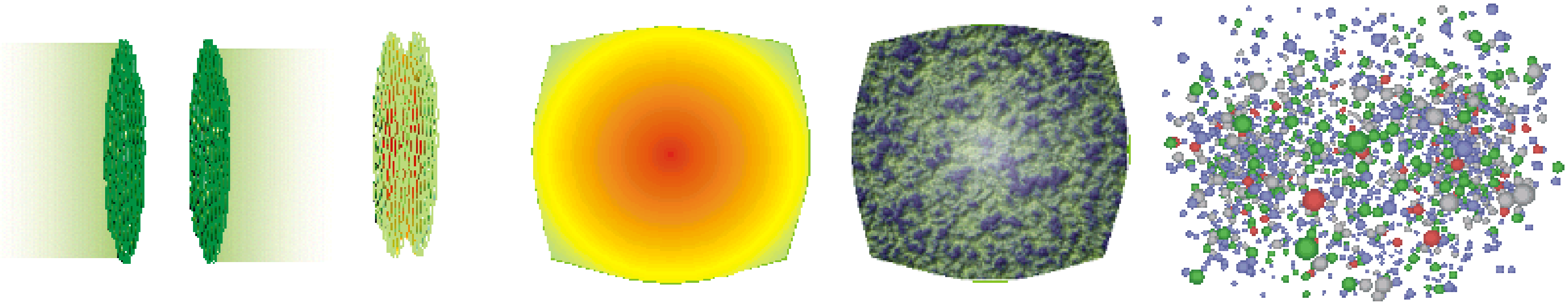
Implications for LHC pA Run from RHIC Results



-------------- sQGP ---------------

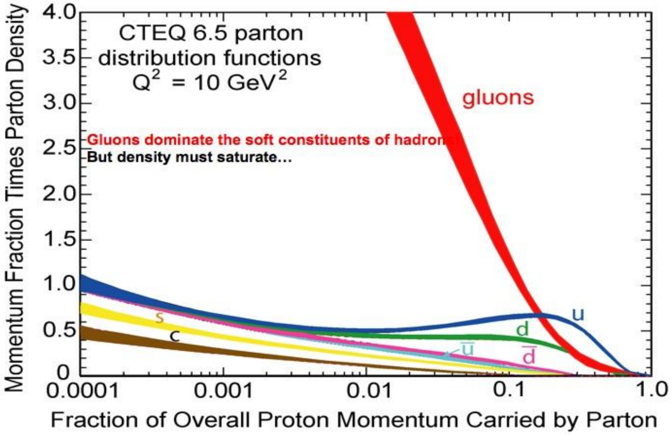
CGC

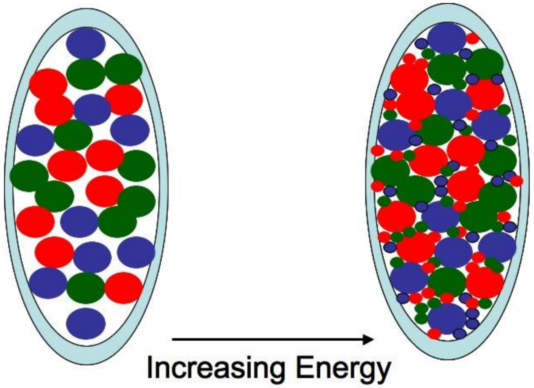
Initial Singularity

Glasma

Thermalized sQGP

Hadron Gas





Asymptotic Freedom:
High density systems are weakly coupled because typical distances are short

$$\alpha_S << 1$$

Possible to understand from first principles

Color Glass Condensate

Color:

Gluons are colored

Condensate:

Gluon occupation number $1/\alpha_S$ is as large as can be, like Higgs condensate or superconductor

High density of gluons is self generated

Glass:

The sources of gluon field are static, evolving over much longer time scales than natural one

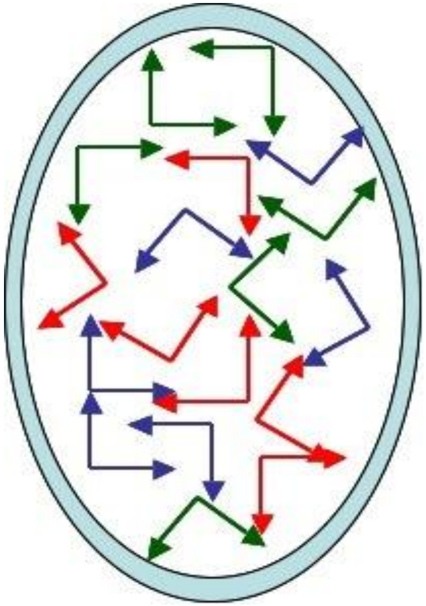
Resulting theory of classical field and real distribution of stochastic source is similar to spin glass

$$\frac{dN}{dyd^2r_Td^2p_T} \sim \frac{1}{\alpha_s}$$

Parton distributions replaced by ensemble of coherent classical fields

Renormalization group equations for sources of these fields

$$Q^2_{sat} >> \Lambda^2_{QCD} \qquad \vec{E} \perp \vec{B} \perp \hat{z}$$



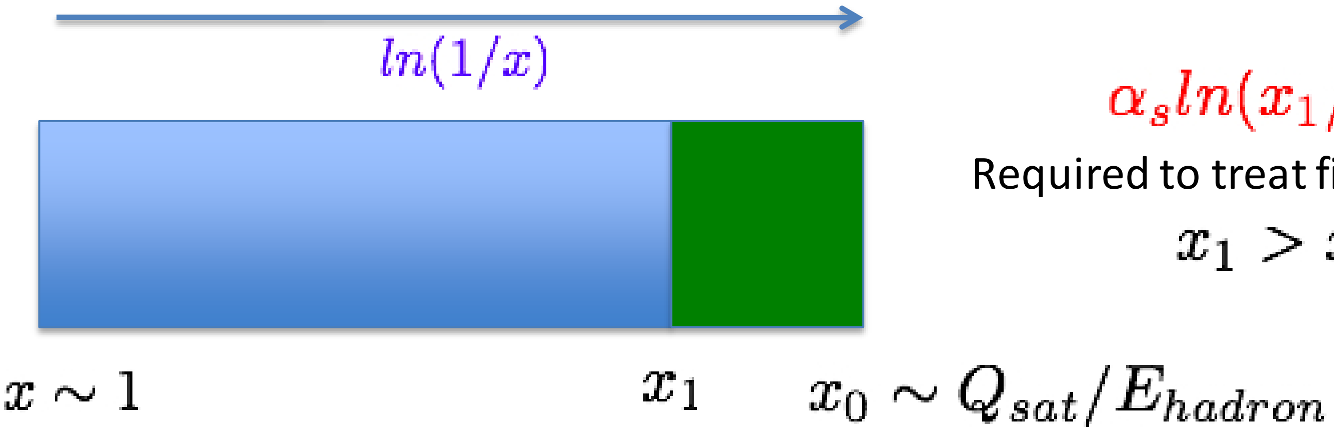
Effective Theory of Color Glass Condensate

$$\frac{dN}{dy\,d^2p_T\,d^2r_T} \sim \frac{1}{\alpha_S} \qquad p_T < Q_{sat}$$

Classical gluon fields at small x
Static sources of gluon fields at large x

Renormalization group changes what is source and what is field as energy increases.
Renormalization group determines distribution of sources

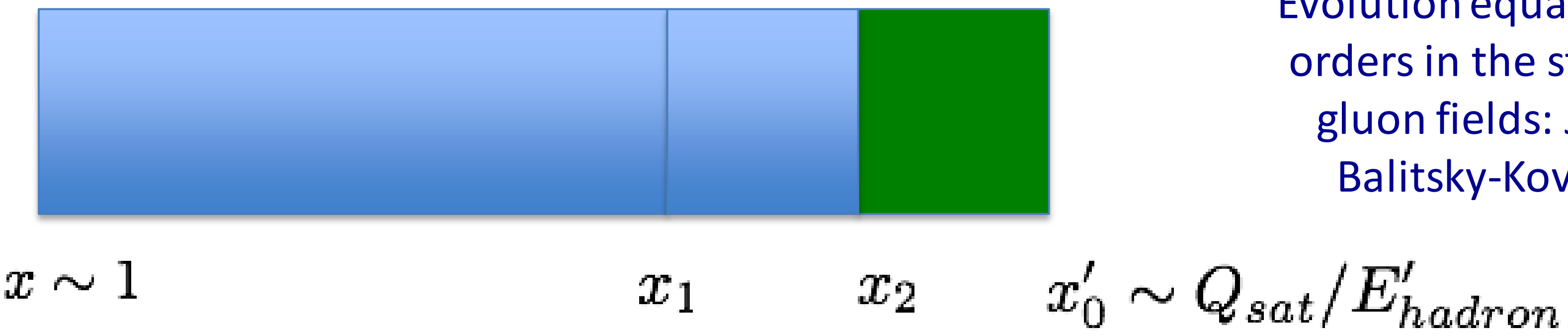
Fixed point of renormalization group => Universality of CGC



$$\alpha_s ln(x_1/x_0) << 1$$

Required to treat fields as classical for

$$x_1 > x > x_0$$



Evolution equations to all
orders in the strength of
gluon fields: JIMWLK;
Balitsky-Kovchegov

Increasing gluon density seen in DGLAP and BFKL evolution equations

Typical gluon size 1/Q

DGLAP:
From momentum Q_0 compute distribution at Q at fixed x
Number of gluons grows but gluons decrease in size rapidly:
Dilute limit

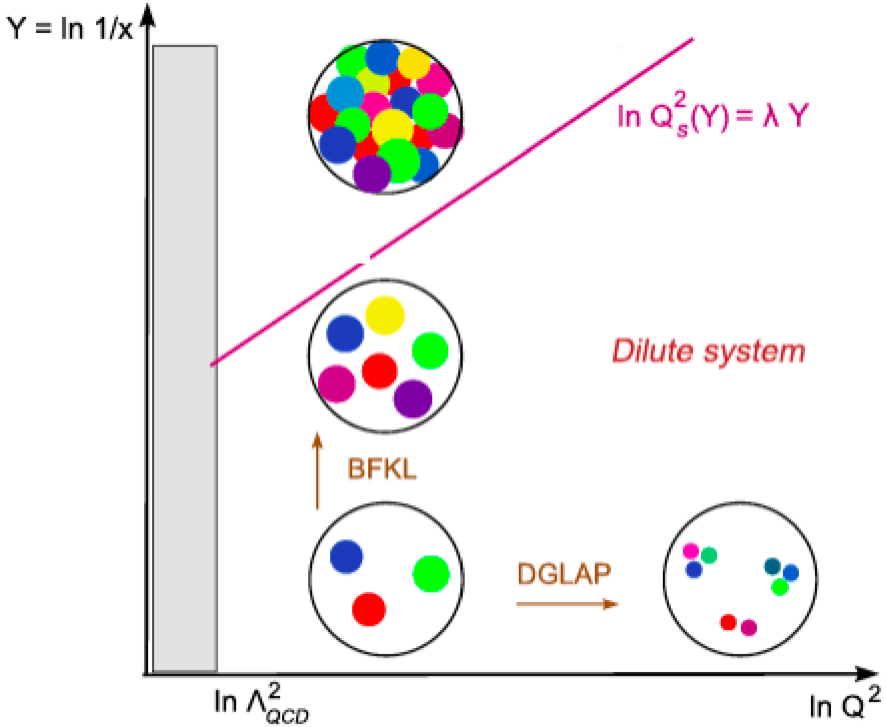
BFKL:
From x_0 to x at Q:
Number of gluons grows but gluons of fixed size:
High density limit

$$q < Q_{sat}$$

Gluons Saturated.

$$Q^2_{sat} \sim Q_0^2 \left(\frac{x_0}{x}\right)^{\delta} \qquad \delta \sim 0.2 - 0.3$$

Grows



How does density at fixed size stop growing?

$1/\alpha_s$ gluons with interaction strength α_s are a hard sphere.

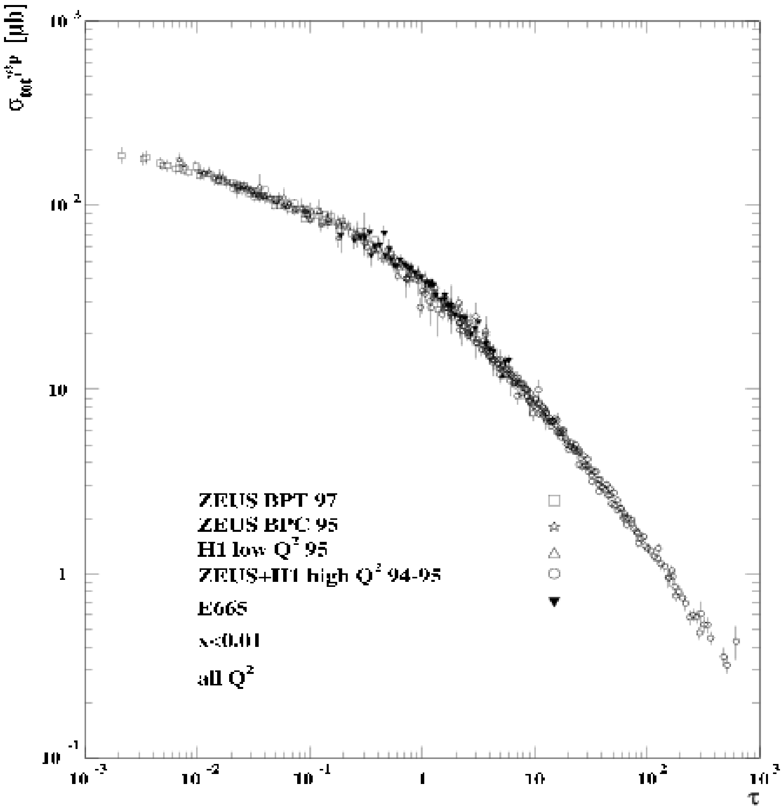
When all gluons with

$$q < Q_{sat}$$

are filled, then begin filling with higher momentum

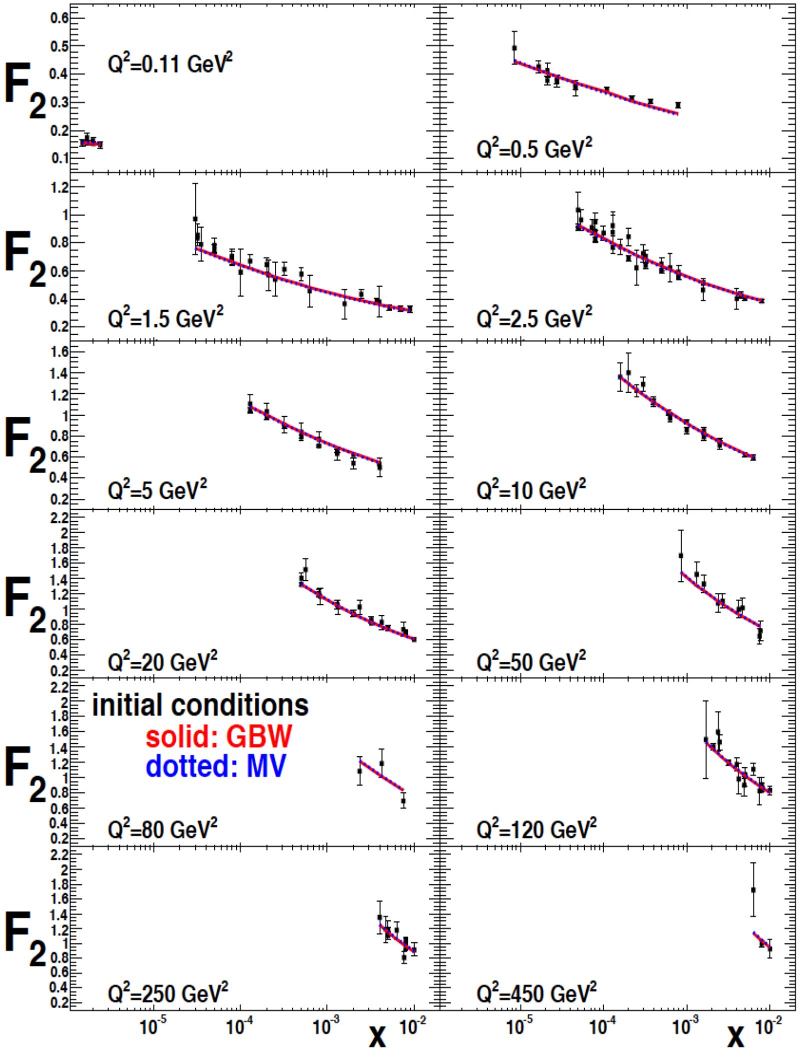
Theory of CGC: First Principles from QCD

Requires saturation momentum $Q_{sat} >> \Lambda_{QCD}$ When is it true?

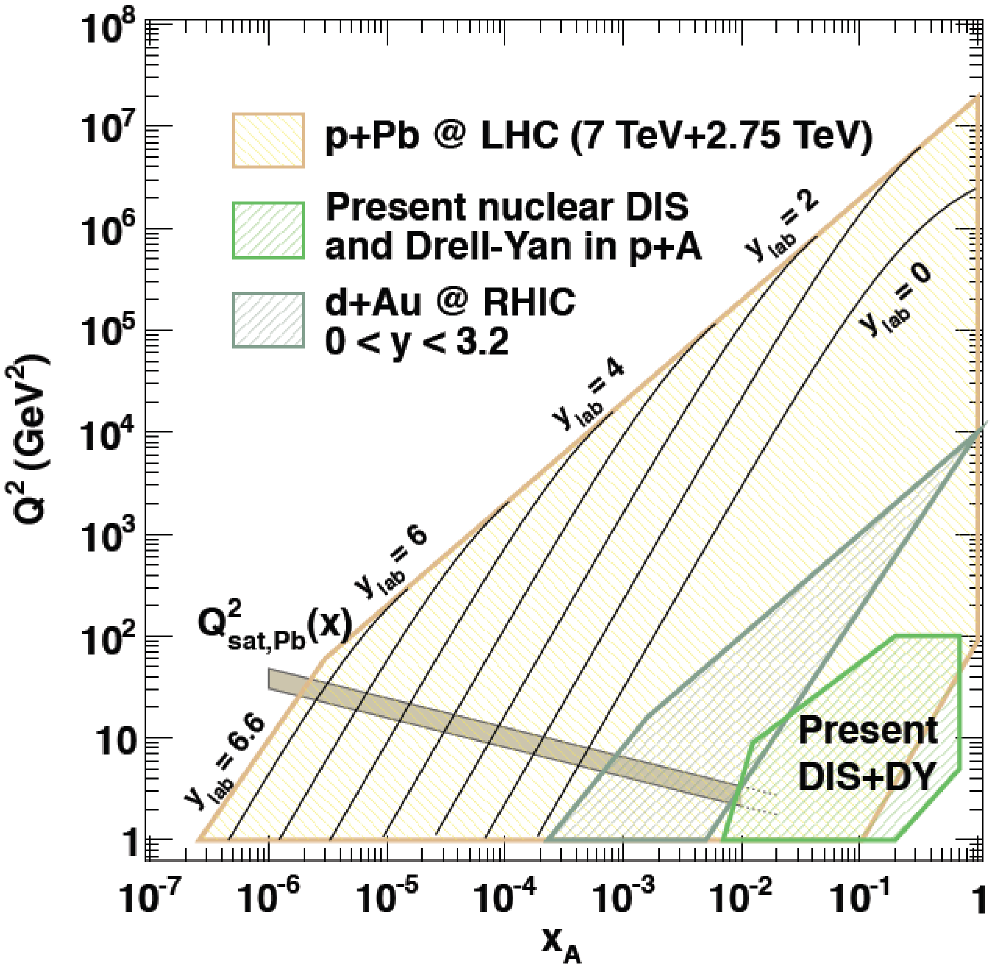


Experimental Evidence: ep Collisions

Distributions from NLO BK-JIMWLK evolution

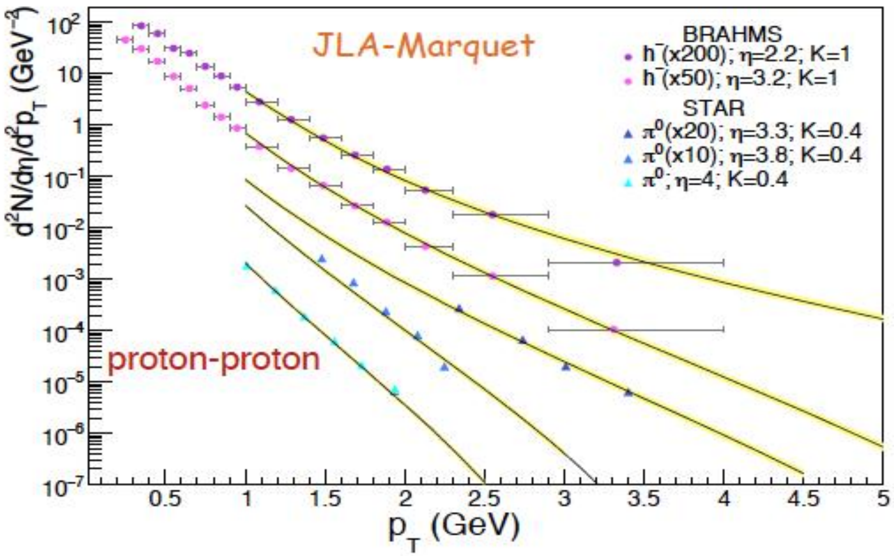


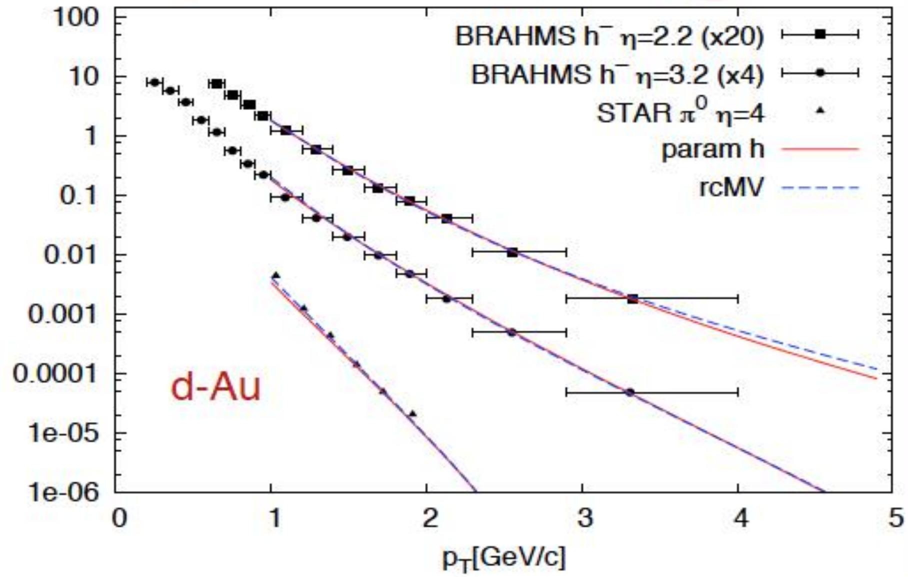
Kinematic Reach in pA Collisions



Comparison to RHIC data

Fujii-Itakura-Kitadono-Nara

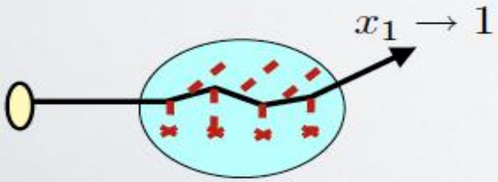




RHIC data do not constrain initial conditions for evolution(MV, gamma>1..."everything works")

Particle production close to the kinematic limit (x->1 in the projectile). K-factors ~ 0.3 for most forward rapidities

Are large-x energy loss effects (not included in the CGC) the cause of the suppression?



Probability of not losing energy:

$$P(\Delta y) \approx e^{-n_G(\Delta y)} \approx (1-x_F)^{\#}$$

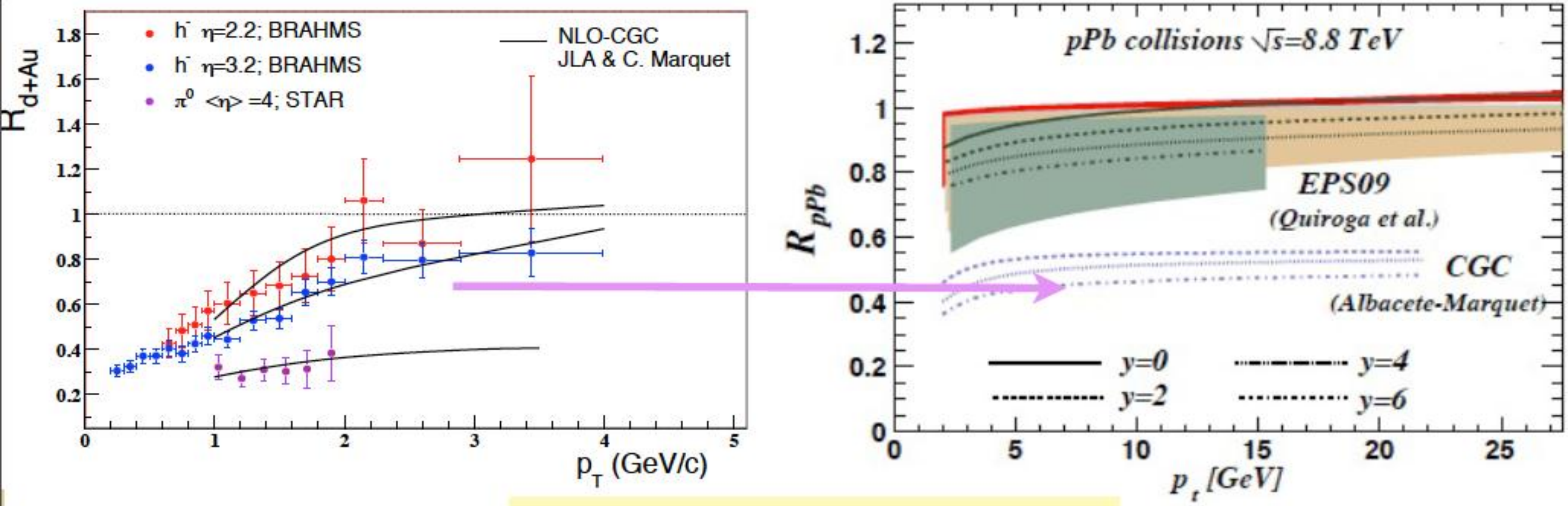
Kopeliovich et al

Slide from Albacete

Nuclear modification factors:

RHIC

predictions for p+Pb @ LHC



R_{dAu}(RHIC $\eta \sim 3$)~ R_{pPb}(LHC $\eta \sim 0$)

Normalization issue:
(lack of knowledge of
b-dependence)!!

$$R_{pA}^{CGC}(k_t >> 1) = \frac{1}{A}\frac{Q_{sA}^2}{Q_{sp}^2}\frac{\int^A d^2b}{\int^p d^2b} \to 1 \quad \text{if} \quad Q_{sA}^2 = A^{1/3}Q_{sp}^2$$

However, in the “trivial”
approach it’s found

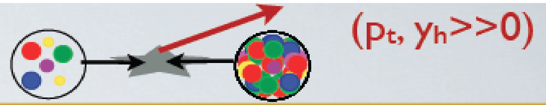
$$\frac{Q_{0sA}^2}{Q_{0sp}^2} \sim 1.5 \div 4 < A^{1/3} \sim 6$$

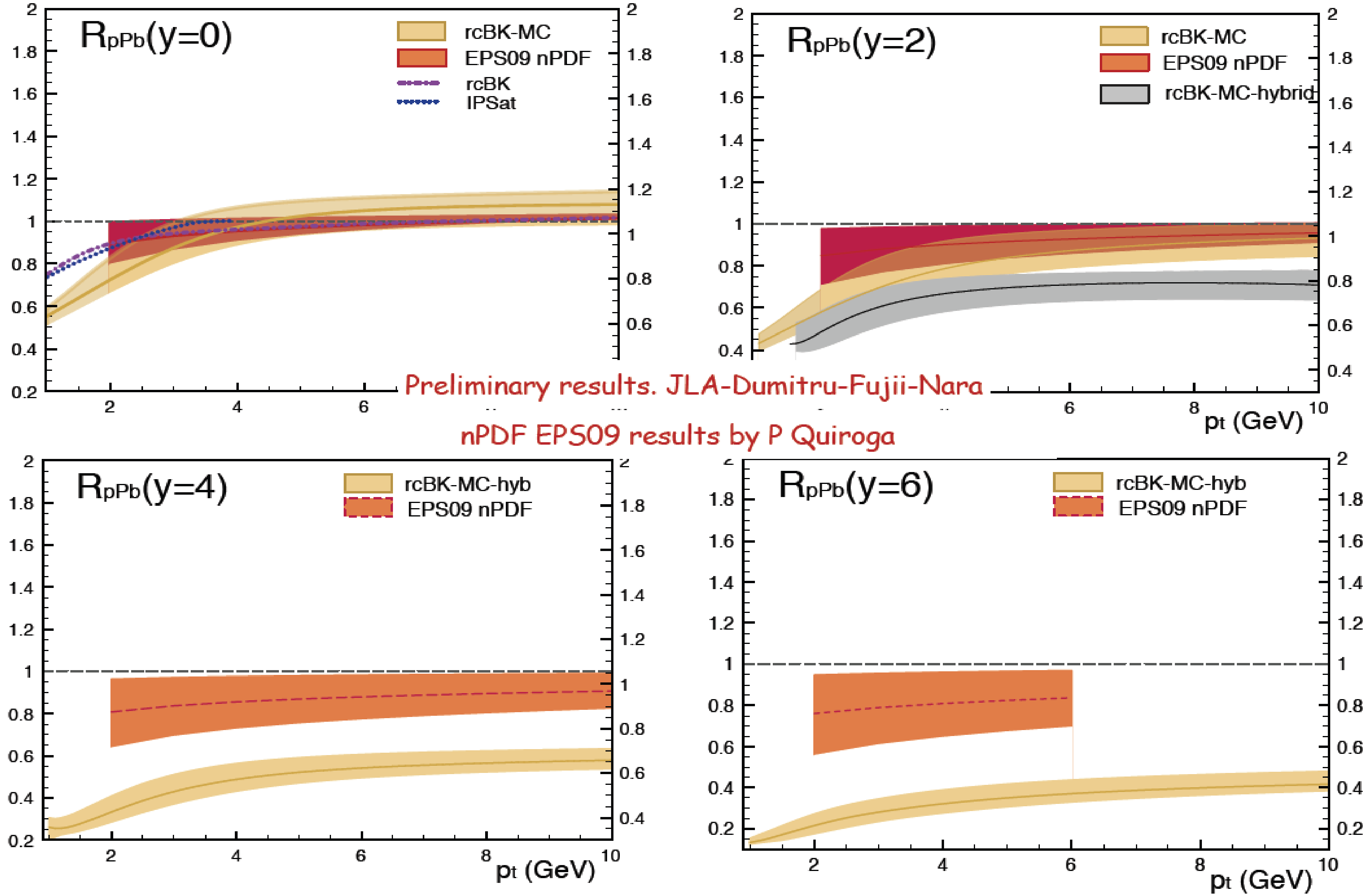
JLA-Marquet
Jalilian Marian - Rezaeian

Problem cured when using Monte Carlo tools for geometry dependence (ensures self consistency)

Slide from Albacete

Moving forward: Testing the evolution





Preliminary results. JLA-Dumitru-Fujii-Nara

nPDF EPS09 results by P Quiroga

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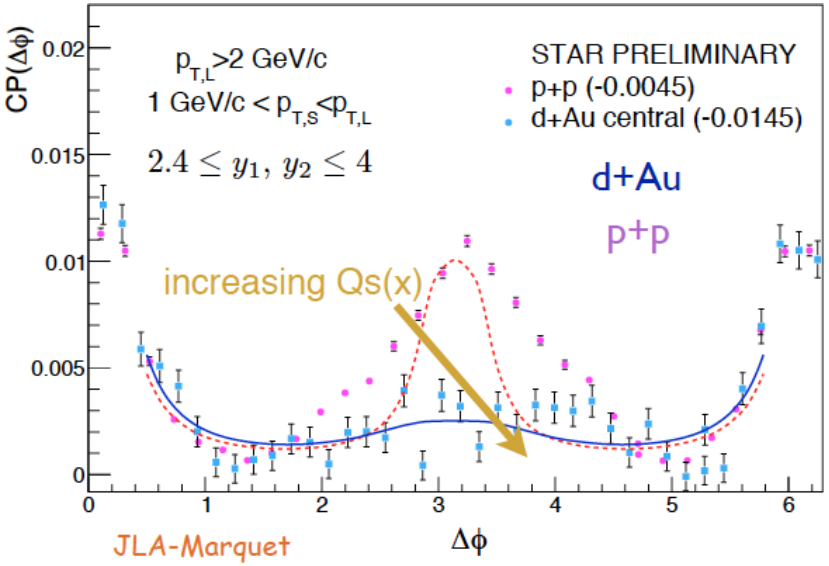
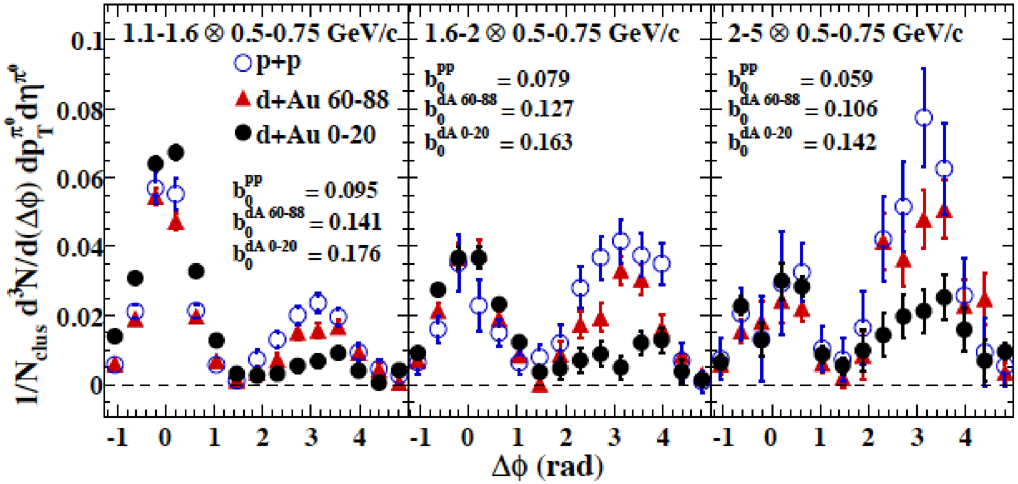
Two Particle Correlations

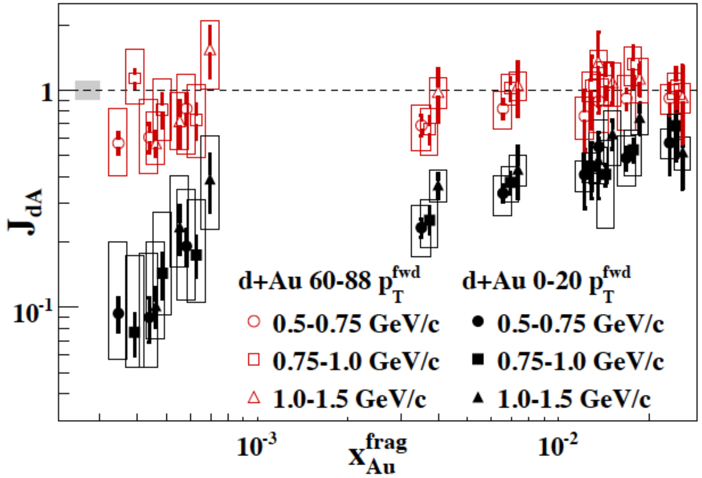


Decorrelation happens if

$$p_{t1(2)} \lesssim Q_s$$

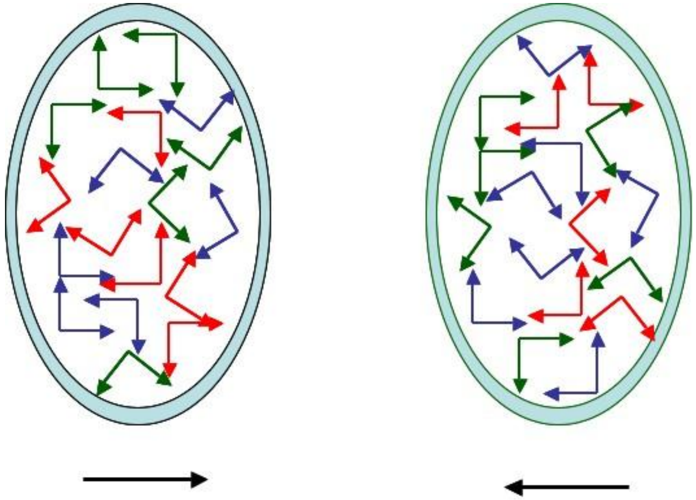
Increase saturation momentum by going forward or making centrality cut





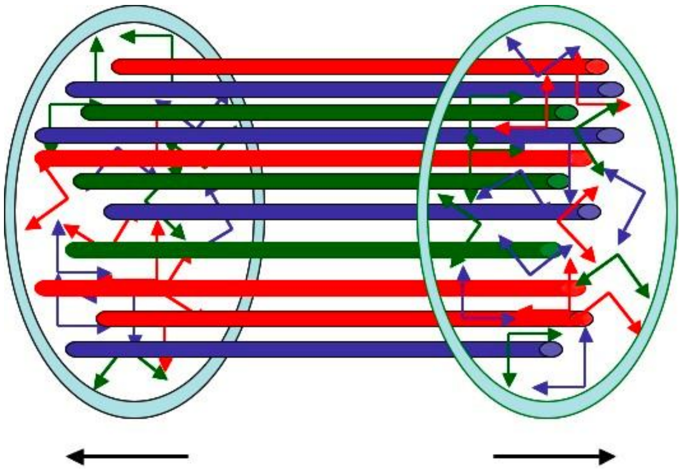
Phenix

Collisions of two sheets of colored glass



Long range color fields form in very short time

Sheets get dusted with color electric and color magnetic fields



Maximal local density of topological charge: Large local fluctuations in CP violating

$$\vec{E} \cdot \vec{B}$$

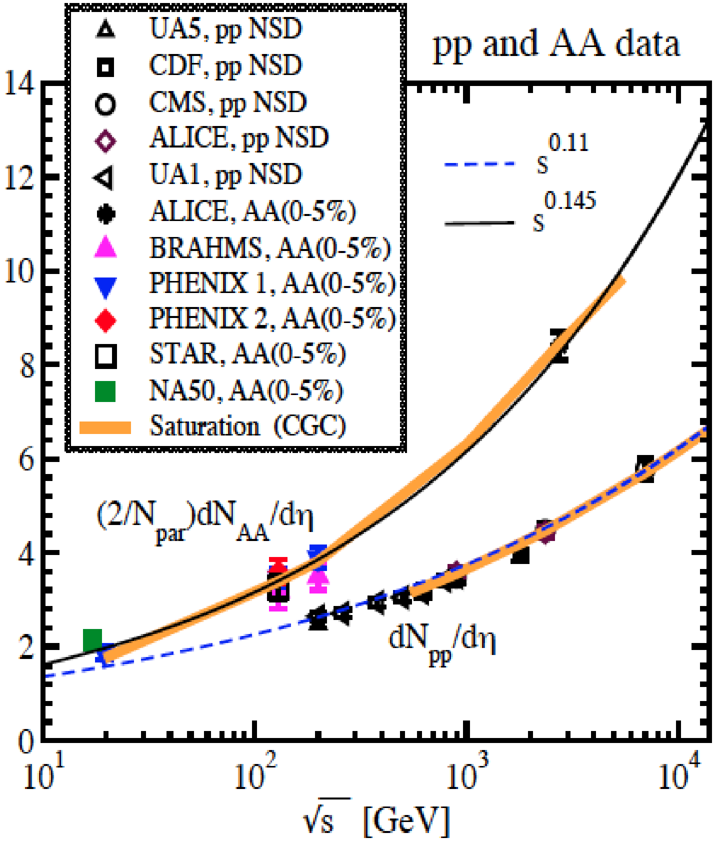
Glasma: Matter making the transition for Color Glass Condensate to Quark Gluon Plasma

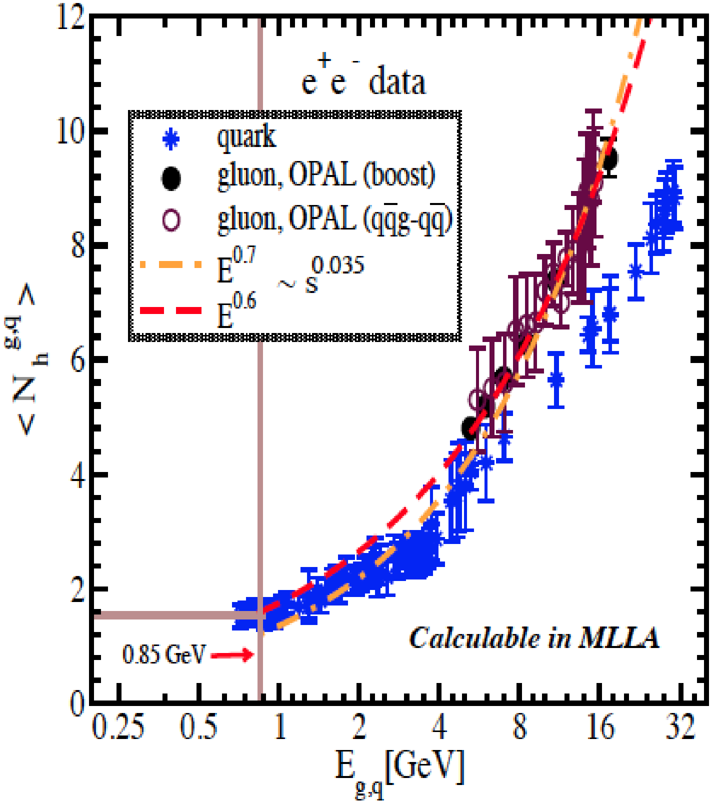
The initial conditions for a Glasma evolve classically and the classical fields radiate into gluons
Longitudinal momentum is red shifted to zero by longitudinal expansion

But the classical equations are chaotic:
Small deviations grow exponentially in time

Dependence of Multiplicity on Energy Understood

Levin and AR, 1102.2385

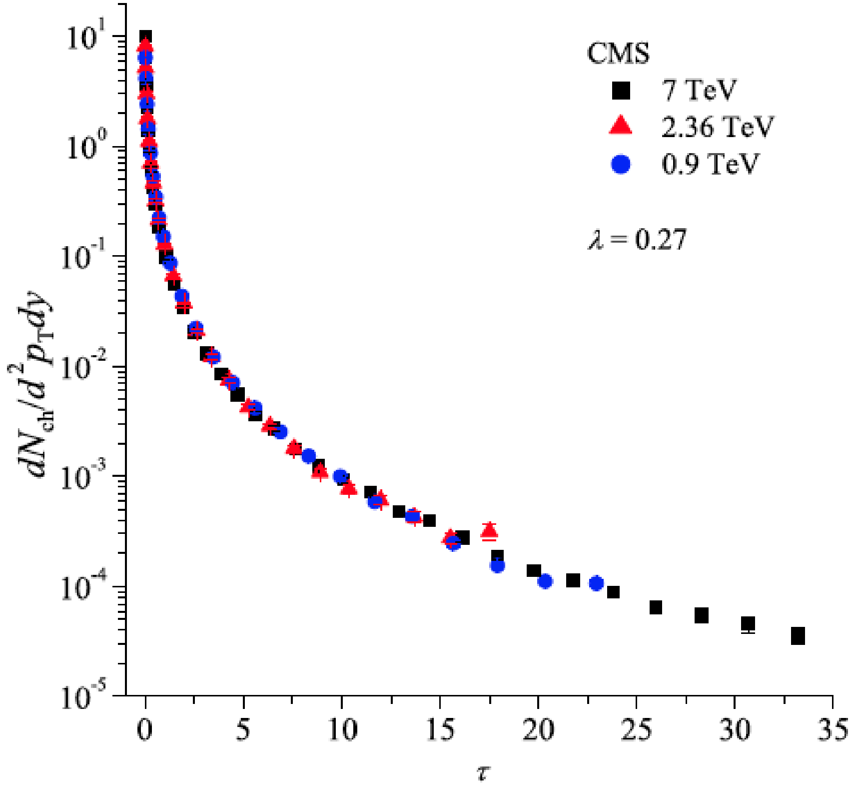


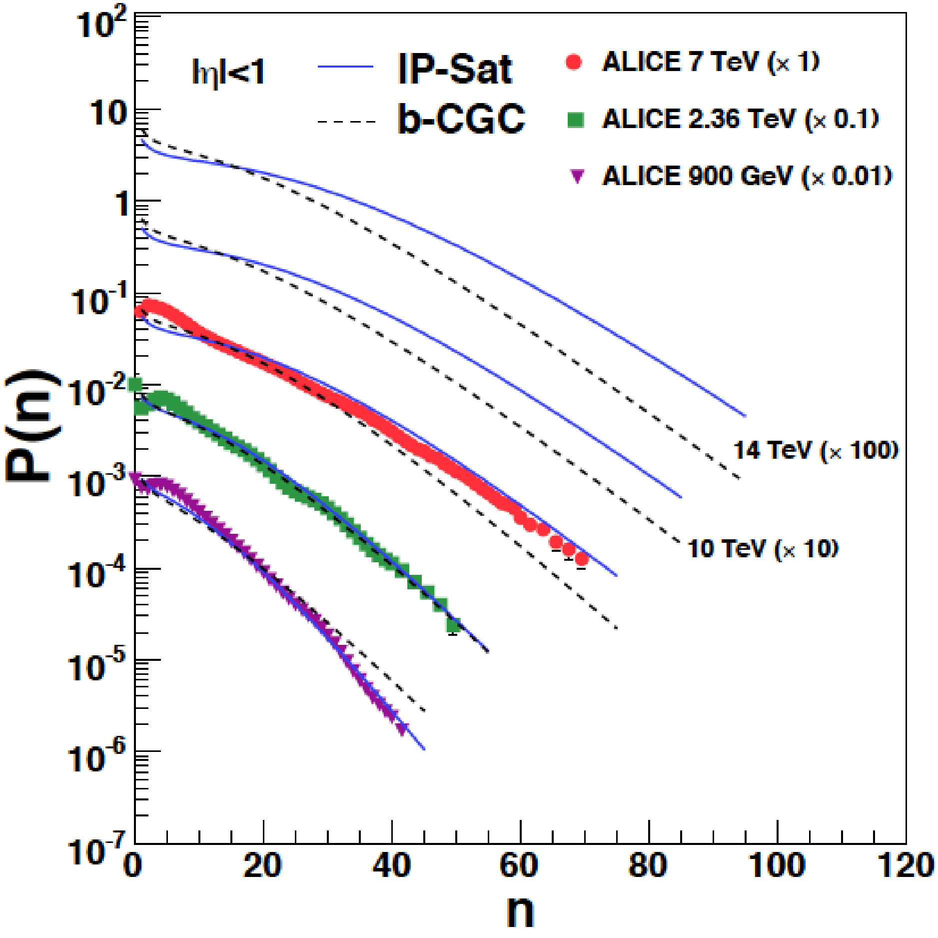


$$\frac{dN_h}{d\eta} \propto Q_s^2 \propto s^{0.11} \quad \text{for} \quad Qs \leq 1 \text{ GeV}$$

$$\frac{dN_h}{d\eta} \propto s^{0.11} * s^{0.035} = s^{0.145} \quad \text{for} \quad Qs > 1 \text{ GeV}$$

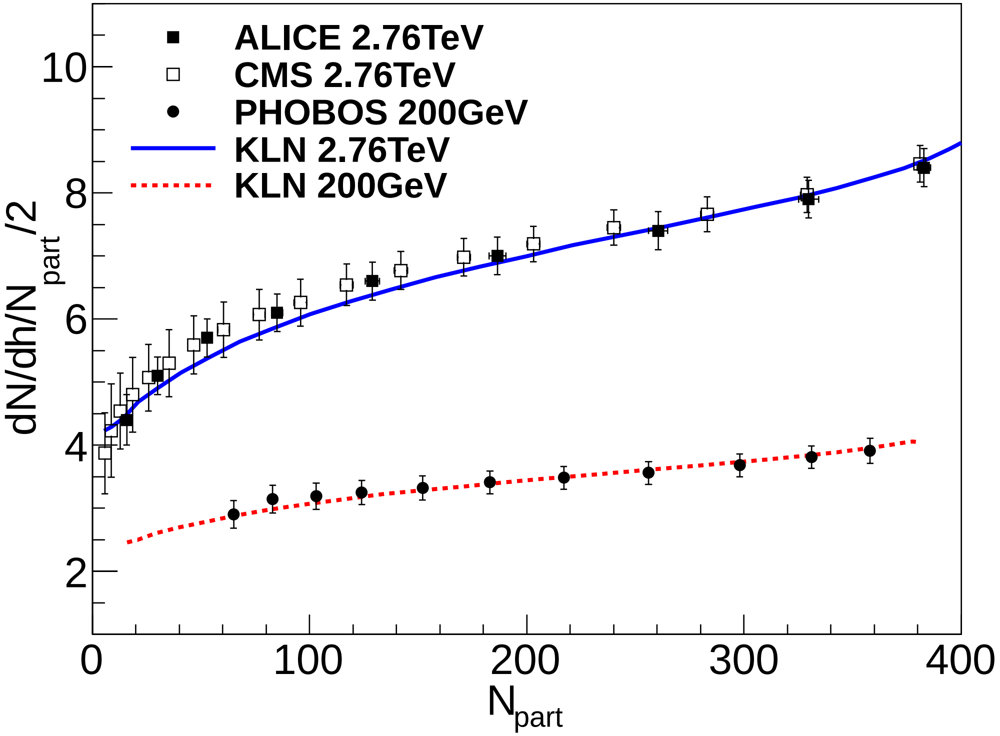
Transverse momentum distributions in LHC pp collisions have geometric scaling
Fluctuations in pp collisions follow predictions form CGC-Glasma





$$\frac{1}{\pi R^2}\frac{dN}{dyd^2p_T} \sim \frac{1}{\alpha_s}F(p_t/Q_{sat}(p_t))$$

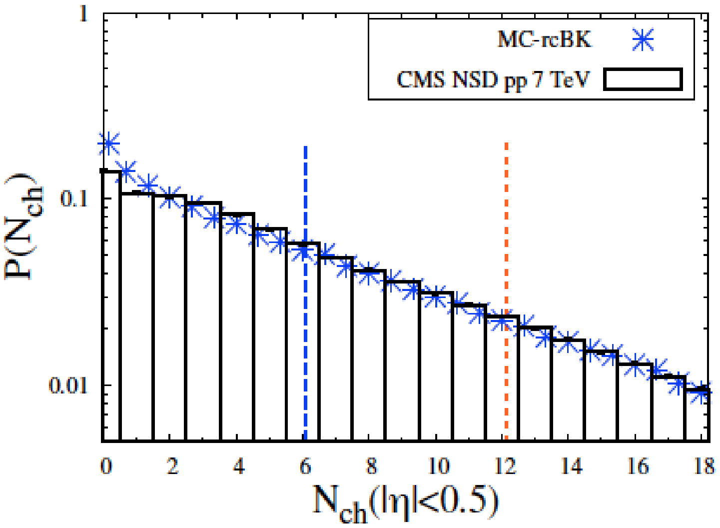
Negative binomial and KNO
quantitatively predicted by CGC-Glasma

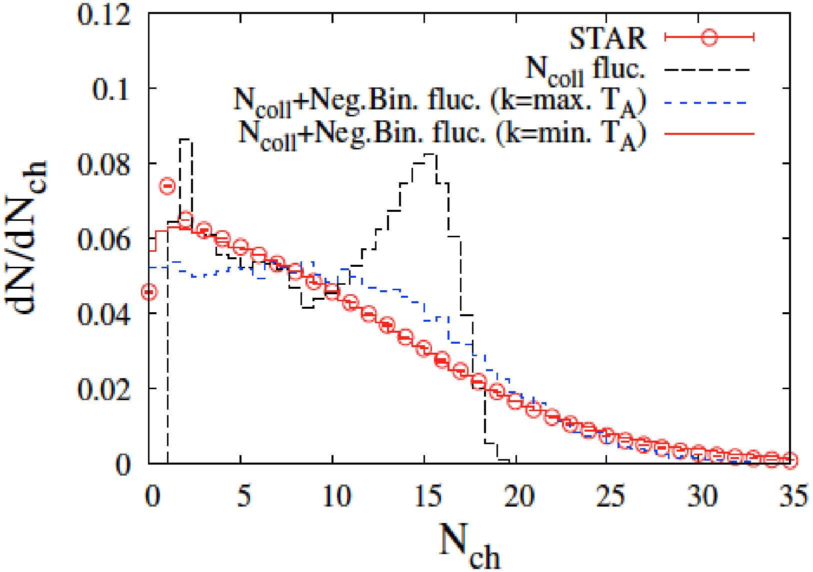


Negative binomial distribution parameters and KNO scaling predicted by CGC

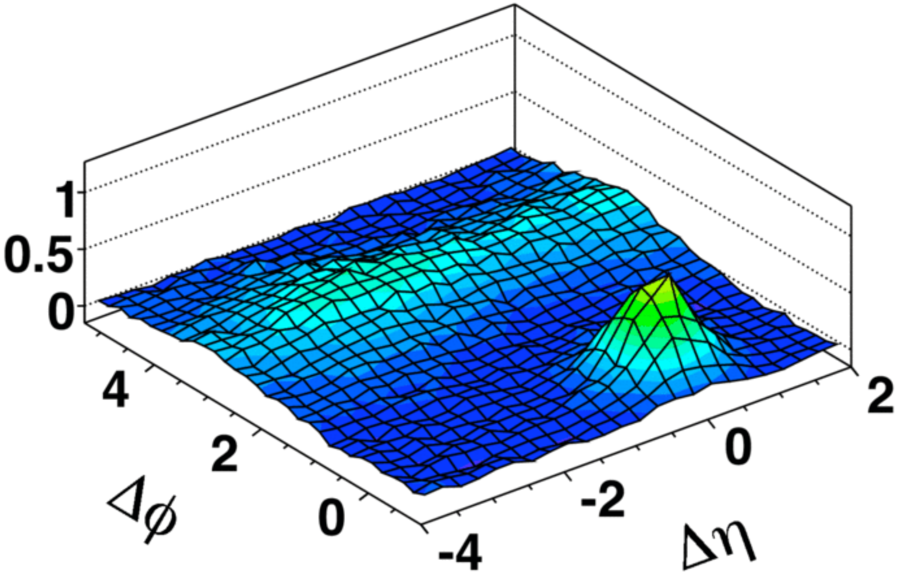
Important for higher order vn flow analysis, and inclusive ridge

Multiplicity distributions in d+Au and p+p well described [Dumitru and Nara, 1201.6382]





Near-side correlations, $\Delta\Phi \ll \pi$
(the “ridge”)

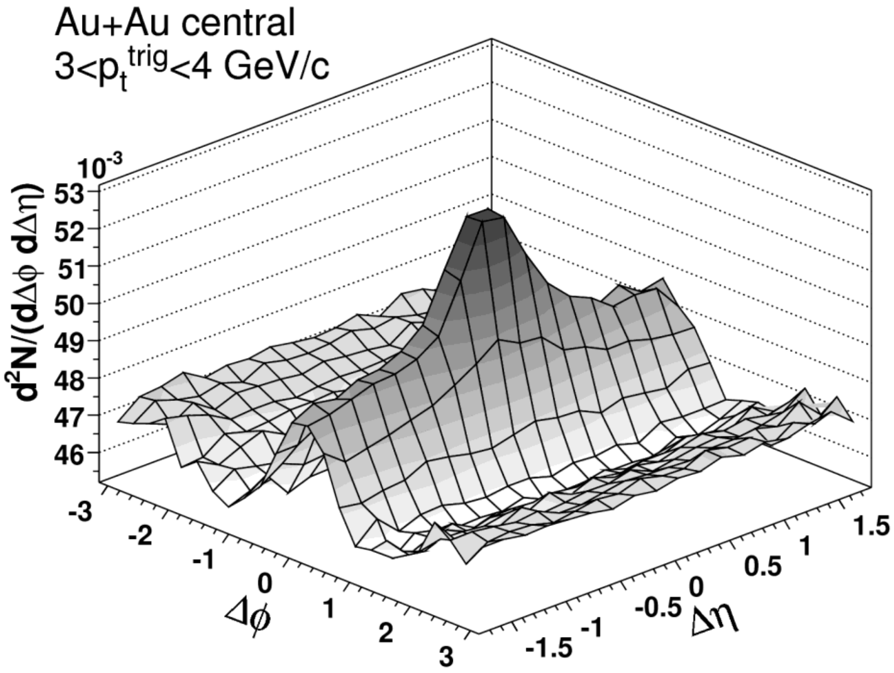


PYTHIA pp, $p_T^{trig} > 2.5$ GeV

STAR (arXiv:0909.0191)

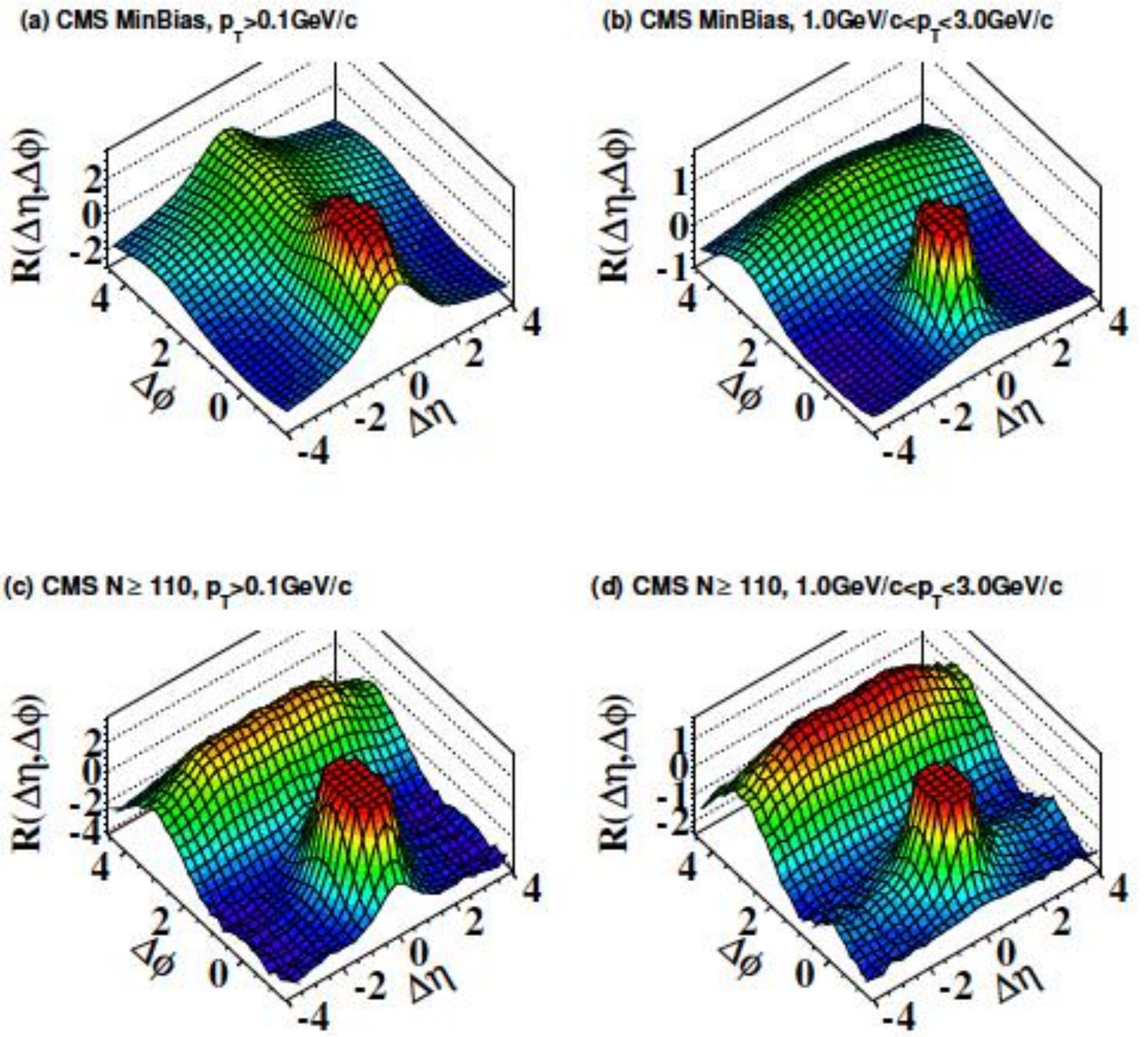
PHOBOS (arXiv:0903.2811):

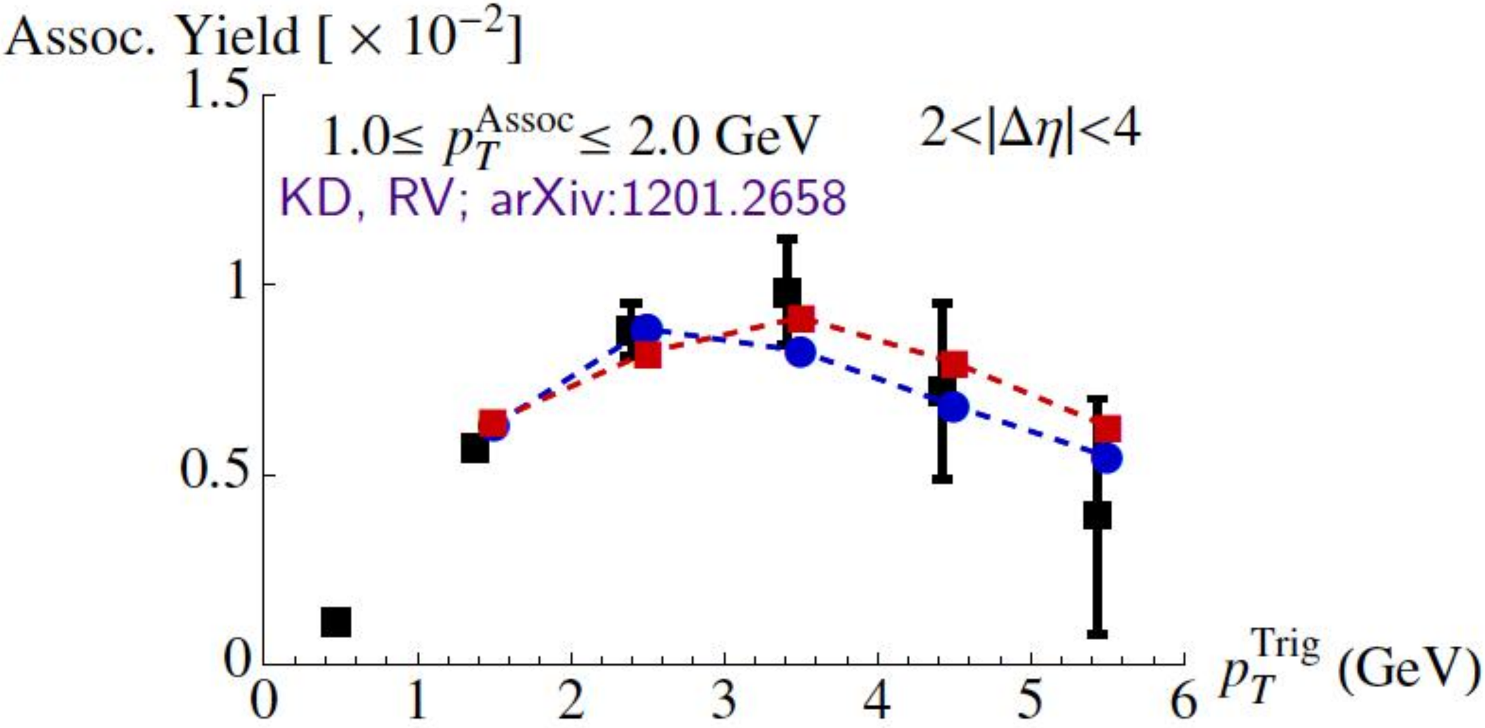
$ln(z\Lambda_{QCD}) \sim \Delta\eta$



Causality requires that
correlations of long range in
rapidity must be made very
early:
Not originating in QGP
Not jet interactions

CMS Sees Ridge over 8 units of rapidity! High Multiplicity Events
p_T ~ 1-3 Gev





Red: Harder Fragmentation

$D = 2(1-x)/x$

Blue: Softer Fragmentation

$D = 3(1-x)^2/x$

The Ridge is a Snapshot of a Color Electric or Magnetic Flux

LHC:

Tubes exist on sub-fermi transverse size scale
Perhaps as small as .2 Fm
They are formed very early in the collision

Angular peaking:

Intrinsic peaking at emission?
Opacity?
Flow or nascent flow effects?

Probably different combination of mechanisms:

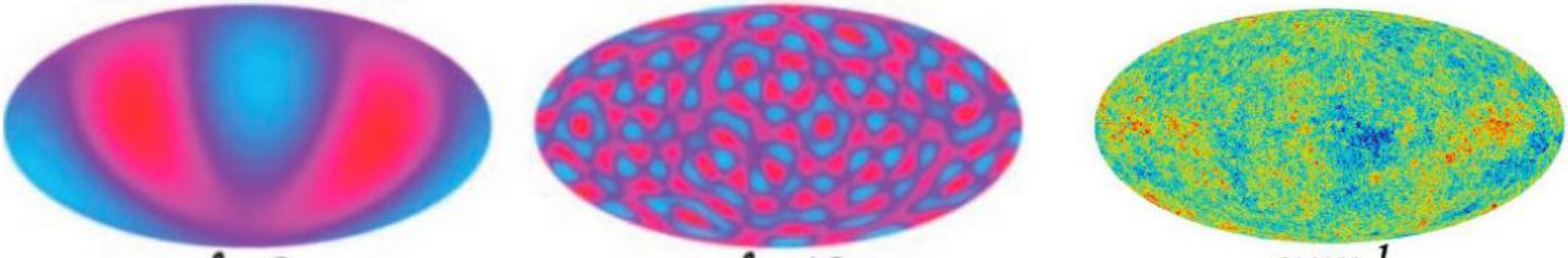
High multiplicity pp
High transverse momentum AA
Inclusive AA

Higher order Eccentricities in AA

$$\epsilon_n = \frac{\sqrt{\langle r^2 \cos(n\phi)\rangle^2 + \langle r^2 \sin(n\phi)\rangle^2}}{\langle r^2\rangle}$$

Analogy: CMB

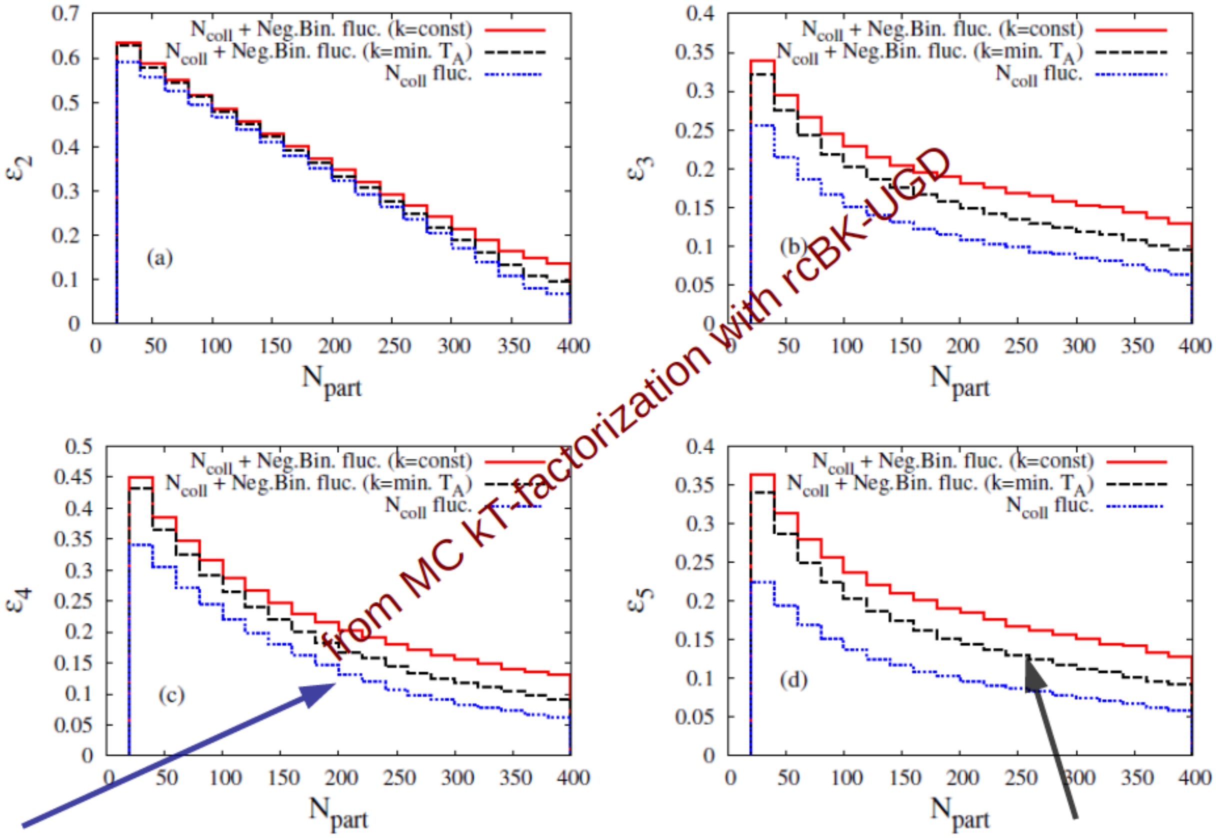
A. Mocsy & P. Sorensen



$\ell = 2$ $\ell = 16$ *sum l*

Sources of Initial Fluctuations in the Transverse Plane:
(always need longitudinal correlations generated by tubular flux tube structures)

Eccentricities ε_n in Au+Au



from MC kT-factorization with rcBK-UGD

Glauber fluc only

Glauber + NBD
k ~ min(T_A,T_B)

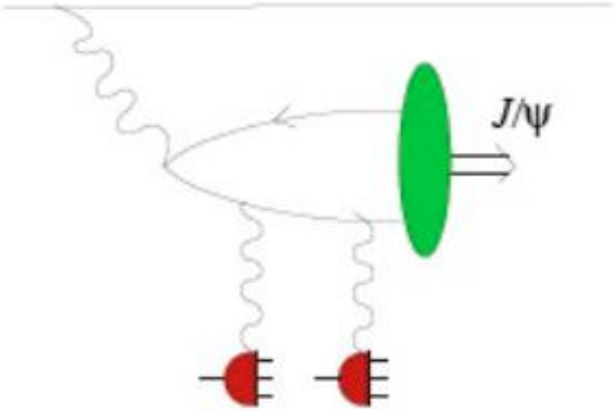
Fluctuations of positions of nucleons in the collisions

Fluctuations in the multiplicity of decays of flux tubes (a boost invariant negative binomial distribution)

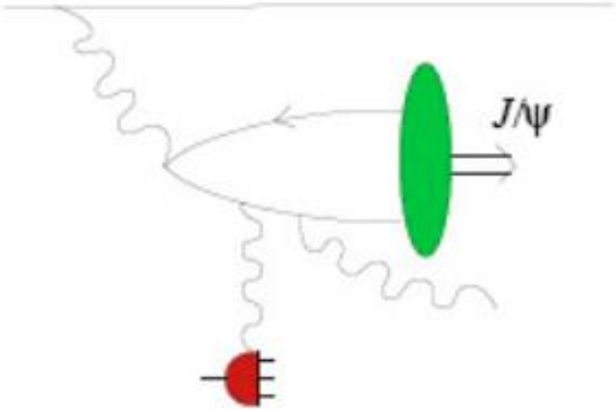
J/Psi Production

If J/Psi mass is less than saturation scale, J/Psi is like a low mass hadron

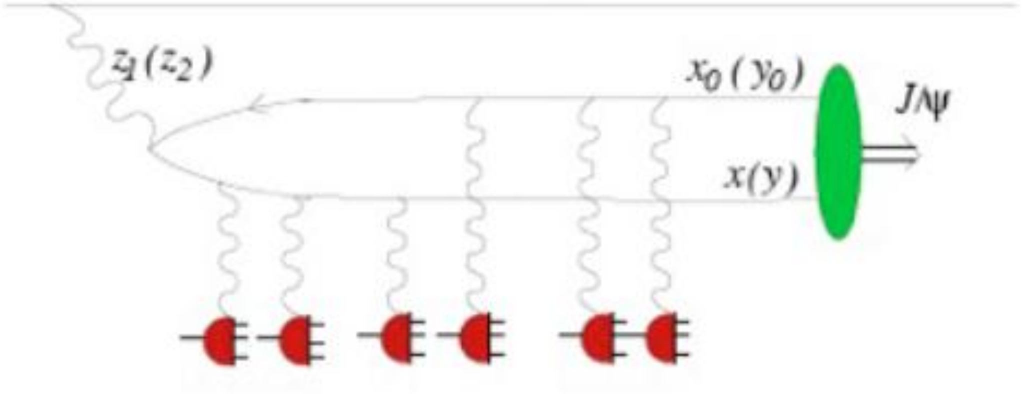
$$\alpha_s^2 A^{1/3} \sim 1$$



$$\alpha_s^6 A^{2/3} \sim \alpha_s^2$$



$$\alpha_s^5 A^{1/3} \sim \alpha_s^3$$

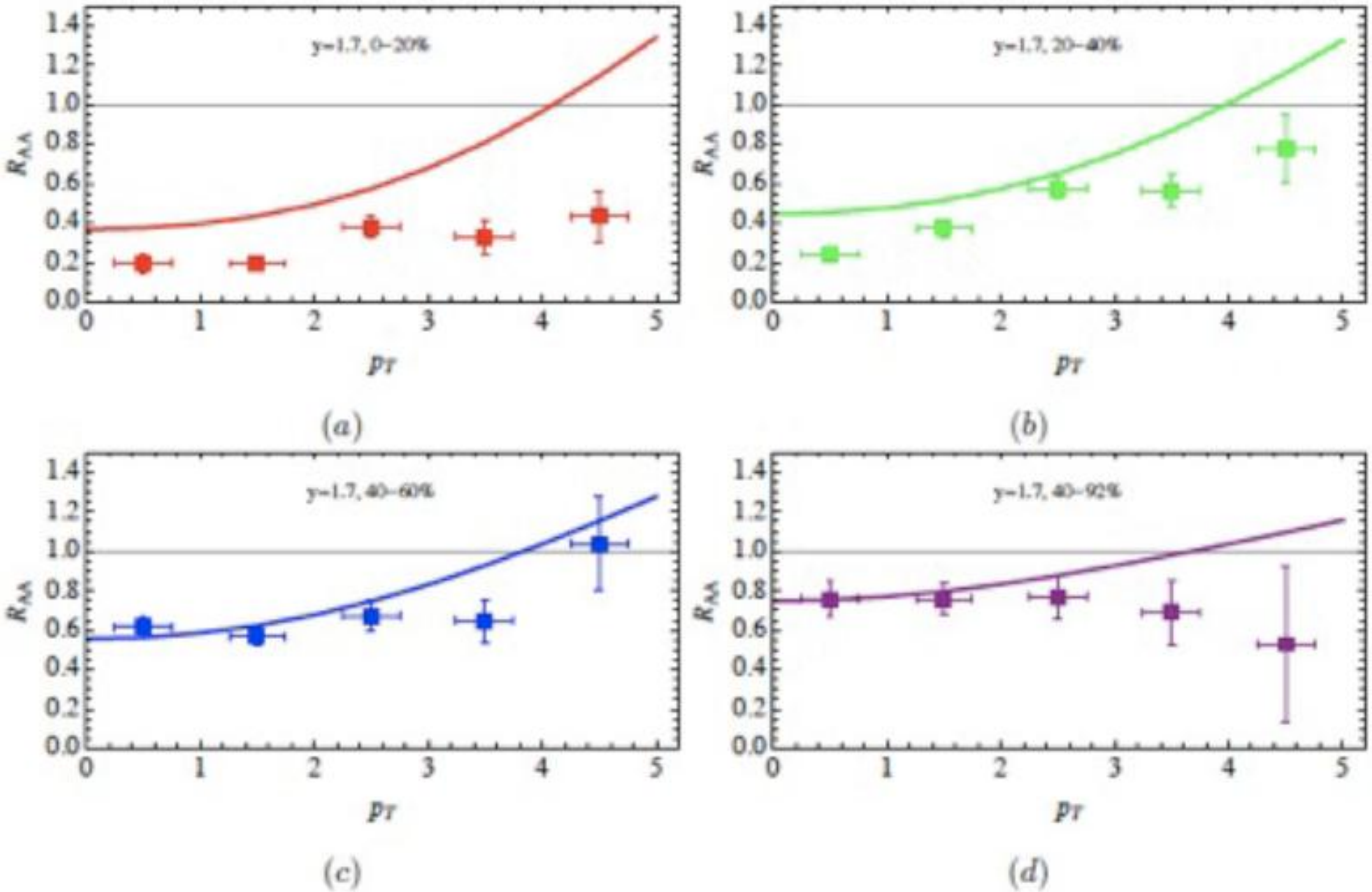


DK, K.Tuchin, hep-ph/0510358

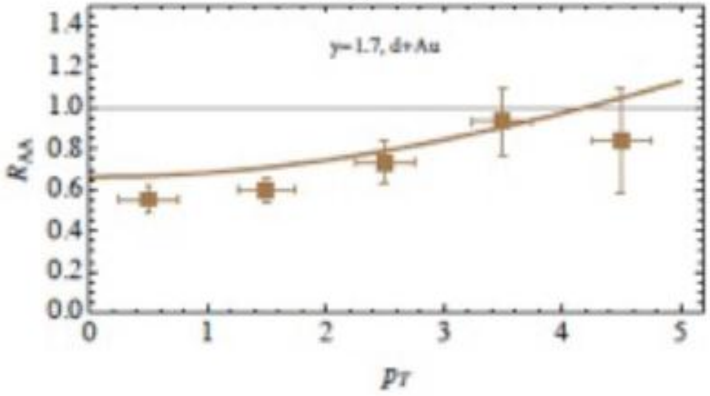
Comparison of expectations from CGC for R_AA expectations at RHIC at forward rapidity

Solid lines are expectations. First four are various centralities of AA

Bottom is dAu



(a) (b) (c) (d)



DK, E.Levin, K.Tuchin, arxiv: 1205.1554

New Phenix Data