Perturbative QCD origin of azimuthal asymmetry, Direct photon V2

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Heavy Ion Collisions at the LHC workshop, CERN 2007

Outstanding questions:

Which microscopic interaction mechanism is responsible for the large observed elliptic flow?

- 1: what is the origin of Fast thermalization.
- 2: Initial conditions for Hydro (τ, T, s) are yet to be understood.
- 3: Elliptic flow at non-zero rapidity and for more prepherial need to be described.
  - Hydrodynamics breakdown for more prepherial collisions.
  - Do longitudinal boost invariance and local thermal equilibrium breakdown away from midrapidity?
- 4: what is the fate of elliptic flow at high p_T.
- 5: Need to understand scaling properites of azimuthal anisotropy: mass ordering, eccentricity scaling, valence quark number scaling (where are gluons?)...
- 6: v2 for direct photon!

- p_T distribution of photon bremsstrahlung in quark-nuclues intercations can be described in terms of the universal dipole cross section $\sigma^q_{q\bar{q}}(r;x)$: Kopeliovich, *et al* PRC 59 (1999) 1609

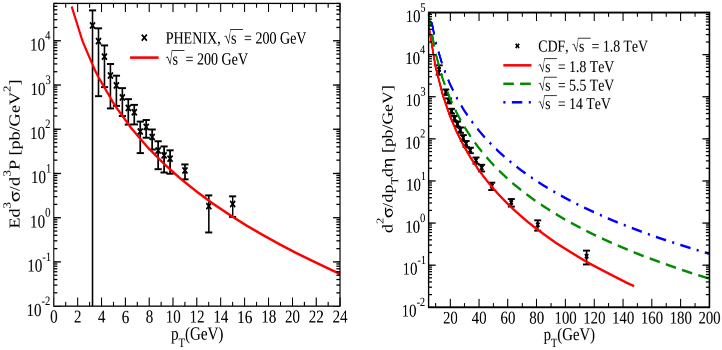
$$\begin{aligned}\frac{d\sigma^{qA}(q\to q\gamma)}{d(ln\alpha)d^2\vec{p}_T d^2b} &= \frac{1}{(2\pi)^2}\sum_{in,f}\sum_{L,T}\int d^2\vec{r}_1 d^2\vec{r}_2 e^{i\vec{p}_T.(\vec{r}_1-\vec{r}_2)} \\ &\times \phi^{\star T,L}_{\gamma q}(\alpha,\vec{r}_1)\phi^{T,L}_{\gamma q}(\alpha,\vec{r}_2)\Sigma_\gamma(x,\vec{r}_1,\vec{r}_2,\alpha,b),\end{aligned}$$

where

$$\begin{aligned}\Sigma_\gamma(x,\vec{r}_1,\vec{r}_2,\alpha,b) &= 1-e^{-\frac{1}{2}\sigma_{q\bar{q}}(x,\alpha r_1)T(b)}-e^{-\frac{1}{2}\sigma_{q\bar{q}}(x,\alpha r_2)T(b)} \\ &+ e^{-\frac{1}{2}\sigma_{q\bar{q}}(x,\alpha(\vec{r}_1-\vec{r}_2))T(b)}.\end{aligned}$$

$$\frac{d\sigma^\gamma(pA\to\gamma X)}{dx_F d^2\vec{p}_T}=\frac{1}{x_1+x_2}\int_{x_1}^1\frac{d\alpha}{\alpha}F_2^p(\frac{x_1}{\alpha},Q)\times\frac{d\sigma^{qA}(q\to q\gamma)}{d(ln\alpha)d^2\vec{p}_T}.$$

Direct photon productions at RHIC and LHC for *pp*



Kopeliovich, Rezaeian, Pirner, Ivan Schmidt, arXiv:0704.0642

- Neither *K*-factor, nor higher twist corrections, no quark-to-photon fragmentation function are to be added.

Elliptic flow and dipole orientation, A Microscopic approach

- The origion of elliptic anisotropy:
- 1: Rescatterings
- 2: Shape of the system
  How do we do it?
- The key function which describes the effect of multiple interactions is eikonal exponential, $\exp(-\frac{1}{2}\sigma_{q\bar{q}}^{q}(r)T_A(b))$ which arises in the Glauber formalism as an approximation to the convolution of cross section and nuclear thickness function:

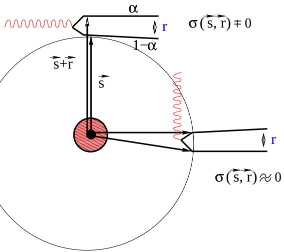
$$\sigma_{q\bar{q}}^{q}(r)T_A(b) \approx \int d^2\vec{s}\sigma_{q\bar{q}}^{q}(\vec{r},\vec{s})T_A(\vec{b}+\vec{s}).$$

The azimutal angle dependence through dipole orientation

$$\sigma^q_{q\bar{q}}(r)\, T_A(b) \rightarrow \int d^2\vec{s}\,\sigma^q_{q\bar{q}}(\vec{r},\vec{s})\, T_A(\vec{b}+\vec{s})$$

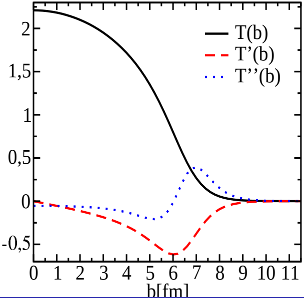
$$f_{ijkl}(\vec{r},\vec{s}) = \lambda_{ij}\lambda_{kl}\int d^2q\,\frac{\alpha_s(q^2)}{q^2+\mu^2}\left(e^{i\vec{q}.(\vec{s}+\vec{r})} - e^{i\vec{q}.\vec{s}}\right)$$

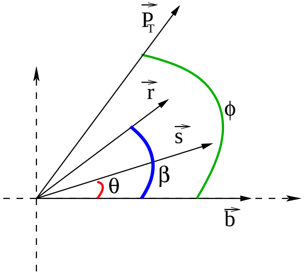
$$\begin{aligned}
\sigma^q_{q\bar{q}}(\vec{r},\vec{s}) &= \frac{1}{3}\sum |f_{ijkl}(\vec{r},\vec{s})|^2 \\
&= (2\pi)^2\frac{16\alpha_s^2}{9}\left[K_0(\mu|\vec{s}+\vec{r}|) - K_0(\mu s)\right]^2 \\
&\approx \left(\frac{\vec{r}.\vec{s}}{s}\right)^2 K_1^2(\mu s) \qquad\qquad (r << s)
\end{aligned}$$

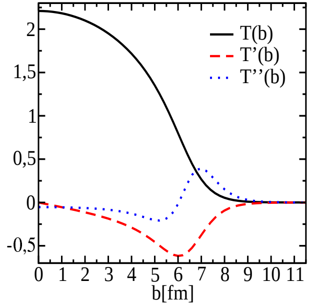


$$T_A(\vec{b}+\vec{s}) = T_A(b) + \left(s\cos(\theta) + \frac{1}{2b}s^2\sin^2(\theta)\right)$$

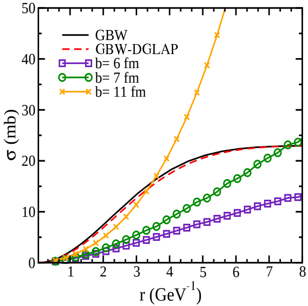
$$\times \quad T'_A(b) + s^2/2\cos^2(\theta)\, T''_A(b) + \ldots (s << b)$$







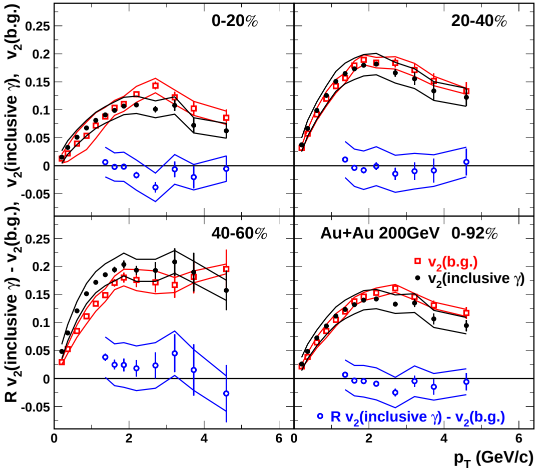
$$\int d^2\vec{s}\sigma^q_{q\bar{q}}(\vec{r},\vec{s})T_A(\vec{b}+\vec{s})$$
$$= \frac{16}{3}\alpha_s^2(p_T)\int d\theta s ds[K_0\left(\mu\sqrt{r^2+s^2+2rs\cos(\beta-\theta)}\right)-K_0\left(\mu s\right)]^2$$
$$T_A\left(\sqrt{b^2+s^2+2bs\cos(\theta)}\right)$$



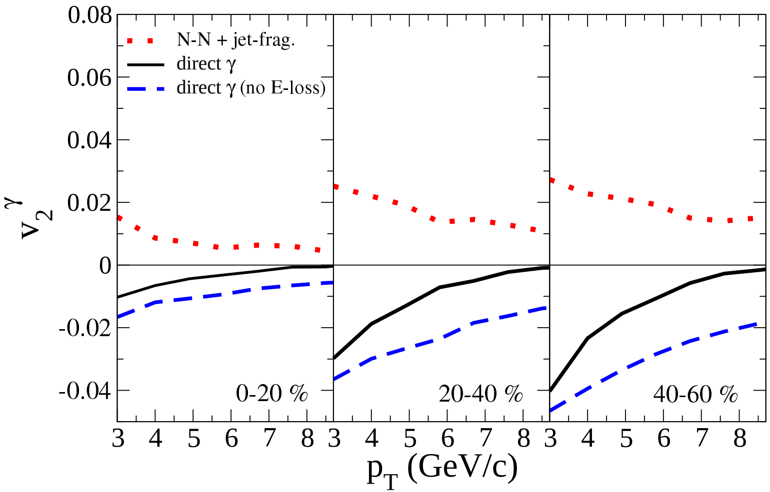
Elliptic flow from pA to AA

$$v_2^{pA}(b, p_T) = \frac{\int_{-\pi}^{\pi} d\phi \cos(2\phi) \frac{dN^{pA}}{d^2\vec{p}_T}}{\int_{-\pi}^{\pi} d\phi \frac{dN^{pA}}{d^2\vec{p}_T}}$$

$$v_2^{AA}(B, p_T) = \frac{\int_{-\pi}^{\pi} d\phi \int d^2\vec{b} \frac{dN^{pA}}{d^2\vec{p}_T} \cos\left(2(\phi+\alpha)\right) T_A(b) T_A(\vec{b}+\vec{B})}{\int_{-\pi}^{\pi} d\phi \int d^2\vec{b} \frac{dN^{pA}}{d^2\vec{p}_T} T_A(b) T_A(\vec{b}+\vec{B})},$$

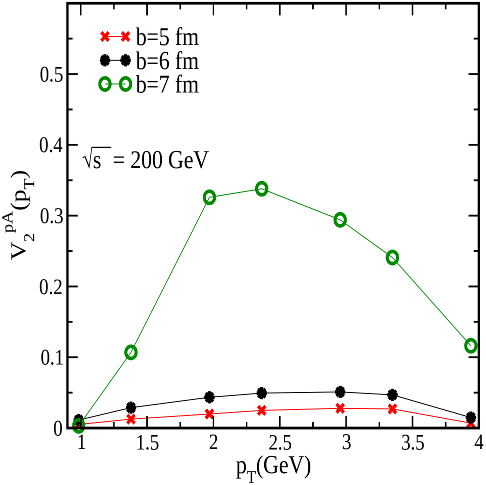


PHENIX collaboration, PRL. 96 (2006) 032302

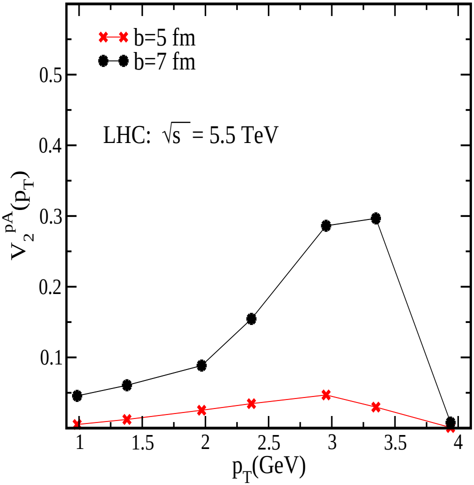


Turbide, Gale and Fries, PRL 96 (2006) 032303

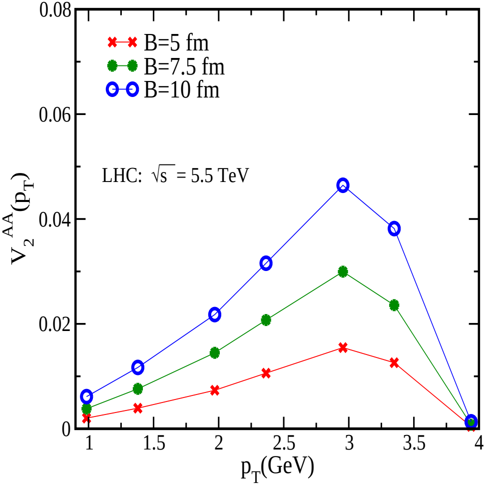
Direct photon Elliptic flow for *pA* at RHIC, preliminary results



Direct photon Elliptic flow for *pA* at LHC, preliminary results



Direct photon Elliptic flow for AA at LHC, preliminary results



Summary and outlook

- The main driving force behind the elliptic flow in our approach originates from sensitivity of parton multiple intercations to the steep variation of the nuclear density at the edge of the nuclei throught dipole orientation.
  Neither medium properties nor thermalization is need.
- Direct photon at both RHIC and LHC flow, $v2 > 0$.