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The nuclear matter at high energies and Cherenkov gluons

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Cherenkov gluons can be used as a probe of nuclear matter. The events with the ring-like structure in the plane perpendicular to the jet axis should be pronounced. First cosmic ray observation of such a structure in 1979 initiated the idea about Cherenkov gluons. Now it is confirmed by RHIC data.

Experimental data (early days + RHIC).
1. Stratospheric event at 10^{16} eV (1979). Its wavelet image (1997). (LHC - 2008!)
2. Pseudorapidity distribution of dense isolated groups in pp at 360 GeV (1989).
3. Wavelet image of the PbPb event at 158 GeV shows ring-like structure (2001).
4. Several emulsion data at accelerator energies indicated on rings (2002).
5. Two-bump distribution at RHIC (central AuAu at 20 TeV - $c_w = 0.33v$) (2004) - Fig.

Theory

If z-axis is along the body propagation, then emission in an **infinite** medium **at rest** is directed along the cone with the polar angle θ:

$$\cos\theta = \frac{c_w}{v}. \tag{1}$$

v is the body velocity. For Cherenkov photons $c_w = c/n$, n is the index of refraction.

$$n(\omega) = 1 + \Delta n = 1 + \frac{2\pi N}{\omega^2}F(\omega). \tag{2}$$

ω is the photon frequency, N is the density of the scatterers (inhomogeneities) of the medium. The forward scattering amplitude $F(\omega)$ is normalized as

$$\mathrm{Im}F(\omega) = \frac{\omega}{4\pi}\sigma(\omega), \tag{3}$$

where $\sigma(\omega)$ is the total cross section of photon interaction in the medium.

For hadrons

$$\mathrm{Re}n(\omega) = 1 + \Delta n_R(\omega) = 1 + \frac{3m_\pi^3}{8\pi\omega}\sigma(\omega)\rho(\omega)\nu, \tag{4}$$

where $\rho(\omega) = \mathrm{Re}F/\mathrm{Im}F$ and now $F(\omega)$ ($\sigma(\omega)$) is the pion-nucleon forward amplitude (cross section), ν-the number of scatterers within a nucleon.

The resonance region:

$$\Delta n_R^r = \frac{3m_\pi^3}{2\omega_r^2\Gamma}. \tag{5}$$

RHIC - Low energy gluons.

For a single resonance at energy E_R and with width Γ_R one gets

$$\mathrm{Re}n(E) = 1 + \frac{2J+1}{(2s_1+1)(2s_2+1)} \cdot \frac{3\mu^3\Gamma_R\nu}{E_R^2} \cdot \frac{E-E_R}{E[(E-E_R)^2+\Gamma_R^2/4]}. \tag{6}$$

Here J is the spin of the resonance, s_i are the spins of "incident particles". We have replaced N by the number of partonic scatterers ν within a single nucleon volume $4\pi/3\mu^3$ with μ the pion mass.

Re$n > 1$ for $E > E_R$ only. It is 1 at $E = E_R$, increases to the maximum approximately at the resonance half-width

$$E_0 = E_R + \frac{\Gamma_R}{2}(1 - \frac{\Gamma_R}{2E_R}) \tag{7}$$

and decreases as $O(1/E^2)$. For $\Gamma_R \ll E_R$ its value at the maximum is

$$\mathrm{Re}n(E_0) \approx 1 + \frac{2J+1}{(2s_1+1)(2s_2+1)} \cdot \frac{3\mu^3\nu}{E_R^3}. \tag{8}$$

The average value of Ren is smaller than its value at the maximum. Therefore, from experimental estimate of this average value equal to 3 one gets the lower bound for the effective number of partons within the nucleon volume ν

$$\nu > \frac{(2s_1+1)(2s_2+1)}{2J+1} \cdot \frac{2E_R^3}{3\mu^3}. \tag{9}$$

$\nu > 40$ for ρ, > 20 for all resonances included.

The average value of Ren is

$$\langle \mathrm{Re}n \rangle \approx 1 + \frac{2J+1}{(2s_1+1)(2s_2+1)} \cdot \frac{6\mu^3}{\pi E_R^3}\langle \nu \rangle. \tag{10}$$

$\langle \nu \rangle = 60$ for ρ, $= 30$ for all.

Another information can be obtained from the height of the peaks in STAR Fig.. For narrow rings ($\delta \ll r_i$) the height of the maximum over the minimum is easily determined as

$$h_{max} = \sqrt{2r_1\delta} - \delta. \tag{11}$$

With $h_{max} \approx 1.6 - 1.2 = 0.4$ and $r_1 = 1.2$ in STAR Fig. one obtains the width:

$$\delta \approx 0.1 \quad (\ll r_1). \tag{12}$$

Dispersion

$$\delta_d = \int_0^{\delta_d} d\theta = \cot\theta_c \int_0^{\infty} \frac{1}{n}\frac{dn}{dE} dE. \tag{13}$$

If the Breit-Wigner expression for $n(E)$ is used, the result is

$$\delta_d = 0. \tag{14}$$

The finite free path length for partons

$$\delta_f \sim \frac{\lambda}{R_f}. \tag{15}$$

For $\lambda \sim 2/E_R$ and $\delta_f < 0.1$ one gets the estimate for the free path length

$$R_f > 20/E_R \sim 4.5/\mu \sim 7 \cdot 10^{-13} cm. \qquad (16)$$

Finally, the width of the ring can become larger due to resonance decays.

The energy loss can be calculated using the standard formula

$$\frac{dE}{dx} = 4\pi\alpha_S \int_{E_R}^{E_R+\Gamma_R} E \left(1 - \frac{1}{n^2(E)}\right) dE \approx 1 GeV/fm. \qquad (17)$$

CONCLUSIONS

QM properties revealed by Cherenkov gluons:

1. The nuclear index of refraction $n \approx 3$. Determined by the Δy-distance between the peaks (ring diameter).

2. The density of partons $\nu \approx 30$ (per nucleon). Use n (with resonance amplitudes).

3. The energy loss $dE/dx \approx 1$ GeV/fm. Determined by the standard formula with n.

4. The free path length for partons $R_f \sim 7$ fm. The height of the peaks (ring width).

5. Ring content - "shifted" resonances.

What is missing?

1. The two-dimensional data in the plane perpendicular to the associated jet axis.

2. Event-by-event correlation analysis within the ring.

3. Search for resonance content in the ring.