Medium-Modified Fragmentation Functions

N.Armesto[1], *L.Cunqueiro*[1], *C. Salgado*[2] *and W.Xiang*[3]

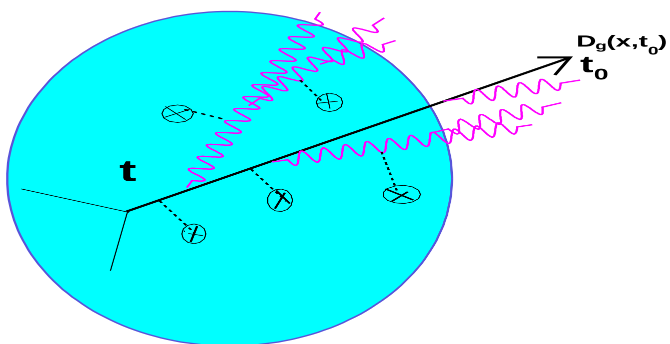
[1] Dep.Física de Partículas and I.G.F.A.E,
Universidade de Santiago de Compostela,Spain
[2] Dip. di Fisica, Universitá di Roma "La Sapienza" and INFN, Roma, Italy
[3] Fakultät für Physik, Universität Bielefeld, D-33501 Bielefeld,Germany

Outline

- Introduction:Medium Induced Gluon Radiation
- Medium-Modified Splitting Functions
- Sudakov Form Factors
- Medium Modified Fragmentation Functions
- Particle Spectra $\longrightarrow R_{AA} \longrightarrow \hat{q}$
- Summary

Introduction:Medium-induced gluon radiation

- Medium-Induced Radiation: A hard parton produced in a Heavy Ion Collision travels through the hot medium. The scattering centers induce successive gluon radiations.



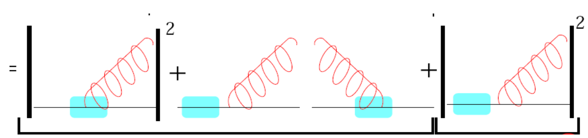
- The hard parton looses virtuality from the initial scale t to the final hadronization one $t_0 \simeq \lambda^2_{QCD}$. Hadronization happens outside the medium.
- We end up with a parent parton degradated in momentum and a surrounding cone of soft partons.
- Medium-Induced gluon radiation is the standard explanation for Jet Quenching observed at RHIC.

Introduction:Medium-induced gluon radiation

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

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

- Two approaches:
  - opacity expansion (in powers of $n(\zeta)\sigma(\zeta)$)
  - BDMPS approximation:$n(\zeta)\sigma(r) \simeq \frac{1}{2}\hat{q}(\zeta)r^2$ The path integral is the one of an harmonic oscillator.
    - ◇ $\hat{q}(\zeta)$ is the transport coefficient $\longrightarrow < q_T^2 > /\lambda$.



◇ $\omega\frac{dI}{d\omega dk_T} \longrightarrow F(\frac{\omega}{\omega_c}, \kappa^2)$, $\omega_C = \frac{1}{2}\hat{q}L^2$, $\kappa^2 = \frac{k_T^2}{\hat{q}L}$

Previous MMFF Calculations

- A Poissonian distribution of independent radiations was assumed (**BMDS**)
$P_E(\epsilon) = \sum_{n=0}^{\infty} \frac{1}{n!}[\prod_{i=1}^{n} \int d\omega_i \frac{d((\omega_i))}{d\omega}]\delta(\epsilon - \sum_{i=1}^{n} \frac{\omega_i}{E})e^{-\int d\omega \frac{dI}{d\omega}}$

- 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:
  - Energy and momentum are not conserved (only a posteriori)
  - There's no evolution in virtuality
  - Medium an vacuum are treated differently

Now:Medium-modified splitting functions

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

- The ansatz is an extension of the former eq. to medium:**Salgado and Polosa (hep-ph/0607295)**
  $\frac{dI}{dzdk_T^2}^{MED} = \frac{\alpha_s P(z)^{MED}_{z\longrightarrow 1}}{2\pi k_T^2}$, $P(z)^{med}_{z\longrightarrow 1} = \frac{2\pi zt}{\hat{q}L} F(\frac{\omega}{\omega_c}, \kappa^2)$

- The formalism of medium induced radiation relies on high energy approximations where previous eqs.are valid.

- The total splitting distribution is assumed to be the vacuum + medium ones:
  $P^{TOTAL}(z) = P^{VACUUM}(z) + P^{MEDIUM}(z, t, \hat{q}, L)$

- **Borghini, Wiedemann** proposal:medium multiplicative factor

Sudakov Form Factors

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

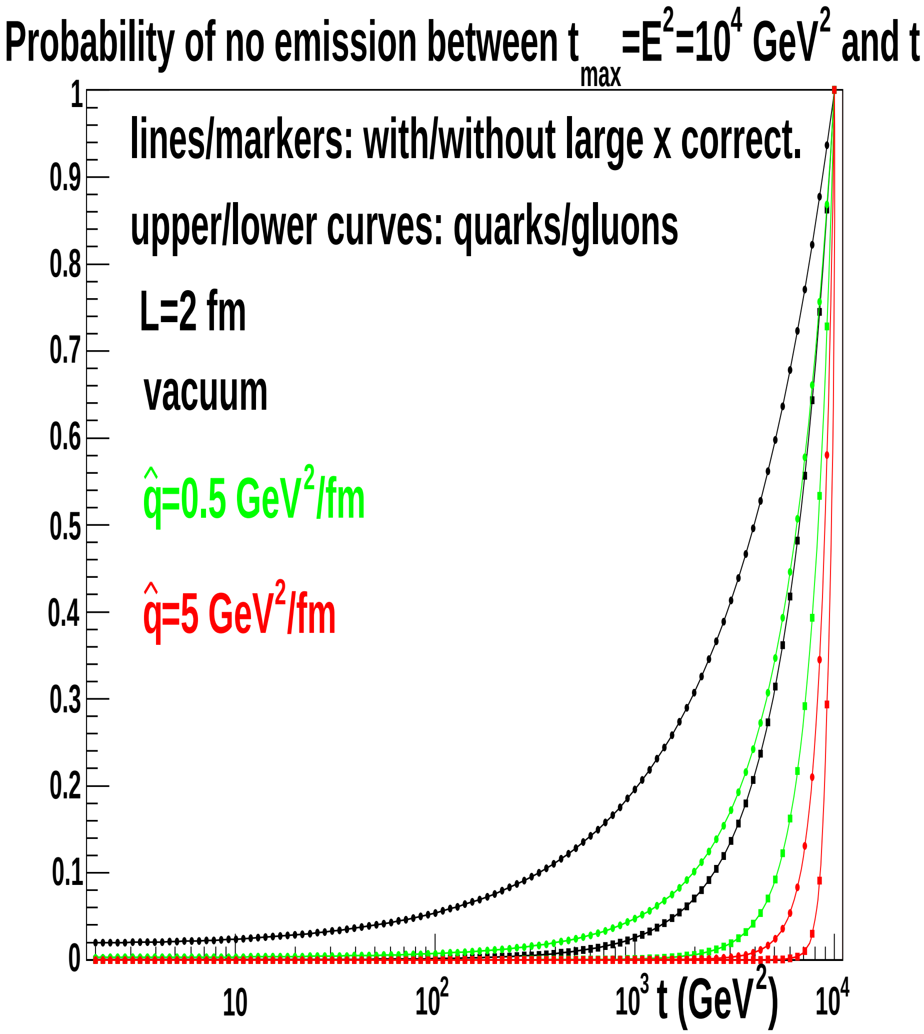
- $\Delta_a(t, t_0^a)$ means the probability for parton a not to branch(resolved) while evolving from an initial virtuality t_0 to a final scale t.

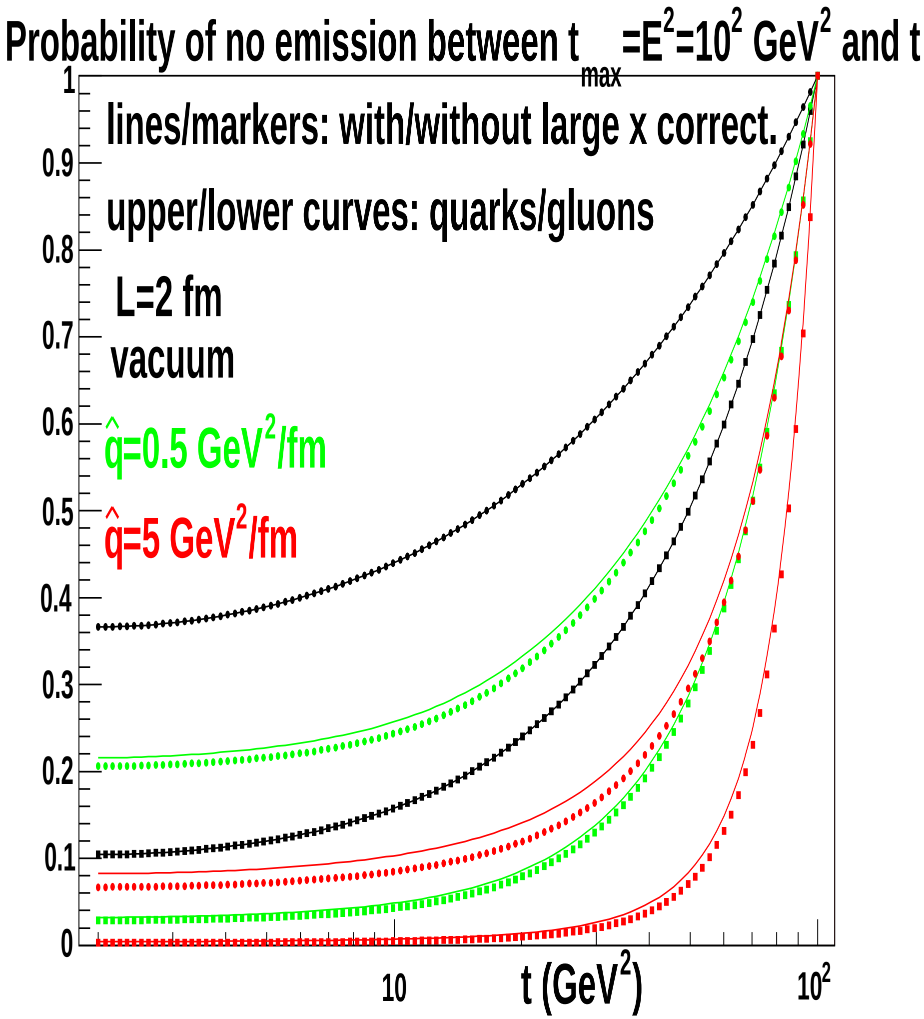
- $\frac{\Delta(t_0,t)}{\Delta(t_0,t')}$ stands for the probability of evolving from the intermediate scale t' to t without branching.

- independent radiation:branching at a scale t does not affect branching at a scale t'.

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

Medium Modified Sudakov Factors





Medium Modified Fragmentation Functions

- DGLAP can be written in terms of the Sudakovs:

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

- We consider only 3 flavors(u,d,s).

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

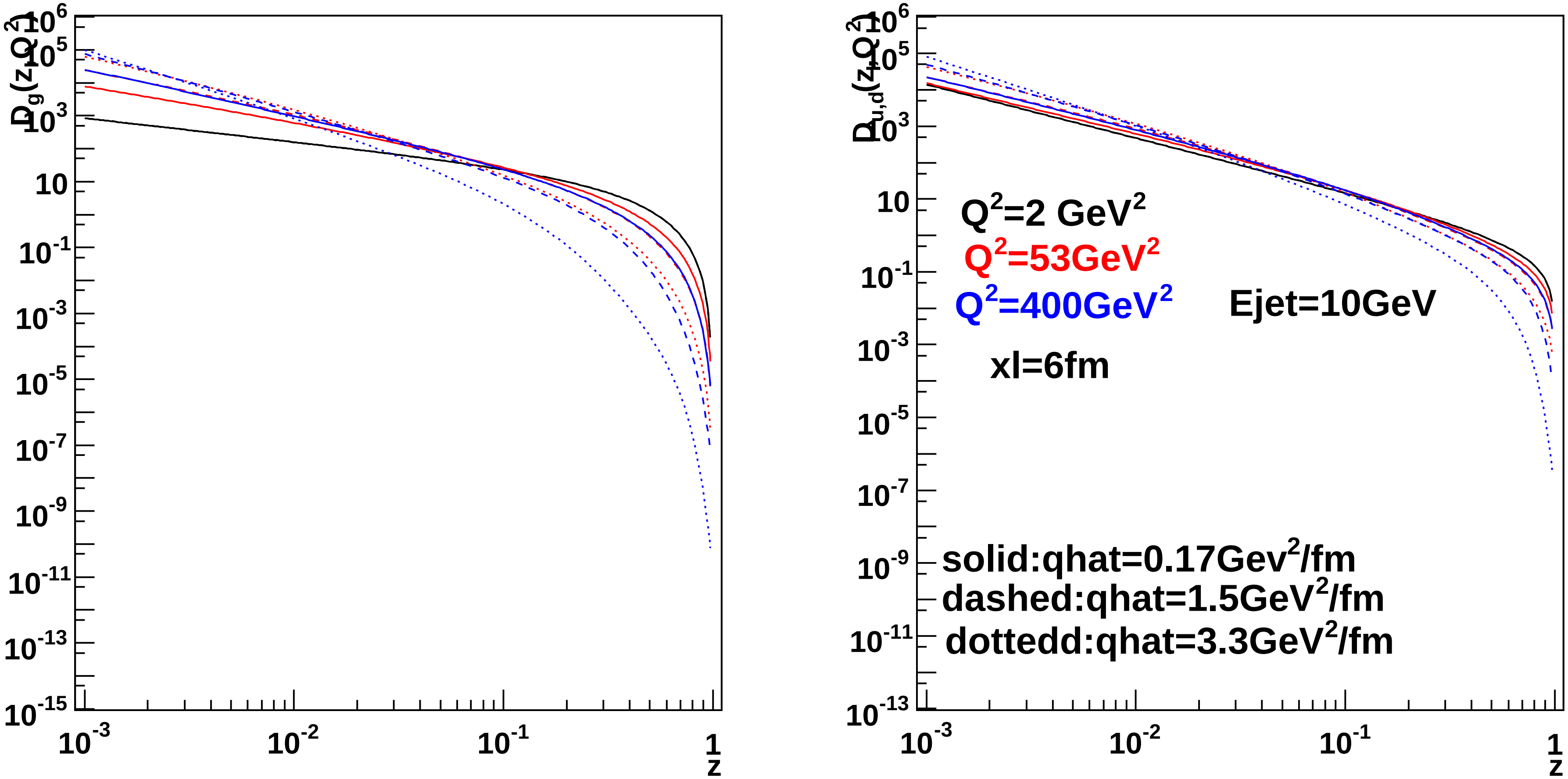
- As initial values for the FF we take the KKP ones at virtuality t $t_0 = 2GeV^2$

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

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

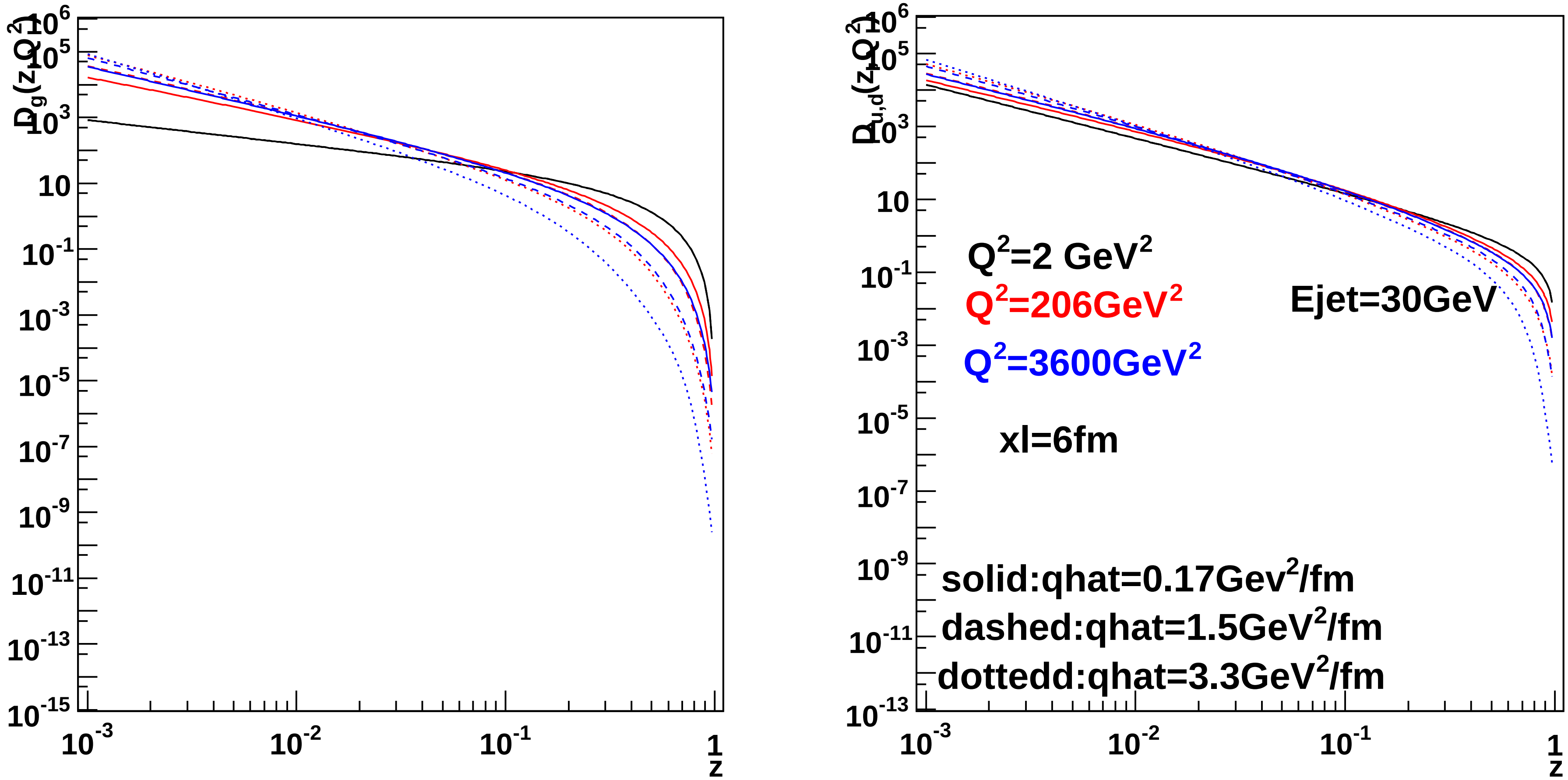
- The induced gluon radiation accelerates the evolution.

Medium Modified Fragmentation Functions



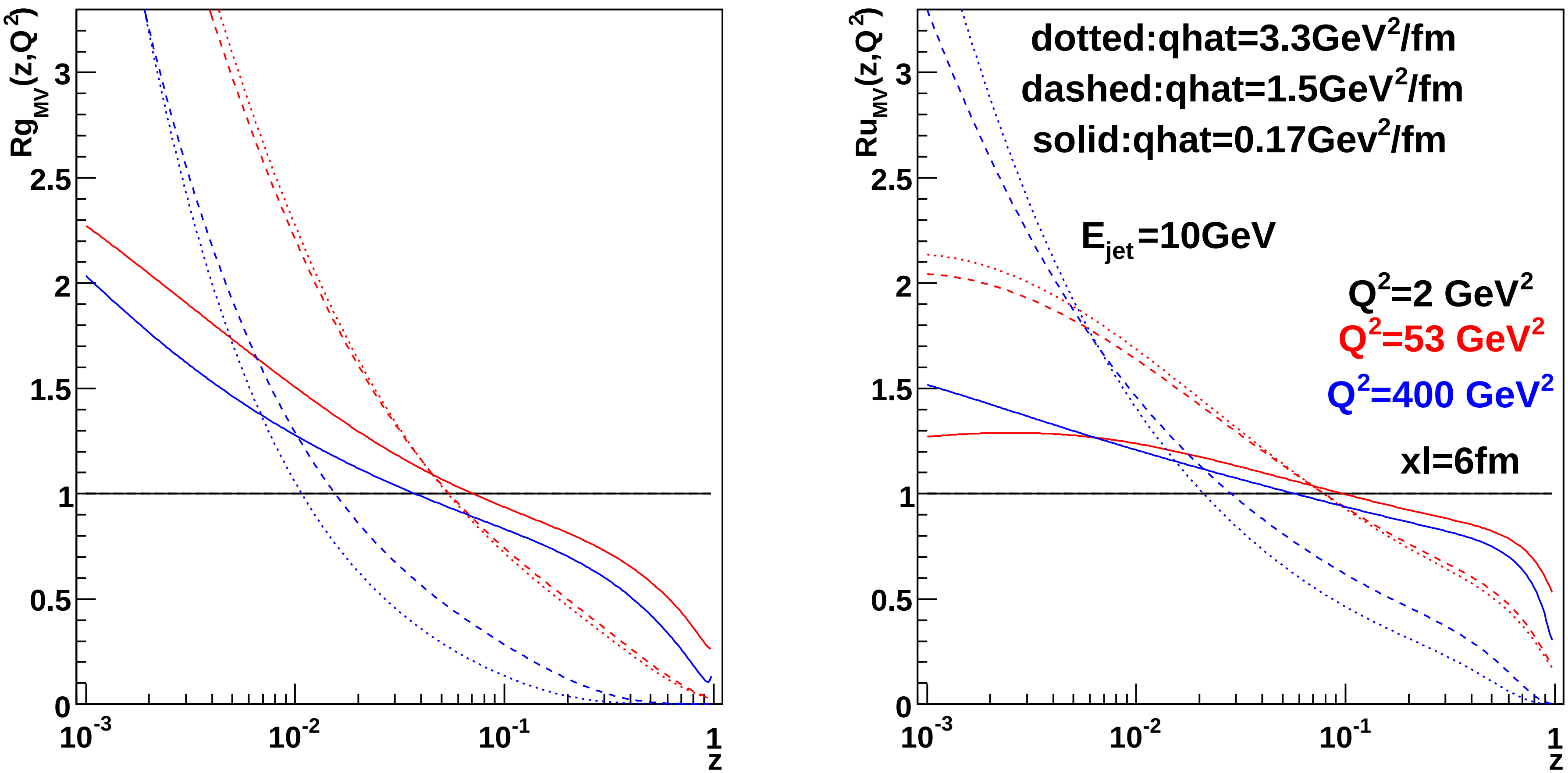
Fragmentation Functions for different medium densities for E_{jet} =10GeV

Medium Modified Fragmentation Functions



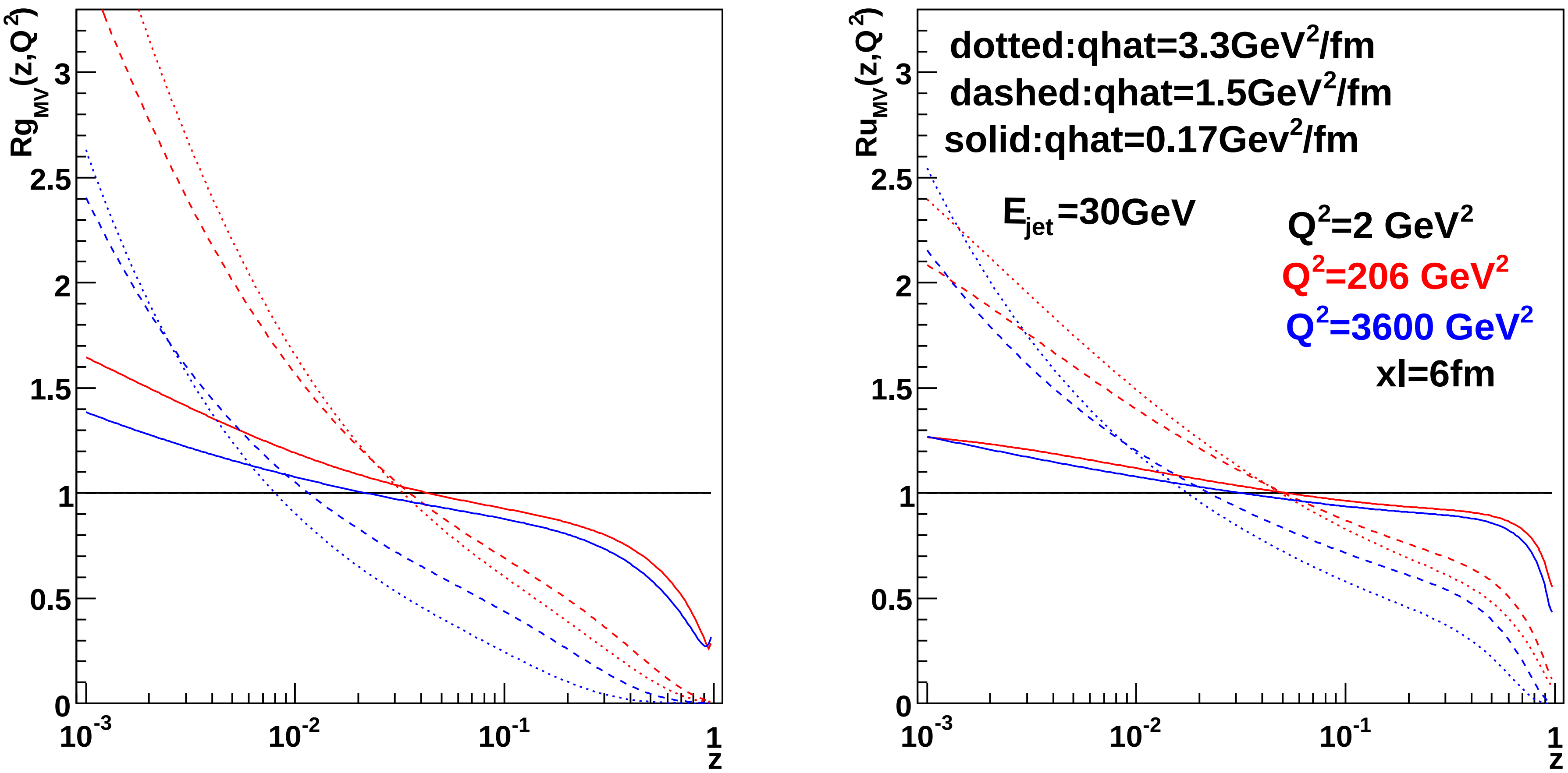
Fragmentation Functions for different medium densities for $E_{jet} = 30GeV$

Medium Modified Fragmentation Functions



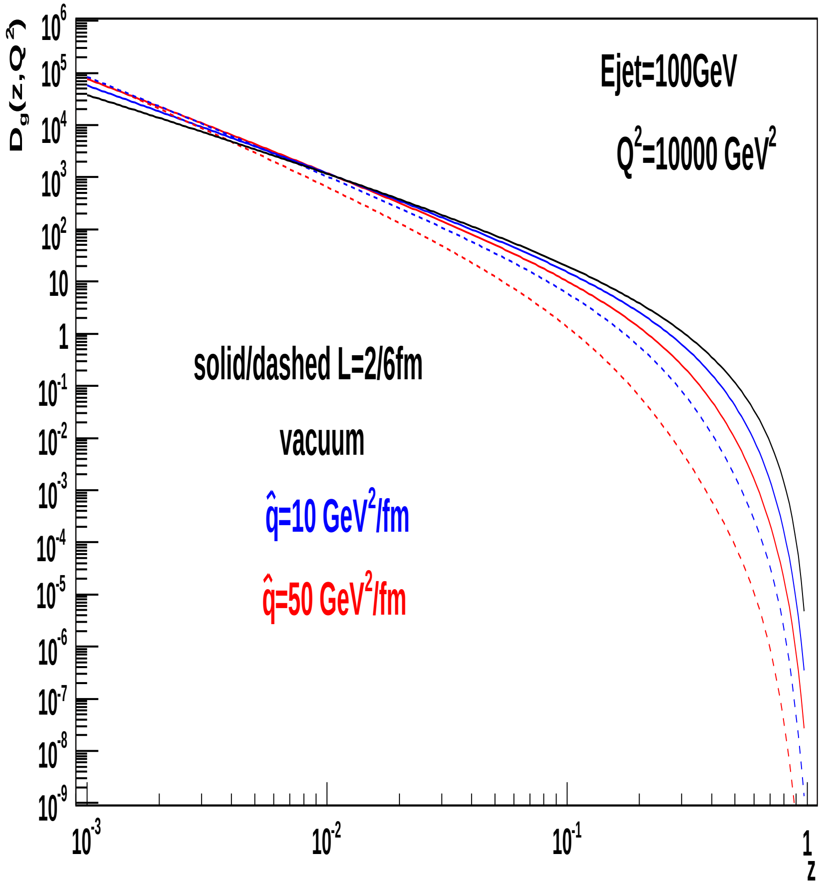
Ratio Medium/Vacuum of the Fragmentation Functions of $E_{jet} = 10GeV$.

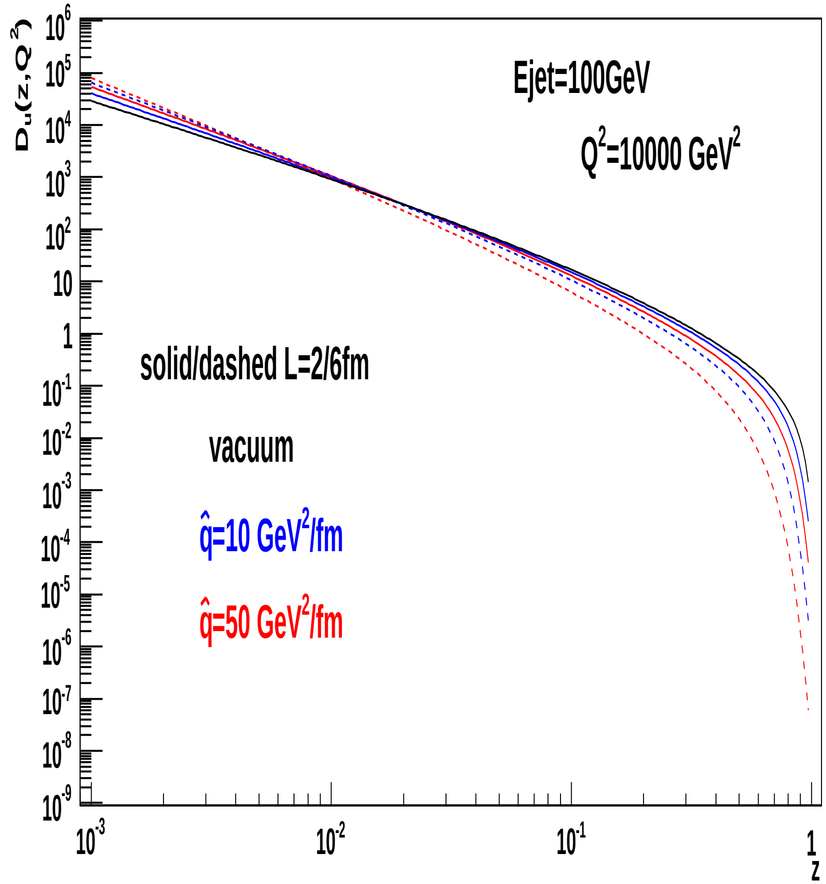
Medium Modified Fragmentation Functions



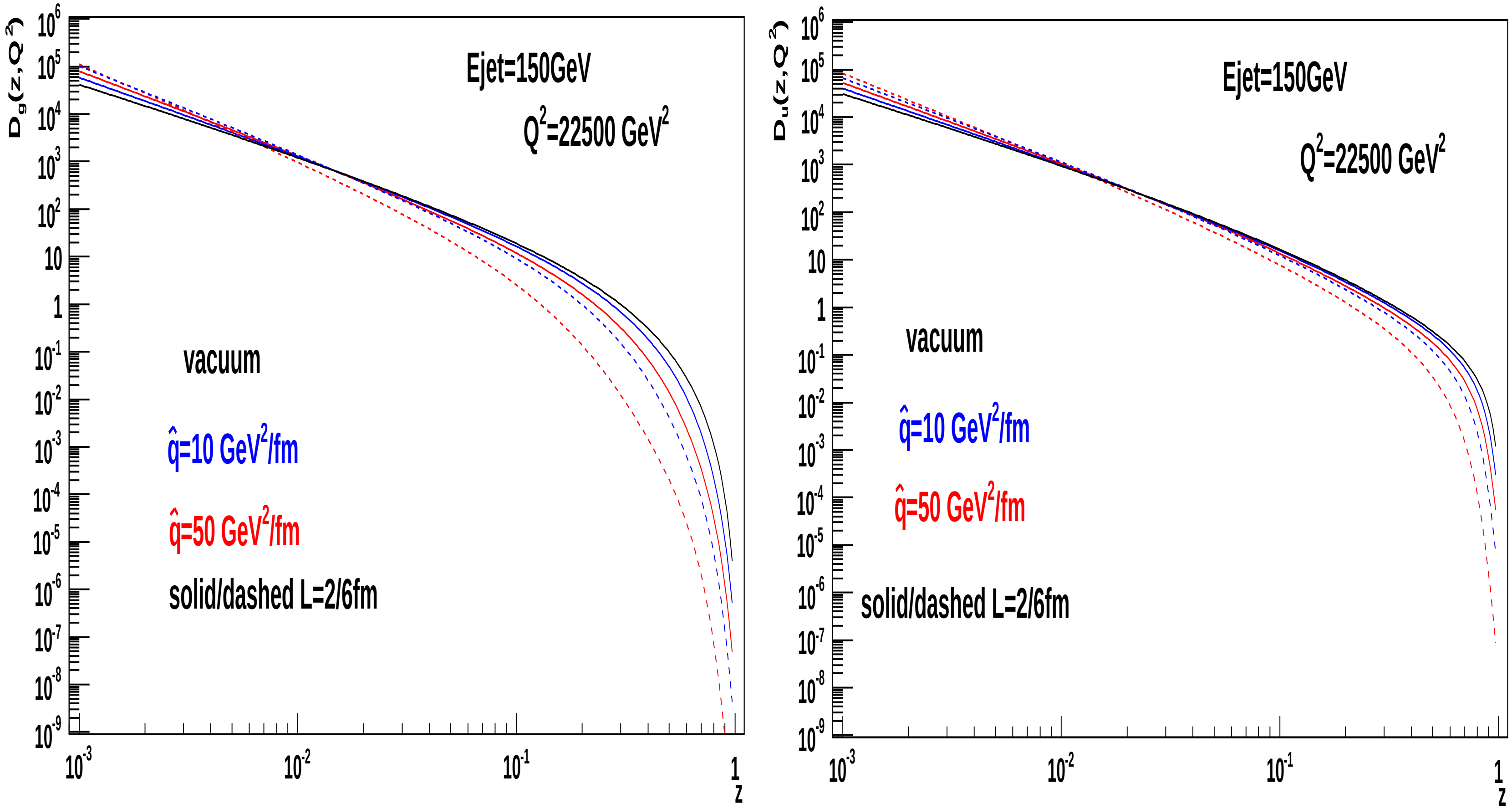
Ratio Medium/Vacuum of the Fragmentation Functions of $E_{jet} = 30GeV$.

Medium Modified Fragmentation Functions:LHC

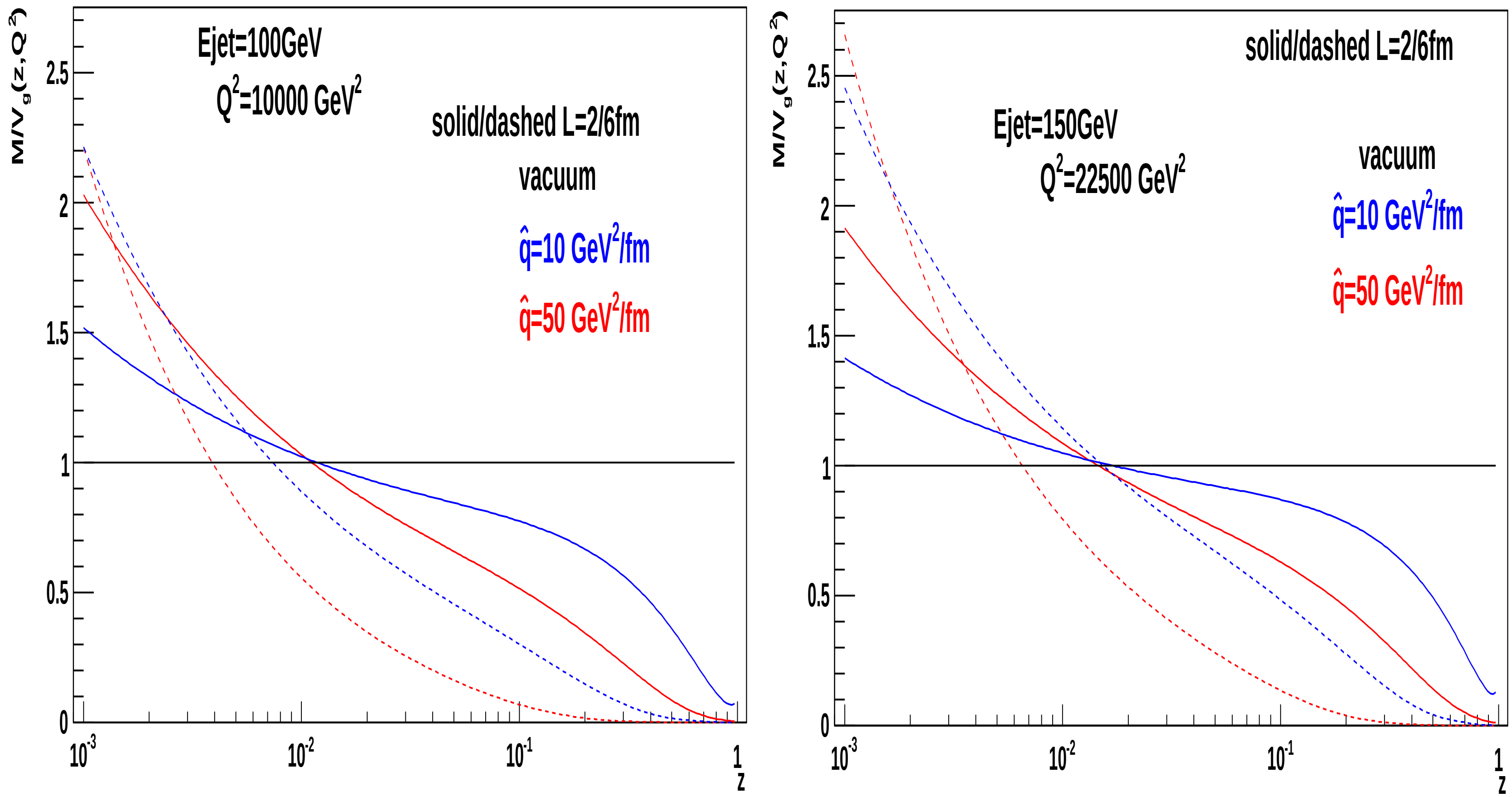




Medium Modified Fragmentation Functions:LHC



Medium Modified Fragmentation Functions:LHC



Particle Spectra: formalism

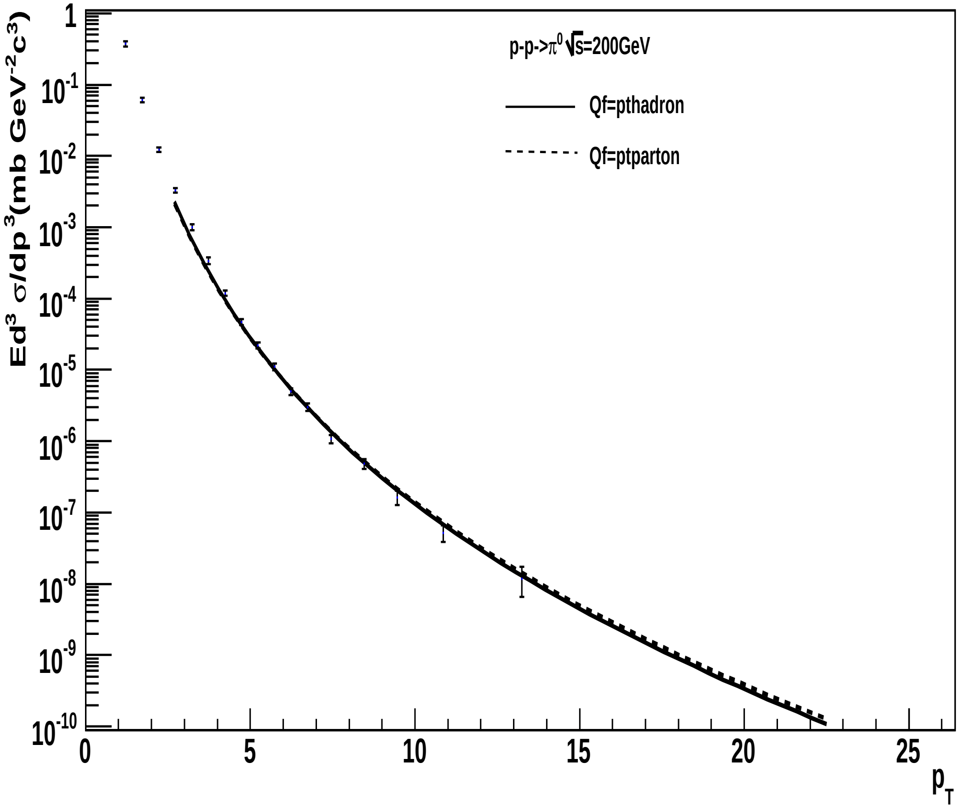
- A typical hard cross section can be written in the form:

- $\sigma^{ABh} = f_A(x1, Q^2) f_B(x2, Q^2) \otimes \sigma(x1, x2, Q^2) \otimes D_{i \longrightarrow h}(z, Q^2)$
  - $D_{i \longrightarrow h}(z, Q^2)$ long distance non perturbative object $\longrightarrow$ we modify its perturbative evolution.

- We define the nuclear modification factor as:

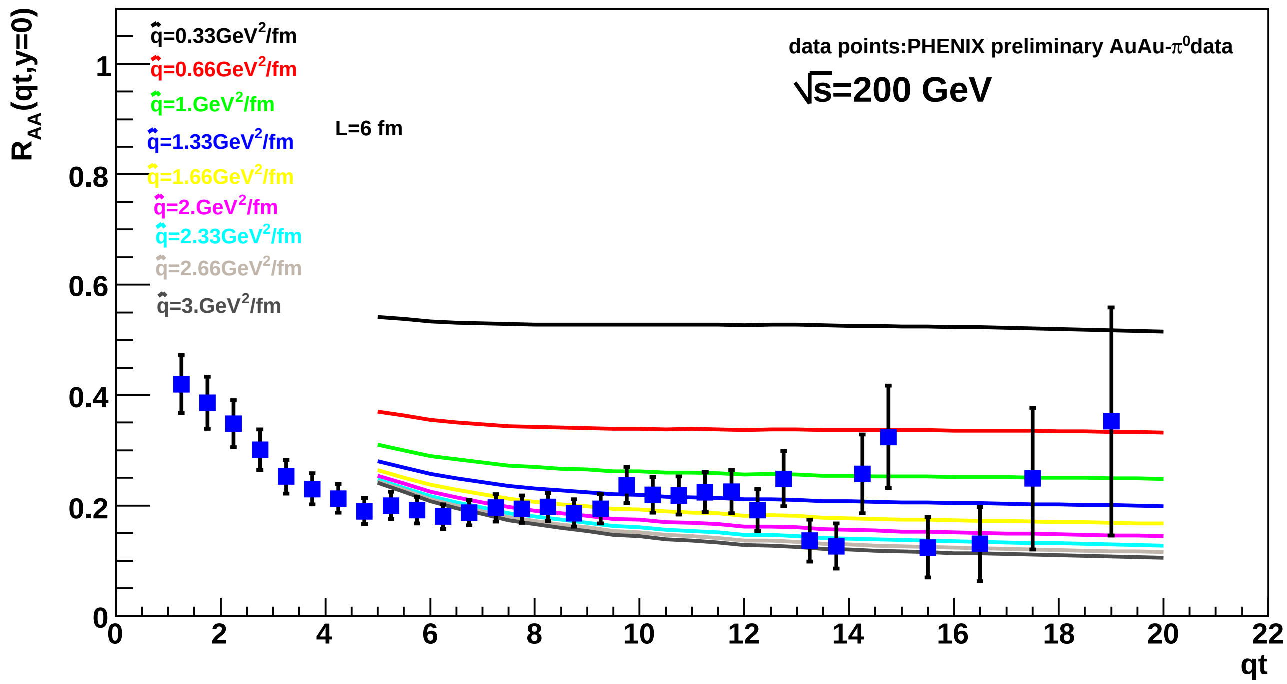
$$R_{AA} = \frac{\frac{d\sigma}{dydq_T^2}(pdf{+}EKS{+}MMFF)}{\frac{d\sigma}{dydq_T^2}(pdf{+}VACFF)}$$

Particle Spectra: pp Reference



- Vacuum pp spectra as a reference.
- CTEQ 4L pdf's, LO. $Q_{fac} = Q_{renor} = k_{T_{parton}}$
- Fragmentation scale:
  - ∘ k_T hadron/parton $\longrightarrow$ different $K(\sqrt{s})$ -see **Eskola et al(Nucl.Phys.A713(2003))**

Nuclear Modification Factor



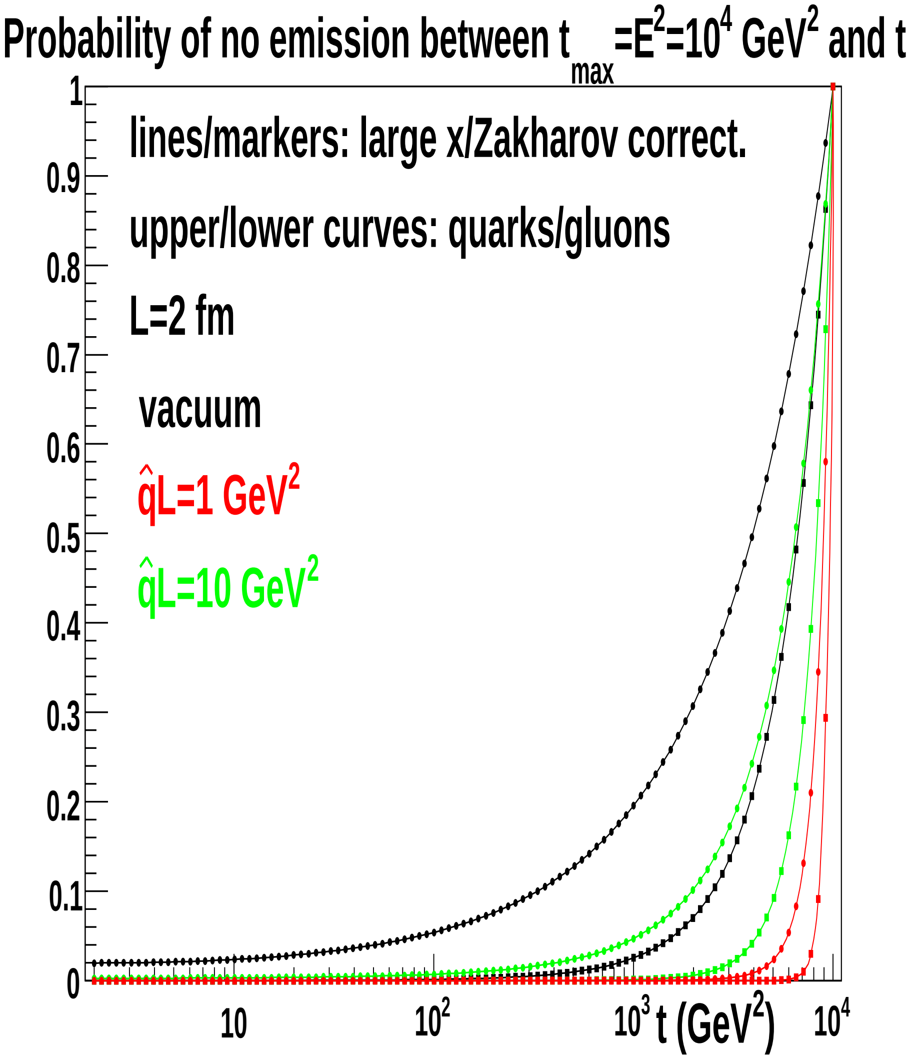
The fragmentation scale is the internal parton momentum

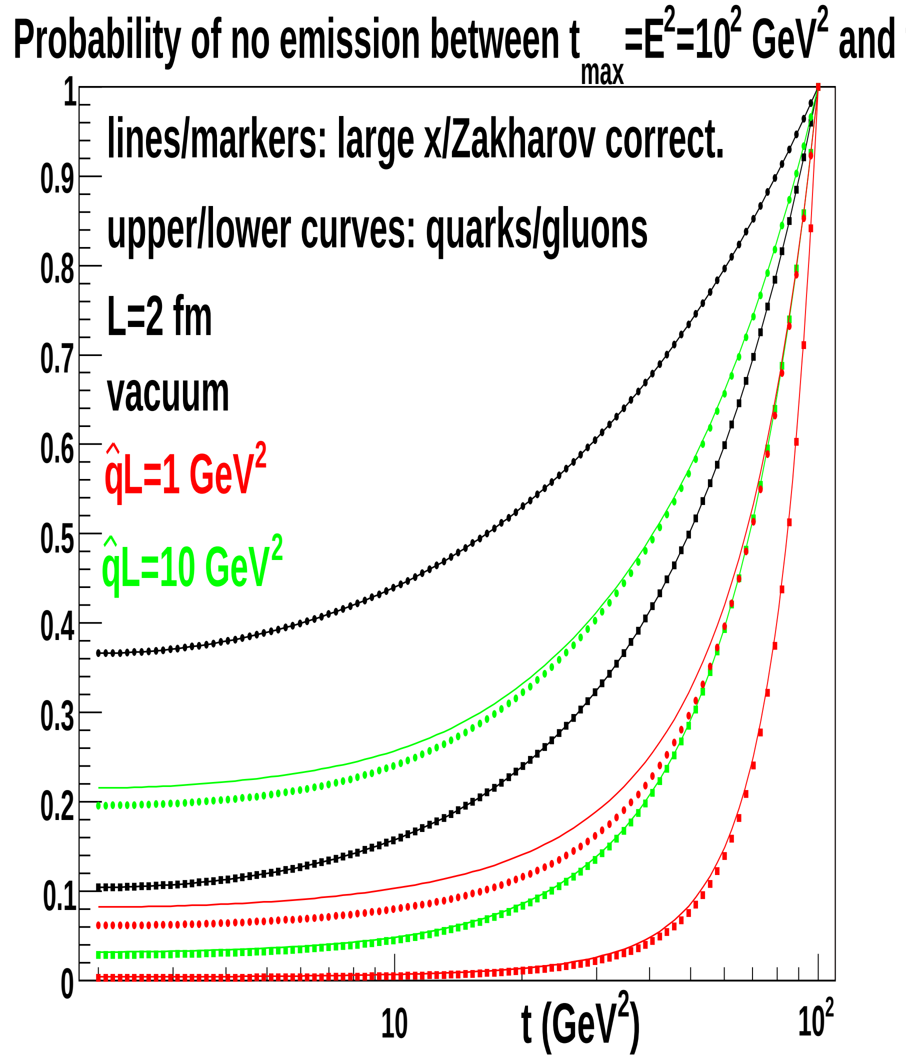
Summary

- Vacuum splitting functions $\longrightarrow$ medium splitting functions
- Sudakov Form Factors in medium
- Medium modified DGLAP evolution via Sudakov Factors
- Medium modified Fragmentation Functions $\longrightarrow$A code will be soon publicly available!
- Some phenomenological applications:
  - Perturbative convolution $\longrightarrow$ Particle distributions
  - Comparison to experimental data: R_{AA}
    - we determine the value of the transport coefficient $\hat{q}$for a fixed L=6fm $\longrightarrow \hat{q} \simeq 1GeV^2/fm$
- Step towards a medium-modified parton branching

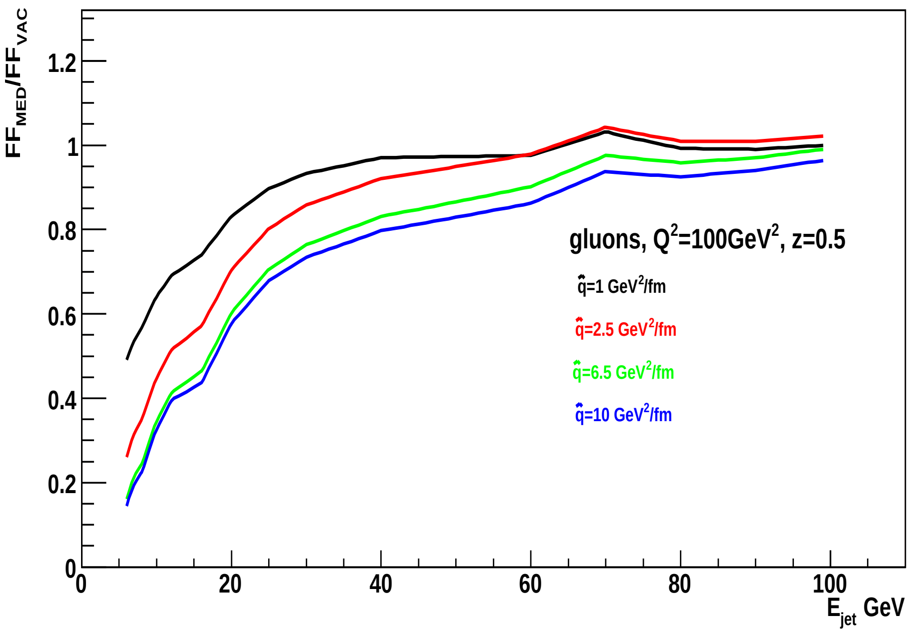
EXTRAS

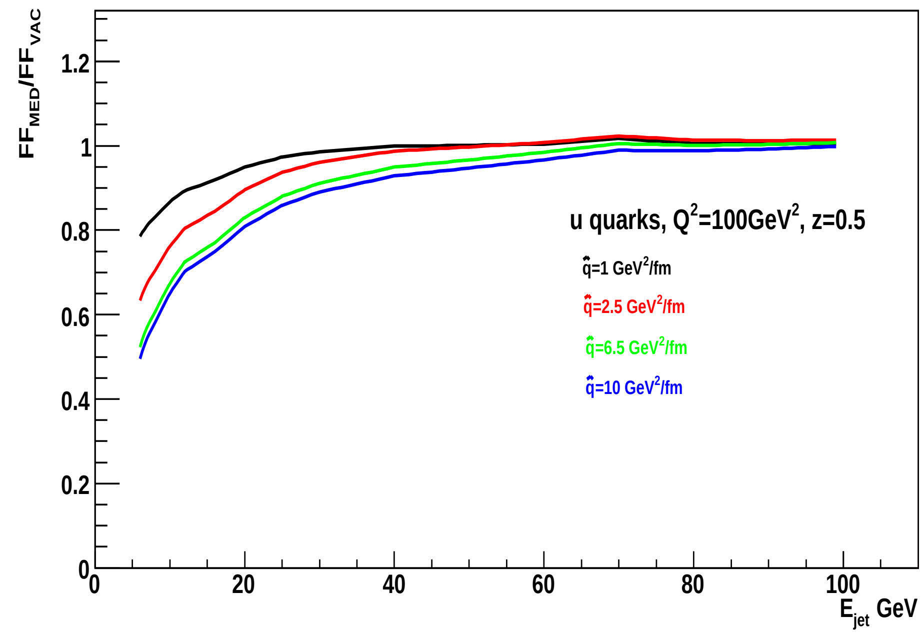
Medium Modified Sudakov Factors





Medium Modified Fragmentation Functions





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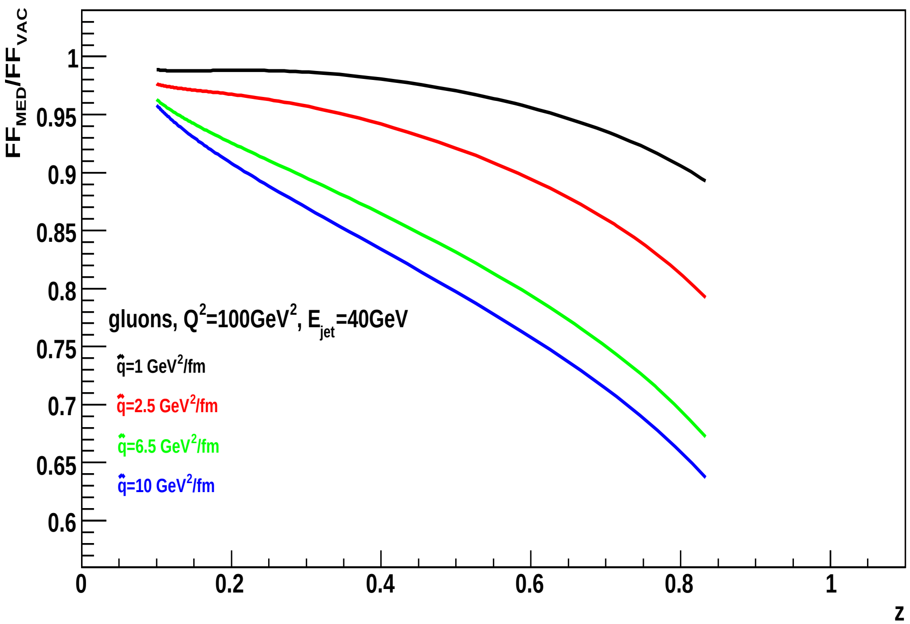

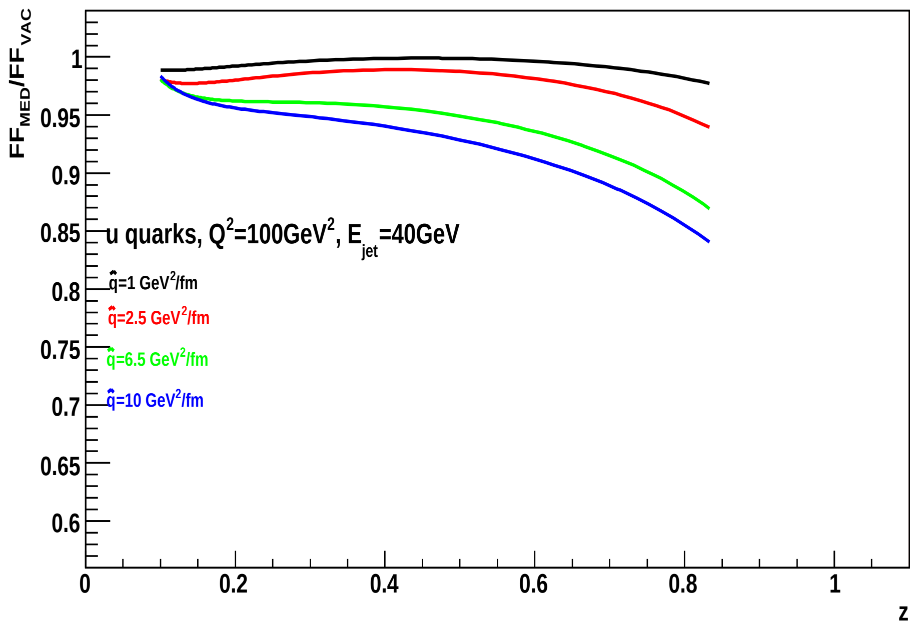

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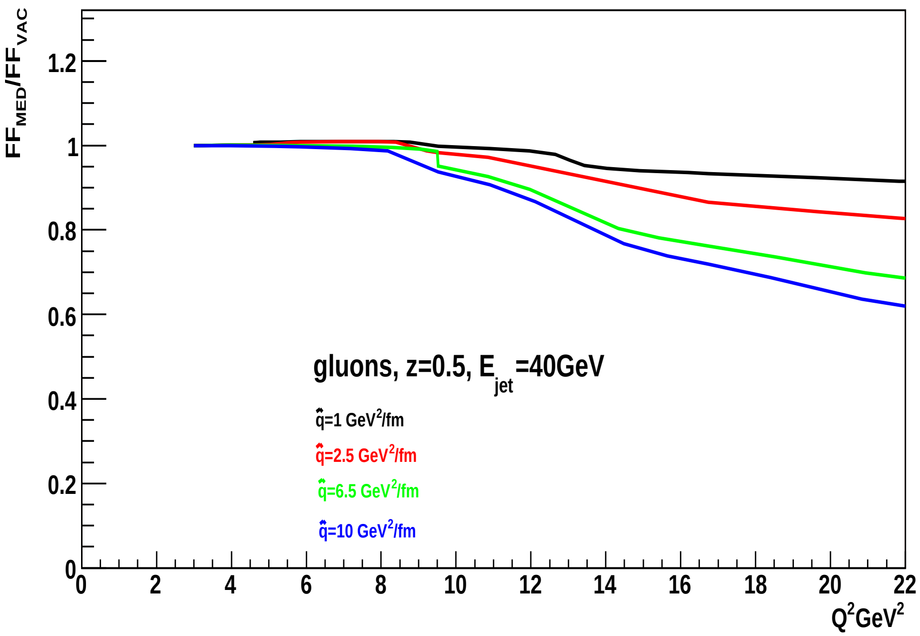

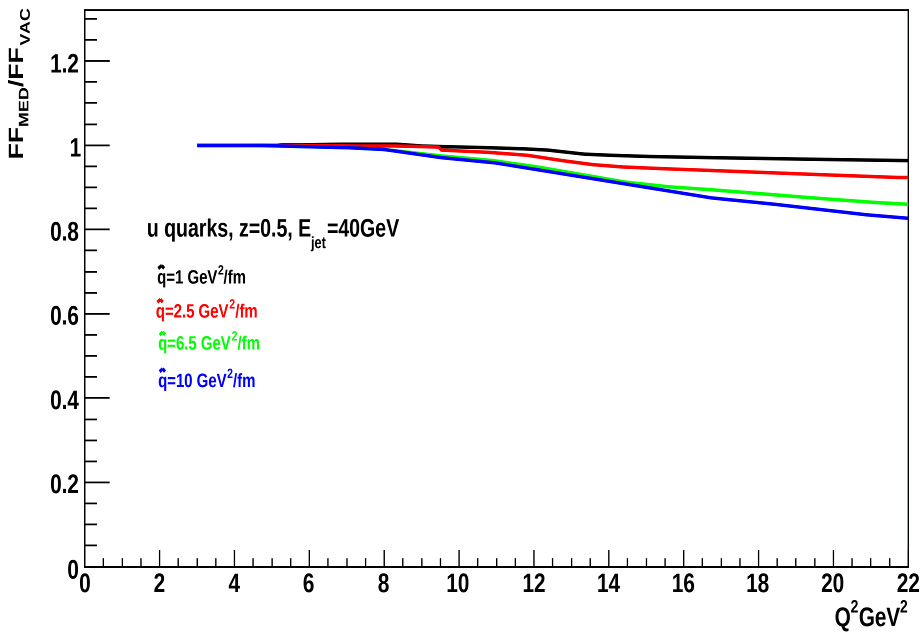

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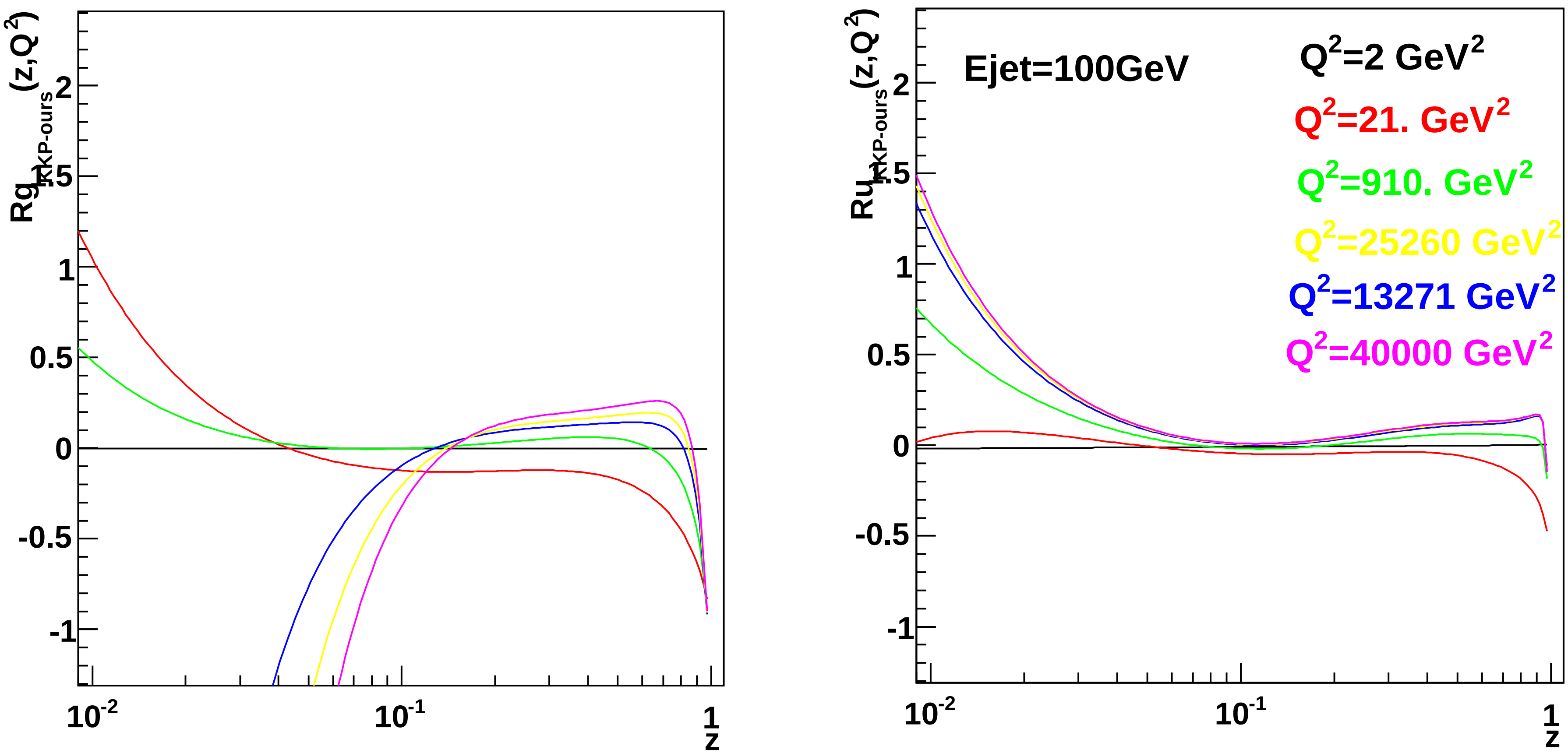
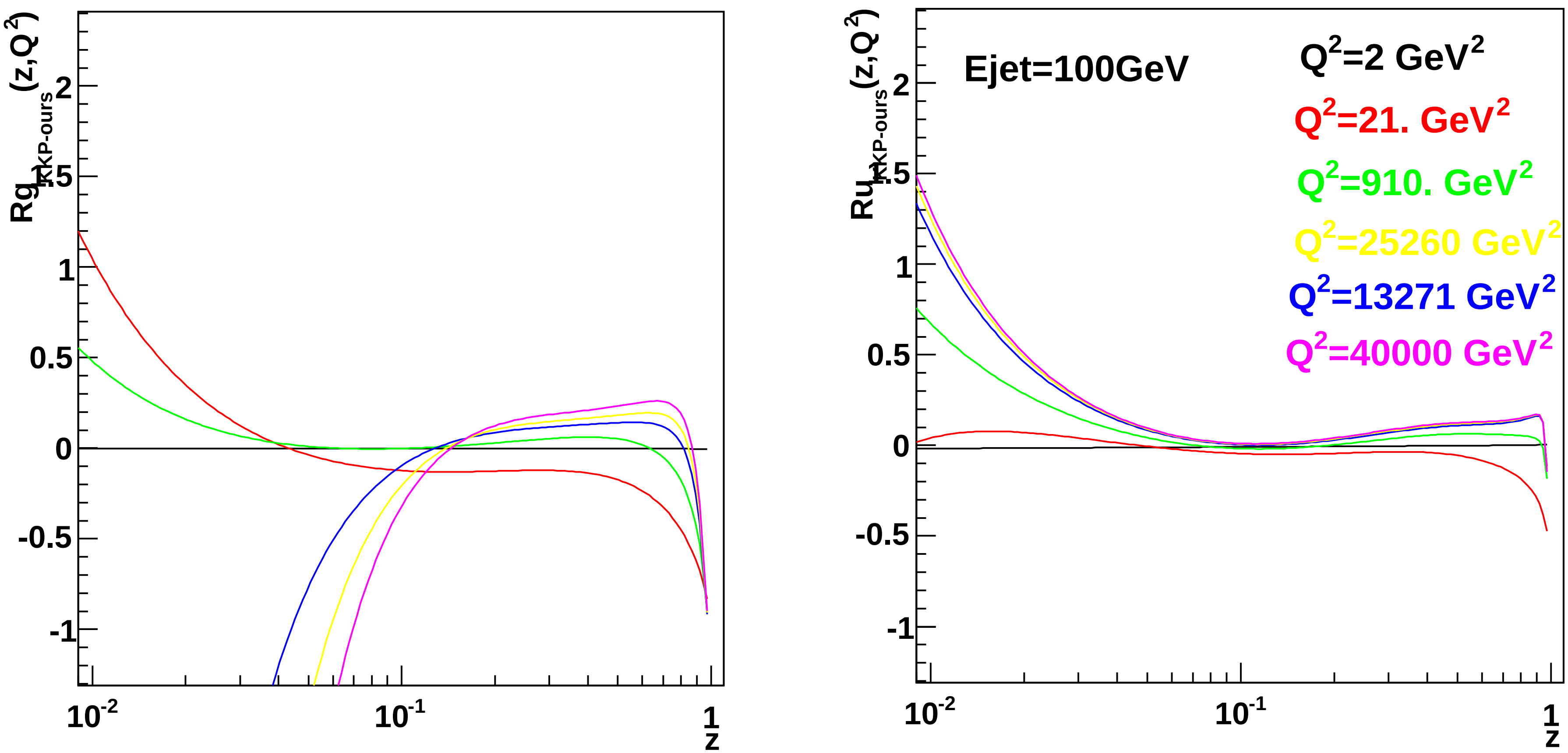


The same but for an initial parton of energy $E_{jet} = 100GeV$.

Medium Modified Fragmentation Functions



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