Influence of a realistic medium description and fluctuations on heavy quark observables

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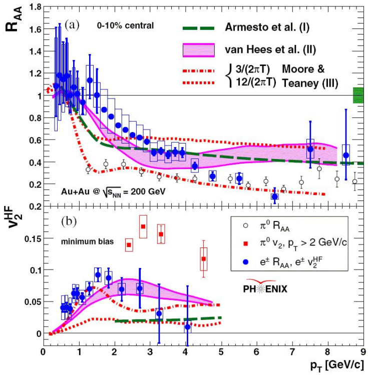
with Pol Bernard Gossiaux, Klaus Werner, Jörg Aichelin

Medium induced energy loss of heavy quarks

RHIC results from Phenix

heavy quarks significantly interact with the QGP medium



- nuclear modification factor:

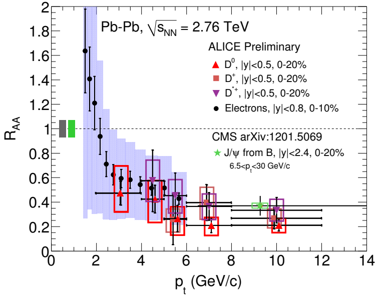
$$R_{AA} = \frac{\mathrm{d}\sigma_{AA}/\mathrm{d}p_t}{N_{bin}\mathrm{d}\sigma_{pp}/\mathrm{d}p_t}$$

- low p_t: thermalization of heavy quarks with the medium?
- high p_t: elastic collisions + gluon bremsstrahlung $\Rightarrow$ energy loss
- v_2 of heavy quarks from p_t-broadening and flow of the medium

no distinction between c and b quarks

Medium induced energy loss of heavy quarks

first preliminary LHC results from ALICE/CMS

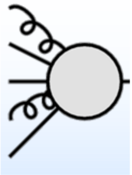


Opportunities:

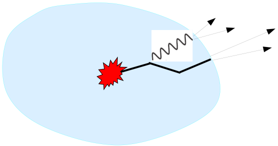
- distinguish between c and b quarks
- clarify contribution from collisional and radiative energy loss?

Setup for heavy quark propagation

initialization:



propagation in the medium and hadronization:



- production process
- cold nuclear matter effects

- interaction with the medium
- medium properties

- hadronization process
- medium modifications

MC@sHQ (remember Pol's talk!)

P. B. Gossiaux, R. Bierkandt and J. Aichelin, Phys. Rev. C **79** (2009) 044906, P. B. Gossiaux and J. Aichelin, Phys. Rev. C **78** (2008) 014904

Setup for heavy quark propagation

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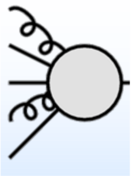
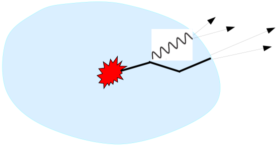


propagation in the medium and hadronziation:



- production process
- cold nuclear matter effects

- interaction with the medium
- medium properties

- hadronization process
- medium modifications

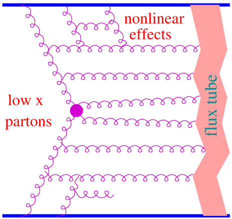
MC@sHQ (remember Pol's talk!)
+
EPOS (remember Klaus' talk!)

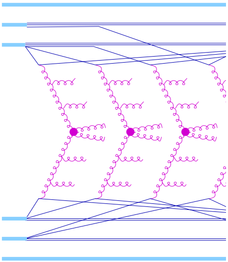
P. B. Gossiaux, R. Bierkandt and J. Aichelin, Phys. Rev. C **79** (2009), P. B. Gossiaux and J. Aichelin, Phys. Rev. C **78** (2008))

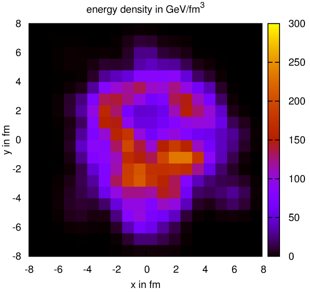
K. Werner, I. .Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, arXiv:1203.5704 [nucl-th])

EPOS initial conditions

- multiple scattering approach
- elementary scattering corresponds to parton ladder
- parton ladder is identified with a flux tube
- high density of flux tubes in AA collisions
- string breaking due to $\bar{q}q$ production
- slow string segments, far from the surface, are mapped to fluid dynamic fields







Pb+Pb at 2.76 TeV, central

K. Werner, I. .Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, arXiv:1203.5704 [nucl-th])

EPOS - comparison with data

EPOS describes various experimental results from the light sector

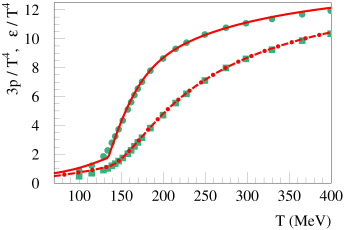
- transverse momentum distributions (π, K, p) for different centralities
- pseudorapidity distributions of charged particles for different centralities
- charged particle R_{AA}
- dihadron correlations, ridge at high p_t
- flow coefficients
- Λ/K ratio

$\Rightarrow$ fluid dynamic medium to use as a background for the propagation of heavy quarks!

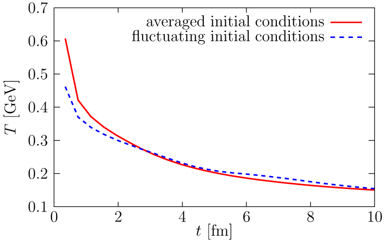
EPOS - medium evolution

- non-viscous fluid dynamic evolution
- equation of state from lattice

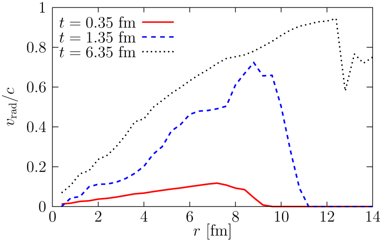
(Wuppertal-Budapest)



temperature evolution

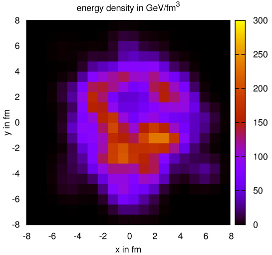


radial velocity



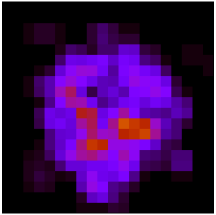
Pb+Pb at 2.76 TeV, central

initialized at the spatial points of nucleon-nucleon collisions in EPOS:

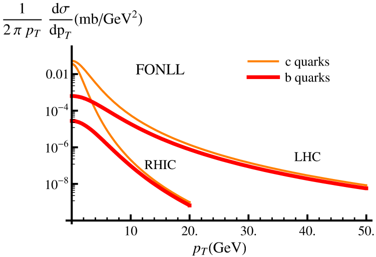


← ini. energy density

NN coll. distribution →



- momentum distribution (FONLL)
- relative contribution of b to c quarks from FONLL : $\sigma_{\bar{b}b}/\sigma_{\bar{c}c} = 7 \cdot 10^{-3}$



M. Cacciari and P. Nason PRL **89** (2002); M. Cacciari et al. JHEP **0407** (2004)

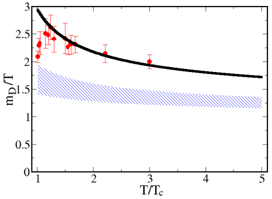
IR divergence of t-channel diagram → regulator in the gluon propagator:

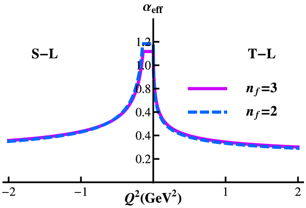
$$\frac{1}{t} \rightarrow \frac{1}{t-\mu^2}$$

$\mu \simeq$ Debye screening mass m_D

evaluate m_D self-consistently:
$\tilde{m}_D^2 = (1+6n_f)4\pi\alpha(\tilde{m}_D^2)T^2$

(A. Peshier, hep-ph/0601119; lattice data: O. Kaczmarek)





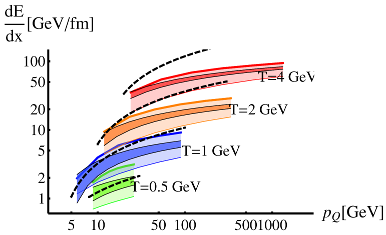
define an effective running $\alpha_{\rm eff}(Q^2)$ coupling, which is finite in the infrared

Dokshitzer (2002)

replace in the gluon propagator:

$$\frac{\alpha_{\text{eff}}(t)}{t} \to \frac{\alpha_{\text{eff}}(t)}{t - \kappa \tilde{m}_D^2}$$

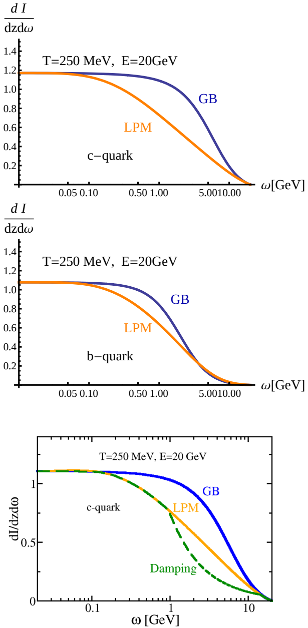
- choose $\mu^2 = \kappa m_D^2$ with the self-consistent m_D
- $\kappa \simeq 0.11$ from calibrating $\frac{dE}{dx}$ to HTL calculation (Braaten-Thoma).



A. Peshier, PRL **97** (2006); S. Peigne and A. Peshier PRD **77**, 114017 (2008)

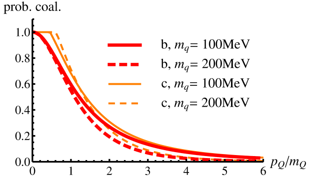
Radiative energy loss

- radiative energy loss (gluon bremsstrahlung) expected to be dominant for large *E*
- incoherent radiation: Gunion-Bertsch spectrum
- QCD-analogon to the LPM-effect (coherent radiation): BDMPS-Z decoherence of radiated gluon and original parton by transverse kicks from the medium
- influence of gluon damping (remember Marcus' talk!)



Hadronization

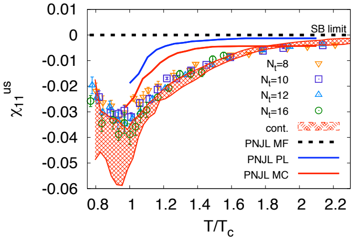
- form D/B mesons at the end of the evolution by either coalescence or fragmentation
- physical picture: b quarks at rest in a fluid cell hadronize ONLY by coalescence
- coalescence probability:

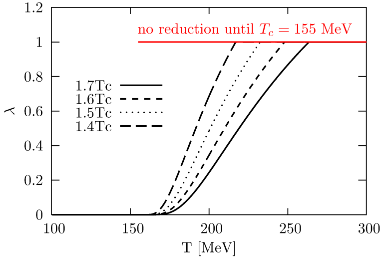


- heavy quarks which do not coalesce fragment M. Cacciari et al., PRL **95** (2005)
- subsequent decay into electrons
- uncertainty in p_t where b starts to dominate

Hadronic bound states above Tc

assumption: no energy loss in the hadronic phase
energy loss is reduced if there are hadronic bound states above $T_c = 155$ MeV.



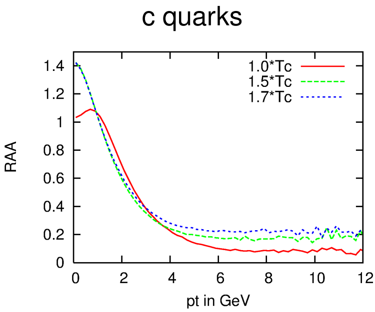


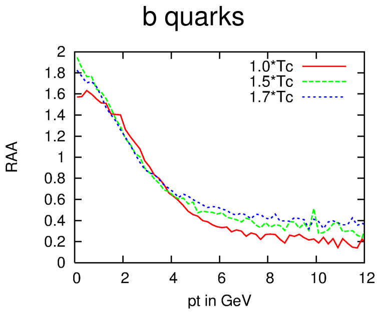
Ratti et al., Phys. Rev. D **85** (2012) 014004

use an exponential decrease of the fraction of partonic degrees of freedom

(caution: thermalized heavy quarks should form hadronic bound states at even larger temperatures, successive formation and dissociation of D- and B- mesons in the medium (Adil/Vitev, van Hees), ...)

RHIC R_{AA} quarks

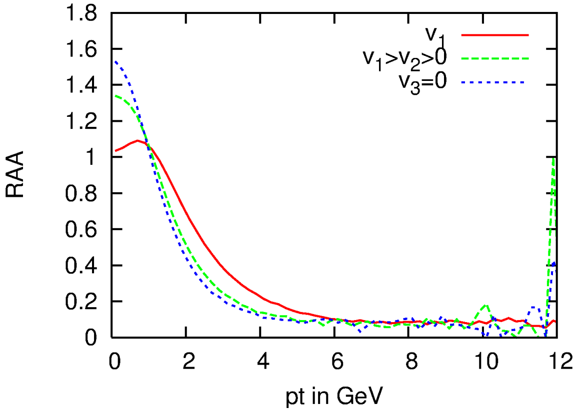




- Hadronic bound states above T_c reduce the energy loss at high p_t.
- Reduction of the interaction with the medium leads to more thermalization...

RHIC - influence of initial radial velocity

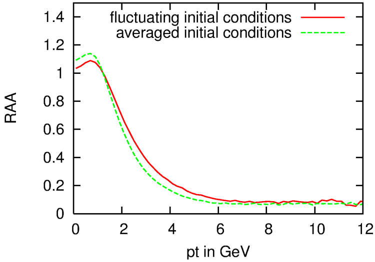
central, R_{AA} of c quarks, no reduction due to hadronic bound states

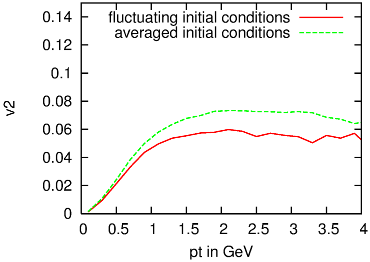


- Highly sensitive to the initial flow in the low- and intermediate-p_t regime!
- A reduction of the interaction also reduces the sensitivity to flow.

RHIC - influence of averaged initial conditions

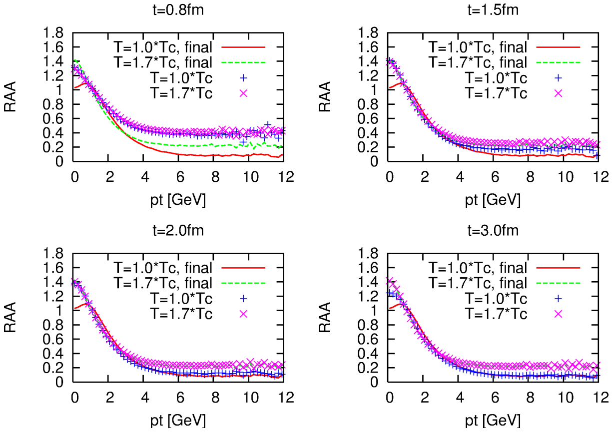
central, c quarks, no reduction due to hadronic bound states





- More thermalization for smoother initial conditions!
- More quenching in smoother initial conditions at high-p_t?
- Enhanced flow for averaged initial conditions.

RHIC R_{AA} c quarks - time evolution

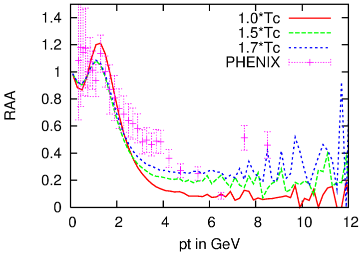


- At high p_t: R_{AA} builds up in the high-T phase.
- Low p_t R_{AA} changes in the later evolution when the interaction is not reduced.

RHIC R_{AA} heavy flavor electrons

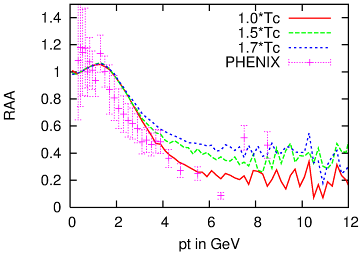
only fragmentation

electrons from D mesons



below the data for intermediate p_t

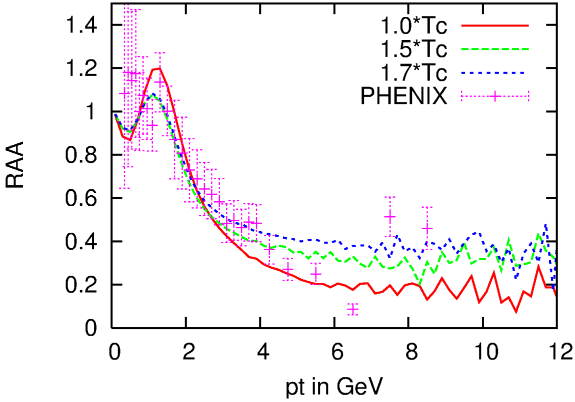
electrons from B mesons



slightly above the data for intermediate p_t

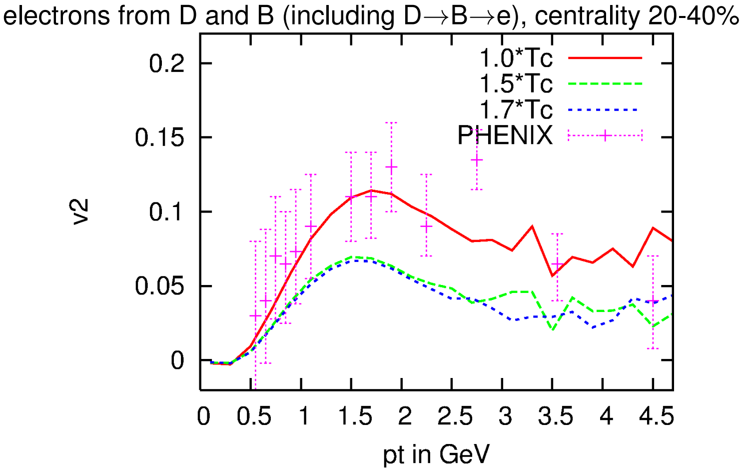
RHIC R_{AA} heavy flavor electrons

electrons from D and B (including D→B→e)



- quite good agreement with the data

RHIC v_2 heavy flavor electrons

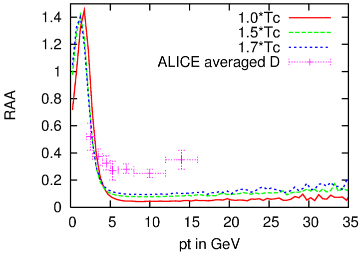


- Stronger flow when the interaction is not reduced.
- Probably strong influence on medium properties...

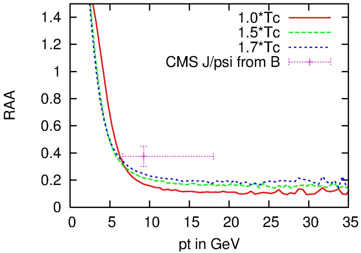
with the same ingredients in MC@sHQ as for RHIC
warning: no nuclear shadowing implemented so far...

central 0-10%, DATA: 0-20%

D mesons



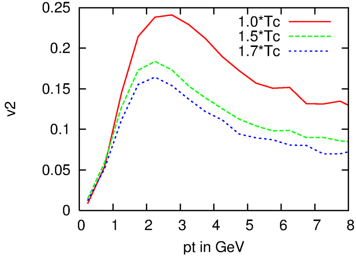
B mesons



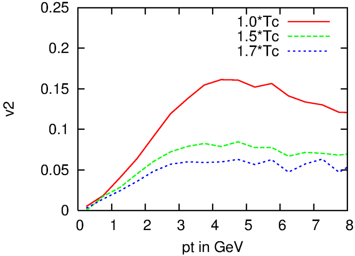
- Smaller effect of hadronic bound states above T_c.
- Too much quenching at LHC.

centrality 30-50%

D mesons



B mesons



- Hadronic bound states above T_c reduce the flow.

Conclusions

- heavy quark propagation (MC@sHQ) coupled to fluid dynamic expansion (EPOS)
- effect of hadronic bound states above T_c at all p_t:
  - less quenching at large p_t
  - less sensitivity to flow at low p_t
  - effect stronger at RHIC than at LHC
- low- and intermediate-p_t regime affected by medium properties, in particular initial conditions
  - initial radial velocity
  - initial fluctuations

many effects and observables to be studied!