

# Ridge correlation structure in high multiplicity pp collisions with CMS

Dragos Velicanu



for the CMS Collaboration

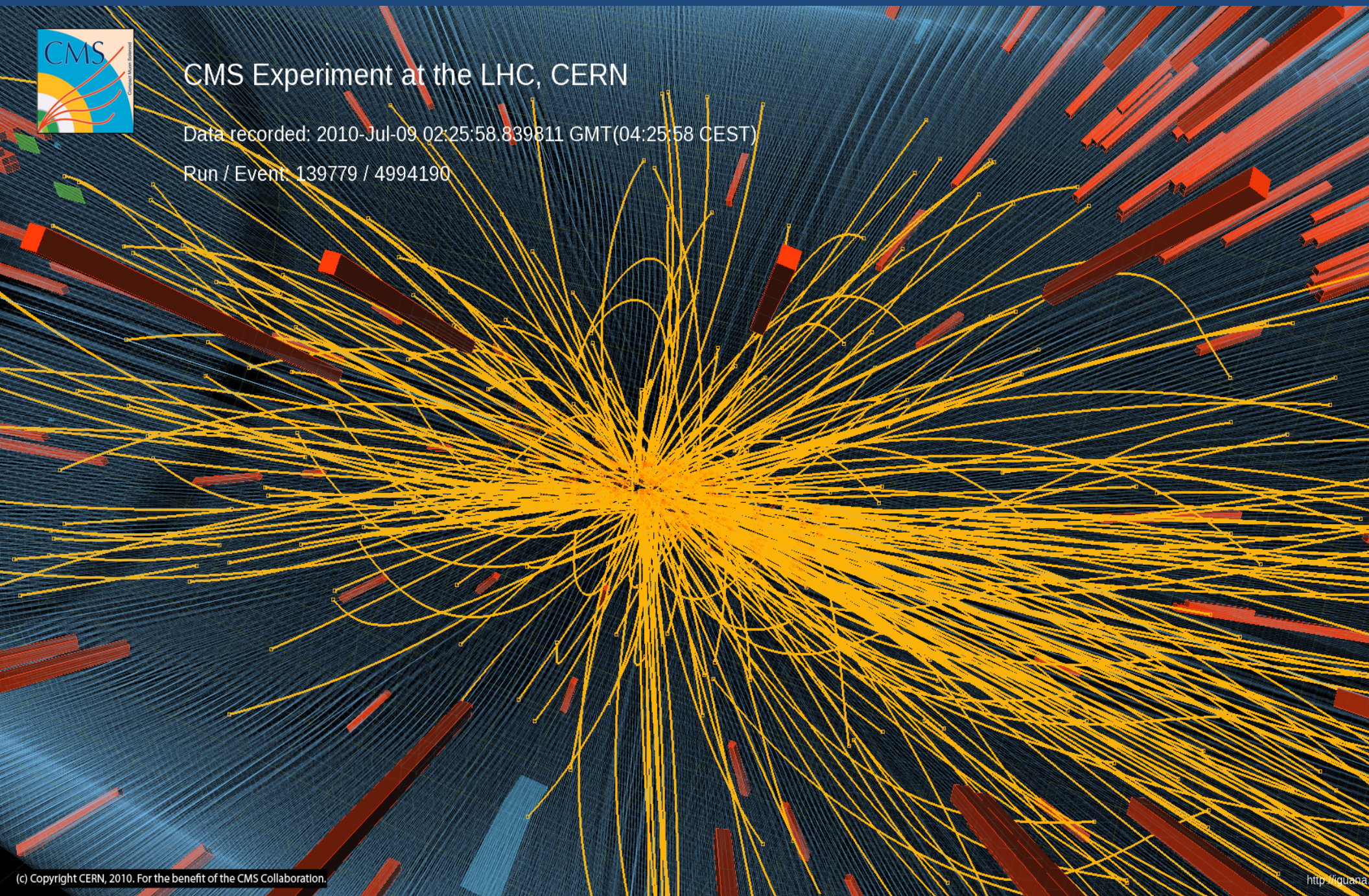
# Results from High Multiplicity pp



CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)

Run / Event: 139779 / 4994190

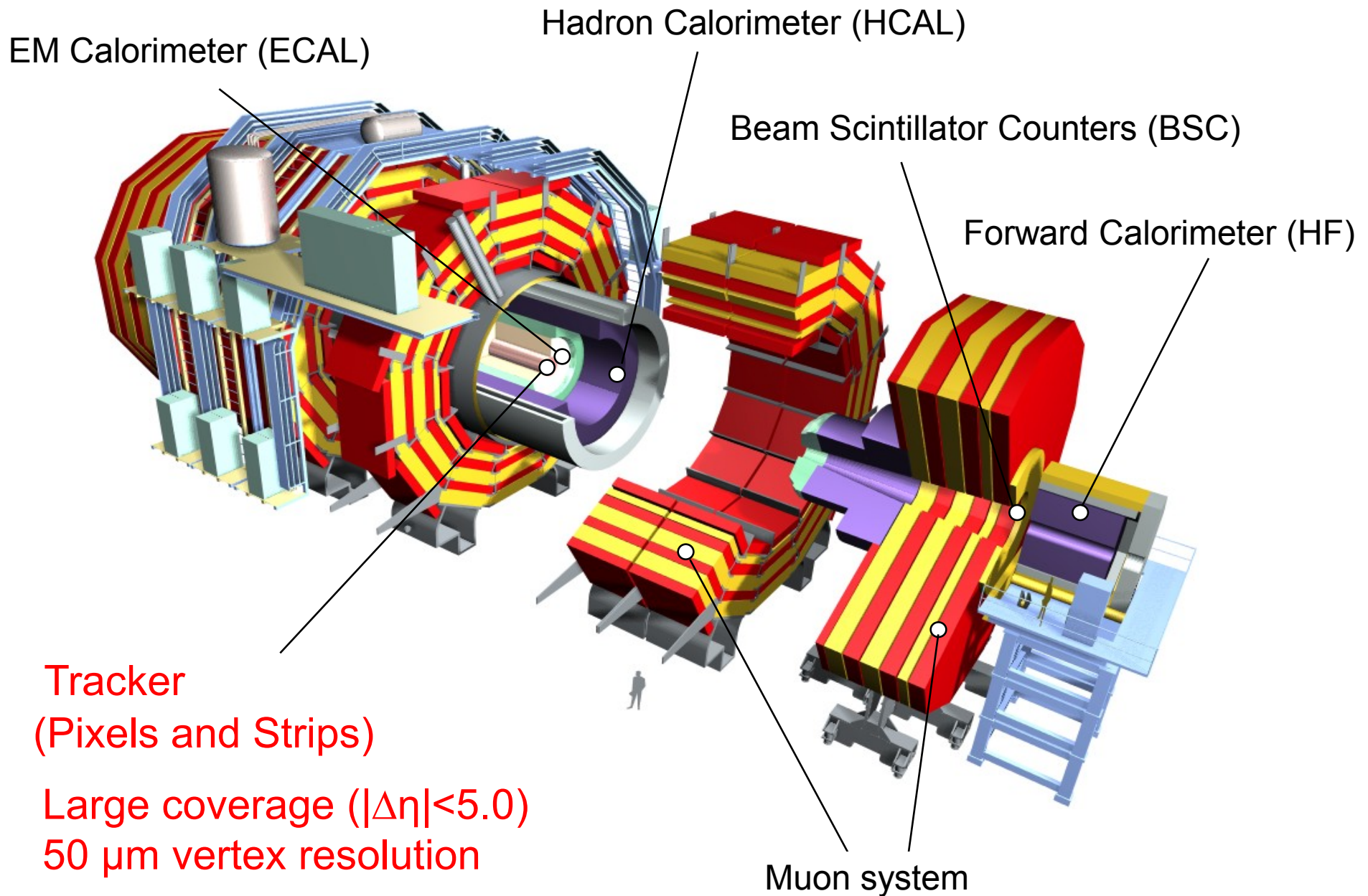


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<http://quana>

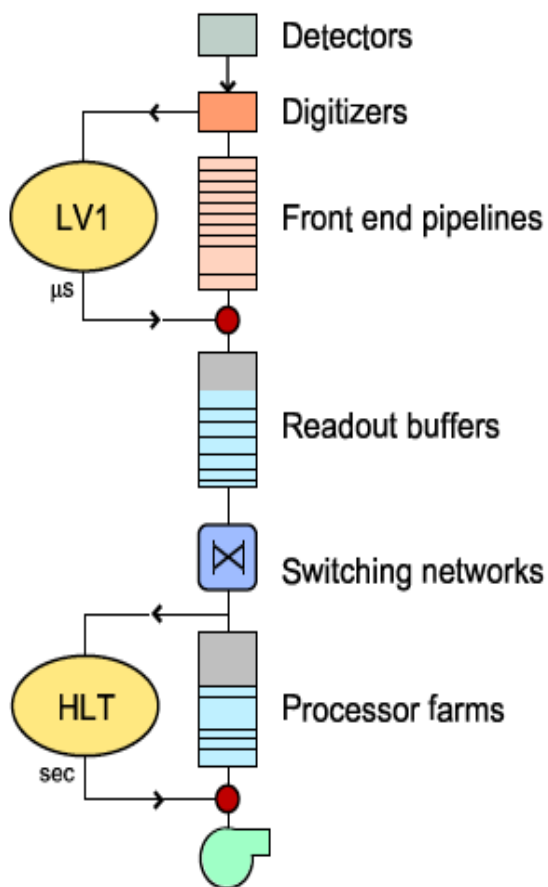


# CMS Experiment



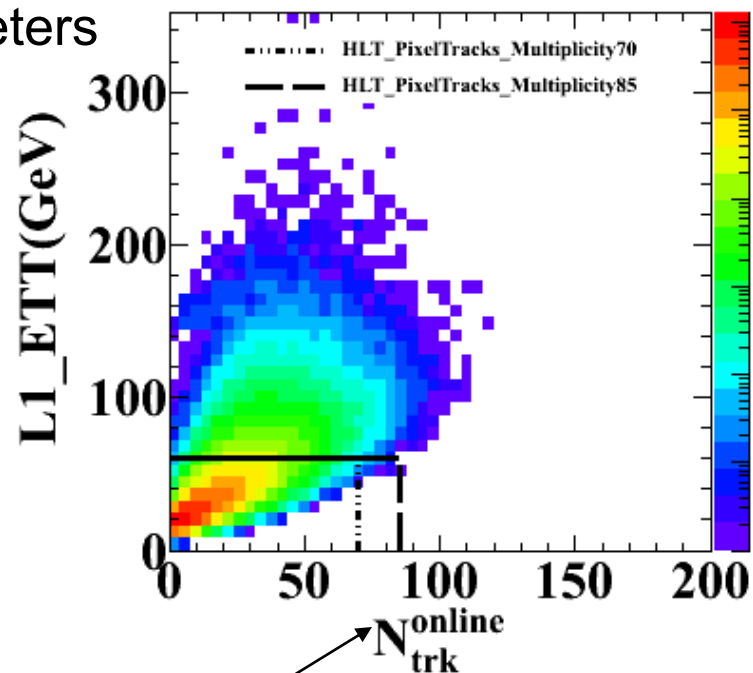
# Trigger on High Multiplicity pp

## CMS trigger and DAQ



### Level-1:

$\Sigma E_T > 60 \text{ GeV}$   
in calorimeters



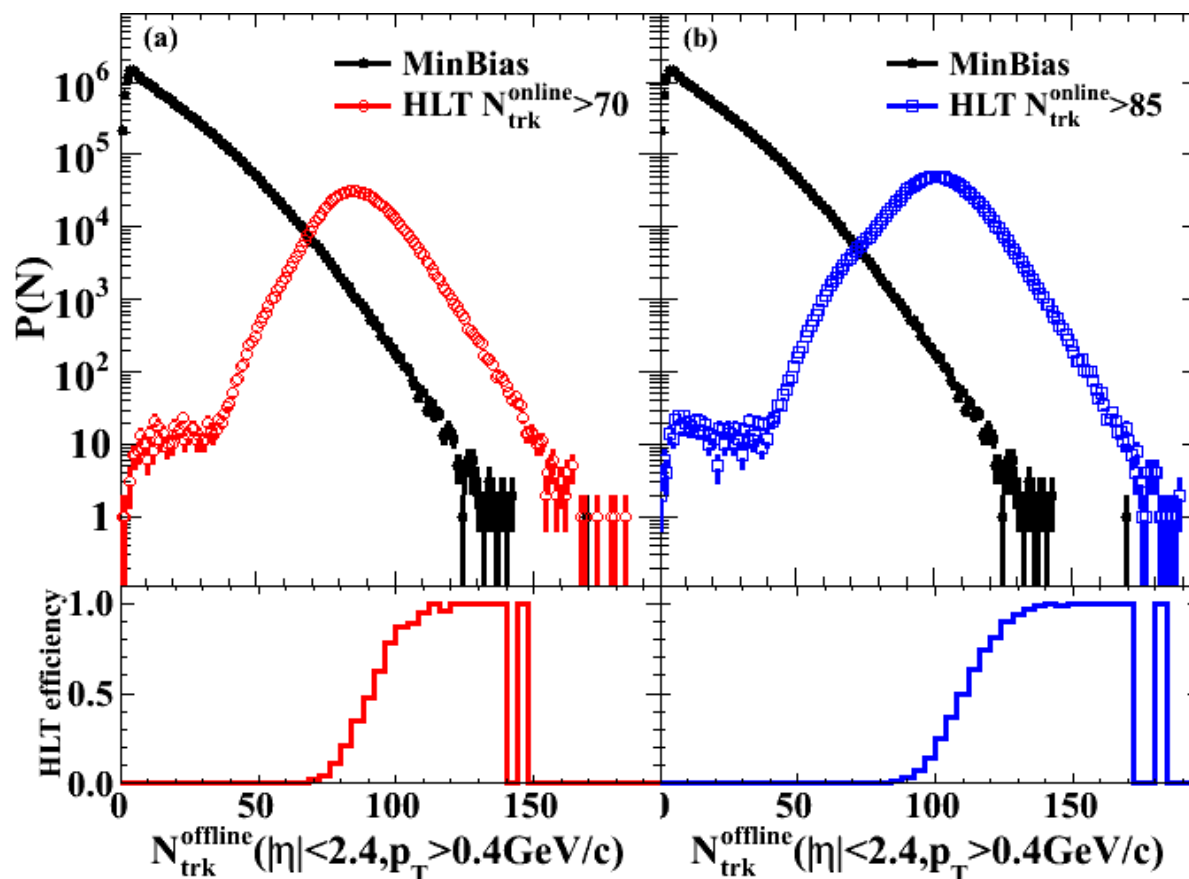
### High-Level trigger:

number of tracks with  $p_T > 0.4 \text{ GeV}/c$ ,  $|\eta| < 2$   
from a single vertex

# Trigger on High Multiplicity pp

*JHEP 1009:091, 2010*

Total integrated luminosity:  $980\text{nb}^{-1}$



Two HLT thresholds:

- $N_{\text{online}} > 70$
- $N_{\text{online}} > 85$

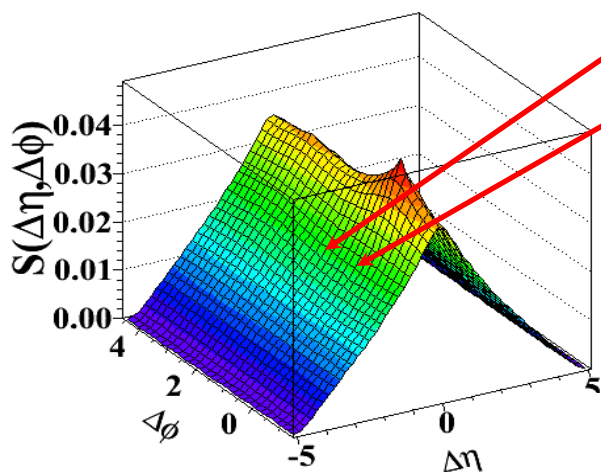
$N_{\text{online}} > 85$  trigger  
un-prescaled for  
full  $980\text{nb}^{-1}$  data set

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

# Angular Correlation Technique

Signal distribution:

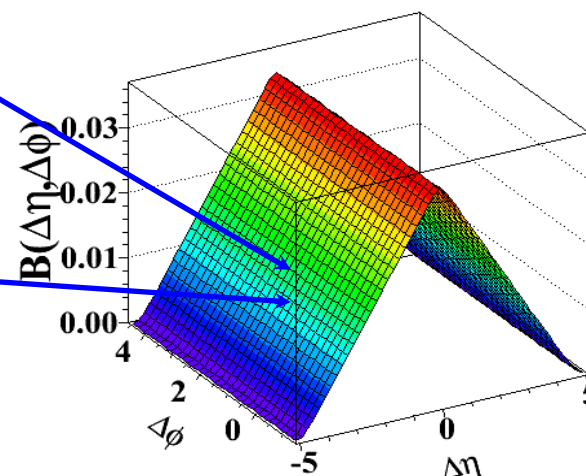
$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{same}}{d\Delta\eta d\Delta\phi}$$



same event pairs

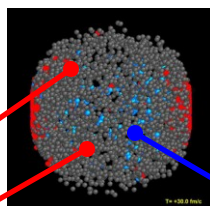
Background distribution:

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

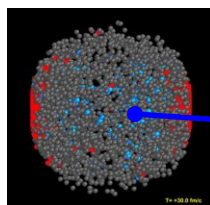


mixed event pairs

Event 1

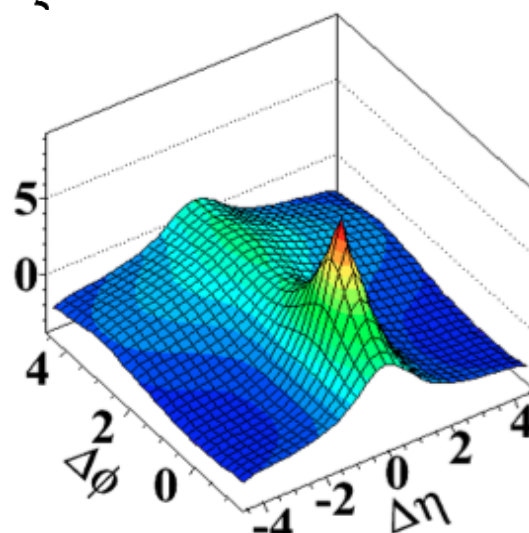


Event 2



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

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



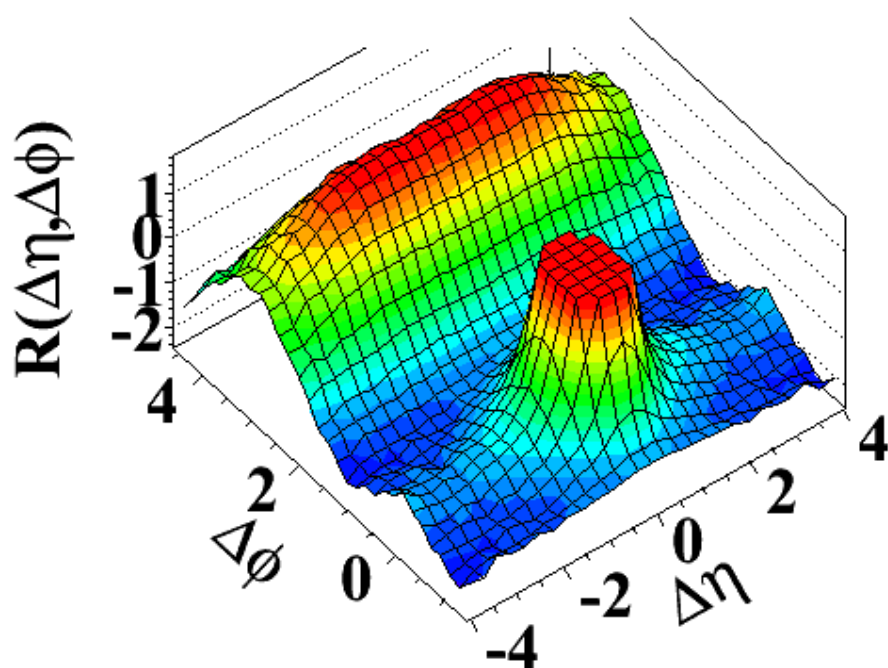
$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S_N(\Delta\eta, \Delta\phi)}{B_N(\Delta\eta, \Delta\phi)}$$

Divide signal by background

# Correlations in High Multiplicity pp

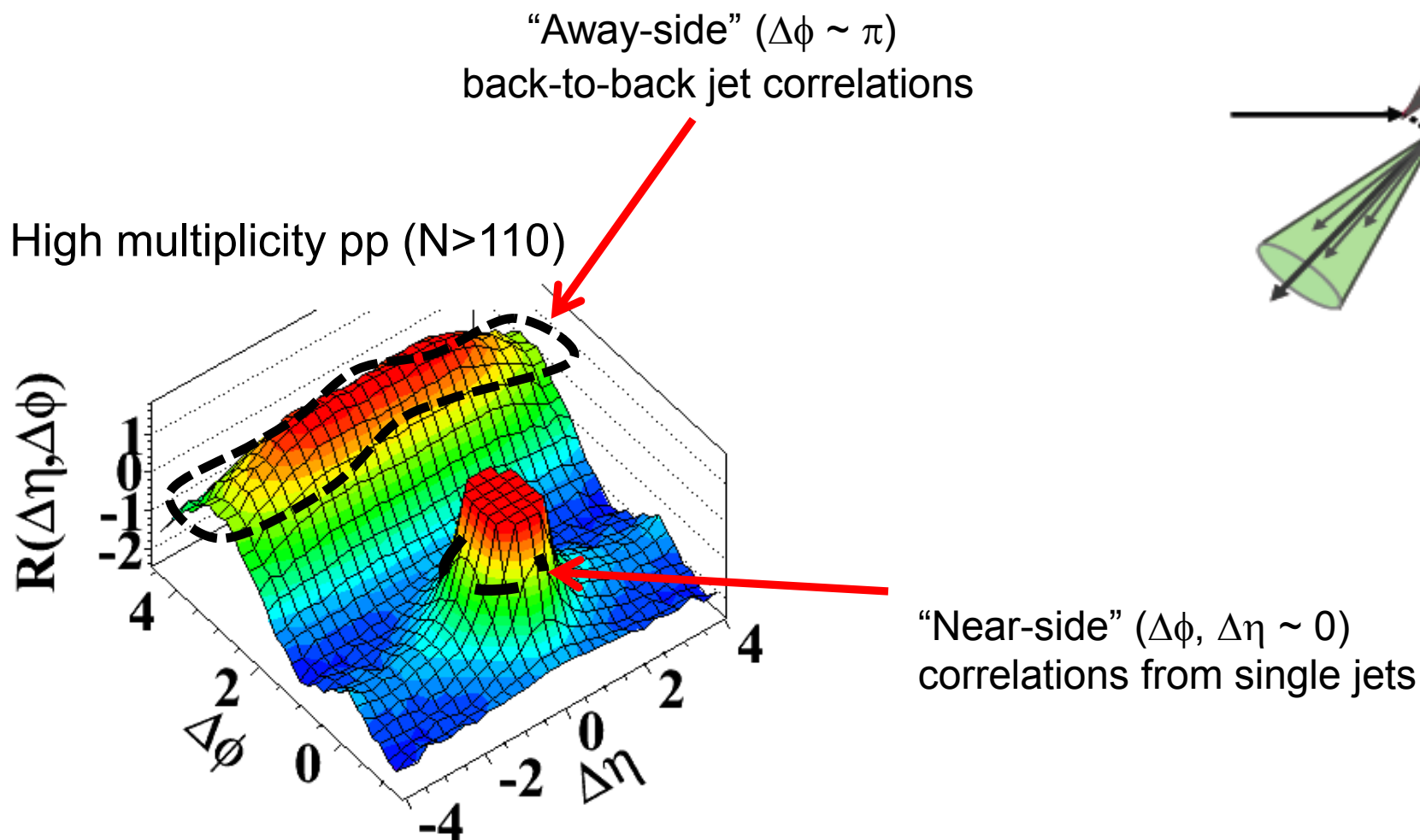
Intermediate  $p_T$ : 1-3 GeV/c

High multiplicity pp ( $N > 110$ )



# Correlations in High Multiplicity pp

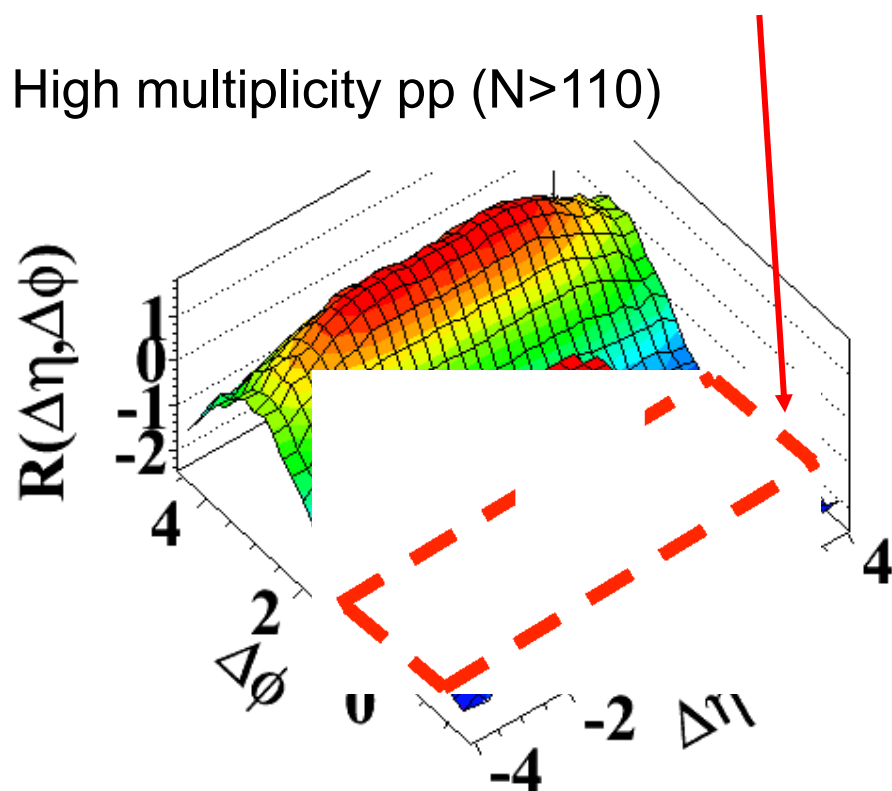
Intermediate  $p_T$ : 1-3 GeV/c



# Correlations in High Multiplicity pp

Intermediate  $p_T$ : 1-3 GeV/c

Striking “**ridge-like**” structure extending over  $\Delta\eta$   
at  $\Delta\phi \sim 0$

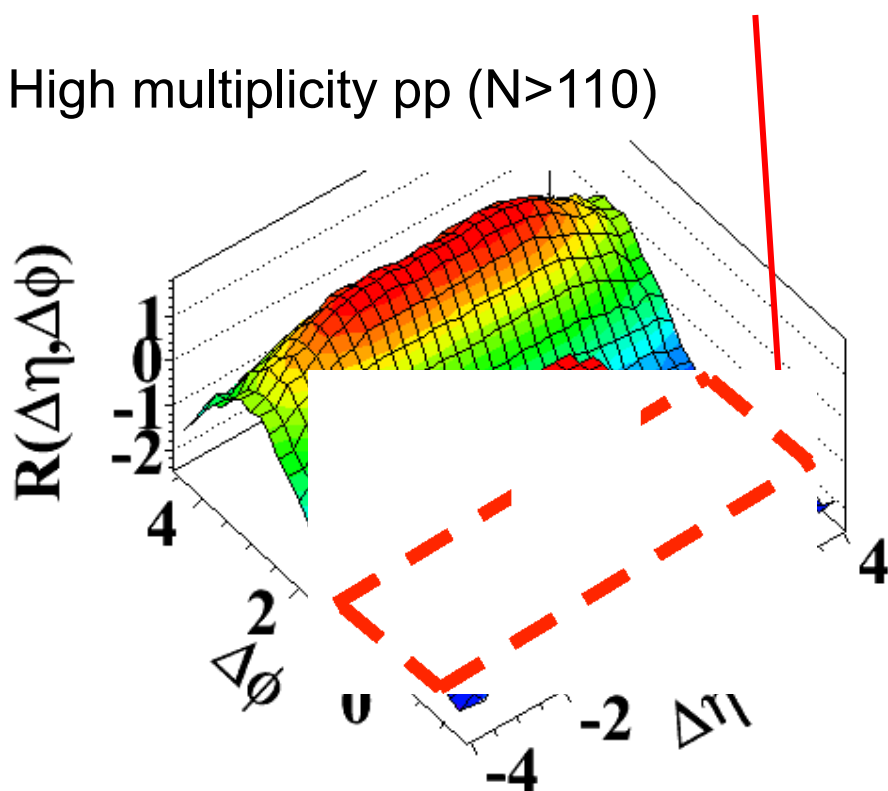


# Correlations in High Multiplicity pp

Intermediate  $p_T$ : 1-3 GeV/c

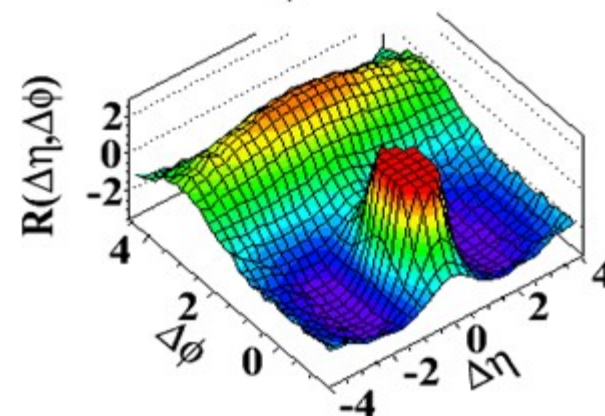
Striking “**ridge-like**” structure extending over  $\Delta\eta$   
at  $\Delta\phi \sim 0$   
(not observed before in hadron collisions or MC models)

High multiplicity pp ( $N > 110$ )



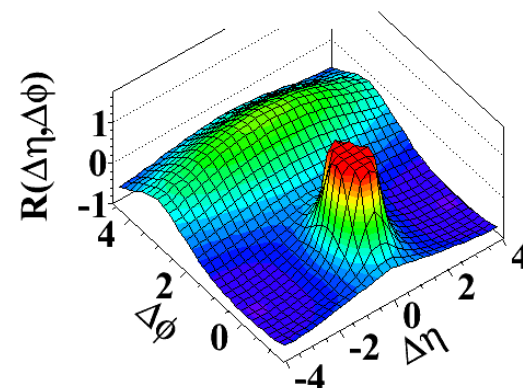
High multiplicity MC

$N > 110, 1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



Minbias pp

(b) MinBias,  $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$

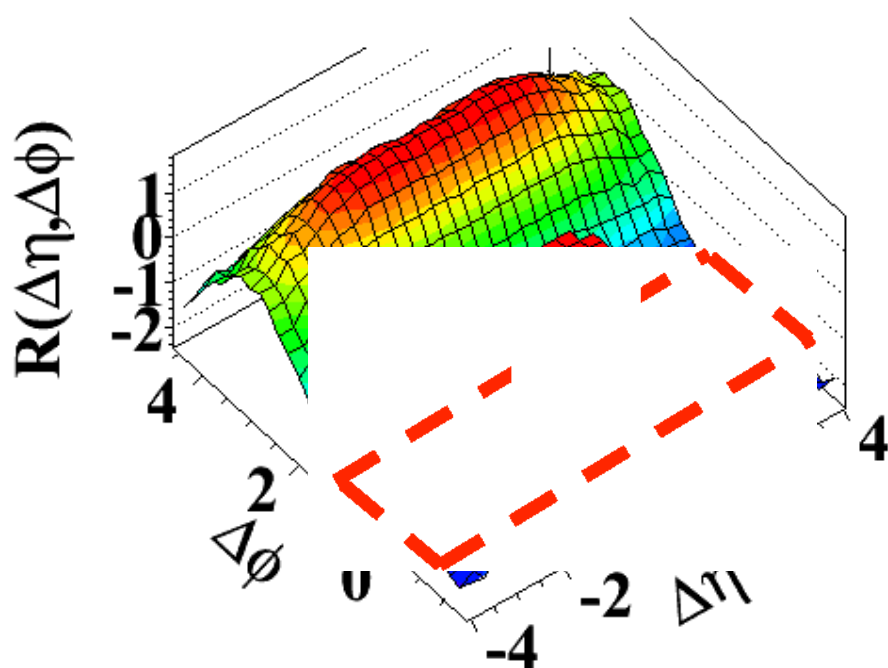


# Correlations in High Multiplicity pp

Intermediate  $p_T$ : 1-3 GeV/c

Striking “**ridge-like**” structure extending over  $\Delta\eta$   
at  $\Delta\phi \sim 0$

High multiplicity pp ( $N > 110$ )



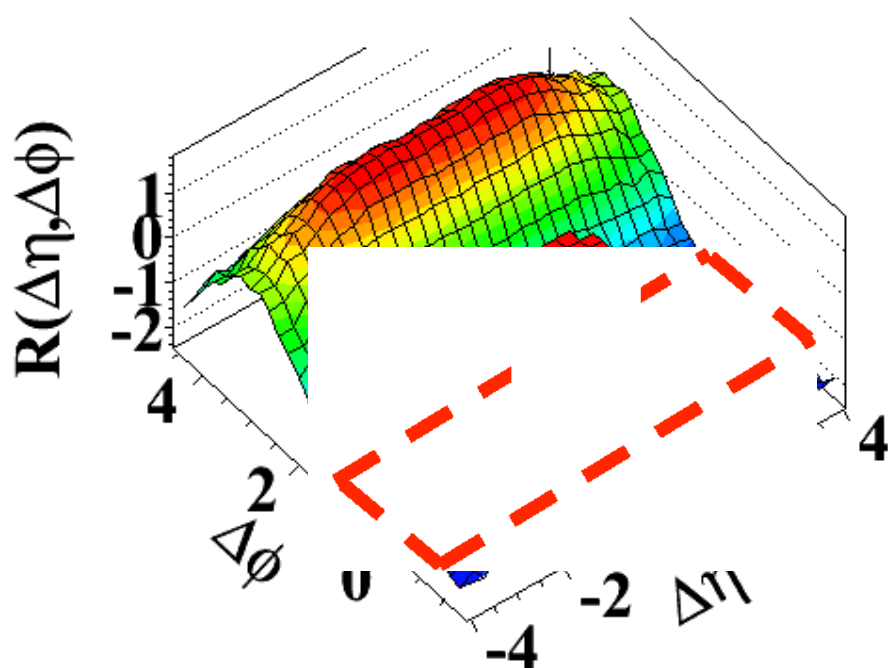
# Correlations in High Multiplicity pp

Intermediate  $p_T$ : 1-3 GeV/c

Striking “**ridge-like**” structure extending over  $\Delta\eta$   
at  $\Delta\phi \sim 0$   
(Similarity to Heavy Ion)

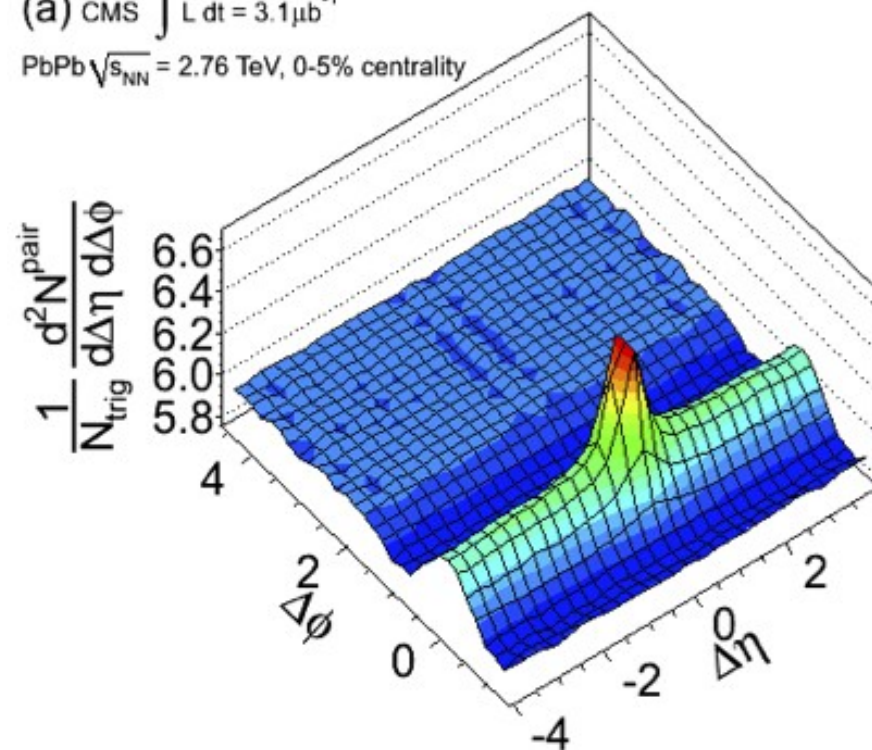
arXiv:1105.2438

High multiplicity pp ( $N > 110$ )



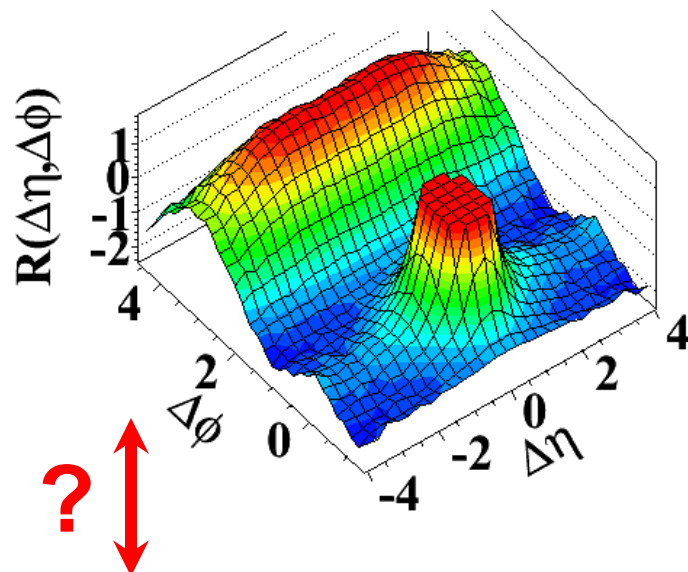
CMS PbPb 2.76 TeV

(a) CMS  $\int L dt = 3.1 \mu\text{b}^{-1}$   
PbPb  $\sqrt{s_{NN}} = 2.76$  TeV, 0-5% centrality

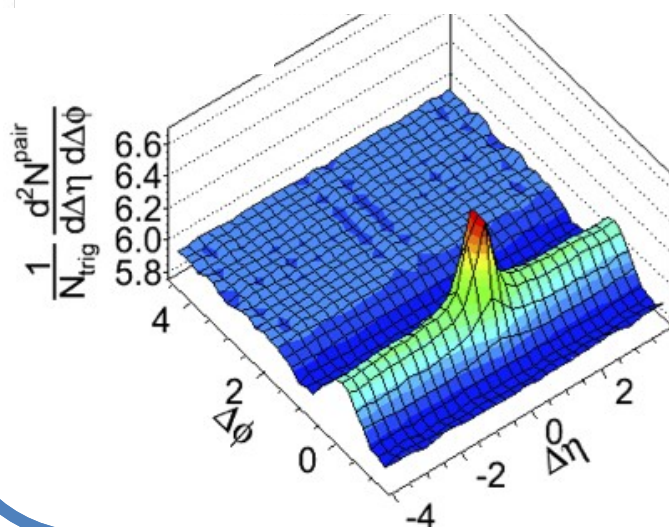


# Interpretations of the Ridge

CMS pp 7 TeV,  $N \geq 110$



CMS PbPb 2.76 TeV, 0-5%



SPiRES

Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC.

By CMS Collaboration (Vardan Khachatryan *et al.*). CMS-QCD-10-002, CERN-PH-EP-2010-031, Sep 2010.

Published in JHEP 1009:091,2010.

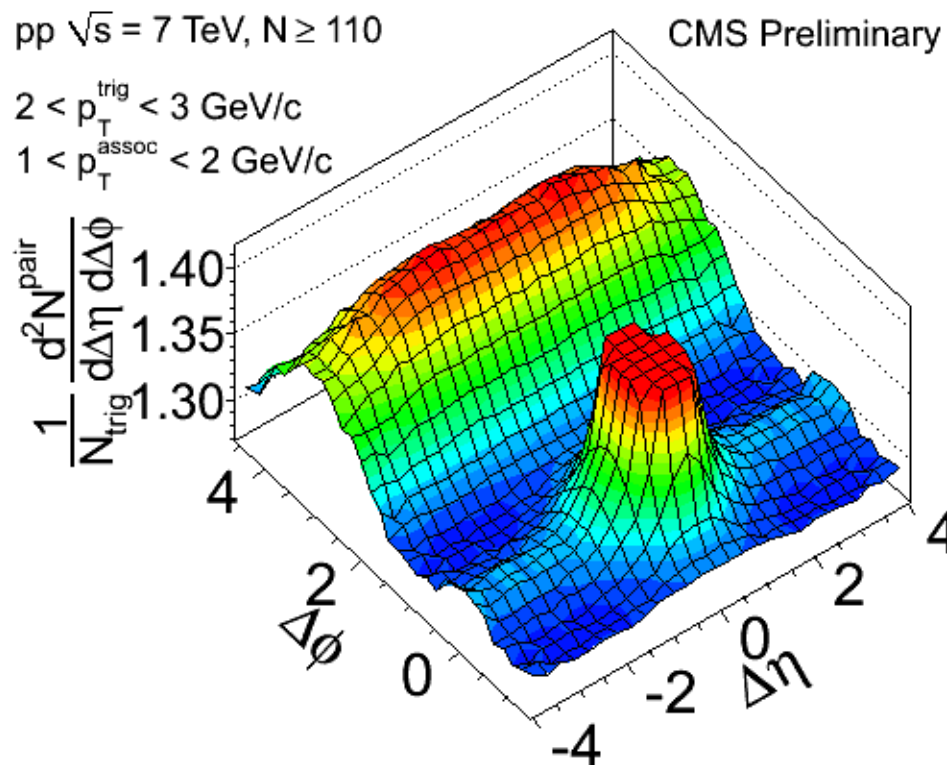
e-Print: arXiv:1009.4122 [hep-ex]

References | [LaTeX\(US\)](#) | [LaTeX\(EU\)](#) | [Harvmac](#) | [BibTeX](#) | [Keywords](#) | Cited 48 times

- 1) Proton-Nucleus Collisions at the LHC: Scientific Opportunities and ...
- 2) The Ridge from the BFKL evolution and beyond.
- 3) Strange hadron production in heavy ion collisions from SPS to RHIC.
- 4) Long-range and short-range dihadron angular correlations in central PbPb...
- 5) Recombination within multi-chain contributions in pp scattering.
- 6) The First Year of the Large Hadron Collider: A Brief Review.
- 7) Bi-Event Subtraction Technique at Hadron Colliders.
- 8) Bose-Einstein Correlations in a Fluid Dynamical Scenario for Proton-Proton...
- 9) A New CMS pixel detector for the LHC luminosity upgrade.
- 10) CMS ridge effect at LHC as a manifestation of bremsstrahlung of gluons due to...
- 11) Elliptic flow in pp-collisions at the LHC.
- 12) Particle Production at High Energy and Large Transverse Momentum - 'The...
- 13) Soft ridge in proton-proton collisions.
- 14) Theoretical considerations on multiparton interactions in QCD.
- 15) Azimuthal correlation of gluon jets created in proton-antiproton annihilation.
- 16) Direct photons at low transverse momentum: A QGP signal in pp collisions at...
- 17) Theory of transverse-momentum parton densities: Solving the puzzle of...
- 18) Role of quantum fluctuations in a system with strong fields.
- 19) Longitudinal hydrodynamic expansion and long range correlations.
- 20) Forward-Backward Correlations and Event Shapes as probes of...
- 21) Measurement of Bose-Einstein Correlations in pp Collisions at  $\sqrt{s}=0.9$  and...
- 22) Azimuthal angle and rapidity dependence of di-hadron correlations in QCD.
- 23) Hadron-Hadron and Cosmic-Ray Interactions at multi-TeV Energies.
- 24) Inclusive Ridge Distributions in Heavy-Ion Collisions.
- 25) Hard Probes 2010: Experimental Summary.
- 26) Long-Range Rapidity Correlations in Heavy Ion Collisions at Strong...
- 27) From many body wee parton dynamics to perfect fluid: a standard model for...
- 28) Phenomenological Relationship between the Ridge and Inclusive Distributions.
- 29) Angular Correlations in Gluon Production at High Energy.
- 30) Heavy Quark Energy Loss in High Multiplicity Proton Proton Collisions at...
- 31)  $SJ/\Psi$  yield vs. multiplicity in proton-proton collisions at the LHC.
- 32) Saturation models of HERA DIS data and inclusive hadron distributions in...
- 33) Rapidity long range correlations, parton percolation and color glass condensate.
- 34) Two-hadron correlations in the Color Glass Condensate formalism.
- 35) Ridge Formation Induced by Jets in SppS Collisions at 7 TeV.
- 36) Gluon correlations in the glasma.
- 37) Quasi-diffraction production of white quark-gluon clusters at superhigh...
- 38) The 'Ridge' in Proton-Proton Scattering at 7 TeV.
- 39) Pair creation in boost-invariantly expanding electric fields and two-particle...
- 40) On correlations in high-energy hadronic processes and the CMS ridge: A...
- 41) Comparing the same-side 'ridge' in CMS p-p angular correlations to RHIC...
- 42) Comments on 'Observation of Long-Range, Near-Side Angular Correlations...
- 43) Towards a common origin of the elliptic flow, ridge and alignment.
- 44) Elliptic flow in proton-proton collisions at  $\sqrt{s}=7.5$  TeV.
- 45) Eccentricity and elliptic flow in proton-proton collisions from parton ...
- 46) The Ridge in proton-proton collisions at the LHC.
- 47) On the ridge-like structures in the nuclear and hadronic reactions.
- 48) Hadron production in p+p, p+Pb, and Pb+Pb collisions with the HIJING 2.0...

# New Results

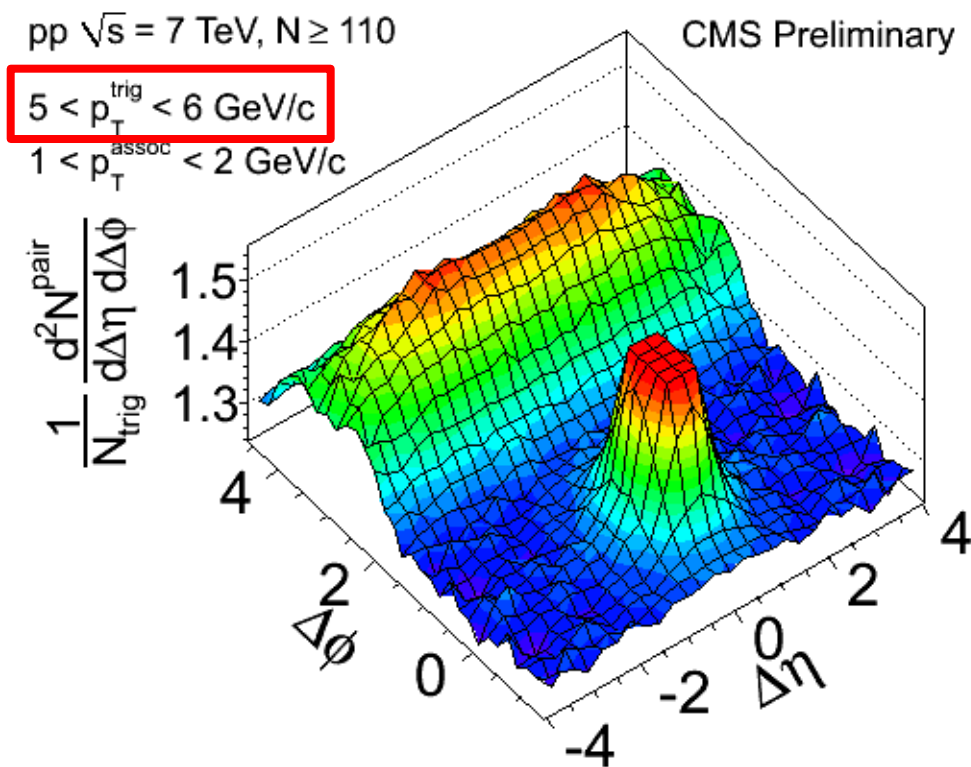
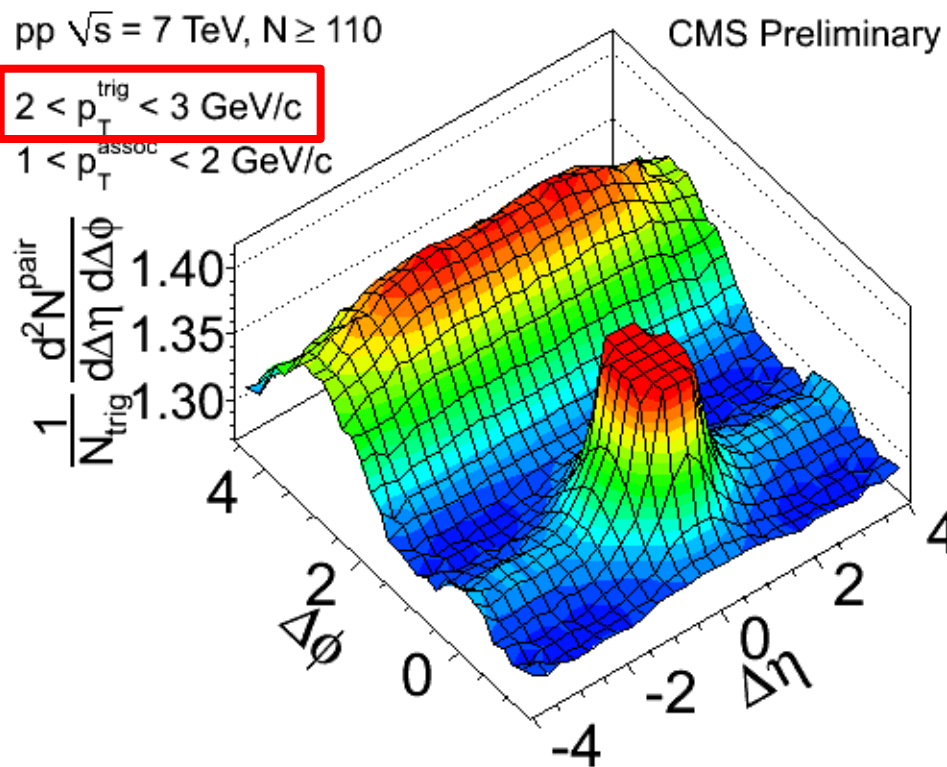
- 2x as much data
  - $|\Delta\eta|$  dependence
  - $p_T$  dependence
  - Multiplicity dependence



# New Results

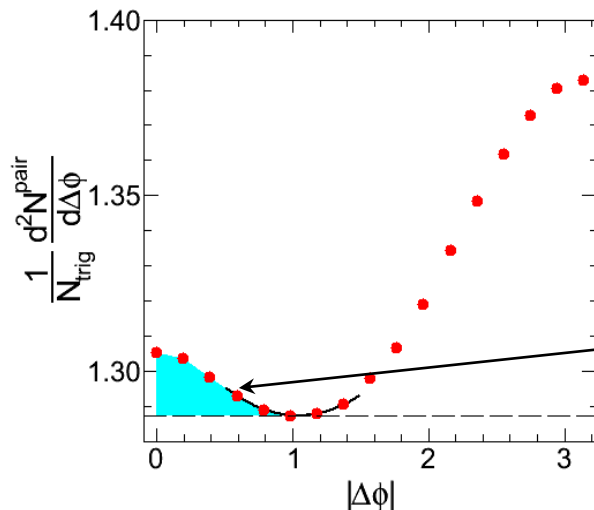
- 2x as much data
  - $|\Delta\eta|$  dependence
  - $p_T$  dependence
  - Multiplicity dependence

Ridge goes away at high  $p_T$



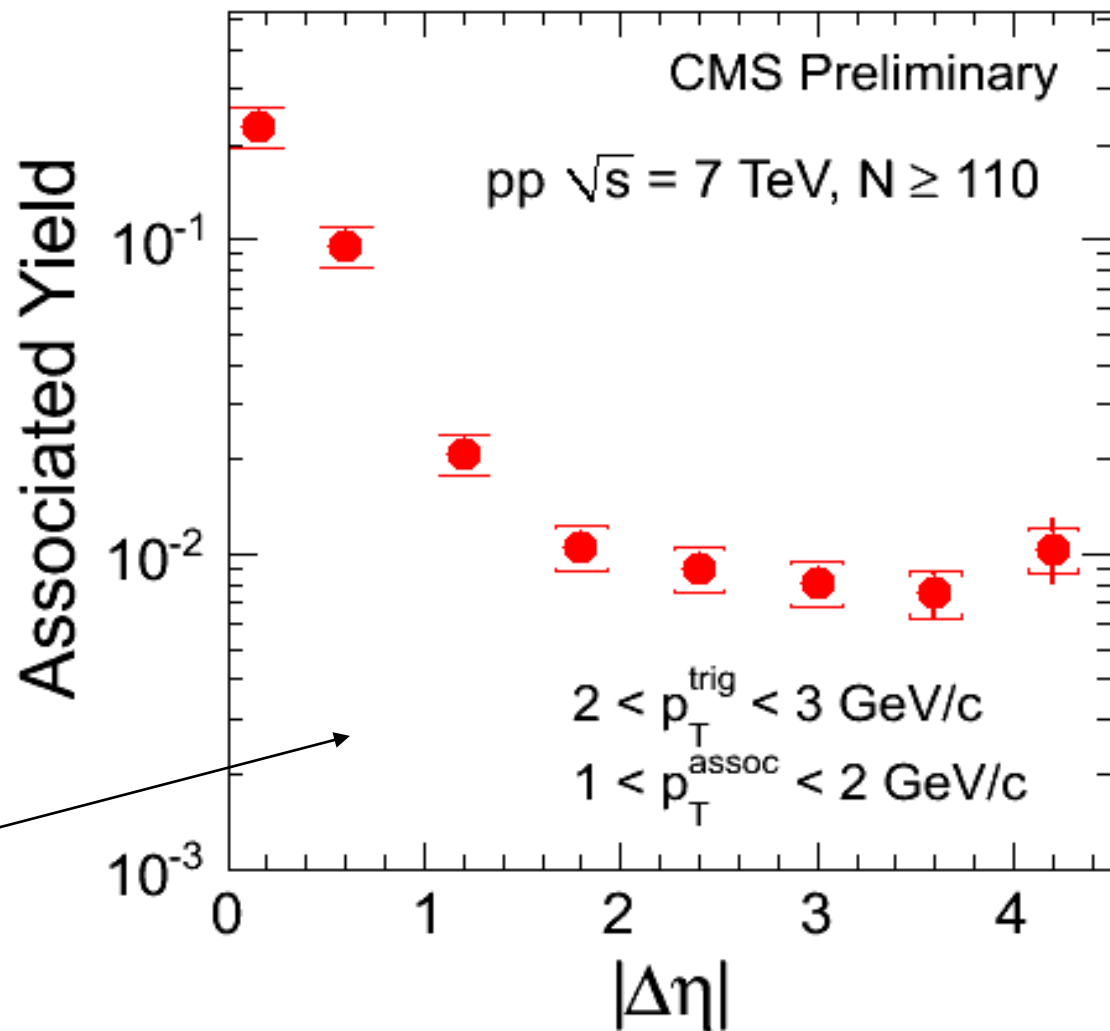
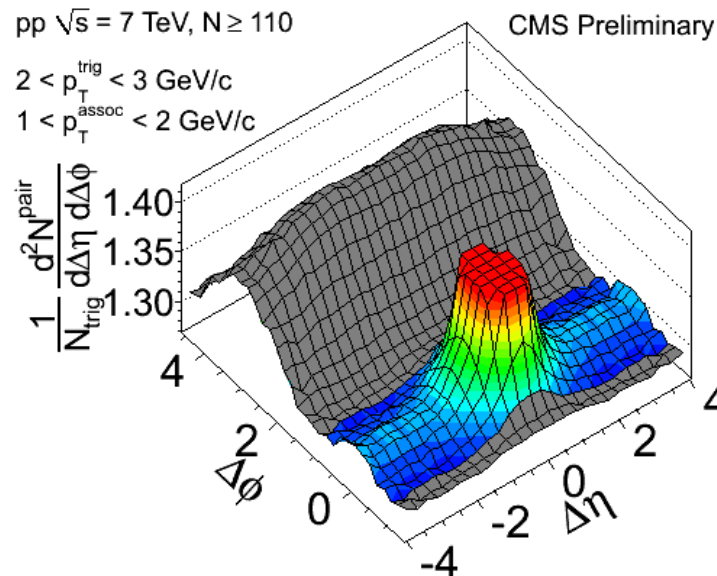
# $|\Delta\eta|$ dependence of the ridge

## Zero-Yield-At-Minimum (ZYAM)



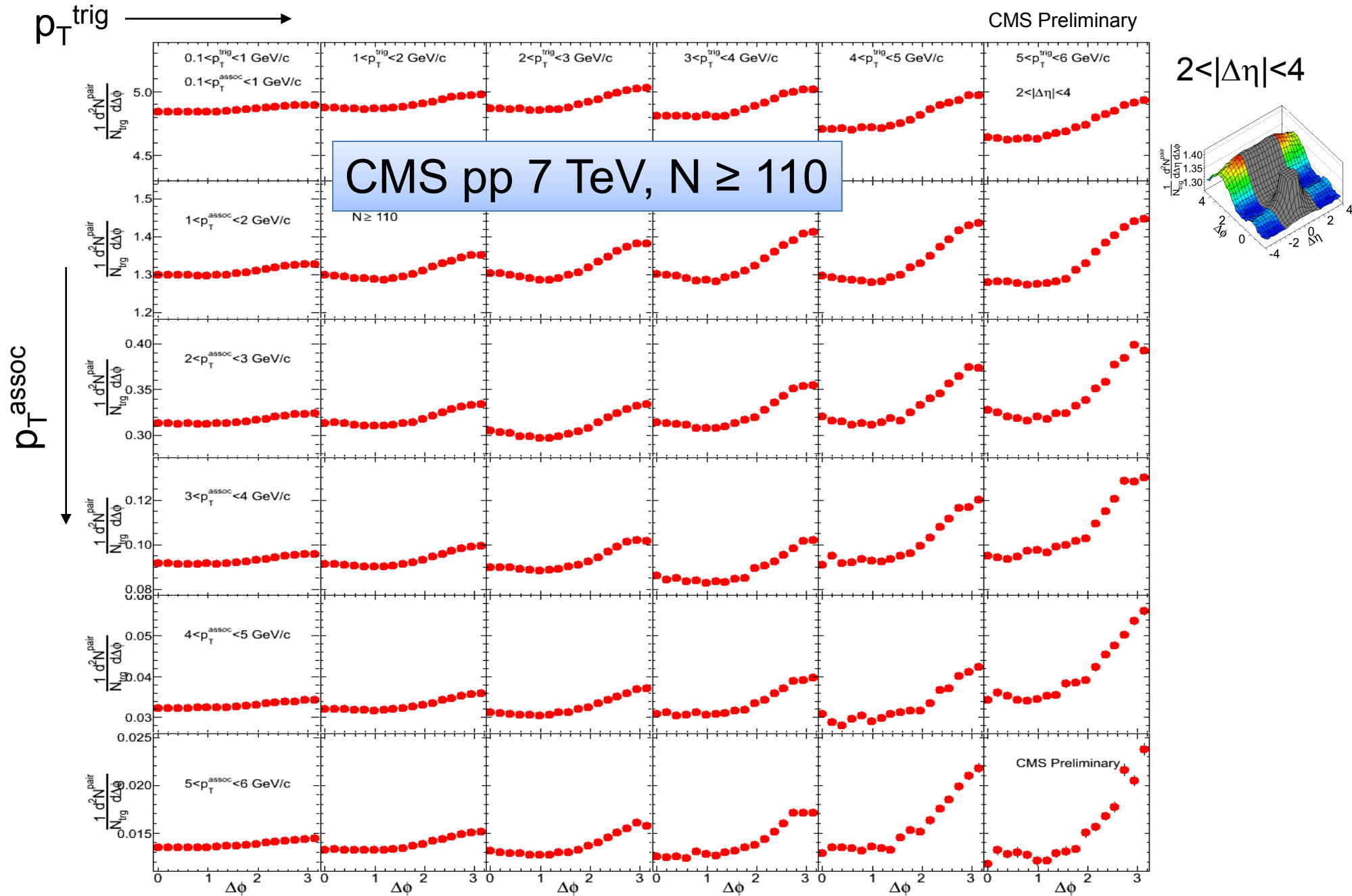
pp  $\sqrt{s} = 7$  TeV,  $N \geq 110$

$2 < p_{\text{T}}^{\text{trig}} < 3$  GeV/c  
 $1 < p_{\text{T}}^{\text{assoc}} < 2$  GeV/c



Ridge is mostly flat in  $|\Delta\eta|$

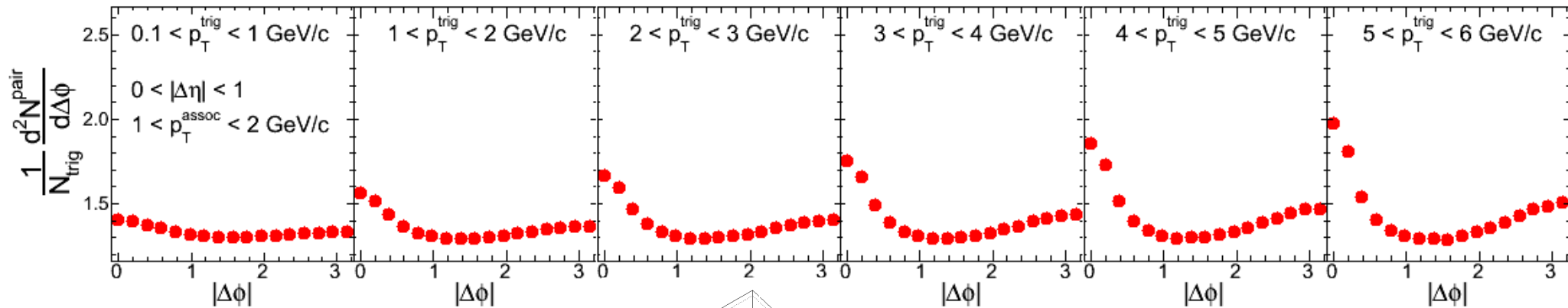
# $\Delta\phi$ projections in various $p_T$ ranges



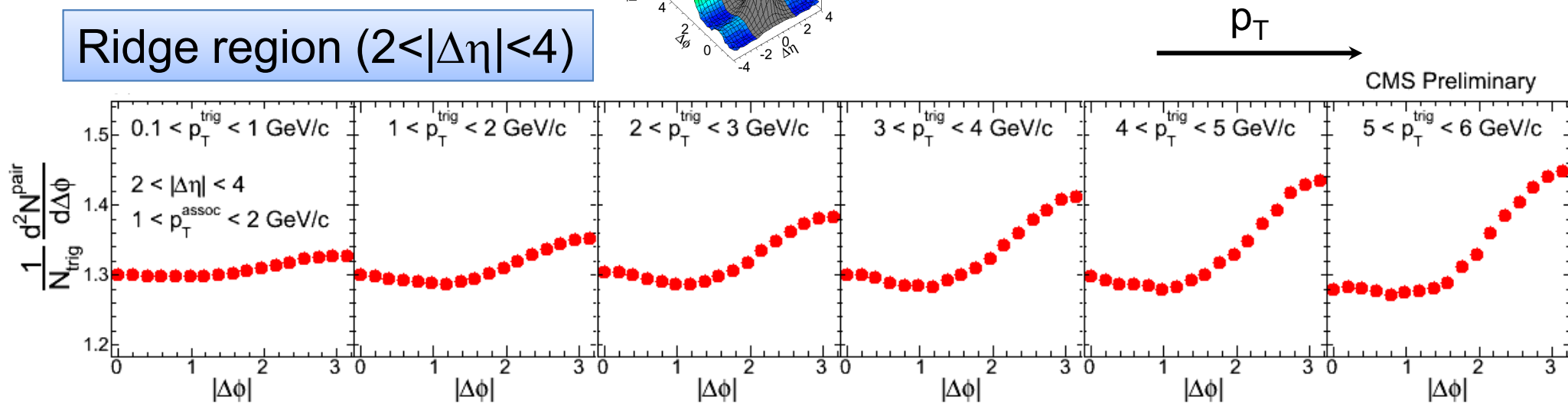
# $\Delta\phi$ projections in bins of $p_T$

CMS pp 7 TeV,  $N \geq 110$

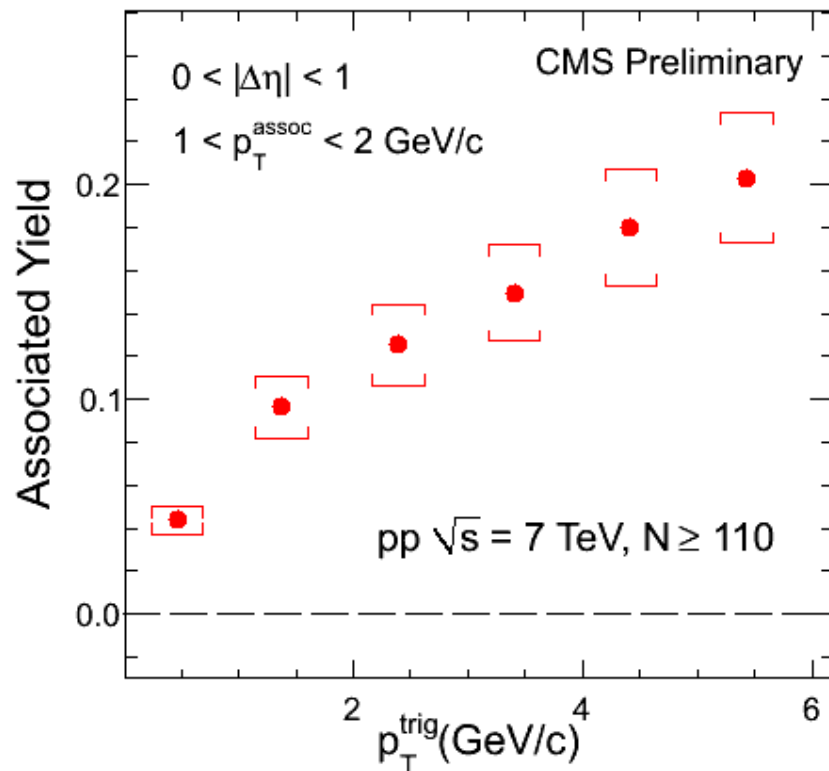
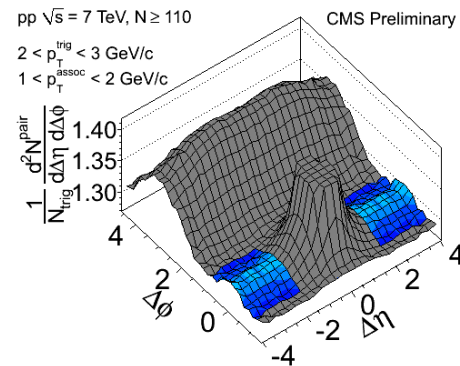
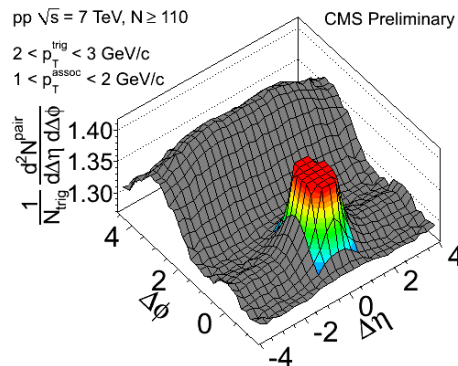
Jet region ( $|\Delta\eta| < 1$ )



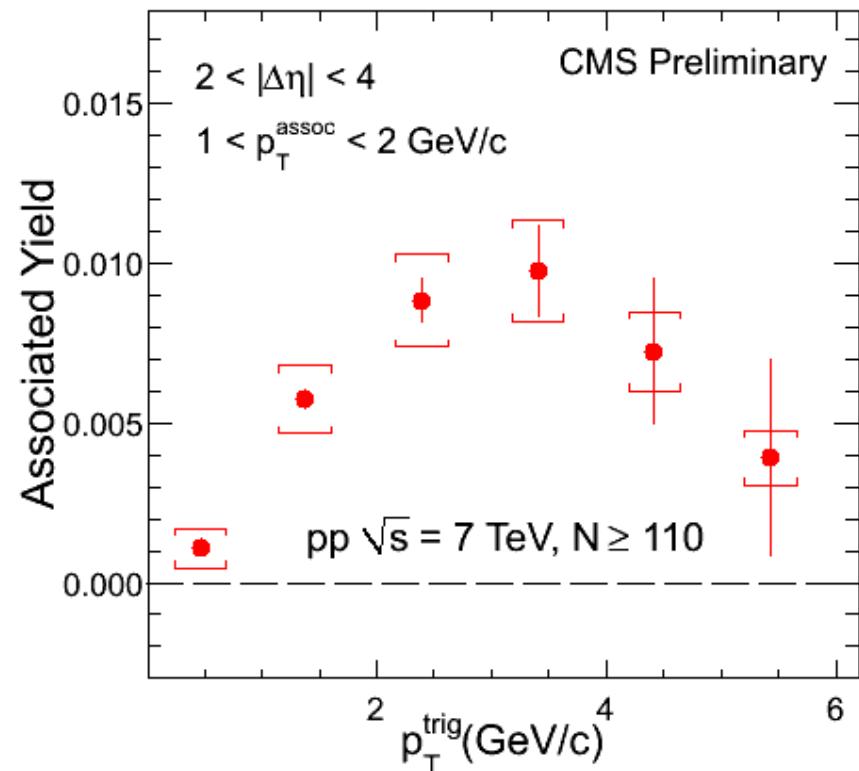
Ridge region ( $2 < |\Delta\eta| < 4$ )



# $p_T$ dependence of the ridge

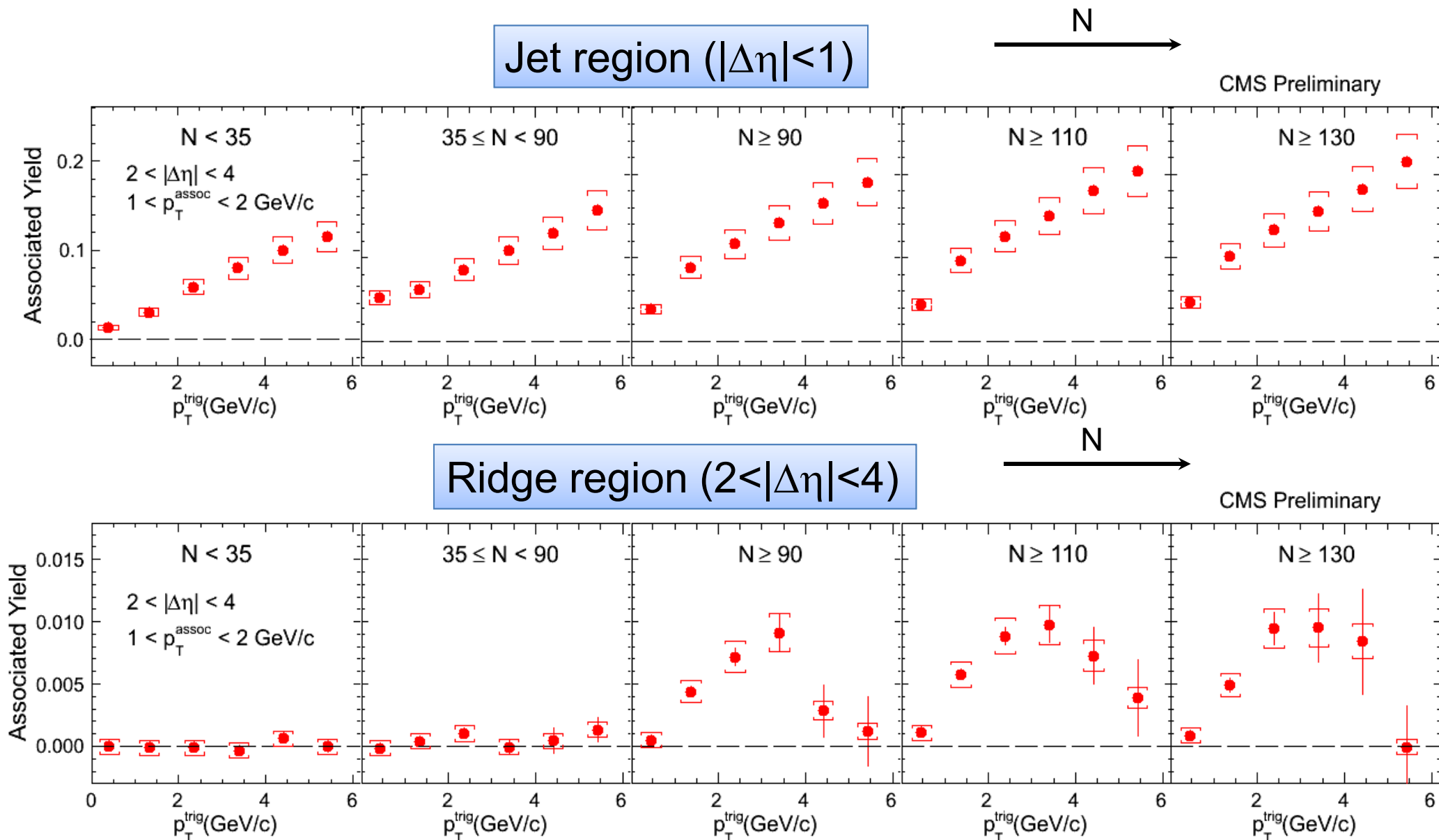


Jet region ( $|\Delta\eta| < 1$ )



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

# Near-side yield vs $p_T$

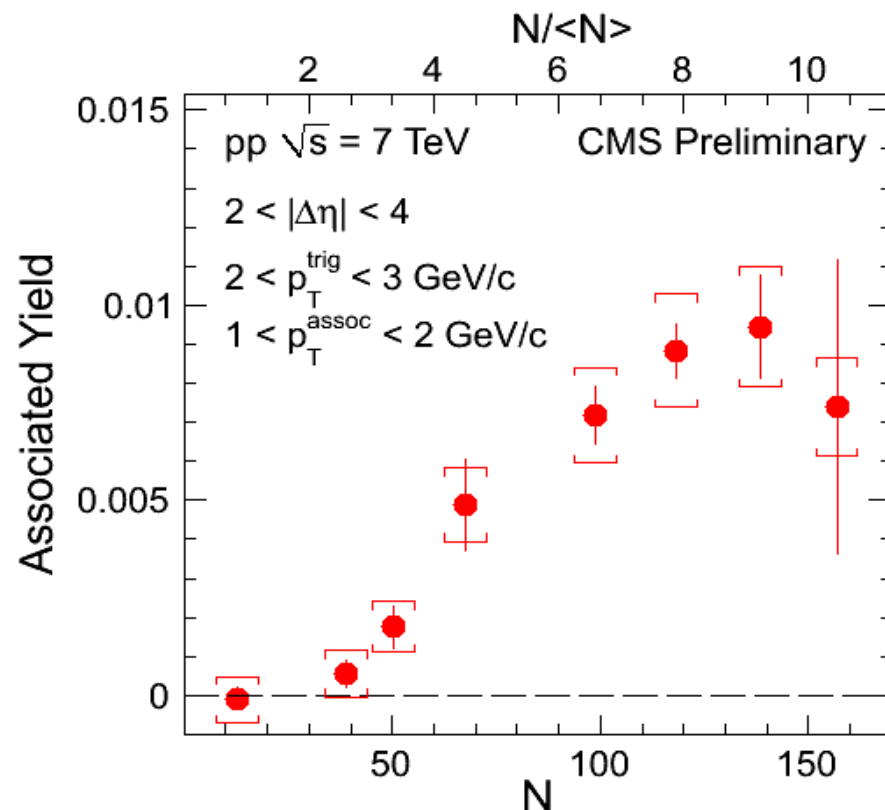
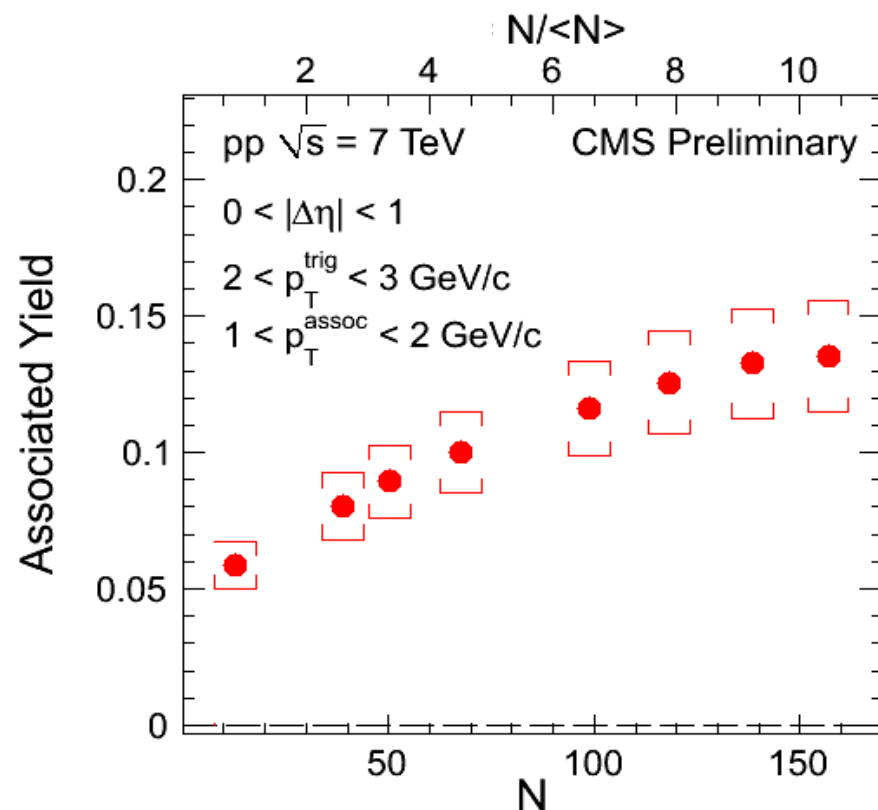


Ridge first increases with  $p_T$ , and then drops at high  $p_T$

# Near-side yield vs Multiplicity

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

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



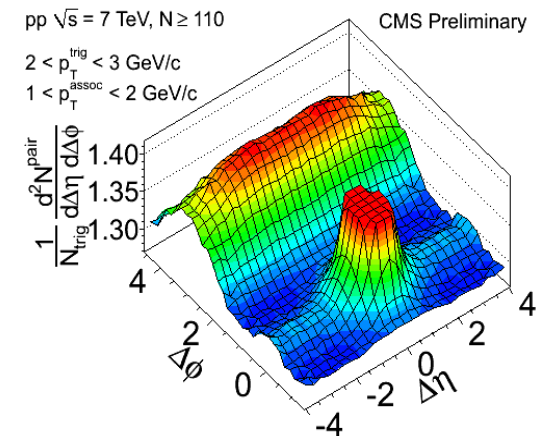
Ridge in pp turns on around  $N \sim 50$ -60 (4x MinBias) smoothly  
( $\langle N \rangle \sim 15$  in MinBias pp events)

# Summary

- Surprising new effect in pp
  - Never before seen in pp or pp MC
  - Similar to HI
- New results provide more detailed properties of ridge
  - pt,  $|\Delta\eta|$ , multiplicity dependence
- New testing ground for high density QCD physics

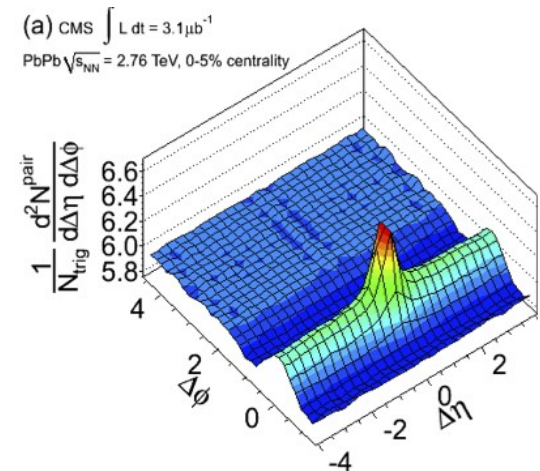
Wei Li (Plenary session Thursday)

CMS pp 7 TeV,  $N \geq 110$



Jeremy Callner (Parallel Tuesday)

CMS PbPb 2.76 TeV, 0-5%



# Backups

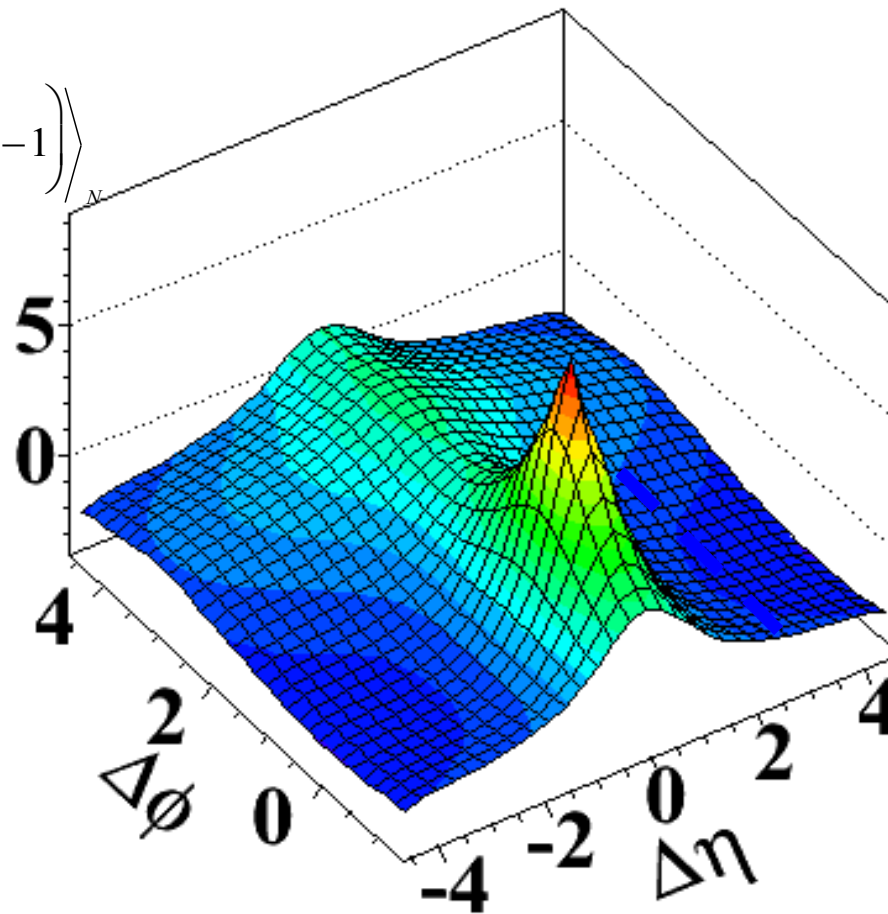
# Understanding the Correlation Structure

$p_T$  inclusive

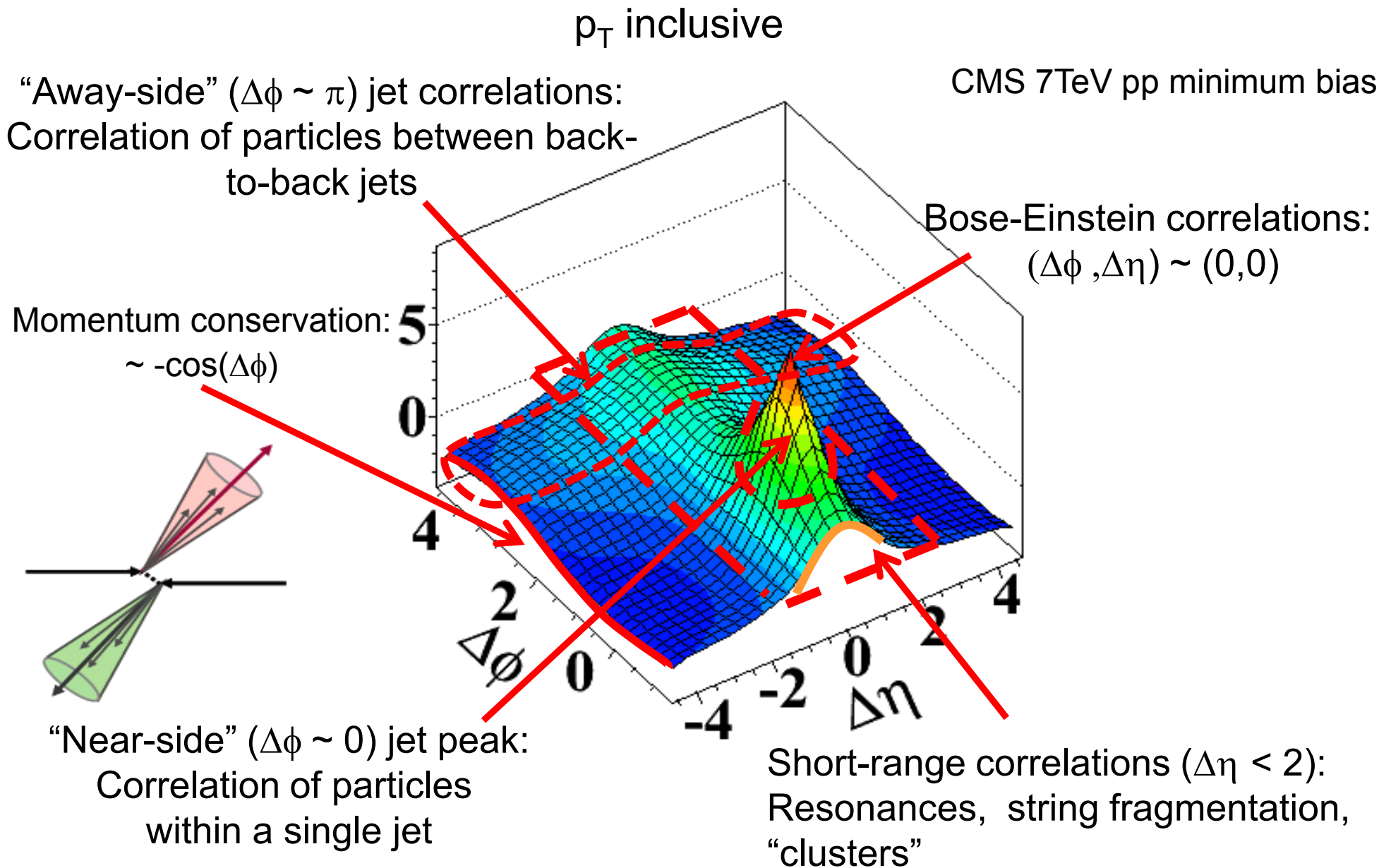
CMS 7TeV pp minimum bias

What was used in  
PHOBOS, ISR, UA5

$$R(\Delta\eta, \Delta\phi) = \left\langle (N-1) \left( \frac{S_N(\Delta\eta, \Delta\phi)}{B_N(\Delta\eta, \Delta\phi)} - 1 \right) \right\rangle$$

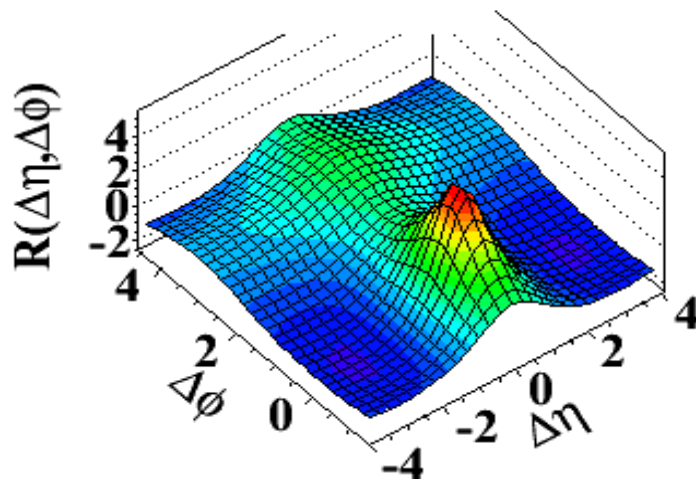


# Understanding the Correlation Structure

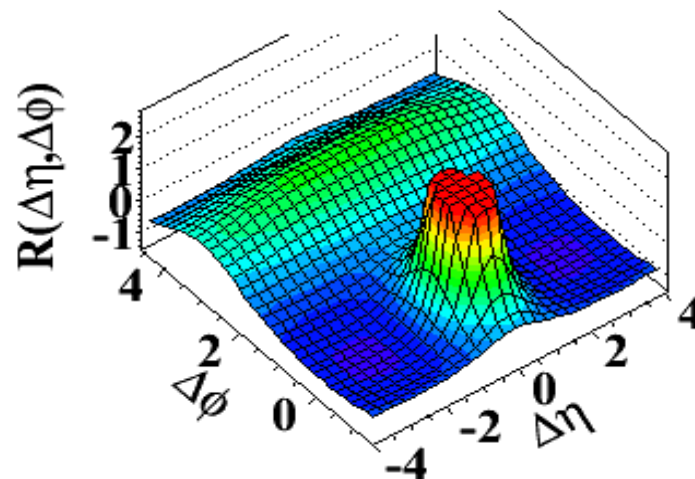


# Comparing to various MC

(a) MinBias,  $p_T > 0.1 \text{ GeV}/c$

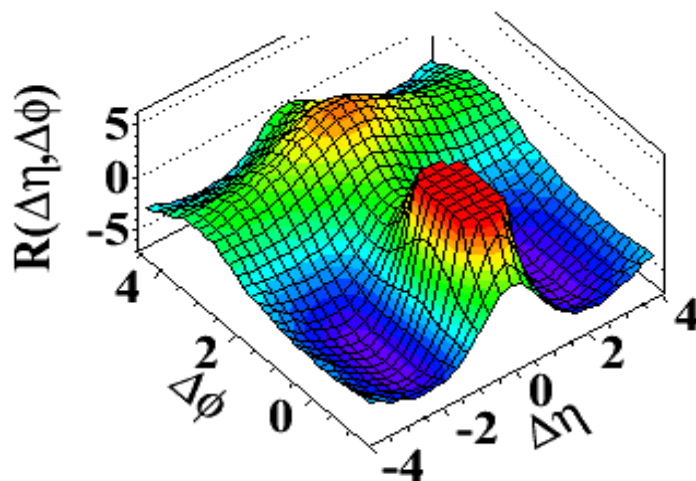


(b) MinBias,  $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$

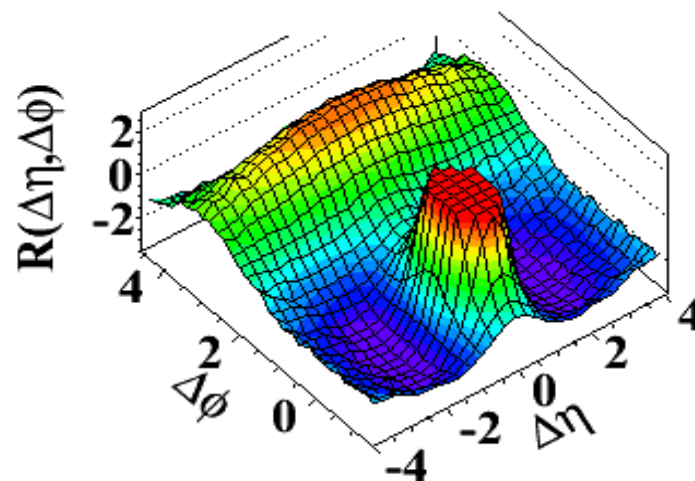


PYTHIA8, v8.135

(c) N>110,  $p_T > 0.1 \text{ GeV}/c$

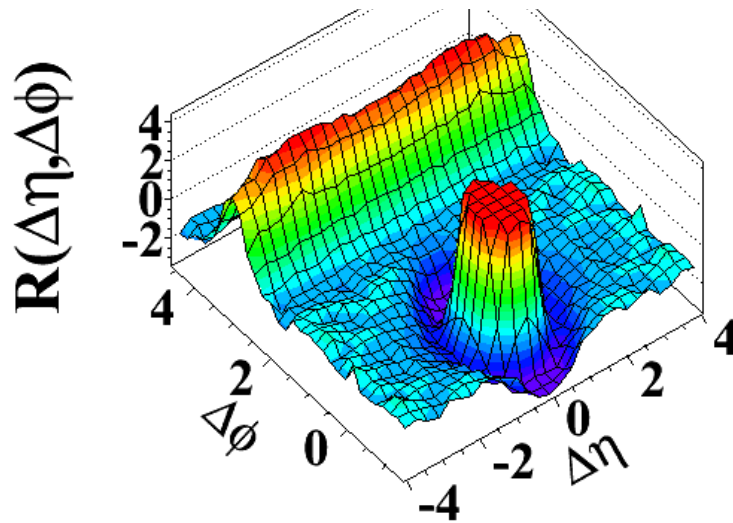


(d) N>110,  $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$

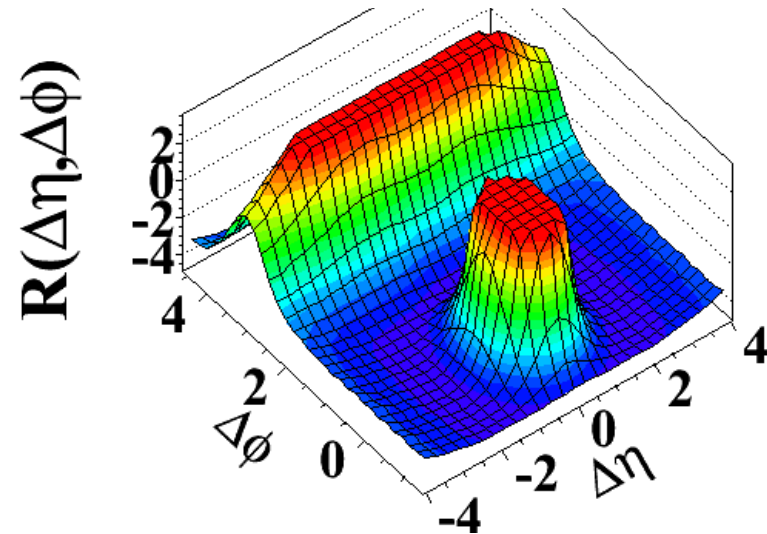


# More MC models

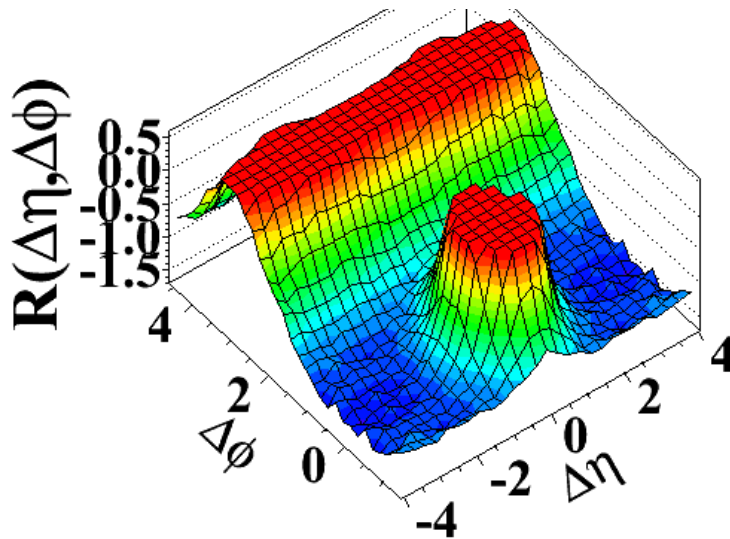
PYTHIA D6T MinBias,  $N > 70$



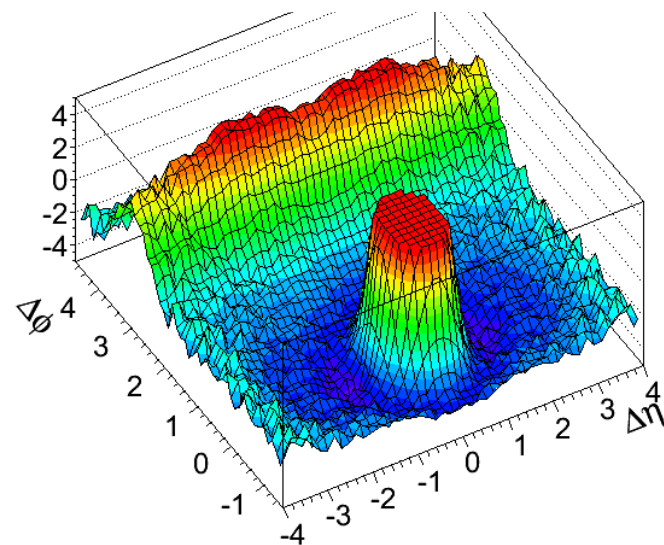
PYTHIA D6T, Dijet 80-120 GeV



HERWIG++,  $N > 110$

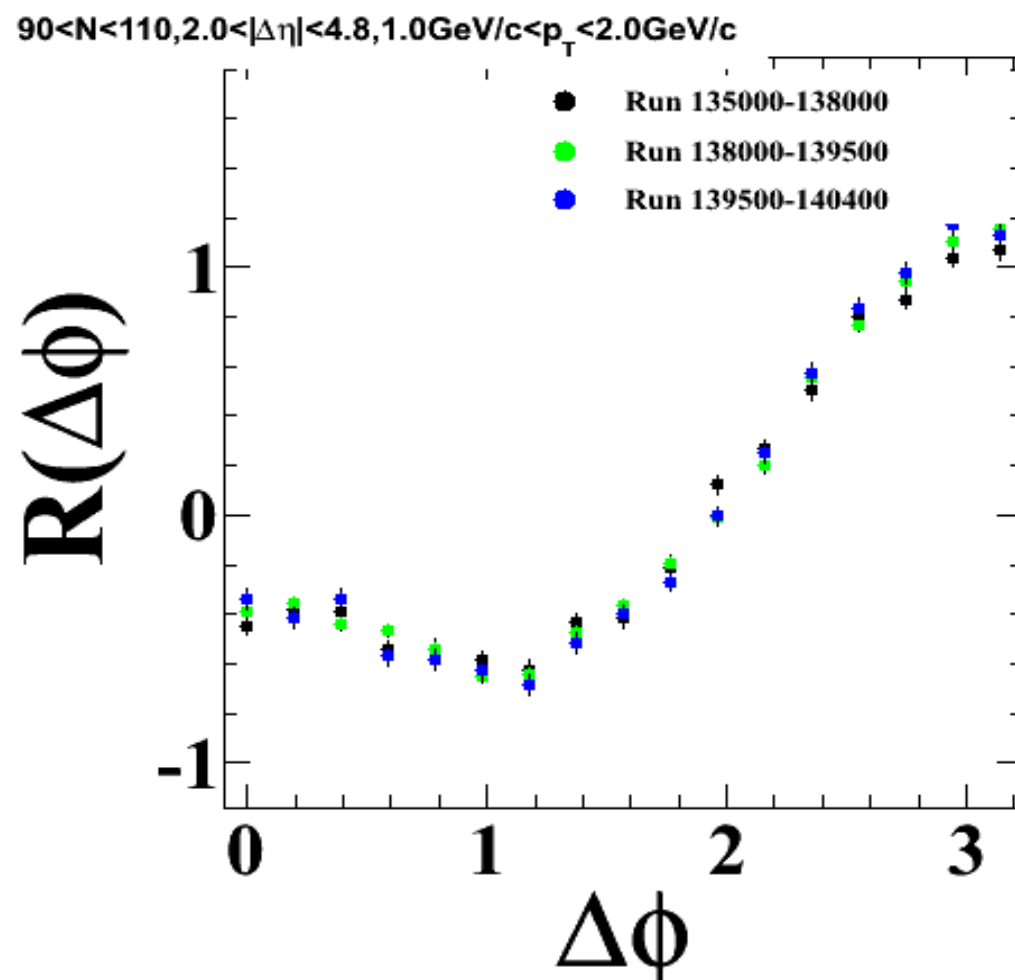


Madgraph, Dijet 100-250 GeV,  $N > 90$



# Cross Check: Event Pileup

Compare different run periods



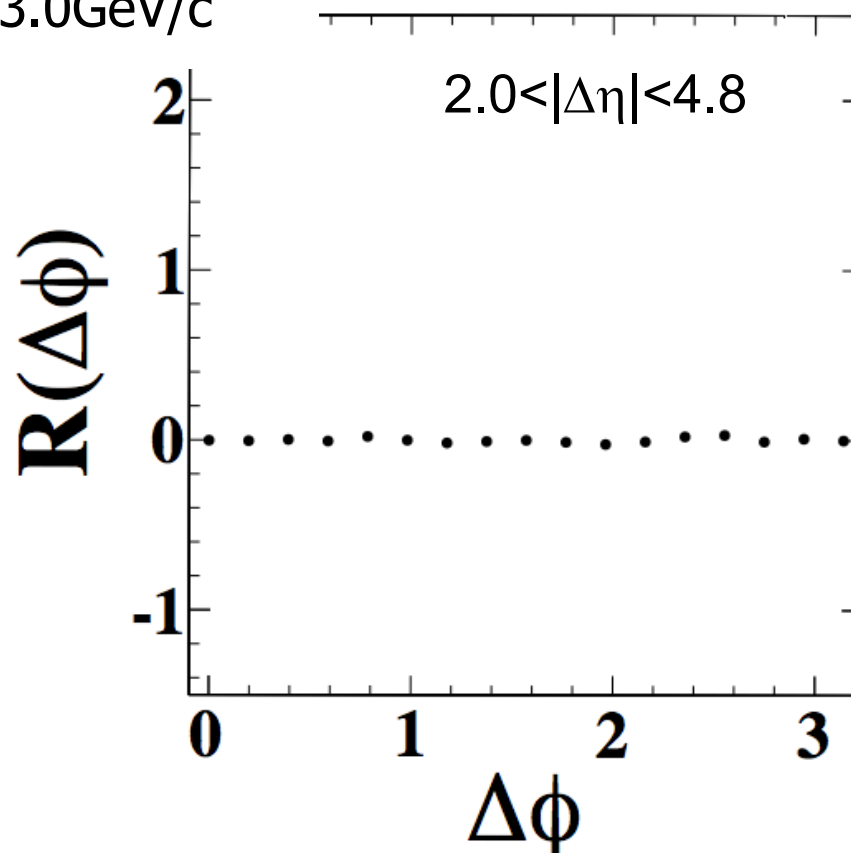
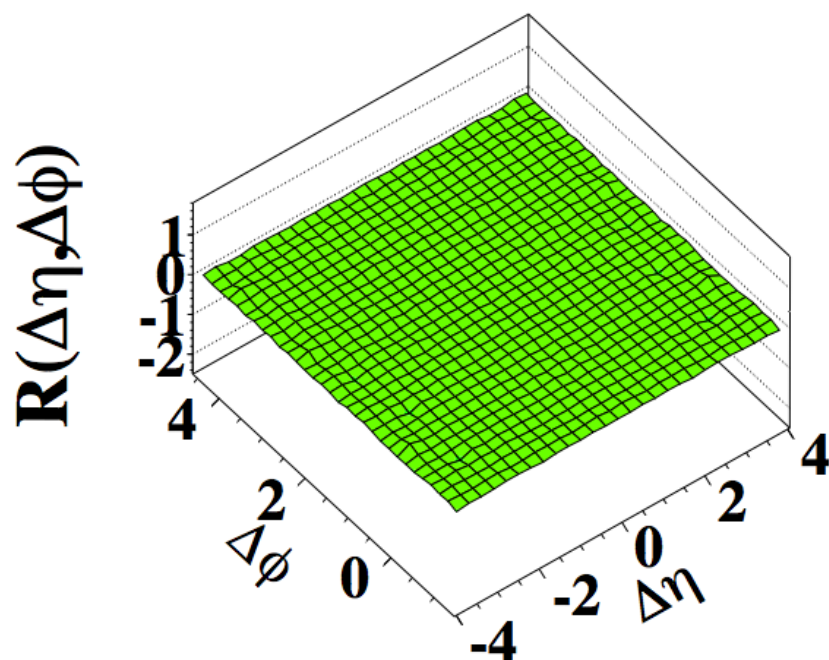
Change in pileup fraction by factor 4-5  
has almost no effect on ridge signal

# Cross Check: Event Pileup

Correlate tracks from high multiplicity vertex with tracks from different collision (vertex) in same bunch crossing

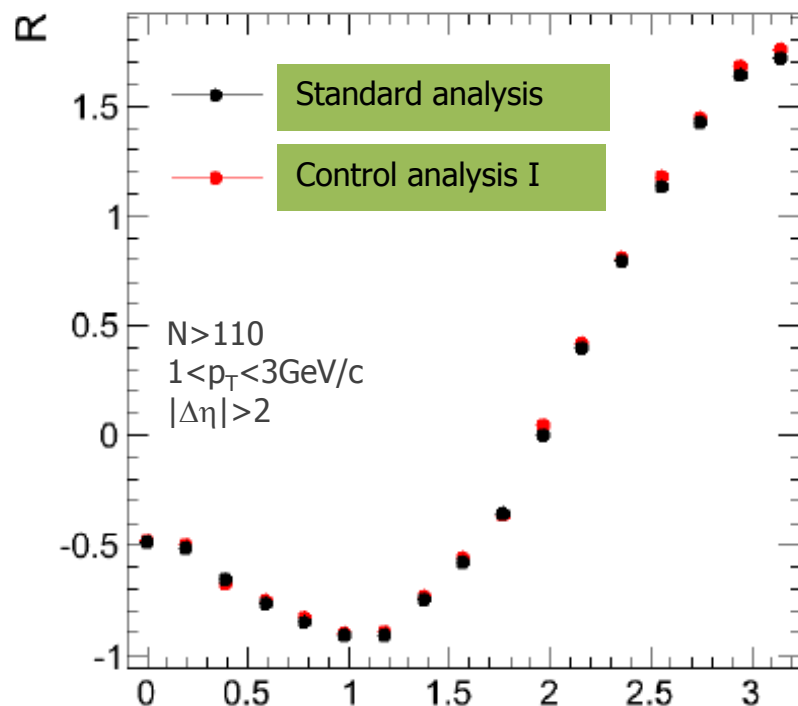
$N > 110$

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

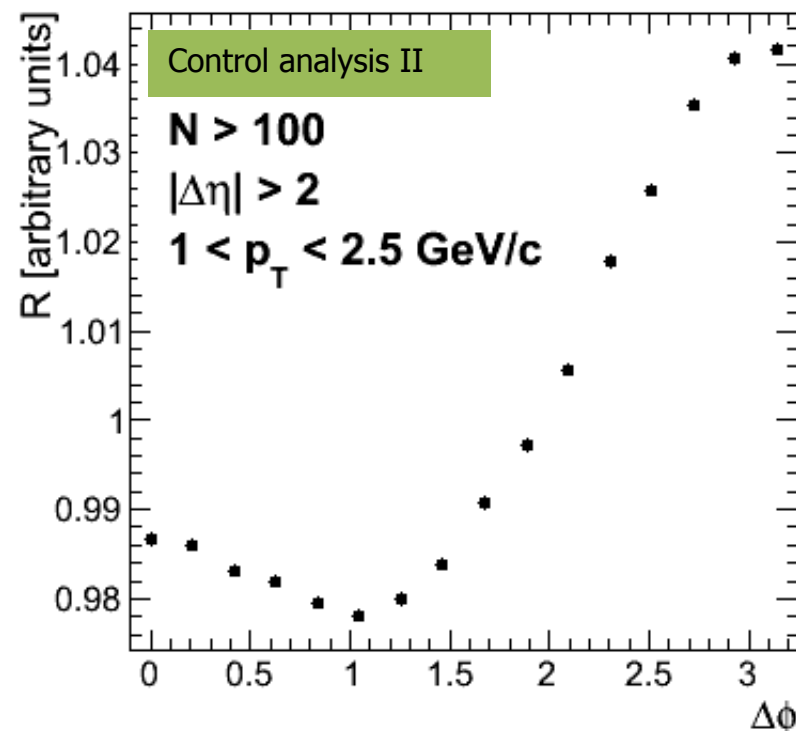


No background or noise effects  
seen in cross-collision correlations

# Cross Check: Analysis Code



Independent code  
Same definition of  $R$   
Same input file (skim)

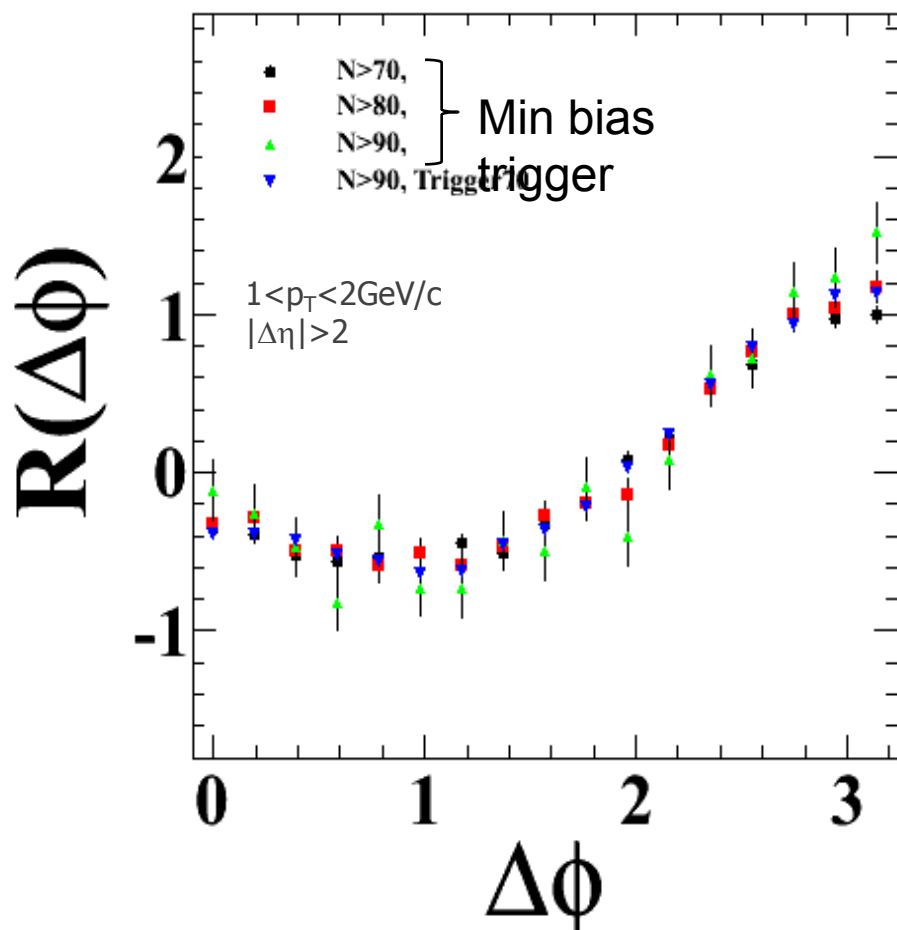


Independent code  
Different definition of  $R$   
Different input file (skim)

Ridge is seen with three independent analysis codes

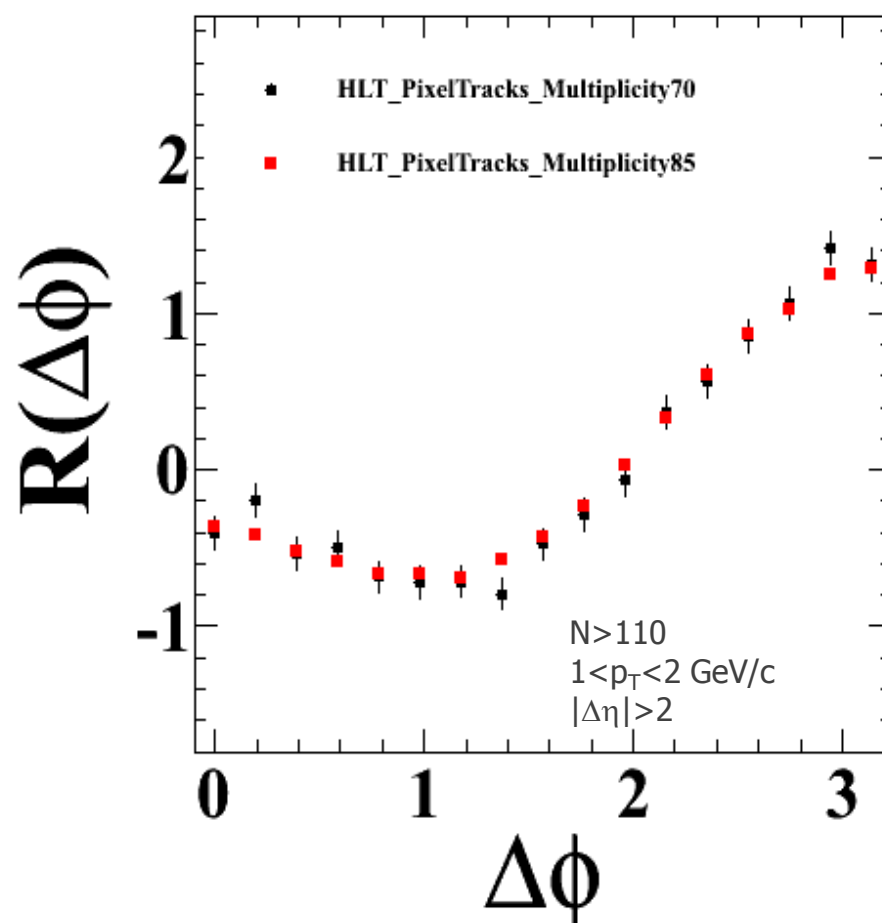
# Cross Check: Trigger

Min-bias trigger vs high mult trigger



Ridge is seen using  
min bias trigger + offline selection

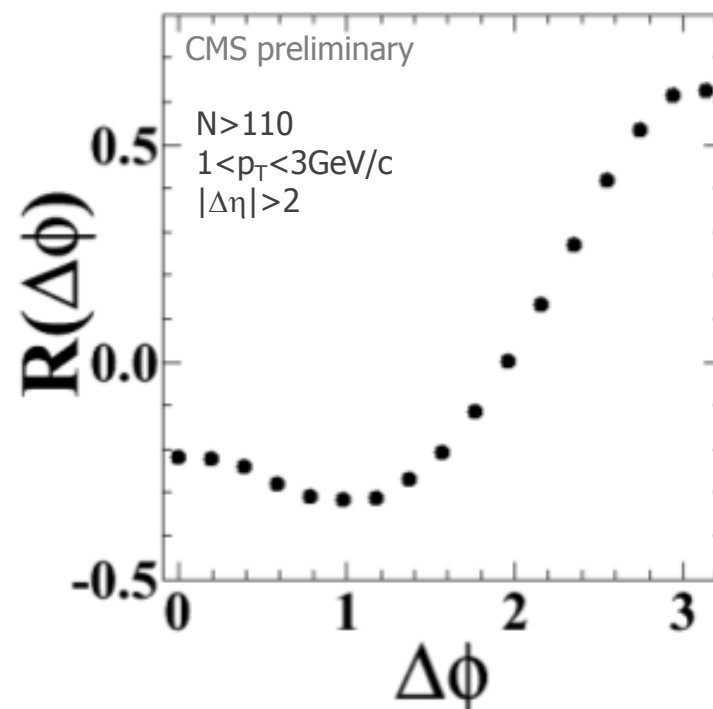
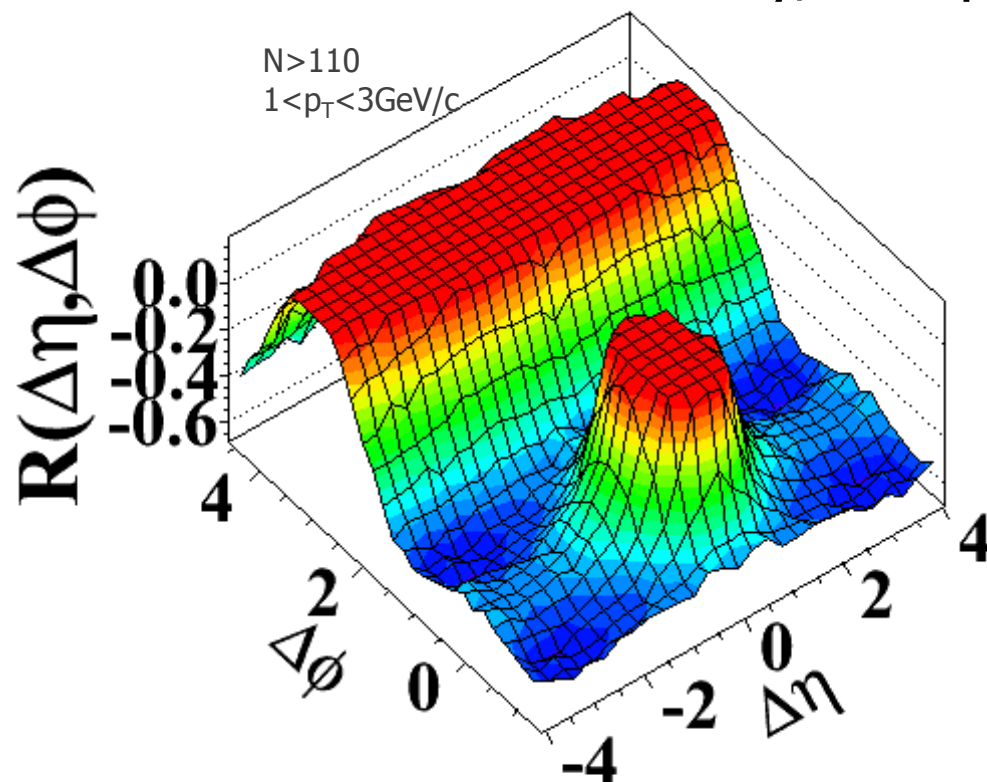
HLT 70 vs HLT 85 for N > 110



No trigger bias seen from  
comparison of trigger paths

# Cross Check: ECAL photons

Use ECAL “photon” signal  
Mostly single photons from  $\pi^0$ 's  
No efficiency, and  $p_T$ ,  $\phi$  smearing corrections



Track-photon correlations

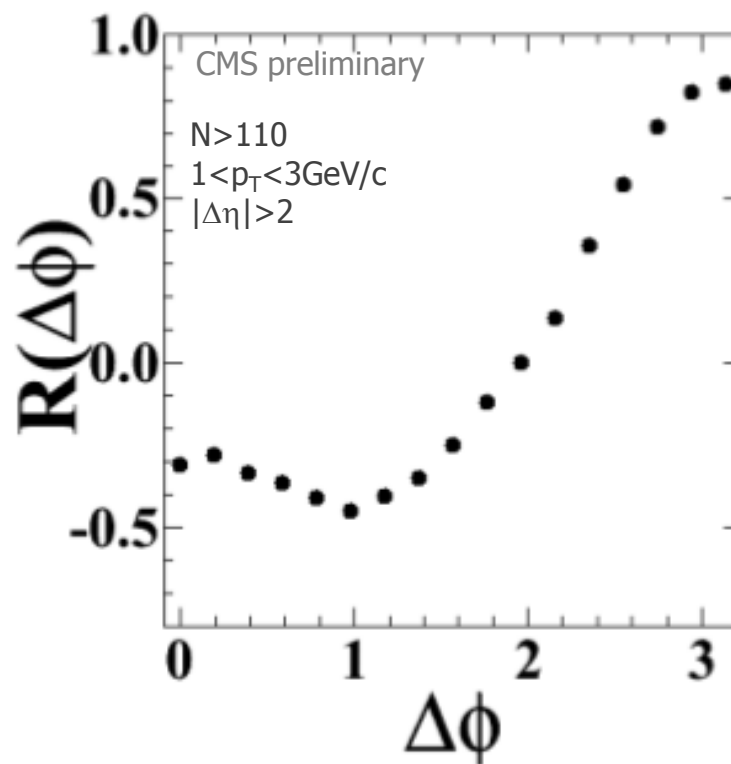
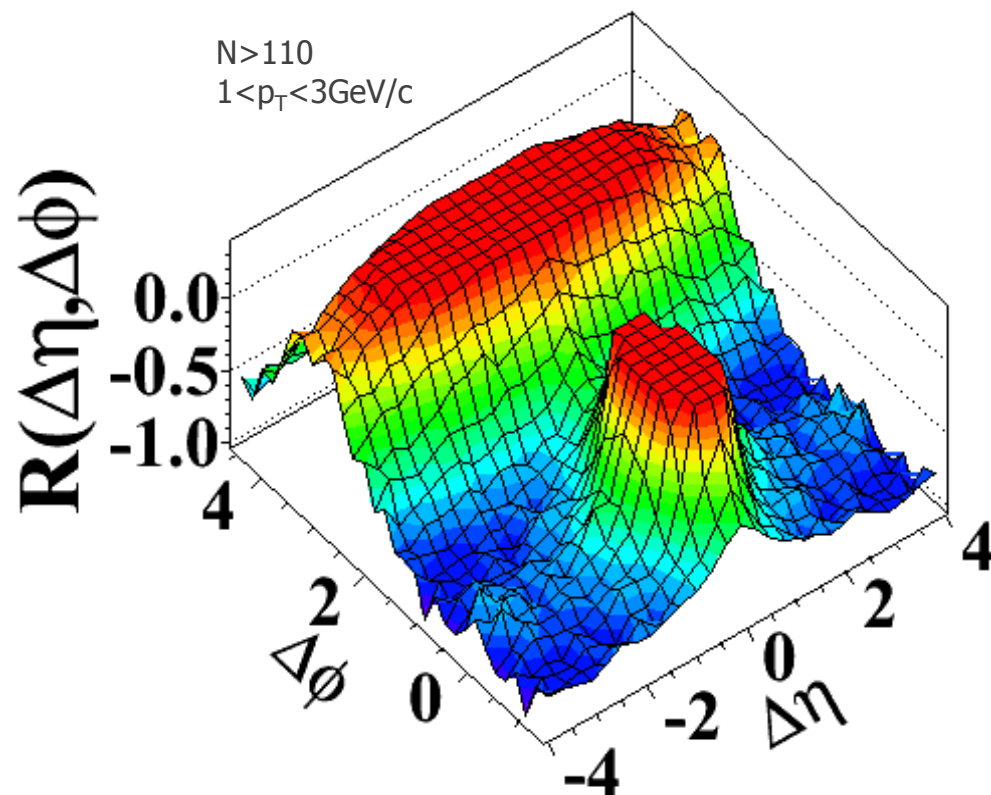
Note: photons reconstructed using “particle flow”  
event reconstruction technique

# Cross Check: ECAL photons

Use ECAL “photon” signal

Mostly single photons from  $\pi^0$ 's

No efficiency, and  $p_T$ ,  $\phi$  smearing corrections



Photon-photon correlations

Qualitative confirmation

Independent detector, independent reconstruction

# Particle density in high Mult pp

- Similar particle densities in these pp collisions as were seen in CuCu at RHIC

