# Top PDFs

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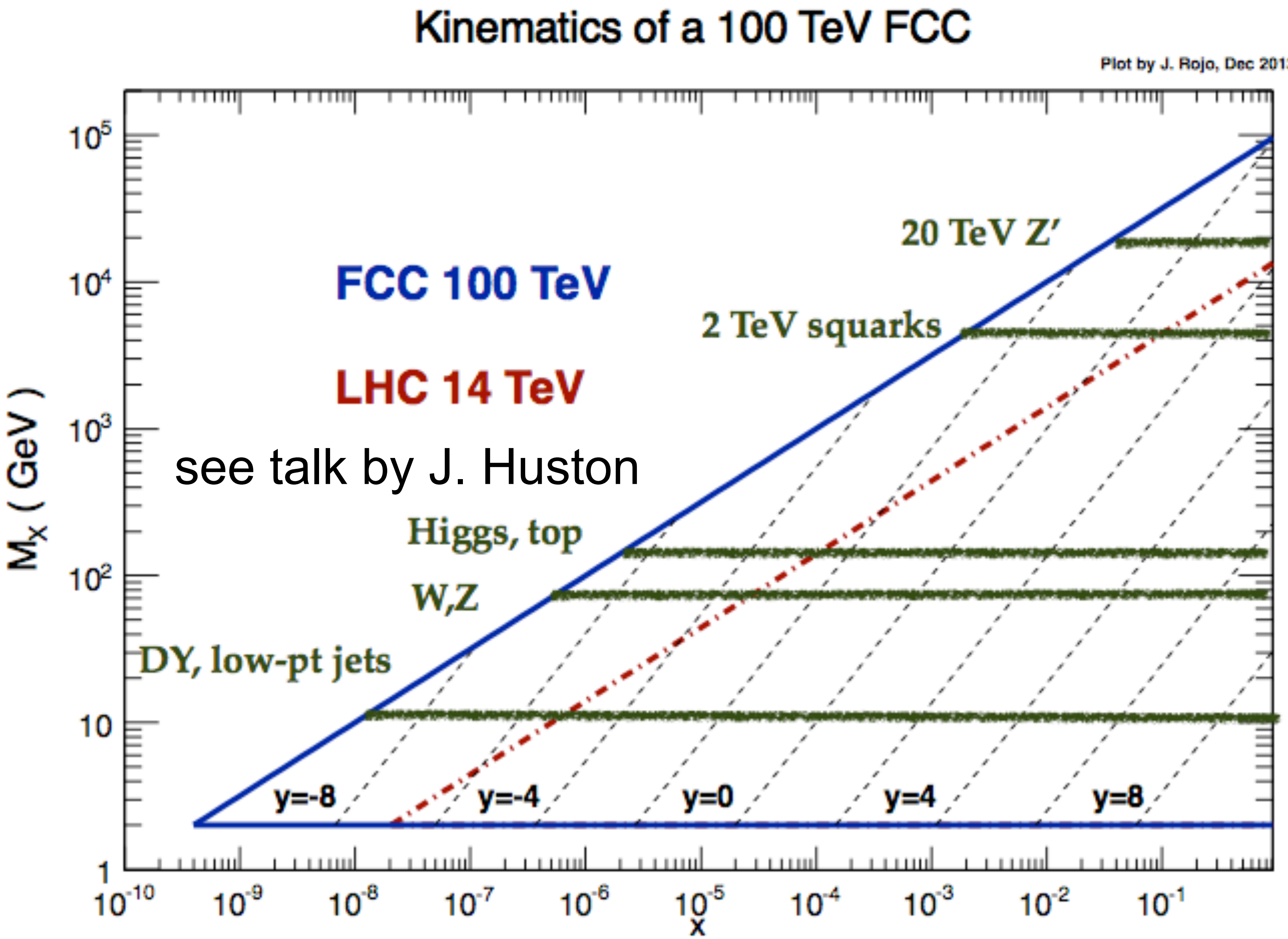
Workshop on Physics at a 100 TeV Collider
April 24, 2014

1405.xxxx
with Sally Dawson and Ian Low

# Outline

- Heavy quark PDFs
- Application: charged Higgs production
- Summary

# PDFs at a 100 TeV collider



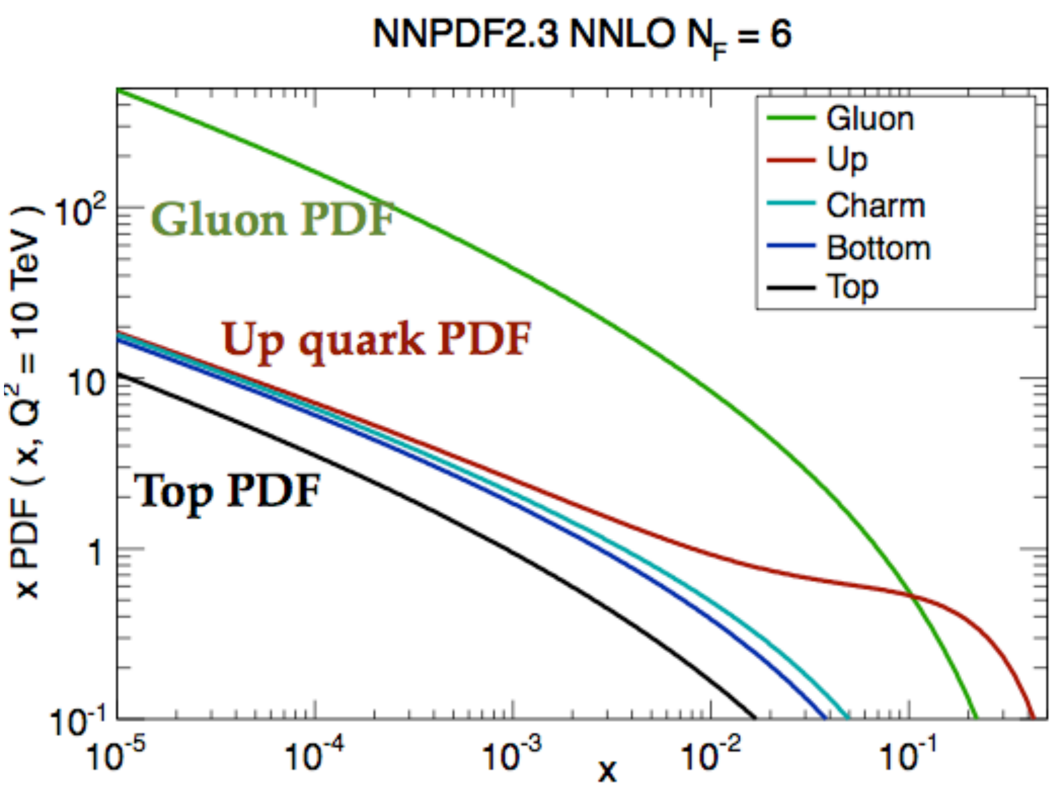

$x = M_X e^y / \sqrt{s}$

see talk by J. Huston

For given Bjorken x, probe heavier energy scales

# PDFs at a 100 TeV collider

- At 100 TeV, even “heavy” quarks have masses below scales of new processes
- Do we need to consider a top PDF?
- Most PDF sets only include five flavors

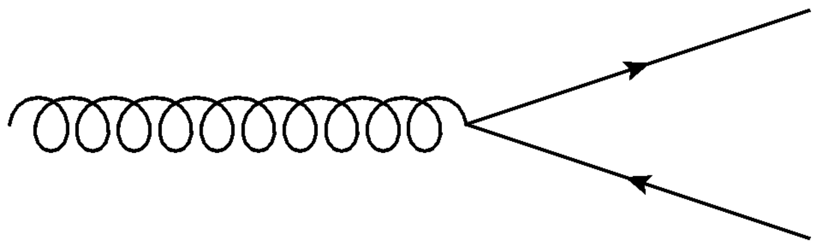



If included, top PDF is non-trivial in size at high scales

J. Rojo, Future Circular Collider Study Kickoff Meeting

# Heavy quark PDFs

- Arise from gluon splitting at scales above quark mass



- Should be able to approximate heavy quark PDF

$$\tilde{f}_Q(x,\mu) = \frac{\alpha_s(\mu)}{2\pi} \log\frac{\mu^2}{m_Q^2} \int_x^1 \frac{dz}{z} P_{qg}(z) f_g(\frac{x}{z},\mu)$$

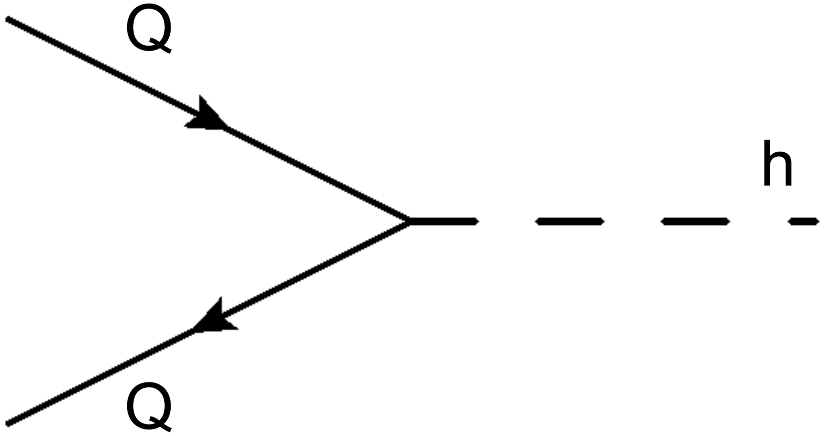
splitting function

$$P_{qg}(z) = \frac{1}{2}(z^2 + (1-z)^2)$$

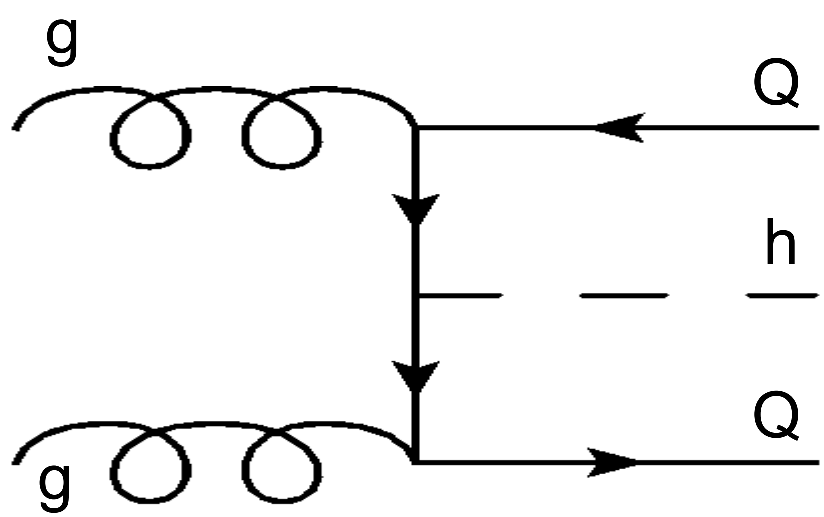
gluon PDF

# Heavy quark PDFs

- If we could calculate to infinite order, it wouldn't matter whether we used a heavy quark PDF or not
- As an example, consider h + X production in the PDF schemes with and without the heavy quark



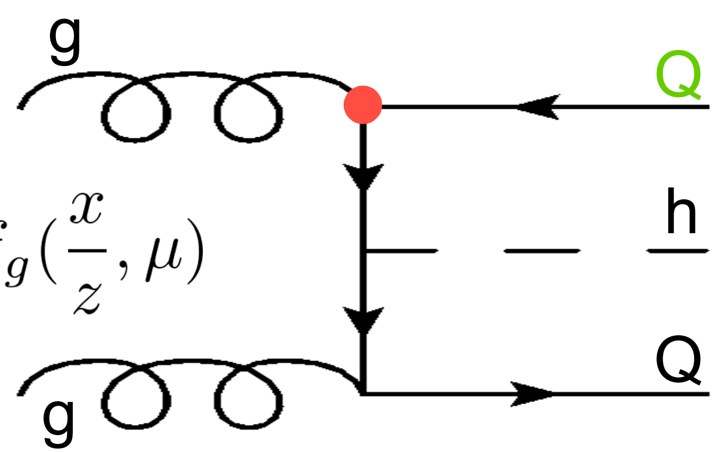

Massless scheme
NF = N




Massive scheme
NF = N - 1

# Heavy quark PDFs

- In the scheme without a heavy quark PDF, the leading diagram for h + X production has a collinear divergence
- When we integrate over the phase space for Q, we pick up a factor $\log(m_h / m_Q)$, as the quark mass regulates this divergence
- At large $m_h$, this is just the approximate heavy quark distribution




$$\tilde{f}_Q(x,\mu) = \frac{\alpha_s(\mu)}{2\pi} \log \frac{\mu^2}{m_Q^2} \int_x^1 \frac{dz}{z} P_{qg}(z) f_g(\frac{x}{z},\mu)$$

see also Dicus et al., hep-ph/9811492

# Heavy quark PDFs

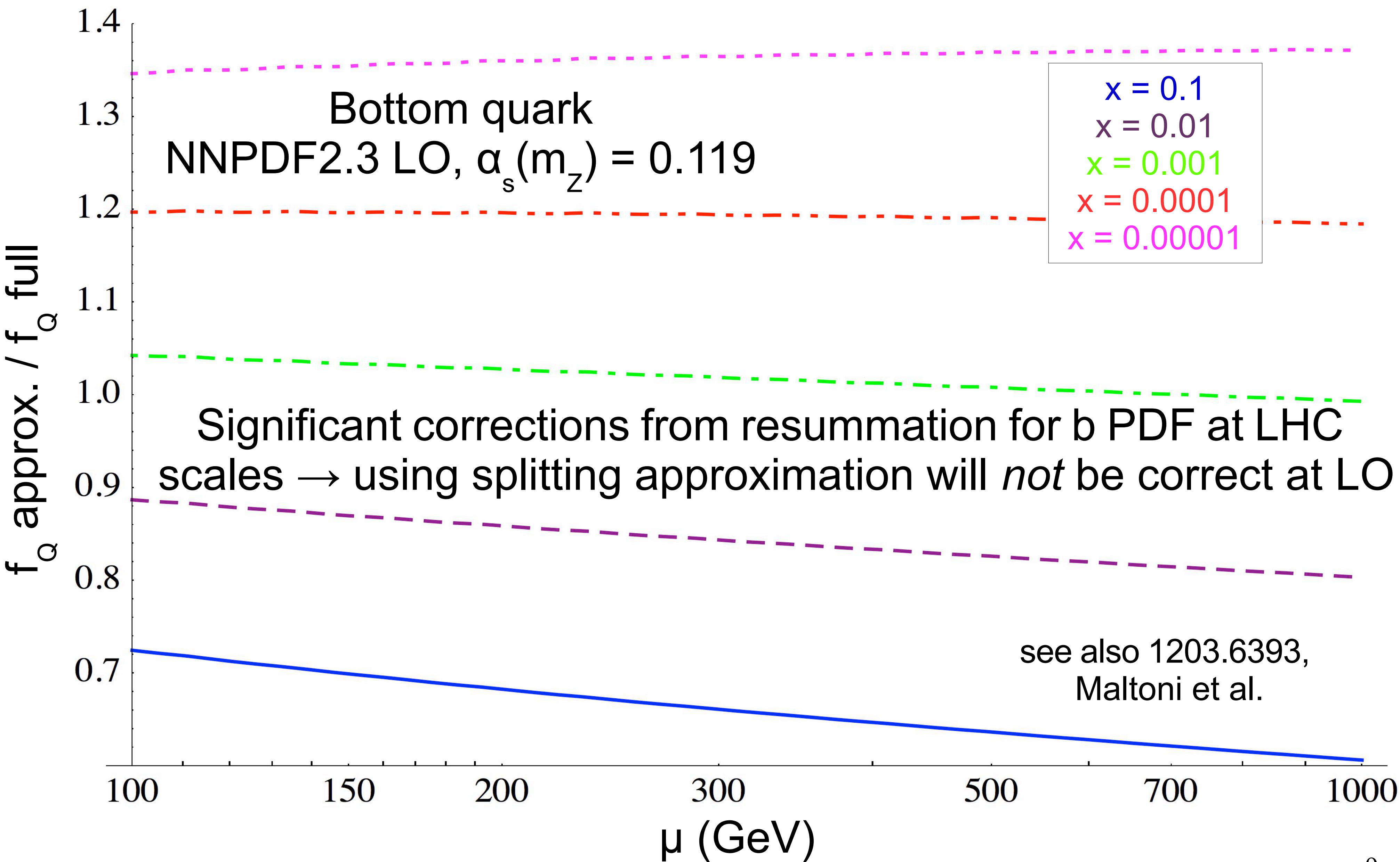
- To get the full heavy quark PDF at leading order, we would have to numerically solve the LO DGLAP equations

$$\frac{d}{d\log\mu^2} f_Q(x,\mu) = \frac{\alpha_s(\mu)}{2\pi}\int_x^1 \frac{dz}{z}\Big(P_{qq}(z) f_Q(\frac{x}{z},\mu) + P_{qg}(z) f_g(\frac{x}{z},\mu)\Big)$$

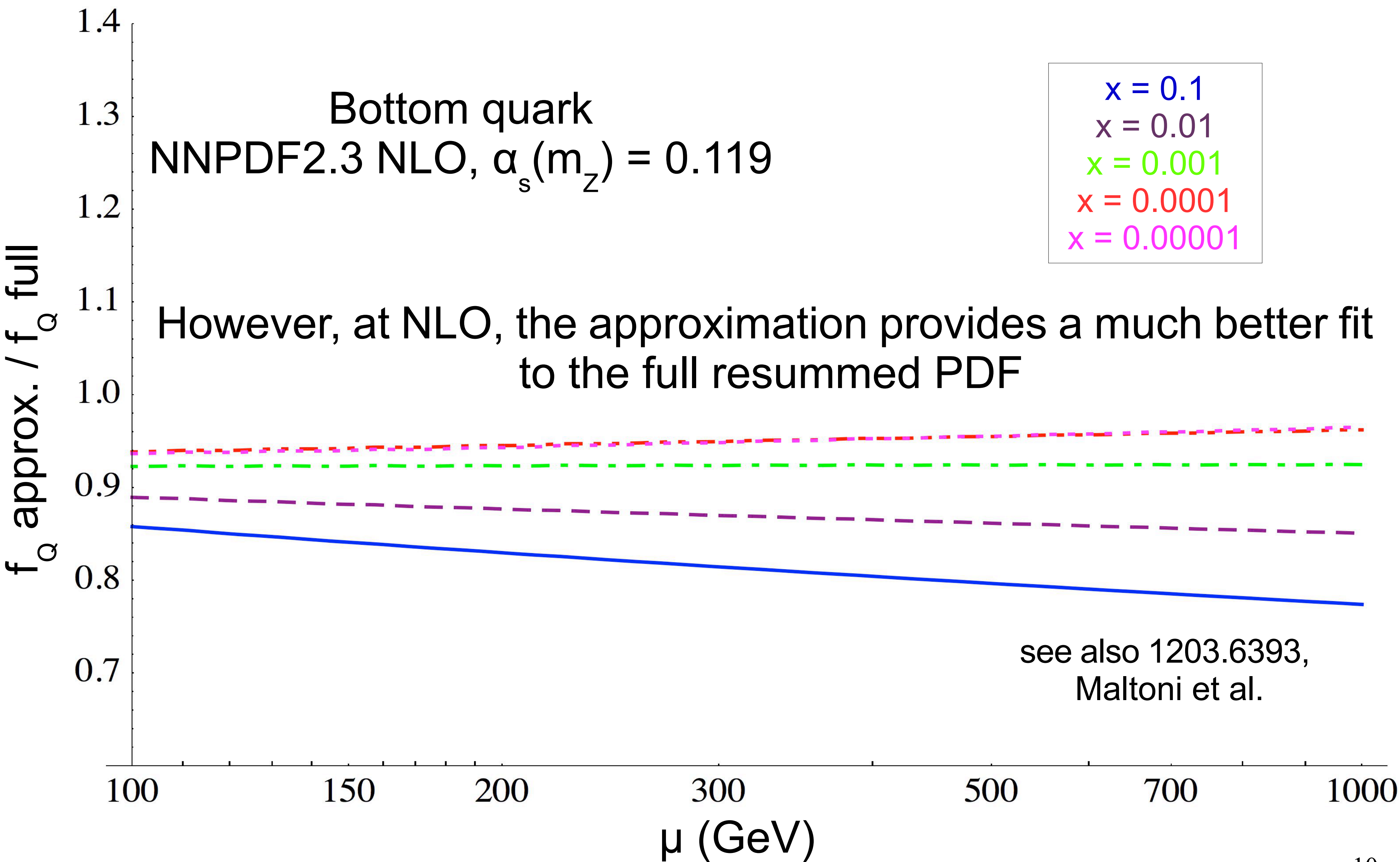
$$f_Q(x, m_Q) = 0$$

- Physically, the difference between our approximation and the full LO heavy quark PDF is the resummation of the logarithms corresponding to multiple parton splittings that are strongly ordered
- How important is this resummation?

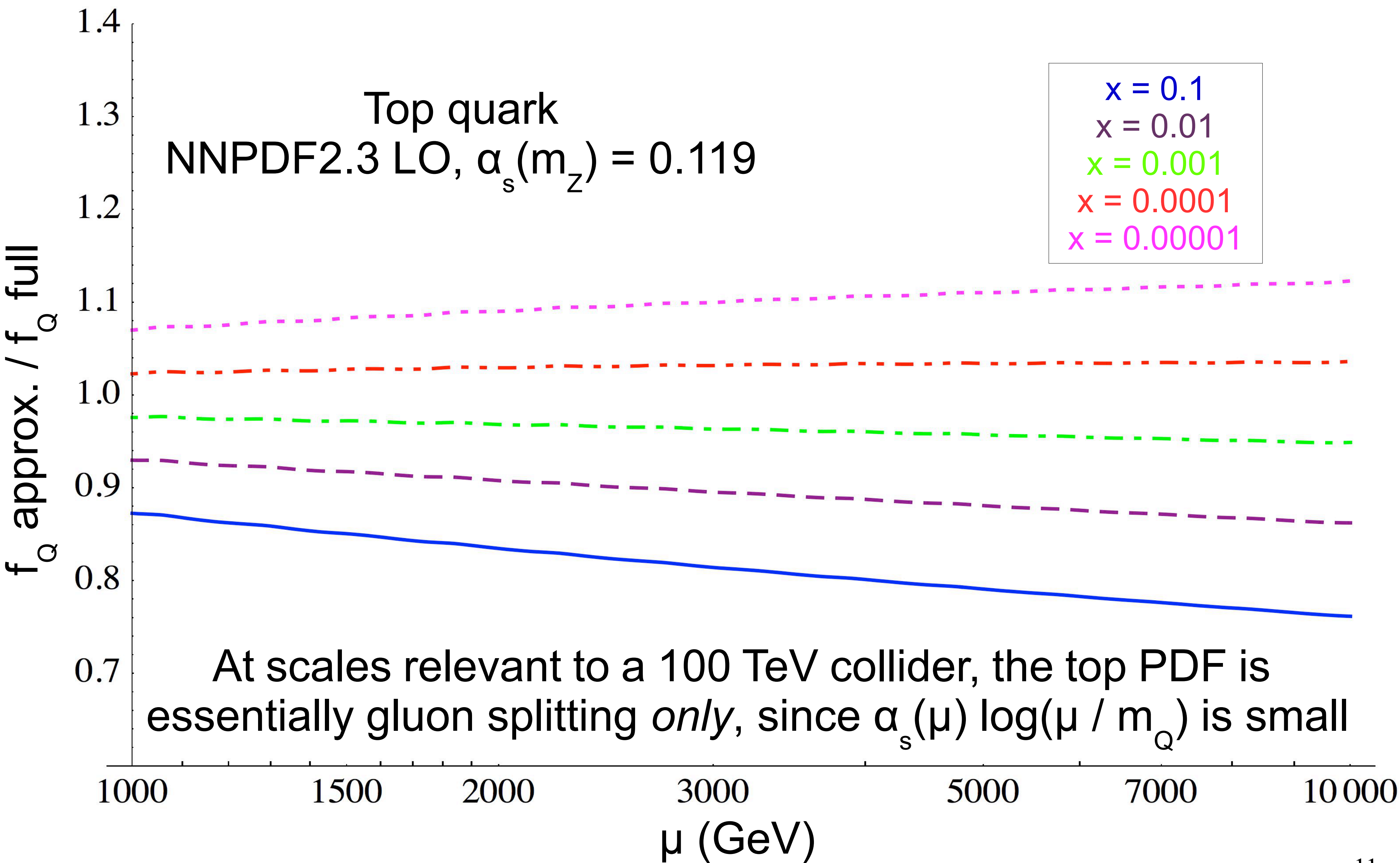
# Approximation versus resummation



# Approximation versus resummation



# Approximation versus resummation



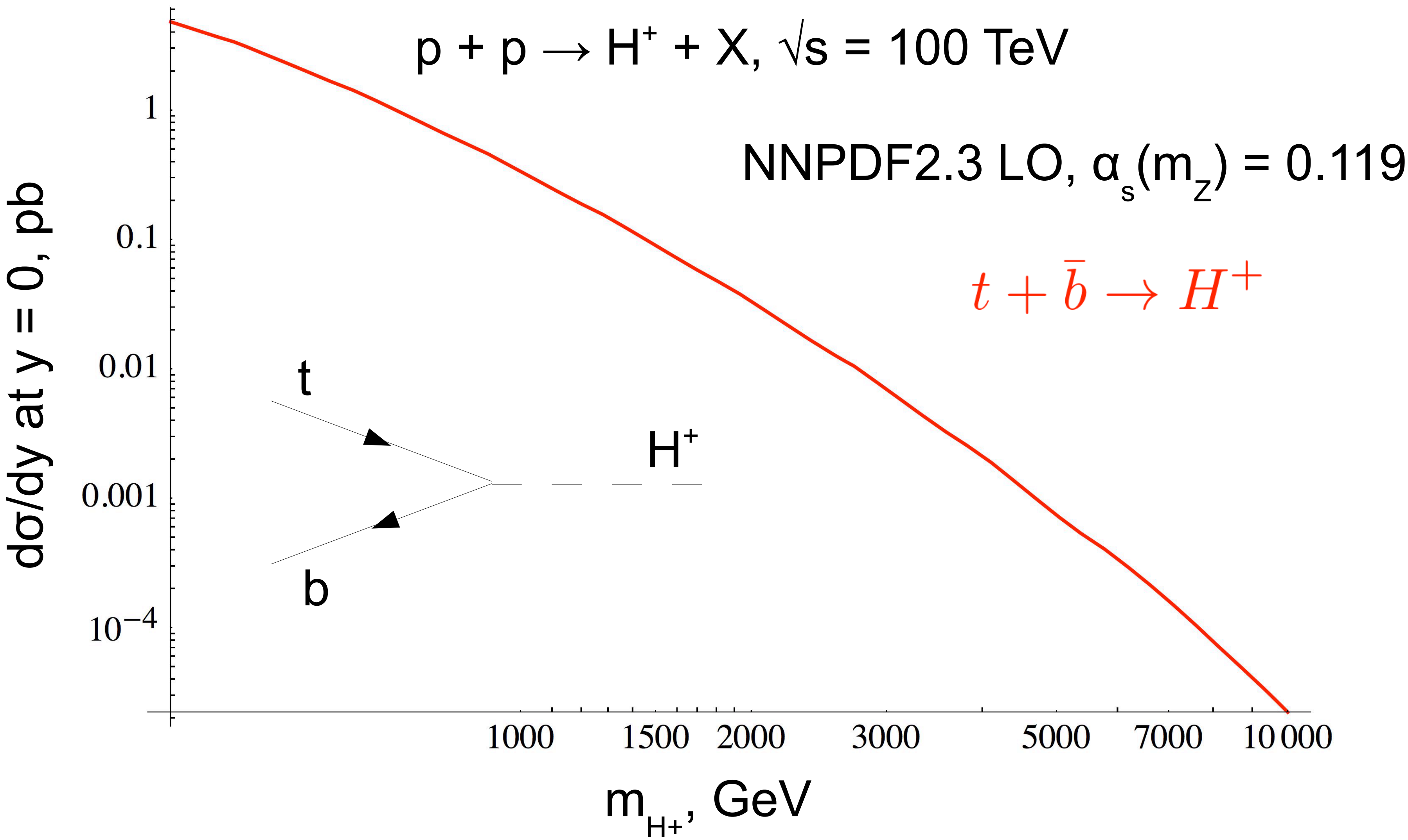
# Charged Higgs production

- We can now apply our PDF studies to a sample process at 100 TeV
- Charged Higgses are generic in models with additional Higgs multiplets, with significant couplings to heavy quarks
- To what extent must we calculate $H^+$ production using a top PDF?

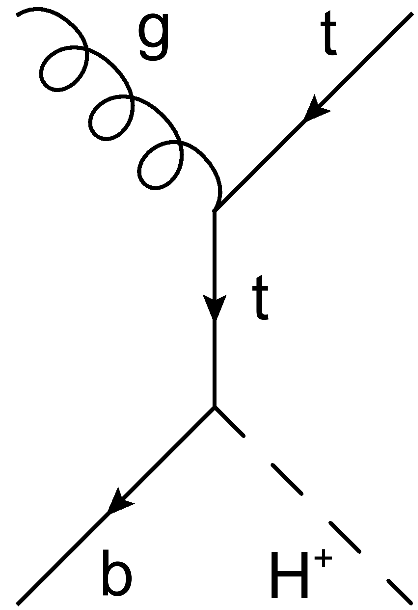
  Barnett, Haber and Soper, Nucl. Phys. B306 (1988) 697
  Olness and Tung, Nucl. Phys. B308 (1988) 813
- We will outline the computation of the cross section in the NF = 6 scheme, including the top PDF
- Assume MSSM-type couplings with tan $\beta$ = 5 for numerics, but this is just an overall factor

# Charged Higgs production

- Leading diagram is $t + \bar{b} \to H^+$



# Charged Higgs production




- At next order, have $g + \bar{b} \to \bar{t} + H^+$

  (note this is the leading diagram for NF = 5)

- In the limit $m_t \to 0$, this process has a divergence

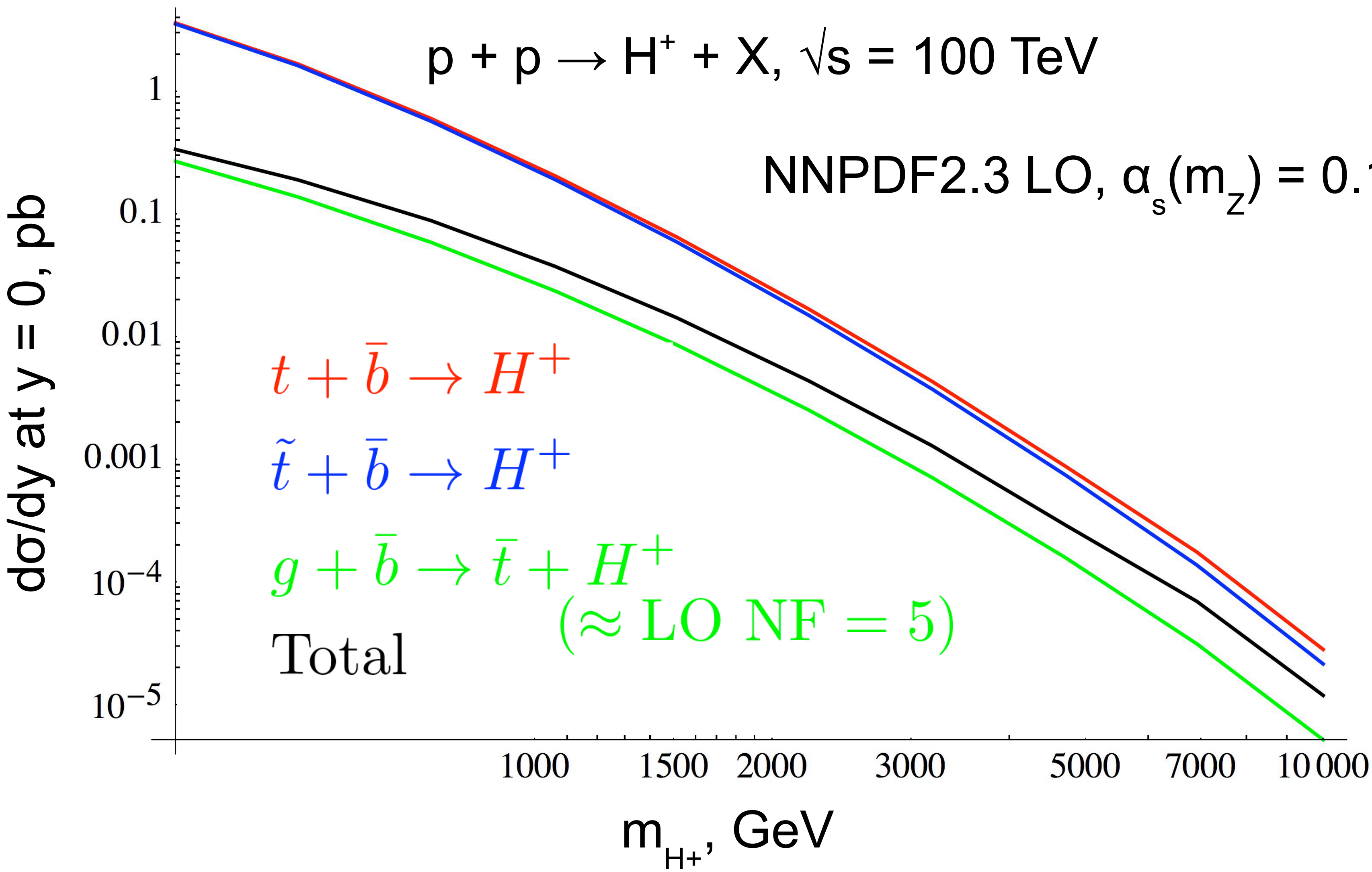
- Adding it to the leading process $t + \bar{b} \to H^+$ would be double-counting the gluon splitting to a collinear pair, so need to perform subtraction

$$\tilde{f}_Q(x,\mu) = \frac{\alpha_s(\mu)}{2\pi} \log \frac{\mu^2}{m_Q^2} \int_x^1 \frac{dz}{z} P_{qg}(z) f_g(\frac{x}{z},\mu)$$

| | | | |
|---|---|---|---|
| $\alpha_s \log \frac{m_H}{m_t}$ | $\alpha_s^2 \log^2 \frac{m_H}{m_t}$ | $\alpha_s^3 \log^3 \frac{m_H}{m_t}$ | $\ldots$ |
| $\alpha_s$ | $\alpha_s^2 \log \frac{m_H}{m_t}$ | $\alpha_s^3 \log^2 \frac{m_H}{m_t}$ | $\ldots$ |
| | $\alpha_s^2$ | $\alpha_s^3 \log \frac{m_H}{m_t}$ | $\ldots$ |
| | | $\ldots$ | $\ldots$ |

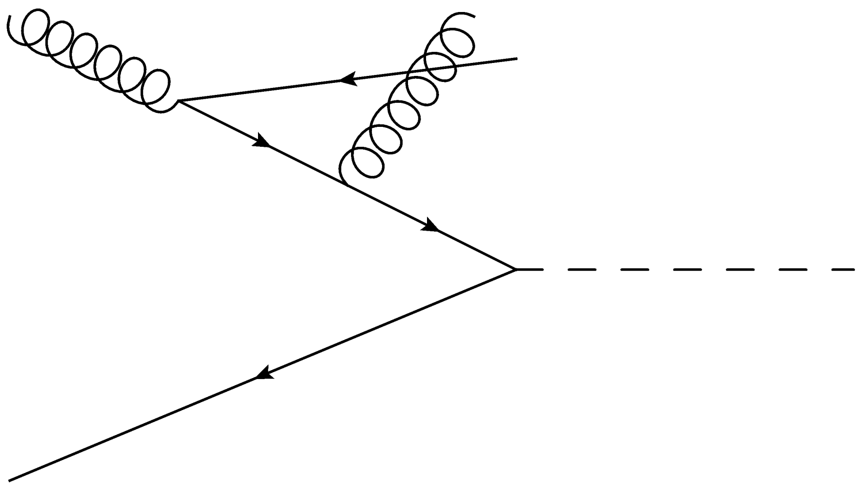
# Charged Higgs production

- Subtraction term is $\tilde{t} + \bar{b} \to H^+$ with approximate LO top PDF



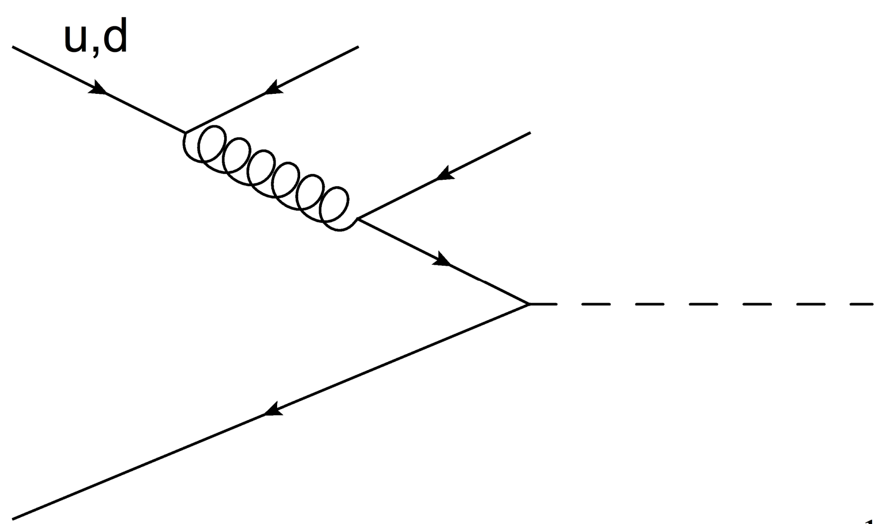
# Charged Higgs production

- The cross section is now complete up to terms of order $\alpha_s^2$ (log $m_H$ / $m_t$) and higher
- Full NLL requires a few more components
  - NLO PDFs rather than LO PDFs



out of order splittings

splittings from light quarks



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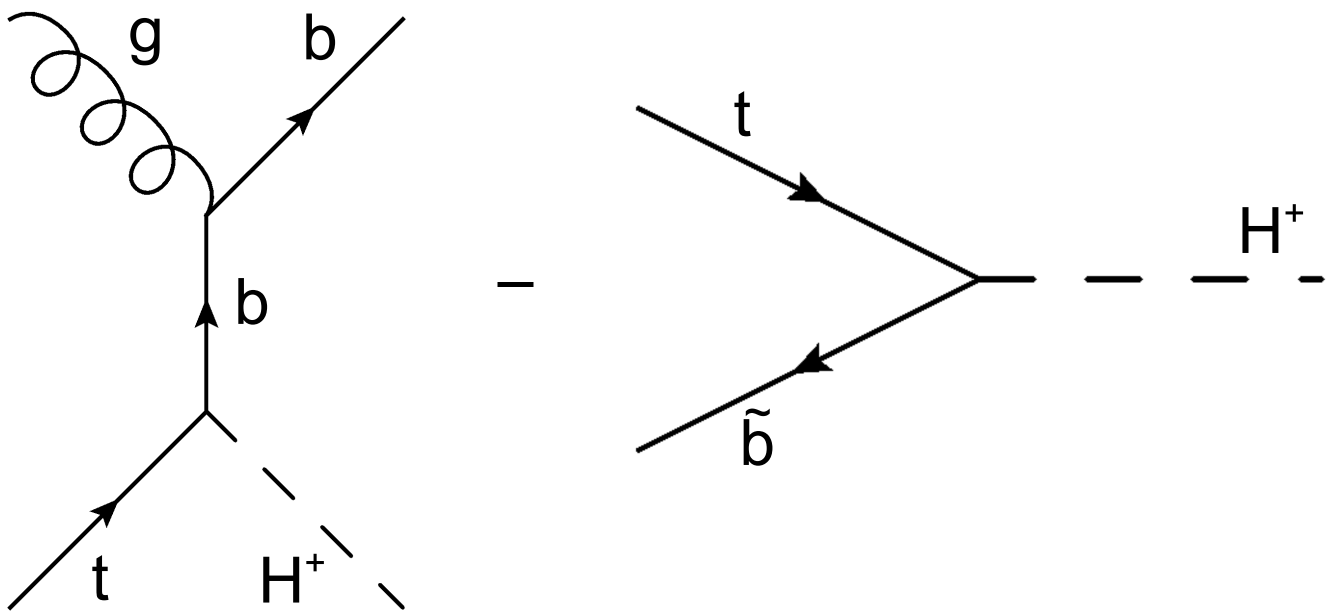
  - The log-suppressed process $g + t \to b + H^+$ with the appropriate subtraction term



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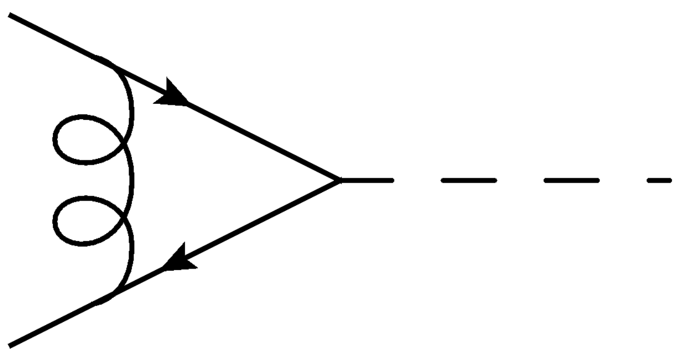
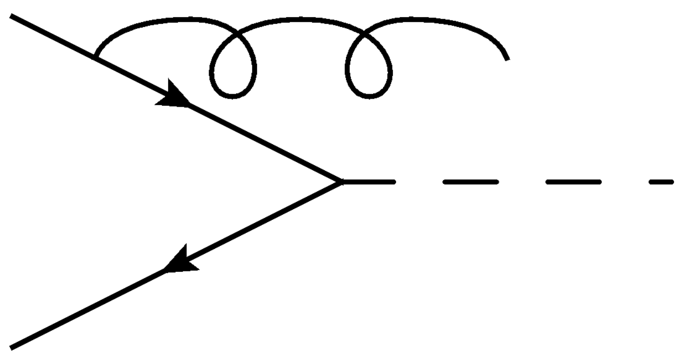
  - The log-suppressed process $g + t \to b + H^+$ with the appropriate subtraction term
  - The virtual and real corrections to $t + \bar{b} \to H^+$





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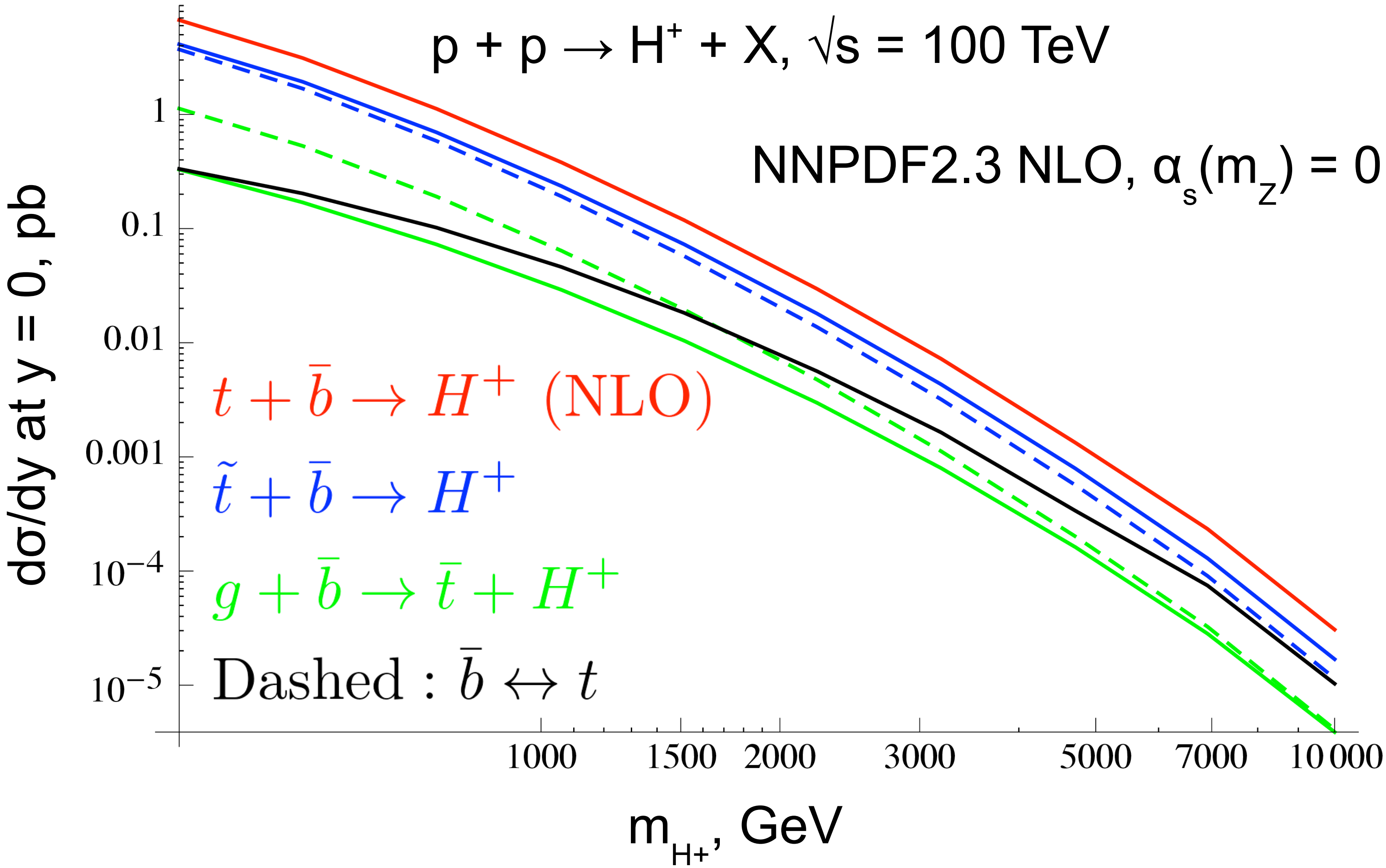
| | | $\ldots$ | $\ldots$ |

# Charged Higgs production

- Total cross section is well approximated by the NF = 5 scheme up to factors of a few at very large $H^+$ mass



# Summary

- The accessibility of high scales at a 100 TeV collider motivates a careful consideration of the top PDF
- Because of $\alpha_s$ running and the heavy top mass, the gain from using a top PDF at a 100 TeV collider is less than that from using a bottom PDF at the LHC
- At very high scales, effect of resummed logs contained in top PDF can change calculated cross sections by a factor of a few, but this translates into only slight changes in search reach
- Otherwise, simple gluon splitting in a five-flavor scheme can capture most of the effective top PDF