NLO single-top and fourth generation quark production

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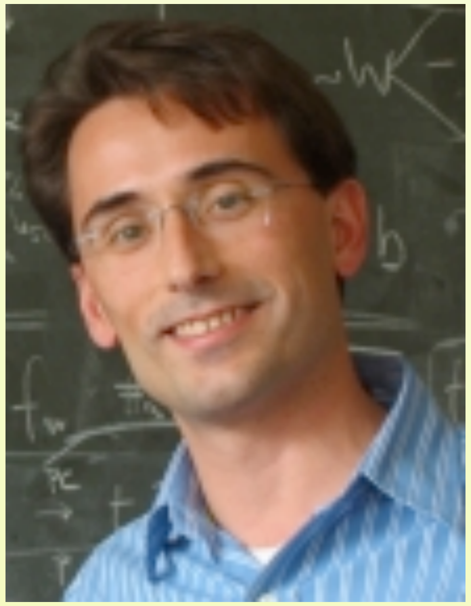
Campbell, Frederix, FM, Tramontano,
PRL(0903.005 [hep-ph]) + JHEP(0907.3933 [hep-ph])

Thanks, Tilman!!



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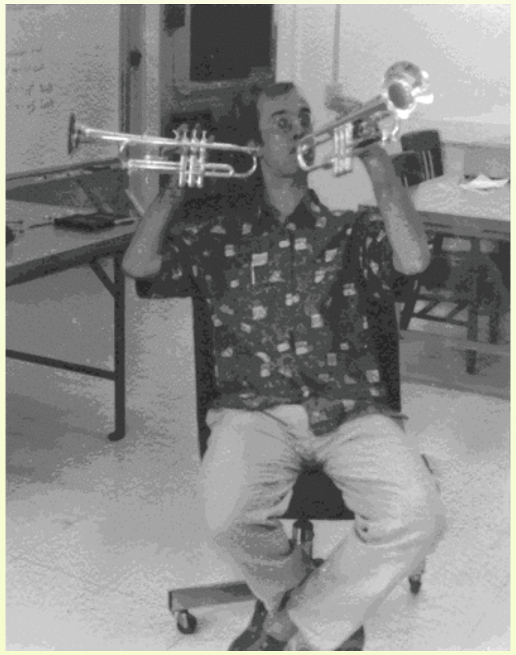

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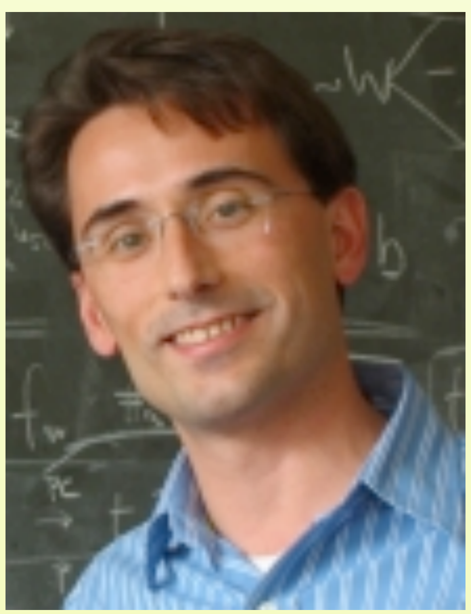
Some of you might have noticed that today I am taller, taliking faster and wearing more glaring colors than usual....



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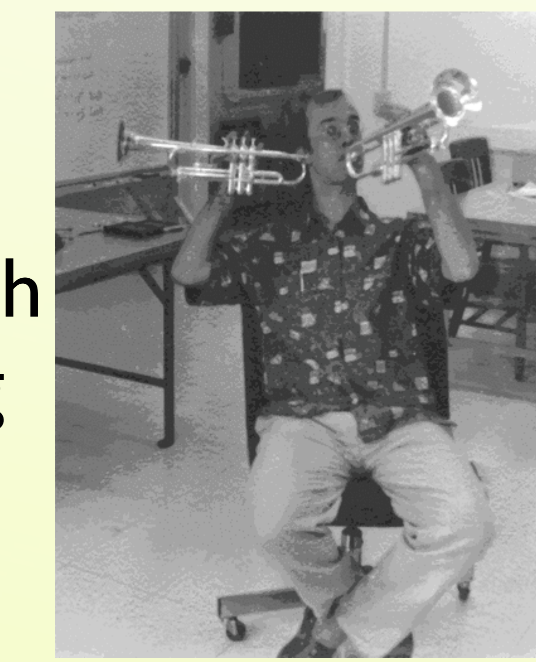

Why single top is way cooler than ttbar?

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At least three reasons...

Reason #1 : Teenager vs Newborn

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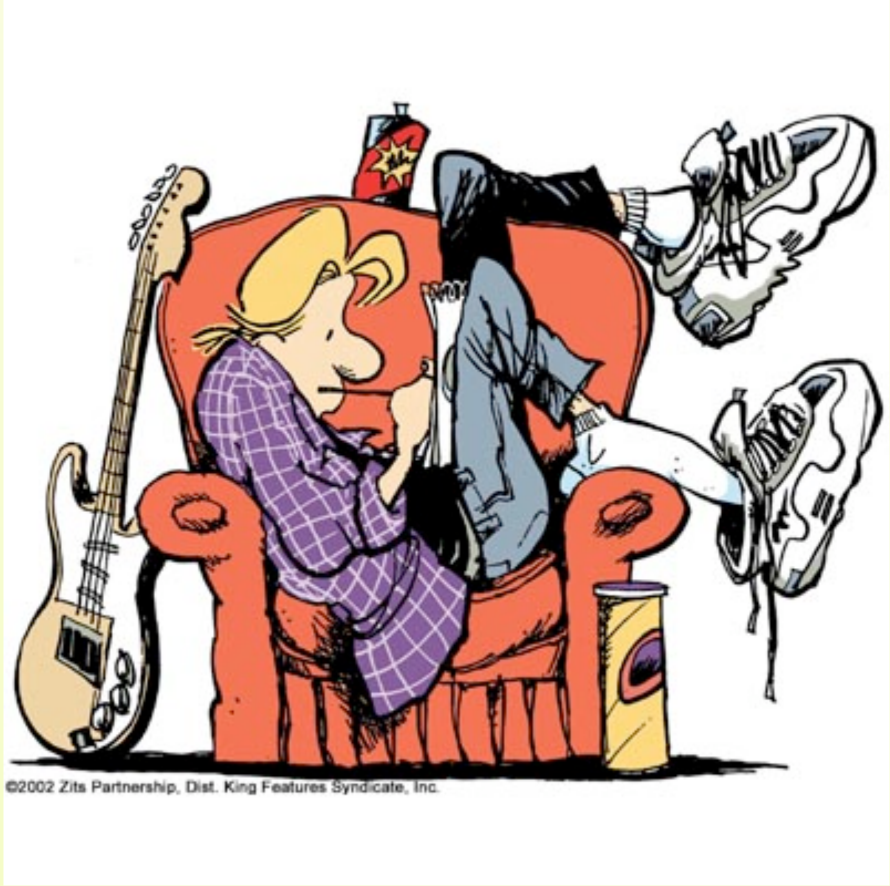
t tbar



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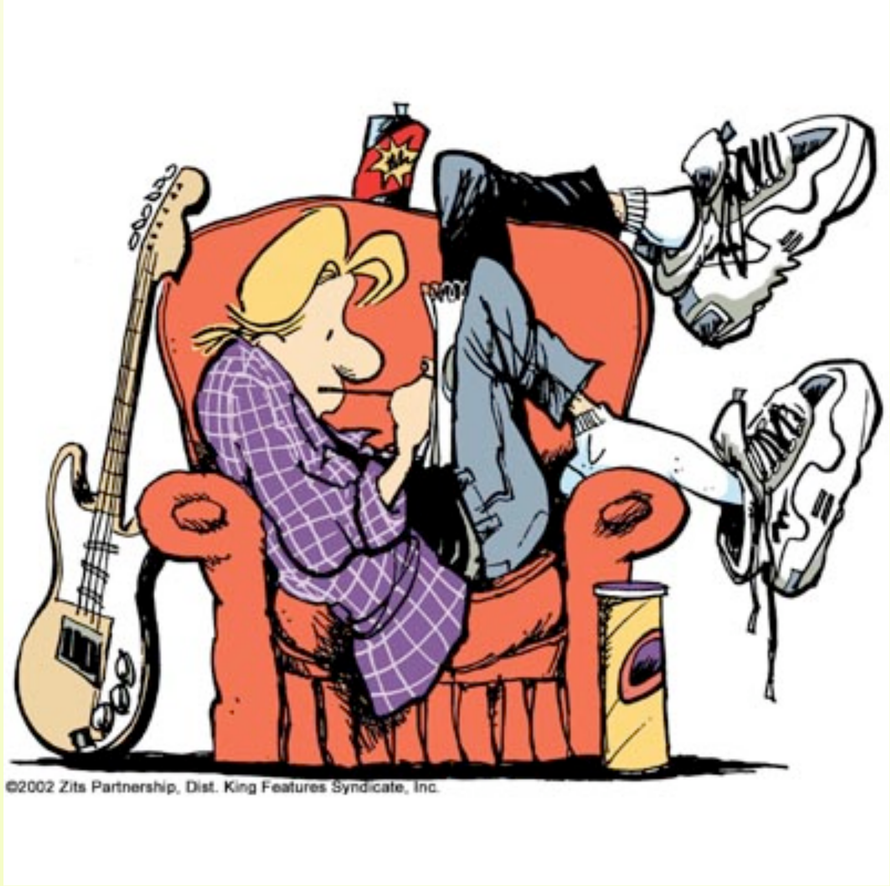

- Born in 1995
- Good : We already know him well
- Bad : We ask him a lot!

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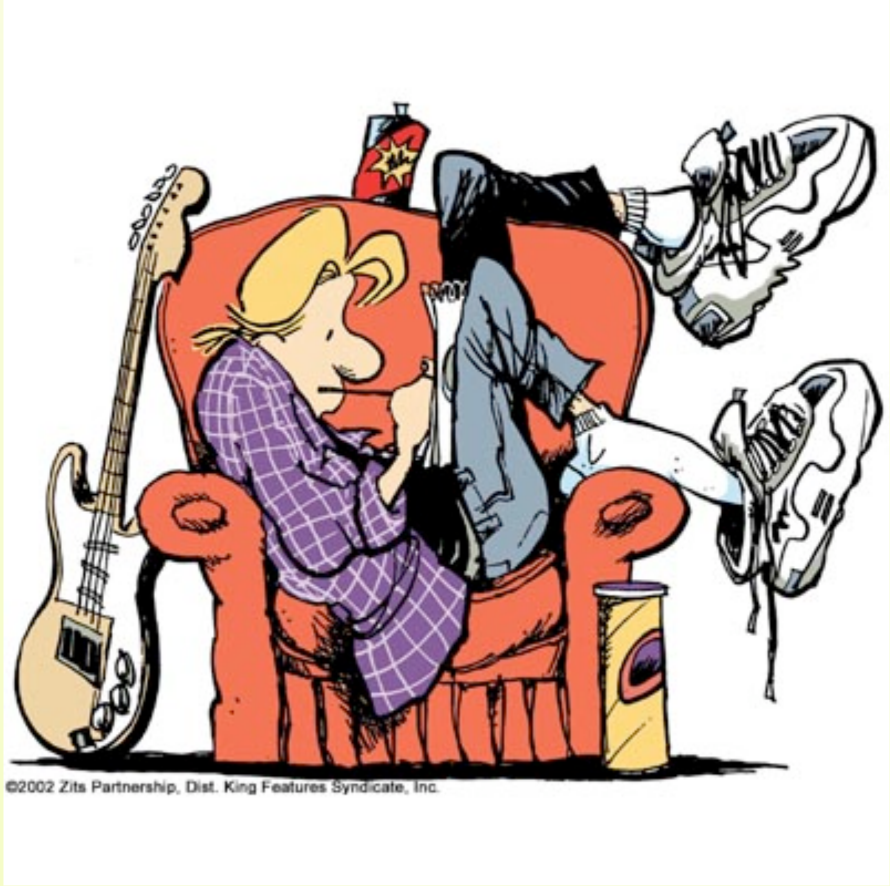

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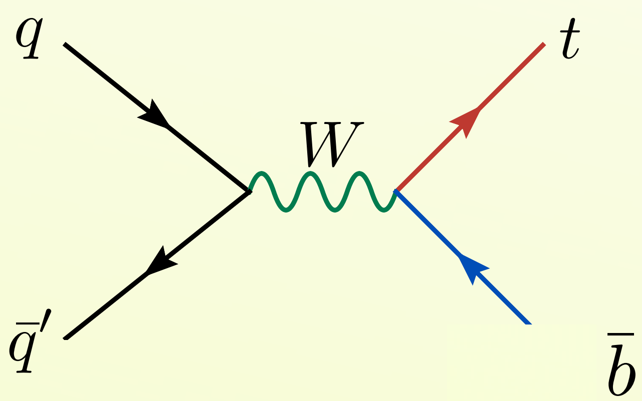
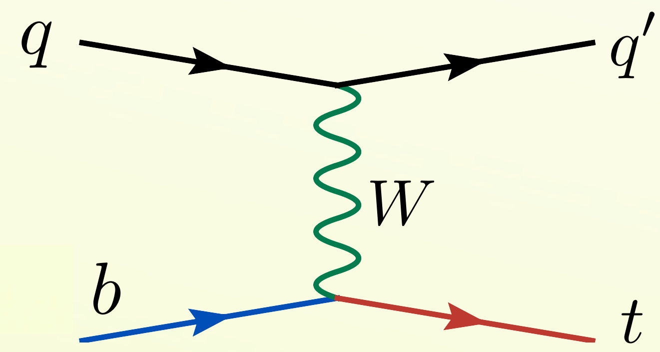
- Good : We already know him well
- Bad : We ask him a lot!

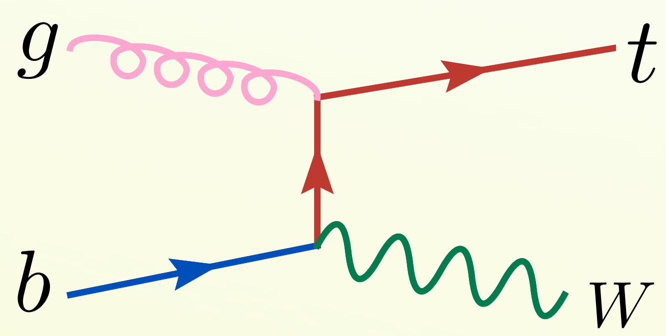
single-top

- Just a few months old!
- Good : a whole new world to explore
- Bad : sleep deprivation...

Reason #2 : Single top comes in more shapes and forms!







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*Theorist's comments

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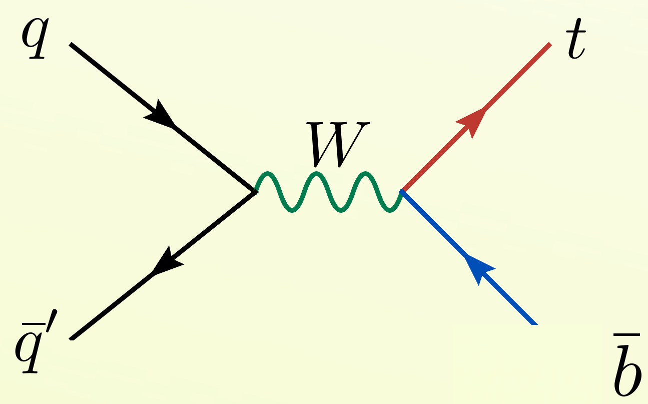

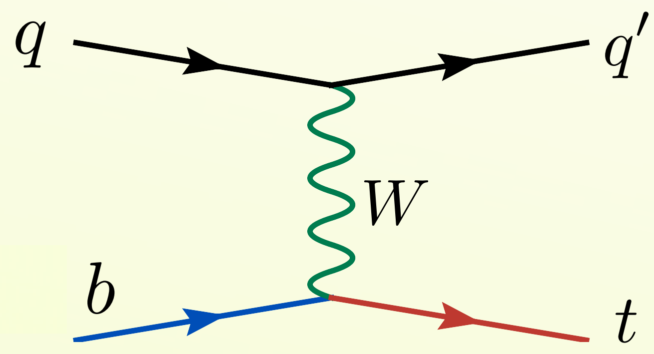

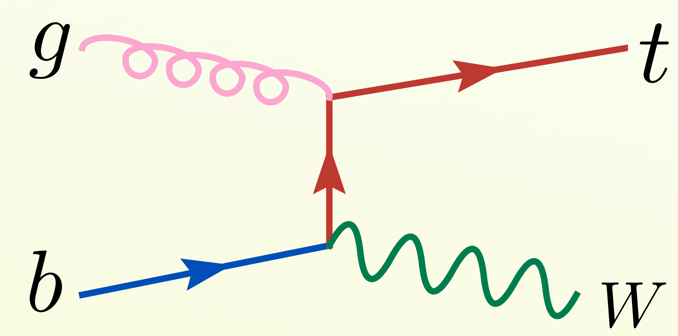

* "Drell-Yan" production mode.
* Tevatron is sizable (~1pb), quite small at the LHC14 (~10 pb).
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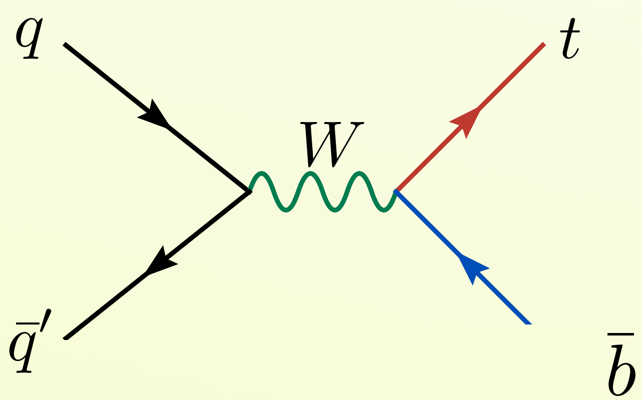

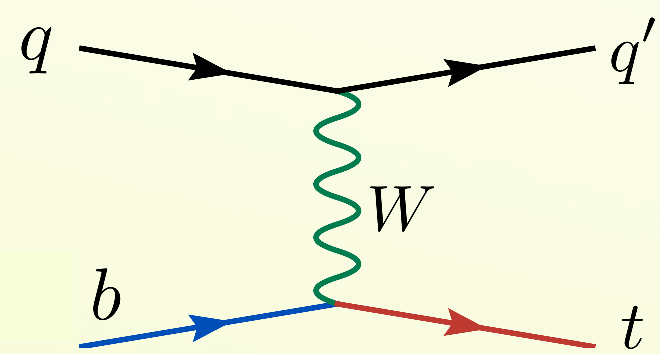

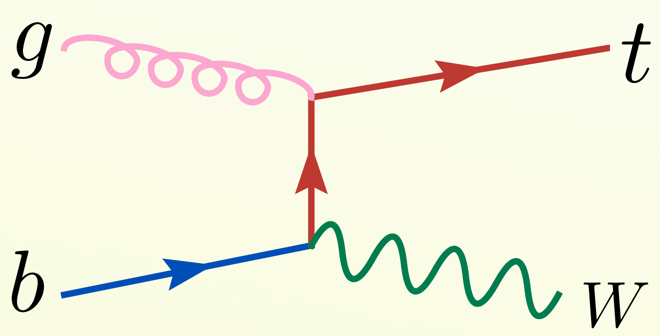

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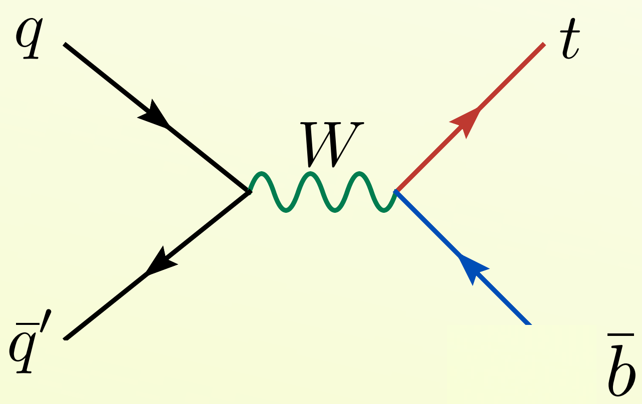

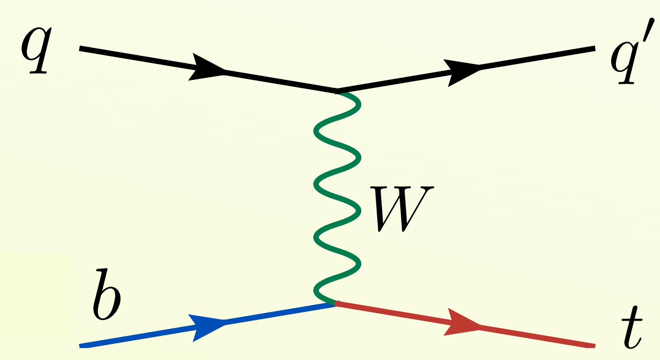

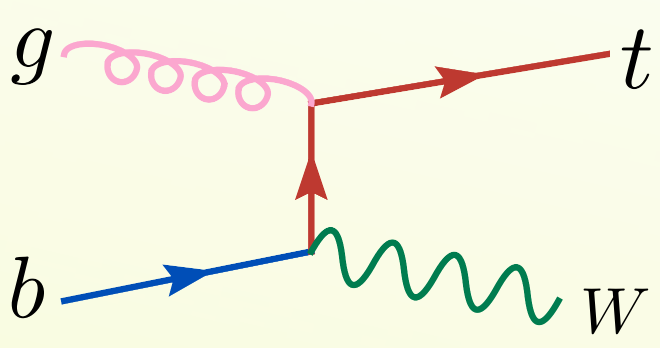

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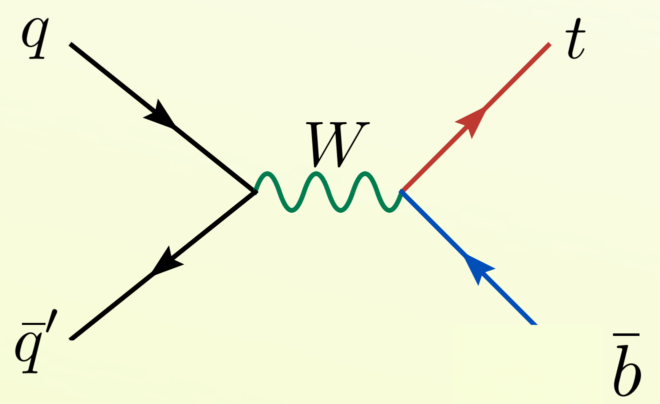

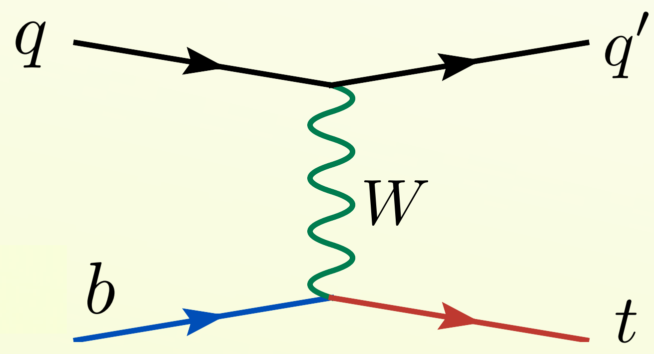

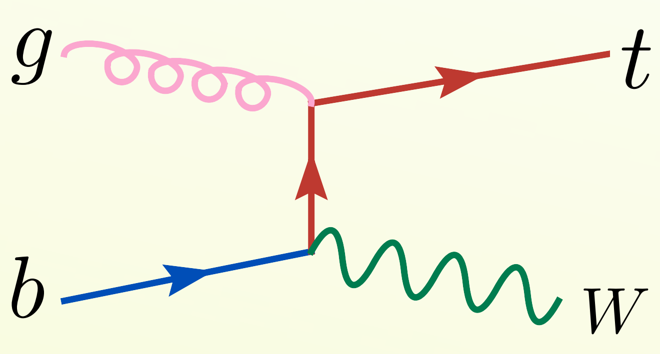

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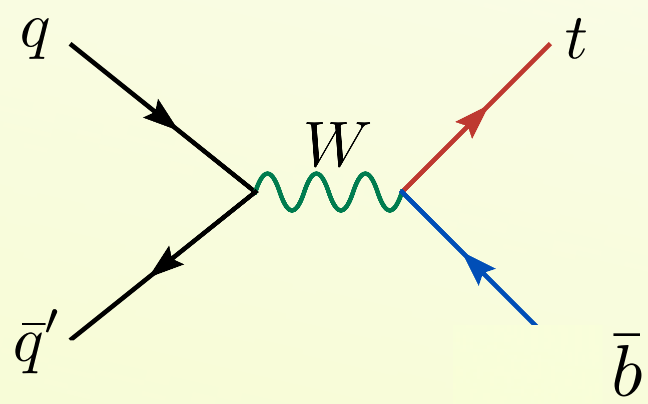

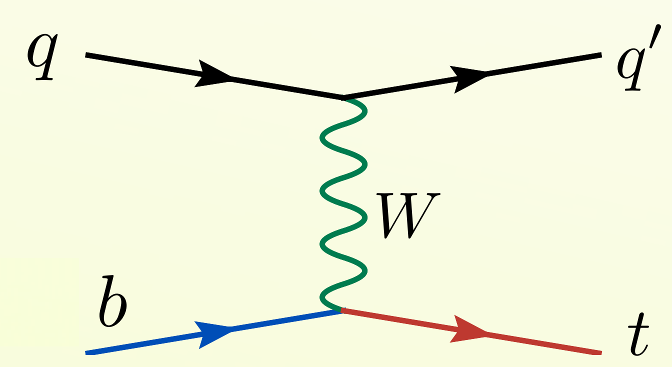

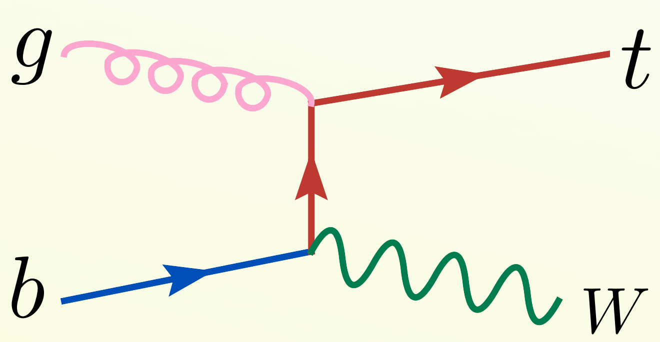

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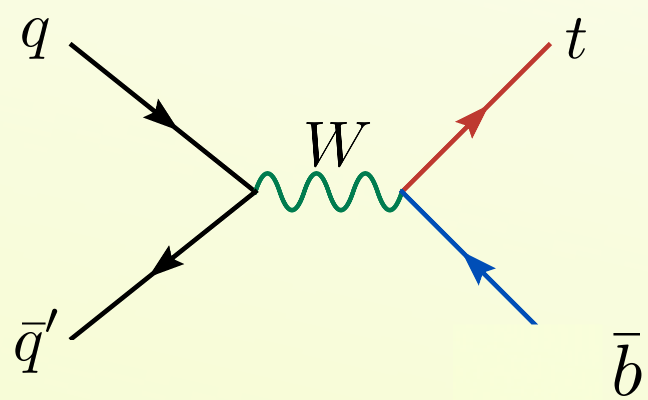

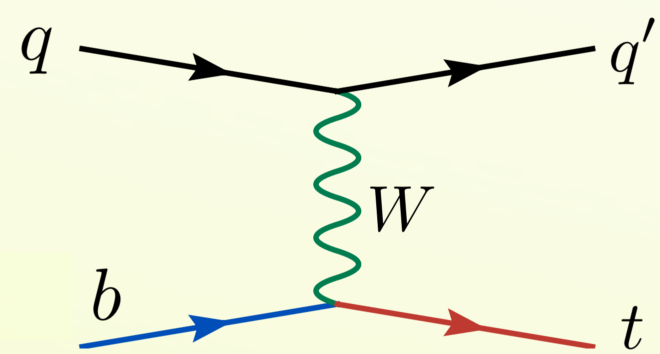

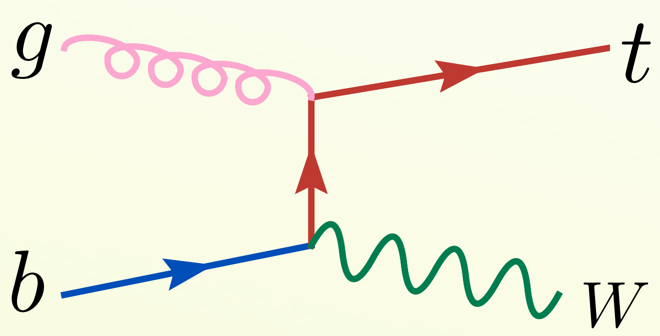

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"Challenging!!" *

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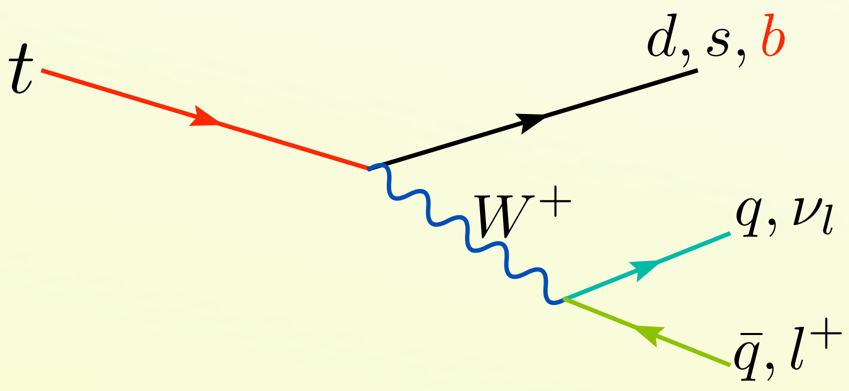
Example: Direct constraints on the 3rd row of CKM

Remember that R is not so sensitive to V_{tb} as we already know that $V_{tb} > V_{ts}, V_{td}$



$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq(= d, s, b))} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

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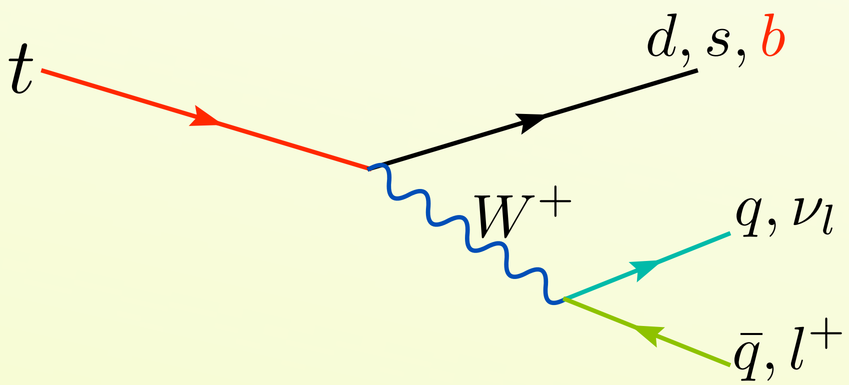

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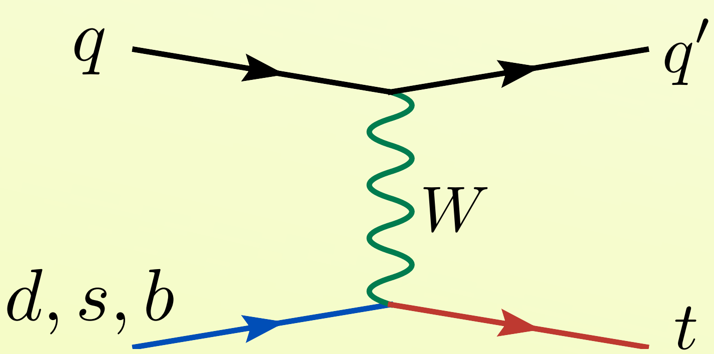
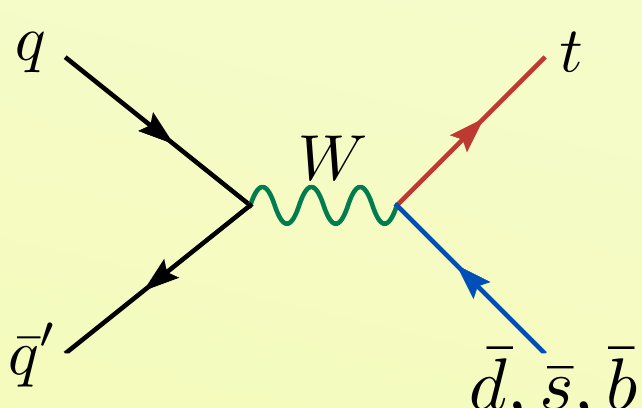
On the other hand, single top is DIRECTLY sensitive to V_{tb}, V_{ts}, V_{td} :



$$\sim |V_{td}|^2 \sigma_d^{\text{t-ch}} + |V_{ts}|^2 \sigma_s^{\text{t-ch}} + |V_{tb}|^2 \sigma_b^{\text{t-ch}}$$

Enhancement due to large *d* and *s* densities



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Signal becomes similar to t-channel (only 1 *b*-jet)

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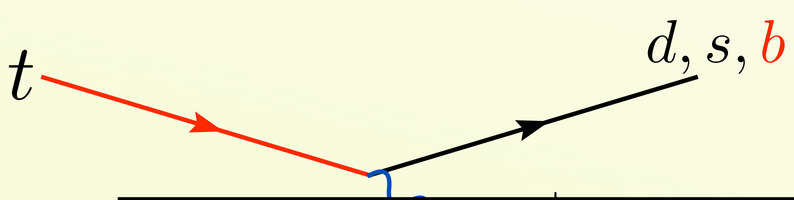


$$R = \frac{\Gamma(t \to Wb)}{\ldots} = \frac{|V_{tb}|^2}{\ldots}$$

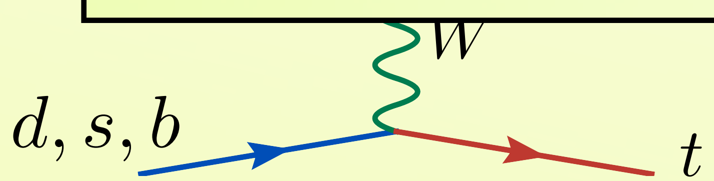
On t

$$\sigma_{1b\text{-tag}} = R \left\{ \sum_{i=b,s,d} |V_{ti}|^2 \sigma_i^{\mathrm{t-ch}} + 2(|V_{td}|^2 + |V_{ts}|^2)\sigma^{\mathrm{s-ch}} \right\}$$

$$\sigma_{2b\text{-tag}} = R\, |V_{tb}|^2\, \sigma^{\mathrm{s-ch}}$$

n.b. : naive estimate

$$\ldots |V_{td}|^2 \sigma_d + |V_{ts}|^2 \sigma_s + |V_{tb}|^2 \sigma_b$$



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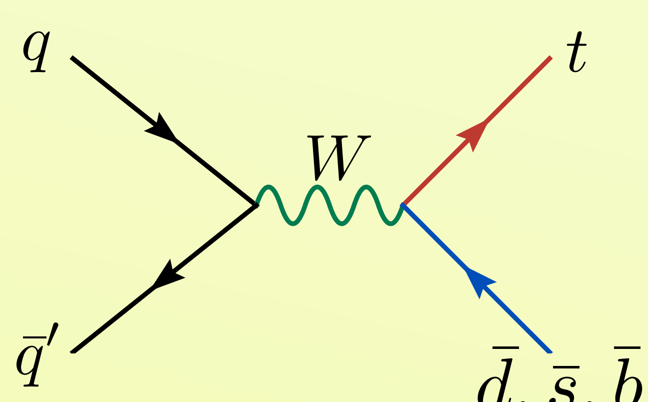

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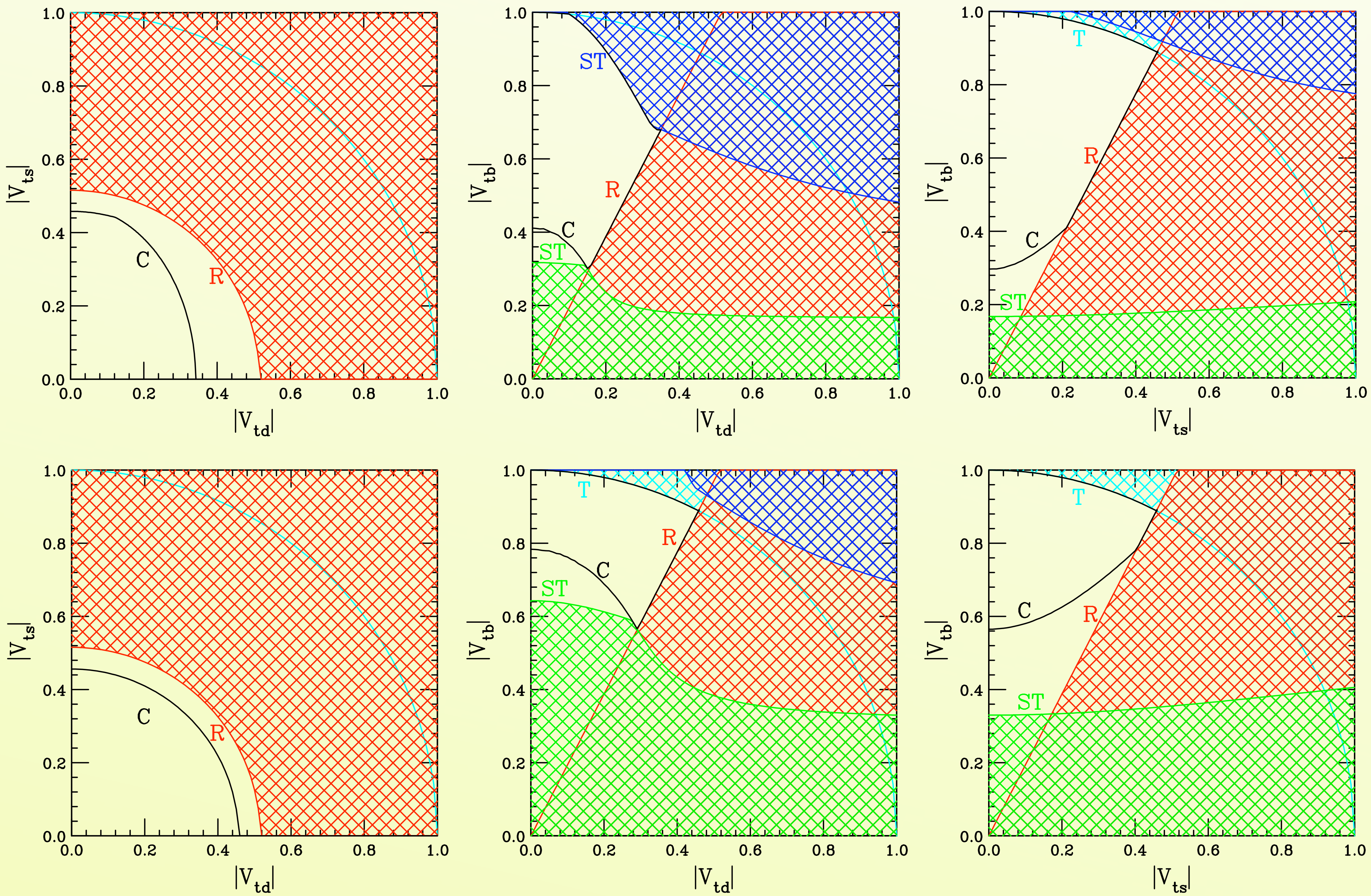
$|V_{td}|$ vs $|V_{ts}|$ $|V_{td}|$ vs $|V_{tb}|$ $|V_{ts}|$ vs $|V_{tb}|$

CDF

DØ



Alwall et al., Eur. Phys, J. C49 791 (2007) + updates

Lacker, FM, Wagner,... more work in progress

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NLO QCD	yes
NLOwPS QCD	yes
Resummed NLO	yes
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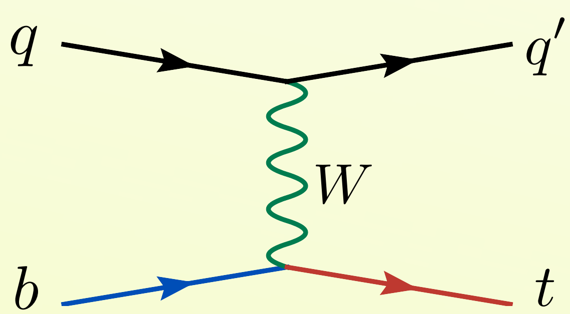
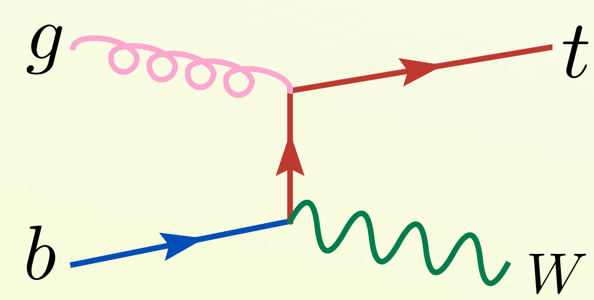
☺ All three 2→2 channels available in MC@NLO [Frixione et al.], w/ spin correlations!

☹ All MC implementations currently available for single top processes neglect m_b.

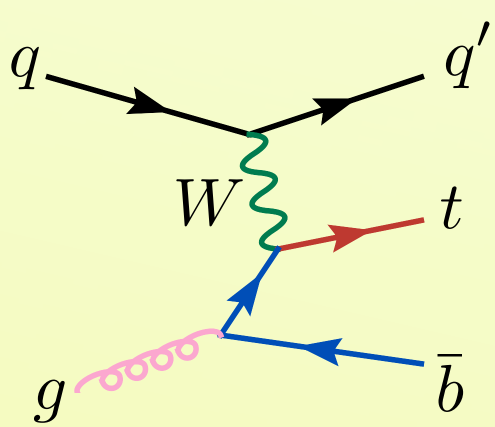
Heavy initial state quarks

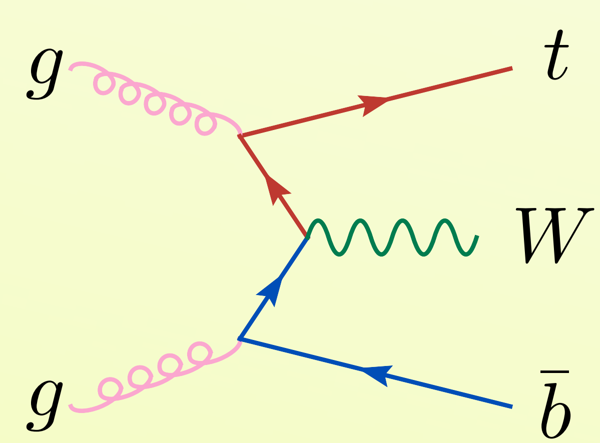
- Both the t-channel as well as the Wt associated production have a (heavy) b quark in the initial state





- There is an equivalent* description with a gluon splitting to b quark pairs





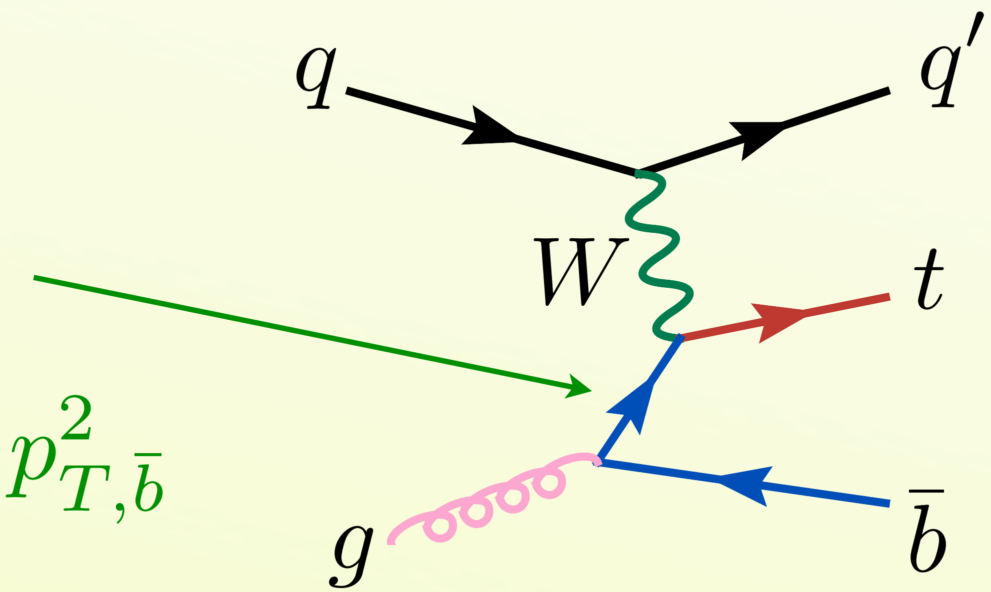
* At all orders. At fixed order differences arise...

Collinear logarithms

- Both t-channel and Wt production are enhanced by a collinear logarithm
- This results from integrating over a t-channel propagator

$$\frac{1}{t - m_b^2} \sim \frac{1}{p_T^2 + m_b^2}$$

$$t = (p_{\bar{b}} - p_g)^2,\, p_T^2 = p_{T,\bar{b}}^2$$



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$$\frac{1}{t-m_b^2} \sim \frac{1}{p_T^2+m_b^2}$$

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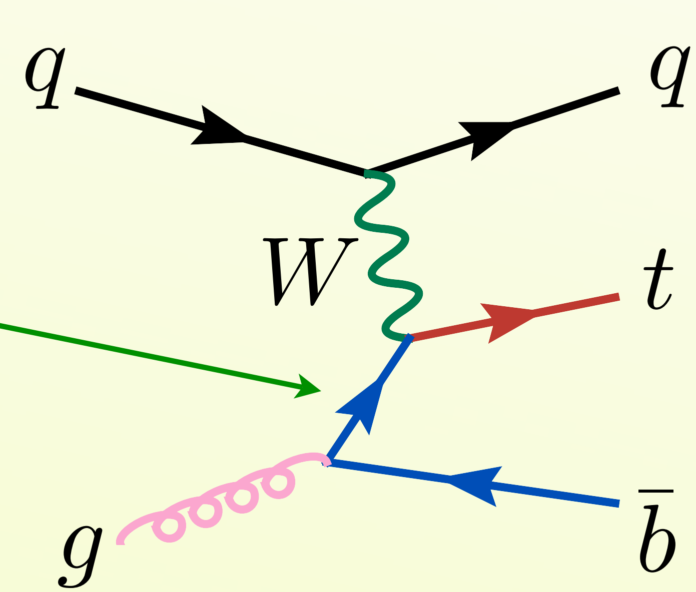

- Contribution to the cross section: $\int_0^{p_{T,\max}^2} \frac{dp_T^2}{p_T^2+m_b^2} = \log\left(\frac{p_{T,\max}^2}{m_b^2}\right) + \ldots$
- Coefficient of the logarithm is:

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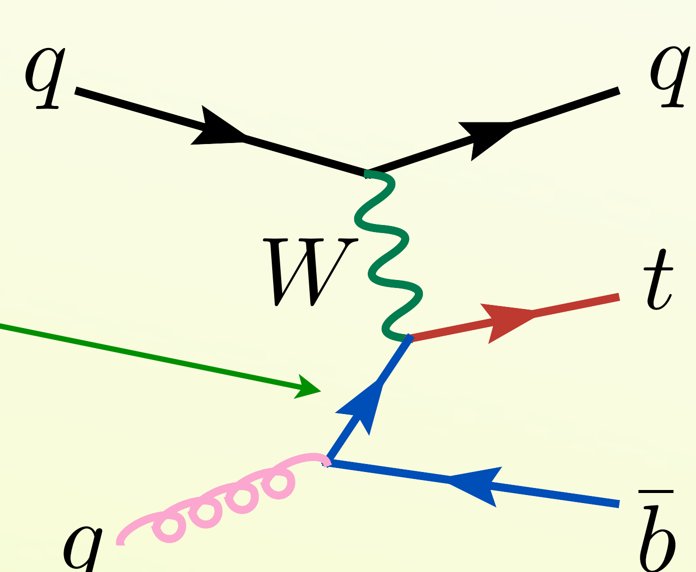
- Both t-channel and Wt production are enhanced by a collinear logarithm
- This results from integrating over a t-channel propagator

$$\frac{1}{t-m_b^2} \sim \frac{1}{p_T^2+m_b^2}$$

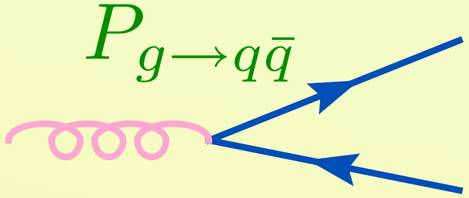
$$t=(p_{\bar{b}}-p_g)^2,\ p_T^2=p_{T,\bar{b}}^2$$



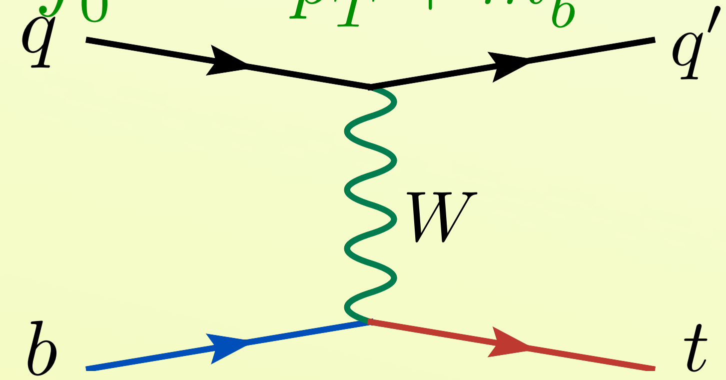
- Contribution to the cross section: $\int_0^{p_{T,\max}^2} \frac{dp_T^2}{p_T^2+m_b^2} = \log\left(\frac{p_{T,\max}^2}{m_b^2}\right)+\ldots$
- Coefficient of the logarithm is:

AP splitting function

$P_{g\to q\bar{q}}$



times



matrix elements with splitting removed

Resummation into PDF

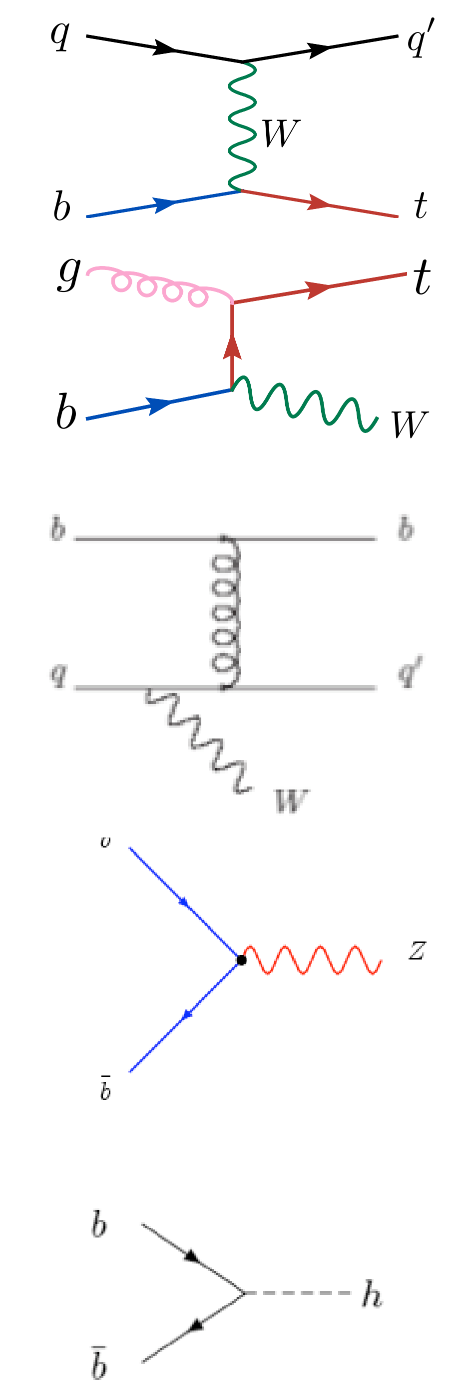
- Putting it together: $\frac{d\sigma(qg \to q' t\bar{b})}{d\log p^2_{T,\max}} \sim \left(\frac{\alpha_s}{2\pi}\right)\left[\int \frac{dx}{x} P_{g\to q\bar{q}} f_g\right] \times \hat{\sigma}(qb \to q't)$
- But the first part resembles the evolution equation for a quark:

$$\frac{df_q}{d\log q^2} \sim \left(\frac{\alpha_s}{2\pi}\right) \int \frac{dx}{x} \left[P_{g\to q\bar{q}} f_g + P_{q\to qg} f_q\right]$$

- So when the logarithms really dominate, we can replace this description by $\sigma(qg \to q' t\bar{b}) \approx \sigma(qb \to q't)$
- Scale of the bottom quark PDF should be related $p_{T,\max}$
- At all orders both description should agree; otherwise, differ by:
  - evolution of logarithms in PDF: they are resummed
  - ranges of integration (obscured here)
  - approximation by large logarithm

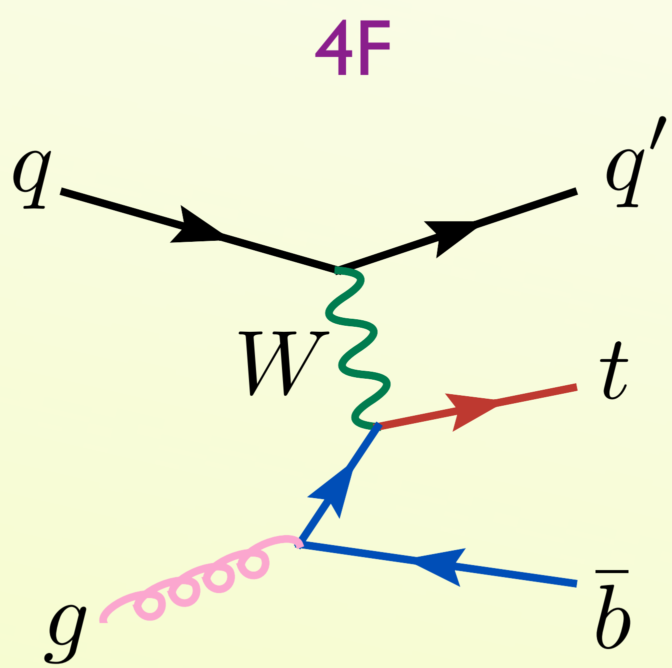
b-initiated processes

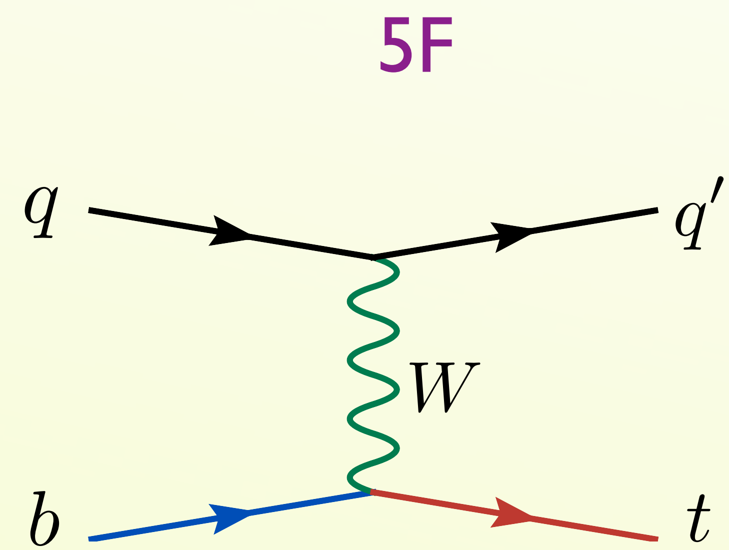
Class	Process	Interest
Top and t',b'	qb→tq qb→t'q,b'q (t-channel)	SM, top EW couplings and polarization, Vtb. Anomalous couplings. H+ : SUSY,2HDM, 4th generation
	gb→t(W,H+)	
Vector Bosons	pp→Wb pp→Wbj	SM, bkg to single top
	bb→Z gb→Zb pp→Zbj	Standard candle: SM BSM bkg, b-pdf
	gb→gamma+b	
Higgs	bb→ (h,A) gb→(h,A)+b	SUSY discovery/ measurements at large tan(beta)



Schemes

Two different ways of computing the same quantities:





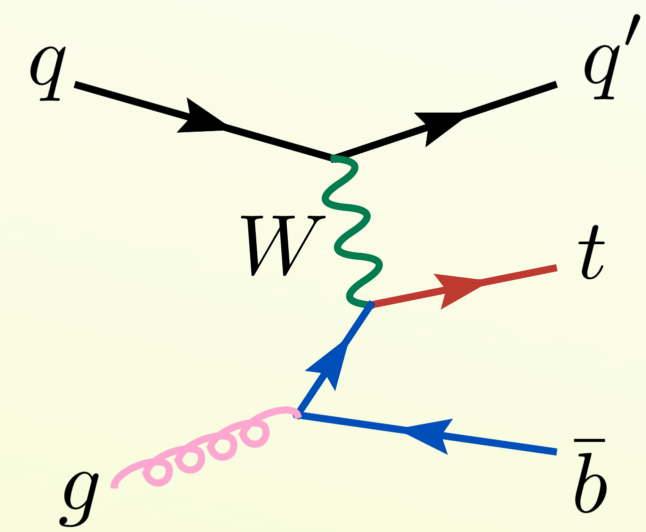
1. It does not resum (possibly) large logs (⇒norm. uncertainties)
2. Going NLO might be difficult.
3. Mass effects are there at any order in PT.
4. MC implementation with ME/PS merging a bit involved.

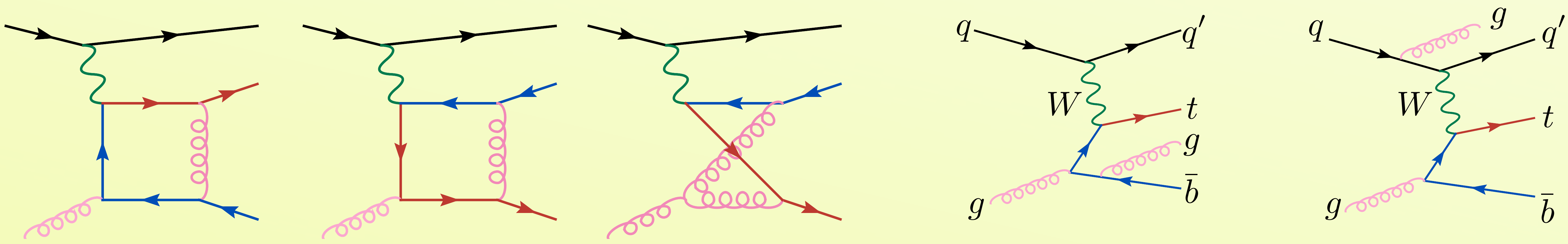
1. It resums initial state large logs in the b pdf, leading to more stable predictions
2. Going NLO (and NNLO) "easy".
3. Mass effects are normally corrections and enter at higher orders.
4. Implementation in MC relies on mass effects given by the PS, which are presently not very accurate.

Let's see a couple of examples...

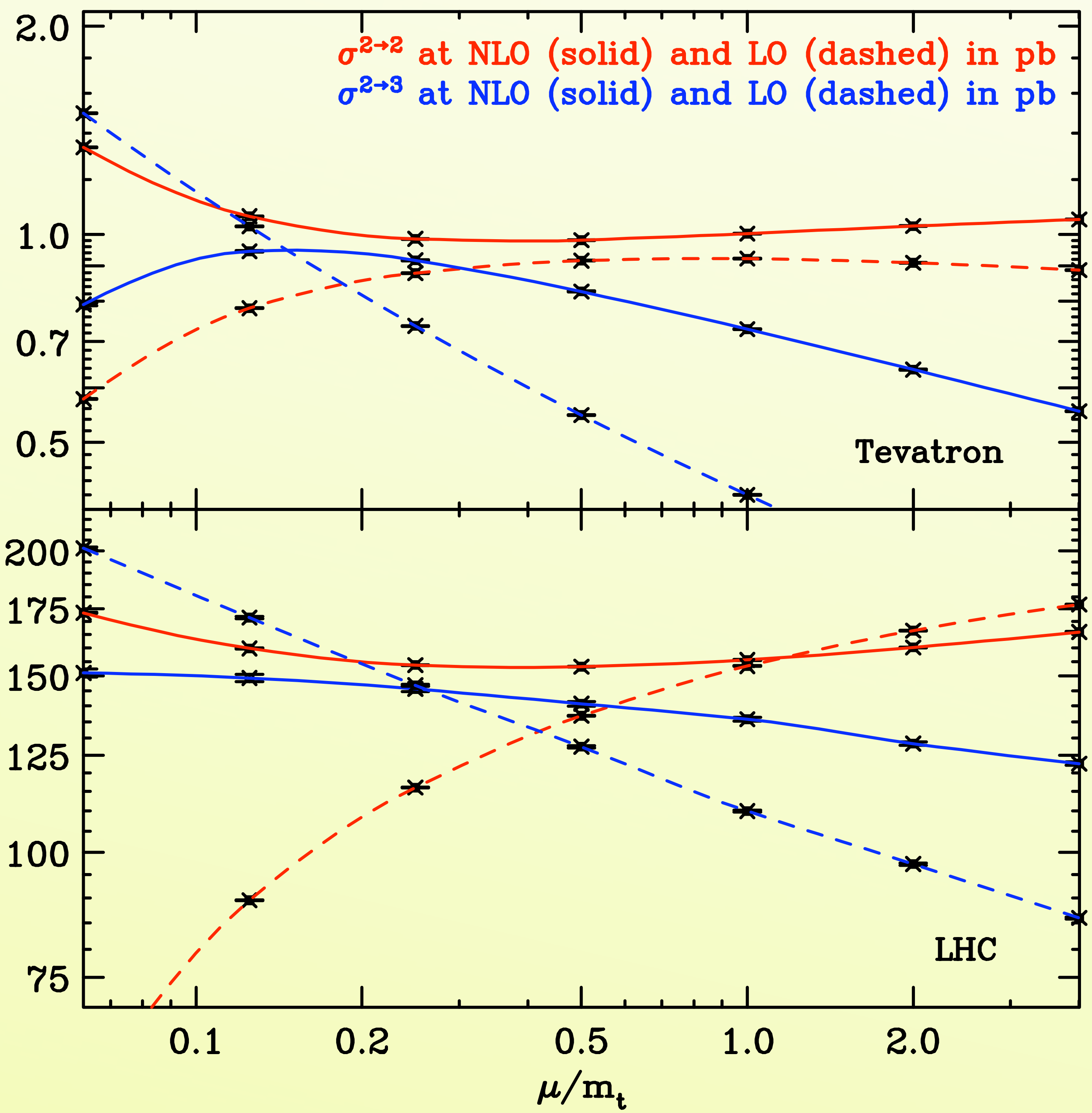
NLO in the four-flavor scheme

- Use the 4-flavor (2 → 3) process as the Born and calculate NLO
  - Much harder calculation due to two different masses and extra parton
  - Spectator b for the first time at NLO
  - Compare to 5F (2 → 2) to asses logarithms and applicability
  - Starting point for future NLO+PS beginning at (2 → 3)



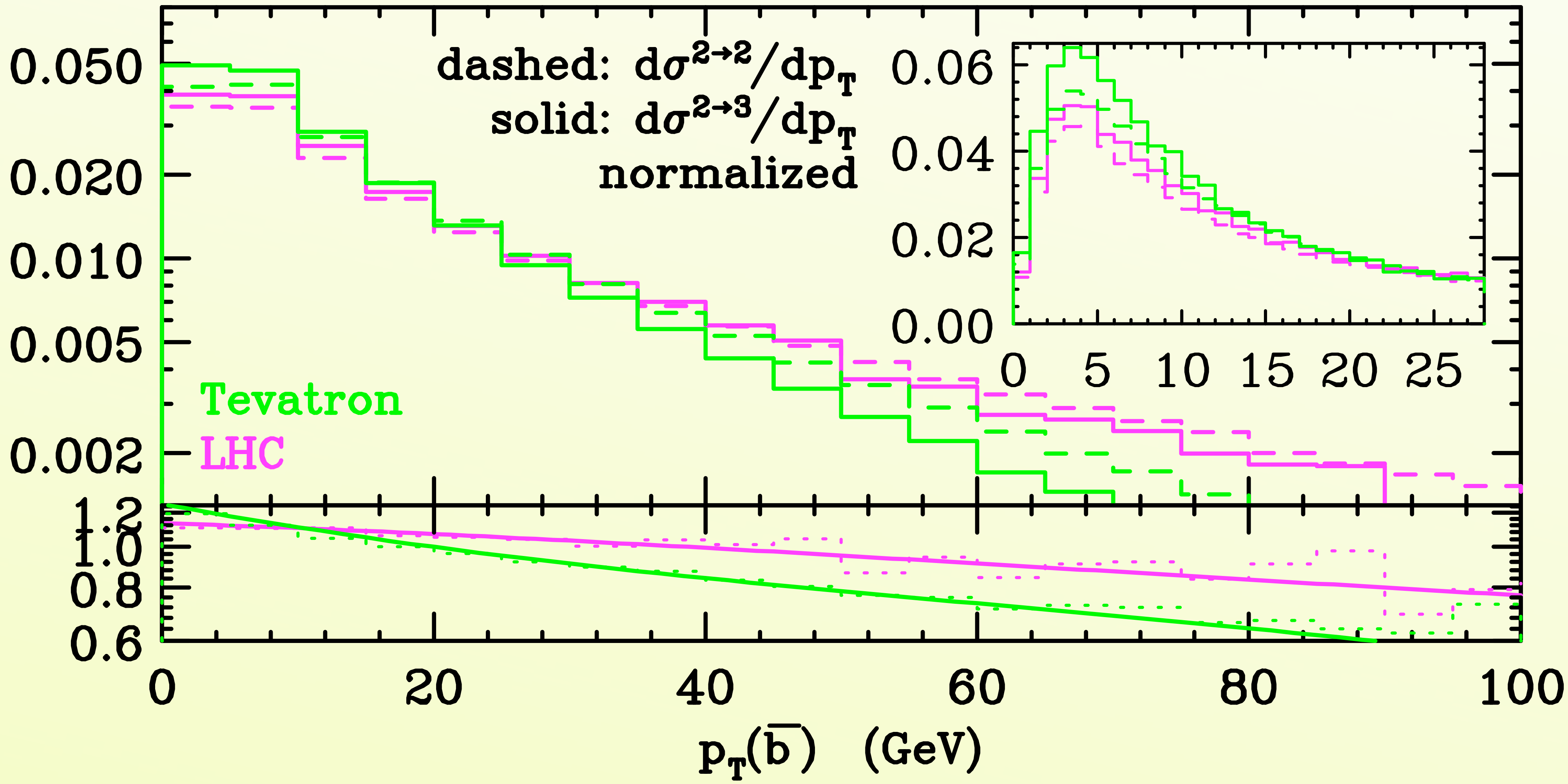


Scale dependence



- Both schemes much improved from LO
- 5F (2 → 2) only mildly sensitive to scales at NLO (use m_t in what follows)
- 4F (2 → 3) expected to be worse, but isn't much
- Hardly a region of overlap between the two
- 4F (2 → 3) prefers smaller scales than m_t, particularly at the Tevatron

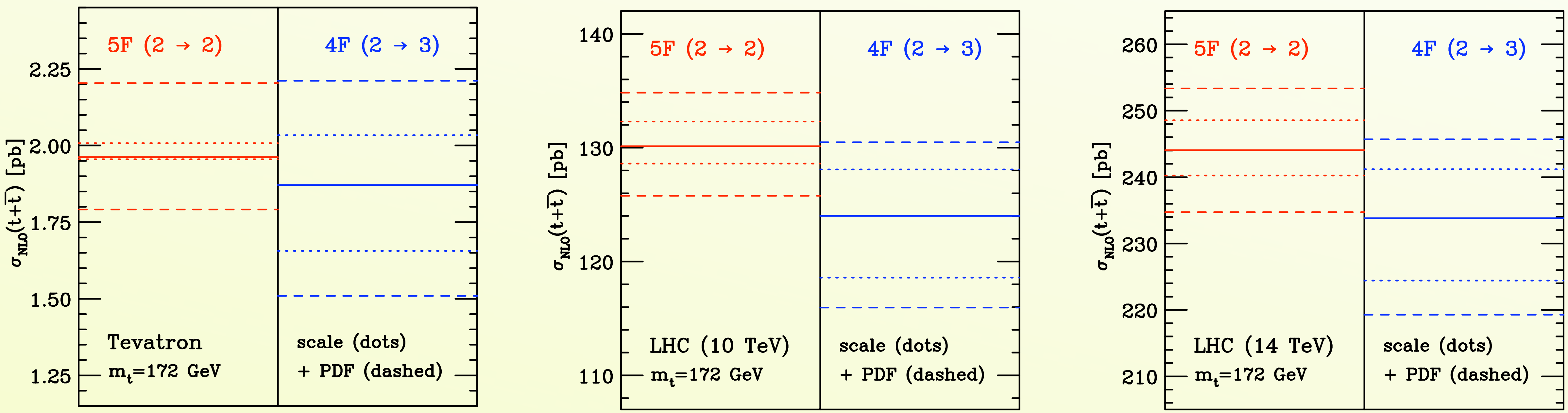
Spectator b



- First NLO prediction for this observable
- Slightly softer in 4F (2 → 3), particularly at the Tevatron
- Deviations up to ~ 20% : perturbatively quite stable
- Average pt of the b is rather low ~ 10 GeV

t-channel best cross sections : 2→2 vs 2→3

[Campbell, Frederix, FM, Tramontano, 0907.3933]

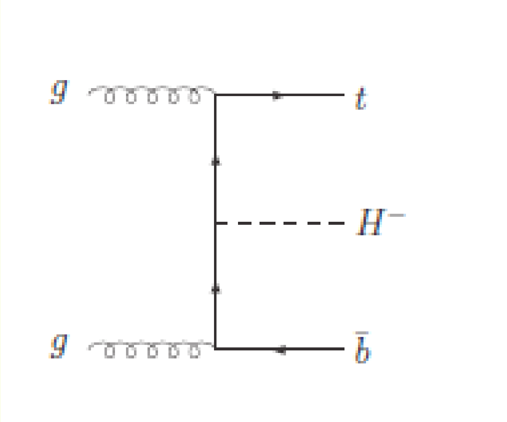


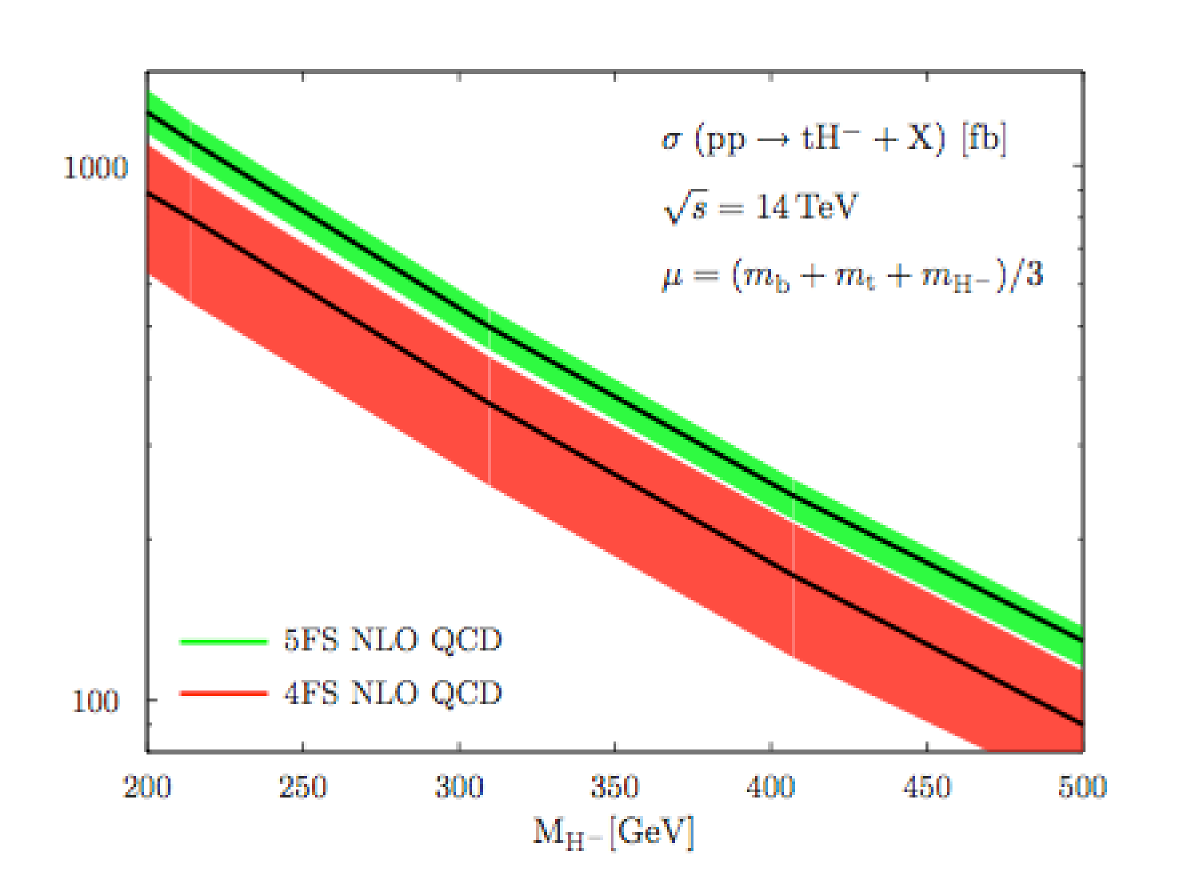
Central scales = mt/4

$\sigma^{NLO}_{t-ch}(t+\bar{t})$	$2 \to 2$ (pb)					$2 \to 3$ (pb)				
Tevatron Run II	1.96	$^{+0.05}_{-0.01}$	$^{+0.20}_{-0.16}$	$^{+0.06}_{-0.06}$	$^{+0.05}_{-0.05}$	1.87	$^{+0.16}_{-0.21}$	$^{+0.18}_{-0.15}$	$^{+0.06}_{-0.06}$	$^{+0.04}_{-0.04}$
LHC (10 TeV)	130	$^{+2}_{-2}$	$^{+3}_{-3}$	$^{+2}_{-2}$	$^{+2}_{-2}$	124	$^{+4}_{-5}$	$^{+2}_{-3}$	$^{+2}_{-2}$	$^{+2}_{-2}$
LHC (14 TeV)	244	$^{+5}_{-4}$	$^{+5}_{-6}$	$^{+3}_{-3}$	$^{+4}_{-4}$	234	$^{+7}_{-9}$	$^{+5}_{-5}$	$^{+3}_{-3}$	$^{+4}_{-4}$

Uncertainties: scales, PDF, m_t (1%), m_b(4%)

tH$^+$: 5F vs 4F

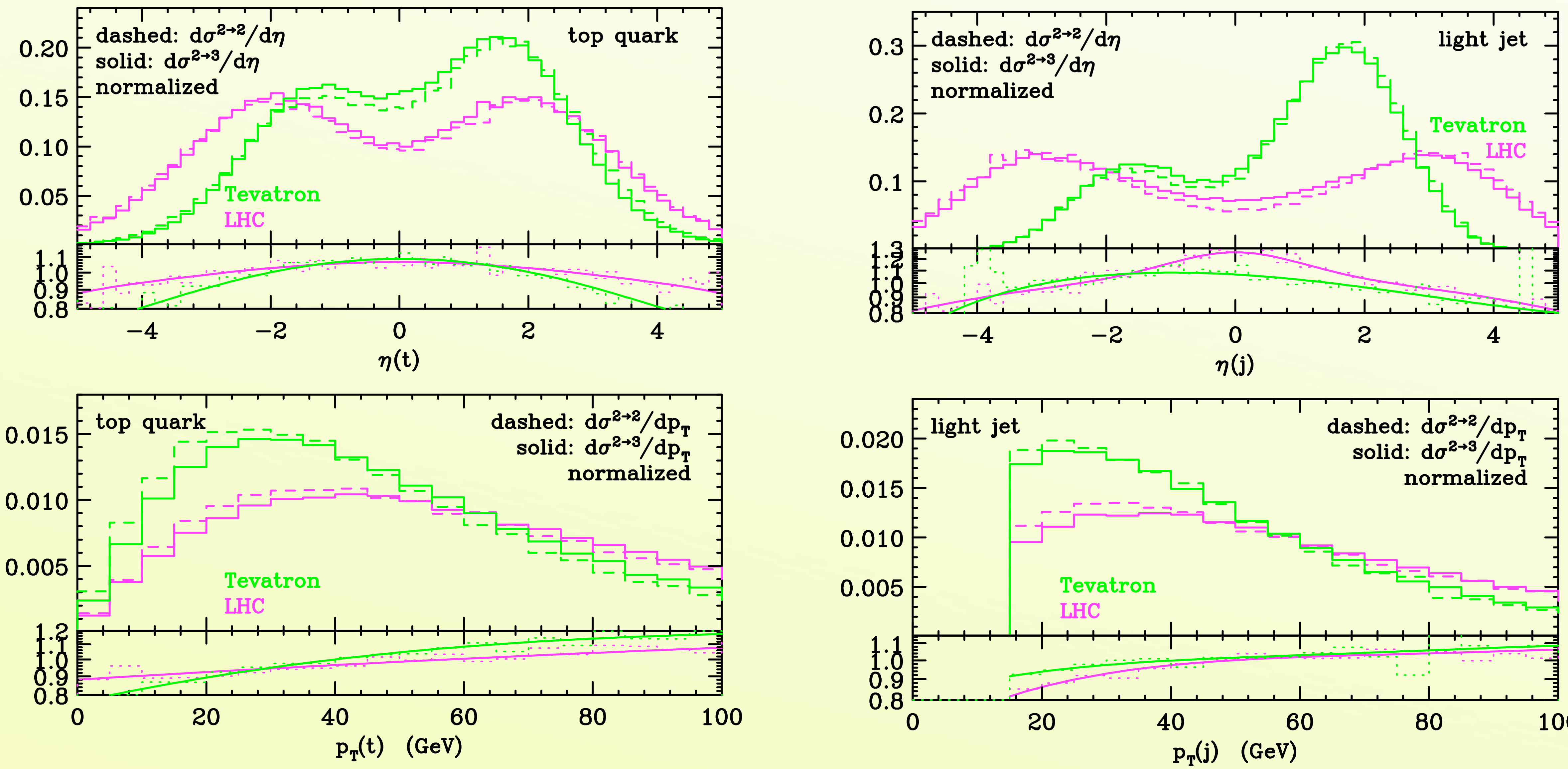




[Dittmaier,Kraemer,Spira,Walser 0906.3933]

- Calculation in the context of SUSY
- Same calculation could be applied to Little Higgs scenarios with a top - vector Tprime - H couplings.
- Also in this case the 5F (2 → 2) approach gives larger and less uncertain cross sections wrt to 4F (2 → 3).
- The calculations appear not to be compatible, however note the quite large scale choice wrt to tb choice...
- The overall picture is the same....

Top and light jet distributions



Some differences, but typically of the order of ~10% in the regions where the cross section is large

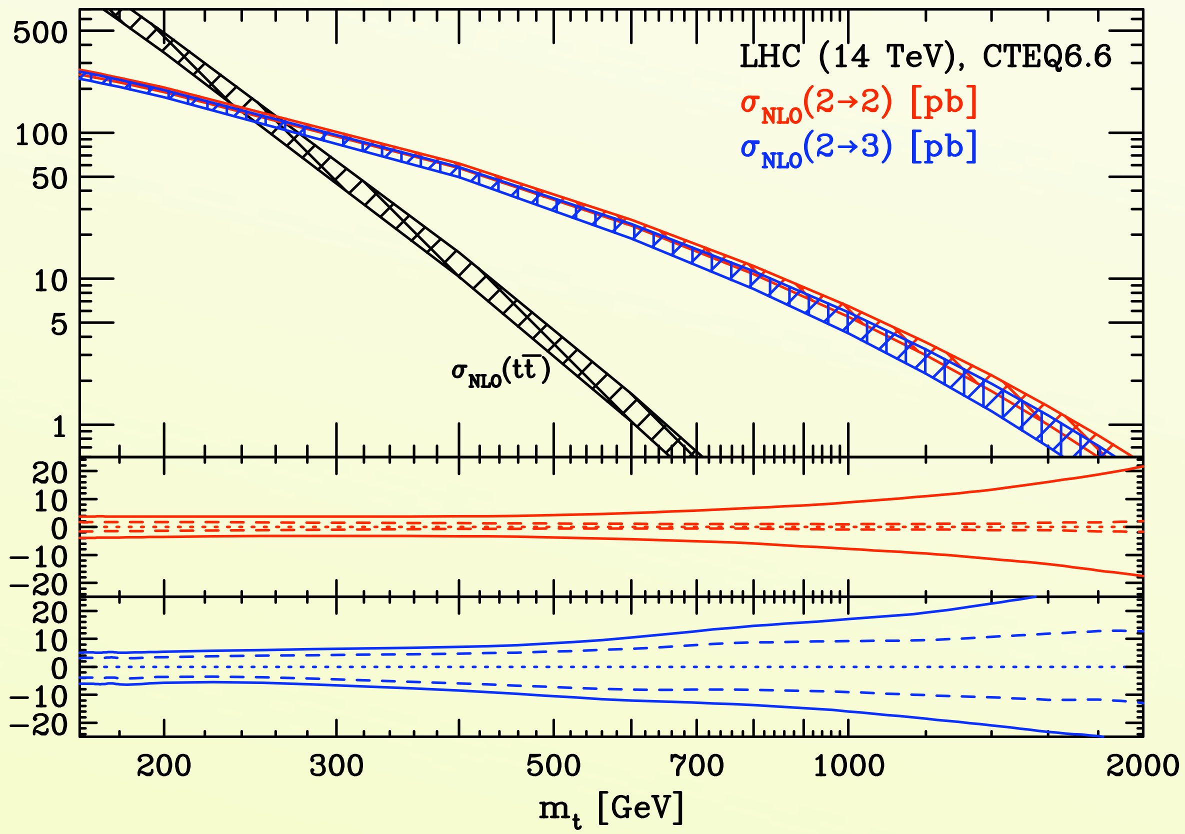
Lessons from the comparing 2→3 vs 2→2

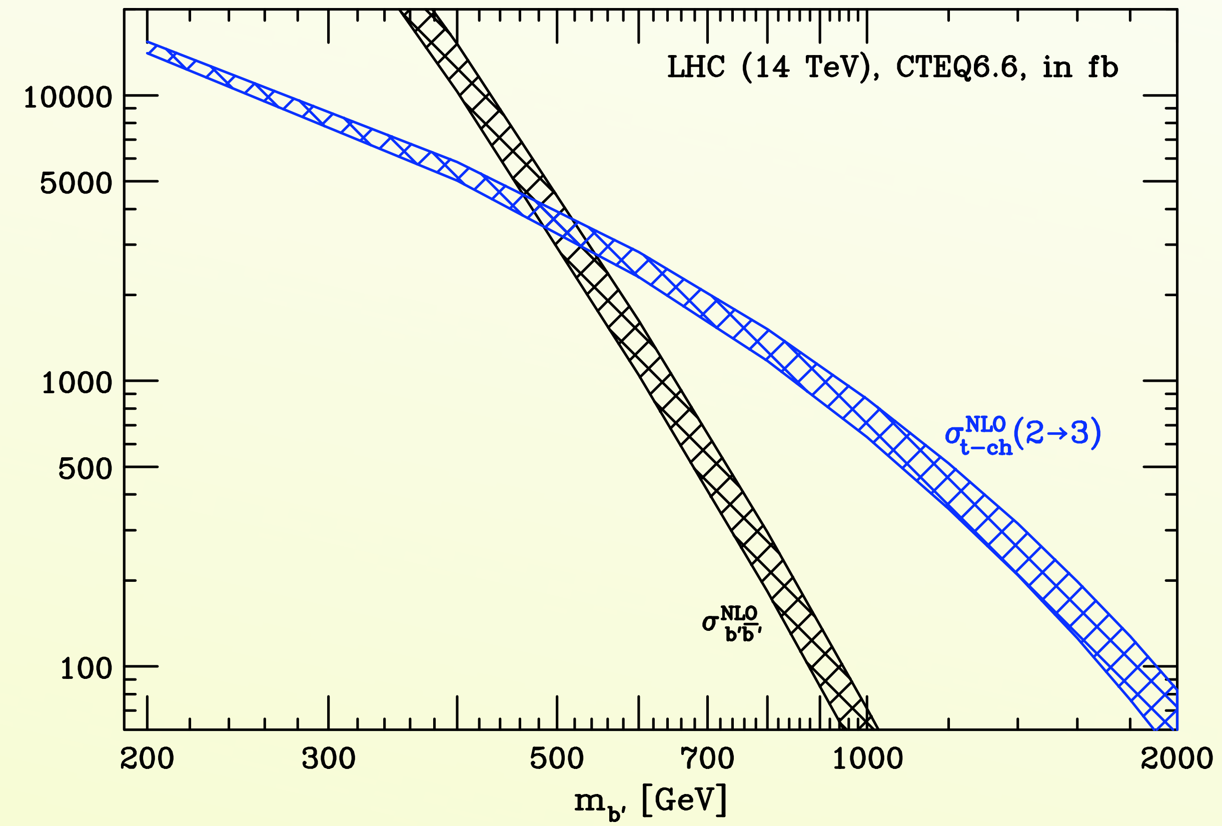
I. Results from the two calculations are consistent, IF a suitable scale choice is performed. 2→3 is a better choice for having all final state istributions at NLO.

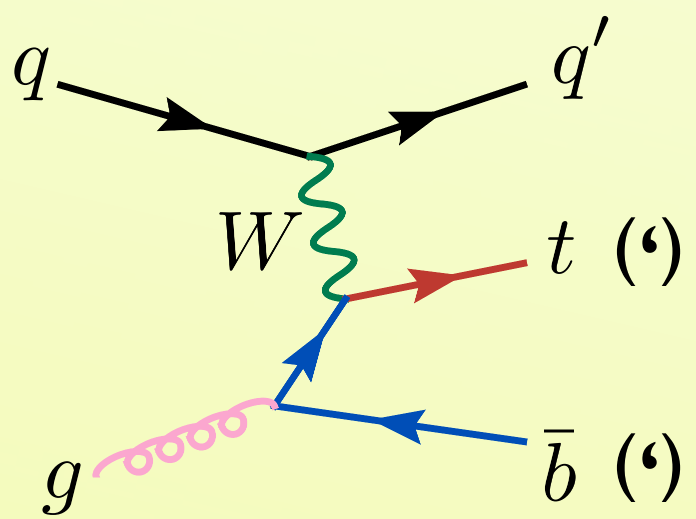
II. Single top (multivariate) analyses rely heavily on the MC's for the expected signal (and to a less extent background) distributions ⇒ NLO calculation necessary!

III. Single top can be also thought as a template for other difficult searches at the LHC such as those of a fourth generation....

Fourth generation x secs.







The NLO 2→3 massive calculation can be also used to make reliable predictions for Tb, Bt and BT cross sections.

It is interesting to see where the cross over between the QCD and the EW productions are at the LHC.(In these plots all the relevant CKM elements are set to one.)

Work in progress to extend these results to FCNC processes : pp→jBb, jTt

Conclusions

- Single top offers unique and exciting opportunities for testing the SM and probing new physics at the Tevatron and even more at the LHC.
- Theory and MC's under continuous improvement to match the needs of the experimental analyses (which are more demanding than those of ttbar!).
- Single top is also one of most "influential" examples of processes that can be described with heavy quarks in the initial state : known but always hot QCD issue.
- EW production cross section at NLO for 4th generation top through charged currents ready. Work in progress on the FCNC production.
- A lot of work and fun ahead...