New unexpected CMS result in pp collisions at 7 TeV

V. L. Korotkikh

DEHEP and DTHEP SINP MSU meeting, Oct 13, 2010

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

JHEP 1009:091,2010
Sep 2010. e-Print: **arXiv:1009.4122** [hep-ex]
CMS Collaboration,

From MSU:

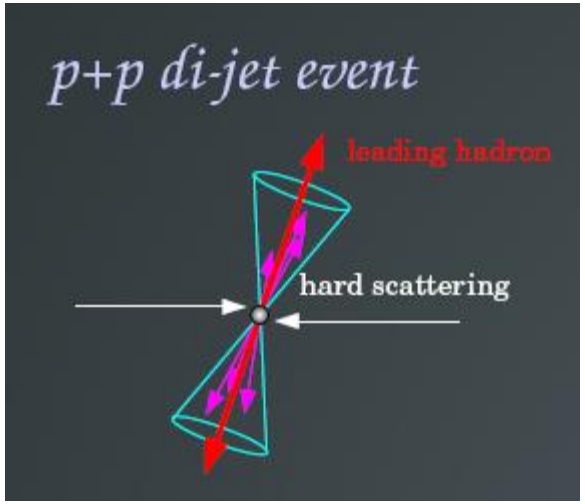
Moscow State University, Moscow, Russia
E. Boos, M. Dubinin[17], L. Dudko, A. Ershov, A. Gribushin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, L. Sarycheva, V. Savrin, A. Snigirev

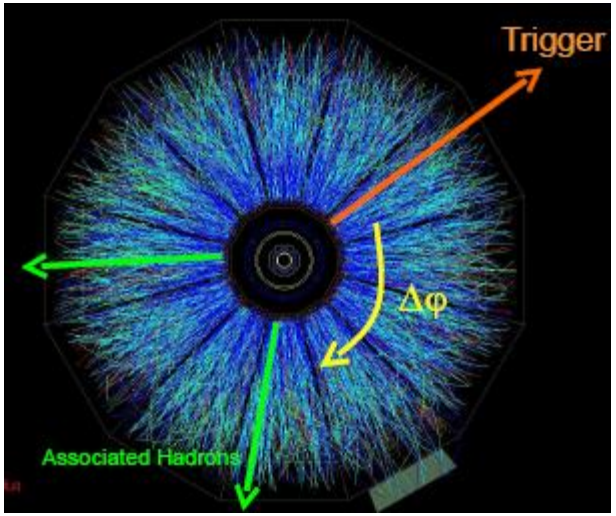
1. **G. Tonneli, G. Roland,** Two reports at CERN seminar Sep.21.2010
2. **Wei Li,** CMS General Weekly Meeting, Sep. 1 and Oct 4, 2010

Инициаторы и главные исполнители: Wei Li, George Stephans[1] and Jeremy Callner, Yuting Bai, Dave Hofman[2]

[1] Massachusetts Institute of Technology
[2] University of Illinois, Chicago

Trigger and Associated particles





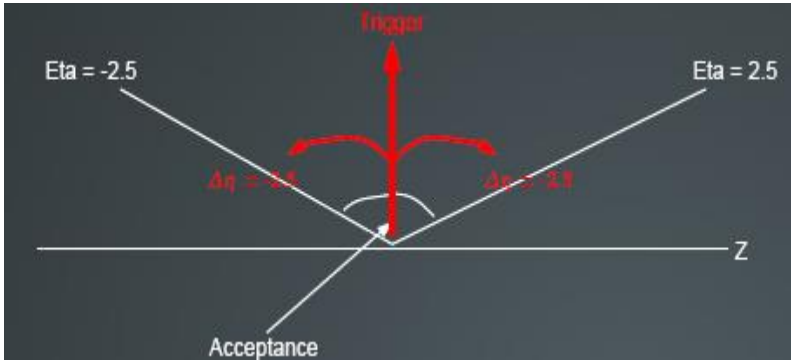
$$\Delta\eta = \eta_1 - \eta_2$$

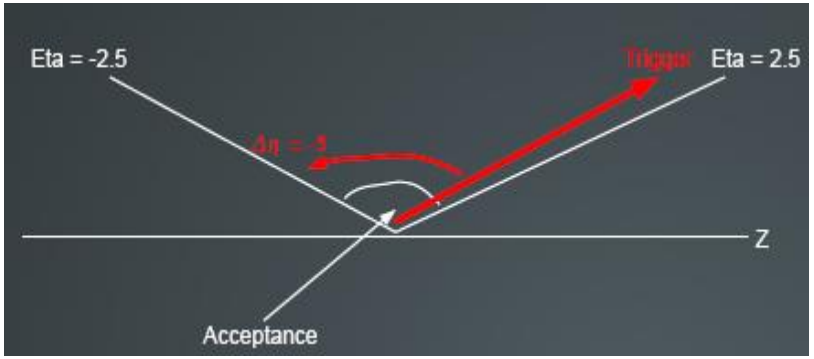
$$\Delta\varphi = \varphi_1 - \varphi_2$$

$3\ \text{GeV} < p_T^{\text{Trig}} < 5\ \text{GeV}$

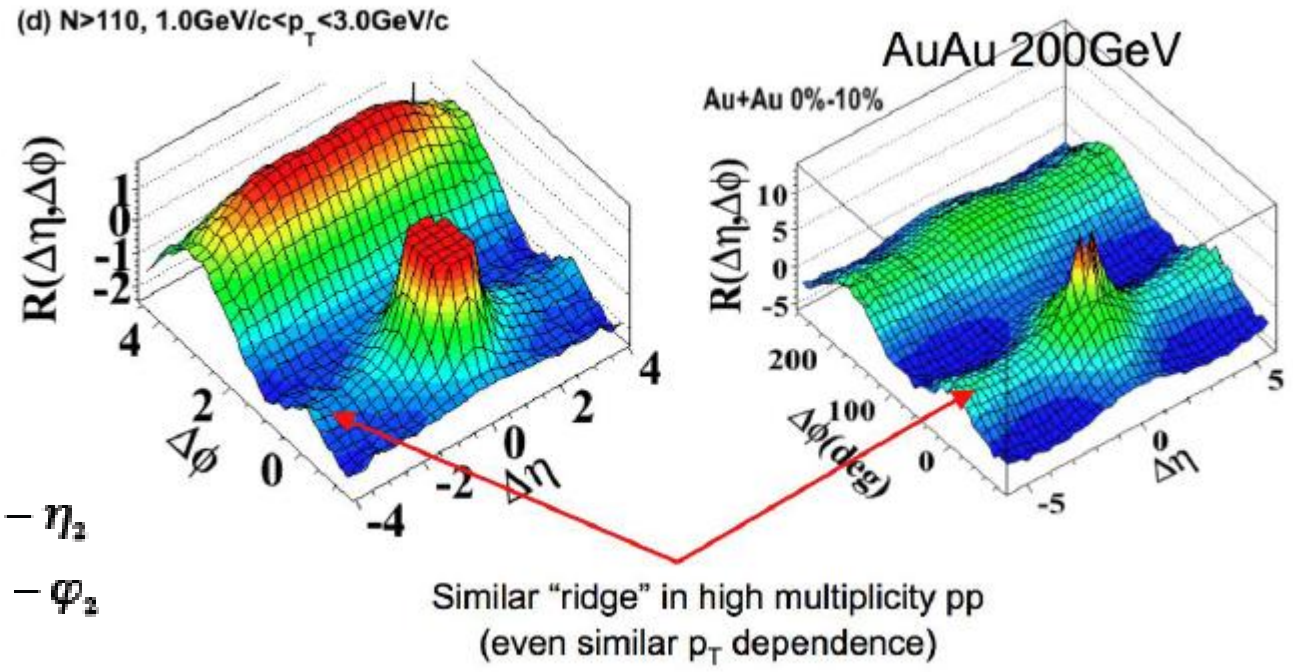
$1\ \text{GeV} < p_T^{\text{Ass}} < 3\ \text{GeV}$

В работе «Long-range correlation» minbias and условие $1 < p_T < 3$ GeV/c





Первое наблюдение Ridje-like структуры в p-p столкновениях



$\Delta\eta = \eta_1 - \eta_2$

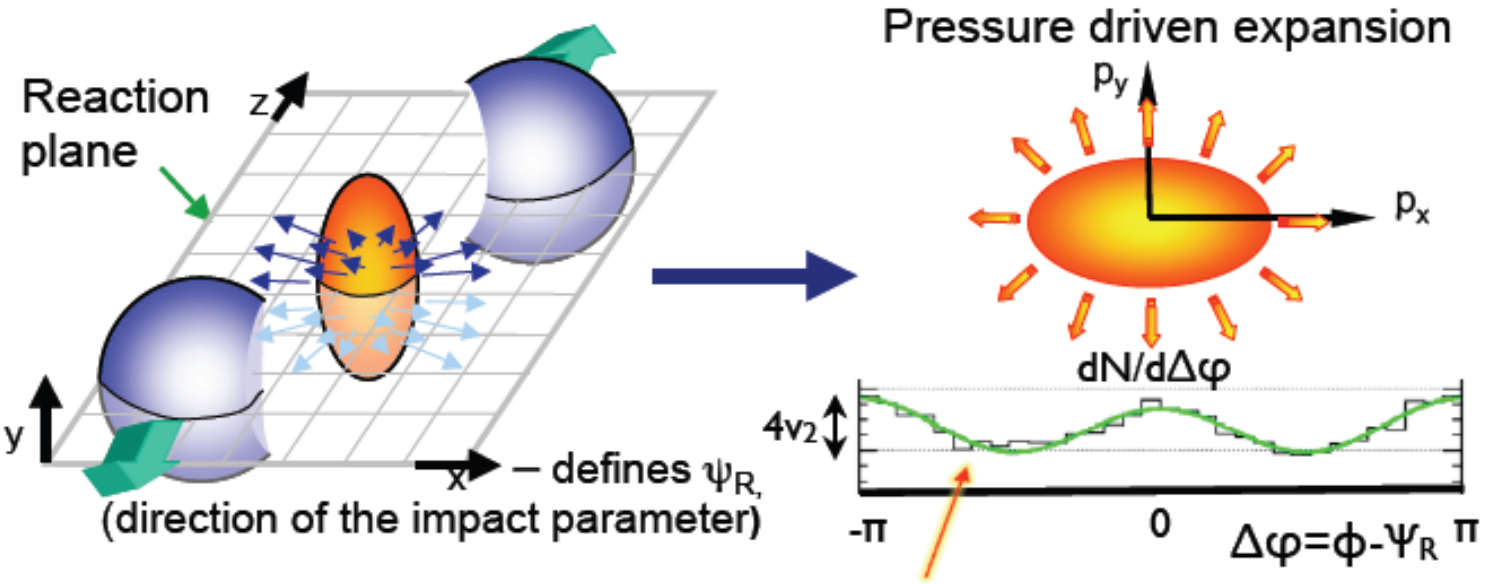
$\Delta\varphi = \varphi_1 - \varphi_2$

Similar “ridge” in high multiplicity pp
(even similar p_T dependence)

Signal is observed at large difference $|\Delta\eta| < 4.8$, large multiplicity N > 90 and at medium particle transverse momentum 1 < pT < 3 GeV/c.

Correlations in Heavy Ion Collisions

Collective flow phenomena:

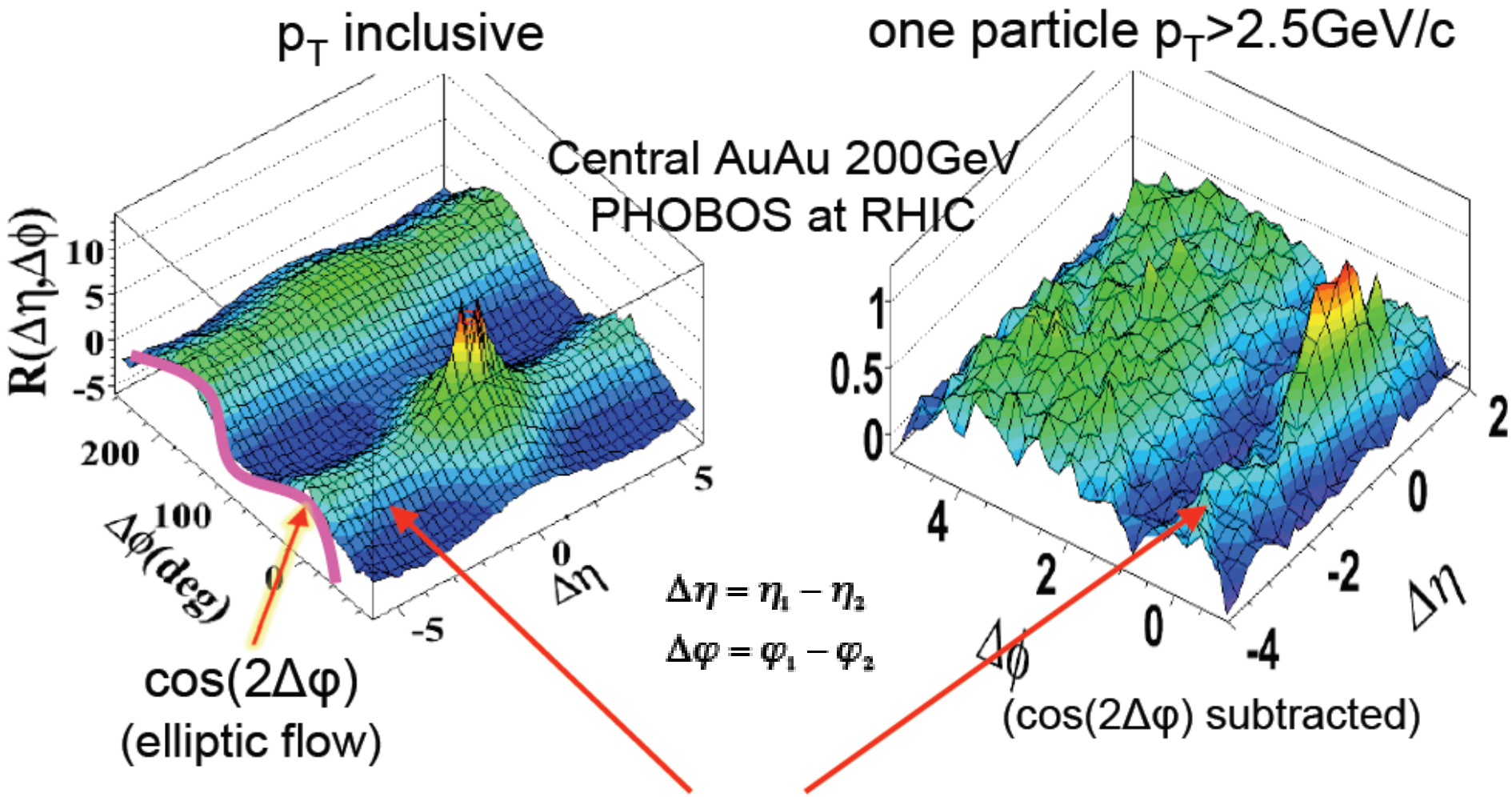


~ cos(2Δφ) (long-range in η)

Extracted shear viscosity of the medium found to be close to theoretical lower bound 1/4π

Most convincing evidence of "perfect liquid" at RHIC!

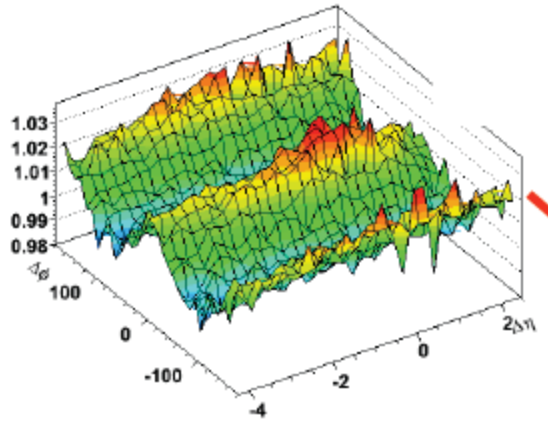
Correlations in Heavy Ion Collisions at RHIC

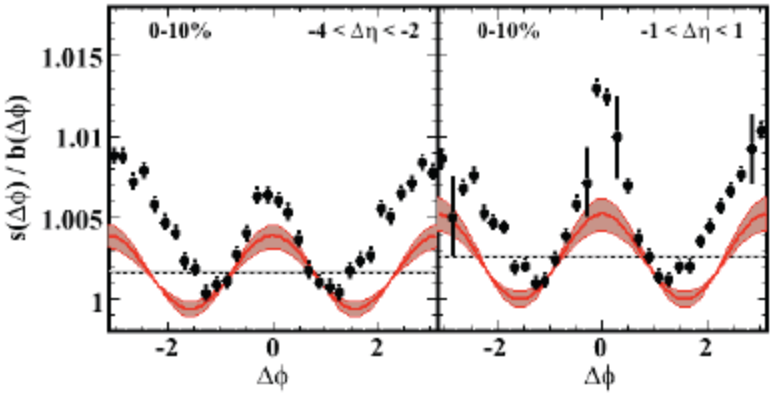


Long-range "Ridge"-like structure in Δη

"Flow subtraction"

"Raw" correlation function

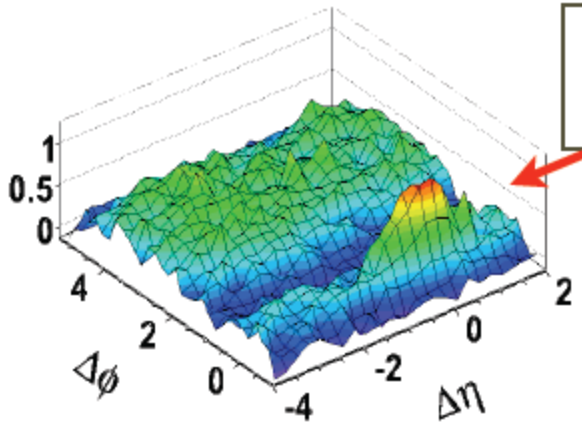




"ZYAM" (zero yield at minimum): assume that one component of the correlations (jets) gives zero contributio at some Δφ; match v_2 flow at that Δφ and subtract

$$\frac{1}{N_{trig}}\frac{d^2N_{ch}}{d\Delta\phi\, d\Delta\eta} = B(\Delta\eta)\left\{\frac{s(\Delta\phi,\Delta\eta)}{b(\Delta\phi,\Delta\eta)} - a(\Delta\eta)\,1 + 2V(\Delta\eta)\cos(2\Delta\phi)\right\}$$

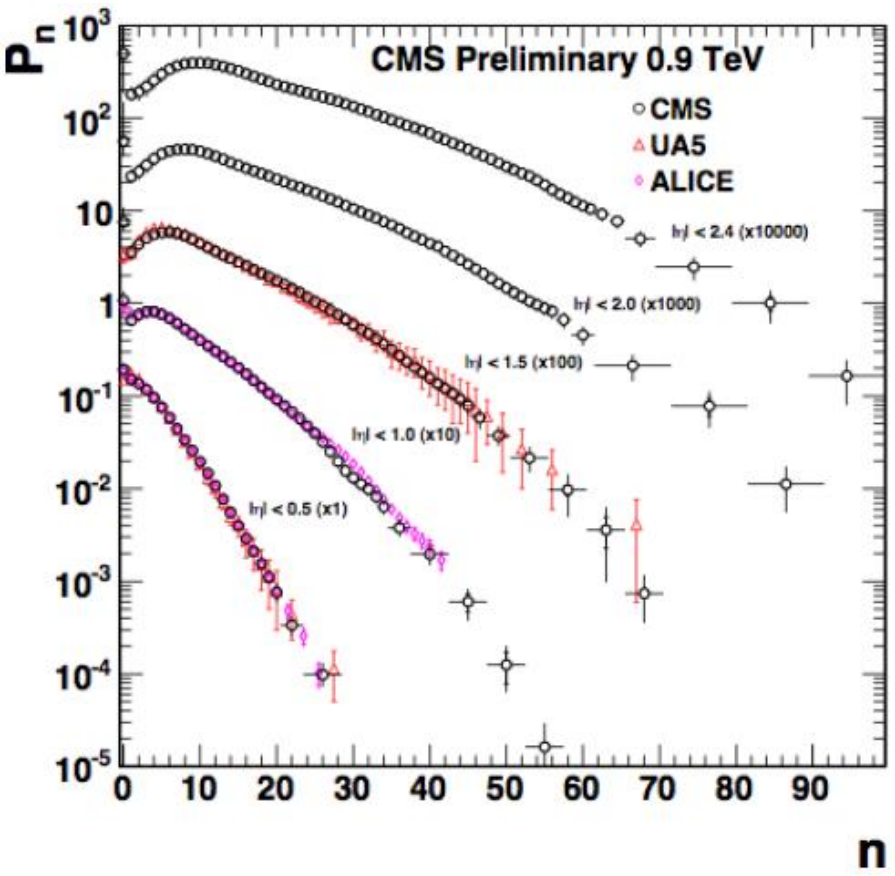
for some measurements: also v_4



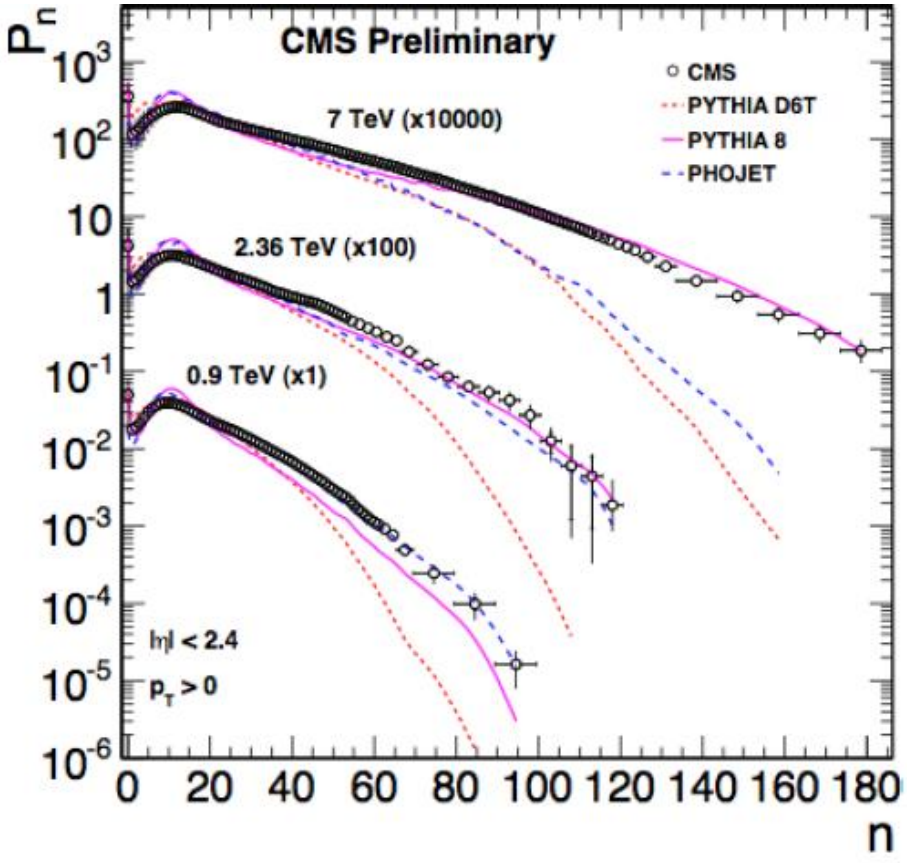
v_2 subtracted "associated yield"

Normalization term to go from correlation amplitude to yield per trigger particle

Multiplicity vs |η| for 0.9 TeV and energy 0.9, 2.36, 7.0 TeV



Multiplicity is increasing with |Δη|

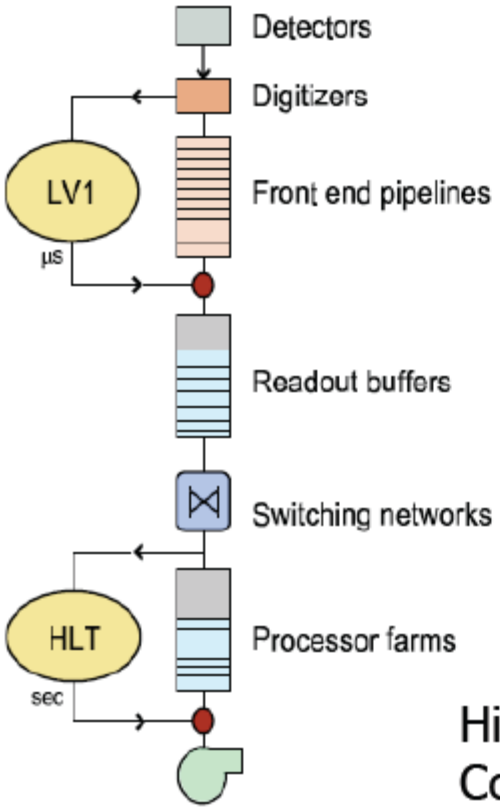


Multiplicity is increasing with energy

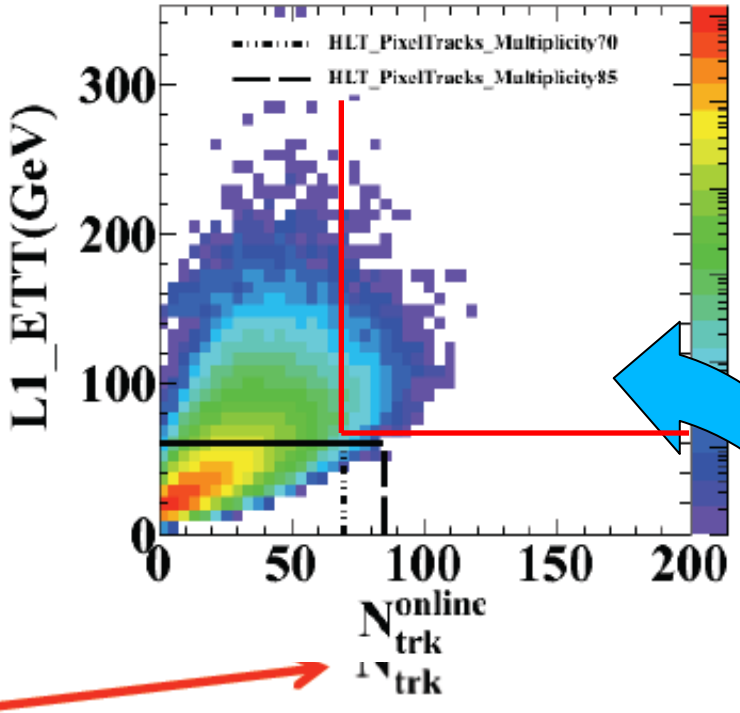
High multiplicity events

Dedicated trigger needed to record highest multiplicities

G. Roland, Report at CERN seminar Sep.21.2010



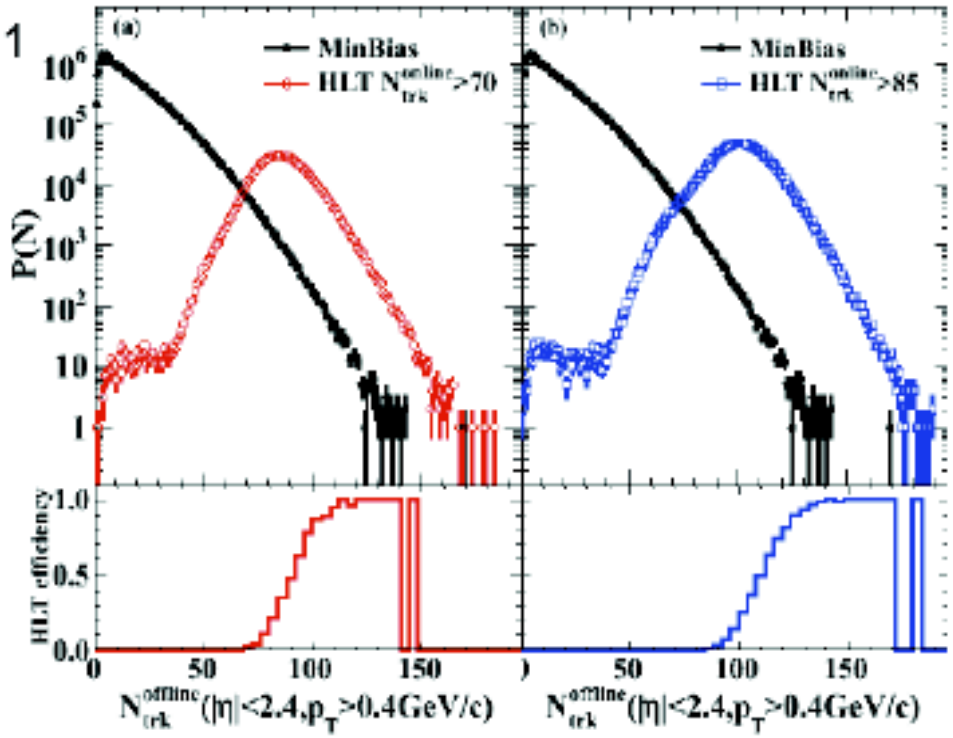
Level-1:
Require E_T> 60 Ge
in calorimeters



High-Level trigger:
Count number of tracks with p_T > 0.4 GeV/c, $|\eta|$ < 2,
within dz < 0.12cm of a **single** vertex with z <10cm

Selection High Multiplicity events in pp collisions at sqrt(s) = 7 TeV.

Triggering on High Multiplicity



Multiplicity binning uses
$p_T > 0.4$ GeV/c
$|\Delta\eta| < 2.4$

Multiplicity bin ($N_{trk}^{offline}$)	Event Count	$\langle N_{trk}^{offline} \rangle$
MinBias	21.43M	15.9
$N_{trk}^{offline} < 35$	19.36M	13.0
$35 \leq N_{trk}^{offline} < 90$	2.02M	45.3
$90 \leq N_{trk}^{offline} < 110$	302.5k	96.6
$N_{trk}^{offline} \geq 110$	354.0k	117.8

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

HLT85 trigger range un-prescaled for full 980nb^{-1}

out of 5x10^{10} collisions

CERN Seminar September 21 2010

Statistics for high multiplicity events enhanced by O(10^3).
Total datasets corresponding to 980nb^{-1}

Long-range near-side angular correlations

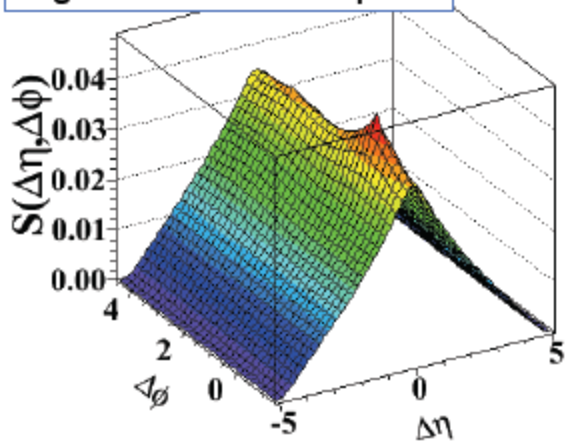
- p_T-inclusive two-particle angular correlations in minimum bias collisions

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

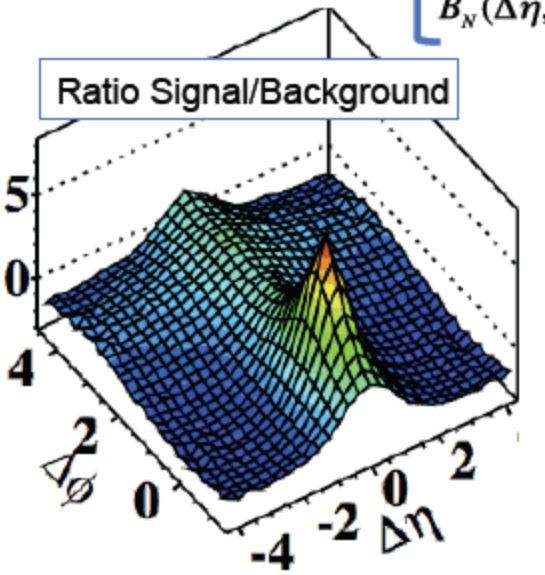
$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$

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

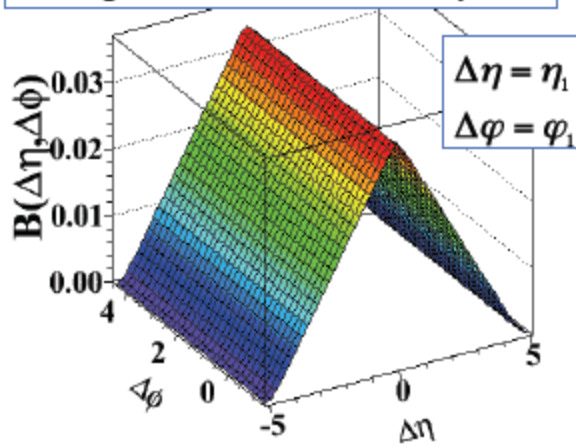
Signal = same event pairs



Ratio Signal/Background



Background = mixed-event pairs



$\Delta\eta = \eta_1 - \eta_2$

$\Delta\varphi = \varphi_1 - \varphi_2$

JHEP 09 (2010) 091

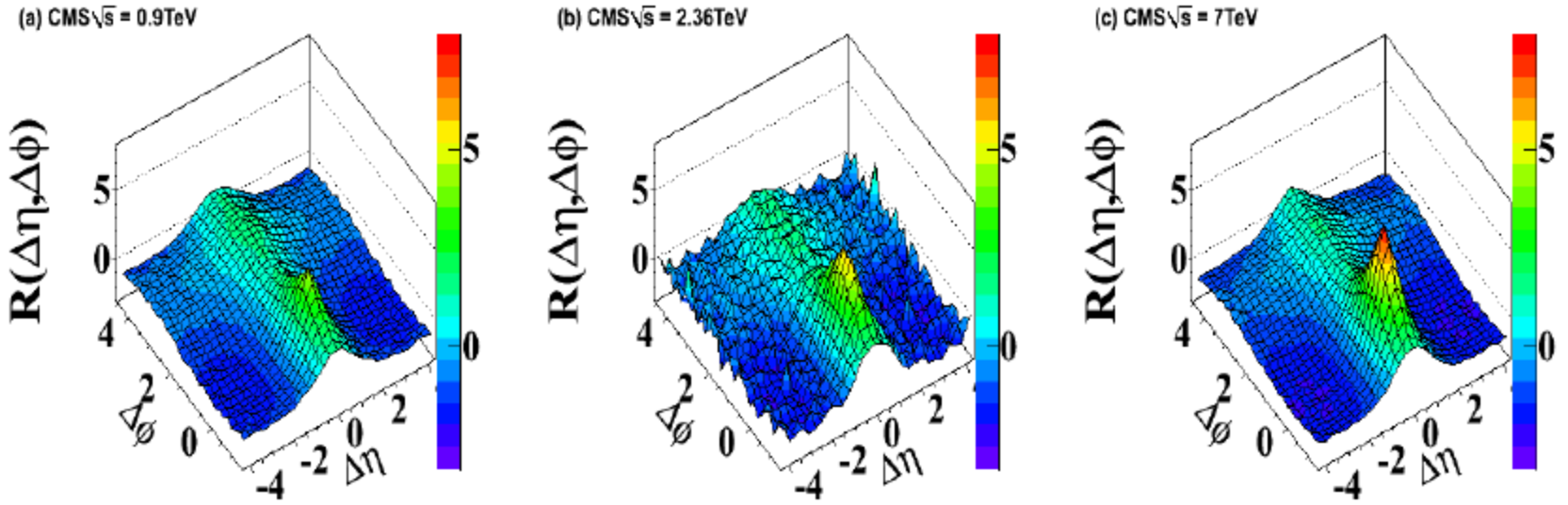
Min bias events in pp collisions at 0.9, 2.36 and 7 TeV

We started studying the correlation function $R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$

For minimum bias events at different energies in p_T inclusive distributions

$\Delta\eta = \eta_1 - \eta_2$

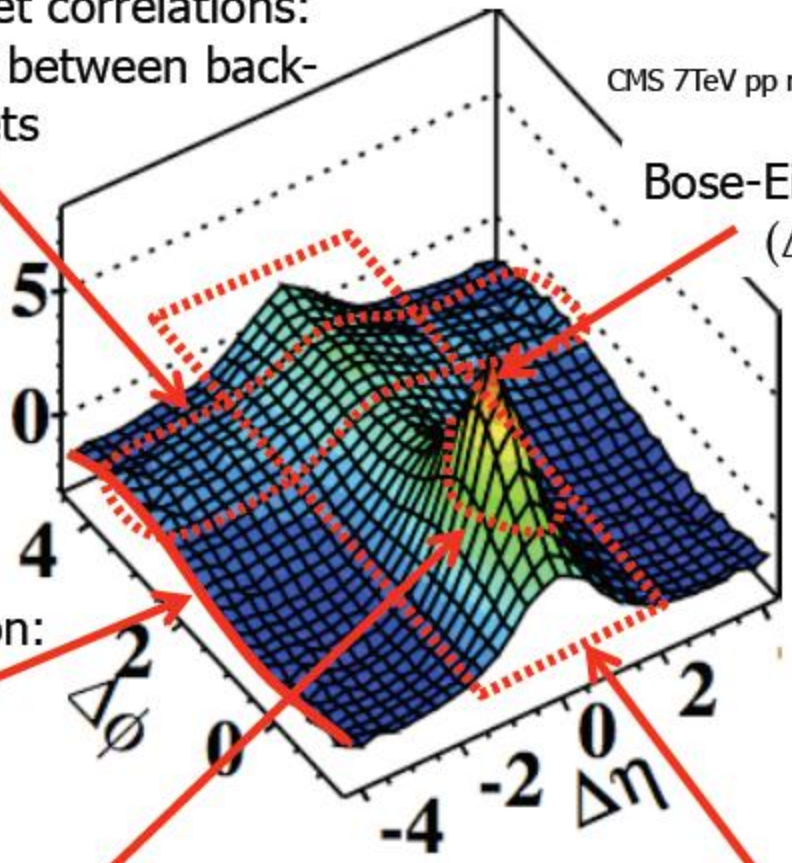
$\Delta\varphi = \varphi_1 - \varphi_2$



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

Обсуждаемые и принятые интерпретации

"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:
$\sim -\cos(\Delta\phi)$

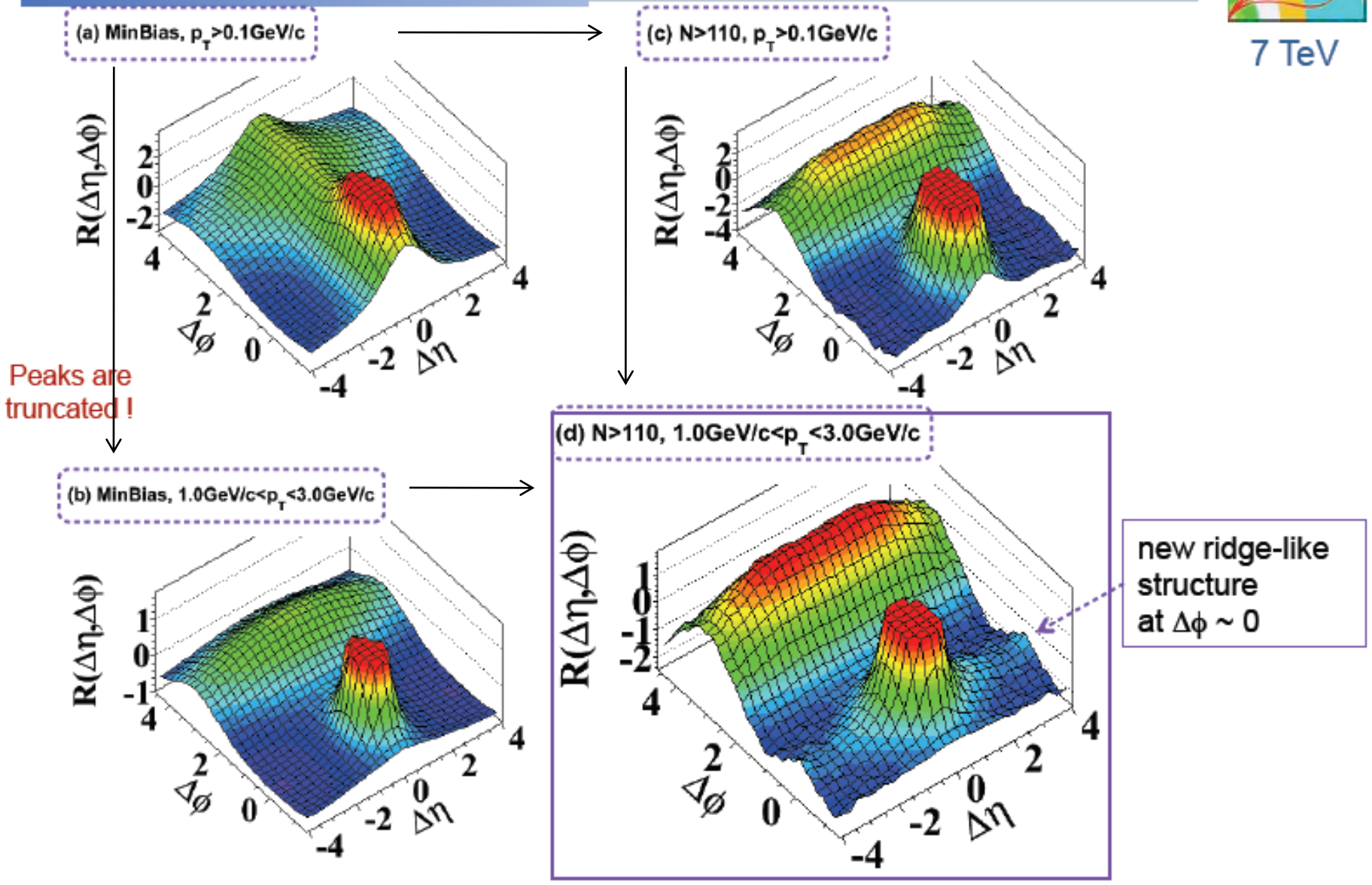
"Near-side" ($\Delta\phi \sim 0$) jet peak:
Correlation of particles within a single jet

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

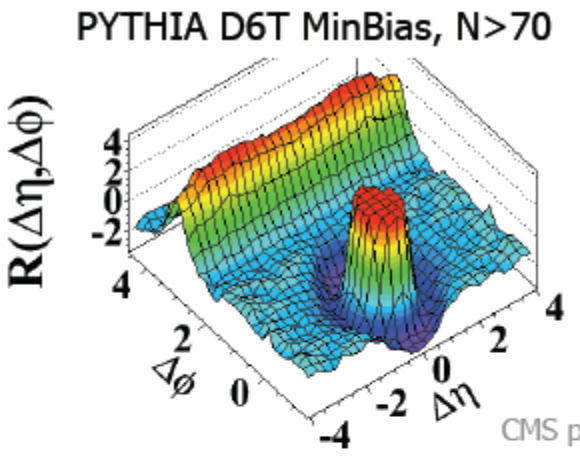
Long-range near-side angular correlations

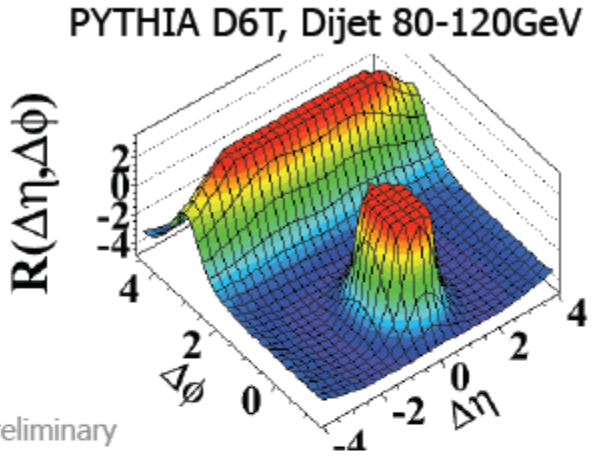
G. Roland's talk

7 TeV



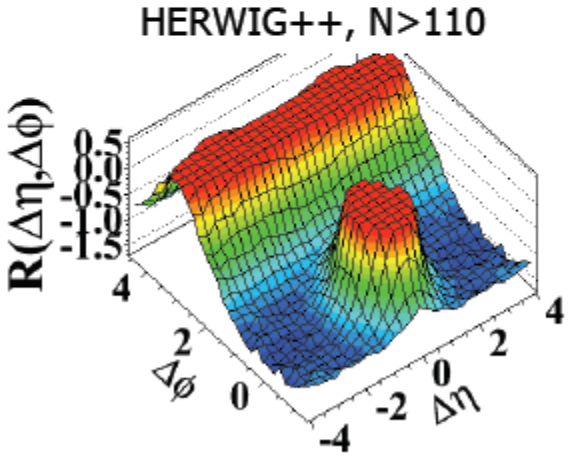
Correlation in pp event generators at high multiplicity

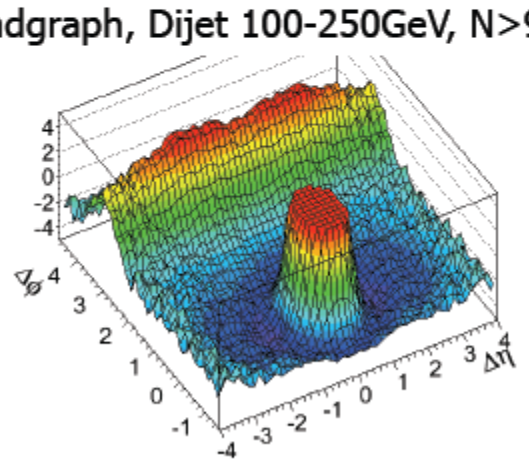




CMS preliminary

1<p_T<3GeV/c



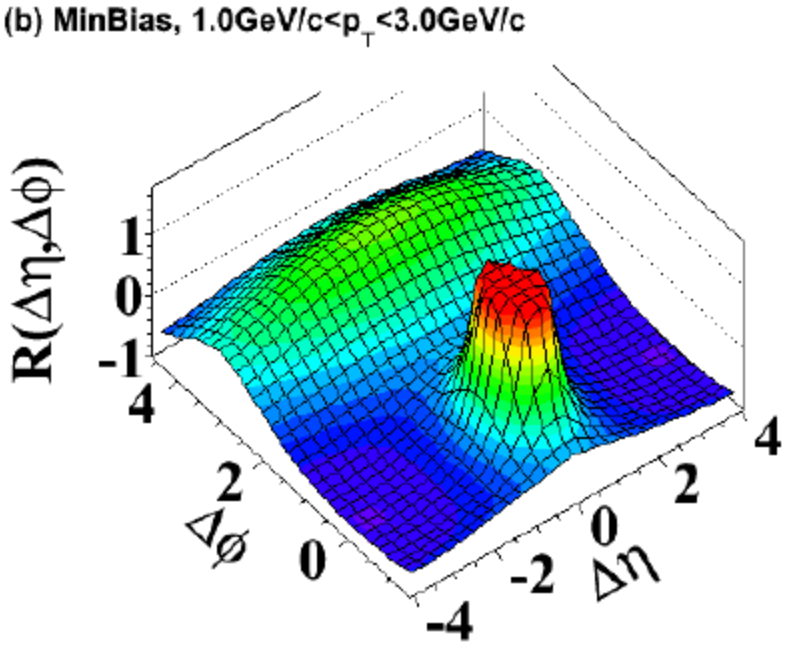


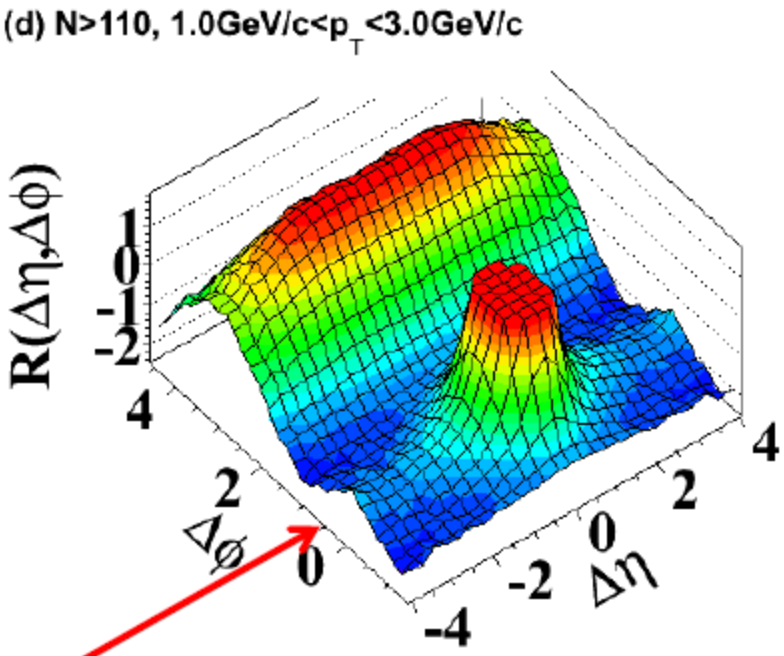
No ridge effect in these models (with the tunes used)

Results for intermediate p_T:1-3GeV/c

Minimum Bias
no cut on multiplicity

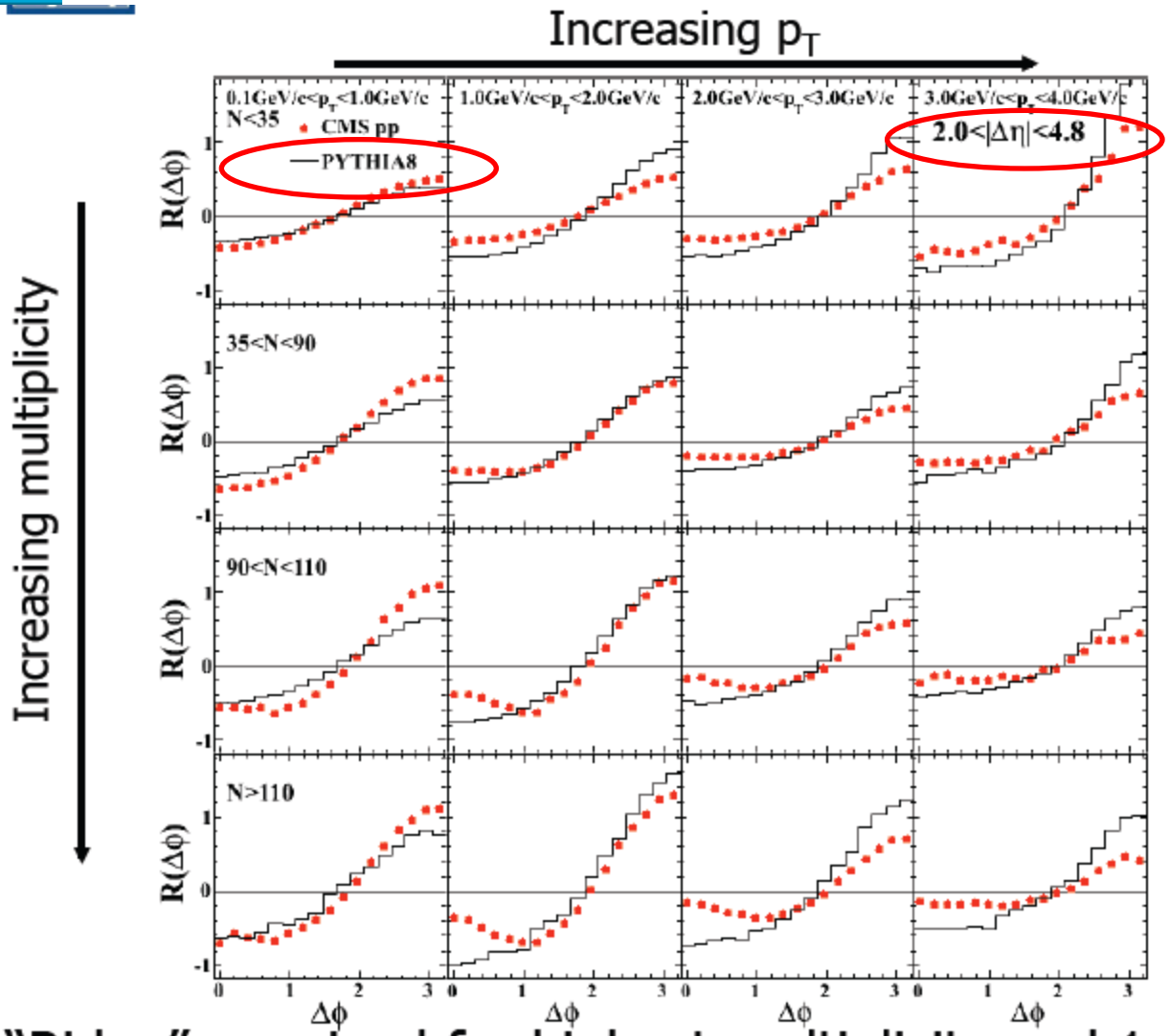
High multiplicity data set
and N>110

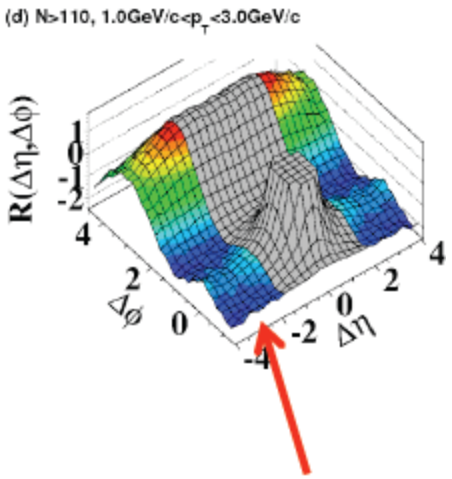




New "ridge-like" structure extending to large $\Delta\eta$ at $\Delta\phi \sim 0$

Multiplicity- and p_T - dependence

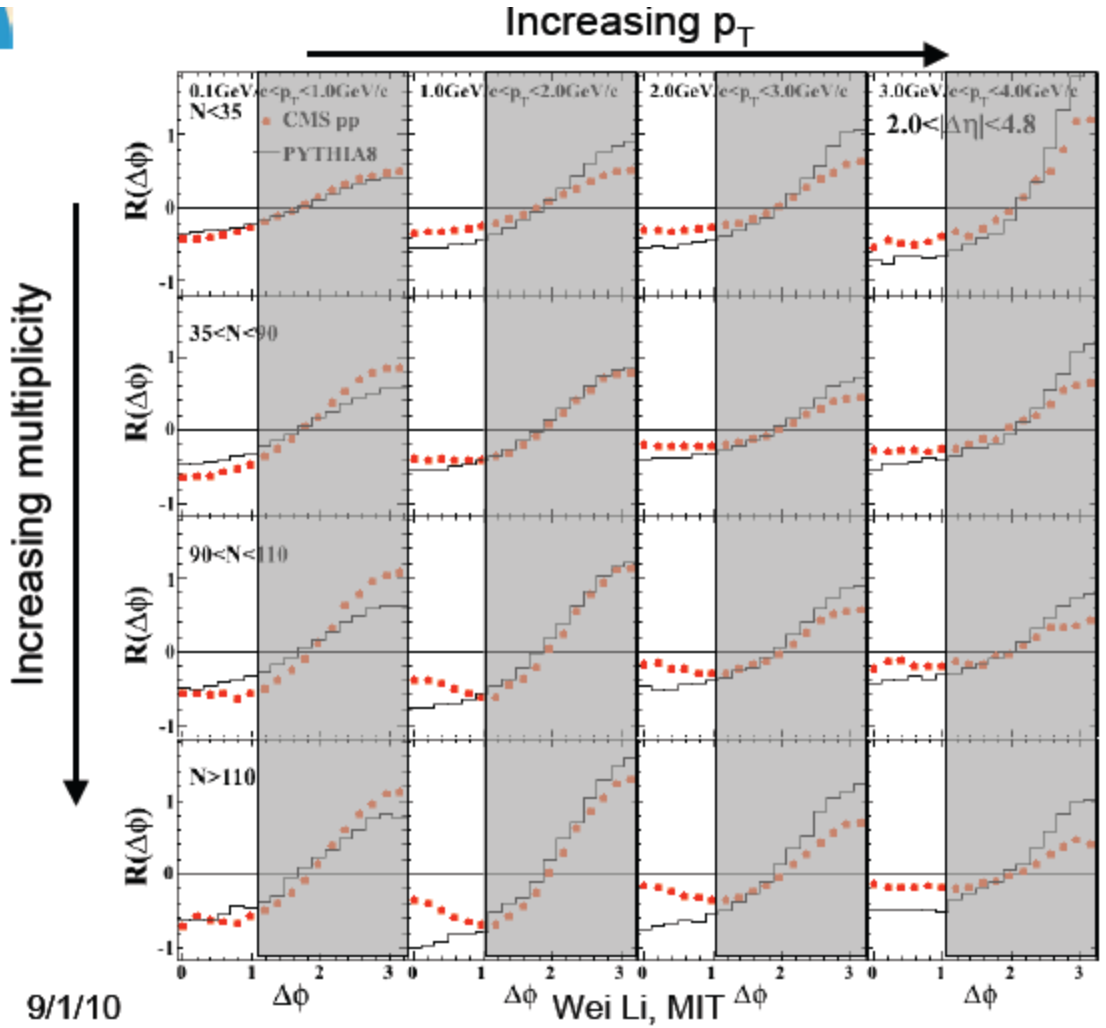




Project $|\Delta\eta| > 2$ onto $\Delta\phi$

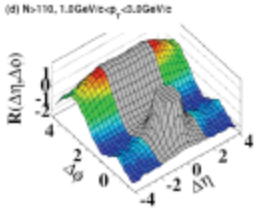
"Ridge" maximal for highest multiplicity and $1 < p_T < 3$ GeV/c

Multiplicity- and p_T - dependence



Hydrodynamic expansion?

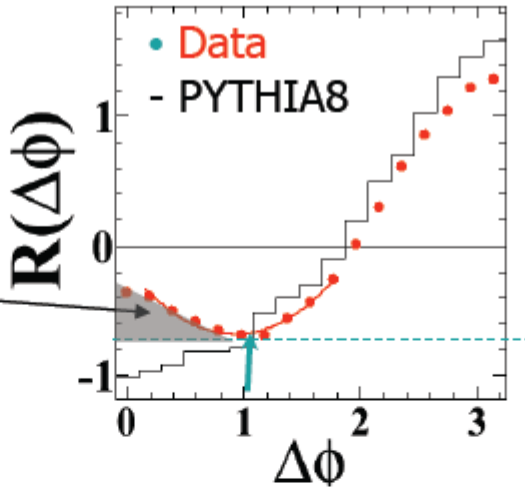
- linear with p_T
- dies at high p_T



Focus on near-side ($|\Delta\phi|<1$)

Multiplicity- and p_T - dependence

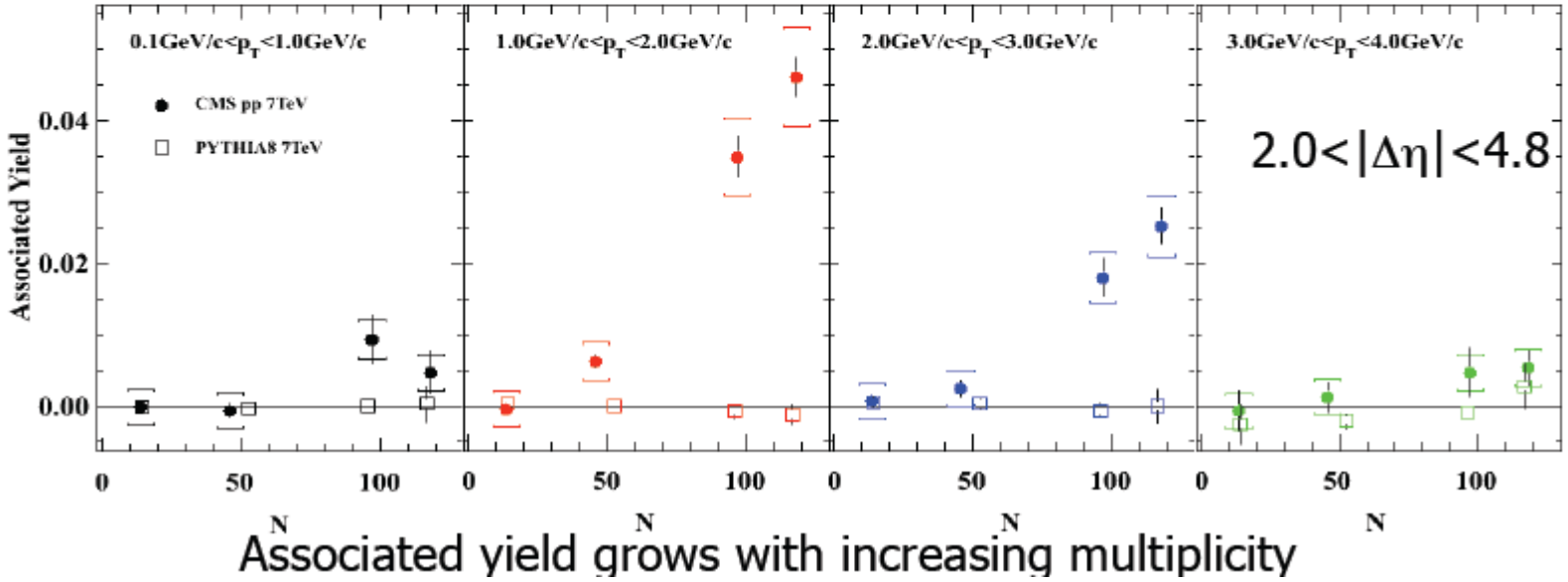
Zero Yield At Minimum (ZYAM)



N>110
2.0<|Δη|<4.8
1GeV/c<p_T<2GeV/c

Associated yield:
correlated multiplicity per particle

Minimum of R



Associated yield grows with increasing multiplicity

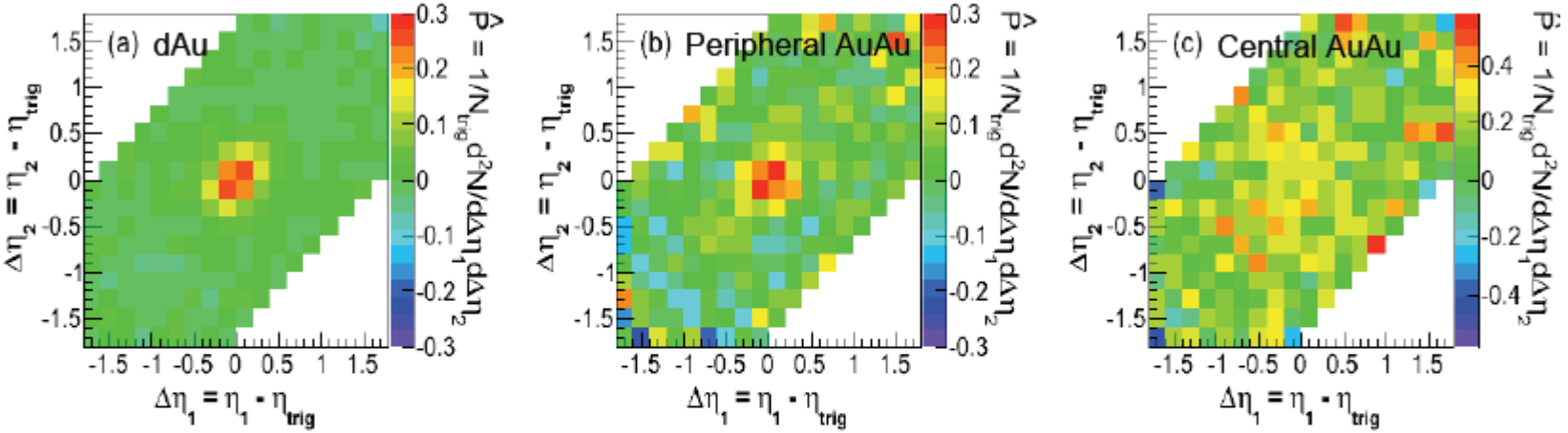
Signal yield is increasing with multiplicity at p_T= 1-3 GeV/c и $2.0<|\Delta\eta|<4.8$.

Physics of the ridge - Jet

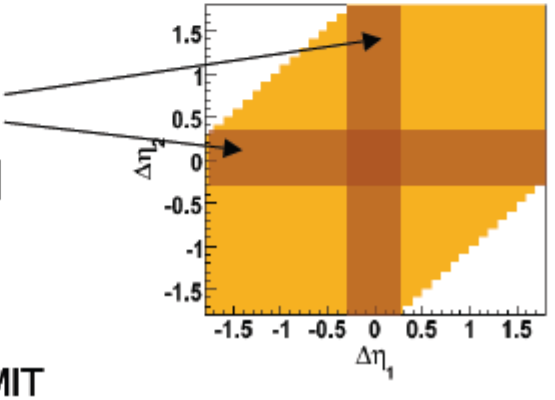
Au-Au

Three-particle correlations in HI from STAR:

$3<p_T^{trig}<10$ GeV/c $1<p_{T,1}^{assoc}, p_{T,2}^{assoc}<3$ GeV/c $|\Delta\phi|<0.7$

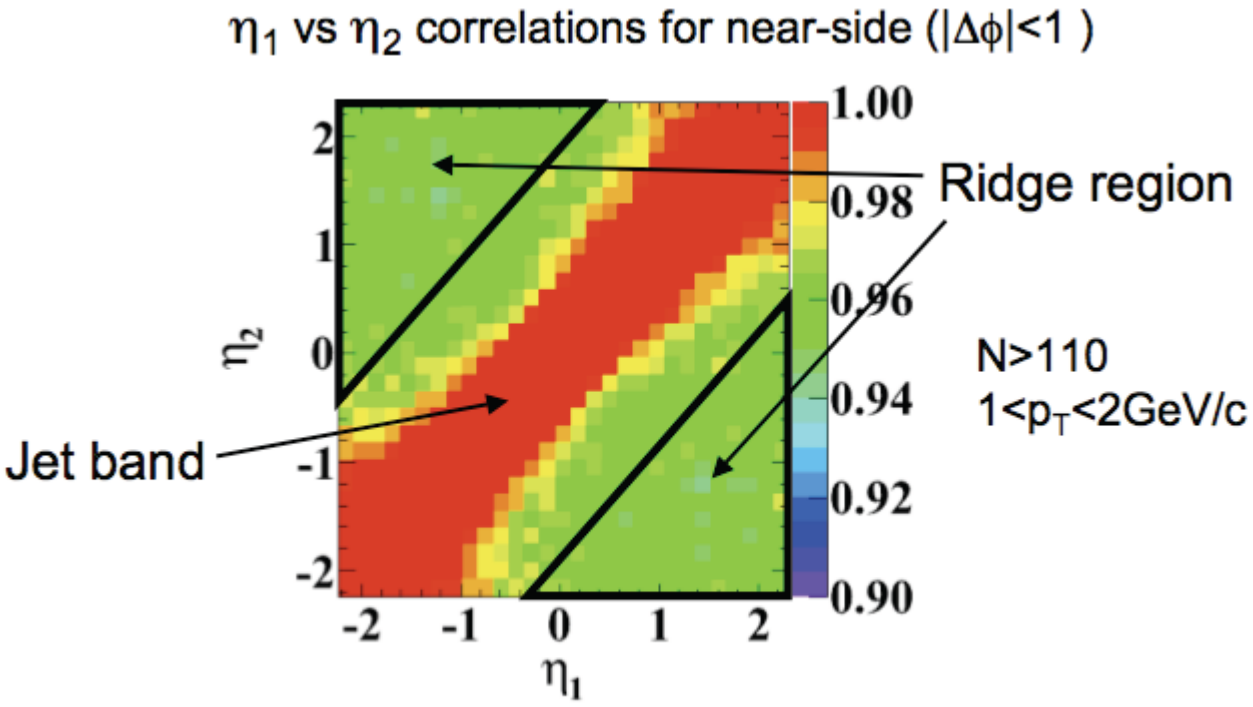


- No jet-ridge cross term in HI
- Ridge seems to be unrelated to the presence of jets in HI



Physics of the ridge - Jet

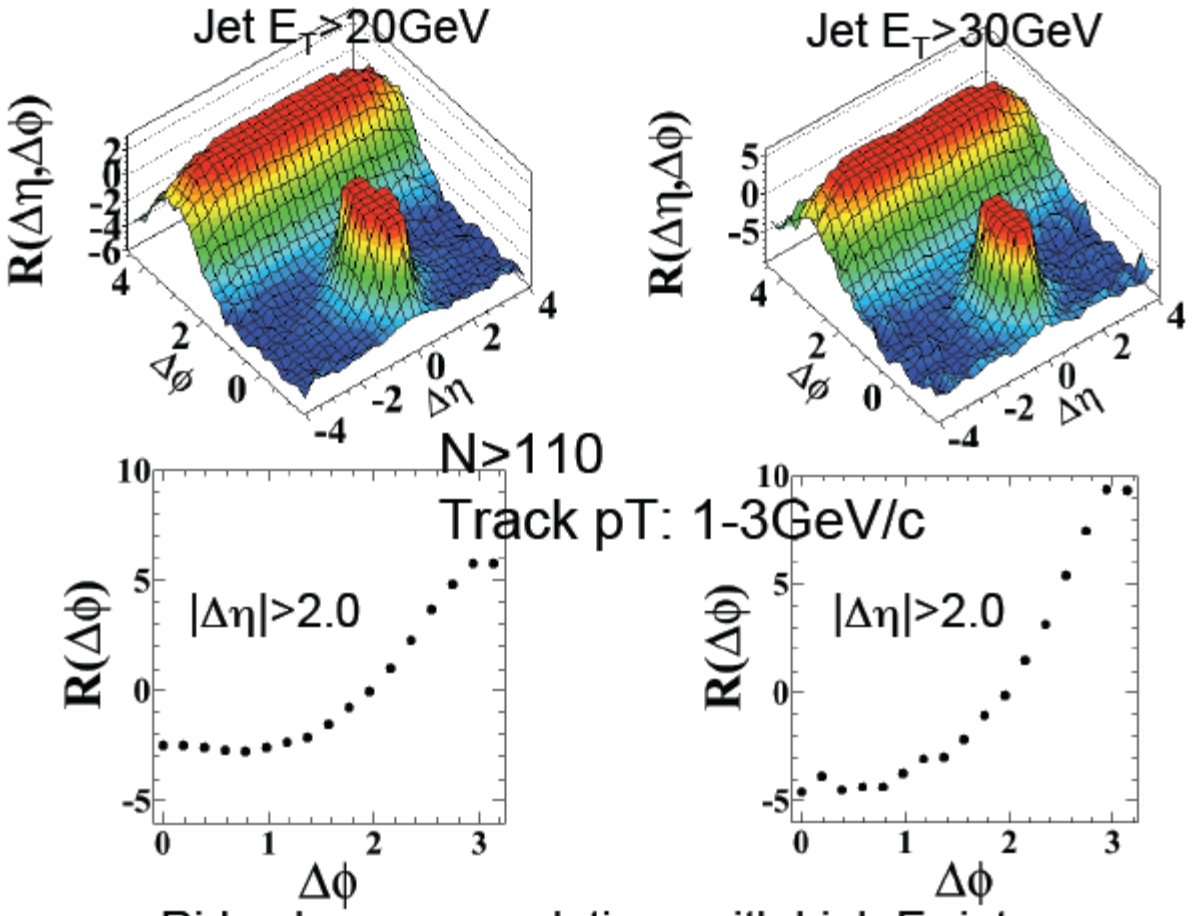
p-p



Ridge region shows no structure in η_1 vs η_2

Physics of the ridge - Jet

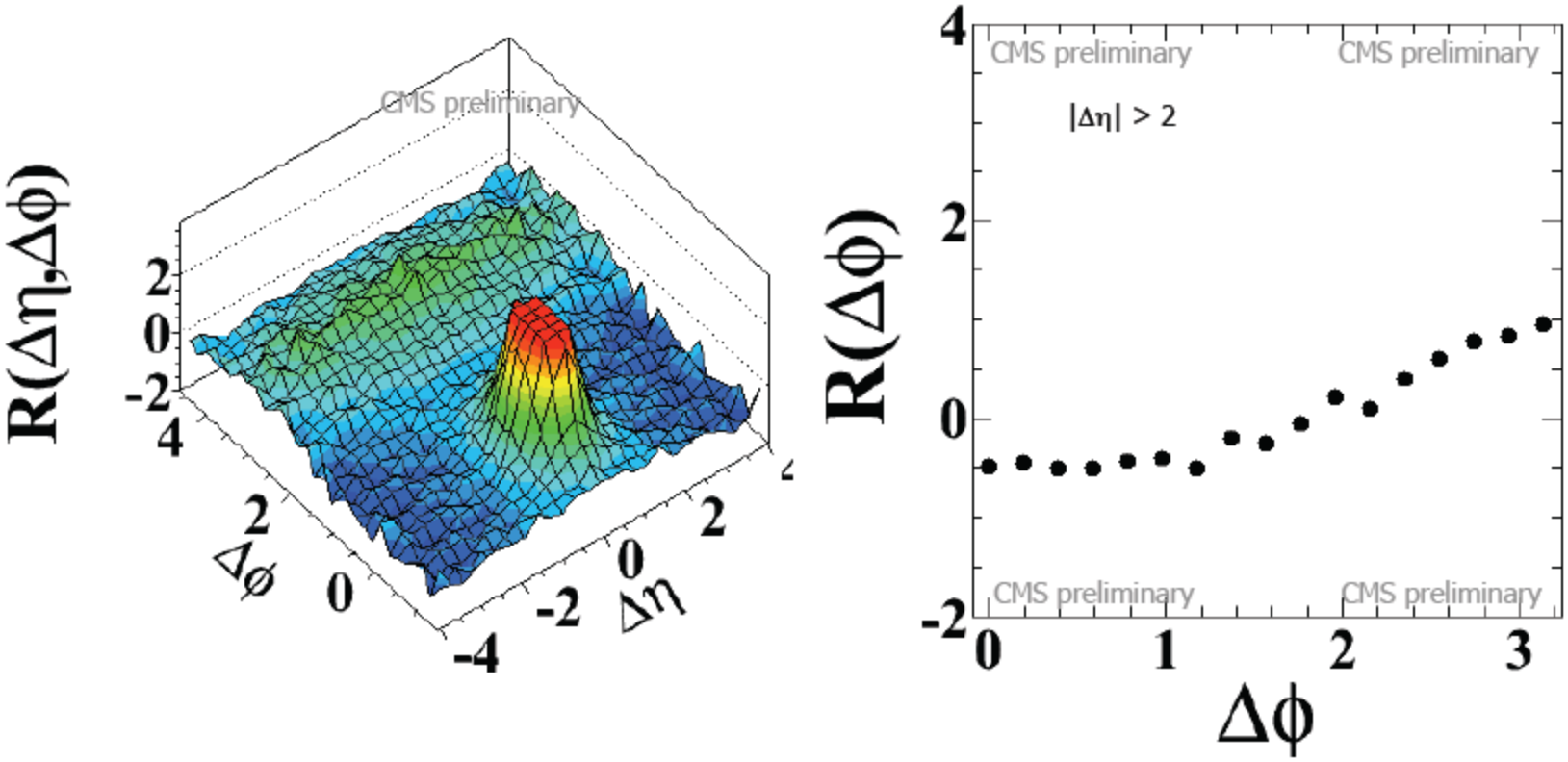
A quick look at jet-hadron correlations:



Ridge has no correlations with high E_T jets

Multi- jet events

$N_{jet}>=4$, $N_{trk}<50$, $1<p_T<2$GeV/c



More work needed to explore connection to jet correlations

Systematic uncertainties

- **No sensibility to beam background.**
- **No sensibility to “pile up”.**
- **Independence to beam centre distance.**
- **Independence to charge particle combination (+,-), (+,+),(-,-**
- **Signal is repeated in 3 different codes.**
- **Independence to HLT Trigger Bias.**
- **Signal is present in events with π0 в ECAL (supercluster).**
- **…**

Summary of main systematics for the new analysis

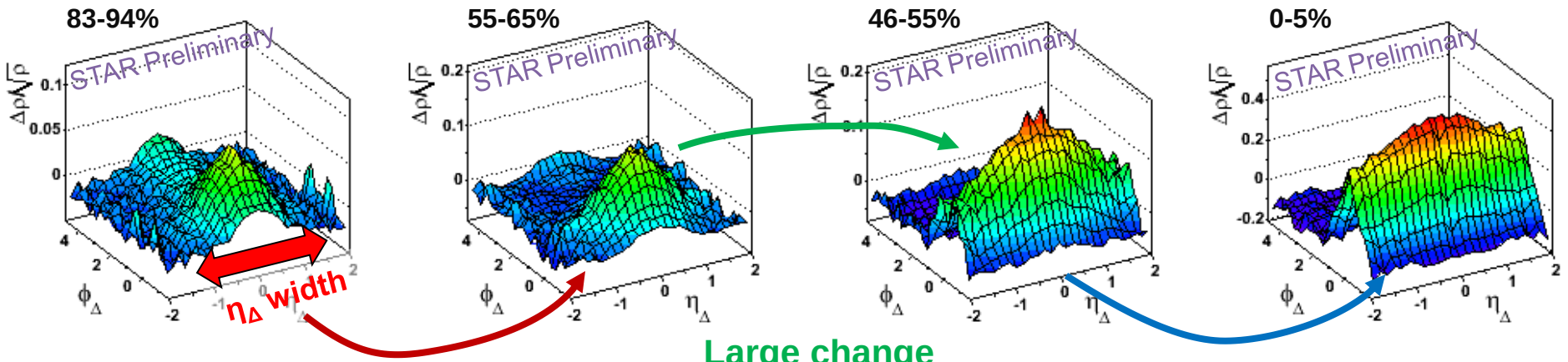
Sources	Syst. on ridge yield
Pileup	15%
HLT efficiency	4-5%
Tracking	1-2%
ZYAM	0.04

Cross-checkings can’t kill Ridge !

Другие свойства HI

M. Daugherity for the STAR Collaboration, QM2008

data - fit (except same-side peak)



Shape changes little from peripheral to quasi-peripheral

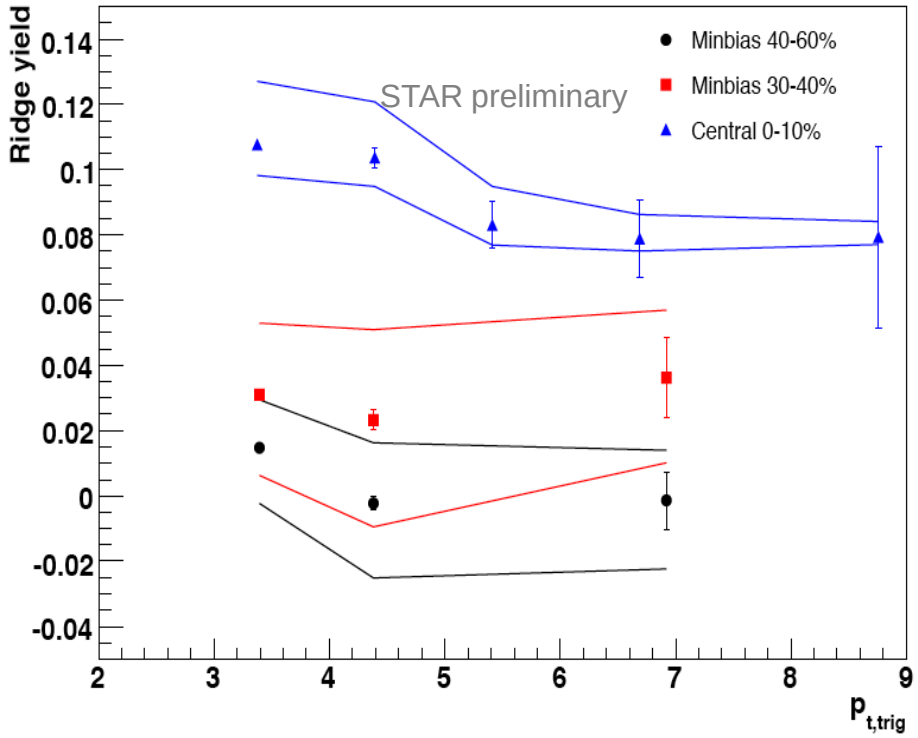
Large change within ~10% centrality

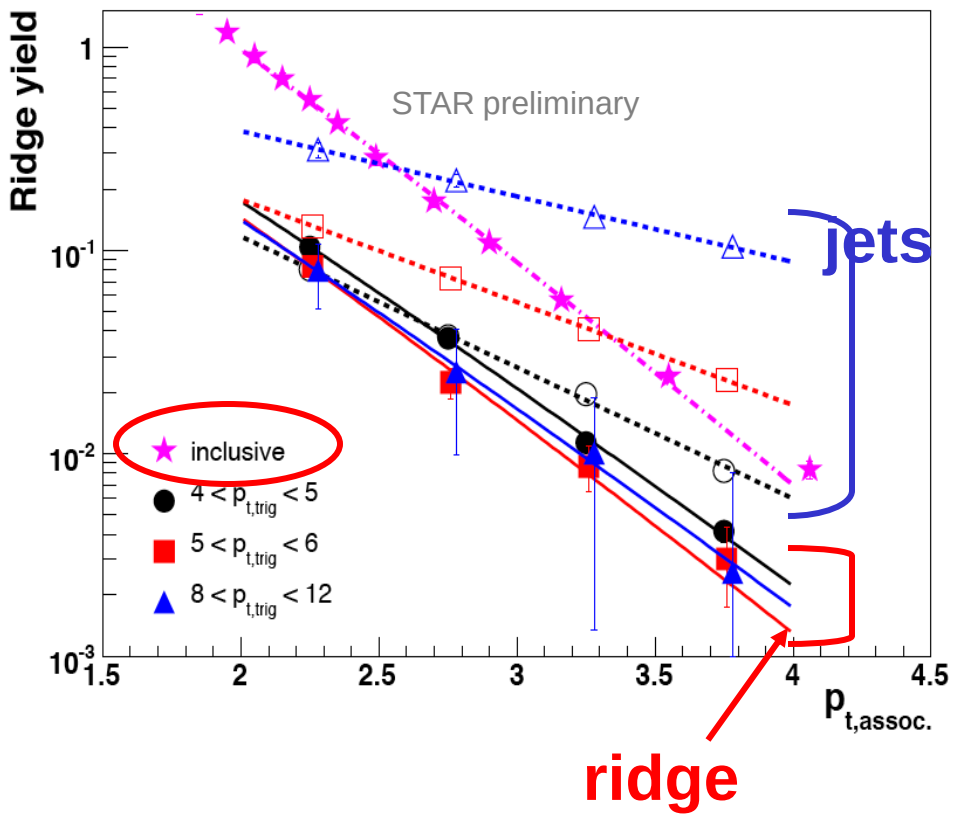
Smaller change from transition to most central

Low-p_T manifestation of the “ridge”

The transition occurs quickly

Другие свойства HI



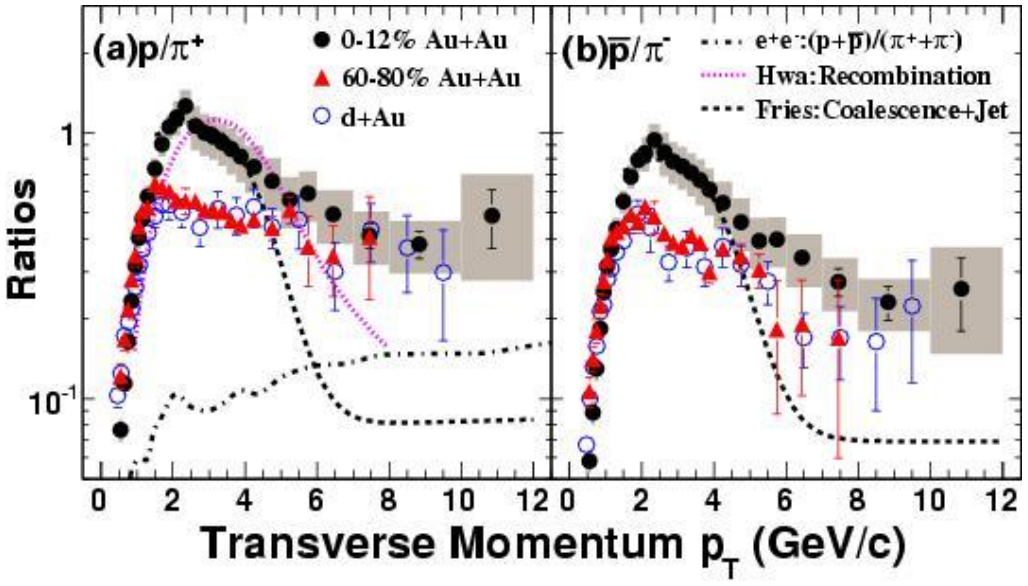


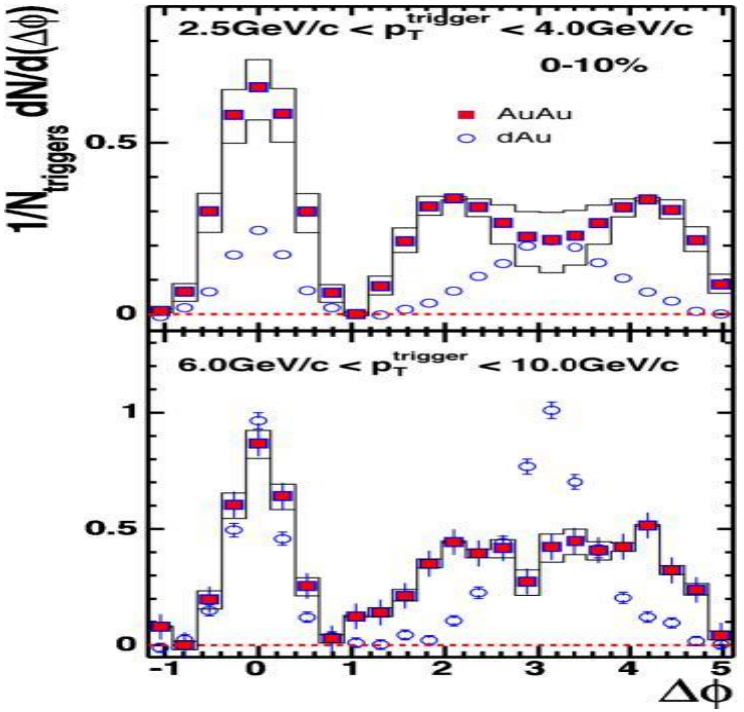
Ridge Independence to trigger momentum

Ridge momentm spectr is soft and very close to min bias

Другие свойства HI

STAR, Au-Au, 200 GeV





Anomal ratio barion/meson, larger then in p+p and e+e- in four times

Deformation away-side peak and two hump appearence

Интерпретация

Physics of the ridge

Jet-Jet or Jet-proton remnant:

- Many questions about the role of jets
- Should predict ridge is always aligned with jet in ϕ

Hydrodynamic flow:

- Original motivation of the analysis
- Possible although degree of thermalization is hard to evaluate

Glasma tube from BNL group

- Glasma tube+radial flow -> ridge in HI
- Intrinsic ridge in pp even without radial flow
- Similar p_T dependence as the data

Wei Li, Oct 4, 2010, CMS QCD meeting

Комментарии в SLAC arXiv

- Interpretations are going fast:
  - http://arxiv.org/abs/1009.4635 (Shuryak)
  - http://arxiv.org/abs/1009.5295 (Dumitru et al)
  - http://arxiv.org/abs/1009.5229 (Troshin and Turyin)

QGM -- **http://arxiv.org/abs/1010.0405** (Bozek)

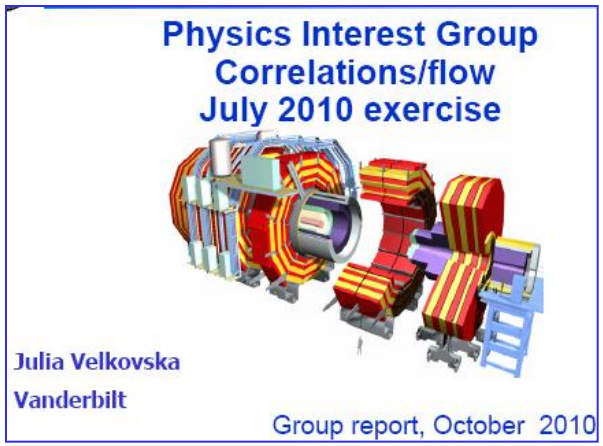
QCD -- **http://arxiv.org/abs/1010.0918 (Dremin, Kim)**

QGM -- **http://arxiv.org/abs/1010.0964**(Tannenbaum, Weiner)

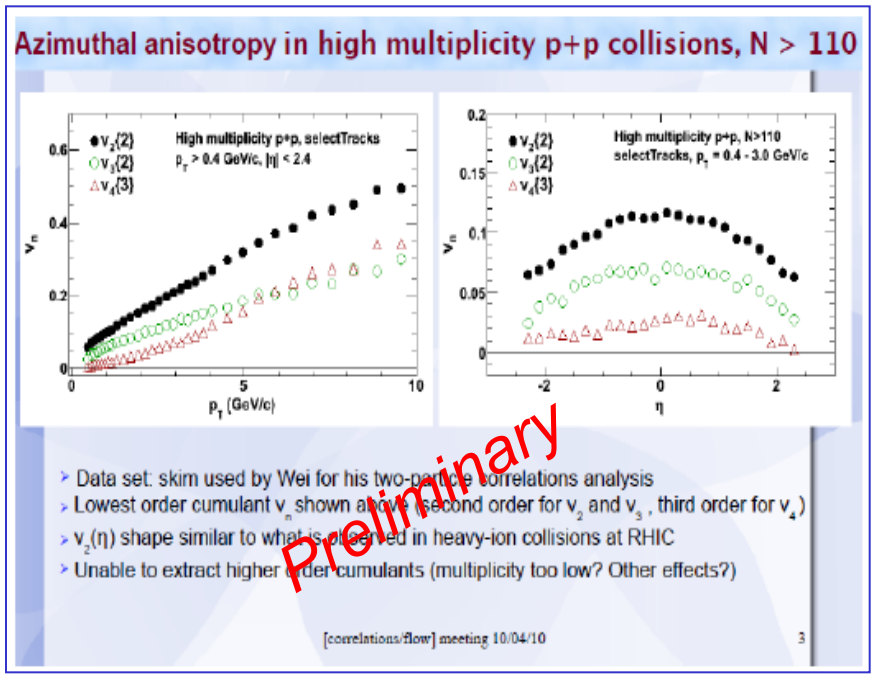
Основные свойства Ridge-эффекта, впервые наблюдаемого в p-p столкновениях

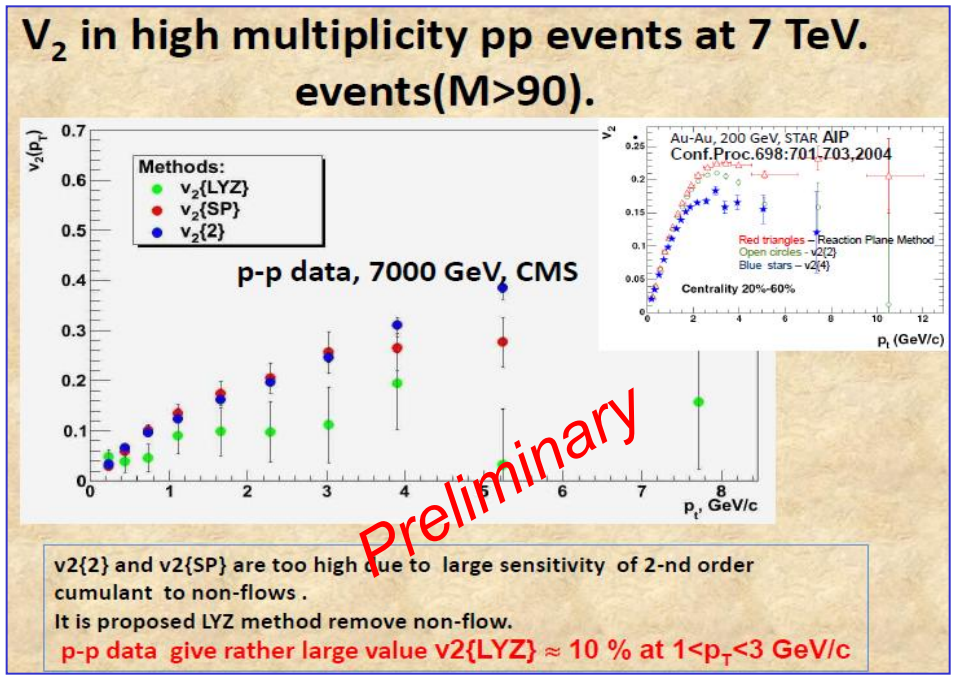
- **Signal is small, but it is clear at $\sqrt{s}$ =7 TeV in events with high multiplicity N > 90.**
- **It is seen at large rapidaty difference , $2.0<|\Delta\eta|<4.8$.**
- **It is seen at intermediate region p_T= 1-3 GeV/c.**
- **Signal is increasing with multiplicity.**
- **It is absent in jet events with ET(jet) > 20 GeV and in multi-jet events with $N_{jet} > 4$**
- **Its properties coincides with Ridge in Au-Au at $\sqrt{s_{NN}}$=200 GeV (RHIC results) and can be checked on other distributions on CMS.**

ЛАВ-ОЭФВЭ-МГУ group/ Corr-flow subgroup



V.L. Korotkikh, I.P. Lokhtin, S.V.Petrushanko,
A.M Snigirev (MSU),
M.Yu. Azarkin (LPI-FIAN),
J.Velkovska, M.Issah,S. Tuo (Vand.Un.),
V.Zhukova (Un.Kansas)
Wei Li (MIT),
J.Callner, Y.Bai, D.Hofman (Un.Ill.Ch.)

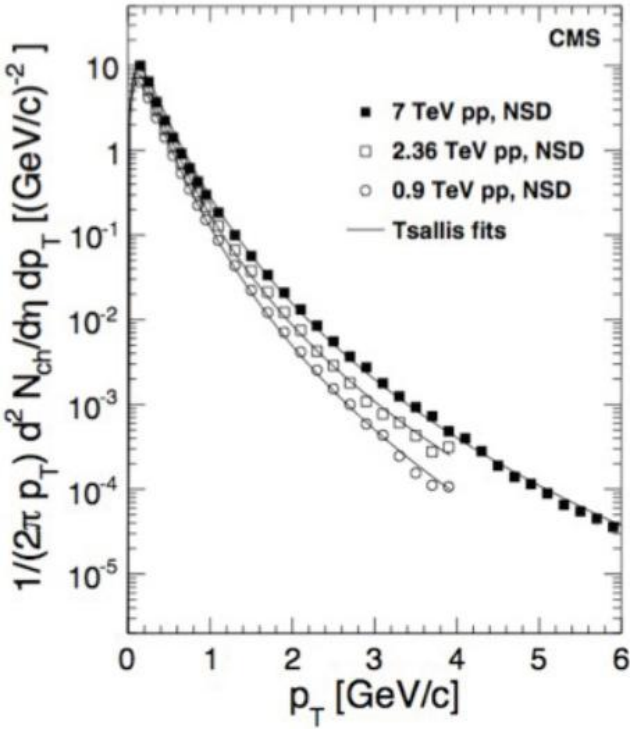




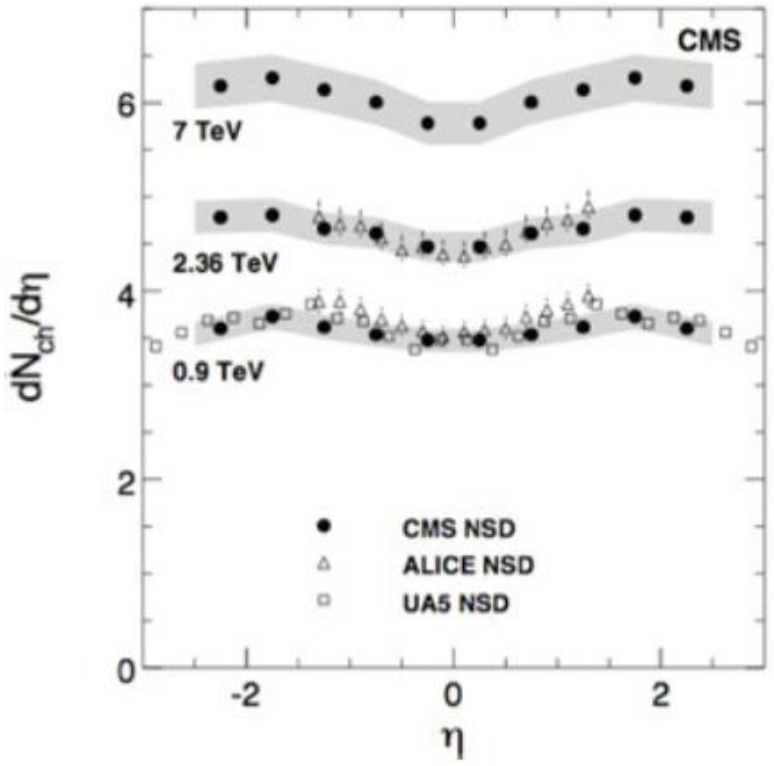
Backup slides

Min bias event in pp collisions

Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV.
By CMS Collaboration **Phys.Rev.Lett.105:022002,2010**.

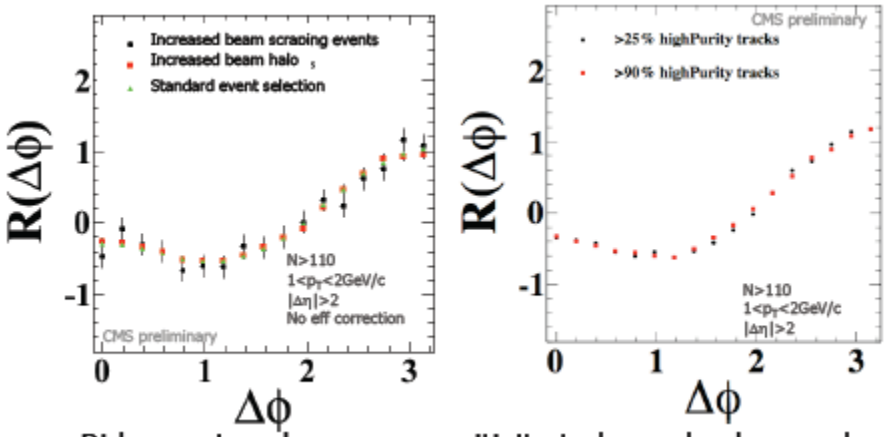


- Results well-described by Tsallis fit function
  - Exponential (low-p_T)
  - Power-law (high-p_T)



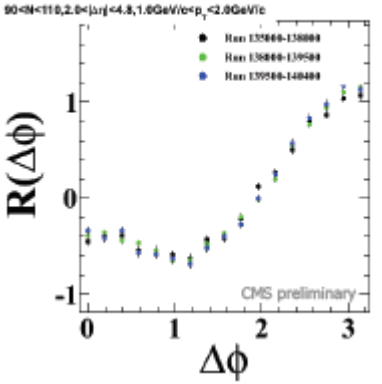
$-2.4 < \eta < 2.4$ CMS
$-1.0 < \eta < 1.0$ ALICE

Systematic uncertainties



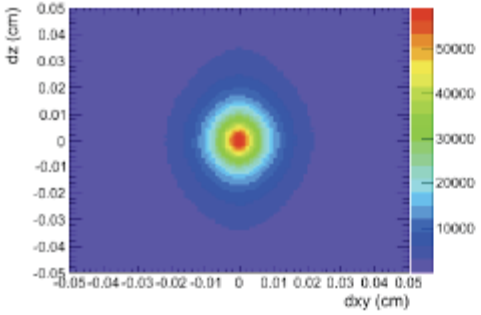
Ridge region shows no sensitivity to beam background

Compare different run periods
(fraction of pileup varies by x4-5)

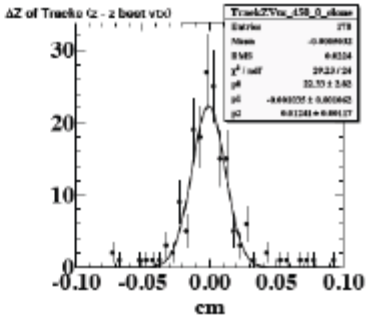


Change in pileup fraction by factor 2-4
has almost no effect on ridge signal

Track longitudinal and
transverse impact parameter
(p_T > 0.4 GeV/c)



Single-event track dz
distribution



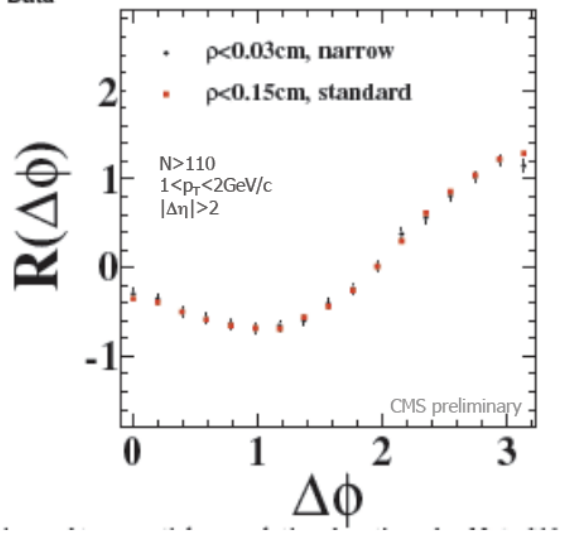
No indication of effect that would fake
ridge signal (irrespective of magnitude)

Sources	Syst. on ridge yield
Pileup	15%
HLT efficiency	4-5%
Tracking	1-2%
ZYAM	0.0025

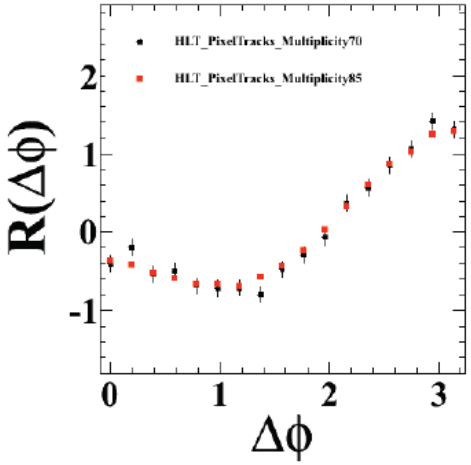
Conservative estimates
of uncertainties on
ridge associated yield

Pileup effects are suppressed due to excellent resolution
Track counting done with σ_{dz}, σ_{dxy} of O(100μm)

Data



N>110 bin from two trigger paths having different efficiency



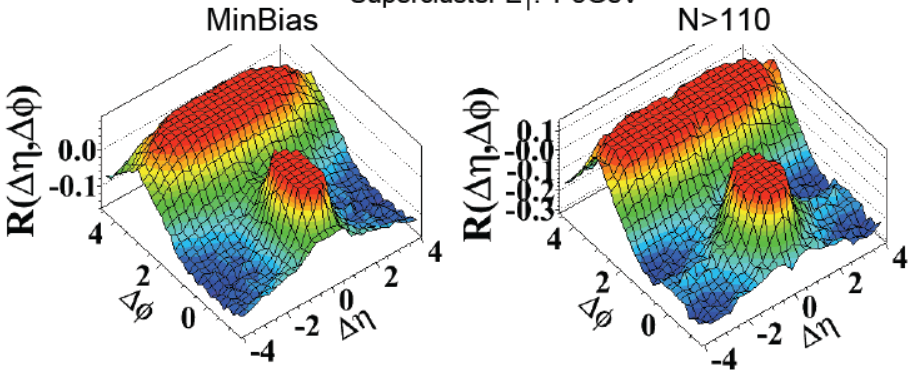
N>110
2.0<|Δη|<4.8
1.0GeV/c<p_T<2.0GeV/c

No dependence on radial distance from center of I

No obvious bias due to HLT trigger, statistics limited!

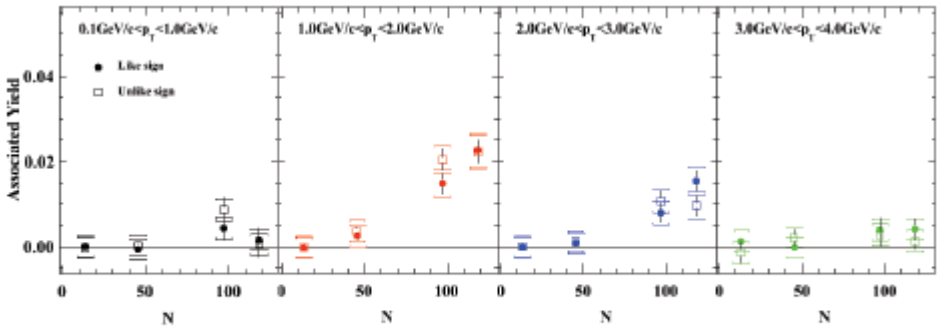
Track - ECAL Supercluster (mostly π^0) correlations

Track p_T: 1-2GeV/c
Supercluster E_T: 1-3GeV

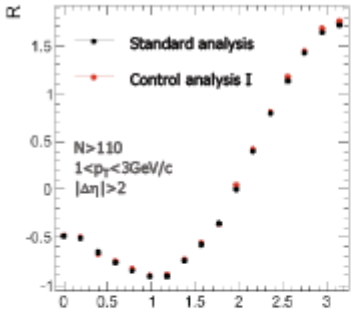


Ridge observed for "π^0"!

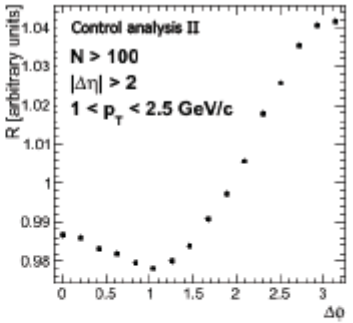
Systematic uncertainties



No dependence on relative charge sign

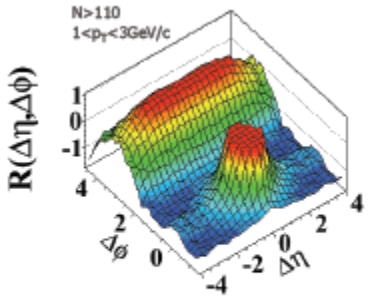


Independent code
Same definition of *R*
Same input file (skim)

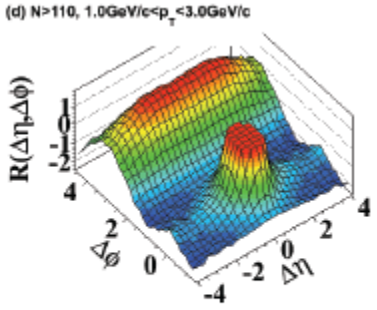


Independent code
Different definition of *R*
Different input file (skim)

Ridge is seen with three independent analysis codes

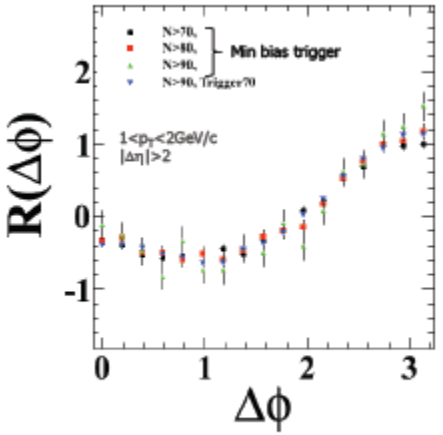


Pixel-only tracks
3 hits in pixel detector



"HighPurity" tracks
Pixel + Silicon Strip tracker

Min-bias trigger vs high mult trigger



Ridge is seen using
min bias trigger + offline selection

First observation of a ridge-like structure in pp collisions

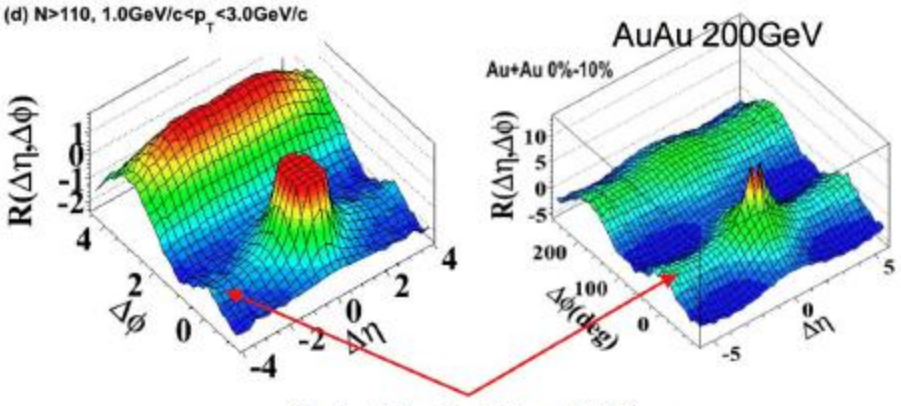
The new feature is clearly seen for large rapidity differences $2 < |\Delta\eta| < 4.8$ in events with N ~ 90 or higher. The enhancement is most evident in the intermediate p_T range $1 < p_T < 3$ GeV/c.

This is the first observation of such a long-range, near-side feature in two-particle correlation functions in pp or p-pbar collisions.

It is a small effect, however, very interesting. Although there are also differences, it resembles a similar feature observed at RHIC that was interpreted as being due to the hot and dense matter formed in relativistic heavy ion collisions.

$$\Delta\eta = \eta_1 - \eta_2$$

$$\Delta\varphi = \varphi_1 - \varphi_2$$

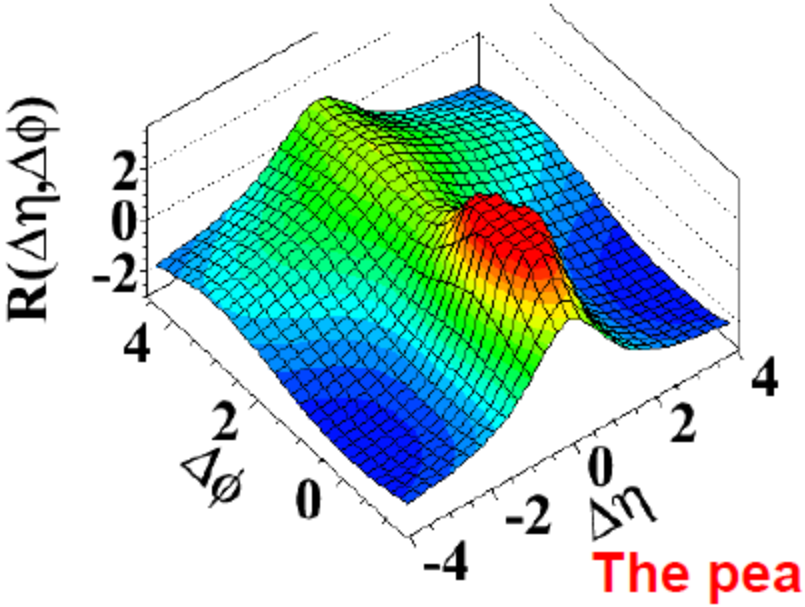


Similar "ridge" in high multiplicity pp

Results for inclusive p_T

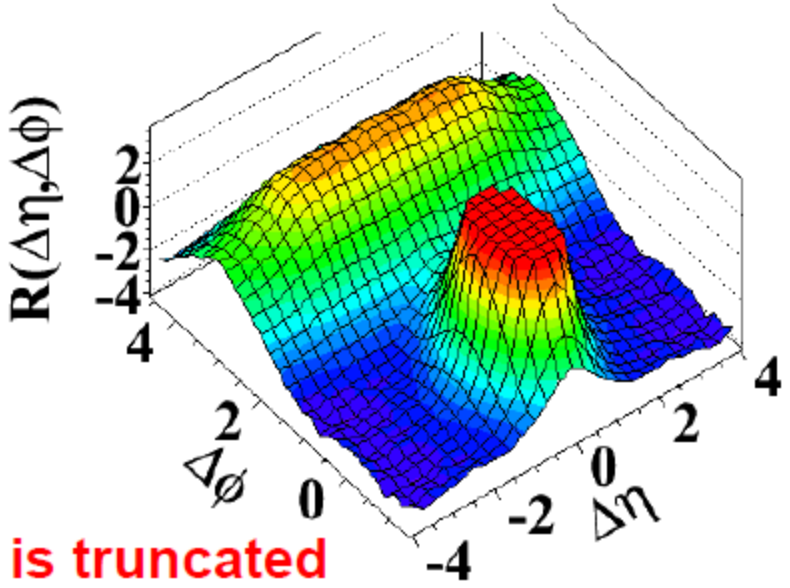
Minimum Bias
no cut on multiplicity

(a) MinBias, p_T>0.1GeV/c



High multiplicity data set
and N > 110

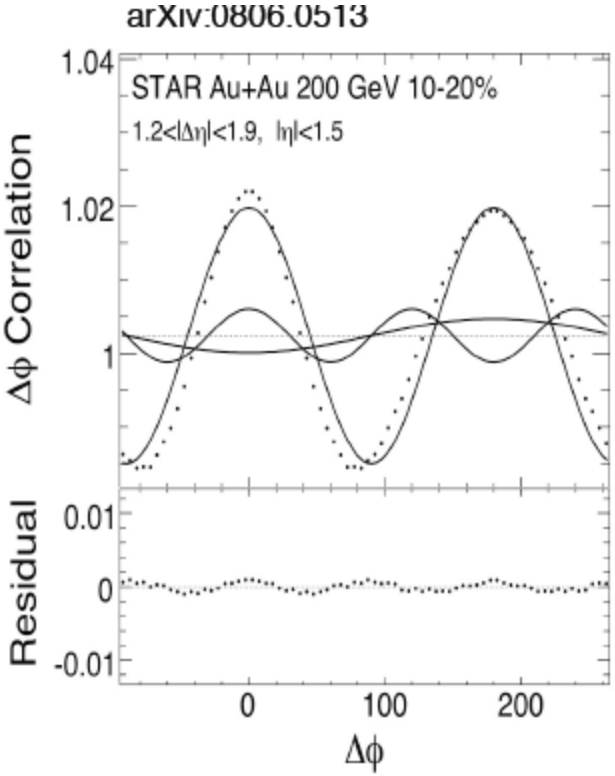
(c) N>110, p_T>0.1GeV/c

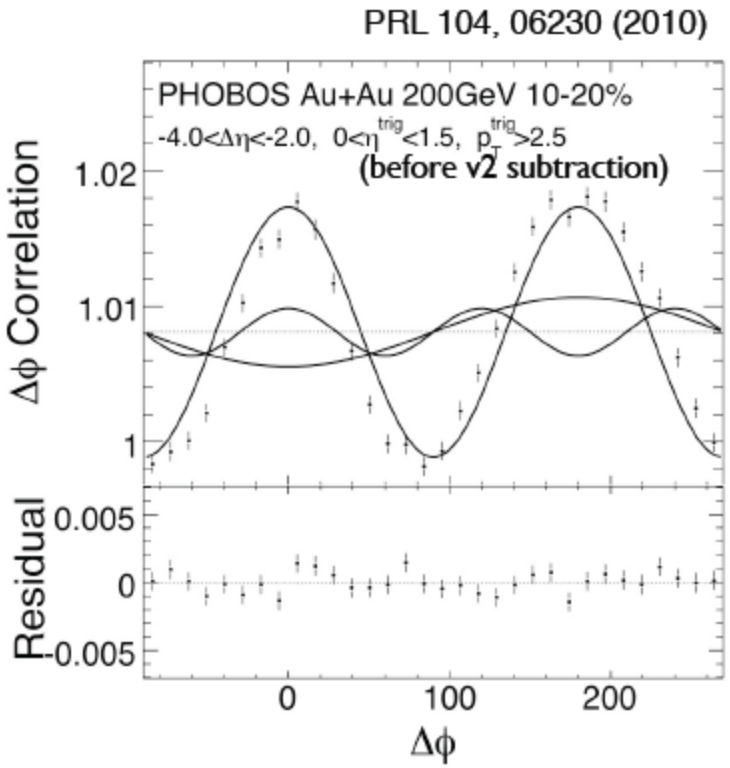


The peak is truncated in both distributions

Back-to-back jet correlations enhanced in high multiplicity sample.

Разложение в ряд Фурье





Existing data are well described by v_1, v_2, v_3, v_4