Radiation in the Nantes Model

(PRD89 074018)

Joerg Aichelin

Calculate the radiation matrix elements in scalar QCD

$$M_{QCD} = M_{SQCD}\left(1 - \frac{(\omega/E)^2}{(1-\omega/E)^2}\right)$$

Implementation of the LPM effect in an approximate way

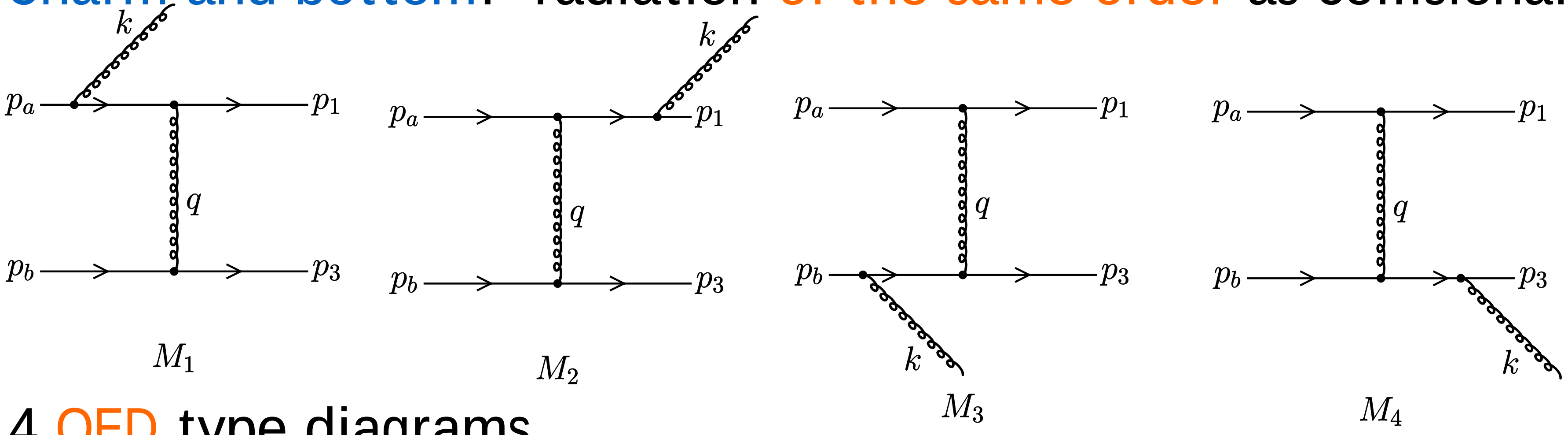
Study of different limits: Gunion Bertsch in the limit of vanishing heavy quark mass

Influence on experimental observables

Inelastic Collisions

Low mass quarks : radiation dominantes energy loss

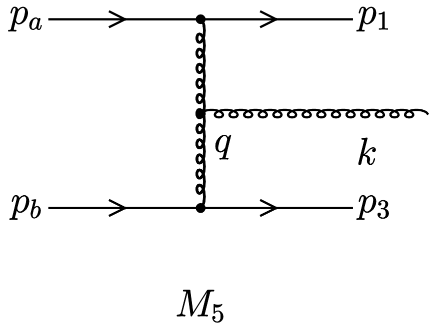
Charm and bottom: radiation of the same order as collisional



4 QED type diagrams

A+ GAUGE

M_4 ,M_5 ~ M/E



1 QCD diagram

Com mutator of the color SU(3) operators

$$T^b T^a = T^a T^b - i f_{abc} T^c$$

M1-M5 : 3 gauge invariant subgroups

$$M^1_{QED} = T^a T^b (M_1 + M_2) \quad M^2_{QED} = T^a T^b (M_3 + M_4)$$

$$M_{QCD} = i f_{abc} T^c (M_1 + M_3 + M_5)$$

M_{QCD} dominates the radiation

M^{SQCD} in light cone gauge

These matrix elements have been calculated in full glory but for the discussion they are useless

In the limit $\sqrt{s} \to \infty$ the radiation matrix elements factorize in

$$M^2_{tot} = M^2_{elast} \cdot P_{rad}$$

k_t , ω = transv mom / energy of gluon E = energy of the heavy quark

$$P_{rad} = C_A \left(\frac{\vec{k}_t}{k_t^2 + (\omega/E)^2 m^2} - \frac{\vec{k}_t - \vec{q}_t}{(\vec{q}_t - \vec{k}_t)^2 + (\omega/E)^2 m^2} \right)^2$$

Emission from heavy q

Emission from g

m=0 -> Gunion Bertsch

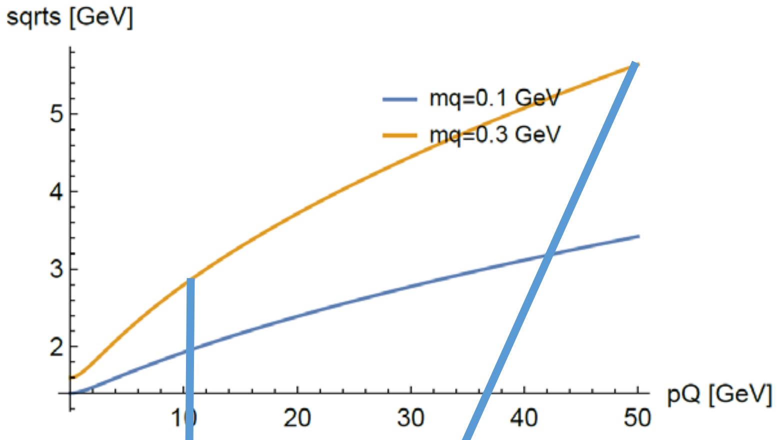
from light q

heals colinear divergences

Energy loss:

$$\frac{\omega d^4 \sigma^{rad}}{dx d^2 k_t dq_t^2} = \frac{N_c \alpha_s}{\pi^2} (1-x) \cdot \frac{d\sigma^{el}}{dq_t^2} \cdot P_{rad}$$

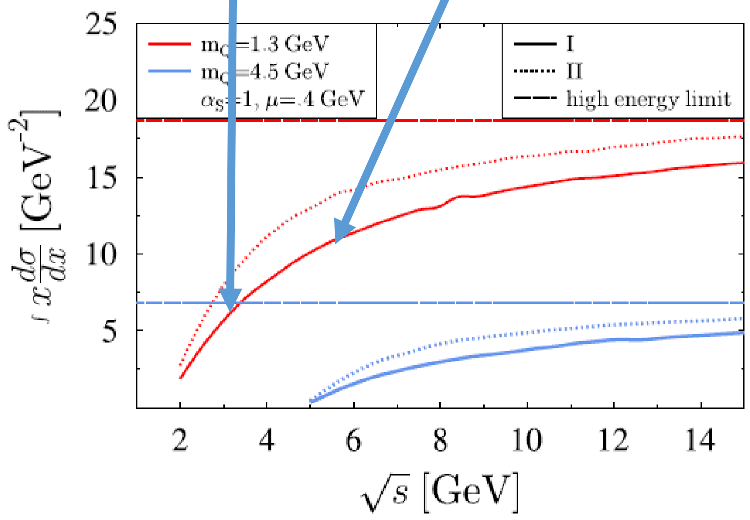
In the energy we are interested in we are NOT in the high energy limit

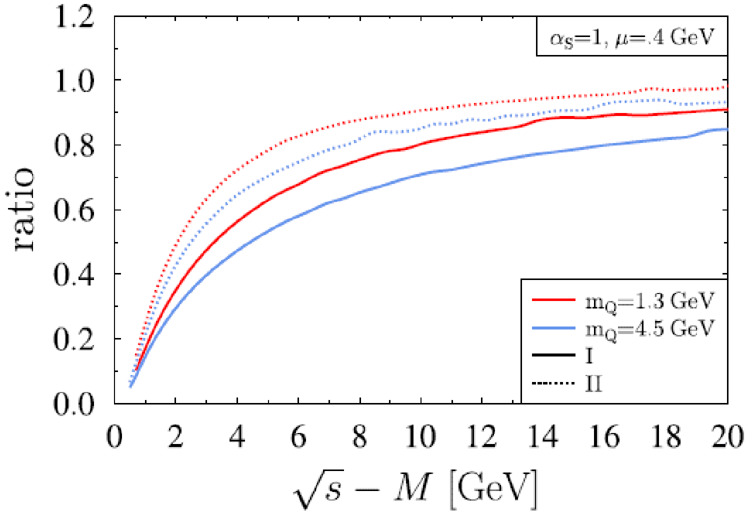


$$\frac{d\sigma^{Qq\to Qgq}}{dx d^2k_t d^2\ell_t} = \frac{1}{2(s-M^2)}|\mathcal{M}|^2\frac{1}{4(2\pi)^5\sqrt{\Delta}}\Theta(\Delta),$$

with $\Delta = (x(1-x)s - xM^2 - \vec{k}_t^2 + 2x\vec{k}_t\cdot\vec{\ell}_t)^2$
$\qquad - 4x(1-x)\vec{\ell}_t^2(xs - \vec{k}_t^2).$

correction factor of 3 for pQ= 10 GeV
factor of 2 for pQ= 50 GeV

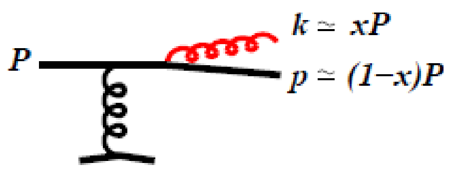




I : full solution
II: large $\sqrt{s}$ limit but exact phase space
presently implemented in EPOSHQ

Landau Pomeranschuk Migdal Effekt (LPM)

reduces energy loss by gluon radiation



Heavy quark radiates gluons

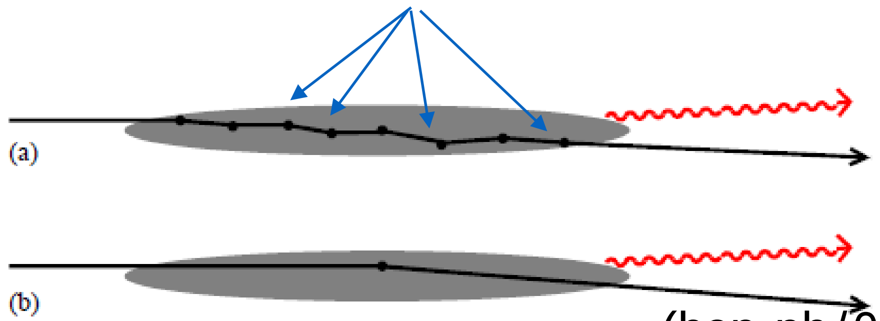
gluon needs time to be formed

Collisions during the formation time

do not lead to emission of a second gluon

emission of one gluon

(not N as in Bethe Heitler)



(hep-ph/0204343)

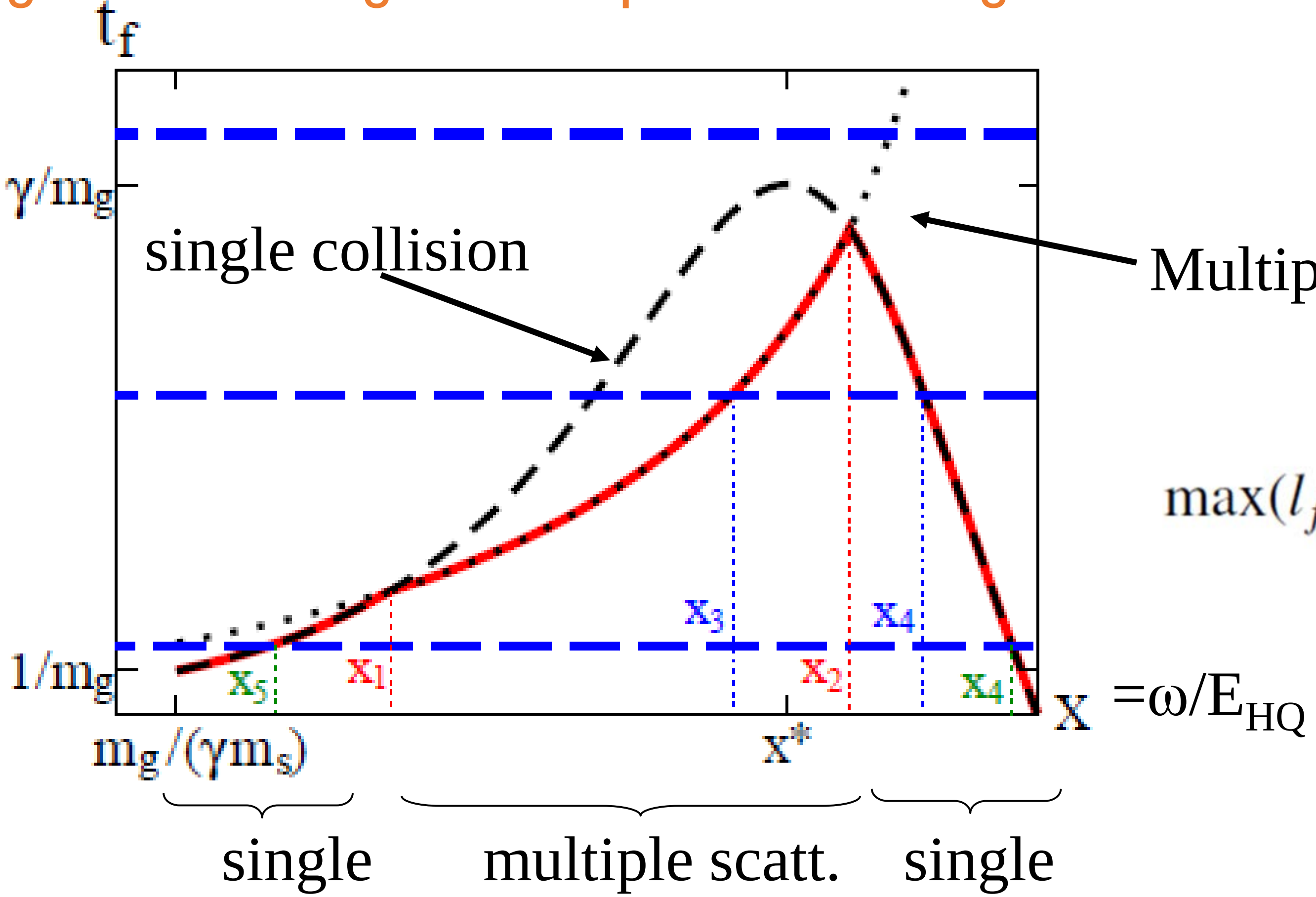
$$t_f \approx \frac{2(1-x)\omega}{\boxed{\underbrace{(\vec{k}_\perp - \vec{q}_\perp)^2}} + \boxed{\underbrace{x^2 M^2 + (1-x) m_g^2}}}$$

Multiple scatt .QCD: $\approx N_{coll}$ $\boxed{\langle k_t^2 \rangle = t_f\ \hat{q}}$ $\boxed{\text{single scatt.}}$

dominates x<1 dominates x≈1 dominates x<<1

$$l_{f,\mathrm{sing}}^{3\,\mathrm{gl}} \approx t_f \approx \frac{2(1-x)\omega}{\underbrace{x^2M^2+(1-x)m_g^2}_{\text{single scattering}}+\underbrace{(\vec{q}_\perp-\vec{k}_\perp)^2}_{\text{multiple scattering}}},$$

$M=m_g=q=0 \;\rightarrow\; l_f \approx \frac{2\omega}{k_\perp^2}$

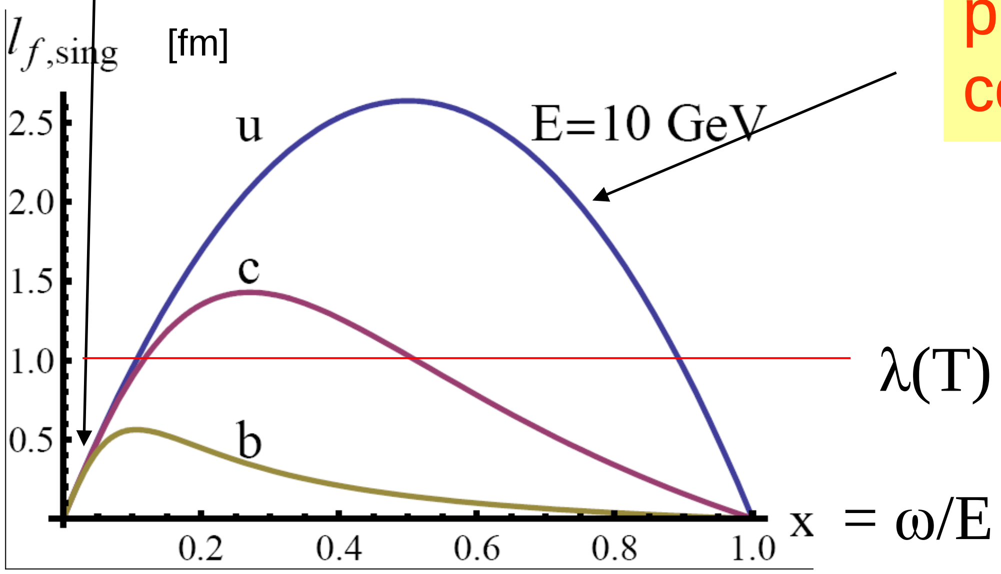


$$\max(l_f) \approx \frac{E}{m_g M}$$

At intermediate gluon energies formation time is determined by multiple scattering

For $x<x_{cr}=m_g/M$, basically no mass effect in gluon radiation

For $x>x_{cr}=m_g/M$, gluons radiated from heavy quarks are resolved in less time then those from light quarks and gluons => radiation process less affected by coherence effects.

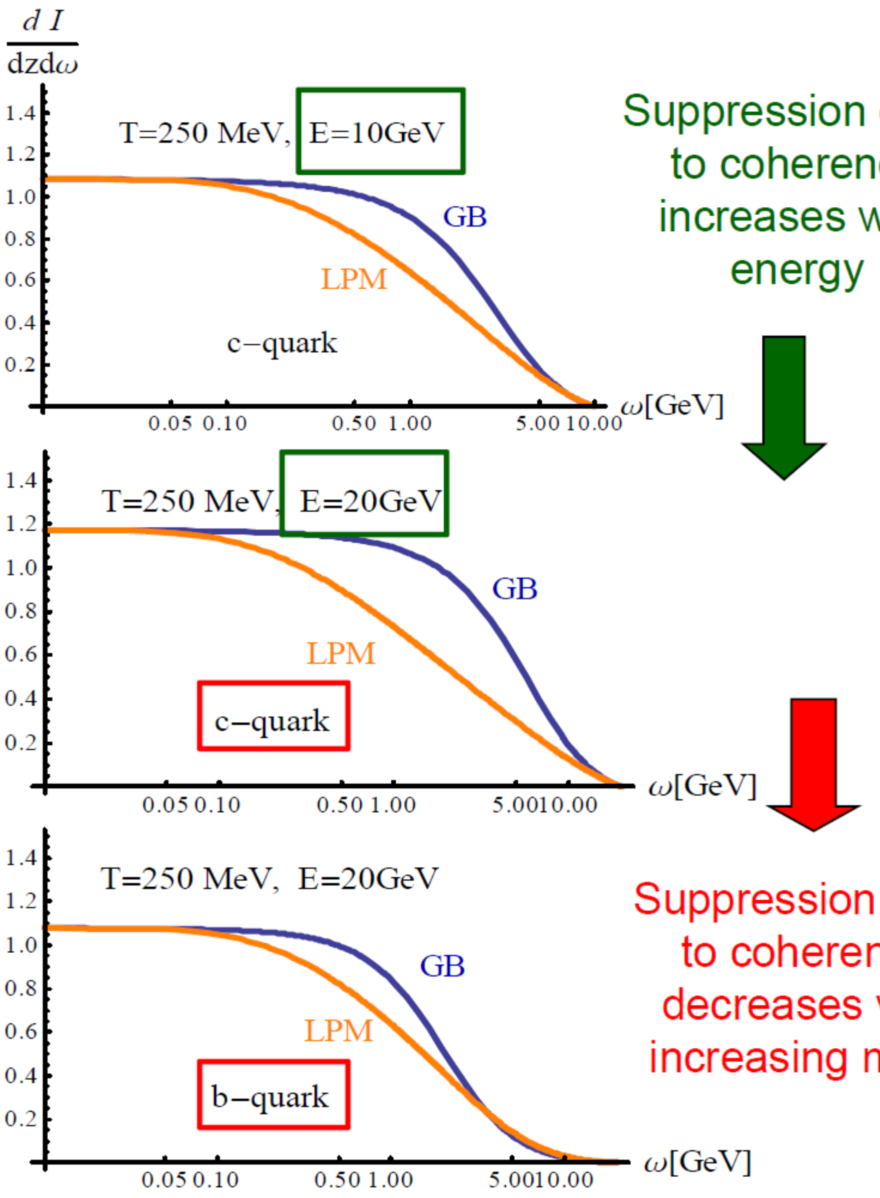


LPM important for intermediate x where formation time is long

Most of the collisions $\frac{d\sigma}{dx}$

Dominant region for average E loss $x\frac{d\sigma}{dx}$

Consequences of LPM on the energy loss



Suppression due to coherence increases with energy

Suppression due to coherence decreases with increasing mass

Are there observables which are sensitive on the interaction mechanism (elast/radiative)?

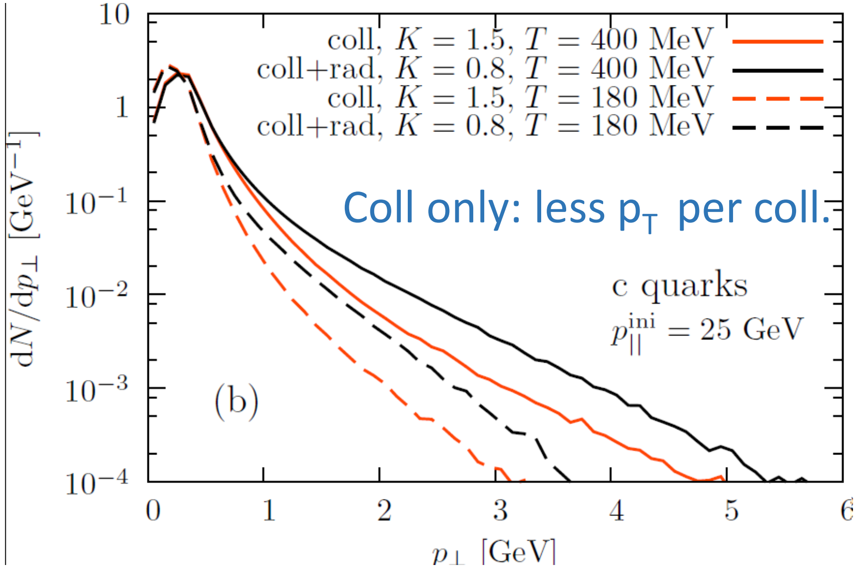
Possible candidate: heavy flavor correlations

They may be sensitive to

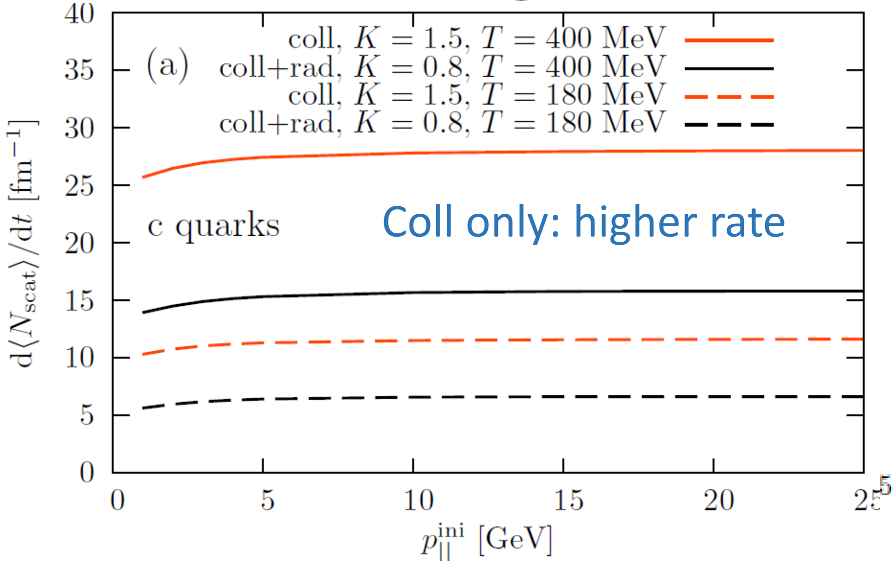
- Properties of the energy loss model: path length dependence? Parton mass dependence?
- Properties of the interaction inside a medium: drag coefficient, jet quenching parameter?

WHY?

Single scattering:



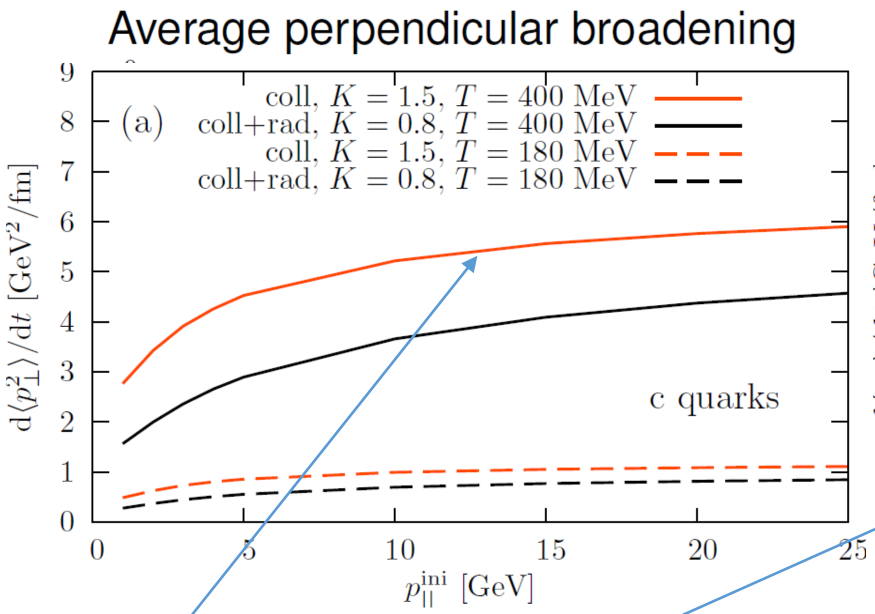
Scattering rate:

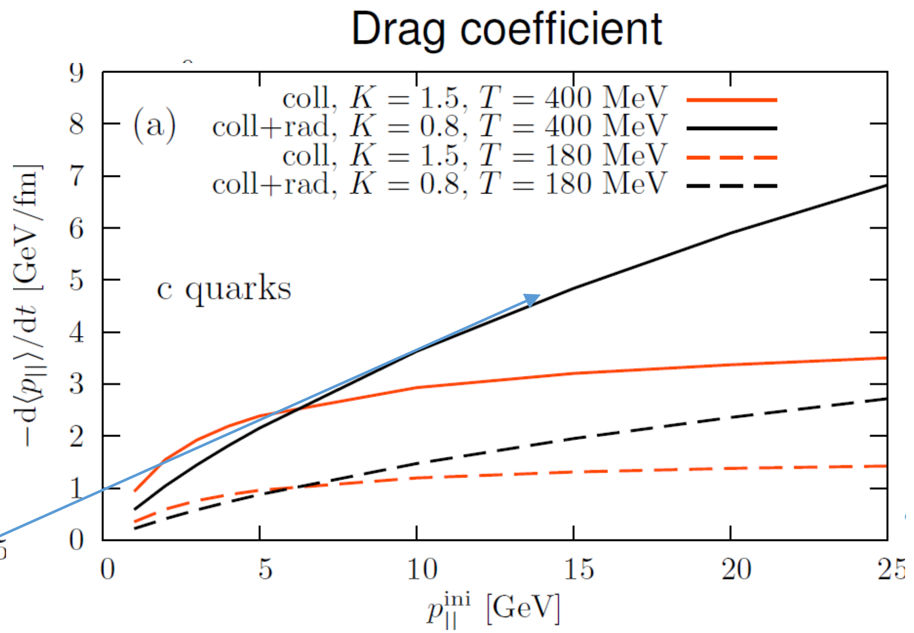


- p_T-distribution in a single scattering: larger $\langle p_T \rangle$ for **coll+rad** ($K = 0.7$).
- Scattering rate is larger for coll ($K = 1.5$)!

Properties of the interaction

arXiv: 1305.3823
1310.2218



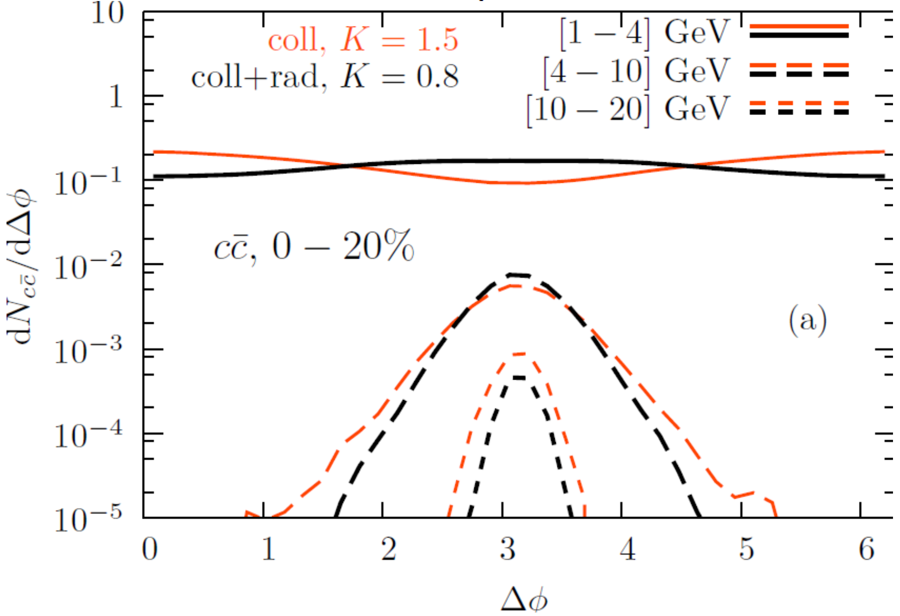


- The purely collisional scatterings lead to a larger average $\langle p_\perp^2 \rangle$ than the **radiative** corrections.
- The final $p_\perp$ also depends indirectly on the drag coefficients.
- The drag coefficients increases faster for the **collisional+radiative** interaction scenario $\Rightarrow$ A quick loss in longitudinal momentum leads to less perpendicular momentum broadening.
- Expectation: Initial correlations will be broadened more effectively in a purely collisional interaction mechanism.

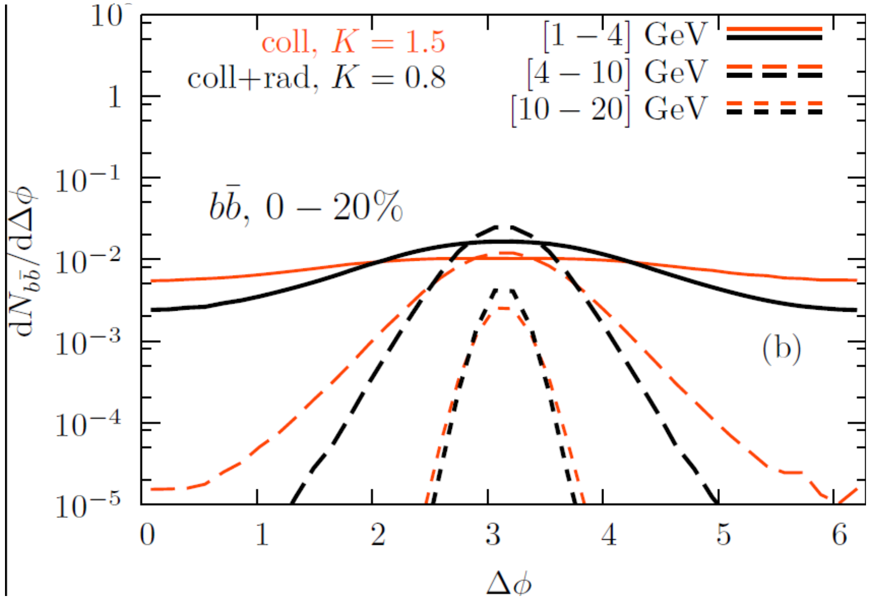
Heavy-quark azimuthal correlations

central collisions, back-to-back initialization, no background from uncorrelated pairs

charm quarks

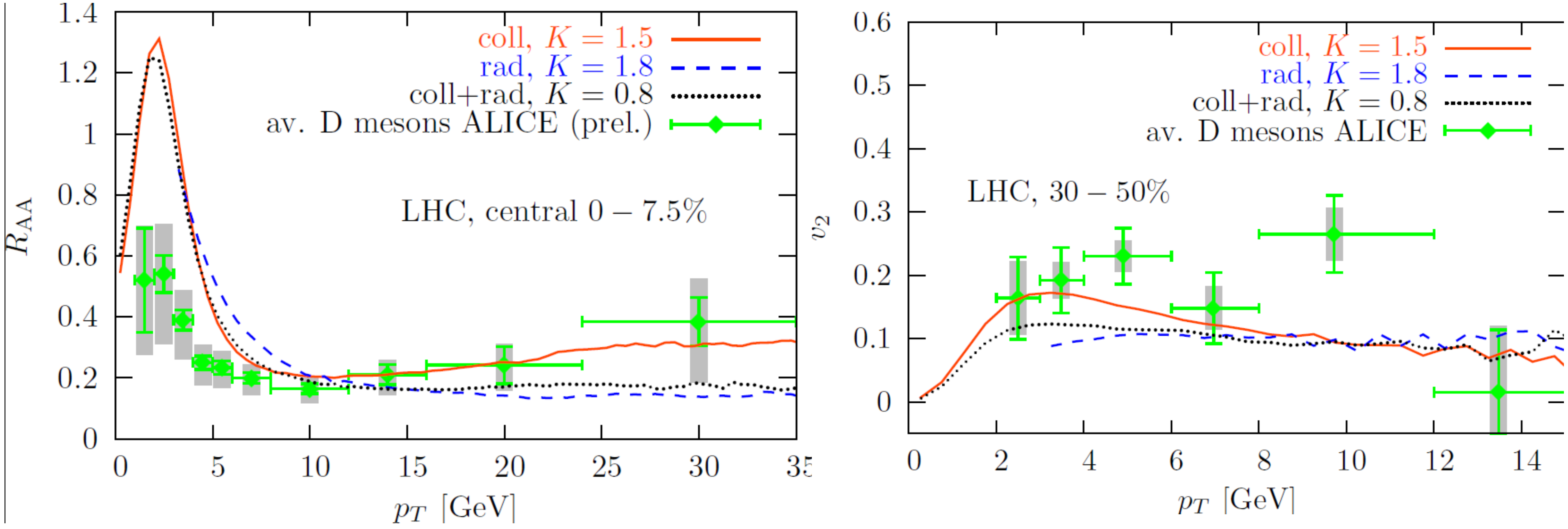


bottom quarks



- Stronger broadening in a purely collisional than in a **collisional+radiative** interaction mechanism
- Variances in the intermediate p_T-range:
  0.18 vs. **0.094** (charm) and 0.28 vs. **0.12** (bottom)
- At low p_T initial correlations are almost washed out: small residual correlations remain for the **collisional+radiative** mechanism, "partonic wind" effect for a purely collisional scenario.
- Initial correlations survive the propagation in the medium at higher p_T.

Unfortunatelly, in an expanding plasma (EPOS event generator) for the known observables the differences are in between the experimental error bars



Three options : Collisions only K factor = 1.5
Collision and radiation K = 0.8
Radiation only K= 1.8

R_{AA} and v_2 for coll and coll + radiat. and radiat. about the same
R_{AA} and v_2 are not a smoking gun for he need of radiation