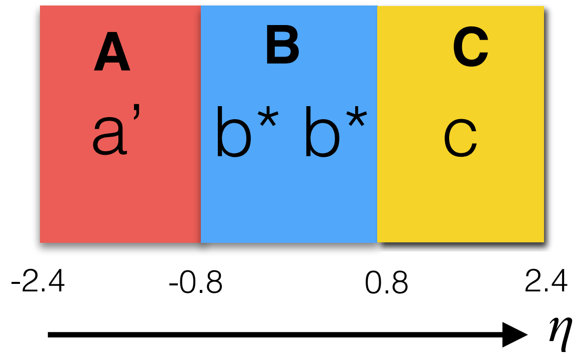
POI : (-0.8<η<0.8)

- $d_n\{4\}_{3sub} = \langle\langle 4\rangle^{a|bb'|c}\rangle - \langle\langle 2\rangle^{a|b'}\rangle \cdot \langle\langle 2\rangle^{b|c}\rangle - \langle\langle 2\rangle^{a|b}\rangle \cdot \langle\langle 2\rangle^{b'|c}\rangle$

Analysis Method

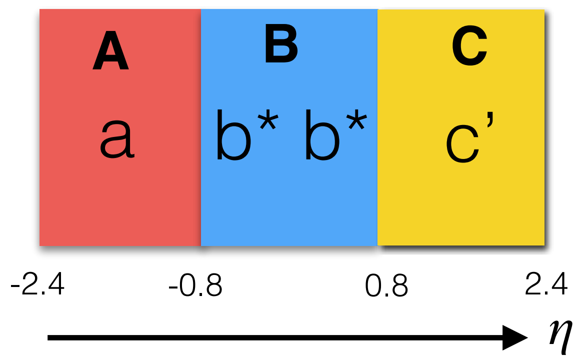
Differential cumulant $d_2\{4\}$ calculation in 3 & 4 subevent method

3 subevent



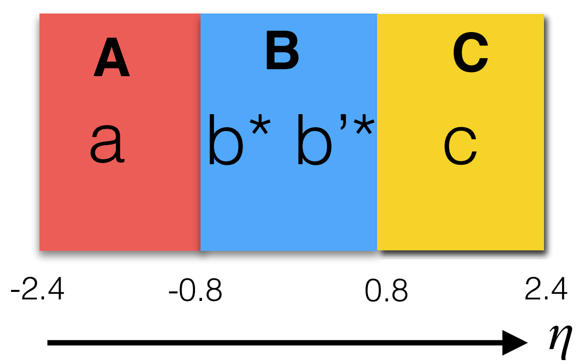
POI : (-2.4<η<0.8)

- $d_n\{4\}_{3sub} = \langle\langle 4\rangle^{a'|bb|c}\rangle - 2\langle\langle 2\rangle^{a'|b}\rangle \cdot \langle\langle 2\rangle^{b|c}\rangle$



POI : (0.8<η<2.4)

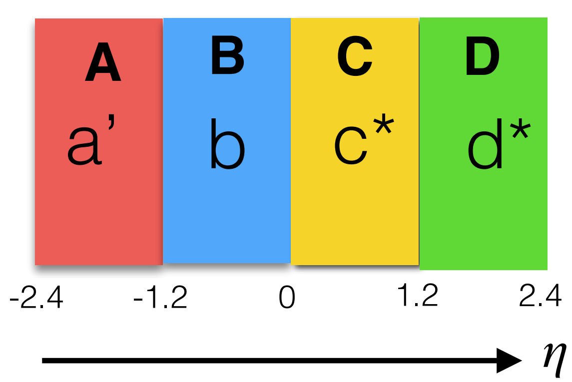
- $d_n\{4\}_{3sub} = \langle\langle 4\rangle^{a|bb|c'}\rangle - 2\langle\langle 2\rangle^{a|b}\rangle \cdot \langle\langle 2\rangle^{b|c'}\rangle$



POI : (-0.8<η<0.8)

- $d_n\{4\}_{3sub} = \langle\langle 4\rangle^{a|bb'|c}\rangle - \langle\langle 2\rangle^{a|b'}\rangle \cdot \langle\langle 2\rangle^{b|c}\rangle - \langle\langle 2\rangle^{a|b}\rangle \cdot \langle\langle 2\rangle^{b'|c}\rangle$

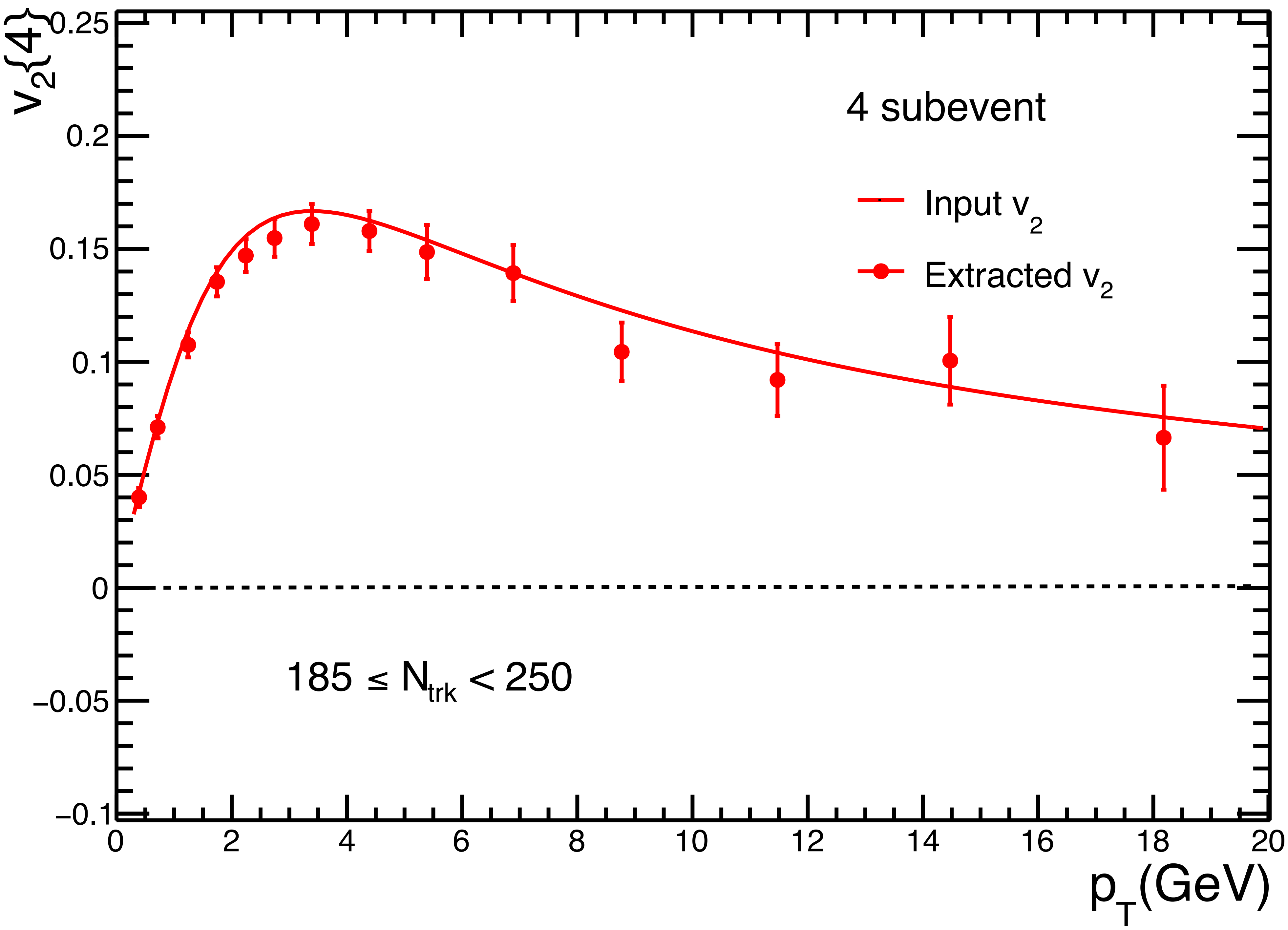
4 subevent



$$d_n\{4\}_{4sub} = \langle\langle 4\rangle^{a'|b|c|d}\rangle - \langle\langle 2\rangle^{a'|c}\rangle \cdot \langle\langle 2\rangle^{b|d}\rangle - \langle\langle 2\rangle^{a'|d}\rangle \cdot \langle\langle 2\rangle^{b|c}\rangle$$

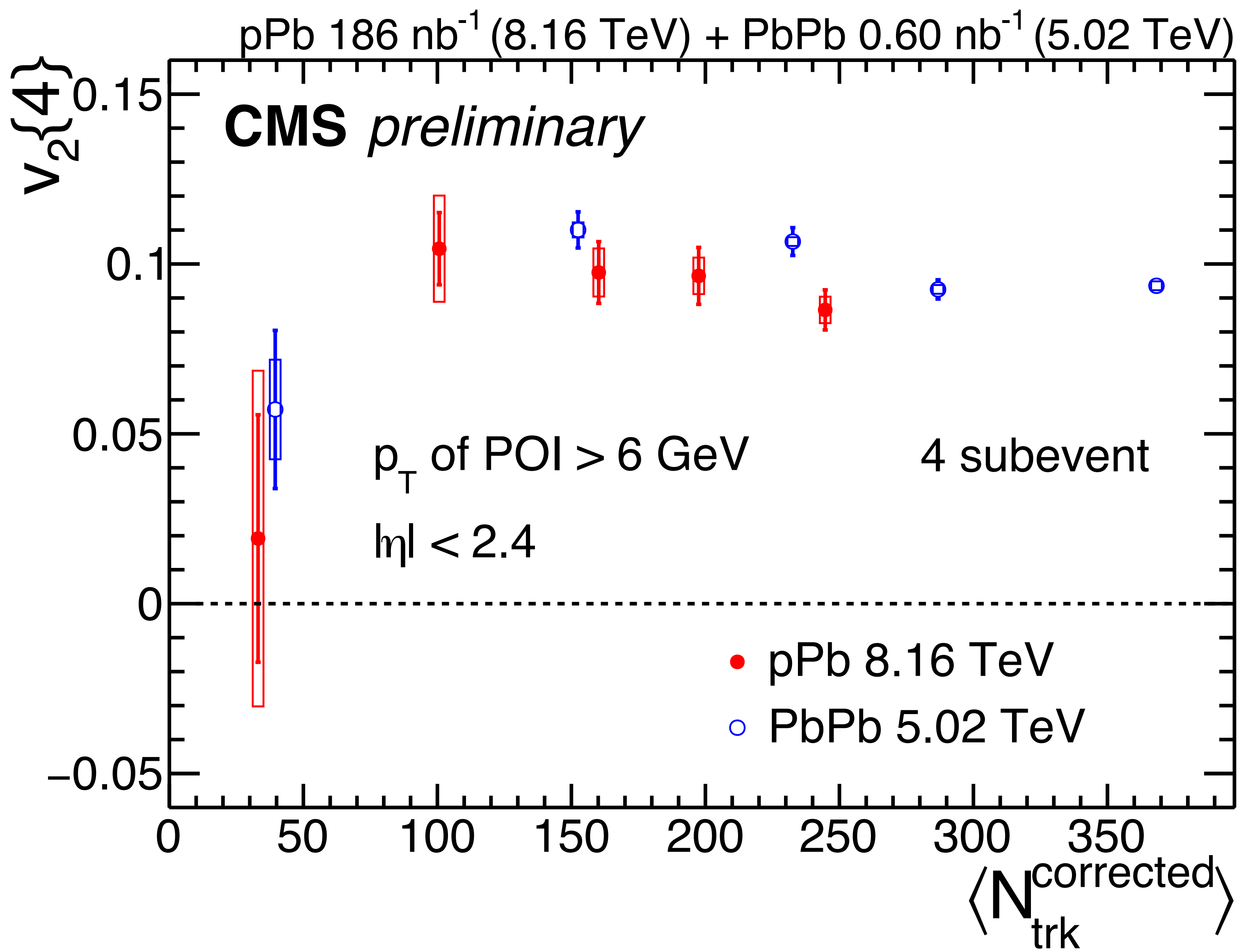
Cross-check

- $v_2\{4\}$ **with toy model simulation**



- **Able to extract almost all input v2 with 4 subevent**

- $v_2\{4\}$ **in different** $N_{trk}^{corrected}$ **bins with POI** $p_T > 6$ **GeV**



	pPb		PbPb	
$N_{trk}^{offline}$ range	$\langle N_{trk}^{offline}\rangle$	$\langle N_{trk}^{corrected}\rangle$	$\langle N_{trk}^{offline}\rangle$	$\langle N_{trk}^{corrected}\rangle$
$(0, 60)$	27	33 ± 1	23	39 ± 2
$[60, 120)$	83	101 ± 4	87	152 ± 6
$[120, 150)$	132	160 ± 6	135	233 ± 10
$[150, 185)$	164	198 ± 7	168	287 ± 12
$[185, 250)$	202	245 ± 10	216	368 ± 16