Dihadron correlation in pp and PbPb collisions

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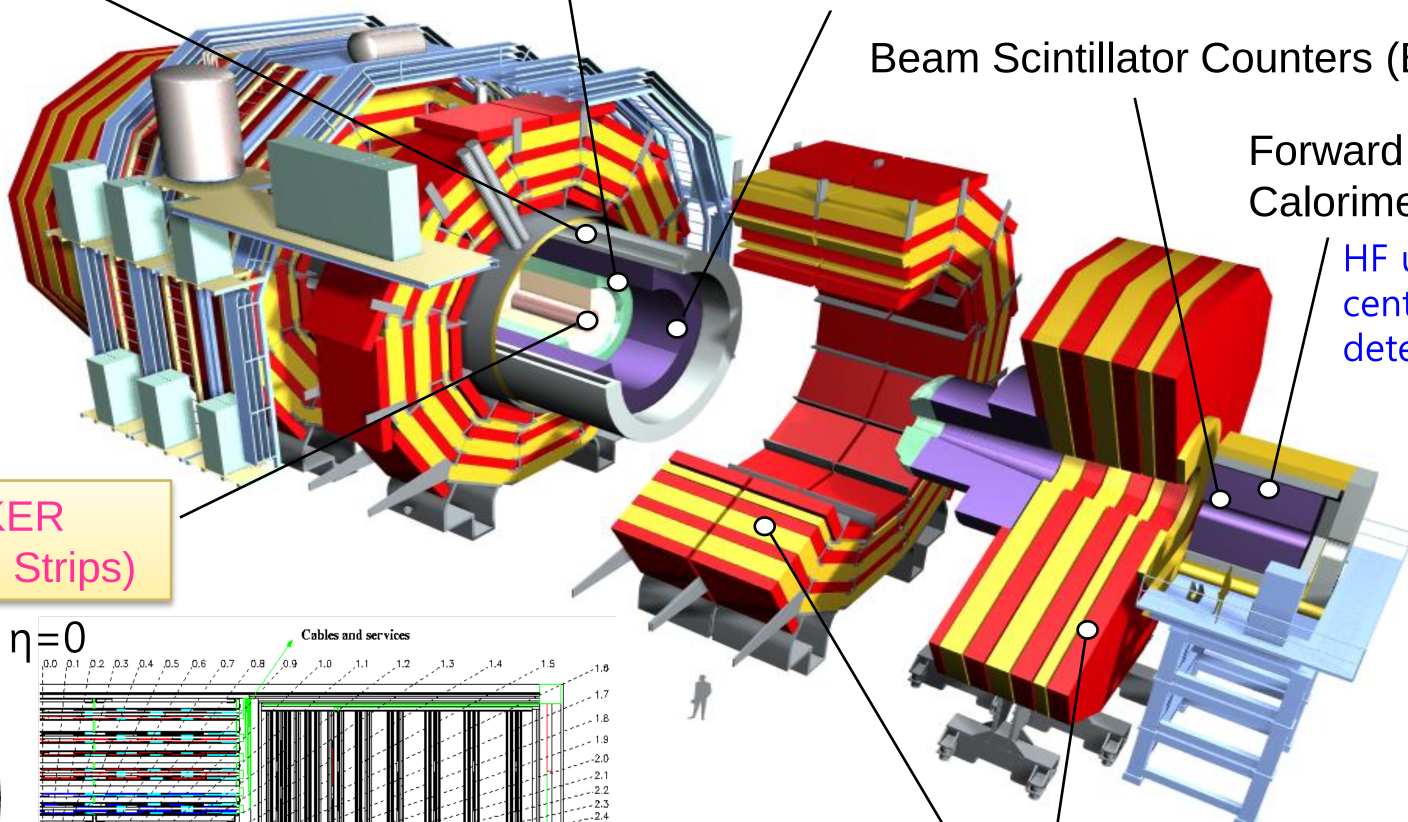
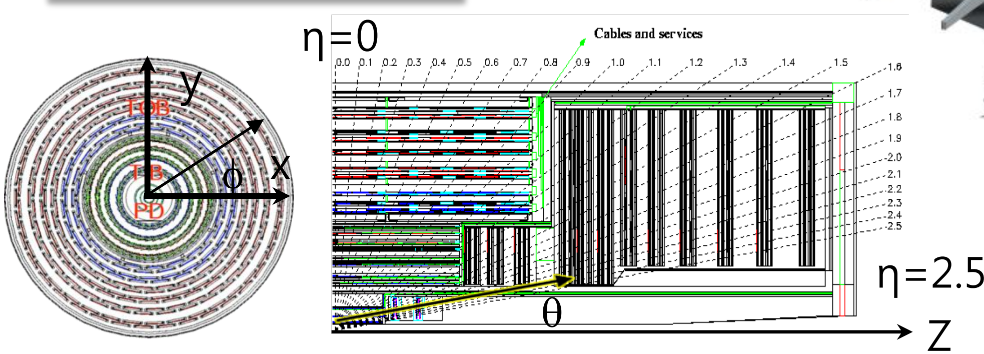
On behalf of the CMS collaboration

Introduction

- Correlation measurements are powerful to :
  - Study the mechanism of hadron production
  - Probe the jet-medium interactions in AA
  - Explore the bulk properties of the medium
- LHC and CMS provide:
  - Higher density system
  - Unprecedented pseudorapidity and p_T reach
- Outline :
  - Correlation in high multiplicity pp at 7 TeV
    - Comprehensive analysis of the ridge correlation structure
  - Correlation in PbPb at 2.76 TeV/NN
    - Explanations of ridge include connections to jet quenching and higher order flow components

CMS detector





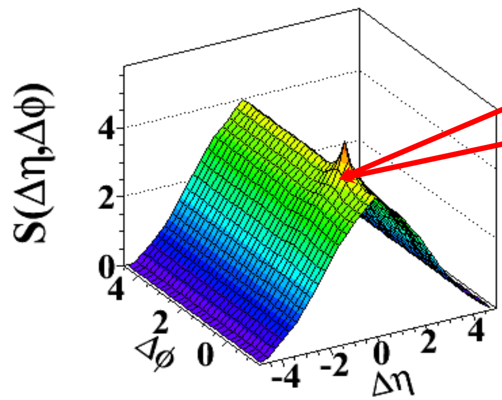
Very large coverage (|η|< 2.5) and high granularity!

Angular Correlation Technique

Particle 1: trigger
Particle 2: associated

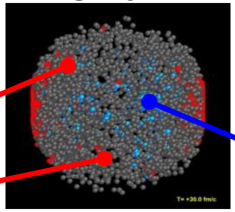
Signal distribution:

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

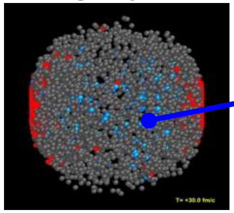


same event pairs

Event 1

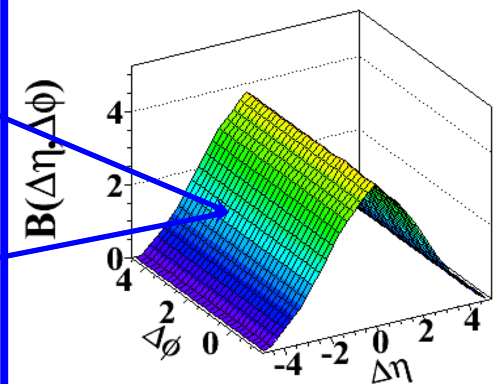


Event 2



Background distribution:

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



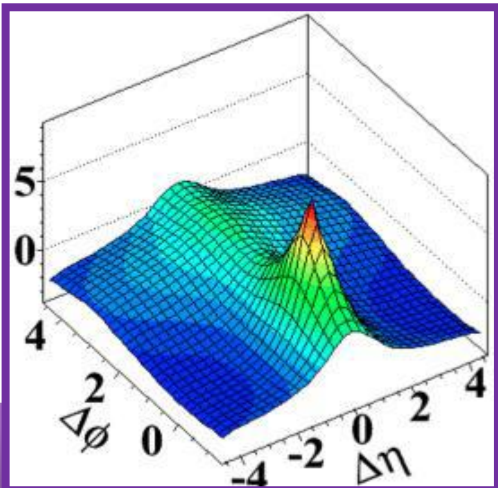
mixed event pairs

$\Delta\eta = \eta^{assoc} - \eta^{trig}$
$\Delta\phi = \phi^{assoc} - \phi^{trig}$

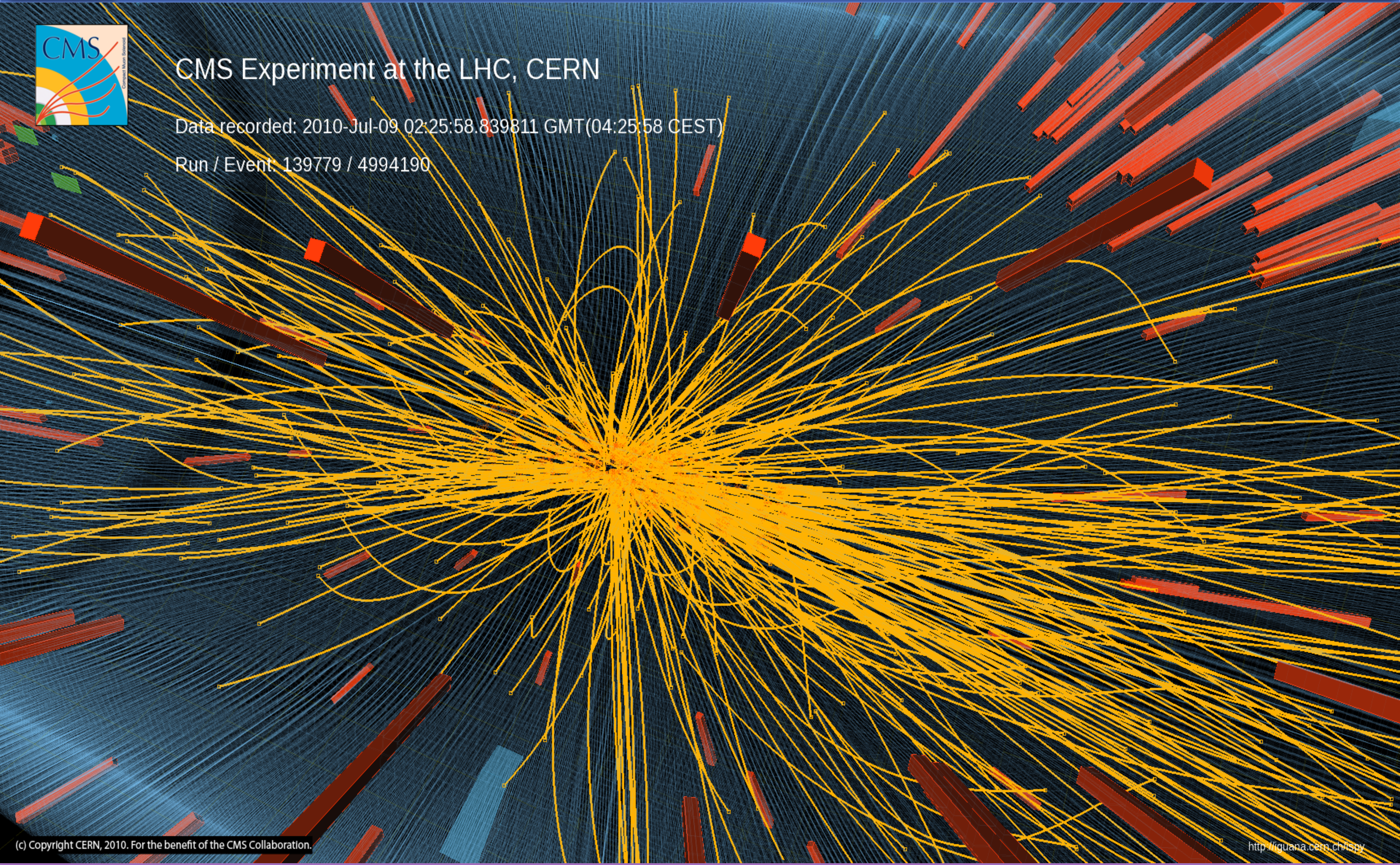
Associated hadron yield per trigger:

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

Divide signal by background



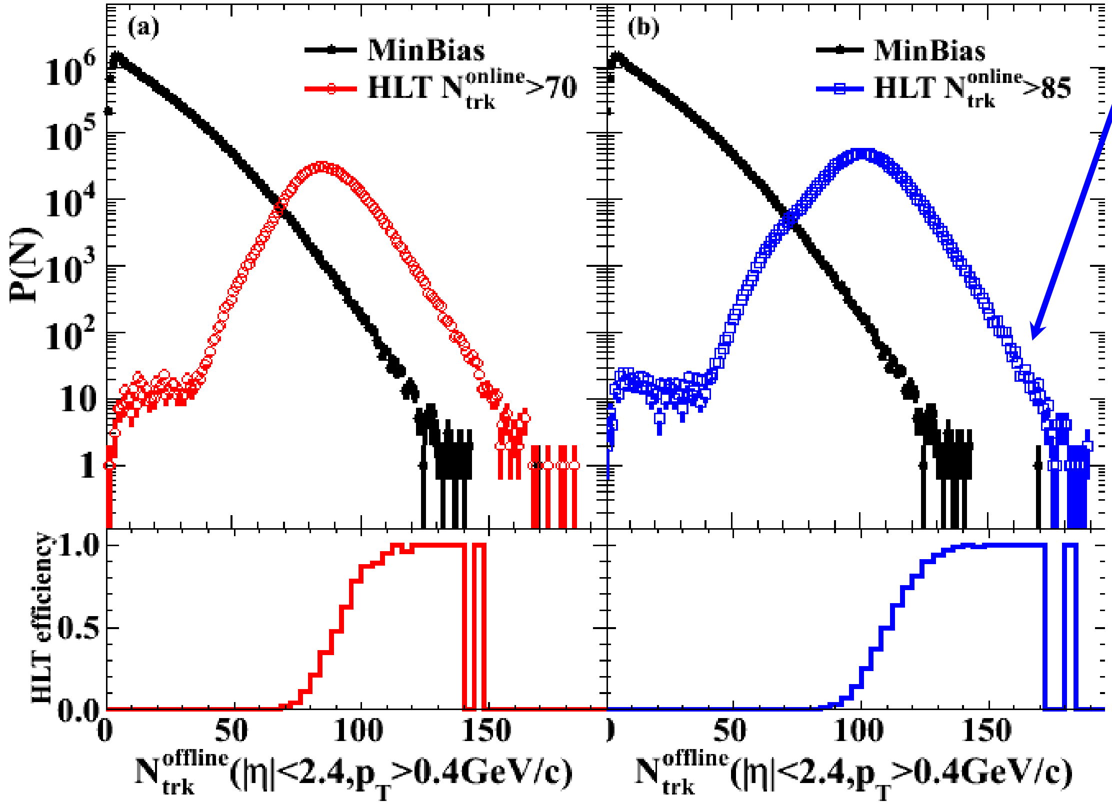
High multiplicity in pp



High multiplicity pp collisions

Very high particle density regime

√s = 7 TeV



Dedicated triggers on high multiplicity events from a single collisions (not pileup!)

N_{trk}^{online} > 85 trigger un-prescaled for full 980nb^{-1} data set

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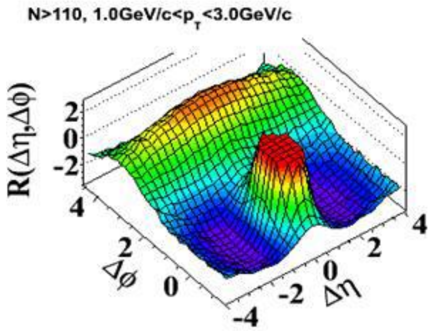
~350K top multiplicity events (N>110) out of 50 billion collisions!

Ridge in high multiplicity pp

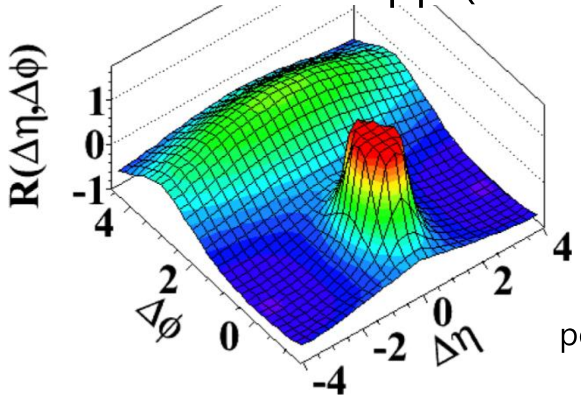
Intermediate p_T: 1-3 GeV/c

350K events



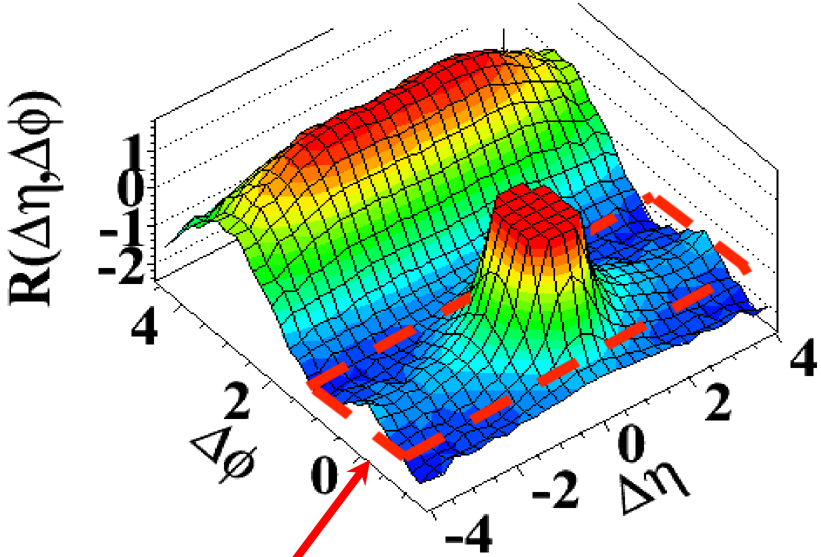
High multiplicity MC

Minimum Bias pp (<N> ~ 15)



peak truncated

High multiplicity pp (N ≥ 110)



JHEP 09 (2010) 091

Striking "ridge-like" structure extending over $\Delta\eta$ at $\Delta\phi \sim 0$
(not observed before in hadron collisions or MC models)

Ridge in high multiplicity pp

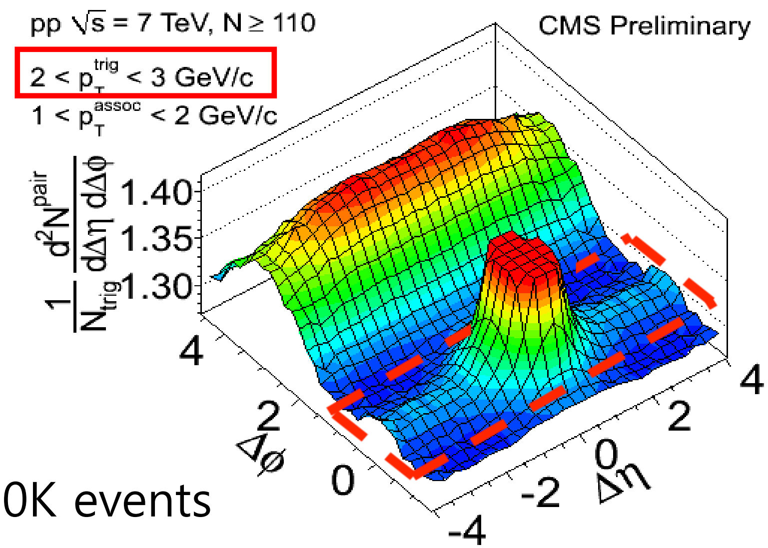
Updated new results:

- ~ 2 x statistics of previous results
- Extend multiplicity reach
- Detailed (p_T^{trig}, p_T^{assoc}) dependence

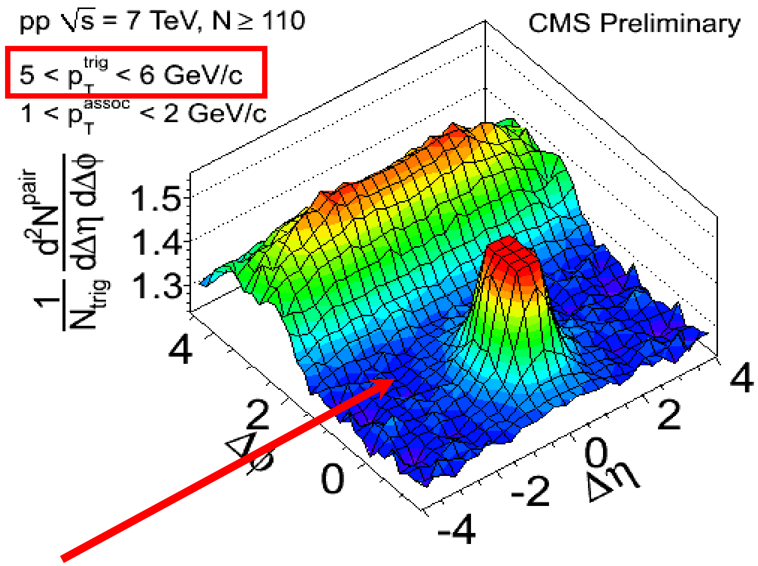
Associated hadron yield per trigger:

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

100 billion (1.78 pb^{-1}) sampled minimum bias events from high-multiplicity trigger



660K events

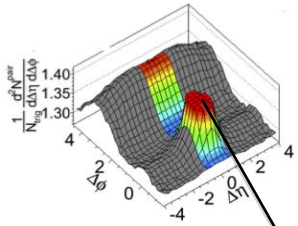


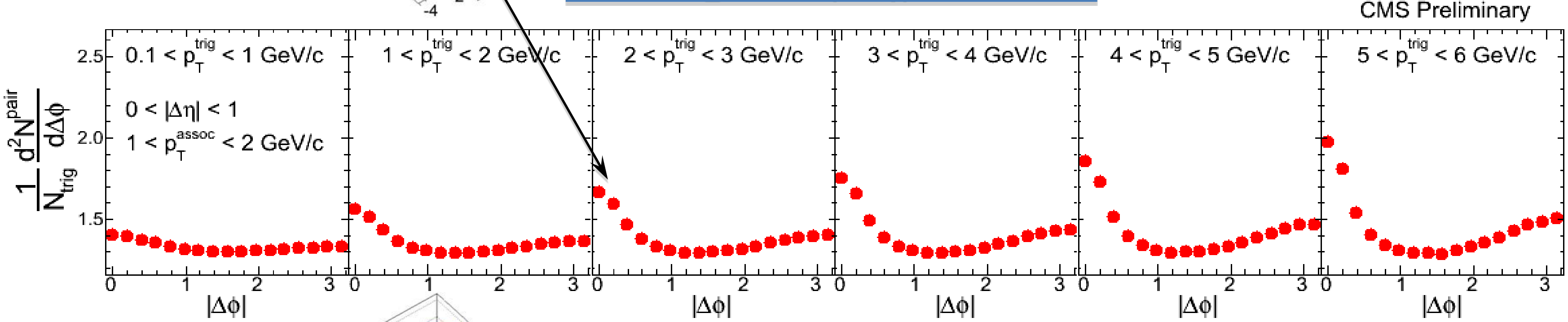
No ridge when correlating to high p_T particles!

Δϕ projections in various p_T ranges

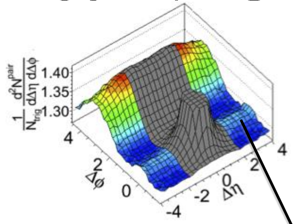
CMS pp 7 TeV, N ≥ 110

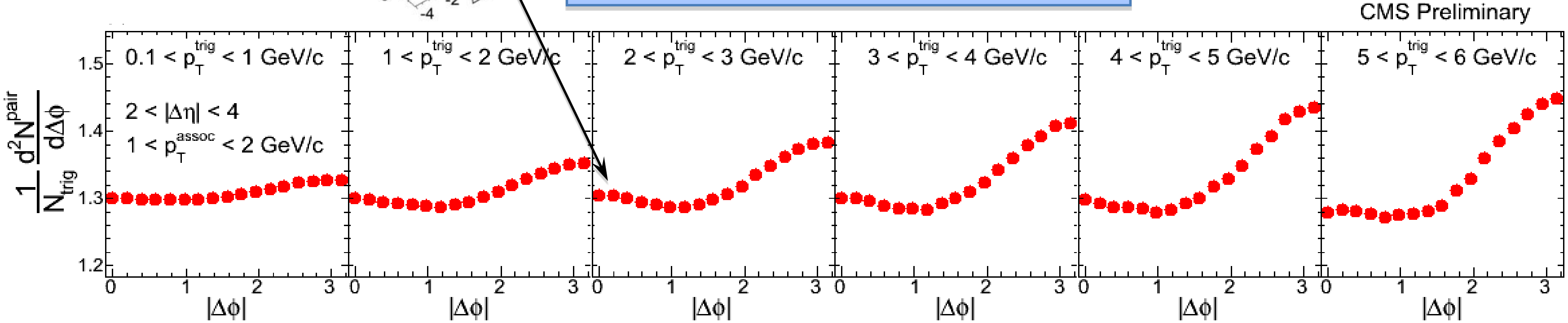
Jet region (|Δη|<1) $\xrightarrow{p_T}$



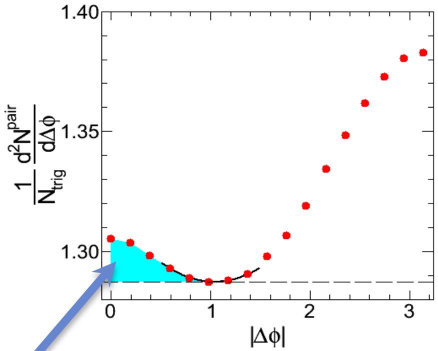


Ridge region (2<|Δη|<4) $\xrightarrow{p_T}$

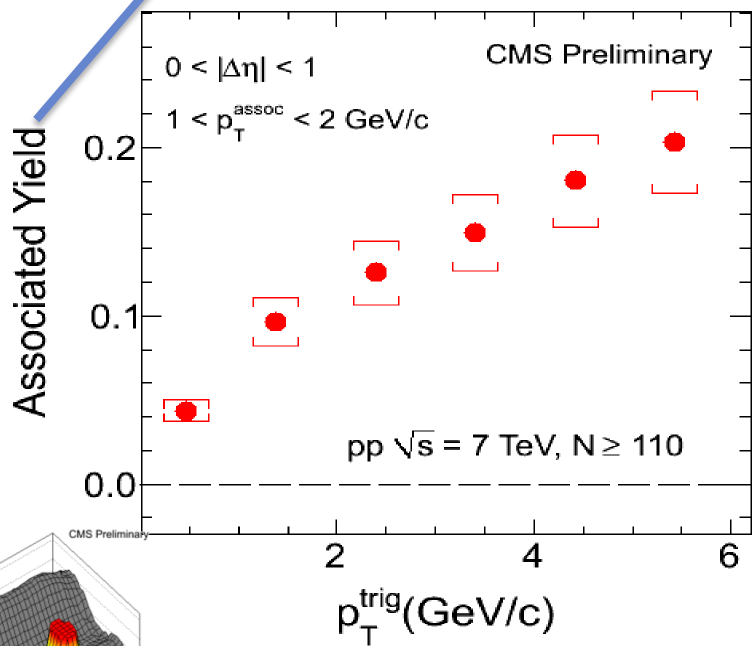


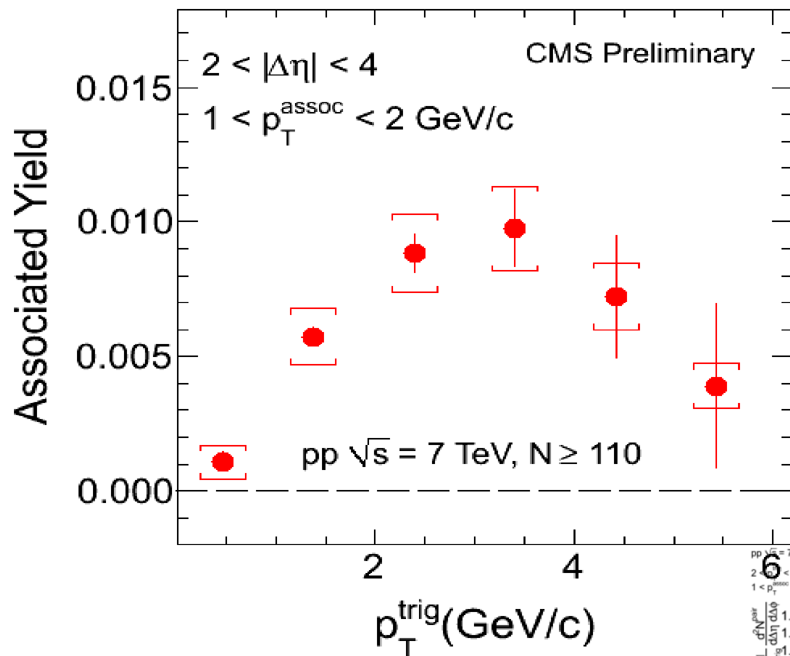


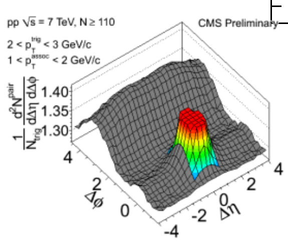
Near-side yield vs p_T in pp (N≥110)



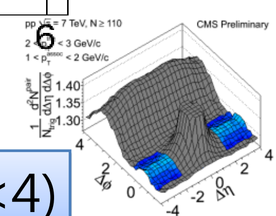
Zero-Yield-At-Minimum (ZYAM)







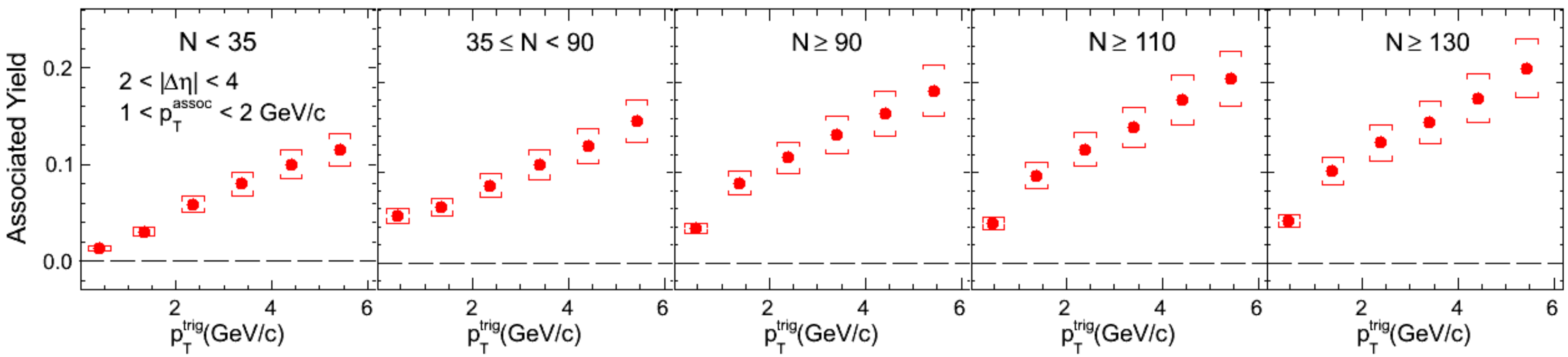
Jet region (|Δη|<1)



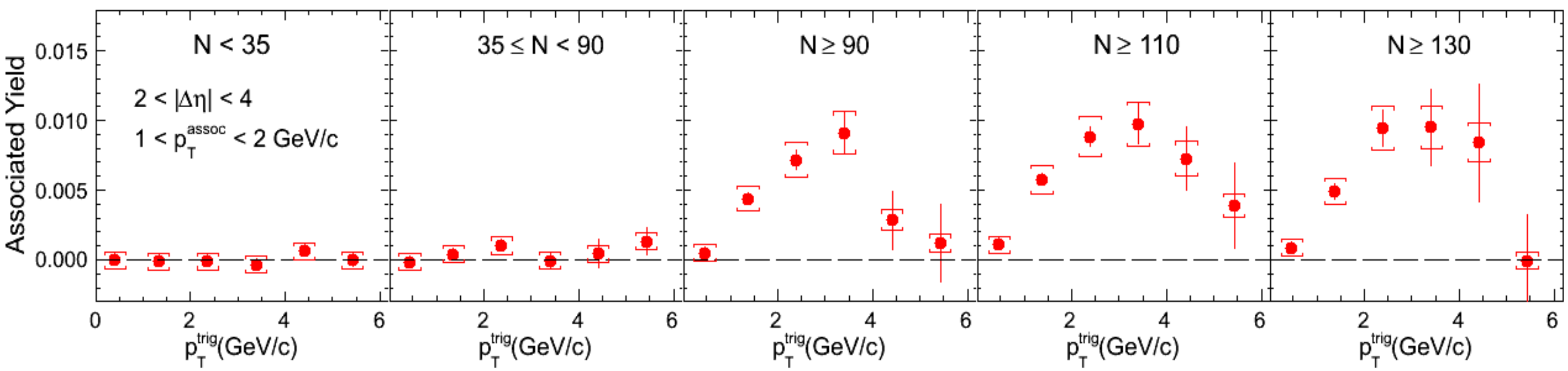
Ridge region (2<|Δη|<4)

Near-side yield vs p_T in pp (N≥110)

Jet region (|Δη|<1)



Ridge region (2<|Δη|<4)

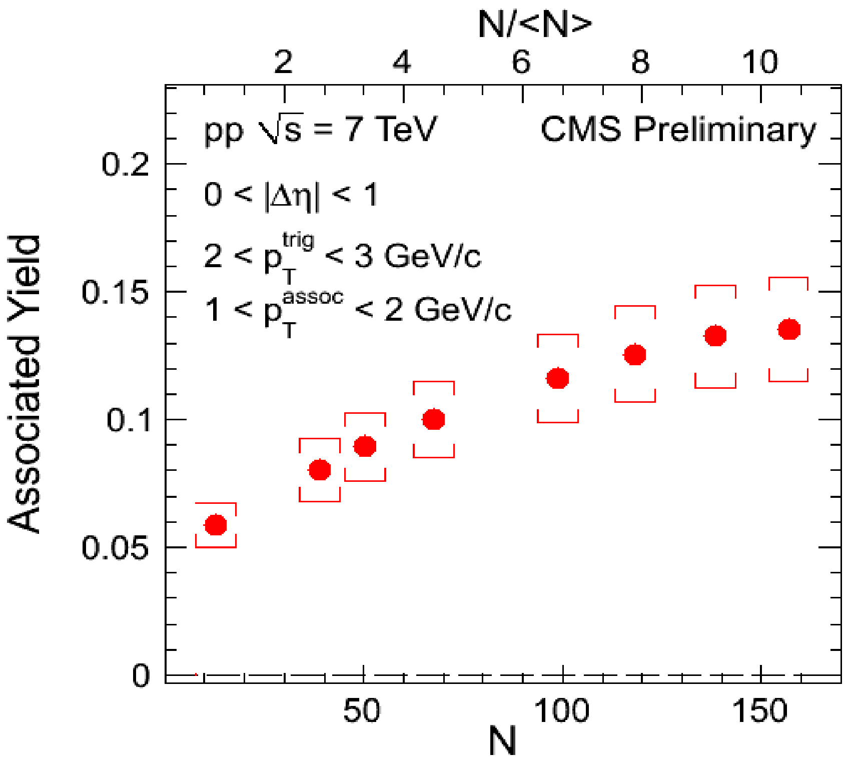


Significant ridge effect for N ≥ 90 in pp

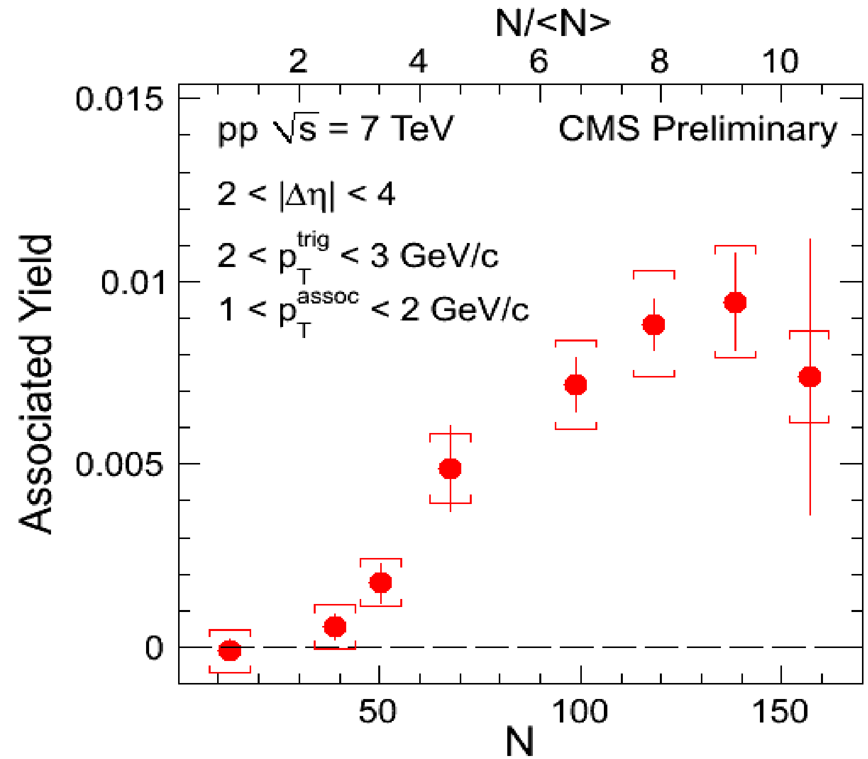
Ridge first rises with p_T, and then drops at high p_T

Near-side yield vs multiplicity in pp

Jet region (|Δη|<1)

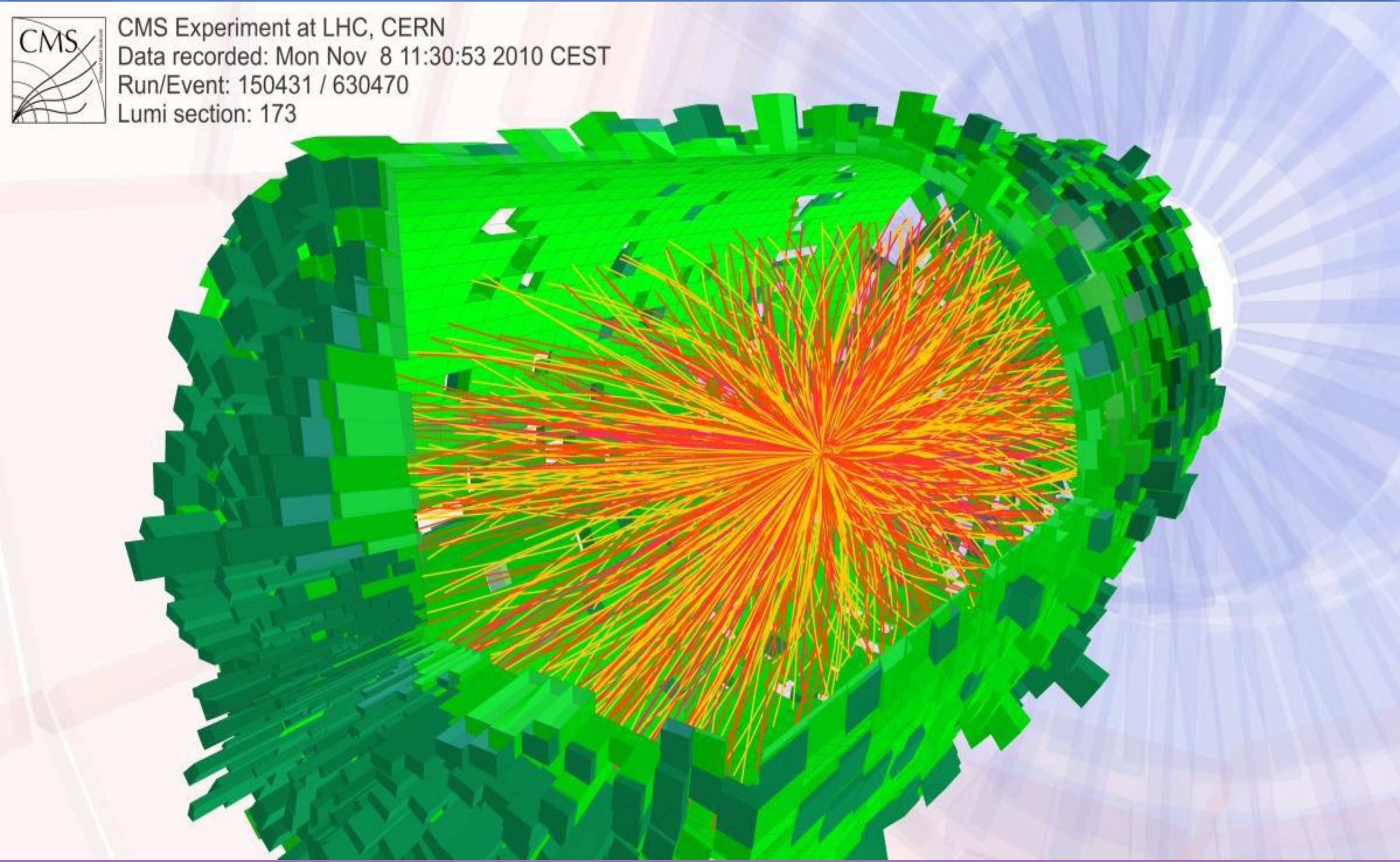


Ridge region (2<|Δη|<4)

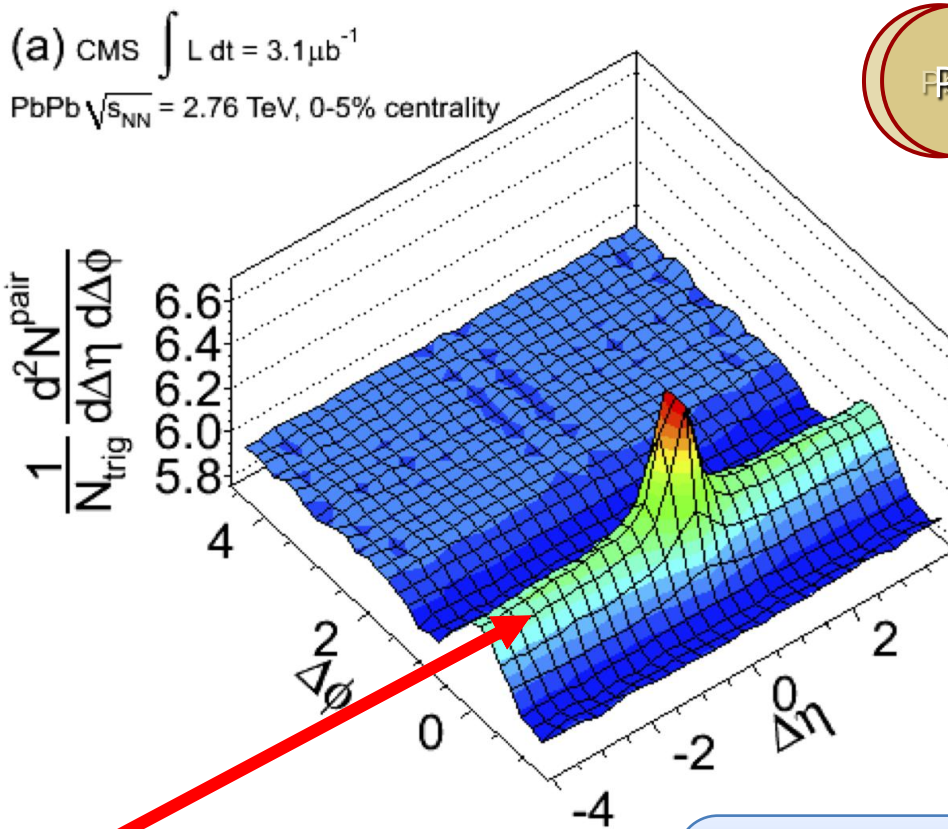


- Jet yield in pp monotonically increases with N
- Ridge in pp turns on around N ~ 50–60 (4 x MinBias) smoothly (<N> ~ 15 in MinBias pp events)

PbPb collisions at LHC



Heavy-ion “ridge” at LHC



0-5% most central

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p_T^{trig} : 4 ~ 6 GeV/c
p_T^{assoc} : 2 ~ 4 GeV/c

Associated hadron yield per trigger:

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

Ridge-like structure extends out to |Δη| = 4

Ridge vs p_T in PbPb

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

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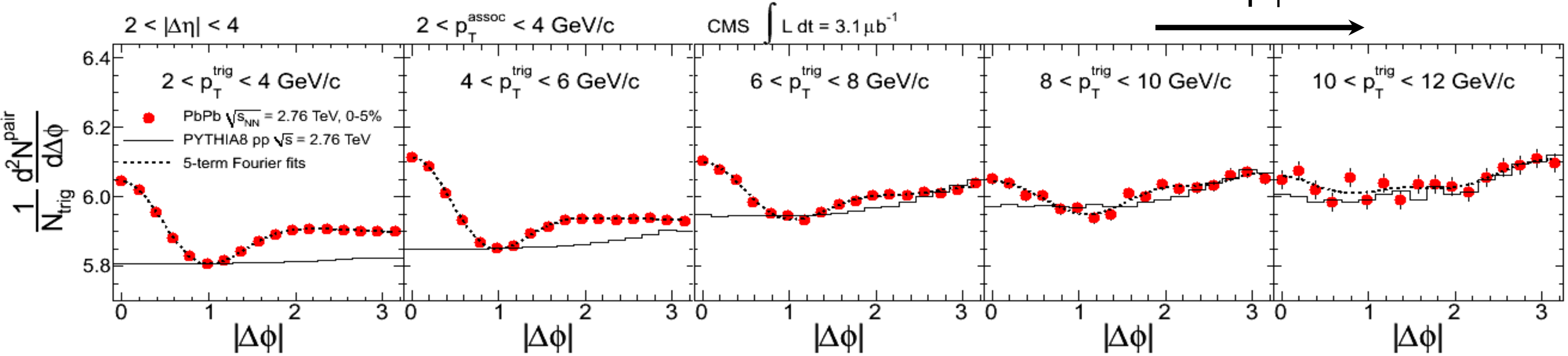
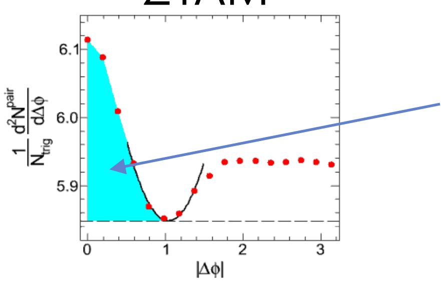
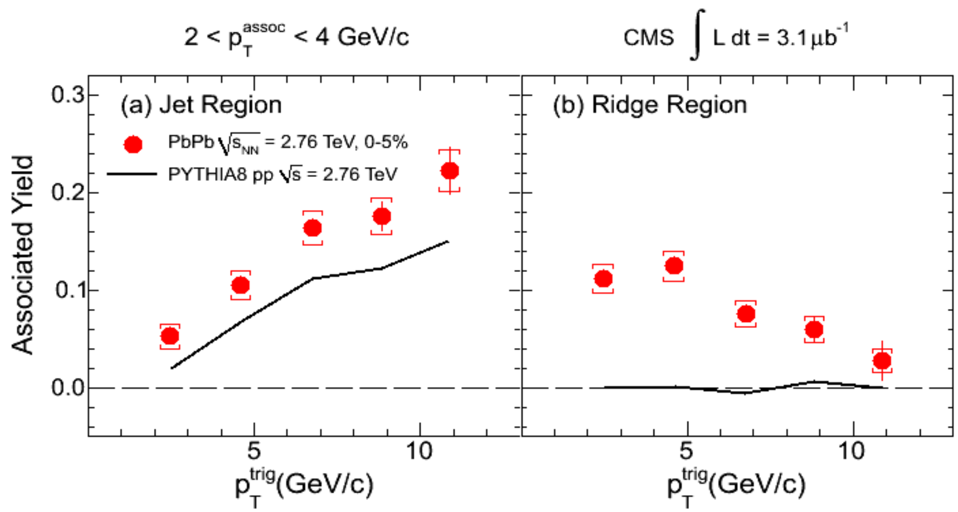
p_T →



ZYAM



v_2 not subtracted



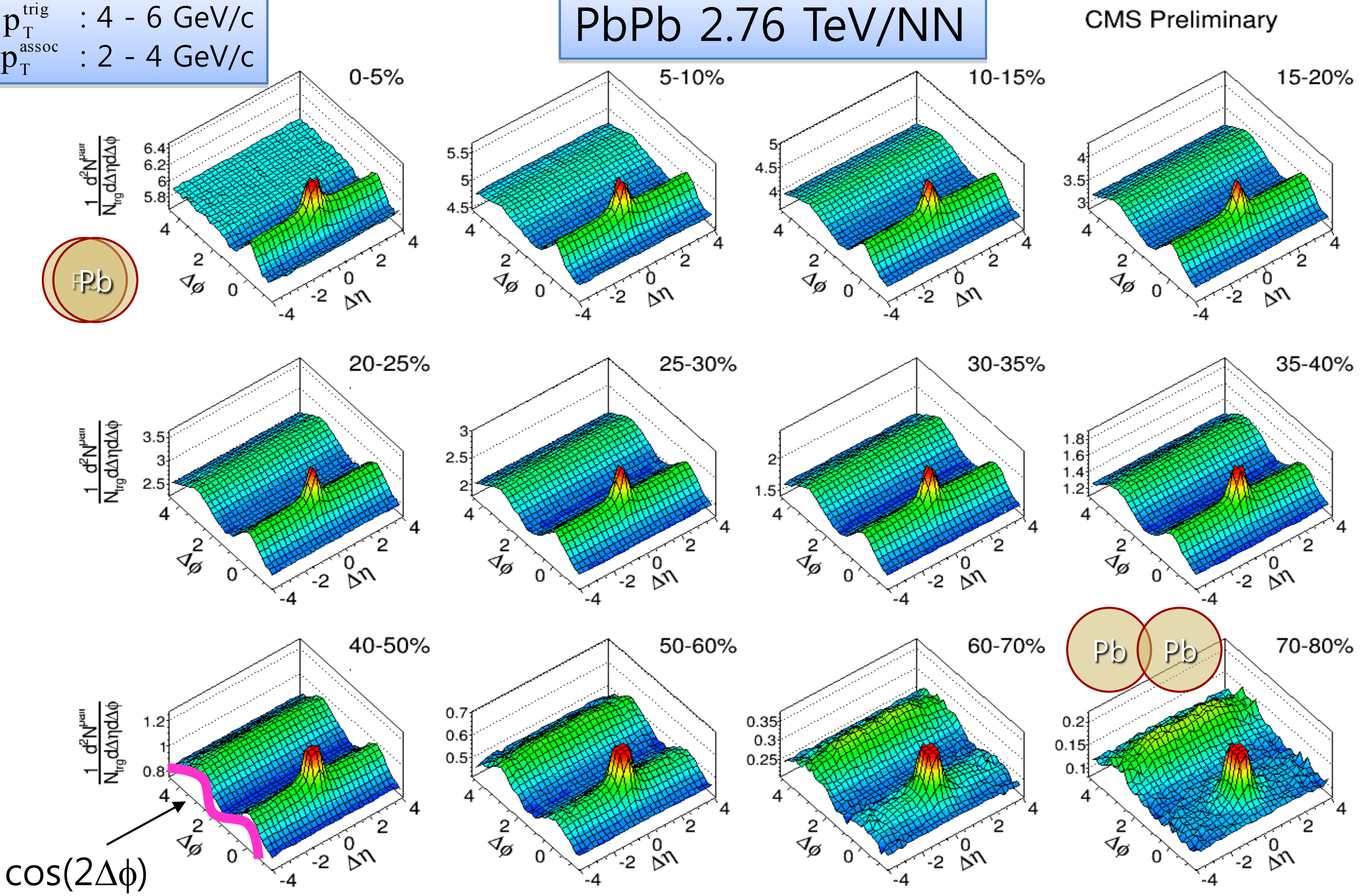
0-5% most central

Ridge in PbPb collisions tends to diminish at high p_T

Centrality dependence in PbPb

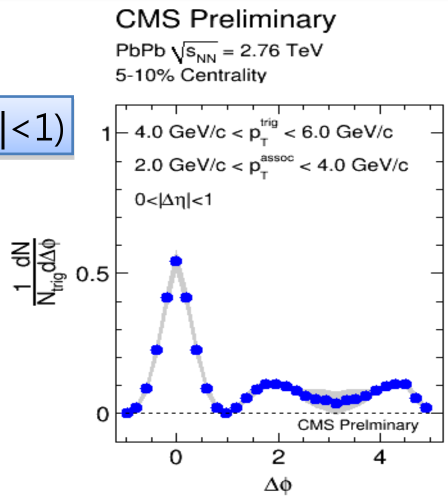
p_T^{trig} : 4 - 6 GeV/c
p_T^{assoc} : 2 - 4 GeV/c

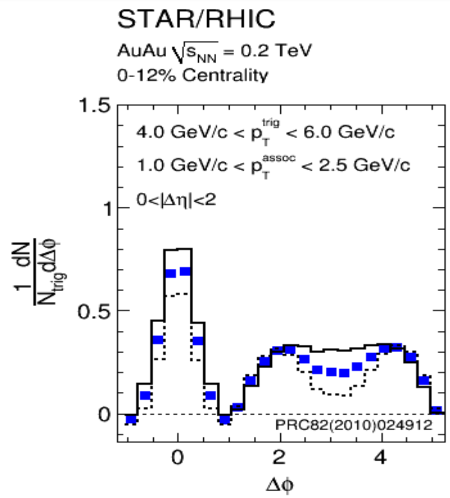
PbPb 2.76 TeV/NN

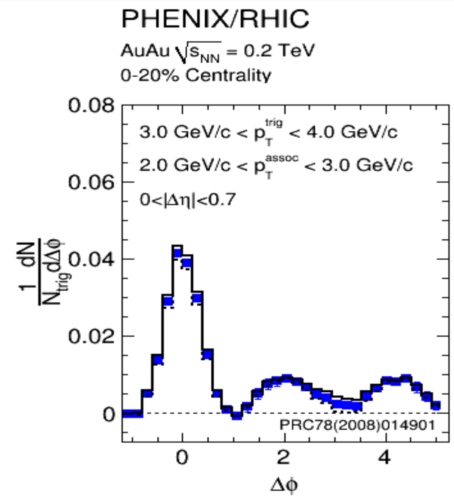


v_2-subtracted associated yield in PbPb

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

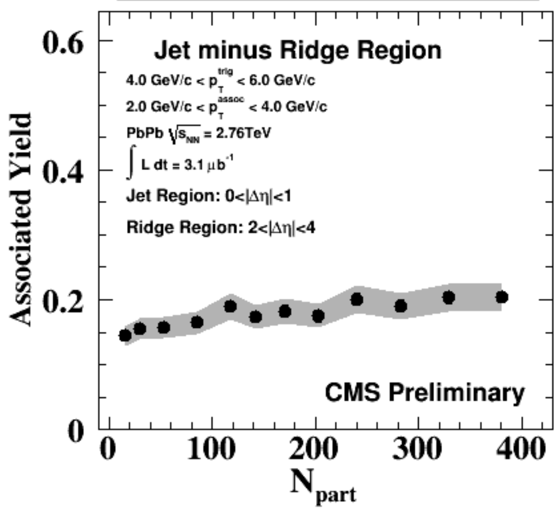


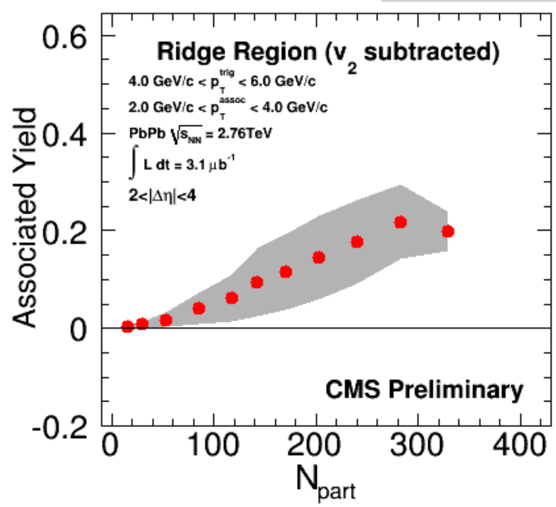


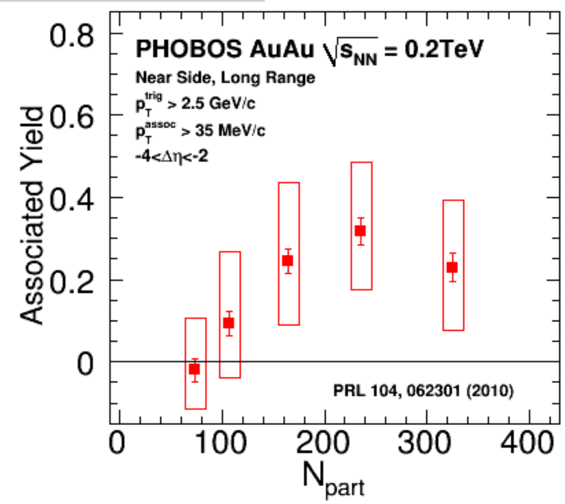


Jet minus ridge region

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



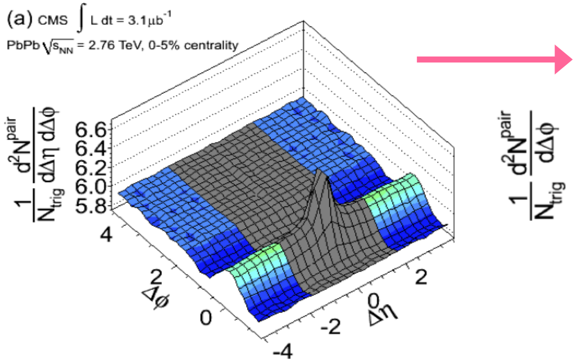




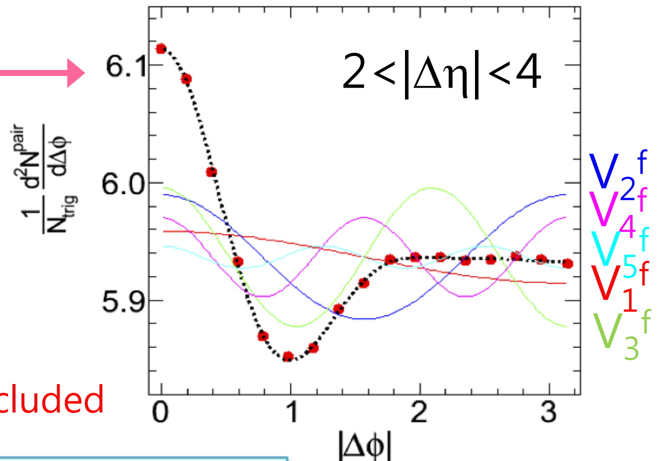
Qualitatively, similar trend in centrality to RHIC results

Fourier analysis of Δϕ correlations

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



Short-range non-flow effects excluded



Flow driven correlations:

$$V_n^f = v_n^f(p_T^{trig}) \times v_n^f(p_T^{assoc})$$

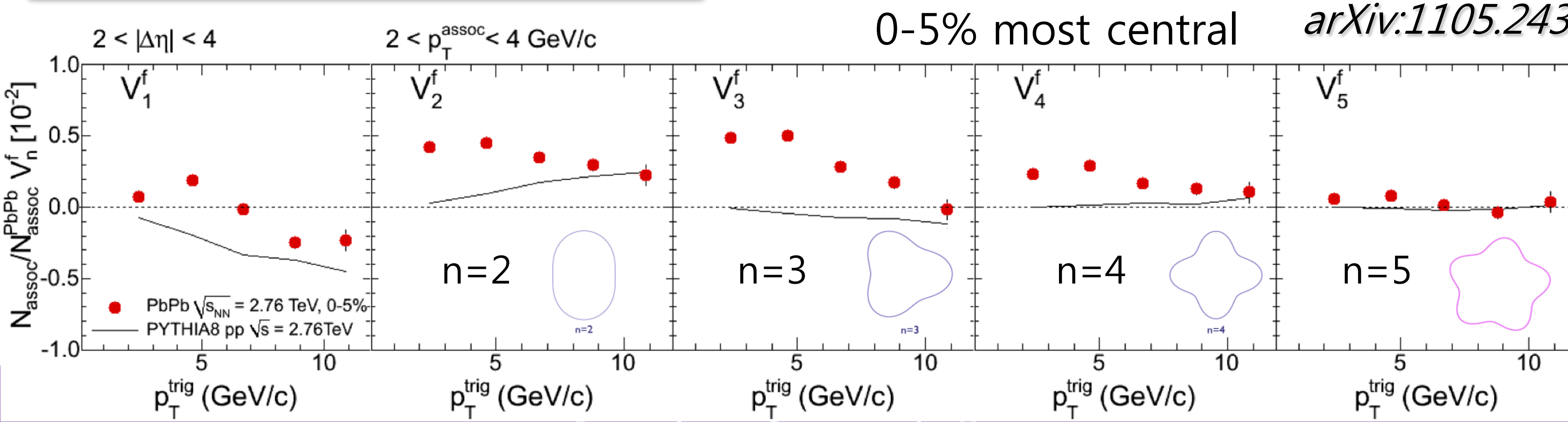
(f: Fourier analysis of long-range dihadron correlations)

$$\sqrt{V_n^f(\text{Fourier})} \rightarrow v_n^f(\text{flow})$$

Extracted Fourier coefficients V_n^f

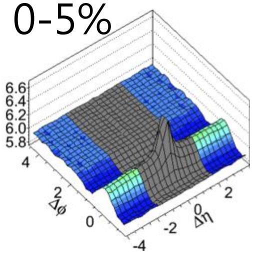
0-5% most central

arXiv:1105.2438

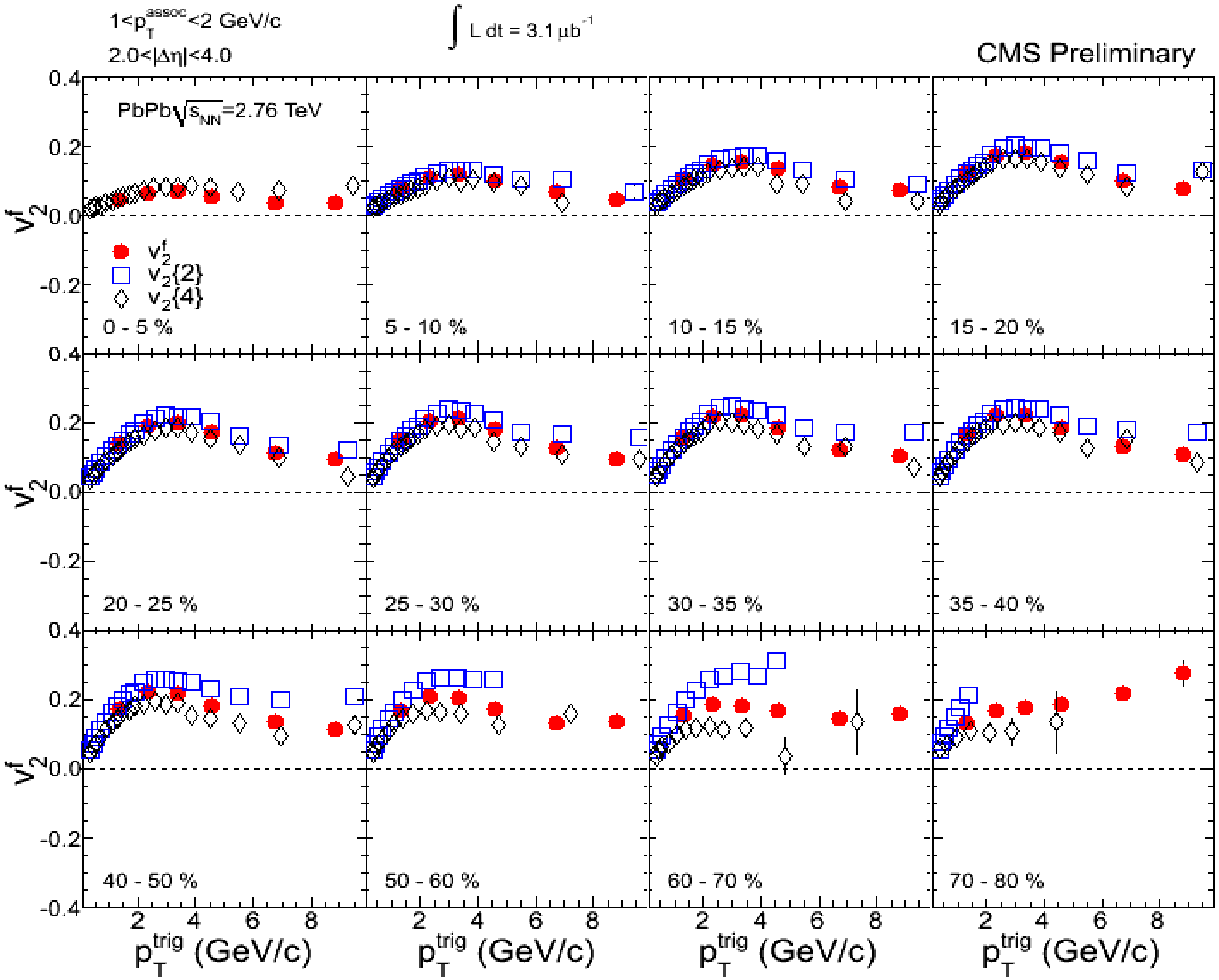


v_2 from long-range correlations

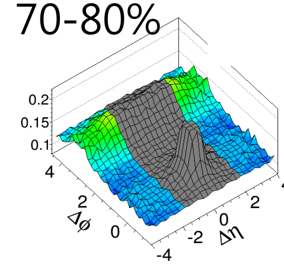
0-5%



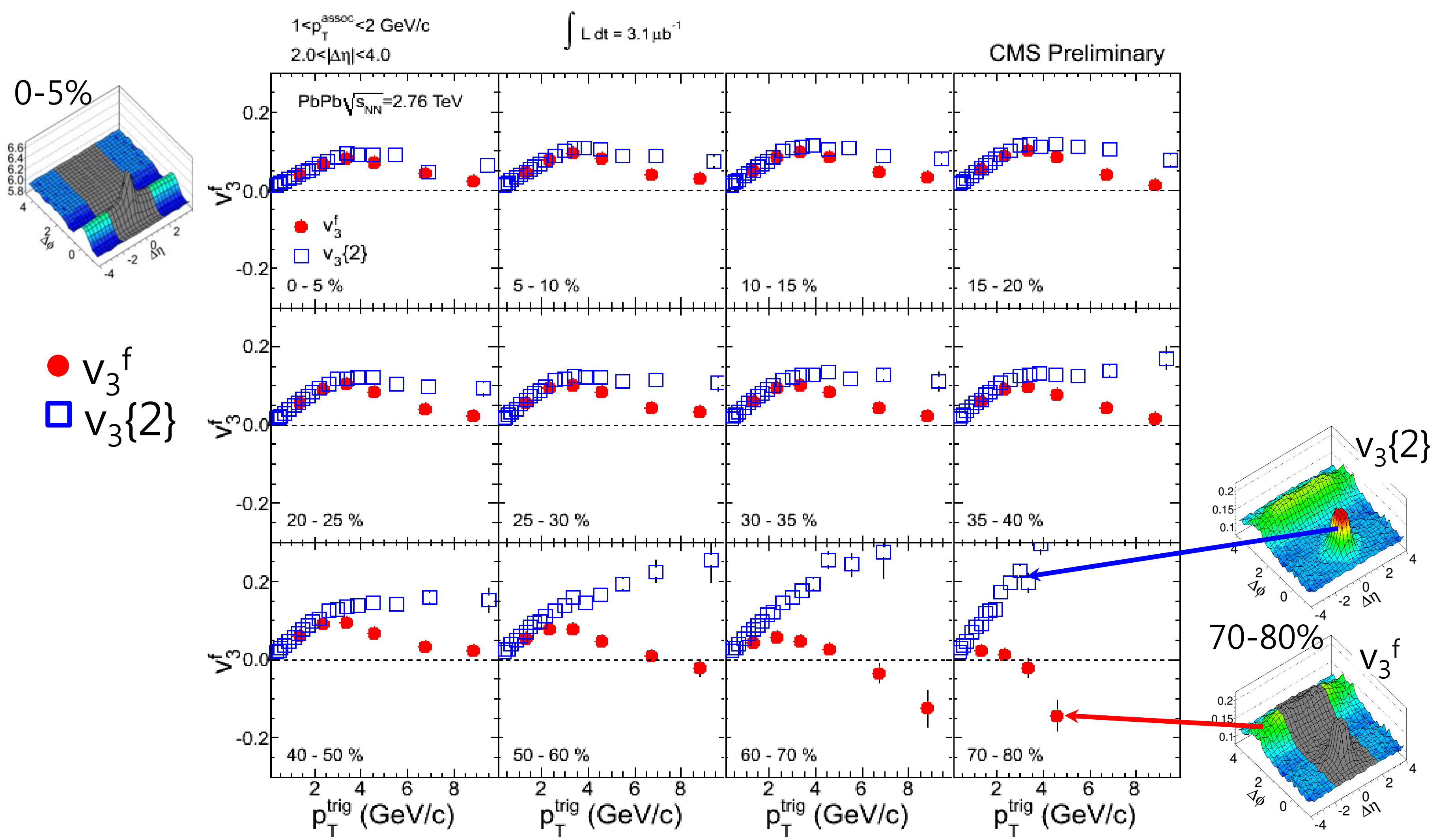
● v_2^f
□ $v_2\{2\}$
◇ $v_2\{4\}$



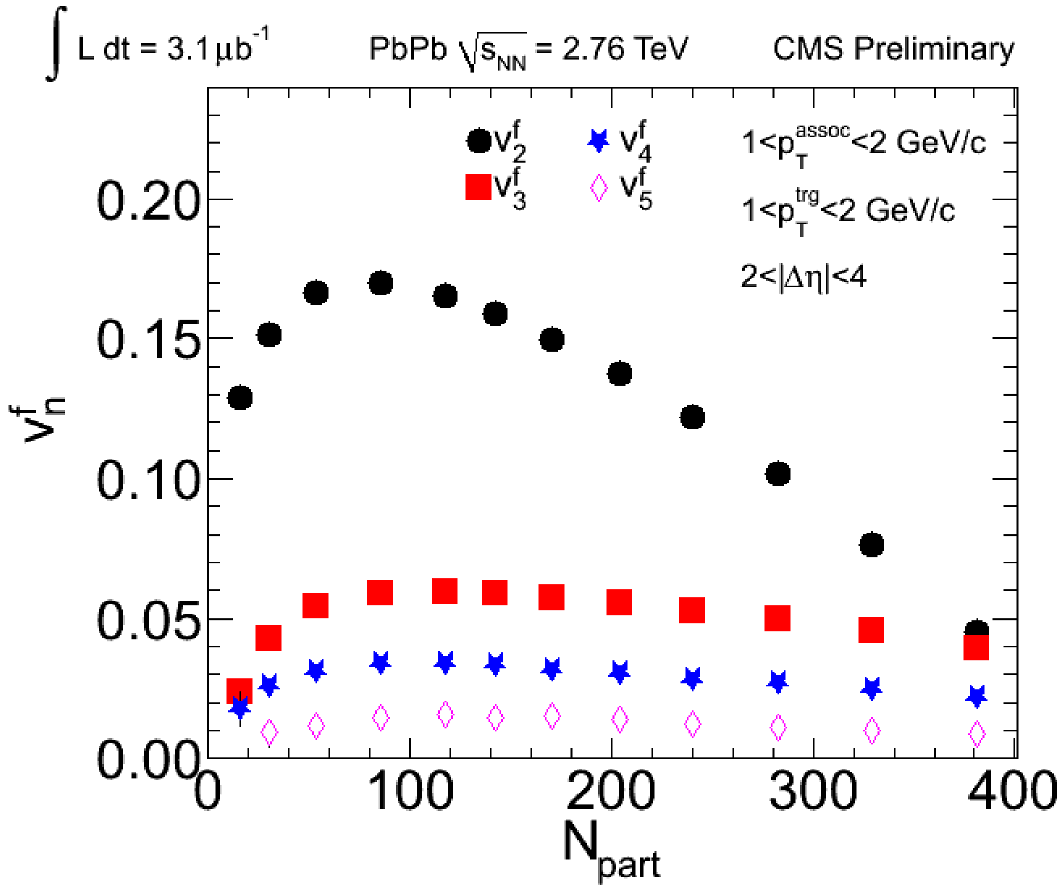
70-80%



v_3 from long-range correlations



Flow coefficients (v^f_n) vs centrality



- Powerful constraints on the viscous property of the medium
- Additional handle on the initial condition of heavy-ion collisions

Summary

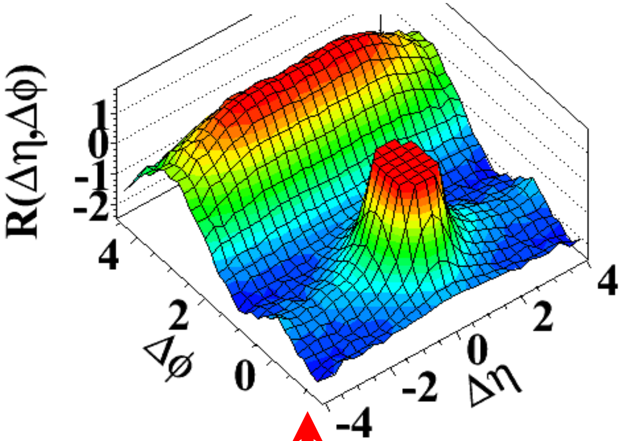
- Observation of a ridge correlation structure in high multiplicity 7 TeV pp
  - Not observed before in pp or pp MC
  - Resembles similar effect in heavy-ion collisions
  - Increases linearly at low p_T and tends to vanish at high p_T
  - Ridge emerges at N ~ 50 – 60 (4 times of <N> in MinBias)

- Comprehensive studies of dihadron correlations in 2.76 TeV/NN PbPb
  - 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
  - First five Fourier terms are sufficient to describe the correlation function in the ridge region

Backup

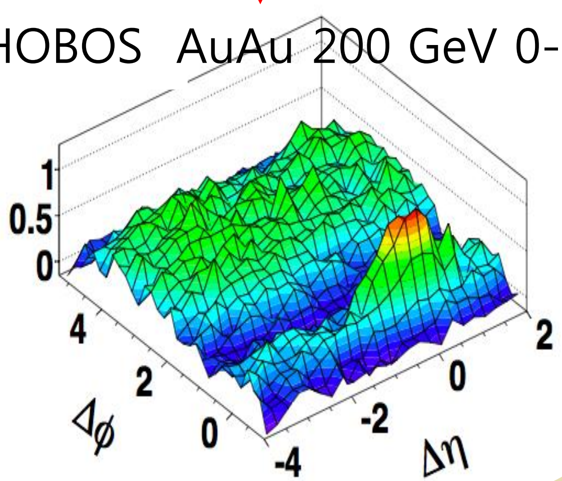
Ridge in pp and PbPb

CMS pp 7 TeV, N ≥ 110



?

PHOBOS AuAu 200 GeV 0-30%



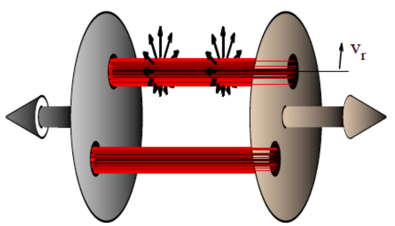
Interpretations:

48 citations

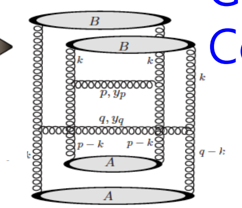
Multi-jet correlations
Jet-Jet color connections
Jet-proton remnant color connections

] Jet

Glasma tube

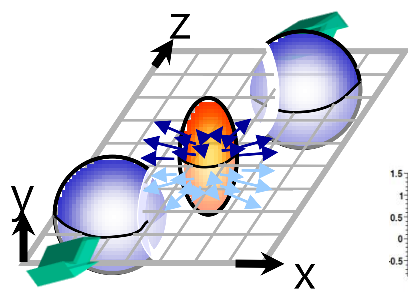


— Color Glass Condensate



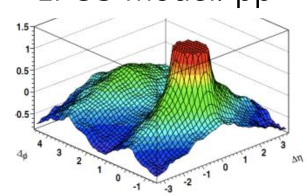
Phys. Lett. B697:21-25, 2011

Hydrodynamic flow



— Quark Gluon Plasma

EPOS model: pp



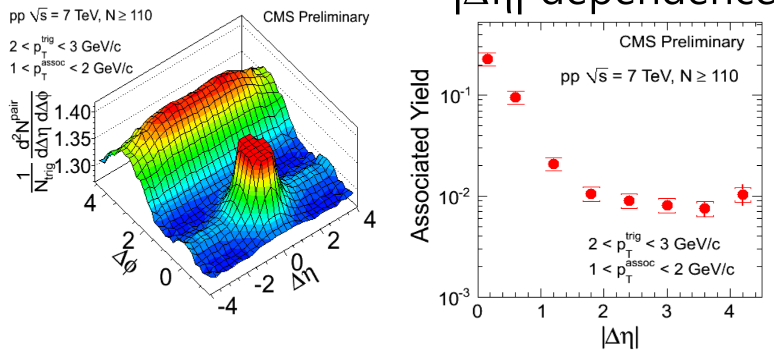
⋮

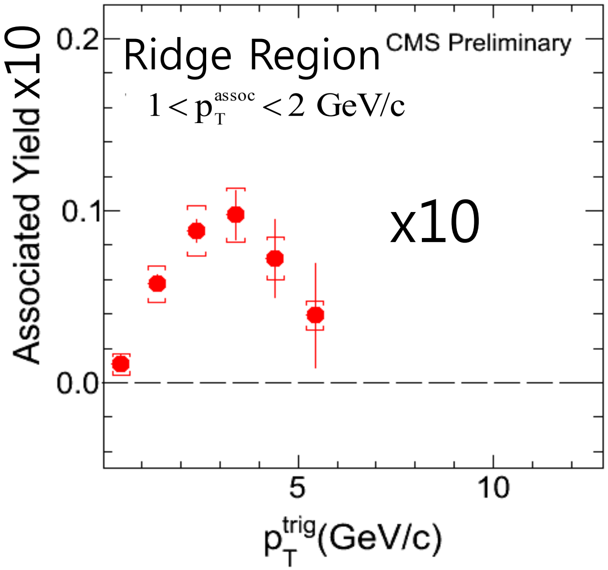
K. Werner, WWND2011

Ridge in pp and PbPb

CMS pp 7 TeV, N ≥ 110

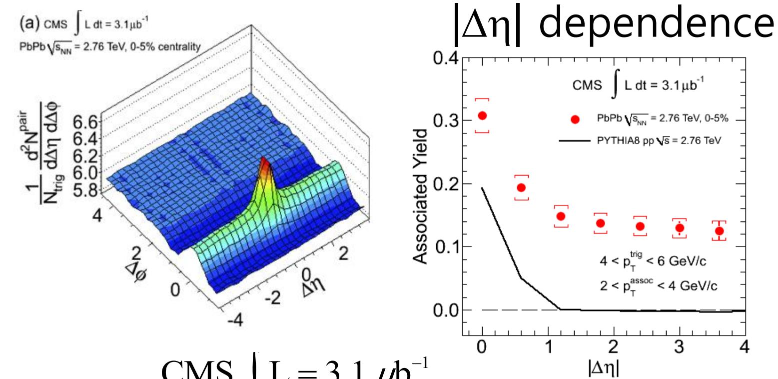
|Δη| dependence



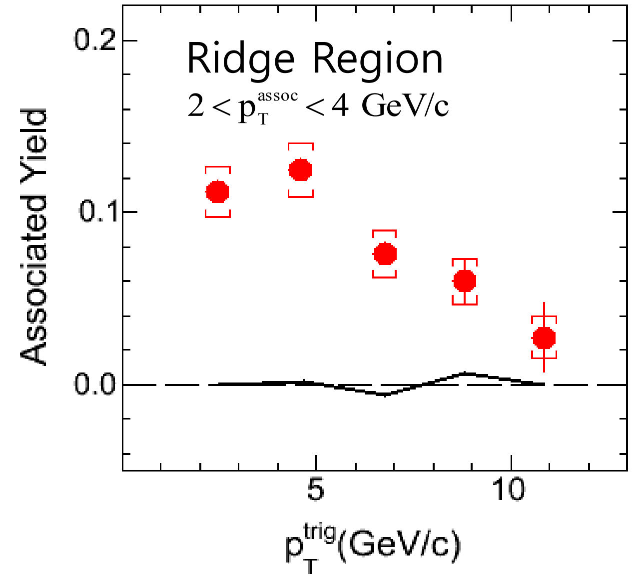


CMS PbPb 2.76 TeV, 0-5%

|Δη| dependence

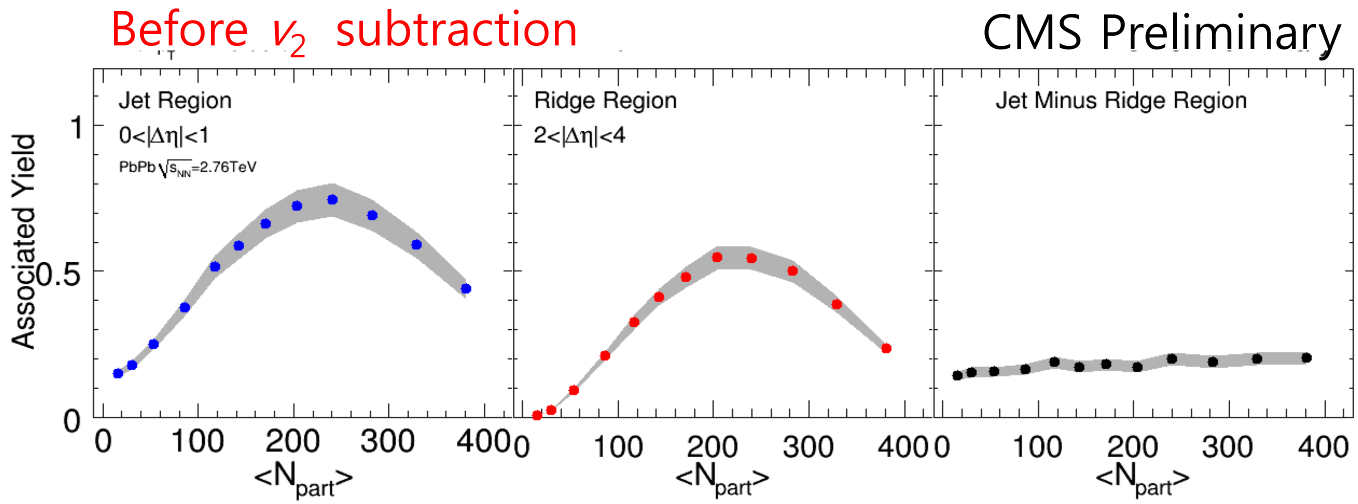


CMS $\int L = 3.1\ \mu b^{-1}$



Associated Yields (ZYAM)

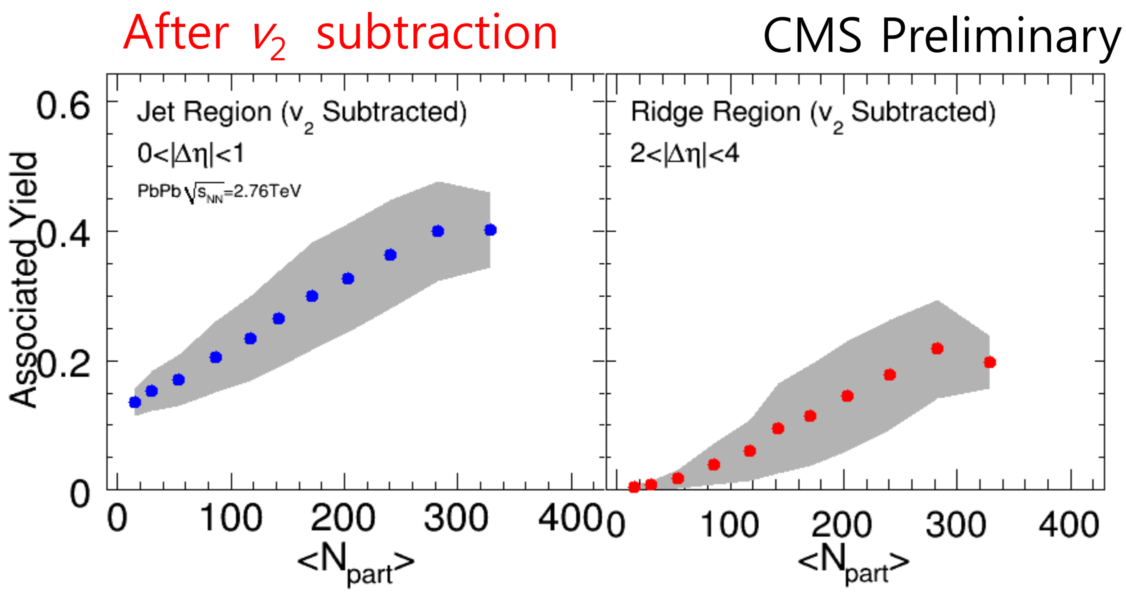
Before v_2 subtraction



$4 < p_T^{trig} < 6$ GeV/c

$2 < p_T^{assoc} < 4$ GeV/c

After v_2 subtraction



1D Correlation – Ridge Region

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

v_2 modulation
(EP + Cum{4}) / 2

v_2 uncertainty

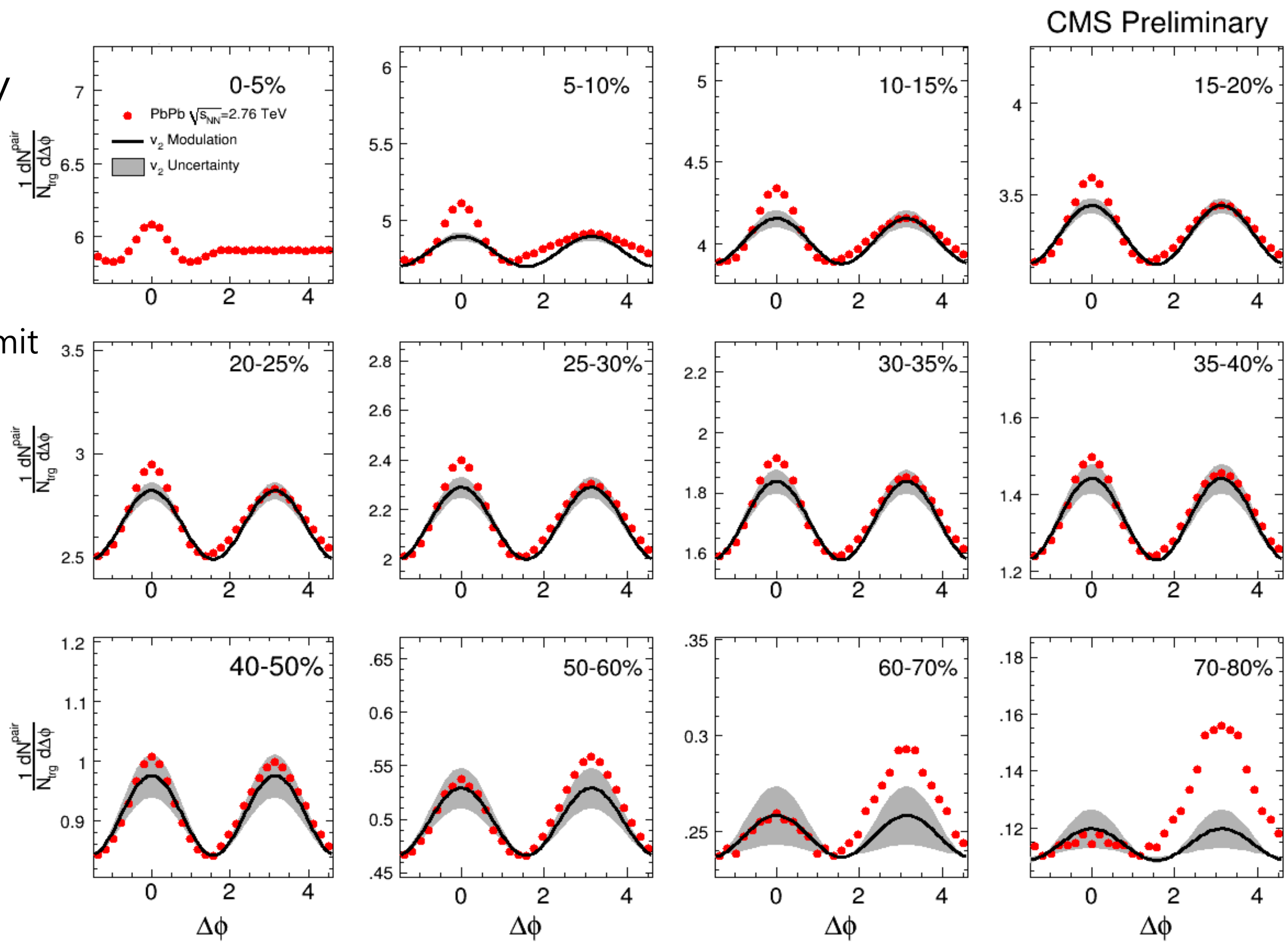
EP method = upper limit
Cum{4} = lower limit

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

$4 < p_T^{trig} < 6$

$2 < p_T^{assoc} < 4$

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



Flow at CMS:
Julia Velkovska (plenary, Tuesday) Victoria Zhukova (parallel, Monday)

v_2 Subtracted Ridge Region

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

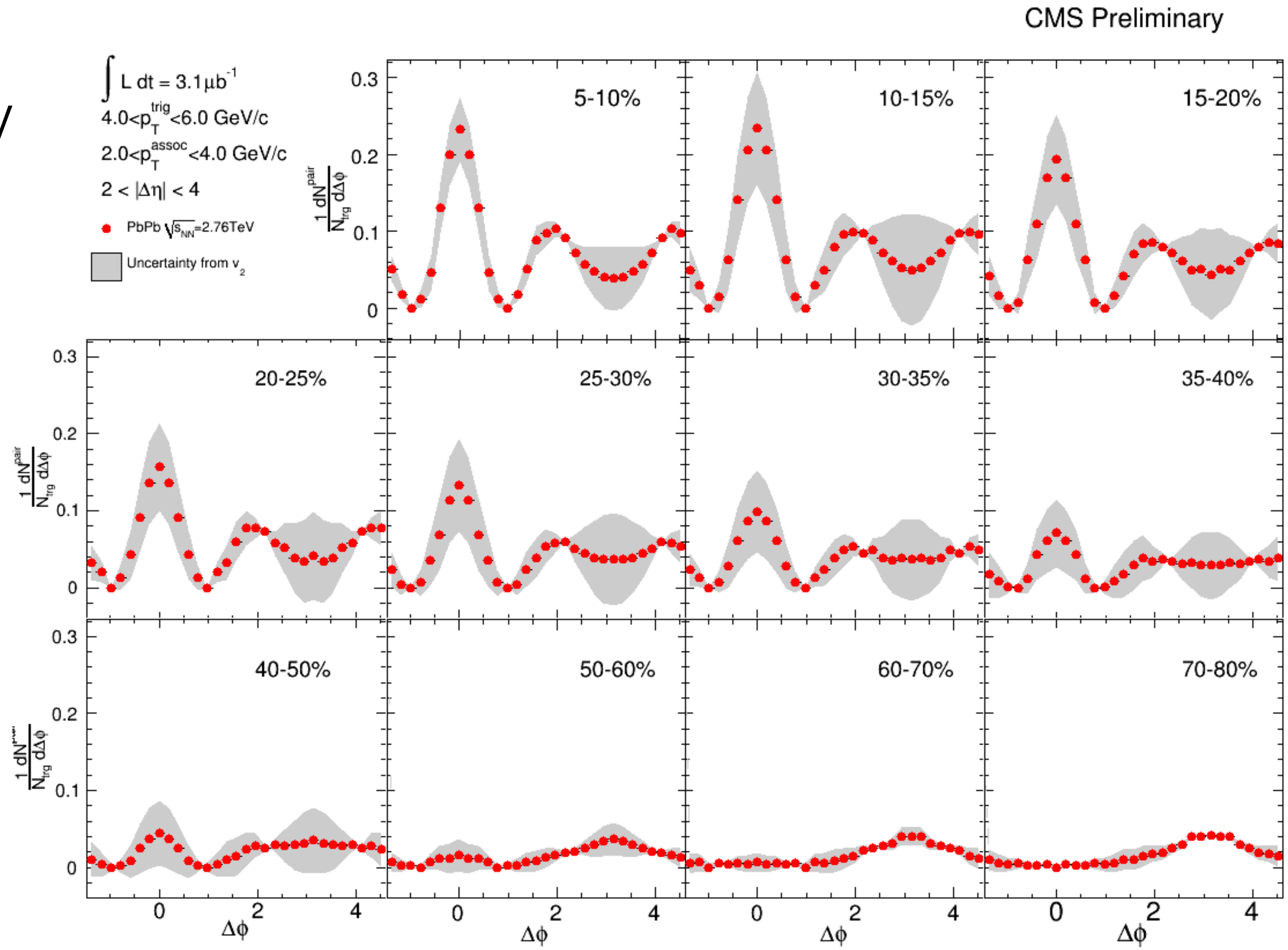
Uncertainty from v_2

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

$4 < p_T^{trig} < 6$

$2 < p_T^{assoc} < 4$

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



1D Correlation – Jet Region

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

v_2 modulation
(EP + Cum{4}) / 2

v_2 uncertainty

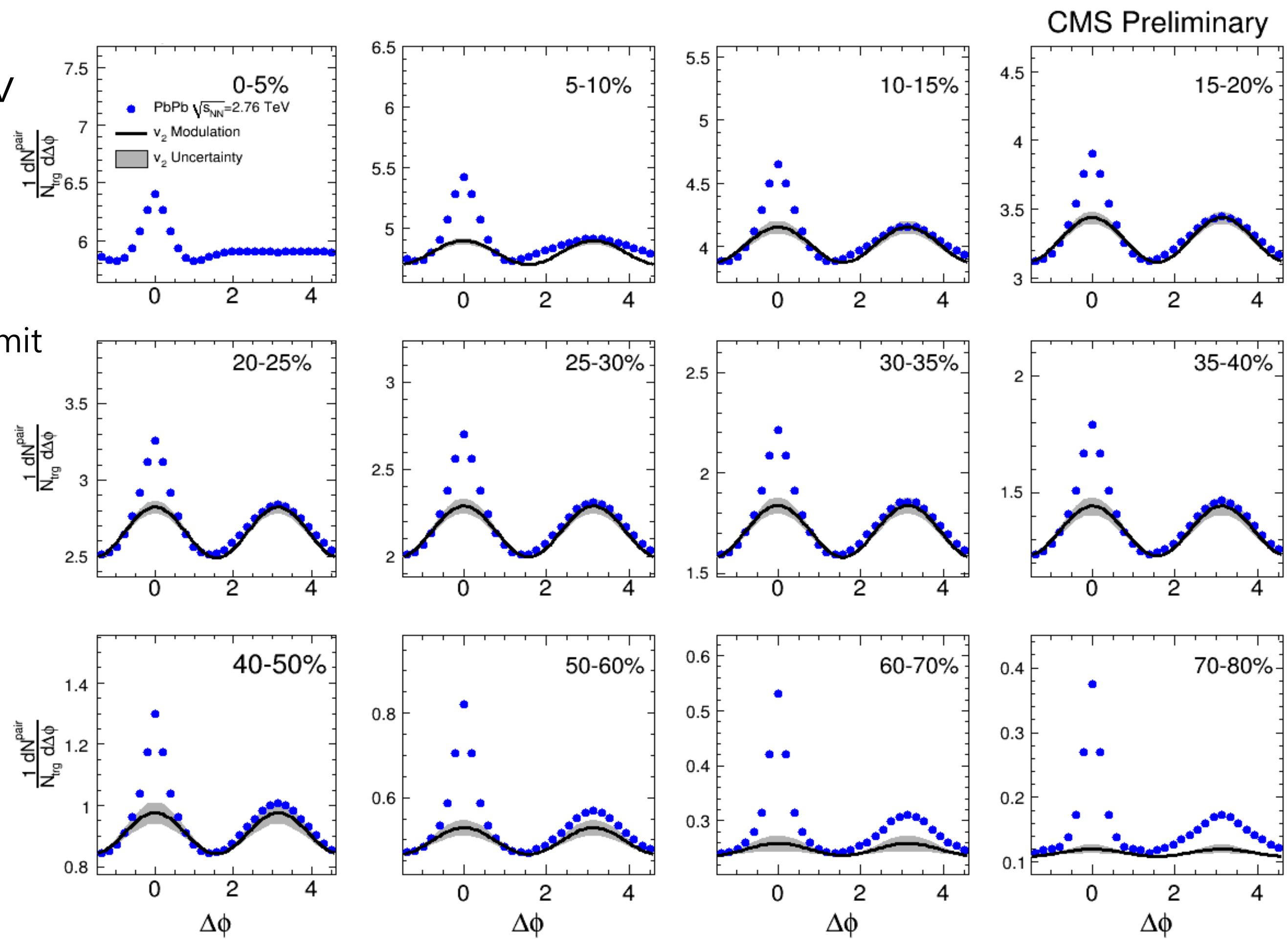
EP method = upper limit
Cum{4} = lower limit

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

$4 < p_T^{trig} < 6$

$2 < p_T^{assoc} < 4$

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

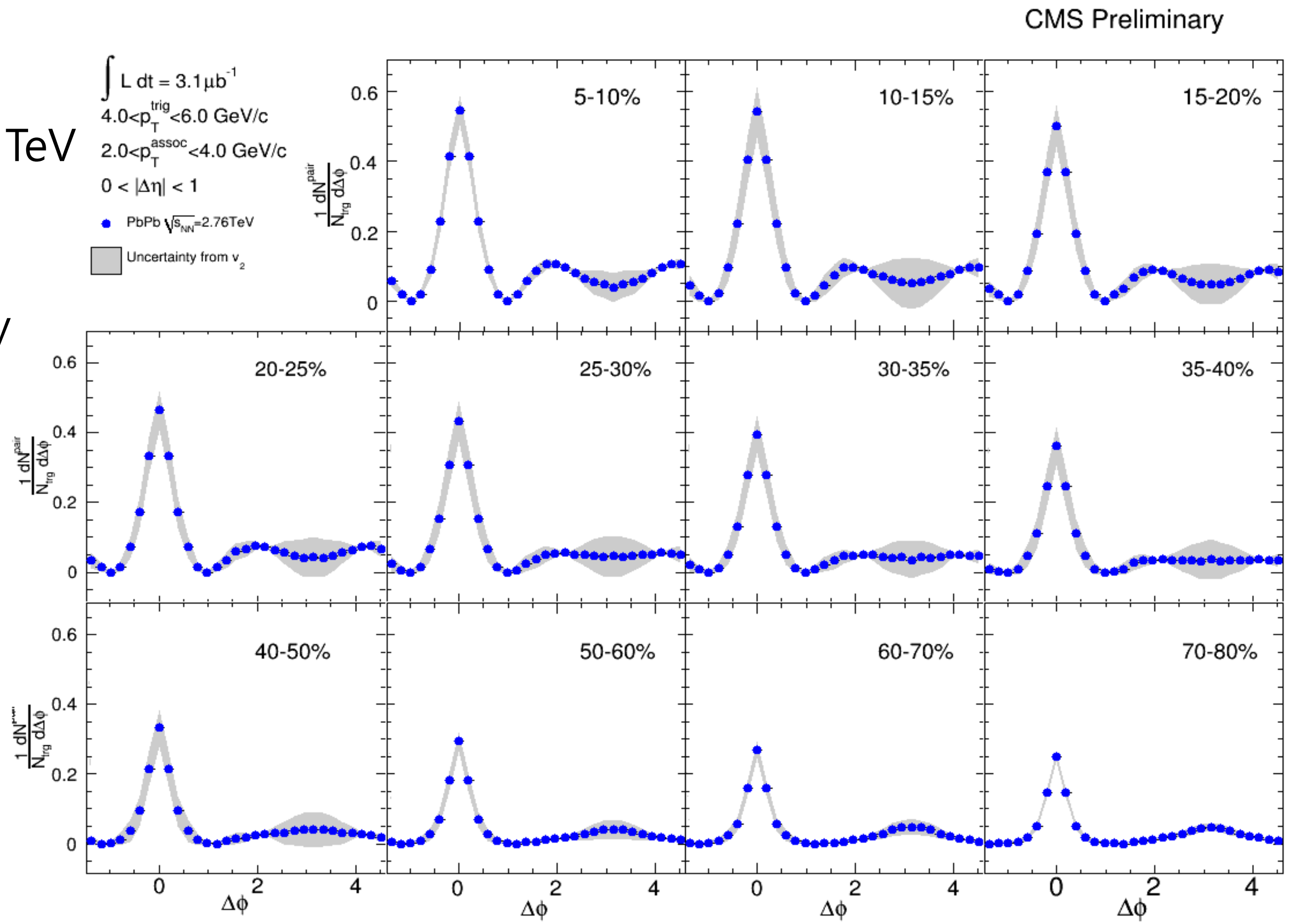


v_2 Subtracted Jet Region

- v_2 subtracted PbPb $\sqrt{s_{NN}}$ = 2.76 TeV *Jet Region*

Uncertainty from v_2

$\int L\,dt = 3.1\mu b^{-1}$
$4 < p_T^{trig} < 6$
$2 < p_T^{assoc} < 4$
$0 < |\Delta\eta| < 1$



Turning V_n^f into v_n

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

$$V_n^f(p_T^{trig}, p_T^{assoc}) = v_n(p_T^{trig}) \times v_n(p_T^{assoc})$$

We could then extract the flow coefficients v_n:

$$\frac{V_n^f(p_T^A, p_T^B)}{\sqrt{V_n^f(p_T^B, p_T^B)}} = \frac{v_n(p_T^A) \times v_n(p_T^B)}{\sqrt{v_n(p_T^B) \times v_n(p_T^B)}} = v_n(p_T^A)$$

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