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Impact of Physical Scheme heavy-quark mass corrections on DIS PDF fits

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Outline

- Introduction

  -Set up and general motivation - what is the ‘Physical Scheme’?

- Main

  - Modified splitting kernels
  - α_s running
  - Physical Scheme coefficient functions for DIS
  - Physical Scheme PDF evolution
  - Physical Scheme structure functions

- Conclusions and outlook

Introduction

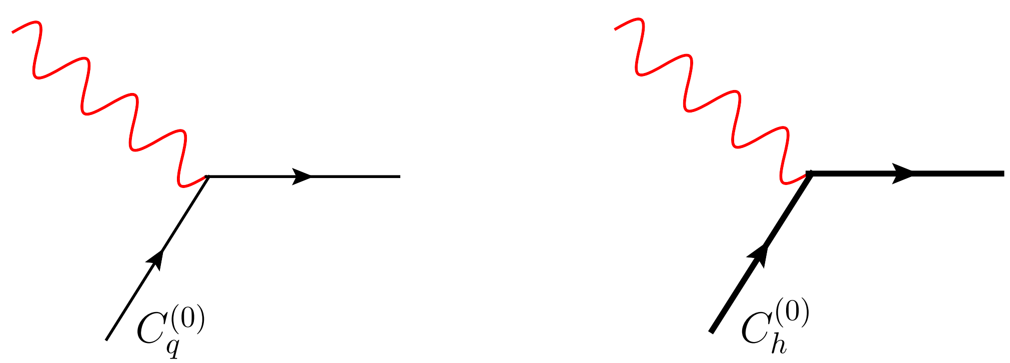
- Originally devised in arXiv:1307.3508[1], the Physical Scheme accounts for heavy quarks and provides a way to smoothly transition over the MSbar heavy quark thresholds

- Explicitly retains mass corrections of $\mathcal{O}(m_h^2/\mu^2)$ in the splitting functions, a modified α_s running and new coefficient functions

- Global analyses now at NNLO but let us study NLO first

- To obtain NLO accuracy, it is sufficient to account for the heavy quark mass m_h only in the *LO* (one loop) splitting function (and α_s)

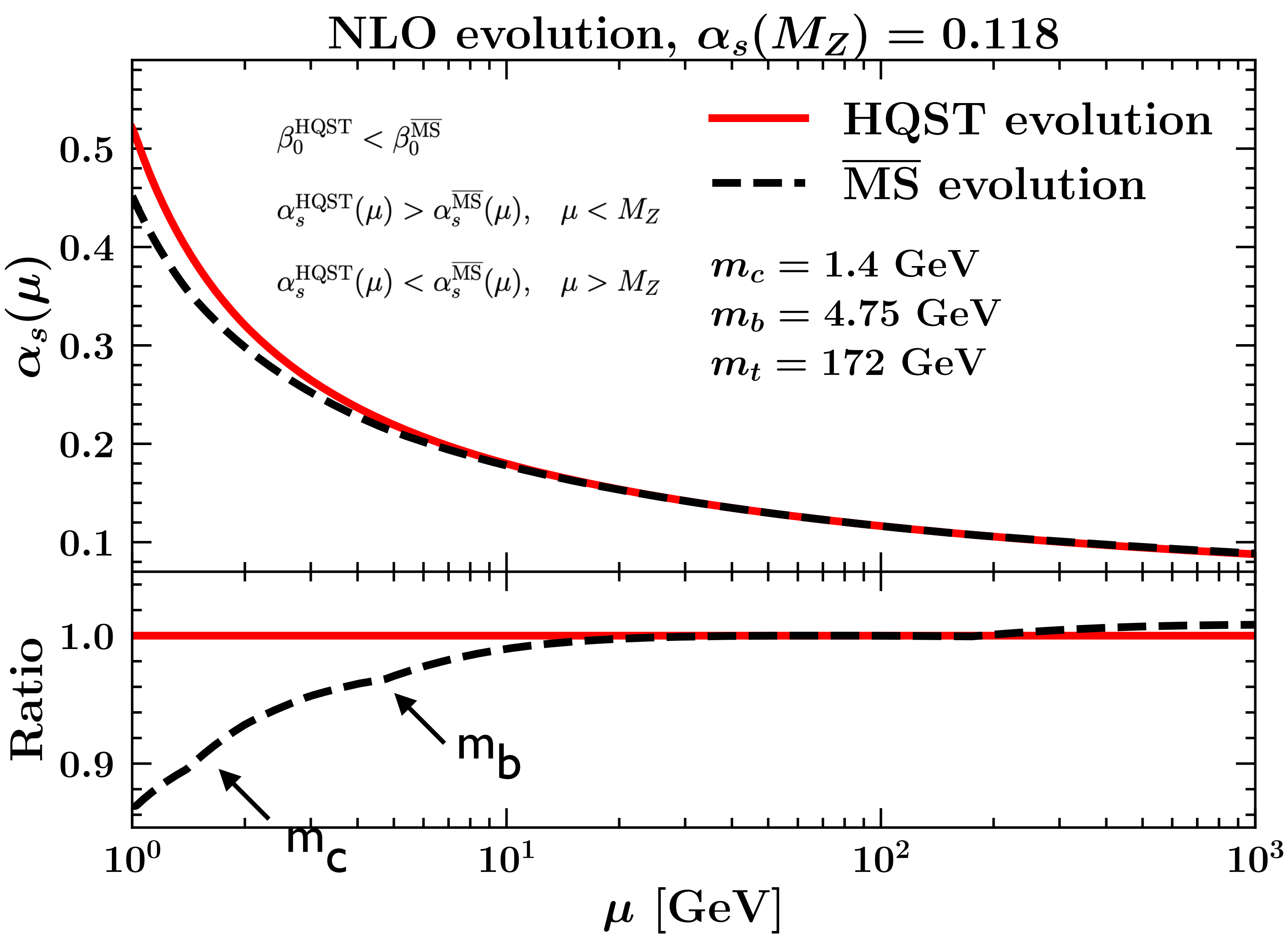
Conventional MSbar | Physical Scheme (HQST)



- **Goal**: Incorporate Physical Scheme into xFitter to assess impact of these heavy quark mass corrections on PDF fits

[1] with minor corrections given in arXiv:1912.09304

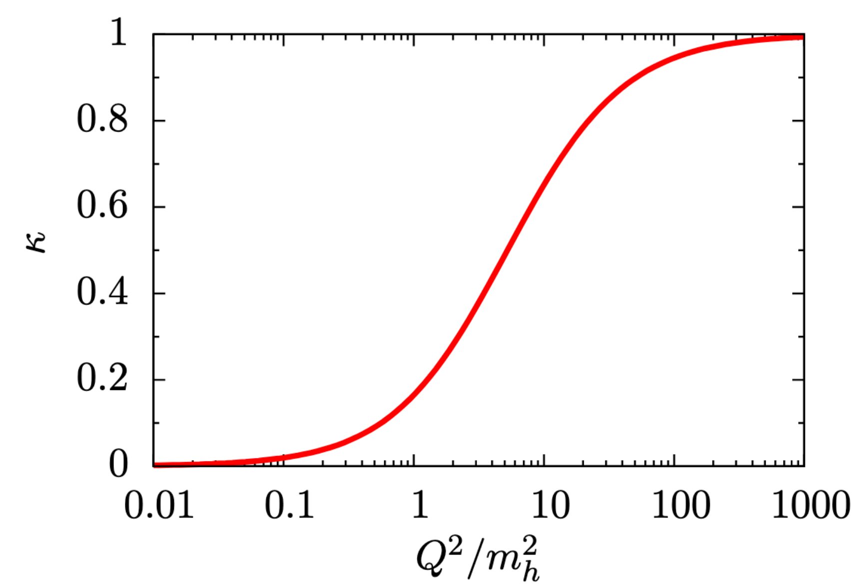
Motivation



Modified n_f term in beta function:

$$\kappa(\xi) = \left[1 - 6\xi + 12\frac{\xi^2}{\sqrt{1+4\xi}} \ln \frac{\sqrt{1+4\xi}+1}{\sqrt{1+4\xi}-1}\right]$$

$$\xi = m_h^2/\mu^2$$

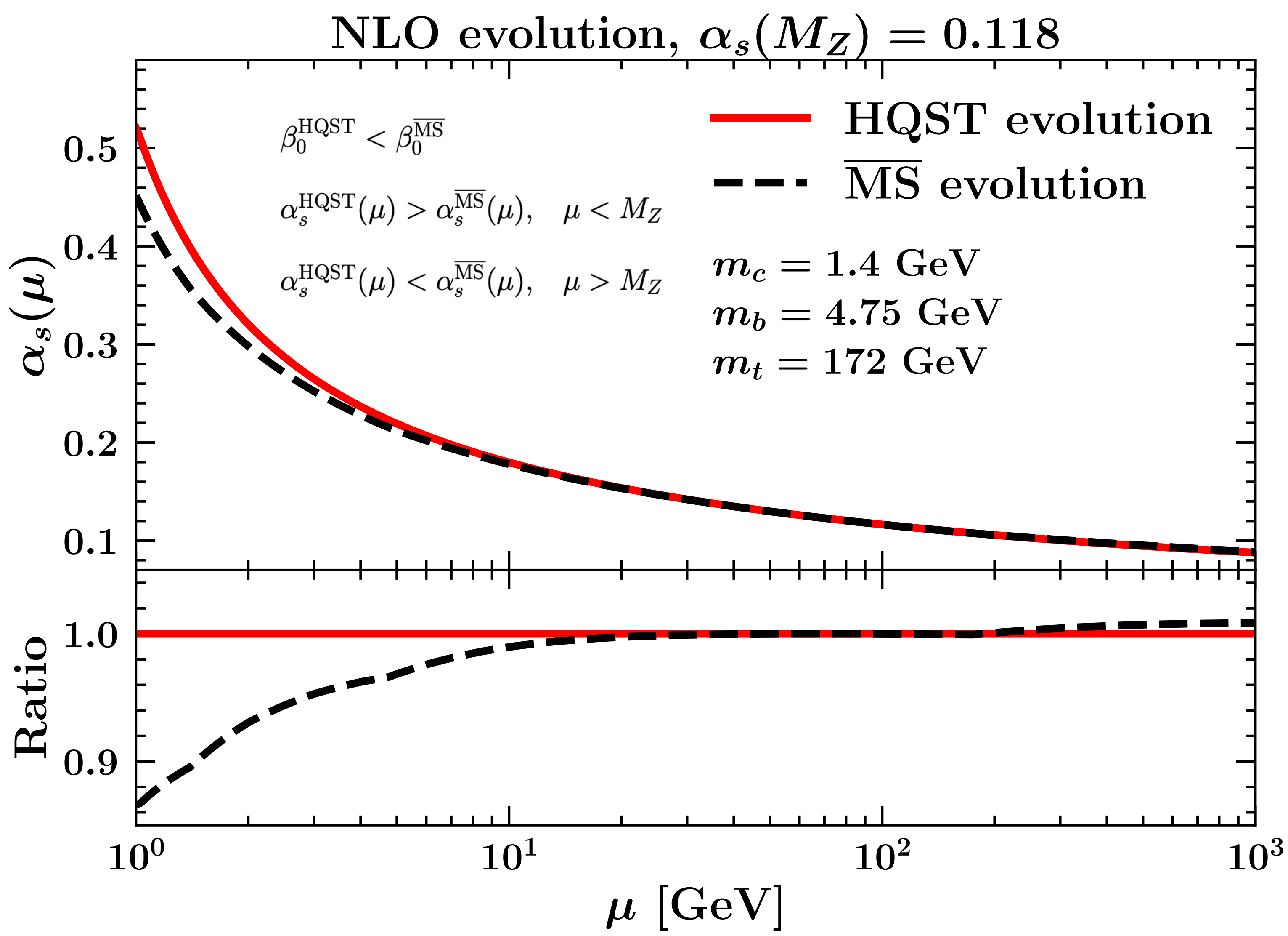


LO HQST splitting functions e.g.

$$P_{hh}(\xi, x) = 2C_F \left[\frac{1+x^2}{1-x}\frac{1}{1+\xi(1-x)} + x(x-3)\frac{\xi}{(1+\xi(1-x))^2}\right]_+$$

$$P_{gh}(\xi, x) = 2C_F \left[\frac{1+(1-x)^2}{x}\frac{1}{1+\xi x} + (x-1)(x+2)\frac{\xi}{(1+\xi x)^2}\right]$$

Motivation



Modified n_f term in beta function:

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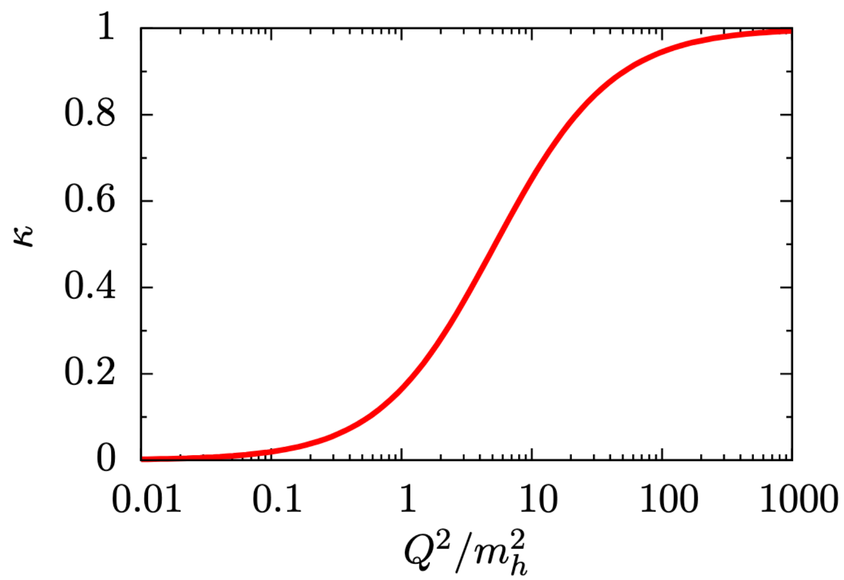


Emphasise: no matching procedure, the heavy quarks are encoded intrinsically within modified splitting functions in a smooth fashion through these scale and mass dependent rational factors and active at all scales

Physical Scheme coefficient functions

ACOT inspired approach:

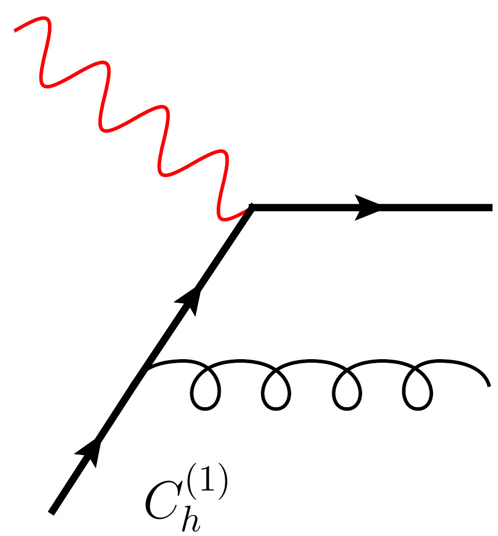
Subtraction term removes logarithmic collinear divergence

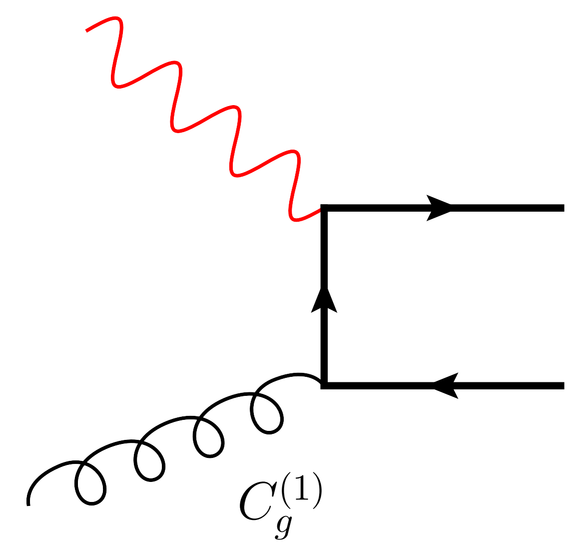
$$C_a^{(1),\mathrm{HQST}}(x,Q,m_h) = C_a^{(1),\mathrm{FF}}(x,Q,m_h) - \frac{\alpha_s(Q)}{4\pi} \sum_{b=g,q,h} C_b^{(0)}(x,Q,m_h) \otimes \int_0^{Q^2} \frac{d\mu^2}{\mu^2} P_{ba}^{(0),\mathrm{HQST}}(x,\xi)$$

- NLO HQST coefficient functions
- NLO FFNS coefficient functions[1,2]
- LO HQST coefficient functions
- LO HQST splitting functions

Note:

- Massless limit of Physical Scheme coefficient functions do *not* coincide with MSbar coefficient functions
- In limit recover collinear divergence but also *additional* (scale independent) term
- This additional term is compensated for in the evolution so that final predictions are scheme independent order by order in pertubation theory.



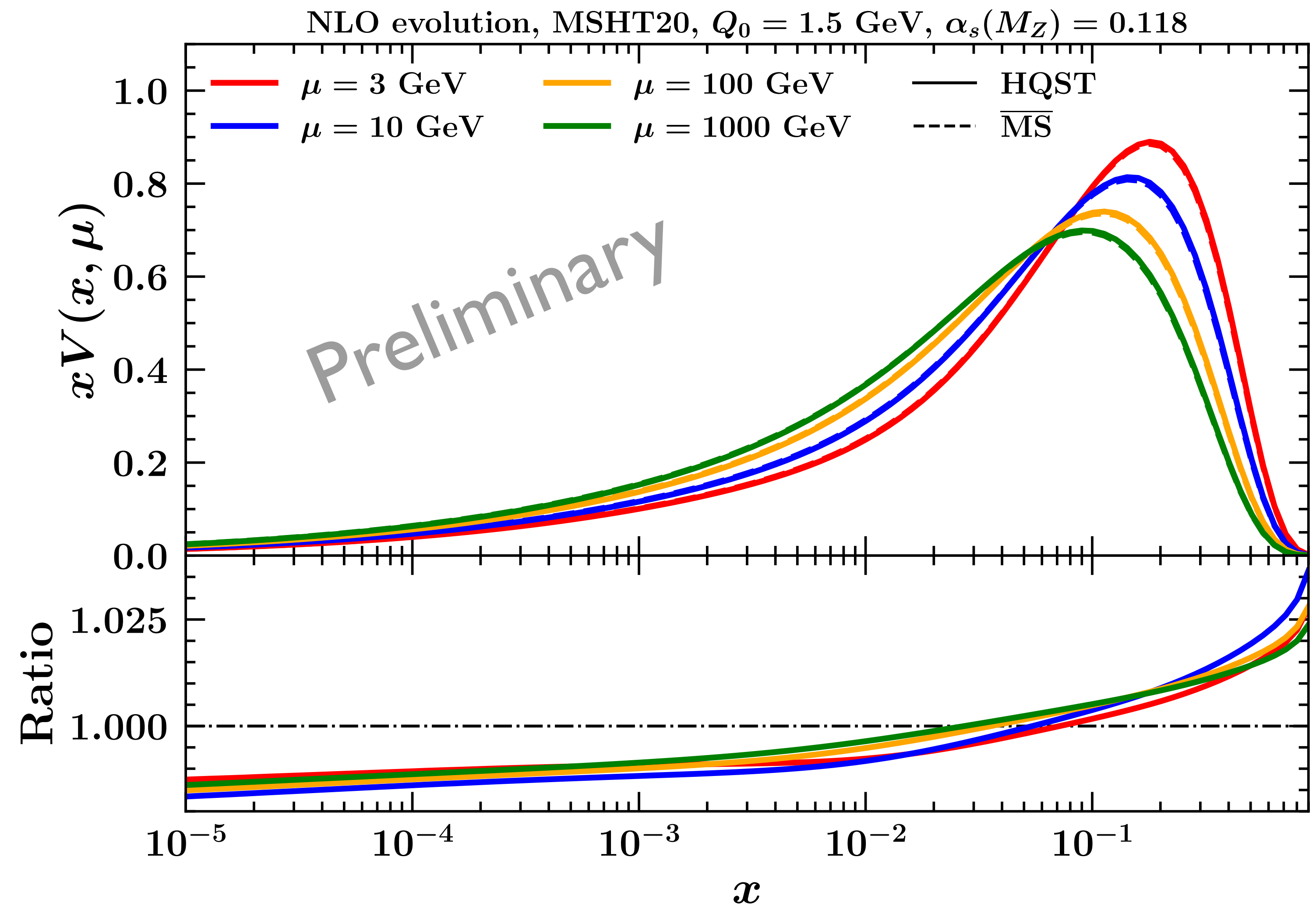


1 for a = g, see arXiv:1001.2312

2 for a = h, see hep-ph/9805233

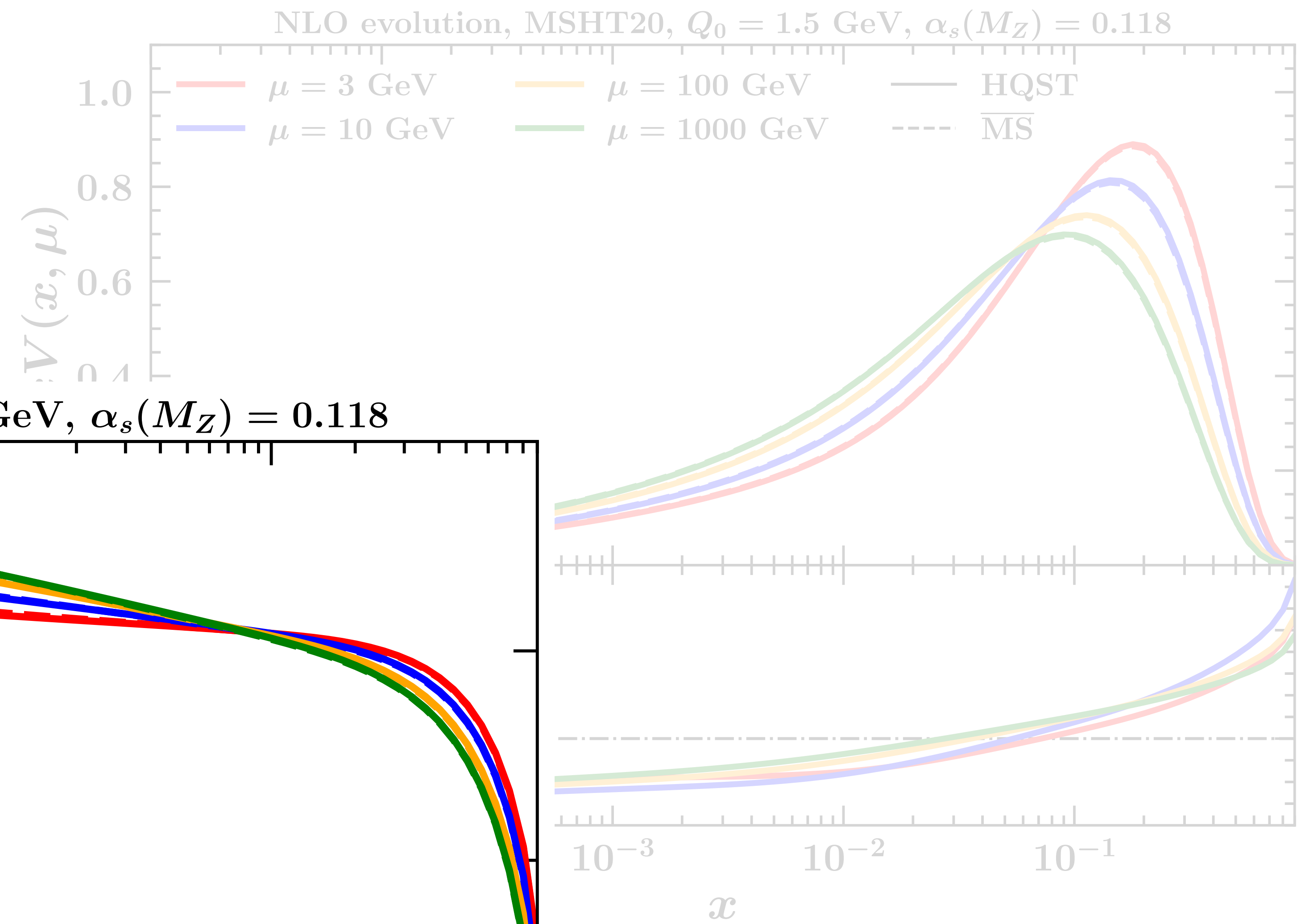
PDF evolution I

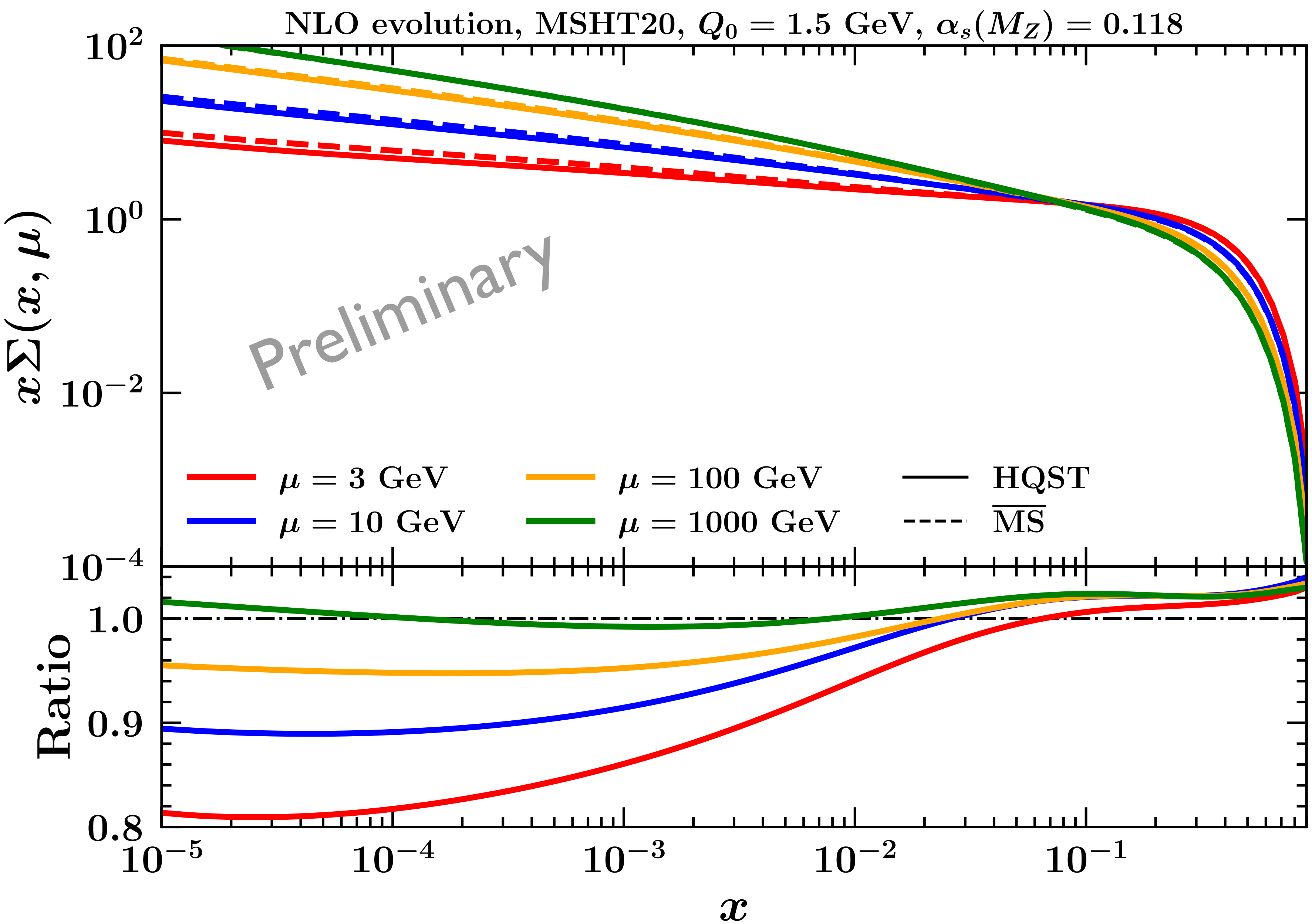
First: S-ACOT inspired approach:



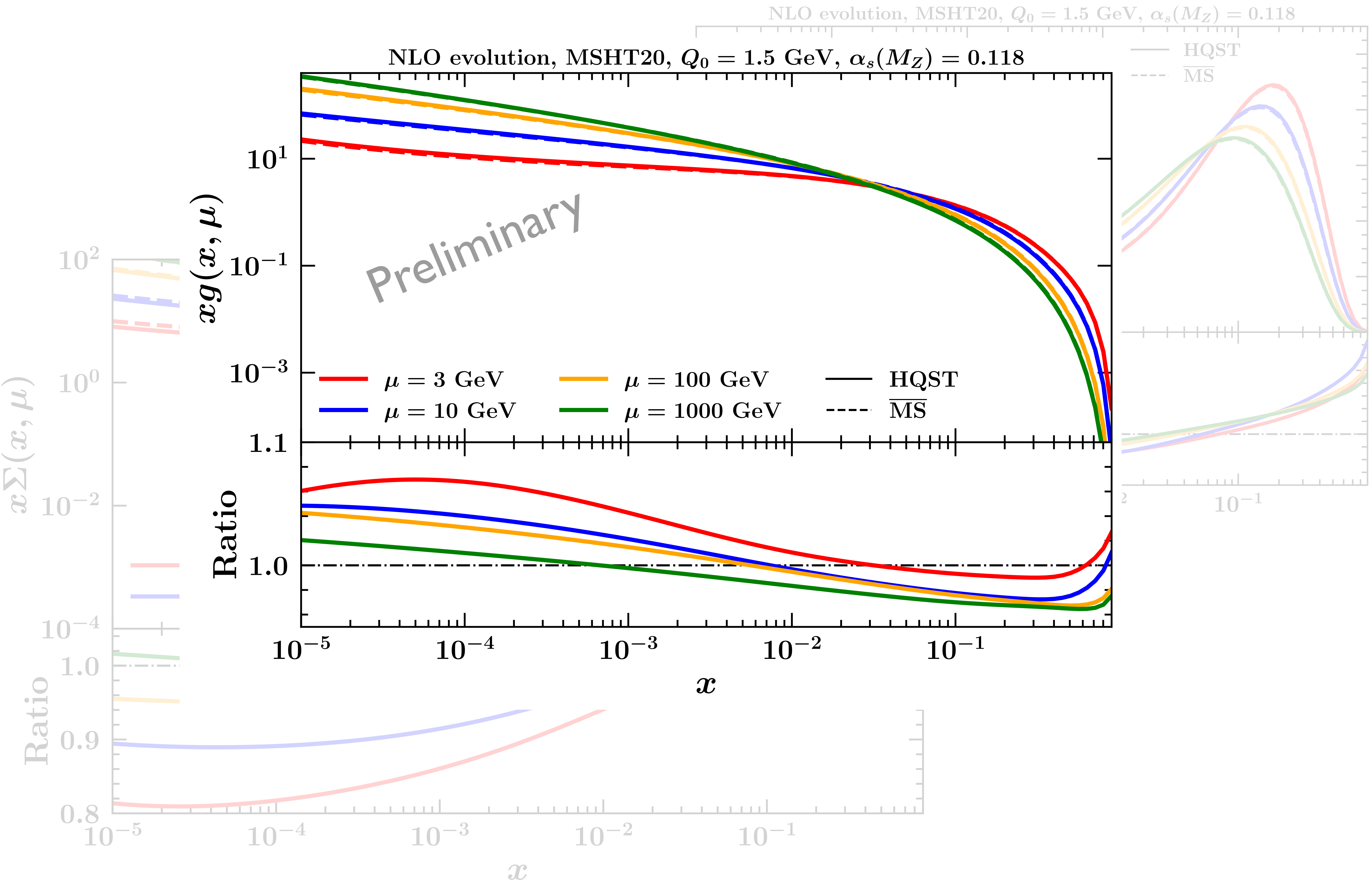
No scheme transformation performed at initial scale here so differences between evolutions obtained in the MSbar and Physical Schemes can be regarded as an upper limit. The final, resulting differences are compensated in the coefficient functions at a fixed order.

PDF evolution I

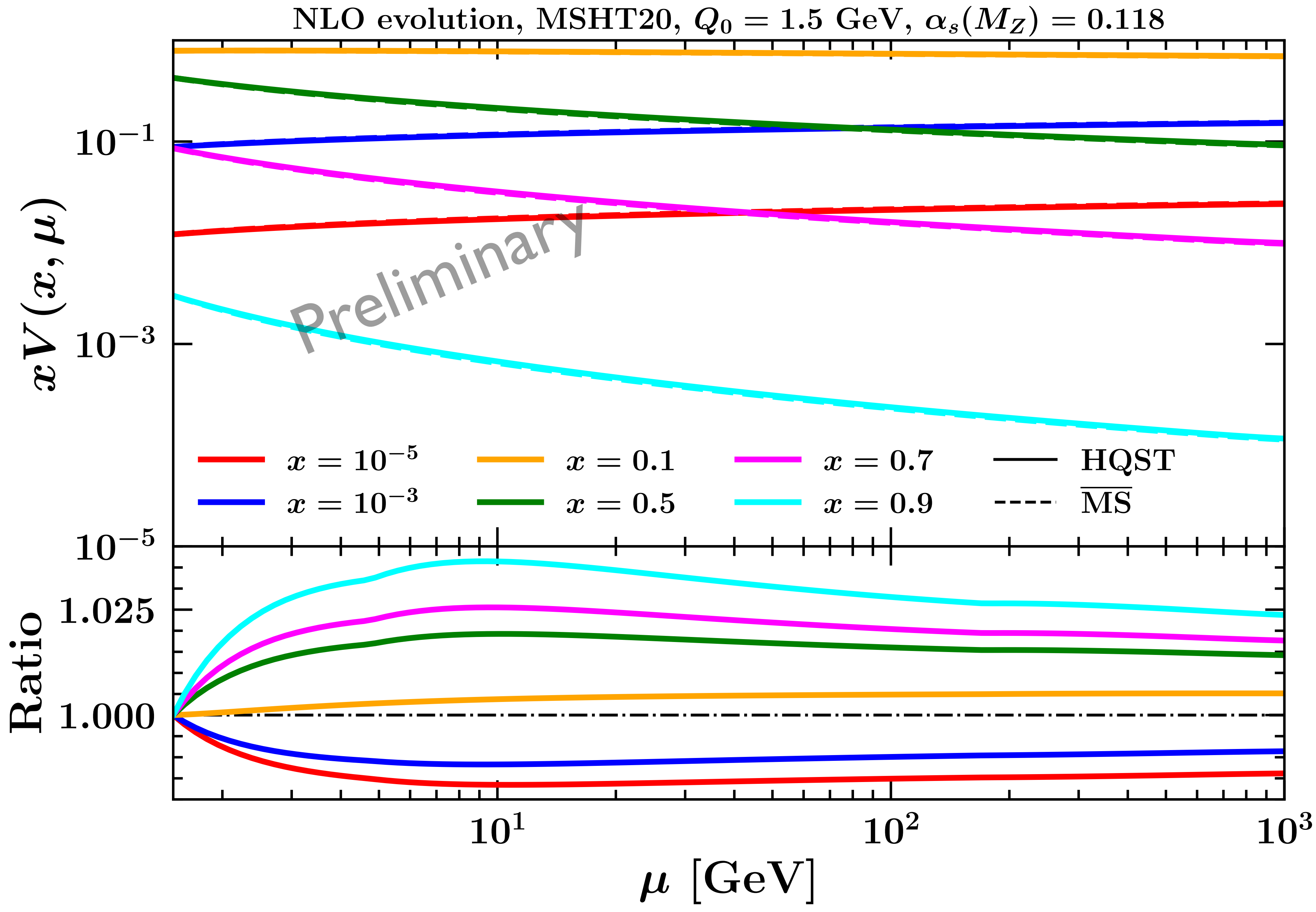




PDF evolution I



PDF evolution II



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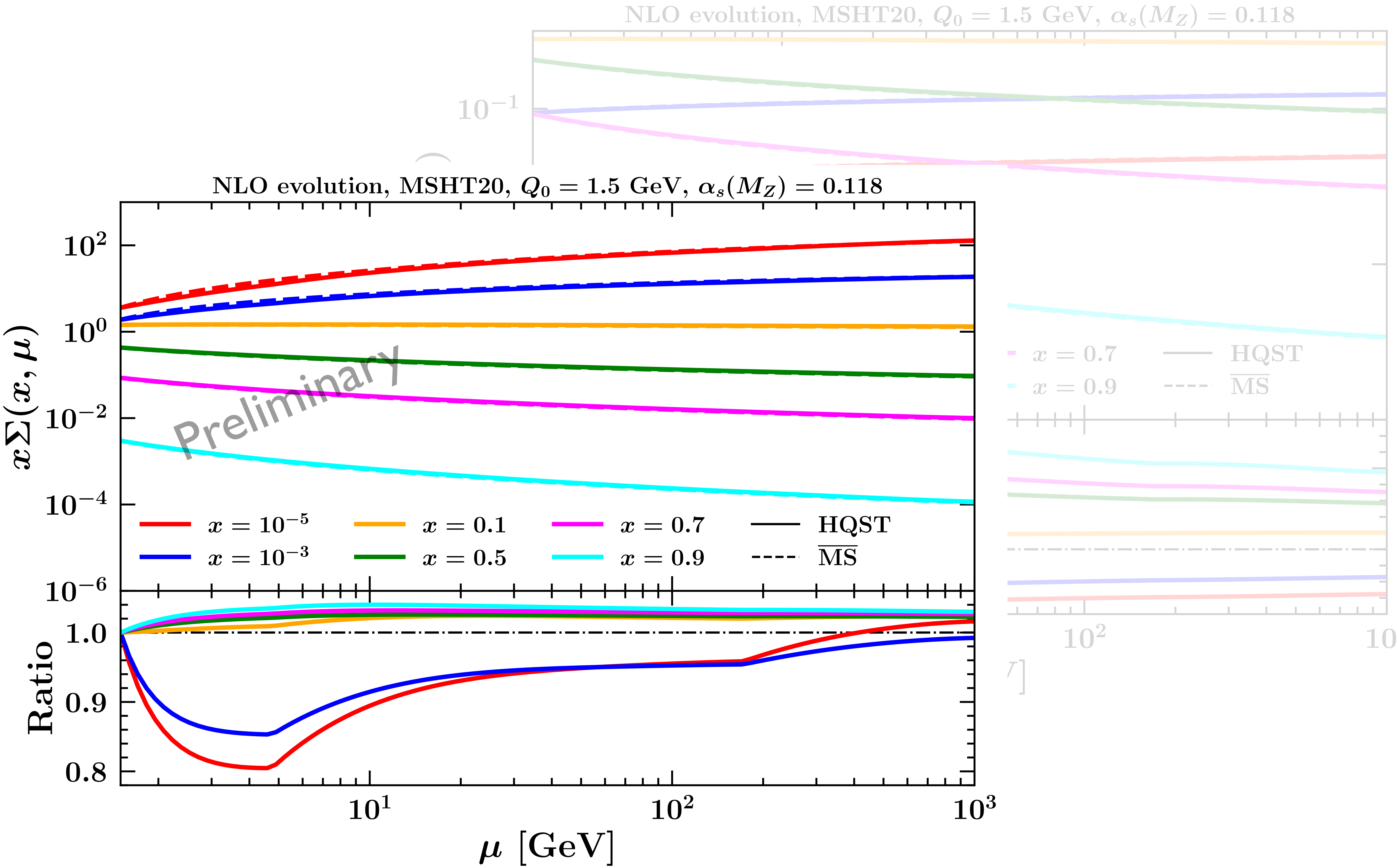
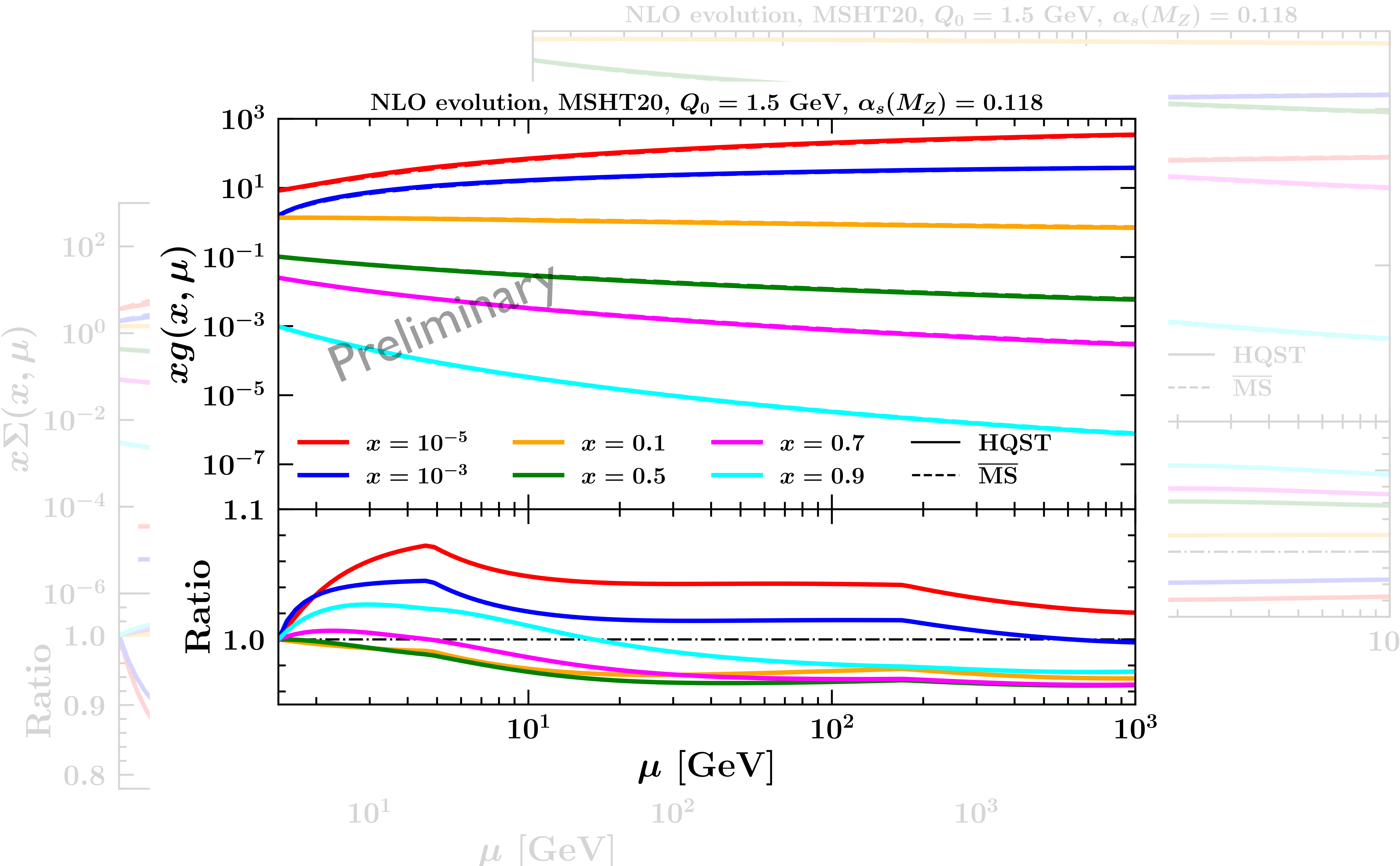


PDF evolution II



Structure functions

$$\frac{\mathrm{d}^2\sigma_{\rm NC}^{e^\pm p}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left(Y_+\tilde{F}_2^\pm \mp Y_- x\tilde{F}_3^\pm - y^2\tilde{F}_L^\pm\right)$$

with

$$\tilde{F}_{2,L}^\pm = F_{2,L} - v_e\left(\frac{\kappa_W Q^2}{Q^2+M_Z^2}\right)F_{2,L}^{\gamma Z} + (v_e^2+a_e^2)\left(\frac{\kappa_W Q^2}{Q^2+M_Z^2}\right)^2 F_{2,L}^Z$$

$$x\tilde{F}_3^\pm = \dots$$

and

$$F_{2,L}(x,Q,m_h) = \sum_a x\int_x^1 \frac{dy}{y} C_{a,2,L}(y,Q,m_h) f_a\left(\frac{x}{y},Q\right)$$

Here computed in HQST scheme

All numerical convolutions performed within APFEL++, which provides all the functionality

Conclusions and outlook

- Retainment of explicit heavy quark mass corrections within 'Physical Scheme'

  → Kinks in α_s in MSbar scheme apparent

  → Provides way for smooth transition over MSbar heavy quark thresholds

- Extract PDFs using DIS HERA data in the Physical Scheme to quantify effect of these corrections and compare to conventional MSbar approach

  → Interface to xFitter

- Important for precision studies and for upcoming statistics from HL-LHC

- State of the art of global PDF analyses is NNLO but first should understand size of effect at NLO