Energy Loss Effects in EECs at LO

28th March 2023, HP 2023

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Based on recent and on-going work with Y. Mehtar-Tani

Energy Correlators

Brookhaven National Laboratory

First considered a long time ago in parallel to jet shapes

Andrés, Monday
Domínguez, Wednesday
Holguin, Wednesday

Energy Correlations in Electron-Positron Annihilation: Testing Quantum Chromodynamics

C. Louis Basham, Lowell S. Brown, Stephen D. Ellis, and Sherwin T. Love
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 21 August 1978)

1-point correlator

$$\frac{d\Sigma}{d\Omega} = \sum_{N=2}^{\infty} \int \sum_{a=1} E_a^{-1} d^3p_a \frac{d^N\sigma}{E_1^{-1}d^3p_1 \cdots E_N^{-1}d^3p_N} S_N \left[\sum_{b=1}^{N} \frac{E_b}{W}\delta(\Omega_b-\Omega)\right]$$

2-point correlator

$$\frac{d^2\Sigma}{d\Omega\, d\Omega'} = \sum_{N=2}^{\infty}\int\prod_{a=1}^{N} E_a^{-1}d^3p_a \frac{d^N\sigma}{E_1^{-1}d^3p_1\cdots E_N^{-1}d^3p_N} S_N\left[\sum_{b,c=1}^{N}\frac{E_bE_c}{W^2}\delta(\Omega_b-\Omega)\delta(\Omega_c-\Omega')\right]$$

- N-particle cross-section
- Energy weighting
- Restricted angular region
- Form pairs out of N partons

It should be emphasized that the measurement of the energy cross section, Eq. (1), *does not require any detailed event-by-event analysis* as is the case for tests which specify a quantity involving the definition of a jet axis in each event.[5]

Energy Correlators

Brookhaven National Laboratory

In mid-1990's, a deeper connection to QFT was first proposed

at high energies. We argue that from the point of view of general quantum field theory, all information about the multijet structure is contained in the values of a family of multiparticle quantum correlators that can be expressed in terms of the energy–momentum tensor.

1995

Jets and Quantum Field Theory

N.A.Sveshnikov [a] and F.V.Tkachov [b]

also Maldacena, Hofman, 2008

i.e.

~ Observable

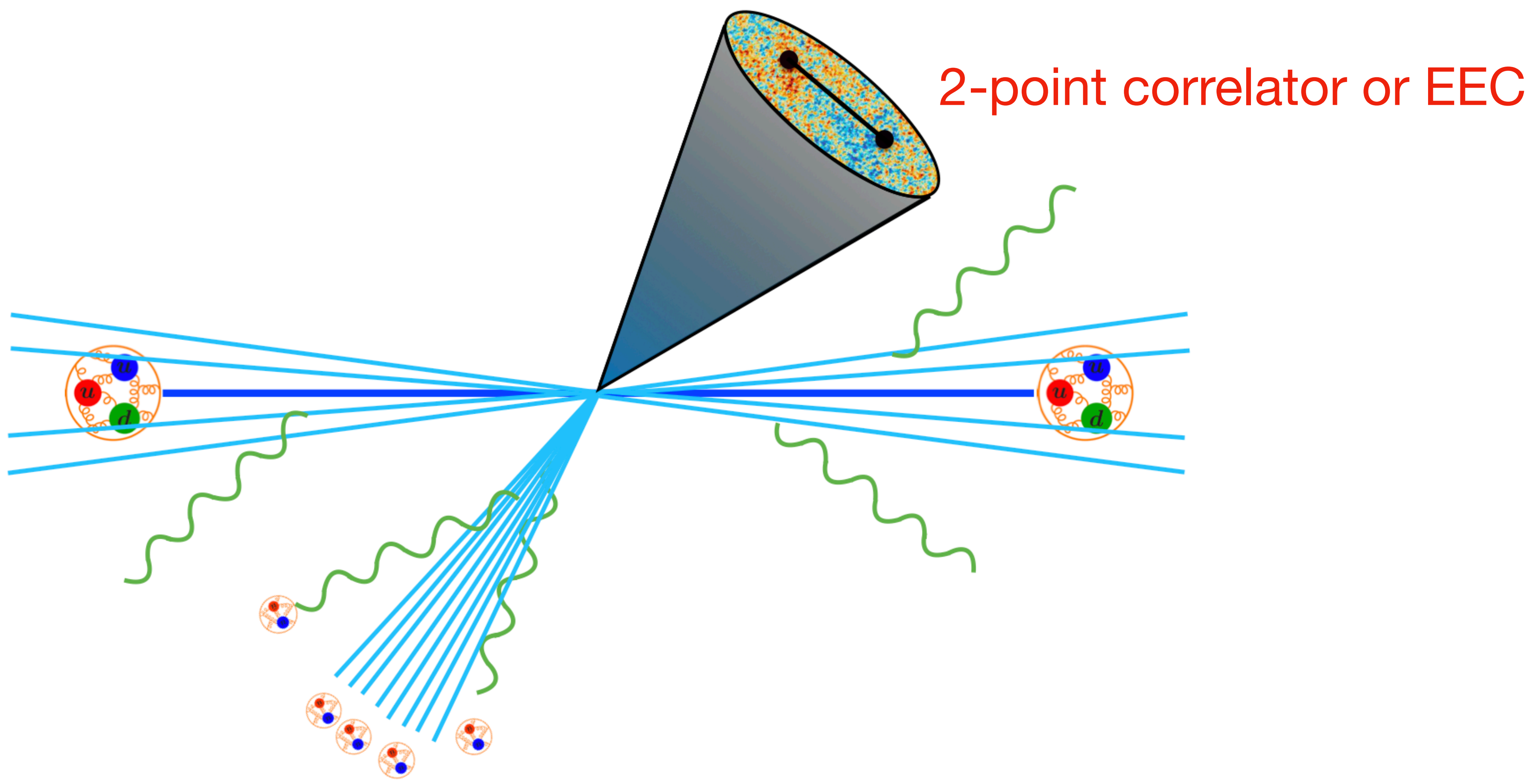
~ N-point correlator

$$\left\langle \textstyle\sum_{i_1} \ldots \sum_{i_N} E_{i_1} \ldots E_{i_N} f_N(\hat{p}_{i_1} \ldots \hat{p}_{i_N}) \right\rangle_{\boldsymbol{P}} = \int dn_1 \ldots \int dn_N \, \langle in | \, \varepsilon(n_1) \ldots \varepsilon(n_N) \, | in \rangle \times f_N(n_1, \ldots, n_N)$$

Flux operator: $\varepsilon(n)\, dn = \lim_{t \to +\infty} \int_0^t \rho^2 d\rho \, n_i T_{0i}(\rho n, t)\, dn$

ECs and jets

When measured inside jets, ECs give a new window into jet substructure



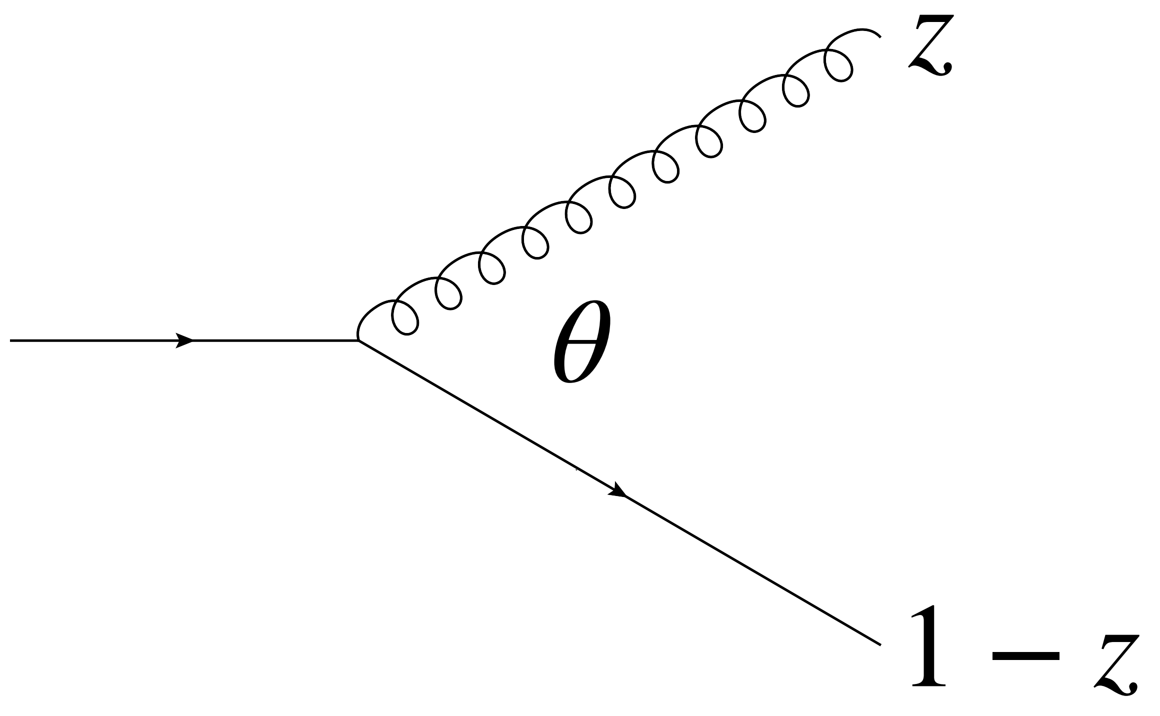
2022

Conformal Colliders Meet the LHC

Kyle Lee,[1,] Bianka Meçaj,[2,] and Ian Moult[2,]

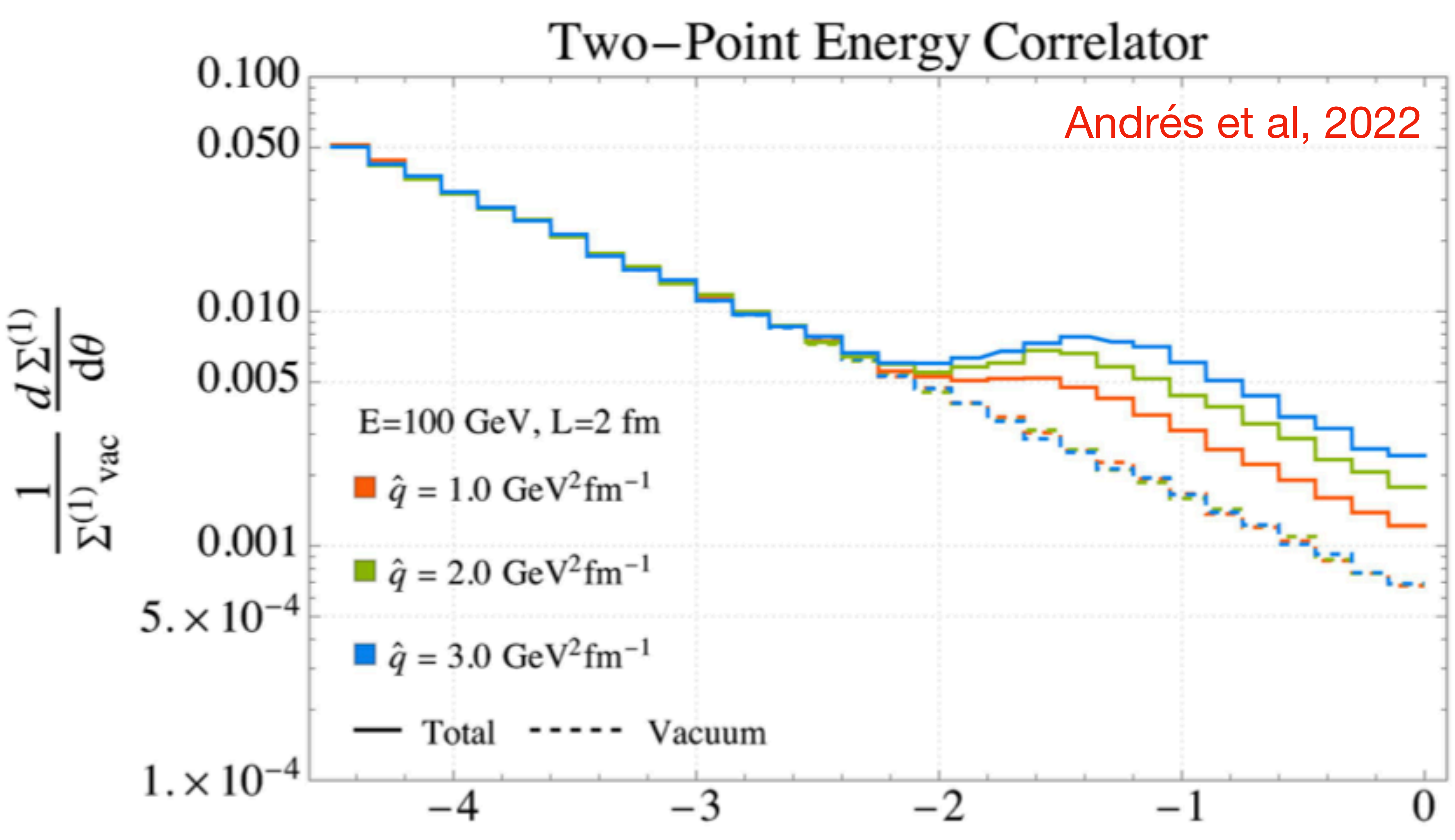
The simplest object is the Energy-Energy correlator (EEC), which reads at LO

$$\frac{d\Sigma}{d\theta} = \int_0^1 dz\, z(1-z) \frac{d\sigma}{\sigma d\theta dz}$$



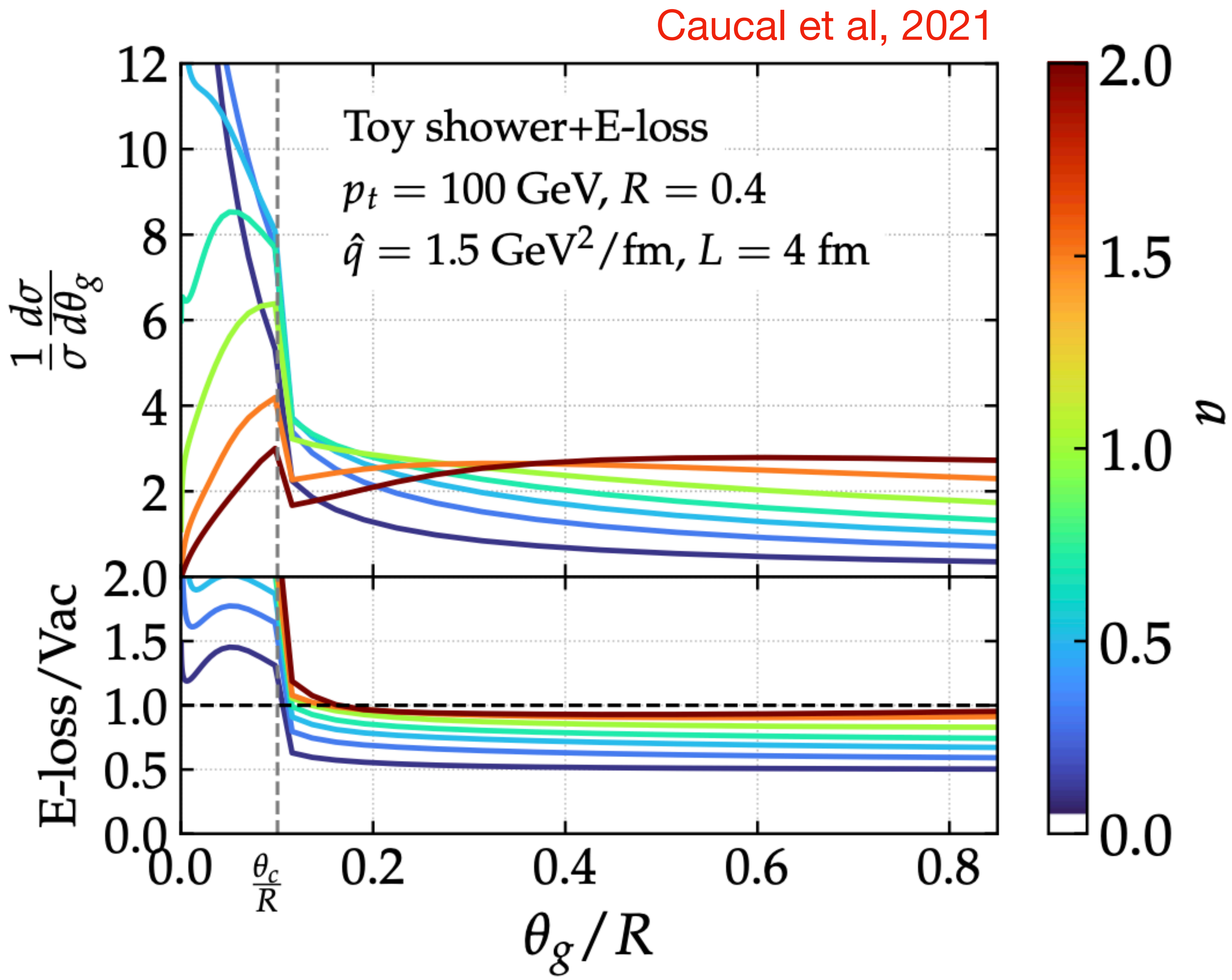
ECs and jets

Recently EEC were considered as a new way to investigate color coherence effects



Modified splitting function

no energy loss (NLO correction)



Modified splitting function and energy loss

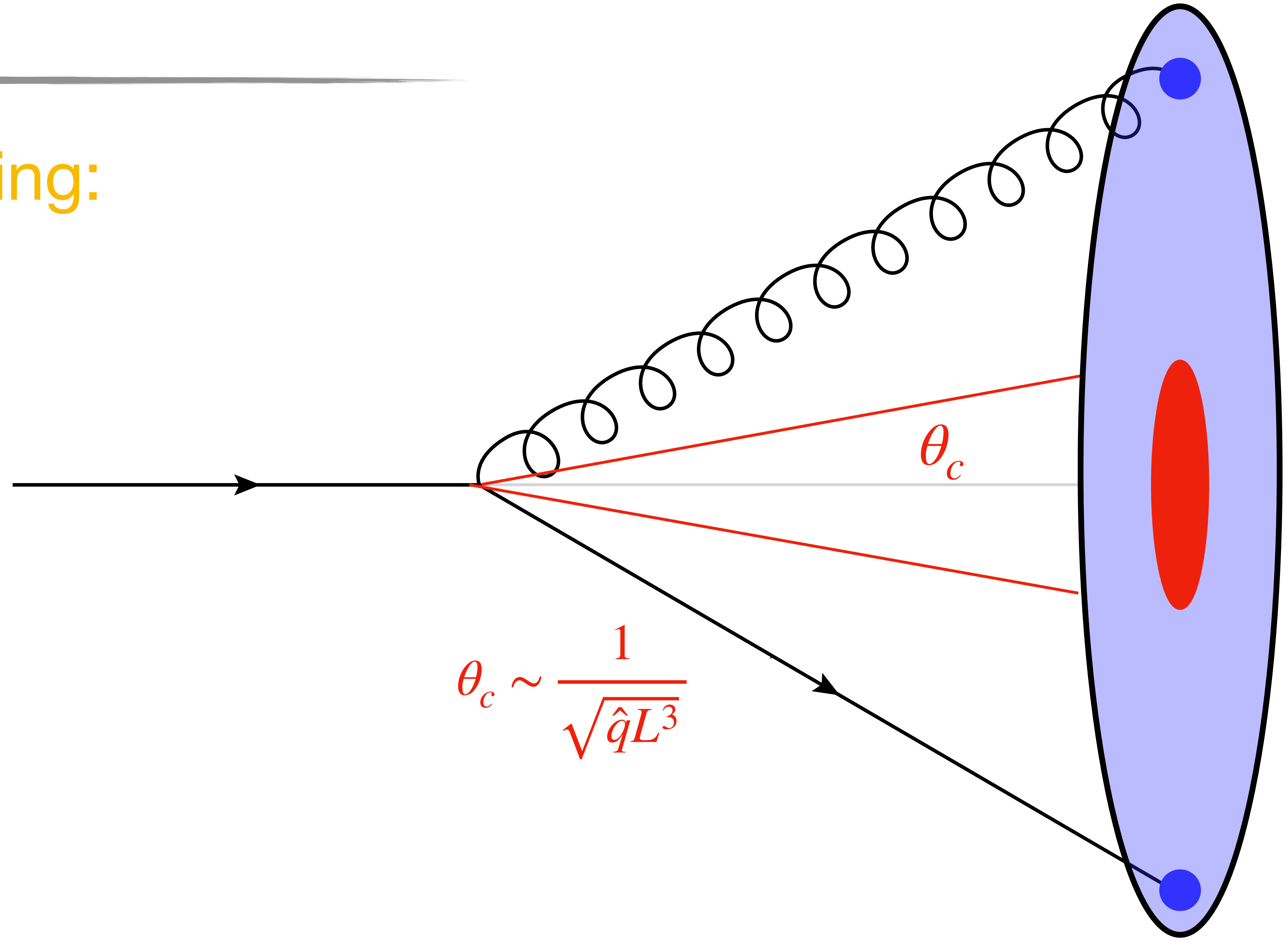
How can energy loss affect the EEC for smaller R jets?

Set up

LO calculation assuming:

$$\theta_c < R < 1$$

$$p_t^{jet} > \omega_c \sim \hat{q}L^2$$



Accounting for the angular resolution by the medium, there are two competing effects:

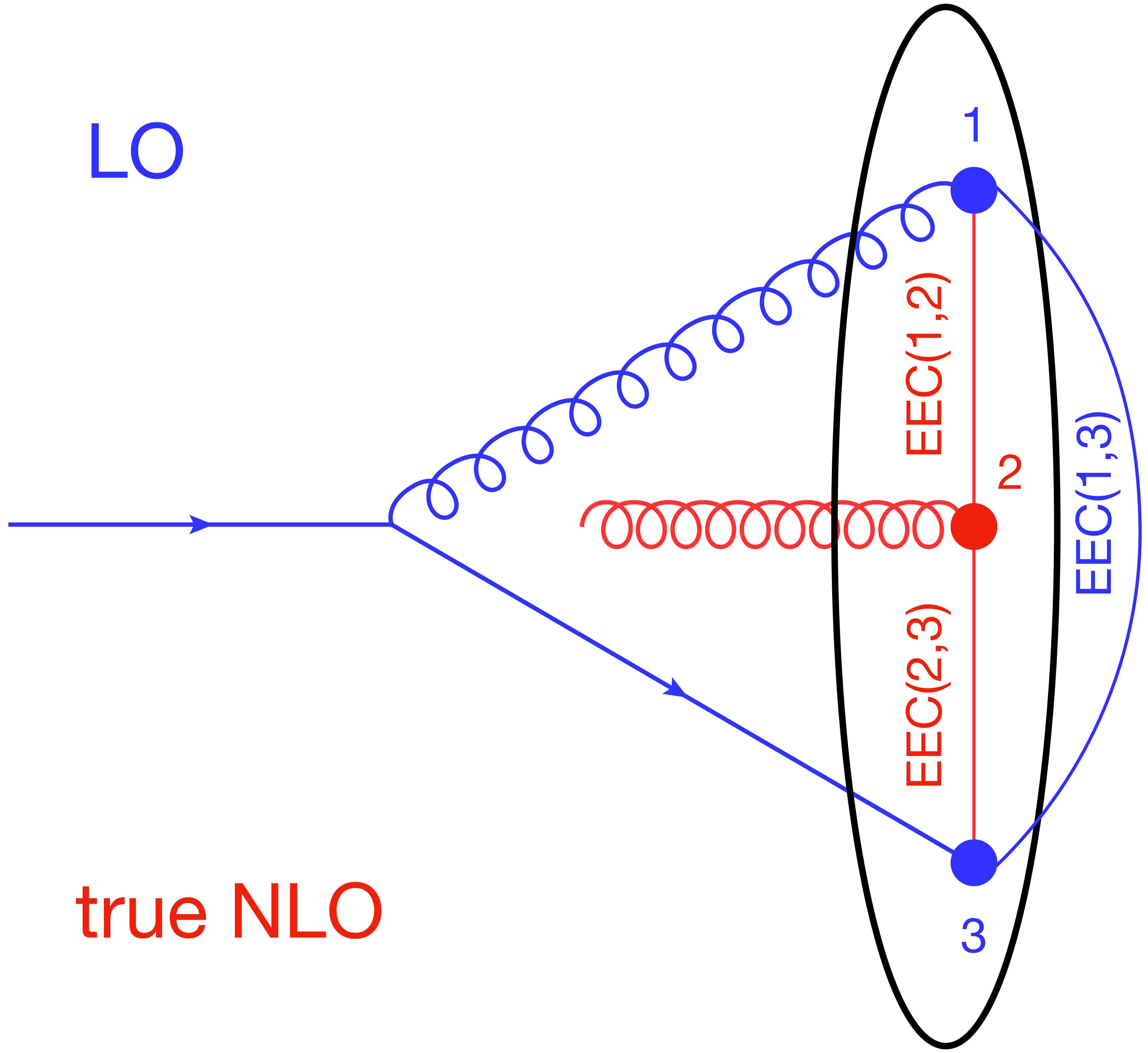
→ Enhanced gluon emission at angles $\theta > \theta_c$ promoted by medium modified kernel

→ Suppression of large angle configurations due to energy loss

What LO means in this calculation

In vacuum $R < 1$

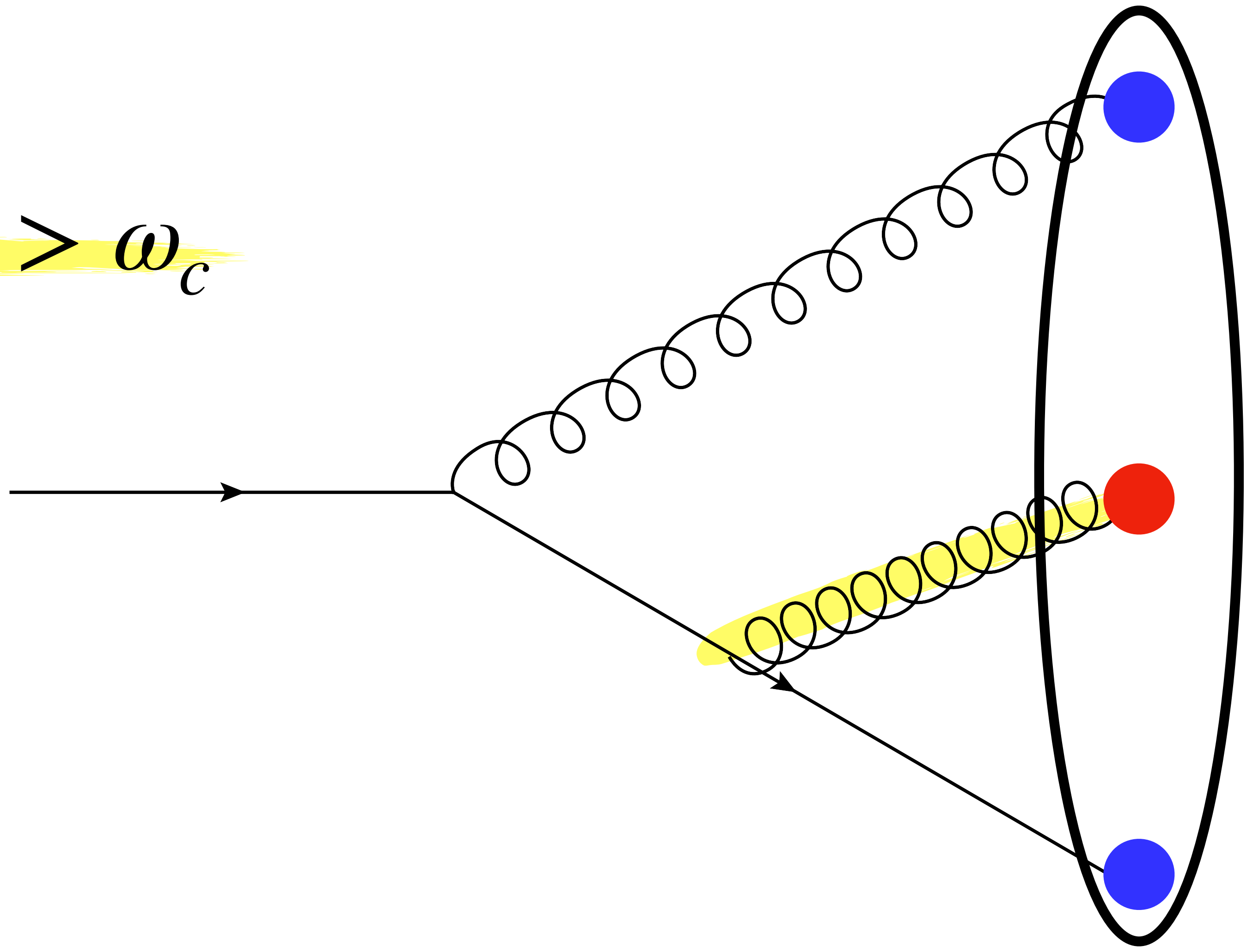
LO



true NLO

In matter $\theta_c < R < 1$

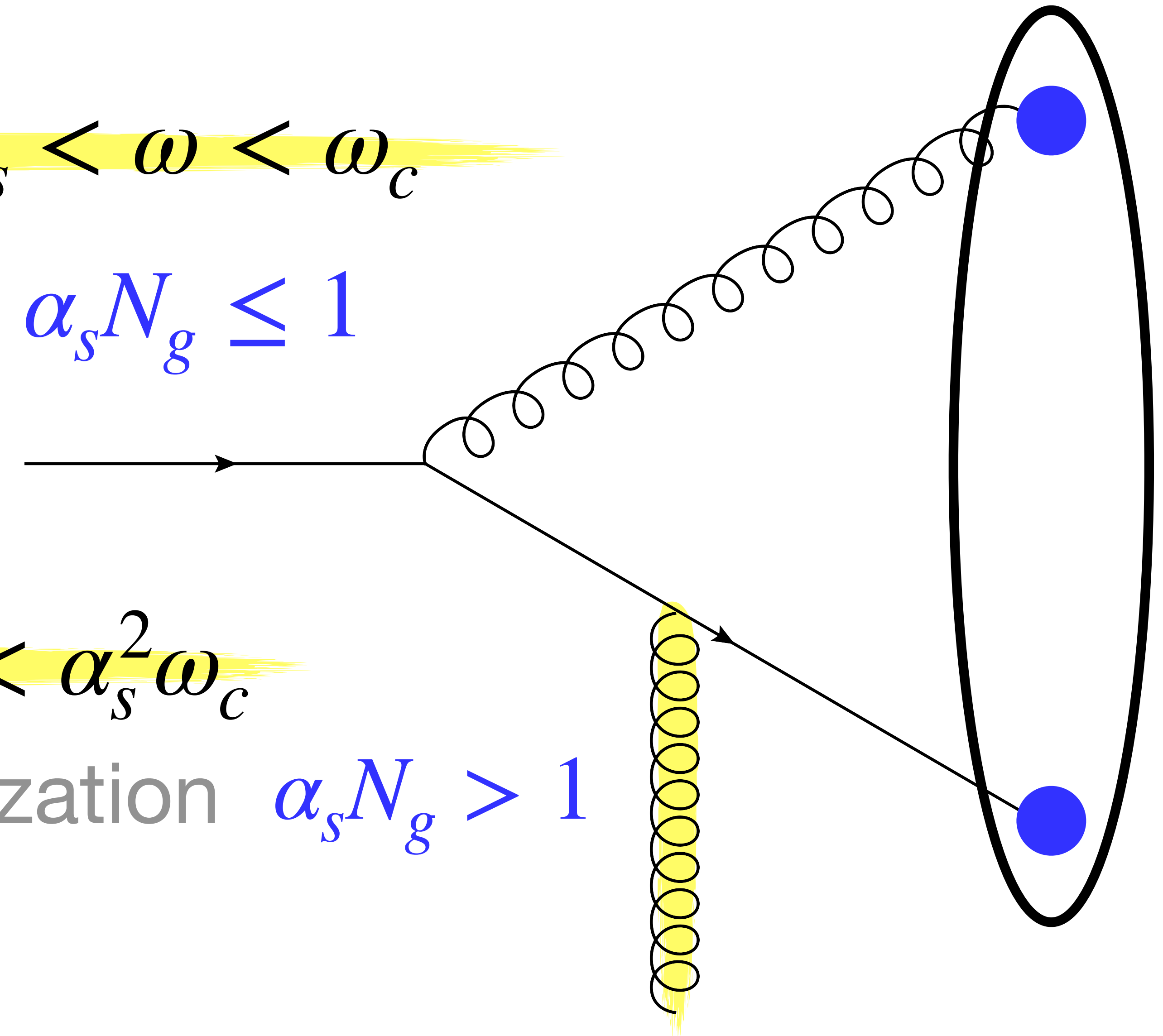
$\theta_{i,g} < \theta_c \quad \omega > \omega_c$



true NLO

$\theta_{i,g} > \theta_c \quad \alpha_s^2 \omega_s < \omega < \omega_c$

Semi—hard gluon $\alpha_s N_g \leq 1$

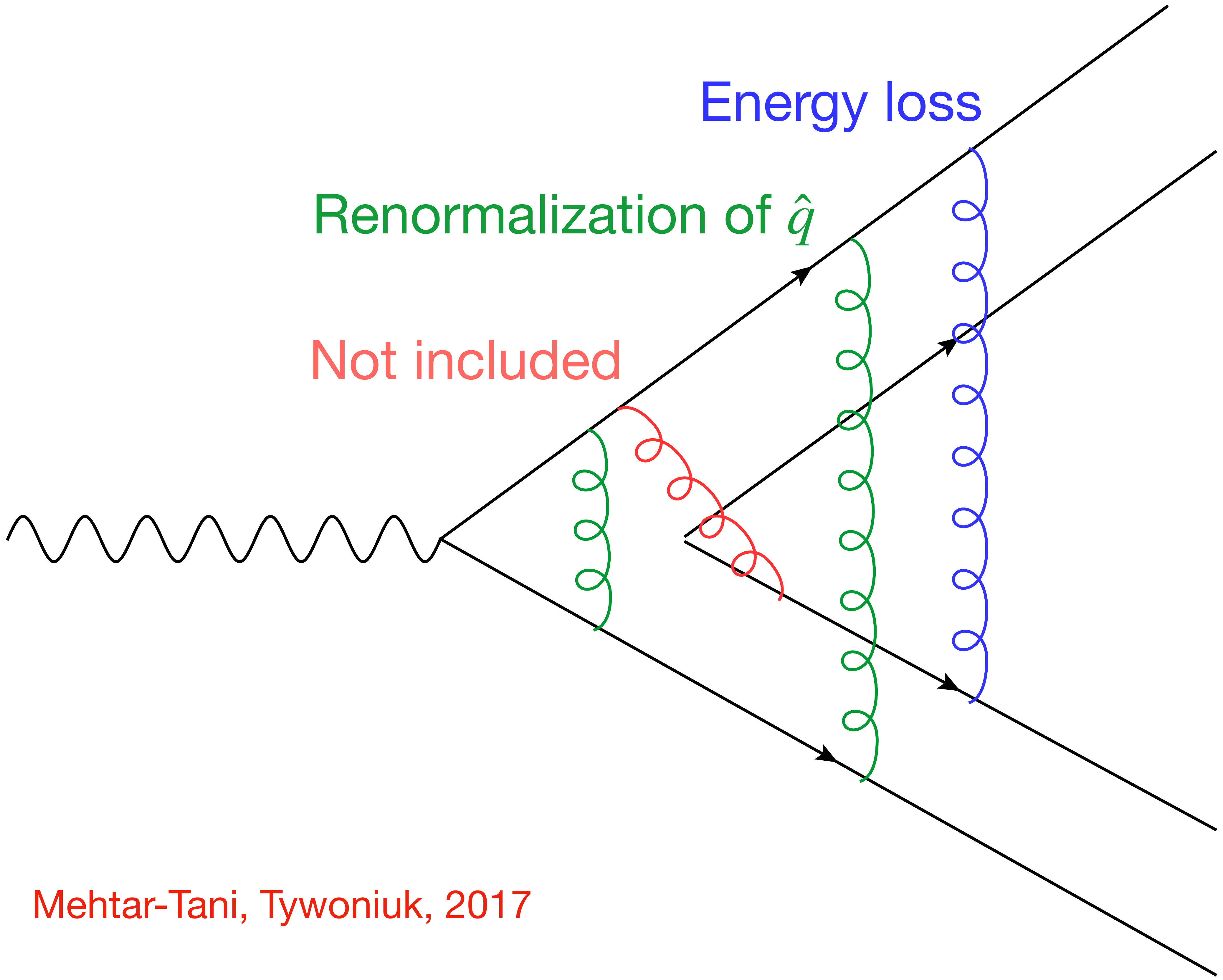


Energy loss

$\theta_{i,g} \gg \theta_c \quad \omega < \alpha_s^2 \omega_c$

Soft gluon; fast thermalization $\alpha_s N_g > 1$

Two body energy loss



Mehtar-Tani, Tywoniuk, 2017

Final result is hard to implement numerically

We use a simple model based on the quenching weight approximation

$$d\sigma^{\text{quenched}}(p_t) = d\sigma^{\text{unquenched}}(p_t) \otimes Q(p_t)$$

For single parton:

n=spectral index

$$Q_i^{(1)}(p_t) = \int d\varepsilon\, P_i^{(1)}(\varepsilon)\, e^{-\frac{n\varepsilon}{p_t}}$$

For two partons:

$$Q_q^{(2)}(p_t, \theta) = Q_q^{(1)}(p_t)\Big((1-\alpha) + \alpha Q_g^{(1)}(p_t)\Big)$$

$$\alpha = \left(1 - e^{-\frac{\theta^2}{\theta_c^2}}\right)\Theta(t_f < t_c)$$

$$t_f \sim \frac{1}{z(1-z)p_t\theta^2}$$

$$t_c \sim \frac{1}{(\hat{q}\theta^2)^{\frac{1}{3}}}$$

Splitting function models

I will show results for three models for the medium modified splitting

Splitting function models

Model 1 : Hard splitting in the medium

Includes medium induced modifications to the splitting function

Neglects momentum broadening for the final state

Andrés et al, 2022

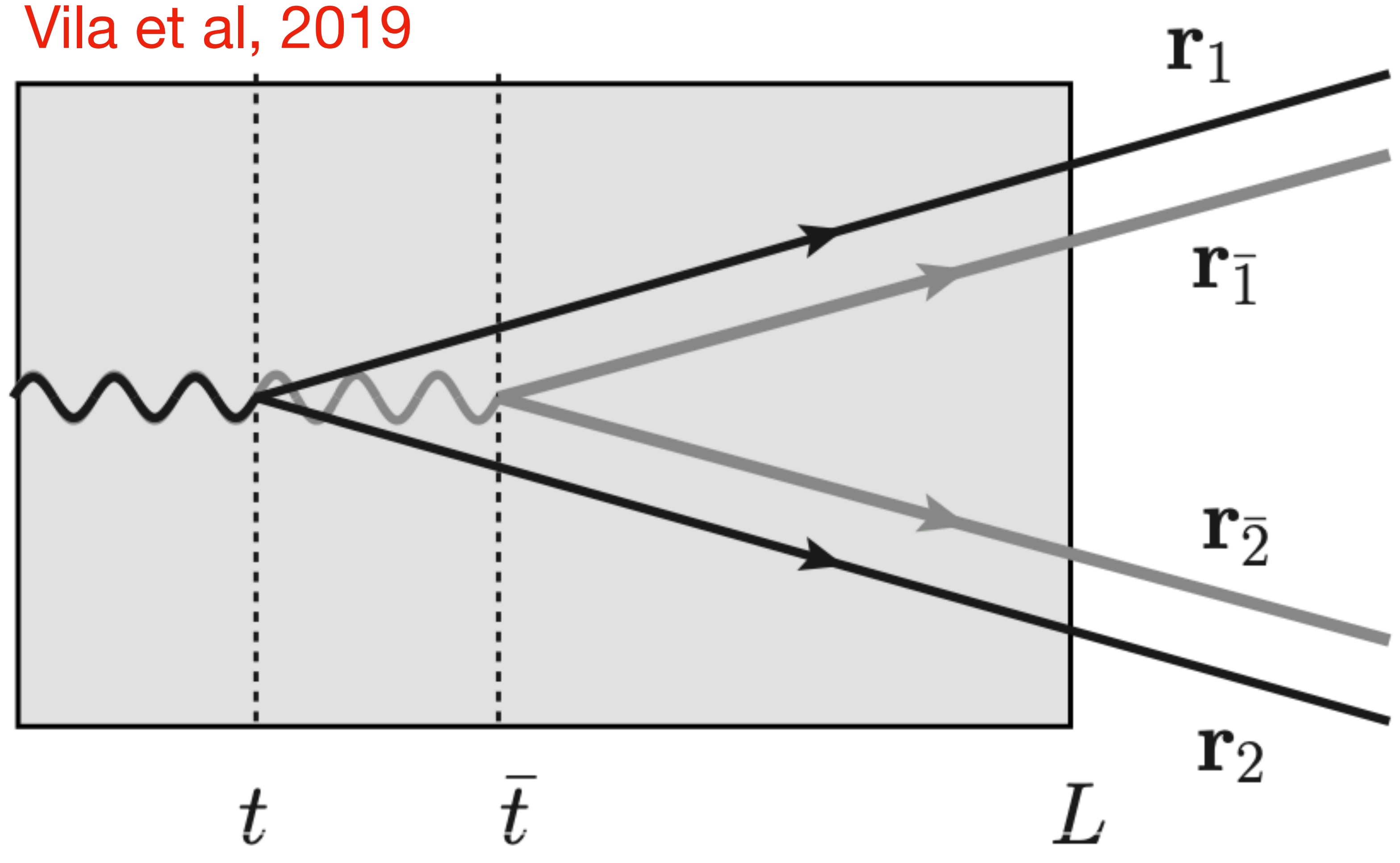
Isaksen, Tywoniuk, 2019, 2023

Isaksen, Wednesday

At LO, gives rise to

we assume that: $E > \omega_c, t_f < L, \perp^2 > \hat{q}L$

Vila et al, 2019



$$\frac{d\Sigma}{d\theta} = \int_0^1 dz\, z(1-z)\frac{d\sigma^{\text{vac}}}{\sigma d\theta dz}\left(1 + F_{\text{med}}\right) \otimes \mathrm{E}_{\text{loss}}$$

$$\frac{d\sigma^{\text{vac}}}{\sigma d\theta dz} \sim P(z)\frac{1}{\theta}$$

Splitting function models

Model 2 (broadening) :

Semi-classical limit of time localized emissions

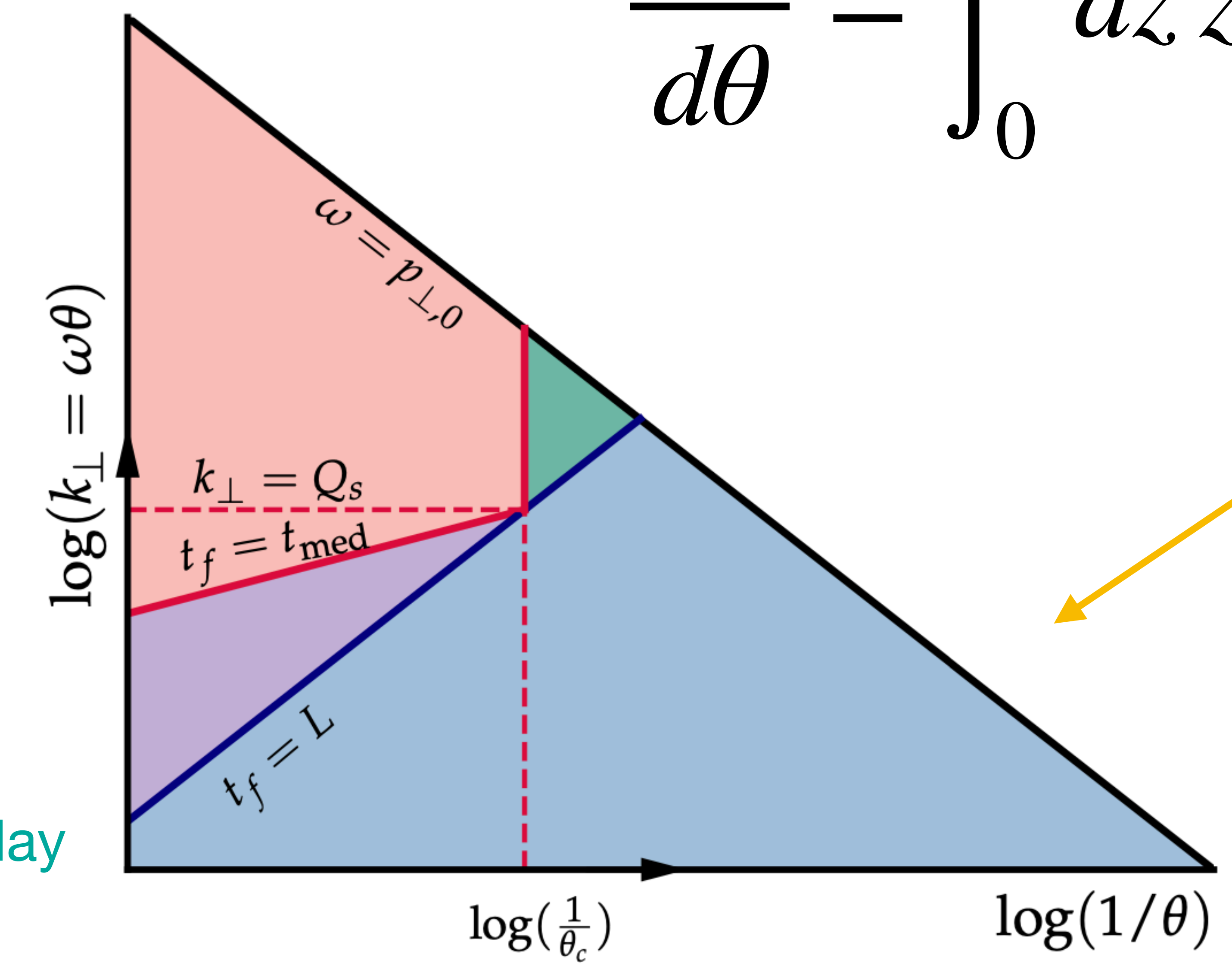
Angular structure driven by final state broadening

Only valid at late times

Caucal et al, 2021

At LO, gives rise to

$$\frac{d\Sigma}{d\theta} = \int_0^1 dz\, z(1-z)\left(\frac{d\sigma^{\mathrm{vac}}}{\sigma d\theta dz} + \frac{d\sigma^{\mathrm{med}}}{\sigma d\theta dz}\right) \otimes \mathrm{E}_{\mathrm{loss}}$$



Iancu, Tuesday

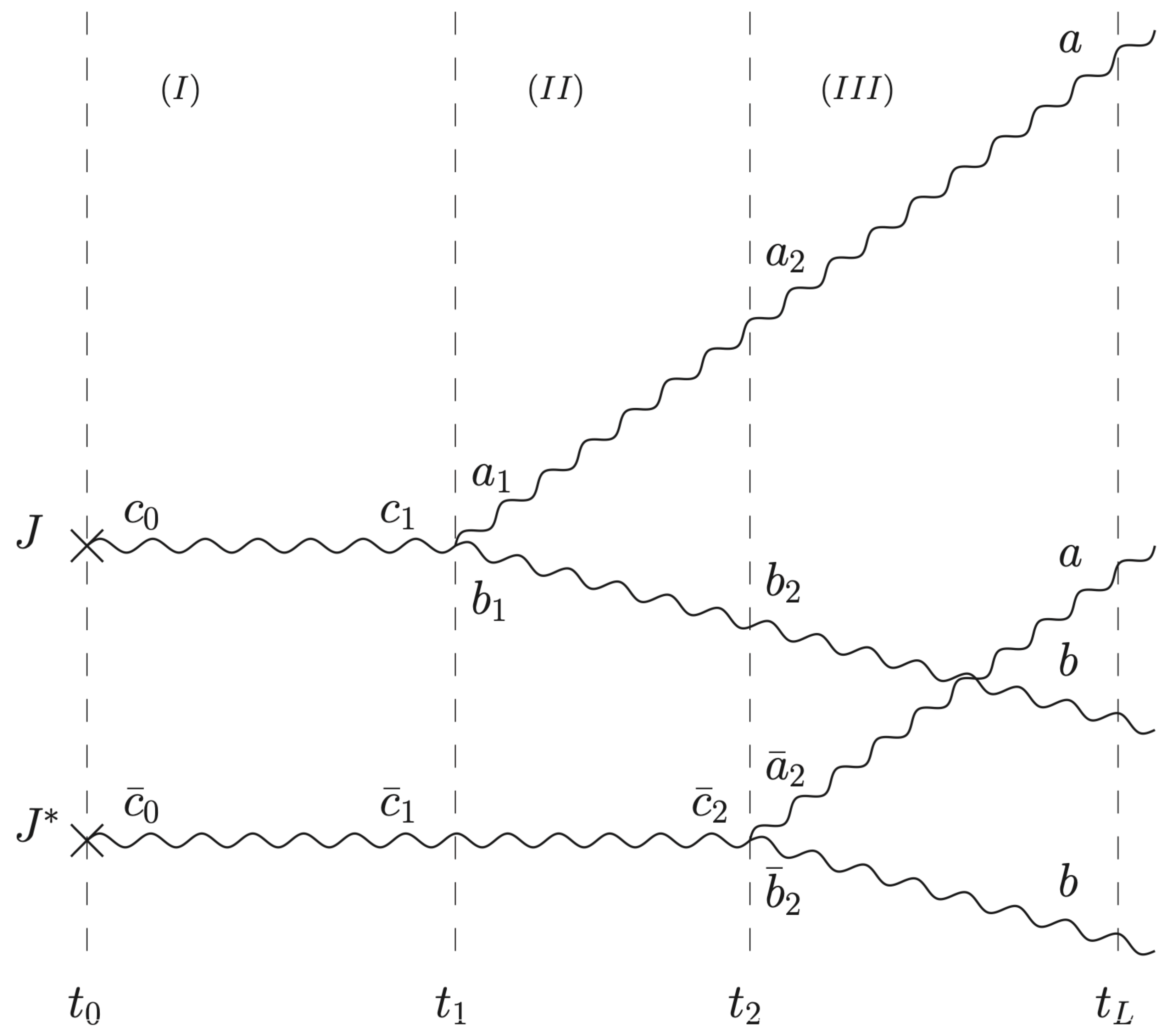
$$d\sigma \sim P_q^{\mathrm{broad.}} \otimes P_g^{\mathrm{broad.}} \otimes K(z)$$

Splitting function models

Model 3 (BDMPS-Z) : BDMPS-Z formula in full (small z)

Valid for soft gluons; only gives qualitative picture

At LO, gives rise to

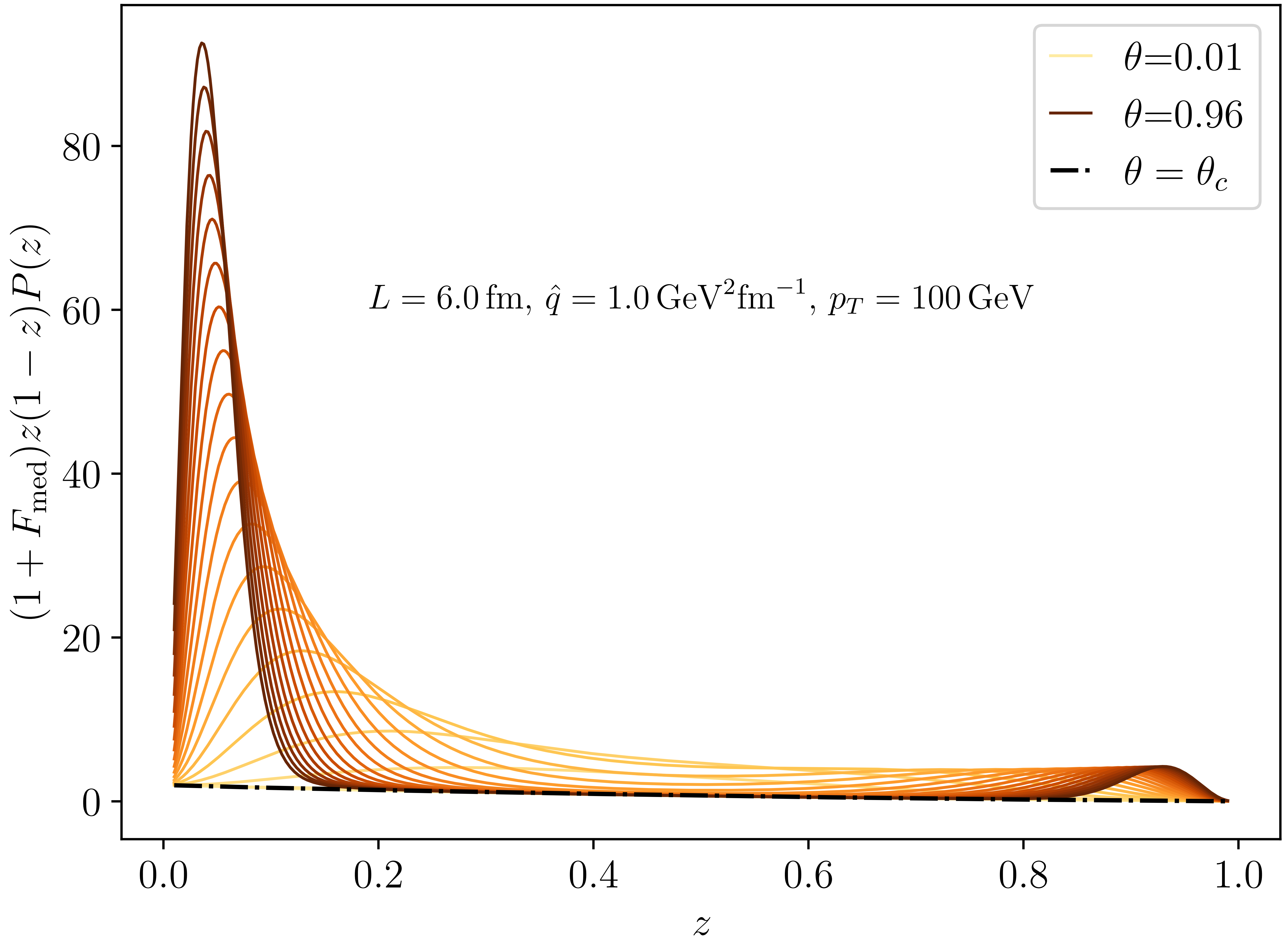


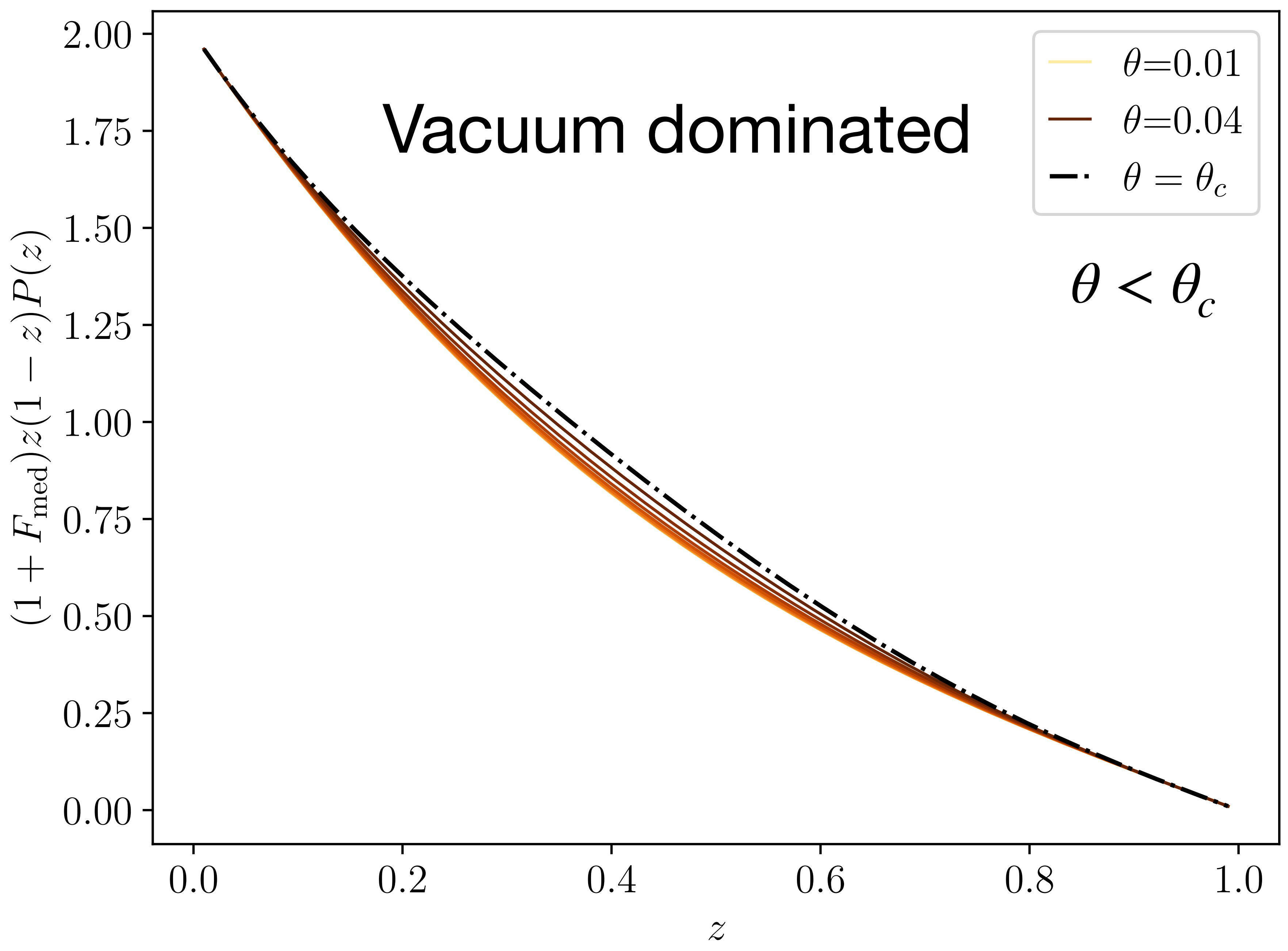
Blaizot et al, 2012

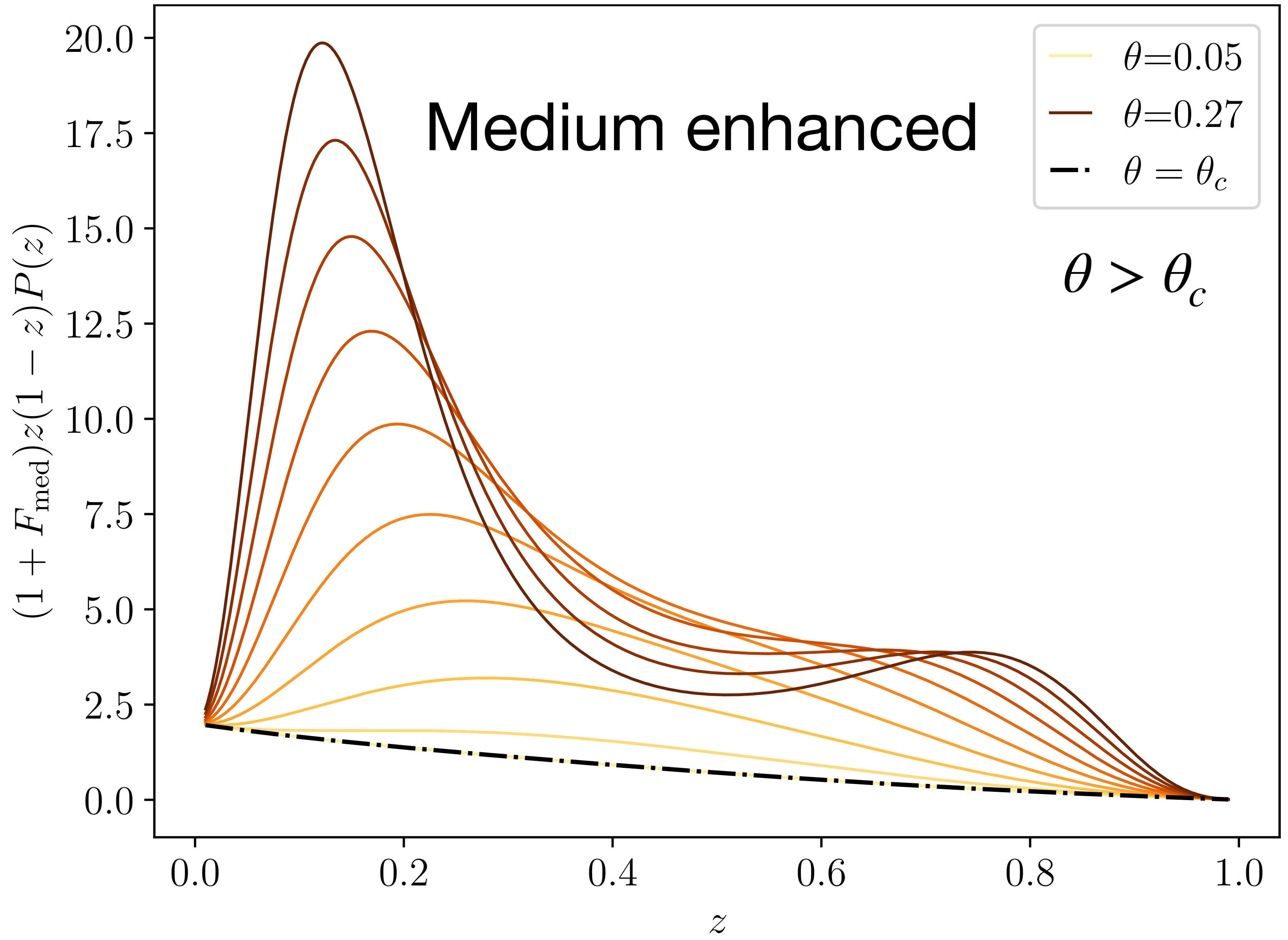
$$\frac{d\Sigma}{d\theta} = \int_0^1 dz\, z(1-z)\left(\frac{d\sigma^{\text{BDMPS-Z}}}{\sigma d\theta dz}\right) \otimes \text{E}_{\text{loss}}$$

Results: splitting kernels

Model 1

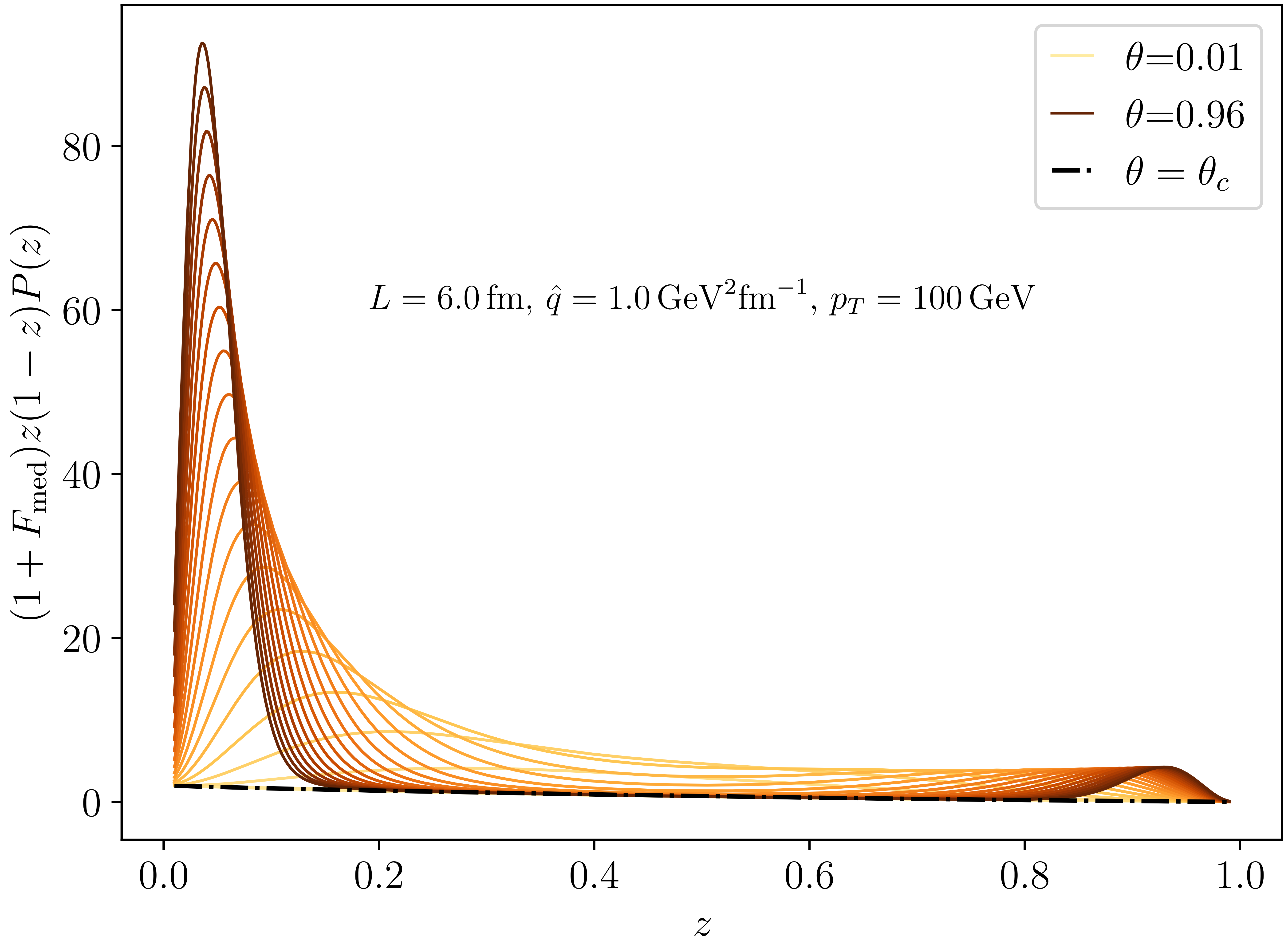




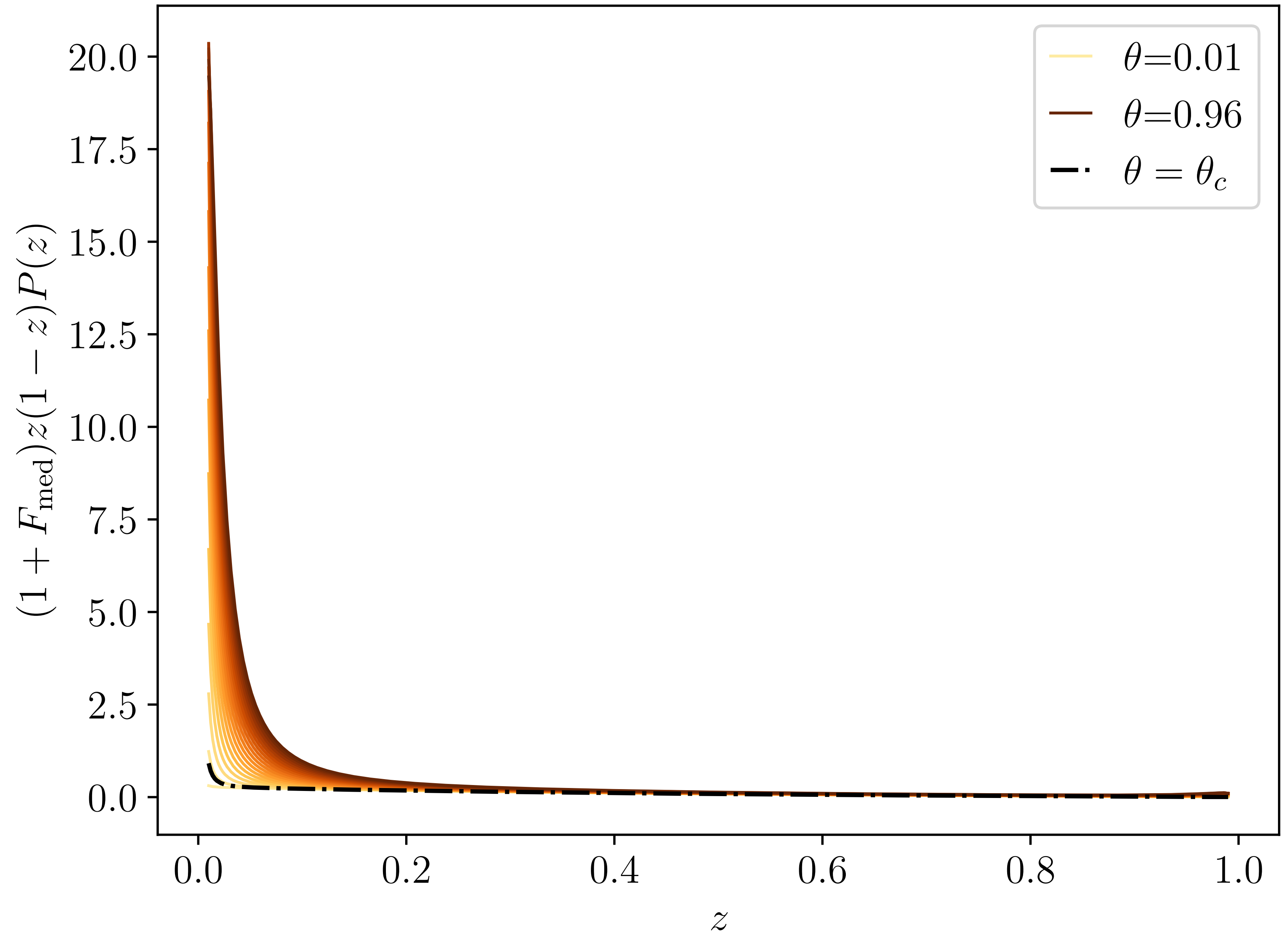


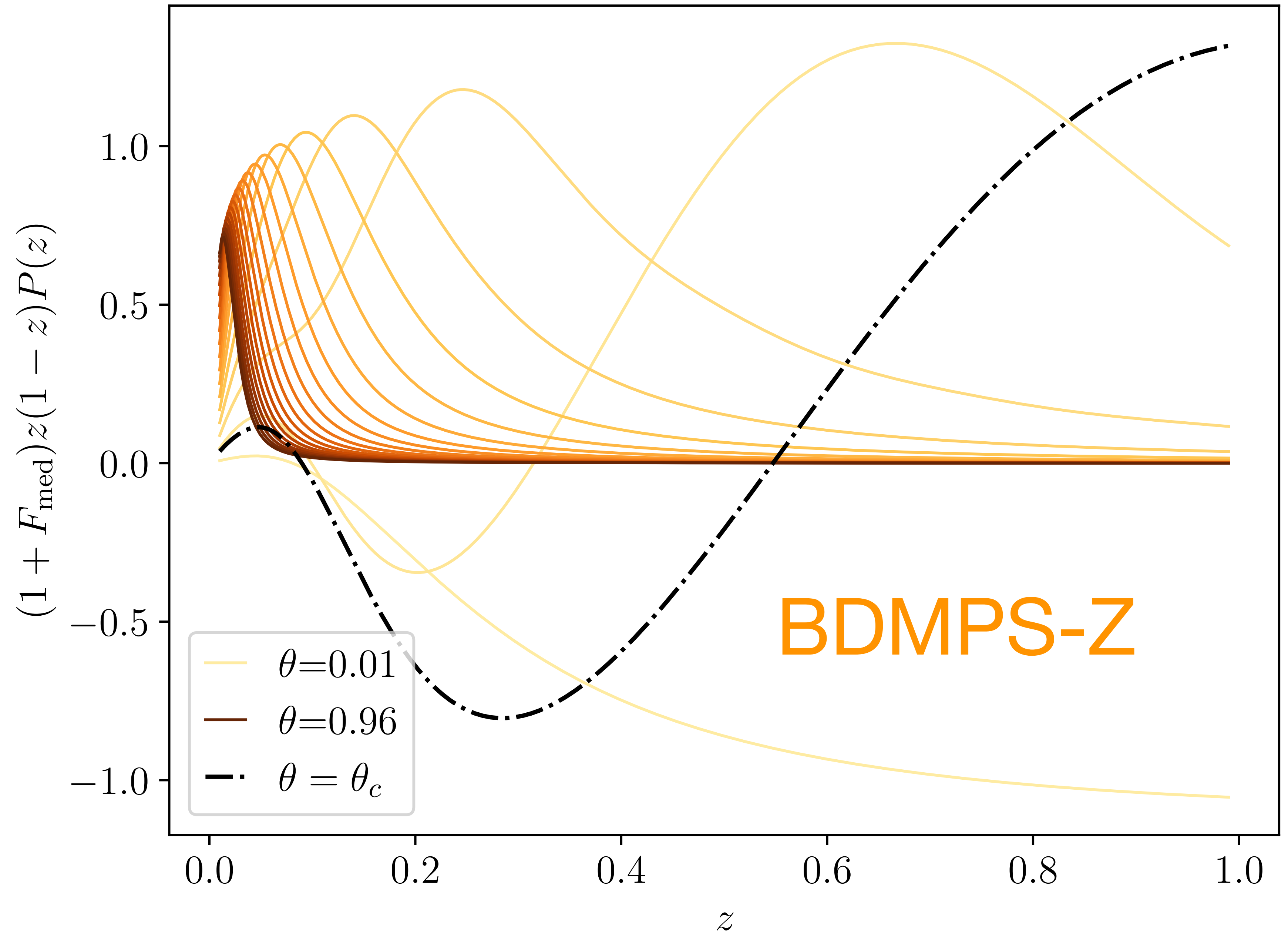
Results: splitting kernels

Model 1



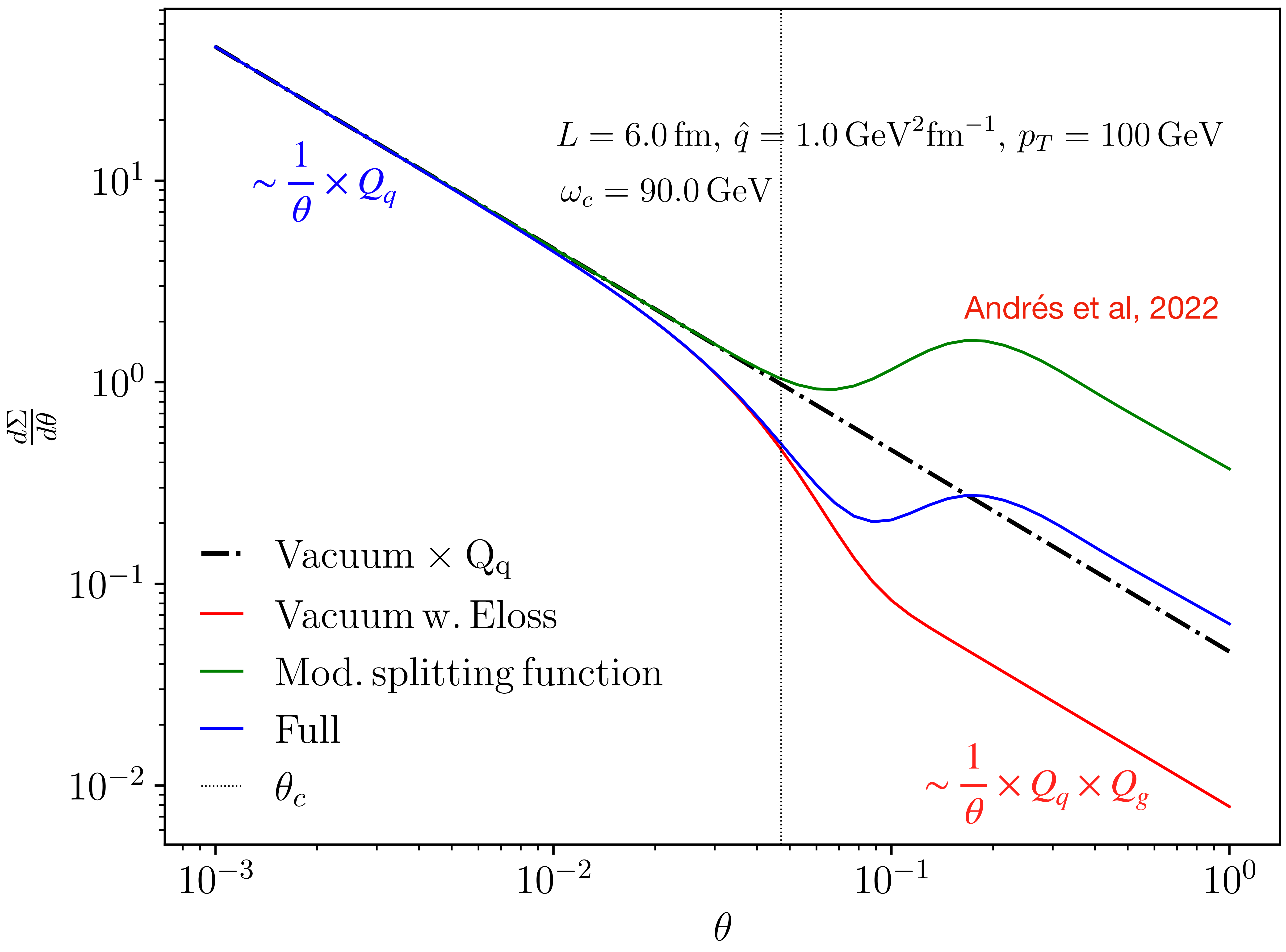
broadening



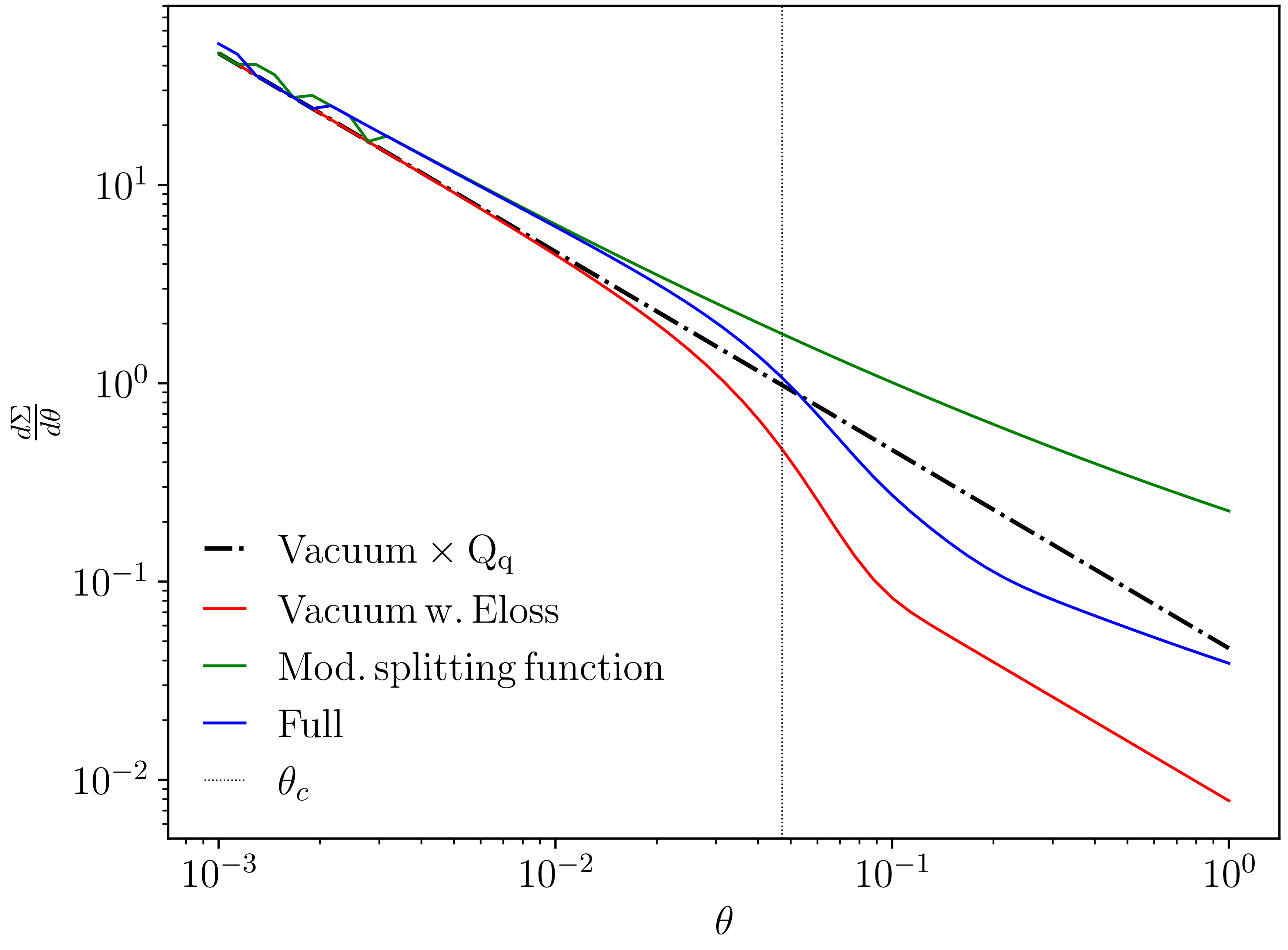


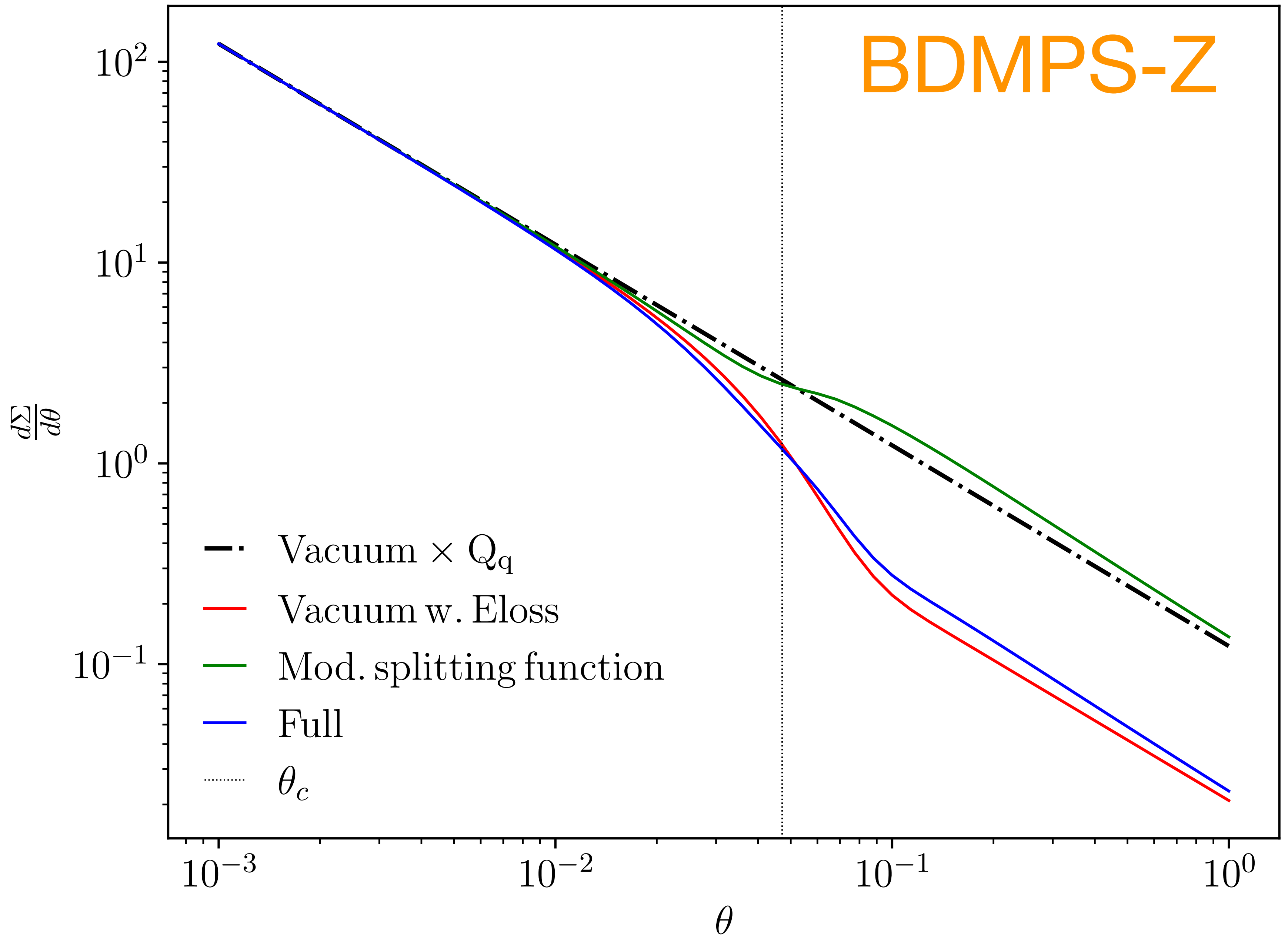
Results: angular distribution

Model 1



broadening





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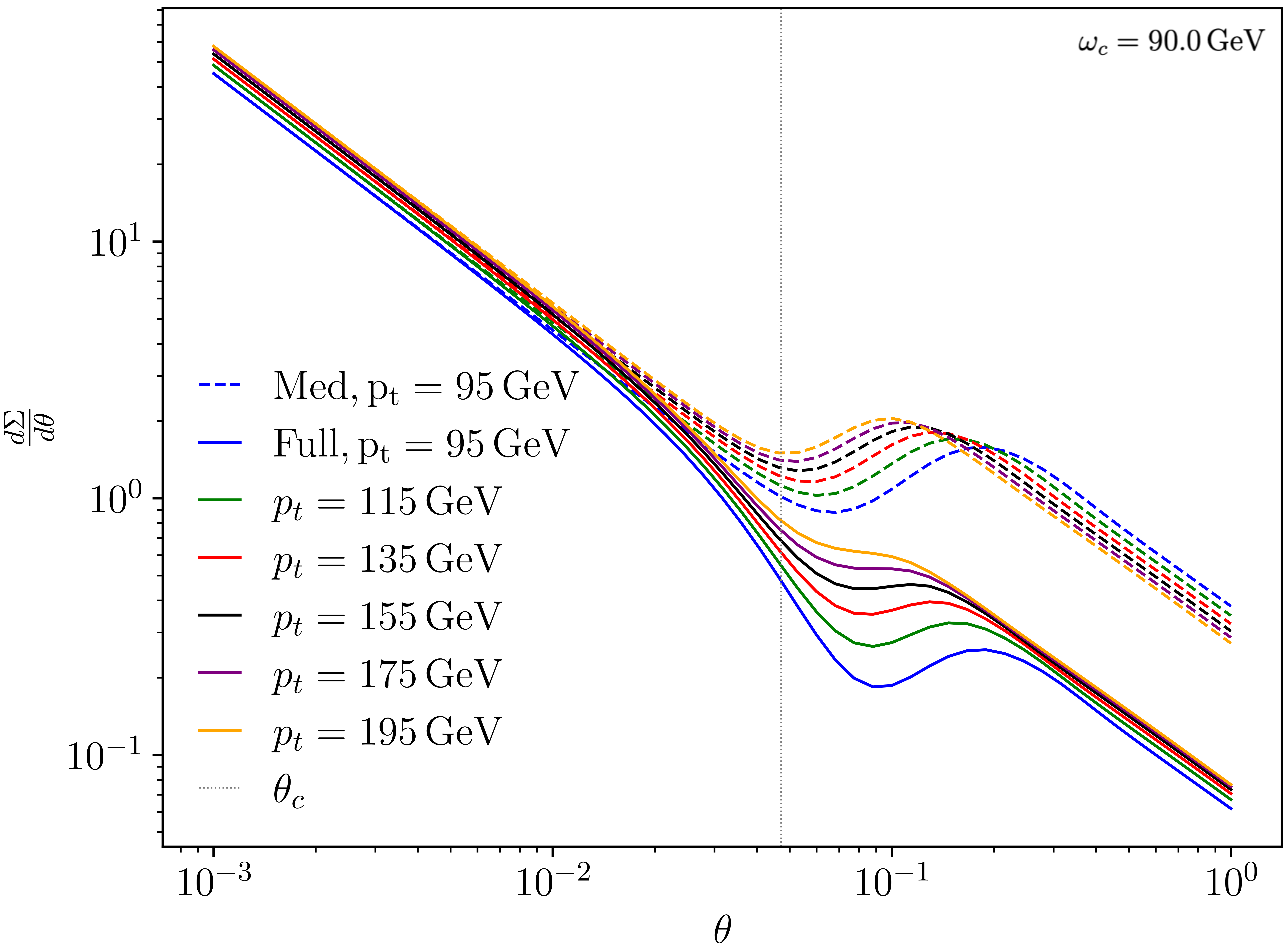
Results: energy dependence



No energy loss:

Shift of distribution peak left

Shape is conserved

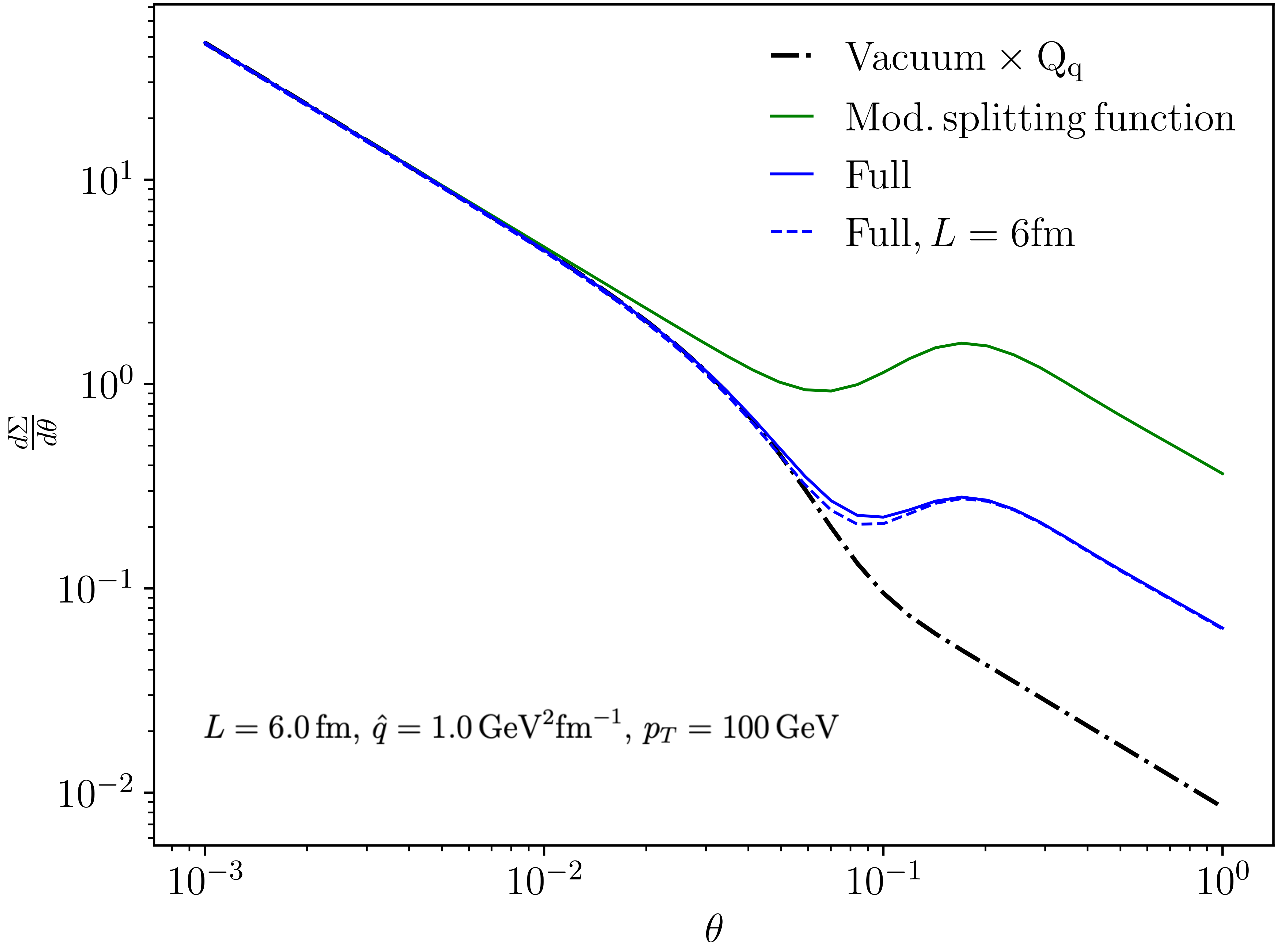
Including energy loss:

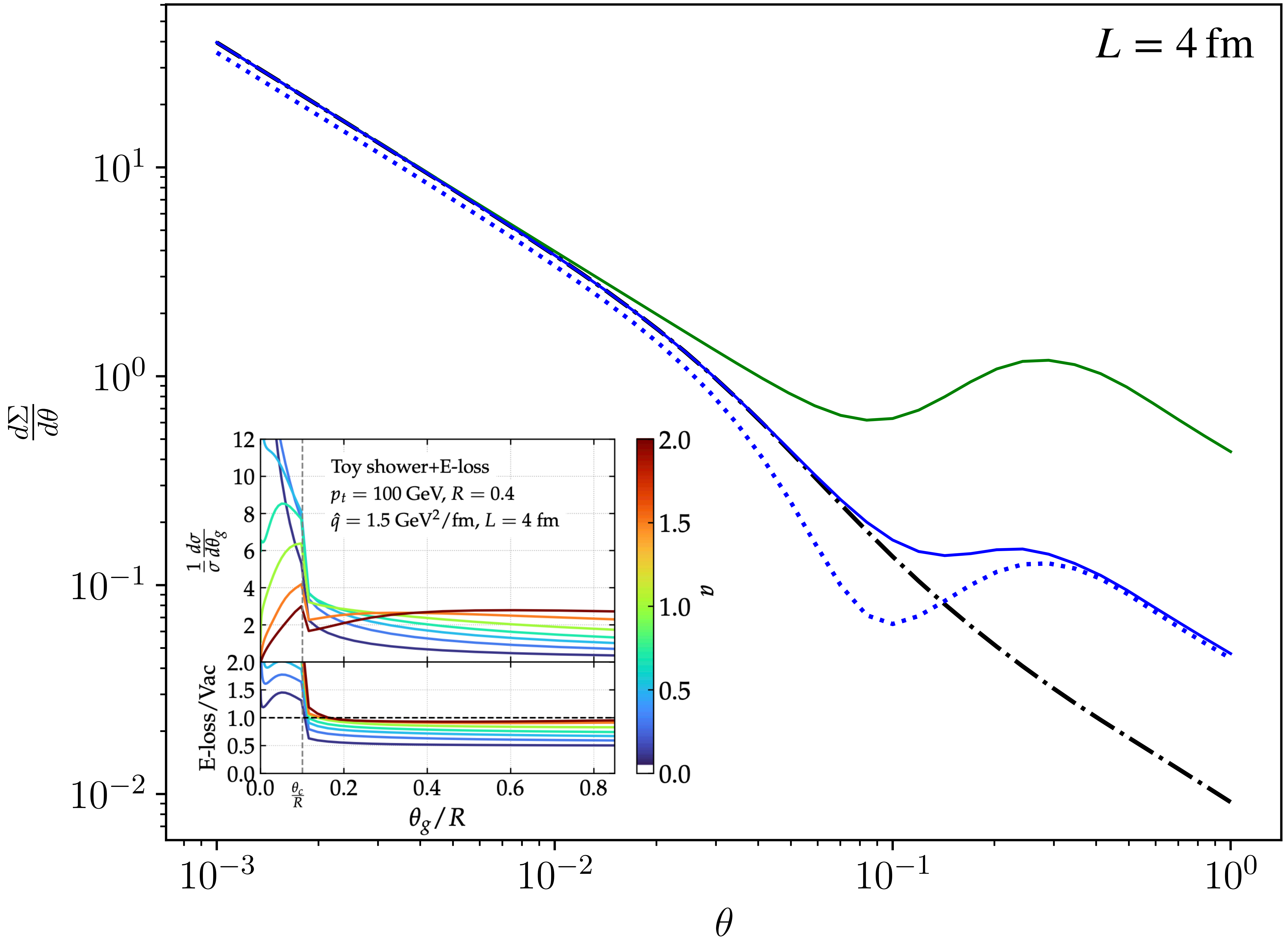
Same shift towards smaller angles

Smearing of transition angle

Results: length smearing

We mimic in-medium length fluctuations by sampling from a Gaussian distribution





Length fluctuations can further smear the distribution peak once energy loss is included

Conclusion and Outlook

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EECs offer a new window into jets' structure

For not very large jet radius they seem to be sensitive to energy loss effects

Requires MC comparison to understand:

If energy loss dependence is indeed this strong

Which analytic elements were overlooked

EECs might access other medium information

JB, Milhano, Sadofyev, in preparation