Finite size effects in jet quenching

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on work w/ C. Gale (arXiv:1006.2379)

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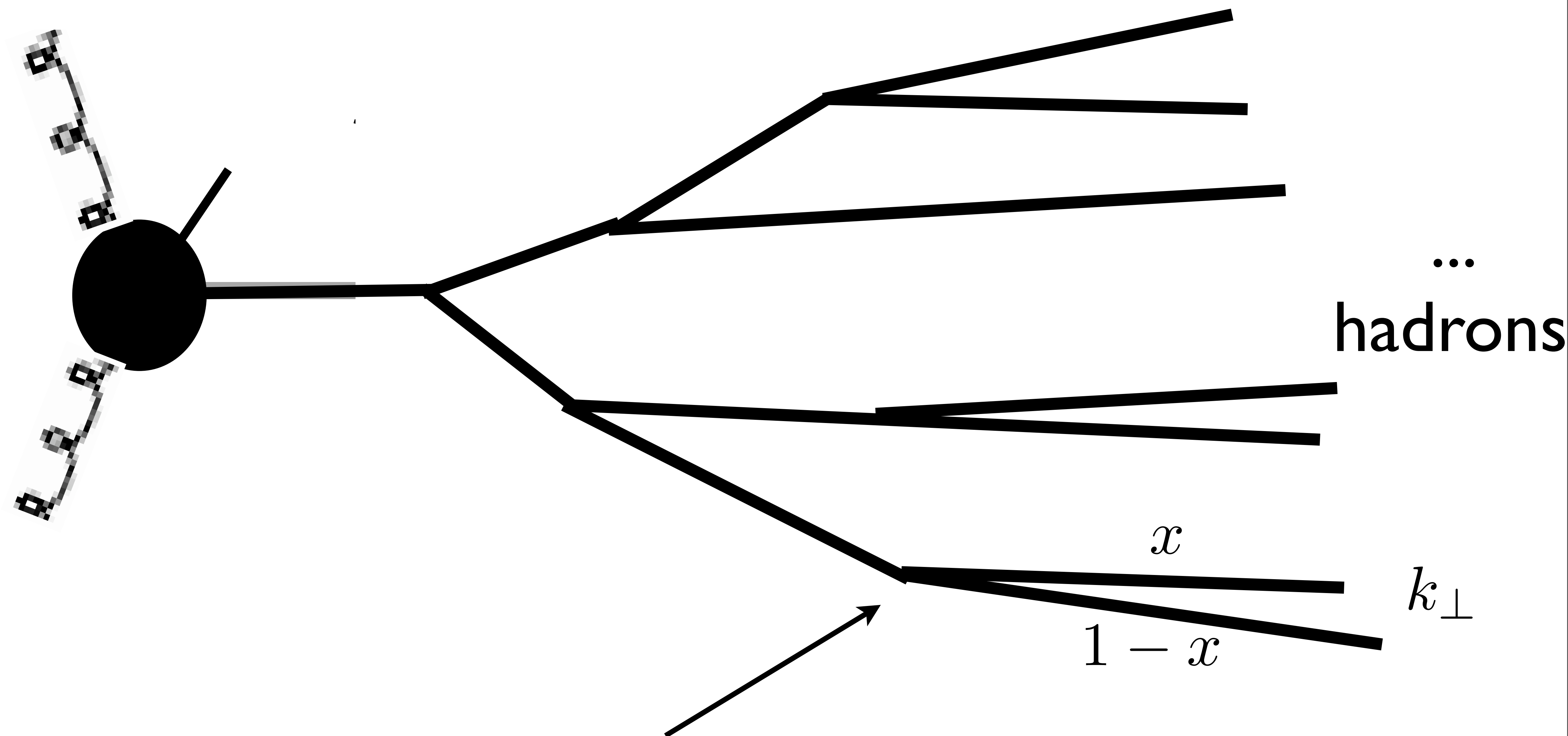
Outline of talk

- What I am going to talk about (BDMPS-Z --> vertex in a Monte Carlo shower)
- BDMPS-Z as a rate equation
- Solution in the brick problem

(see also, BRICK report)

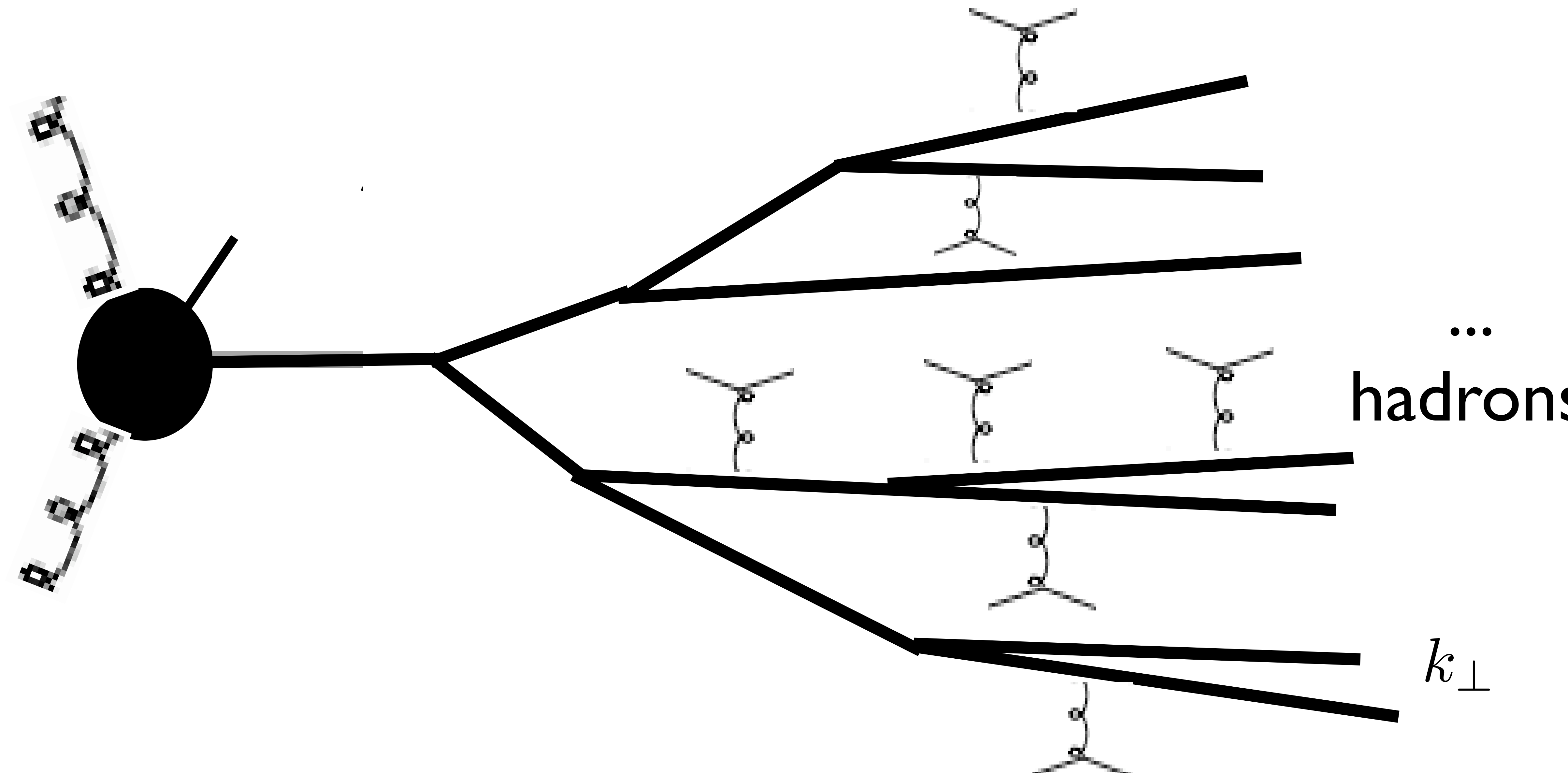
Jet quenching



$$\frac{dP}{dx d^2 k_\perp} = \frac{P^a_{bc}(x)}{k_\perp^2}$$

DGLAP vertex

Jet quenching



In a medium, extra 'kicks' induce further bremsstrahlung

$$\frac{dP}{dx d^2 k_\perp} = \frac{P^a_{bc}(x)}{k^2_\perp} + P^{\mathrm{BDMPS}}$$

Jet quenching

- For a while it was thought this was thought to be the whole story
- (for a pQCD jet propagating through a weak *or* strong QGP)
- Further leading-order effects were uncovered recently (destruction of color coherence)

(Leonidov & Nechitailo `10,
Mehtar-Tani, Salgado & Konrad Tywoniuk `10,
see Mehtar-Tani's talk)

Note for theorists

- The following theoretical problem appears at present to have *unsolved* status:

  "Find a modification of vacuum jet shower, such that all:
  -collinear logarithms $\alpha_s \log Q^2$
  -soft logarithms $\alpha_s \log z$
  -length-enhanced effects $\alpha_s L/\ell_{\rm mfp}$
  are resummed."

- I would argue it's a well-defined problem, thus having a unique and well-defined solution.

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  "Find a modification of vacuum jet shower, such that all:
  -collinear logarithms $\alpha_s \log Q^2$ (DGLAP `71)
  -soft logarithms $\alpha_s \log z$ (angle-ordered parton showers, 80's)
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- I would argue it's a well-defined problem, thus having a unique and well-defined solution.

the modified vertex: BDMPS-Z

$$\frac{dP^a_{bc}}{dk} = \frac{P^{a(0)}_{bc}(x)}{\pi p} \times \mathrm{Re} \int_0^\infty dt_1 \int_{t_1}^\infty dt_2 \frac{\partial}{\partial \mathbf{x}} \cdot \frac{\partial}{\partial \mathbf{y}} \left[K(t_2, \mathbf{x}; t_1, \mathbf{y}) - (\mathrm{vac})\right]_{\mathbf{x}=\mathbf{y}=0} .$$

$$0 = [-i\partial_t + \delta E(\mathbf{p}) - i\mathcal{C}_3(\mathbf{x})]K$$

(BDMPS-Zakharov)

JETP Lett. 63 952 (1996)

↙ ↓ ↓ ↘

BDMPS (with or without further approx) | GLV | AMY | ASW | (HT?)

Appears to be a universally agreed-upon starting point

We can learn something by solving it exactly

What do the eqs. look like?

$$i\partial_t K \quad = \quad HK, \quad H = \frac{-\partial_{\mathbf{x}}^2 + m_{\mathrm{eff}}^2}{2Ex(1-x)} - i\mathcal{C}_3(\mathbf{x})$$

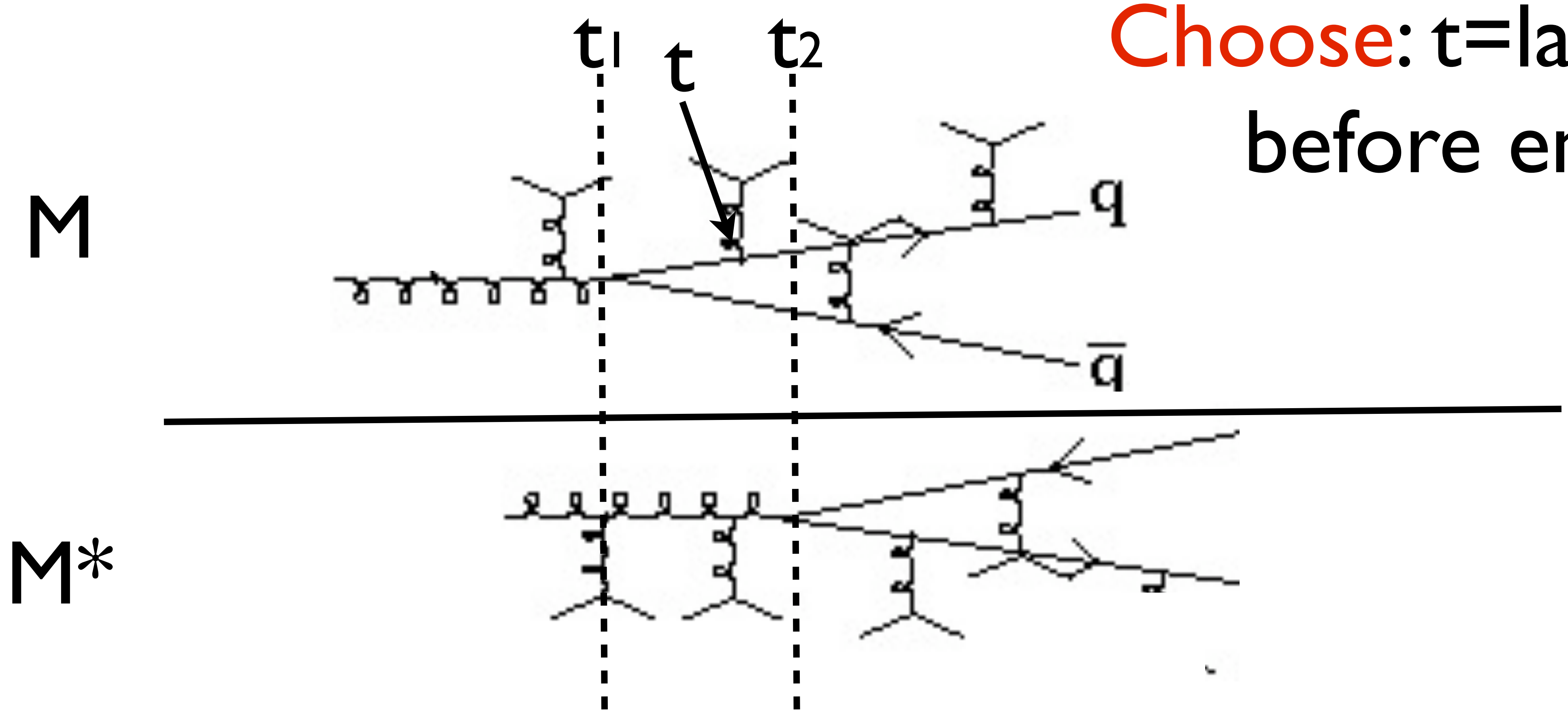
Physics content:

- Schrodinger form: ‘lightcone Hamiltonian’ for jet wavefunction
- (Instantaneous) elastic collisions go into a *C*
- Whole thing is integrated over two ‘hard collinear’ vertices

Sounds hard...

Step 1: define a meaningful rate instead of probability

Choose: t=last collision before emission



(physics before t1 or after t2, the splitting vertices, does not alter the brem. probability) (Migdal, 1958)

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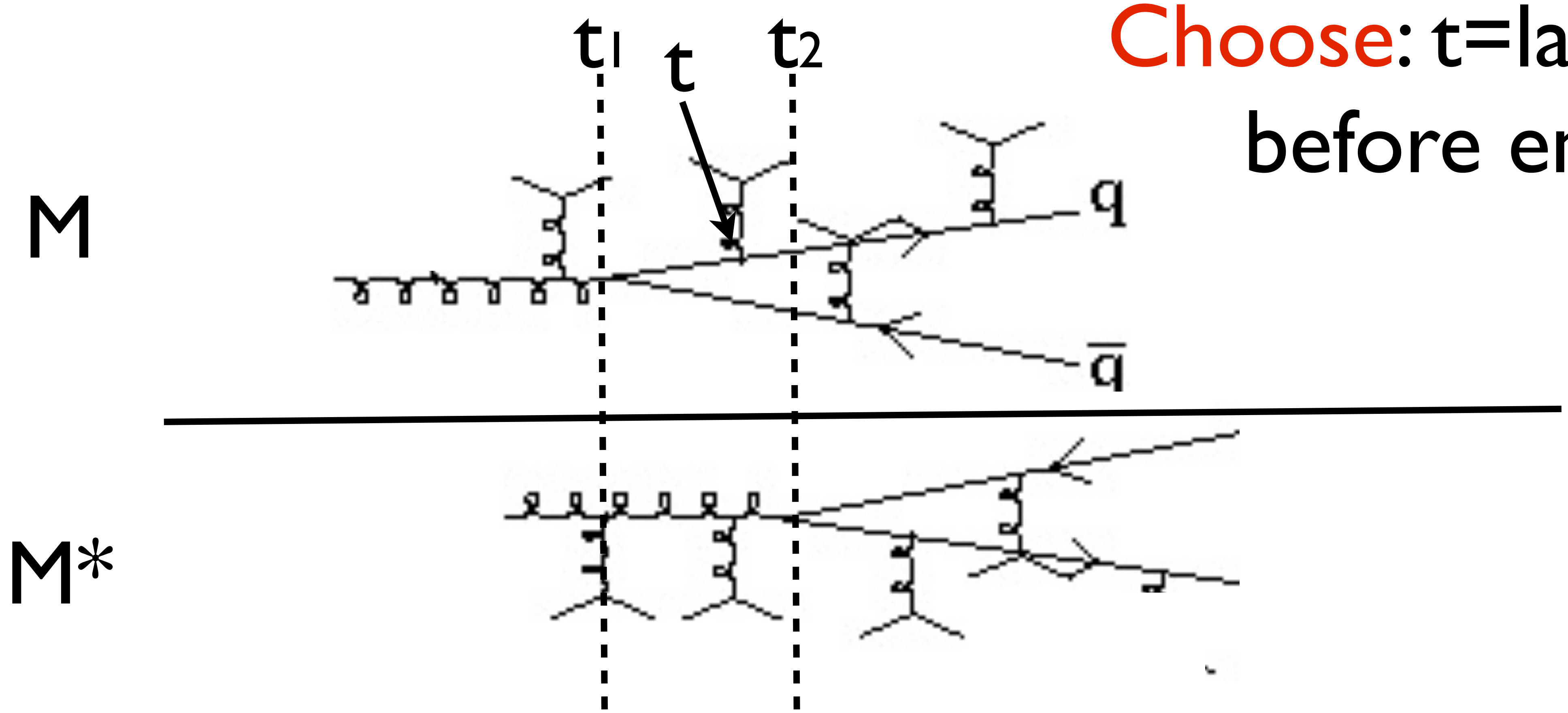
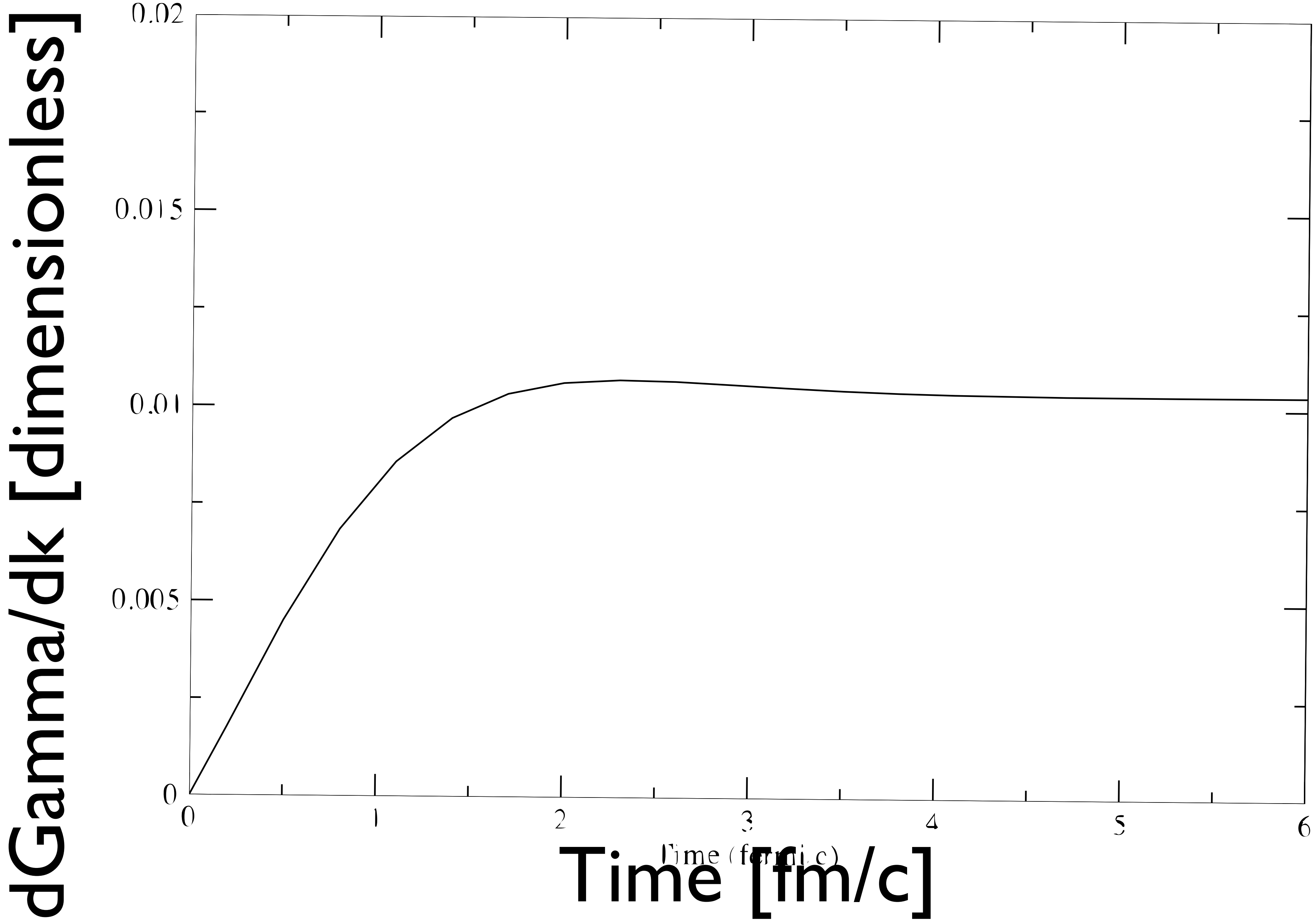


$$\frac{d^3\Gamma^a_{bc}(t)}{dkd^2\mathbf{p}} \equiv \frac{P^{a(0)}_{bc}(x)}{\pi p}\mathrm{Re}\int_0^t dt_1 \int_{\mathbf{q}} \frac{i\mathbf{q}\cdot\mathbf{p}}{\delta E(\mathbf{q})}\mathcal{C}(t)K(t,\mathbf{q};t_1,\mathbf{p}).$$

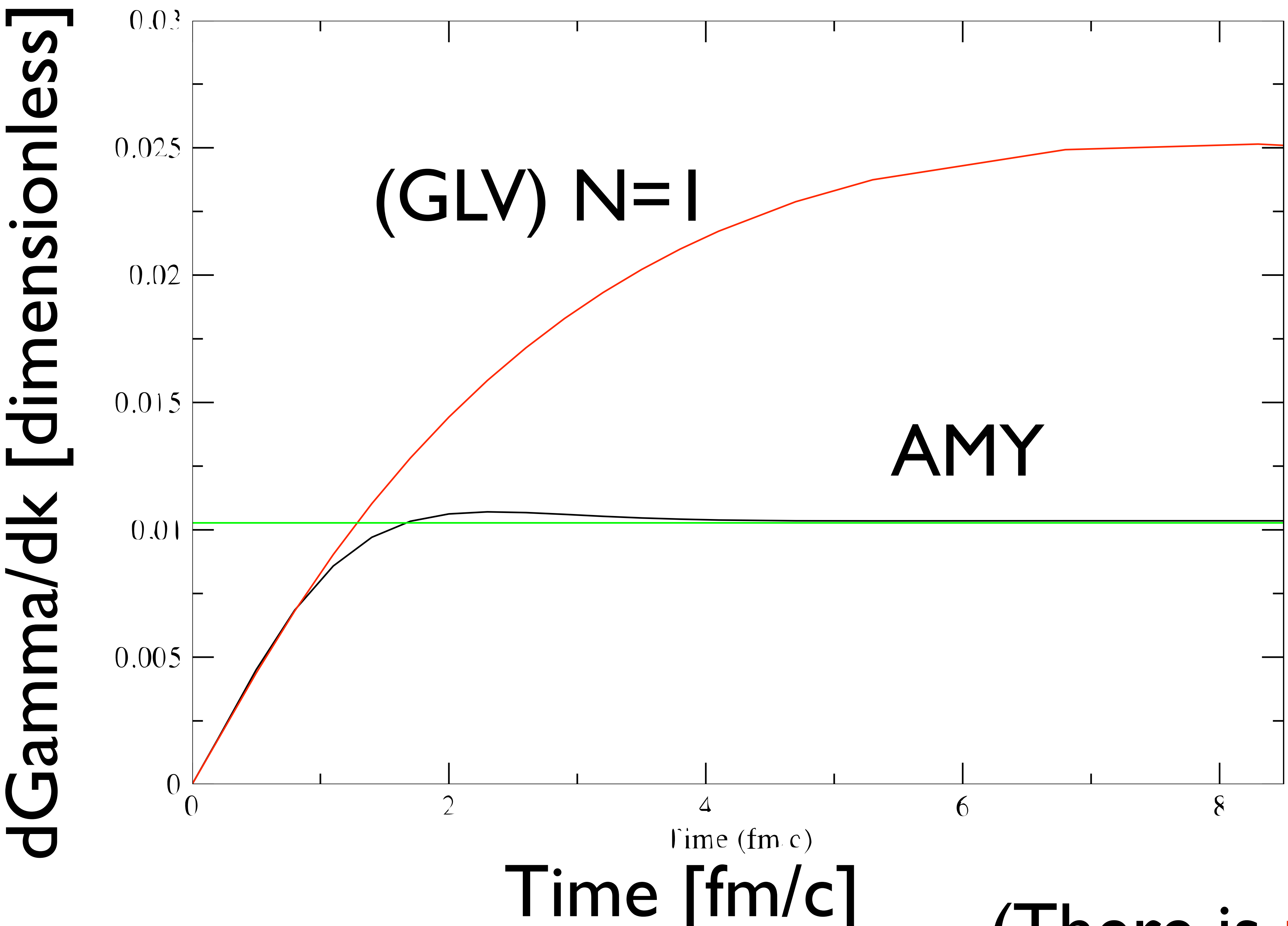
This rate (equivalent to BDMPS-Z) looks like:



For this talk: a 16 GeV quark radiates a 3 GeV gluon

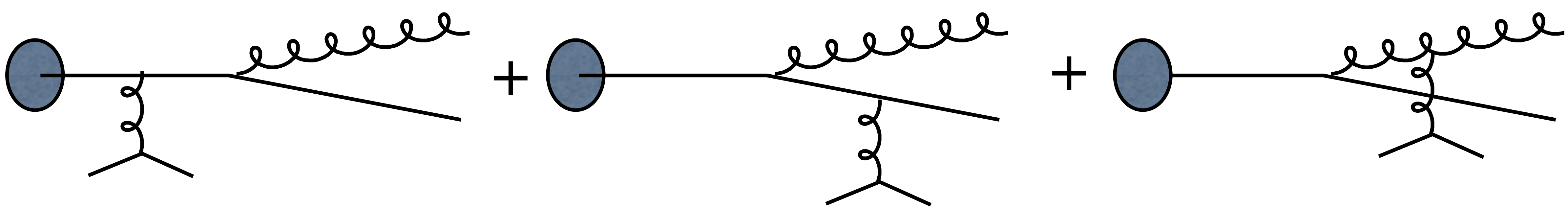
Uniform brick T=250 MeV, alpha_s=0.3

Limiting behaviors



(There is no fitting parameter here!)

Why linear at small t?
--> interference w/ vac. radiation

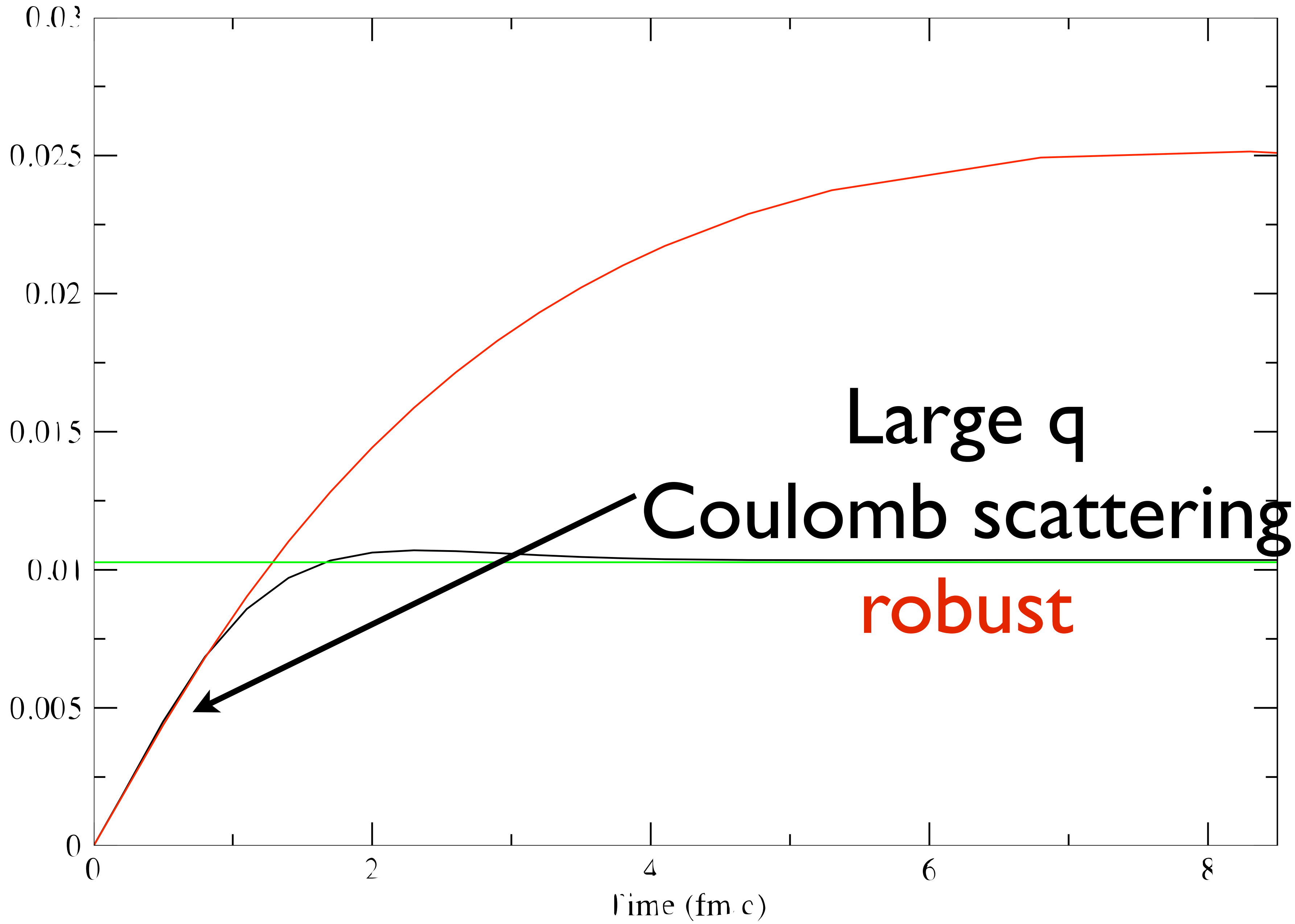


At small t, the jet is very virtual

It will not care about the medium unless it is hit very hard $q_\perp^2 > E_{\rm eff}/t$

Such collisions are rare: $d\Gamma_{\rm el} \sim \alpha_s^2 \frac{d^2 q_\perp}{q_\perp^4}$

$$\int_{q_\perp^2 > E_{\rm eff}/t} d\Gamma_{\rm el} \sim \frac{\alpha_s^2 t}{E_{\rm eff}}$$



dGamma/dk [dimensionless]

Time [fm/c]

Large time behavior: AMY

- AMY consider radiation in infinite homogeneous media.
- Same as our problem at large t
- We must reproduce AMY when $t>t_{form}$!

Zakharov& Aurenche

Large time behavior: AMY

- AMY consider radiation in infinite homogeneous media.
- Same as our problem at large t
- We must reproduce AMY when $t > t_{form}$!
- Note: AMY use:
  ...and so did we.

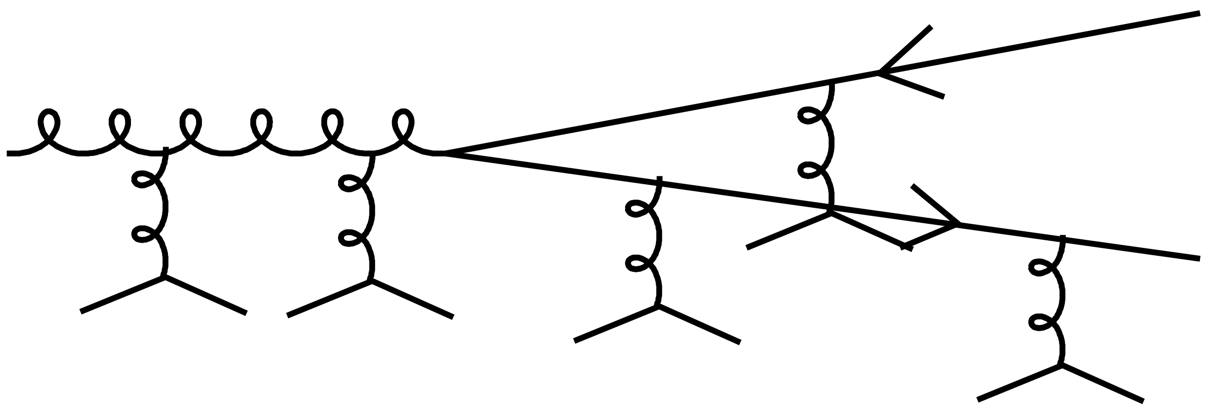
Zakharov& Aurenche

$$(2\pi)^2 \frac{d^2\Gamma_{\rm el}}{d^2\mathbf{q}} = \frac{g^2 m_D^2 C_s T}{\mathbf{q}^2(\mathbf{q}^2+m_D^2)}$$

Aurenche, Gelis& Zaraket
(See also, Djordjevic & Heinz)

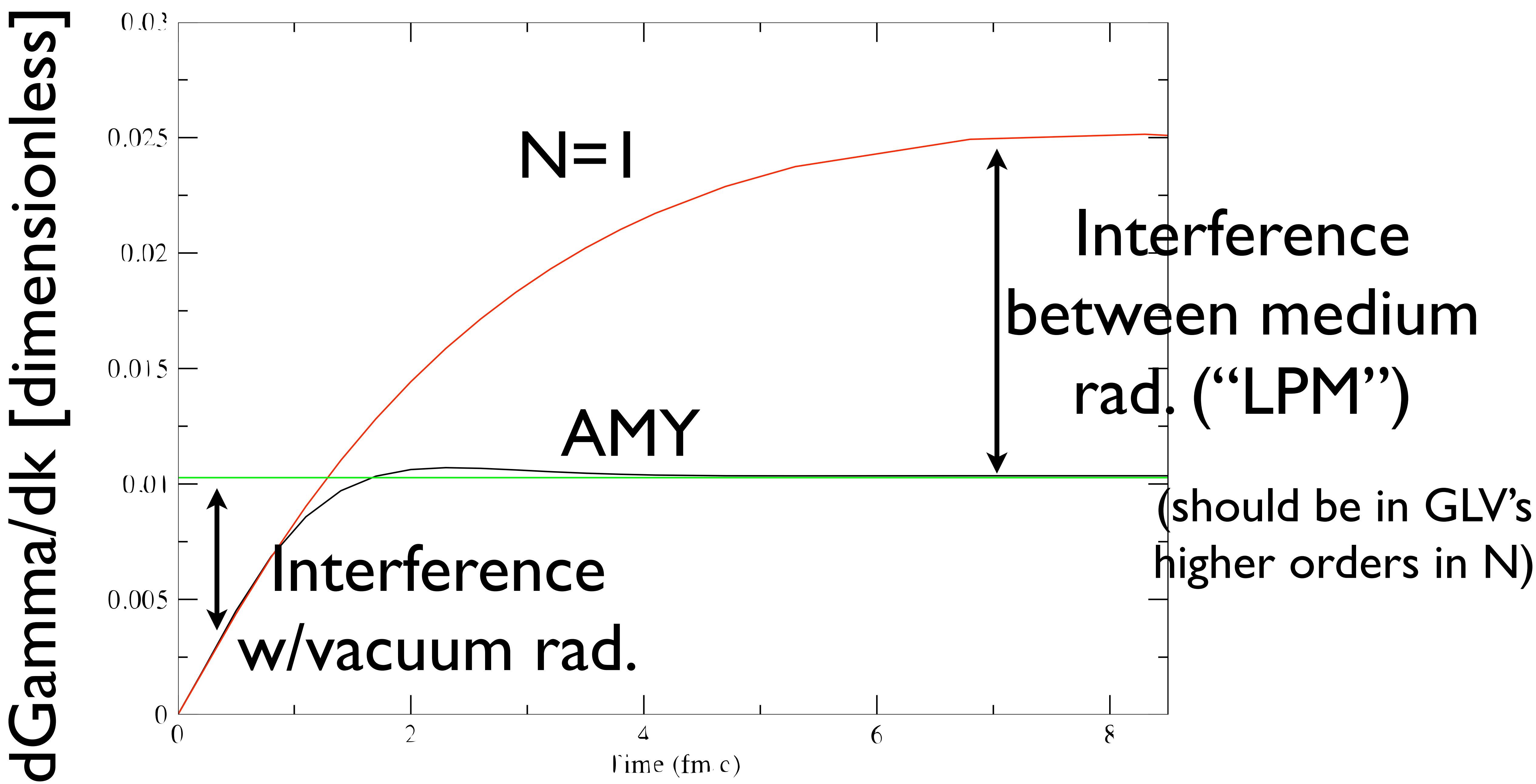
- This input is not really known theoretically
  (NLO corrections are large) (SCH 2008)

LPM effect



- As formation times get longer at higher energies (>> 1fm!), single-collision is no longer reasonable
- Each collision will NOT induce a new radiation
- LPM effect: nearby collisions get blurred, leading to a suppression. This is included by AMY (and BDMPS-Z)

Summary: two distinct types of interference



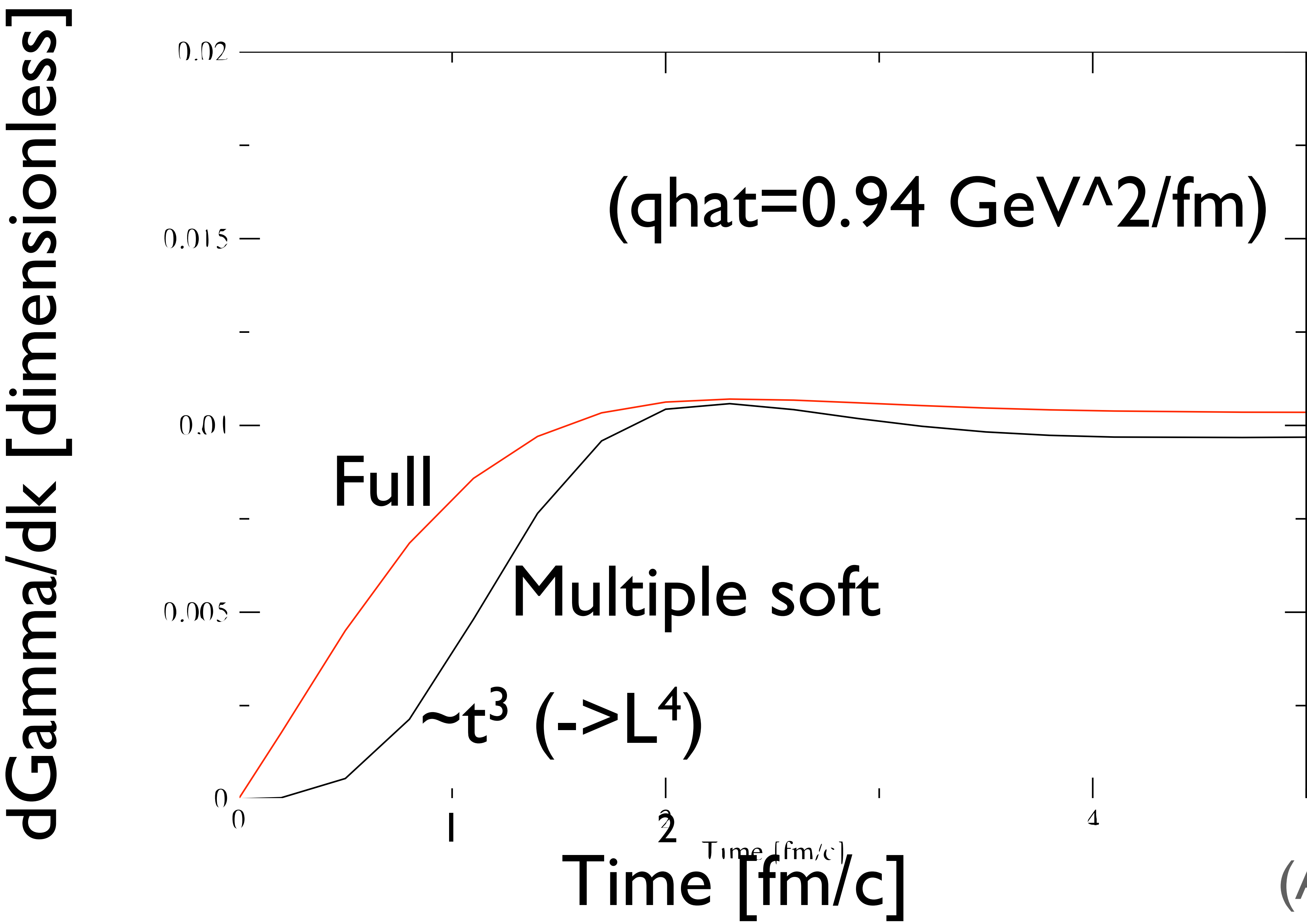
Another common approx.: Multiple soft scattering

- In the deep LPM regime there are many collisions (order ~ t_{form})
- Can replace them with a diffusive process

$$\langle \mathbf{p}^2 \rangle \to \hat{q} t$$

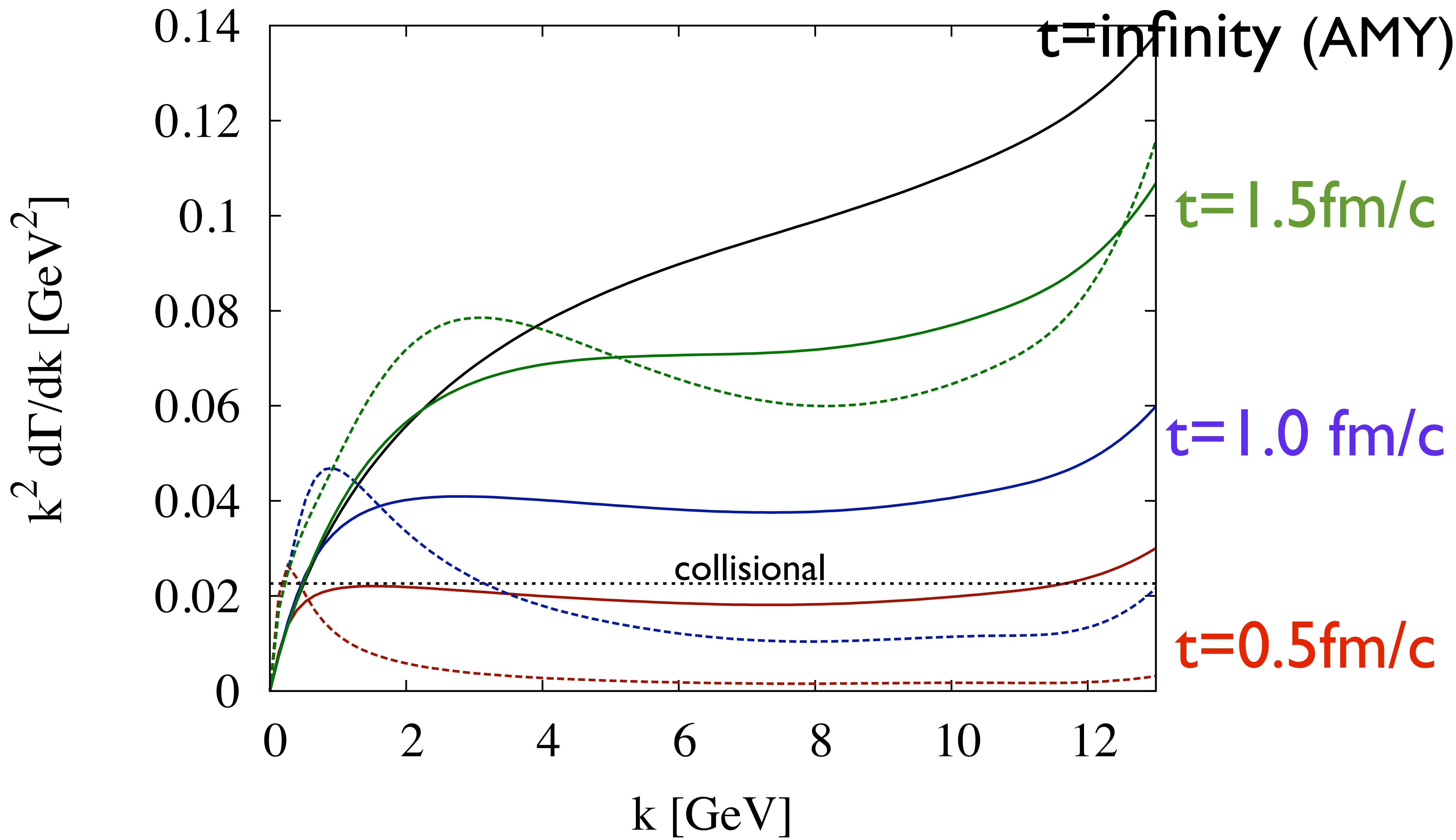
- Used in BDMPS' original paper

“Multiple soft” approx.?

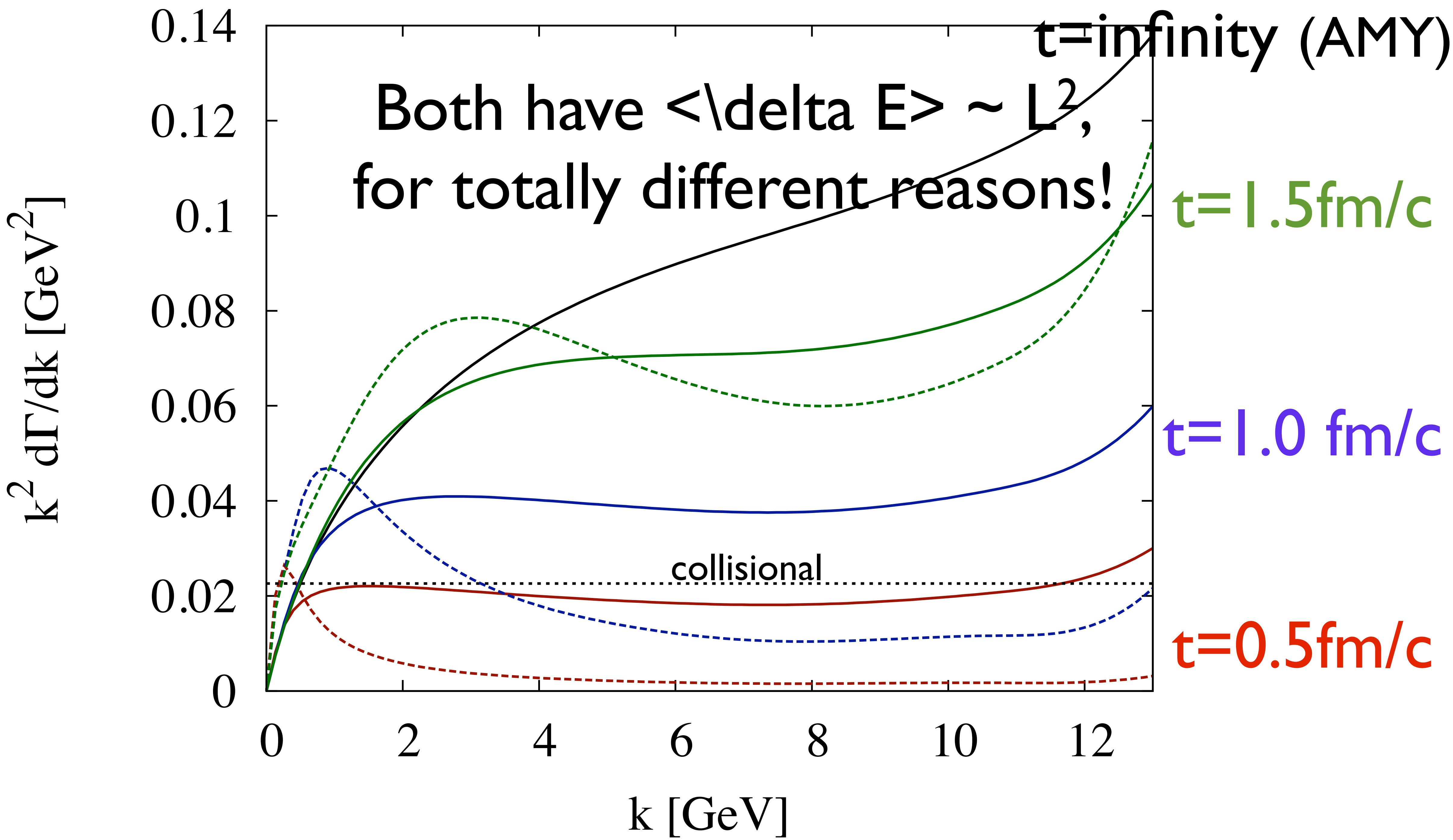


(Arnold, `10)

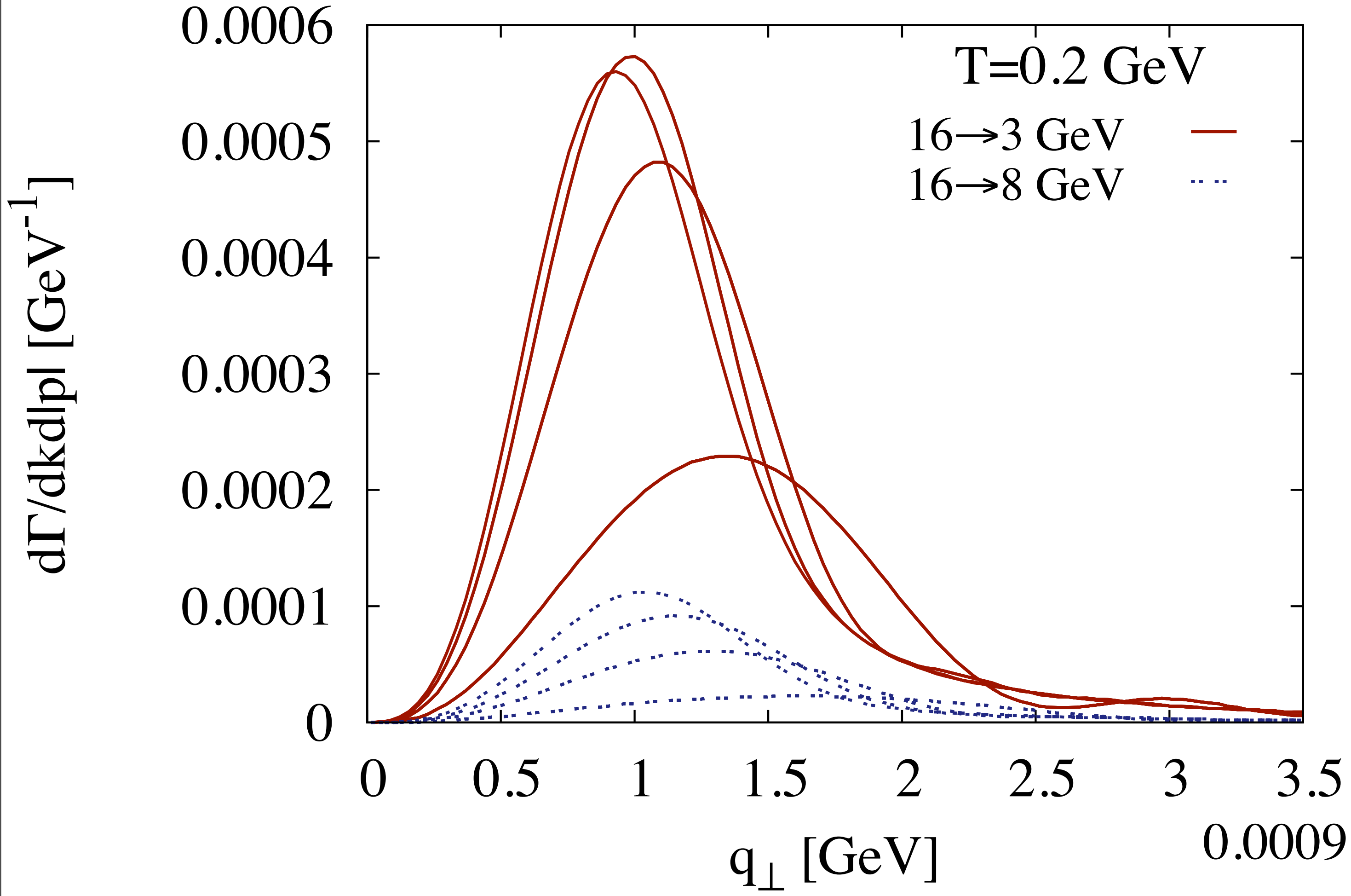
Rad. spectra from a 16 GeV quark: full vs. mult. soft

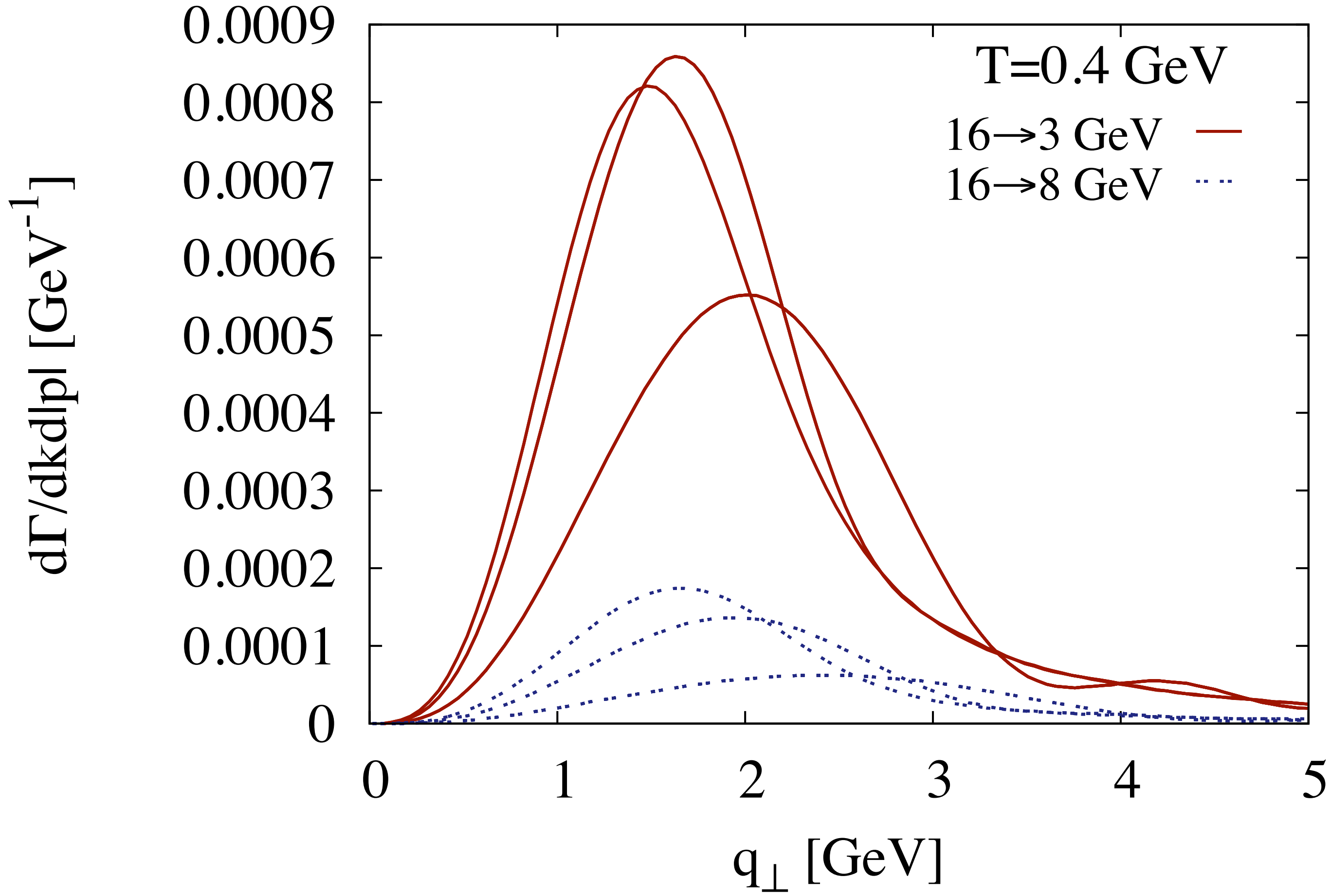


Rad. spectra from a 16 GeV quark: full vs. mult. soft



Transverse momentum of radiation $\frac{\text{“}d^3P\text{”}}{dt\,d^2\mathbf{p}}$





How can the medium be characterized?

Curves are functions of $\frac{d^2\Gamma_{\rm el}}{d^2\mathbf{q}}(\mathbf{q},t)$ ‘gluon density’

- At small time, N=1 dominates. $\sum_i g_s^4 C_i n_i/d_i$
  - Rad. measures partonic charge
    at short distances (jet is highly virtual)

- Large time is largely controlled by multiple-soft approx., e.g. ‘qhat’.

Need two transport coefficients!

$$v(x_\perp) \quad \sim \quad C_1 x_\perp^2 \log(\mu_0^2 x_\perp^2) + \frac{1}{4} x_\perp^2 \hat{q}(\mu_0) + O(x_\perp^4)$$

Conclusions

- BDMPS-Z can be solved in full, in any regime and on top of any hydro background
  Available upon request
- Rate formulation makes transition between regimes trivial to describe
- To characterize the physics in all regimes, ‘qhat’ *and* a color charge density in UV necessary