Overview of results on flow and correlations from the CMS collaboration

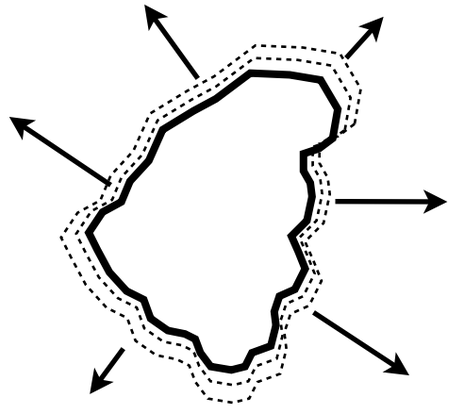
Steve Sanders
(U. Kansas)
for the CMS Collaboration

Quark Matter Conference, Washington DC
13 Aug 2012

Overview

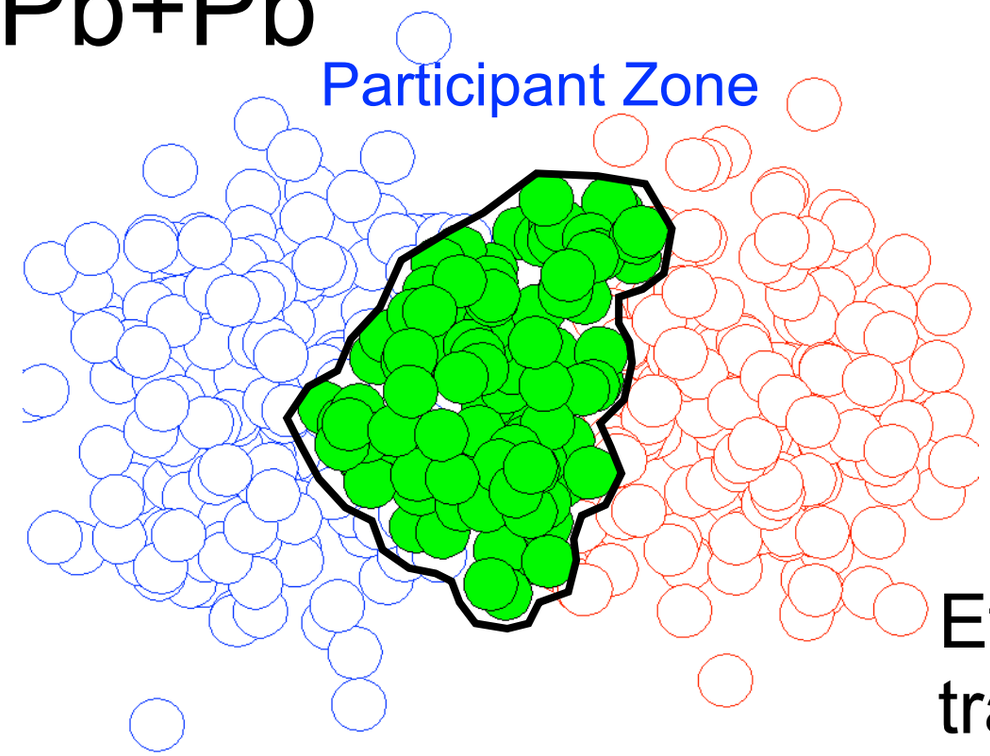
Azimuthal Particle Correlations:

Outward flow of medium...



Pb+Pb

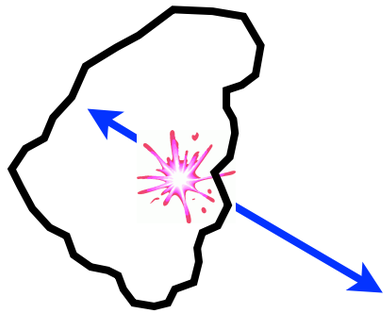
Participant Zone



- EoS
- Viscosity (η/s)
- Initial Conditions

Increasing p_T

Effect of medium on transiting particles...



- Opacity of plasma

New 2011 Triggers:
Ultra Central
High-p_T Single Track

CMS Presentations

Elliptic Flow (Eric Appelt)
–Friday 2:30 p.m.–

Higher-order Flow (Shengquan Tuo)
–Friday 5:30 p.m.–

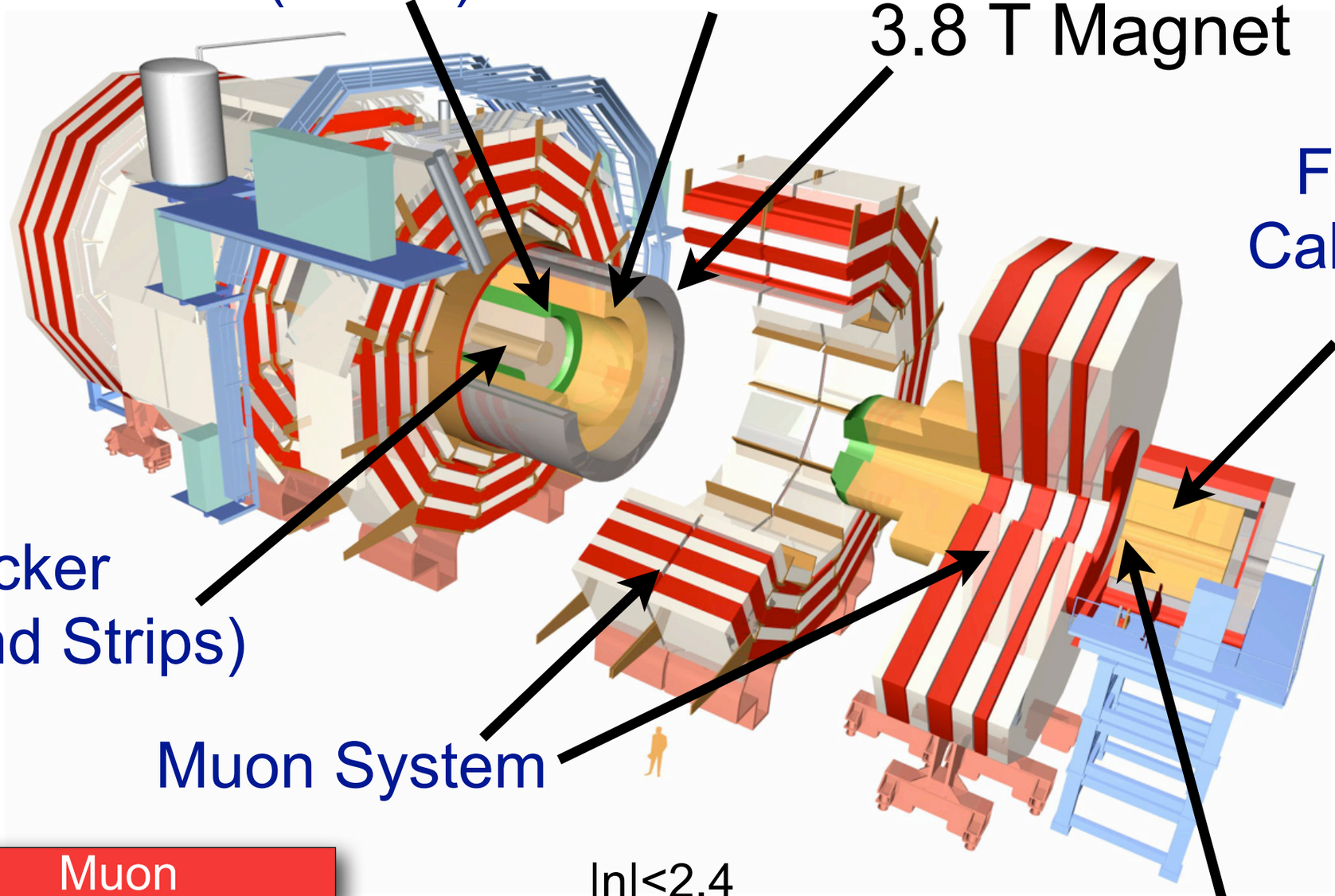
π^0 Anisotropy (Monika Sharma)
–Poster: Reception–

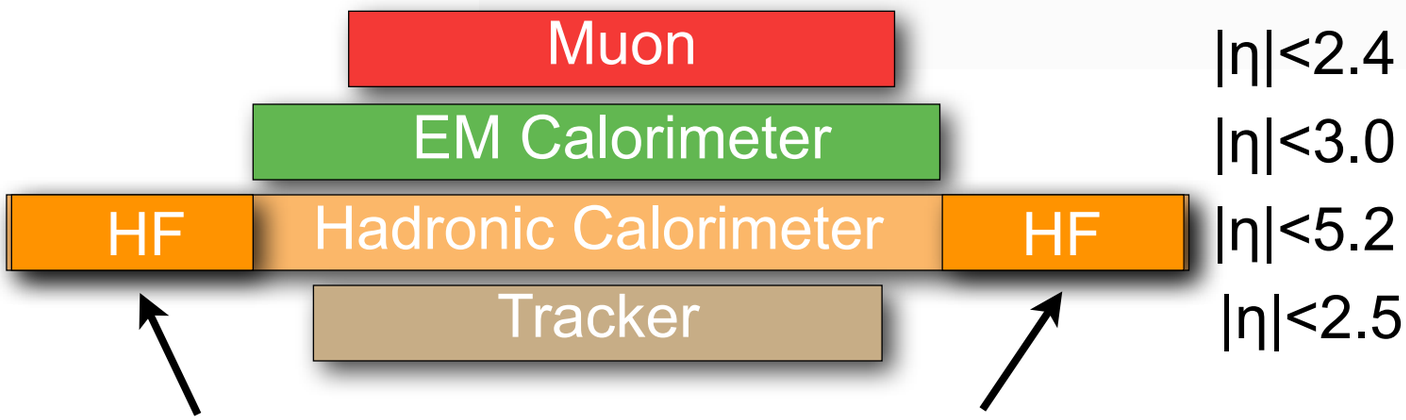
Ultra-central Collision Anisotropy (Wei Li)
–Poster: Reception–

High-p_T Anisotropy (Victoria Zhukova)
–Tuesday 3:55 p.m.–

Very high-p_T Dihadron Correlations (Rylan Conway)
–Tuesday 3:15 p.m.–

CMS Experiment



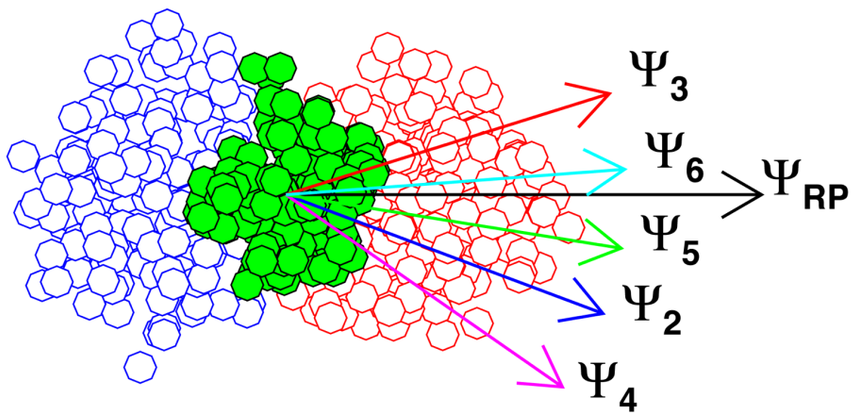


Event-plane determination

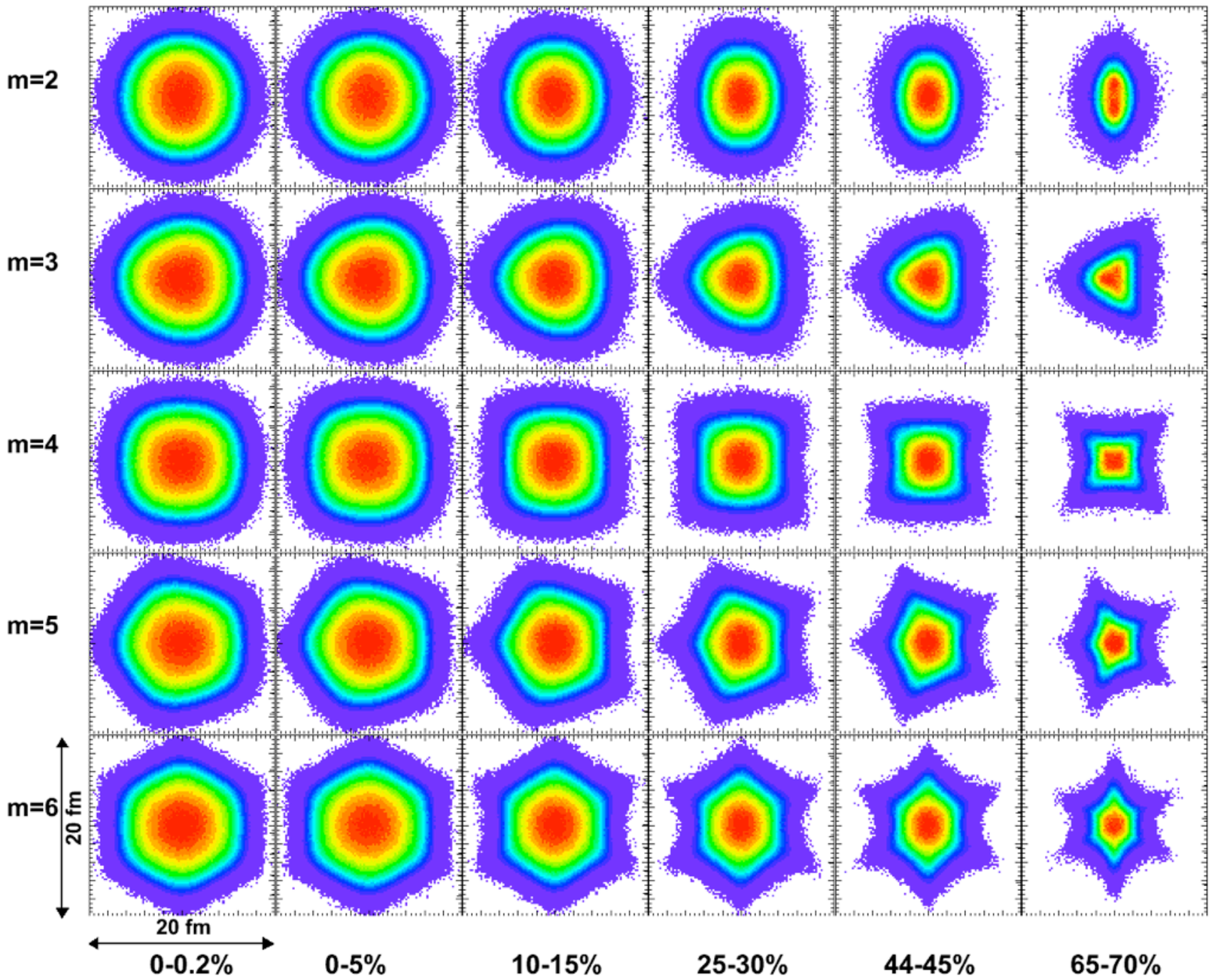
Correlations with Participant Plane

$$\frac{d^3N}{p_T dp_T d\eta d\phi} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T d\eta}\left(1+\sum_{k=1}^{\infty} 2v_{n=km}(p_T,\eta)\cos\left[n\left(\phi-\Psi_m\right)\right]\right)$$

Glauber Picture



$$\Psi_m^{pp} = \frac{1}{m}\tan^{-1}\left\{\frac{\sum_{i=1}^{N_{part}} r_i^m \sin(m\phi_i)}{\sum_{i=1}^{N_{part}} r_i^m \cos(m\phi_i)}\right\} - \frac{\pi}{m}$$

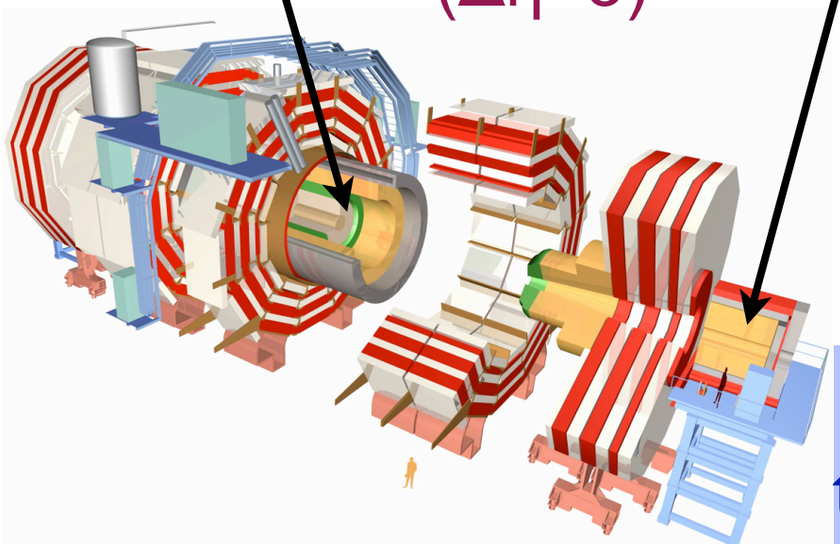


Participant density relative to m[th]-order participant plane.

Elliptic Flow (n=2)

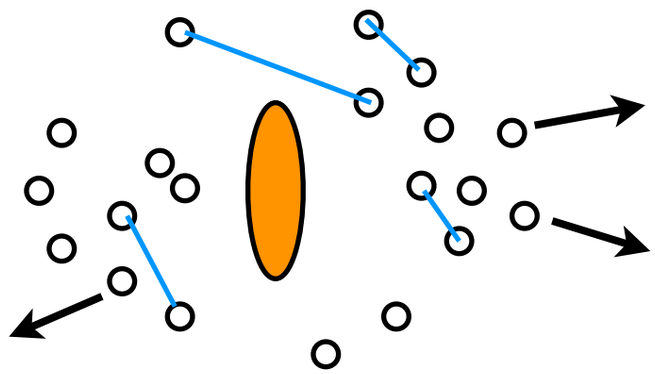
Event Plane

Correlate particles in tracker with those in HF. ($\Delta\eta>3$)



Two-particle Cumulant

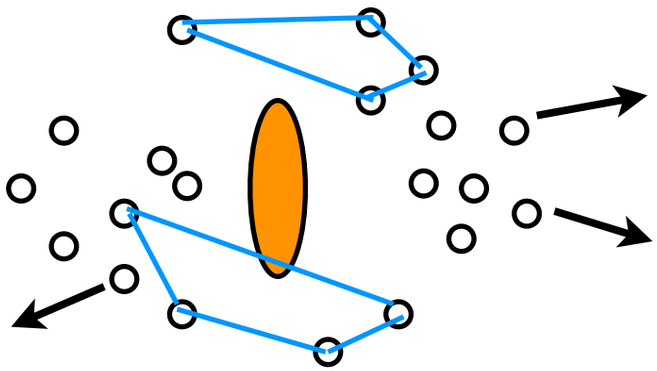
Consider all two-particle correlations.



Methods have different sensitivity to event-by-event fluctuations and non-flow effects.

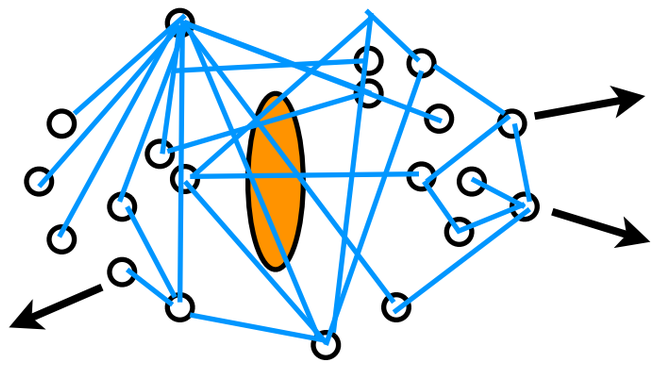
Four-particle Cumulant

Consider all four-particle correlations.



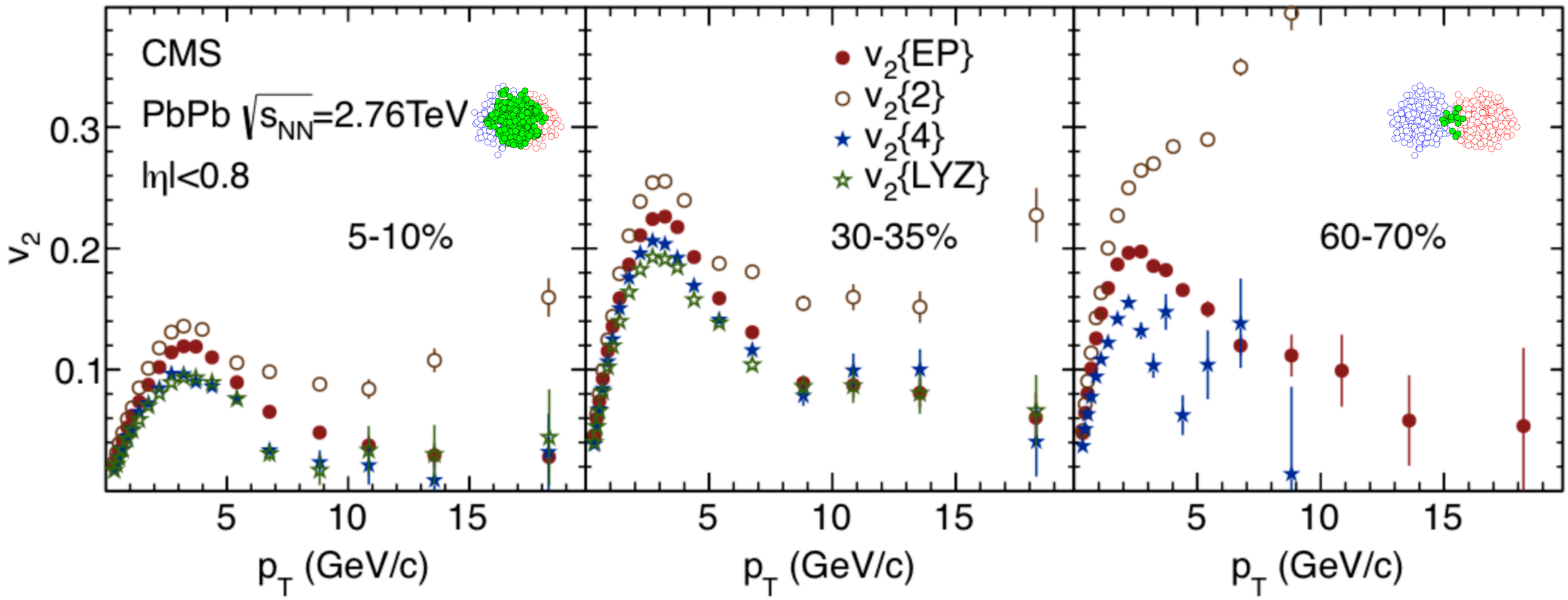
Lee-Yang Zeros

Consider all particle correlations -(Not all shown!).



Elliptic Flow (n=2)

Eric Appelt: Parallel 6D



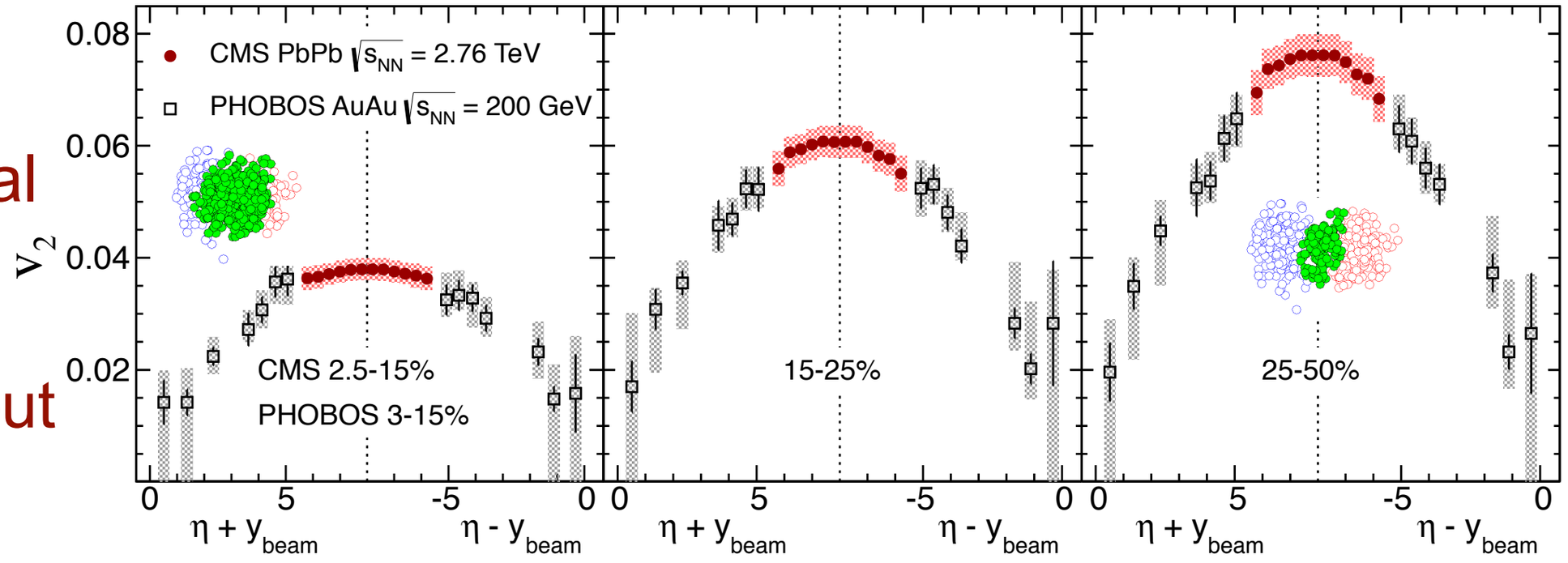
- v_2{EP} determined with 3-unit η-gap between EP and v_2 tracks to suppress non-flow effects.
- v_2{4} and v_2{LYZ} inherently suppress non-flow effects.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

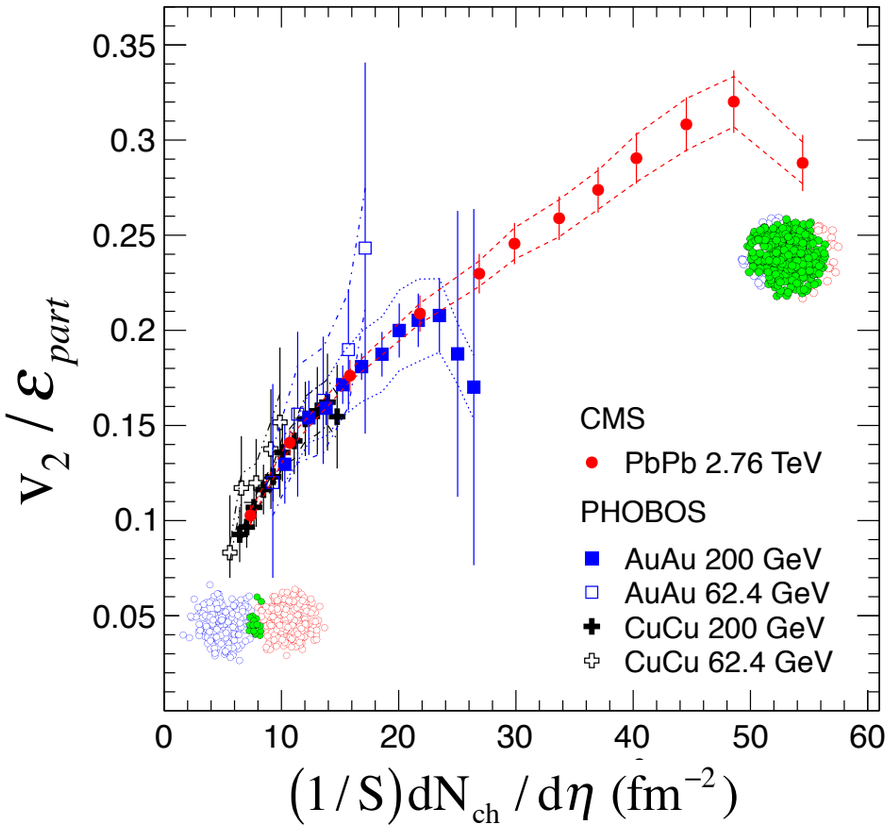
Elliptic Flow Scaling (n=2)

Eric Appelt: Parallel 6D

- ***Extended longitudinal scaling.*** Integral v_2 connects smoothly with RHIC results, but flattens.



- ***Transverse particle density scaling.*** $v_2\{EP\}/\varepsilon_{part}$ scales with transverse particle density over very large beam energy range.

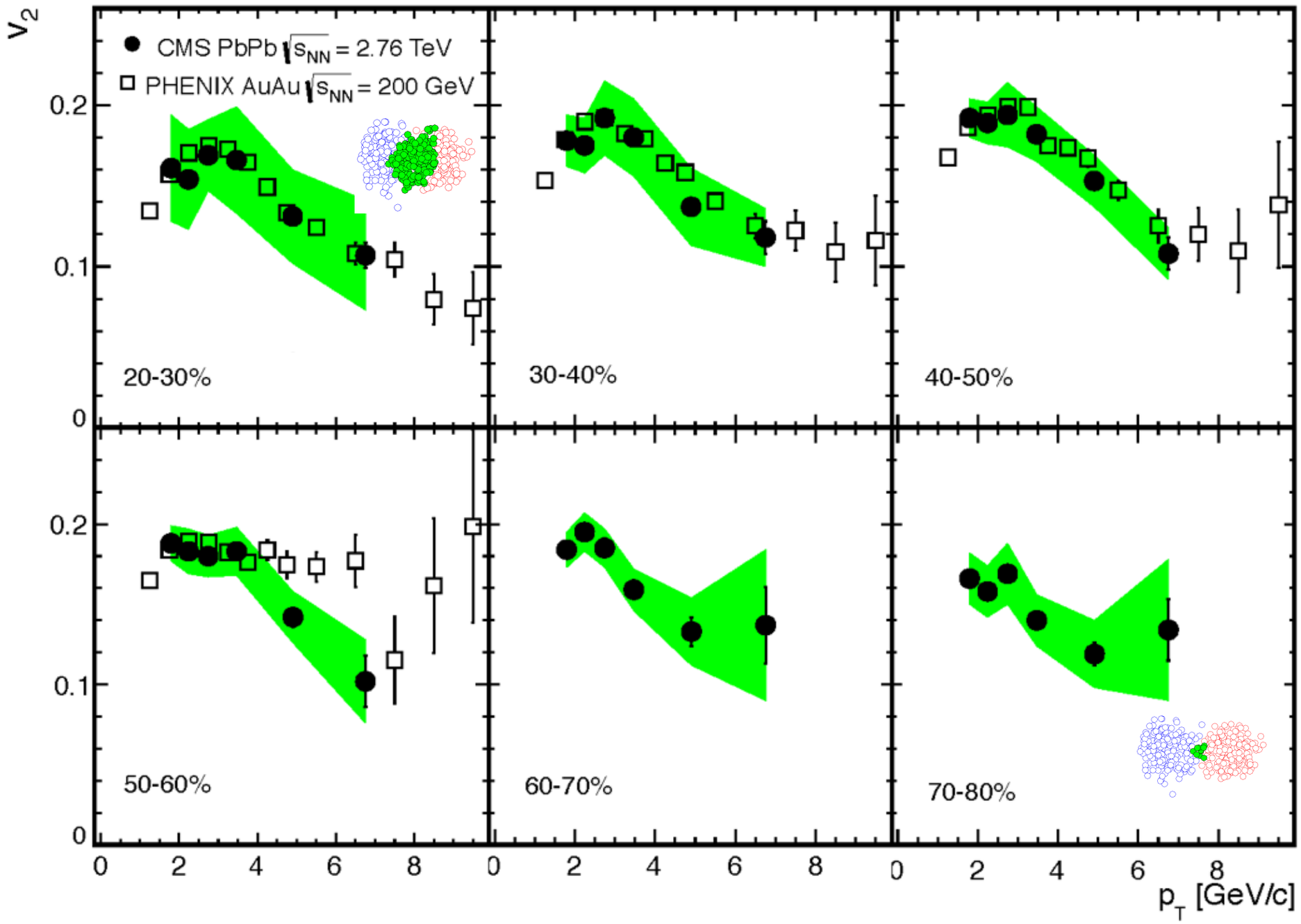


π⁰ Elliptic Flow (n=2)

- Detected through γγ coincidences.
- Correlated with HF event planes.

Monika Sharma: Poster

Eric Appelt: Parallel 6D

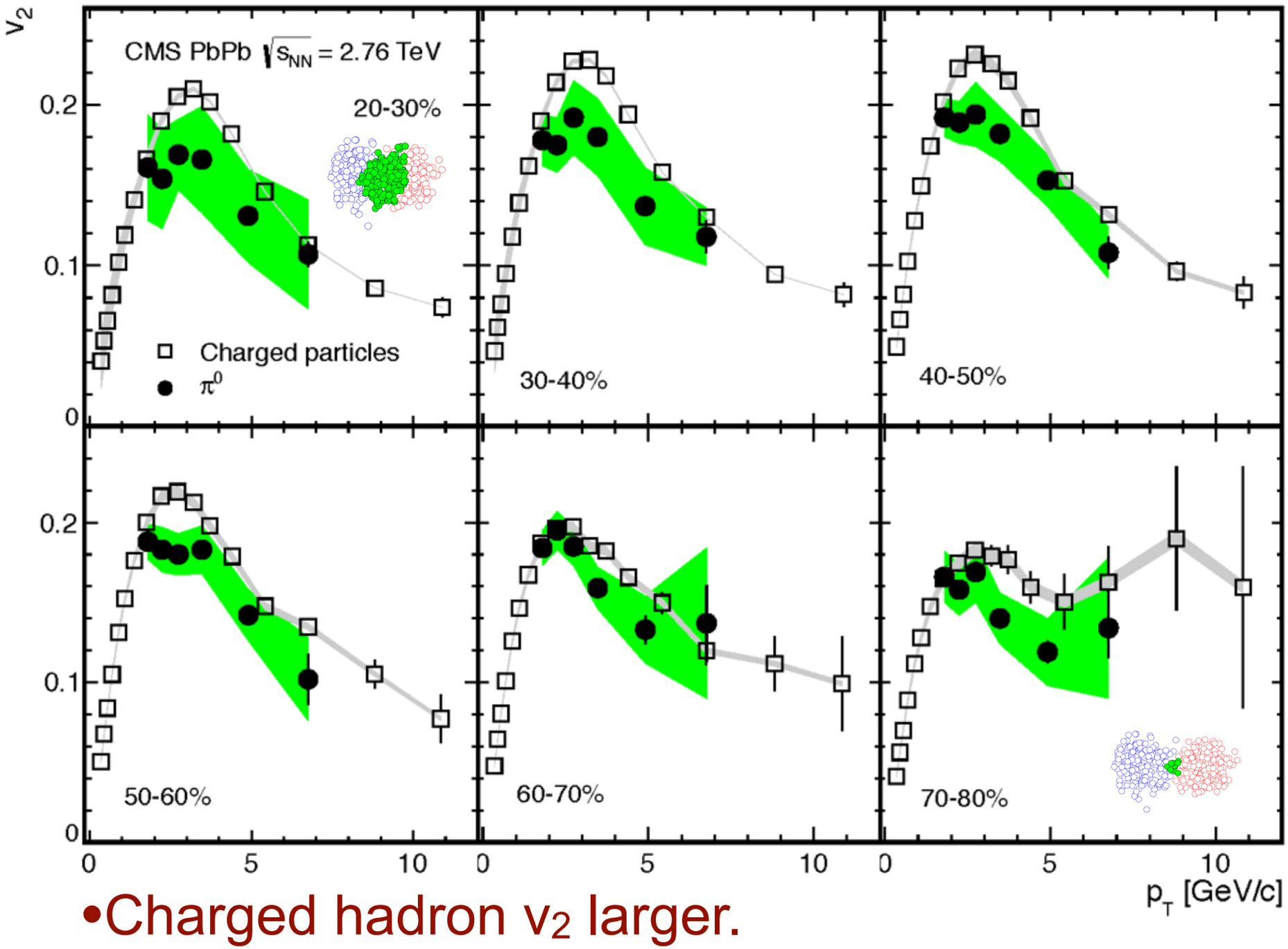


- With x14 increase in energy, no significant change from RHIC.

π° Elliptic Flow (n=2)

Monika Sharma: Poster

Eric Appelt: Parallel 6D

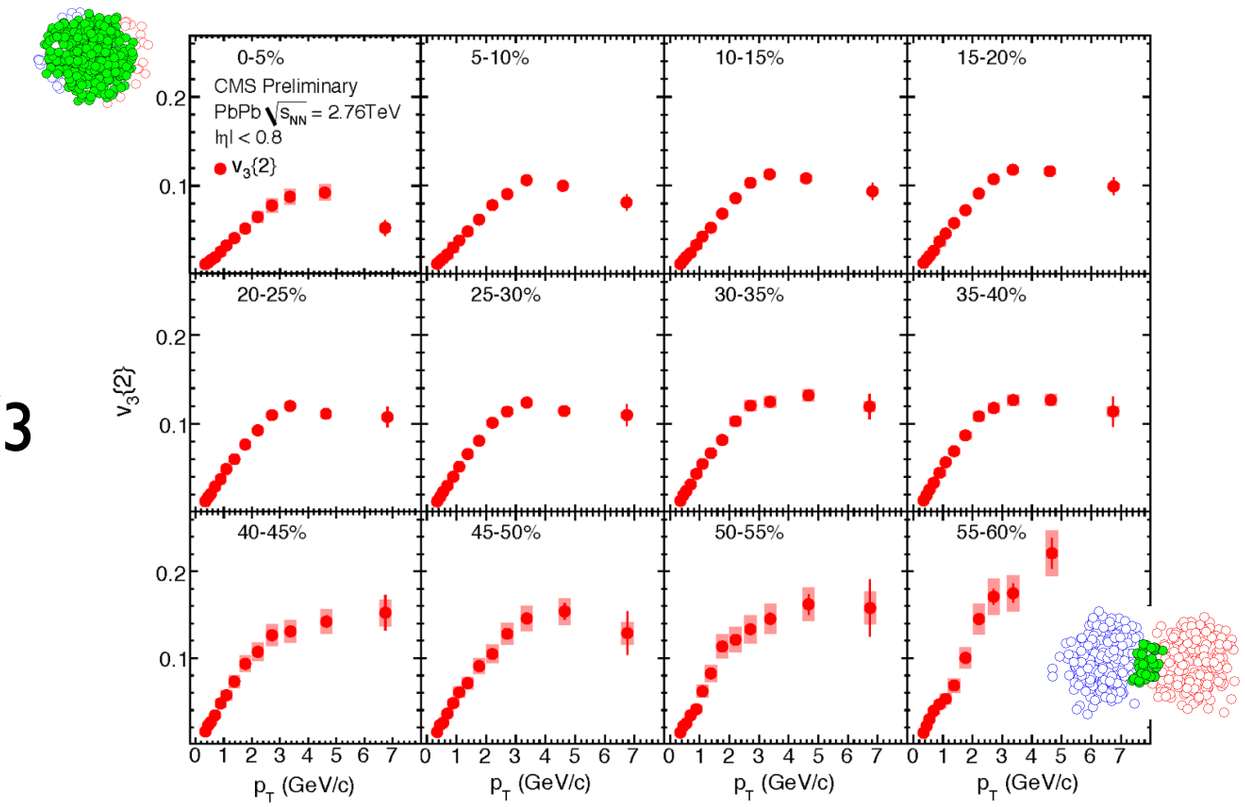


- Charged hadron v_2 larger.
- Consistent with higher v_2 for baryons.

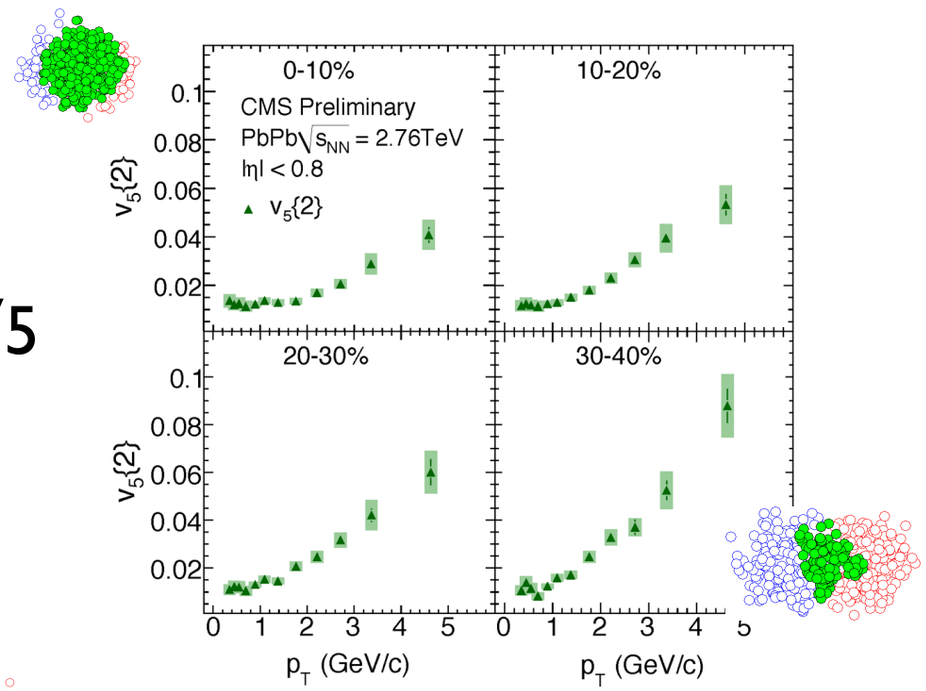
Higher-harmonics Anisotropy (n>2)

Shengquan Tuo: Parallel 7D

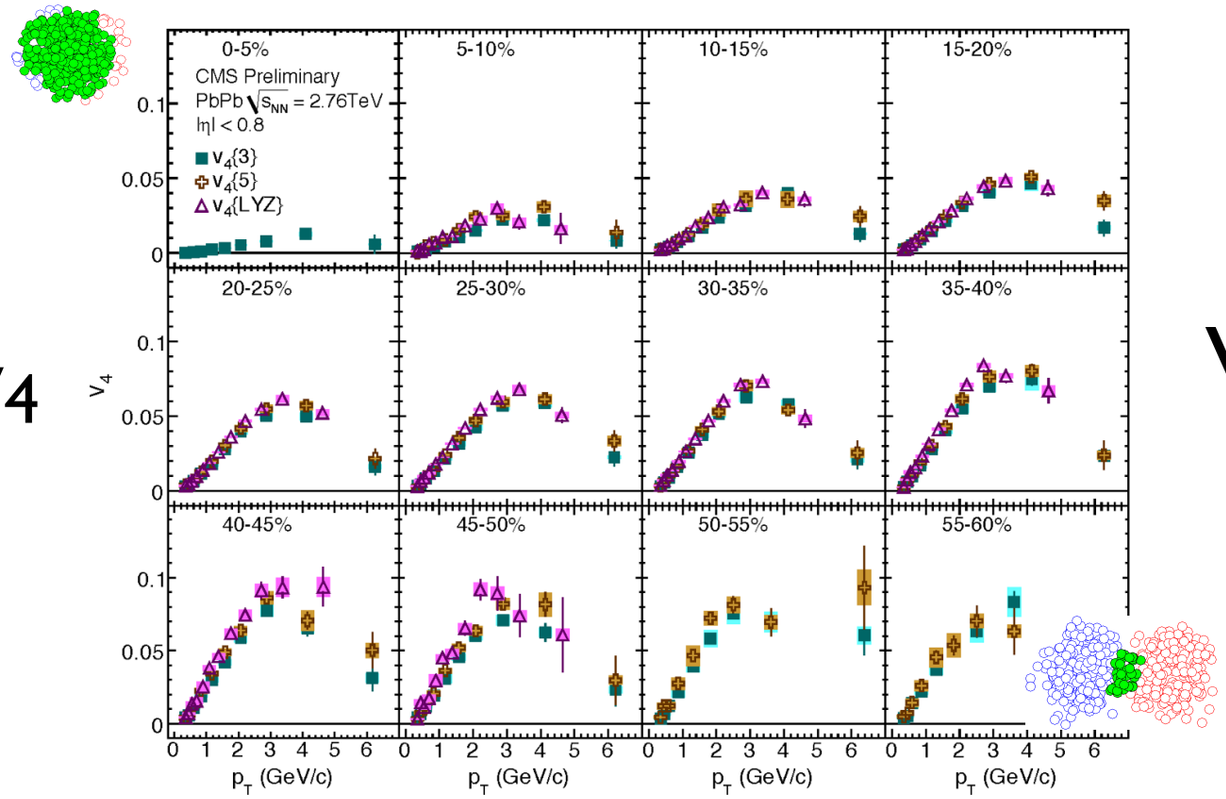
v_3



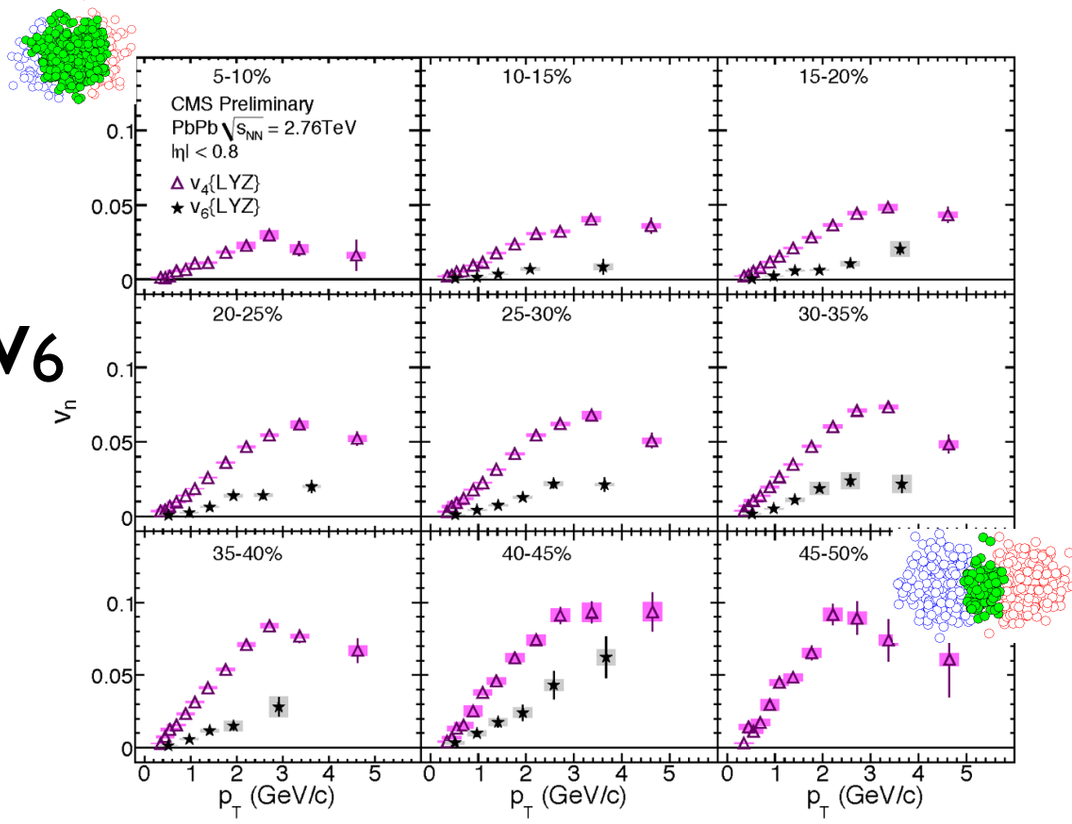
v_5



v_4



v_4&v_6



Higher-Harmonics Anisotropy (n>2)

Add dihadron correlations to analysis
mix of cumulants and Lee-Yang zeros...

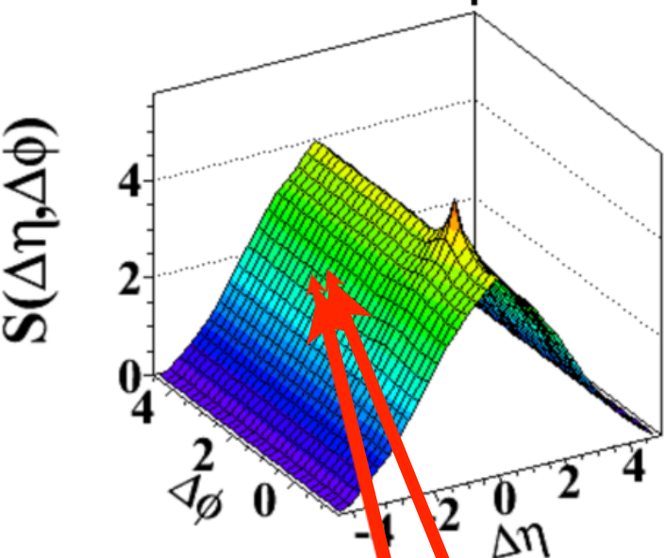
Signal pair distribution:

$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\varphi}$$

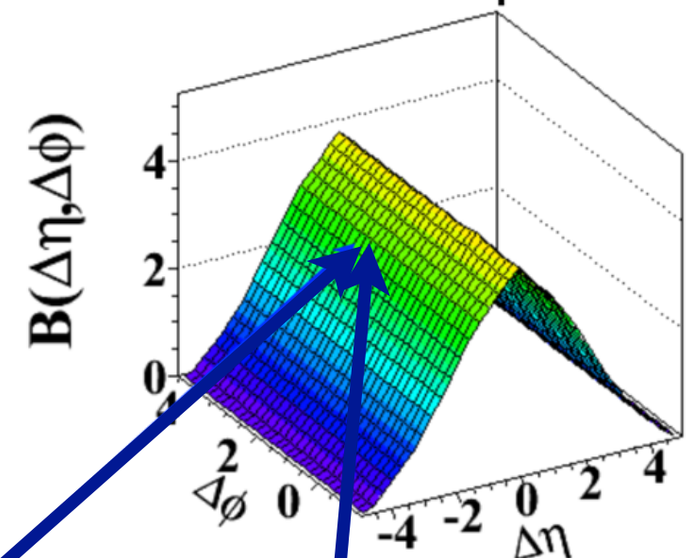
Background pair distribution:

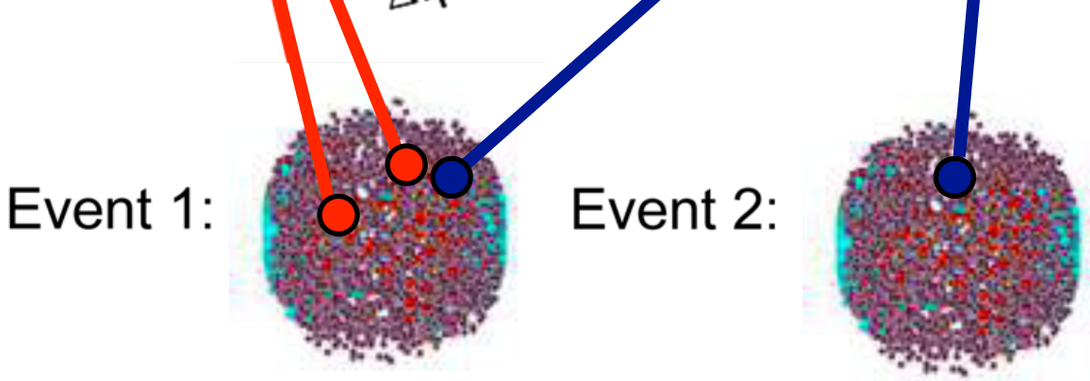
$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$

same event pairs



mixed event pairs





$\Delta\eta=\eta_{trig}-\eta_{assoc}$

$\Delta\Phi=\Phi_{trig}-\Phi_{assoc}$

Higher-Harmonics Anisotropy (n>2)

Add dihadron correlations to analysis mix of cumulants and Lee-Yang zeros...

Shengquan Tuo: Parallel 7D

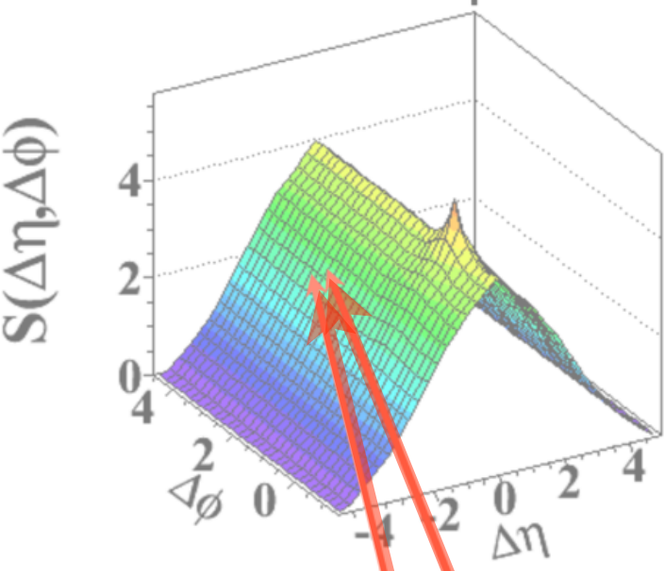
Signal pair distribution:

$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\varphi}$$

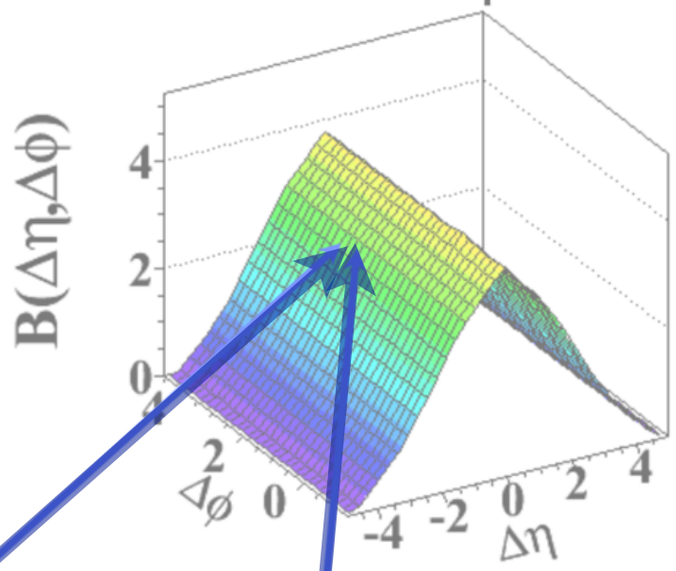
Background pair distribution:

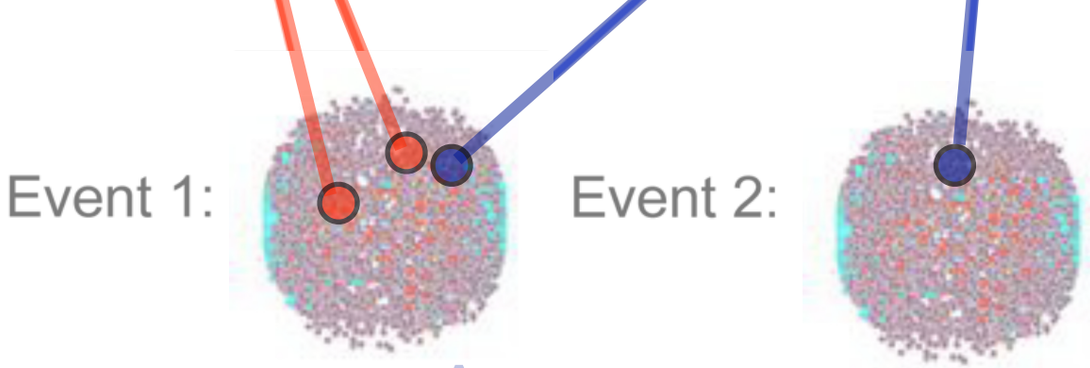
$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$

same event pairs



mixed event pairs

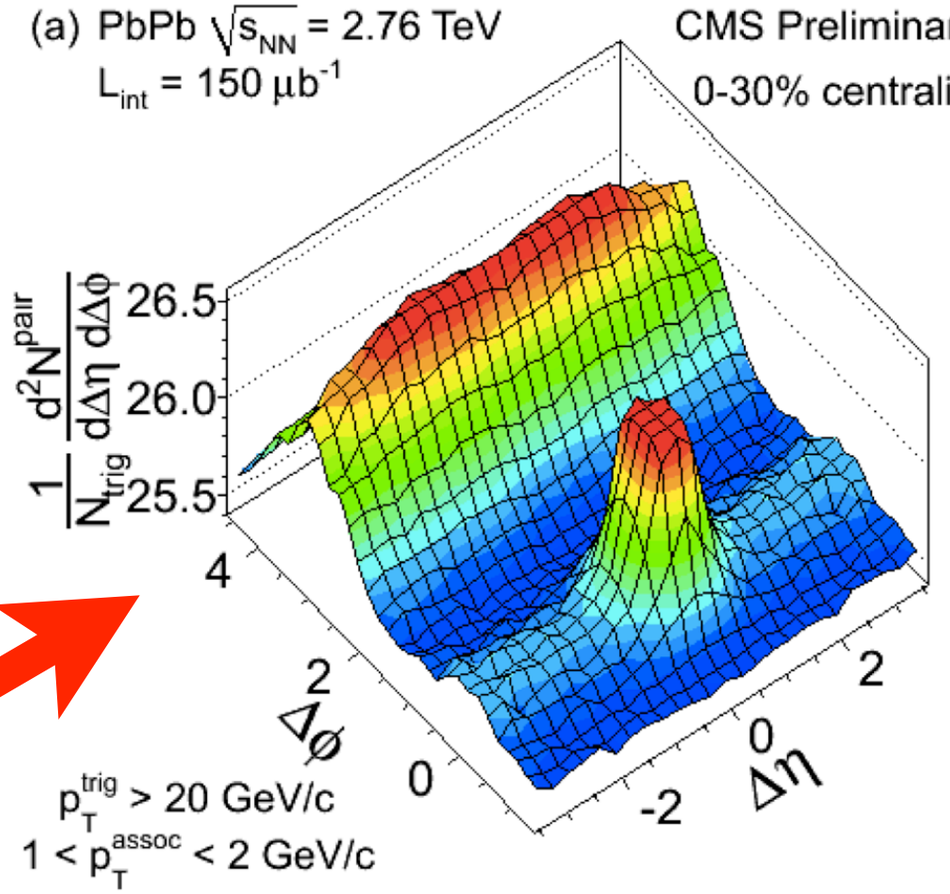




$\Delta\eta=\eta_{trig}-\eta_{assoc}$

$\Delta\Phi=\Phi_{trig}-\Phi_{assoc}$

Associated Hadron Yield per Trigger



$$\frac{dN^{pair}}{d\Delta\phi} \sim 1 + 2\sum_{n=1} V_{n\Delta}\cos(n\Delta\phi)$$

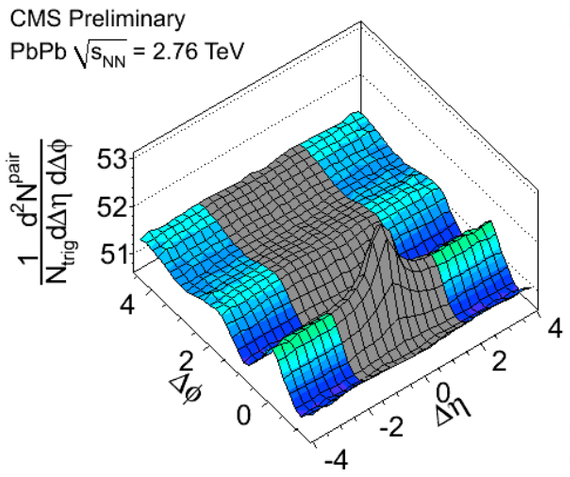
Low-p_T and high-$\Delta\eta$ factorization:

$$V_{n\Delta} = v_n\left(p_T^{trig}\right) \times v_n\left(p_T^{assoc}\right)$$

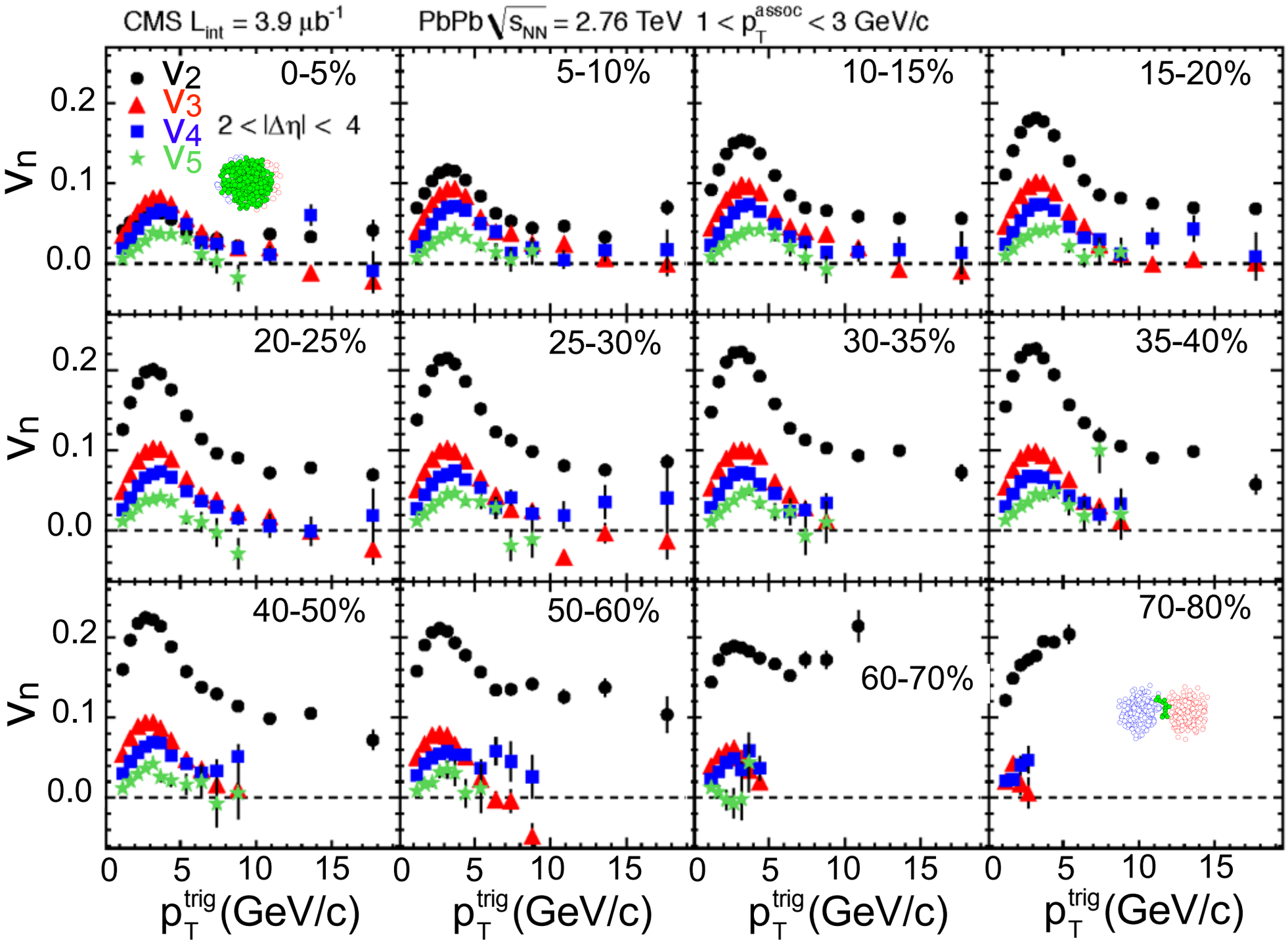
Higher-Harmonics Anisotropy (n>2)

Dihadron Correlation Results |Δη|>2

Shengquan Tuo: Parallel 7D

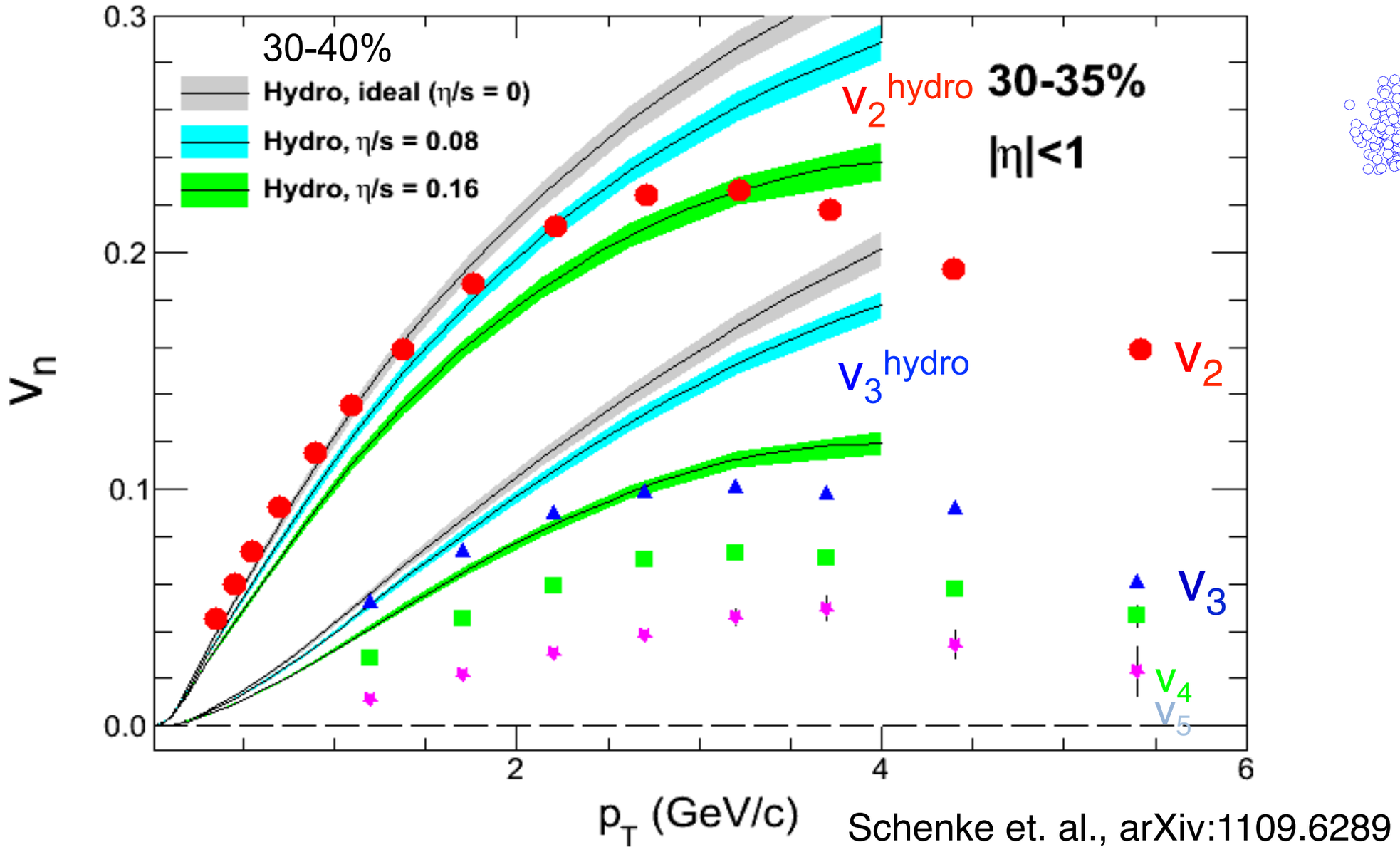


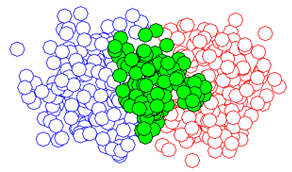
- Little change of n>2 harmonics with centrality.



Higher-Harmonics Anisotropy (n>2)

Shengquan Tuo: Parallel 7D





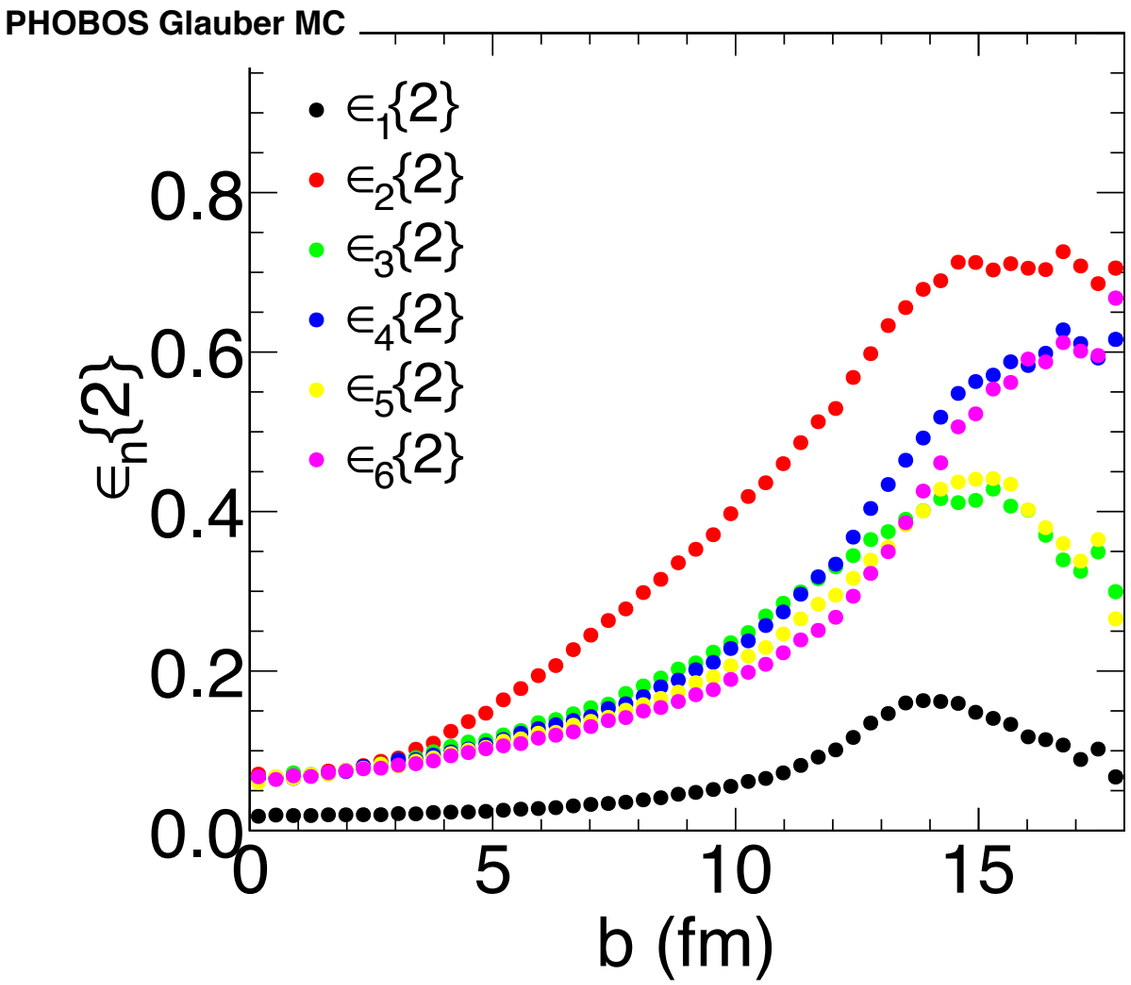
Schenke et. al., arXiv:1109.6289

- Reasonable scaling of theory with harmonic.
- η/s close to quantum limit.

Ultra-Central Collisions

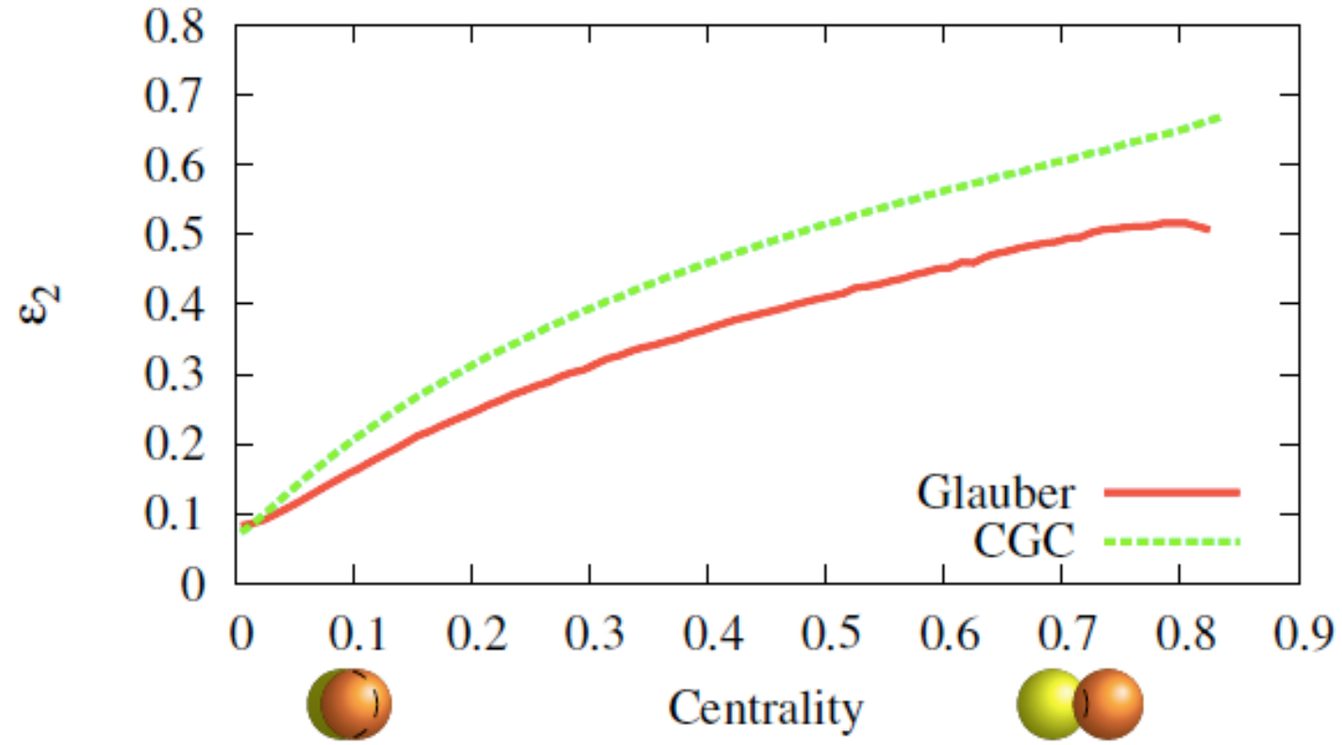
Wei Li: Poster

Why Ultra Central?



- Comparable excitation of all harmonics >1.

Matt Luzum, QNP 2012



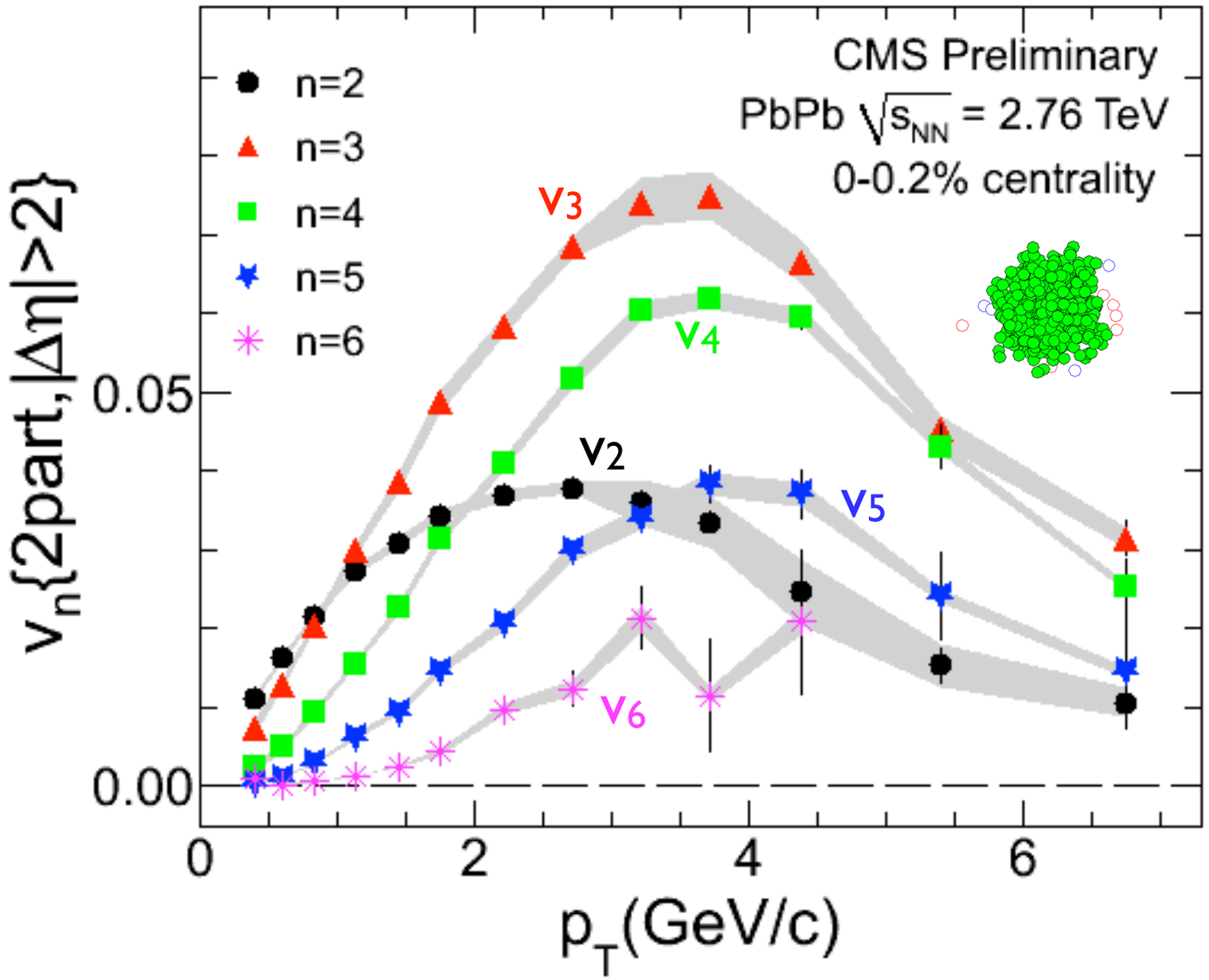
- Influence of initial conditions minimized.

Ultra-central Collisions

Wei Li: Poster

Centrality<0.2%.
Dihadron correlation results.

- Higher harmonics strongly excited.
- v_3-v_5 rise above elliptic flow (v_2) value.



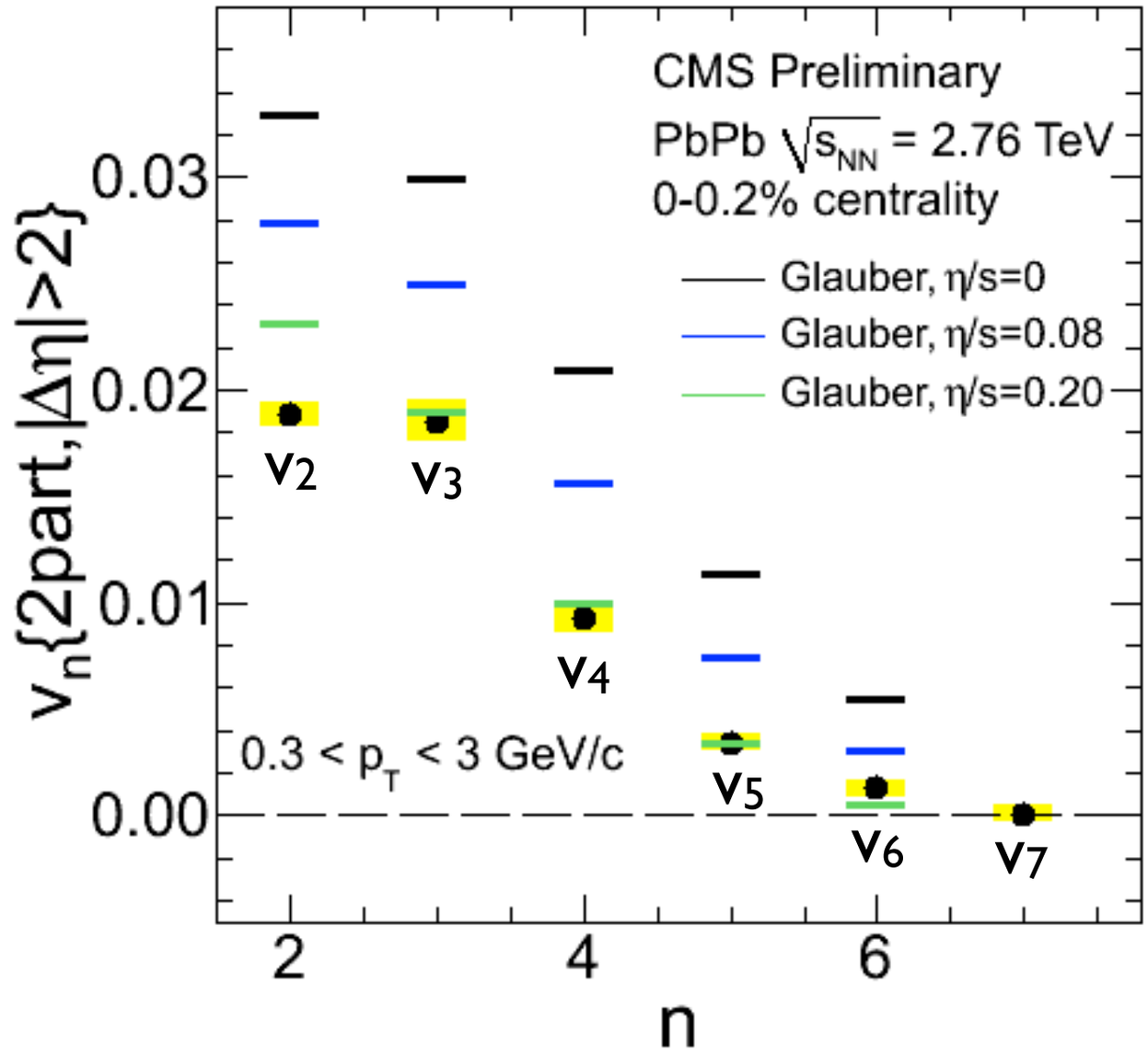
New Ultra-Central Trigger for 2011.

Ultra-central Collisions

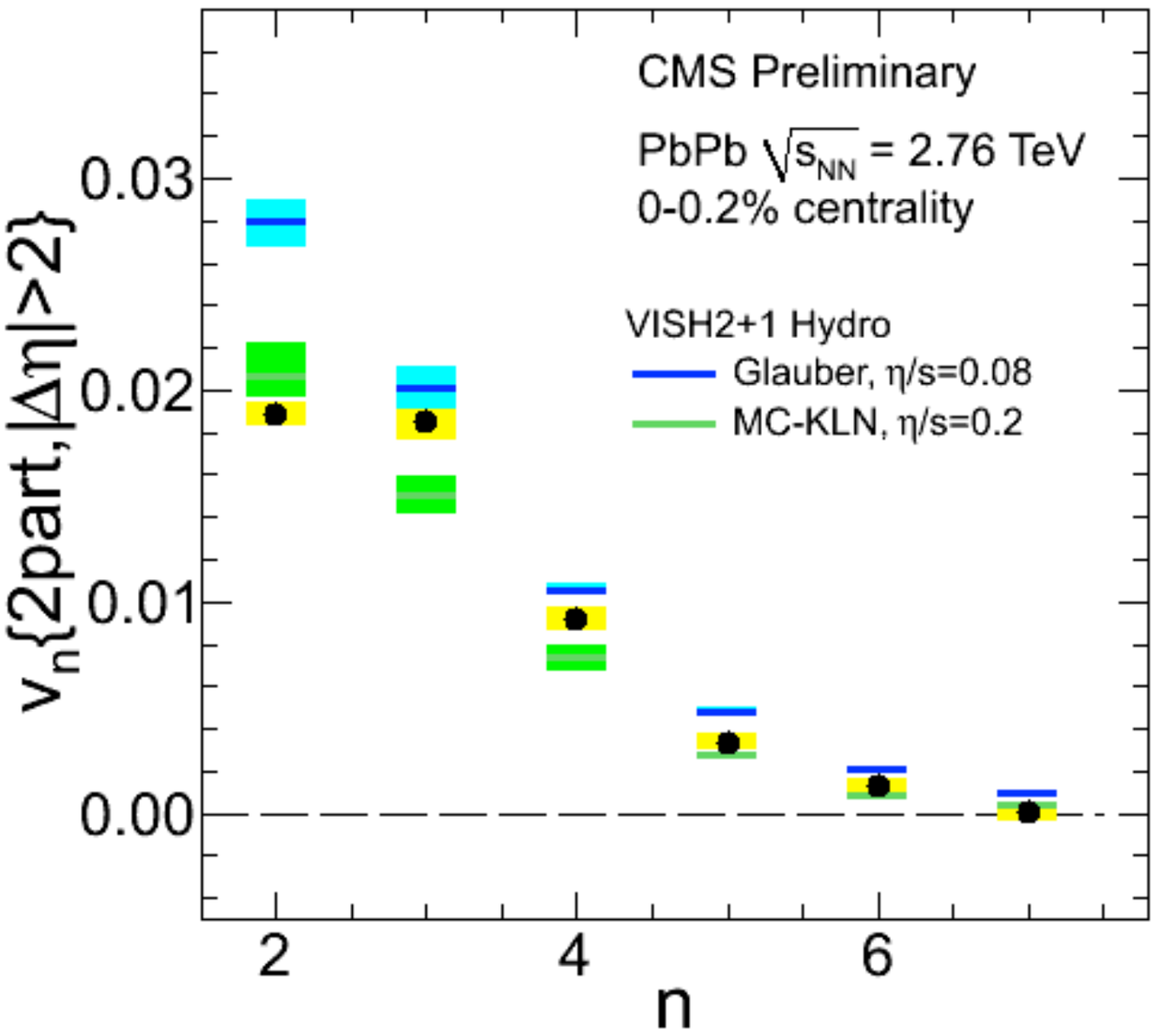
Wei Li: Poster

Shengquan Tuo: Parallel 7D

M. Luzum and J. Ollitrault.



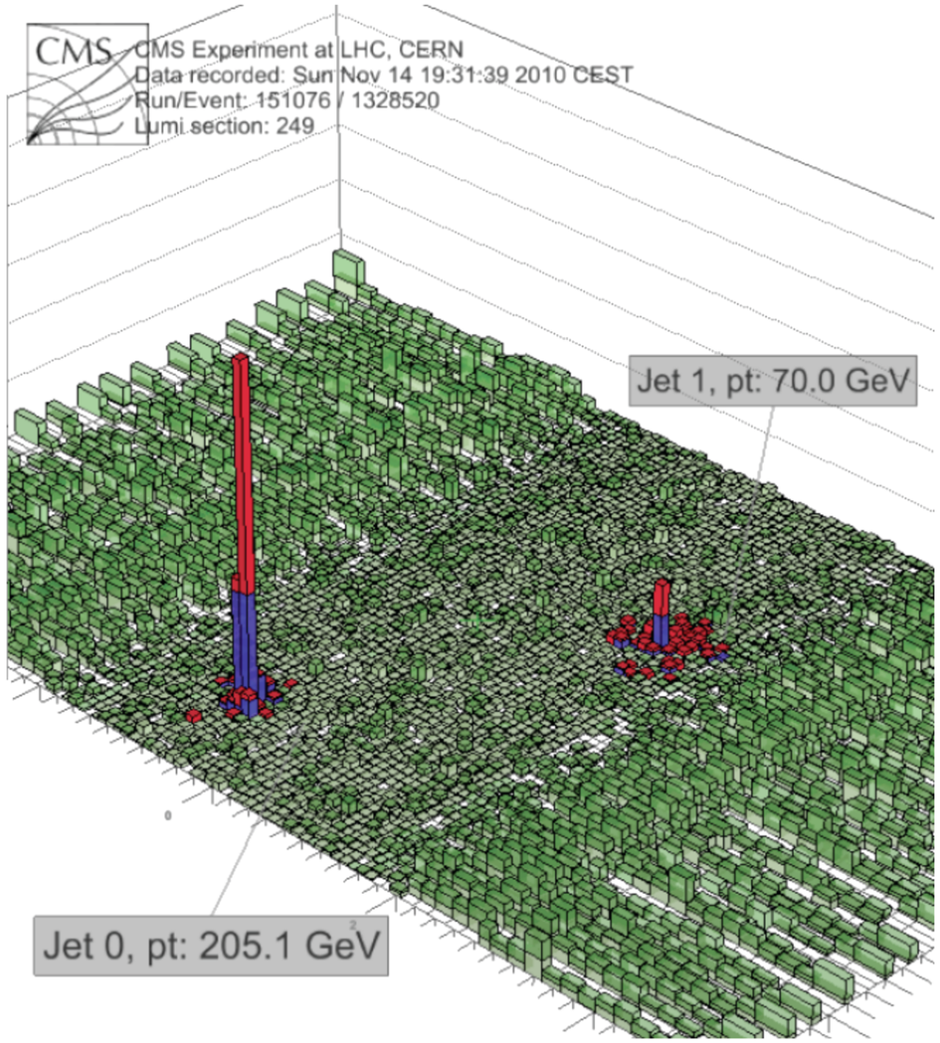
C. Shen, Z. Qiu, and U. Heinz.



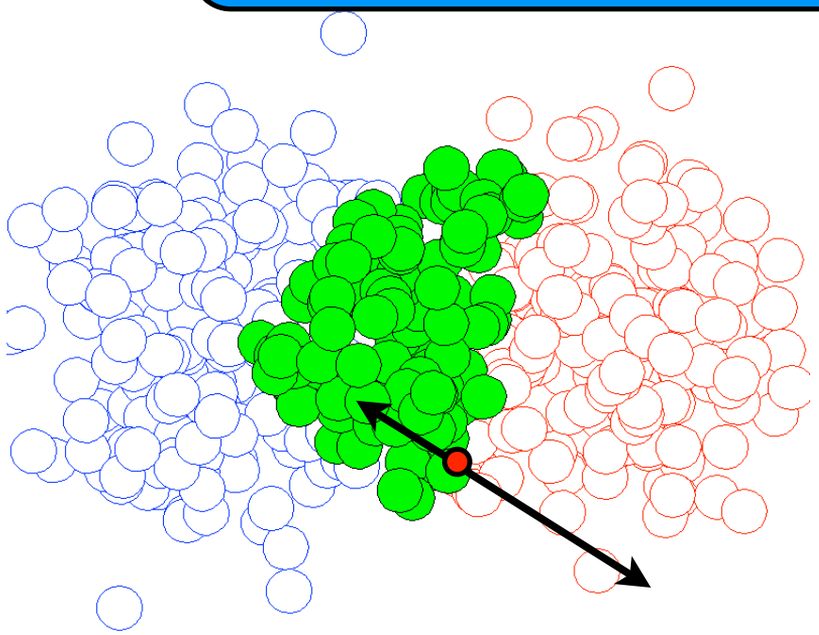
- Good scaling for n>2.
- v_2 breaks from trend.

High-p_T Correlations

Victoria Zhukova: Parallel 1C



CMS Central Collision Dijet Example

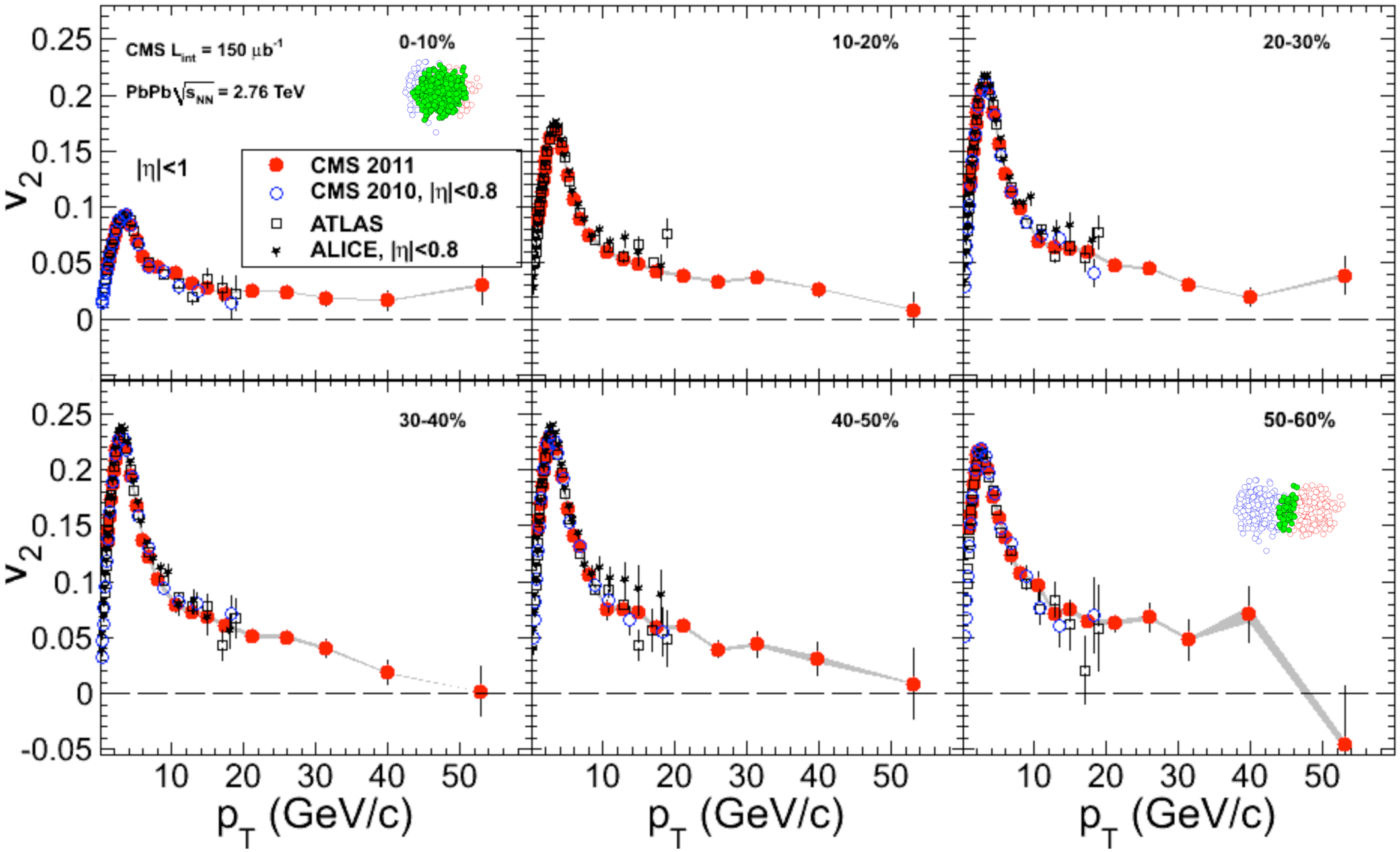


The azimuthal distribution of the high-p_T particles depends on the path-length dependence of the parton energy loss in the medium and can be characterized by a v_2 coefficient.

$$\Delta E \propto \begin{cases} L & \text{pQCD, collisional} \\ L^2 & \text{pQCD, radiative} \\ L^3 & \text{AdS/CFT} \end{cases}$$

High-p_T Correlations

Victoria Zhukova: Parallel 1C



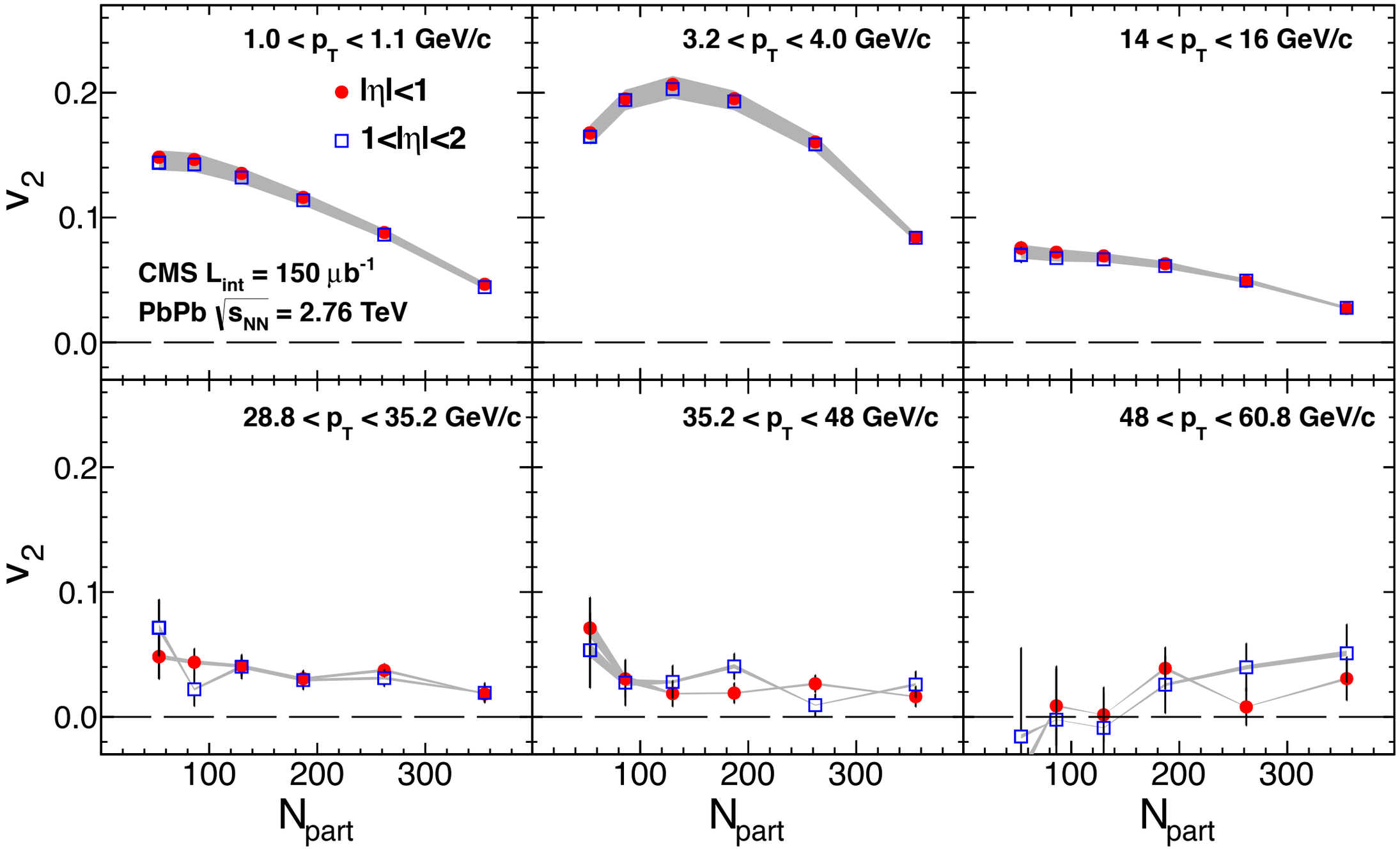
- $v_2(p_T)$ persists to at least 40 GeV/c.

ATLAS: Phys. Lett. B 707, 330 (2012)
ALICE: arXiv:1205.5761

New High-p_T Trigger for 2011.

High-p_T Correlations

Victoria Zhukova: Parallel 1C

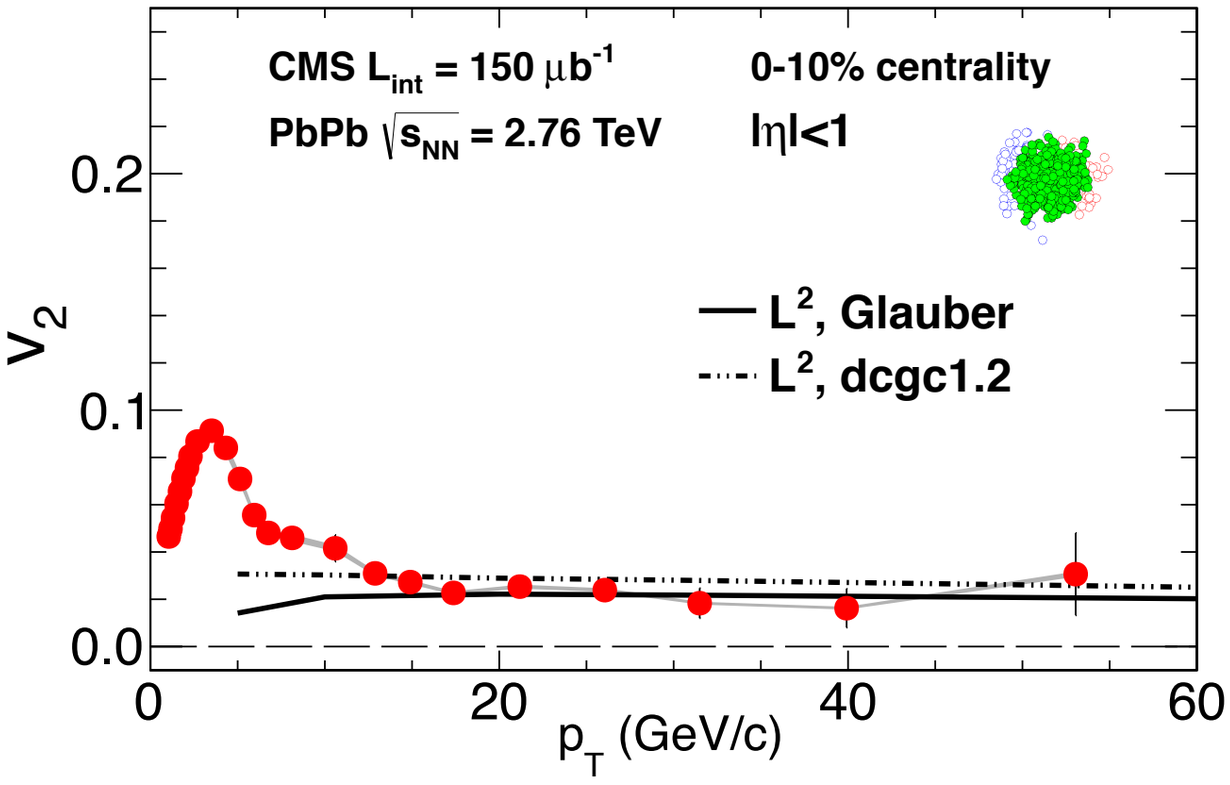


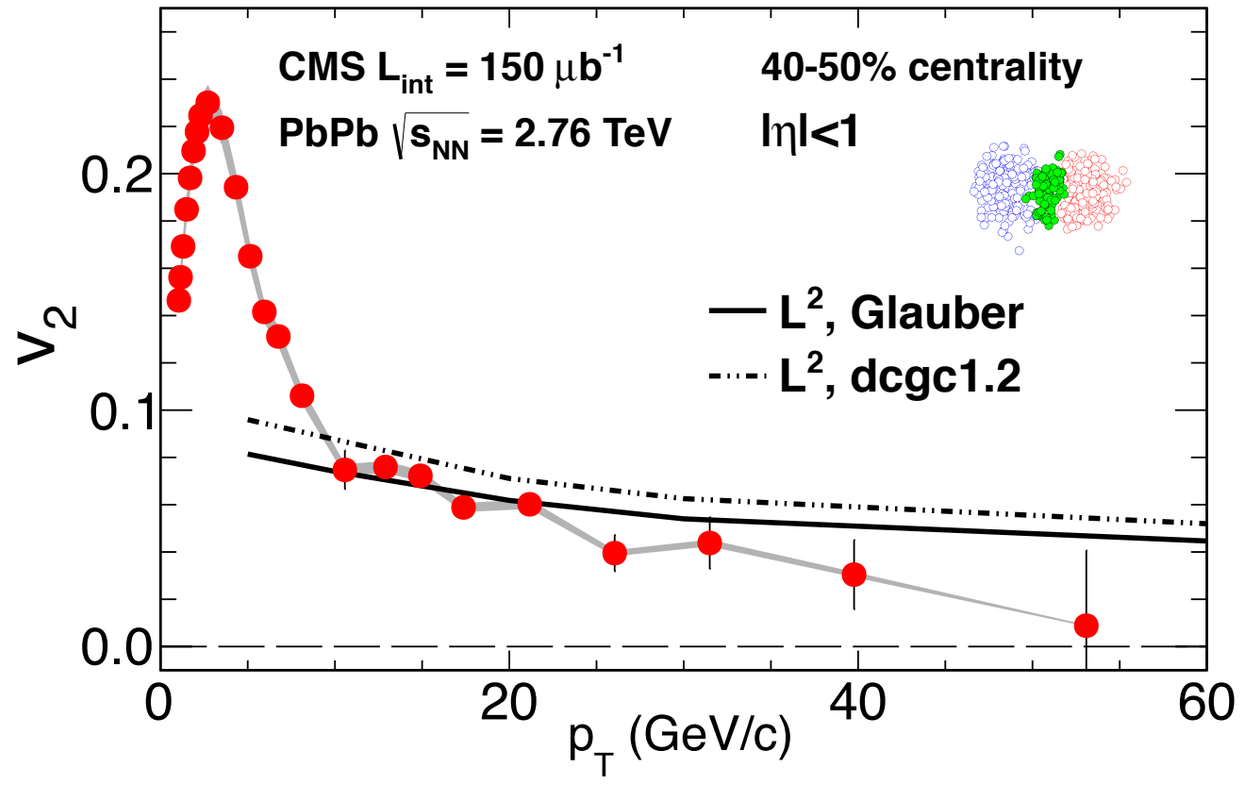
- v_2 at high p_T depends on geometry and remains finite to at least 40 GeV/c for all centralities.

High-p_T Correlations

Victoria Zhukova: Parallel 1C

Theory Comparison (radiative $\Delta E \sim L^2$ scaling):





Theory: B.Betz, M. Gyulassy; arXiv:1201.0281

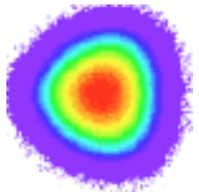
- CMS high-p_T results add significant constraints on jet-quenching scenarios.

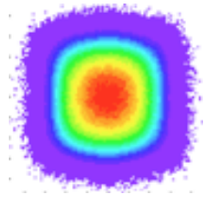
High-p_T Correlations

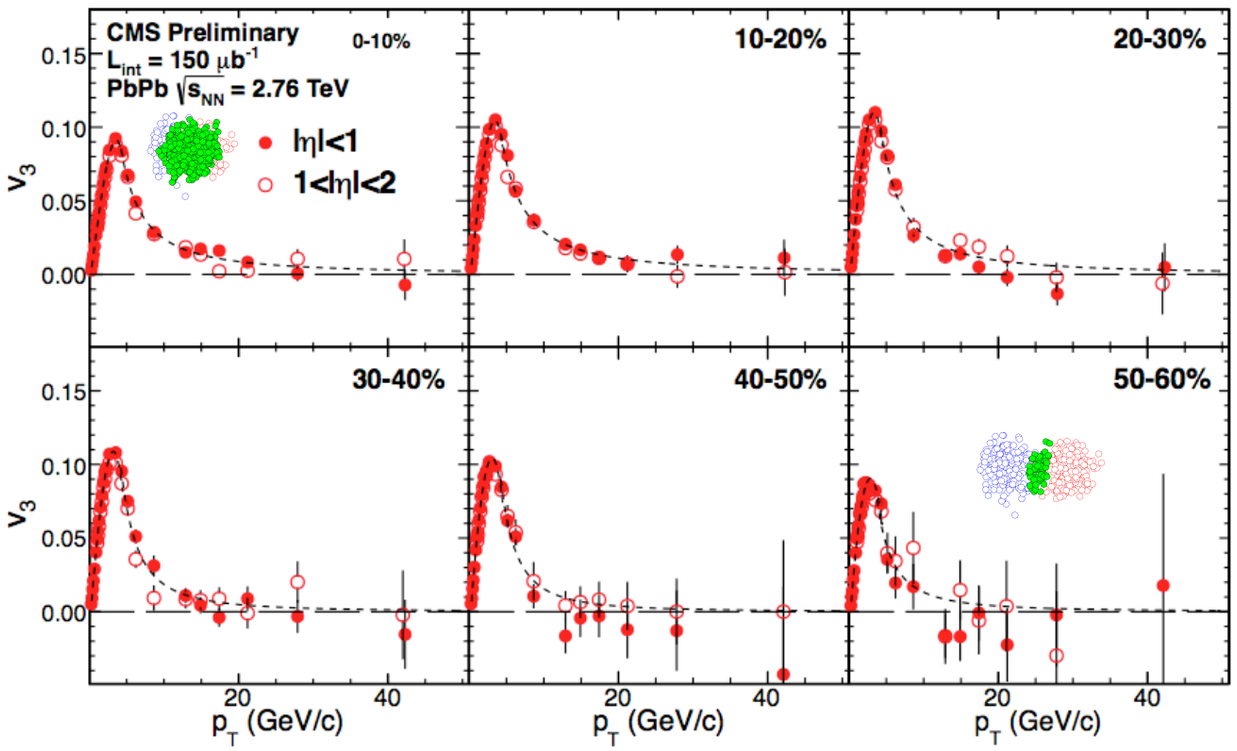
Victoria Zhukova: Parallel 1C

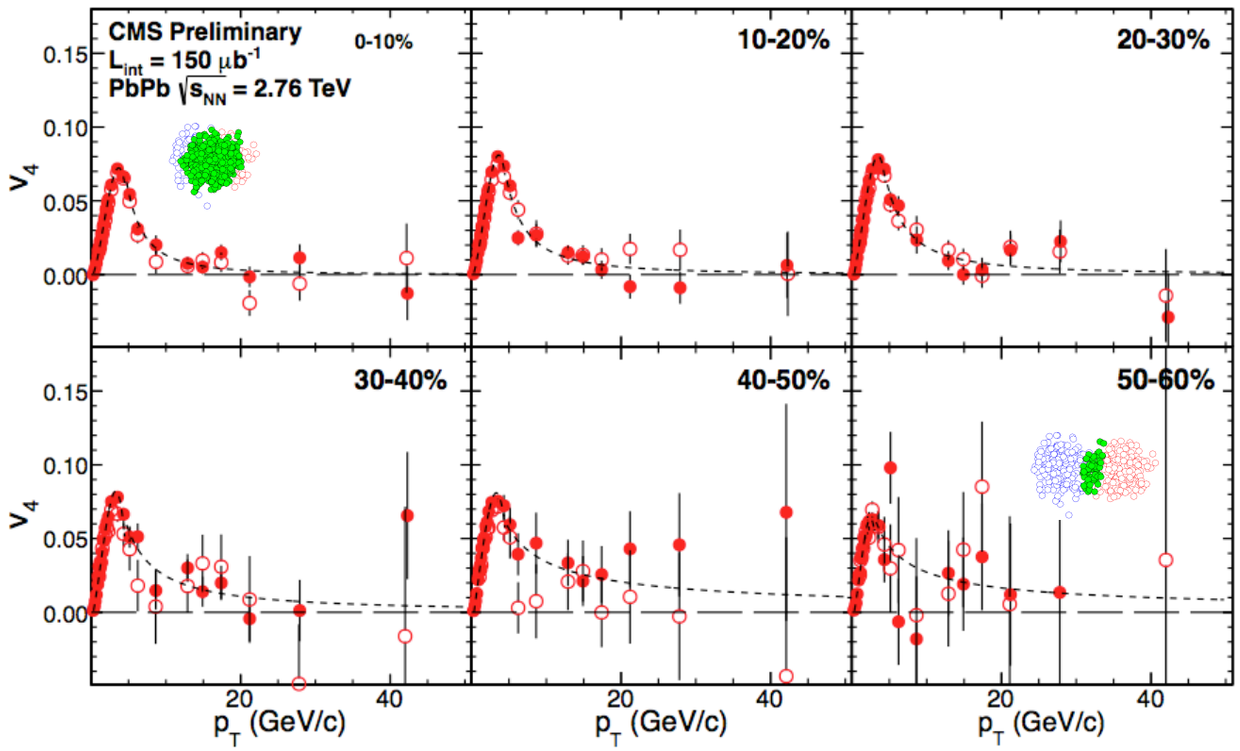
Rylan Conway: Parallel 1C

EP analysis (η_{gap}>3) for v_3 and v_4.

$v_3\{\Psi_3\}$ 

$v_4\{\Psi_4\}$ 





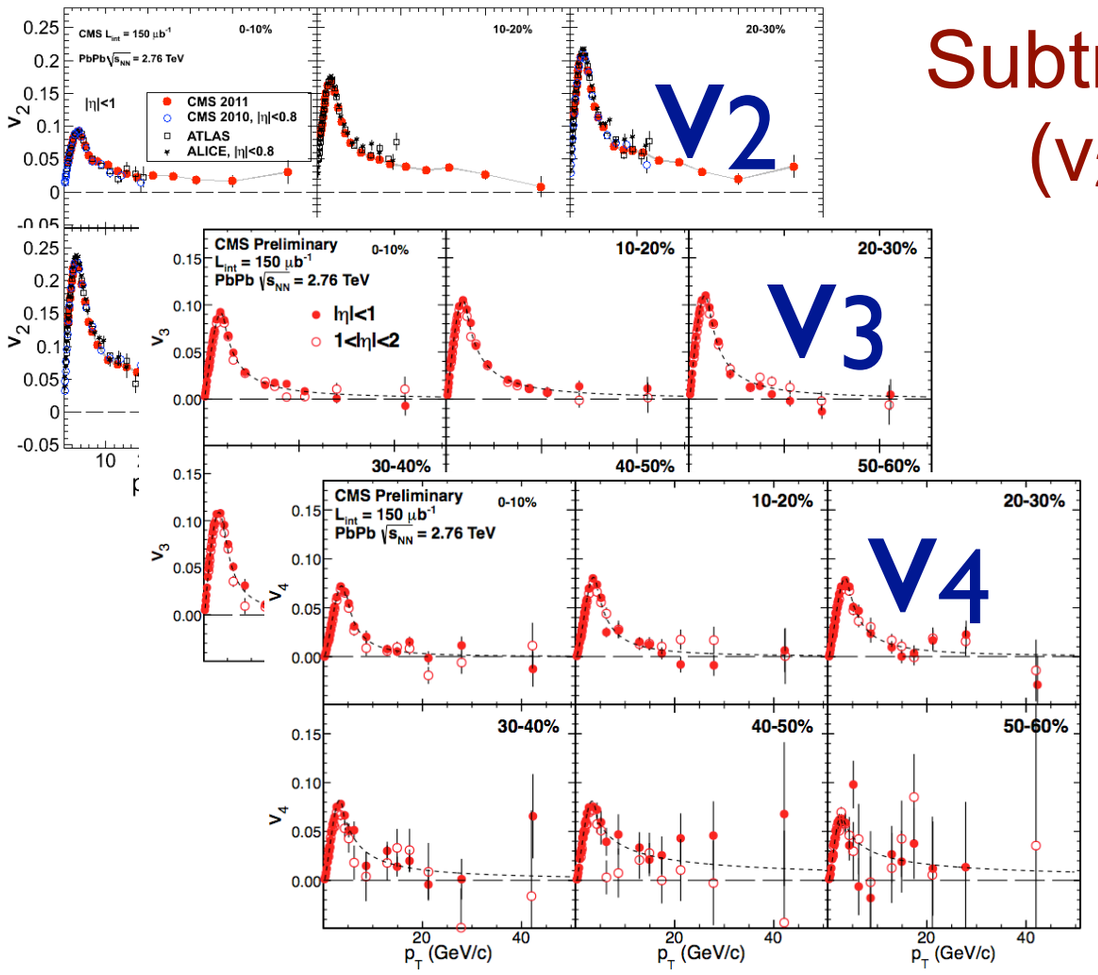
- Asymmetries above 20 GeV/c small.

New High-p_T Trigger for 2011.

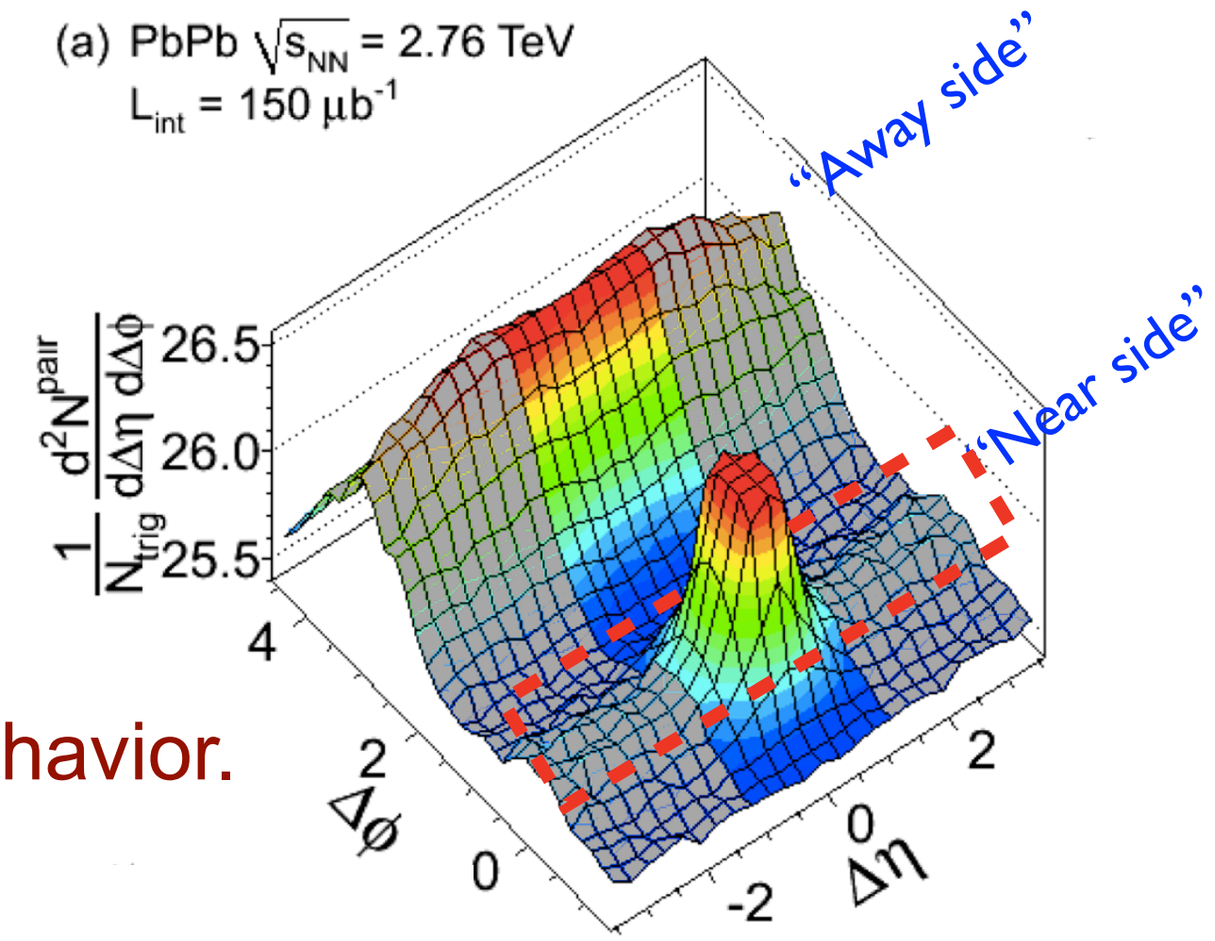
Very High-p_T Dihadron Correlations

Now that we have high-p_T v_n...

Rylan Conway: Parallel 1C



Subtract event-plane related correlations (v_2-v_4) from dihadron correlations...



...to better study dijet behavior.

New High-p_T Trigger for 2011.

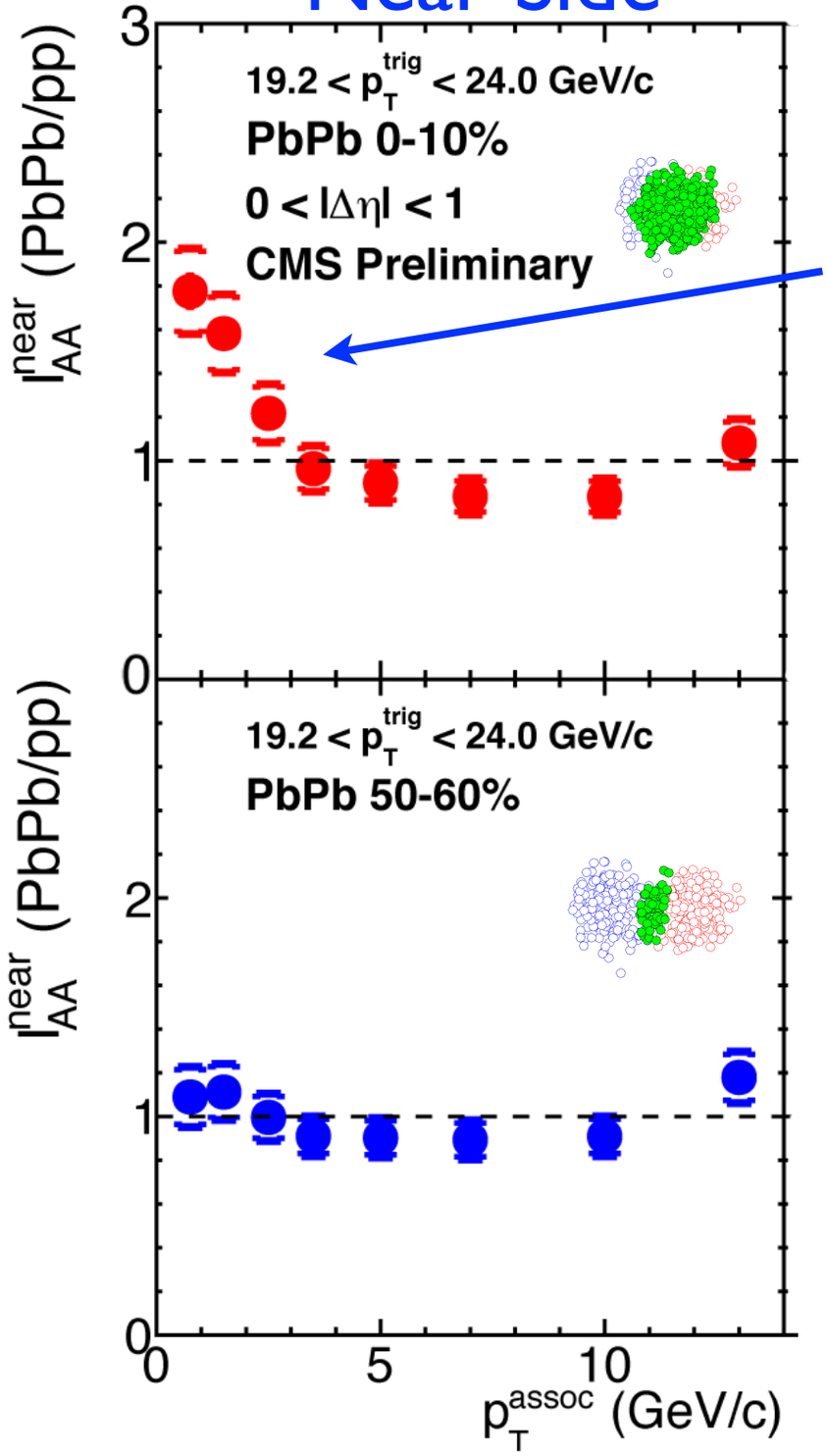
Very High-p_T Dihadron Correlations

Compare to pp:

$$I_{AA} = \frac{Y^{\mathrm{PbPb}}}{Y^{\mathrm{pp}}}$$

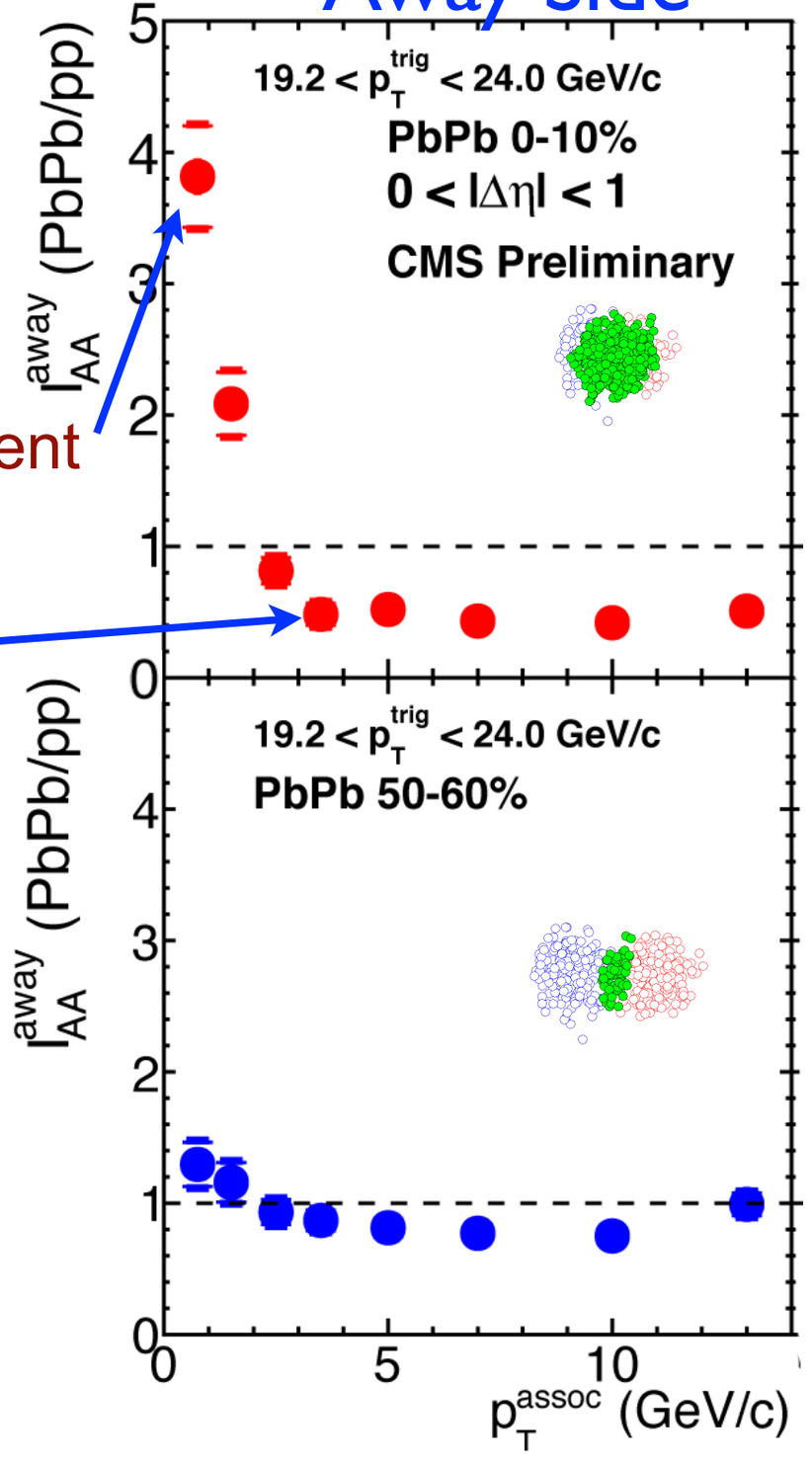
Rylan Conway: Parallel 1C

Near Side



Small low-p_T enhancement for central events.

Away Side

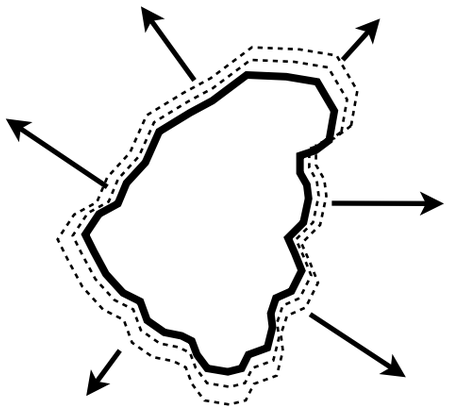


Sigificant low-p_T enhancement for central events.

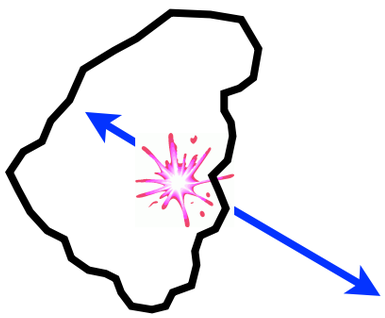
High-p_T deficit for central events.

- Clear medium effects for central events.

Conclusions



- LHC azimuthal asymmetry ≈ RHIC.
- Transverse particle density scaling of $v_2\{EP\}/\varepsilon_{part}$.
- Extended longitudinal scaling persists RHIC to LHC.
- New ultra-central collision trigger places new constraints on η/s, EoS, and initial conditions of created medium.



- Event-plane related azimuthal asymmetries persist to very high p_T.
- Suppression of away-side high-p_T particles accompanied with significant enhancement at low p_T.
- New high-p_T single-track trigger is allowing medium effects to to studied with unprecedented precision.