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Towards azimuthal anisotropy of direct photons

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PHENIX Collaboration (Phys. Rev. Lett. 104, 132301 (2010)):

In central Au+Au collisions, the excess of direct photon yield over p+p is exponential in transverse momentum, with inverse slope T = 221 +/- 19 (stat) +/- 19 (syst) MeV. Hydrodynamical models with initial temperatures ranging from 300–600 MeV at times of 0.6 - 0.15 fm/c after the collision are in qualitative agreement with the data.

PHENIX Collaboration (Phys. Rev. Lett. 109, 122302 (2012)):

The second Fourier component v(2) of the azimuthal anisotropy with respect to the reaction plane is measured for direct photons at midrapidity and transverse momentum (p(T)) of 1-12 GeV/c in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. .... in the p(T) $<$ 4 GeV/c region dominated by thermal photons, we find a substantial direct-photon v(2) comparable to that of hadrons, whereas model calculations for thermal photons in this kinematic region underpredict the observed v(2).

A serious contradiction with expected dominance of photon production from QGP

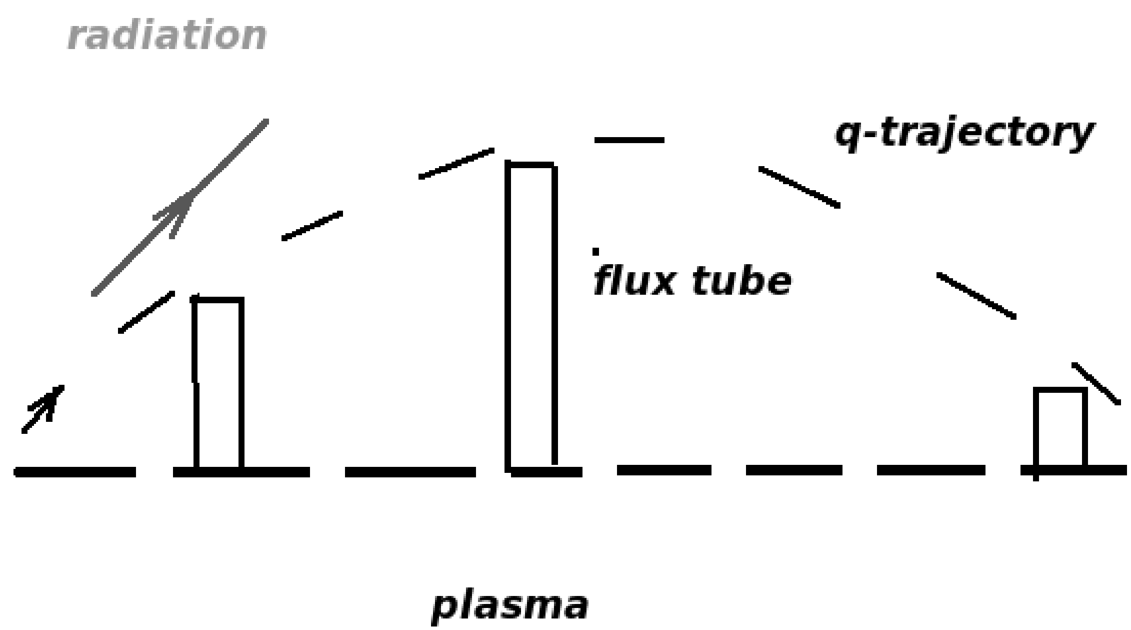
Our explanation of this PHENIX (+ ALICE now) puzzle :

Intensive radiation of magnetic bremsstrahlung type (synchrotron radiation) resulting from the interaction of escaping quarks with the collective confining colour field is discussed as a new possible mechanism of observed direct photon anisotropy.

Theoretically, the basic conditions to have such a radiation available are easily realized as:
1 — the presence of relativistic light quarks (u and d quarks) in QGP;
2 — the semiclassical nature of their motion;
3 — confinement.

Then as a result, each quark (antiquark) at the boundary of the system volume moves along a curve trajectory and (as any classical charge undergoes an acceleration) emits photons.

The interaction of escaping quarks with the collective confining color field (in the chromo-electric flux tube model):



From our old calculations (Yad. Fiz.; Z. Phys. C; Phys. Lett. B (1988)):

$$\frac{N^{\gamma}_{\text{surface}}}{N^{\gamma}_{\text{volume}}} = \frac{\text{const}}{r T_c^{1/3} \sigma^{1/3}},$$

where T_c is the phase-transition temperature, r is the transverse size of cylindrically symetric plasma volume with the longitudinal expansion, $\sigma \simeq 0.2$ Gev^2 is the quark confining force. Volume photons come from the channels $gq \to \gamma q$, $q\bar{q} \to \gamma g$.

Taking into account the value of constant we find

$$N^{\gamma}_{\text{surface}}/N^{\gamma}_{\text{volume}} \approx 2 \text{ at } r = 10 \text{ fm} .$$

The similar estimation can be obtained for hard enough photons also.

Obviously, the photon emanation from the surface mechanism of noncentral ion collisions is nonisotropic. Indeed, photons are emitted mainly around the direction determined by the normal to the ellipsoid-like surface.

In the transverse (x-y) plane (the beam is running along (z)-axis) the direction of this normal (emitted photons) is determined by the spatial azimuthal angle $\phi_s = \tan^{-1}(y/x)$ as

$$\tan(\phi_\gamma) = (R_x/R_y)^2 \tan(\phi_s).$$

The shape of quark-gluon system surface in transverse plane is controlled by the radii $R_x = R\sqrt{1-\epsilon}$ and $R_y = R\sqrt{1+\epsilon}$ with the eccentricity $\epsilon = b/2R_A$ (b is the impact parameter, R_A is the radius of the colliding (identical) nuclei).

The photon azimuthal anisotropy can be characterized by the second Fourier component

$$v_2^\gamma = \frac{\int d\phi_\gamma \cos(2\phi_\gamma)(dN^\gamma/d\phi_\gamma)}{\int d\phi_\gamma (dN^\gamma/d\phi_\gamma)}$$

and is proportional to the "mean normal"

$$v_2^\gamma \propto \frac{\int d\phi_s \cos(2\phi_\gamma)}{2\pi} = \epsilon.$$

Summarizing we would like to maintain positively that the surface mechanism of photon production is intensive enough, develops the azimuthal anisotropy and is capable of resolving the PHENIX direct photons puzzle still without appealing to the non-equilibrium dynamics of heavy ion collision process.