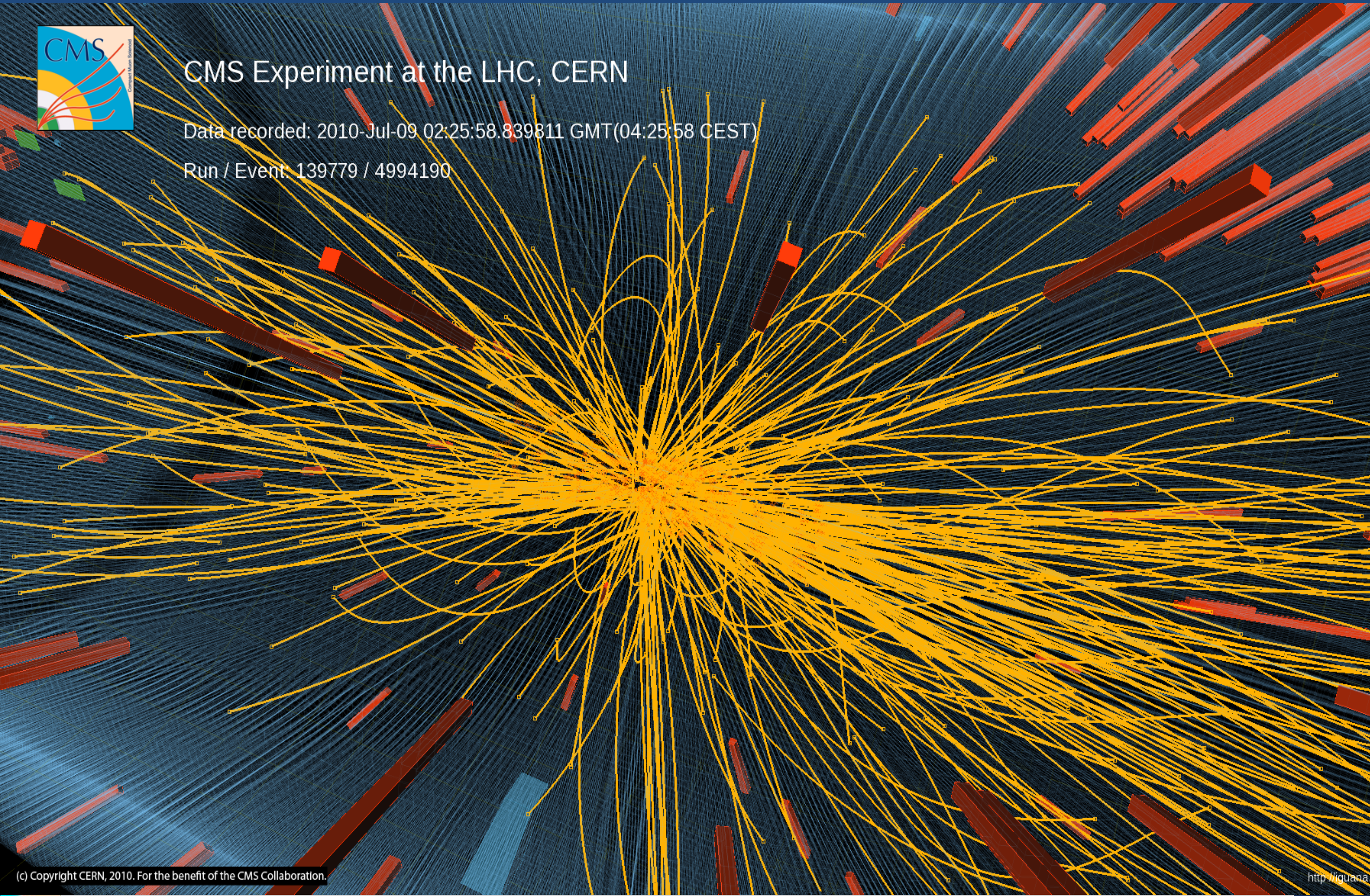
Ridge correlation structure in high multiplicity pp collisions with CMS

Dragos Velicanu

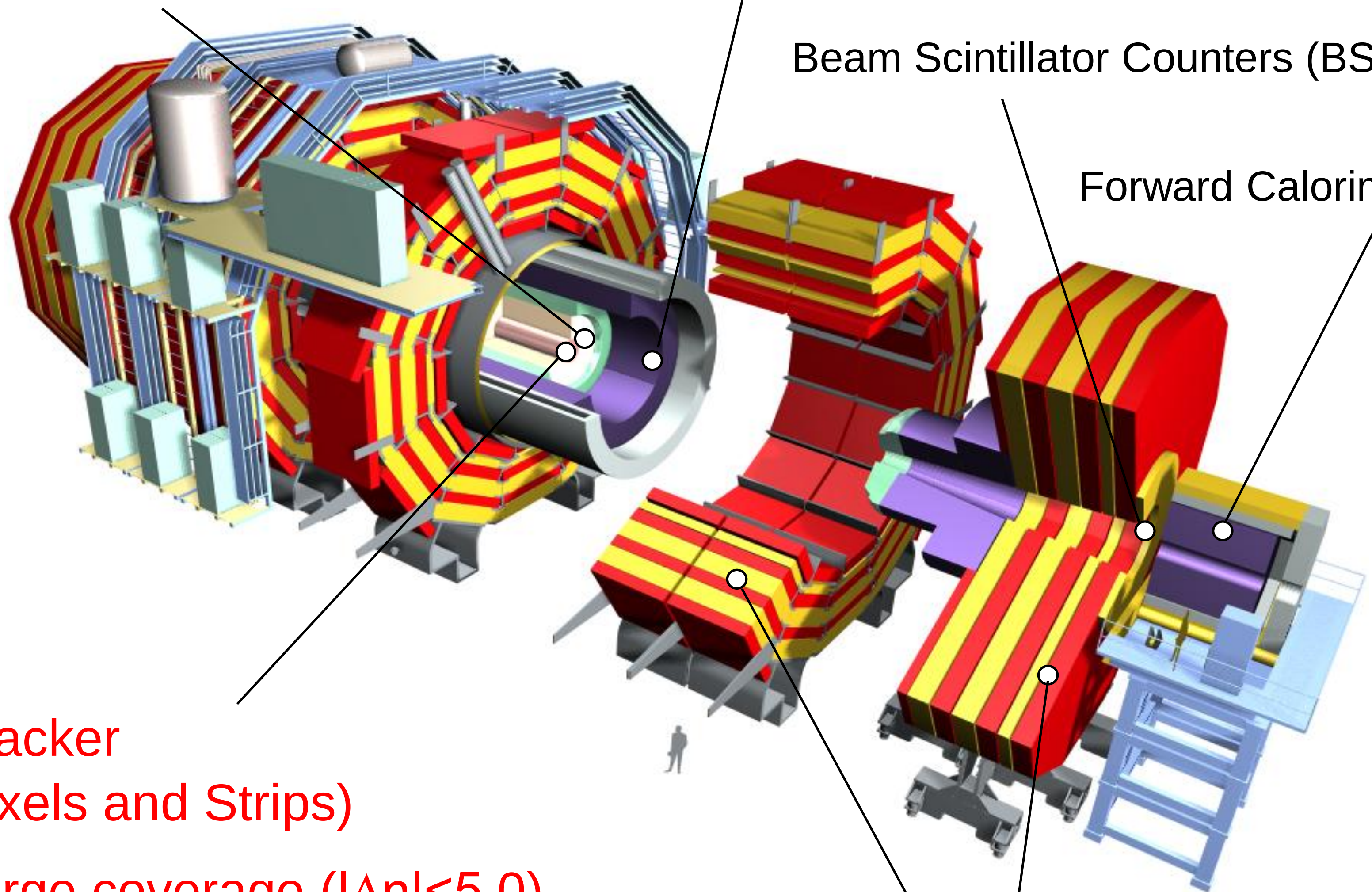
Massachusetts Institute of Technology

for the CMS Collaboration

Results from High Multiplicity pp



CMS Experiment

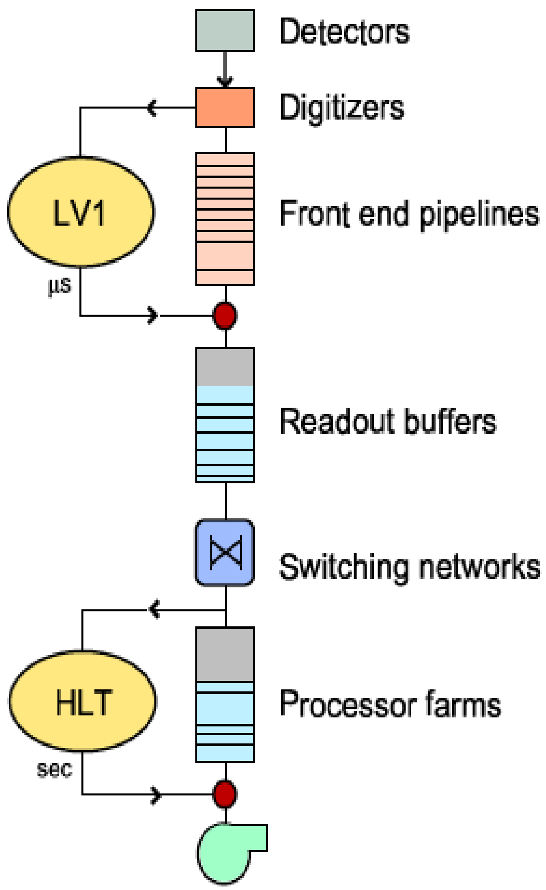


Tracker
(Pixels and Strips)

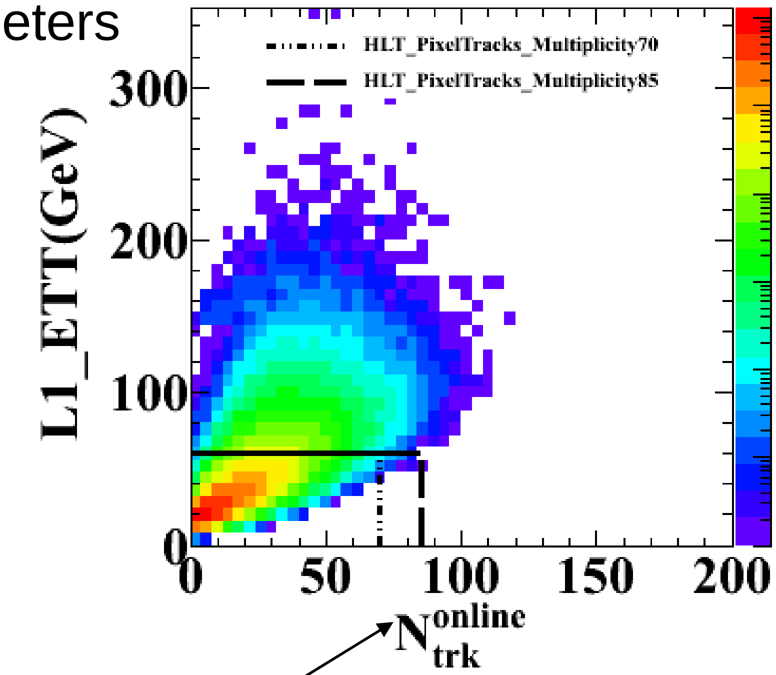
Large coverage ($|\Delta\eta|<5.0$)
50 μm vertex resolution

Trigger on High Multiplicity pp

CMS trigger and DAQ



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

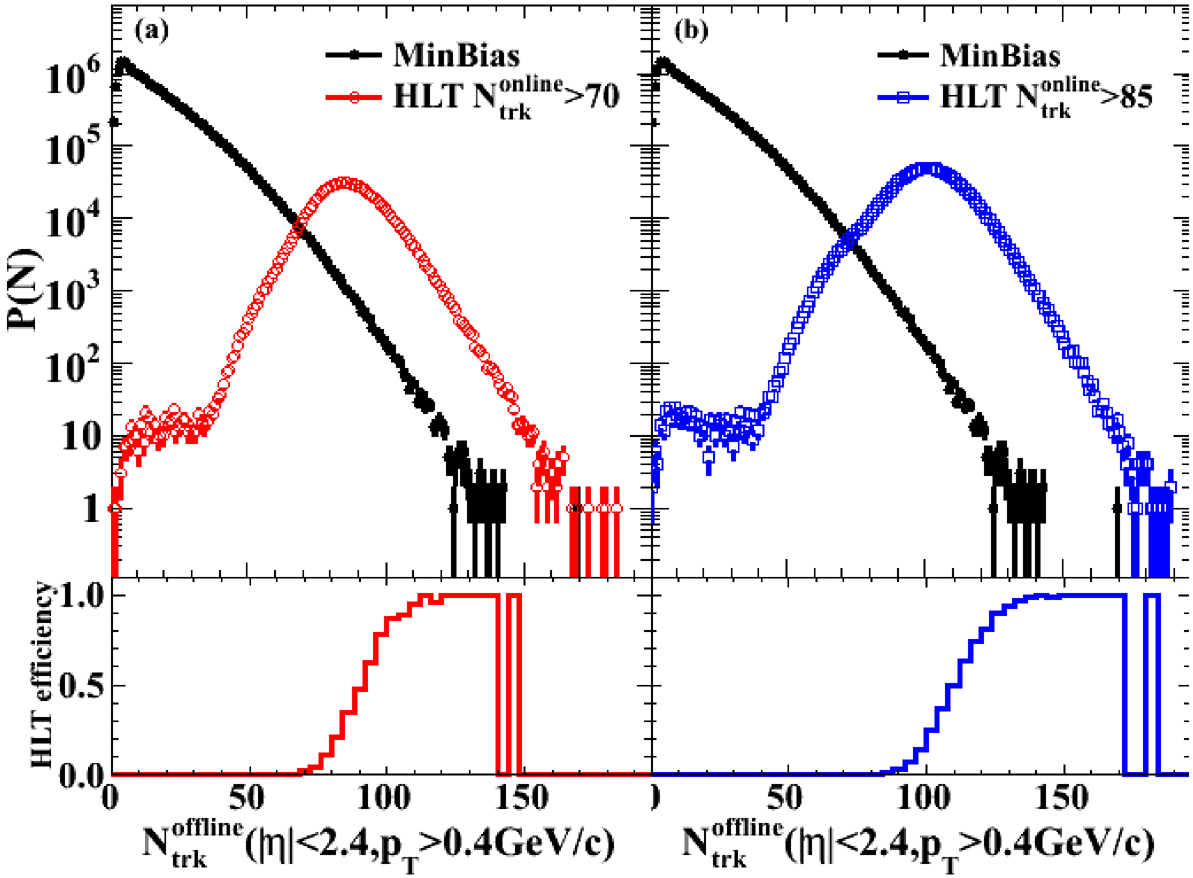


High-Level trigger:
number of tracks with p_T>0.4 GeV/c, |η|<2
from a **single** vertex

Trigger on High Multiplicity pp

JHEP 1009:091, 2010

Total integrated luminosity: 980nb^{-1}



Two HLT thresholds:

- N^{online} > 70
- N^{online} > 85

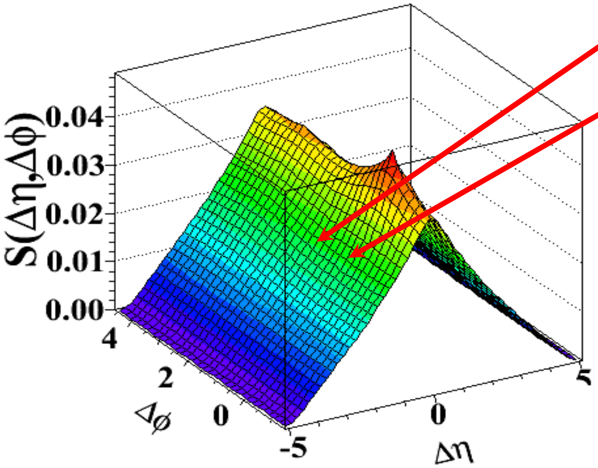
N^{online} > 85 trigger un-prescaled for full 980nb^{-1} data set

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

Angular Correlation Technique

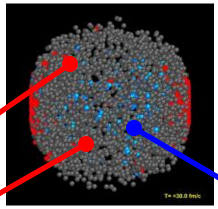
Signal distribution:

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

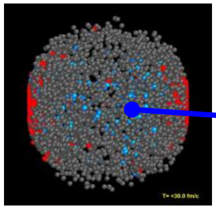


same event pairs

Event 1

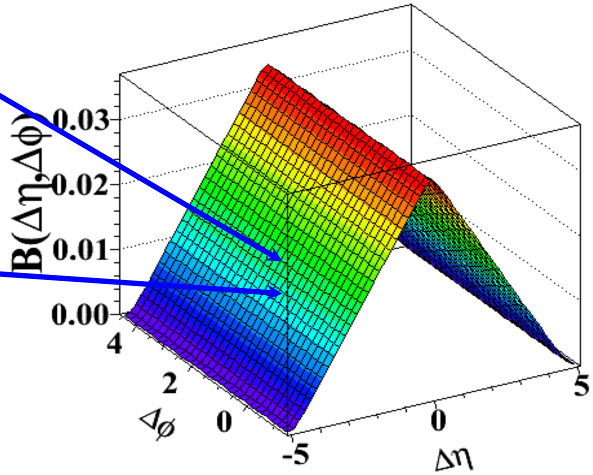


Event 2



Background distribution:

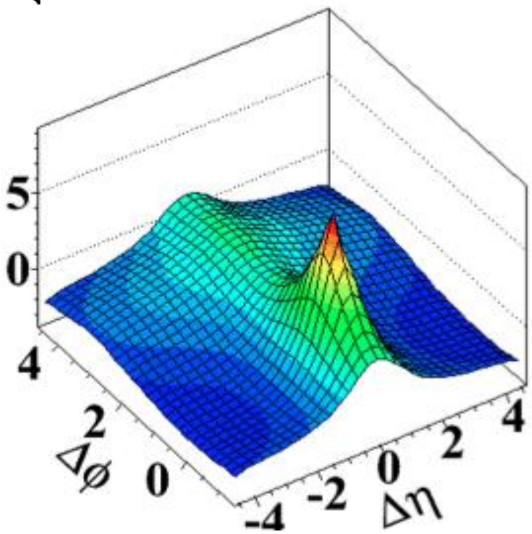
$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2 N^{mix}}{d\Delta\eta d\Delta\varphi}$$



mixed event pairs

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

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



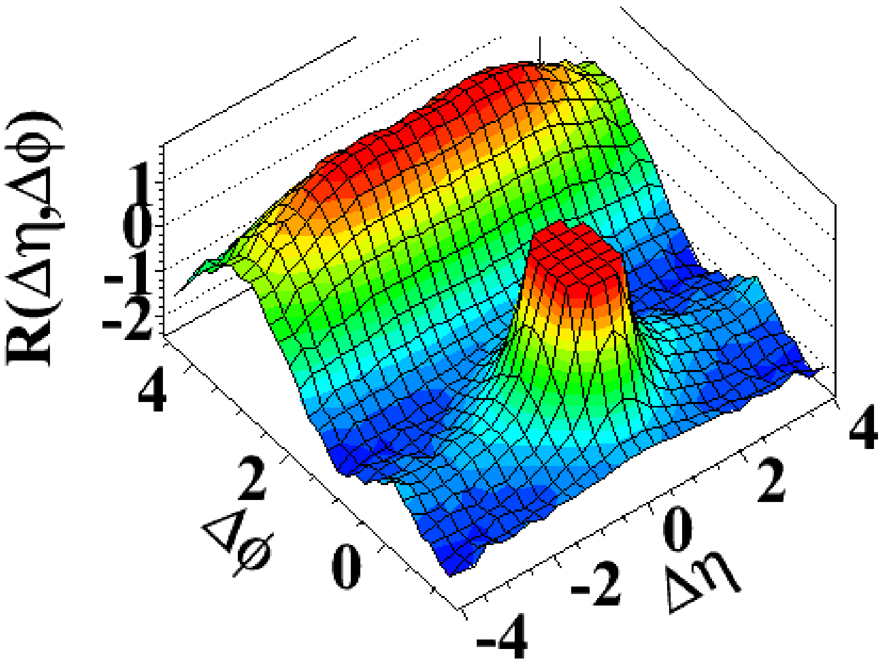
$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)}$$

Divide signal by background

Correlations in High Multiplicity pp

Intermediate p_T: 1-3 GeV/c

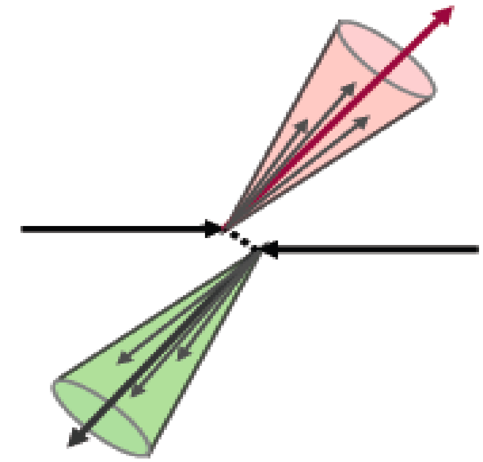
High multiplicity pp (N>110)



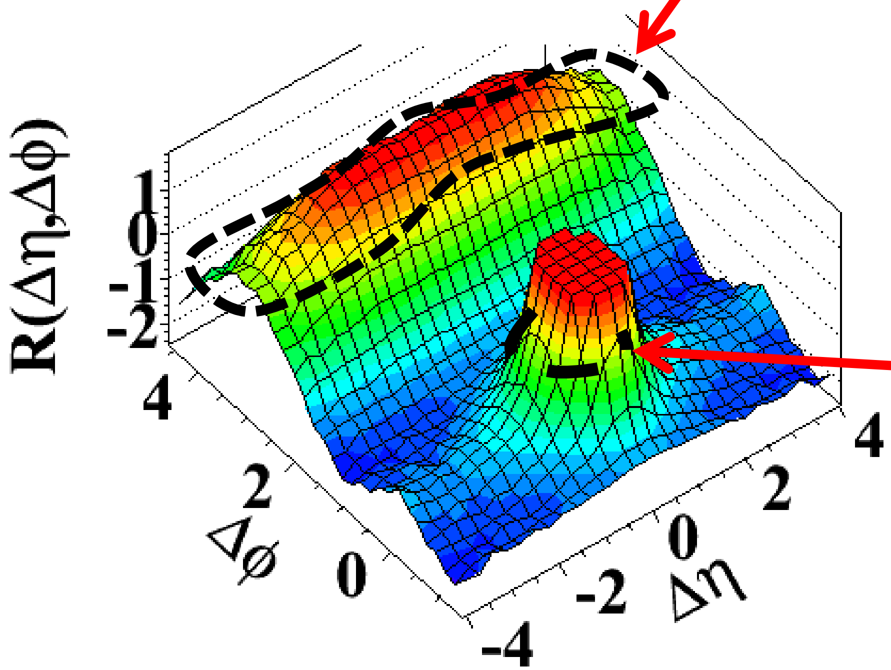
Correlations in High Multiplicity pp

Intermediate p_T: 1-3 GeV/c

"Away-side" ($\Delta\phi \sim \pi$)
back-to-back jet correlations



High multiplicity pp (N>110)



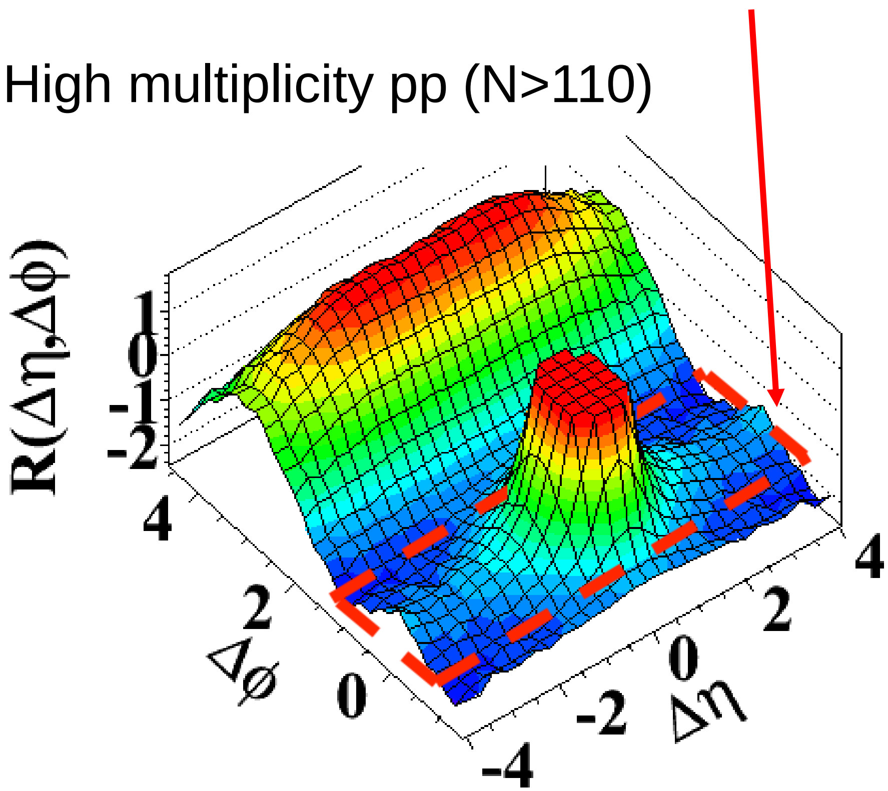
"Near-side" ($\Delta\phi$, $\Delta\eta \sim 0$)
correlations from single jets

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)



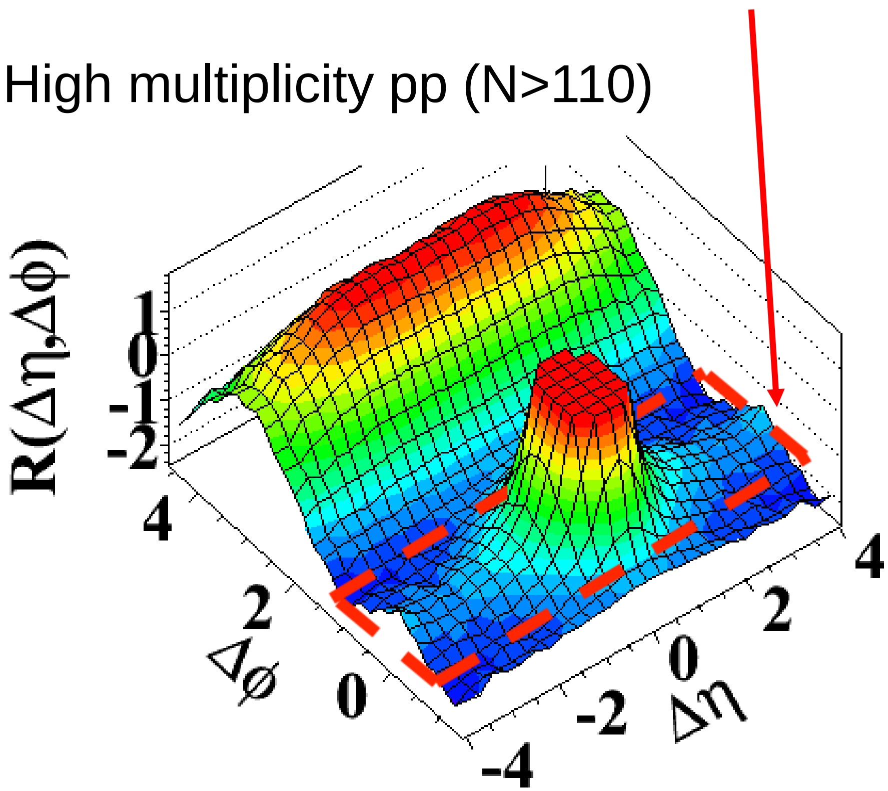
Correlations in High Multiplicity pp

Intermediate p_T: 1-3 GeV/c

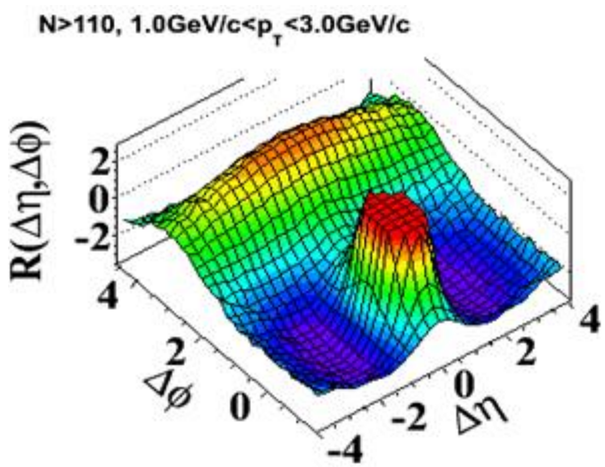
Striking "**ridge-like**" structure extending over $\Delta\eta$ at $\Delta\phi \sim 0$

(not observed before in hadron collisions or MC models)

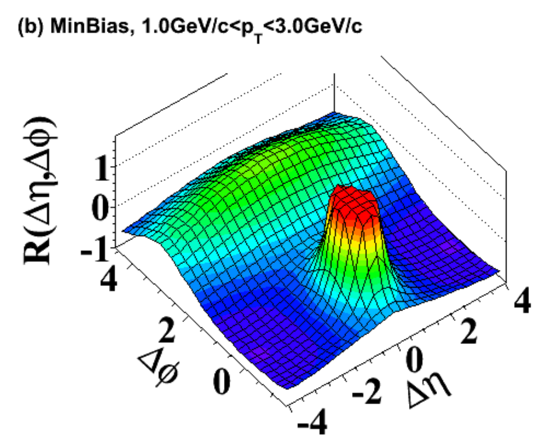
High multiplicity pp (N>110)



High multiplicity MC



Minbias pp

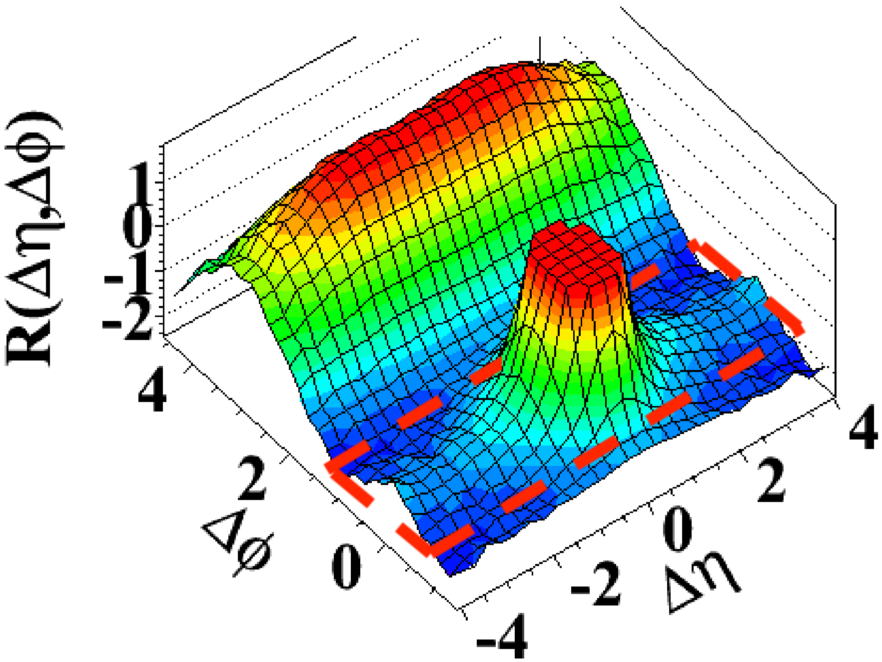


Correlations in High Multiplicity pp

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

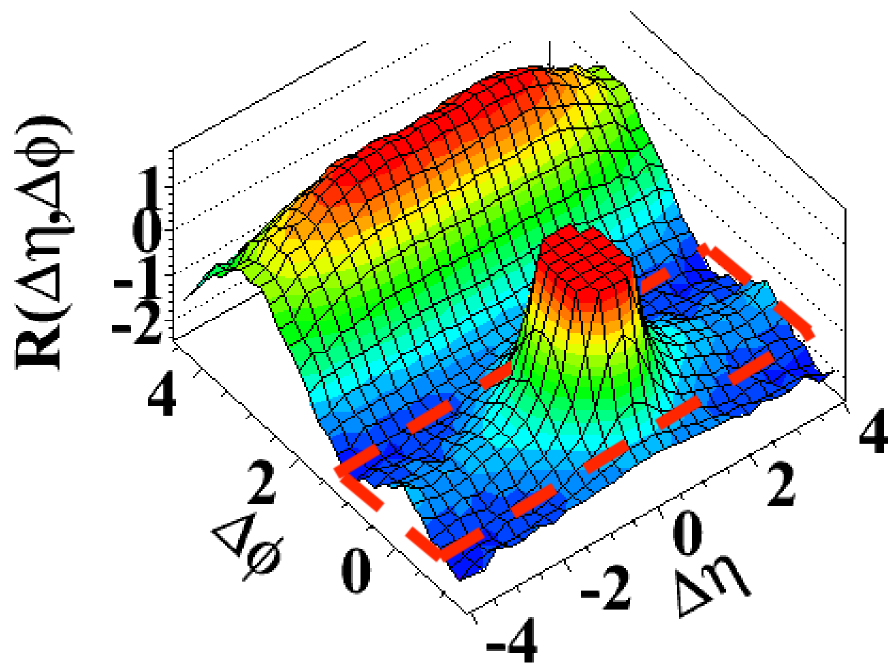
Intermediate p_T: 1-3 GeV/c

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

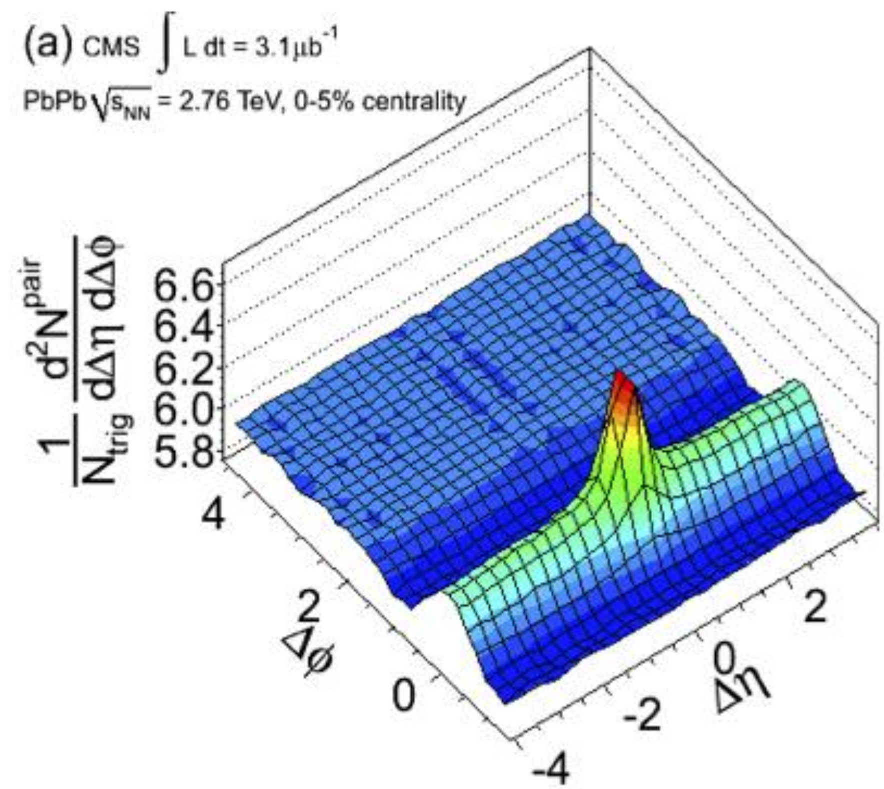
(Similarity to Heavy Ion)

arXiv:1105.2438

High multiplicity pp (N>110)

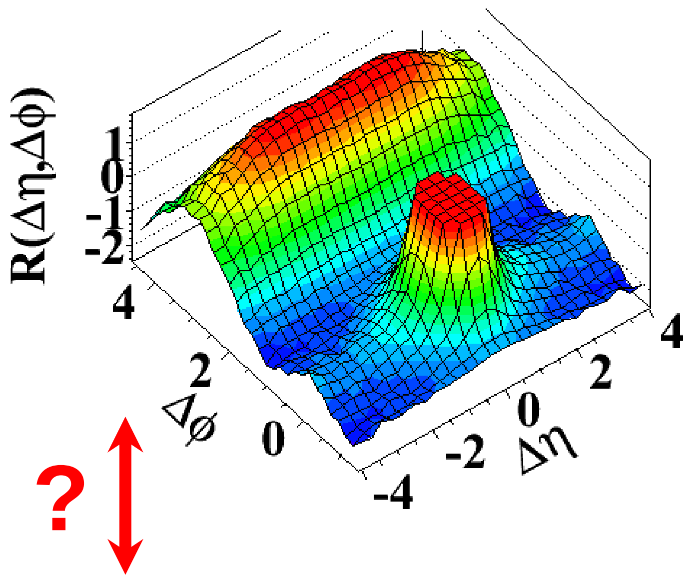


CMS PbPb 2.76 TeV

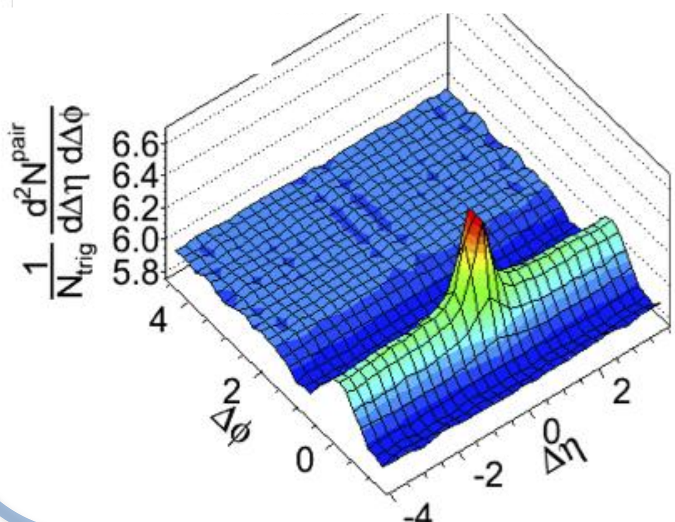


Interpretations of the Ridge

CMS pp 7 TeV, N ≥ 110



CMS PbPb 2.76 TeV, 0-5%



SPIRES

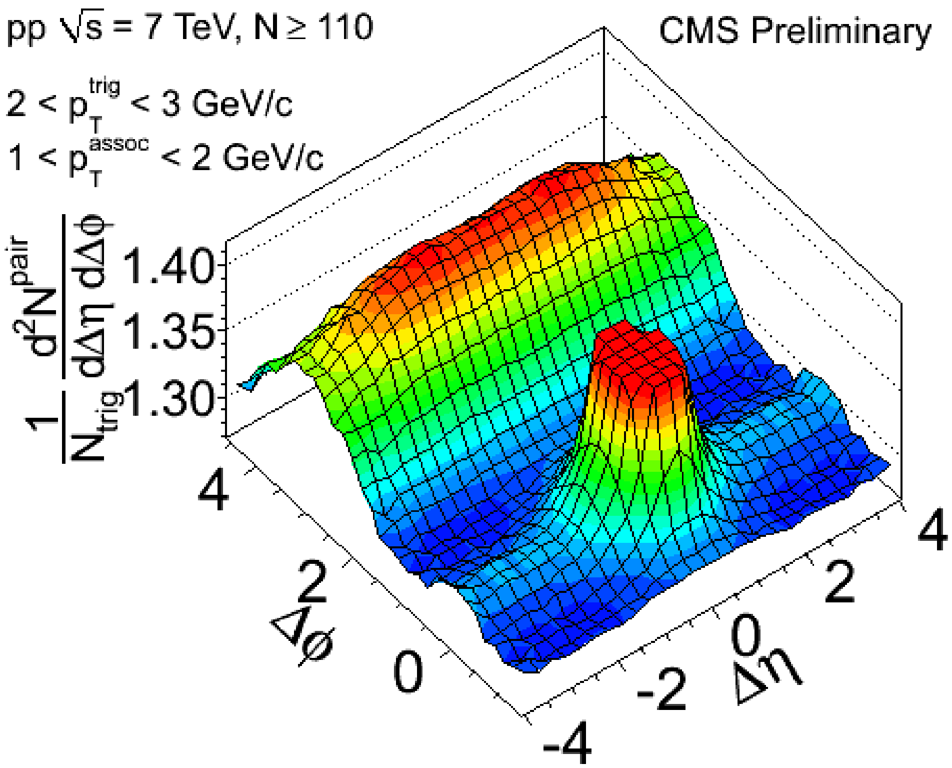
Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC.
By CMS Collaboration (Vardan Khachatryan *et al.*). CMS-QCD-10-002, CERN-PH-EP-2010-031, Sep 2010.
Published in **JHEP 1009:091,2010**.
e-Print: **arXiv:1009.4122** [hep-ex]

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 bremstralung 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 rangle 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) J/Ψ 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 pp 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 $\sqrt(S) = 7$ 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

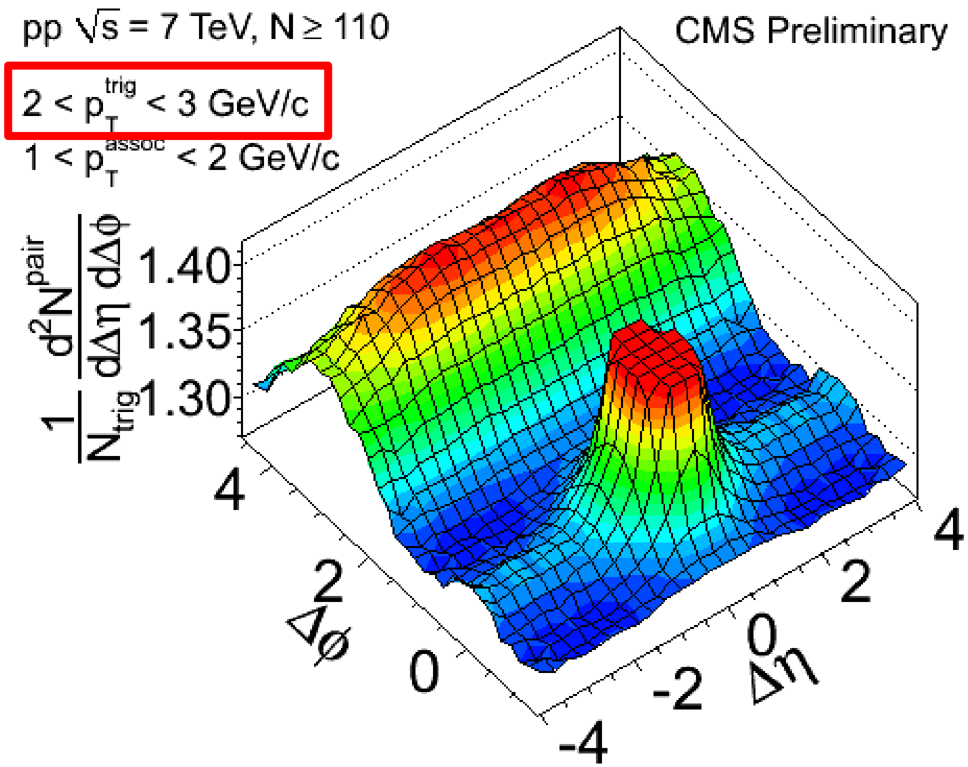
- 2x as much data
  - $|\Delta\eta|$ dependence
  - p_T dependence
  - Multiplicity dependence

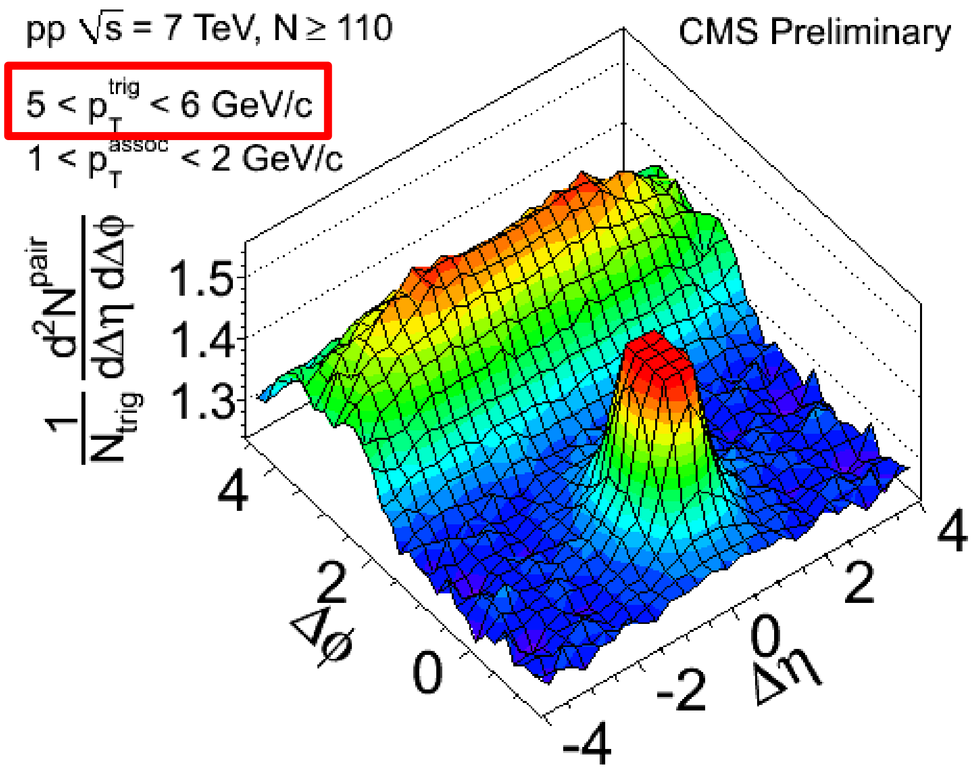


New Results

- 2x as much data
  - |Δη| dependence
  - p_T dependence
  - Multiplicity dependence

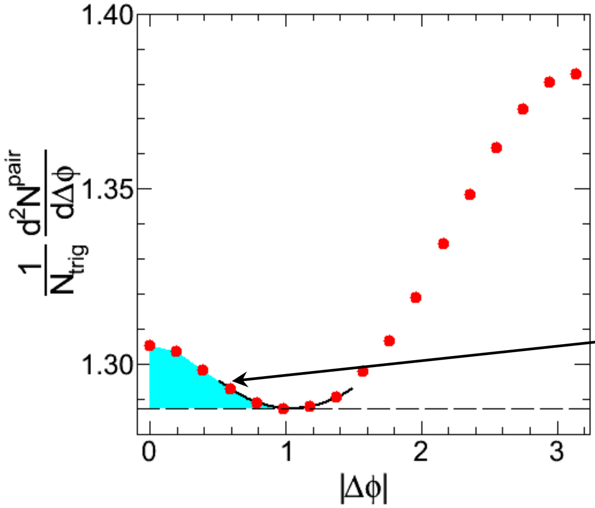
Ridge goes away at high p_T

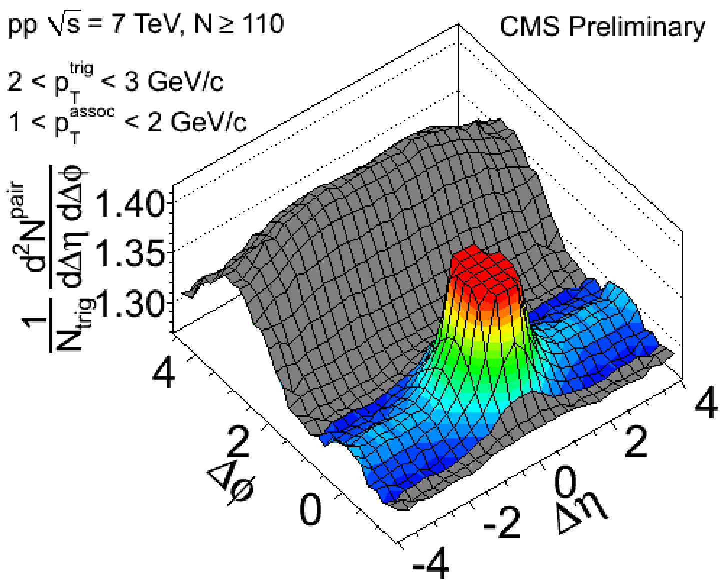


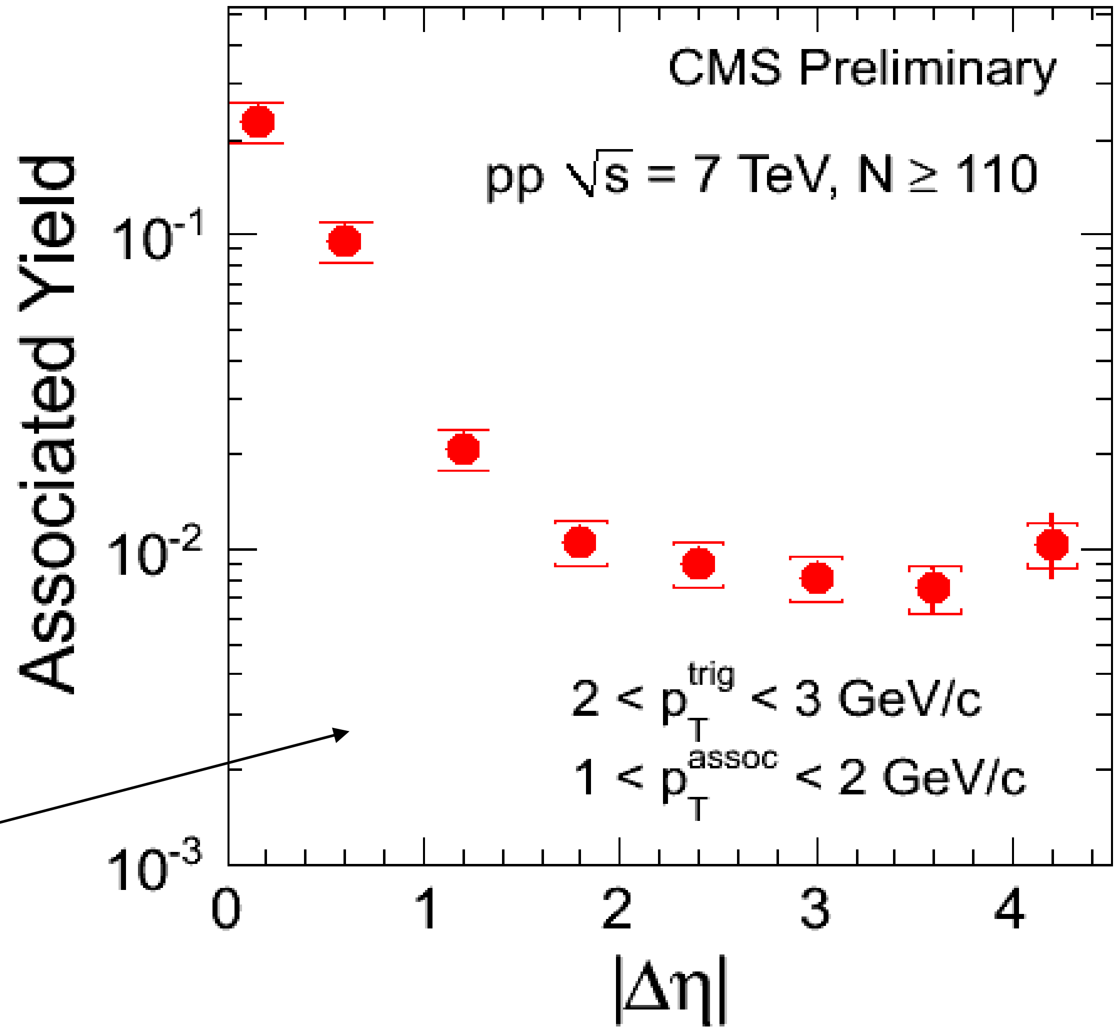


|Δη| dependence of the ridge

Zero-Yield-At-Minimum (ZYAM)

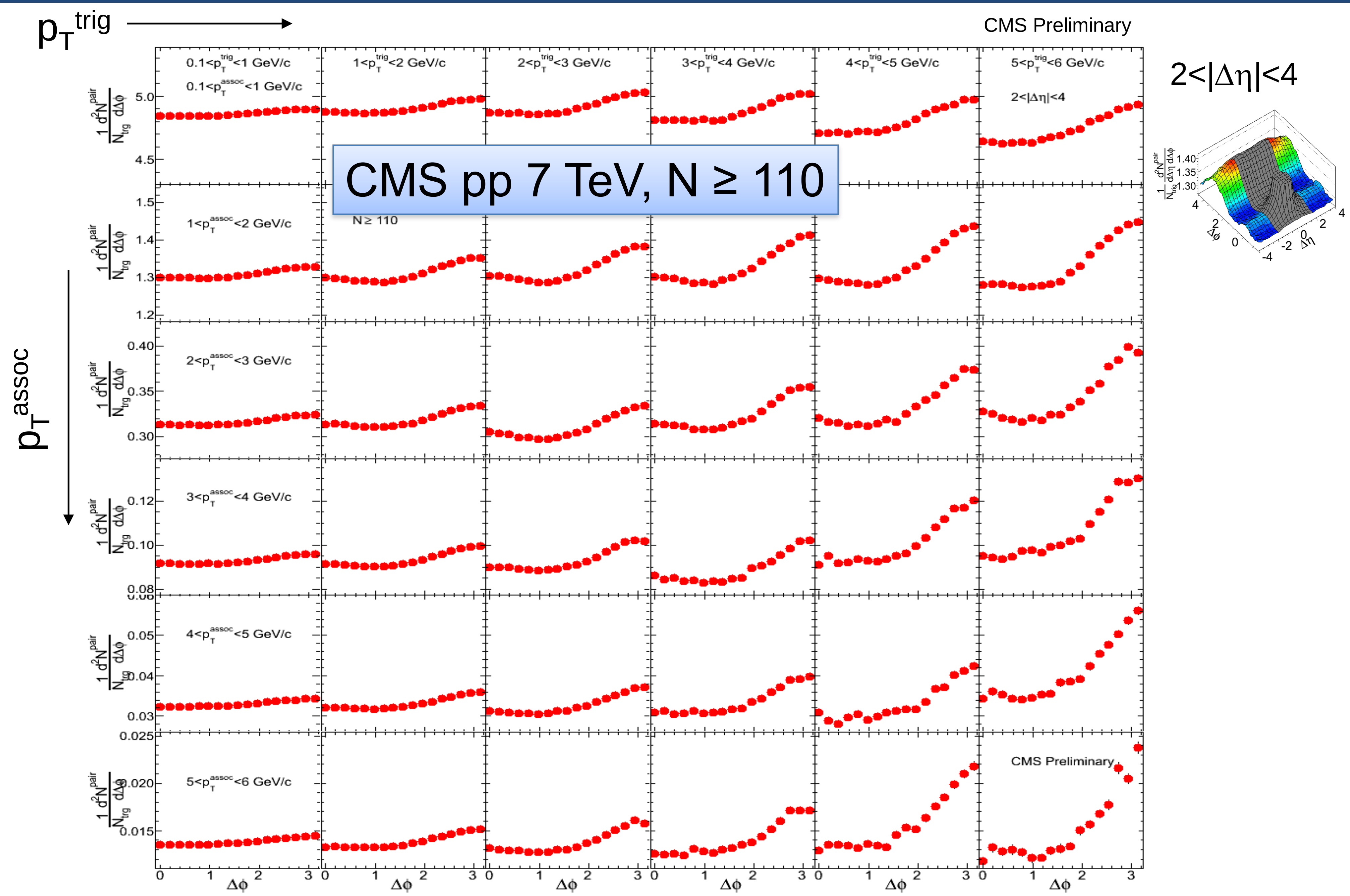






Ridge is mostly flat in |Δη|

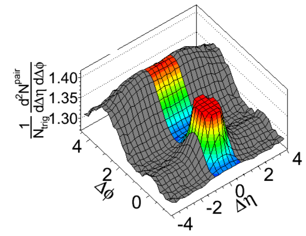
Δφ projections in various p_T ranges



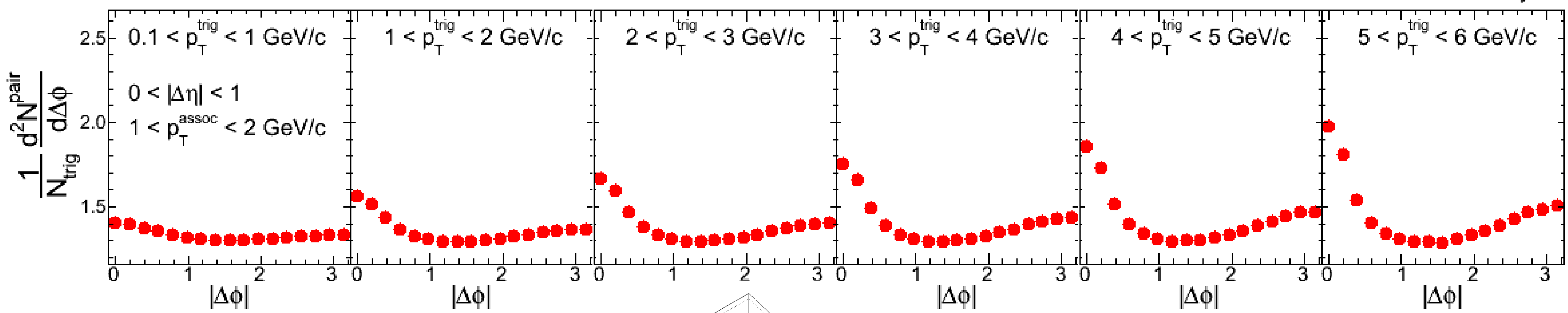
Δϕ projections in bins of p_T

CMS pp 7 TeV, N ≥ 110

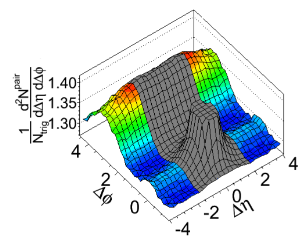
Jet region (|Δη|<1)



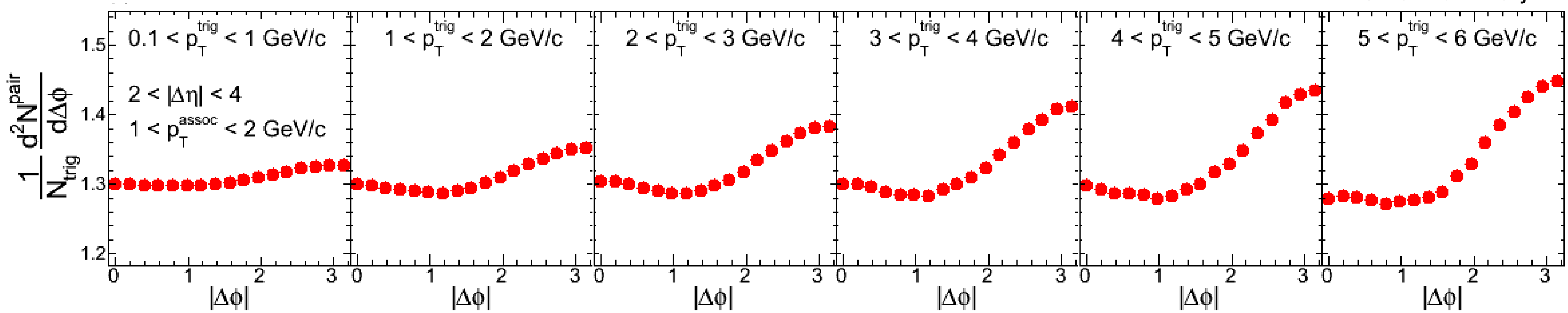
p_T →



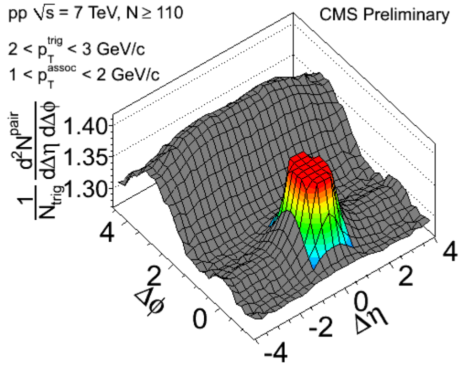
Ridge region (2<|Δη|<4)

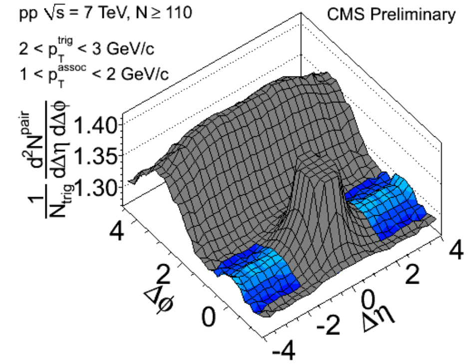


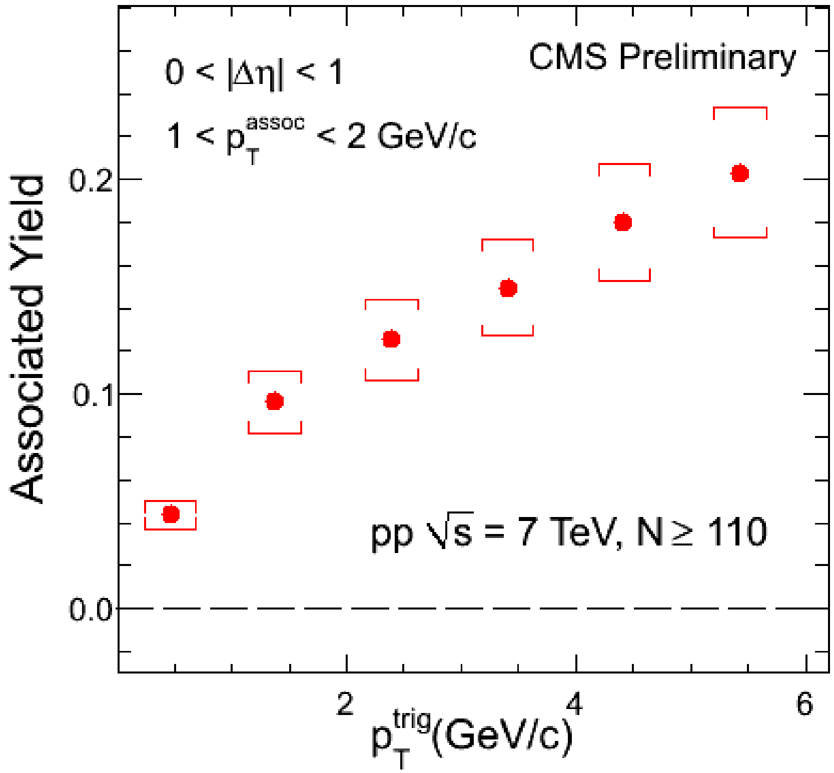
p_T →



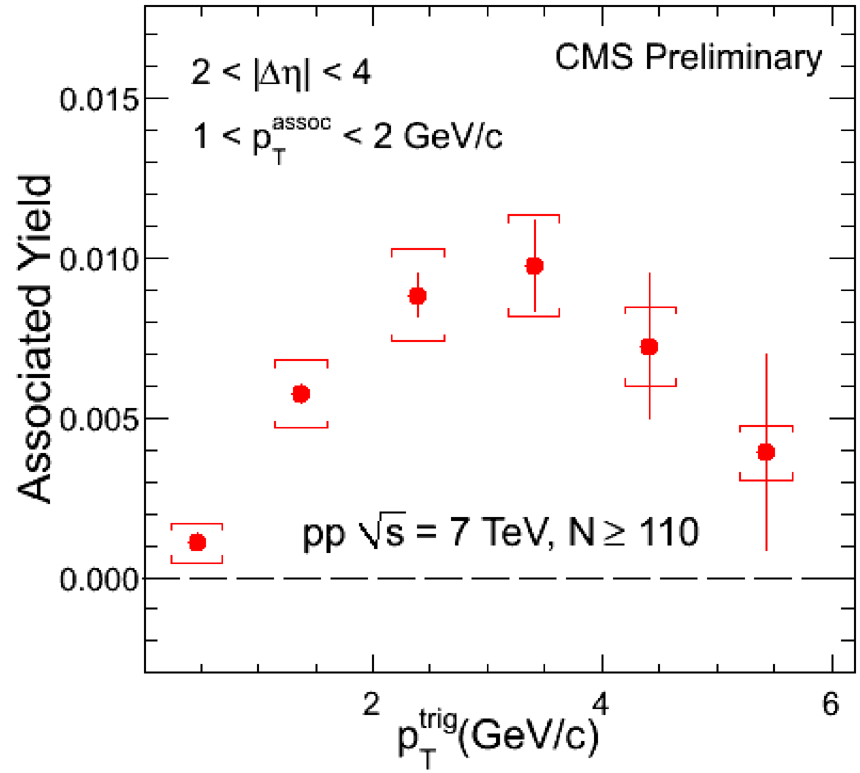
p_T dependence of the ridge







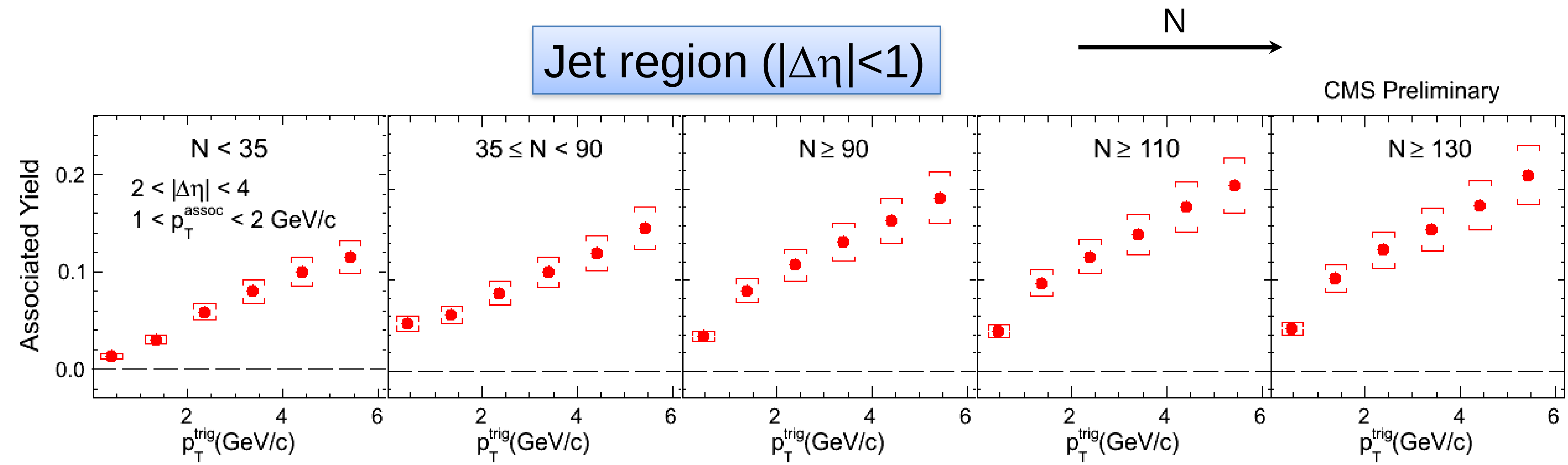
Jet region ($|\Delta\eta|<1$)



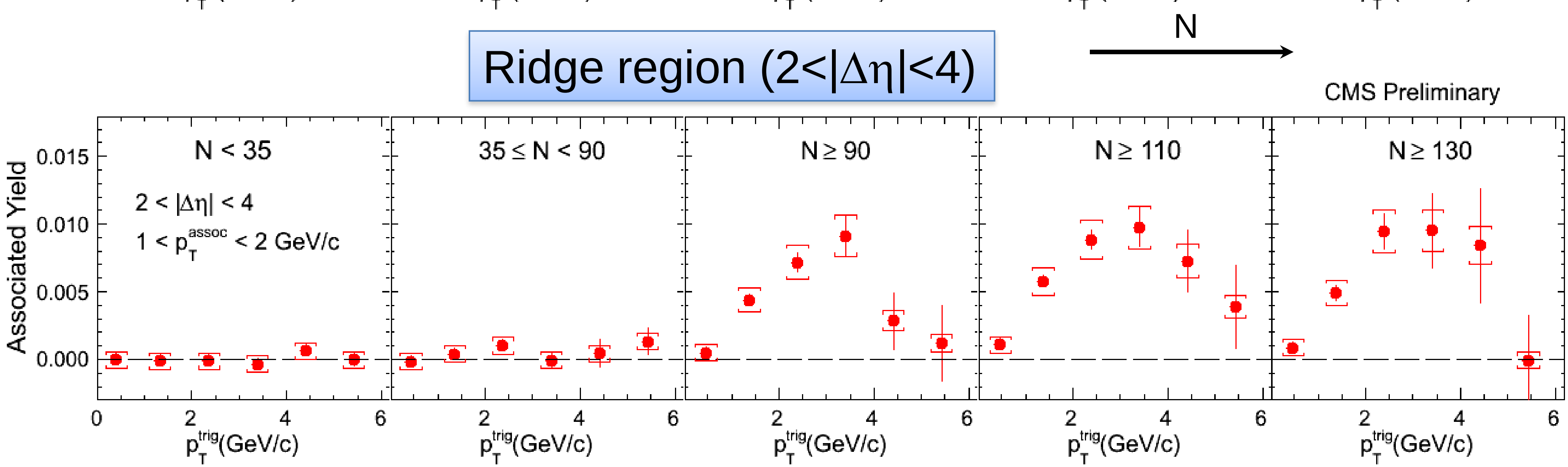
Ridge region ($2<|\Delta\eta|<4$)

Near-side yield vs p_T

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



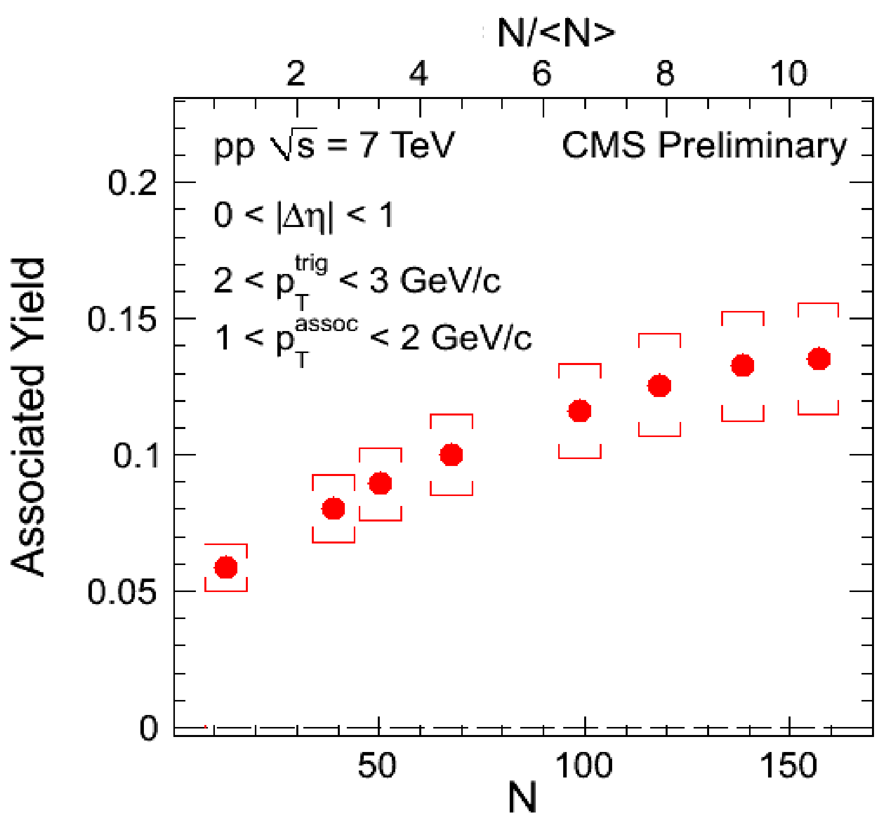
Ridge region ($2<|\Delta\eta|<4$)



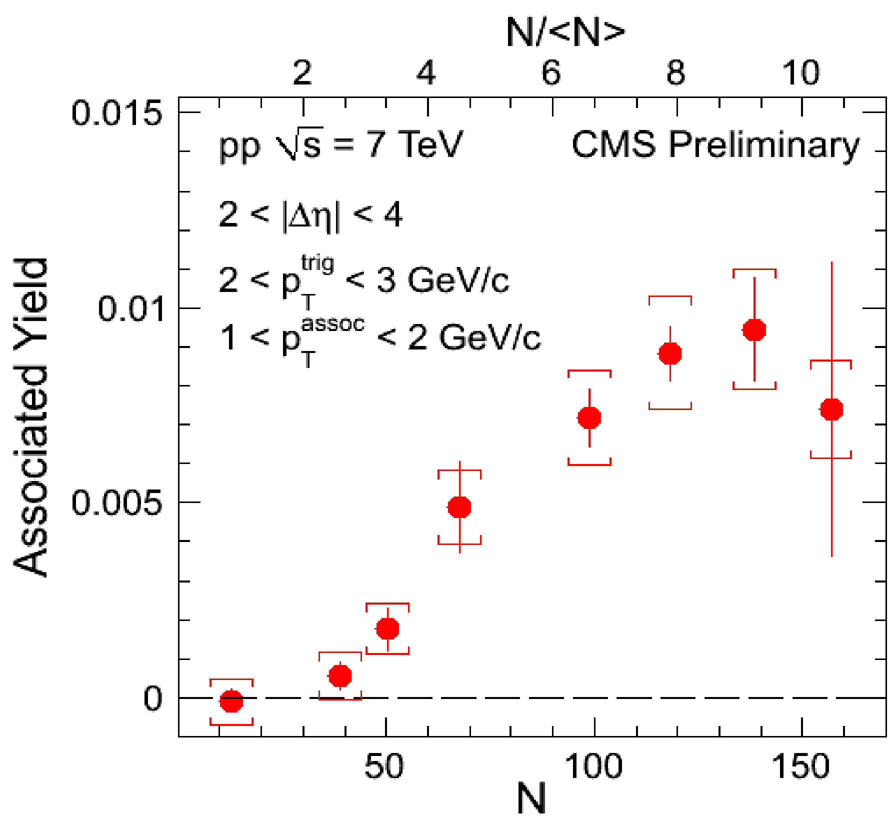
Ridge first increases with p_T, and then drops at high p_T

Near-side yield vs Multiplicity

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



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



Ridge in pp turns on around N ~ 50-60 (4x MinBias) smoothly

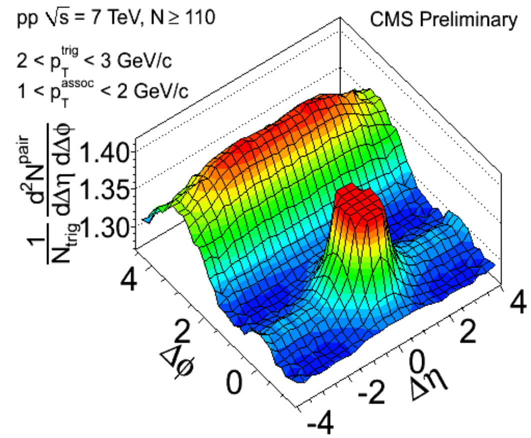
(<N> ~ 15 in MinBias pp events)

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, |Δη|, multiplicity dependence
- New testing ground for high density QCD physics

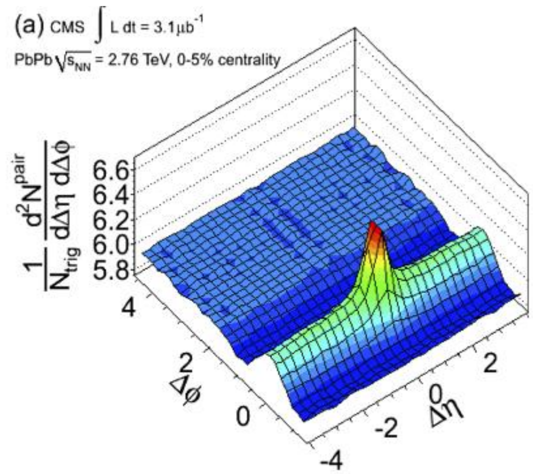
Wei Li (Plenary session Thursday)

CMS pp 7 TeV, N ≥ 110



Jeremy Callner (Parallel Tuesday)

CMS PbPb 2.76 TeV, 0-5%



Backups

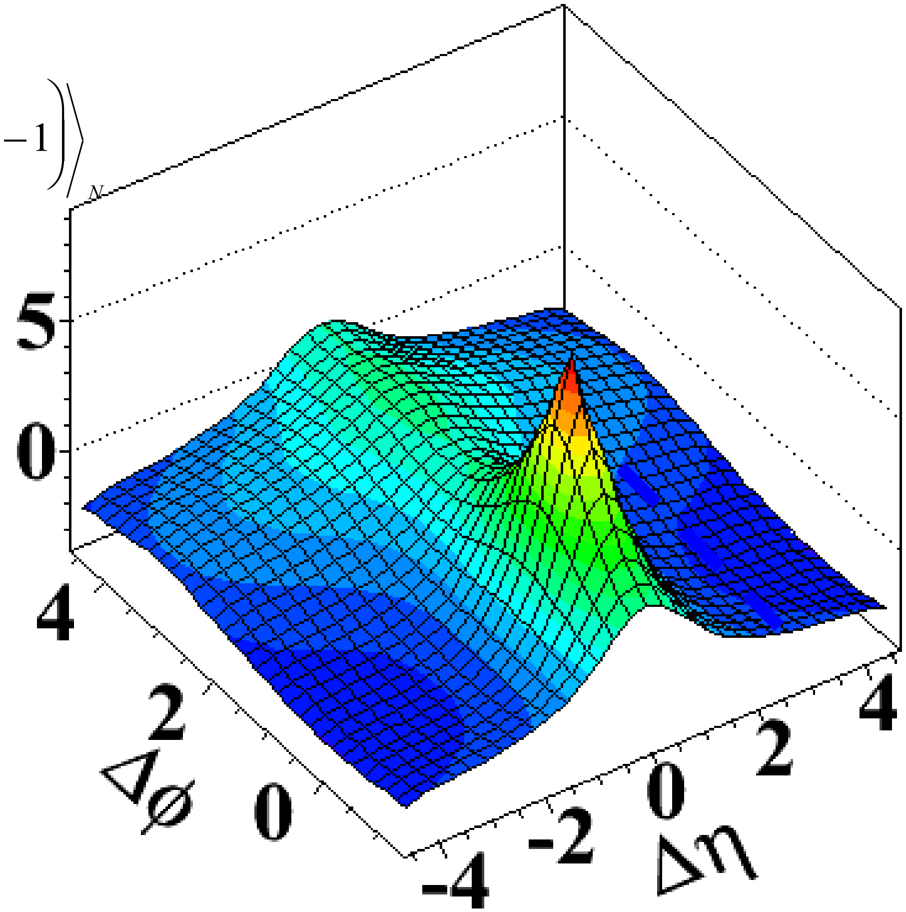
Understanding the Correlation Structure

p_T inclusive

What was used in
PHOBOS, ISR, UA5

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

CMS 7TeV pp minimum bias



Understanding the Correlation Structure

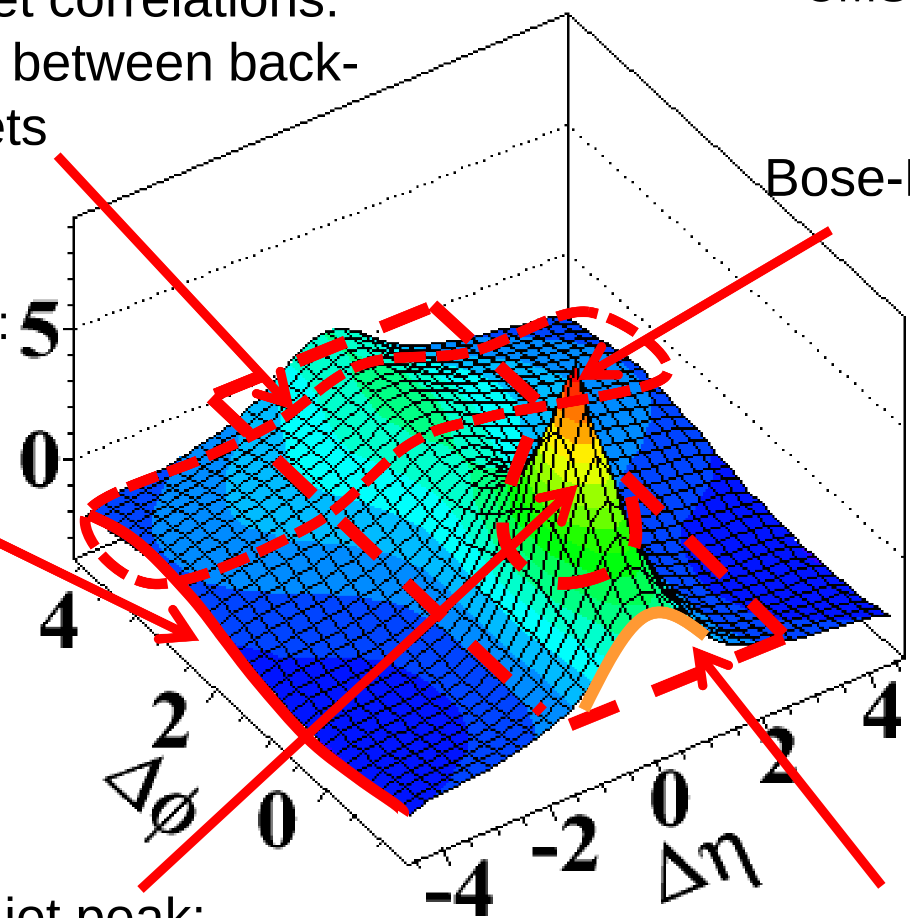
p_T inclusive

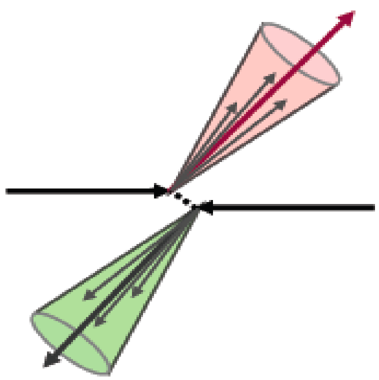
CMS 7TeV pp minimum bias

“Away-side” ($\Delta\phi \sim \pi$) jet correlations: Correlation of particles between back-to-back jets

Bose-Einstein correlations: ($\Delta\phi$,$\Delta\eta$) ~ (0,0)

Momentum conservation: ~ -cos($\Delta\phi$)

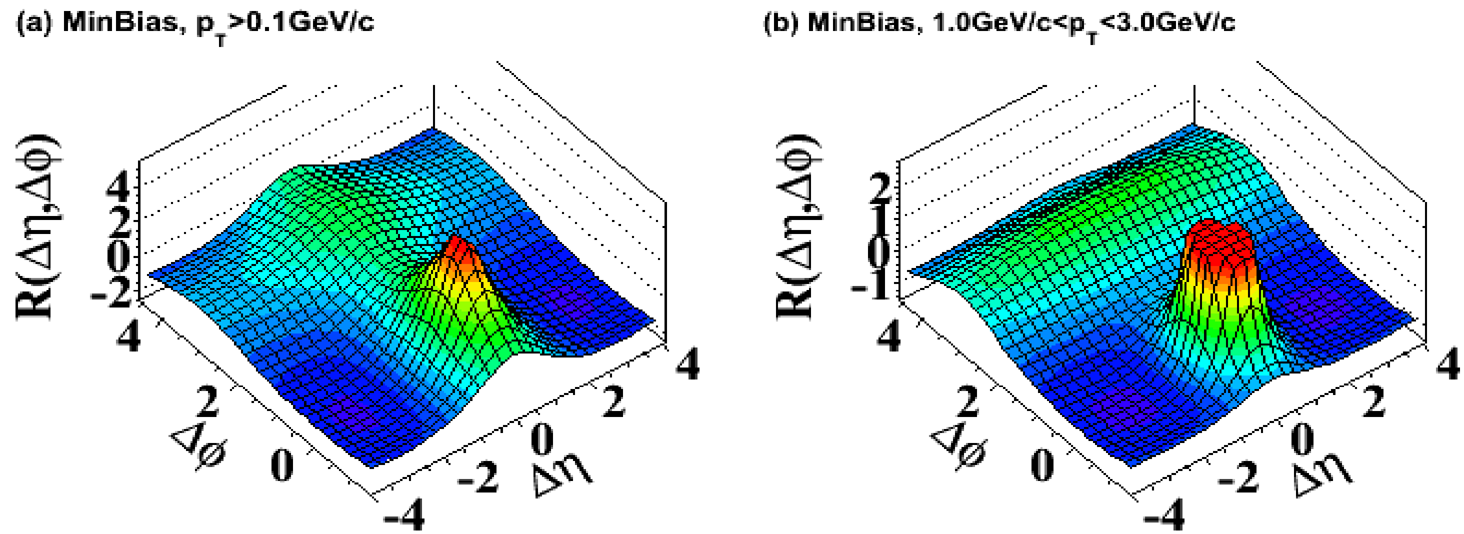




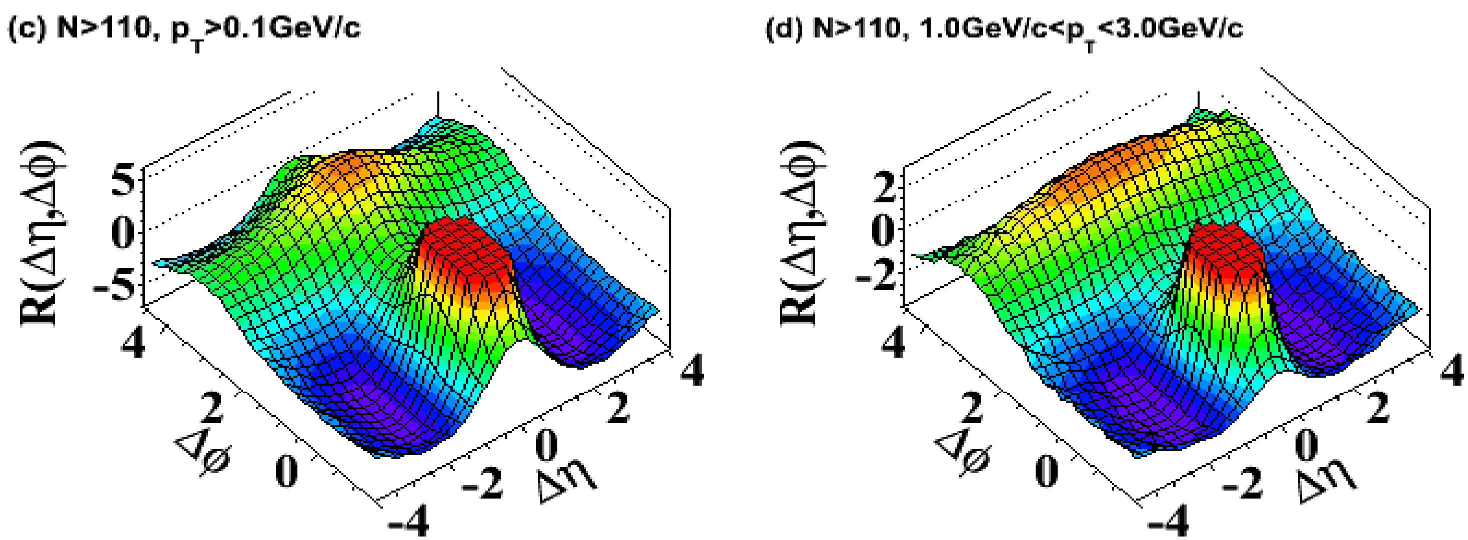
“Near-side” ($\Delta\phi \sim 0$) jet peak: Correlation of particles within a single jet

Short-range correlations ($\Delta\eta < 2$): Resonances, string fragmentation, “clusters”

Comparing to various MC

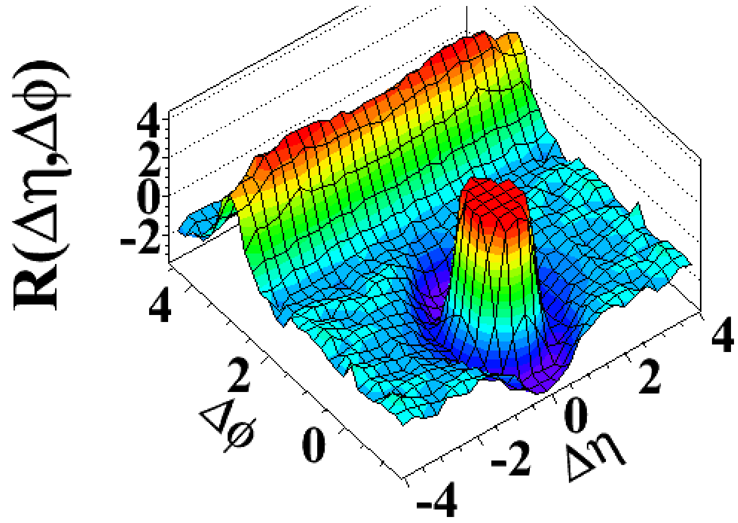


PYTHIA8, v8.135

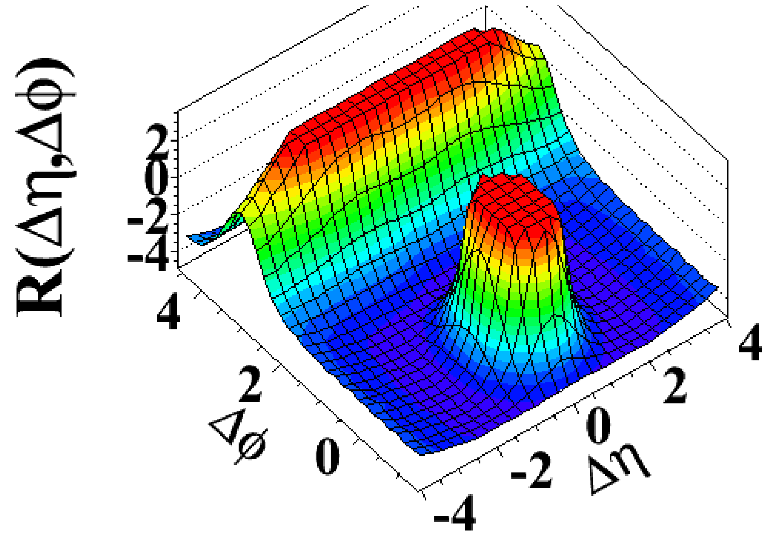


More MC models

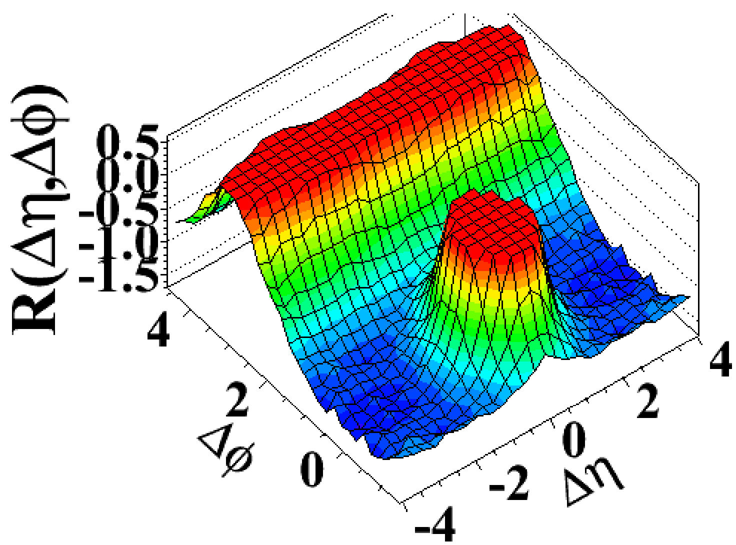
PYTHIA D6T MinBias, N>70



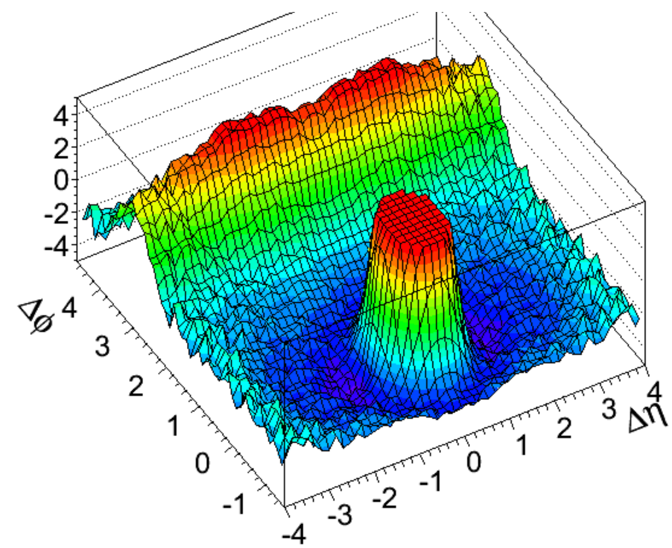
PYTHIA D6T, Dijet 80-120GeV



HERWIG++, N>110

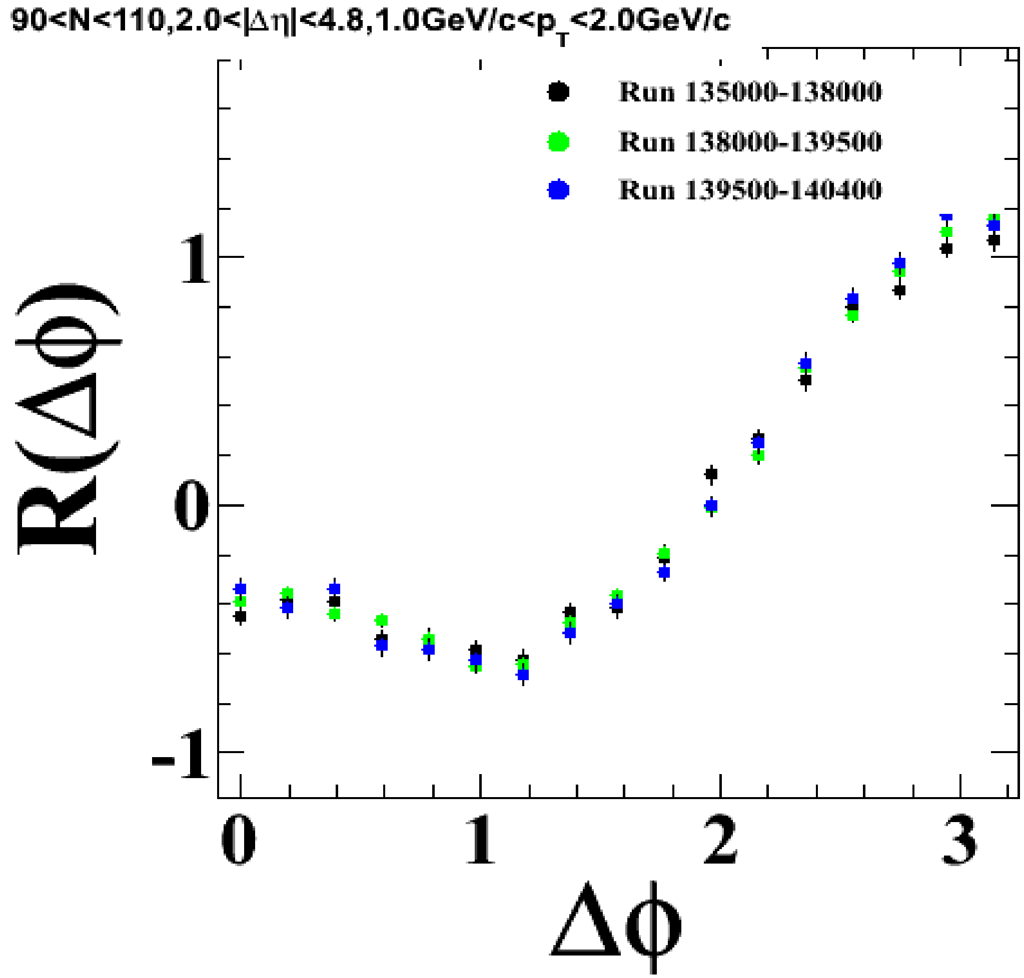


Madgraph, Dijet 100-250GeV, N>90



Cross Check: Event Pileup

Compare different run periods

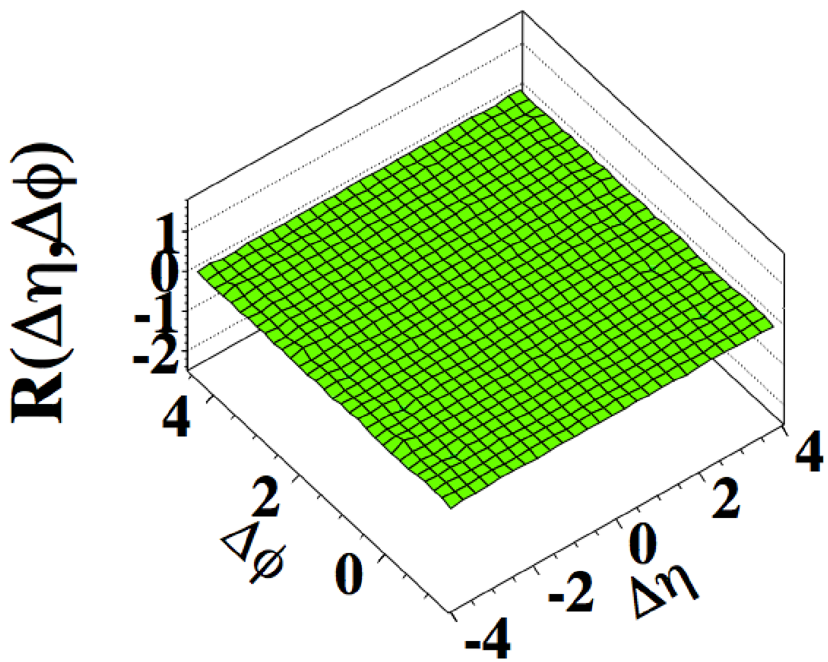


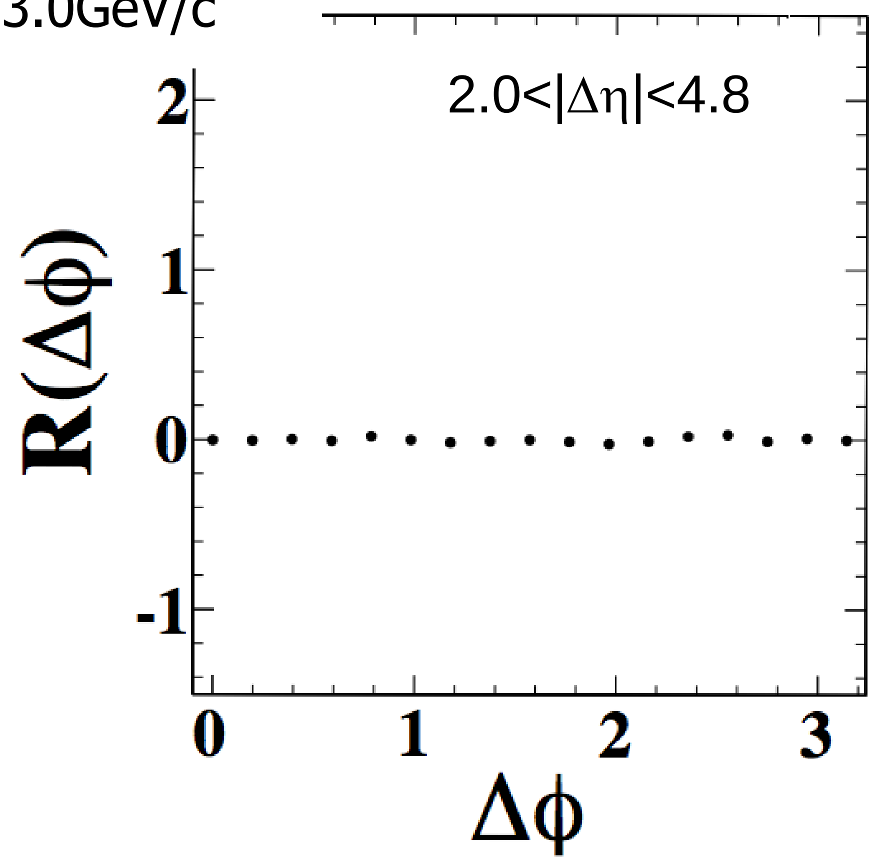
Change in pileup fraction by factor 4-5
has almost no effect on ridge signal

Cross Check: Event Pileup

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

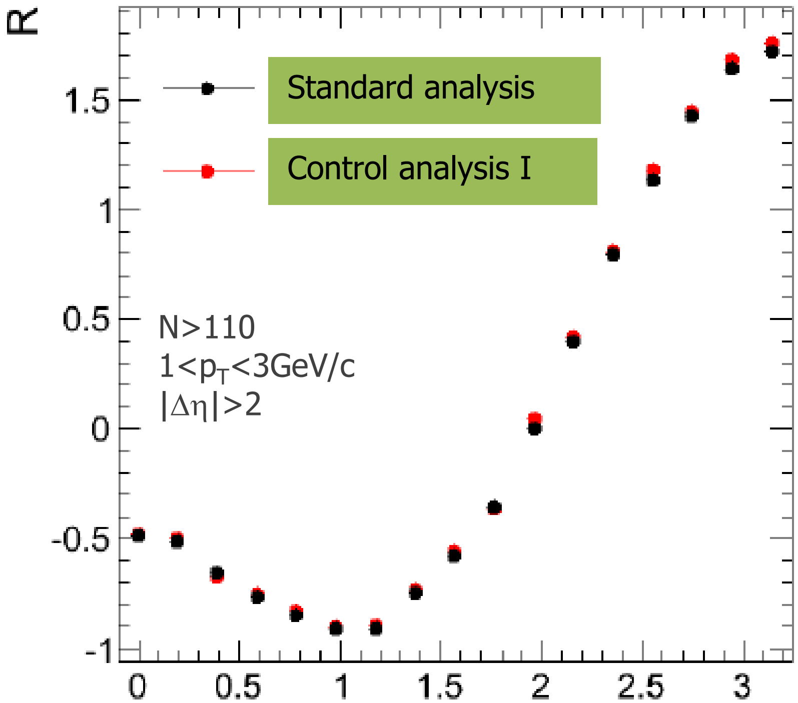
N>110
1.0GeV/c<p_T<3.0GeV/c



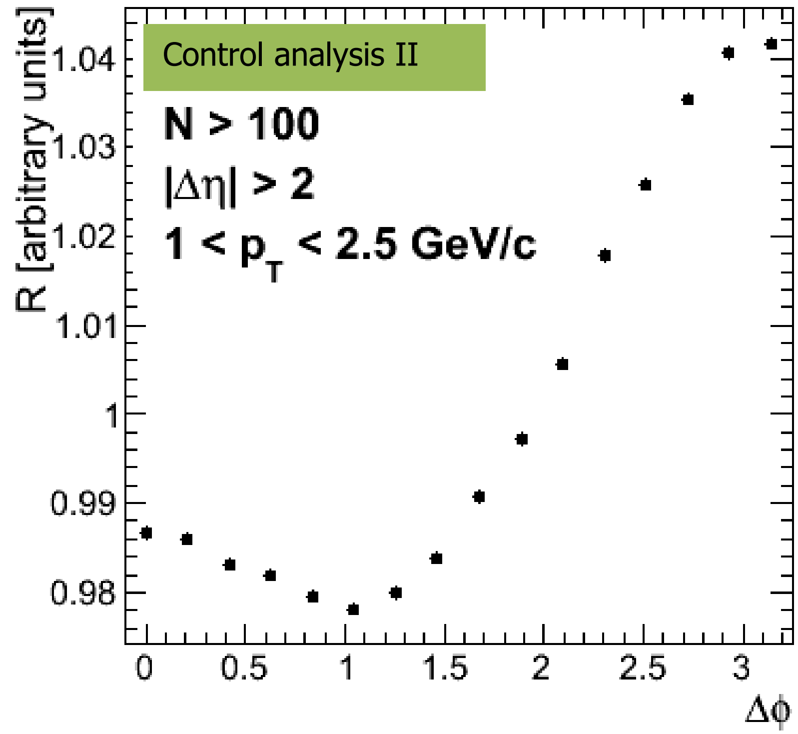


No background or noise effects seen in cross-collision correlations

Cross Check: Analysis Code



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

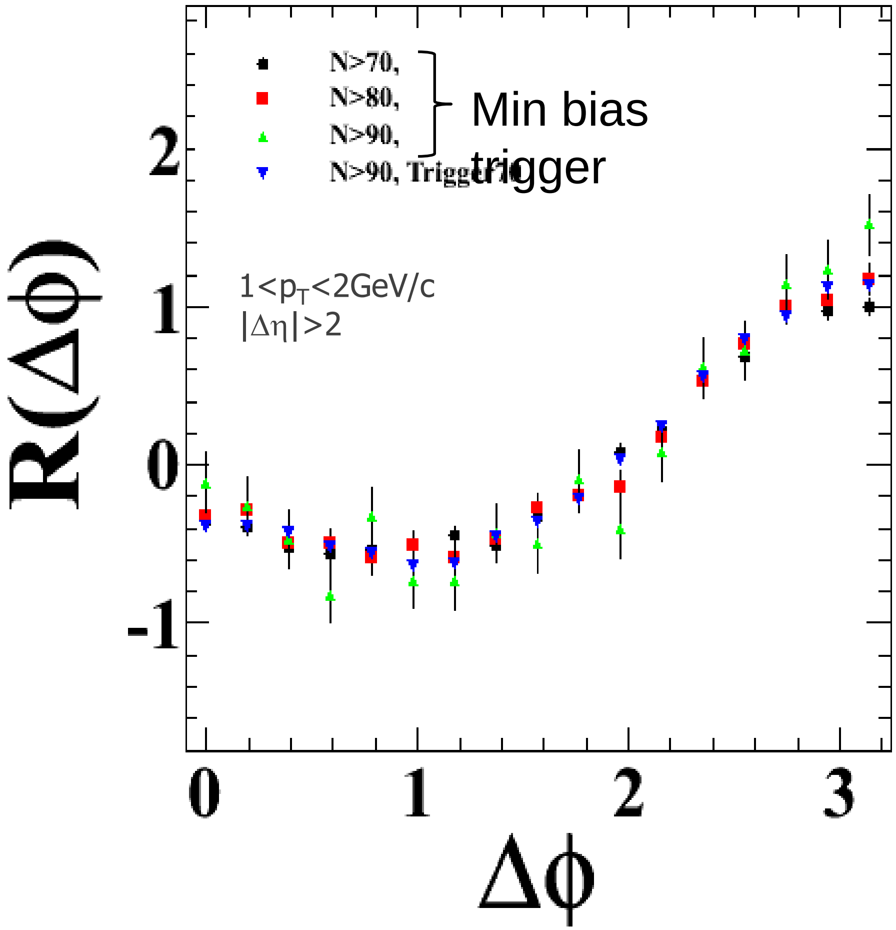


Independent code
Different definition of *R*
Different input file (skim)

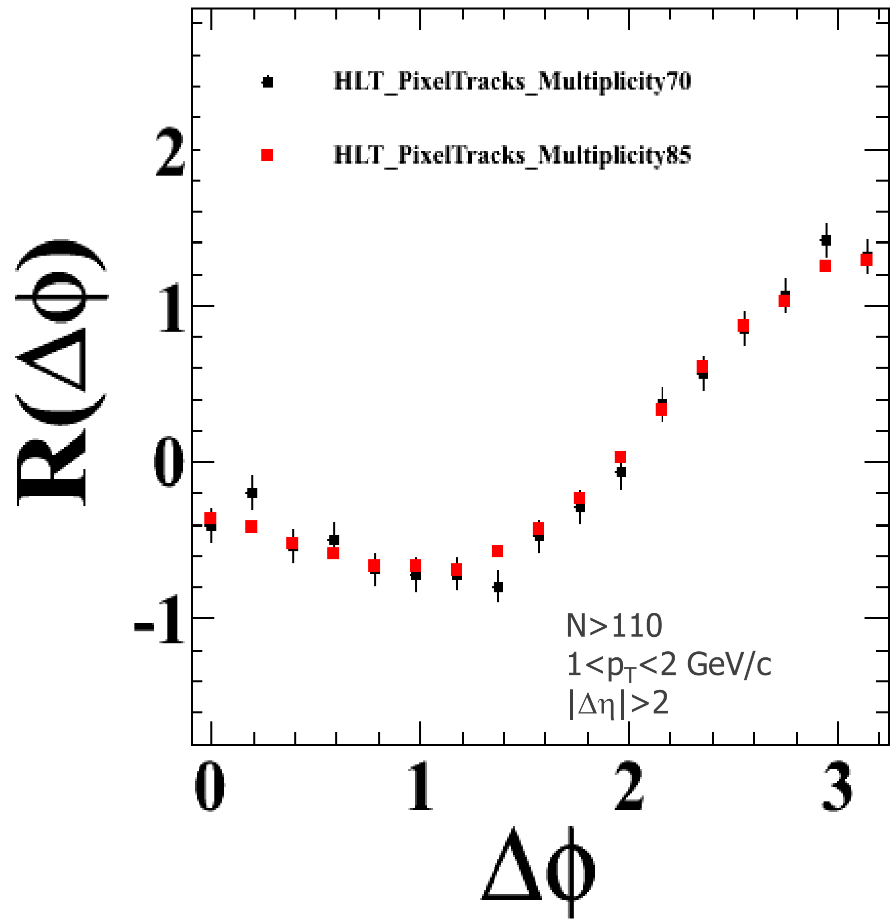
Ridge is seen with three independent analysis codes

Cross Check: Trigger

Min-bias trigger vs high mult trigger



HLT 70 vs HLT 85 for N > 110

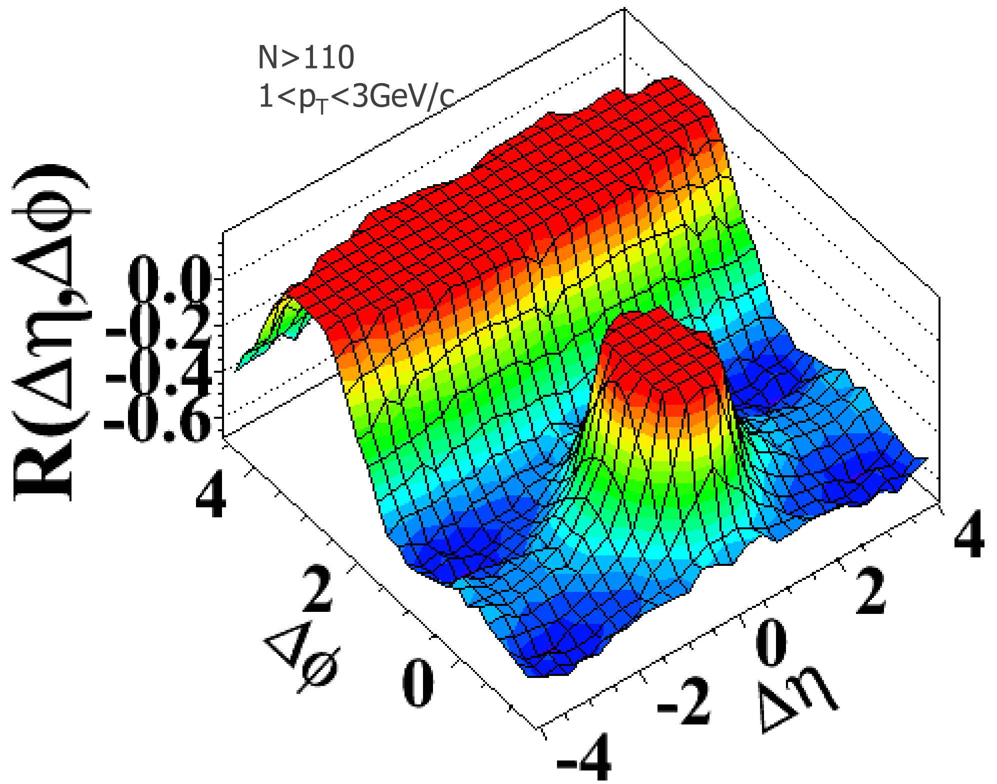


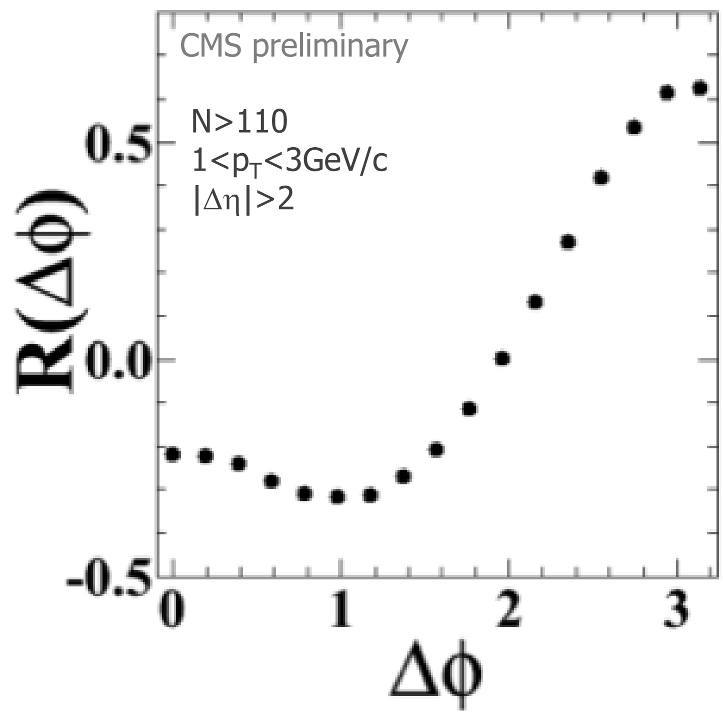
Ridge is seen using
min bias trigger + offline selection

No trigger bias seen from
comparison of trigger paths

Cross Check: ECAL photons

Use ECAL "photon" signal
Mostly single photons from π^0's
No efficiency, and p_T, ϕ smearing corrections



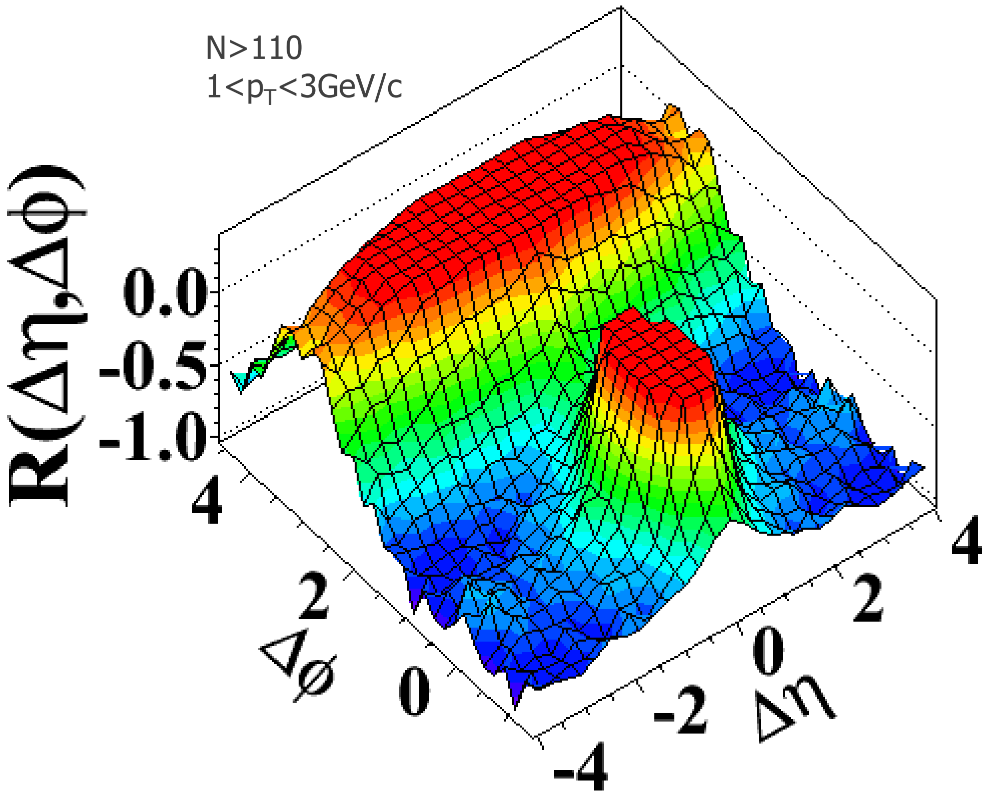


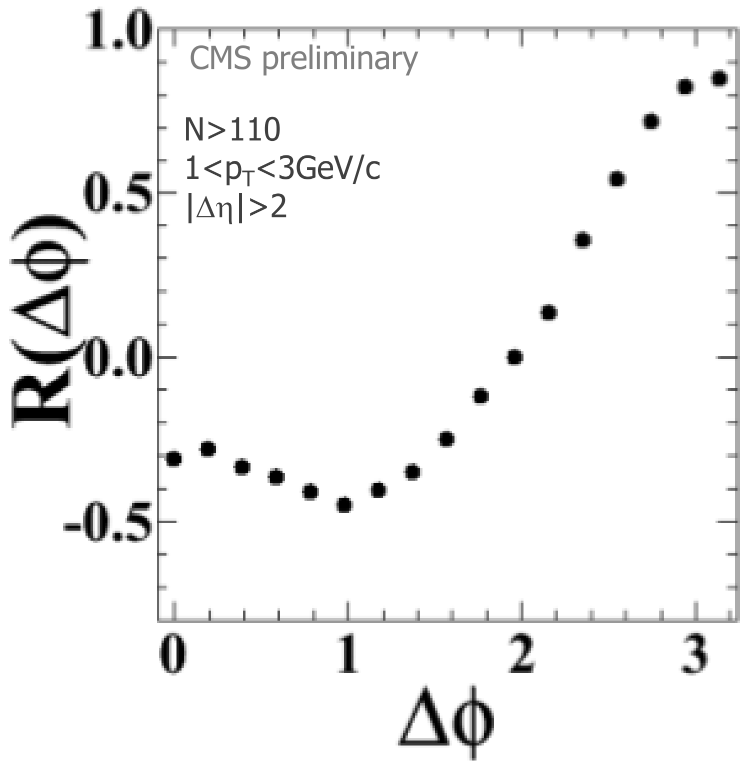
Track-photon correlations

Note: photons reconstructed using "particle flow" event reconstruction technique

Cross Check: ECAL photons

Use ECAL "photon" signal
Mostly single photons from π^0's
No efficiency, and p_T, ϕ 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