A fragmentation-based study of heavy quark production

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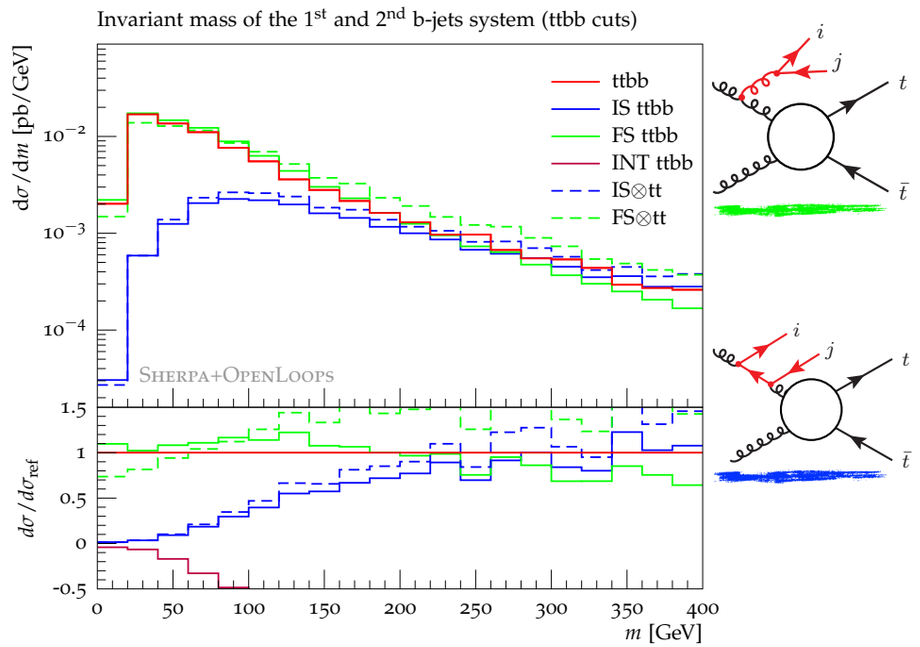
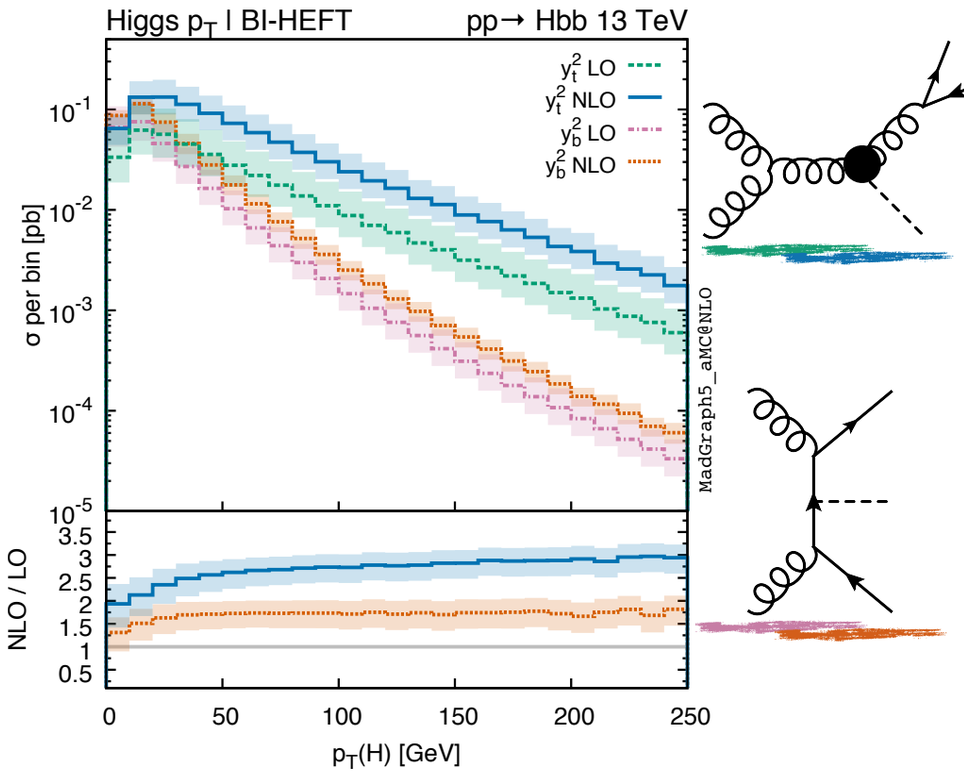
In collaboration with Giovanni Ridolfi and Maria Ubiali

(to appear)

On the simulation of processes with final-state $g \to b\bar{b}$ splittings

- Processes relevant for Higgs physics receive large contributions from topologies with final-state $g \to b\bar{b}$ splittings
- $t\bar{t}b\bar{b}$ is one example: FS splittings dominant in most PS
  Jezo et al, arXiv:1802.00426
- Another example is ggH+$b\bar{b}$, which dominates H$b\bar{b}$ producion
  Maltoni, Deutschmann, Wiesemann, MZ, arXiv:1808.01660
- Is it appropriate to simulate these splittings at the matrix-element level?





A close look on a $g \to b\bar{b}$ splitting

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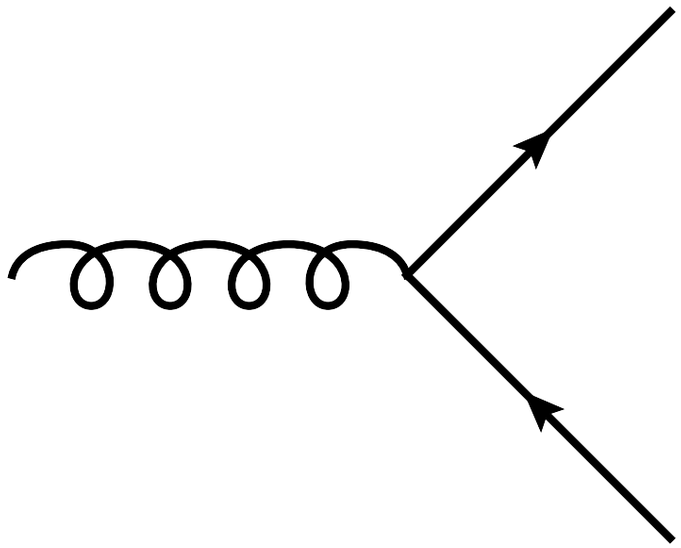

LO

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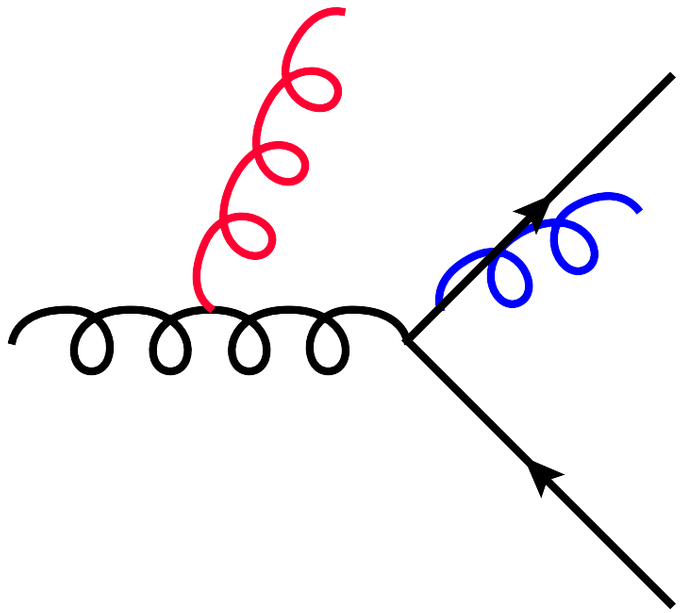
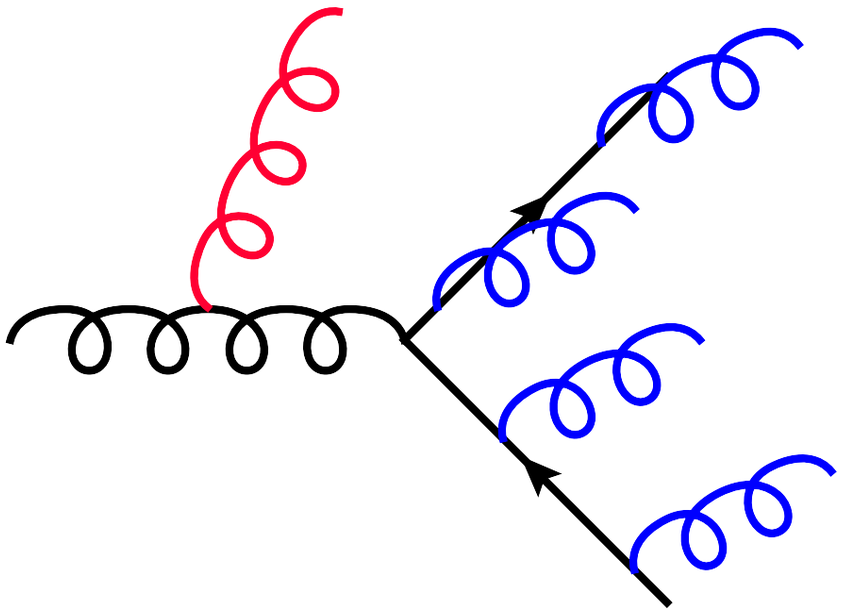


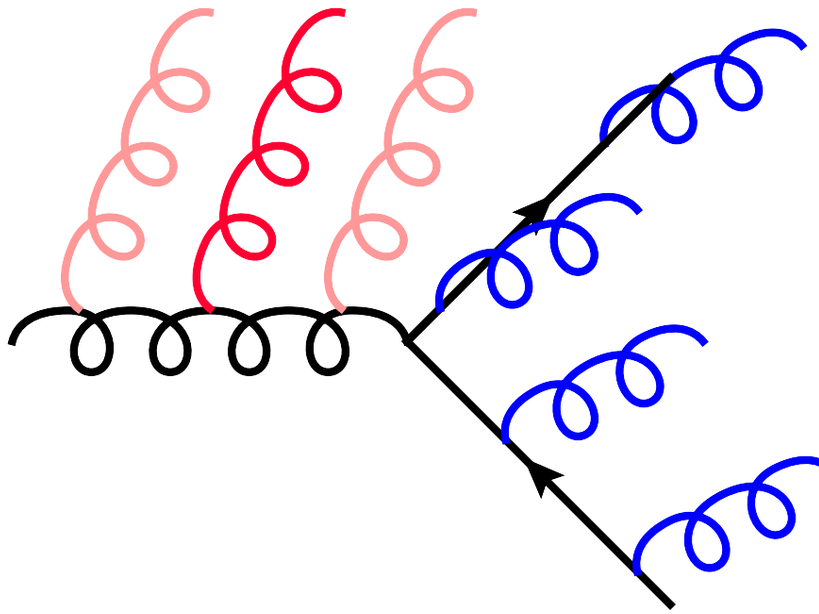
NLO

A close look on a $g \to b\bar{b}$ splitting



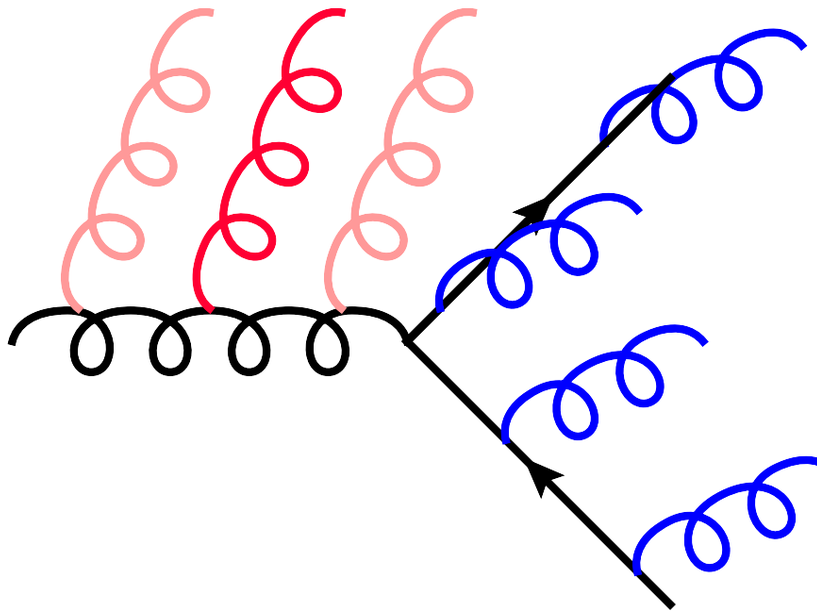
NLO+PS

A close look on a $g \to b\bar{b}$ splitting



QCD evolution

A close look on a $g \to b\bar{b}$ splitting



QCD evolution

- Extra radiation off parent gluon missing if b quarks generated at ME level, even at NLO+PS
  →How important is it?

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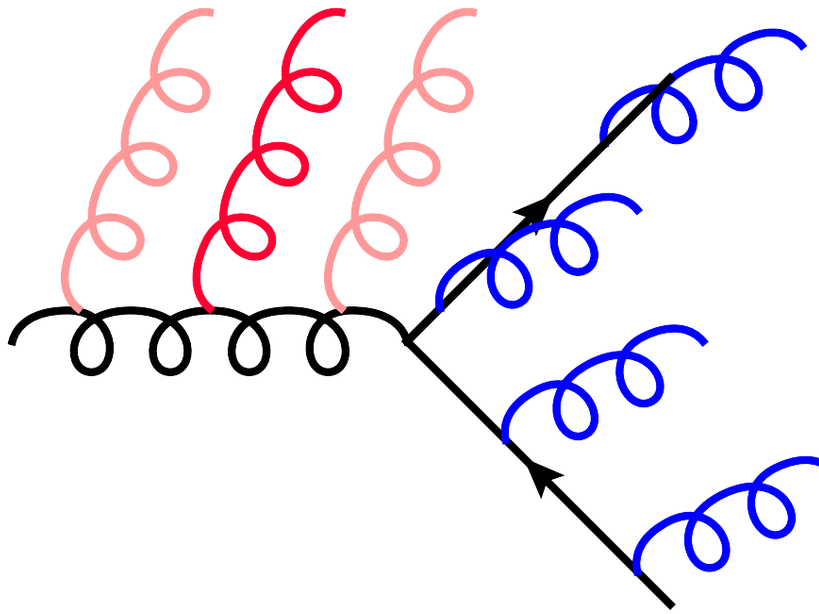
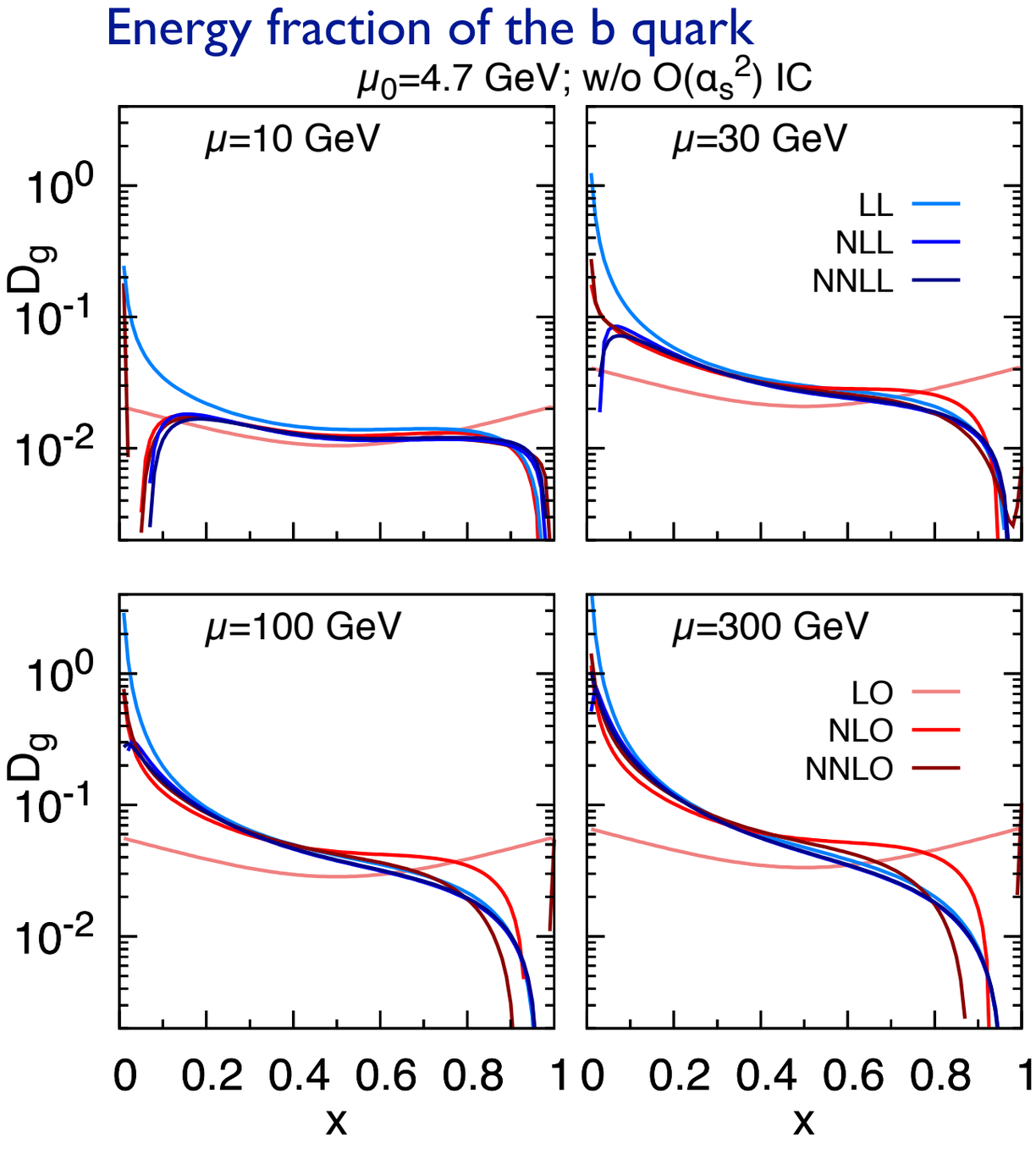


QCD evolution

- Extra radiation off parent gluon missing if b quarks generated at ME level, even at NLO+PS
  → How important is it?
- Importance can be assessed using fragmentation functions
  - FFs include collinear emissions at all orders and resum $\log(\mu_F/m)$
  - Use FFs at different logarithmic accuracy and their truncation at different orders of α_s.
    Truncated results ⟺ fixed-order computations
  - Evolution up to NNLL provided by MELA
    Bertone et al, arXiv:1501.00494

A fragmentation-based study of $g \to b\bar{b}$ splittings



- LO shape does not change with scale
  - ✦ Not reliable prediction
- Resummed predictions very close to each other
  - ✦ Correct shower description (LL) for gluon fragmentation
- NLO prediction harder than resummed ones (+70% for μ=100GeV)
- NNLO has decent agreement with resummed predictions
  - ✦ Justifies $t\bar{t}b\bar{b}$+jet @NLO as reference for $t\bar{t}b\bar{b}$
- Dominant effect from radiation off the parent gluon
  - ✦ Not included when b quarks are generated at the ME level
  - ✦ Large effect on *exclusive* observables

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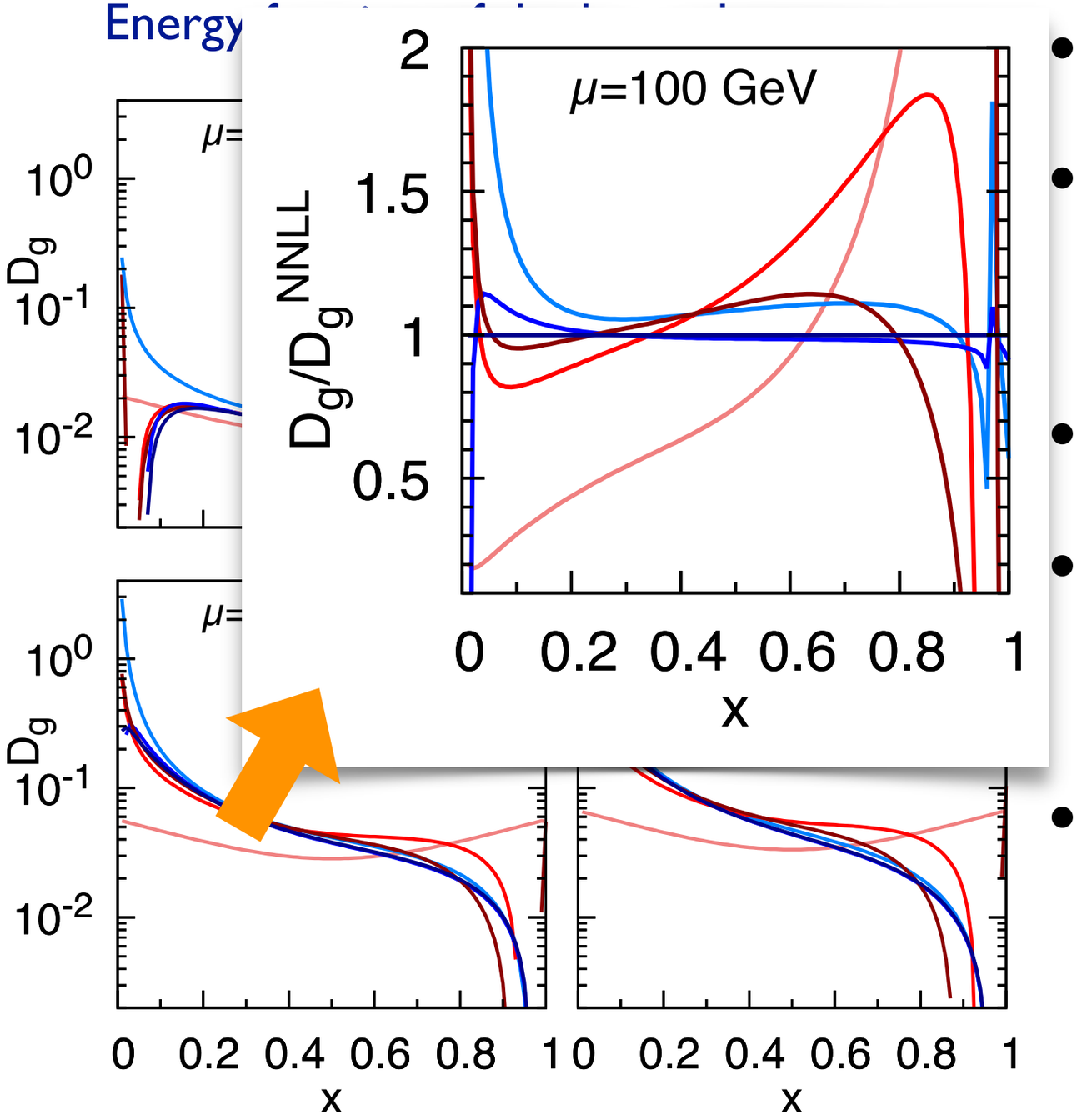

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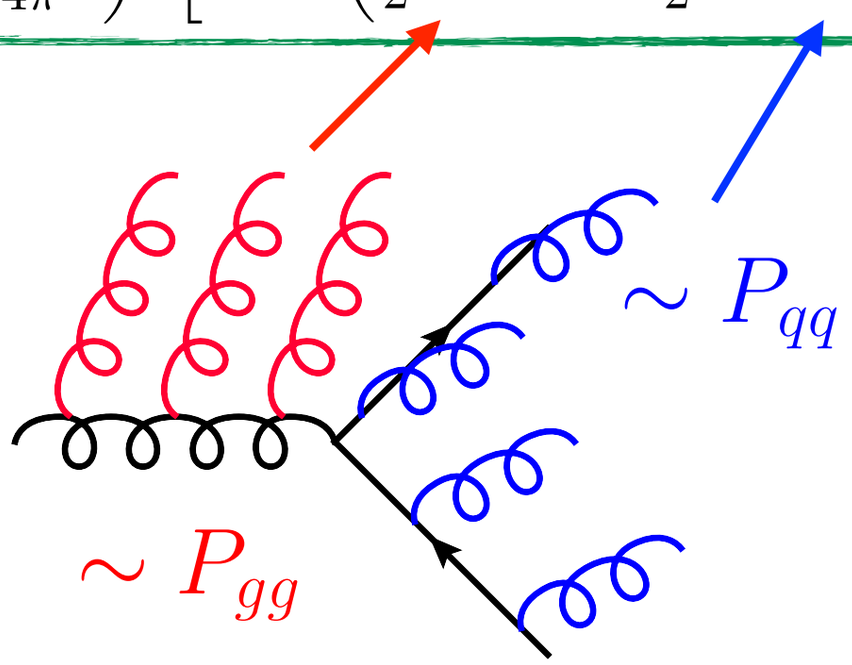
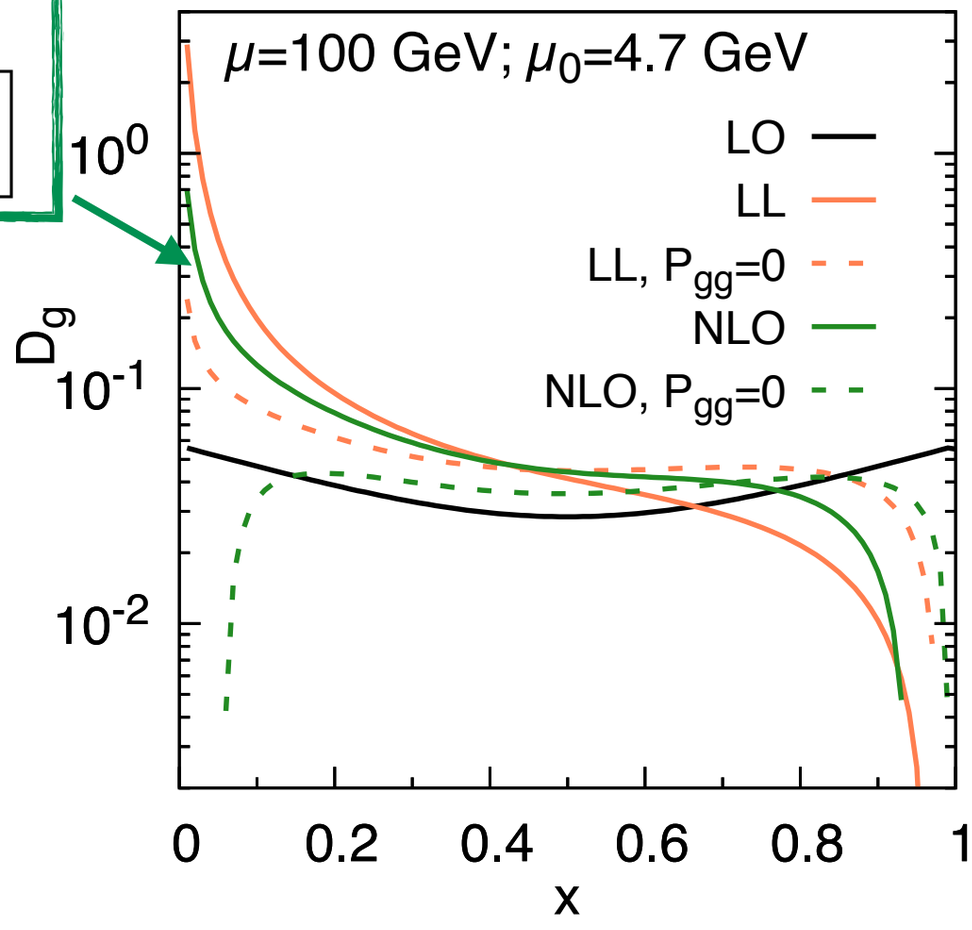
Effects from radiation off the parent gluon in $g \to b\bar{b}$

$$D_g(\mu) = \frac{\alpha_s(\mu)}{4\pi}\left[d_g^{(1)}(\mu_0) + \gamma_{qg}^{(0)} t\right] + \left(\frac{\alpha_s(\mu)}{4\pi}\right)^2 \left[\ldots + \left(\frac{1}{2}\gamma_{gg}^{(0)}\gamma_{qg}^{(0)} + \frac{1}{2}\gamma_{qg}^{(0)}\gamma_{qq}^{(0)} + 2\pi b_0 \gamma_{qg}^{(0)}\right) t^2\right]$$

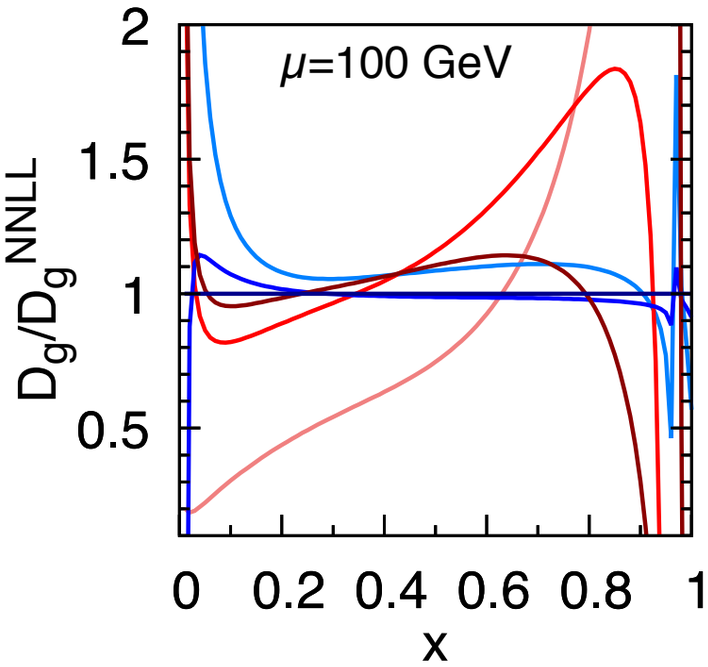
NLO





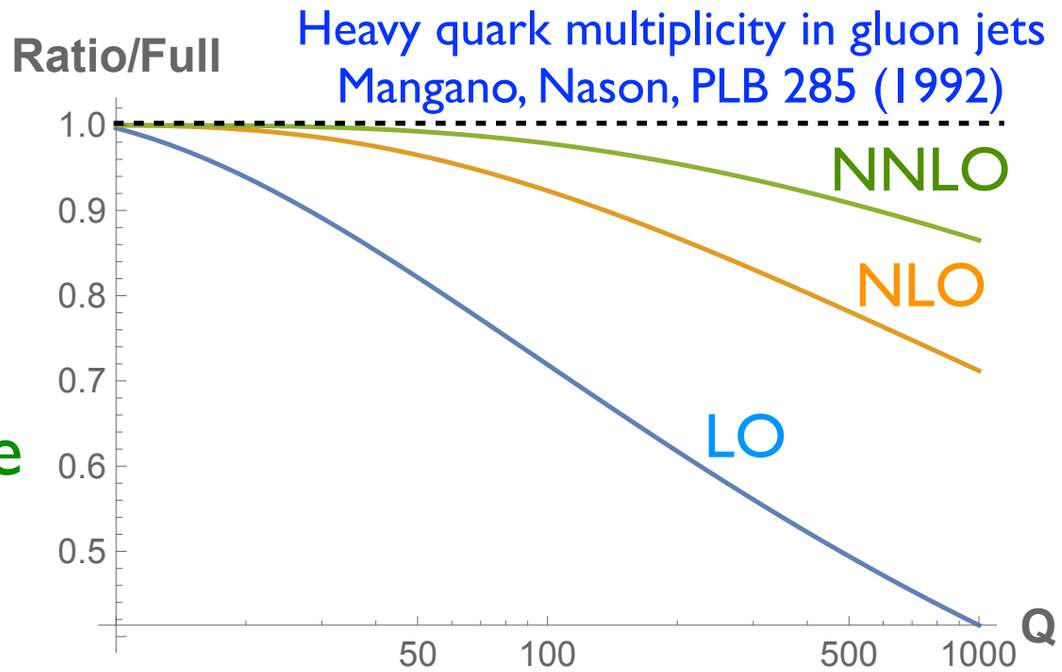
Important effects from P_{gg} terms

Effects on inclusive observables



Exclusive

Inclusive



- Inclusive observables (e.g. heavy quark multiplicity) display much smaller effects due to higher-orders and resummation
  - ✦ (Coherence effects need to be included in order to get the correct multiplicity)
- Open questions:
  - ✦ Shall we worry about the details of b-quark kinematics?
  - ✦ Can this mis-modelling have effects on relevant observables?

Conclusions

- FF-based studies highlight possible pathologies in the simulation of final-state $g \to b\bar{b}$ splittings at the ME-level, for *exclusive* observables
  - ✦ This holds regardless of $m_b=0$ or $m_b \neq 0$ in the ME simulation
- Radiation off parent gluon plays an important role and should be included
  - ✦ Either go to NNLO (~$t\bar{t}b\bar{b}$ + jet @ NLO in the case of $t\bar{t}b\bar{b}$) or use PS to evolve gluon
  - ✦ Methods exist to merge 5FS and 4FS simulations even at fully-differential level
    Hoeche et al, arXiv:1904.09382
- How does this translate for more inclusive observables? Do we expect problems there?
  - ✦ Effects seem to be much milder for heavy quark multiplicities
  - ✦ Need to understand importance of effects for physical quantities, realistic observables (b-jet), and beyond collinear kinematics (recoil, etc…)