Heavy quark observables in a fluid dynamic medium: complementarity RHIC/LHC

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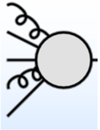
QGP France, Etretat, Septembre 2012

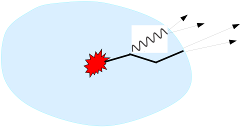
with Pol Bernard Gossiaux, Klaus Werner, Jörg Aichelin

Heavy quark propagation in the QGP

initialization:



propagation in the medium and hadronization:



- interaction with the medium

- production process

MC@sHQ

- hadronization process

- medium properties

fluid dynamics from Kolb/Heinz OR from EPOS initial conditions

P. B. Gossiaux, R. Bierkandt and J. Aichelin, PRC **79** (2009), P. B. Gossiaux and J. Aichelin, PRC **78** (2008); P. F. Kolb, U. W. Heinz,in Hwa et al., *Quark gluon plasma* 634-714; K. Werner, I. .Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, PRC **85** (2012)

Collisional energy loss

Running coupling and Debye mass

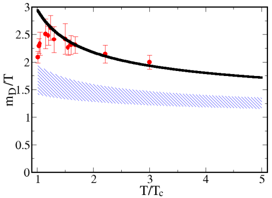
IR divergence of t-channel diagram → regulator in the gluon propagator:

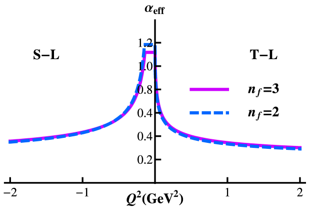
$$\frac{1}{t} \to \frac{1}{t-\mu^2}$$

$\mu \simeq$ 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 $\alpha_{\text{eff}}(Q^2)$ coupling, which is finite in the infrared

Dokshitzer (2002)

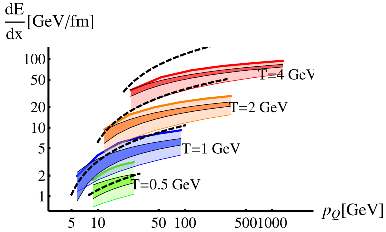
Collisional energy loss

Energy loss

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).



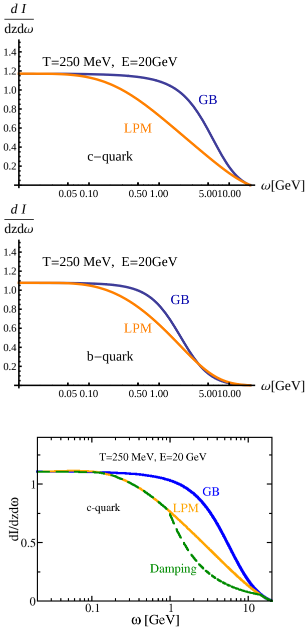
A. Peshier, PRL **97** (2006); S. Peigne and A. Peshier PRD **77**, 114017 (2008)

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 (not in this talk)

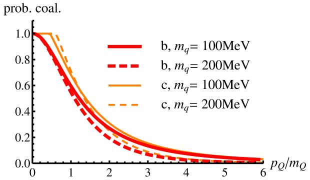
M. Bluhm, P. B. Gossiaux, J. Aichelin, PRL **107** (2011),

arXiv:1204.2469



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

The medium description

given by fluid dynamic simulations

Kolb/Heinz:

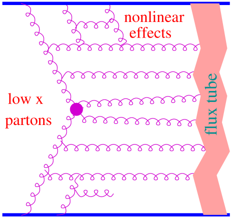
- non-viscous
- equation of state with a first order phase transition
- $2 + 1$ d
- zero initial radial velocity
- smooth initial conditions

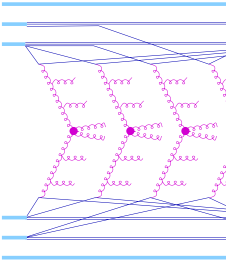
EPOS:

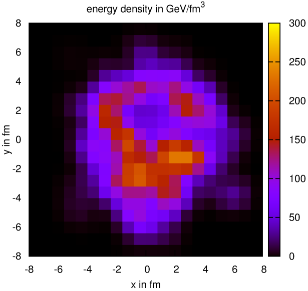
- non-viscous
- equation of state from lattice QCD
- $3 + 1$ d
- finite initial radial velocity
- event-by-event fluctuating initial conditions

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





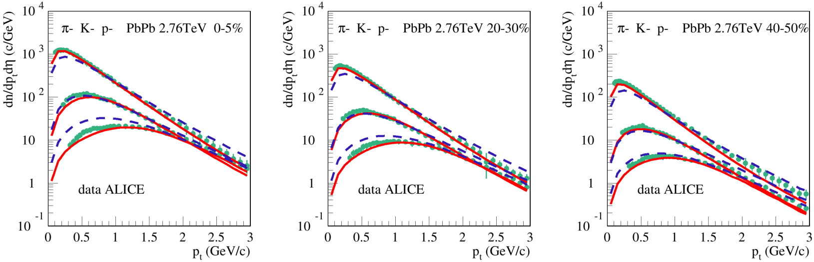


Pb+Pb at 2.76 TeV, central

(K. Werner, I. .Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, PRC **85** (2012))

EPOS - light quark sector

transverse momentum distributions (π, K, p) for different centralities

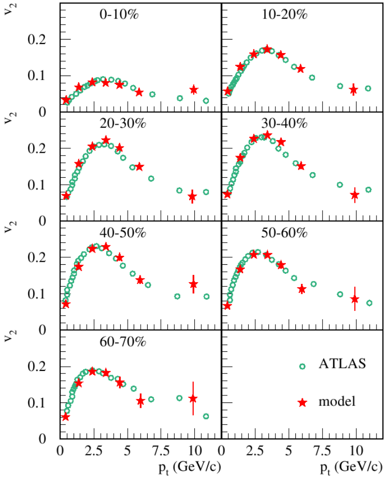


green: ALICA data
blue dashed: without hadronic cascade
red solid lines: full calculations

(K. Werner, I. .Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, PRC **85** (2012))

EPOS - light quark sector

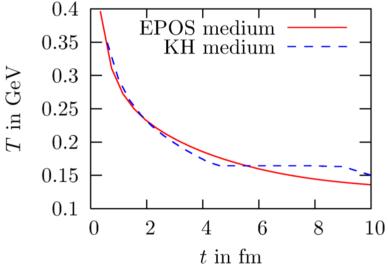
elliptic flow of charged particles
for different centralities



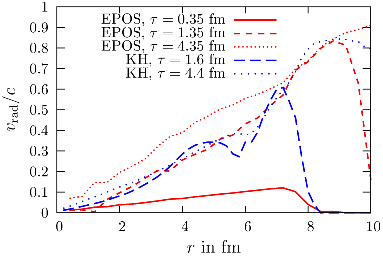
(K. Werner, I. .Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, PRC **85** (2012))

The medium description - temperature and velocities

temperature evolution (central RHIC)



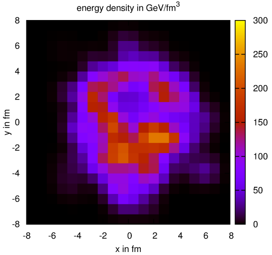
evolution of the radial velocity (central RHIC)



- first order phase transition in Kolb/Heinz
- higher initial temperatures in the EPOS medium
- EPOS medium develops larger radial velocities

Initialization of heavy quarks

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

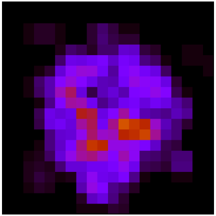


←

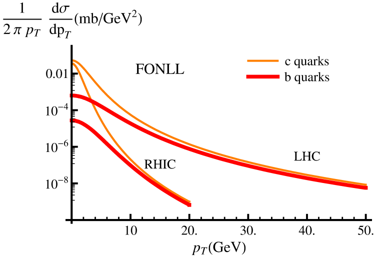
ini. energy density

NN coll. distribution

→



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

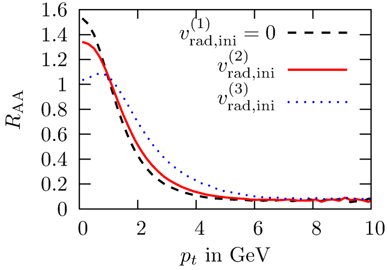


M. Cacciari and P. Nason PRL **89** (2002); M. Cacciari et al. JHEP **0407** (2004)

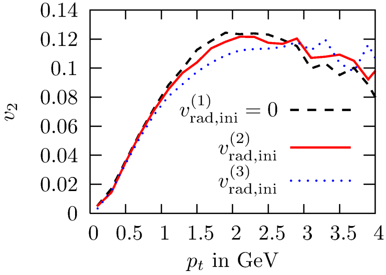
Influence of the initial radial velocity

- EPOS medium averaged over initial fluctuations
- stop the evolution at $T \simeq 155$ MeV
- c quarks, RHIC

R_{AA}, central



elliptic flow, $b = 7$ fm

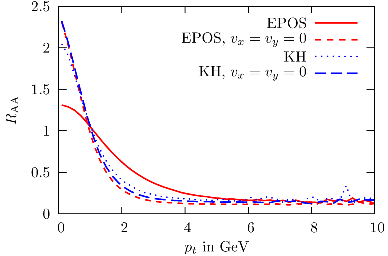


- larger radial velocity shifts the peak in the R_{AA} towards larger p_t
- at smaller p_t the elliptic flow is smaller for larger initial radial velocity.

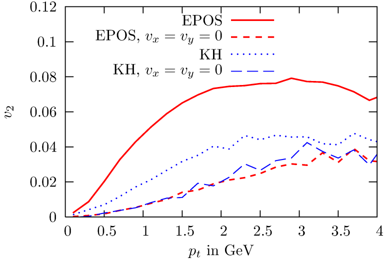
Influence of the initial radial velocity

- comparing the Kolb/Heinz and the EPOS medium (averaged over initial fluctuations)
- stop the evolution above the phase transition ($T \simeq 168$ MeV)
- set radial velocities to zero by hand
- c quarks, RHIC

R_{AA}, central



elliptic flow, $b = 7$ fm

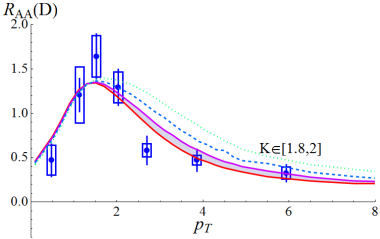


Different flow patterns significantly influence the heavy quark observables in both media!

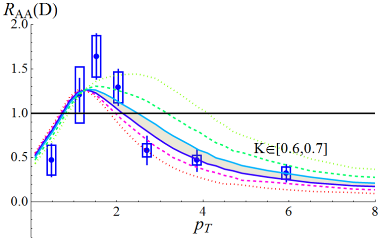
Kolb/Heinz at RHIC

- Allow for one extra parameter: K (cranking of the interaction rate) to quantify neglected effects, e. g. missing resummations,...

only collisional energy loss



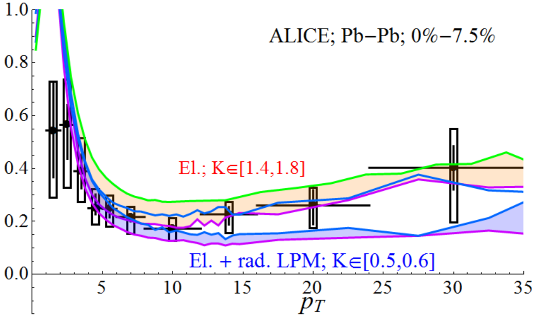
collisional+radiative energy loss



- good agreement with the 0-10% D mesons data from RHIC
- distinction between purely collisional or collisional plus radiative energy loss not possible

Kolb/Heinz at LHC

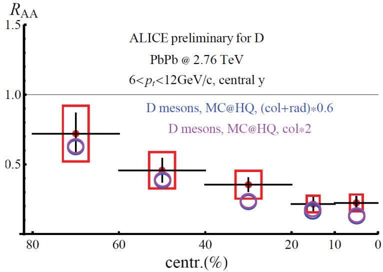
- same microscopic ingredients as for RHIC
- shadowing effects are not included yet



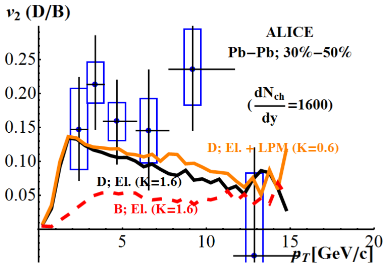
- good agreement with ALICE data with slightly decreasing rates
- better agreement with purely collisional energy loss!
- R_{AA} stays flat including radiative energy loss

Kolb/Heinz at LHC

dependence on centrality



elliptic flow

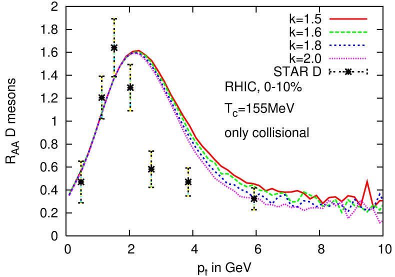


- good agreement over many centralities
- possible hadronic contribution to the flow (not included in our approach)

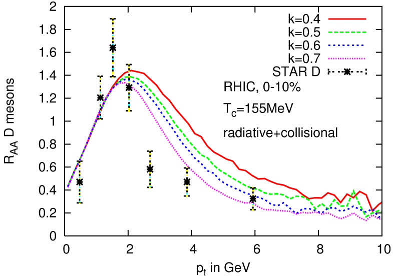
EPOS at RHIC

central collisions, nuclear modification factor of D mesons

only collisional



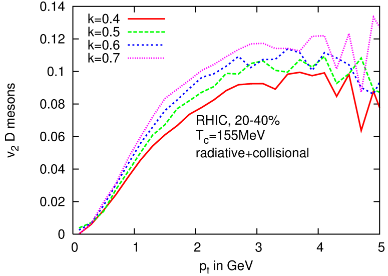
collisional+radiative



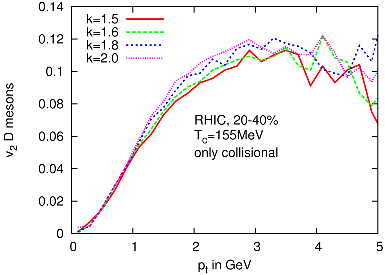
- similar behaviour in EPOS as in Kolb/Heinz
- slight discrepancy at small-intermediate p_t (radial flow?)

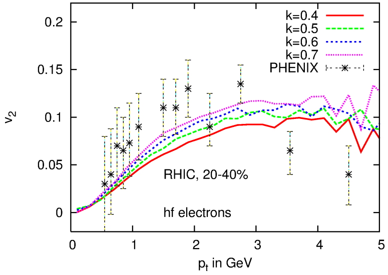
EPOS at RHIC

collisional+radiative



only collisional



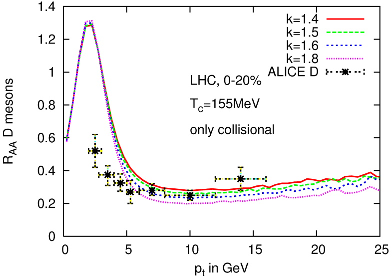


20-40% centrality, elliptic flow of D mesons and hf electrons

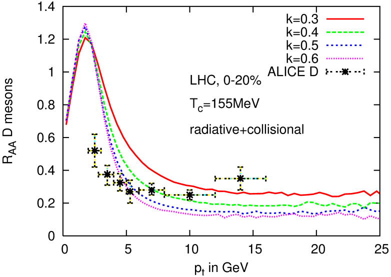
EPOS at LHC

central collisions, nuclear modification factor of D mesons

only collisional



collisional+radiative

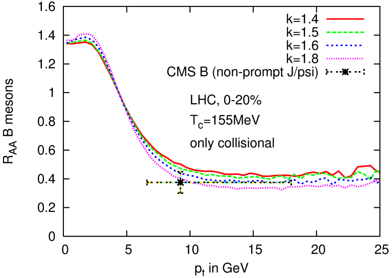


- same trends as in Kolb/Heinz
- slightly lower K-factor needed to reproduce data at large $p_t \rightarrow$ slightly more quenching power in the EPOS medium
- discrepancy at small-intermediate $p_t \rightarrow$ important to take shadowing into account

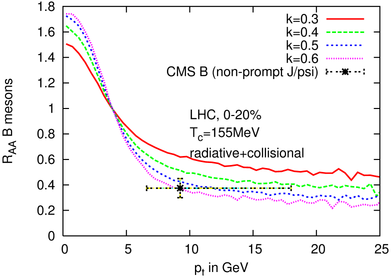
EPOS at LHC

central collisions, nuclear modification factor of B mesons

only collisional



collisional+radiative

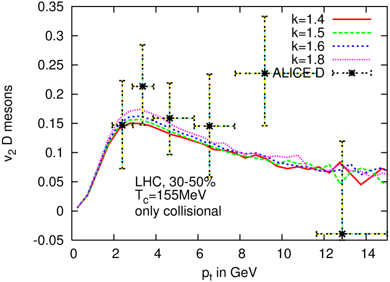


- quenching of B mesons is smaller than that of D mesons

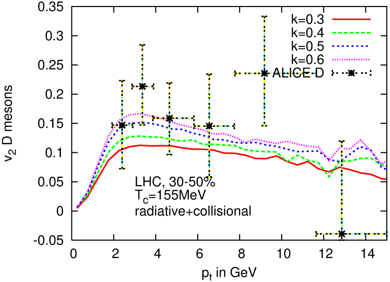
EPOS at LHC

30-50% centrality, elliptic flow of D mesons

only collisional



collisional+radiative

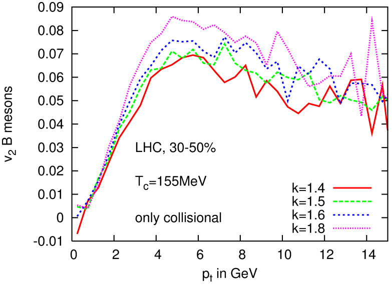


- good agreement with the data, but allowing still for contributions from the hadronic phase

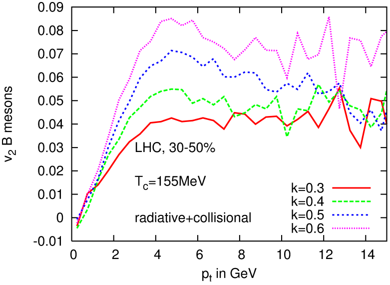
EPOS at LHC

30-50% centrality, elliptic flow of B mesons

only collisional



collisional+radiative



Conclusions

- heavy quark propagation (MC@sHQ) coupled to fluid dynamic expansion (EPOS)
- influence of the initial radial velocity and the flow which develops during the evolution
  - more flow in EPOS shifts the heavy quark spectra to higher p_t.
- *both*, R_{AA} and v_2, are in good agreement with the new data for D mesons at RHIC and LHC
- purely collisional energy loss can better reproduce the data at high p_t
- using a more realistic medium description allows for shadowing effects.

many more effects (e. g. interplay between EOS and HQ energy loss) and observables to be studied!