

Nuclear like effects in pp collisions and the clustering of color sources

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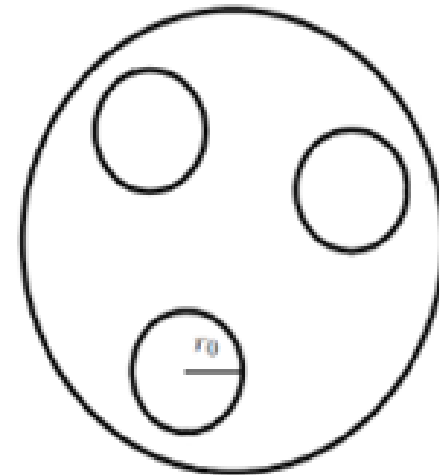
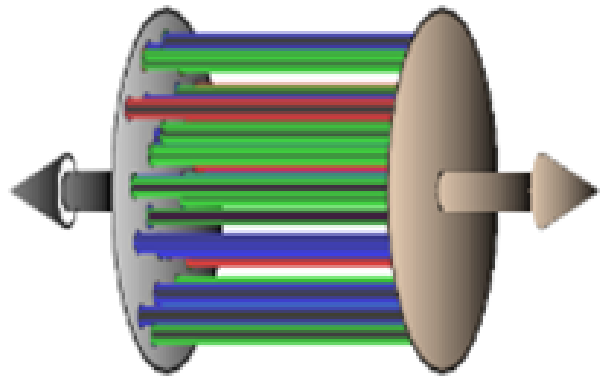
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QCD challenges from pp to AA

Puebla (31st Oct-3rd Nov 2017)

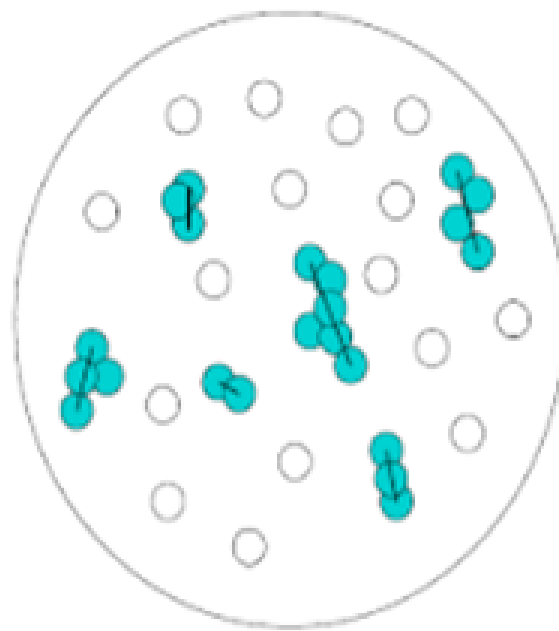
- String percolation model (clustering of color sources)
- The onset of the ridge structure and the critical percolation point
- The azimuthal dependence
- Elliptic flow in pp collisions
- Quarkonia dependence on the multiplicity

Physical picture



$$r_0 = 0.2 - 0.25 \text{ fm}$$

- 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 $r_0 \sim 0.2 \text{ fm}$.
- 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.

- 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

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

- Using the Schwinger formula

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

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



■ Limiting cases

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

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

- 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

$$(1 - e^{-\rho}).$$

- 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

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

More realistic profile and also low density

- Mean fraction of the area covered by clusters

$$A(\rho) = \frac{1}{1 + ae^{-(\rho - \rho_0)/b}};$$

$$f(p_t) = \int W(x) f(x, p_T) .$$

$$P(n) = \int dN W(N) P(N, n)$$

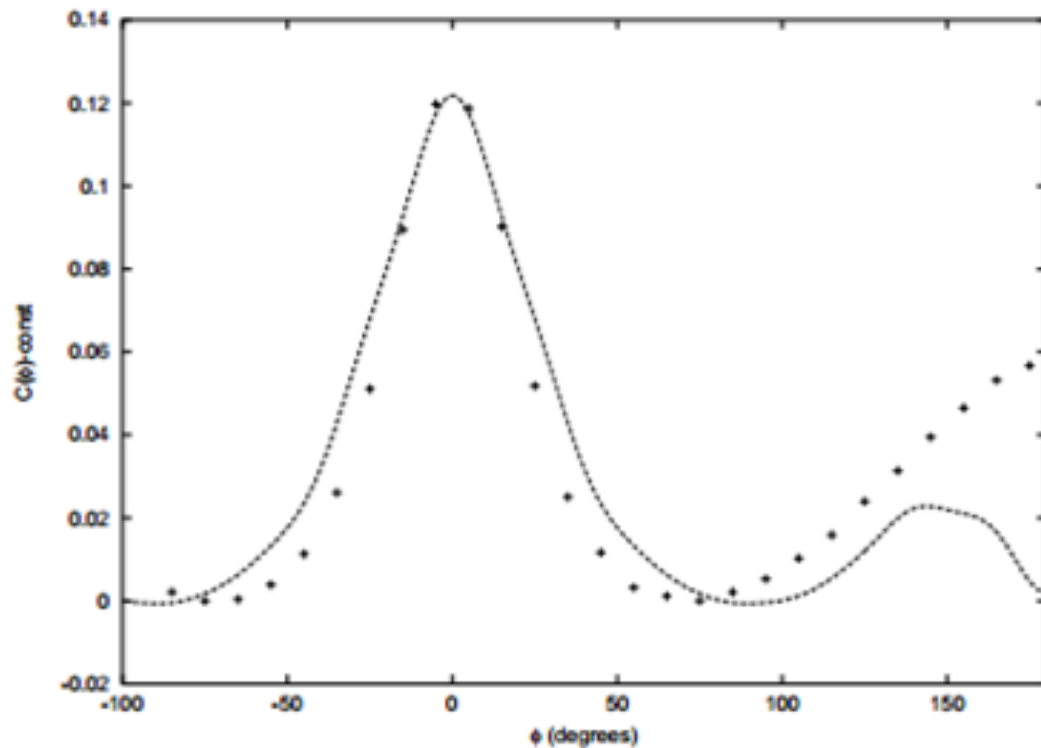
$$W(x) = \frac{\gamma}{\Gamma(k)} (\gamma x)^{k-1} \exp(-\gamma x) .$$

$$\frac{1}{\left(1 + \frac{F^2(\eta) p_I^2}{k \langle p_I^2 \rangle_1}\right)^k} \qquad \frac{\langle x^2 \rangle - \langle x \rangle^2}{\langle x \rangle^2} = \frac{1}{k} .$$

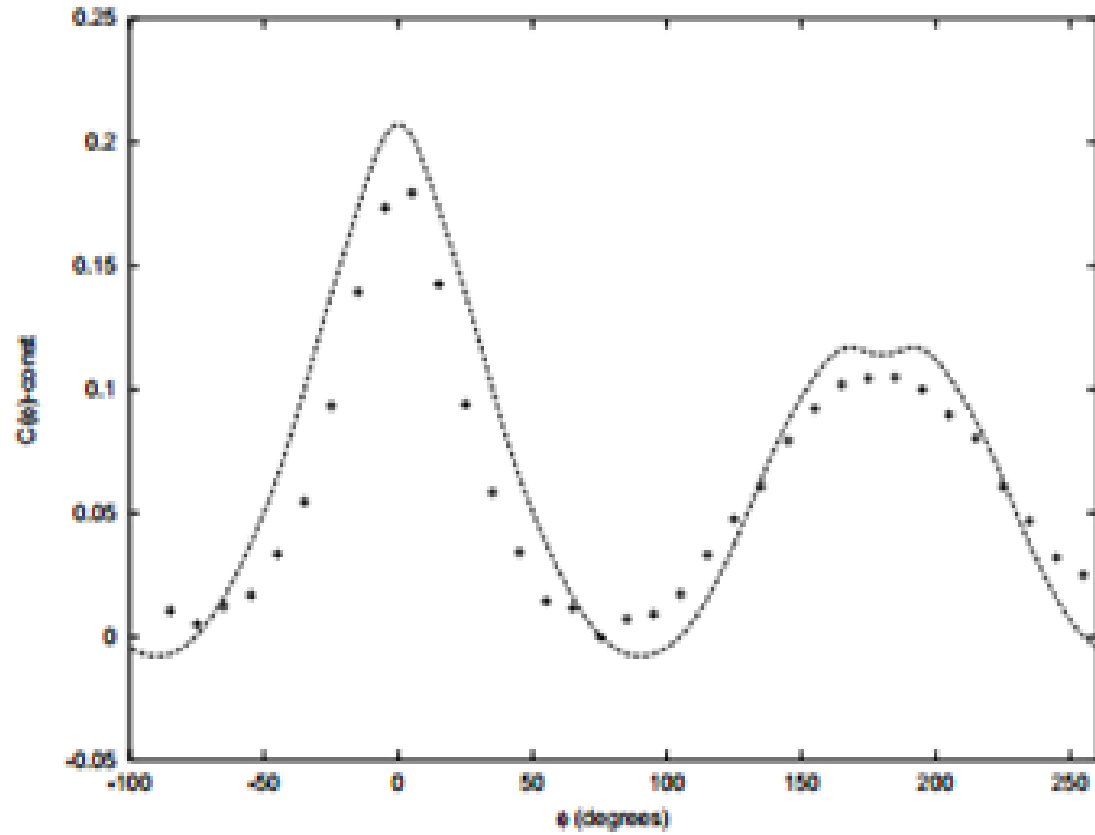
- If there are domains or clusters of strings which decay in partons, these partons interact with the color field of other clusters or domains, losing energy or momentum in their path to get out the area of the collision.
- In QED, the loss of energy of a charged particle moving in an external E.M. field is known. It has been shown, on the basis of ADS/CFT, that in N=4 SUSY with N_c large the same result is obtained.

$$P(p, \phi) = C e^{-\frac{p_0}{\sqrt{T/2}}}.$$

$$p_0(p, l) = p \left(1 + \kappa p^{-1/3} T^{2/3} l \right)^3$$



: Correlation coefficient $C(\phi)$ for pp collisions at 7 TeV with triple multiplicity



Correlation coefficient $C(\phi)$ for p-Pb collisions at 5.02 TeV for central collisions

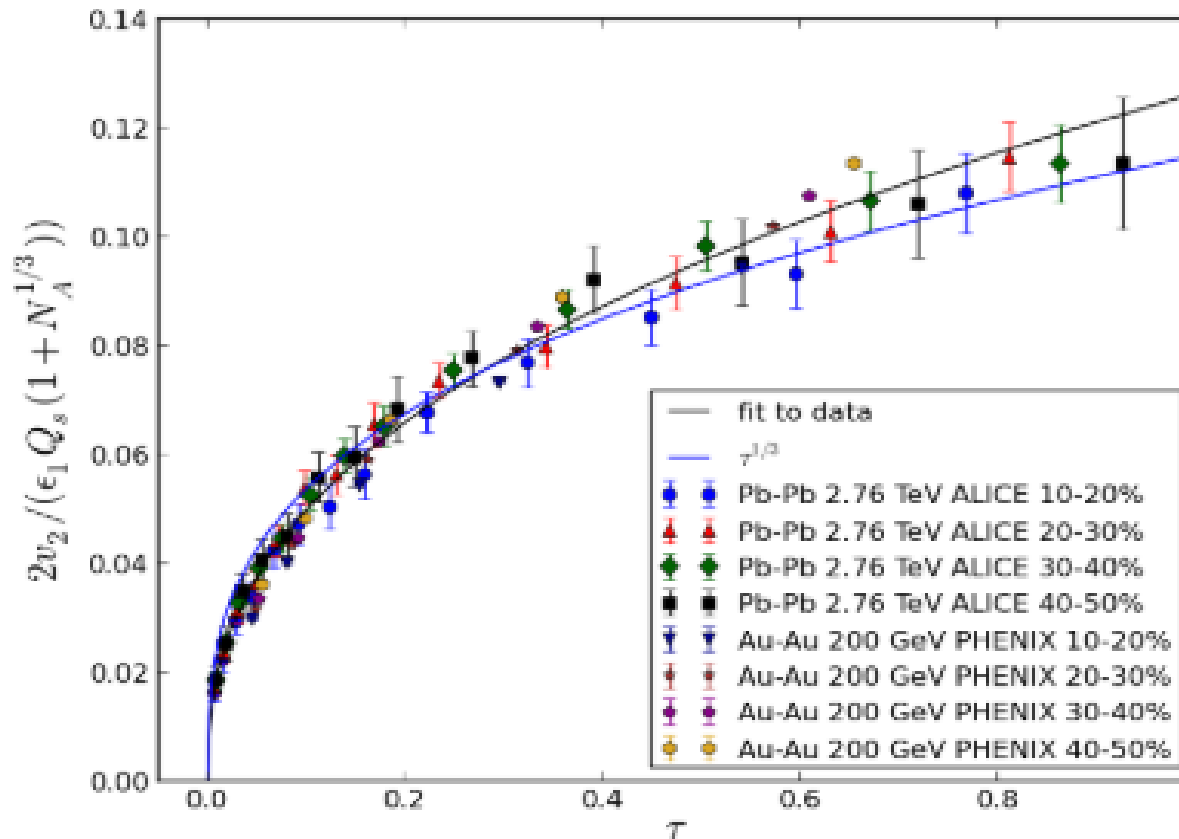
The scaling law

$$\frac{v_2(p_T)}{\epsilon_1 Q_s^A L} = f(\tau) \qquad \tau = \frac{p_T^2}{(Q_s^A)^2}$$

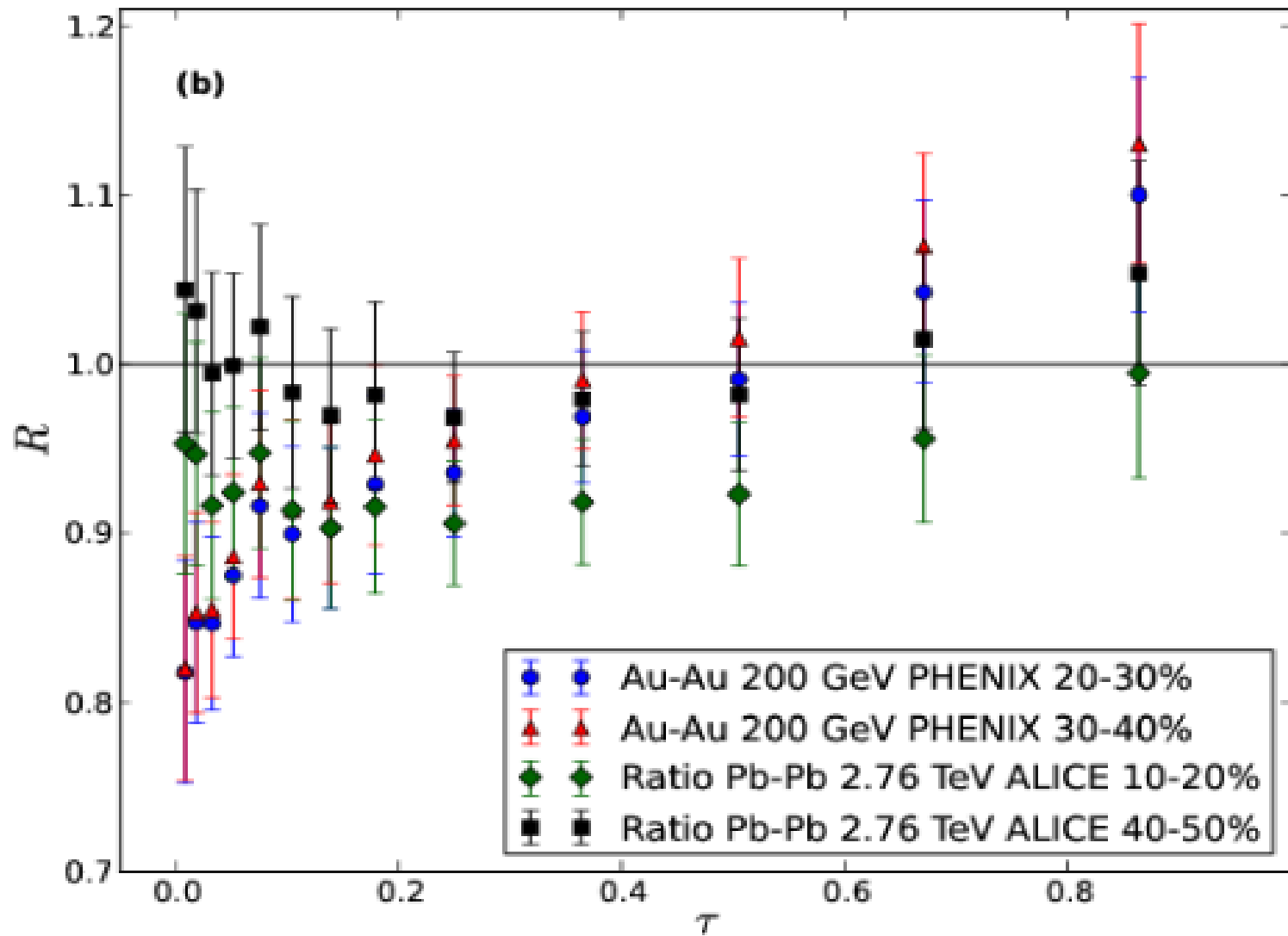
$$v_n \propto p^{2/3} \tilde{\tau}^{1/3} \ell \qquad \tilde{\tau} \sim Q_s$$

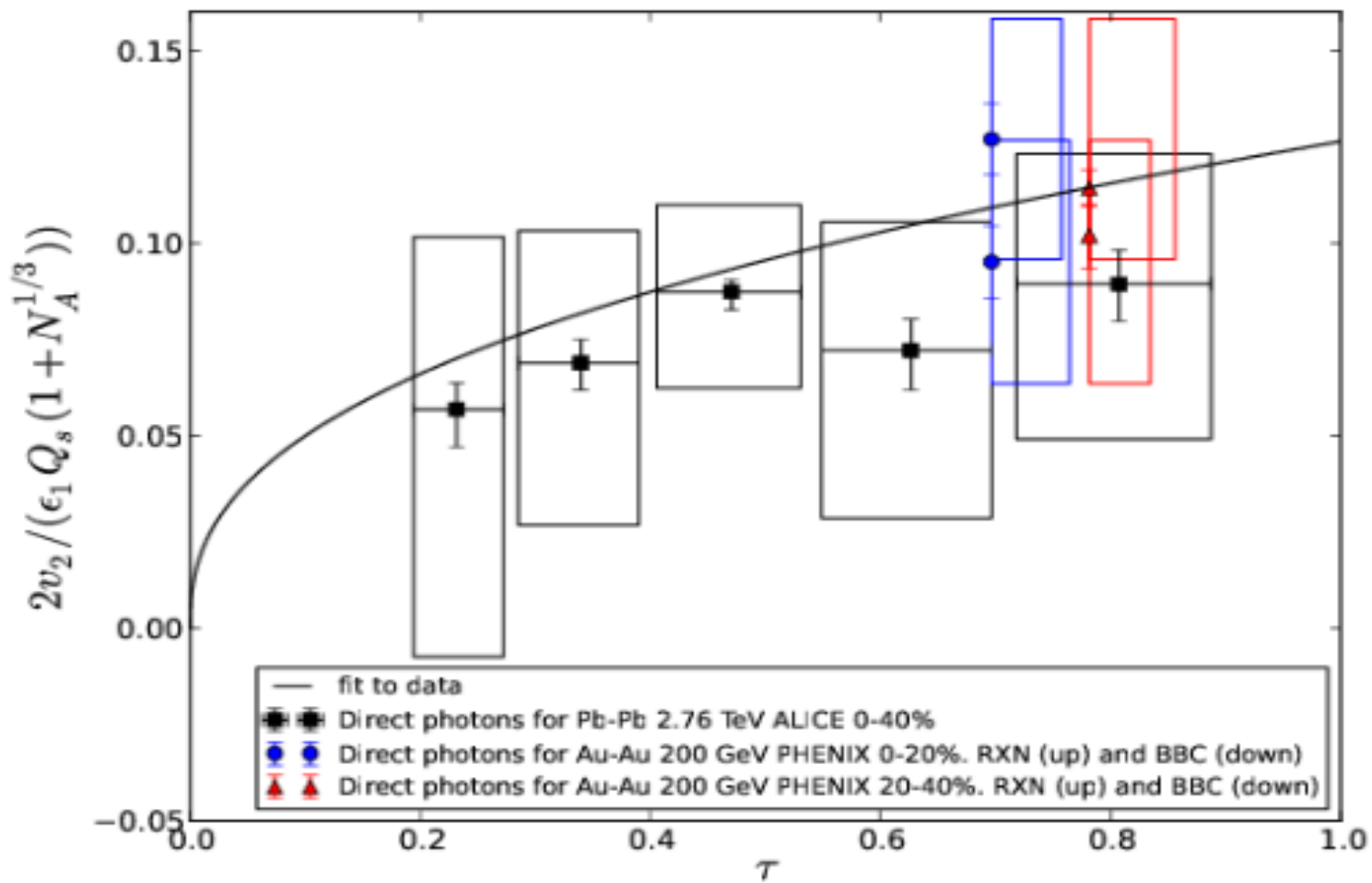
$$\frac{v_n}{\ell Q_s} = \frac{p^{2/3} Q_s^{1/3} \ell}{\ell Q_s} = \left(\frac{p^2}{Q_s^2} \right)^{1/3}$$

$$f(\tau) = \tau^{1/3}$$

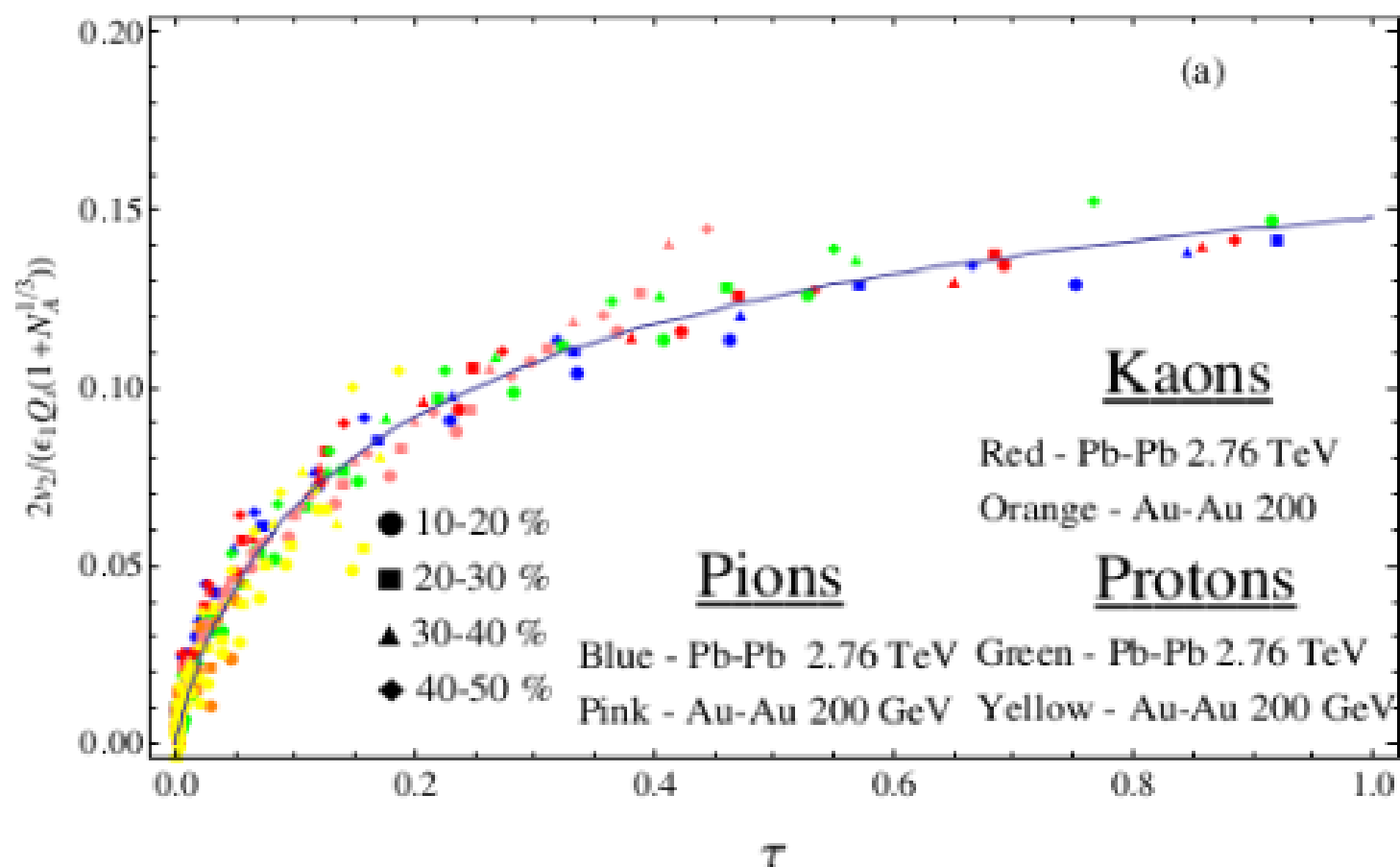


C.Andres, J.Dias de Deus, A. Moscoso, C. Pajares and C Salgado, Phys. Rev. C **92**, 034901 (2015).





v_2 -scaling of pions and kaons

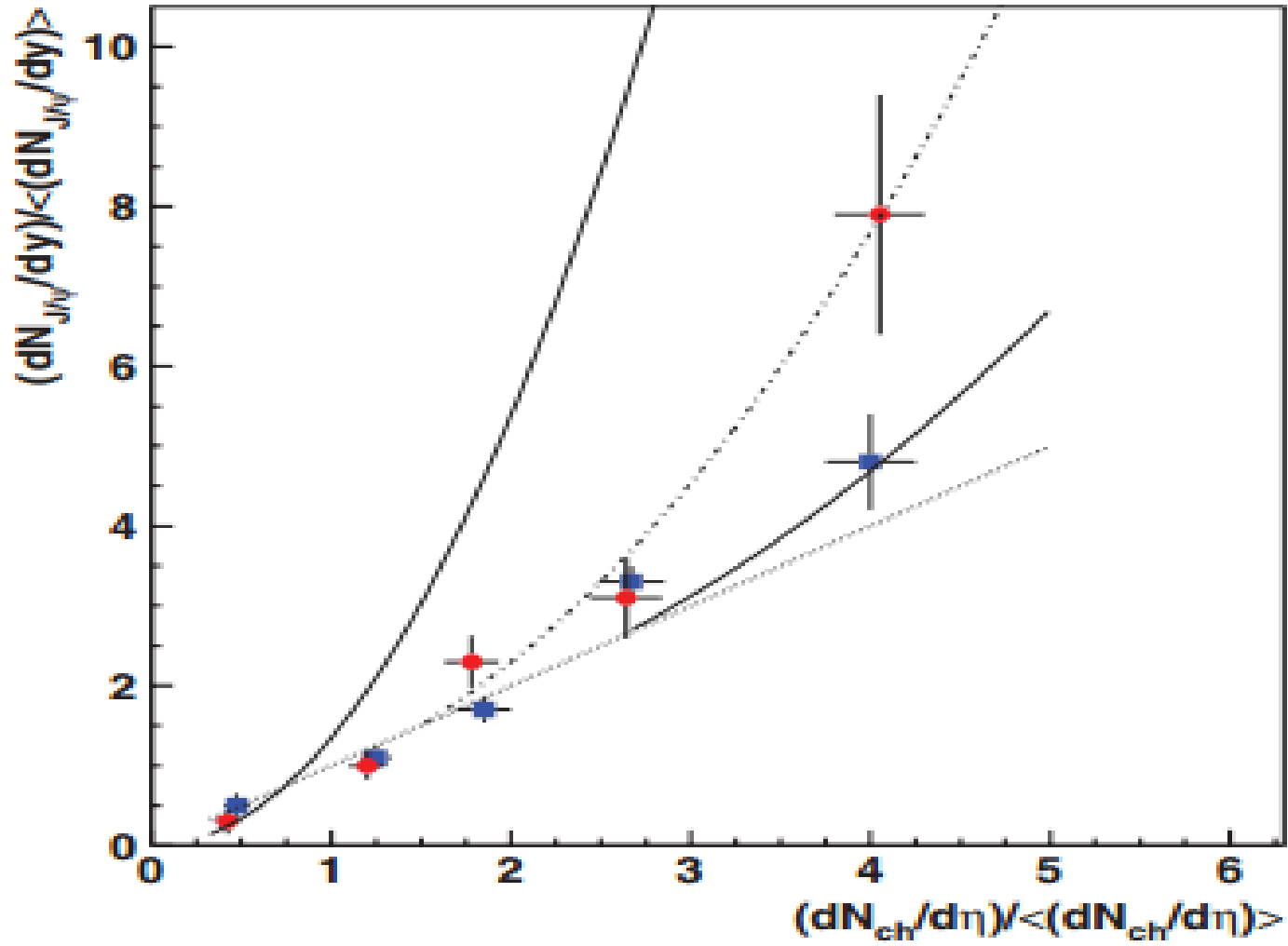


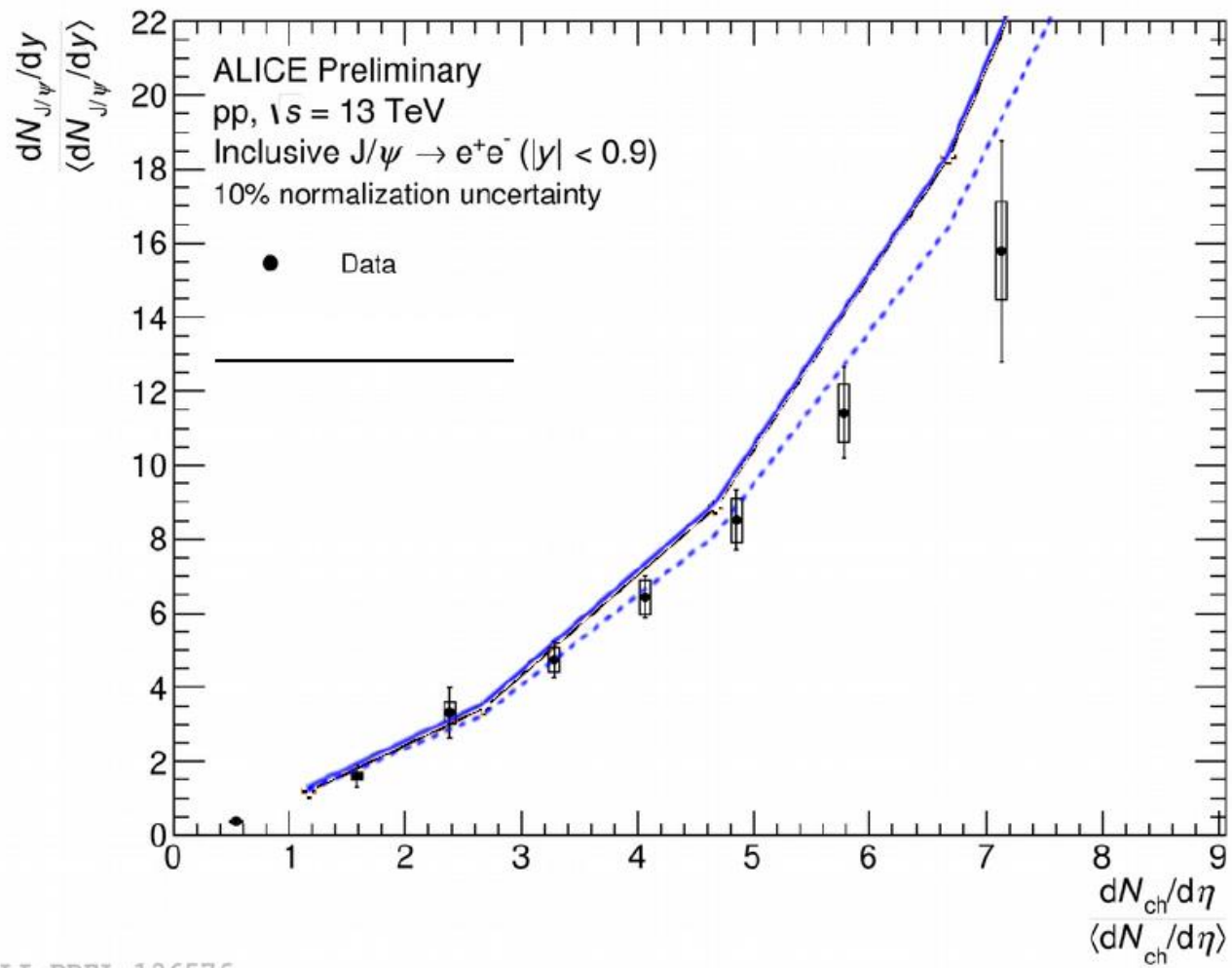
$$\frac{dN}{d\eta} = F(\rho) N_s \mu \quad F(\rho) = \sqrt{\frac{1 - e^{-\rho}}{\rho}} \quad \rho = \frac{N_s \sigma_0}{\sigma}$$

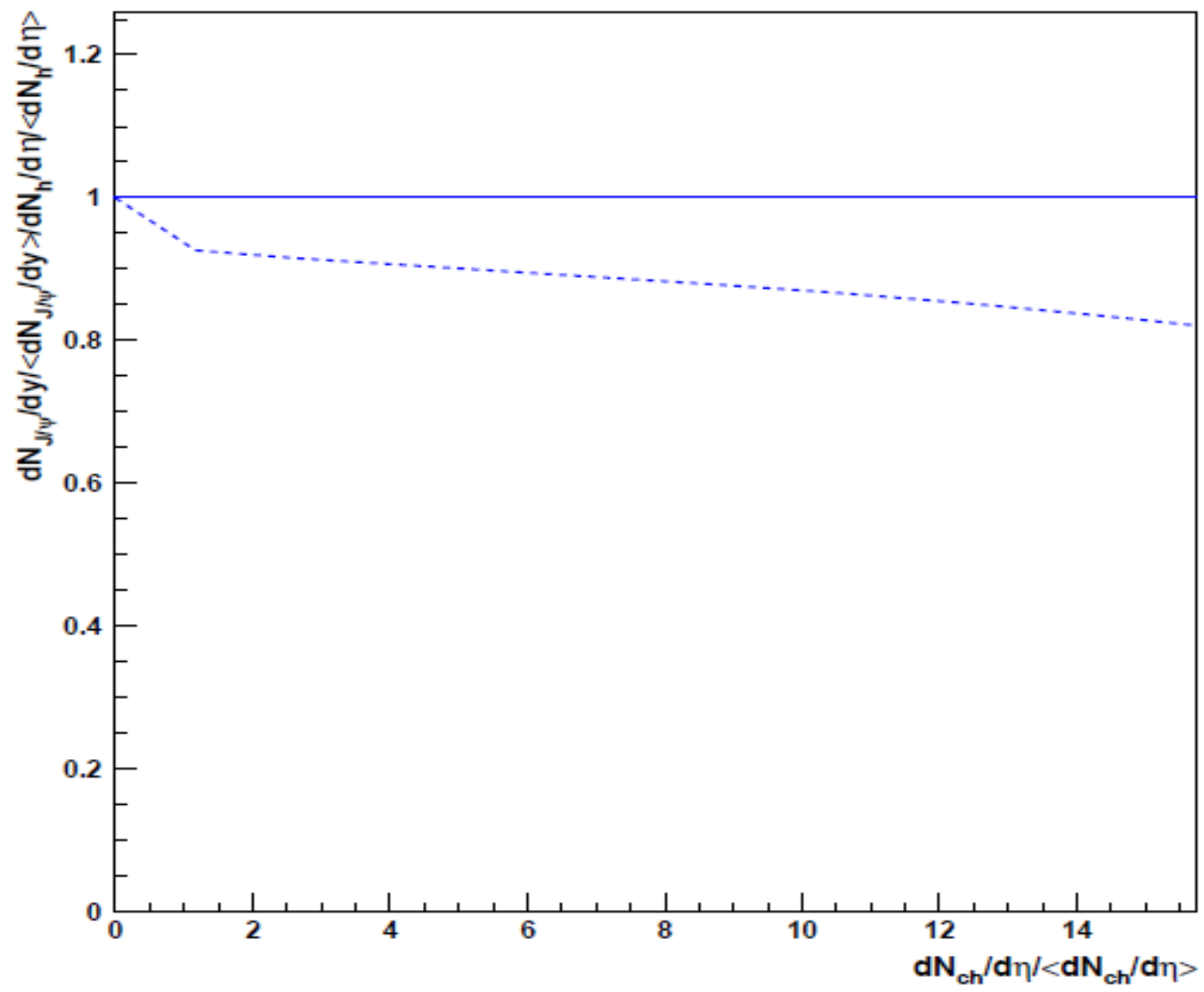
$$\frac{\langle n_{J/\psi} \rangle}{\langle N_s \rangle} = \frac{N_s}{\langle N_s \rangle}$$

$$\frac{\frac{dN}{d\eta}}{\left(\frac{dN}{d\eta}\right)} = \left(\frac{\langle n_{J/\psi} \rangle}{\langle N_s \rangle}\right)^{1/2} \left[\frac{1 - e^{-\frac{\langle n_{J/\psi} \rangle}{\langle N_s \rangle}(\rho)}}{1 - e^{-\rho}} \right]^{1/2},$$

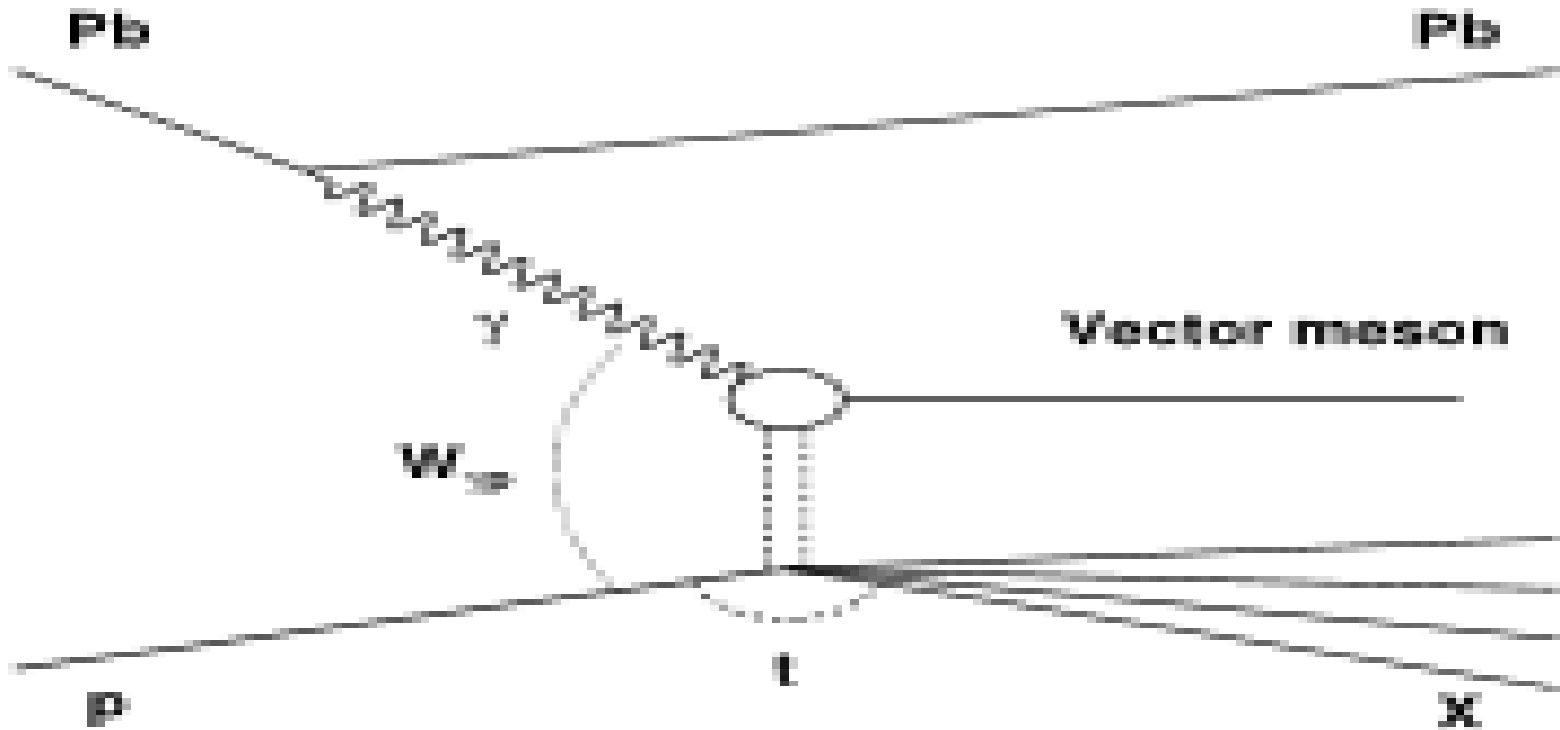
$$(\rho) = \langle N_s \rangle \frac{\sigma_0}{\sigma}.$$







Incoherent diffractive dissociation J/psi production



$$\left. \frac{d\sigma(\gamma p \rightarrow J/\psi Y)}{dt} \right|_{T,L} = \frac{(R_g^{T,L})^2}{16\pi} \left(\left\langle \left| A(x, Q^2, \vec{\Delta})_{T,L} \right|^2 \right\rangle - \left| \left\langle A(x, Q^2, \vec{\Delta})_{T,L} \right\rangle \right|^2 \right)$$

$$A(x, Q^2, \vec{\Delta})_{T,L} = iA_b(\vec{\Delta})A_r(x, Q^2, \vec{\Delta})_{T,L}$$

$$\begin{aligned} A_b &\equiv \int d\vec{b} e^{-i\vec{b} \cdot \vec{\Delta}} T(\vec{b}) \\ &= e^{-B_{hs} \Delta^2 / 2} \frac{1}{N_{hs}} \sum_{i=1}^{N_{hs}} e^{-i\vec{b}_i \cdot \vec{\Delta}} \end{aligned}$$

$$T(\vec{b}) = \frac{1}{N_{hs}} \sum_{i=1}^{N_{hs}} T_{hs}(\vec{b} - \vec{b}_i),$$

$$T_{hs}(\vec{b} - \vec{b}_i) = \frac{1}{2\pi B_{hs}} e^{-\frac{(\vec{b} - \vec{b}_i)^2}{2B_{hs}}}, \quad B_{hs} = 0.8 \text{ GeV}^{-2}$$

$$N_{hs}(x) = p_0 x^{p_1} (1 + p_2 \sqrt{x}),$$

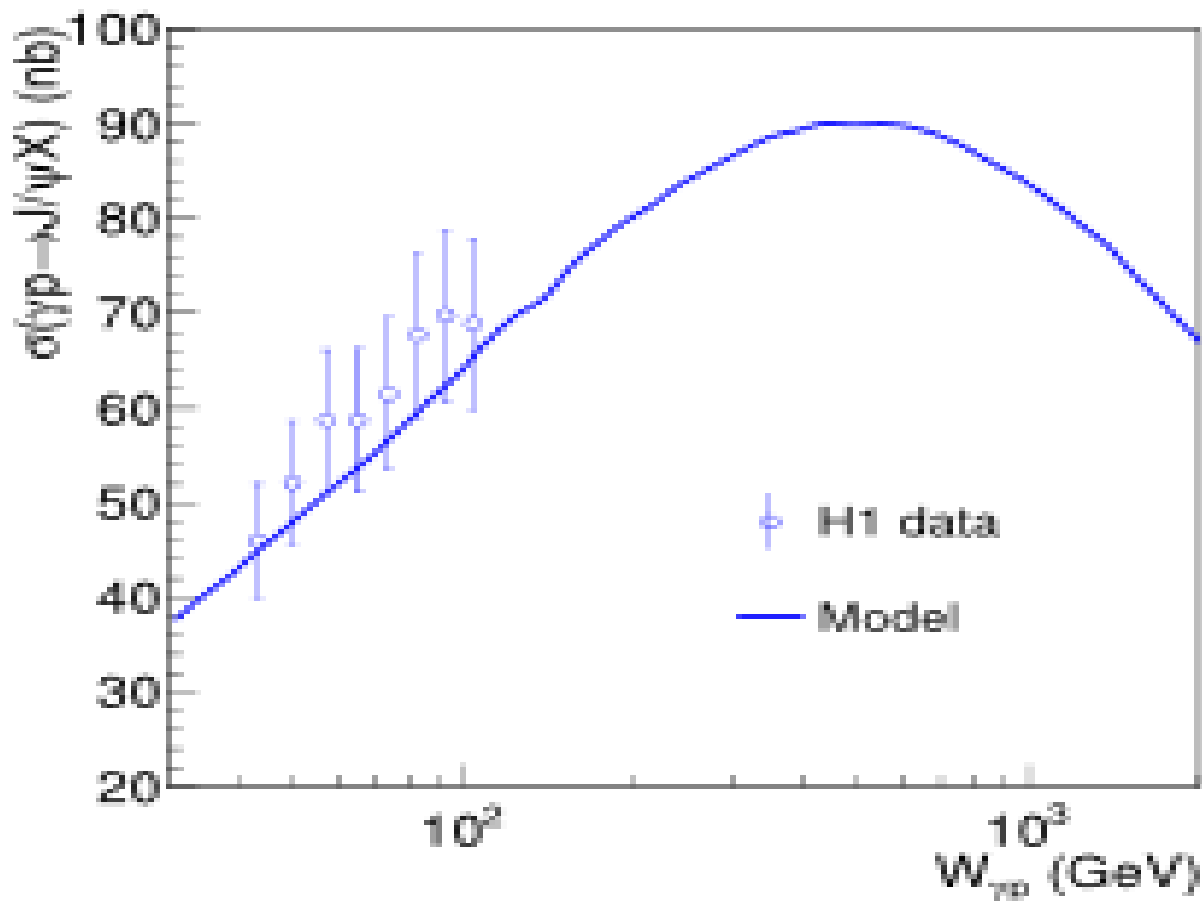
where we set $p_0 = 0.011$, $p_1 = -0.58$ and $p_2 = 250$

$$A_r(x, Q^2, \Delta)_{T,L} \equiv \int dr r N(x, r) A_z(r, \Delta)_{T,L}$$

$$N(x, r) = \left(1 - e^{-r^2 Q_s^2(x)/4}\right)$$

with the saturation scale given by

$$Q_s^2(x) = Q_0^2 (x_0/x)^\lambda$$



Conclusions

- The clustering of color sources(percolation) describes the azimuthal correlations
- The rise of the dependence of J/psi production on the multiplicity marks the differences on the dependence on the multiplicity of a hard process and the total multiplicities
- A possible suppression of the J/psi free of nuclear effects, could be seen looking at the dependence on the multiplicity of the ratio of J/psi production and hard process
- The energy dependence of the incoherent J/psi production cross section should turn off above a critical energy corresponding to the percolation of the hot spots

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Physics Reports 599 1-50(2015)

- Transverse size

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

CGC

$$1/Q_s$$

- 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

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

Low density limit: **n is basically Poisson-like** $\implies k \rightarrow \infty$

High density limit: $\langle N^2 \rangle - \langle N \rangle^2 \approx \langle N \rangle \implies k \rightarrow \langle N \rangle \rightarrow \infty$

$$k = \frac{\sqrt{\rho} (R/\tau_0)^2}{1 - e^{-\rho}} = \frac{\langle N \rangle}{(1 - e^{-\rho})^{3/2}}.$$

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

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

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

$\rho_c = 1.5$	$a = 1.5$	$b = 0.75$	for Au-Au
		$b = 0.35$	pPb and pp.

$$P(p, \phi) = C e^{-\frac{p_0}{\sqrt{T/2}}}. \quad (2)$$

To describe the energy loss of the parton due to gluon emission one may use the corresponding QED picture for a charged particle moving in the external electromagnetic field [31]. This leads to the the quenching formula [22]

$$p_0(p, l) = p \left(1 + \kappa p^{-1/3} T^{2/3} l \right)^3, \quad (3)$$

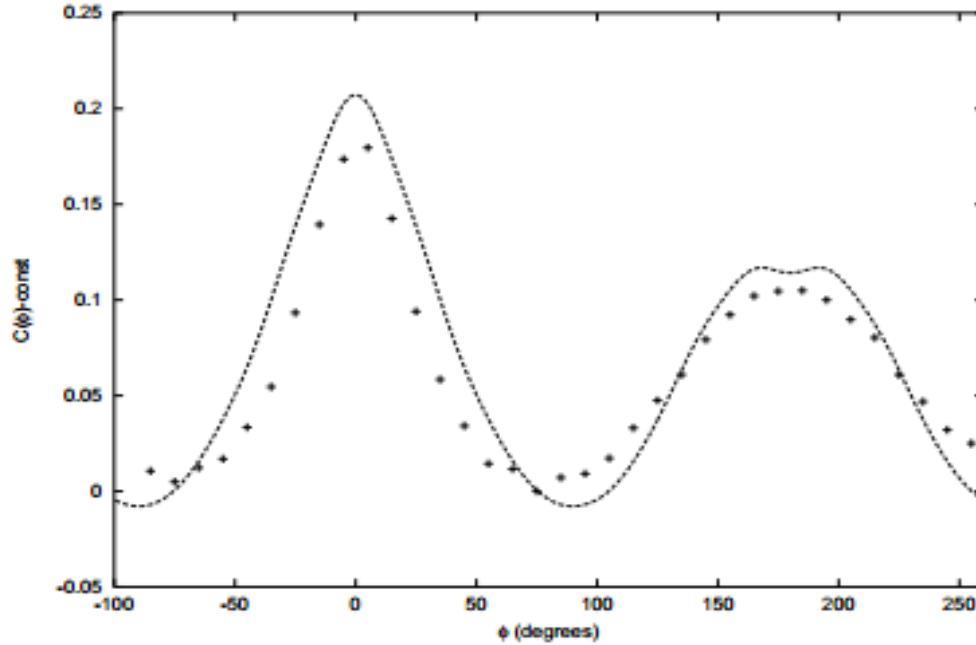


Figure 10: Correlation coefficient $C(\phi)$ for p-Pb collisions at 5.02 TeV for central collisions compared to the data in [3] (with the ZYAM procedure).

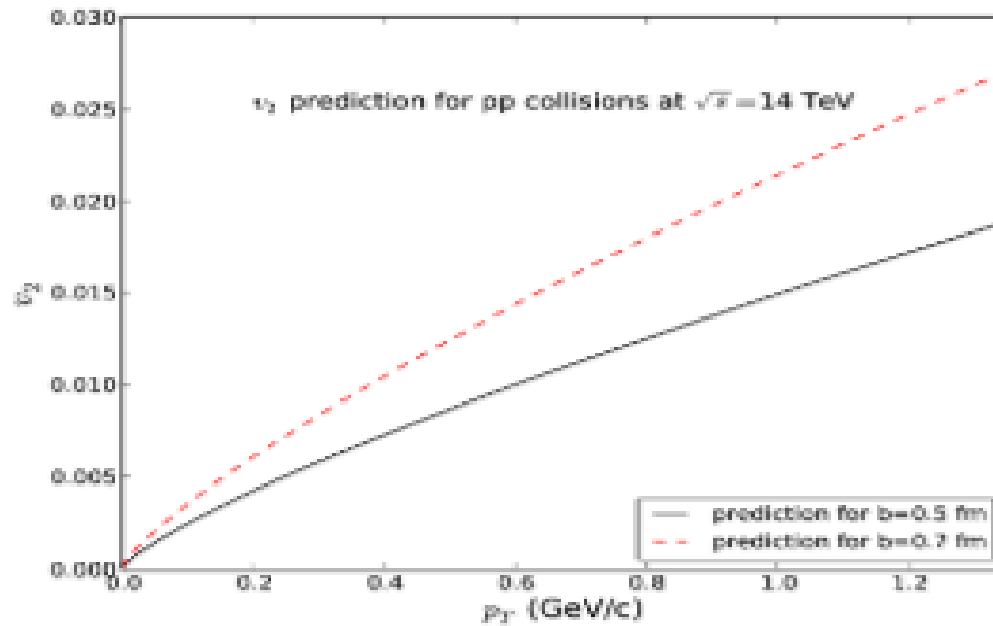


Figure 5. (Color online.) v_2 prediction for pp collisions at $\sqrt{s} = 14$ TeV for impact parameters values of $b = 0.5$ fm (solid black curve) and $b = 0.7$ fm (dashed red curve) as a function of p_T .

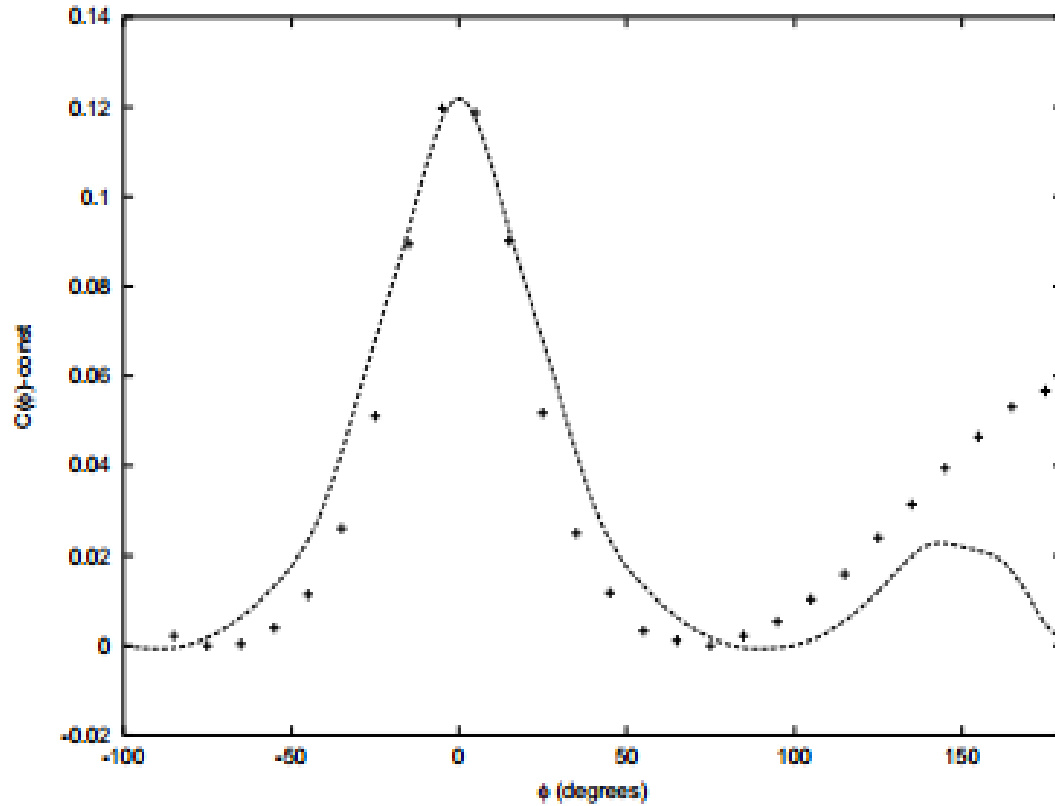


Figure 15: Correlation coefficient $C(\phi)$ for pp collisions at 7 TeV with triple multiplicity compared to the the experimental data from [1] (with the ZYAM procedure at positive ϕ)

