Gluon radiation by heavy quarks

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Energy loss

- quark and gluon energy loss is a central topic in ultra-relativistic heavy ion collisions
- collisional and radiative
- light quark and heavy quark

Heavy quark transport

- understanding transport of heavy quarks in the medium produced in heavy ion collisions $\rightarrow$ MC@HQ program
- collisional energy loss implemented using pQCD-type $Q - q$ elastic scattering

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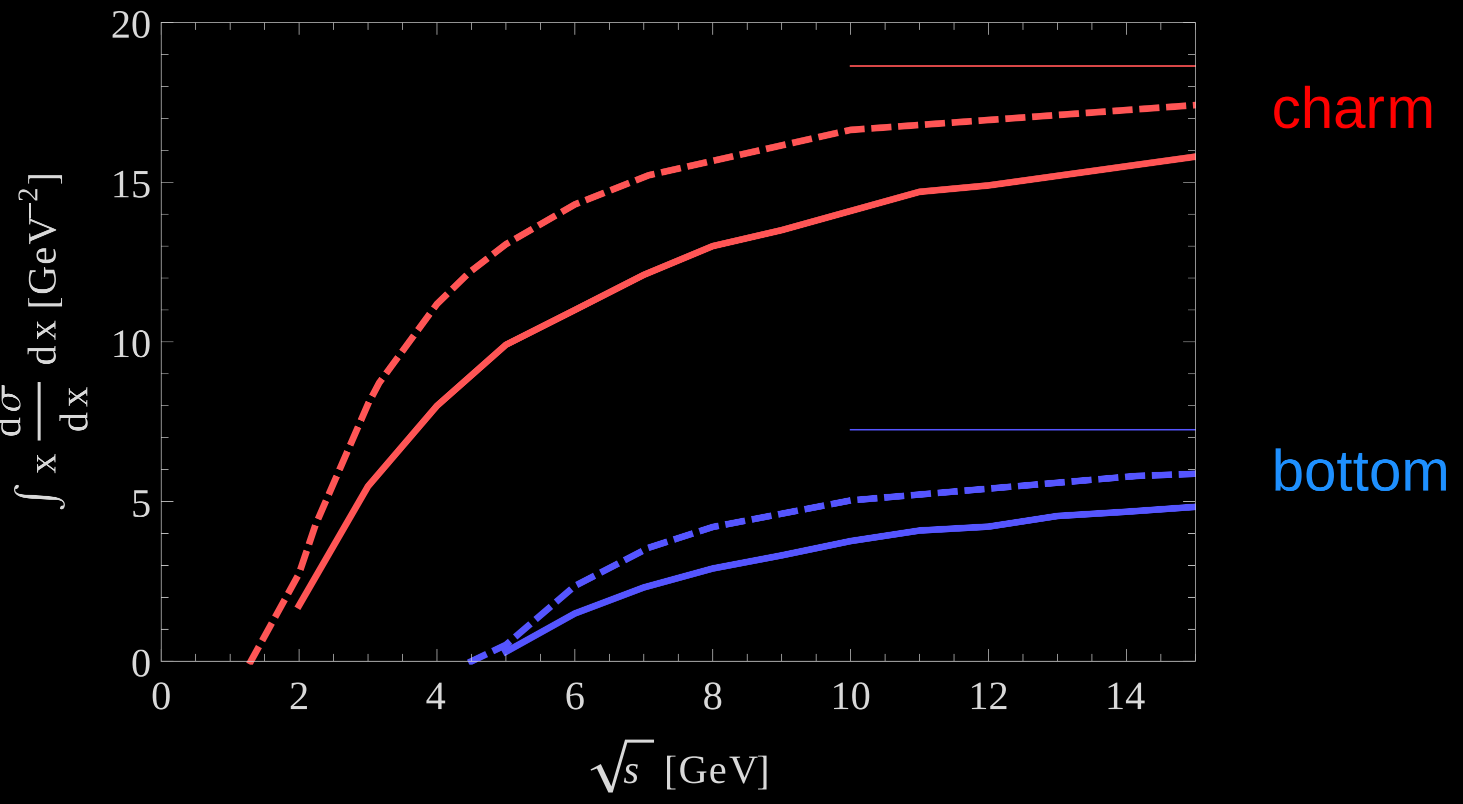
will consider relativistic HQ, but intermediate energy where coherence effects are not dominant

  - extension of the Gunion-Bertsch model to heavy quarks
  - investigating the influence of a finite energy

$$\int x \frac{d\sigma}{dx}\, dx$$

Energy loss
HQ transport
$\int x\, d\sigma$
$x\, d\sigma / dx$
Kinematics
High-energy
Screening
Hard scattering
Soft scattering
Finite energy

Outlook



$$\int x \frac{d\sigma}{dx} dx \sim \frac{1}{\rho E_{\text{beam}}} \frac{dE_{\text{rad}}}{dz}$$

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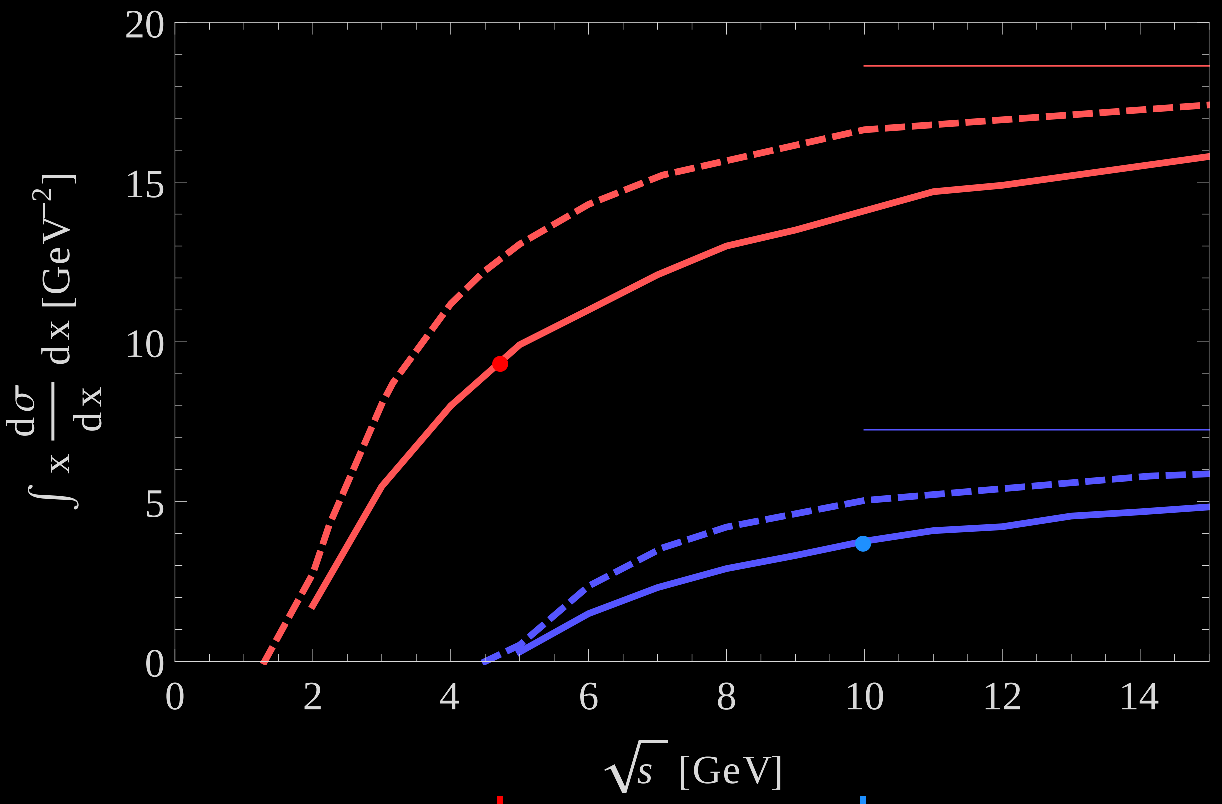
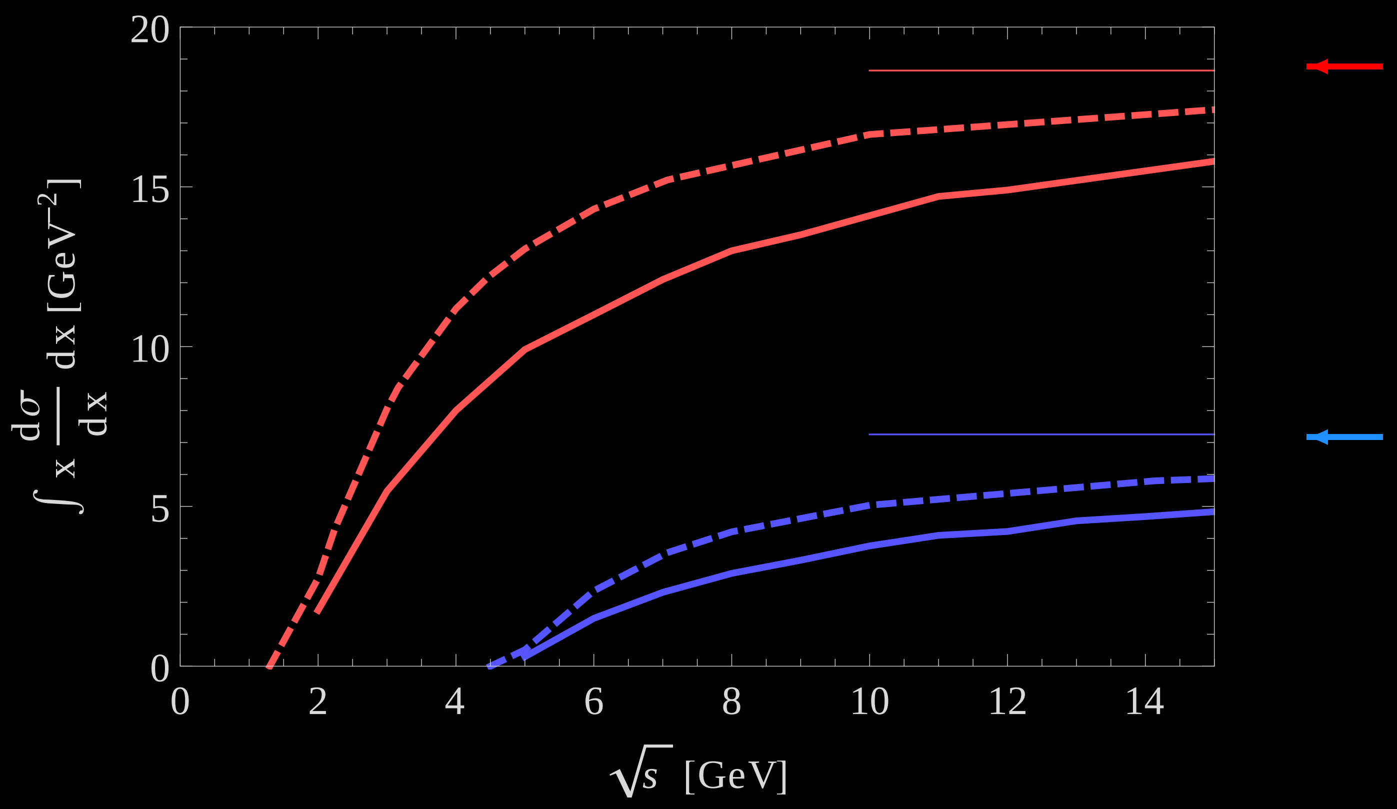


$E_c \sim 10$ GeV

$E_b \sim 40$ GeV

$$\int x \frac{d\sigma}{dx}\, dx$$



asymptotic behavior $\propto \dfrac{1}{\mu\, m_Q}$

- suppression of heavy quark radiation $\propto 1/m_Q$
- sensitivity to the details of screening

$$x\frac{d\sigma}{dx}$$

$\dfrac{1}{\mu\, m_Q} \leftarrow \int x\dfrac{d\sigma}{dx}\,dx$ receives contributions from both below $x_M = \mu/m_Q$ ('hard' collisions) and above ('soft' collisions)

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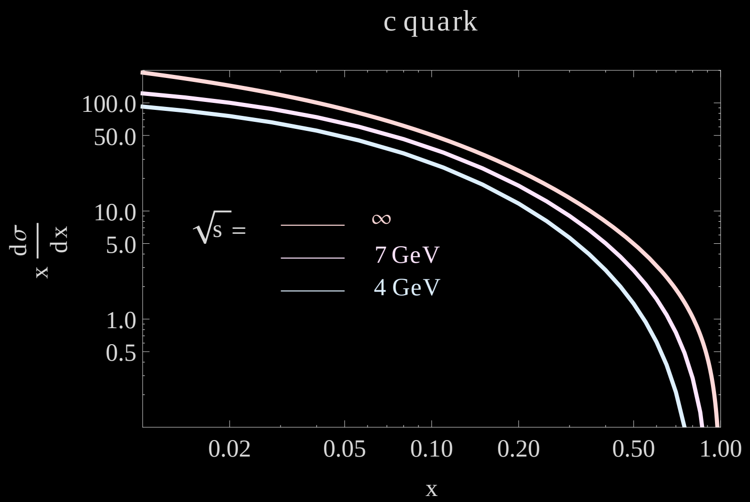

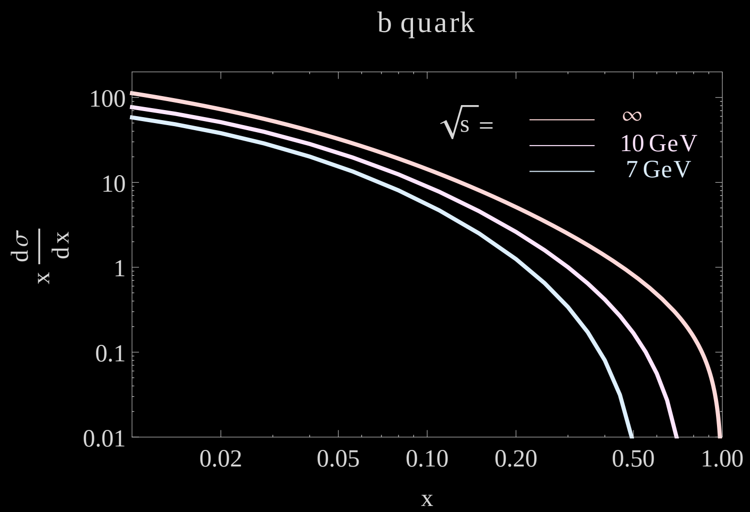

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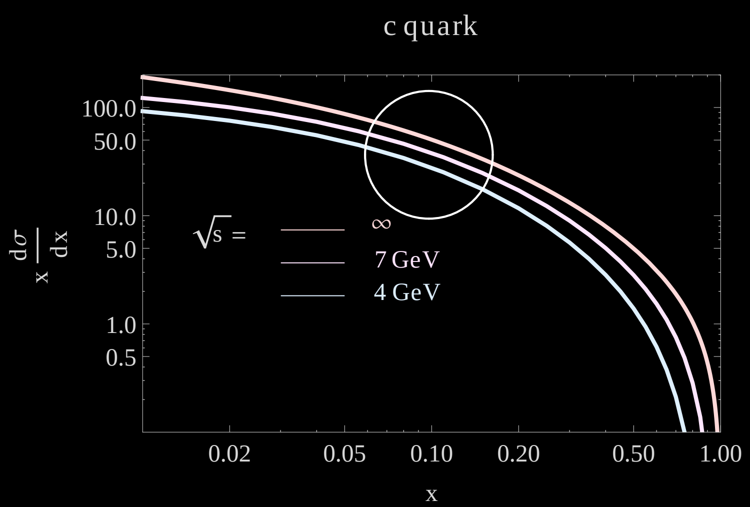

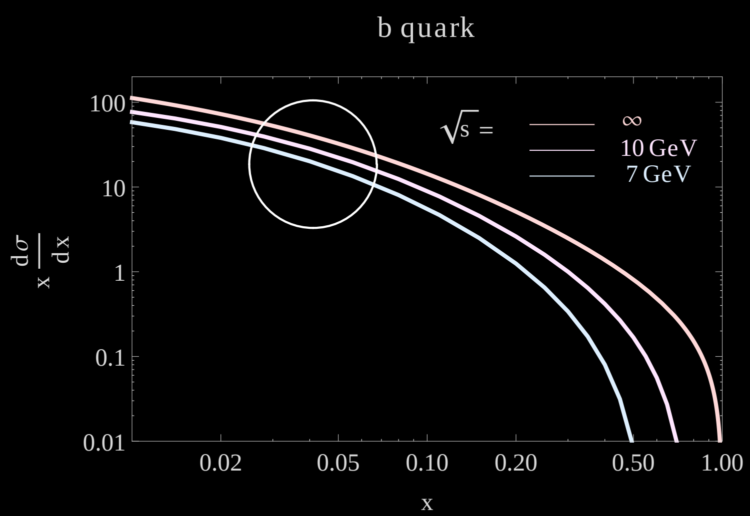

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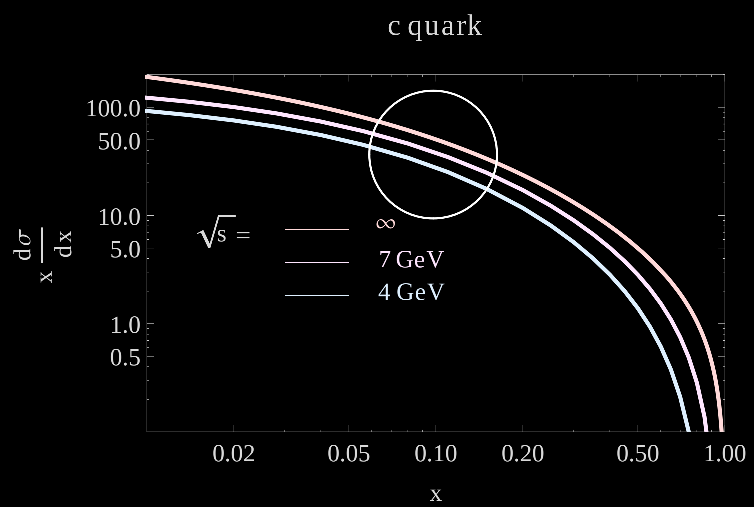
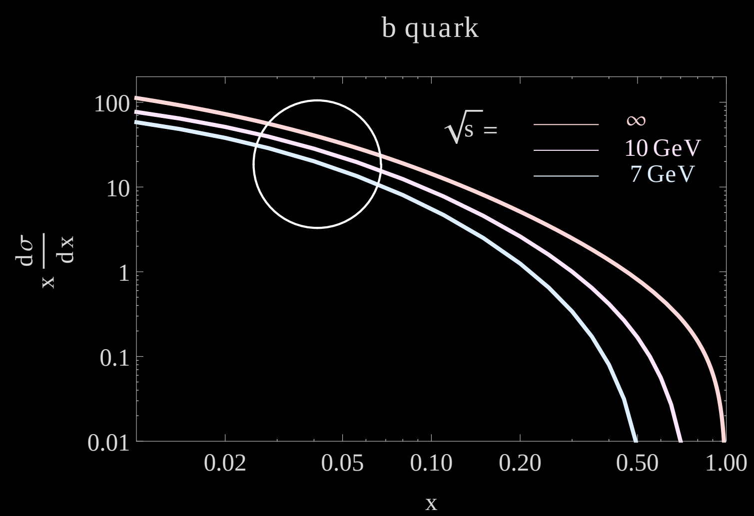
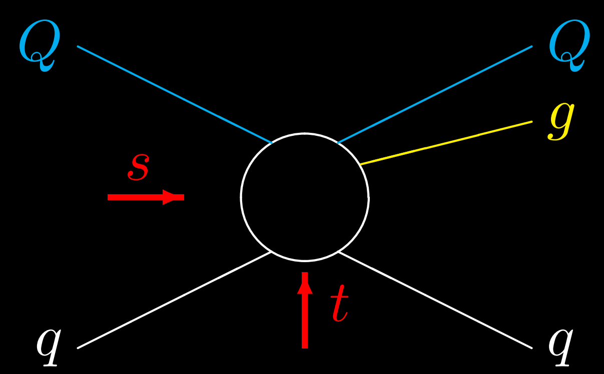




$\longrightarrow$ some details on the origin of radiation

Kinematics



p, q two light-like vectors such that $2\,p\cdot q = s - m_Q^2$

$$Q: \quad P = p + \frac{m_Q^2}{s - m_Q^2} q$$

$$g: \quad k = x\,p + y\,q + \vec{k}_\perp$$

$$q: \quad \text{momentum transfer } q - q' = \ell,\ t = \ell^2$$

High-energy

At large s

$$\frac{d\sigma}{dx\, d^2k_\perp d^2\ell_\perp} \approx \frac{d\sigma_{\rm el}}{d^2\ell_\perp} \times P_g(x, \vec{k}_\perp, \vec{\ell}_\perp)$$

high-energy is when $s - m_Q^2 \gg |t|, \vec{k}_\perp^{\,2}$

where s-dependence disappears from the cross section (either *differential* or *integrated*)

- since $\dfrac{d\sigma_{\rm el}}{d^2\ell_\perp} \propto \dfrac{1}{t^2}$ at large $|t|$
- and $P_g \propto \dfrac{1}{k_\perp^4}$ at large $k_\perp$

Debye screening effect

at small $t \longrightarrow$ will use prescription

$$\frac{d\sigma_{\mathrm{el}}}{d^2\ell_\perp} \propto \frac{1}{t^2} \longrightarrow \frac{1}{(t-\mu^2)^2}$$

with μ related to $m_D \longrightarrow$ natural scale for $\ell_\perp \sim \mu$

$\ell_\perp \gg x\, m_Q$ — hard scattering regime

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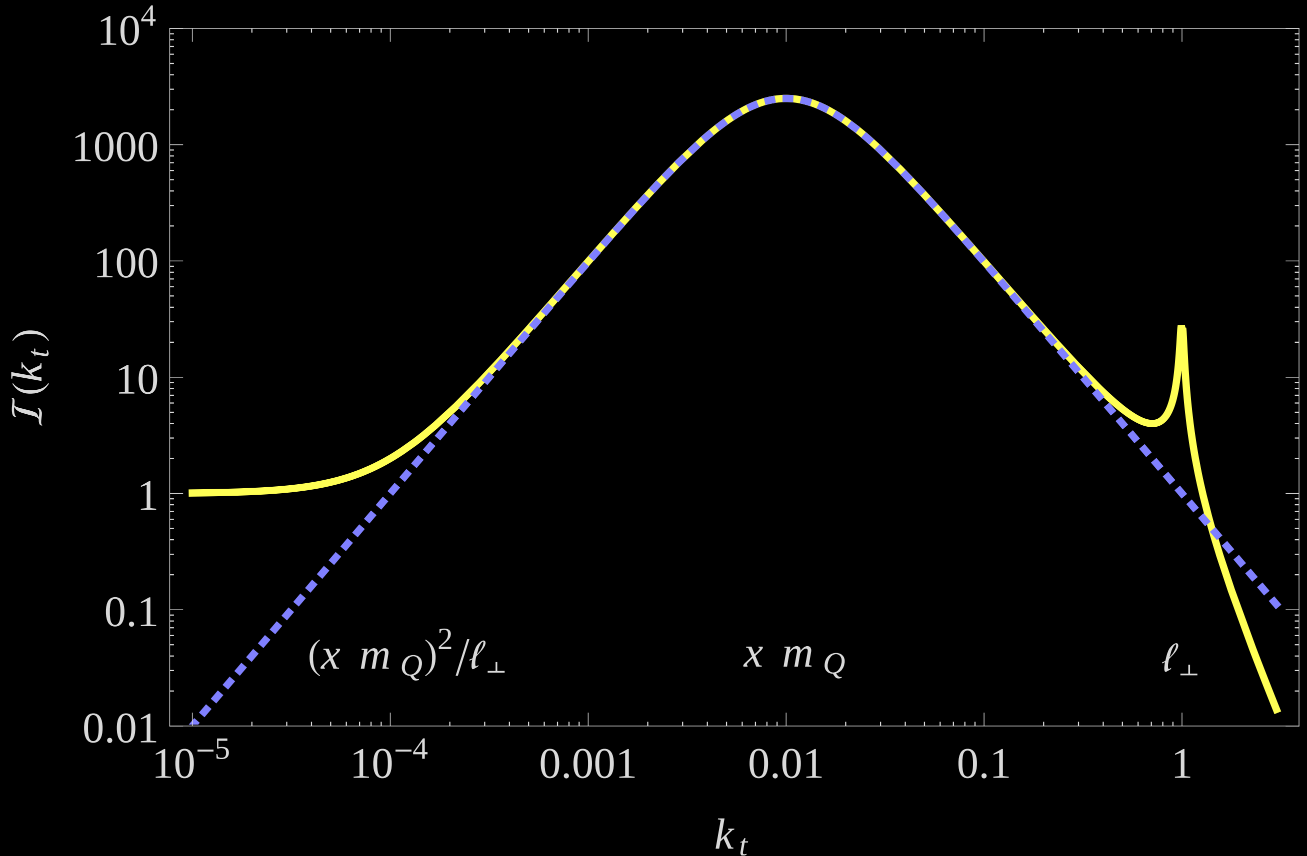
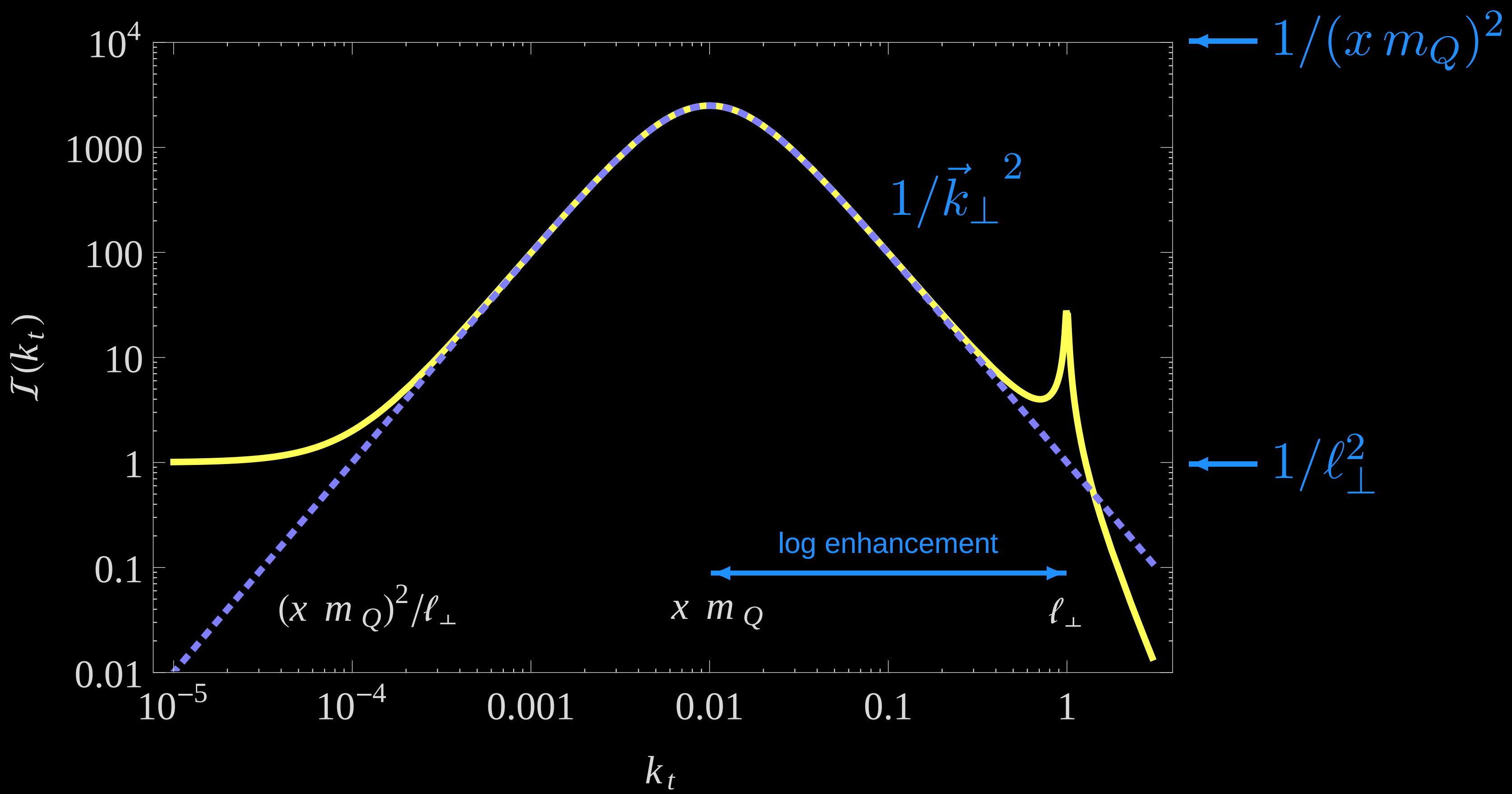


$$P_g \propto \left(\frac{\vec{k}_\perp}{\vec{k}_\perp{}^2 + x^2 m_Q^2} - \frac{\vec{k}_\perp - \vec{\ell}_\perp}{(\vec{k}_\perp - \vec{\ell}_\perp)^2 + x^2 m_Q^2} \right)^2$$

$\ell_\perp \gg x\, m_Q$ — hard scattering regime



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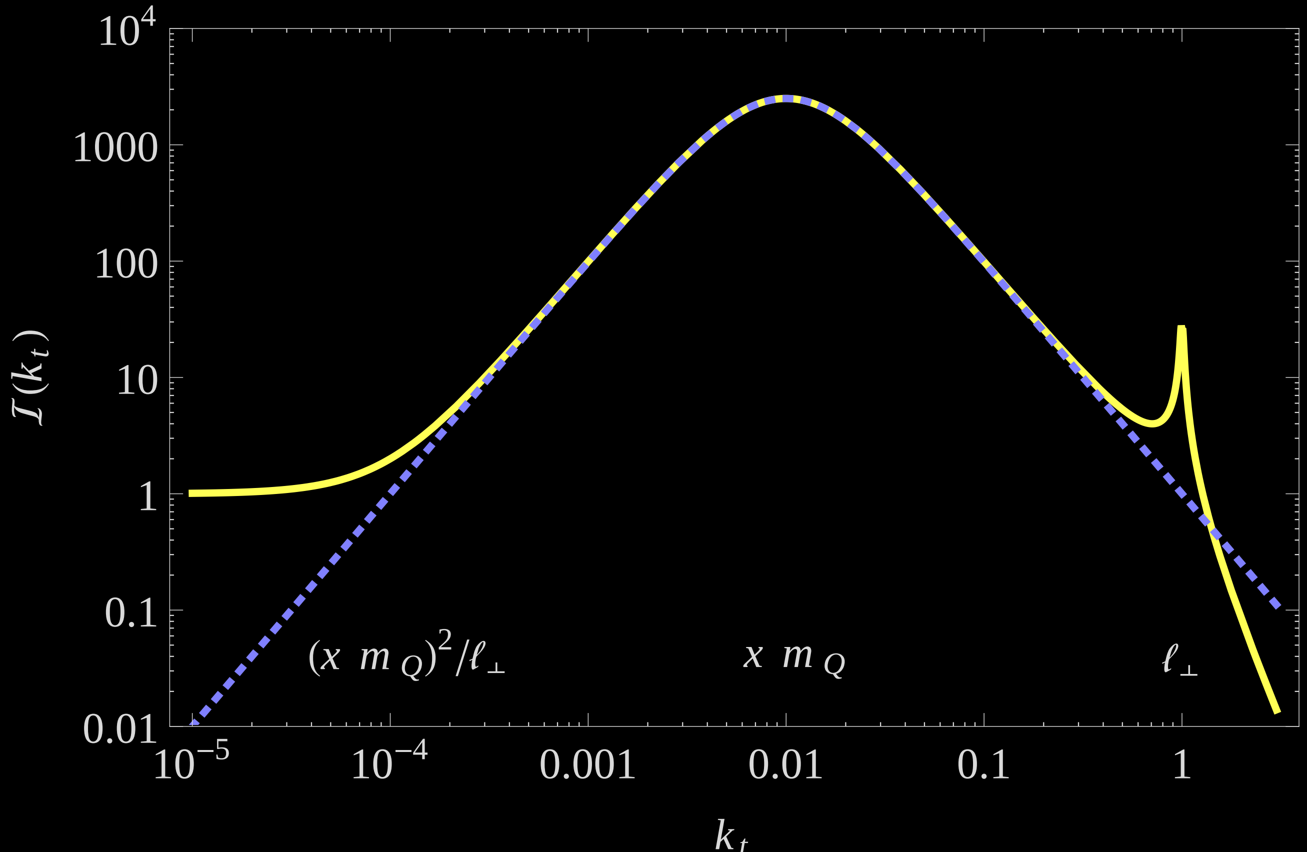
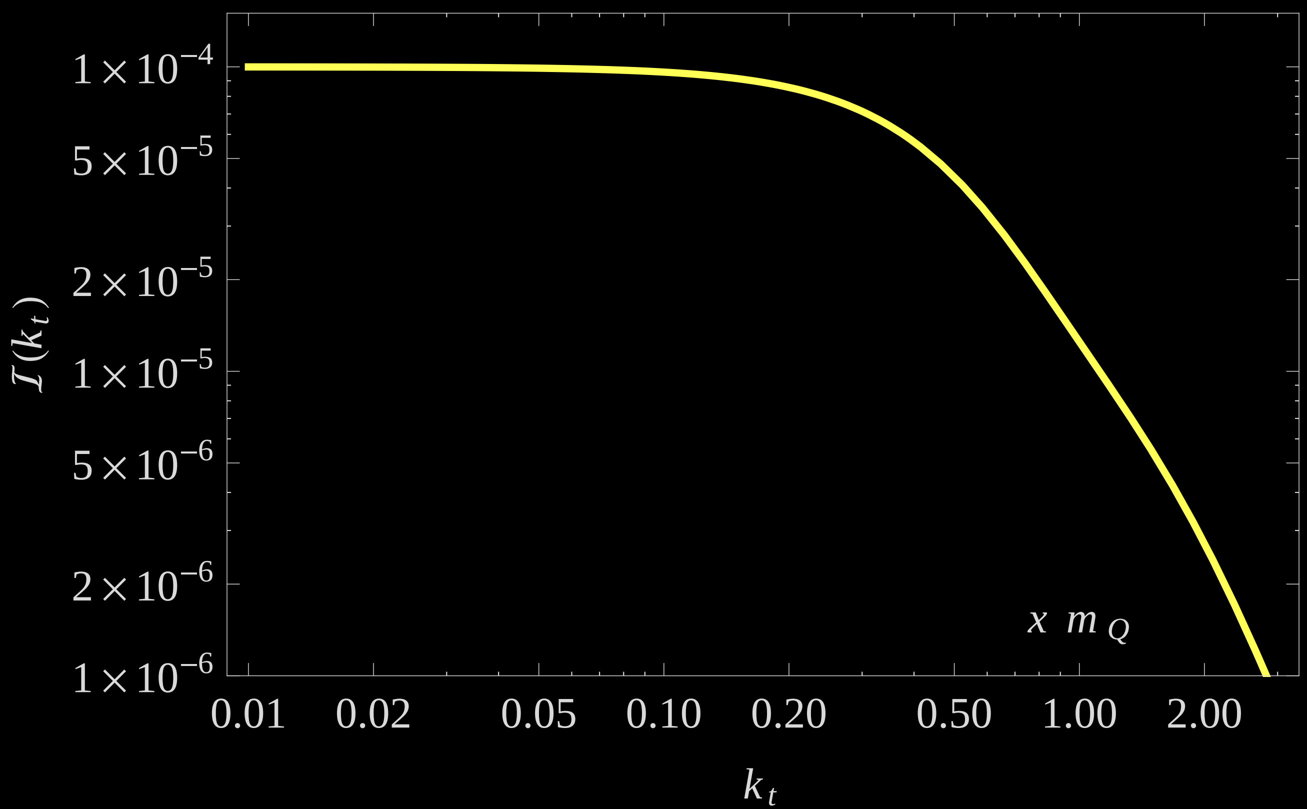


$$\int P_g\, d^2k_\perp \sim \ln \frac{\ell_\perp}{x\, m_Q}$$

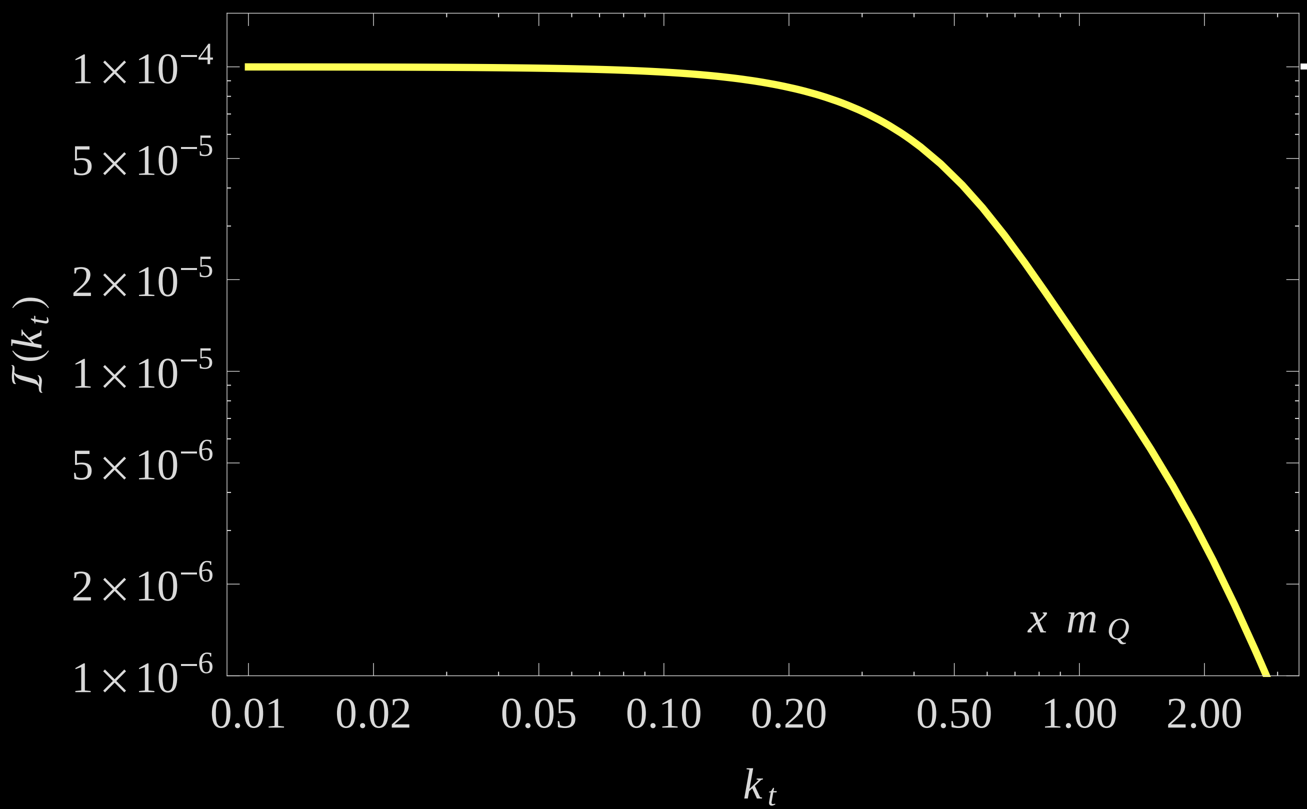
$$\ell_\perp \to \mu : \ x < x_M \equiv \mu/m_Q$$

$\ell_\perp \ll x\, m_Q$ — soft scattering regime



$\longrightarrow$ strong interference

$\ell_\perp \ll x\, m_Q$ — soft scattering regime



$$\frac{\ell_\perp^2}{(x\, m_Q)^2}\,\frac{1}{(x\, m_Q)^2}$$

$$P_g \propto \left(\frac{\vec{k}_\perp}{\vec{k}_\perp{}^2 + x^2 m_Q^2} - \frac{\vec{k}_\perp - \vec{\ell}_\perp}{(\vec{k}_\perp - \vec{\ell}_\perp)^2 + x^2 m_Q^2} \right)^2$$

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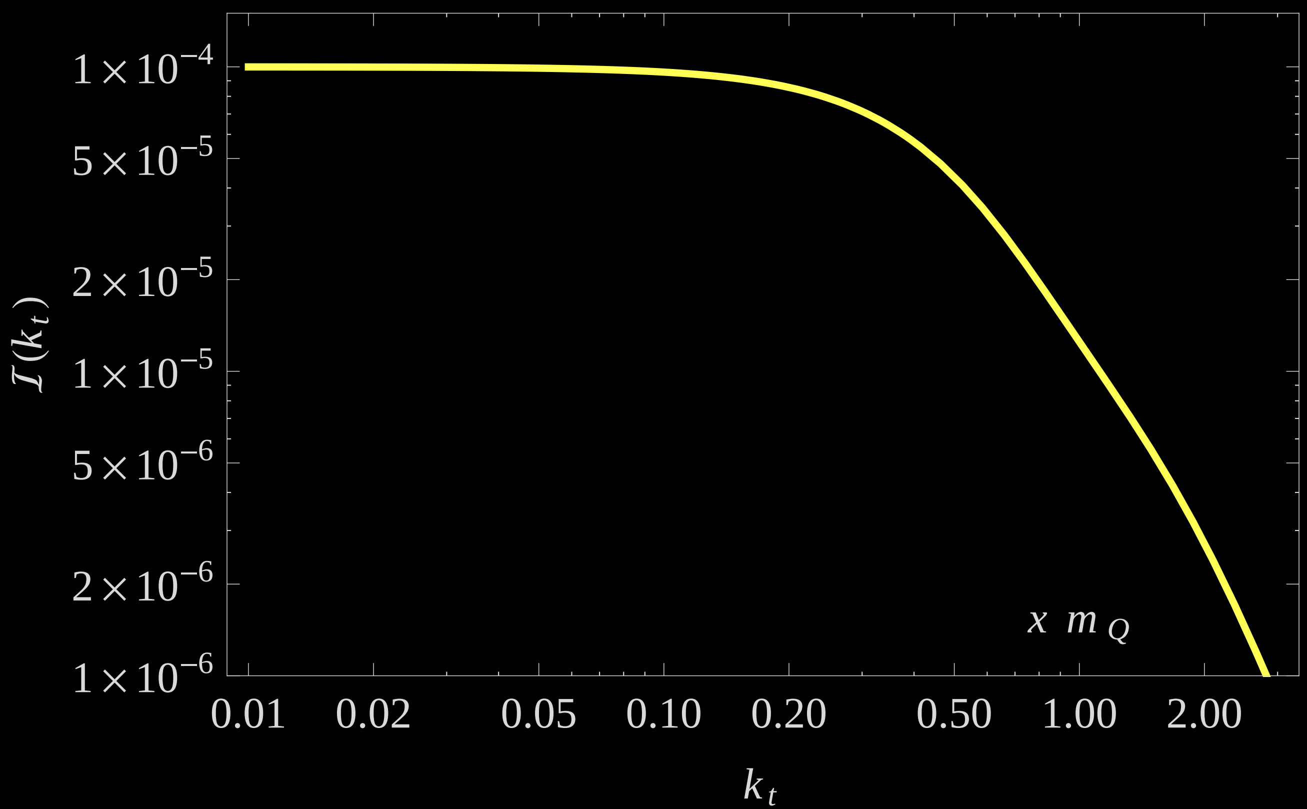

$$\int P_g\, d^2k_\perp \sim \frac{\vec{\ell}_\perp^{\,2}}{x^2\, m_Q^2}$$

$$\ell_\perp \to \mu :\ x > x_M$$

Finite energy

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

$$\mathcal{M} = g\,C_3\left(\frac{-2\,g^2\,(s-m_Q^2)}{t^2}\right) \times\vec{\epsilon}_t\cdot\left(\frac{(2(1-x)-x')\vec{k}_\perp}{\vec{k}_\perp{}^2+x^2m_Q^2}-\frac{2(1-x-x')(\vec{k}_\perp-\vec{\ell}_\perp)}{(\vec{k}_\perp-\vec{\ell}_\perp)^2+(x+x')^2m_Q^2}\right)$$

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$x' \equiv x'(x, \vec{k}_\perp, \vec{\ell}_\perp)$ momentum fraction of the outgoing light quark

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$x' \to 0$ at high-energy

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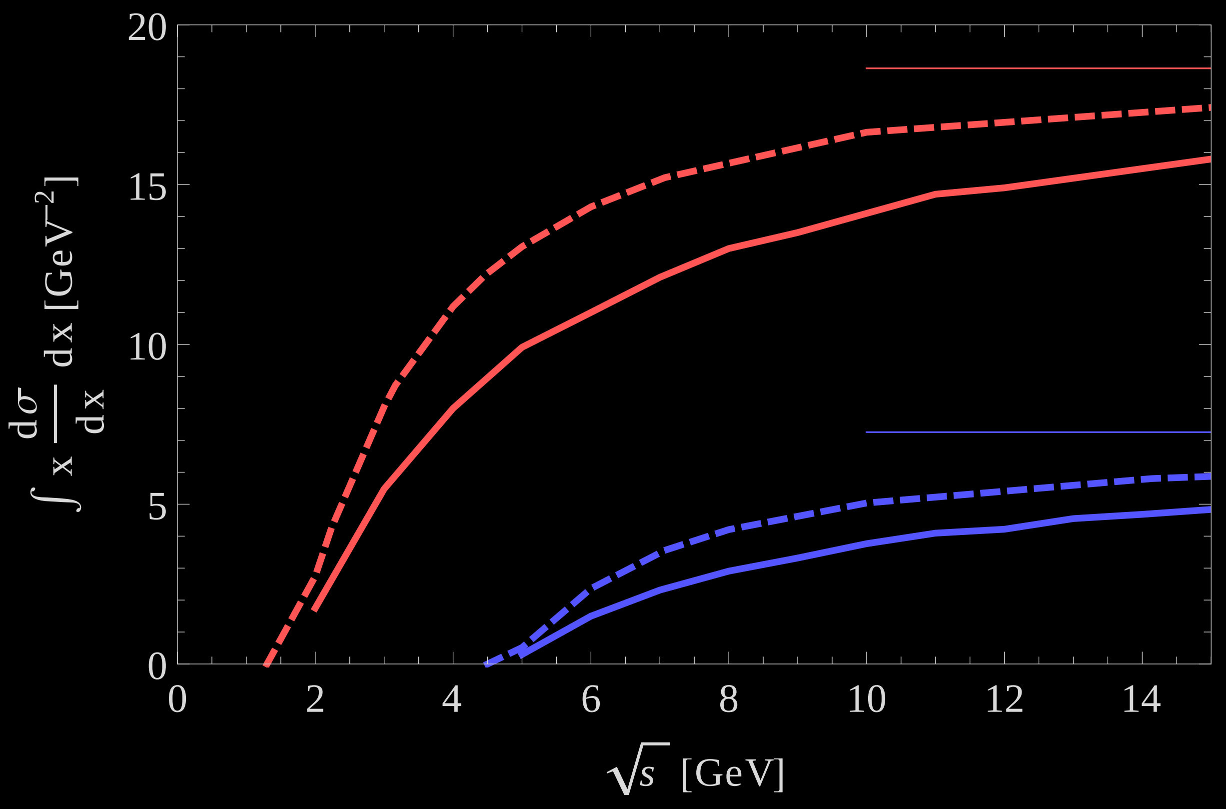
compact expression but numerical integration needed



Outlook

- Gluon radiation by HQ in the Bethe-Heitler regime, at large and intermediate energies

- Coherence effects to be investigated

$\rightarrow$ embedding in MC@HQ generator $\rightarrow$ talk of Pol Gossiaux on friday afternoon