The first heavy ion collisions at the LHC - HIC10
01.09.2010

A.L., V. Nechitailo, arXiv:1006.0366[nucl-th]

Decoherence effects in QCD cascades in medium

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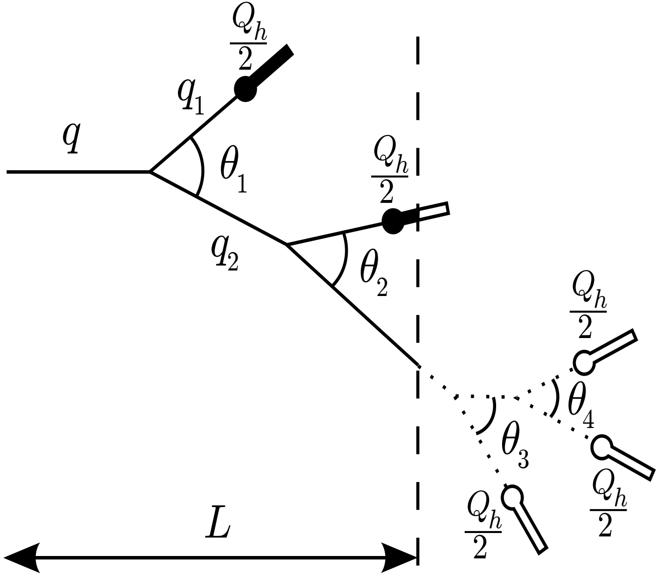
In-medium QCD cascade



In-medium QCD cascade: models

- Two types of QCD cascades:
  - Cascade driven by degradation of virtuality (DGLAP)
  - Cascade driven by medium-induced particle production (similar to electromagnetic showers in matter)

- Rigorous description combining both effects is currently not available. Medium effects are taken into account by phenomenological "deformations" of one of the two basic alternatives

- Most studies "deform" the DGLAP evolution.

In-medium QCD cascade: models

- "Pionization"

  Dremin I.M. *JETP Lett.* **31** 185 (1980)
  Dremin I.M., A.L. *Sov. Journ. Nucl. Phys.* **35** 247 (1982)
  A.L., Ostrovsky D.M. *Phys. Atom. Nucl.* **60** 110 (1997);
  62 701 (1999)

- PYQUEN

  I.P. Lokhtin, A.M. Snigirev *Eur. Phys. J.* **C45** (2006), 211

- JEWEL

  Zapp K, Ingelman G, Rathsman J, Stachel J, Wiedemann U A,
  Eur. Phys. J **C60** 617 (2009)

- QPYTHIA

  Armesto N, Cunqueiro L, Salgado C A, *Eur. Phys. J* **C63** 679 (2009)

- QHERWIG

  Armesto N, Corcella G, Cunqueiro L, Salgado C A,
  JHEP 0911:122 (2009)

Main ingredients of the model

- Setup same as in JEWEL.
- Timelike mass-ordered QCD cascade with initial energy E_0 and virtuality Q_0^2 stopping at final virtuality $Q_h^2/4$.
- Angular ordering switched off for vertices generated inside the medium.
- Effect of nonradiative energy losses taken into account both for intercascade and final gluons.
- Medium-induced radiative losses not taken into account.

Mass-ordered QCD cascade

- Sequence of decays $q \to q_1 + q_2$
- Lifetime of the parton $\tau = E\left(\frac{1}{Q^2} - \frac{1}{Q^2_{\rm par}}\right)$
- Exact restrictions on $z = E_1/E$ from kinematics

$$\tilde{z}_-(E, Q^2|\ Q_1^2, Q_2^2) < z < \tilde{z}_+(E, Q^2|\ Q_1^2, Q_2^2)$$

$$\tilde{z}_\pm(E, Q^2|\ Q_1^2, Q_2^2)) = \frac{1}{2}\left(1 + \frac{q_+ q_-}{Q^2} \pm \sqrt{\left(1 - \frac{Q^2}{E^2}\right)\left(1 - \frac{q_+^2}{Q^2}\right)\left(1 - \frac{q_-^2}{Q^2}\right)}\right)$$

$$q_\pm = \sqrt{Q_1^2} \pm \sqrt{Q_2^2}.$$

- Angular ordering $\theta_4 < \theta_3$ but $\theta_2 \not< \theta_1$

Mass-ordered QCD cascade

- Simplified restrictions on $z = E_1/E$ from kinematics used in computing the Sudakov formfactor

$$z_-(E, Q^2|\ Q_h^2) < z < z_+(E, Q^2|\ Q_h^2)$$

$$z_\pm(E, Q^2|\ Q_h^2) \equiv \tilde{z}_\pm\left(E, Q^2|\ \frac{Q_h^2}{4}, \frac{Q_h^2}{4}\right) = \frac{1}{2}\left(1 \pm \sqrt{\left(1 - \frac{Q^2}{E^2}\right)\left(1 - \frac{Q_h^2}{Q^2}\right)}\right)$$

- The main quantity determining the structure of the cascade is the Sudakov formfactor

$$S\left(Q^2, E|Q_{\rm par}^2; Q_h^2\right) = \exp\left[-\int_{Q^2}^{Q_{\rm par}^2} \frac{dt^2}{t^2} \int_{z_-(E,\ t^2|\ Q_h^2)}^{z_+(E,\ t^2|\ Q_h^2)} dz \right.$$

$$\left. \times \frac{\alpha_s[z(1-z)t^2]}{2\pi} N_c \left(\frac{1}{z(1-z)} - 2 + z(1-z)\right)\right]$$

- $S\left(Q^2, E|Q_{\rm par}^2; Q_h^2\right)$ is the probability of having no decays in between the parent scale $Q_{\rm par}^2$ and a candidate scale Q^2 .

Numerical procedure

- One draws the scale Q^2 at which the gluon under consideration branches into two new gluons. Let us note that at this step one fixes the lifetime of the gluon $\tau = E(1/Q^2 - 1/Q^2_{\rm par})$.
- One draws the value of the splitting variable z determining the energies of the offspring gluons $E_1 = zE$ and $z_2 = (1-z)E$.
- With the energies of the offspring gluons fixed, one draws their final invariant masses $Q^2_{1,2}$ and, therefore, fix their lifetimes

$$\tau_{1,2} = E_{(1,2)} \left(1/Q^2_{(1,2)} - 1/Q^2 \right)$$

- The values of $Q^2_{1,2}$ are accepted if they do not violate the condition

$$\tilde{z}_-(E, Q^2 |\; Q_1^2, Q_2^2) < z < \tilde{z}_+(E, Q^2 |\; Q_1^2, Q_2^2)$$

- If necessary, one ensures angular ordering by drawing the splitting variables for the decays of the offspring gluons $z_{1,2}$ and accepting them if

$$z_{1,2}(1 - z_{1,2}) > \frac{1-z}{z} \left(\frac{Q^2_{1,2}}{Q^2} \right)$$

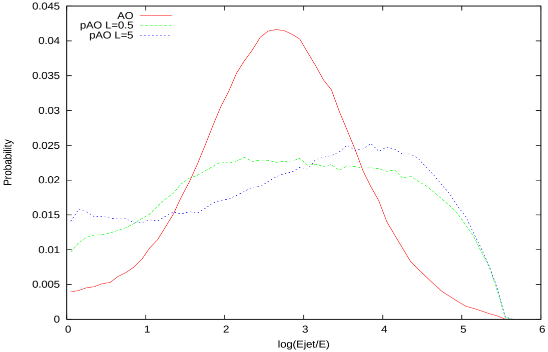
Decoherence

- Angular ordering follows from quantum coherence based on covariant conservation of color
- In the hot zone the cascade develops in random color field, so that the color is no longer conserved and coherence and, consequently, angular ordering is expected to be broken
- In QGP the time scale for color rotation t_c is much faster than that of the momentum change t_p

$$\begin{aligned} t_p &\approx \left[4\alpha_s^2 T \ln(1/\alpha_s)\right]^{-1} \\ t_c &\approx \left[3\alpha_s T \ln(m_E/m_M)\right]^{-1}, \end{aligned}$$

A.V. Selikhov, M. Gyulassy, *Phys. Rev.* **C49** (1994), 1726

Rapidity distribution $P(y)$ of final prehadrons



- $L = 0$ fm, full angular ordering, red, solid
- $L = 0.5$ fm, partial angular ordering, green, dashed
- $L = 5$ fm, partial angular ordering, blue, dotted.

$\Rightarrow$ Substantial softening of rapidity distribution already at times $\lesssim 1$ fm

- Decoherence due to random impact from the medium

$$\Downarrow$$

- Disruption of the angular ordering in the cascade

$$\Downarrow$$

- Dramatic softening of rapidity distributions

COLLISIONAL LOSSES

- Probability distribution for collisional energy losses ΔE_c of intercascade gluons per unit length (1 fm):

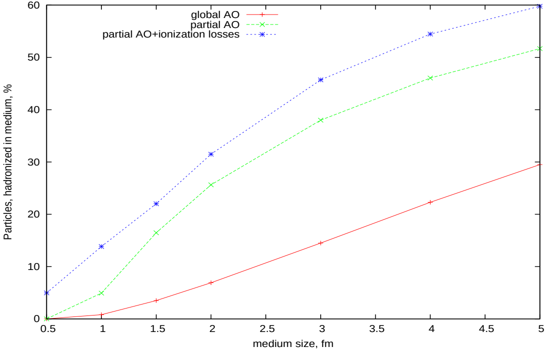
$$\mathcal{P}(\Delta E_c |\, \mu_c, \sigma_c) = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{\mu_c}{\sigma_c\sqrt{2}}\right)\right]\delta(\Delta E_c) + \frac{1}{\sqrt{2\pi\sigma_c^2}}\exp\left\{-\frac{(\Delta E_c - \mu_c)^2}{2\sigma_c^2}\right\}\Theta(\Delta E_c)$$

  In our computations we used $\mu_c = \sigma_c = 1\ \mathrm{GeV}$.

- Energy losses of final prehadrons $\Delta E_c = 1\ \mathrm{GeV/fm}$.

- Particle considered stopped if its energy reaches a critical value of $E_{\mathrm{crit}} = Q_h/2$.

Relative yield of prehadrons formed inside the medium



- Global angular ordering, red, solid
- Partial angular ordering, green, dashed
- Partial angular ordering and collisional losses, blue, dotted.

$\Rightarrow$ Prehadron formation inside the fireball enhanced

- All existing models assume hadronization taking place in the vacuum

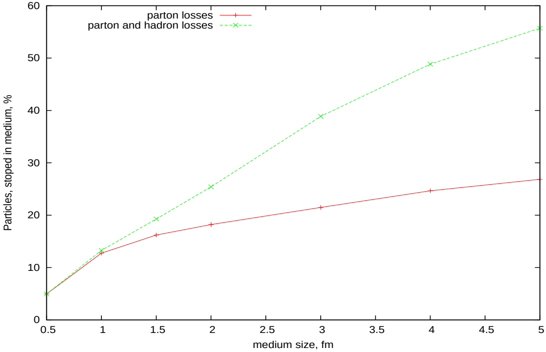
$$\Downarrow$$

- We see, that a significant yield of prehadrons is formed inside the hot zone

$$\Downarrow$$

- Clear necessity to modify description of hadronization of QCD jets in the medium

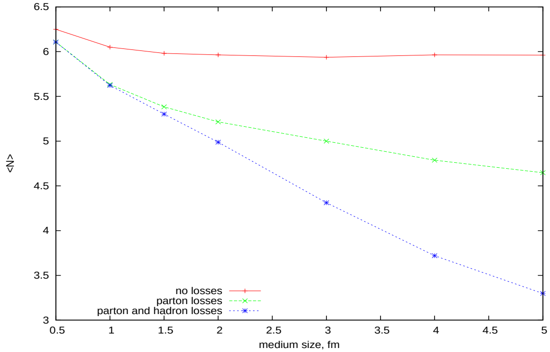
Relative yield of particles stopped inside the medium



- Parton losses, red, solid
- Parton and hadron losses, green, dashed

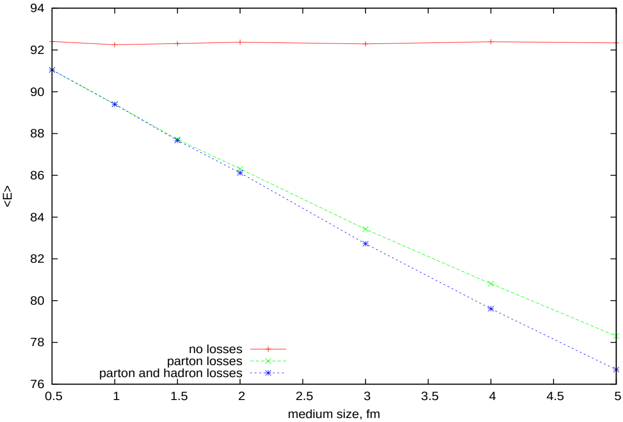
⇒ The effect is especially important for final prehadrons formed inside the fireball

Mean jet multiplicity as a function of medium size



- No losses, red, solid
- Intracascade parton losses, green, dashed
- Intracascade and final state losses, blue, dotted.

Mean jet energy as a function of medium size

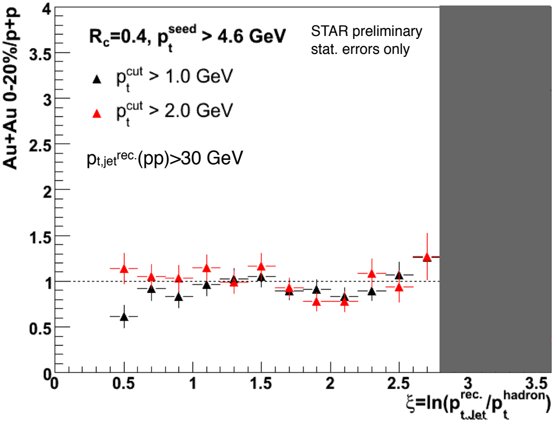


- No losses, red, solid
- Intracascade parton losses, green, dashed
- Intracascade and final state losses, blue, dotted.

EXPERIMENTAL RESULTS ON JET STRUCTURE AT RHIC

J. Putschke, EPJ **C61** (2009), 629
E. Bruna, NP **A830** (2009), 267C

Ratio of fragmentation functions in AA and pp collisions



Current conclusions on the experimental situation:

- Observed fragmentation functions in AA collisions are the same as in pp ones.
- Natural explanation: jet finding procedures bias the ensemble in such a way that only jets coming from the surface of the hot fireball are detected.
- Prospects of improving the situation unclear.

Conclusions

- Effects of medium-induced disruption of angular ordering of the mass-ordered gluon cascade and non-radiative energy loss inside the hot fireball studied within the Monte Carlo model
- Substantial softening of the intrajet rapidity spectrum
- Substantial increase of the yield of prehadrons formed inside the hot fireball