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Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

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Testing Radiative Energy Loss at RHIC and the LHC

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Testing radiative energy loss at RHIC and the LHC

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See the talks by F. Arleo, N. Bianchi, D. d’Enterria, B. Z. Kopeliovich, H. J. Pirner, J. W. Qiu, C. A. Salgado and U. A. Wiedemann

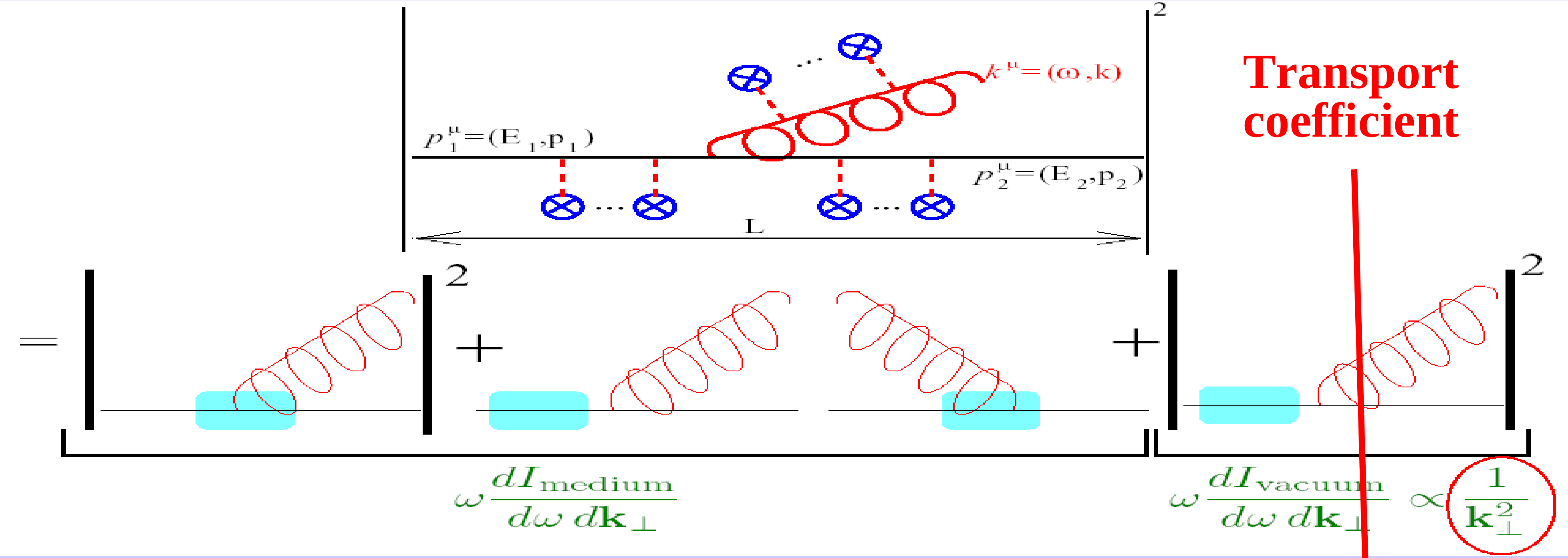
Contents

*With Andrea Dainese (Padova),
Carlos A. Salgado and Urs A. Wiedemann (CERN),
Phys. Rev. D71 (2005) 054027 (hep-ph/0501225).*

*With the former plus Matteo Cacciari
(Paris VI), hep-ph/0511257
(Phys. Lett. B in press).*

1. Motivation (I):

(Baier et al '00; Kovner et al '03; Gyulassy et al '03)



Transport coefficient

The BDMPS(-GLV-ZW-WZ) formalism describes this in pQCD: interference of production and re-scatterings of the radiated gluon leading to

$$\Delta E \simeq \int d\omega\, \omega \frac{dI}{d\omega} \propto \alpha_s C_R \omega_c = \alpha_s C_R \hat{q} L^2/2 \qquad n(z)\sigma(r) \propto \hat{q}(z) r^2$$

→ Interference and mass effects: $\exp\left(-\Delta z \frac{k_\perp^2 + x^2 m^2}{2\omega}\right), \quad x = \frac{\omega}{E} \ll 1$

1. Motivation (II):

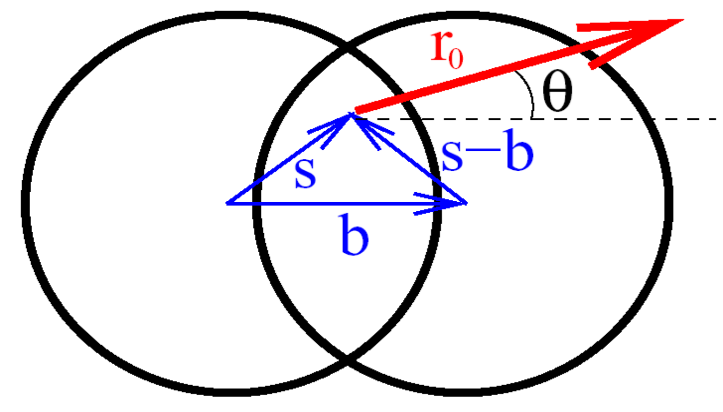
It has become the 'canonical' explanation for the suppression of leading particle spectra at large p_T and y=0:

$$R_{AB}(p_T)=\frac{\left.\frac{\mathrm{d}N^{AB\to h}_{\rm medium}}{\mathrm{d}p_T\,\mathrm{d}y}\right|_{y=0}}{\langle N^{AB}_{\rm coll}\rangle\left.\frac{\mathrm{d}N^{pp\to h}_{\rm vacuum}}{\mathrm{d}p_T\,\mathrm{d}y}\right|_{y=0}}$$

→ Magnitude of the suppression: $n(z)\sigma(r)$.

→ Dependence of the suppression with centrality and azimuth: L^2.

→ Disappearance of back-to-back correlations: NP $\sigma(r)$, tangential emission?



To further test it and constrain parameters:

→ High p_T particle correlations, jet shapes and multiplicities.

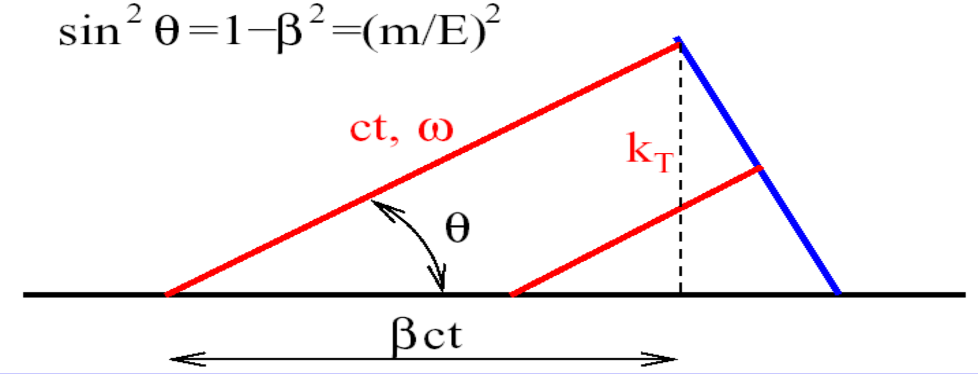
Genuine prediction of this approach:

ΔE (g) > ΔE (q) > ΔE (Q)

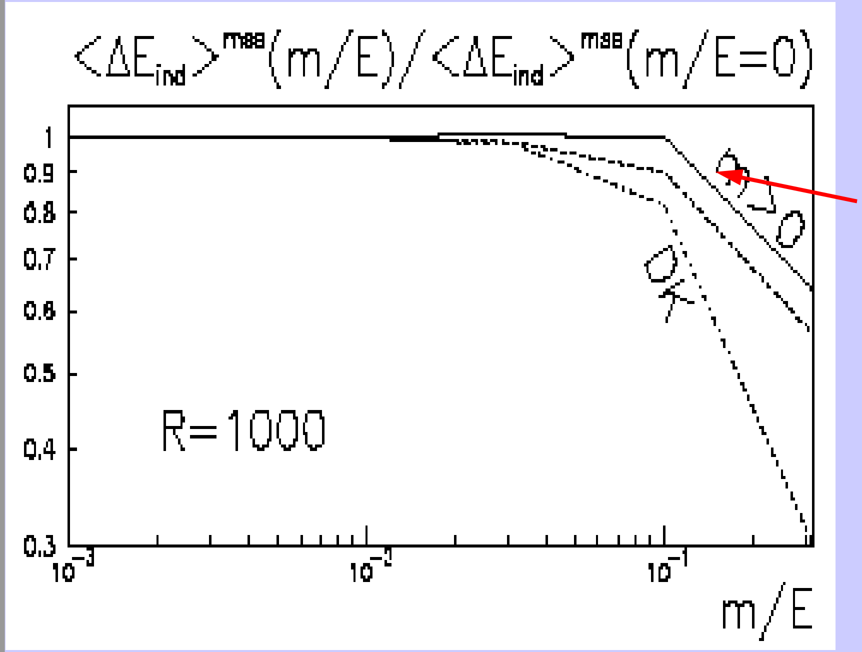
color charge **mass effect**

1. Motivation (III):

- Massive partons radiate less in the vacuum: **dead cone effect,** postulated for the medium *(Dokshitzer-Kharzeev '01).*
- Technically: rescattering+dead cone *(Djordjevic et al '03; Zhang et al '03; Armesto et al '03).*



- **Heavy-to-light ratios $R_{D,B/h}=R_{AA}^{D,B}/R_{AA}^{h}$: sensitive to** *(Armesto et al '05)*



→ **Color-charge dependence** (g to light hadrons important, increases $R_{D,B/h}$).

→ **Mass dependence** (Q radiate less, increases $R_{D,B/h}$).

→ Detailed behavior of the partonic p_T spectrum (softer for Q, increases $R_{D,B/h}$) and fragmentation functions (harder for Q, decreases $R_{D,B/h}$).

2. Model (I):

Standard LO pQCD (PYTHIA):

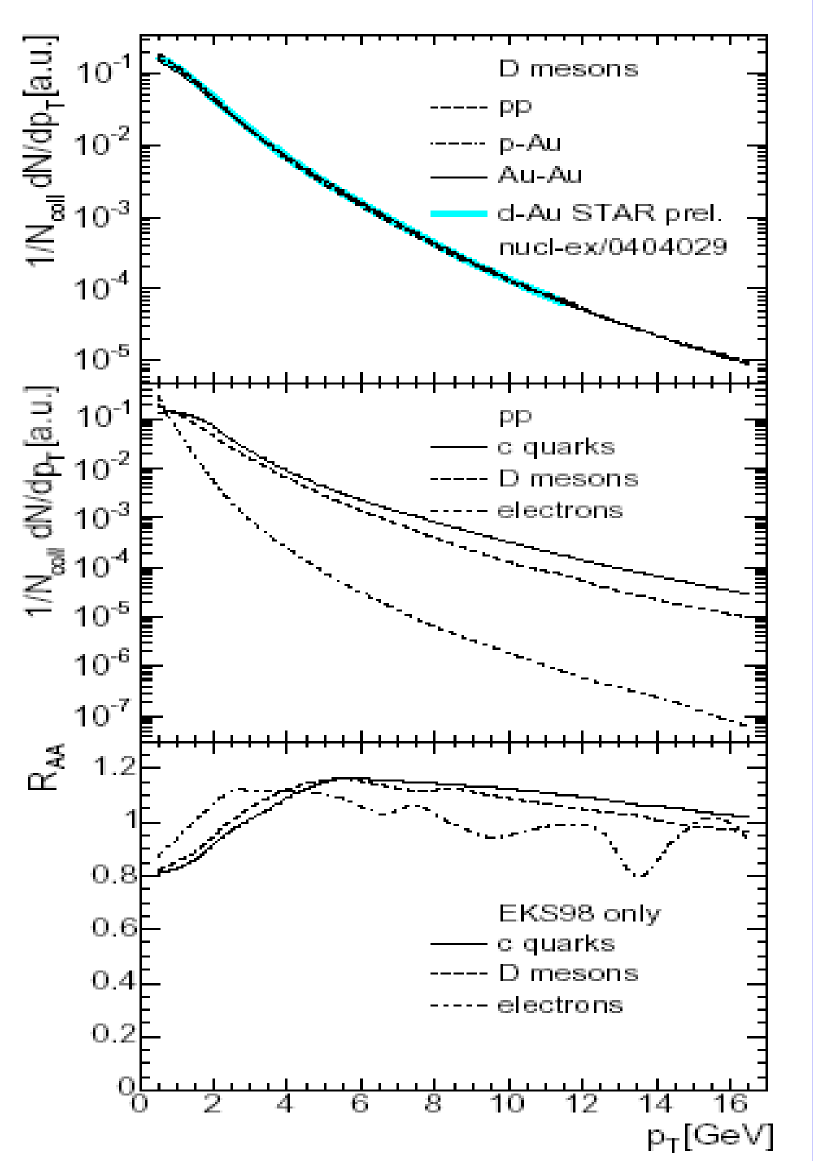
$$\left.\frac{\mathrm{d}N^{AB\to h}_{\mathrm{medium}}}{\mathrm{d}p_T\,\mathrm{d}y}\right|_{y=0} = \sum_{i,j}\int \mathrm{d}x_i\,\mathrm{d}x_j\,\mathrm{d}(\Delta E/E)\,\mathrm{d}z_k\,f_{i/A}(x_i)\,f_{j/B}(x_j)$$

$$\times\left.\frac{\mathrm{d}\hat{N}^{ij\to k}(p_{T,k}+\Delta E)}{\mathrm{d}p_{T,k}\mathrm{d}y}\right|_{y=0}\boxed{P(\Delta E/E,R,\omega_c,m/E)}\,\frac{D_{k\to h}(z_k)}{z_k^2}$$

Quenching weights (www.pd.infn.it/~dainesea/qwmassive.html)**:** probability for medium energy loss, they contain a no-eloss contribution.

- CTEQ4L pdf's, EKS98.
- All channels into account.
- Ff into D (B) and semileptonic e-decays.
- RHIC: tune to STAR D-meson data.
- LHC: tune to NLO pQCD calculation.

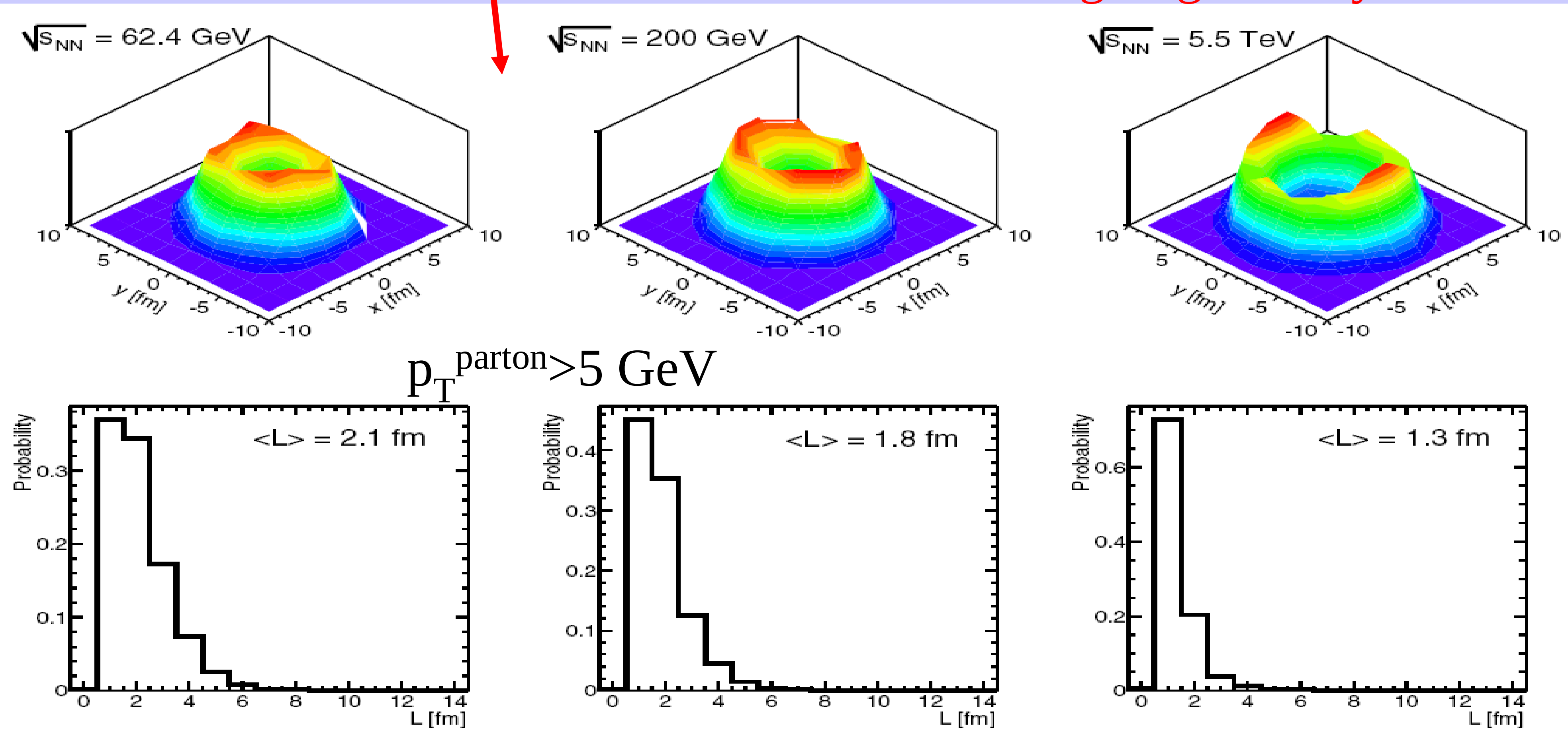
RHIC, no medium effects



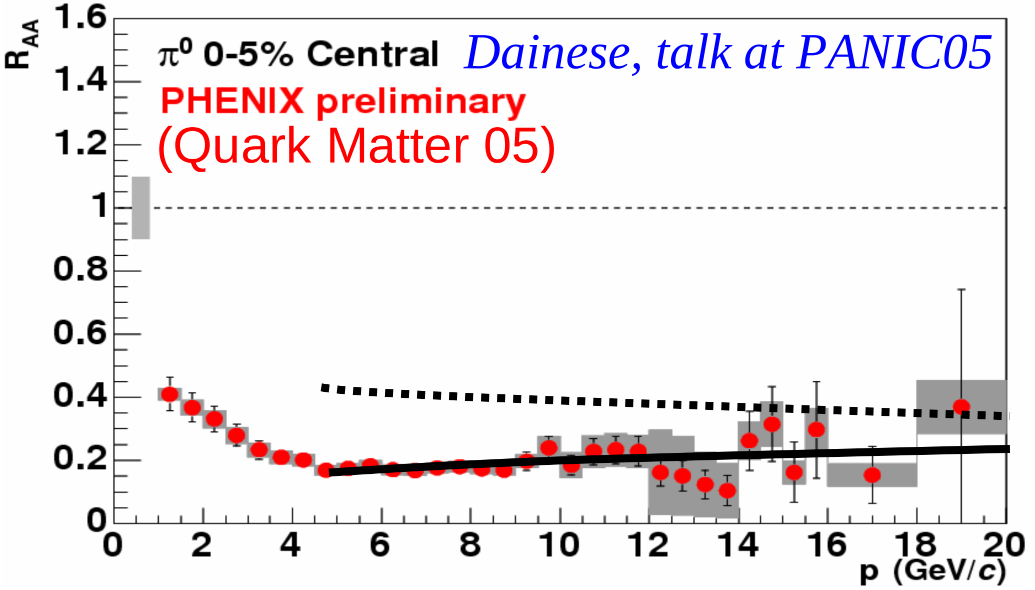
2. Model (II):

(Dainese et al '04, '05; Eskola et al '04)

Detailed modeling of geometry.

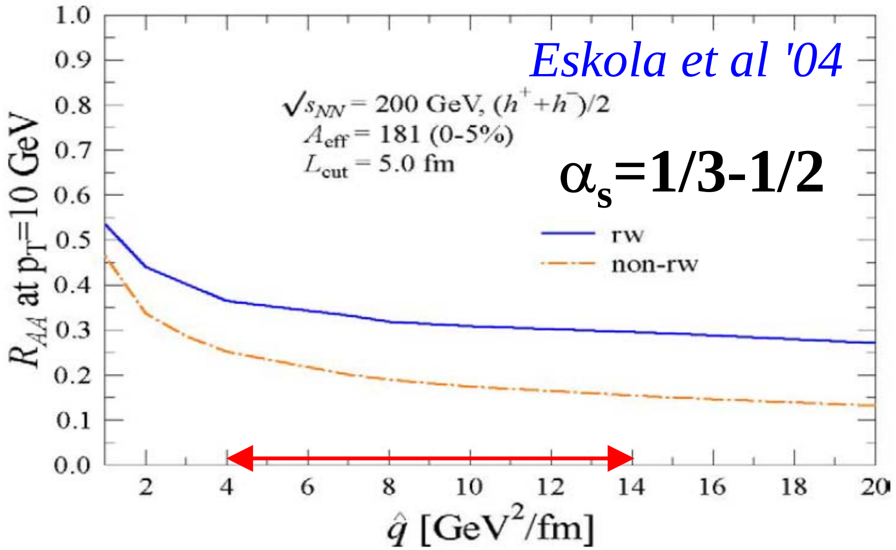


p_T^{parton}>5 GeV

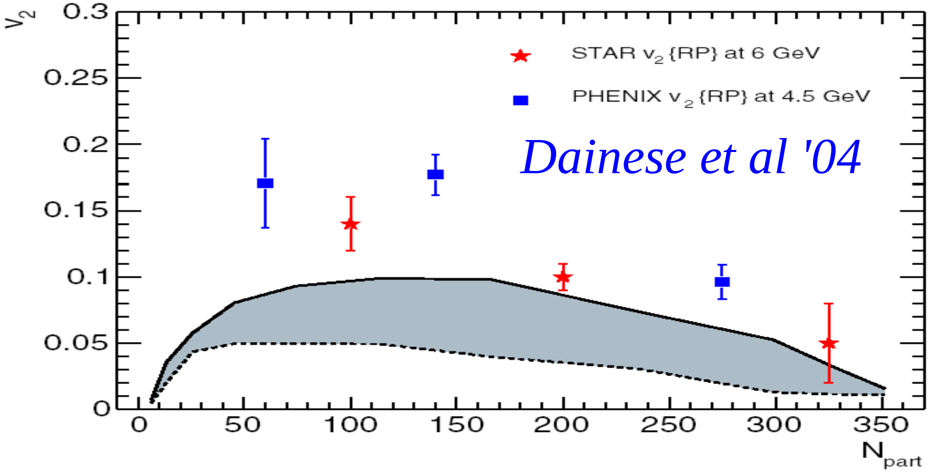

Dainese, talk at PANIC05

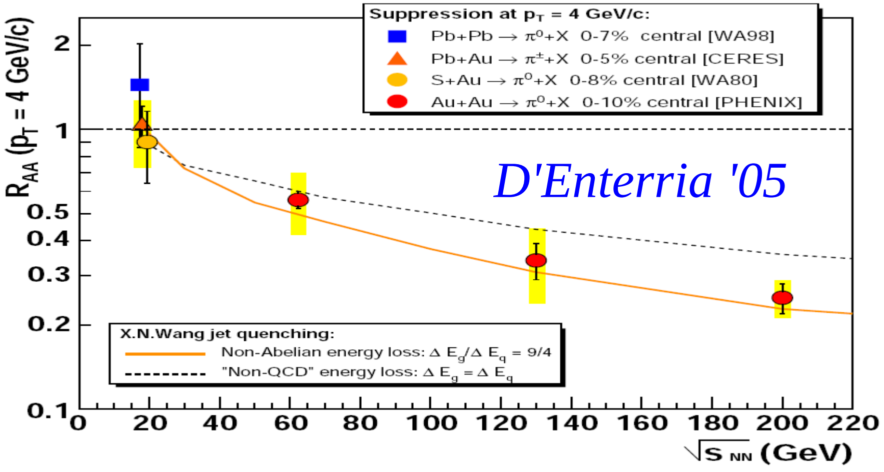
PHENIX preliminary

(Quark Matter 05)

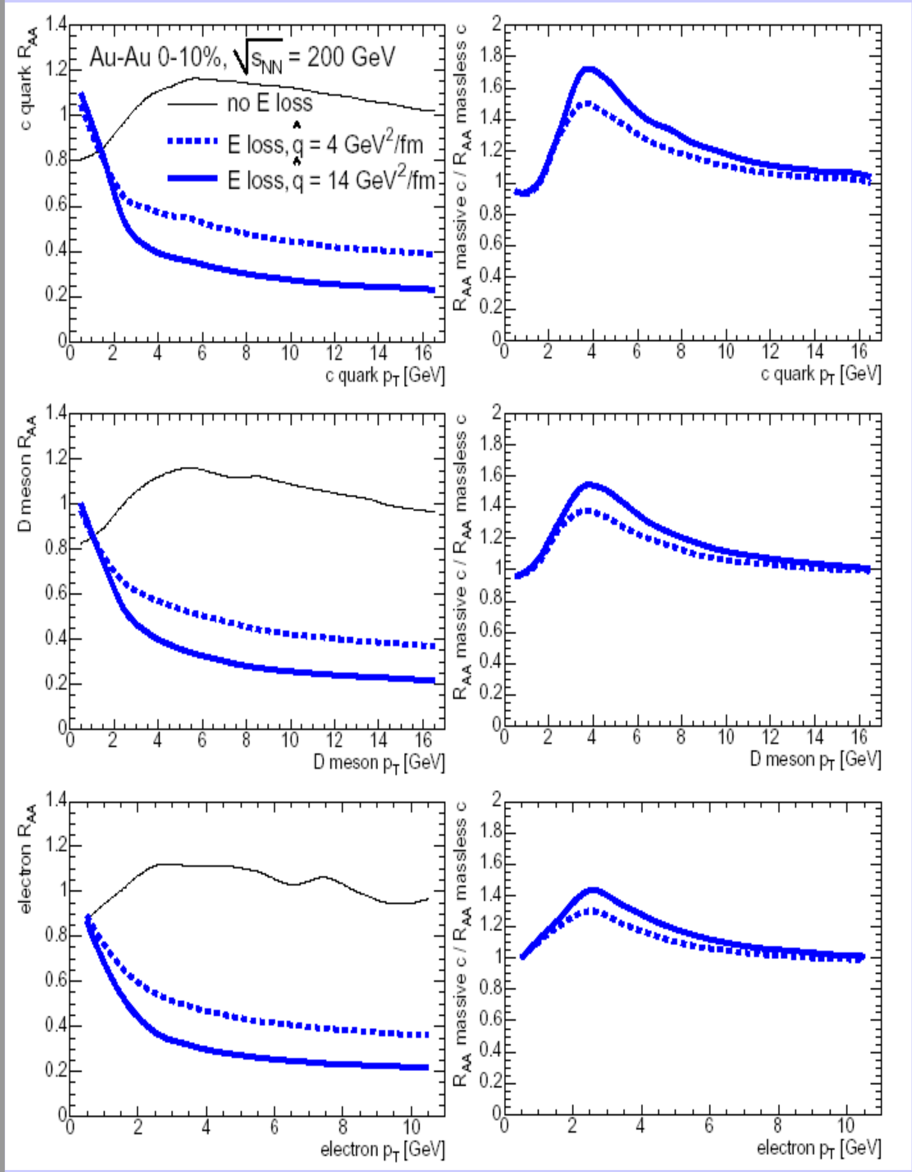

Eskola et al '04

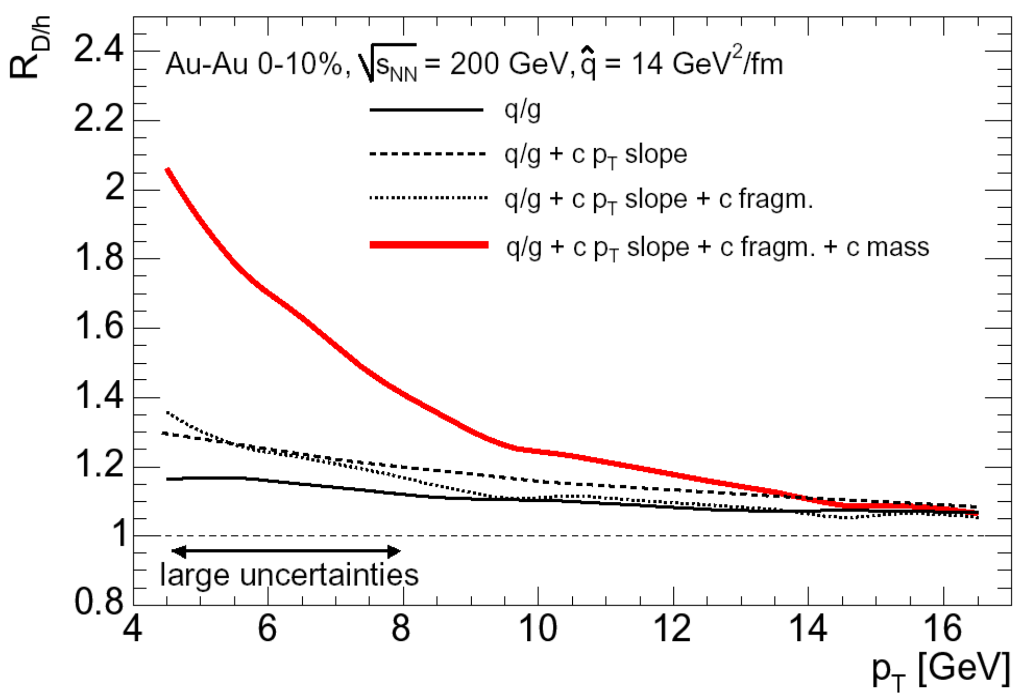
α_s=1/3-1/2


Dainese et al '04


D'Enterria '05

3. Results for RHIC:





$R_{D/h}=R_{AA}{}^{D}/R_{AA}{}^{h}$ *(Dokshitzer-Kharzeev '01).*

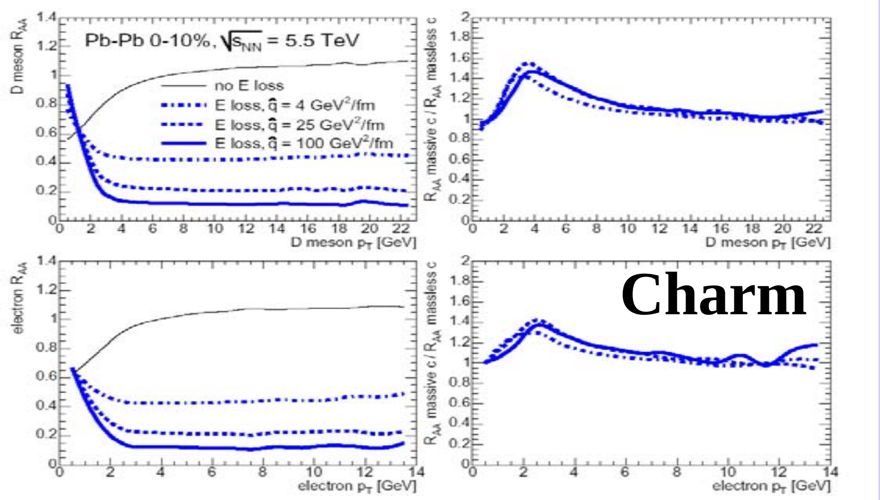
→ q/g difference affects all p_T.

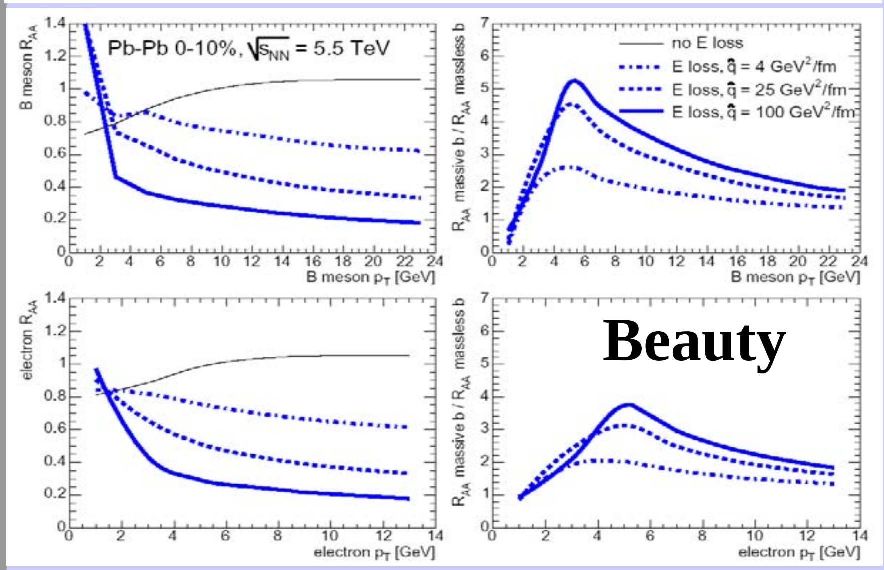
→ Mass effects sizeable for p_T<12 GeV.

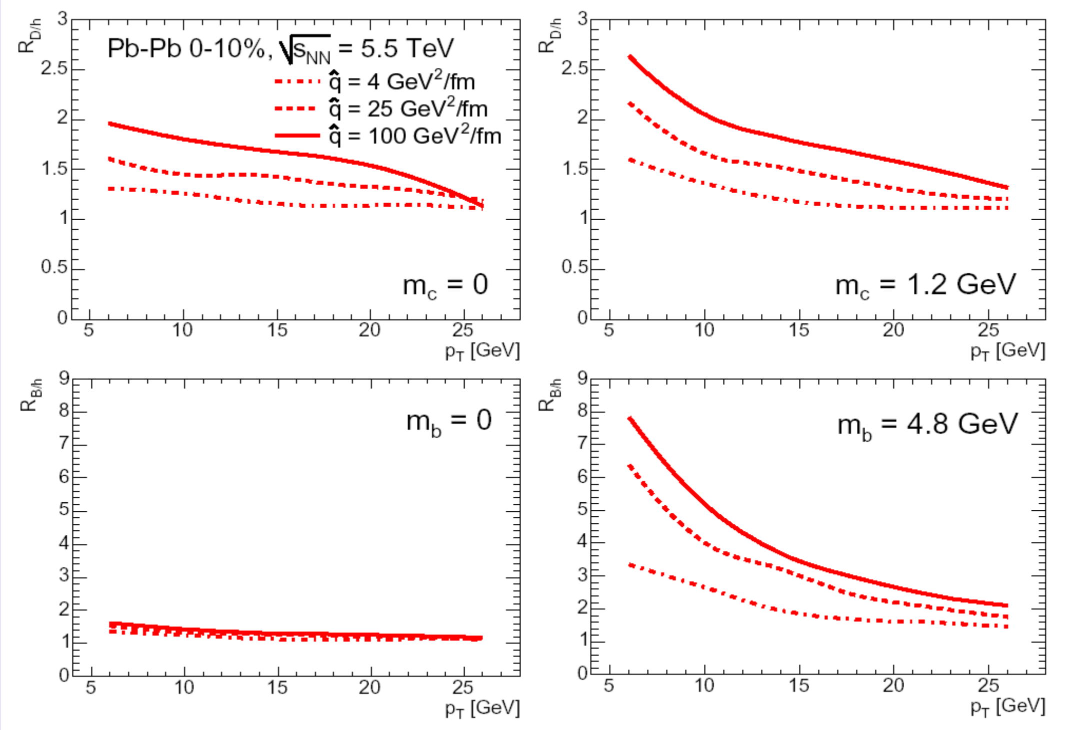
→ Look at 7< p_T<12 GeV.

4. Results for the LHC:

Transport coefficient (density) scaled by multiplicity: factor 2.5 to 7 larger at the LHC than at RHIC *(Armesto et al '04, Eskola et al '04)*.







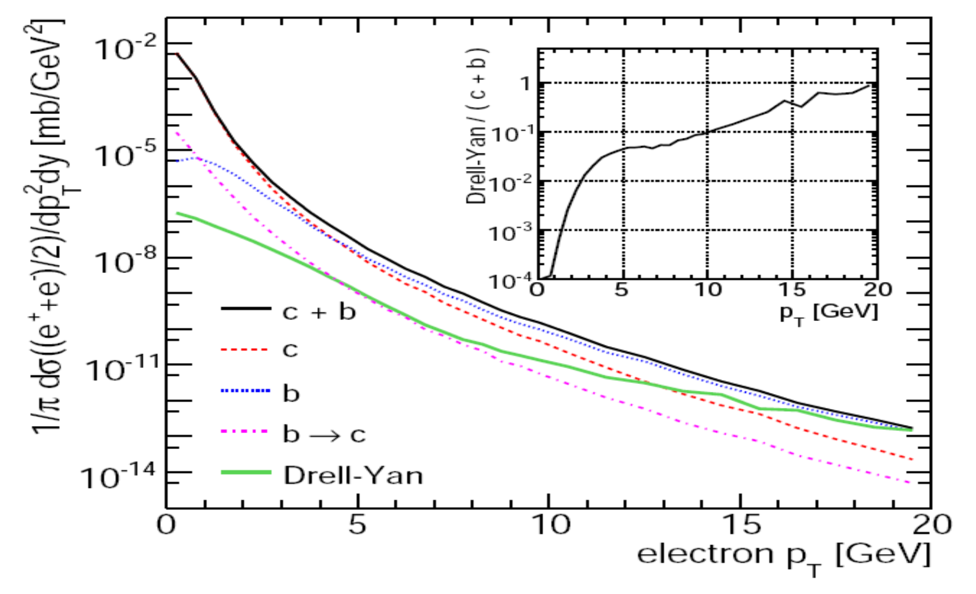
- Small difference between massless c and b.
- $10<p_T<20$ GeV: charm sensitive to color (g at low x), bottom to mass.

5. Single electrons at RHIC (I):

- RHIC data in AuAu: non-photonic electron spectra (measured - cocktail - conversion*: PHENIX '06; STAR '05)*, weak correlation in p_T with parent D, and other contributions (B's) *(Djordjevic et al '05; '06; Armesto et al '05)*.

- Heavy flavor: FONLL *(Cacciari et al '98; '01; '05)* partonic spectra supplemented with radiative eloss via quenching weights plus FONLL fragmentation:

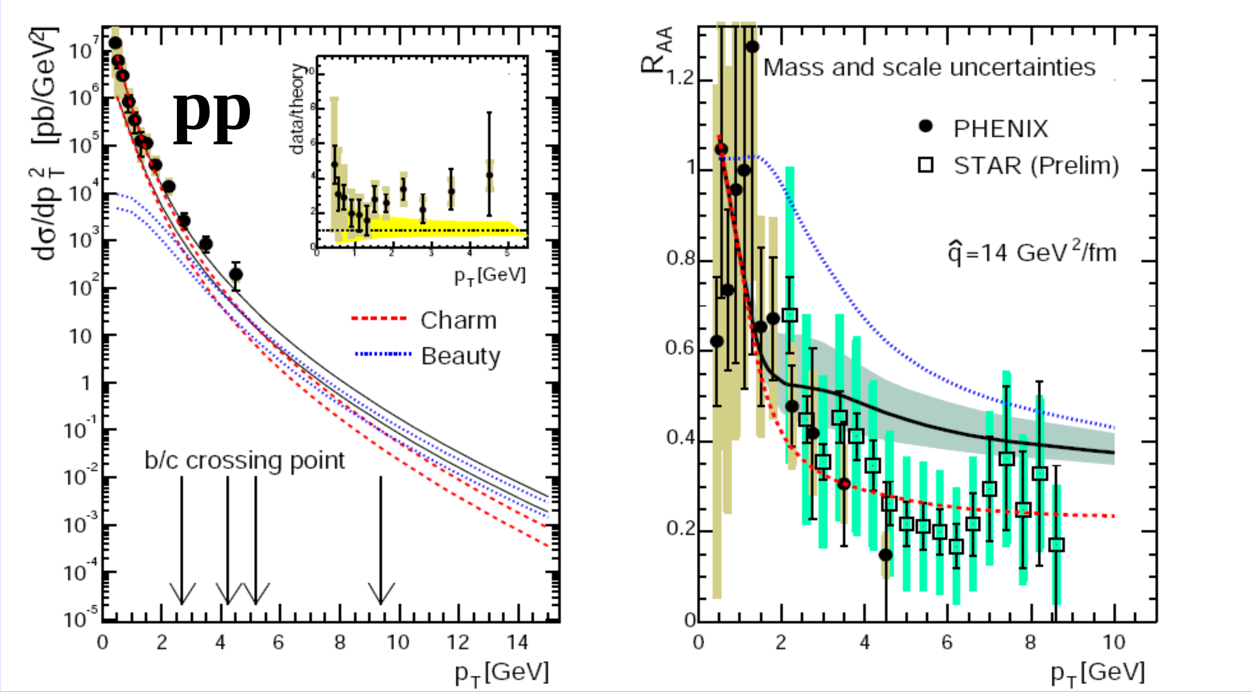
  * Uncertainties (mass and scale variation).



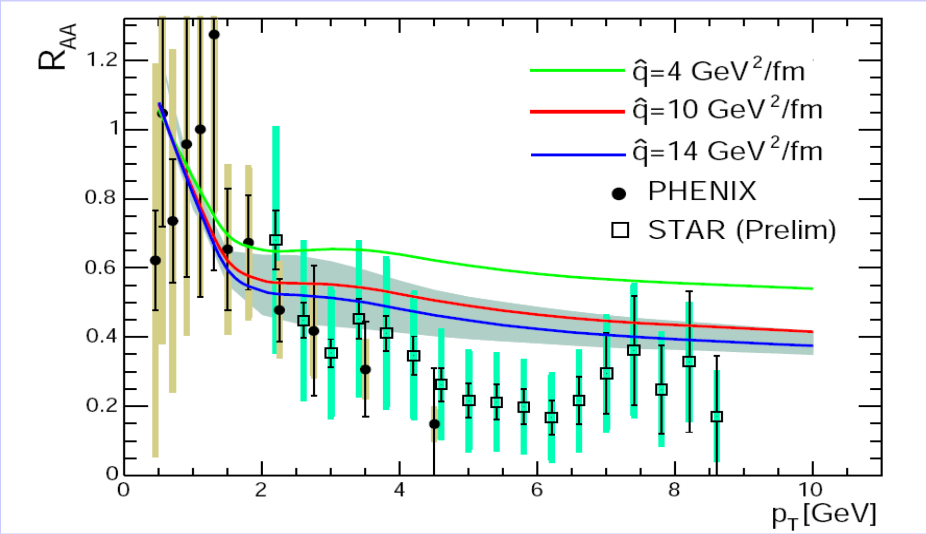
- DY: PYTHIA tuned to NLO *(Gavin et al '95)*, it may become important for $p_T > 10$ GeV.

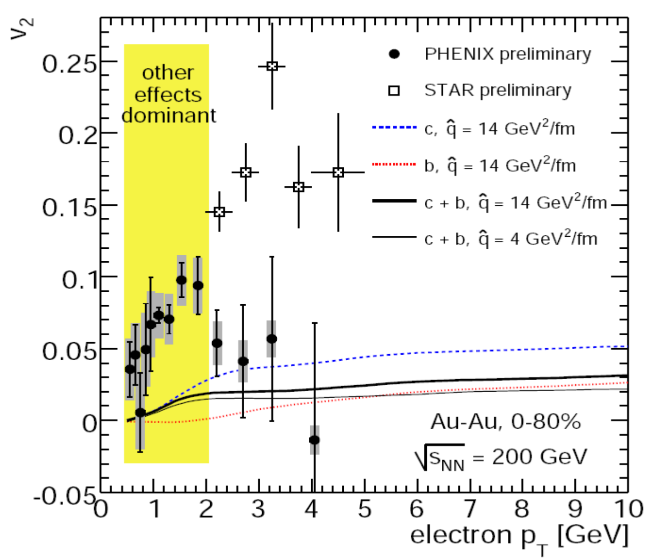
- A 10% contribution from DY may influence R_{AuAu}^{e} as much as 0.1.

5. Single electrons at RHIC (II):



- pp data underestimated by FONLL *(Cacciari et al '05)*.
- **Suppression in AuAu compatible with c only**.
- Variations in qhat ~ uncertainties.
- v_2 compatible with data *(PHENIX '05)*.

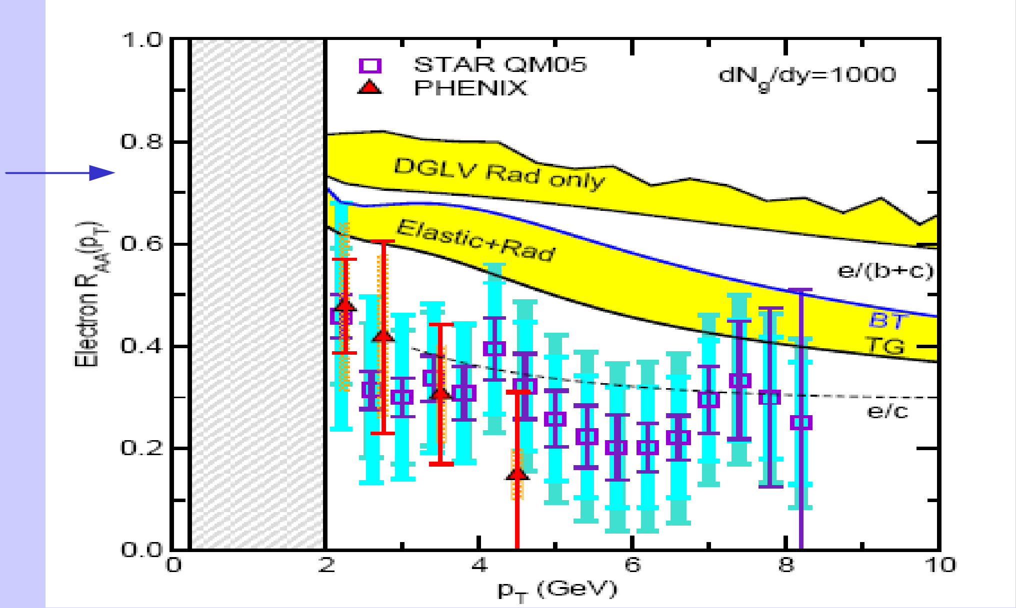




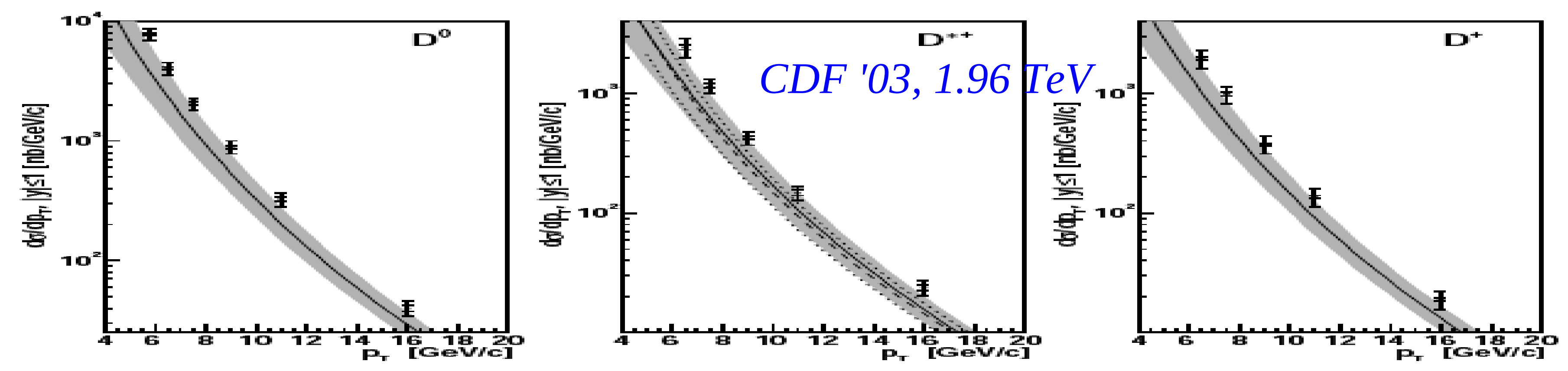
5. Single electrons at RHIC (III):

If $R_{AuAu}^{e}<0.4$ in the range $5<p_T<10$ GeV:

- Strong interaction of Q with the medium; hadronization inside, **elastic scattering**? *(Djordjevic et al '06, Hees et al 05, Teaney et al '05)*.
- Larger transport coefficient? (but upper bound to come, hopefully, from correlations *(PHENIX '05; STAR '06)*).



- How well do we control the production of heavy flavors at RHIC?



CDF '03, 1.96 TeV

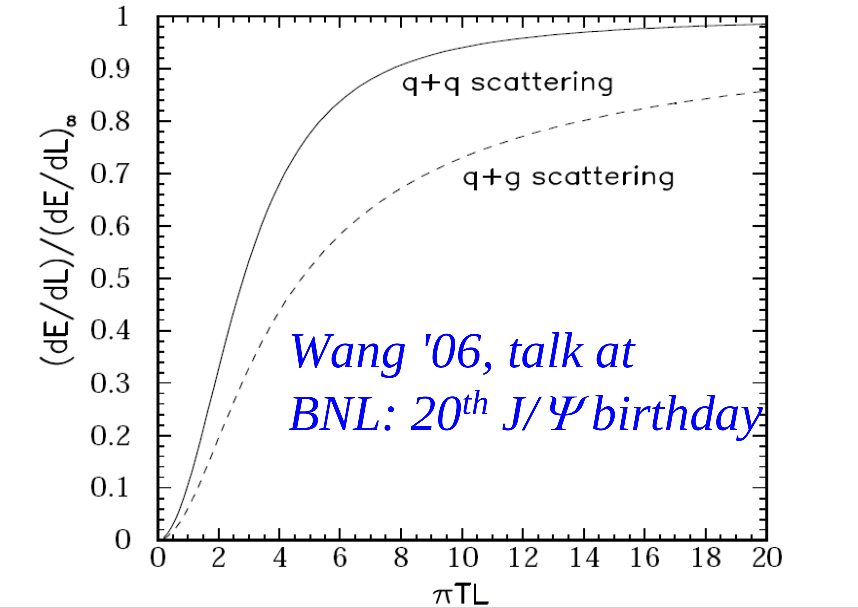
Note: elastic scattering

- Historically considered << than radiative eloss *(Bjorken '82; Gyulassy-Braaten-Thoma '91).*

- *Mustafa '05; Djordjevic et al '06; Alam et al '06:* new interest due to single electron data, idea extended from heavy to light flavors.

- *Peigne et al '05:* elastic eloss strongly reduced due to finite L.

- *Djordjevic '06:* effect of finite interaction time (L) negligible.



Wang '06, talk at BNL: 20th J/Ψ birthday

- *Wang '06:* elastic and inelastic elosses in the same multiple scattering formalism. For **light** flavors:

$\Delta E_{rad}/\Delta E_{el}$ ~ 3.14 α_sLT ln(EL/11) **~ 22**

for *E*=10 GeV, T=0.2 GeV, L=6 fm, α_s=0.3

6. Conclusions:

- Heavy flavors constitute an experimentally accessible testing ground for our understanding of radiative energy loss.

- Both at RHIC and at the LHC heavy-to-light ratios offer solid possibilities to check the formalism like those presented here.

- Single electrons in AuAu at RHIC may demand other effects like elastic scattering, hadronization in medium, strong interactions,…

BUT

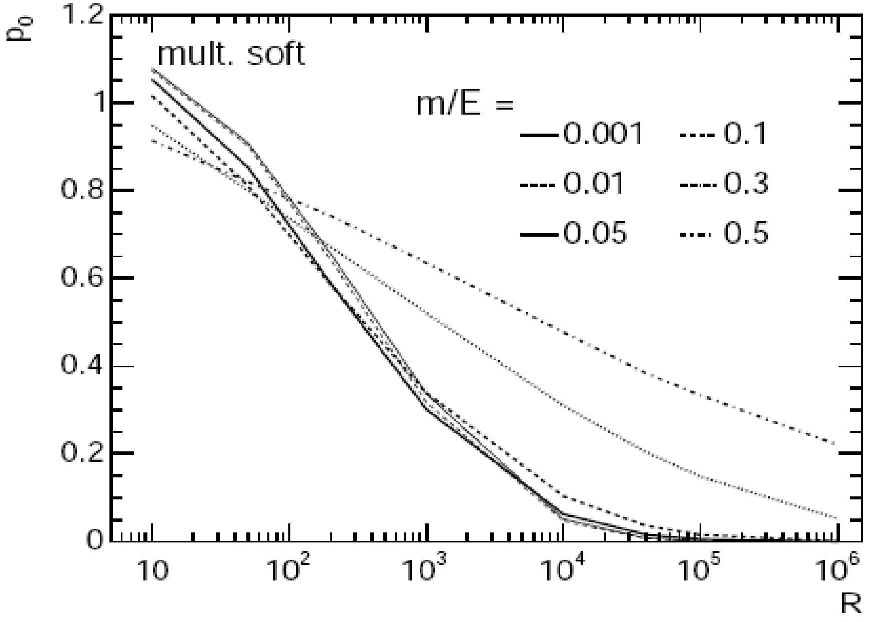
experimental data are not inconsistent with radiative eloss.

- **Clarification of this issue will demand (**at RHIC and at the LHC):
  - * pp/dAu reference to be controlled.
  - * If possible, data for mesons, not only for electrons.

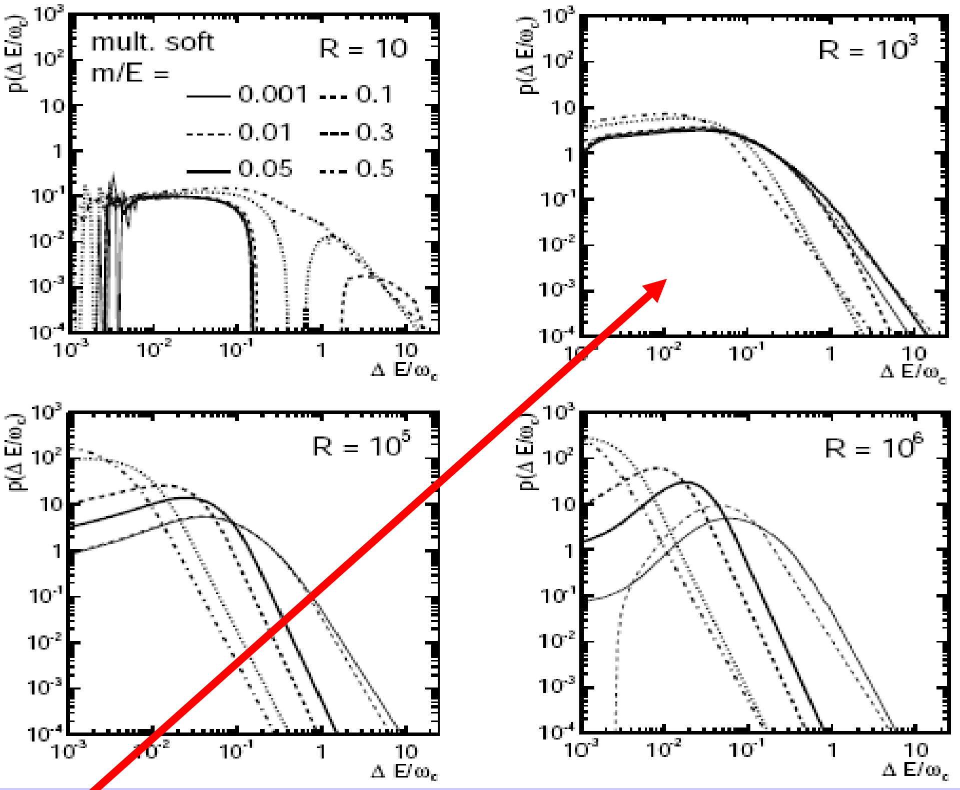
- Further work needed: energy constraints, consideration of virtualities,…, crucial for associated particle production.

Backup I: quenching weights

probability of no-energy loss



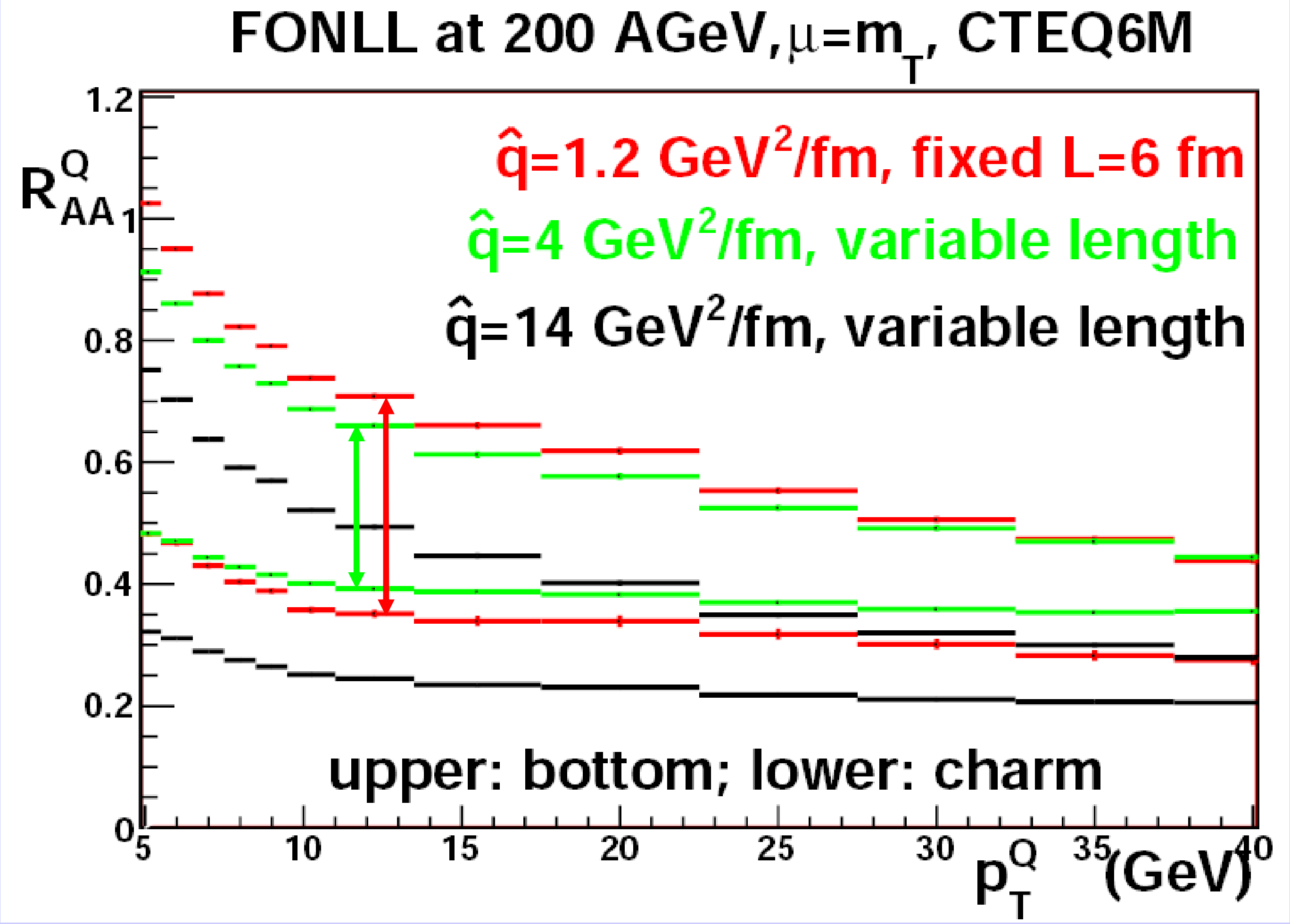
$R \equiv \omega_c L$



Mass effect smaller for smaller R=qhat $L^3/2$, so smaller for smaller lengths.

Backup II: fixed vs. variable L

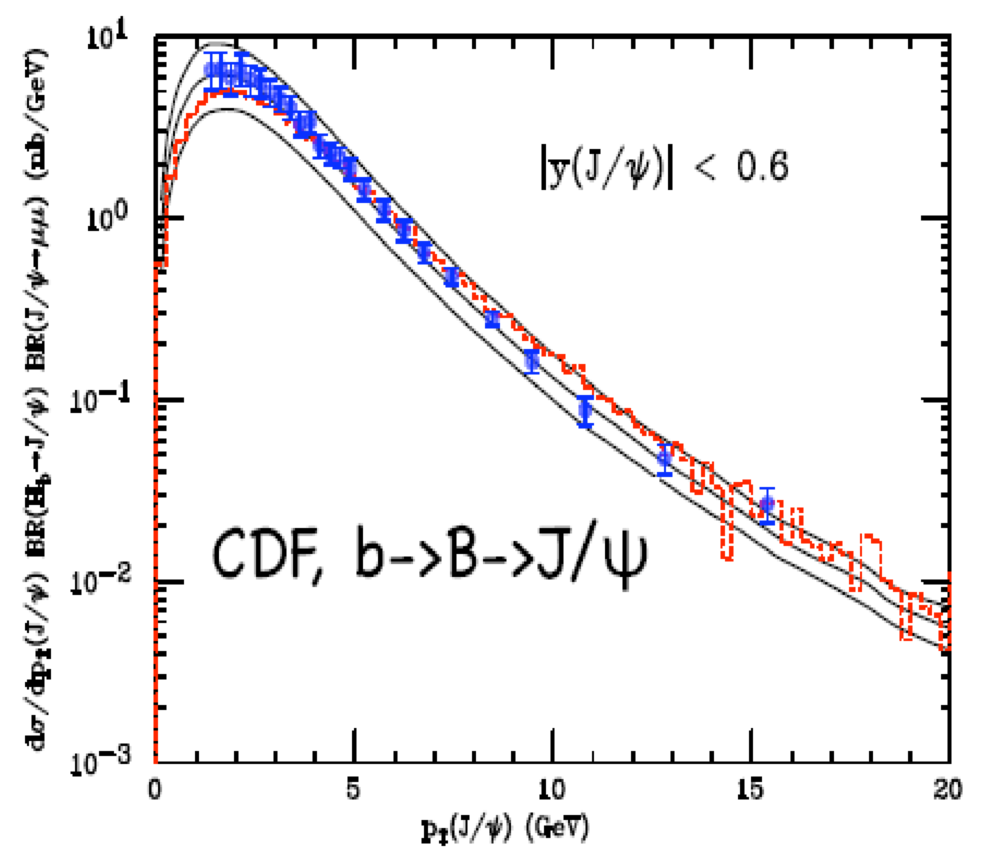
To try to understand a disagreement with Djordjevic et al '05



- m_c=1.5 GeV, m_b=4.75 GeV; no fragmentation.
- qhat=1.2 GeV^2/fm with fixed L=6 fm reproduce R_{AA}(0-10%) ~0.2 for pions.
- A large fixed length produces a larger effect of the mass on the eloss: mass effect small for small L.

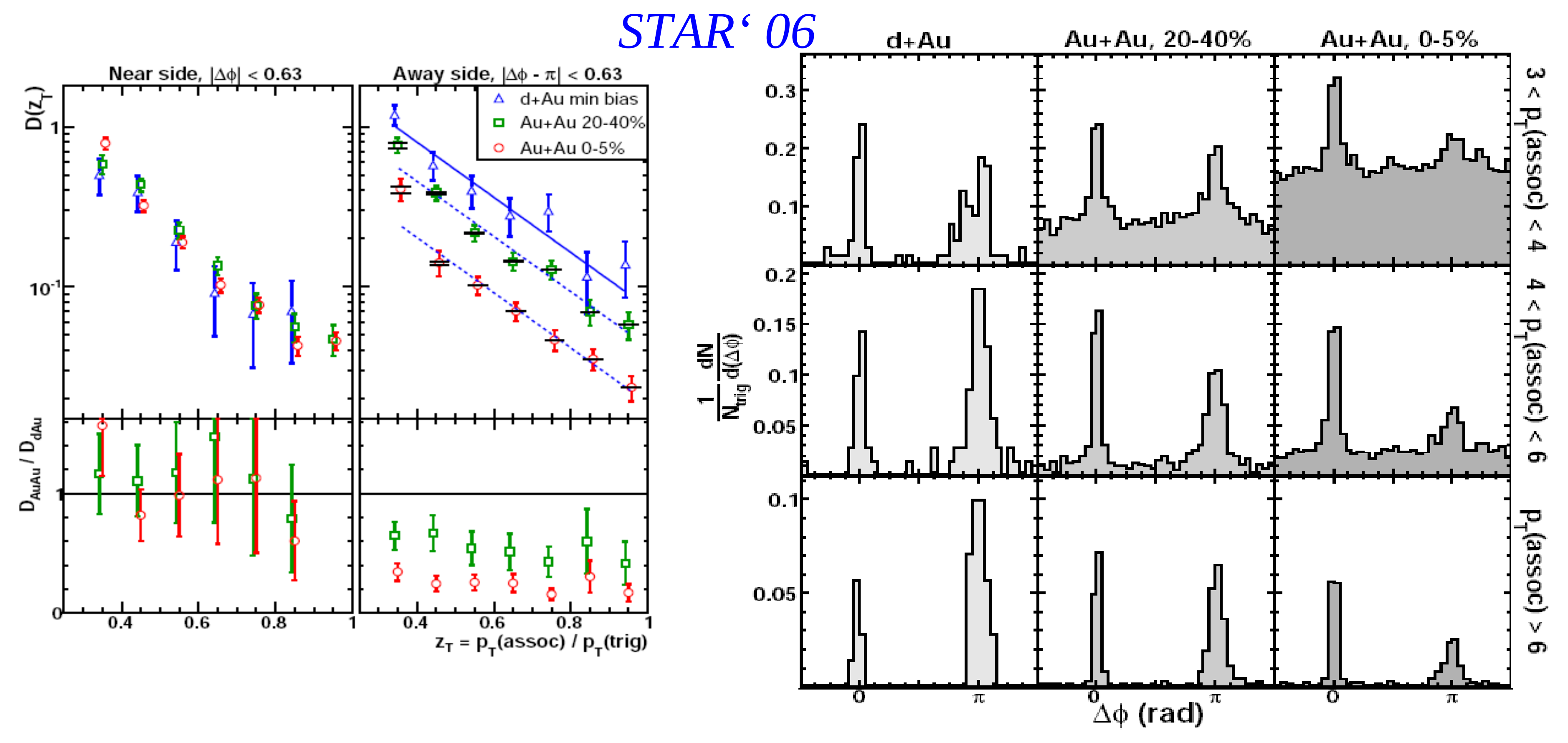
Backup III: bottom in FONLL

Cacciari et al '03; '04



Reasonable description of b production.

Backup IV: further contraints on qhat



STAR‘ 06

Tangential emission *(Dainese '05)*; **associated spectra not yet understood.**