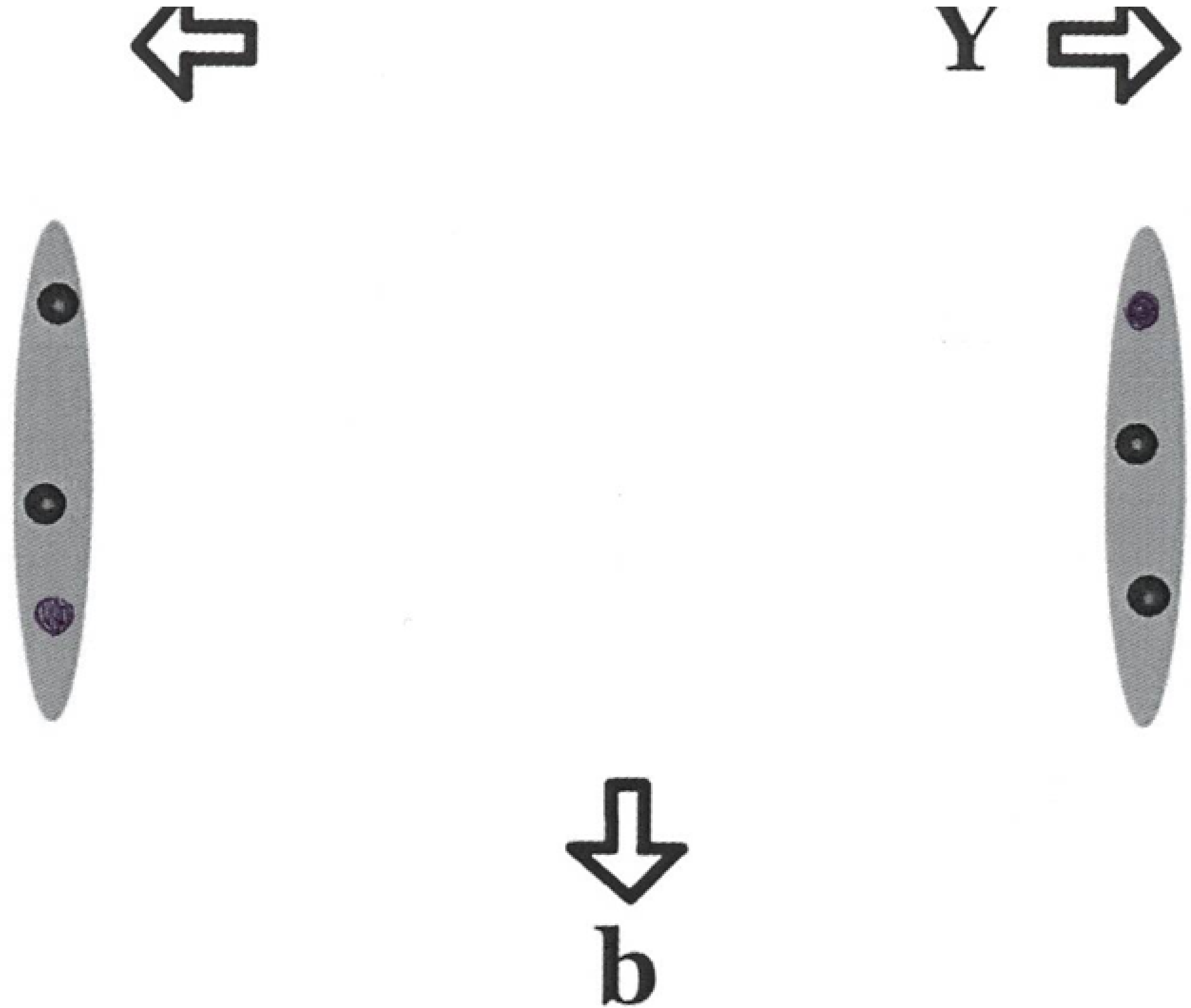
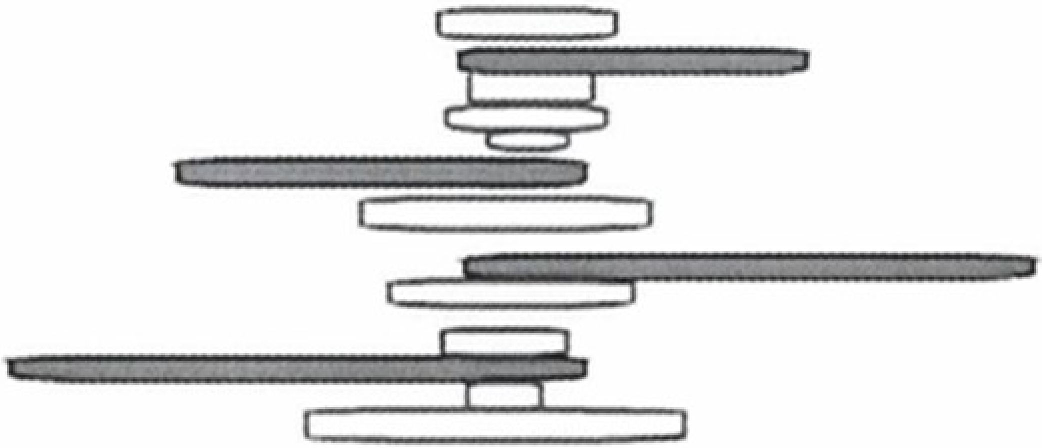
Comments on Elliptic flow (Elliptic flow at RHIC and LHC and percolation of strings)

C.Pajares
University Santiago de Compostela
Collaboration with J.Dias de Deus,I.Bautista

Outline

- Brief description of string percolation
- Elliptic flow in percolation
- RHIC and LHC results
- Shear viscosity/entropy in percolation

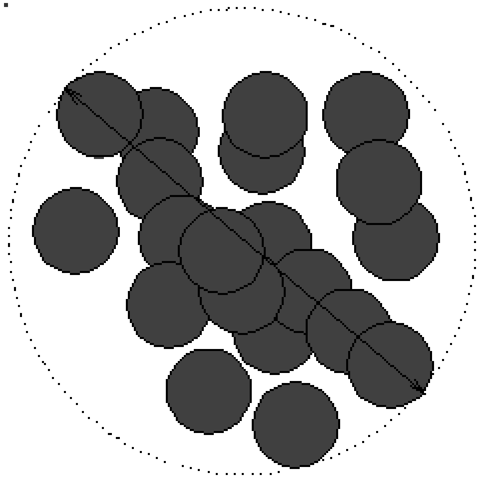

Y
b



- 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 η_c (central PbPb at SPS, central AgAg at RHIC, central SS at LHC) a macroscopic cluster appears which marks the percolation phase transition (second order, non thermal).



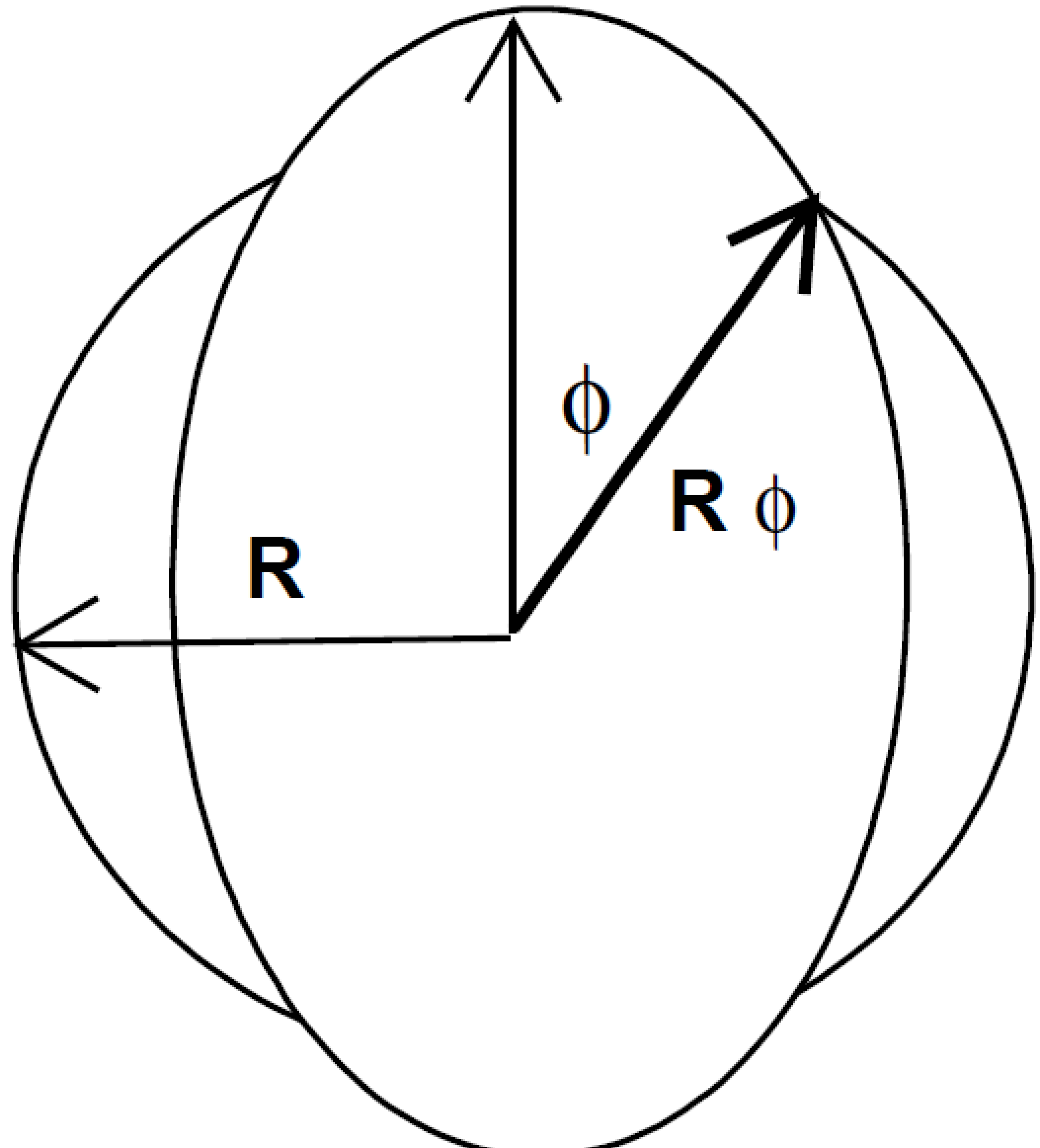
$$\eta = N_{st}\frac{S_1}{S_A}\ , \quad S_1 = \pi r_0^2, \quad r_0 = 0.2 \ \ \text{fm}, \quad \eta_c = 1.1 \div 1.2.$$

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

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.



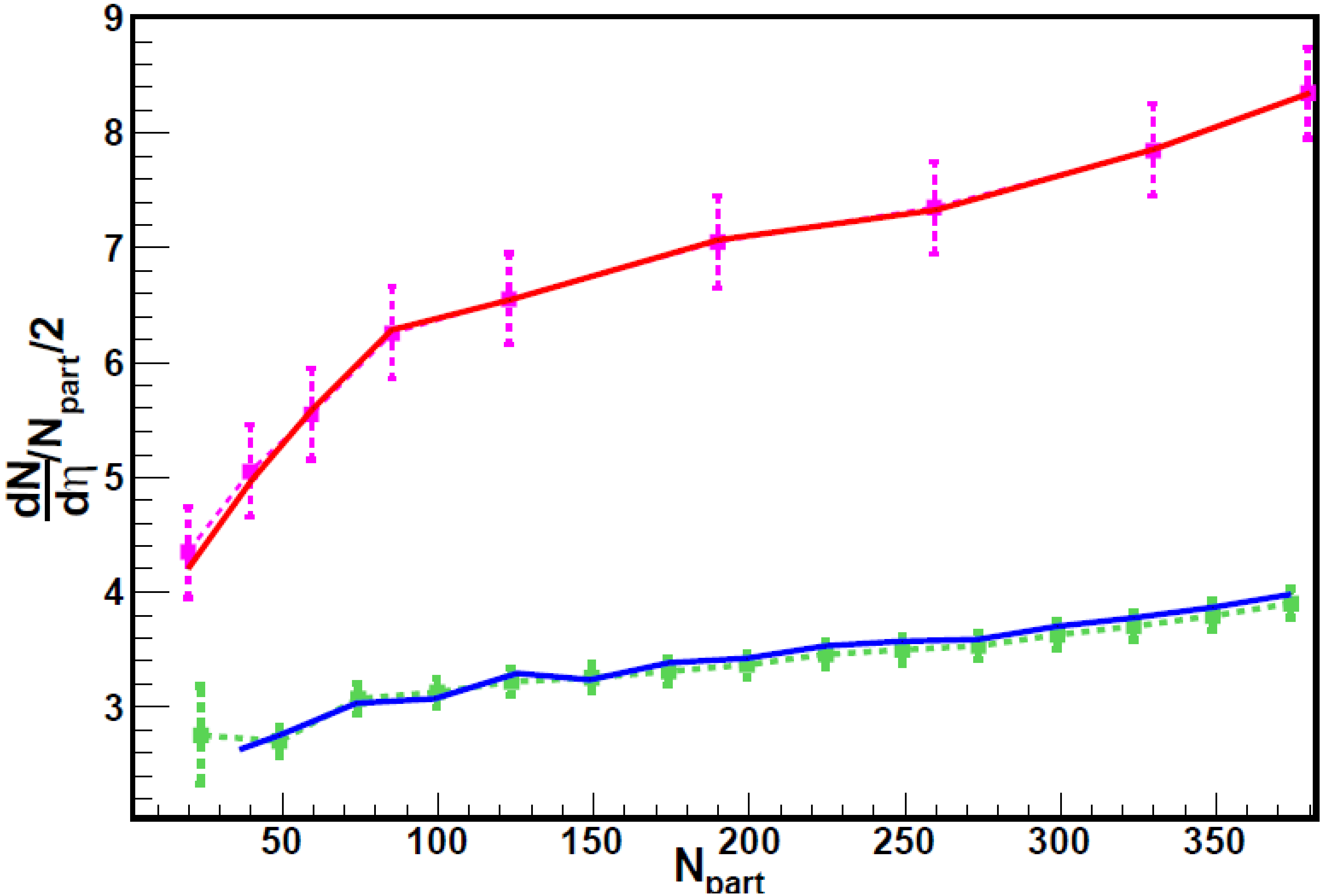
ϕ
R ϕ
R

$$\eta_\varphi = \eta(\frac{R}{R_\varphi})^2$$

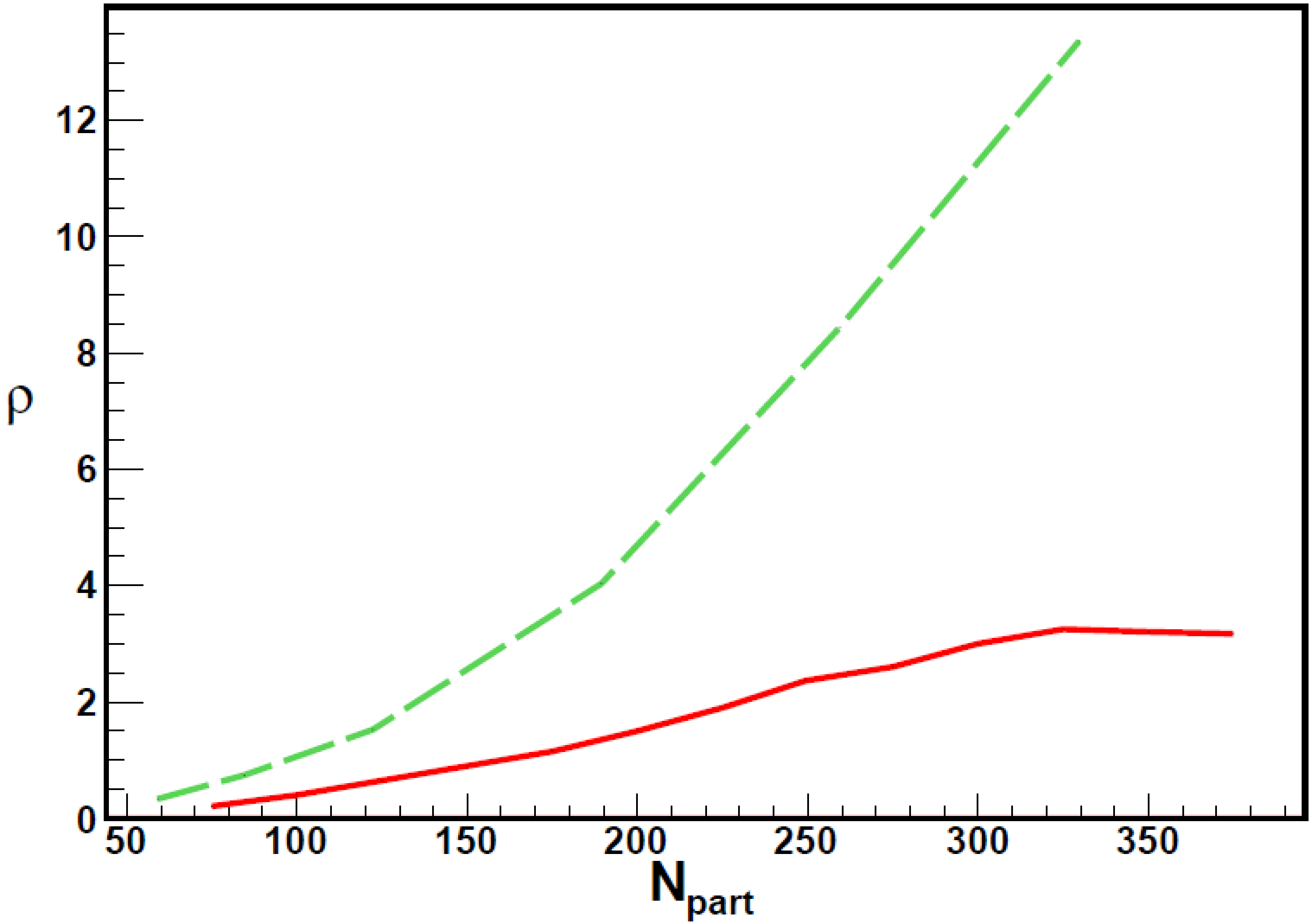
$$v_2(p_T^2, y) = \frac{2}{\pi}\int_0^{\pi/2} d\varphi cos(2\varphi)[1 + \frac{\partial \ln f(p_T^2,\eta,y)}{\partial R^2}(R_\varphi^2 - R^2)]$$

$$= \frac{2}{\pi}\int_0^{\pi/2} d\varphi cos2\varphi(\frac{R_\varphi}{R})^2(\frac{e^{-\eta}-F(\eta)^2}{2F(\eta)^2})\frac{F(\eta)p_T^2/<p_T^2>_1}{(1+F(\eta)p_T^2/<p_T^2>_1)}$$

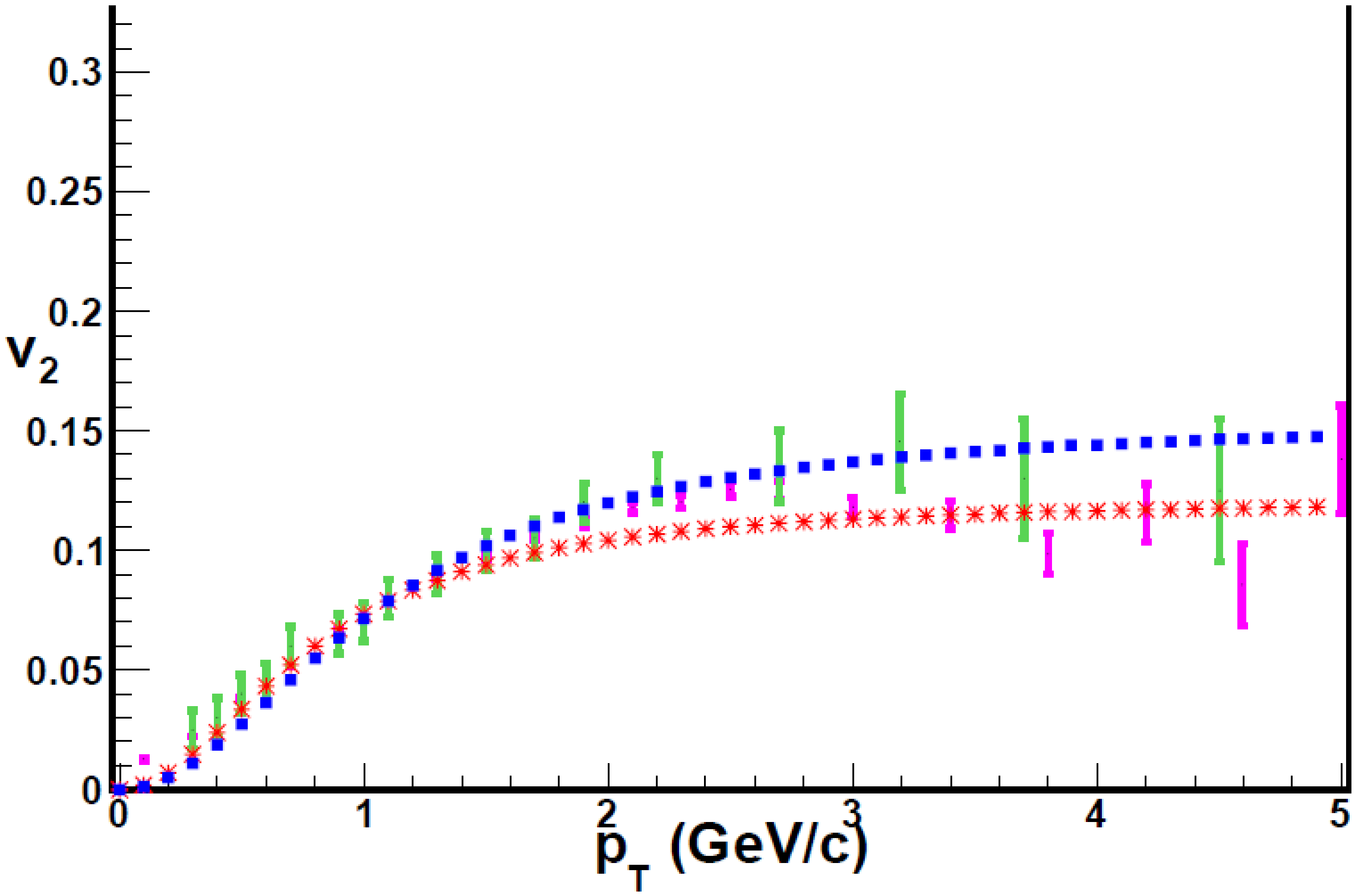
$$v_2 = \frac{2}{\pi}\int_0^{\pi/2} d\varphi cos(2\varphi)(\frac{R_\varphi}{R})(\frac{e^{-\eta}-F(\eta)^2}{2F(\eta)^3})\frac{R}{R-1}$$



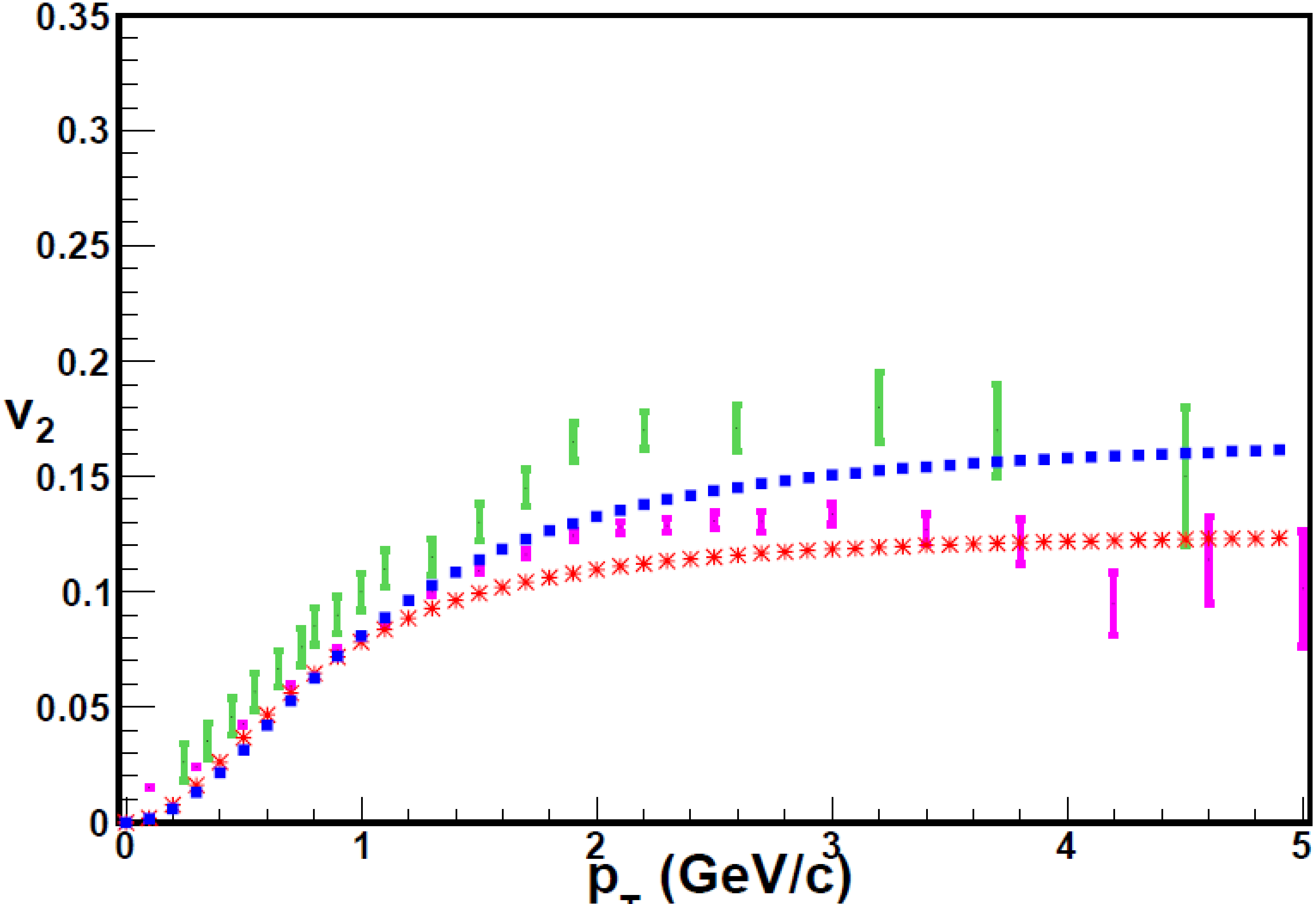
9
8
7
6
5
4
3
$\frac{dN}{d\eta}/N_{part}/2$
50
100
150
200
250
300
350
N_{part}



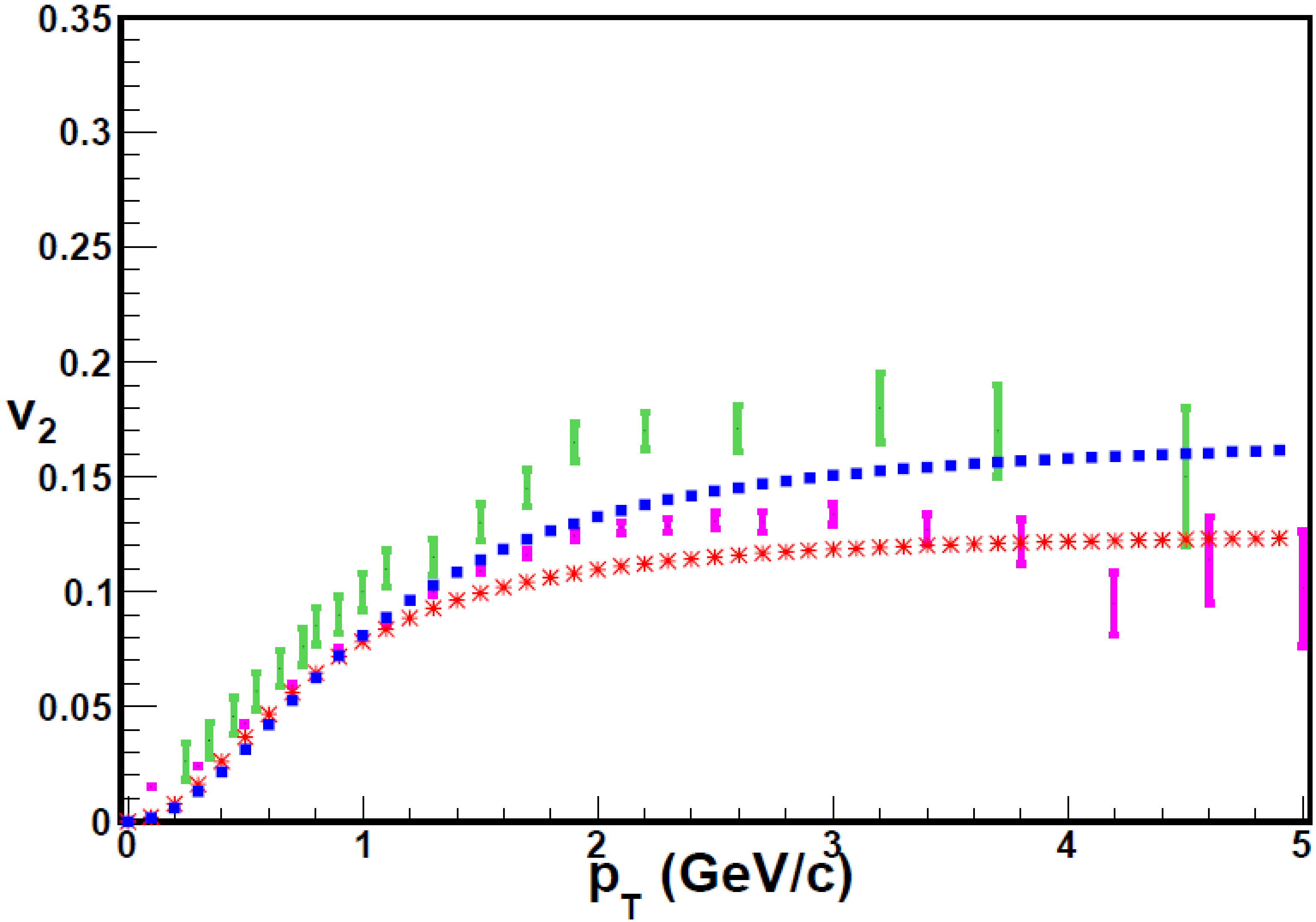
12
10
8
6
4
2
0
ρ
50
100
150
200
250
300
350
N_{part}



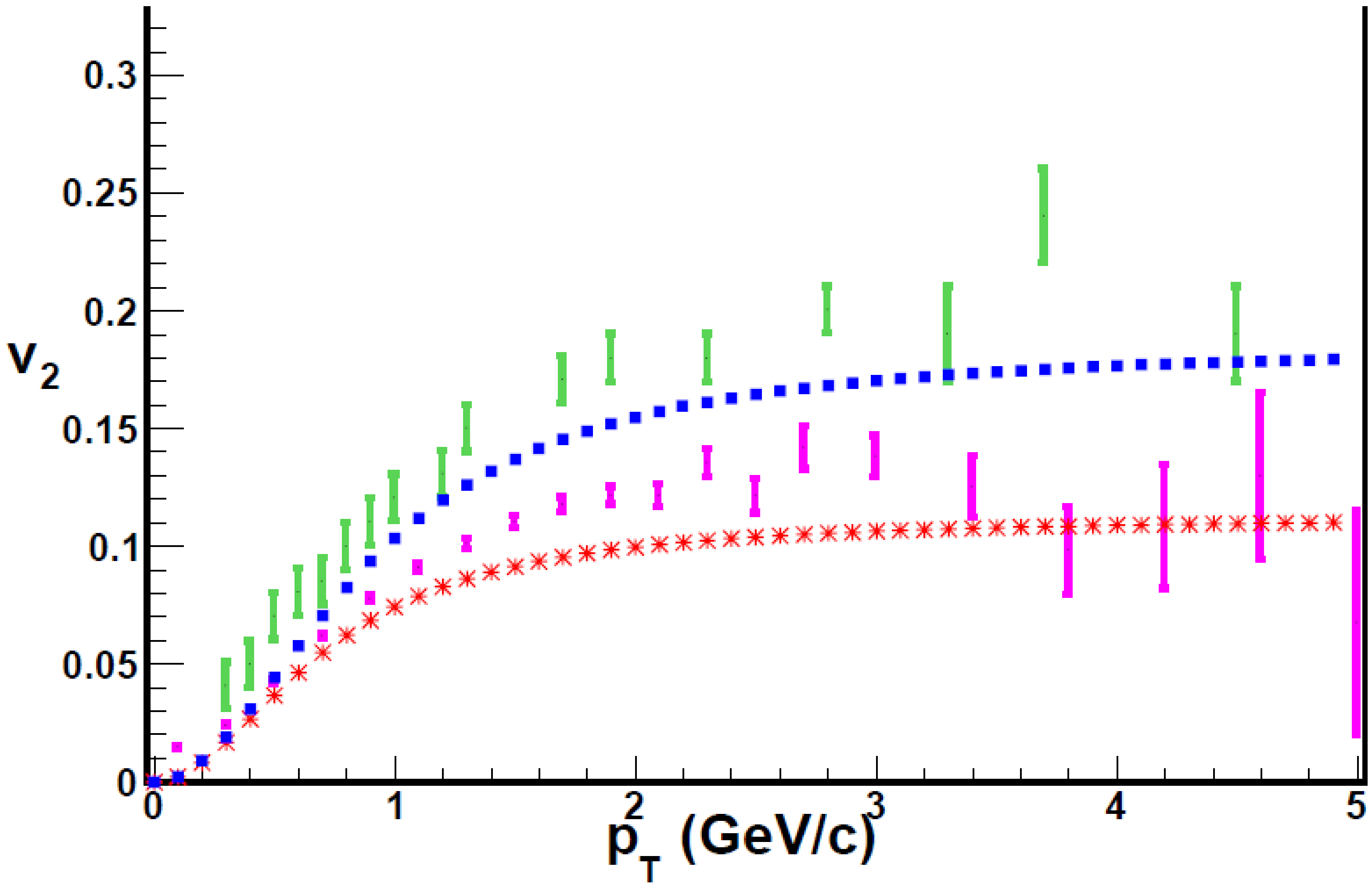
0.3
0.25
0.2
v_2
0.15
0.1
0.05
0
0
1
2
3
4
5
p_T (GeV/c)



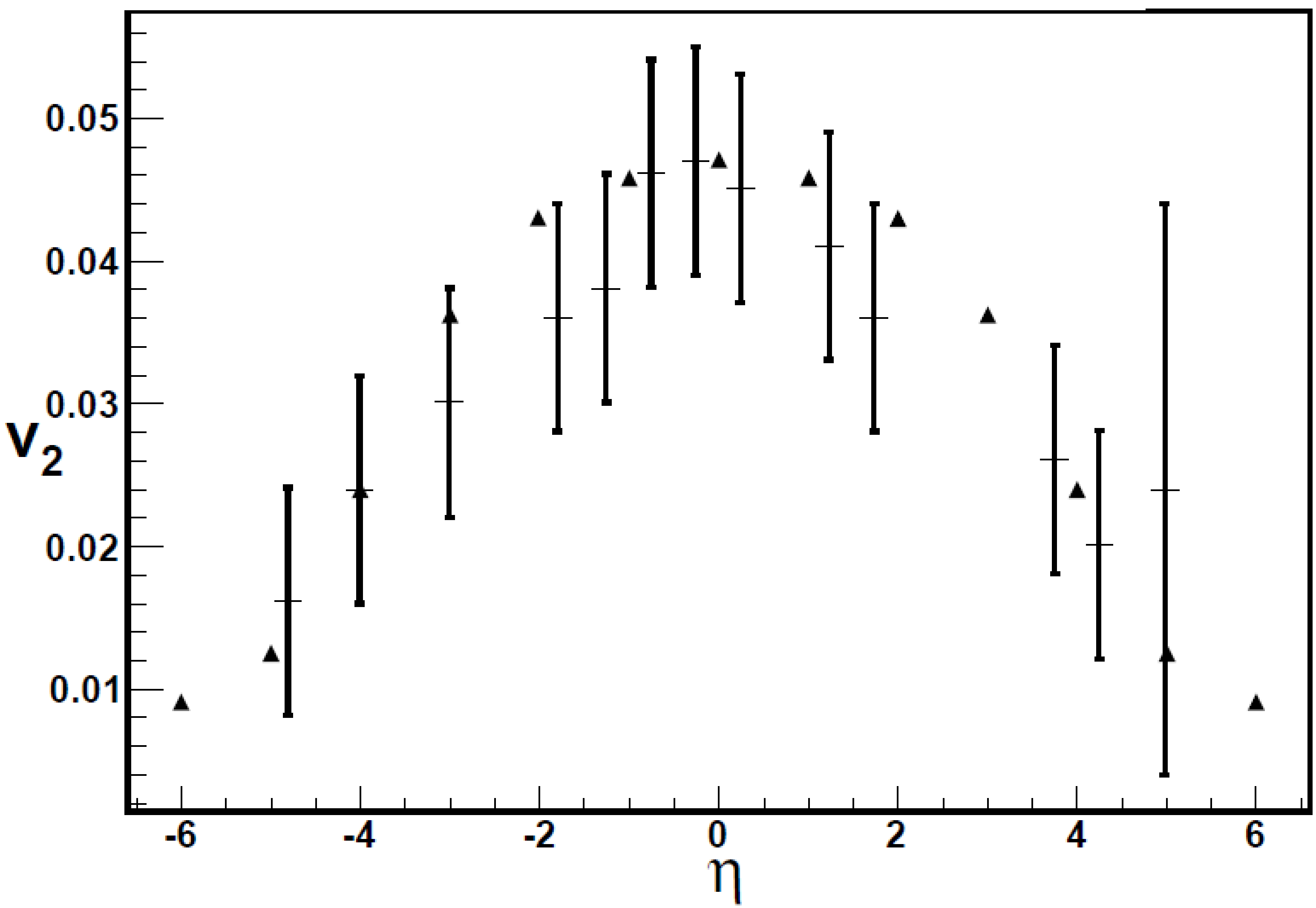
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
v_2
0
1
2
3
4
5
p_T (GeV/c)

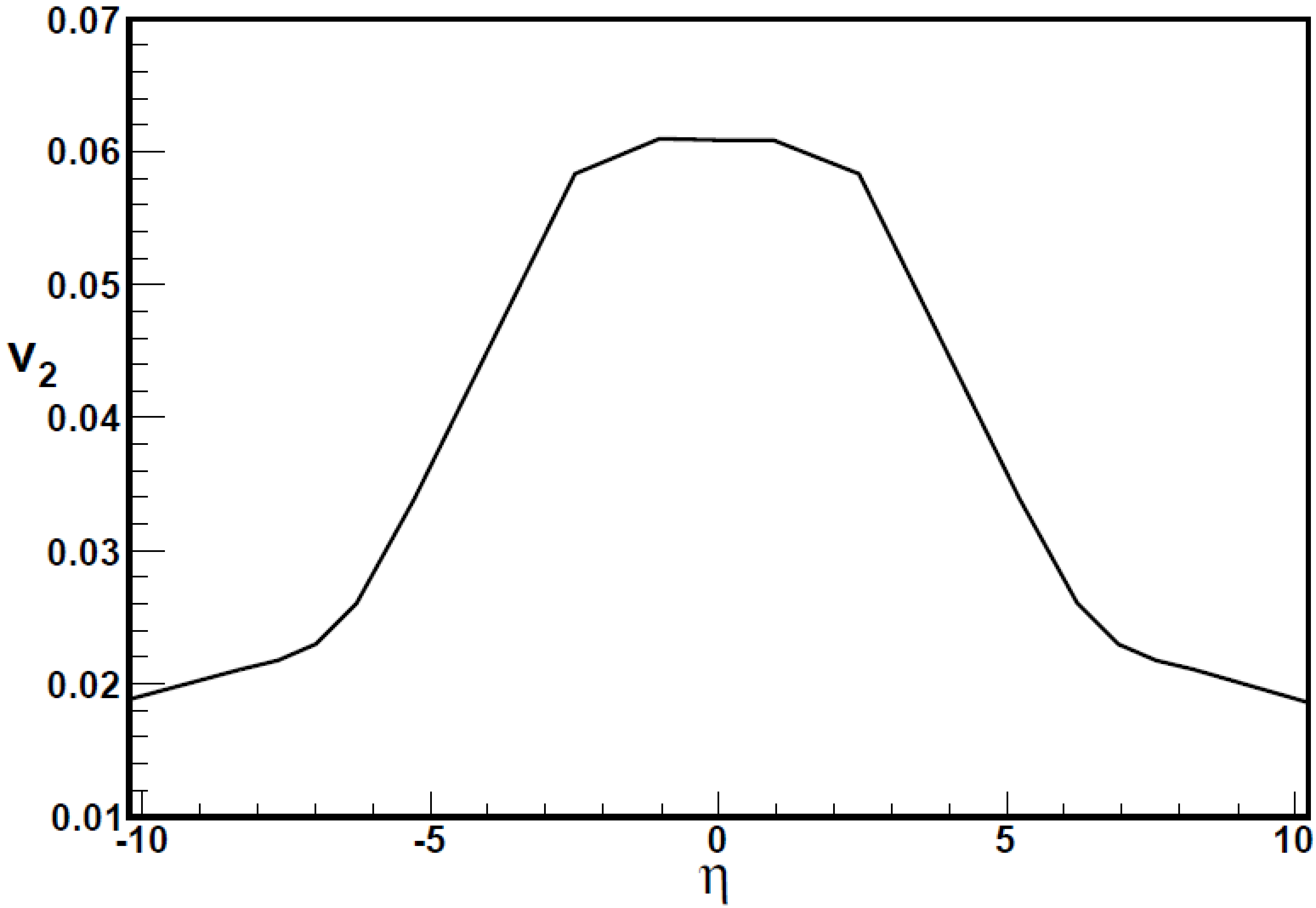


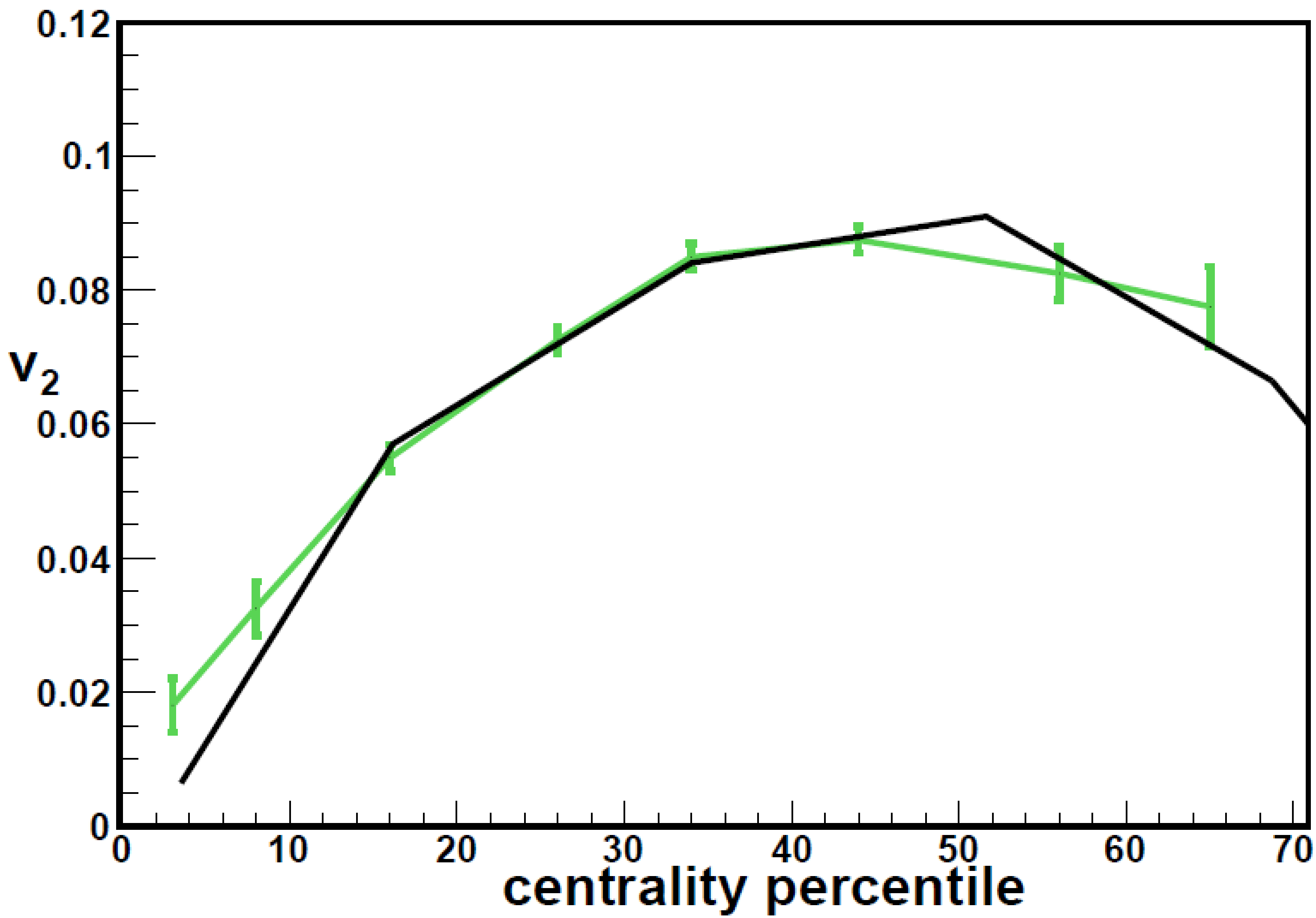
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
v2
0
1
2
3
4
5
pT (GeV/c)



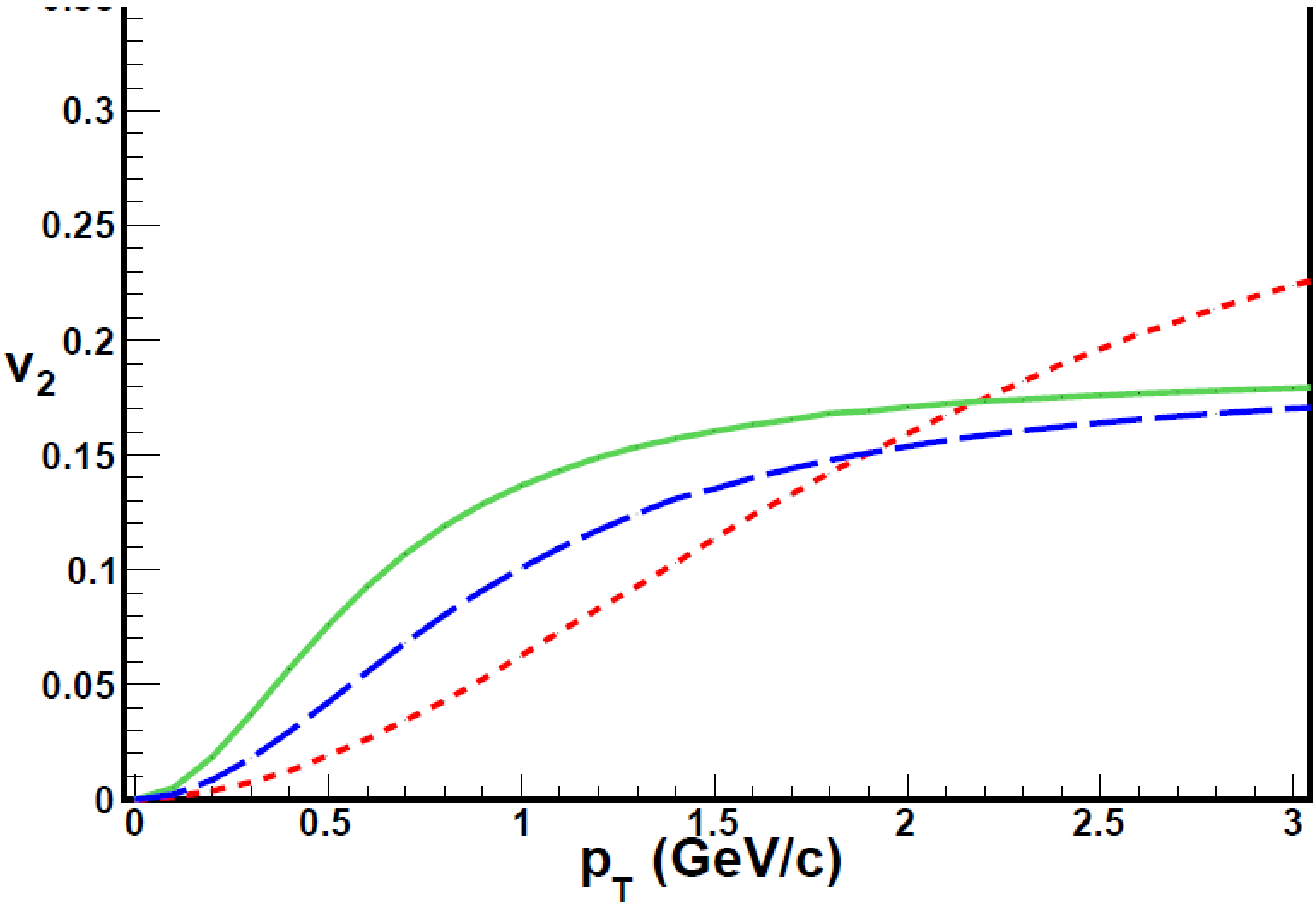
0.3
0.25
0.2
0.15
0.1
0.05
0
v_2
0
1
2
3
4
5
p_T (GeV/c)


0.05
0.04
0.03
0.02
0.01
v_2
-6
-4
-2
0
2
4
6
η

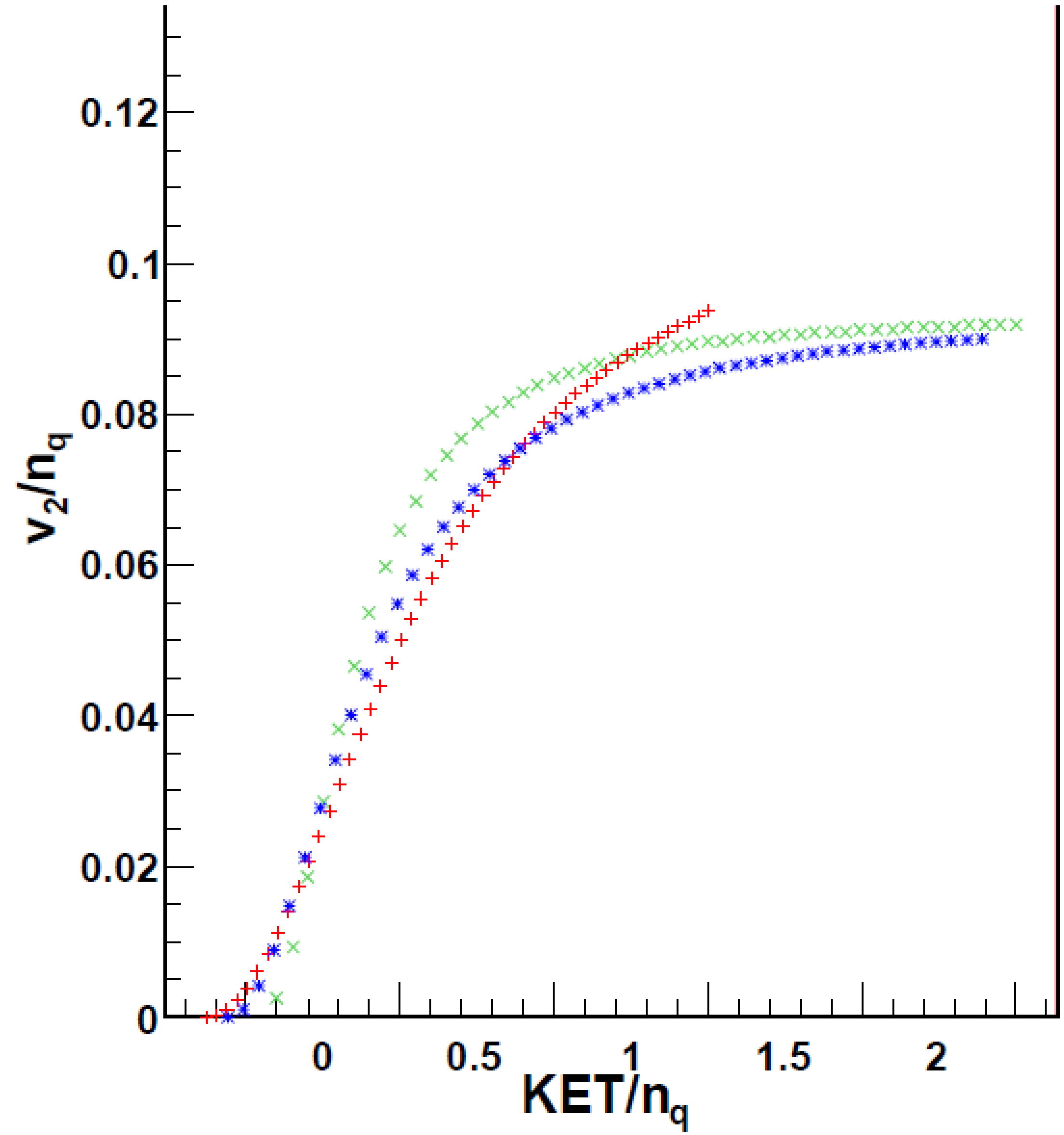

0.07
0.06
0.05
0.04
0.03
0.02
0.01
v_2
-10
-5
0
5
10
η



0.12
0.1
0.08
0.06
0.04
0.02
0
v_2
0
10
20
30
40
50
60
70
centrality percentile

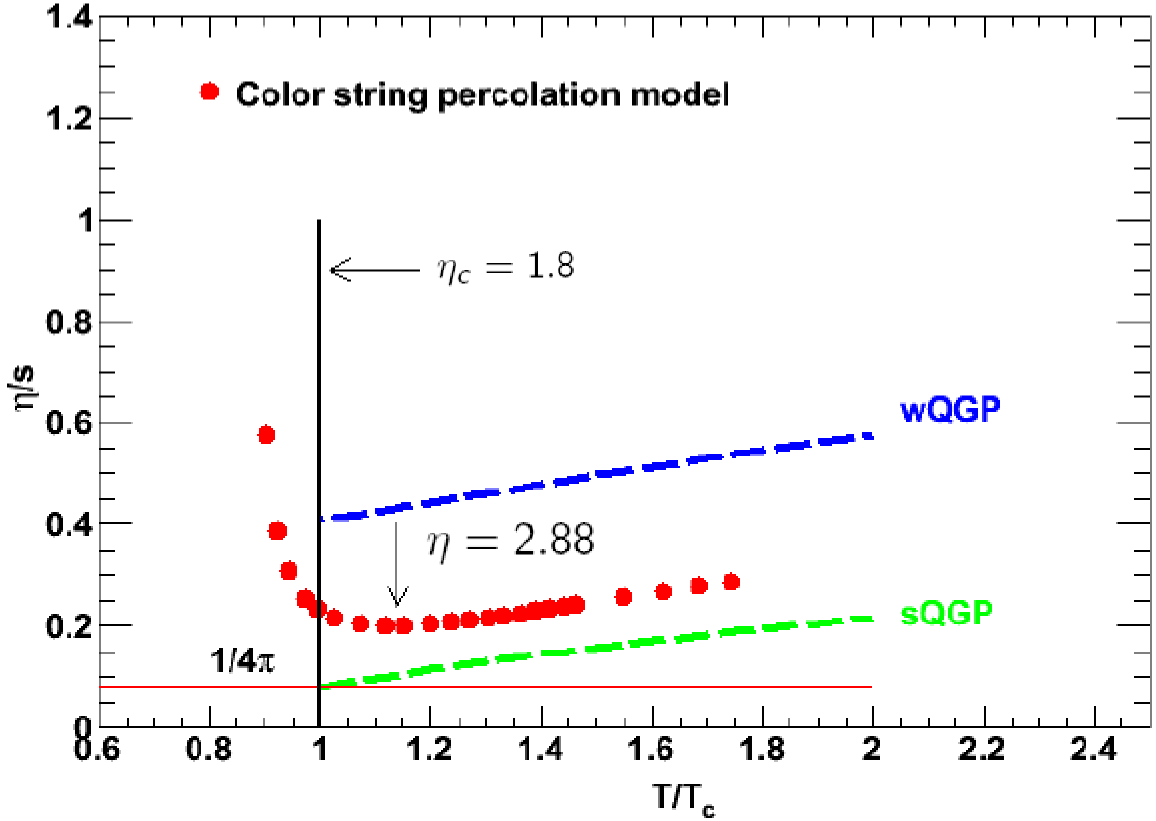


0.3
0.25
0.2
0.15
0.1
0.05
0
v_2
0
0.5
1
1.5
2
2.5
3
p_T (GeV/c)



0.12
0.1
0.08
0.06
0.04
0.02
0
v_2/n_q
0
0.5
1
1.5
2
KET/n_q

$$\frac{\eta}{s} = \frac{1}{5\sqrt{2}} \frac{<p_T>_1 \eta^{1/4}}{(1-e^{-\eta})^{5/4}} L$$



Color string percolation model
$\eta_c = 1.8$
$\eta = 2.88$
wQGP
sQGP
1/4π
η/s
T/T$_c$
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4

Conclusions

--- A good agreement with RHIC and LHC data(Close analytical formula)

--- Low ratio shear viscosity/entropy density

in the whole energy range RHIC-LHC

(increasing very slowly as a power1/4 of the

string density)

--- Percolation provides an microscopic framework

of the elliptic flow