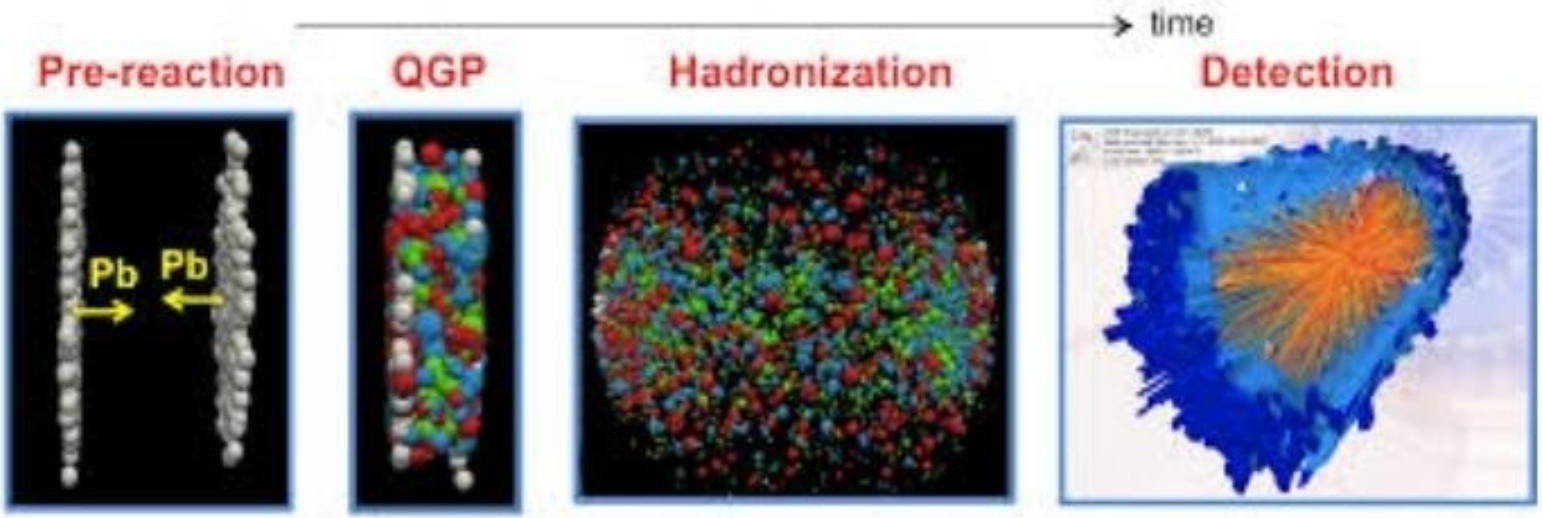
Memory effect on diffusion of heavy quark in QGP



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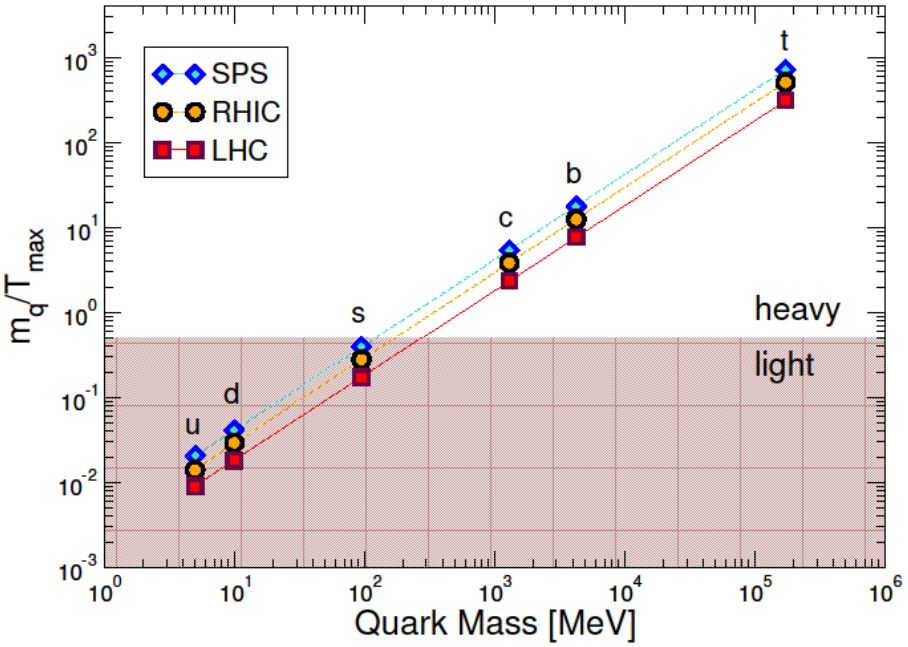
OUTLINE .....

- Introduction
- Heavy quark diffusion in QGP
- Impact of memory
- Summary and outlook

Heavy Quark & QGP



SPS to LHC

$\sqrt{s} = 17.3GeV \; to \; 2.76TeV$ **~100 times**

$T_i = 200 \; MeV \; to \; 600 \; MeV$ **~3 times**

$M_{c,b} >> \Lambda_{QCD}$

Produced by pQCD process (before equilibrium) (Early production)

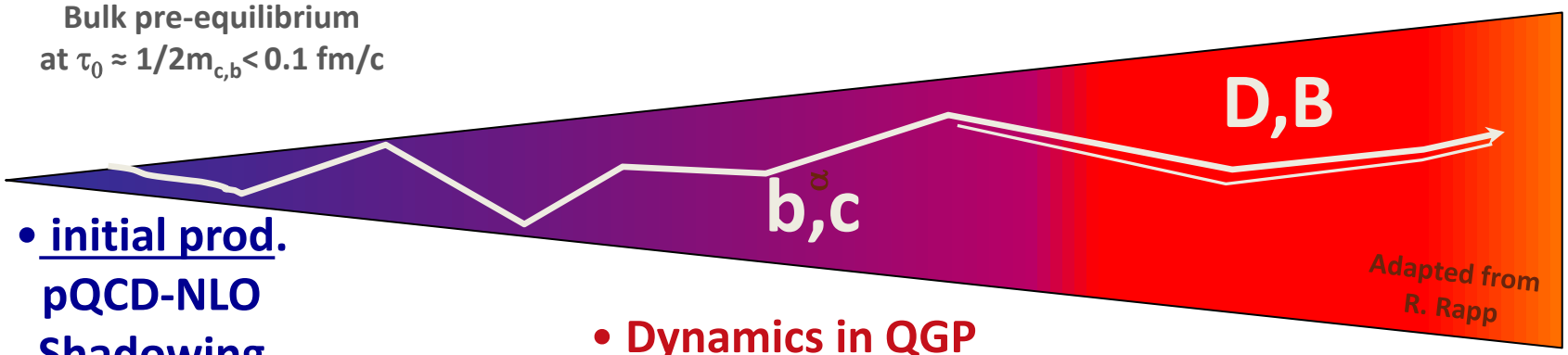
$\tau_{c,b} >> \tau_{QGP}$

They go through all the QGP life time

$M_{c,b} >> T_0$

No thermal production

Studying the HF dynamics in HIC

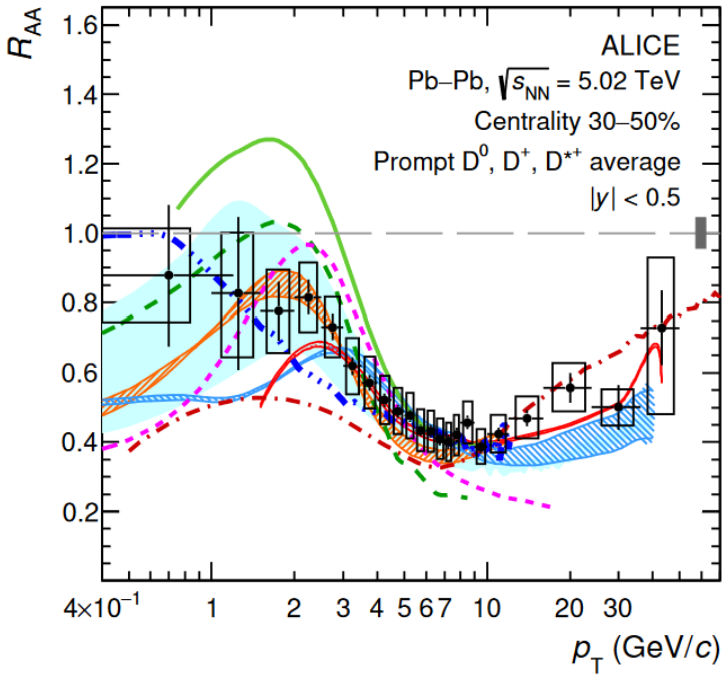


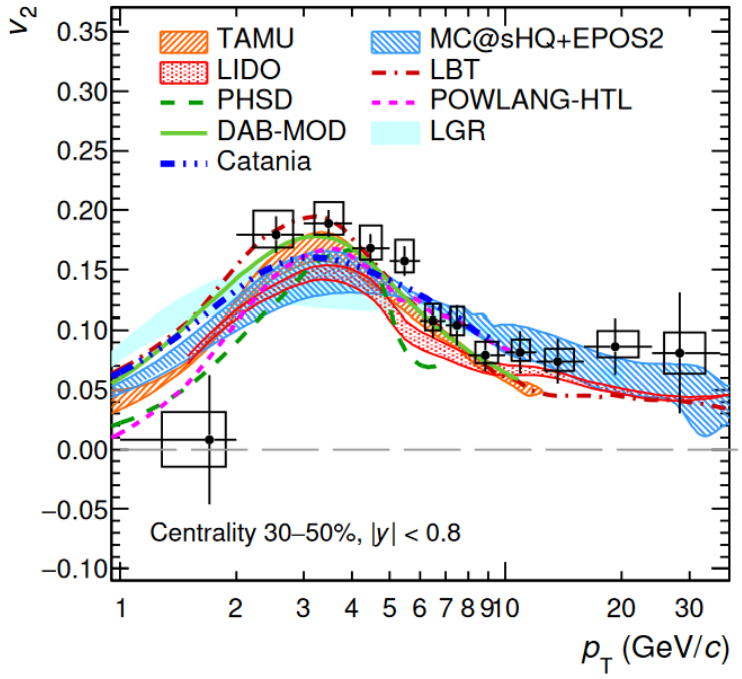
• initial prod.
pQCD-NLO
Shadowing
Pre-equilibrium
Effect/Glasma
Electromagnetic
filed

• Dynamics in QGP
Heavy quark QGP interaction
Transp. coeff. of QCD matter
-> thermalization ?!
Mass & color in Jet quenching
Heavy quark momentum evol.
(Langevin/Boltzmann/E. loss model)

• hadronization:
coalescence and/or
fragmentation.
Hadronic rescattering

R_{AA} and v_2
Comparison with models



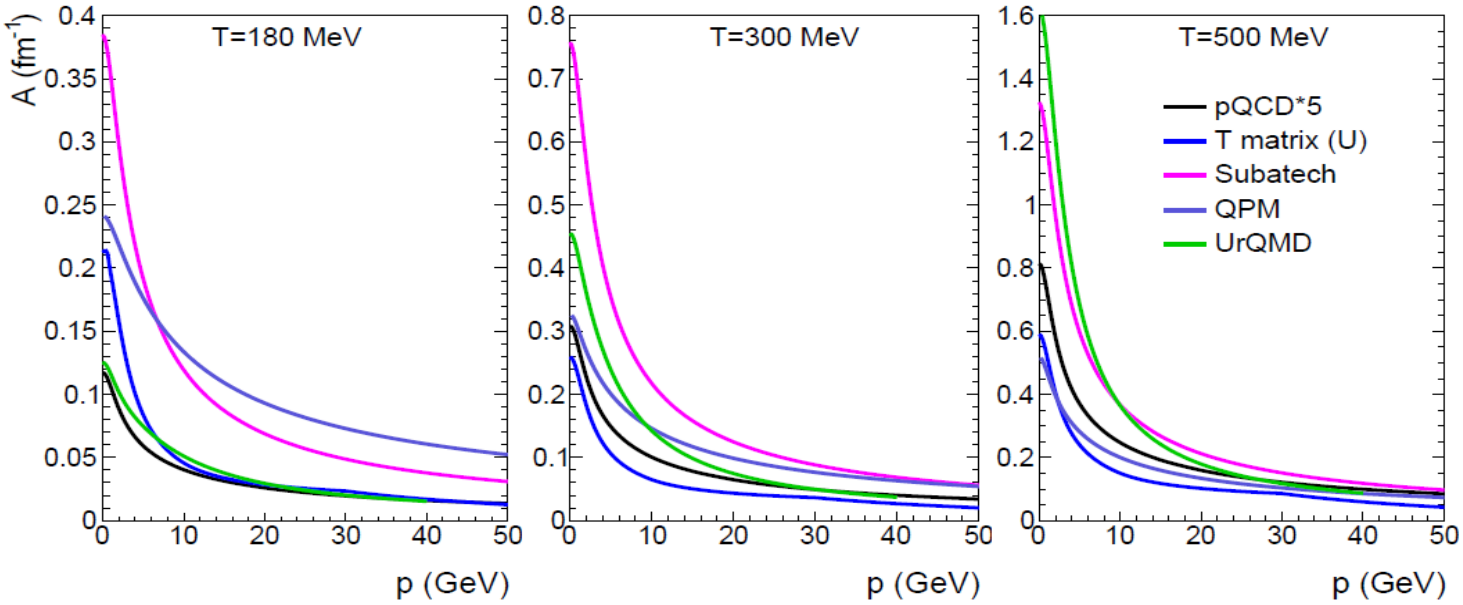


ALICE, JHEP 01 (2022) 174

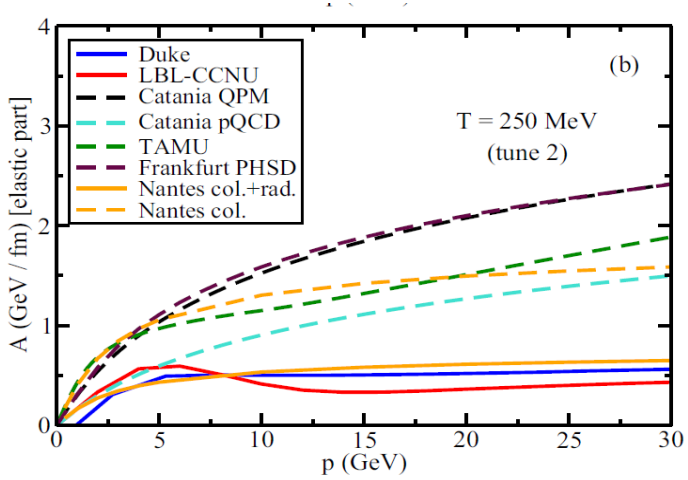
Most of the models able to describe both R_{AA} and v_2 in certain p_T domain

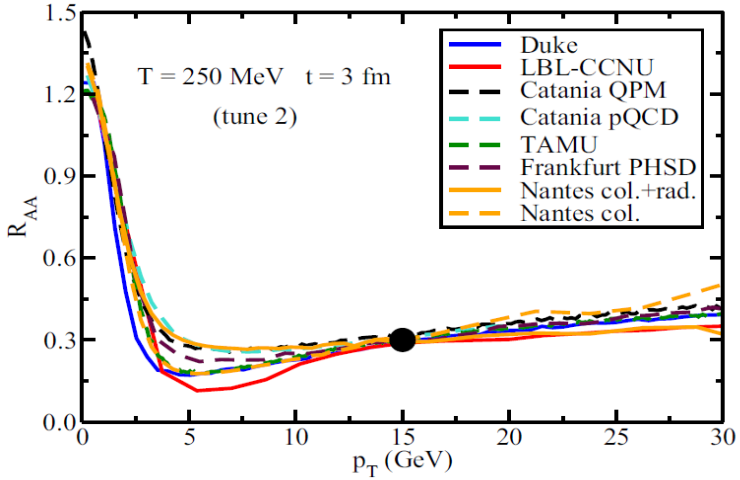
Simultaneous description of R_{AA} and v_2 is still a challenge in the whole measured p_T and centrality ranges

A systematic attempts are going on within the EMMI-RRTF and "JET-HQ" working groups to find a common agreement between different groups:



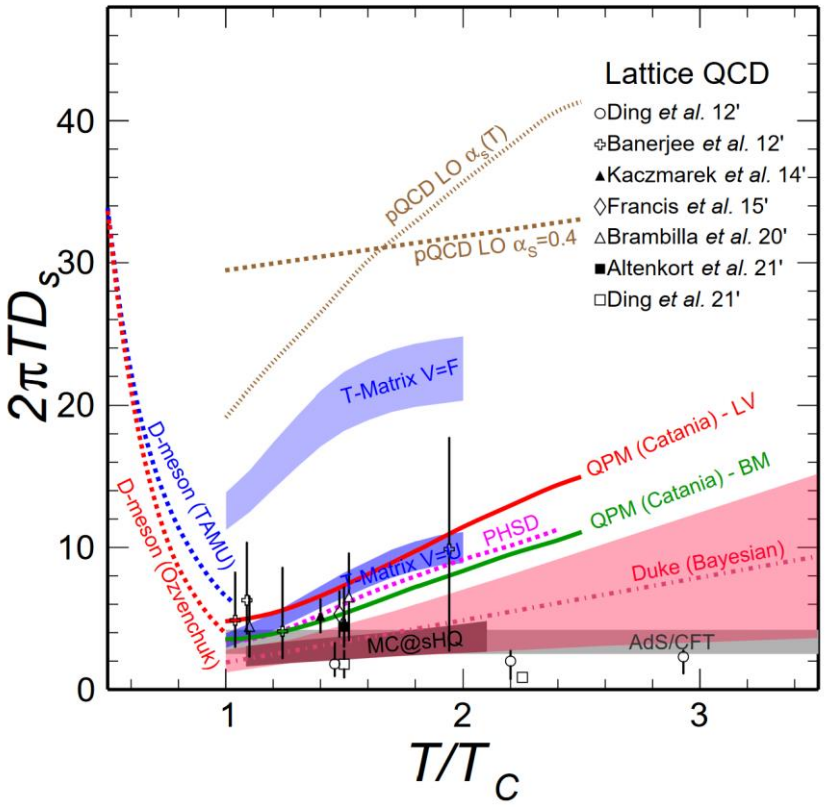
R. Rapp et.al NPA 979 (2018) (EMMI-RRTF)

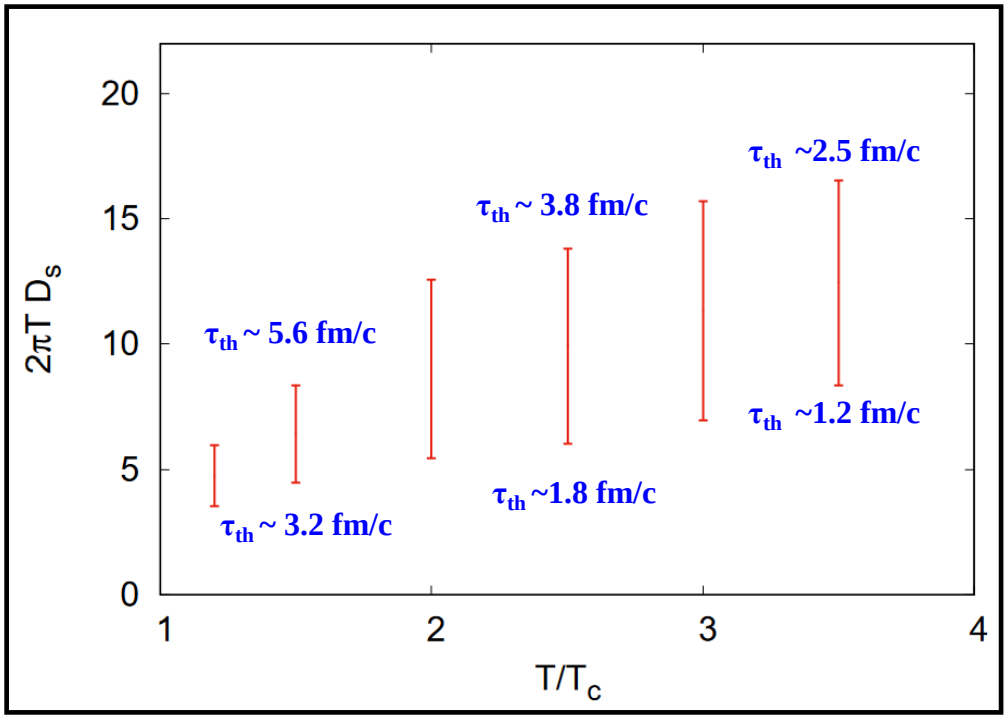




S. Cao et. al PRC 99, 054907 (2019) (JET-HQ)

Heavy quark diffusion





$$D_s = T/M * \gamma(p \to 0)$$

He, Fries, Rapp, PRL,110, 112301 (2013)

Banerjee, Datta, Gavai, Majumdar
arxiv: 2206.15471 [hep-ph]

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

$2\pi T D_s \propto T^2$, corresponds to a constant thermalization time.

Scardina, Das, Minissale, Plumari, Greco
PRC,96, 044905 (2017)

Heavy quark dynamics with memory effect

- Langevin Equation

$$\frac{d\mathbf{p}}{dt} = -\gamma\mathbf{p} + \eta(t)$$

- $\langle \eta(t) \rangle = 0$
- $\langle \eta(t)\eta(t') \rangle = 2D\delta(t - t')$

- Generalized Langevin Equation

$$\frac{dp}{dt} = -\int_0^t \gamma(t, t')p(t')dt' + \eta(t)$$

Ruggieri, Pooja, Jai Prakash, Das
PRD, 106 (2022) 3, 034032

- The correlation of fluctuations

$$\langle \eta(t)\eta(t')\rangle = 2Df(|t-t'|)$$
$$\langle \eta(t)\rangle = 0$$

$$f(|t-t'|) = \frac{1}{2\tau} e^{-|t-t'|/\tau}$$

- Ancillary process

$$\eta(t) = \sqrt{\frac{2D}{\tau}}\, h(t)$$

$$\frac{dh}{dt} = -\alpha h + \alpha\rho$$

$$\alpha = \frac{1}{\tau}$$

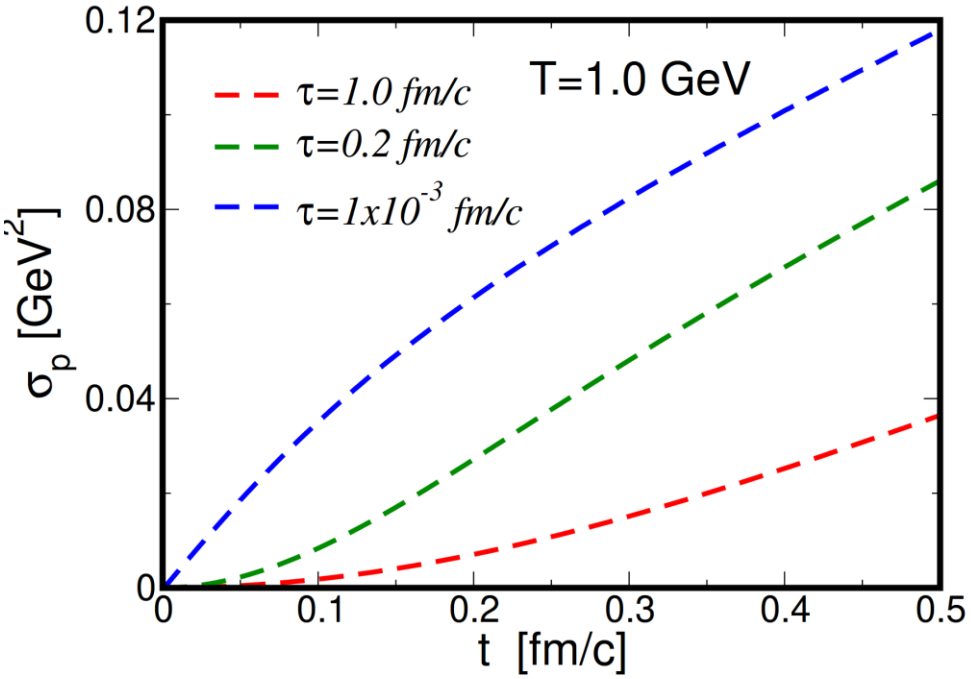
$$\langle h(t)h(t')\rangle \approx \frac{e^{-\alpha|t-t'|}}{2}$$

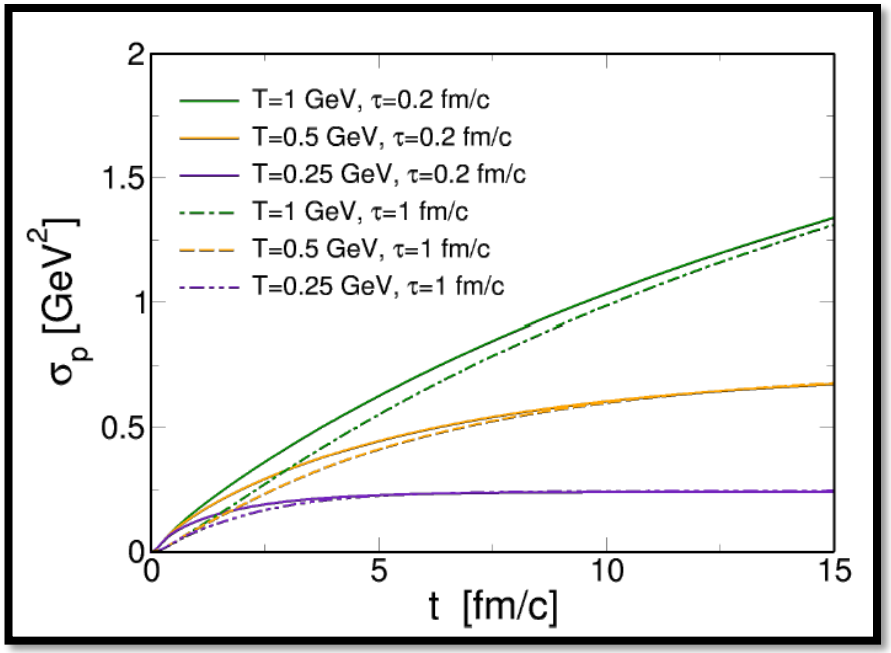
The drag from FDT:

$$\gamma(t,t') = \frac{2D}{ET}\frac{e^{-|t-t'|/\tau}}{2\tau}$$

Ruggieri, Pooja, Jai Prakash, Das
PRD, 106 (2022) 3, 034032

Impact of memory on heavy quark thermalization





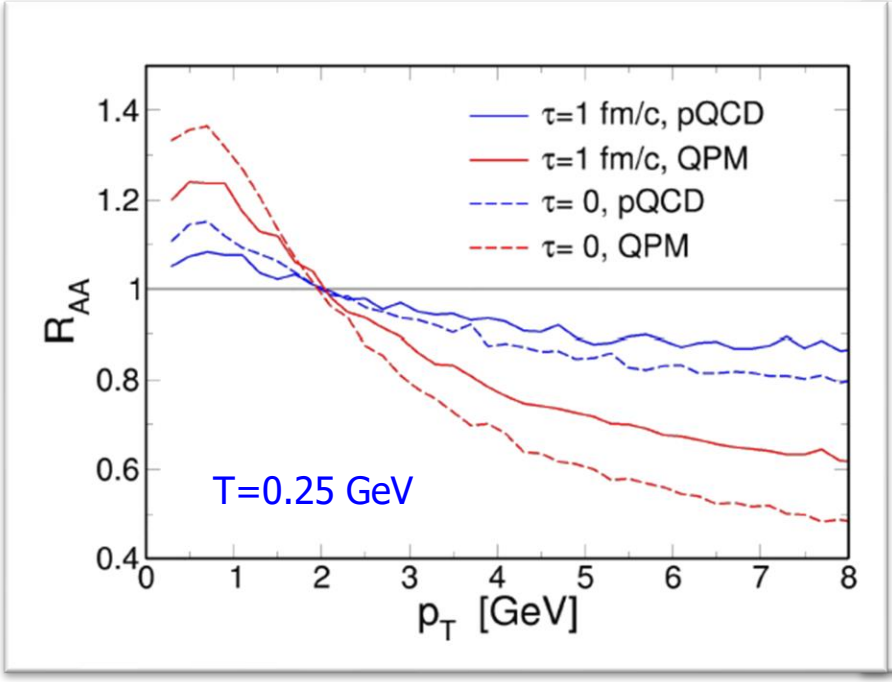
$$\sigma_p = \langle (p_T - \langle p_T \rangle)^2 \rangle$$

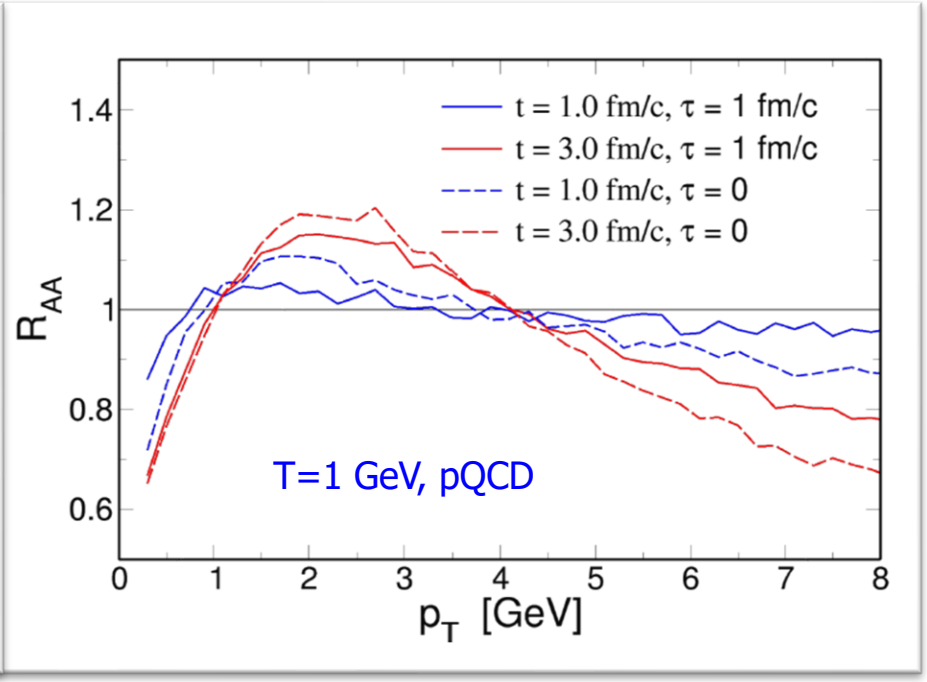
Memory delay the thermalization time

Liu, Das, Greco, Ruggieri, PRD 103, 034029 (2021)

Ruggieri, Pooja, Jai Prakash, Das, PRD, 106 (2022) 3, 034032

Impact of memory on heavy quark suppression

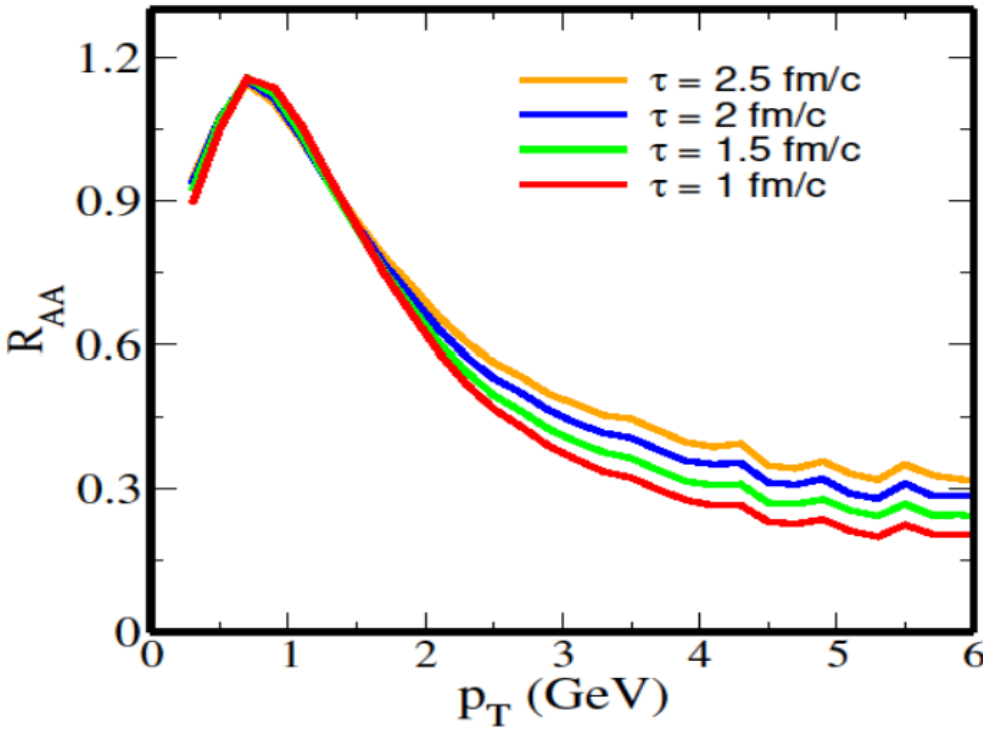


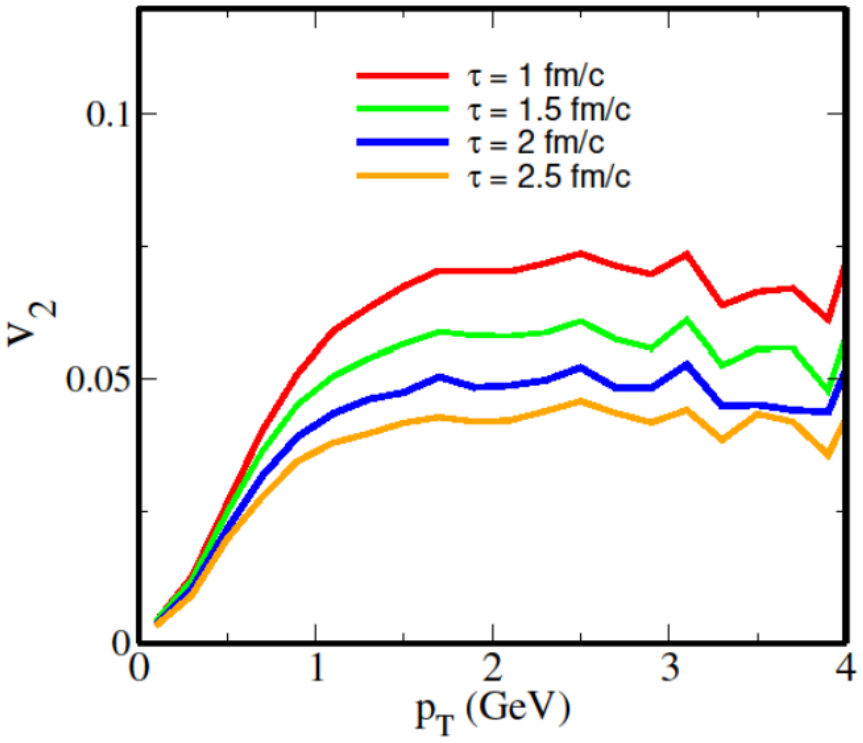


Formation of R_{AA} are slowed down by memory

Ruggieri, Pooja, Jai Prakash, Das
PRD, 106 (2022) 3, 034032

Impact of memory on expanding medium at RHIC





- **Memory slow down the R_{AA} and v_2**
- **Large transport coefficient needed to reproduce the same R_{AA} and v_2**
- **Will impact D_s**

Jai Prakash, Pooja, Ruggieri, Das
Under preparation

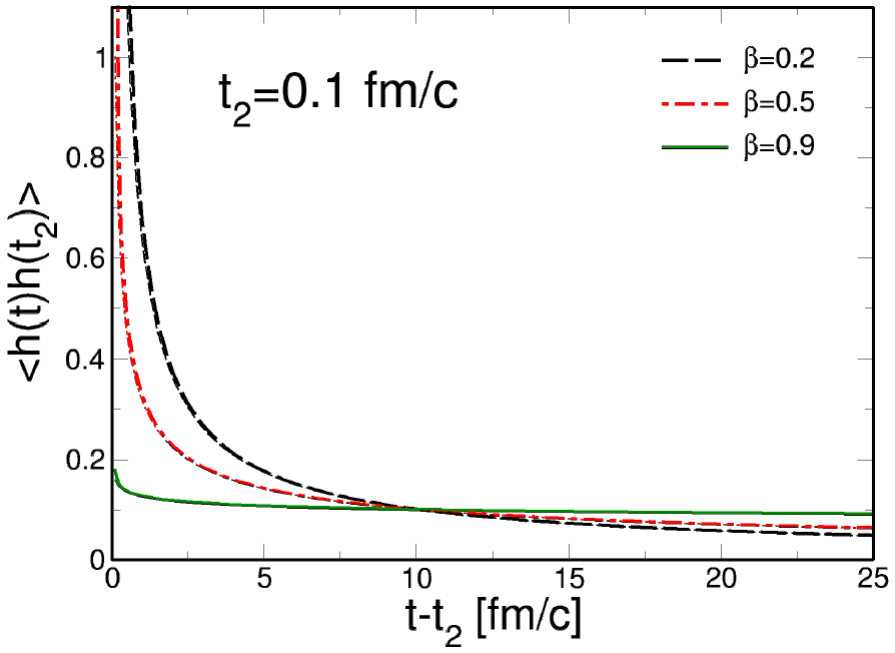
Longtail memory: time correlations decaying with a power law

$$h(t) = \frac{\sqrt{\beta}}{\tau^{\beta}} \int_0^t (t-u)^{\beta-1} \xi(u) du, \qquad 0 < \beta < 1$$

β fixes the power law at which correlations decay.

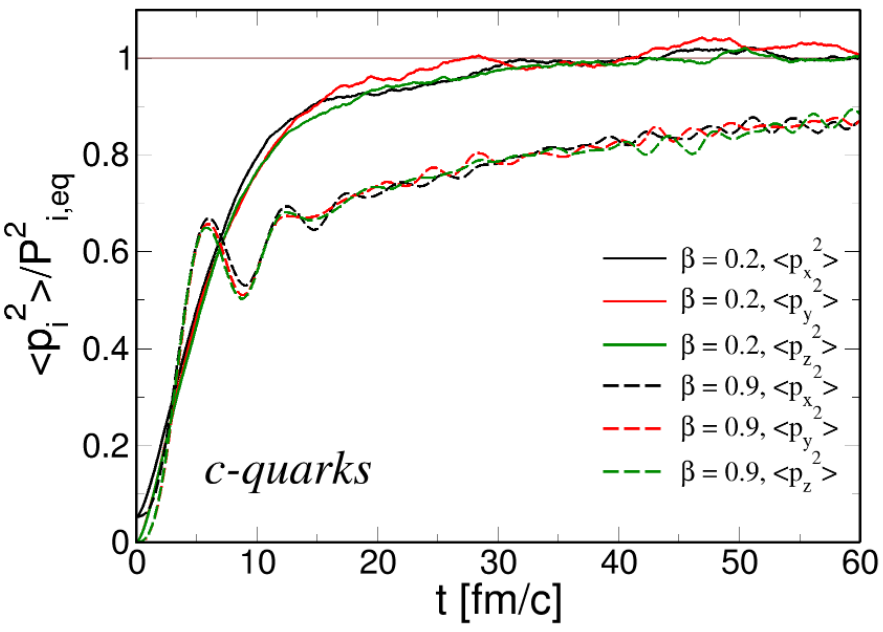
ξ is a standard Gaussian noise

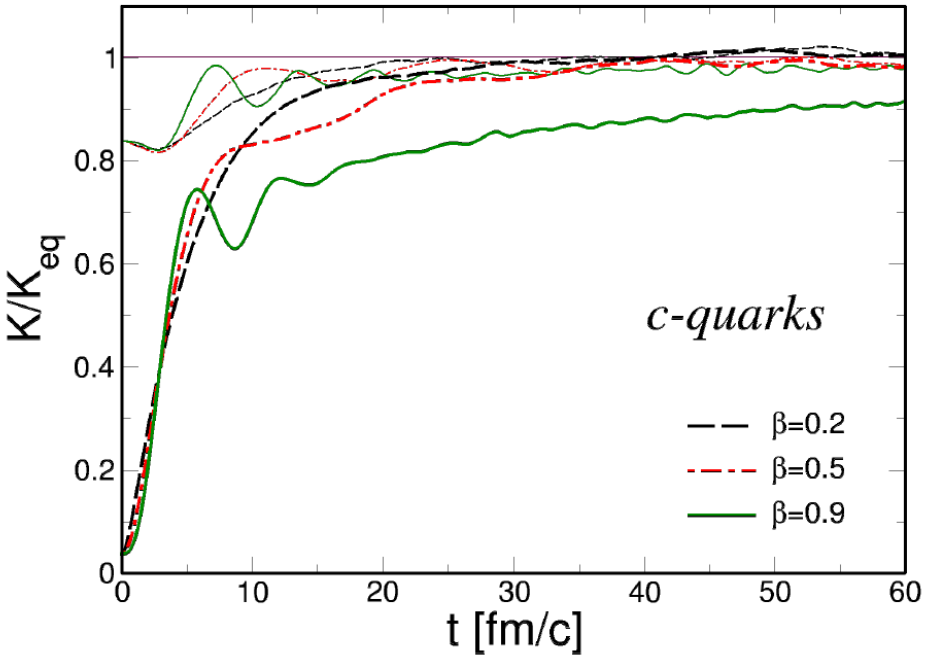
$$\langle h(t_1) h(t_2) \rangle = \tau^{-2\beta+1} \beta \int_0^{t_{\min}} (t_1 - u)^{\beta-1} (t_2 - u)^{\beta-1} du,$$



Pooja, Das, Greco, Ruggieri
Under preparation

Longtail memory: time correlations decaying with a power law





Memory delay the thermalization

Pooja, Das, Greco, Ruggieri
Under preparation

Conclusions and Perspectives:

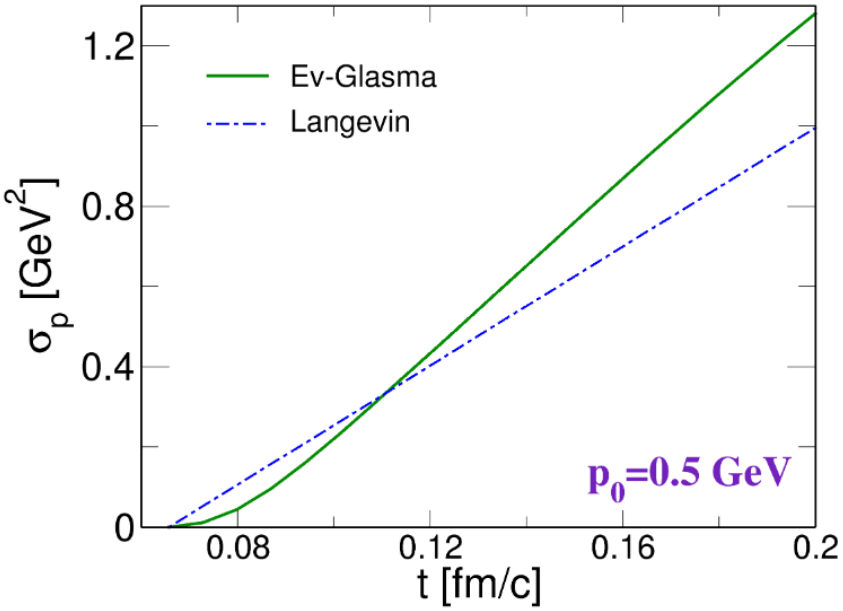
- Memory slows down the momentum evolution of heavy quarks
- Formation of R_{AA} and v_2 are slowed down by memory
- Thermalization time of the heavy quarks become larger.
- Will affect the D_s.

4th Heavy Flavour Meet

IIT-Goa, 2-4 Nov 2023


Thank You

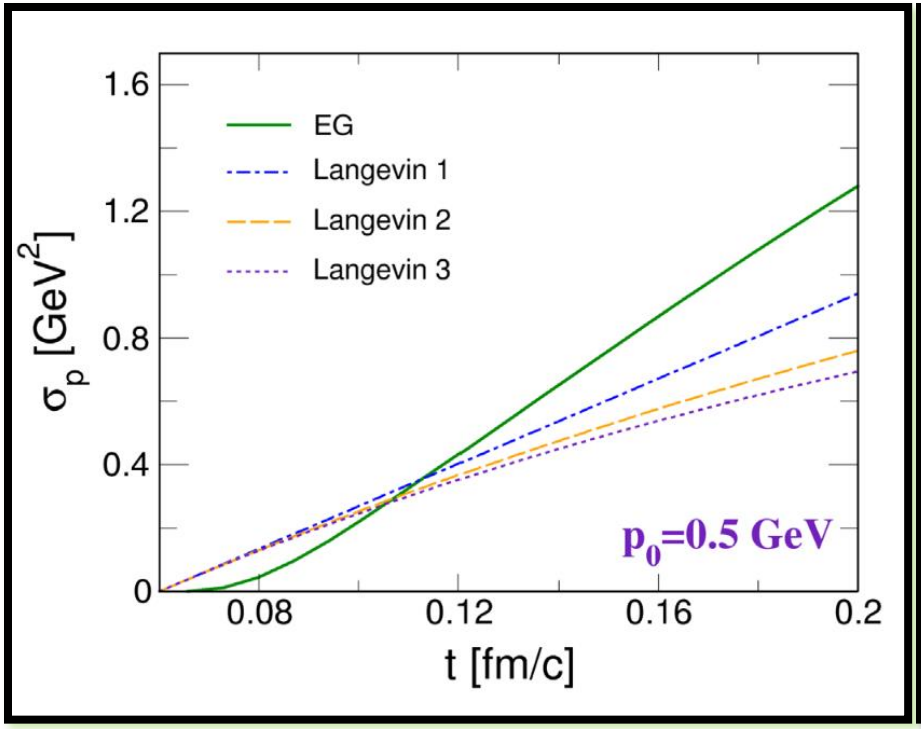
Impact of memory on heavy quark thermalization

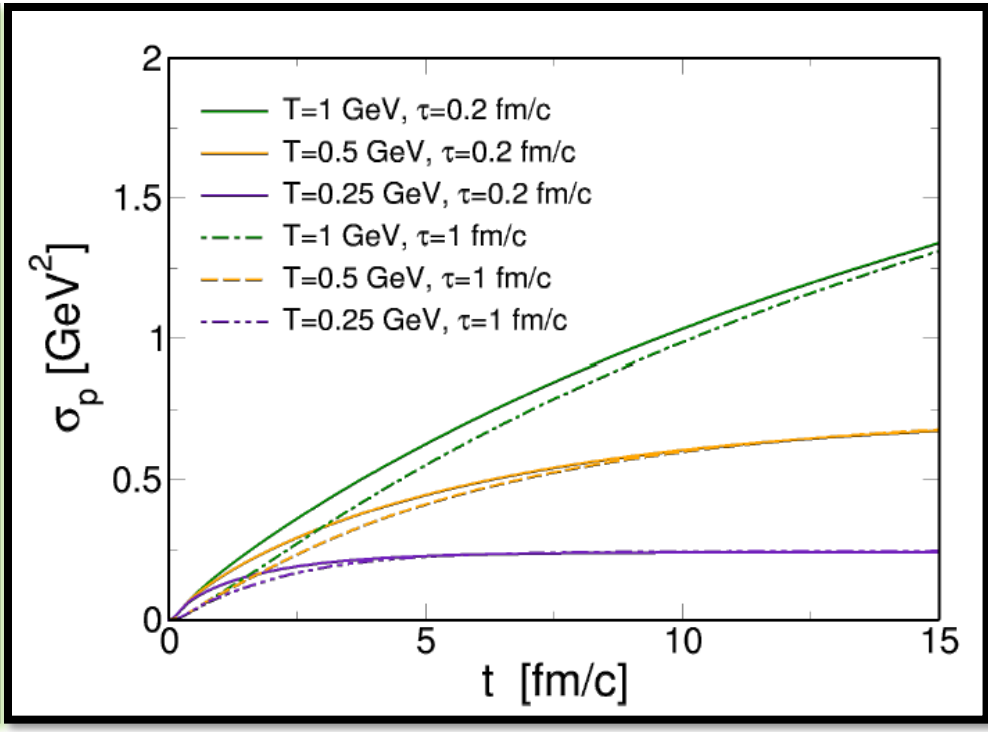


$$\sigma_p = \frac{1}{2}\langle (p_x(t) - p_{0x})^2 + (p_y(t) - p_{0y})^2 \rangle$$

Liu, Das, Greco, Ruggieri, PRD 103, 034029 (2021)

Impact of memory on heavy quark thermalization





$$\sigma_p = \frac{1}{2}\langle (p_x(t) - p_{0x})^2 + (p_y(t) - p_{0y})^2 \rangle$$

$$\sigma_p = \langle (p_T - \langle p_T \rangle)^2 \rangle$$

Memory delay the thermalization time

Liu, Das, Greco, Ruggieri, PRD 103, 034029 (2021)

Ruggieri, Pooja, Jai Prakash, Das, arxiv: 2203.06712 [hep-ph]