

Theory issues with HF treatment

Davide Napoletano, LHCP, 05/06/2018



Prologue:

Theory aspects of vector boson and heavy flavour associated production

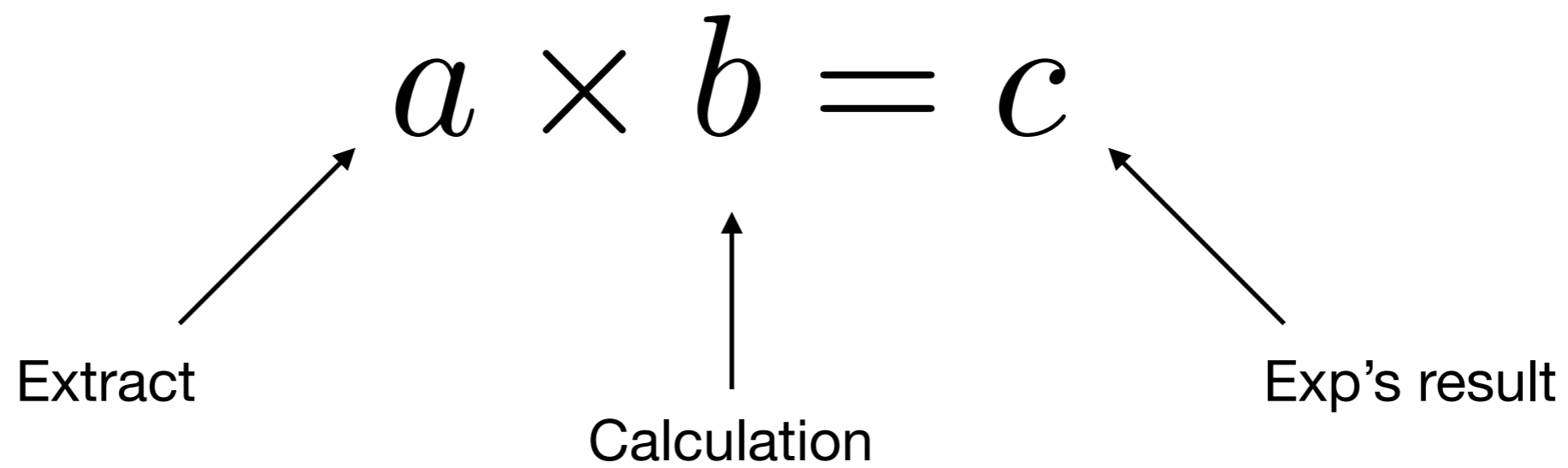
Davide Napoletano, SM@LHC, 10/04/2018

$$a \times b = c$$

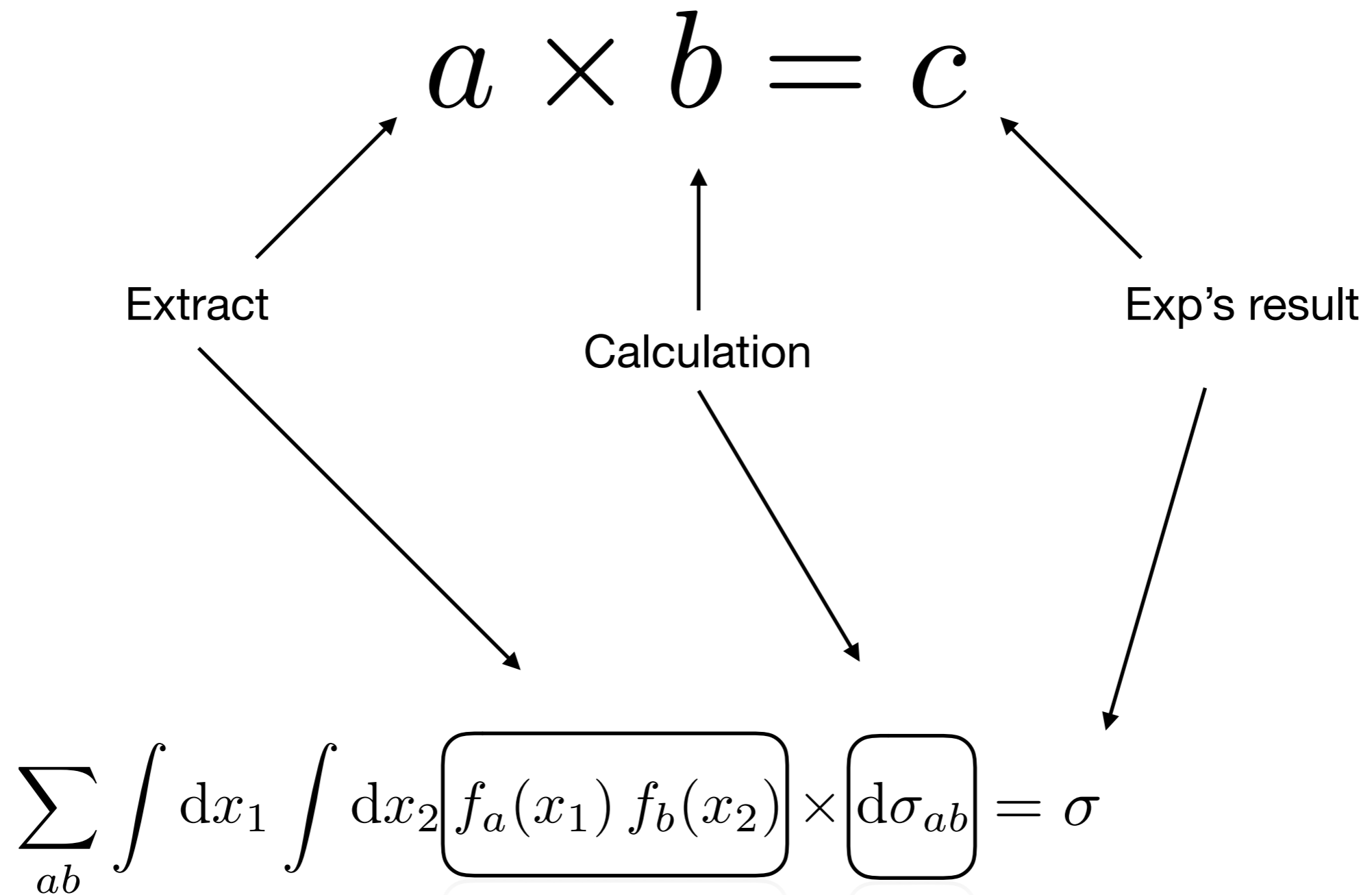
$$a \times b = c$$

↑
Calculation

←
Exp's result

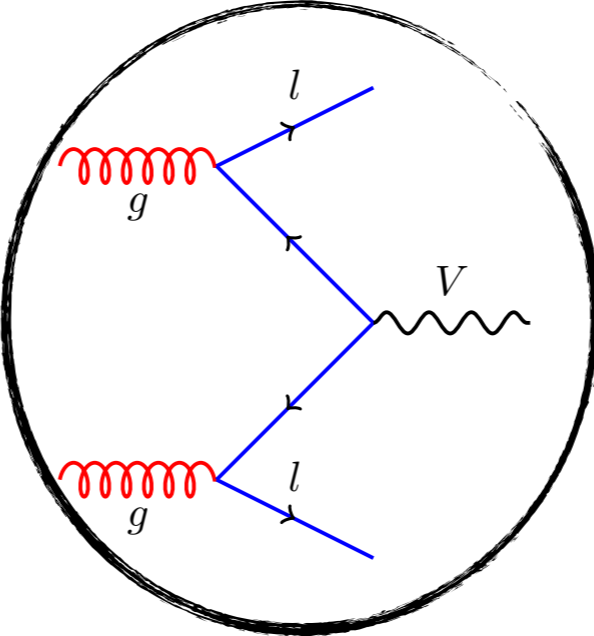


Example: Factorisation (not the only one!)

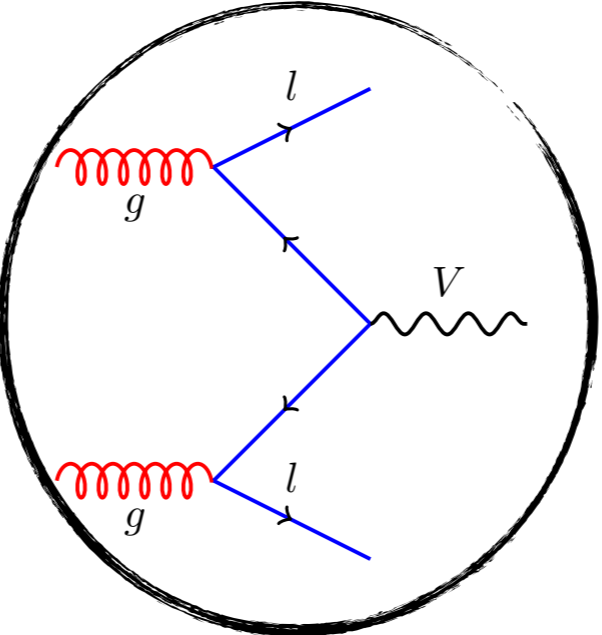


$$\sum_{ab} \int dx_1 \int dx_2 f_a(x_1) f_b(x_2) \times d\sigma_{ab} = \sigma$$

- Def of a and b , is arbitrary as long as it is compensated in $d\sigma$
- Extreme ex: only gluons in the proton, compute Drell-Yan

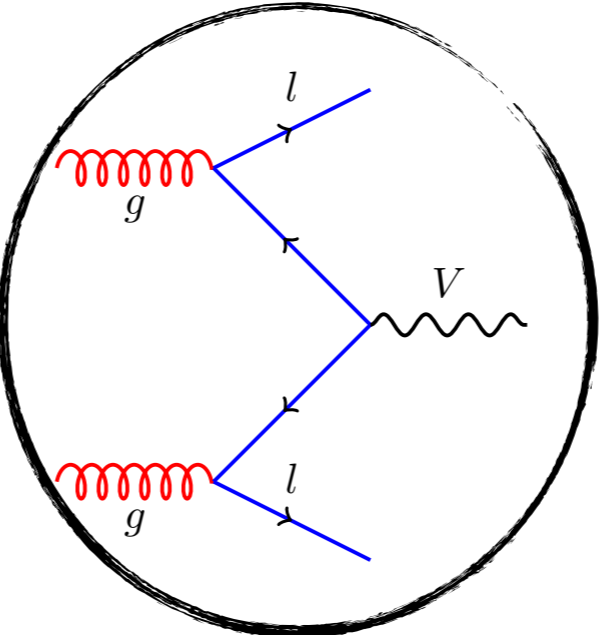
$$\int dx_1 \int dx_2 f_g(x_1) f_g(x_2) \times$$


The diagram shows a circular loop (bubble) with two red wavy lines on the left side, each labeled with the letter g . Two blue straight lines with arrows pointing to the right are on the right side, each labeled with the letter l . A wavy line labeled V connects the two vertices where the blue lines meet, forming a bridge across the top of the loop.

$$\int dx_1 \int dx_2 f_g(x_1) f_g(x_2) \times$$


The diagram shows a circular loop (bubble) with two red wavy lines on the left, each labeled g , representing gluon legs. Two blue straight lines on the right, each labeled l , represent lepton legs. A wavy line on the right, labeled V , represents a vector boson. The diagram is enclosed in a black circle. An arrow points from the right side of the circle to the expression $\frac{1}{\epsilon^2}$.

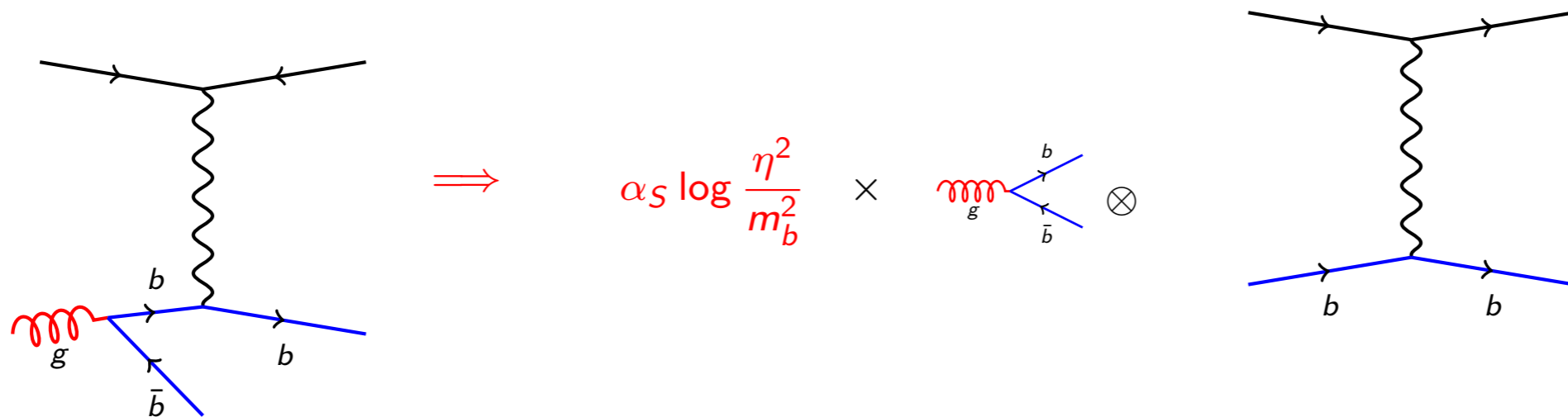
$$\frac{1}{\epsilon^2}$$

$$\int dx_1 \int dx_2 f_g(x_1) f_g(x_2) \times$$


$$\frac{1}{\epsilon^2}$$

What if they're not massless? $\longrightarrow \alpha_s^2 \log^2 \left(\frac{\eta^2}{m^2} \right)$

$$\eta = p_T \sim 10 \text{ GeV}; \quad m = 2 \times 10^{-6} \text{ GeV}; \quad \log \sim 16 \sim \frac{1}{\alpha_s}$$



$$\lim_{m_b^2/\eta^2 \rightarrow 0} f_g \otimes \hat{\sigma}_{Xg \rightarrow b\bar{b}Y} = \underbrace{\alpha_s \log \frac{\eta^2}{m_b^2} P_{qg}}_{= \tilde{b}(x, \mu^2)} \otimes f_g \sigma_{Xb \rightarrow Y}$$

DGLAP equations:

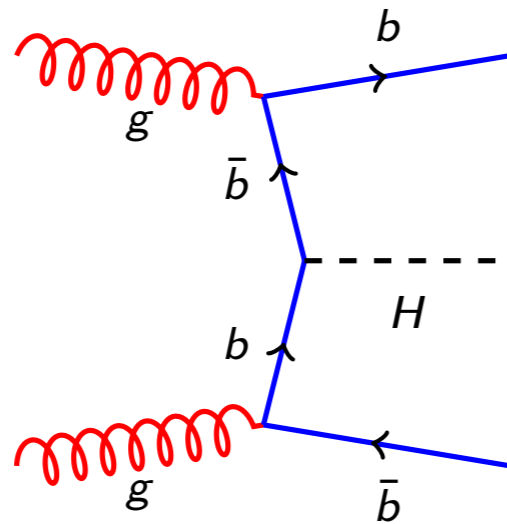
$$\frac{df_b(x, \mu^2)}{d \log \mu^2} = \alpha_s P_{qg} \otimes f_g \quad \rightarrow \quad f_b(x, \eta^2) = \alpha_s \log \frac{\eta^2}{m^2} P_{qg} \otimes f_g$$

at LL...

$$\int dx_1 \int dx_2 f_a(x_1, \mu^2) f_b(x_1, \mu^2) d\sigma_{ab}(\mu^2) = \sigma$$

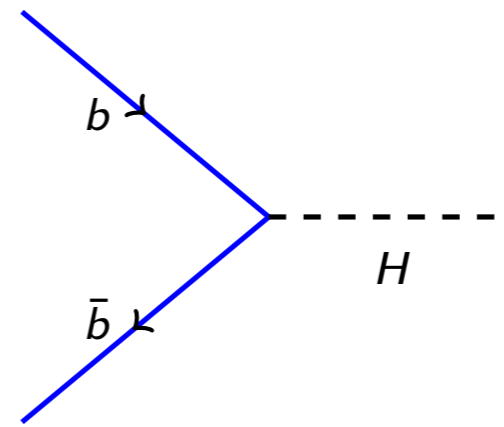
- Varying the scale simply shuffles terms around
- expansion in coupling makes everything more complicated

4F Scheme:



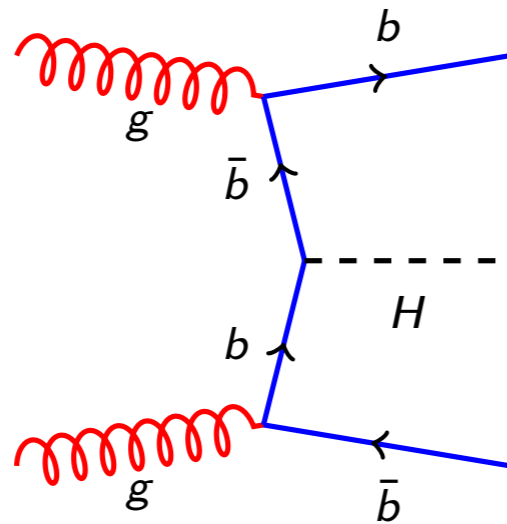
- LO more complicated
- possible log problems
- exact mass dep

5F Scheme:



- LO and HO easy, but not much info
- no log problems
- no mass dep...

4F Scheme:

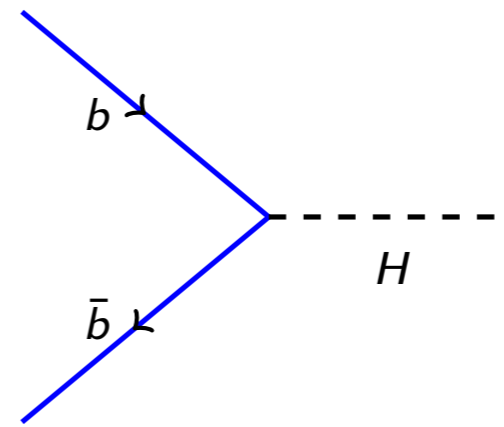


- LO more complicated
- possible log problems
- exact mass dep

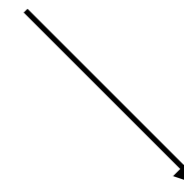


Better for differential observables

5F Scheme:

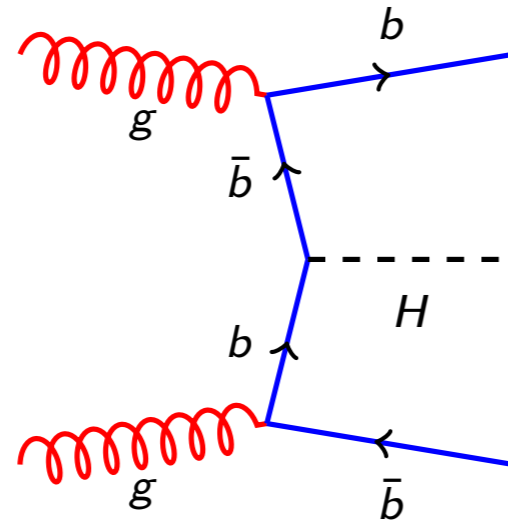


- LO and HO easy, but not much info
- no log problems
- no mass dep...



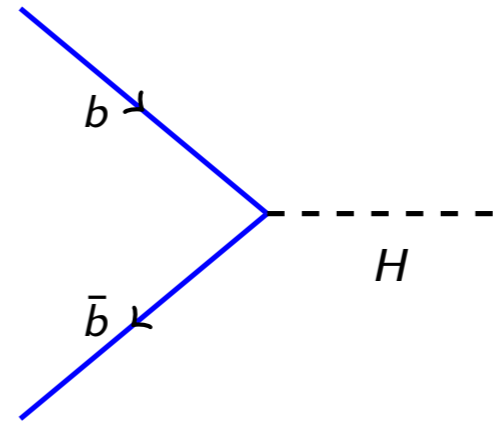
Better for inclusive ones

4F Scheme:

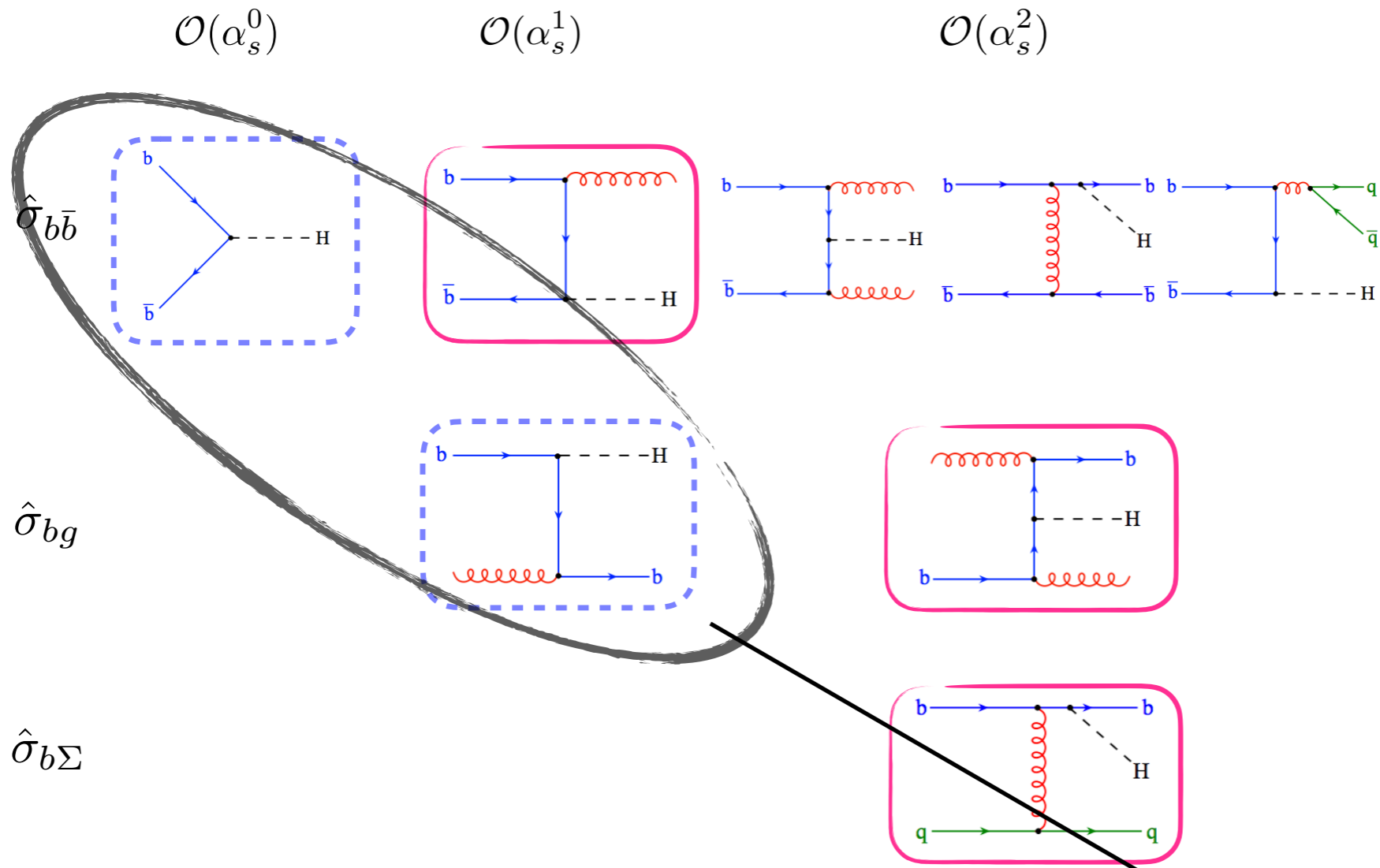


$$\alpha_s^2 \left[c^{(2)} \left(\frac{m^2}{\eta^2} \right) L^2 + c^{(1)} \left(\frac{m^2}{\eta^2} \right) L + \frac{m^2}{\eta^2} c^{(0)} + K \right]$$

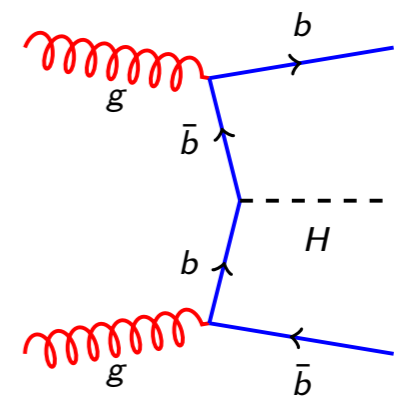
5F Scheme:



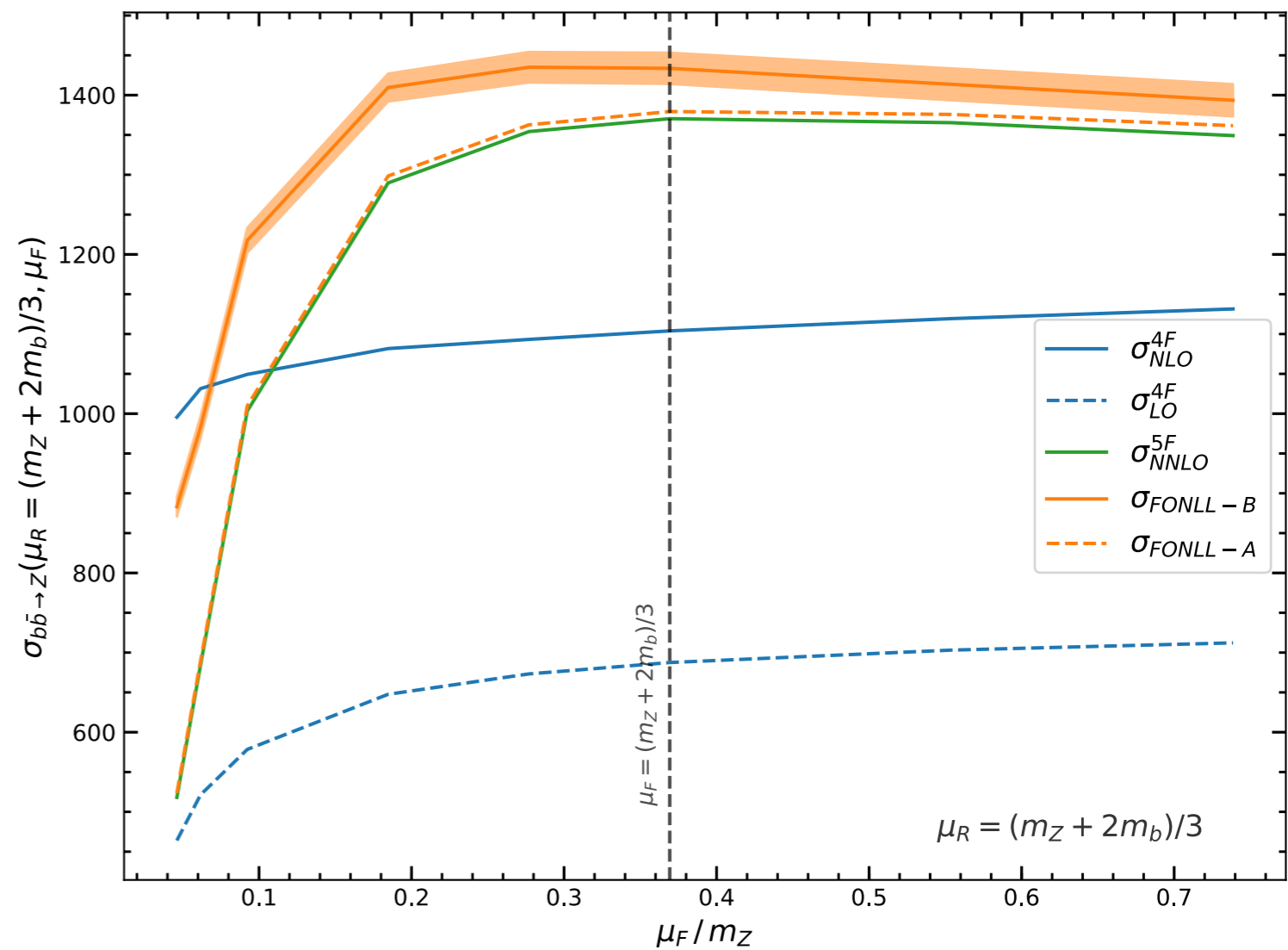
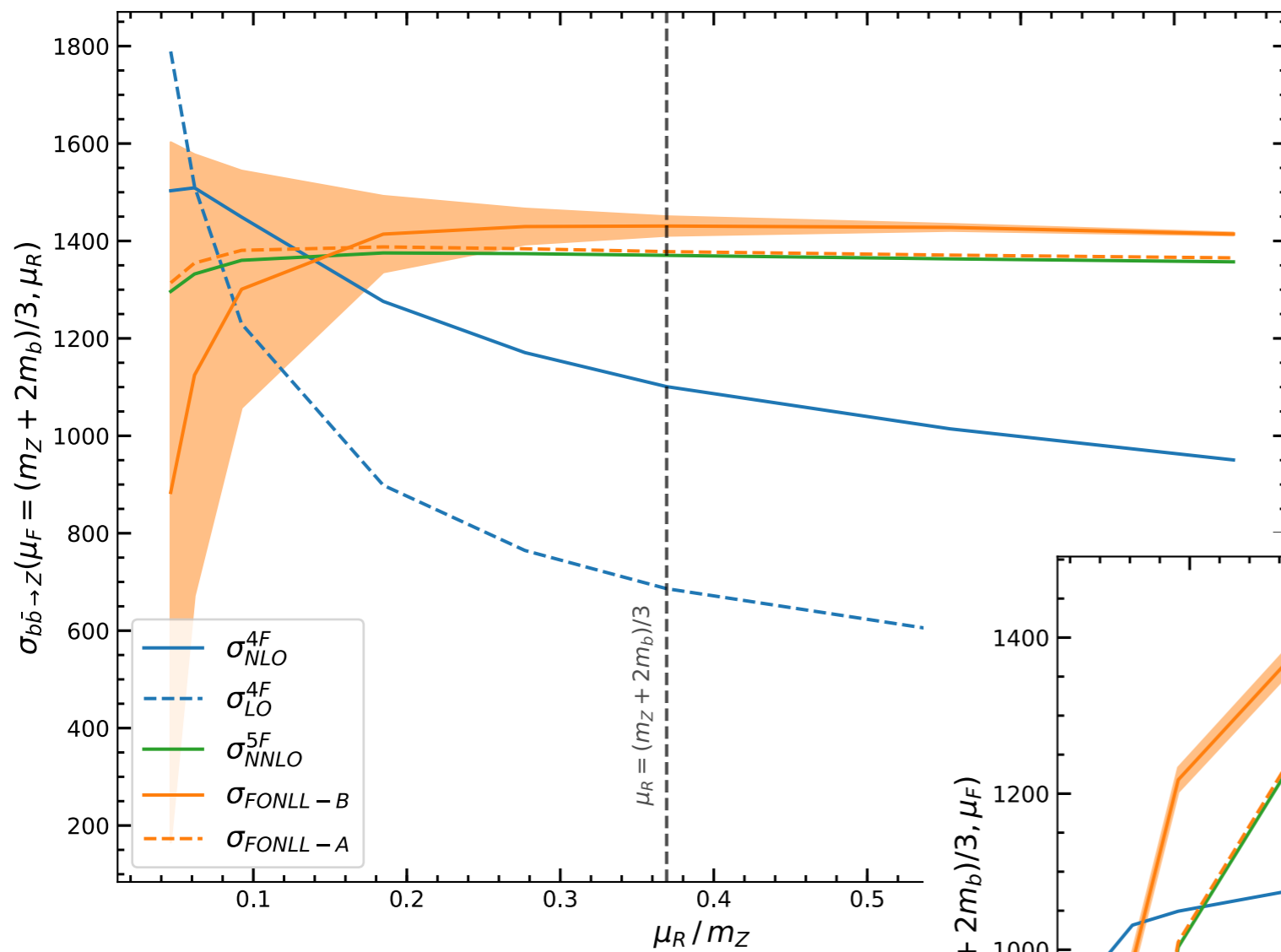
$$\left(1 - e^{-\alpha_s^2 [c^{(2)} L^2 + c^{(1)} L^1 + K]} + \mathcal{O}(\alpha_s^3) \right)$$



4F and 5F have actually the same contributions...

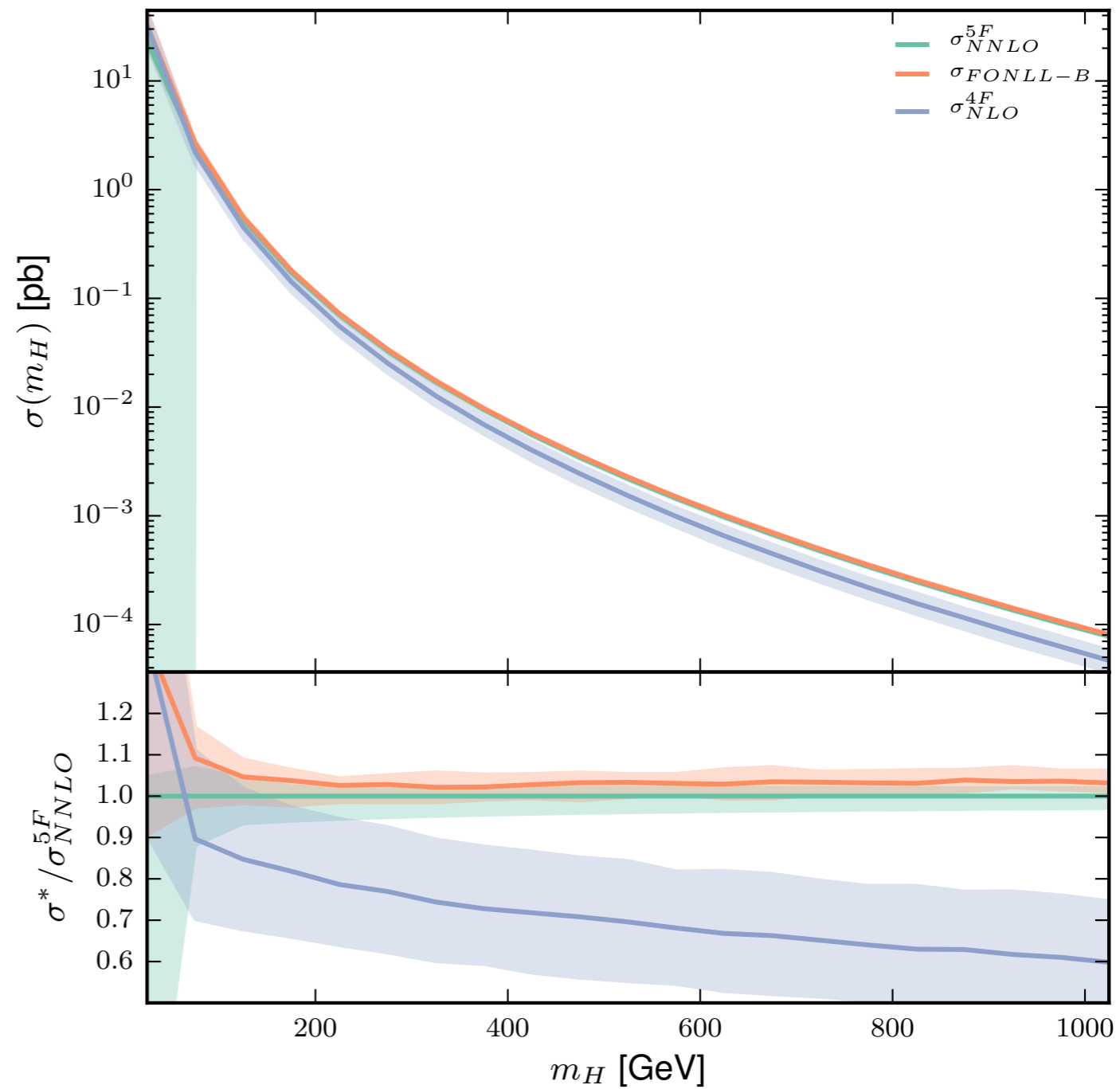


Z prod ... matched result

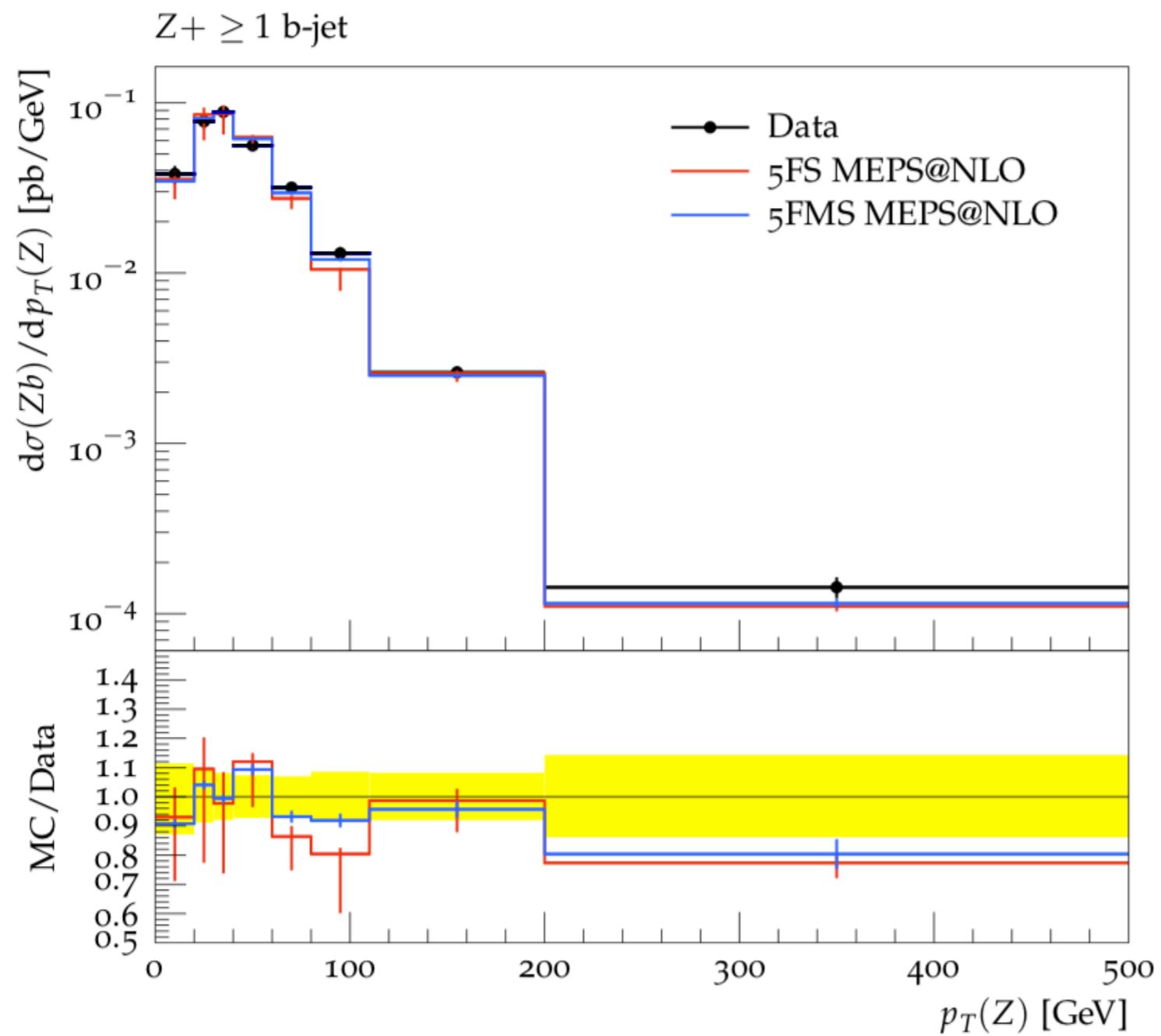


$$\sigma^{\text{matched}} = \sigma^{(5F)} + \sigma^{(4F)} - d.c.$$

$$\sigma^{\text{FONLL}} - \sigma^{5F} = A \frac{m^2}{m_A^2} + K$$



- Inclusive XS, it does seem like 5F better approximation...
- Can we something on more differential obs?
- What to do for more complicated procs?



Massive b @ MC-NLO

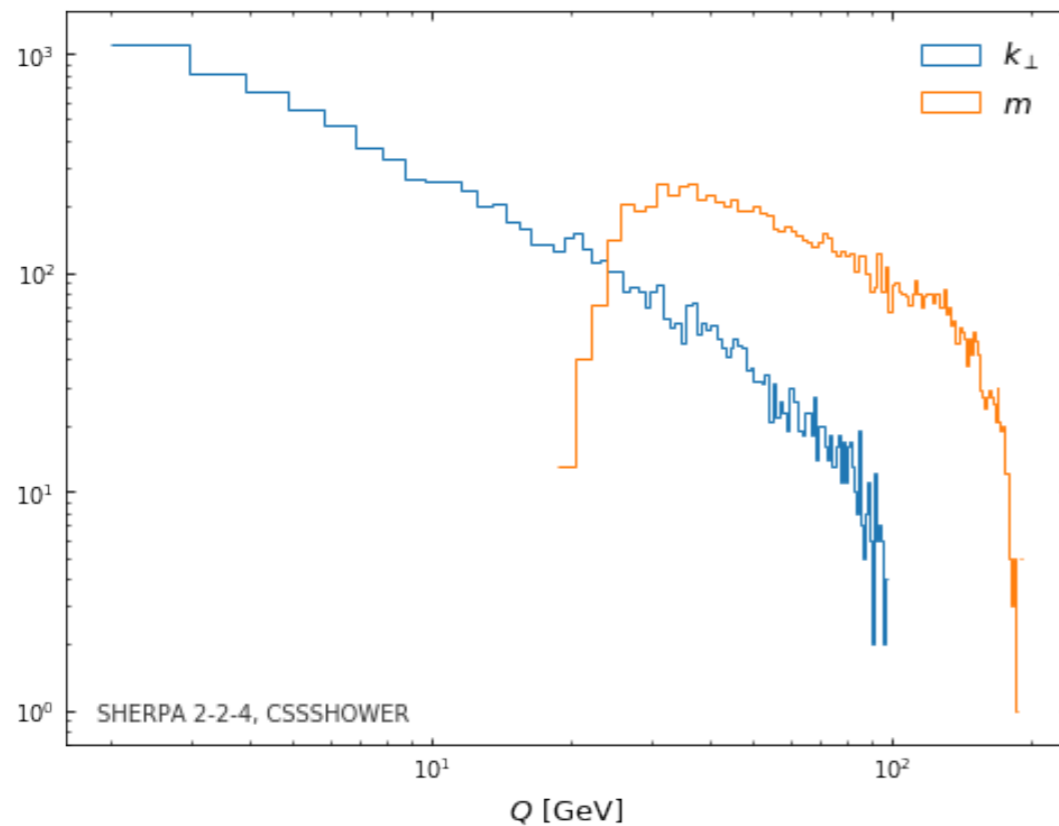
Gluon Splitting (shower uncertainties)

- Freedom in choice

$$P_{g \rightarrow Q\bar{Q}} \propto \frac{\alpha_s(X)}{2\pi} \left[P_{g \rightarrow q\bar{q}}^{(m_q=0)} + \frac{m_Q^2}{Y_{Q\bar{Q}}} \right]$$

- Problems with threshold (k_{\perp} - showers):

$$k_{\perp} \ll m$$



Formation time argument :

$$\tau_g \sim \frac{E}{t^2} \ll \tau_{Q\bar{Q}} \sim \frac{E'}{t'^2} + \frac{1}{m} \quad k_{\perp} \gg m$$

Seymour Nucl.Phys. B436 (1995) 163-183

- Theory uncertainties?
- What can we learn from matched results?
- Phenomenological model are on the rise, but need to be checked
- Experiments?