PANIC11

RUTHERFORD CENTENNIAL

# Long-range dihadron correlations in pp and PbPb from CMS


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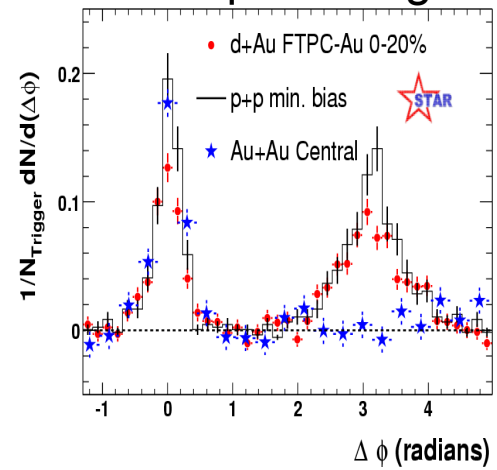
for the CMS Collaboration

# Physics motivations

Correlation measurements are powerful tools to:

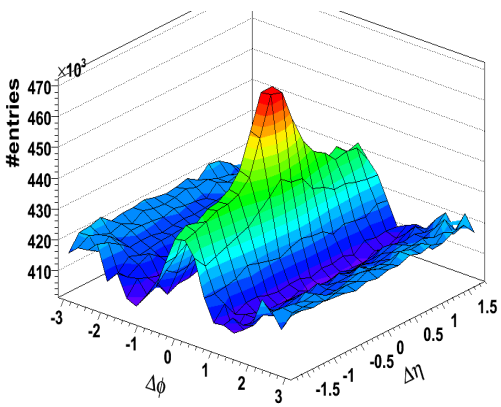
- Study the mechanism of hadron production
- Probe the jet-medium interactions in AA
- Explore the initial conditions and medium properties

Jet quenching



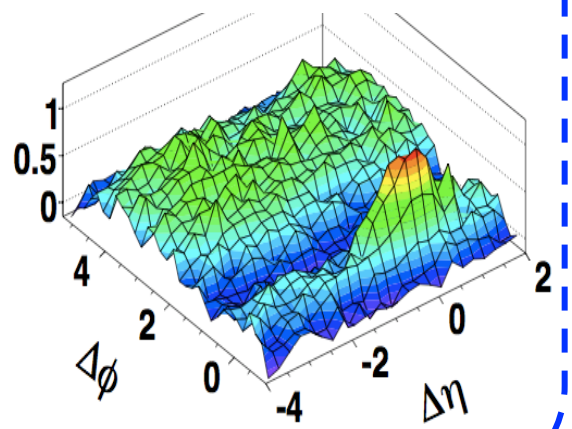

## Intriguing ridge structure at RHIC

STAR Au+Au 0-10%




*PRC 80 (2009) 64912*

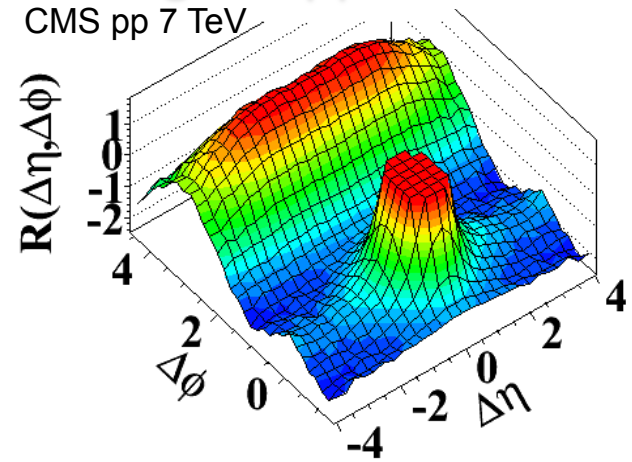
PHOBOS Au+Au 0-30%




*PRL 104, 062301 (2010)*

## Ridge in pp at LHC!

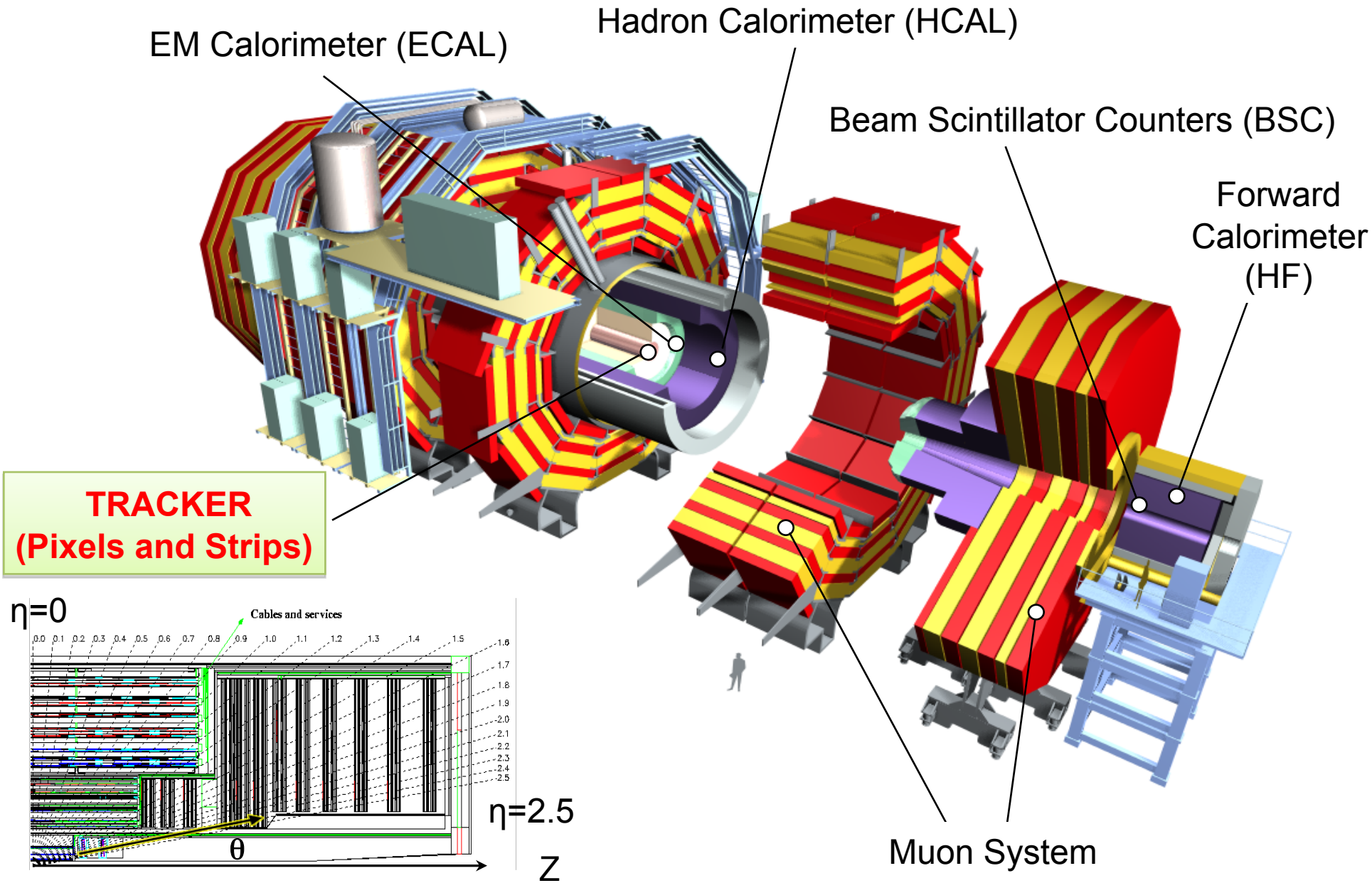
CMS pp 7 TeV




*JHEP 09 (2010) 091*

**With wider kinematics reach and better precision, LHC is ideally suited for correlation studies!**

# CMS experiment

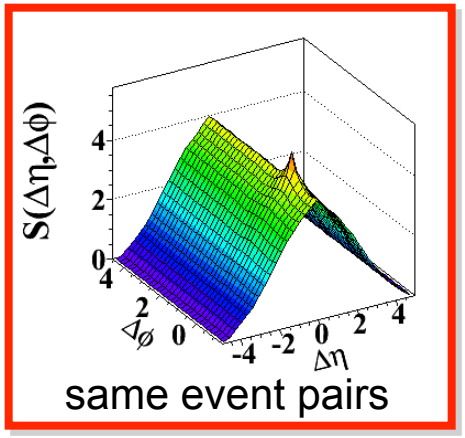



Very large coverage (|Δη| up to 5.0)!

# Dihadron correlations in CMS

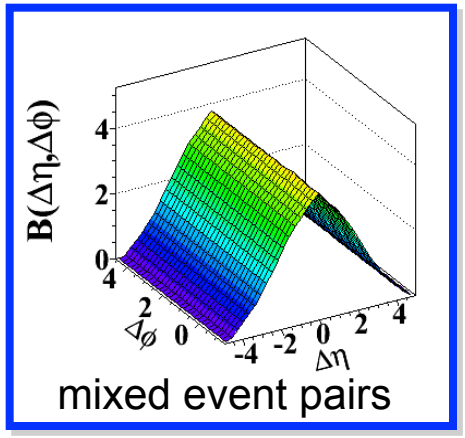
Signal pair distribution:

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




Background pair distribution:

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



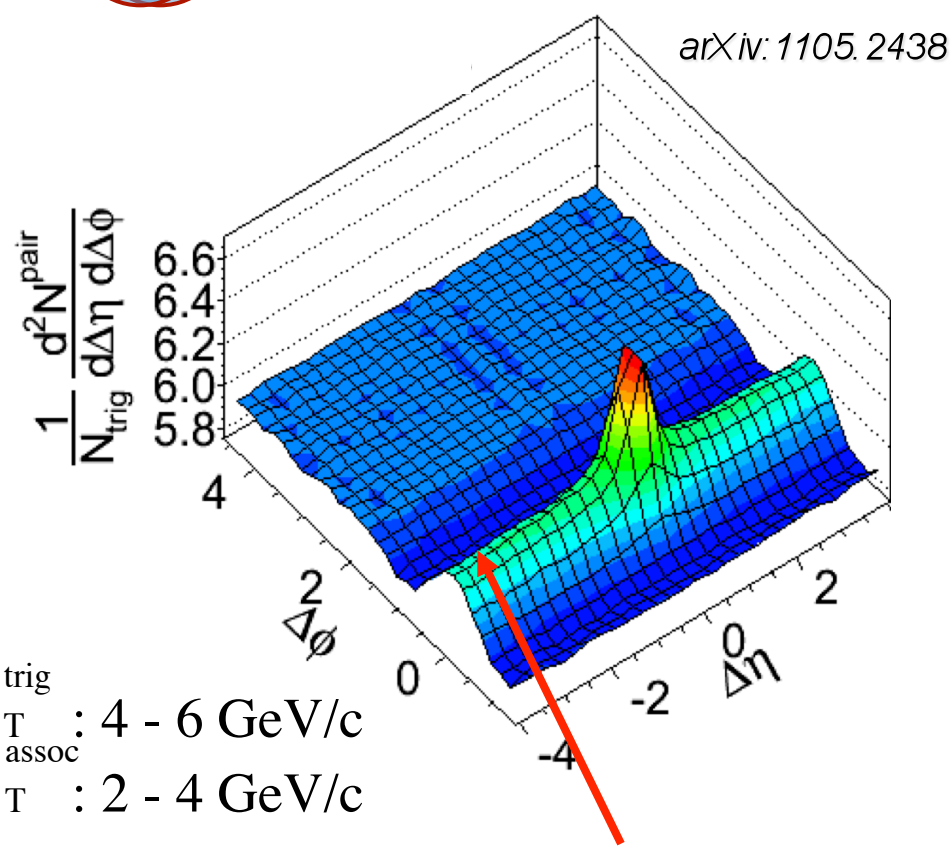

$$\Delta\eta = \eta^{assoc} - \eta^{trig}$$
$$\Delta\phi = \phi^{assoc} - \phi^{trig}$$

Associated hadron yield per trigger:

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

0-5% central PbPb 2.76 TeV

arXiv:1105.2438

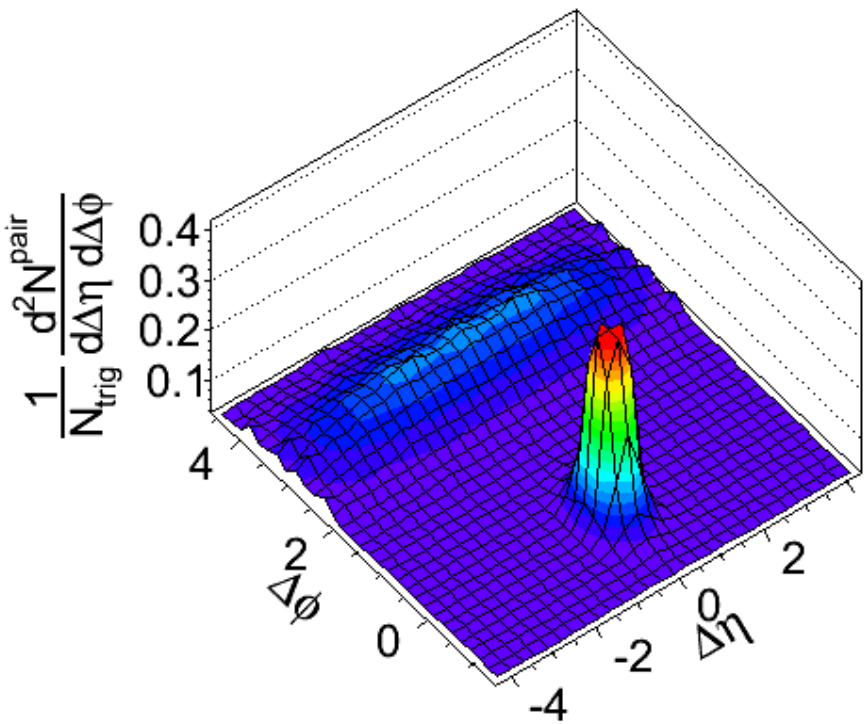



$p_T^{trig}$ : 4 - 6 GeV/c
$p_T^{assoc}$ : 2 - 4 GeV/c

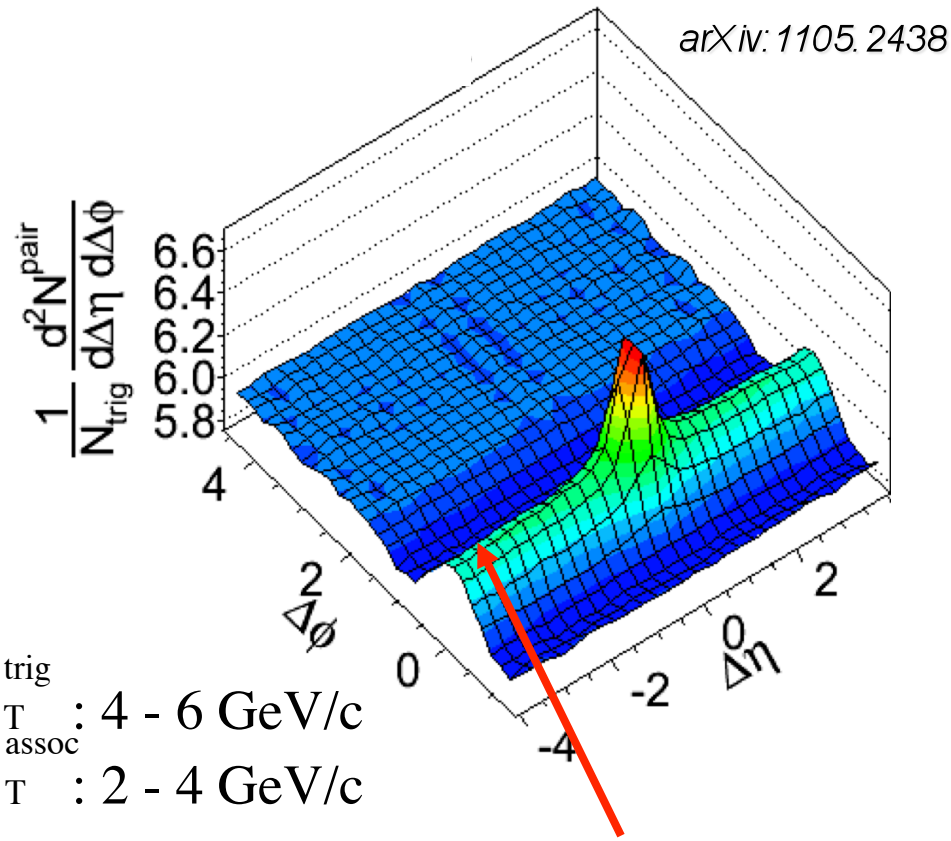
Significant ridge structure!

# Dihadron correlations in CMS

PYTHIA8 pp simulation 2.76 TeV




0-5% central PbPb 2.76 TeV



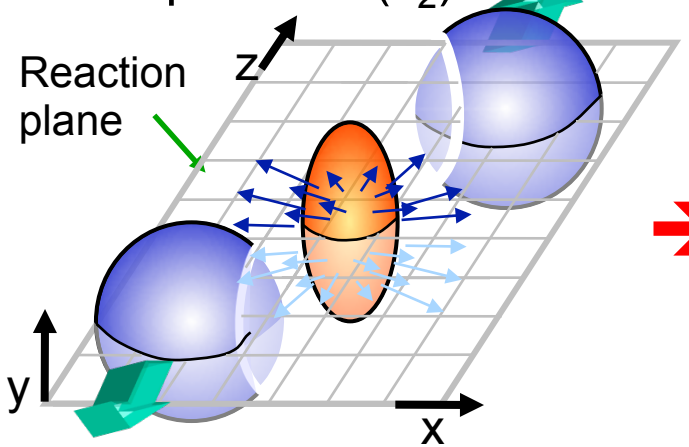

$p_T^{trig}$ : 4 - 6 GeV/c
$p_T^{assoc}$ : 2 - 4 GeV/c

Significant ridge structure!

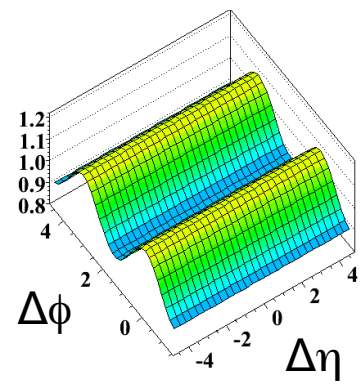
# Ridge from higher-order flow harmonics

Long-range rapidity correlations ➔ early-time dynamics

Elliptic flow ($v_2$)



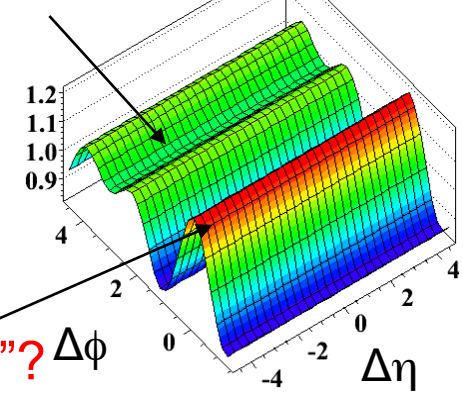

➔




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

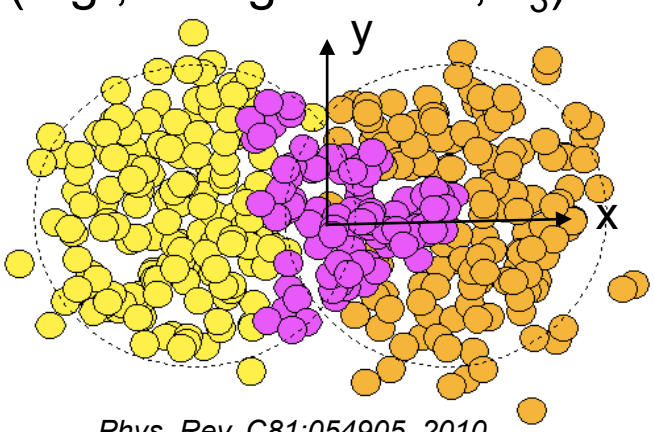
Add $V_{2\Delta}$ and $V_{3\Delta}$

"Shoulder"?



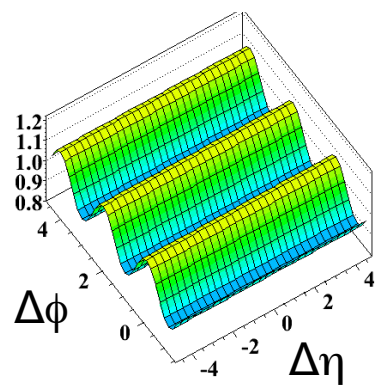

"Ridge"?

Fluctuating initial condition ➔ higher-order flow harmonics (e.g., triangular flow, $v_3$)




*Phys. Rev. C81:054905, 2010*

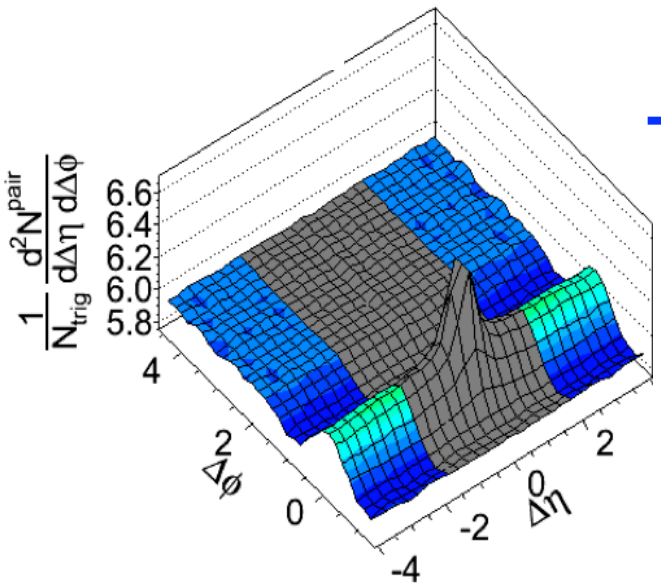
➔

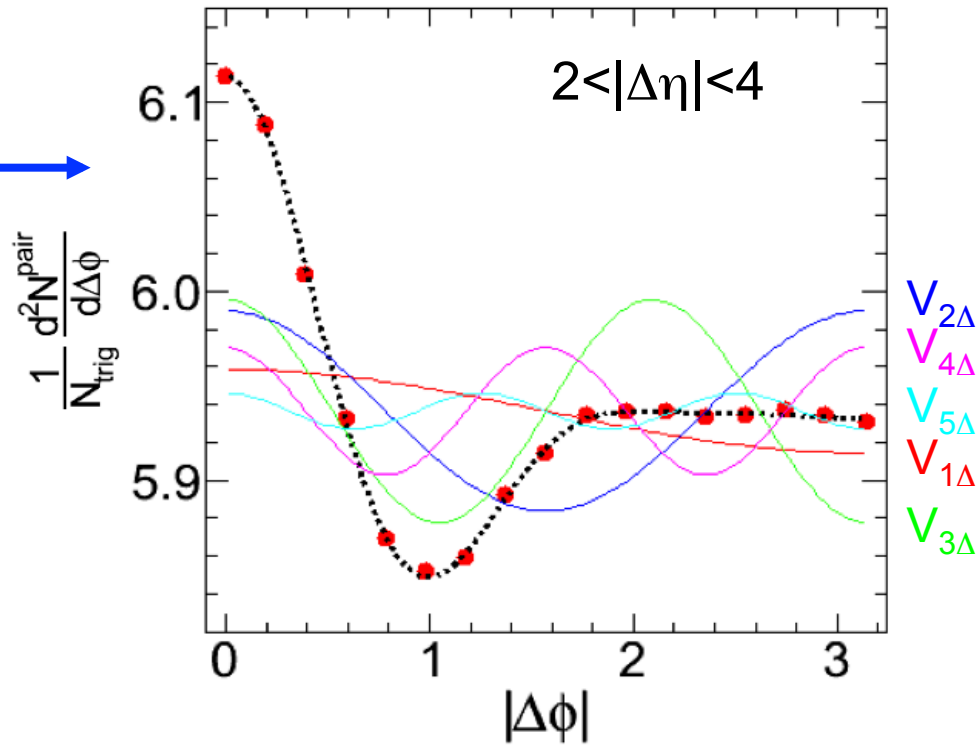



~ $V_{3\Delta}\cos(3\Delta\phi)$

# Fourier analysis of Δϕ correlations

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




Short-range non-flow effects excluded!

Ridge structure exhausted by first 5 Fourier terms

For flow-driven correlations:

$$V_{n\Delta} = v_n^{trig} \times v_n^{assoc}$$

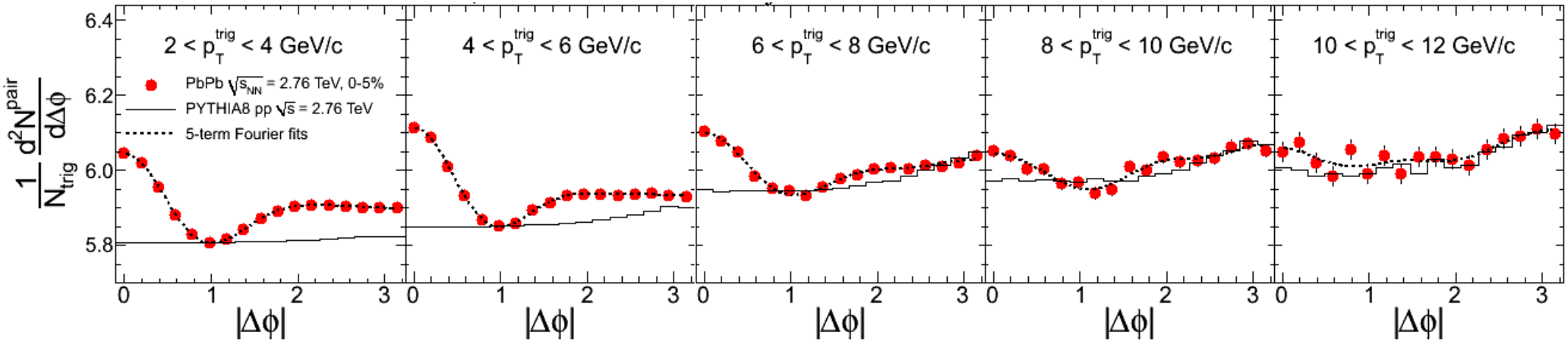
# Fourier analysis of $\Delta\phi$ correlations

1-D $\Delta\phi$ projections at long-range ($2<|\Delta\eta|<4$)

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

$p_T^{trig}$ →

arXiv:1105.2438




Ridge persists to high $p_T$ but decreases in magnitude

# Fourier analysis of Δϕ correlations

1-D Δϕ projections at long-range (2<|Δη|<4)

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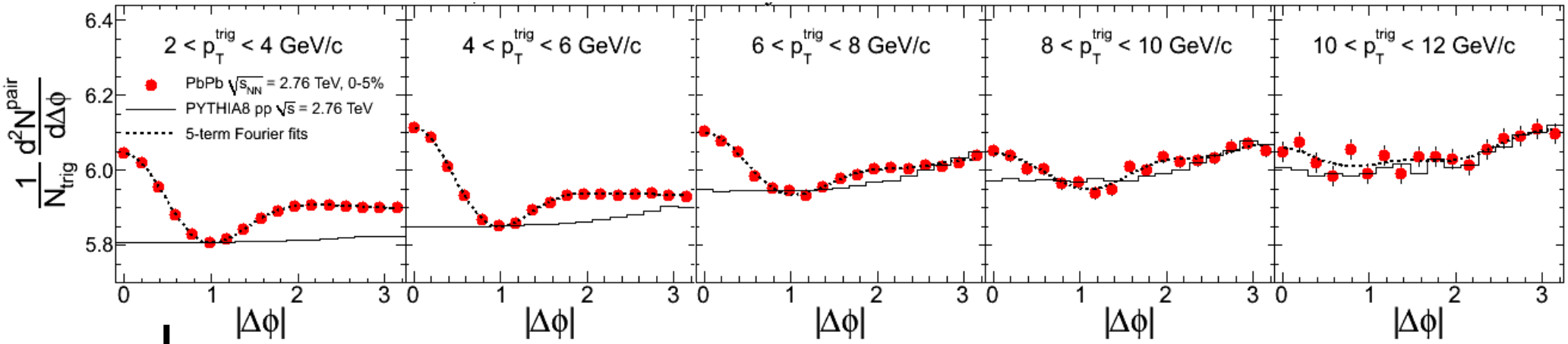
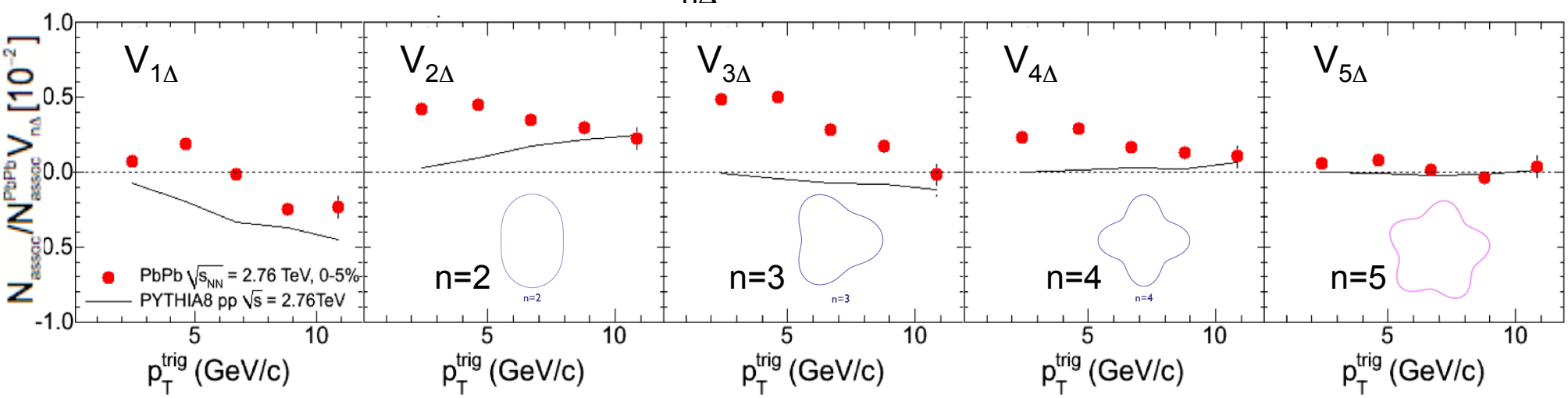



Ridge persists to high $p_T$ but decreases in magnitude

Extracted Fourier coefficients $V_{n\Delta}$

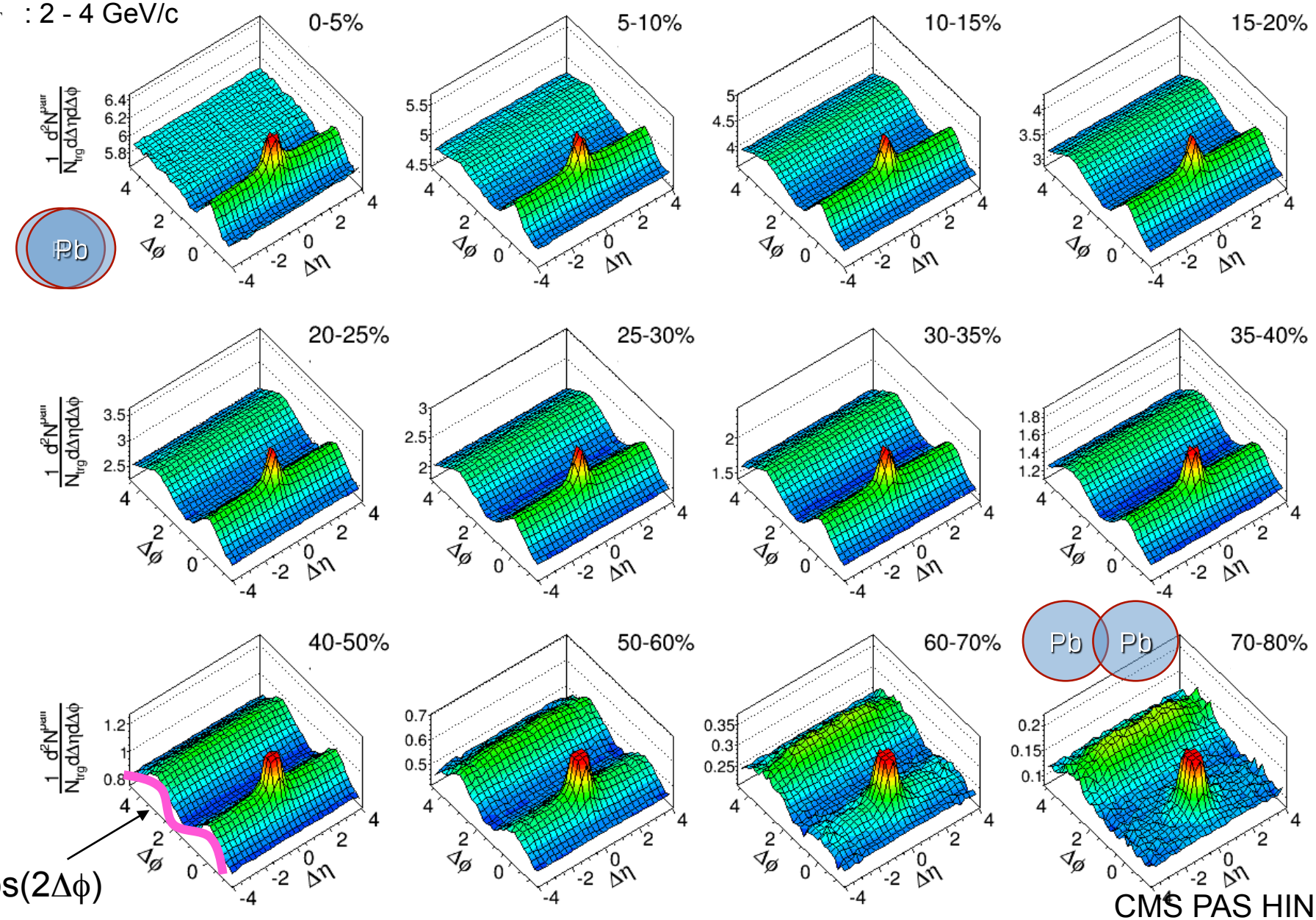


# Centrality dependence in PbPb

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

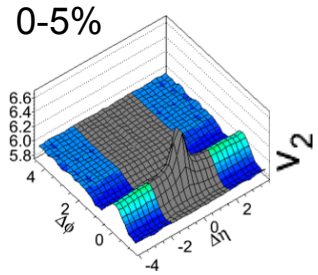
PbPb 2.76 TeV

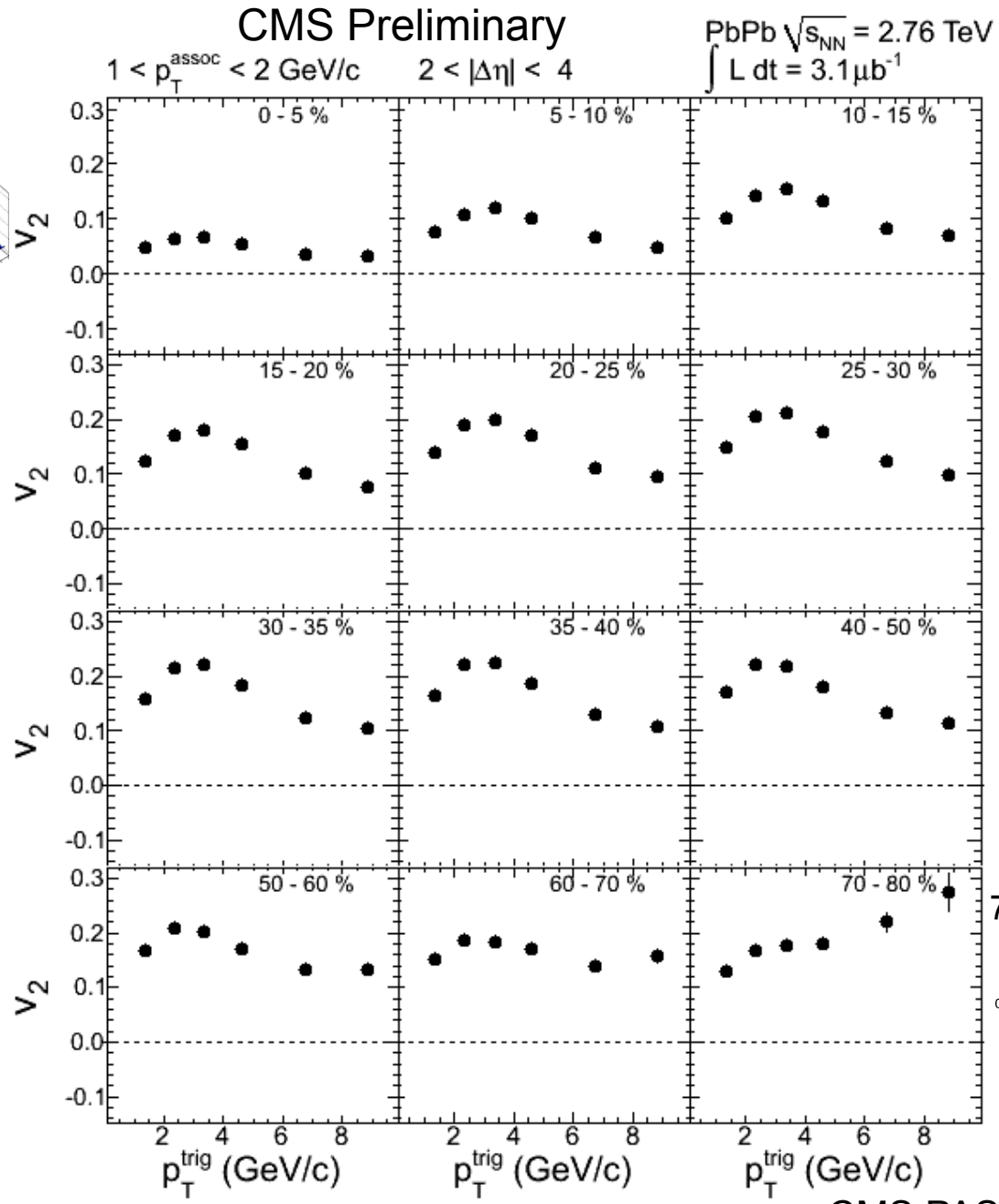
CMS Preliminary

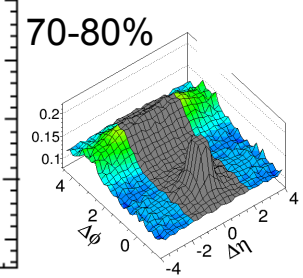



CMS PAS HIN-11-006

# Flow harmonics ($v_n$) from the ridge




If assume factorization:

Off-diagonal terms

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

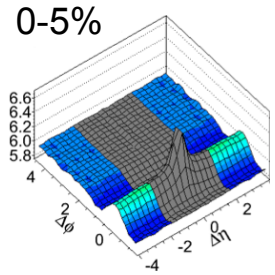
Diagonal terms

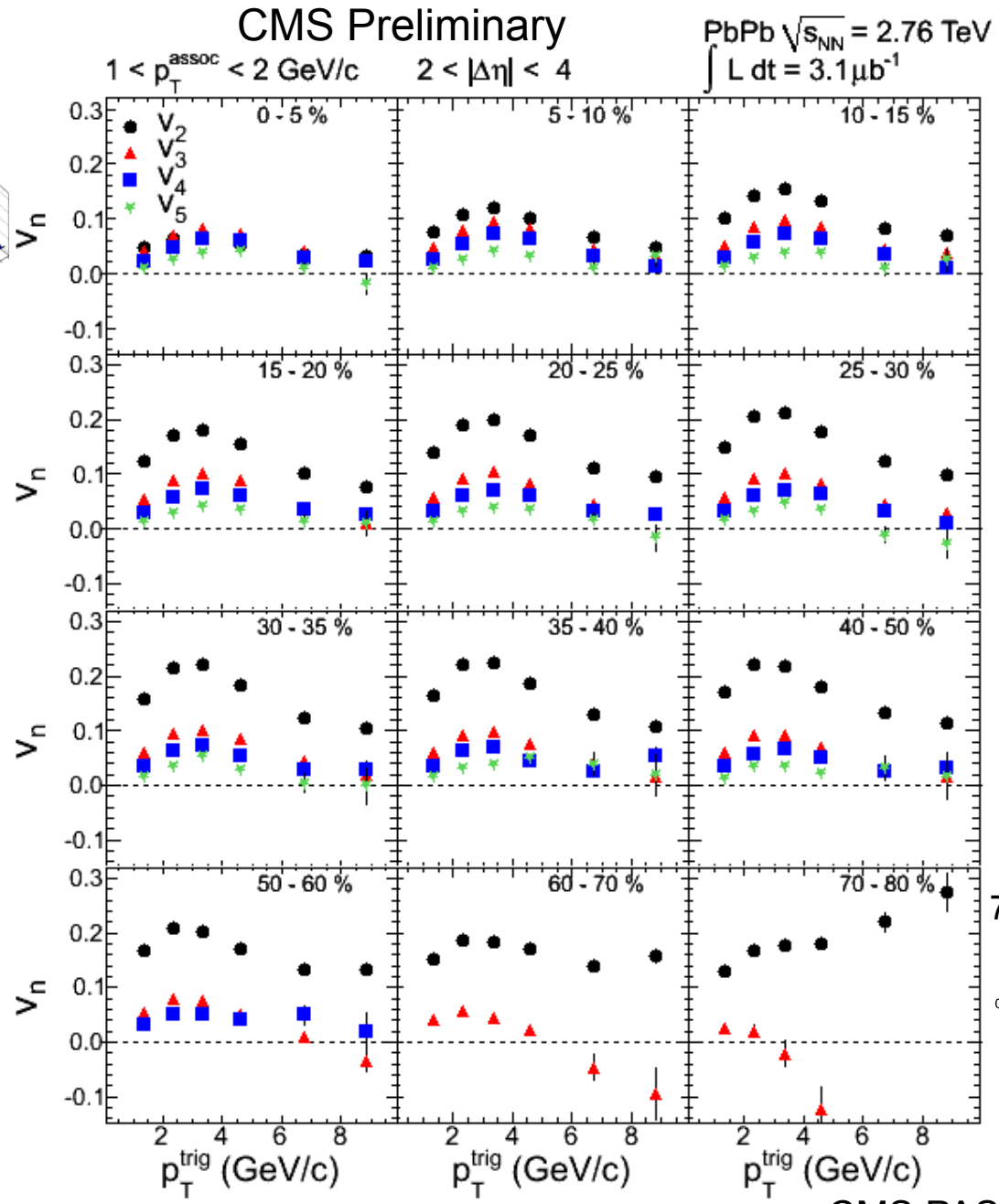
Keep low $p_T^{assoc}$ (1-2 GeV/c) to minimize non-flow effects

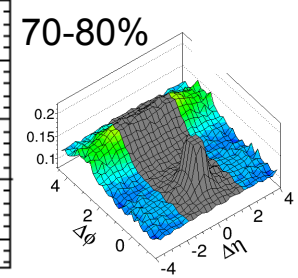
Consistent results with other flow methods (EP, cumulant, LYZ)

CMS PAS HIN-11-006

# Flow harmonics ($v_n$) from the ridge

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

Diagonal terms

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

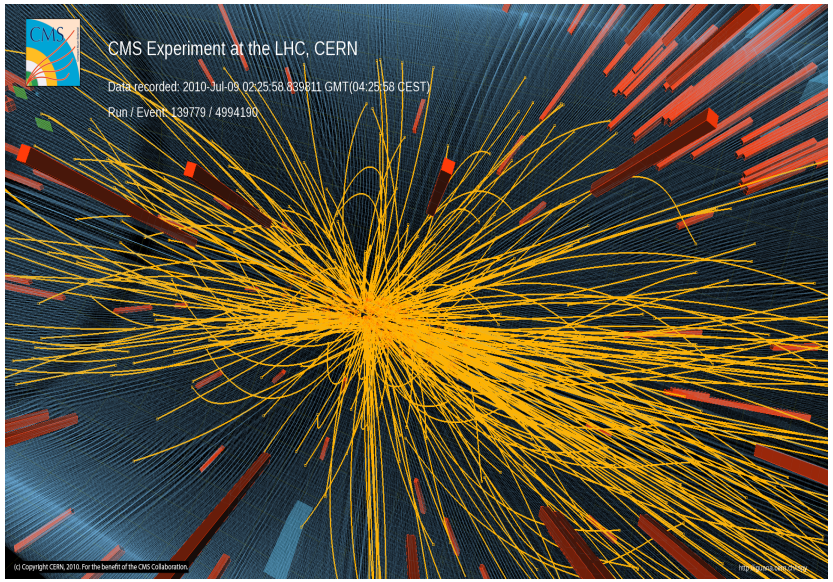
Consistent results with other flow methods (EP, cumulant, LYZ)

CMS PAS HIN-11-006

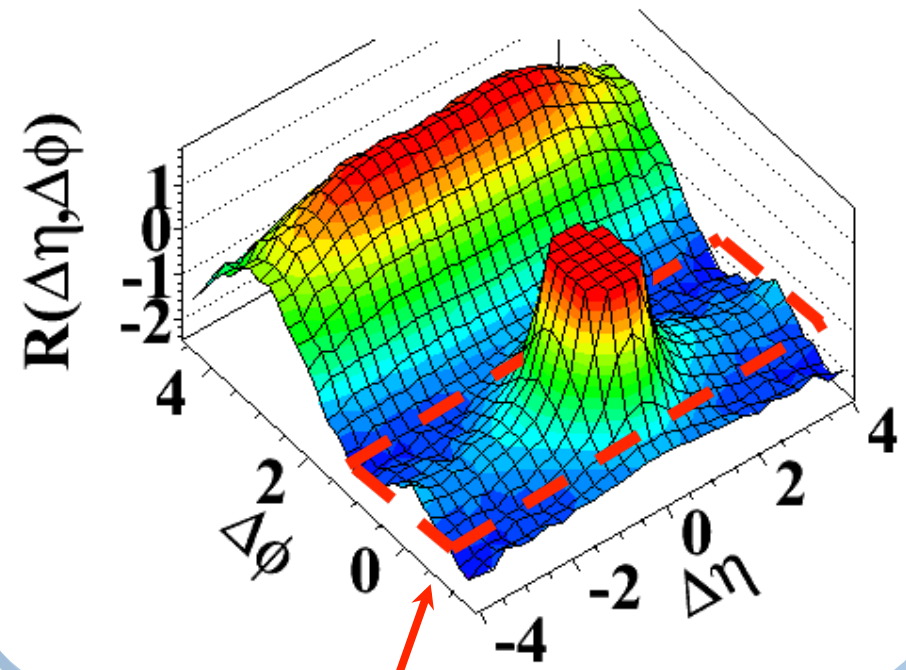
# Ridge in high multiplicity pp

$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

pp 7TeV ($N_{ch}$ ~ 268)




High multiplicity pp (N ≥ 110)




$$R(\Delta\eta,\Delta\phi) = \left\langle (N-1)\left(\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle_N$$

*JHEP 09 (2010) 091*

Unexpected "**ridge-like**" structure in pp

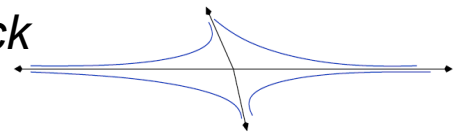
# Interpretations of the ridge in pp

## Jet-induced ridge

*Jet-Jet color connections*

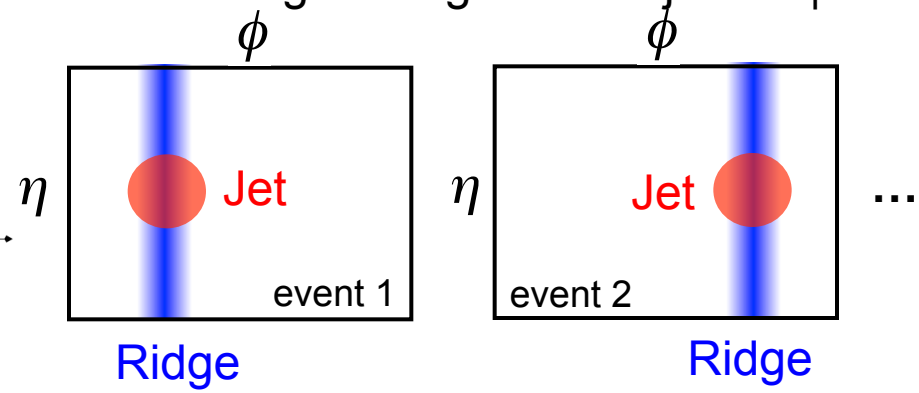
*Jet-proton remnant color connections*

*Jet-string momentum kick*

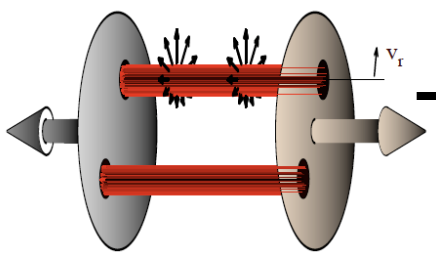


Persist up to high $p_T$ tracks or jets?

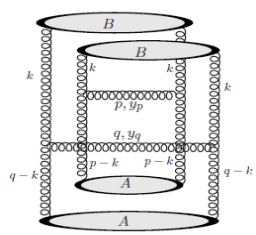
Ridge is aligned with jets in $\phi$




## Glasma tube

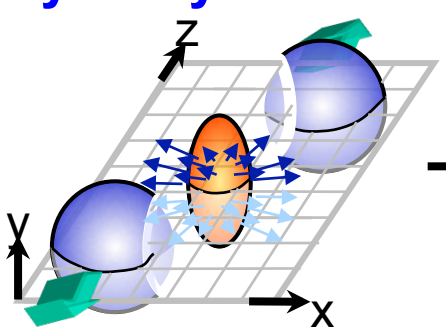


Maximal for $p_T^{trig}=p_T^{assoc}$

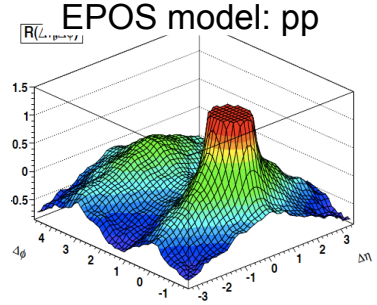


*Phys. Lett. B697:21-25, 2011*

## Hydrodynamic flow

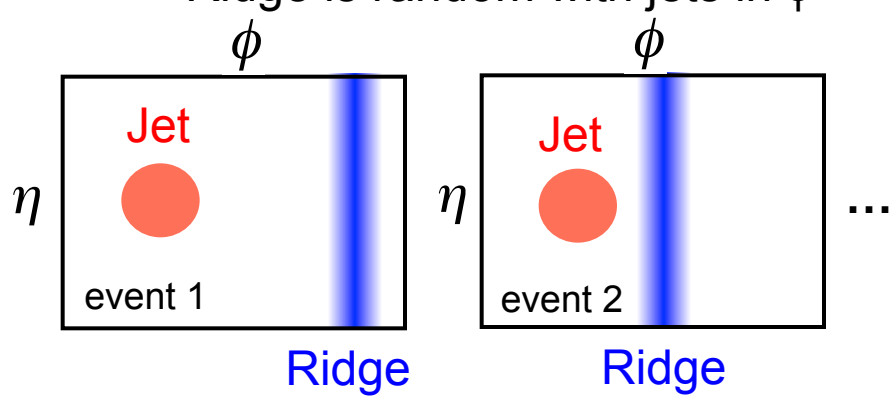



EPOS model: pp



K. Werner, WWND2011

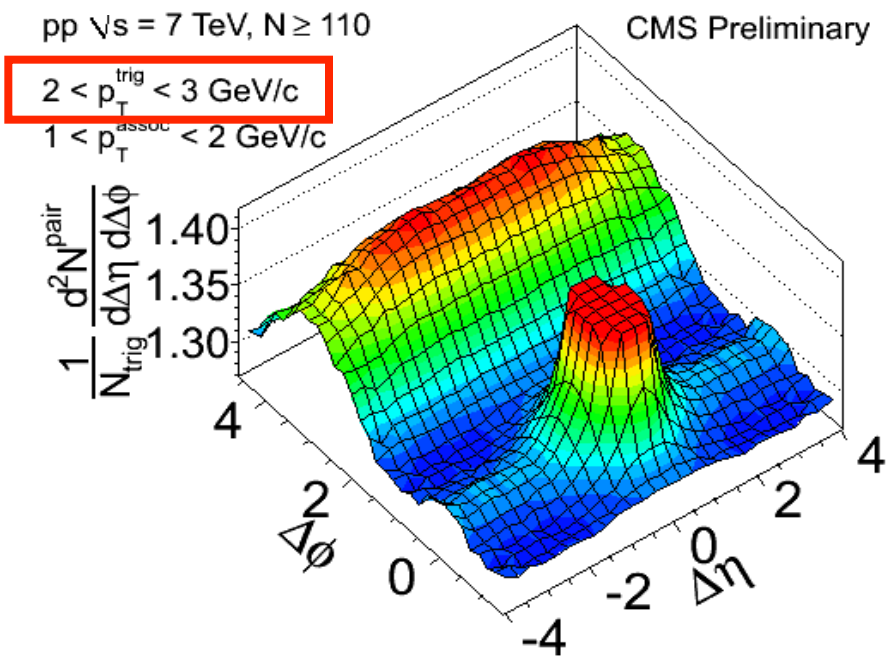
Ridge is random with jets in $\phi$



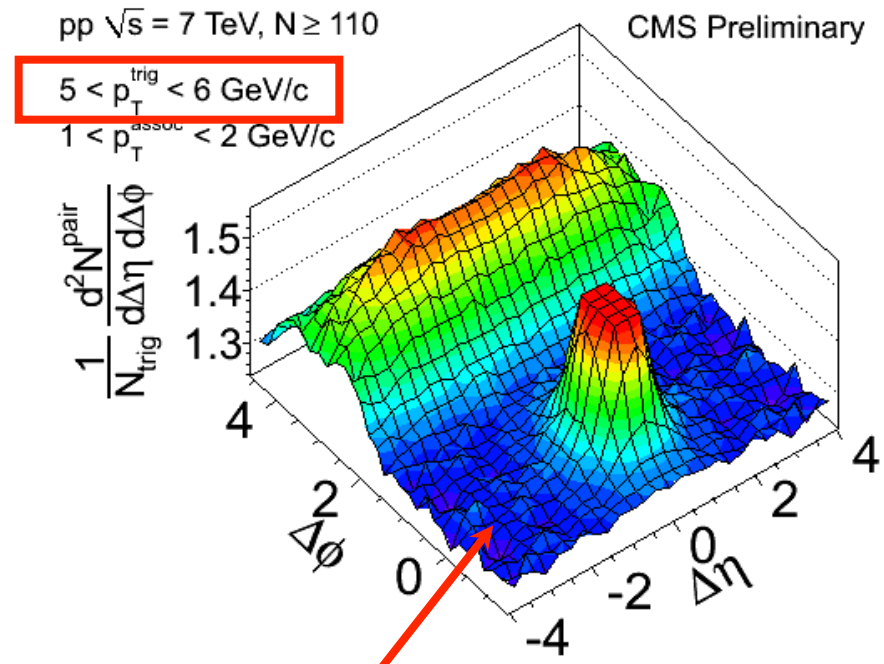

Ridge may go away at high $p_T$

# Ridge in high multiplicity pp

Updated new results: (full 2010 dataset!)



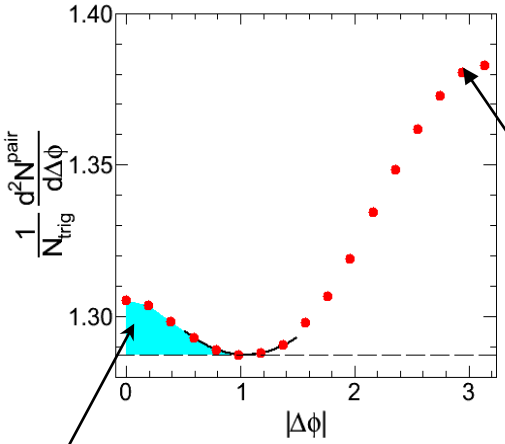

CMS PAS HIN-11-006




No ridge for higher $p_T$ particles!

*100 billion (1.78 $pb^{-1}$) sampled minimum bias events*

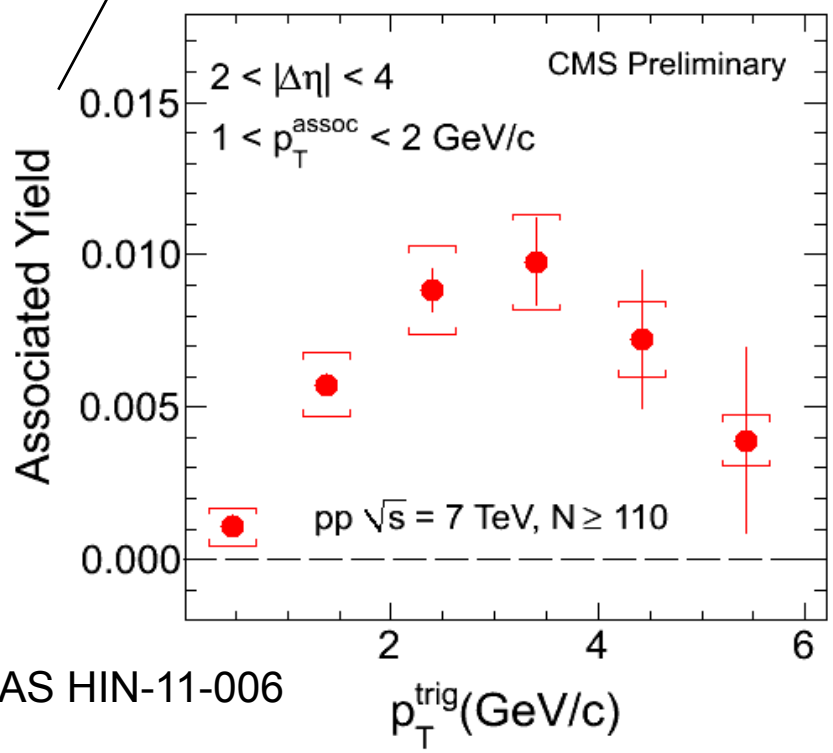
# Ridge in high multiplicity pp




Zero-Yield-At-Minimum (ZYAM)

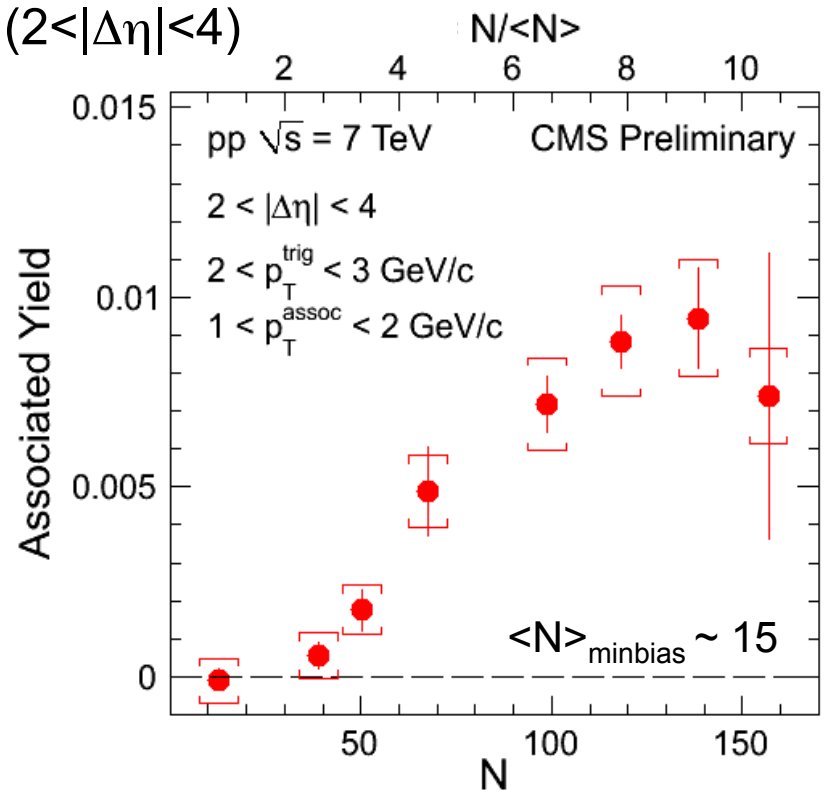
Direct Fourier analysis is hard due to away-side jet peak

Ridge region (2<|Δη|<4)




CMS PAS HIN-11-006

Rise and fall of the ridge with $p_T^{trig}$




Effect turns on at N ~ 4 x <N>$_{minbias}$

# Summary

**Unique capability of studying short-range and long-range correlations in pp and PbPb at CMS**

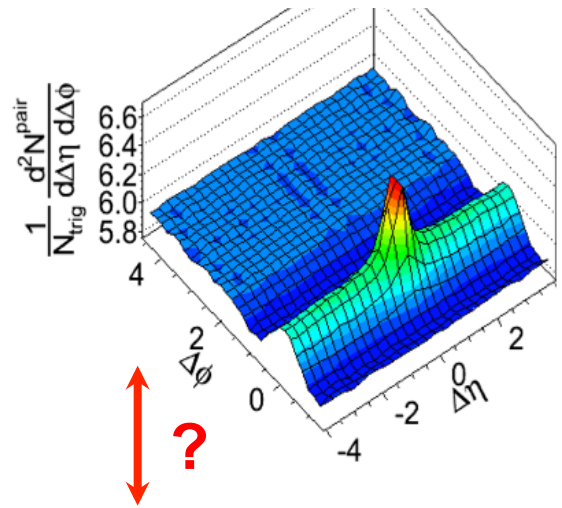
## Studies of dihadron correlations in PbPb

- Ridge can be described by higher-order flow ($v_n$)
- $v_n$ extracted from a Fourier analysis of long-range correlations as a function of $p_T$ and centrality
- Support a picture of fluctuating initial condition

## Observation of the ridge in high multiplicity pp

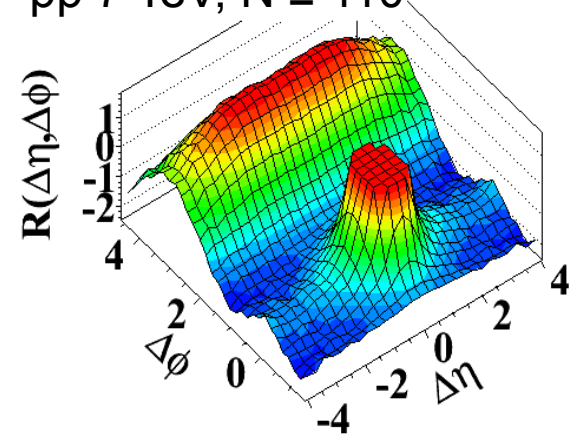
- New phenomena in pp physics
- Intriguing similarity to the ridge in heavy-ion collisions
- *Exciting new direction in high-density QCD physics!*

PbPb 2.76 TeV, 0-5%




?

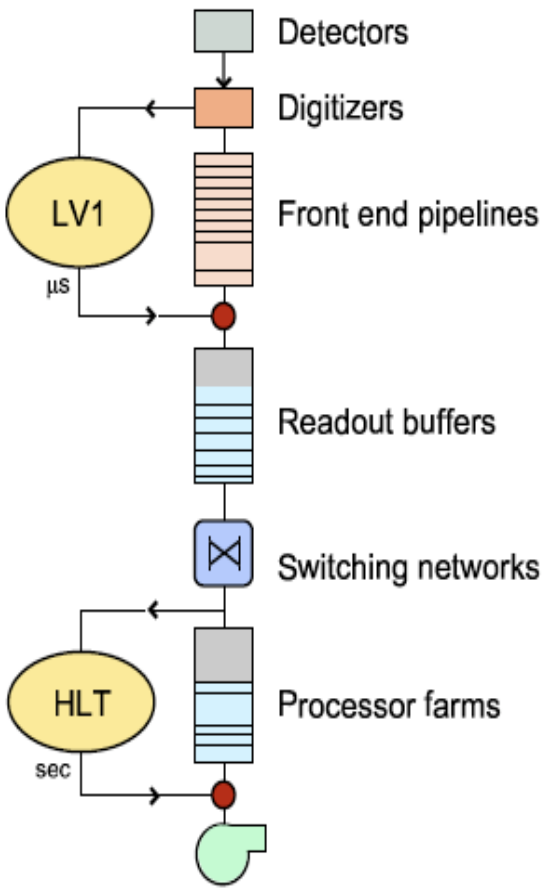
pp 7 TeV, N ≥ 110



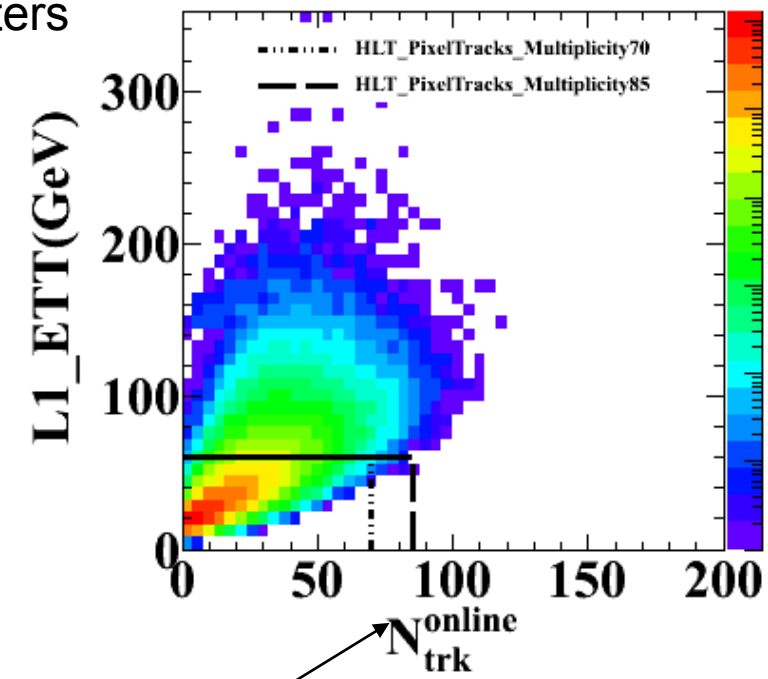
# Backups

# Trigger on High Multiplicity pp

CMS trigger and DAQ

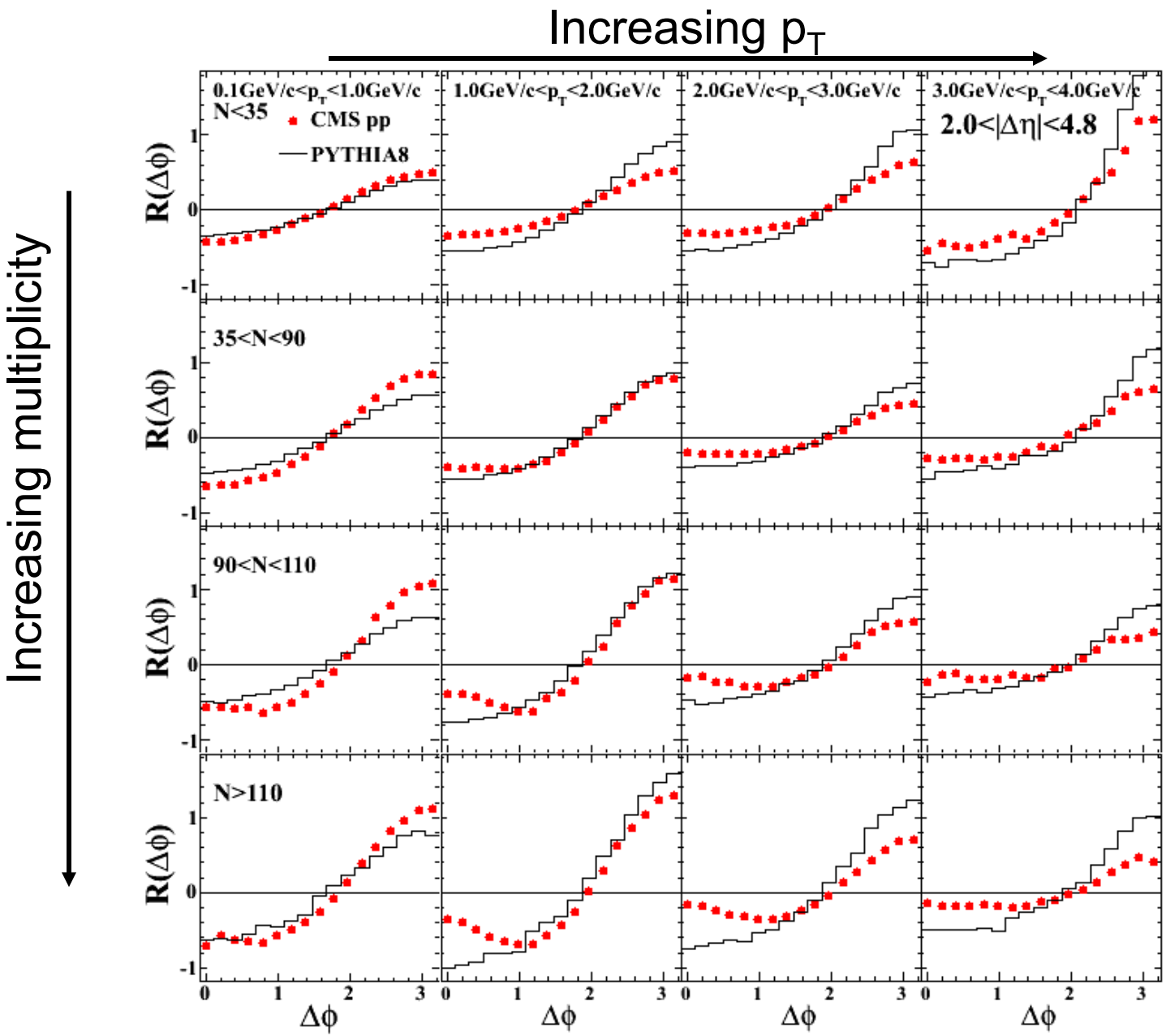


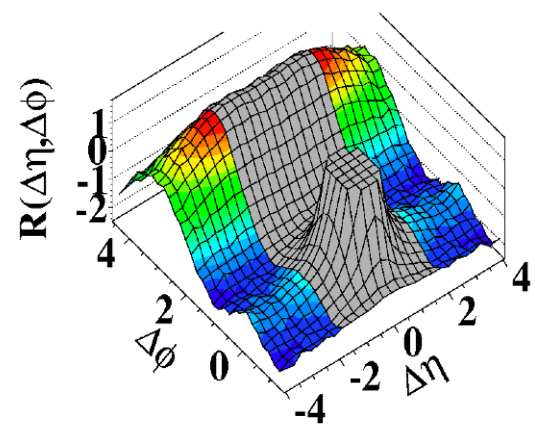

**Level-1:**
$\sum E_T$> 60 GeV
in calorimeters




**High-Level trigger:**
number of tracks with $p_T$>0.4 GeV/c, |h|<2 from a **single** vertex

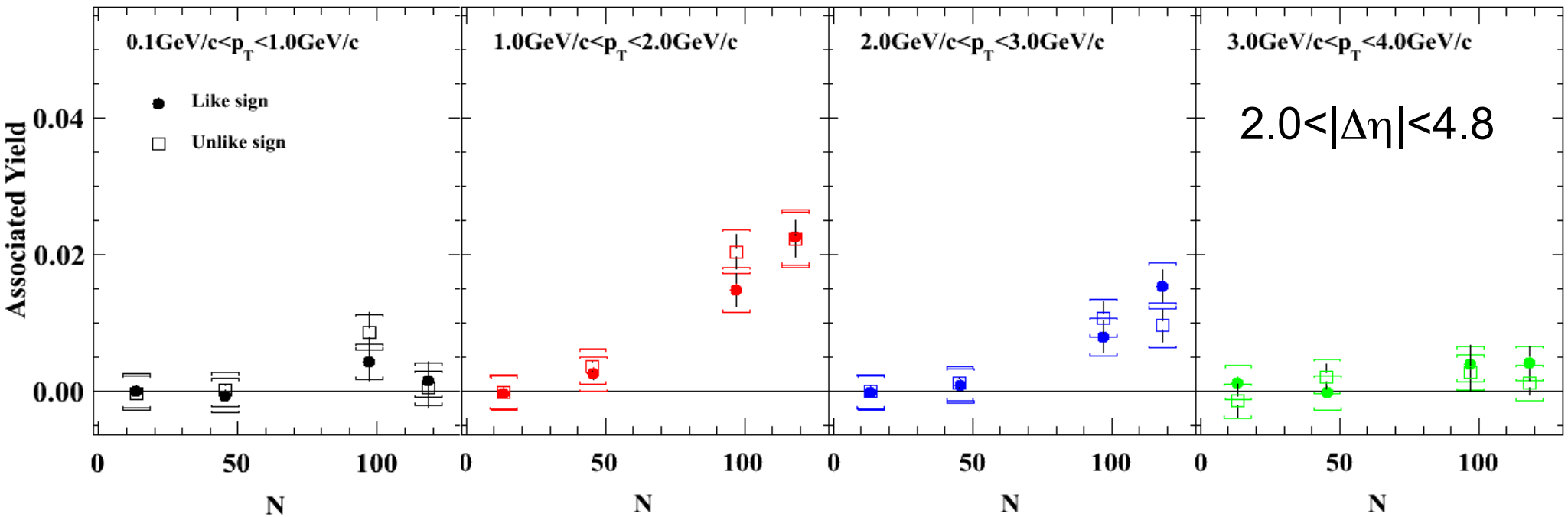
# 1-D projected R(Δϕ) at large Δη



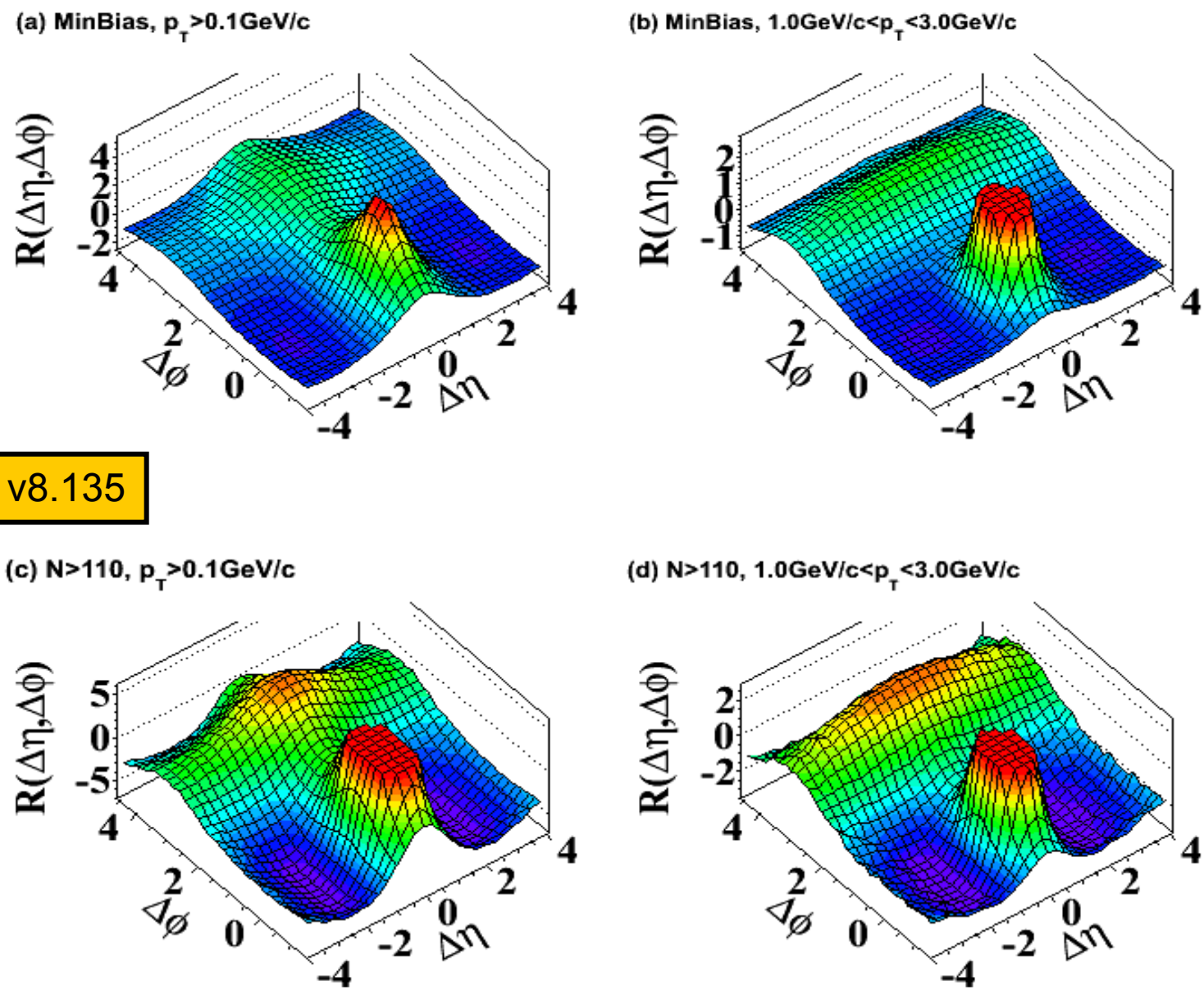
# Charge Dependence of the Ridge

Like-sign (++,--) and unlike-sign (+-) pair correlations:




No charge sign dependence of the ridge!

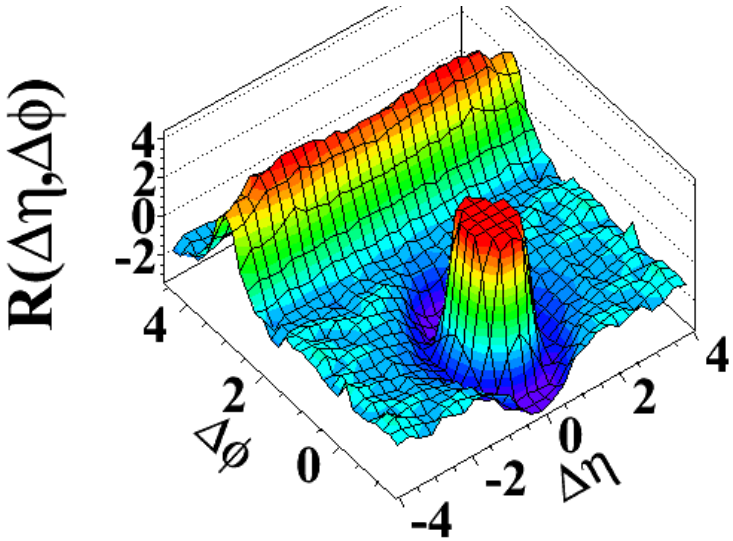
# Comparing to various MC



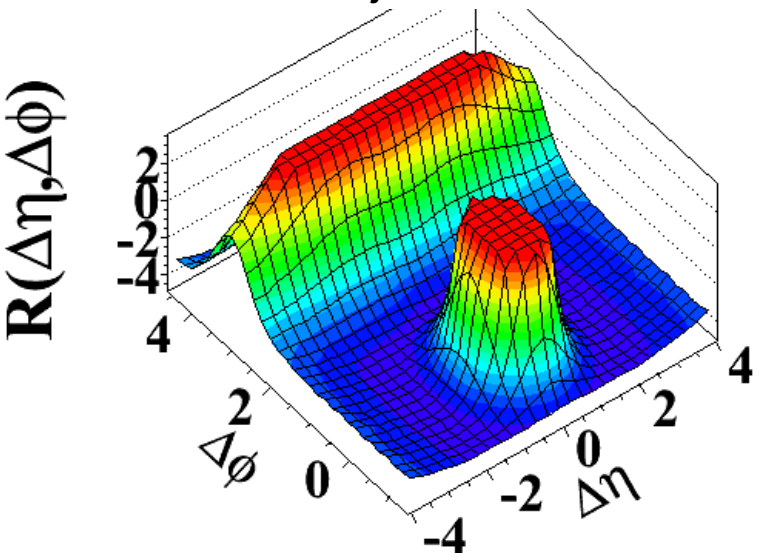

PYTHIA8, v8.135

# More MC models

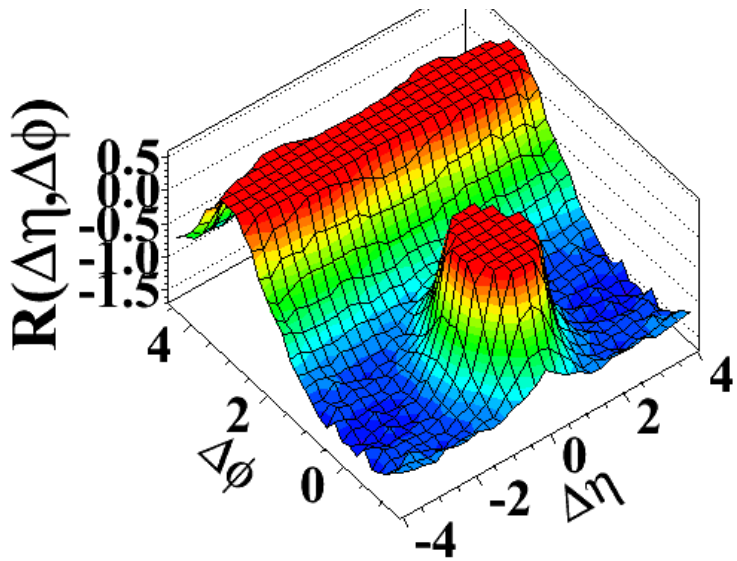
PYTHIA D6T MinBias, N>70



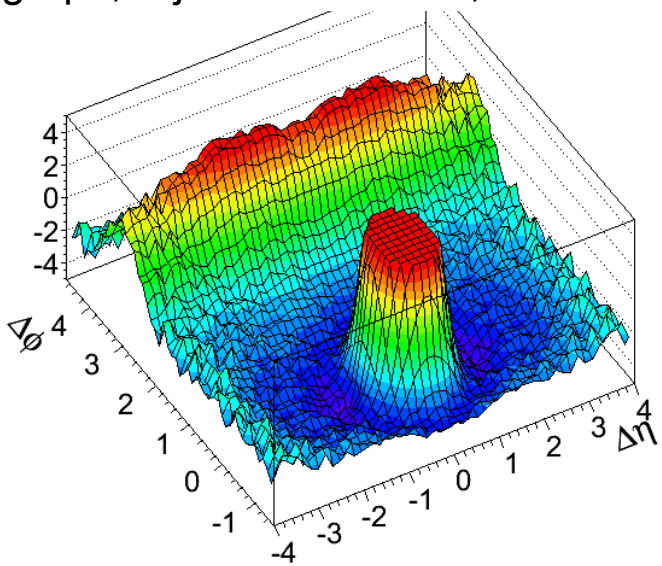

PYTHIA D6T, Dijet 80-120GeV




HERWIG++, N>110




Madgraph, Dijet 100-250GeV, N>90

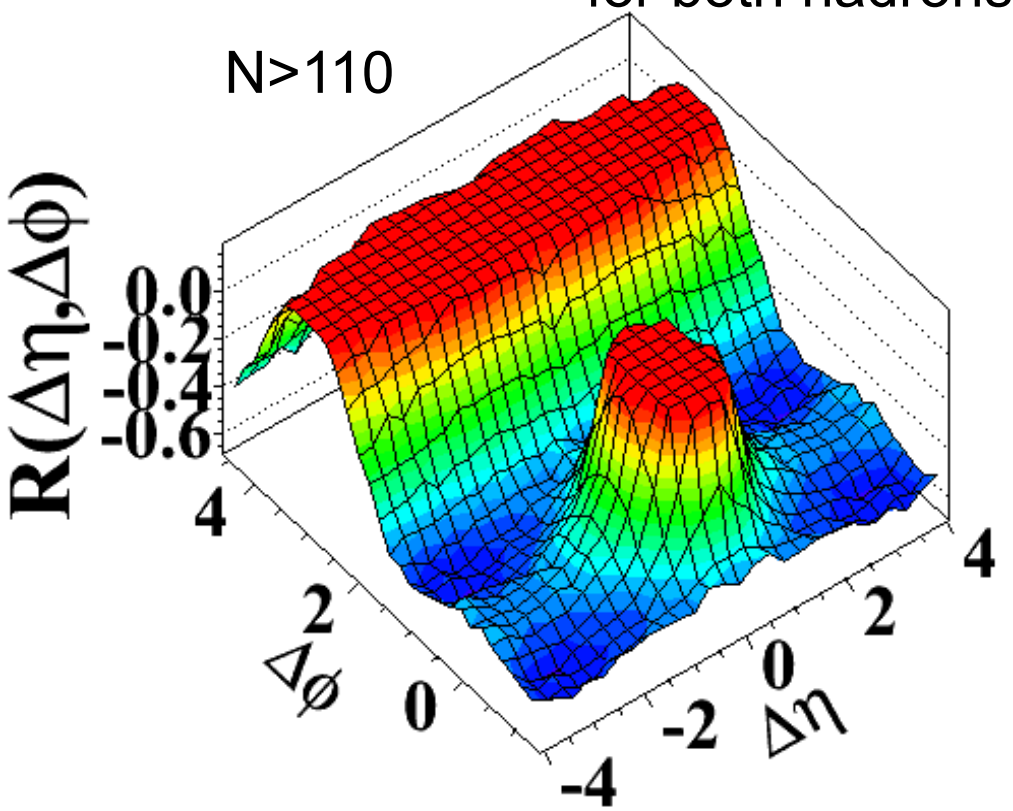


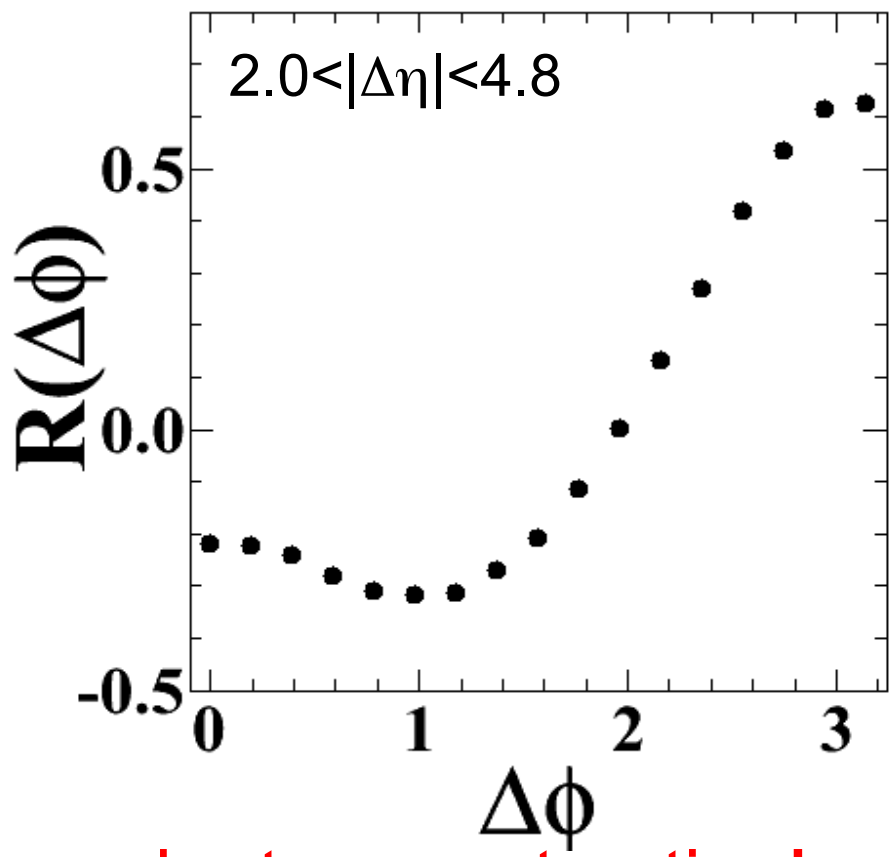
# Cross check: ECAL Photons

## Charged hadron - photon correlations

(photons are mostly from $\pi^0$ decay)

$1.0\text{GeV}/c<p_T<3.0\text{GeV}/c$
for both hadrons and photons



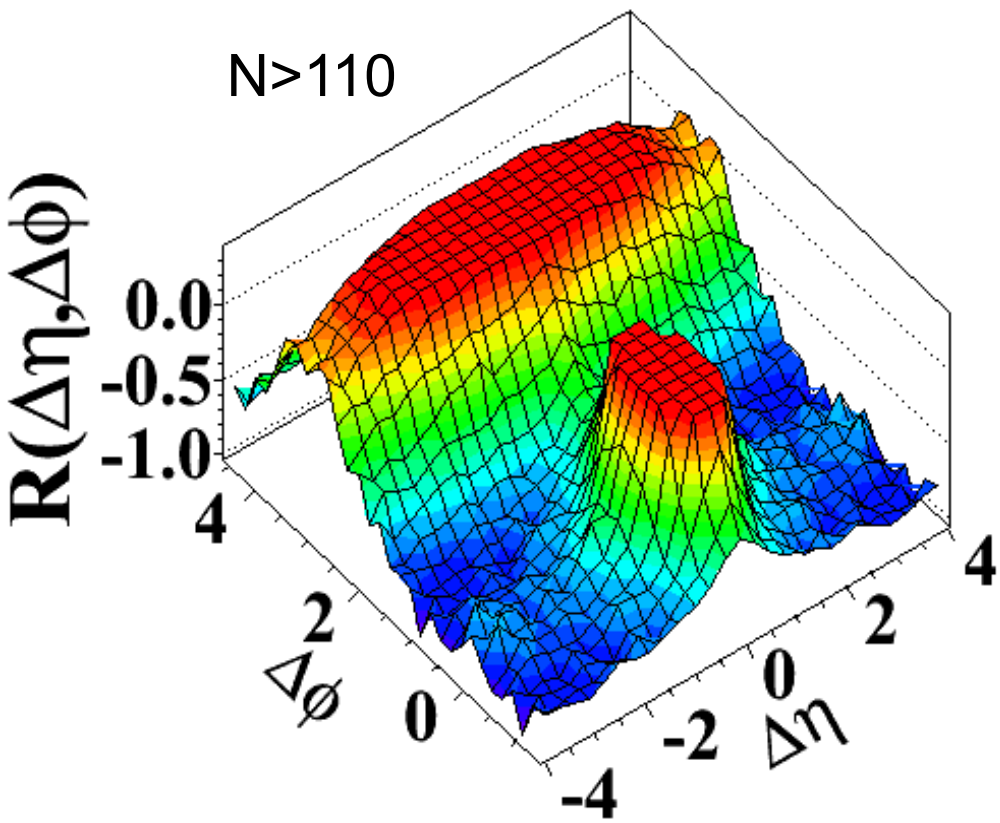

Independent detector, independent reconstruction!

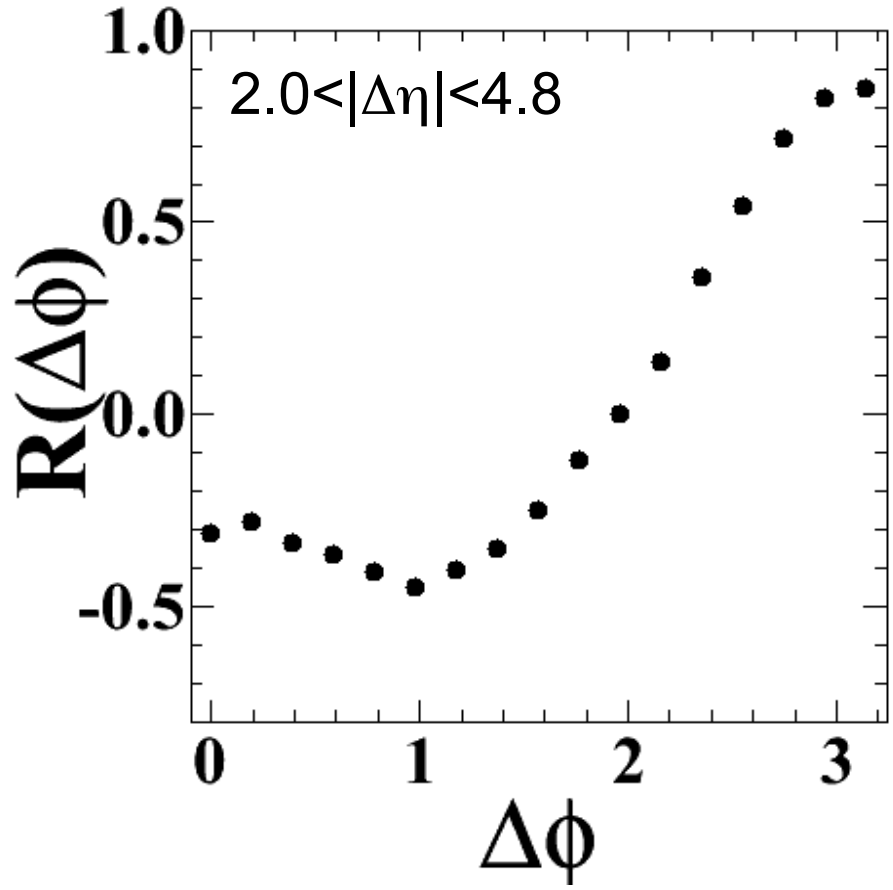
# Cross check: ECAL Photons

photon - photon correlations

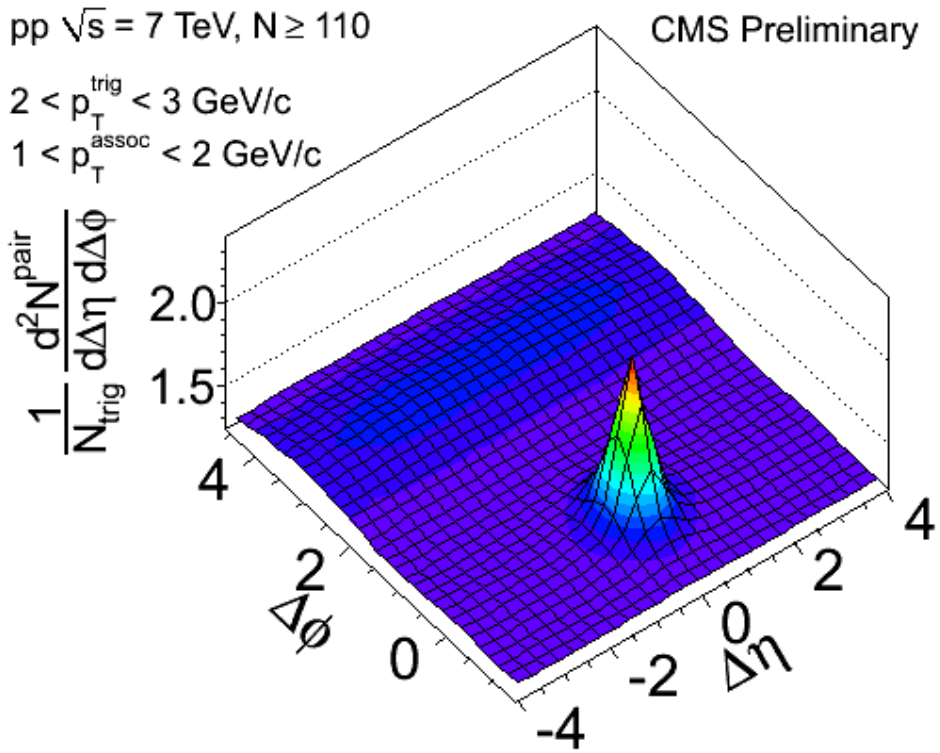
(photons are mostly from $\pi^0$ decay)

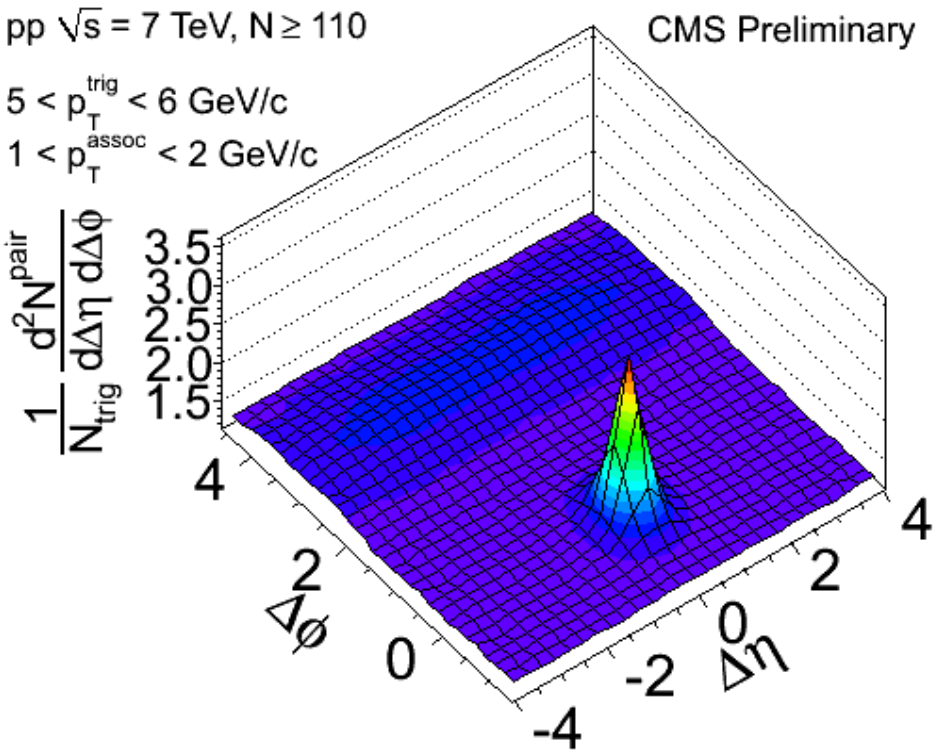
$1.0\text{GeV/c}<p_T<3.0\text{GeV/c}$



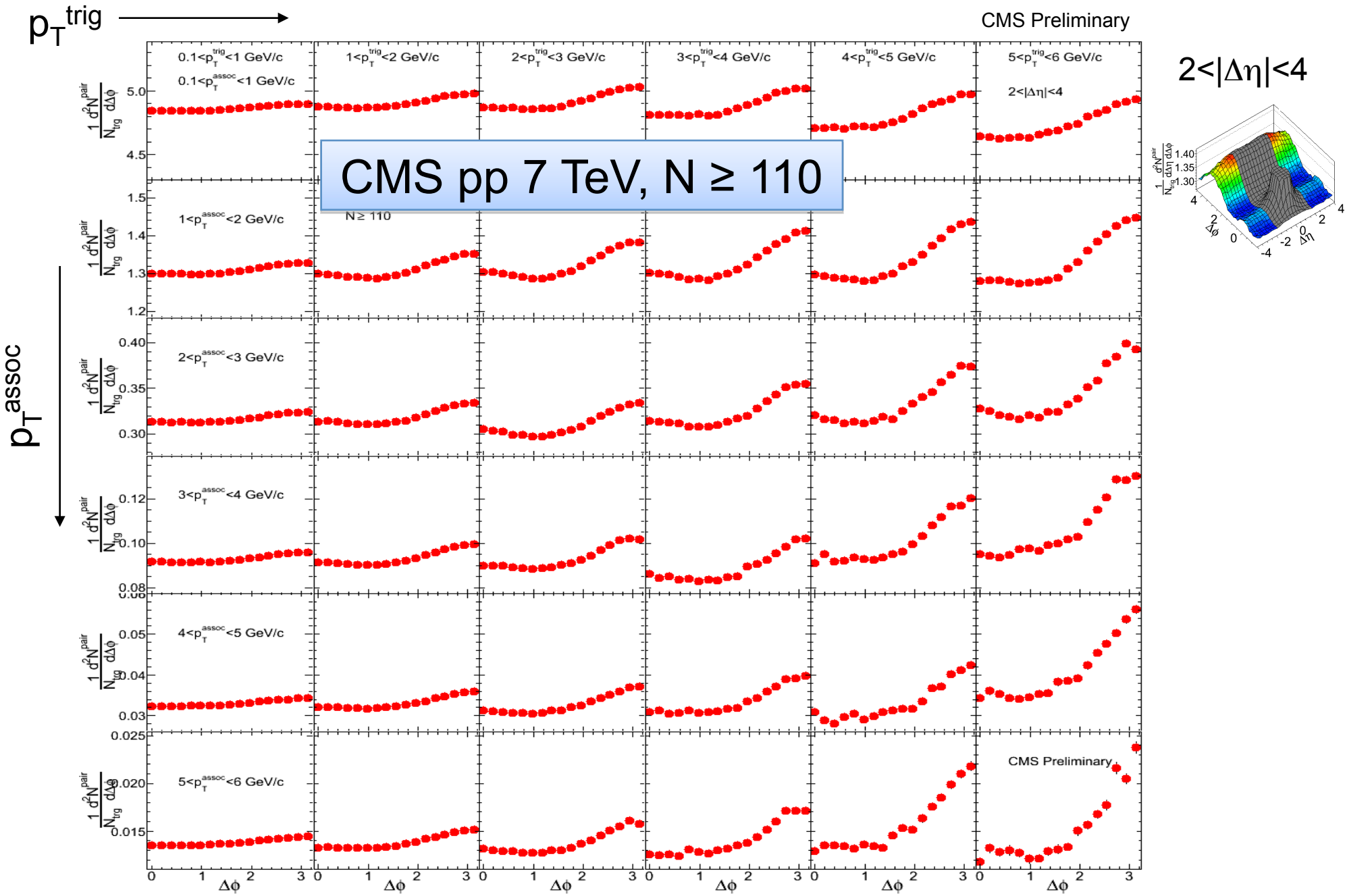




Independent detector, independent reconstruction!


pp √s = 7 TeV, N ≥ 110
CMS Preliminary
2 < p_T^trig < 3 GeV/c
1 < p_T^assoc < 2 GeV/c
1/N_trig d²N^pair/dΔη dΔφ
2.0
1.5
4
2
0
Δφ
-4
-2
0
2
4
Δη


pp √s = 7 TeV, N ≥ 110
CMS Preliminary
5 < p_T^trig < 6 GeV/c
1 < p_T^assoc < 2 GeV/c
1/N_trig d²N^pair/dΔη dΔφ
3.5
3.0
2.5
2.0
1.5
4
2
0
Δφ
-4
-2
0
2
4
Δη

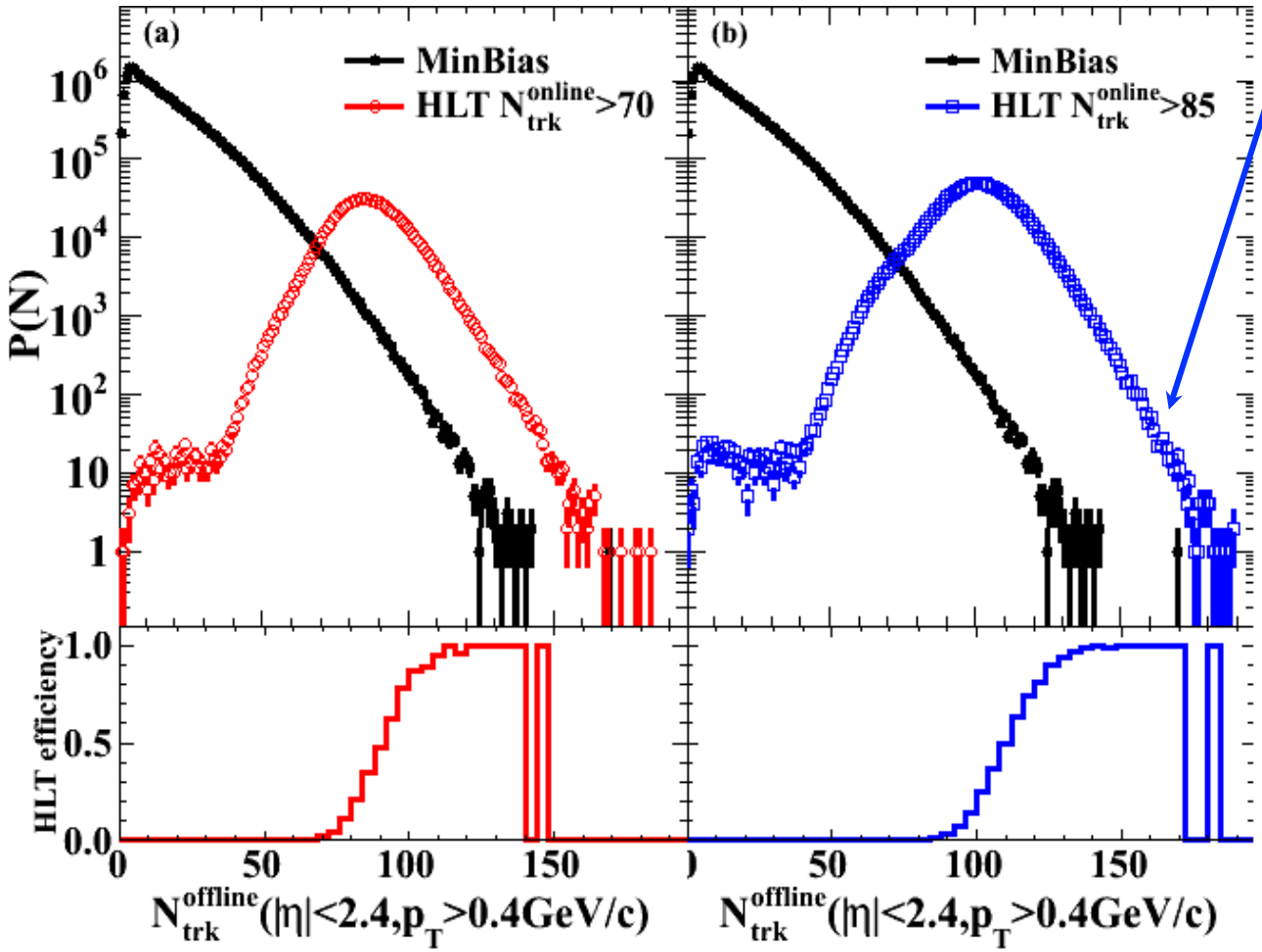
# $\Delta\phi$ projections in various $p_T$ ranges



# High multiplicity pp collisions

See talk by Dragos Velicanu
(05/23, 3:00pm)

Very high particle density regime
*Is there anything interesting happening?*




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

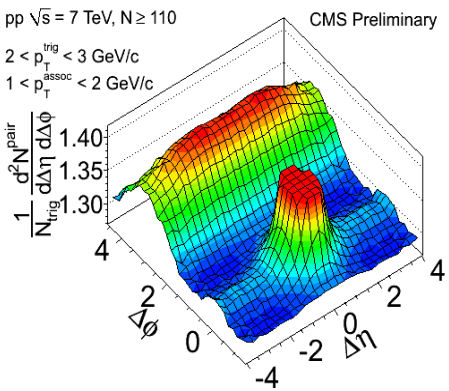
$N^{online}$ > 85 trigger <u>un-prescaled</u> for full 980nb$^{-1}$ data set

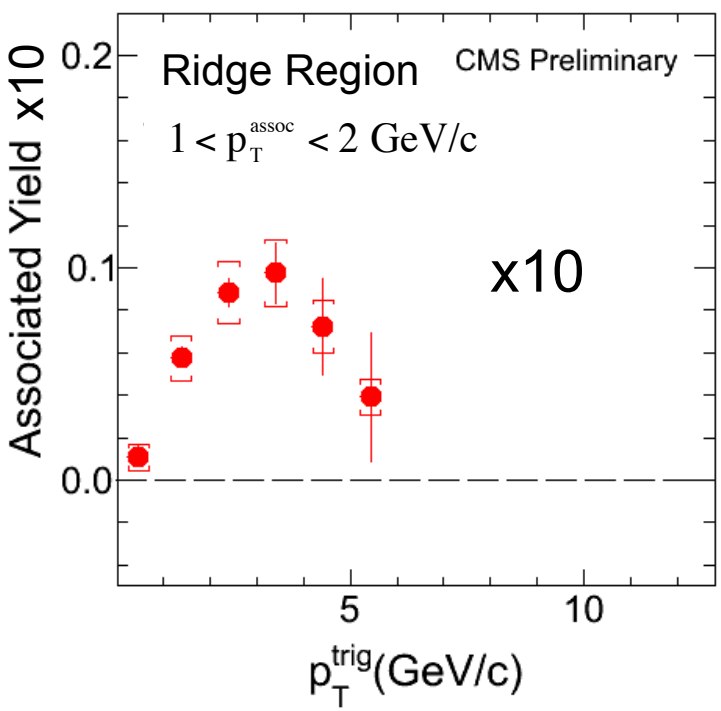
*JHEP 09 (2010) 091*

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

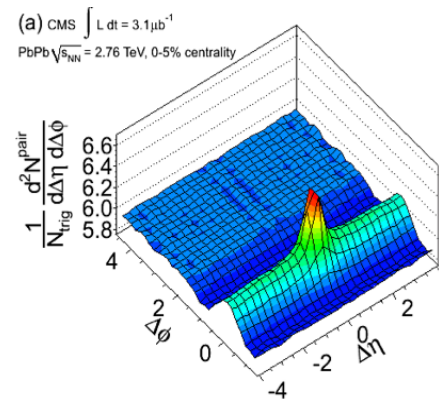
# Ridge in pp and PbPb

## CMS pp 7 TeV, N ≥ 110

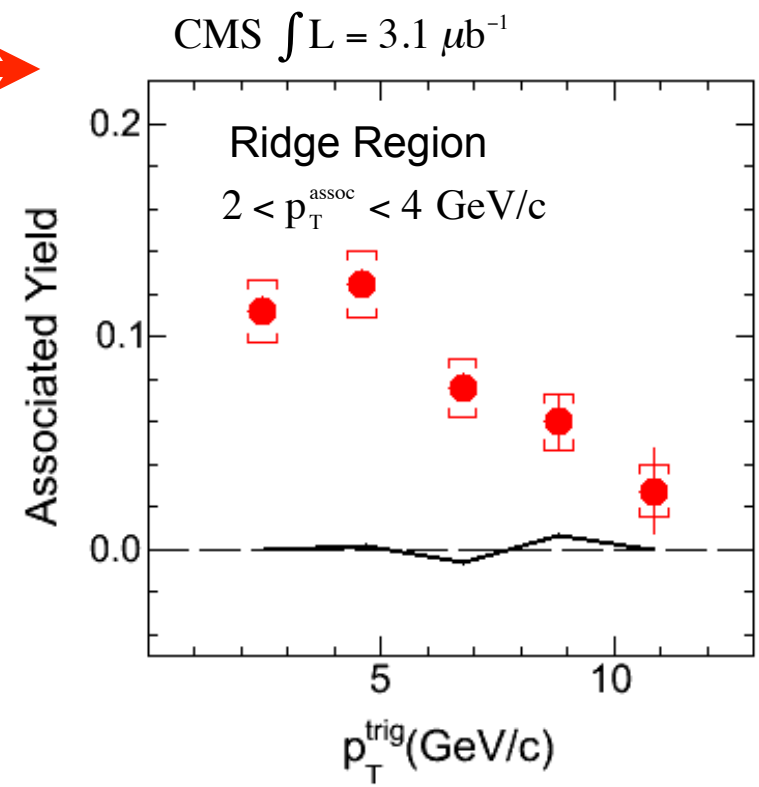



## CMS PbPb 2.76 TeV, 0-5%

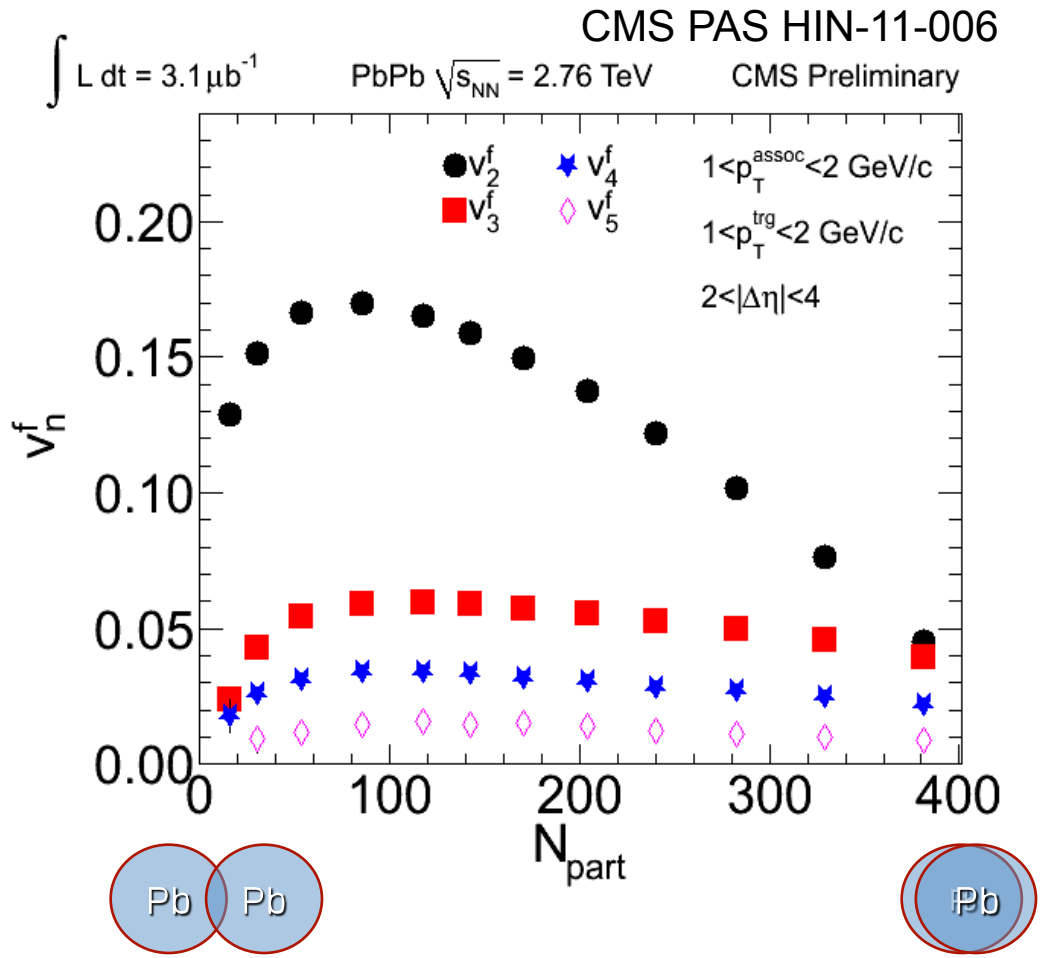



?



# Flow harmonics ($v_n$) from the ridge

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




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

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