Universal geometrical scaling of the elliptic flow

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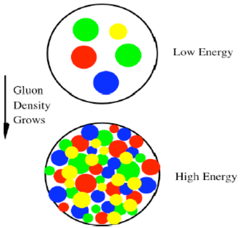
VI CPAN
Sevilla
October 20, 2014

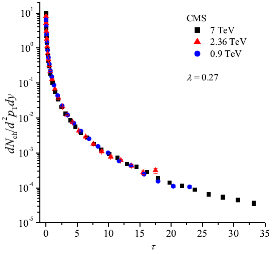
Outline

Geometrical scaling in pp collisions. Color Glass Condensate.

- CGC: An effective theory of QCD at high energies and high gluon occupation numbers.
- Dynamical scale $Q_s \gg \Lambda_{QCD}$, called saturation momentum.
- This framework predicts geometrical scaling in pp collisions

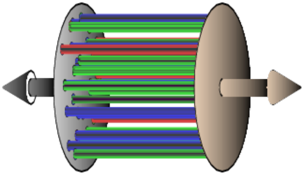
$$\frac{dN}{dy dp_T^2} = \frac{1}{Q_0^2} F(\tau) \qquad \tau = \frac{p_T^2}{Q_s^2} \qquad Q_0^2 \approx 1 \text{ GeV}$$

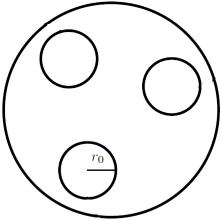




GS in Heavy Ion Collisions?

Physical picture

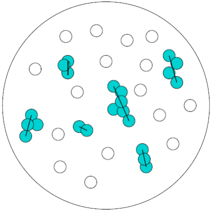


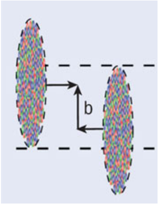


$r_0 = 0.2 - 0.25\ fm$

- 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 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.

Physical picture





- With growing energy and/or mass number of colliding particles, the number of **sources** grows → The **number of strings** grows with energy and/or mass number.
- The **number of strings** also increases with increasing centrality.
- The basic degree of freedom is the **density of strings**

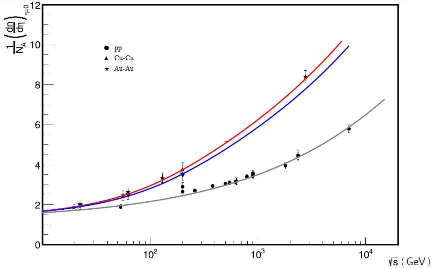
$$\rho = \frac{S_1}{S_A} N_s$$

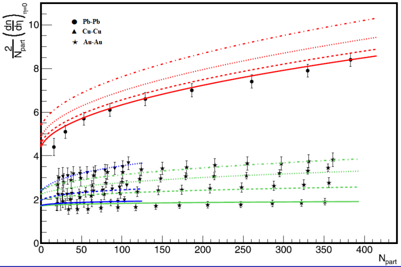
Multiplicity distributions

- In the framework of percolation of strings:

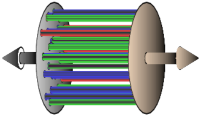
$$\rho_A = \rho_p A^{\alpha(s)} N_A^{1/3}$$

$$\alpha(s) = \frac{1}{3}\left(1 - \frac{1}{1+\ln\left(\sqrt{s/s_0}+1\right)}\right) \qquad N_A = N_{part}/2$$





Percolation of strings ↔ CGC



- Transverse size of a string/flux tube

Percolation

$$r_0^2 \sqrt{\frac{1 - e^{-\rho}}{\rho}}$$

CGC

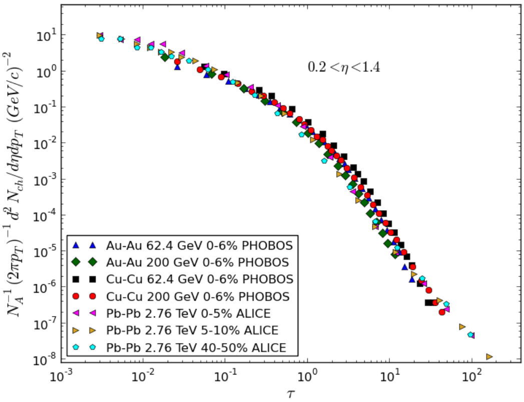
$$1/Q_s^2$$

- In the high density limit $\longrightarrow \sqrt{\rho} \sim Q_s^2$.

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

Geometrical scaling in heavy ion collisions

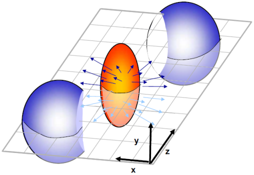
- Using the same approach as in pp collisions



GS in Heavy Ion Collisions

Elliptic flow

- Common interpretation of azimuthal anisotropy: **Spatial anisotropy** $\Leftrightarrow$ **momentum anisotropy** (but not the only one!)

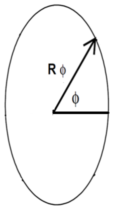


- Fourier decomposition of momentum distribution to measure this anisotropy

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} v_n(p_T, y)\cos(n\phi)\right)$$

  - $v_2(p_T, y) \Rightarrow$ **Elliptic Flow**

Scaling of the elliptic flow



- Higher density for lower R_ϕ
- $\Rightarrow$ ϕ-**dependent density**

$$\Rightarrow \boxed{\left(Q^A_{s\phi}\right)^2 \equiv \frac{L}{\lambda_{mfp}} \frac{1}{R^2_\phi} = \frac{Q^A_s L}{R^2_\phi}}$$

- L is the length associated to the size of the collision area at a given impact parameter and energy $L \propto (1 + N_A^{1/3})/2$

Scaling of the elliptic flow

- Changing $\left(Q_s^A\right)^2 \leftrightarrow \left(Q_{s\phi}^A\right)^2$

$$v_2 = \frac{4\int_0^{\pi/2} d\phi \cos 2\phi \frac{dN}{dp_T^2 d\phi}}{\frac{dN}{dp_T^2}} = \frac{4\int_0^{\pi/2} d\phi \cos 2\phi F(\tau_\phi)}{F(\tau)}$$

- For non very peripheral collisions we can expand in powers of $R^2 - R_\phi^2$

$$v_2 = \frac{2}{\pi}\int_0^{\pi/2} d\phi \cos 2\phi \frac{R^2 - R_\phi^2}{R^2} \frac{4}{F(\tau)} \frac{dF}{d\tau} \tau Q_s^A L$$

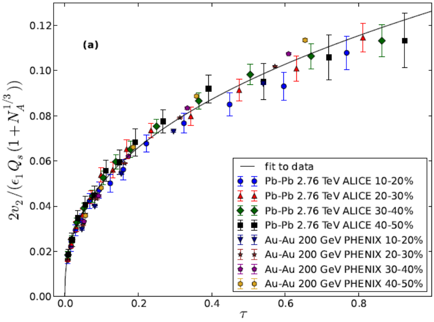
- Defining

$$\boxed{\frac{4}{F(\tau)}\frac{dF}{d\tau} = \varphi(\tau)}\,, \quad \boxed{\epsilon_1 = \frac{2}{\pi}\int_0^{\pi/2} d\phi \cos 2\phi \frac{R^2 - R_\phi^2}{R^2}}$$

Scaling of the elliptic flow in heavy ion collisions

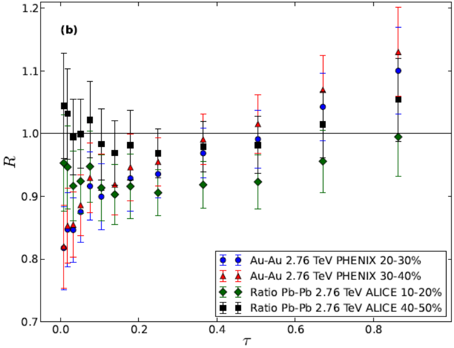
- We obtain the scaling law

$$\frac{v_2}{\epsilon_1 Q_s^A L} = \tau\varphi(\tau)$$



Scaling of the elliptic flow in heavy ion collisions

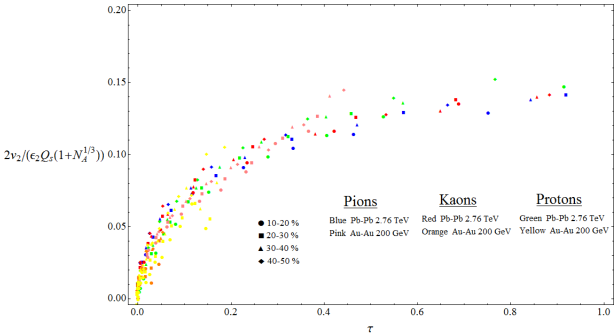
- Ratio over Pb-Pb 30-40% at 2.76 TeV



Scaling of the elliptic flow in heavy ion collisions: Identified hadrons

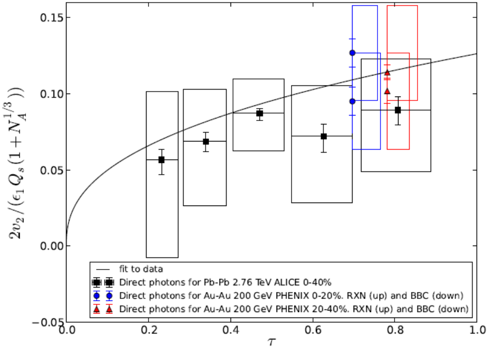
- In this framework, multiplicity distributions change:

$$p_T \to \sqrt{p_T^2 + m^2} - m$$



Scaling of the elliptic flow in heavy ion collisions: Photons

- Elliptic flow of photons is difficult to explain in final-state models because they interact weakly with QGP



Conclusions

- Elliptic flow of charged and identified particles satisfies a scaling law.
- Photon data are lying on the same scaling curve.
- Indication of possible initial-state effects in flow.
- Study of possible scaling of the rest of harmonics.