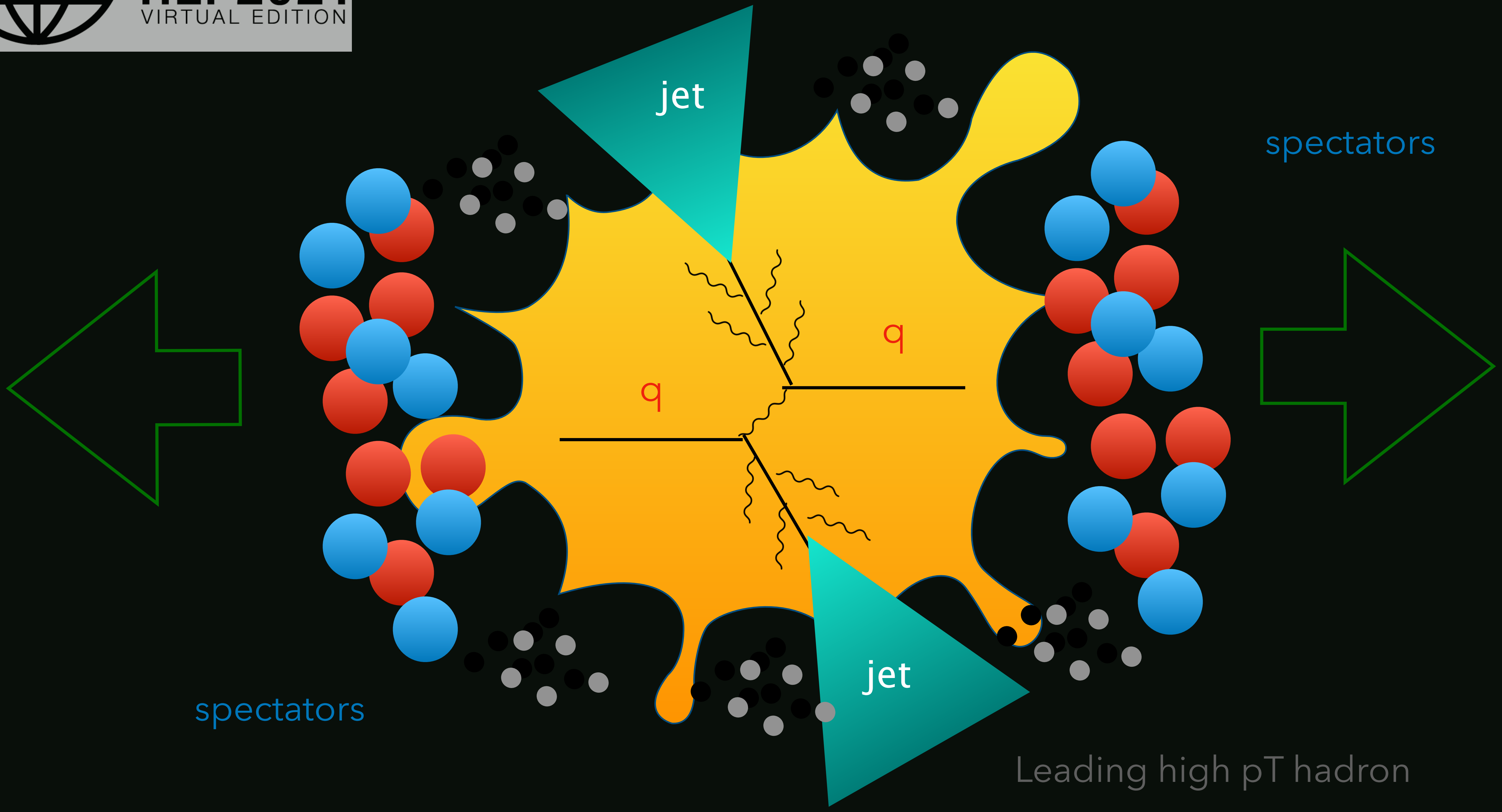


Quenching features of quark and gluon initiated parton cascades in expanding media

Based on : JHEP 07 (2020) 150;
arXiv: 2106.02592 (2021)

Souvik Priyam Adhya
[in collaboration with K. Tywoniuk[1], M. Spousta[2] and C. Salgado[3]]

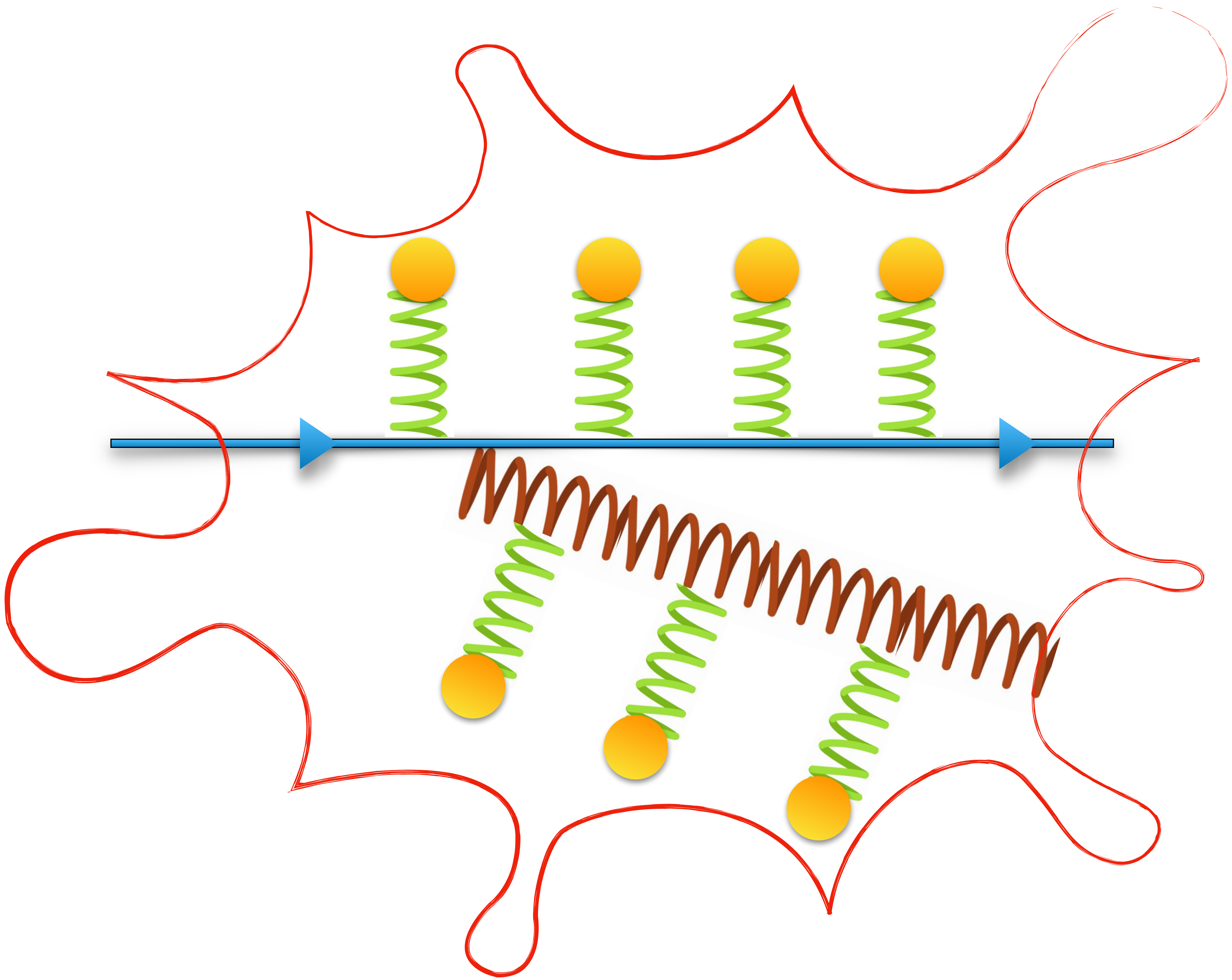
Institute of Nuclear Physics, Polish Academy of Sciences

1. University of Bergen, Bergen.
2. Charles University, Prague.
3. IGFAE, Santiago de Compostela.

Jet formation

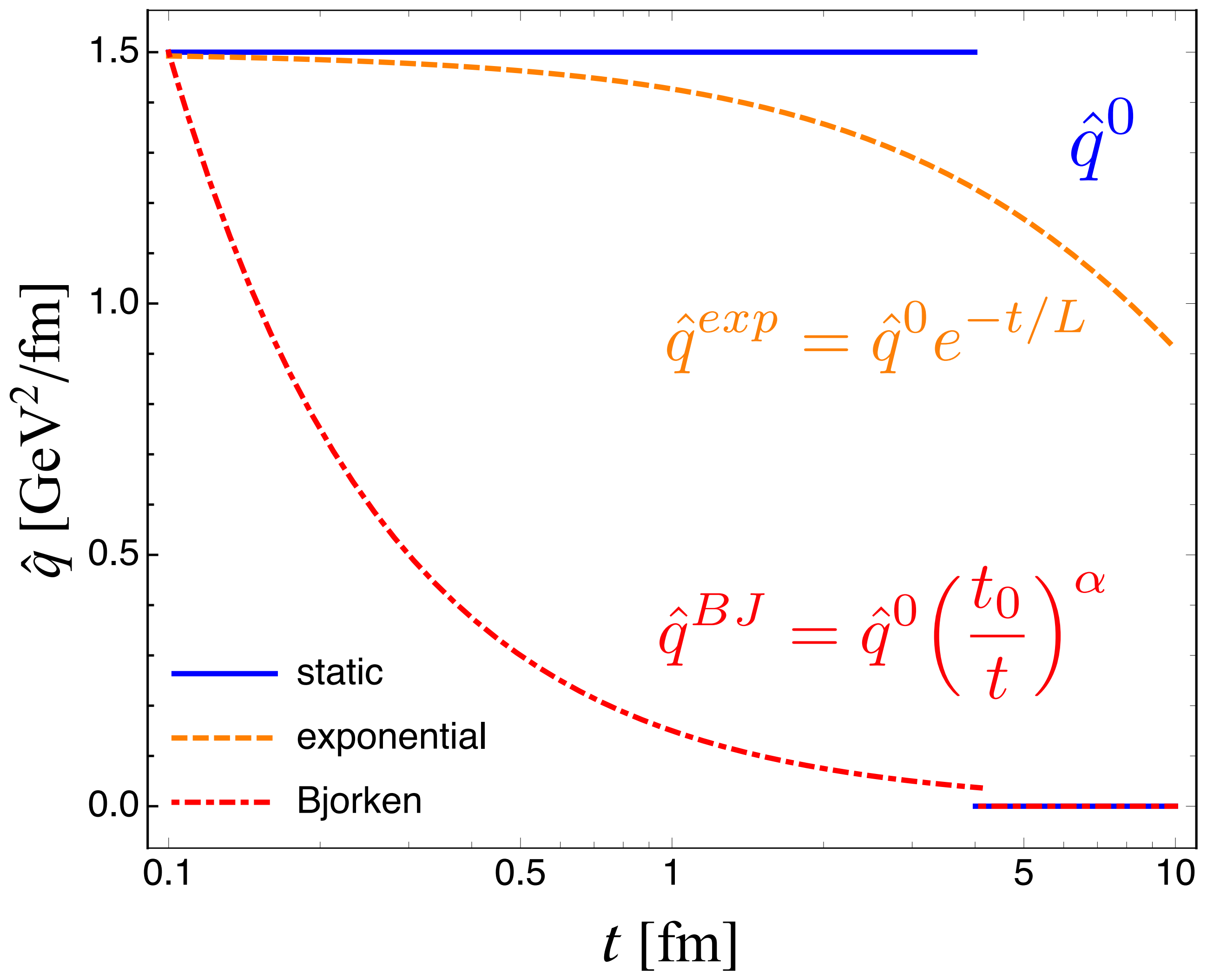
- High energy partons, resulting from an initial hard scattering, will create a high energy collimated spray of particles → JETS

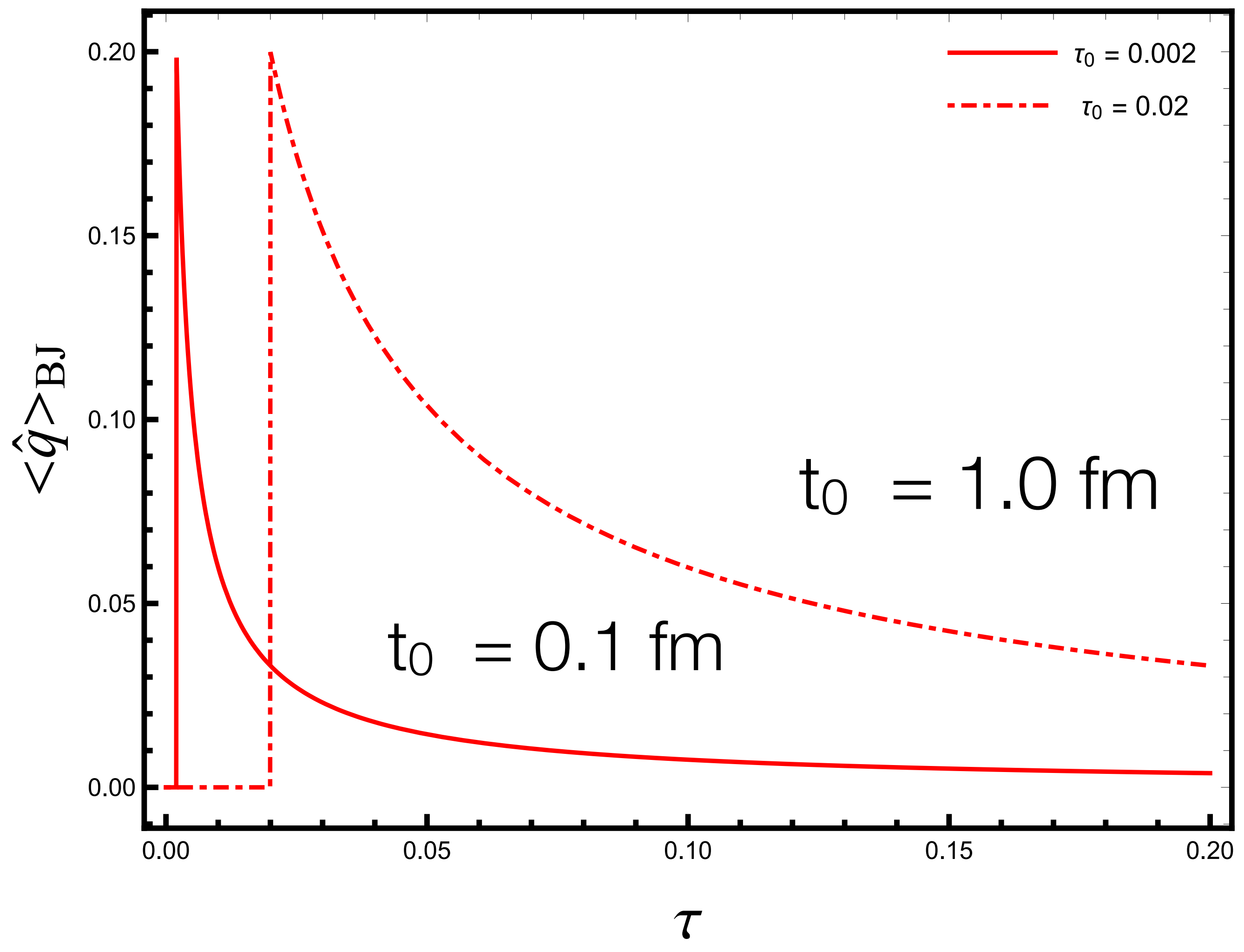
- Partons traveling through a dense color medium are expected to lose energy via **medium induced gluon radiation**, "jet quenching". We have adopted the *BDMPS-Z* (Baier, Dokshitzer, Mueller, Peigné, Schiff; Zakharov) formalism (*multiple soft scattering in medium*).

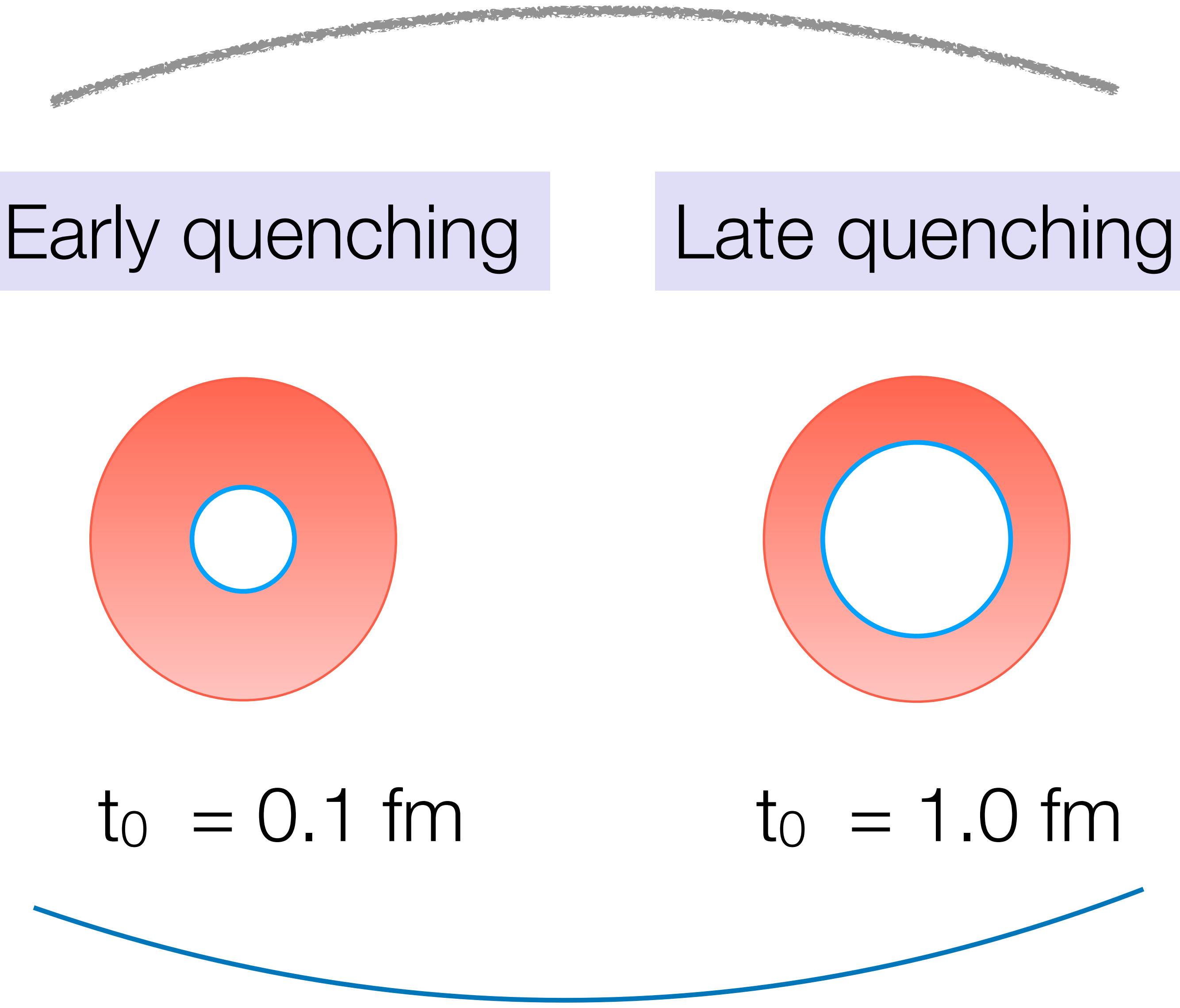


Medium profiles and calculation workflow :

Quenching parameter →







Early quenching

Late quenching

t_0 = 0.1 fm

t_0 = 1.0 fm

Bjorken initial conditions

Evolution equations =>

$$\frac{\partial}{\partial\tau} D_g(x,\tau) = \int_0^1 dz K_{gg}\left[\sqrt{\frac{z}{x}} D_g\left(\frac{x}{z}\right) - \frac{z}{\sqrt{x}} D_g(x)\right] - \int_0^1 z K_{qg}(z) \frac{z}{\sqrt{x}} D_g(x) + \int_0^1 z K_{gq}(z) \sqrt{\frac{z}{x}} D_S\left(\frac{x}{z}\right)$$

$$\frac{\partial}{\partial\tau} D_S(x,\tau) = \int_0^1 dz\, K_{qq}(z)\left[\sqrt{\frac{z}{x}} D_S\left(\frac{x}{z}\right) - \frac{1}{\sqrt{x}} D_S(x)\right] + \int_0^1 dz\, K_{gq}(z) \sqrt{\frac{z}{x}} D_g\left(\frac{x}{z}\right)$$

Ds = q singlet spectra
Dg = gluon spectra
K = splitting rate
τ = evolution variable

S. S and Y. M-T ; JHEP 09 (2018) 144.

Calculation flowchart

Single parton emission spectra (D) in BDMPS-Z formalism for static, exponential and Bjorken expanding media →

Splitting rates in static, exponential and Bjorken expanding media →

Kinematic rate equation taking into account all the possible splittings for quark & gluon initiated jets →

Optimisation in the Quenching factor for jets with combined q and g fractions through modified power law →

Study of rapidity dependence and estimation of elliptic flow

Scaling behaviour of the spectrum

The single gluon emission spectra are given as :

$$\frac{dI}{dz}^{static,soft} \simeq \frac{\alpha_s P(z)}{\pi}\sqrt{\frac{\omega_c}{2\omega}}$$

$$\frac{dI}{dz}^{static} = \frac{\alpha_s}{\pi} P(z)\,\mathrm{Re}\ln[\cos(\Omega_0 L)]$$

$$\frac{dI}{dz}^{expo} = \frac{\alpha_s}{\pi} P(z)\,\mathrm{Re}\ln J_0(2\Omega_0 L)$$

$$\frac{dI}{dz}^{BJ} = \frac{\alpha_s}{\pi} P(z)\,\mathrm{Re}\ln\left[\left(\frac{t_0}{L+t_0}\right)^{1/2}\frac{J_1(z_0)Y_0(z_L)-Y_1(z_0)J_0(z_L)}{J_1(z_L)Y_0(z_L)-Y_1(z_L)J_0(z_L)}\right]$$

$$P_{gg} = 2C_A\frac{(1-z(1-z))^2}{z(1-z)}$$

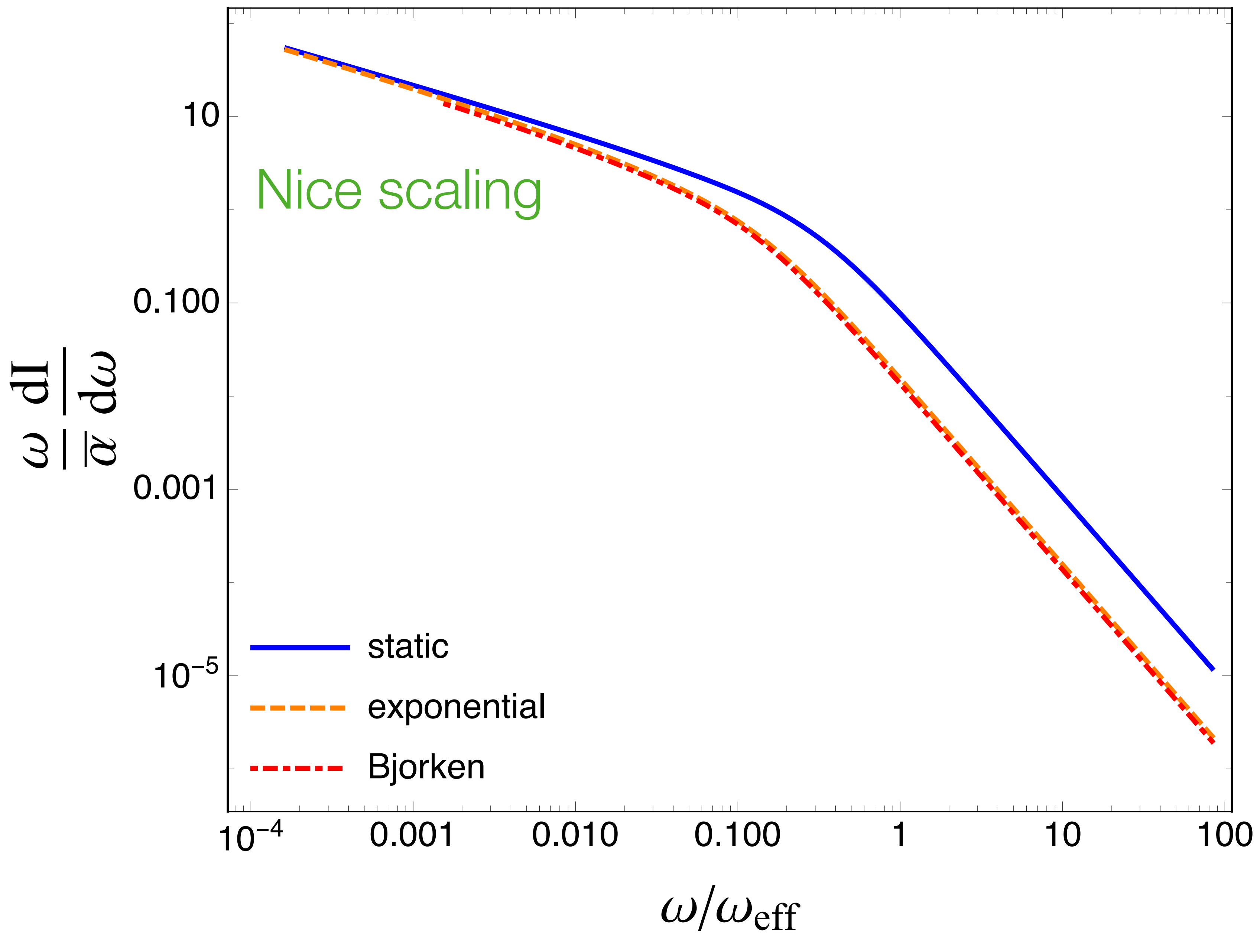
$$\tau \equiv \sqrt{\frac{\hat{q}_0}{p}}L$$

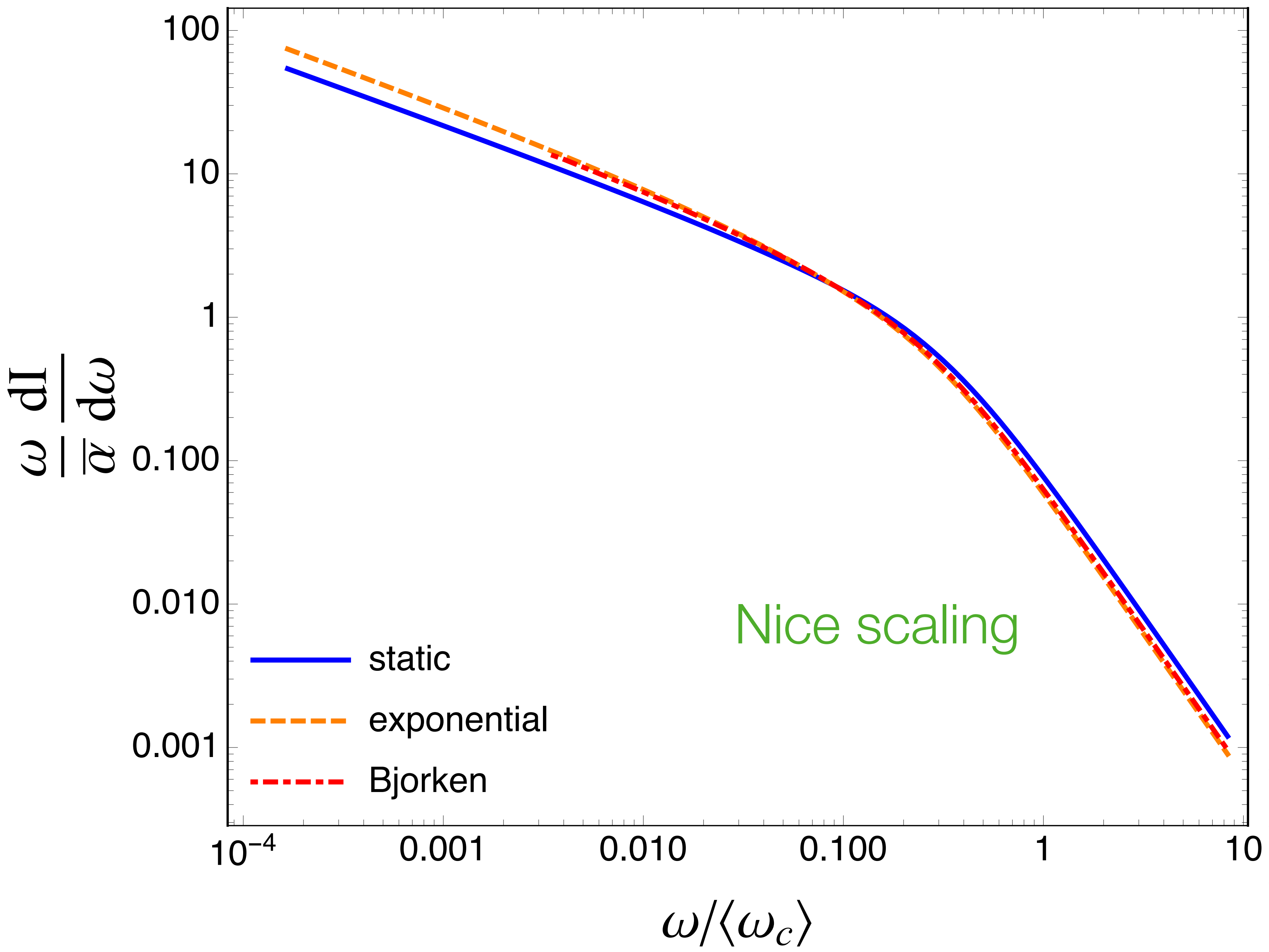
$$z_0 \equiv (1-i)\kappa(z)\tau_0$$

$$z_L \equiv (1-i)\kappa(z)\sqrt{\tau_0(\tau+\tau_0)}\,,$$

P. B. Arnold, Phys. Rev. D 79 (2009) 065025.

Can we interpret the scalings in different kinematical limits ?





Effective parameter

$$\frac{dI}{dz}^{static,sing} \simeq \frac{dI}{dz}^{expo,sing} \simeq \frac{dI}{dz}^{BJ,sing}$$

The singular spectra can be re-scaled

$$\omega_{\mathrm{eff}} = \begin{cases} \frac{1}{2}\hat{q}_0 L^2 & \text{static medium} \\ 2\hat{q}_0 L^2 & \text{exponentially expansion} \\ 2\hat{q}_0 t_0 L & \text{Bjorken expansion} \end{cases}.$$

$$\hat{q}_{eff}^{expo} = 4\hat{q}_0$$

$$\hat{q}_{eff}^{BJ} = 4\hat{q}_0 t_0/L$$

Medium evolved gluon spectra

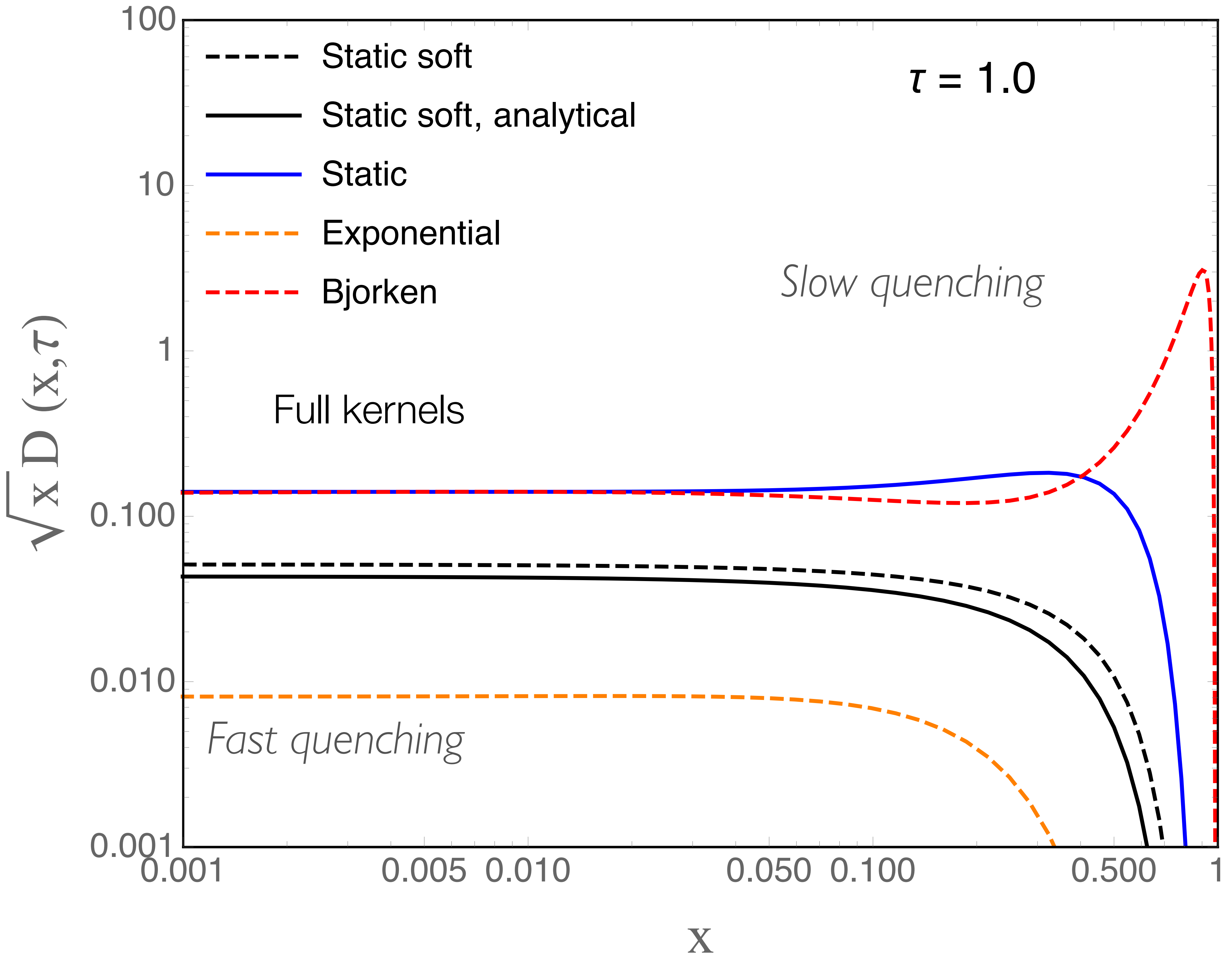
J.-P. Blaizot, E. Iancu, and Y. Mehtar-Tani,
Phys.Rev.Lett. 111 (2013) 052001.

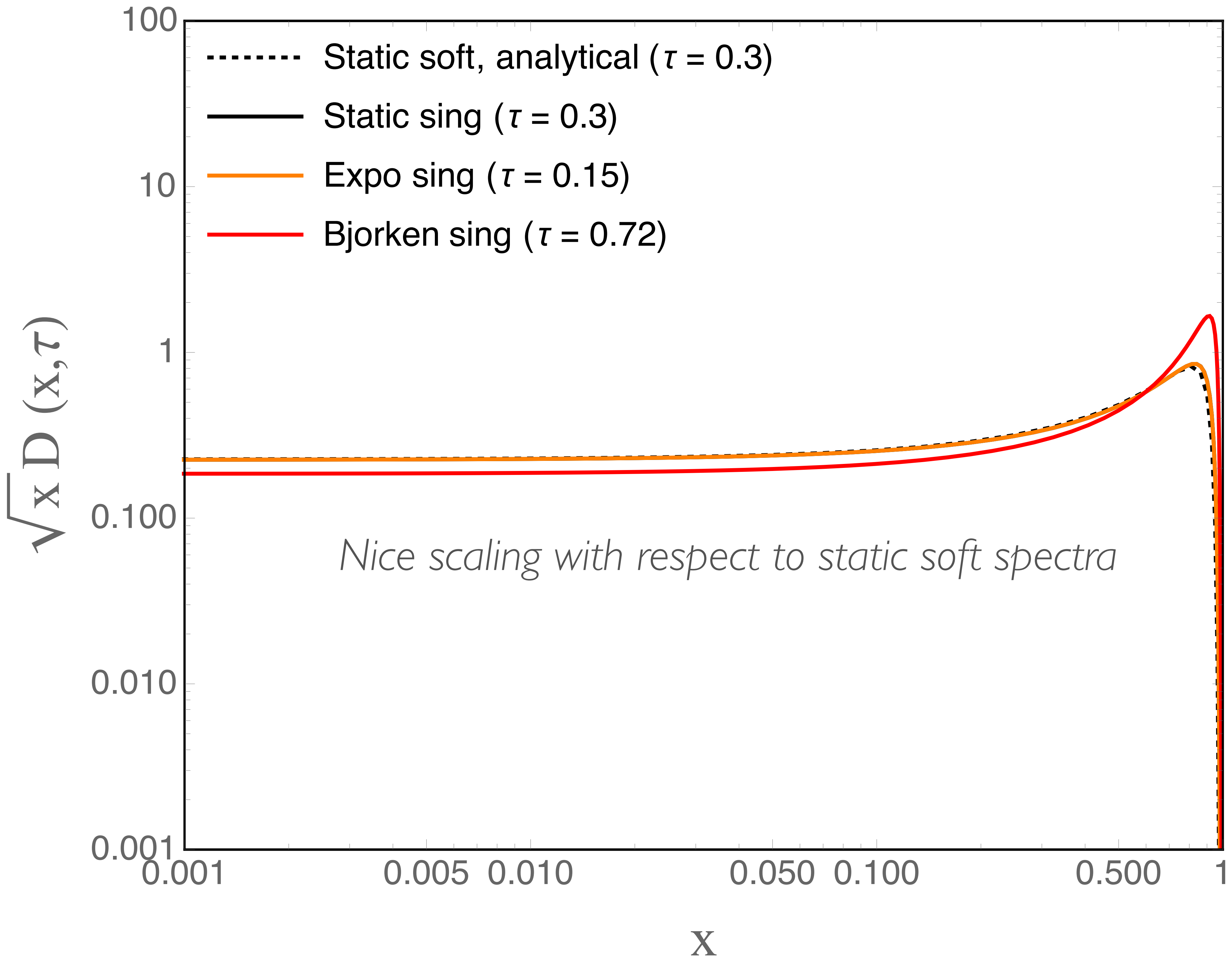
- The kinematic evolution equation (GAIN + LOSS terms) in terms of gluon spectra :

$$\frac{\partial D(x,t)}{\partial\tau} = \int dz\,\mathcal{K}(z,\tau|p)\left[\sqrt{\frac{z}{x}}\,D\left(\frac{x}{z},\tau\right) - \frac{z}{\sqrt{x}}\,D(x,\tau)\right]$$

Static, soft (analytical) gluon spectra

$$D(x,\tau) = \frac{\tau}{\sqrt{x}(1-x)^{3/2}}\,\mathrm{e}^{-\pi\frac{\tau^2}{1-x}}$$





- Gluon spectra:

A. Singular rates ==> Nice scaling in τ_{eff} .

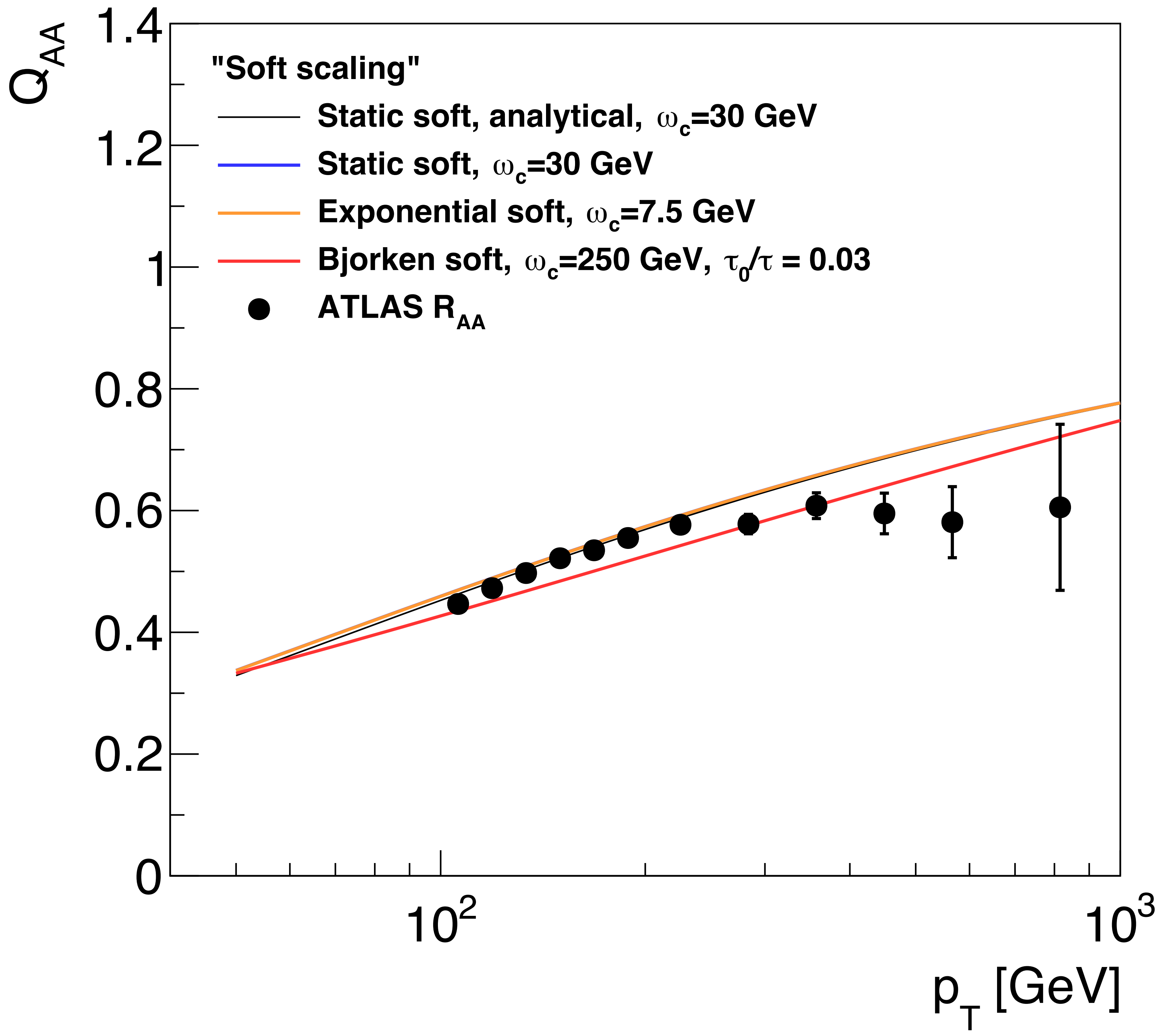
B. Full rates ==> No scaling in τ_{eff}.

See k_T *broadening* of cascades : M. Rohrmoser talk

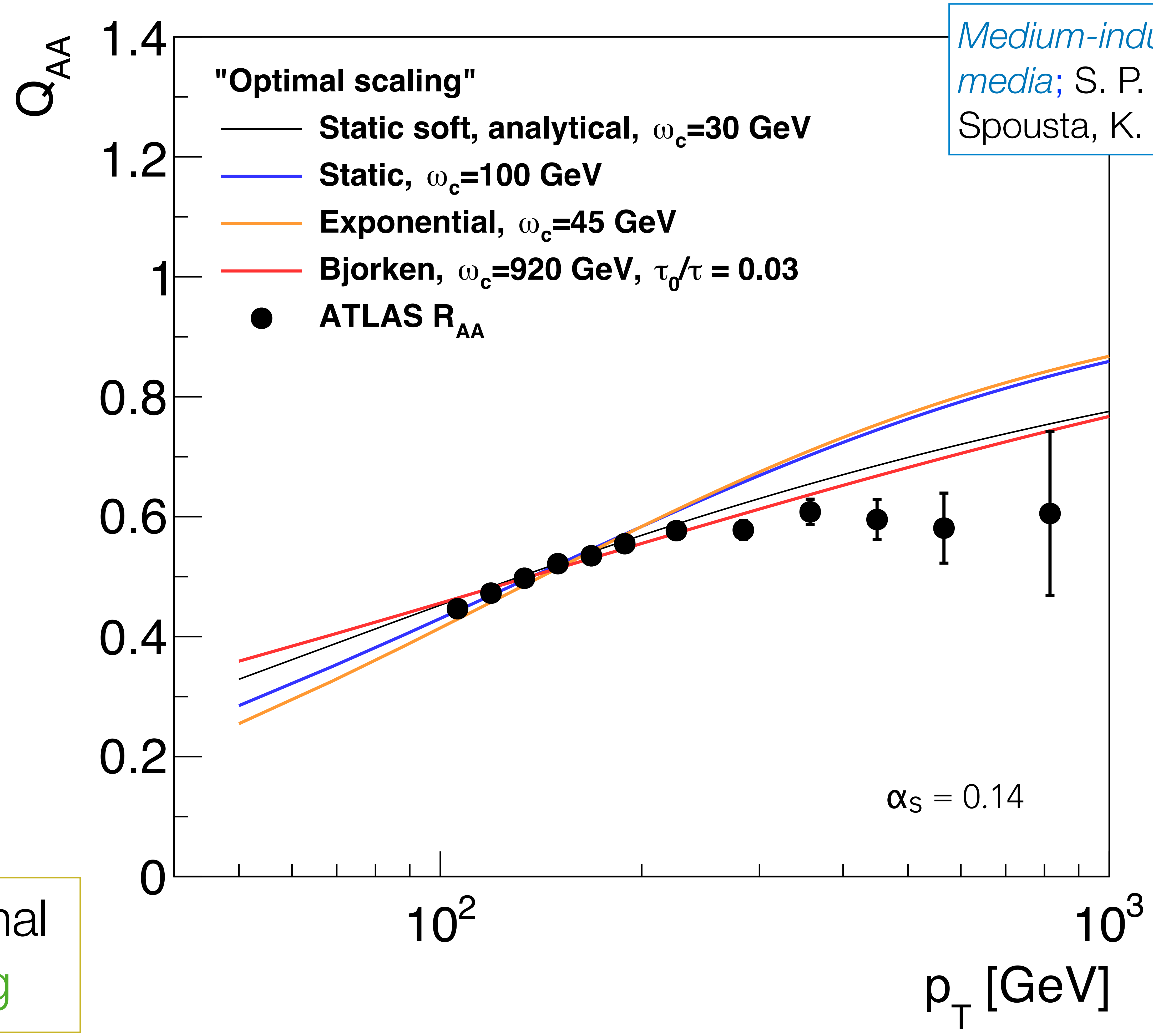
- At low x, we see a 1/(√x) behaviour of all the profiles >> *recovered from the similar gluon splitting at low x.*

Gluonic cascades

Is it possible to re-scale Q_{AA} for different medium ?



The Bjorken profile depends on additional choice of (τ_0/τ) : No universal scaling



Medium-induced cascade in expanding media; S. P. Adhya, C. A. Salgado, M. Spousta, K. Tywoniuk; JHEP 07 (2020) 150.

- Significant differences in values of the quenching parameter for different types of medium and kinematical ranges point to the importance of precise modelling of the jet quenching phenomenon !

- Good, but not perfect scaling is achieved by optimisation.
- Scaling for expo medium ~ average scaling.

But we did for GLUONIC cascades only.
Next, we go for **multi- partonic cascades** …

Does the media behave differently as a function of rapidity ?

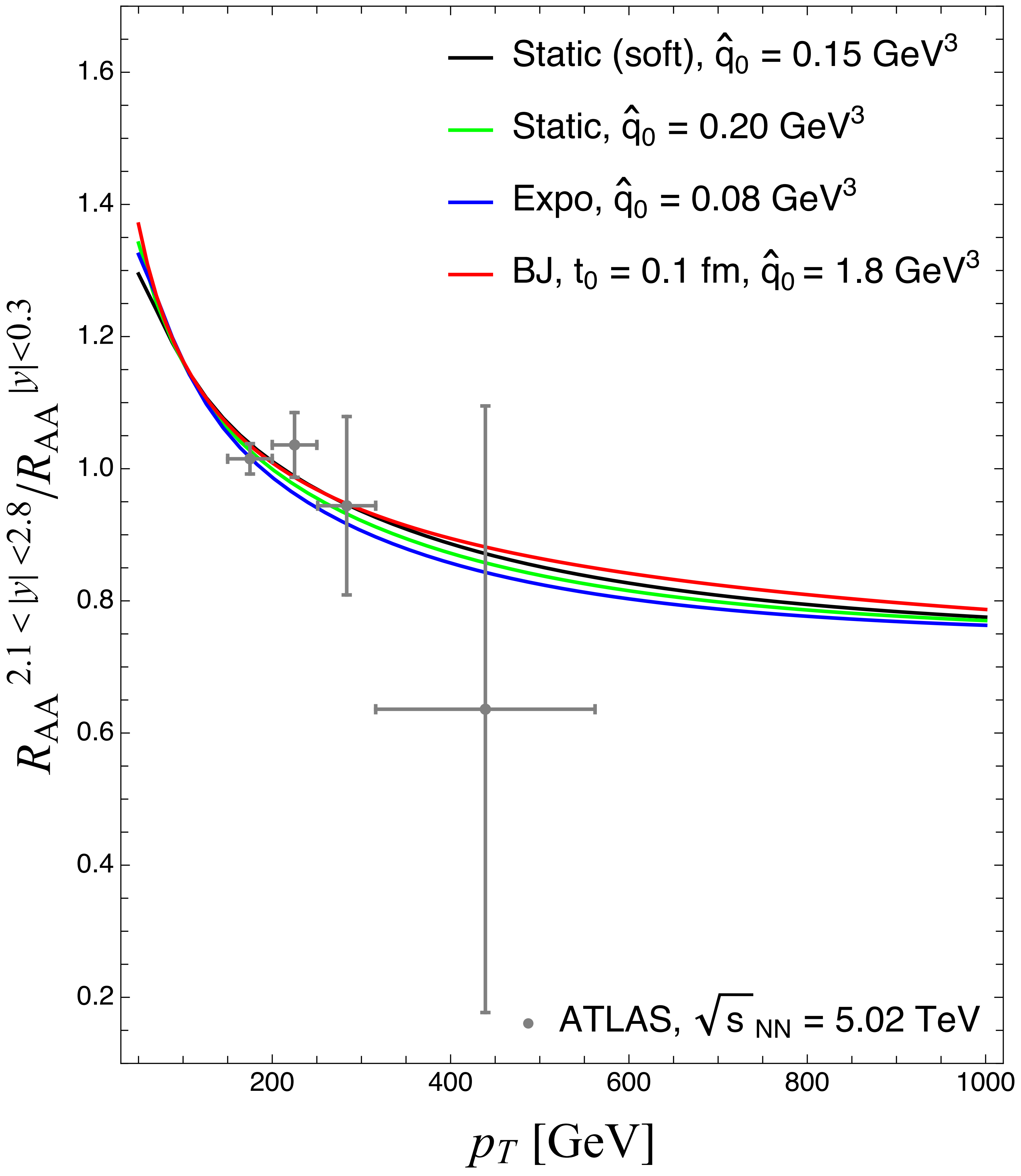
S. P. Adhya., C. A. S., M. S., K. T.
arXiv:2106.02592 (2021)

Multipartonic cascades

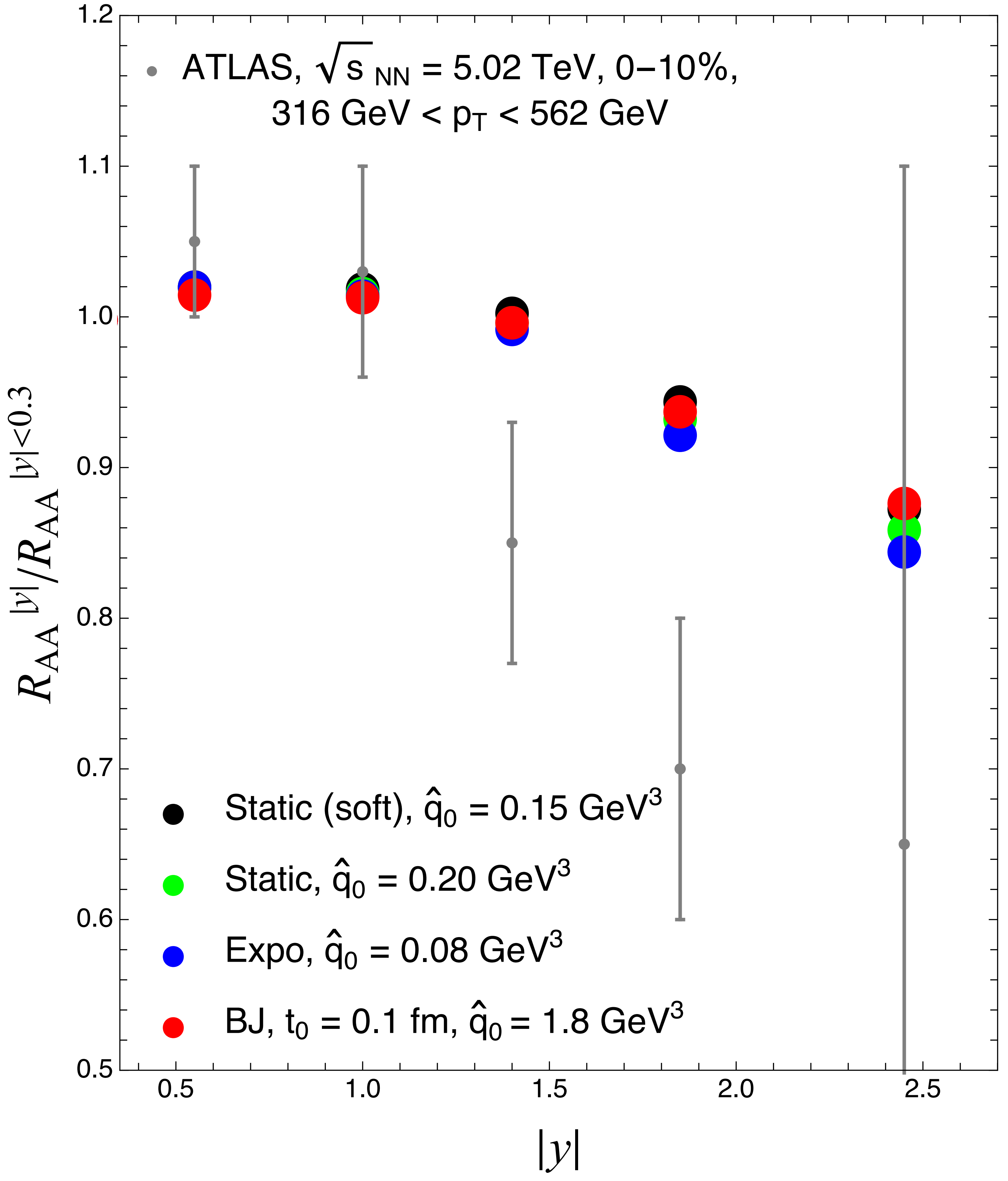
No

No

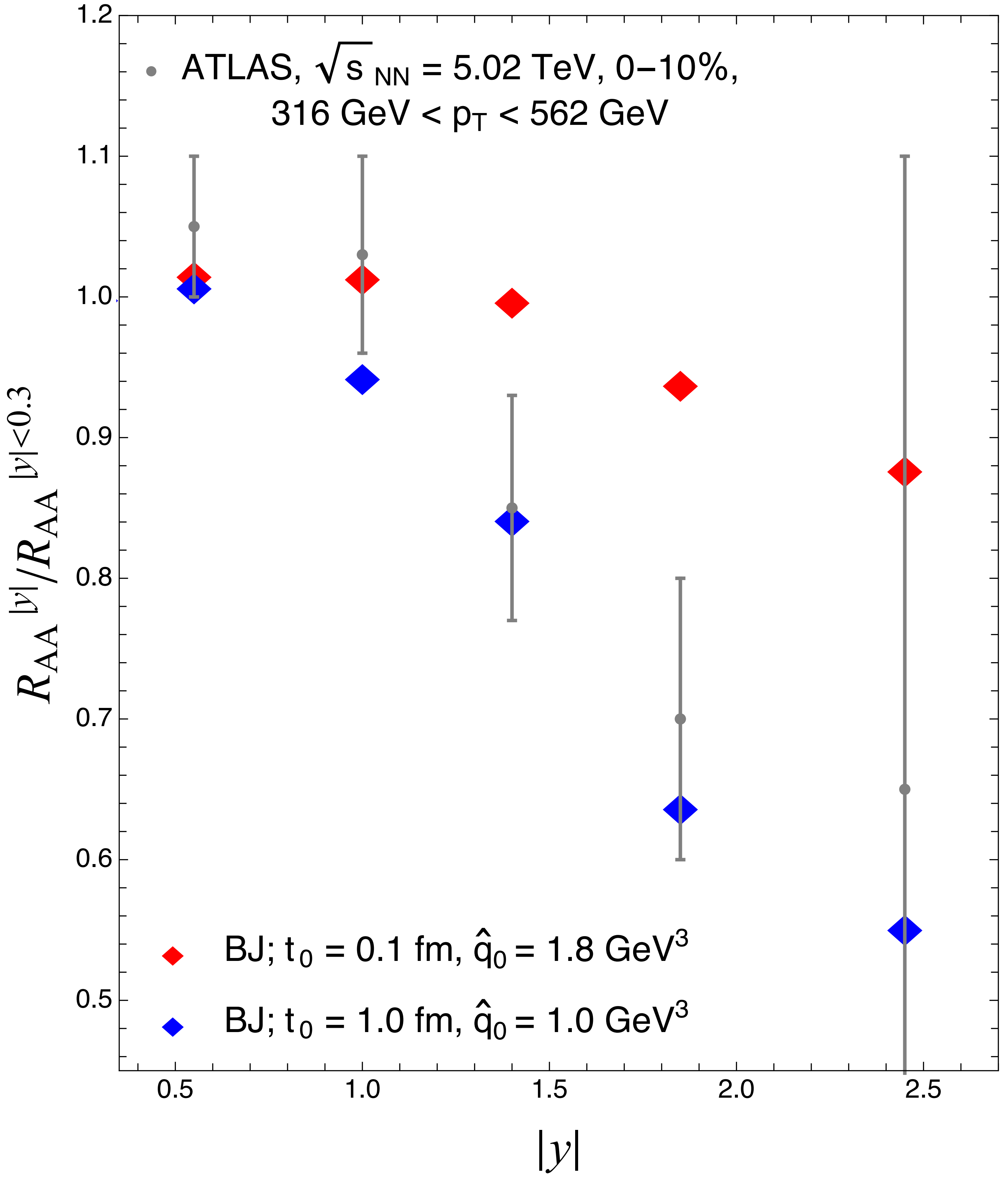
Yes



Rapidity ratio for different medium profiles wrt pT



Rapidity ratio for different medium profiles wrt |y|



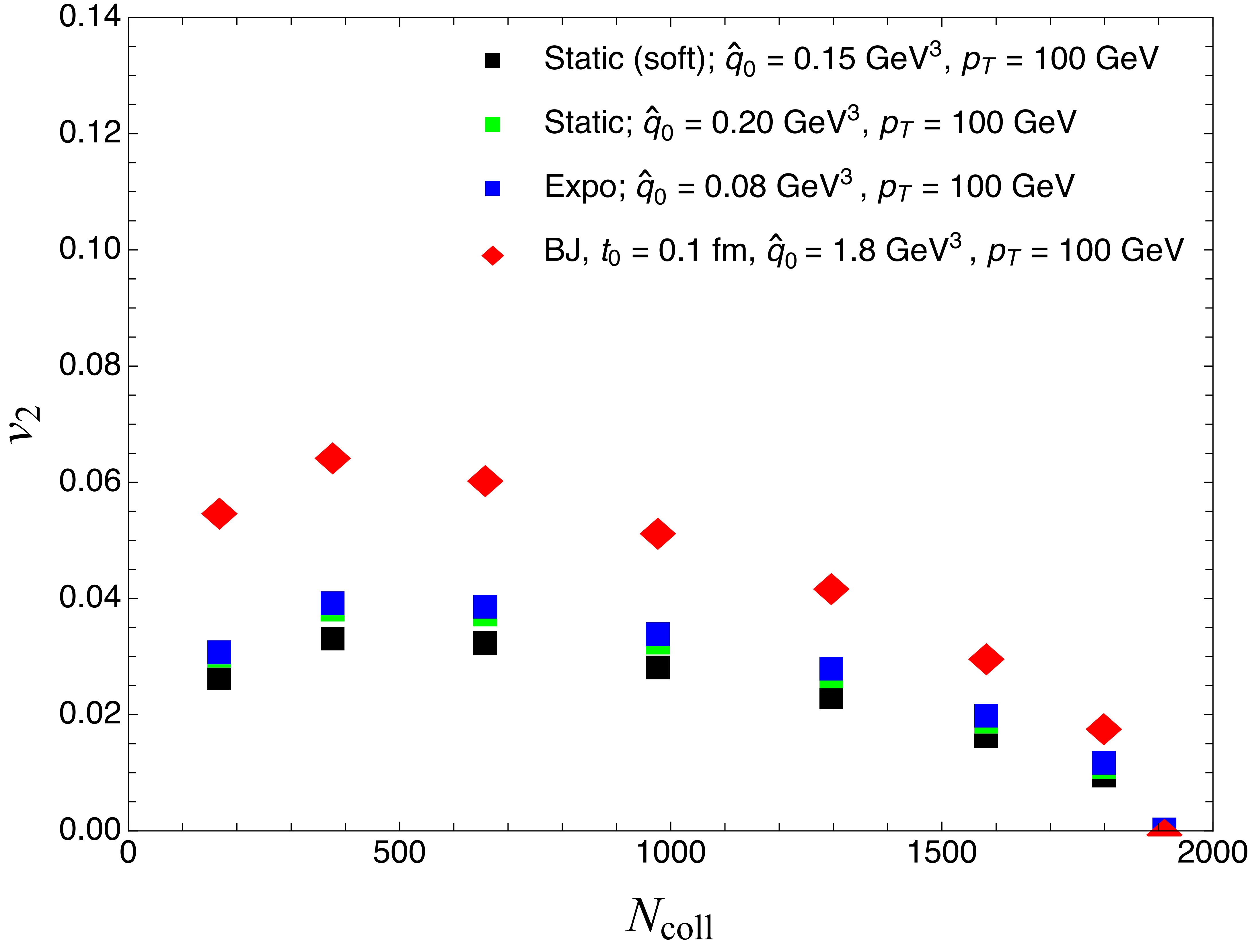
Rapidity ratio for different start of quenching time for the Bjorken

Does the media behave differently with respect to v_2?

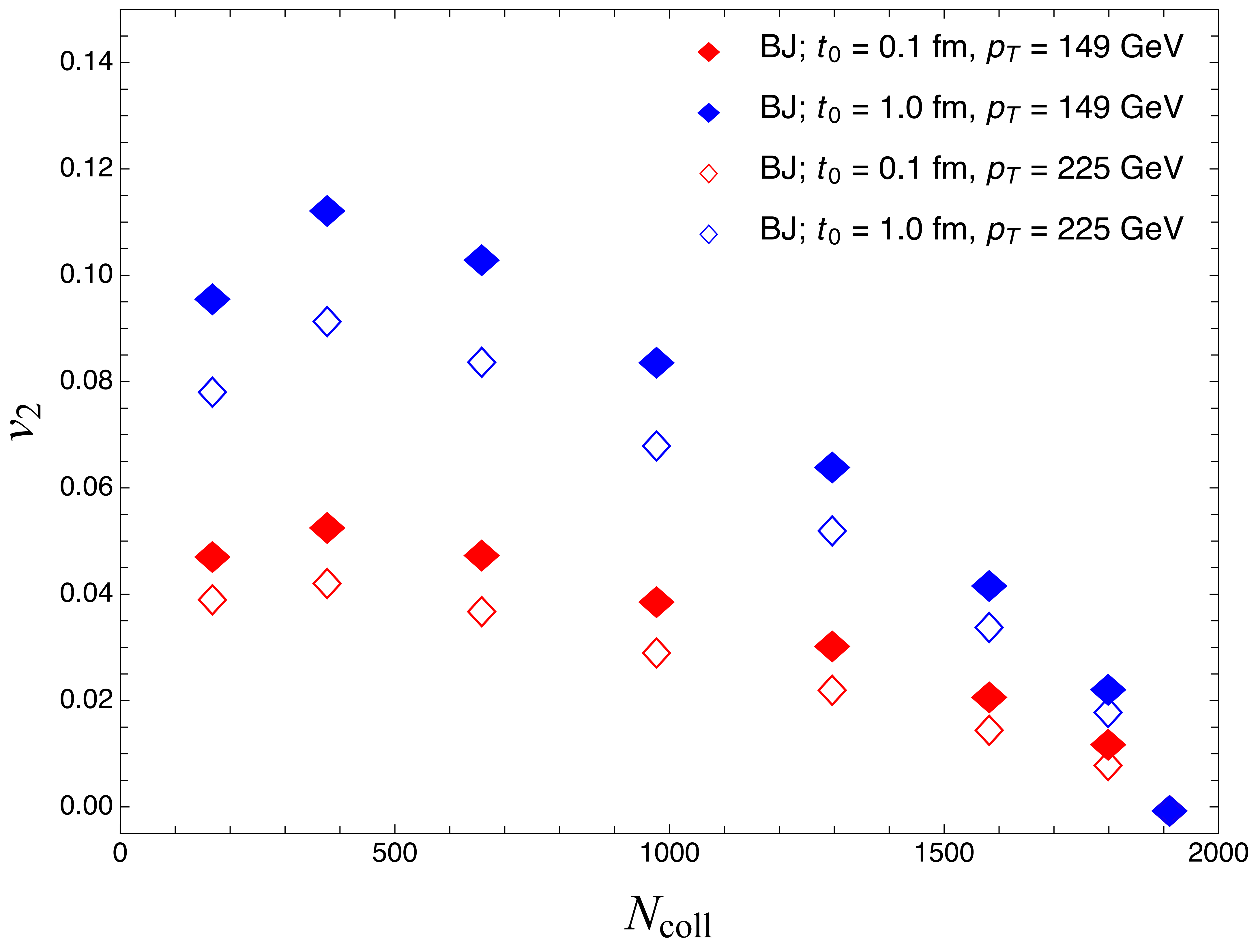
Zijic et. al.; J. Phys. G 46 (2019) 085101.

$$v_2 = \frac{1}{2}\frac{Q_{\mathrm{AA}}(L^{in}) - Q_{\mathrm{AA}}(L^{out})}{Q_{\mathrm{AA}}(L^{in}) + Q_{\mathrm{AA}}(L^{out})}$$

Yes and no



Yes



- The impact of the medium expansion can be largely scaled out by a suitable choice of qˆ [*confirming Adhya et. al., 2020*].
- The jet v_2 remains sensitive to choice of t_0.

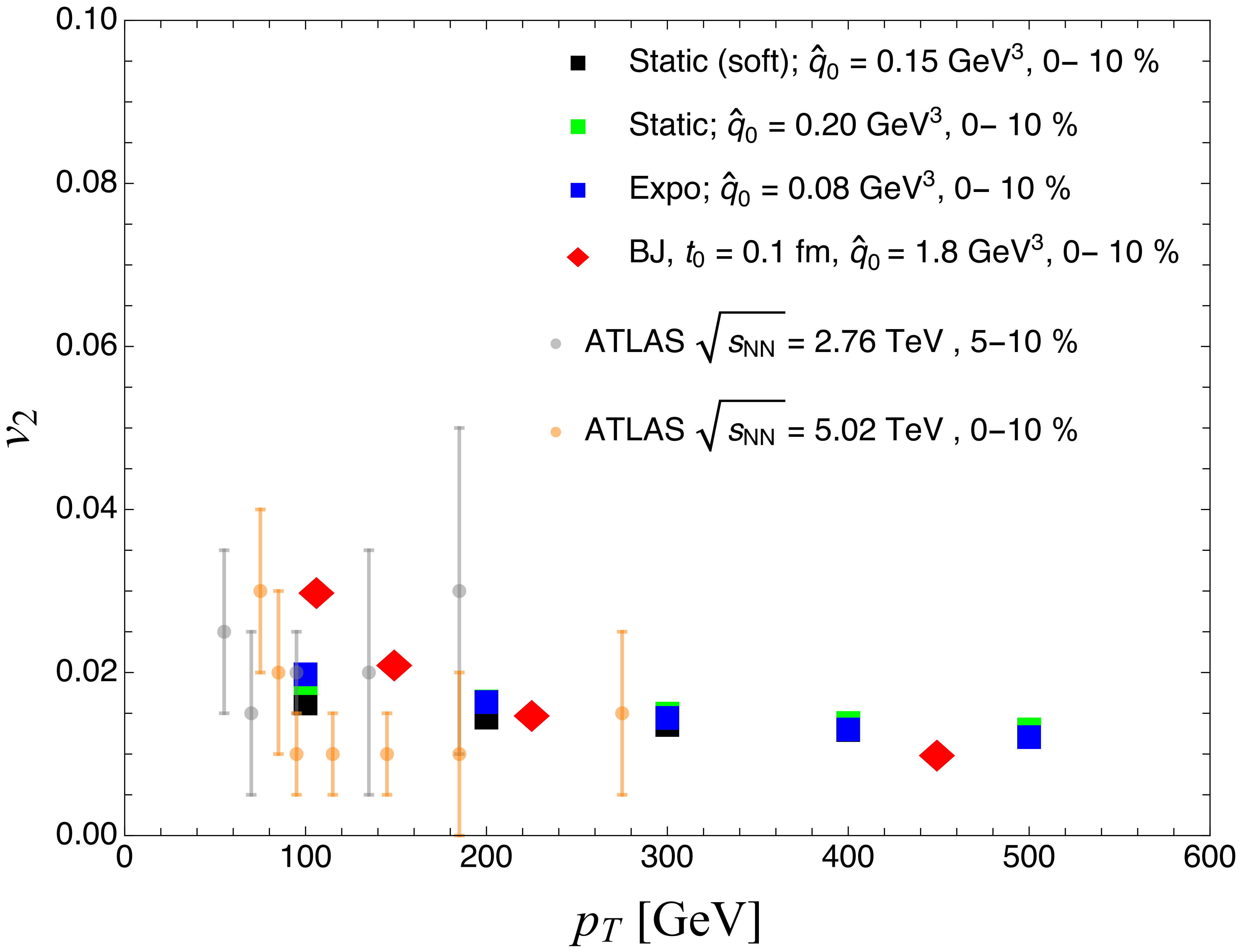
S. P. A., C. A. S., M. S., K. T. arXiv:2106.02592 (2021)

Does the media behave differently with respect to v_2?

S. P. A., C. A. S., M. S., K. T.
arXiv:2106.02592

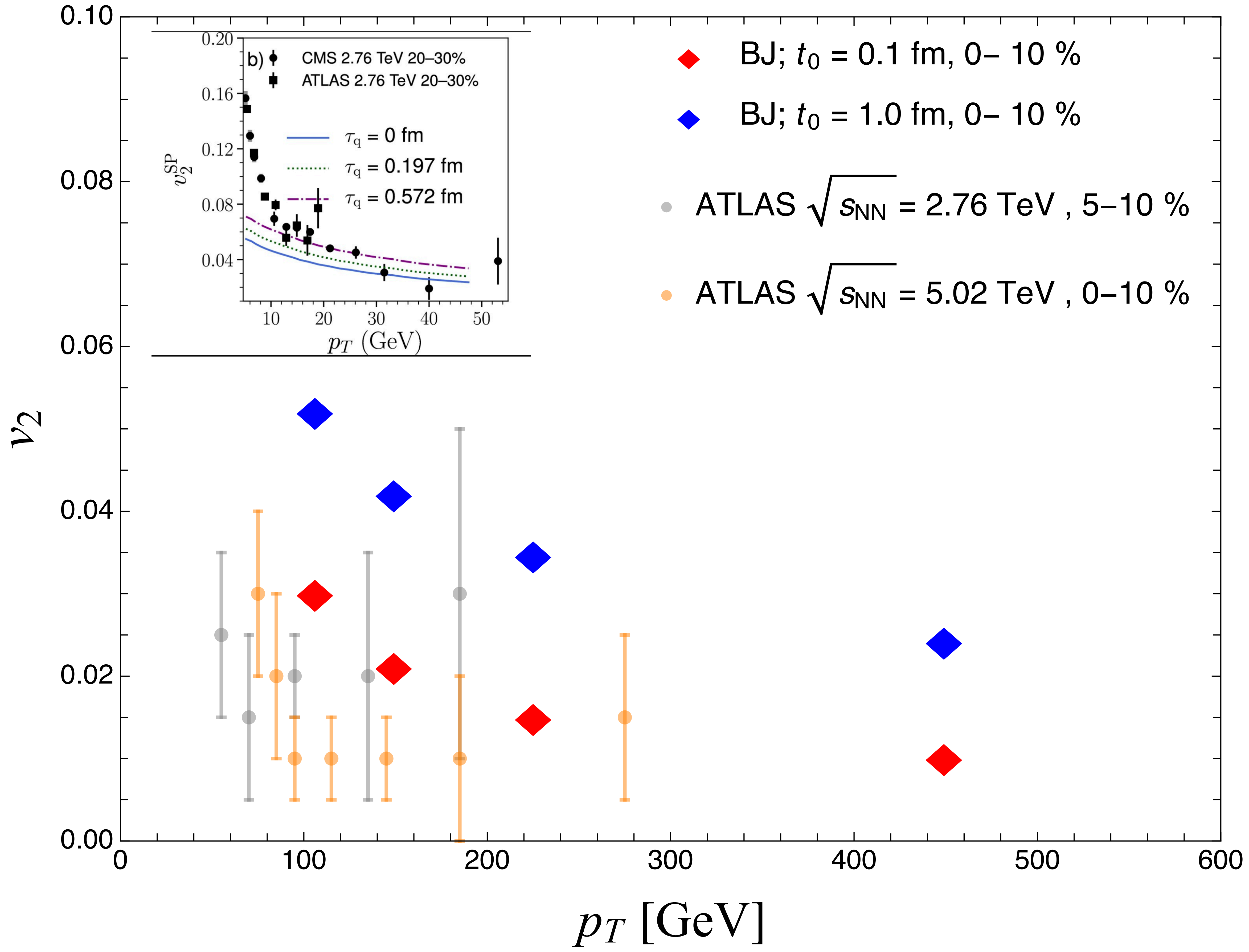
Yes and no

Elliptic flow v_2 as a function of p_T for different media



Yes

Elliptic flow v_2 as a function of p_T for Bjorken initial conditions



- Agreement with findings of the sensitivity of v_2 on t_0 [*Carlota et. al., PLB, 2020 (inset)*] which was done in more complex modelling of the collision geometry, but less complex modelling of the medium induced showering.

Thanks !

BACKUP

ATLAS measurements