# Dihadron Correlations in pp and PbPb Collisions in CMS

6th International Workshop High-$p_T$ Physics at LHC

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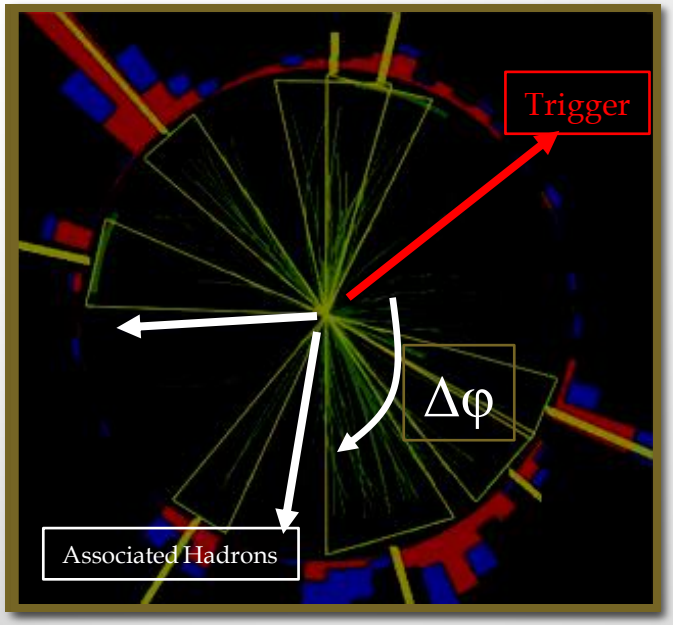
For the CMS Collaboration
April 4th, 2011

# Introduction

- There are several unique and non-trivial features found in AA collisions at RHIC
  - Near side ridge
  - Broadened away side
  - Disappearance of back-to-back correlations
- Explanations include:
  - Connections to jet quenching
  - Higher order components of hydrodynamic flow ($v_n | n>2$)
- LHC and CMS provide:
  - Expanded pseudorapidity and $p_T$ reach
  - Higher density system than before
- We see a long-range correlation (ridge) in PbPb, and for the first time (high multiplicity) pp

# The Technique




- Correlate "associate" particles in $\phi$ and $\eta$ with respect to other "trigger" particles in each event
- Measurement made on a statistical basis
- Compare heavy-ion, dAu and pp collisions

Terminology (for this talk)

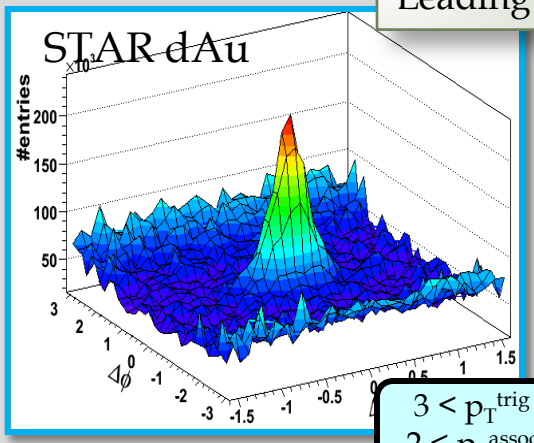
- Correlations can be "triggered" ($p_T$ cuts) or "untriggered"
- Triggered correlations can be "leading hadron" or "inclusive"

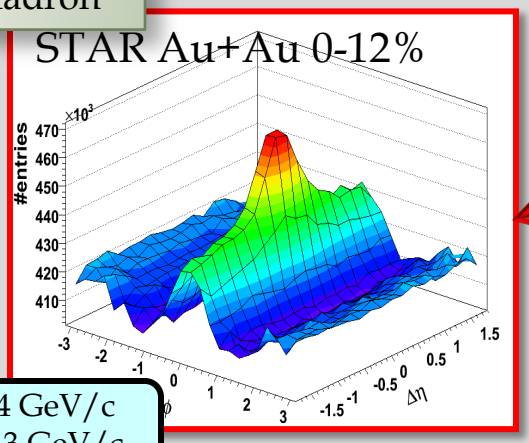
# A Feature of the Δη–Δϕ Correlation

**"The Ridge" as seen at RHIC in Heavy Ions**

$\sqrt{s_{NN}} = 200$ GeV

Leading Hadron

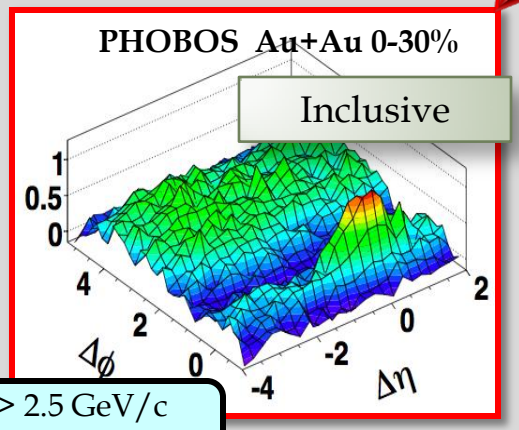



Near side ridge seen in AuAu

$3 < p_T^{trig} < 4$ GeV/c
$2 < p_T^{assoc} < 3$ GeV/c

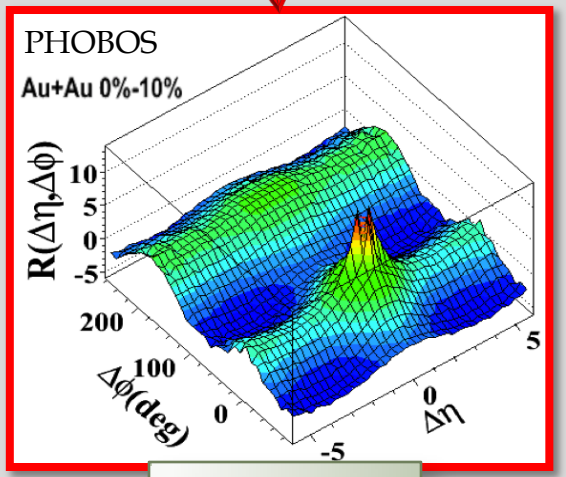
Triggered




Inclusive

No ridge seen in cold nuclear matter

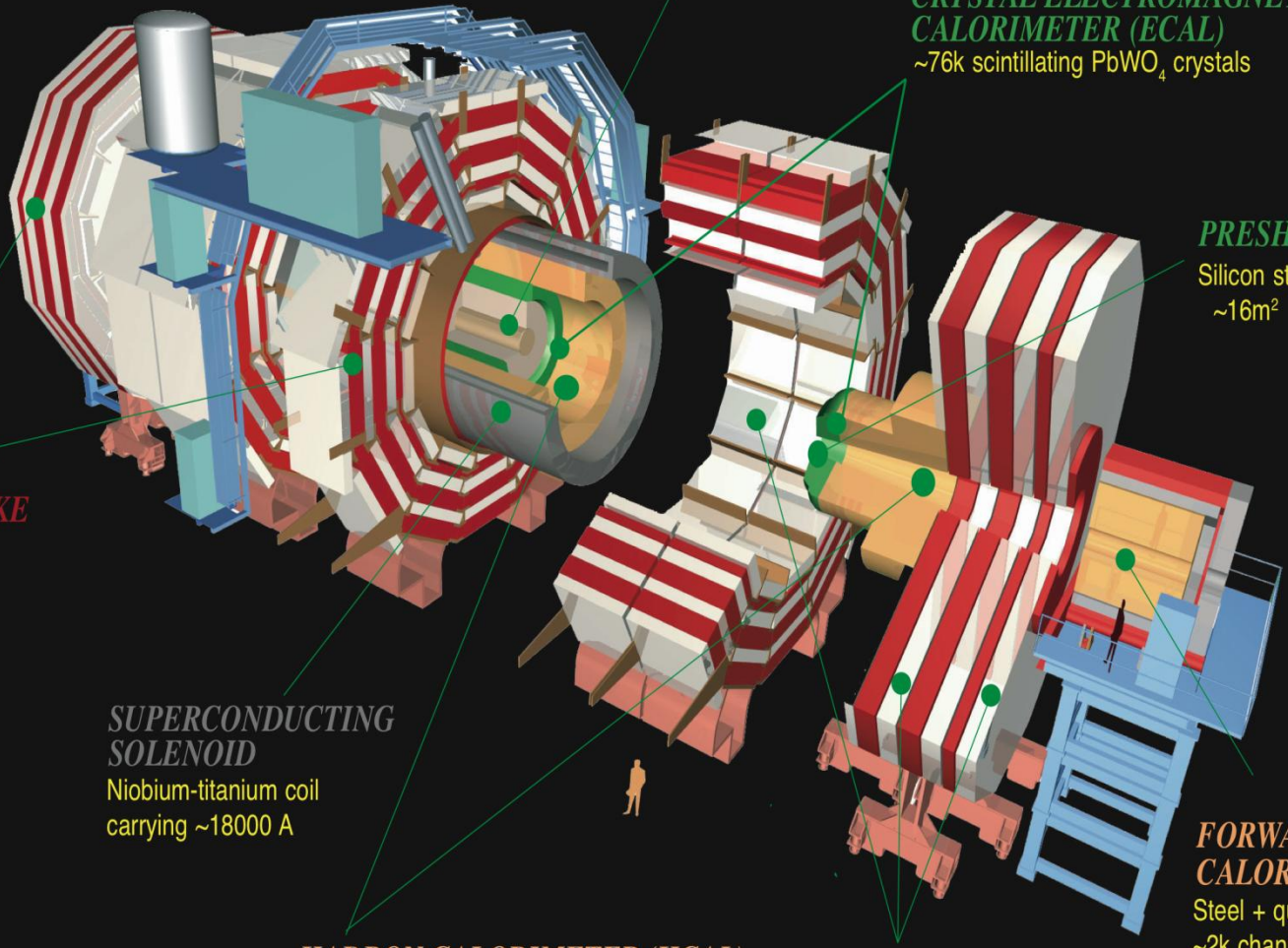
$p_T^{trig} > 2.5$ GeV/c
$p_T^{assoc} > 4$-35 MeV/c




Untriggered

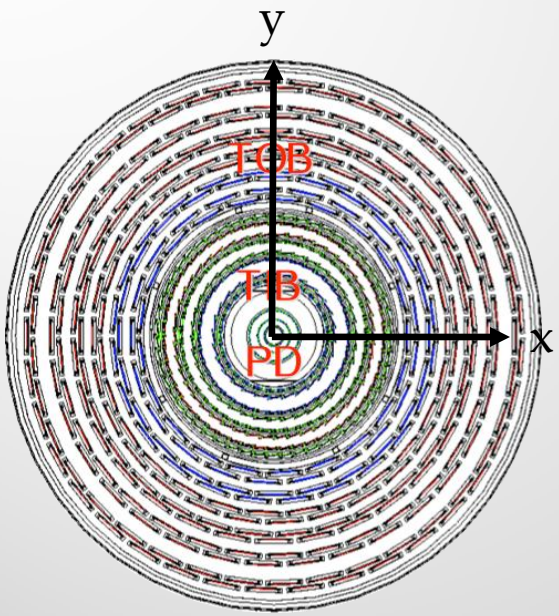
# CMS Detector

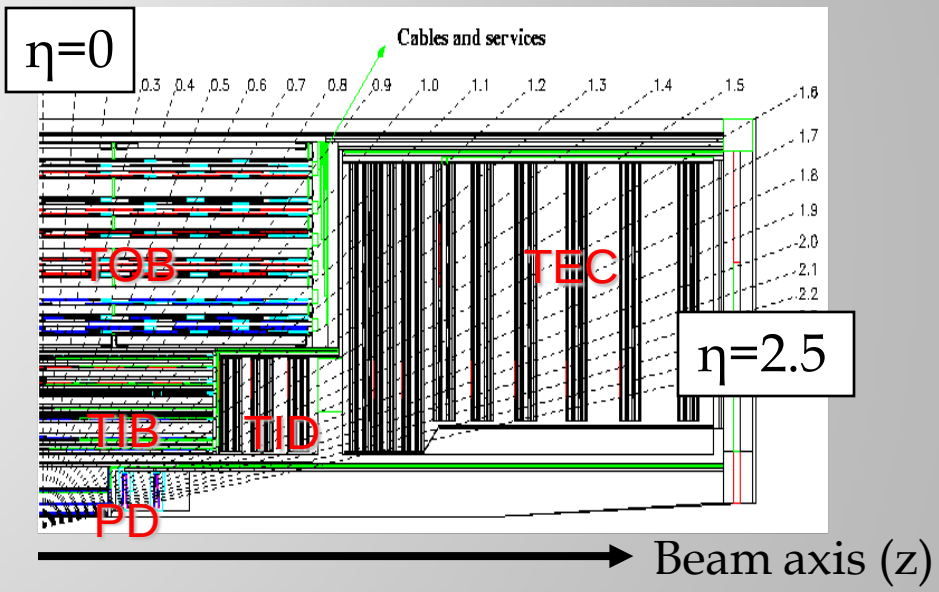
Compact Muon Solenoid




| | |
|---|---|
| Total weight | : 14000 tonnes |
| Overall diameter | : 15.0 m |
| Overall length | : 28.7 m |
| Magnetic field | : 3.8 T |

# CMS All Silicon Tracking System



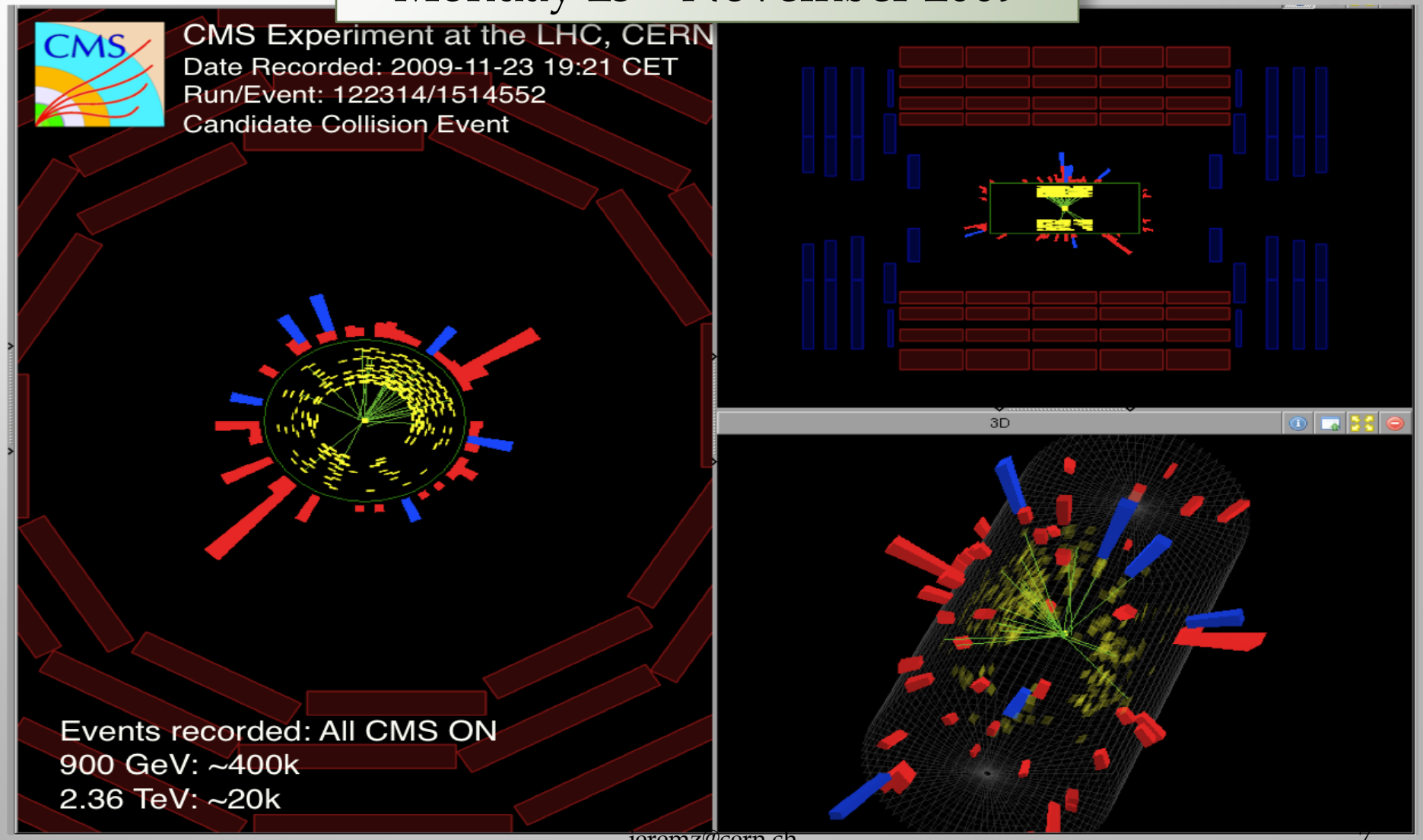




## The largest Silicon Tracker ever built:

- Strips: 9.3M channels; Pixels: 66M channels. >98% of channels operational
- Extremely high granularity
- Coverage over **|η| < 2.4**

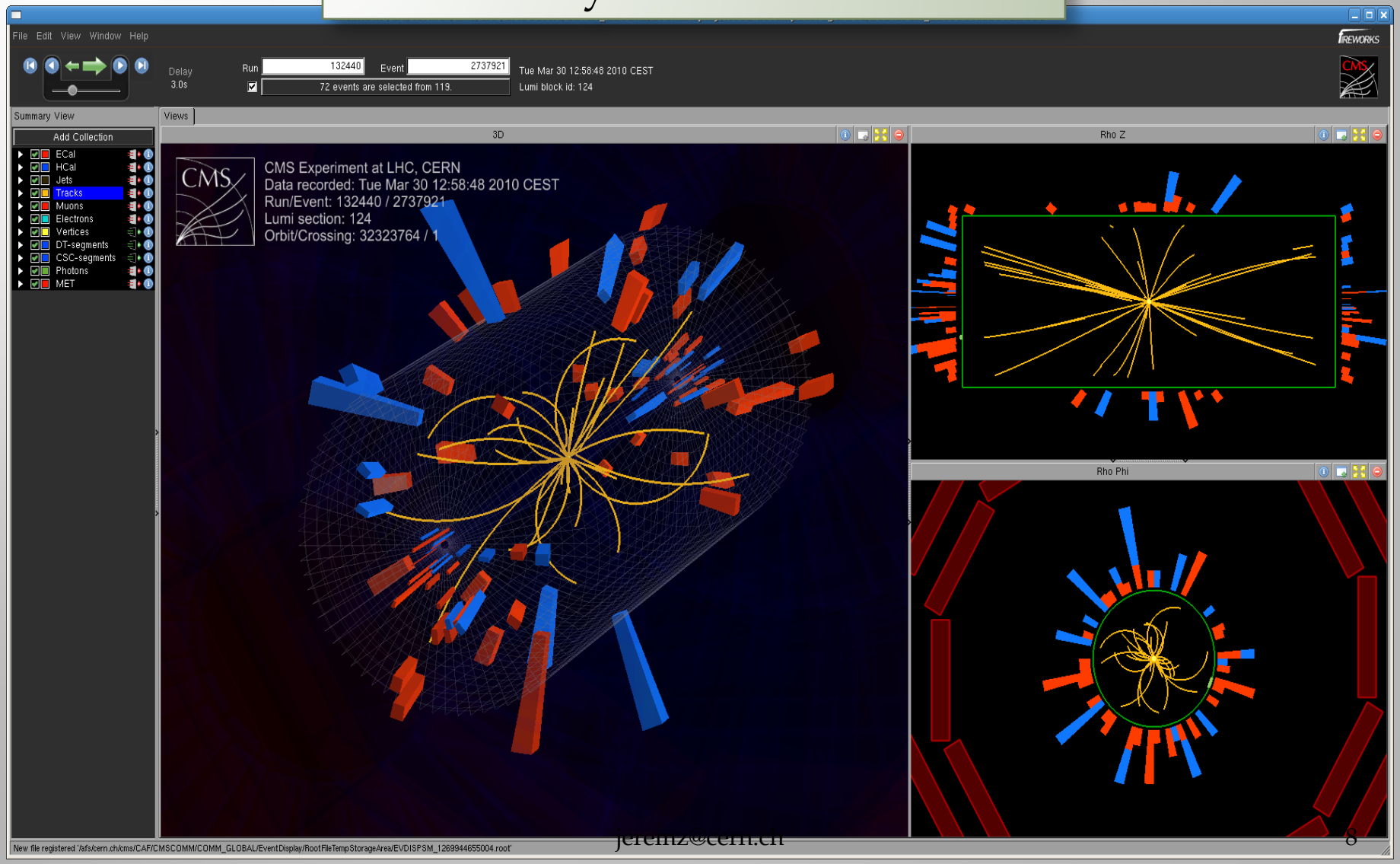
# Start of the LHC: First Collisions

Monday 23rd November 2009



# First Collisions at 7TeV

## Tuesday 30th March 2010



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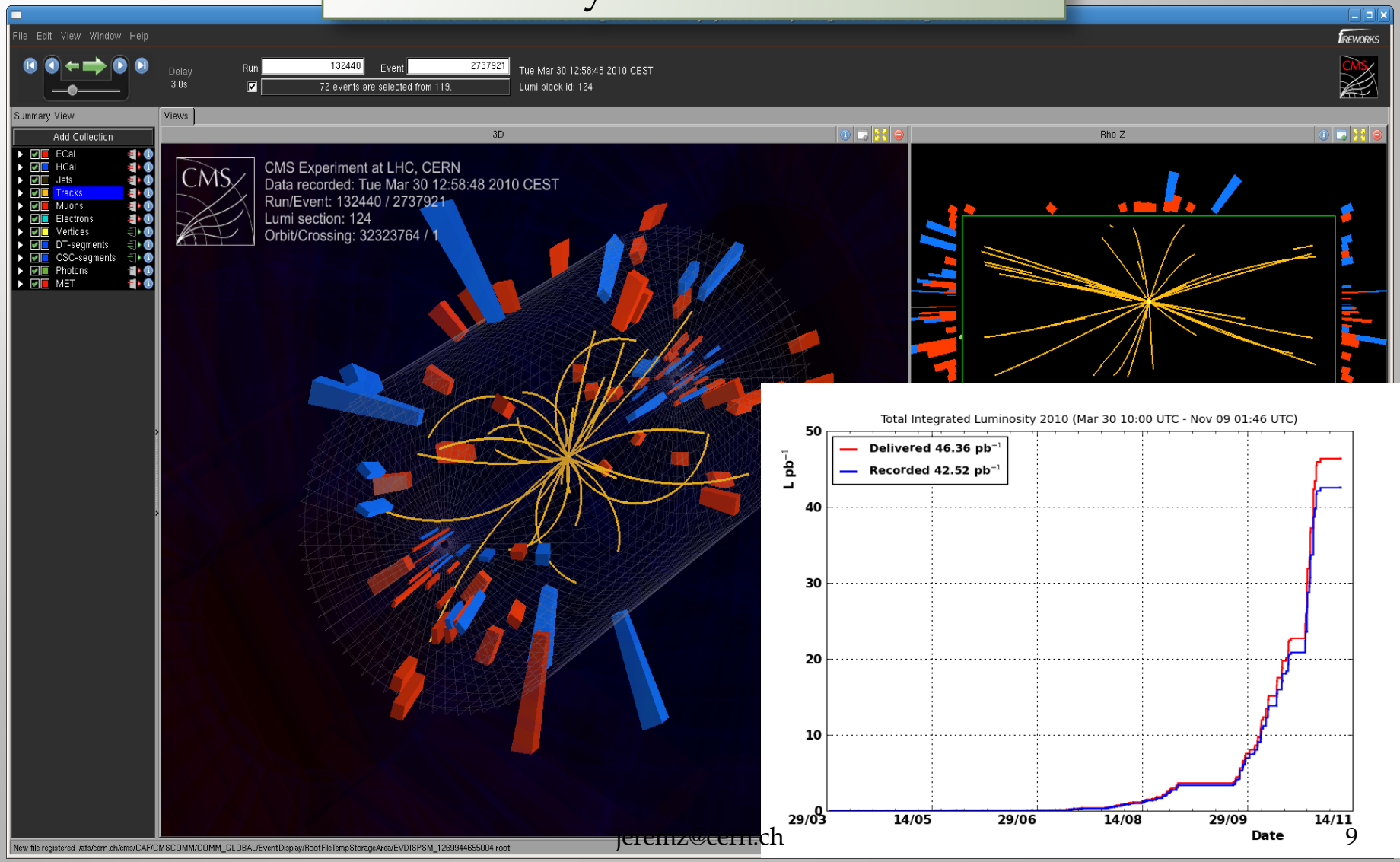

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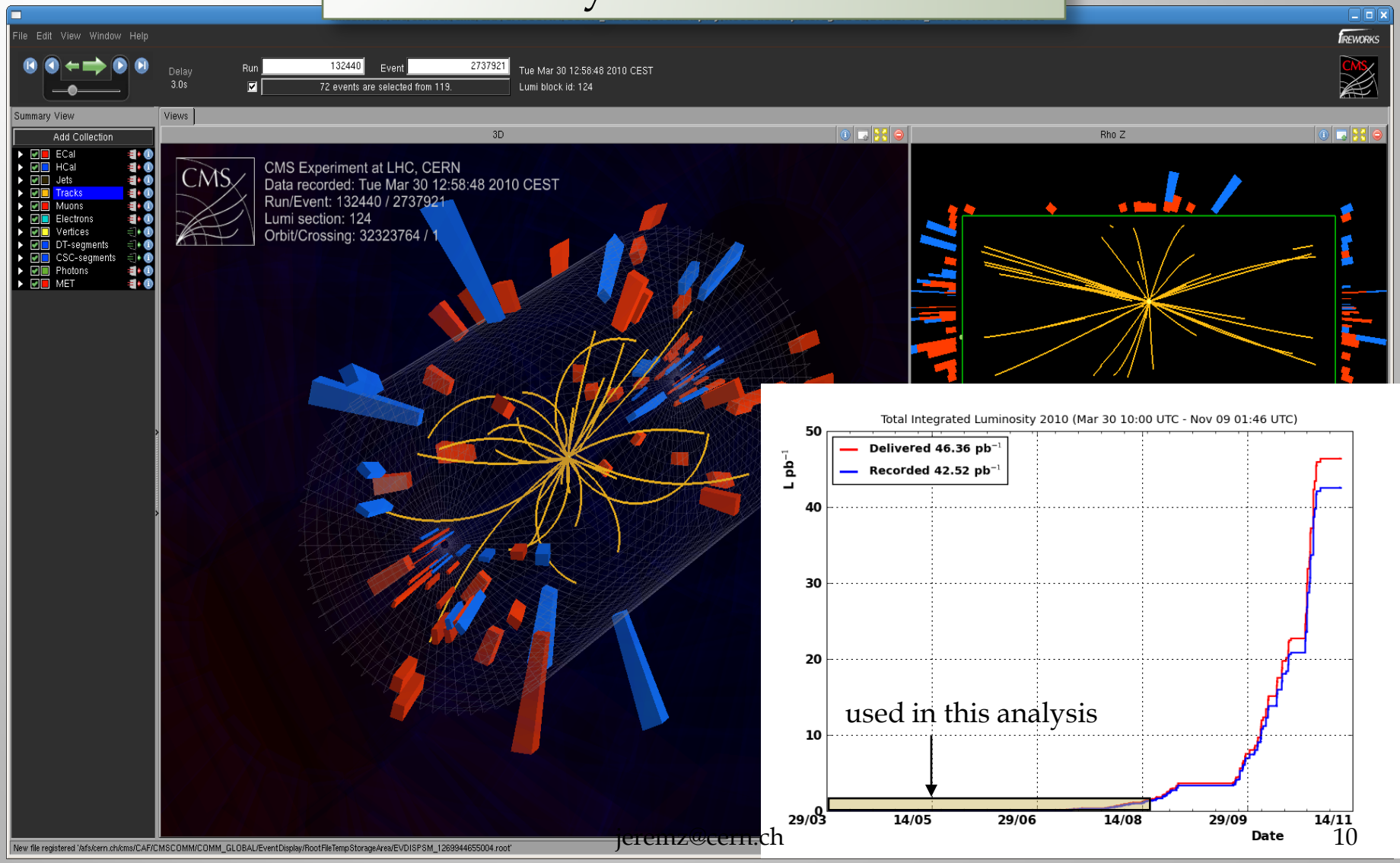
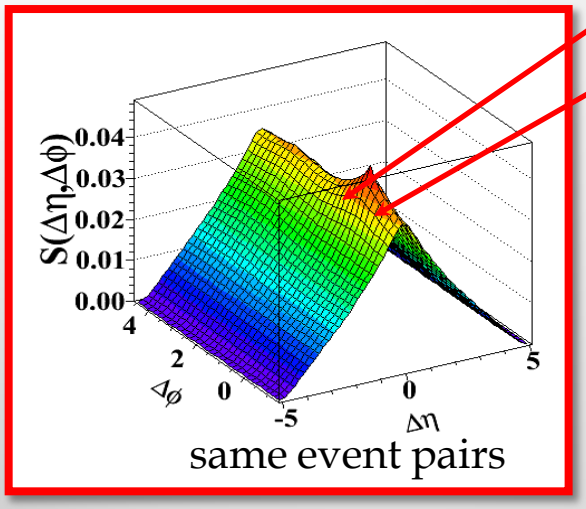


# Inclusive Correlation Technique –Wei Li

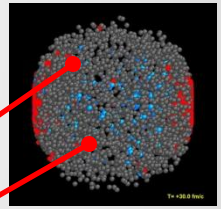
Signal distribution:

$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$



same event pairs

Event 1



$\Delta\eta = \eta_1 - \eta_2$
$\Delta\phi = \phi_1 - \phi_2$

CMS 7 TeV pp

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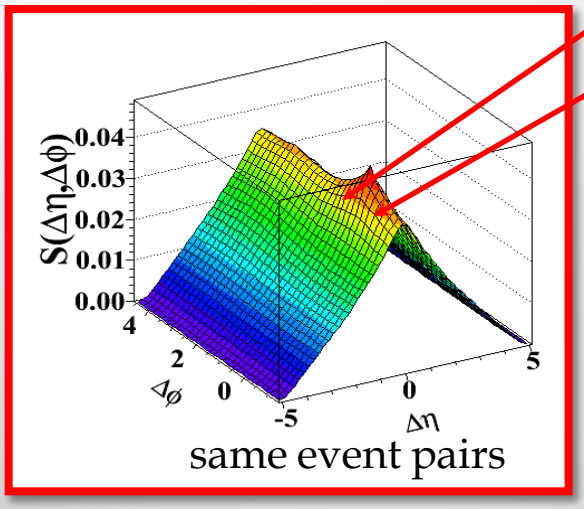

same event pairs

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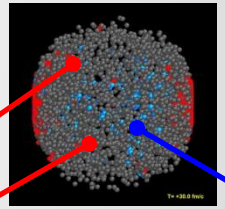
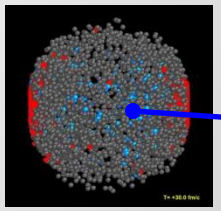
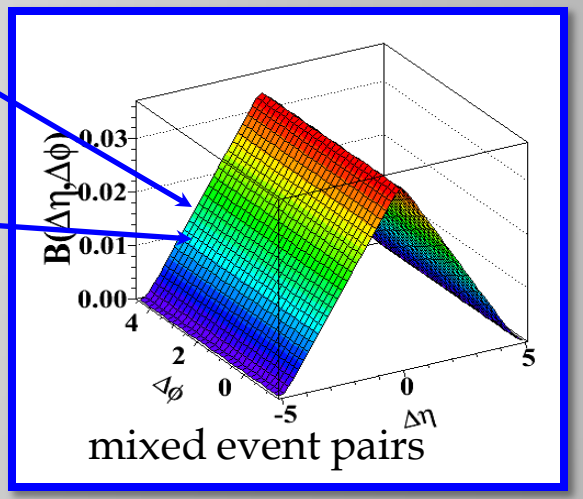


Event 2



Background distribution:

$$B_N(\Delta\eta,\Delta\varphi) = \frac{1}{N^2}\frac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$$



mixed event pairs

$\Delta\eta = \eta_1 - \eta_2$
$\Delta\phi = \phi_1 - \phi_2$

CMS 7 TeV pp

# Inclusive Correlation Technique –Wei Li

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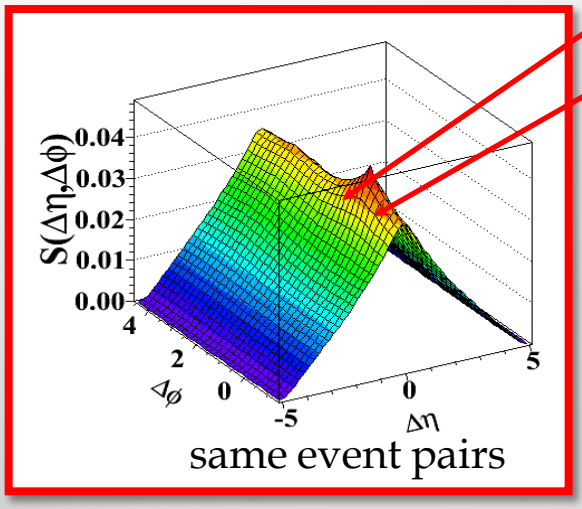
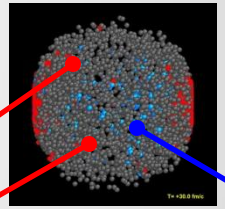
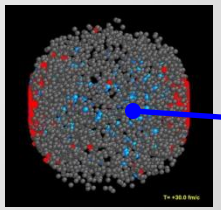


same event pairs

Event 1



Event 2



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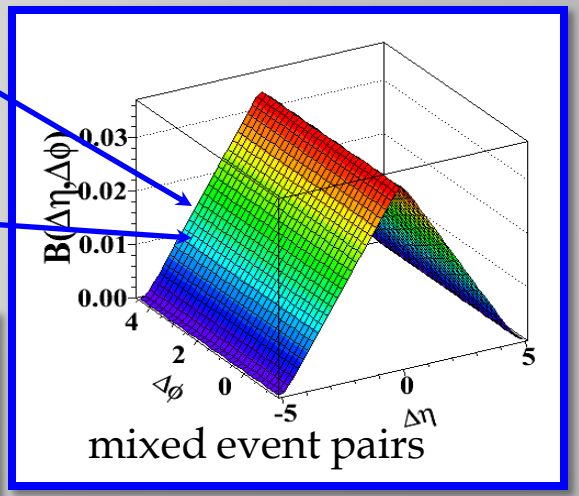
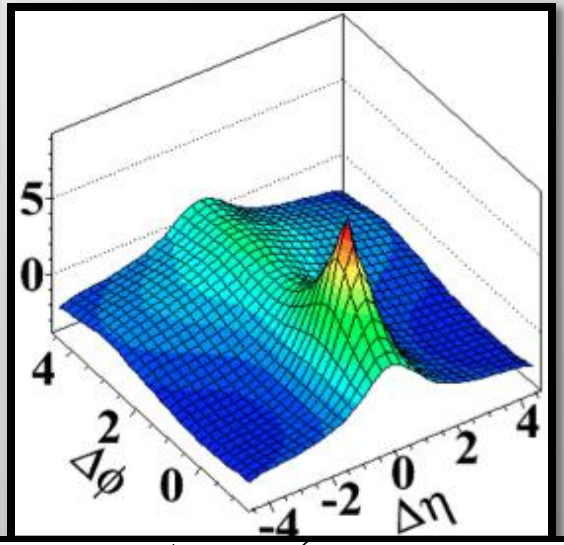


mixed event pairs




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

$\Delta\eta = \eta_1 - \eta_2$
$\Delta\phi = \phi_1 - \phi_2$

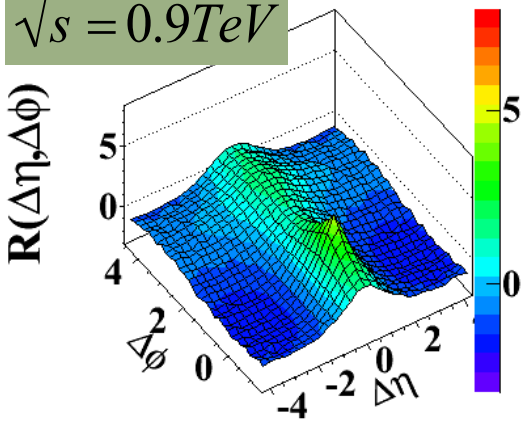
CMS 7 TeV pp

$p_T$-inclusive two-particle angular correlations in Minimum Bias collisions

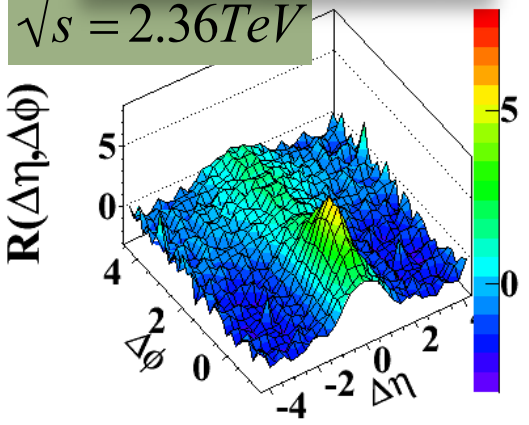
# Correlations in Minimum Bias pp

CMS pp DATA

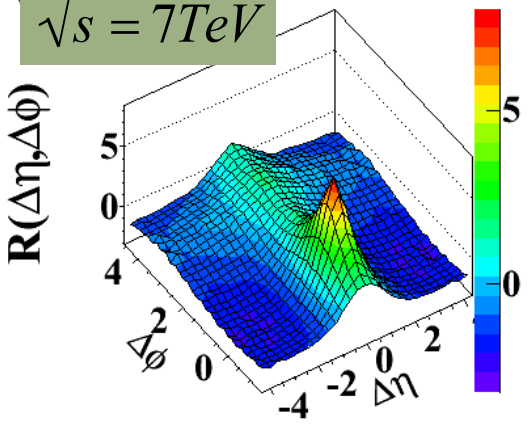
$\sqrt{s} = 0.9TeV$




$\sqrt{s} = 2.36TeV$

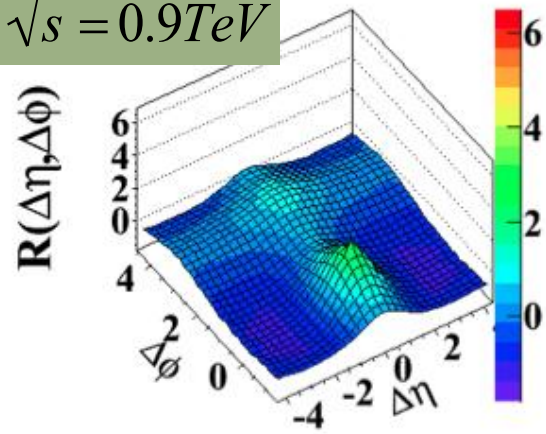



$\sqrt{s} = 7TeV$




PYTHIA D6T

$\sqrt{s} = 0.9TeV$

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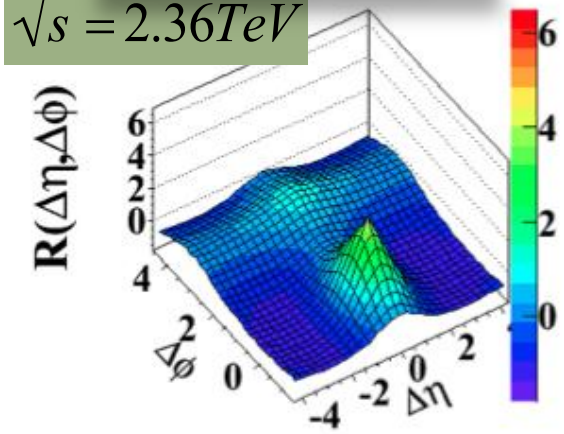


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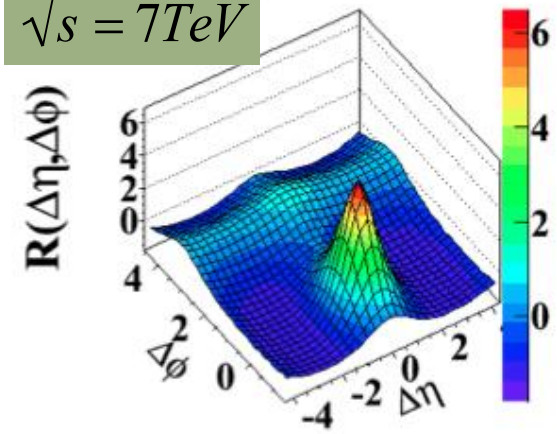
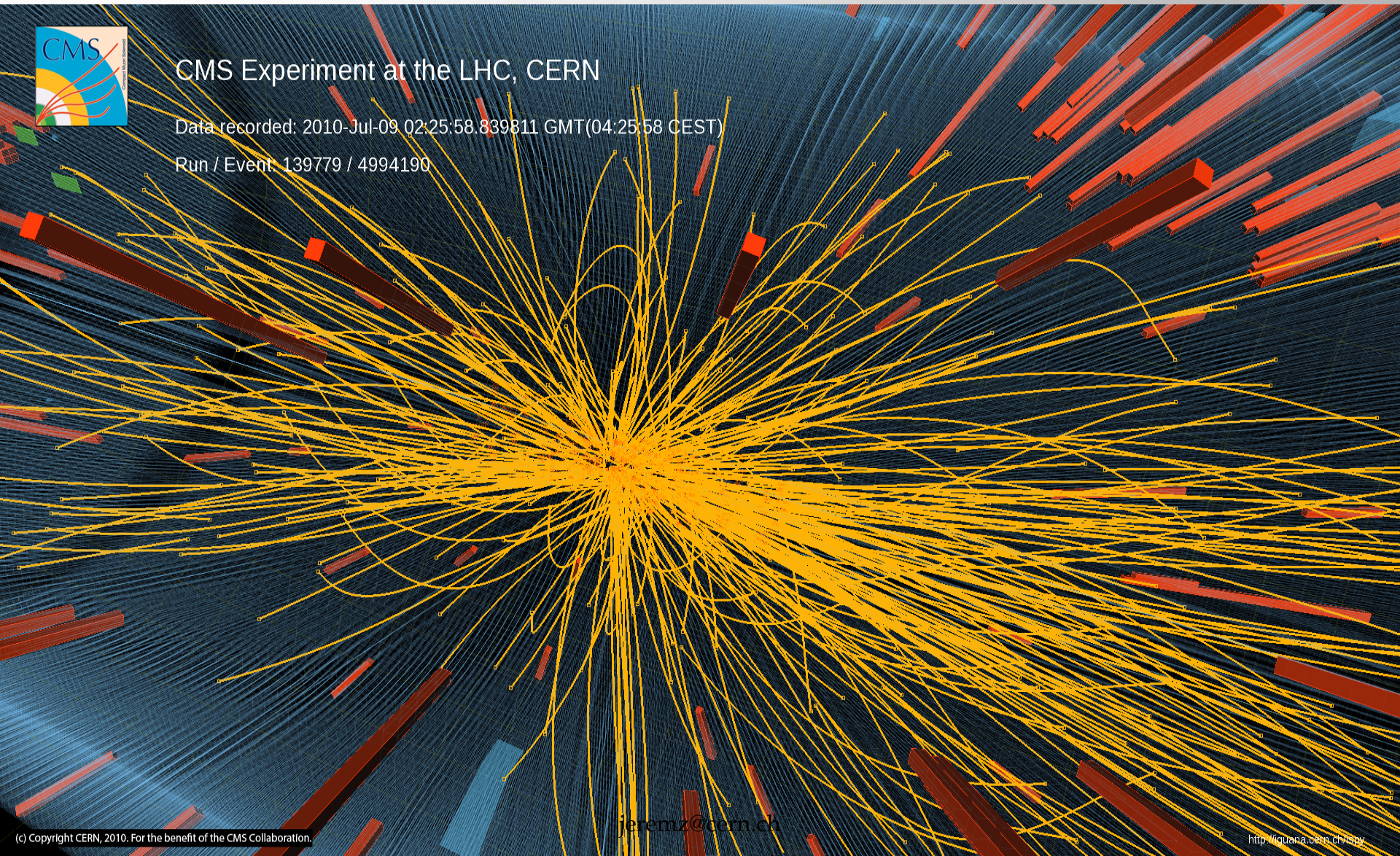


# High Multiplicity pp collisions




jeremz@cern.ch



http://iguana.cern.ch/i3py

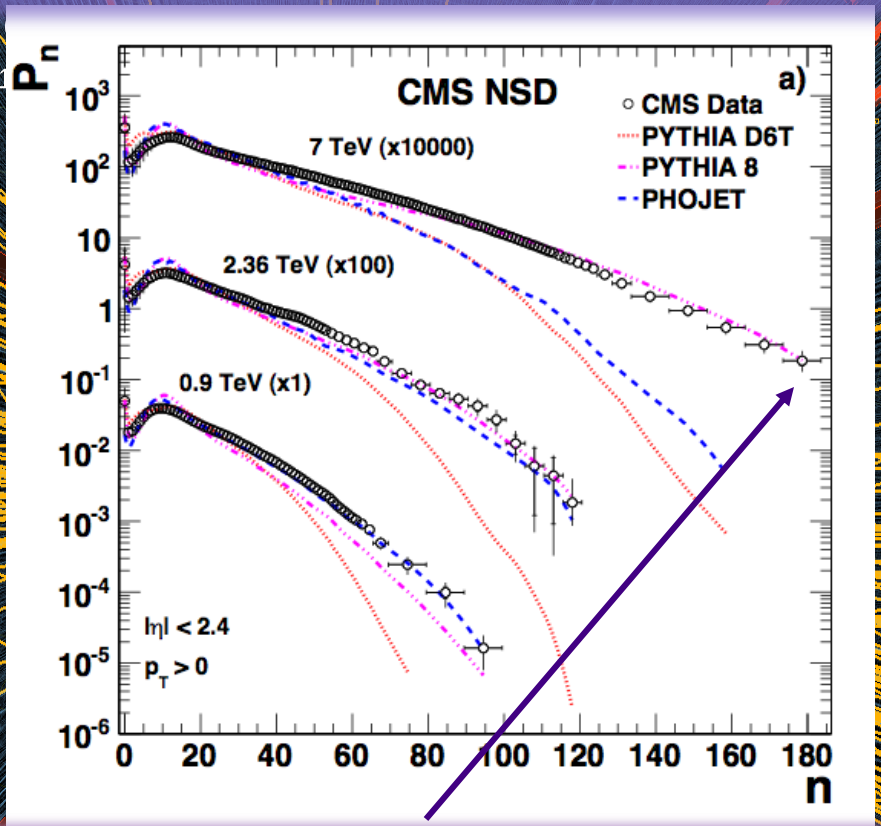
# High Multiplicity pp collisions

CMS Experiment

Data recorded: 2010-Jul-09

Run / Event: 139779 / 49941

## High Multiplicity events are rare in nature




Very high particle density regime

➔ *Is there anything peculiar happening there?*

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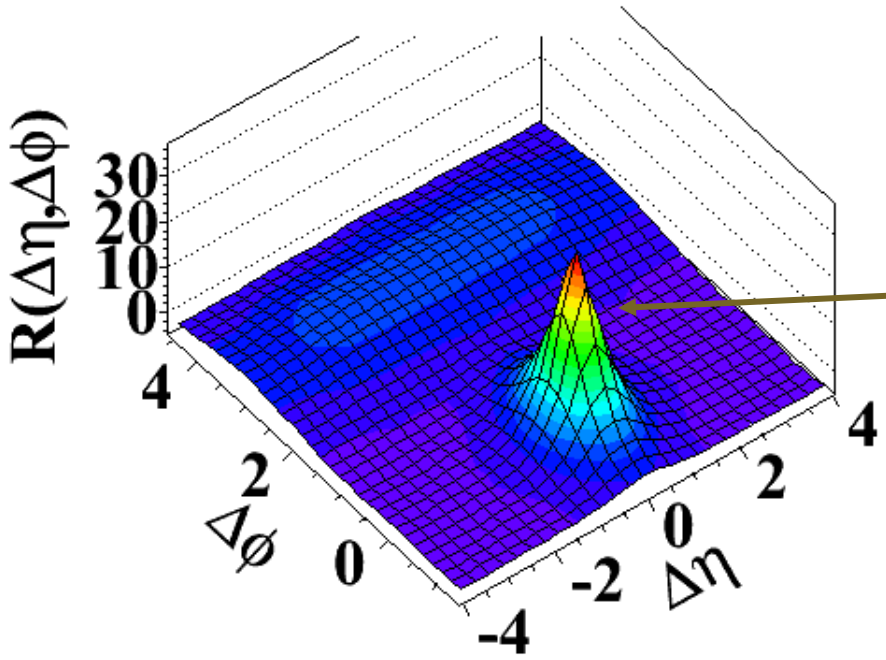
# Correlations in High Multiplicity pp

Non-Triggered

$p_T$ > 0.1 GeV



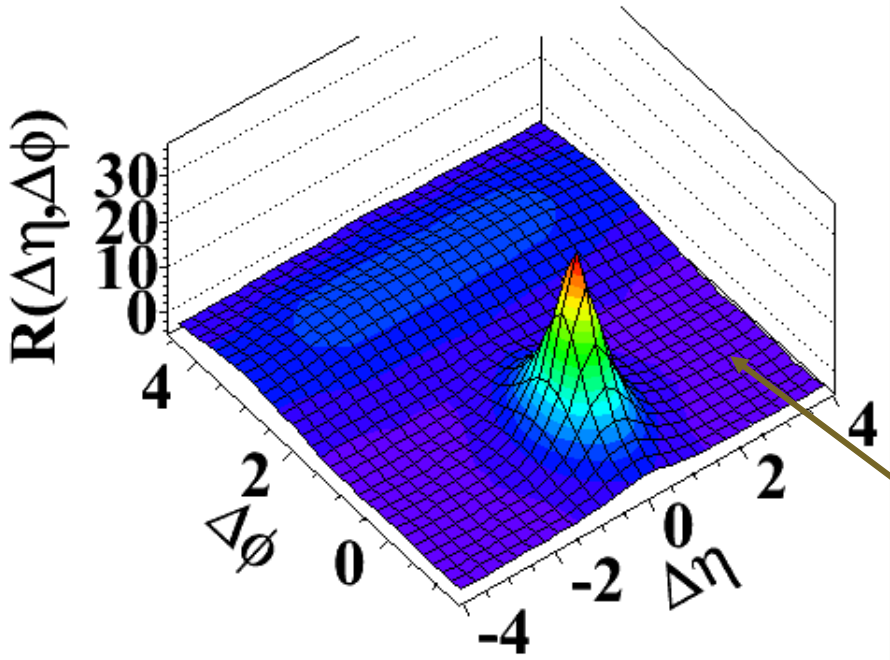

Inclusive Correlation
High multiplicity pp
(N>110)

Dominated by jet-like correlation

# Correlations in High Multiplicity pp

Non-Triggered

$p_T$ > 0.1 GeV



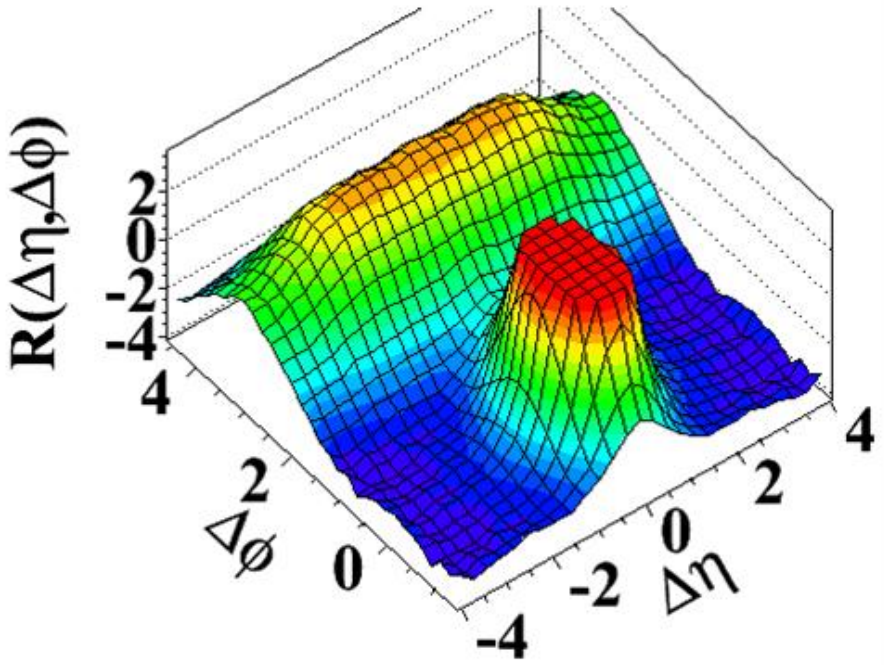

Inclusive Correlation
High multiplicity pp
(N>110)

No ridge, but what if we zoom in…

# Correlations in High Multiplicity pp

Non-Triggered

$p_T$ > 0.1 GeV



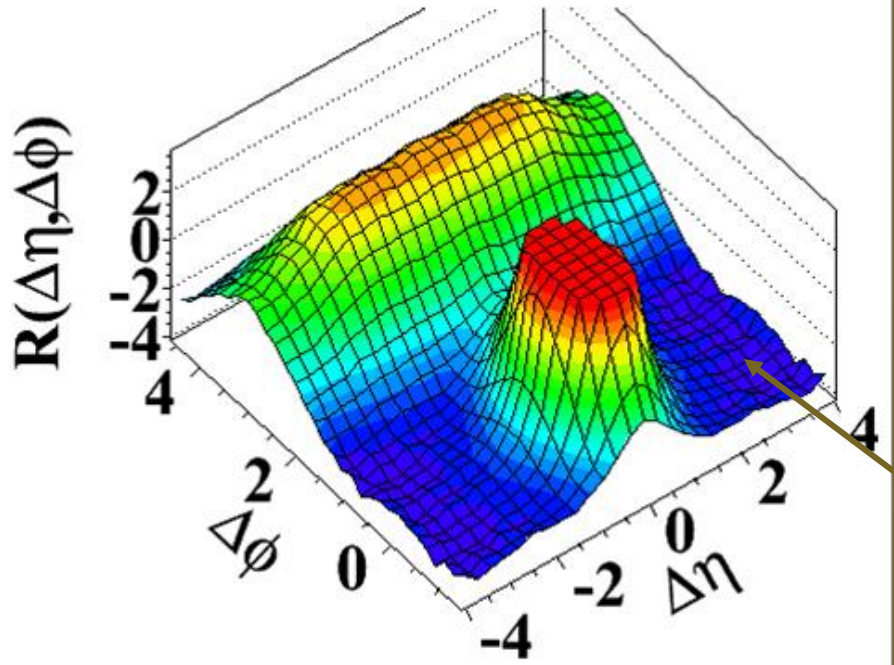

Inclusive Correlation
High multiplicity pp
(N>110)

Zoomed in to see the finer structure underneath

# Correlations in High Multiplicity pp

Non-Triggered

$p_T$ > 0.1 GeV




Inclusive Correlation
High multiplicity pp
(N>110)

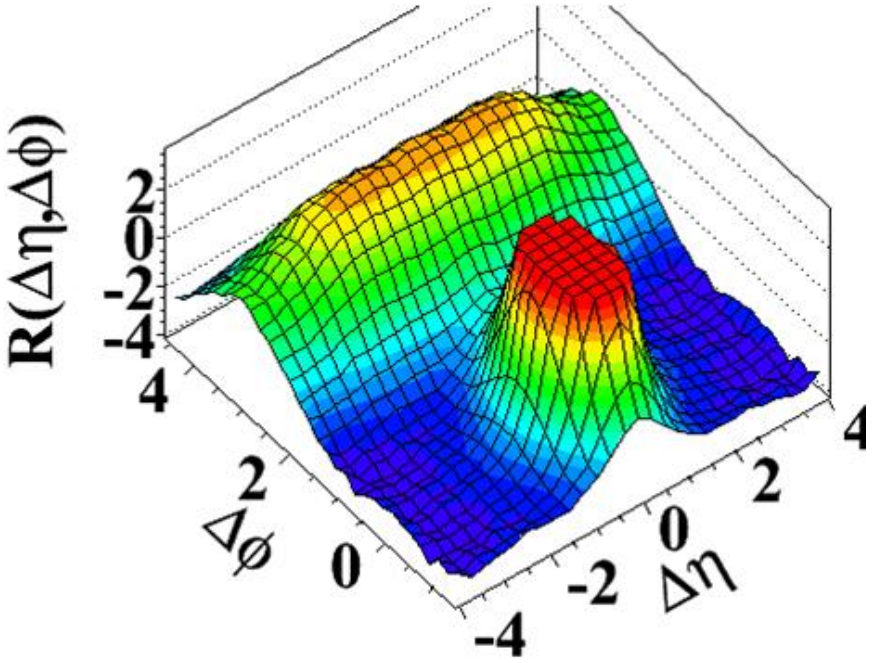
Zoomed in to see the finer structure underneath

Still no ridge, but what if trigger on a little higher $p_T$…

# Correlations in High Multiplicity pp

## Non-Triggered

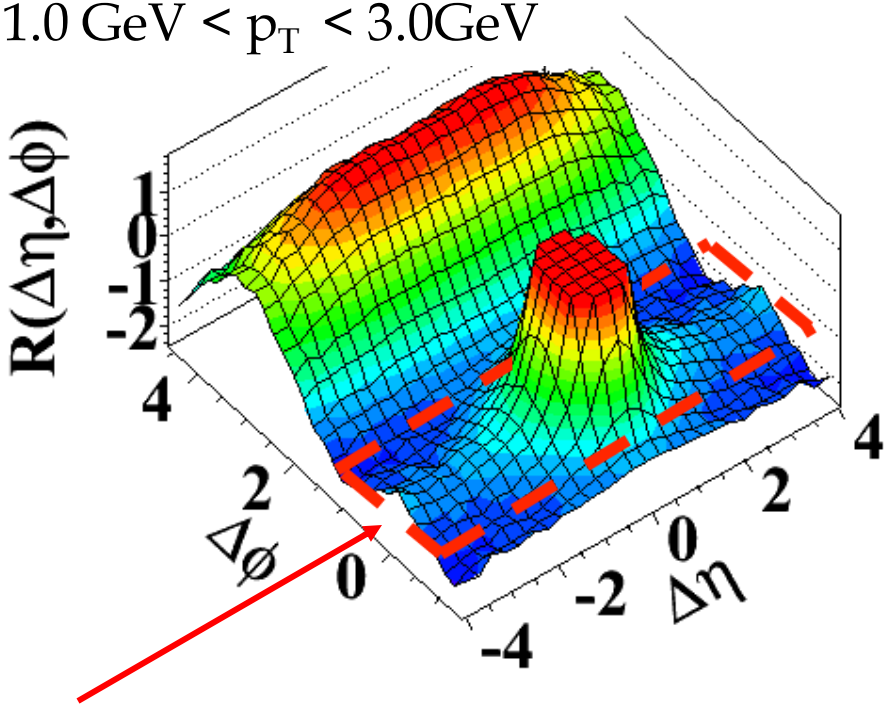
$p_T$ > 0.1 GeV




## Triggered

Inclusive Triggered

1.0 GeV < $p_T$ < 3.0GeV

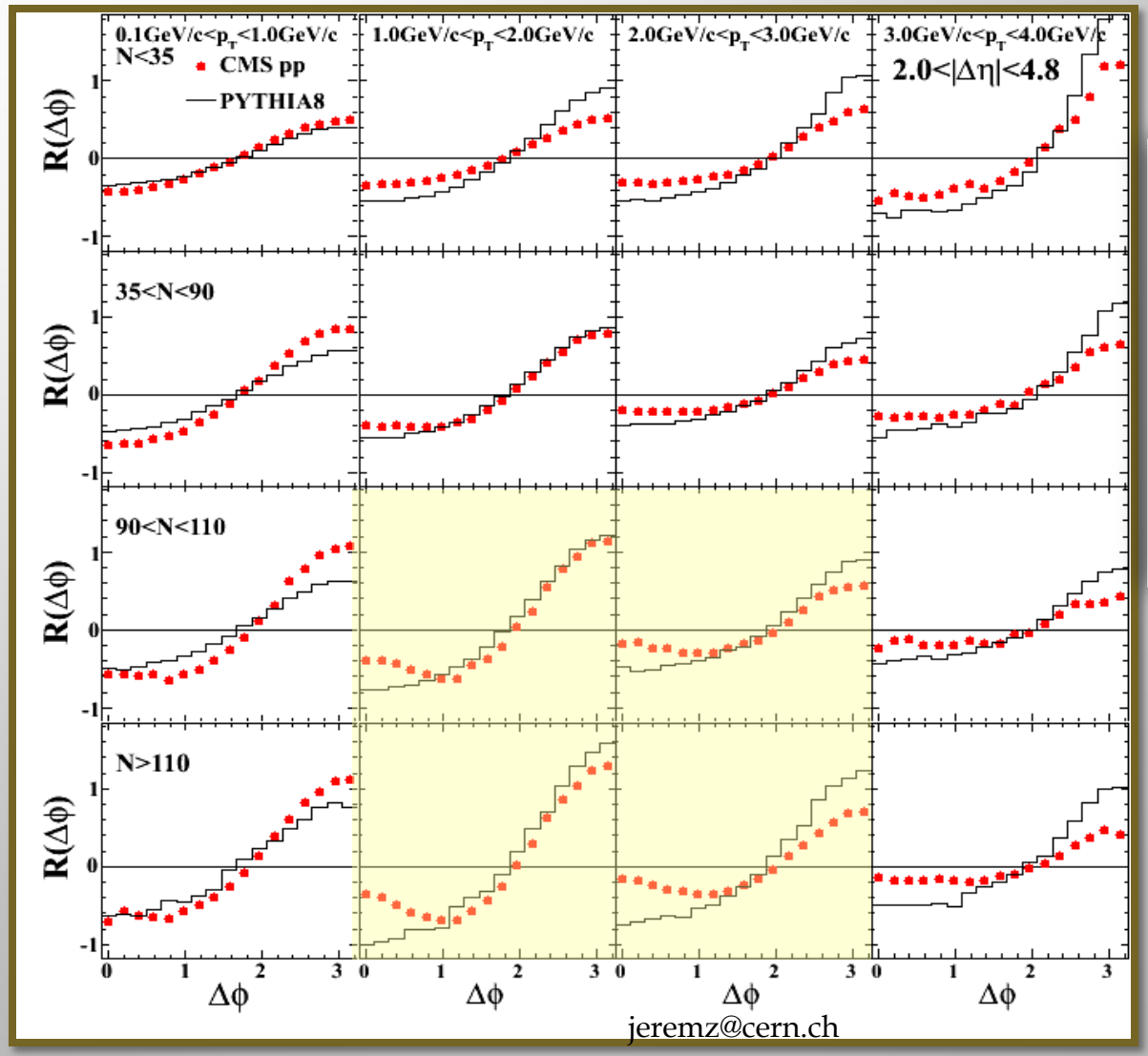


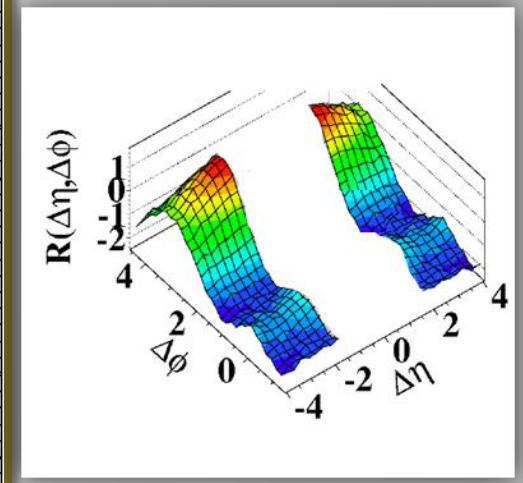

Striking "ridge-like" structure extending over Δη at Δφ ~ 0

# 1-D projected R(Δϕ) at large Δη

Increasing $p_T$

Increasing multiplicity



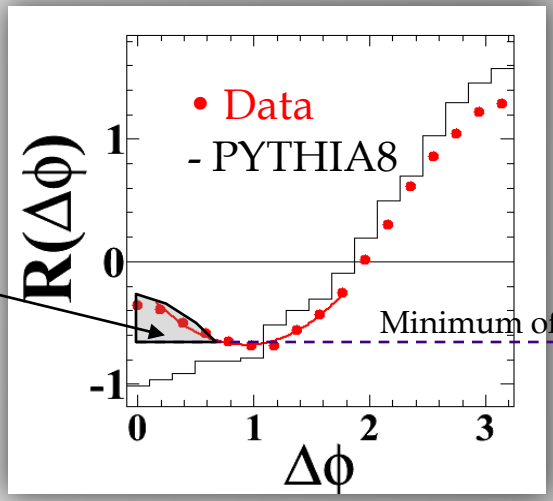



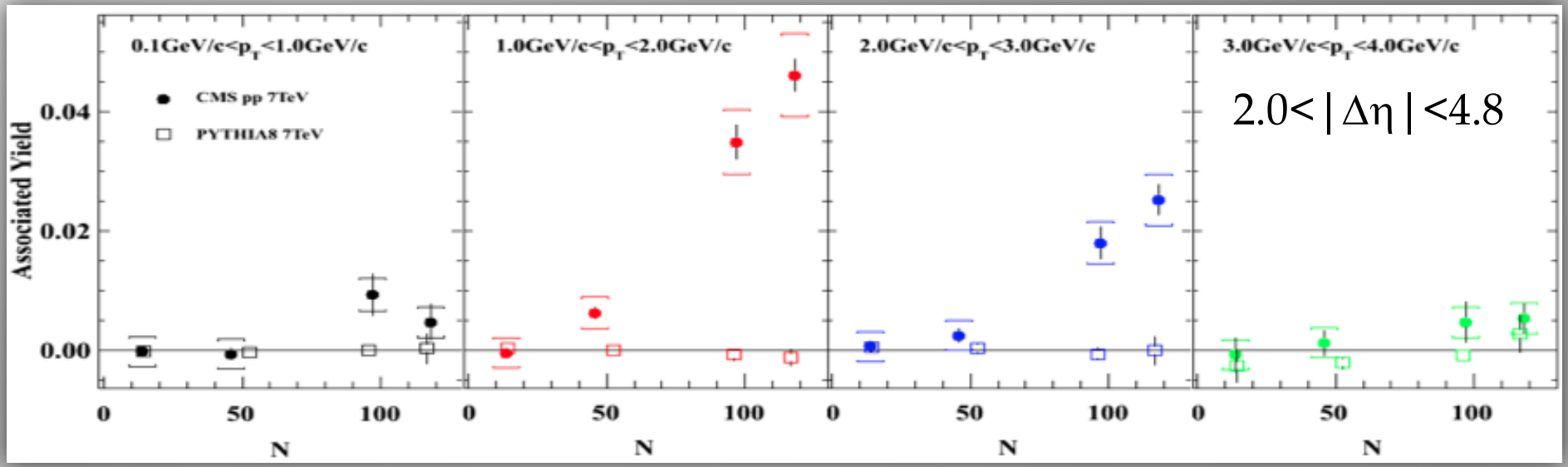
# Quantifying the pp Ridge

Zero Yield At Minimum (ZYAM)

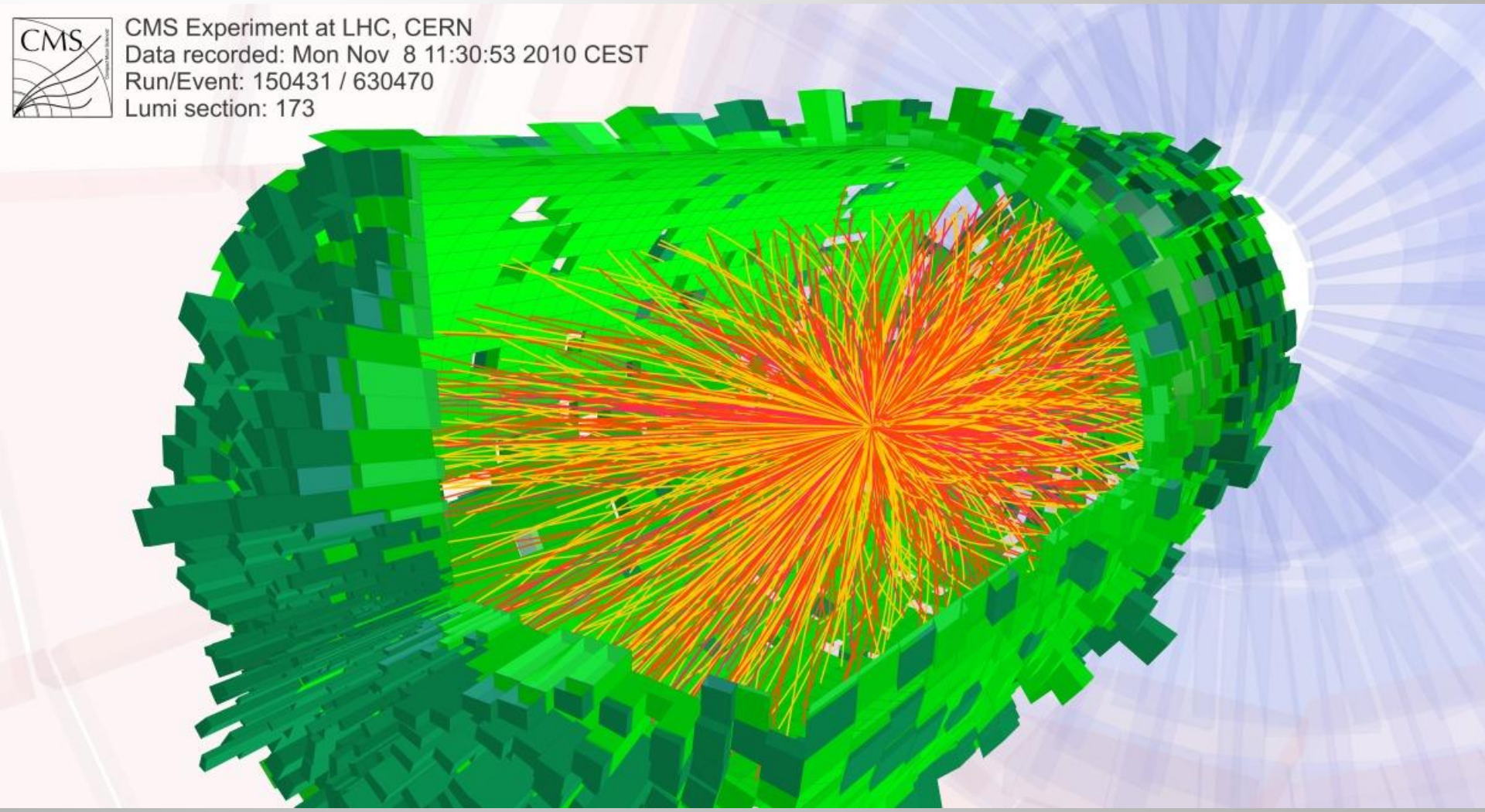
N>110
2.0<|Δη|<4.8
1GeV/c<$p_T$<2GeV/c

Associated yield: correlated multiplicity per particle



# Heavy Ions at the LHC



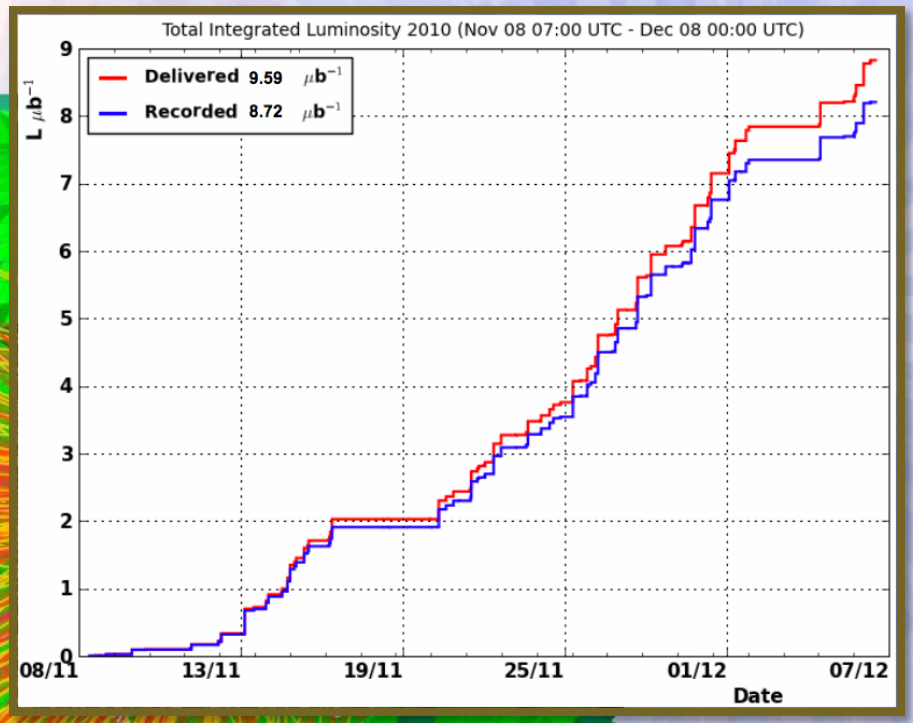
# Heavy Ions at the LHC

CMS Experiment at LHC, CERN
Data recorded: Mon Nov 8 11:30:53 2010 CEST

In November and December of 2010, the LHC delivered over 9 $\mu b^{-1}$ of 2.76 TeV PbPb data

CMS recorded over 90% of these collisions

We used 0.44 $\mu b^{-1}$ in this analysis



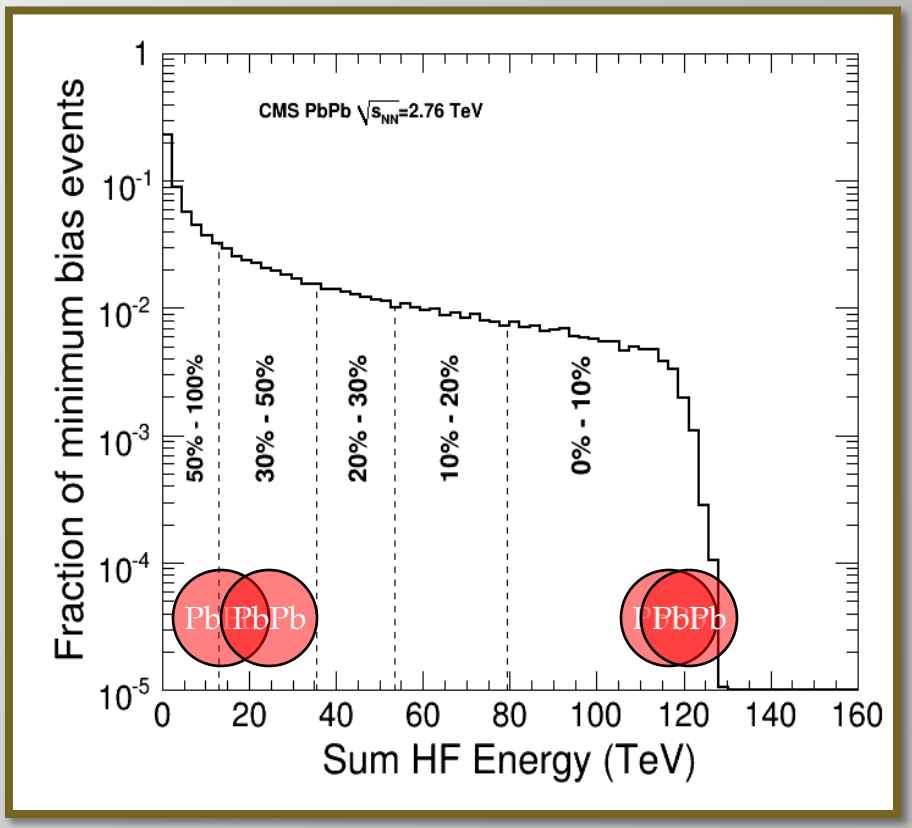
# Centrality in HI

Focus on 0-5% most central events in this analysis

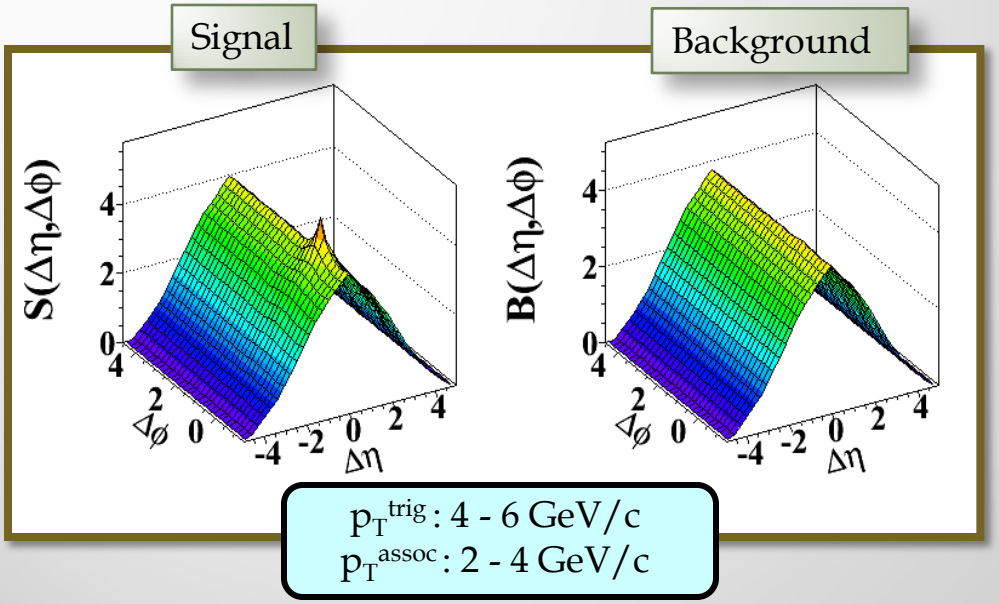
Trigger efficiency 100%for these events

Flow not taken into account in this analysis

177K events after cuts



# Analysis Technique



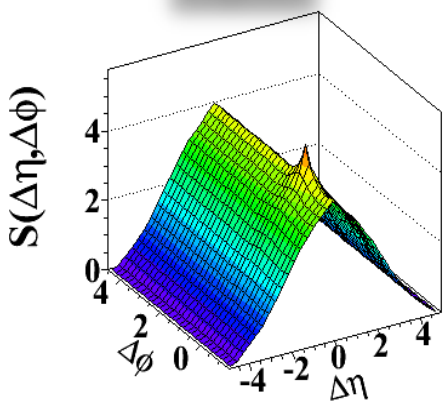

Pair acceptance correction for the triangular shape in Δη

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

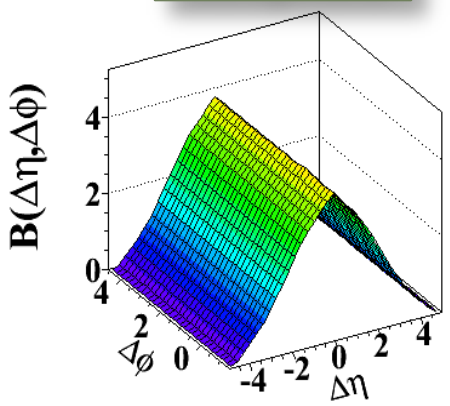
This is a different way of normalizing the correlation than that used in the pp analysis

# Analysis Technique

Signal



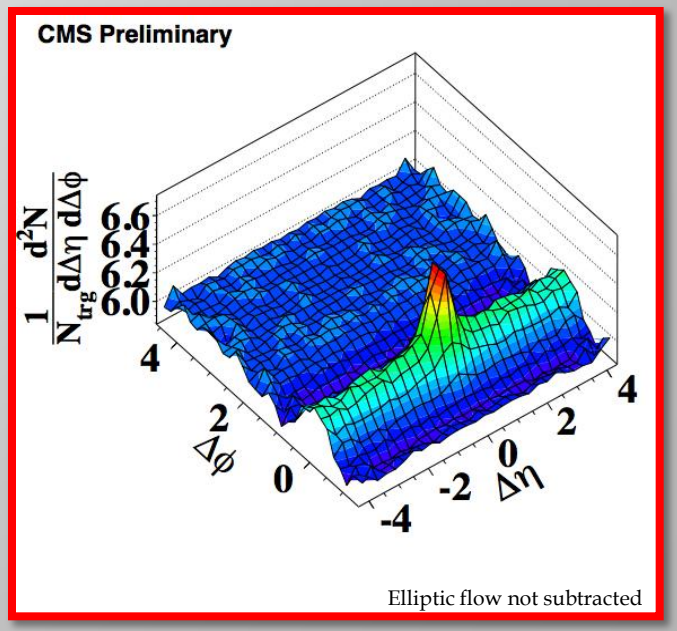

Background




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

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

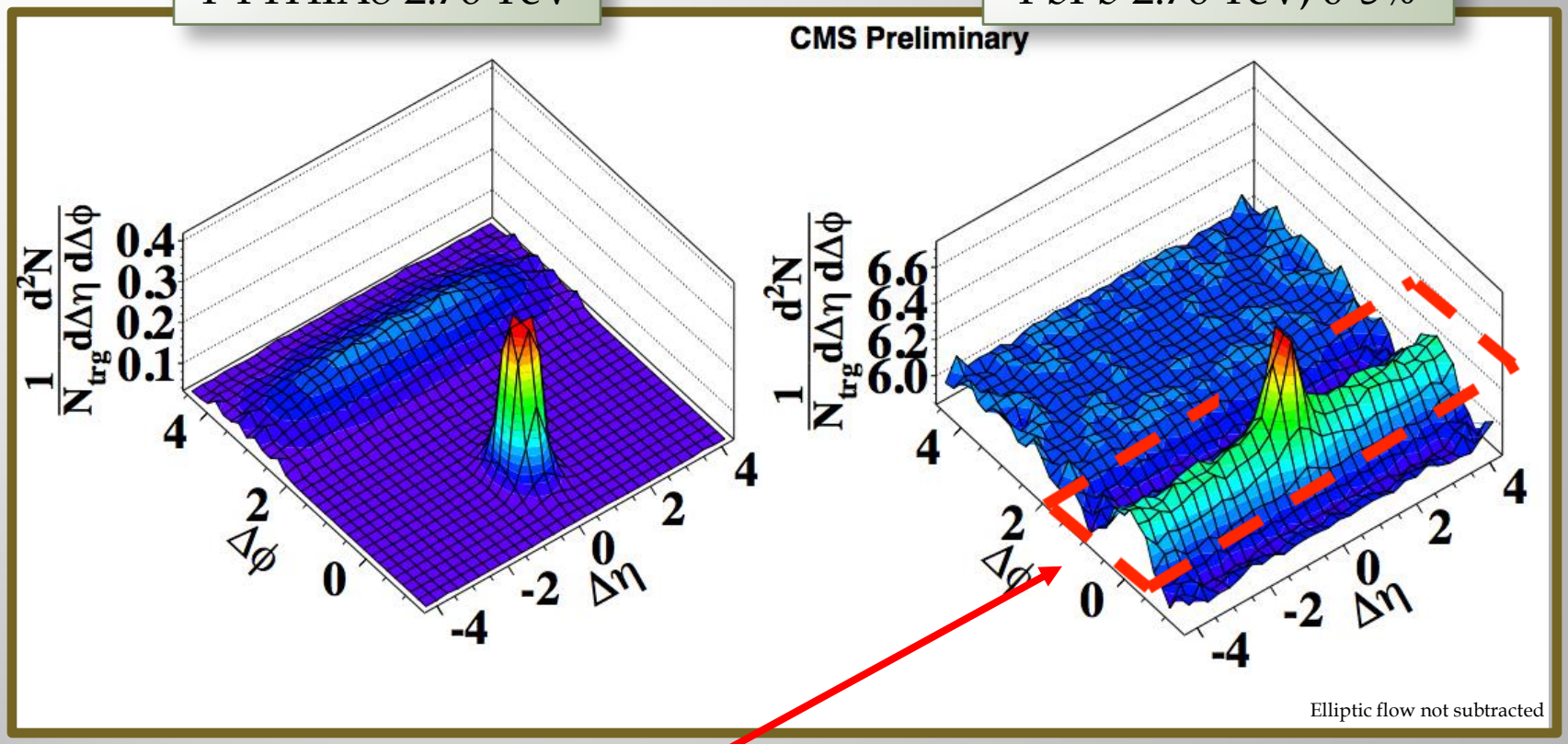
There's a ridge



# Final Results - 2D

PYTHIA8 2.76 TeV

PbPb 2.76 TeV, 0-5%

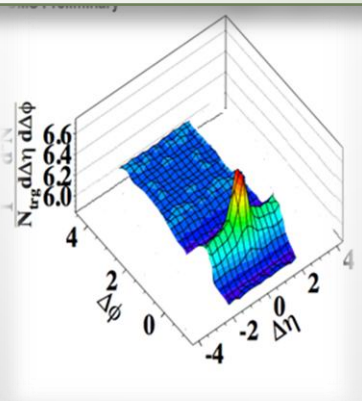


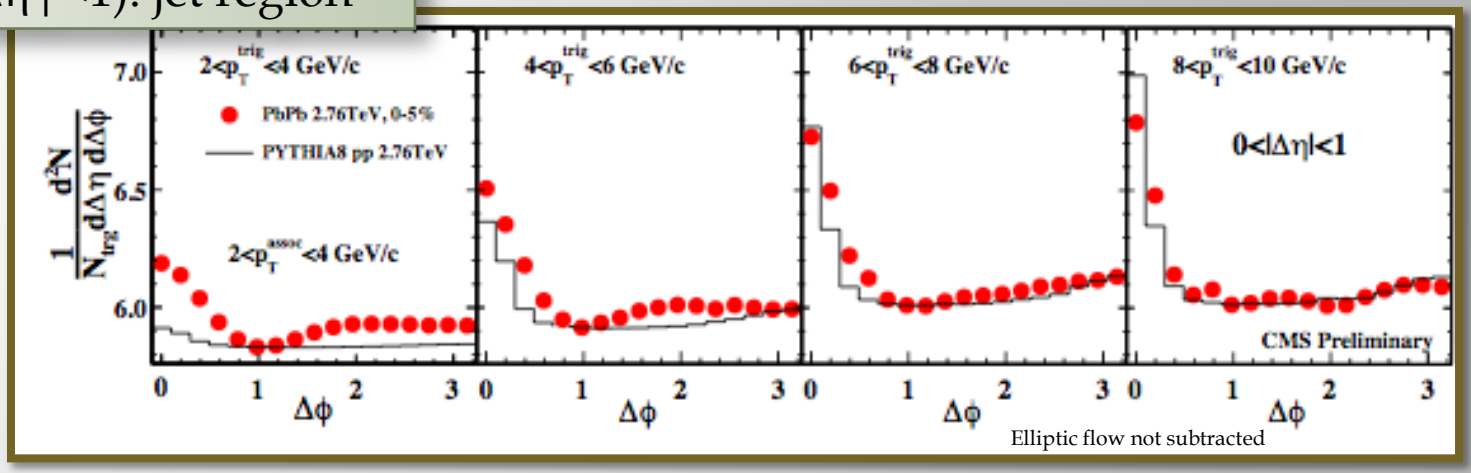

$p_T^{trig}$ : 4 - 6 GeV/c
$p_T^{assoc}$ : 2 - 4 GeV/c

✓ Prominent long-range, near side ridge

# Final Results - 1D Δφ projections

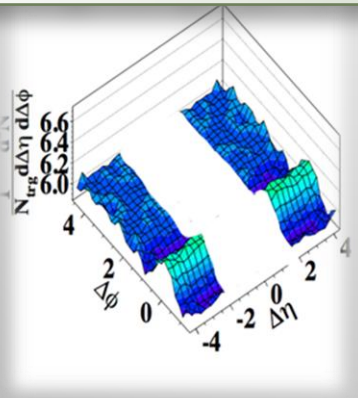
## Short-range (0<|Δη|<1): jet region

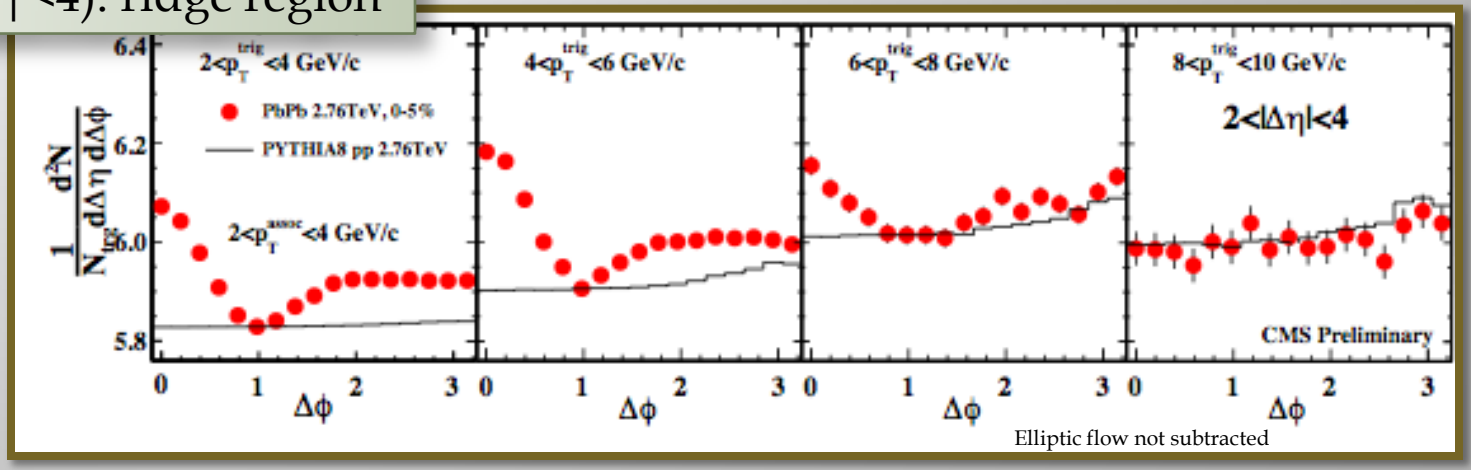



Elliptic flow not subtracted

## Long-range (2<|Δη|<4): ridge region

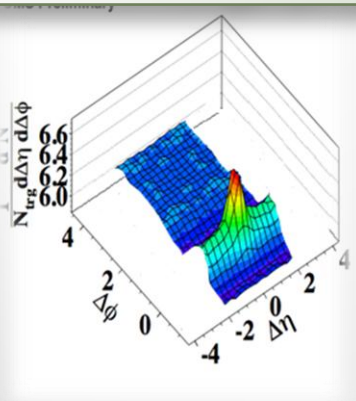


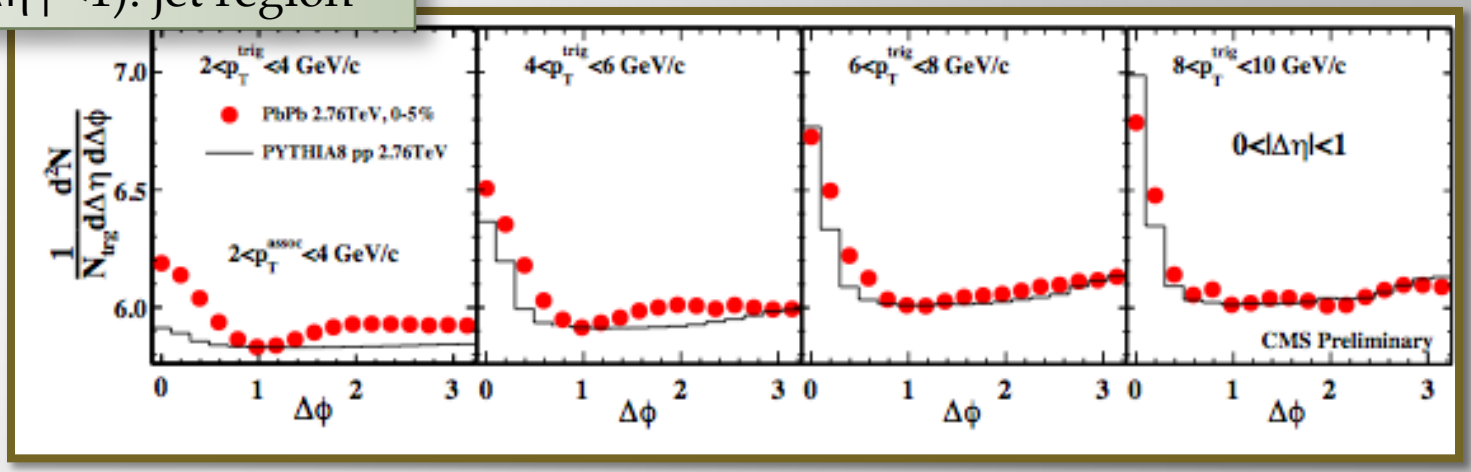




Elliptic flow not subtracted

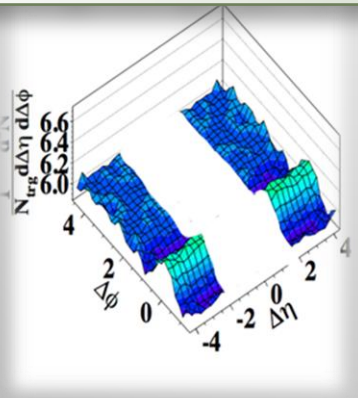
# Final Results - 1D Δφ projections

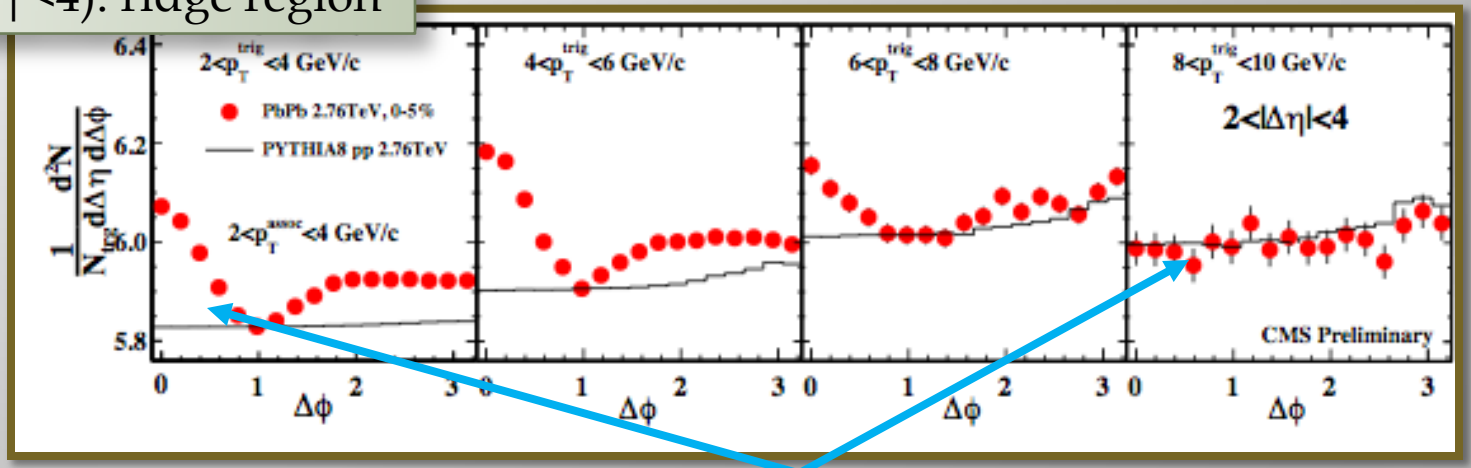
Short-range (0<|Δη|<1): jet region




Long-range (2<|Δη|<4): ridge region

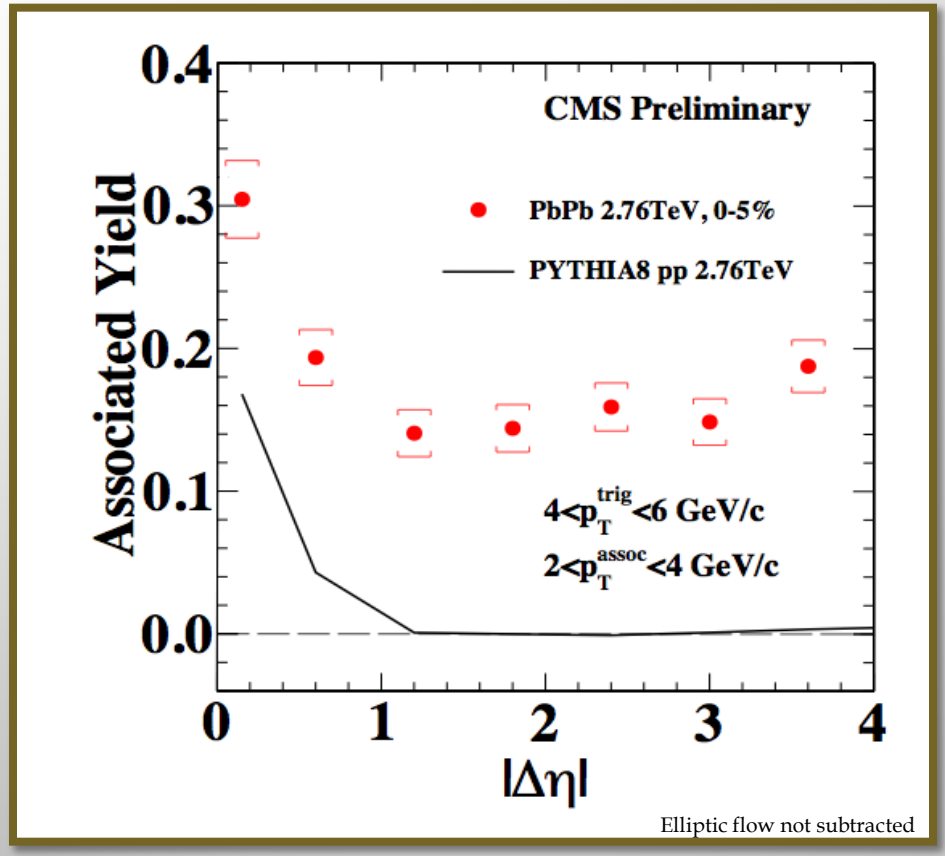



✓ Enhancement seems to disappear at high $p_T$

# Integrated Associated Yield

Elliptic flow not subtracted




Δη dependence of the near-side yield

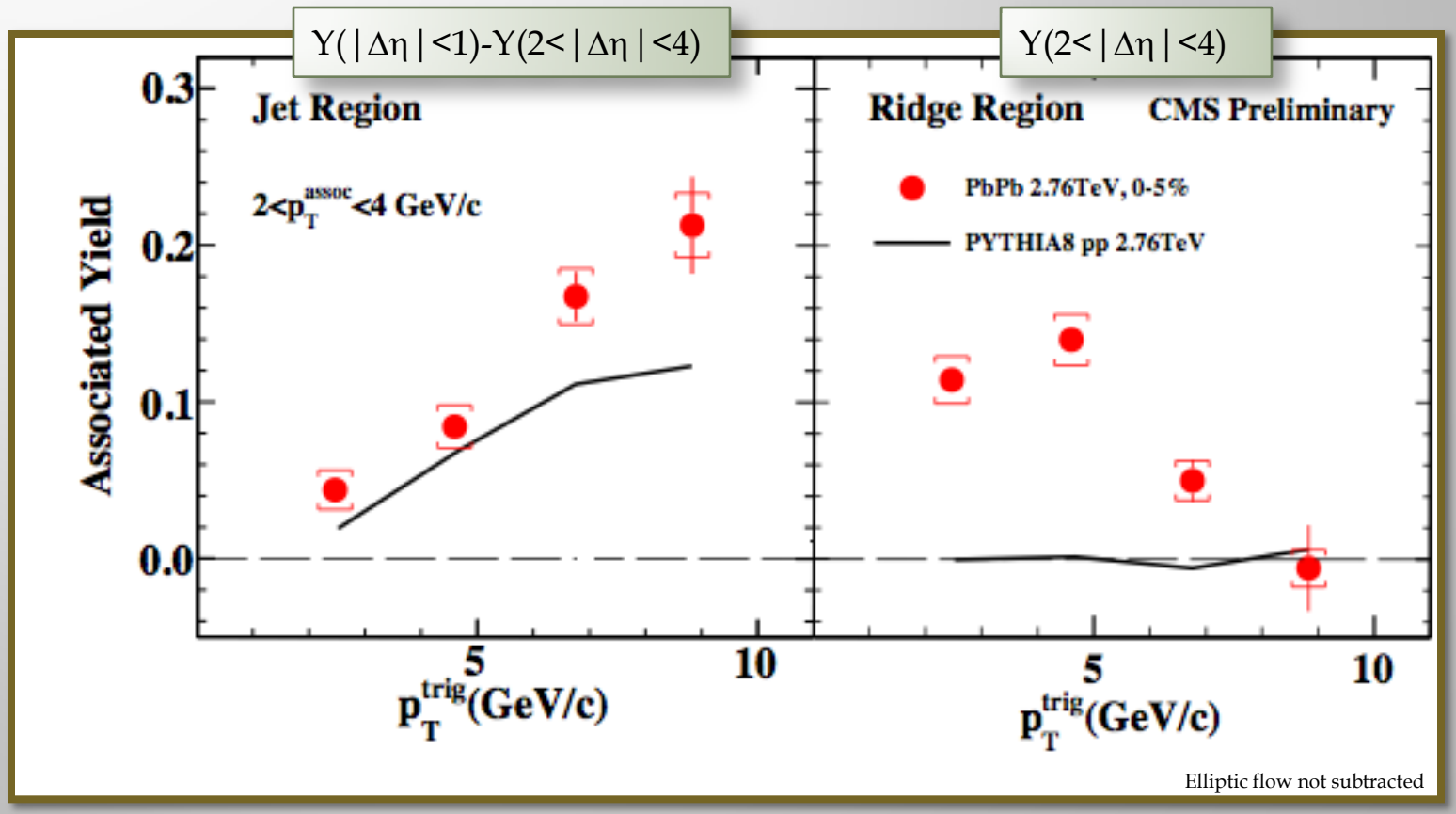
(measured in Δη slices of 0.6)

✓ Flat near-side ridge structure in PbPb for $|\Delta\eta| > 1$

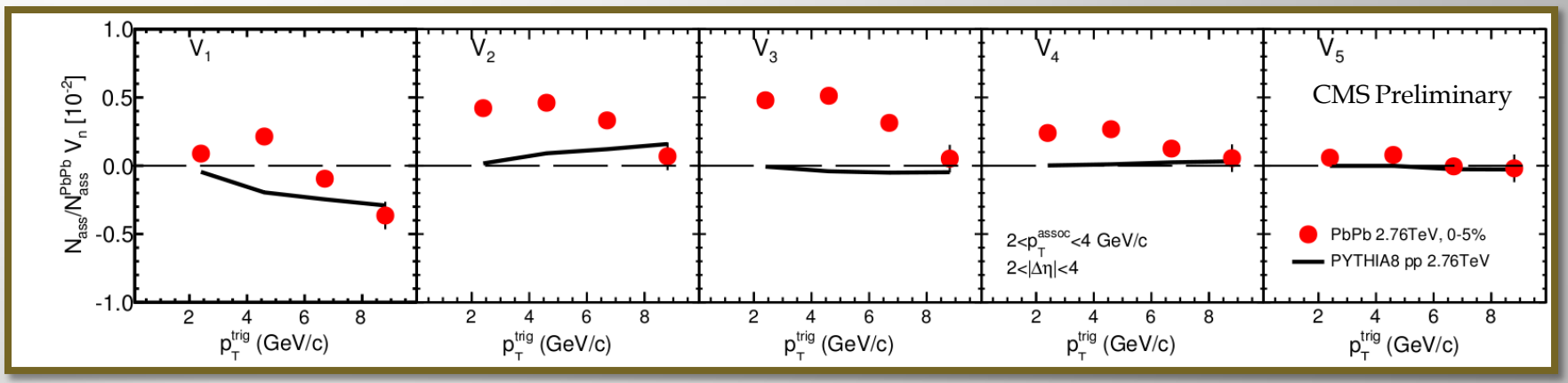
✓ Similar jet peak between PYTHIA8 and PbPb

# Integrated Associated Yield

Associated Yield (Y) vs trigger $p_T$ in jet and ridge region



# Fourier Decomposition




An alternative way to quantify the results
Relevant to the ridge-as-hydrodynamic-flow perspective

# Conclusions

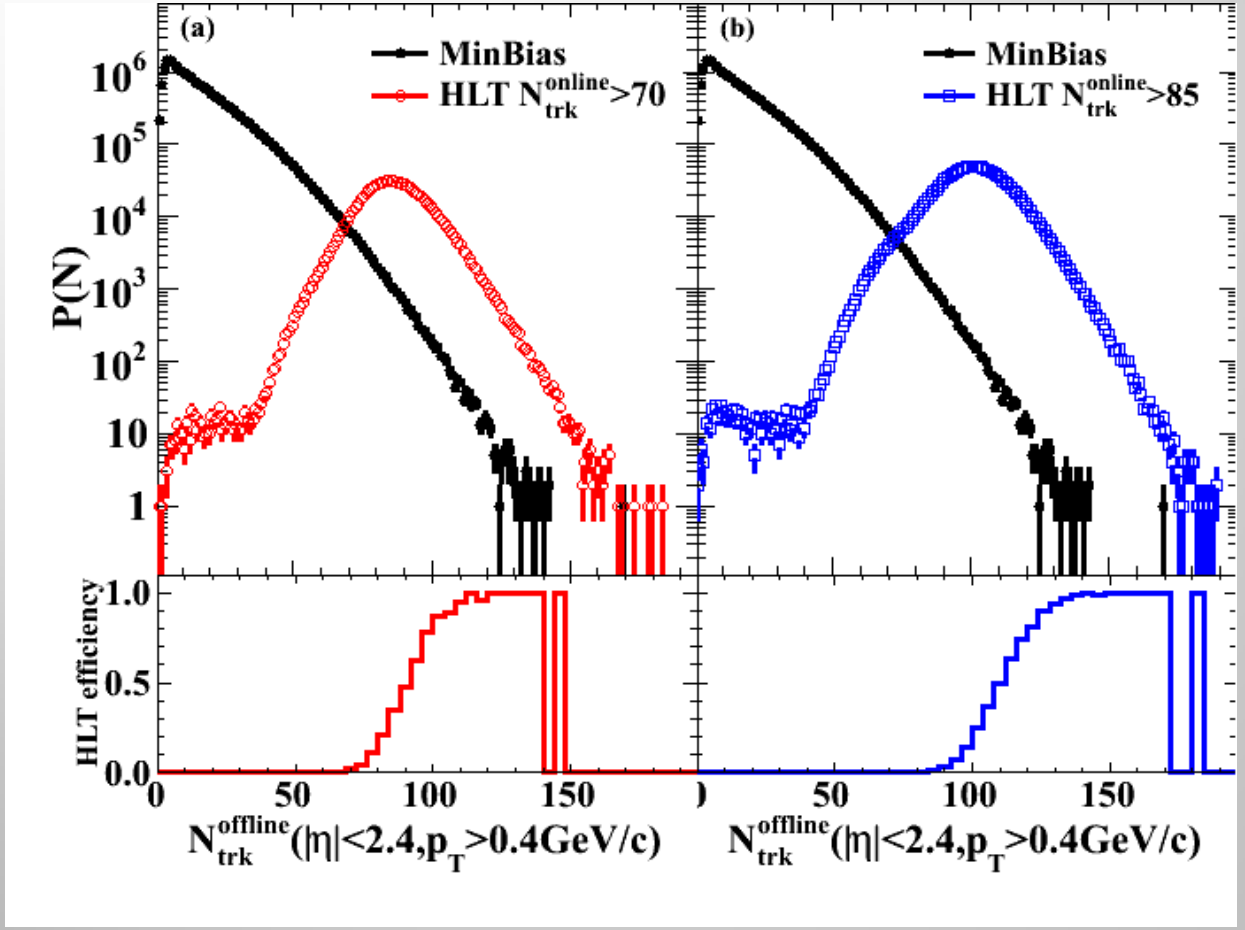
- Ridge-like structure now found in both pp and heavy ion collisions
- It appears constant out to large relative pseudorapidity in 2.76 TeV central PbPb collisions (out to 4)
- Measured ridge-like enhancement disappears at higher $p_T$ trigger ~8 – 10 GeV/c


UIC UNIVERSITY OF ILLINOIS AT CHICAGO

# BACKUP

# Trigger on High Multiplicity pp

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



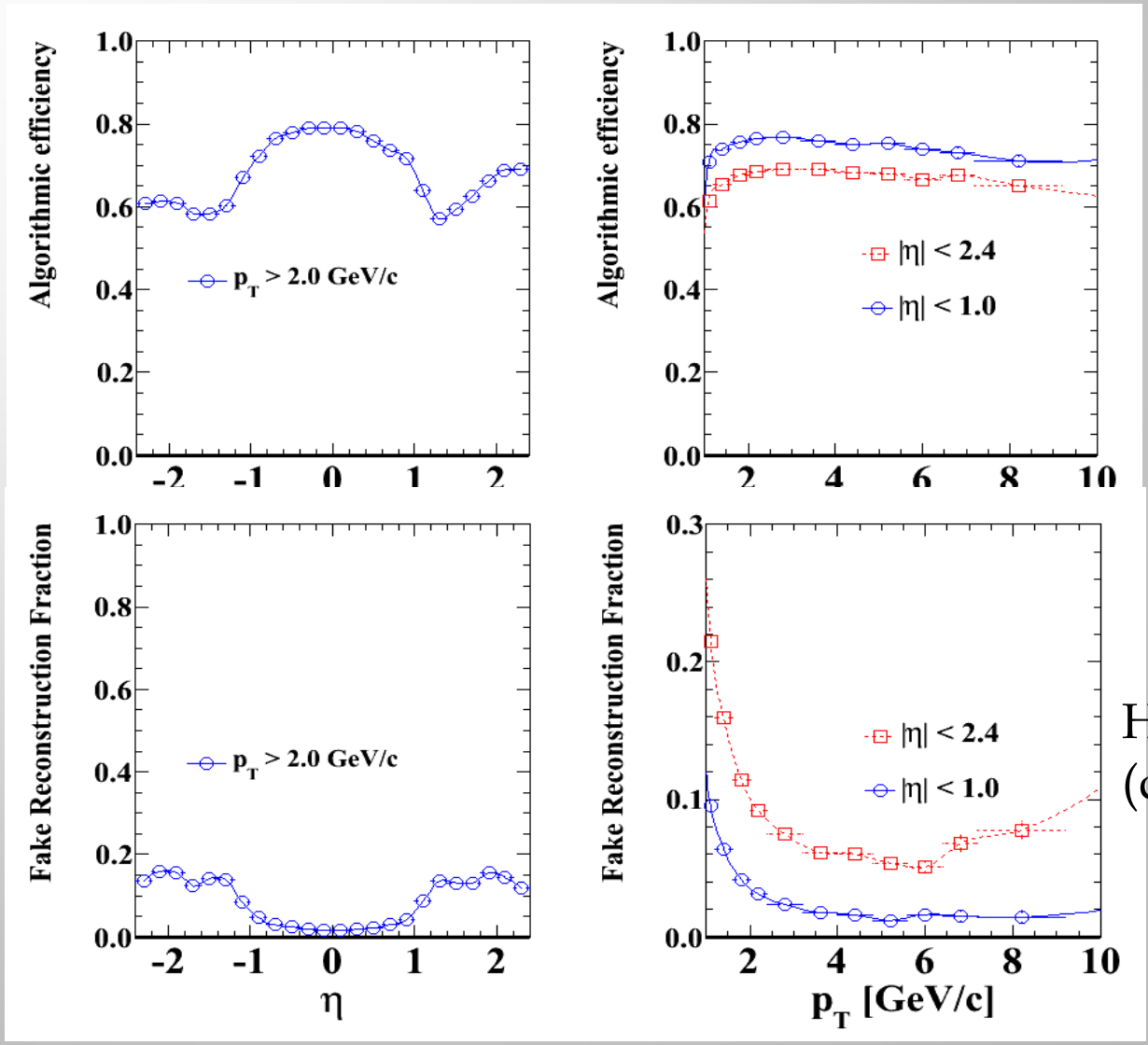

Two HLT thresholds:
- $N^{online}$ > 70
- $N^{online}$ > 85

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

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

# Tracking in CMS HI

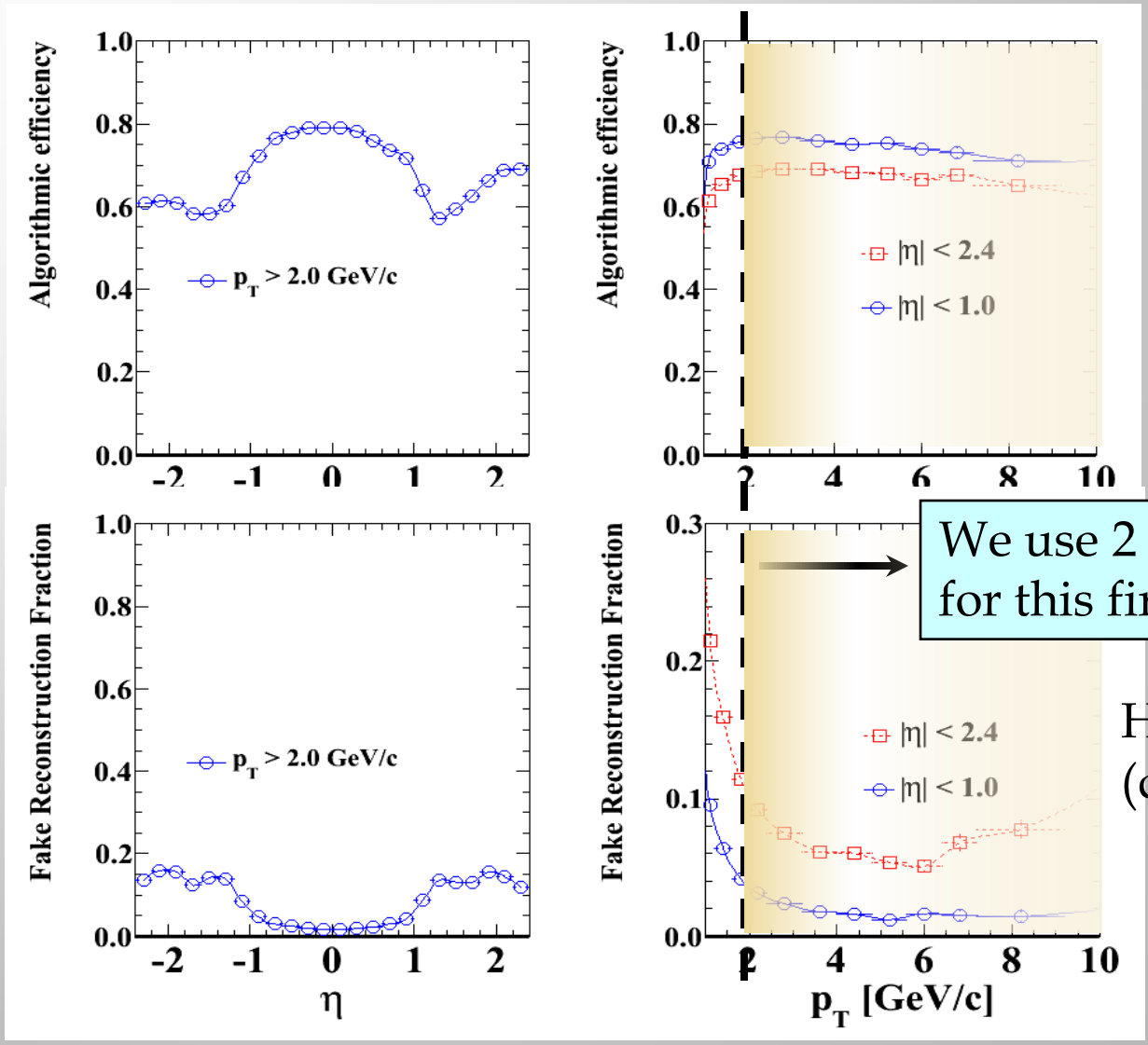
HI Tracking Performance from HYDJET MC




HYDJET 0-5%
(dN/dη ~ 1500)

# Tracking in HI

HI Tracking Performance from HYDJET MC



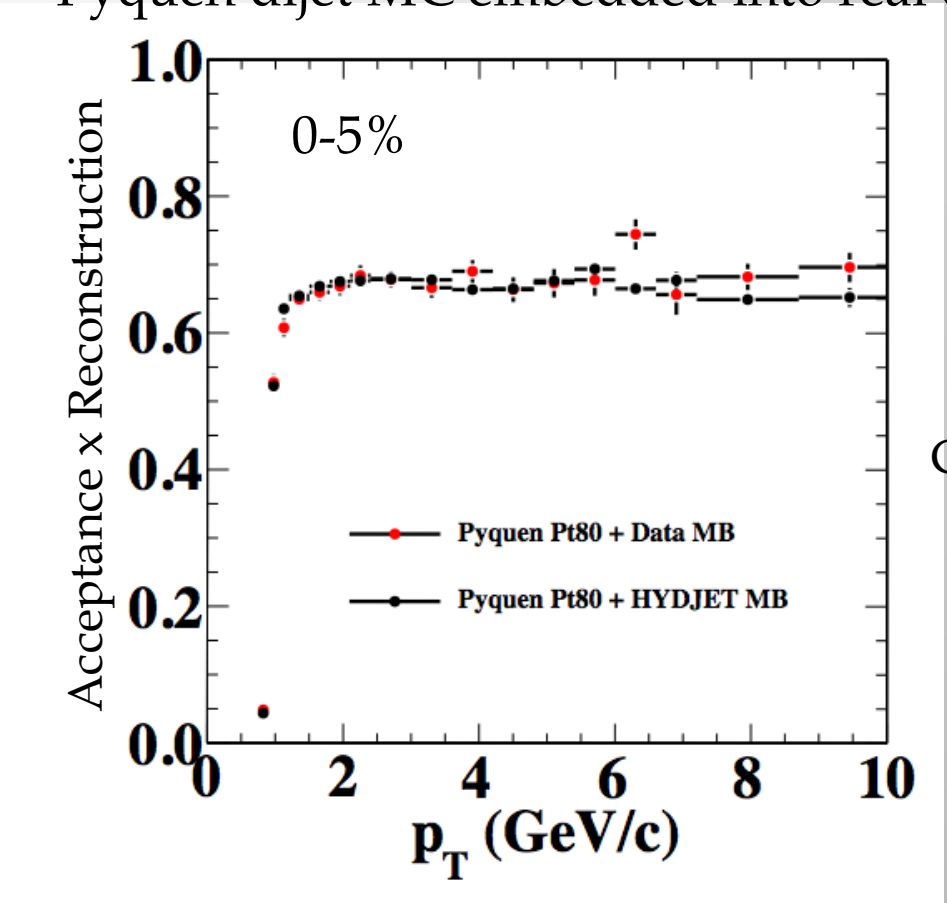

We use 2 - 10 GeV/c for this first analysis

HYDJET 0-5% ($dN/d\eta \sim 1500$)

# Tracking in HI

## Semi data-driven tracking efficiency

Pyquen dijet MC embedded into real data




Good agreement!

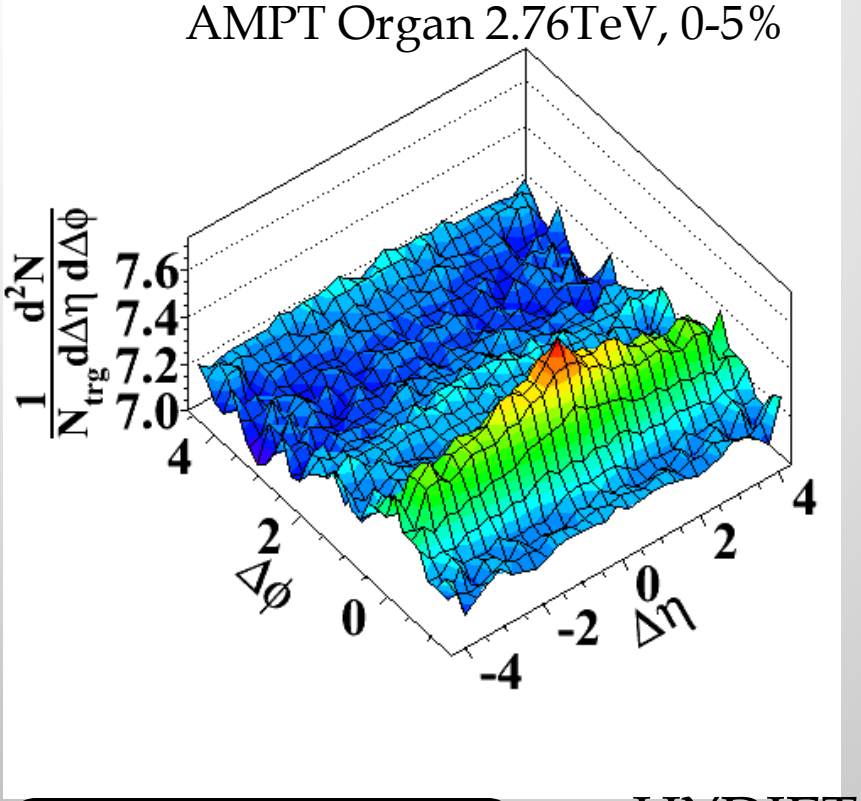
# Event Selection

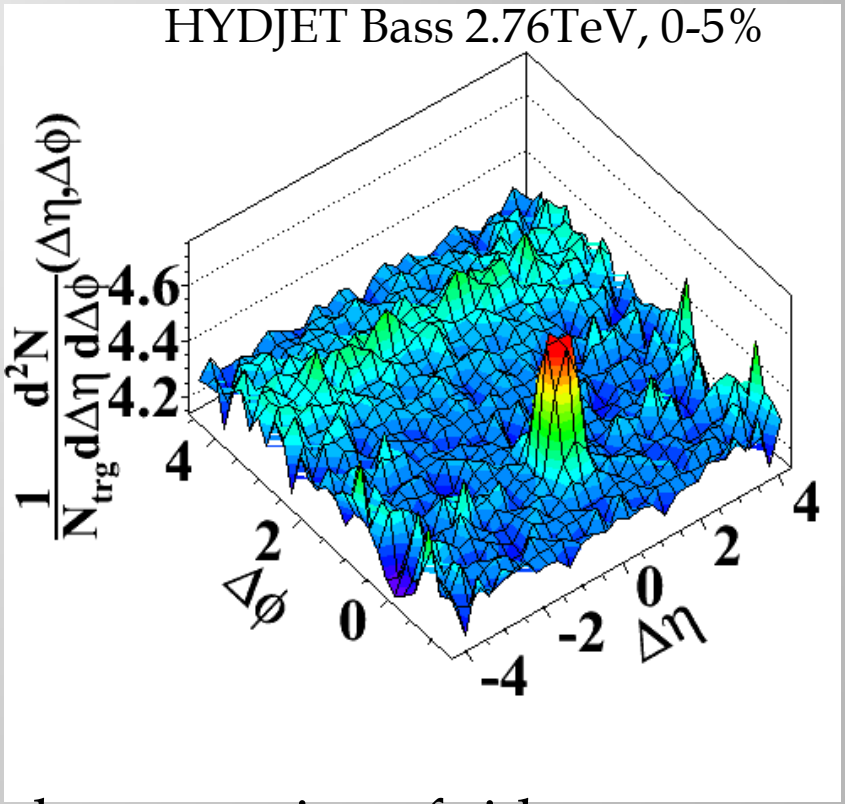
- Online trigger: HLT_HIMinBiasHfOrBSC_Core
  - BSC OR HF tower coincidence
  - > 97% efficiency (<1Hz noise rate)

- Offline selections:
  - Veto beam halo trigger bits
  - 3 HF towers (E > 3 GeV) on each side
  - Beam-scraping events removed with pixel cluster vertex compatibility
  - Reconstructed primary vertex with at least 2 tracks, $|z_{vtx}|$<15cm, r<0.02cm

Total # of MinBias events selected: 3.4 Million

# HI MC models

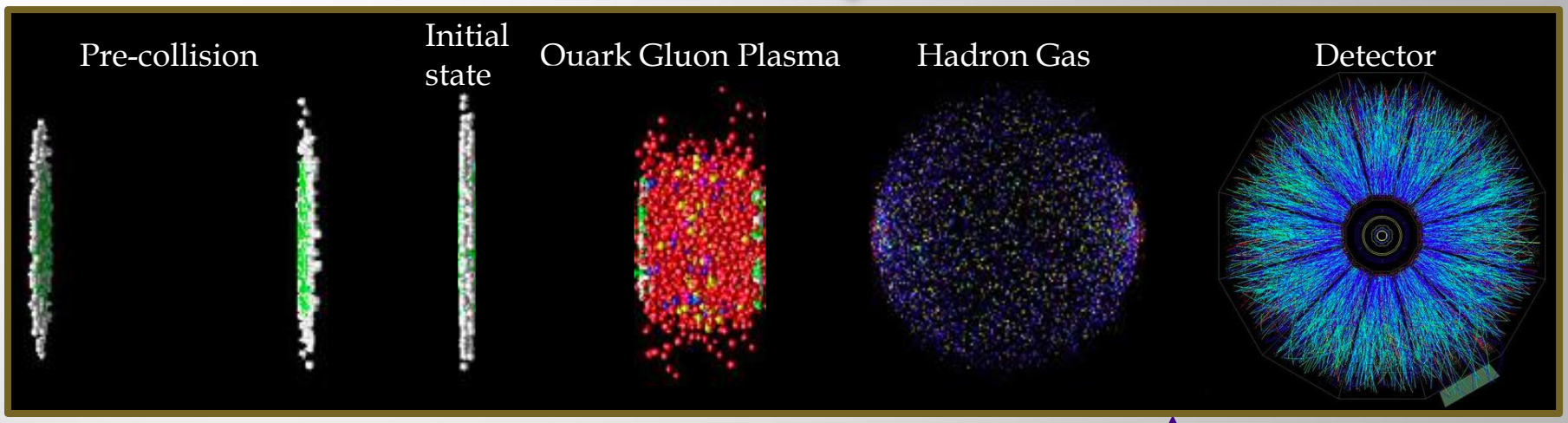


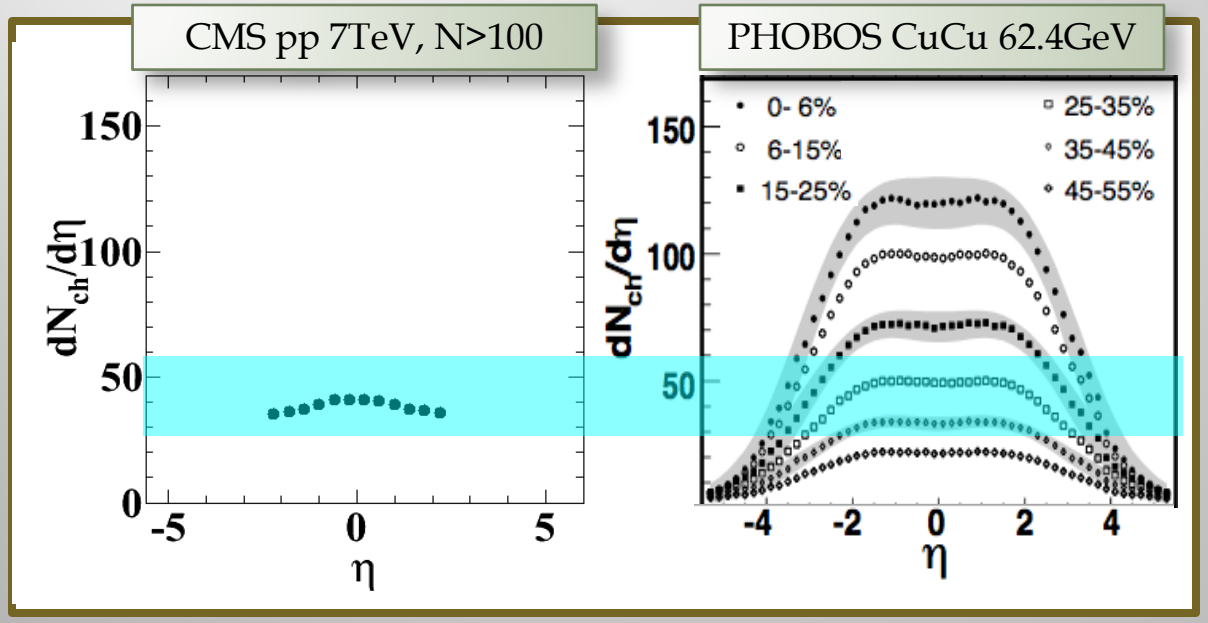




$p_T^{trig}$ : 4 - 6 GeV/c
$p_T^{assoc}$ : 2 - 4 GeV/c

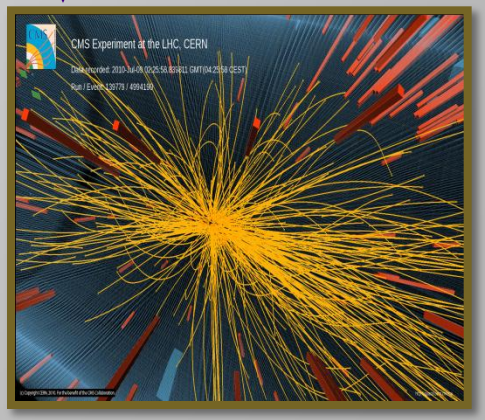
- HYDJET shows no sign of ridge
- AMPT has ridge but misses hard processes

# Relativistic Heavy Ion Collision



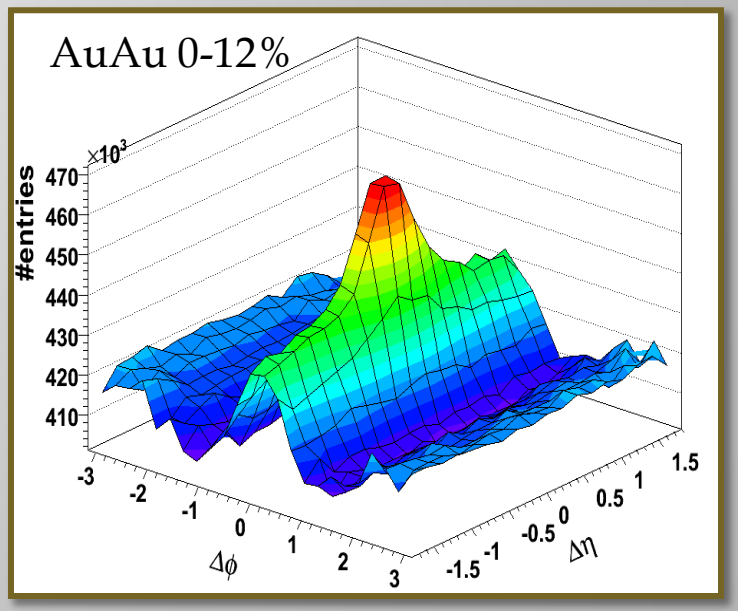




medium?

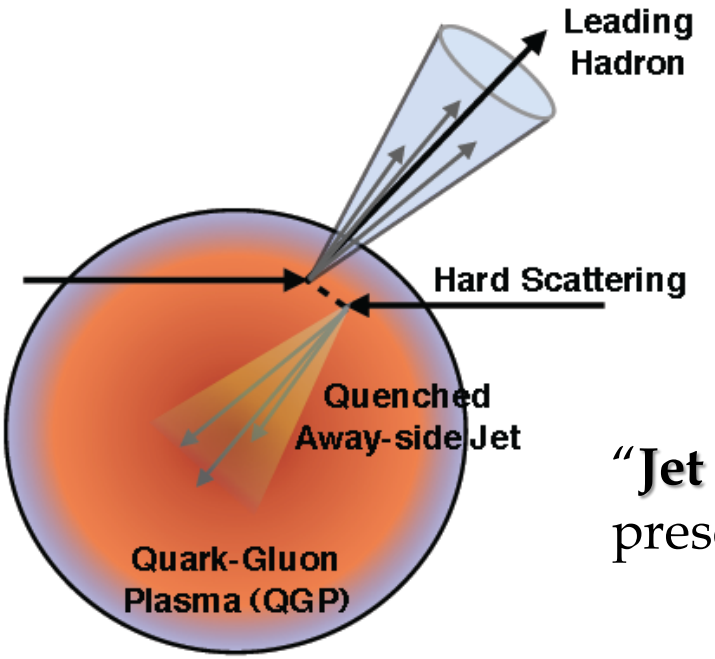


# The Ridge at RHIC

- Seen in different correlation techniques by different experiments in 200 GeV AuAu data
- There is not yet a consensus on its origin, however it is believed to be a medium effect
- The LHC can and CMS are uniquely suited to study quantitative features of the ridge like $p_T$ and pseudorapidity reach



# Dijet Events in Heavy Ions

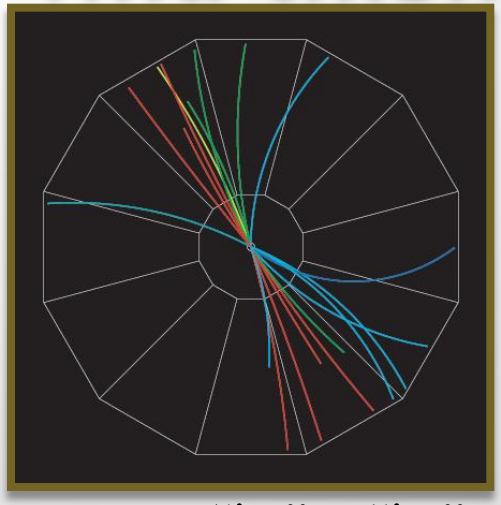



"**Jet Quenching**" in the presence of a medium

- Dijets are a useful probe of the medium

# So how do you…

## find this…

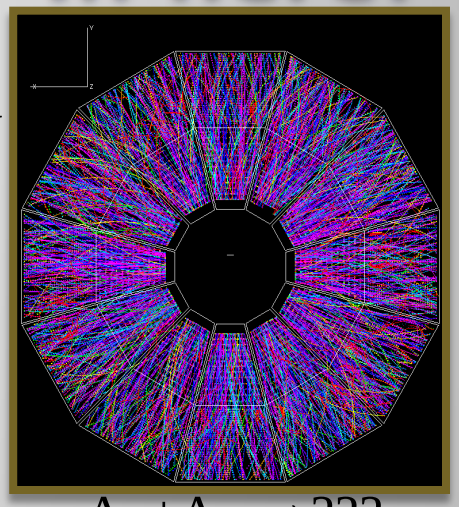


p+p →"jet" + "jet"
(STAR@RHIC)

$\sqrt{s_{nn}} = 200\ \text{GeV}$

Beam into /
out-of screen

## in here?



Au+Au →???
(STAR@RHIC)

- The challenge: Jet reconstruction is difficult in heavy ions for low $p_T$
  (First RHIC measurements had $p_T$ reach of ~ 7 GeV/c)
- A solution: Make a statistical measurement via correlations