Theory issues with HF treatment

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Prologue:

Theory aspects of vector boson and heavy flavour associated production

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$$a \times b = c$$

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Calculation

Exp’s result

$$a \times b = c$$

Extract

Calculation

Exp's result

Example: Factorisation (not the only one!)

$$a \times b = c$$

Extract

Calculation

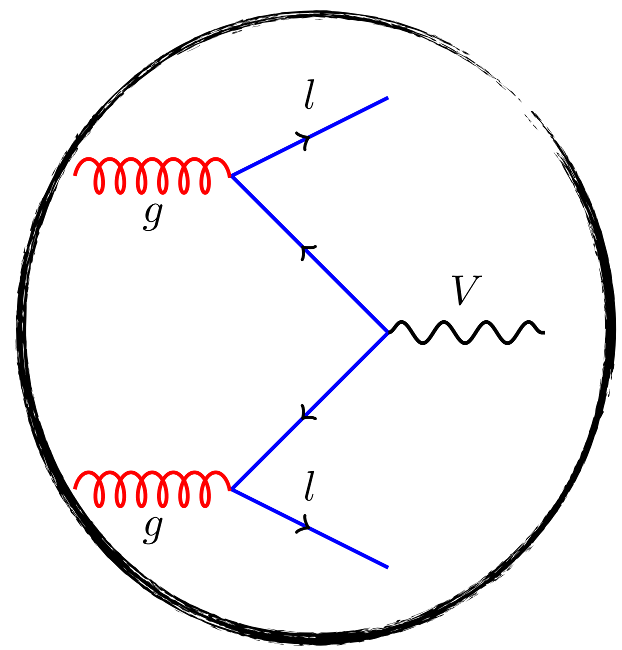
Exp's result

$$\sum_{ab} \int \mathrm{d}x_1 \int \mathrm{d}x_2 \boxed{f_a(x_1)\, f_b(x_2)} \times \boxed{\mathrm{d}\sigma_{ab}} = \sigma$$

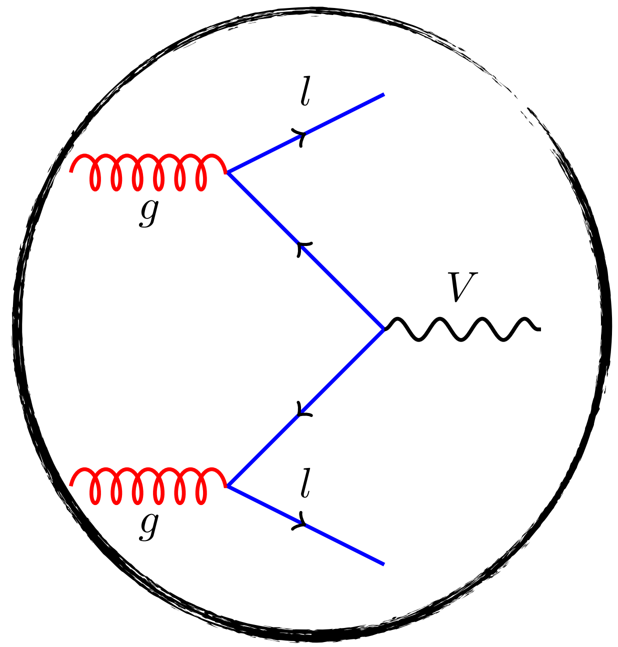
$$\sum_{ab} \int \mathrm{d}x_1 \int \mathrm{d}x_2 \, f_a(x_1) \, f_b(x_2) \times \mathrm{d}\sigma_{ab} = \sigma$$

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

$$\int \mathrm{d}x_1 \int \mathrm{d}x_2\, f_g(x_1)\, f_g(x_2) \times$$

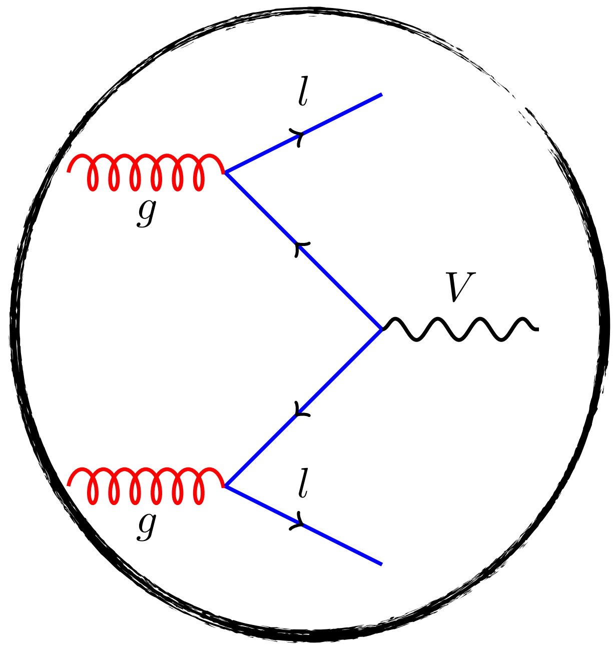


$$\int \mathrm{d}x_1 \int \mathrm{d}x_2 \, f_g(x_1)\, f_g(x_2) \times$$



$$\rightarrow \frac{1}{\varepsilon^2}$$

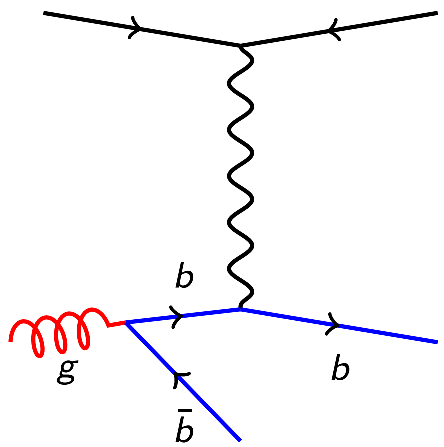
$$\int \mathrm{d}x_1 \int \mathrm{d}x_2\, f_g(x_1)\, f_g(x_2) \times$$



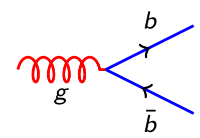
$$\to \frac{1}{\varepsilon^2}$$

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

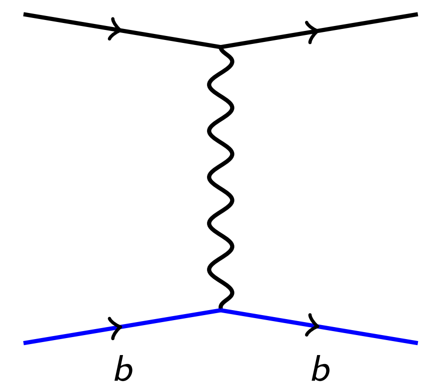
$$\eta = p_T \sim 10 \text{ GeV}; \quad m = 2 \times 10^{-6} \text{ GeV}; \quad \log \sim 16 \sim \frac{1}{\alpha_s}$$



$$\Longrightarrow \quad \alpha_S \log \frac{\eta^2}{m_b^2} \quad \times$$



$$\otimes$$



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

DGLAP equations:

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

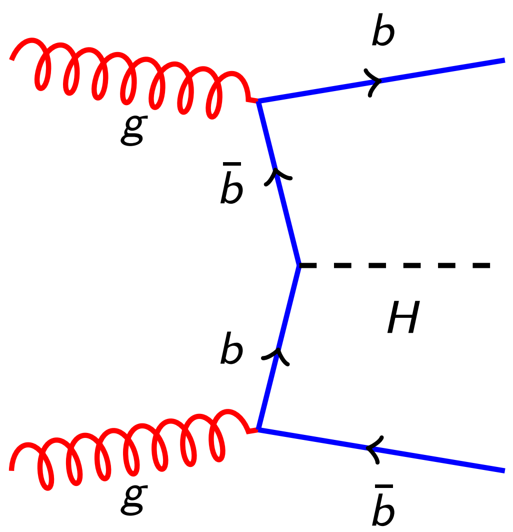
at LL...

$$\int \mathrm{d}x_1 \int \mathrm{d}x_2\, f_a(x_1, \mu^2)\, f_b(x_1, \mu^2)\, \mathrm{d}\sigma_{ab}(\mu^2) = \sigma$$

- Varying the scale simply shuffles terms around

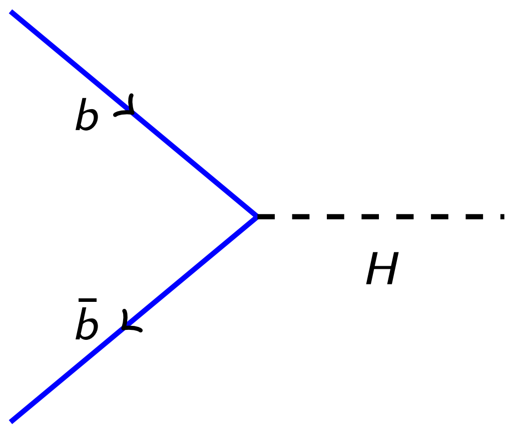
- expansion in coupling makes everything more complicated

4F Scheme:



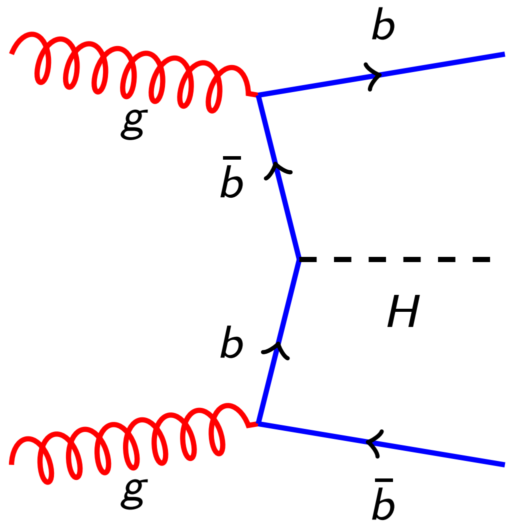
- LO more complicated
- possible log problems
- exact mass dep

5F Scheme:



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

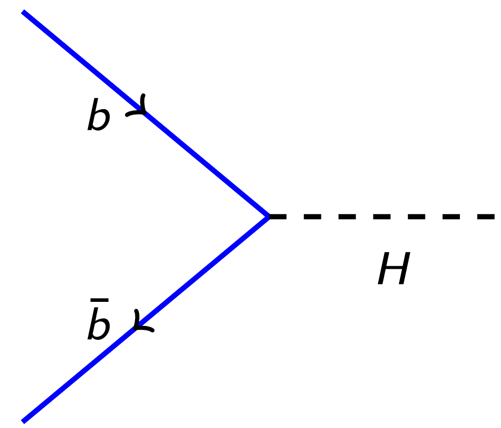
4F Scheme:



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

Better for differential observables

5F Scheme:



- LO and HO easy, but not much info
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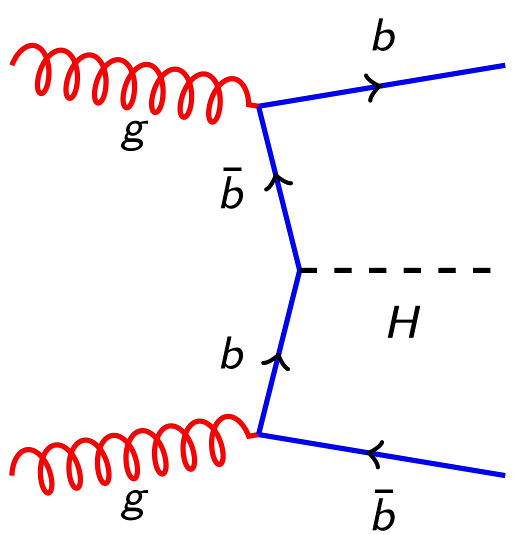
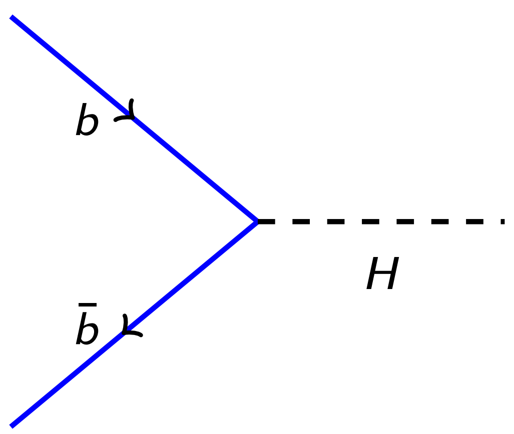
Better for inclusive ones

4F Scheme:

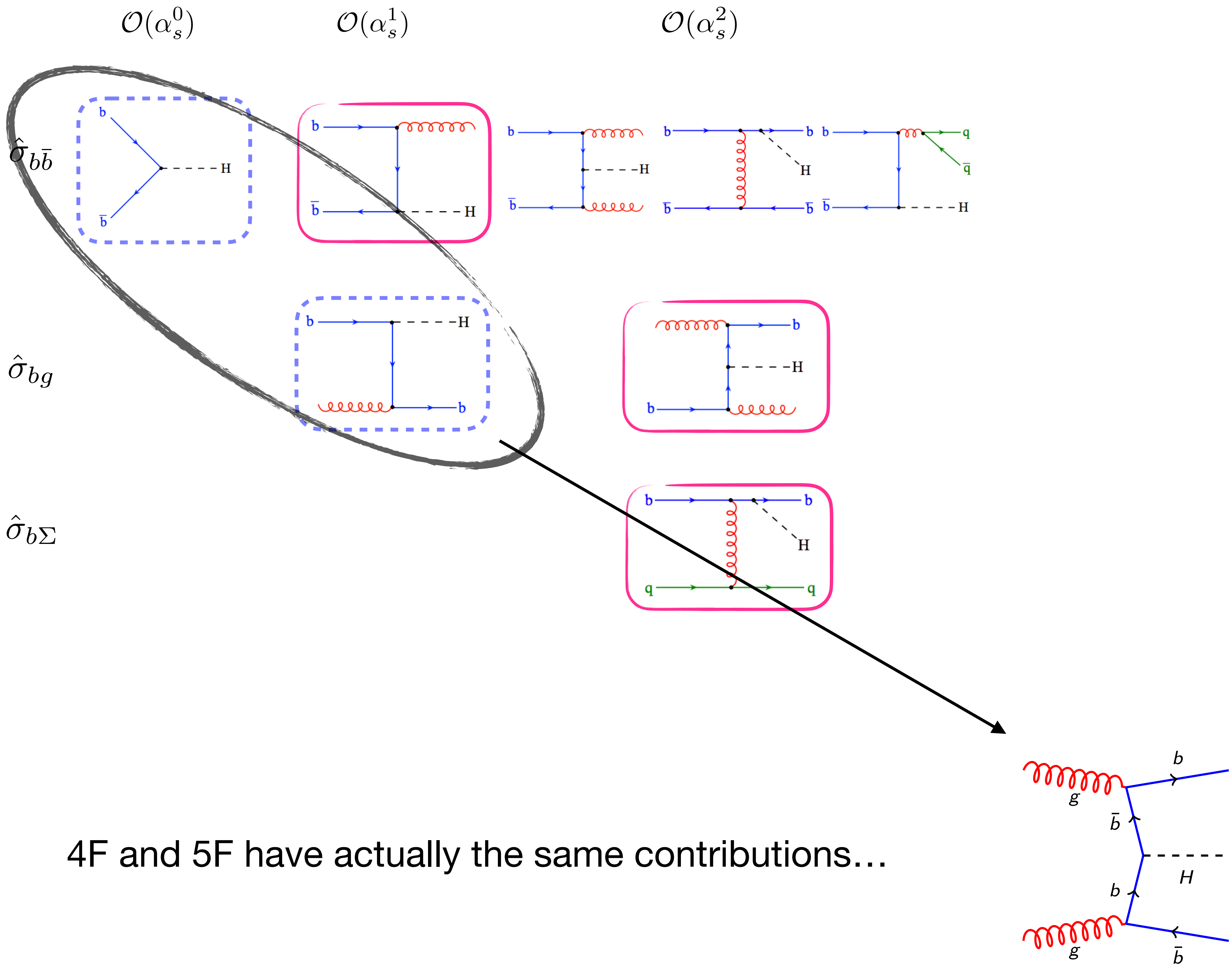


$$\alpha_s^2 \left[c^{(2)} \left(\frac{m^2}{\eta^2} \right) L^2 + c^{(1)} \left(\frac{m^2}{\eta^2} \right) L + \frac{m^2}{\eta^2} c^{(0)} + K \right]$$

5F Scheme:

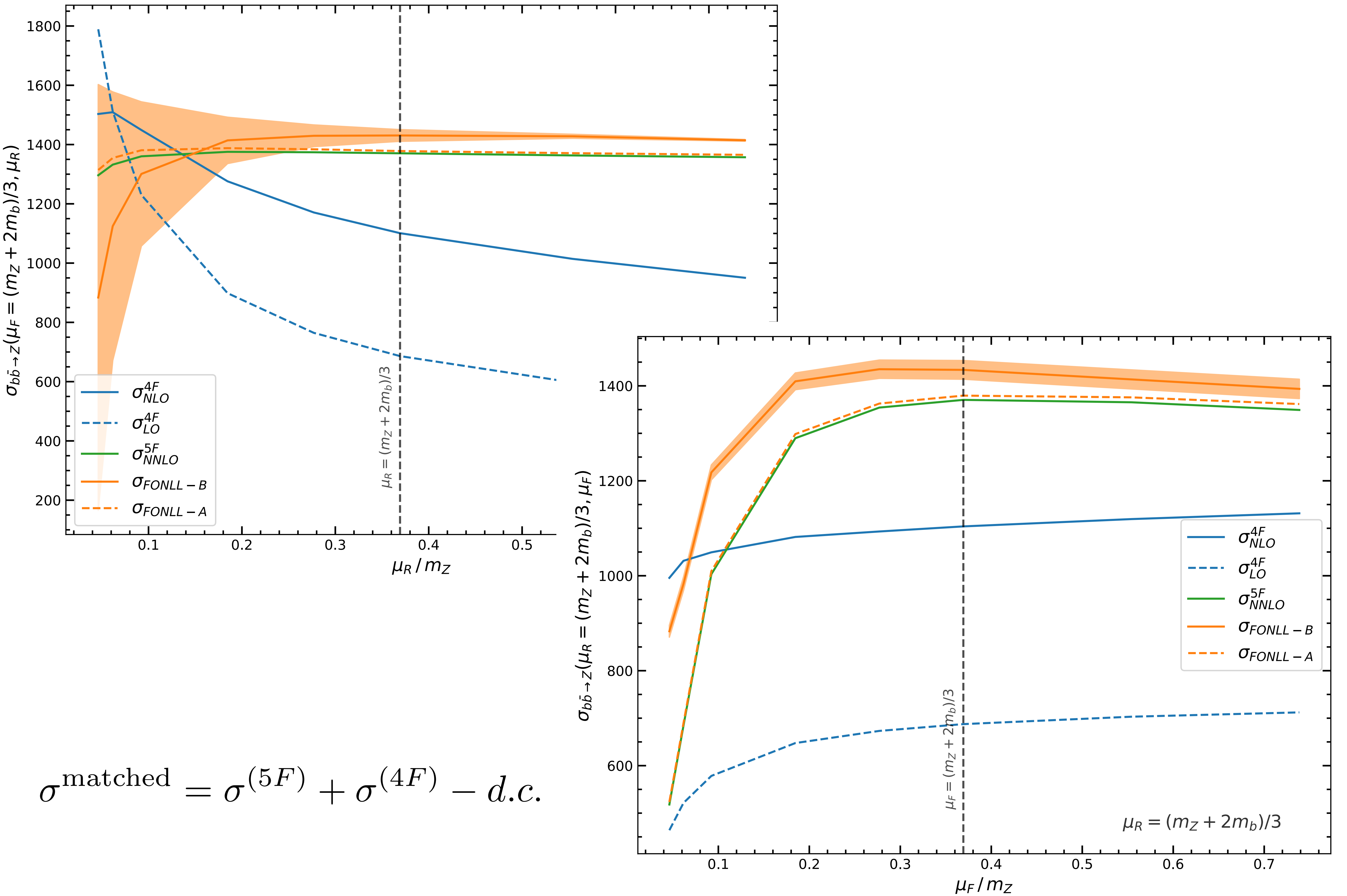


$$\left(1 - e^{-\alpha_s^2 \left[c^{(2)} L^2 + c^{(1)} L^1 + K \right] + \mathcal{O}(\alpha_s^3)} \right)$$



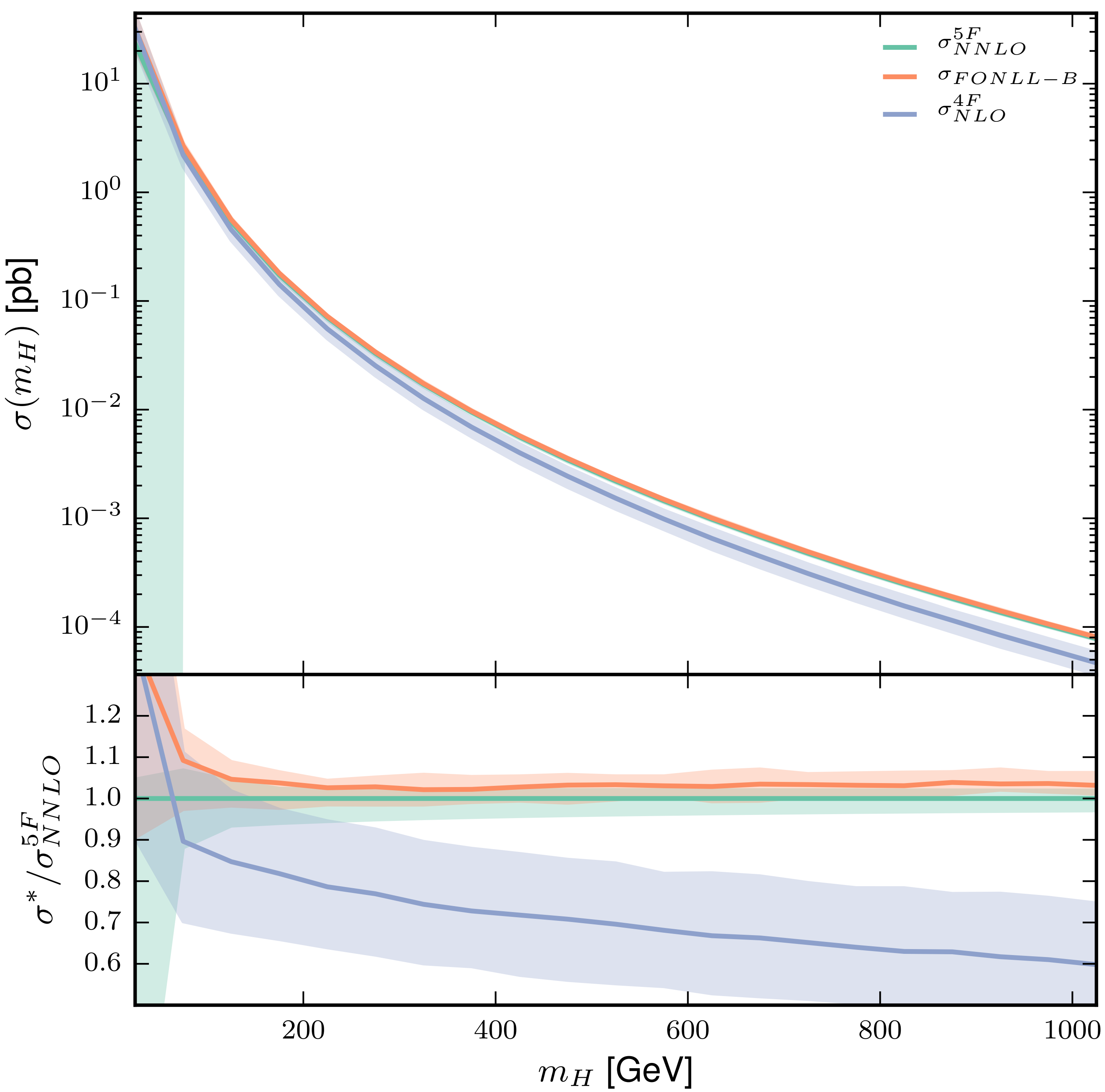
4F and 5F have actually the same contributions…

Z prod … matched result



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

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

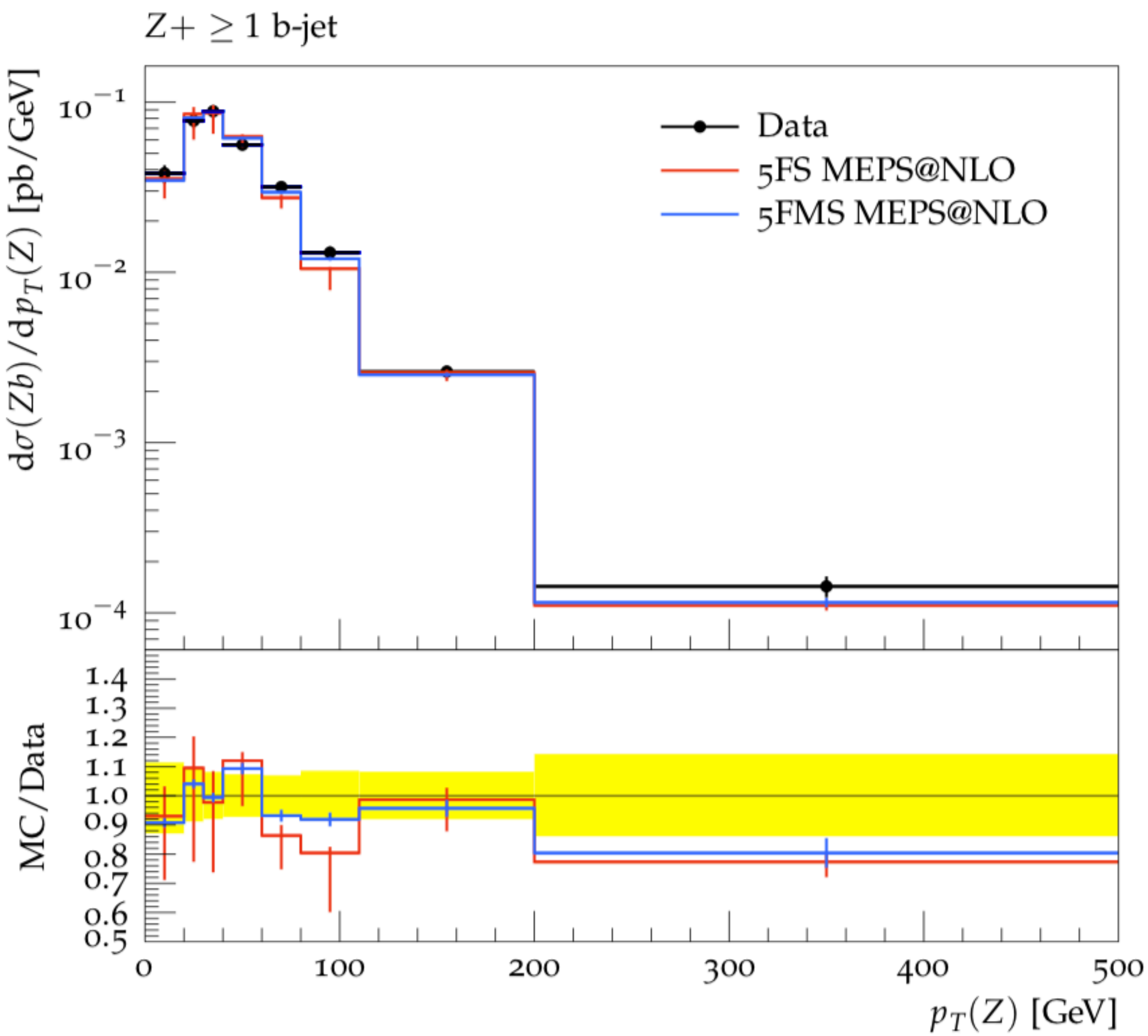


- Inclusive XS, it does seem like 5F better approximation…

- Can we something on more differential obs?

- What to do for more complicated procs?

Krauss, DN arXiv:1803.04336

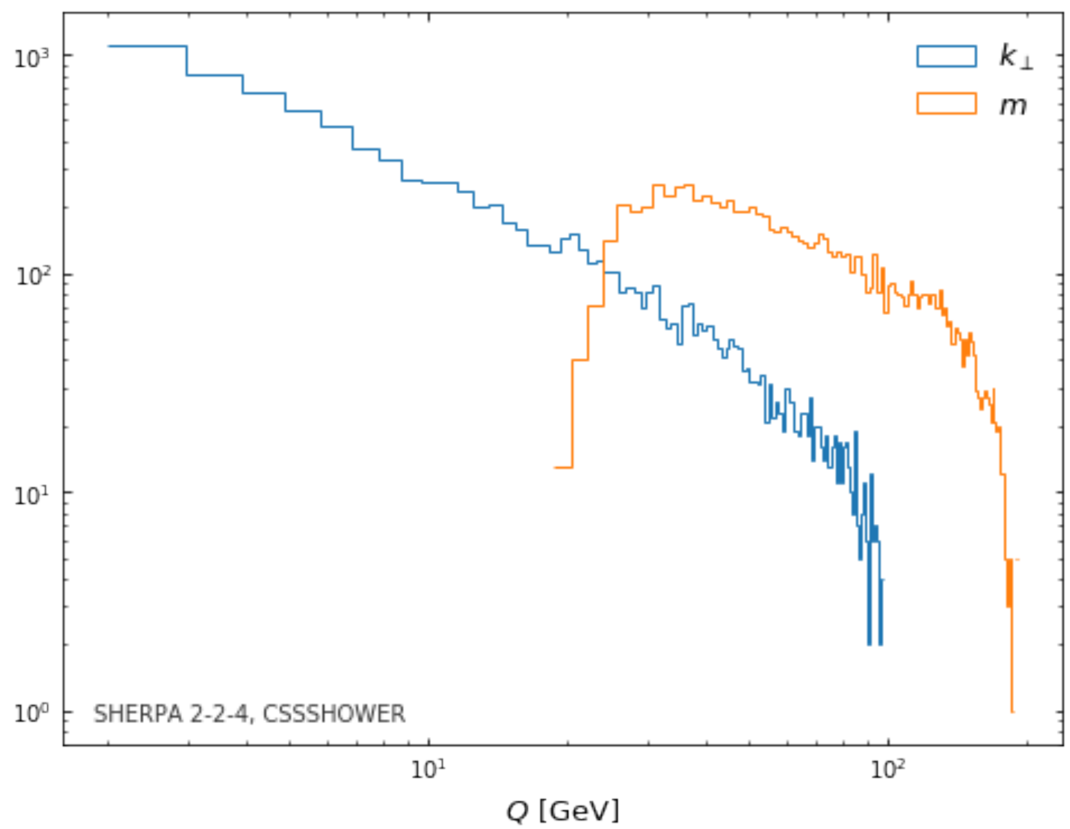


Massive b @ MC-NLO

Gluon Splitting (shower uncertainties)

- Freedom in choice $$P_{g\to Q\bar{Q}} \propto \frac{\alpha_s(X)}{2\,\pi}\left[P^{(m_q=0)}_{g\to q\bar{q}} + \frac{m_Q^2}{Y_{Q\bar{Q}}}\right]$$

- 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?