Heavy quark collisional energy loss

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PRESCRIPTIONS
PHARMACIST ON DUTY
PETER HIGGS
PETER HIGGS
BUY 1 GET 1

Heavy ion collisions

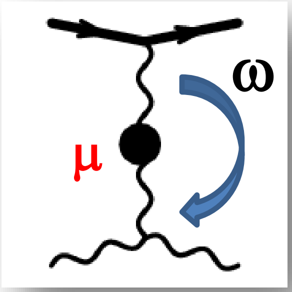
Quark-gluon plasma signals

- ❑ **soft probes**
  - ○ ...
  - ○ ...

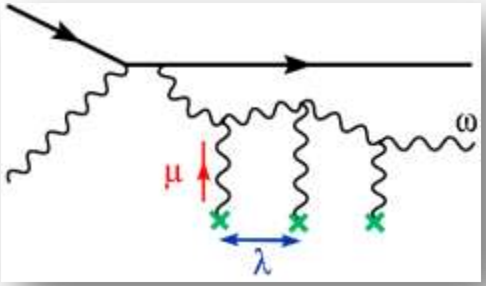
- ❑ **hard probes**
  - ○ jet quenching ... partonic energy loss
  - ○ ...

2 mechanisms

binary collisions



induced radiation



Energy Loss of Energetic Partons in Quark - Gluon Plasma: Possible Extinction of High p(t) Jets in Hadron - Hadron Collisions.
J.D. Bjorken (Fermilab). Aug 1982. 20 pp.
FERMILAB-PUB-82-059-THY, FERMILAB-PUB-82-059-T

High energy quarks and gluons propagating through quark-gluon plasma suffer differential energy loss via elastic scattering from quanta in the plasma. This mechanism is very similar in structure to ionization loss of charged particles in ordinary matter. The dE/dx is roughly proportional to the square of the plasma temperature. For hadron-hadron collisions with high associated multiplicity and with transverse energy dE_T/dy in excess of 10 GeV per unit rapidity, it is possible that quark-gluon plasma is produced in the collision. If so, a produced secondary high-p_T quark or gluon might lose tens of GeV of its initial transverse momentum while plowing through quark-gluon plasma produced in its local environment. High energy hadron jet experiments should be analysed as function of associated multiplicity to search for this effect. An interesting signature may be events in which the hard collision occurs near the edge of the overlap region, with one jet escaping without absorption and the other fully absorbed.

similar to ionization loss

jet quenching

correlations

dE/dx ... (t)

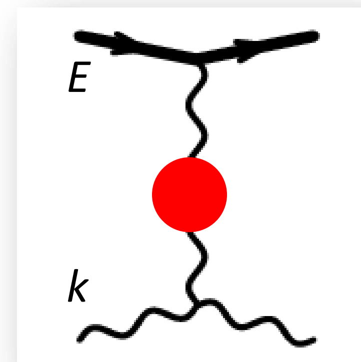
Bjorken 1982

$$\frac{dE}{dx} \sim \alpha^2 T^2 \ln \frac{ET}{m_D^2}$$

Bethe-Bloch ... Bjorken

$$\frac{dE_i}{dx} \simeq \int_{k^3} n_i(k) \int dt \, \frac{d\sigma_i}{dt} \underbrace{\text{FluxFactor} \times \omega}_{\simeq -t/2k}$$

targets i = {gluons, light flavors}



dominating at large *E:* $\frac{d\sigma}{dt} \propto \frac{\alpha^2}{t^2}$

$$\frac{dE}{dx} \propto \int \frac{d^3k}{(2\pi)^3} \frac{n(k)}{2k} \int_{-ET}^{-\mu^2} dt \, \frac{\alpha^2}{t^2} (-t)$$

$$\propto \quad T^2 \, \alpha^2 \ln \frac{ET}{\mu^2}$$

screening

uncertainties ...

dE/dx ... (t)

Braaten & Thoma 1991	Bjorken 1982
$\frac{dE}{dx} \sim \alpha^2 T^2 \left(\ln \frac{ET}{m_D^2} + \tilde{c} \right)$	$\frac{dE}{dx} \sim \alpha^2 T^2 \ln \frac{ET}{m_D^2}$

dE/dx ... (t)

AP 2006

$$\frac{dE}{dx} \sim \alpha(m_D^2)\alpha(ET)\, T^2 \ln\frac{ET}{m_D^2}$$

Braaten & Thoma 1991

$$\frac{dE}{dx} \sim \alpha^2 T^2 \left(\ln\frac{ET}{m_D^2} + \tilde{c}\right)$$

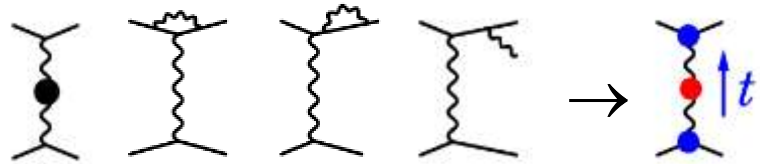
Bjorken 1982

$$\frac{dE}{dx} \sim \alpha^2 T^2 \ln\frac{ET}{m_D^2}$$

Whatever they do – ... RUN ... ?

Whatever they do - RUN

quantum corrections to Born X-section	
thermal contributions	**vacuum** contributions
screening	running coupling



running coupling $\alpha(t) = \dfrac{4\pi/\beta_0}{\ln(-t/\Lambda^2)}$ **crucial** for QCD energy loss

$$\frac{dE}{dx} \propto \int \frac{d^3k}{(2\pi)^3}\frac{n(k)}{2k}\int_{-s}^{-m_D^2} dt \left(\frac{4\pi/\beta_0}{\ln(-t/\Lambda^2)}\right)^2 \frac{1}{t^2}(-t)$$

$$\propto \quad T^2 \quad \alpha(m_D^2)\,\alpha(ET)\,\ln\frac{ET}{m_D^2}$$

AP 2006

- ❖ **predictive** leading log result
- ❖ NB: **d*E*/dx → constant** for large *E*

dE/dx ... (t)

Peigné & AP 2008

$$\frac{dE}{dx} \sim \alpha(m_D^2)\alpha(ET)T^2 \ln\frac{ET}{m_D^2} + \alpha(M^2)\alpha(ET)T^2 \tfrac{2}{9}\ln\frac{ET}{M^2} + \alpha(ET)\alpha(m_D M)\,T^2 c$$

AP 2006

$$\frac{dE}{dx} \sim \alpha(m_D^2)\alpha(ET)\,T^2 \ln\frac{ET}{m_D^2}$$

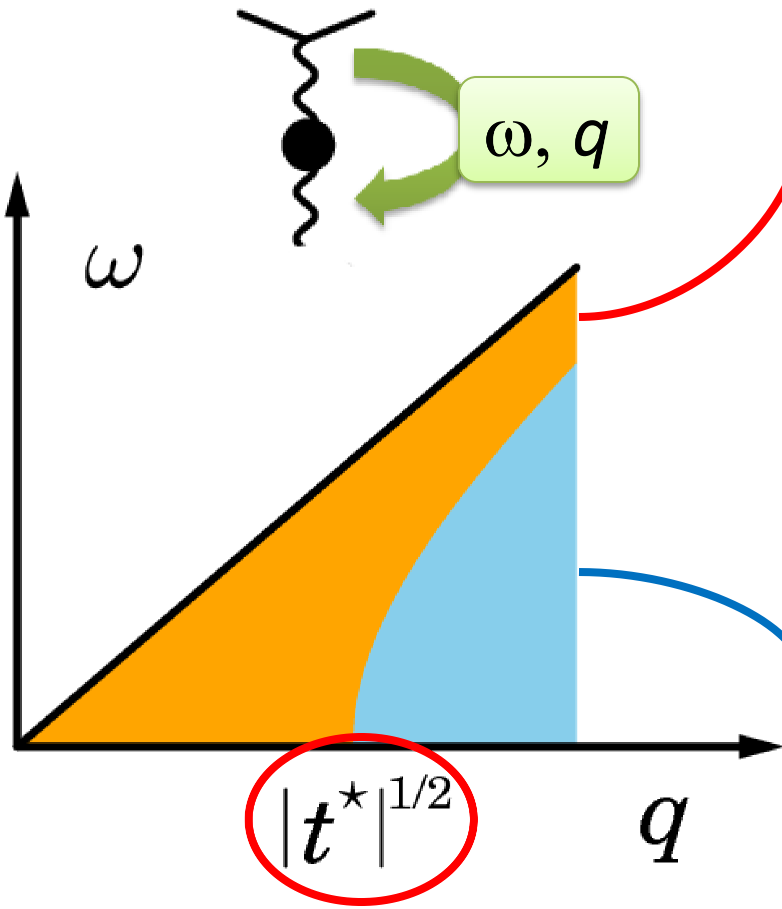
Braaten & Thoma 1991

$$\frac{dE}{dx} \sim \alpha^2 T^2 \left(\ln\frac{ET}{m_D^2} + \tilde{c}\right)$$

Bjorken 1982

$$\frac{dE}{dx} \sim \alpha^2 T^2 \ln\frac{ET}{m_D^2}$$

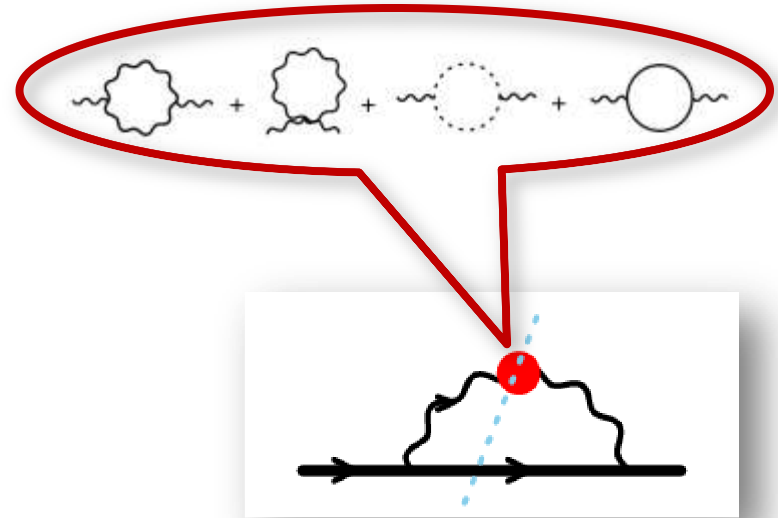
PP approach



separation scale,
drops out in final result

soft contribution

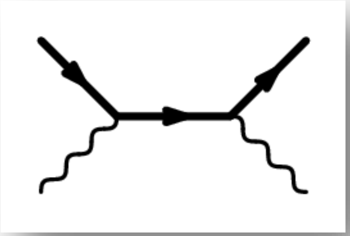
hard themal loop
perturbation theory



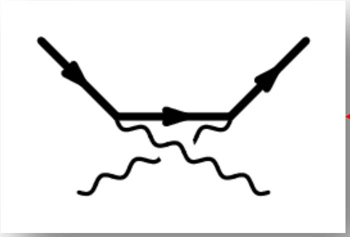
hard contribution

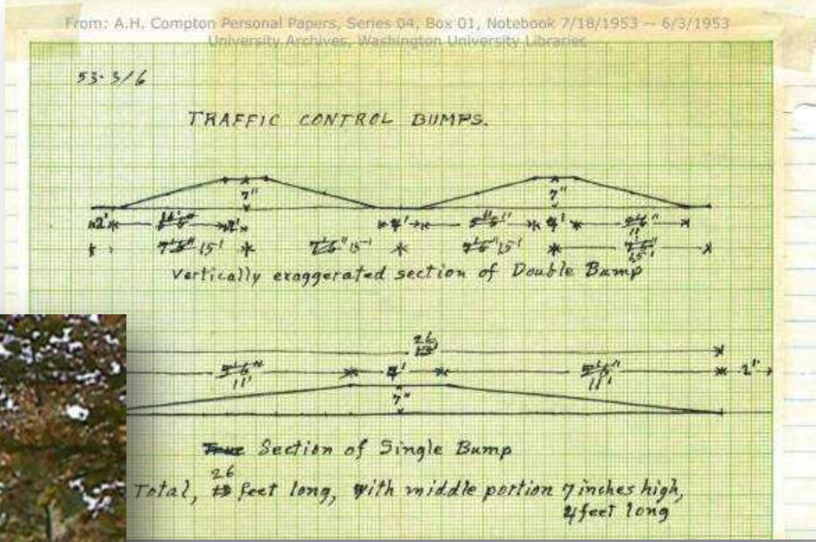
with Born X-sections

Compton - full stop.



$$\frac{dE^{\mathrm{C}}}{dx} \sim \alpha(M^2)\alpha(ET)T^2 \ln\frac{ET}{M^2}$$



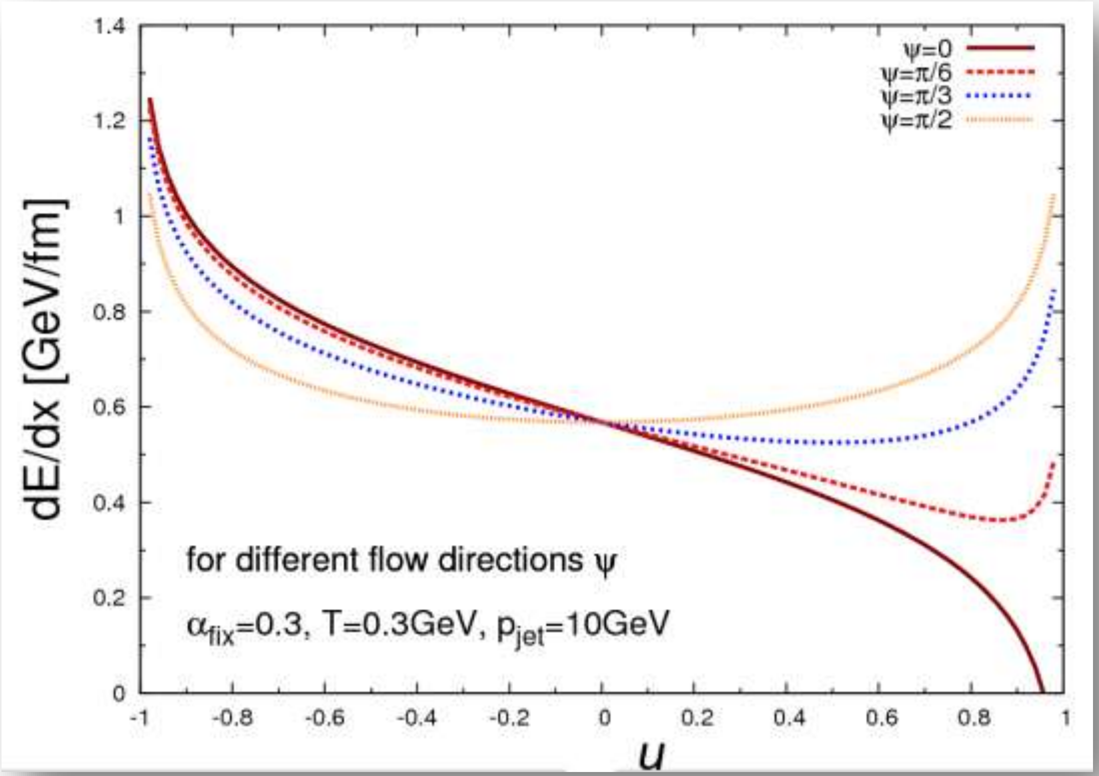


dE/dx with flow

$$\frac{dE}{dx} \sim \int \frac{d^3k}{(2\pi)^3} \frac{n\left(K_\mu u^\mu\right)}{2k} \int dt \, \frac{d\sigma}{dt} \, (-t)$$

$$\sim T^2 \alpha(P_\mu u^\mu \, T) \left[\alpha(m_D^2) \ln \frac{P_\mu u^\mu \, T}{m_D^2} + \frac{2}{9} \, \alpha(M^2) \ln \frac{P_\mu u^\mu \, T}{M^2} \right]$$

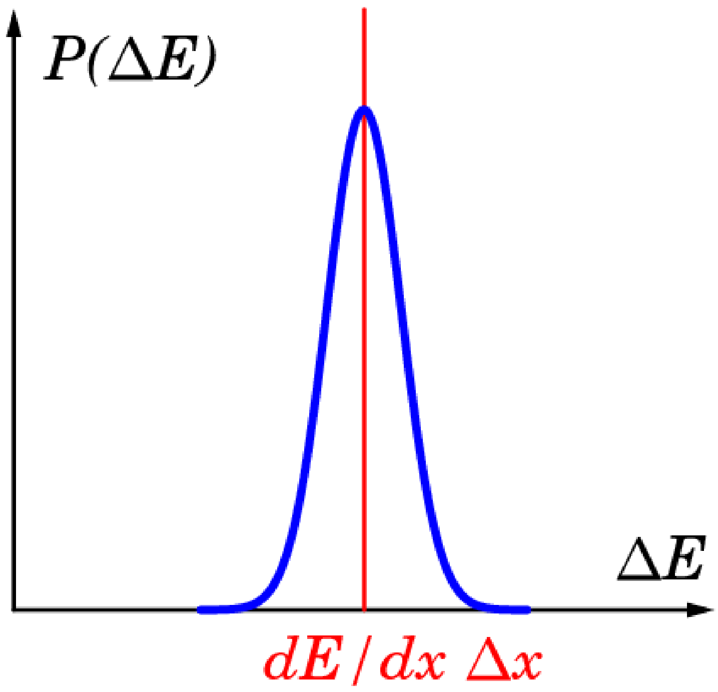
Meistrenko, Uphoff, Greiner & AP 2012



Probabilistic description

dE/dx is `stopping power' ... there is also `range straggling'

→ need **probabilistic approach**



- **how to <u>NOT</u> get the PDF**
  - deterministic loss
  - Gauss smearing
  - via Fokker-Planck eqn.

Collision rate

✓ quantum statistics

✓ kinematics

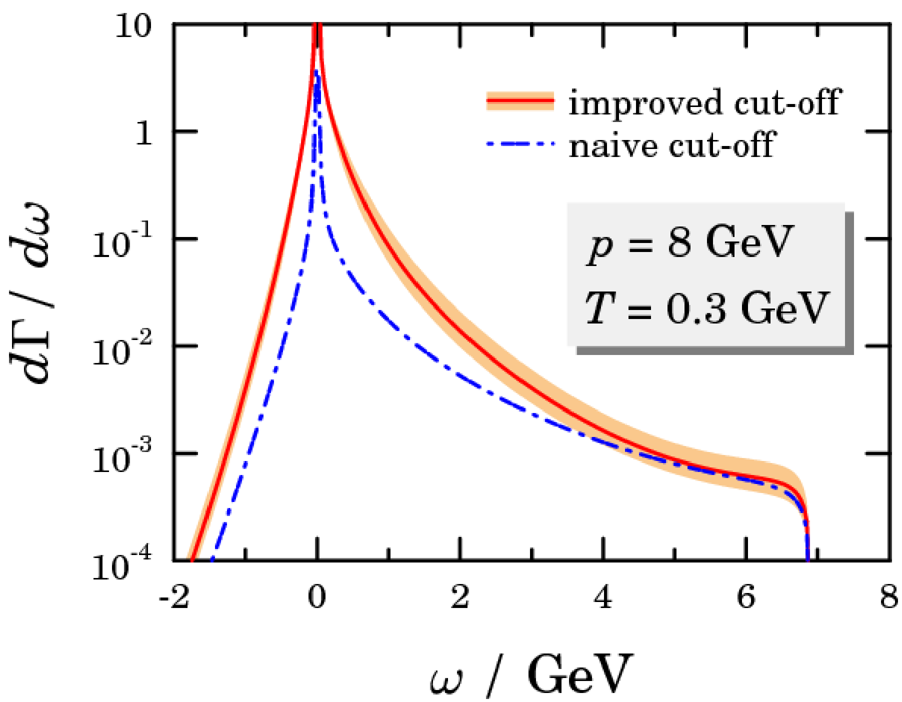
$$\frac{dE}{dx} = \frac{v^{-1}}{2E}\int_k \frac{n_k}{2k}\int_{k'}\frac{1\pm n_{k'}}{2k'}\int_{p'}\frac{(2\pi)^4}{2E'}\,\delta^{(4)}(P+K-P'-K')\,\left\langle|\mathcal{M}|^2\right\rangle\omega$$

$$= \int d\omega\,\frac{d\Gamma}{d\omega}\,\omega$$

✓ running coupling

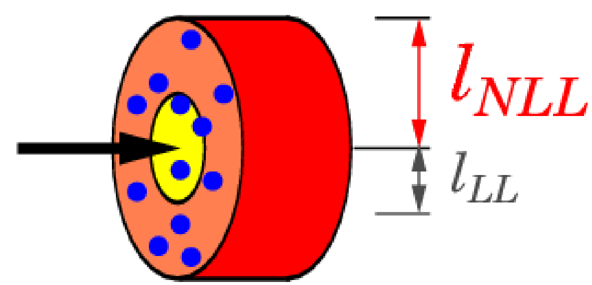
✓ effective mass cutoff

$$\mu^2(t) = \kappa\, 4\pi\left(1+\frac{n_f}{6}\right)\alpha(t)\,T^2$$



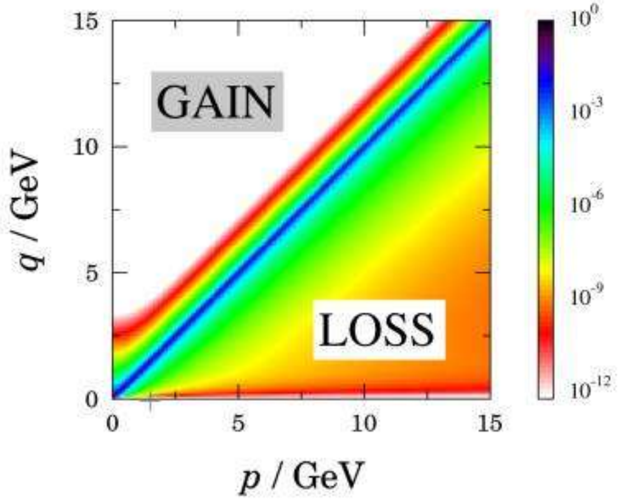
$\kappa \approx 0.2$

→ **enhanced interaction rate**



AP 2008

Markov$_{\text{(= Boltzmann)}}$ evolution



Consider **ensemble** of test particles.

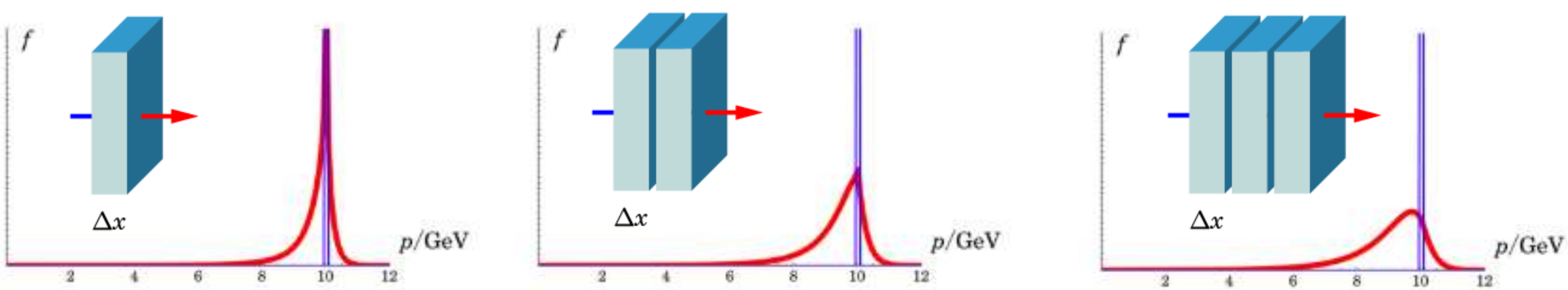
Evolution of spectrum is 1st order Markov process.

- in small interval δt:

$$f(q) \to f(q, \delta t) = f(q) - \delta t\, \Gamma(q) f(q) + \delta t \int dp\, \mathcal{P}(q,p)\, f(p)$$

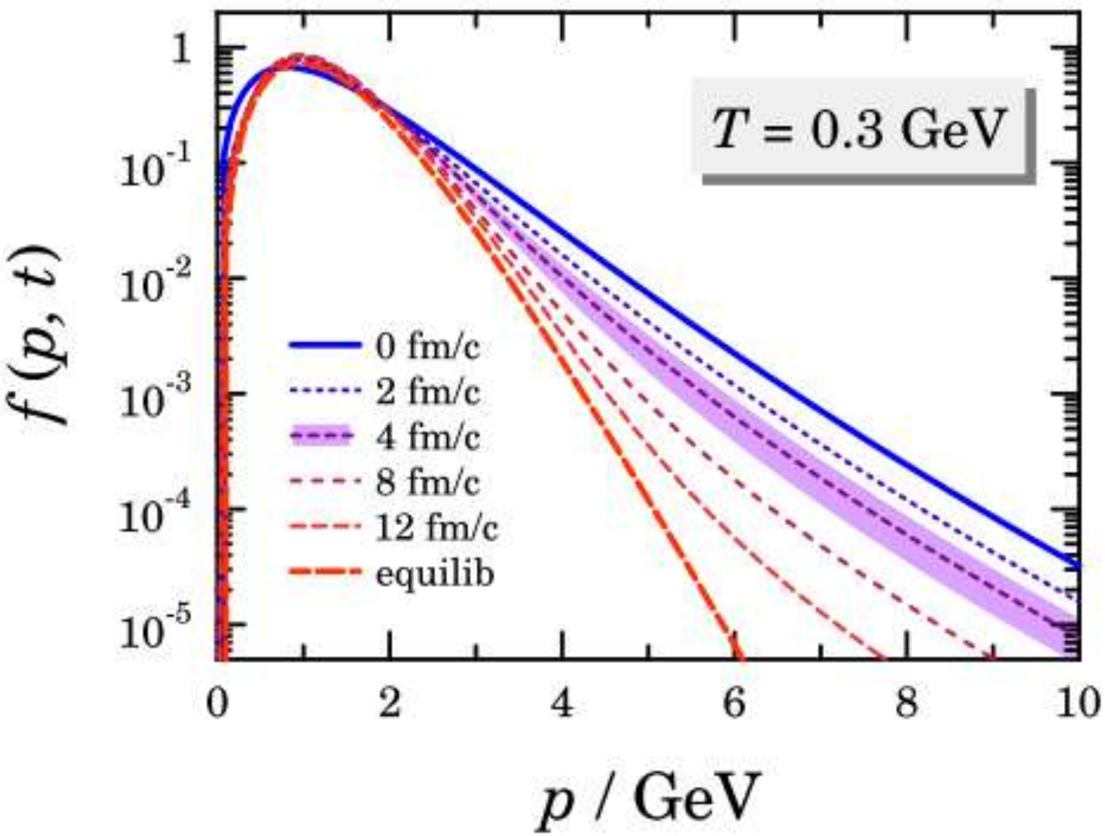
$$\equiv \int dp\, \mathcal{T}(q, p; \delta t)\, f(p) \qquad \text{transition matrix}$$

- discretize (bin) momenta: $f_q(t) = (\mathcal{T}_{qp})^n f_p$ *evolution = matrix power*



Charm (partonic) equilibration

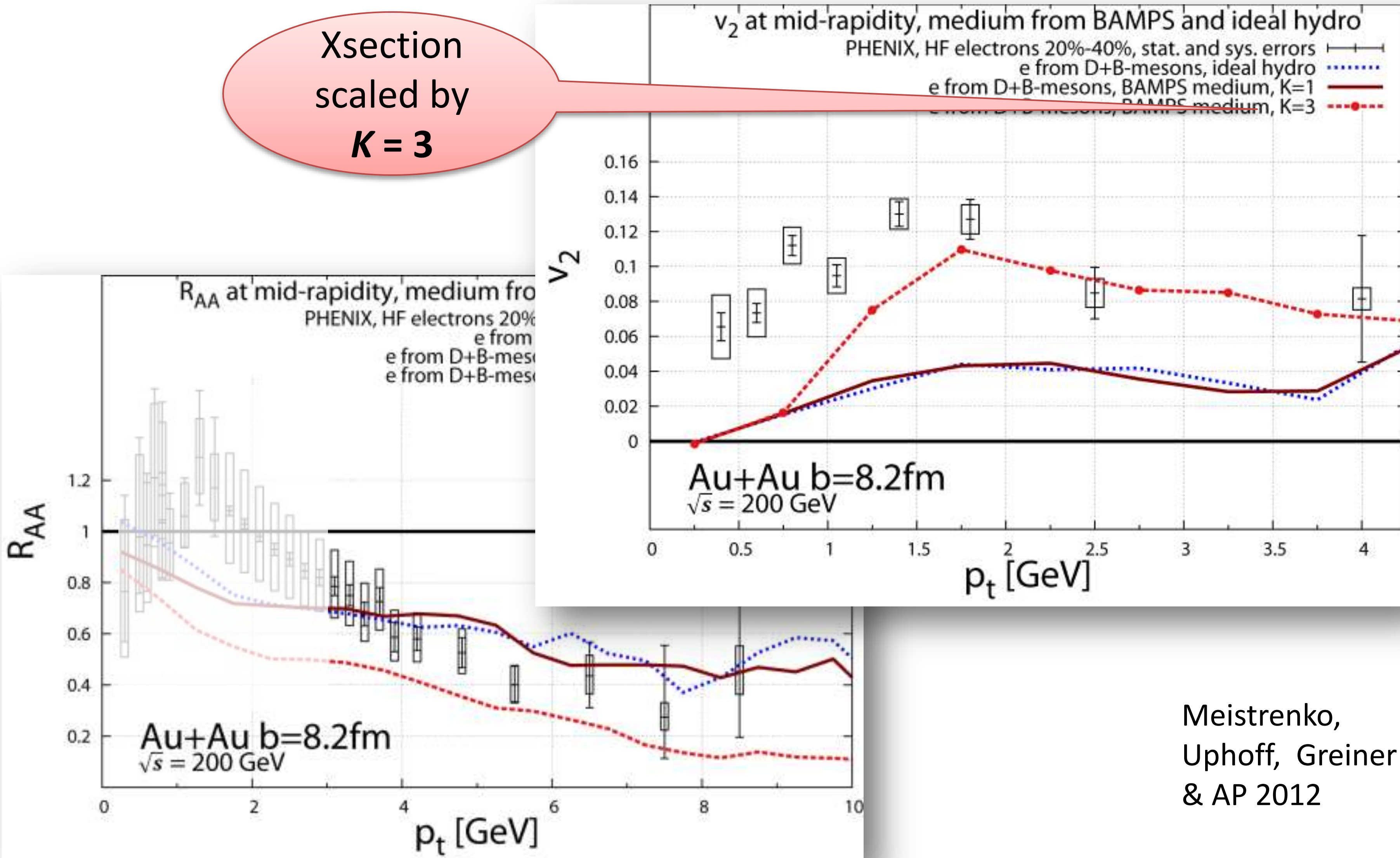
Initial charm spectrum in heavy ion collisions: $f(p,0) = \left.\frac{dN}{dp}\right|_{ini} \sim p^{-\nu}$



κ^{-1}-faster approach to therm. equilibrium

AP 2008

Heavy flavor R_{AA} & v_2



Meistrenko, Uphoff, Greiner & AP 2012

Resumé

- need to be more precise than `prescriptions'/questionable approximations
- collisions need to be considered, besides gluon radiation, to understand heavy charm quenching and anisotropy
- stay tuned ☺