STRING PERCOLATION AND THE NEW LHC DATA

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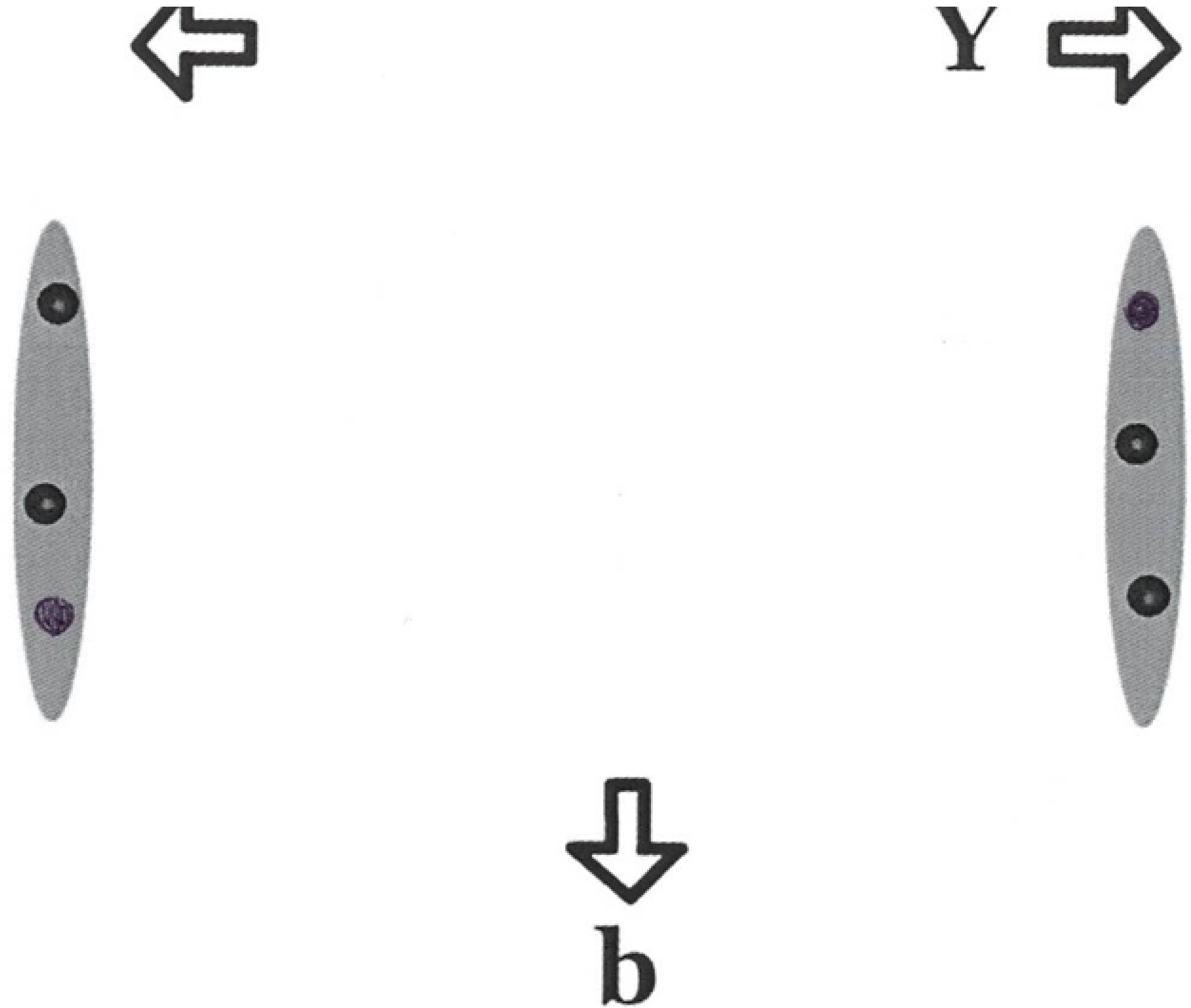
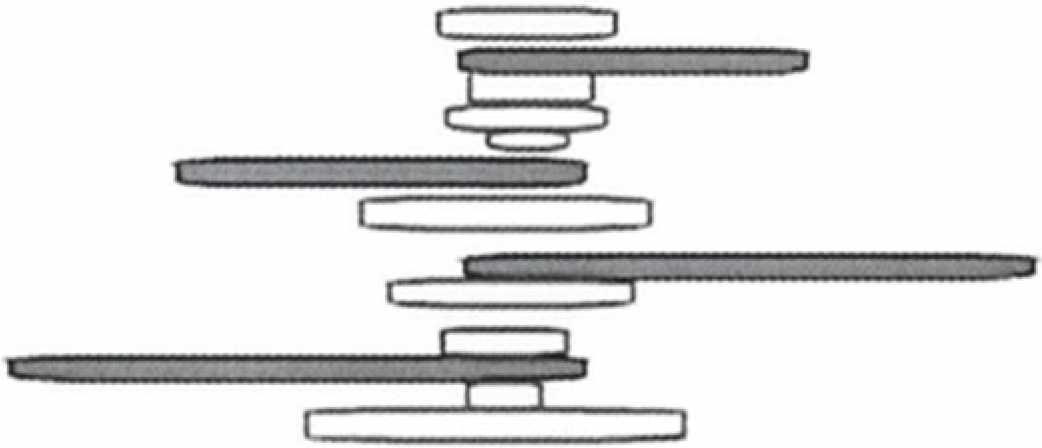
Outline

- Brief description of string percolation
- dn/dy in pp and Pb-Pb
- Rapidity long range correlations,Ridge in pp and AA
- Elliptic flow in percolation,comparison at RHIC and LHC

  Shear viscosity/entropy in percolation



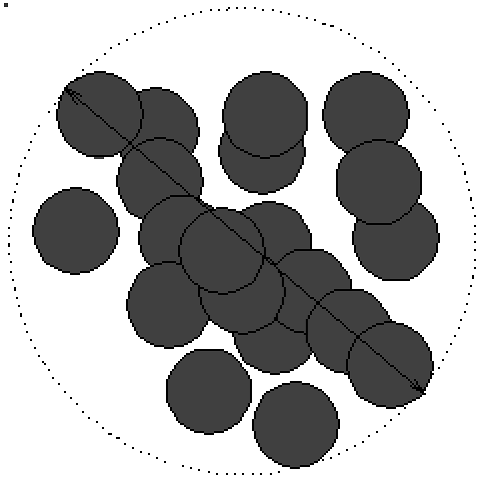
Y
b



- 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).



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

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

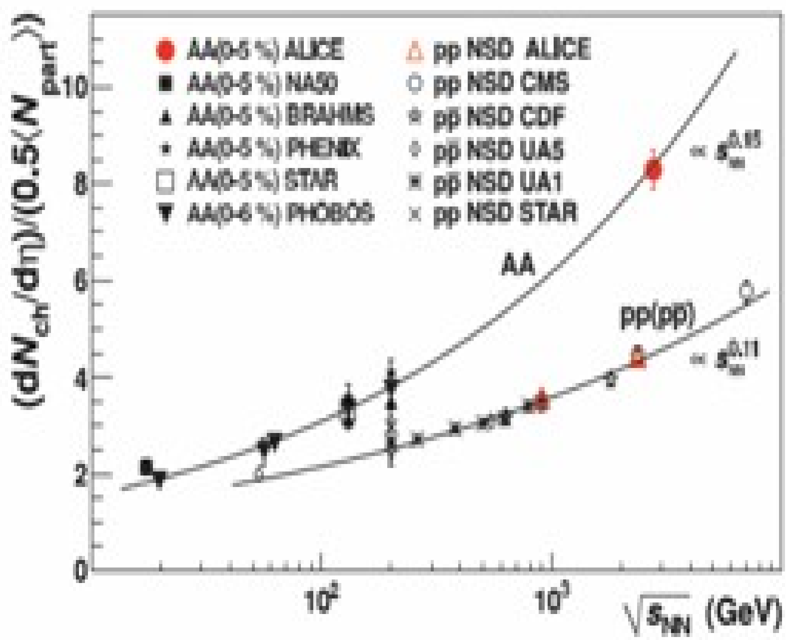
Energy-momentum of the cluster is the sum of the energy-momemtum of each string.

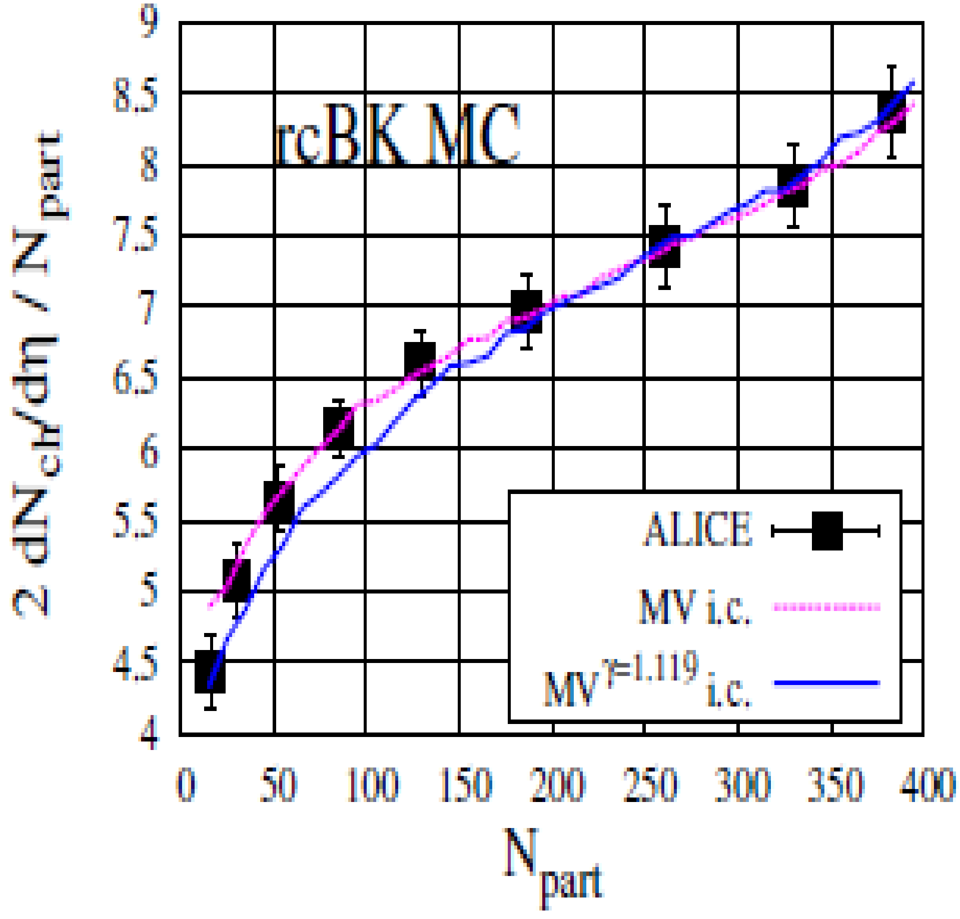
As the individual color field of the individual string may be oriented in an arbitrary manner respective to one another, $Q_n^2 = nQ_1^2$

- 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.

New data: multiplicities

[ALICE: arxiv:1011.3916]





rcBK MC
ALICE
MV i.c.
MV$^{\gamma=1.119}$ i.c.
2 dN$_{ch}$/dη / N$_{part}$
N$_{part}$
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
0
50
100
150
200
250
300
350
400

$$\frac{1}{N_A}\frac{dn}{dy}|_{N_A N_A} = \frac{dn}{dy}|_{pp}[1 + \gamma(\sqrt{s})\frac{F(\eta_{N_A})}{F(\eta_p)}(N_A^{1/3} - 1)]$$

with $\gamma(\sqrt{s}) = 1 - \frac{\sqrt{s_{th}}}{\sqrt{s}}$

at high energy $\gamma \to 1$

$$\frac{1}{N_A}\frac{dn}{dy}|_{N_A N_A} = \frac{dn}{dy}|_{pp}[1 + (\frac{N_A}{A})^{1/6}(1 - \frac{1}{N_A^{1/3}})]$$

(The shape as a function of N_A is independent of energy)

Two-Particle Angular Correlations

Published in
J. High Energy Phys. 09 (2010) 091

First surprising result from the LHC:
Observation of Long-Range Near-Side Angular Correlations in pp Collisions

MinBias | high multiplicity (N>110)

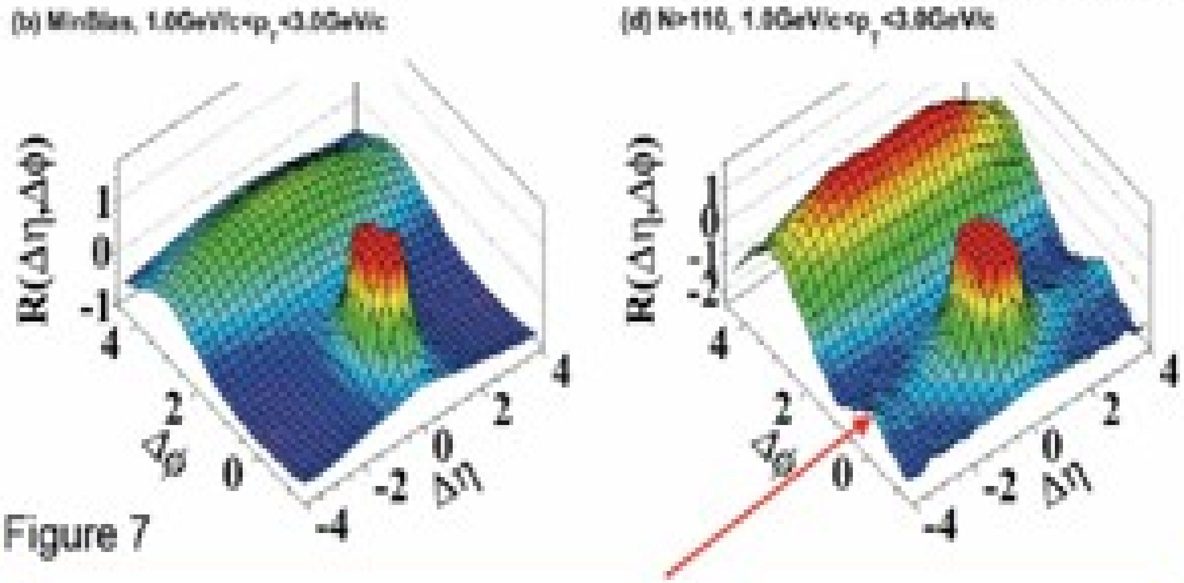


Figure 7

Why Protons?

In String Percolation…

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

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

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

$$\eta_c \approx 1.15$$

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

LHC

- As the string density in Au-Au peripheral collisions at 200Gev is the same as in pp high multiplicity events(three times m.b)

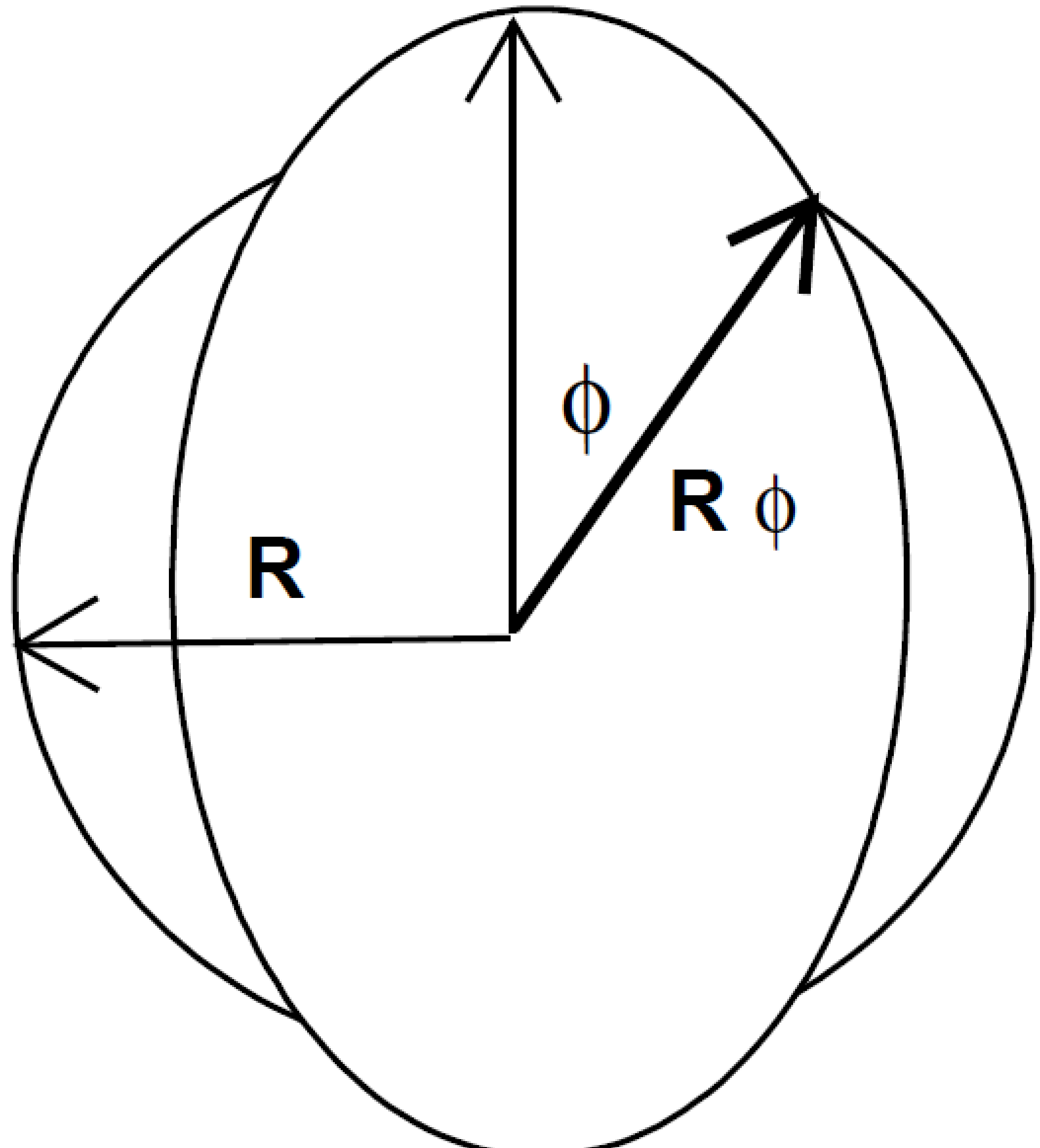
If there is a ridge structure in Au-Au at RHIC

It should be seen the same structure in pp

as it was seen CMS collaboration

L.Cunqueiro,J Dias de Deus and CP

Eur Phys J C 65 423 (2010)



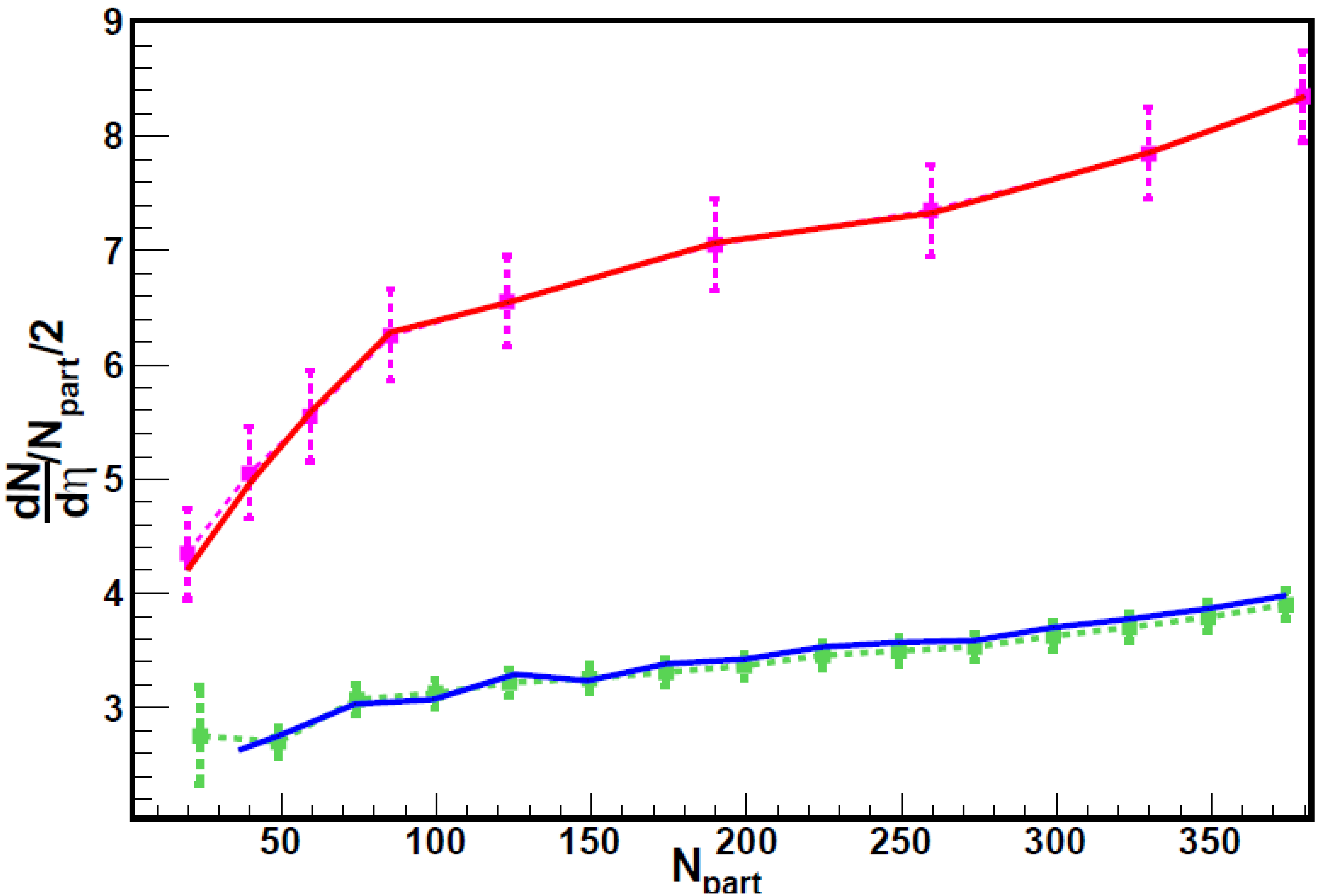
ϕ
R ϕ
R

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

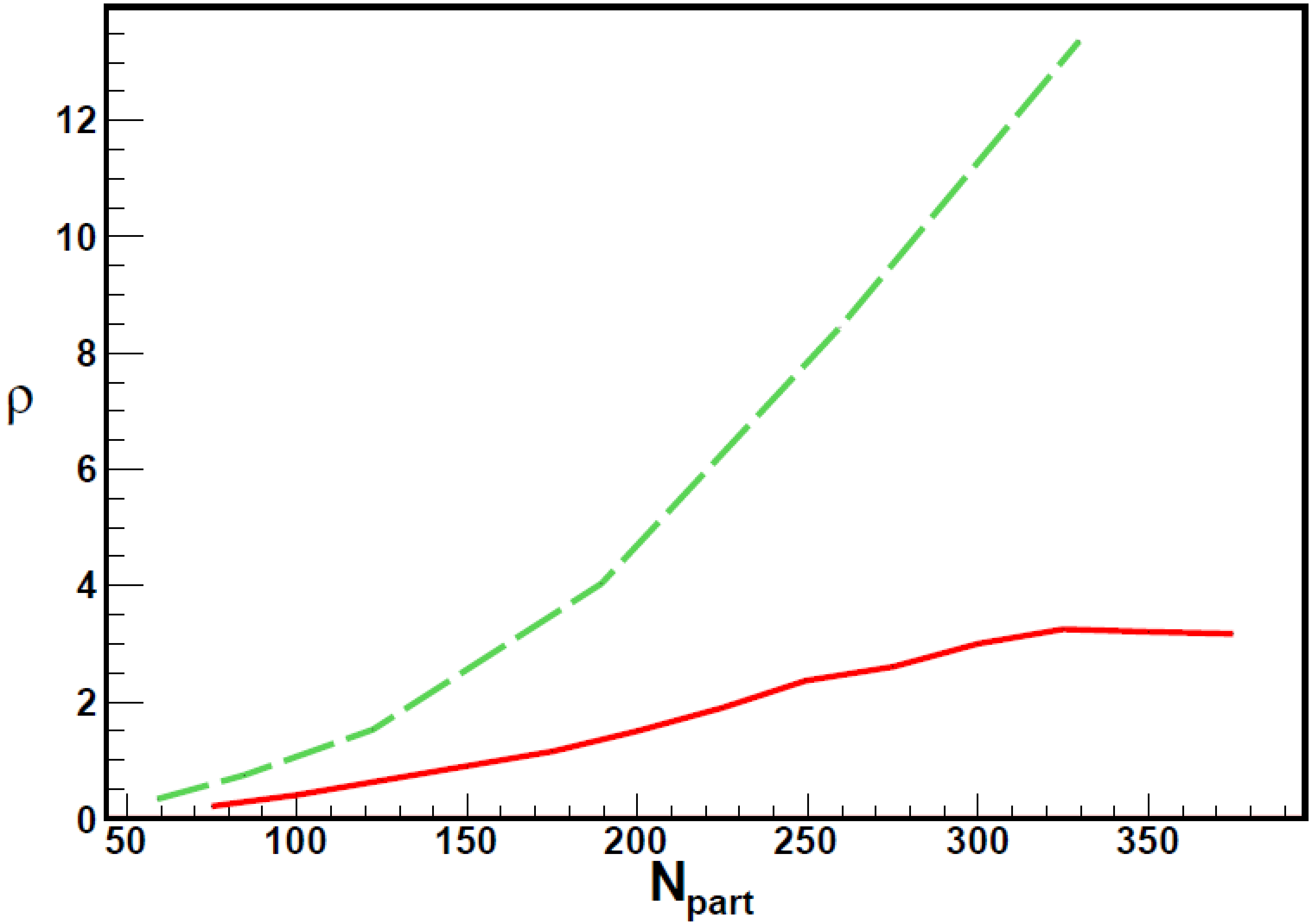
$$v_2(p_T^2, y) = \frac{2}{\pi}\int_0^{\pi/2} d\varphi cos(2\varphi)[1 + \frac{\partial \ln f(p_T^2, \eta, y)}{\partial R^2}(R_\varphi^2 - R^2)]$$

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

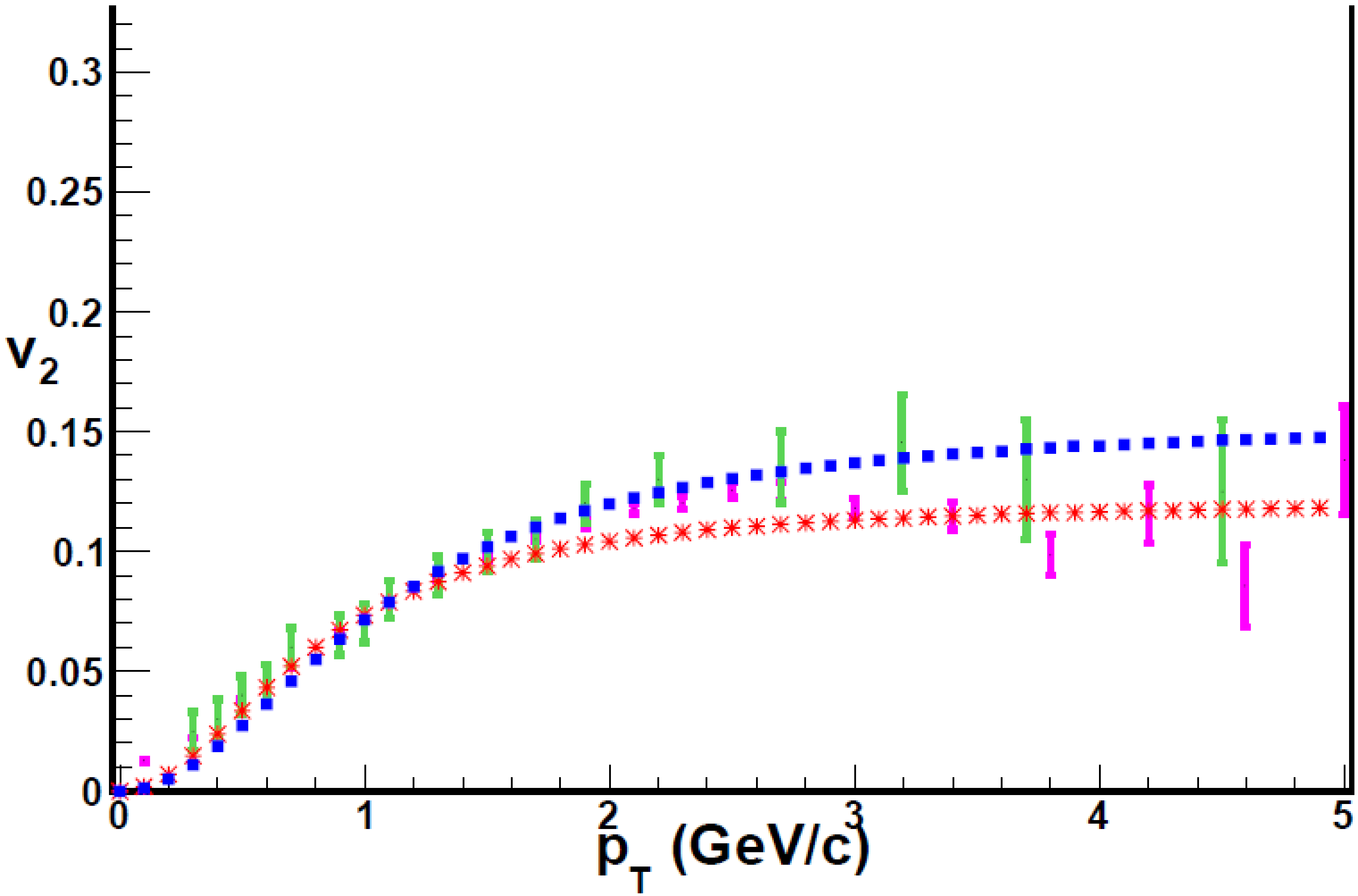
$$v_2 = \frac{2}{\pi}\int_0^{\pi/2} d\varphi cos(2\varphi)(\frac{R_\varphi}{R})(\frac{e^{-\eta} - F(\eta)^2}{2F(\eta)^3})\frac{R}{R-1}$$



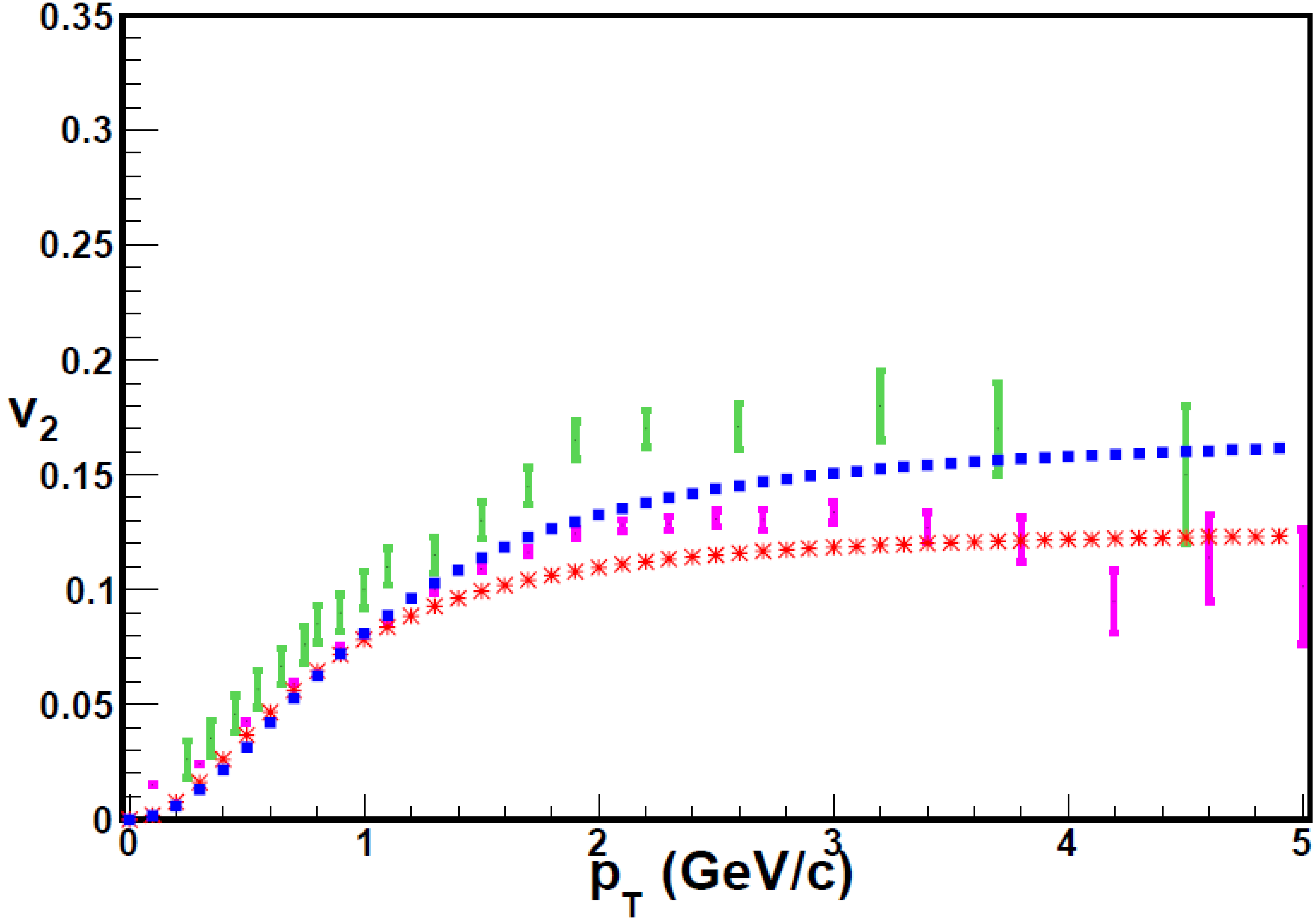
9
8
7
6
5
4
3
$\frac{dN}{d\eta}/N_{part}/2$
50
100
150
200
250
300
350
N_{part}



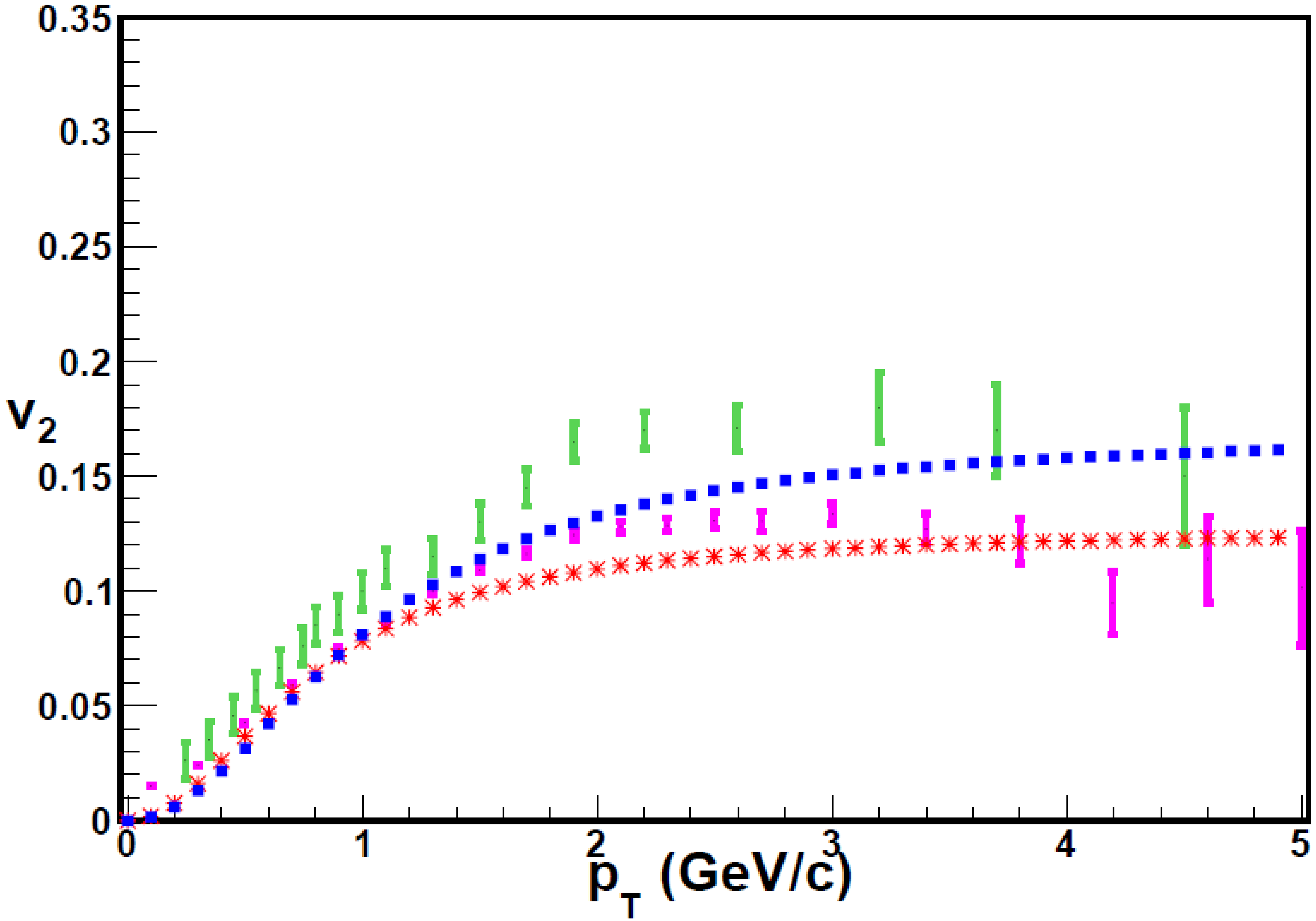
12
10
8
6
4
2
0
ρ
50
100
150
200
250
300
350
N part



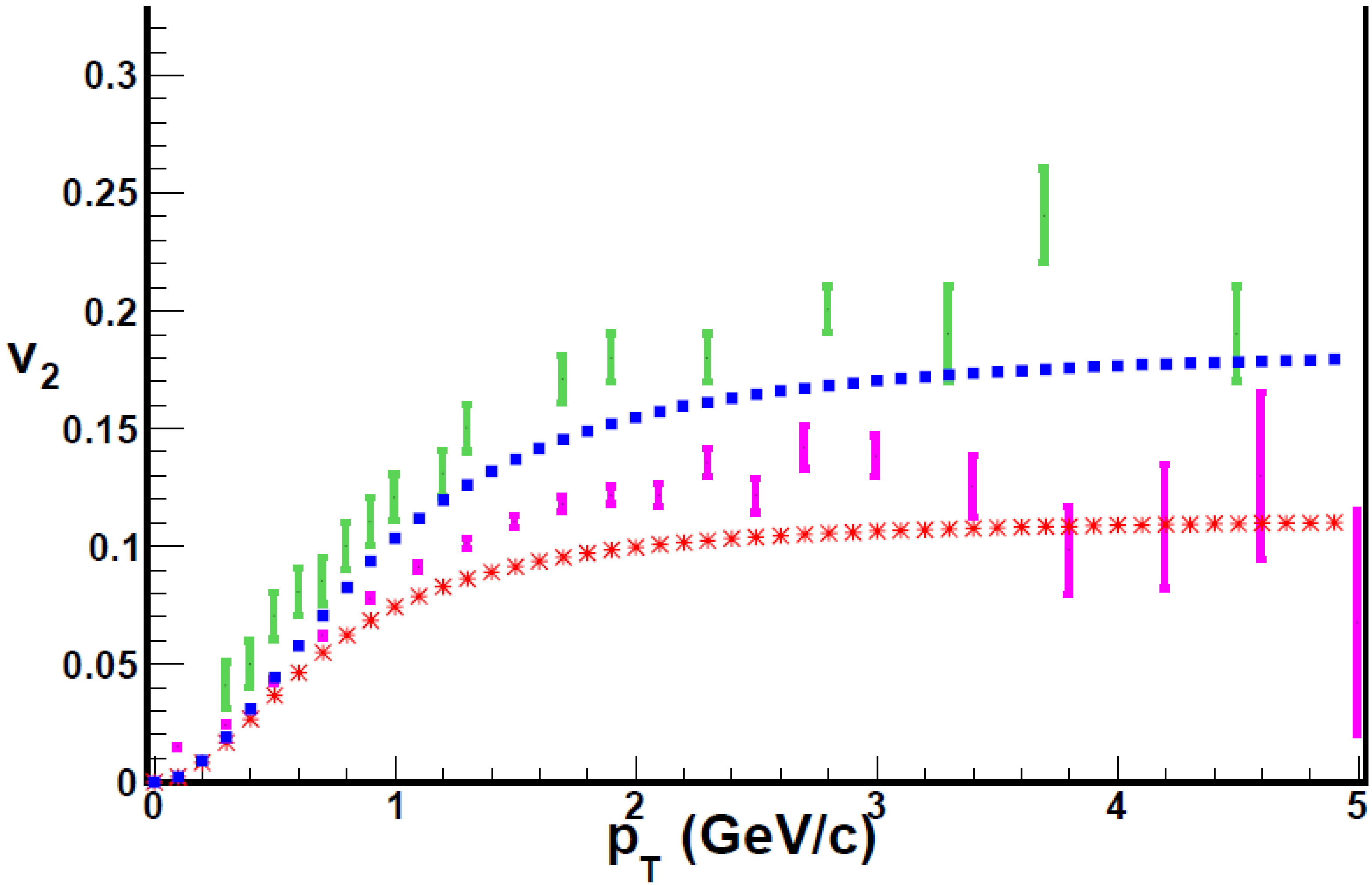
v_2
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
p_T (GeV/c)



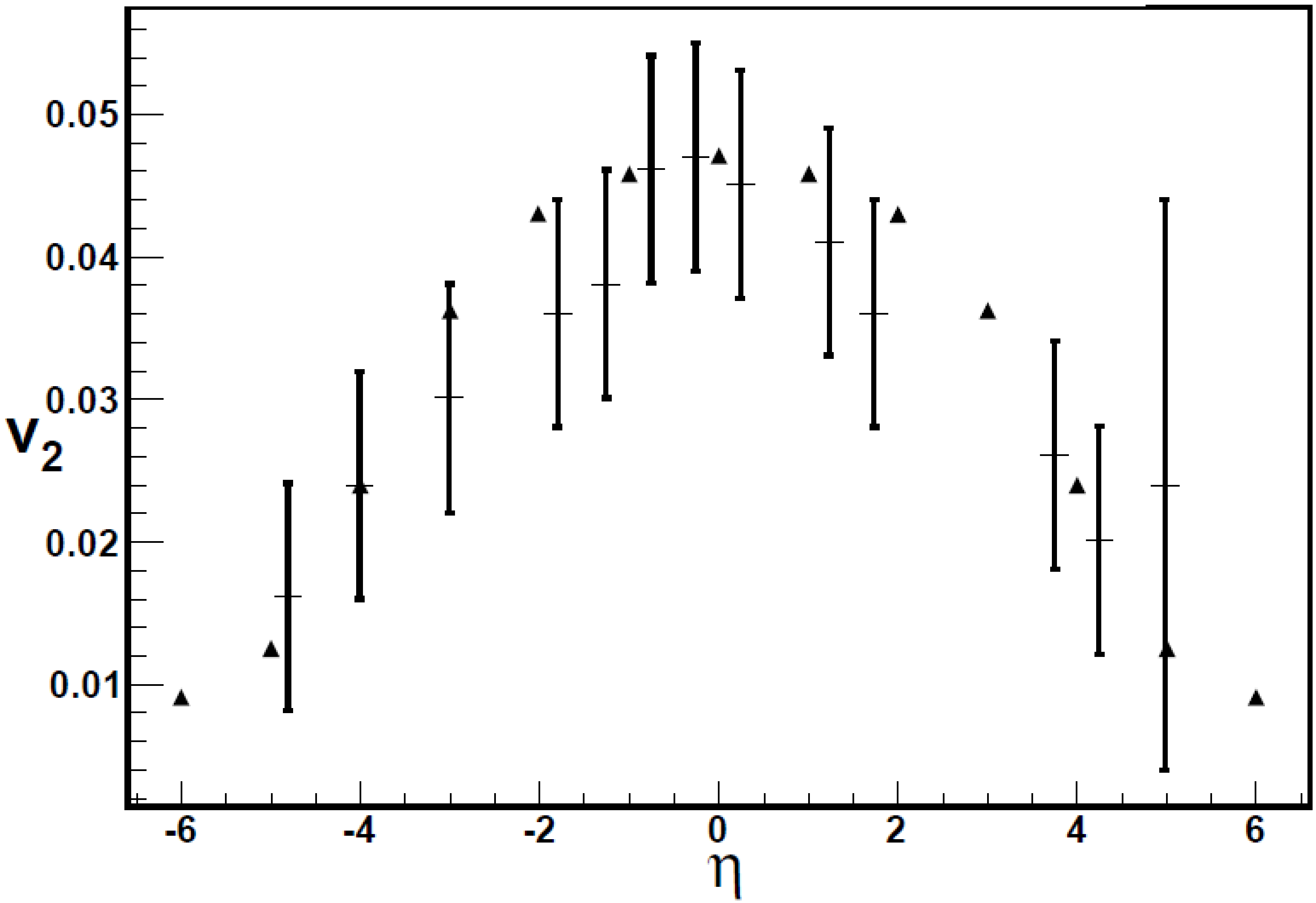
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
v2
0
1
2
3
4
5
pT (GeV/c)



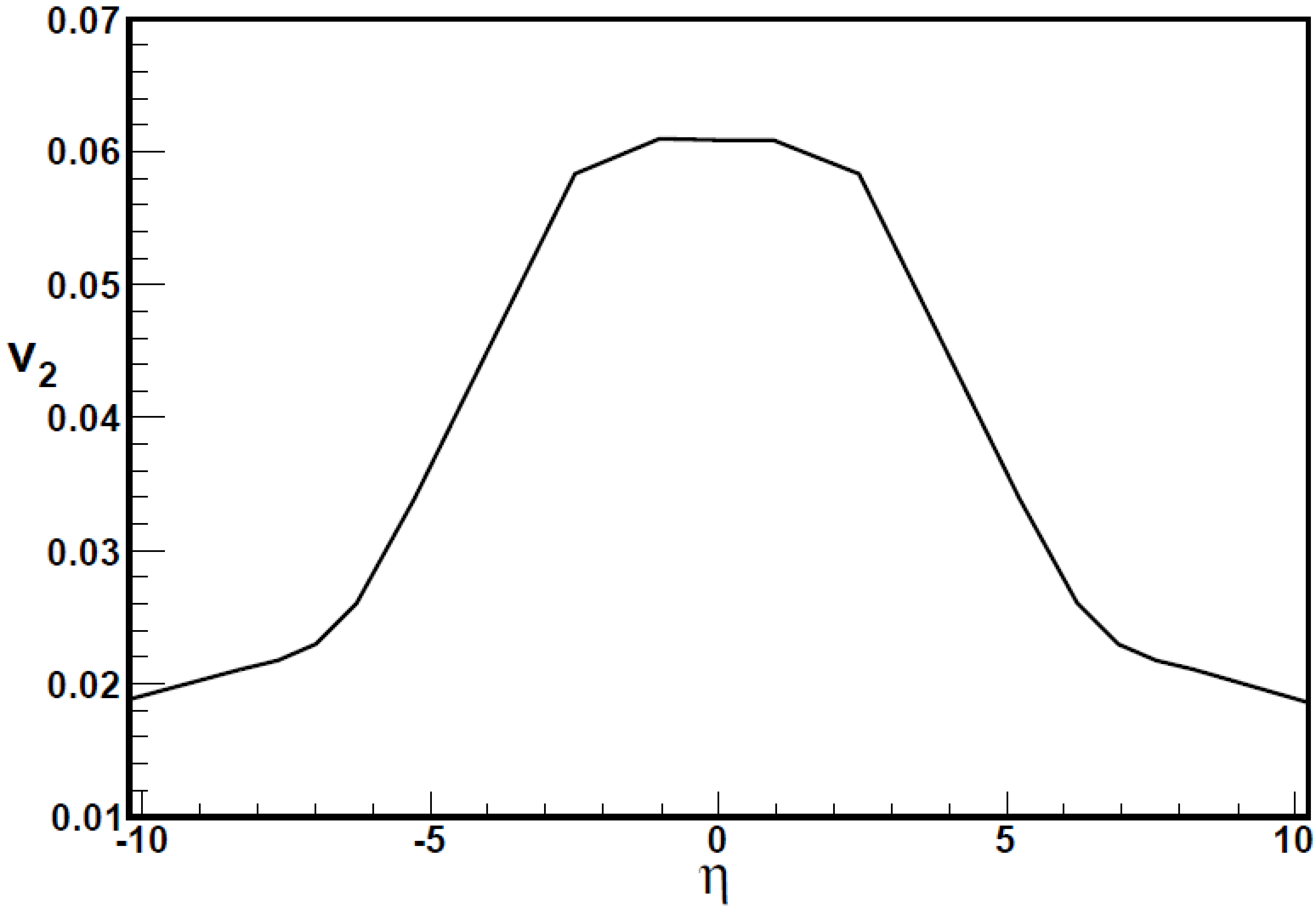
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
v_2
0
1
2
3
4
5
p_T (GeV/c)

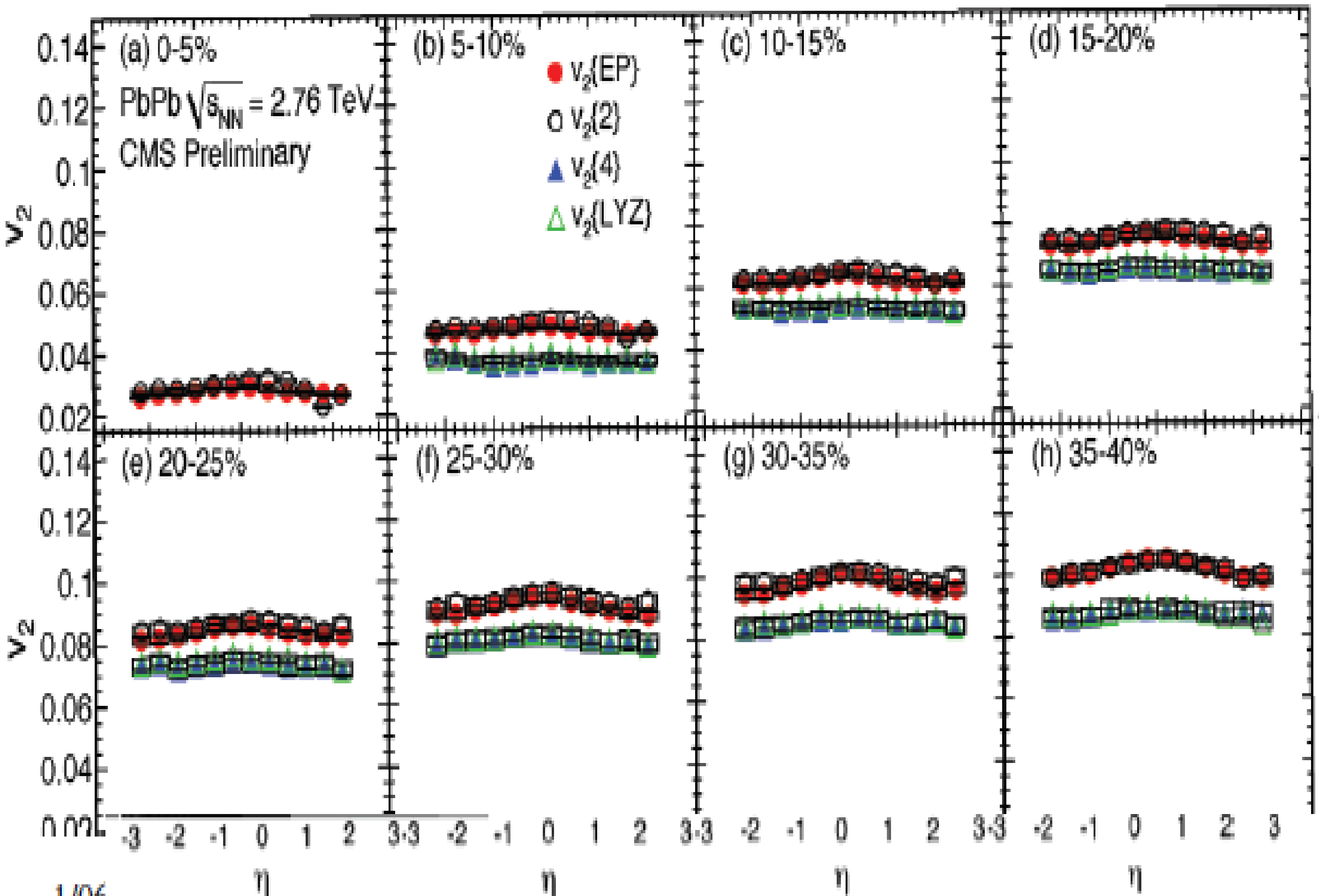


0.3
0.25
0.2
0.15
0.1
0.05
0
v_2
0
1
2
3
4
5
p_T (GeV/c)



0.05
0.04
0.03
0.02
0.01
v2
-6
-4
-2
0
2
4
6
η

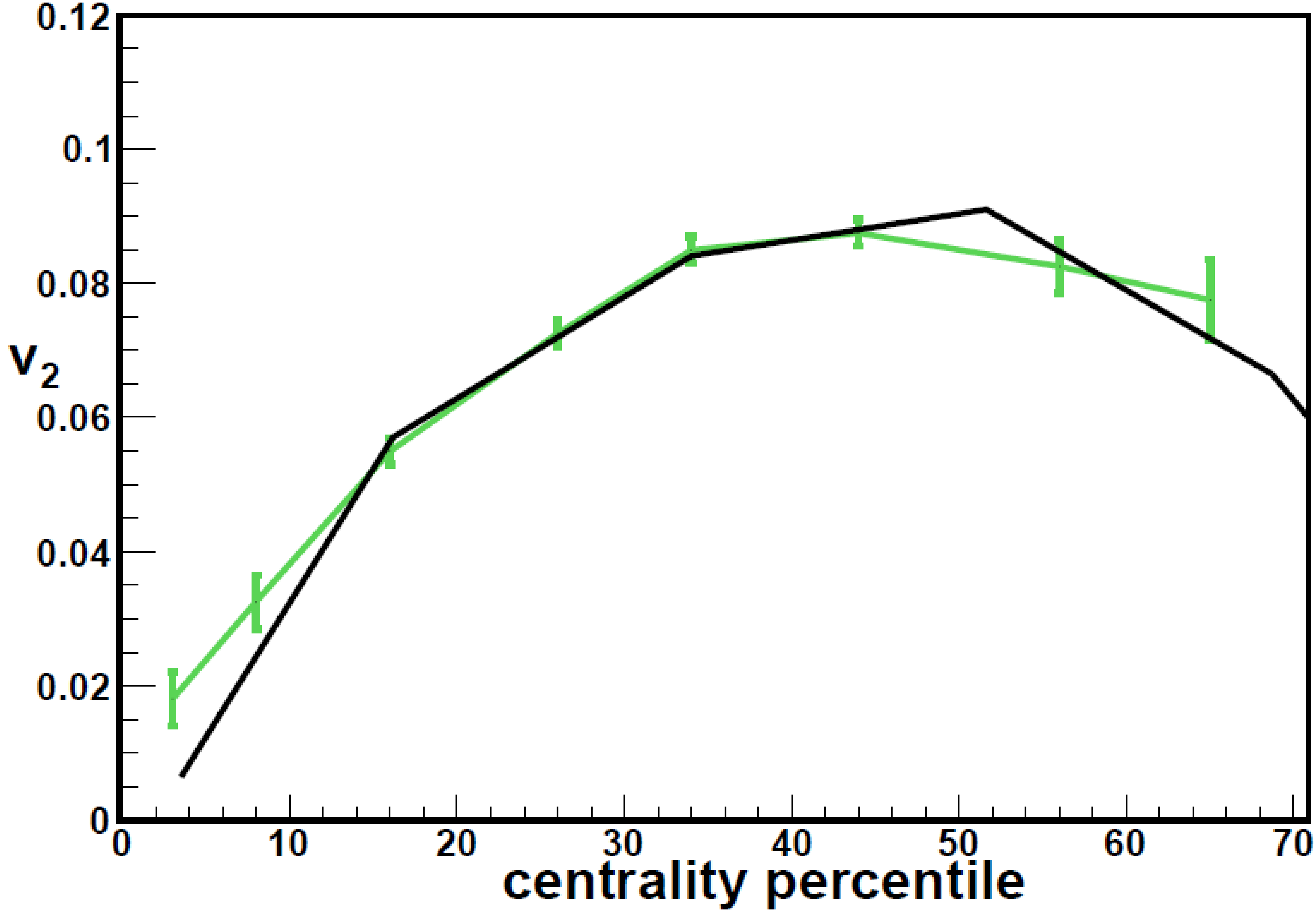

0.07
0.06
0.05
0.04
0.03
0.02
0.01
v_2
-10
-5
0
5
10
η


(a) 0-5%
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
CMS Preliminary
(b) 5-10%
v_2{EP}
v_2{2}
v_2{4}
v_2{LYZ}
(c) 10-15%
(d) 15-20%
(e) 20-25%
(f) 25-30%
(g) 30-35%
(h) 35-40%
v_2
η

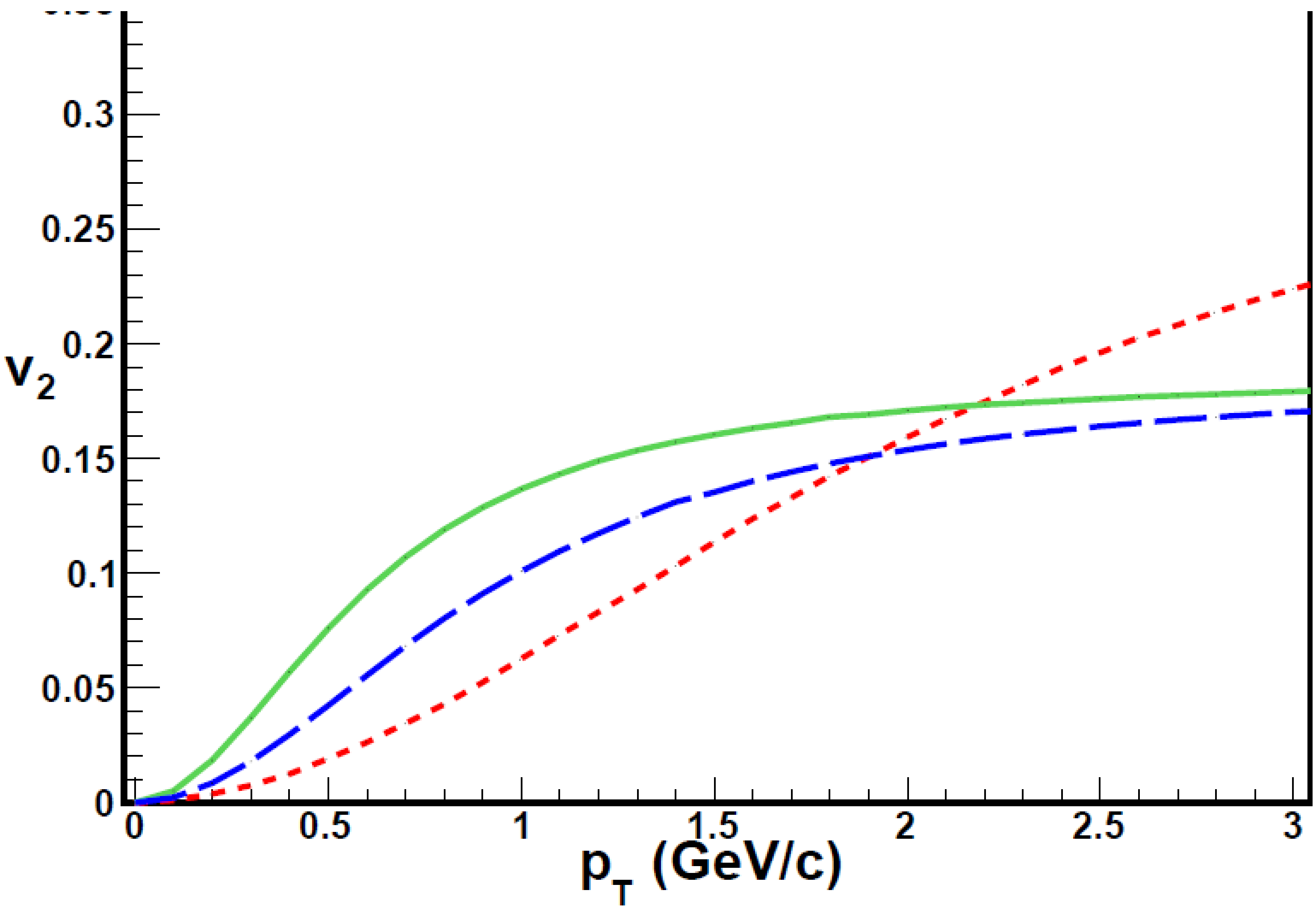
0-20%

20-40

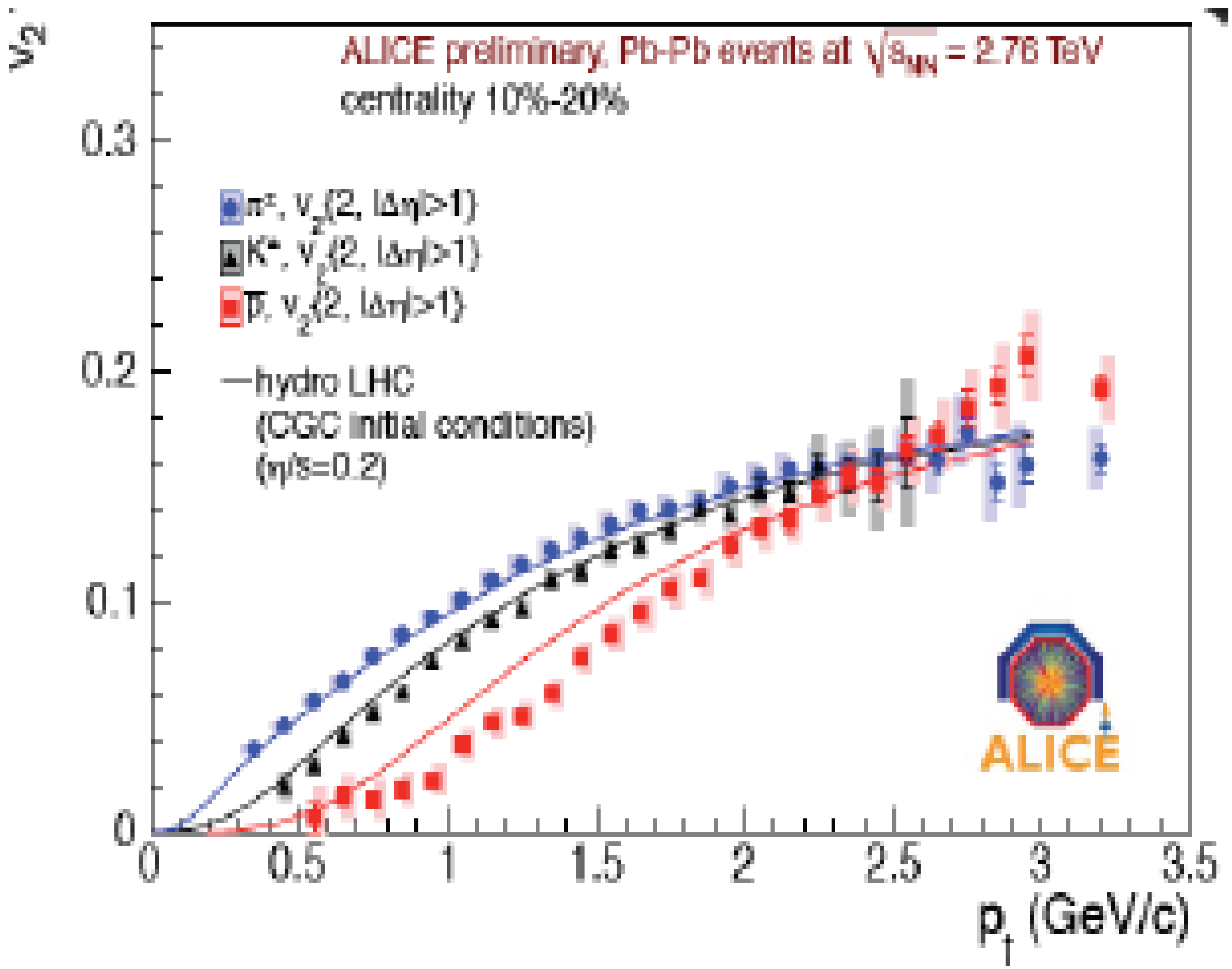
1/06

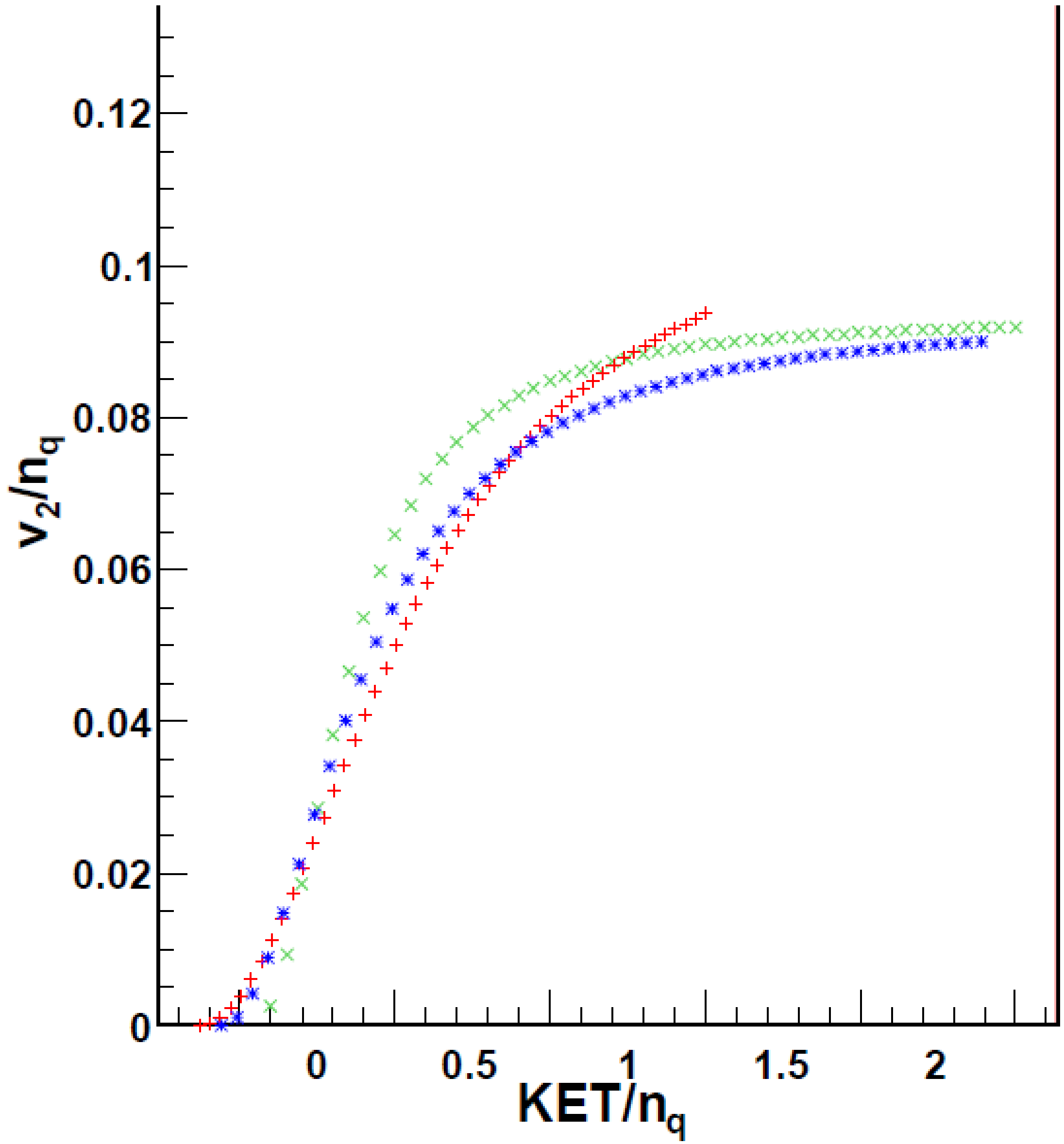


0.12
0.1
0.08
0.06
0.04
0.02
0
v_2
0
10
20
30
40
50
60
70
centrality percentile



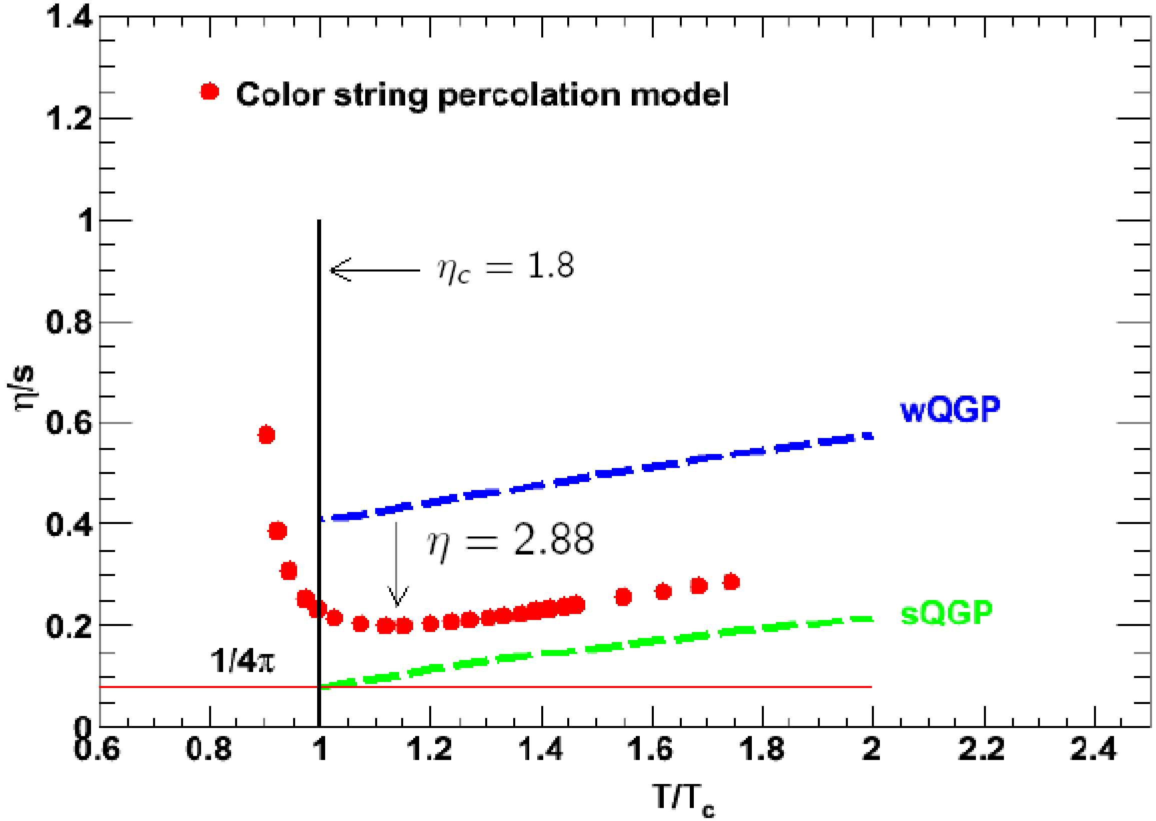
0.3
0.25
0.2
0.15
0.1
0.05
0
v2
0
0.5
1
1.5
2
2.5
3
pT (GeV/c)


ALICE preliminary, Pb-Pb events at $\sqrt{s_{NN}}$ = 2.76 TeV
centrality 10%-20%
$\pi^{\pm}$, $v_2\{2, |\Delta\eta|>1\}$
$K^{\pm}$, $v_2\{2, |\Delta\eta|>1\}$
$\bar{p}$, $v_2\{2, |\Delta\eta|>1\}$
hydro LHC
(CGC initial conditions)
(η/s=0.2)
v_2
0
0.1
0.2
0.3
0.5
1
1.5
2
2.5
3
3.5
p_t (GeV/c)
ALICE



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$_c$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
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,for dN/dy dependences on energy and centrality.

---It was predicted rapidity long range correlations and ridge structure in pp at high multiplicity

---Good description of v2 at RHIC and LHC including the rapidity dependences

--- Low ratio shear viscosity/entropy density

in the whole energy range RHIC-LHC