New Challenges for open HF physic in URHICs

Yifeng Sun

INFN-LNS

Istituto Nazionale di Fisica Nucleare

In collaboration with:

S. Plumari, S. K. Das, V. Minissale, G. Coci, M. Ruggieri, V. Greco

Outline

✧ HF dynamics in QGP: estimates of T dependence of D_s

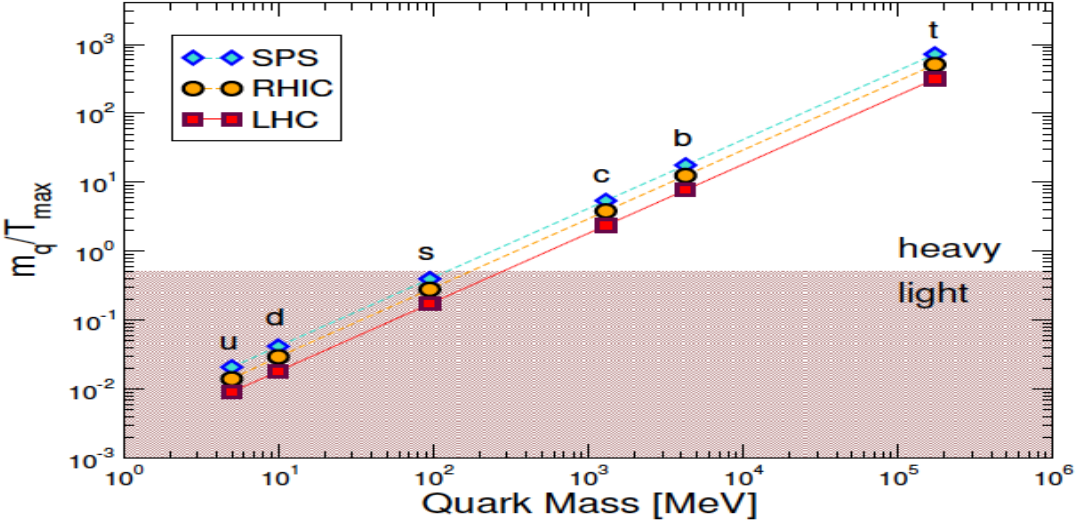
✧ Hadronization mechanism on Λ_c/D ratios

✧ New observables: v_n(light)- v_n(heavy), σ_{vn}/v_n

✧ Impact of initial stages on HF dynamics: EM field, vorticity and Glasma

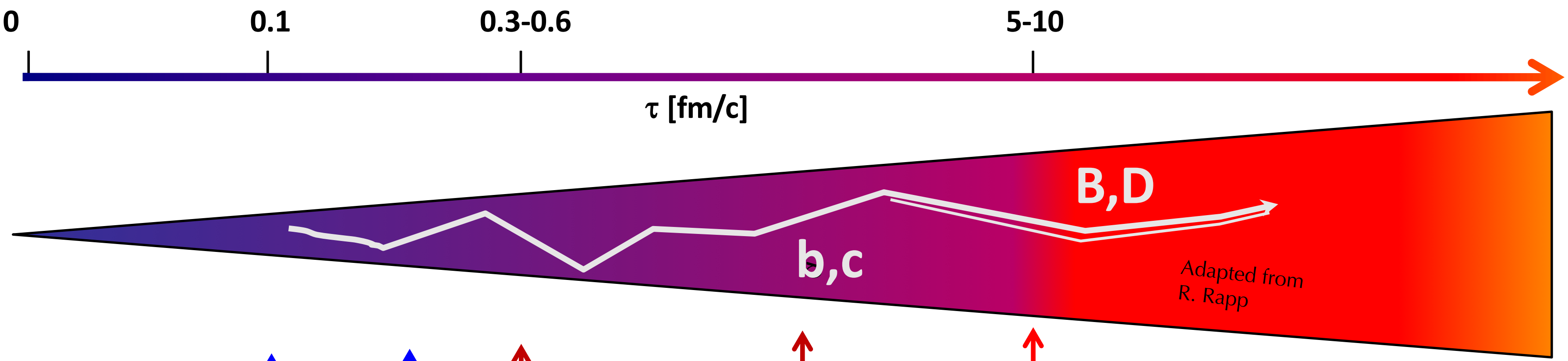
HF dynamics in QGP and estimates of T dependence of D_s

Specific of Heavy Quarks



- $m_{c,b} >> \Lambda_{QCD}$ production by pQCD hard processes
- $m_{c,b} >> T_{RHIC,LHC}$ negligible thermal production
- $m_{c,b} >> q^2 \sim gT_{RHIC,LHC}$ soft scatterings → Brownian motion
- $\tau_0 \approx 1/2m_Q << \tau_{QGP}$ witness of all the QGP evolution
- $\tau_{th} \approx \tau_{QGP} >> \tau_{q,g}$ carry more information of their evolution

HF in all stages of URHICs



HQs prod.

Formation of QGP with large vorticity

- **Hadronization mechanism**
  - coalescence and/or fragm.

HQs in:
- Glasma
- EM field

- **Dynamics in QGP**
  - Transp. coeff. of QGP
  - Thermalization time

Relativistic Boltzmann at finite η/s

$$p^{\mu}\partial_{\mu}f_{q}(x,p)+m(x)\,\partial_{\mu}^{x}m(x)\partial_{p}^{\mu}f_{q}(x,p)=C[f_{q},f_{g}]$$
$$p^{\mu}\partial_{\mu}f_{g}(x,p)+m(x)\,\partial_{\mu}^{x}m(x)\partial_{p}^{\mu}f_{g}(x,p)=C[f_{q},f_{g}]$$

free streaming | Interaction ε-3p≠0 | collision term gauged to some η/s≠0

Equivalent to viscous hydro

Heavy Quarks evolution

$$p^{\mu}\partial_{\mu}f_{Q}(x,p)=\mathcal{C}[f_{q},f_{g},f_{Q}](x,p)$$

$\mathcal{M}$ scattering matrix by QPM model fit to lQCD thermodynamics

Hadronization by coalescence plus fragmentation

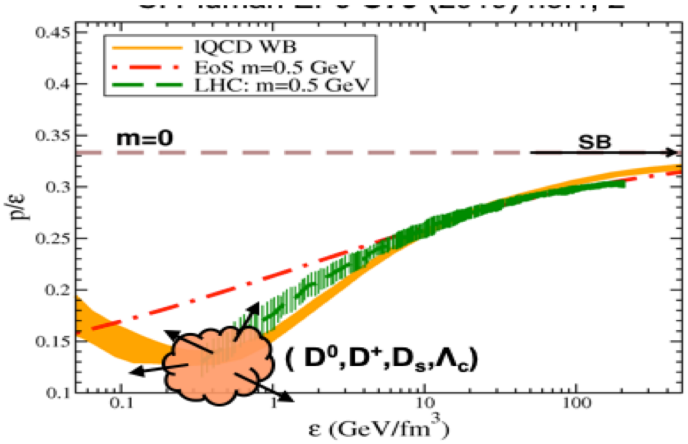
S. Plumari et al., EPJ**C78** (2018) no.4, 348

$$\frac{dN_{Hadron}}{d^2p_T}=g_H\int\prod_{i=1}^{n}p_i\cdot d\sigma_i\frac{d^3p_i}{(2\pi)^3}f_q(x_i,p_i)\,f_W(x_1,...,x_n;p_1,...,p_n)\,\delta(p_T-\sum_i p_{iT})$$

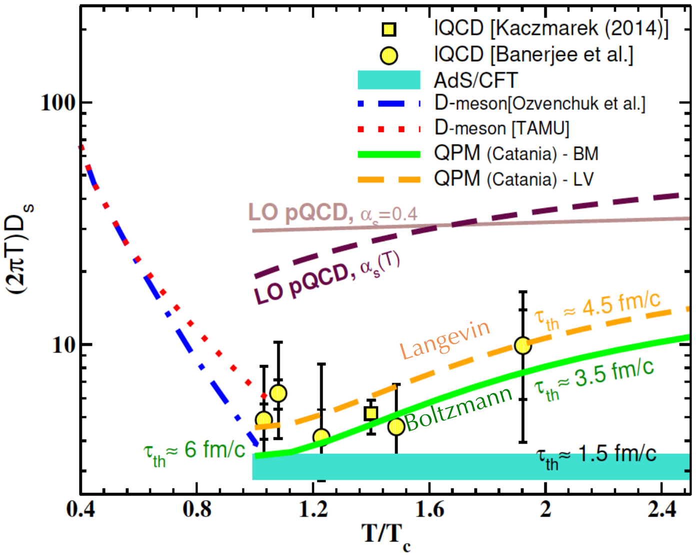
$$\frac{dN_h}{d^2p_h}=\sum_f\int dz\frac{dN_f}{d^2p_f}D_{f\to h}(z)$$

Good description of spectra D^0,D^+,D_s , Λ_c, B, Λ_b

S. Plumari EPJ **C79** (2019) no.1, 2



What is the underlying D_s?



Scardina et al., PRC96(2017) 044905

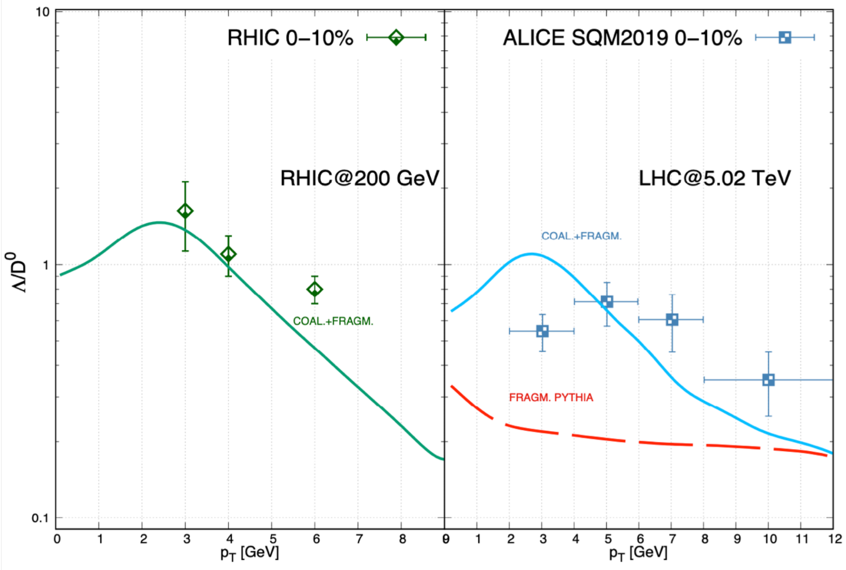
Not a model fit to lQCD data! The result is gotten from the simultaneous discription of $R_{AA}(p_T)$ & $v_2(p_T)$

- ❖ Get close AdS/CFT at T≈Tc
- ❖ We have a probe with $\tau_{therm} \approx \tau_{QGP}$

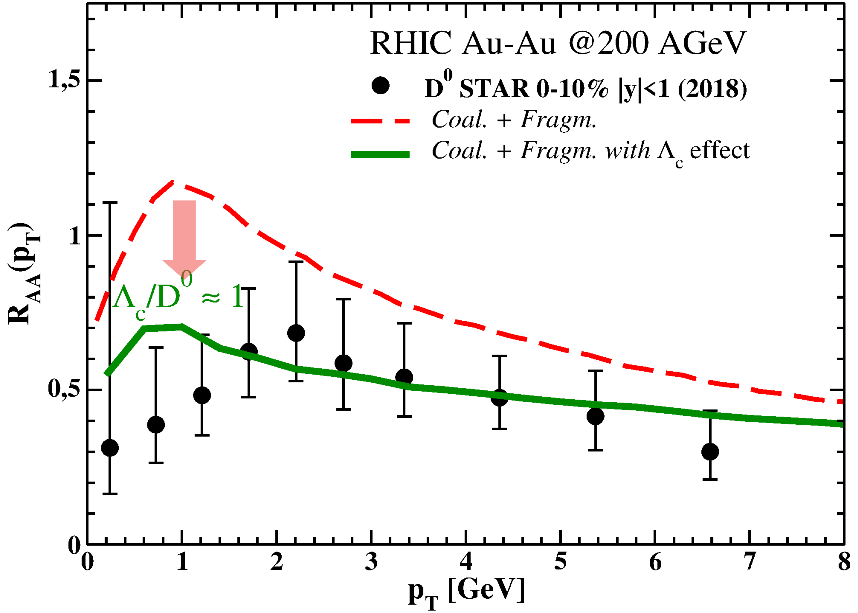
$$\tau_{th} = \frac{M}{2\pi T^2}(2\pi T D_s) \cong 1.8 \frac{2\pi T D_s}{(T/T_c)^2} \text{ fm/c}$$

Hadronization mechanism on Λ_c/D ratio

Λ_c/D from hadronization mechanism



S. Plumari et al., EPJ**C78** (2018) no.4, 348



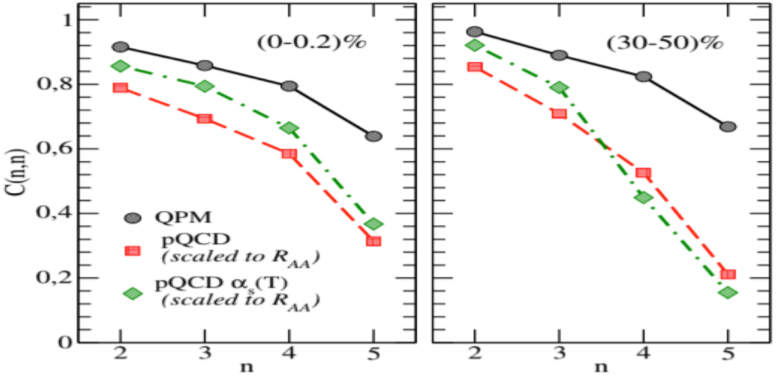
STAR Collaboration PR**C99** (2019) no.3, 034908

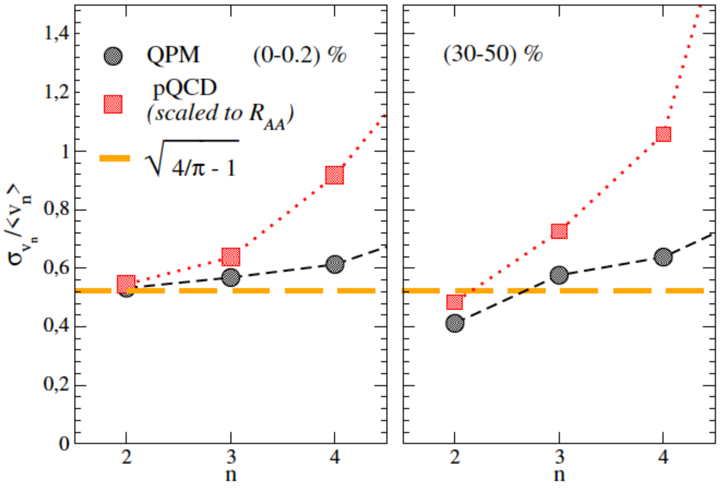
- **With the same coalescence plus fragmentation model we describe the Λ_c/D^0 for RHIC and LHC**

- **This open a new paradigma in studying HF**
- **The effect will be even larger for because larger Λ_b/B**

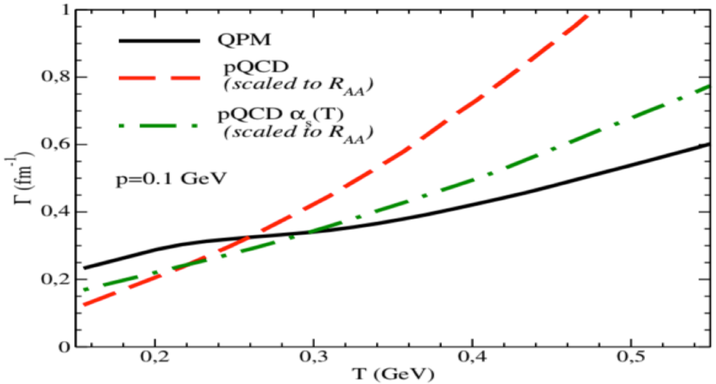
New observables: v_n(light)- v_n(heavy), σ_{vn}/v_n

Sensitivity of C(n,n) and v_n variances on $D_s(T)$





$$C\left(v_n^{light}, v_m^{heavy}\right) = \left\langle \frac{\left(v_n^{light} - \langle v_n^{light} \rangle\right)\left(v_m^{heavy} - \langle v_m^{heavy} \rangle\right)}{\sigma_{v_n^{light}} \sigma_{v_m^{heavy}}} \right\rangle$$



- C(n,n) and σ_{vn}/v_n is sensitive to T dependence of D_s

Impact of initial stages on HF dynamics by EM field, vorticity and Glasma

HF dynamics in vorticity and EM field

We solve the relativistic Boltzmann eq coupled with the external EM field.

$$p^{\mu}\partial_{\mu}f_{q}(x,p)+m(x)\partial_{\mu}^{x}m(x)\partial_{p}^{\mu}f_{q}(x,p)+q\,F_{ext}^{\mu\nu}p_{\mu}\partial_{\mu}f_{q}(x,p)=C[f_{q},f_{g}]$$

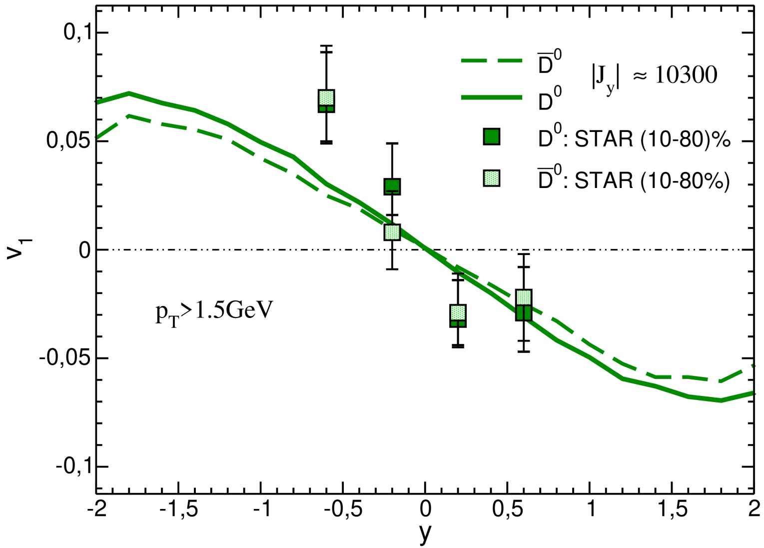
$$p^{\mu}\partial_{\mu}f_{g}(x,p)+m(x)\partial_{\mu}^{x}m(x)\partial_{p}^{\mu}f_{g}(x,p)=C[f_{q},f_{g}]$$

Heavy quark evolution

$$p^{\mu}\partial_{\mu}f_{Q}(x,p)+q\,F_{ext}^{\mu\nu}p_{\mu}\partial_{\mu}f_{Q}(x,p)=C[f_{q},f_{g},f_{Q}]$$

- **Charm transport coefficient constrained by experimental data on the $R_{AA}(p_T)$ and v_2 of D meson**
- **Vorticity employed for Λ polarization and v_1 of light particles**
- **EM field is calculated with fast moving protons in colliding nuclei assuming a constant conductivity of medium**

Impact of EM Field + Vorticity on D



V. Greco, QM2017, NPA (2017)
S. Das et al., PLB768 (2017)

- Large average v_1 of D meson due to vorticity, a lot larger than for charged particles
- A sizable v_1 spilitting for D meson than for charged particles predicted $v_1 \approx 10^{-3}$-10^{-4} [Gursoy et al., PRC89 (2014)] using the same EM field

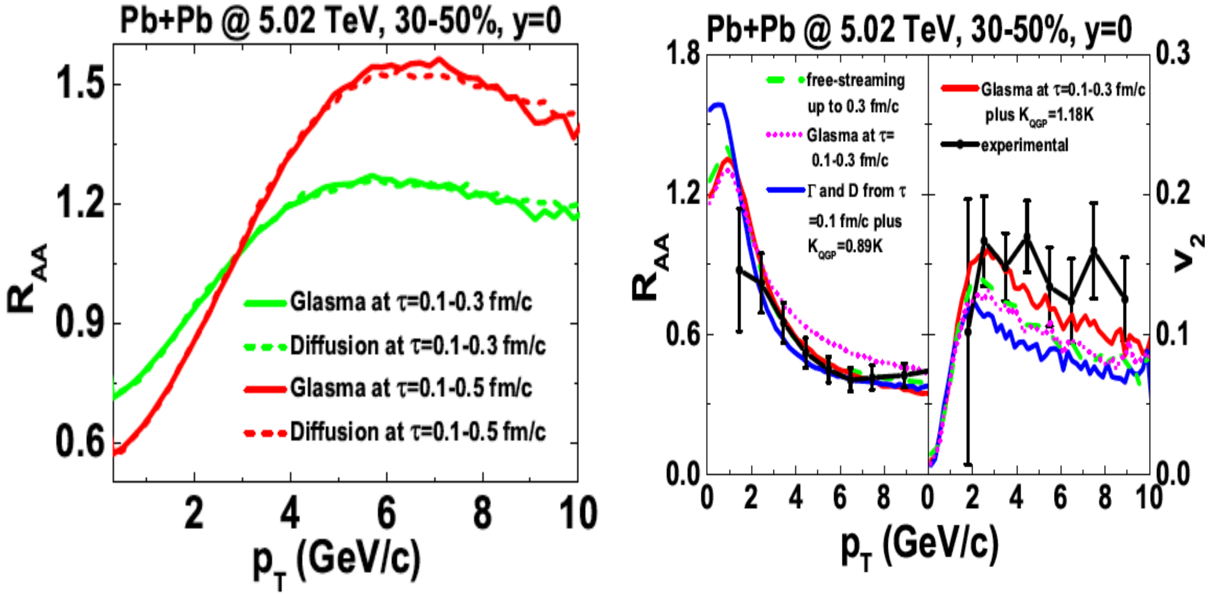
- At LHC energy we get much less than experimental data (???)

HQ in Glasma

$$\frac{dx_i}{dt} = \frac{p_i}{E},$$

$$E\frac{dp_i}{dt} = Q_a F^a_{i\nu} p^\nu,$$

$$E\frac{dQ_a}{dt} = -Q_c \varepsilon^{cba} A_b \cdot p,$$



Y. Sun et al., PLB **798** (2019) 134933

- ✧ **Enhancement of $R_{AA}(p_T)$**
- ✧ The effect is similar to Fokker-Planck with only diffusion and negligible drag
- ✧ **Gain in v_2**: larger interaction in the QGP to have same $R_{AA}(p_T)$

Summary & Outlook

❖ Prediction of both R_{AA} ,v_2 gives us **D_s(T) of QGP ≈ lQCD**

❖ Λ_c/D from Coal.+Fragm. explained in AA (RHIC & LHC)

❖ **v_n(HQ)-v_n(QGP) and σ_{vn}/v_n,** new observables probing D_s(T)

❖ Charm directed flow can probe the initial strong EM field and vorticity

❖ Glasma effect on HF

There are more things to do and to learn than expected!