Universal geometrical scaling of the elliptic flow

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ISMD Bologna Sept2014

Outline

-----Experimental Scaling of Elliptic Flow of charged particles

-----Scaling of Photons

-----From Geometrical Scaling in pt Distributions to GS of Elliptic Flow

-----v3 Scaling?

-----Possible implications(initial states or final states interaction)

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

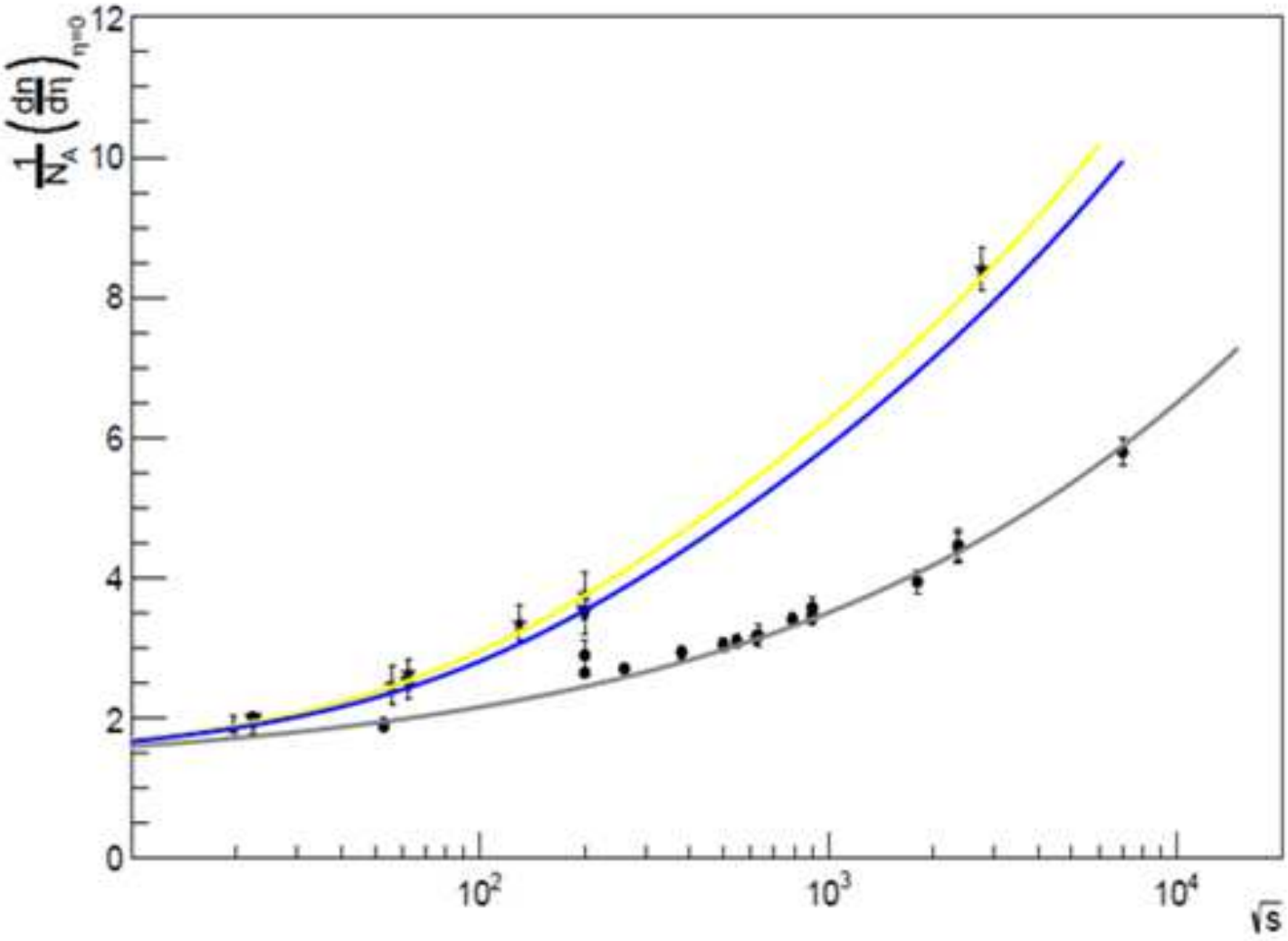
$$\left(Q_s^A\right)^2 = \left(Q_s^p\right)^2 A^{\alpha(s)/2} N_A^{1/6}$$

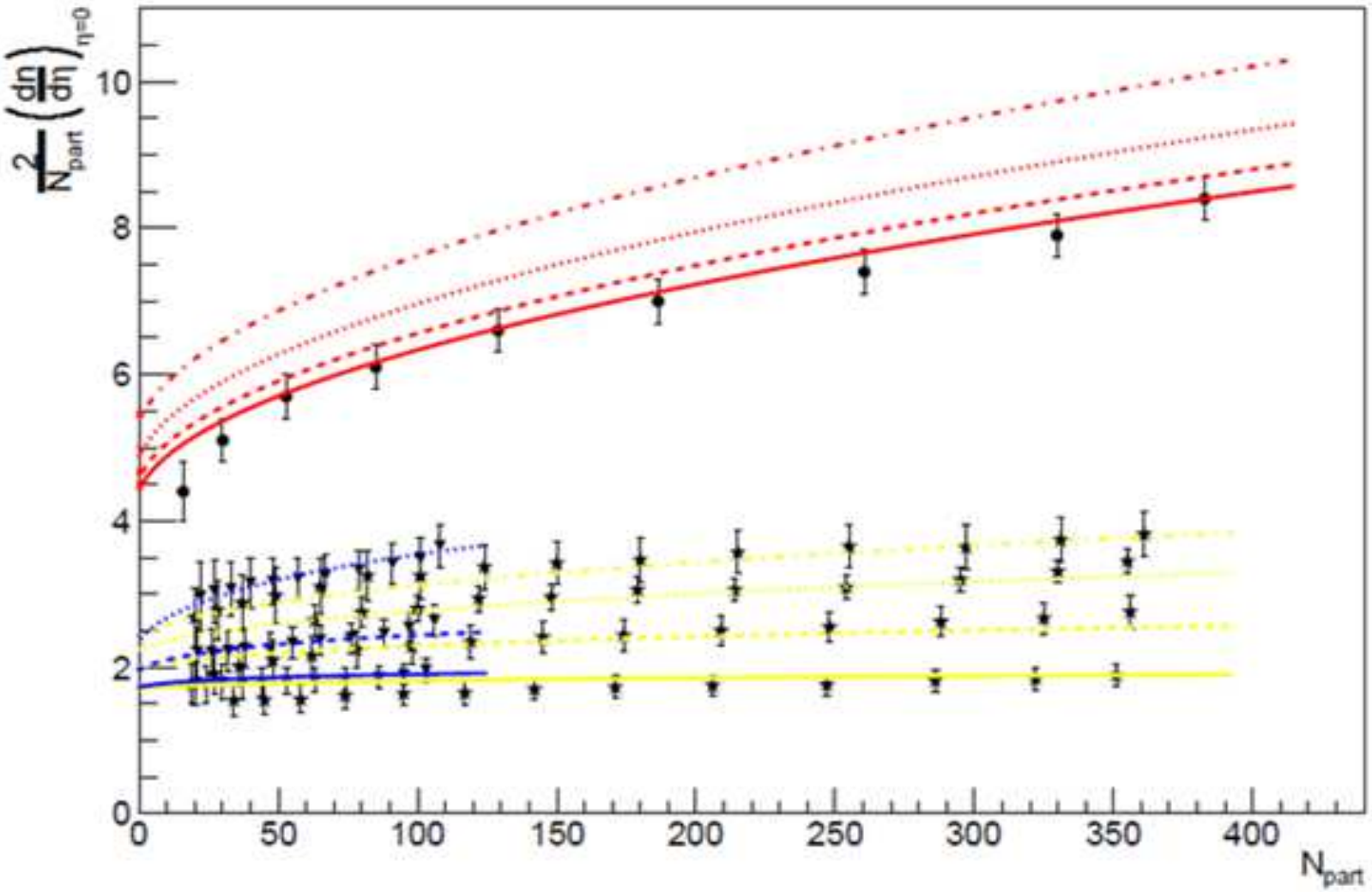
$$\alpha(s) = \frac{1}{3}\left(1 - \frac{1}{1 + \ln\left(\sqrt{s/s_0} + 1\right)}\right)$$

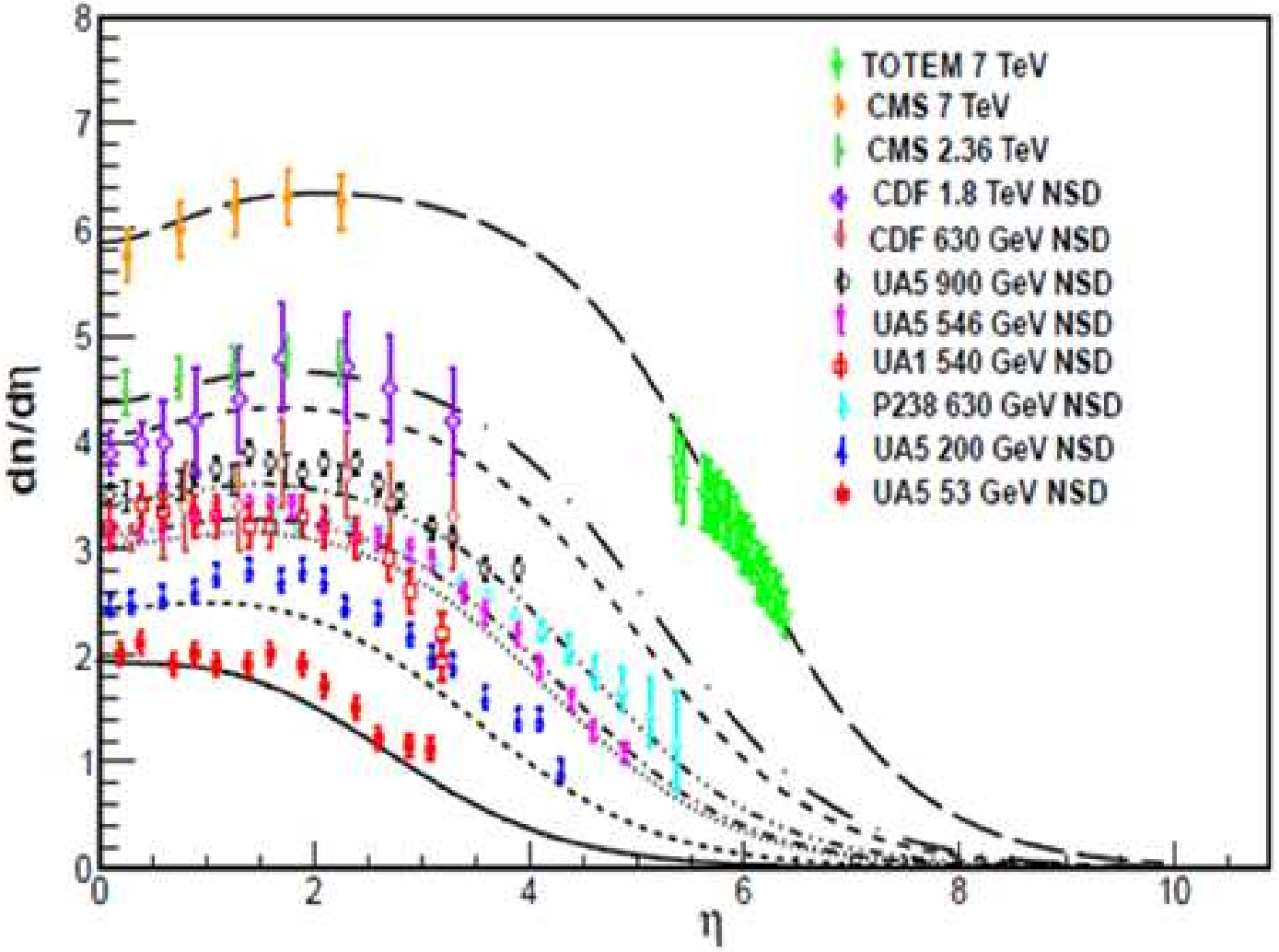
and

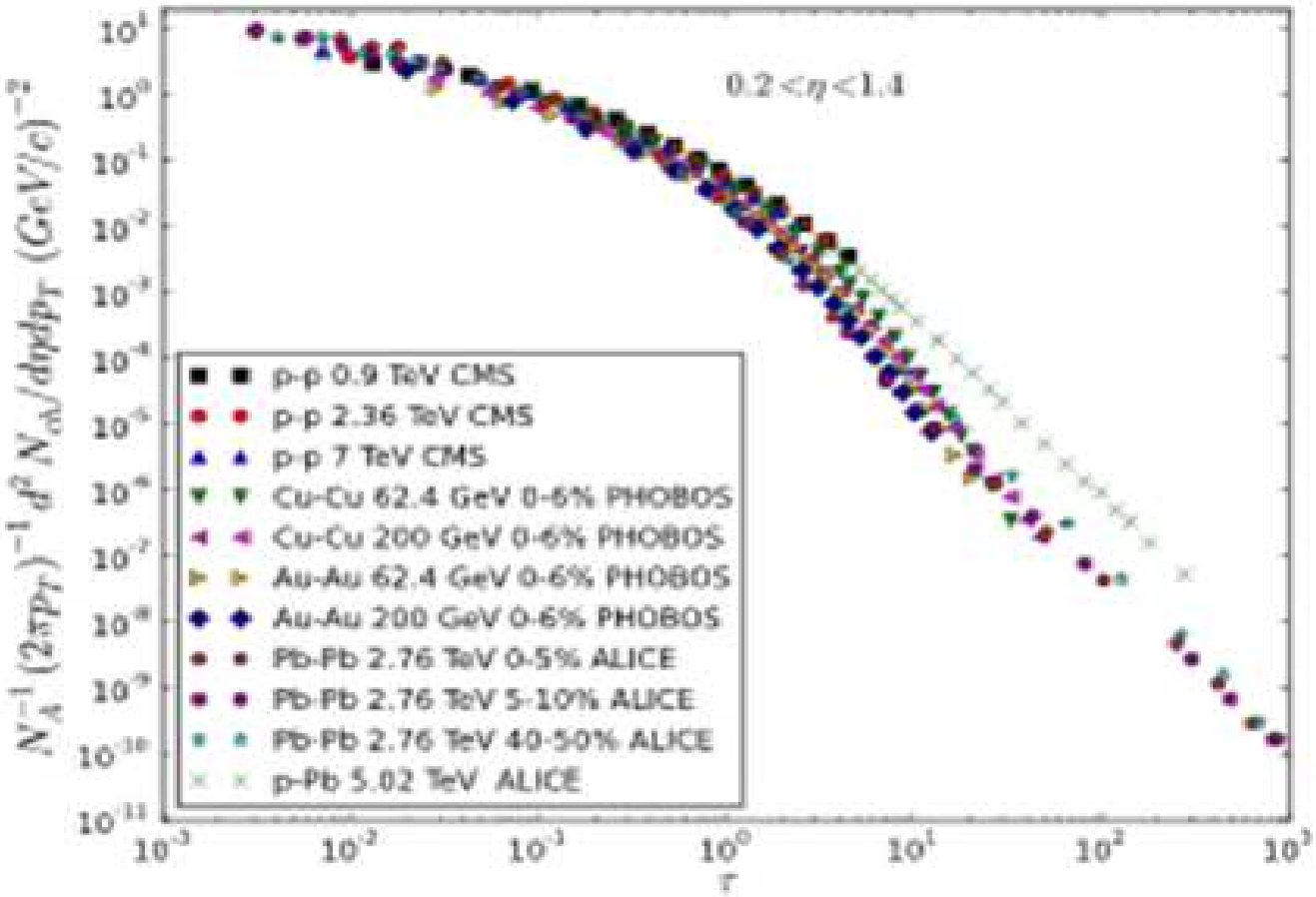
$$\left(Q_s^p\right)^2 = Q_0^2 \left(\frac{W}{p_T}\right)^{\lambda},$$

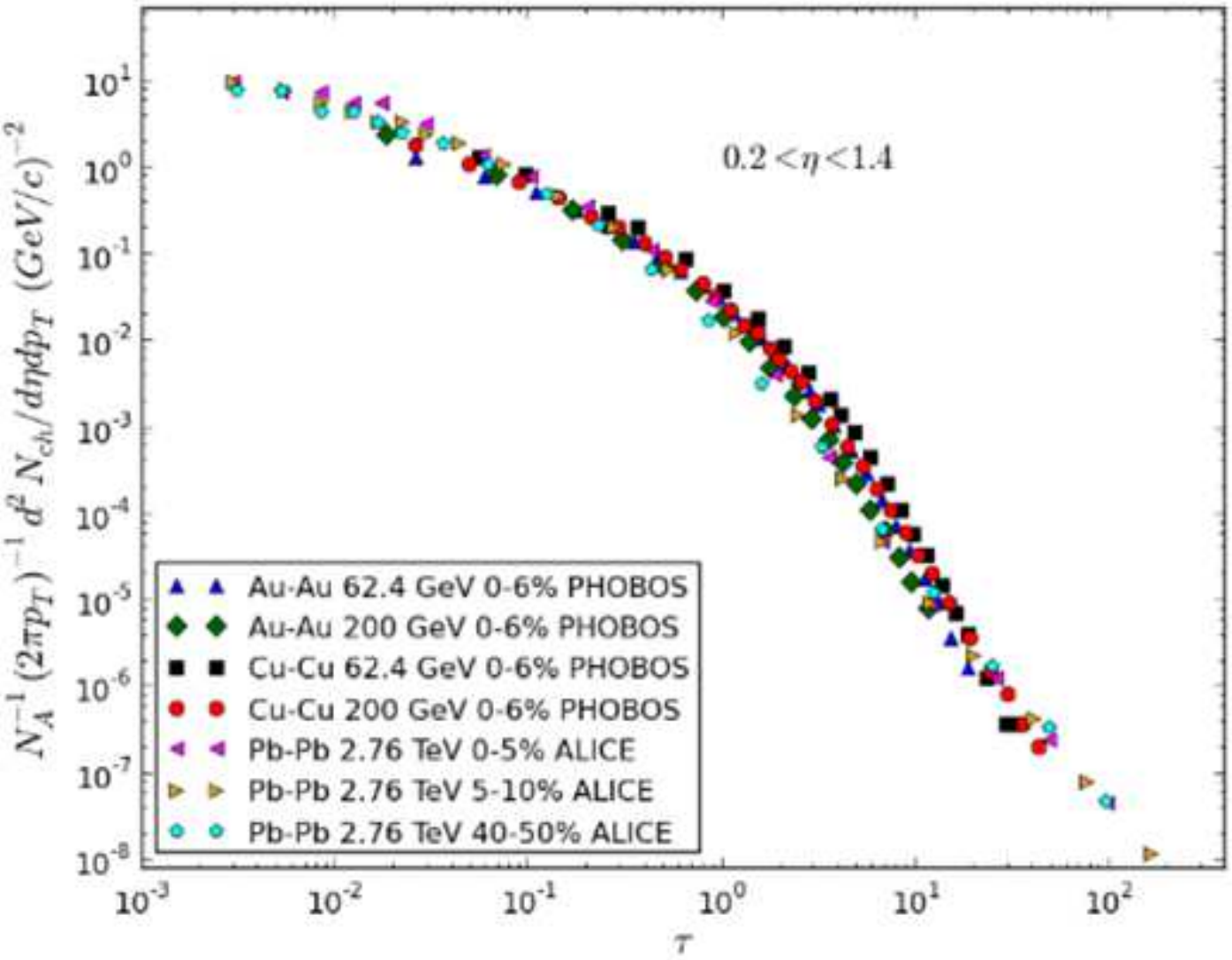
with $Q_0 = 1$ GeV, $W = \sqrt{s} \times 10^{-3}$ and $\lambda = 0.27$.


$\frac{1}{N_A}\left(\frac{dn}{d\eta}\right)_{\eta=0}$
12
10
8
6
4
2
0
10^2
10^3
10^4
$\sqrt{s}$

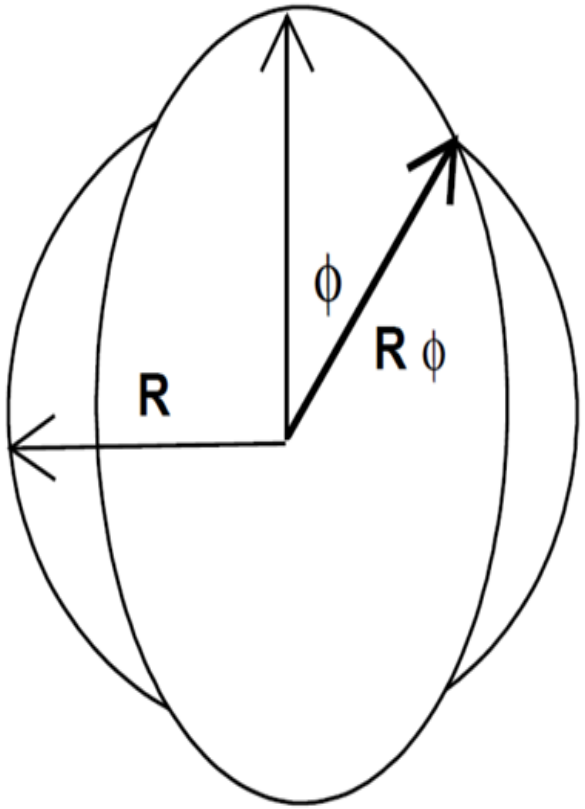

$\frac{2}{N_{part}}\left(\frac{dn}{d\eta}\right)_{\eta=0}$
0
2
4
6
8
10
0
50
100
150
200
250
300
350
400
N_{part}


TOTEM 7 TeV
CMS 7 TeV
CMS 2.36 TeV
CDF 1.8 TeV NSD
CDF 630 GeV NSD
UA5 900 GeV NSD
UA5 546 GeV NSD
UA1 540 GeV NSD
P238 630 GeV NSD
UA5 200 GeV NSD
UA5 53 GeV NSD
dn/dη
η
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10


$0.2 < \eta < 1.4$
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
$N_A^{-1}\,(2\pi p_T)^{-1}\,d^2N_{ch}/d\eta dp_T\ (GeV/c)^{-2}$
τ


$0.2 < \eta < 1.4$
Au-Au 62.4 GeV 0-6% PHOBOS
Au-Au 200 GeV 0-6% PHOBOS
Cu-Cu 62.4 GeV 0-6% PHOBOS
Cu-Cu 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
$N_A^{-1}(2\pi p_T)^{-1} d^2 N_{ch}/d\eta dp_T \ (GeV/c)^{-2}$
T
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

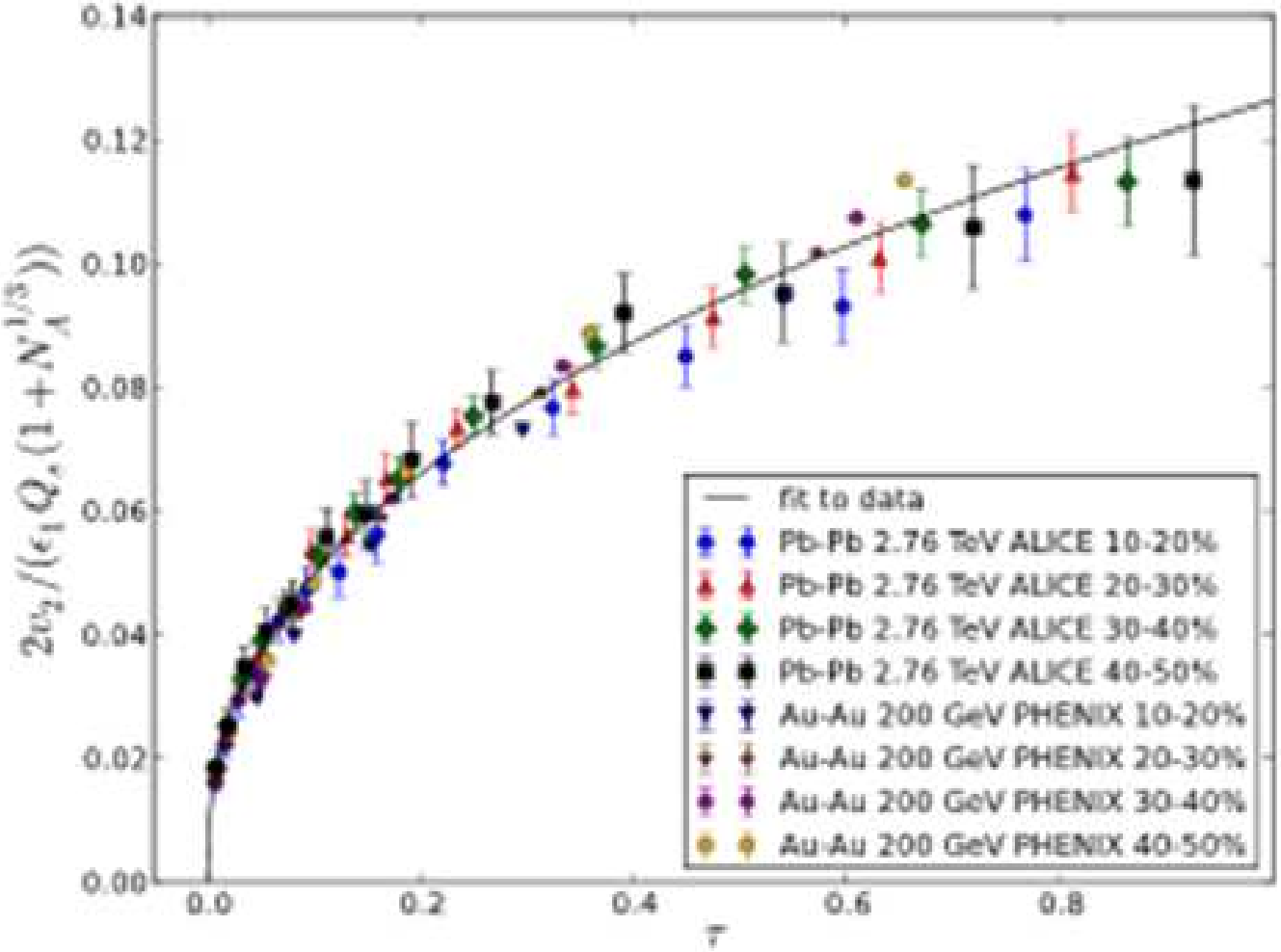
$$\frac{v_2(p_T)}{\epsilon_1 Q_s^A L} = f(\tau) \qquad \text{or} \qquad v_2 k_n = \epsilon_1 \tau \varphi(\tau) \qquad k_n = \frac{\lambda_{mfp}}{L}$$

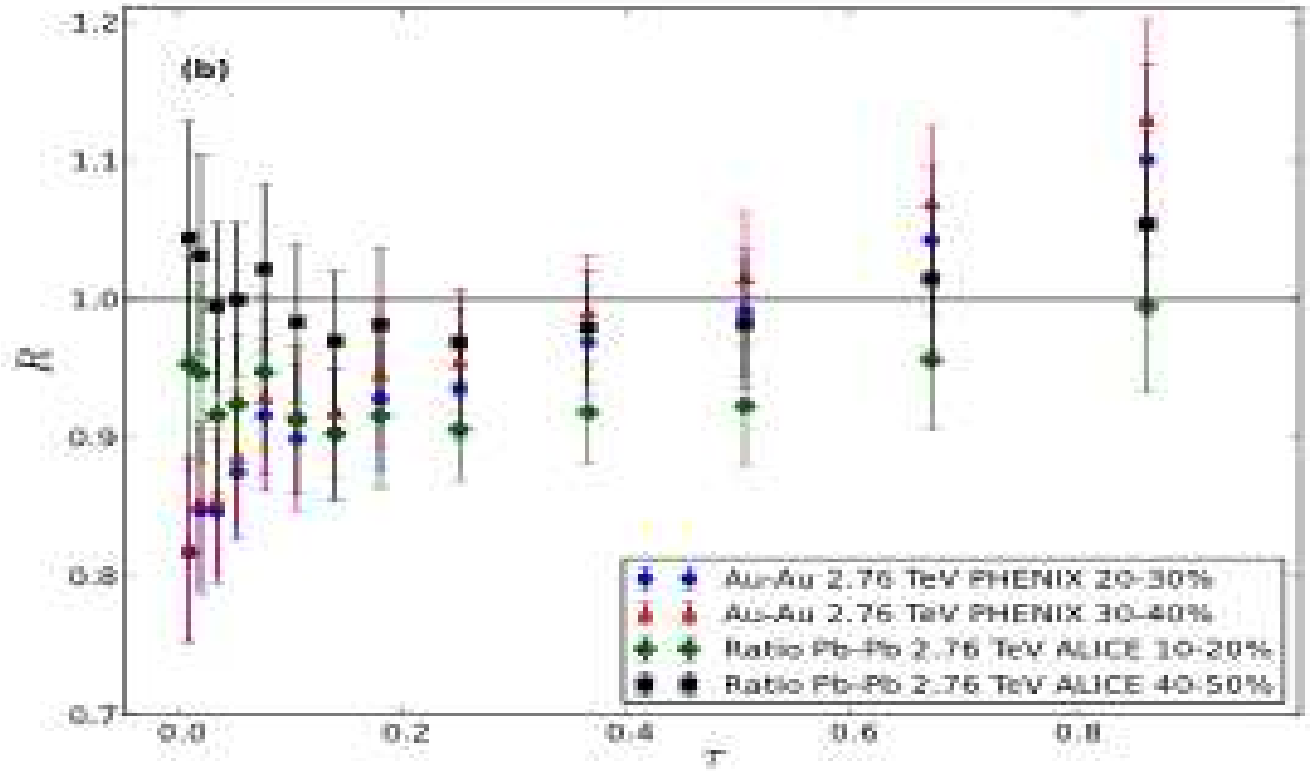


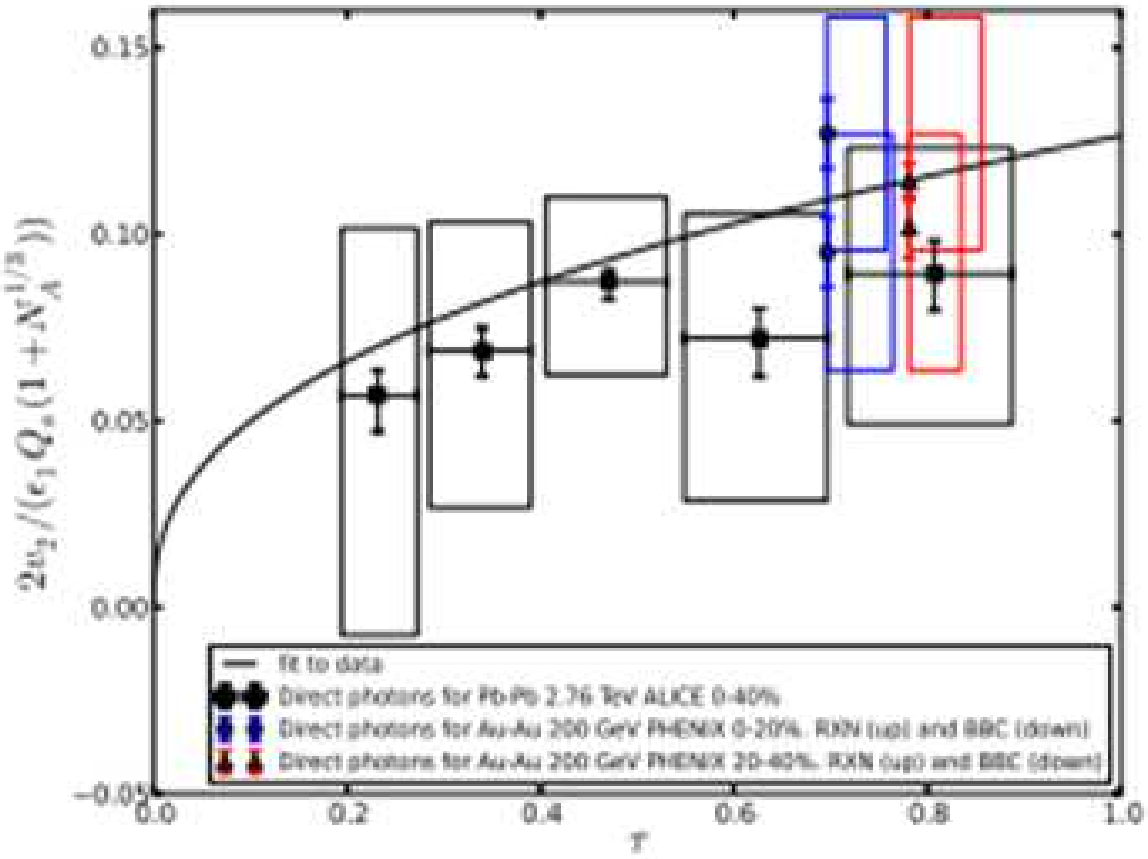
$$\epsilon_1 = \frac{2}{\pi}\int_0^{\pi/2} d\varphi \cos 2\varphi \frac{R^2 - R_\varphi^2}{R^2}, \quad R_\varphi = \frac{R_A \sin(\varphi - \alpha)}{\sin\varphi}$$

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

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


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
$2v_2/(\epsilon_1 Q_* (1+N_A^{1/3}))$
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%


(b)
1.2
1.1
1.0
0.9
0.8
0.7
R_{AA}
0.0
0.2
0.4
0.6
0.8
τ
Au-Au 2.76 TeV PHENIX 20-30%
Au-Au 2.76 TeV PHENIX 30-40%
Ratio Pb-Pb 2.76 TeV ALICE 10-20%
Ratio Pb-Pb 2.76 TeV ALICE 40-50%


0.15
0.10
0.05
0.00
−0.05
0.0
0.2
0.4
0.6
0.8
1.0
T
$2v_2/(\epsilon_1 Q_s(1+N_A^{1/3}))$
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)

$$\left(Q_{s\varphi}^{A}\right)^{2} \equiv \frac{L}{\lambda_{mfp}} \frac{1}{R_{\varphi}^{2}} = \frac{1}{k_{n} R_{\varphi}^{2}} = \frac{Q_{s}^{A} L}{R_{\varphi}^{2}},$$

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

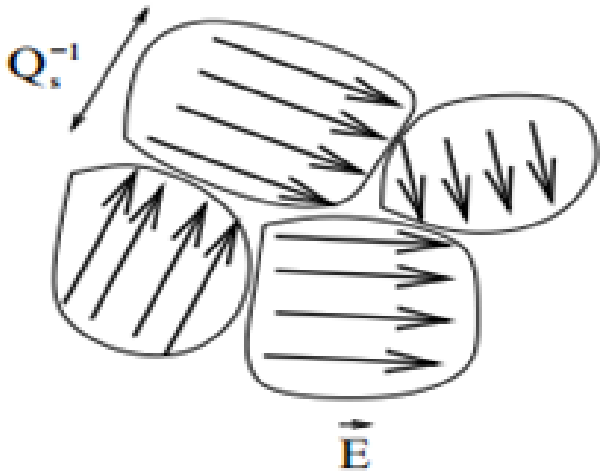
where

$$\tau_\varphi \equiv \frac{p_T^2}{\left(Q_{s\varphi}^{A}\right)^2} = \frac{p_T^2}{\left(Q_s^A\right)^2} \frac{R_\varphi^2}{L} Q_s^A = \tau \frac{R_\varphi^2}{L} Q_s^A$$

$$v_2 = \frac{2}{\pi} \int_0^{\pi/2} d\varphi \cos 2\varphi \frac{R^2 - R_\varphi^2}{R^2} \frac{1}{2\pi F(\tau)} \frac{dF}{d\tau} \tau Q_s^A L,$$

--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
and arXiv:1407.4590 hep-ph

CONCLUSIONS

Elliptic flow of charged particles satisfies a scaling law

Photon data are lying on the same scaling line

This scaling is obtained encoding all the azimuthal dependence in an additional momentum saturation

The flow has to do also with initial state interaction

Study of possible scaling of the rest of harmonics