

Measurement of Fourier components from two-particle correlations in PbPb collisions with CMS

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On behalf of the CMS Collaboration

Hard Probes 2012
Cagliari, Italy



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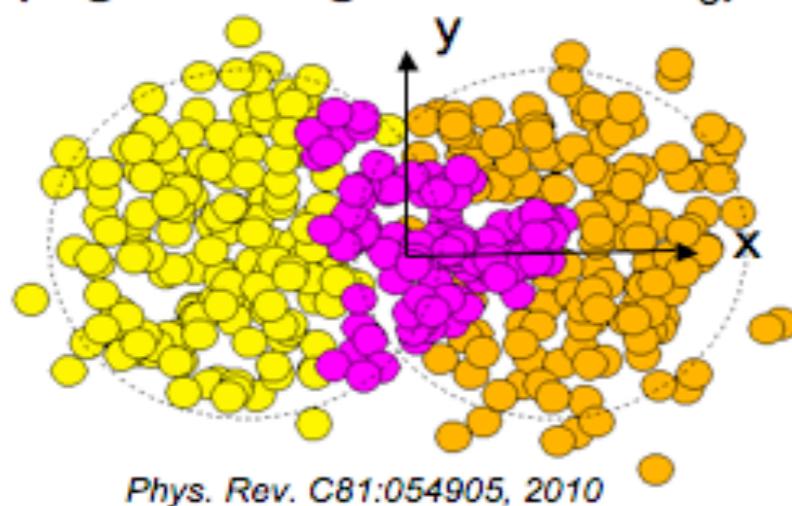


Motivation

Two-particle correlations are powerful tools to:

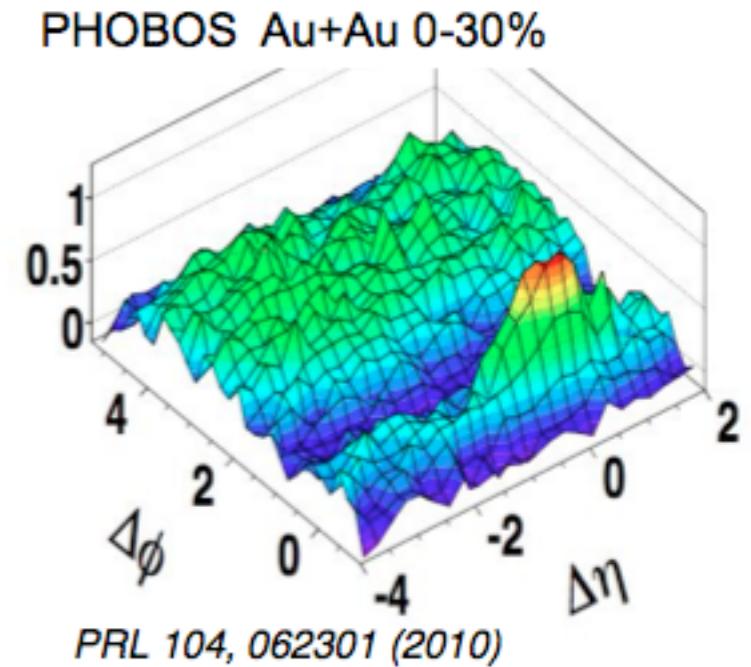
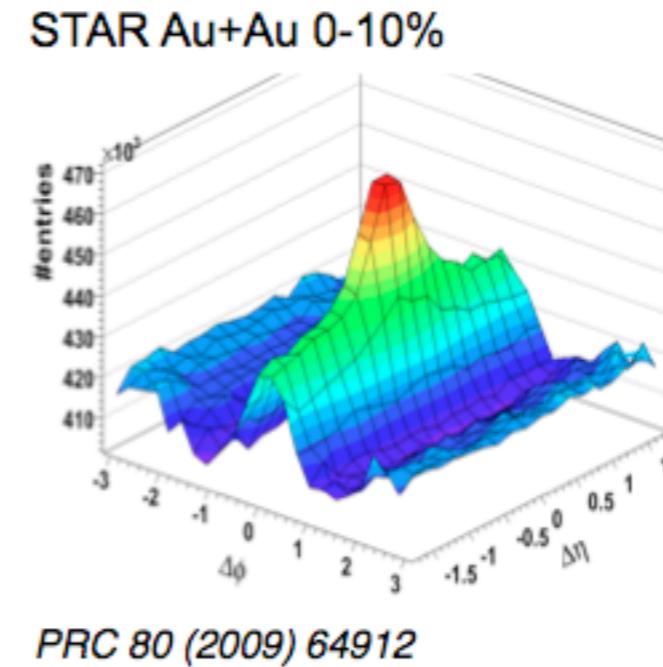
- Explore the bulk properties of the medium
- Constrain hydrodynamic models
- Investigate the effects of fluctuations in initial conditions

Fluctuating initial condition –
higher-order flow harmonics
(e.g., “triangular flow”, v_3)



Phys. Rev. C81:054905, 2010

Intriguing ridge structure at RHIC



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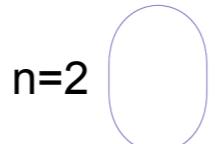
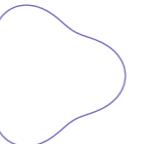
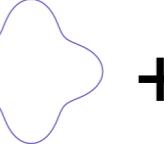


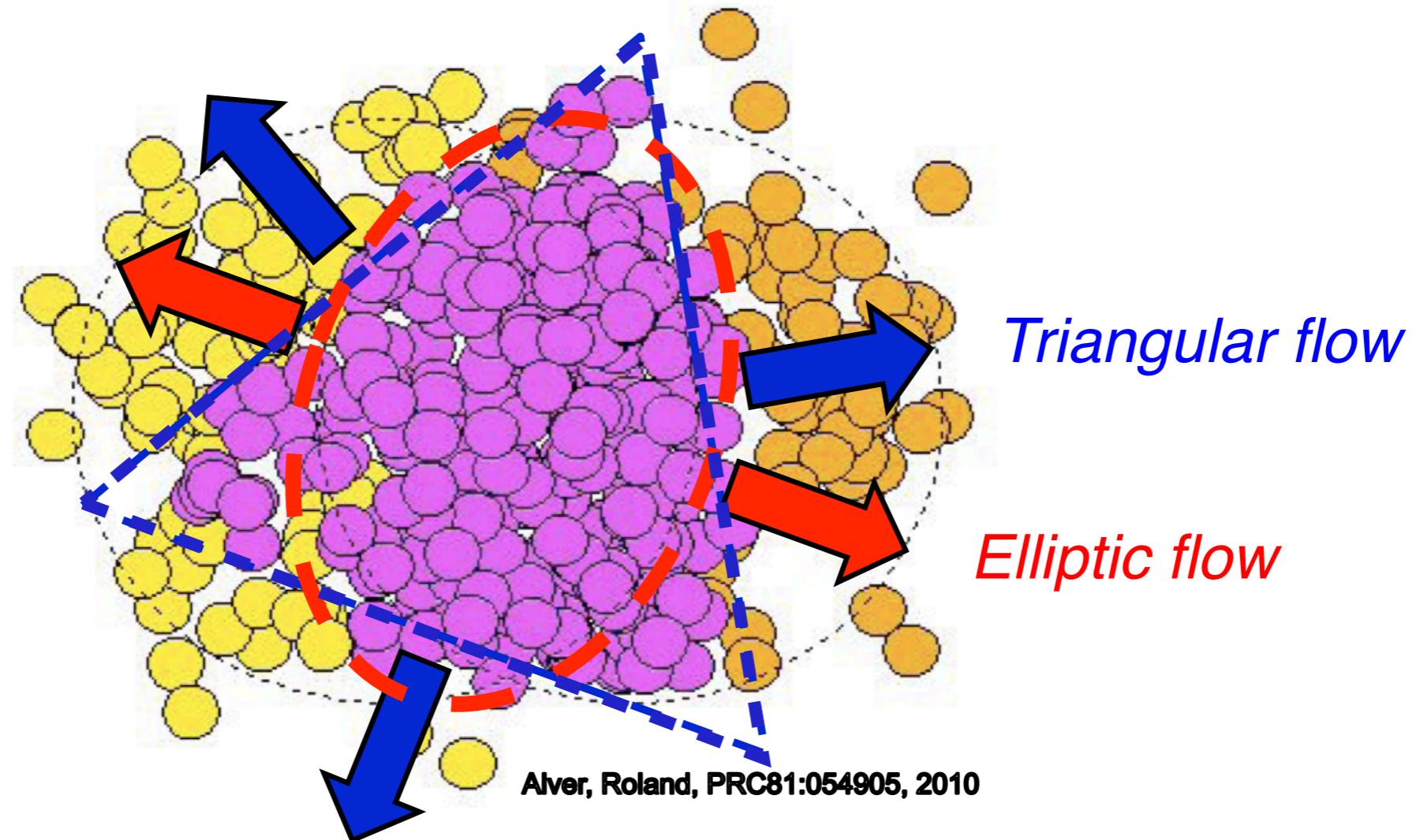
Fluctuations in the Initial Collision Geometry

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

Elliptic flow Triangular flow

Two-Particle Correlation $\Rightarrow \frac{dN^{pair}}{d\Delta\phi} \sim 1 + 2v_2^2 \cos 2\Delta\phi + 2v_3^2 \cos 3\Delta\phi + \dots$

$n=2$  + $n=3$  + $n=4$  + $n=5$ 



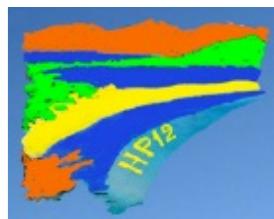
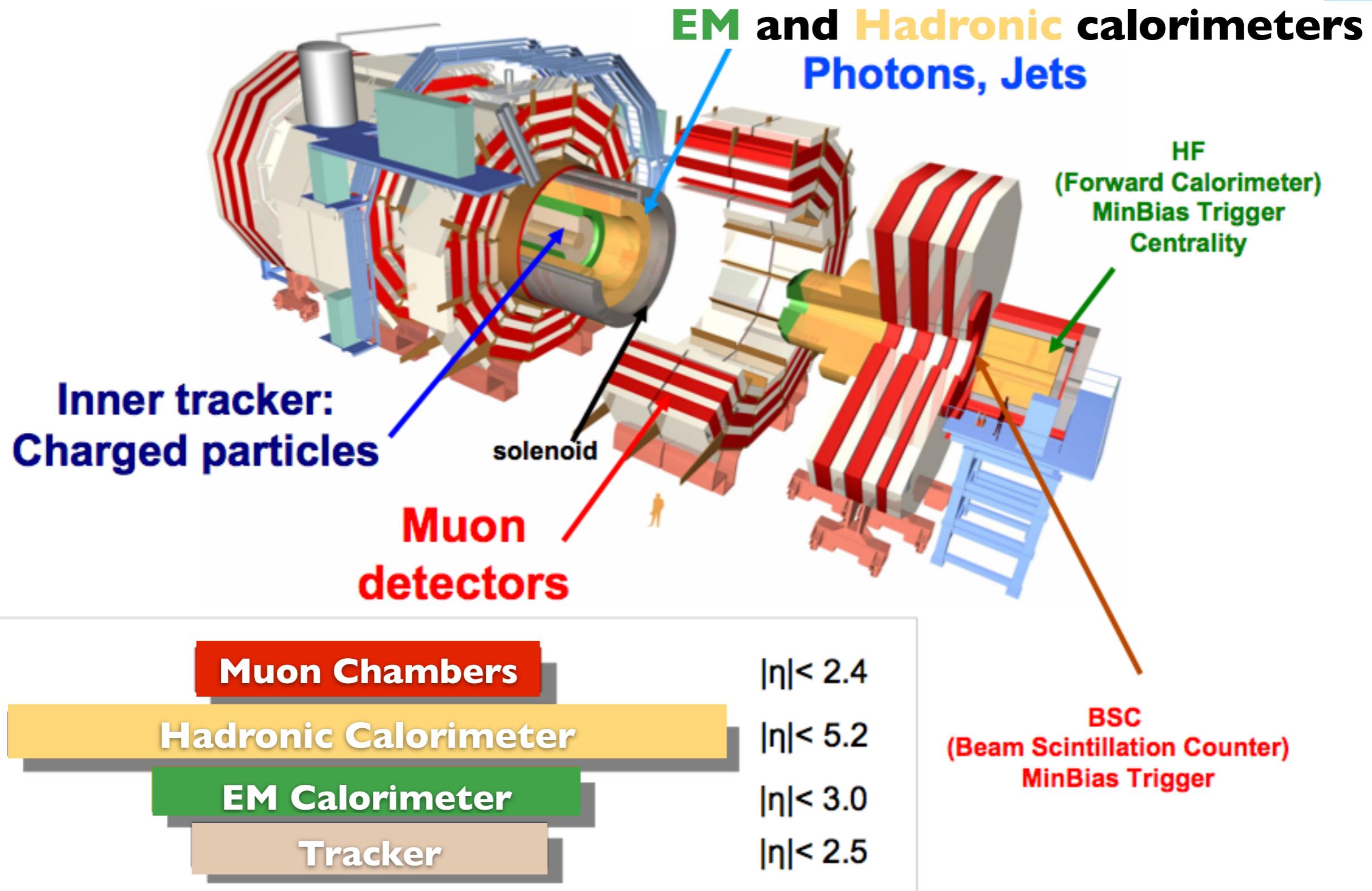
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The CMS Detector



Di-hadron Correlations

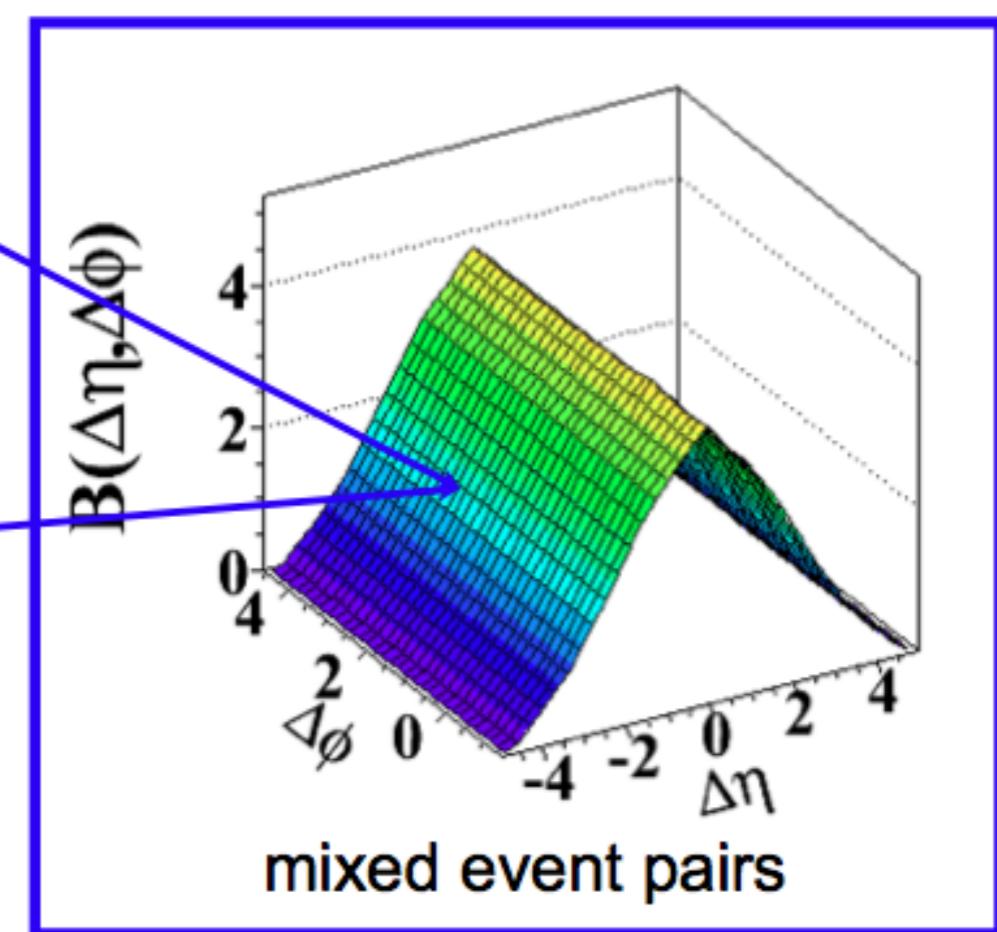
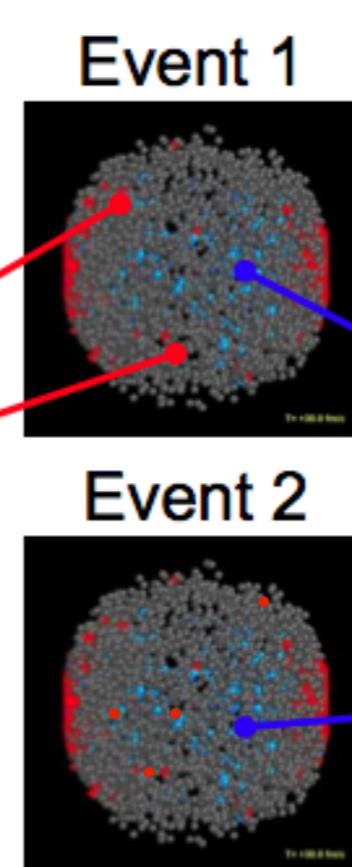
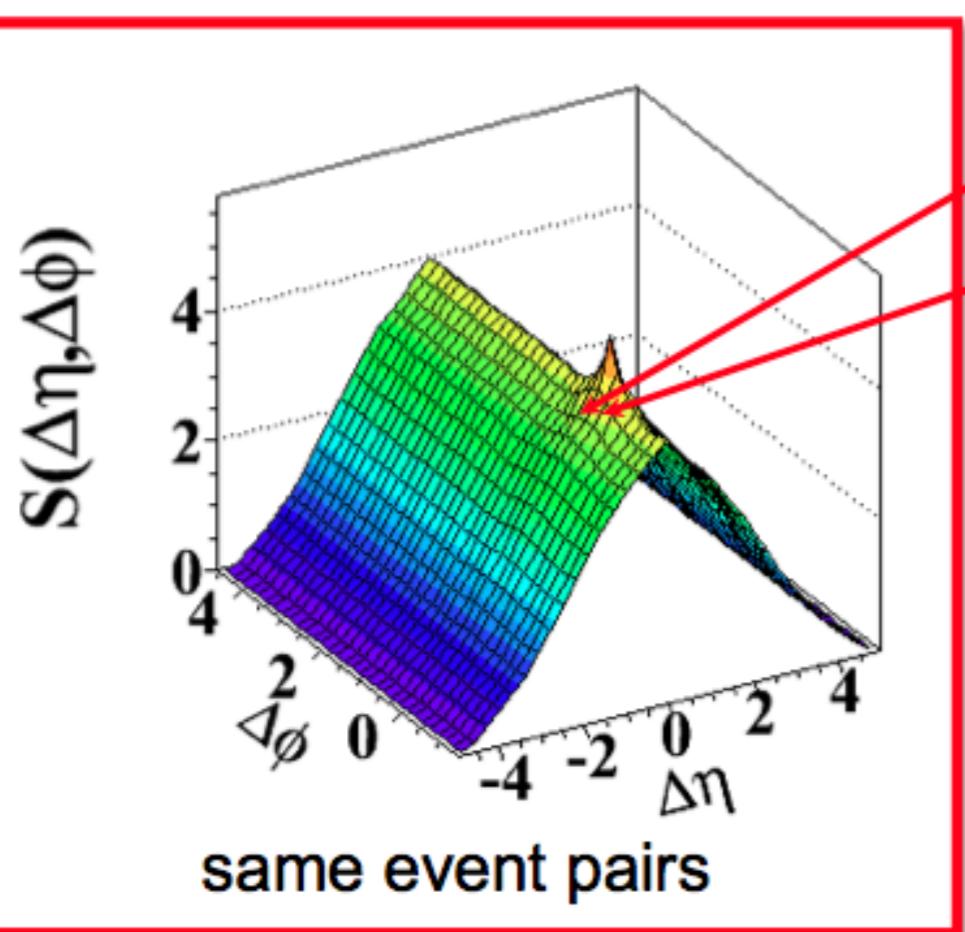
Signal distribution:

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

Particle 1: trigger
Particle 2: associated

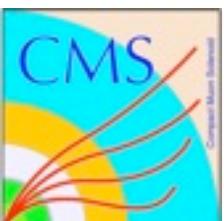
Background distribution:

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



Mixed events must be similar, i.e.

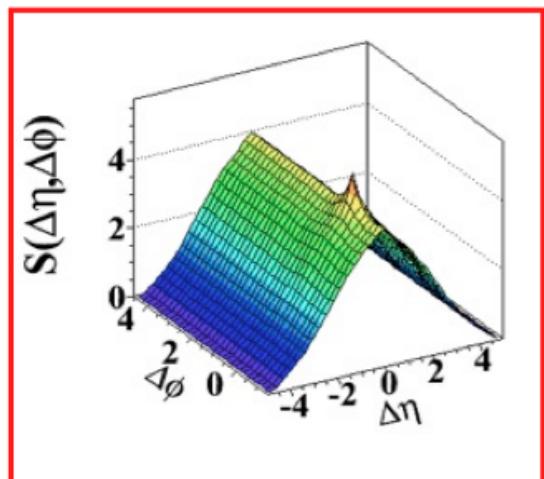
- same collision centrality
- $|\Delta z_{\text{vtx}}| < 2 \text{ cm}$



Di-hadron Correlations

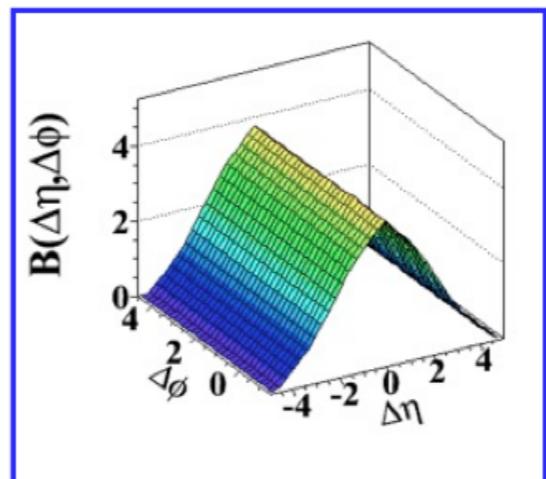
Signal pair distribution:

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



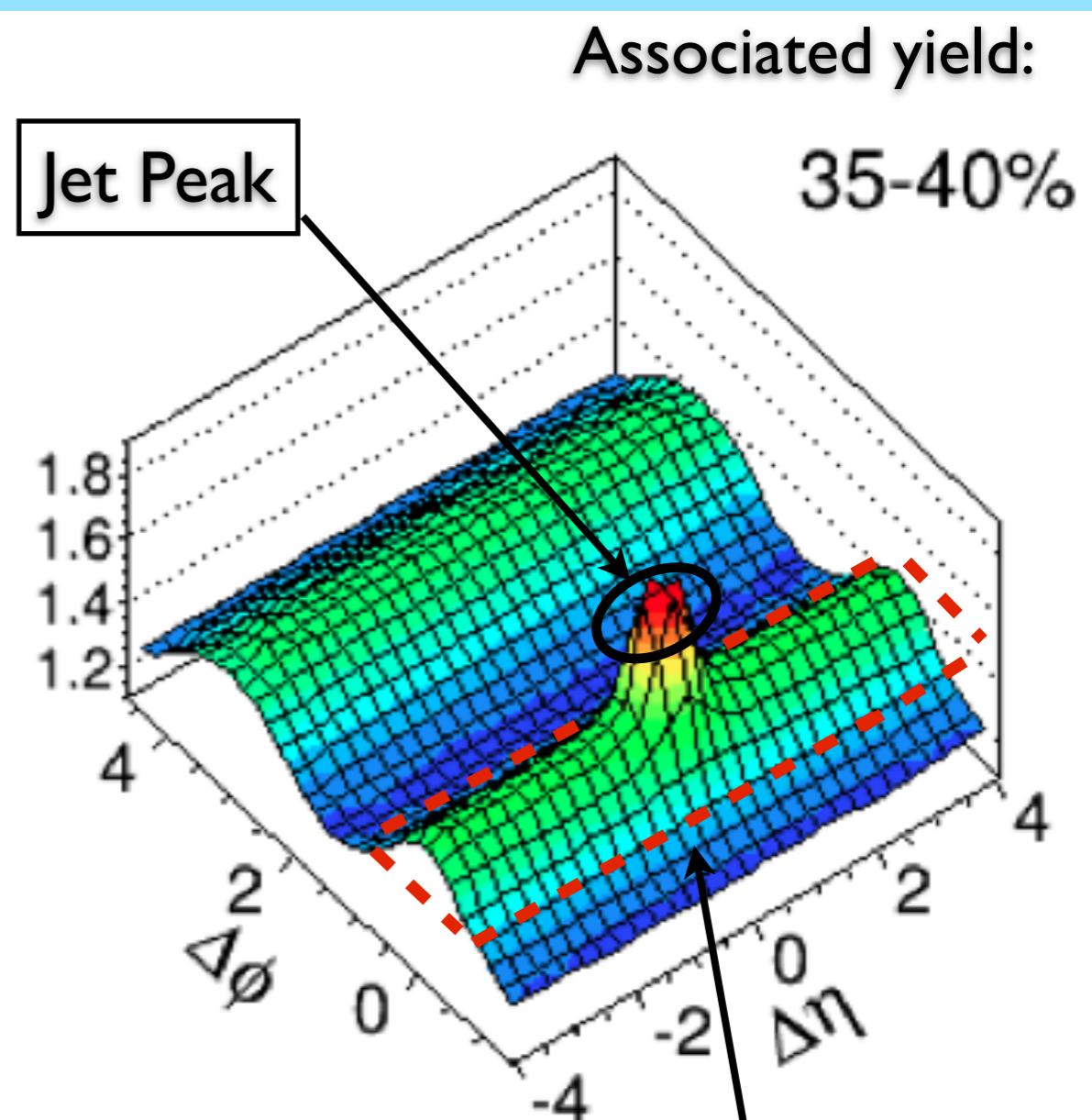
Background pair distribution

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



Associated hadron yield per trigger particle:

$$\frac{1}{N_{\text{trig}}} \frac{d^2N^{\text{pair}}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$



Associated yield:

35-40%

$$\begin{aligned} 4 < p_T^{\text{trig}} &< 6 \\ 2 < p_T^{\text{assoc}} &< 4 \\ \Delta\eta &= \eta^{\text{assoc}} - \eta^{\text{trig}} \\ \Delta\phi &= \phi^{\text{assoc}} - \phi^{\text{trig}} \end{aligned}$$

Long-Range Near-Side Structure



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2D Correlations vs. Centrality

arXiv:1201.3158
arXiv:1204.1409



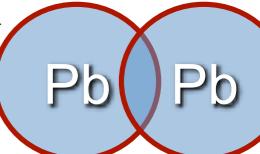
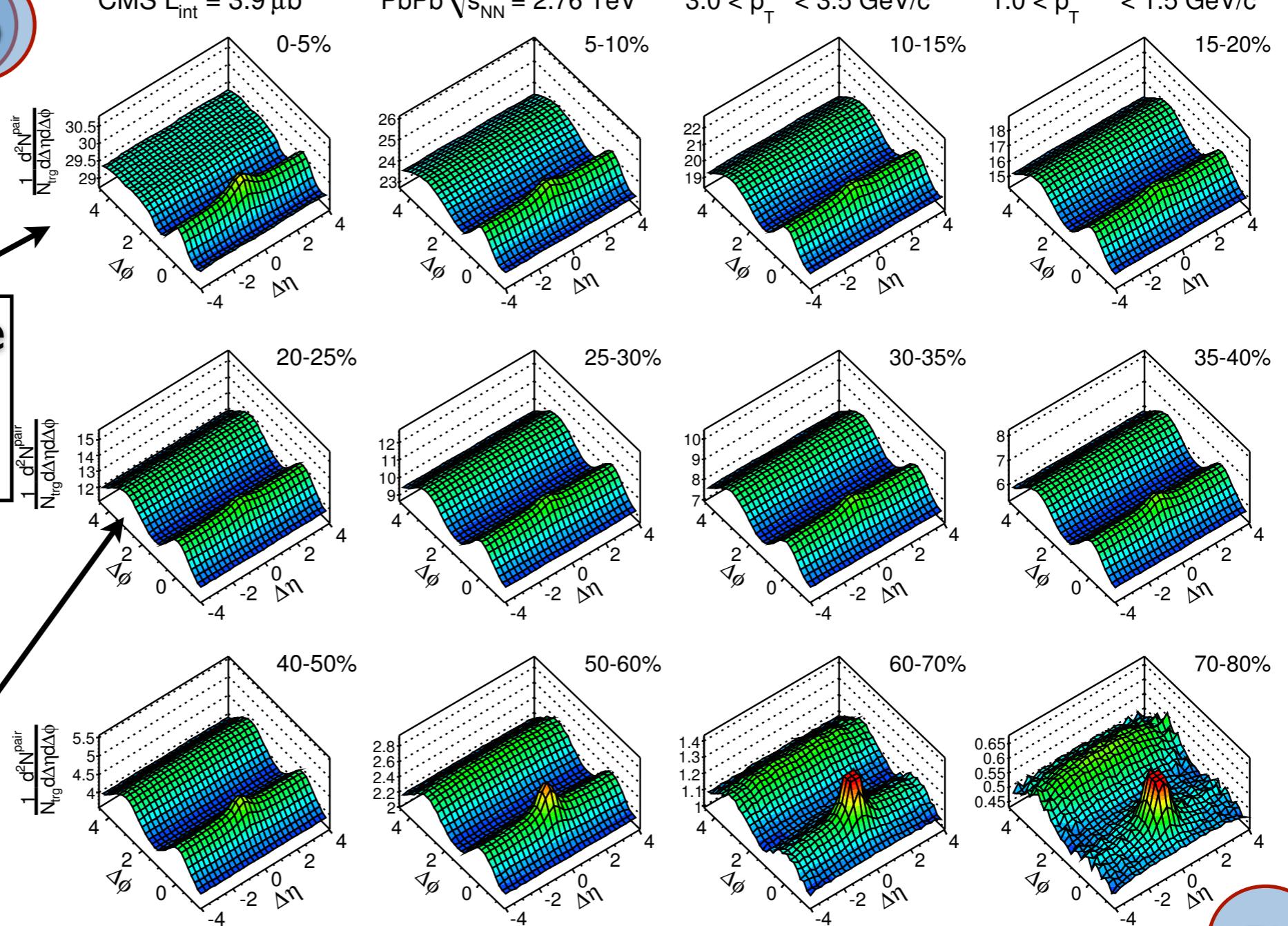
CMS $L_{\text{int}} = 3.9 \mu\text{b}^{-1}$

PbPb $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$

$3.0 < p_T^{\text{trig}} < 3.5 \text{ GeV}/c$

$1.0 < p_T^{\text{assoc}} < 1.5 \text{ GeV}/c$

Away-side structure
is flattened in
central collisions



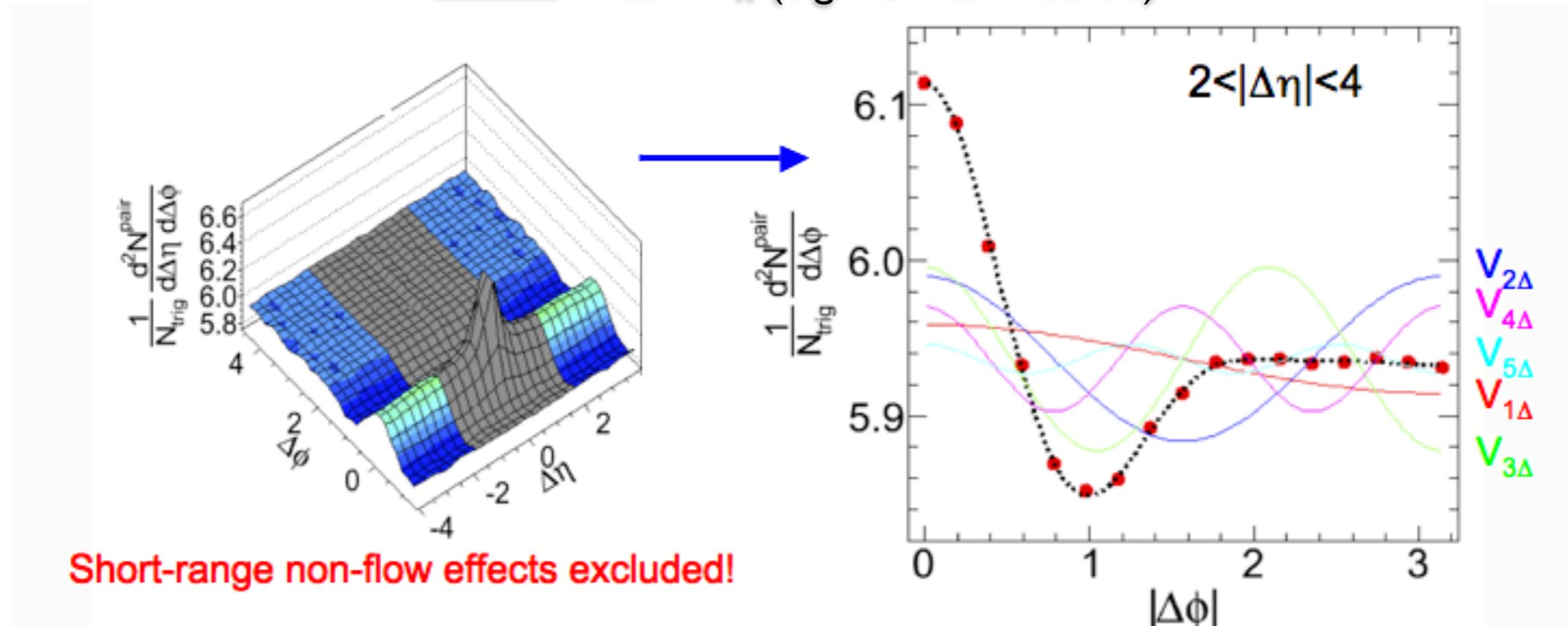
A $\cos(2\Delta\phi)$ modulation is clearly visible at large
values of $\Delta\eta$ in non-central PbPb collisions



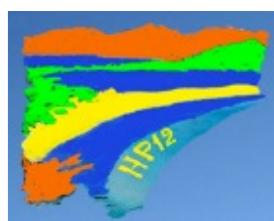
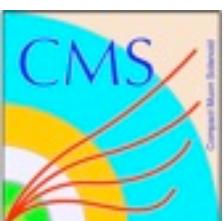
Fourier Decomposition

$$\begin{aligned} \frac{1}{N_{\text{trig}}} \frac{dN^{\text{pair}}}{d\Delta\phi} &= \frac{N_{\text{assoc}}}{2\pi} (1 + 2 \sum_{n=1} V_{n\Delta} \cos(n\Delta\varphi)) \\ &= \frac{N_{\text{assoc}}}{2\pi} (1 + 2V_{1\Delta} \cos(\Delta\varphi) + 2V_{2\Delta} \cos(2\Delta\varphi) + 2V_{3\Delta} \cos(3\Delta\varphi) + \dots) \end{aligned}$$

Note: $V_{n\Delta} \neq v_n$ (e.g. from EP method)

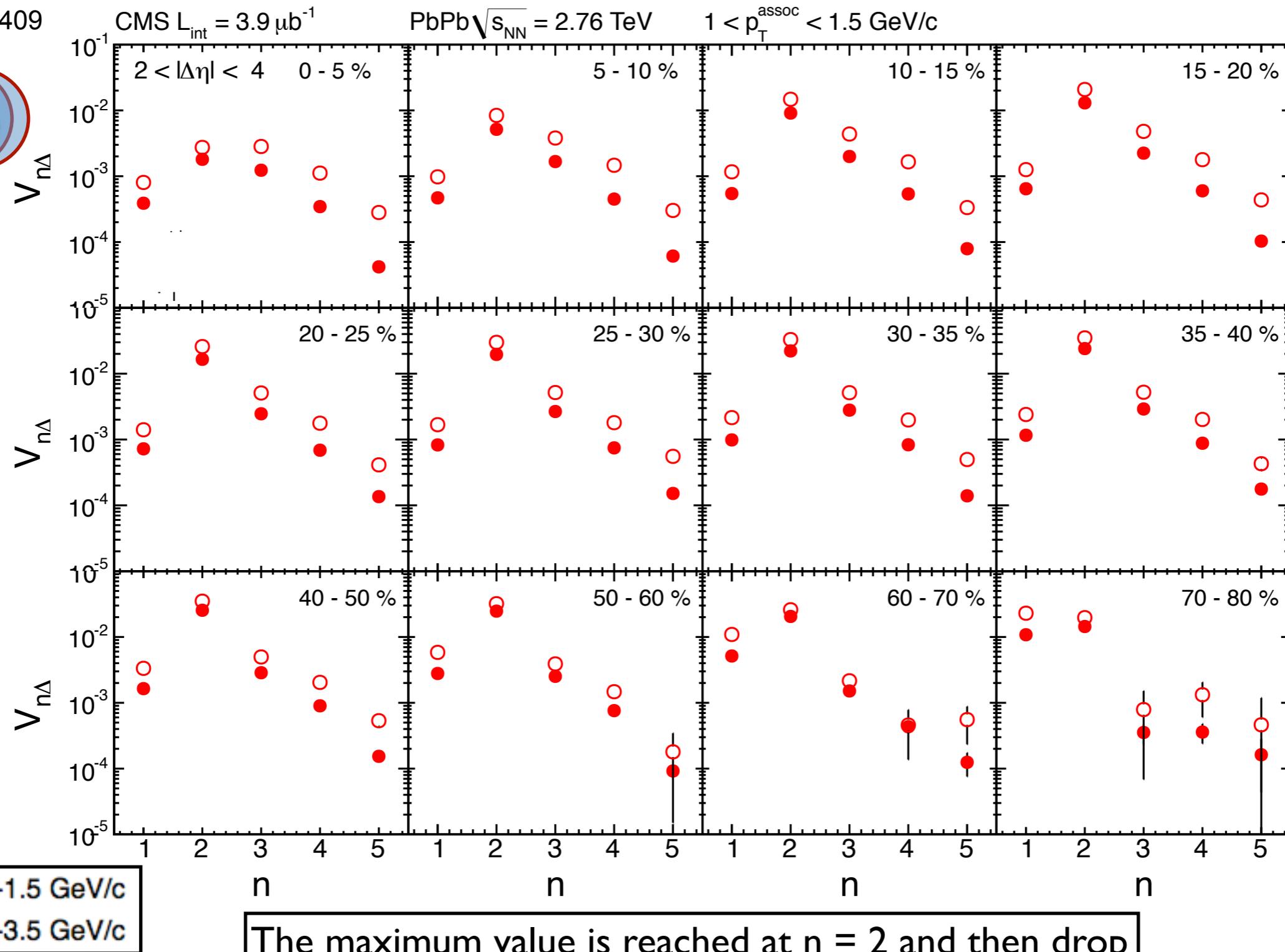


The coefficients $V_{n\Delta}$ are a function of centrality, p_T^{trig} , and p_T^{assoc}

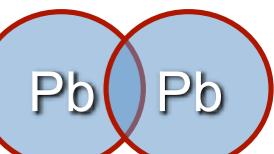


Long-Range Fourier Coefficients

arXiv:1201.3158
arXiv:1204.1409



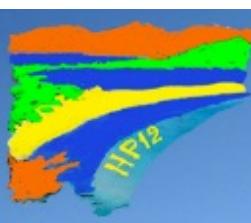
The maximum value is reached at $n = 2$ and then drop dramatically towards larger n values for all centralities



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Factorization of Fourier Coefficients

If the observed long-range azimuthal dihadron correlations are driven only by flow then

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

If we assume the factorization relation holds then we can measure the single-particle flow coefficients:

$$v_n(p_T^{\text{trig}}) = \frac{V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}})}{v_n(p_T^{\text{assoc}})}$$

Note: we calculate the denominator by setting

$$p_T^{\text{assoc}} = p_T^{\text{trig}}, \text{ then}$$

$$v_n(p_T^{\text{assoc}}) = \sqrt{V_{n\Delta}(p_T^{\text{assoc}}, p_T^{\text{assoc}})}$$

Factorization

We can then test the factorization assumption by calculating the ratio

$$\frac{V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}})}{v_n(p_T^{\text{trig}}) \times v_n(p_T^{\text{assoc}})} \stackrel{?}{=} 1$$

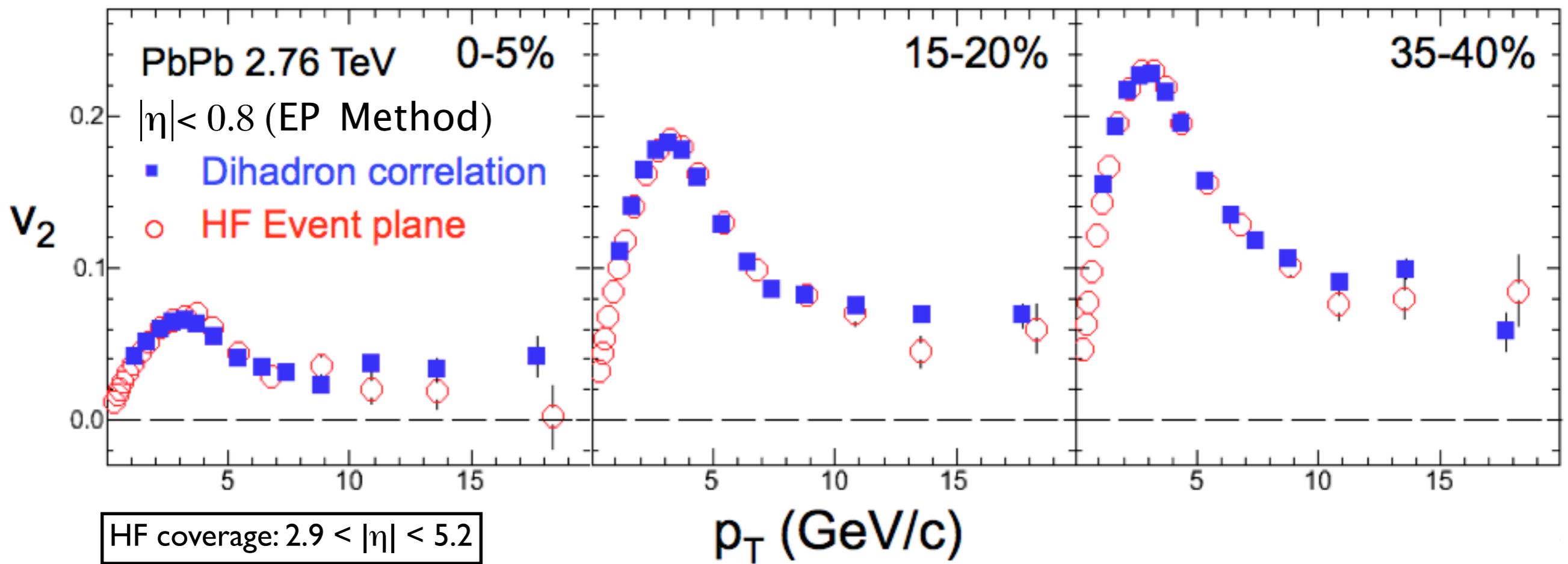
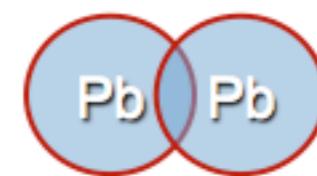
Two Caveats

- Non-flow, such as dijet correlations, can also factorize
- flow fluctuations can cause the factorization to break down

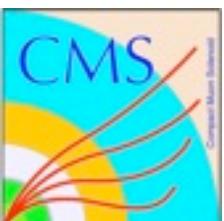


Comparison with Event Plane Method

arXiv:1201.3158
arXiv:1204.1409



$v_2(p_T)$ from correlation method derived using fixed p_T^{assoc} of 1 - 1.5 GeV/c agrees well with EP method



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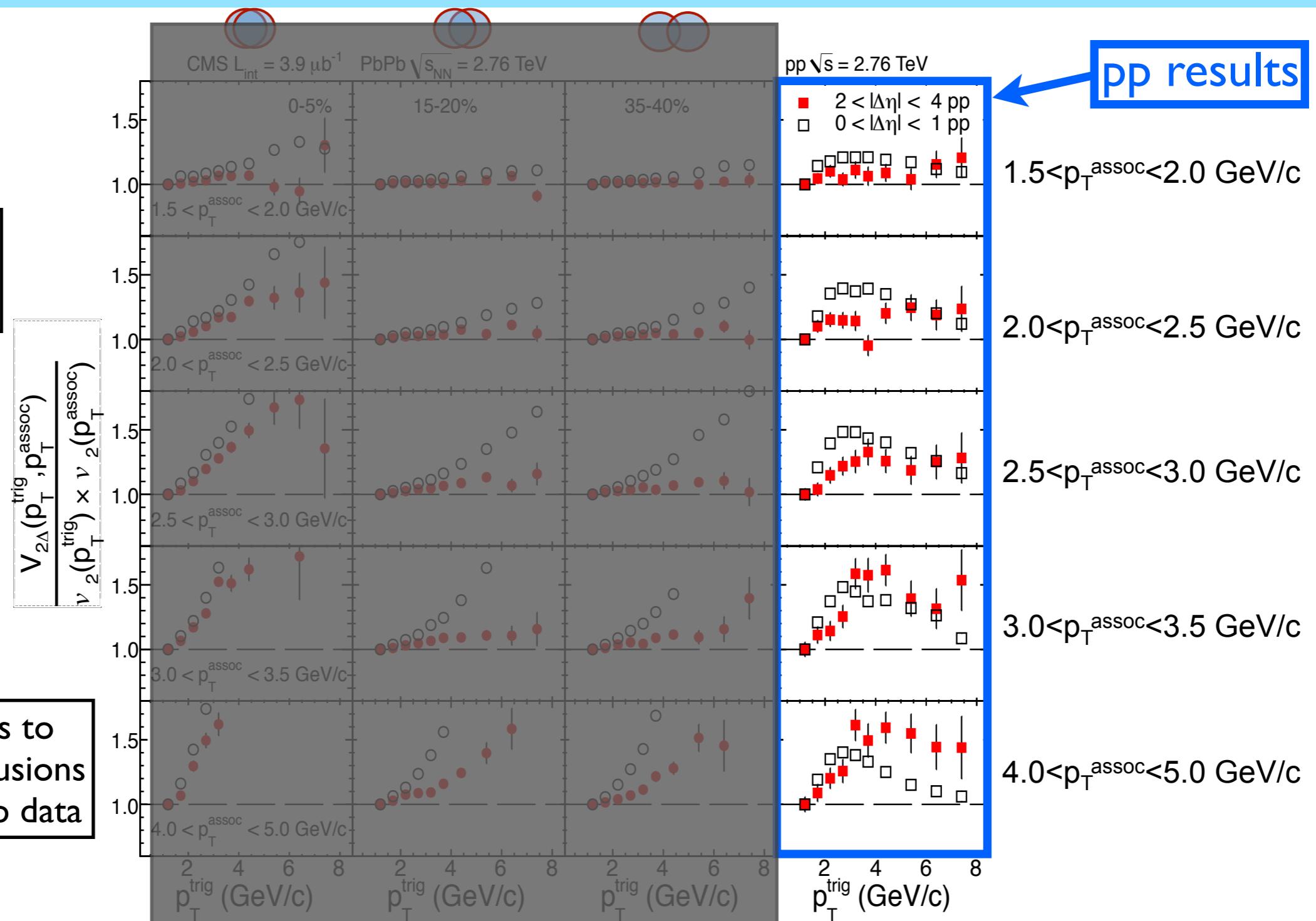


Direct Test of Factorization: n=2

arXiv:1201.3158
arXiv:1204.1409

n=2

- $2 < |\Delta\eta| < 4$
- $0 < |\Delta\eta| < 1$



pp results

$1.5 < p_T^{\text{assoc}} < 2.0 \text{ GeV}/c$

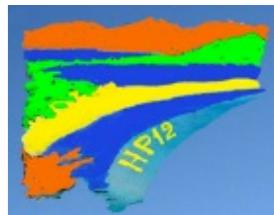
$2.0 < p_T^{\text{assoc}} < 2.5 \text{ GeV}/c$

$2.5 < p_T^{\text{assoc}} < 3.0 \text{ GeV}/c$

$3.0 < p_T^{\text{assoc}} < 3.5 \text{ GeV}/c$

$4.0 < p_T^{\text{assoc}} < 5.0 \text{ GeV}/c$

$V_{2\Delta}$ from short-range pp data factorizes better as you increase p_T^{trig} because you have a cleaner jet signal. Contamination from non-jet correlated particles cause it to breakdown at lower p_T^{trig}

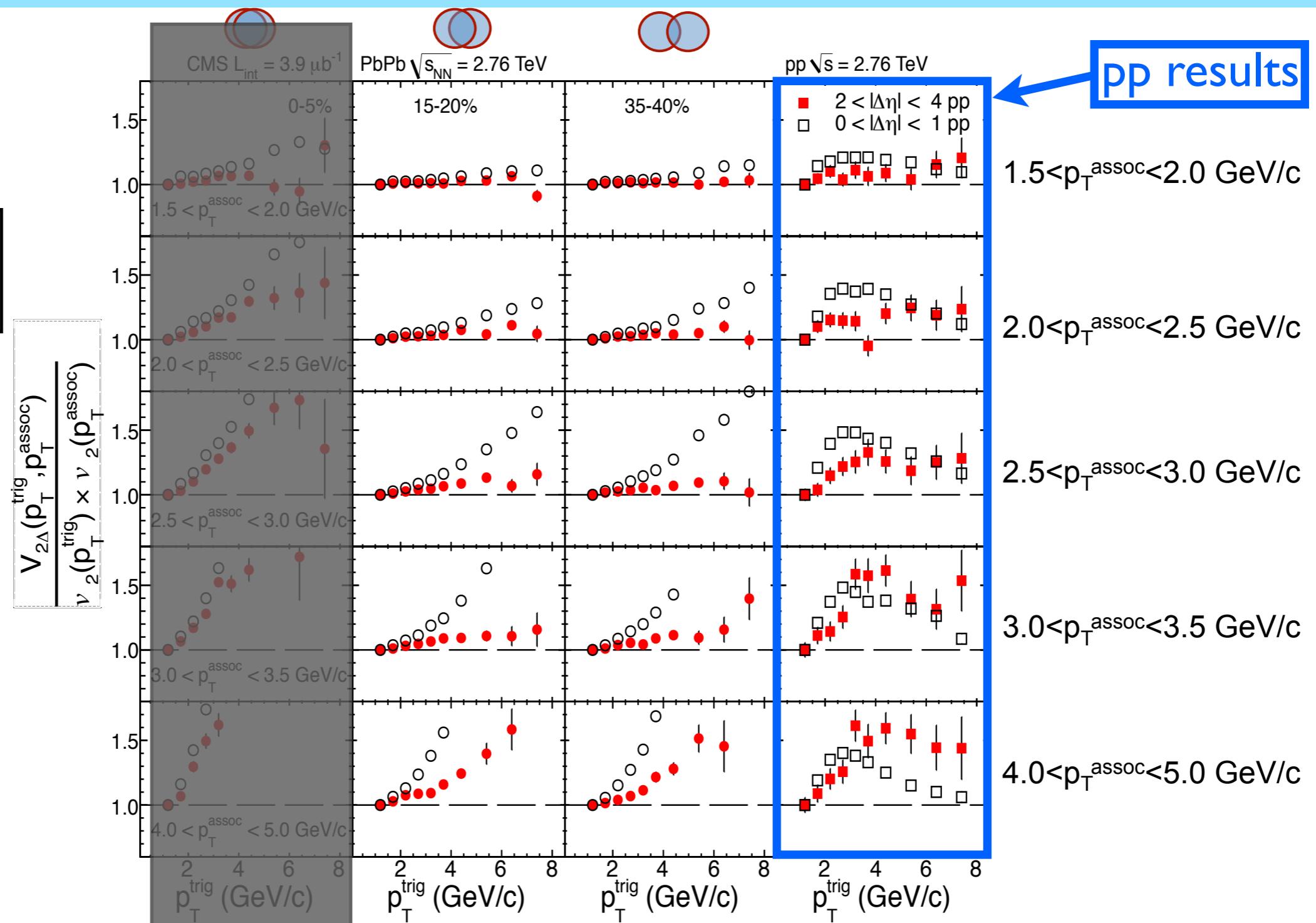


Direct Test of Factorization: n=2

arXiv:1201.3158
arXiv:1204.1409

n=2

● $2 < |\Delta\eta| < 4$
○ $0 < |\Delta\eta| < 1$



- $V_{2\Delta}$ from long-range shows factorization for not very central PbPb collisions
- Jet-like correlations cause factorization to break down in the short-range region

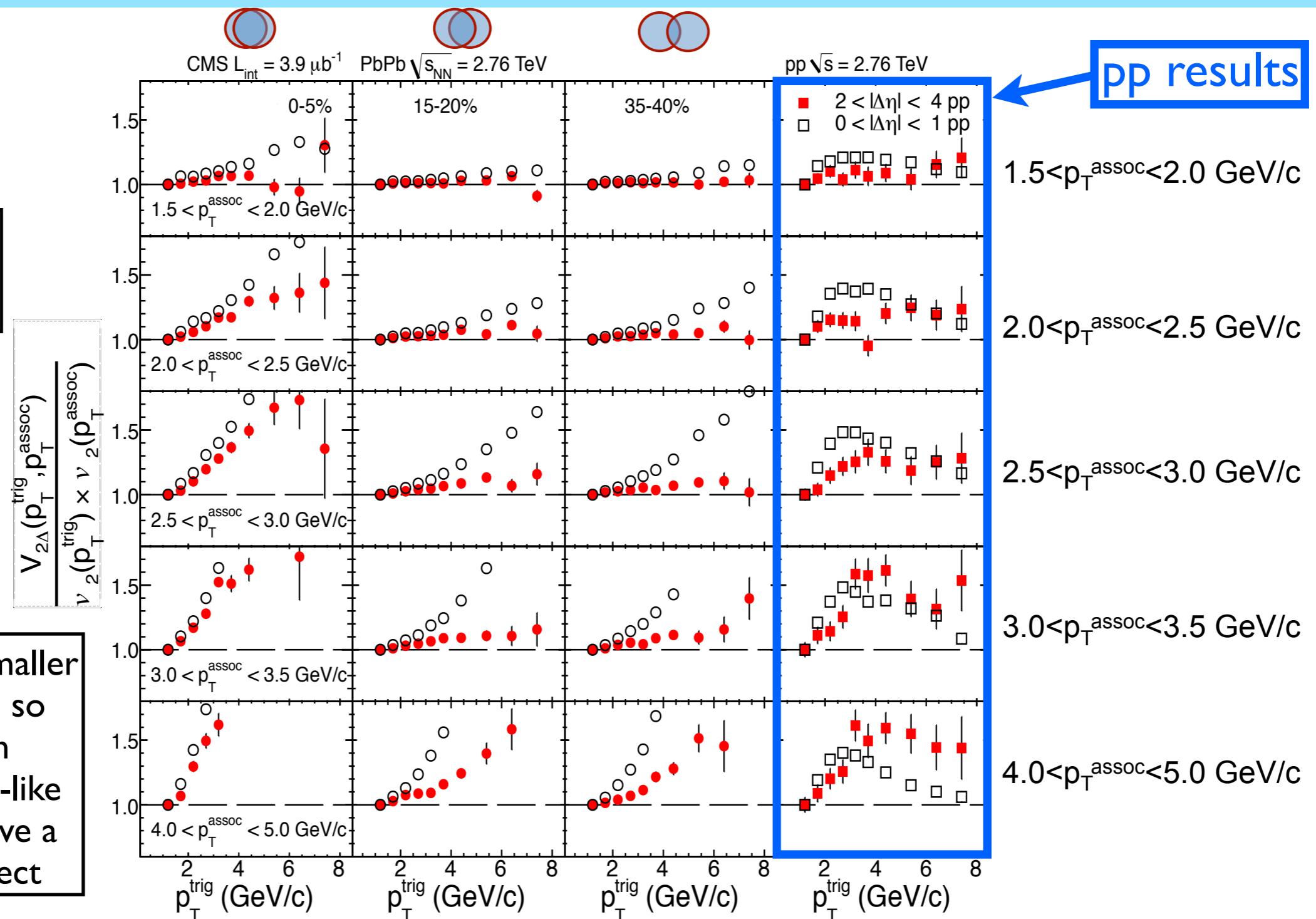


Direct Test of Factorization: n=2

arXiv:1201.3158
arXiv:1204.1409

n=2

● $2 < |\Delta\eta| < 4$
○ $0 < |\Delta\eta| < 1$



V_2 is significantly smaller in central collisions so contamination from fluctuations and jet-like correlations will have a more significant affect

- $V_{2\Delta}$ from long-range shows factorization for not very central PbPb collisions
- Jet-like correlations cause factorization to break down in the short-range region



Direct Test of Factorization: n=3

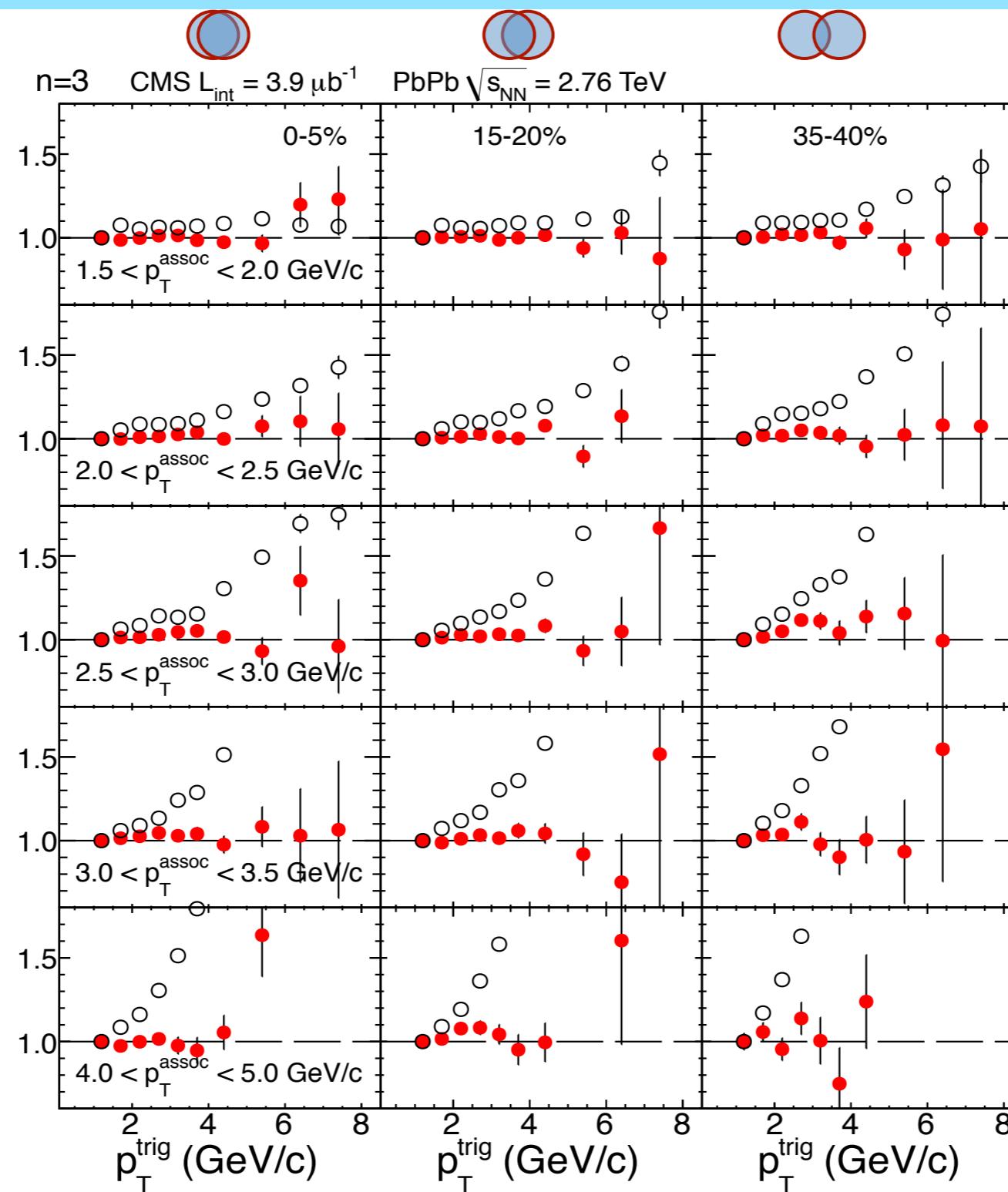
arXiv:1201.3158
arXiv:1204.1409

n=3

- $2 < |\Delta\eta| < 4$
- $0 < |\Delta\eta| < 1$

$$\frac{V_{3\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}})}{V_3(p_T^{\text{trig}}) \times V_3(p_T^{\text{assoc}})}$$

V₃ factorization is unique to PbPb collisions



1.5 < p_T^{assoc} < 2.0 GeV/c

2.0 < p_T^{assoc} < 2.5 GeV/c

2.5 < p_T^{assoc} < 3.0 GeV/c

3.0 < p_T^{assoc} < 3.5 GeV/c

4.0 < p_T^{assoc} < 5.0 GeV/c

V_{3Δ} from long-range shows good factorization



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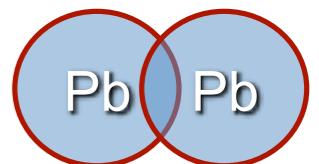
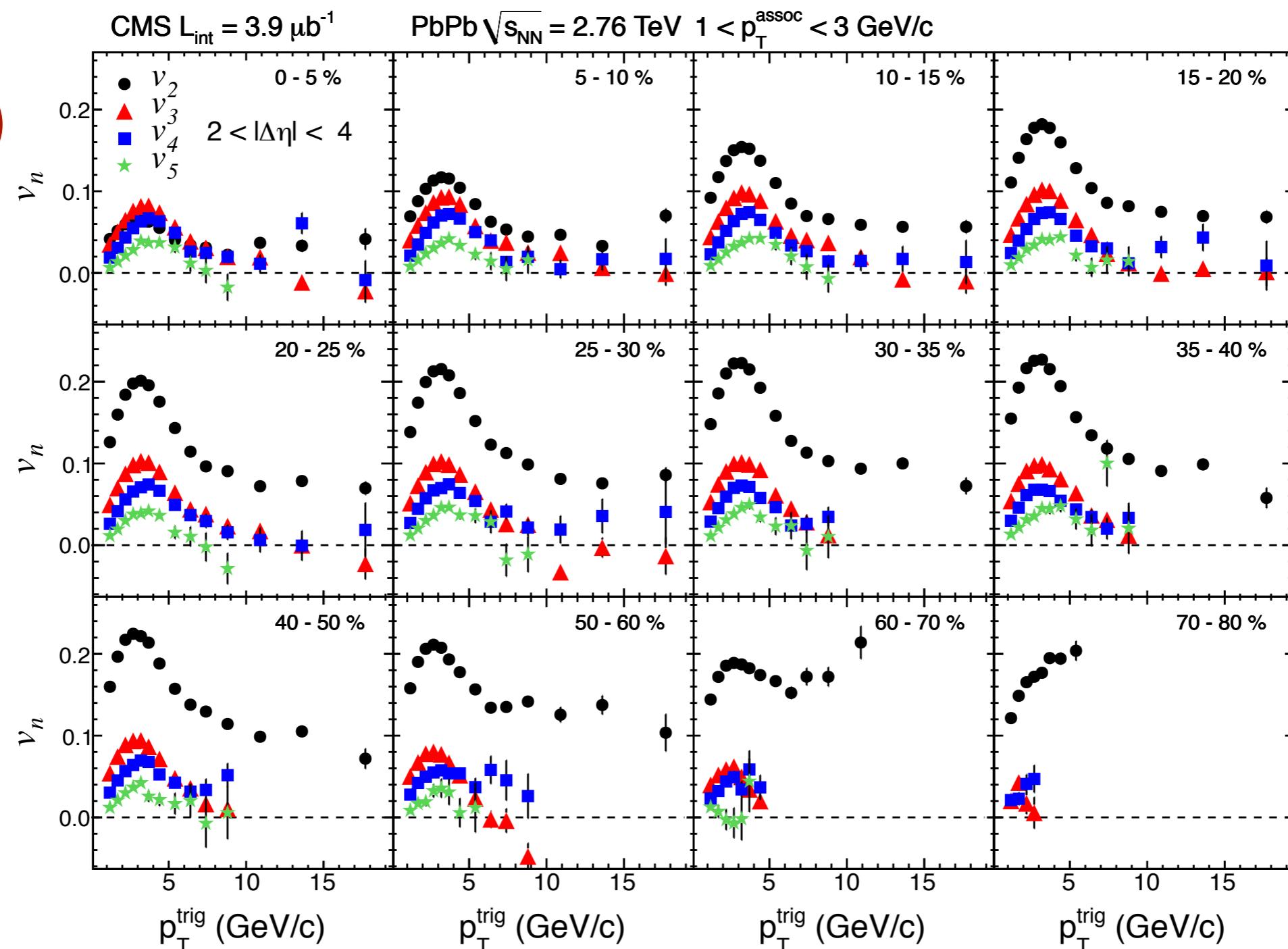
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Higher-order Coefficients vs. p_T

arXiv:1201.3158
arXiv:1204.1409



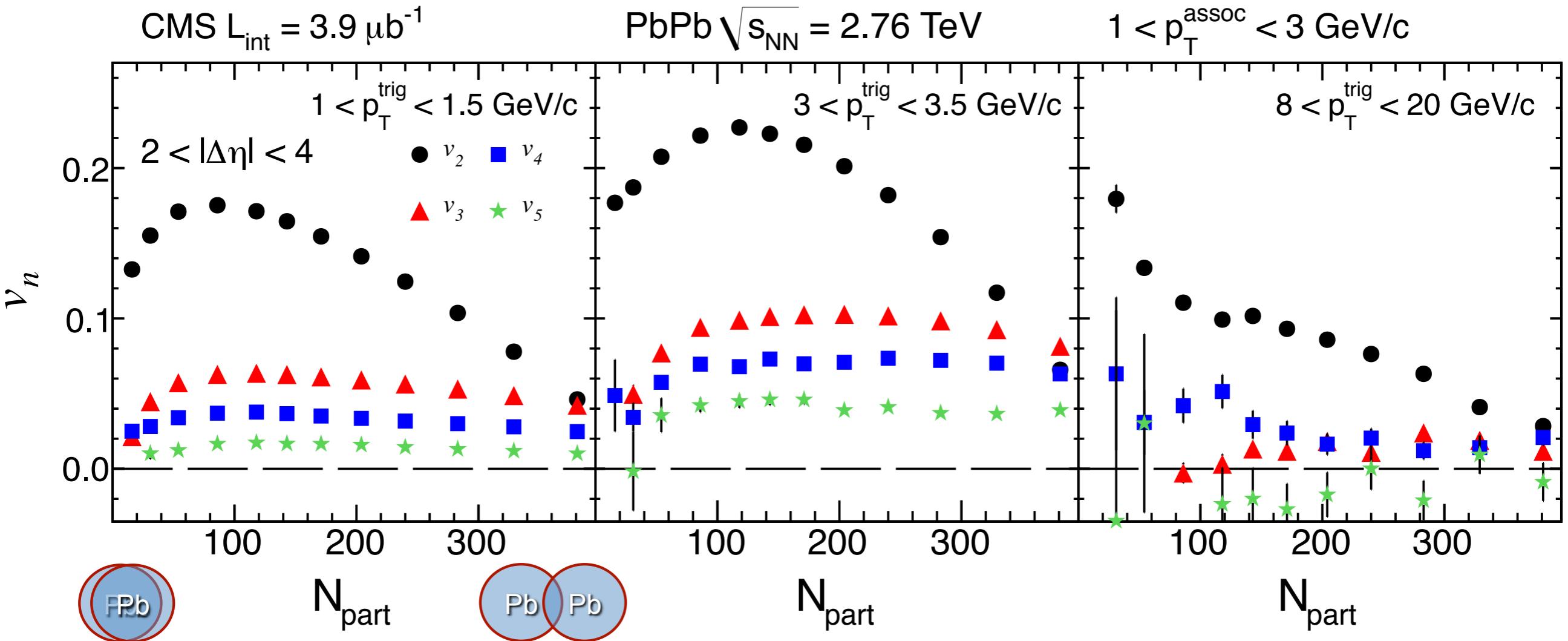
A strong p_T dependence of v_2 is observed as expected in the context of hydrodynamic flow and the path-length dependence of parton energy loss



Higher-Order Coefficients vs. N_{part}

arXiv:1201.3158

arXiv:1204.1409



Higher-order coefficients, $n > 2$, do not show a significant centrality dependence, which is consistent with fluctuations in the initial collision geometry being the driving force



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Summary

- Ridge-like structure extends out to $|\Delta\eta| < 4$
- The broadening of the away-side structure in central collisions can be explained by the contributions from higher-order Fourier coefficients
- Fourier coefficient factorization assumption is valid at low p_T , from 1.5 - 3.5 GeV/c
- Measurements of single-particle flow coefficients using dihadron factorization are consistent with the event plane method



Backups



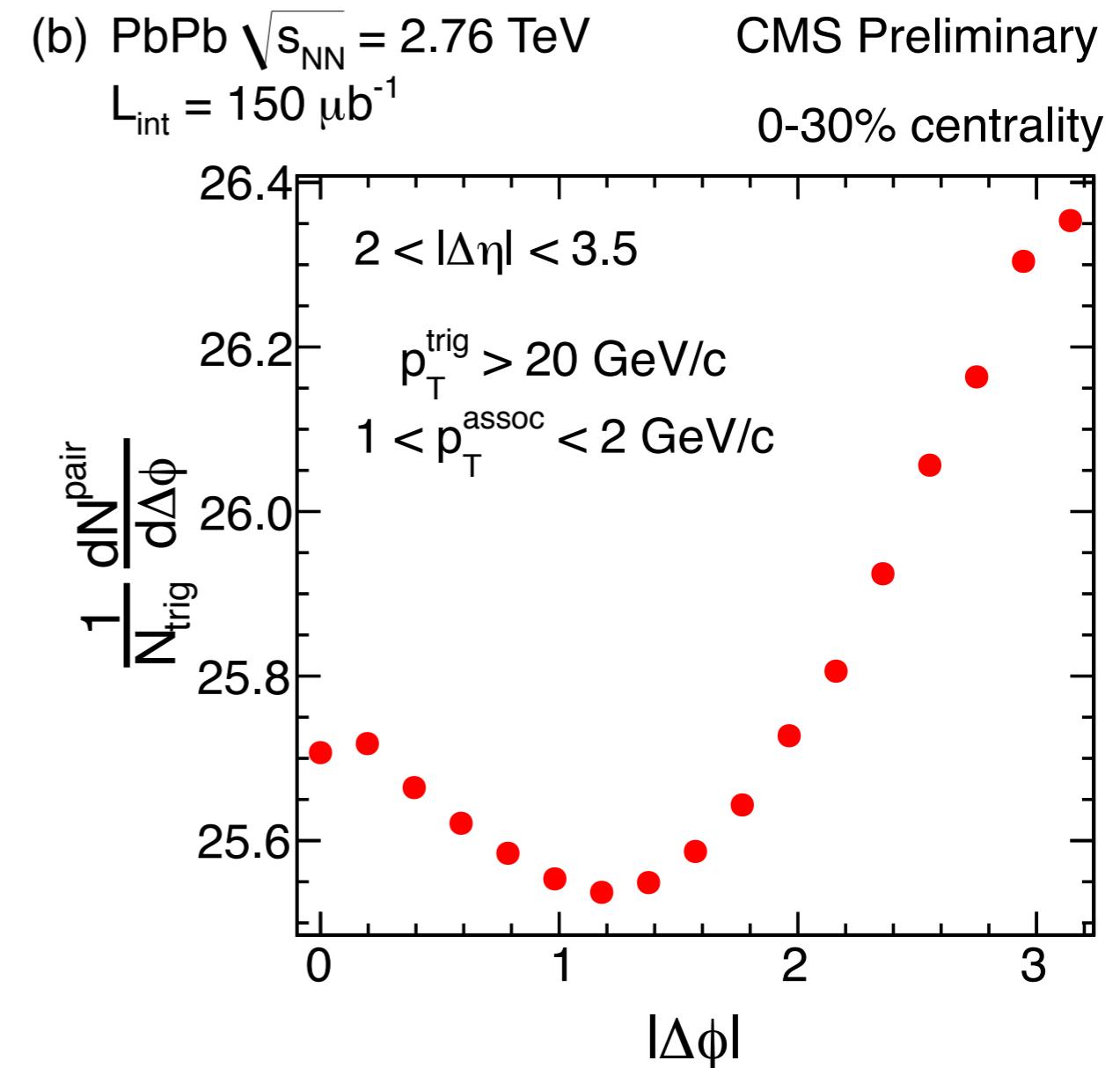
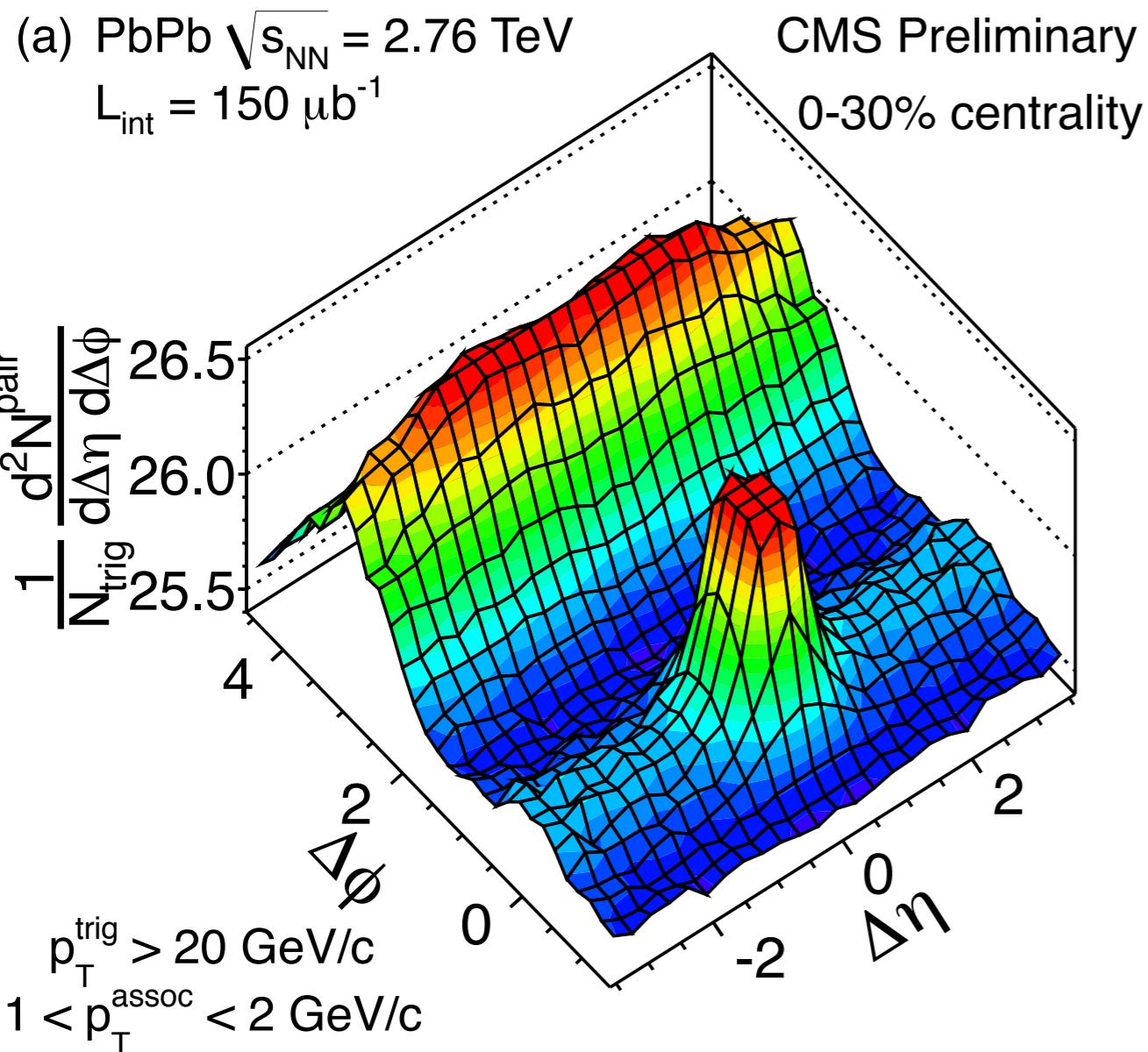
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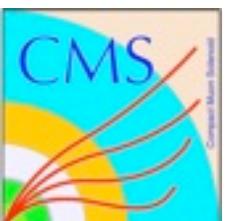
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High pT 2D Correlation



Even for the long-range correlations the away-side jet peak dominates



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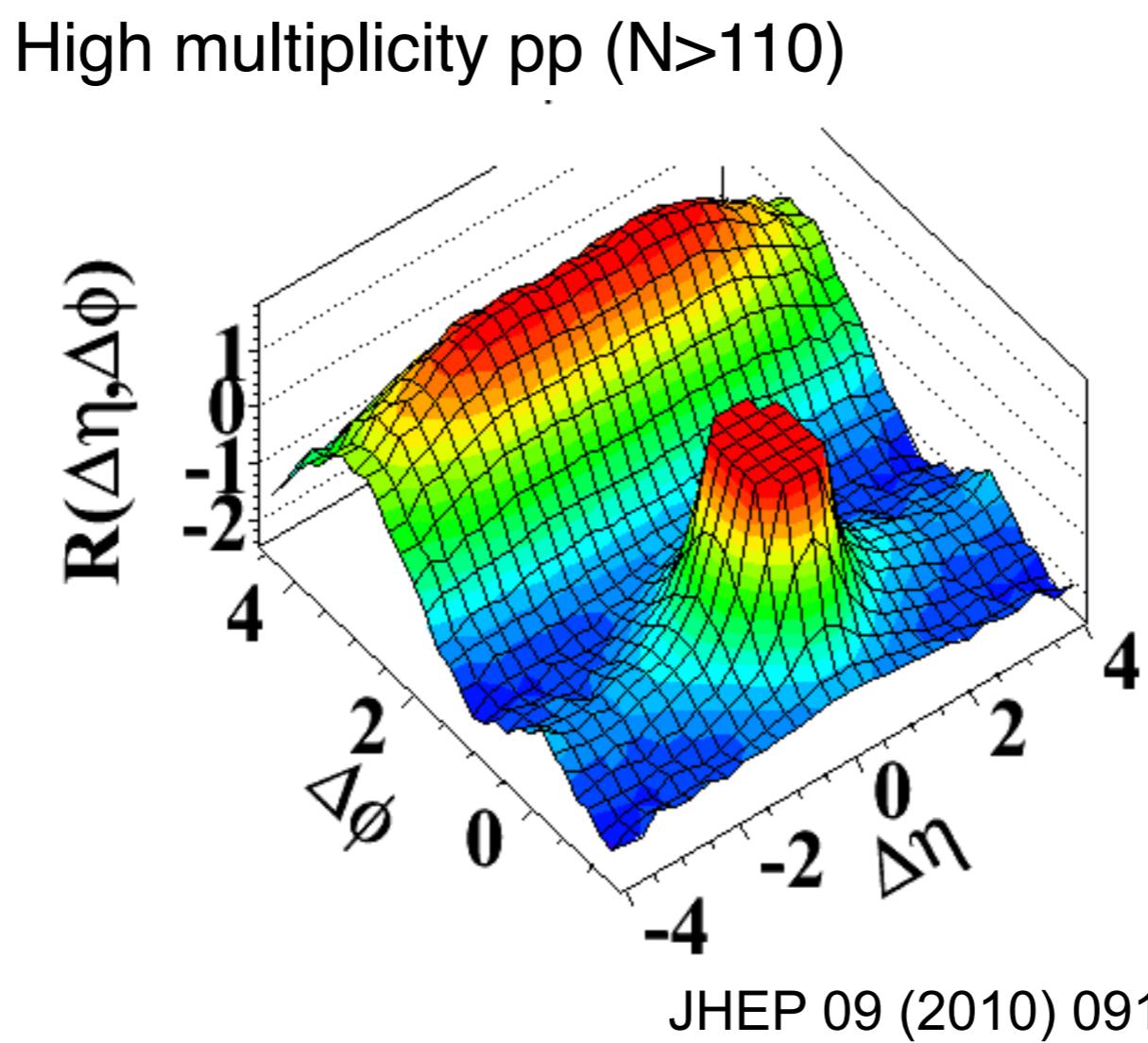
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2D Correlations in pp Collisions

Moderate $p_T^{\text{trig}}, p_T^{\text{assoc.}}$: 1-3 GeV/c



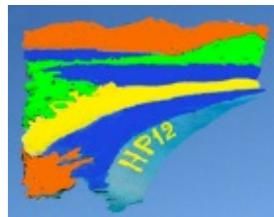
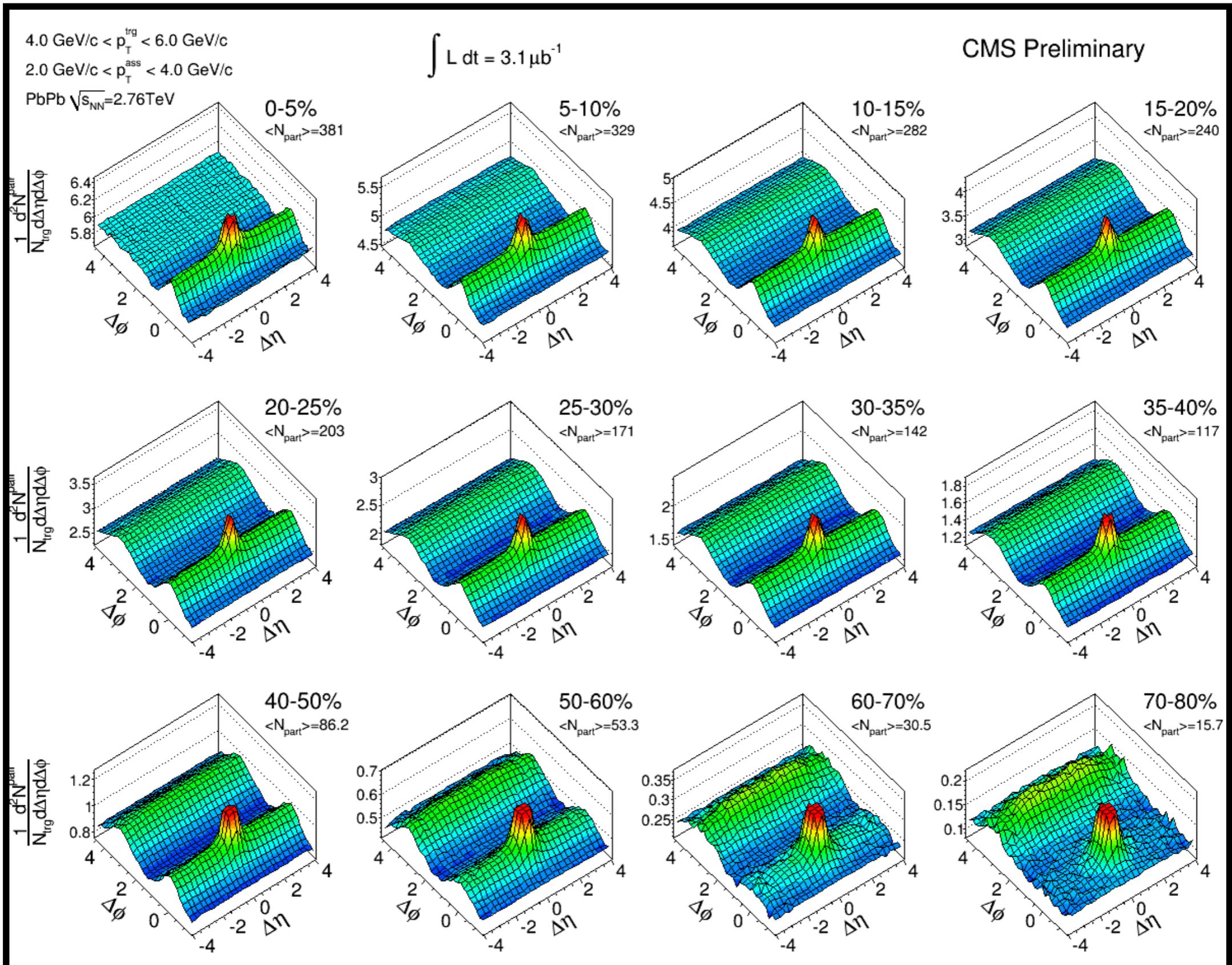
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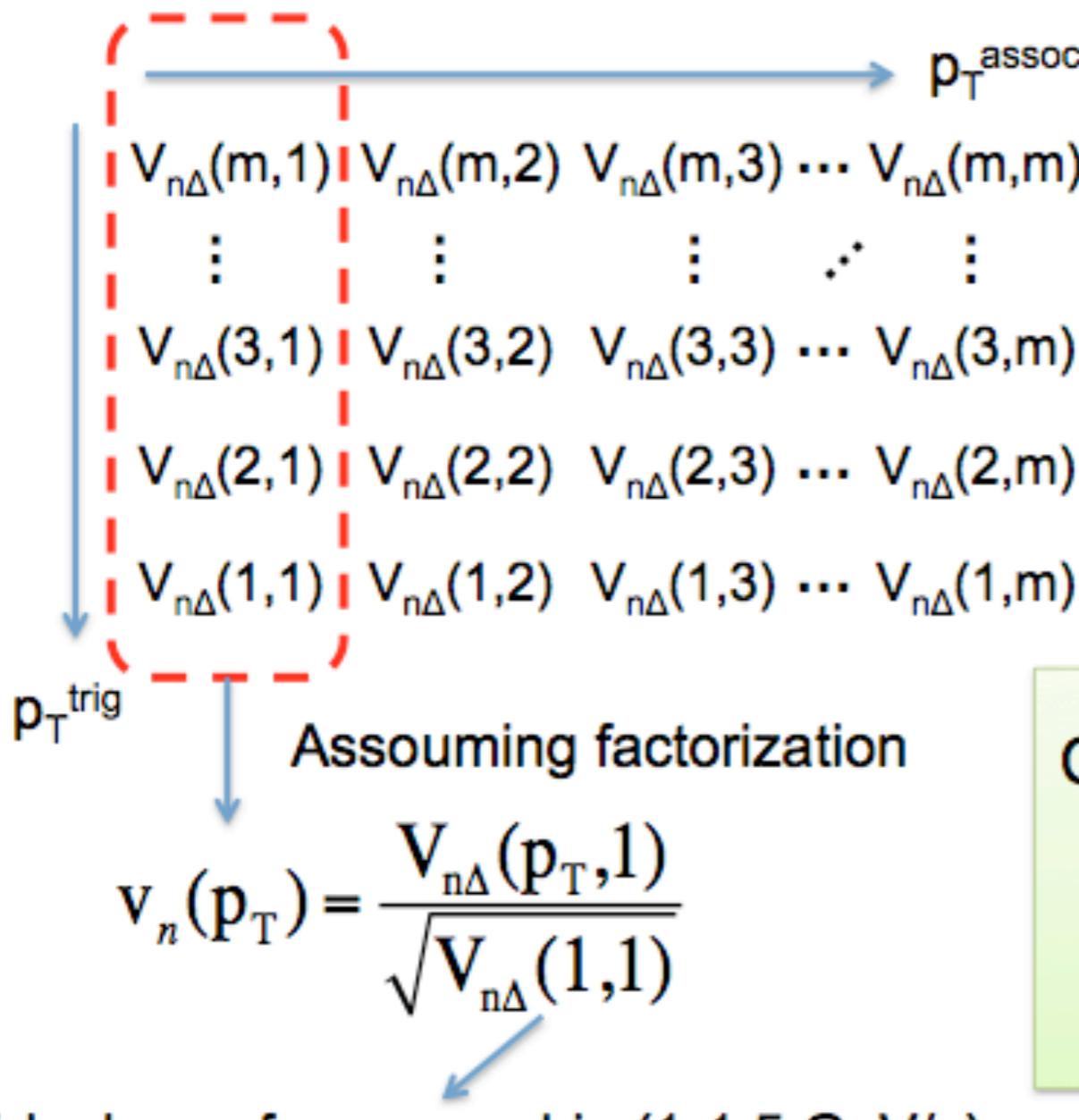


2D Correlations vs. Centrality



Factorization

Test of factorization: $V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}}) \xleftarrow{?} v_n(p_T^{\text{trig}}) \times v_n(p_T^{\text{assoc}})$



Take low reference p_T bin (1-1.5 GeV/c)

Check if $v_n(p_T)$ can derive rest of matrix:

$$\frac{V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}})}{v_n(p_T^{\text{trig}}) \times v_n(p_T^{\text{assoc}})} = 1$$

