Towards an understanding of the RHIC single electron data…

P.B. Gossiaux
SUBATECH, UMR 6457
Université de Nantes, Ecole des Mines de Nantes, IN2P3/CNRS

Collaborators

J. Aichelin, A. Peshier, R. Bierkandt

TU Berlin

GOAL of the STUDY

Recent revival of the collisional energy loss in order to explain the large "thermalization" of heavy quarks in Au+Au collisions at RHIC

Most often, however:

1) No "real" pQCD implemented

No running α_s (cf. previous work of Peshier), "crude" IR regulator

2) Fokker – Planck equation

Might not be applicable : "hard" transfers, # of collisions not systematically large at the periphery

From a more phenomenological point of view:

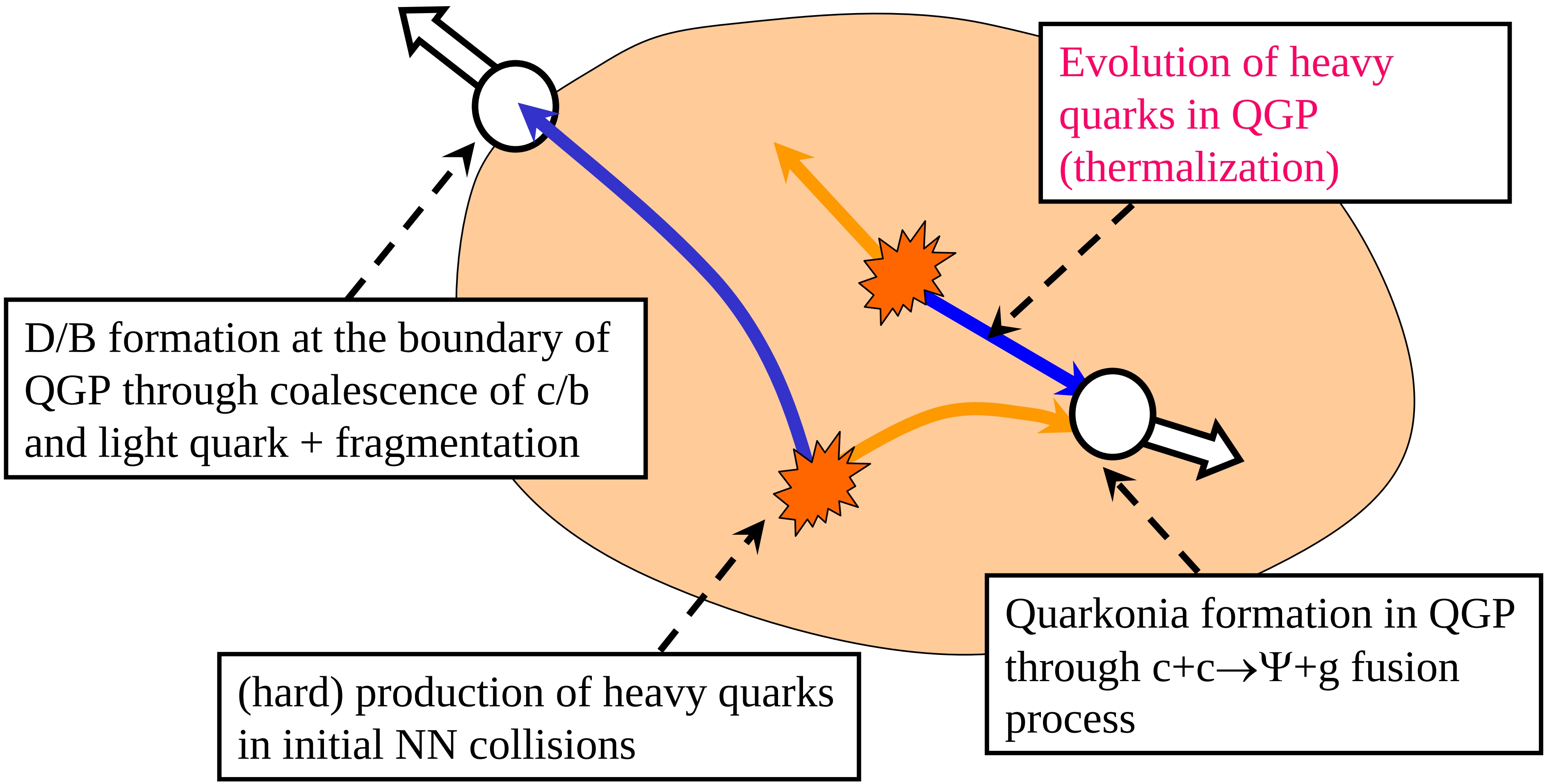
3) Need to crank up the $2\to2$ cross sections in order to reproduce the R_{AA}

4) Difficulty to reproduce both the R_{AA} and the v_2 without "exotic" processes (like in-QGP resonances)

Our approach: consider heavy-Q evolution in QGP according to Boltzmann equation with improved $2\to2$ cross sections and look whether this helps solving points 3) and 4)

If yes: consider other observables and make predictions for LHC

Global Model



Heavy quarks in QGP

In pQGP, heavy quarks are assumed to interact with partons of type "i" (massless quarks and gluons) with local 2→2 rate:

$$R_i = \frac{1}{2E_p}\int\frac{d^3k}{(2\pi)^3 2k}\int\frac{d^3k'}{(2\pi)^3 2k'}\int\frac{d^3p'}{(2\pi)^3 2E'}$$
$$n_i(k)\times\ (2\pi)^4\delta^{(4)}(P+K-P'-K')\sum|\mathcal{M}_i|^2$$

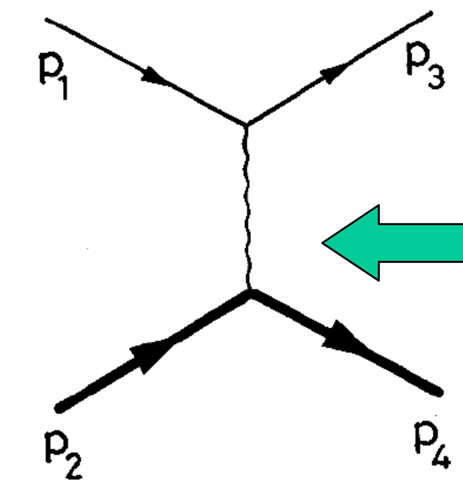
Associated transport coefficient (drag, energy loss,…) depend on the QGP macroscopic parameters (T, **v**, μ) at a given 4-position (t,x). These parameters are extracted from a "standard" hydro-model (Heinz & Kolb: boost invariant)

We follow the hydro evolution of partons and sample the rates R_i "on the way", performing the Qq→Q'q' & Qg→Q'g' collisions: MC approach

Oldies

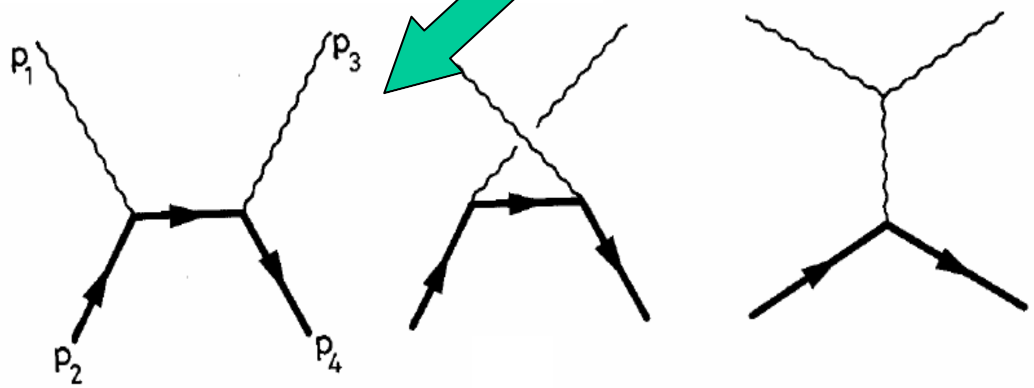
Cross sections

We start from Combridge (79) as a basis:



$$\sum |\mathcal{M}|^2 = \frac{64\pi^2\alpha^2(Q^2)}{9}\,\frac{(M^2-u)^2+(s-M^2)^2+2M^2t}{t^2}$$

$$\sum|\mathcal{M}|^2=\pi^2\alpha^2(Q^2)\Big[\frac{32(s-M^2)(M^2-u)}{t^2}+\frac{64}{9}\,\frac{(s-M^2)(M^2-u)+2M^2(s+M^2)}{(s-M^2)^2} + \frac{64}{9}\,\frac{(s-M^2)(M^2-u)+2M^2(M^2+u)}{(M^2-u)^2}+\frac{16}{9}\,\frac{M^2(4M^2-t)}{(s-M^2)(M^2-u)} +16\,\frac{(s-M^2)(M^2-u)+M^2(s-u)}{t\,(s-M^2)} -16\,\frac{(s-M^2)(M^2-u)-M^2(s-u)}{t\,(M^2-u)}\Big]$$



However, t-channel is IR divergent => modelS

Naïve regulating of IR divergence:

$$\frac{1}{t} \to \frac{1}{t-\mu^2}$$

With μ(T) or μ(t)

Models A/B: no α_s - running

$\mu^2(T) = m_D^2 = 4\pi\alpha_s(1+3/6)xT^2$

$\alpha_s(Q^2) \to \begin{cases} 0.3 \text{ (mod A)} \\ \alpha_s(2\pi T) \text{ (mod B)} \end{cases}$ (≈ 0.3)

Customary choice

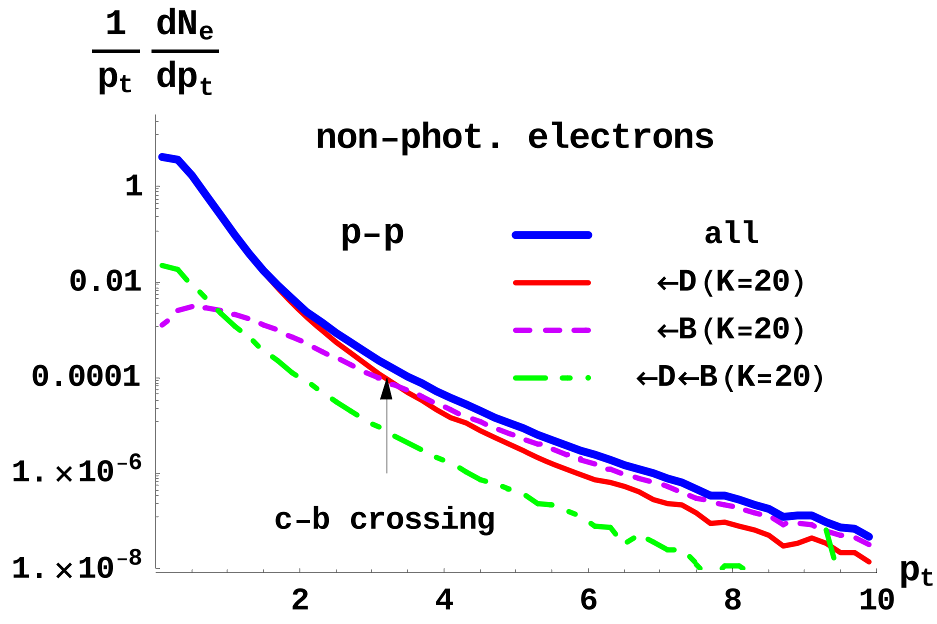
$\frac{dE_{coll}(c)}{dx}$

T(MeV) \p(GeV/c)	10	20
200	0.18	0.27
400	0.35	0.54

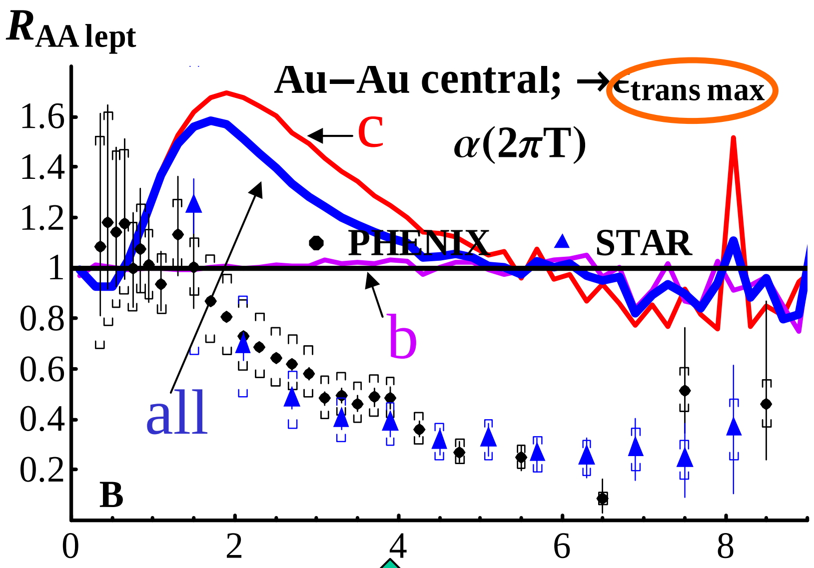
… of the order of a few % !

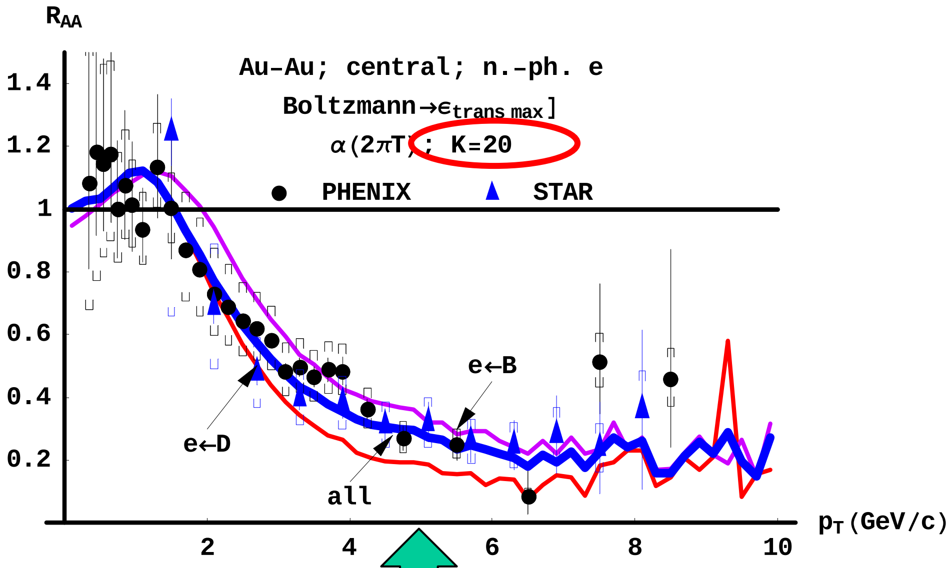
Other hypothesis / ingredients of the model

- Au–Au collisions at 200 AGeV: 17 c-cbar pairs in central collisions
- Q distributions: adjusted to NLO & FONLL
- Cronin effect (0.2 GeV^2/coll.).
- No force on HQ before thermalization of QGP (0.6 fm/c)
- Evolution according to Bjorken time until the beginning or the end of the cross-over
- Q-Fragmentation and decay $\rightarrow$ e as in Cacciari, Nason & Vogt 2005.
- No D (B) interaction in hadronic phase



Results for model B:





Evolution → beginning of cross-over

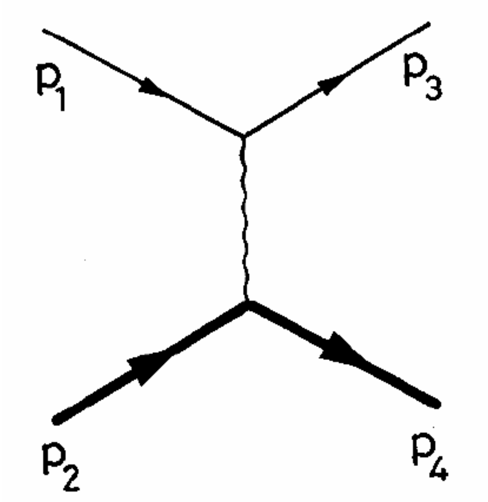
: Cranking factor

N.B.: Overshoot due to coalescence

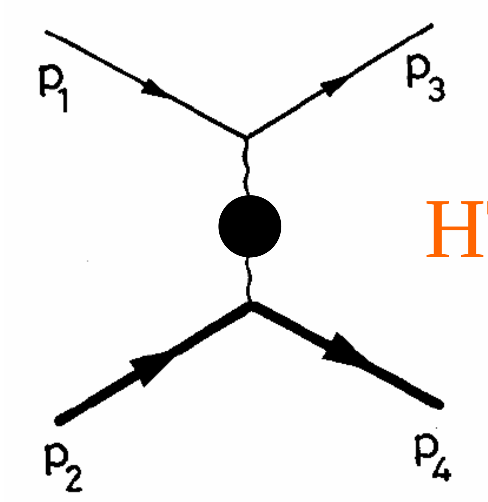
One reproduces the R_{AA} shape at the price of a *huge cranking K-factor* ⇒ The end of coll Eloss in pQGP ?

$\mu^2(T) = m_D^2$? Model C: remembering of HTL

(but still no α_s–running vs Q^2)



Low |t|



HTL

Idea: Take $\mu^2(T)$ in the propagator of Combridge in order to reproduce the "standard" Braaten – Thoma Eloss

$$\frac{1}{t} \rightarrow \frac{1}{t-\mu^2}$$

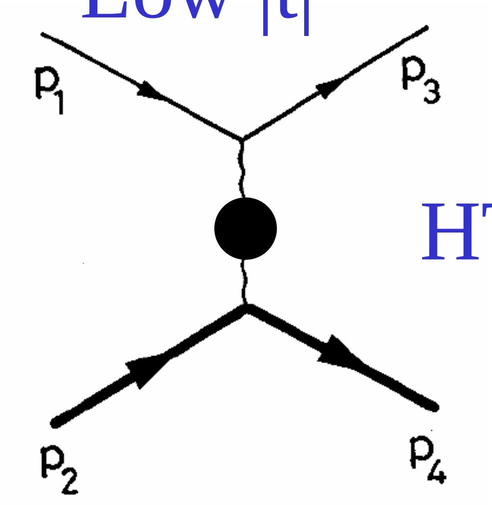
With $\mu(T)$ calibrated on BT

Braaten-Thoma:

(Peshier – Peigné)

(provided $g^2T^2 << |t^*| << T^2$)

Low |t|

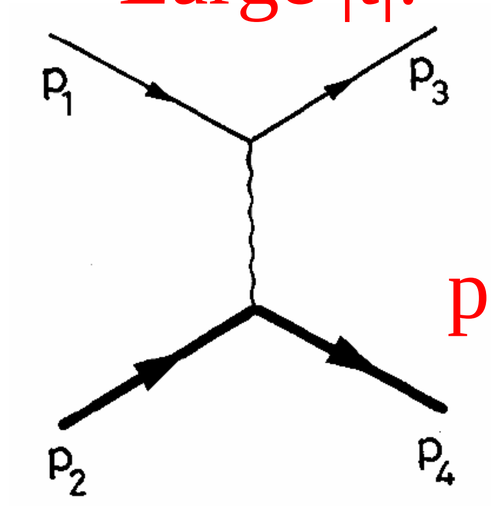


HTL

$|t^*|$

+

Large |t|:



Bare propagator

$$G_{\mu\nu}(Q) = \frac{-\delta_{\mu 0}\delta_{\nu 0}}{q^2 + \Pi_{00}} + \frac{\delta_{ij} - \hat{q}_i \hat{q}_j}{q^2 - \omega^2 + \Pi_T}$$

$$\frac{dE_{soft}}{dx} = \frac{2}{3}\alpha\, m_D^2 \ln\left(\frac{\sqrt{t^*}}{m_D/\sqrt{3}}\right) + \ldots$$

$$G_{\mu\nu}(Q) = \frac{-\delta_{\mu\nu}}{q^2 - \omega^2}$$

$$\frac{dE_{hard}}{dx} = \frac{2}{3}\alpha\, m_D^2 \ln\left(\frac{\sqrt{ET}}{\sqrt{t^*}}\right) + \ldots$$

SUM: $$\frac{dE}{dx} = \frac{2}{3}\alpha\, m_D^2 \ln\left(\frac{\sqrt{ET}}{m_D/\sqrt{3}}\right)$$

Indep. of |t*| !

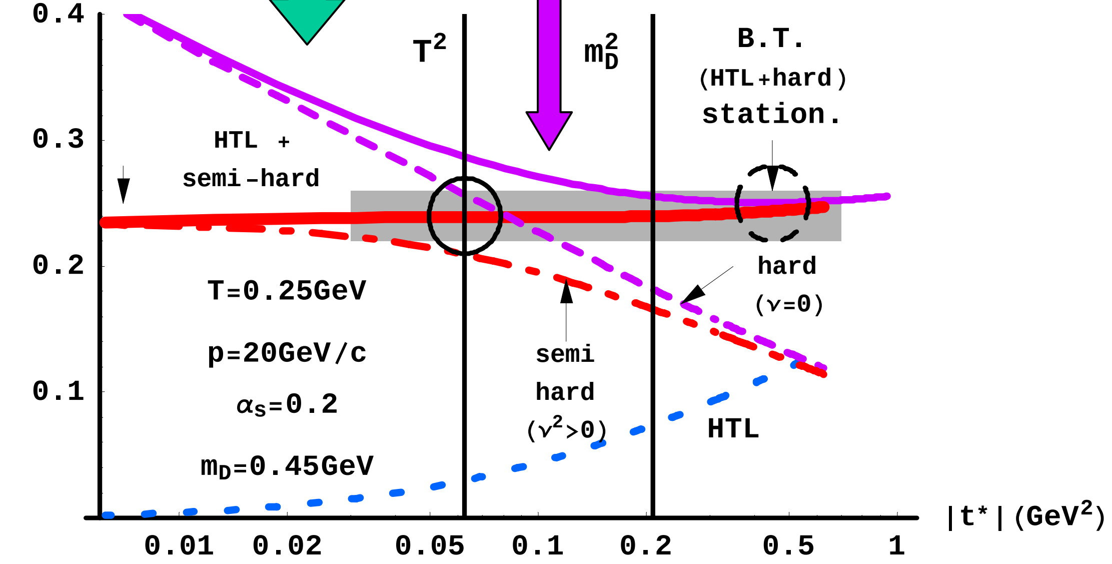
Comparing with dE/dx in our model: $\mu^2(T) \approx 0.2\, m_D^2(T)$

In QGP: $g^2T^2 > T^2$!!!

provided

$g^2T^2 << |t^*| << T^2$

BT: Not Indep. of |t*| !



We introduce a semi-hard propagator --$1/(t-\nu^2)$-- for $|t|>|t^*|$ to attenuate the discontinuities at t^* in BT approach.

Recipy: ν^2 in the semi-hard prop. is *chosen* such that the resulting E loss is maximally $|t^*|$-independent.

This allows a matching at a sound value of $|t^*| \approx T$

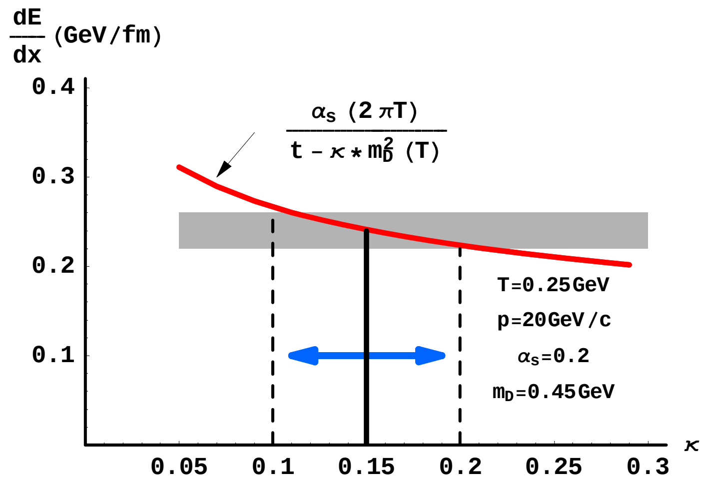
Model C: no Q^2 – running, optimal μ^2

Also Refered as mod C

THEN: Optimal choice of μ in our OBE model:

$$\frac{\alpha_s(2\pi T)}{t-\mu^2}$$

$$\mu^2(T) \approx 0.15\ m_D^2(T)$$



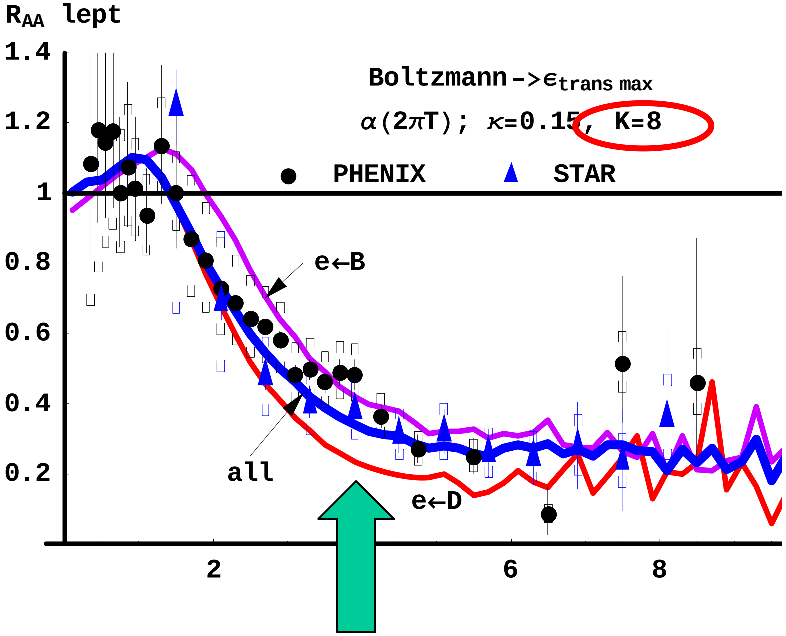
with $m_D^2 = 4\pi\alpha_s(2\pi T)(1+3/6)xT^2$

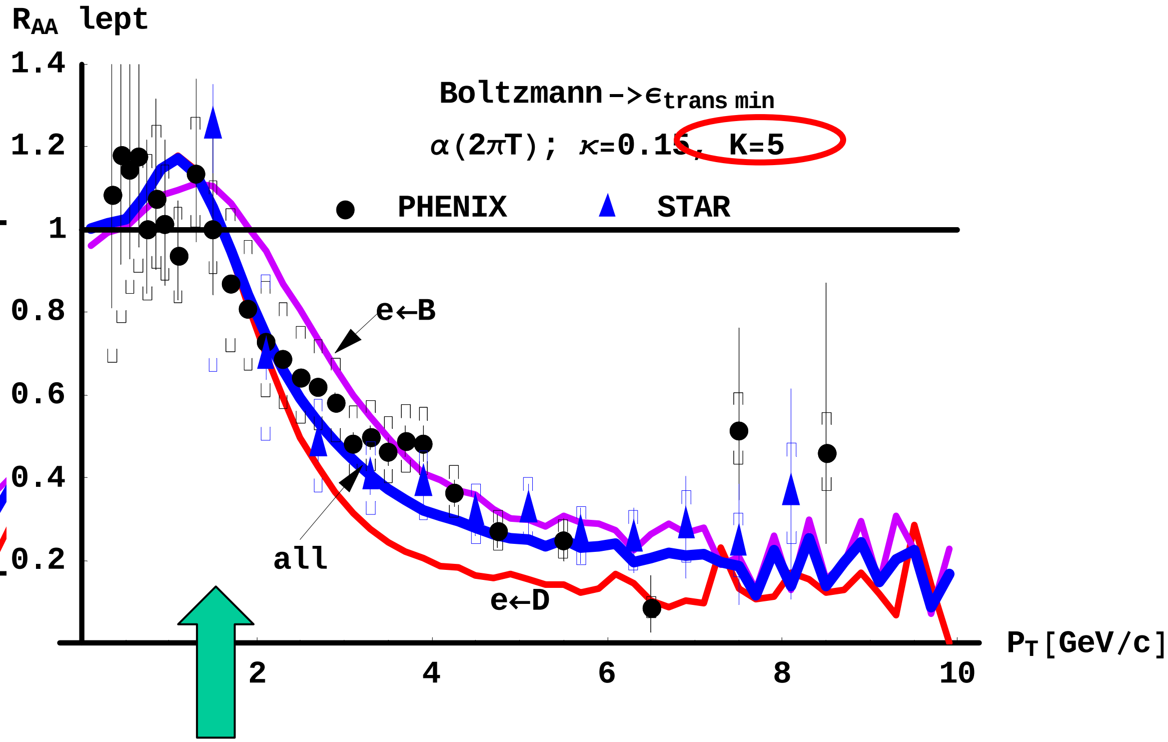
$$\frac{dE_{coll}(c)}{dx}$$

T(MeV) \p(GeV/c)	10	20
200	0.36 (0.18)	0.49 (0.27)
400	0.70 (0.35)	0.98 (0.54)

… factor 2 increase w.r.t. mod B

Results for model C:





Evolution → beginning of cross-over

Evolution → end of cross-over

: Cranking factor

Rate chosen "as at T_c"

One reproduces the R_{AA} shape at the price of a *large* cranking K-factor (8-5)

More recently (2-3 years → now)

Model D: running α_s

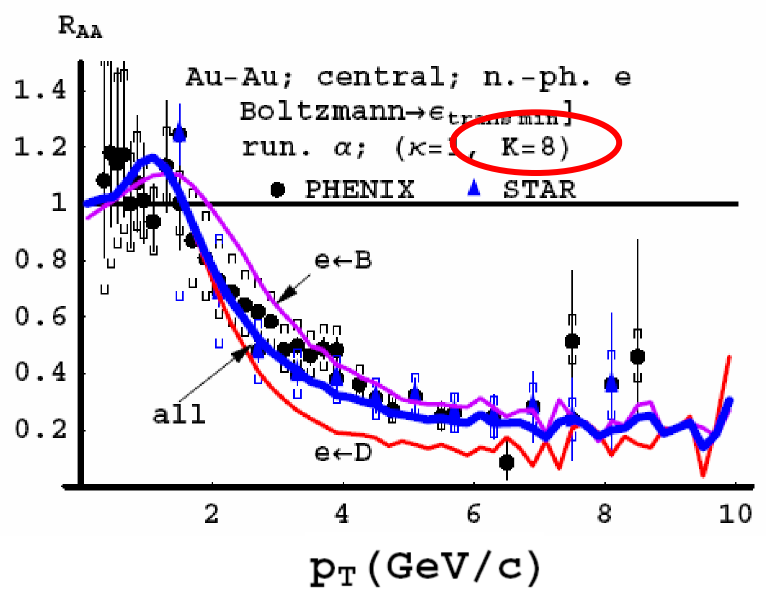
$$\mu^2(T) \approx m_{Dself}^2\,(T^2) = (1+n_f/6)\,4\pi\alpha_s(\,m_{Dself}^2)\,xT^2$$

$$\frac{dE}{dx} \propto \alpha_S (2\pi T)^2 T^2 \ln \frac{ET}{m_D^2}$$

$$\frac{dE}{dx} \propto \alpha_S(\mu^2) T^2$$

Self consistent m_D

Cf Peshier hep-ph/0607275



$\frac{dE_{coll}}{dx}$

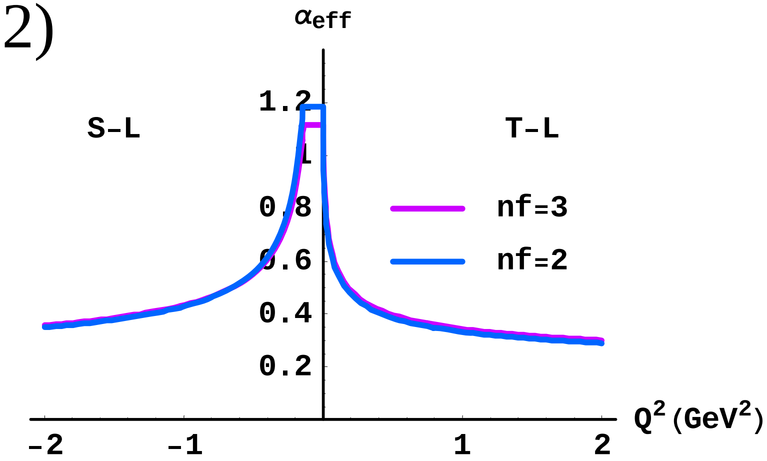
T(MeV) \p(GeV/c)	10	20
200	0.30 (0.18)	0.36 (0.27)
400	0.63 (0.35)	0.80 (0.54)

Indeed reduction of log increase…

…not much effect seen on the R_{AA}

Model E : running α_s AND optimal μ^2

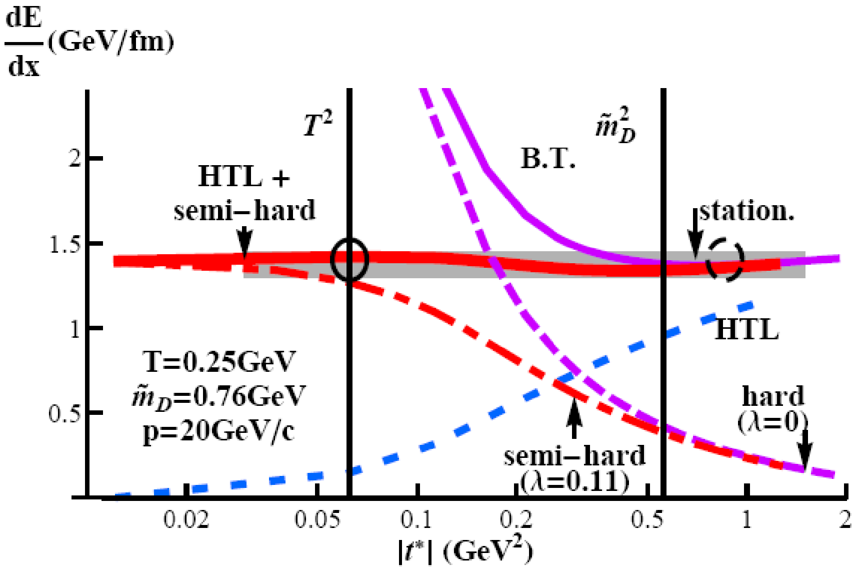
- Effective $\alpha_s(Q^2)$ (Dokshitzer 95, Brodsky 02)



- Bona fide "running HTL": $\alpha_s \to \alpha_s(Q^2)$

same method as for model C:

semi-hard propag. $\frac{\alpha_{\rm eff}(t)}{t} \longrightarrow \frac{\alpha_{\rm eff}(t)}{t-\lambda m_D^2(T,t)}$

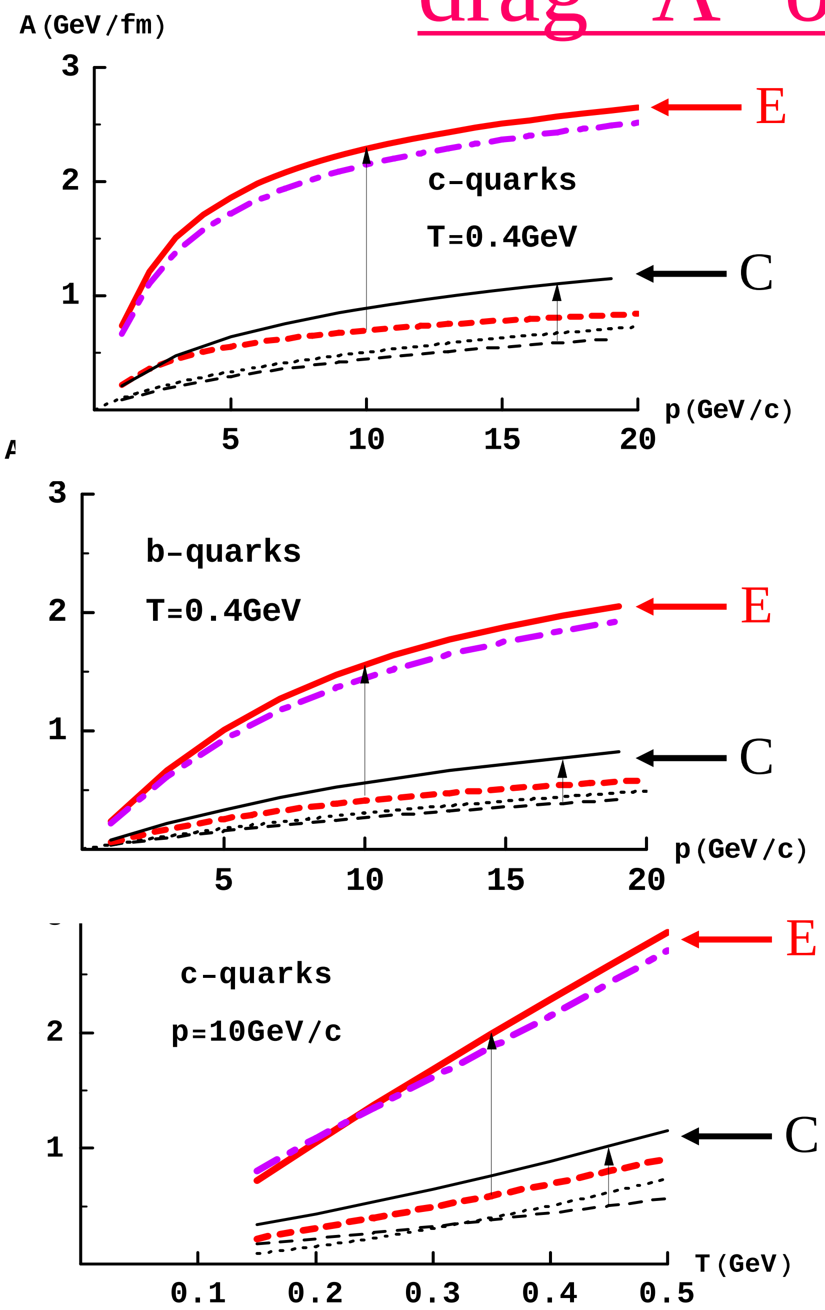


$$\frac{dE_{coll}(c/b)}{dx}$$

T(MeV) \p(GeV/c)	10	20
200	**1 / 0.65**	**1.2 / 0.9**
400	**2.1 / 1.4**	**2.4 / 2**

$\mu^2(T) \approx 0.2\, m_{Dself}{}^2(T)$

drag "A" of heavy quarks



Reminder: $\frac{d}{dt}<\vec{p}>_f = <-\vec{A}>_f$

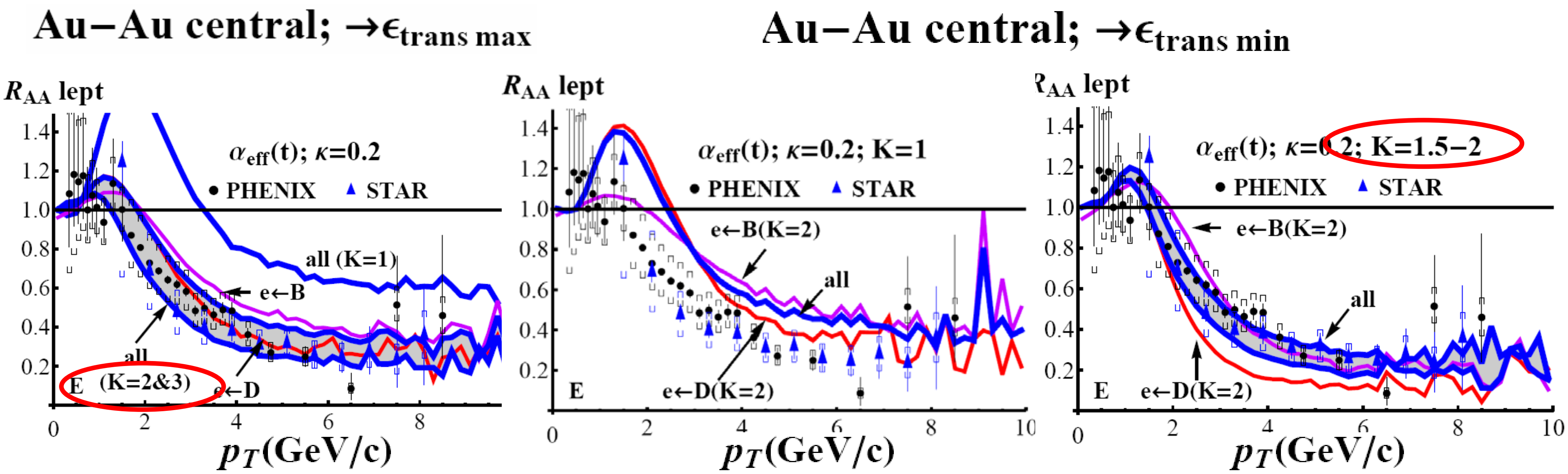
$$\frac{d<E>}{dx} = \approx -A$$

At large velocity

	α_S	μ^2	line form	figure color
A	0.3	m_D^2	dotted thin	black
B	$\alpha_S(2\pi T)$	m_D^2	dashed thin	black
C	$\alpha_S(2\pi T)$	$0.15 \times m_D^2$	full thin	black
D	running (eq.17)	$\tilde{m}_D^2$	dashed bold	red
E	running (eq.17)	$0.2 \times \tilde{m}_D^2$	full bold	red
F	running (eq.17)	$0.11 \times 6\pi\ \alpha_{\rm eff}(t)\, T^2$	dashed dotted bold	purple

Conclusion: including running α_s *and* IR regulator calibrated on HTL leads to much larger values of coll. Eloss as in previous works

Central RAA for model E & interm. conclusion:



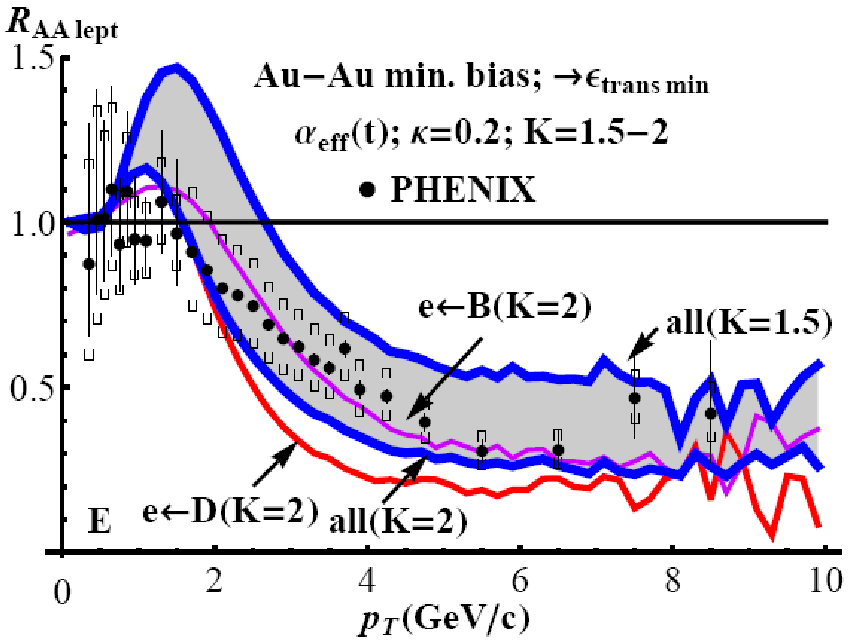
I. One reproduces R_{AA} for K=1.5-2 (<<20 with naïve model 1) *on all* p_T *range* provided one performs the evolution → end of mixed phase

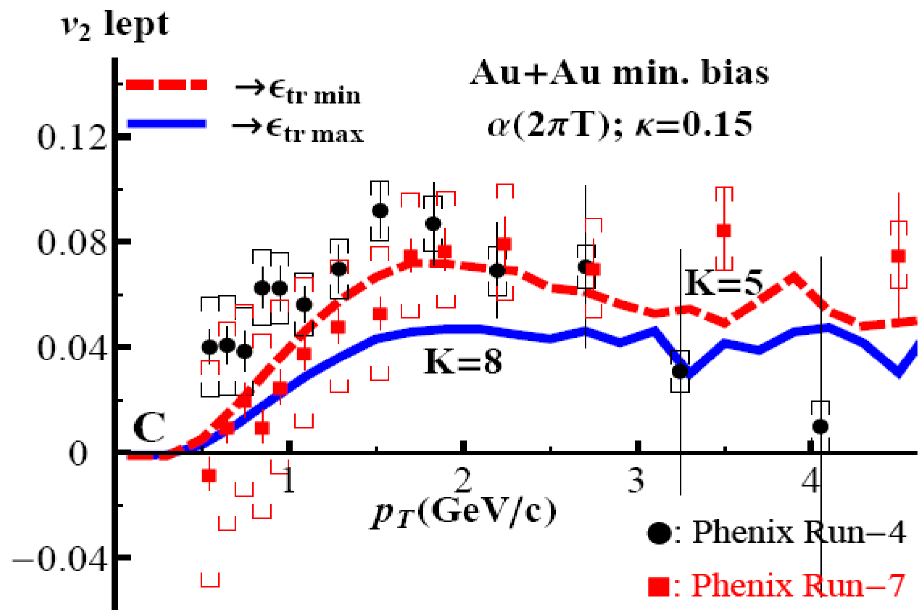
Our present framework

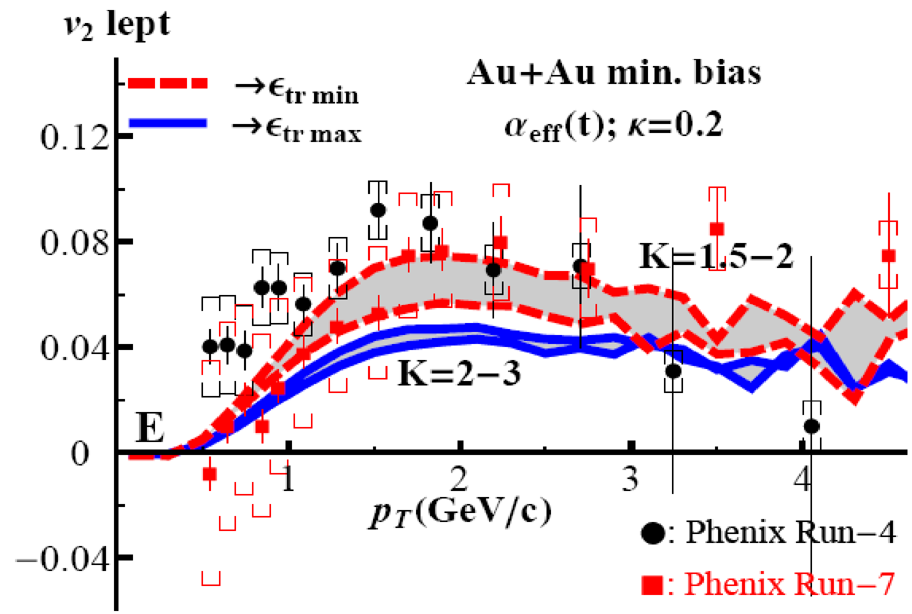
II. Despite the unknowns (b-c crossing, precise kt broaden.,…), unlikely that collisional energy loss could explain it all alone

III. It is however not excluded that the "missing part" could be reproduced by some conventional pQGP process (radiative Eloss)

Min. bias Results for model C &E :







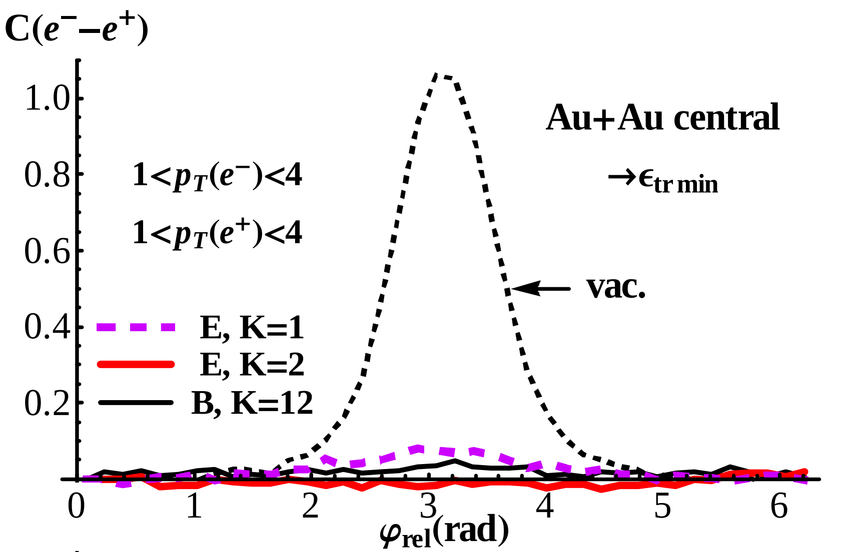
mixed phase responsible for 40% of the v2 irrespectively of the model ?!

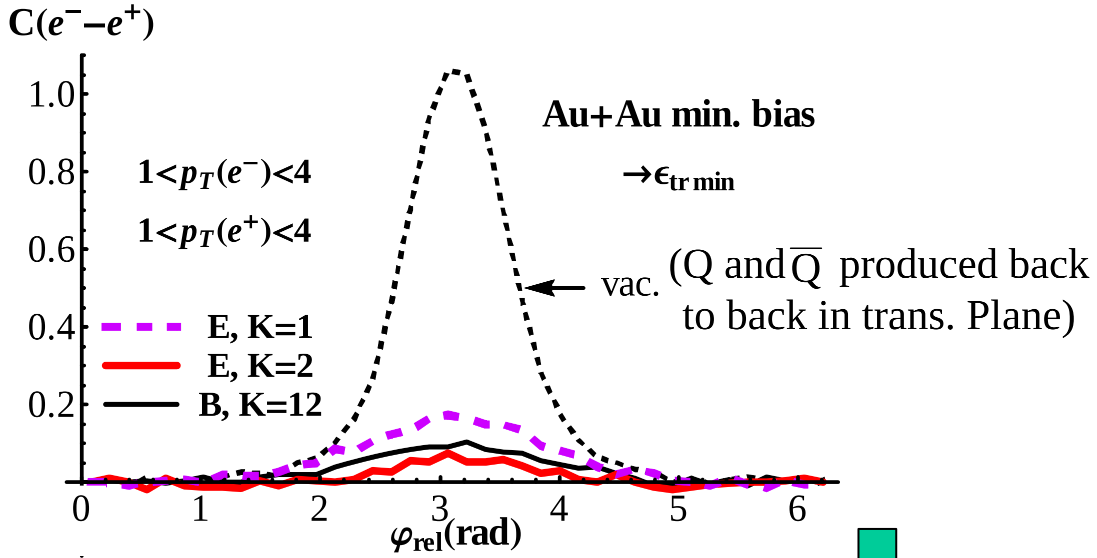
"Characterization of the Quark Gluon "Plasma with Heavy Quarks" ?

Could other observables help ?

Azimutal correlations at RHIC:

* **Intermediate p_T**: both p_T >1GeV/c and < 4GeV/c





≈ no correlation left for central collisions

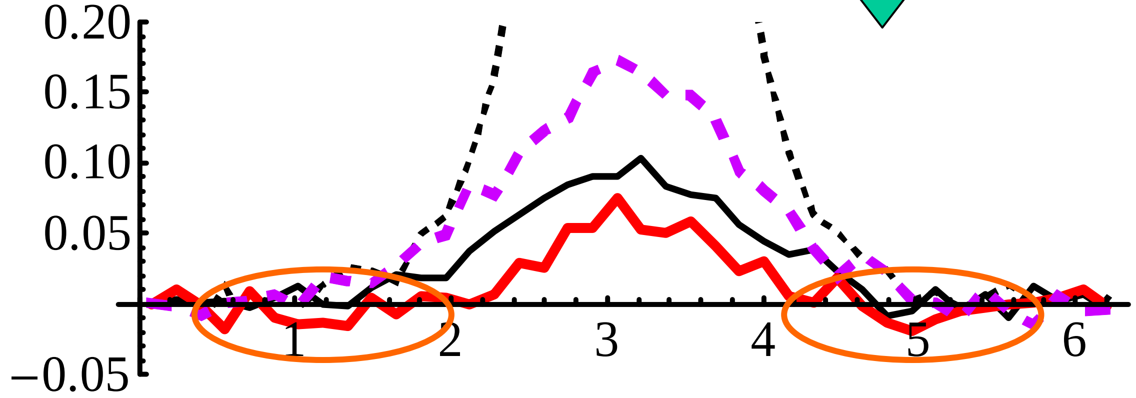
10-20 % correlation left for min bias collisions

magnify

Similar width for the 2 upper curves (smaller dE/dx)

Mexican hat (?) for model E

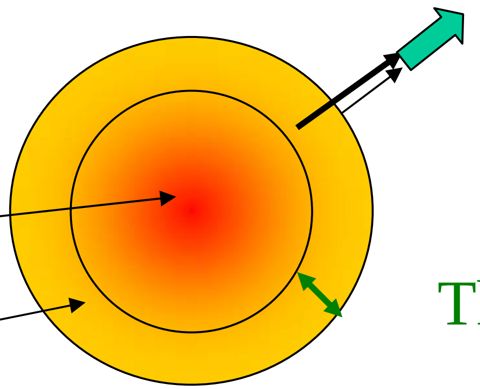
Possible discrimination ?



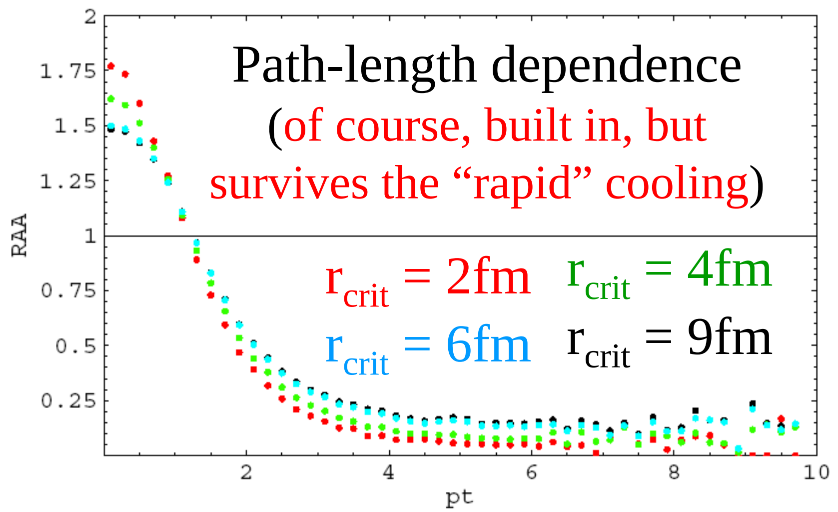
Probing the energy loss with R_{AA} at large p_T:

* **large p_T**: mostly corona effect (?)

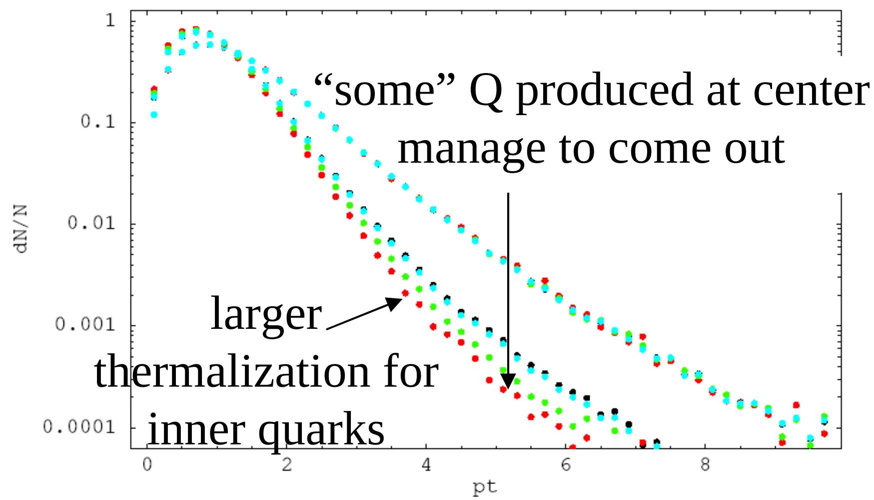
* Naïve view (b=0):



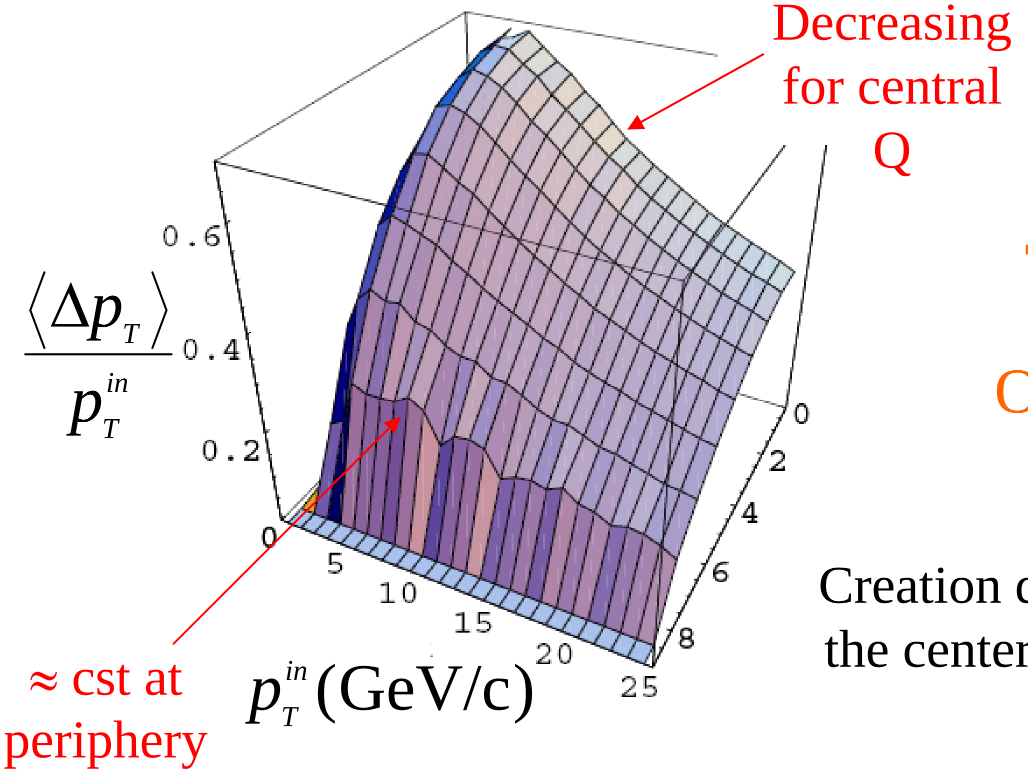
* More quantitatively: let us focus – within the model E – on c-quarks produced at transverse position < r_{crit}



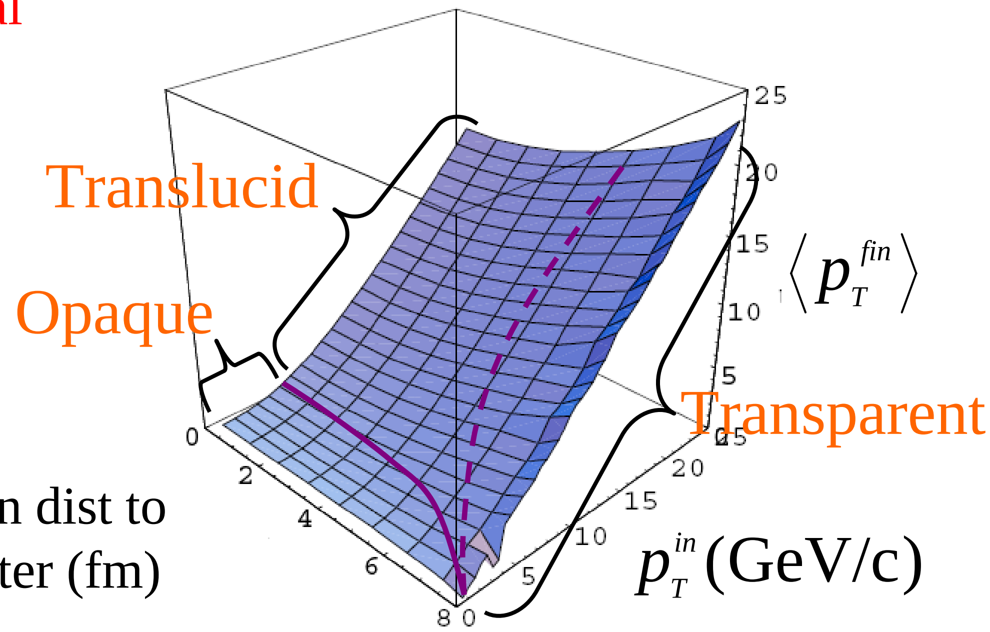
Fin. vs init. distribution of c



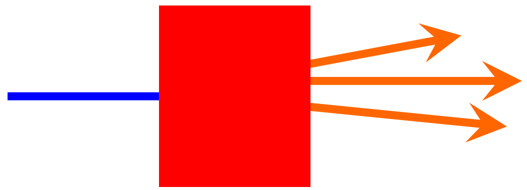
More theoretical cuts:



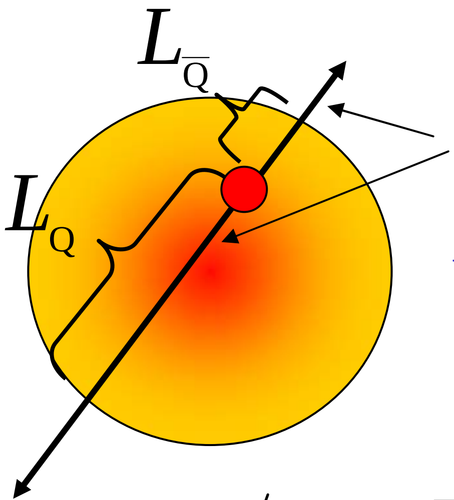
Creation dist to the center (fm)



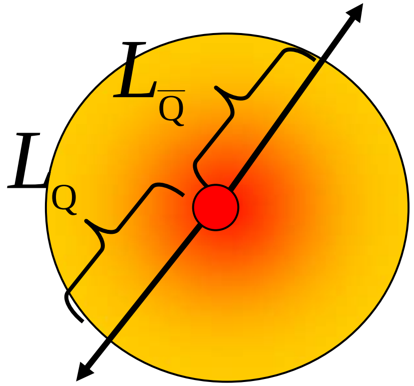
* Challenge: tagging on the “central” Q, i.e. getting closer to the ideal “penetrating probe” concept:



Q-Qbar correlations (at RHIC):



while

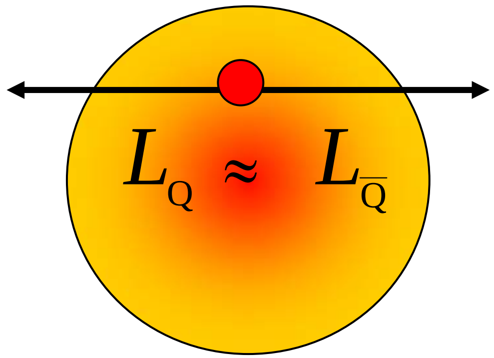


$$L_{\overline{Q}} \approx L_Q \Rightarrow \langle \Delta p_T(\overline{Q}) \rangle \approx \langle \Delta p_T(Q) \rangle$$

$$L_{\overline{Q}} < L_Q \Rightarrow \langle \Delta p_T(\overline{Q}) \rangle < \langle \Delta p_T(Q) \rangle$$

* Reversing the argument: selecting $\langle \Delta p_T(\overline{Q}) \rangle \approx \langle \Delta p_T(Q) \rangle$ might bias the data in favor of "central" pairs

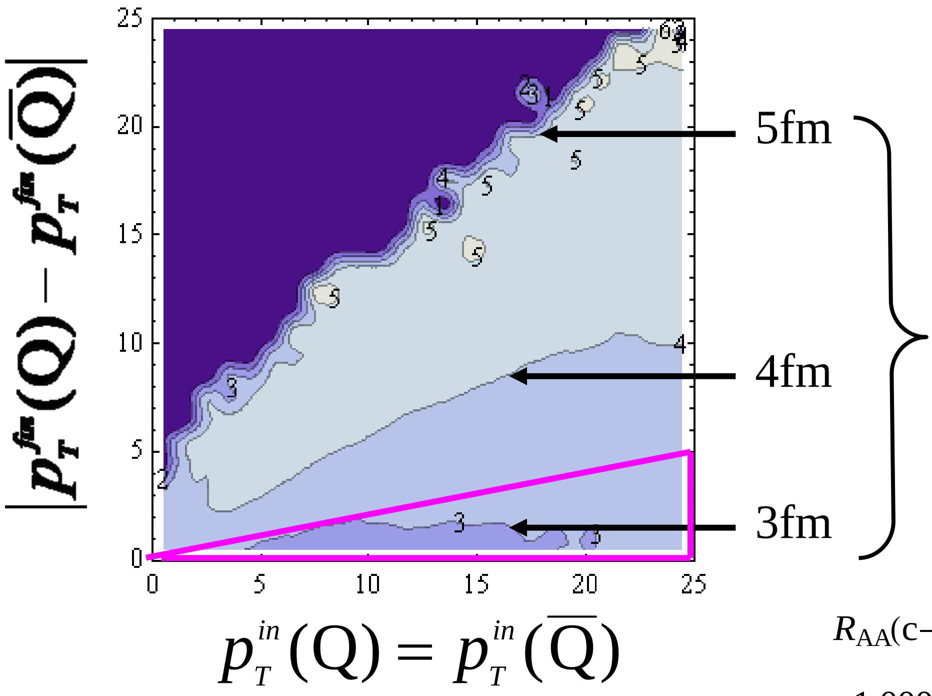
Possible caveat:



⇒ Need for a numerical study

Q-Qbar correlations (at RHIC):

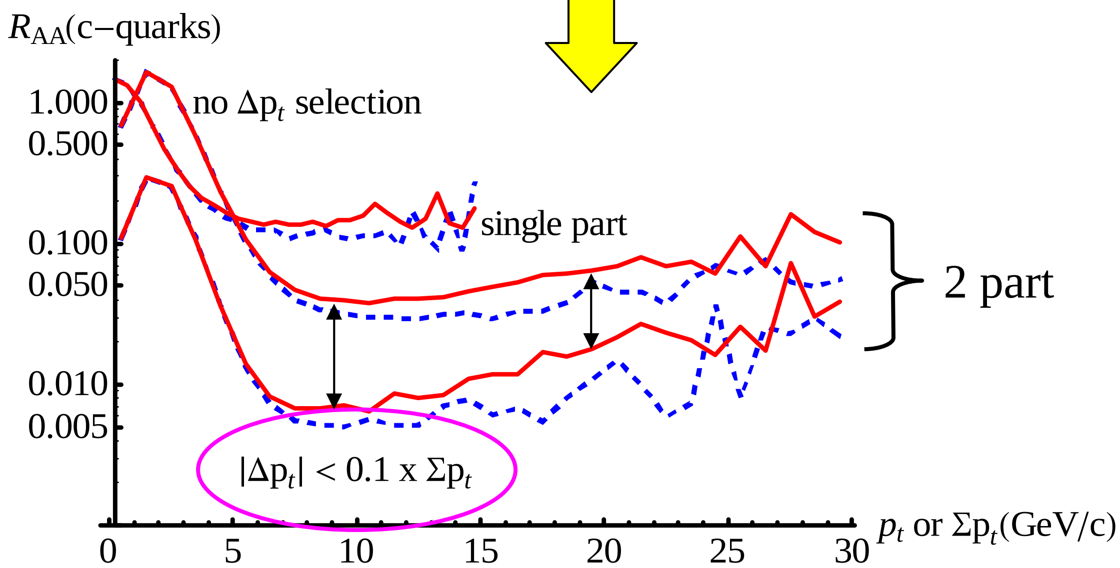
Average dist. to center



Privilege of simulation: retain Q and Qbar from the same "mother" collision (exper.: background substraction)

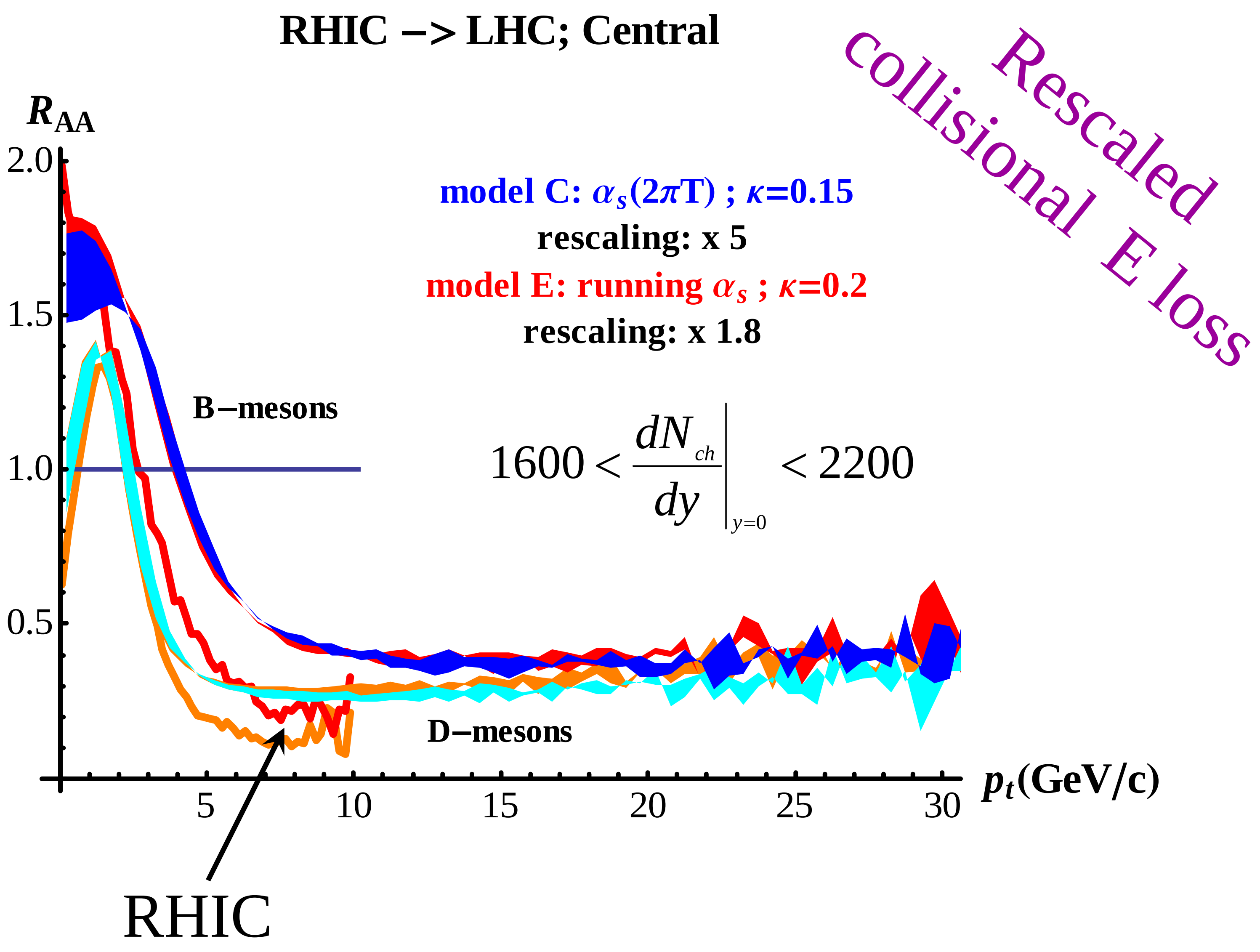
Indeed some (favorable) bias for init p_T > 5GeV/c

Some hope to discriminate between "running" and "non running" models (From the theorist point of view at least)

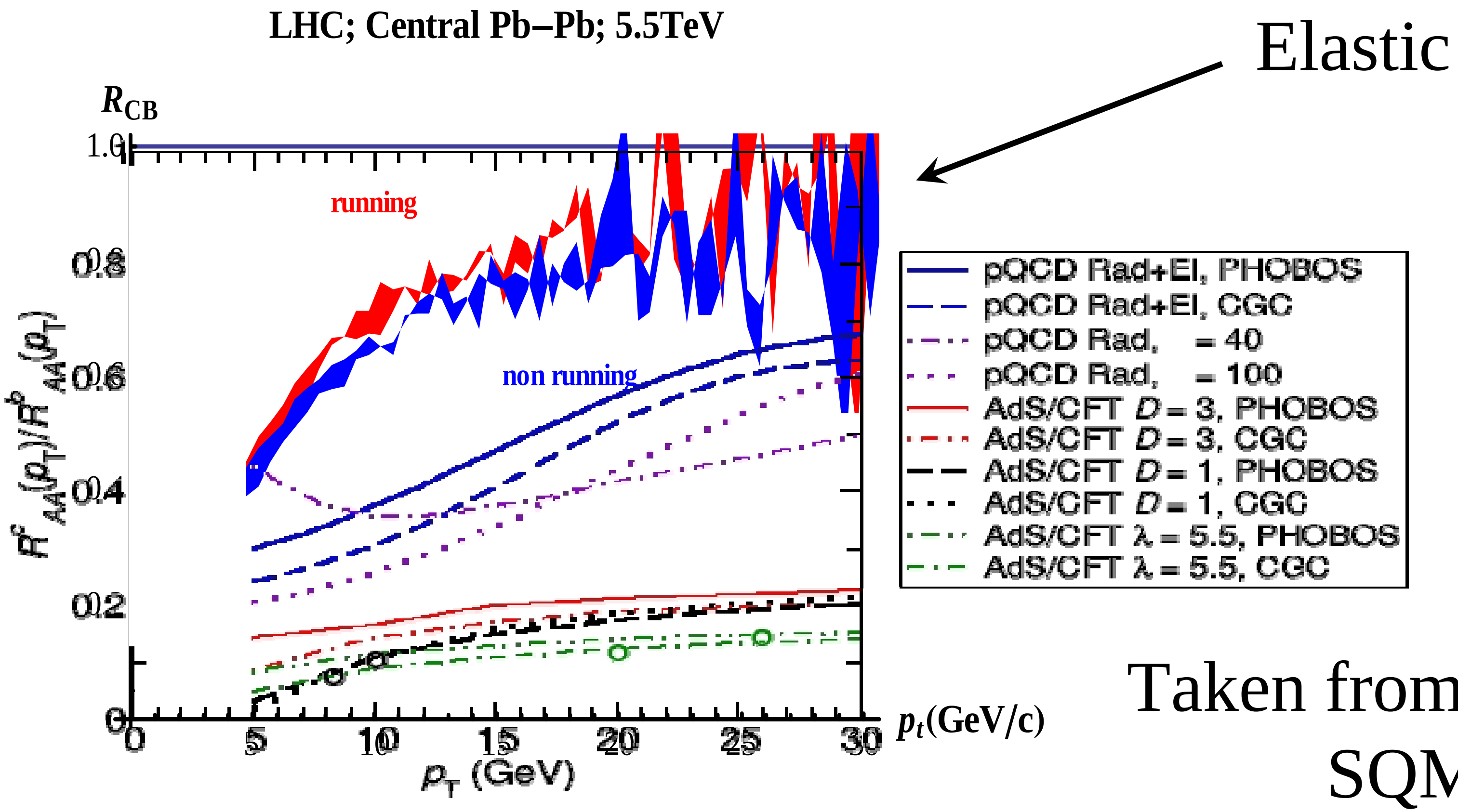


Towards… LHC

D & B mesons at LHC



R_{CB} at LHC



Taken from Horowitz SQM07

At least, Clear distinction between various models