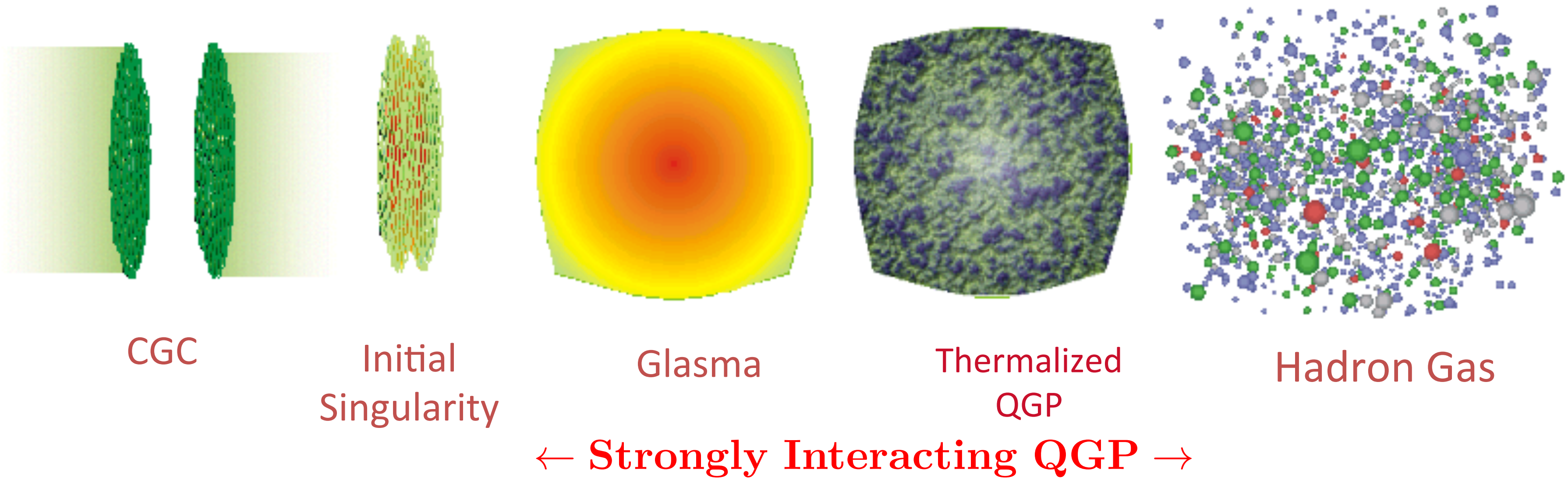
The Ridge in pp and pA Collisions: CGC? Hydro?

Larry McLerran, February 2012, EMMI, Darmstadt, Germany



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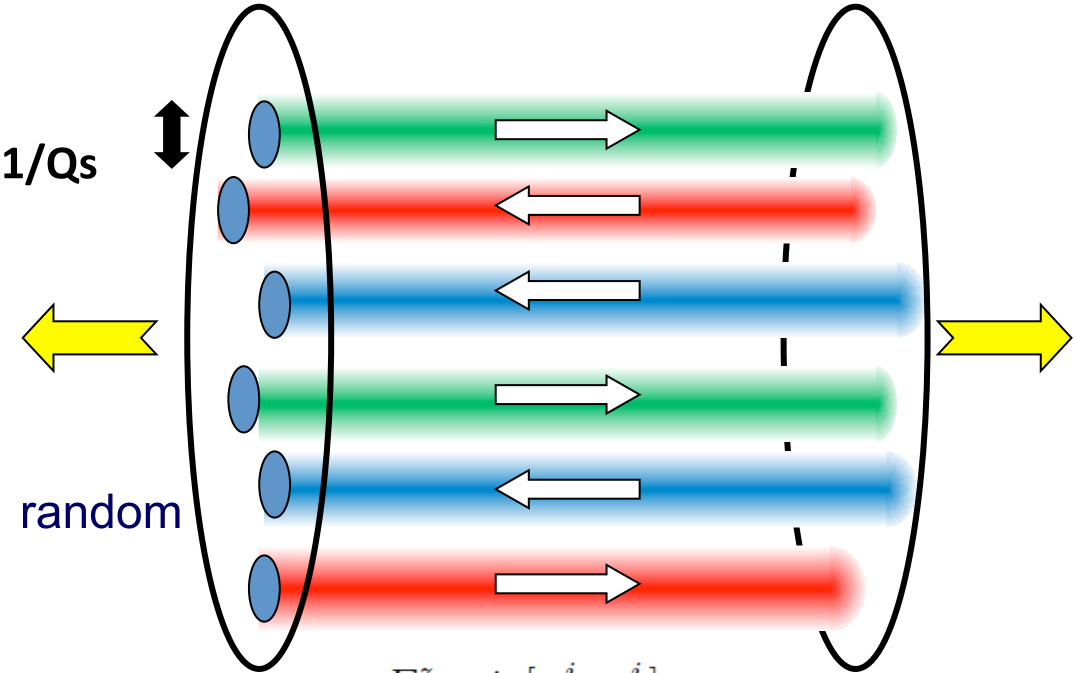
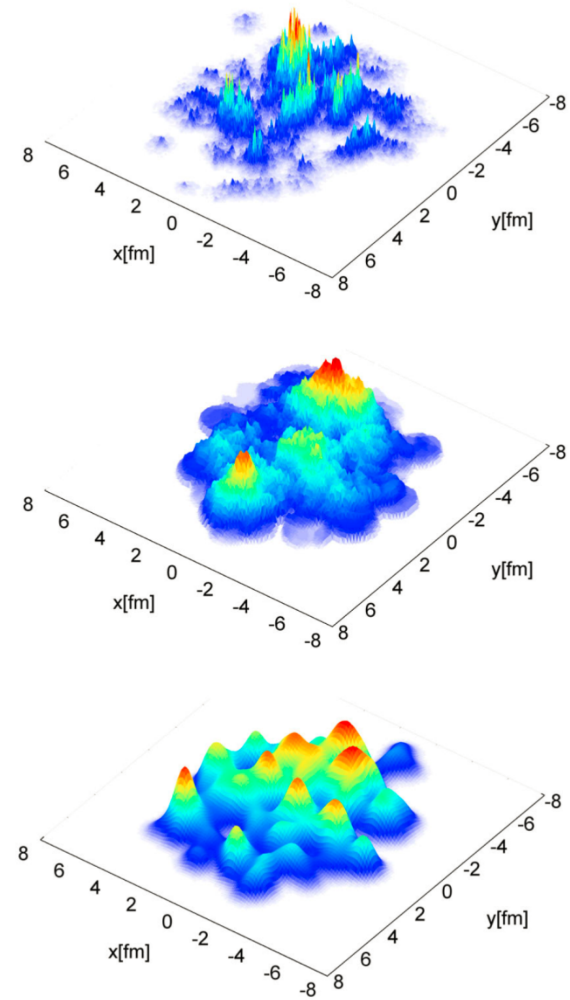
The Glasma



$$E^z = ig[\alpha_1^i, \alpha_2^i]$$
$$B^z = ig\epsilon^{ij}[\alpha_1^i, \alpha_2^j].$$

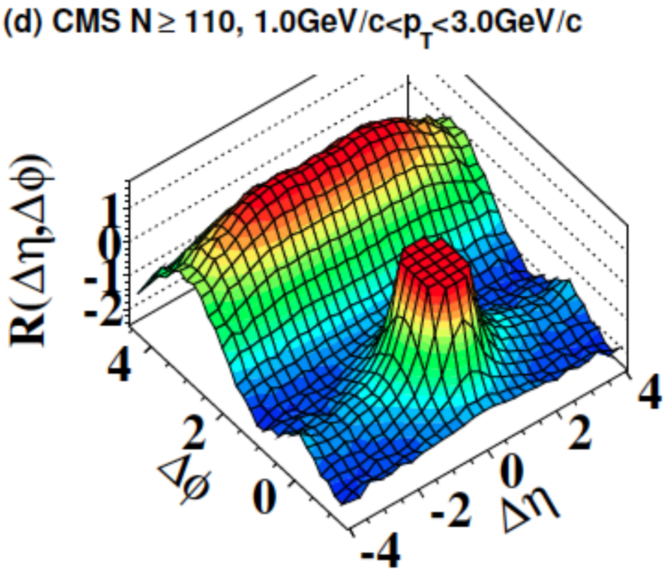
Typical configuration of a single event
just after the collision



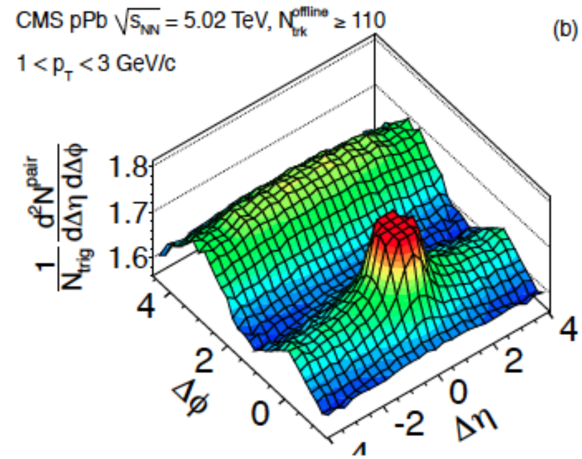
Highly coherent colored fields:
Stringlike in longitudinal direction
Stochastic on scale of inverse saturation momentum in transverse direction
Multiplicity fluctuates as negative binomial distribution

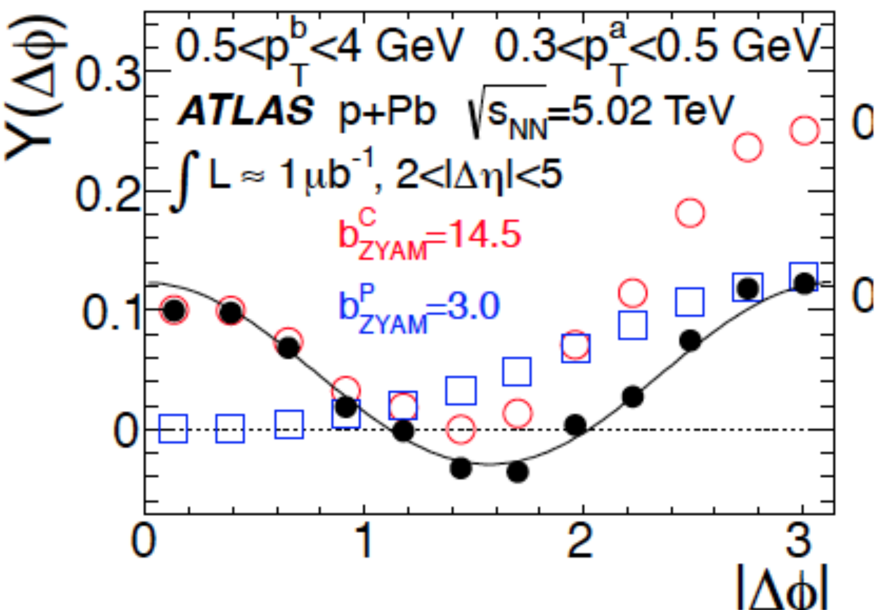
p+p @ 7TeV

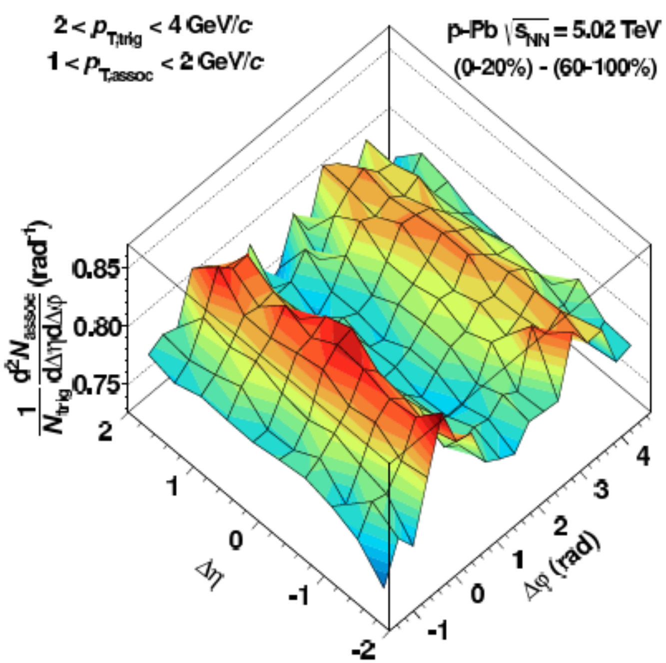
LHC Results



p+Pb @ 5.02TeV







Can this be due to Hydrodynamic Flow?

These are high multiplicity events so it is not impossible to have significant final state results

What is the transverse size of region where there is matter produced?

In pp collisions: The proton size R < 1 Fm.

Bozek and Broniowski in pA Collisions:

Glauber Monte Carlo Model with no fluctuations in multiplicity for pp colisions

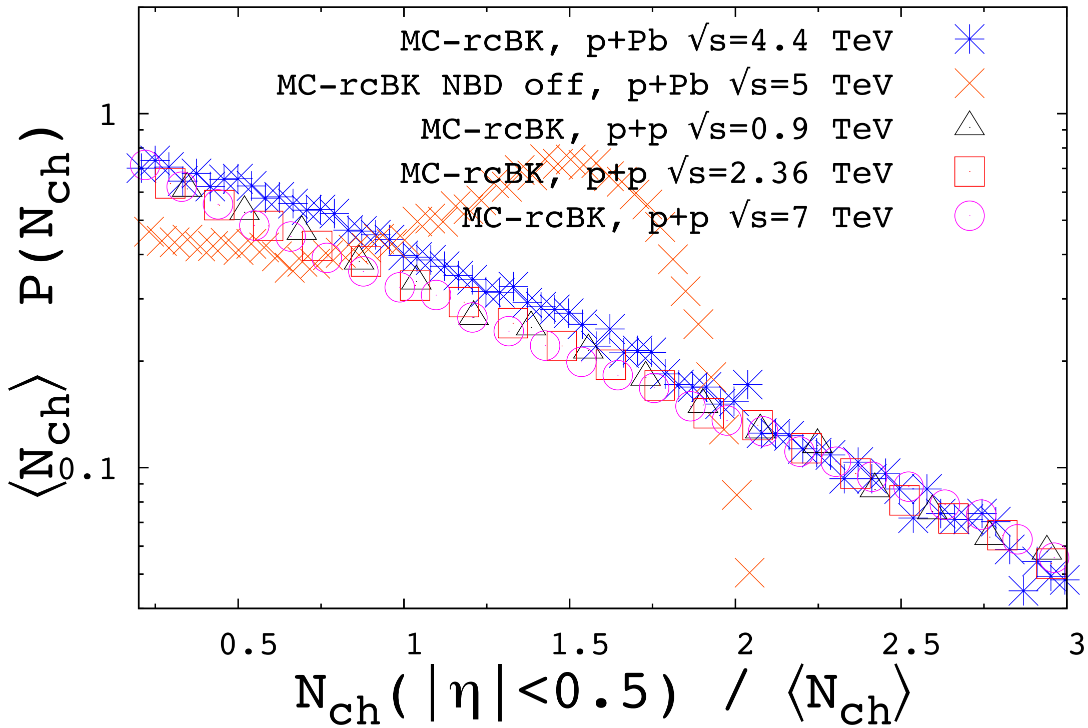
"Typically, the size and
life-time of the collective source formed in central p-Pb
collisions is 3-4 fm [31]."

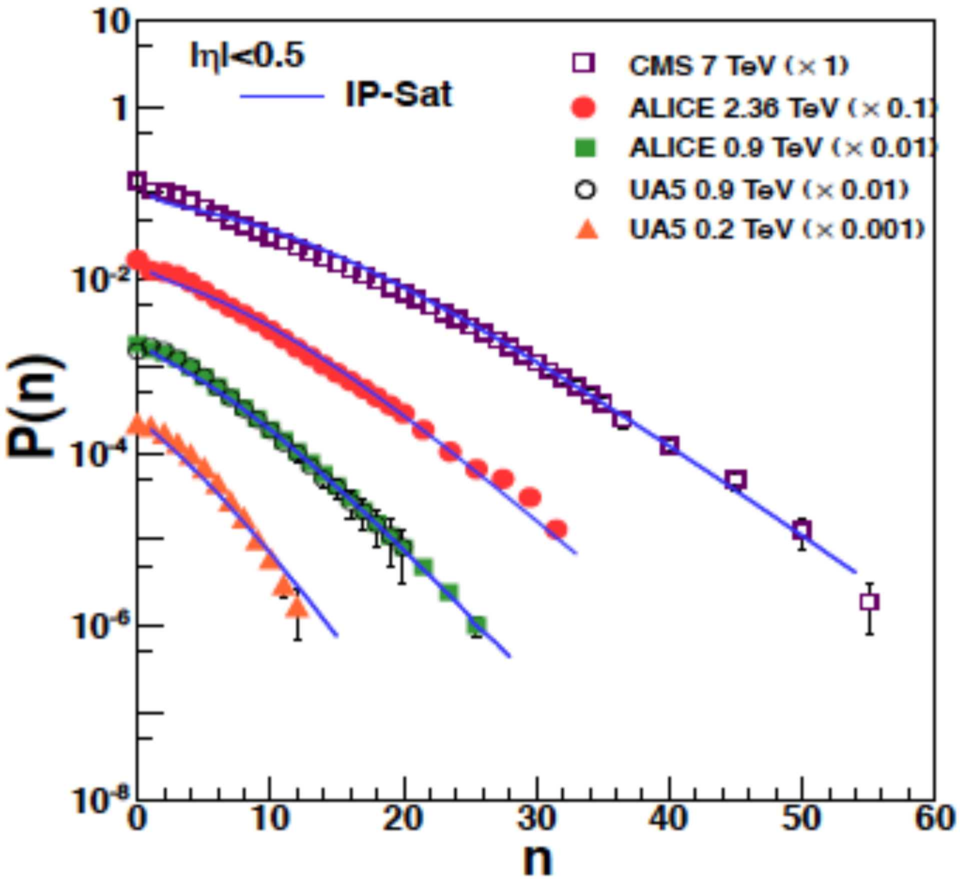
Fluctuations are generated by fluctuations in positions of nucleons in target.

Is this reasonable?

If there are no fluctuations in pp interactions, the only way one can have high multiplicity is by interactions with many nucleons. The highest multiplicity events are generated by interactions with nucleons over the entire nucleus. This requires either that the interactions are at distances much larger than the range of nucleon interactions or that all the nucleons in the nucleus fluctuate so that they sit on top of one another. The latter is not likely because of short distance nucleon-nucleon repulsion.

STAR data show that one MUST include negative binomial fluctuations in multiplicity of pp interactions





Understand source of fluctuations:

Decay of color electric and color magnetic fields. On a subatomic size scale

Including fluctuations makes a big difference:

Size of region is

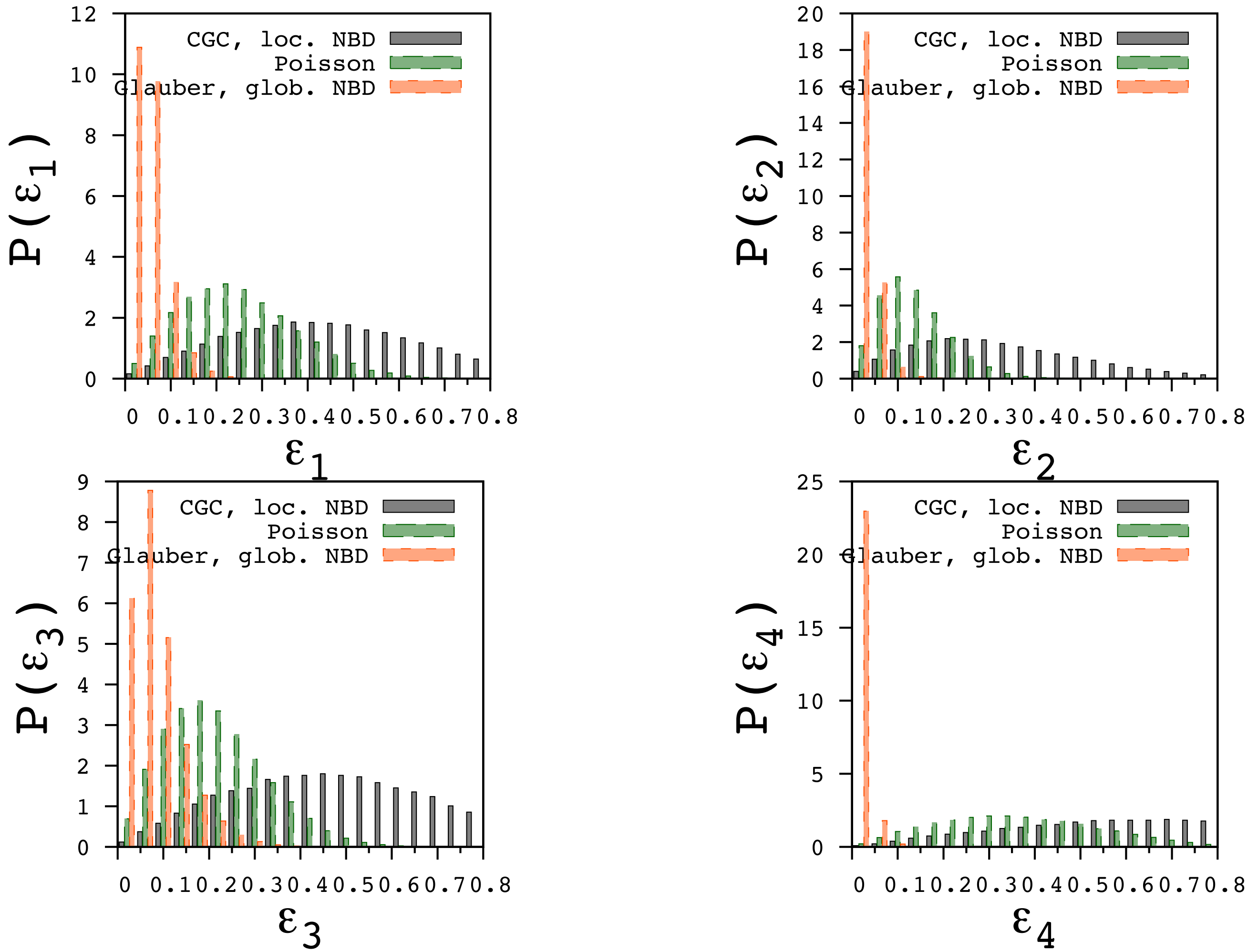
$$R \sim 1\ Fm$$

dN/dy ~ 30-50

$$\Delta r \sim 1/Q_{sat} \sim .1 - .3Fm$$

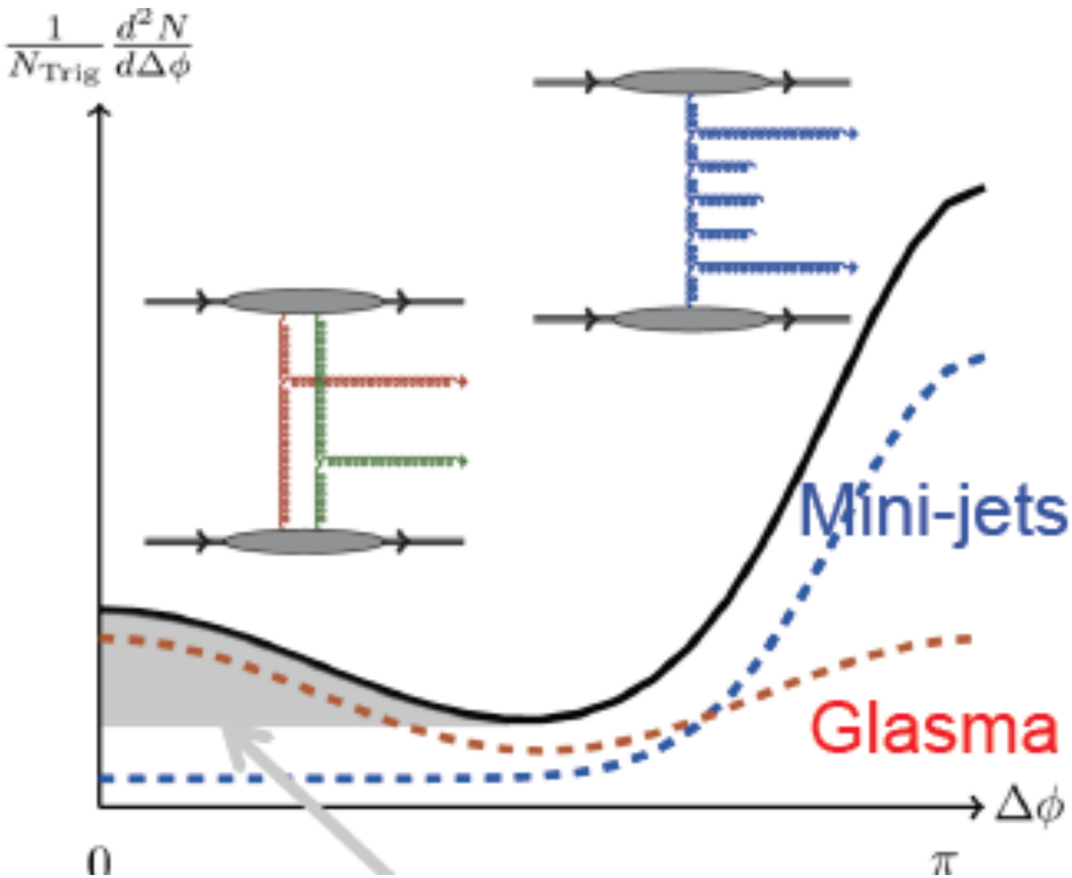
Physics of the flucutations in both pp and pA is on the subatomic scale size

When computing eccentricities, it makes a difference:



Physically: A high multiplicity pp or pA collisions in hydro should have similar trends for eccentricities, v_N as for AA. This is born out in modeling of initial state where sub-nucleonic substructure is included

A two particle correlation at large rapidity should include a contribution from a jet, which will be asymmetric in azimuthal angle and an underlying non-jet piece



How to subtract jet contribution? If we assume matter is hydrodynamical at transverse momentum of interest, cannot subtract an unmodified jet. Jet would be strongly modified by media. Would need to simulate jet production in a medium where most jets would stop, and to model the entire jet!

If the there are not significant final state interactions, then can subtract the jet component, and are left with an underlying correlation.

Inconsistent to subtract jet and assume remainder arises from perfect fluid!

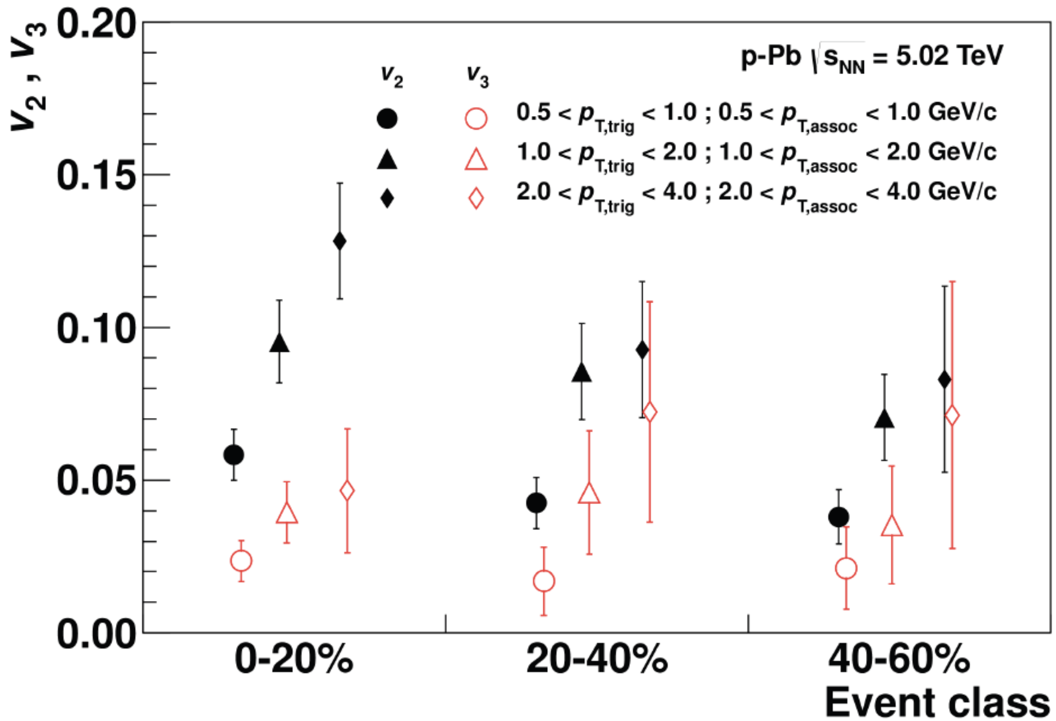
But for fun of it, plug one's nose and ask what results **(You gotta believe)**:

Generically:

eccentricities are typical of those for central heavy ion collisions and rather weakly decrease upon increasing centrality for head on collisions

V_2 and v_3 are both large and their ratio is slowly varying function of increasing centrality for head on collisions

V_2 for pPb is 4-5 times larger than in pp at same multiplicity!



Alice:

In pPb: increse of v_2 with increasing centrality

v_3 is small and slowly varying

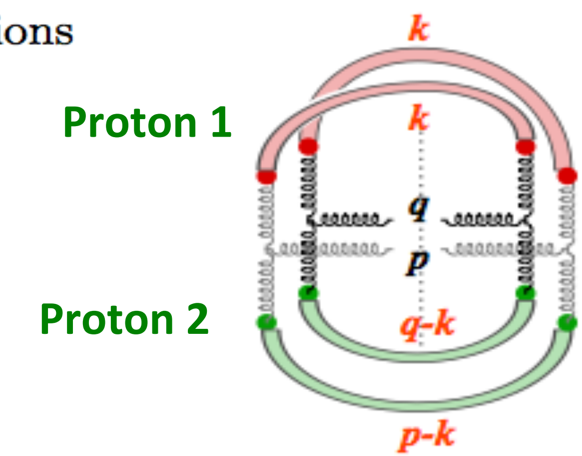
Inconsistent with expectations of perfect fluid hydro and reasonable initial conditions

Let us now go to the opposite limit:
Small final state interactions => subtraction of jet contribution is sensible. Maybe some small effects of the subtraction which make it not quite perfect, but should be a good approximation
Correlation seen must arise from intrinsic correlation of the Glasma flux lines as they decay:

Dumitru,Dusling,Gelis,Jalilian-Marian,Lappi,RV, arXiv:1009.5295

RG evolution of two particle correlations C(p,q) expressed in terms of "unintegrated gluon distributions" in the proton

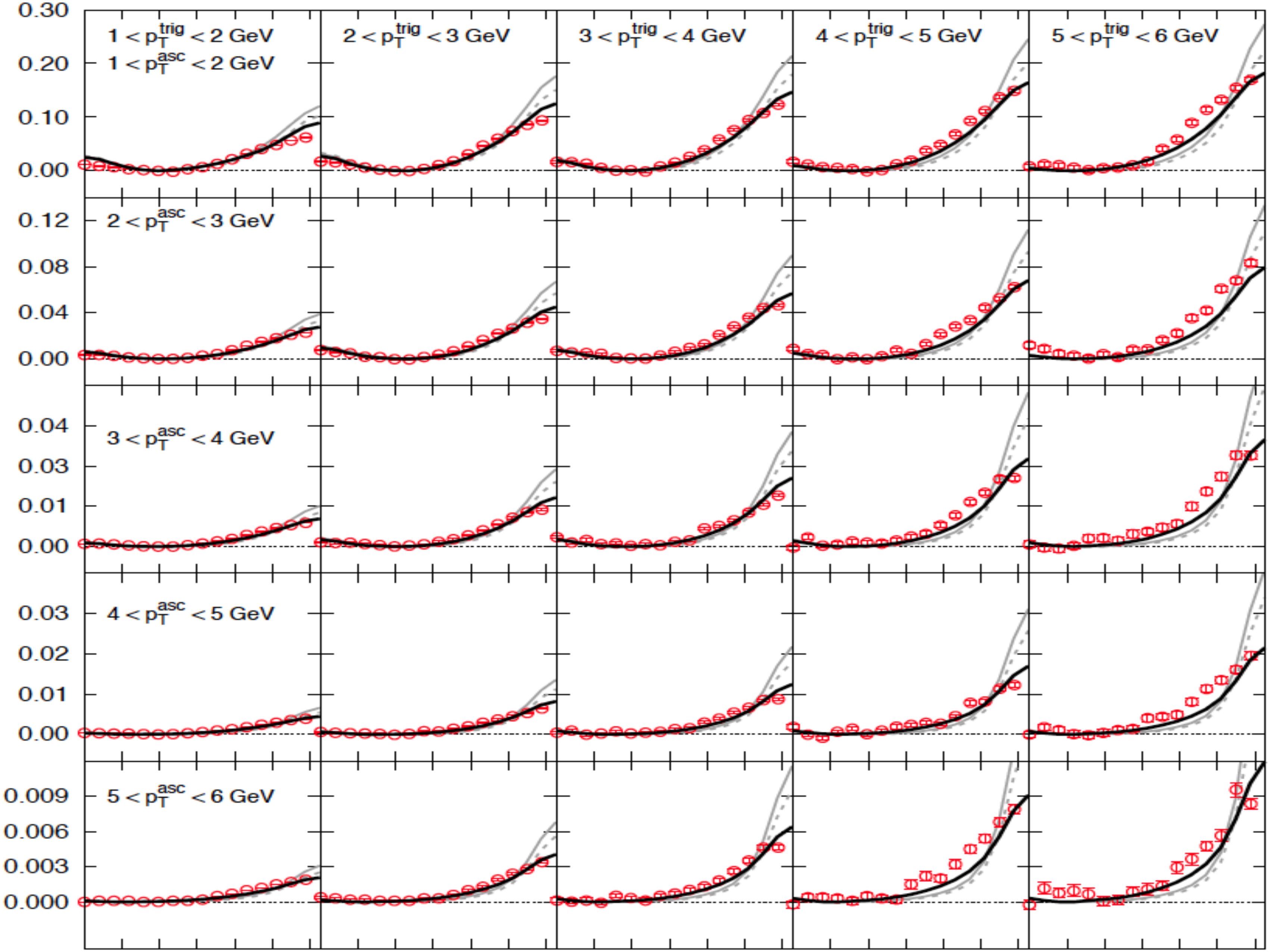
$$C(\mathbf{p},\mathbf{q}) \propto \frac{g^4}{\mathbf{p}_\perp^2\mathbf{q}_\perp^2}\int \mathrm{d}^2\mathbf{k}_{1\perp}\,\Phi^2_{A_1}(y_p,\mathbf{k}_{1\perp})\Phi_{A_2}(y_p,\mathbf{p}_\perp-\mathbf{k}_{1\perp})\Phi_{A_2}(y_q,\mathbf{q}_\perp-\mathbf{k}_{1\perp})$$
$$+ \quad \text{permutations}$$



Contribution ~ α_S^6/N_c^2 in min. bias, High mult. -> $1/\alpha_S^2 N_c^2$
– enhancement of $1/\alpha_S^8$ ~ factor of 10^5 !

CGC-Glasma Description of pp angular correlation:

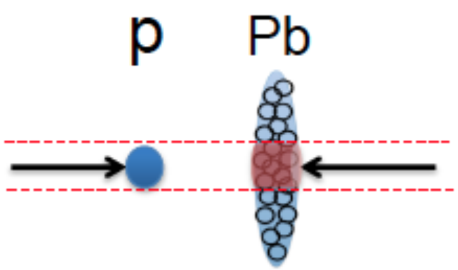
Dusling, RV: 1201.2658
1210.3890

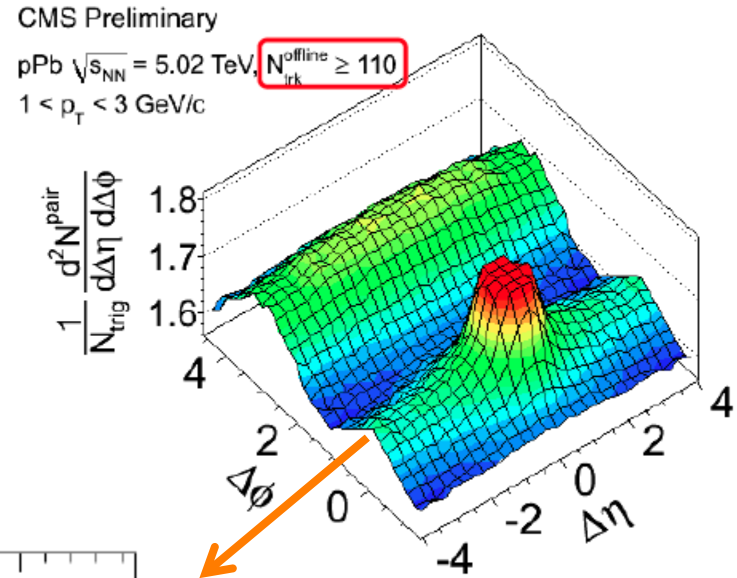


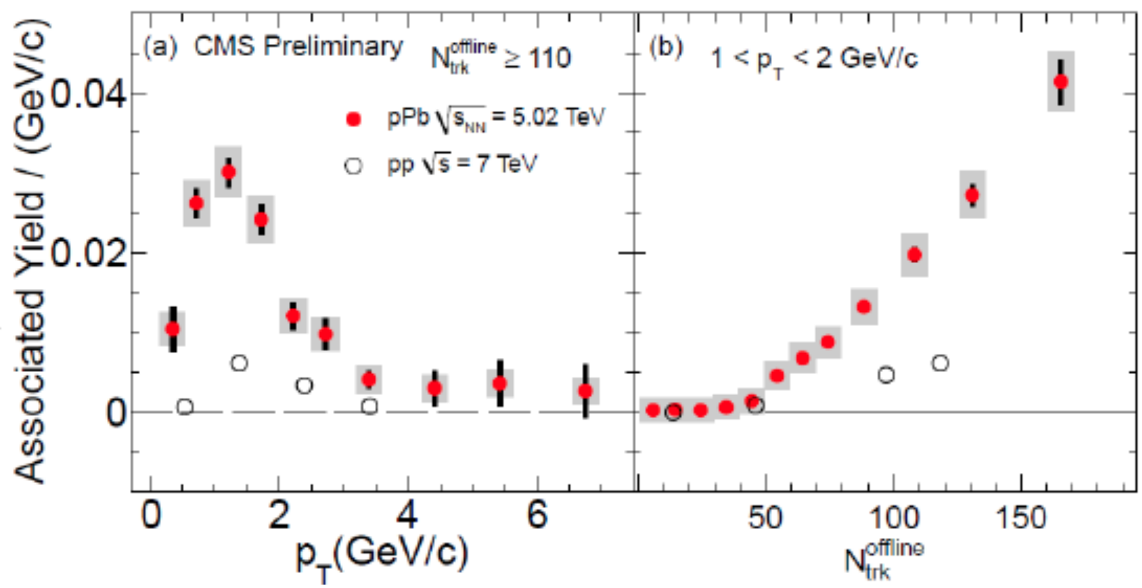
Previous 2 and remaining slides courtesy of R. Venugopalan

Exciting first results on proton lead collisions

CMS coll. arXiv:1210.5482, Phys. Lett. B







Key observation: Ridge much bigger than p+p for the *same* multiplicity !

Exciting results on proton lead collisions

Multiplicity

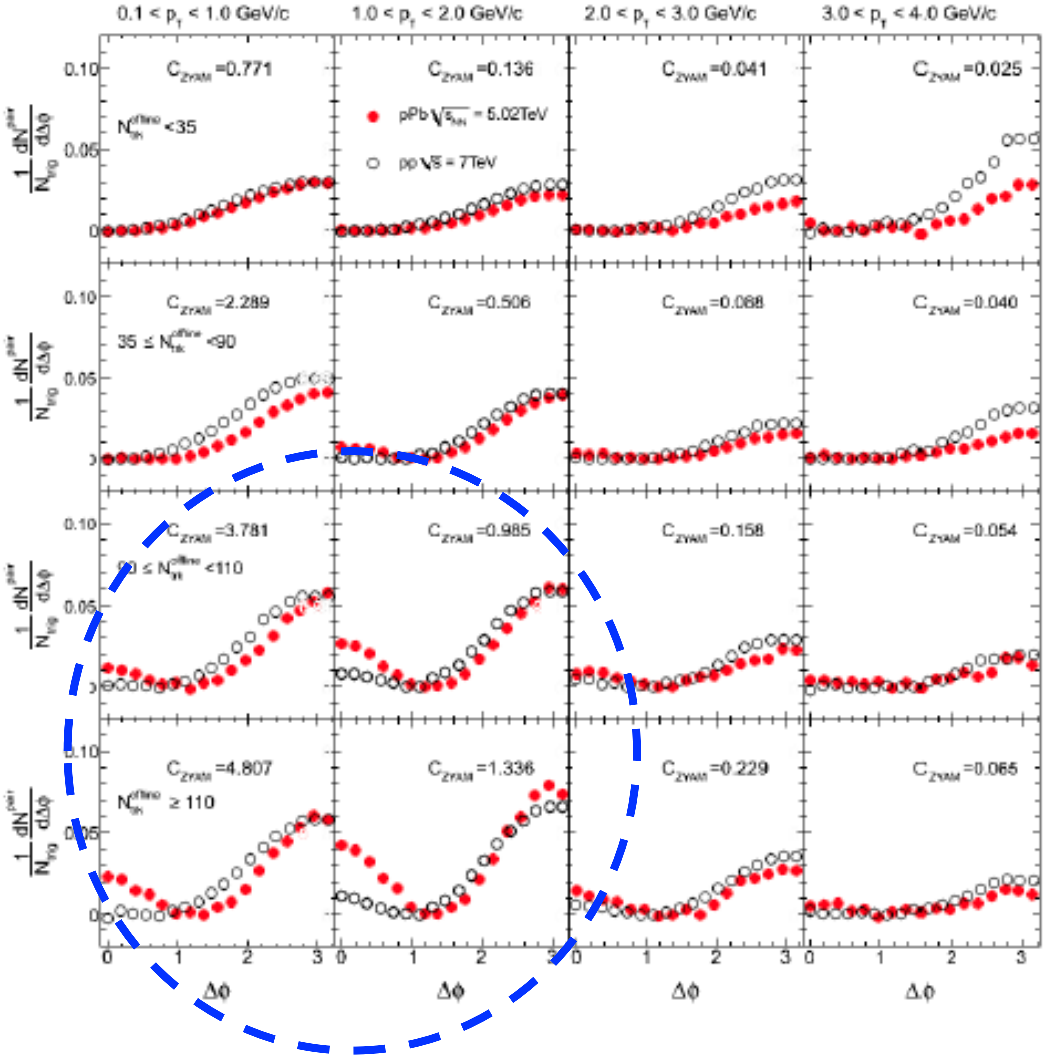
0 – 1 | 1 – 2 | 2 – 3 | 3 – 4 p_T (GeV/c)

N<35

35<N<90

90<N<110

N>110



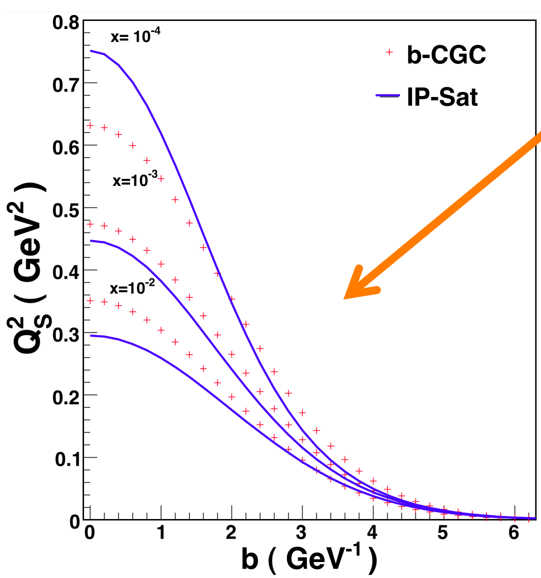
CMS
Preliminary

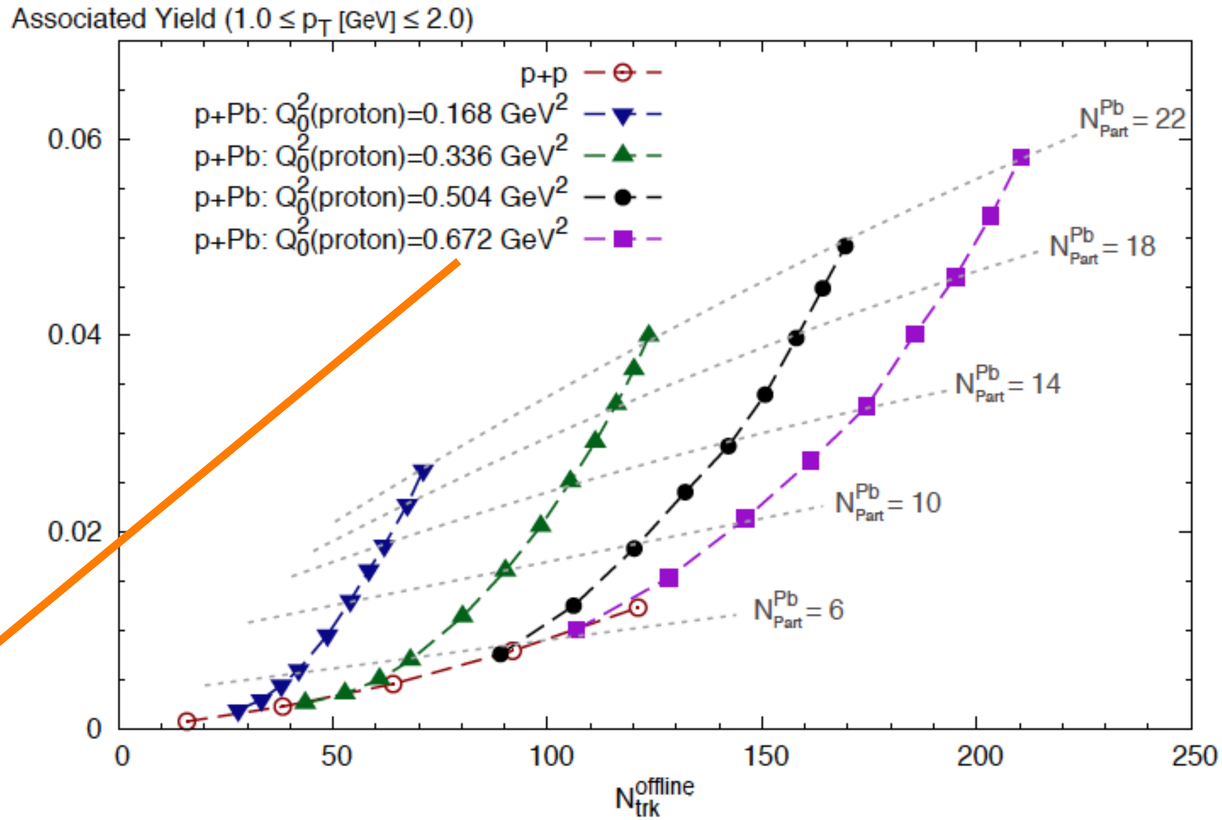
Systematics of p+Pb data explained

Dusling, RV: 1211.3701

$Q_0^2(\text{lead}) = N_{Part}^{Pb} * Q_0^2(\text{proton})$

of "wounded" nucleons in Lead nucleus





Glasma signal is ~ $N_{part} * N_{track}$

p+Pb data explained

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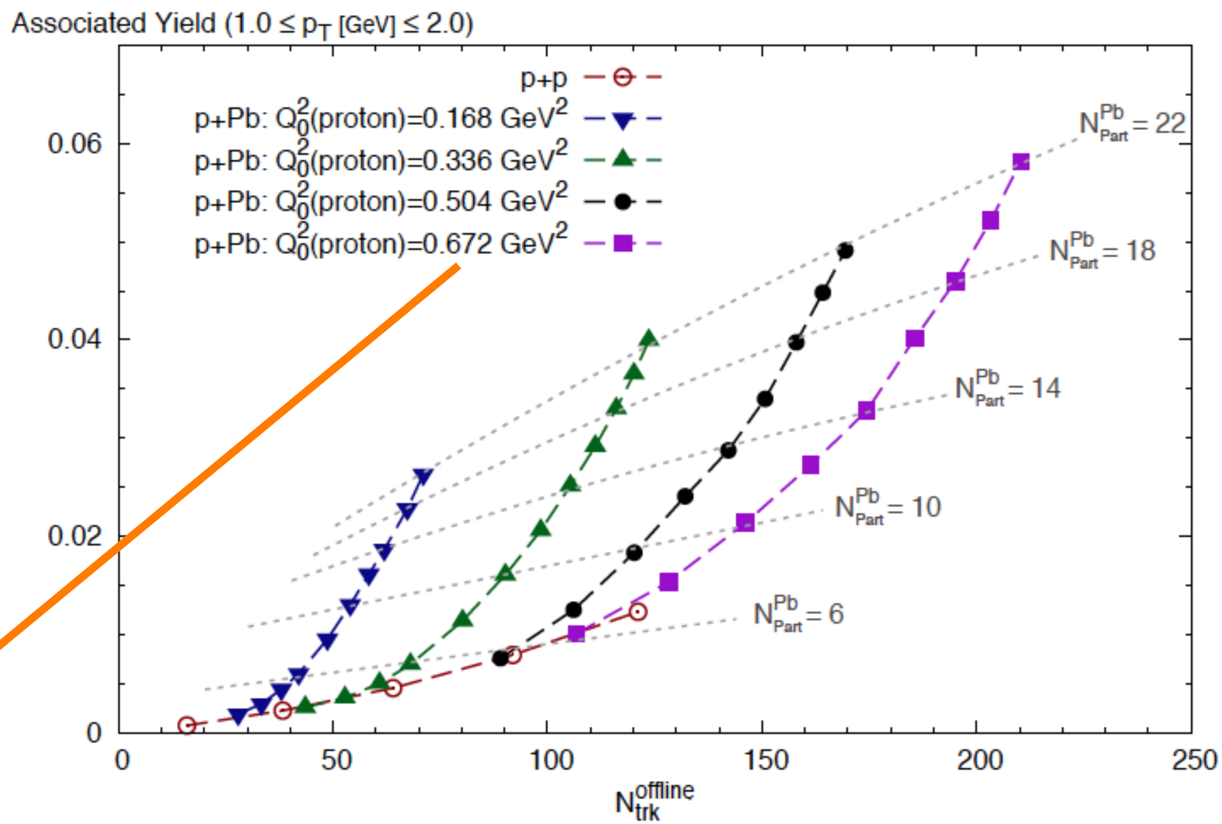
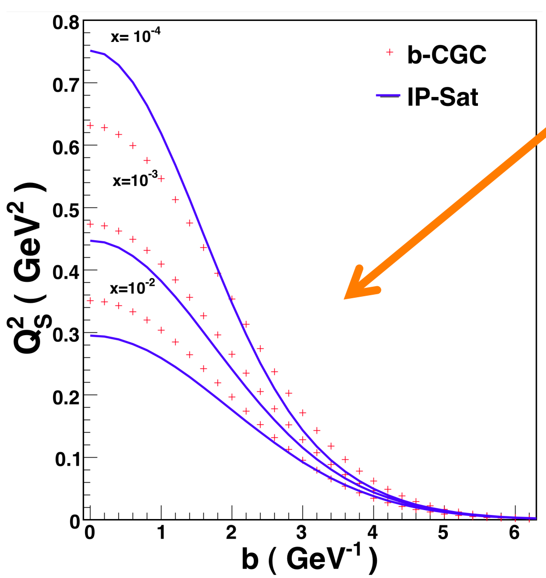
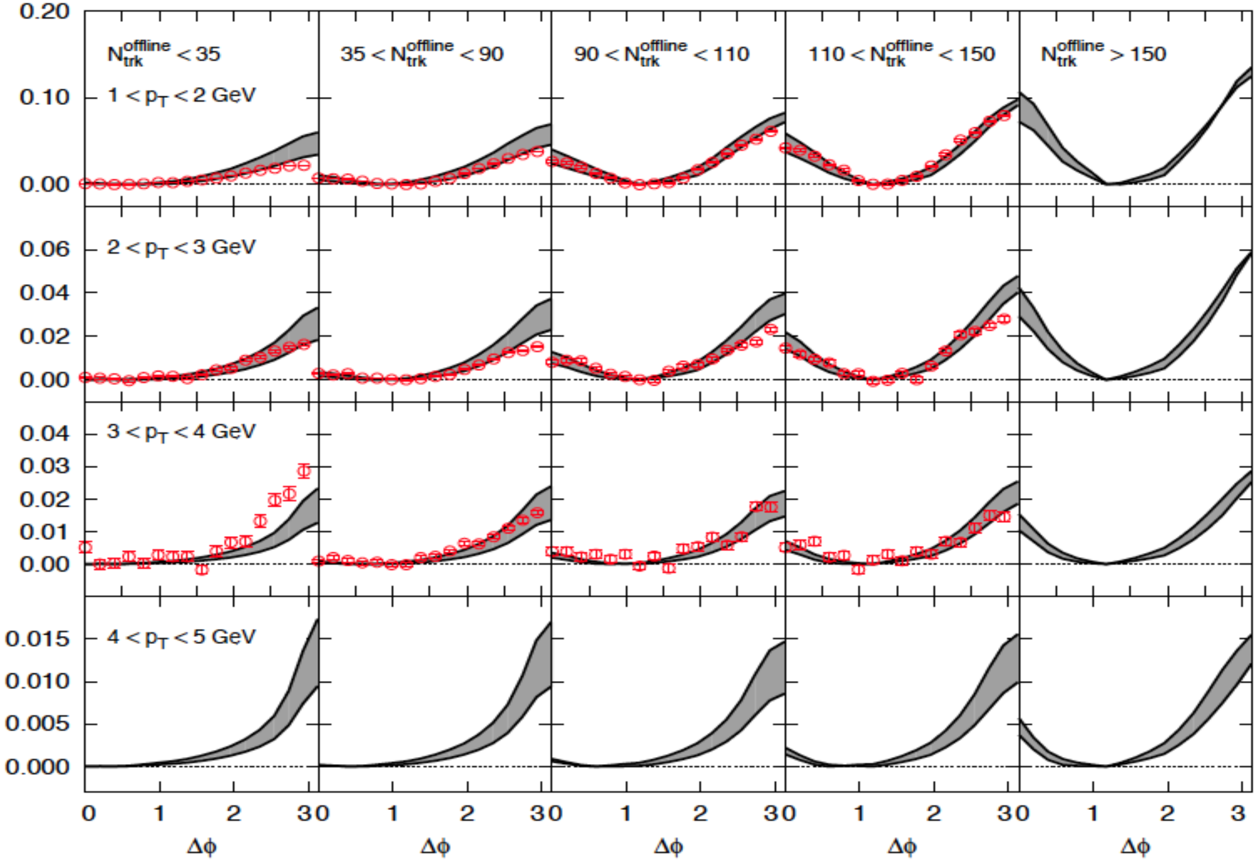




Large “ridge” seen in Color Glass Condensate by varying saturation scale in proton and # of wounded nucleons

CMS p+Pb data explained

Dusling, RV: 1211.3701



Smoking gun for gluon saturation and BFKL dynamics ?

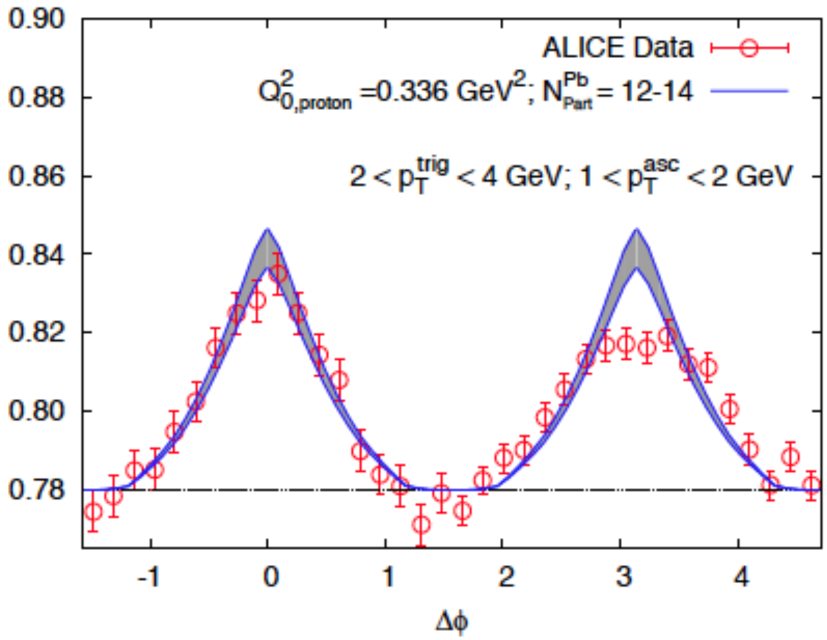
ALICE data on the p+Pb ridge

ALICE coll. arXiv:1212.2001

Different acceptance ($|\Delta\eta| < 1.8$) than CMS ($2 < |\eta| < 4$) and ATLAS ($2 < |\eta| < 5$).

ALICE subtracts away-side "jet" contribution at 40-60% centrality from most central events

–this gives dipole shape of correlation



Different analysis technique from CMS/ATLAS

-- same normalization as for CMS/ATLAS

Curves for $Q_{0,proton}^2$ =0.336 GeV^2 & N_{part}^{Pb} = 12 - 14

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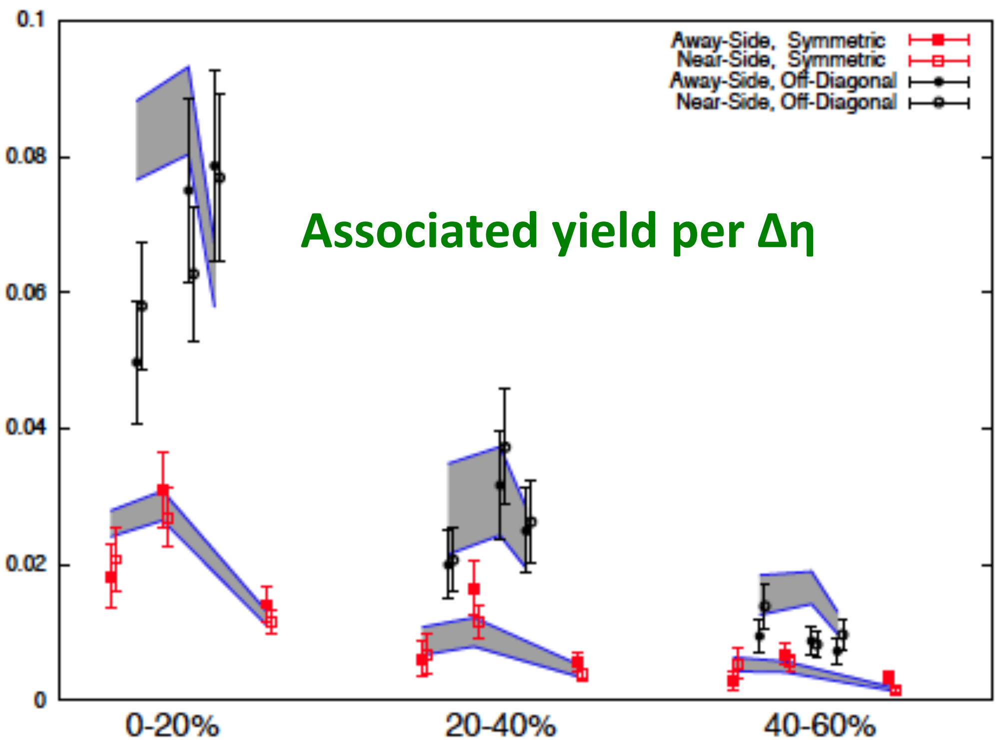


0-20% : $Q_{0,proton}^2$ =0.336 GeV^2 & N_{part}^{Pb} = 12 – 14

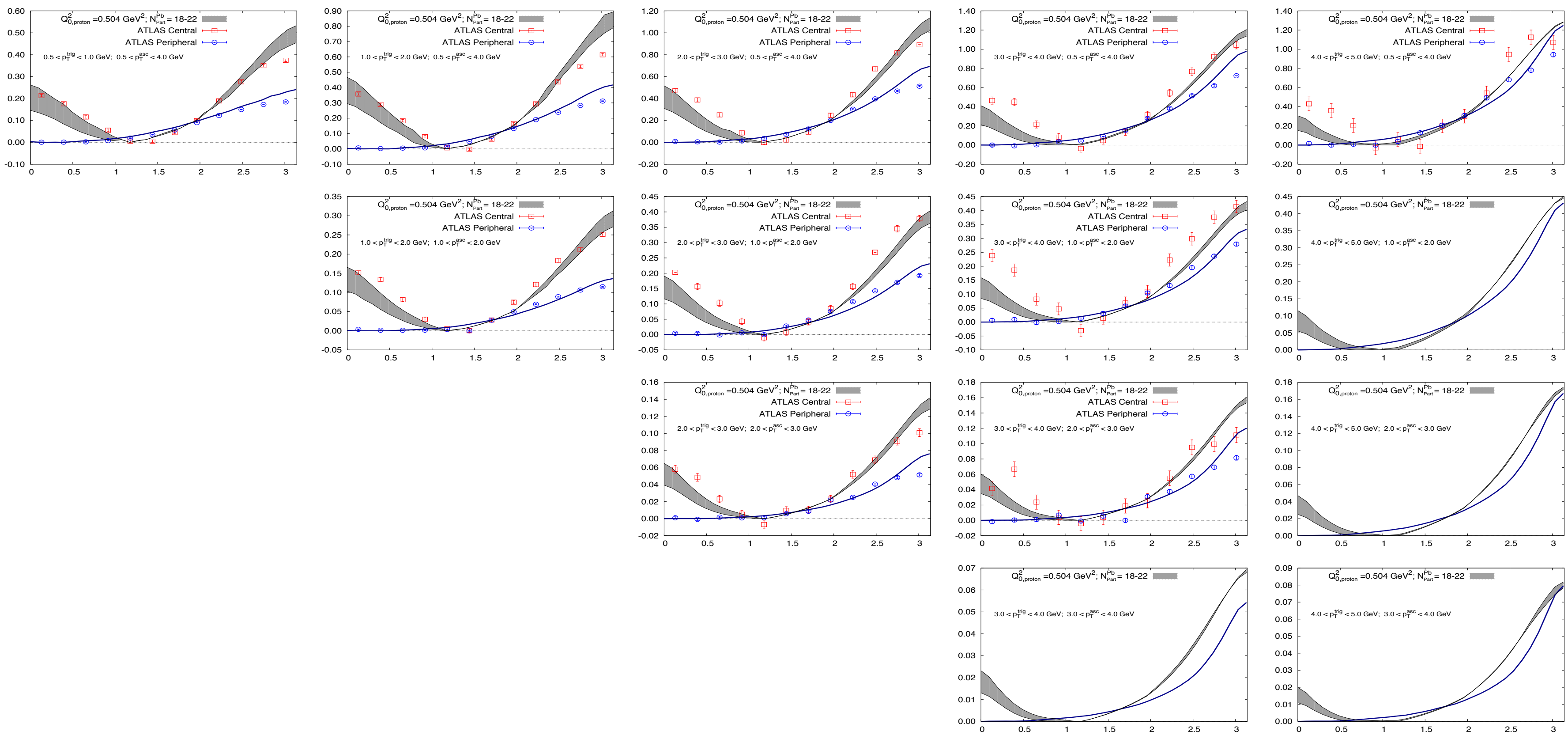
20-40% : $Q_{0,proton}^2$ =0.336 GeV^2 & N_{part}^{Pb} = 4 – 6

40-60%: $Q_{0,proton}^2$ =0.168 GeV^2 & N_{part}^{Pb} = 3-4

Comparison to ATLAS p+Pb ridge

ATLAS coll. arXiv: 1212.5198

ATLAS yields in asymmetric p_T windows compared to Glasma + BFKL:



Glasma graph contributions compared to ATLAS central – ATLAS peripheral