Ridge correlation structure in high multiplicity pp collisions with CMS

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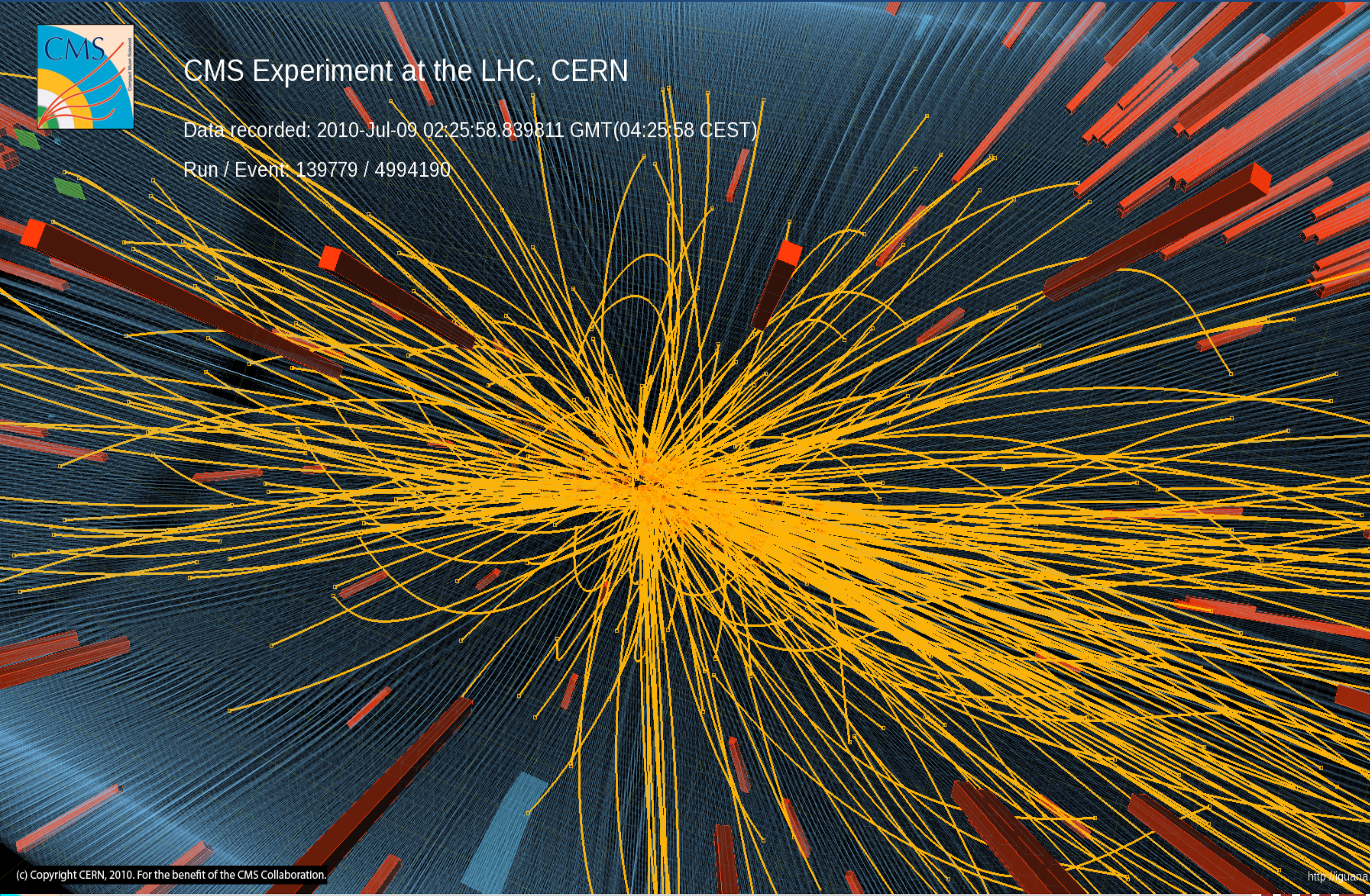
Massachusetts Institute of Technology

for the CMS Collaboration

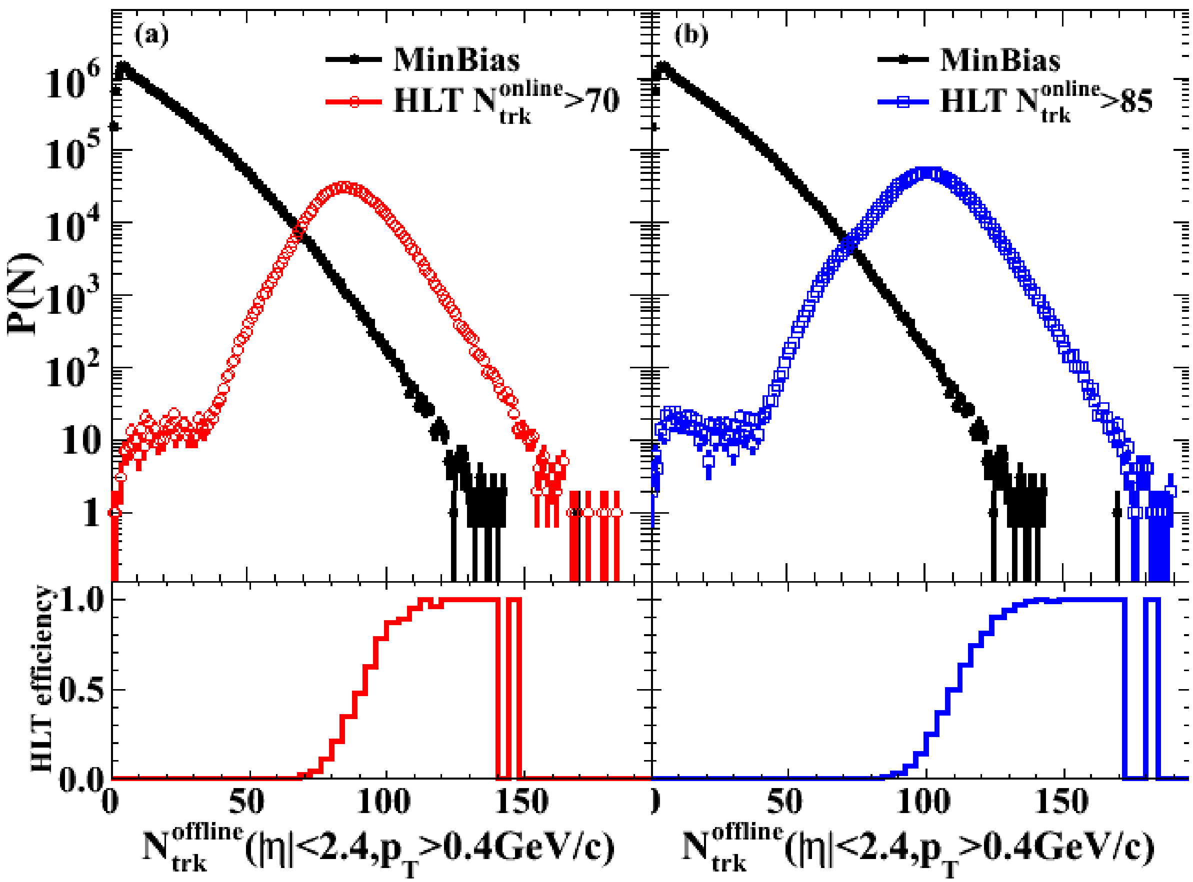
Results from High Multiplicity pp



Trigger on High Multiplicity pp

JHEP 1009:091, 2010

Total integrated luminosity: 980nb^{-1}



Two HLT thresholds:

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

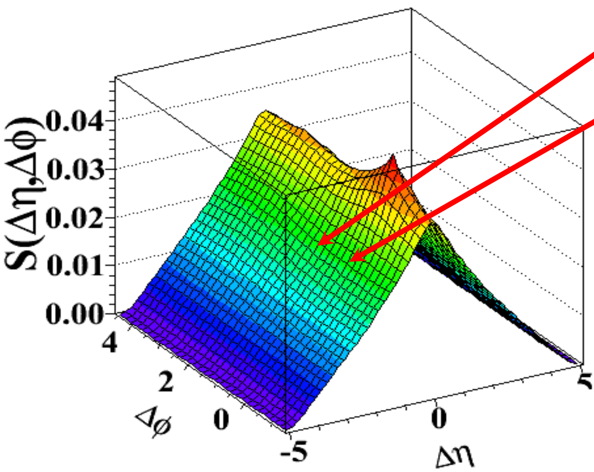
N^{online} > 85 trigger un-prescaled for full 980nb^{-1} data set

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

Angular Correlation Technique

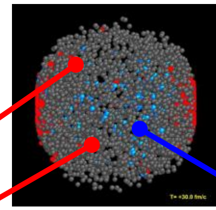
Signal distribution:

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

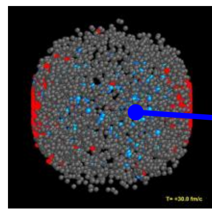


same event pairs

Event 1

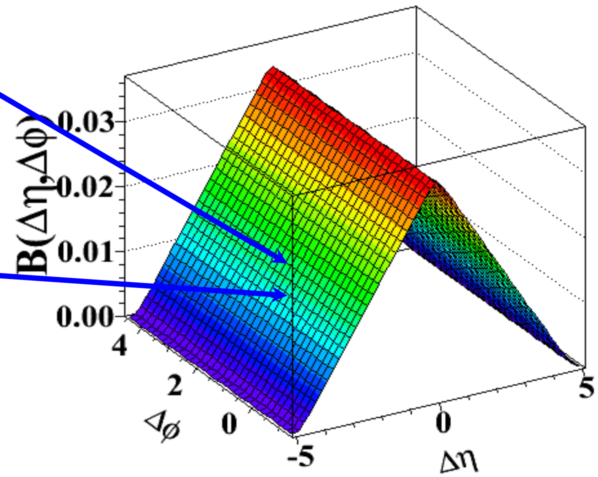


Event 2



Background distribution:

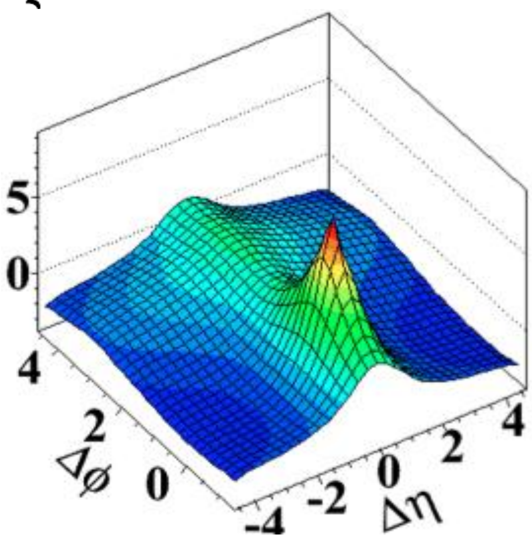
$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2 N^{mix}}{d\Delta\eta d\Delta\varphi}$$



mixed event pairs

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

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



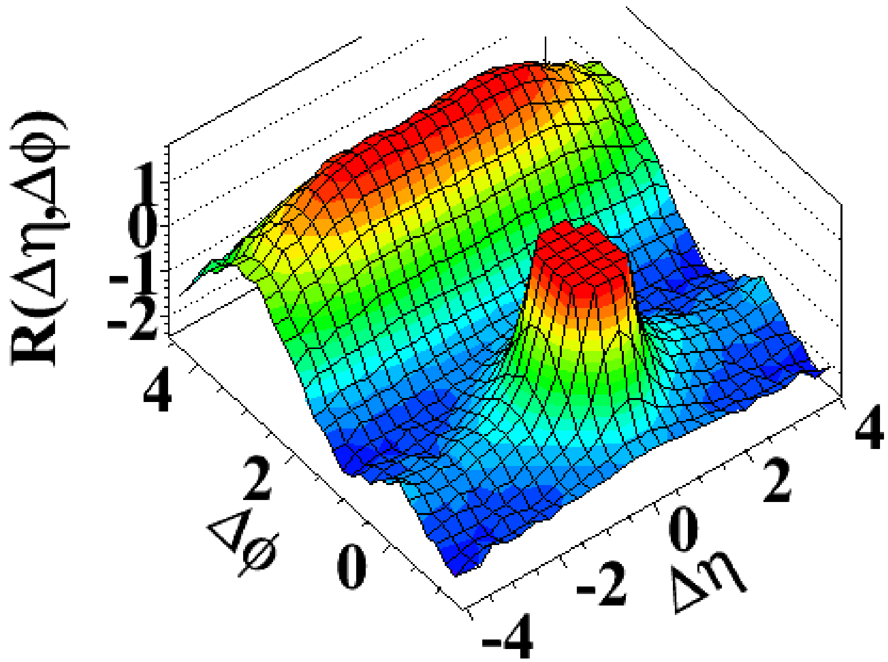
$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)}$$

Divide signal by background

Correlations in High Multiplicity pp

Intermediate p_T: 1-3 GeV/c

High multiplicity pp (N>110)

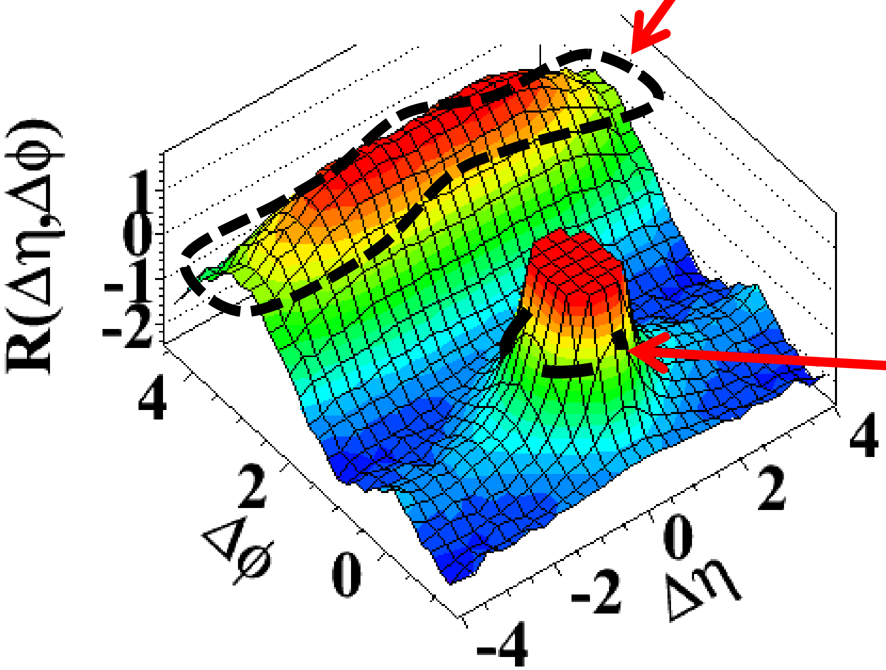


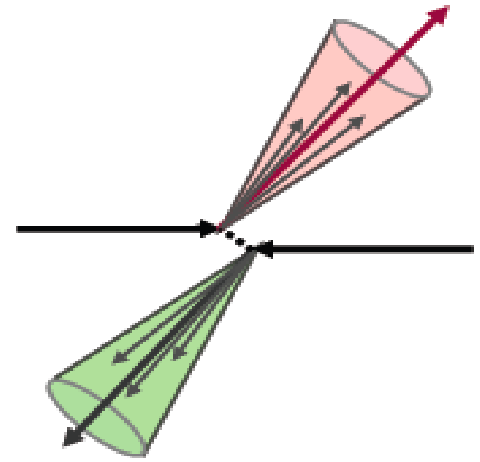
Correlations in High Multiplicity pp

Intermediate p_T: 1-3 GeV/c

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

High multiplicity pp (N>110)





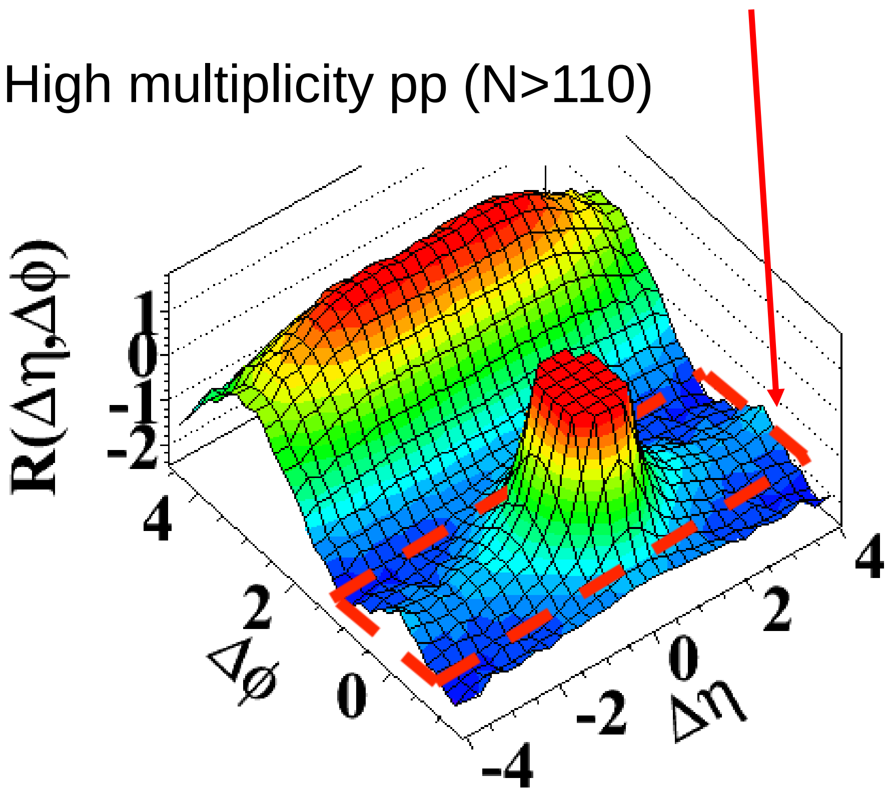
“Near-side” ($\Delta\phi$, $\Delta\eta \sim 0$)
correlations from single jets

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)



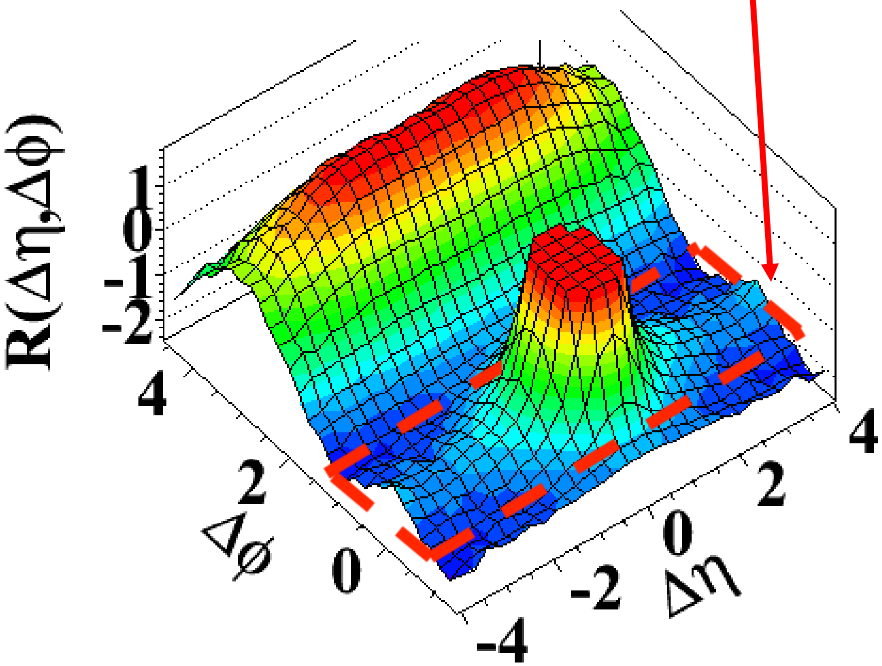
Correlations in High Multiplicity pp

Intermediate p_T: 1-3 GeV/c

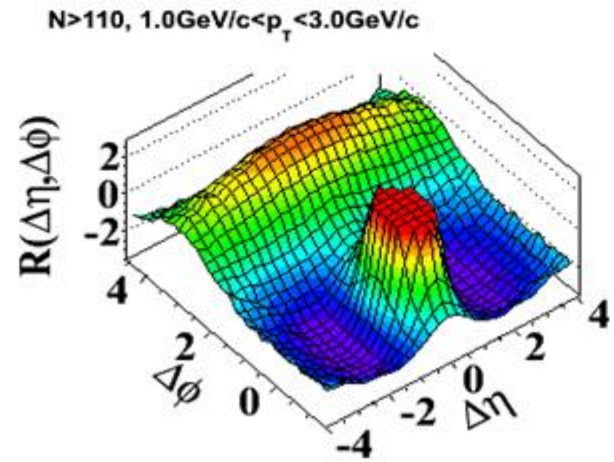
Striking "**ridge-like**" structure extending over $\Delta\eta$ at $\Delta\phi \sim 0$

(not observed before in hadron collisions or MC models)

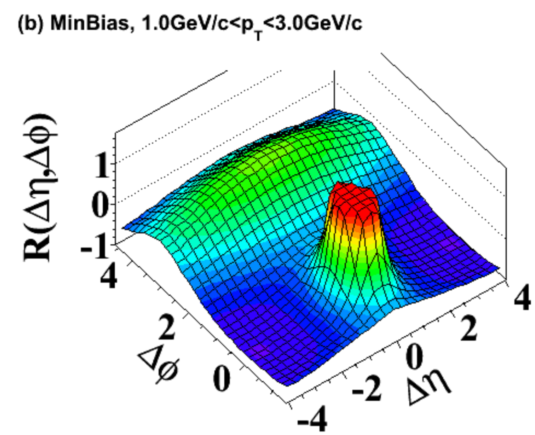
High multiplicity pp (N>110)



High multiplicity MC



Minbias pp

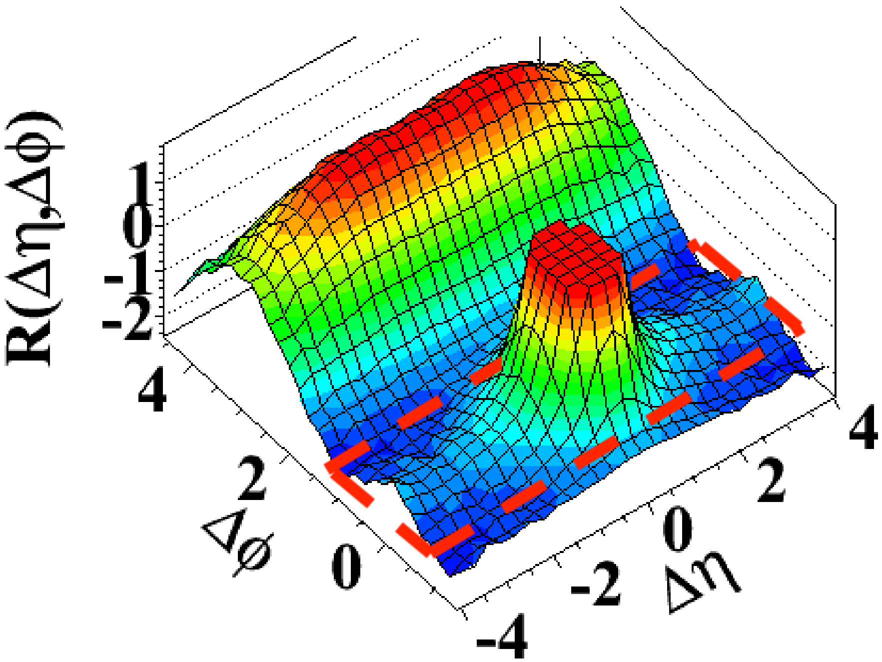


Correlations in High Multiplicity pp

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

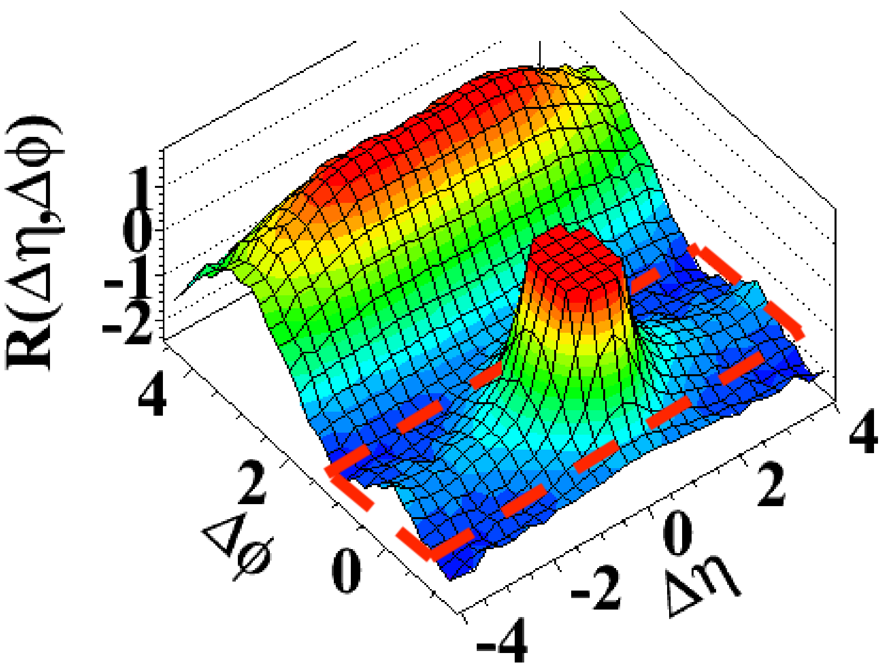
Intermediate p_T: 1-3 GeV/c

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

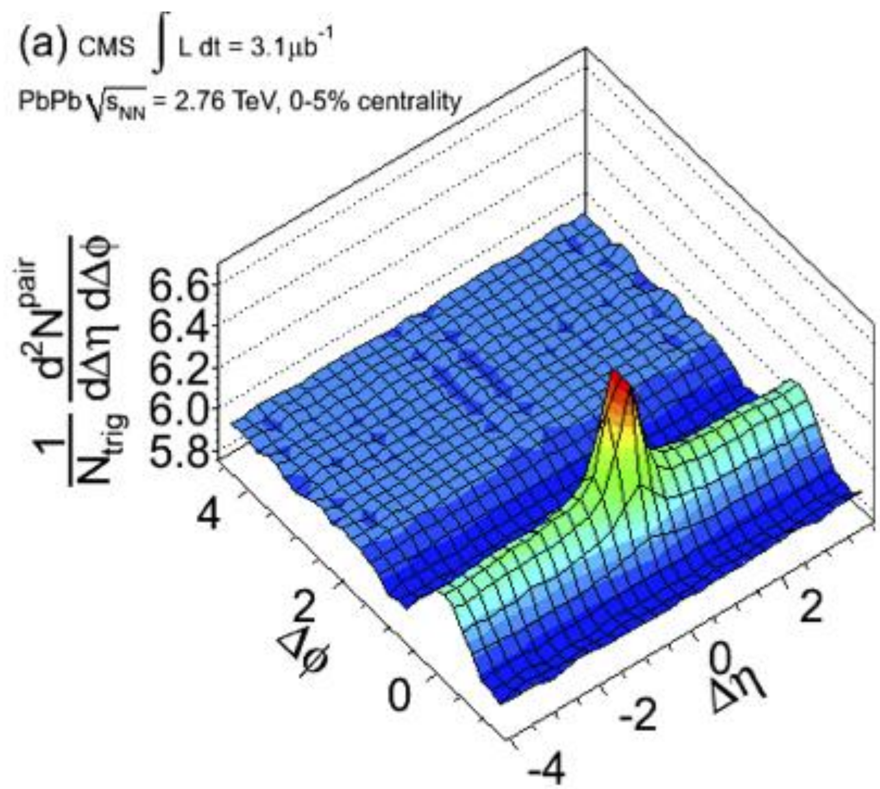
arXiv:1105.2438

(Similarity to Heavy Ion)

High multiplicity pp (N>110)

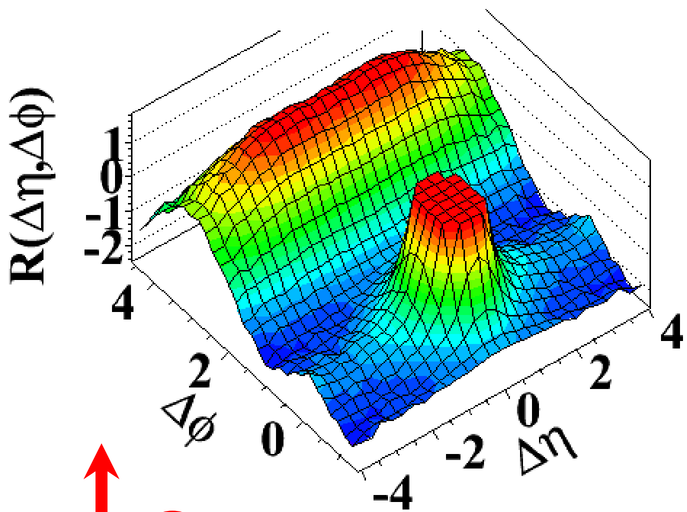


CMS PbPb 2.76 TeV



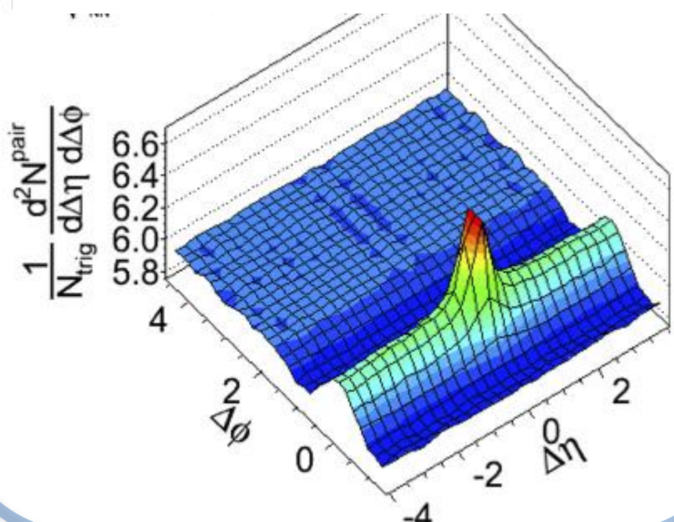
Ridge in high multiplicity pp

CMS pp 7 TeV, N ≥ 110



?

CMS PbPb 2.76 TeV, 0-5%



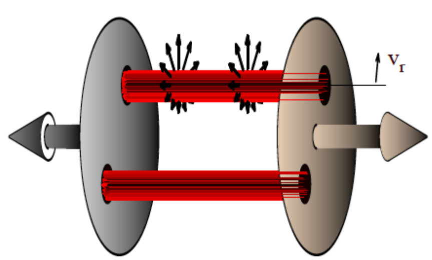
Interpretations:

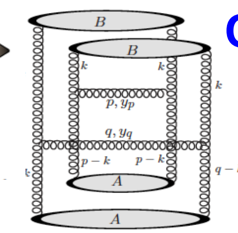
59 citations
[*(link to SPIRES)*]

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

Jet

Glasma tube

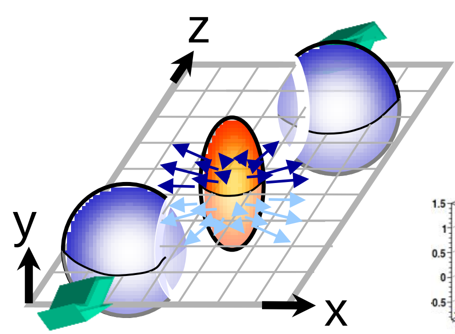




— **Color Glass Condensate**

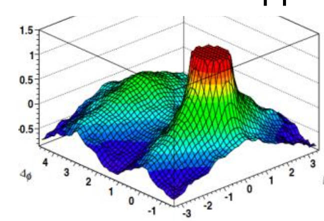
Phys. Lett. B697:21-25, 2011

Hydrodynamic flow



— **Quark Gluon Plasma**

EPOS model: pp

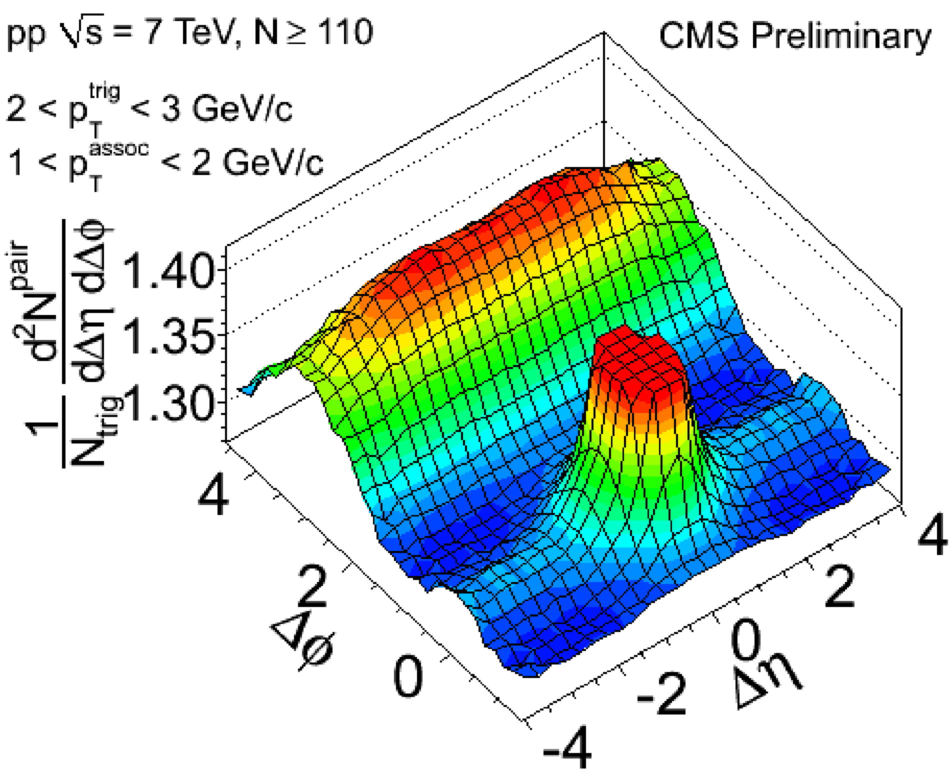


K. Werner, WWND2011

⋮

New Results

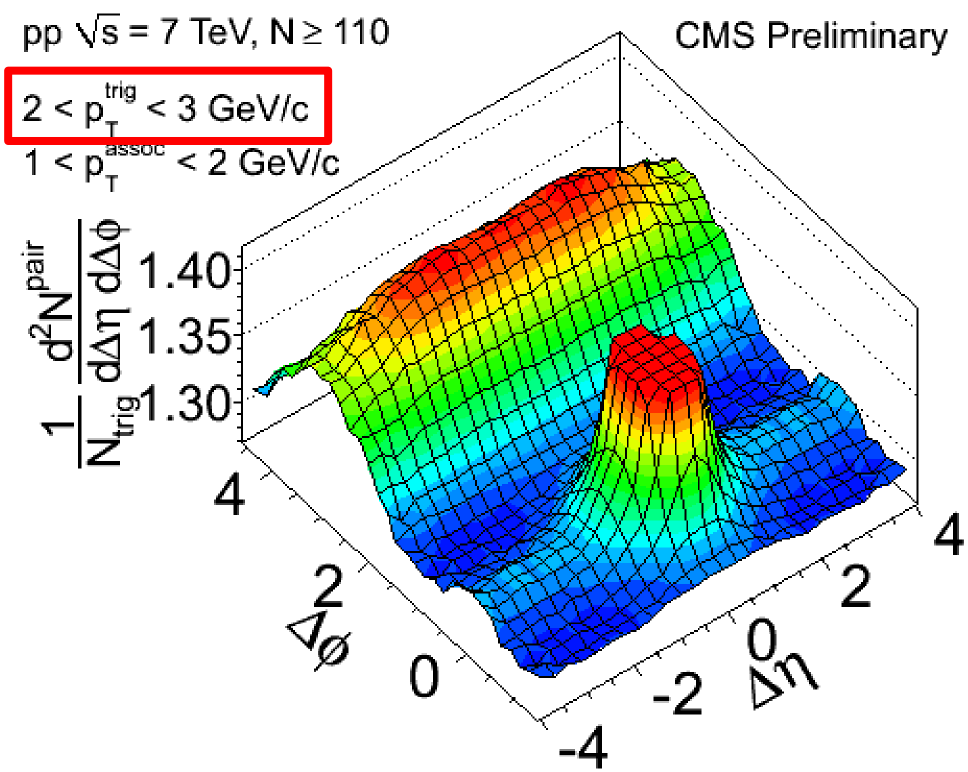
- 2x as much data
  - |Δη| dependence
  - p_T dependence
  - Multiplicity dependence

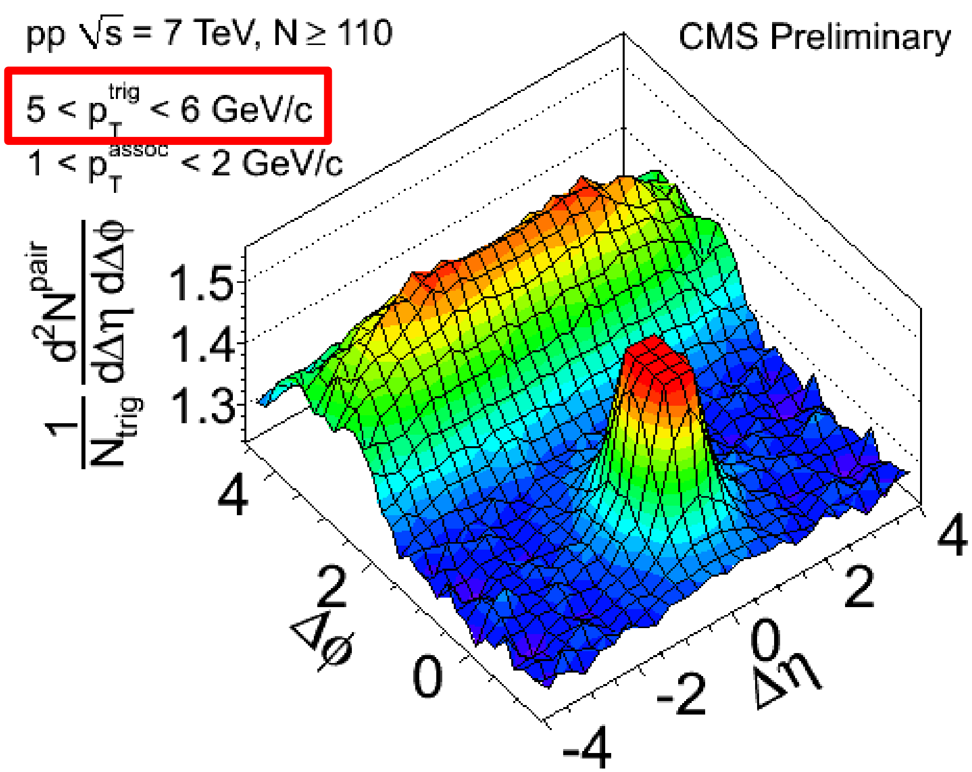


New Results

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

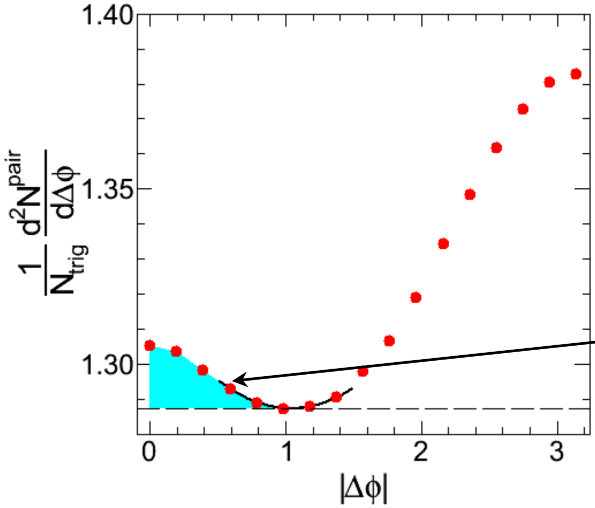
Ridge goes away at high p_T

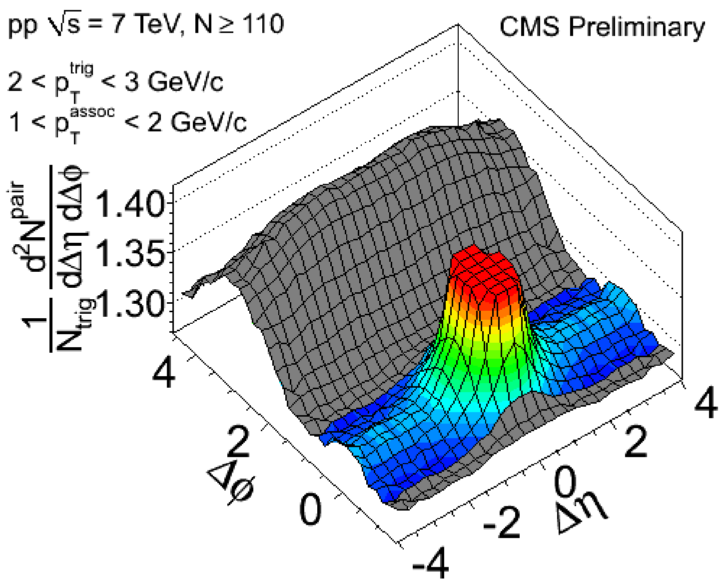


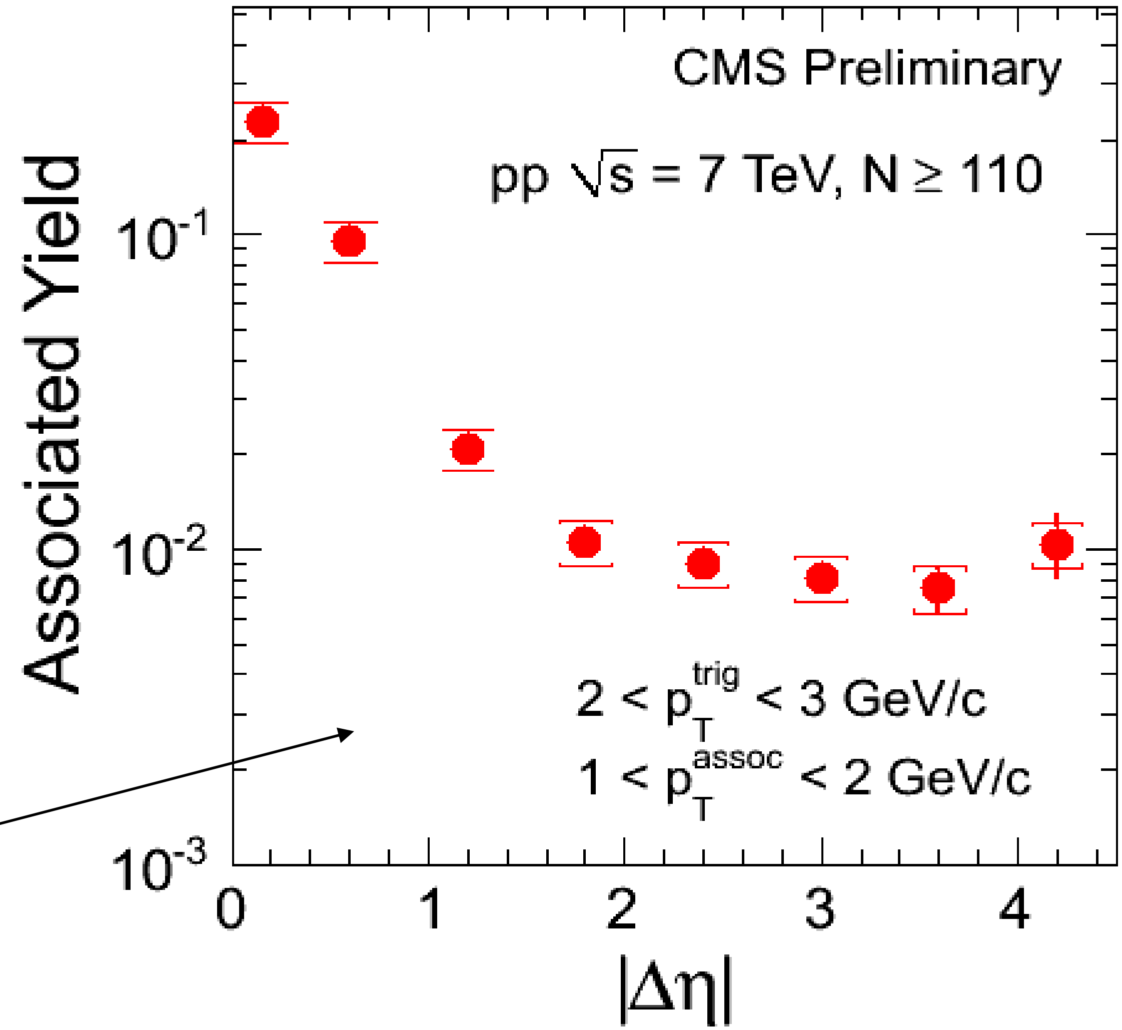


$|\Delta\eta|$ dependence of the ridge

Zero-Yield-At-Minimum (ZYAM)

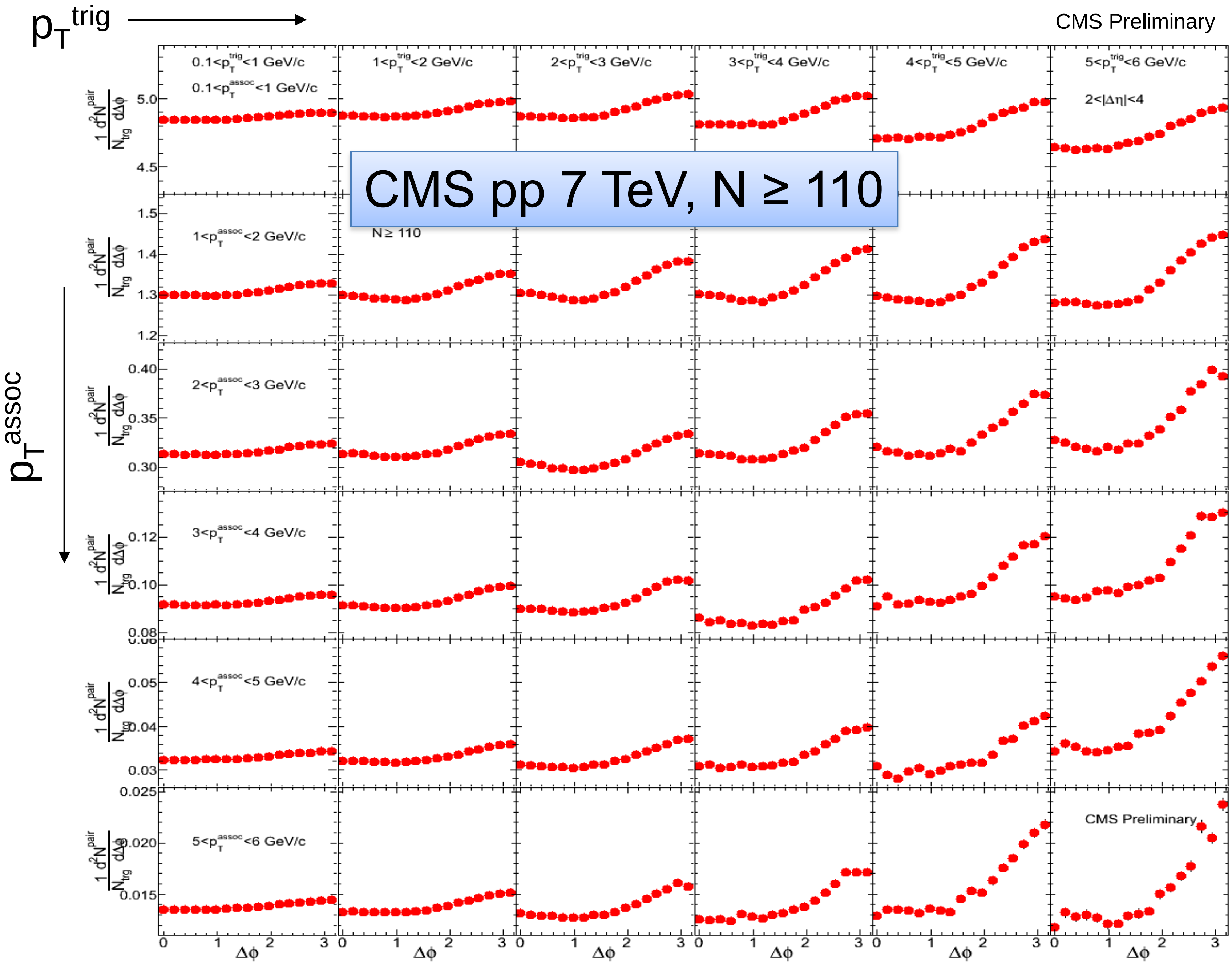




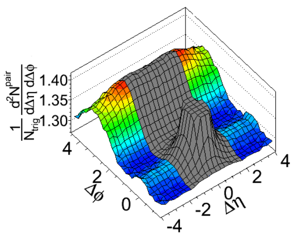


Ridge is mostly flat in $|\Delta\eta|$

Δϕ projections in various p_T ranges



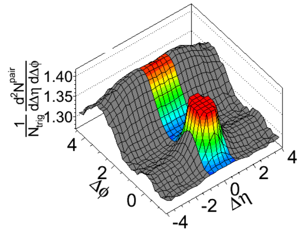
2<|Δη|<4



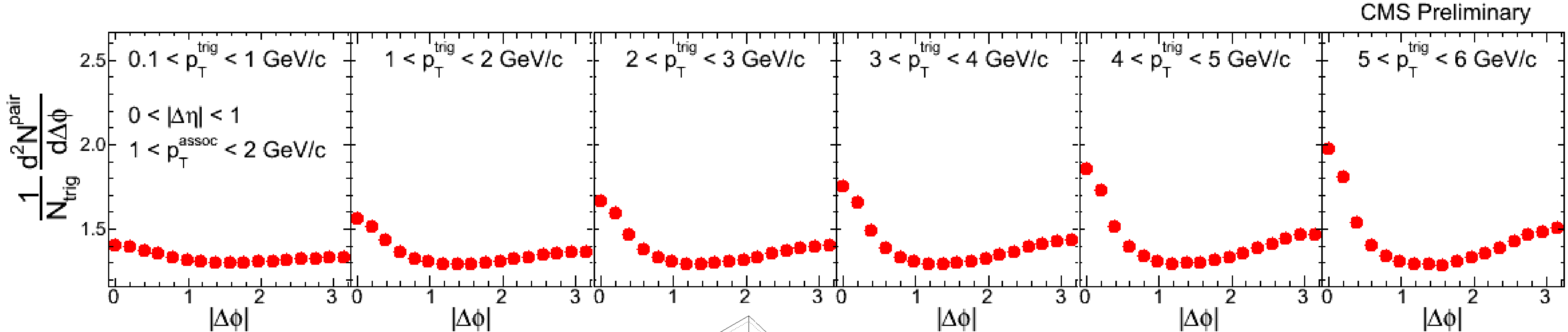
Δφ projections in bins of p_T

CMS pp 7 TeV, N ≥ 110

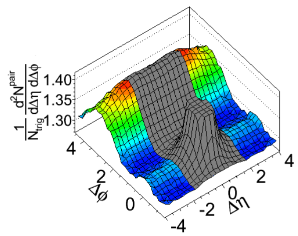
Jet region (|Δη|<1)



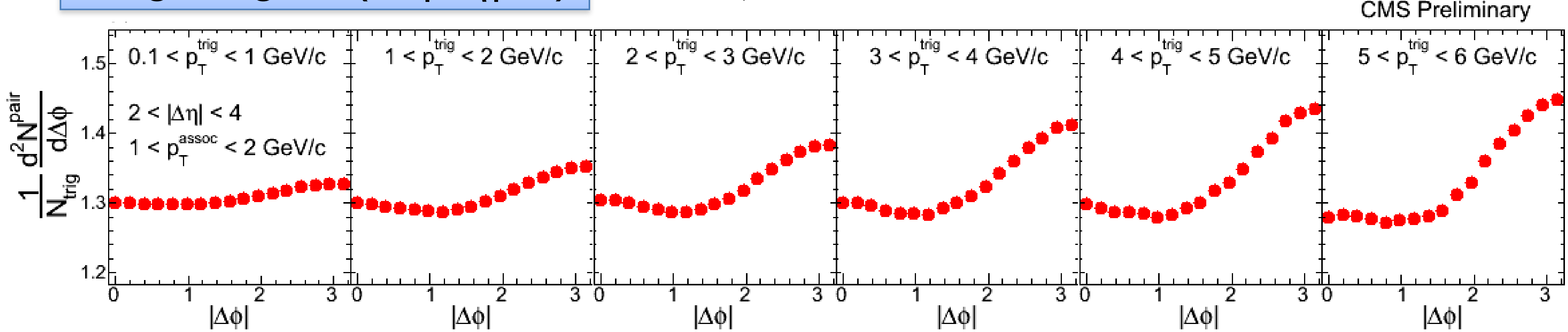
p_T →



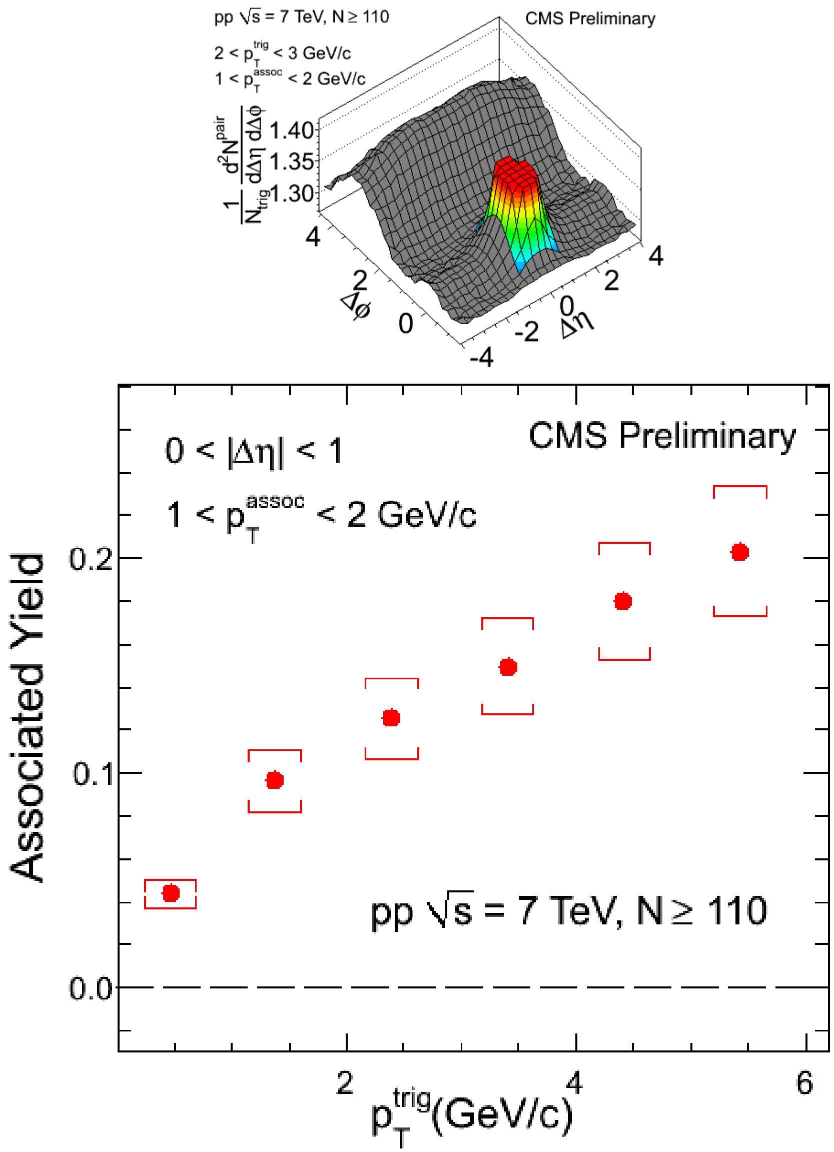
Ridge region (2<|Δη|<4)



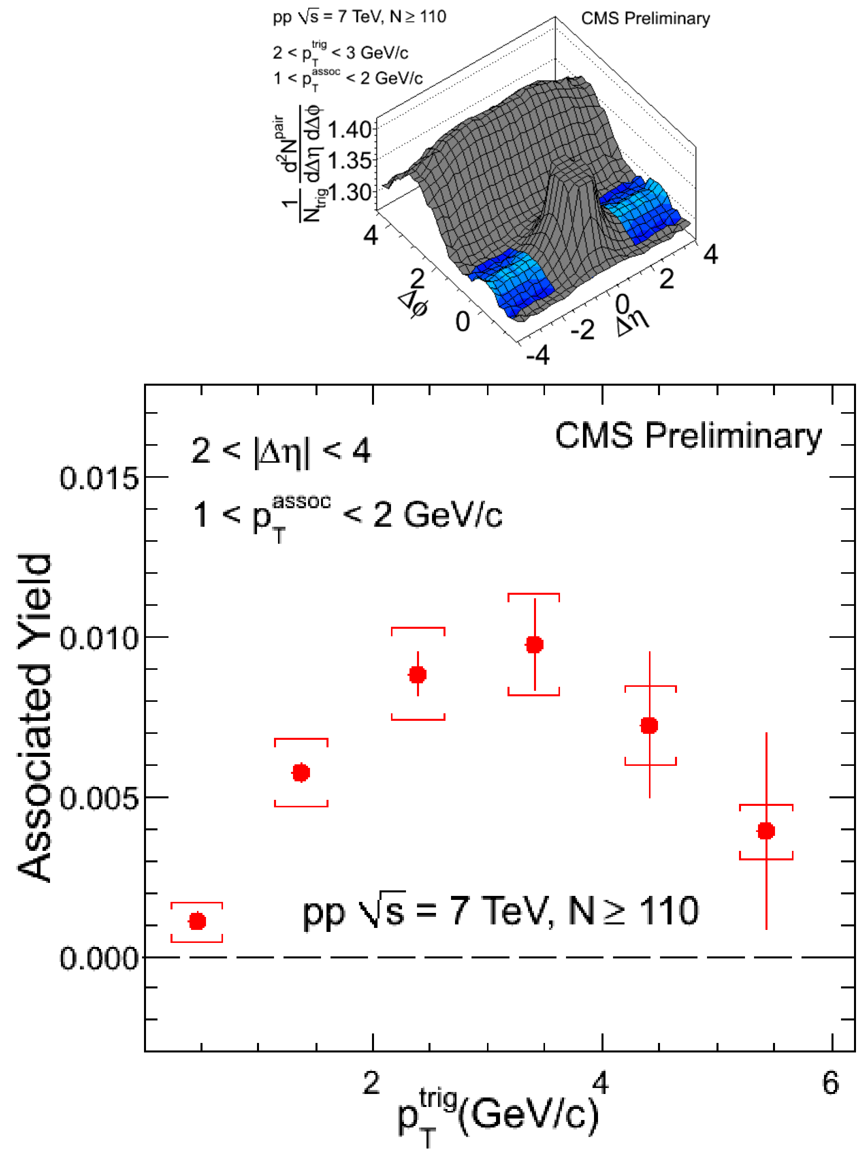
p_T →



p_T dependence of the ridge



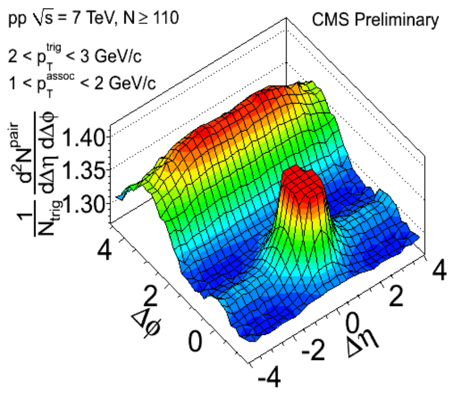
Jet region ($|\Delta\eta|<1$)



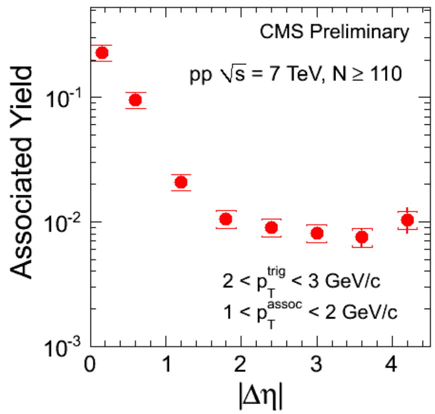
Ridge region ($2<|\Delta\eta|<4$)

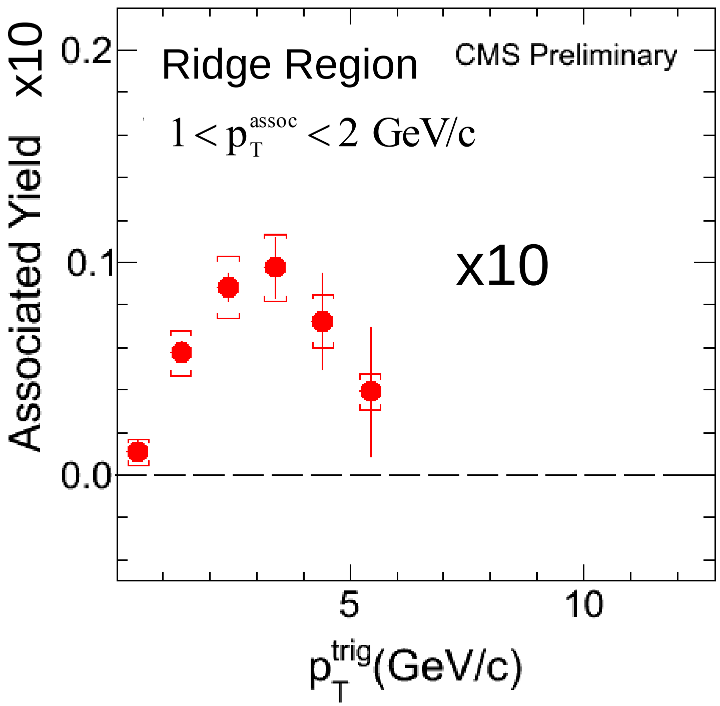
Ridge in pp and PbPb

CMS pp 7 TeV, N ≥ 110

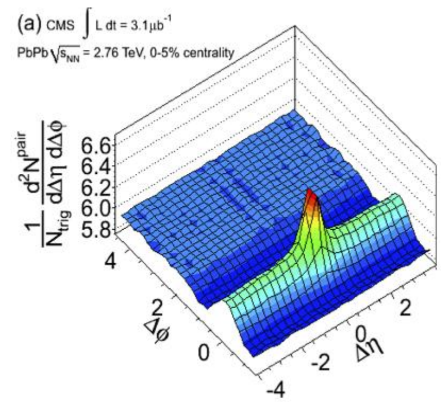


|Δη| dependence

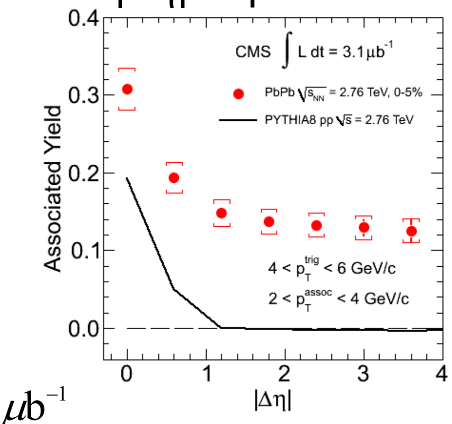


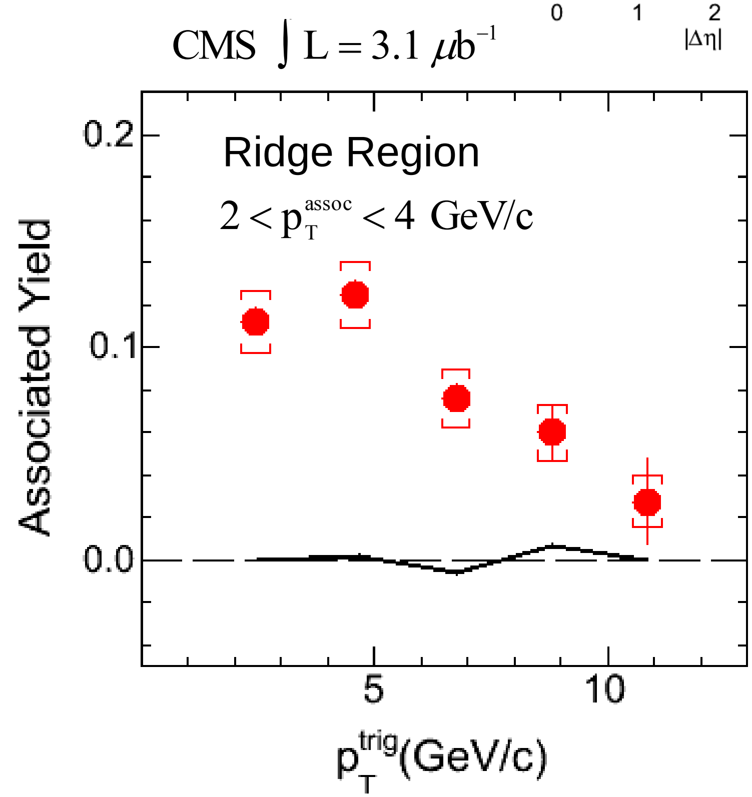


CMS PbPb 2.76 TeV, 0-5%



|Δη| dependence



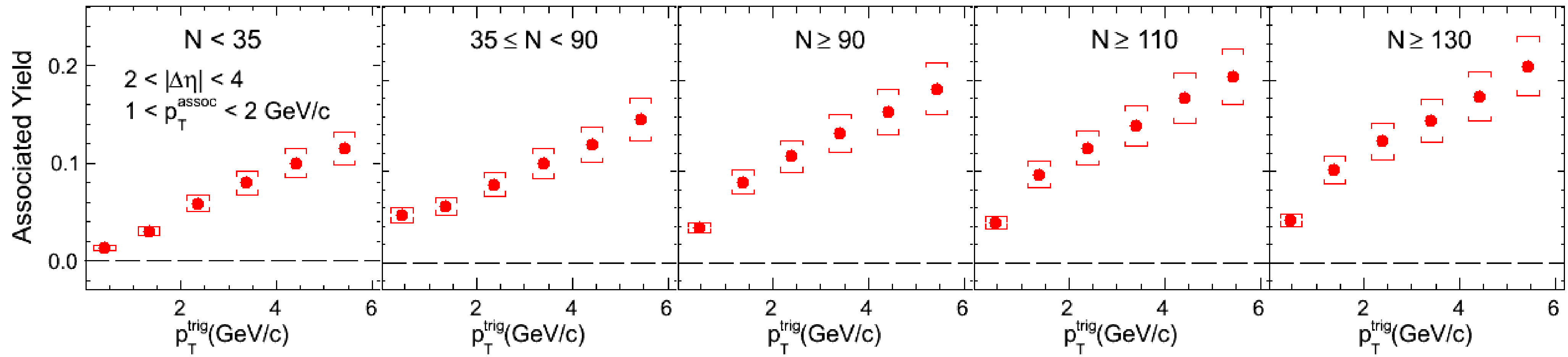


Near-side yield vs p_T

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

N

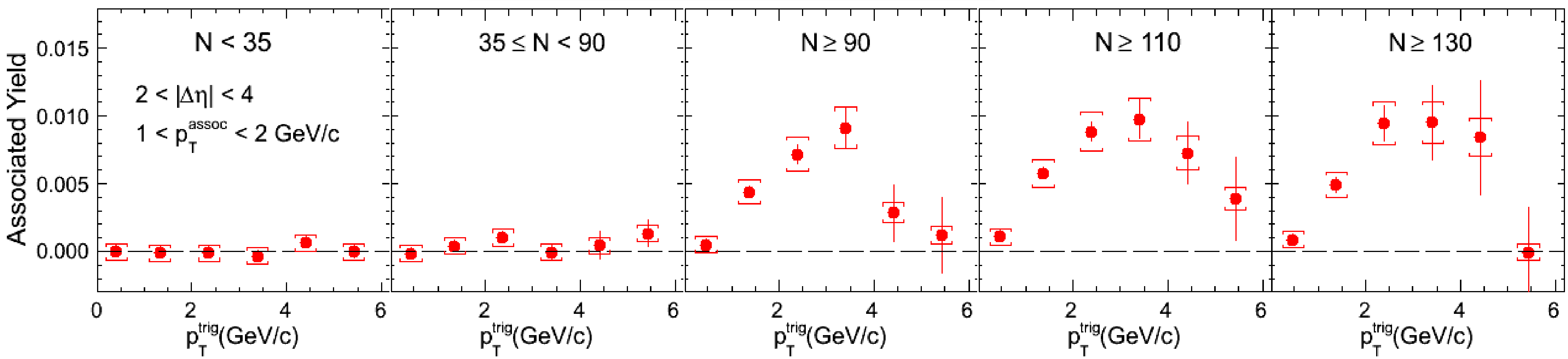
CMS Preliminary



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

N

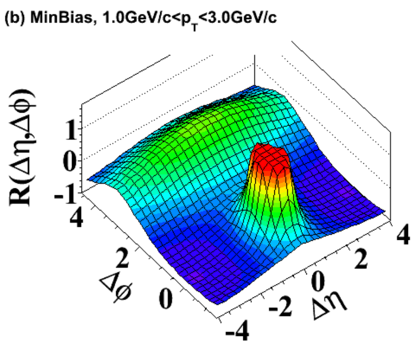
CMS Preliminary



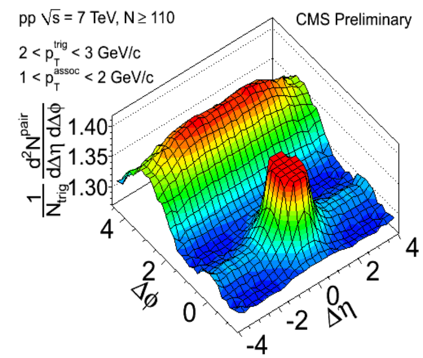
Ridge first increases with p_T, and then drops at high p_T

Near-side yield vs p_T

MinBias-like

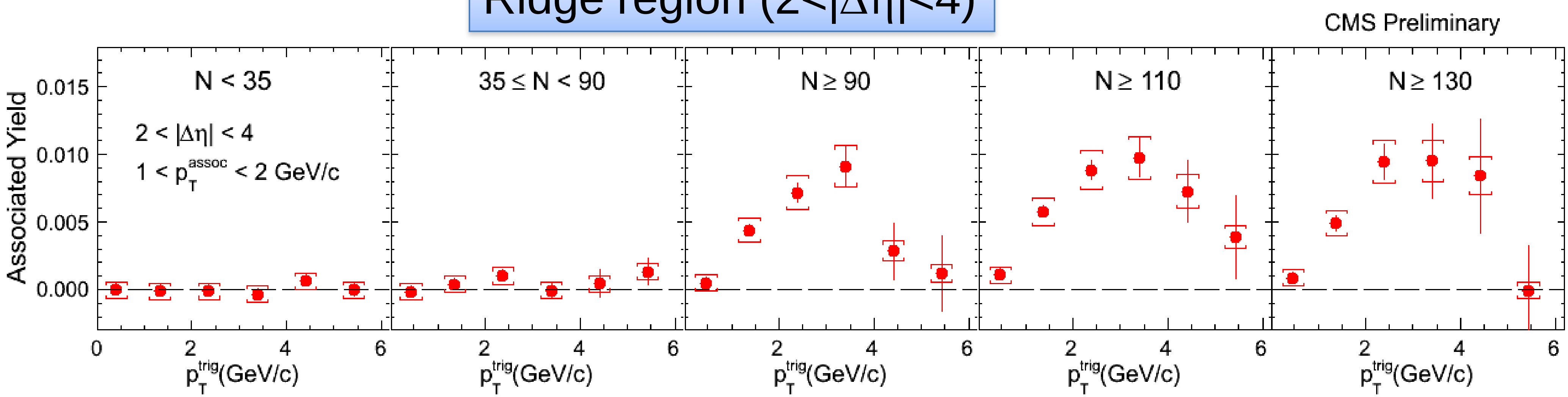


HighMult-like



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

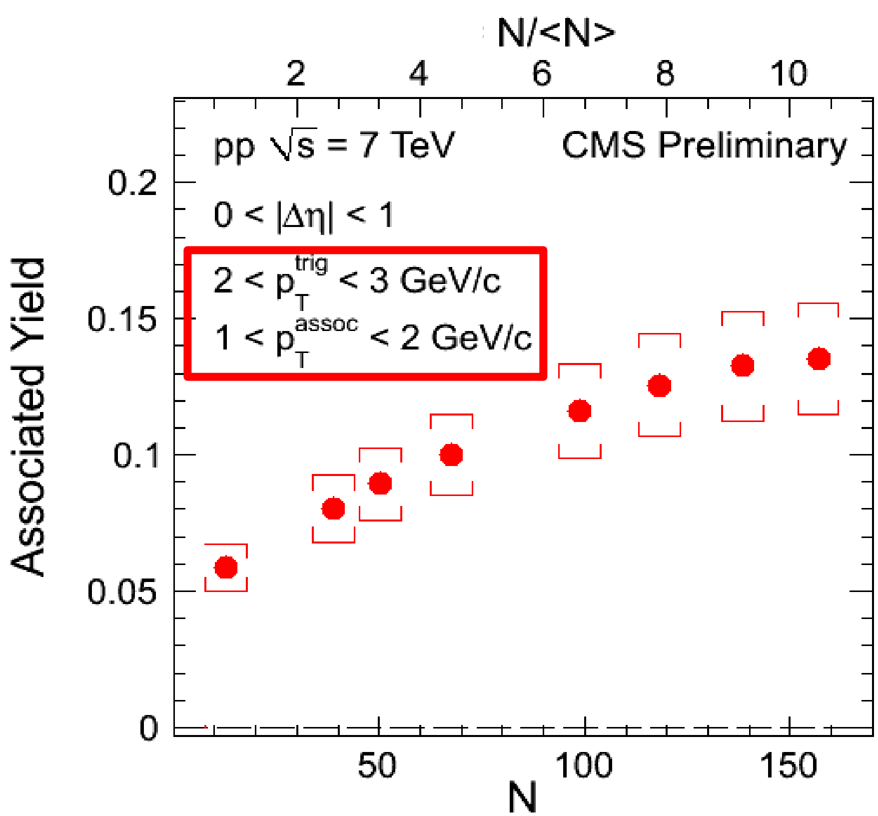
N



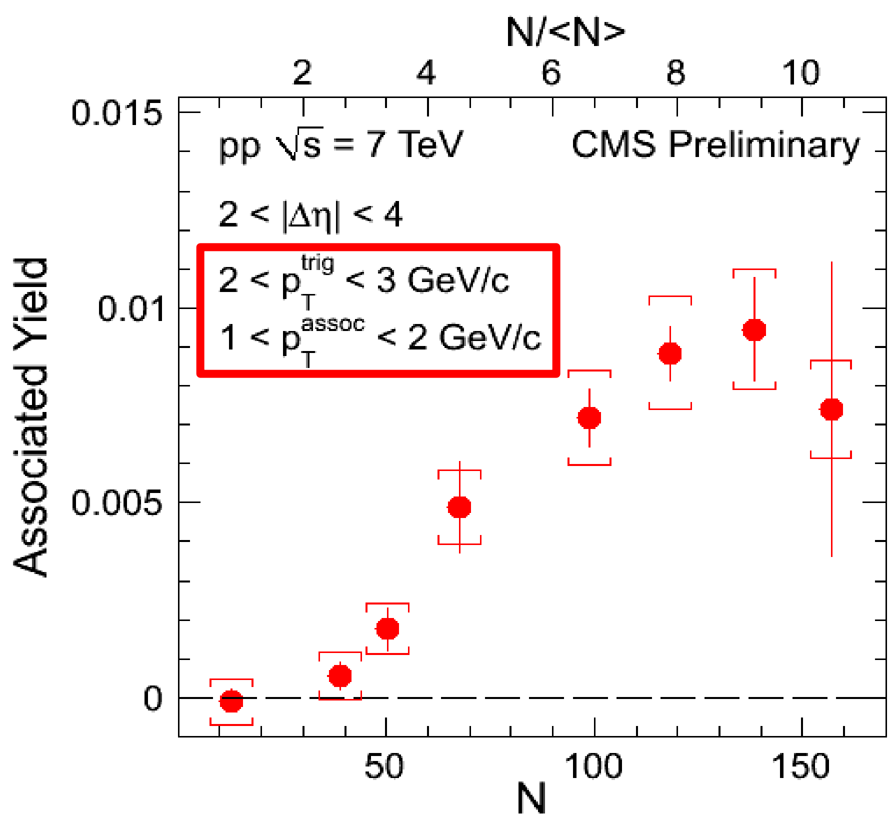
Ridge first increases with p_T, and then drops at high p_T

Near-side yield vs Multiplicity

Jet region (|Δη|<1)



Ridge region (2<|Δη|<4)



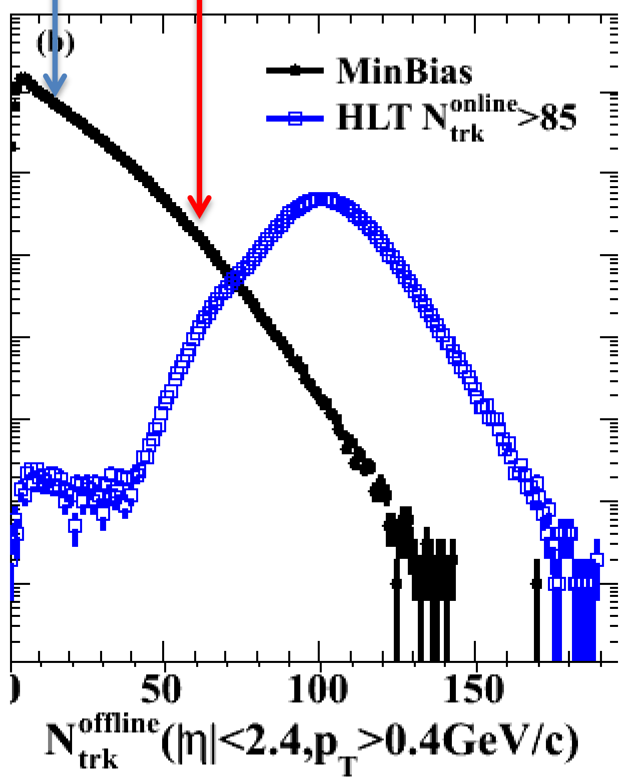
Ridge in pp turns on around N ~ 50-60 (4x MinBias) smoothly

(<N> ~ 15 in MinBias pp events)

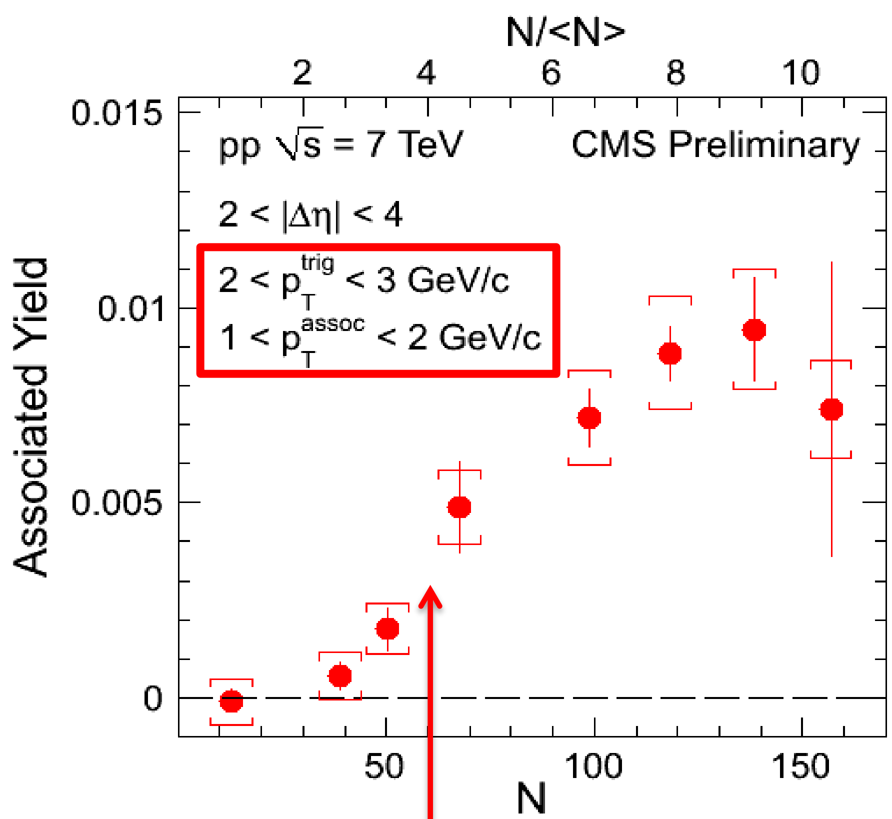
Near-side yield vs Multiplicity

Ridge starts to turn on

<N>



Ridge region (2<|Δη|<4)



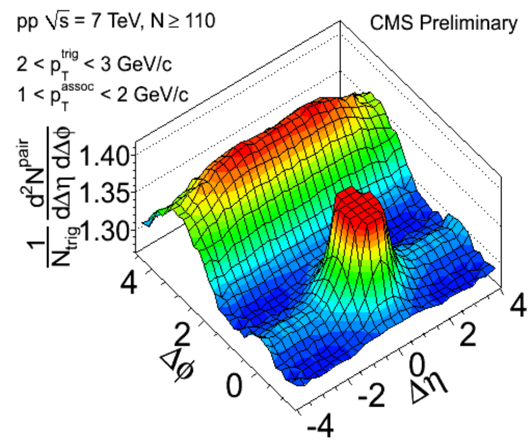
Ridge in pp turns on around N ~ 50-60 (4x MinBias) smoothly

(<N> ~ 15 in MinBias pp events)

Summary

- Surprising new effect in pp
- pt, |Δη|, multiplicity dependence
- New testing ground for high density QCD physics
- Outlook
  - pt distribution, global properties, PID correlations…
  - Check more HI observables (jet quenching, dijet asymetry, low pt PID spectra…)

CMS pp 7 TeV, N ≥ 110



Backups

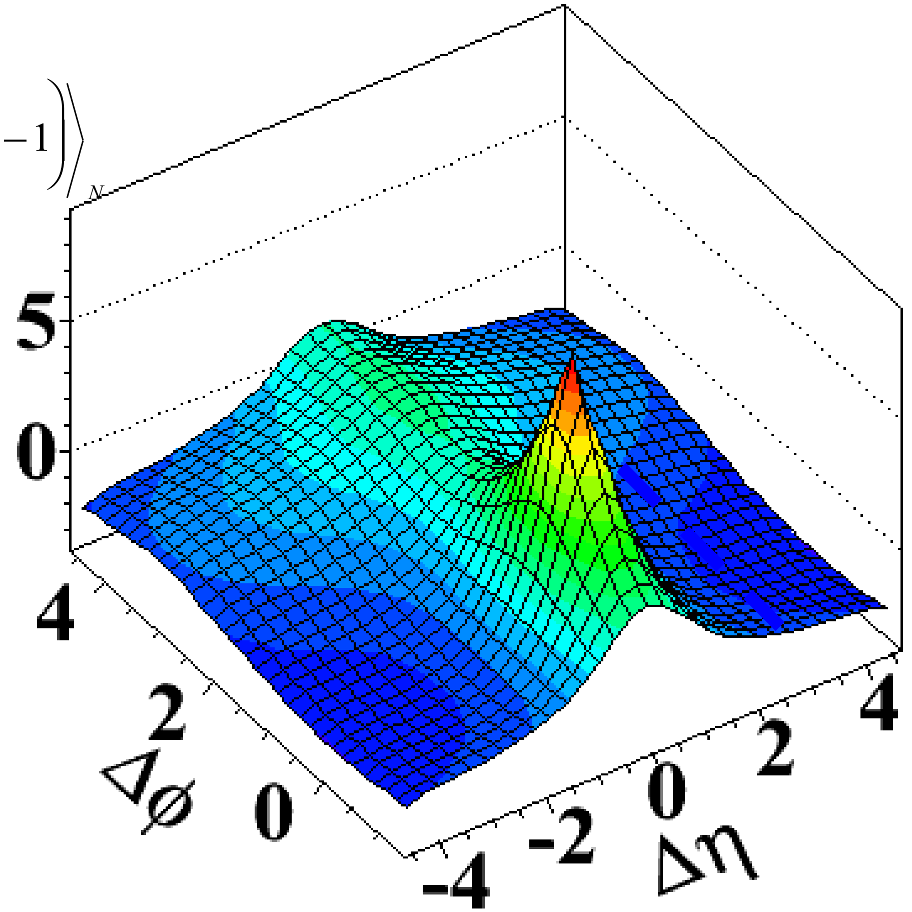
Understanding the Correlation Structure

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

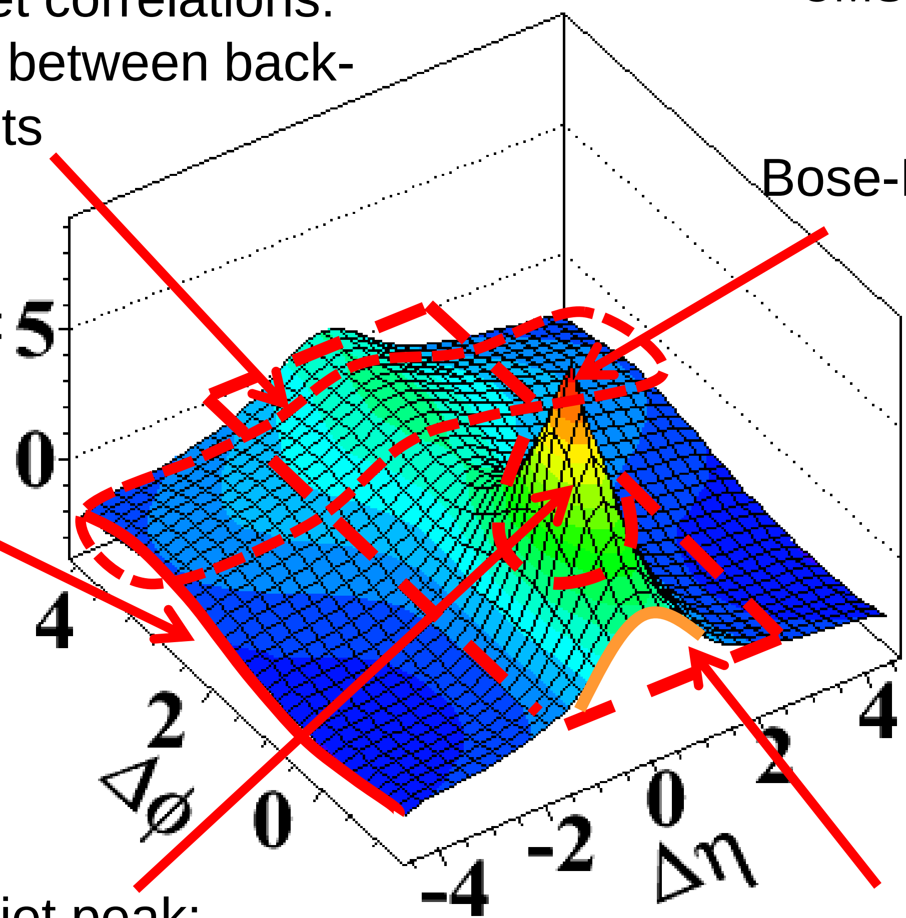
p_T inclusive

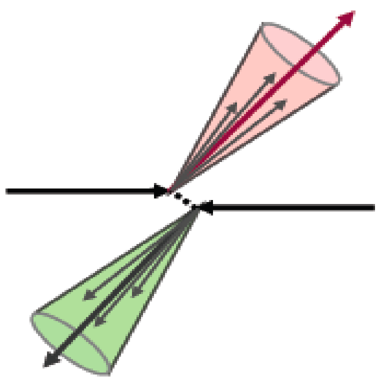
CMS 7TeV pp minimum bias

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

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

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

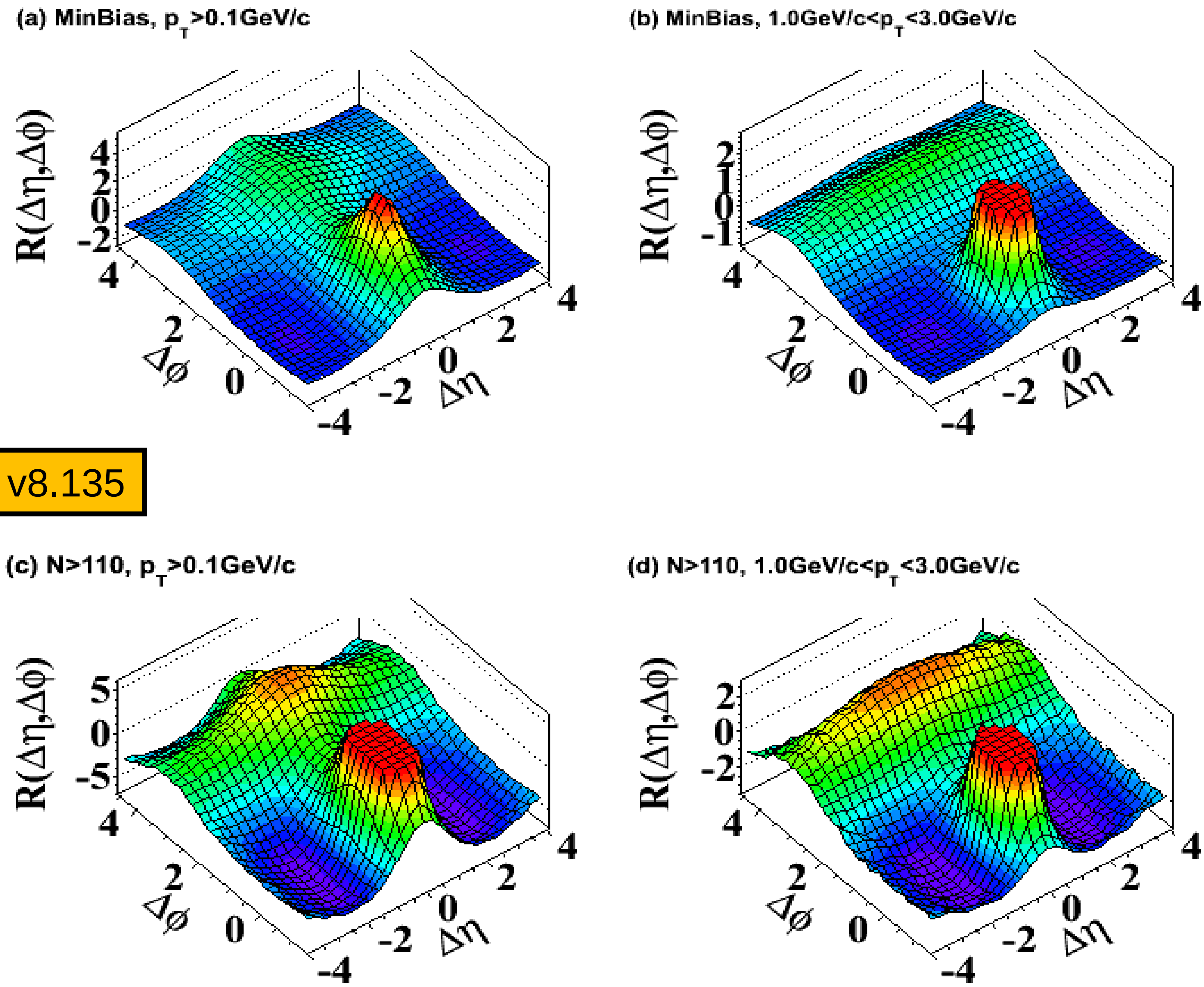




"Near-side" ($\Delta\phi \sim 0$) jet peak: Correlation of particles within a single jet

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

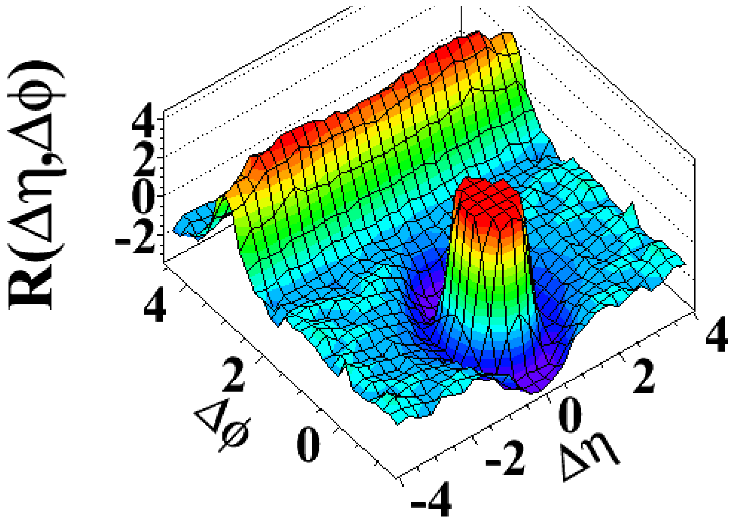
Comparing to various MC



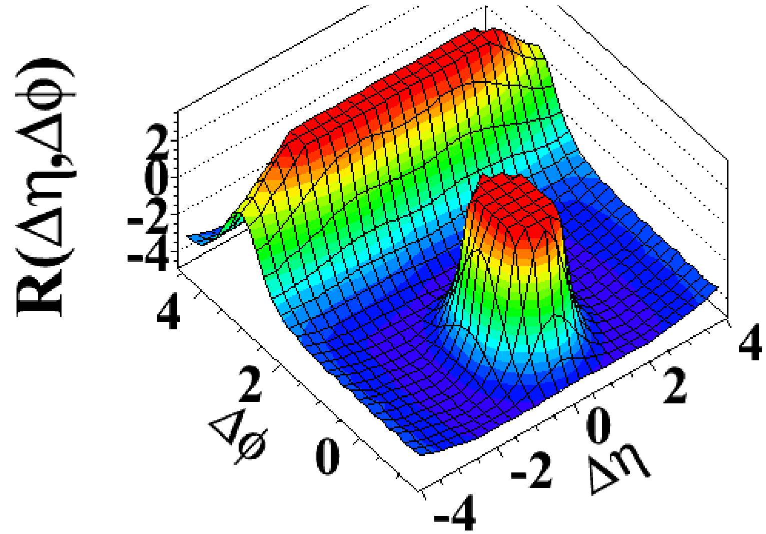
PYTHIA8, v8.135

More MC models

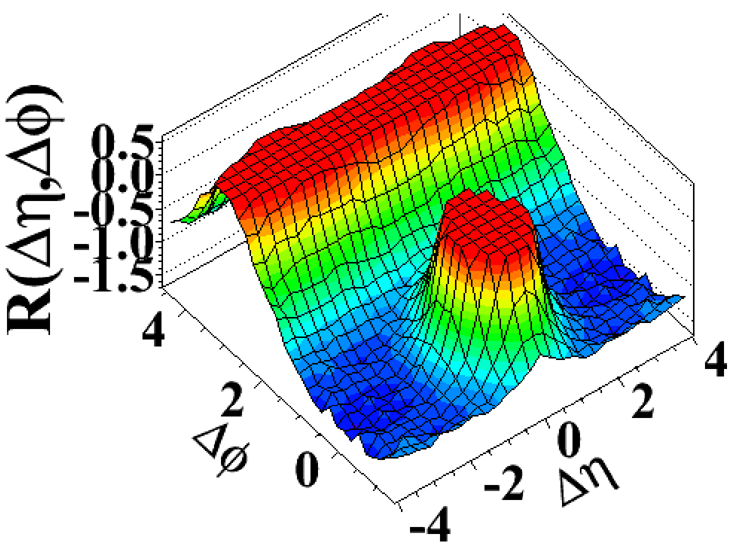
PYTHIA D6T MinBias, N>70



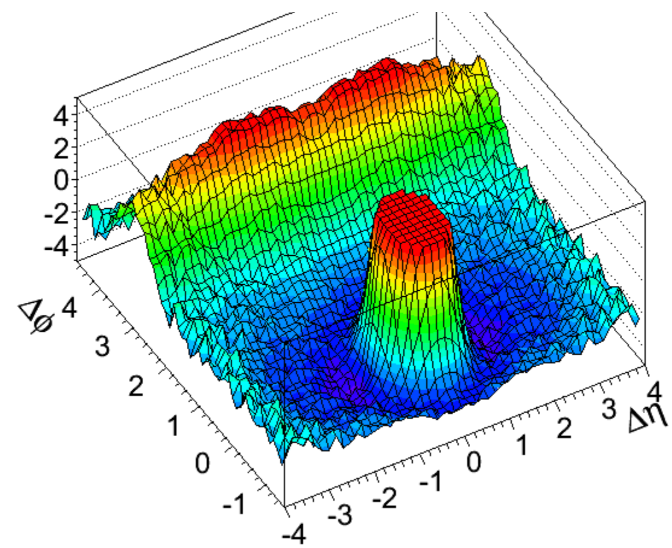
PYTHIA D6T, Dijet 80-120GeV



HERWIG++, N>110

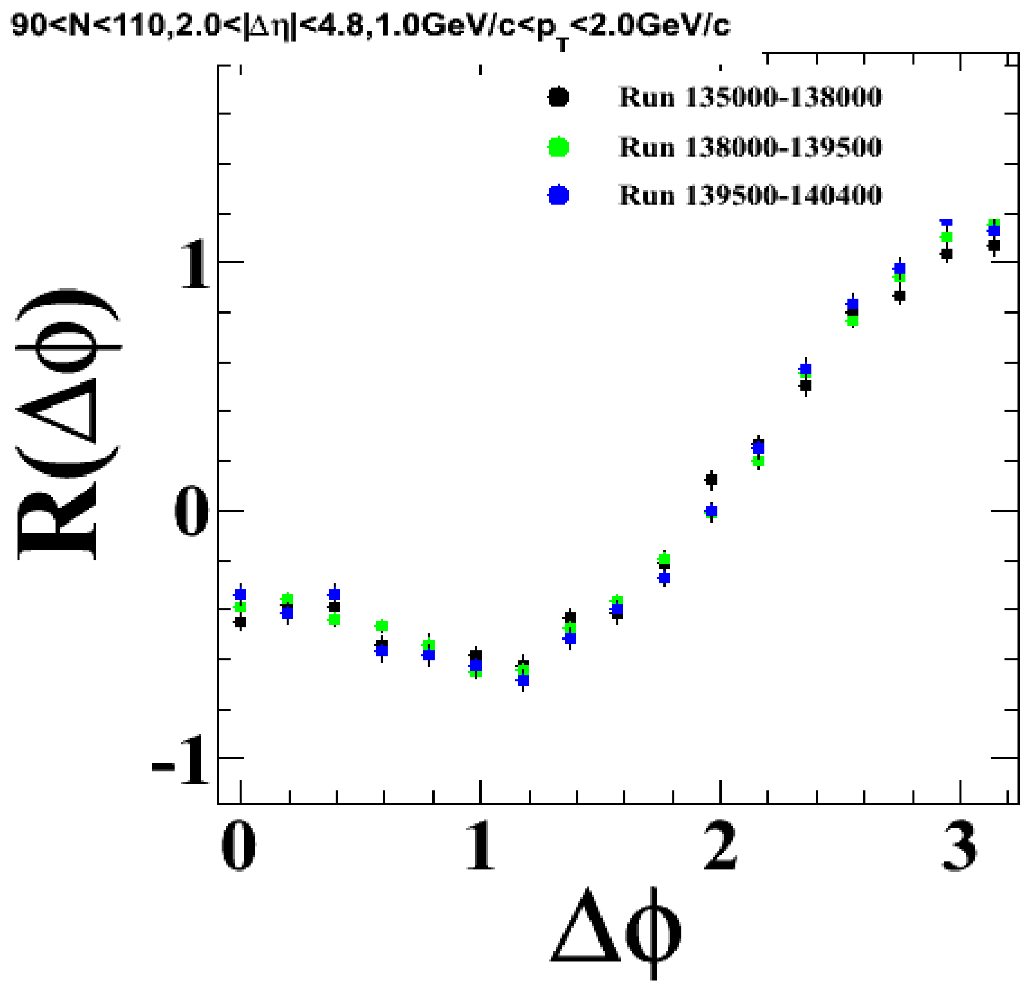


Madgraph, Dijet 100-250GeV, N>90



Cross Check: Event Pileup

Compare different run periods

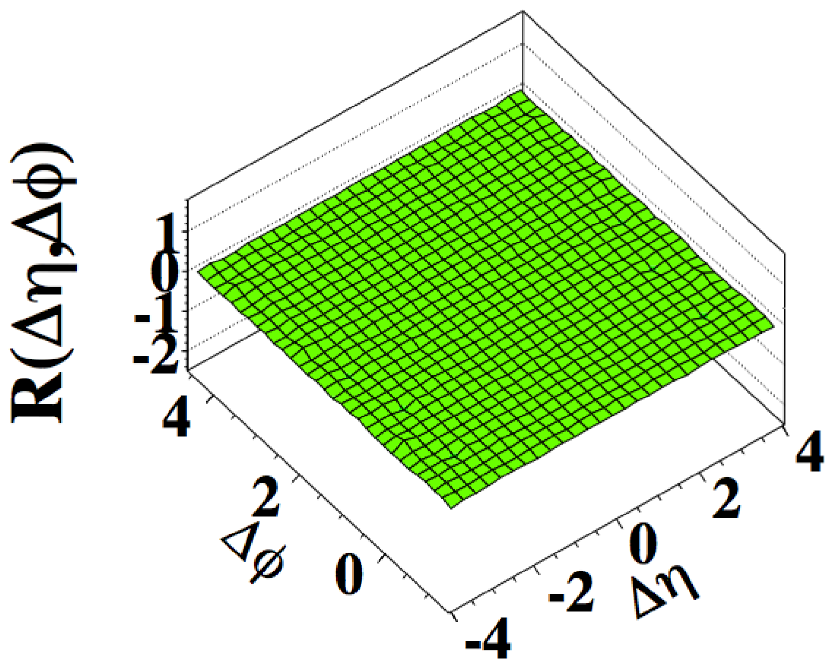


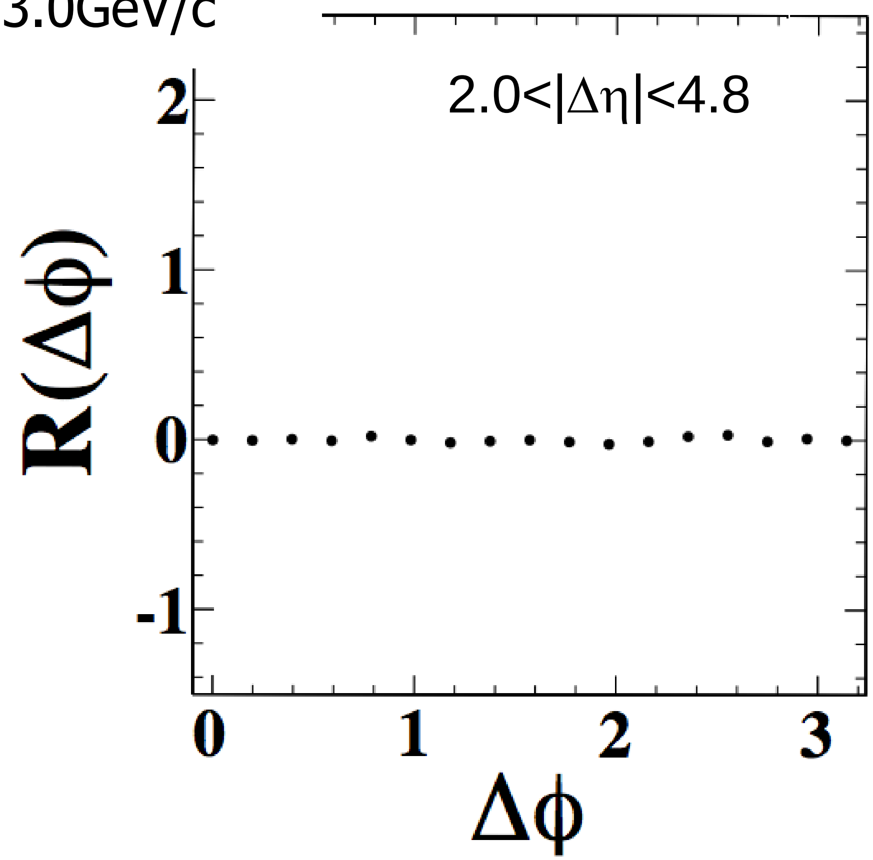
Change in pileup fraction by factor 4-5
has almost no effect on ridge signal

Cross Check: Event Pileup

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

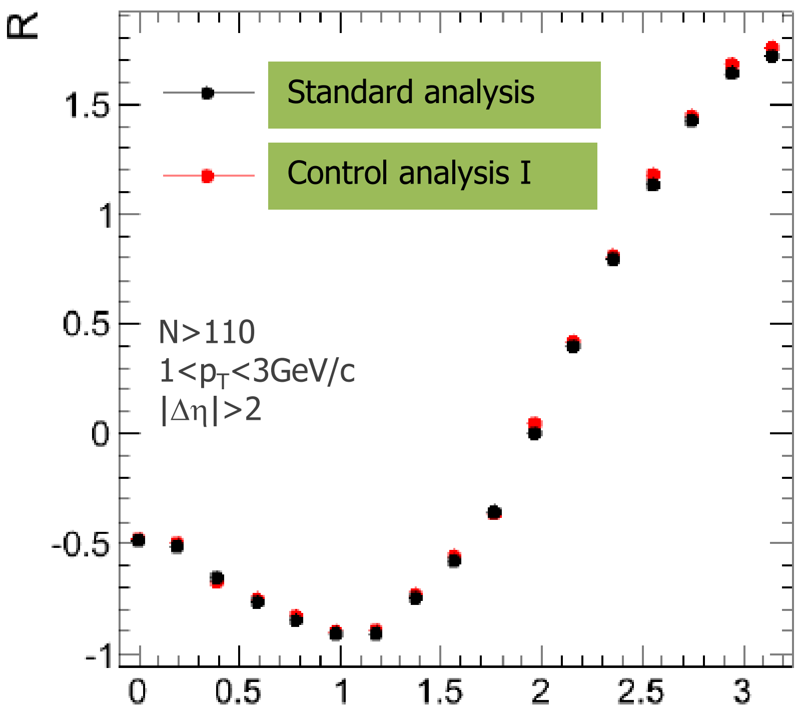
N>110
1.0GeV/c<p_T<3.0GeV/c



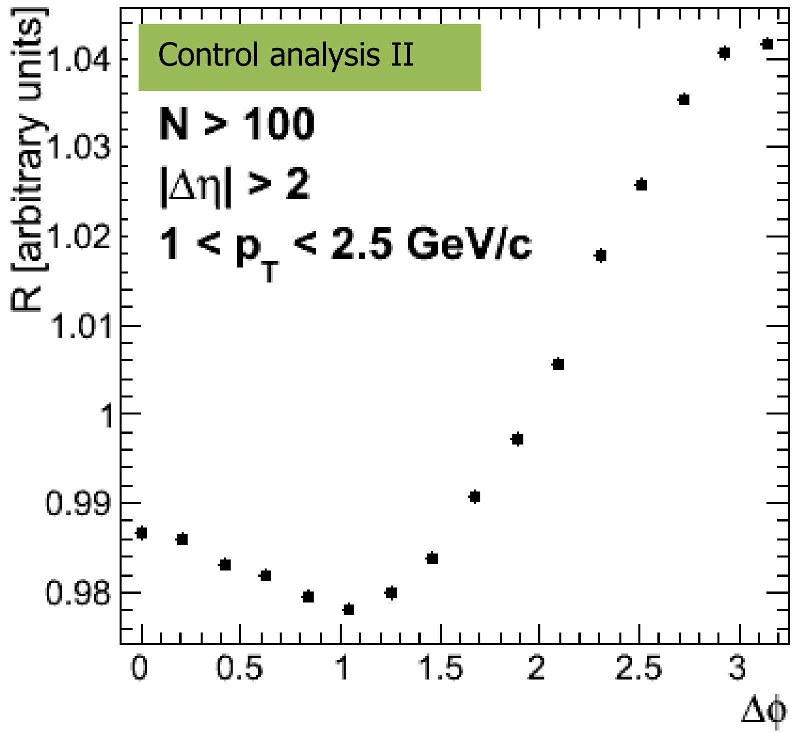


No background or noise effects seen in cross-collision correlations

Cross Check: Analysis Code



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

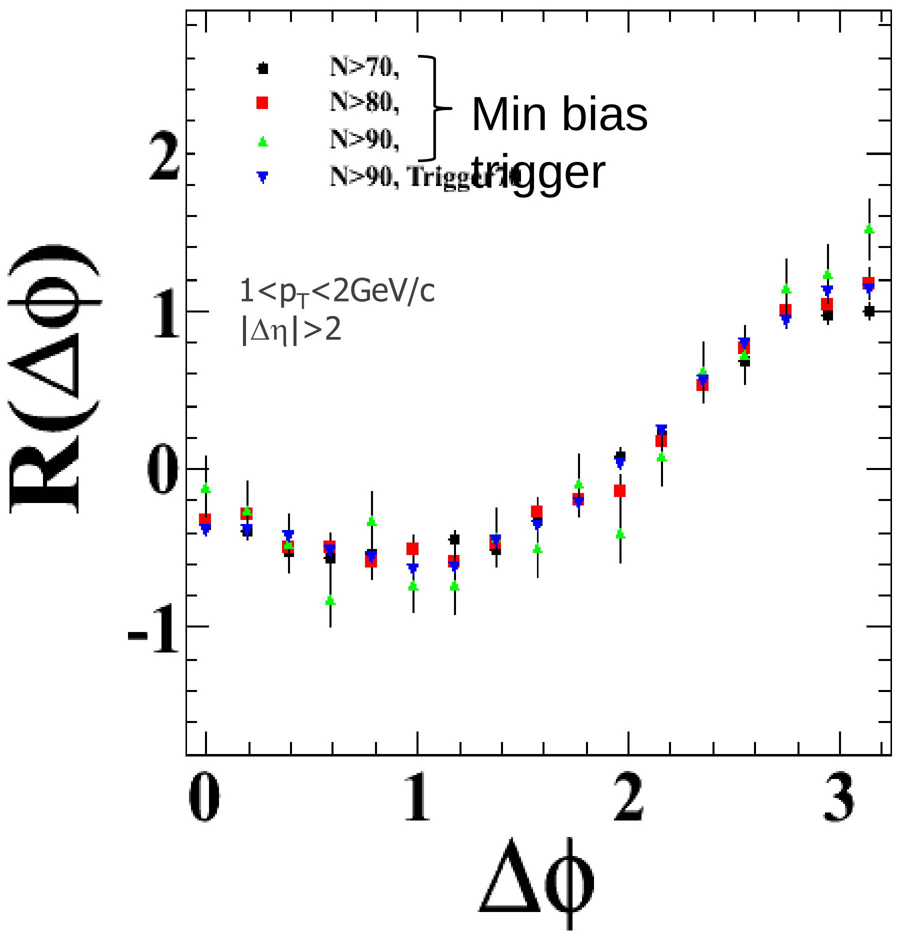


Independent code
Different definition of *R*
Different input file (skim)

Ridge is seen with three independent analysis codes

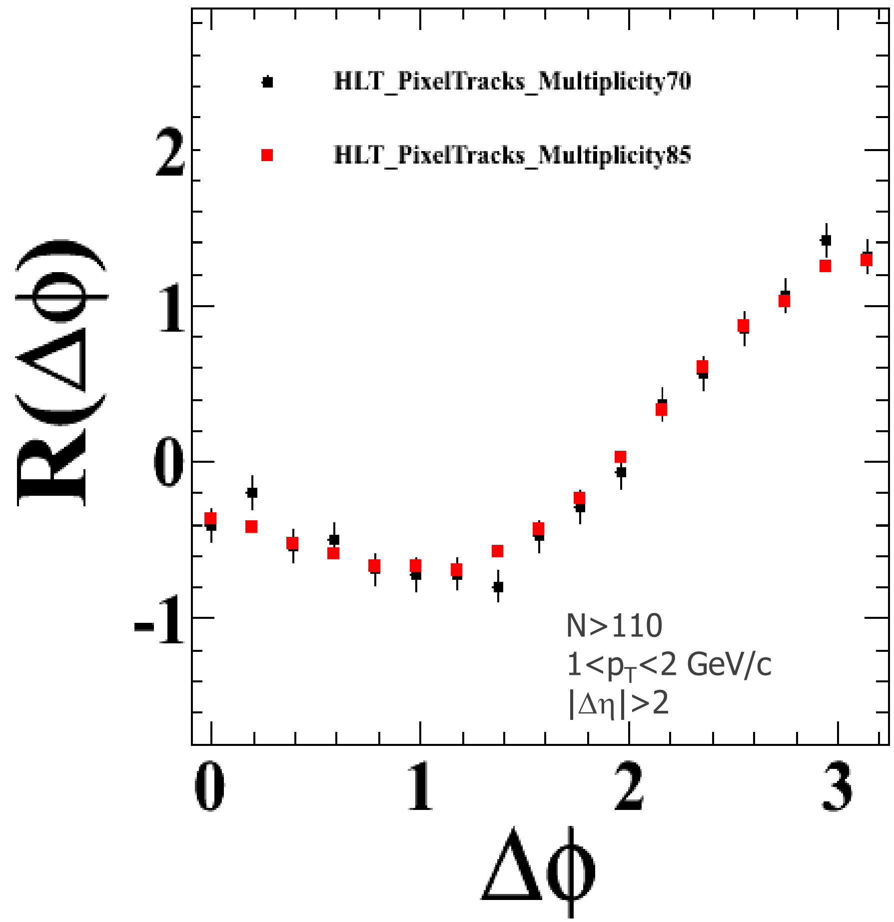
Cross Check: Trigger

Min-bias trigger vs high mult trigger



Ridge is seen using
min bias trigger + offline selection

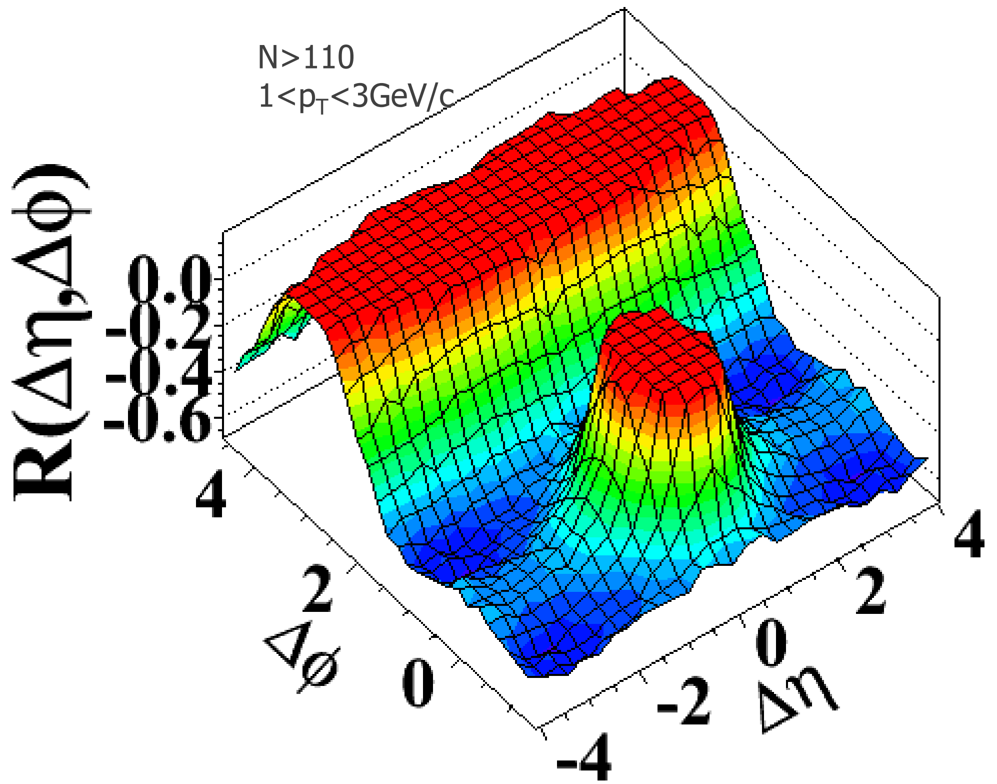
HLT 70 vs HLT 85 for N > 110

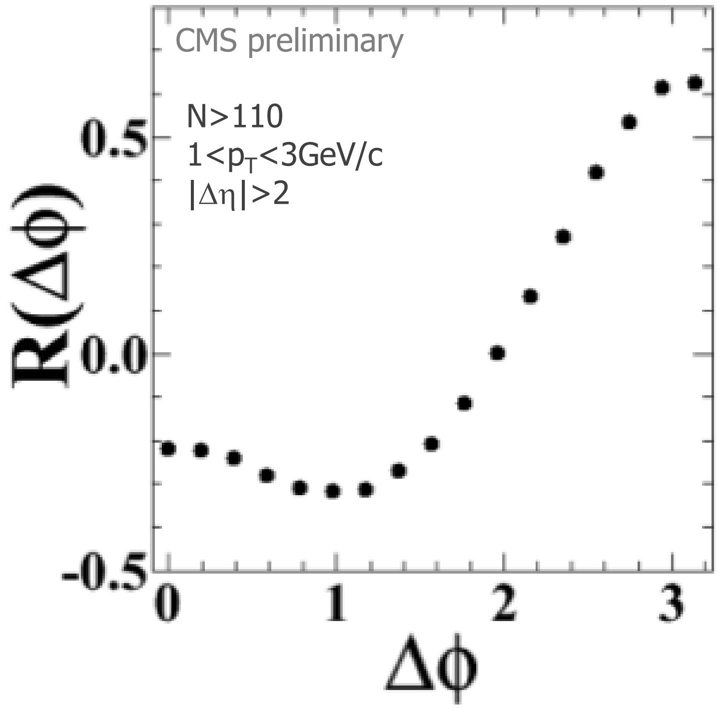


No trigger bias seen from
comparison of trigger paths

Cross Check: ECAL photons

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



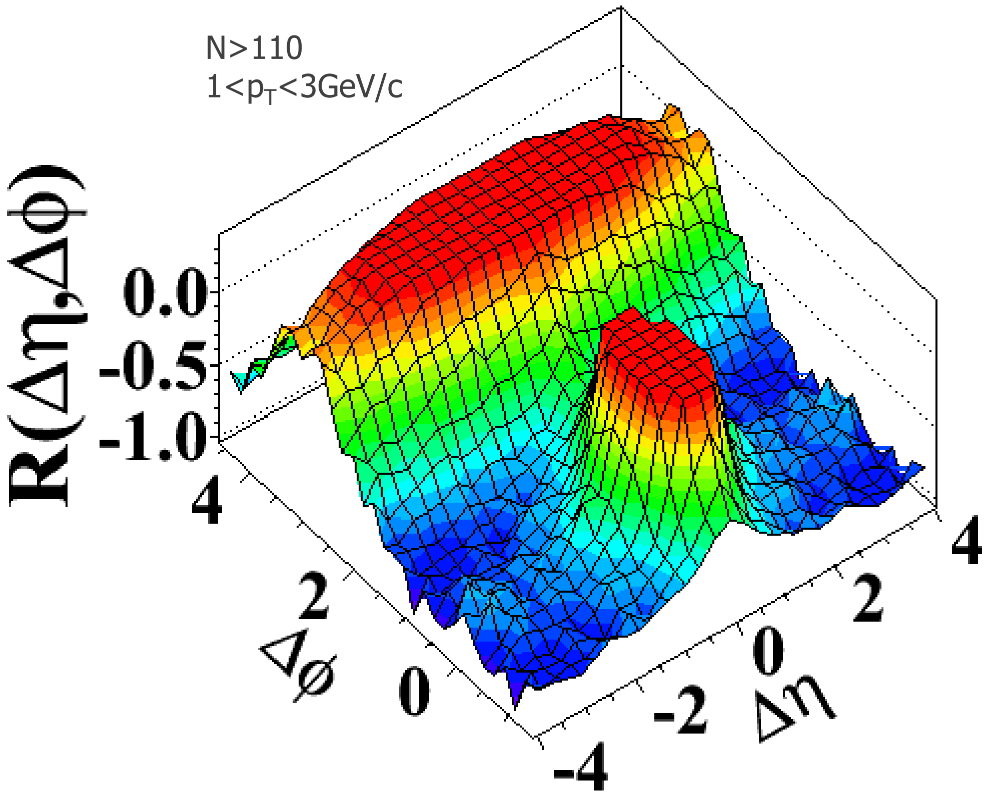


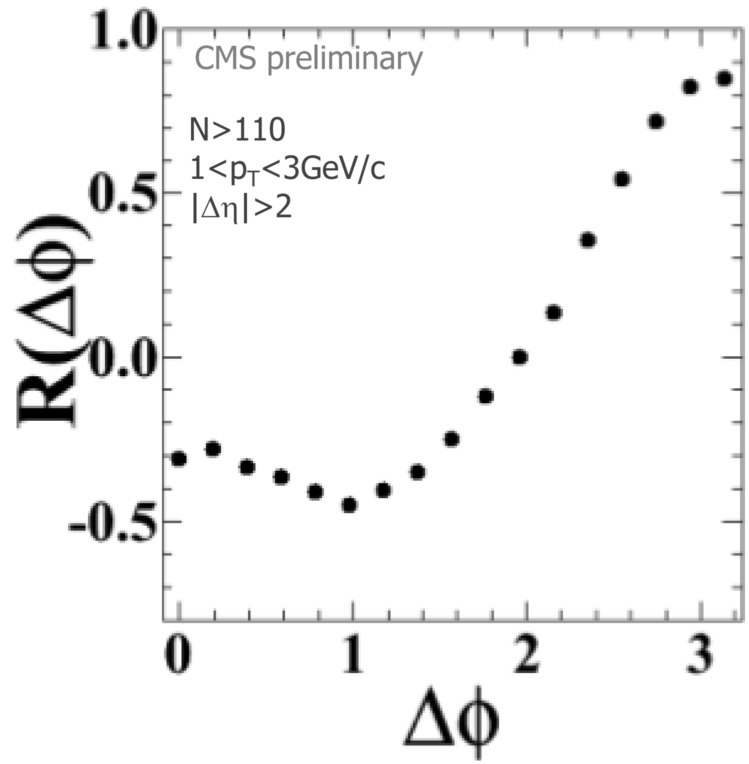
Track-photon correlations

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

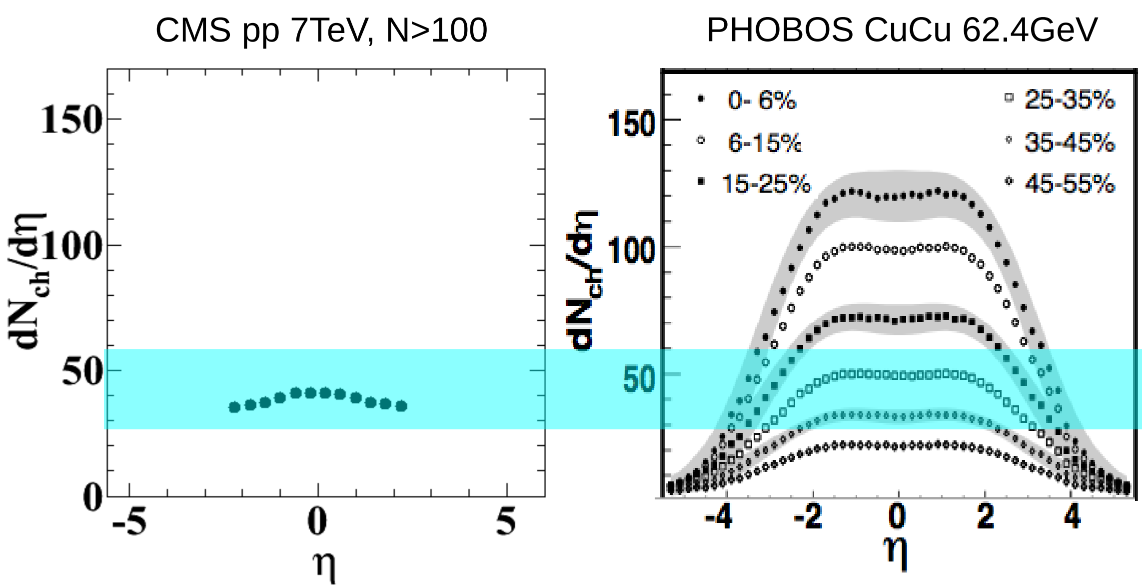




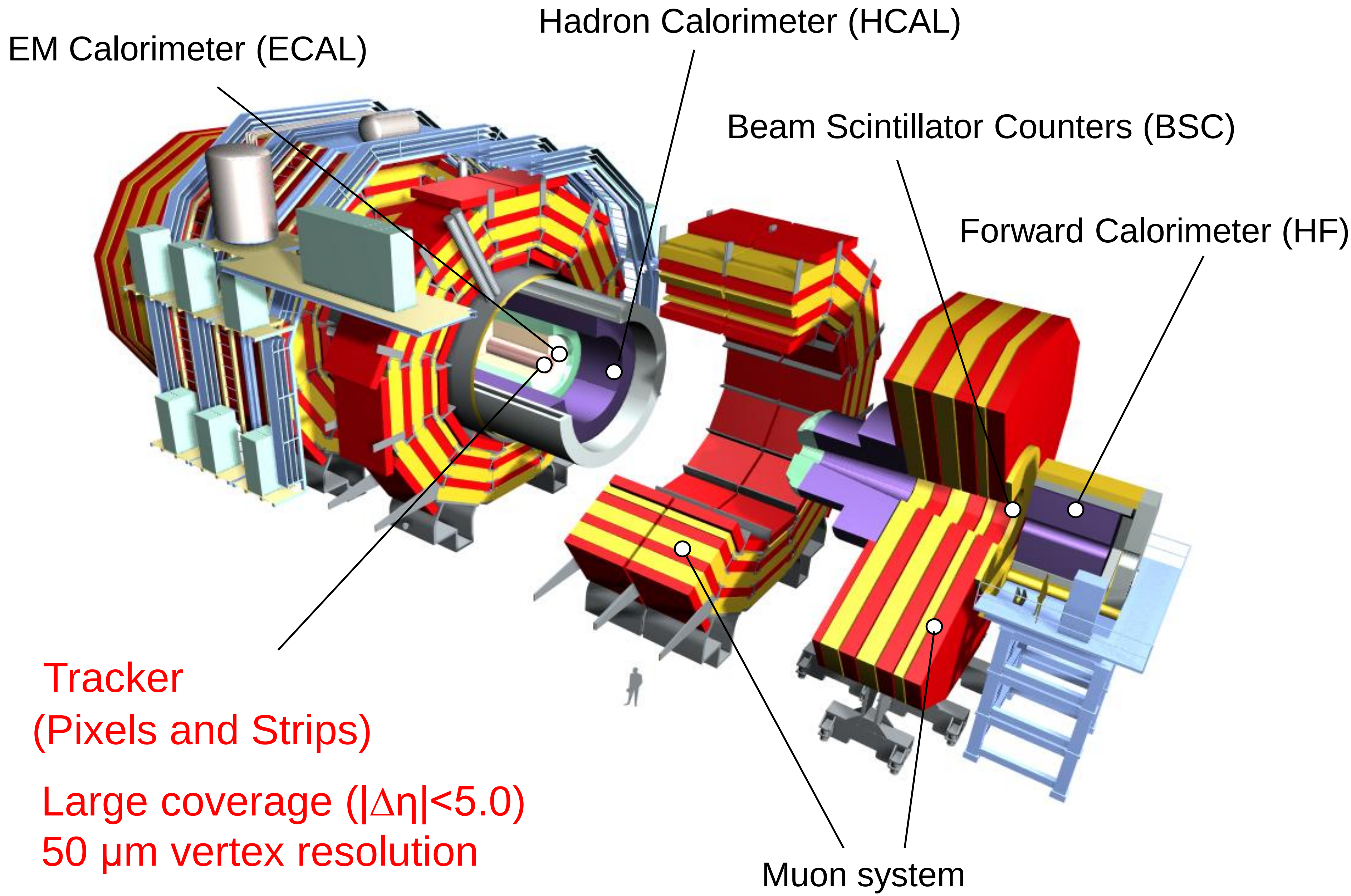
Photon-photon correlations
Qualitative confirmation
Independent detector, independent reconstruction

Particle density in high Mult pp

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

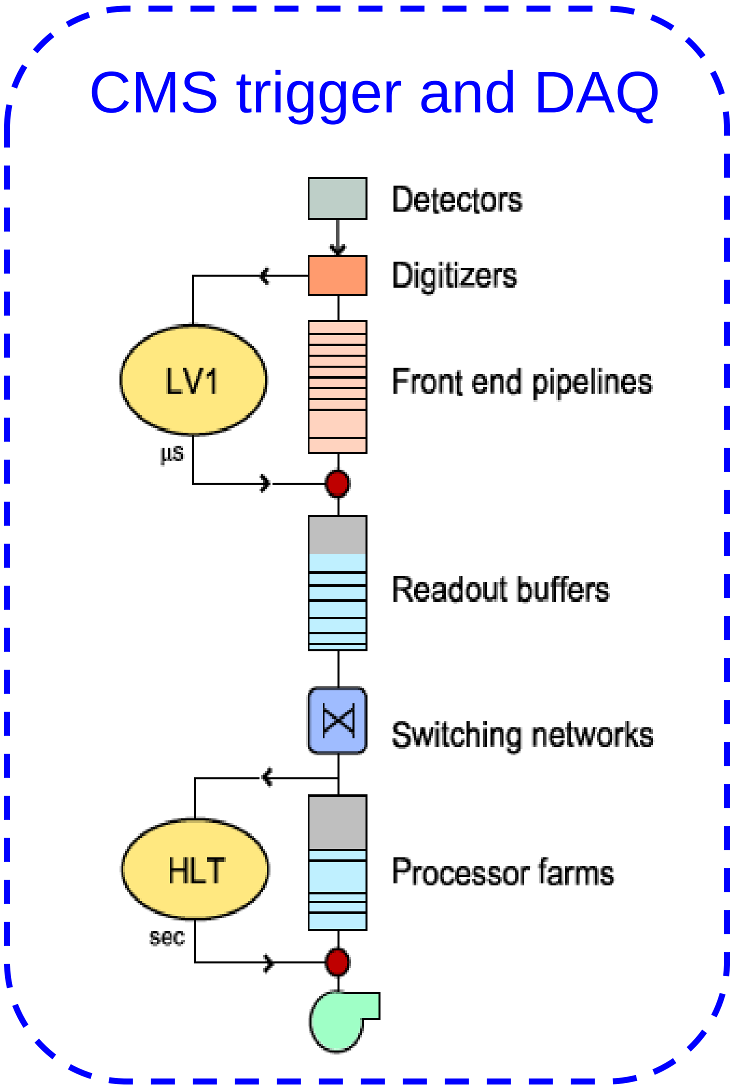


CMS Experiment

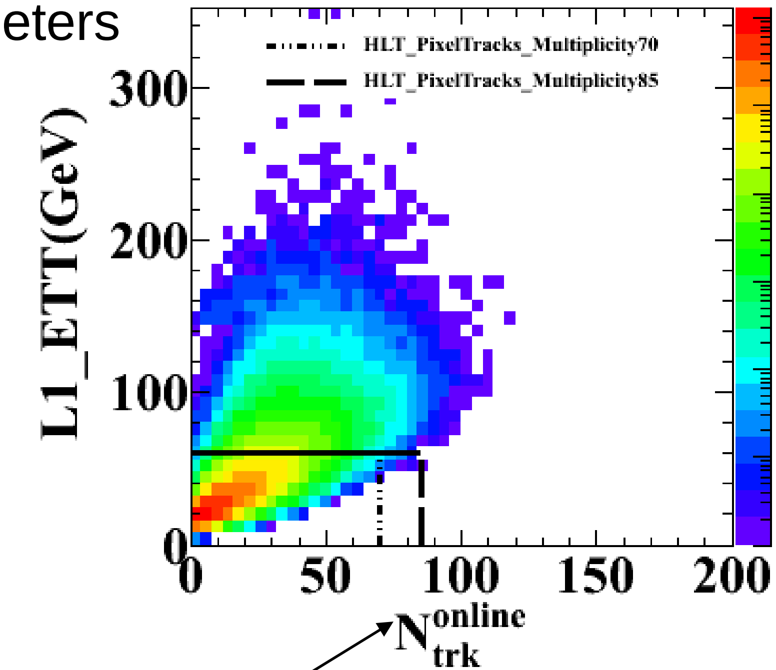


Large coverage (|Δη|<5.0)
50 μm vertex resolution

Trigger on High Multiplicity pp



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



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