Jet Flavor Tomography of the sQGP at RHIC and LHC

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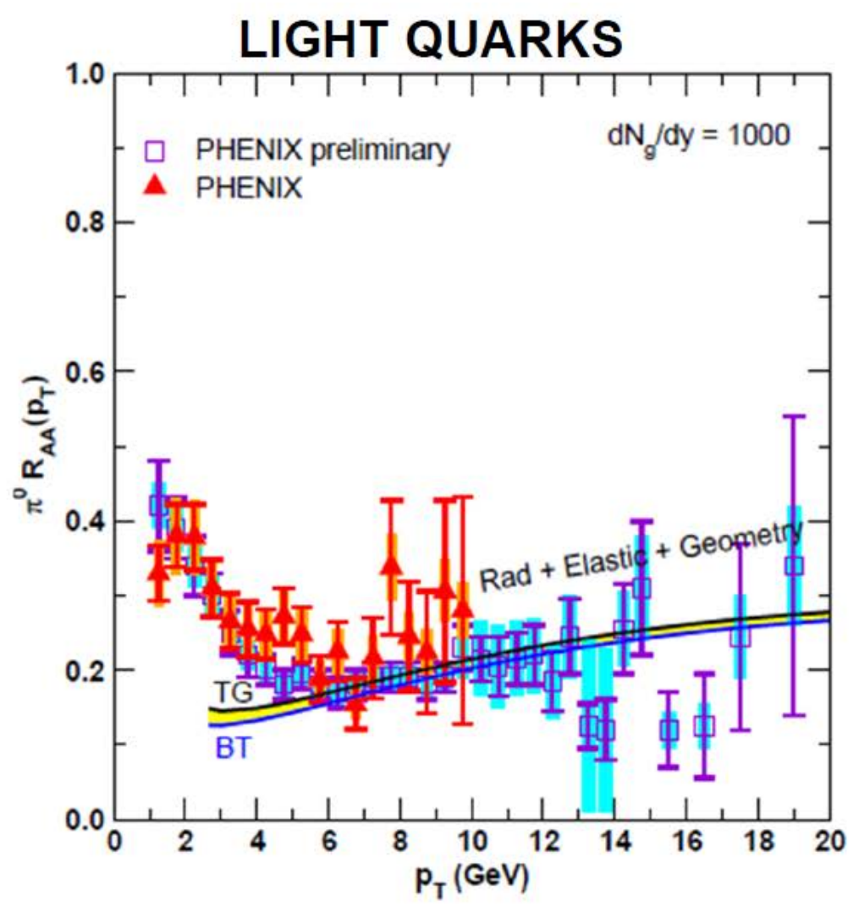
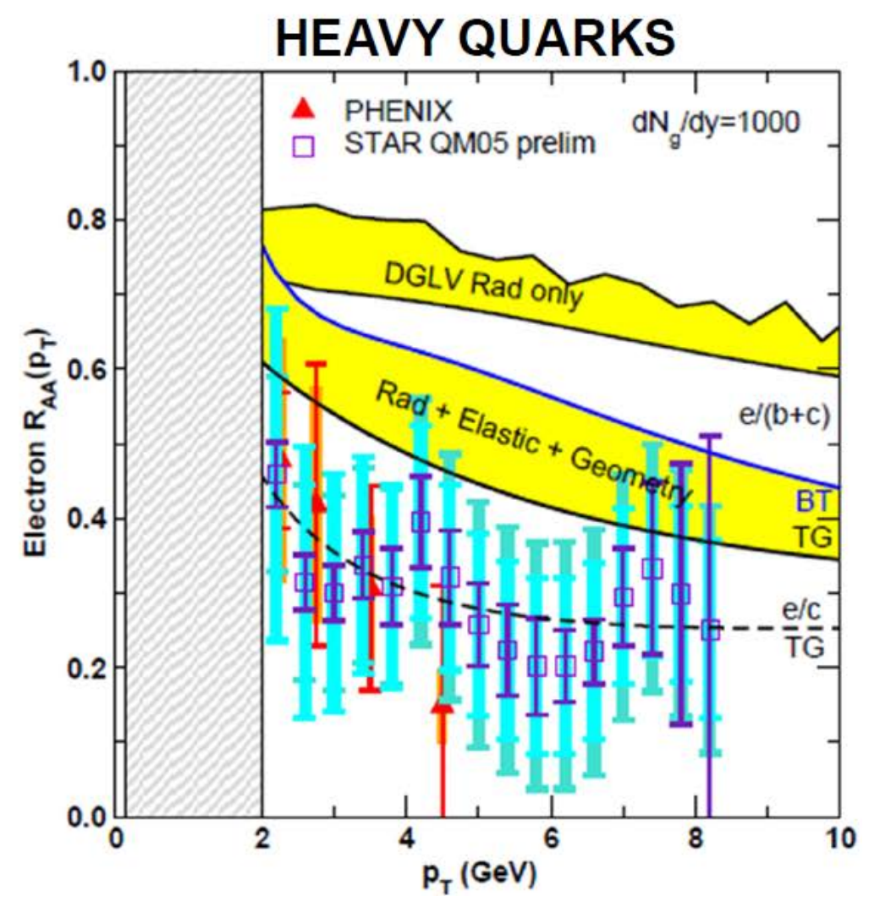
Motivation

Perturbative QCD approaches to energy loss in Quark-Gluon Plasma have proven able to fit the pion R_{AA} at RHIC energies ($\sqrt{s} = 200\ AGeV$), but consistent extrapolation into the LHC range has shown significant disagreement with the experimental data.
The long-standing puzzle of heavy quark jet quenching observed at RHIC, despite numerous attempts to relatively increase the energy loss of c and b quarks in the medium with respect to light partons, still remains unresolved [2].





Whether proposed gravity dual holographic descriptions should ultimately take over pQCD models of the energy loss mechanism strongly depends on the ability to successfully settle the issues raised above.

BWHDG Monte Carlo [1]

Focusing on strictly Hard Thermal Loop QCD dynamical effects, we developed a numerical Monte Carlo tool to implement dynamical (magnetic) scattering effects and to significantly improve the way geometrical effects are taken into account in the numerical computations.
Relevant features, neglected in earlier works, comprise:

- new effective magnetic enhanced potential:

$$\bar{v}^2(z,\boldsymbol{q};r_m) = \frac{\mu_e(z)^2\mathcal{N}(r_m)}{\pi}\frac{1}{(\boldsymbol{q}^2+\mu_e^2(z))(\boldsymbol{q}^2+r_m^2\mu_e^2(z))}$$

- possibility to generalize for high order corrections in the opacity series;
- full τ integration over a one dimensional Bjorken expanding participant density profile
(here for $r_m = 0$ [4]):

$$\frac{dN_g}{dx_+}(x,\phi) = \frac{C_R\alpha_s}{\pi}\int d\tau \frac{d^2k}{\pi}\frac{d^2q}{\pi}\frac{1}{x_+}\frac{\frac{9}{2}\pi\alpha^2}{\boldsymbol{q}^2(\boldsymbol{q}^2+\mu^2(\tau))}$$
$$\times\frac{2(\boldsymbol{k}+\boldsymbol{q})}{(\boldsymbol{k}+\boldsymbol{q})^2+\chi(\tau)}\left(\frac{(\boldsymbol{k}+\boldsymbol{q})}{(\boldsymbol{k}+\boldsymbol{q})^2+\chi(\tau)}-\frac{\boldsymbol{k}}{\boldsymbol{k}^2+\chi(\tau)}\right)$$
$$\times\left(1-\cos\left(\frac{(\boldsymbol{k}+\boldsymbol{q})^2\chi(\tau)}{2x_+E}\tau\right)\right)\rho_{QGP}(\boldsymbol{x}+\boldsymbol{v}\tau,\tau)$$

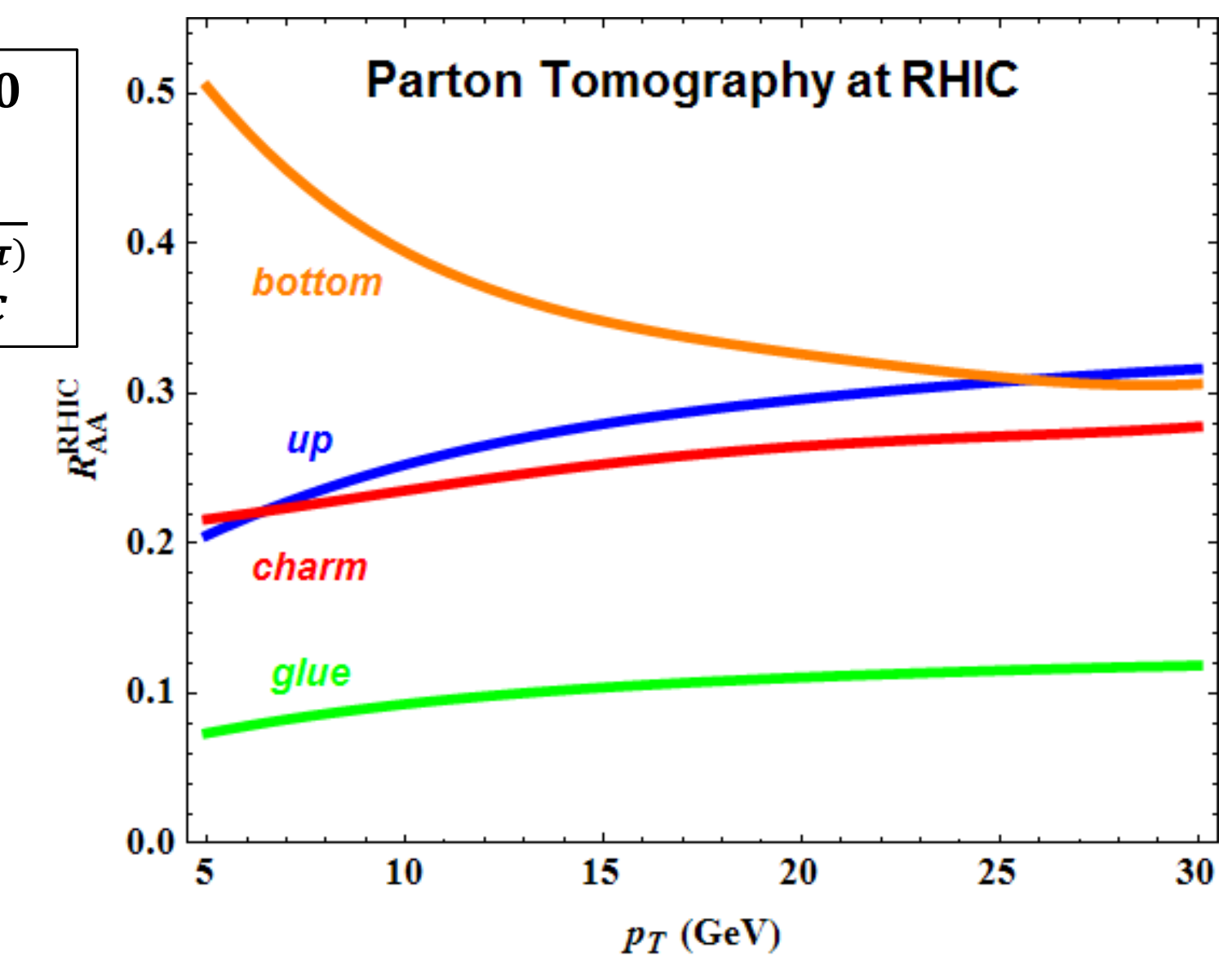
- estimate of the uncertainties due to the modeling of the initial transient time τ_0 and final decoupling τ_f:

$$\rho_{QGP}(x,\tau) = \frac{dN/dy}{N_{part}}\frac{\rho_{part}(x)}{\tau_0}f(\tau/\tau_0)$$

- inheritance of the WHDG [3] features beyond radiative energy loss (DGLV [3]): Poissonian radiated gluon number fluctuations, Gaussian fluctuations of elastic energy loss (Thoma-Guylassy model [5])
- full incorporation of LO pQCD initial quark production spectra in the computation of R_{AA}, without resorting to a local logarithmic spectral index approximation:

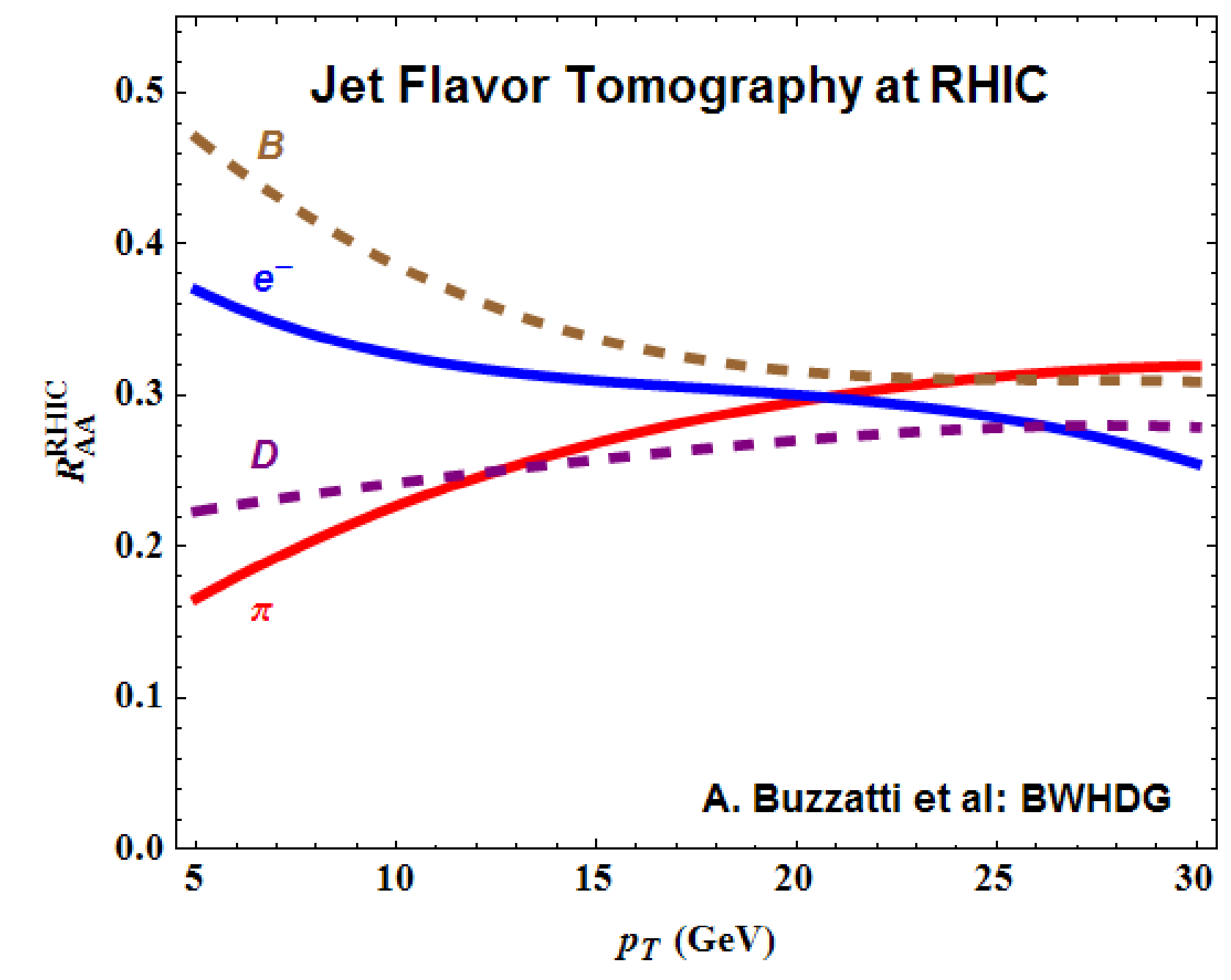
$$\frac{d\sigma_f(p_f)}{dyd^2p_f} \equiv R_{AA}(p_f)\frac{d\sigma_0(p_f)}{dyd^2p_f} = \int\frac{d\phi}{2\pi}d\boldsymbol{x}\,\rho_{Jet}(\boldsymbol{x})\int d\epsilon$$
$$\times\left(\frac{d^2p_i}{d^2p_f}\right)\frac{d\sigma_0(p_i=p_f/(1-\epsilon))}{dyd^2p_f}\ P(\boldsymbol{x},\phi;p_i,\epsilon)$$

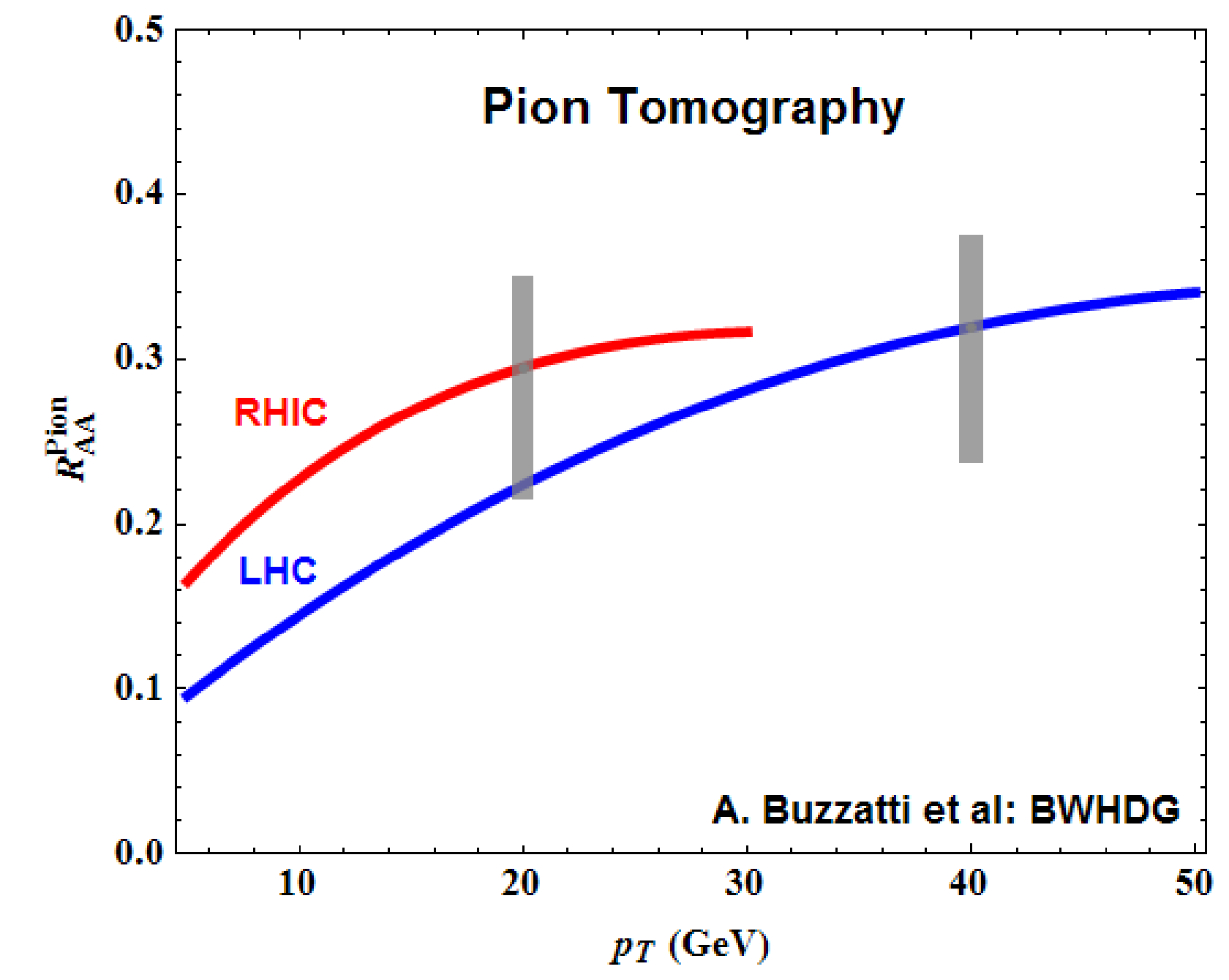
$dN/dy = 1000$
$\alpha_s = 0.3$
$f(\tau/\tau_0) = \frac{\tau_0}{(\tau_0+\tau)}$
$\tau_0 = 0.5\ fm/c$



Heavy quark jet quenching puzzle at RHIC

In the parton R_{AA} (above) we can notice two effects: the anomalous quenching of charm and even bottom quarks at high p_T compared to up quark jets, and the mass splitting between c and b jets.
This leads to a difference between pion and electron R_{AA} (below) which is still wide at very low p_T but vanishes for values above ~15 GeV.
Isolating and observing experimentally the charged B and D mesons will be critical in differentiating pQCD and holographic gravity dual models of jet-plasma interactions.

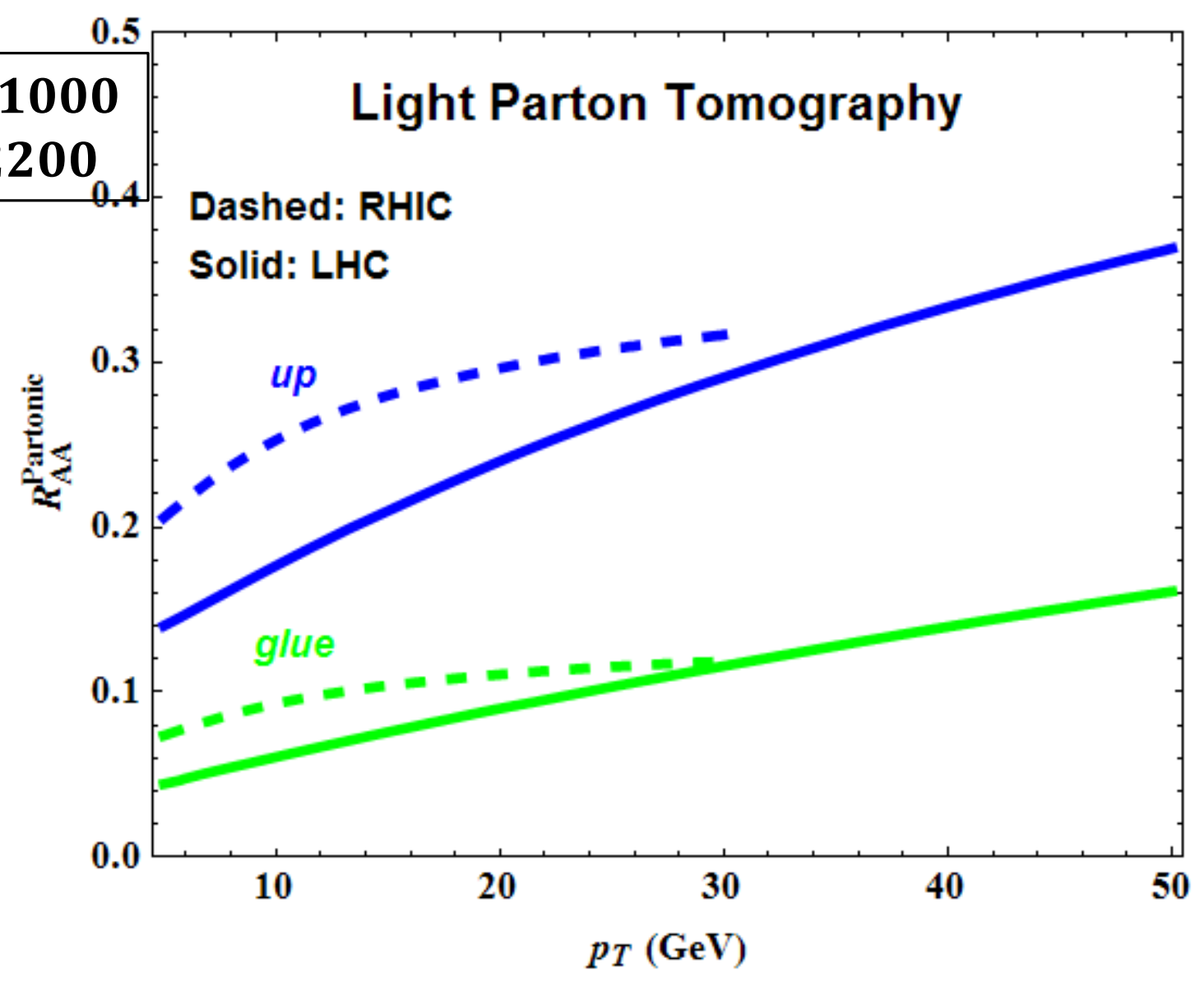




Pion RAA at LHC energies

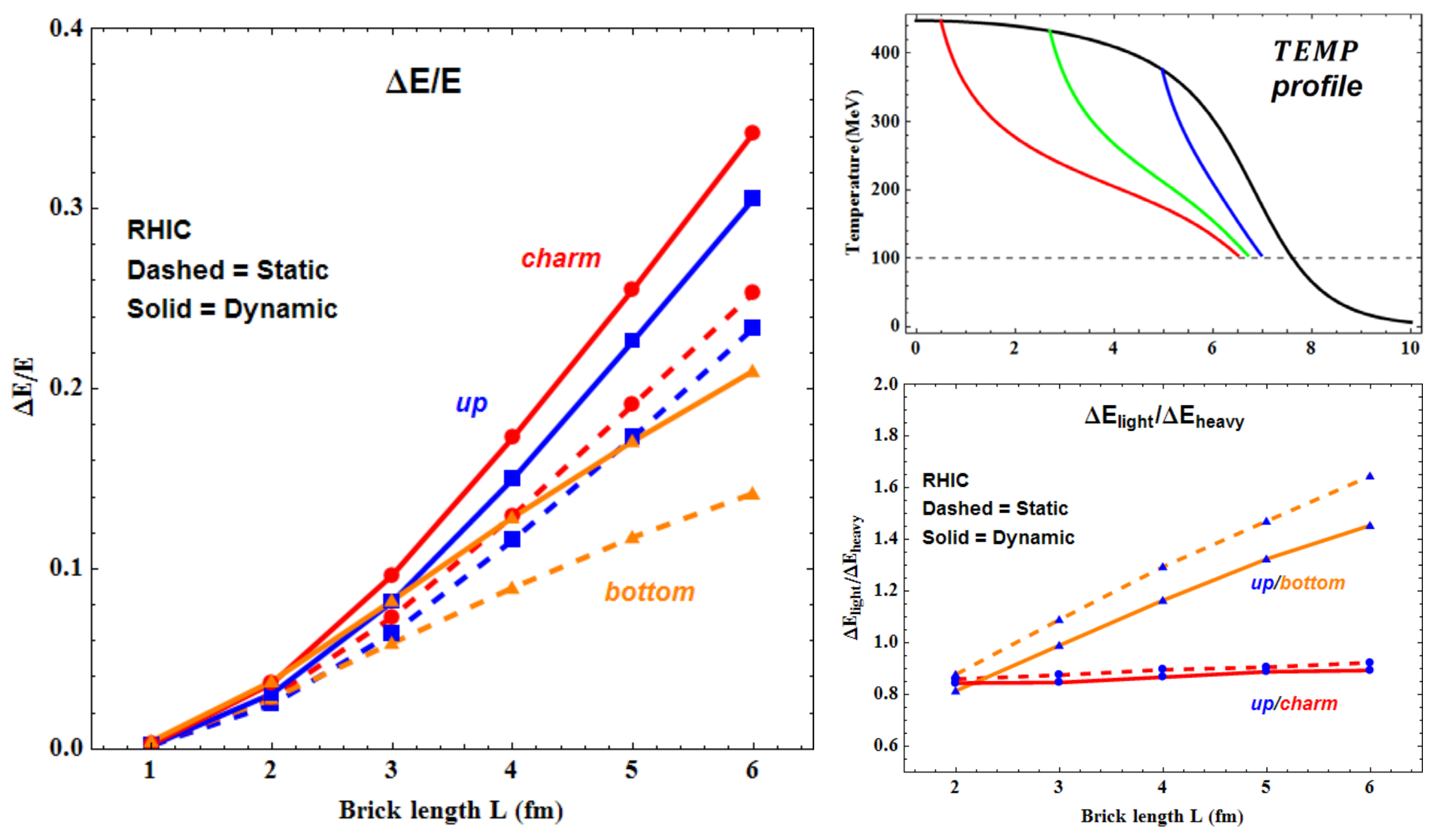
The pion R_{AA} at RHIC and LHC (above) are sensibly different, the latter being suppressed by the increased energy loss in a denser plasma. Fixing R_{AA}(RHIC) to fit PHENIX data, we notice that R_{AA}(LHC) lies at the edge of the ALICE systematic error range of charged hadron R_{AA}.
The sensitivity to the initial proper time parameter τ_0 leads to a remarkable though correlated uncertainty evidenced by the grey error bars.
From the parton R_{AA} (below), we see how the gluons almost do not contribute to the pion yield.

$dN^{RHIC}/dy = 1000$
$dN^{LHC}/dy = 2200$

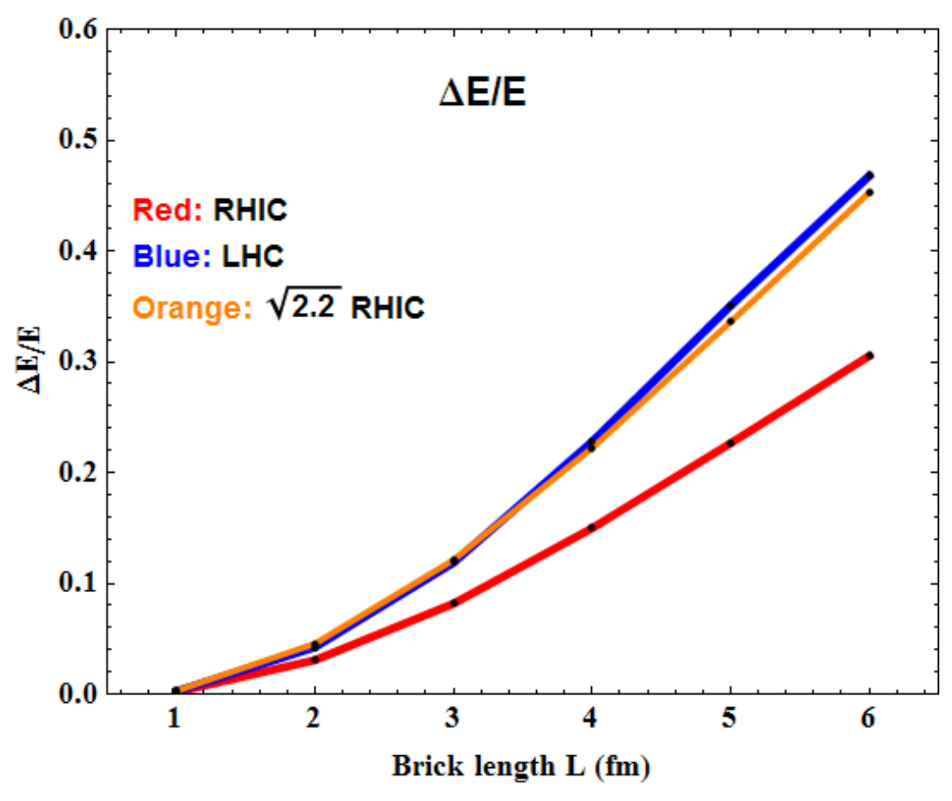


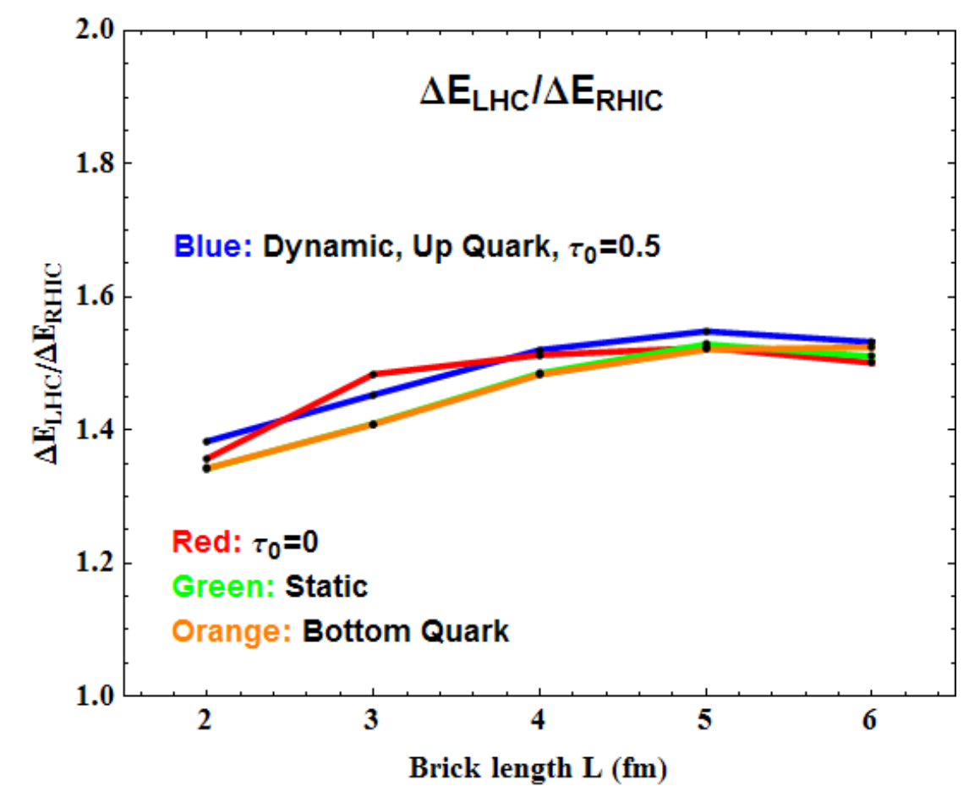
In details: the expanding brick exercise

We present here a brief analysis of the dynamical model used in the previous computations with respect to the static DGLV potential. We use a transversally expanding brick setup with a non uniform initial density profile, which we let vary mimicking the difference between RHIC and LHC conditions.



The energy loss computed using the dynamical model is significantly greater (by approximately 50%), even though the mass splitting is quite negligible.
We observe a similar behavior between light and charm quarks, implying that the anomalous charm R_{AA} seen above is mostly determined by the effects of a steeper spectral distribution.
Raising the density by a factor of 2.2 (opacity fixed by dNdy=2200 (LHC) instead of 1000 (RHIC), in the following plots), we observe a scaling of the energy loss approximately equal to $\sqrt{2.2}$, independent of τ_0, of the potential (static or dynamic), and of the mass of the propagating quark.





Conclusions

The implementation of dynamical scattering effects, limited here at first order in opacity but easily generalizable to higher order corrections, alongside with an improved inclusion of geometrical effects, allows us to fit RHIC R_{AA} with $dN/dy = 1000$ and $\alpha_s = 0.3$.
Features such as the anomalous charm R_{AA} and the crossover between electron and pion R_{AA} at ~15 GeV arise. The results are affected by large uncertainties due to the modeling of the thermalization process (τ_0).
We observe the splitting between RHIC and LHC pion R_{AA}.

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