The Ridge effect at LHC
high density in pp?

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- 1. Bare facts
- 2. Some history/antecedents
- 3. Interpretation?

Long-Range, Near-Side Angular Correlations in Proton-Proton Interactions in CMS

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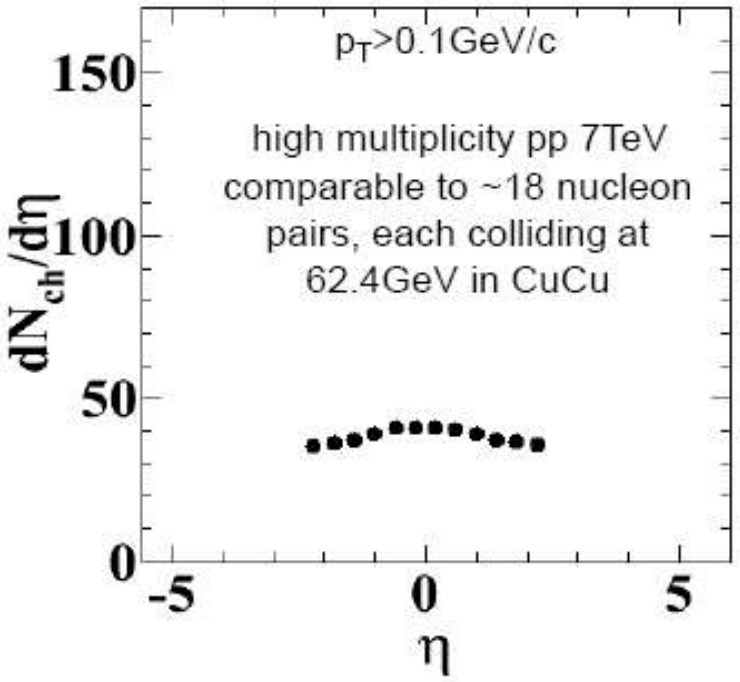
Massachusetts Institute of Technology (MIT)

On behalf of the CMS Collaboration

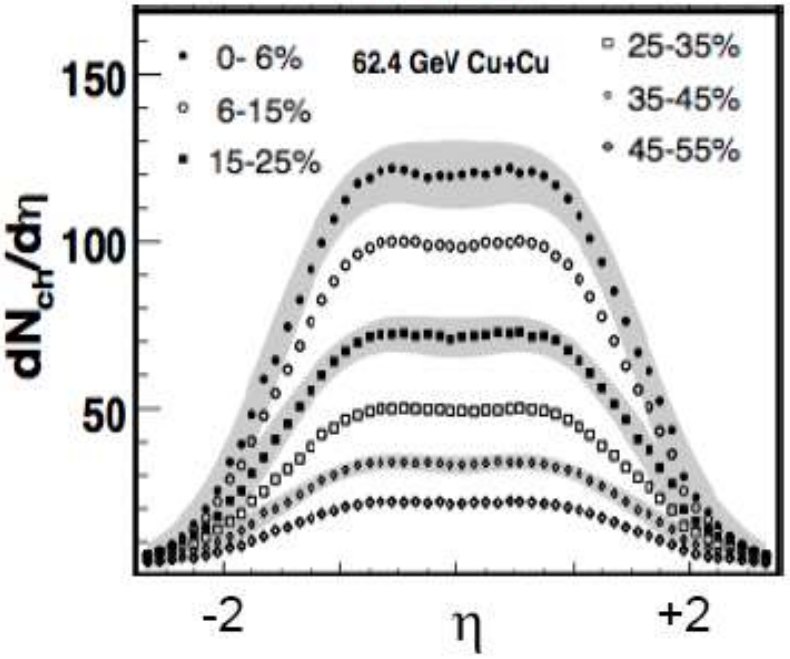
- Now published:
- Observation of near side Long Range
- Angular Correlations in pp Collisions at the LHC
- By CMS Collaboration (Vardan Khachatryan et al.)
- Published in JHEP 1009:021, 2010

Additional motivation for high multiplicity studies

CMS



PHOBOS

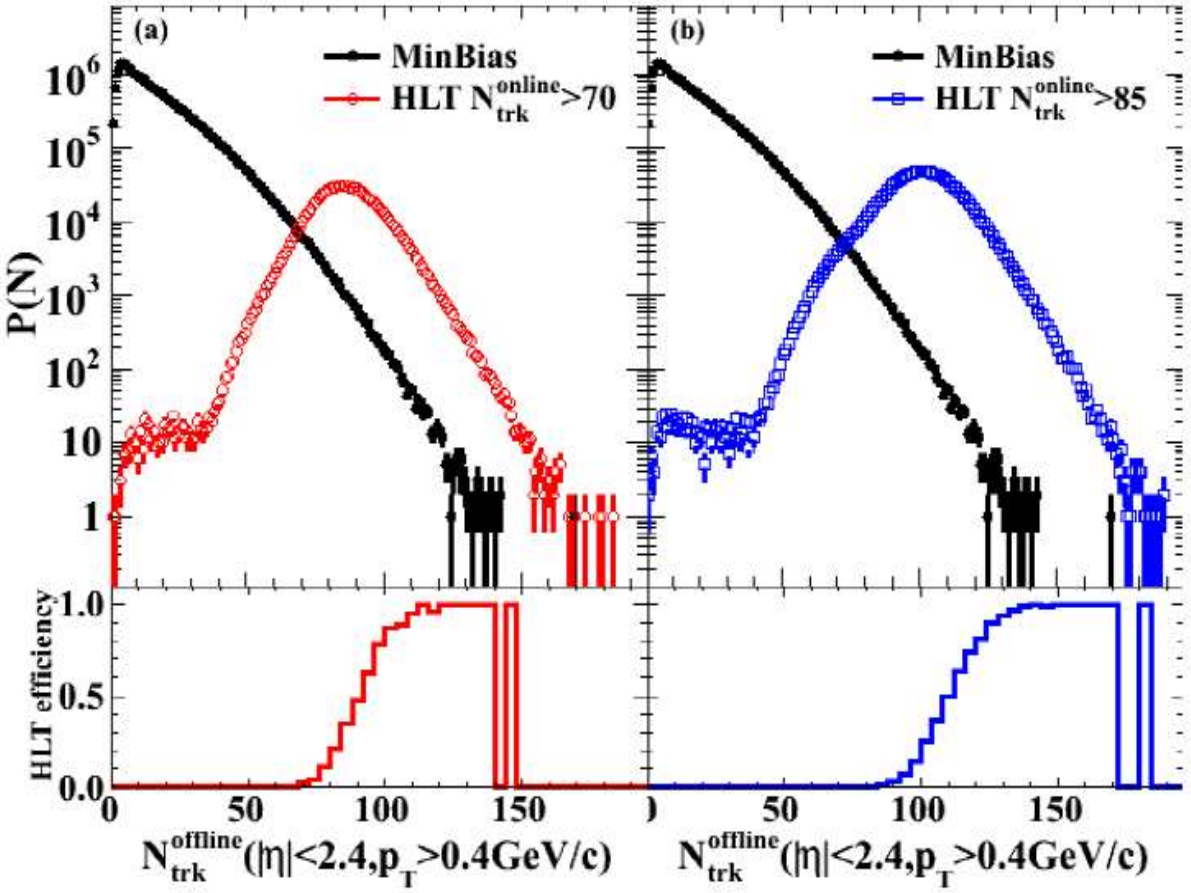


The particle densities in the high multiplicity events of proton-proton collisions at 7TeV begin to approach those in high-energy collisions of nuclei such as Copper.

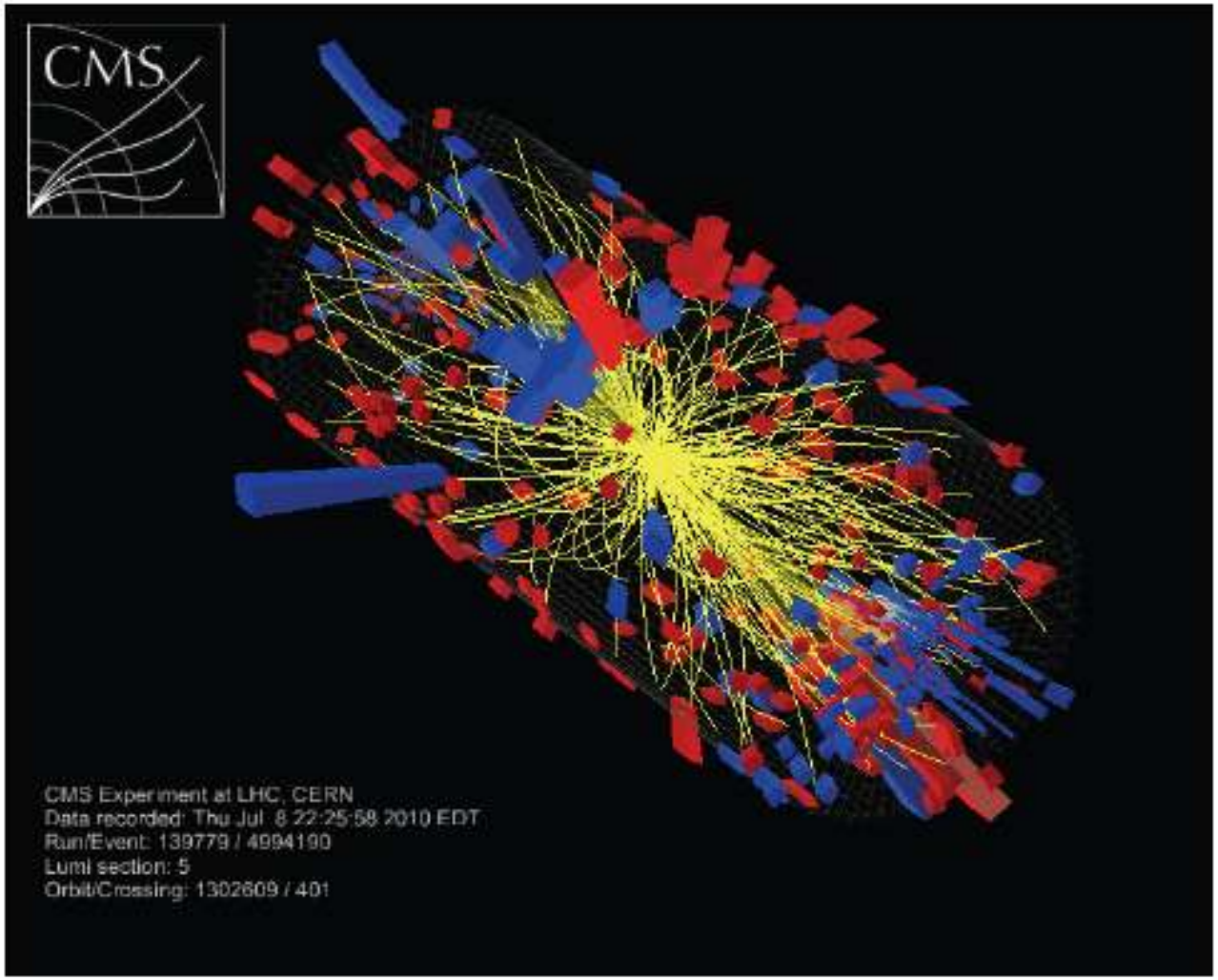
It was considered natural to study the two particle angular correlations in LHC and compare the results with the ones obtained in relativistic heavy ion colliders like RHIC.

Triggering on high multiplicity

A **dedicated high multiplicity trigger** was implemented in the two levels of the CMS trigger system. Level 1 (L1): Sum of the total E_T (ECAL, HCAL, and HF) > 60 GeV.
High-level trigger (HLT): Number of online tracks built from 3 pixel detector layers > 70 and 85.



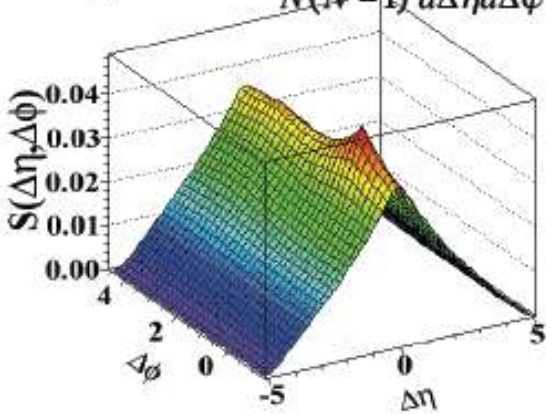
Statistics for high multiplicity events enhanced by O(10^3).
Total datasets corresponding to 980nb^{-1}


CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Jul 8 22:25:58 2010 EDT
Run/Event: 139779 / 4994190
Lumi section: 5
Orbit/Crossing: 1302609 / 401

Correlation Function Definition

Signal distribution:

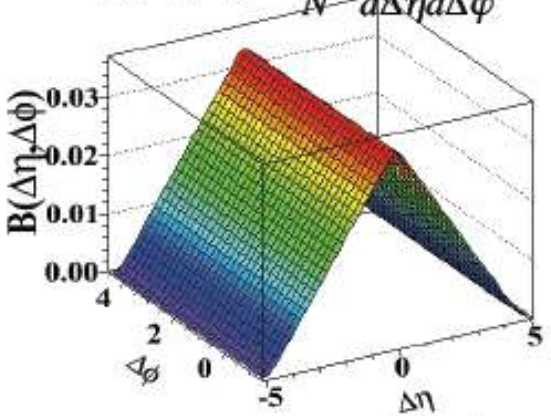
$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$



Same event pairs

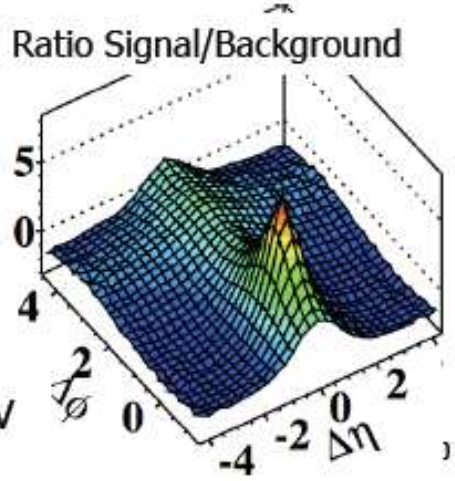
Background distribution:

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



Mixed event pairs

Ratio Signal/Background



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

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

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

CMS pp 7TeV

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

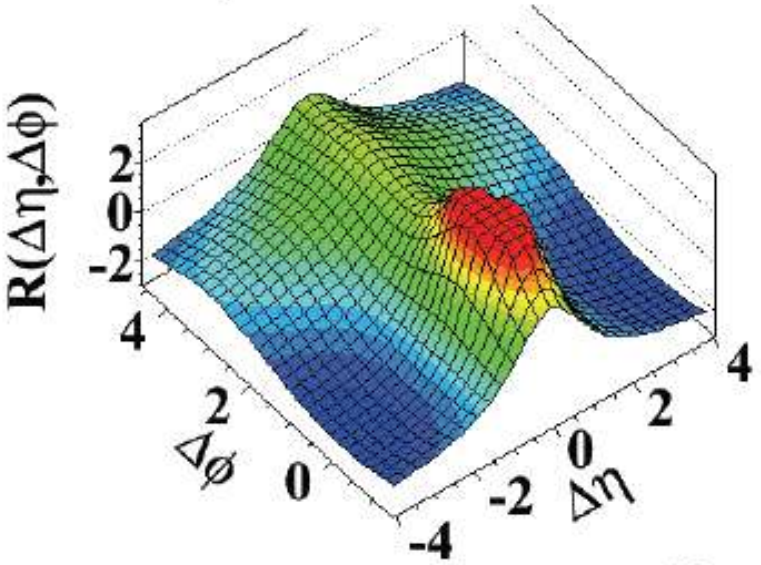
3

Results

Inclusive p_T

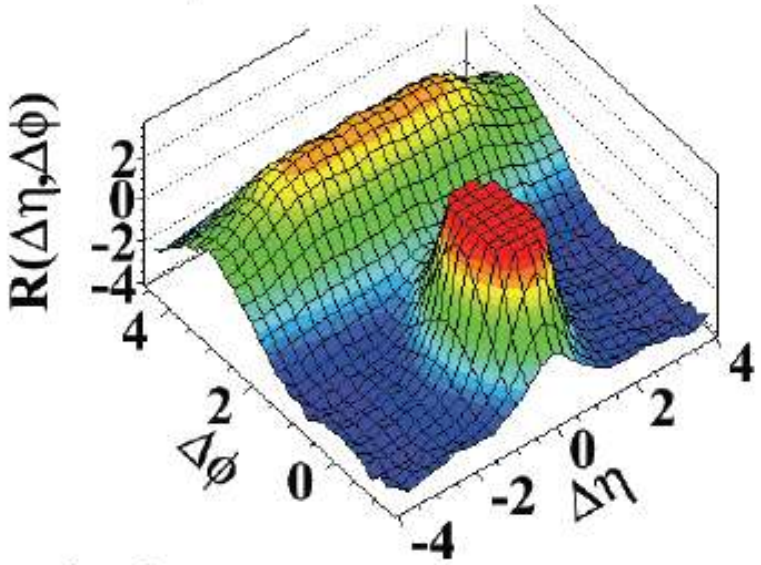
MinBias

(a) MinBias, p_T>0.1GeV/c



high multiplicity (N>110)

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



Cut off peak at (0,0):

Shows structure of away-side ridge (back-to-back jets)

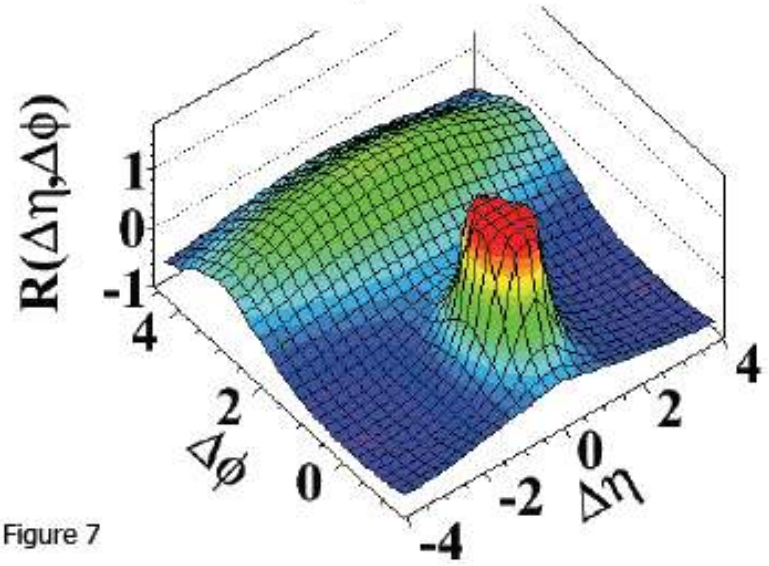
Small change for large $\delta\eta$ around $\delta\phi \sim 0$?

Results

Intermediate p_T: 1-3 GeV/c

MinBias

(b) MinBias, 1.0GeV/c<p_T<3.0GeV/c



high multiplicity (N>110

(d) N>110, 1.0GeV/c<p_T<3.0GeV/c

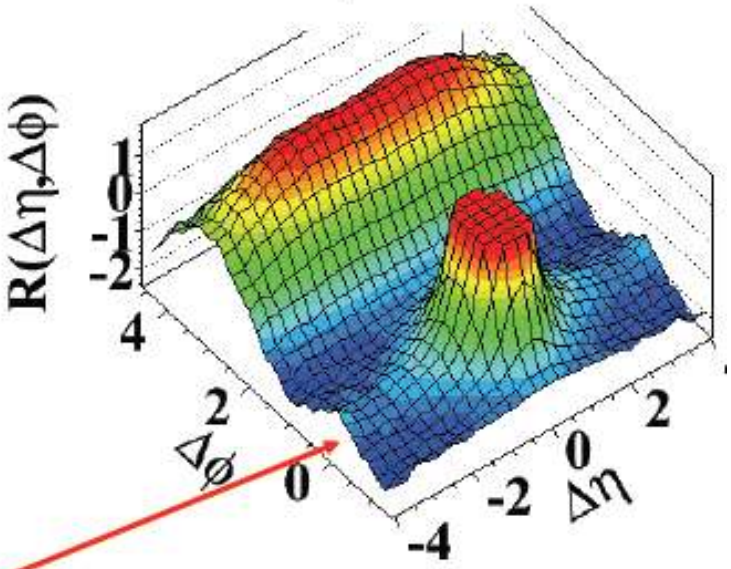


Figure 7

Pronounced structure at large $\delta\eta$ around $\delta\phi \sim 0$!

Signal grows with event multiplicity

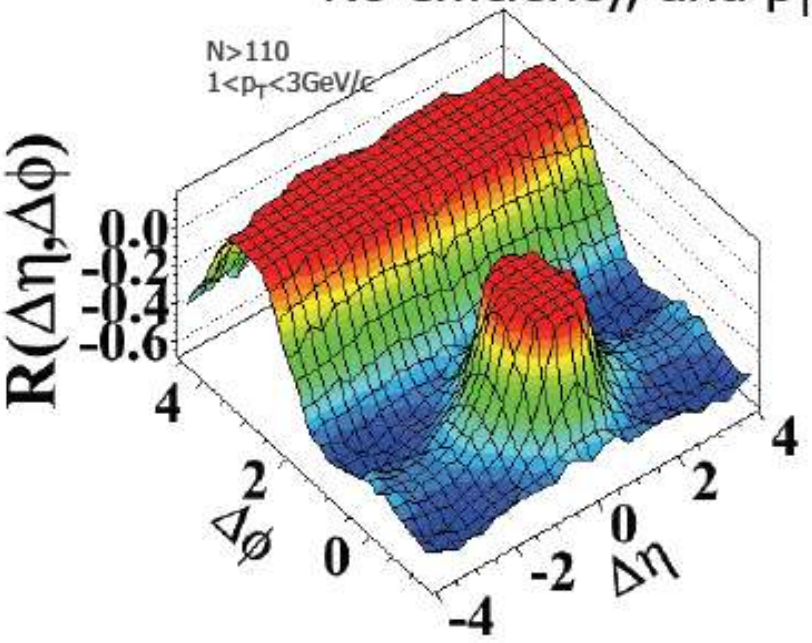
Effect is maximal in the $1 < p_T < 3$ GeV/c range

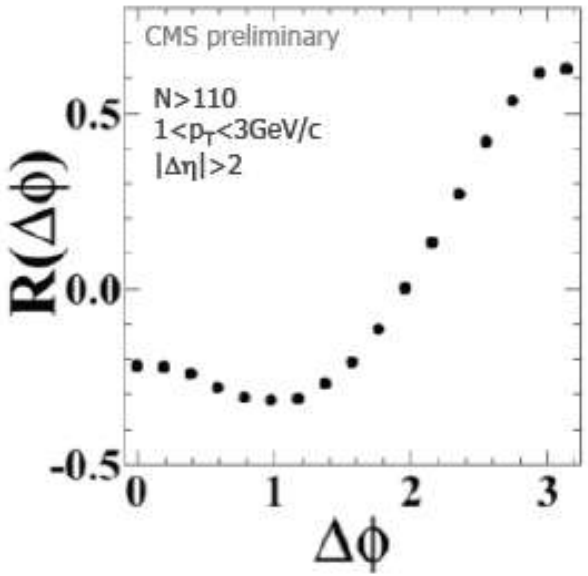
No $\delta\phi \sim 0$ structure in PYTHIA 8 at large $\delta\eta$
Same for Herwig++, madgraph, PYTHIA6

Ridge is seen with three independent analysis codes

Final Test: ECAL photons

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

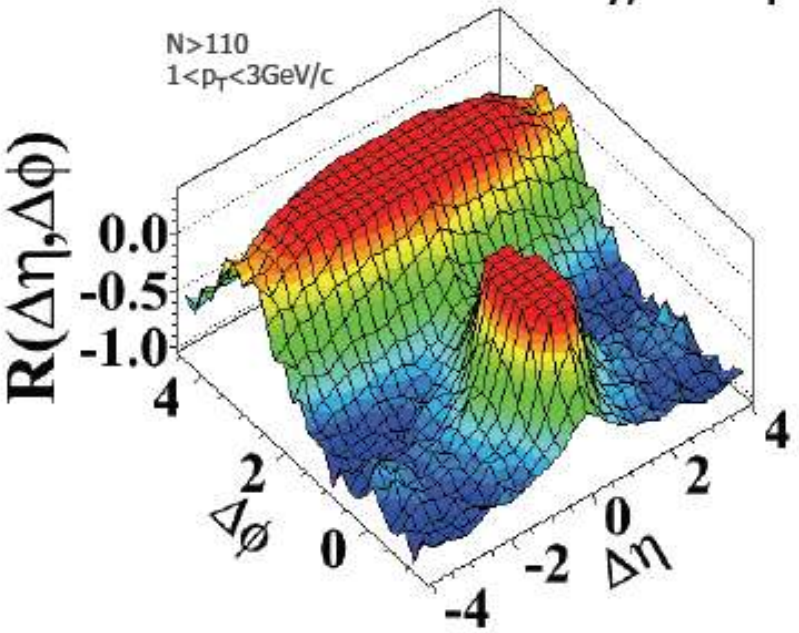


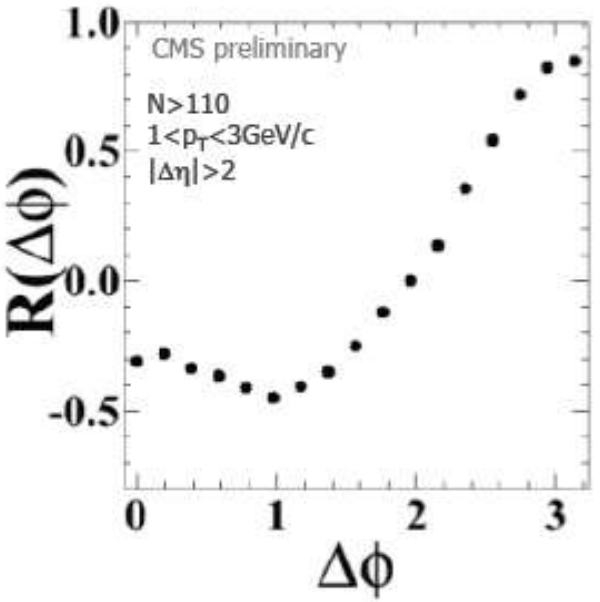


Track-photon correlations

Final Test: 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

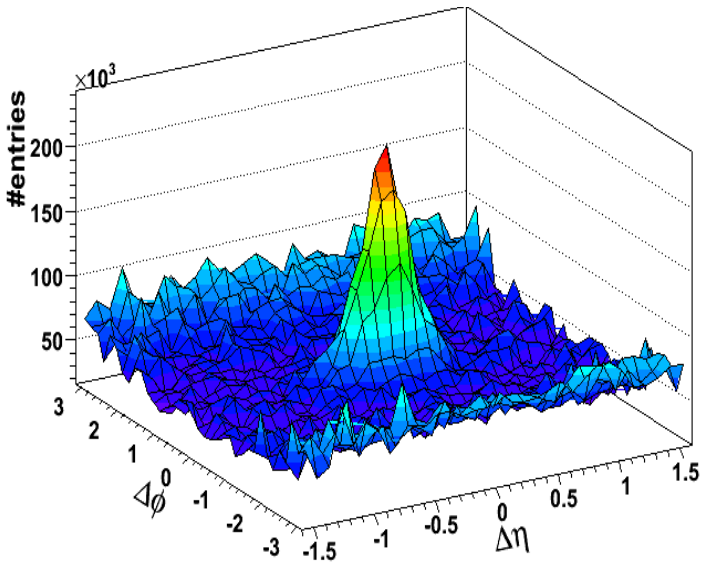
CERN CMS seminar summary: (quotation)

Long-range, near-side correlation is not seen in low multiplicity events and generators, but resembles effects seen in heavy-ion collisions at high energies

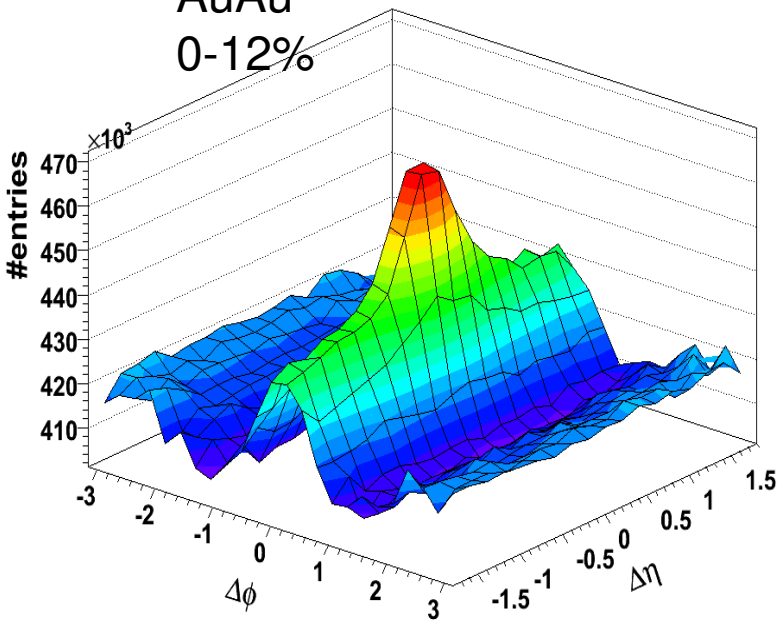
2.Some history:
Ridge: what we already know from AA

STAR Preliminary

dAu



AuAu
0-12%



2-particle correlation shows prominent ridge along $\Delta\eta$ in near side ($|\Delta\phi|<0.7$)

Ridge properties are similar to bulk

Some details:

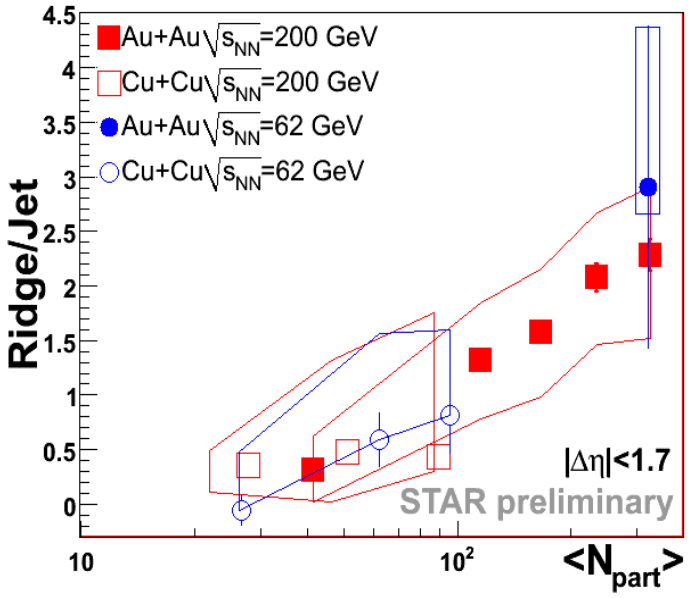
In A-A collisions – study of di-hadron correlations:

for high pT trigger (> 6 GeV) – jet like correlation at small angular separation (small pseudorapidity pair separation and small delta phi)
Unmodified in central Au Au relative to dAu
This suggests **dominant jet fragmentation outside the dense medium**

For lower pT – **significant near side correlation at large pair separation in delta eta**

At moderately large pT the near side correlation can be factored into a jet-like (properties similar to pp) and an elongated contribution approximetely independent on eta – the ridge (not present In pp)

STAR 2009



Ridge seen for few GeV p_T (trigger and associate)

Ridge particles properties similar to bulk

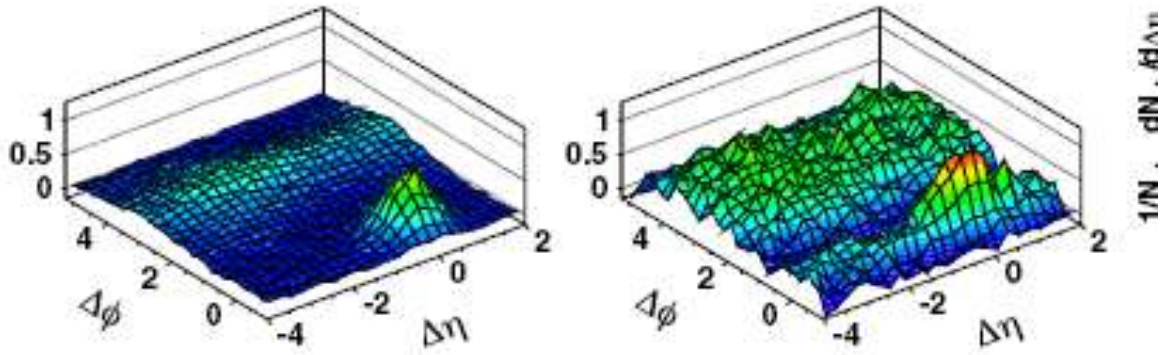
- Correlated with jet and persists to highest trigger p_T
- Jet yield decreases with beam energy, consistent with pQCD
- Ridge/jet ratio consistent between 200 and 62 GeV data

Attemps at interpretation: STAR

The observed longitudinal extent of the ridge ($|\Delta\eta| > 1.5$) indicates qualitatively that the ridge is formed early in the evolution of the fireball (for example, as color flux tubes from a CGC initial state

PHOBOS 2010

Wider pseudorapidity range



(a) p+p PYTHIA (version 6.325) (b) Au+Au 0%–30% (PHOBOS)

In this Letter, the long-range correlation of particles aligned azimuthally with a high p_T trigger particle—a unique feature of heavy ion collisions—is shown to extend over at least four units of pseudorapidity. This represents a dramatic extension of previous measurements, providing powerful constraints on the nature of particle production in heavy ion collisions. The persistence of this correlation to such large pseudorapidity separations suggests it is imprinted in the earliest moments after the collision, naturally favoring interpretations that invoke global features of the system like collision geometry and radial flow, rather than local features like medium-modified fragmentation.

3. Prediction, postdictions, comments for pp at LHC:

- CERN presentation: Sept 21

E.V.Shuryak on arXiv: Sept 23

‘perhaps this observation is the first hint for an explosive behaviour in pp, which was anticipated for decades…’

A.Dumitru et al..,on arXiv Sept 27:

’We show that key features [of LHC result] can be understood in the Color Glass Condensate framework of QCD’.

- P.Bożek on Oct 3:

‘the elliptic flow explains everything’, ‘it would mean that the short-lived multiparticle system created in the collision is very strongly interacting and some degree of collectivity appears’

- Along the same line: T.Trainor on Oct 15:

extrapolation of azimuth quadrupole systematics (e.g elliptic flow?) in pp from 0.2 TeV to 7TeV gives just about the CMS result

- Finally – and perhaps firstly: M.Tannenbaum and R.Wagner comment on arXiv (Oct):

‘A correlation strikingly similar to that in [CMS preprint] was observed in a p-p experiment at the CERN ISR’:

M.Albrow et al.., Studies of Proton-Proton Collisions at the CERN ISR with an Identified Charged Hadron of High Transverse Momentum at 90 deg
Nucl.Phys. B 145 (1978) 305

(pp 52.6 GeV)

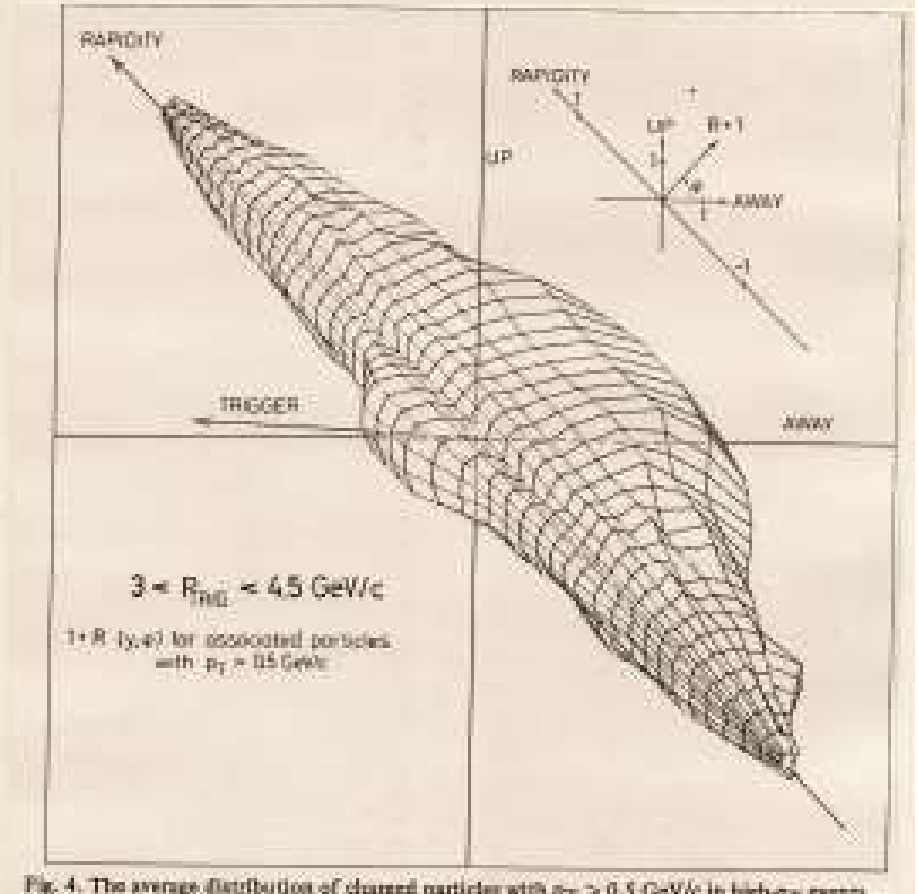


Fig. 4. The average distribution of charged particles with $p_T > 0.5$ GeV/c in high-p_T events ($6 < p_{T,trig} < 7$ GeV/c) relative to the distribution observed in minimum-bias events. The ratio $R + 1$ is shown as a function of y and ϕ in cylindrical coordinates. The coordinate system ($R + 1$, ϕ, y) is indicated in the insert.

What do we really see here:

For `high' pt trigger, a higher value of the correlation function in small region in y and phi near the trigger particle

and a much larger increase on the away side, extending to rapidity ~3

This is not a true long range correlation!

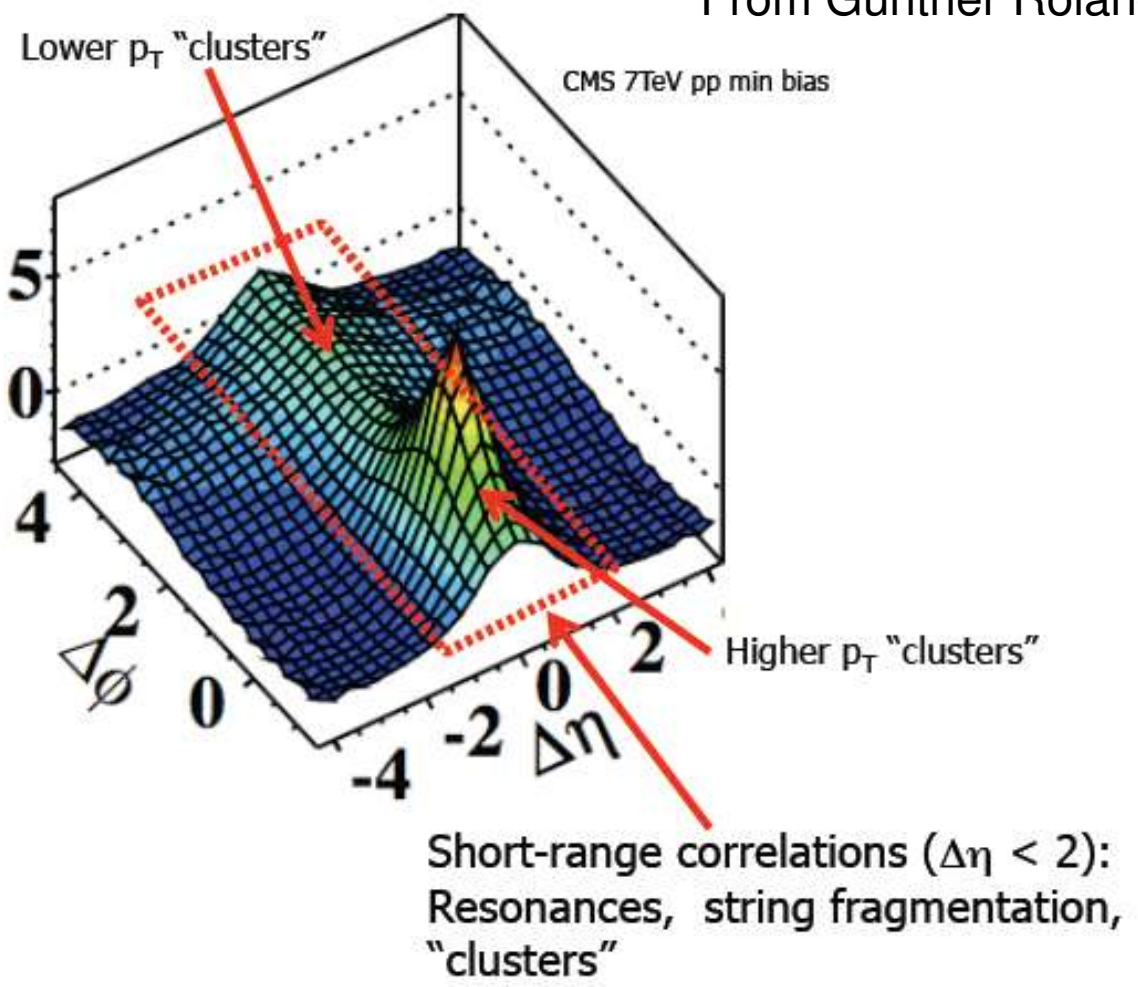
(authors observe `an increase of the density of high pT particles with charge opposite to trigger in the small solid angle around trigger inside y<1')

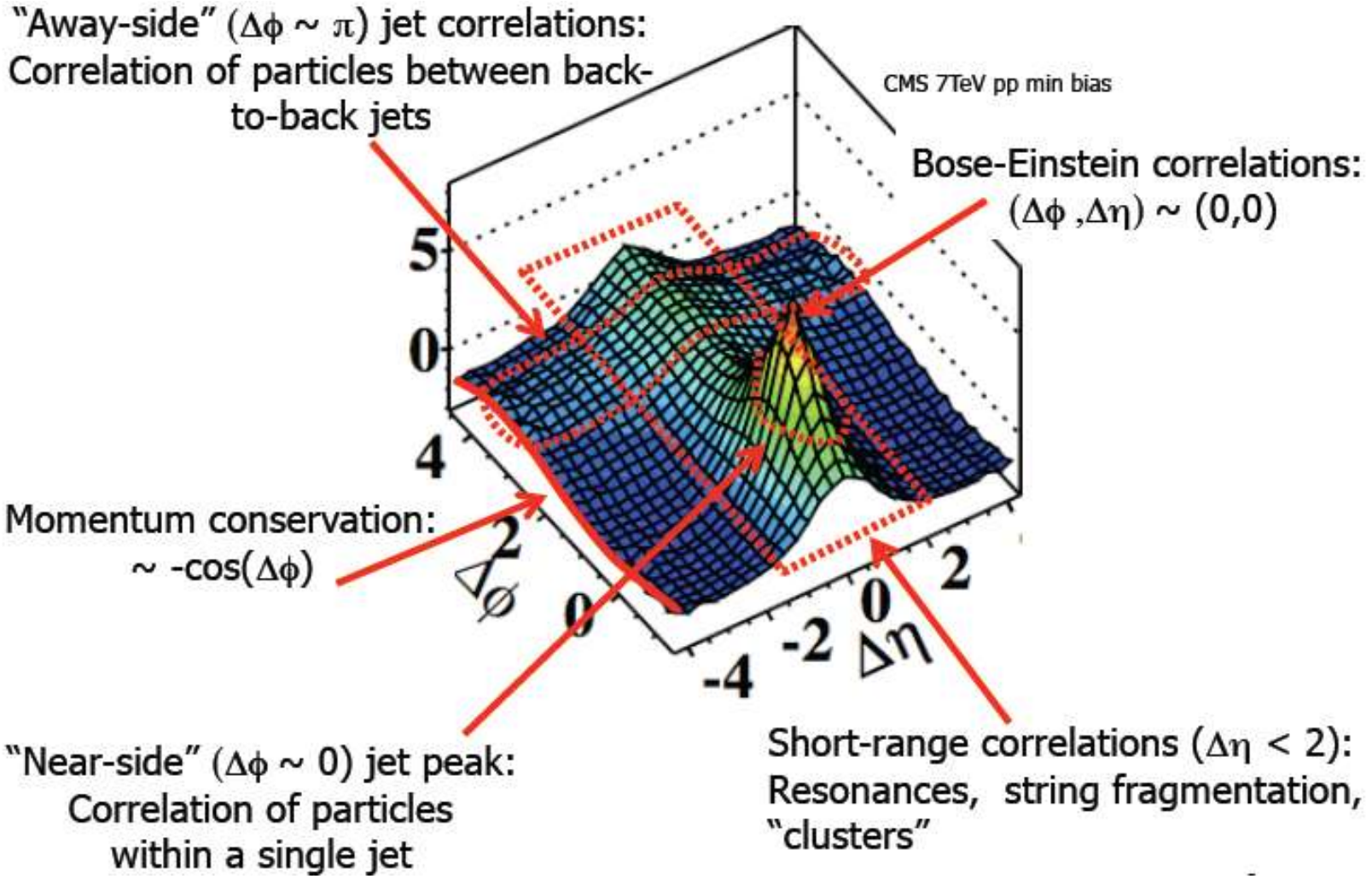
More voices from the past:

- Correlations indeed were observed in pp in UA5 (SPS), E735 (TeVatron)
- These were not ‘hard’ (e.g only high multiplicity or high p_t selected events
- UA5: forward-backward multiplicity correlations, interpreted in terms of a cluster model (rather small clusters, on average – 2 particles)
- E735: also F – B multiplicity correlations, also clusters

At LHC: ridge is not desctribed by short range clusters:

From Gunther Roland seminar:

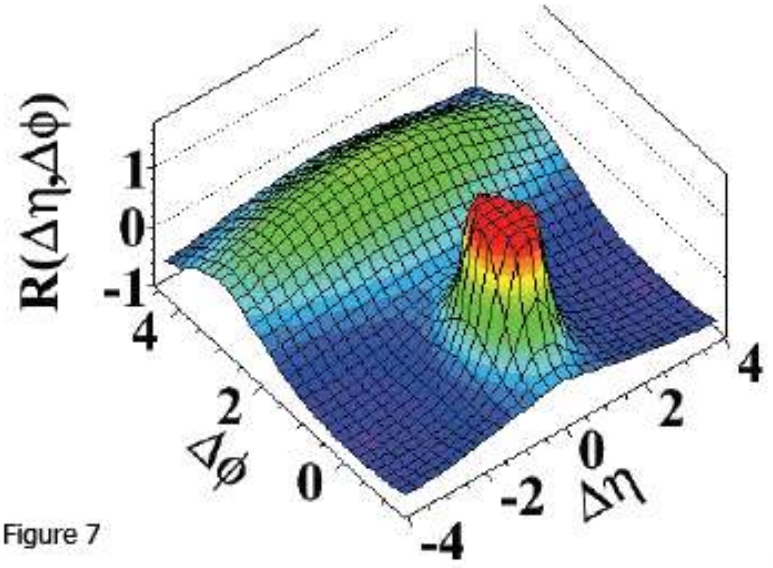



"Away-side" (Δφ ~ π) jet correlations:
Correlation of particles between back-to-back jets
CMS 7TeV pp min bias
Bose-Einstein correlations:
(Δφ ,Δη) ~ (0,0)
Momentum conservation:
~ -cos(Δφ)
"Near-side" (Δφ ~ 0) jet peak:
Correlation of particles within a single jet
Short-range correlations (Δη < 2):
Resonances, string fragmentation, "clusters"
5
0
4
2
Δφ
0
-4
-2
0
2
Δη

Intermediate p_T: 1-3 GeV/c

MinBias

(b) MinBias, 1.0GeV/c<p_T<3.0GeV/c



high multiplicity (N>110)

(d) N>110, 1.0GeV/c<p_T<3.0GeV/c

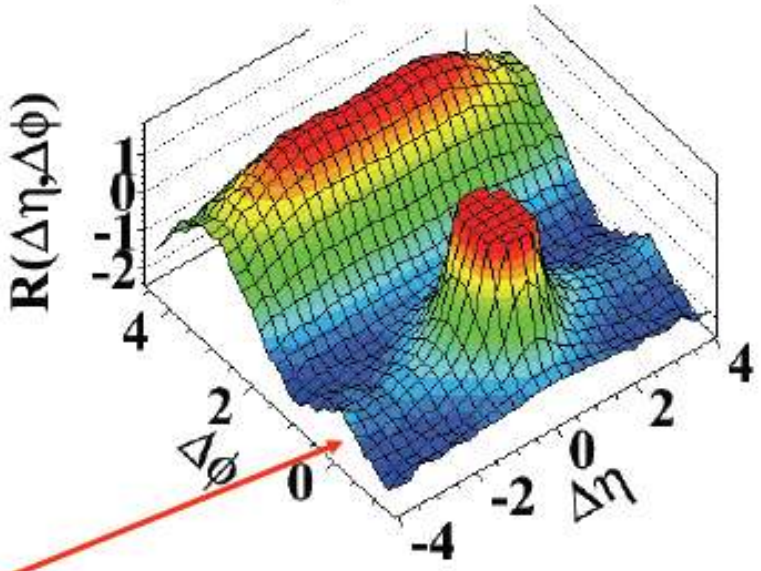


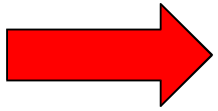
Figure 7

Pronounced structure at large $\delta\eta$ around $\delta\phi \sim 0$!

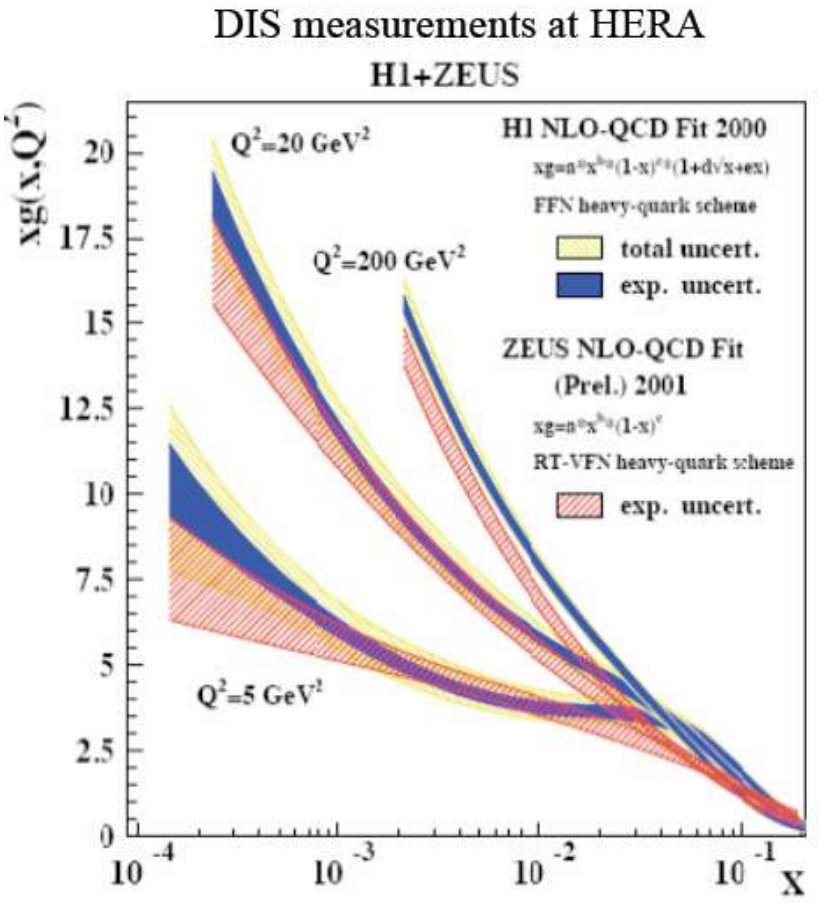
Back to Color Glass Condensate

At high en most of the particles produced are produced from incoming partons that carry a very small fraction x of the longitudinal momentum of the projectile.

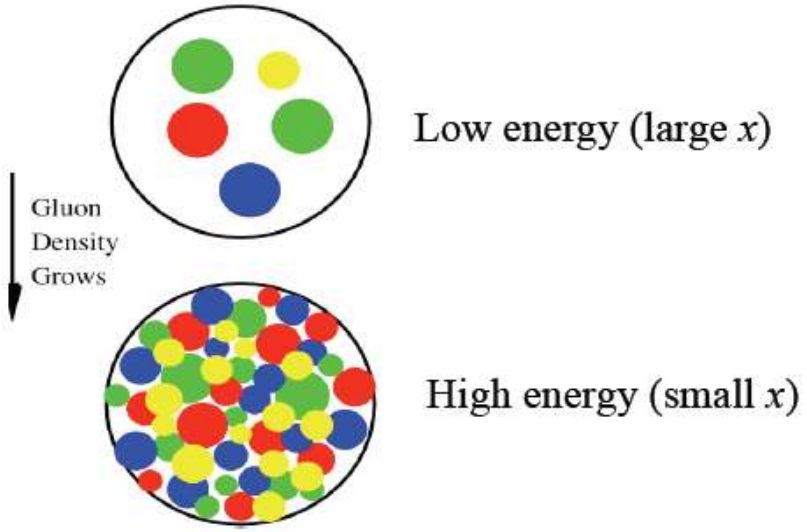
At RHIC typical value of $x \sim 10^{-2}$
At LHC $\sim 10^{-4}$
At such small x – the gluon density in a proton (or a nucleus) becomes large



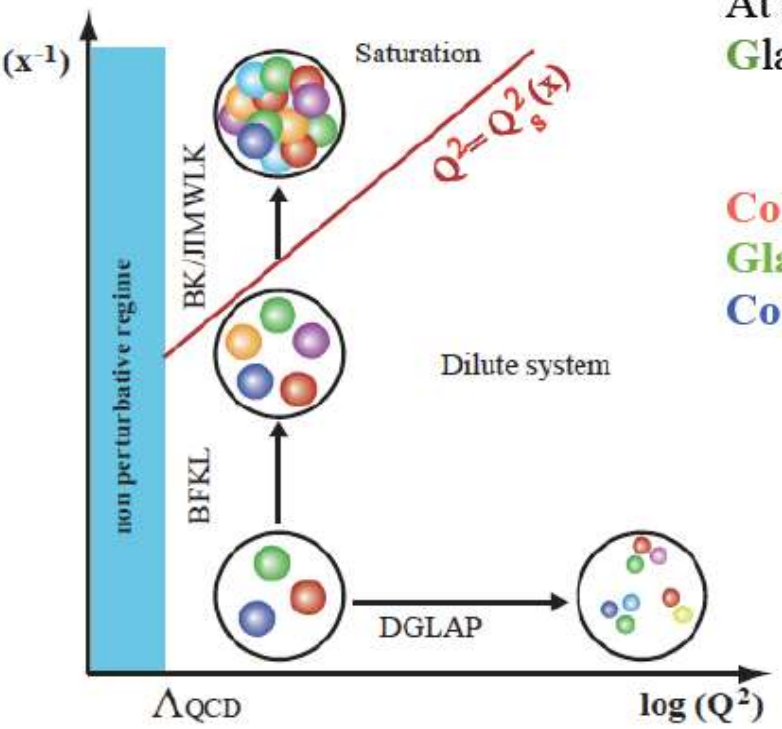
gluon saturation



Small-x rise of $xg(x)$: saturation of the gluon density



Colour Glass Condensate



At small-x, hadronic matter can be described by the Colour Glass Condensate (CGC) model

McLerran, Venugopalan, Iancu, Leonidov, Mueller, ...

Colour gluons are coloured
Glass fast partons as "frozen" sources of soft gluons
Condensate high gluon occupancy

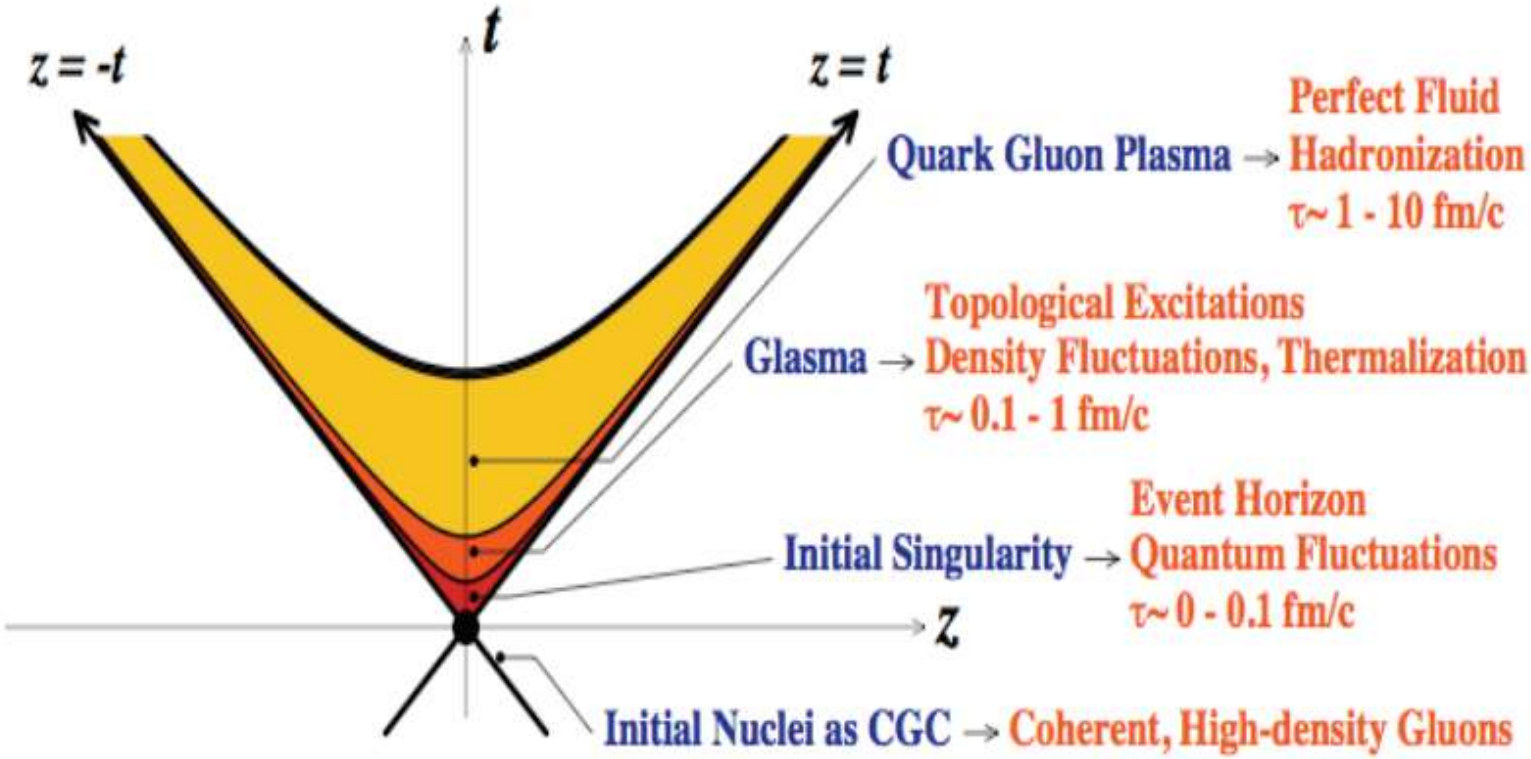
If large Q^2_s : weakly coupled QCD-based theory but not necessarily perturbative → CGC is a classical effective theory

$Q^2_s \propto x^{-0.3} A^{1/3}$ → saturation for low x (high $\sqrt{s}=1/x$), large A

→ $Q^2_{s,LHC} = 3\ Q^2_{s,RHIC}$

→ $Q^2_{s,Pb} = 6\ Q^2_{s,p}$

CGC as initial state of heavy ion collisions



CGC framework can describe heavy ion collisions up to $\tau = 1/Q_s$

When two hadrons (**or nuclei**) collide at high energy, the CGC framework predicts that strong longitudinal chromo-electric and chromo-magnetic fields are produced. Long range correlations arise as a consequence of the saturation of gluons.

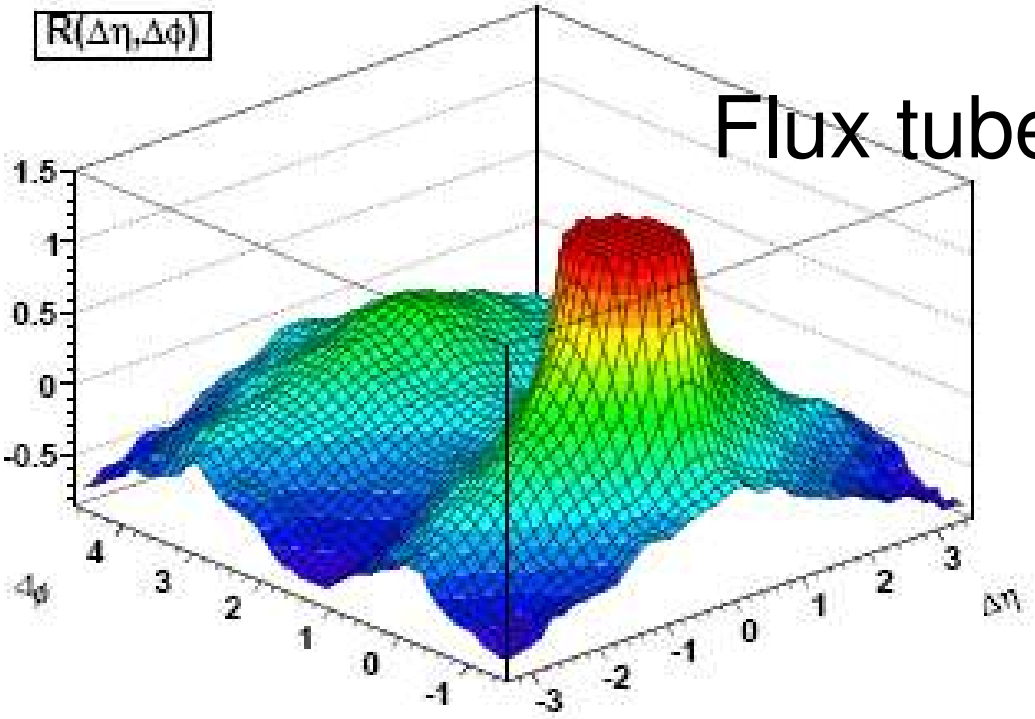
If long range rapidity correlations exist, the correlation must be formed at proper time earlier than:

$$\tau_{\rm init.} = \tau_{\rm f.o.} \exp\left(-\frac{1}{2}\Delta y\right) ,$$

Rapidity correlation delta eta ~ 5
suggests correlations formed nearly instantaneously
Sensitive to strong color fields in the initial state

Dumitru et al. perform calculations – and roughly describe the ridge as observed in CMS – including p_t dependence and the observation, that the correlation has the same strenght for both like and unlike sign pairs (same at RHIC; consistent with gluon emission ('glasma flux tube')

New pa So does pp scattering provide as well a liquid, just ten 1
times smaller than a heavy ion collision? It seems so!



Flux tubes plus hydro

Figure 1: (Color online) Two particle correlation function R versus $\Delta\eta$ and $\Delta\phi$ for high multiplicity events in pp collisions at 7 TeV, as obtained from a hydrodynamical evolution based on flux tube initial conditions. We consider particles with p_t between 1 and 3 GeV/c.

More new papers:

R.Hwa & C. Yang on arXiv Nov 3:

An interpretation of ridge in pp given in terms of
enhancement of soft partons
due to energy loss of semihard jets

v2 of Dumitru et al.: radial flow effects may enhance the effect – but not dominate it, **so CGC is the main culprit**

And (obviously) AdS/CFT joined:

(a spin-off from string theory that relates the strong coupling limit of quarks and gluons to a theory of gravity in a higher dimension)

H.Grigoryan, Y.Kovchegov on arXiv Dec27:

`Modeling the colliding heavy ions by shock waves on the gravity side we observe at early times … **long range correlations**, and that … late time medium dynamics can not wash out the long range rapidity correlations formed at early times.'
`These results may provide an insight on the nature of `ridge' at RHIC and in pp collisions at LHC'.

But `calculations appear to be prohibitively complicated to do analytically at the moment'.

So, what we are left with?

- If the effect holds firm, it may indicate **some form of high energy density creation** in pp at 7 TeV
- If someone dares to speak about **QGP in pp**: **look for jet quenching in pp**, that is – search for **suppression of high pt particles** in high multiplicity events , or for **dijet asymmetry** in those events
- (jet quenching in such signals observed already in 2.76 TeV Pb-Pb, by ATLAS, CMS and ALICE)