QUANTUM RADIATION OF CHERENKOV GLUE

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Plan of the talk

- Quantum picture for Cherenkov radiation.
- Model for the chromopermittivity.
- Cherenkov radiation of quark currents.
- Cherenkov radiation of gluon currents.
- Double Cherenkov decay of gluon currents.
- Comparison with the experimental data.
- Conclusions.

Quantum picture for Cherenkov radiation

- In the medium the dispersion relation (as seen from the propagator's poles) for excitations changes:

$$\frac{1}{\omega^2 - \mathbf{k}^2} \Longrightarrow \frac{1}{\omega^2 - \epsilon(\omega, \mathbf{k})\mathbf{k}^2}. \tag{1}$$

- Of special interest are the nonlinear interactions of excitations. The leading nonlinear effect is a three-wave interaction corresponding to the decay of a quasiparticle into two quasiparticles

$$(\omega_1, \mathbf{k}_1) \to (\omega_2, \mathbf{k}_2) \oplus (\omega_3, \mathbf{k}_3). \tag{2}$$

- Cherenkov radiation is a decay of a free vacuum particle into a quasiparticle and a free particle.
- Cherenkov decay is a decay of a free vacuum particle into two quasiparticles.

Model for chromopermittivity

- Generically the colored medium is characterized by chromopermittivity

$$\varepsilon^{ab}(\omega, \mathbf{k}). \tag{3}$$

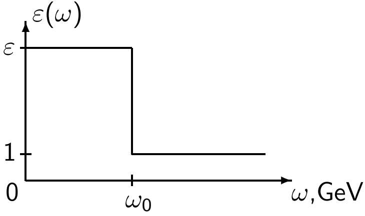
- We shall consider the quasiabelian case and neglect the spatial dispersion:

$$\varepsilon^{ab}(\omega, \mathbf{k}) \longrightarrow \delta^{ab}\varepsilon(\omega). \tag{4}$$

- Experimental data from RHIC suggest the step-like model for $\varepsilon(\omega)$

$$\varepsilon(\omega) = \varepsilon > 1, \ \omega < \omega_0 \tag{5}$$

$$\varepsilon(\omega) = 1, \ \omega > \omega_0. \tag{6}$$



Kinematically allowed processes

There exist three processes that are kinematically allowed.

- Cherenkov radiation of the quark current

$$q(\omega_1, \mathbf{k}_1) \to q(\omega_2, \mathbf{k}_2) \oplus \tilde{g}(\omega_3, \mathbf{k}_3) \tag{8}$$

- Cherenkov radiation of the gluon current

$$g(\omega_1, \mathbf{k}_1) \to g(\omega_2, \mathbf{k}_2) \oplus \tilde{g}(\omega_3, \mathbf{k}_3) \tag{9}$$

- Double Cherenkov decay of the gluon current

$$g(\omega_1, \mathbf{k}_1) \to \tilde{g}(\omega_2, \mathbf{k}_2) \oplus \tilde{g}(\omega_3, \mathbf{k}_3) \tag{10}$$

Kinematics of Cherenkov radiation

- Cherenkov radiation can happen only for special angles between the radiating particle and its quasiparticle successor (Cherenkov angle)

$$\cos\theta = \frac{1}{\sqrt{\varepsilon}}\left(1 + \frac{\varepsilon - 1}{2}\frac{\omega}{E}\right). \tag{11}$$

- Restriction on ω/E:

$$\frac{\omega}{E} < \frac{2}{\sqrt{\varepsilon}+1}. \tag{12}$$

- For the radiation of the gluon current we have $E > \omega_0$.
- When the energy of the initial particle $E > \frac{\sqrt{\varepsilon}+1}{2}\omega_0$, the energy of the emitted Cherenkov gluon is bounded by ω_0. For the gluon current we have an additional restriction $\omega \leq E - \omega_0$.

Kinematics of double Cherenkov decay

- In the case of the double Cherenkov decay the angle between the gluon and its quasiparticle successor with the energy ω is

$$\cos\theta = \sqrt{\varepsilon} - \frac{\varepsilon - 1}{2\sqrt{\varepsilon}} \frac{E}{\omega} \tag{13}$$

- This decay angle also leads to the restrictions on the energy of the emitted Cherenkov gluons

$$\frac{1}{2} - \frac{1}{2\sqrt{\varepsilon}} < \frac{\omega}{E} < \frac{1}{2} + \frac{1}{2\sqrt{\varepsilon}}. \tag{14}$$

- The double Cherenkov decay can occur for the energies of the initial gluon $\omega_0 < E < 2\omega_0$.

Calculation of the spectrum

- Basic radiation spectrum

$$P(\omega|E) = \omega\gamma(\omega|E) = \frac{\omega}{2E}\int d\Pi_f \delta\left(\omega - \frac{|\mathbf{q}|}{\sqrt{\varepsilon}}\right)\frac{1}{2}\sum_{i,j,k=1,2}|\mathcal{M}|^2. \tag{15}$$

- After integration

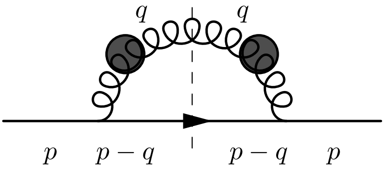
$$P(\omega|E) = \frac{\varepsilon\omega}{16\pi E^2}\frac{1}{2}\sum_{i,j,k=1,2}|\mathcal{M}|^2 \tag{16}$$

- Energy losses per unit length

$$\frac{dE}{dl} = \int_0^{\omega_{max}} d\omega P(\omega|E), \tag{17}$$

where ω_{max} is the maximum energy of Cherenkov gluon allowed by the kinematics of the process.

Cherenkov radiation of the quark current



- The corresponding differential decay rate for this process is

$$\gamma_{q\to q\tilde{g}}(\omega|E) = \alpha_s \frac{N_c^2-1}{2N_c}\left(1-\frac{1}{\varepsilon}\right)\left(1-\frac{\omega}{E}+\frac{\varepsilon+1}{4}\frac{\omega^2}{E^2}\right) \tag{18}$$

Angular differential energy flow and energy losses for the quark current

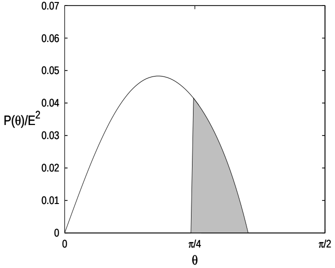


Figure: $\varepsilon = 5$, $\omega_0 = 3$ GeV and $E = 10$ GeV

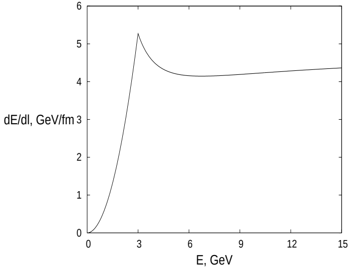
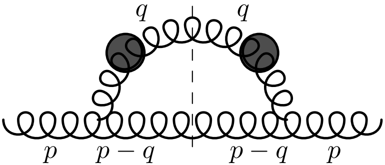


Figure: $\varepsilon = 5$, $\omega_0 = 3$ GeV

Cherenkov radiation of gluon current



- The corresponding differential decay rate for this process is

$$\gamma_{g\to g\tilde{g}}(\omega|E) = \alpha_s N_c \left(1-\frac{1}{\varepsilon}\right)\left(1-\frac{\omega}{E}-\frac{\varepsilon-1}{4}\frac{\omega^2}{E^2}\right)\times$$
$$\times\left[1+\frac{1}{2}\left(\varepsilon+\frac{\varepsilon+1}{1-\frac{\omega}{E}}+\frac{\varepsilon}{\left(1-\frac{\omega}{E}\right)^2}\right)\frac{\omega^2}{E^2}+\frac{(\varepsilon+1)^2}{8\left(1-\frac{\omega}{E}\right)^2}\frac{\omega^4}{E^4}\right]. \tag{19}$$

Angular differential energy flow and energy losses for the gluon current

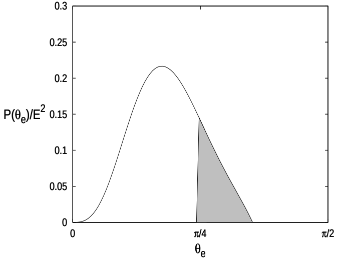


Figure: $\varepsilon = 5$, $\omega_0 = 3\ \mathrm{GeV}$ and $E = 10\ \mathrm{GeV}$

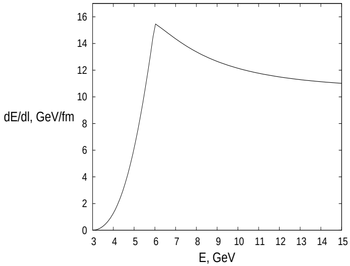
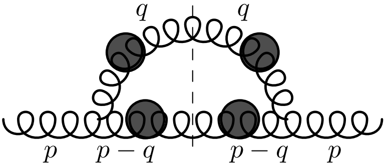


Figure: $\varepsilon = 5$, $\omega_0 = 3\ \mathrm{GeV}$

Cherenkov decay of gluon current



The corresponding differential decay rate for this process is

$$\gamma_{g\to\tilde{g}\tilde{g}}(\omega|E) = \frac{\alpha_s N_c}{2}\left[1-\left(\sqrt{\varepsilon}-\frac{\varepsilon-1}{2\sqrt{\varepsilon}}\frac{E}{\omega}\right)^2\right]\times \tag{20}$$

$$\left[1+\varepsilon\frac{\omega^2}{E^2}+\frac{\frac{\omega^2}{E^2}}{(1-\frac{\omega}{E})^2}+\varepsilon\left(1-\frac{\varepsilon-1}{2\varepsilon}\frac{1}{1-\frac{\omega}{E}}+\frac{\frac{\omega^2}{E^2}}{1-\frac{\omega}{E}}\right)^2\right].$$

Angular differential energy flow and the lifetime of the gluon through double Cherenkov decay

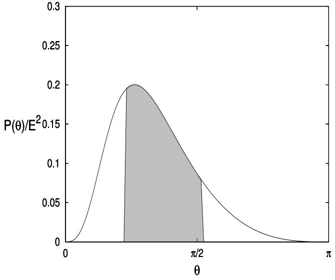


Figure: $\varepsilon = 5$, $\omega_0 = 3\ \mathrm{GeV}$ and $E = 5\ \mathrm{GeV}$.

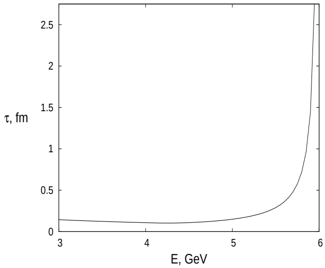


Figure: $\varepsilon = 5$, $\omega_0 = 3\ \mathrm{GeV}$.

- For the energy of the initial particle $E = 5$ GeV the energy losses are about 35 GeV/fm.

Experimental data on two-particle azimuthal correlations

STAR Collaboration, arXiv:1004.2377

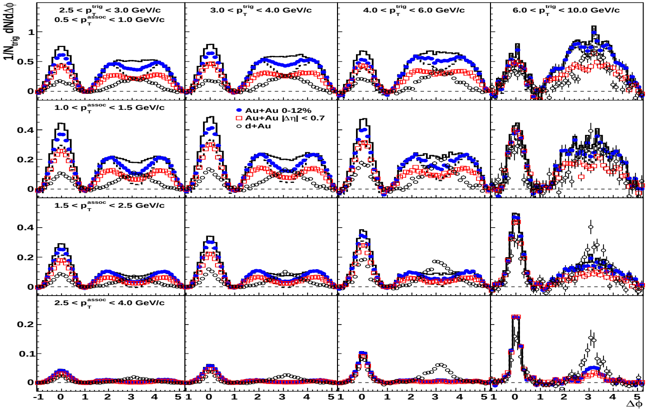


Figure:

Conclusions

- Quantum Cherenkov radiation of gluon current computed.
- For quark currents the only available decay channel is the single Cherenkov decay.
- A new mechanism for energy losses is introduced (double Cherenkov decay).
- For incident gluons with energy in the interval $\omega_0 < E < 2\omega_0$ the leading contribution to the energy loss comes from the double Cherenkov decay. In the domain $E > 2\omega_0$ the Cherenkov radiation is the only contributing process.
- Qualitative agreement with the experimental data at RHIC is obtained, where the pattern of angular correlations corresponds to two peaks around the direction of propagation of the decaying gluon.