

Strange Hadron Collectivity in pPb and PbPb Collisions



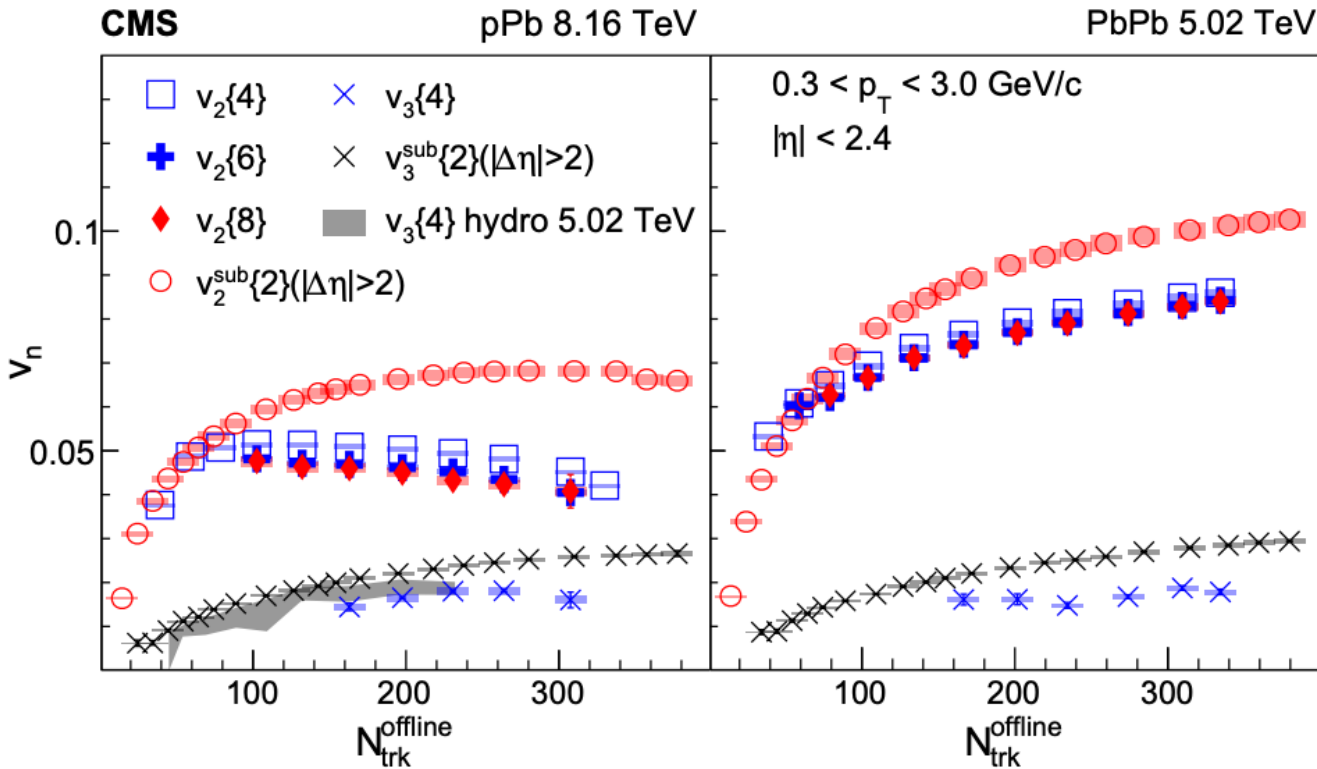
Quan Wang
(Univ. of Kansas)



for the CMS Collaboration

April 7th, 2022

Collectivity in Small/Large System



PRC **101**, (2020) 014912

Long-range:

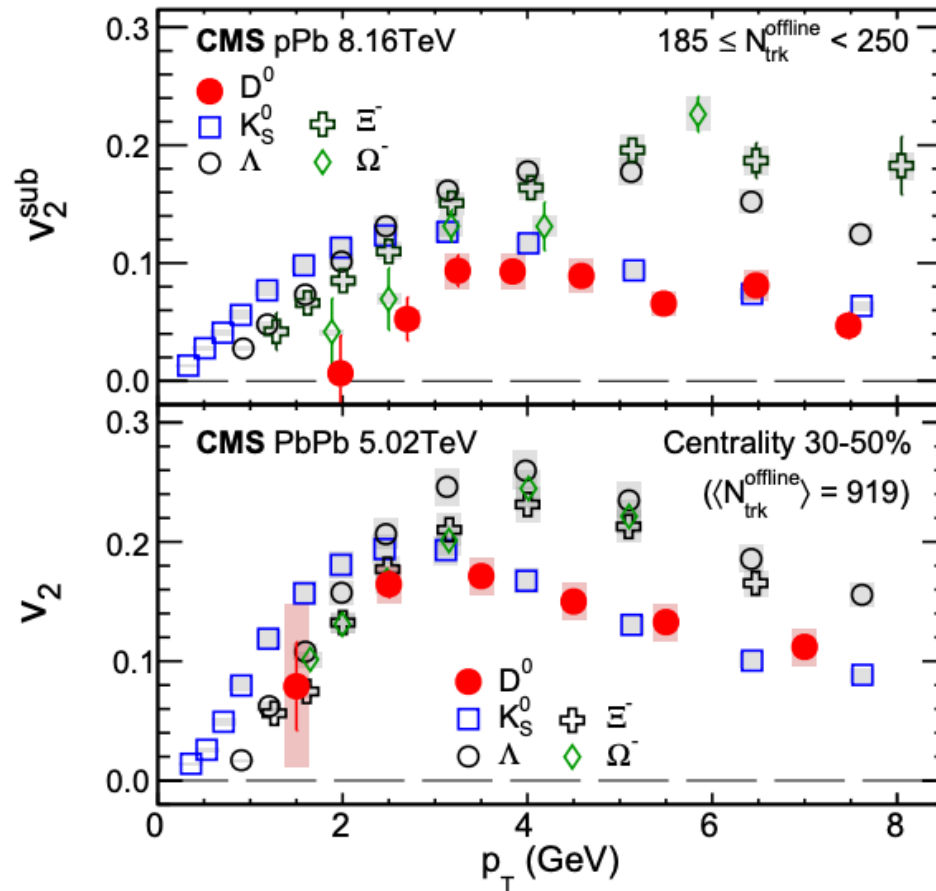
2-particle with η-gap

Collectivity:

multi-particle correlation

➤ **Charge hadron long-range correlations and collectivity in small (pPb) and large (PbPb) systems**

Long-range Correlations



PRL **121**, (2018) 082301

Long-range:

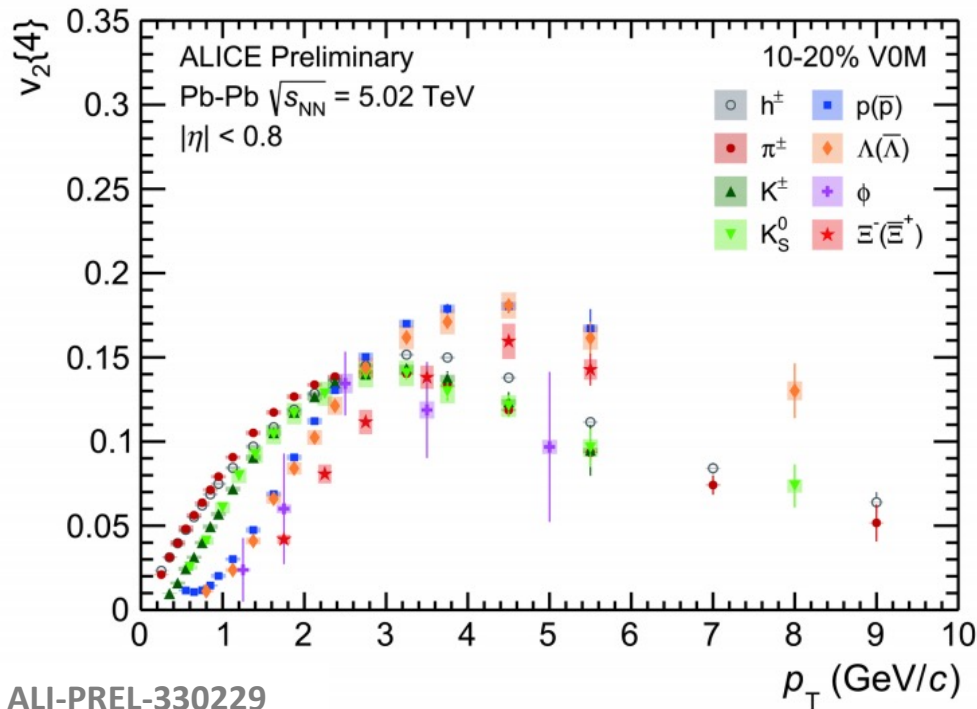
2-particle with η -gap

Collectivity:

multi-particle correlation

➤ **Strange** hadron long-range correlations in small and large systems

Strange Hadron Collectivity



Long-range:

2-particle with η -gap

Collectivity:

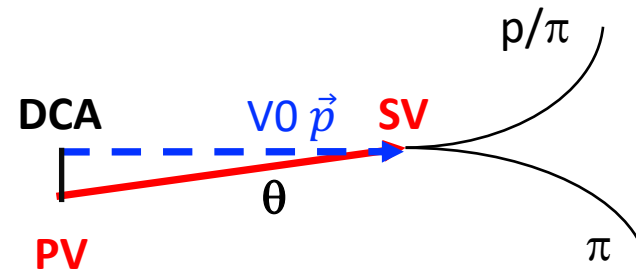
multi-particle correlation

- **Strange** hadron collectivity in large system (PbPb)
- What about **strange** hadron collectivity in small system (pPb)?
- Full picture of strangeness flow and its fluctuations

V0 in PbPb/pPb at CMS

$$K_S^0 \rightarrow \pi^+ + \pi^-$$

$$\Lambda \rightarrow p + \pi$$

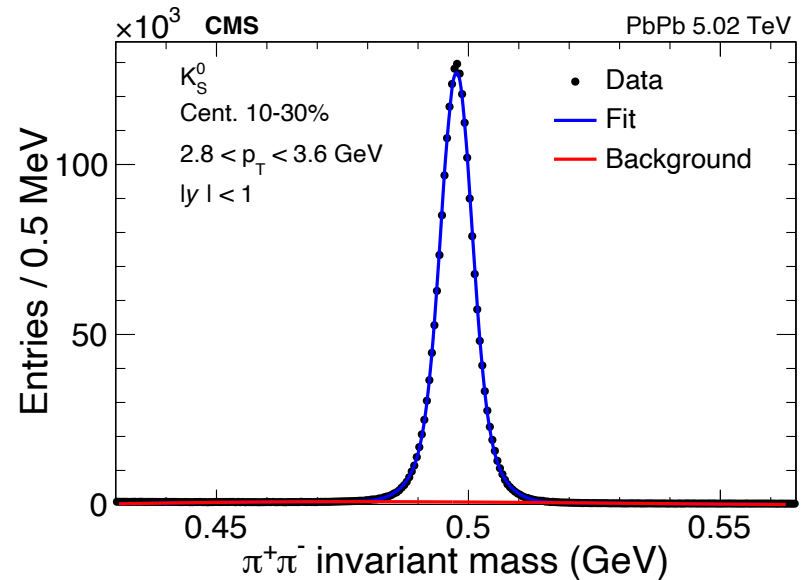


2016 pPb @ 8.16 TeV:

- High Multiplicity $N_{\text{trk}}^{\text{offline}} > 120$
- 862M events
- **Cut** based selection

2018 PbPb @ 5.02 TeV:

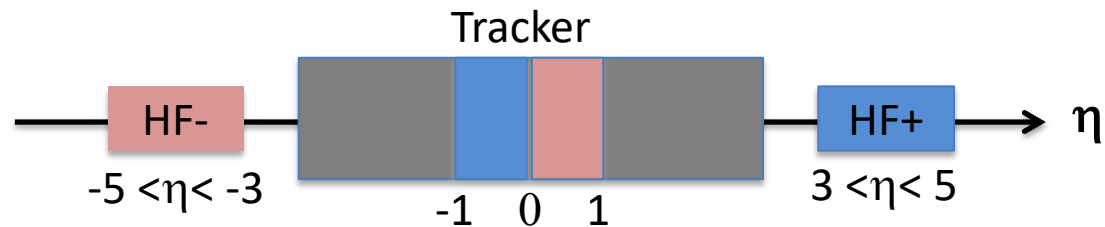
- Minimum Bias
- 4.27B events
- **BDT MVA** selection



Methods

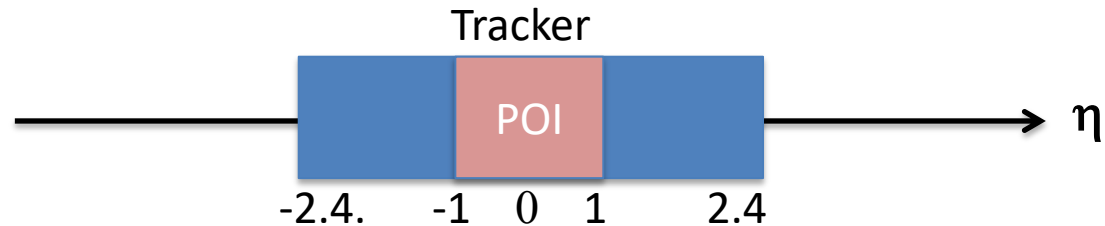
➤ Scalar-product $v_2\{SP\}$

☐ POI wrt HF ($\Delta\eta > 3$)



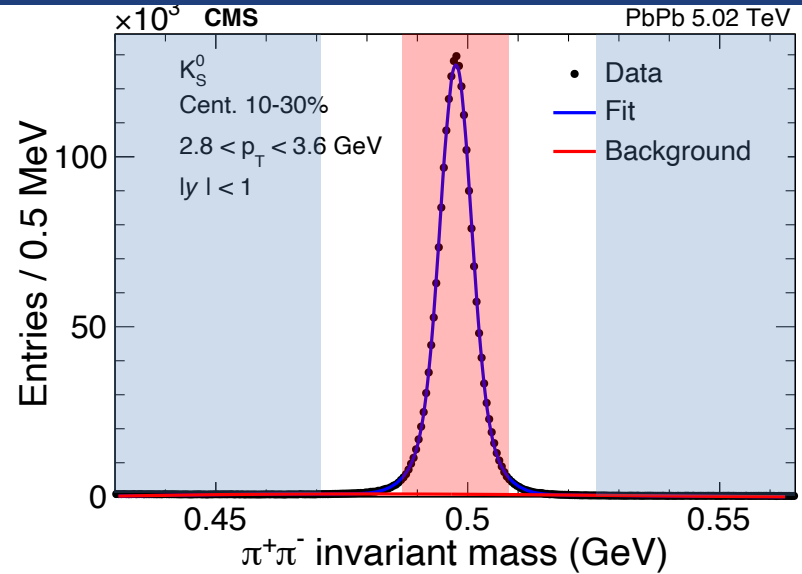
➤ Multiparticle cumulant $v_2\{4,6,8\}$

☐ Q-cumulant



Strange Particle v_2^{sig}

- Peak region v_2^{obs}
- Sideband region v_2^{bkg}



$$F_{sig} = \frac{sig}{sig + bkg}$$

Sideband background
<-3 σ

Peak region
 $\pm 2\sigma$

Sideband background
>3 σ

$$v_2^{obs} = F_{sig} v_2^{sig} + (1 - F_{sig}) v_2^{bkg}$$

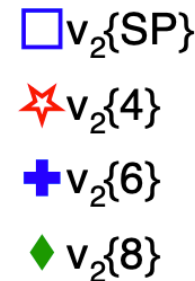
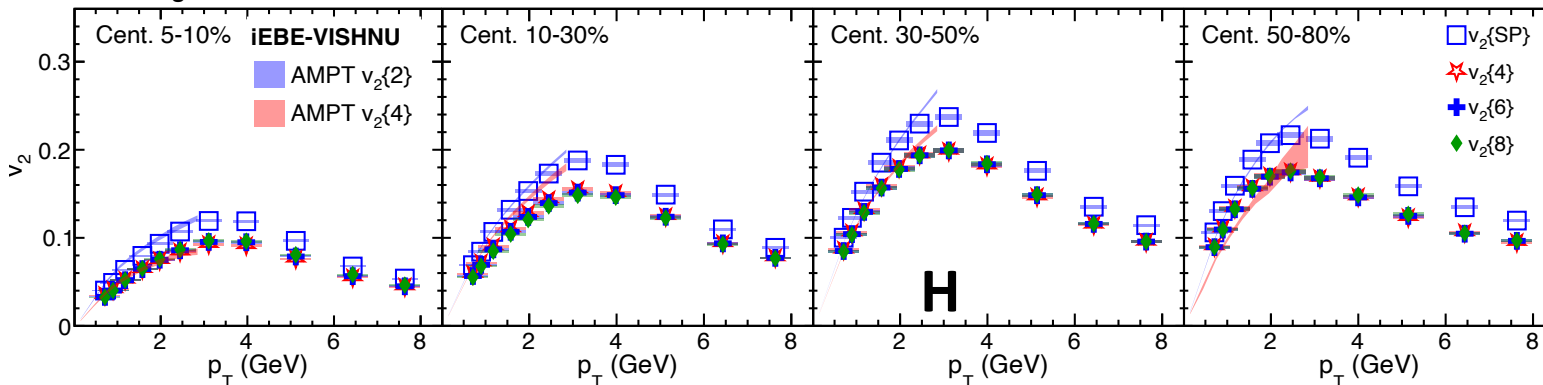
$$v_2^{sig} = (v_2^{obs} - (1 - F_{sig}) v_2^{bkg}) / F_{sig}$$

Charge Hadron v_2 in PbPb

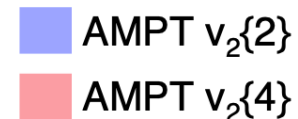


CMS Charged hadron

PbPb 5.02 TeV



iEBE-VISHNU



➤ $v_2\{SP\} > v_2\{4\} \approx v_2\{6\} \approx v_2\{8\}$

➤ Compared to Hydrodynamic calculations with AMPT IC [EPJC **77** (2017) 645]

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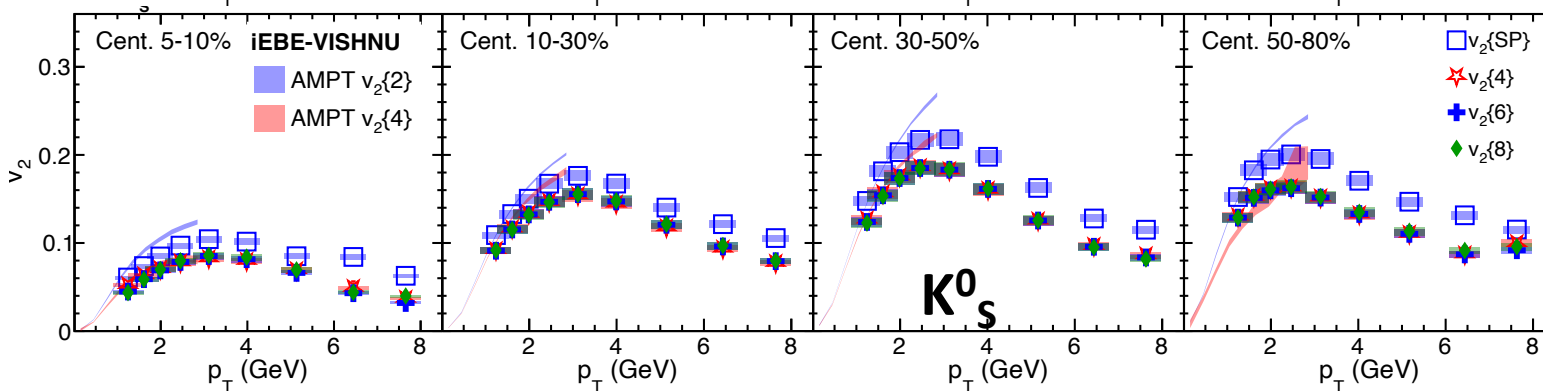
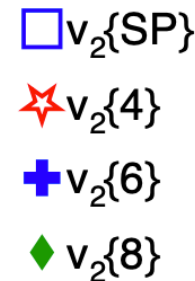
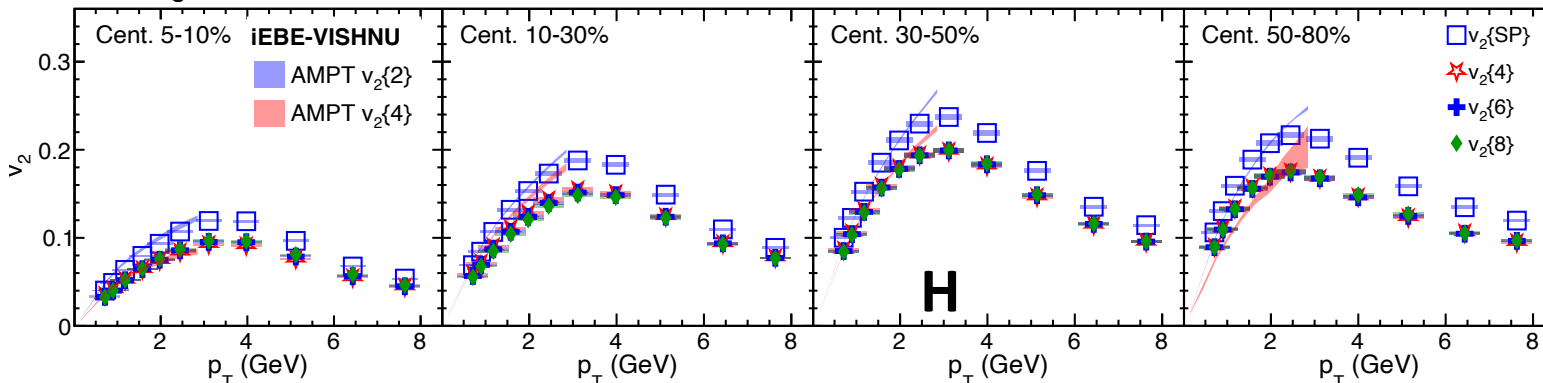


Strange Hadron v_2 in PbPb

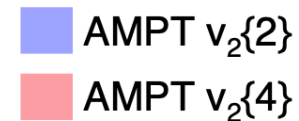


CMS Charged hadron

PbPb 5.02 TeV



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Strange Hadron v_2 in PbPb



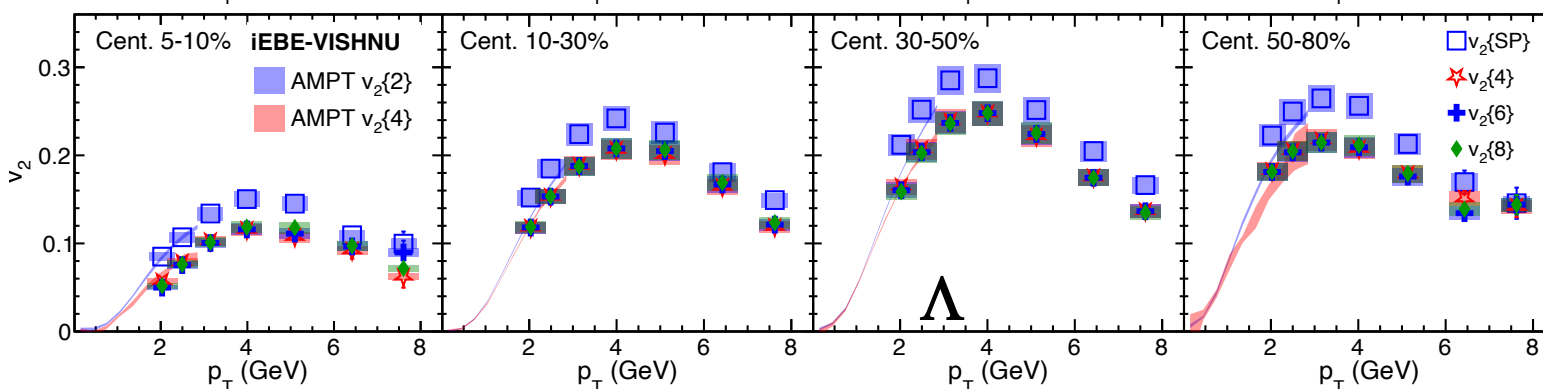
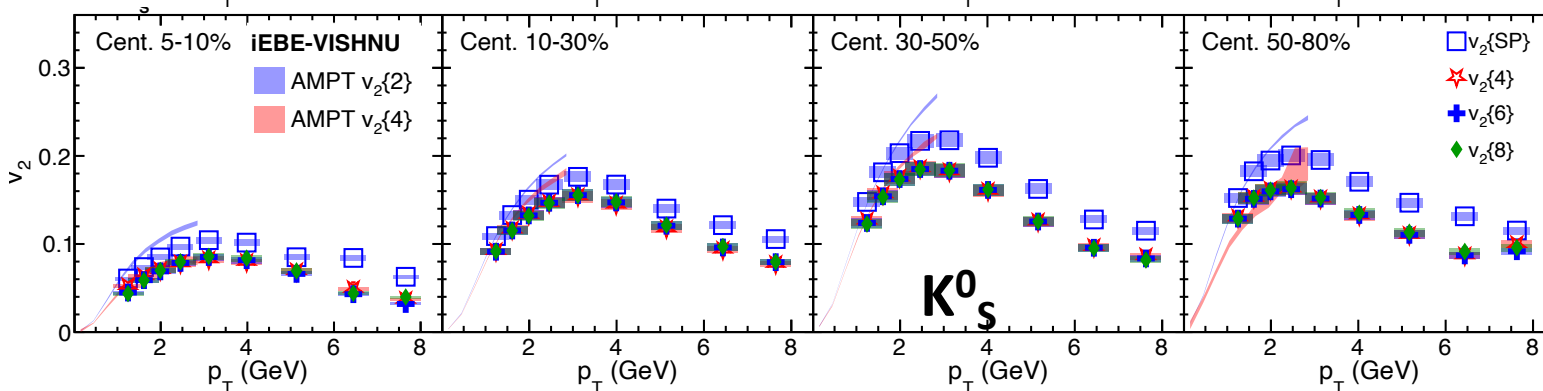
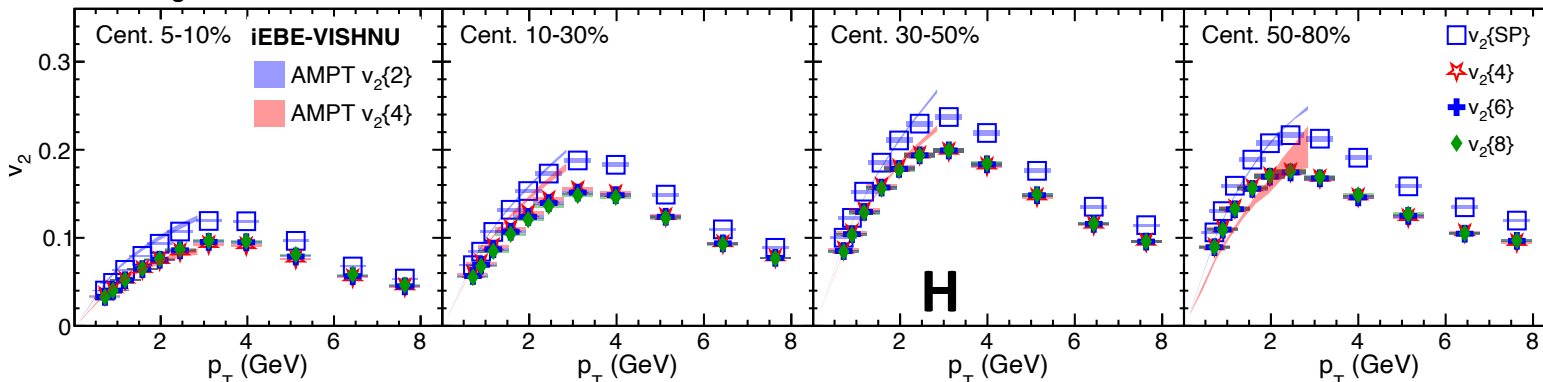
CMS Charged hadron

PbPb 5.02 TeV

- $v_2\{SP\}$
- ★ $v_2\{4\}$
- + $v_2\{6\}$
- ◆ $v_2\{8\}$

iEBE-VISHNU

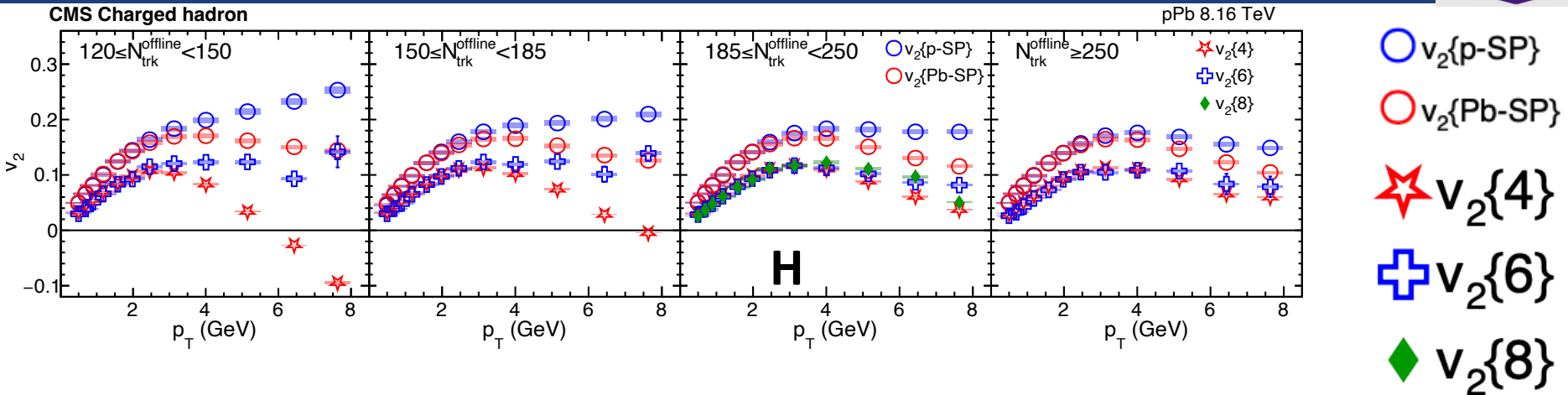
- AMPT $v_2\{2\}$
- AMPT $v_2\{4\}$



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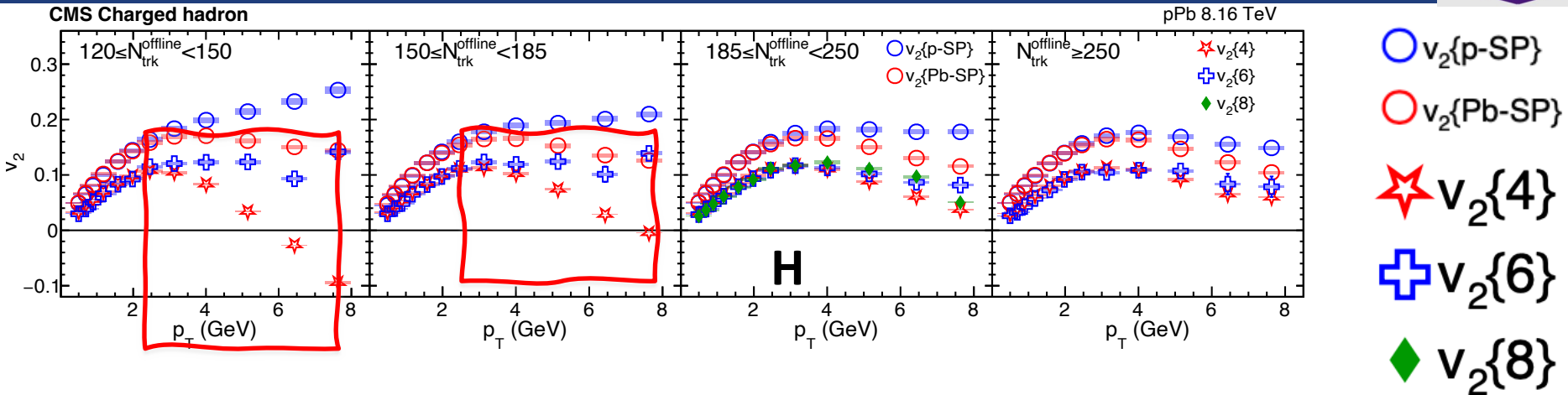


Charge Hadron v_2 in pPb



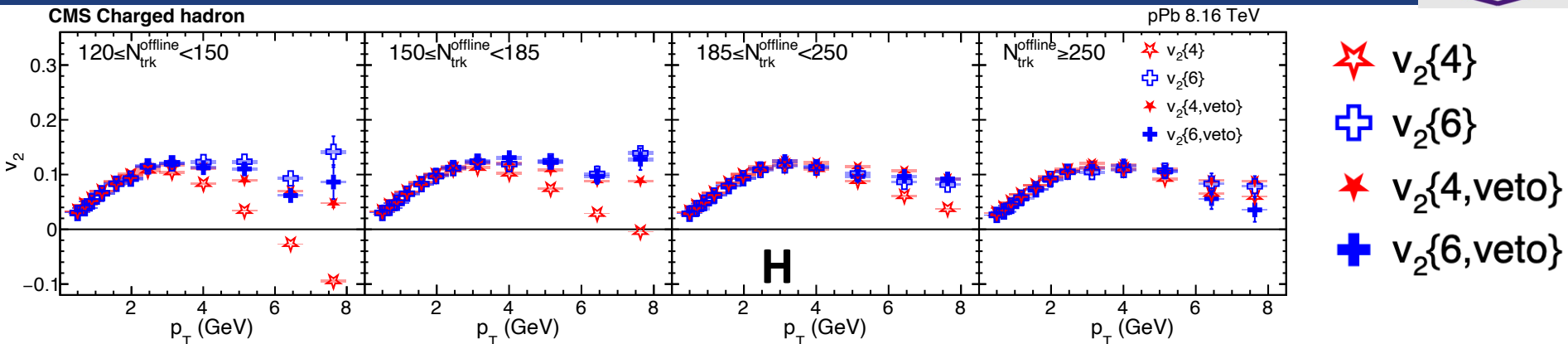
- $v_2\{SP\}$ with respect to p- and Pb-going EP
- $v_2\{SP\} > v_2\{4,6,8\}$

Charge Hadron v_2 in pPb



- $v_2\{SP\}$ with respect to p- and Pb-going EP
- $v_2\{SP\} > v_2\{4,6,8\}$
- **$v_2\{4\} < v_2\{6\}$!!** Large jet-related nonflow in low $N_{trk}^{offline}$
- To remove nonflow, jet veto method
- **Reject** events with at least one jet $p_T > 20\text{GeV}$

Jet-related nonflow in pPb



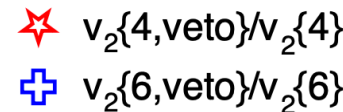
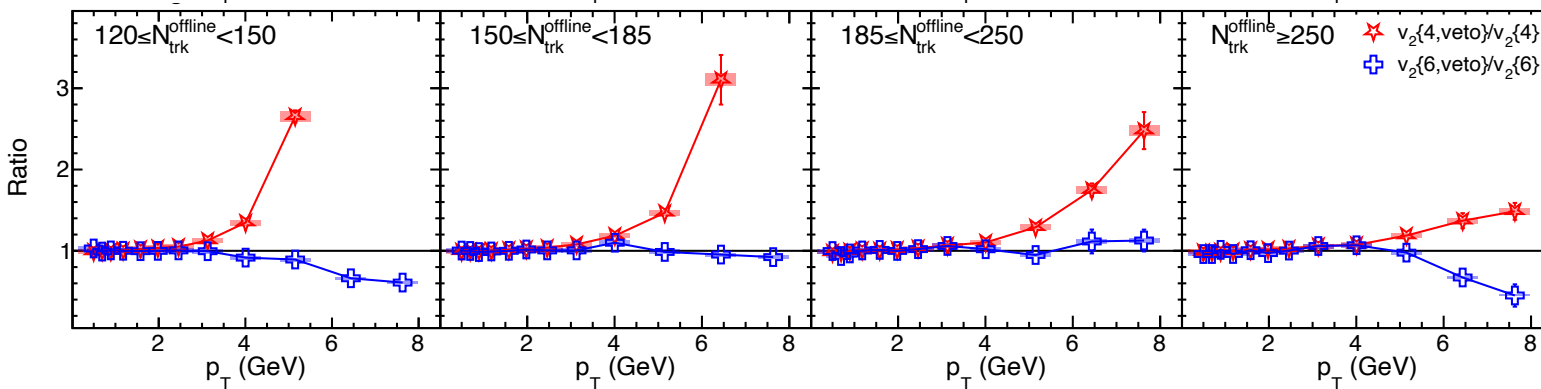
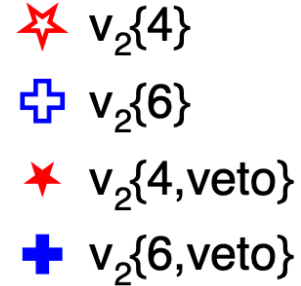
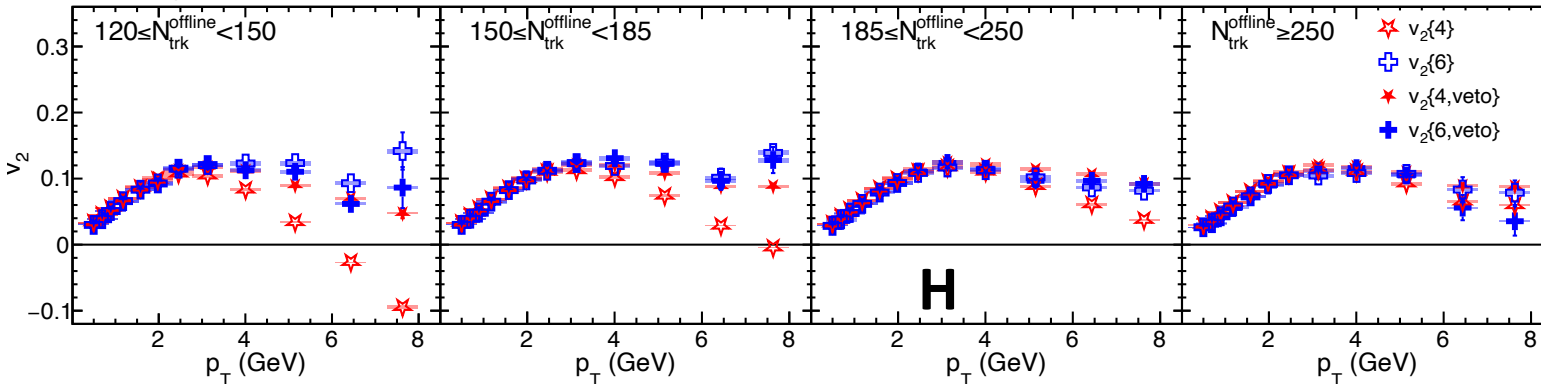
➤ $v_2\{4,veto\} > v_2\{4\}$, $v_2\{4,veto\} \approx v_2\{6,veto\} \approx v_2\{6\}$

Jet-related nonflow in pPb



CMS Charged hadron

pPb 8.16 TeV



- $v_2\{4,veto\} > v_2\{4\}$, $v_2\{4,veto\} \approx v_2\{6,veto\} \approx v_2\{6\}$
- Larger nonflow effect in low $N_{trk}^{Offline}$, high p_T

CMS-HIN-19-004

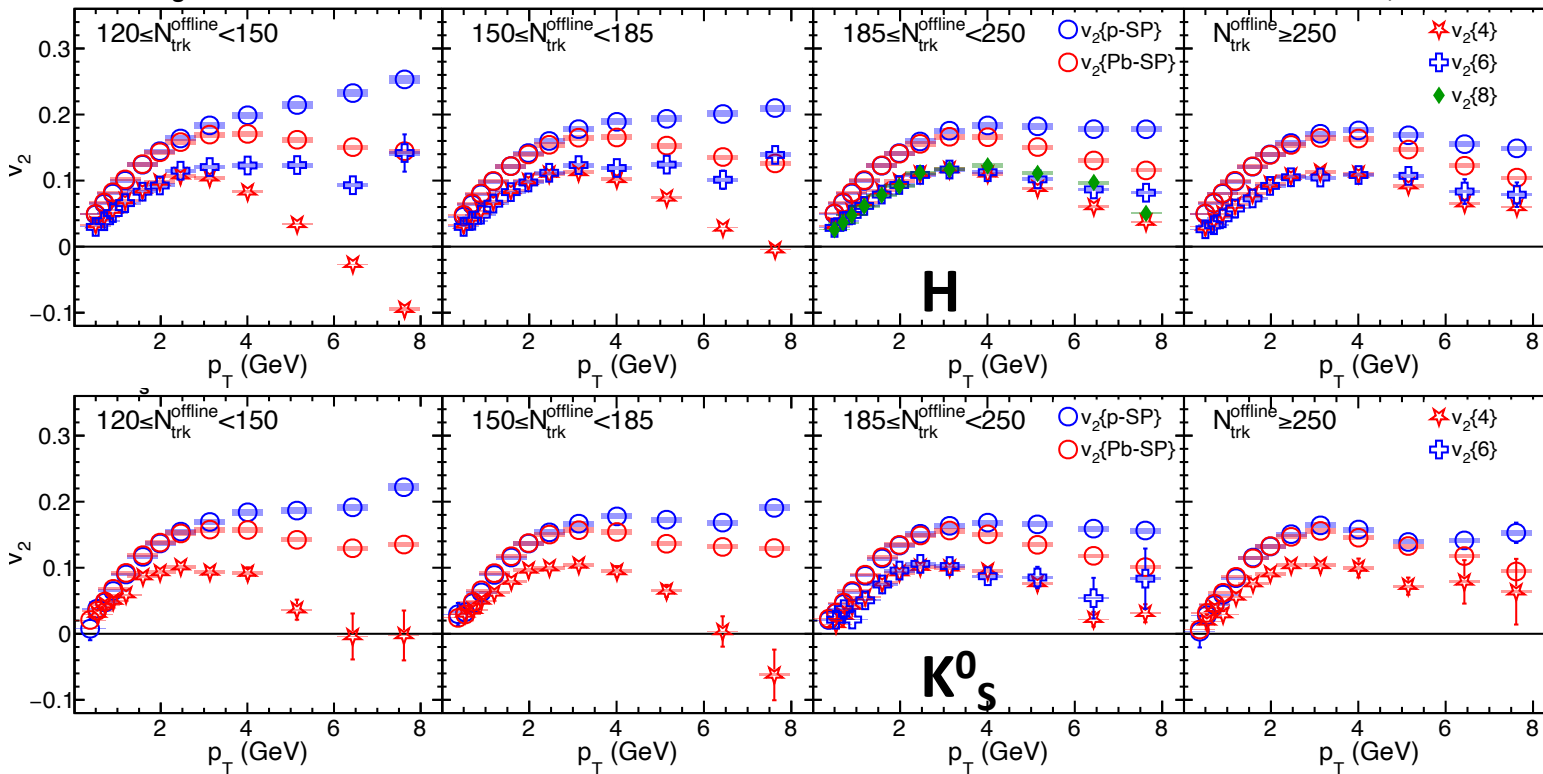


Strange Hadron v_2 in pPb



CMS Charged hadron

pPb 8.16 TeV



- $v_2\{p\text{-SP}\}$
- $v_2\{\text{Pb-SP}\}$
- ★ $v_2\{4\}$
- + $v_2\{6\}$
- ◆ $v_2\{8\}$

CMS-HIN-19-004



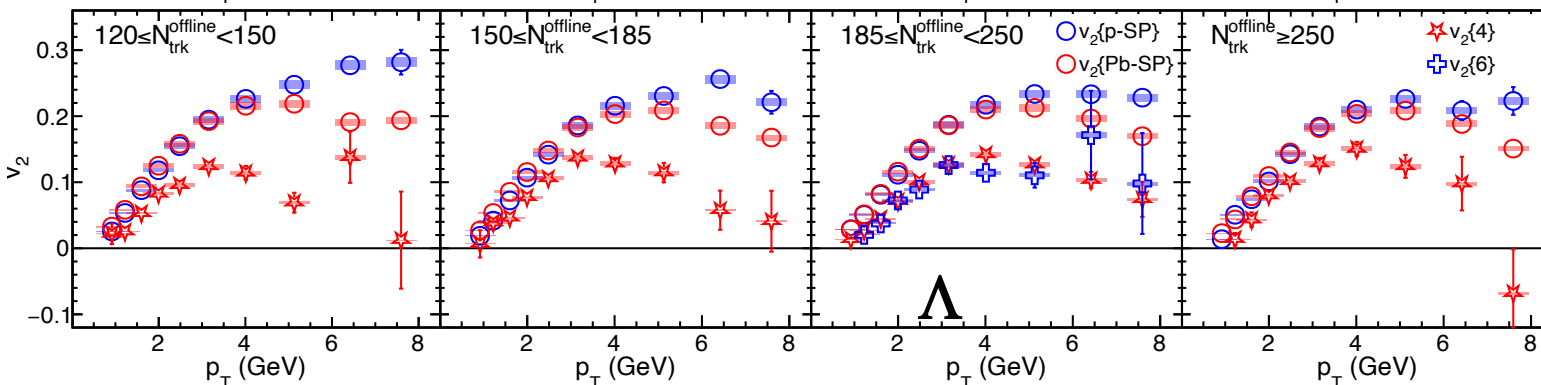
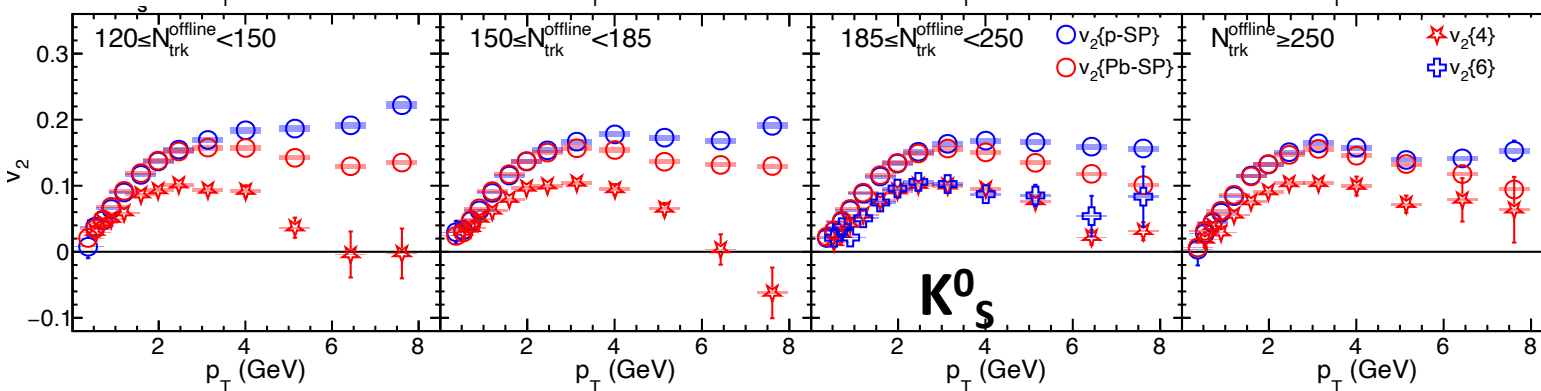
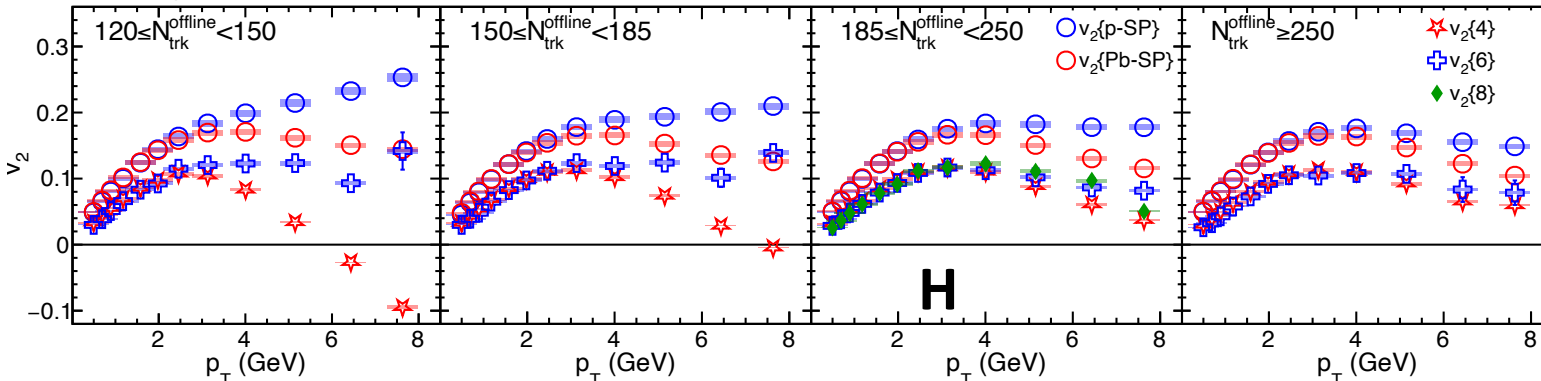
Strange Hadron v_2 in pPb



CMS Charged hadron

pPb 8.16 TeV

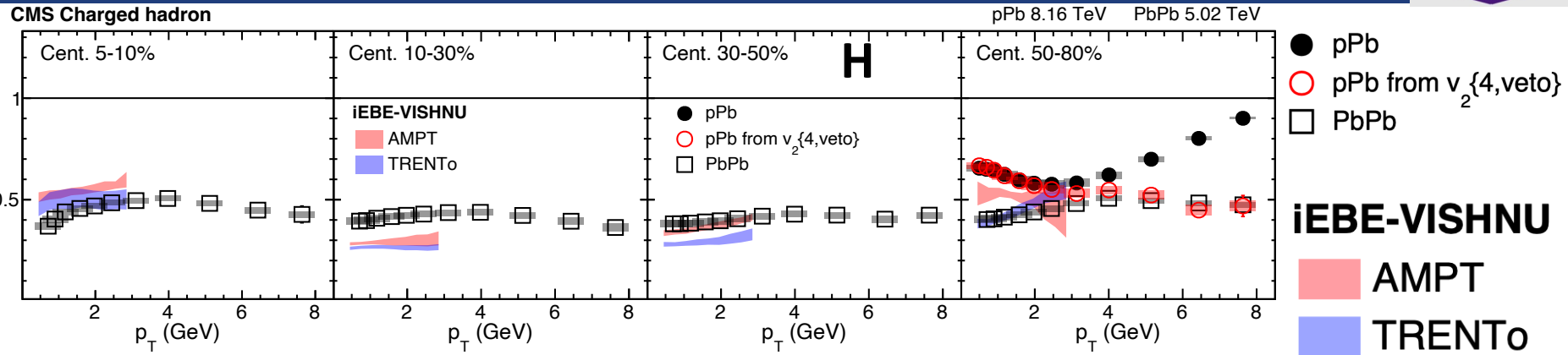
- $v_2\{p\text{-SP}\}$
- $v_2\{\text{Pb-SP}\}$
- ★ $v_2\{4\}$
- + $v_2\{6\}$
- ◆ $v_2\{8\}$



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Flow Fluctuations



- Flow σ reflects IS geometry fluctuations

$$v_2\{\text{SP}\}^2 = \langle v_2 \rangle^2 + \sigma^2$$

$$v_2\{4\}^2 \approx \langle v_2 \rangle^2 - \sigma^2$$

$$\Rightarrow \frac{\sigma}{\langle v_2 \rangle} = \sqrt{\frac{v_2\{\text{SP}\}^2 - v_2\{4\}^2}{v_2\{\text{SP}\}^2 + v_2\{4\}^2}}$$

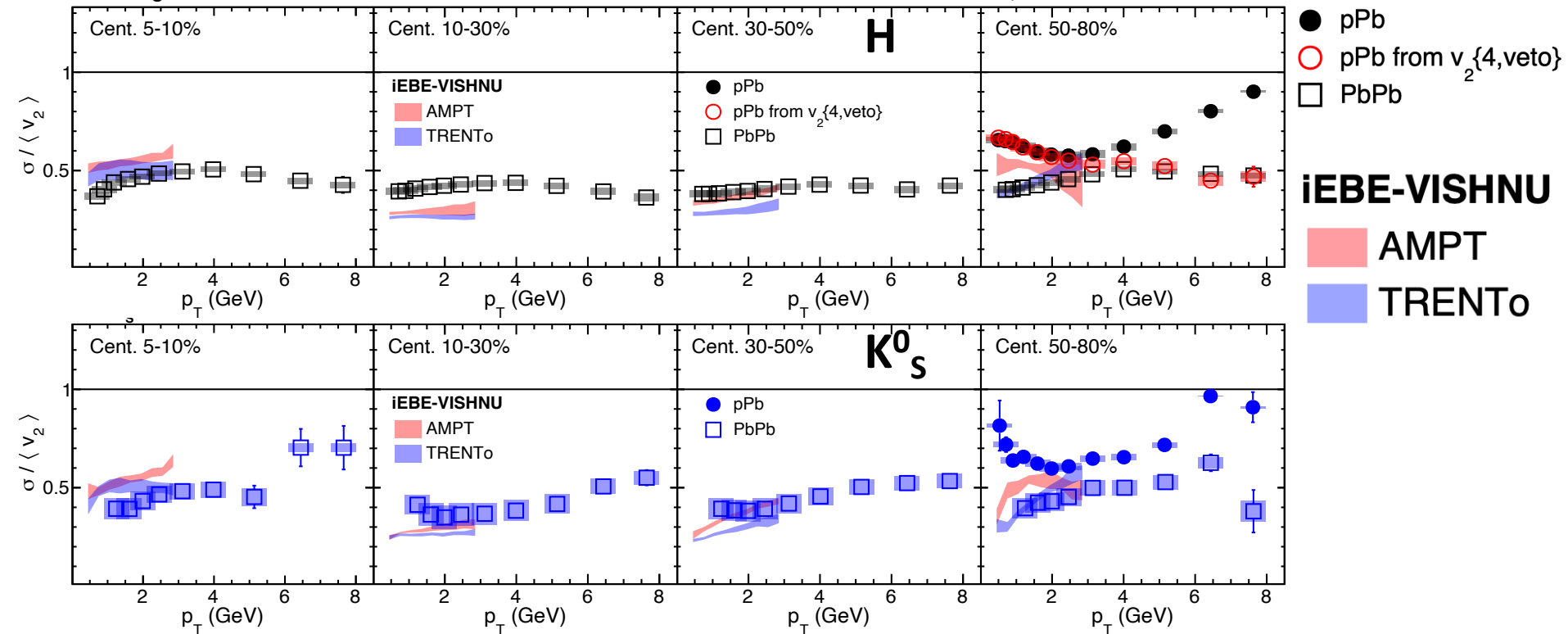
- Relatively flat over p_T
- Compared to Hydrodynamic calculations
- Much larger fluctuations in pPb low p_T

Flow Fluctuations



CMS Charged hadron

pPb 8.16 TeV PbPb 5.02 TeV



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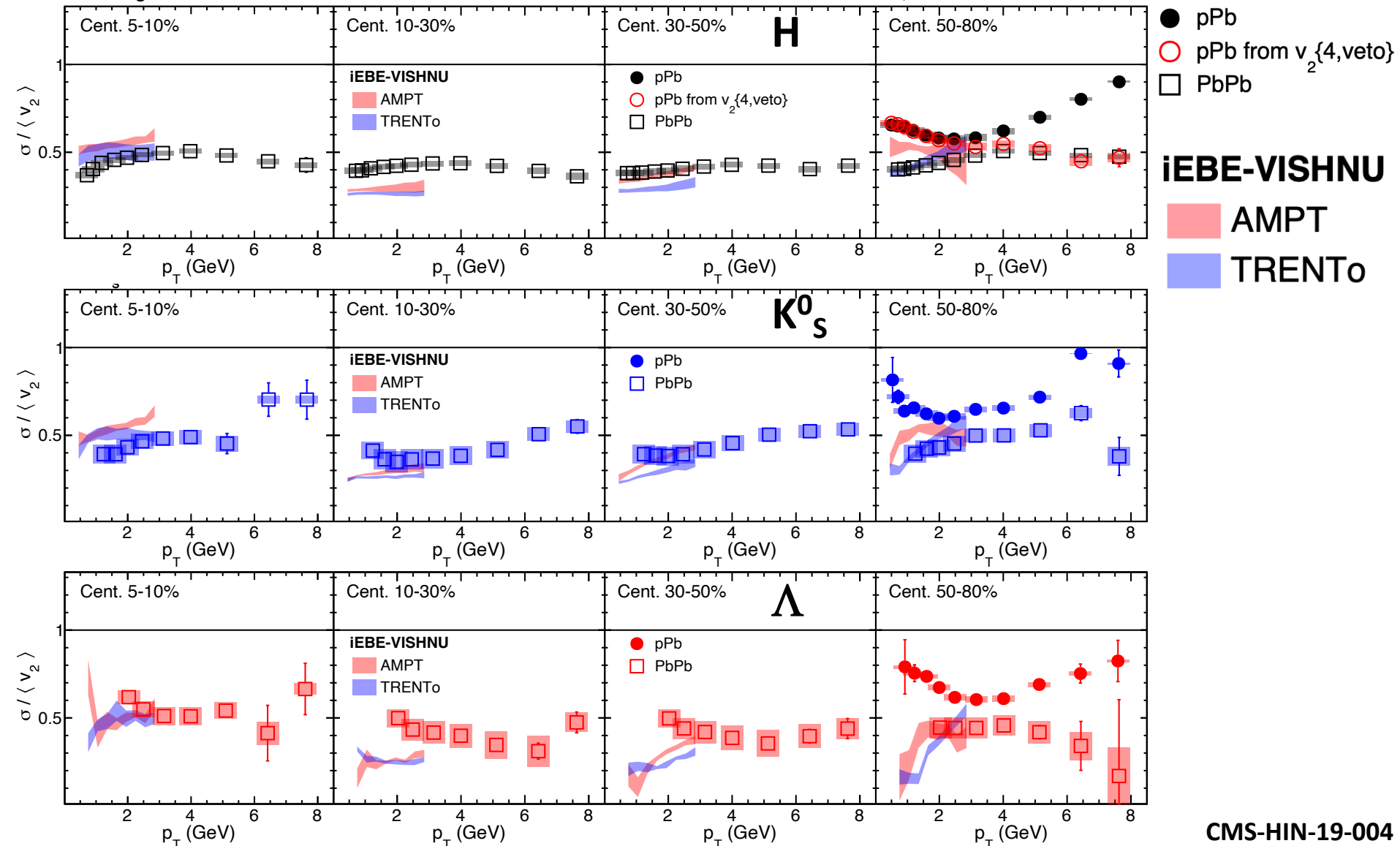


Flow Fluctuations



CMS Charged hadron

pPb 8.16 TeV PbPb 5.02 TeV



CMS-HIN-19-004

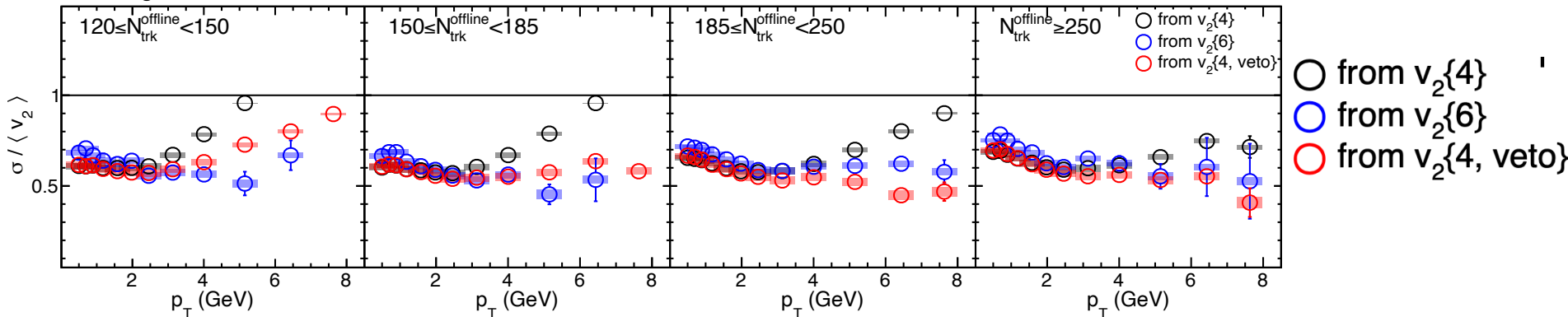


Nonflow on Flow Fluctuations



CMS Charged hadron

pPb 8.16 TeV



➤ Use $v_2\{6\}$ to suppress nonflow

➤ Use **veto jet** method to suppress jet-related nonflow

➤ Fluctuations

❑ High p_T , similar to PbPb

❑ Low p_T , greater than PbPb

$$\frac{\sigma}{\langle v_2 \rangle} = \sqrt{\frac{v_2\{SP\}^2 - v_2\{4\}^2}{v_2\{SP\}^2 + v_2\{4\}^2}}$$

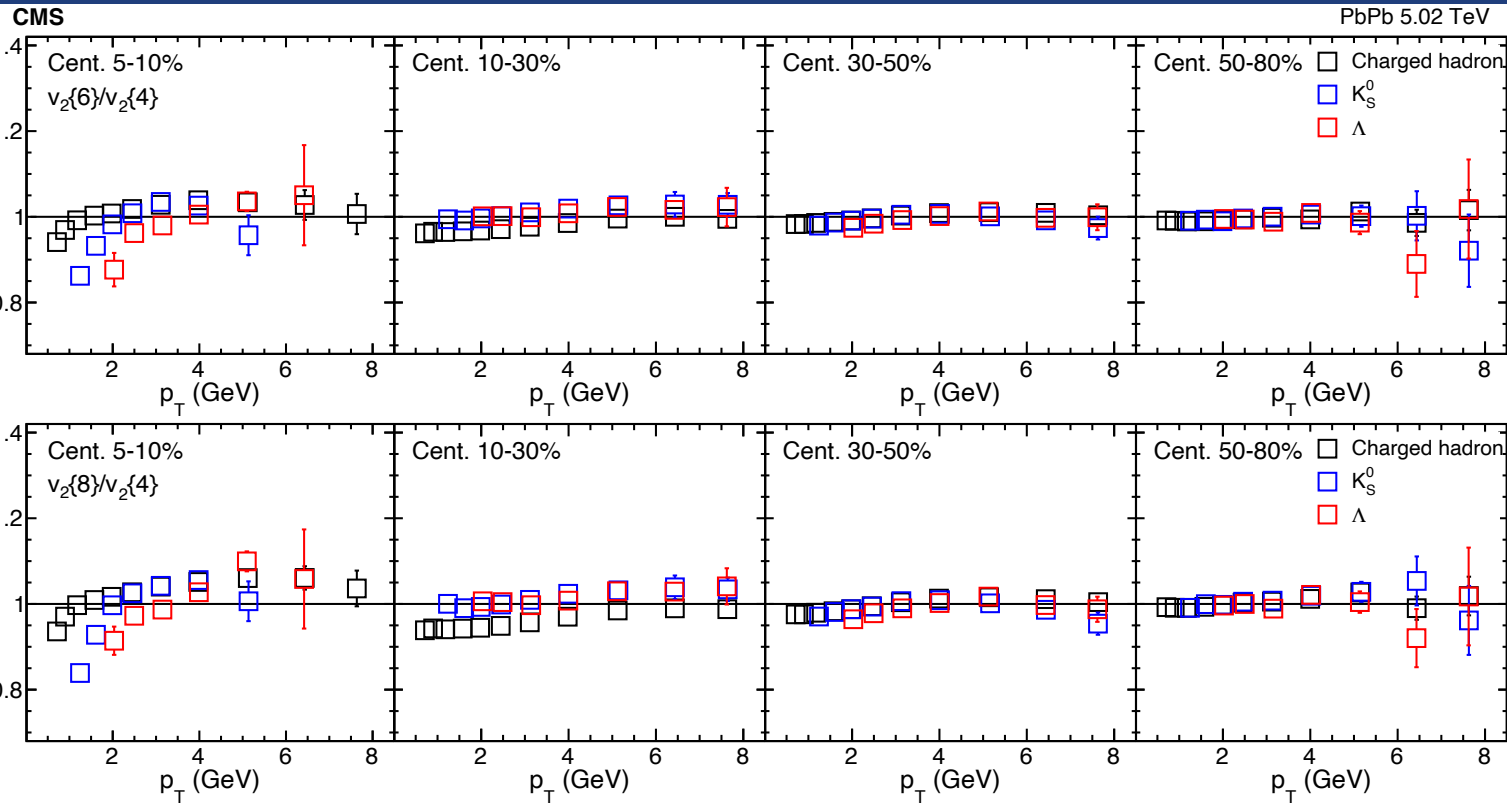
$$\frac{\sigma}{\langle v_2 \rangle} = \sqrt{\frac{v_2\{SP\}^2 - v_2\{6\}^2}{v_2\{SP\}^2 + v_2\{6\}^2}}$$

$$\frac{\sigma}{\langle v_2 \rangle} = \sqrt{\frac{v_2\{SP\}^2 - v_2\{4, \text{veto}\}^2}{v_2\{SP\}^2 + v_2\{4, \text{veto}\}^2}}$$

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Non-Gaussian Flow Fluctuations



$v_2\{6\}/v_2\{4\}$

$v_2\{8\}/v_2\{4\}$

- Deviation of $v_2\{6\}/v_2\{4\}$ and $v_2\{8\}/v_2\{4\}$ from unity suggests non-Gaussian fluctuation
- Large deviation in central PbPb, some PID dependence

Summary

- For the first time, high order cumulant of strange hadron v_2 measured, showing collectivity in pPb and compared to PbPb
- Direct comparison to Hydro model calculation
- Jet-veto shown significant effect on pPb $v_2\{4\}$
- Flow fluctuations compared between pPb and PbPb systems, no PID dependence observed

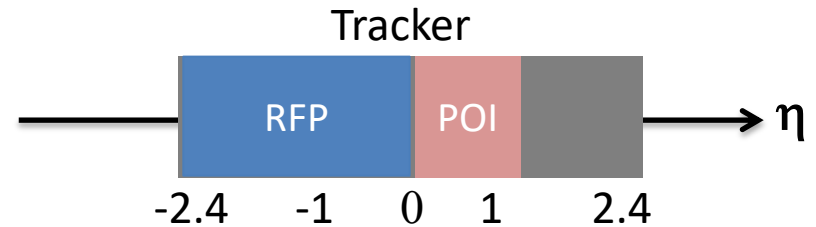
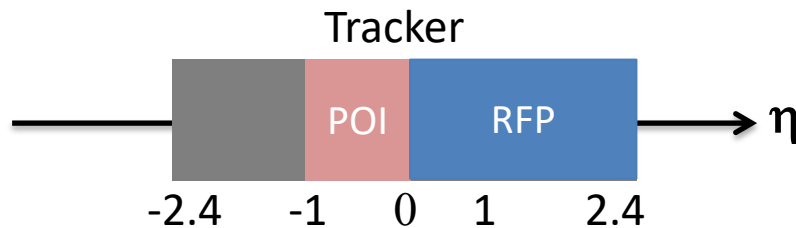
Paper about to be submitted: <http://cds.cern.ch/record/2767034>

BACKUP

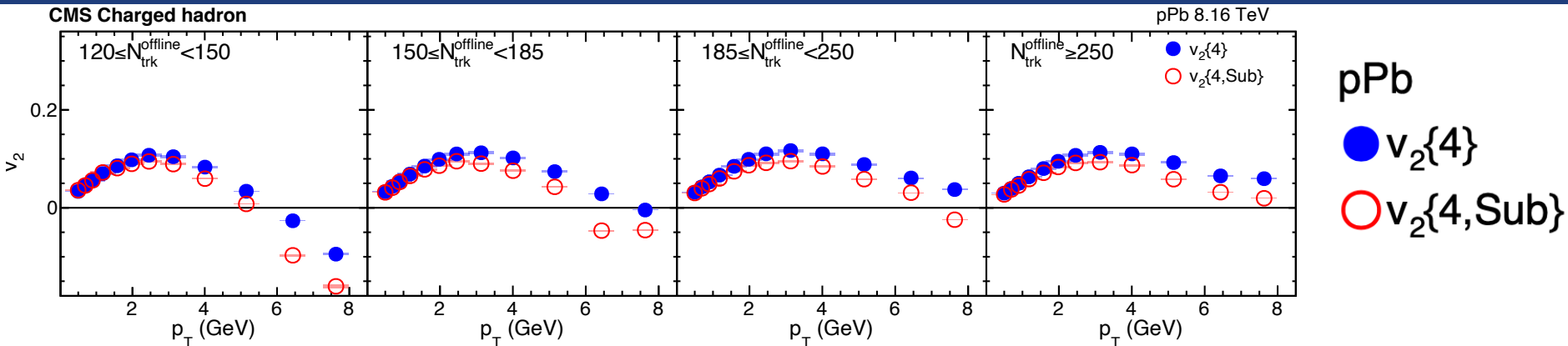


Subevent Cumulant in pPb

- Subevent cumulant to suppress short-range correlations
- POI: $-1 < \eta < 0$ ($0 < \eta < 1$)
- RFP: $0 < \eta < 2.4$ ($-2.4 < \eta < 0$)



Subevent Cumulant in pPb



- Subevent cumulant to suppress short-range correlations
- POI: $-1 < \eta < 0$ $(0 < \eta < 1)$
- RFP: $0 < \eta < 2.4$ $(-2.4 < \eta < 0)$
- $v_2\{4,Sub\} < v_2\{4\}$
- Decorrelation might be the dominating effect

Subevent Cumulant in PbPb

CMS Charged hadron

pPb 8.16 TeV PbPb 5.02 TeV

pPb

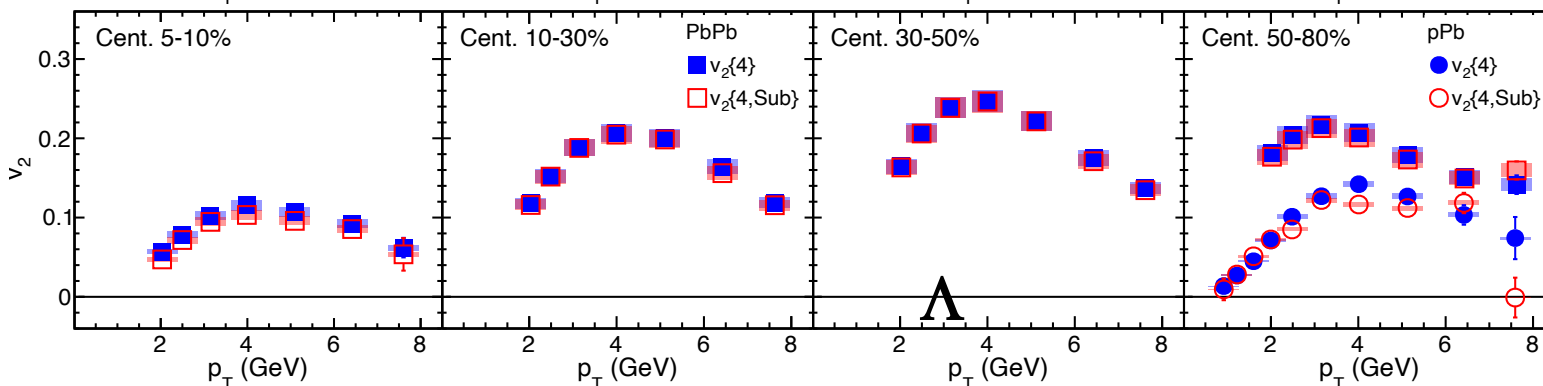
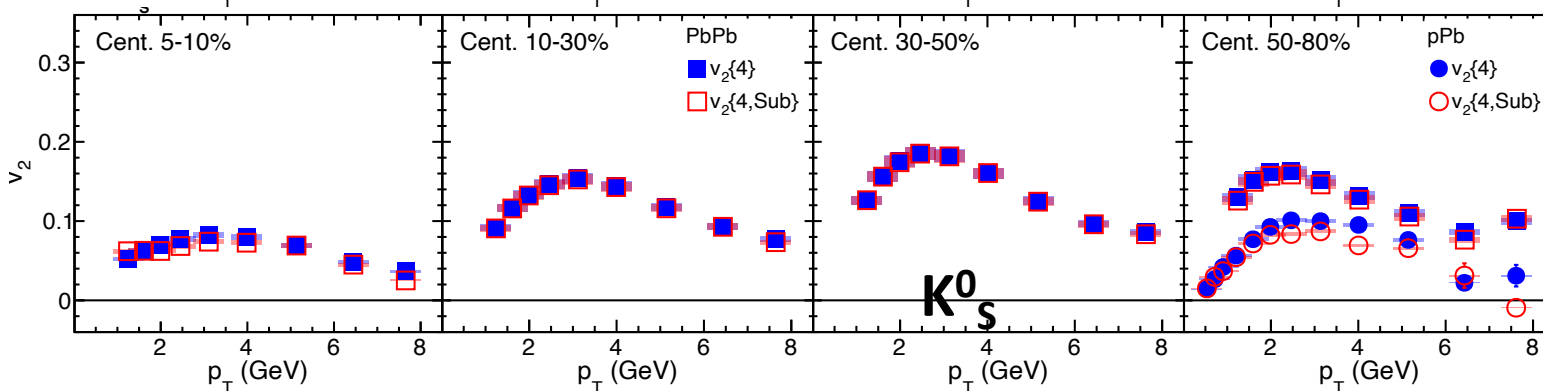
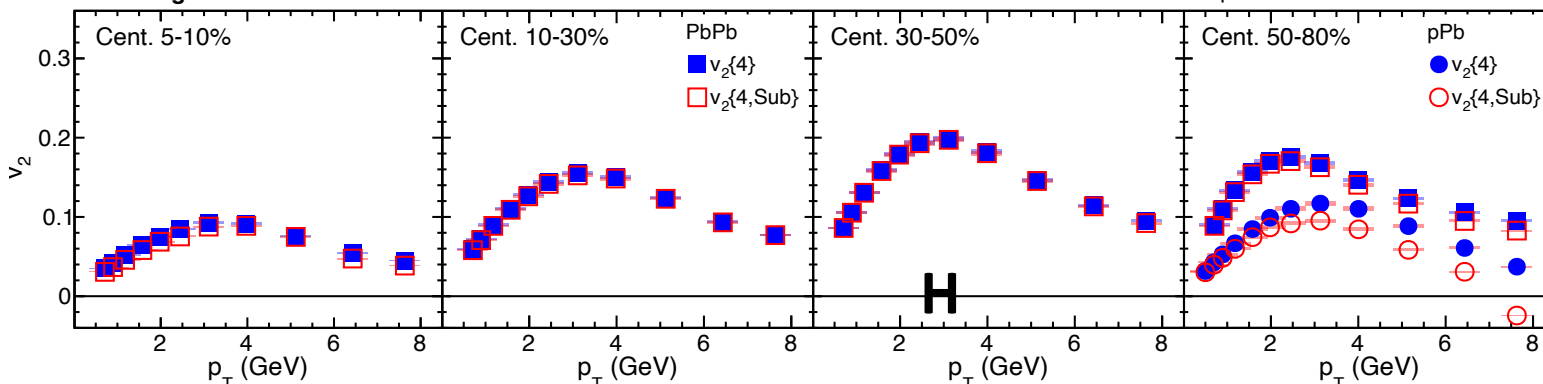
● $v_2\{4\}$

○ $v_2\{4,Sub\}$

PbPb

■ $v_2\{4\}$

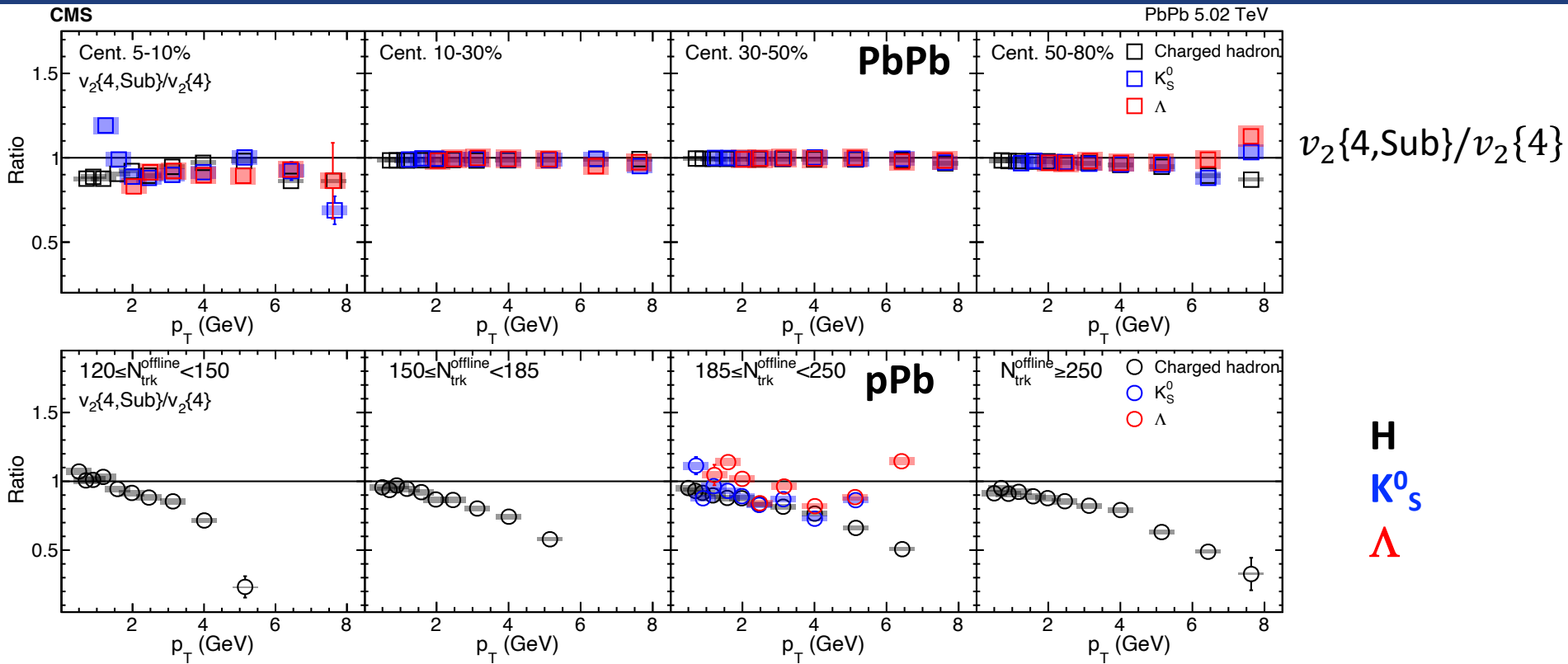
□ $v_2\{4,Sub\}$



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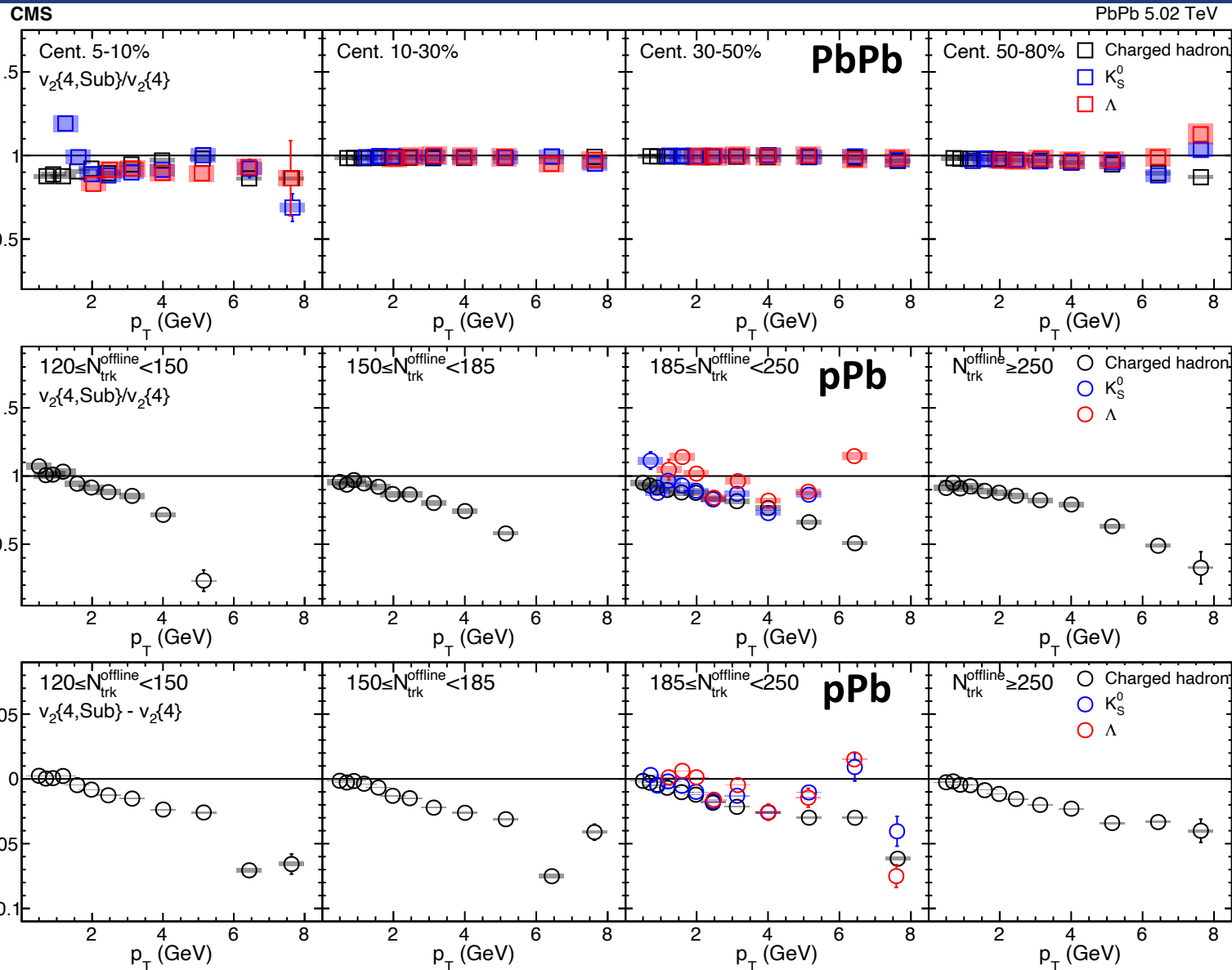


Subevent Cumulant Ratios



- Small effect in PbPb
- Large effect in pPb, up to 50% in high p_T
- No PID dependence in pPb and PbPb

Subevent Cumulant Ratios

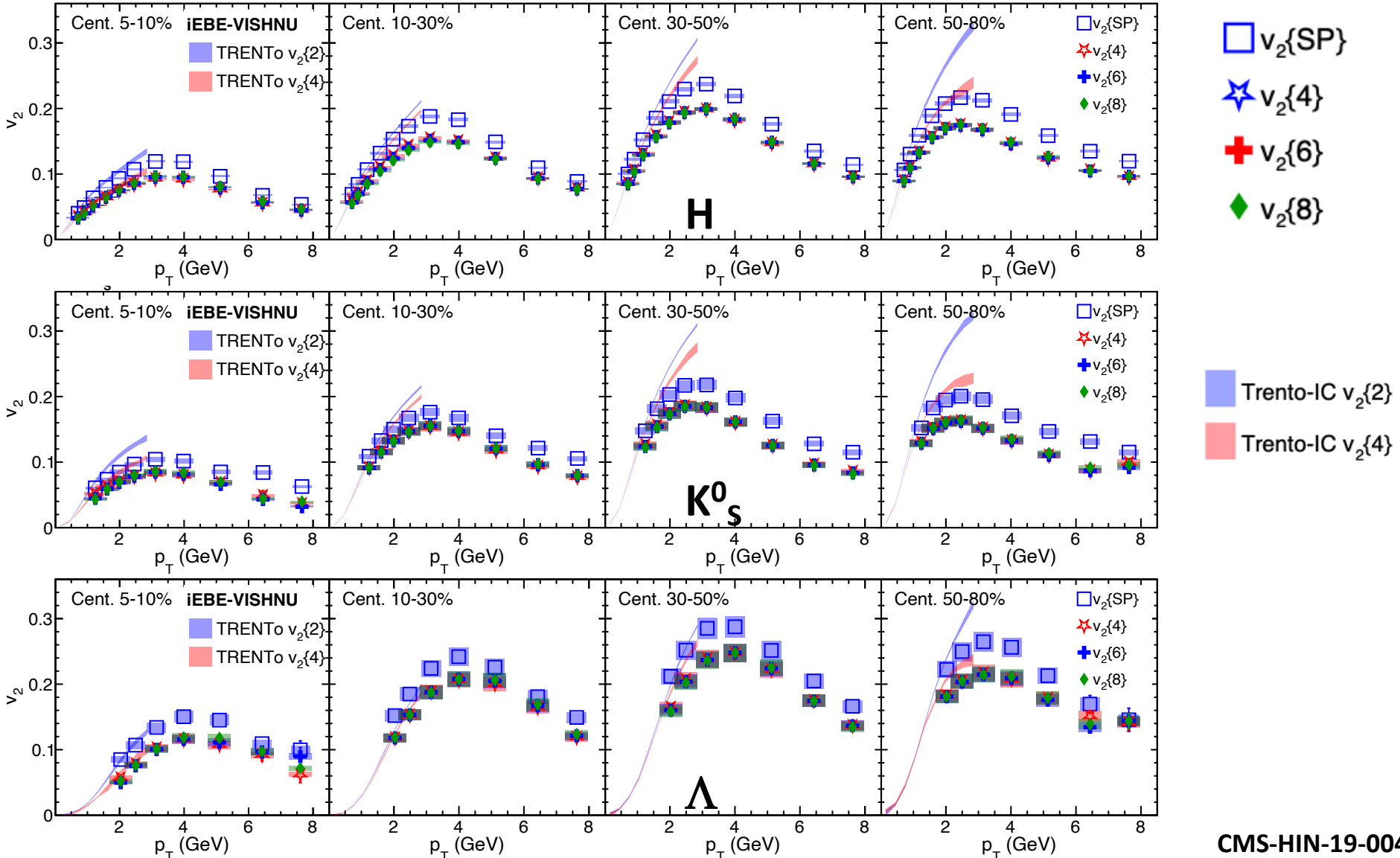


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Strange Hadron v_2 in PbPb

CMS Charged hadron

PbPb 5.02 TeV



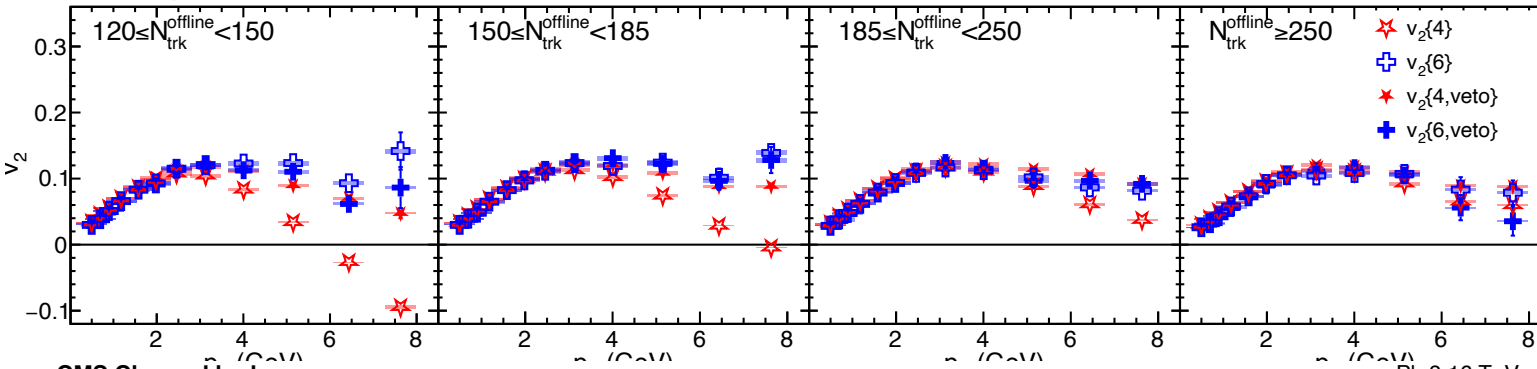
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Jet-related nonflow in pPb

CMS Charged hadron

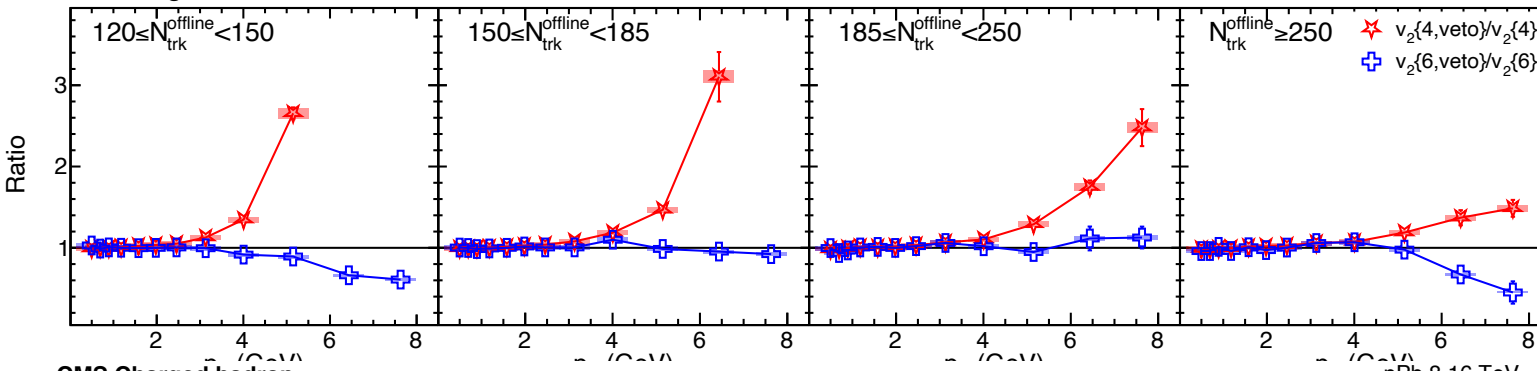
pPb 8.16 TeV



- ★ $v_2\{4\}$
- + $v_2\{6\}$
- ★ $v_2\{4,veto\}$
- + $v_2\{6,veto\}$

CMS Charged hadron

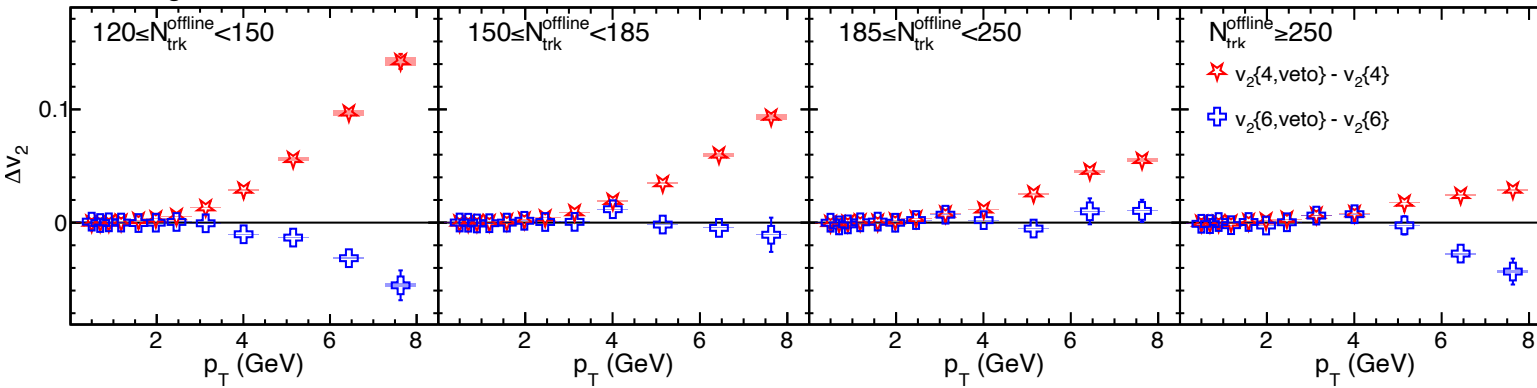
pPb 8.16 TeV



- ★ $v_2\{4,veto\}/v_2\{4\}$
- + $v_2\{6,veto\}/v_2\{6\}$

CMS Charged hadron

pPb 8.16 TeV



- ★ $v_2\{4,veto\} - v_2\{4\}$
- + $v_2\{6,veto\} - v_2\{6\}$

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