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Medium-Modified Fragmentation Functions

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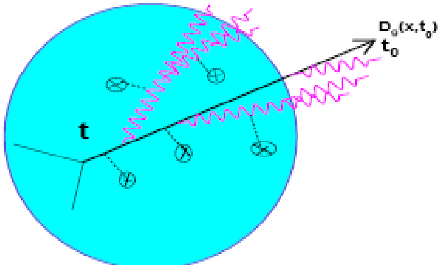
Outline

- Medium induced gluon radiation
- Medium modified splitting functions
- Medium modified Sudakov form factor
- Medium modified fragmentation functions
- Nuclear modification factor
- Conclusions

Medium induced gluon radiation

- A hard parton produced in the early stage of Heavy Ion Collisions travels through the hot and dense QCD matter. The scattering centers induce successive gluon radiations.
- The hard parton looses virtuality from the initial scale t to the final hadronization one $t_0 \simeq \lambda^2_{QCD}$ Hadronization happens outside the medium.



- Medium induced gluon radiation is the standard explanation for Jet Quenching observed at RHIC.

- The single inclusive distribution of medium induce gluons with energy ω and transverse momentum k_t from a parent parton of energy E:

$$\omega\frac{dI}{d\omega dk_T} = \frac{\alpha_S C_R}{(2\pi)^2\omega^2} 2Re \int_0^\infty dy_l \int_{y_l}^\infty d\bar{y_l} du e^{-ik_T u} e^{-\frac{1}{2}\int_{\bar{yl}}^\infty d\zeta n(\zeta)\sigma(u)}$$
$$\frac{\partial}{\partial y}\frac{\partial}{\partial u}\int_{y=0=r(y_l)}^{u=r(\bar{y_l})} \mathcal{D}r e^{i\int_{y_l}^{\bar{y_l}} d\zeta \frac{\omega}{2}\left(\dot{r}^2 - \frac{n(\zeta)\sigma(r)}{i\omega}\right)}$$

- Two approximations
  - ✓ Opacity expansion, in powers of $n(\zeta)\sigma(\zeta)$.
  - ✓ multiple soft scattering: $n(\zeta)\sigma(r) \simeq \frac{1}{2}\hat{q}(\zeta)r^2$, the path integral is one of a harmonic oscillator.
    - $\hat{q}(\zeta)$ is the transport coefficient, $< q_T^2 > / \lambda$
    - The $\omega\frac{dI}{d\omega dk_T} \longrightarrow F(\frac{\omega}{\omega_c}, \kappa^2)$, $\omega_C = \frac{1}{2}\hat{q}L^2$, $\kappa^2 = \frac{k_T^2}{\hat{q}L}$

Previous MMFF calculations

- A Poissonian distribution of independent radiations was assumed by BDMPS

$$P_E(\epsilon) = \sum_{n=0}^{\infty} \frac{1}{n!}[\prod_{i=1}^{n} \int d\omega_i \frac{d((\omega_i))}{d\omega}]\delta(\epsilon - \sum_{i=1}^{n} \frac{\omega_i}{E})e^{-\int d\omega \frac{dI}{d\omega}}$$

- The MMFF were calculated shifting the vacuum ones

$$D_{kh}^{(med)}(z, Q^2) = \int_0^1 d\epsilon P_E(\epsilon) \frac{1}{1-\epsilon} D_k(\frac{z}{1-\epsilon}, Q^2)$$

- Limitations
  - ✓ The energy and momentum are not conserved
  - ✓ There is no evolution in virtuality
  - ✓ The medium and vacuum are treated differently

Now Medium modified splitting functions

- The total medium-induced gluon radiation spectrum:

$$\omega \frac{dI}{d\omega\, d\mathbf{k}_\perp} = \omega \frac{dI^{\text{vac}}}{d\omega\, d\mathbf{k}_\perp} + \omega \frac{dI^{\text{med}}}{d\omega\, d\mathbf{k}_\perp}$$

- The vacuum case $\frac{dI^{vac}}{dz dk_T^2} = \frac{\alpha_s P(z)^{vac}_{z\longrightarrow 1}}{2\pi k_T^2}$, $P(z)^{vac}_{z\longrightarrow 1} \simeq \frac{2C_R}{1-z}$, $z = 1 - x$

- The ansatz is an extension of the former vacuum one to medium case: Salgado and Polosa (hep-ph/0607295)

$$\frac{dI}{dz dk_T^2}^{MED} = \frac{\alpha_s P(z)^{MED}_{z\longrightarrow 1}}{2\pi k_T^2} , P(z)^{med}_{z\longrightarrow 1} = \frac{2\pi z t}{\hat{q}L} F(\frac{\omega}{\omega_c}, \kappa^2)$$

- The total splitting distribution is assumed to be the vacuum+medium ones:

$$P^{TOTAL}(z) = P^{VACUUM}(z) + P^{MEDIUM}(z)$$

Sudakov form factor

- The sudakov factor

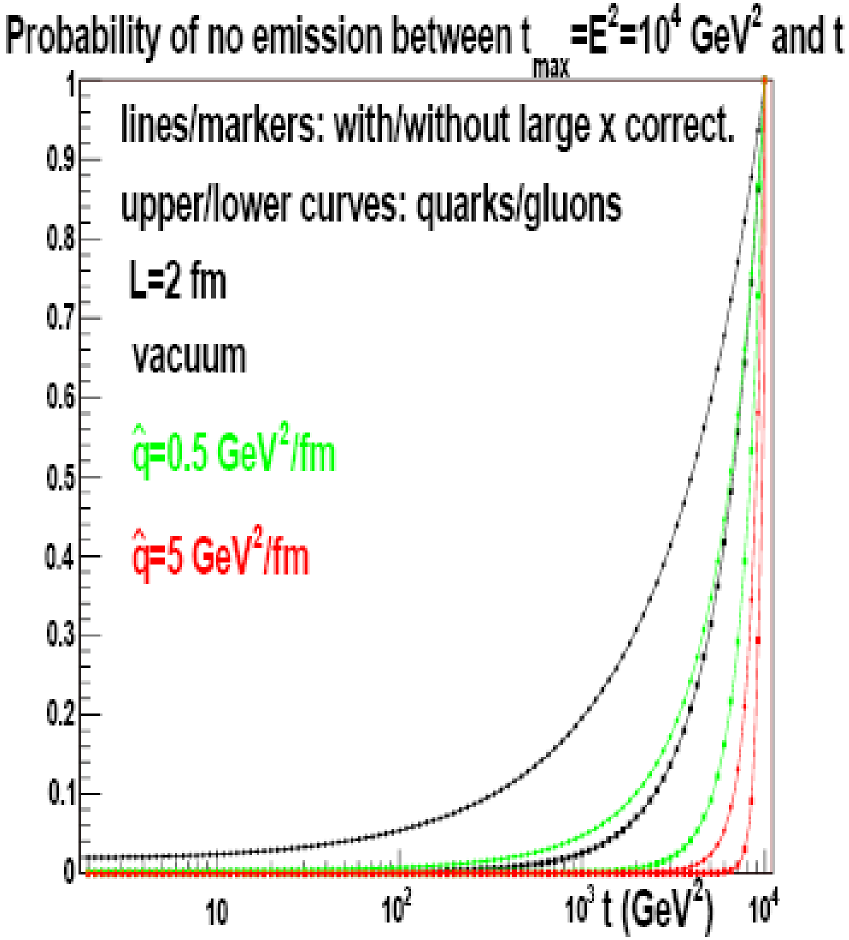
$$\Delta_a(t, t_0^a) = e^{-\sum_{a-cc'} \int_{t_0^a}^{t} \frac{dt'}{t'} \int_{z_{min}(t')}^{1-z_{min}(t')} dz \frac{\alpha_S(t',z)}{2\pi} P_{ca}(z)}$$

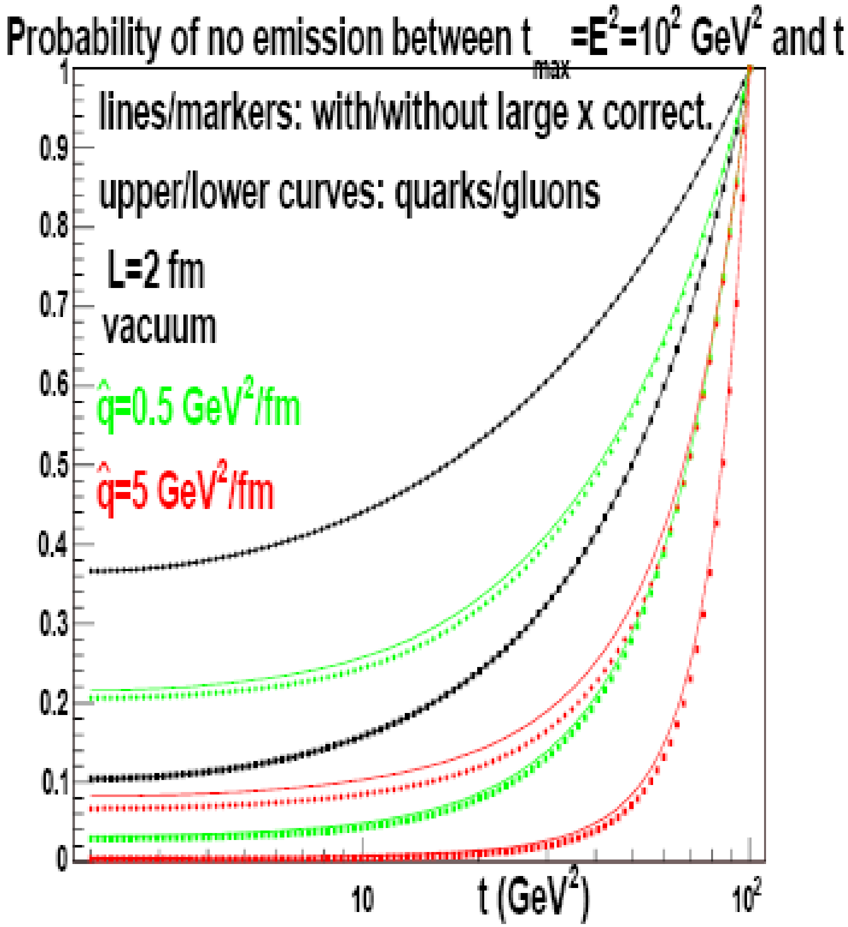
- $\Delta_a(t, t_0^a)$ means the probability for a parton not to branch while evolving from an initial virtuality t to a final scale t_0

- We modify the sudakov factor:

$$\Delta_a(t, t_0^a) = e^{-\sum_{a-cc'} \int_{t_0^a}^{t} \frac{dt'}{t'} \int_{z_{min}(t')}^{1-z_{min}(t')} dz \frac{\alpha_S(t',z)}{2\pi} (P_{ca}(z)^{vac} + P_{ca}(z)^{med})}$$

Medium modified sudakov factor





Medium modified fragmentation functions

- DGLAP evolution equation can be written in terms of the sudakovs:

$$t\frac{\partial}{\partial t}\left(\frac{D_a^h(x,t)}{\Delta_a(t,t_0^a)}\right) = \int_x^{1-z_{min}(t)} \frac{dz}{z}\frac{\alpha_S(k_T^2,z)}{2\pi}P_{ba}(z)\frac{D_b^h(\frac{x}{z},t)}{\Delta_a(t,t_0^a)}$$

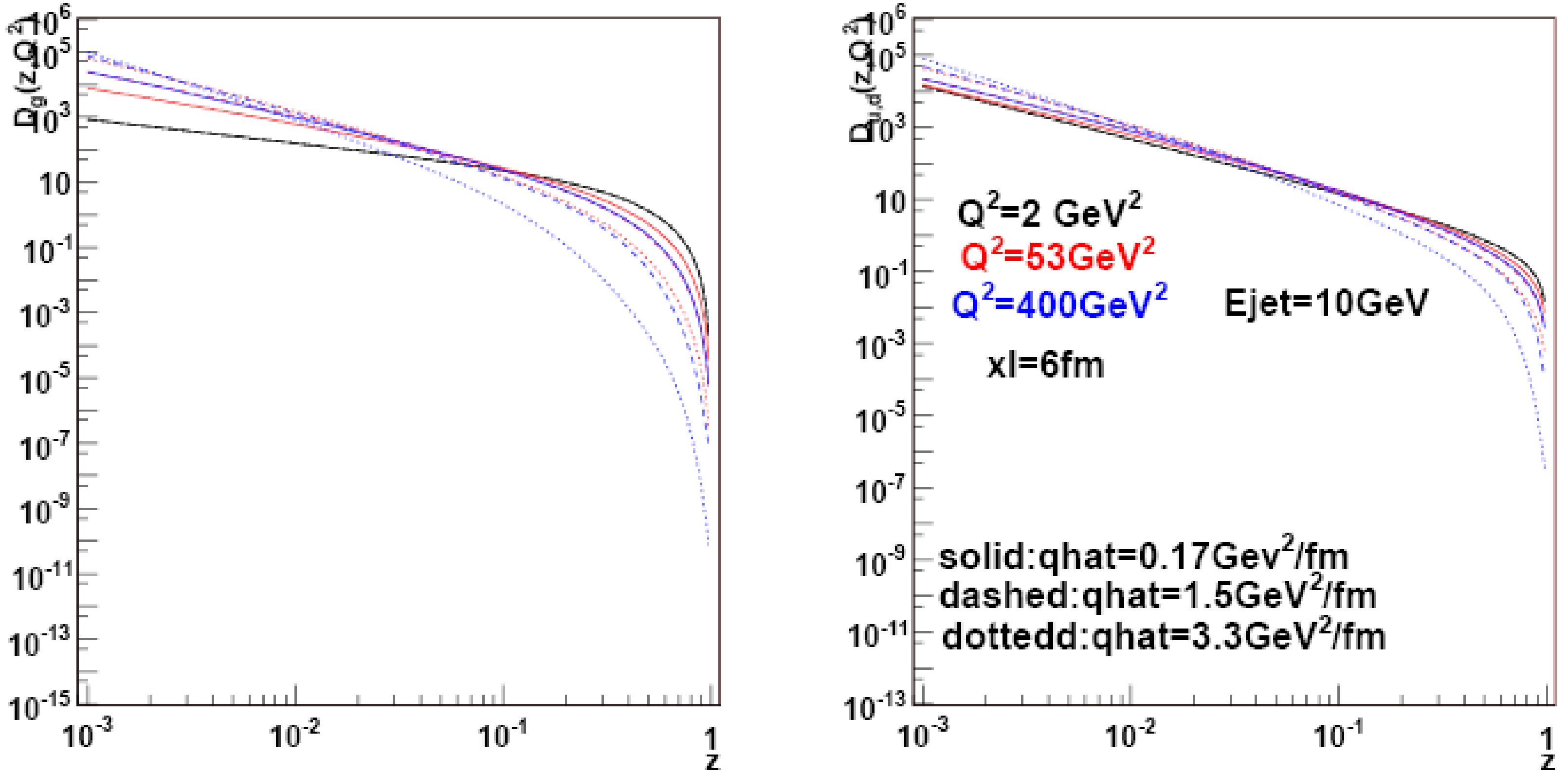
- The renormalization scale is $t(1-z)z = k_T^2$

- The initial values for the FF we take the KKP ones at virtuality t

- For each parton energy, $t_0 = 2GeV^2$ $t_0 < t < 4E^2$ and $t_0/t < z(t) < 1 - t_0/t$

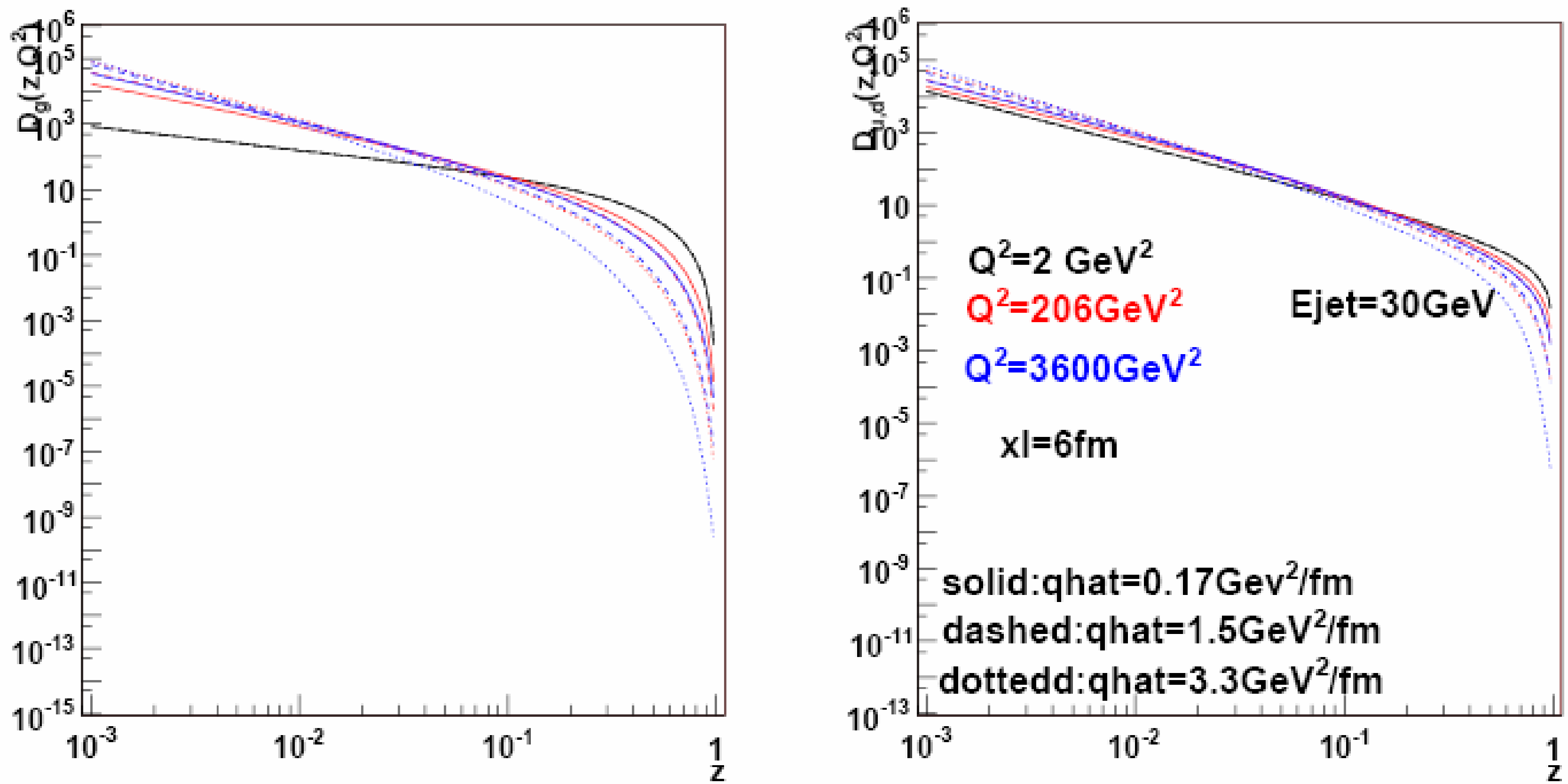
- Our evolution depends on the initial parton energy through the scale range in the Sudakov.

Medium modified fragmentation functions



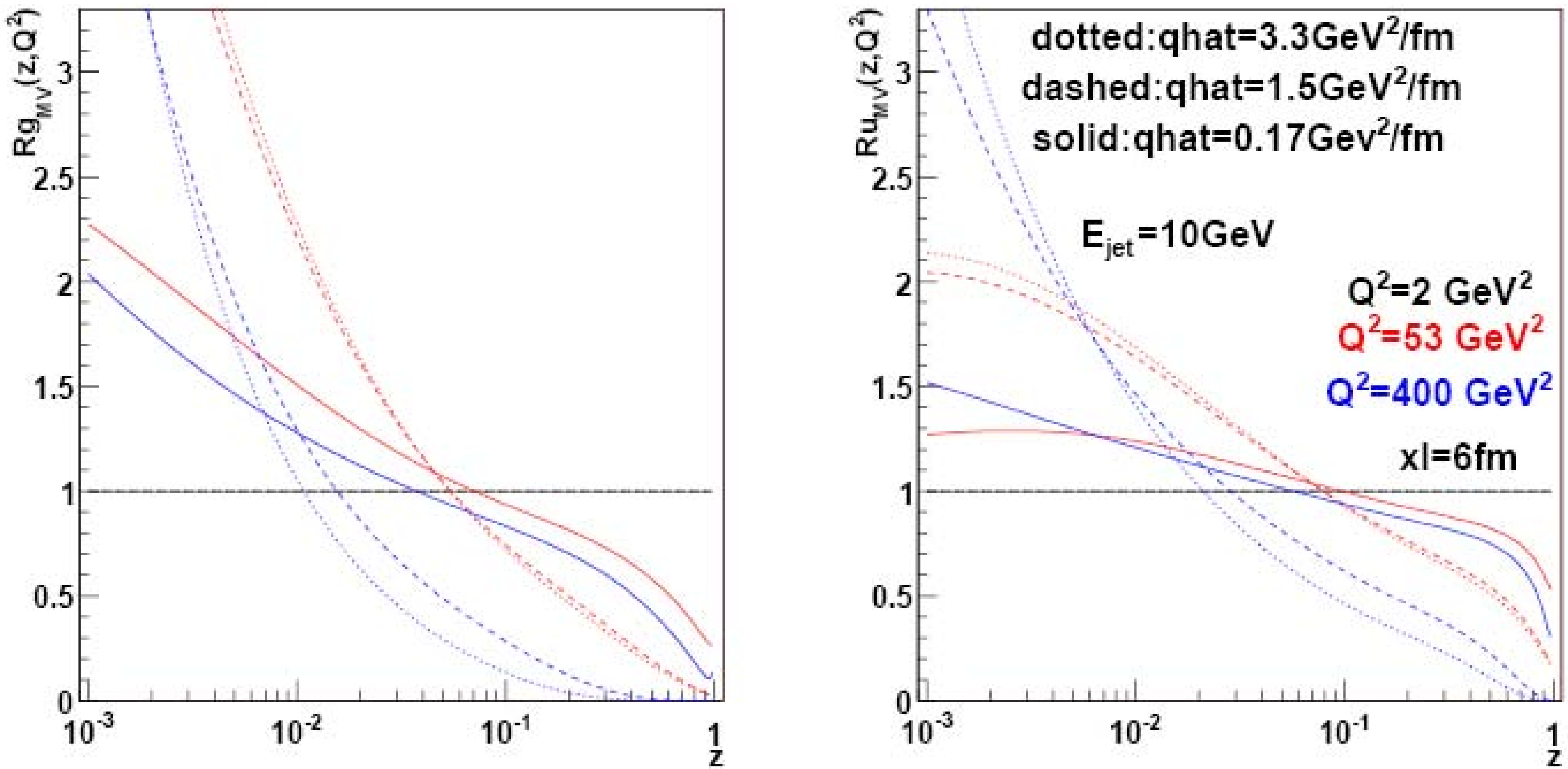
Fragmentation functions for different medium densities for E_jet=10 GeV

Medium modified fragmentation functions



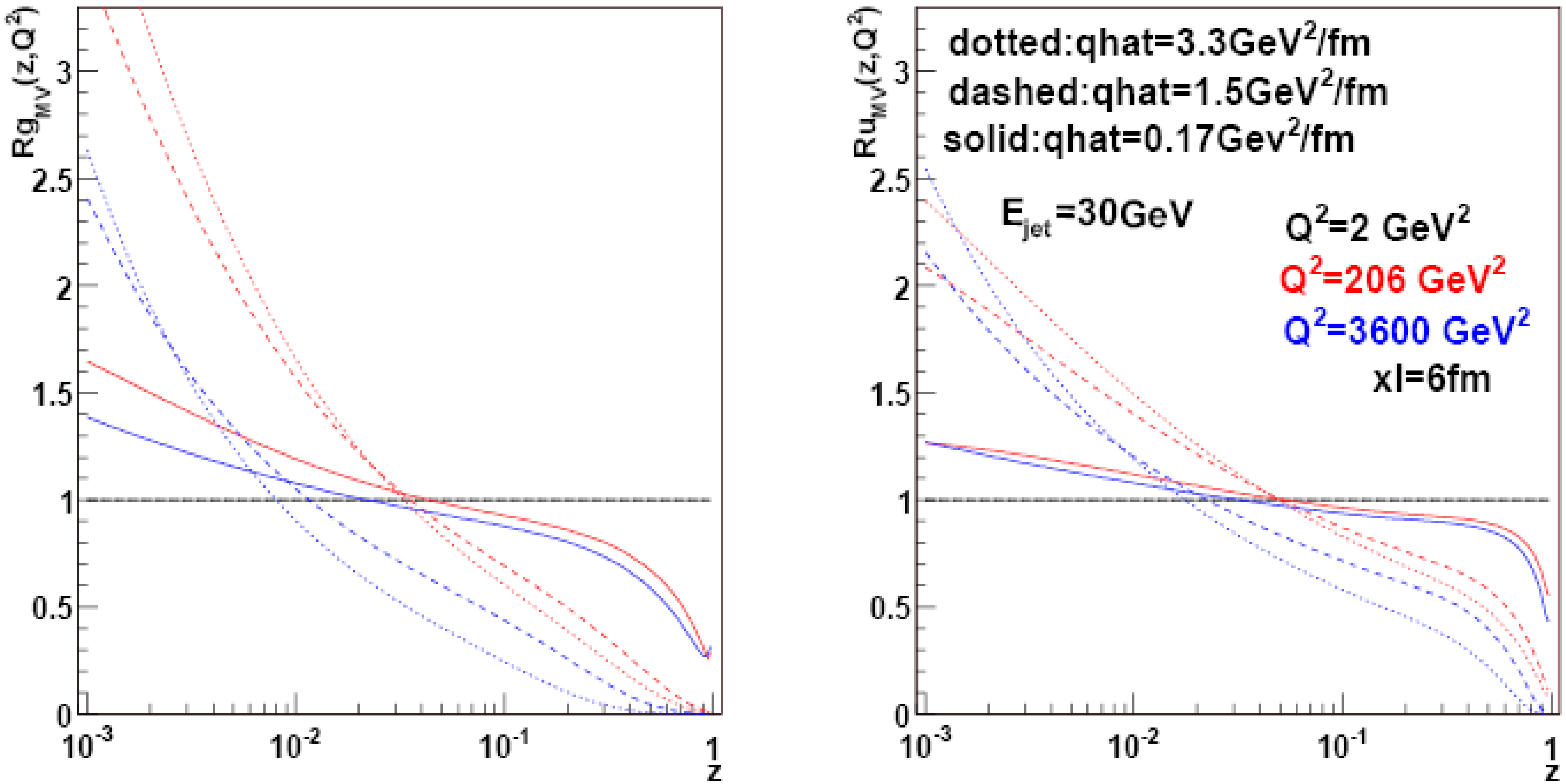
Fragmentation functions for different medium densities for E_jet=30 GeV

Medium modified fragmentation functions



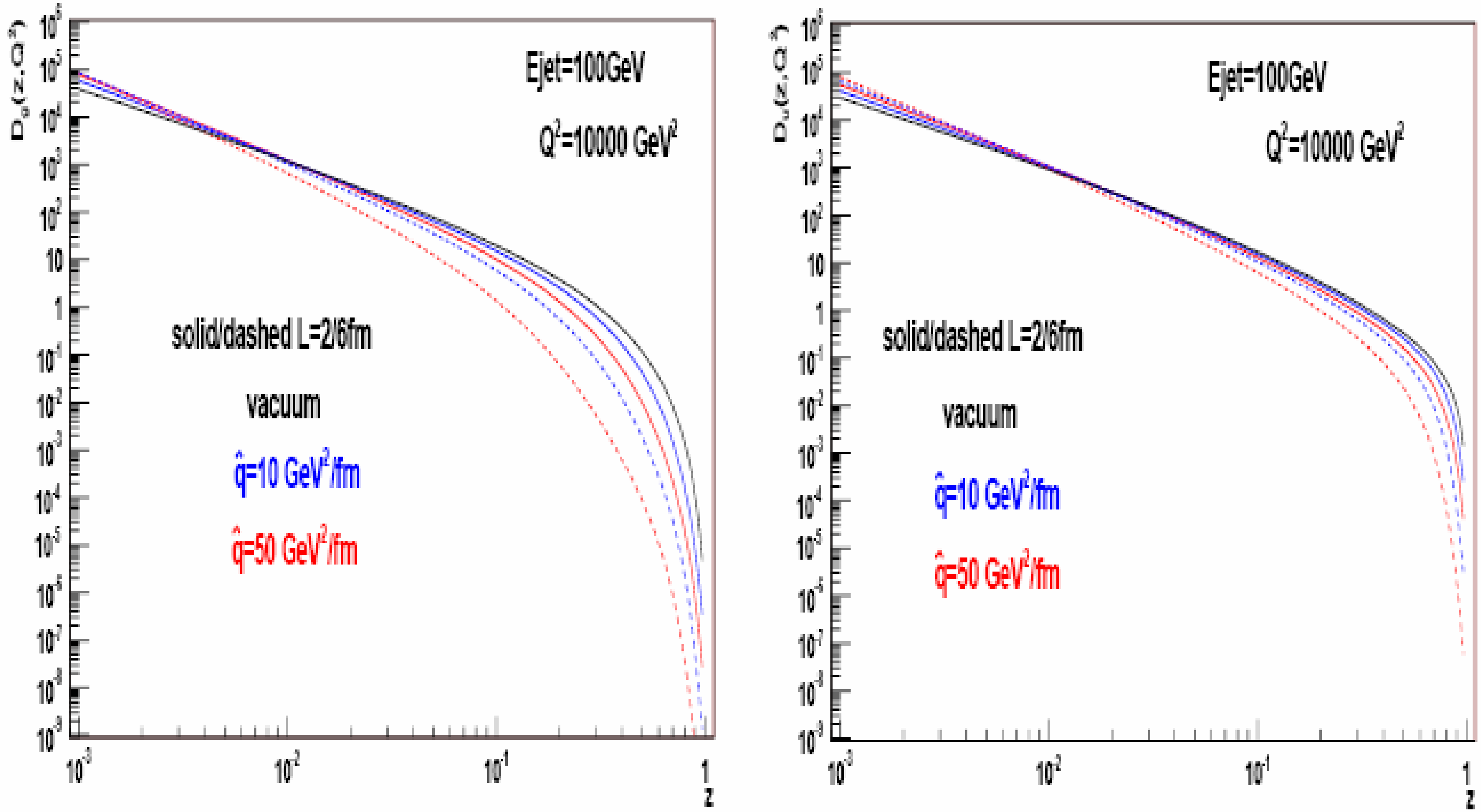
Ratio Medium/Vacuum of the fragmentation functions for E_jet=10 GeV

Medium modified fragmentation functions

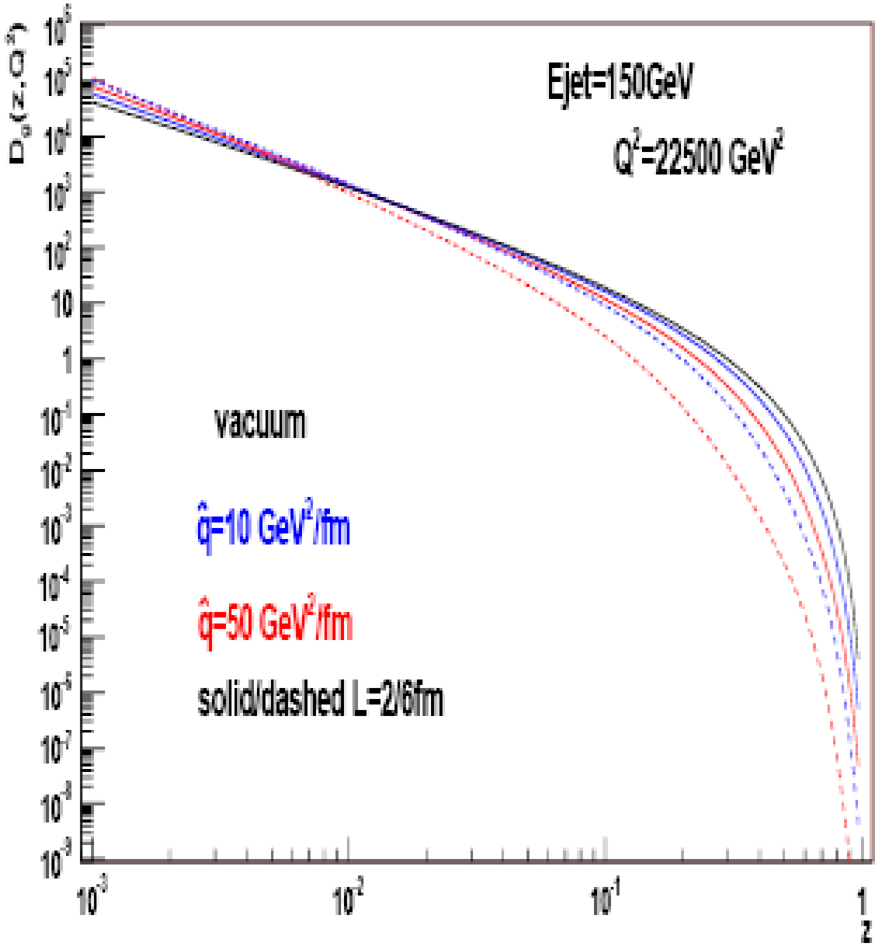


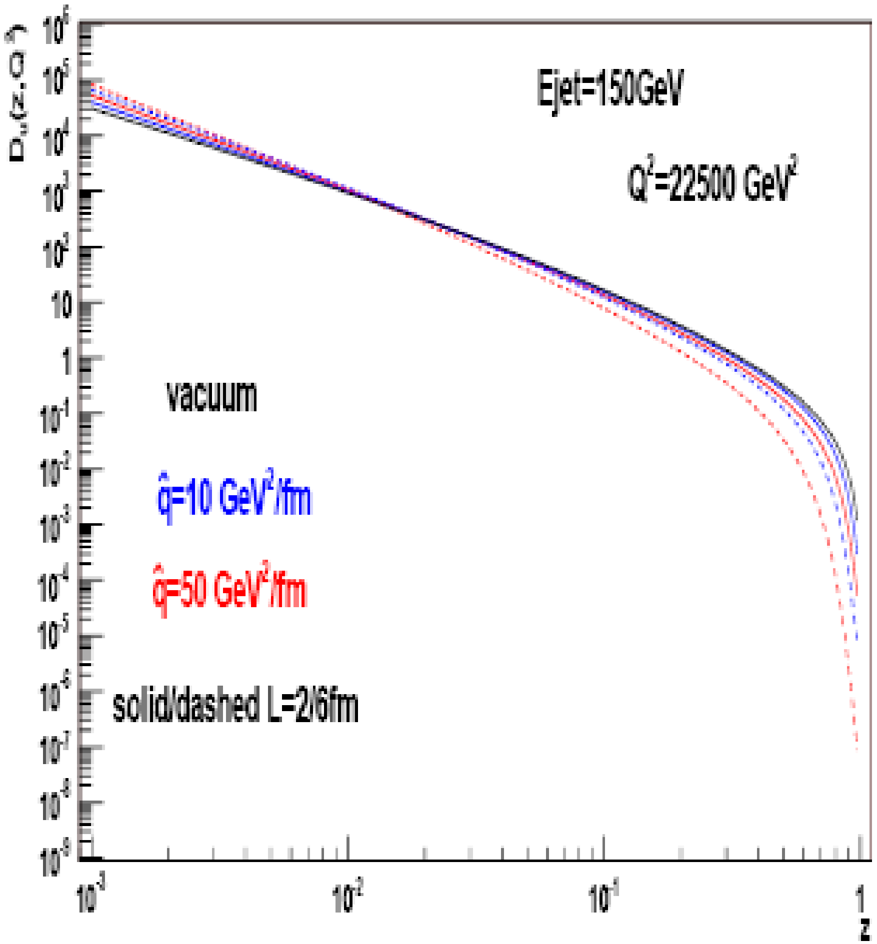
Ratio Medium/Vacuum of the fragmentation functions for E_jet=30 GeV

Medium modified fragmentation functions: LHC energy

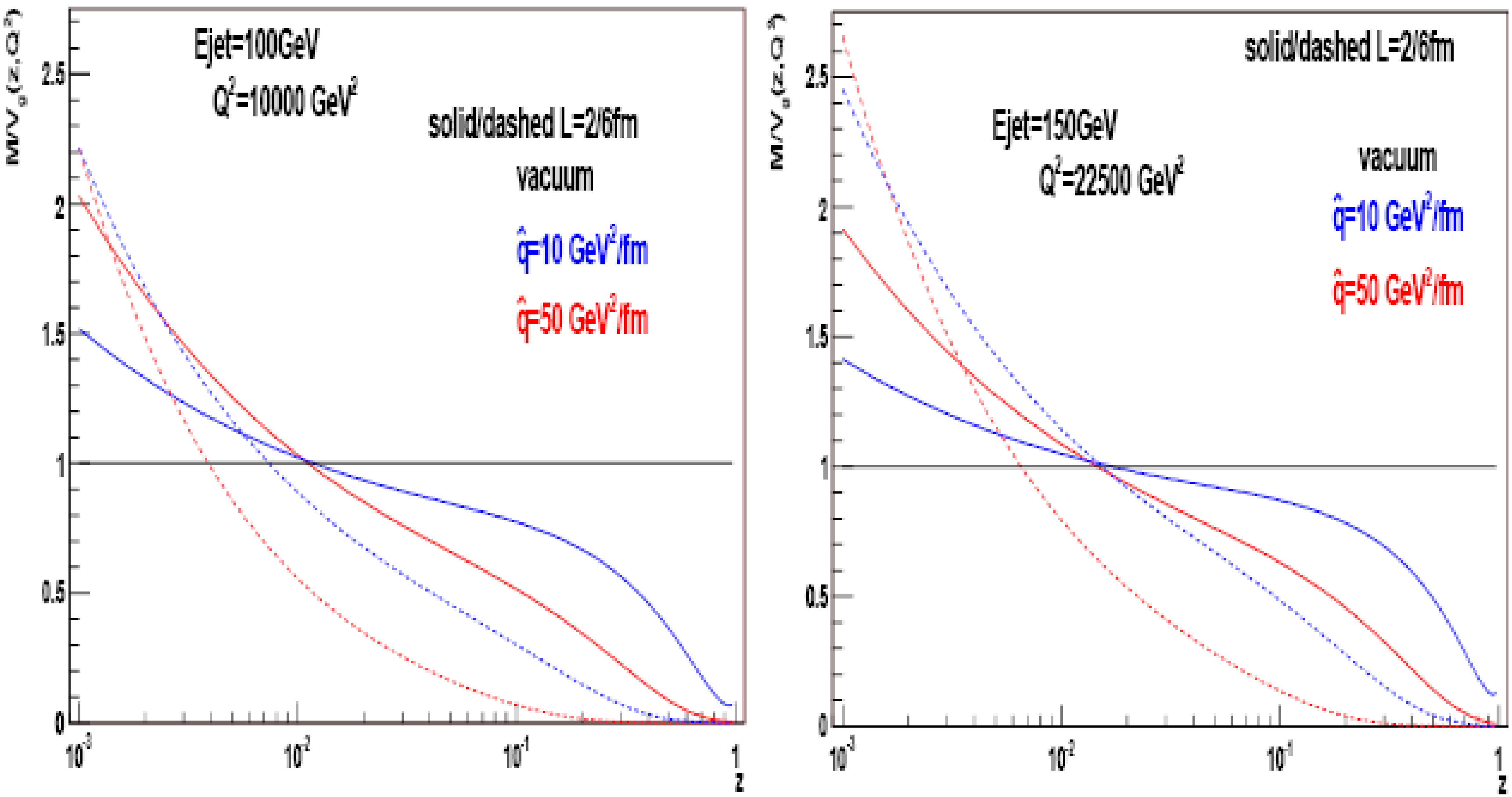


Medium modified fragmentation functions: LHC energy





Medium modified fragmentation functions: LHC energy



Particle production

- A typical hard cross section can be written in the form:

$$\sigma^{ABh} = f_A(x1,Q^2) f_B(x2,Q^2) \otimes \sigma(x1,x2,Q^2) \otimes D_{i \longrightarrow h}(z,Q^2)$$

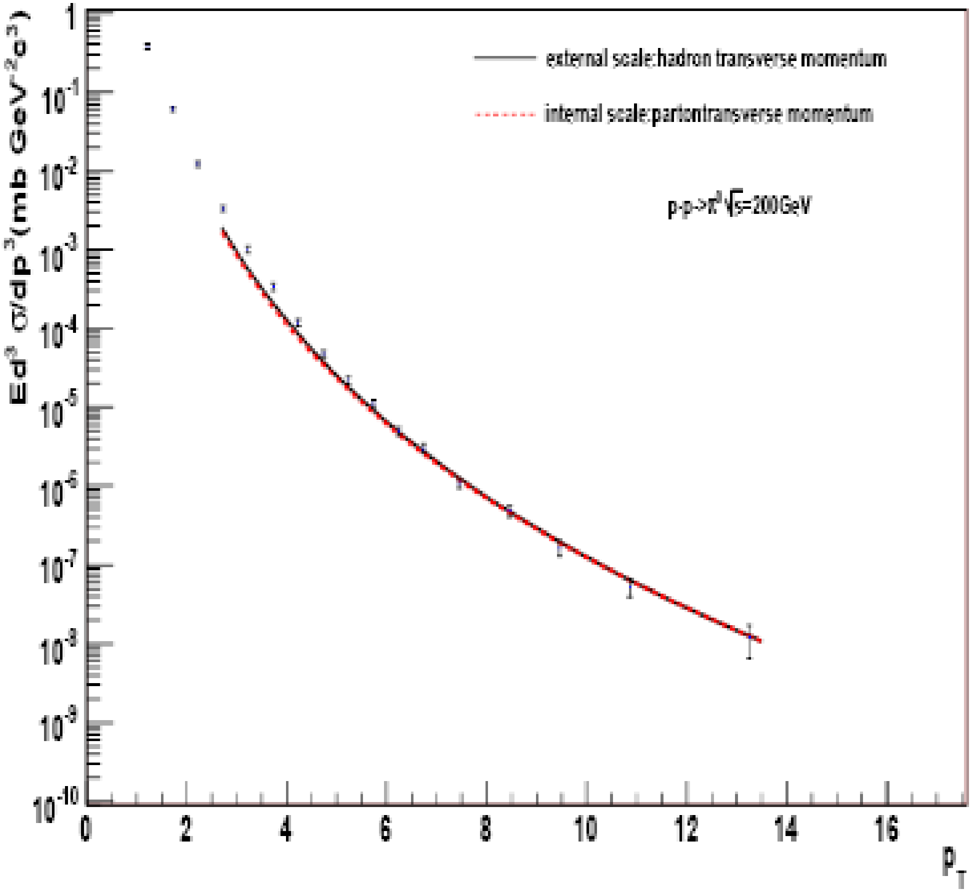
- We define the nuclear modification factor as:

$$R_{AA} = \frac{\frac{d\sigma}{dydq_T^2}(pdflib+EKS+MMFF)}{\frac{d\sigma}{dydq_T^2}(pdflib+EKS+VACFF)}$$

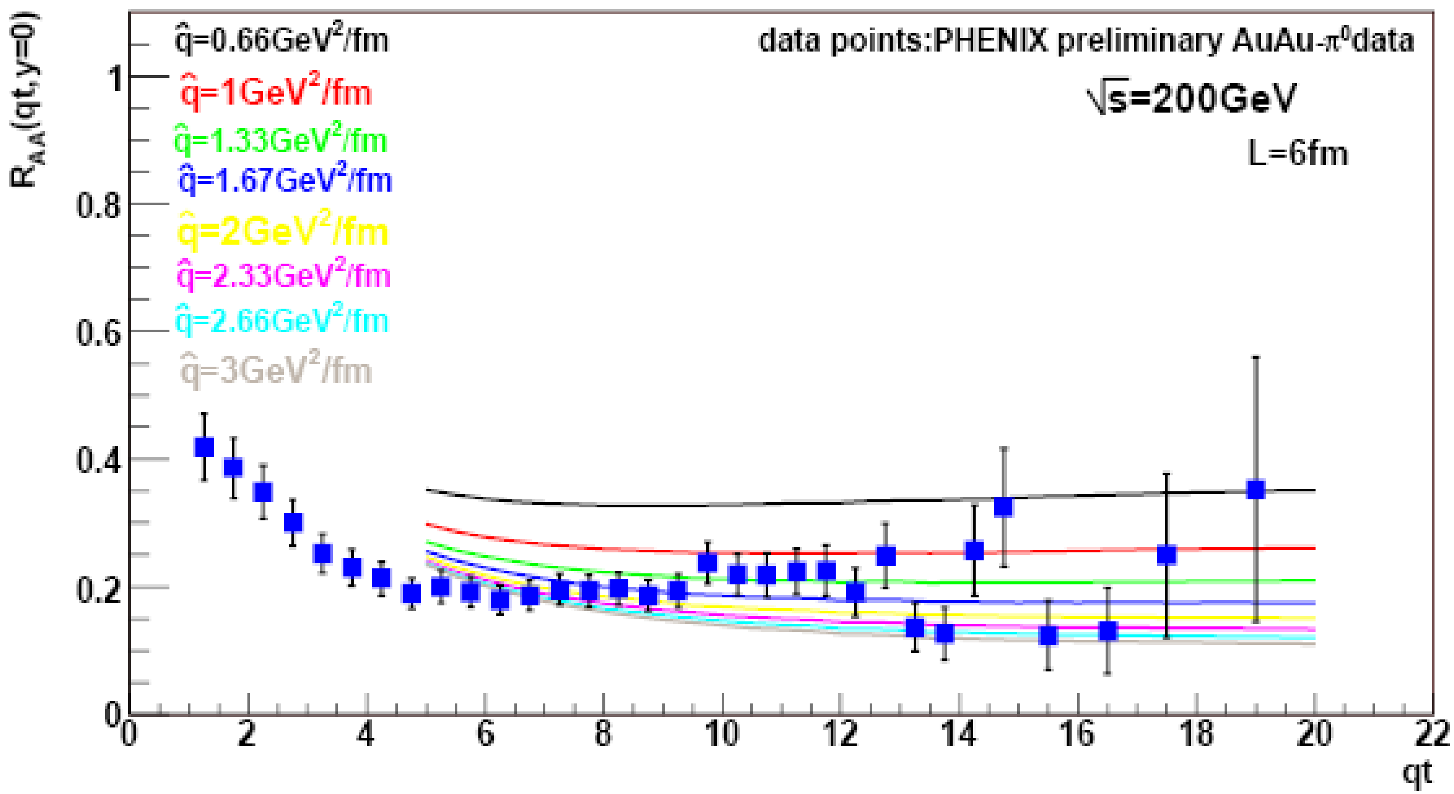
PP reference

✓ Vacuum pp spectra as a reference.

✓ CTEQ 4L pdf 's LO.



Nuclear modification factor



The fragmentation scale is the internal parton momentum

conclusions

- Vacuum splitting functions → medium splitting functions
- Sudakov form factors in medium
- Medium modified DGLAP evolution via Sudakov factor
- Medium modified Fragmentation Functions → A code will be soon publish available.
- Some phenomenological applications:
  - ✓ Perturbative convolution → particle distributions
  - ✓ Comparison to experimental data: Nuclear modification factor

  we determine the value of the transport coefficient for a fixed pass length L=6 fm

$$\rightarrow \quad \hat{q} \simeq 1GeV^2/fm$$