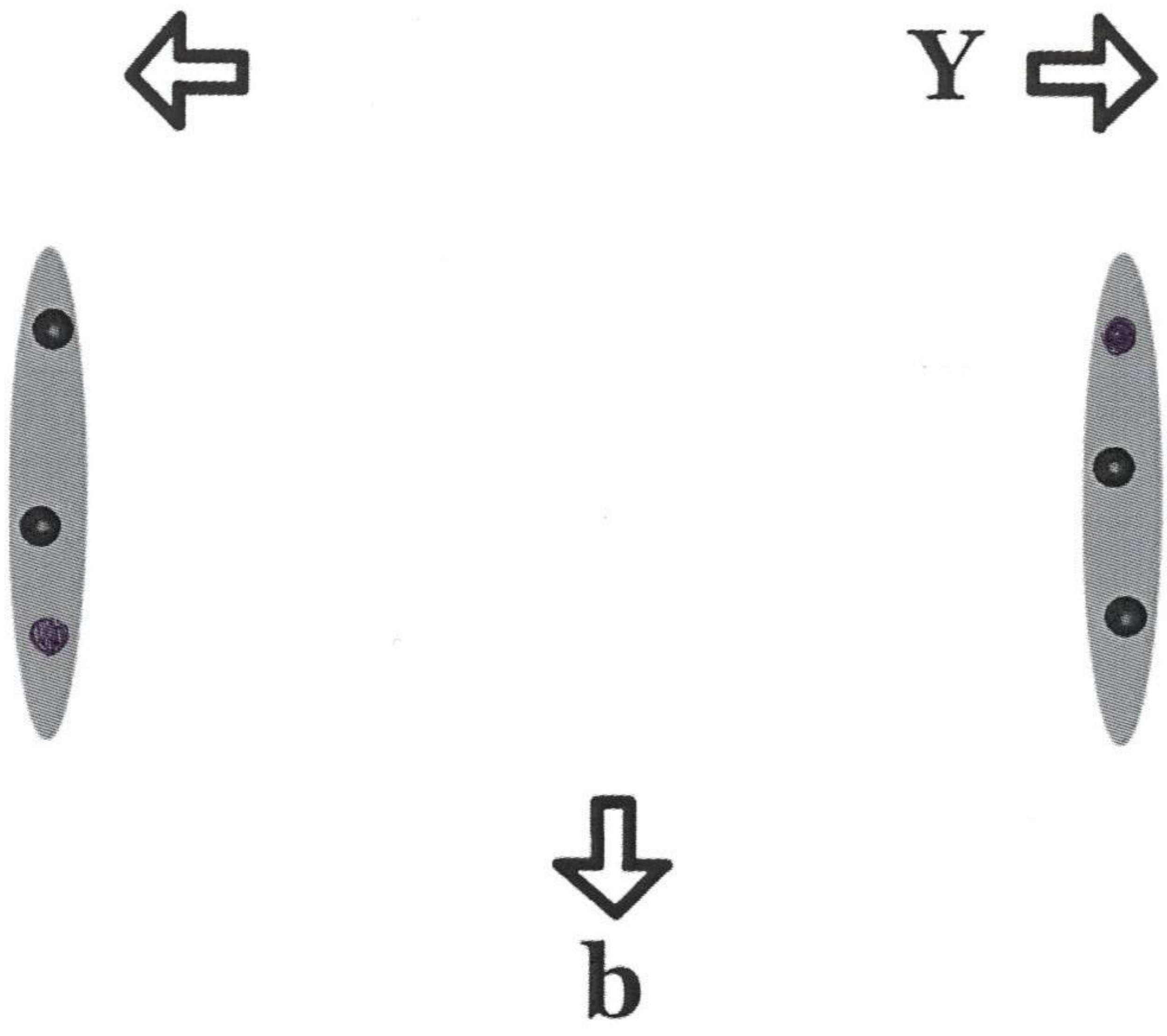
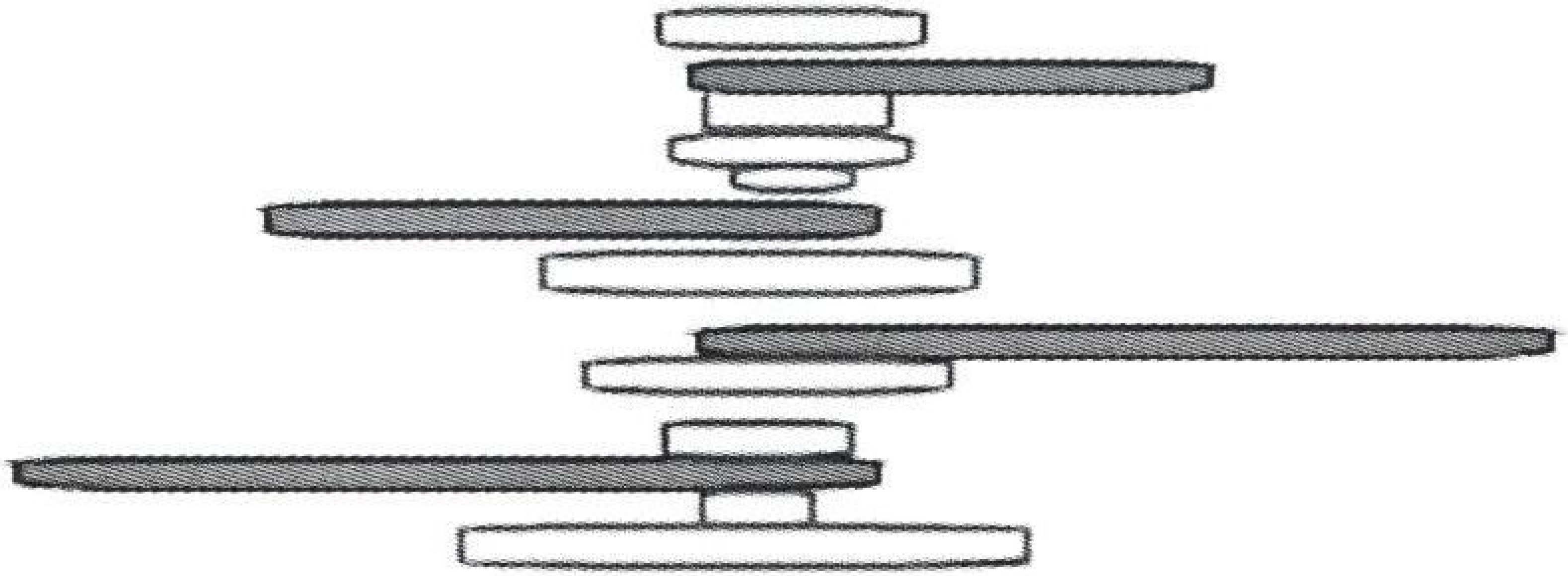
# Effects of strong color fields in pp high multiplicity events

C.Pajares
Dept Particle Physics and IGFAE
University Santiago de Compostela

Clustering of color sources
Multiplicity distributions
pp and Pb Pb scales
Supression of pt
Elliptic flow in pp
Rapidity long range correlations
Heavy flavour
Conclusions


Y
b

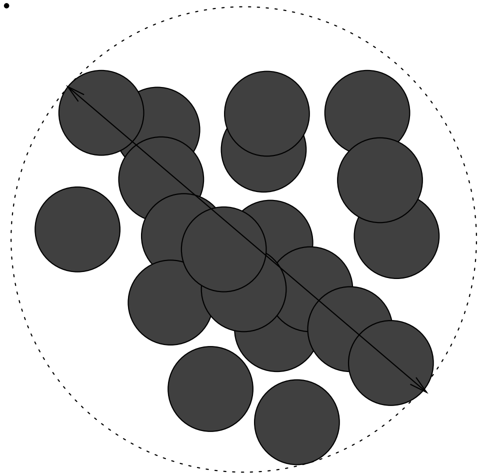


# CLUSTERING OF COLOR SOURCES

- Color strings are stretched between the projectile and target
- Strings = Particle sources: particles are created via sea qq production in the field of the string
- Color strings = Small areas in the transverse space filled with color field created by the colliding partons
- With growing energy and/or atomic number of colliding particles, the number of sources grows
- So the elementary color sources start to overlap, forming clusters, very much like disk in the 2-dimensional percolation theory
- In particular, at a certain critical density, a macroscopic cluster appears, which marks the percolation phase transition

(N. Armesto et al., PRL77 (96); J.Dias de Deus et al., PLB491 (00); M. Nardi and H. Satz(98).

- How?: Strings fuse forming clusters. At a certain critical density $\eta_c$ (central PbPb at SPS, central AgAg at RHIC, central pp at LHC ) a macroscopic cluster appears which marks the percolation phase transition (second order, non thermal).



$$\eta = N_{st}\frac{S_1}{S_A}\,, \quad S_1 = \pi r_0^2, \quad r_0 = 0.2 \ \ \text{fm}, \quad \eta_c = 1.1 \div 1.2.$$

- Hypothesis: clusters of overlapping strings are the sources of particle production, and central multiplicities and transverse momentum distributions are little affected by rescattering.

$$\mu_n = \sqrt{\frac{nS_n}{S_1}}\mu_1 \;;\; < p_T^2 >_n = \sqrt{\frac{nS_1}{S_n}} < p_T^2 >_1$$

Energy-momentum of the cluster is the sum of the energy-momemtum of each string.

As the individual color field of the individual string may be oriented in an arbitrary manner respective to one another, $Q_n^2 = nQ_1^2$

- At high densities
  - $< \mu >_n = nF(\eta) < \mu >_1 \;\; < p_T^2 >_n = \frac{<p_T^2>_1}{F(\eta)}$
  - $F(\eta) = \sqrt{\frac{1-e^{-\eta}}{\eta}},\; \eta = N_S \frac{\pi r_0^2}{S_A}$
  - $r_0$ is the transverse size of a single string $\simeq$ 0.2 fm.

# Why Protons?

In String Percolation…

$$\eta_{AA} = \left(\frac{r}{R}\right)^2 \overline{N}^{s} \cong \frac{N_A^{4/3}}{N_A^{2/3}} \left(\frac{r}{R_p}\right)^2 \overline{N}_p^{s}$$

$$\eta_{AA}(s) = N_A^{2/3} \eta_{pp}(s)$$ and $$\overline{N} \sim s^{2/7}$$

$$\eta_{PbPb}(\sqrt{s}) \cong 20\,GeV$$

$$\eta_c \approx 1.15$$

$$\eta_{PP}(\sqrt{s}) \cong 6TeV$$ ← LHC

- $p_T$ distributions will be the superposition of $p_T$ distributions of clusters, each with a tension which depends on the number of strings of the cluster and its surface.

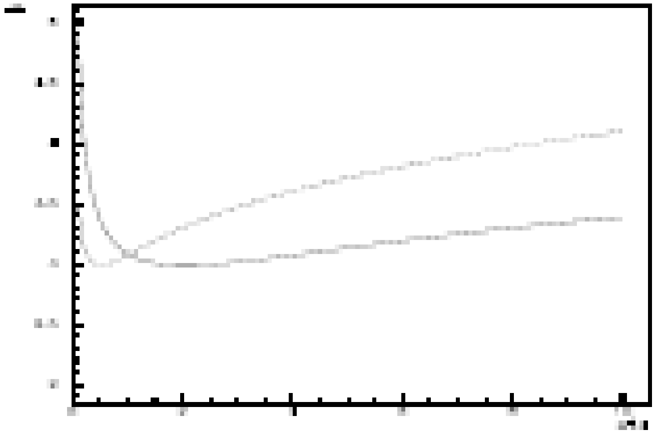
- $$f(p_T) = \int dx W(x) f(x, p_T)$$

- $f(x, p_T)$ is the $p_T$ distribution of cluster x

$f(x, p_T) \simeq e^{-x p_T^2}$

- W(x) is the cluster size distribution

$W(x) \simeq x^{k-1} e^{-k \frac{x}{<x>}}$



- $$\frac{1}{k} = \frac{<x^2> - <x>^2}{<x>^2}$$

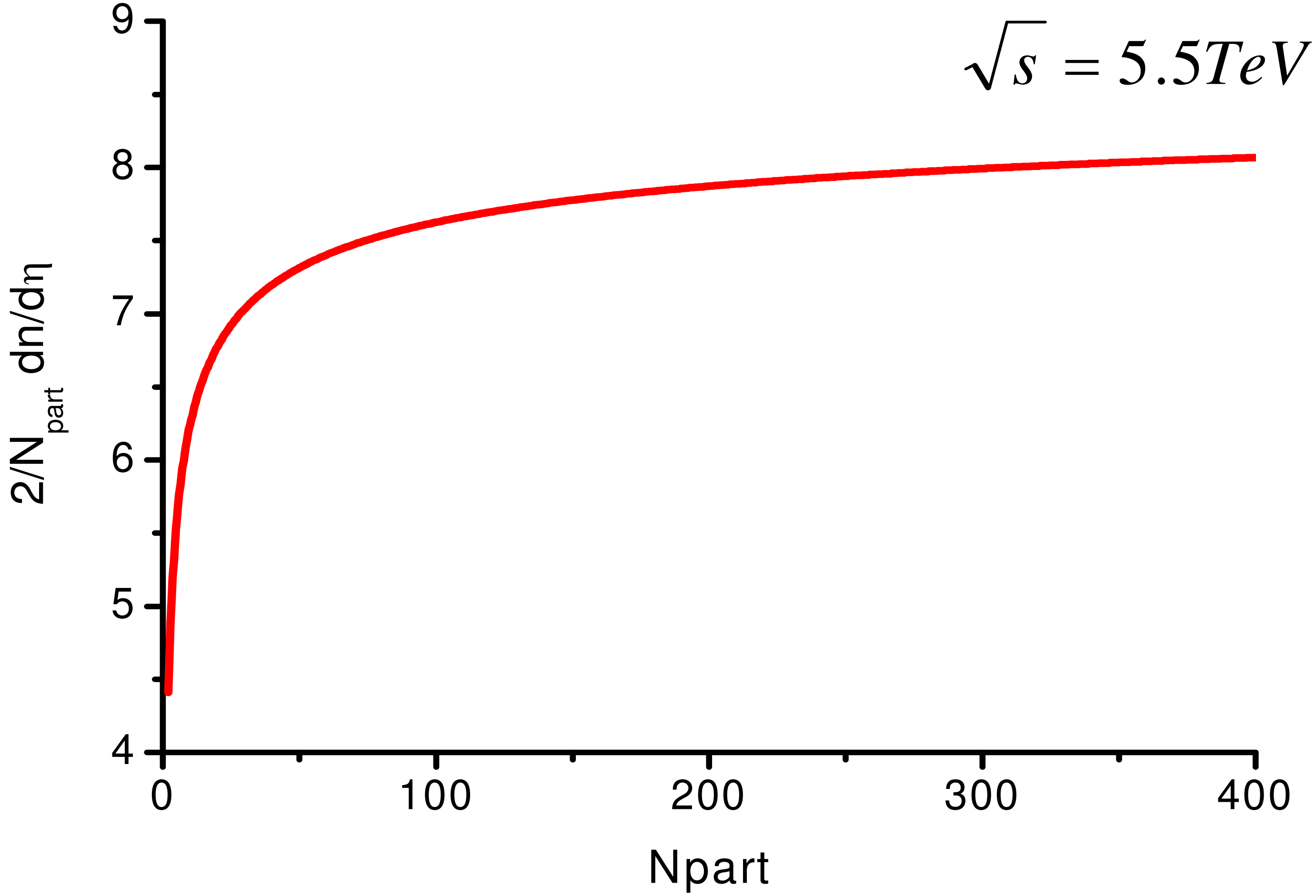
  low density (only clusters of one string, $k \longrightarrow \infty$)
  very high density (one cluster with all strings, also $k \longrightarrow \infty$)

- This behaviour also explains the multiplicity and transverse momentum dynamical correlations.

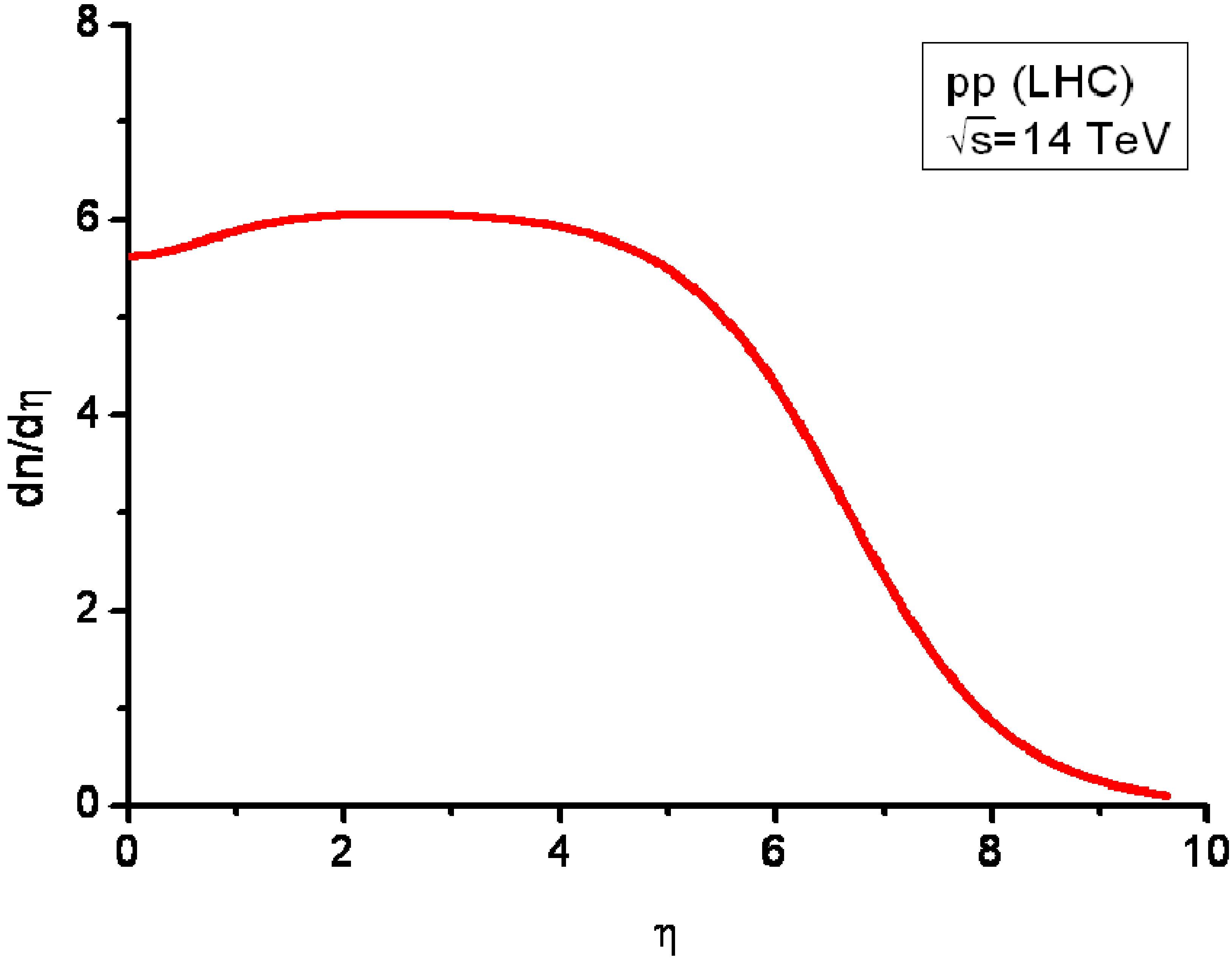
- $$f(p_T, y) = \frac{dN}{dy}\frac{(k-1)F(\eta)}{k\langle p_T^2\rangle_1 i}\frac{1}{(1+\frac{F(\eta)p_T^2}{k\langle p_T^2\rangle_i})^k}$$

- At low density $F(\eta) \longrightarrow 1$, $k \longrightarrow \infty$, $f(p_T, y) \simeq e^{-\frac{p_T^2}{\langle p_T^2\rangle_i}}$

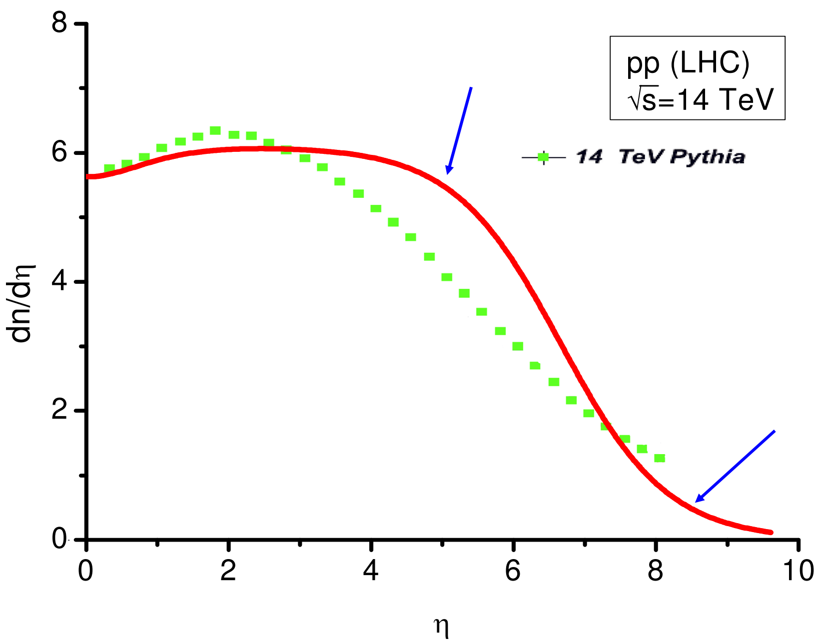
- At very high density, $k \longrightarrow \infty$, $f(p_T, y) \simeq e^{-\frac{p_T^2}{F(\eta)\langle p_T^2\rangle_i}}$



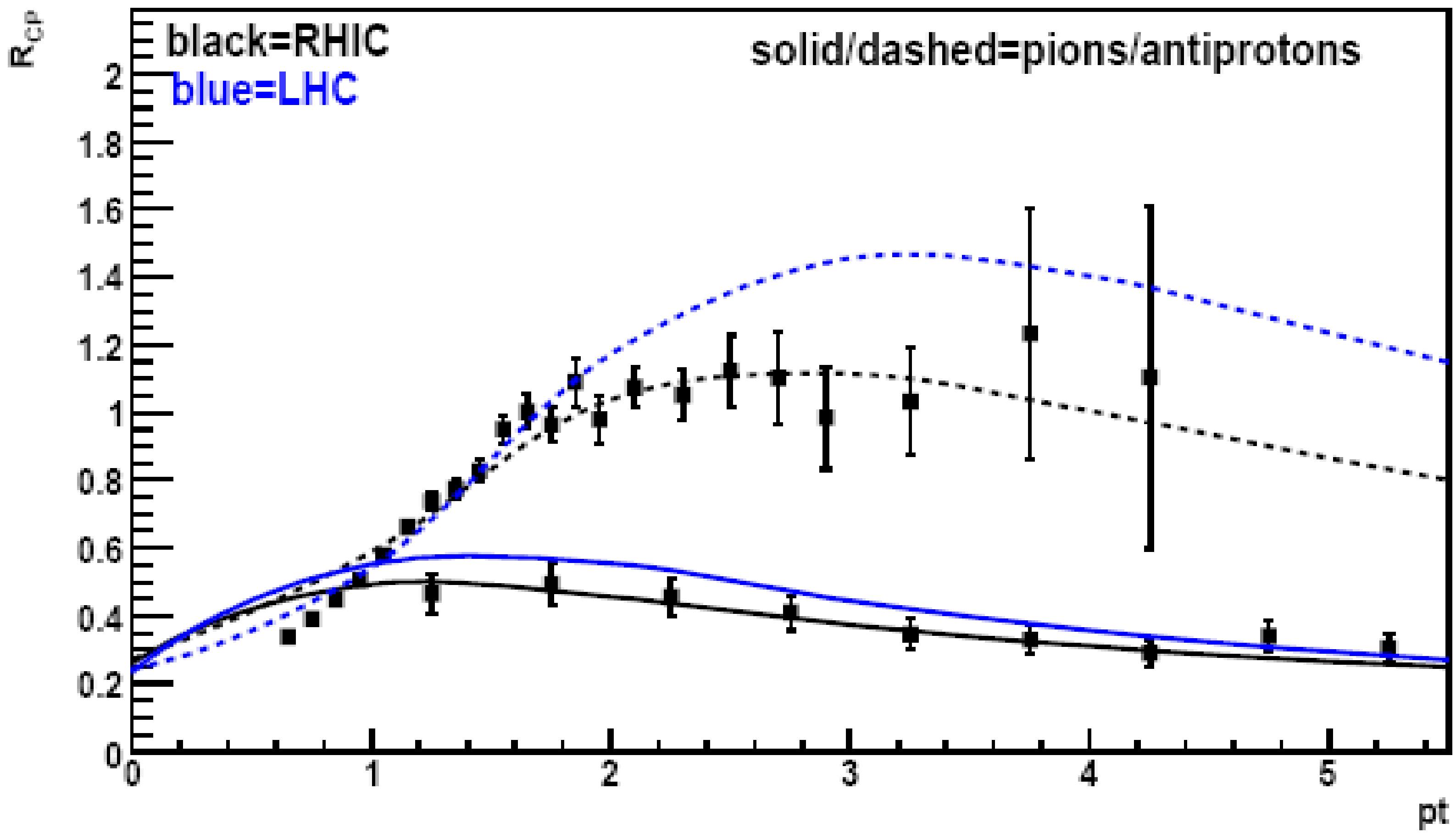
$\sqrt{s} = 5.5TeV$
9
8
7
6
5
4
$2/N_{part}\ dn/d\eta$
0
100
200
300
400
Npart



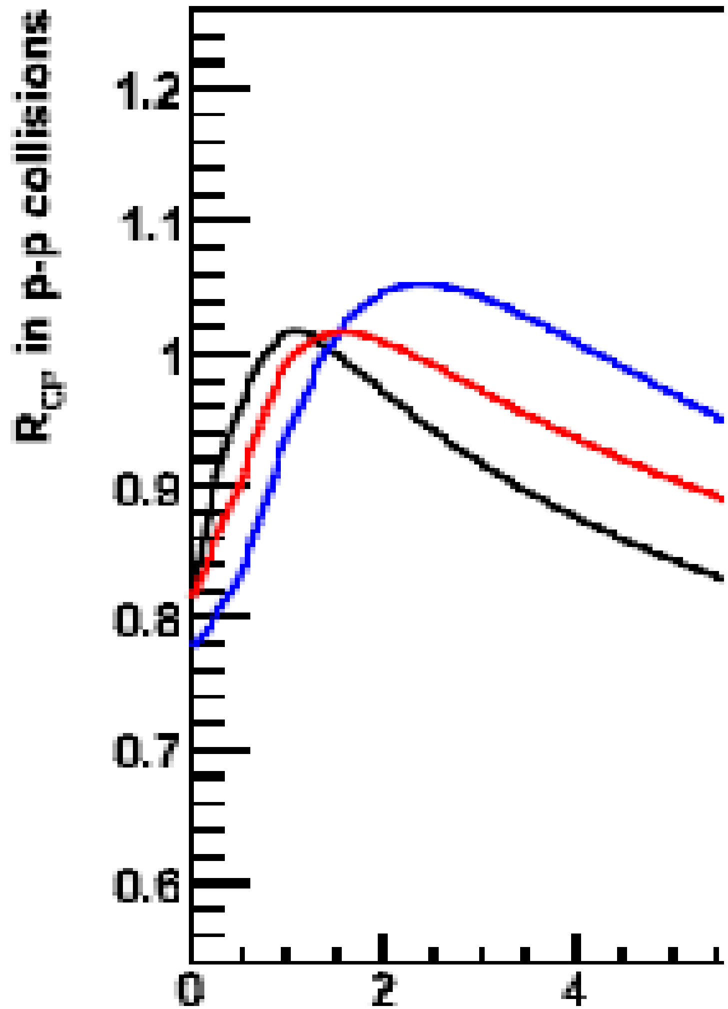
pp (LHC)
$\sqrt{s}$=14 TeV
dn/dη
η
0
2
4
6
8
10



pp (LHC)
√s=14 TeV
14 TeV Pythia
dn/dη
η
0
2
4
6
8
10



black=RHIC
blue=LHC
solid/dashed=pions/antiprotons
R_CP
pt
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
1
2
3
4
5

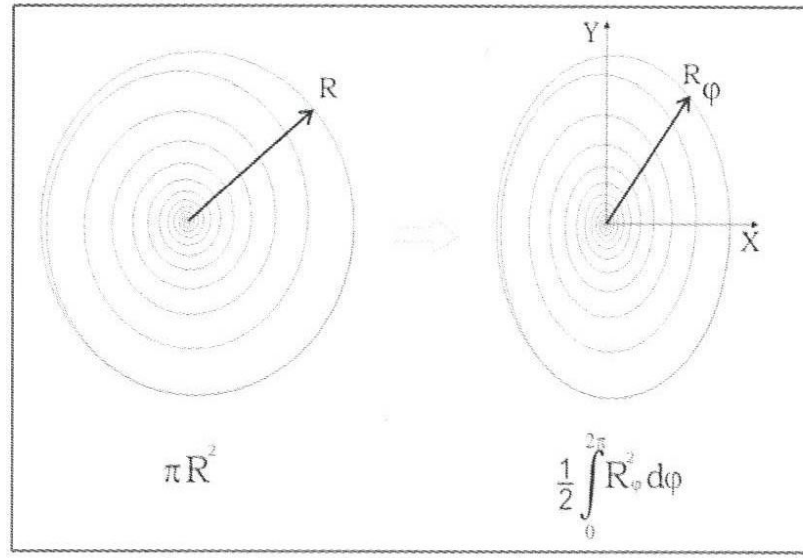


R_CP in p-p collisions
1.2
1.1
1
0.9
0.8
0.7
0.6
0
2
4

# Elliptic Flow

$$p_T^2 \to F(\eta) p_T^2 \to F(\eta_\varphi) p_T^2$$

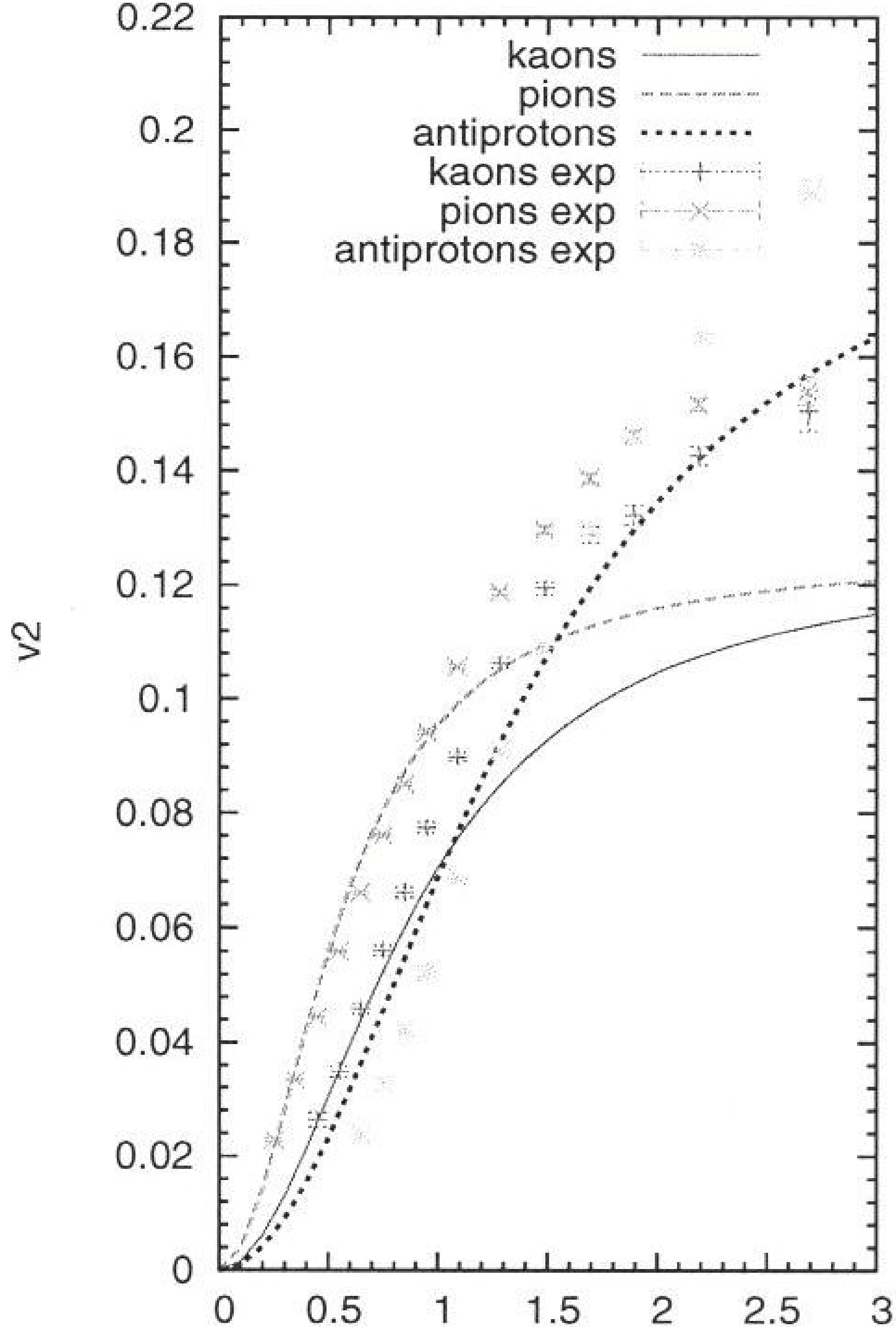
$$\eta \to \eta_\varphi \equiv \eta\, R^2 / R_\varphi^2$$



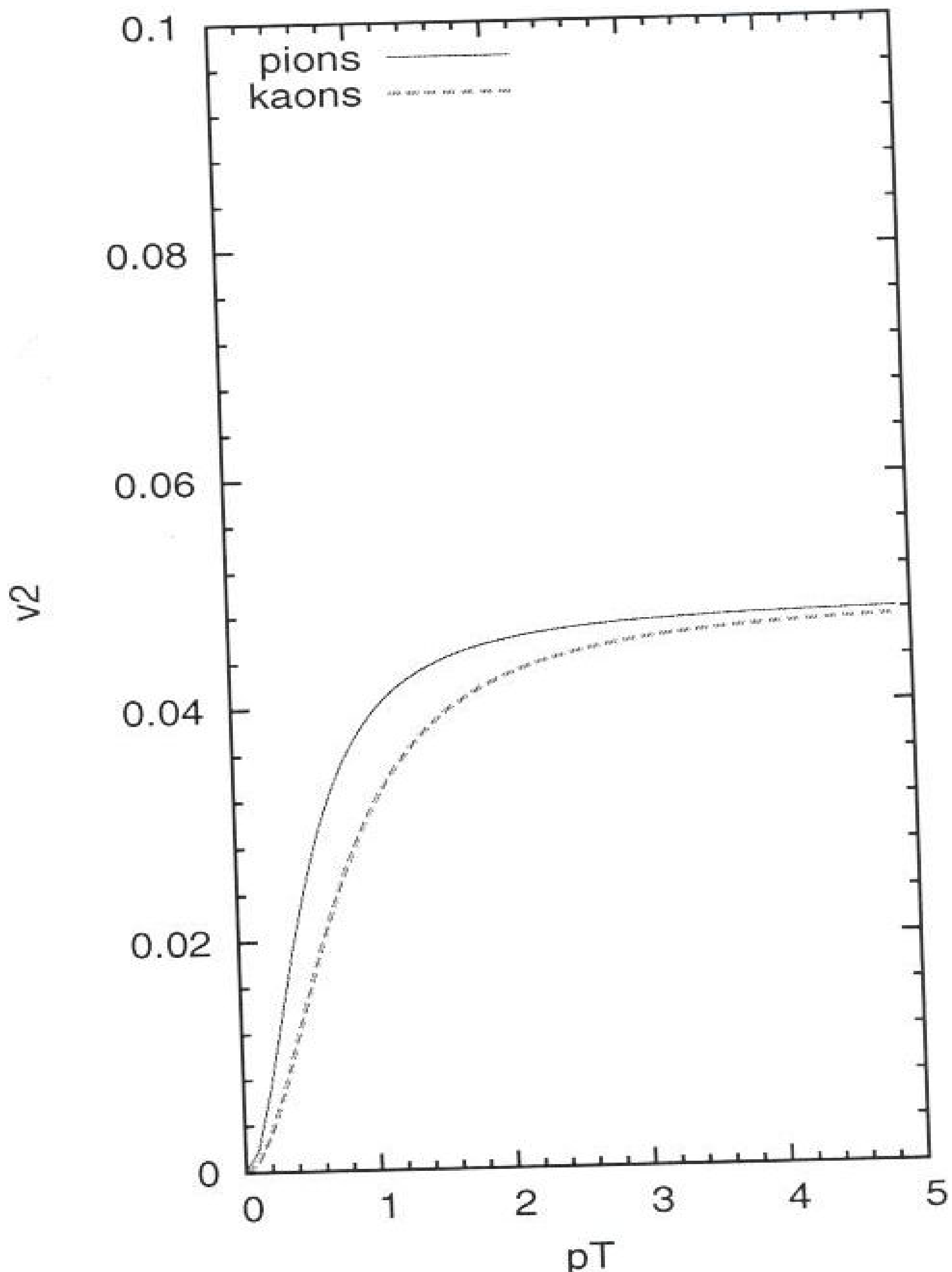

**Approximation:** $f(R_\varphi^2, p_T^2) \cong \frac{1}{2\pi}\left\{ f(R^2, p_T^2) + \frac{\partial f(R_1^2 p_T^2)}{\partial R^2}(R_\varphi^2 - R^2)\right\}$

**Definition:** $v_2 = \langle \cos(2\varphi) \rangle$

$$v_2 = \frac{1}{2\pi}\int_0^{2\pi} d\varphi \cos(2\varphi)\left(e^{-\eta}/F(\eta)^2 - 1\right)\frac{F(\eta)p_T^2}{2\overline{p_1^2}}\frac{1}{\left(1 + \frac{F(\eta)p_T^2}{r\overline{p_1^2}}\right)}\left(\frac{R_\varphi^2}{R^2} - 1\right)$$



kaons
pions
antiprotons
kaons exp
pions exp
antiprotons exp
v2
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5
1
1.5
2
2.5
3



pions
kaons
0.1
0.08
0.06
0.04
0.02
0
v2
0
1
2
3
4
5
pT

| | $\sqrt{s}$ | $b$ (fm) | $\epsilon$ | $S$ (fm$^2$) | $dN_{ch}/dy$ | $v_2$ |
|---|---|---|---|---|---|---|
| $pp$ $0-10\%$ | 14 TeV | 0.36 | 0.17 | 2.42 | 12-15 | 0.008 |
| $pp$ min bias | 14 TeV | 1.18 | 0.49 | 0.93 | 6 | 0.035 |
| $pp$ min bias | 0.2 TeV | 0.8 | 0.35 | 1.58 | 3 | 0.004 |

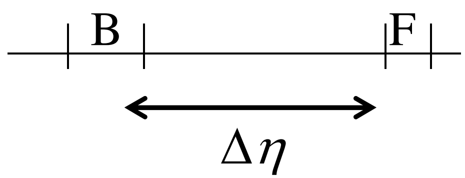
# LONG RANGE CORRELATIONS

- A measurement of such correlations is the backward–forward dispersion

$$D^2_{FB} = <n_B\, n_F> - <n_B><n_F>$$

where $n_B(n_F)$ is the number of particles in a backward (forward) rapidity

$$D^2_{FB} = <N>\left(<n_{1B} n_{1F}> - <n_{1B}><n_{1F}>\right) + \left(<N^2> - <N>^2\right)<n_{1F}><n_{1B}>$$




$<N>$ number of collisions: $<n_{1B}>$,$<n_{1F}>$ F and B multiplicities in one collision

- In a superposition of independent sources model, $D^2_{BF}$ is proportional to the fluctuations($D^2_N$)on the number of independent sources (It is assumed that Forward and backward are defined in such a way that there is a rapidity window $\Delta_\eta \geq 1.0$ to eliminate short range correlations).

$$< n_B >= a + b n_F$$

with

$$b \equiv D_{BF}^2 / D_{FF}^2$$

- b in pp increases with energy. In hA increases with A also in AA,increases with centrality

The dependence of b with rapidity gap is quite interesting, remaining flat for large values of the rapidity window.

Existence of long rapidity correlations at high density

# Correlation Parameter b

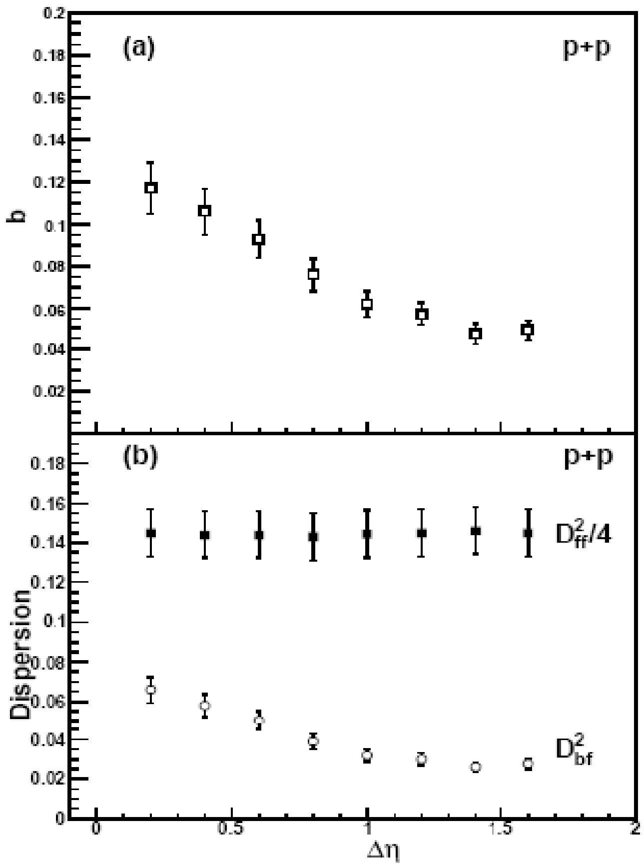
**I Situation:** Symmetrica

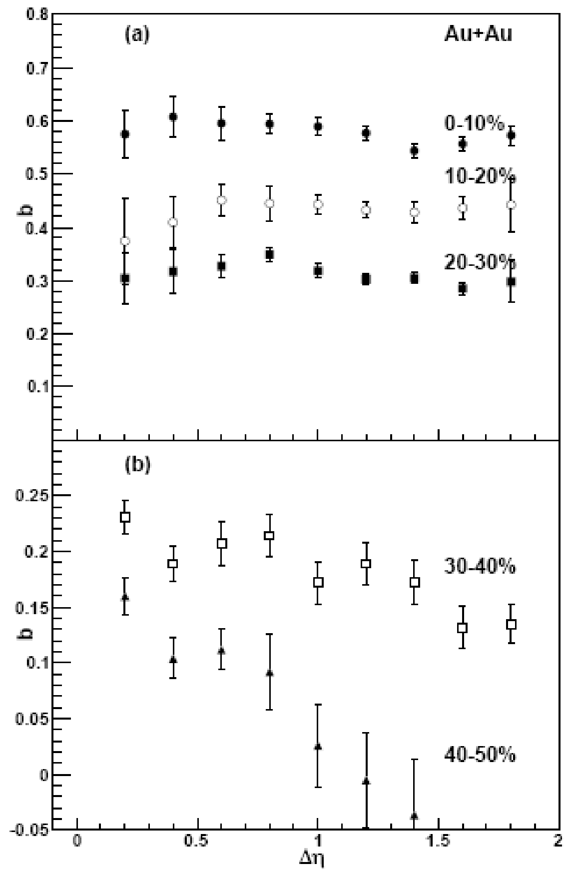
:

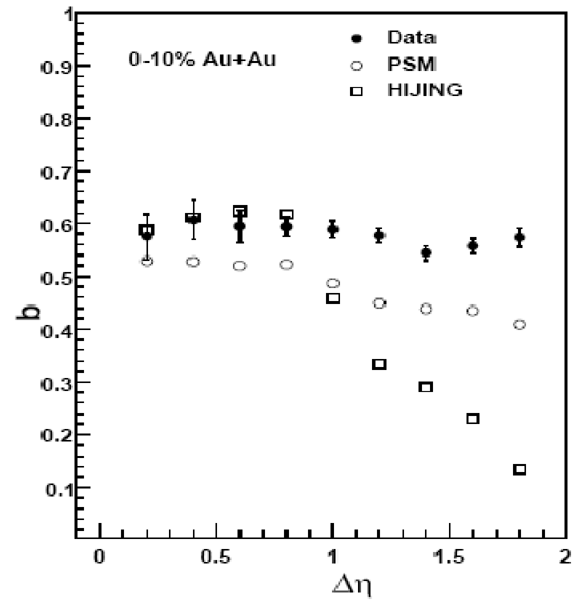
$$b \equiv \frac{1}{1 + \frac{K}{< n_F >}}$$

- 1/K is the squared normalized fluctuations on effective number of strings(clusters)contributing to both forward and backward intervals

The heigth of the ridge structure is proportional to n/k
Similar results to CGC.Qs is related to our F(eta)


(a)
p+p
(b)
p+p
$D_{ff}^2/4$
$D_{bf}^2$
b
Dispersion
Δη


(a)
Au+Au
0-10%
10-20%
20-30%
(b)
30-40%
40-50%
b
Δη


0-10% Au+Au
Data
PSM
HIJING
b
Δη

# Comments

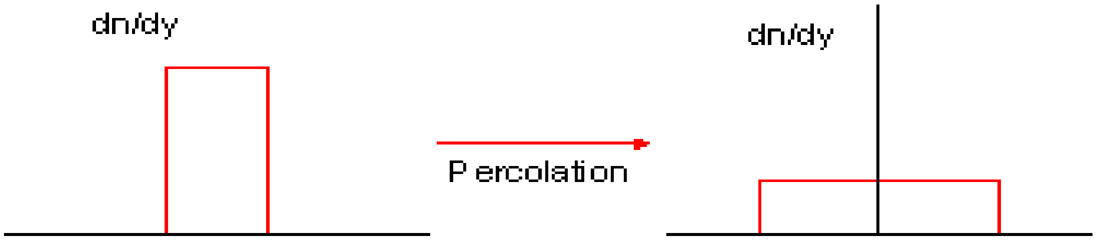
- Data (RHIC)
- FB Correlations YES: SO LONG?

  Colour Flux Tube: OK

  Strings : TOO SHORT

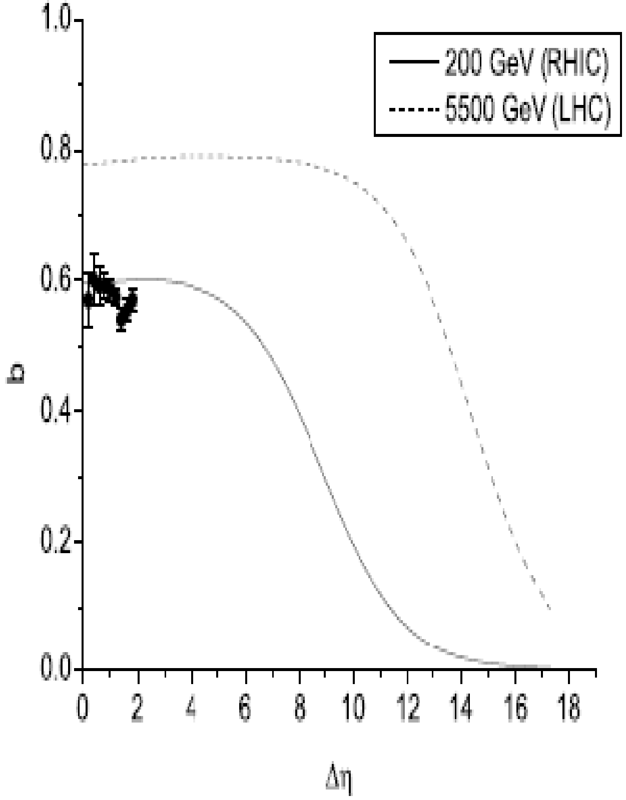
One String: $x^{+} = x^{-} = x = 1/\sqrt{s} \Rightarrow \Delta y_1$

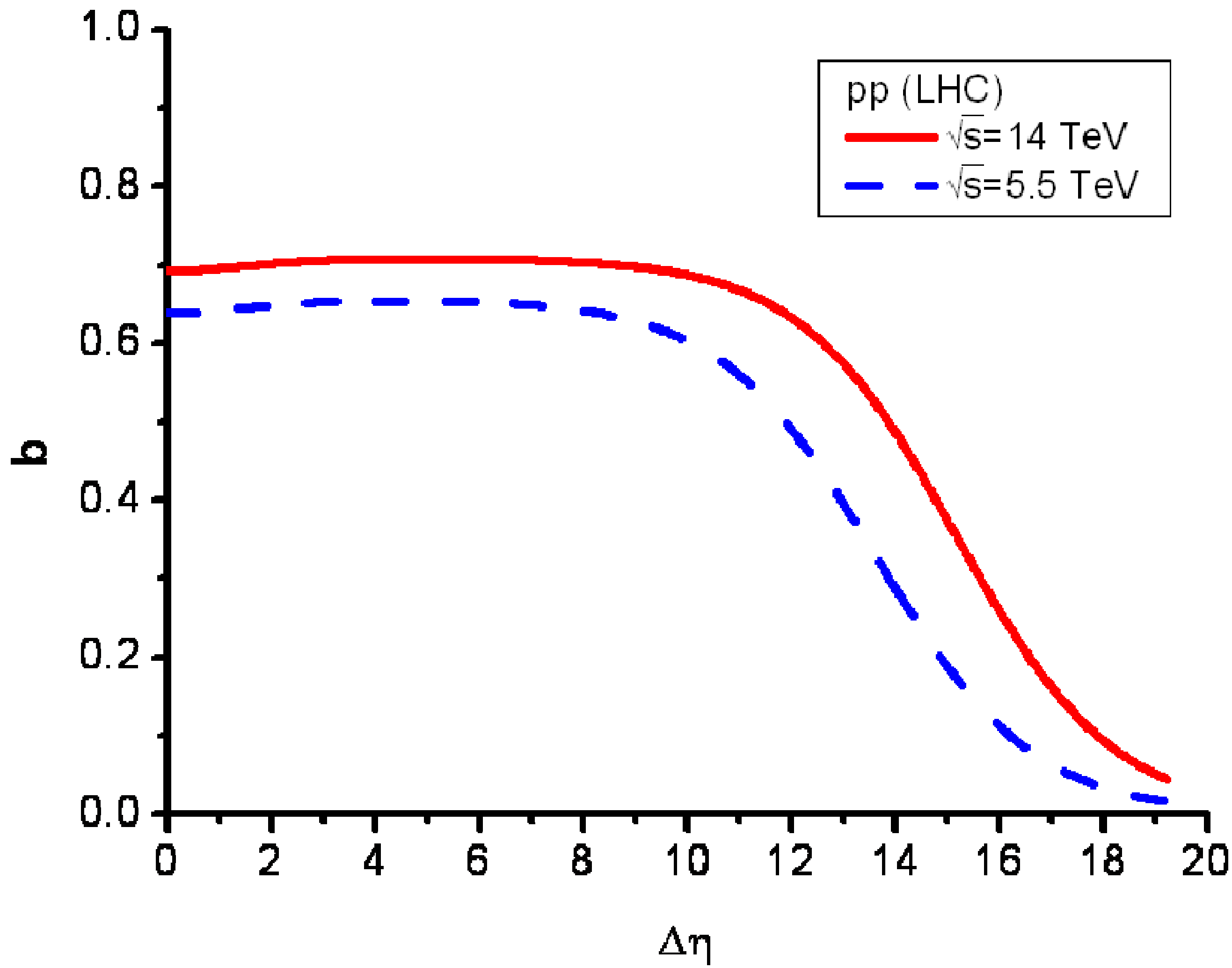
$N^s$ Strings: $\Delta y_{N_s} = \Delta y_1 + 2\ln(N_s)$



- b at LHC is in the range 0.65-0.78

(we have uncertainties on k)





1.0
0.8
0.6
0.4
0.2
0.0
b
0
2
4
6
8
10
12
14
16
18
20
Δη
pp (LHC)
√s=14 TeV
√s=5.5 TeV

# Color Glass Condensate; Clustering Color Sources

$$E, B \sim Q_s^2 \sim A^{1/3} S^{\lambda} Q_0^2$$

$$E, B \sim \frac{< p_T^2 >_1}{F(\eta)} \sim \eta^{1/2} < p_T^2 > \sim s^{\lambda} A^{1/3} < p_T^2 >_1$$

MULTIPLICITY

NUMBER OF GLUONS x NUMBER of COLOR FLUX TUBE

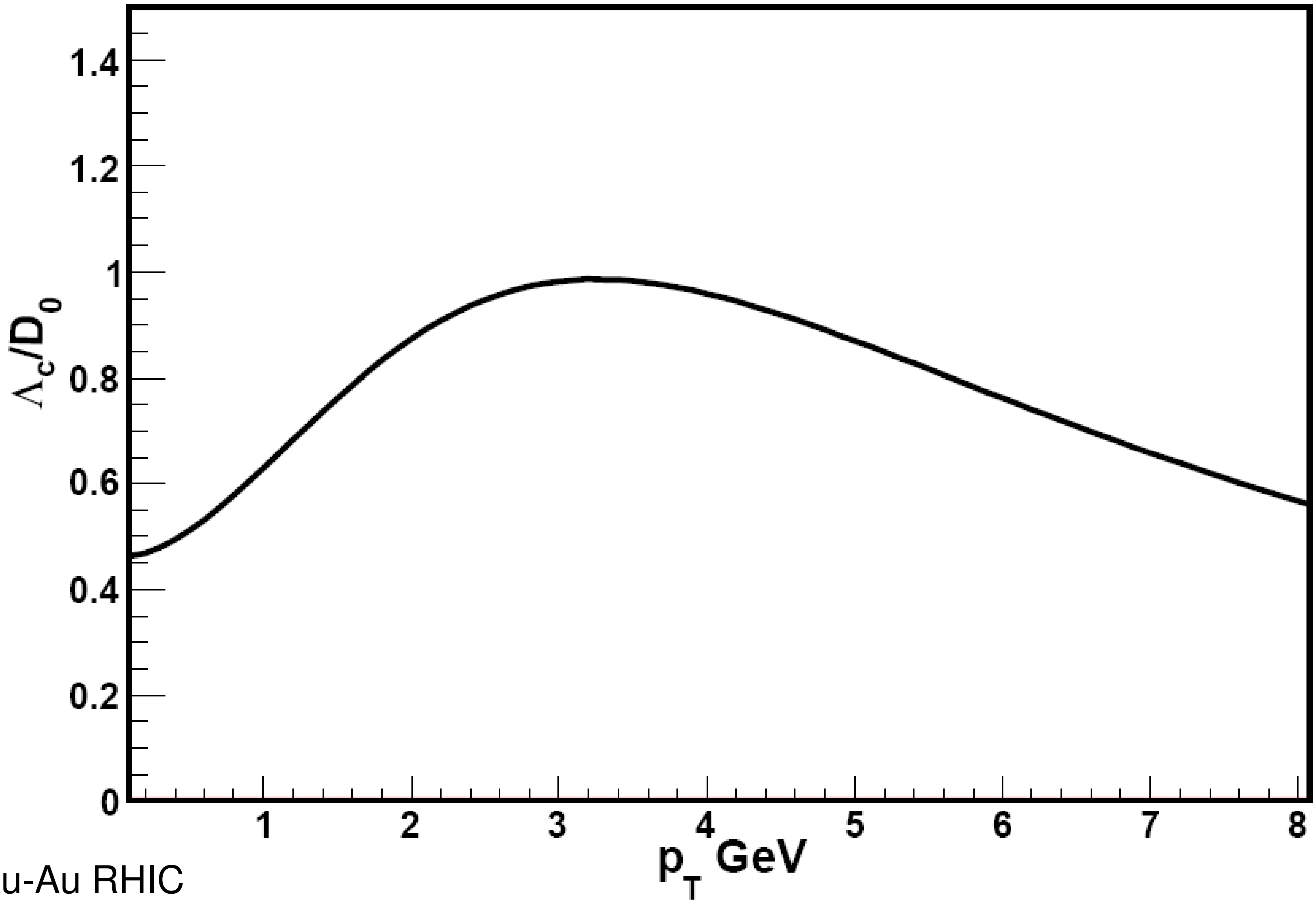
$$\frac{1}{\alpha_S} Q_s^2 R_A^2 \quad \square \quad \frac{1}{\alpha_s} s^{\lambda} A$$

- FRACTION of OCCUPIED AREA x EFFECTIVE NUMBER OF CLUSTERS

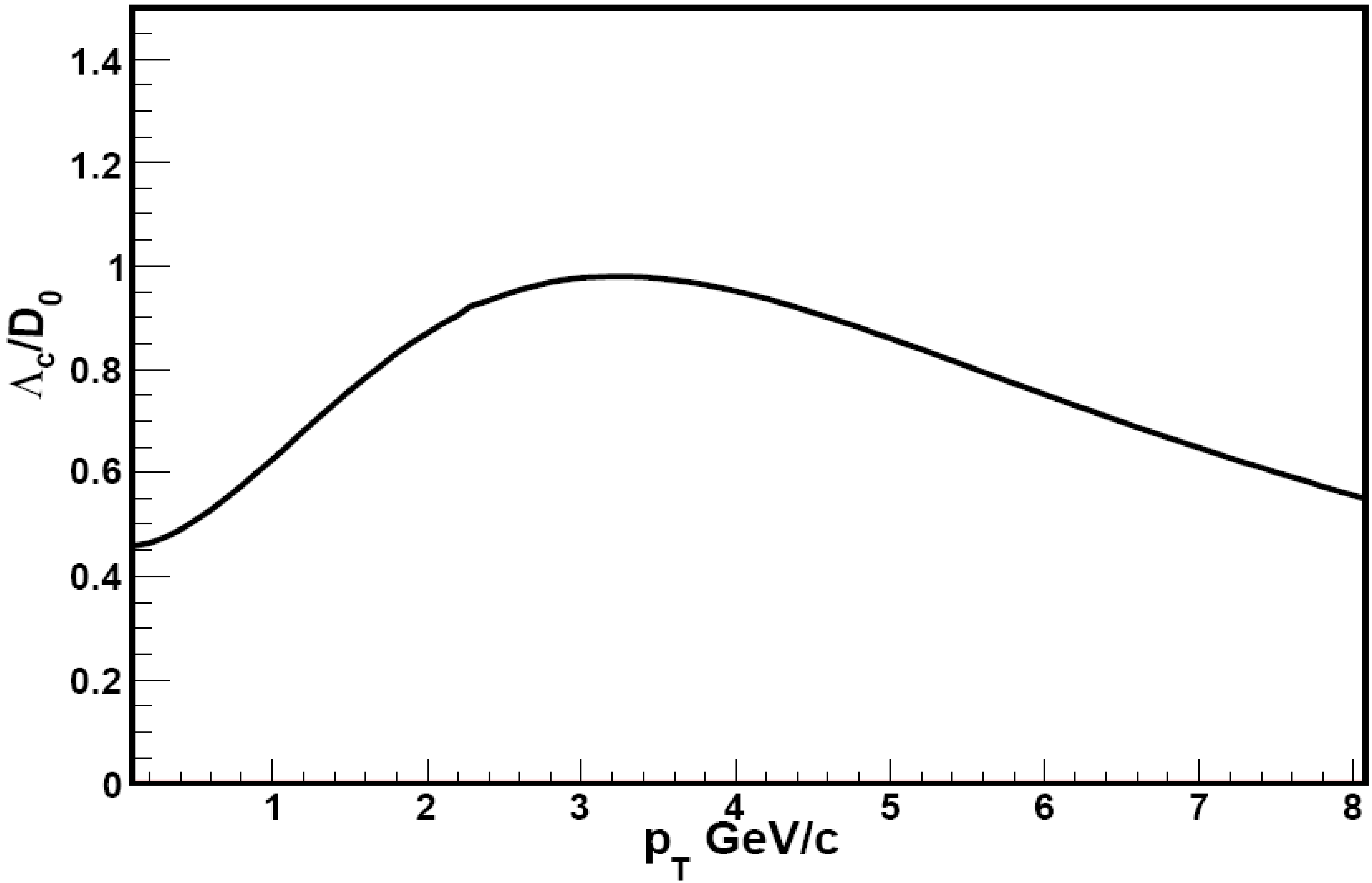
$$N_s F(\eta) \mu_1 = (1 - \exp(-\eta))^{1/2} s^{\lambda} A$$

- LONGITUDINALY EXTENDED COLOR FIELDS

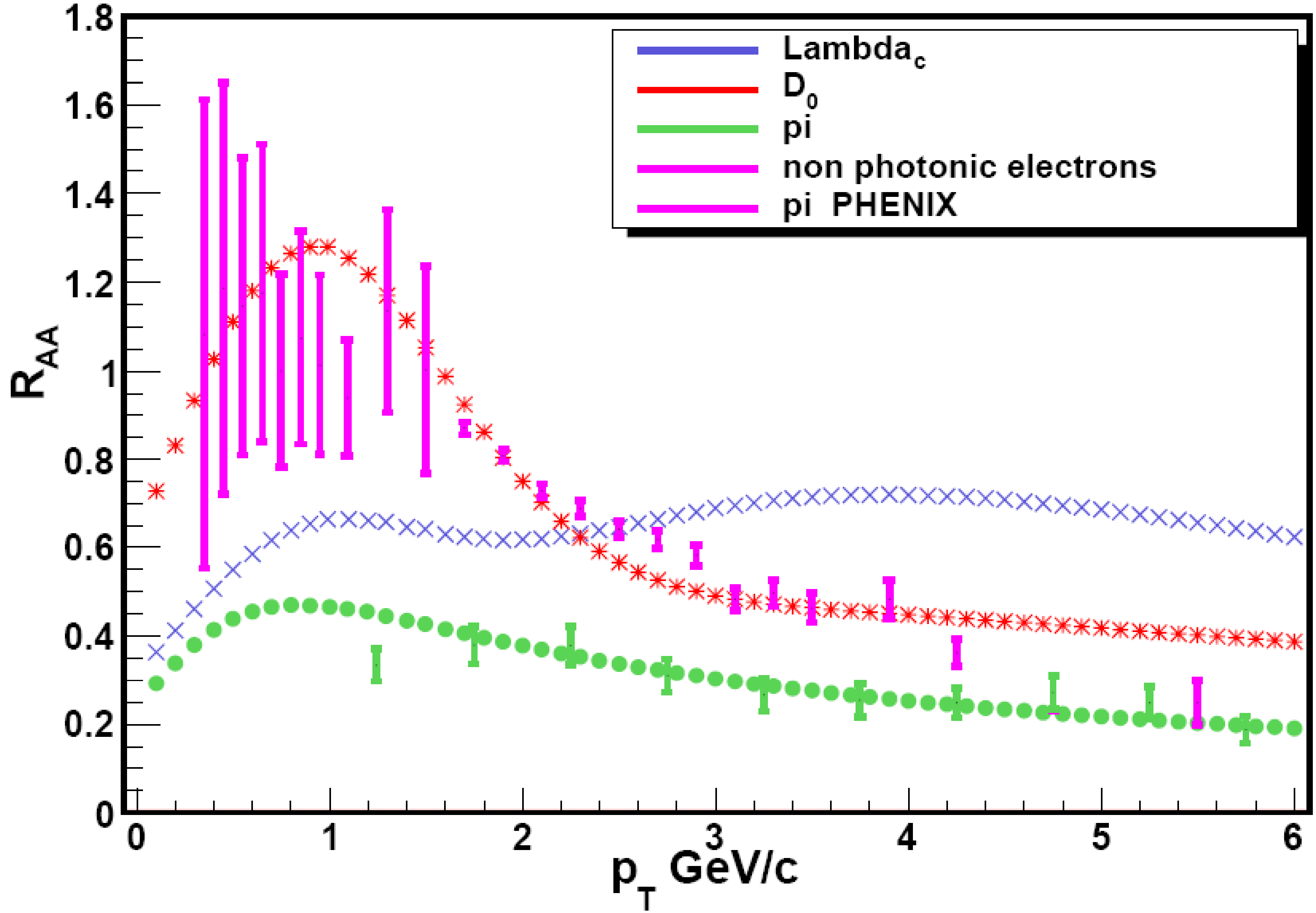
$$\frac{1}{\alpha_S} \qquad \Delta y_1 + 2 \ln N_s$$




Au-Au RHIC




pp at 14Tev for multiplicities larger than 3 times minimum bias multiplicity



Lambda$_c$
$D_0$
pi
non photonic electrons
pi PHENIX
$R_{AA}$
$p_T$ GeV/c
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6

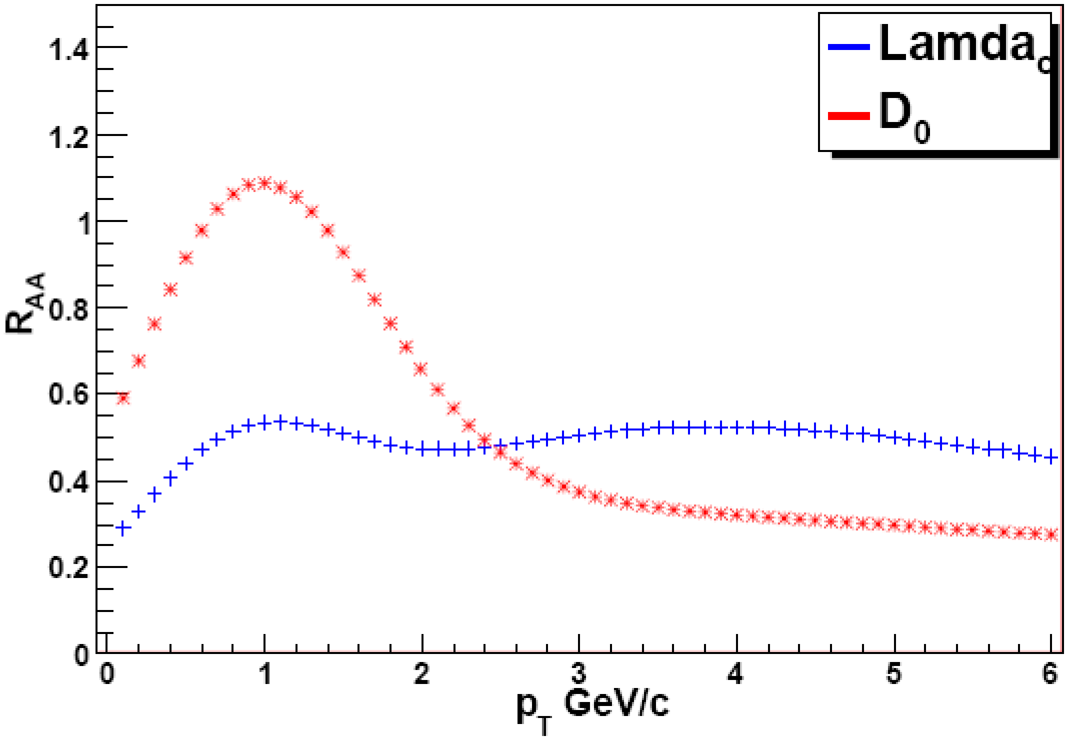



Figure 1:

Ratio between events with 3 times larger multiplicity over Minimum bias in pp at 14Tev

# Conclusions

- For pp at LHC are predicted the same phenomena observed at RHIC in Au-Au

- Reduction of multiplicities
- High pt supression(lack of jet back to back correlations)
- Sizable elliptic flow
- Long range correlations extended more than 10 units of rapidity.Ridge structure
- Similar open heavy flavour pt supression