Measurements of flow in PbPb collisions at CMS

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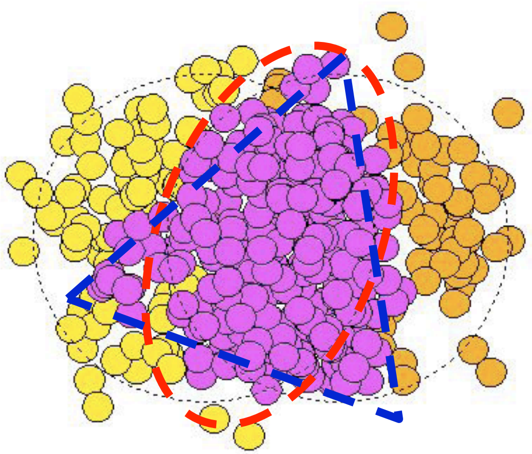
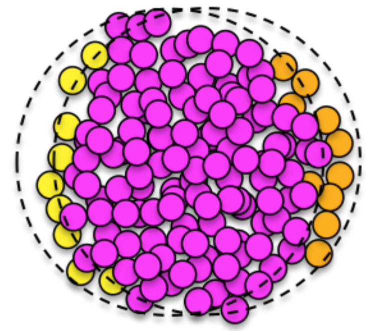
for the CMS Collaboration

Flow Harmonics at CMS

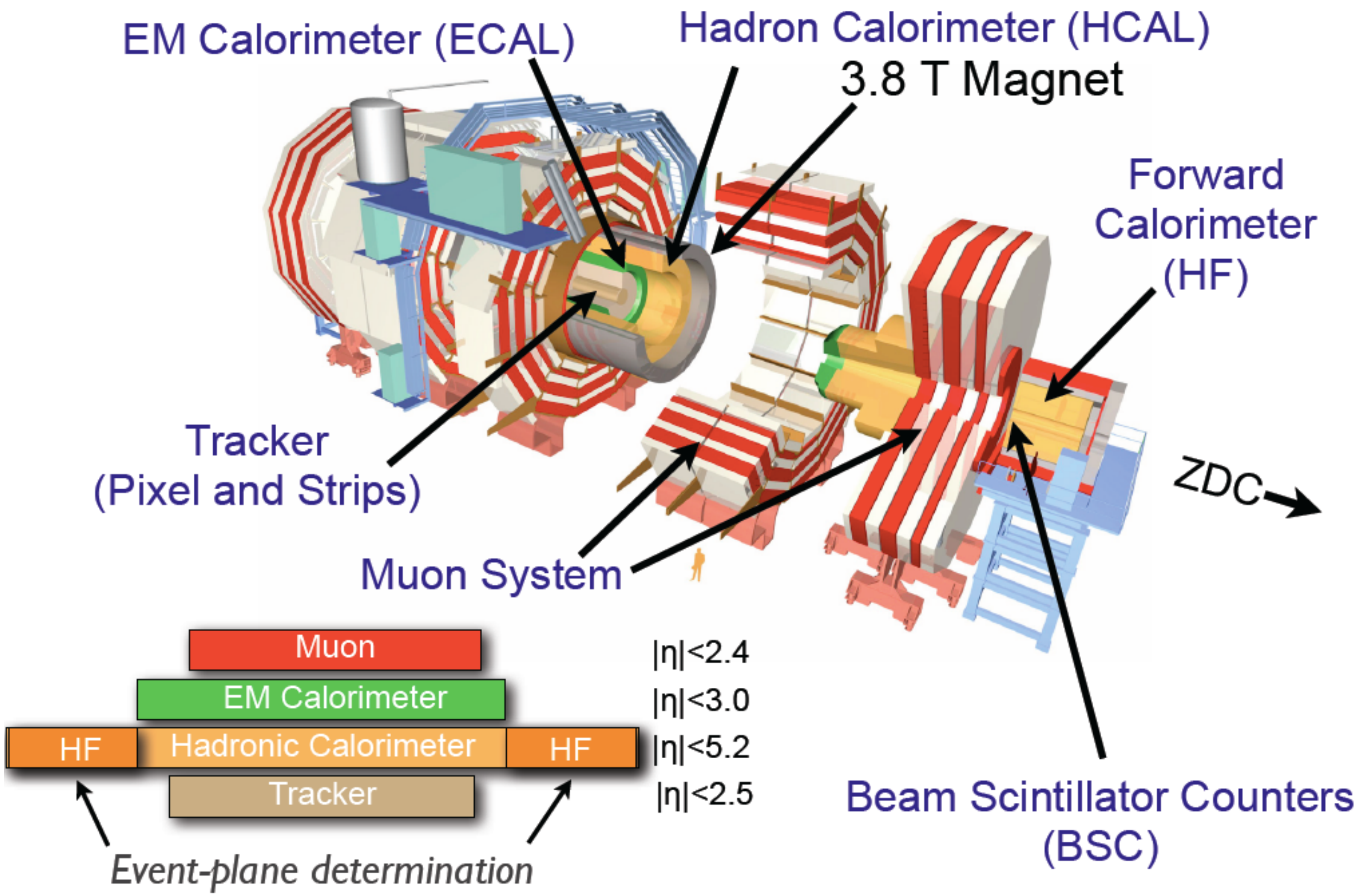
- Higher-order harmonics
- Ultra-central PbPb



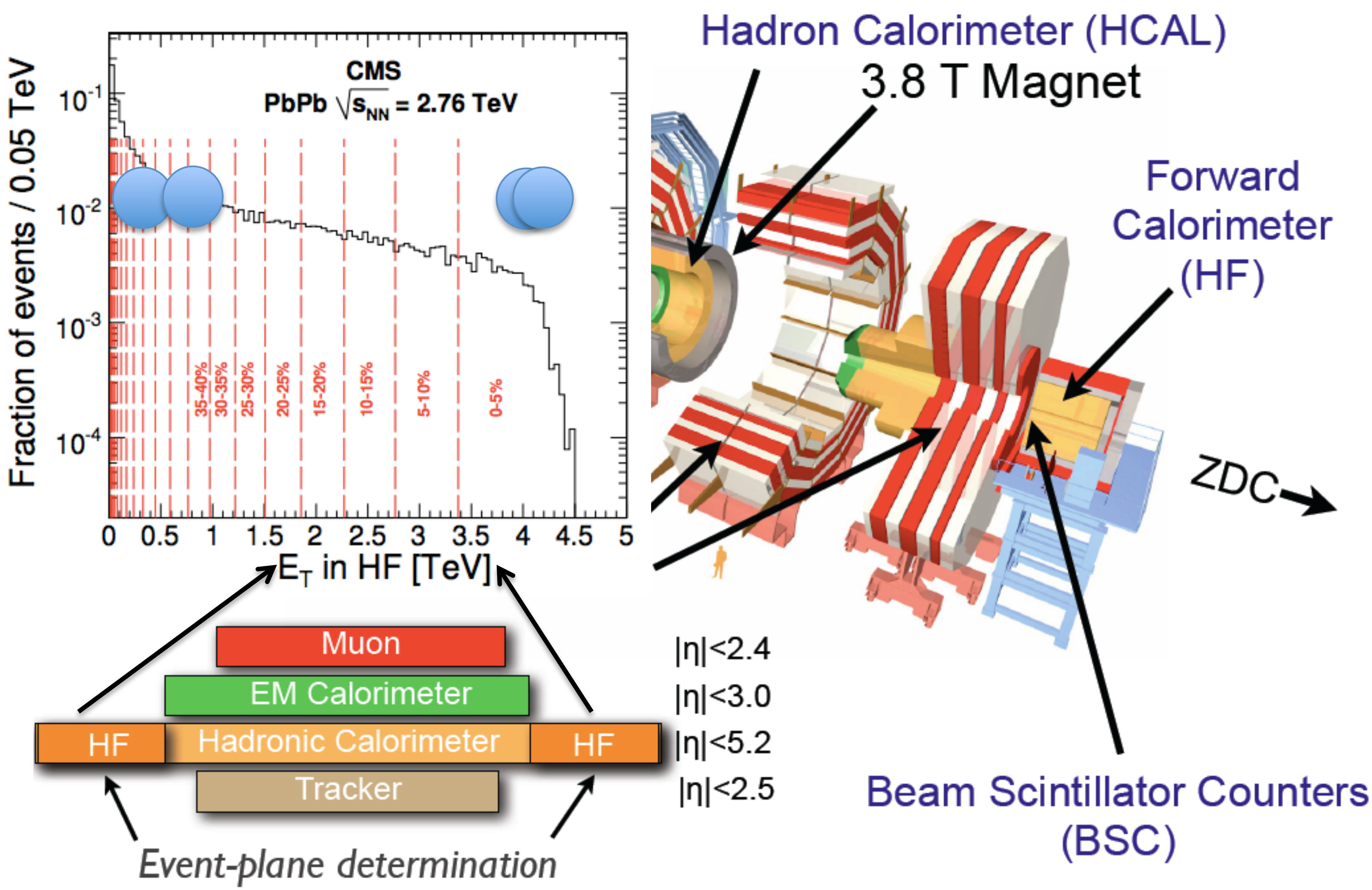


$$\frac{dN}{d\phi} \sim 1 + 2v_2 \cos 2(\phi - \psi_2) + 2v_3 \cos 3(\phi - \psi_3) + \ldots$$

The CMS Detector

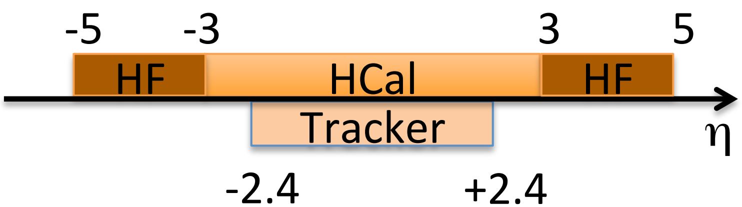


The CMS Detector



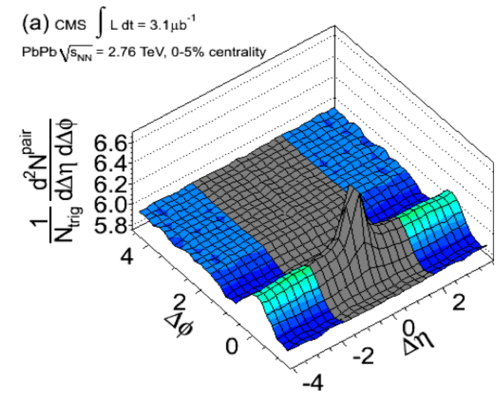
v_n Measurement Methods

Event-Plane

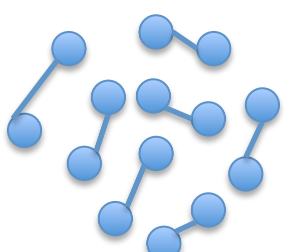


$$\frac{dN}{d\phi} \sim 1 + 2v_2 \cos 2(\phi - \psi_2) + 2v_3 \cos 3(\phi - \psi_3) + \ldots$$

Di-hadron Correlation

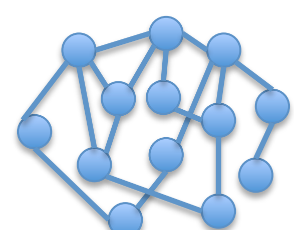


Cumulant



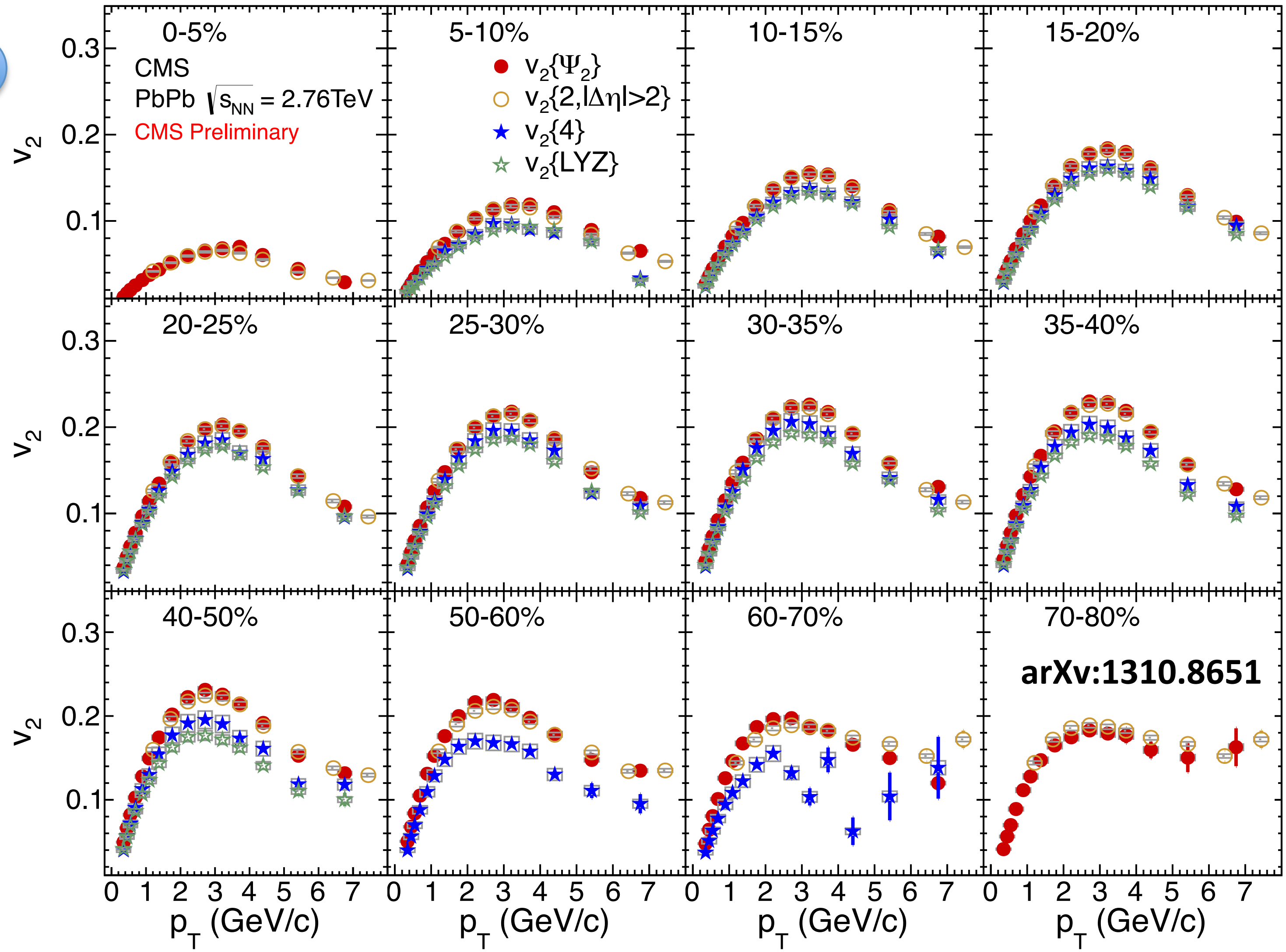
Genuine 2- and 4-particle correlations

Lee-Yang-Zeros



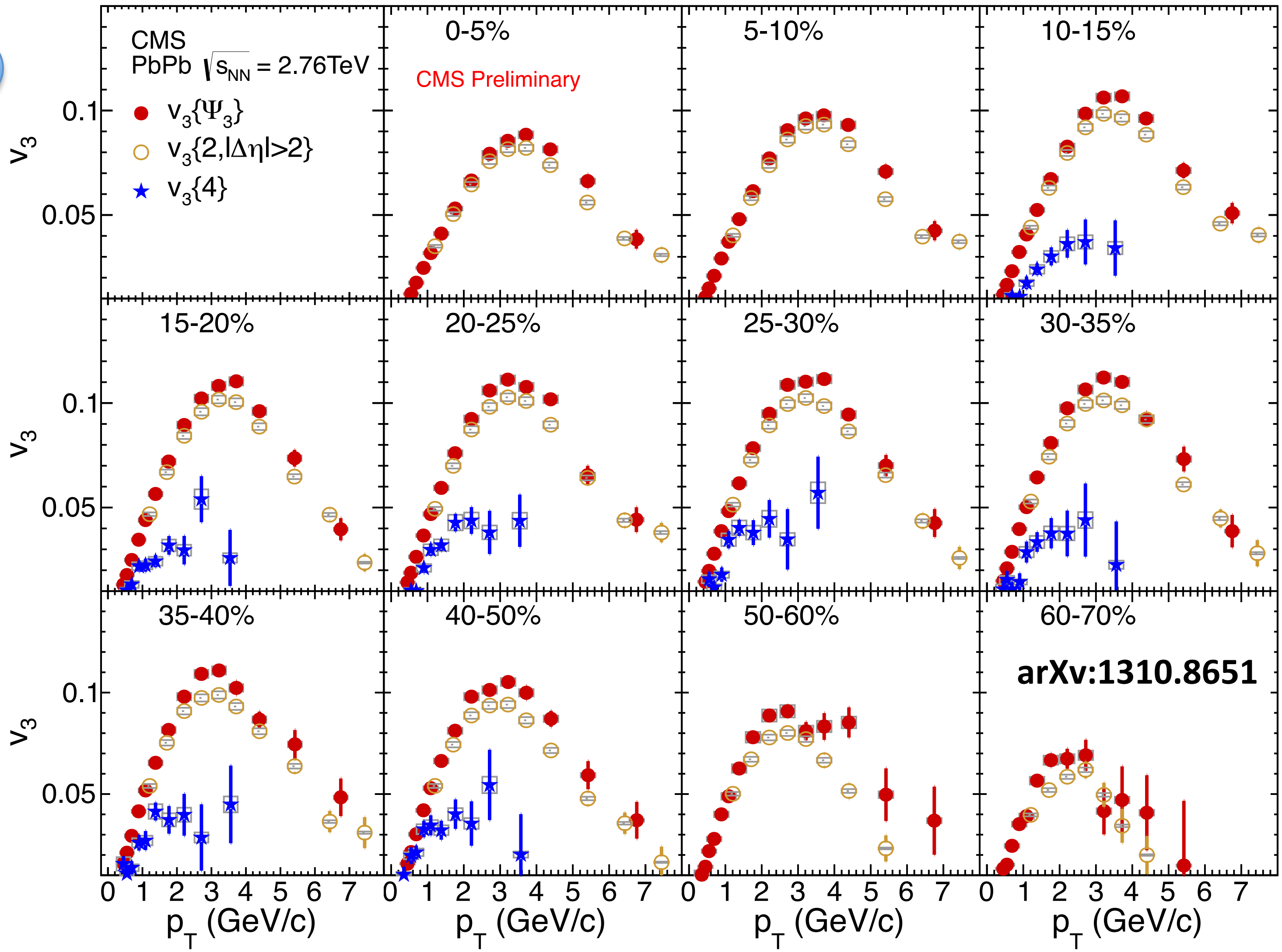
Genuine all particle correlations

PbPb Charged Particle v_2 Results



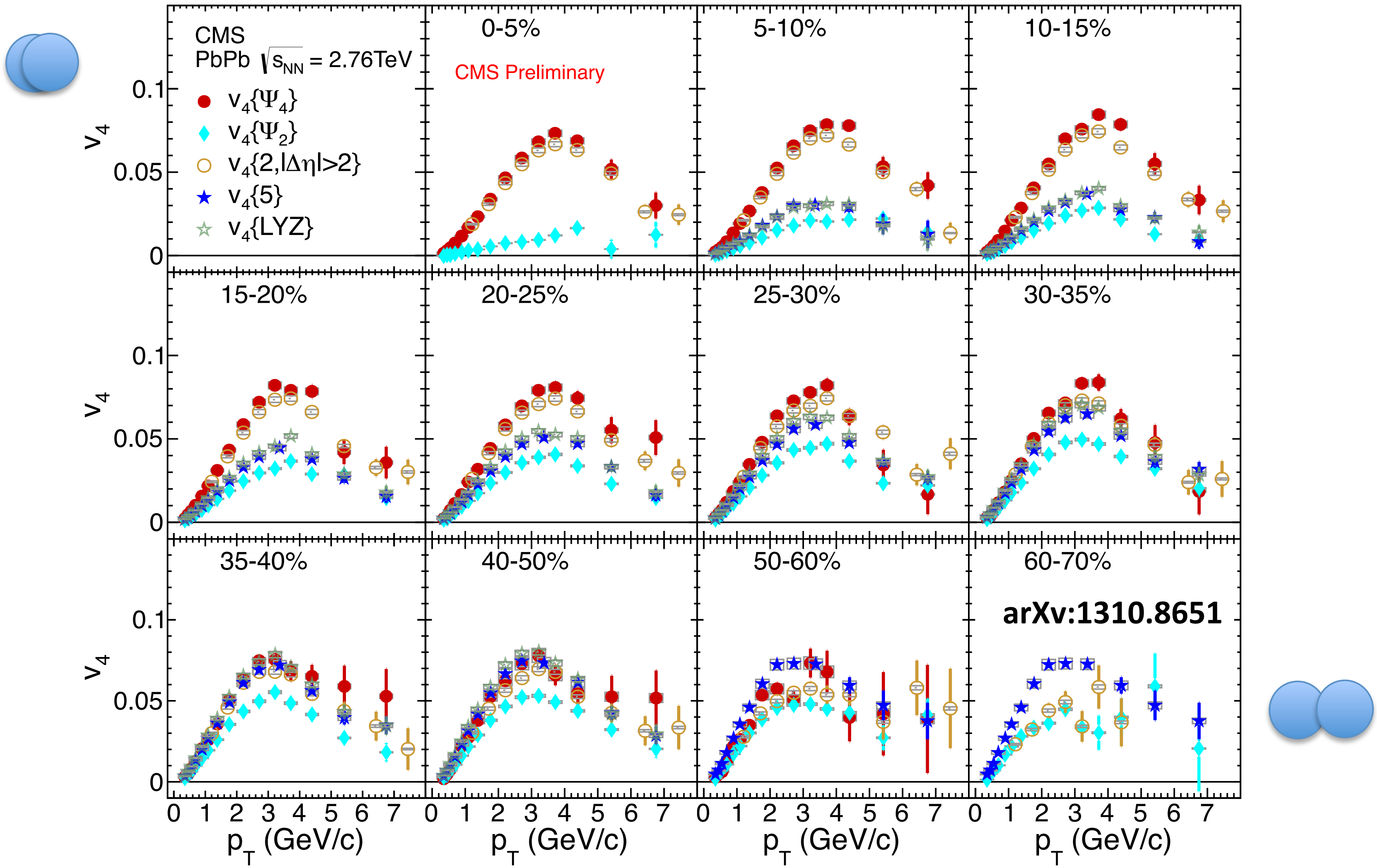
➢ **Four methods, different non-flow sensitivity**

PbPb Charged Particle v_3 Results



➢ **Little centrality dependence, fluctuations dominate**

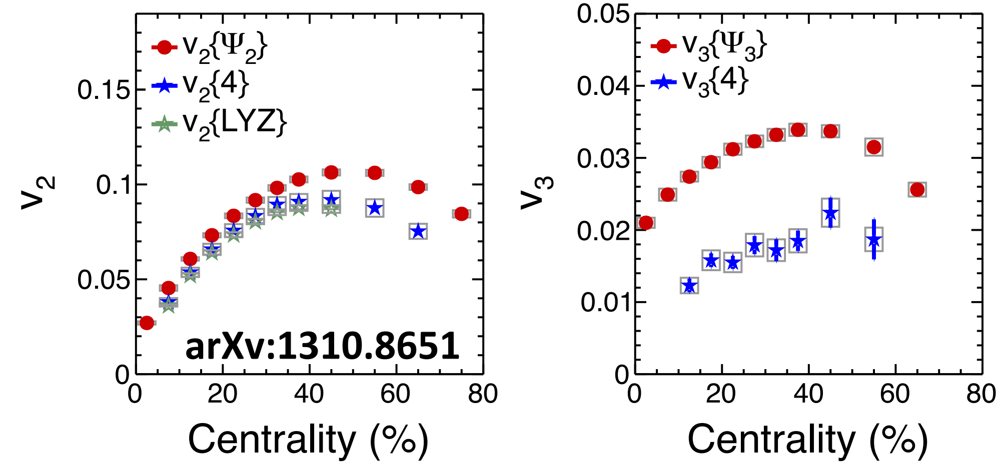
PbPb Charged Particle v_4 Results

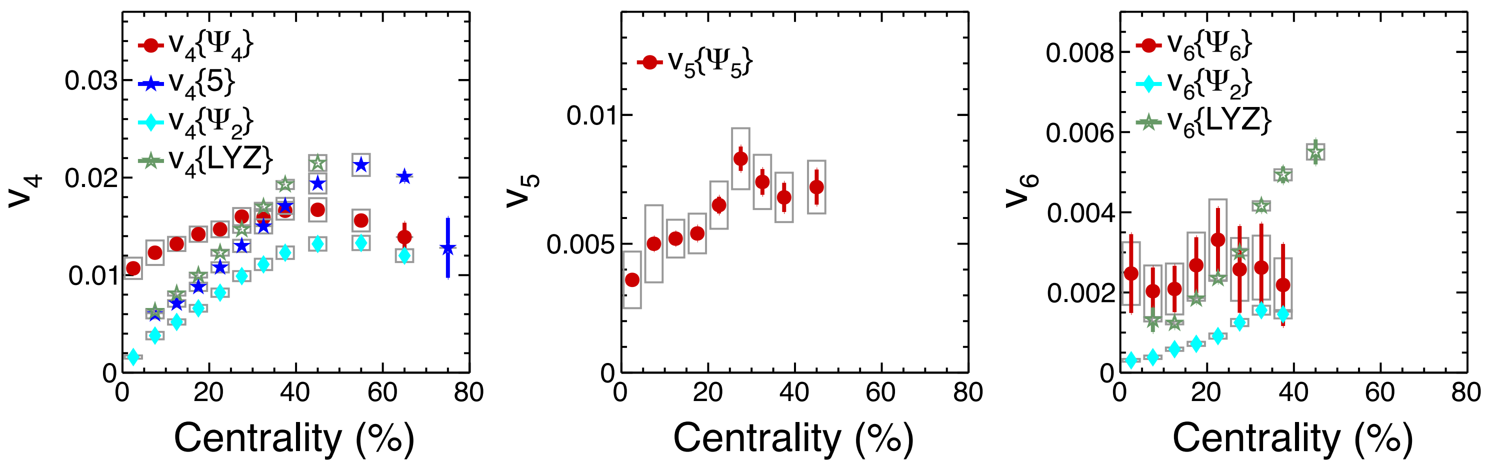


- Weak centrality dependence Ψ_4 reference, fluctuations dominate
- Strong centrality dependence $v_4\{\Psi_2\}$, $v_4\{5\}$, $v_4\{LYZ\}$, initial geometry driven

Centrality Dependence

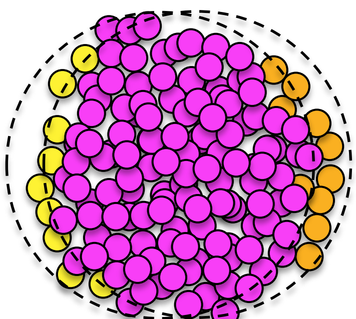
- Weak centrality dependence for $v_n\{\Psi_n\}$ (n>2)
- Strong centrality dependence for v_4 and v_6 using mixed harmonics with Ψ_2

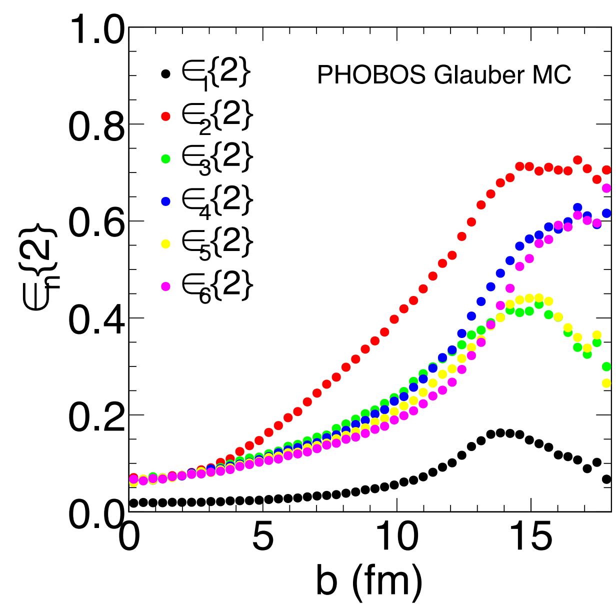




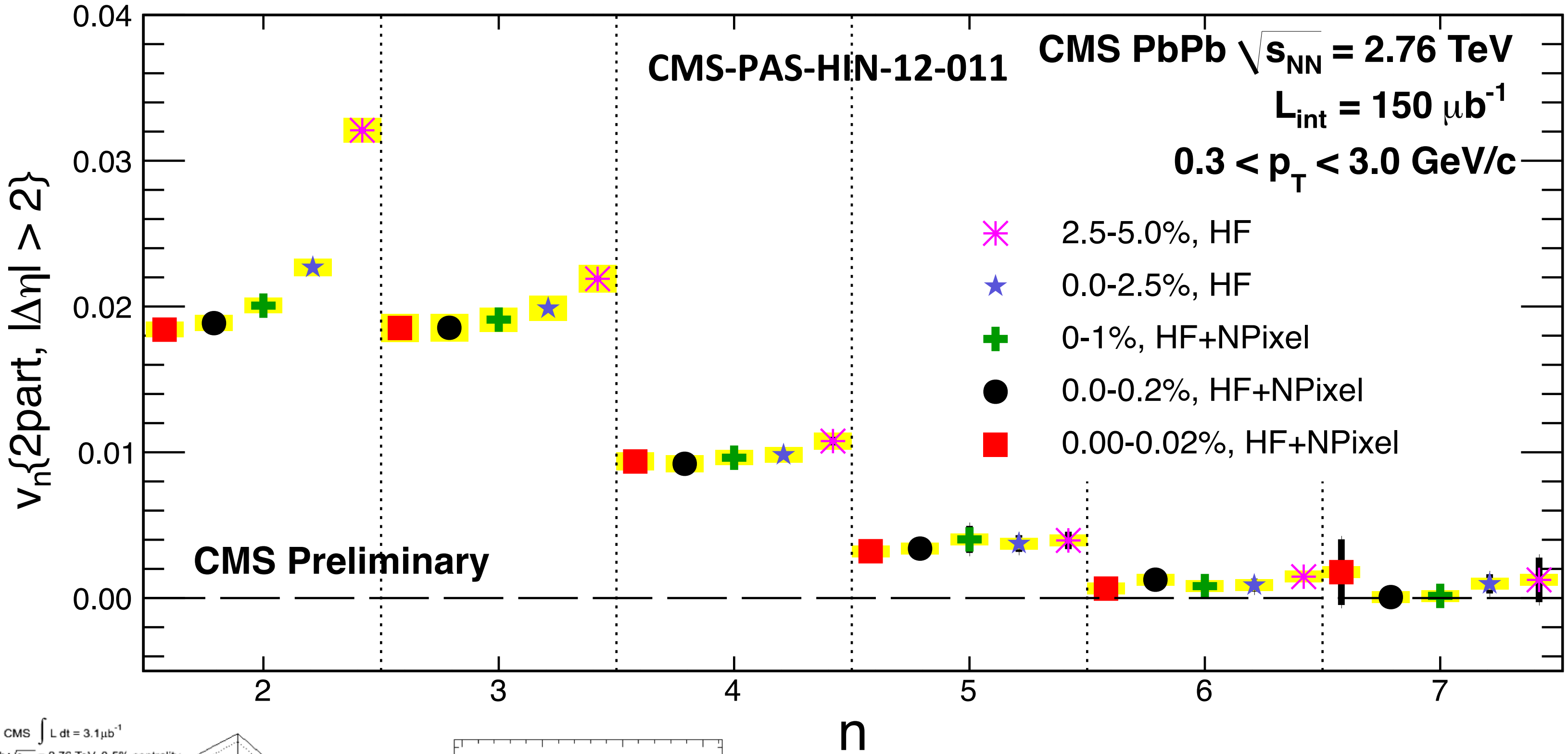
Ultra-central Collisions

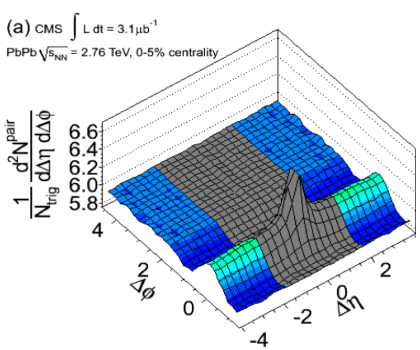
- In ultra-central collisions (b->0), all ε_n are purely driven by fluctuations, constrain η/s
- Dedicated trigger selecting 0-0.2% centrality range, 2M events recorded

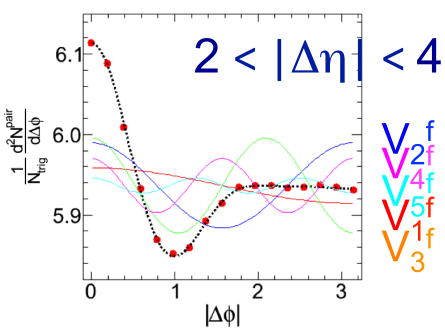




Di-hadron Ultra-central v_n Harmonics



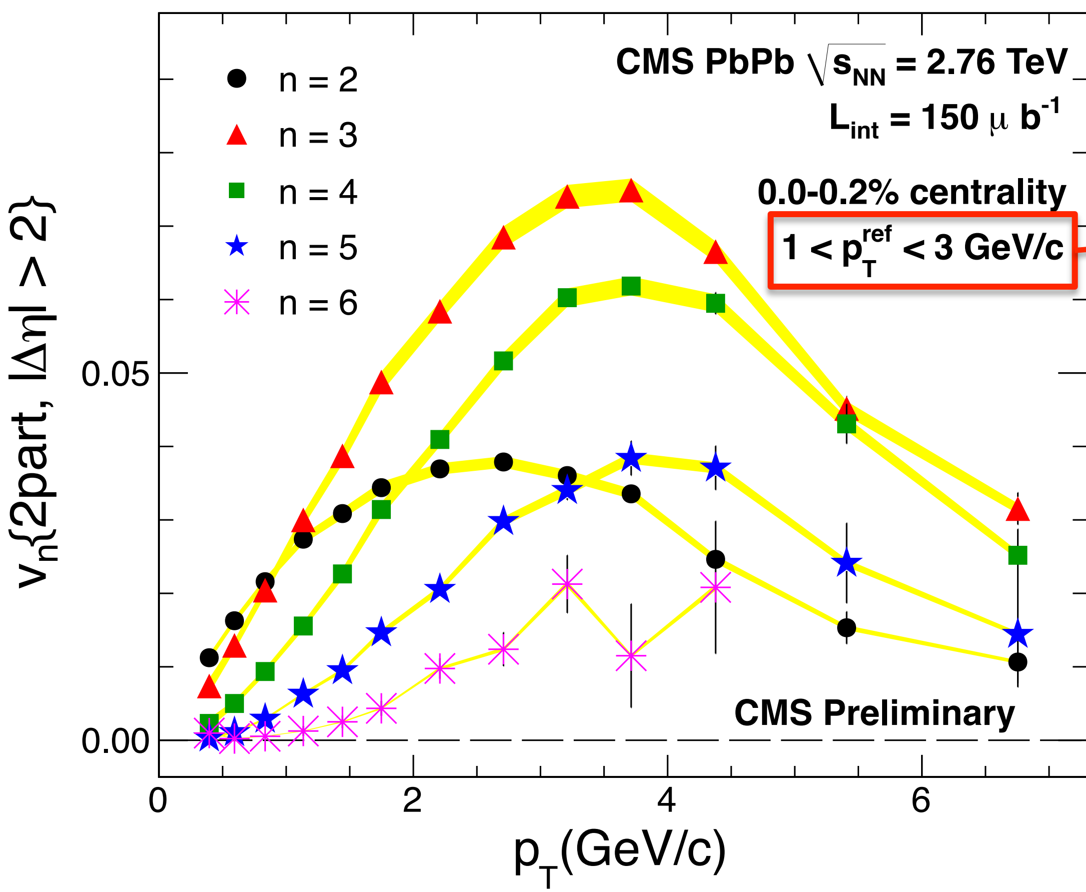




v_n dominated by fluctuations, saturates at 0.2% centrality

p_T Dependence of Ultra-central v_n

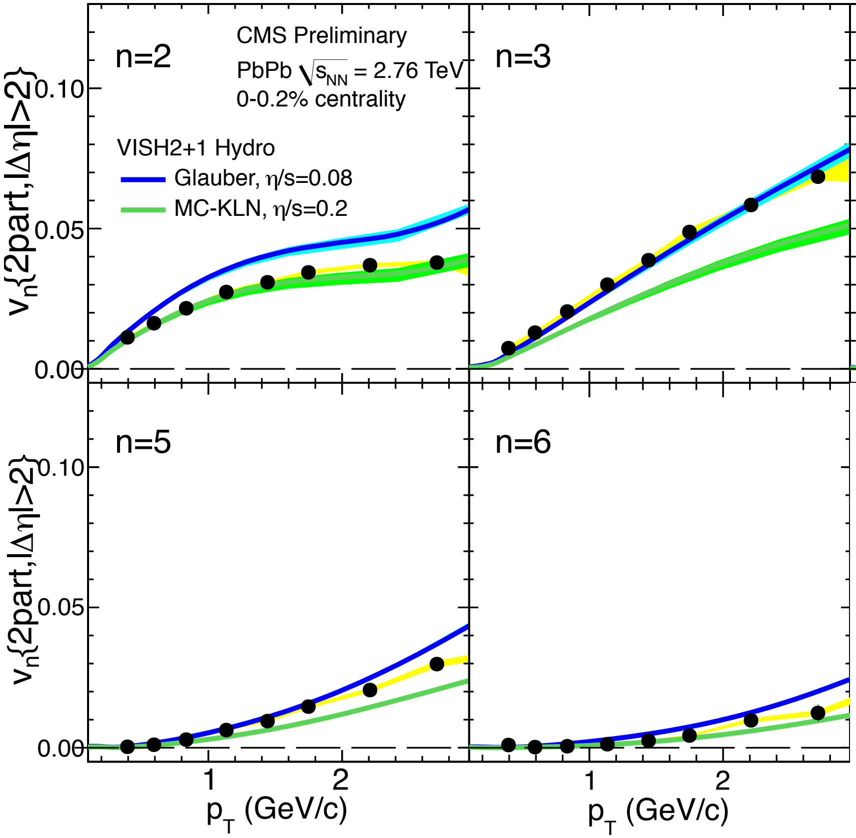
CMS-PAS-HIN-12-011



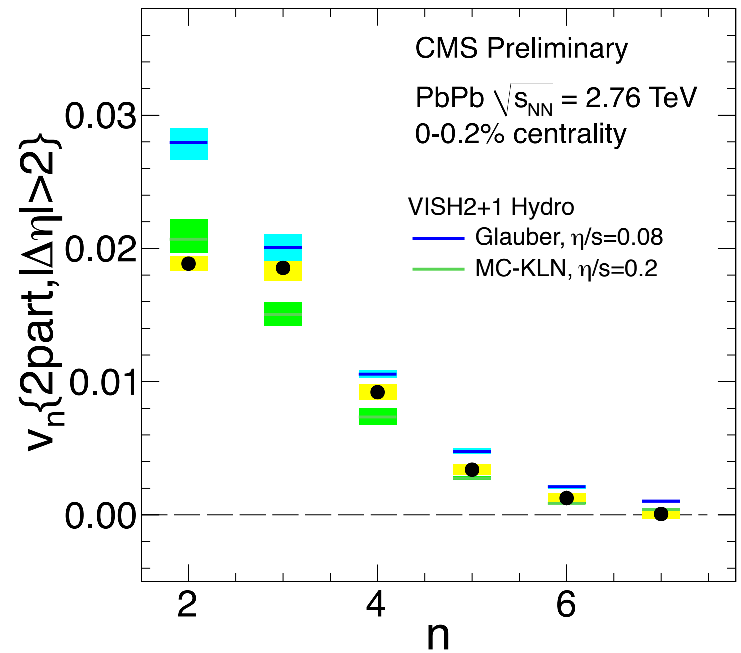
$$v_n(p_T) = \frac{V_{n\Delta}(p_T, p_T^{ref})}{\sqrt{V_{n\Delta}(p_T^{ref}, p_T^{ref})}}$$

- Higher order harmonics are strongly excited
- v_3, v_4, v_5 rise above v_2

Compare to Hydrodynamics



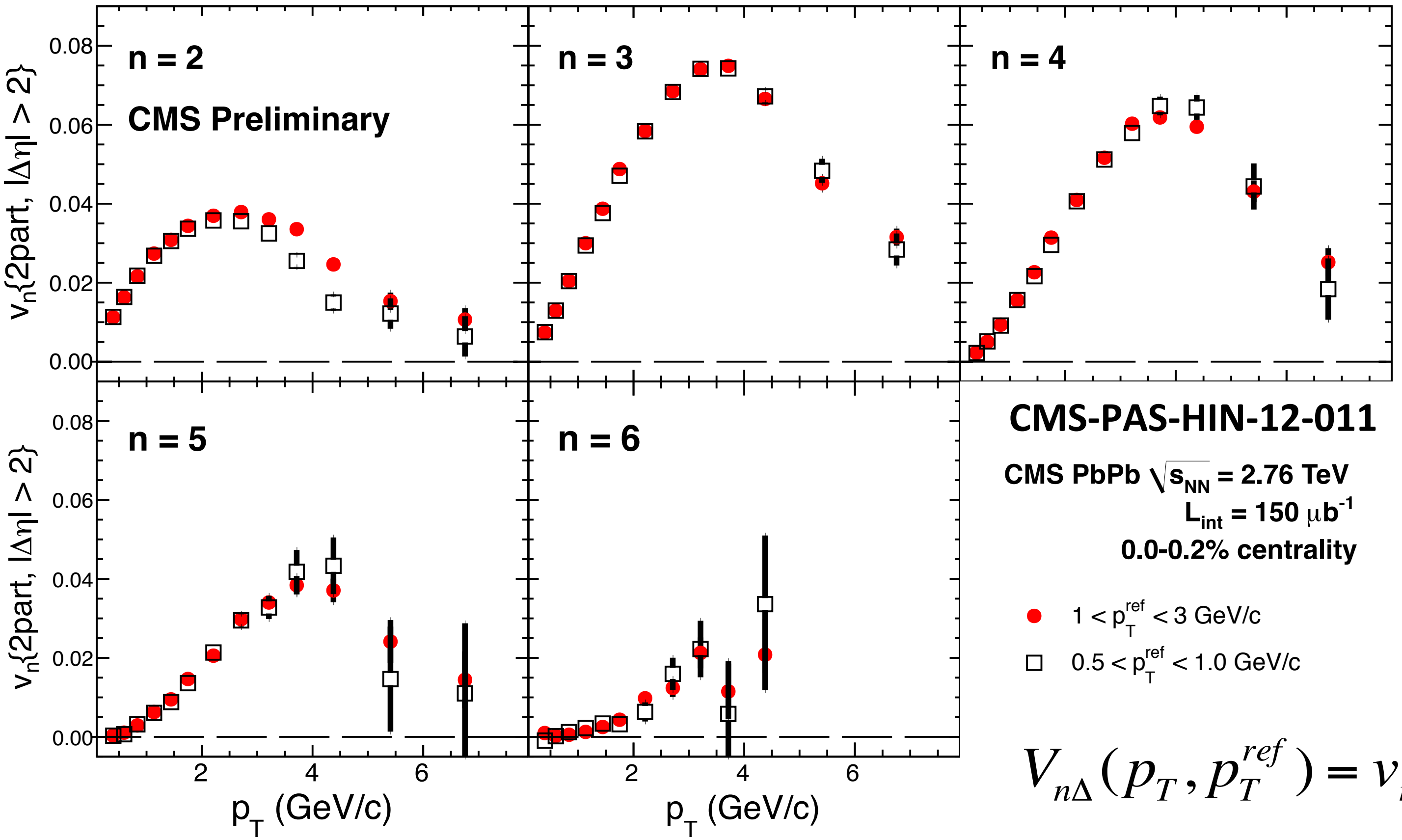
CMS-PAS-HIN-12-011



- Viscos hydrodynamics with initial state fluctuations can reproduce data
- η/s is constrained between 0.08 and 0.2

Factorization

- Basic assumption – $V_{n\Delta}$ factorize if purely flow driven
- Factorization breakdown <=> hydro breakdown



$$V_{n\Delta}(p_T, p_T^{ref}) = v_n(p_T) \times v_n(p_T^{ref})$$

Factorization Breakdown

$$\frac{2\pi}{N}\frac{dN}{d\phi} = 1 + 2\sum_{n=1}^{\infty} v_n(p_T,\eta)\cos[n(\phi - \Psi_n(p_T)]$$

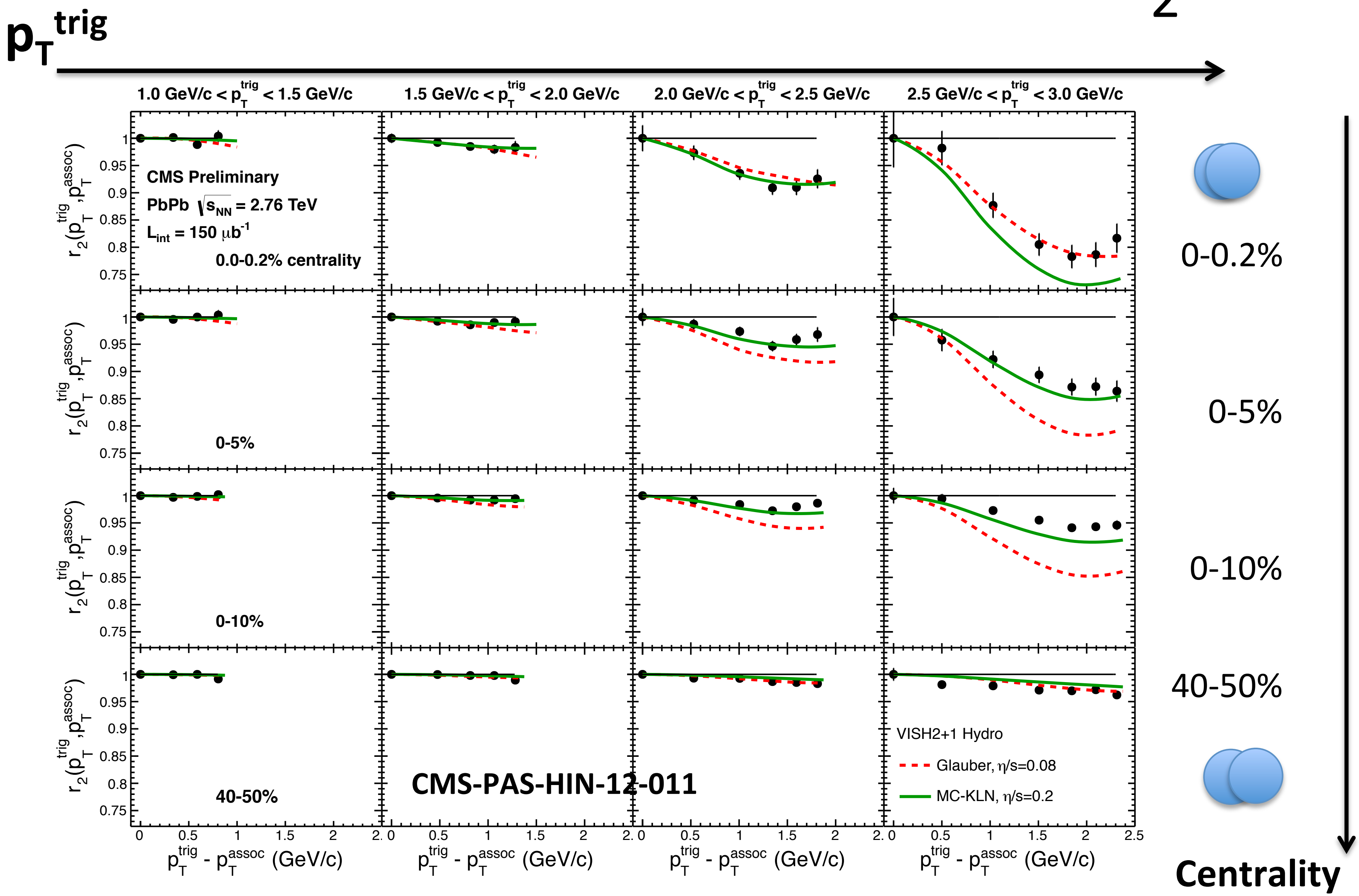
- Different p_T can correspond to different event-plane angle
- Factorization breakdown is then a natural consequence of fluctuating initial-state geometry arXv:1211.0989 arXv:1302.3535
- To test factorization

$$r_n \equiv \frac{V_{n\Delta}(p_T^{trig}, p_T^{asso})}{\sqrt{V_{n\Delta}(p_T^{trig}, p_T^{trig})V_{n\Delta}(p_T^{asso}, p_T^{asso})}}$$

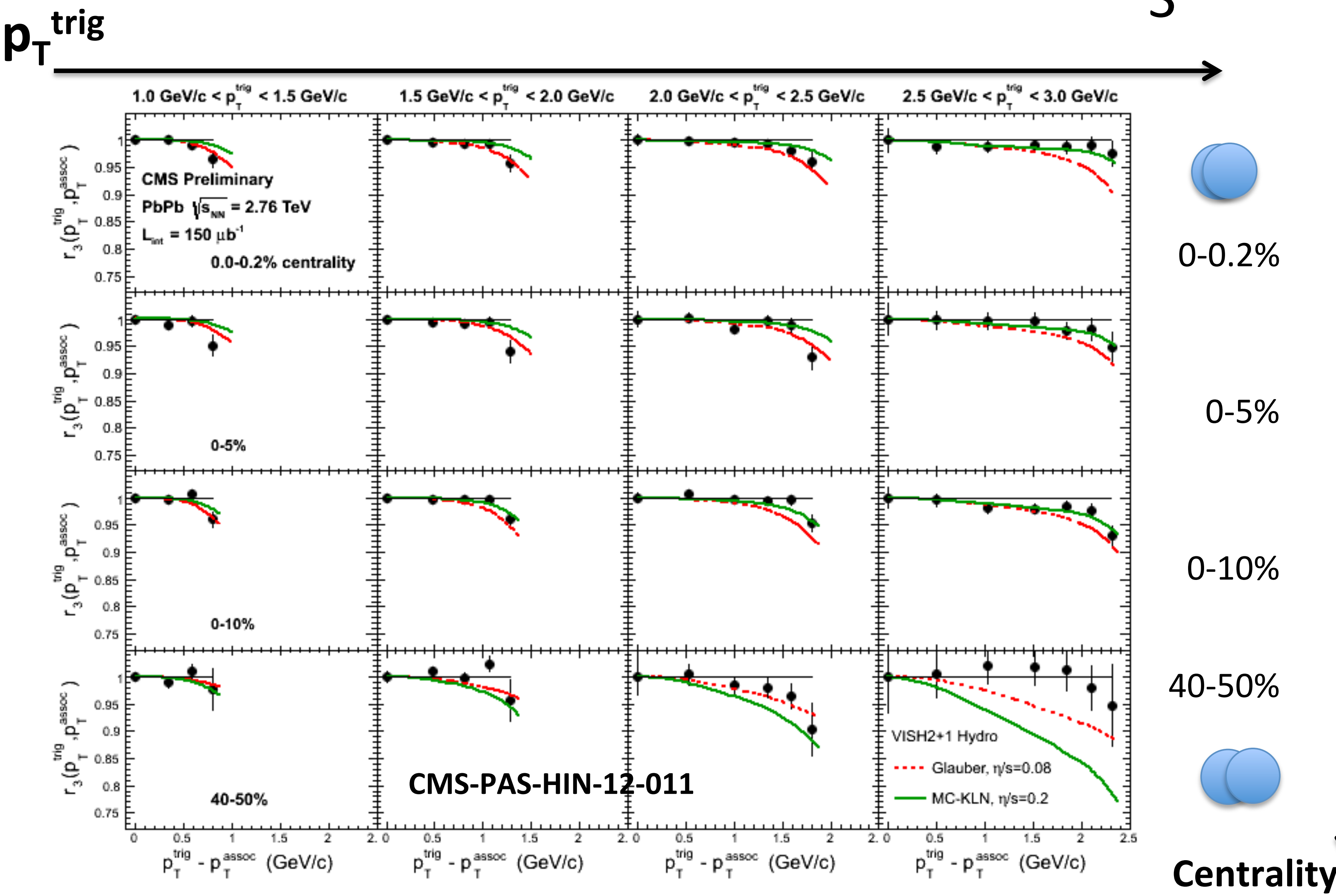
$$= \frac{\left\langle v_n(p_T^{trig})v_n(p_T^{asso})\cos[n(\Psi_n(p_T^{trig}) - \Psi_n(p_T^{asso}))]\right\rangle}{\sqrt{v_n^2(p_T^{trig})v_n^2(p_T^{asso})}}$$

If factorize, r_n saturates to unity, otherwise r_n<1.

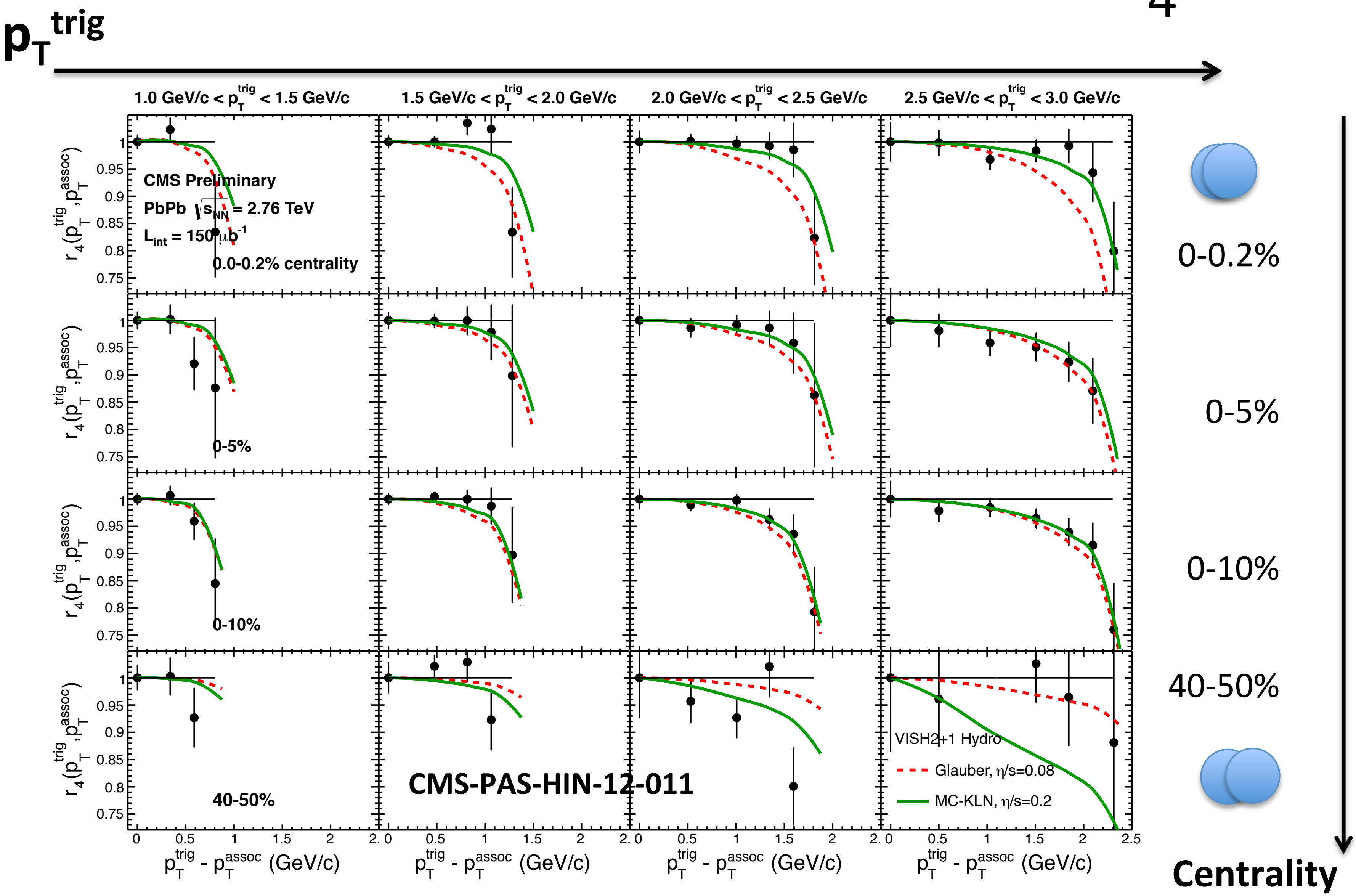
Factorization Breakdown r_2



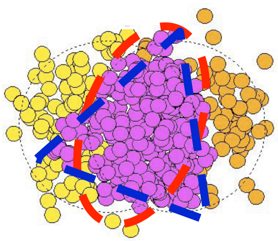
Factorization Breakdown r_3



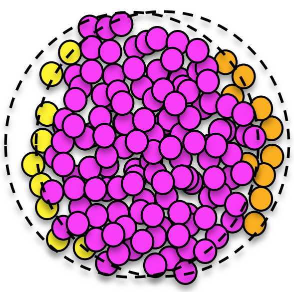
Factorization Breakdown r_4



Summary



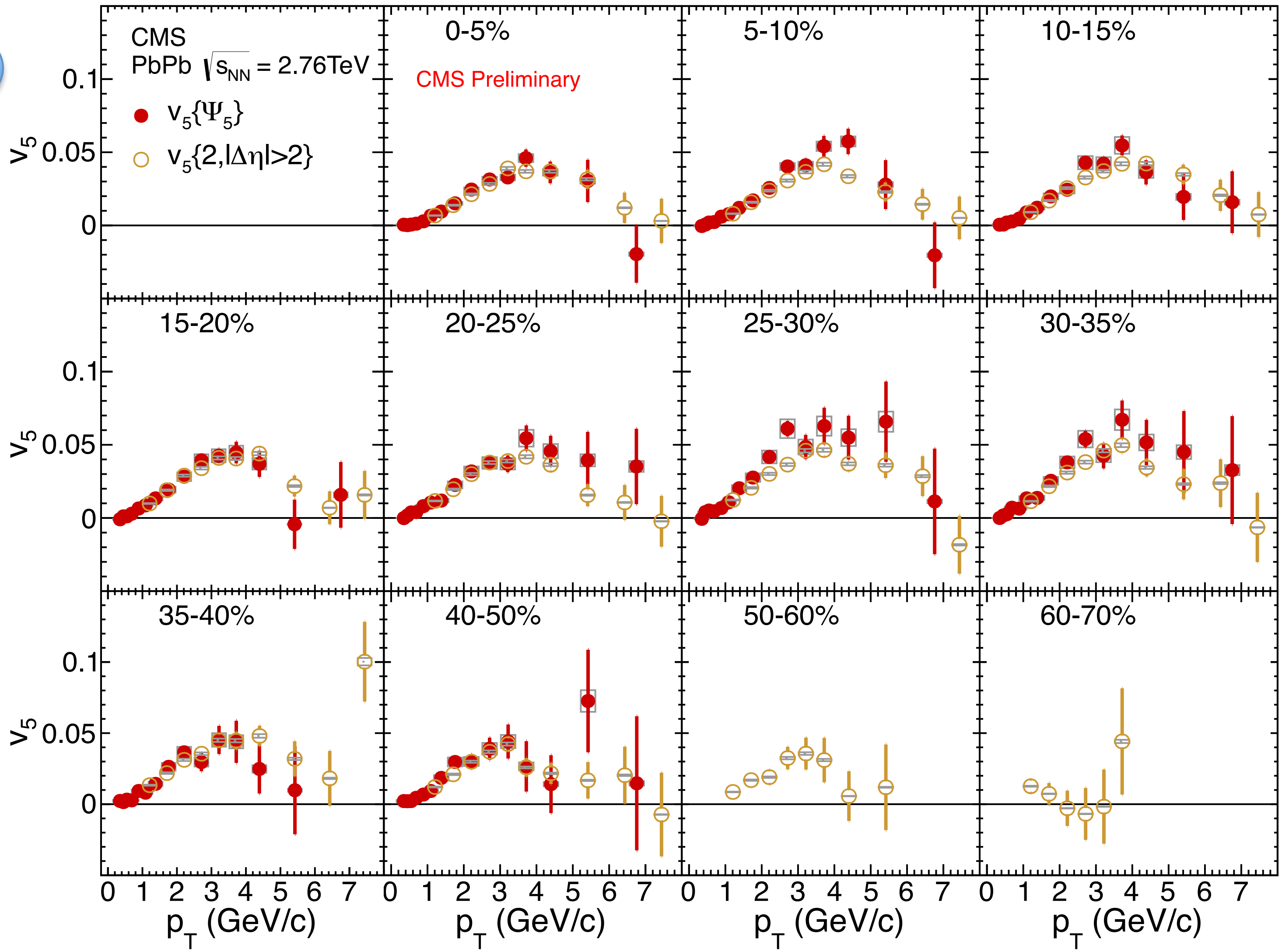
- Comprehensive measurements of higher order flow harmonics are performed at CMS, providing insights on flow fluctuations and non-flow



- Ultra-central v_n results provide constraints on η/s with fluctuating initial geometry
- Factorization breakdown is consistent with hydrodynamics with event-by-event p_T dependent event-plane angle

BACKUP

PbPb Charged Particle v_5 Results



PbPb Charged Particle v_6 Results