

# Universal features of the medium-induced gluon cascade and jet quenching in expanding media

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## Introduction

Comprehensive understanding of *medium-induced radiative energy loss* is of a paramount importance in describing observed jet quenching in heavy-ion collisions.

- We calculate the *medium-modified gluon splitting rates* for different profiles of the expanding partonic medium, namely *profiles for static, exponential, and Bjorken expanding medium*.
- The *medium-evolved gluon spectra* are systematically calculated using the kinetic rate equation for all the medium profiles and a study of the distinctive features at low and high momentum fractions of radiated gluons are provided.

We provide an estimation of the jet  $R_{AA}$  which quantifies a sensitivity of the inclusive jet suppression on the way how the medium expands.

Comparisons of predicted jet  $R_{AA}$  with experimental data from the LHC are also provided.

## Formalism

- Medium-induced gluon energy distribution radiated off a hard parton in *multiple soft medium-induced scattering* approximation; Baier-Dokshitzer- Mueller- Peigne’- Schiff- Zakharov [BDMPSZ] formalism.
- For arbitrary many soft scattering centres, the projectile performs a Brownian motion in transverse momentum (path integral is equivalent to harmonic oscillator).
- Development of in medium gluon cascade through the evolution equation.
- Quenching parameters :**
$$\hat{q}(t)^{expo} = \hat{q}_0 e^{-t/L} \quad \hat{q}(t)^{BJ} = \hat{q}_0 (t_0/t)^\alpha \quad \hat{q}^0 = \text{Static}$$
- Gluon spectra for different medium profiles :
$$P_{gg} = 2C_A \frac{(1-z(1-z))^2}{z(1-z)}$$

$$\frac{dI}{dz} = \frac{\alpha_s}{\pi} P(z) \sqrt{\frac{q_0}{p}} \kappa(z) L \quad \xrightarrow{\text{Static medium; soft gluons}}$$

$$\frac{dI}{dz} = \frac{\alpha_s}{\pi} P(z) \text{Re} \ln [\cos(\Omega_0 L)] \quad \xrightarrow{\Omega_0 L = \sqrt{\frac{-i q_0}{2 p}} \kappa(z) L}$$

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

## Evolution equation

- The kinematic evolution equation (**GAIN** + **LOSS** terms) :

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

- The splitting rate is given as :

$$\mathcal{K}(z, \tau | p) \equiv \sqrt{\frac{p}{\hat{q}_0}} \hat{\mathcal{K}}(z, L | p) = \sqrt{\frac{p}{\hat{q}_0}} \frac{dI}{dz dL} \quad \tau \equiv \sqrt{\frac{\hat{q}_0}{p}} L$$

## Discussions

- Three types of the medium expansions are studied within the framework of multiple soft scattering limit.
- Splitting rates** of gluon emission are evaluated from single gluon emission spectrum and **medium evolved gluon spectra** are calculated by means of numerical solutions of the evolution equation for the gluon radiation; highlighting the distinctive features at low and high  $x$ .
- The medium evolved spectra for different medium profiles is used to calculate the **nuclear modification factor of jets**.
- The **scaling properties** with respect to the quenching parameter are analysed for the nuclear modification factor of the jets.

## Results for the rate and spectra

The gluon splitting rate for different medium profiles :

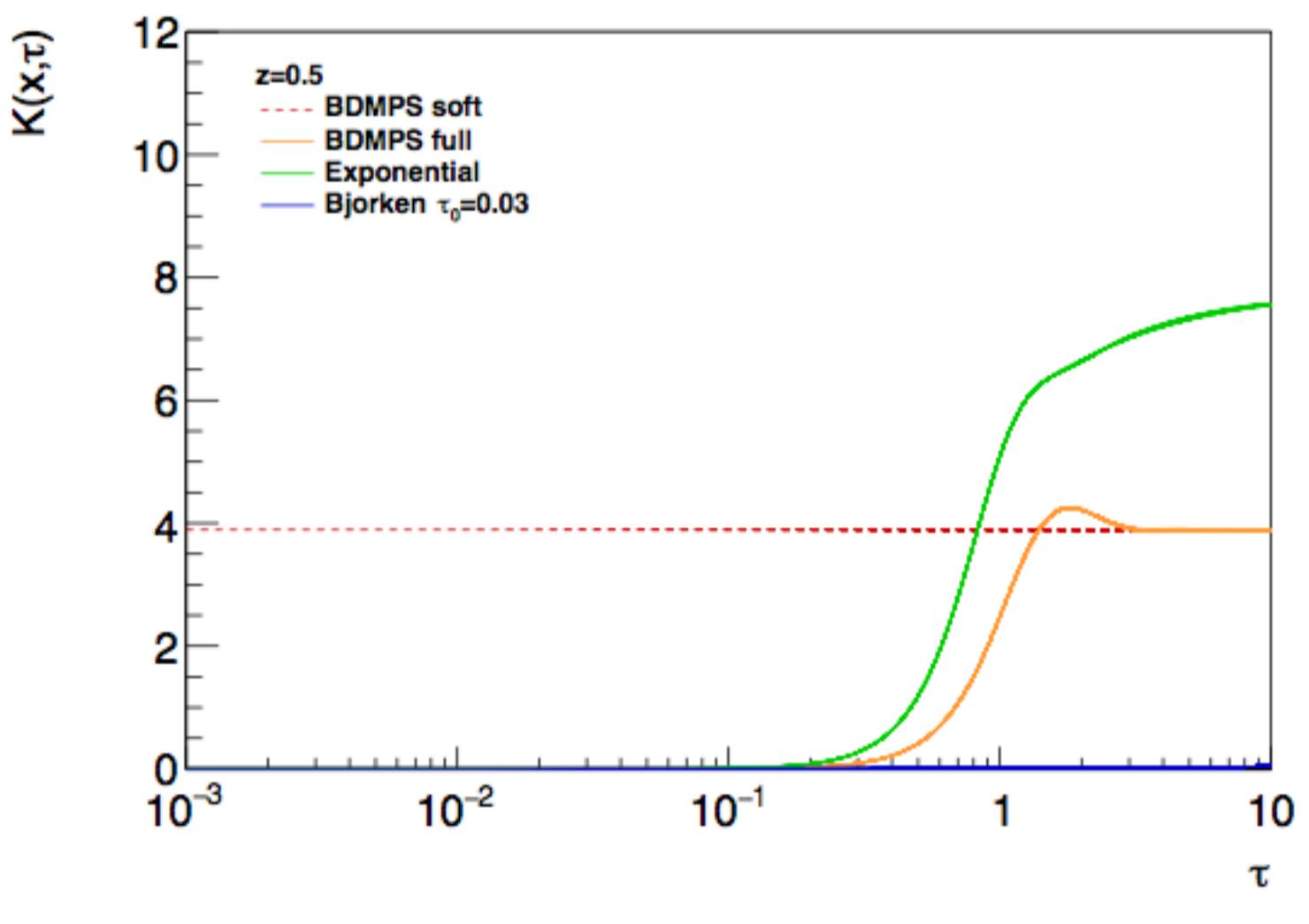
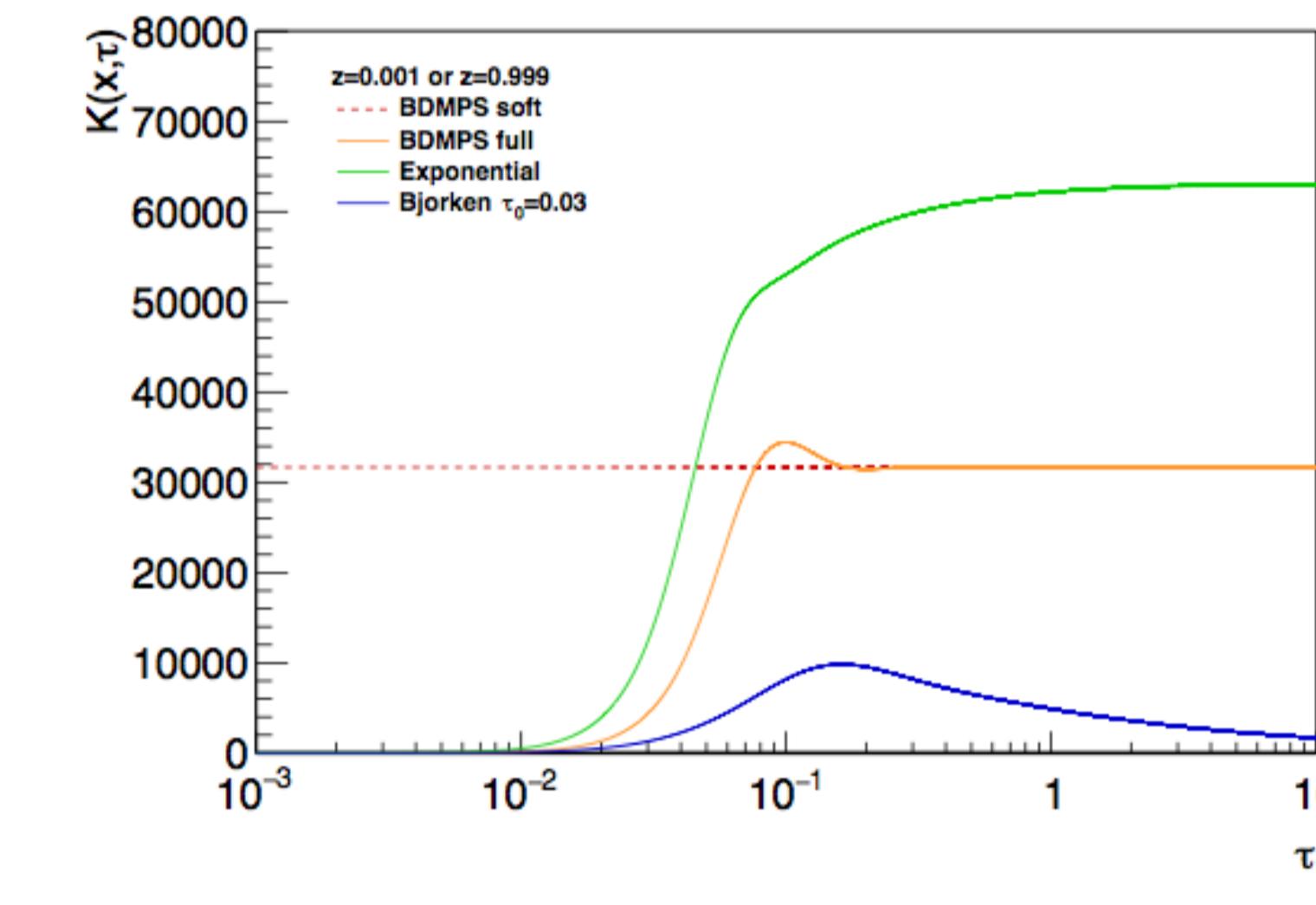
$$\hat{\mathcal{K}}(z, \tau) = \frac{\alpha_s}{2\pi} P(z) \kappa(z) \quad \text{Static medium; soft gluons only}$$

$$\hat{\mathcal{K}}(z, \tau) = \frac{\alpha_s}{2\pi} P(z) \kappa(z) \text{Re} \left[ (i-1) \tan \left( (1-i) \kappa(z) \tau / 2 \right) \right] \quad \text{Static medium}$$

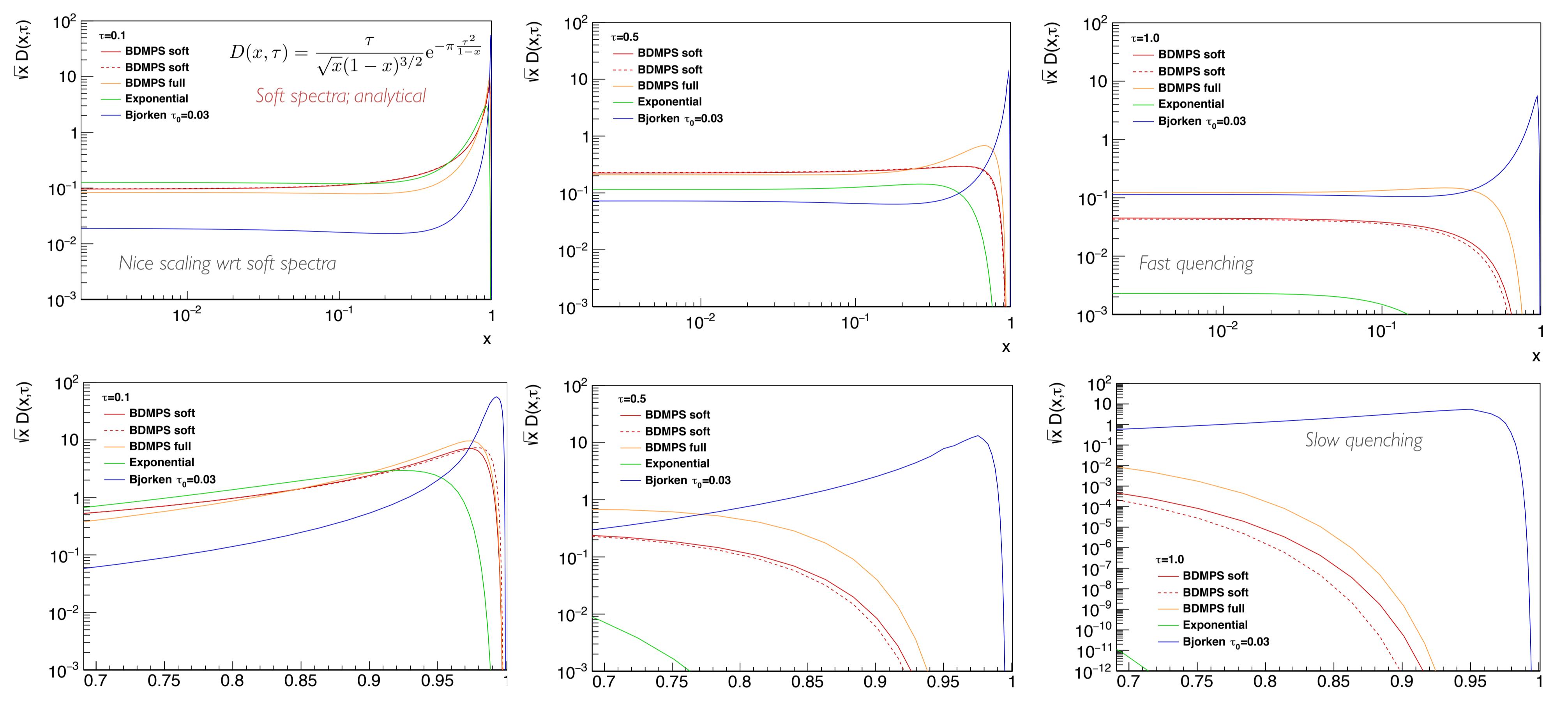
$$\mathcal{K}(z, \tau) = \frac{\alpha_s}{\pi} P(z) \kappa(z) \text{Re} \left[ (i-1) \frac{J_1((1-i)\kappa(z)\tau)}{J_0((1-i)\kappa(z)\tau)} \right] \quad \text{Expanding exponentially}$$

$$\mathcal{K}(z, \tau) = \frac{\alpha_s}{2\pi} P(z) \kappa(z) \sqrt{\frac{\tau_0}{\tau + \tau_0}} \text{Re} \left[ (1-i) \frac{J_1(z_L)Y_1(z_0) - J_1(z_0)Y_1(z_L)}{J_1(z_0)Y_0(z_L) - J_0(z_L)Y_1(z_0)} \right] \quad z_0 = (1-i)\kappa(z)\tau_0 \\ z_L = (1-i)\kappa(z)\sqrt{\tau_0(\tau + \tau_0)}$$

- Static (soft) has a constant splitting rate.
- Exponential and Bjorken profiles have highest and lowest rates respectively.
- The rates for all the profiles except the BDMPS soft profile are similar at very low evolution time or length of the medium.



- The medium evolved gluon spectra for different medium profiles :



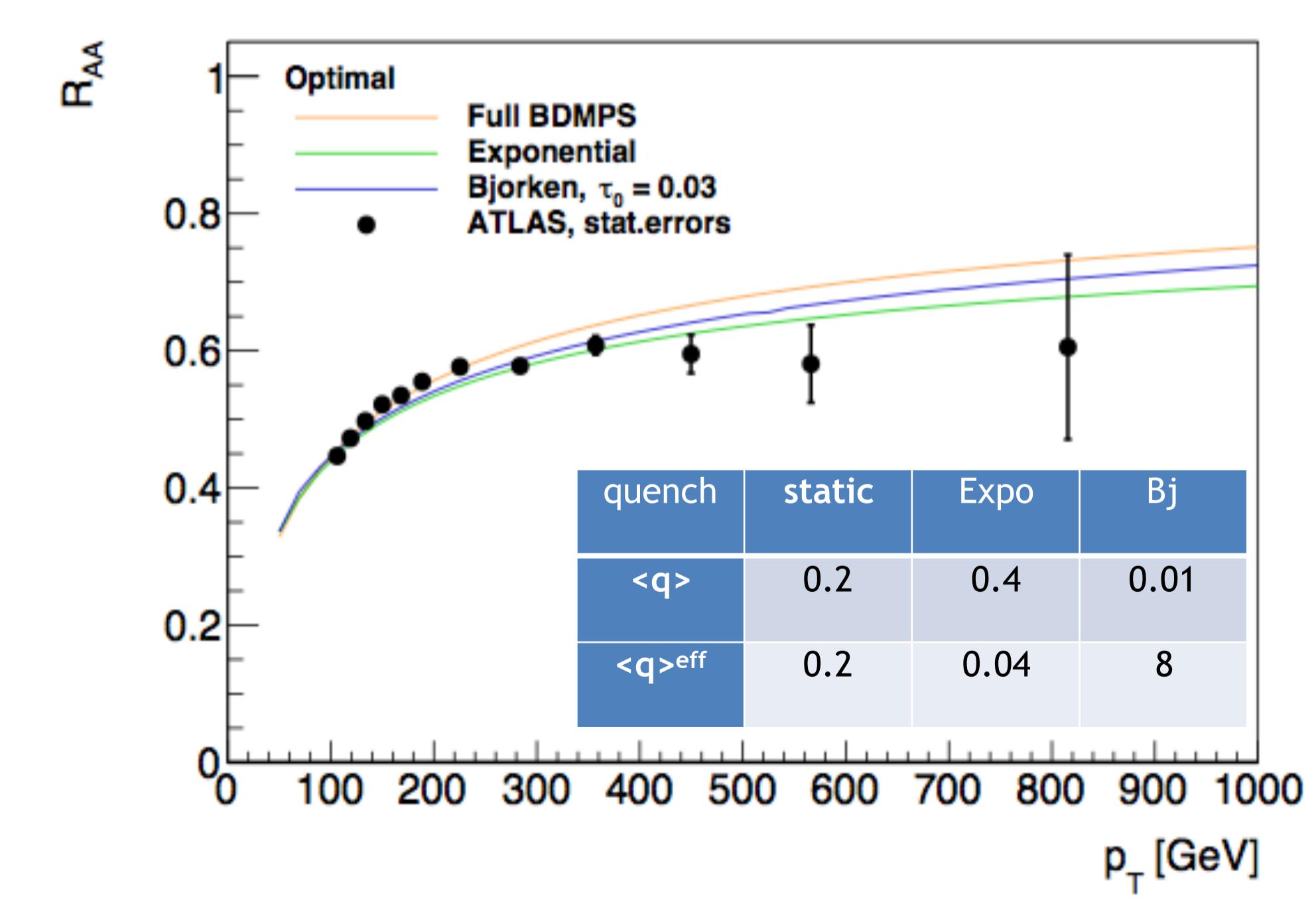
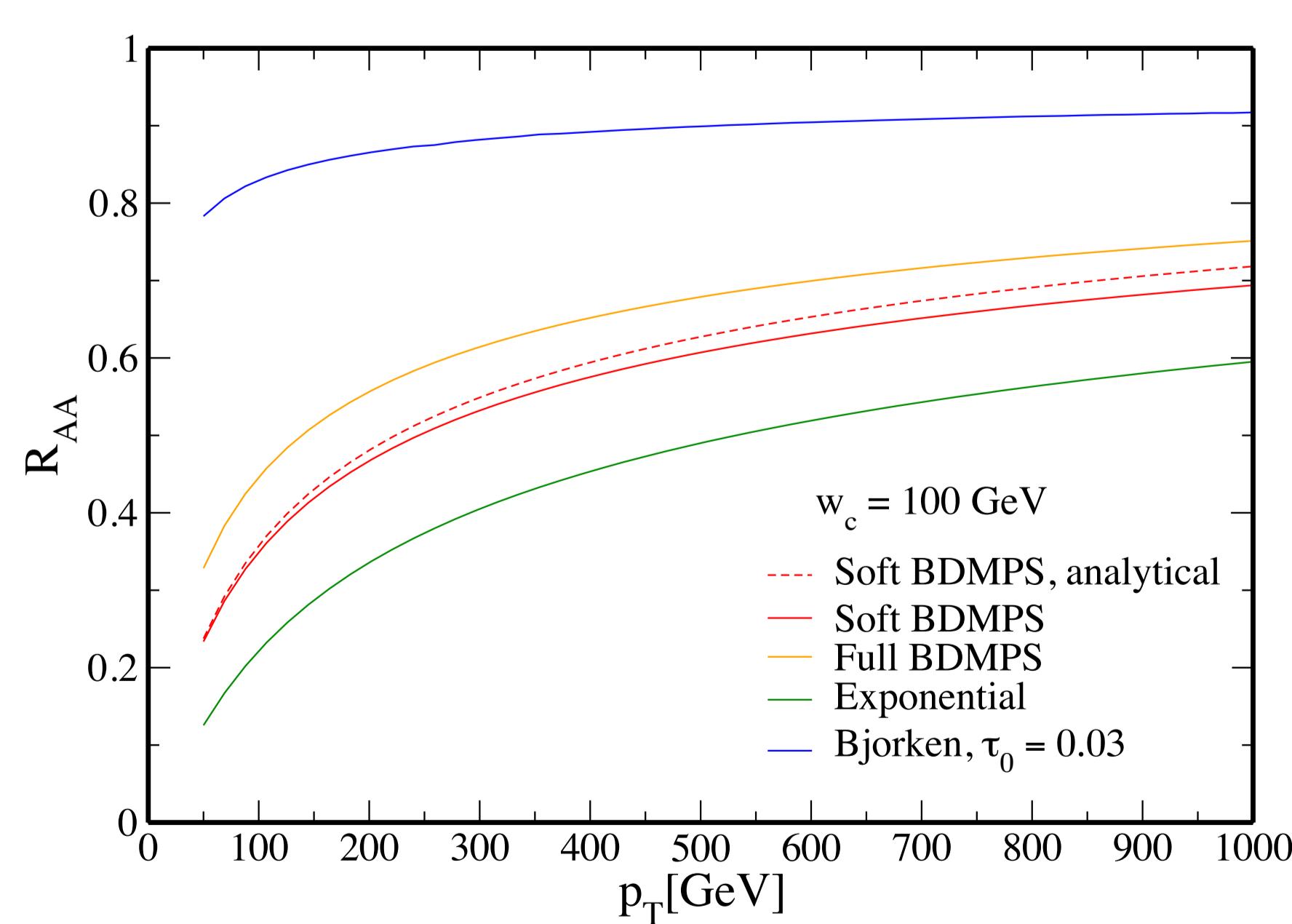
## The final story : Quenching

- Considering the formula for the parton spectrum at high-pT ,

$$\frac{d\sigma_{AA}}{dp_T} = \int dp'_T \int_0^1 \frac{dx}{x} \delta(p_T - xp'_T) D\left(x, \tau \equiv \sqrt{\hat{q}/p'_T}\right) \frac{d\sigma_0}{dp'_T}$$

- A steeply falling hard spectrum, with  $N = 5.6$ ,

$$R_{AA} \simeq Q(p_T) = \int_0^1 dx x^{N-1} D(x, \sqrt{x}\tau)$$



## Scope

- Going beyond energy loss: medium-modified intra-jet and out-of-jet distribution of particles to be studied.
- Generalization to complicated medium models such as implementation of hot spots.

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