Heavy quark energy loss-Applications to RHIC

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The Ter-Mikayelian effect on QCD Radiative Energy Loss
Phys.Rev.C68:034914,2003
HEAVY QUARK RADIATIVE ENERGY LOSS IN QCD MATTER.
nucl-th/0310076, Nucl.Phys.A in press

- **Motivation**
- **Radiative heavy quark energy loss**

  - Ter-Mikayelian effect (Djordjevic-Gyulassy)

  - Transition energy loss (Zakharov)

  - Medium induced radiative energy loss

(Dokshitzer-Kharzeev, Djordjevic-Gyulassy, Armesto-Salgado-Wiedemann)

- **How big is the heavy quark suppression at RHIC?**
- **Conclusion**

Motivation

One of the most important goals of high energy heavy ion physics is the formation and observation of a quark-gluon Plasma (QGP).

Is the QGP discovered at RHIC?

Collective flow and Jet Quenching of light partons strongly suggest yes, but further detailed tests of jet tomography using heavy quarks could be decisive as a complementary test of the theory.

Open charm suppression, which can now be measured at RHIC by comparing pt distributions of D-mesons in *D-Au* and *Au-Au* collisions, is a novel probe of QGP dynamics.

1997 Shuryak proposed that charm quarks may suffer a **large energy loss** when propagating through a high opacity plasma, which could lead to large suppression of D mesons.

2001 Dokshitzer and Kharzeev proposed that due to "dead cone" effect, the charm quark **energy loss** would be **small**.

*PHENIX single e data seem to see no charming nuclear effect !

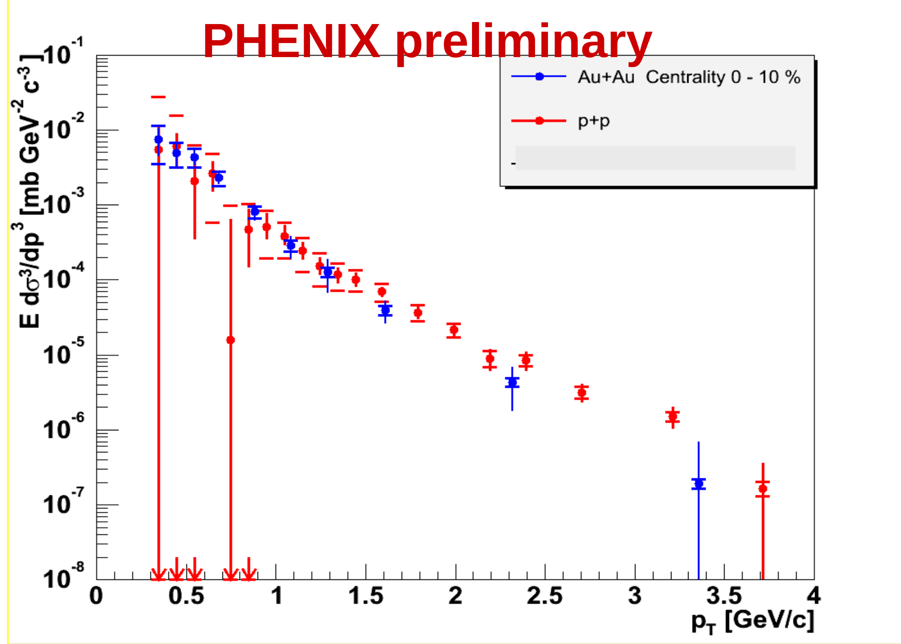
First Au+Au->e X data show no hint of Charm energy loss ! ??
PHENIX Collaboration (K. Adcox *et al.*) **Phys.Rev.Lett.88:192303,2002**

Moderate p_T charm is not suppressed according to PHENIX.

Takashi Hachiya - poster Q15.

But new STAR D data
may indicate large energy loss?

QM04 1/12/04



The motivation for our study of heavy quark energy loss in a dense QCD medium:

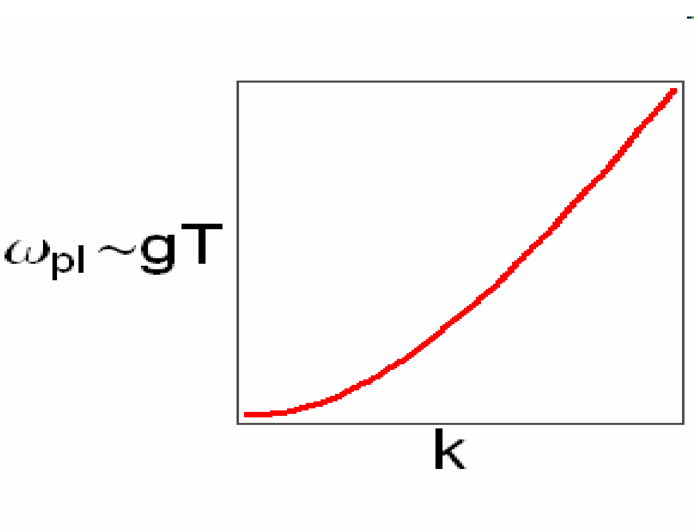
1. To compute quantitatively the magnitude of radiative energy loss by heavy quarks.

2. To present theoretical predictions that can be compared with upcoming experimental results in order to test the QGP theory.

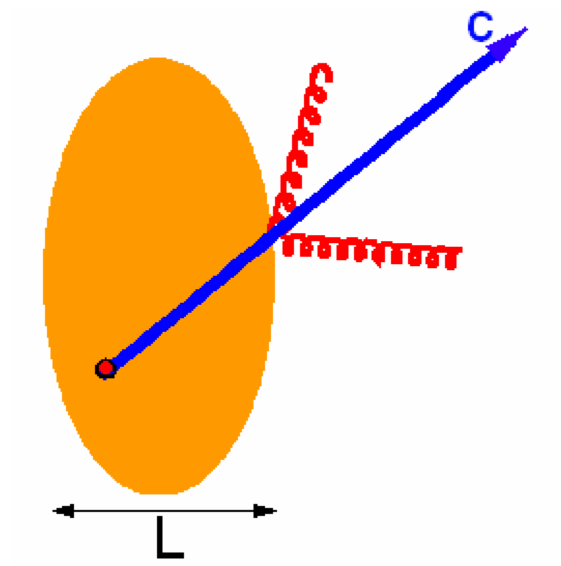
Radiative heavy quark energy loss

There are three important medium effects that control the radiative energy loss at RHIC

1) **Ter-Mikayelian effect** **(Djordjevic-Gyulassy)**
2) **Transition rediation** **(Zakharov)**
3) **Energy loss due to the interaction with the medium** **(DG)**



1)



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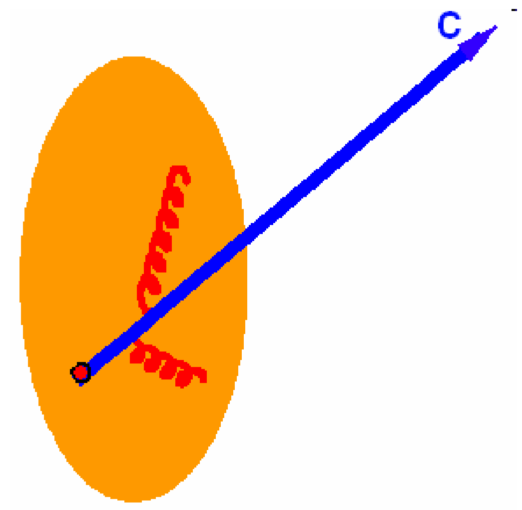


3)

Ter-Mikayelian effect

This is a non-abelian analog of the well known dielectric effect in electrodynamics.

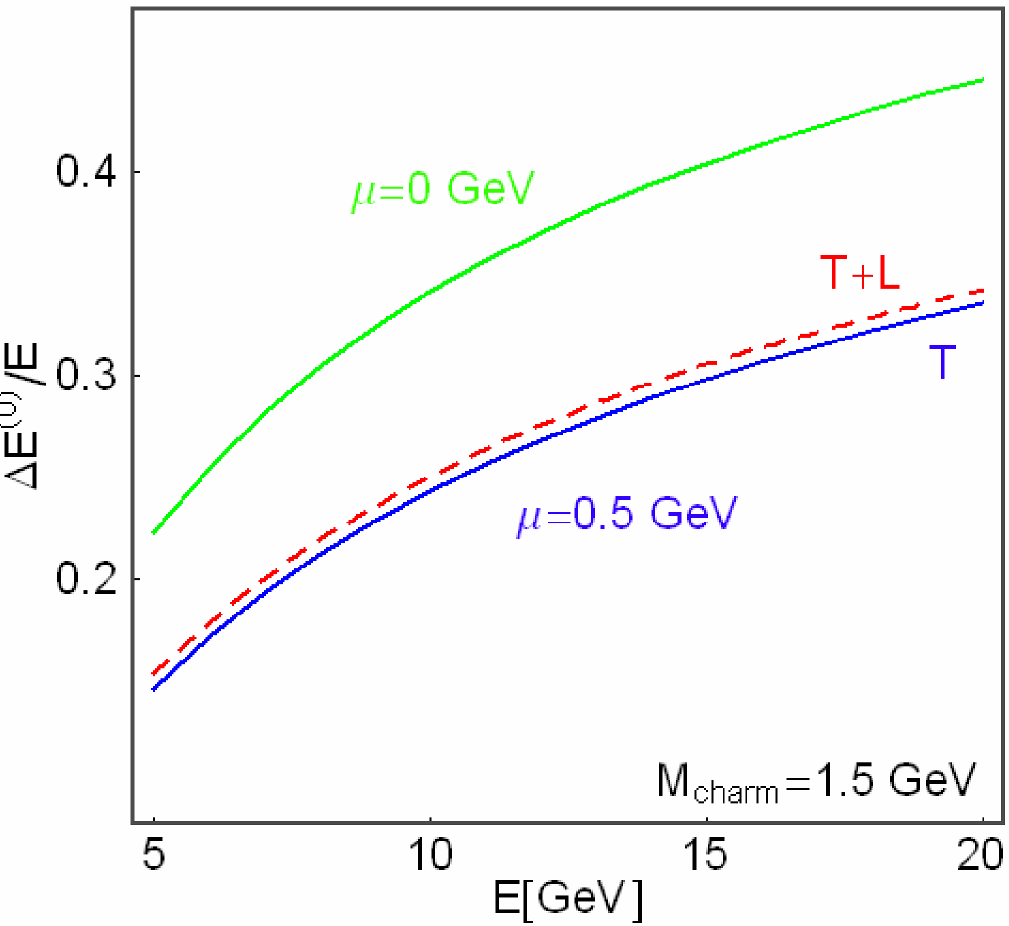
Effect is connected with the plasma modification of the gluon self energy.

In perturbative QCD vacuum gluons are massless and transversely polarized partons. However, in the medium gluon propagator has both transverse and longitudinal polarization parts.

We have computed both longitudinal and transverse contribution to the 0^{th} order in opacity, by taking into account the momentum dependence of gluon self energy (one-loop (HTL) polarization tensor) extending work of Kampfer-Pavlenko (2000).

The Ter-Mikayelian effect on QCD Radiative Energy Loss
M. Djordjevic, M. Gyulassy, **Phys.Rev.C68:034914,2003**

Comparison between medium and vacuum 0th order in opacity fractional energy loss is shown on Fig. 1:



- **Longitudinal contribution is negligible.**
- **The plasmon effect on transverse contribution is important, since for charm it leads to ~30% suppression of the vacuum radiation.**

The Ter-Mikayelian effect thus *enhances* the yield of high transverse charm quarks relative to the vacuum case.

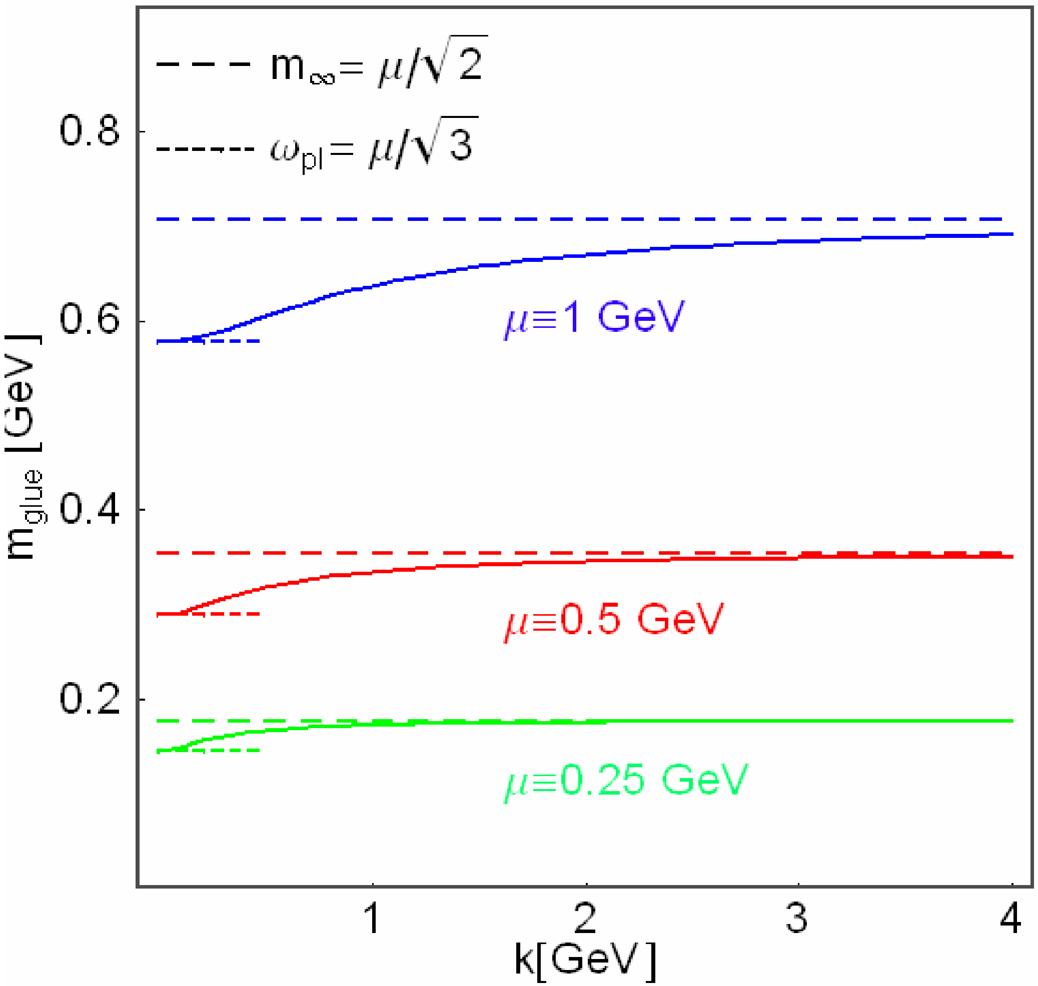


Fig.2 shows the one loop transverse plasmon mass ***$m_g(k) \equiv \sqrt{(\omega^2 - k^2)}$*****.**

We see that ***m_g*** **starts with the value** ***$\omega_{pl} = \mu/\sqrt{3}$*** **at low k, and that as k grows,** ***m_g*** **asymptotically approaches the value of** ***$m_\infty = \mu/\sqrt{2}$*****, in agreement with**

Rebhan A, Lect. Notes Phys. 583, 161 (2002).

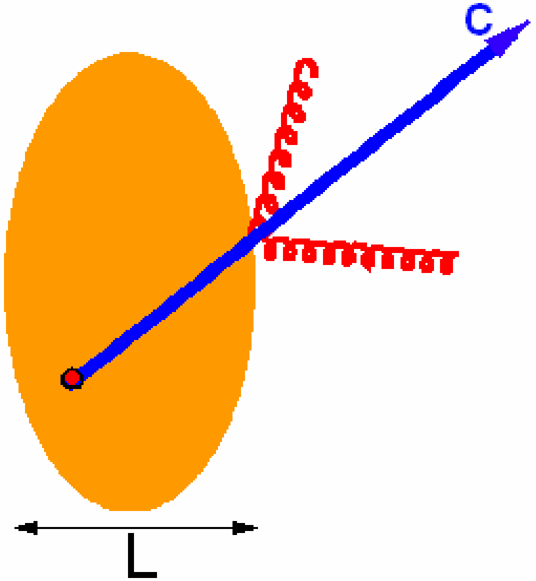
We can conclude that we can approximate the Ter-Mikayelian effect by simply taking ***$m_g \approx m_\infty$*****.**

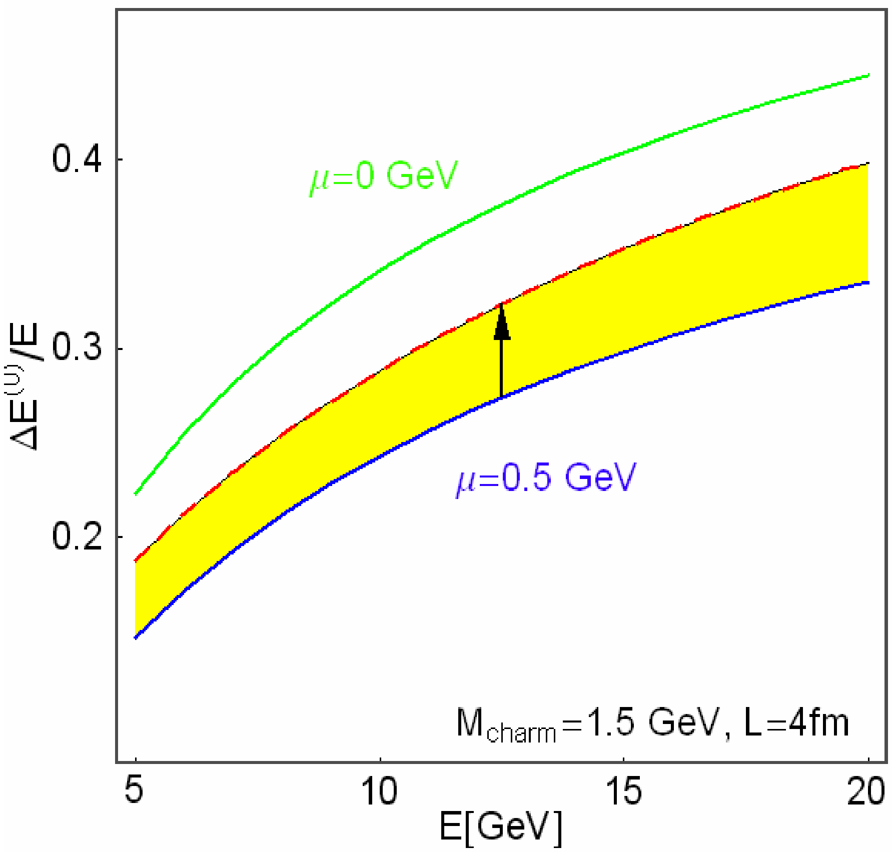
Transition radiation

However, we also need to take into account that medium has finite size.

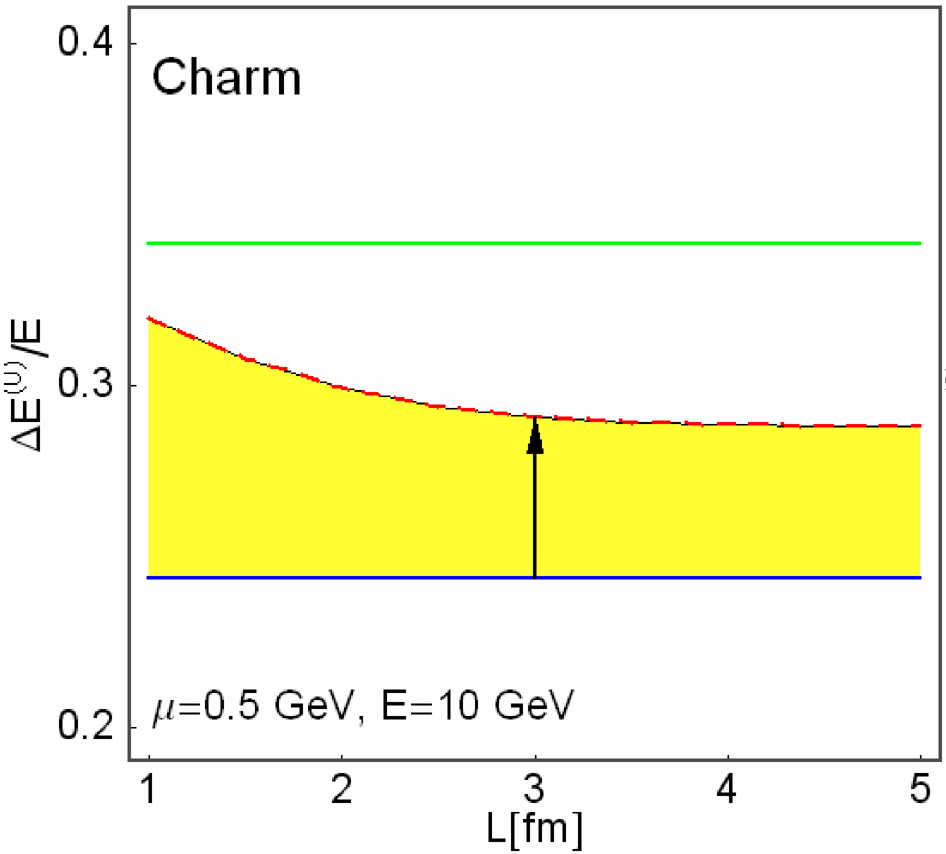
To correctly compute the 0th order energy loss in the medium we need to include additional radiation which occurs in the boundary between medium and vacuum. We call this energy loss transition radiation.

To estimate transition radiation we use the results from Zakharov (B.G. Zakharov, JETP Lett.76:201-205,2002).





For massive quarks and medium thickness greater than 3 fm transition radiation becomes independent on the thickness of the medium.

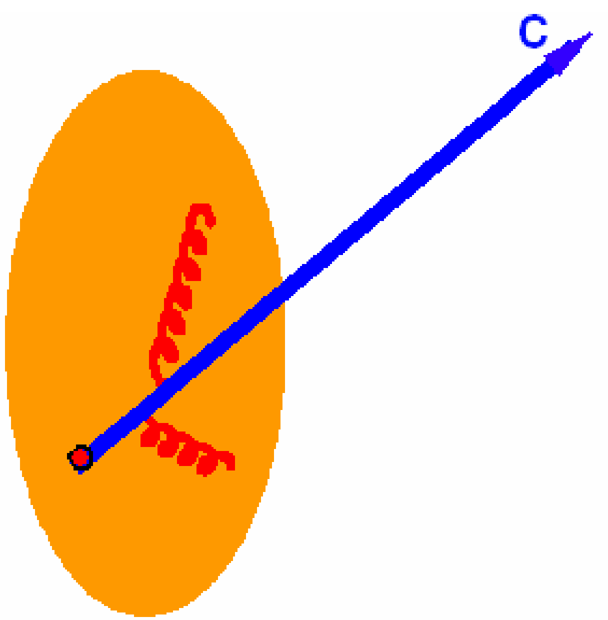


Transition radiation lowers Ter-Mikayelian effect from 30% to 15%.

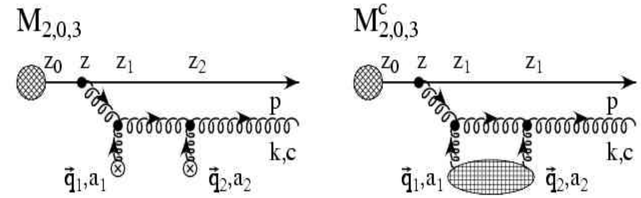
Energy loss due to the interaction with the medium

The third important effect on the energy loss is the induced gluon radiation caused by the multiple interactions of partons in the medium.

To compute medium induced radiative energy loss for heavy quarks we extend Gyulassy-Levai-Vitev (GLV) method, by introducing both quark M and plasmon mass $m_g = m_\infty$.



We have generalized GLV Opacity Induced Radiation (**GLV, Nucl.Phys.B594(01)**) to finite M (**DG, nucl-th/0310076, in Nucl.Phys.A press**)



+ …

$$x\frac{dN^{(n)}}{dx\,d^2\mathbf{k}} = \frac{C_R\alpha_s}{\pi^2}\frac{1}{n!}\int\prod_{i=1}^{n}\left(d^2\mathbf{q}_i\,\frac{L}{\lambda_g(i)}\left[\bar{v}_i^2(\mathbf{q}_i)-\delta^2(\mathbf{q}_i)\right]\right)\times$$

$$\times\left(-2\,\tilde{\mathbf{C}}_{(1,\cdots,n)}\cdot\sum_{m=1}^{n}\tilde{\mathbf{B}}_{(m+1,\cdots,n)(m,\cdots,n)}\left[\cos\left(\sum_{k=2}^{m}\Omega_{(k,\cdots,n)}\Delta z_k\right)-\cos\left(\sum_{k=1}^{m}\Omega_{(k,\cdots,n)}\Delta z_k\right)\right]\right)$$

Hard, Gunion-Bertsch, and Cascade ampl. in GLV generalized to finite M

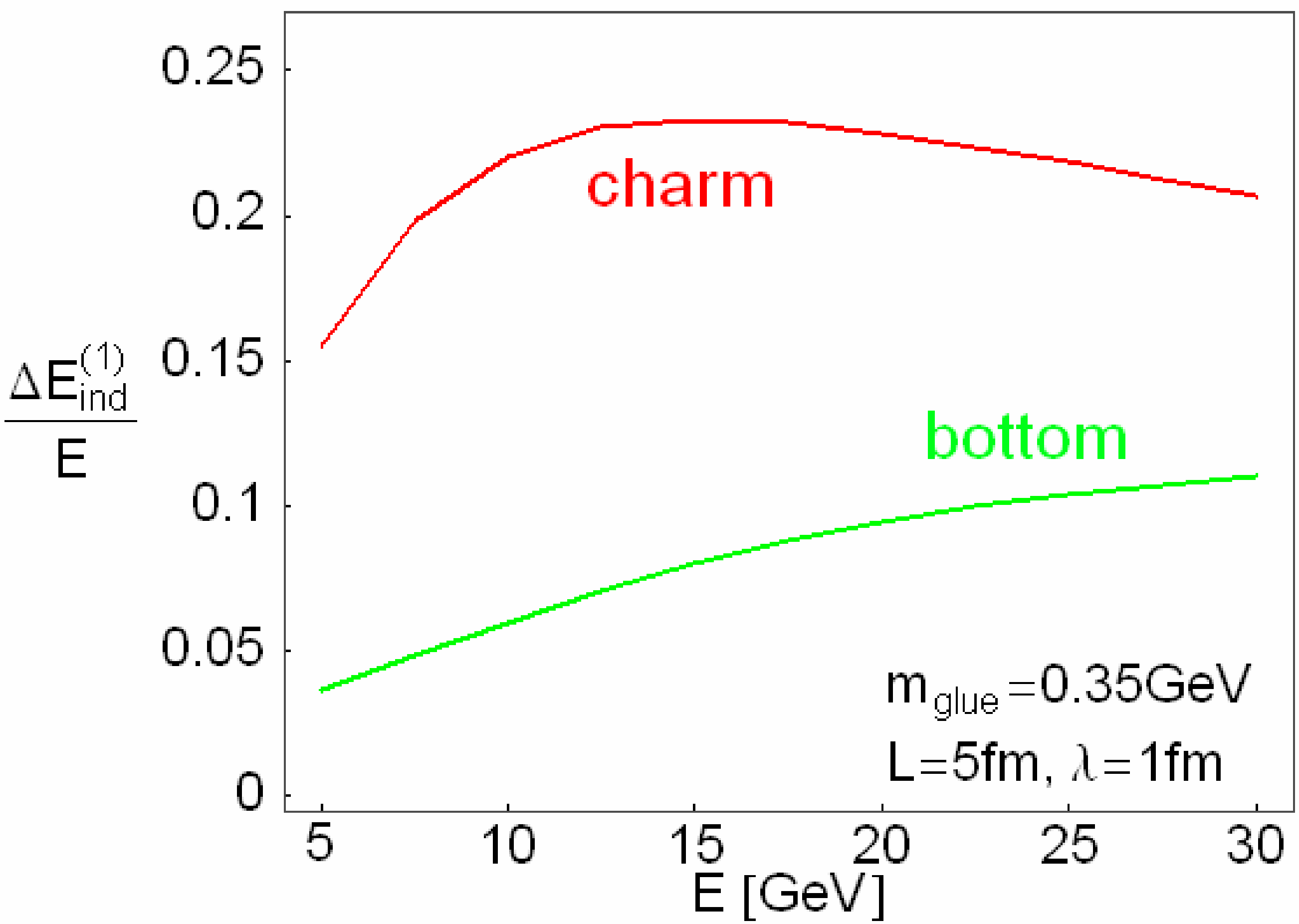
$$\tilde{\mathbf{H}} = \frac{\mathbf{k}}{\mathbf{k}^2+m_g^2+M^2x^2}\,,\qquad \tilde{\mathbf{C}}_{(i_1i_2\cdots i_m)} = \frac{(\mathbf{k}-\mathbf{q}_{i_1}-\mathbf{q}_{i_2}-\cdots-\mathbf{q}_{i_m})}{(\mathbf{k}-\mathbf{q}_{i_1}-\mathbf{q}_{i_2}-\cdots-\mathbf{q}_{i_m})^2+m_g^2+M^2x^2}$$

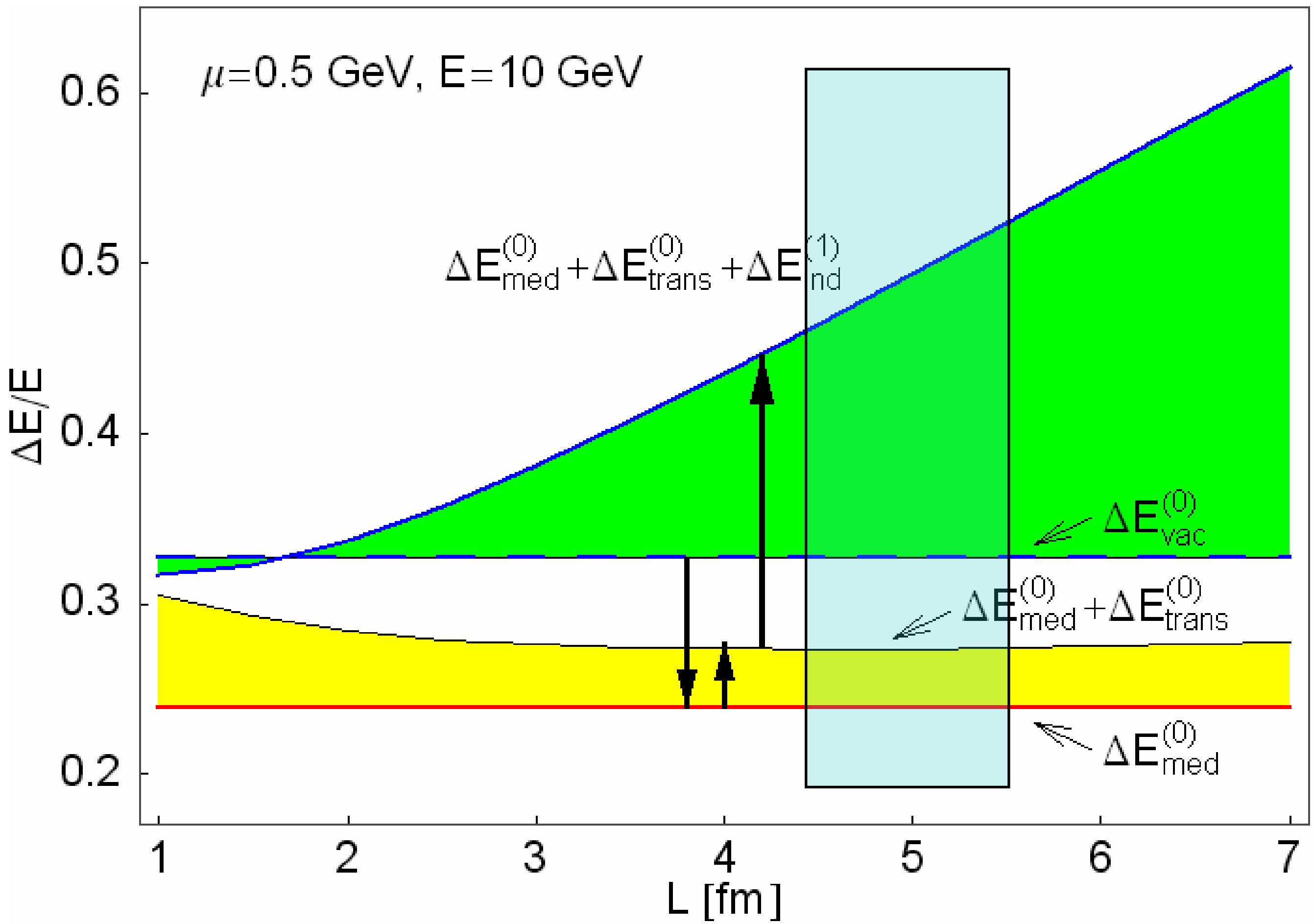
$$\tilde{\mathbf{B}}_i = \tilde{\mathbf{H}}-\tilde{\mathbf{C}}_i\,,\qquad \tilde{\mathbf{B}}_{(i_1i_2\cdots i_m)(j_1j_2\cdots i_n)} = \tilde{\mathbf{C}}_{(i_1i_2\cdots j_m)}-\tilde{\mathbf{C}}_{(j_1j_2\cdots j_n)}\,.$$

$$\omega_{(m,\cdots,n)} = \frac{(\mathbf{k}-\mathbf{q}_m-\cdots-\mathbf{q}_n)^2}{2xE}\rightarrow\Omega_{(m,\cdots,n)}\equiv\omega_{(m,\cdots,n)}+\frac{m_g^2+M^2x^2}{2xE}$$

The numerical results for induced radiative energy loss are shown for first order in opacity.

When we include all energy loss effects, we get that effective plasma opacity should be approximately 5 fm.



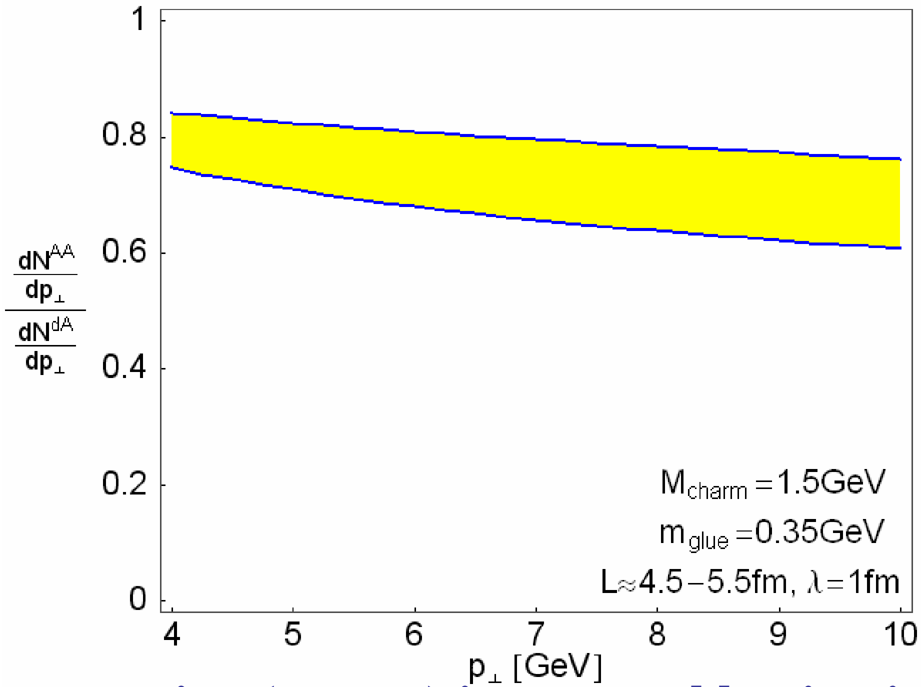


We see that in the region 4.5-5.5 fm additional energy loss is approximately 15%.

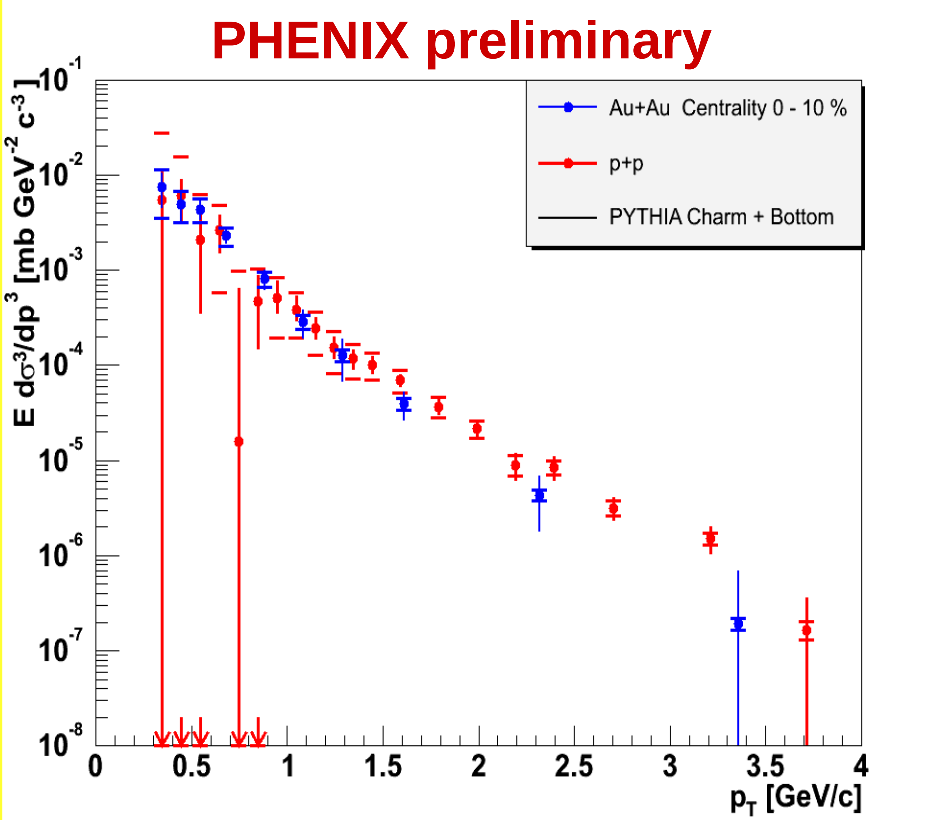
We now want to estimate the value of suppression that comes from this energy loss.

To estimate suppression we have used the method described in GLV, Phys.Lett.B538:282-288,2002.

We assume that initial charm p_t distribution is in the region $\frac{C_1}{p^4} < \frac{dN}{dp} < \frac{C_2}{p^8}$, where C_1 and C_2 are constants, and that medium opacity is in the region 4.5-5.5 fm.



Small value of suppression (0.6-0.8) is expected having in mind low value of additional energy loss (15%).



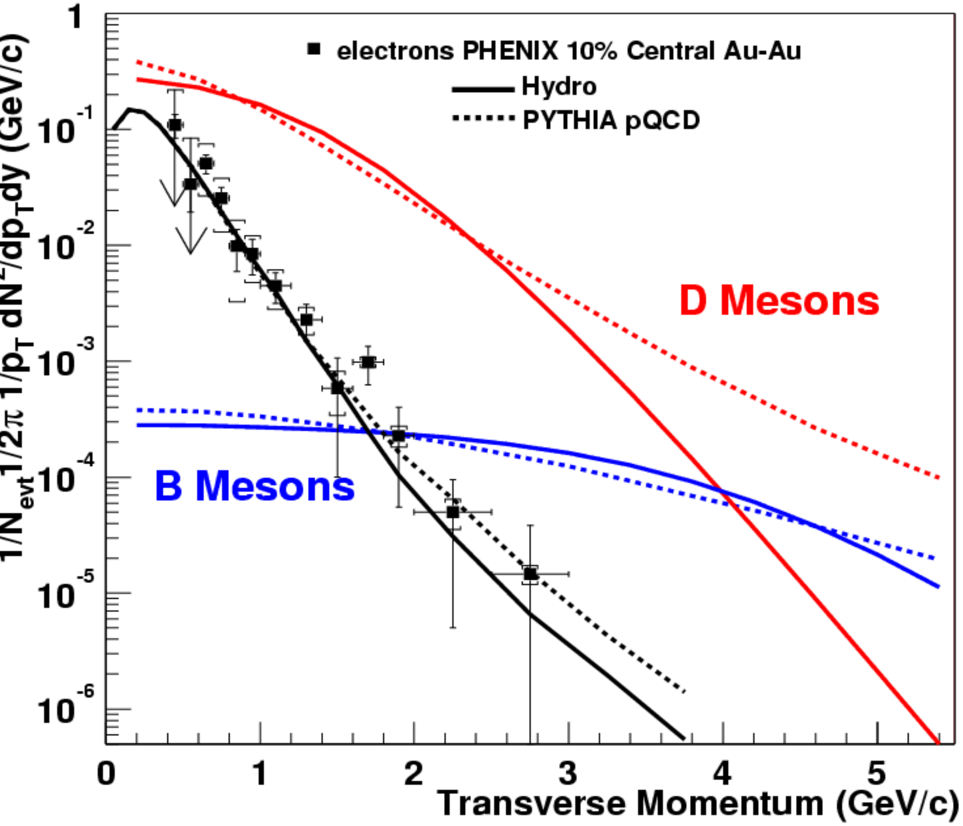
This suppression is consistent with PHENIX data.

But possibly inconsistent with STAR?

Caveats:

1) **Error bars are too large in the region 3-4GeV. Therefore, even much larger suppression would nicely fit the data.**

2) **Pt distribution of single electrons is not very sensitive to energy loss. We see that significantly different pt distributions of D mesons from PYTHIA and Hydro produce similar pt distributions of single electrons.**



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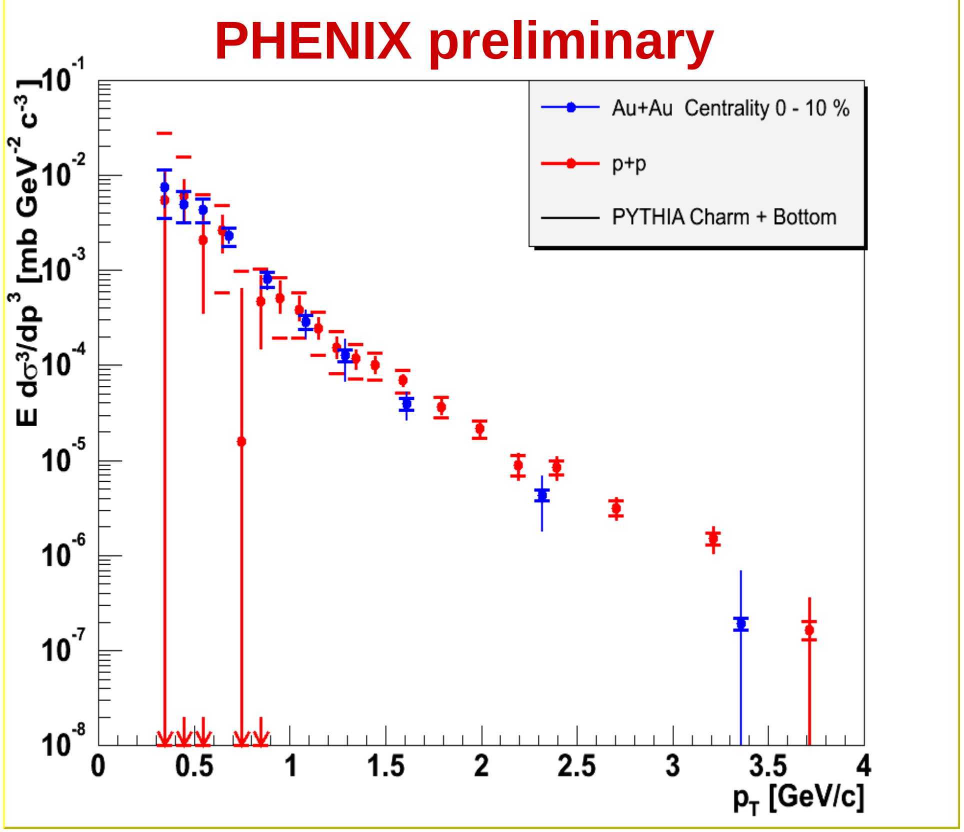

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Conclusions

The upcoming D meson data for 200 GeV *D-Au* and *Au-Au* results will soon become available. According to our results, charm quark suppression should be small ~ 0.6-0.8. Therefore, this suppression should be definitely much smaller than the already observed pion suppression (0.2).

If this result is confirmed, then Jet Tomography of QGP will pass another stringent test. On the other hand, if the prediction is falsified, then either the tomographic or the QGP paradigm will have to be revised or abandoned.