CHERENKOV GLUONS
(predictions and proposals)

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Heavy ion collisions at the LHC
Last call for predictions

CERN, 14 May - 8 June 2007

+ US, August 2007

PREHISTORY (1904 - 10 - 26).

HISTORY:

a) photons (34 - 37 - 39).

Transverse Bremsstrahlung vs
longitudinal polarization of the medium
by Cherenkov photons.

Emission by a particle vs
coherent collective emission by the medium.

b) mesons (49 ...).

c) gluons (79 ...).

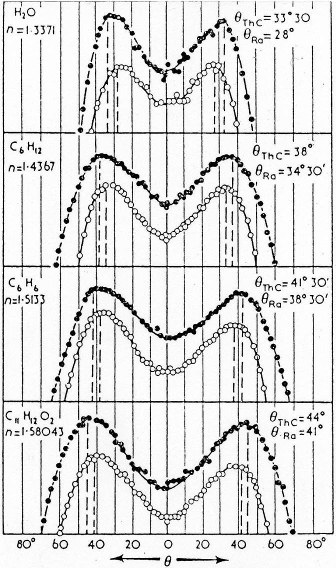


FIG. 1.8. The variation of θ with n, for two different sources of γ-rays. (Čerenkov, 1937d and 1938c.)

The Figure is from the book of J. Jelley "Cherenkov radiation and its applications", 1958

THE GENERAL RELATION

$$\Delta n = \mathrm{Re} n - 1 = 8\pi N_s \mathrm{Re} F(E, 0^o)/E^2.$$

N_s - the density of scattering centers; $E^2 = s$.

Necessary condition $\Delta n > 0$ or $\mathrm{Re} F(E, 0^o) > 0$.

Hadronic amplitudes:

Low energies - resonances;
High energies - experiment+dispersion relations;
threshold.

SCENARIO:

Emitted gluon affects the medium as an "effective" wave which accounts also for the waves emitted by other scattering centers. Beside incoherent scattering, there are collective processes which can be described as the refraction of the initial wave along the path of the coherent wave. The Cherenkov effect is the induced coherent radiation by a set of scattering centers positioned on the way of propagation of the gluon.

- **Rings around the "low"-energy partons - trigger experiments:**
  I.D., Nucl. Phys. A767 (2006) 233; A785 (2007) 369.
  A. Majumder, X.N. Wang, Phys. Rev. C73 (2006) 172302.
  V. Koch, A. Majumder, X.N. Wang, Phys. Rev. Lett. 96 (2006) 172302.
- **The low-mass dilepton excess:**
  I.D., V.A. Nechitailo, hep-ph/0704.1081
- **Rings around the high-energy partons - non-trigger experiments:**
  I.D., JETP Lett. 30 (1979) 140; Sov. J. Nucl. Phys. 33 (1981) 726.

Review: I.D., Int. J. Mod. Phys. A22 (2007) 1.

Coherent Cherenkov emission is along the conical surface with the cone angle θ_c to the momentum of the parton-emitter in the **rest system** of the **infinite** medium:

$$\cos\theta_c = \frac{1}{\beta n}. \tag{1}$$

$\beta(\approx 1$ for relativistic partons) is the ratio of the velocities of the parton and light.

Cherenkov rings in the plane perpendicular to the parton momentum with radius equal to θ_c.

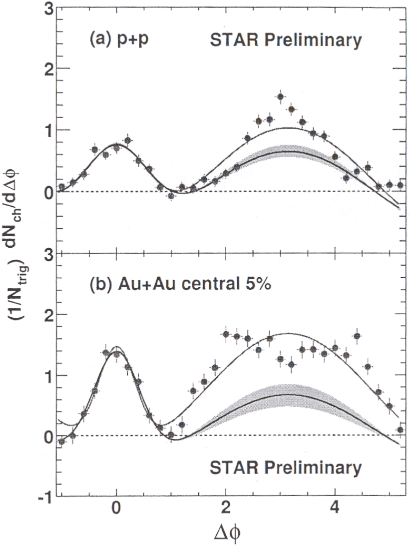
Prediction 1. According to Eq. (1) the ring-like two-dimensional distribution of particles must be observed in the plane perpendicular to the momentum of the parton.

Proposal 1. Plot the one-dimensional pseudorapidity $(\eta = -\ln\tan\theta/2)$ distribution of ALL particles with trigger momentum as z-axis neglecting the mismatch of trigger and away-side jets directions. It should have maximum at (1).

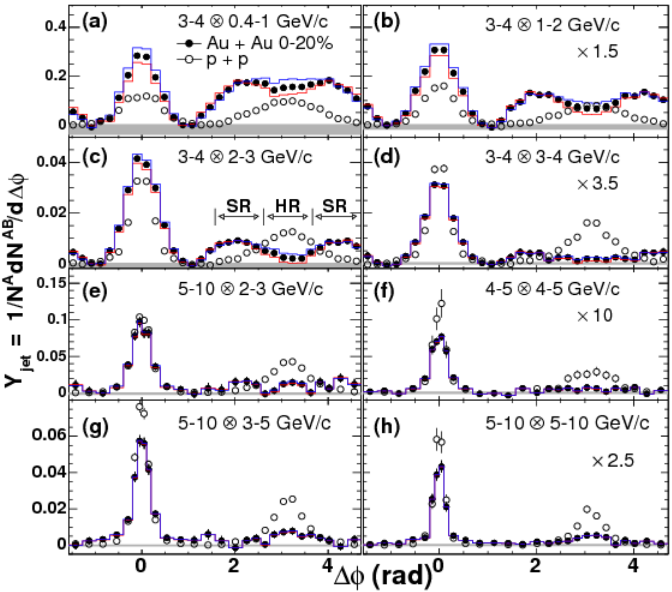
This plot is still unavailable at RHIC.

RHIC experiments have shown the two-bump structure of the azimuthal angle distribution (now with z-axis chosen along the collision axis) near the away-side jets in central heavy-ion collisions.

This is the projection of the ring on its diameter.



The $\Delta\phi$-distribution of particles produced by trigger and companion jets at RHIC shows two peaks in *pp* and three peaks in AuAu-collisions.



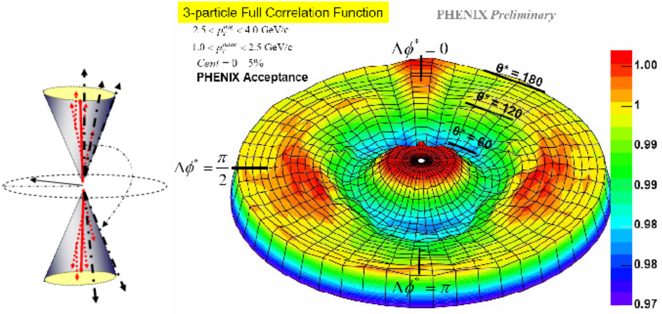
(A. Adare et al for PHENIX collaboration, arXiv0705.3238)
Per-trigger yield versus $\Delta\phi$ in *pp* and Au-Au collisions.

Proposal 1a. Plot the $\Delta\phi$-distribution of particles produced by trigger and companion jets for different energy intervals $E^A \otimes E^B$ in place of transverse momenta intervals $p_T^A \otimes p_T^B$ done by PHENIX.

Physics motivation: particles within the ring must have the same energy distribution independent of the ring sector. p_T-projection violates this requirement filling the $\Delta\phi \approx \pi$ -region (HR) by more energetic particles than the shoulder region (SR). That can be seen from the relations $p_T^B \approx E^B \cos\theta_c$ at $\Delta\phi = \pi$ and $p_T^B \approx E^B$ at $\Delta\phi = \pi \pm \theta_c$.

The maxima at the shoulder regions should become more pronounced for the low energy away-side interval.

The 3-particle correlations reveal clearly the ring-like structure around the away-side jet.



(N.N. Ajitanand for PHENIX Collaboration, nucl-ex/0609038)

Coordinate system (left) and full 3-particle correlation surface for charged hadrons in central Au+Au collisions at RHIC.

THE NUCLEAR MEDIUM PROPERTIES

1. The refractive index;
2. The density of partons;
3. The energy loss of Cherenkov gluons;
4. The free path length of gluons.

1. $n \approx 3$ from the distance between the peaks using (1),
2. $\nu \approx 20$ from averaged (2), **LIQUID (!?)**

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

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

4. $$R_f > 20/E_R \sim 4.5/m_\pi \sim 7 \cdot 10^{-13}\mathrm{cm}.$$

from the width of the ring.

THE LOW-MASS DILEPTON EXCESS

Prediction 2. According to Eq. (2) the Cherenkov states formed within the ring have masses less than m_R that leads to the asymmetry of decay spectra of resonances with substantial contribution of low masses.

Proposal 2. Plot the distribution of masses of $\pi^+\pi^-$, $\mu^+\mu^-$ or e^+e^--pairs near resonance peaks.

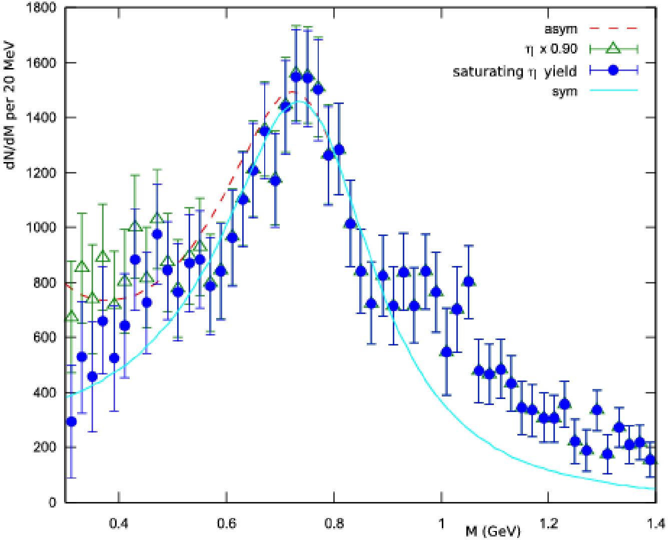
The excess of n over 1 in the left wing of any Breit-Wigner resonance leads to Cherenkov gluons and excess of low-mass lepton pairs.

$$\frac{dN}{dM} = \frac{A}{(m_\rho^2 - M^2)^2 + M^2\Gamma^2} \left(1 + w\frac{m_\rho^2 - M^2}{M^2}\theta(m_\rho - M)\right.$$

where

$$\Delta n = \frac{N_s}{\Gamma}\sigma_{BW}\frac{m_\rho^2 - M^2}{M^2},$$

$$\sigma_{BW} = \frac{2J+1}{(2S_1+1)(2S_2+1)}\frac{16\pi\Gamma^2}{(m_\rho^2 - M^2)^2 + M^2\Gamma^2}.$$



Excess dilepton mass spectrum in semi-central In-In collisions at 158 AGeV (dots - NA60 data) compared to the in-medium ρ-meson peak with additional Cherenkov effect (dashed line).

MEASURE:

1. the angular distribution of the lepton pairs with different masses.
2. the average mass of lepton pairs as a function of their polar emission angle (pseudorapidity).

The transverse momenta distribution - lower p_T for coherent processes at low masses than for incoherent scattering at larger masses.

The Cherenkov dominance region of masses from 400 MeV to 600 MeV below the ρ-resonance has softer p_T-distribution compared to the resonance region from 600 MeV to 900 MeV filled in by usual incoherent scattering (NA60).

The prediction of asymmetrical in-medium widening of **any** resonance at its low-mass side due to Cherenkov gluons is universal. This **universality** is definitely supported by experiment.
KEK - ρ, ω and ϕ.
CBELSA/TAPS - ω.
RHIC - indications for J/ψ-meson.

For the sake of simplicity, Eqs. valid at small Δn typical for gases are used. The value $n = 3$ corresponds to a dense liquid. Therefore, one must use the Lorenz-Lorentz formula

$$\frac{n^2-1}{n^2+2} = \frac{m_\pi^3 \nu \alpha}{4\pi} =$$

$$\sum_R \frac{2J_R+1}{(2s_1^R+1)(2s_2^R+1)} \cdot \frac{4m_\pi^3 \Gamma_R \nu}{EE_R^2} \cdot \frac{E_R - E}{(E-E_R)^2 + \Gamma_R^2/4},$$

where α denotes the color polarizability of the color-neutral medium. The value ν obtained from this expression is almost twice lower than given above. It does not change the qualitative conclusions about the dense medium.

THE HIGH-ENERGY PARTONS

Prediction 3. Very high energy forward moving partons can emit high energy Cherenkov gluons producing jets.

Proposal 3. Plot the pseudorapidity distribution of dense groups of particles in individual events (now again with collision axis chosen as z-axis) and look for maxima at angles determined by Eq. (1).

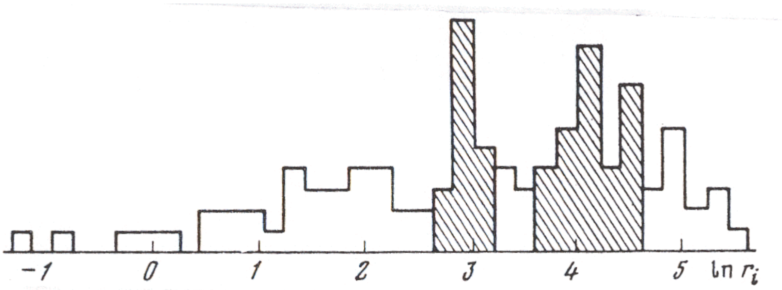
Processes with gluons of such energy at RHIC would ask for the event-by-event analysis. They are rare and rings are concentrated at the central rapidities where the background is high. They will become more abundant at the LHC.

$$\Delta n_R(E_t) \approx \frac{a\nu_h}{E_t}\theta(E_t - E_{th}).$$

$E_{th} \sim 100$ GeV in the target rest system.

GAS (!?)

Maximum Δn at $E_{t,p} \approx 1$ TeV. $x_p \sim 10^{-4} - 10^{-5}$.



The distribution of produced particles in the stratospheric event at 10^{16} eV as a function of the distance from the collision axis (pseudorapidity) has two pronounced peaks.

The two rings with radii $r_1 = 1.75$ cm and $r_2 = 5$ cm are produced by forward and backward moving (in c.m.s.) partons. The transformation of angles from target (t) to c.m.s. (c)

$$\tan \frac{\theta_c}{2} \approx \gamma \theta_t.$$

The ratio

$$\frac{\theta_{1t}}{\theta_{2t}} = \frac{r_1}{r_2} = \frac{\tan \theta_{1c}/2}{\tan \theta_{2c}/2} = 0.35.$$

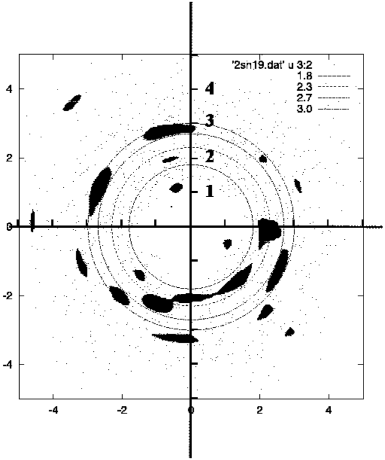
The symmetry of rings $\theta_{2c} = \pi - \theta_{1c}$ gives $\theta_{1c} \approx 61^o$ and $\gamma \approx 2.3 \cdot 10^3$, i.e. $E_t \approx 10^{16}$ eV (LHC!).

The target rest system angle is $\theta_{1t} \approx 2.6 \cdot 10^{-4}$ and the height $H = r_1/\theta_{1t} \approx 68$ m. It corresponds rather well to the experimental estimates obtained by three different methods ranging from 50 m to 100 m. Even though the observed angles were quite small in the target rest system, at LHC they would correspond to large c.m.s. angles about 60^o - 70^o.

Proposal 4. Use triggers at different angular positions.

Different rest systems and transverse momenta (x, Q^2) - different $\cos\theta_c$ - different n - different N_s.

Scan $(1/x, Q^2)$-plane by plotting the observed density of scatterers N_s.



The two-dimensional $(\eta - \phi)$ plot of the wavelet coefficients at scale $j = 5$ obtained from analysis of PbPb event at 158 GeV. Dark regions denote large values of wavelet coefficients, i.e. strongly correlated groups of particles. The ring regions $1.8 < \eta < 2.3$ and $2.7 < \eta < 3.0$ correspond to peaks of the pseudorapidity distribution. $\eta = 2.5$ is equivalent to c.m.s. angle $\pi/2$. The dots indicate particle positions.

Proposal 5. Do the event-by-event wavelet analysis - the "tomography" of the phase space.

Rings; v_2, v_4 etc as "cucumbers", "flowers" ...; others (?)