On the onset of the ridge structures and the universal geometrical scaling of the elliptic flow

C.Pajares
Deparment Particle Physics and IGFAE
University Santiago de Compostela
ICNFP 2014 Creta

Non orthodox view of ridge and elliptic flow

Scaling law(geometrical scaling) for the elliptic flow

Onset of the ridge structures in pp,pA and AA as interactions among strings,above a critical string density(string percolation)

$$\frac{1}{N_A}\frac{dN_{ch}}{dp_T^2} = \frac{1}{Q_0^2}F(\tau), \qquad \tau = \frac{p_T^2}{\left(Q_s^A\right)^2}$$

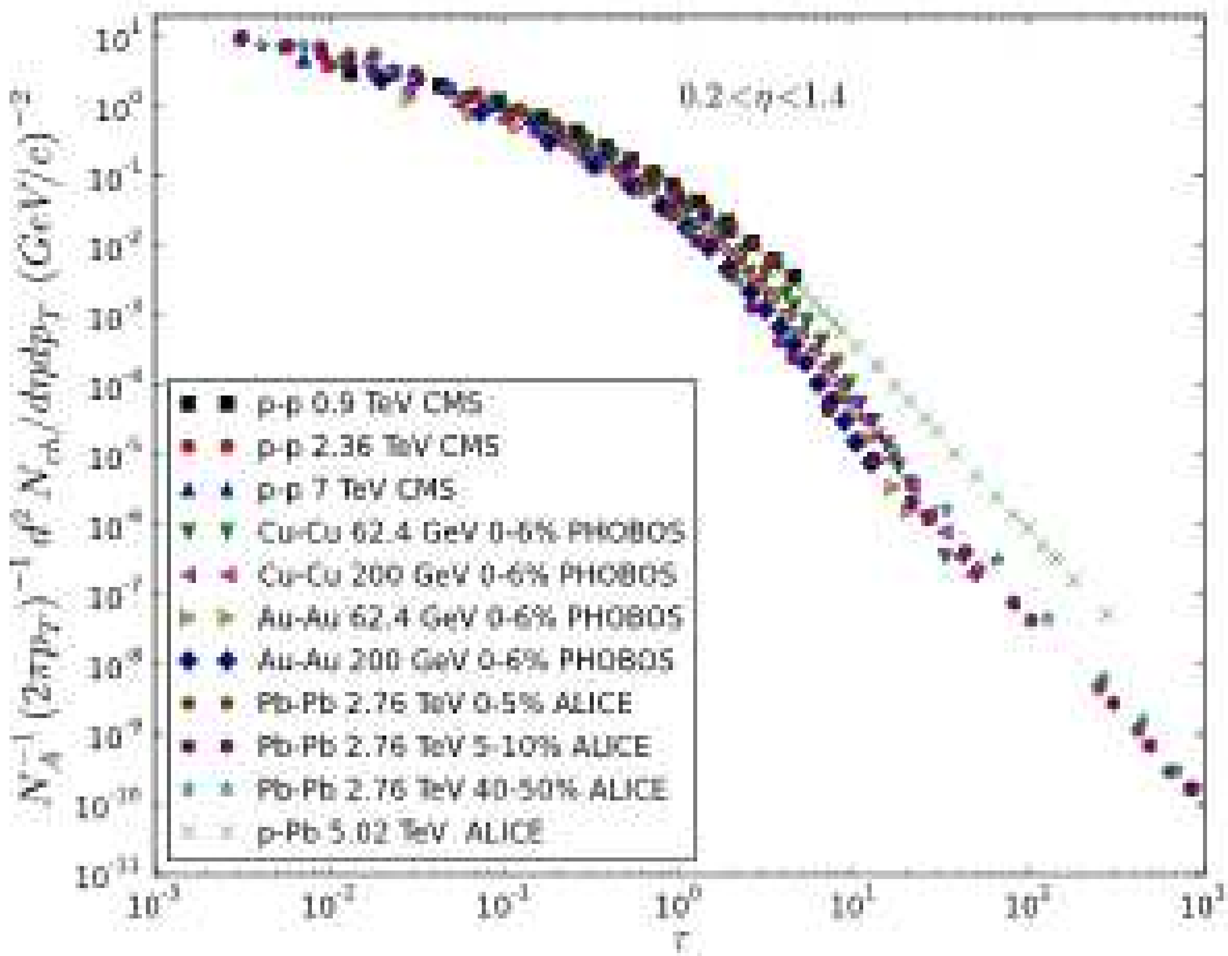
$$\left(Q_s^A\right)^2 = \left(Q_s^p\right)^2 A^{\alpha(s)/2} N_A^{1/6}$$

$$\alpha(s) = \frac{1}{3}\left(1 - \frac{1}{1 + \ln\left(\sqrt{s/s_0} + 1\right)}\right)$$

and

$$\left(Q_s^p\right)^2 = Q_0^2\left(\frac{W}{p_T}\right)^{\lambda},$$

with $Q_0 = 1$ GeV, $W = \sqrt{s} \times 10^{-3}$ and $\lambda = 0.27$.



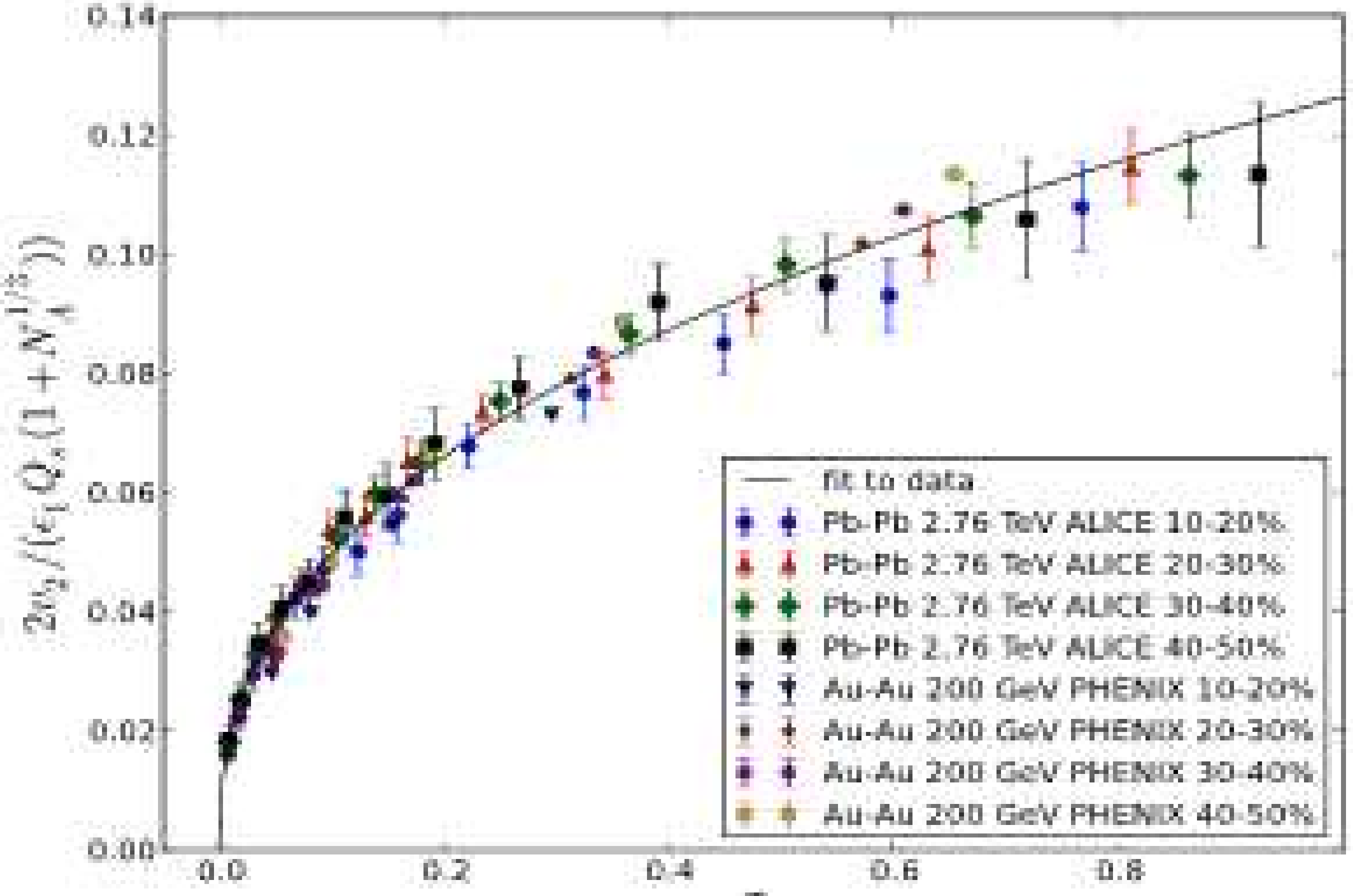
0.2<η<1.4
p-p 0.9 TeV CMS
p-p 2.36 TeV CMS
p-p 7 TeV CMS
Cu-Cu 62.4 GeV 0-6% PHOBOS
Cu-Cu 200 GeV 0-6% PHOBOS
Au-Au 62.4 GeV 0-6% PHOBOS
Au-Au 200 GeV 0-6% PHOBOS
Pb-Pb 2.76 TeV 0-5% ALICE
Pb-Pb 2.76 TeV 5-10% ALICE
Pb-Pb 2.76 TeV 40-50% ALICE
p-Pb 5.02 TeV ALICE

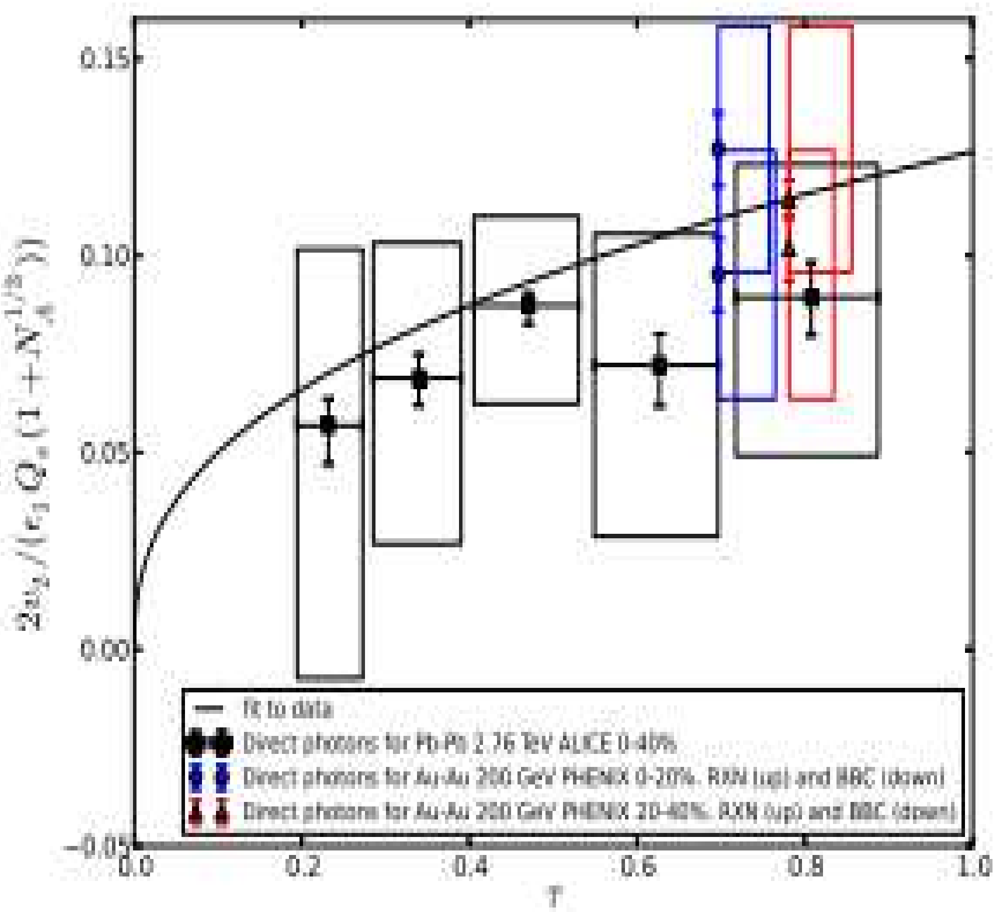
$$\frac{v_2(p_T)}{\epsilon_1 Q_s^A L} = f(\tau) \qquad \text{or} \qquad v_2 k_n = \epsilon_1 \tau \varphi(\tau) \qquad k_n = \frac{\lambda_{mfp}}{L}$$

$$\epsilon_1 = \frac{2}{\pi}\int_0^{\pi/2} d\varphi \cos 2\varphi \frac{R^2 - R_\varphi^2}{R^2}, \quad R_\varphi = \frac{R_A \sin(\varphi - \alpha)}{\sin\varphi}$$

$$\alpha = \arcsin(\frac{b}{2R_A}\sin\varphi), \quad R^2 = \langle R_\varphi^2 \rangle = \frac{2}{\pi}\int_0^{\pi/2} d\varphi R_\varphi^2$$

$$L = (1 + N_A^{1/3})/2,$$


0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.2
0.4
0.6
0.8
τ
fit to data
Pb-Pb 2.76 TeV ALICE 10-20%
Pb-Pb 2.76 TeV ALICE 20-30%
Pb-Pb 2.76 TeV ALICE 30-40%
Pb-Pb 2.76 TeV ALICE 40-50%
Au-Au 200 GeV PHENIX 10-20%
Au-Au 200 GeV PHENIX 20-30%
Au-Au 200 GeV PHENIX 30-40%
Au-Au 200 GeV PHENIX 40-50%


fit to data
Direct photons for Pb-Pb 2.76 TeV ALICE 0-40%
Direct photons for Au-Au 200 GeV PHENIX 0-20%, RXN (up) and BBC (down)
Direct photons for Au-Au 200 GeV PHENIX 20-40%, RXN (up) and BBC (down)
0.15
0.10
0.05
0.00
−0.05
0.0
0.2
0.4
0.6
0.8
1.0
T

$$\left(Q^A_{s\varphi}\right)^2 \equiv \frac{L}{\lambda_{mfp}}\frac{1}{R^2_\varphi} = \frac{1}{k_n R^2_\varphi} = \frac{Q^A_s L}{R^2_\varphi}.$$

$$v_2 = \frac{\int_0^{\pi/2} d\varphi \cos 2\varphi \frac{dN}{dp_T^2 d\varphi}}{\frac{1}{2\pi}\frac{dN}{dp_T^2}} = \frac{\int_0^{\pi/2} d\varphi \cos 2\varphi F(\tau_\varphi)}{\frac{1}{2\pi}F(\tau)}$$

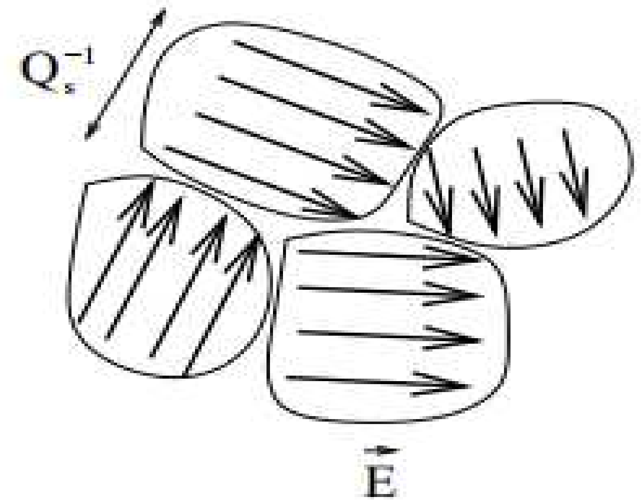
where

$$\tau_\varphi \equiv \frac{p_T^2}{\left(Q^A_{s\varphi}\right)^2} = \frac{p_T^2}{\left(Q^A_s\right)^2}\frac{R^2_\varphi}{L}Q^A_s = \tau\frac{R^2_\varphi}{L}Q^A_s$$

$$v_2 = \frac{2}{\pi}\int_0^{\pi/2} d\varphi \cos 2\varphi \frac{R^2 - R^2_\varphi}{R^2}\frac{1}{2\pi F(\tau)}\frac{dF}{d\tau}\tau Q^A_s L.$$

--Hydrodynamics,probably is not at the origin of encoding all the phi dependence in Qs and only at most can preserve it

--It suggests models including gluon saturation(or string parcolation)with a domain like structure(or cluster of strings structure)



--A parton interacts with the color fields of the cluster of strings(domain) in its way out, loosing energy.This gives rise to the elliptic flow

--Two partons leaving the same cluster are correlated with a transverse correlation length(1/Qs),and therefore are collimated in azimuthal angle(near side ridge structure)

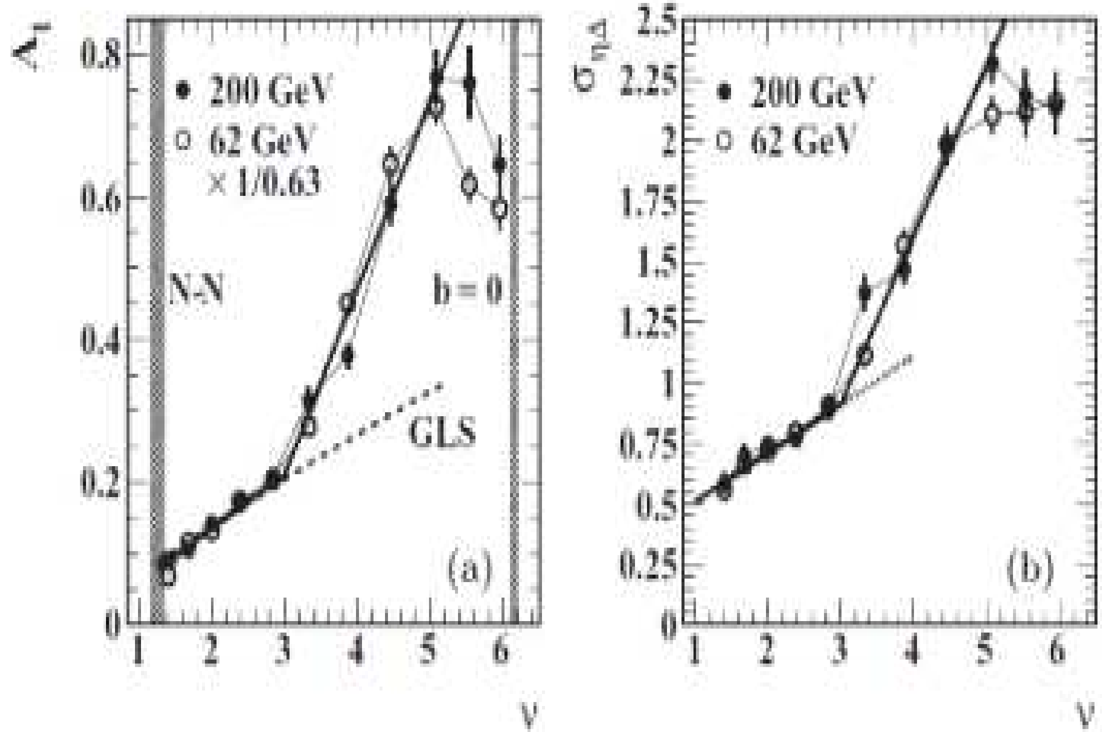
A.Kovner et al Phys Rev C83 034017 2011

M.A.Braun et al Nucl Phys A 906 14 2013

Results on 62 and 200 GeV Au-Au data from STAR

PHYSICAL REVIEW C 86, 064902 (2012)

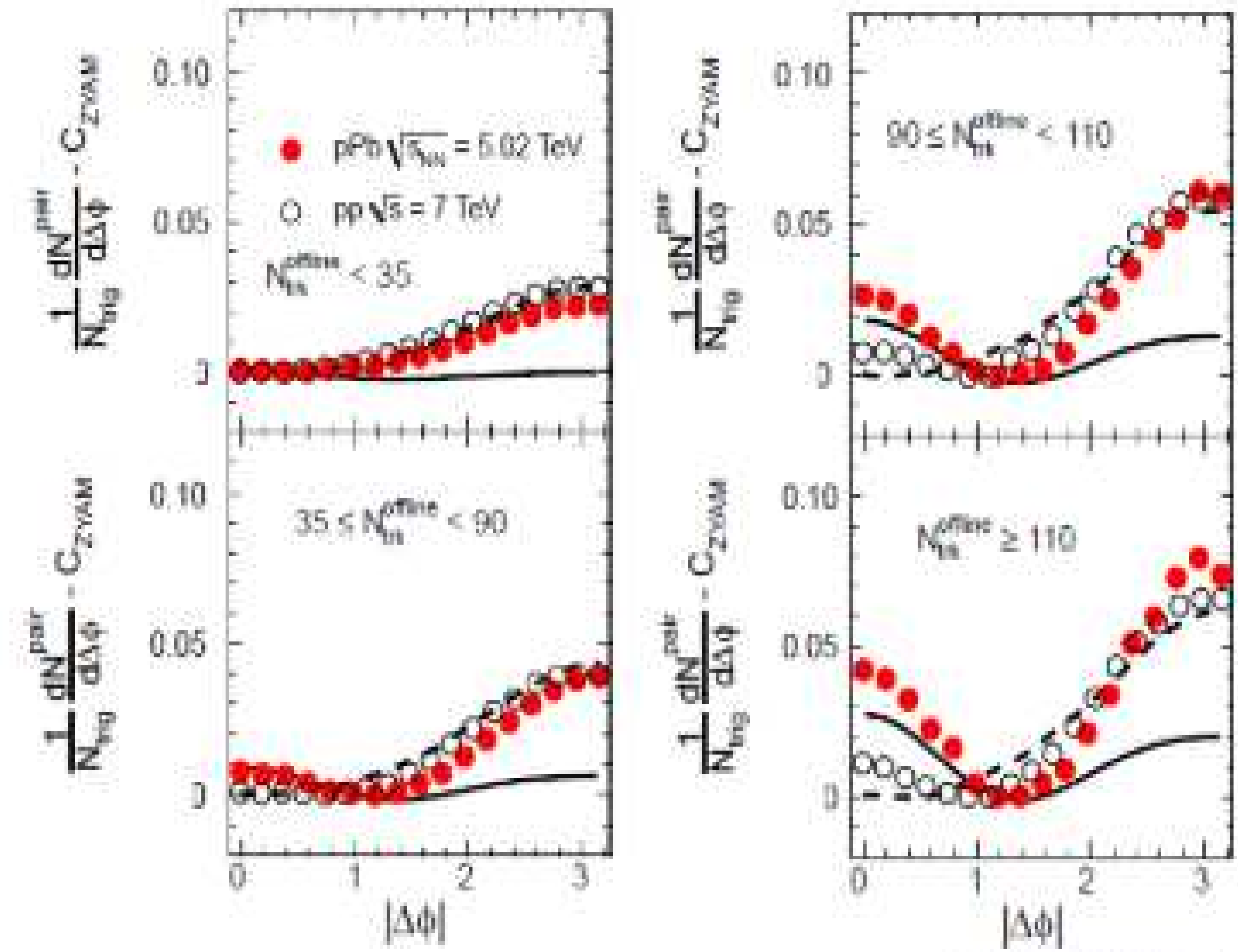
Anomalous centrality evolution of two-particle angular correlations from Au-Au collisions at $\sqrt{s_{NN}} = 62$ and 200 GeV



Physics Letters B 718 (2013) 795–814

Observation of long-range, near-side angular correlations in pPb collisions at the LHC ☆

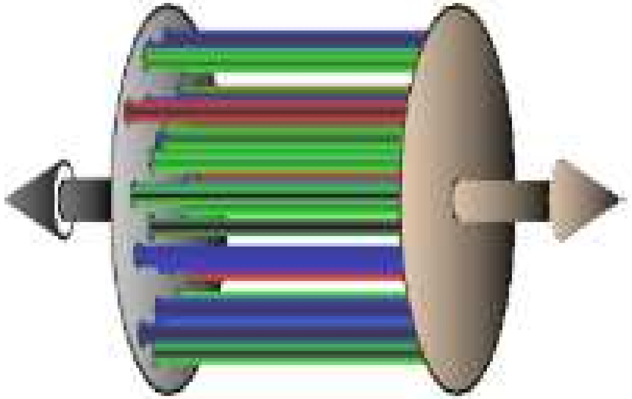
CMS Collaboration *

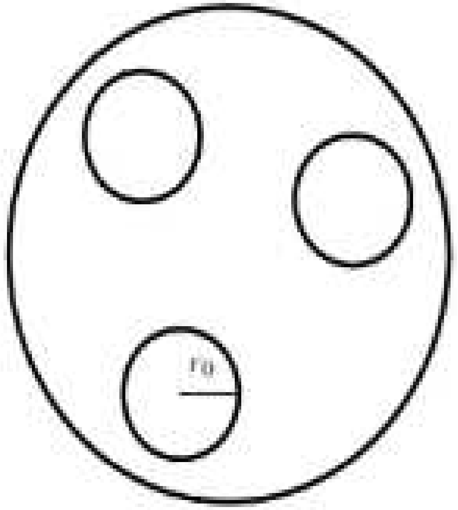


Outline

1. The string percolation model
2. Ridge structure
3. Results

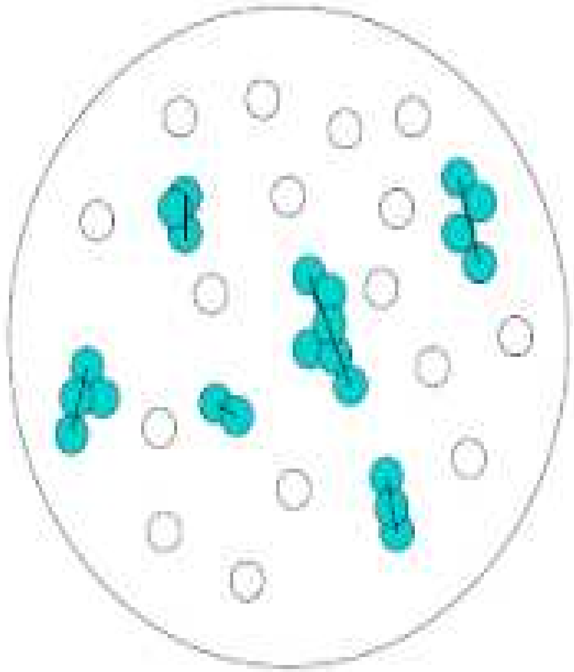
Physical picture





$r_0 = 0.2 - 0.25\ fm$

- Projectile and target interact via color field created by the constituent partons of the nuclei.
- Color field is confined in a region with transverse size $r_0 \sim$ **0.2 fm**.
- We can see them as small areas in transverse plane.
- These color "strings" break producing $q\bar{q}$ pairs (Schwinger mechanism) that subsequently lead to the observed hadrons.



- With growing energy and/or atomic number of colliding particles, the number of **sources** grows → The **number of strings** grows with energy and/or atomic number.
- The **number of strings** also increases with increasing centrality.
- Strings are **randomly distributed** in transverse plane so they can overlap forming clusters.

String fusion

- A cluster of n strings **behaves like a single string with a color field**

$$\vec{Q}_n = \sum_{1}^{n} \vec{Q}_1$$

.

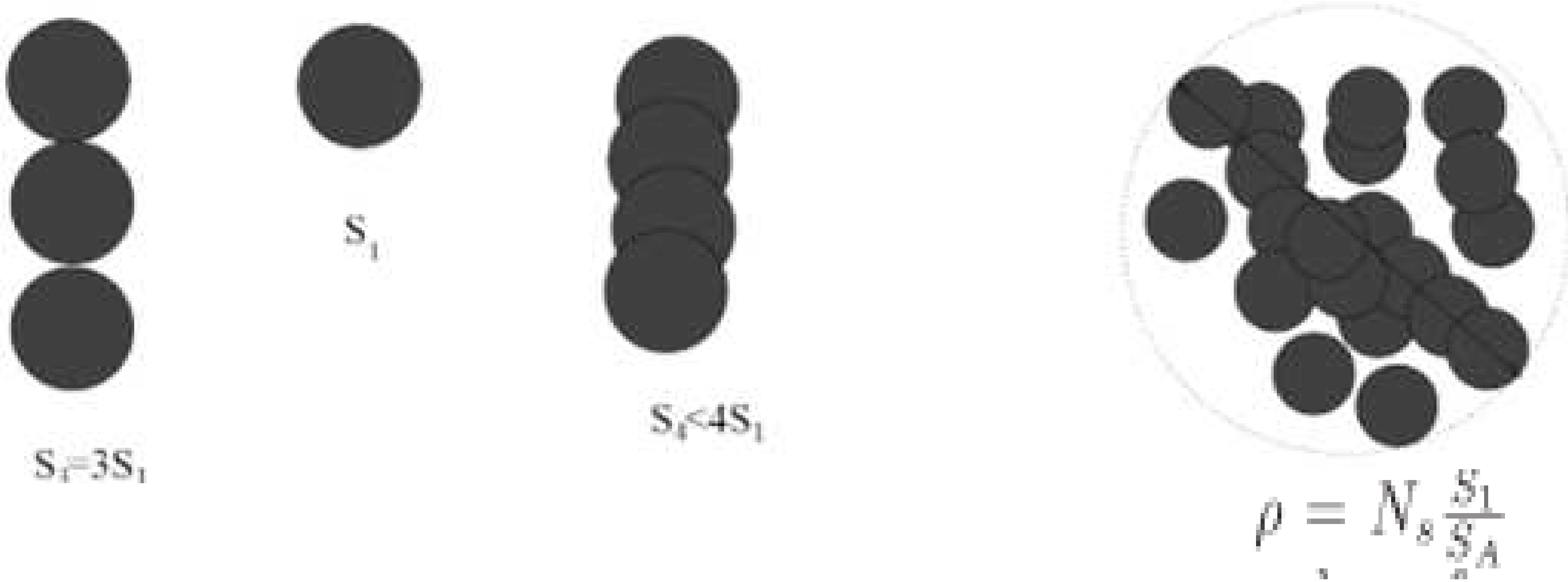
- The field is **randomly oriented** so

$$\left\langle \vec{Q}_n^2 \right\rangle = n \left\langle \vec{Q}_1^2 \right\rangle$$

- Using the Schwinger formula

$$\mu_n = \sqrt{\frac{nS_n}{S_1}}\mu_1 , \quad \left\langle p_T^2 \right\rangle_n = \sqrt{\frac{nS_1}{S_n}} \left\langle p_T^2 \right\rangle_1$$

where μ_n and $\left\langle p_T^2 \right\rangle_n$ are, respectively, the multiplicity and the mean p_T^2 of the particles created by the fragmentation of a cluster of n strings ocupping an area S_n.



- Limiting cases

$$\text{a)}\quad S_n = nS_1 \longrightarrow \mu_n = n\mu_1\,, \quad \langle p_T^2 \rangle_n = \langle p_T^2 \rangle_1$$

$$\text{b)}\quad S_n = S_1 \longrightarrow \mu_n = \sqrt{n}\mu_1\,, \quad \langle p_T^2 \rangle_n = \sqrt{n}\,\langle p_T^2 \rangle_1$$

- **At a certain critical density 1.2-1.5 a macroscopic cluster appears which marks the percolation transition.**

Homogeneous and high density case

- Mean fraction of the area covered by clusters

$$\left(1 - e^{-\rho}\right)$$

More realistic profile and also low density

- Mean fraction of the area covered by clusters

$$A(\rho) = \frac{1}{1 + ae^{-(\rho-\rho_c)/b}}$$

- So the basic equations concerning clusters are

$$\mu_n = N_s F(\rho)\mu_1, \quad \langle p_T^2 \rangle_n = \langle p_T^2 \rangle_1 / F(\rho).$$

where

$$F(\rho) = \sqrt{\frac{1 - e^{-\rho}}{\rho}}.$$

String percolation and CGC

- Transverse size

Percolation	CGC
$r_0 F(\rho)^{1/2}$.	$1/Q_s$

- Effective number of clusters $\longrightarrow$ flux tubes

$$\langle N \rangle = \frac{(1-e^{-\rho})R^2}{r_0^2 F(\rho)} = \sqrt{1-e^{-\rho}}\sqrt{\rho}\left(\frac{R}{r_0}\right)^2 .$$

$$\langle N \rangle = \frac{1}{\alpha_s} Q_s^2 R_A^2$$

- **Normalized 2-particle correlation function**

$$\Re \equiv \frac{\langle n^2 \rangle - \langle n \rangle^2 - \langle n \rangle}{\langle n \rangle^2} = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle^2} = \frac{1}{k}$$

Low density limit: **n is basically Poisson-like** $\Longrightarrow k \to \infty$
High density limit: $\langle N^2 \rangle - \langle N \rangle^2 \approx \langle N \rangle \Longrightarrow k \to \langle N \rangle \to \infty$

$$k = \frac{\sqrt{\rho}\,(R/r_0)^2}{1 - e^{-\rho}} = \frac{\langle N \rangle}{(1 - e^{-\rho})^{3/2}}.$$

The two particle correlations can be written in a factorized form,

$$\frac{\Delta\rho}{\sqrt{\rho_{ref}}} = \mathcal{R}\frac{dn}{dy}G(\phi), \qquad \mathcal{R}\frac{dn}{dy} = \frac{\langle N \rangle}{k} = \left(1 - e^{-\rho}\right)^{3/2}$$

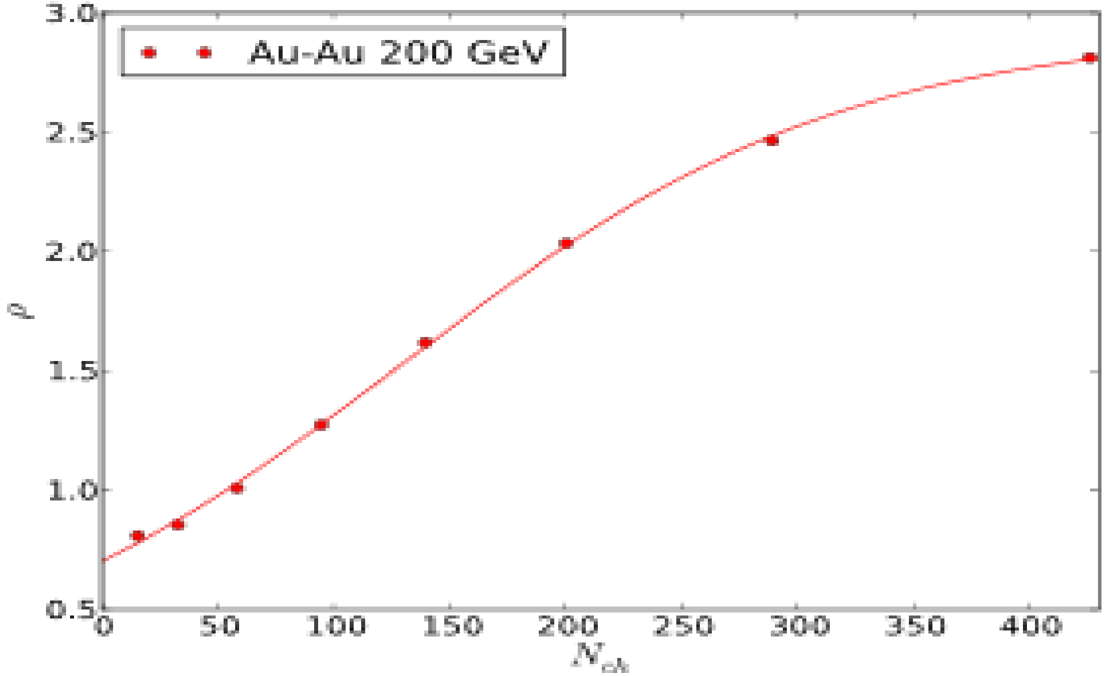
$$A_1 = cA(\rho)^{3/2} \qquad A(\rho) = \frac{1}{1 + ae^{-(\rho-\rho_c)/b}}$$

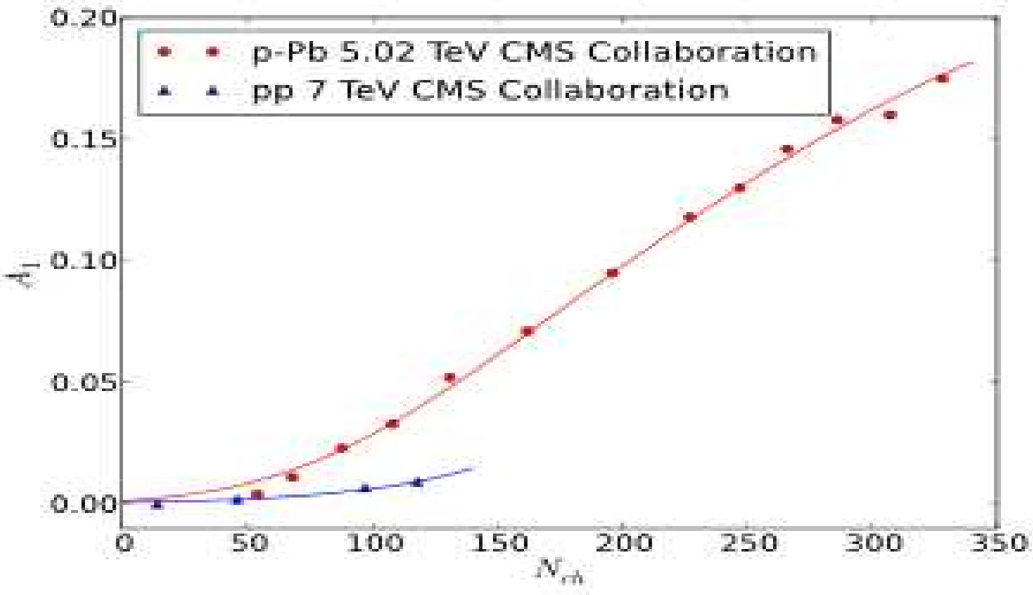
$\rho_c = 1.5$ $\quad a = 1.5$ $\quad b = 0.75$ for Au-Au

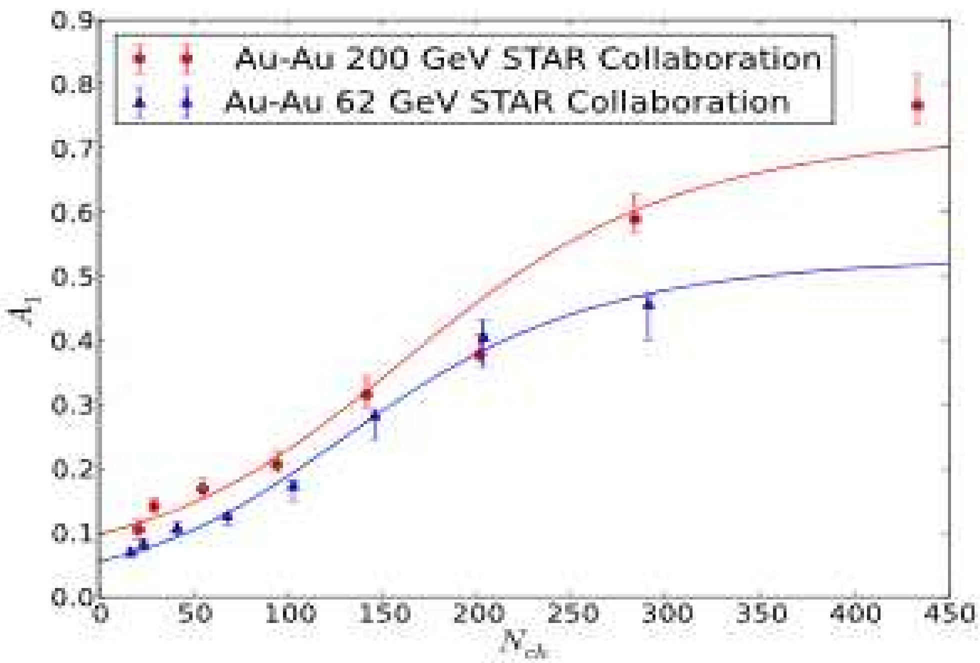
$b = 0.35$ pPb and pp.

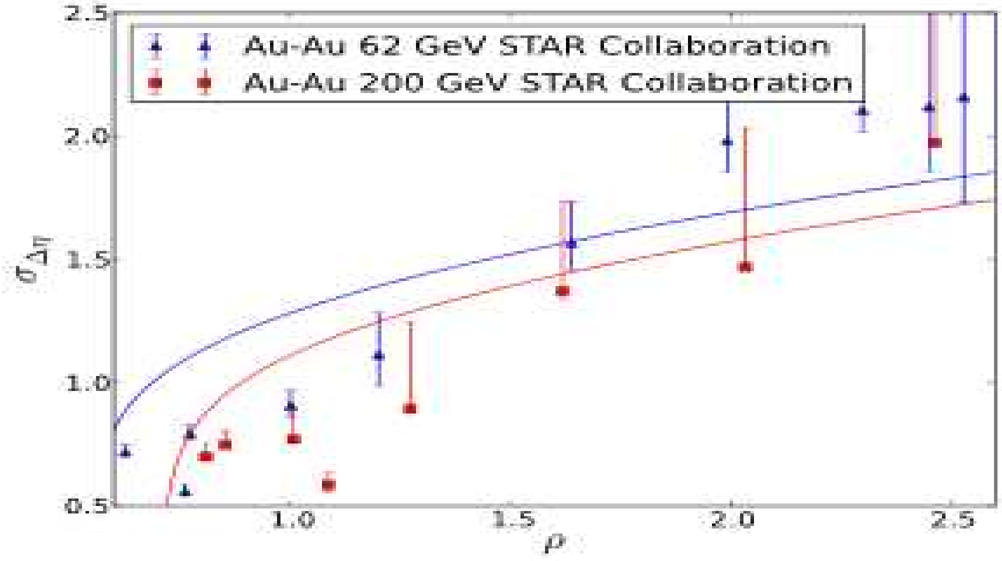
$$\sigma_{\Delta y} = c_1 \left(1 - \frac{N_A}{N_C}\right) \ln \frac{s}{s_0} + \ln \sqrt{\frac{\rho}{1 - e^{-\rho}}},$$

$$r_0 F(\rho)^{1/2} \qquad\qquad \sigma_{\Delta\phi} = c_2 \left(\frac{1 - e^{-\rho}}{\rho}\right)^{1/4}.$$

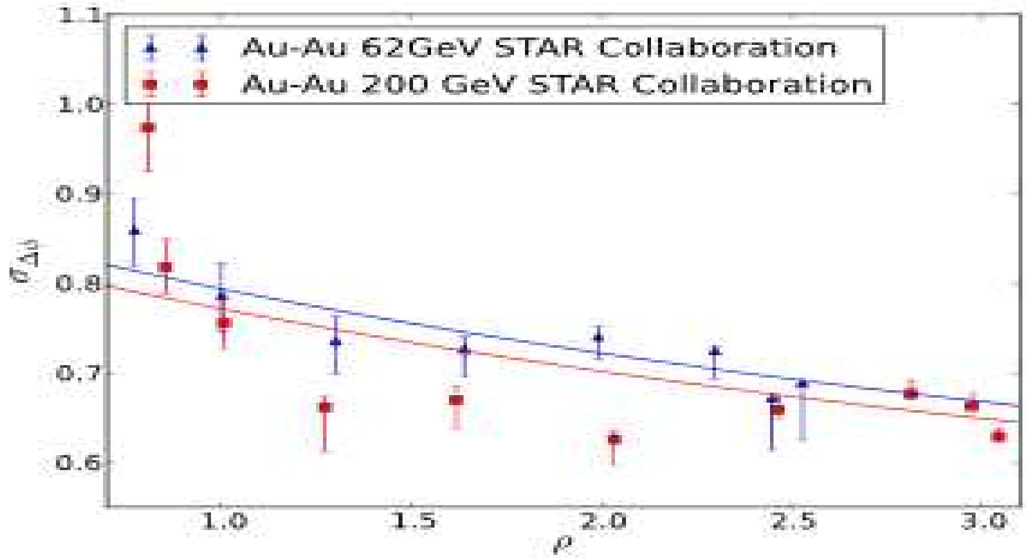



p-Pb 5.02 TeV CMS Collaboration
pp 7 TeV CMS Collaboration
A_1
N_{ch}
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
350


Au-Au 200 GeV STAR Collaboration
Au-Au 62 GeV STAR Collaboration
A_1
N_{ch}
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
450



Au-Au 62 GeV STAR Collaboration
Au-Au 200 GeV STAR Collaboration
$\sigma_{\Delta\eta}$
ρ



Au-Au 62GeV STAR Collaboration
Au-Au 200 GeV STAR Collaboration
$\sigma_{\Delta\phi}$
ρ

Conclusions

--The strength of the near side ridge is well described in string percolation for AA,pA and pp collisions

--This strength has to do with the fraction of the collision surface covered by strings(color sources) and therefore with the profile functions

--The widths of the pseudorapidity and azimuthal distributions are qualitatively described