‘Efekt wierchu’/The Ridge Effect w zderzeniach pp – pPb - PbPb przy LHC

Helena Białkowska

- What is a Ridge effect?
- History: RHIC data
- Surprise: Ridge at LHC in pp
- First interpretations
- Sequel 1: Ridge at LHC in PbPb
  `Correlation` = flow (with higher terms)?
- Sequel 2: Ridge at LHC in pPb

Definition:

Particle 1: trigger

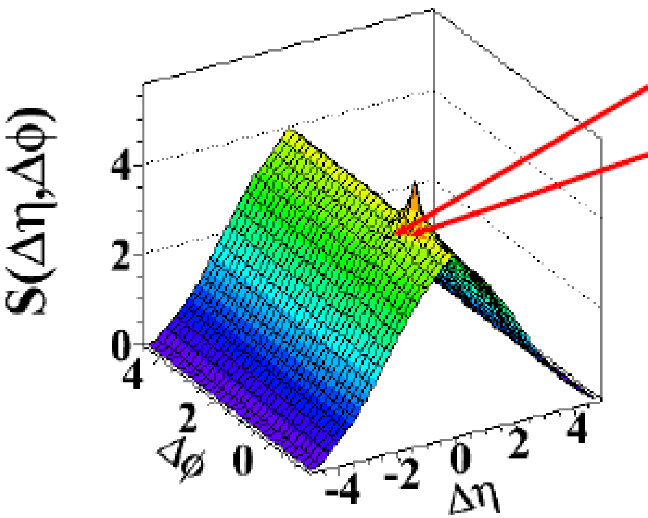
Particle 2: associated

Signal distribution:

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

Background distribution:

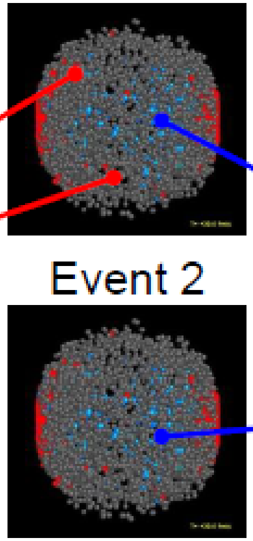
$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$

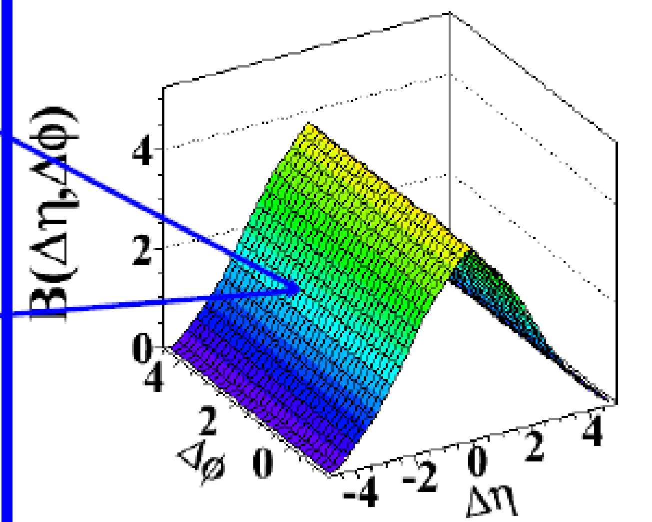


same event pairs

Event 1

Event 2





mixed event pairs

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

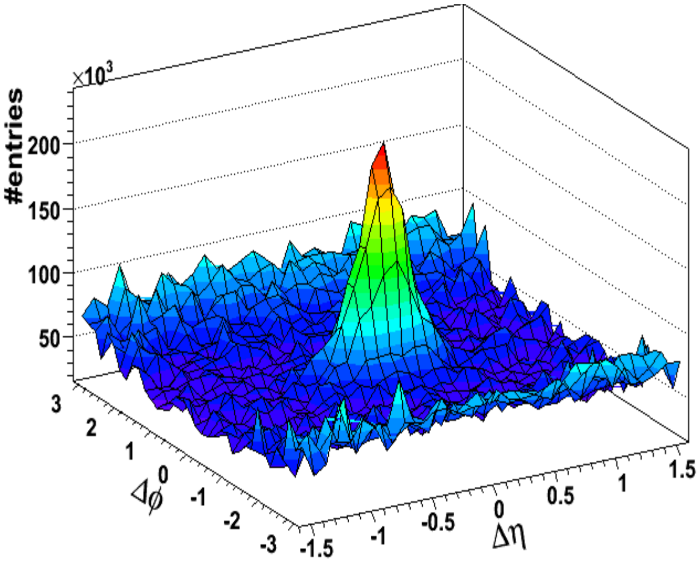
$\Delta\phi = \phi^{assoc} - \phi^{trig}$

Associated hadron yield per trigger:

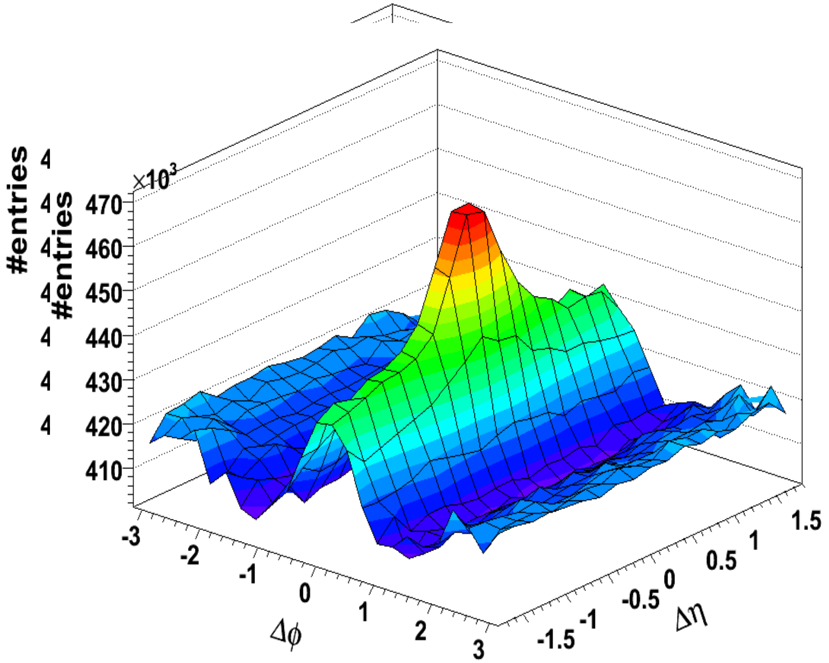
$$\frac{1}{N_{trig}} \frac{d^2N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

History: STAR at RHIC:

d Au



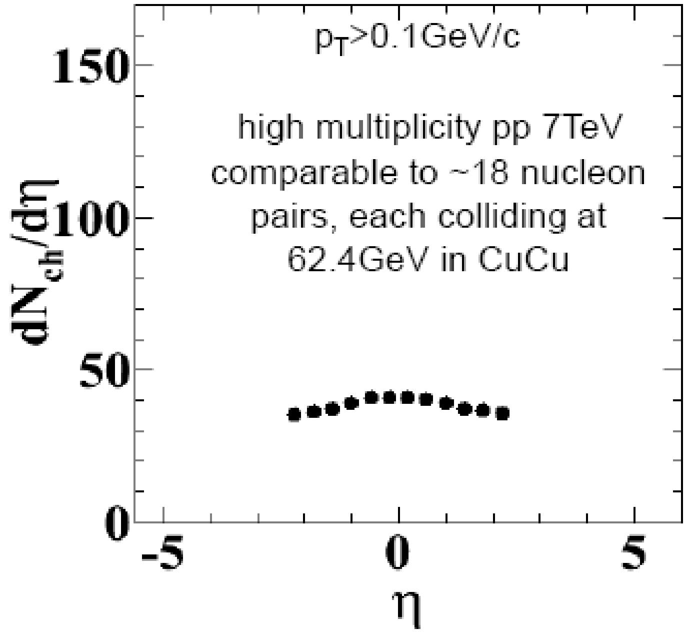
Au Au 0 – 12%



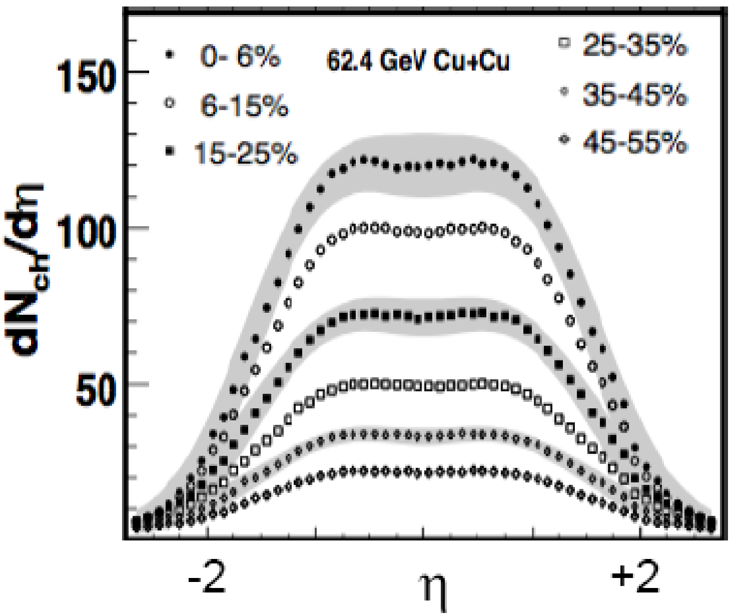
2-particle correlation shows prominent **ridge** along $\Delta\eta$ in near side ($|\Delta\phi|<0.7$)

Additional motivation for high multiplicity studies

CMS



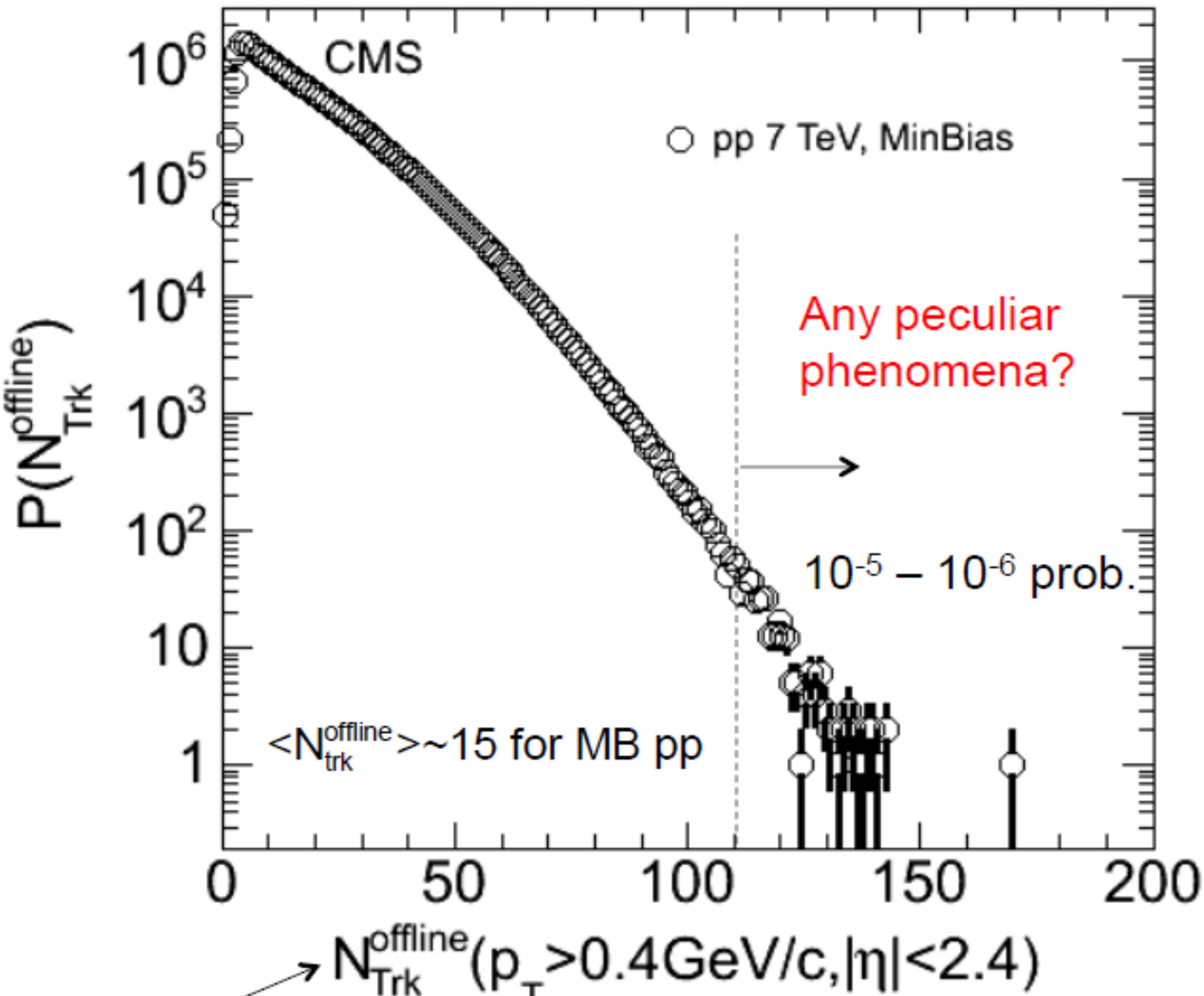
PHOBOS



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.

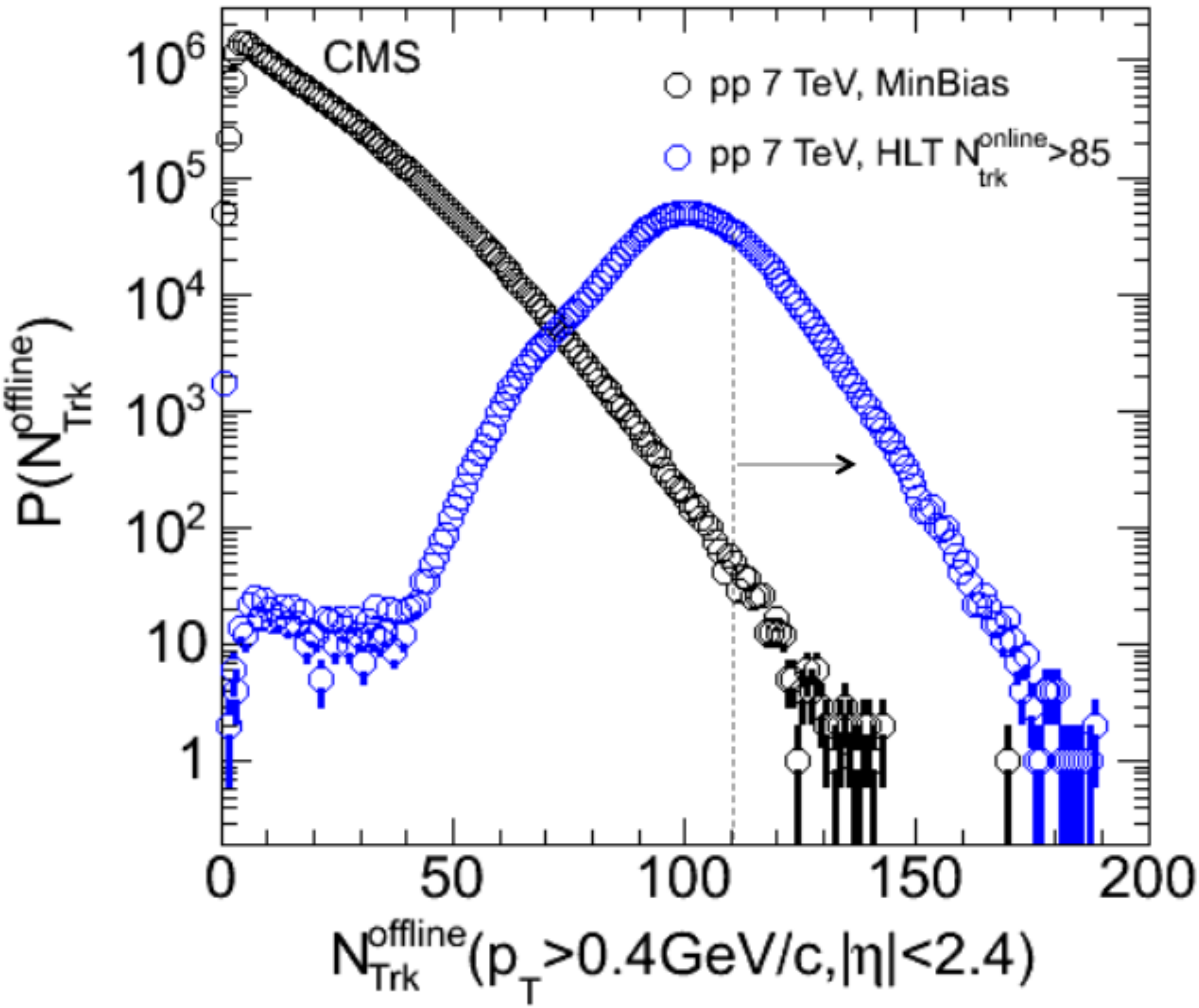
It was considered natural to study the two particle angular correlations in LHC and compare the results with the ones obtained in relativistic heavy ion colliders like RHIC.

Very high-multiplicity pp events are rare in nature



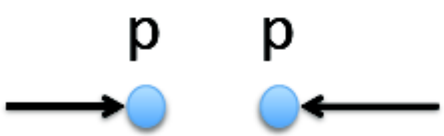
Raw counts of tracks!

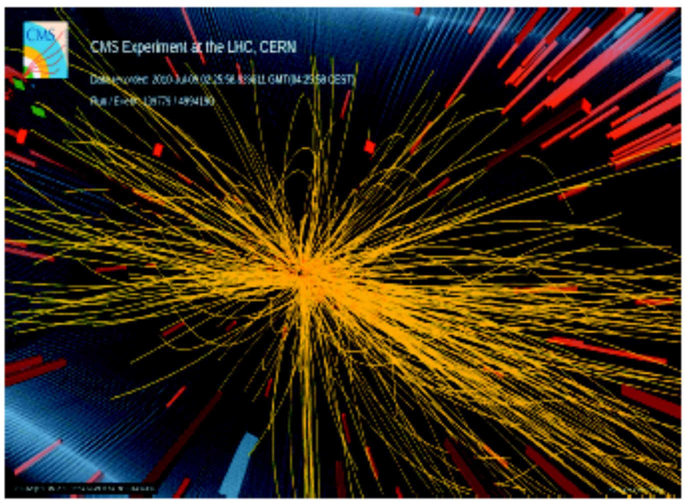
Dedicated online selection of high multiplicity events



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

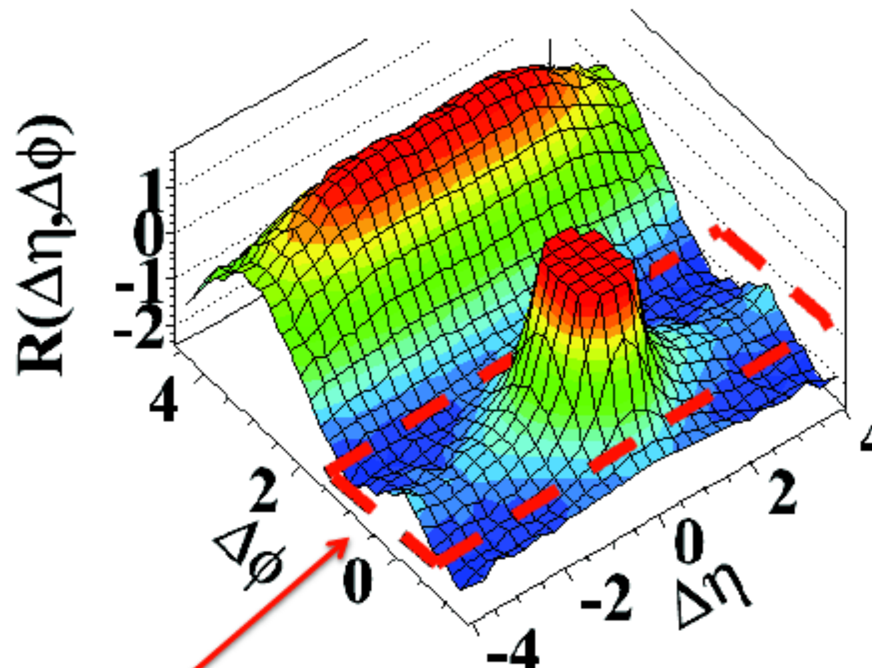
CMS collaboration, JHEP 09 (2010) 09





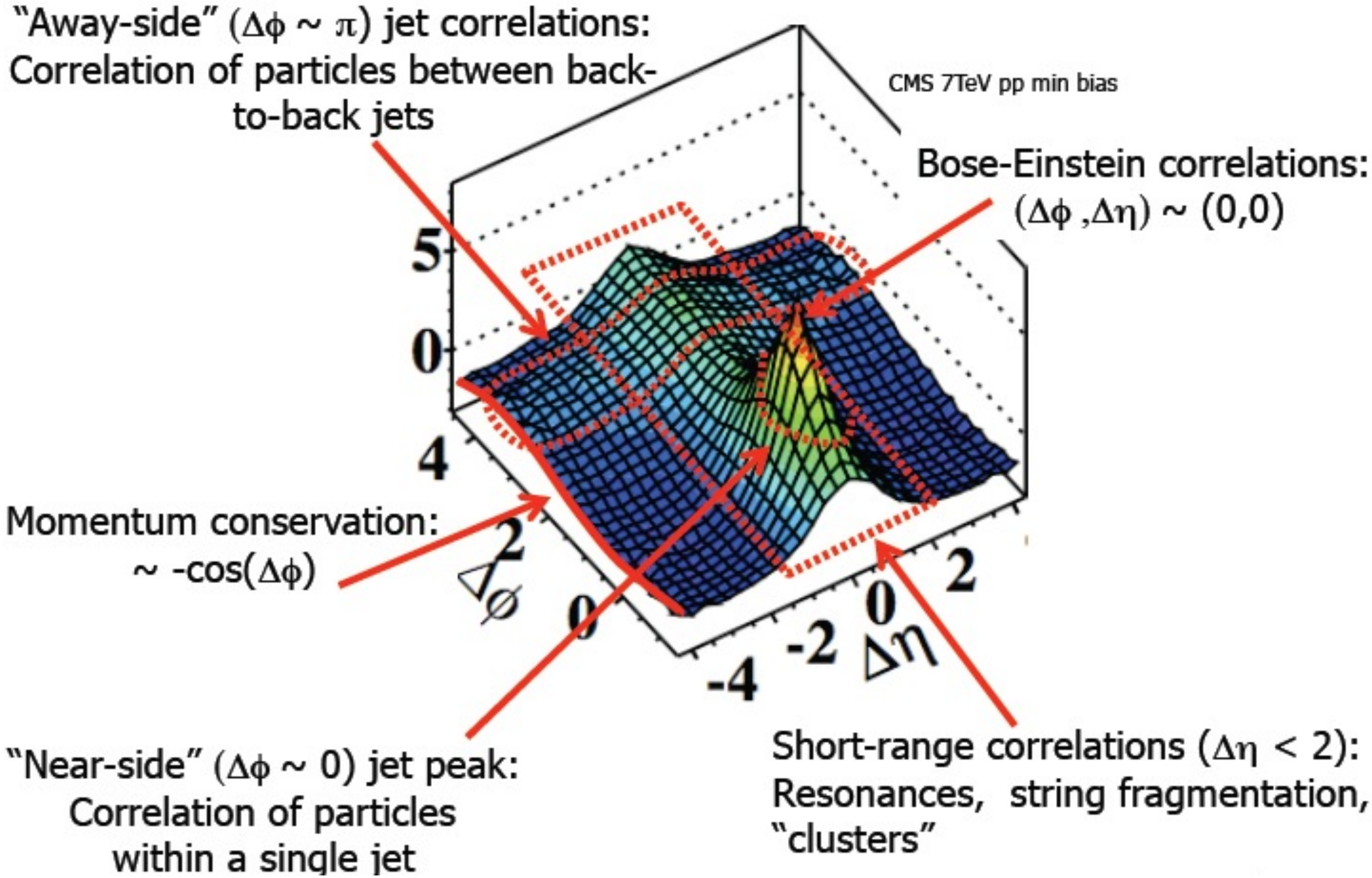
Event with more than 200 charged particles

pp N>110, $1<p_T<3$ GeV/c



Unexpected ridge-like correlations in high multiplicity pp!

Different structures:

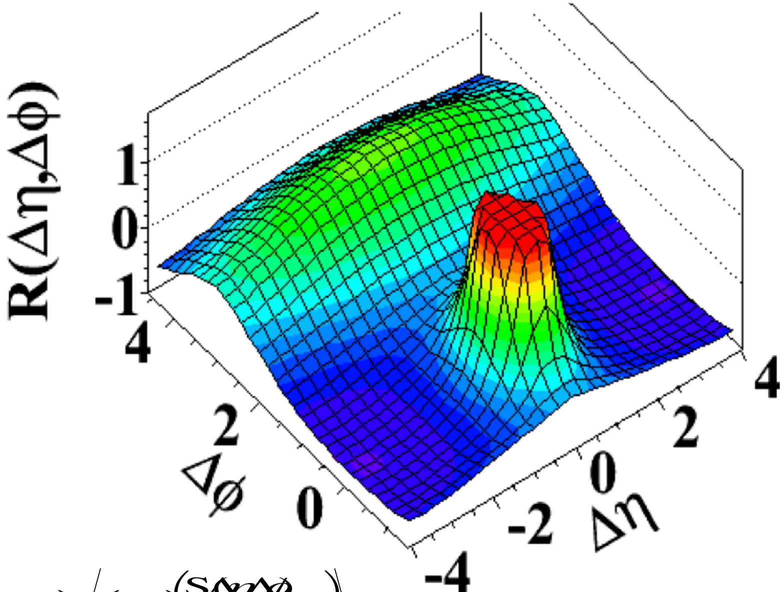


Ridge in high multiplicity pp

Intermediate p_T: 1-3 GeV/c

350K events

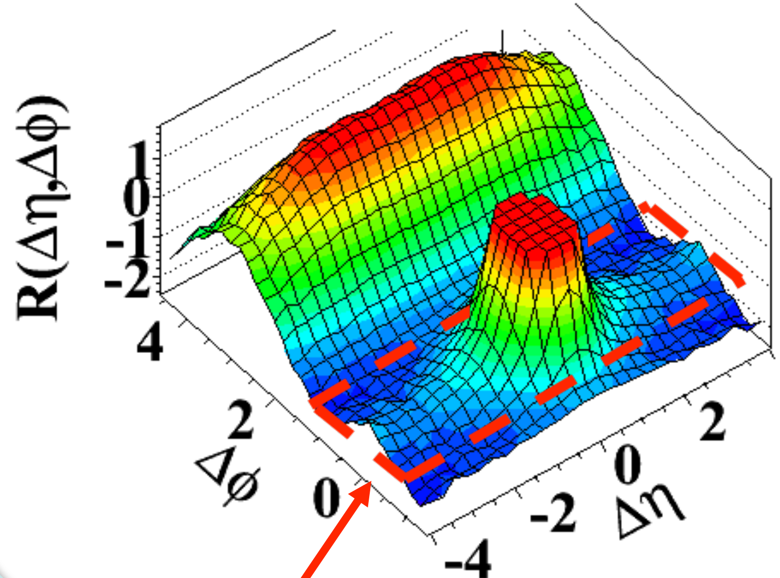
Minimum Bias pp (<N> ~ 15)



$$R(\Delta\eta,\Delta\phi) = \left\langle (N-1)\left(\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle$$

peak truncated

High multiplicity pp (N ≥ 110)



JHEP 09 (2010) 091

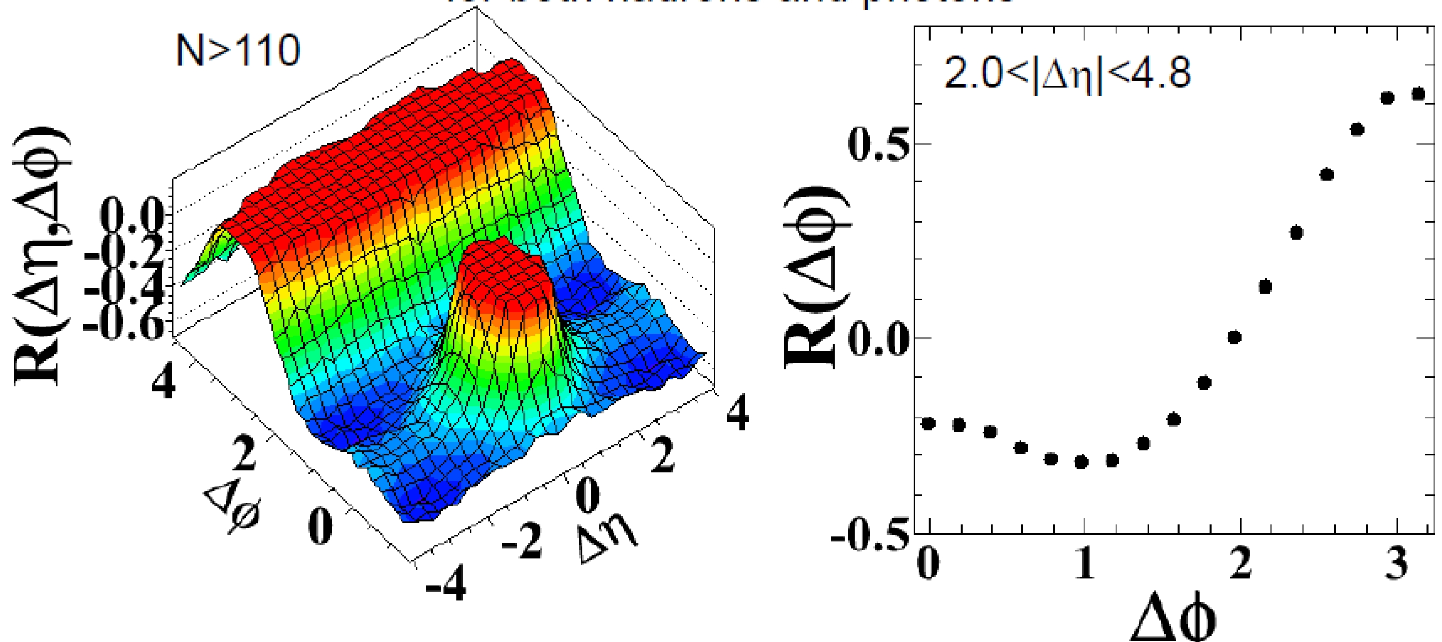
Striking “**ridge-like**” structure extending over $\Delta\eta$ at $\Delta\phi \sim 0$

(not observed before in hadron collisions or MC models)

Charged hadron - photon correlations

(photons are mostly from π^0 decay)

1.0GeV/c<p_T<3.0GeV/c
for both hadrons and photons

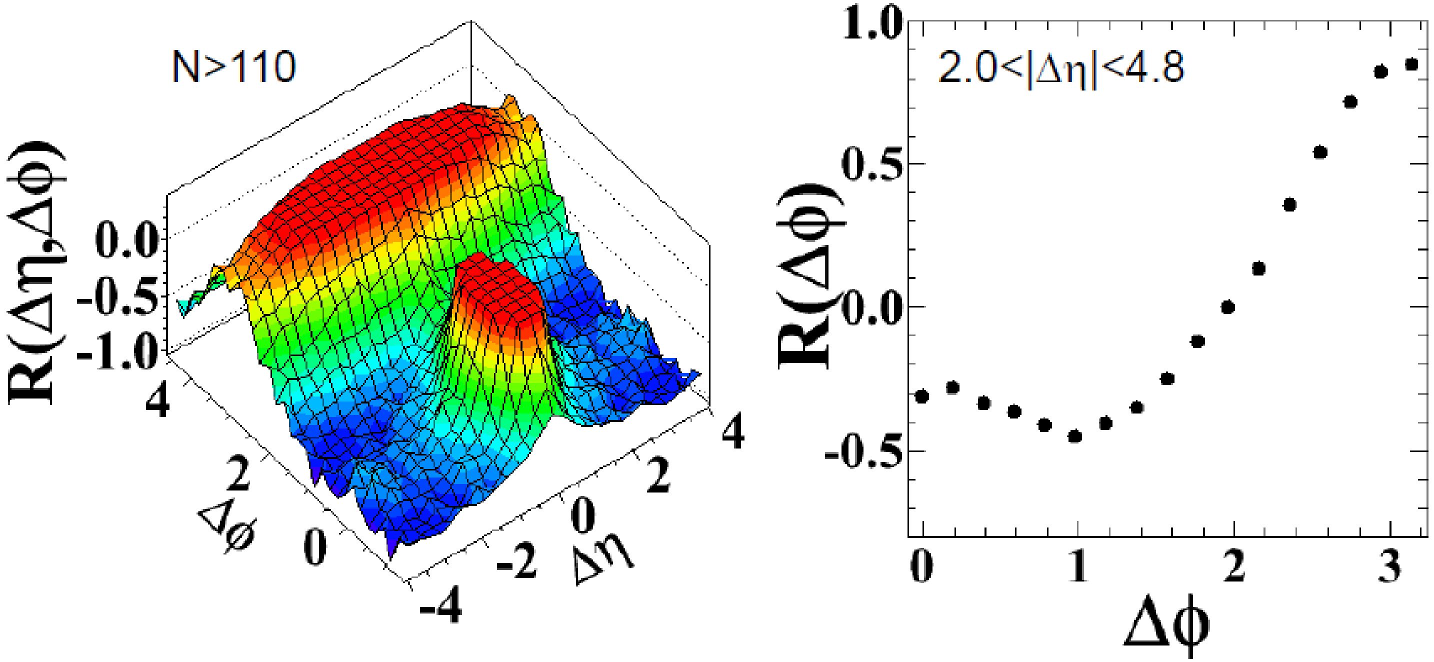


Independent detector, independent reconstruction!

photon - photon correlations

(photons are mostly from π^0 decay)

$1.0\mathrm{GeV}/c < p_T < 3.0\mathrm{GeV}/c$



Independent detector, independent reconstruction!

Prediction, postdictions, comments for pp at LHC:

- CERN presentation: Sept 21, 2010
- 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’.

If long range rapidity correlations exist, the correlation must be formed at

proper time earlier than:

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

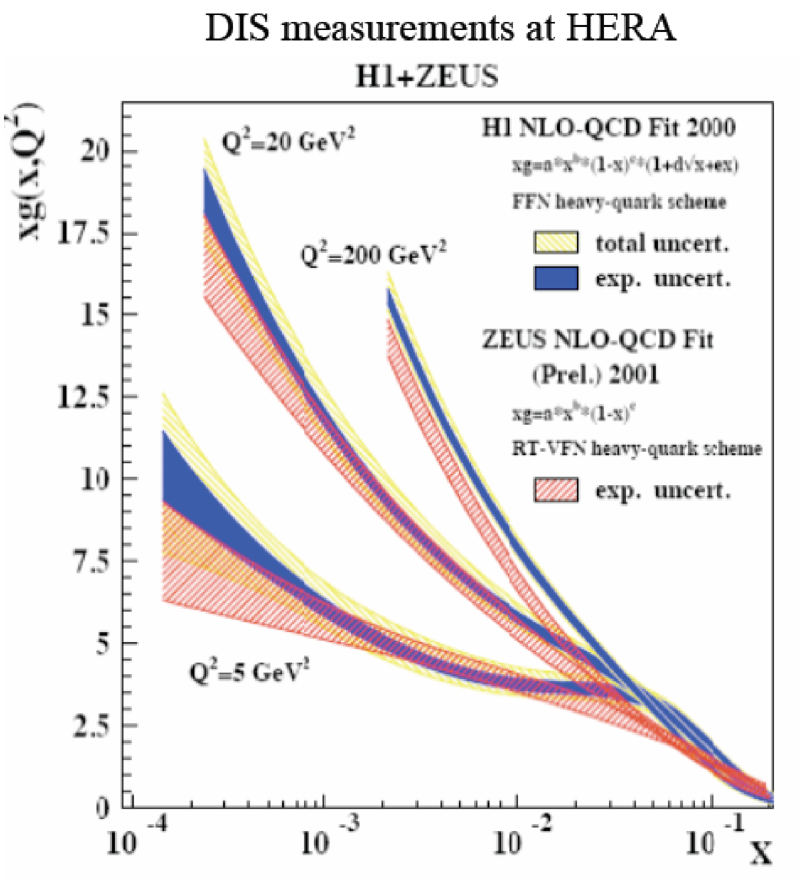
Color Glass Condensate:

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

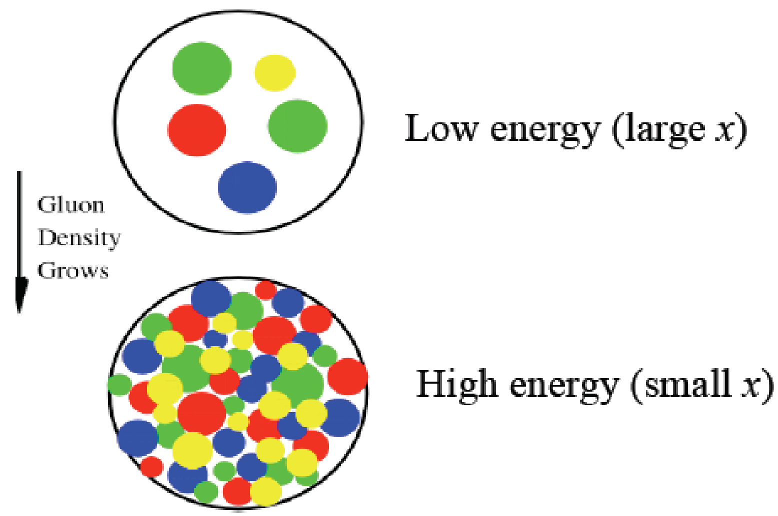
At RHIC typical value of x ~ 10^{-2}
At LHC ~10^{-4}
At such small x – the gluon density in a proton (or a nucleus) becomes large

→ gluon saturation

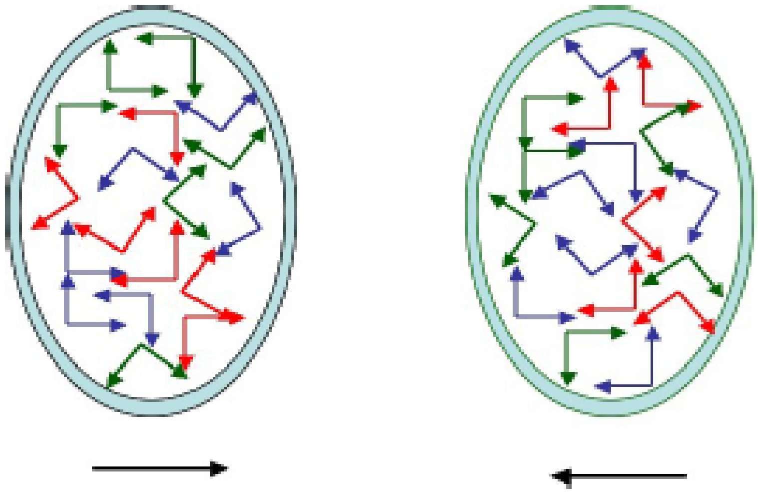
What do we know about saturation:



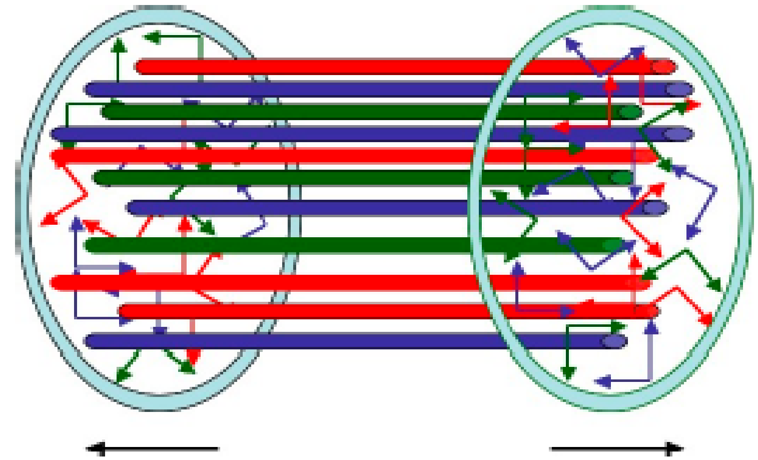
Small-x rise of $xg(x)$: saturation of the gluon density



High Energy Collisions:



Explicit realization of Bjorken space-time picture

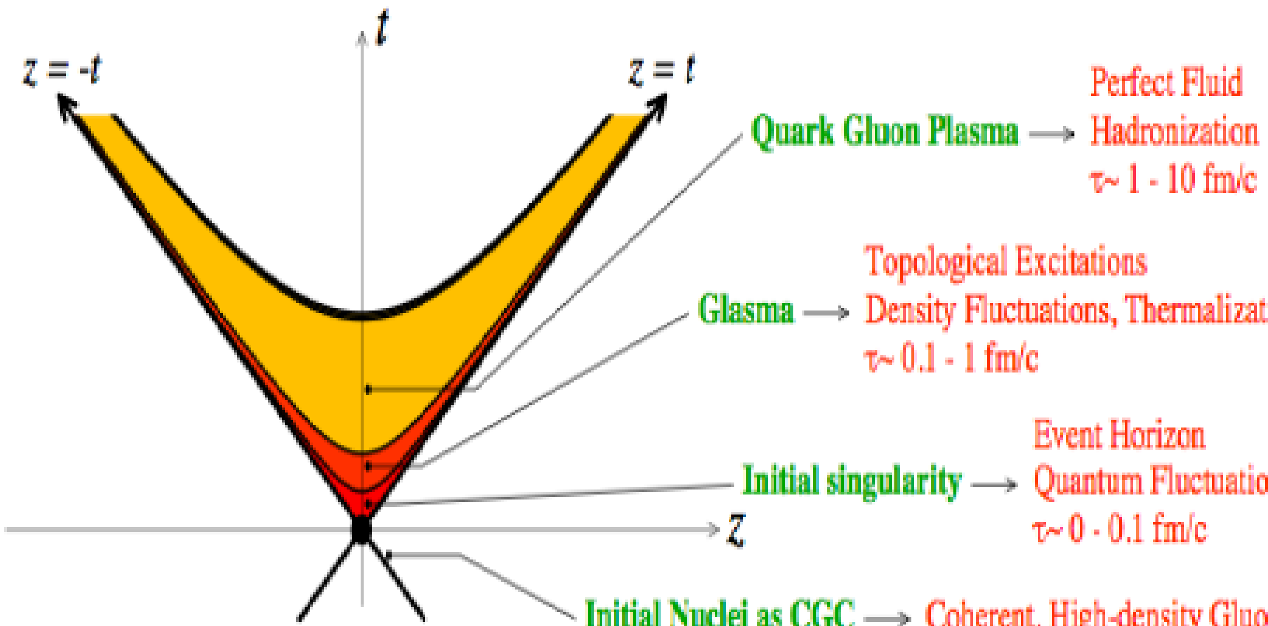


“Instantaneously” develop longitudinal color E and B fields

Two sheets of colored glass collide

Glass melts into gluons and thermalize

QGP is made which expands into a mixed phase of QGP and hadrons



Dumitru et al. perform calculations – and roughly describe the ridge as observed in CMS pp – 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’))

P.Bożek on Oct 3:

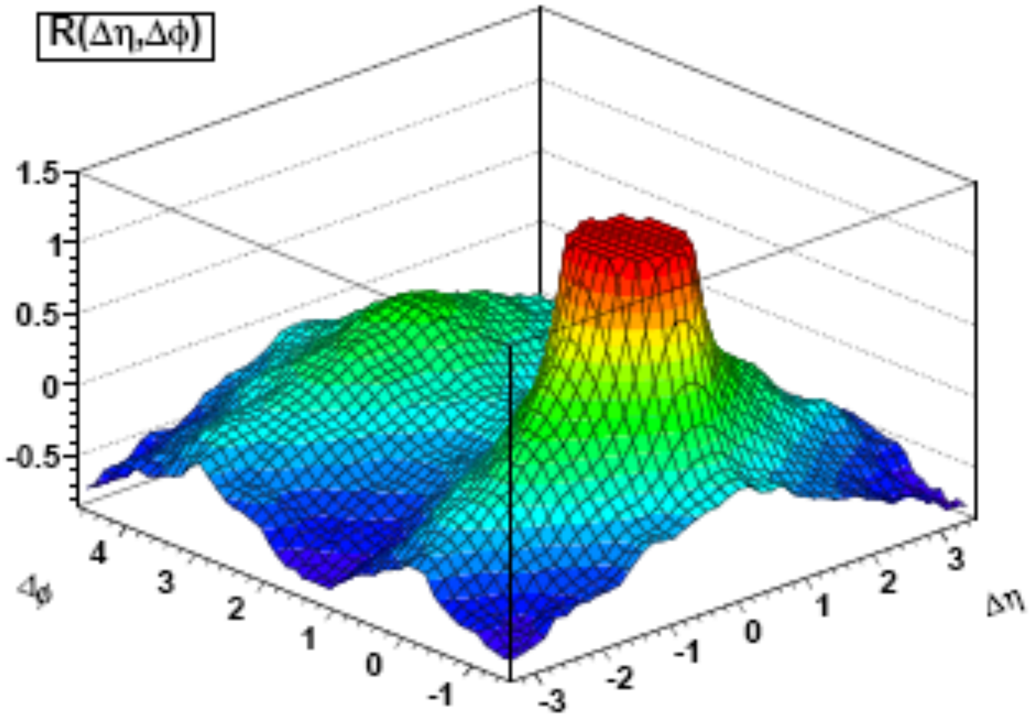
‘the collective flow/hydrodynamics explains everything’,

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

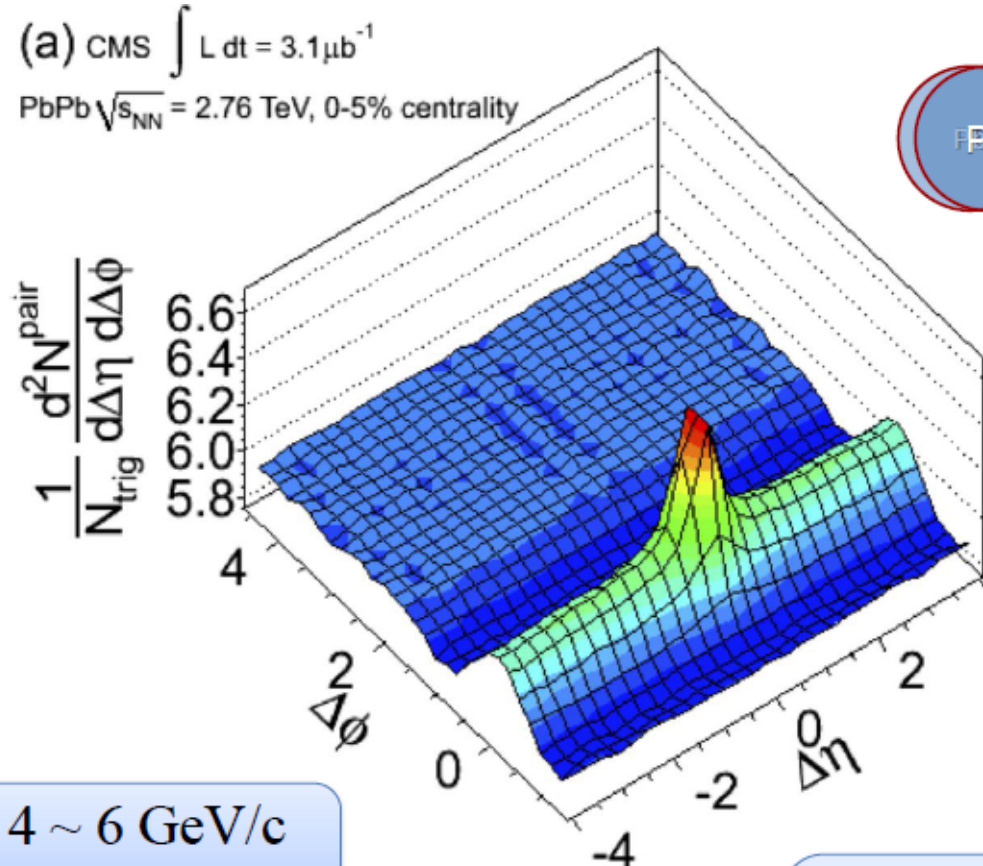
K.Werner, Yu.Karpenko, T.Pierog, arXiV., Nov 1

Flux tubes plus hydro

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



Now for the Pb Pb at 2.76 TeV/N:



0-5% most central

arXiv:1105.2438

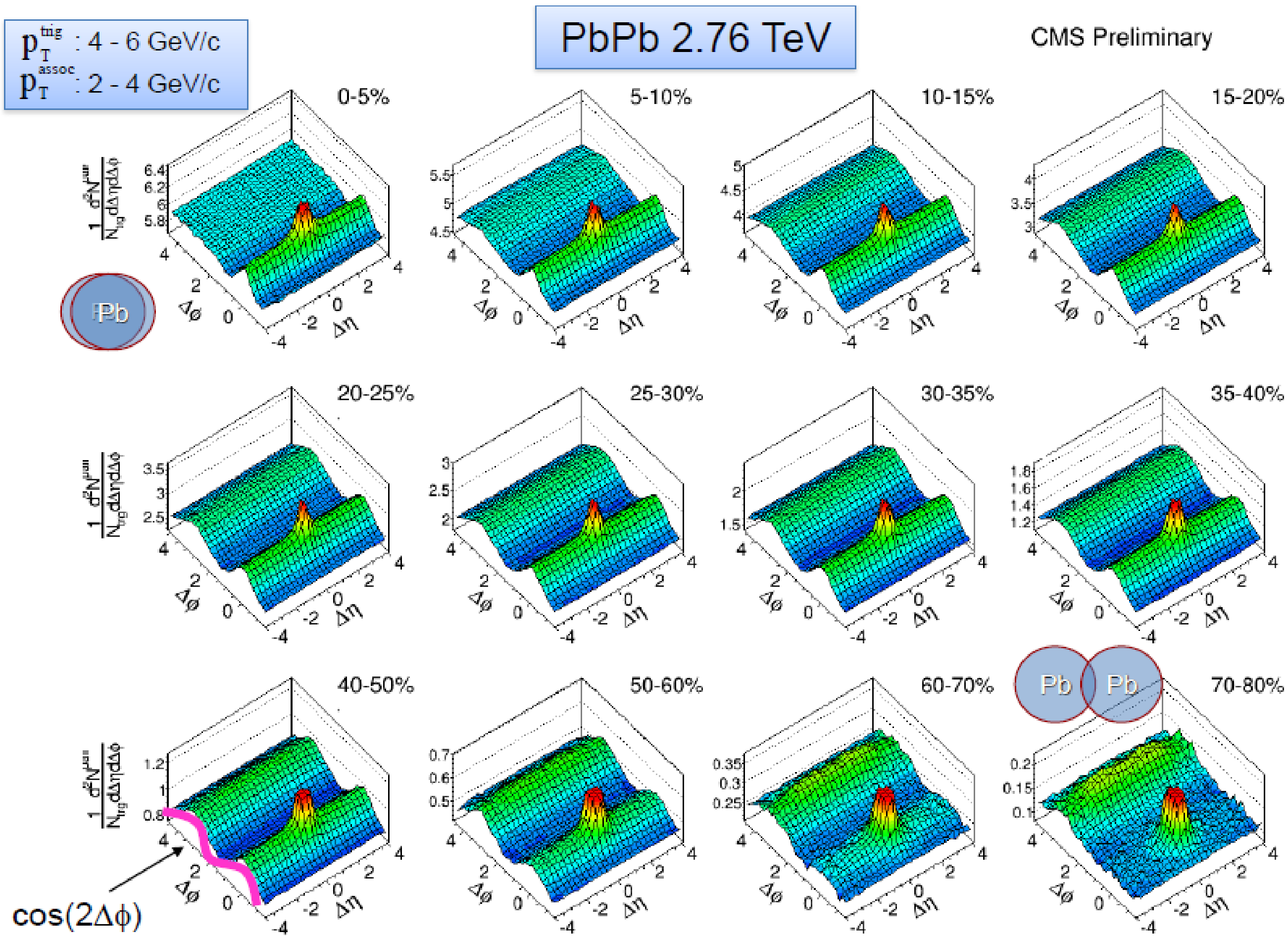
p_T^{trig} : 4 ~ 6 GeV/c

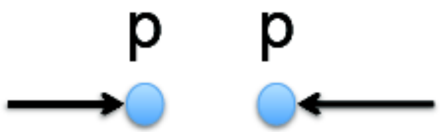
p_T^{assoc} : 2 ~ 4 GeV/c

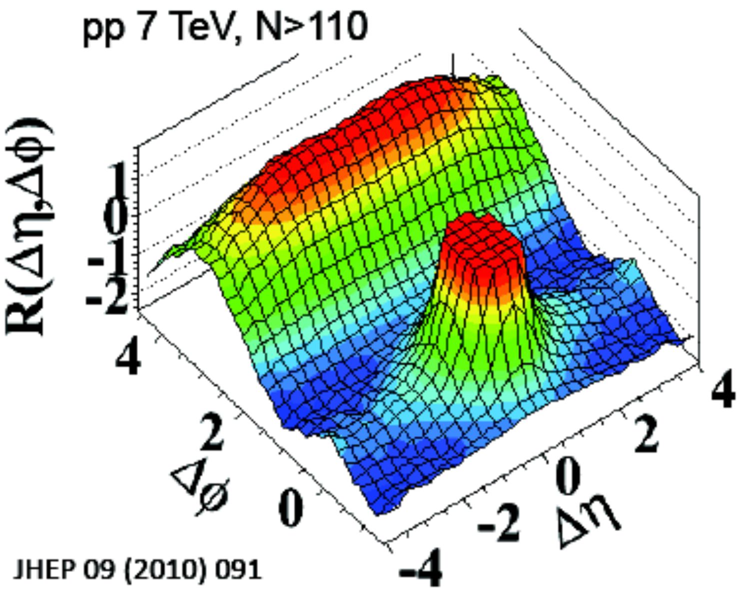
Associated hadron yield per trigger:

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

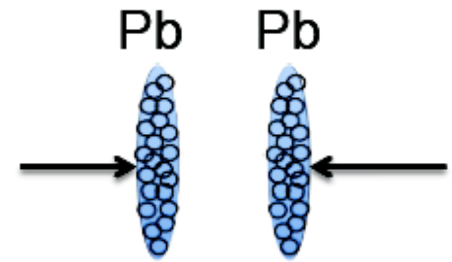
Centrality evolution:

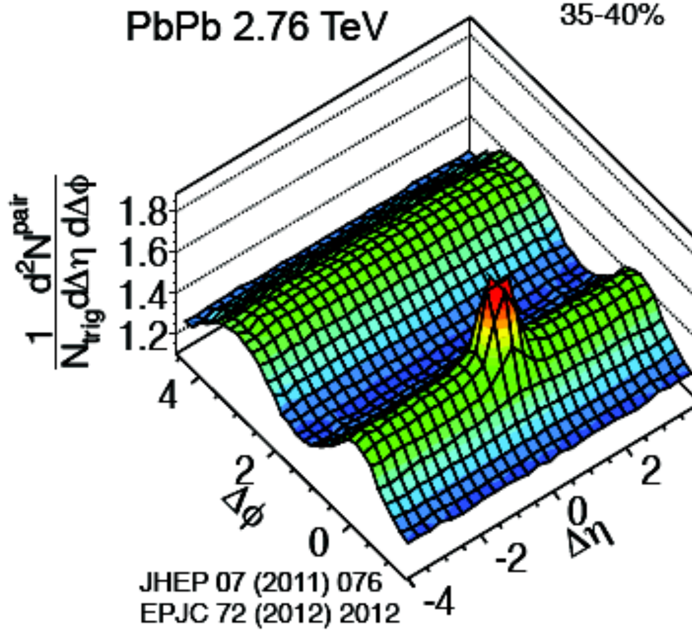






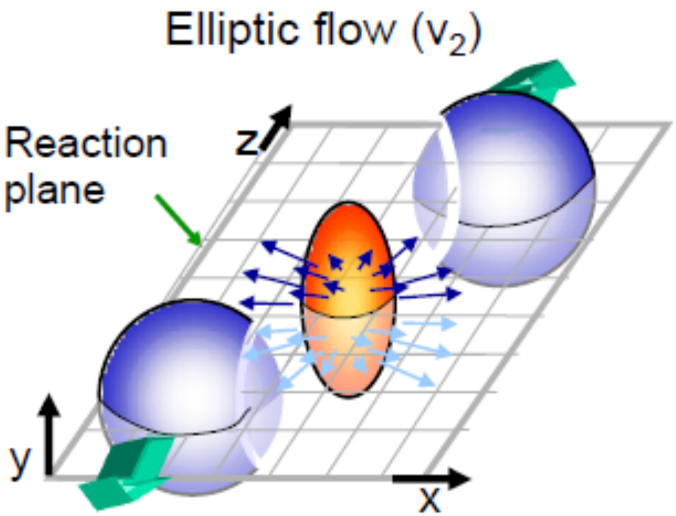
JHEP 09 (2010) 091





JHEP 07 (2011) 076
EPJC 72 (2012) 2012

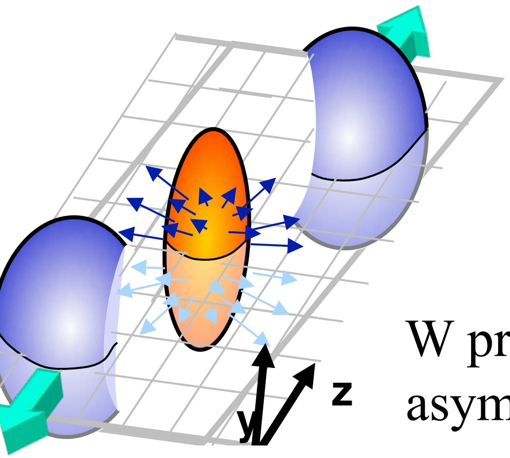
New approach: Fourier analysis of azimuthal correlations (recall Bożek…)



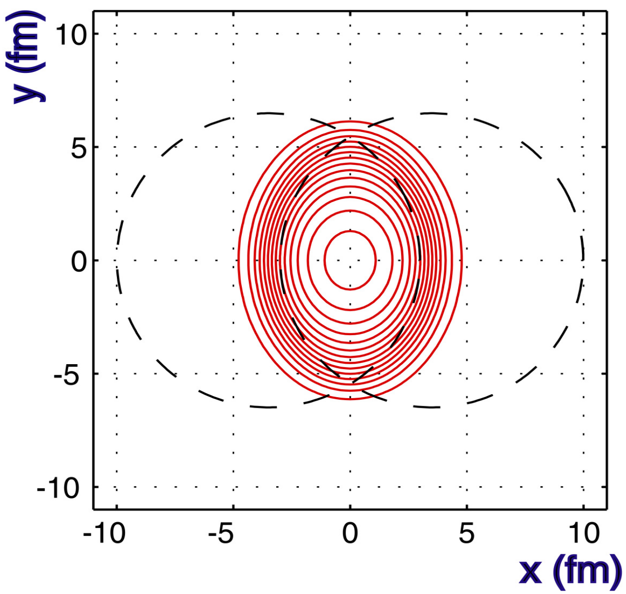
`Standard azimuthal asymmetry in nucler collisions: elliptic flow as a consequence of collective (hydro) behaviour

Large elliptic flow interpreted as evidence for low viscosity, almost perfect fluid

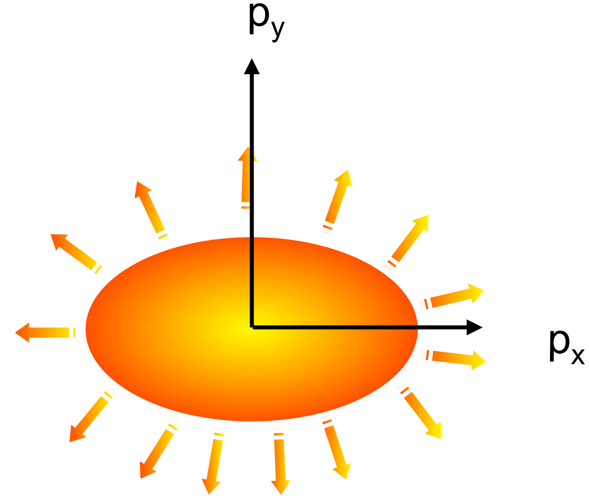
Symmetries of measured momentum distributions reflect the symmetries of event-averaged initial conditions



W przestrzeni położeń asymetria



W przestrzeni pędów – też asymetria



Jak się mierzy ‘elliptic flow’:

Trzeba wyznaczyć płaszczyznę reakcji: intuicyjnie proste, ‘płaszczyzna wyznaczona przez wszystkie wyprodukowane cząstki’, prostopadle do wiązki pierwotnej

Wyznaczyć tę płaszczyznę dla każdego przypadku :Ψ

A dalej – zrobić rozkład kąta między pędem danej cząstki a wektorem płaszczyzny reakcji,

i rozwinąć go w szereg Fouriera

współczynnik przy cos 2(ϕ - Ψ) to właśnie v_2 czyli ‘elliptic flow’

Skoro mamy dużą gęstość energii to możliwa ‘szybka termalizacja’

Wtedy duży gradient ciśnienia

Dla p_t < ~2-3 GeV/c dobry opis

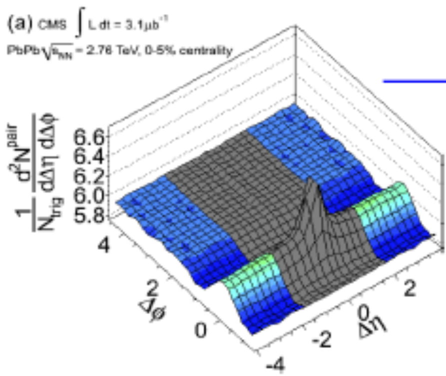
hydrodynamiczny

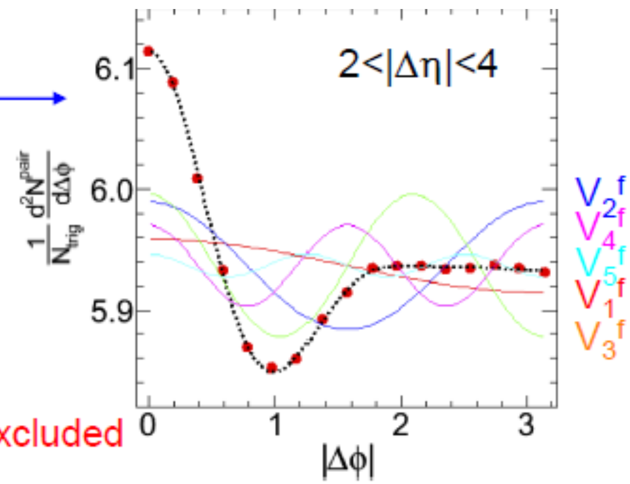
M.Luzum at QM11:
Event by event fluctuations break the apparent symmetry of the collision system – higher order odd **and even** harmonics may be important

Thus – the need for more terms in Fourier expansion of azimuthal distribution

Study Fourier expansion of pair distribution

Fourier decomposition: $$\frac{1}{N_{trig}}\frac{dN^{pair}}{d\Delta\phi} = \frac{N_{assoc}}{2\pi}(1+2\sum_{n=1} V_n^f \cos(n\Delta\phi))$$





Flow driven correlations:

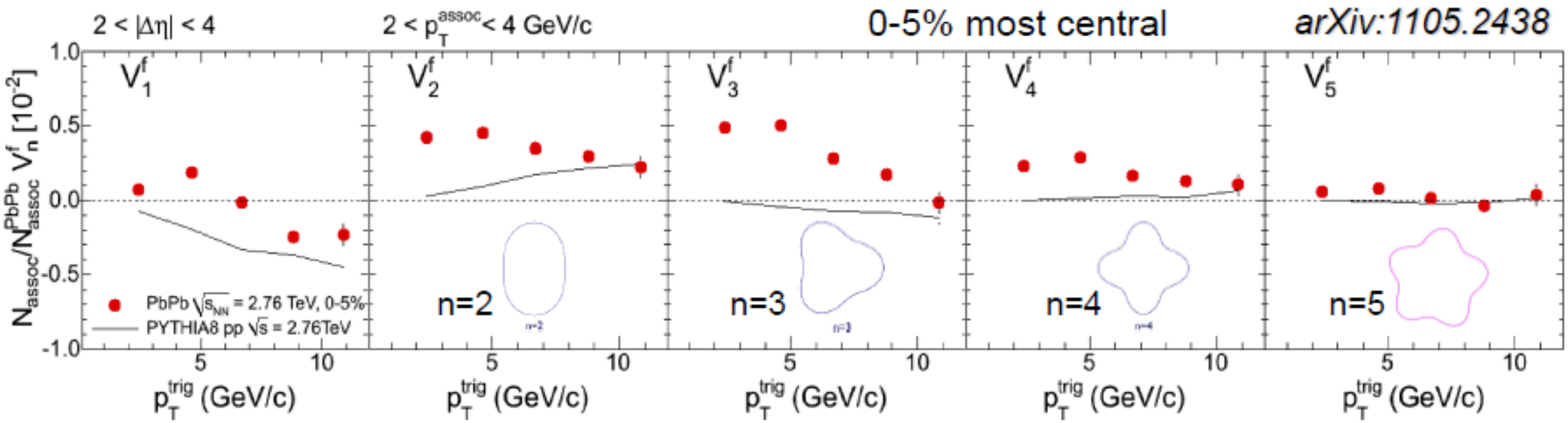
$$V_n^f = v_n^f(p_T^{trig}) \times v_n^f(p_T^{assoc})$$

(f: Fourier analysis of long-range dihadron correlations)

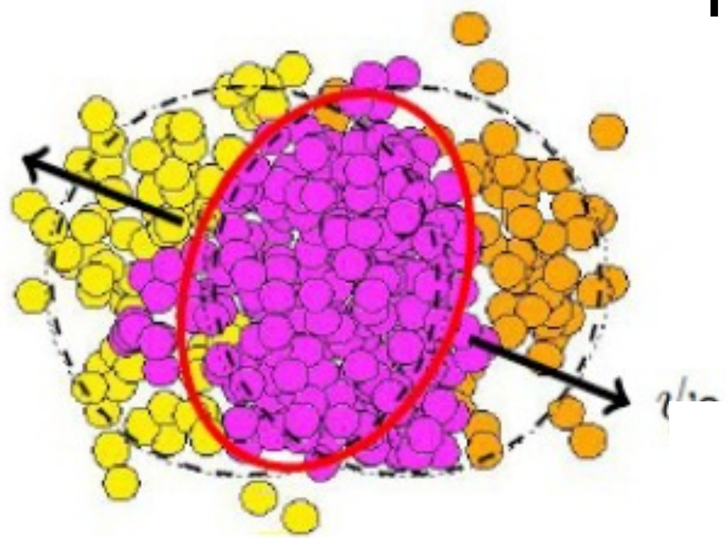
Short-range non-flow effects excluded

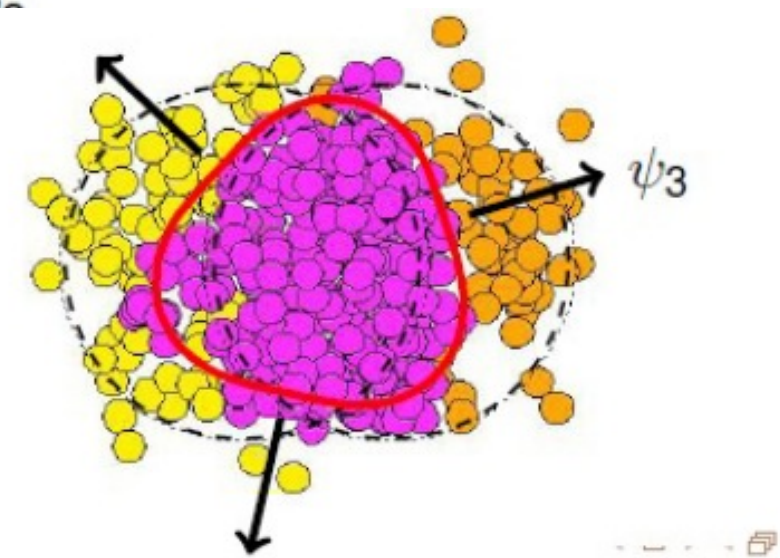
0-5% most central

arXiv:1105.2438



Initial state fluctuations:





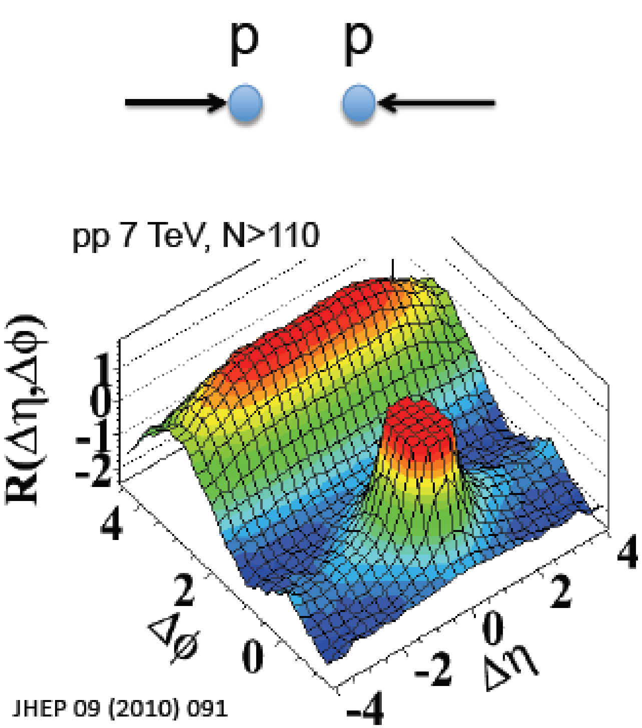
Perhaps the Ridge is just the result of this interplay between fluctuations in the initial state and viscosity of the hot, dense medium

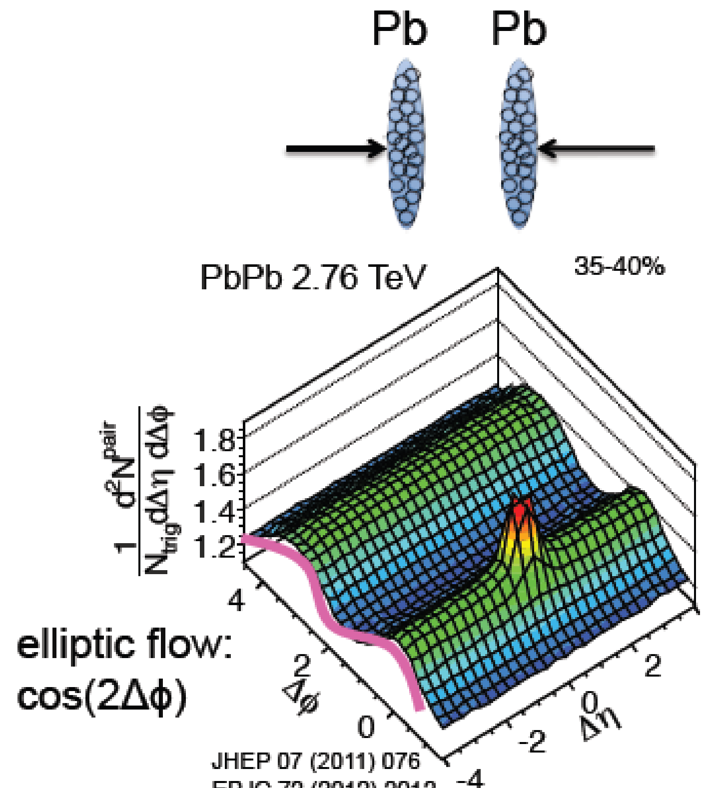
(very lively discussions on the above…)

Fluctuations in the position of individual nucleons

→ hydrodynamic expansion → higher order harmonics

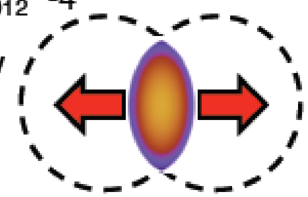
So – where are we now:



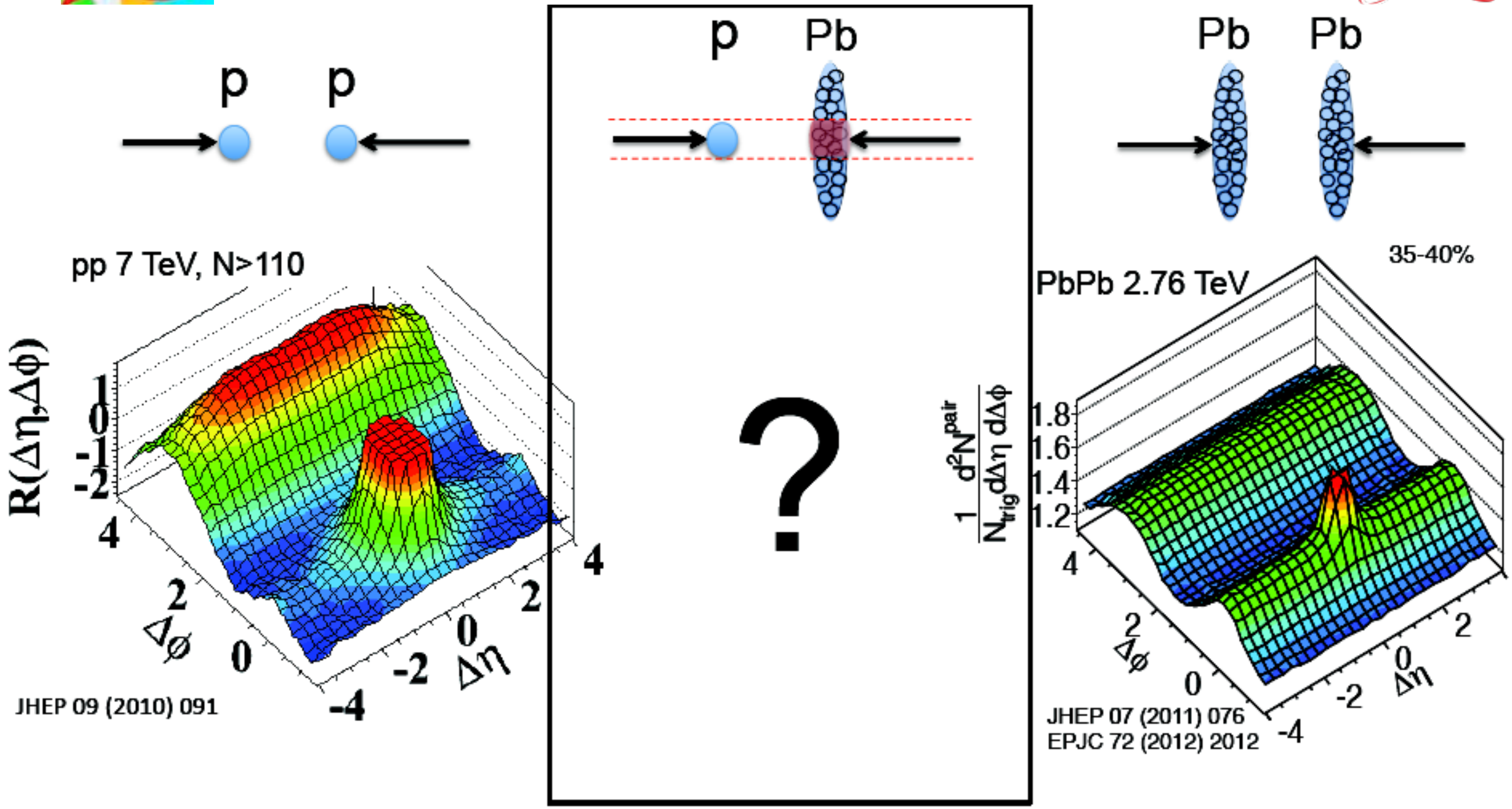


Physical origin of pp ridge is still not completely clear

Initial-state geometry
+
collective expansion



"Smoking gun" of a strongly interacting QGP liquid!

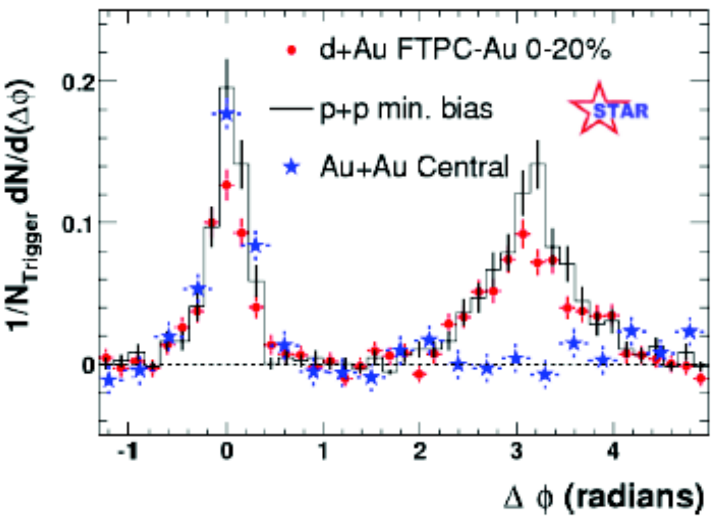


What if colliding a proton and a nucleus?

Is there a ridge and how big is it?

Why studying pA collisions?

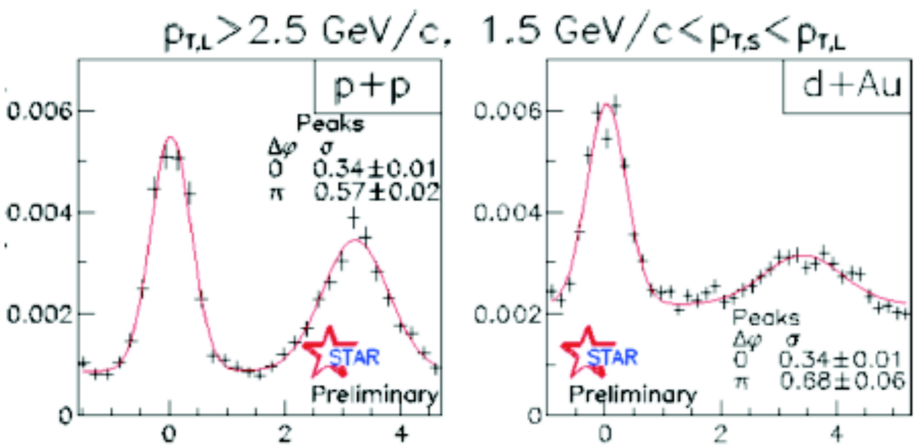
- Reference for nucleus-nucleus collisions: to address the issue of cold nuclear matter effects



Observation of jet quenching in AuAu but not in pp or dAu

➔Final-state effect

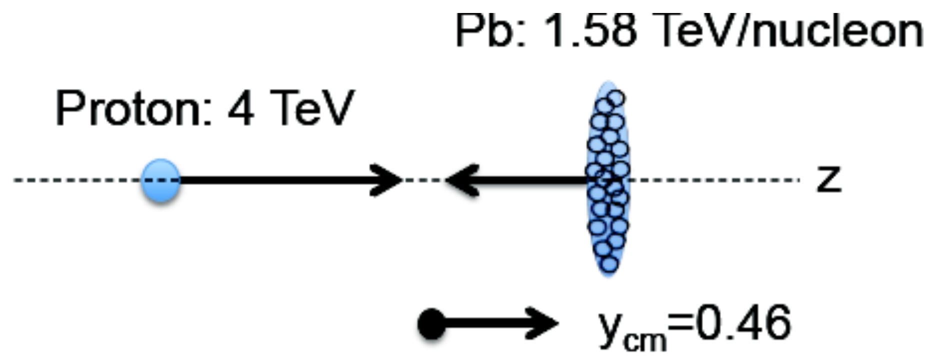
- Probe nucleus structure at extremely small-x regime



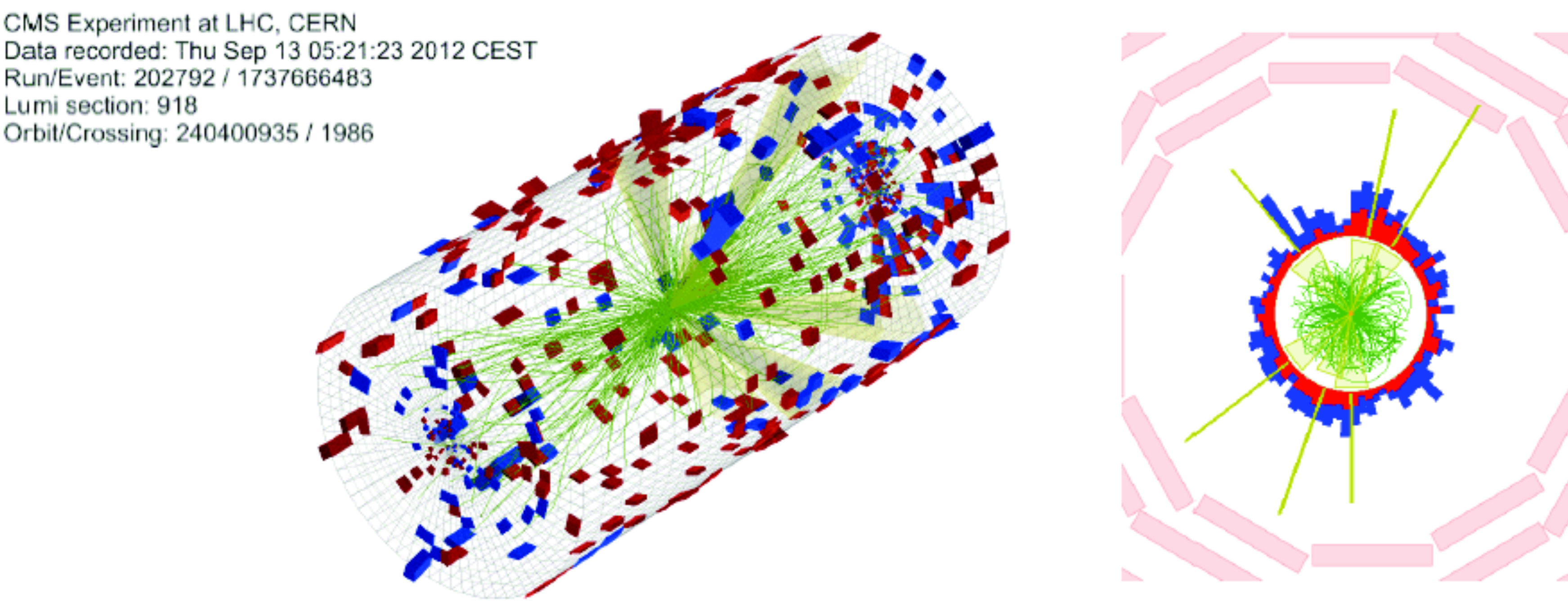
Modification of away side In dAu at forward rapidity

➔Saturation of small-x gluons?

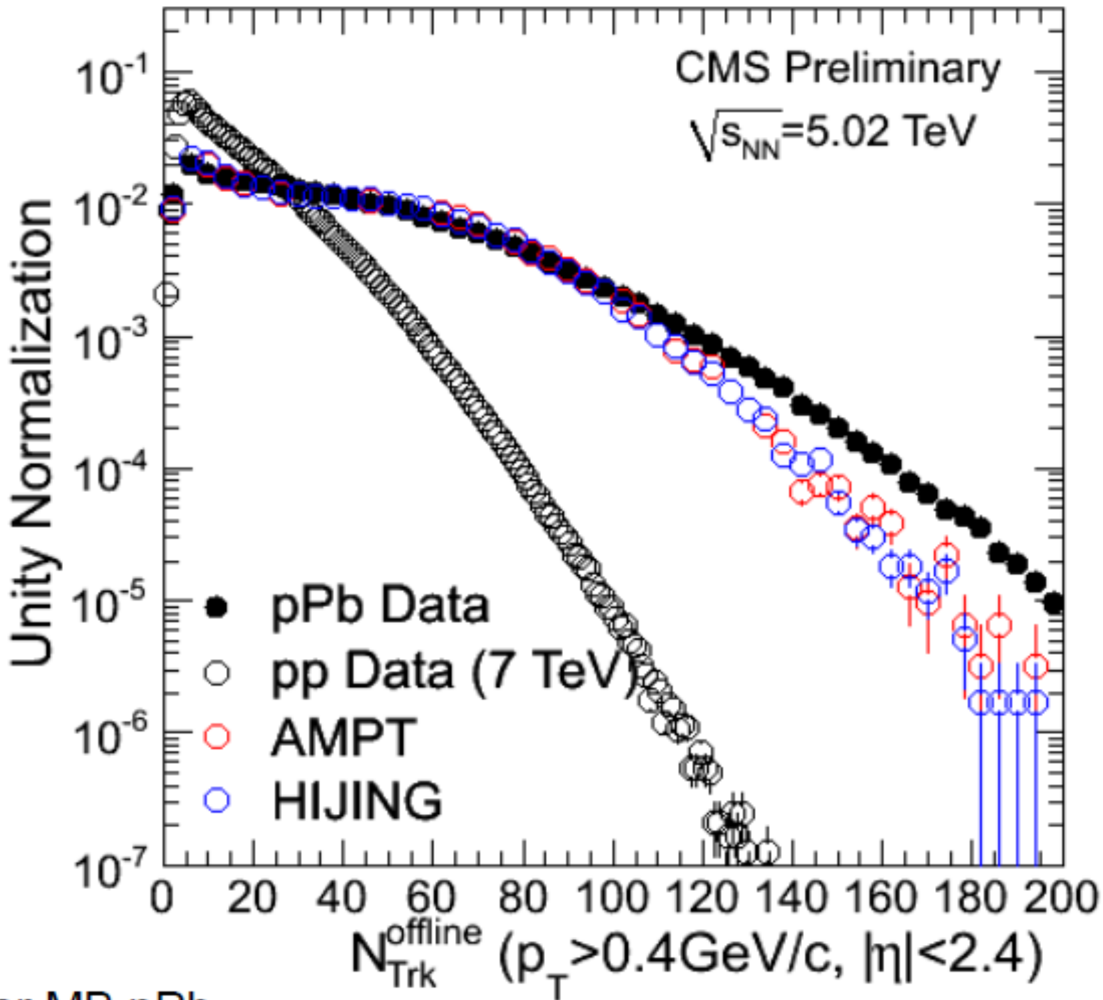
pPb pilot run at the LHC on September 13, for ~ 8 hours



Center-of-mass energy: $\sqrt{s_{NN}}$ = 5.02 TeV

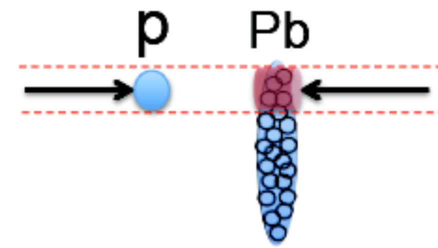


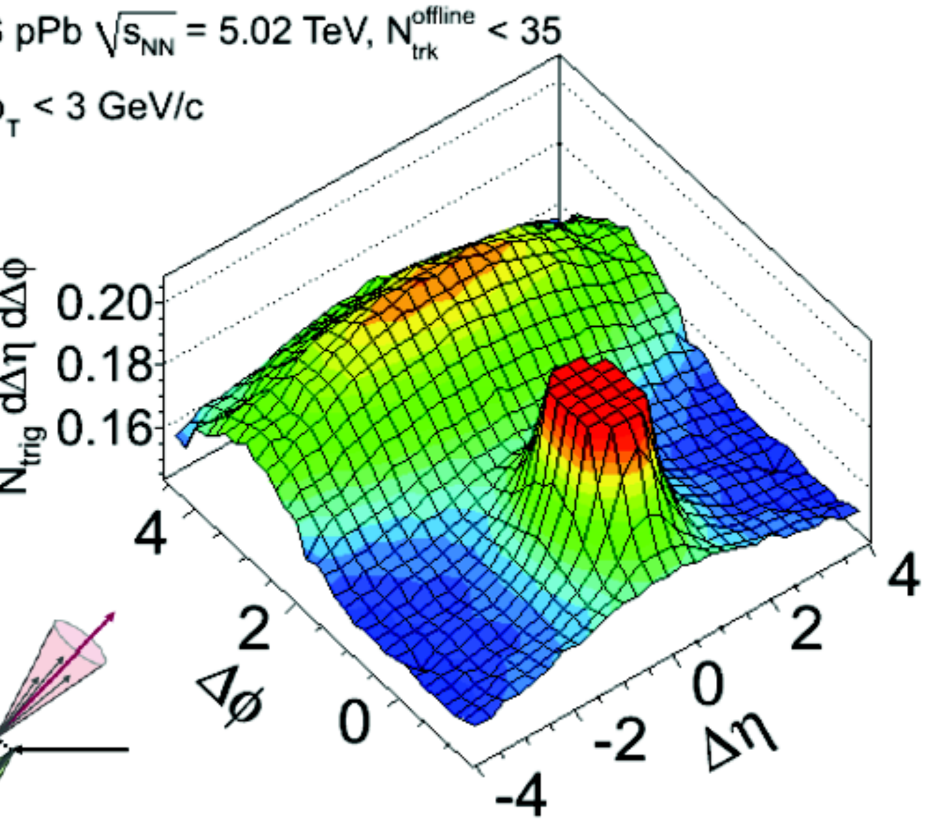
~ 2 million minimum bias pPb events were collected (1 μb^{-1})

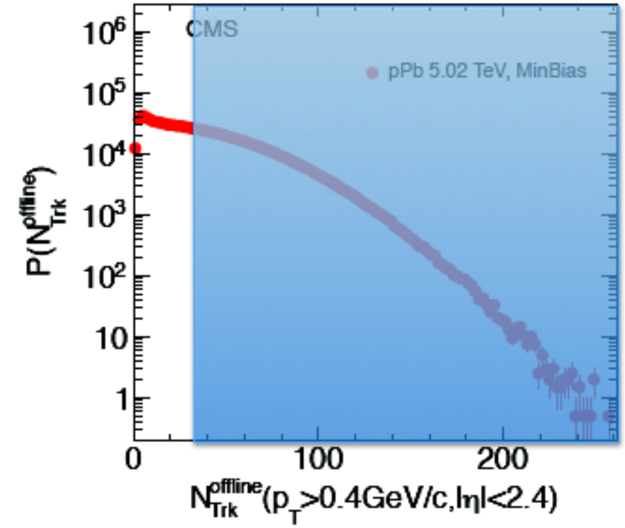


$\langle N_{trk}^{offline} \rangle$~40 for MB pPb

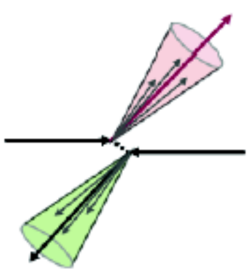
$N_{trk}^{offline} < 35$





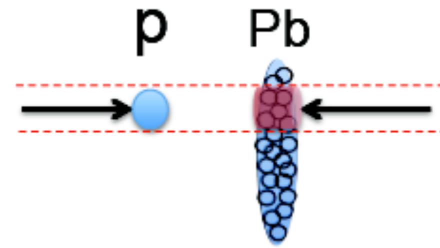


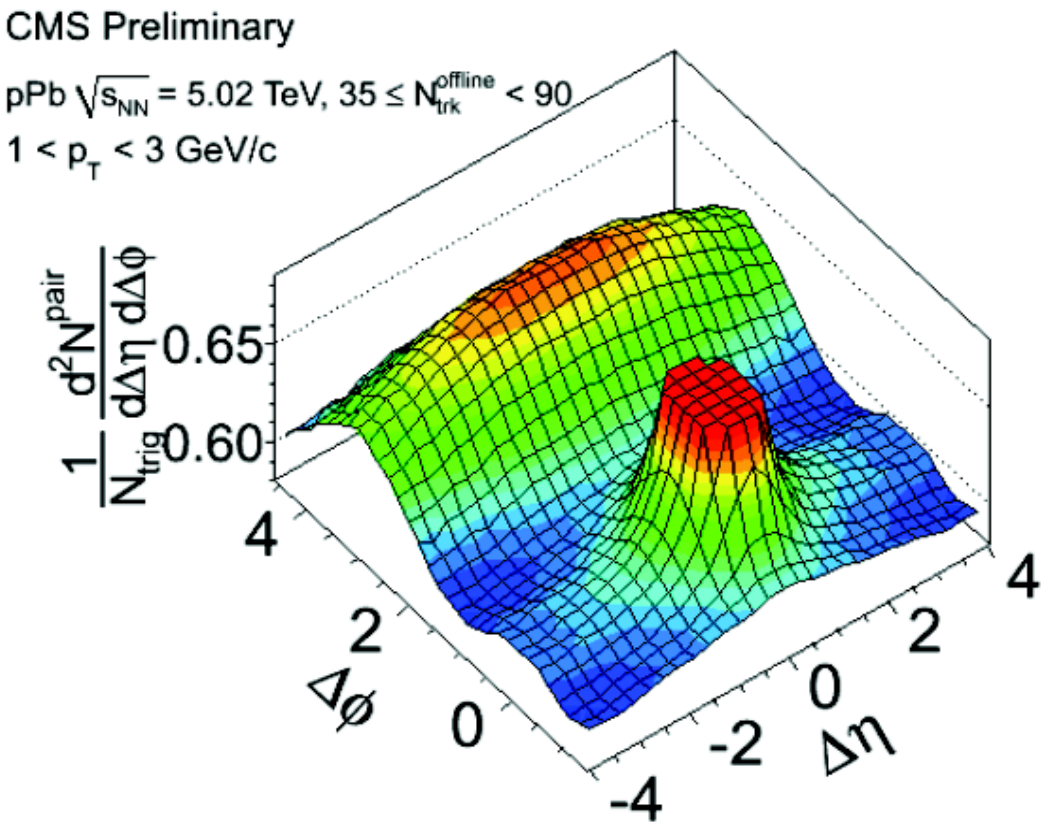
Fraction of cross section: 50.4%

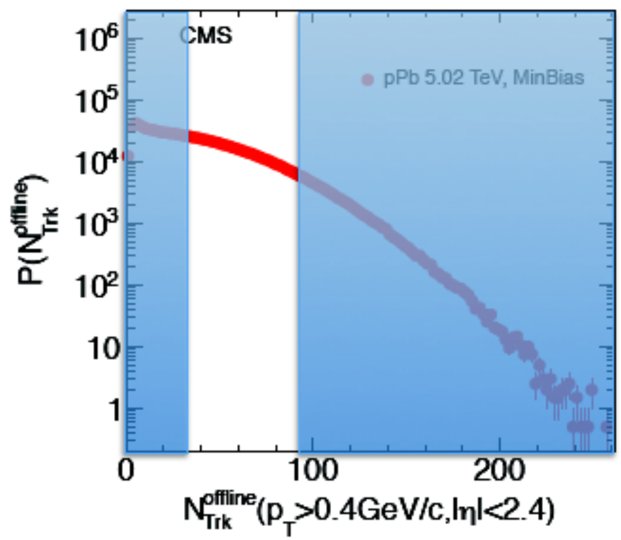


Dijet-like correlations in low multiplicity (or peripheral) pPb!

$35 \leq N_{trk}^{offline} < 90$



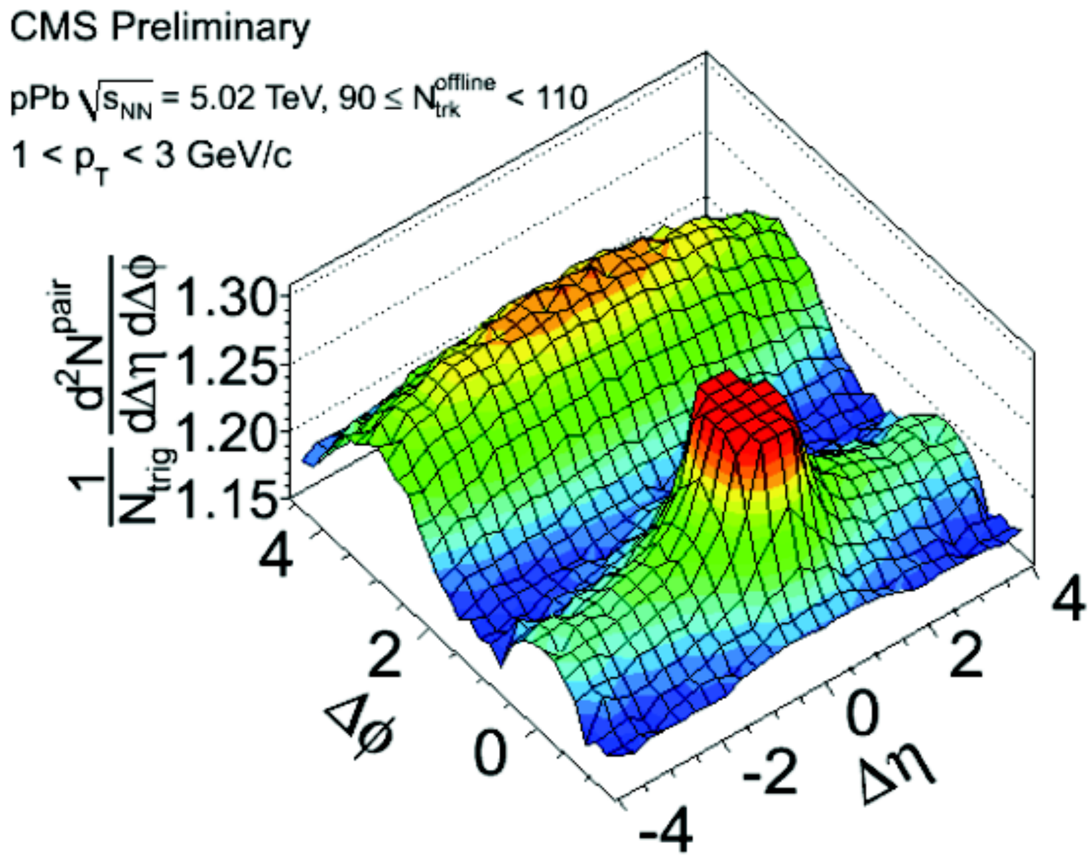


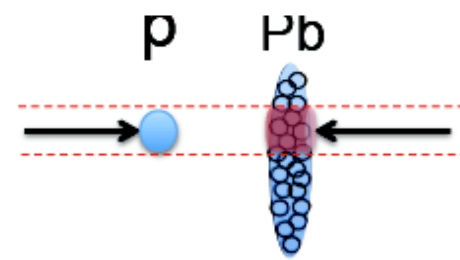


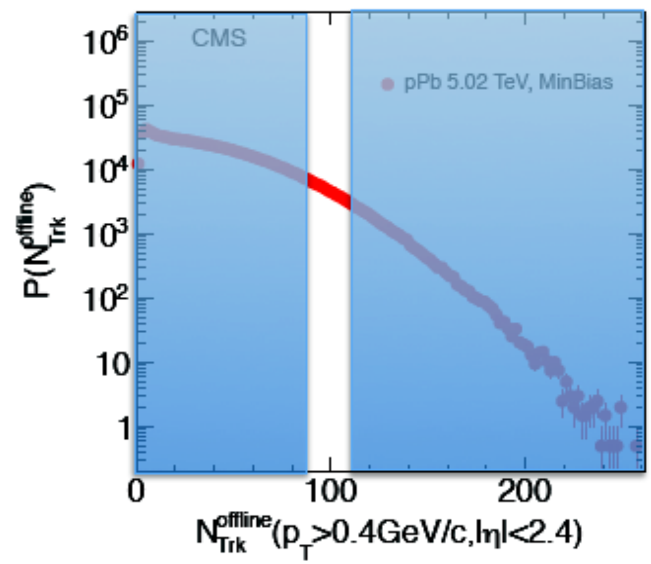
Fraction of cross section: 41.9%

Ridge-like structure on the near side ($\Delta\phi$~0) turns on as multiplicity increases

$90 \leq N_{trk}^{offline} < 110$

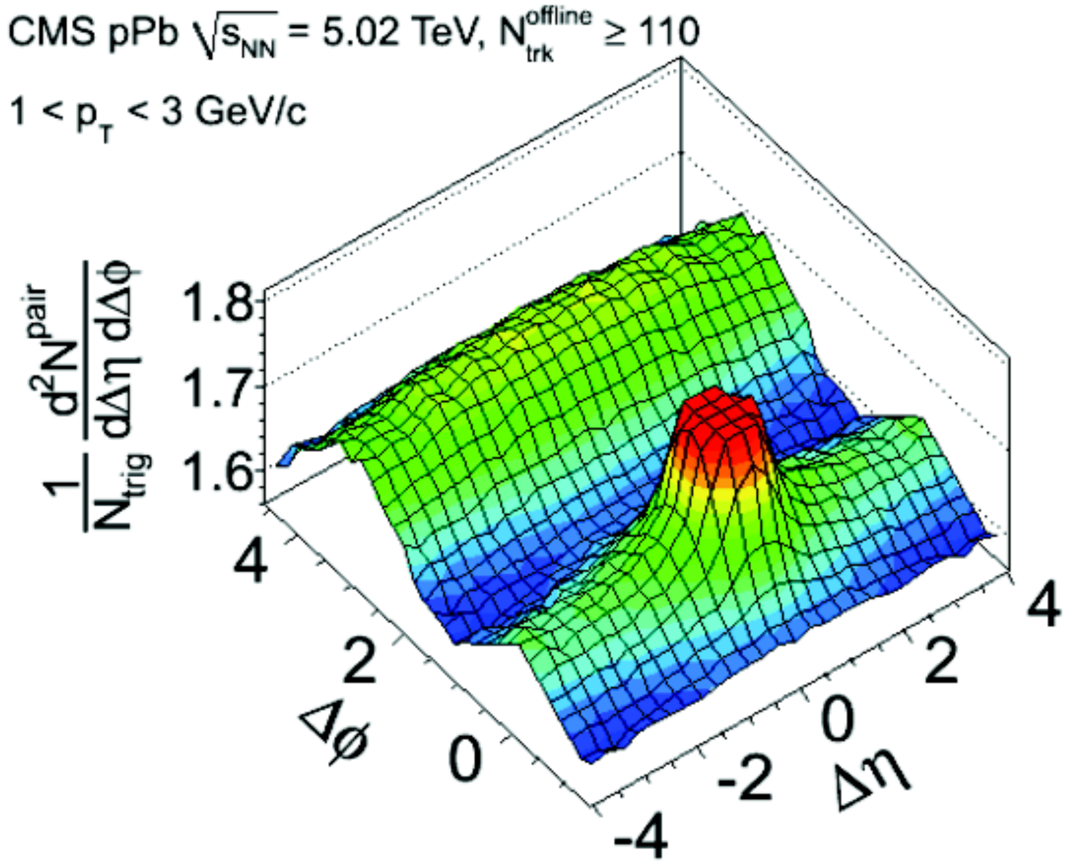


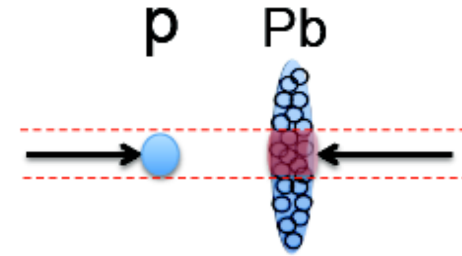


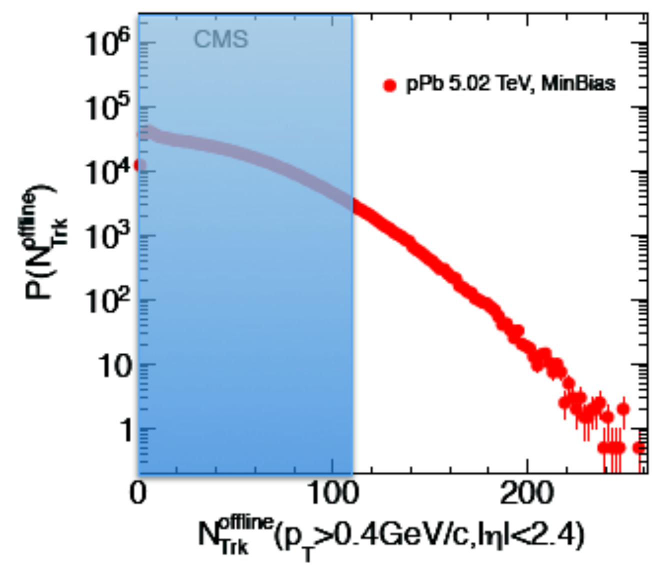


Fraction of cross section: 4.6%

$N_{trk}^{offline} \geq 110$

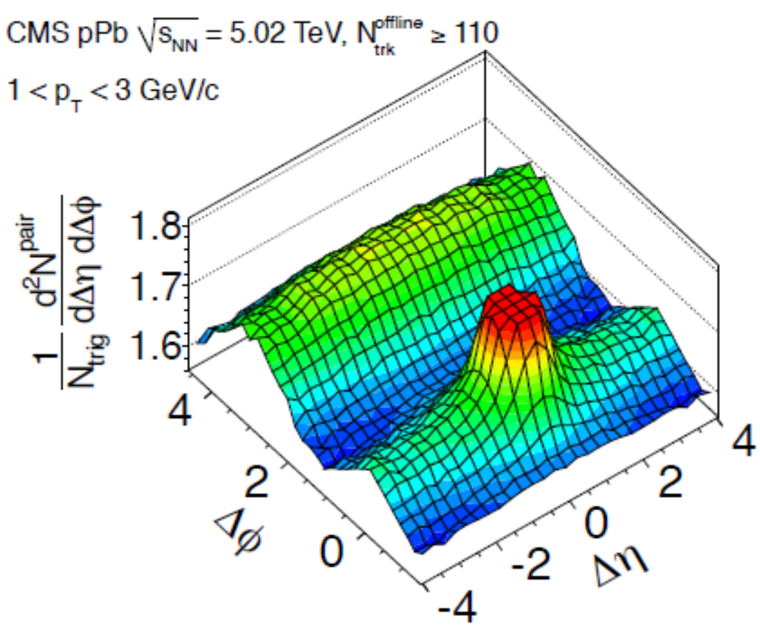




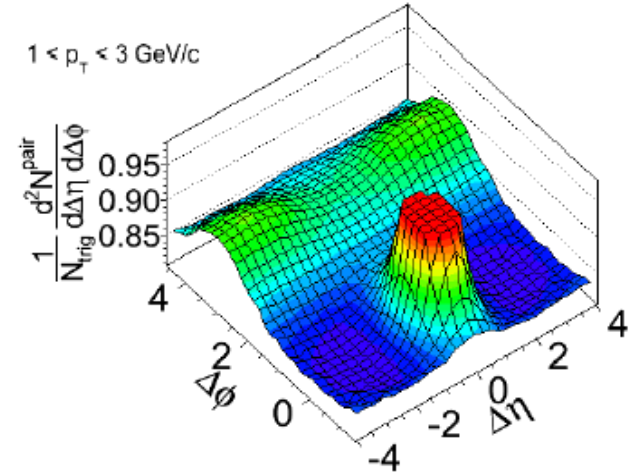


Fraction of cross section: 3.1%

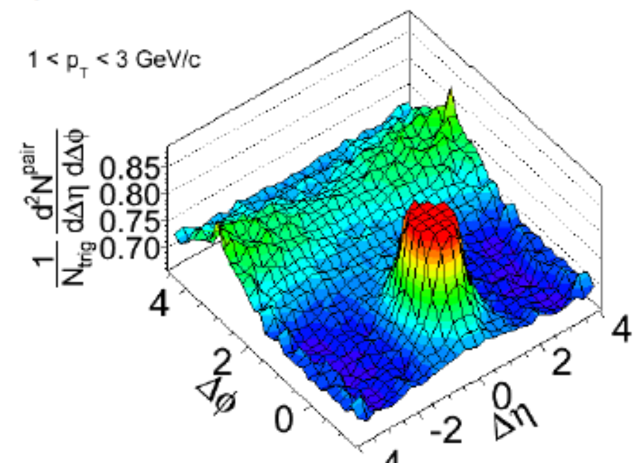
No “ridge” in pPb MC models



pPb HIJING, N>120

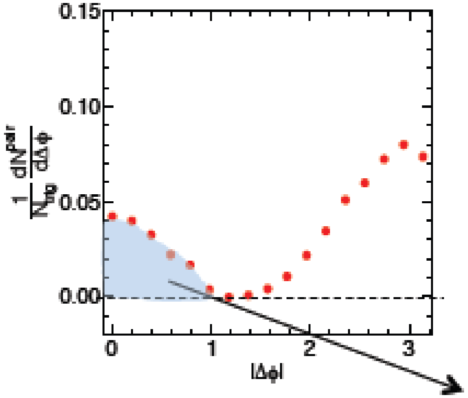


pPb AMPT, N>100

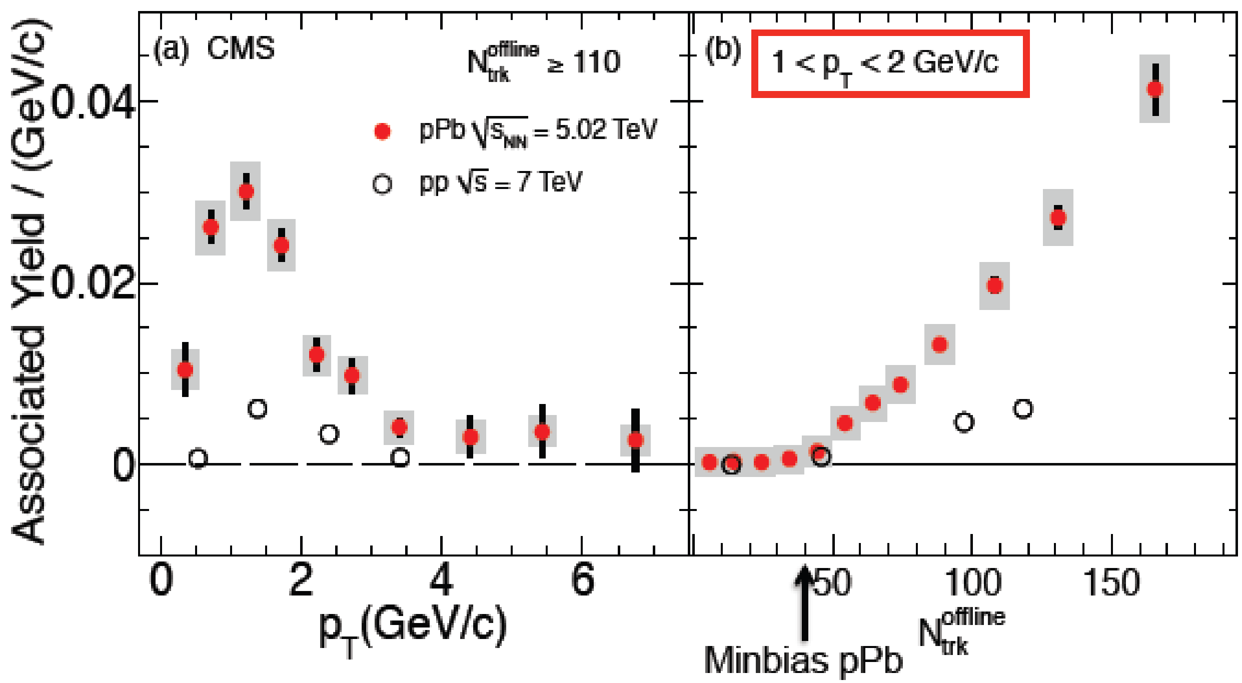


Ridge is not predicted by common pPb MC event generators, as in pp!

Quantify the ridge



PLB718 (2013) 795

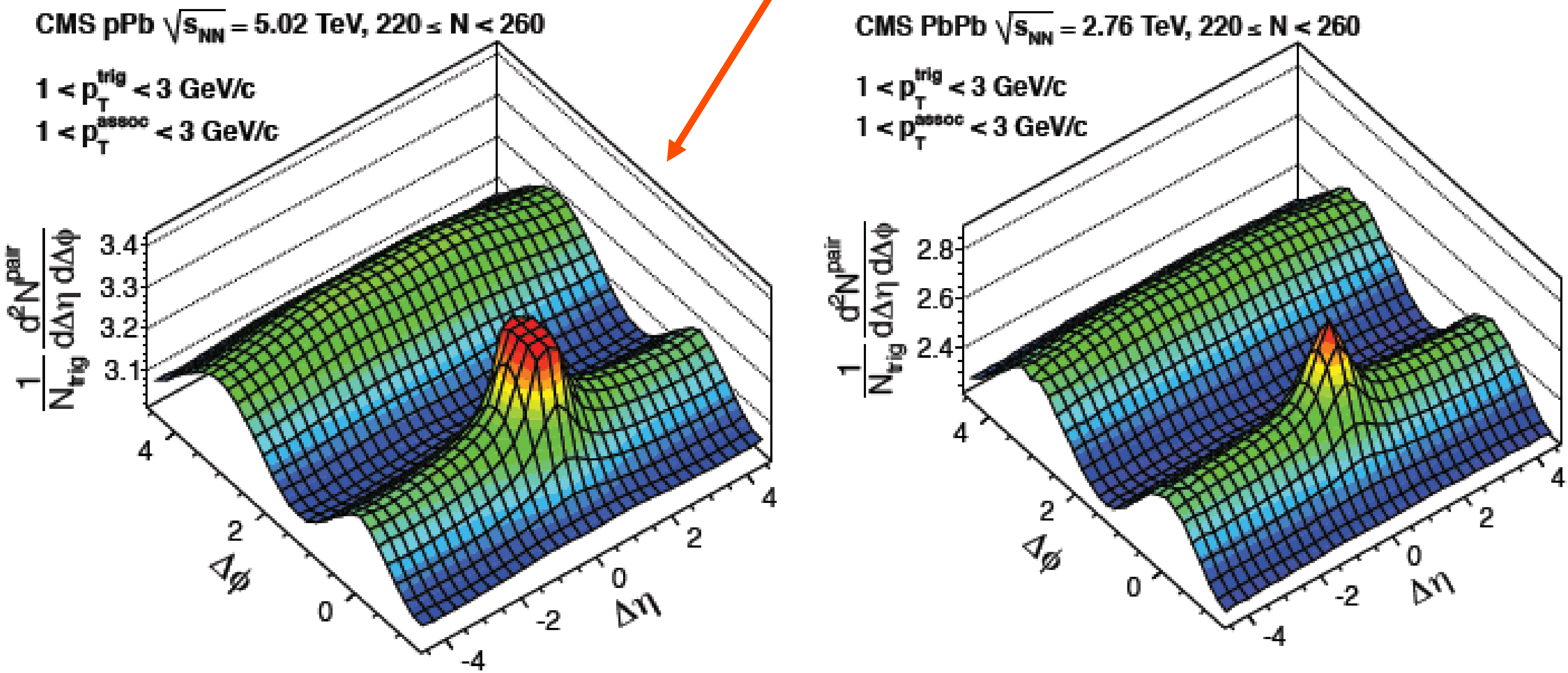


- Magnitude of the ridge is much large in pPb than in pp
- "Rise and Fall" as a function of p_T, similar to pp (even PbPb)!
- Become significant at N=40-50 and linearly increases, similar to pp!

Summary of CMS pPb (as on Oct 2012):

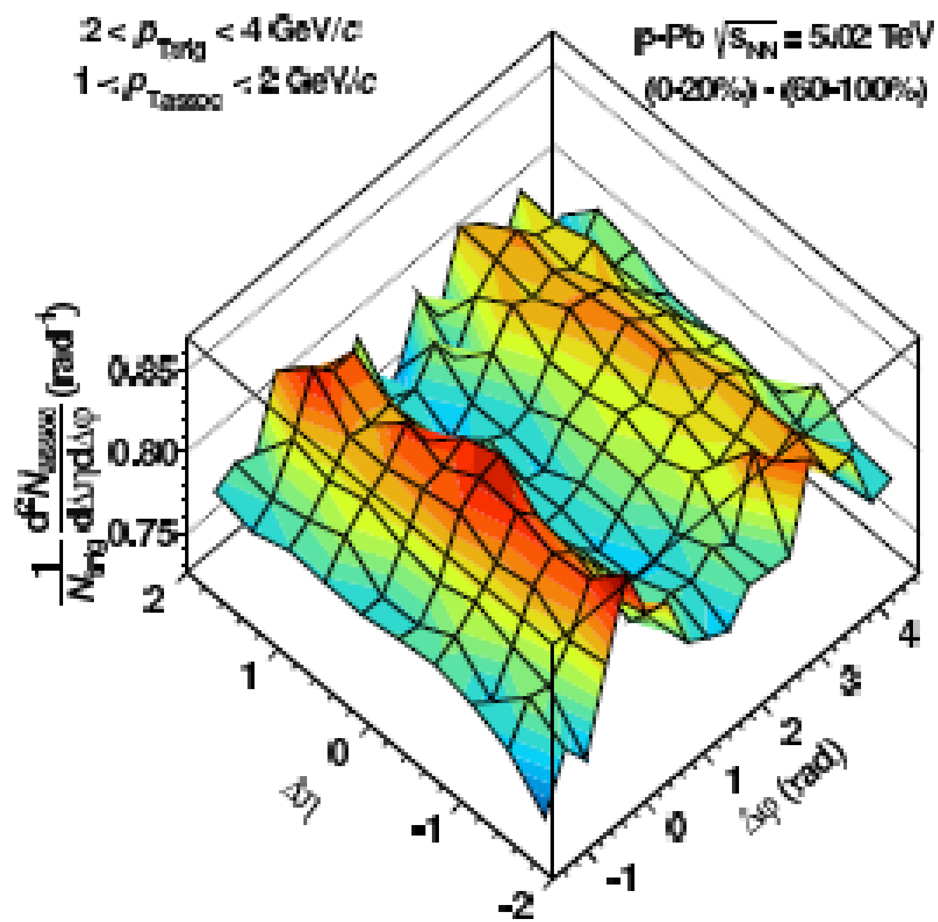
- CMS observed a significant long-range near-side correlation ("ridge") in high multiplicity (central) pPb collisions at 5.02 TeV
  - much stronger than in pp
  - not in common pPb MC models
- Multiplicity and p_T dependence of the ridge in pPb have been investigated:
  - turns on slightly above average minimum bias multiplicity
  - rises and falls with p_T, similar trend as observed in PbPb and pp

After 30nb run of 2013:
(not yet public!)



Rediscover the very strong ridge signal in pPb

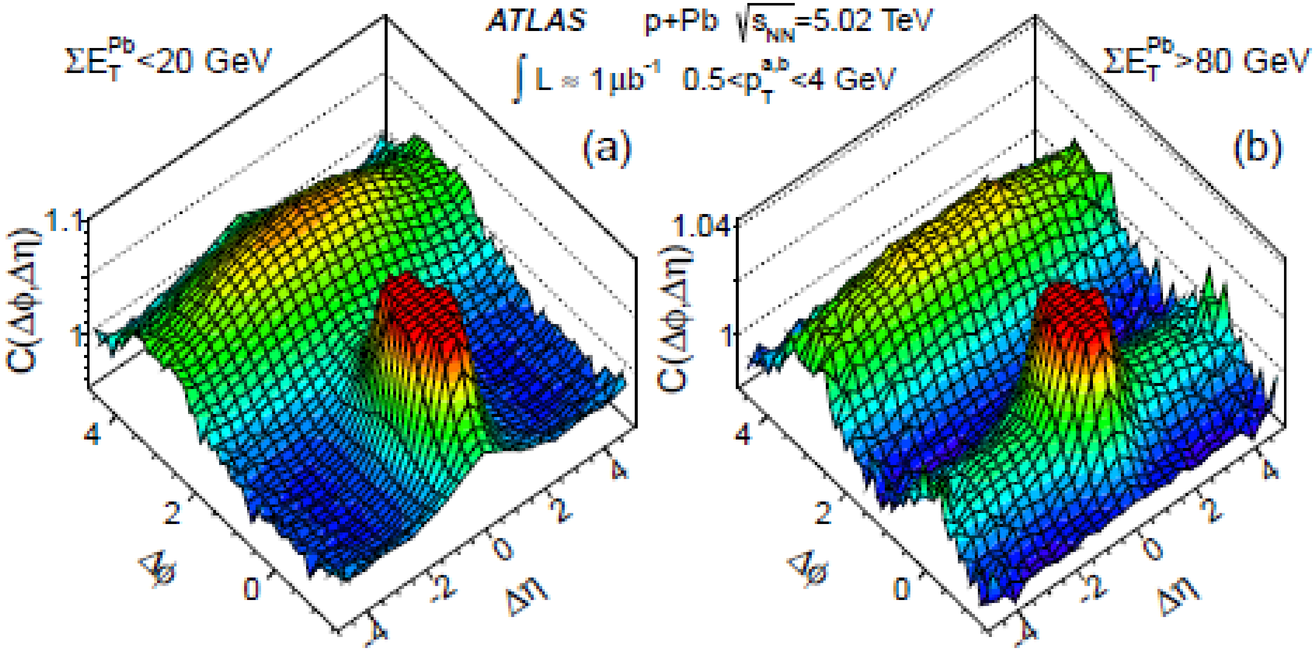
ALICE looks for Ridge in pPb both near and away – and finds it



Notice: this is the difference between `central' and `peripheral'

.25

And so does ATLAS:

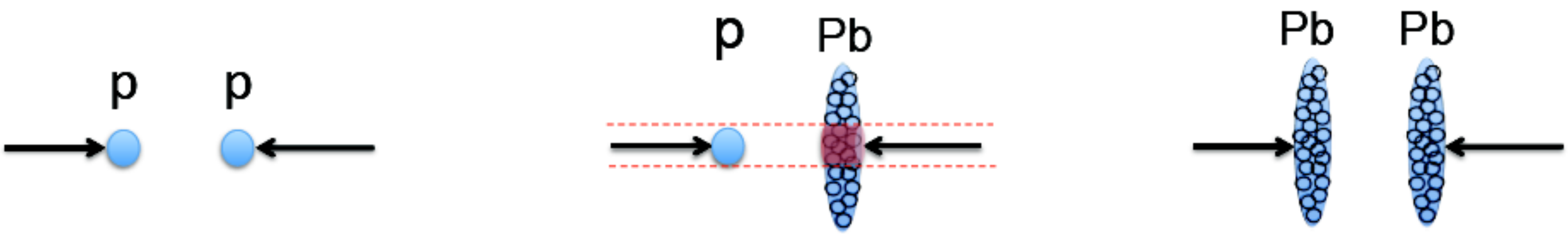


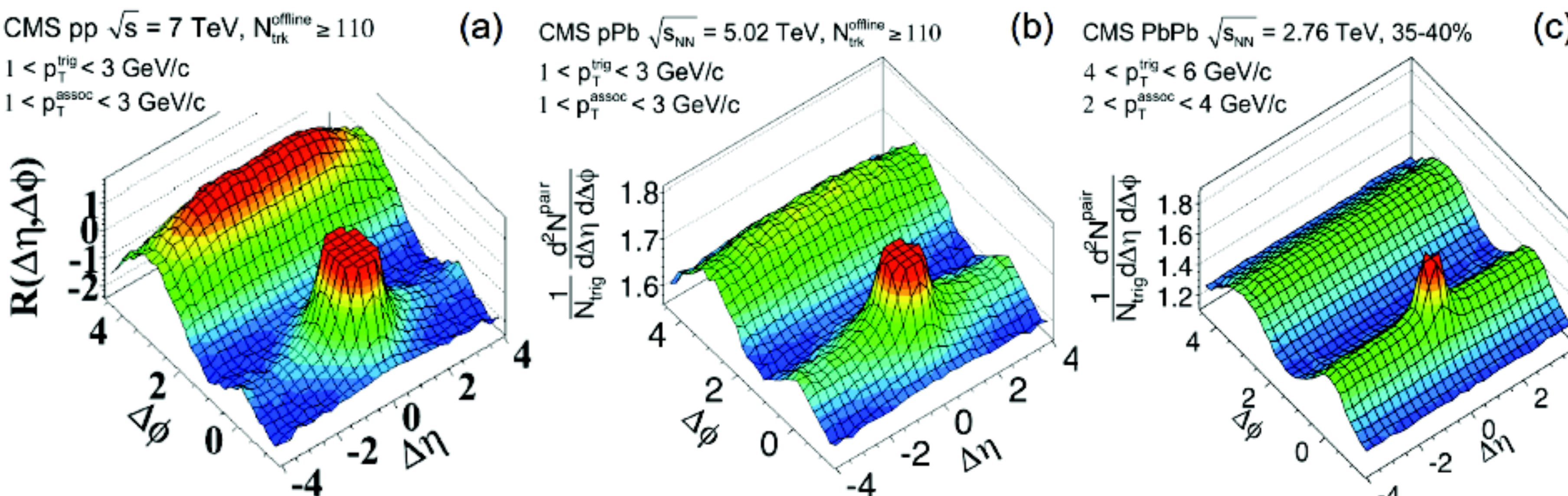
\`peripheral' \`central'

(truncated max at 0,0)

To sum up:

A complete picture of ridge correlations





Is there a common origin of the ridge in all systems?

- Hydrodynamic flow effect like in PbPb?

Attempts at interpretation:

Fluctuations plus hydrodynamics?

Color Glass Condensate/saturation?

For PbPb recent observation of azimuthal anisotropy for high E_T cannot result from hydro – comes from jet quench ?

Look for jet quenching in pp?

What about pPb?

Wait for detailed analysis of full data sets!

(and for data–driven explanations…)