

Dihadron Correlations in PbPb Collisions at 2.76 TeV with CMS

Yuting Bai



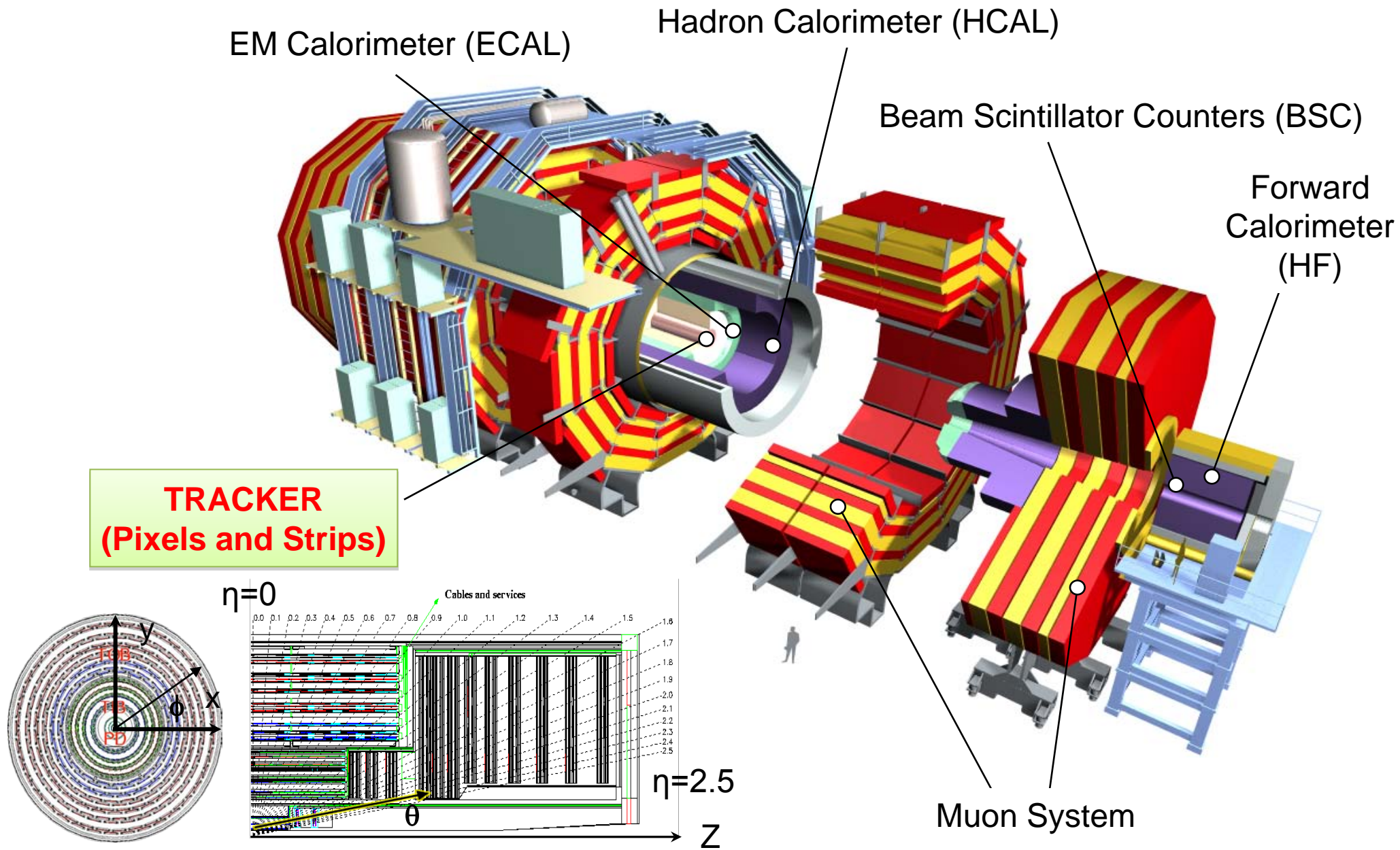
for the CMS Collaboration



Dihadron Correlations

- Features found in AA collisions at RHIC:
 - Broadened away side
 - Disappearance of back-to-back correlations
 - Near-side ridge
- Explanations of ridge include:
 - Connections to jet quenching
 - Higher order flow components (v_n | $n>2$)
- LHC and CMS provide:
 - Higher density system
 - Unprecedented pseudorapidity and p_T reach

CMS experiment



Very large coverage ($|\Delta\eta|$ up to 5.0)!

Dihadron correlations in CMS

Signal distribution:

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

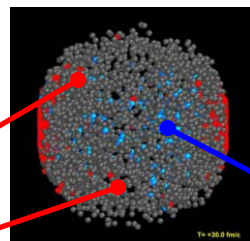
Particle 1: trigger

Particle 2: associated

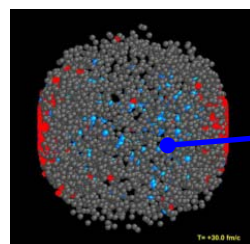
Background distribution:

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

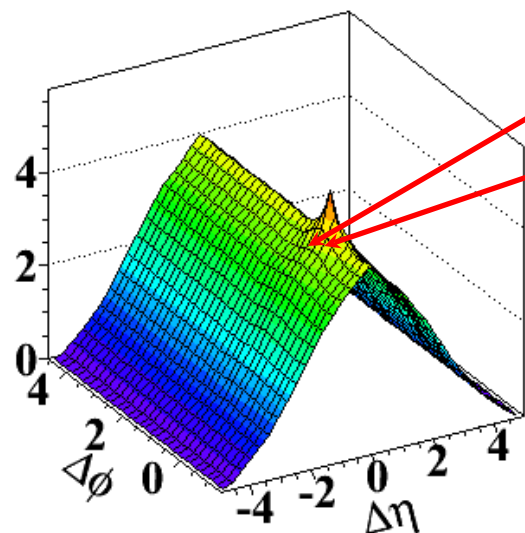
Event 1



Event 2

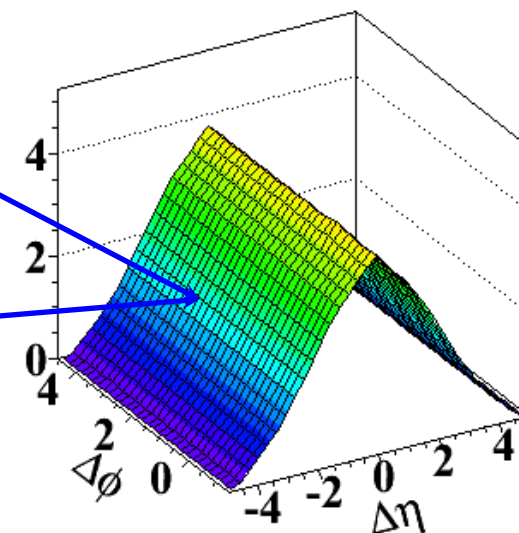


$S(\Delta\eta, \Delta\phi)$



same event pairs

$B(\Delta\eta, \Delta\phi)$



mixed event pairs

$$\begin{aligned} \Delta\eta &= \eta^{\text{assoc}} - \eta^{\text{trig}} \\ \Delta\phi &= \phi^{\text{assoc}} - \phi^{\text{trig}} \end{aligned}$$

Associated hadron yield per trigger:

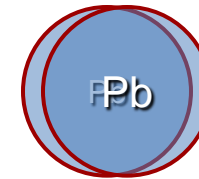
$$\frac{1}{N_{\text{trig}}} \frac{d^2 N^{\text{pair}}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$

Heavy-ion “ridge” at LHC

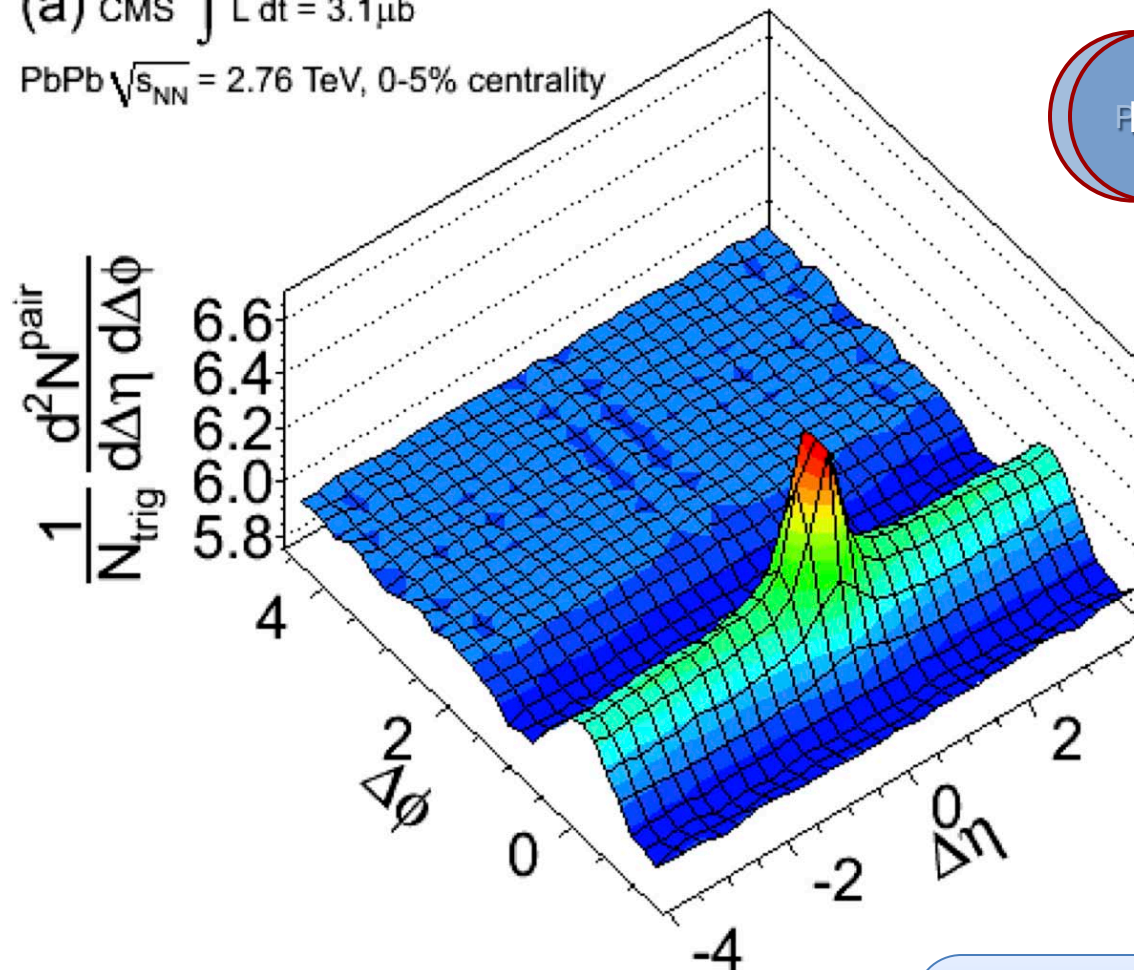
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(a) CMS $\int L dt = 3.1 \mu\text{b}^{-1}$

PbPb $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$, 0-5% centrality



0-5% most central



$p_T^{\text{trig}} : 4 \sim 6 \text{ GeV}/c$
 $p_T^{\text{assoc}} : 2 \sim 4 \text{ GeV}/c$

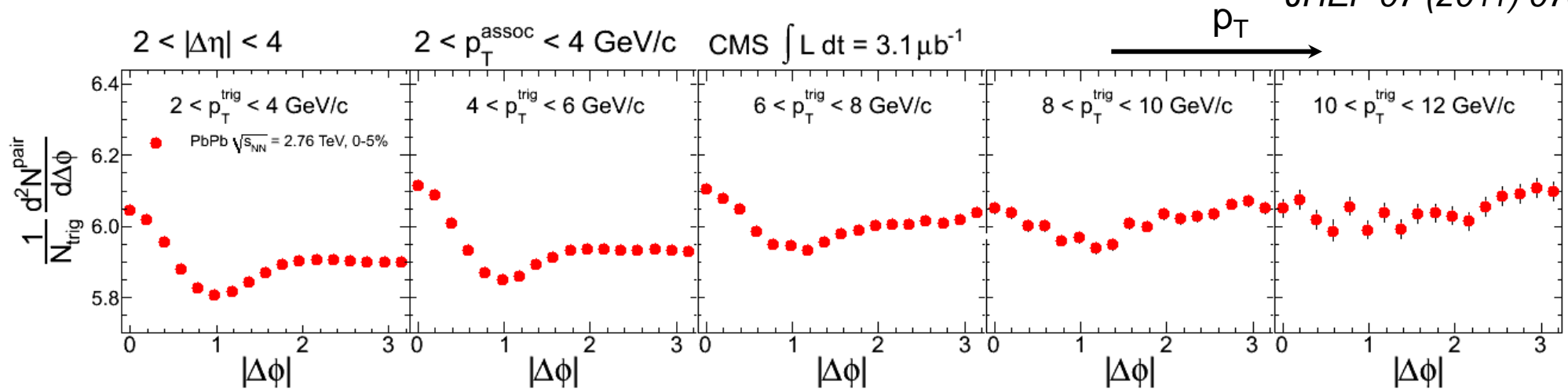
**Ridge-like structure
extends out to $|\Delta\eta| = 4$**

Associated hadron yield per trigger:

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

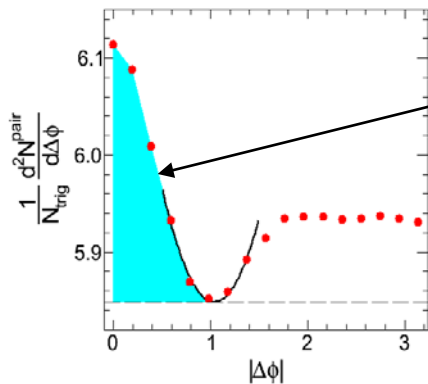
1D Correlation - Central 0-5% Ridge Region

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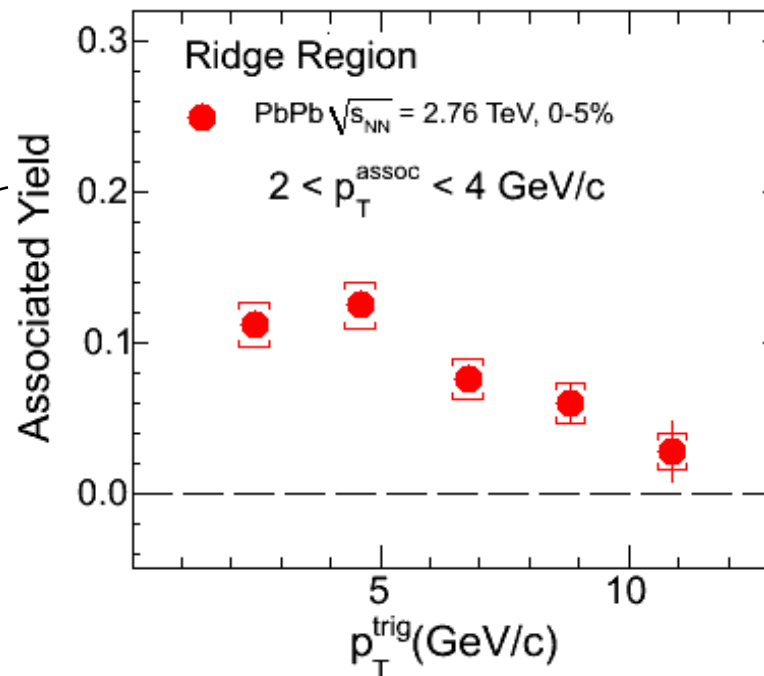


Ridge region ($2 < |\Delta\eta| < 4$)

ZYAM



v_2 not subtracted



Ridge in central PbPb collisions tends to diminish at high p_T

Centrality dependence in PbPb

$p_T^{\text{trig}} : 4 - 6 \text{ GeV/c}$
 $p_T^{\text{assoc}} : 2 - 4 \text{ GeV/c}$

PbPb 2.76 TeV

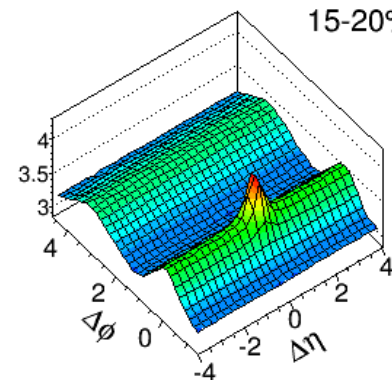
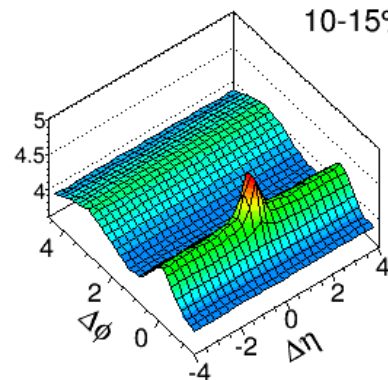
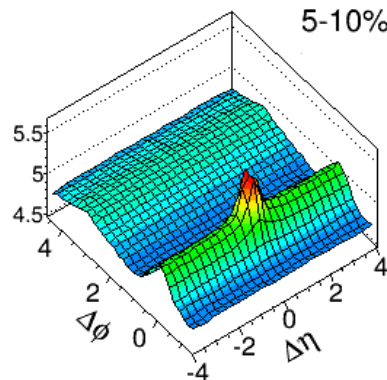
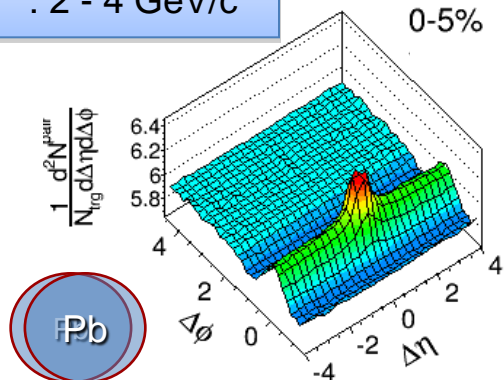
CMS Preliminary

0-5%

5-10%

10-15%

15-20%

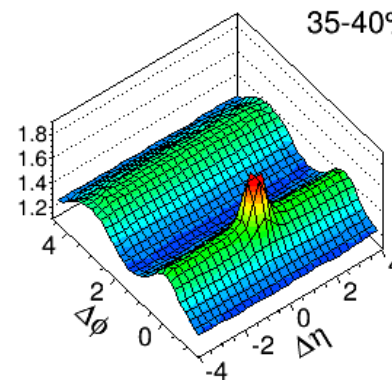
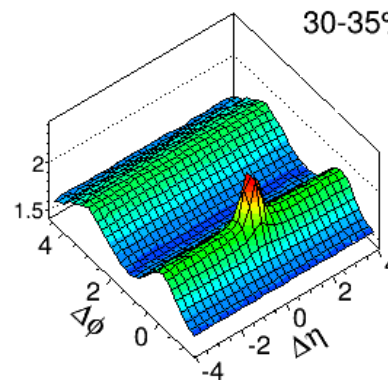
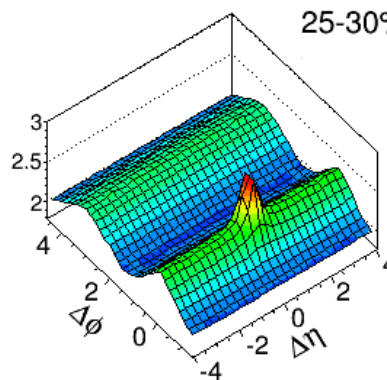
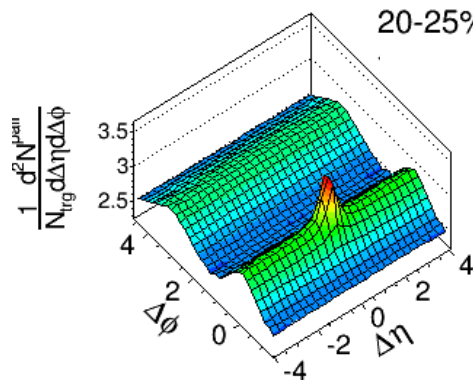


20-25%

25-30%

30-35%

35-40%

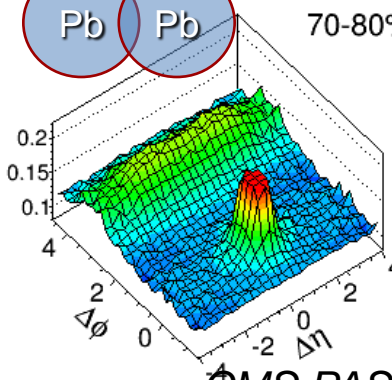
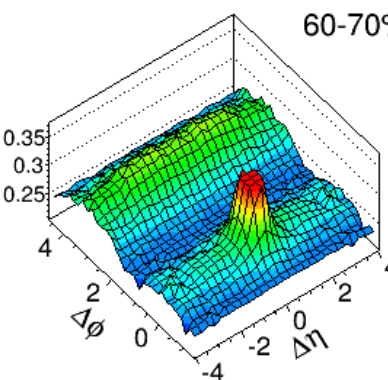
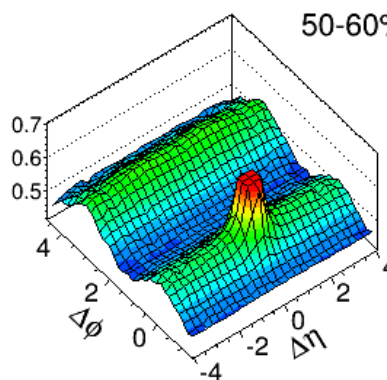
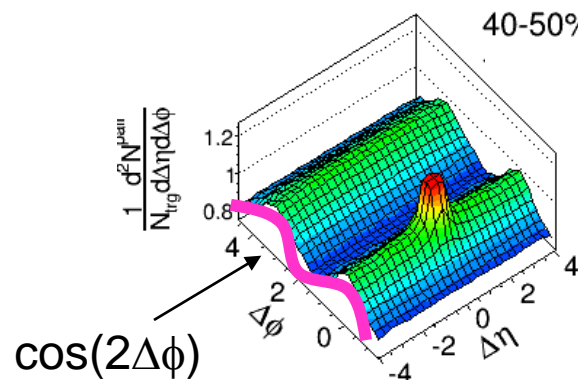


40-50%

50-60%

60-70%

70-80%



CMS PAS HIN-11-006

1D Correlation – Ridge Region

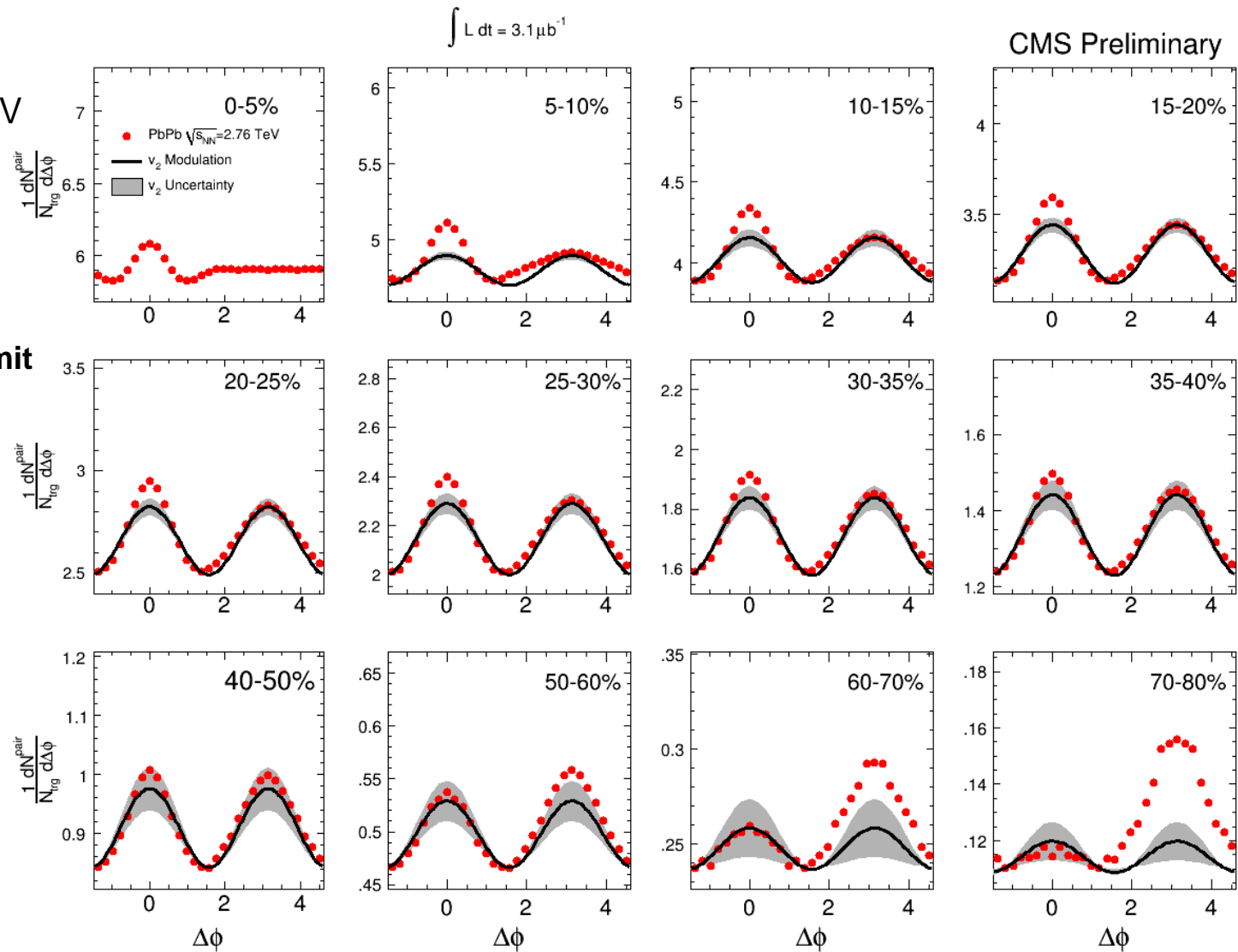
- PbPb $\sqrt{s_{NN}} = 2.76$ TeV
- v_2 modulation
(EP + Cum{4}) / 2
- v_2 uncertainty
- EP method = upper limit
Cum{4} = lower limit

$$\int L dt = 3.1 \mu b^{-1}$$

$$4 < p_T^{\text{trig}} < 6$$

$$2 < p_T^{\text{assoc}} < 4$$

$$2 < |\Delta\eta| < 4$$



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v_2 Subtracted Ridge Region

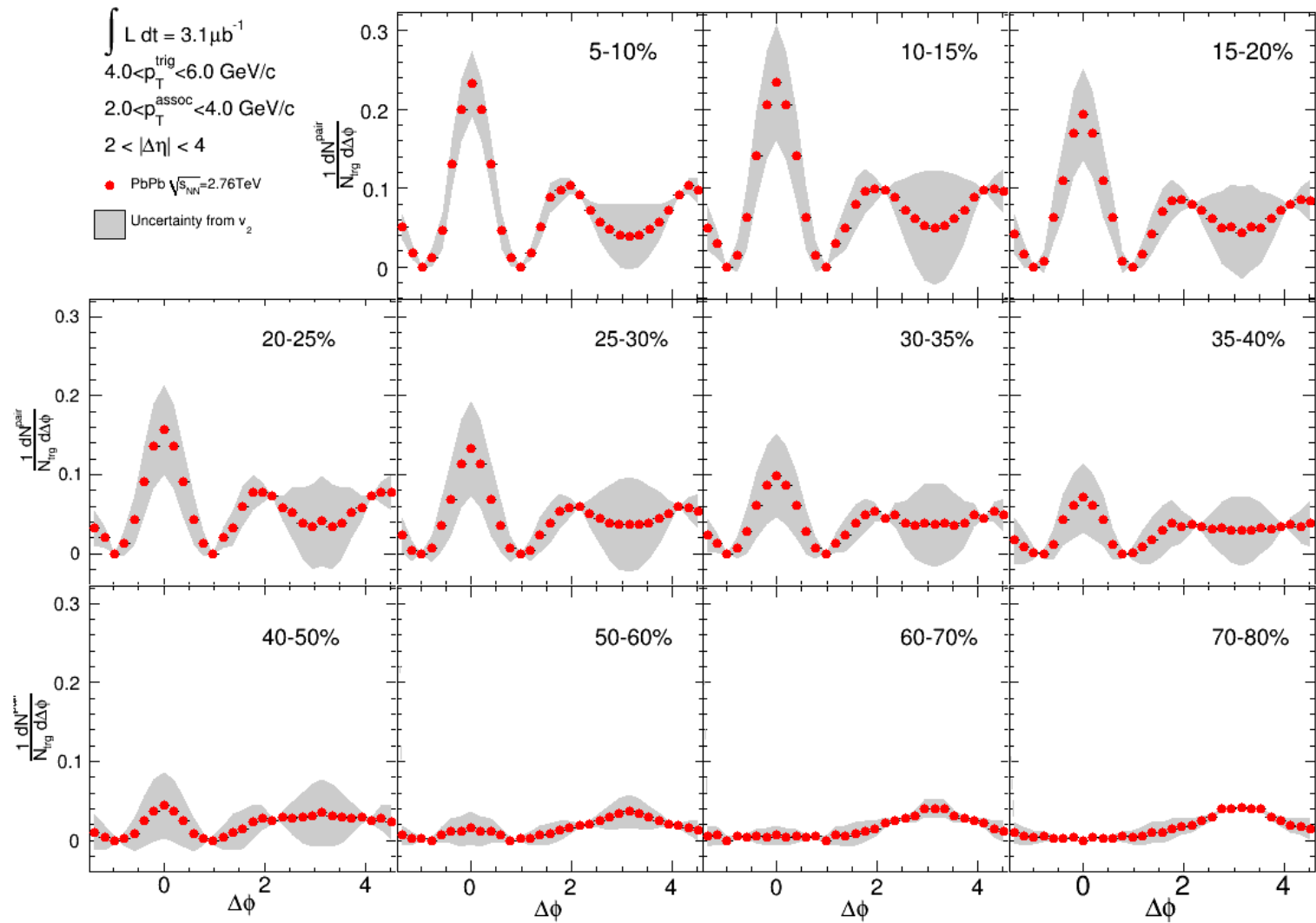
CMS Preliminary



v_2 subtracted
PbPb $\sqrt{s_{NN}} = 2.76$ TeV

Uncertainty
from v_2

$$\begin{aligned} 4 < p_T^{\text{trig}} < 6 \\ 2 < p_T^{\text{assoc}} < 4 \\ 2 < |\Delta\eta| < 4 \end{aligned}$$



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1D Correlation – Jet Region

● PbPb $\sqrt{s_{NN}} = 2.76$ TeV

— v_2 modulation
($EP + \text{Cum}\{4\}$) / 2

■ v_2 uncertainty

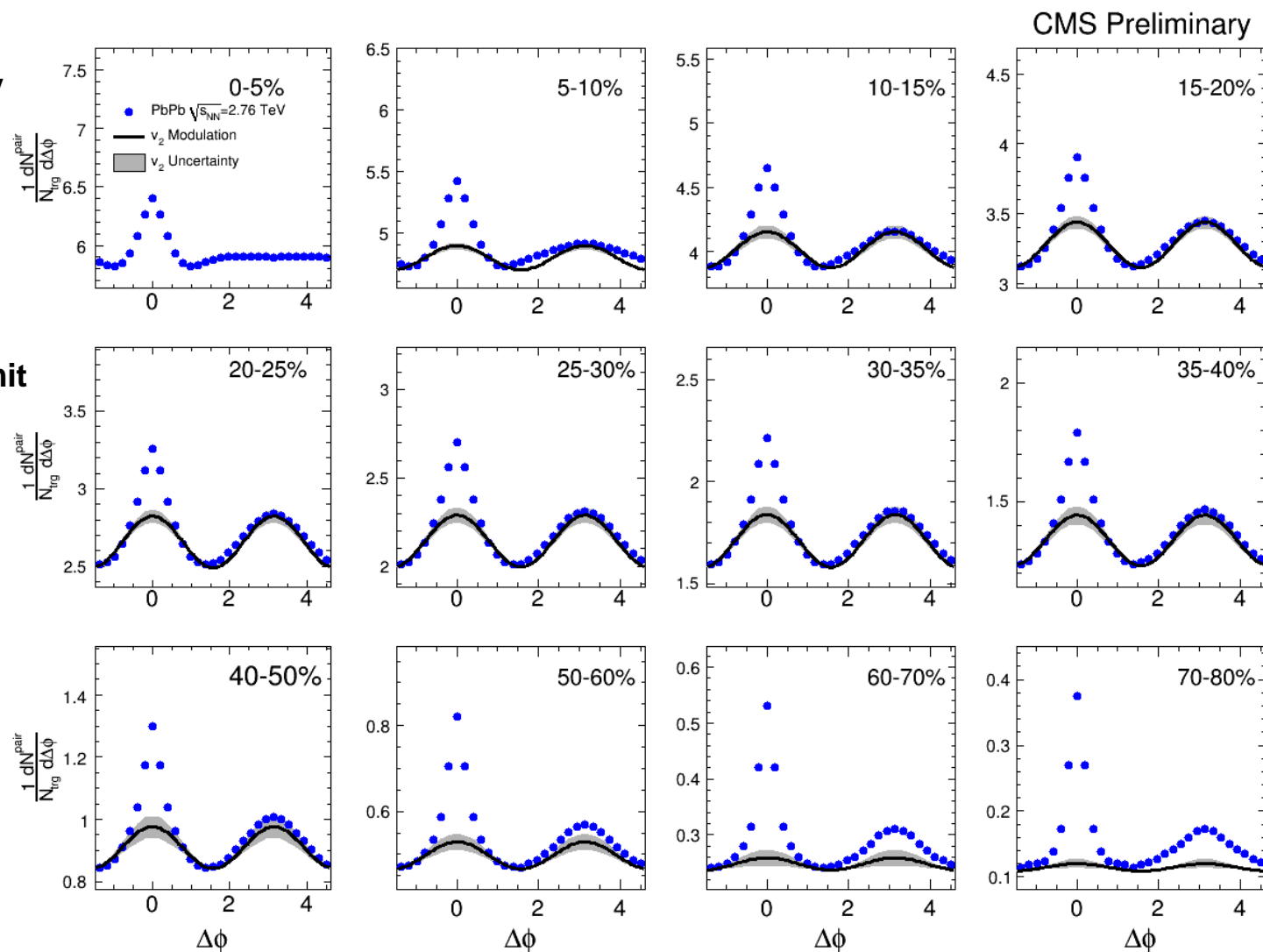
EP method = upper limit
 $\text{Cum}\{4\}$ = lower limit

$$\int L dt = 3.1 \mu\text{b}^{-1}$$

$$4 < p_{T}^{\text{trig}} < 6$$

$$2 < p_{T}^{\text{assoc}} < 4$$

$$0 < |\Delta\eta| < 1$$



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v_2 Subtracted Jet Region

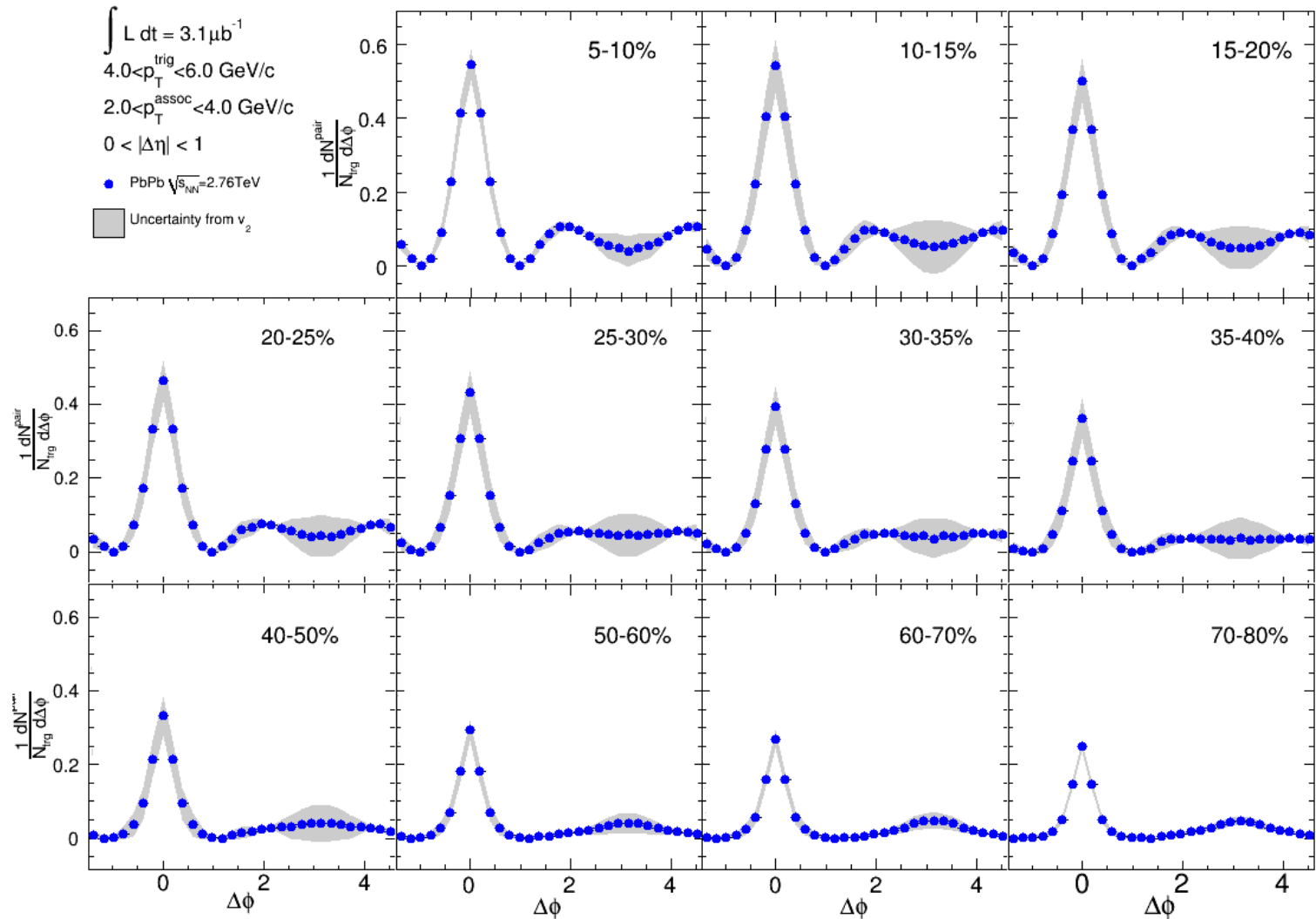
CMS Preliminary



v_2 subtracted
PbPb $\sqrt{s_{NN}} = 2.76$ TeV

Uncertainty
from v_2

$\int L dt = 3.1 \mu b^{-1}$
 $4.0 < p_T^{trig} < 6.0$ GeV/c
 $2.0 < p_T^{assoc} < 4.0$ GeV/c
 $0 < |\Delta\eta| < 1$
● PbPb $\sqrt{s_{NN}} = 2.76$ TeV
■ Uncertainty from v_2



$4 < p_T^{trig} < 6$
 $2 < p_T^{assoc} < 4$
 $0 < |\Delta\eta| < 1$

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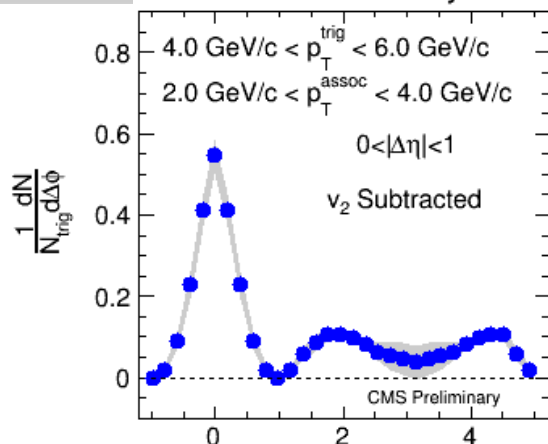
Comparison with RHIC

CMS Preliminary

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

5-10% Centrality

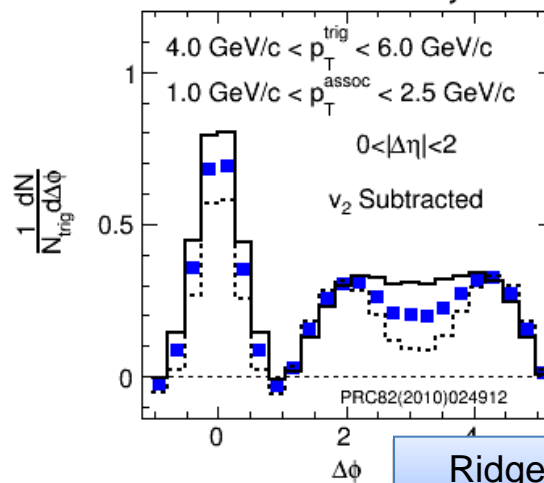
Jet region ($|\Delta\eta| < 1$)



STAR

AuAu $\sqrt{s_{NN}} = 0.2$ TeV

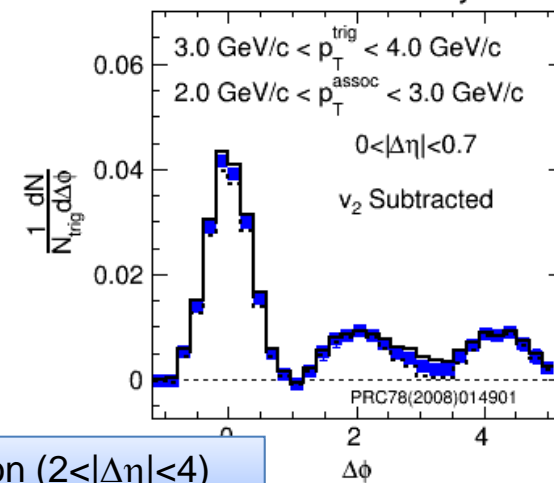
0-12% Centrality



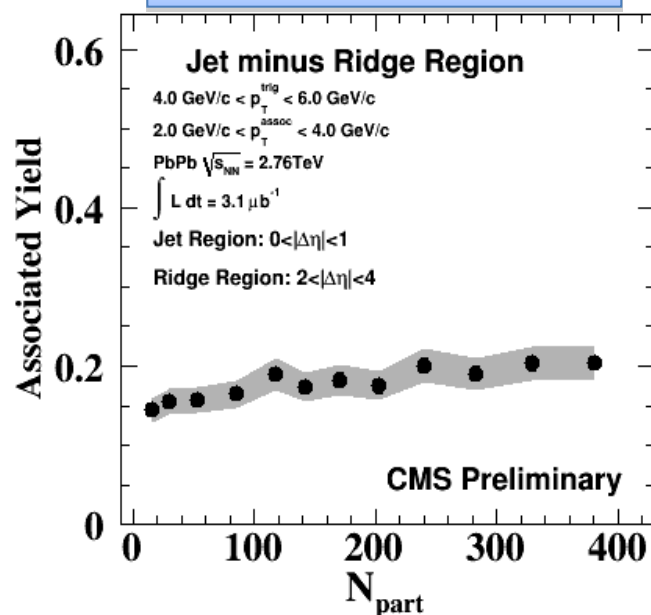
PHENIX

AuAu $\sqrt{s_{NN}} = 0.2$ TeV

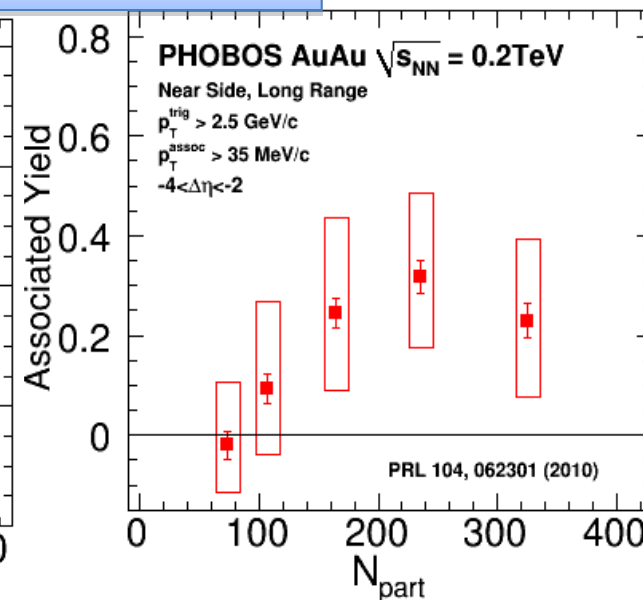
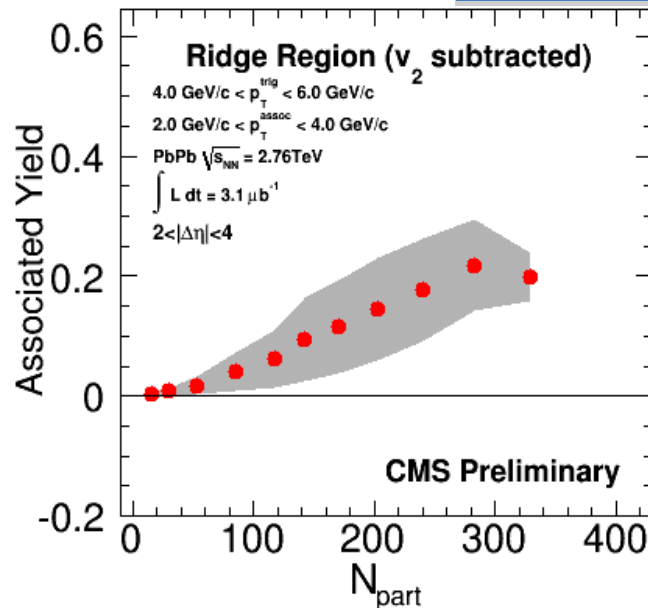
0-20% Centrality



Jet minus ridge region



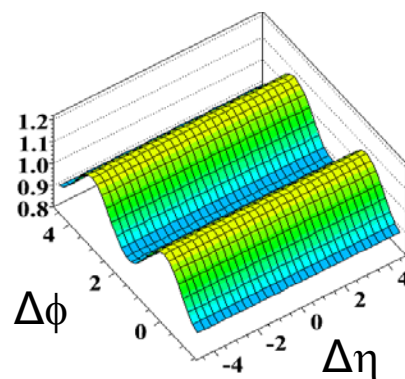
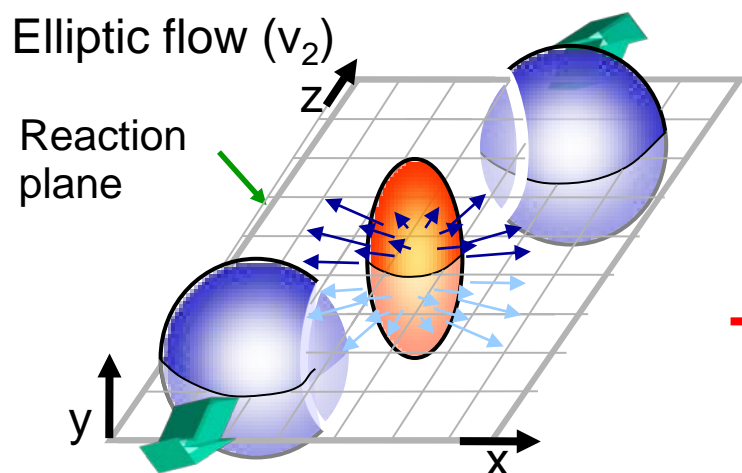
Ridge region ($2 < |\Delta\eta| < 4$)



Qualitatively, similar trend in centrality to RHIC results

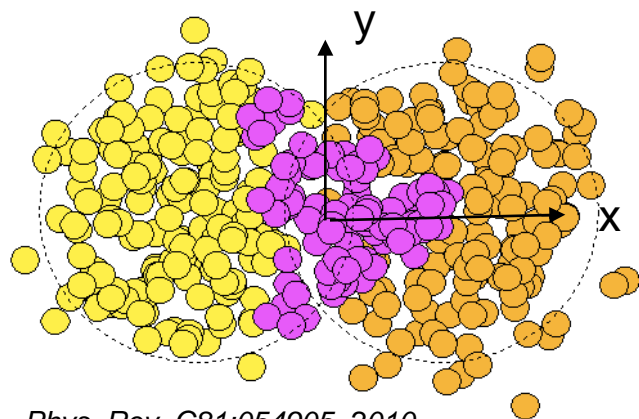
Ridge from higher-order flow harmonics

Long range rapidity correlations \rightarrow early time dynamics

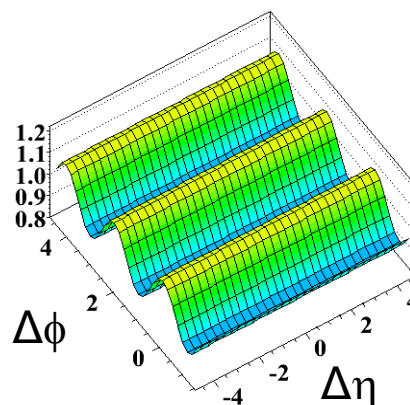


$$\sim V_{2\Delta} \cos(2\Delta\phi)$$

Initial condition fluctuations \rightarrow
higher order odd flow harmonics
(e.g., triangle flow, v_3)



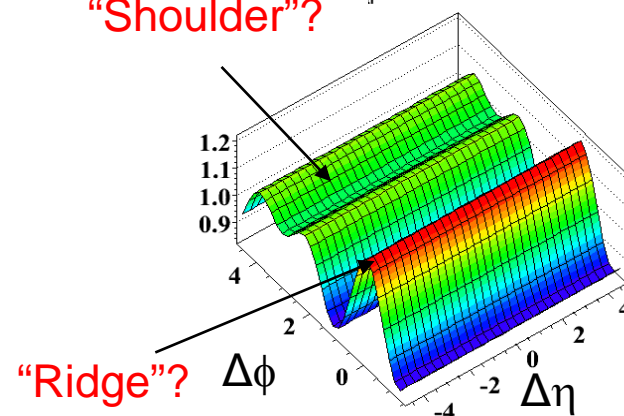
Phys. Rev. C81:054905, 2010



$$\sim V_{3\Delta} \cos(3\Delta\phi)$$

Add $V_{2\Delta}$ and $V_{3\Delta}$

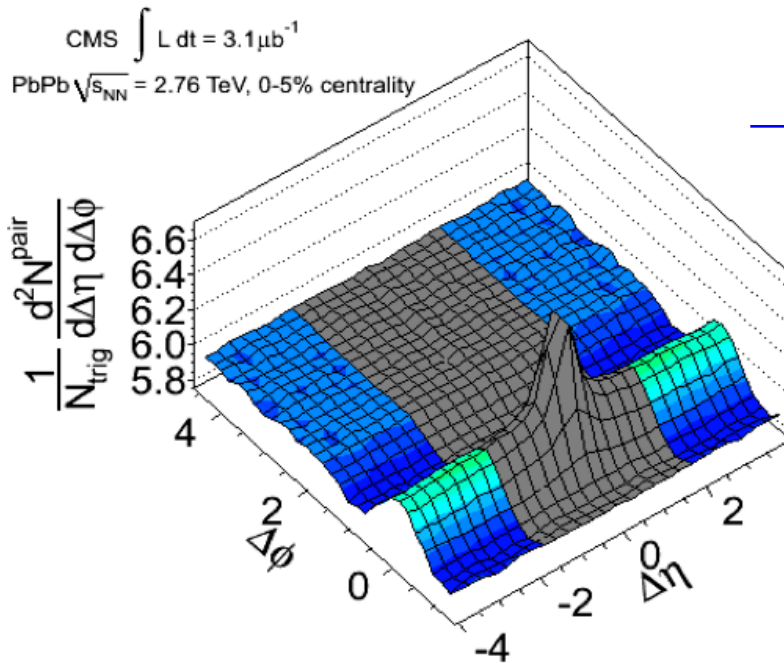
“Shoulder”?



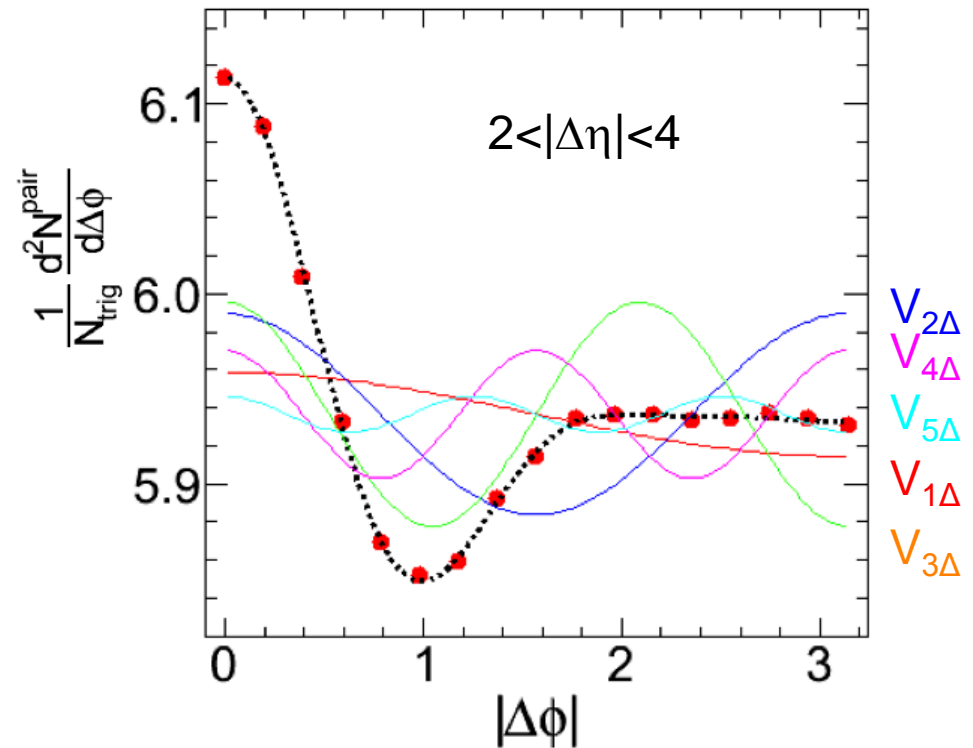
“Ridge”?

Fourier analysis of $\Delta\phi$ correlations

Fourier decomposition:
$$\frac{1}{N_{\text{trig}}} \frac{dN^{\text{pair}}}{d\Delta\phi} = \frac{N_{\text{assoc}}}{2\pi} \left(1 + 2 \sum_{n=1} V_{n\Delta} \cos(n\Delta\phi) \right)$$



Short-range non-flow effects excluded



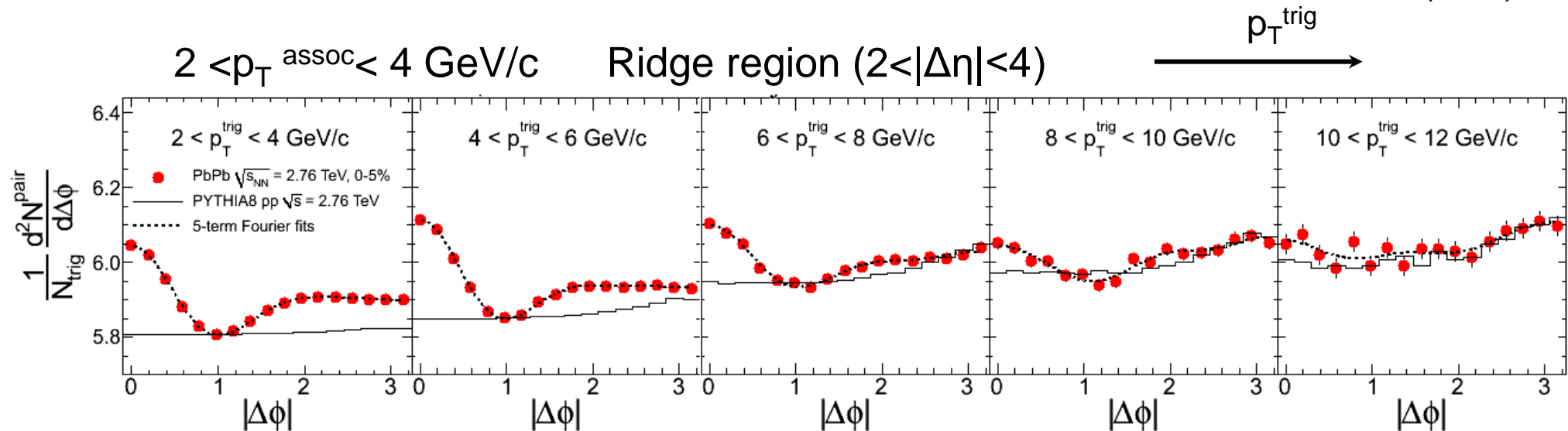
Ridge structure exhausted by first 5 Fourier terms

Flow driven correlations:
$$V_{n\Delta} = V_n^{\text{trig}} \times V_n^{\text{assoc}}$$

(factorization relation can be tested directly!)

Fourier analysis of $\Delta\phi$ correlations

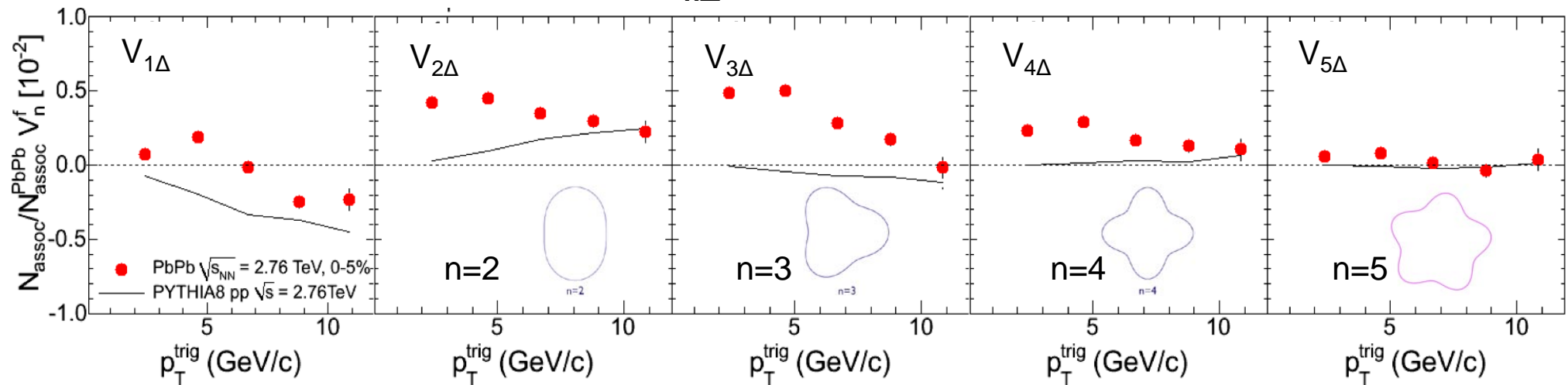
JHEP 07 (2011) 076



0-5% most central

Ridge persists to high p_T but decreases in magnitude

Extracted Fourier coefficients $V_{n\Delta}$



Flow harmonics (v_n) from the ridge

If **assume** flow **alone** is responsible for the ridge **and** there is no away side jet contribution in the correlation,

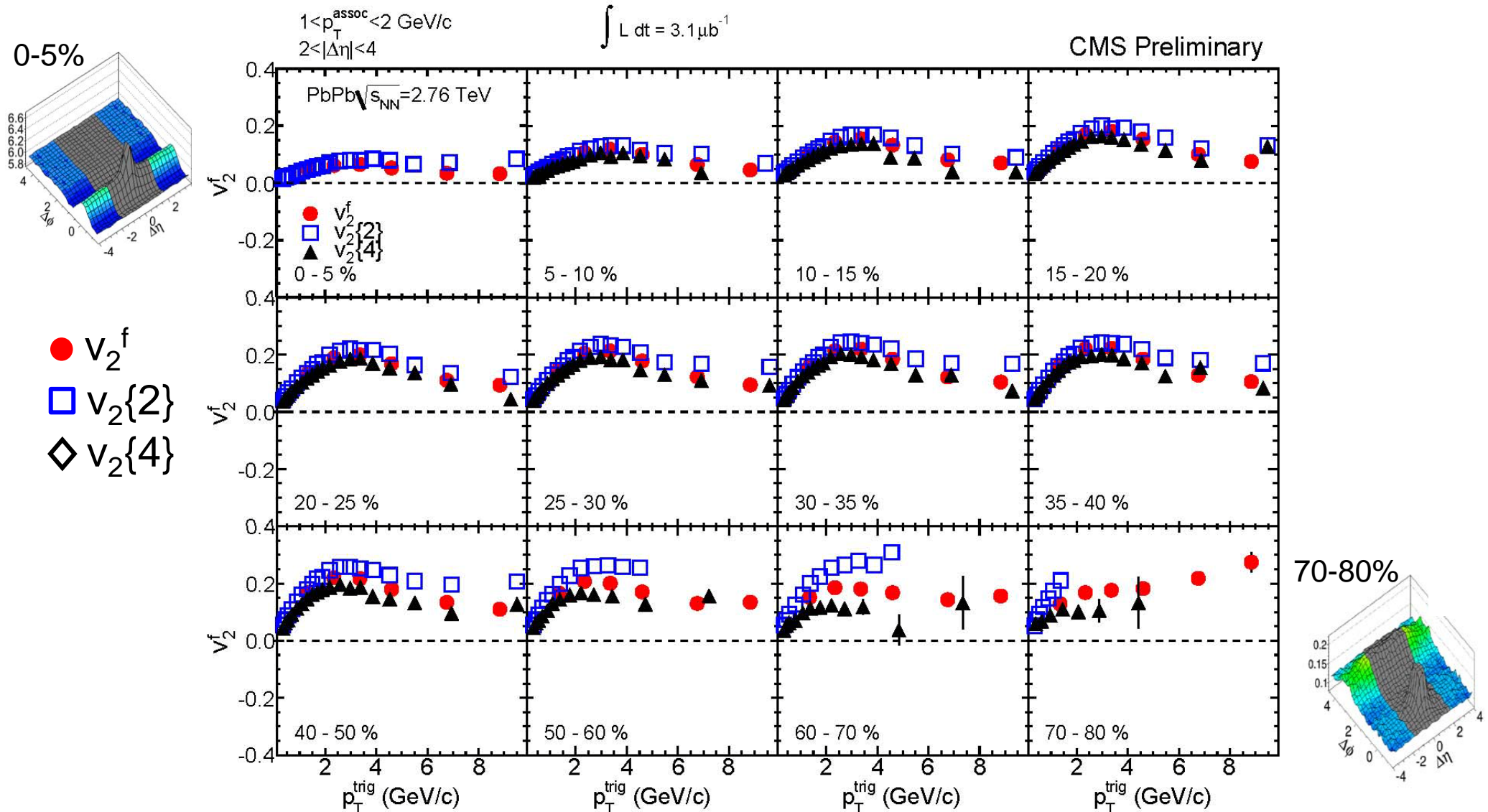
$$V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}}) = v_n(p_T^{\text{trig}}) \times v_n(p_T^{\text{assoc}})$$

flow coefficients v_n could be extracted :

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

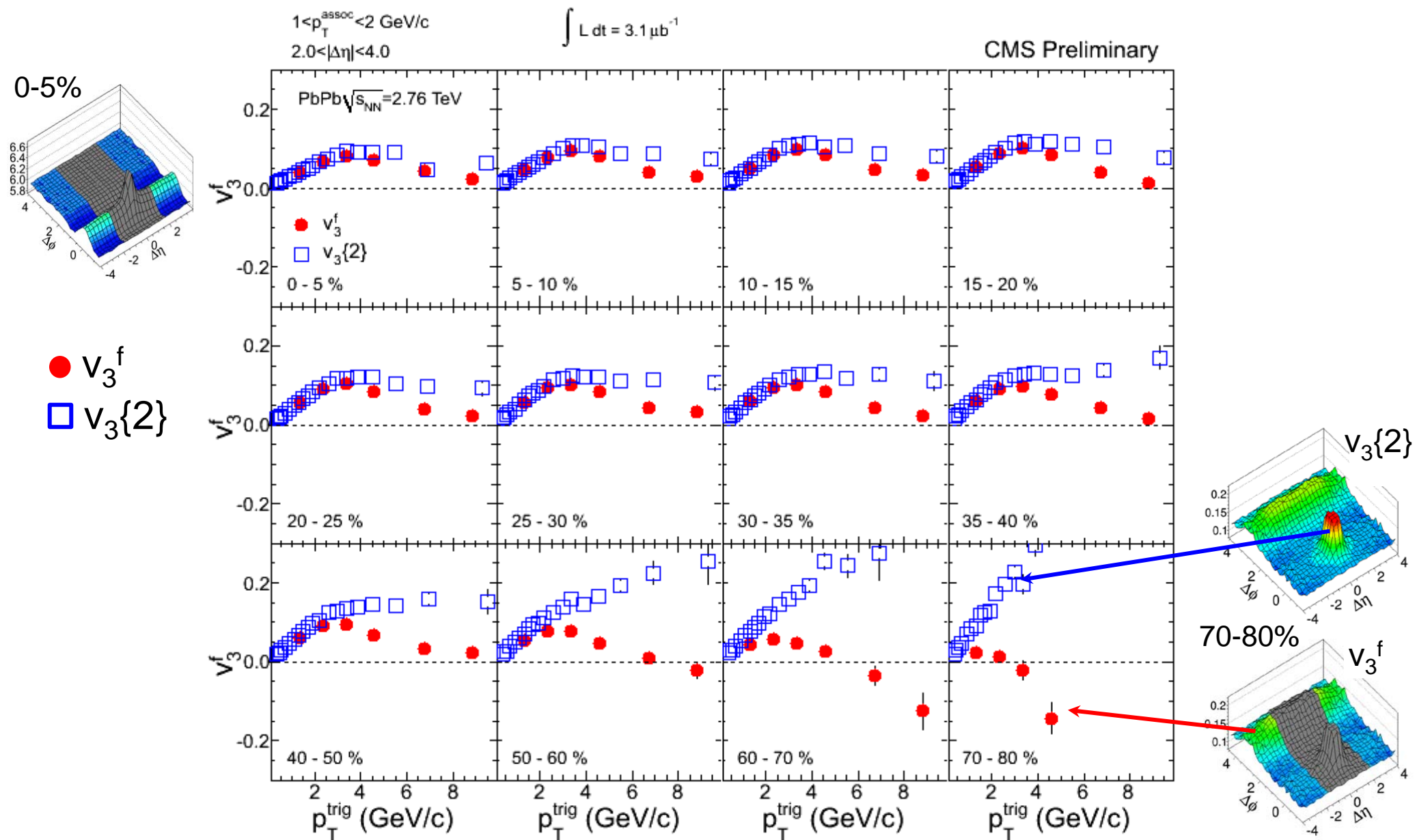
Keep low p_T^{assoc} ($1 < p_T^{\text{assoc}} < 2 \text{ GeV/c}$) to minimize non-flow effects

v_2 from long-range correlations



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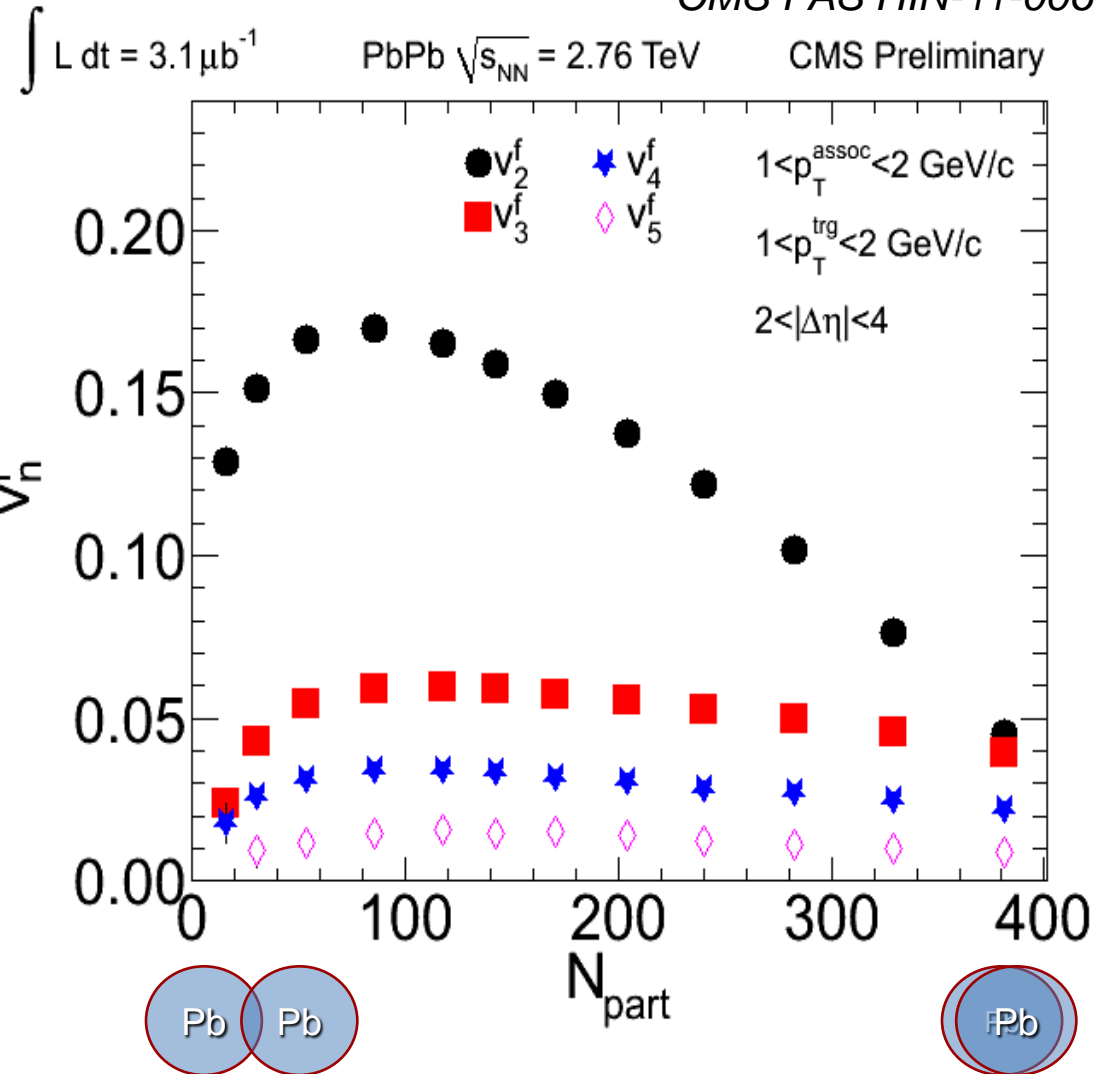
v_3 from long-range correlations



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Flow coefficients (v_n^f) vs centrality

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Centrality dependence of v_n follows expectation from hydrodynamics (initial geometry and its fluctuation)

Powerful constraints on the initial condition and viscous property

Further systematic checks of $V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}})$ factorization

- Disentangle flow and non-flow correlations
- Study jet-medium interactions (after flow subtraction)

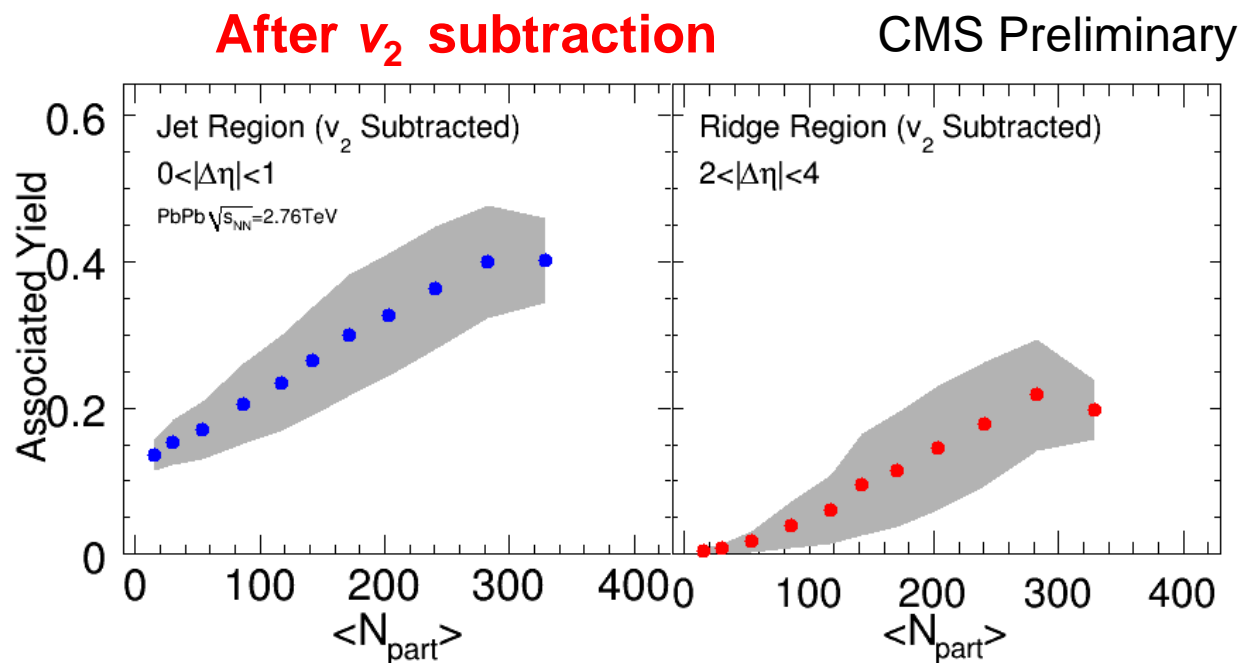
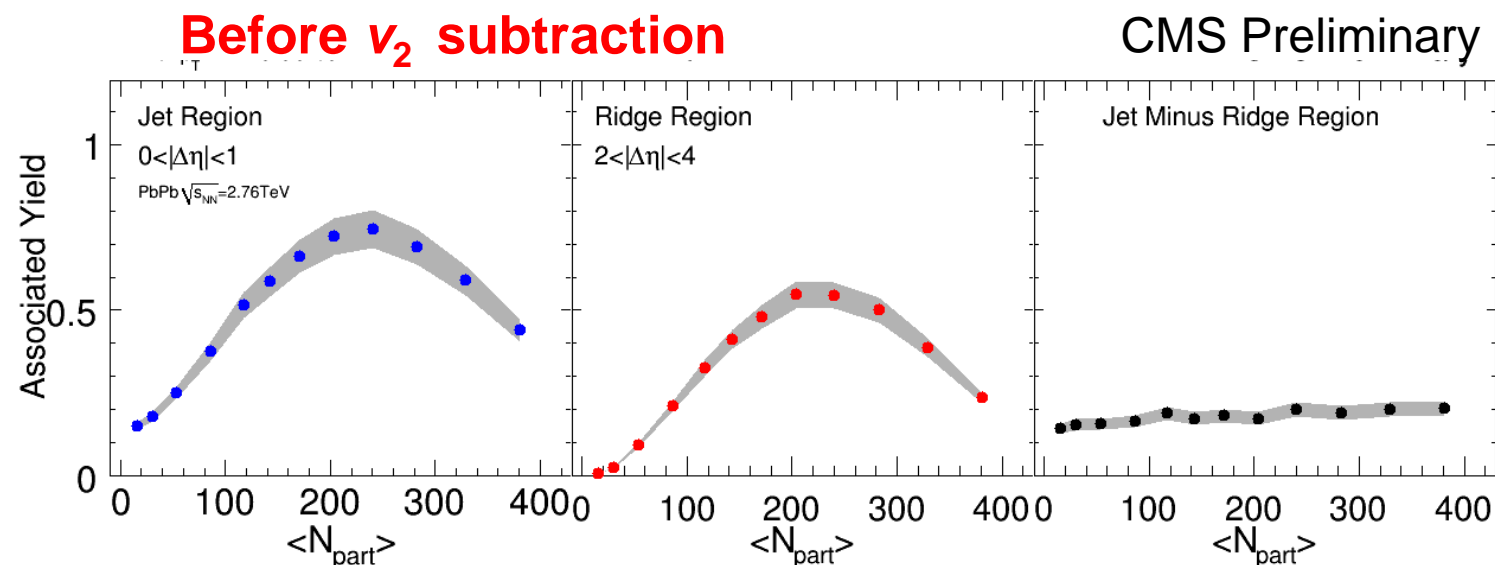
Summary

- Ridge-like structure extends out to $|\Delta\eta| < 4$ and tends to disappear with increasing p_T
- Standard v_2 -subtracted ridge results are qualitatively consistent with RHIC
- Ridge can be described by higher order flow (v_n), which supports a picture of fluctuating initial condition
- Results of Fourier analysis of the ridge region are consistent with standard flow measurements

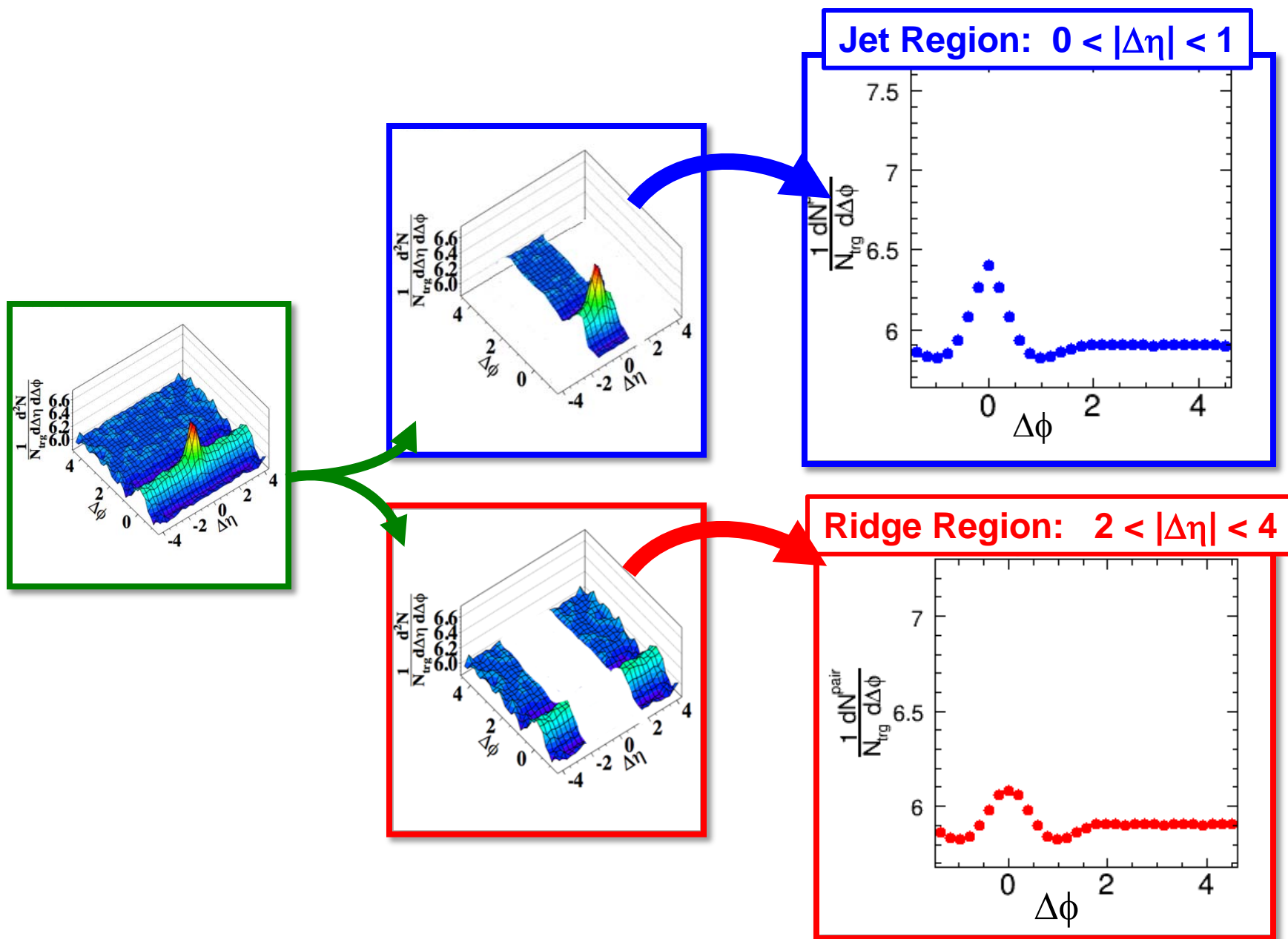
BACKUP

v_2 -subtracted associated yield in PbPb

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Jet and Ridge Regions



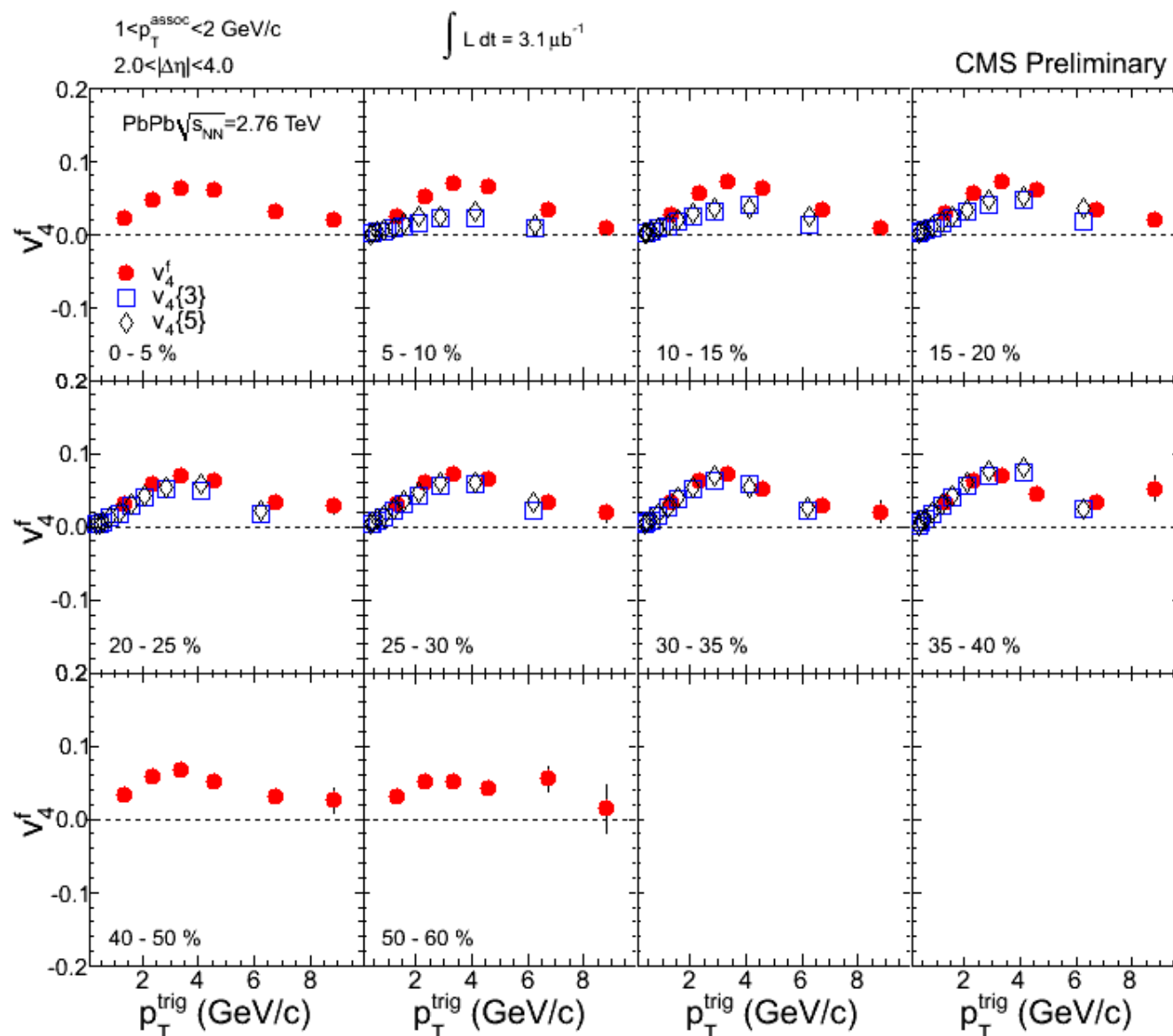
v_4 from long-range correlations

- v_4^f
- $v_{4\{3\}}$
- ◇ $v_{4\{5\}}$

$$\int L dt = 3.1 \mu\text{b}^{-1}$$

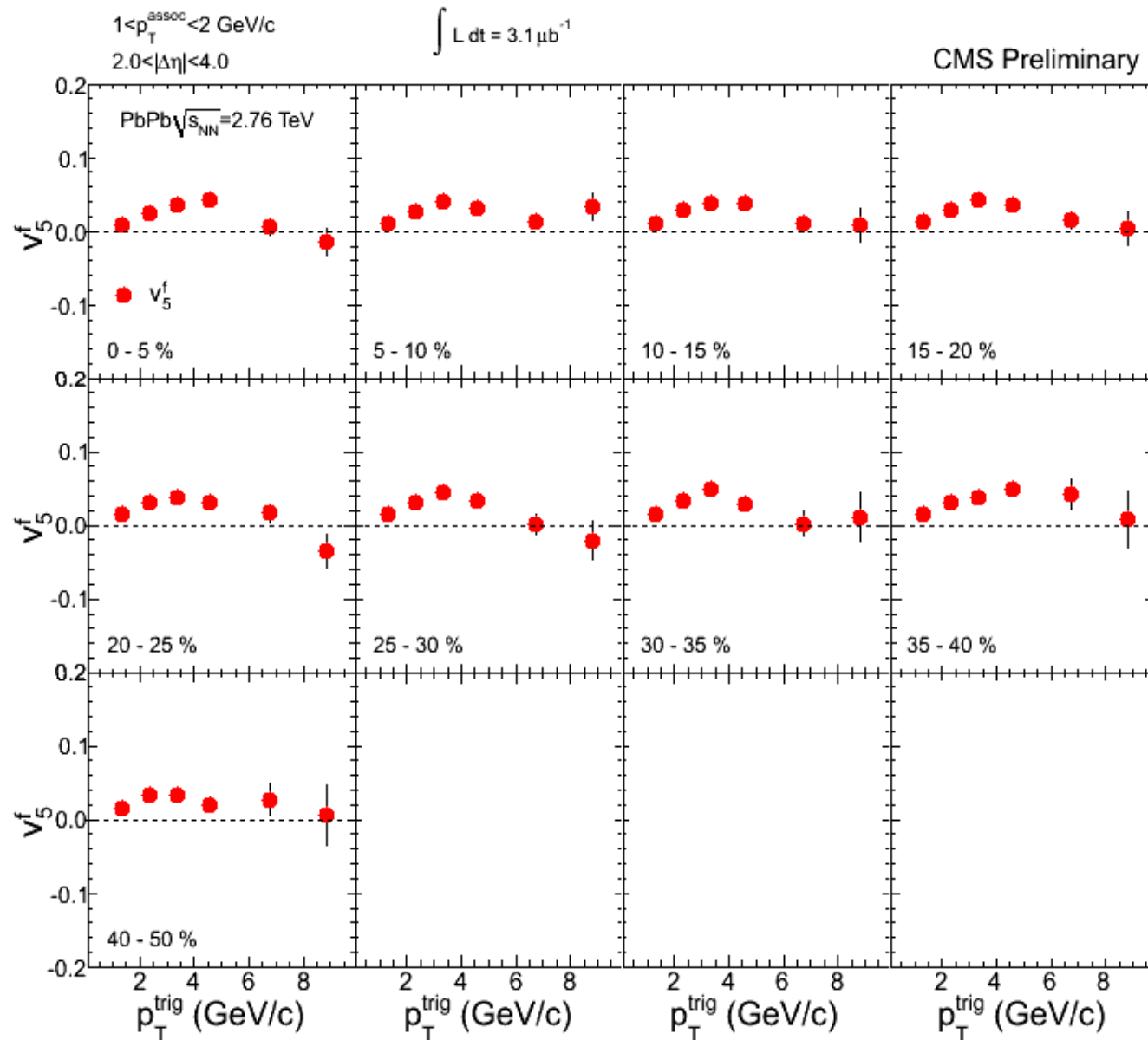
$$1 < p_T^{\text{assoc}} < 2$$

$$2 < |\Delta\eta| < 4$$



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v_5 from long-range correlations



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