Single top : SM and BSM

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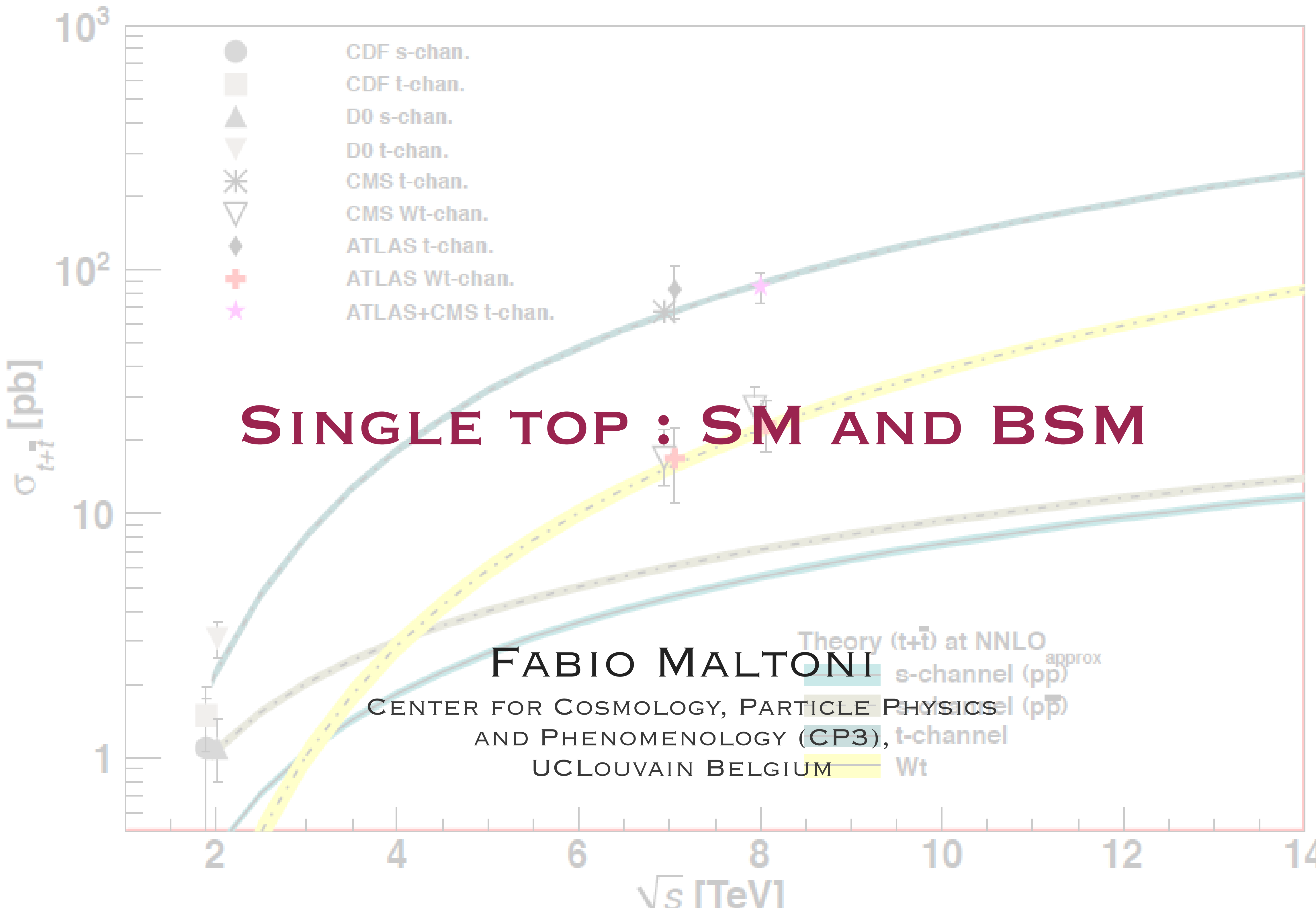
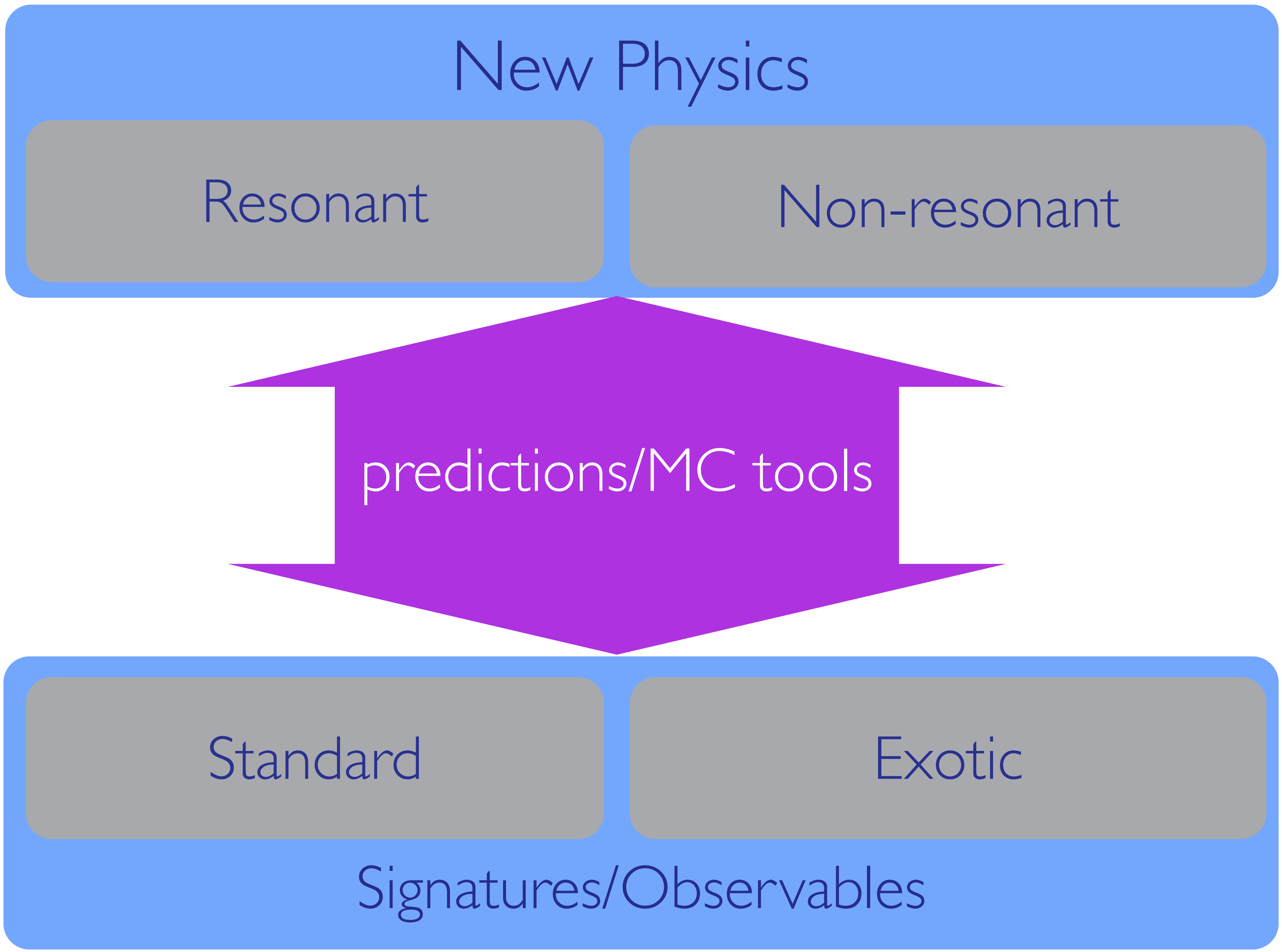


TOP-QUARK PHYSICS IN THE  ERA

- Are the theoretical motivations for thinking the top-quark might play a special role in EWSB and as a portal to New Physics still there ?
- What do the current Higgs measurements tell us ?
- How does the Higgs discovery impact on the current "SM" top-quark campaign of measurements ?
- And on the top-quark related BSM searches ?
- Do we have to retune our NP search strategies for the LHC Run II ?
- If so, do we have the TH results and simulation tools up to the new challenges ? Urgent needs ? New opportunities ?

NEW PHYSICS SEARCHES



THE TOP-QUARK GATEWAY TO NP

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Strategies:

- Precision SM top-quark properties measurements
- Search for non-SM top-quark interactions
- Searches of top-quark partners and other states

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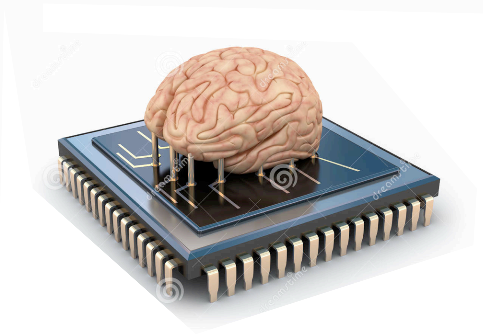
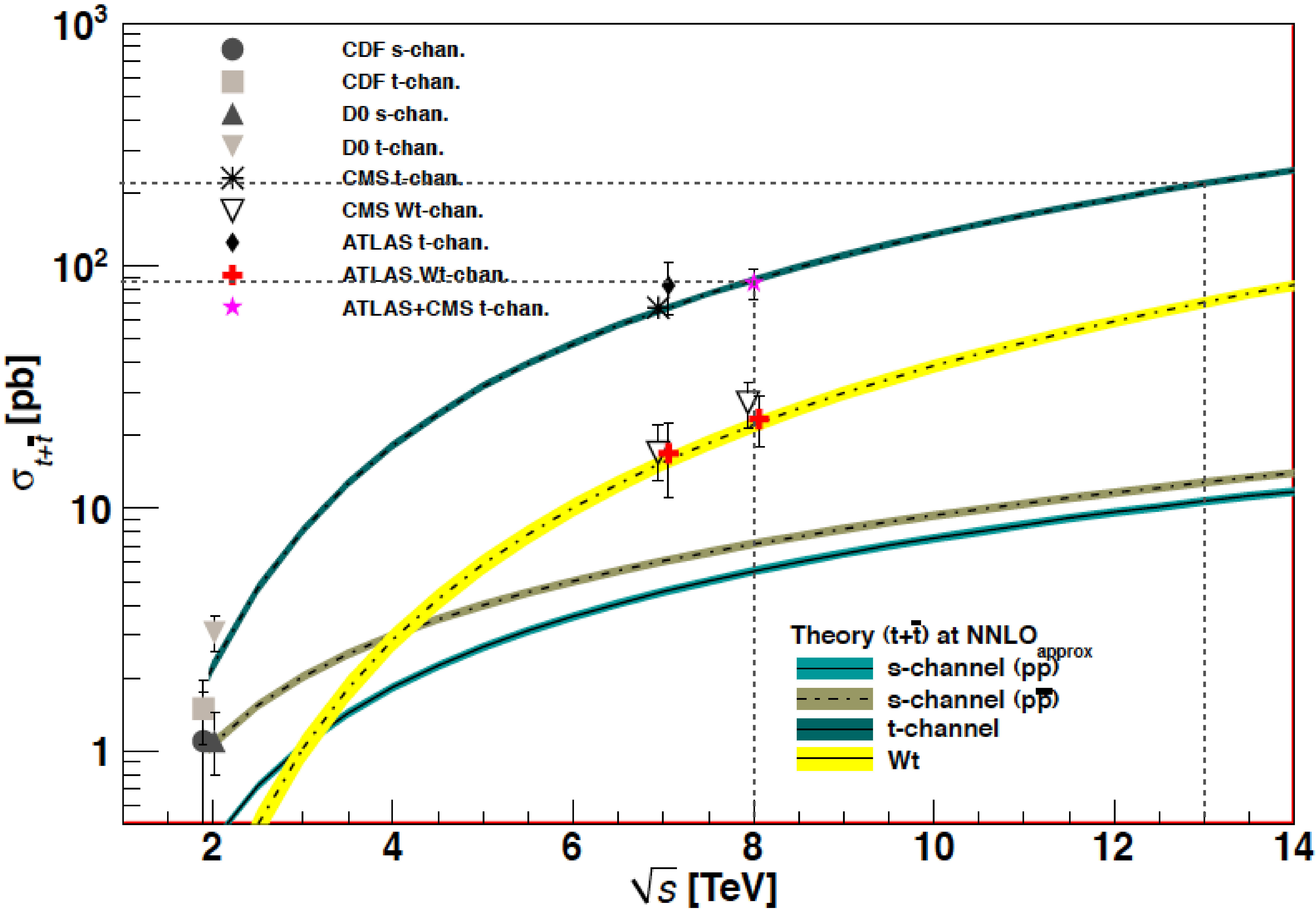


Needs:

- High precision predictions (NNLO in QCD and NLO EW) for key SM obs
- NLO for any SM and BSM process in the form of automatic MC tools
- A consistent and complete model-independent framework = EFT

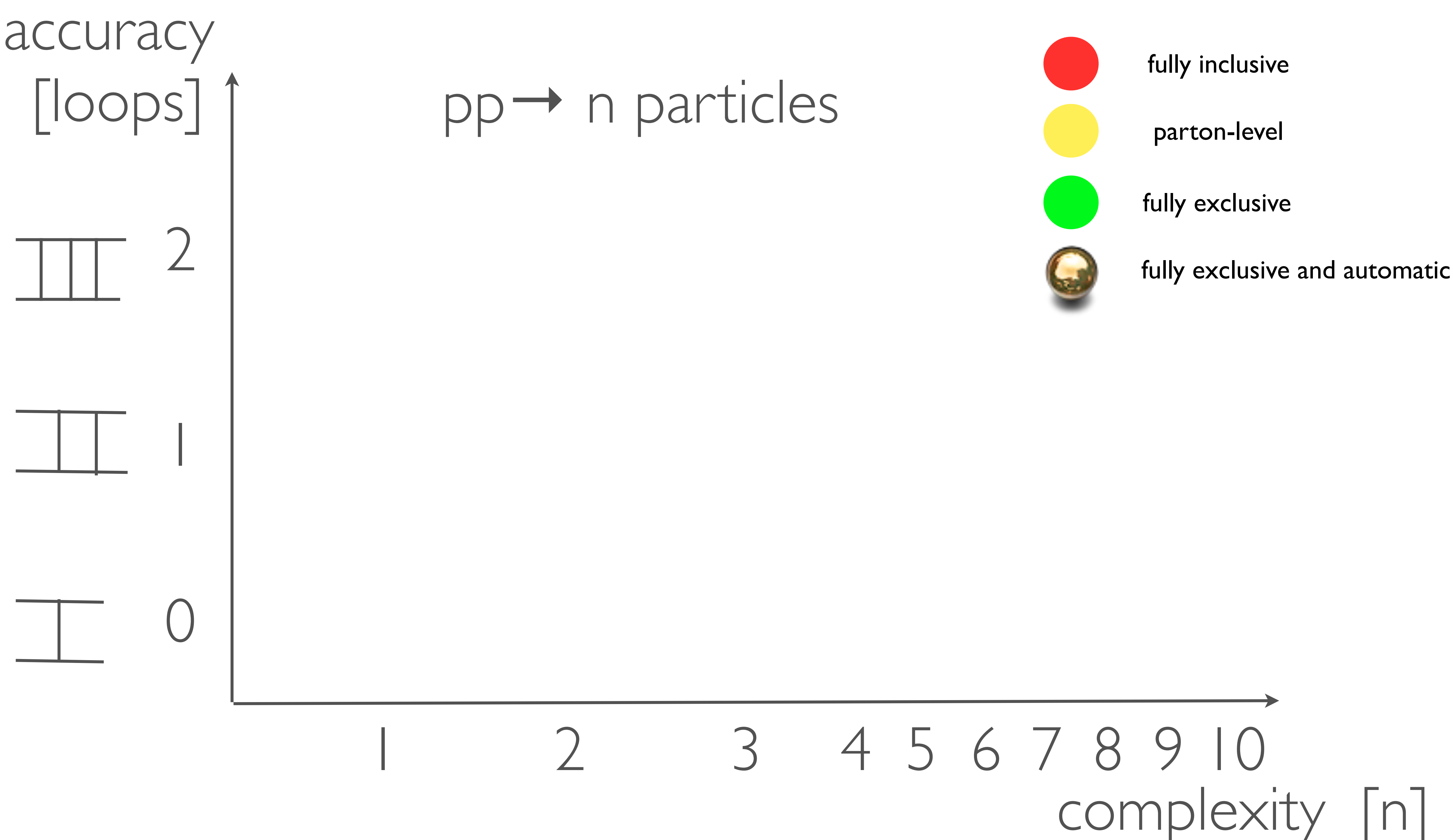


CDF s-chan.
CDF t-chan.
D0 s-chan.
D0 t-chan.
CMS t-chan.
CMS Wt-chan.
ATLAS t-chan.
ATLAS Wt-chan.
ATLAS+CMS t-chan.
Theory (t+t̄) at NNLO approx
s-channel (pp)
s-channel (pp̄)
t-channel
Wt
$\sigma_{t+\bar{t}}$ [pb]
$\sqrt{s}$ [TeV]

Single top-quark before run II

- Standard Model predictions available at the NNLOapprox + NLL resummation for total cross sections. Uncertainties are rather small. NNLO exact possible (at least two groups working on it).
- Measurements do agree pretty well with predictions for t-channel, tW channels and limits for s-channels.
- Spin correlations mostly used as discriminants in the SM measurements, but do also agree.
- Remains very good an extremely sensitive probe for new physics both in the coupling measurements and resonant searches.

AUTOMATIC MC's AT NLO



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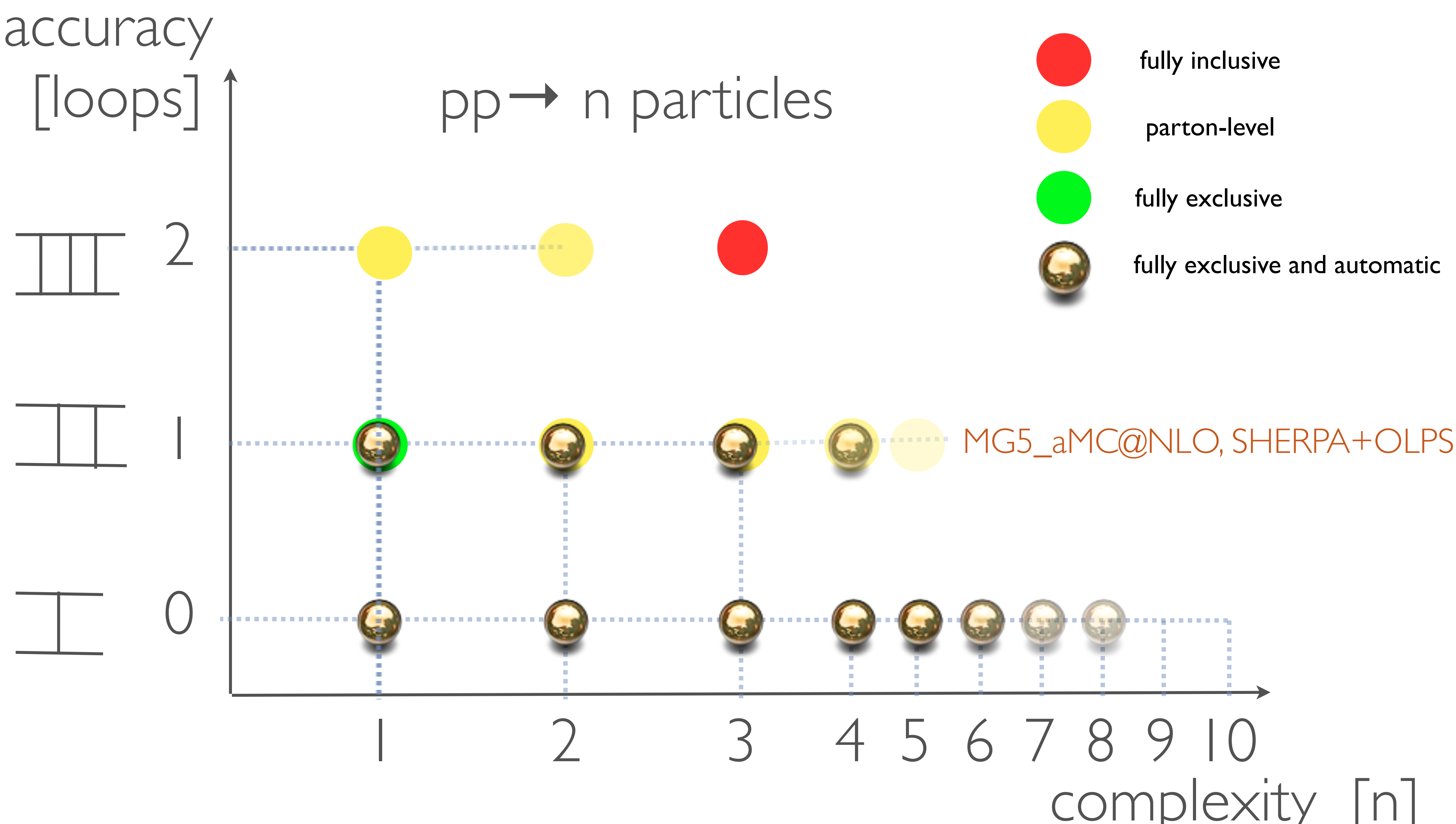

AUTOMATIC MC's AT NLO

Entire classes of processes of substantial complexity and unthinkable only a few months ago are now available at the touch of a button. For single-top:

	Process Single-top	Syntax	Cross section (pb) LO 13 TeV	NLO 13 TeV
f.1	$pp \to tj$ (t-channel)	`p p > tt j $$ w+ w-`	$1.520 \pm 0.001 \cdot 10^{2}$ $^{+9.4\%}_{-11.9\%}$ $^{+0.4\%}_{-0.6\%}$	$1.563 \pm 0.005 \cdot 10^{2}$ $^{+1.4\%}_{-1.8\%}$ $^{+0.4\%}_{-0.6\%}$
f.2	$pp \to t\gamma j$ (t-channel)	`p p > tt a j $$ w+ w-`	$9.956 \pm 0.014 \cdot 10^{-1}$ $^{+6.4\%}_{-8.8\%}$ $^{+0.9\%}_{-1.0\%}$	$1.017 \pm 0.003 \cdot 10^{0}$ $^{+1.3\%}_{-1.2\%}$ $^{+0.8\%}_{-0.9\%}$
f.3	$pp \to tZj$ (t-channel)	`p p > tt z j $$ w+ w-`	$6.967 \pm 0.007 \cdot 10^{-1}$ $^{+3.5\%}_{-5.5\%}$ $^{+0.9\%}_{-1.0\%}$	$6.993 \pm 0.021 \cdot 10^{-1}$ $^{+1.6\%}_{-1.1\%}$ $^{+0.9\%}_{-1.0\%}$
f.4	$pp \to tbj$ (t-channel)	`p p > tt bb j $$ w+ w-`	$1.003 \pm 0.000 \cdot 10^{2}$ $^{+13.8\%}_{-11.5\%}$ $^{+0.4\%}_{-0.5\%}$	$1.319 \pm 0.003 \cdot 10^{2}$ $^{+5.8\%}_{-5.2\%}$ $^{+0.4\%}_{-0.5\%}$
f.5*	$pp \to tbj\gamma$ (t-channel)	`p p > tt bb j a $$ w+ w-`	$6.293 \pm 0.006 \cdot 10^{-1}$ $^{+16.8\%}_{-13.5\%}$ $^{+0.8\%}_{-0.9\%}$	$8.612 \pm 0.025 \cdot 10^{-1}$ $^{+6.2\%}_{-6.6\%}$ $^{+0.8\%}_{-0.9\%}$
f.6*	$pp \to tbjZ$ (t-channel)	`p p > tt bb j z $$ w+ w-`	$3.934 \pm 0.002 \cdot 10^{-1}$ $^{+18.7\%}_{-14.7\%}$ $^{+1.0\%}_{-0.9\%}$	$5.657 \pm 0.014 \cdot 10^{-1}$ $^{+7.7\%}_{-7.9\%}$ $^{+0.9\%}_{-0.9\%}$
f.7	$pp \to tb$ (s-channel)	`p p > w+ > t b~, p p > w- > t~ b`	$7.489 \pm 0.007 \cdot 10^{0}$ $^{+3.5\%}_{-4.4\%}$ $^{+1.9\%}_{-1.4\%}$	$1.001 \pm 0.004 \cdot 10^{1}$ $^{+3.7\%}_{-3.9\%}$ $^{+1.9\%}_{-1.5\%}$
f.8*	$pp \to tb\gamma$ (s-channel)	`p p > w+ > t b~ a, p p > w- > t~ b a`	$1.490 \pm 0.001 \cdot 10^{-2}$ $^{+1.2\%}_{-1.8\%}$ $^{+1.9\%}_{-1.5\%}$	$1.952 \pm 0.007 \cdot 10^{-2}$ $^{+2.6\%}_{-2.3\%}$ $^{+1.7\%}_{-1.4\%}$
f.9*	$pp \to tbZ$ (s-channel)	`p p > w+ > t b~ z, p p > w- > t~ b z`	$1.072 \pm 0.001 \cdot 10^{-2}$ $^{+1.3\%}_{-1.5\%}$ $^{+2.0\%}_{-1.6\%}$	$1.539 \pm 0.005 \cdot 10^{-2}$ $^{+3.9\%}_{-3.2\%}$ $^{+1.9\%}_{-1.5\%}$

And in association with Higgs:

g.17	$pp \to Htj$	`p p > h tt j`	$4.994 \pm 0.005 \cdot 10^{-2}$ $^{+2.4\%}_{-4.2\%}$ $^{+1.2\%}_{-1.3\%}$	$6.328 \pm 0.022 \cdot 10^{-2}$ $^{+2.9\%}_{-1.8\%}$ $^{+1.5\%}_{-1.6\%}$
h.15	$pp \to HHtj$	`p p > h h tt j`	$1.844 \pm 0.008 \cdot 10^{-5}$ $^{+0.0\%}_{-0.6\%}$ $^{+1.8\%}_{-1.8\%}$	$2.444 \pm 0.009 \cdot 10^{-5}$ $^{+4.5\%}_{-3.1\%}$ $^{+2.8\%}_{-3.0\%}$

AUTOMATIC MC'S AT NLO

Recent studies:

- ➡ 4F and 5F in NLO+PS [Frederix, Re, Torrrielli] [FM, Ridolfi, Ubiali]
- ➡ WbWb at NLO [Frederix] [Cascioli et al.]
- ➡ Wbj at NLO [Papanastasiou et al]
- ➡ tHj at NLO [Farina et al]

automatic MC's at NLO

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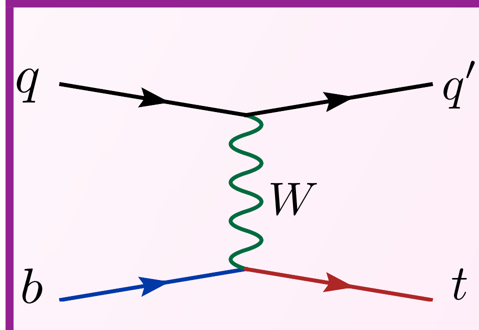
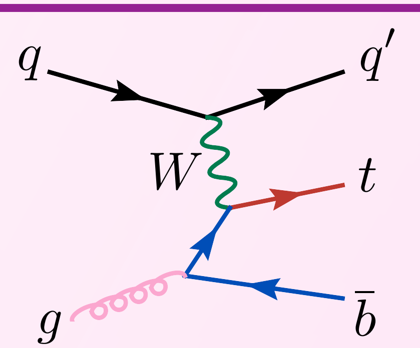
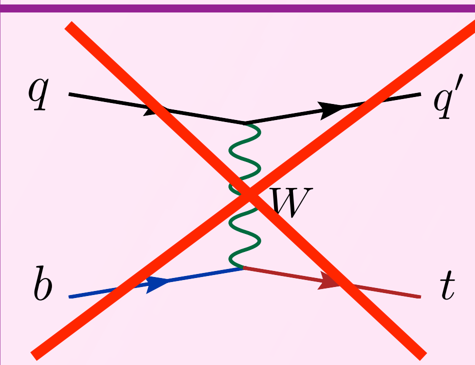
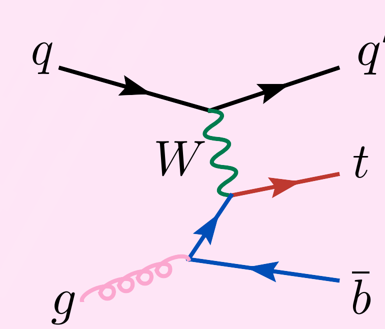
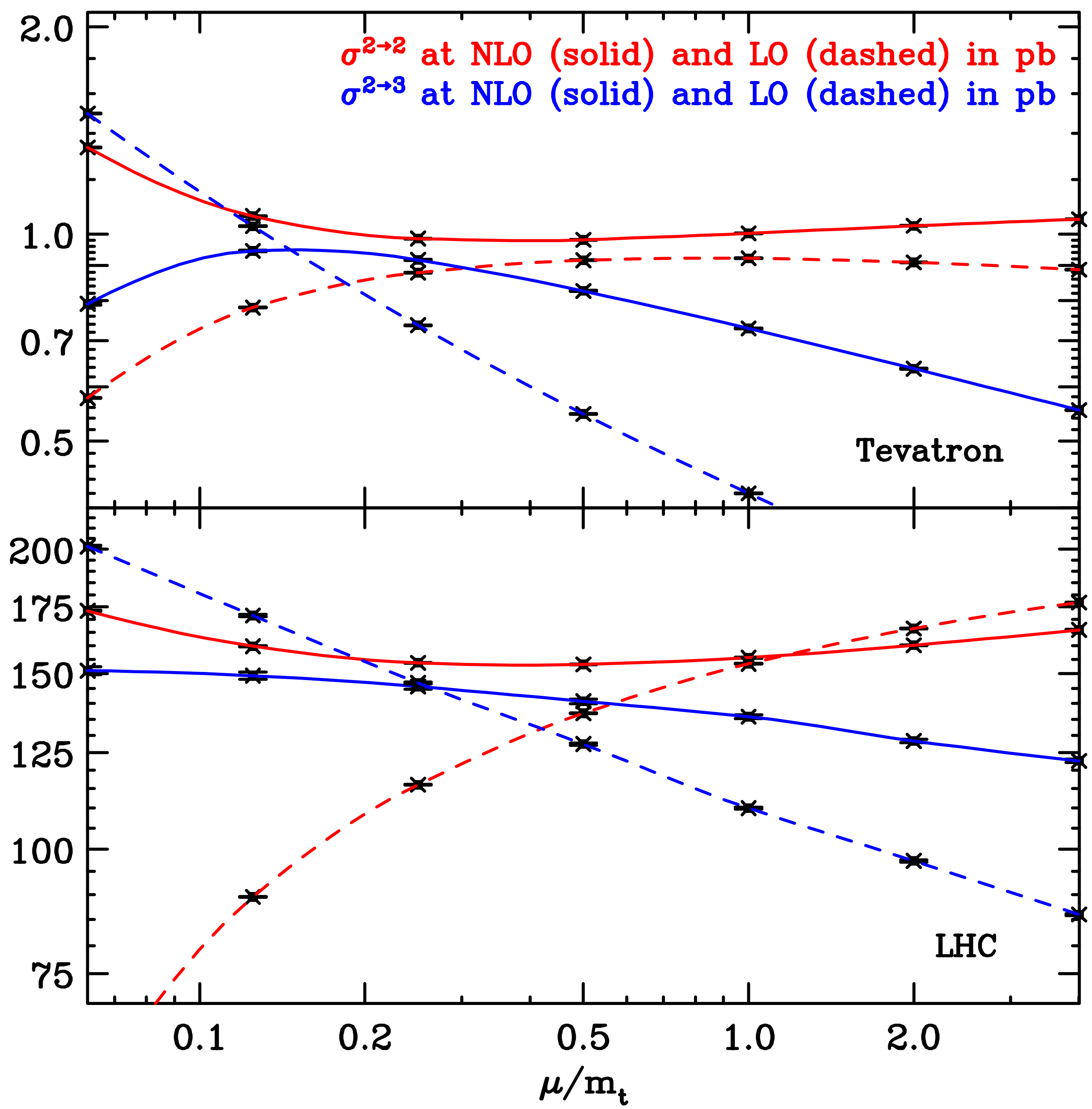
4- & 5-flavor schemes

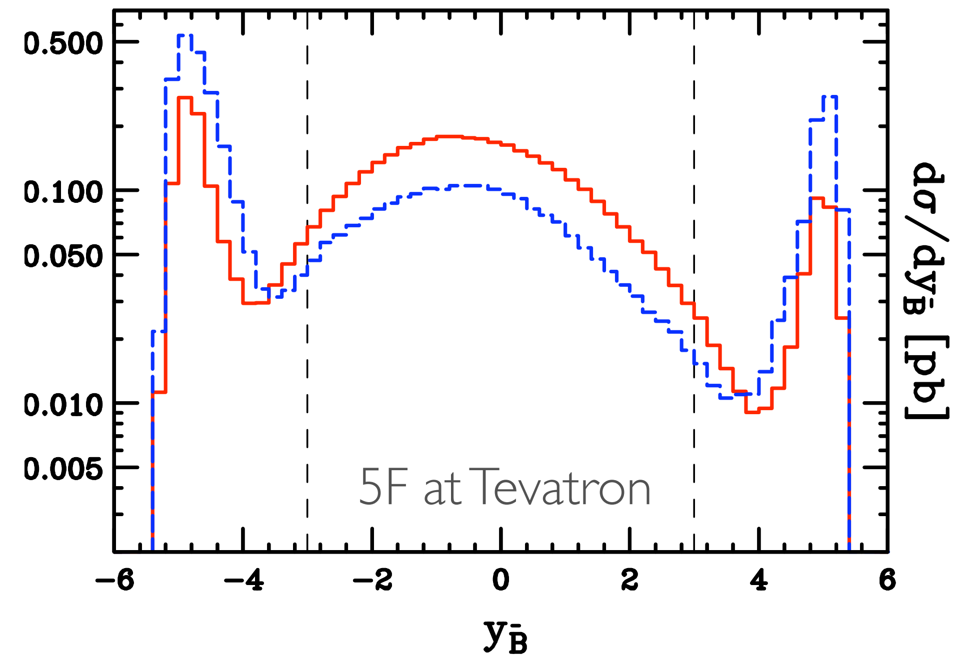
2 ways of making predictions	
5 flavour scheme	**4 flavour scheme**
massless b	massive b
PDF includes initial state b quarks	No b quarks in PDF
Log[m_b/μ_F] resummed in PDF	Finite terms correctly included
Simpler calculation	More involved prediction
 leading order  (contribution to) NLO	 Does not exist  (part of) leading order
Descriptions are equivalent when including all orders in perturbation theory	

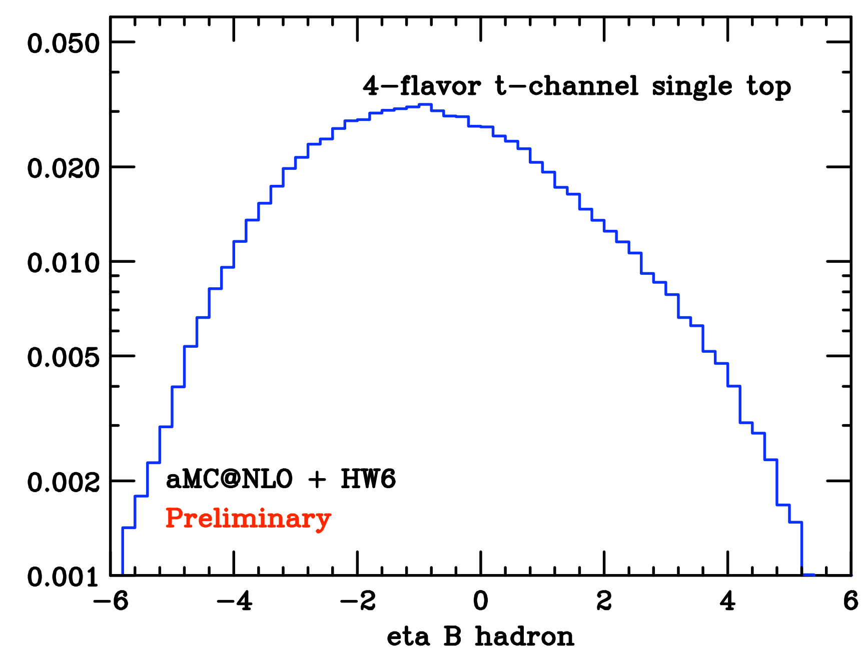
4- & 5-flavor schemes

A series of puzzles have arised over the years:



MC@NLO and POWHEG





4- & 5-FLAVOR SCHEMES

In [FM, Ridolfi, Ubiali] it was shown that a large set of TH results obtained in the 4F and 5F schemes at higher order can be consistently understood, taking into account that:

1. The resummation effects of the initial state logarithms in to the b-PDF is important only at large Bjorken-x.

2. The initial state $L = \log \mathcal{Q}^2(z)/m_b^2$ associated to a generic one-b-initiated process at the LHC (single top encompassing all other cases) can be written in terms of

$$\mathcal{Q}^2(z) = (M^2 + Q^2)\frac{(1-z)^2}{z}\frac{1}{1 - \frac{zQ^2}{M^2+Q^2}} \qquad \overset{Q^2\to 0}{\Rightarrow} L_{\mathrm{DY}} = \log\left[\frac{M^2}{m_b^2}\frac{(1-z)^2}{z}\right]$$

$$z = \frac{M^2 + Q^2}{s + Q^2} \qquad \overset{M\to 0}{\Rightarrow} L_{\mathrm{DIS}} = \log\left[\frac{Q^2}{m_b^2}\frac{1-z}{z}\right]$$

4- & 5-flavor schemes

- Estimate of the theory uncertainty:
  - independent variation of renormalization and factorization scales by a factor 2
  - 44 eigenvector CTEQ6.6 PDF's
  - Top mass: 172 ± 1.7 GeV (sorry, it's a bit of an old table!)
  - Bottom mass: 4.5 ± 0.2 GeV
- Uncertainties from scales slightly larger in 4F (as expected)
- Other sources are comparable in size
- Don't forget the uncertainty from the bottom quark mass uncertainty!

$\sigma^{\rm NLO}_{\rm t-ch}(t+\bar{t})$	$2 \to 2$ (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 (7 TeV)	62.6	$^{+1.1}_{-0.5}$	$^{+1.4}_{-1.6}$	$^{+1.1}_{-1.1}$	$^{+1.1}_{-1.1}$	59.4	$^{+2.1}_{-3.4}$	$^{+1.4}_{-1.4}$	$^{+1.0}_{-1.0}$	$^{+1.3}_{-1.2}$
LHC (14 TeV)	244	$^{+5}_{-4}$	$^{+5}_{-6}$	$^{+3}_{-3}$	$^{+4}_{-4}$	234	$^{+7}_{-9}$	$^{+5}_{-5}$	$^{+3}_{-3}$	$^{+4}_{-4}$

Fac. & Ren. scale

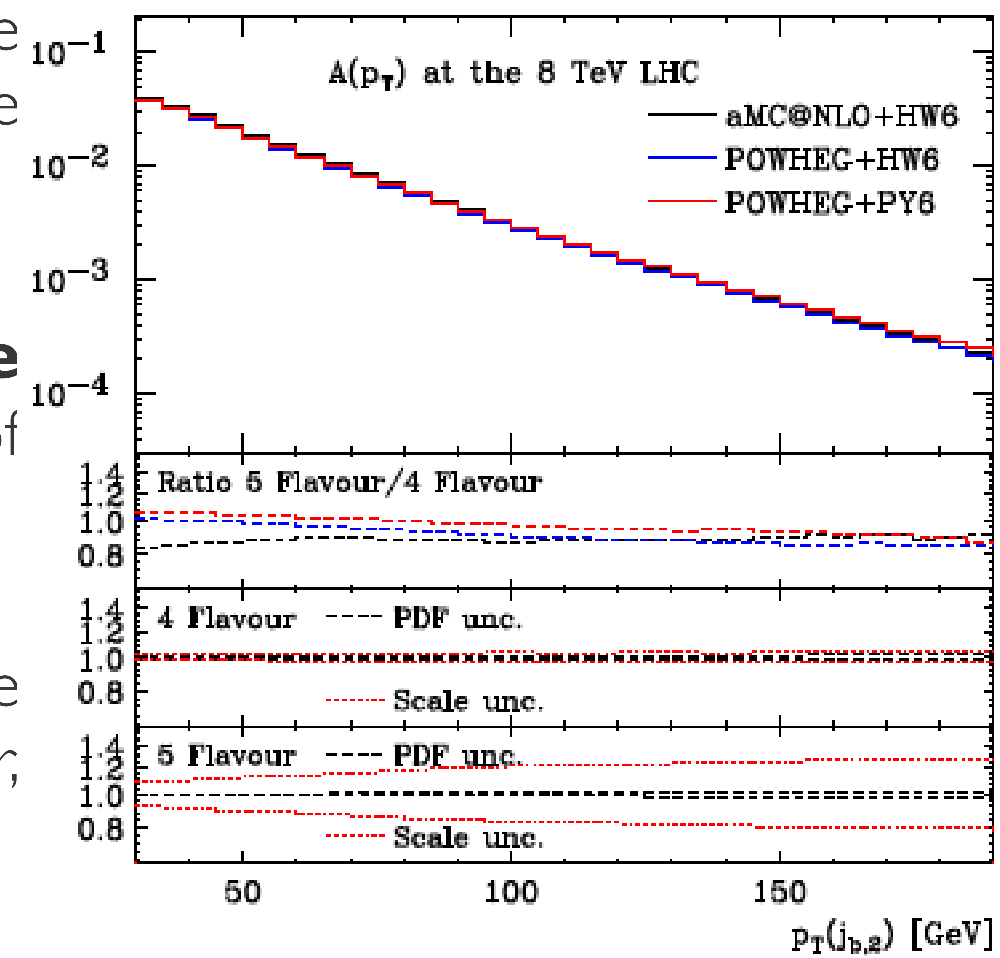
PDF

top mass

b mass

4- & 5-flavor schemes

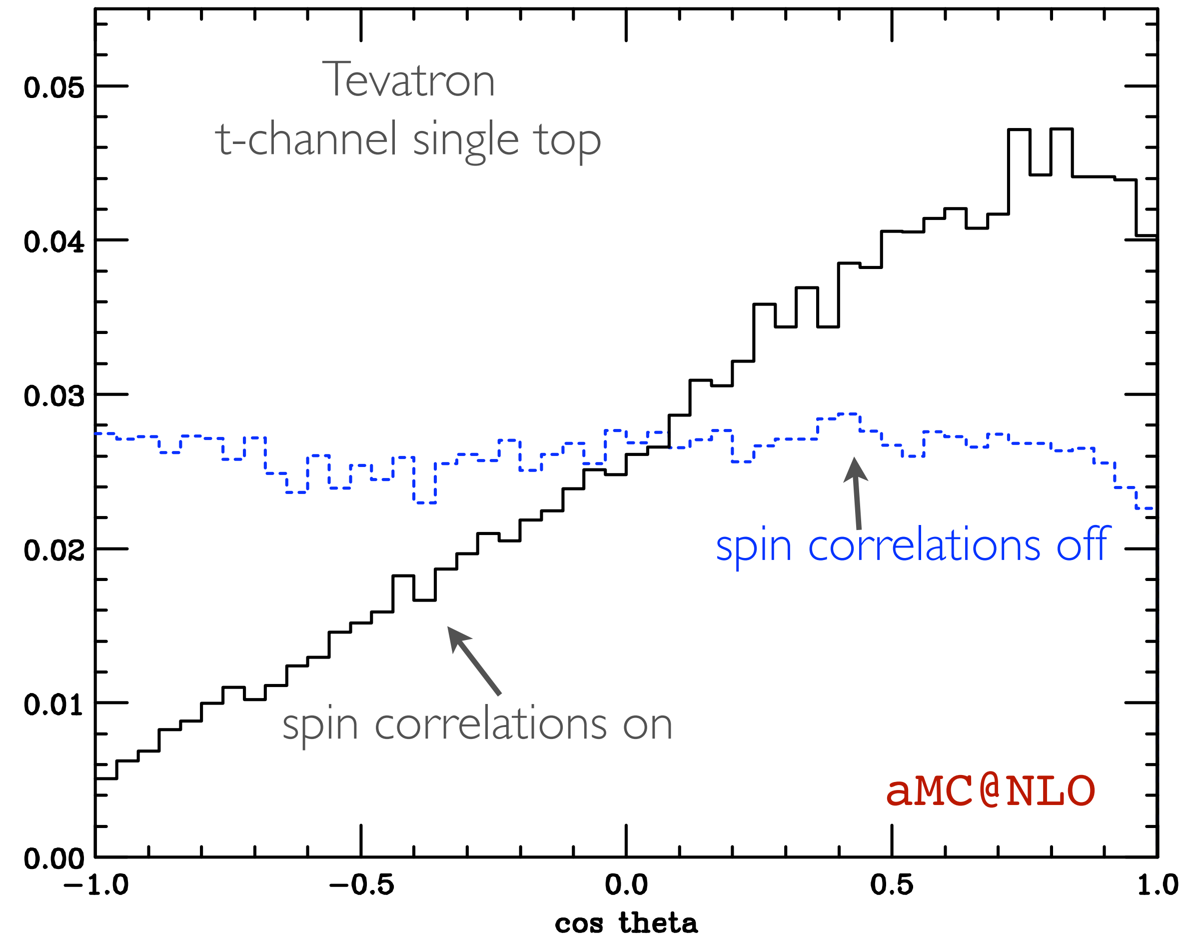
- Use the NLO+PS 4-flavour scheme predictions for the kinematics, but normalised to the (N)NLO 5-flavour scheme with an overall factor
  - All kinematics of the top, the light jet and **the “spectator b-quark”** are NLO correct because of the 4 flavour scheme
  - Overall normalisation is improved because log’s are resummed in the PDF in the 5 flavour scheme. However, such logs are not that large...



4- & 5-flavor schemes

- In aMC@NLO, spin correlations can be included using MadSpin
  - Uses only tree-level information
  - Includes some off-shell effects
- Also POWHEG events can be decayed with MadSpin this way (when not directly available in POWHEG, i.e. single top 4 flavour), although some MadGraph-style information should be added to the header of the event file to tell MadSpin the process definition and all that.

aMC@NLO+MadSpin



automatic MC's at NLO

Recent studies:

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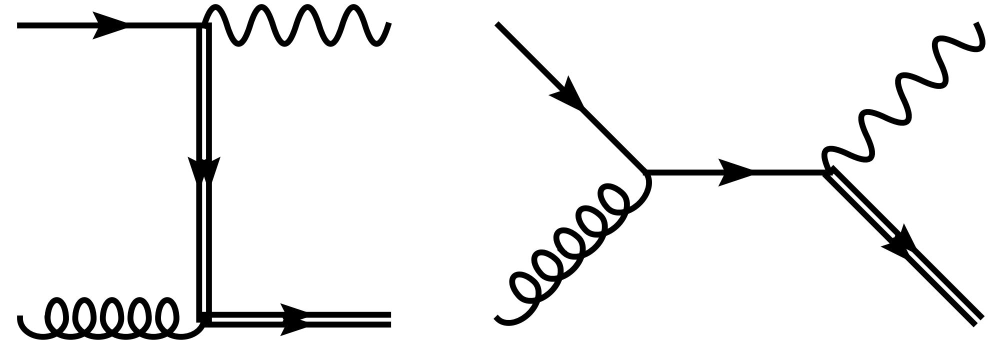
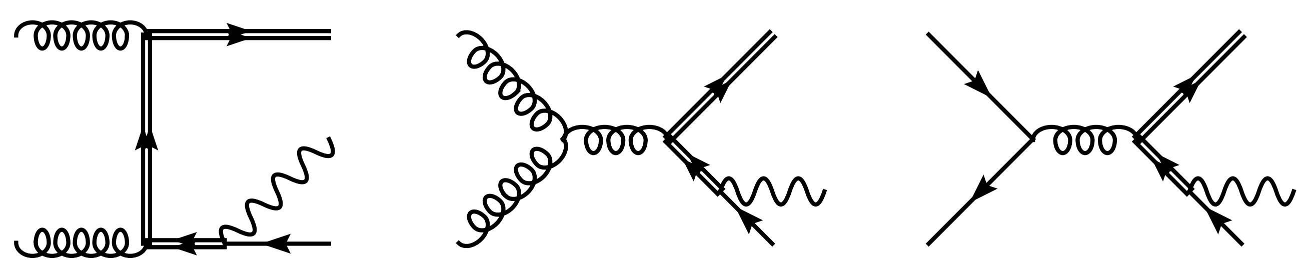
➡ tHj at NLO [Farina et al]

WWbb at NLO



- Biggest issues in single top modeling are coming from the W-boson associated single top channel
- At NLO, the real-emission diagrams have a contribution from top pair production



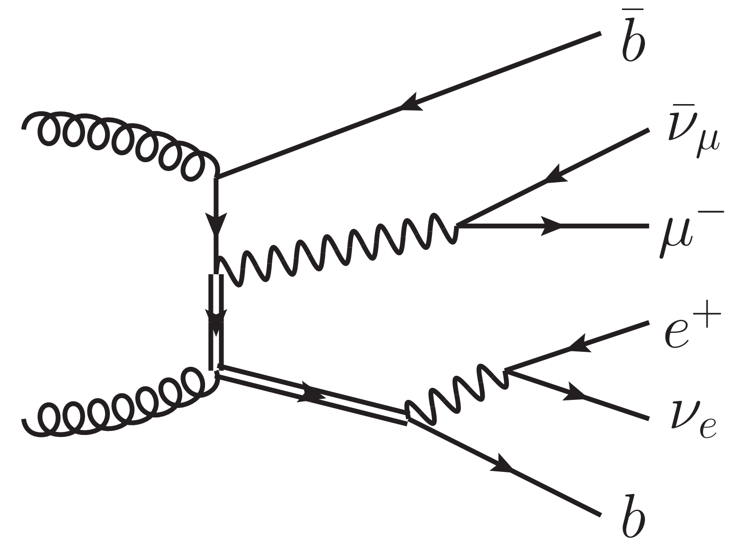
- "Perturbation theory breaks down": the full NLO corrections to Wt production are much larger than the Born, because they receive a contribution from LO top pair production
- DR/DS scheme has been developed to remove/subtract them

WWbb at NLO

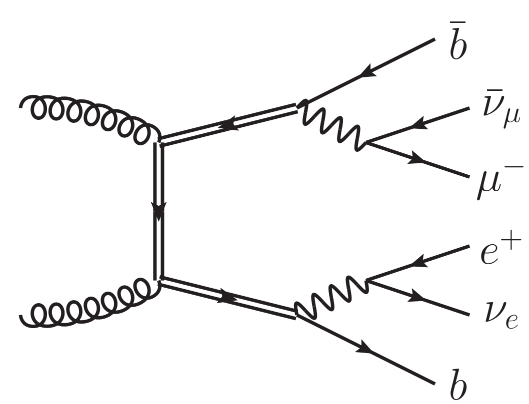
- Remove double resonant (ttbar-like) contributions at the level of amplitude (DR) or matrix elements (DS)
- Difference is the interference between Wt and ttbar production
- Both descriptions are formally not gauge invariant
- Wt with DR/DS available in MC@NLO and POWHEG
- Being validated now in aMC@NLO in a general (model independent) form.

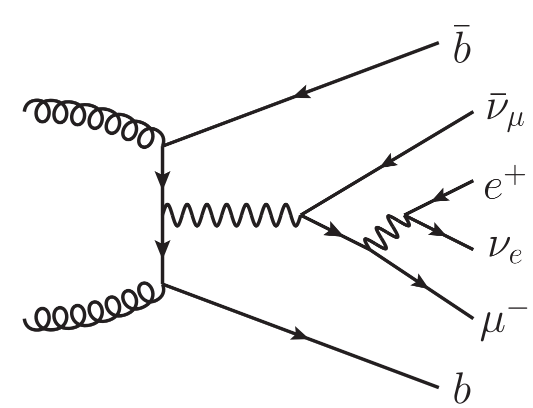
WWbb at NLO

- In the 4-flavour scheme, the problem is even more severe



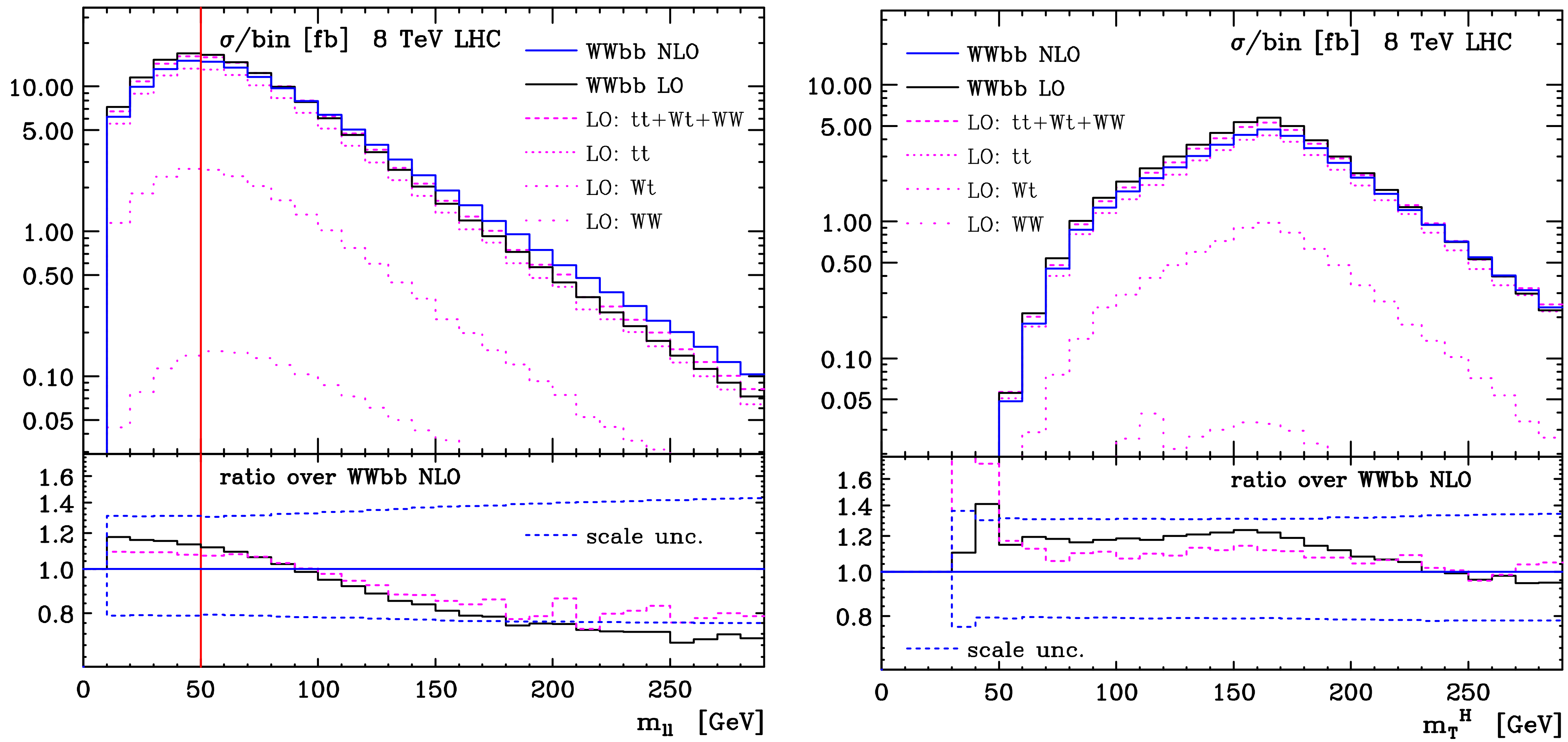
- Already at LO Wt and ttbar interfere, but no "break down of perturbation theory"
- However the solution is much simpler: compute the NLO corrections to this process and one captures
  - No longer a separate definition of Wt and ttbar production
  - Single and double and non-resonant contributions included at NLO
  - All interferences included
  - All off-shell effects included
  - Technical challenge





WWbb at NLO

[Frederix]



- This has recently been achieved and applied to the H -> WW* measurement channel in the one-jet bin, requiring a single jet
- Long list of cuts to suppress backgrounds
- For these observables, NLO scale dependence remains large

automatic MC's at NLO

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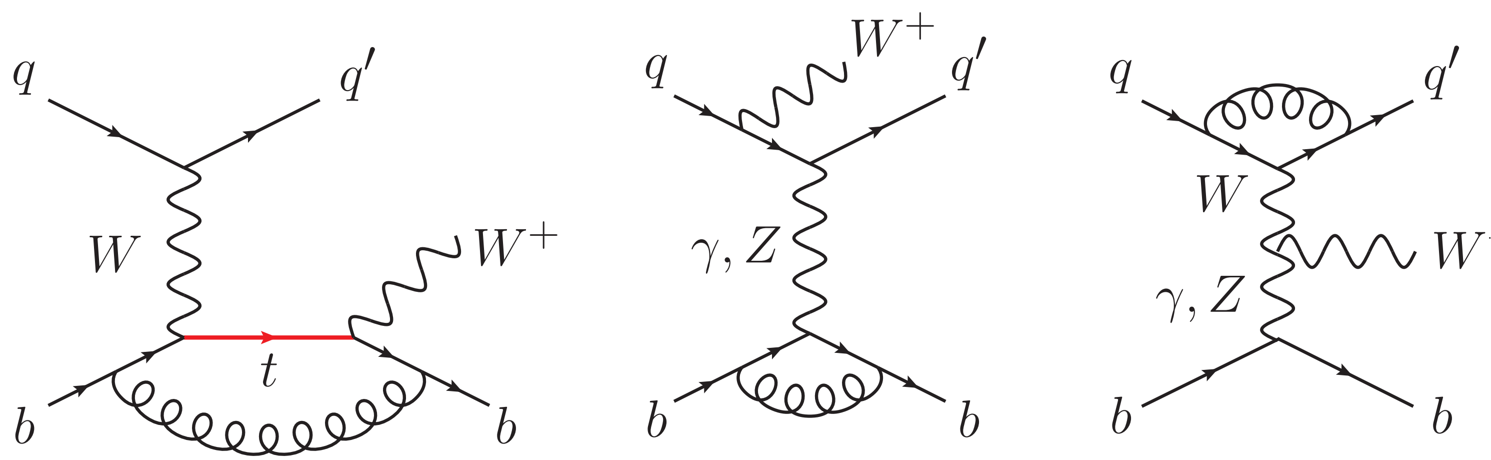
Wbj at NLO

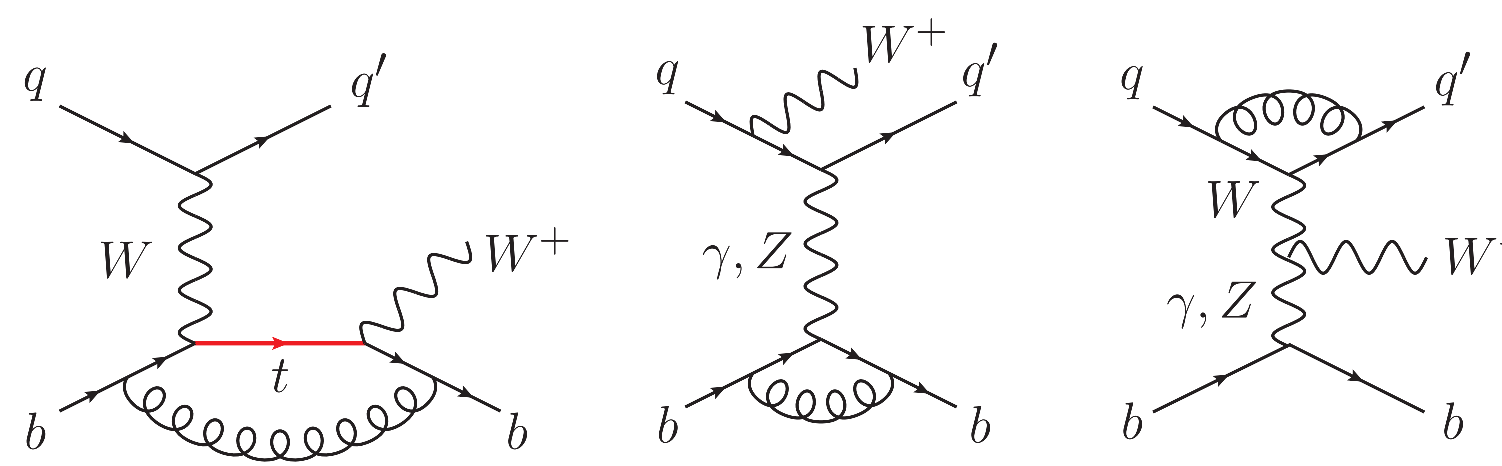


- To include the full NLO spin correlations, as well as all the all off-shell effects, the complete set of diagrams are needed

- Not really possible for single top in the 4 flavour scheme, because of the EW nature of the single top process, QCD corrections mix with the EW corrections to a corresponding QCD process

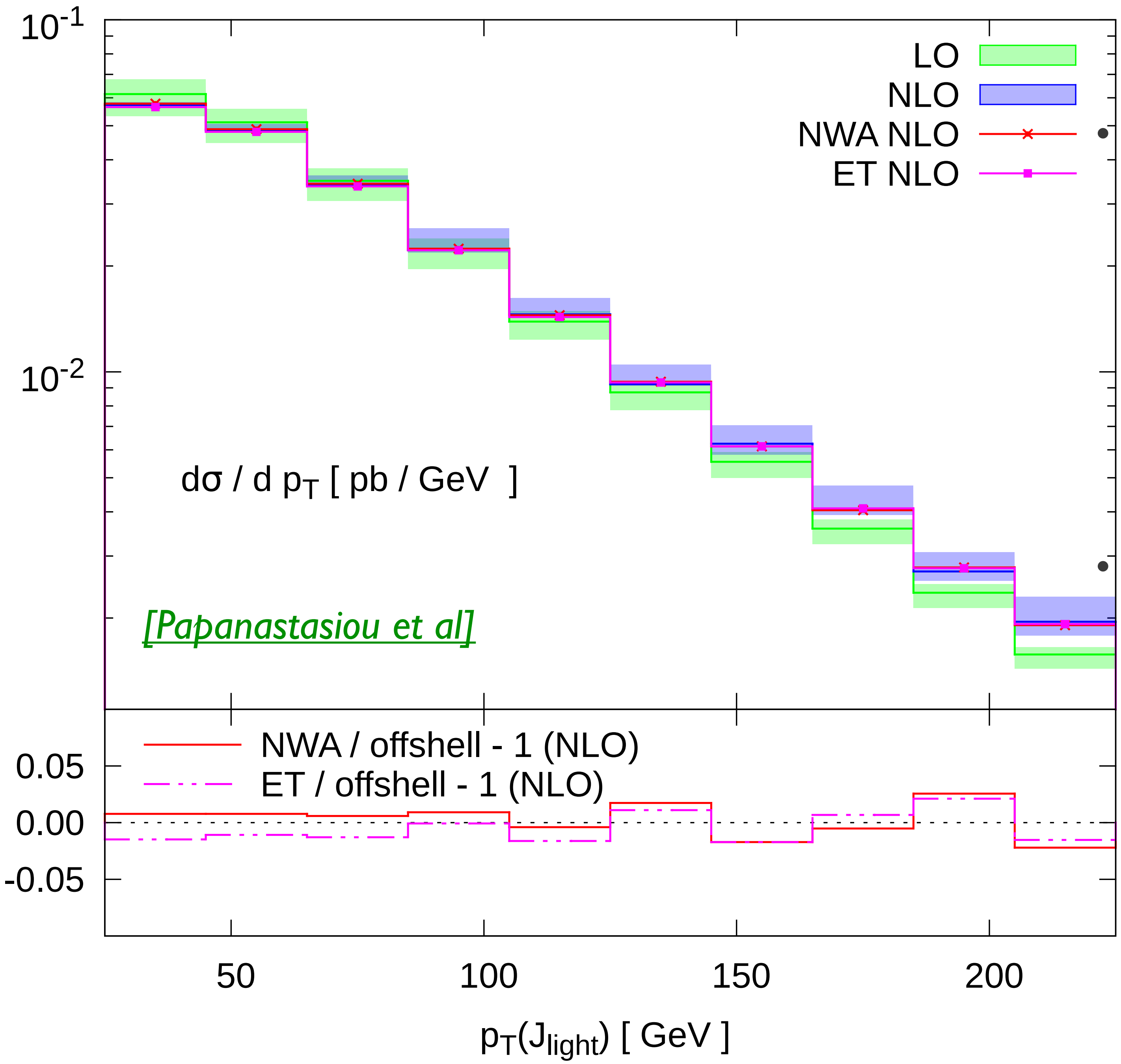
Wbj at NLO

- Particular care needed in process definition: $p\,p \rightarrow W^+\,J_b\,J_{\rm light} + X$
  - Single top production is EW process. In general QCD corrections to an EW process cannot be disentangled from EW corrections to a QCD process
    - Need to use diagonal CKM matrix (at least for the 3rd generation) to prevent interference from QCD Born with EW Born. Only possible for 5F scheme calculations, not possible in the 4F scheme.
  - Setting V_{tb}=1 also allows for separation of t and s-channel contributions (which results in easier comparison with literature)
  - With decays, the process is not finite: need a cut on the b-jet
    - s-channel could be included in our approach bur requires that J_b does not include two b quarks



- With V_{tb}=1, the NLO corrections to the t-channel process are finite and well defined, provided that J_b has a non-zero transverse momentum

Wbj at NLO

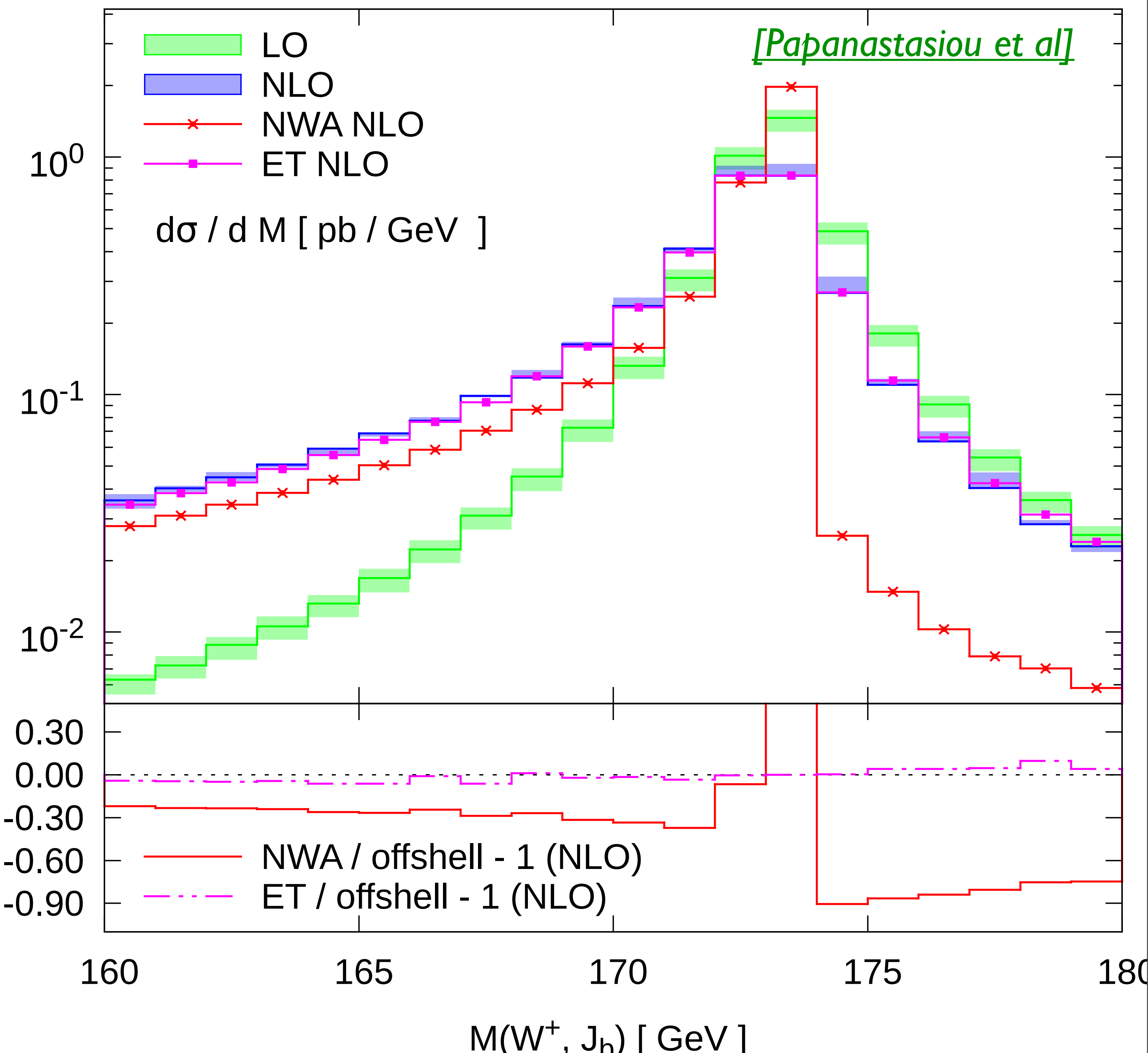


- Comparison of LO, NLO, NLO in the narrow width approximation (NWA) [MCFM] and the effective theory (ET) approach [Falgari, Mellor, Signer arXiv:1007.0893; + Giannuzzi arXiv:1102.5267] that includes the leading contributions beyond the NWA

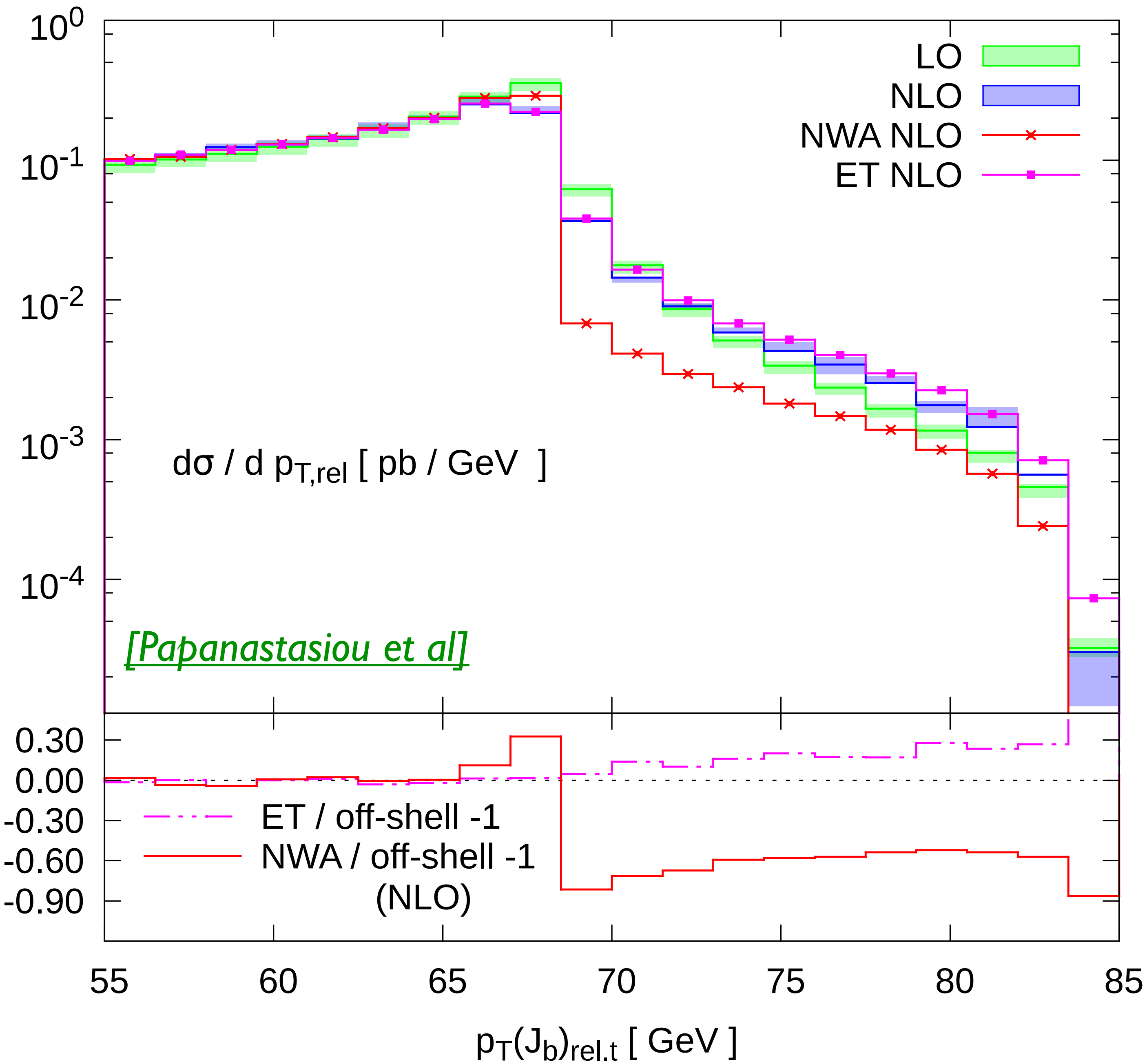
- For observables that are integrated over the top resonance peak, differences between NWA, ET and full NLO are rather small:
    - No visible effects in shape of the transverse momentum of the light jet

Wbj at NLO

- Invariant mass of the W-boson and the b-jet
- LO prediction greatly undershoots the NLO results below the peak: no radiation from the b-jet
  - Including parton shower should get most of this right
- Above peak, NWA undershoots by a long way: no off-shell effects are included
- Effective theory approach results in an excellent description over the whole range plotted here



Wbj at NLO



- At LO with on-shell top quarks, this distribution has a kinematic cut-off at $p_T(J_b)=(m_t^2-m_W^2)/(2m_t)$
- In the NWA this cut-off largely remains
- Again ET approach does a very good job, apart in the far tail. This is a sign that subleading Γ_t contributions become important

Wbj at NLO

- Most observables are well-described by the NWA
- However, always keep this approximation in mind: care must be taken when observables as $M(W^+, J_b)$ or $p_T(J_b)_{rel,t}$ are used (e.g. in template fitting).
- Effective theory approach does an excellent job close to the resonance, but will ultimately fail as well
  - Excellent for top quarks as signals
  - When top quarks are background, and on-shell contributions are removed with cuts, relative enhancement of non-resonant contributions

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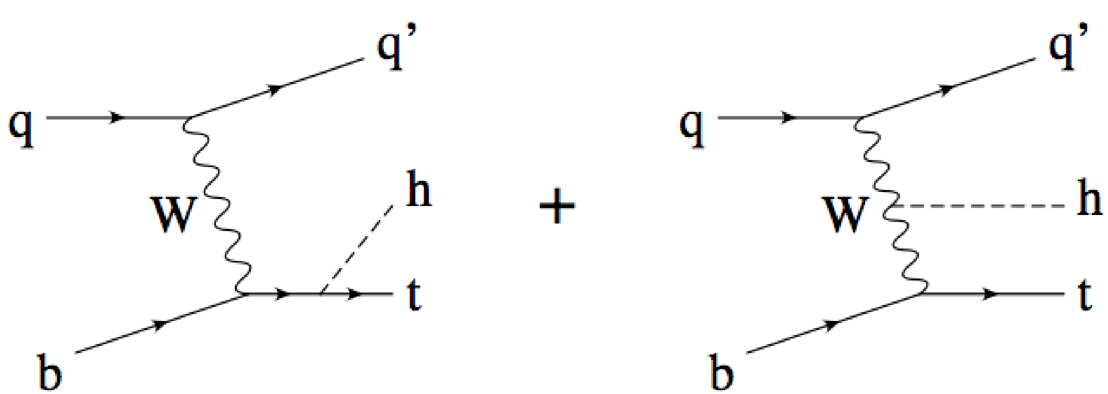
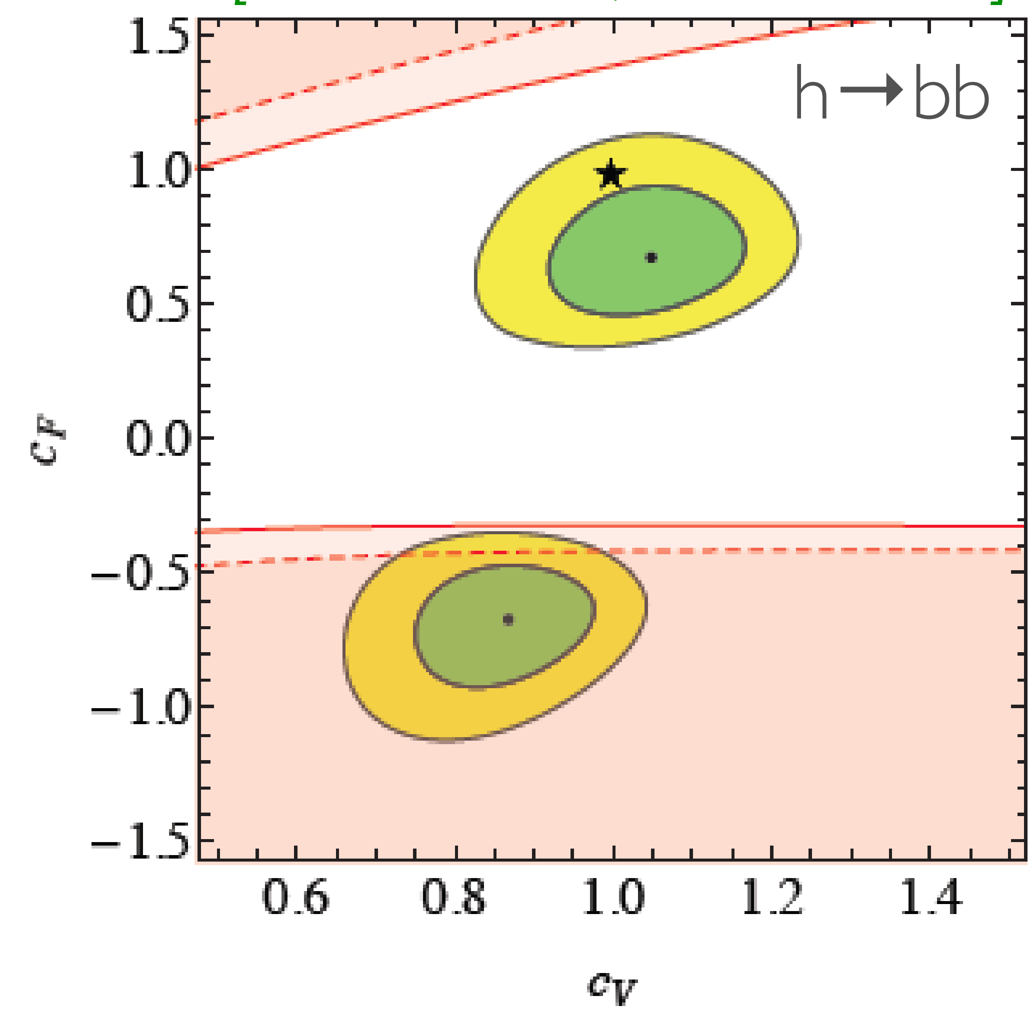
Top-higgs interactions

Sign of the Yukawa coupling enters in the destructive interference between W and top loops in $h \to \gamma\gamma$. Another process exists with a similar behaviour:



aMC@NLO	$\sigma^{\mathrm{NLO}}(pp \to thj)$ [fb] $c_F = 1$	$c_F = -1$
8 TeV	$18.28^{+0.42}_{-0.38}$	$233.8^{+4.6}_{-0.}$
14 TeV	$88.2^{+1.7}_{-0.}$	982^{+28}_{-0}

[Biswas et al. 2012, Farina et al. 2012]



automatic MC's at NLO

What's next :

- CMS with PS effects
- EW corrections embedded in a MC as NLO in QCD

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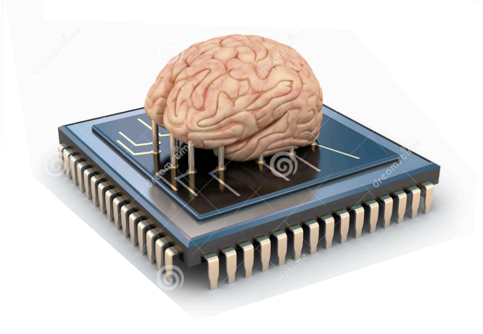
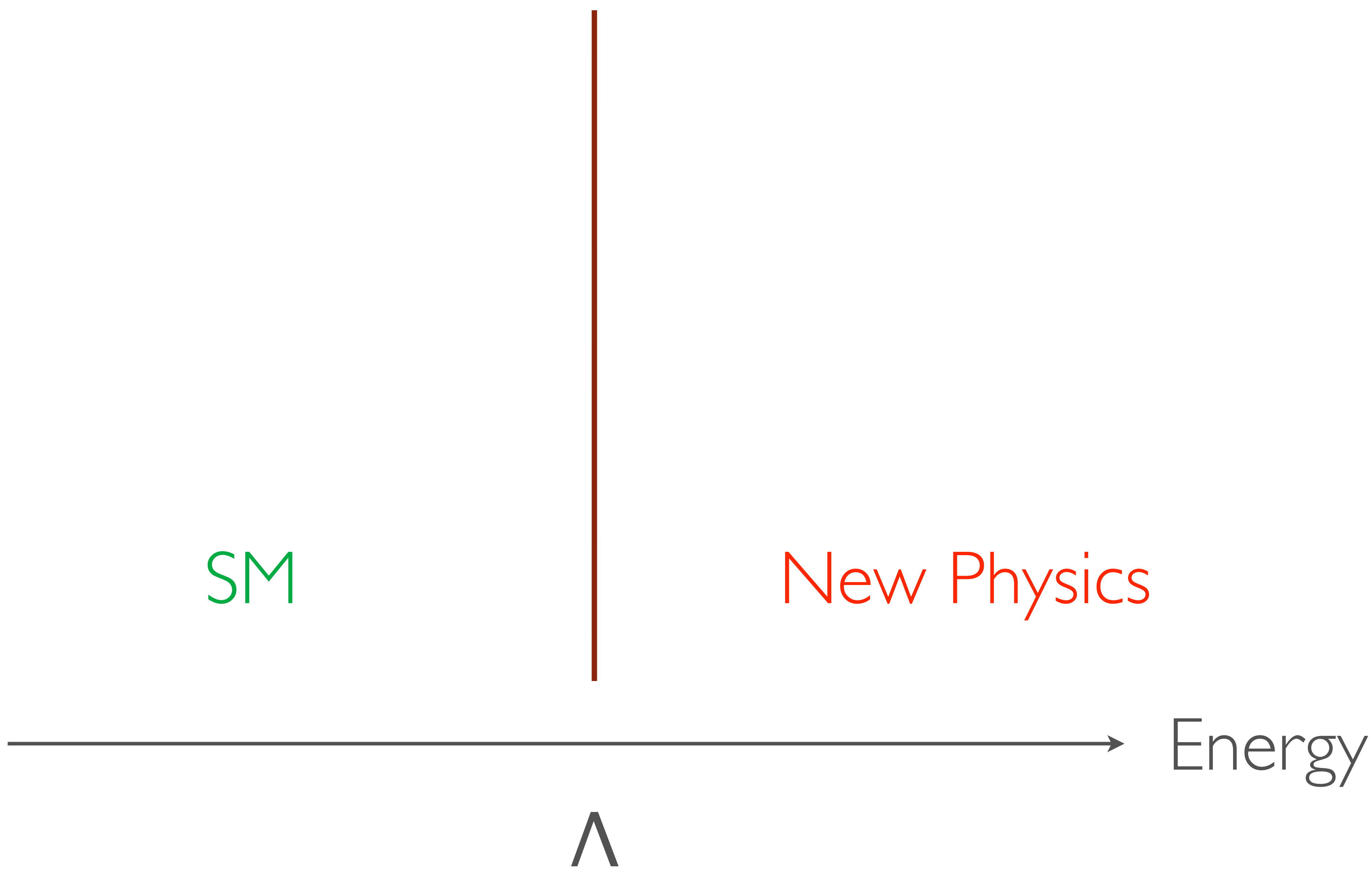
- Search for non-SM top-quark interactions
- Searches of top-quark partners and other states



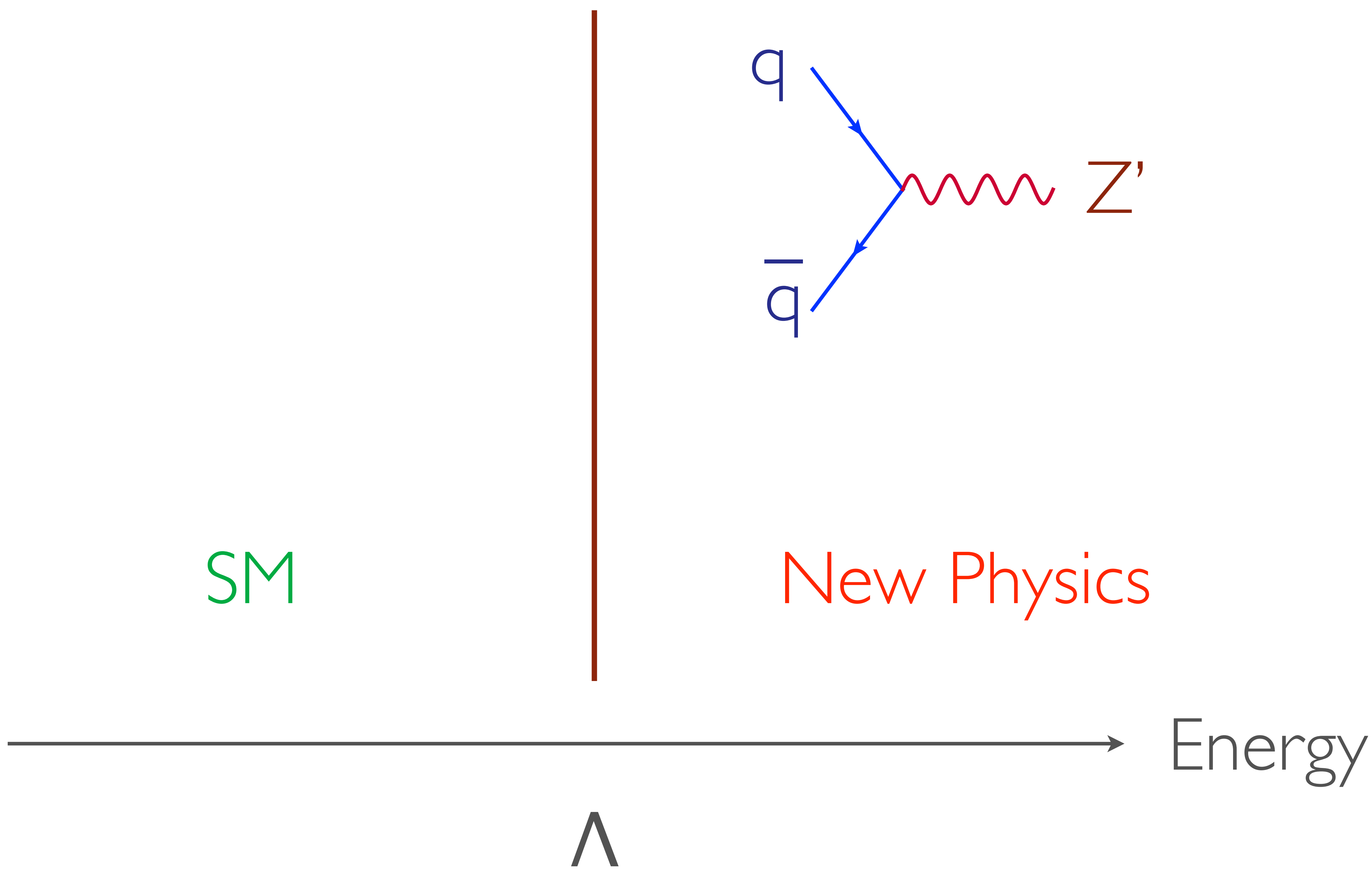
Needs:

- High precision predictions (NNLO in QCD and NLO EW) for key SM obs
- NLO for any SM and BSM process in the form of automatic MC tools
- A consistent and complete model-independent framework = EFT

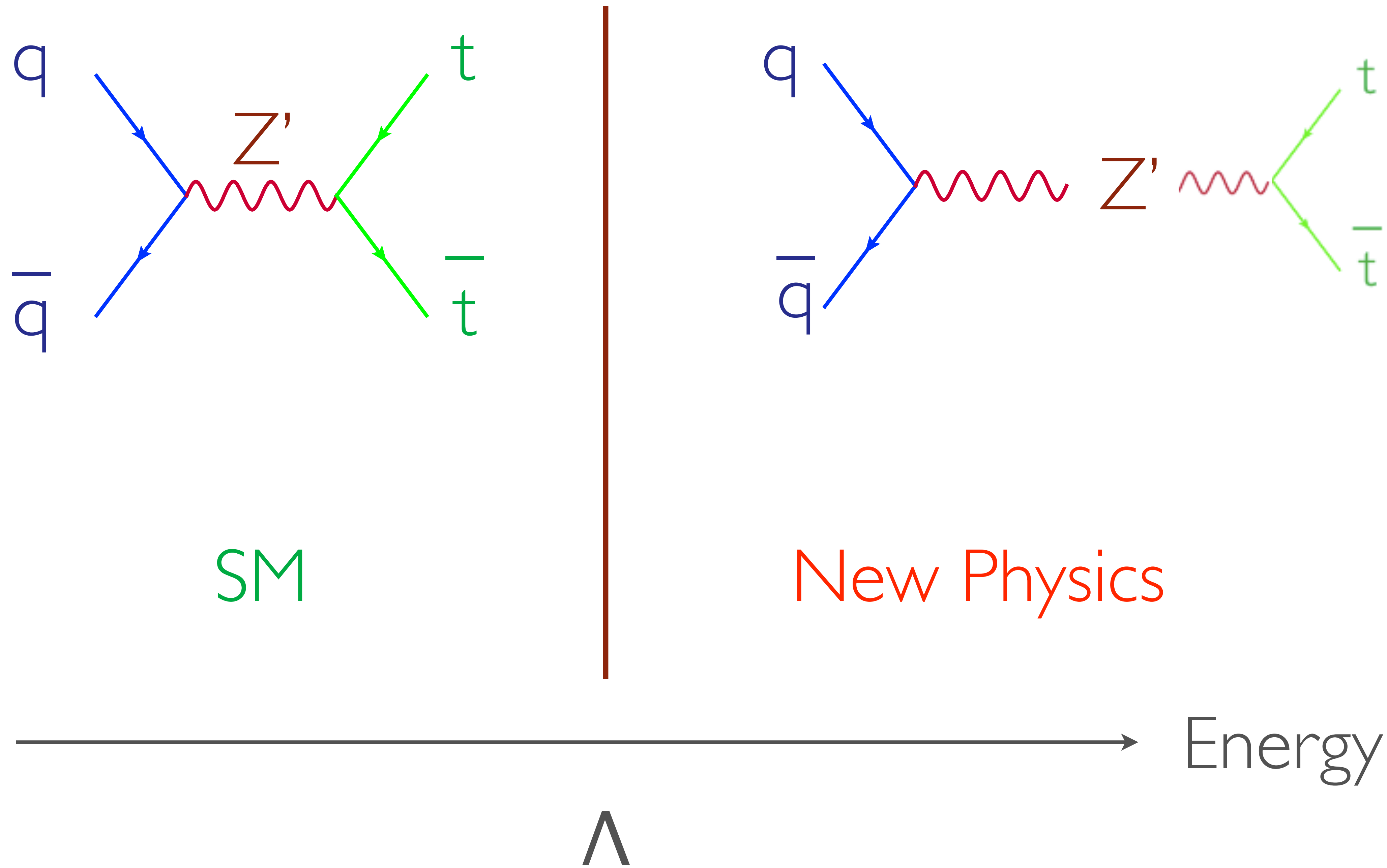
Effective field theory



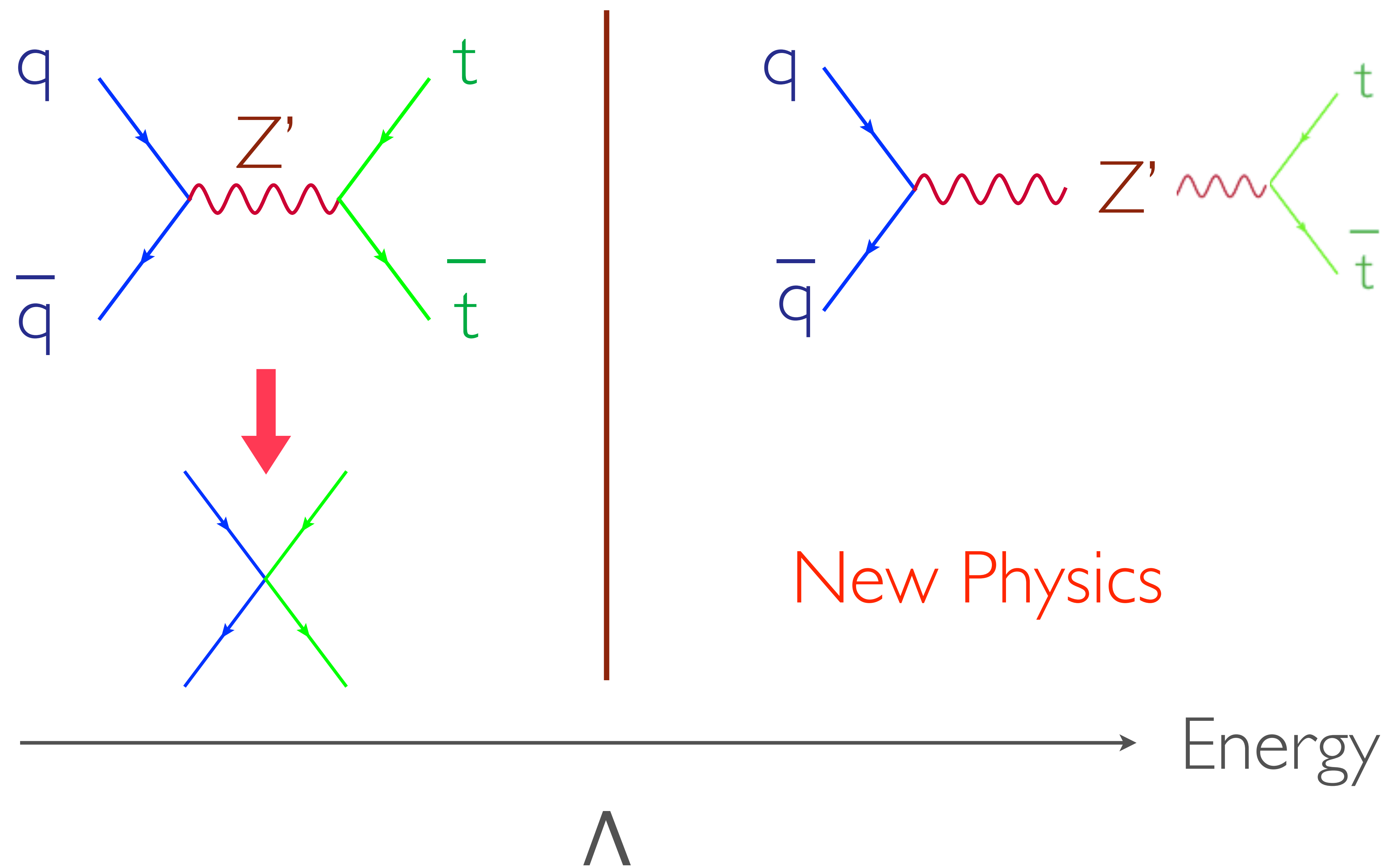
Effective field theory



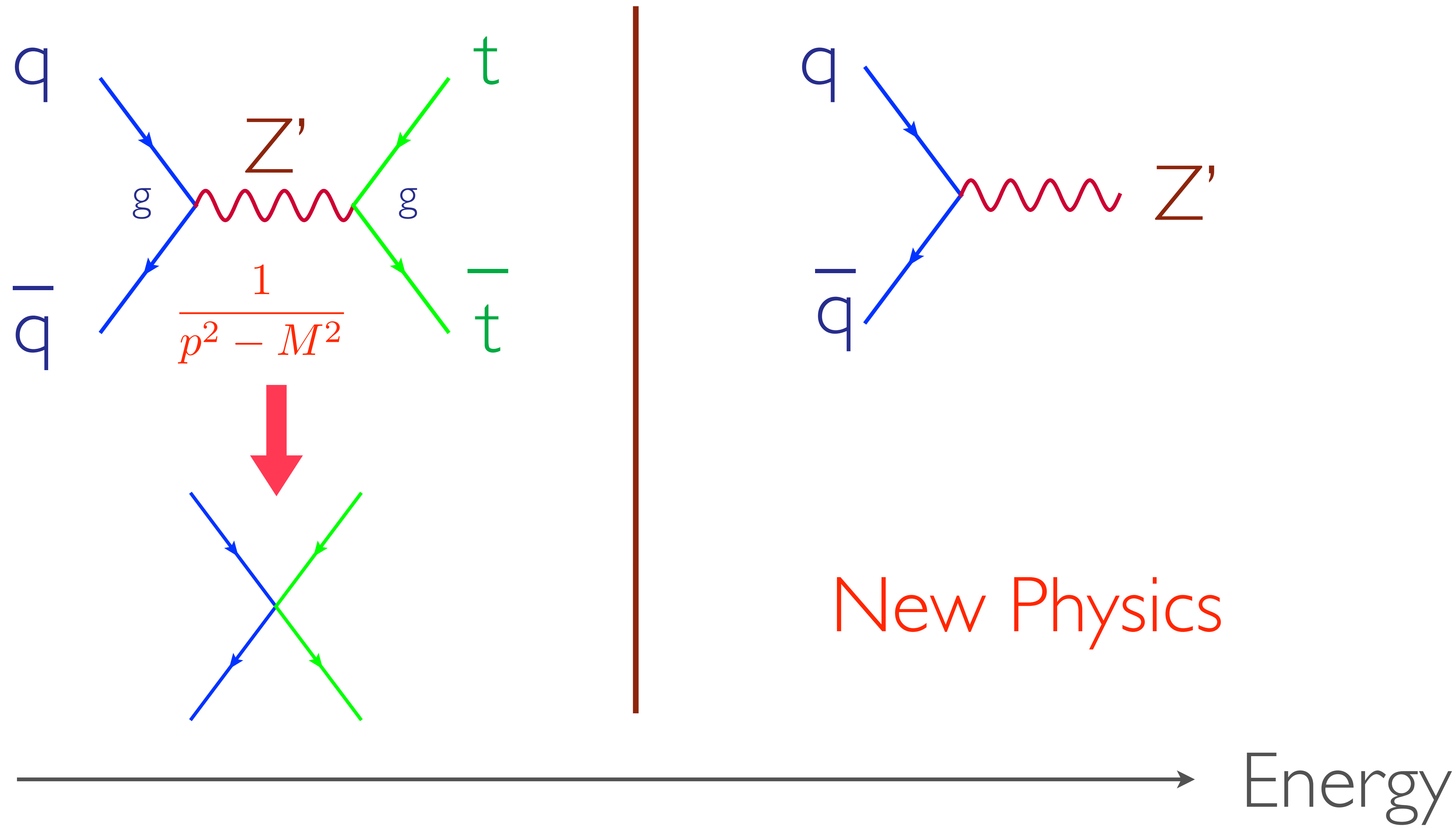
Effective field theory



Effective field theory

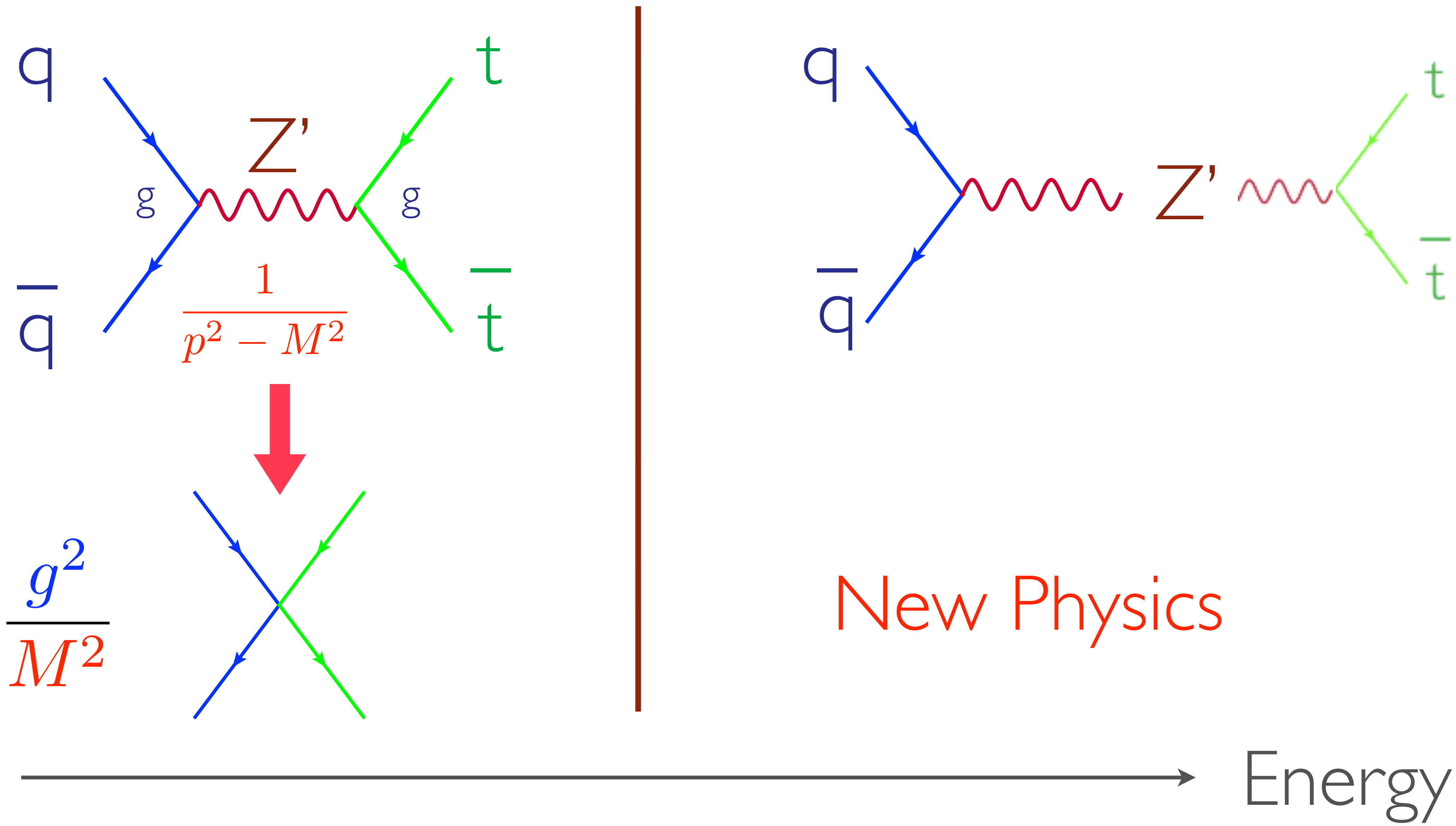


Effective field theory



Λ=M

Effective field theory

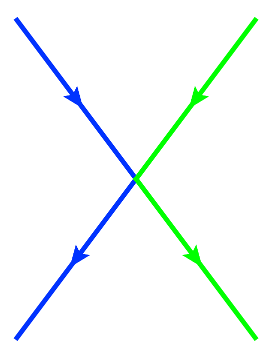


$\Lambda = M$

Tuesday 8 April 2014

Effective field theory

$$\frac{g^2}{M^2}$$



$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{g^2}{M^2}\bar{\psi}\psi\bar{\psi}\psi$$

Effective field theory

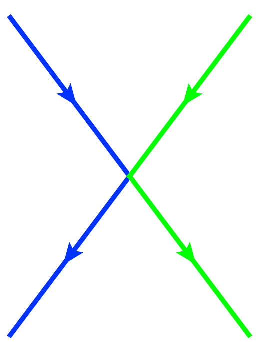
$$\hbar = c = 1$$

$$\dim A^\mu = 1$$

$$\dim \phi = 1$$

$$\dim \psi = 3/2$$

$$\frac{g^2}{M^2}$$



$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{\mathrm{dim}=6}$$

Bad News: 59 operators *[Buchmuller, Wyler, 1986]*

Good News : an handful are unconstrained and can significantly contribute to top phenomenology!

[Willenbrock and Zhang 2011, Aguilar-Saavedra 2011, Degrande et al. 2011]

Effective field theory

☺ Based on all the symmetries of the SM

☺ New physics is heavier than the resonance itself : $\Lambda > M_X$

☺ QCD and EW renormalizable (order by order in $1/\Lambda$)

☺ Number of extra couplings reduced by symmetries and dimensional analysis

☹ Valid only up to the scale Λ

Effective field theory

Very few operators of dim-6:

[Willenbrock and Zhang 2011, Aguilar-Saavedra 2011, Degrande et al. 2011]

operator	process
$O_{\phi q}^{(3)} = i(\phi^+ \tau^I D_\mu \phi)(\bar{q}\gamma^\mu \tau^I q)$	top decay, single top
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W_{\mu\nu}^I$ (with real coefficient)	top decay, single top
$O_{qq}^{(1,3)} = (\bar{q}^i \gamma_\mu \tau^I q^j)(\bar{q}\gamma^\mu \tau^I q)$	single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi}G_{\mu\nu}^A$ (with real coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_G = f_{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$gg \to t\bar{t}$
$O_{\phi G} = \frac{1}{2}(\phi^+\phi)G_{\mu\nu}^A G^{A\mu\nu}$	$gg \to t\bar{t}$
7 four-quark operators	$q\bar{q} \to t\bar{t}$

CP-even

operator	process
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W_{\mu\nu}^I$ (with imaginary coefficient)	top decay, single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi}G_{\mu\nu}^A$ (with imaginary coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_{\tilde{G}} = f_{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$gg \to t\bar{t}$
$O_{\phi\tilde{G}} = \frac{1}{2}(\phi^+\phi)\tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$gg \to t\bar{t}$

CP-odd

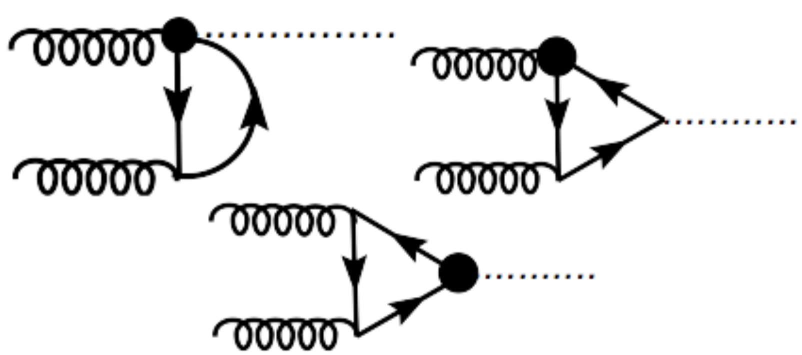
TOP-HIGGS INTERACTIONS

Consider, for example, the following top-Higgs interactions:

$$\mathcal{O}_{hg} = \left(\bar{Q}_L H\right) \sigma^{\mu\nu} T^a t_R G^a_{\mu\nu},$$
$$\mathcal{O}_{Hy} = H^\dagger H \left(H \bar{Q}_L\right) t_R$$
$$\mathcal{O}_{HG} = \frac{1}{2} H^\dagger H G^a_{\mu\nu} G^{\mu\nu}_a$$

At NLO in QCD the first two operators mix: $\gamma = \frac{2\alpha_s}{\pi} \begin{pmatrix} \frac{1}{6} & 0 \\ -2 & -1 \end{pmatrix}$

In addition, the third operator receives contributions from the first two at one loop:

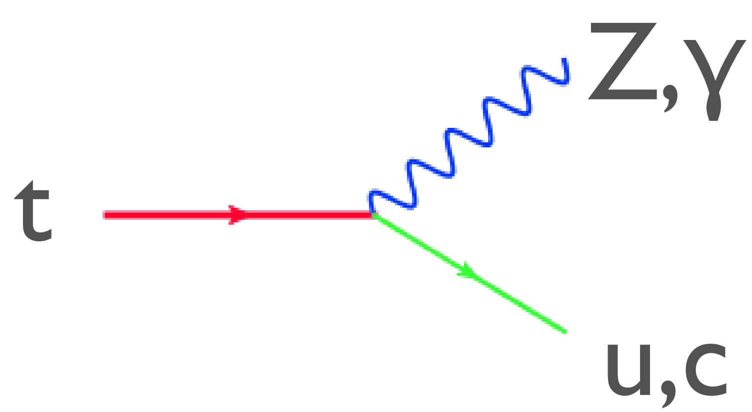


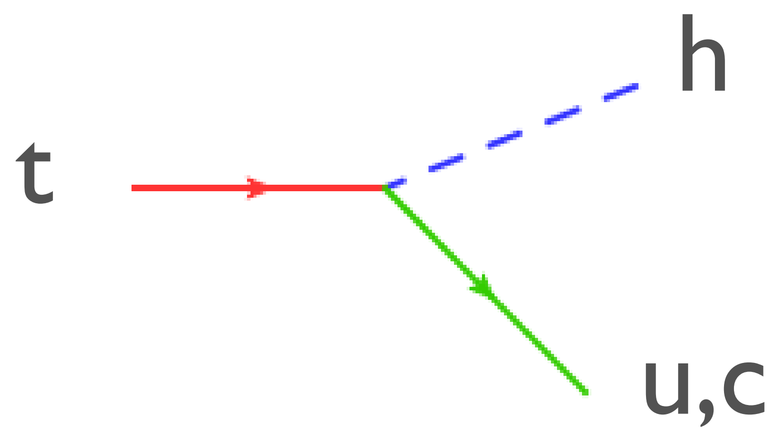
A meaningful analysis can only be made by considering them all!

top-quark FCNC

The study of FCNC couplings can bring new information:

[Drobnak, 2012 based on CMS and ATLAS results] [Kao et al. 2011 , Kai-Feng et al 2013] [Zhang FM, 2013] [Zhang, 2014]

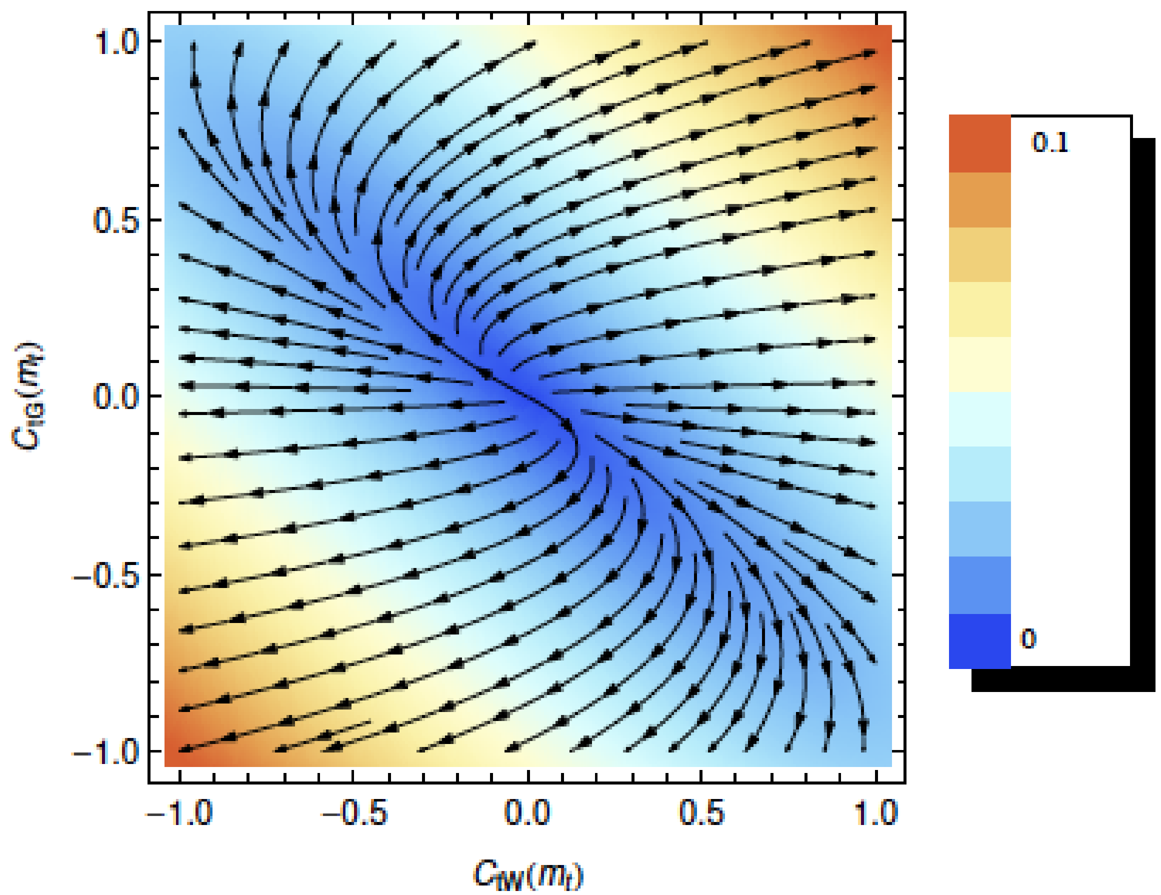


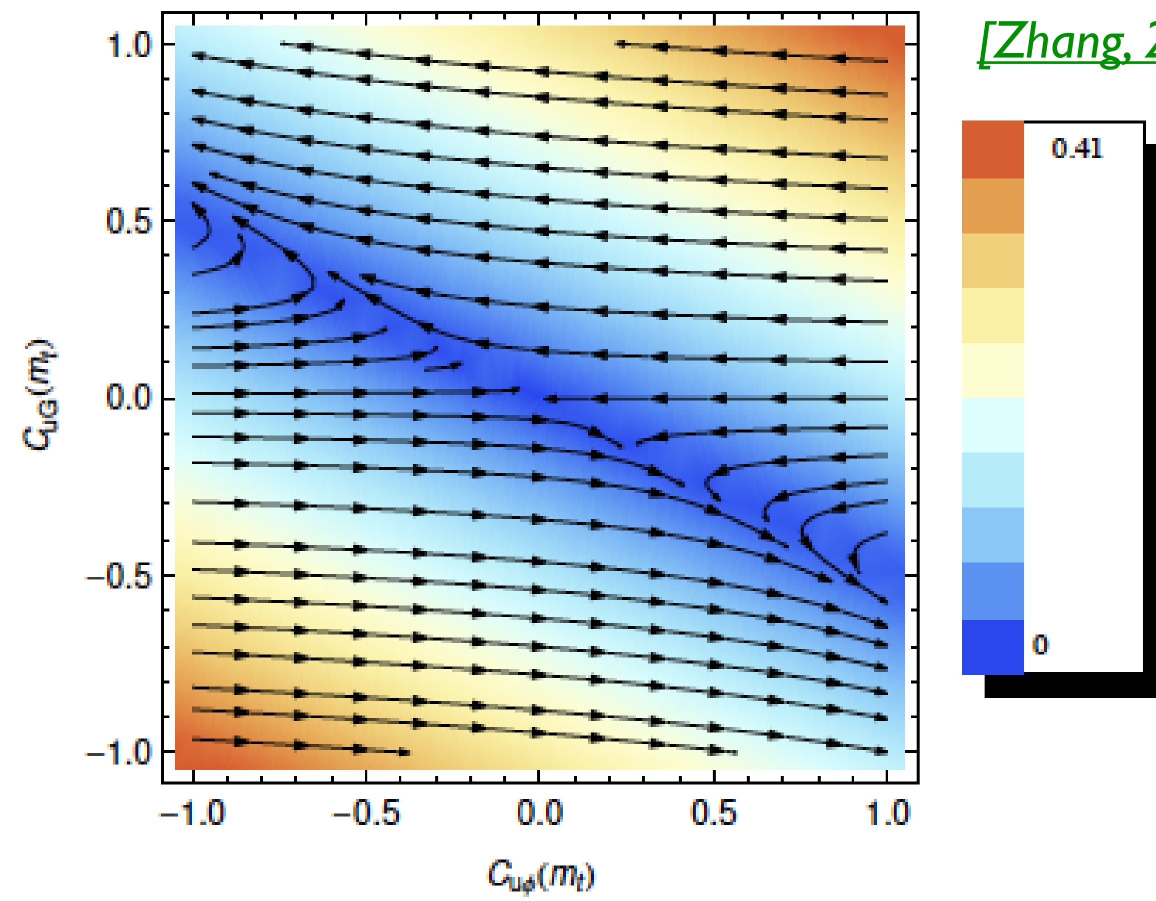


While the exp searches are completely different, one has to remember that the decay rates will depend on several operators that are linked by gauge symmetry and might mix at NLO in QCD.

TOP-QUARK FCNC

8





[Zhang, 2014]

$$O_{tG} = y_t g_s (\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\varphi}G^A_{\mu\nu}$$
$$O_{tW} = y_t g_W (\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi}W^I_{\mu\nu}$$
$$O_{tB} = y_t g_Y (\bar{Q}\sigma^{\mu\nu} t)\tilde{\varphi}B_{\mu\nu}$$
$$O_{t\varphi} = -y_t^3(\varphi^\dagger\varphi)(\bar{Q}t)\tilde{\varphi}\ .$$

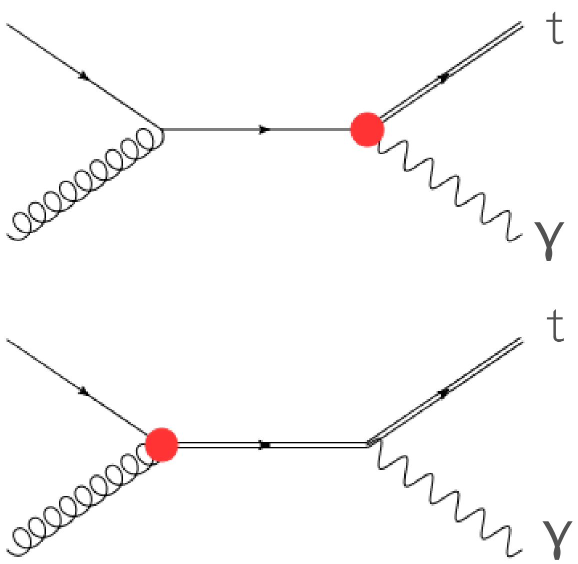
$$\gamma = \frac{2\alpha_s}{\pi}\begin{pmatrix} \frac{1}{6} & 0 & 0 & 0 \\ \frac{1}{3} & \frac{1}{3} & 0 & 0 \\ \frac{5}{9} & 0 & \frac{1}{3} & 0 \\ -4 & 0 & 0 & -1 \end{pmatrix}$$

$$O^{(13)}_{uG} = y_t g_s (\bar{q}\sigma^{\mu\nu}T^A t)\tilde{\varphi}G^A_{\mu\nu}$$
$$O^{(13)}_{uW} = y_t g_W (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi}W^I_{\mu\nu}$$
$$O^{(13)}_{uB} = y_t g_Y (\bar{q}\sigma^{\mu\nu} t)\tilde{\varphi}B_{\mu\nu}$$
$$O^{(13)}_{u\varphi} = -y_t^3(\varphi^\dagger\varphi)(\bar{q}t)\tilde{\varphi}\ .$$

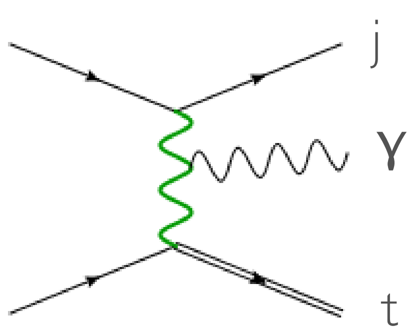
$$\gamma = \frac{2\alpha_s}{\pi}\begin{pmatrix} \frac{1}{6} & 0 & 0 & 0 \\ \frac{1}{3} & \frac{1}{3} & 0 & 0 \\ \frac{5}{9} & 0 & \frac{1}{3} & 0 \\ -2 & 0 & 0 & -1 \end{pmatrix}$$

TOP-QUARK FCNC

$pp \to t\gamma$



$pp \to t\gamma j$ (SM)



Two contributions appear at LO: one from O_{uB} and one from O_{uG}.

At NLO in QCD O_{uG} mixes with all the other operators so it has always to be included.

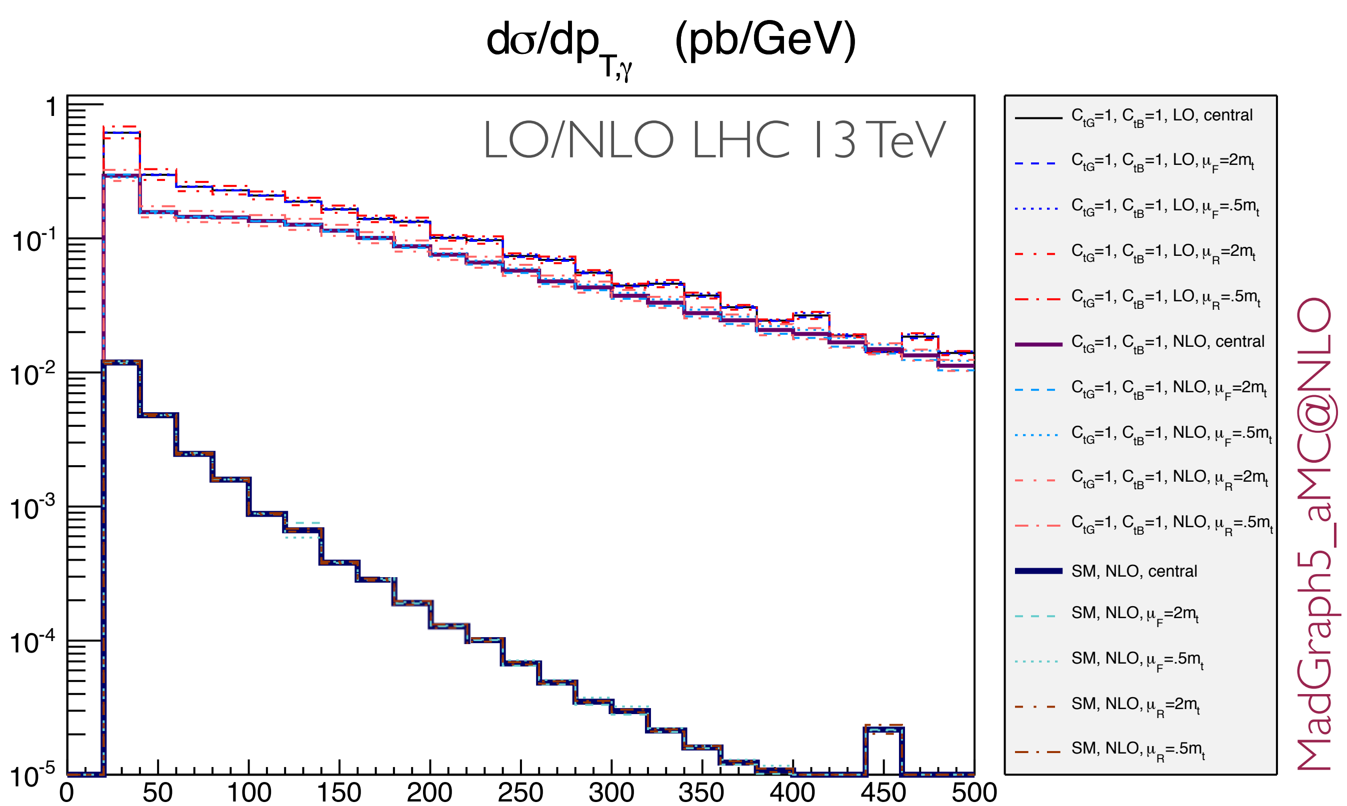
It also means that if a specific (arbitrary) choice of coefficient operators is made at high scales (where one can imagine a full theory to live) many operators become active when evolved to lower scales.

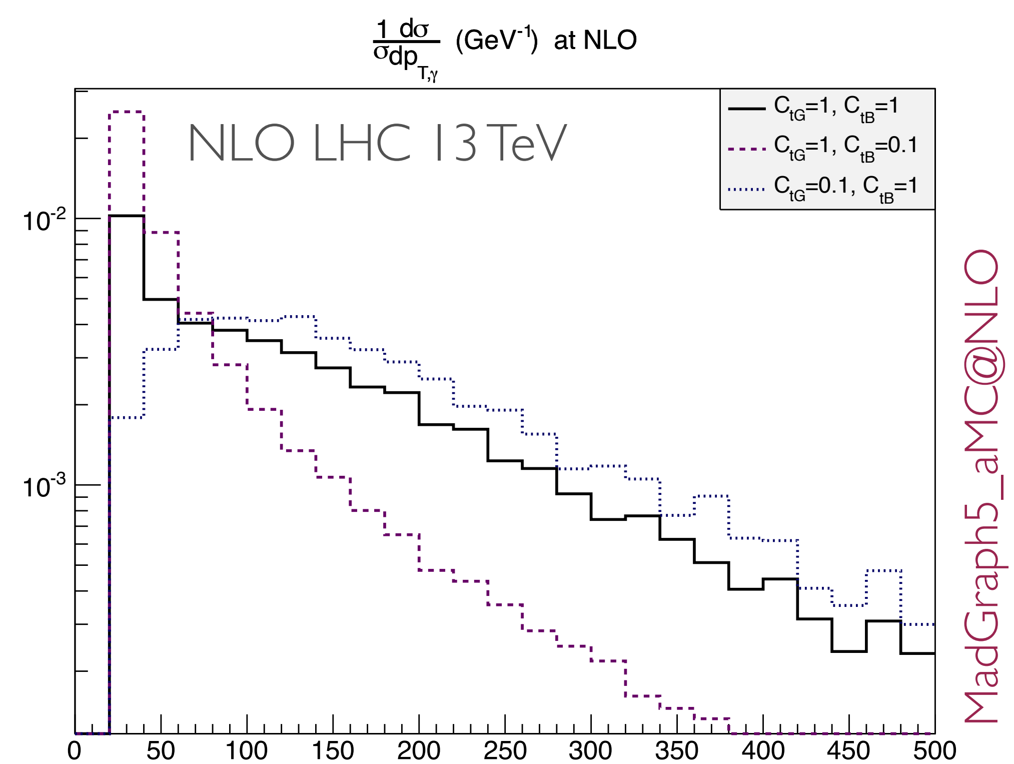
Only a global/fit approach on constraining such operators at the same time can be useful stragegy and it has to be at least NLO in QCD.

TOP-QUARK FCNC

The operators have been implemented in FeynRules, the model was upgraded to NLO automatically and then passed to MG5_aMC. *[Degrande, FM, Wang, Zhang]*

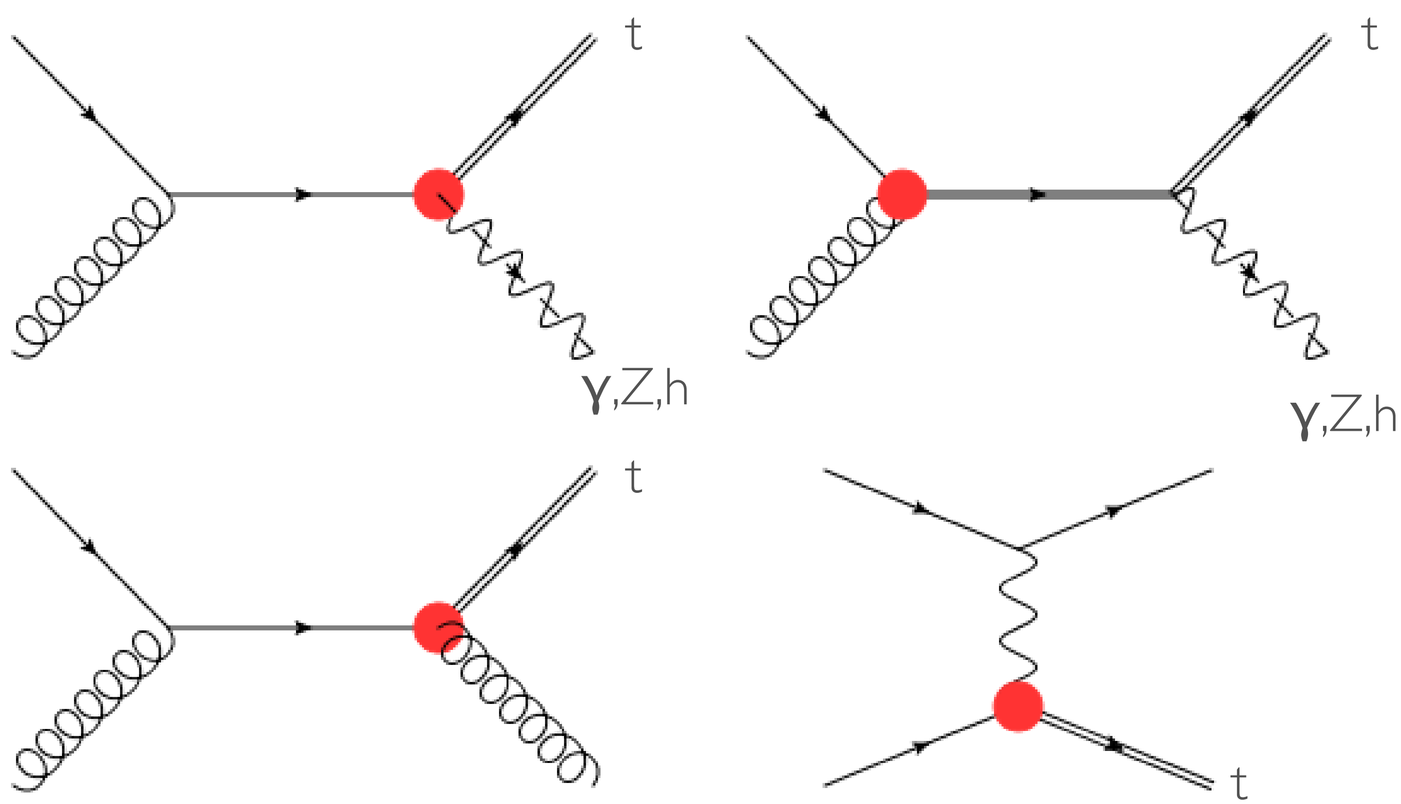
Results shown here at fNLO. SM pp →tγj interesting process by itself...





Complete implementation of all operators of dim=6 at NLO (including four fermion operators) in QCD is on going.

TOP-QUARK FCNC



A rich set of processes that will be studied at NLO(+PS)

pp → tγ
pp → tZ
pp → th
pp → tj

Effective field theory

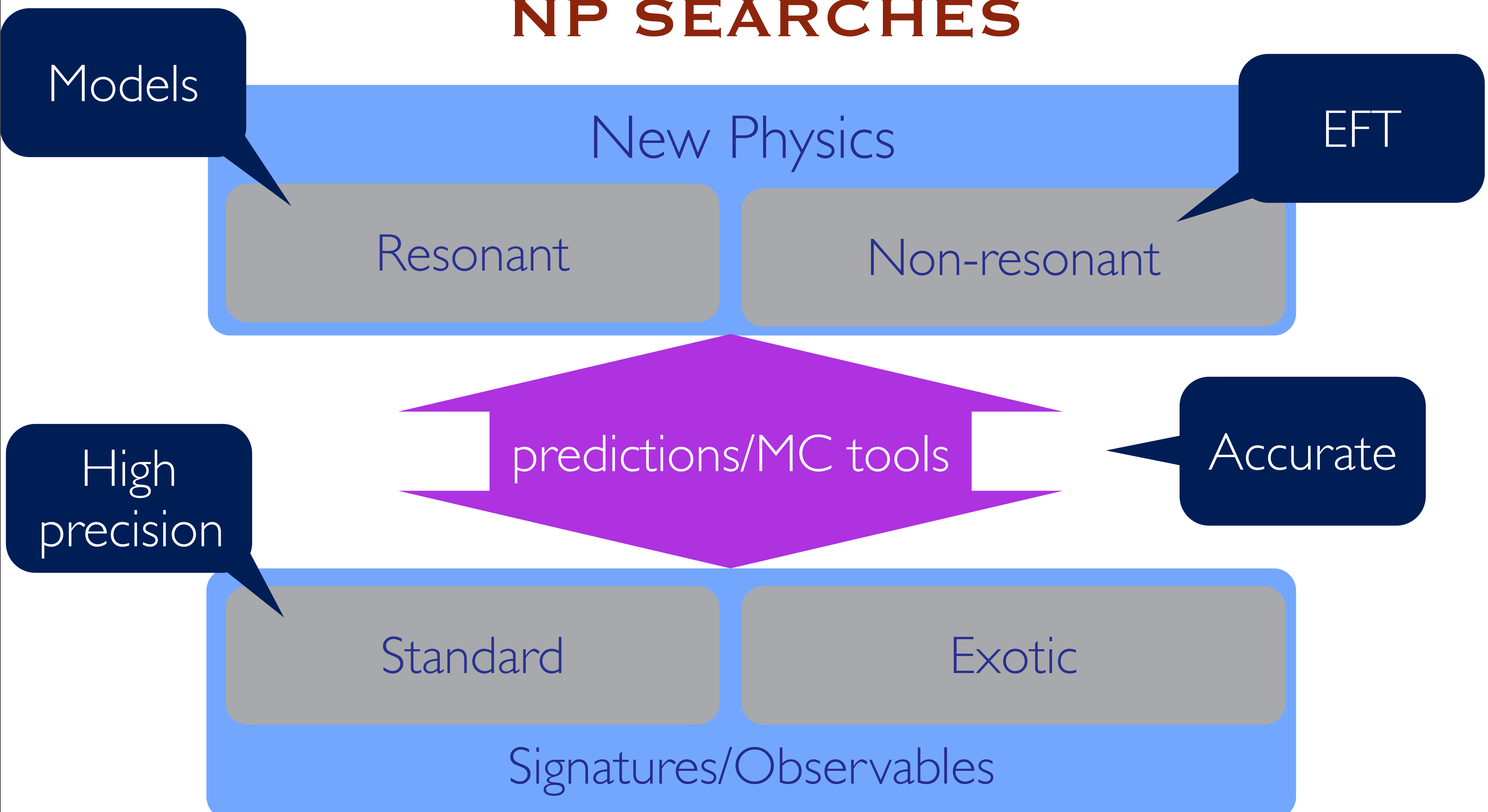
- The only consistent, complete theoretical framework where predictions can be systematically improved, several measurements of different observables or processes can be interpreted and useful information (constraints) be obtained by global fits.

- Constraining one or few "anomalous coupling" at the time is not consistent with the fact that the operators mix and run under RGE equations: they need to be determined via a global fit at a given scale.

- Consistent global EFT analyses for top physics to be performed at least at NLO in QCD, i.e. considering both operator mixing and genuine short distance QCD effects in production/decay.

Full EFT@NLO framework for top physics in progress

NP SEARCHES


Models
New Physics
EFT
Resonant
Non-resonant
predictions/MC tools
Accurate
High precision
Standard
Exotic
Signatures/Observables

CONCLUSIONS

- Progress in the predictions:
  - Automatic NLO+PS predictions for any SM process now available. BSM (including EFT's) expected soon.
  - EW corrections to come
  - NNLO corrections in the works.
- The only complete, consistent framework for constraining NP in top phenomenology is the EFT and it is available. Some of QCD effects are known and a full framework at NLO expected soon.

OUTLOOK

...and after 20 years the top still is,

together with the Higgs,

our best gateway to the TeraWorld!

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