Review of Top Quark Physics: Theory

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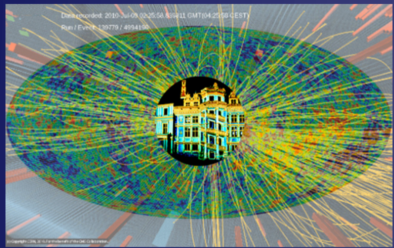
#tops@LHC : 2 7 6 . 8 3 0



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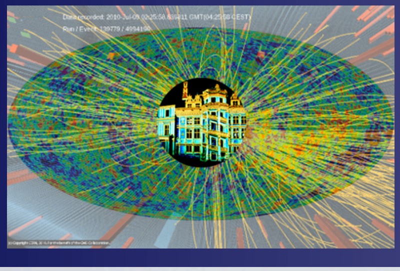

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- The importance of being Top

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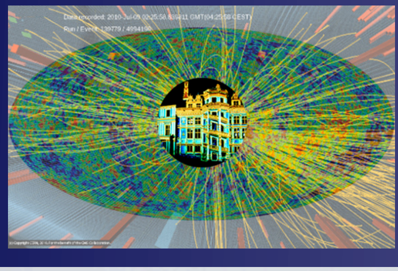

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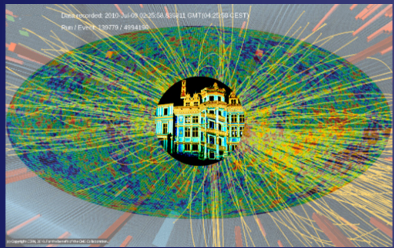
- The importance of being Top
- Precision SM Top Physics
- Top as tool for BSM pheno: strategies with examples
- Outlook



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- Precision SM Top Physics
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1. with a "natural mass"

$$m_{top} = y_t\, v/\sqrt{2} \approx 174 \text{ GeV} \Rightarrow y_t \approx 1$$

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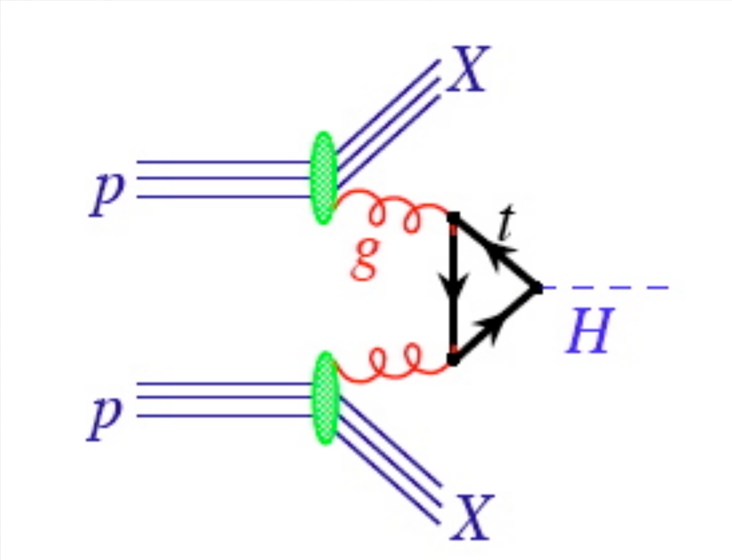
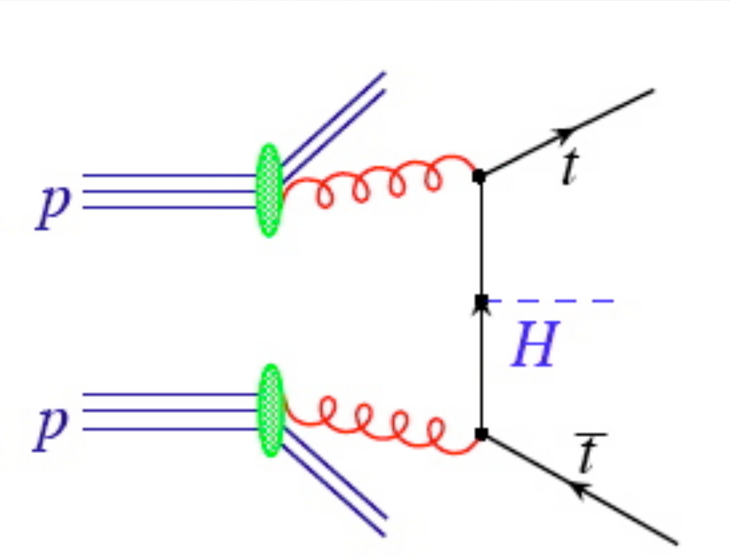


It can easily excite the Higgs



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$\tau_{had} \approx h/\Lambda_{QCD} \approx 2 \cdot 10^{-24}$ s

$\tau_{top} \approx h/\Gamma_{top} = 1/(G_F\, m_t^3\, |V_{tb}|^2/8\pi\sqrt{2}) \approx 5 \cdot 10^{-25}$ s

(with $h=6.6\ 10^{-25}$ GeV s)

Compare with $\tau_b \approx (G_F^2\, m_b^5\, |V_{bc}|^2\, k)^{-1} \approx 10^{-12}$ s)

It is a "naked" quark : flavor and EW physics at their best!

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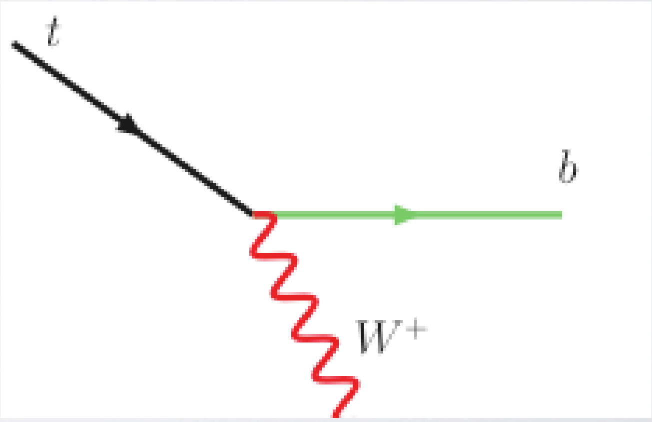

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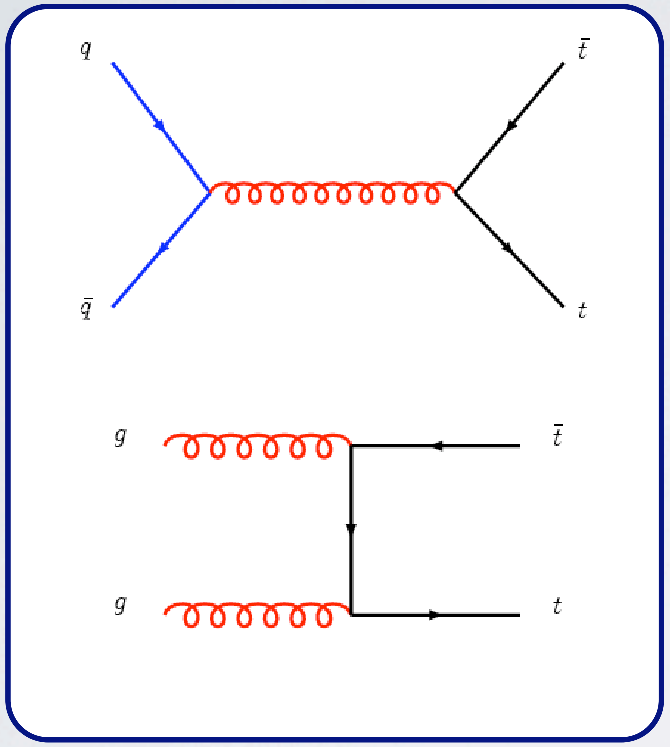

Largest cross section (LO at α_S^2):

~ 10 pb at Tevatron
~ 150 pb at LHC7

Precision physics studies

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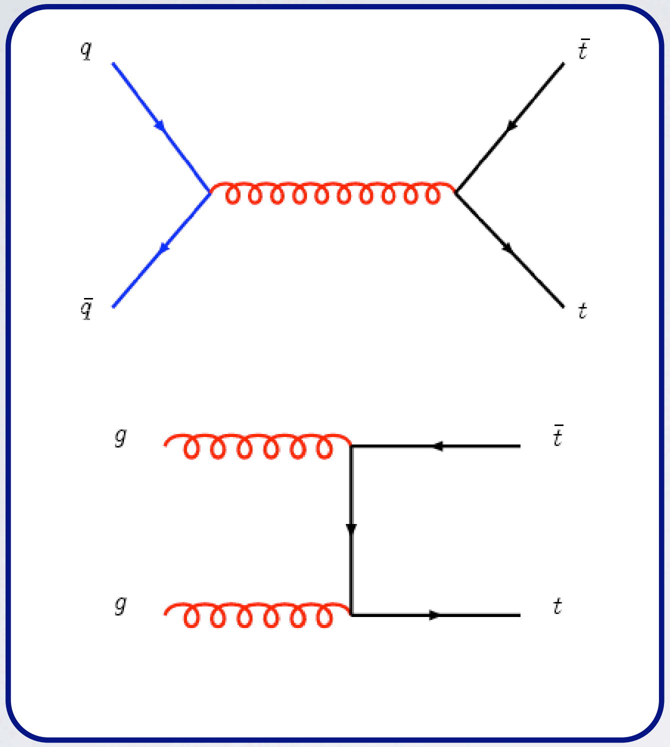

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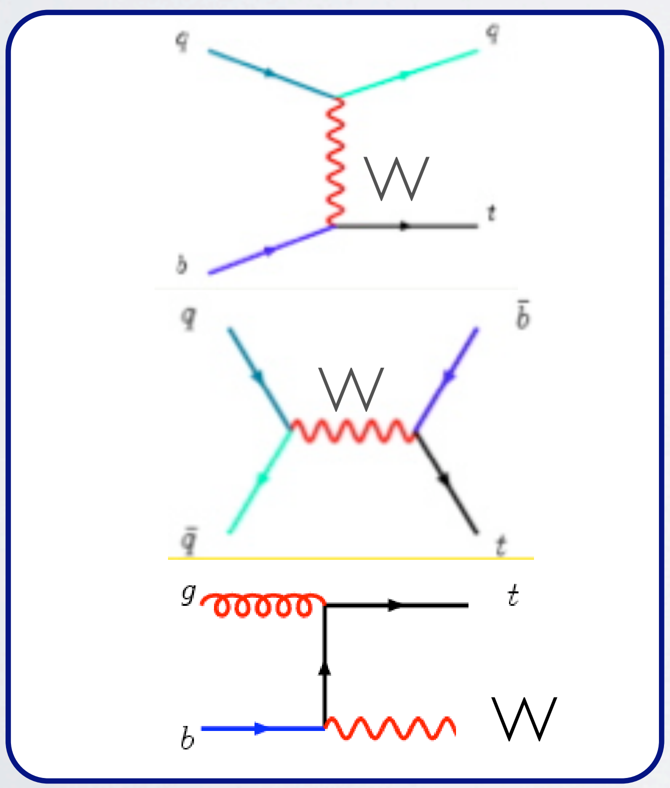

Weak process : same diagrams as the top decay!

Cross sections smaller than QCD but enhanced by a lower energy cost:

~ 3 pb at Tevatron
~ 60pb at LHC7

Three independent channels.

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- ttbar cross section
- W-boson helicity fractions
- Spin correlations between the top quarks are measured by fitting a double distribution
- Forward-backward asymmetry: $A_{FB} = 0.15 \pm 0.07 \pm 0.02$
- m_{tt}, p_t , H_T distributions
- Decay width: $\Gamma_t < 7.4$ GeV at 95% C.L.
- Branching fraction:
  $(t \rightarrow W^+ b)/(t \rightarrow W^+ q) > 0.61$ at 95% C.L.
- Electric charge: $Q_t = -4/3$ excluded at 87% C.L
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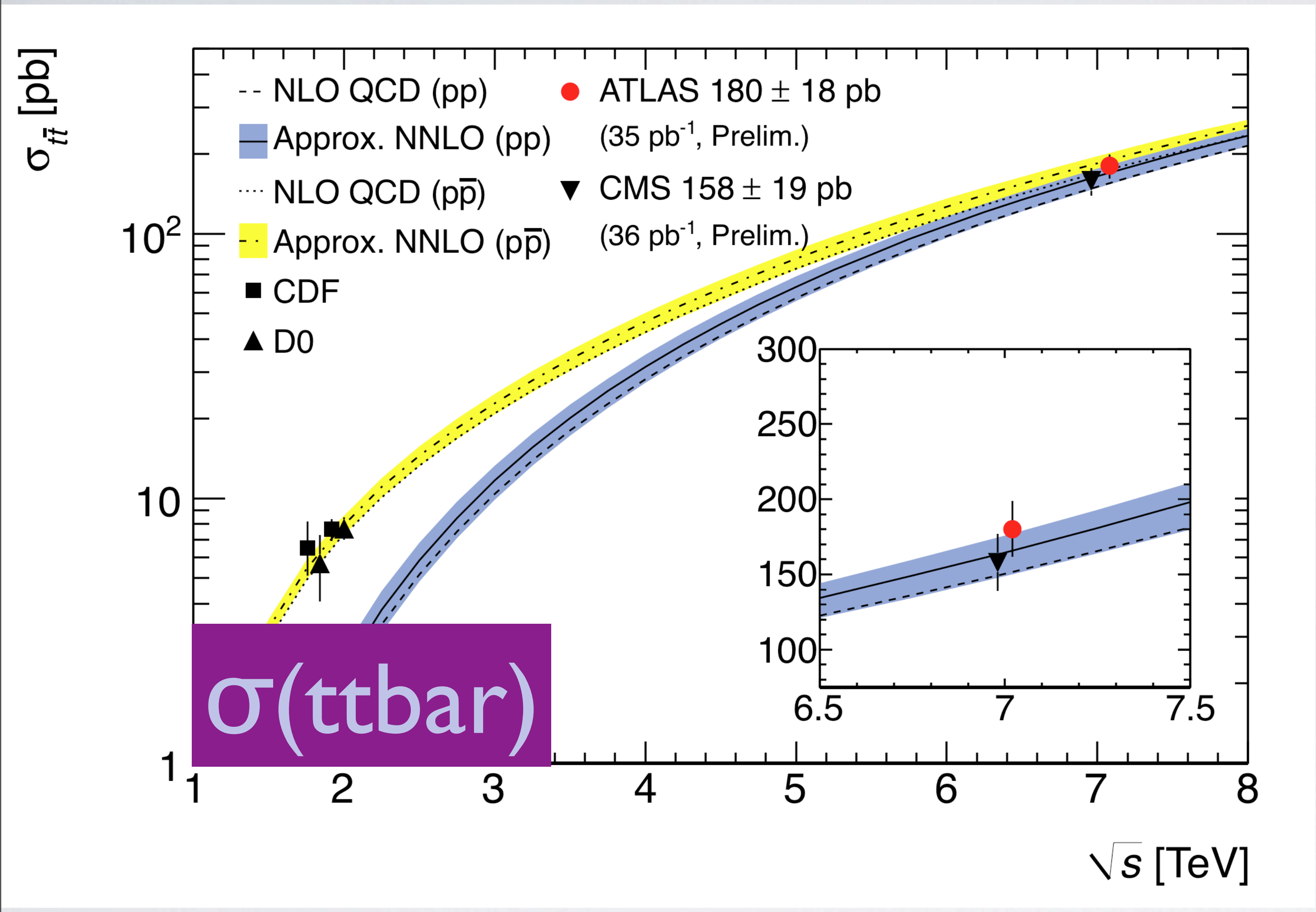

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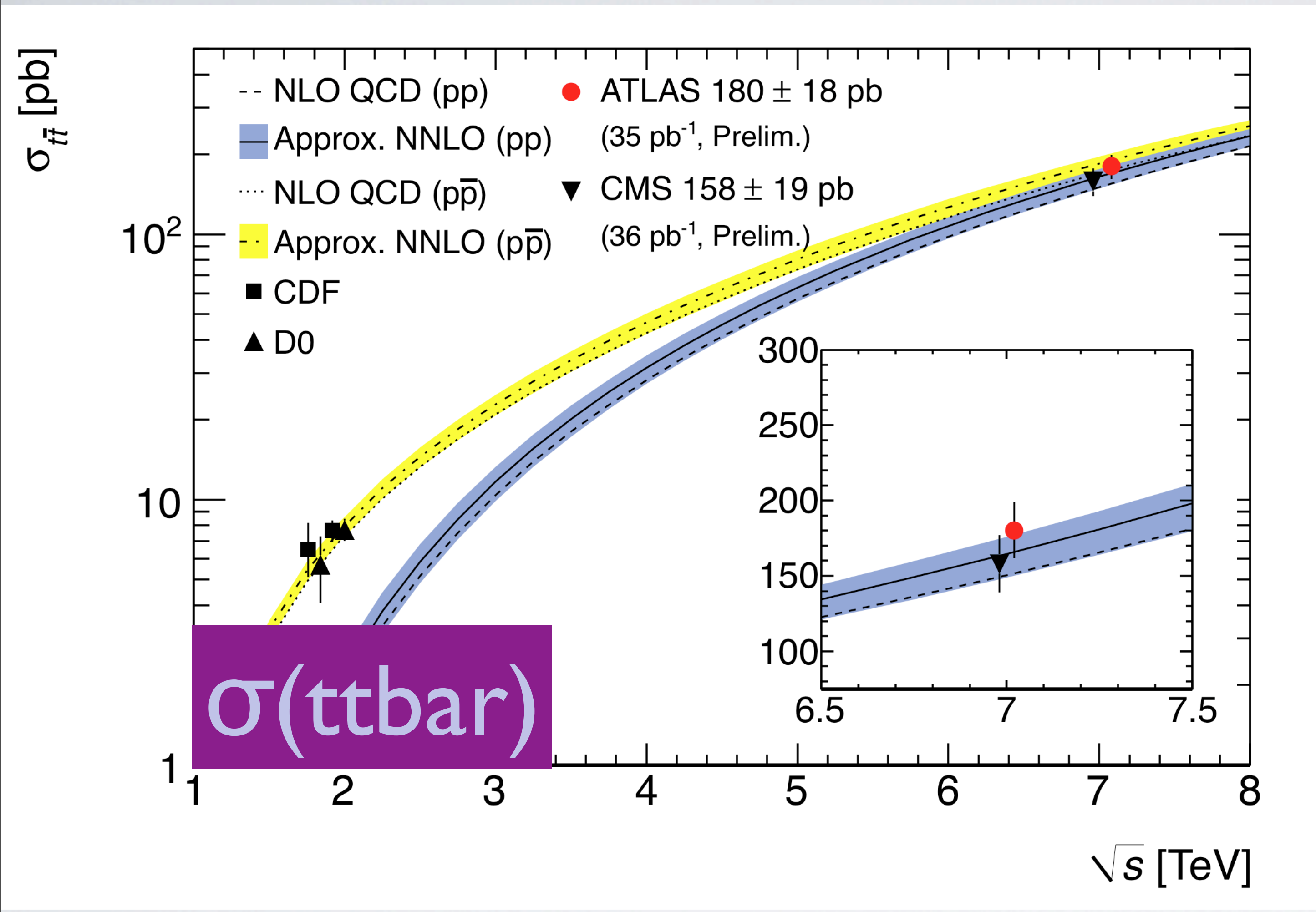

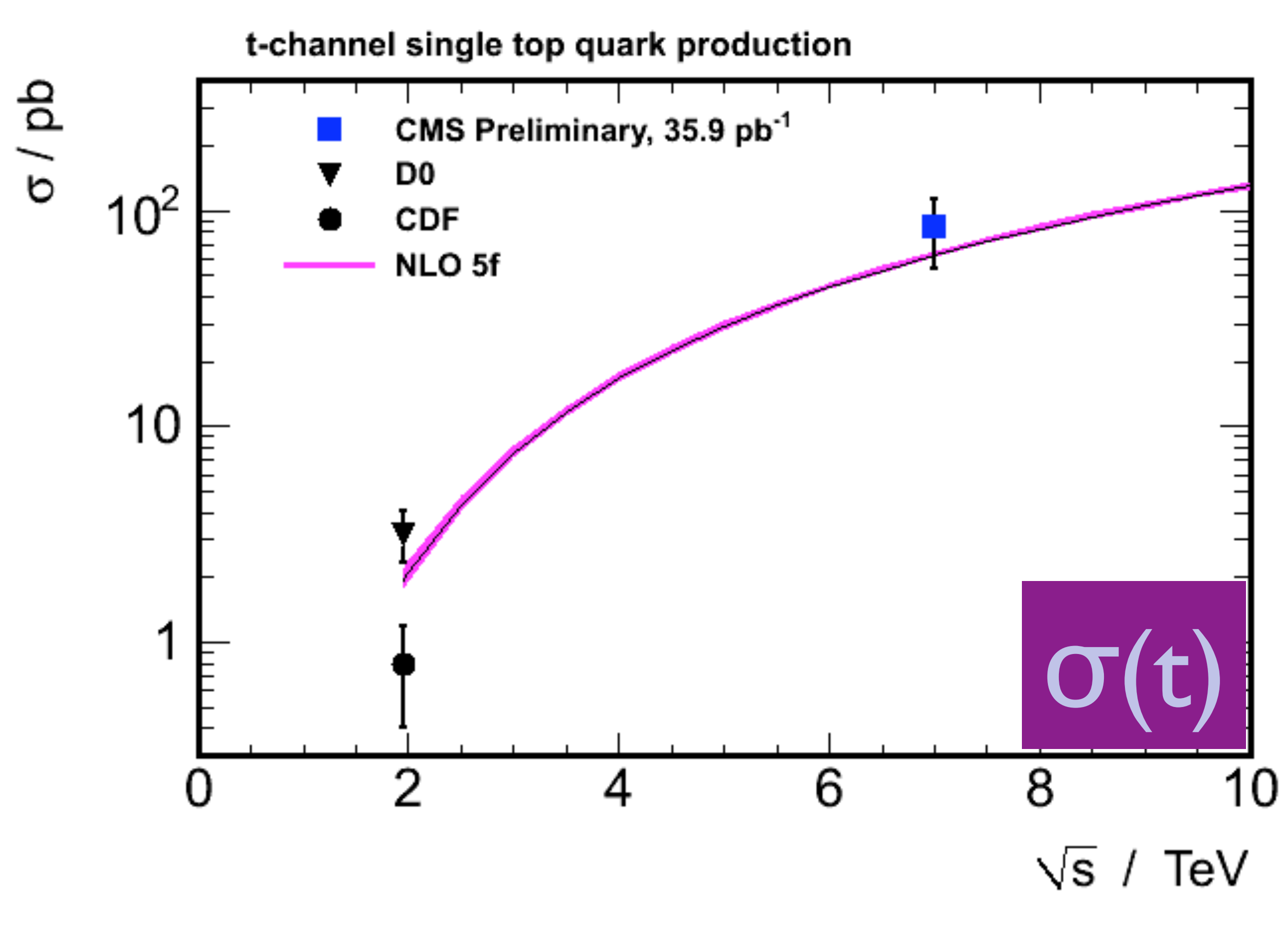

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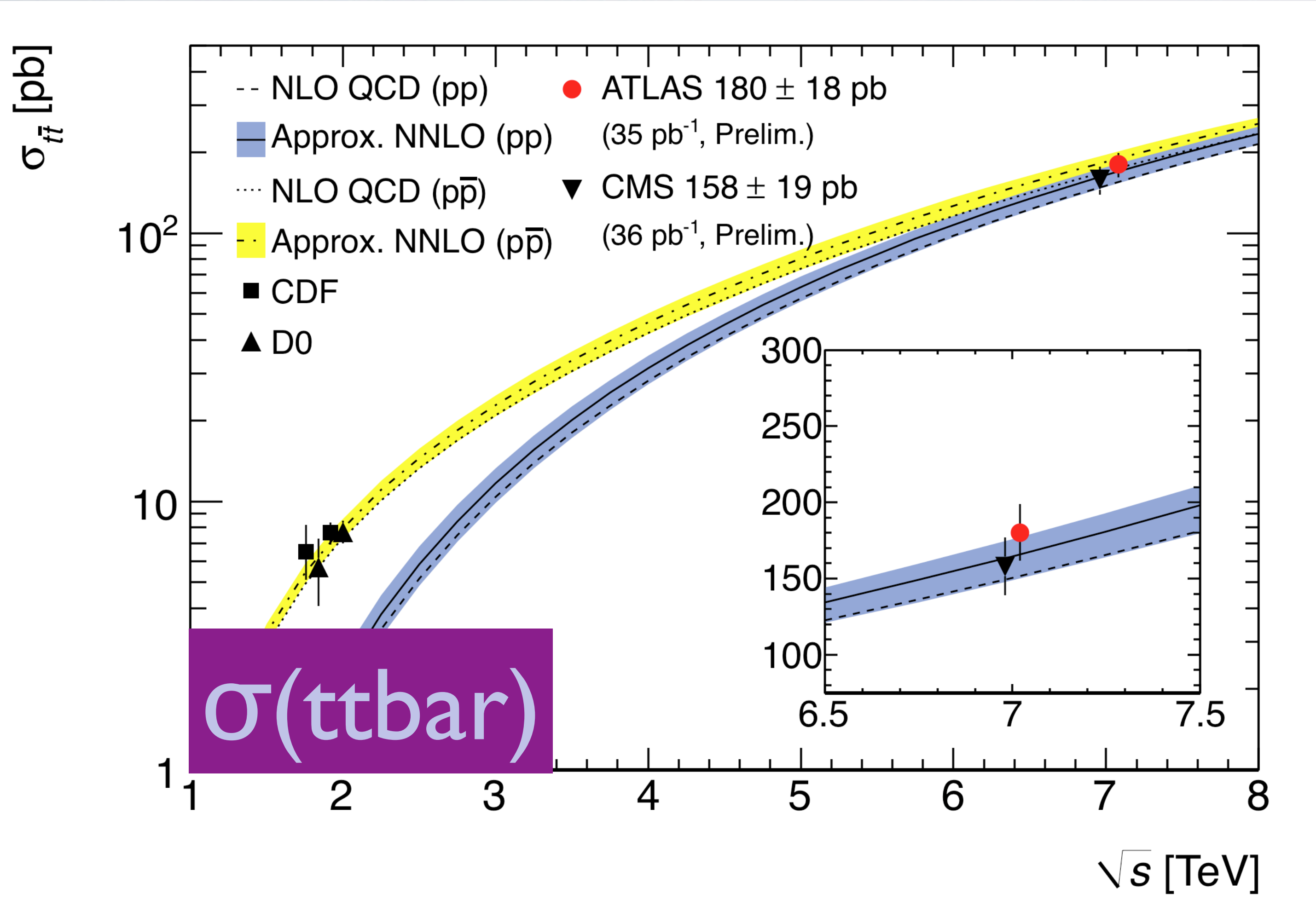

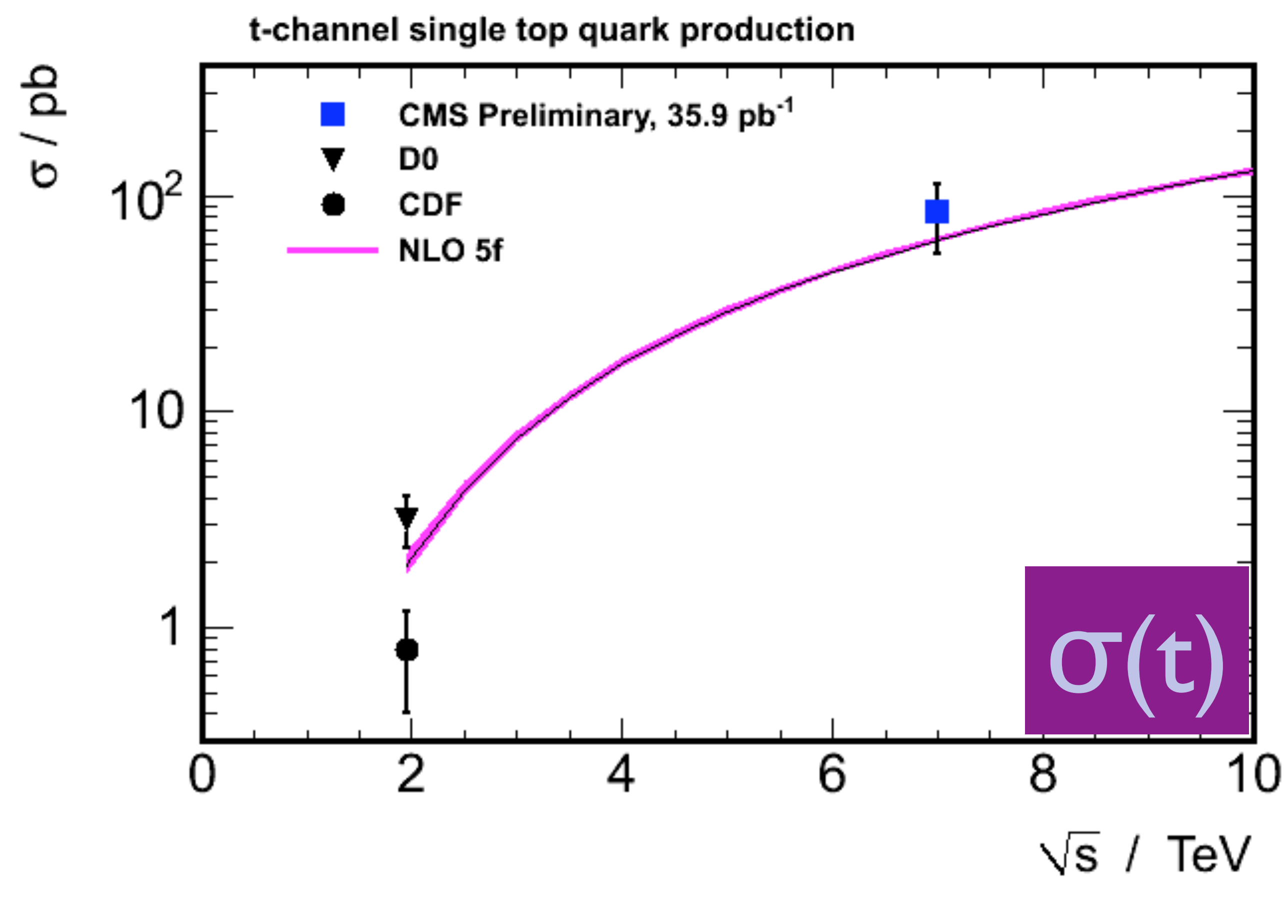

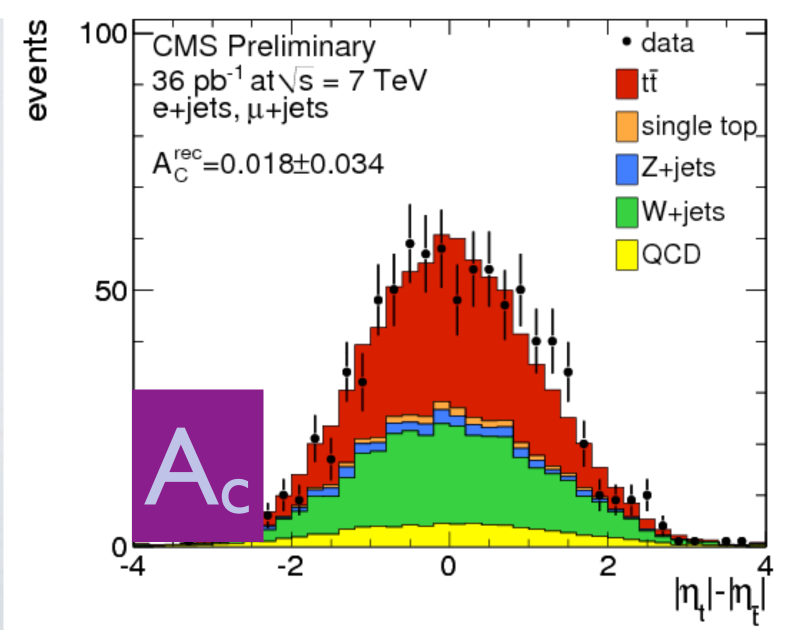

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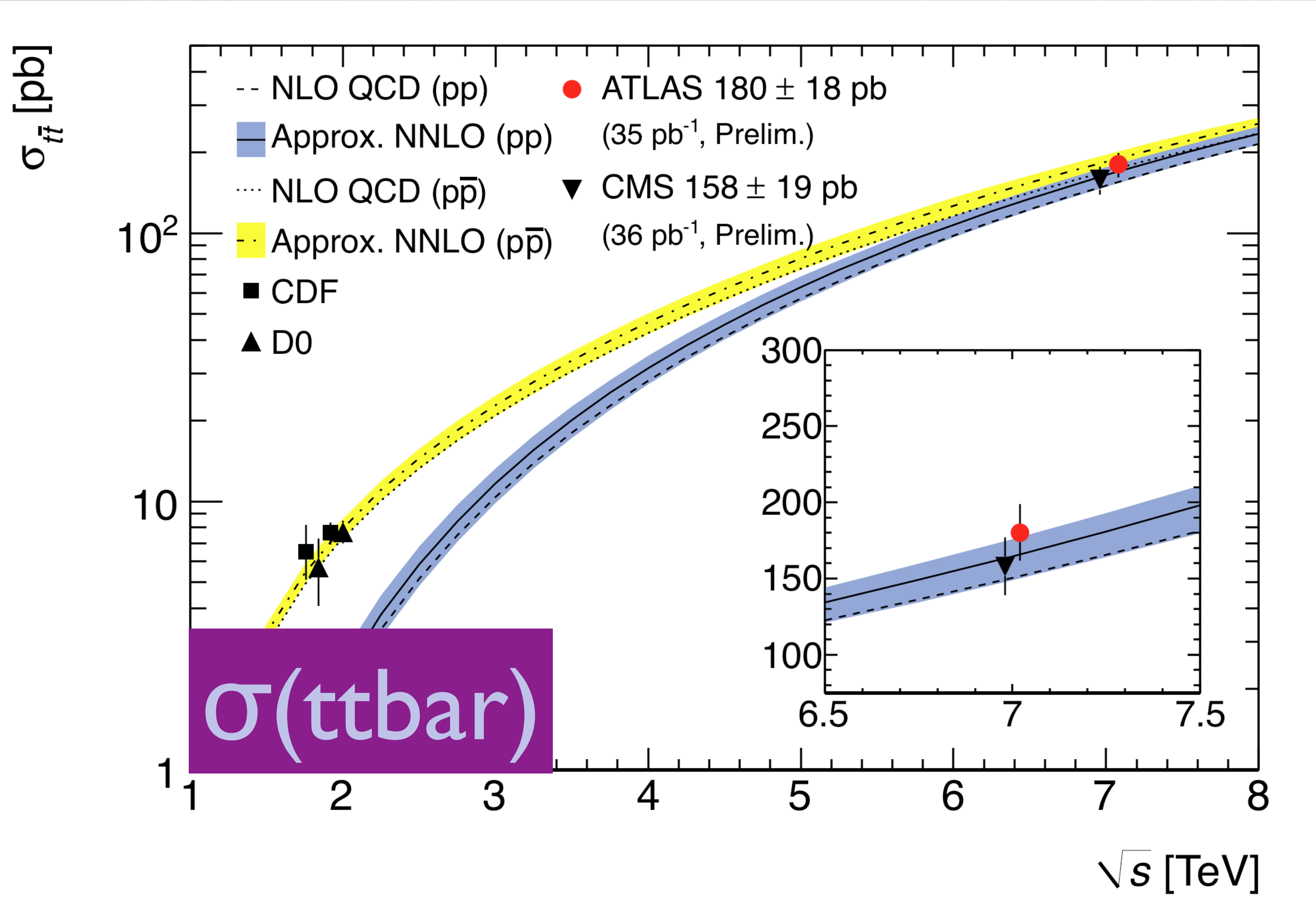

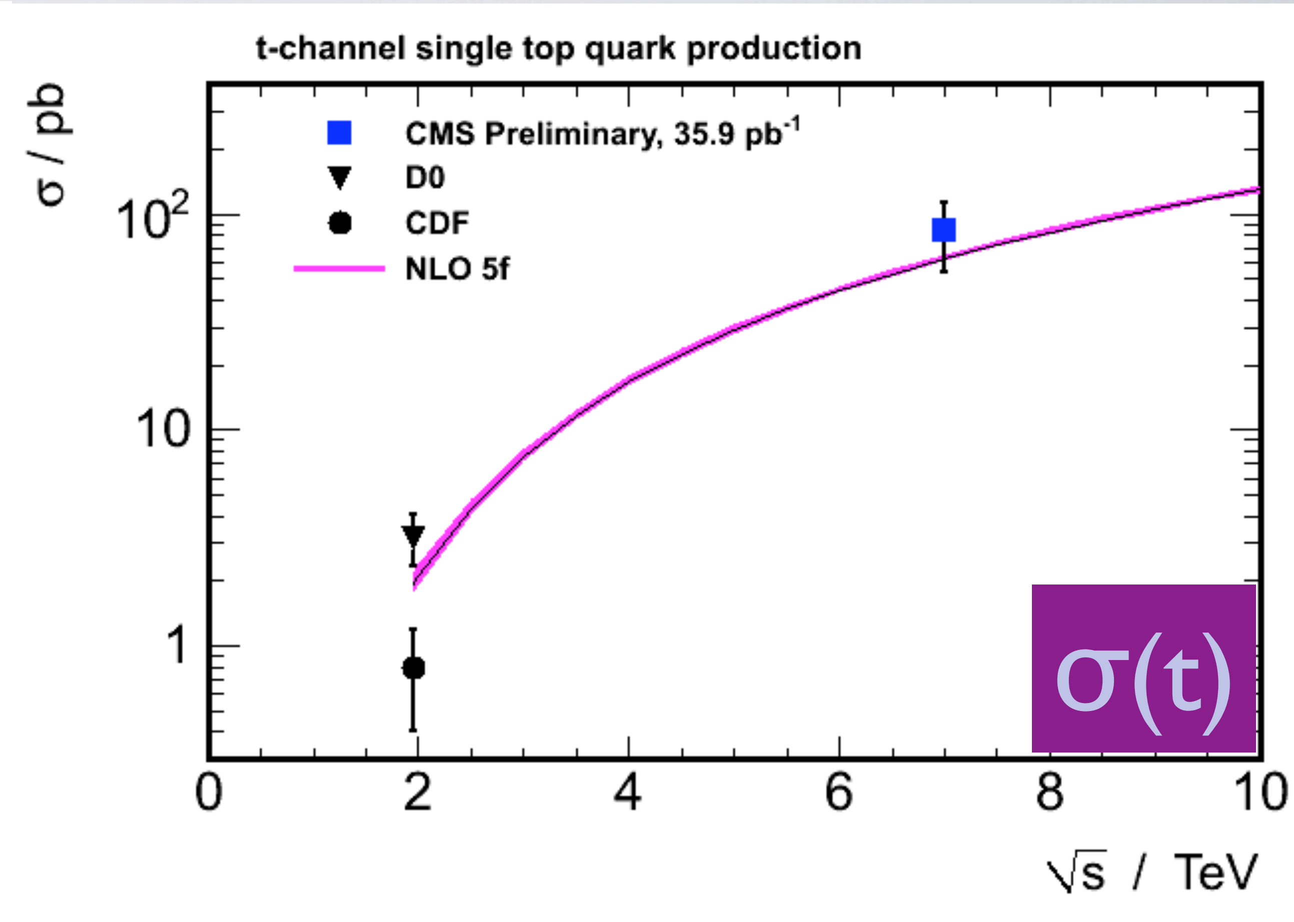

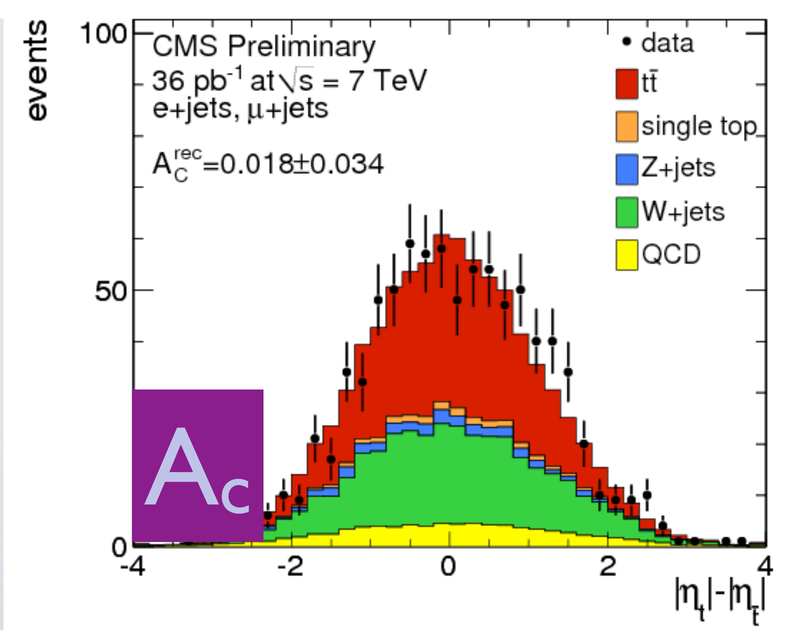

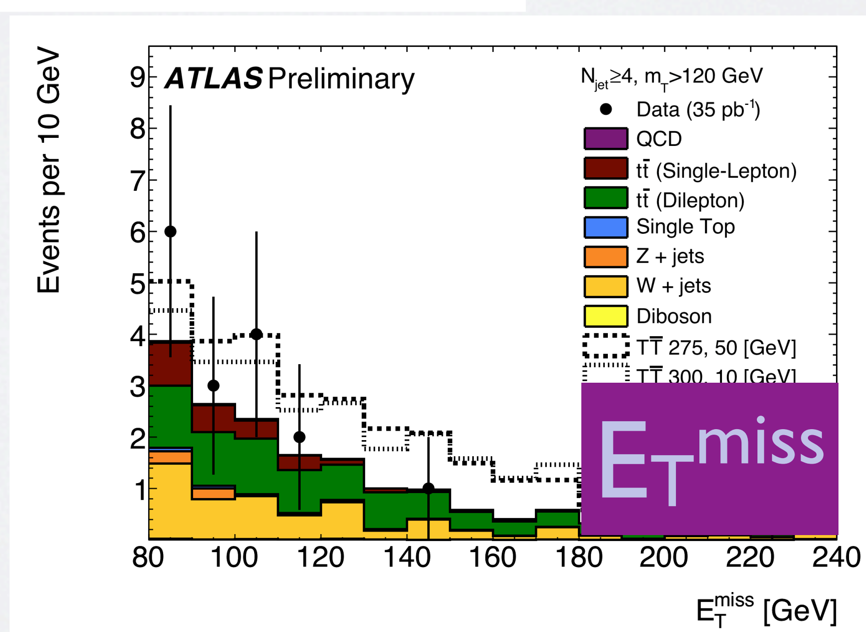

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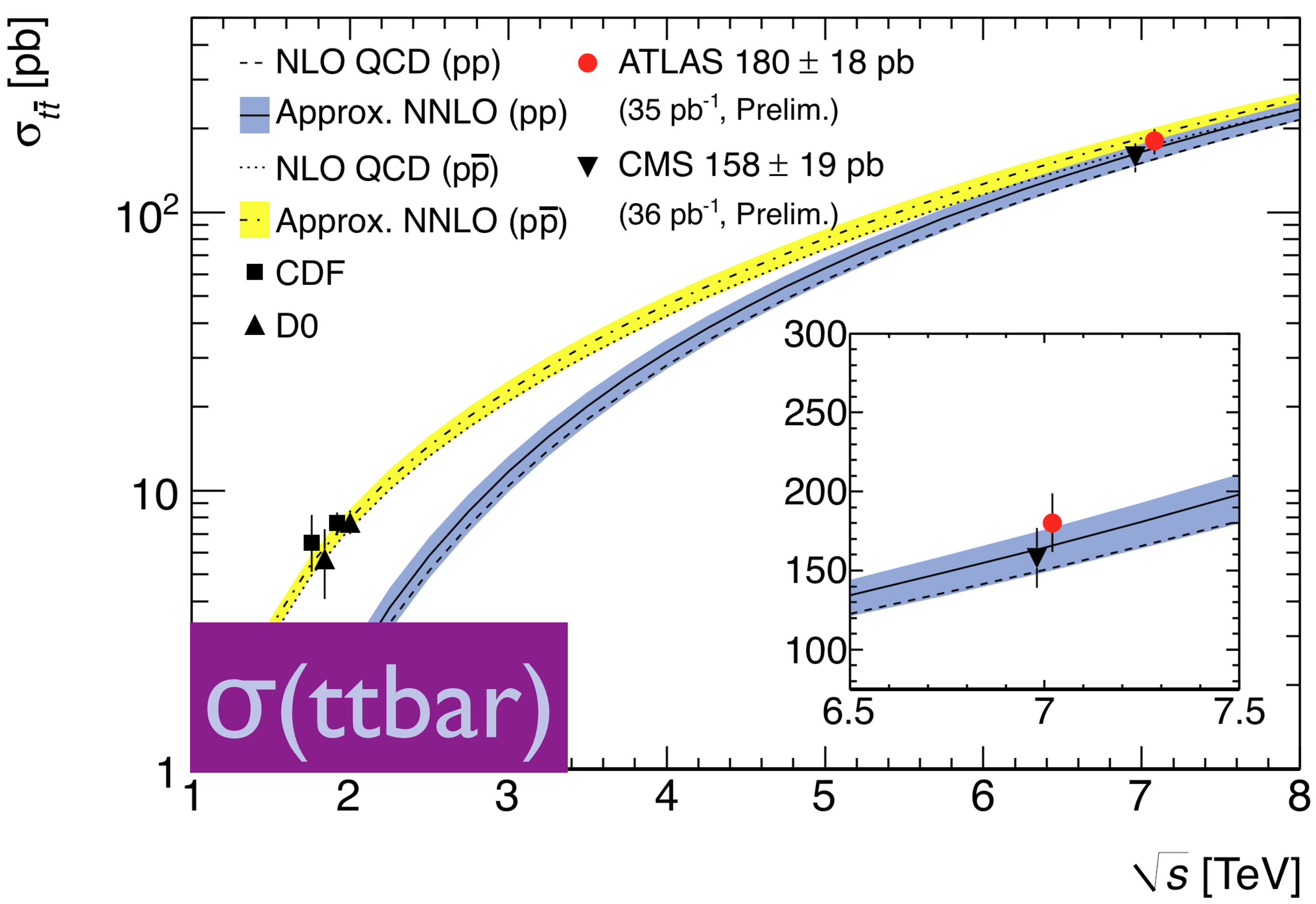

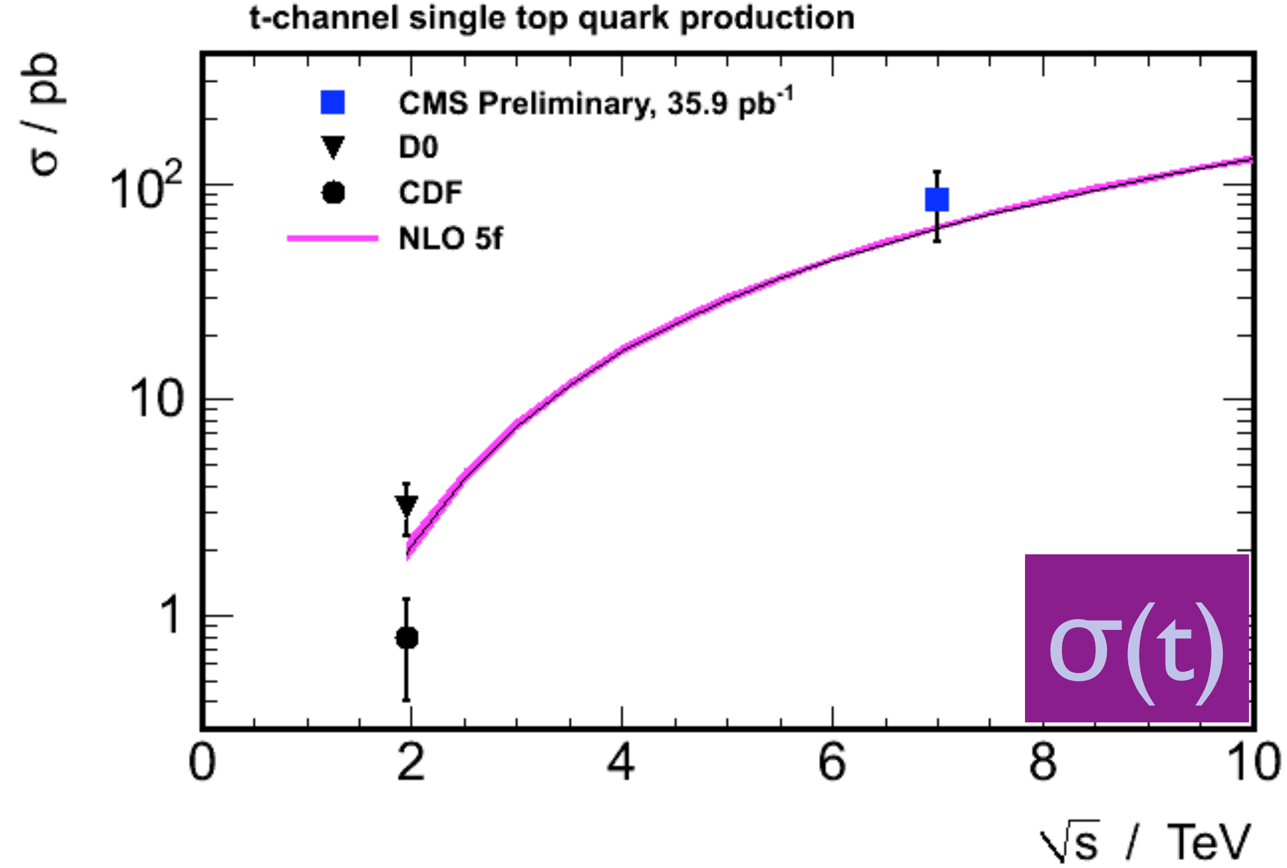

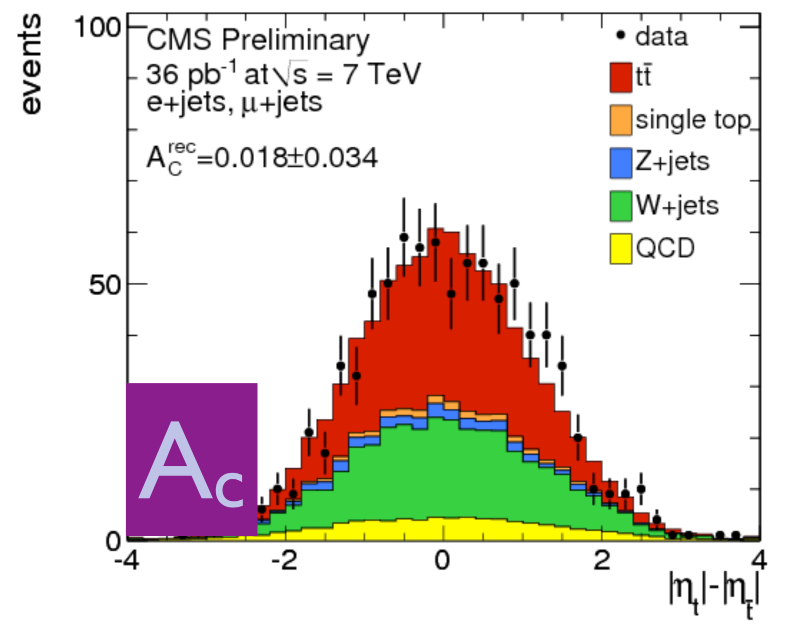

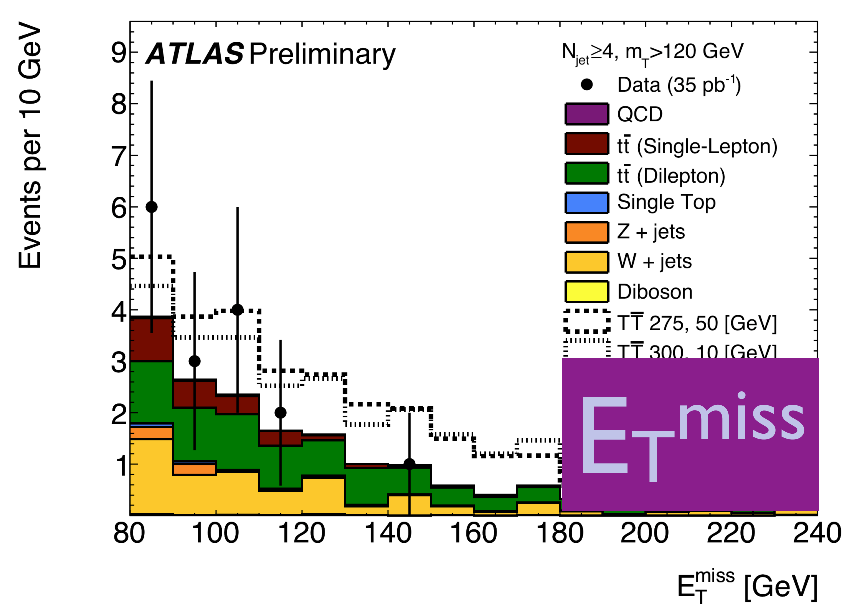

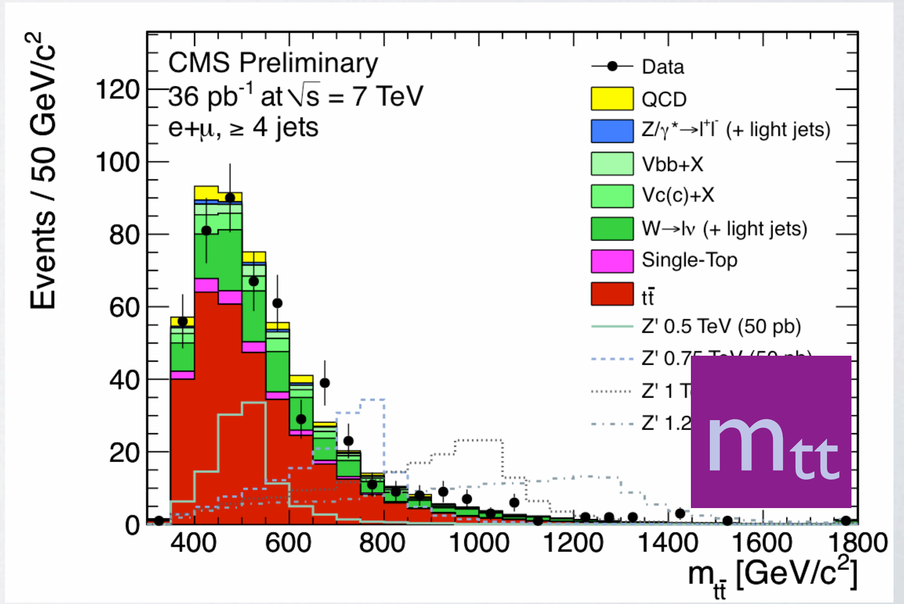

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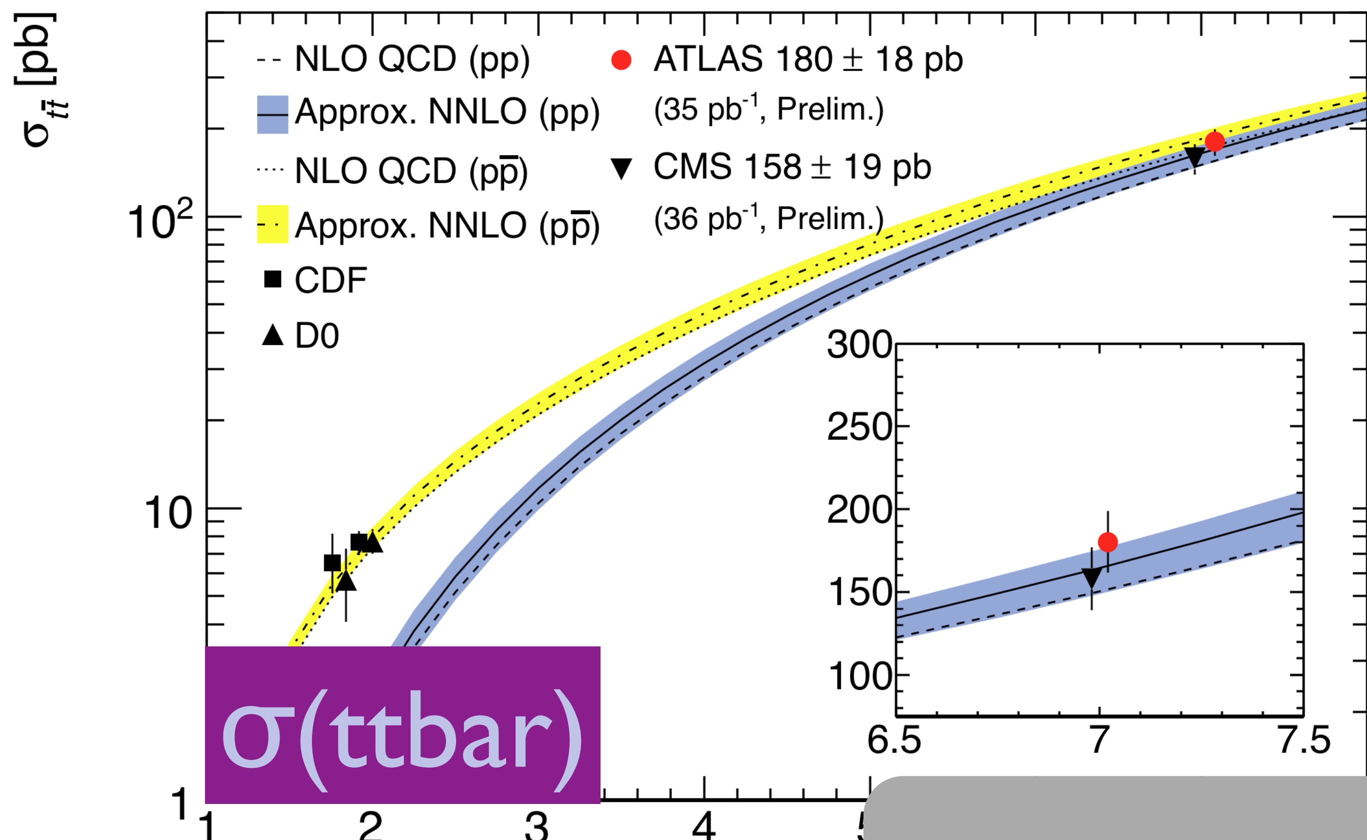
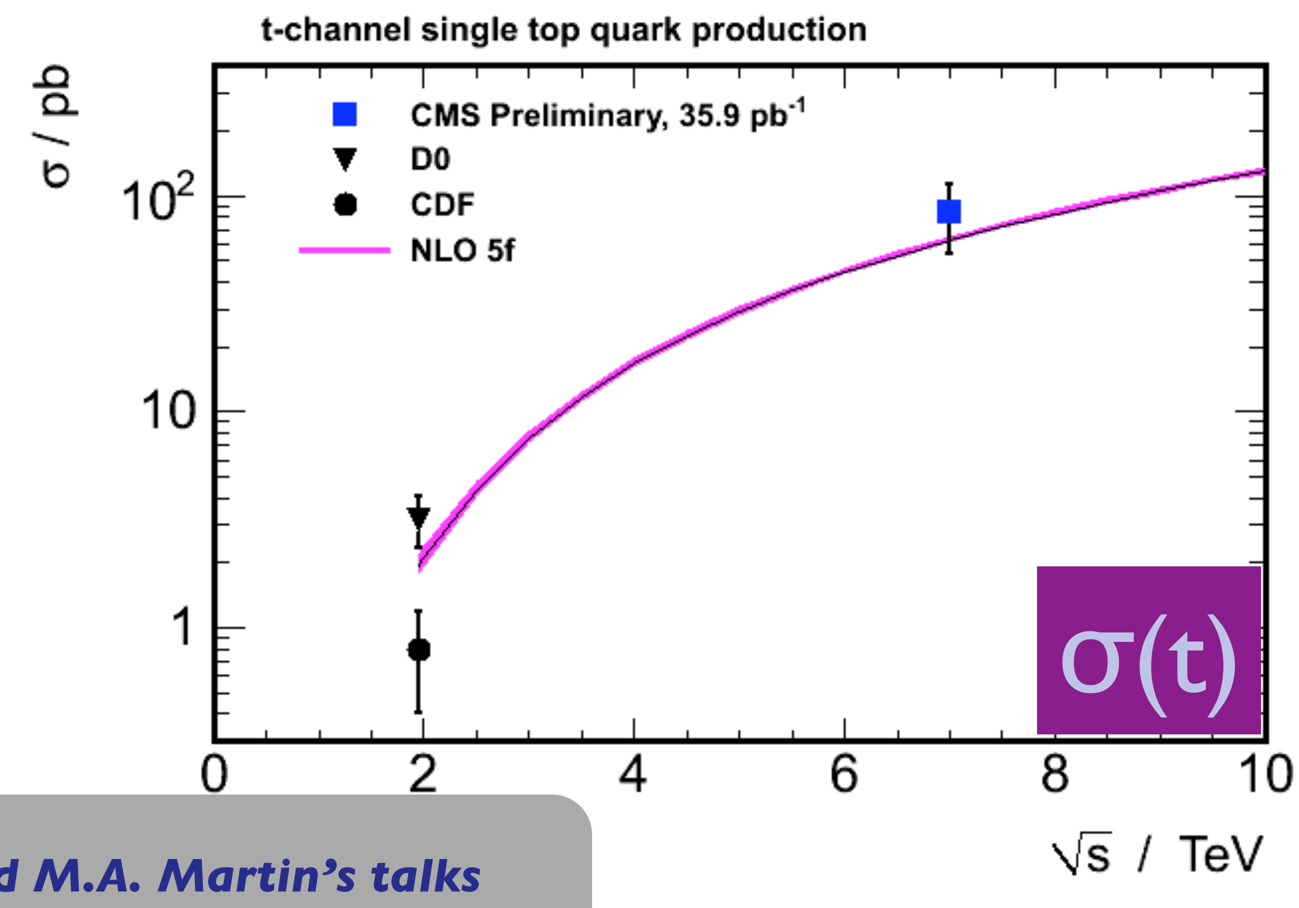
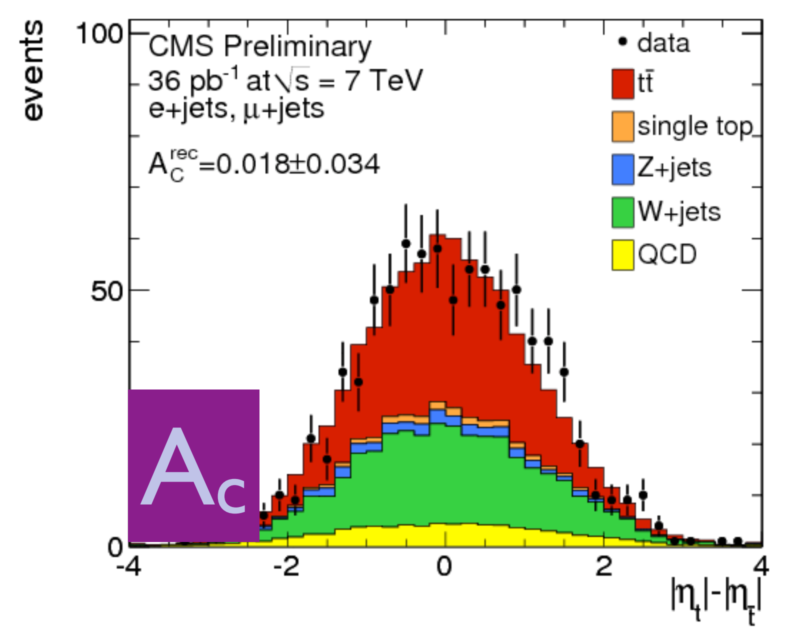
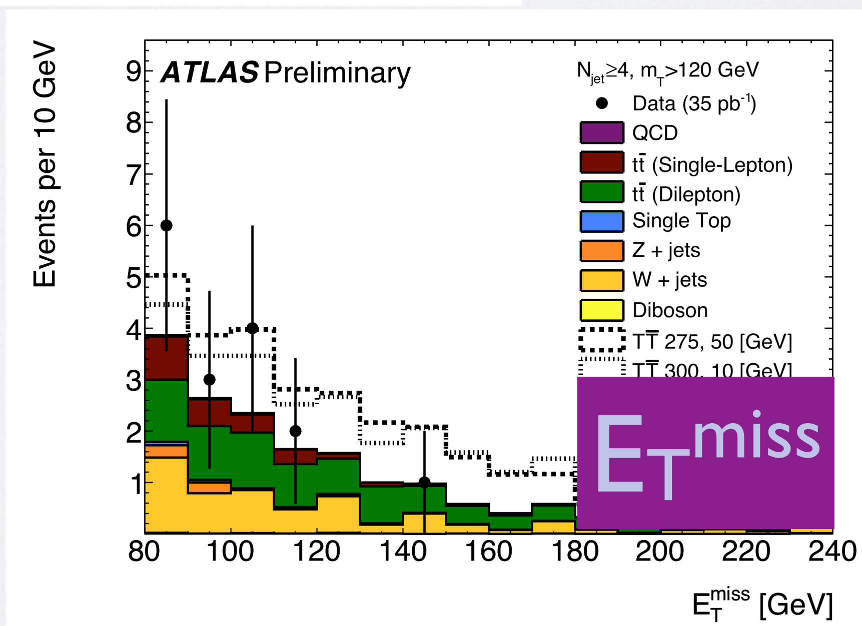
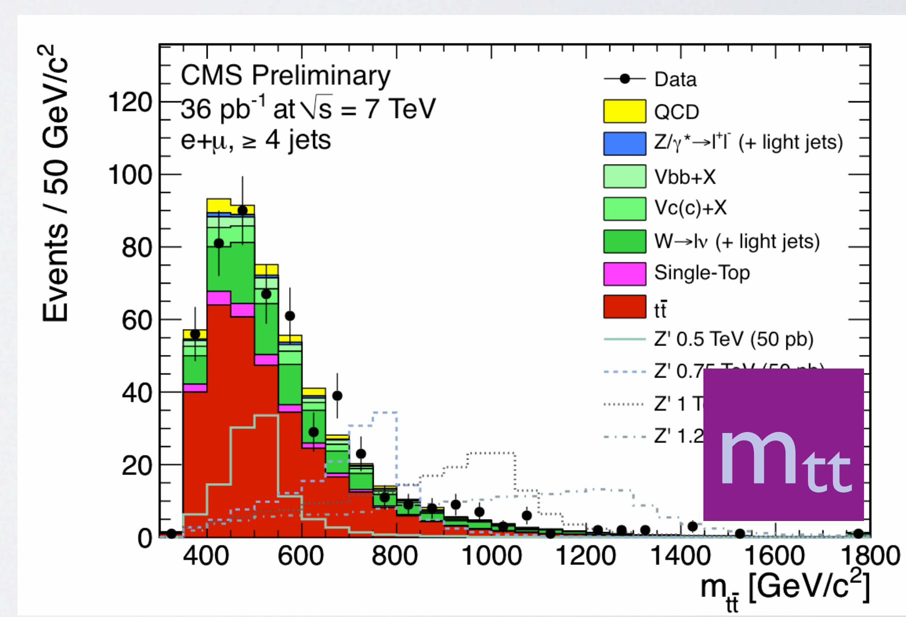




see M. Saleem's and M.A. Martin's talks







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modified by the speaker

PROGRESS IN SM TOP PREDICTIONS

Top pair cross section and distributions:

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- NNLL extensions at threshold: two slightly different definitions of threshold *Czakon et al.; Beneke et al.; Ahrens et al.*
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$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2 \, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \; \times \hat{\sigma}_{ab \to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2})$$

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Total cross section at NLO:

[Dawson et al, Beenakker et al. , Bonciani et al. Kao, Wackeroth, Bernreuther et al, Kuhn, Scharf, Uwer]

$$\sigma^1 = \frac{\#}{\beta} + \# \log^2 \beta + \# \log \beta + c_1$$

$$\beta = \sqrt{1 - \frac{4m_t^2}{s}}$$

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$$\sigma^1 = \frac{\#}{\beta} + \# \log^2 \beta + \# \log \beta + c_1$$

$$\beta = \sqrt{1 - \frac{4m_t^2}{s}}$$

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$$\sigma^2 = \frac{\#}{\beta^2} + \frac{\# \log^2 \beta + \# \log \beta + \#}{\beta} + \# \log^4 \beta + \# \log^3 \beta + \dots + c_2$$

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 1: SIGMA(T TBAR)

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1,\mu_F^2) f_b(x_2,\mu_F^2) \times \hat{\sigma}_{ab\to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2})$$

$$\hat{\sigma}_{ab\to X} = \sigma_0 + \alpha_S \sigma_1 + \alpha_S^2 \sigma_2 + \dots$$

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Beware: NNLO corrections not known exactly yet!!

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 1: SIGMA(T TBAR)

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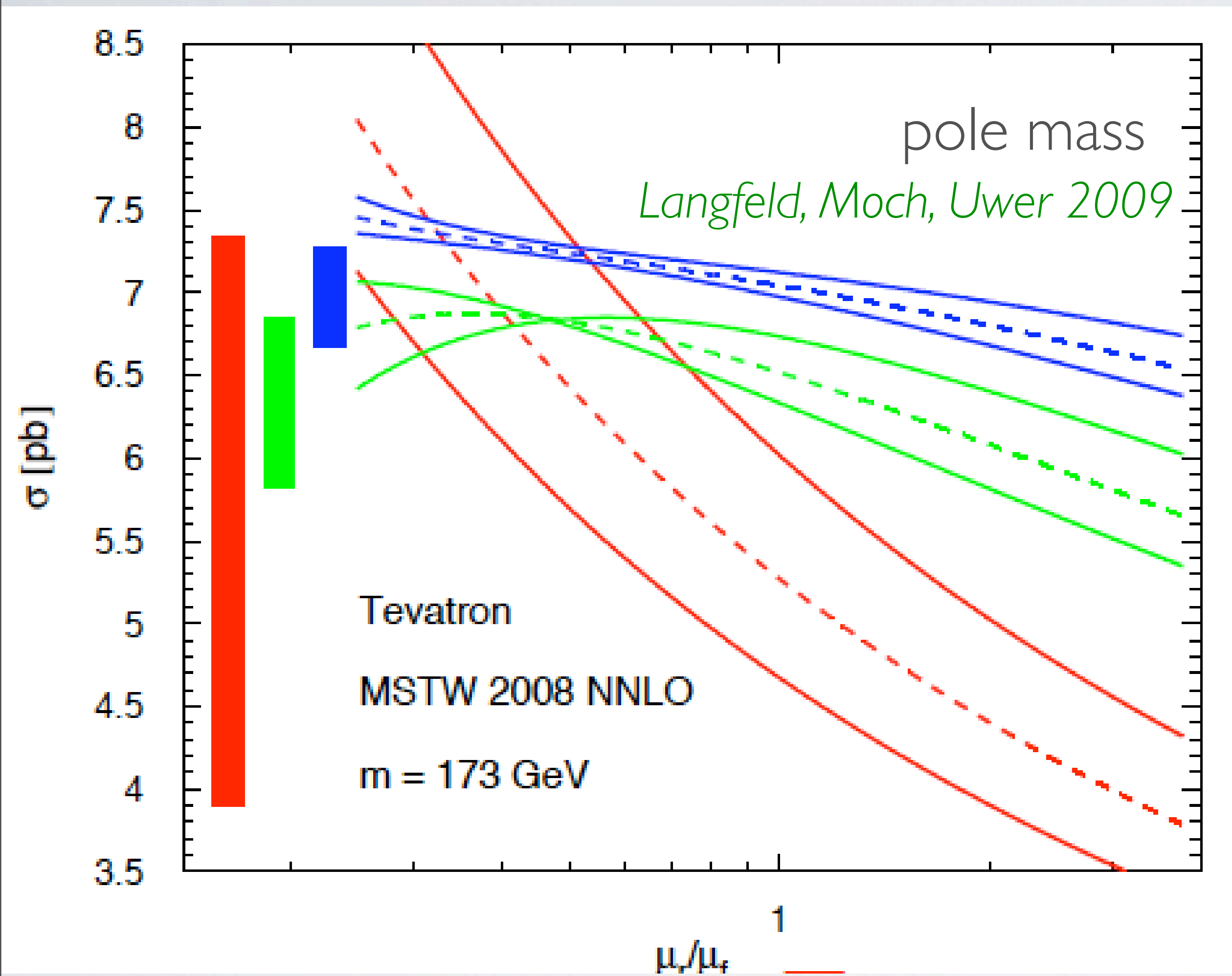

Approximated NNLO results:
very good scale dependence improvement:

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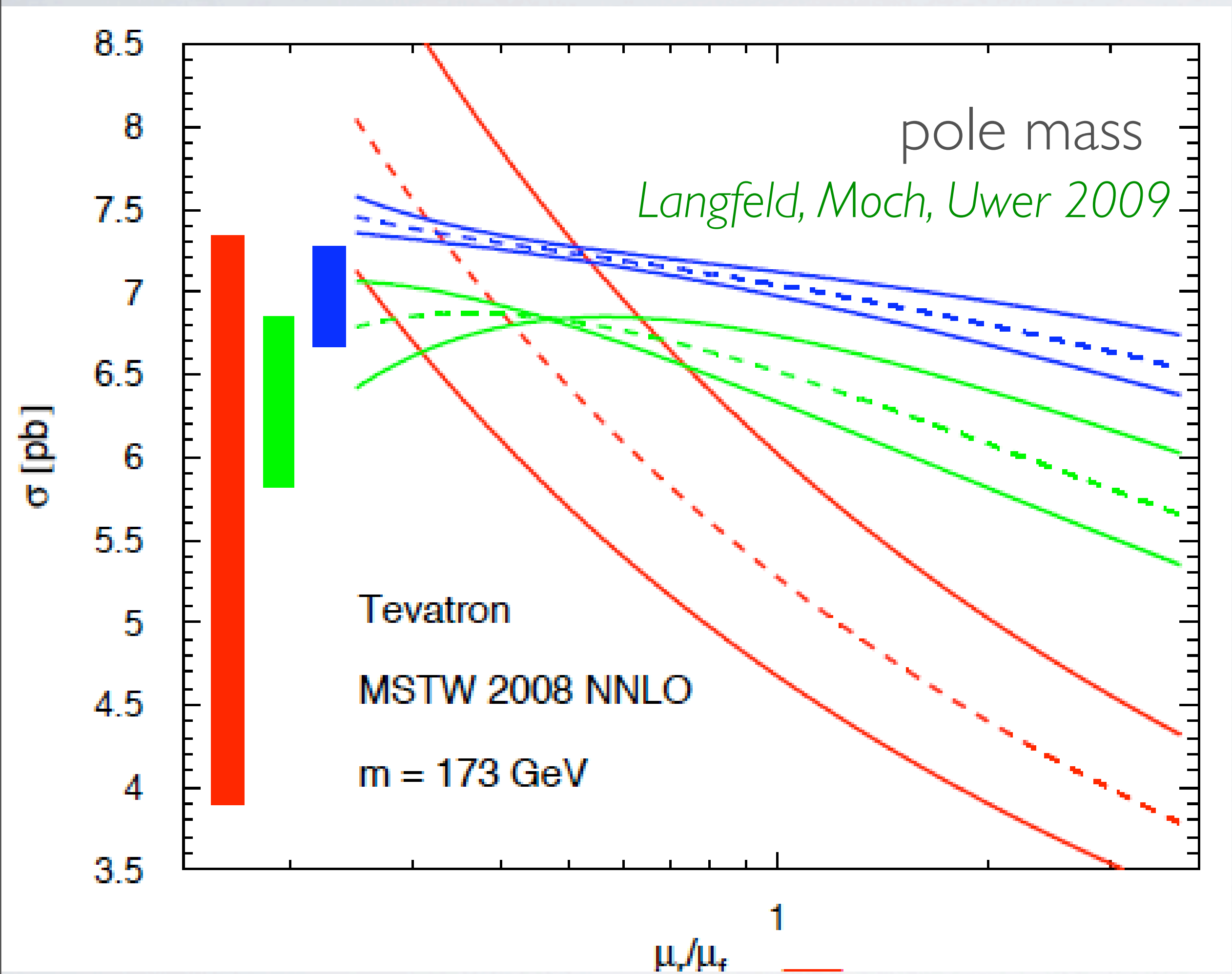

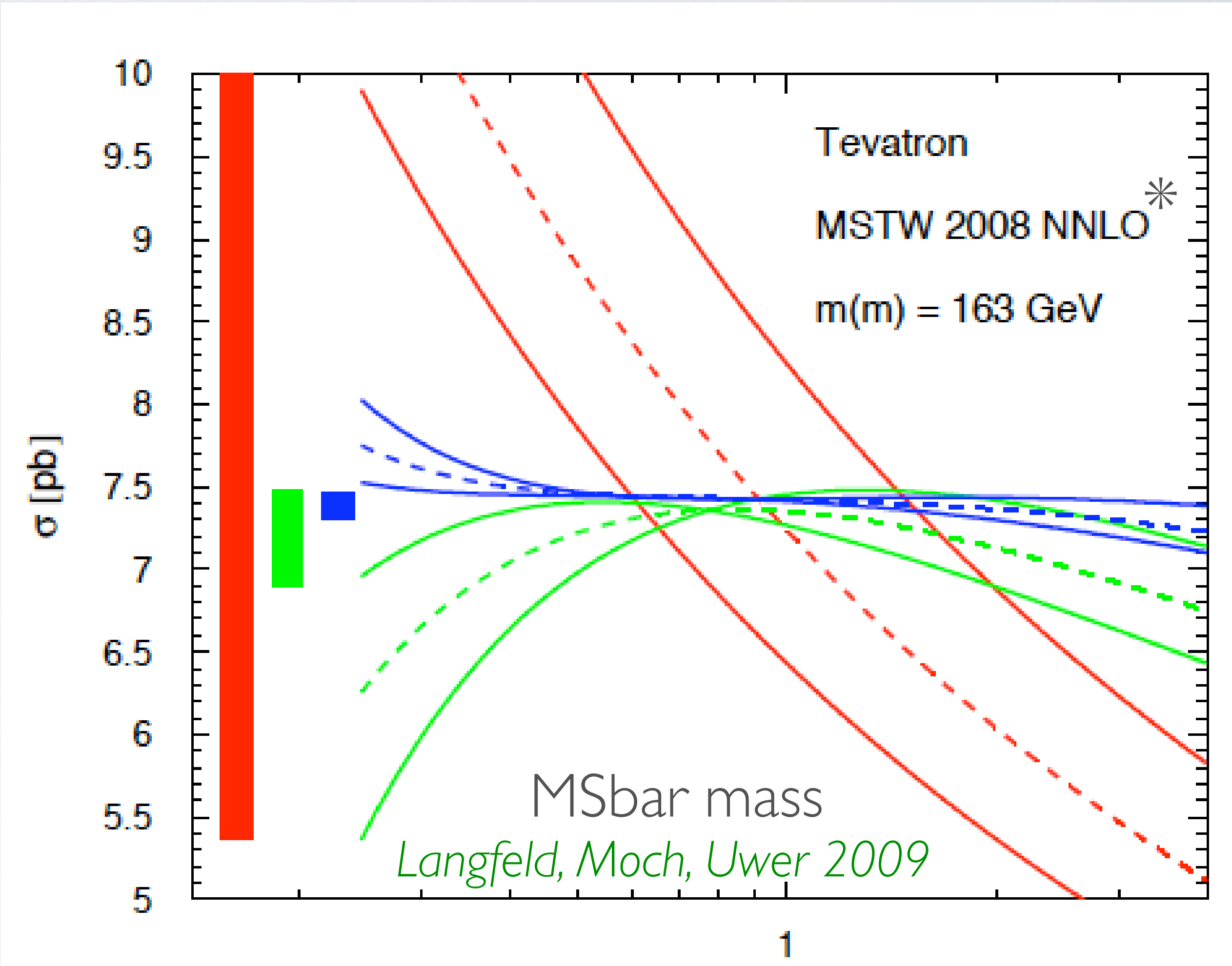

Approximated NNLO results:
very good scale dependence improvement:

Even better if the MSbar mass is used as a parameter in the calculation : possibility of extracting the mass from the cross section.

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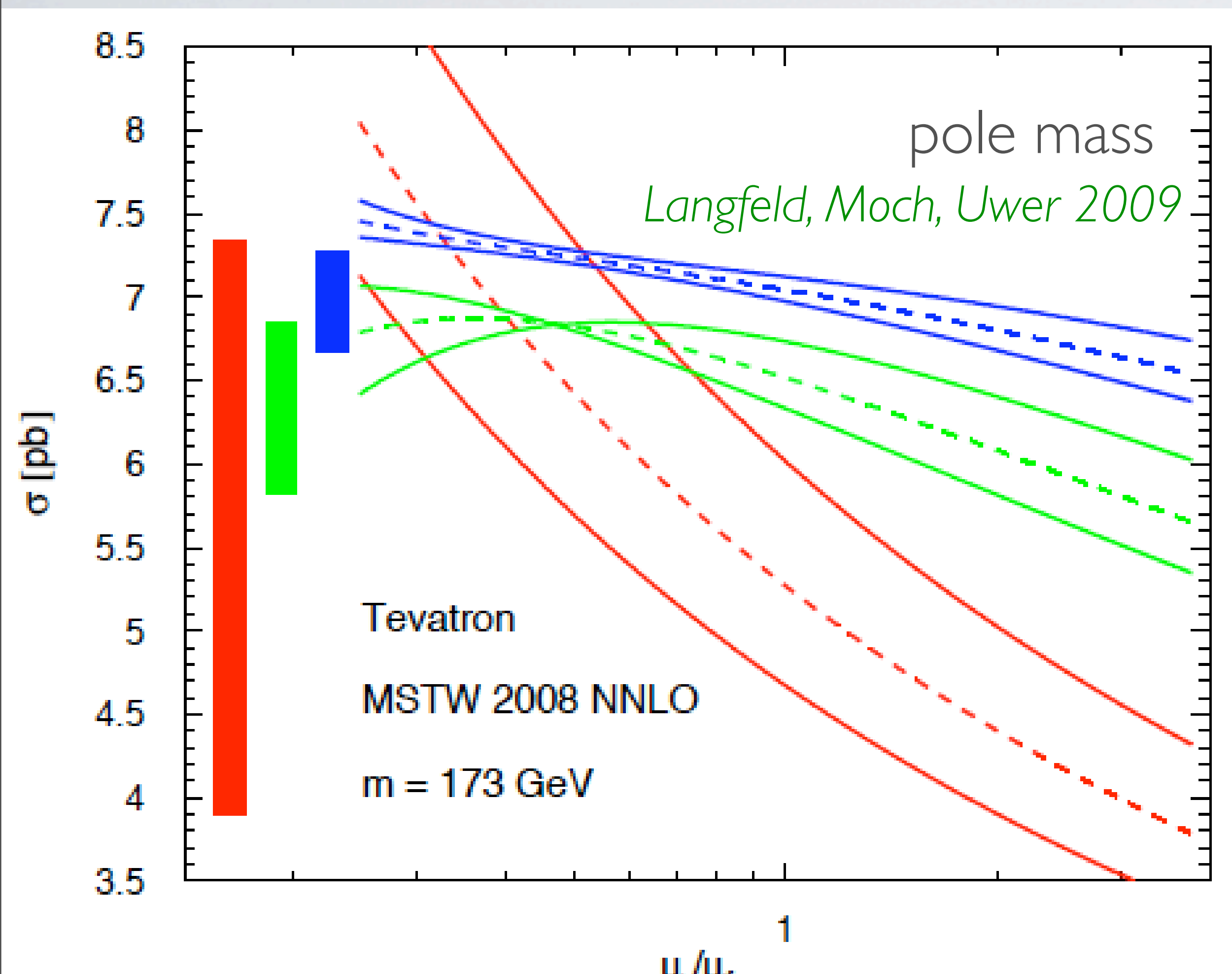

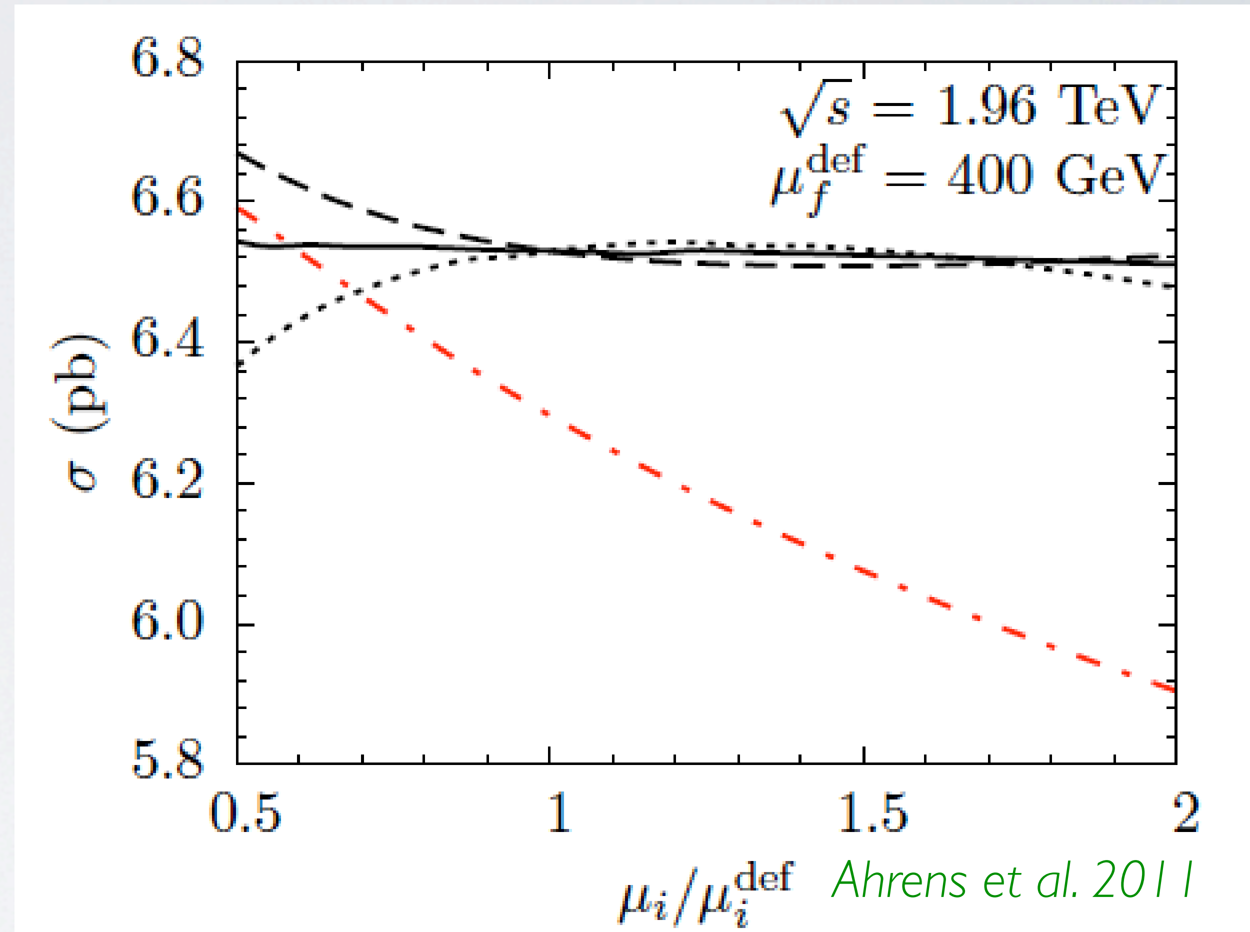

Approximated NNLO results:
very good scale dependence improvement:

Different approach (SCET).
Prediction is somewhat lower than previous results.
Differences are smaller at the LHC

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 2: WWBB

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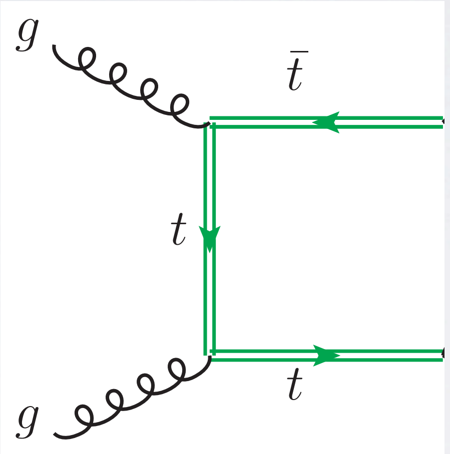

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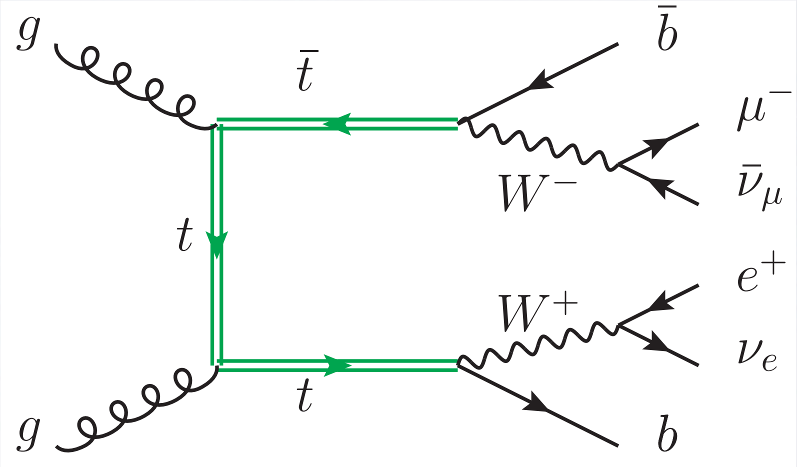

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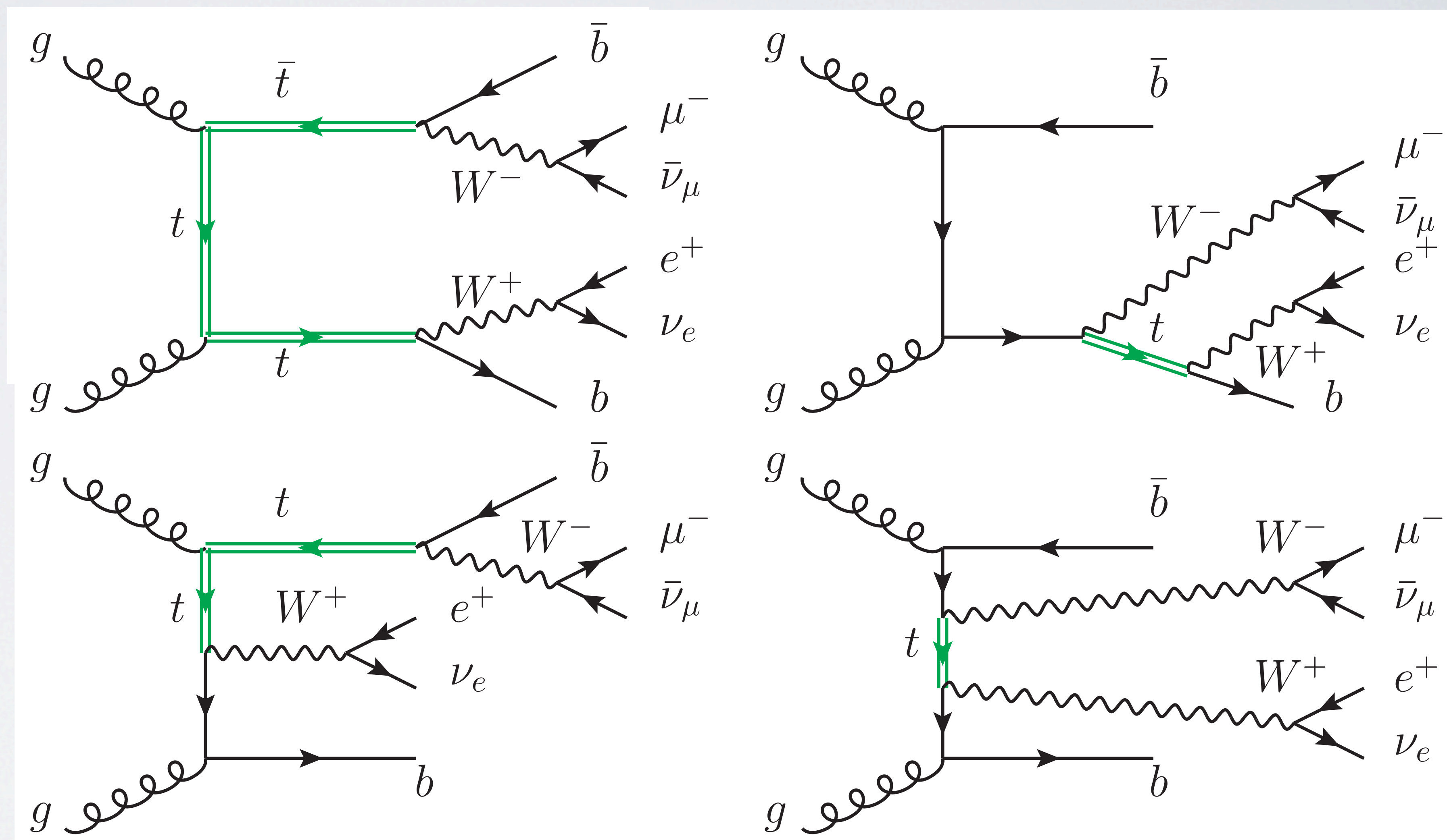

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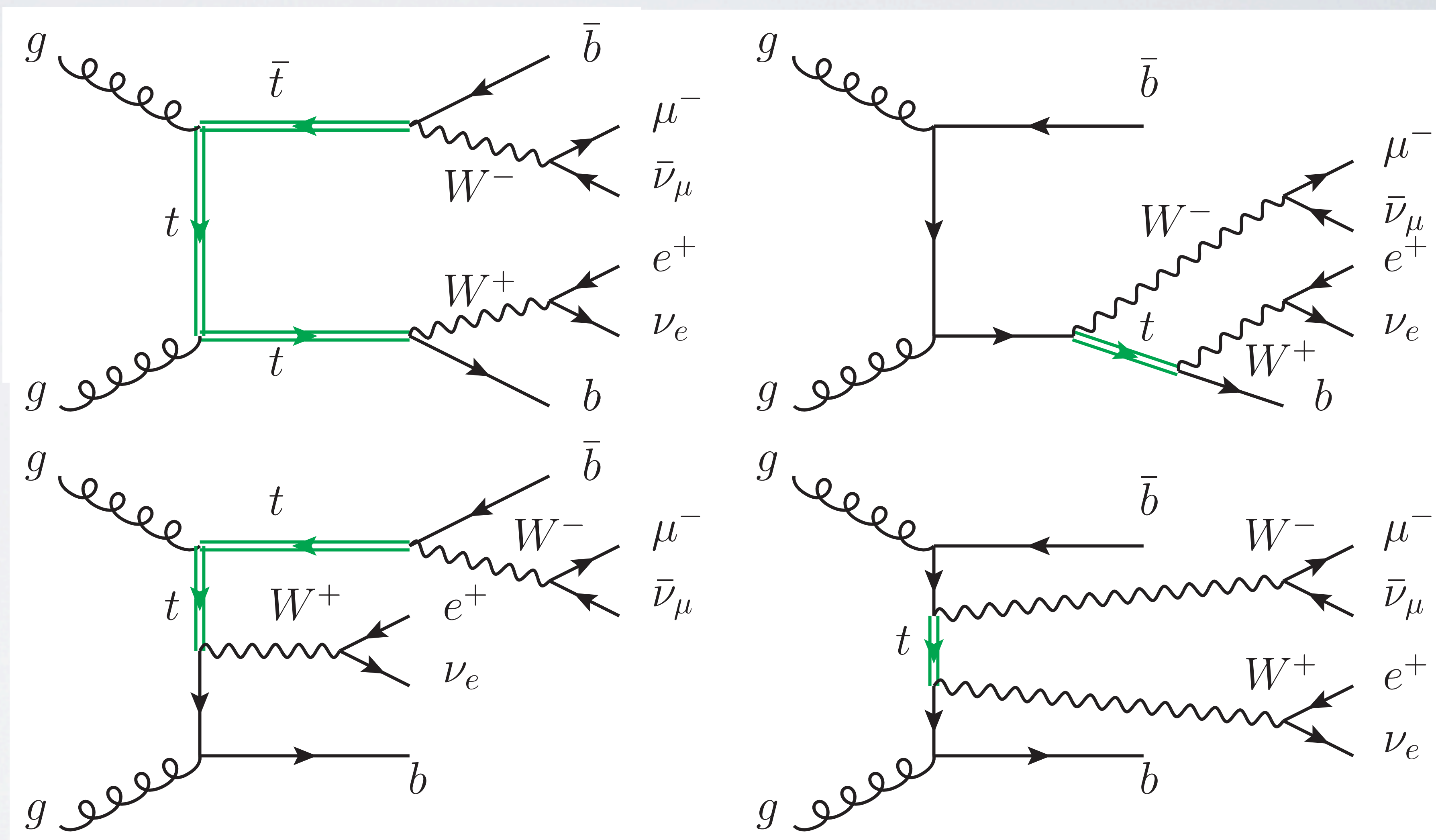
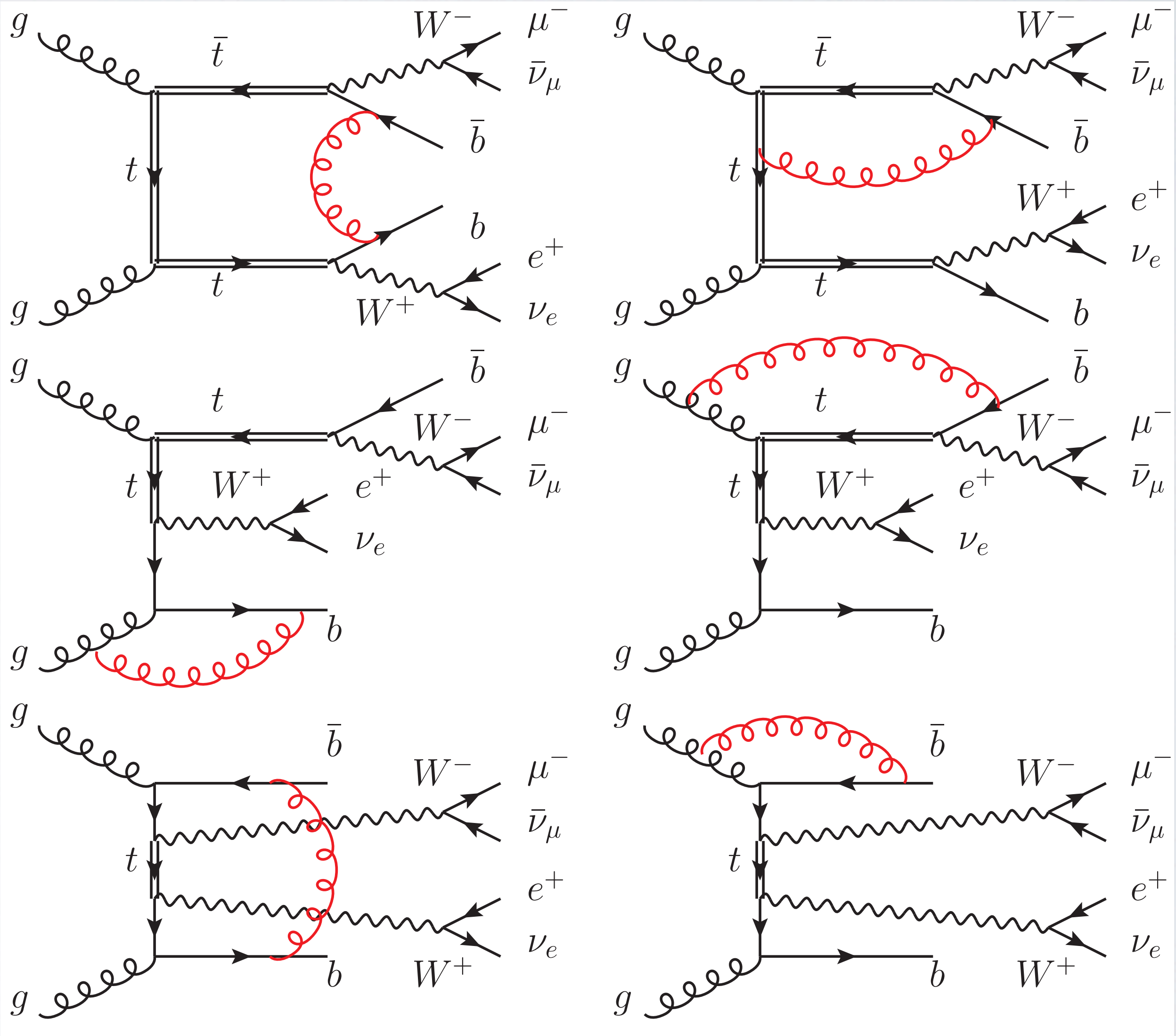


- Gauge invariance guides us to include also single-resonant and non-resonant production. Note that there is interference between the diagrams above

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 2: WWBB

- Recently, the full NLO computations to the WWbb process were calculated by two independent groups *Denner et al.; Bevilacqua et al.*
- Consistent description of top pair, single top and non-resonant contributions at NLO
- Particularly important when cuts require tops to be off-shell
- No need to disentangle top pair and Wt and apply separate K-factors when studying the "top" background to e.g. H ➞ WW



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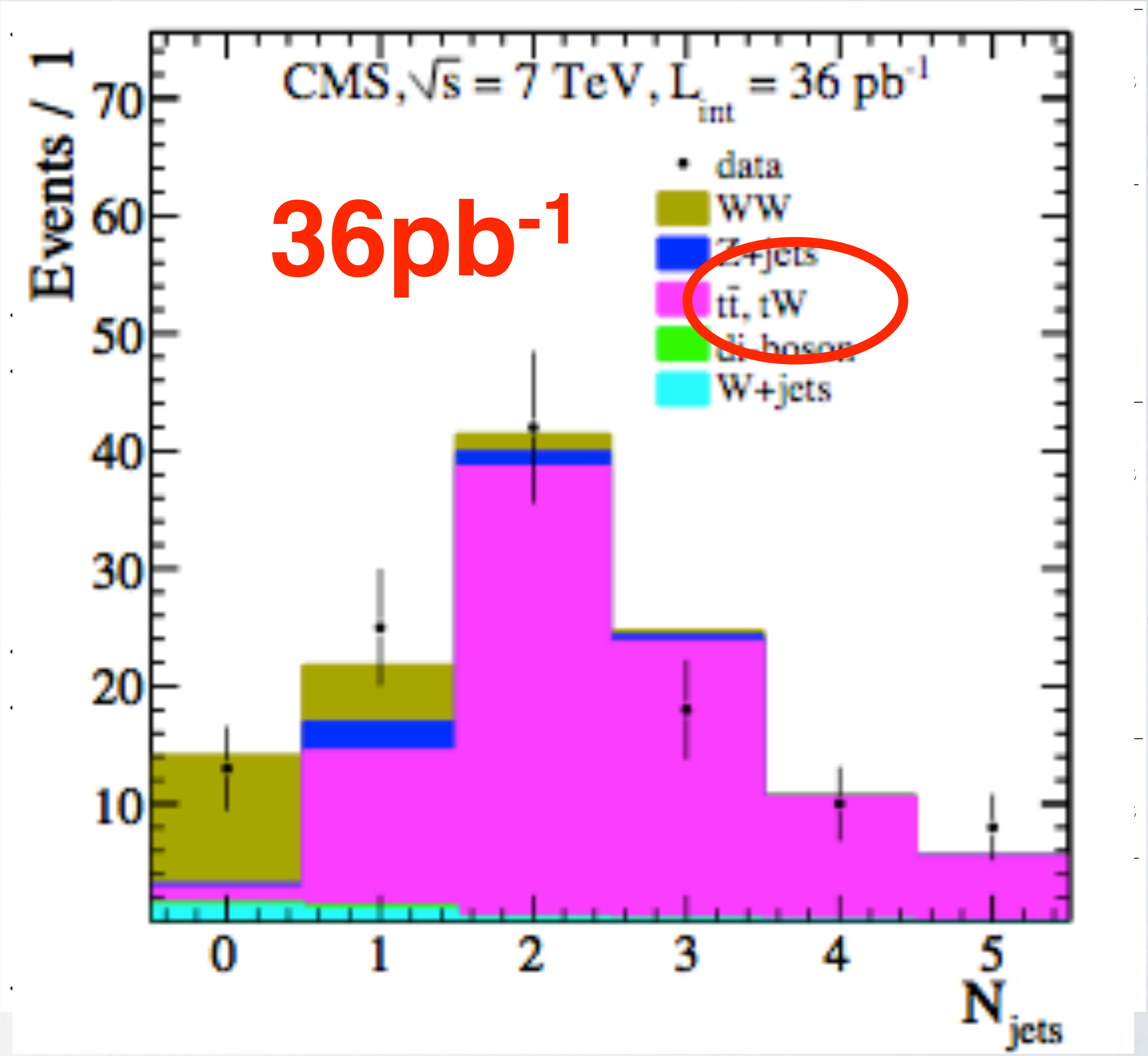
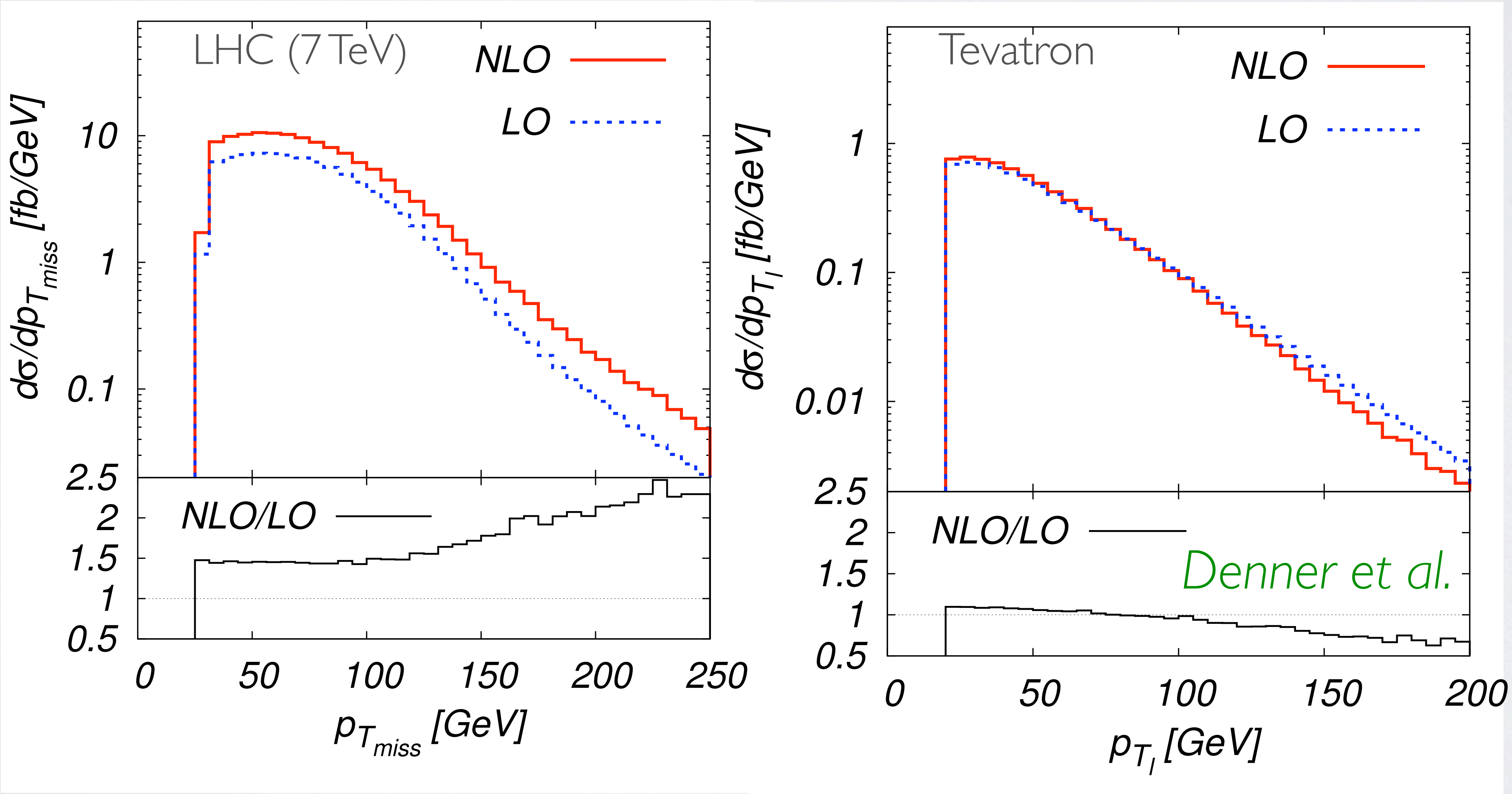


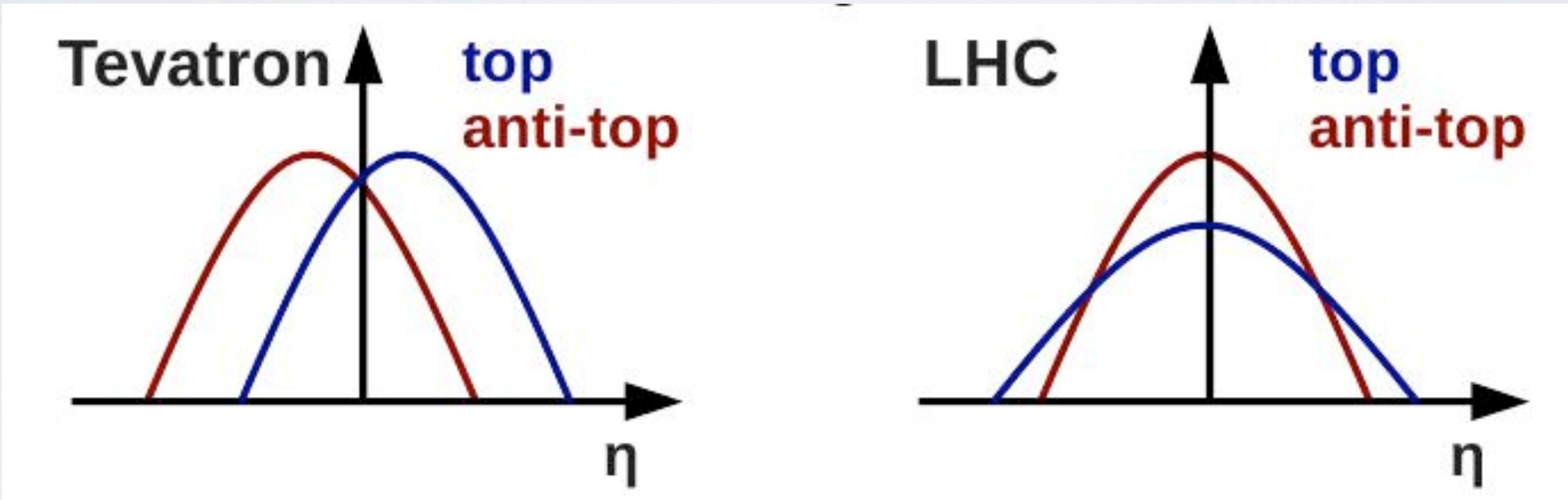
PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 2: WWBB

- Compared to the LO WWbb production, the NLO corrections do **not** lead to an overall change in normalization:



PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: COLOR CHARGE ASYMM.

$$A_{CC}^{t\bar{t}} = \frac{\sigma(\Delta y > 0) - \sigma(\Delta y < 0)}{\sigma(\Delta y > 0) + \sigma(\Delta y < 0)}$$

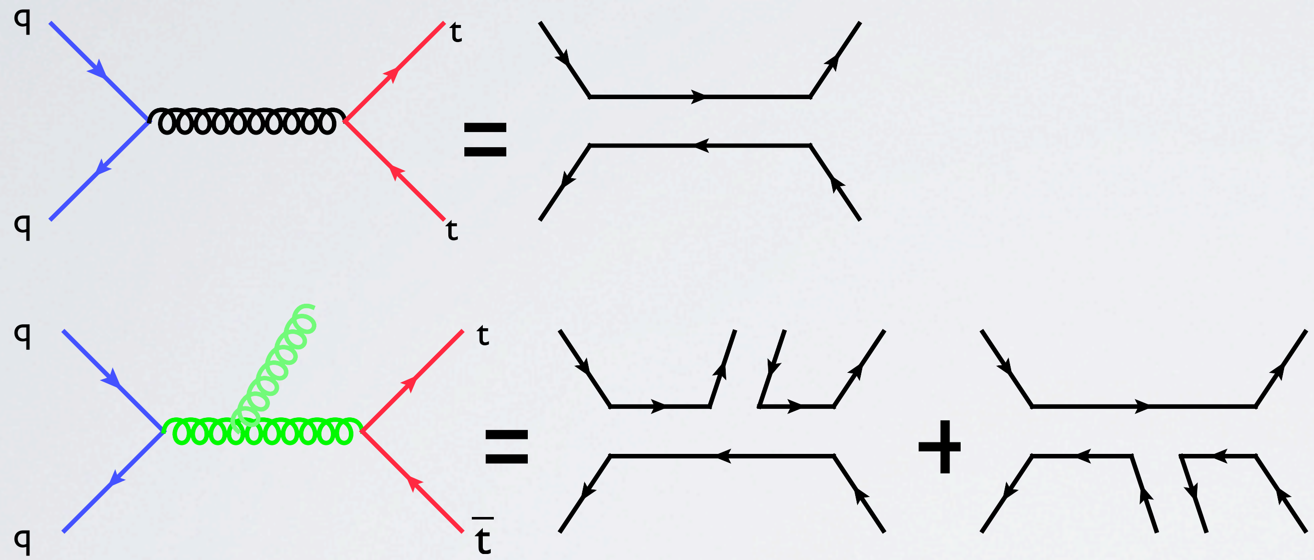


$$\Delta y^{\mathrm{TEV}} = y_t - y_{\bar{t}} \qquad \Delta y^{\mathrm{LHC}} = |y_t| - |y_{\bar{t}}|$$

Other definitions are used: lab frame at Tevatron, central charge [Antunano, et al,] and one-side asymmetries [Wang et al. 2010] at the LHC which depend on a cut. A_{CC} at the LHC has been introduced by CMS (in terms of pseudo-rapidity). LHCB does not need any special definition [Kagan et al.]

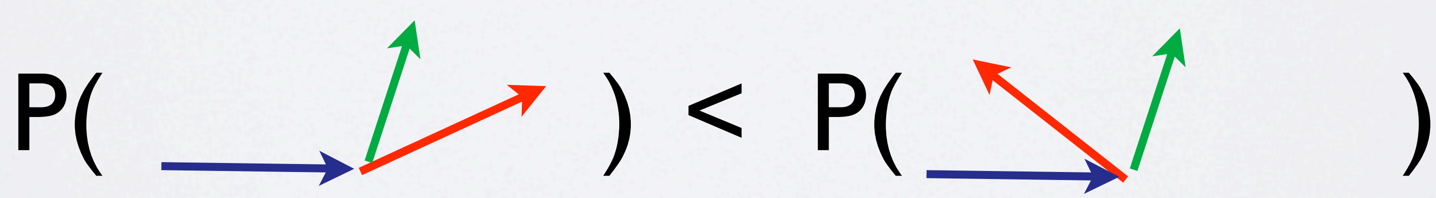
PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: COLOR CHARGE ASYMM.

Intuitive picture:



In the soft limit $$|A_{soft}|^2 \simeq |A_{born}|^2 \left(\frac{q \cdot t}{q \cdot k \; t \cdot k} + \frac{\bar{q} \cdot \bar{t}}{\bar{q} \cdot k \; \bar{t} \cdot k} \right) \qquad q \cdot t = E_q E_t (1 - \cos\theta)$$

The probability to emit a gluon is larger the more the top is accelerated (like in QED) and therefore going backwards, so the contribution to the A_{FB} asymmetry is negative

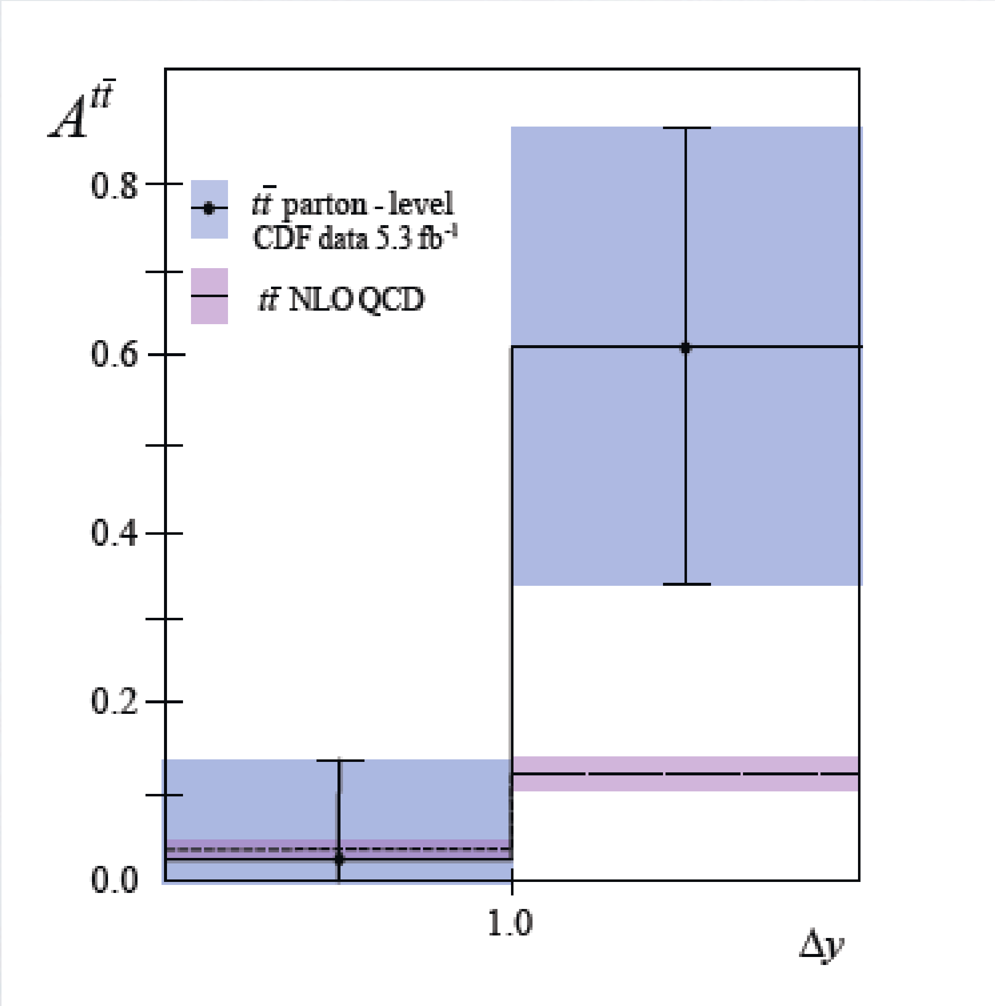


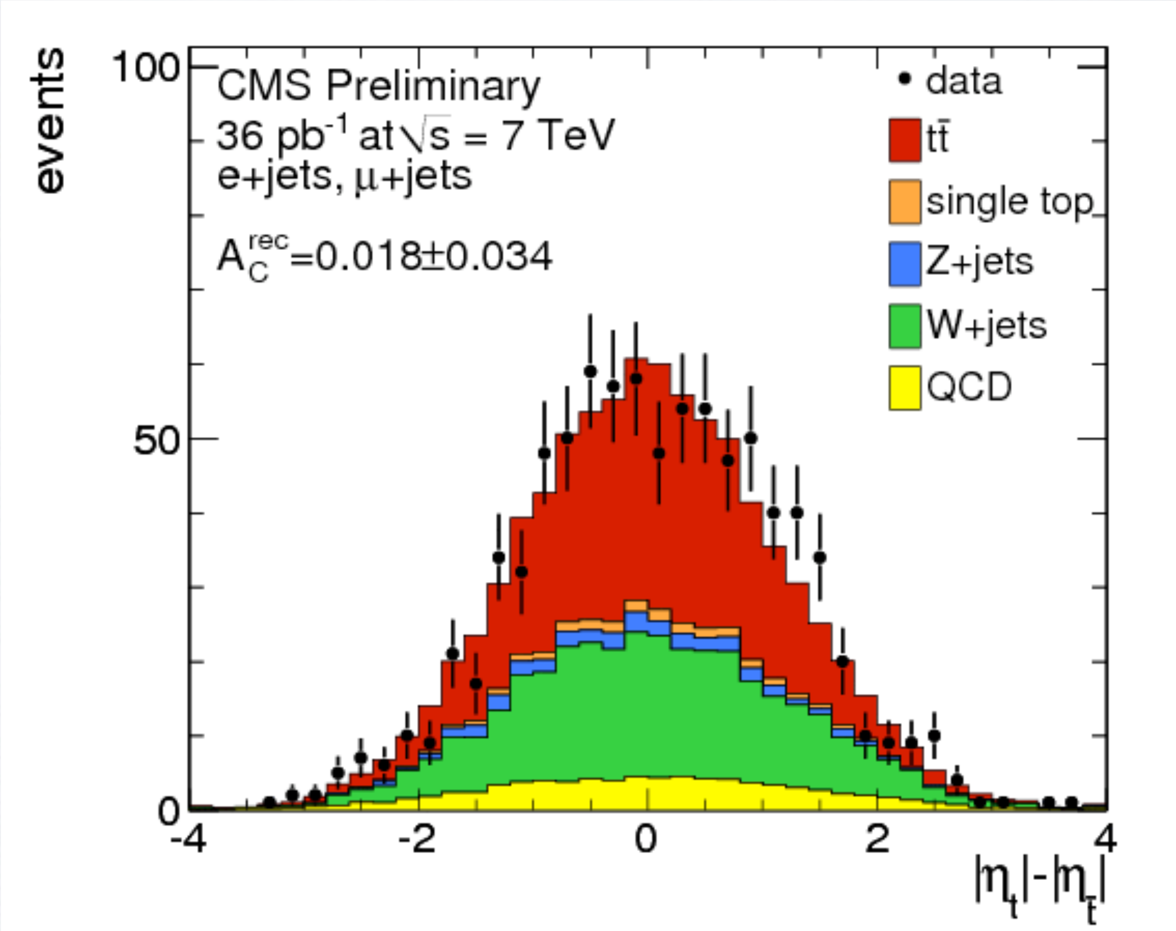
The virtuals have to cancel the soft divergences of the reals and therefore the contribution is of the opposite sign and in fact positive and much larger.

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: COLOR CHARGE ASYMM.

	$M_{t\bar{t}} < 450$ GeV	$M_{t\bar{t}} > 450$ GeV
CDF	-0.116 ± 0.154	0.475 ± 0.114
MCFM	0.040 ± 0.006	0.088 ± 0.013

de facto
confirmed by D0
and by dilepton channel in CDF.





PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: A_{FB} (COLOR CHARGE ASYMM.)

$$A_{CC}^{t\bar{t}} = \frac{A\alpha_S^3 + B\alpha_S^4 + \ldots}{C\alpha_S^2 + D\alpha_S^3 + \ldots}$$

Observable only
known only at the leading order!

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α_S^4 (NNLO) calculation for the sigma(ttbar) not available yet. However,

1. Improved approx NNLO results indicate no major changes
[Almeida et al; 2010 Ahrens et al. 2010; Antunano et al 2010.; Kidonakis 2011]

2. Studies on ttj indicate that the nature of the asymmetry is twofold and no genuinely new contributions should arise at higher order.
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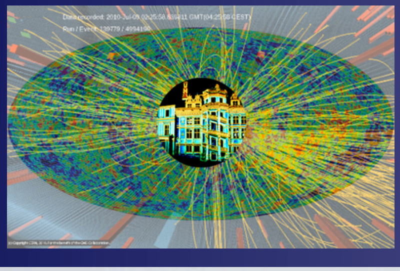
Note, on the other hand, the interesting pattern:
t tbar : LO=0 + Virtual>0 (large) + Real<0 (small) = 0.05
t tbar j : LO<0 (-0.08) + Virtual>0 (large) + Real<0 (small) = -0.02
t tbar jj : LO <0
Virtuals always dominate : what about the two-loop contributions? to be seen...



OUTLINE

- The importance of being Top
- Precision SM Top Physics
- **Top as tool for BSM pheno: strategies with examples***
- Outlook

****see also G. Moreau's talk***

Ok, top is special and a lot of data coming, but why are we getting **so** excited about it?

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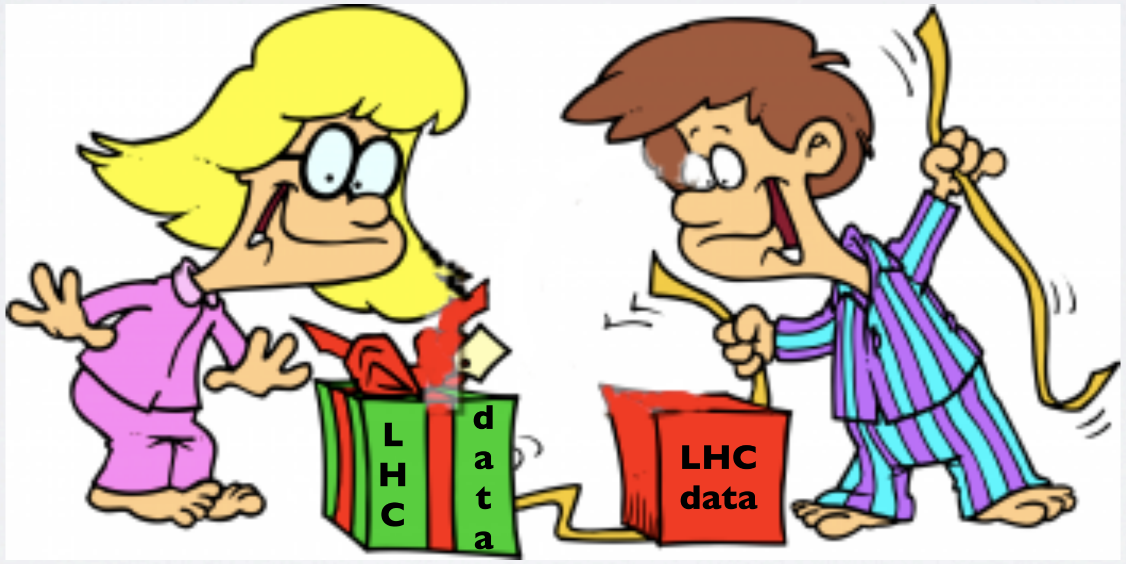
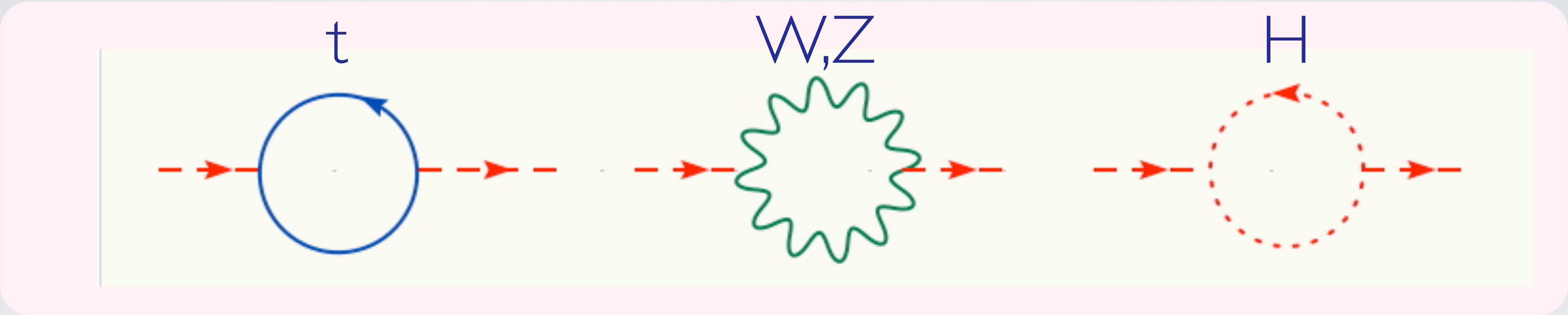


Top as a link to BSM

The top quark dramatically affects the stability of the Higgs mass.
Consider the SM as an effective field theory valid up to scale Λ:



$$m_H^2 = m_{H0}^2 \quad - \frac{3}{8\pi^2} y_t \Lambda^2 \quad + \frac{1}{16\pi^2} g^2 \Lambda^2 \quad + \frac{1}{16\pi^2} \lambda^2 \Lambda^2$$

Putting numbers, I have:

$$(200\,\mathrm{GeV})^2 = m_{H0}^2 + \left[-(2\,\mathrm{TeV})^2 + (700\,\mathrm{GeV})^2 + (500\,\mathrm{GeV})^2\right] \left(\frac{\Lambda}{10\mathrm{TeV}}\right)^2$$

Top as a link to BSM

$m_h^2 \sim (200\ \mathrm{GeV})^2$

$$(200\,\mathrm{GeV})^2 = m_{H0}^2 + \left[-(2\,\mathrm{TeV})^2 + (700\,\mathrm{GeV})^2 + (500\,\mathrm{GeV})^2\right]\left(\frac{\Lambda}{10\mathrm{TeV}}\right)^2$$

Definition of naturalness: less than 90% cancellation:

$$\Lambda_t < 3\,\mathrm{TeV} \qquad \Lambda_t < 9\,\mathrm{TeV} \qquad \Lambda_t < 12\,\mathrm{TeV}$$

One can actually prove that this case in model independent way, i.e. that the scale associated with top mass generation is very close to that of EWSB

Top as a link to BSM

There have been many different suggestions! Fortunately, we can say that they group in 1+3 large classes:

1. Denial: There is no problem. Naturalness is our problem not Nature's. Pro's: we'll find the Higgs. Cons: that's it.

2. Weakly coupled model at the TeV scale:
   Introduce new particles to cancel SM "divergences".

3. Strongly coupled model at the TeV scale:
   New strong dynamics enters at ~1TeV.

4. New space-time structure:
   Introduce extra space dimensions to lower the Planck scale cutoff to 1 TeV.

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   KK-excitations

BSM : TOP-DOWN APPROACH

New Physics

Signatures/Observables

BSM : TOP-DOWN APPROACH

New Physics

↓

Signatures/Observables

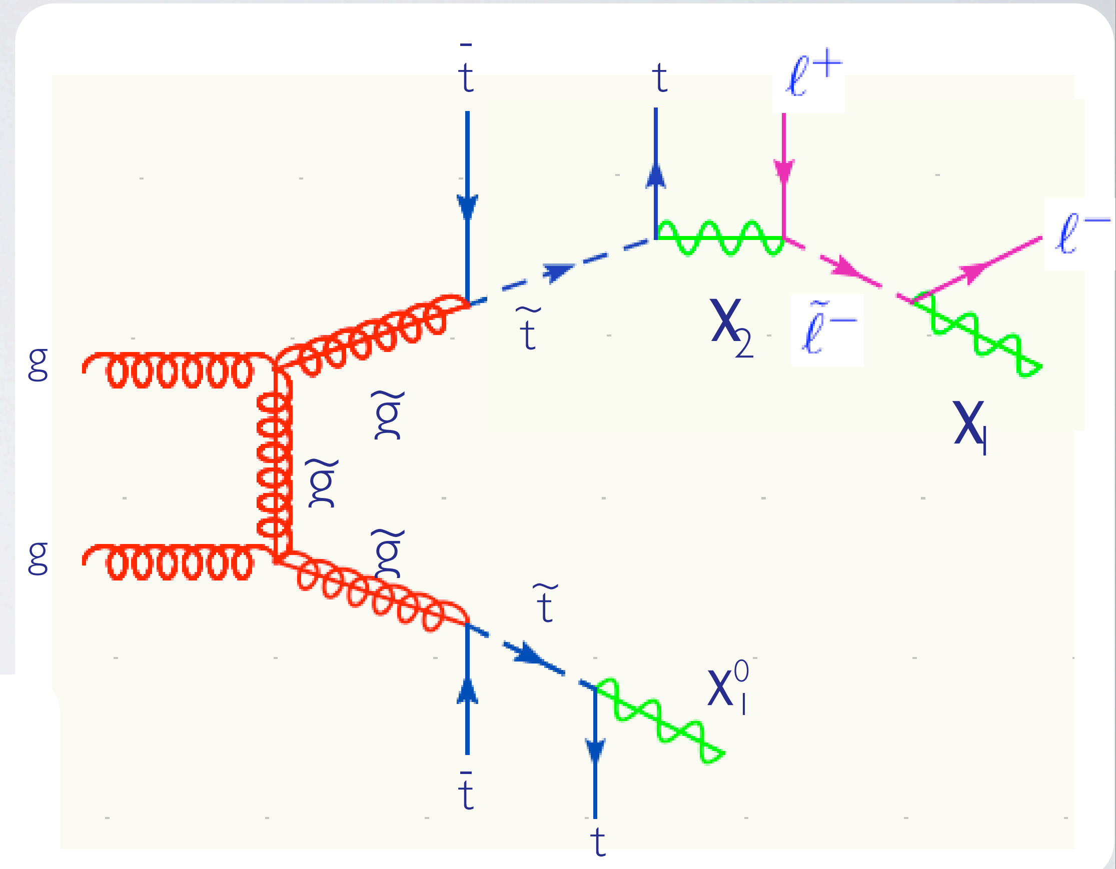
BSM : TOP-DOWN APPROACH

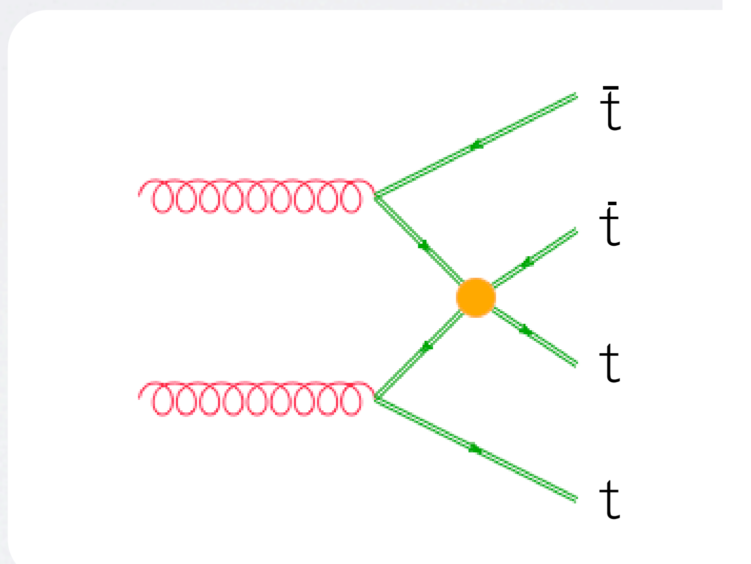
* New Physics model with top partners (SUSY, UED, LH, 4th Gen..)
* Consider viable benchmark points.
* Identify the signatures with top.
* Set exclusion limits on the model parameters
* Optional : learn "model independent" lessons...

BSM : top-down approach

Examples: signatures with top:

- $\tilde{t}\tilde{t}^* \to t\bar{t} + X$, $\tilde{g}\tilde{g} \to t\bar{t}\ (t\bar{t}) + X$
- $b'b' \to t\, t\, W^- W^+$
- $t'\bar{t}' \to b\, \bar{b}\, W^+ W^-$
- $t'\bar{t}' \to Z\, Z\, t\, \bar{t}$
- 4tops





In general, very rich and energetic final states, large H_T , very spectacular and "easy" to detect in principle.
Looks great, if one model at the time is studied.
In fact, very difficult to discriminate which NP leads to it.

Bottom-up approach

New Physics

Signatures/Observables

Bottom-up approach

New Physics

↑

Signatures/Observables

Bottom-up approach

Model independent (bottom-up) strategy for New Physics :

1. Focus on a specific SM observable that is

    a. naturally sensitive to BSM
    b. is well-predicted & possibly "background free"

   and look for deviations

2. Look for "exotic top signatures" (no-SM equivalent),

Bottom-up approach

New Physics

↑

Signatures/Observables

Bottom-up approach

New Physics

Signatures/Observables

Bottom-up approach

New Physics

Standard

Signatures/Observables

Bottom-up approach

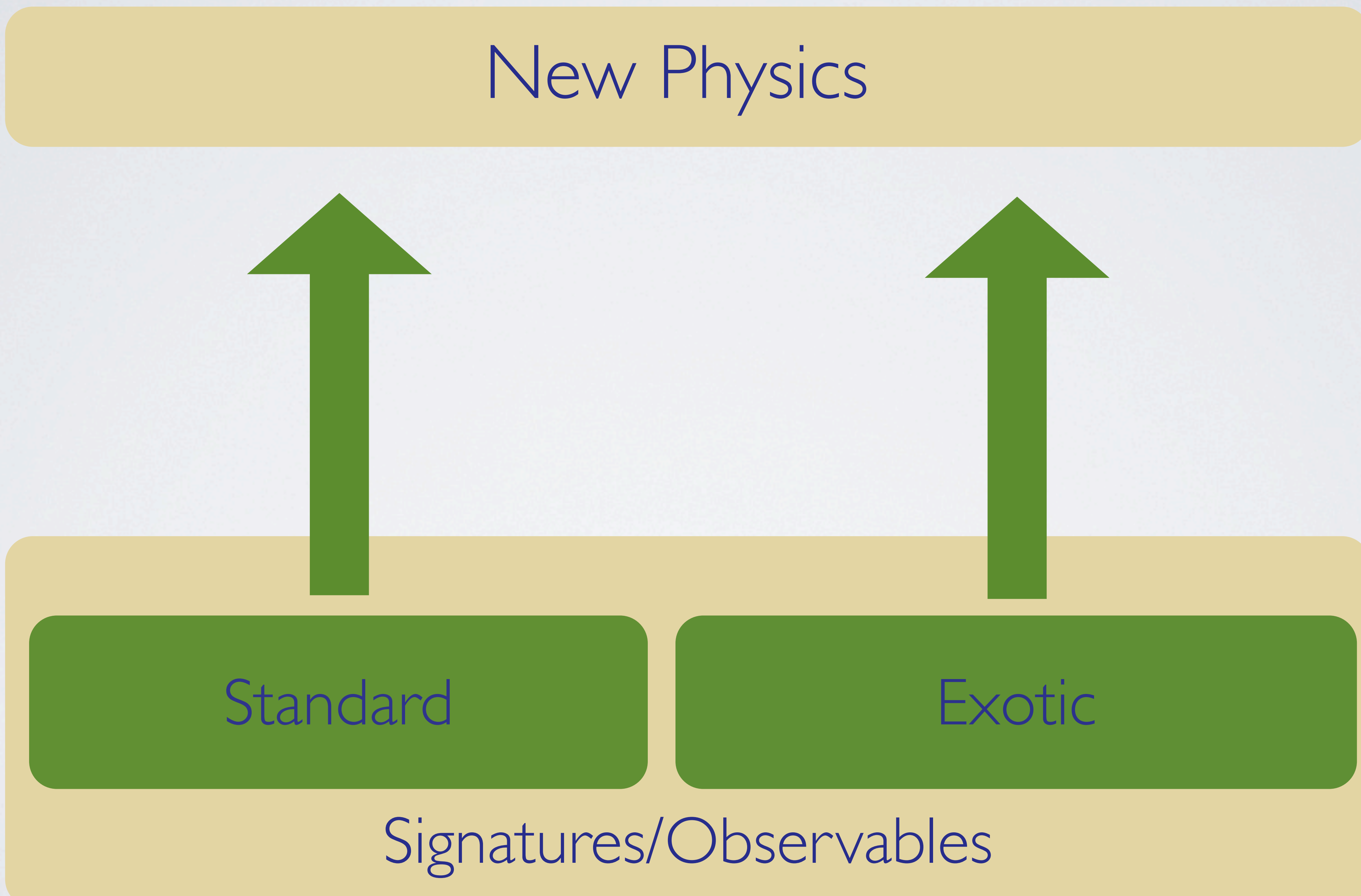
New Physics

Standard

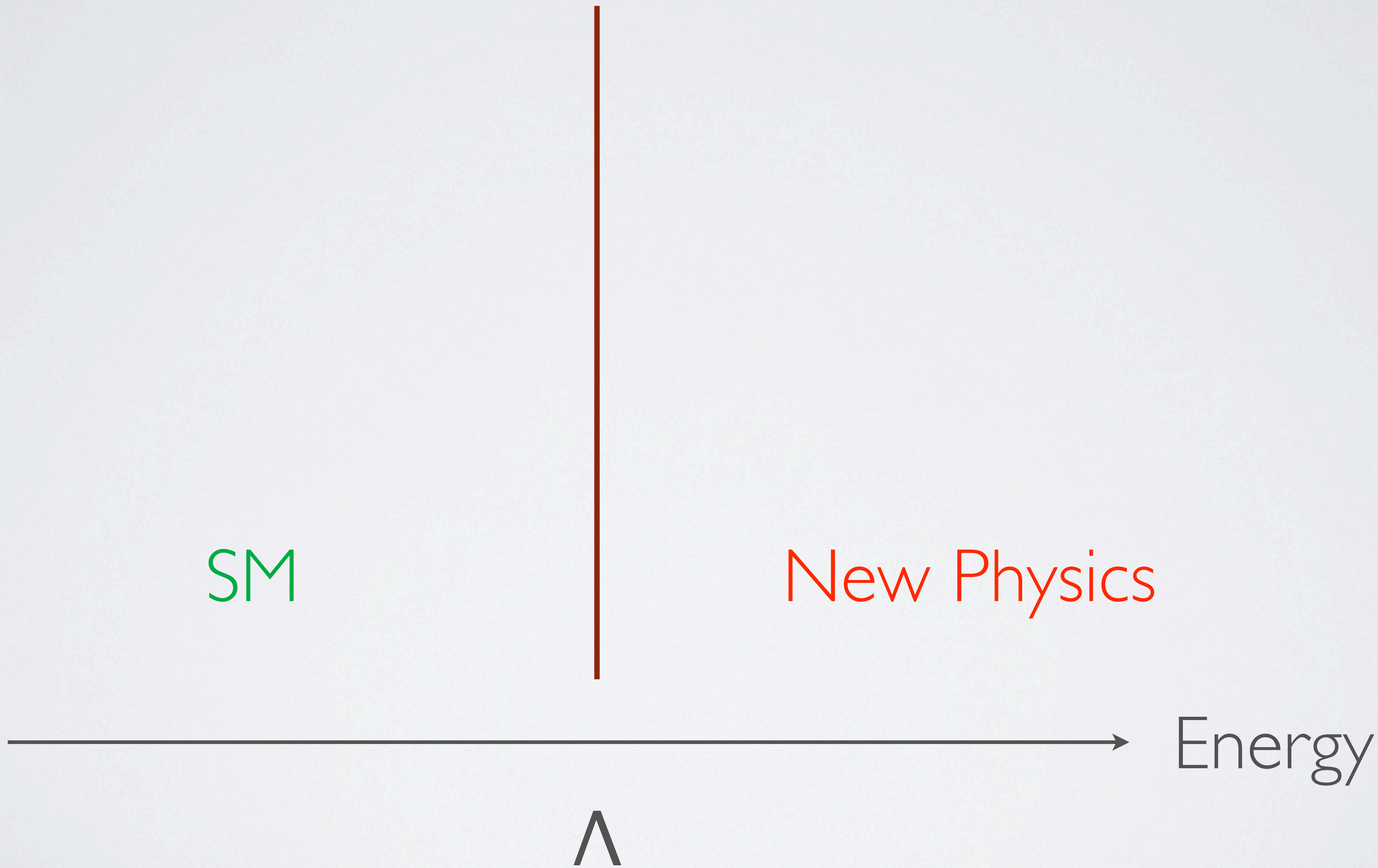
Exotic

Signatures/Observables

Bottom-up approach



New Physics : Two possibilities



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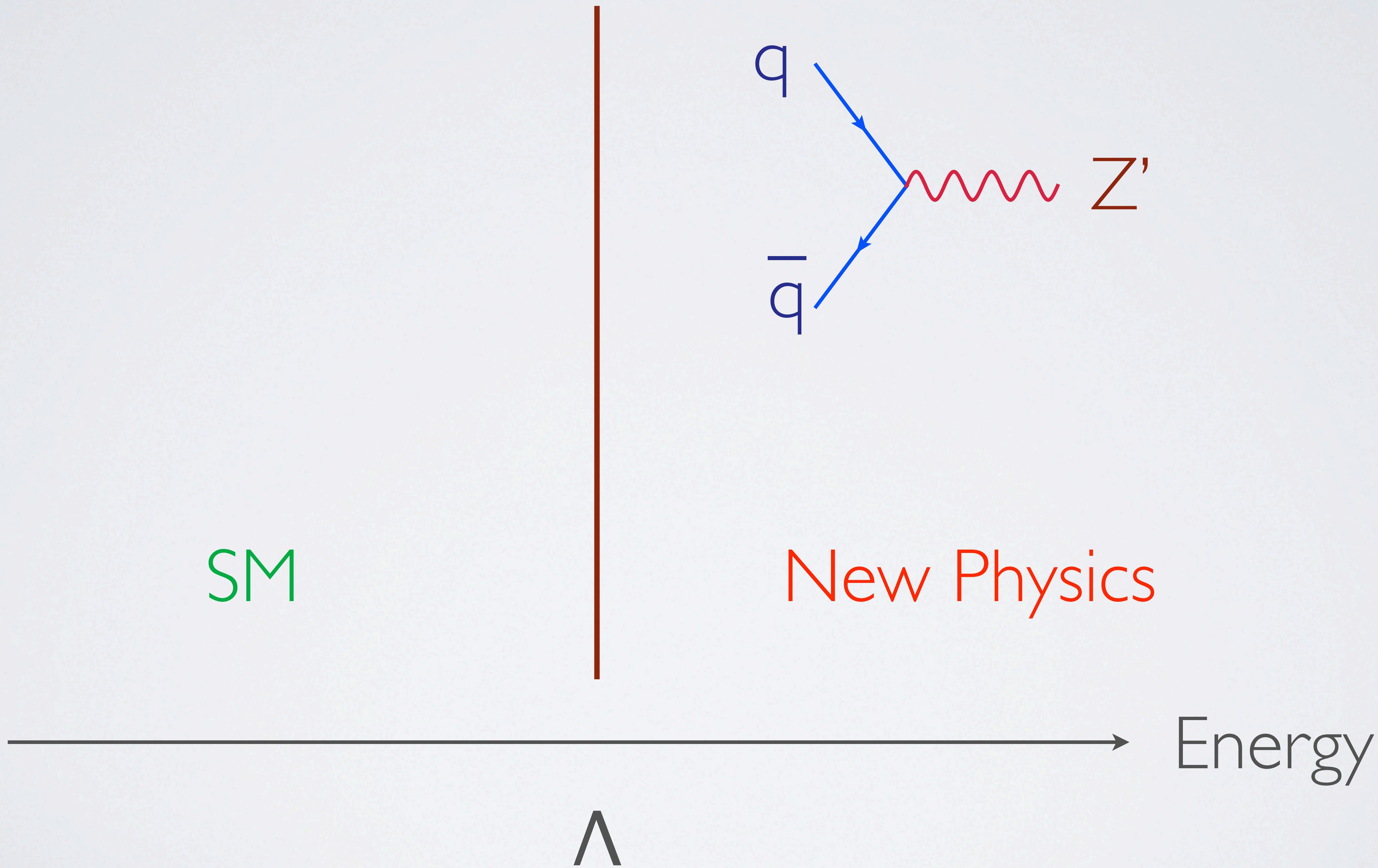

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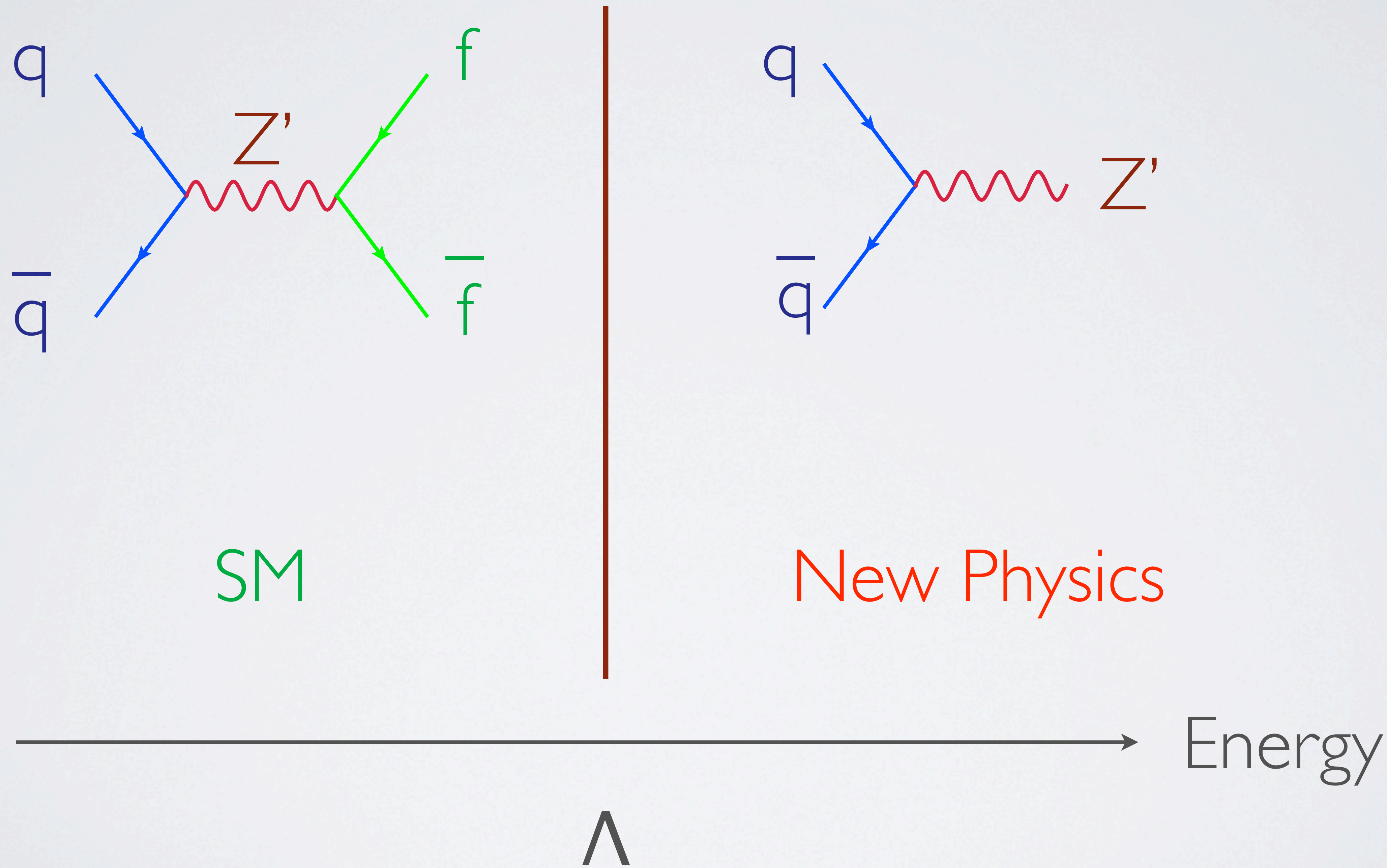

Monday 30 May 2011

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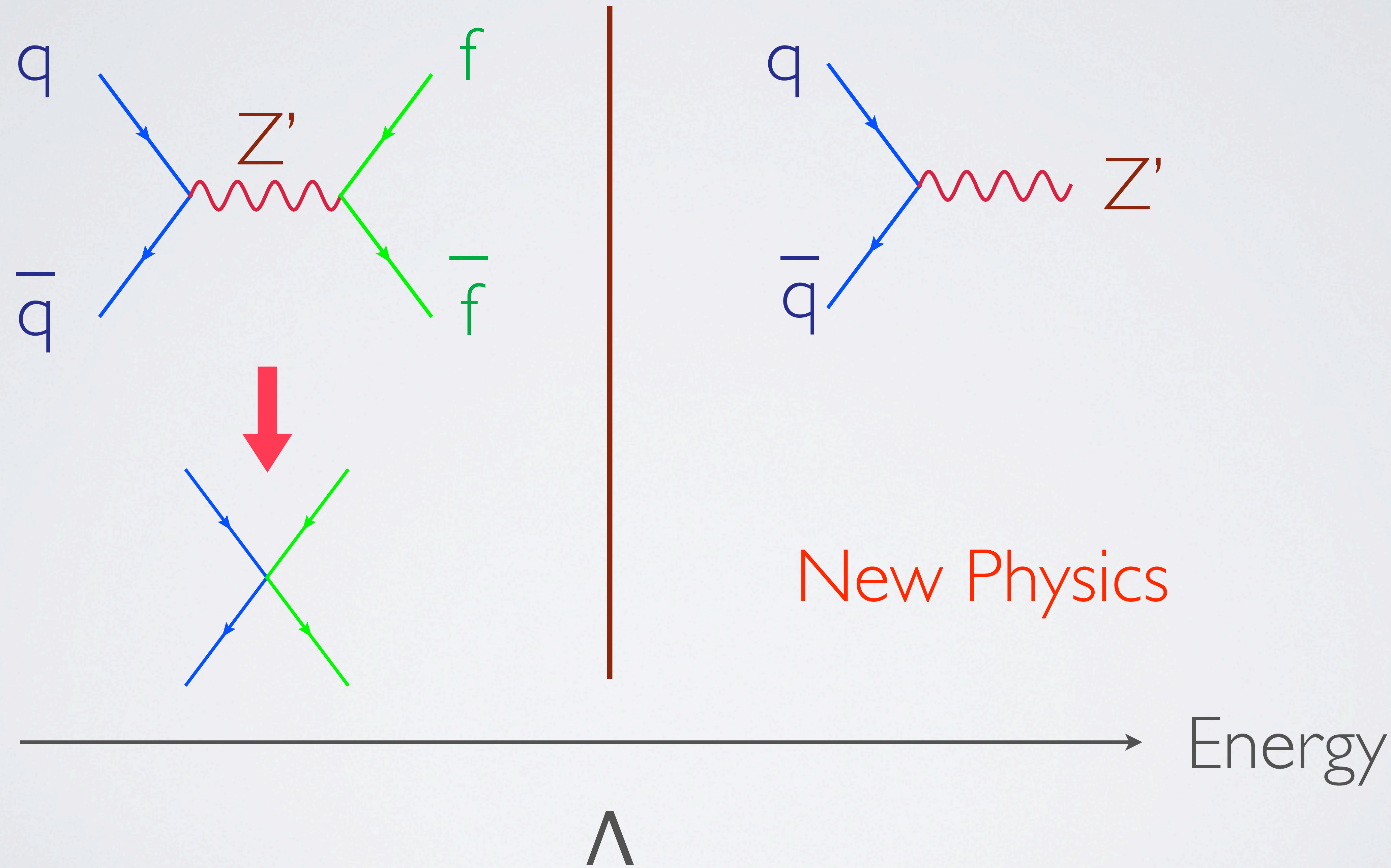

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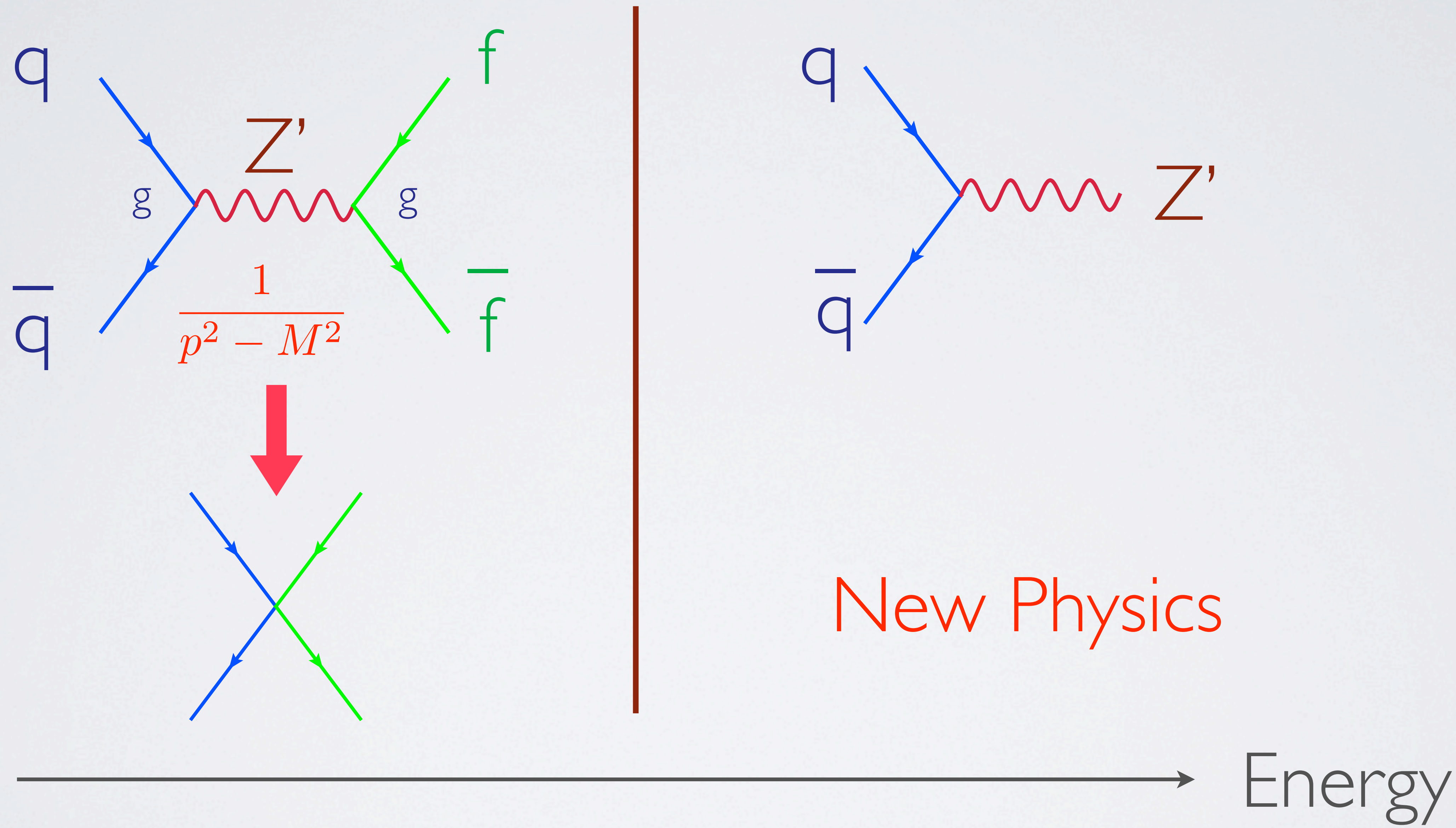
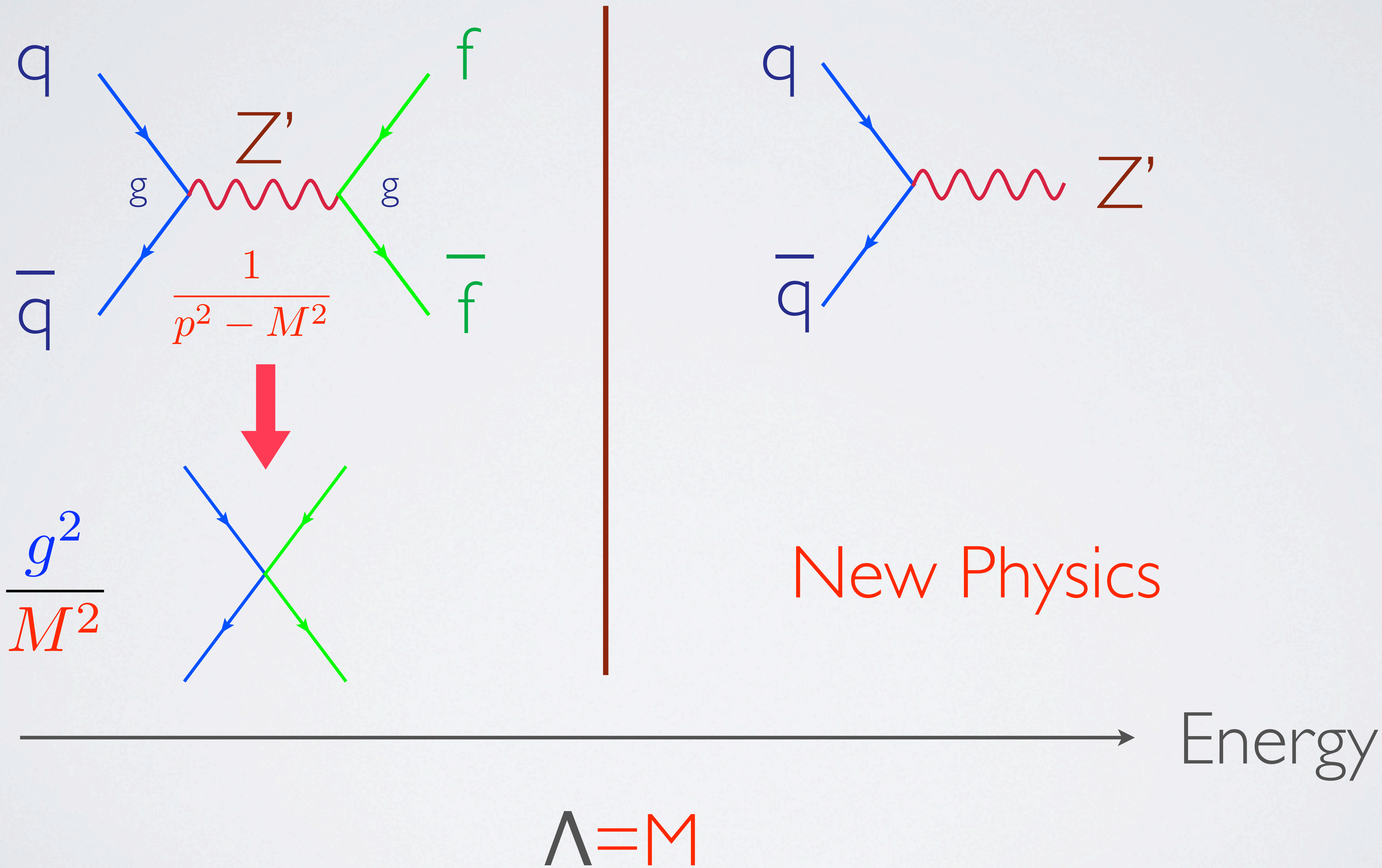


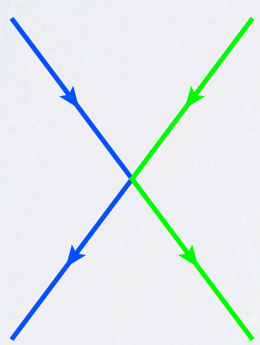
Λ=M

New Physics : Two possibilities



New Physics : Two possibilities

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



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

New Physics : Two possibilities

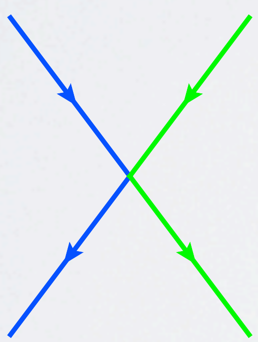
$$\hbar = c = 1$$

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

$$\dim \phi = 1$$

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

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

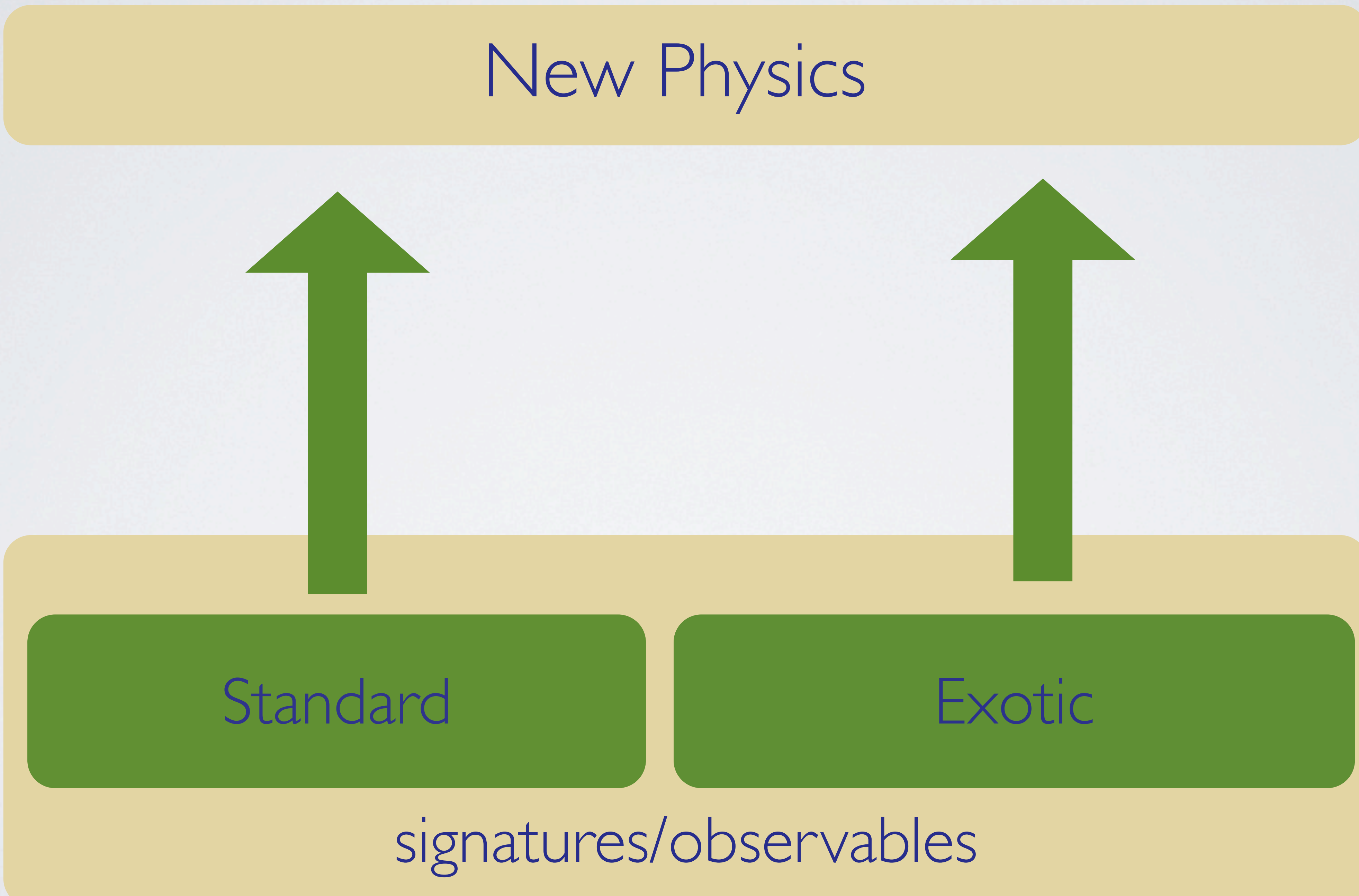


$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{\mathrm{dim}=6}$$

Bad News: $>$ 60 operators *[Buchmuller, Wyler, 1986]*

Good News : an handful are unconstrained and can signifcantly contribute to top physics!
[Aguilar-Saavedra 2010, Willenbrock et al. 2010, Degrande et al 2010]

Bottom-up approach



Bottom-up approach

New Physics

Standard

Exotic

signatures/observables

Bottom-up approach

New Physics

Resonant

Standard

Exotic

signatures/observables

Bottom-up approach

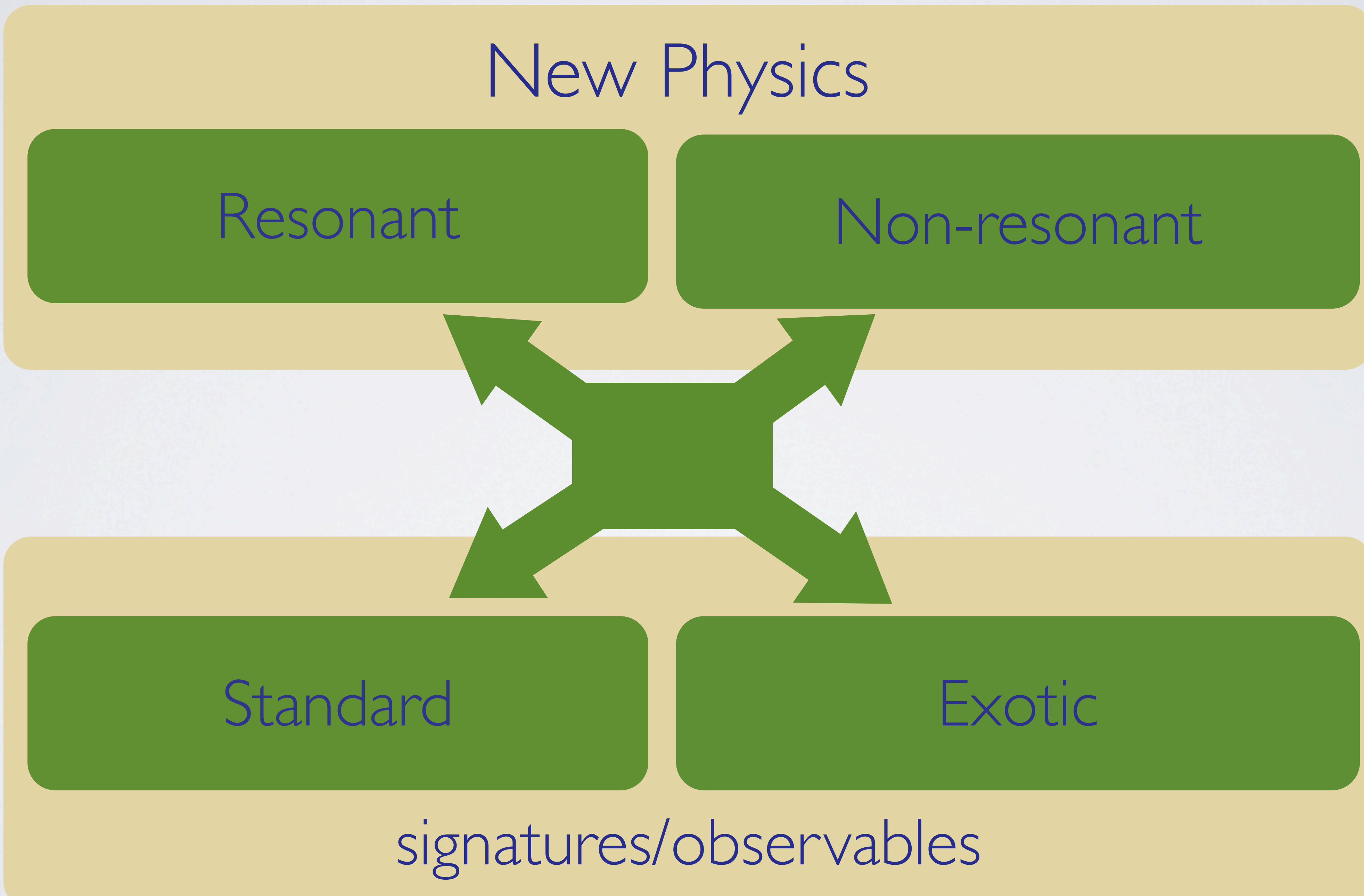
New Physics

Resonant | Non-resonant

Standard | Exotic

signatures/observables

Bottom-up approach



MODEL INDEPENDENT BSM SEARCHES: EXAMPLES

I. Search for resonances in m_{ttbar} (and boosted tops)

II. EFT approach to ttbar (including A_{FB})

III. (Exotic: Same sign tops)

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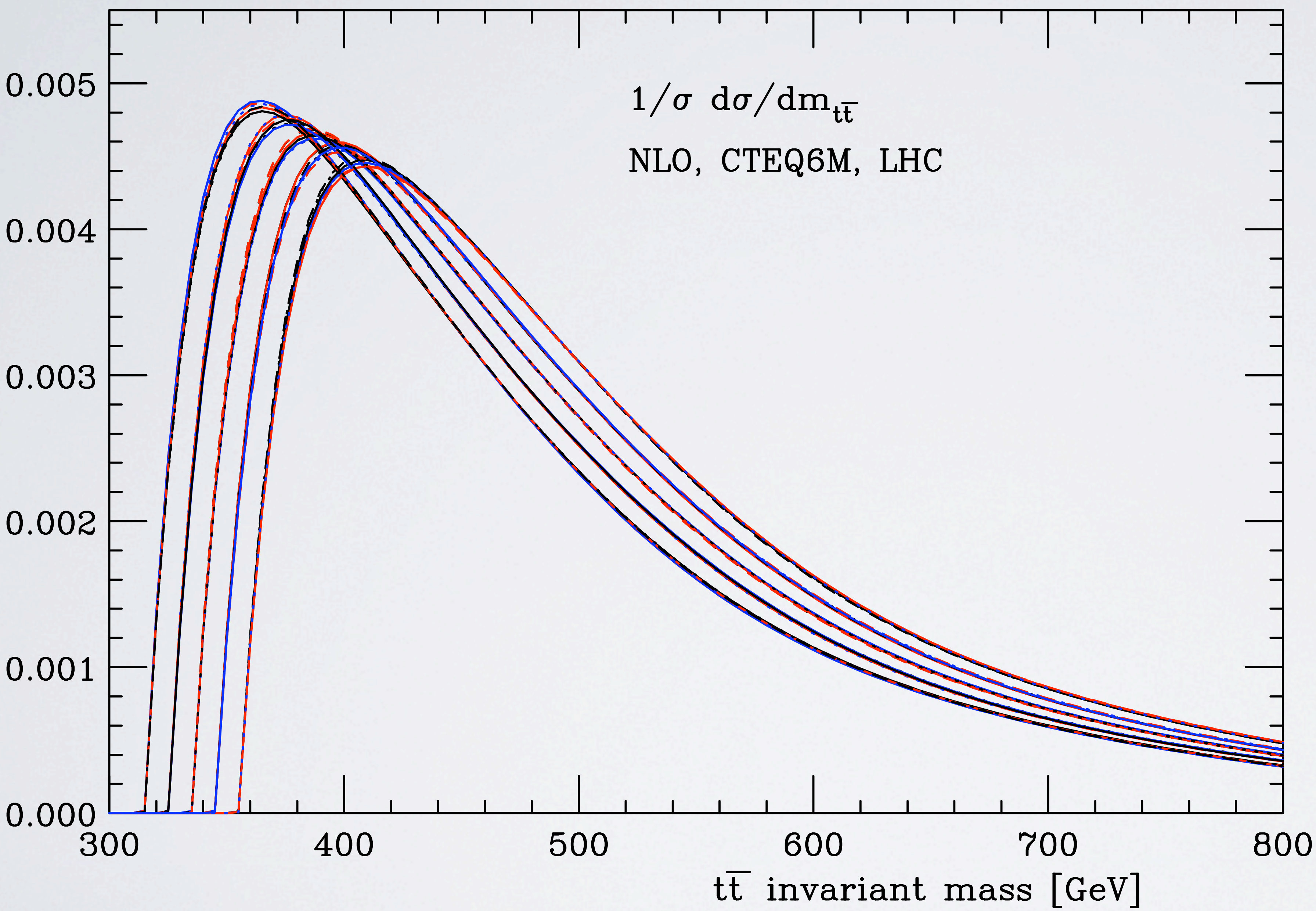
New Resonances in ttbar



Interesting observable.

Shape very well predicted.

This could be also used to measure the top mass!

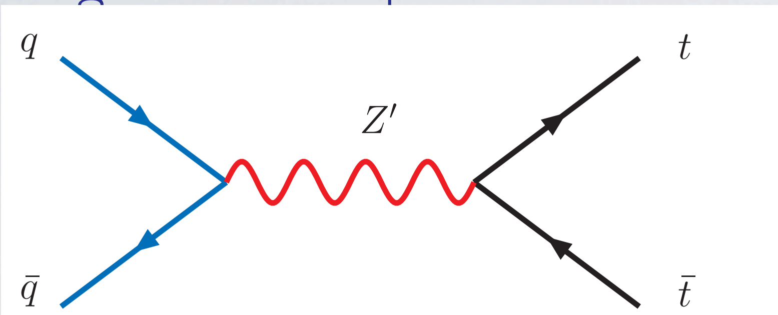
Reconstruction systematics is different from the usual top mass invariant mass reconstruction.

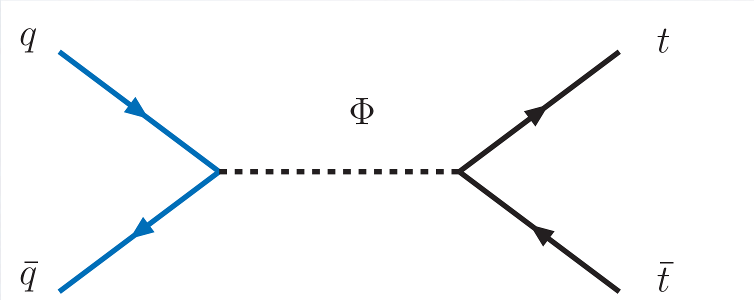
Any BSM effect would distort this shape =>

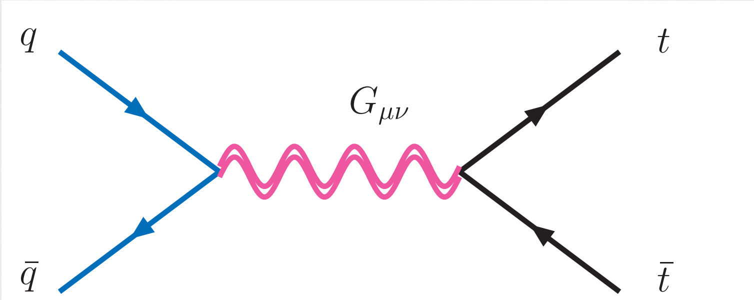
Model independent search for new Physics!

New Resonances in ttbar

In many scenarios for EWSB new resonances show up, some of which preferably couple to 3rd generation quarks.



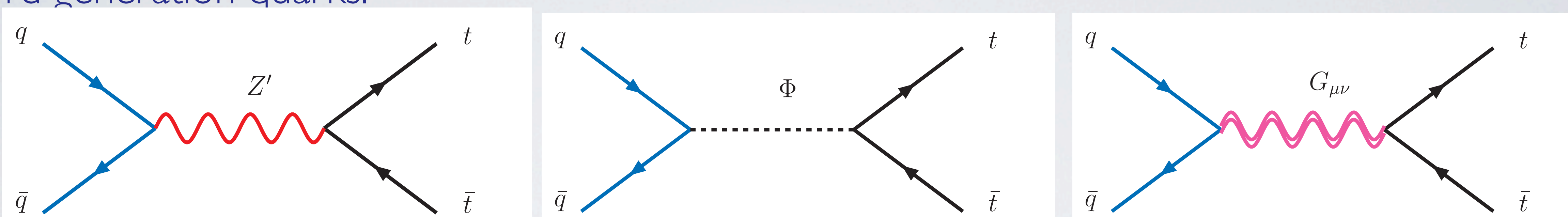




Given the large number of models, in this case is more efficient to adopt a "model independent" search and try to get as much information as possible on the quantum numbers and coupling of the resonance.

New Resonances in TTBAR

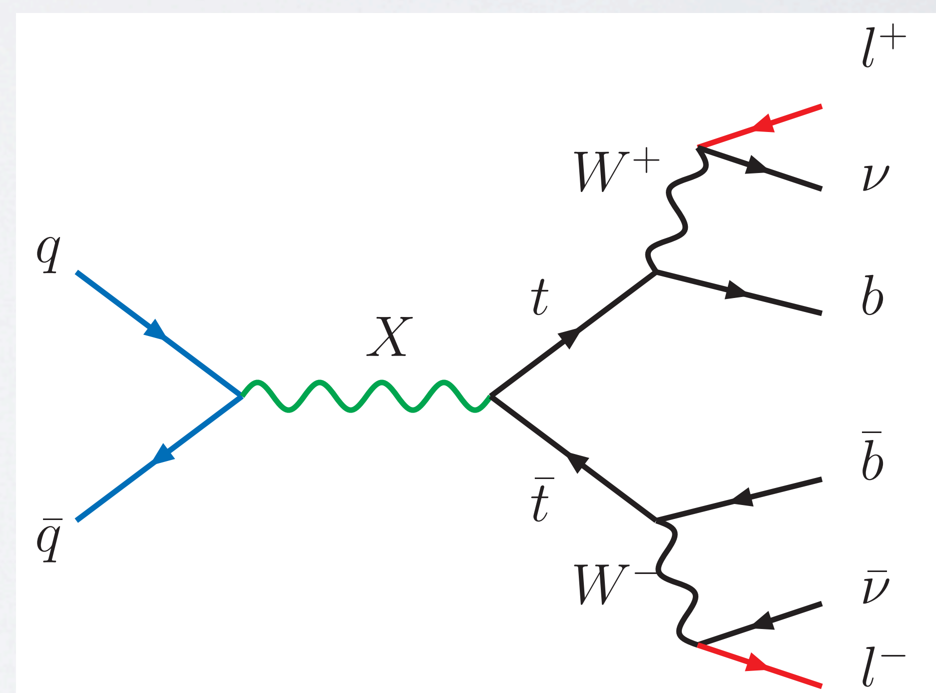
In many scenarios for EWSB new resonances show up, some of which preferably couple to 3rd generation quarks.



Given the large number of models, in this case is more efficient to adopt a "model independent" search and try to get as much information as possible on the quantum numbers and coupling of the resonance.

To access the spin of the intermediate resonance spin correlations should be measured.

It therefore mandatory for such cases to have MC samples where spin correlations are kept and the full matrix element pp>X>tt>6f is used.



New Resonances in ttbar

Spin	Color	(1,γ_5) [L,R]	SM-interf	Example
0	0	(1,0)	no	Scalar
	0	(0,1)	no	PseudoScalar
	0	(0,1)	yes	Boso-phobic
	8	(0,1),(1,0)	no	Techni-pi0[8]
1	0	[sm,sm]	yes/no	Z'
	0	(1,0),(0,1)(1,1),(1,-1)	yes	vector
	8	(1,0)	yes	coloron/kk-gluon
	8	(0,1)	"yes"	axigluon
2	0	--	yes	kk-graviton

[Frederix, FM, arXiv:0712.2355]

New Resonances in ttbar

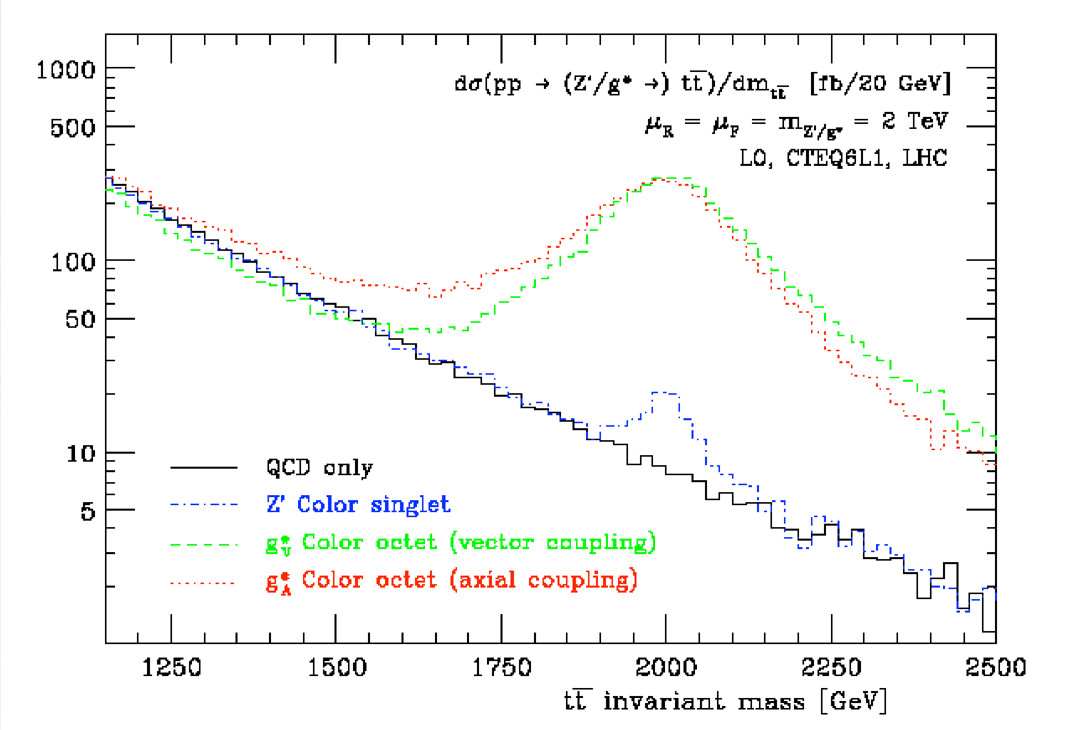
1. Discovery

2. Spin

3. Couplings

New Resonances in ttbar

1. Discovery



M

σ•Br

Γ

2. Spin

3. Couplings

New Resonances in ttbar

1. Discovery

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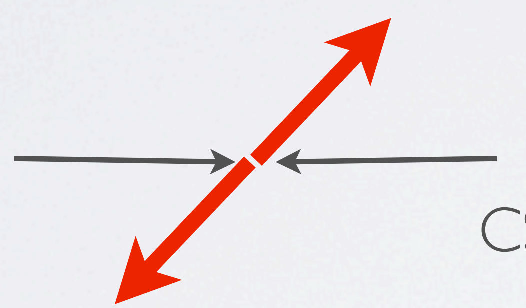
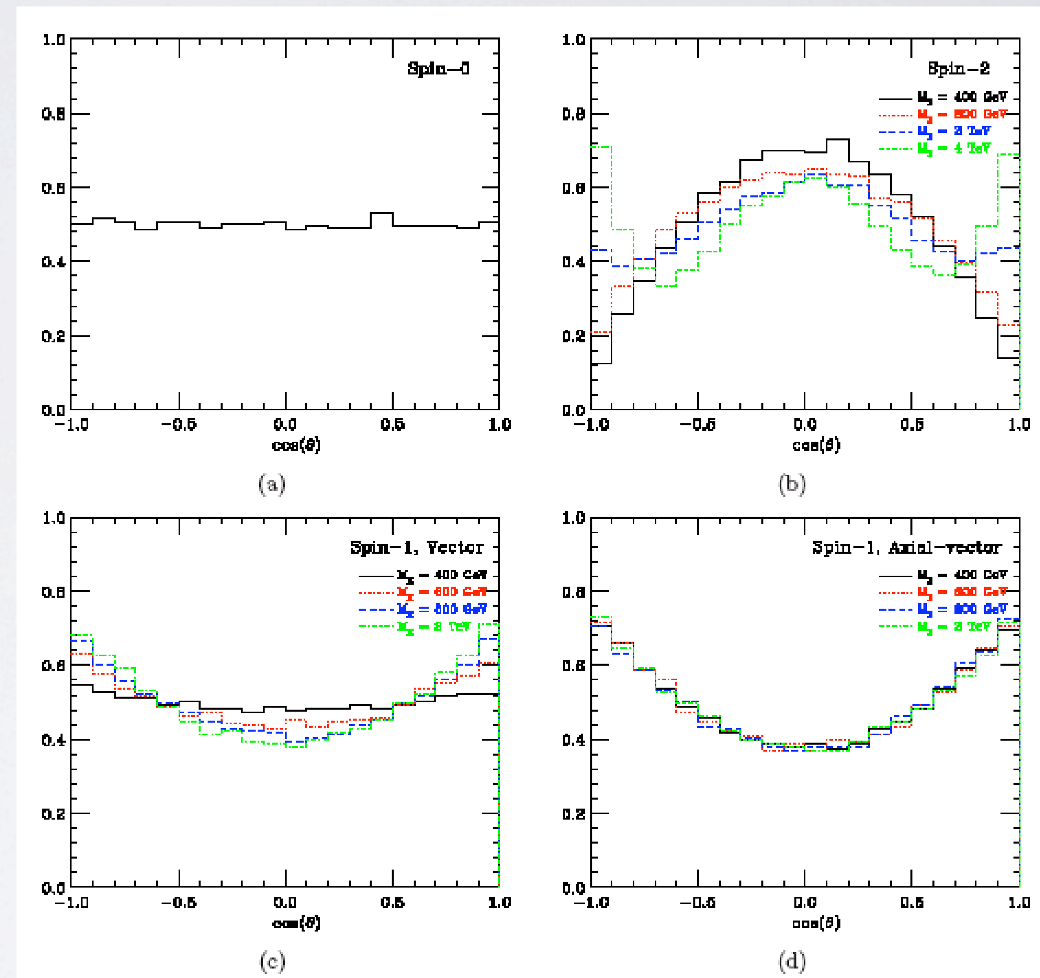
New Resonances in TTBAR

1. Discovery

2. Spin





3. Couplings

New Resonances in ttbar

1. Discovery

2. Spin

3. Couplings

New Resonances in ttbar

1. Discovery

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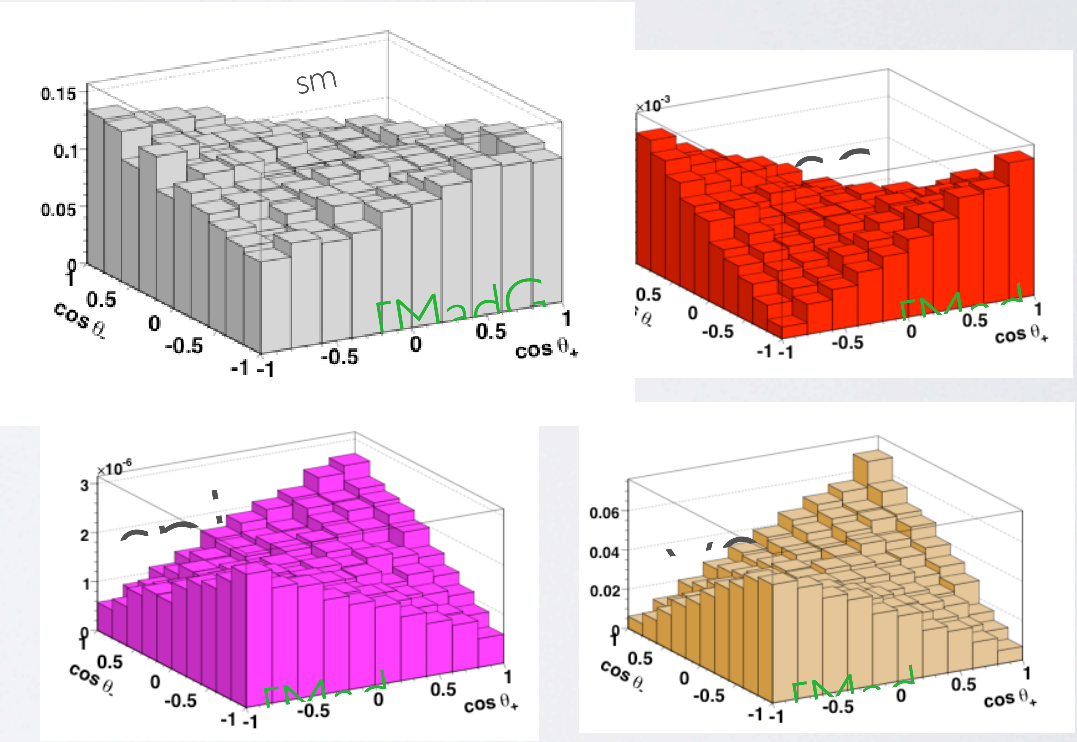
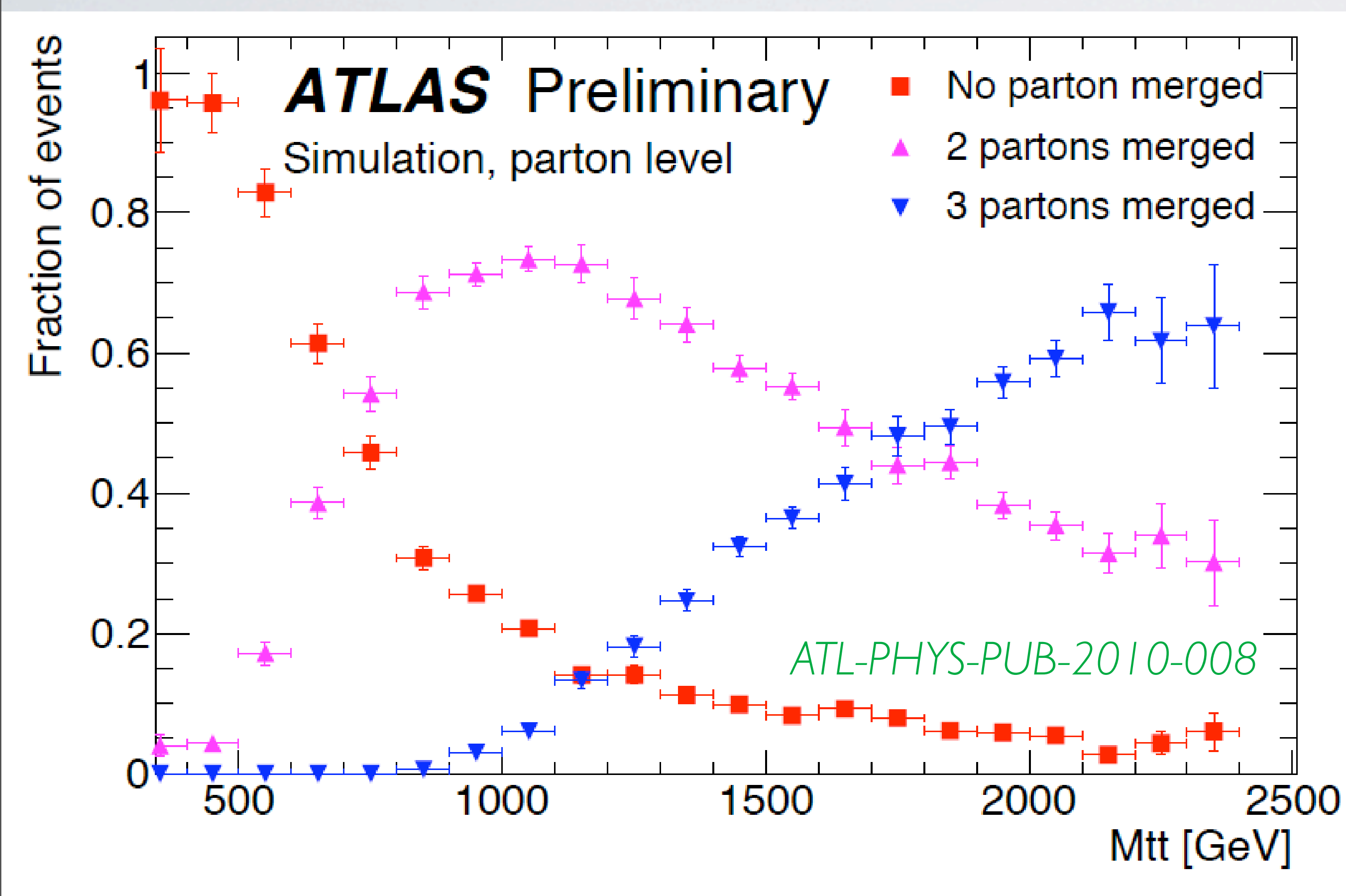


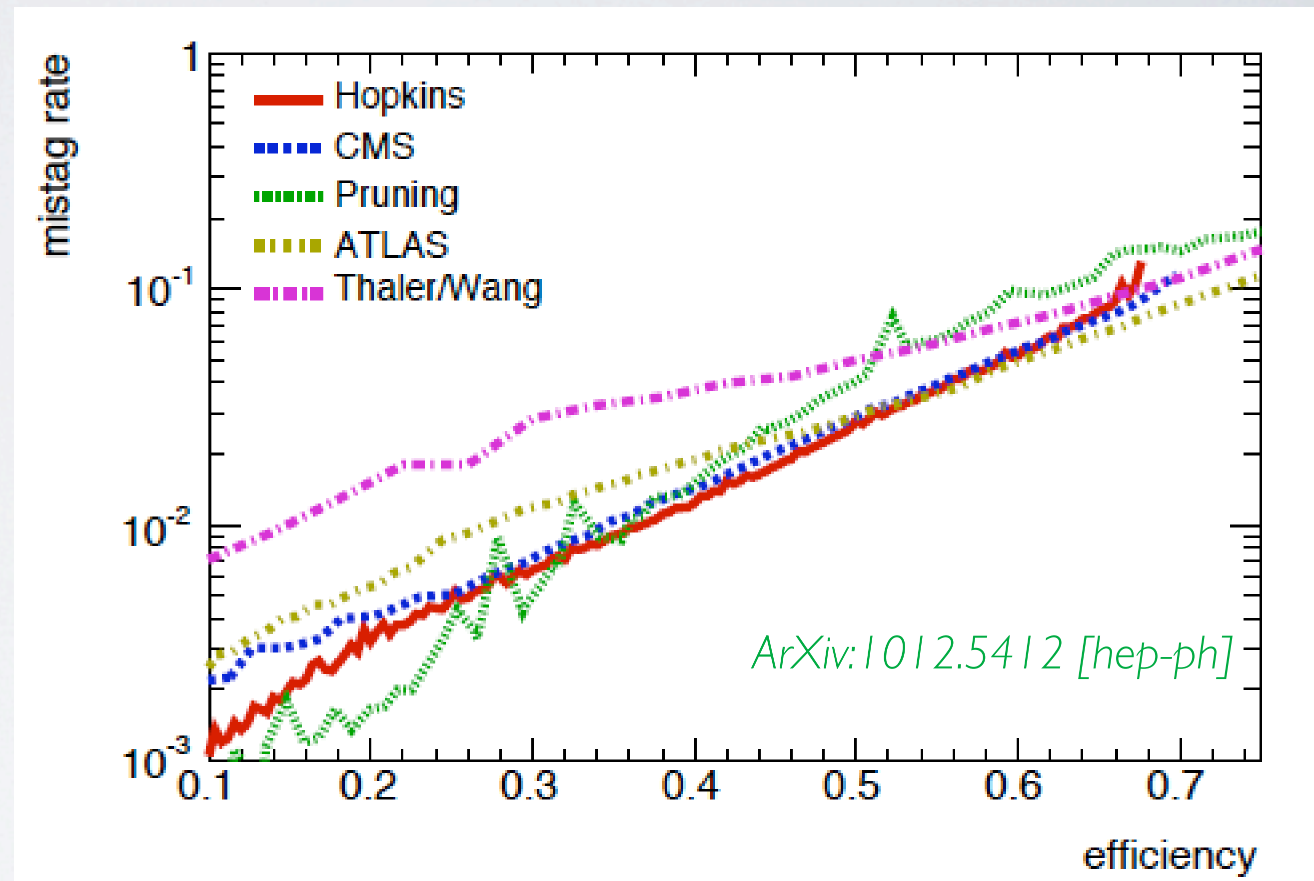
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4}\left(1 + \kappa_t \kappa_{\bar{t}} D \cos\theta_- \cos\theta_+\right)$$

New Resonances in ttbar : boosted tops

[Kaplan et al. , 2008, Thaler et al., 2008, Almeida et al. 2008, Salam 2008]

See Abdesselam, ArXiv:1012.5412 [hep-ph] and Boost2011 Conference in May





"Top quarks : LHC = Bottom quarks : Tevatron"

see M. Takeuchi's talk

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Effective Field Theory Approach to t tbar production

[Aguilar-Saavedra 2010, Willenbrock et al. 2010, Degrande et al 2010]

Very few operators of dim-6:

Dim-6 operators that affect top pair production **at tree level by interference with the SM** (QCD) amplitudes (we neglect weak corrections)

CP-even

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

CP-odd

operator	process
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W^I_{\mu\nu}$ (with imaginary coefficient)	top decay, single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi} G^A_{\mu\nu}$ (with imaginary coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
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Effective Field Theory Approach to t tbar production

Very few operators of dim-6:

Dim-6 operators that affect top pair production **at tree level by interference with the SM** (QCD) amplitudes (we neglect weak corrections)

Top-philic operators
(modifying top couplings
and not only gluons couplings)

CP-even

operator	process
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$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W^I_{\mu\nu}$ (with real coefficient)	top decay, single top
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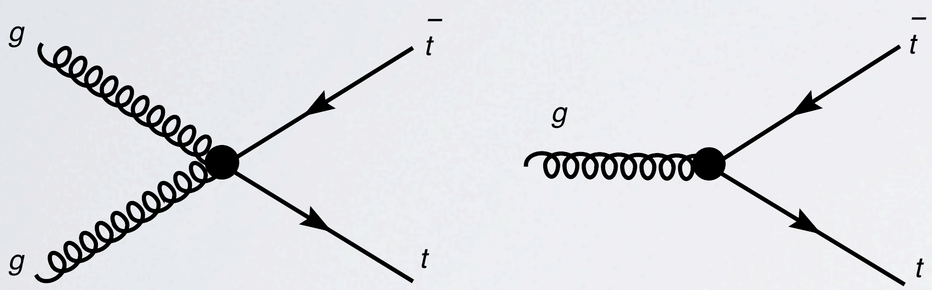
TTBAR PRODUCTION

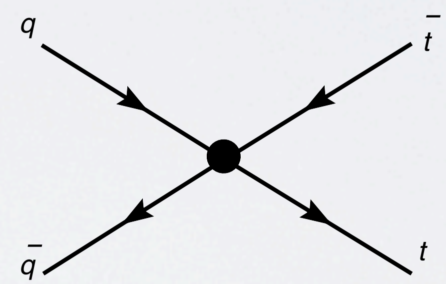
One can show that you end up with five main operators,

$$\mathcal{L}_{t\bar{t}} = \mathcal{L}_{t\bar{t}}^{SM} + \frac{1}{\Lambda^2}\left[g_h \mathcal{O}_{hg} + c_R \mathcal{O}_{Rg} + a_R \mathcal{O}_{Ra}^{8} + (R \leftrightarrow L)\right]$$

and in case one is interested only in total rates (and spin independent / FB symmetries) only three parameters are left : g_h , $c_V=c_R+c_L$ and $a_A = a_R - a_R$

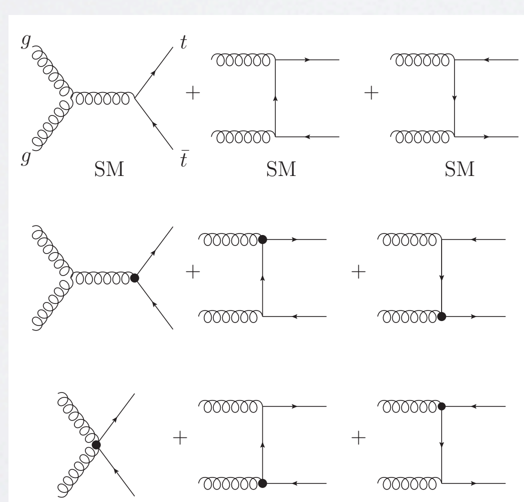


Chromomagnetic operator $\mathcal{O}_{hg} = (H\bar{Q})\sigma^{\mu\nu}T^A t\, G^A_{\mu\nu}$

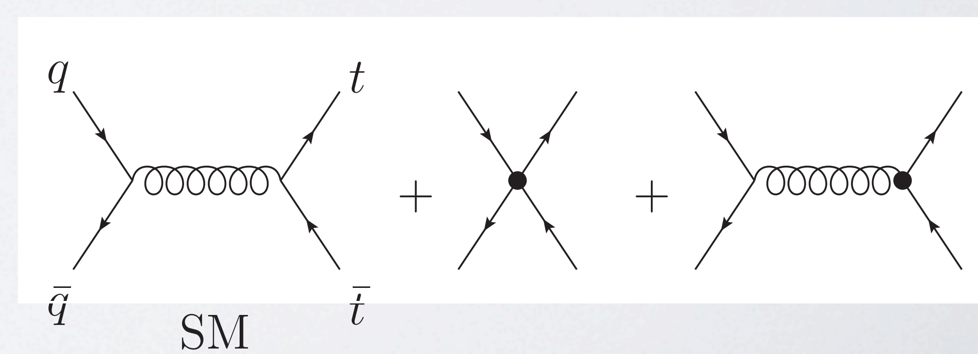


Four-fermion operators

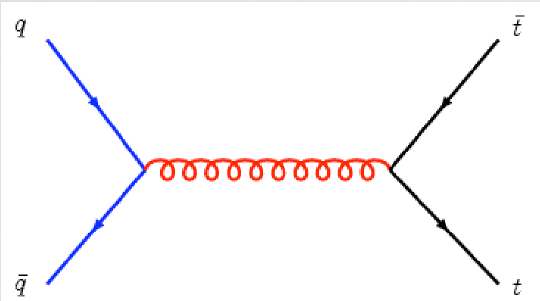
gluon fusion
corrections from c_{hg} only



qq annihilation:
both c_{hg} and 4-fermion operators

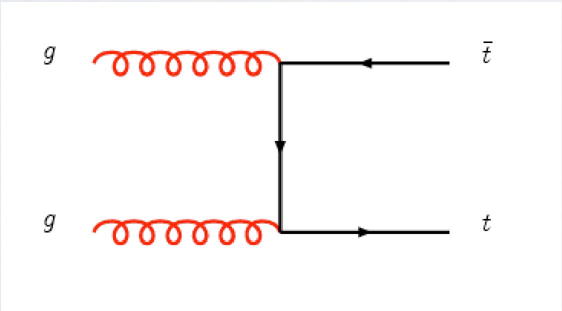


σ(t tbar) : Tevatron vs LHC

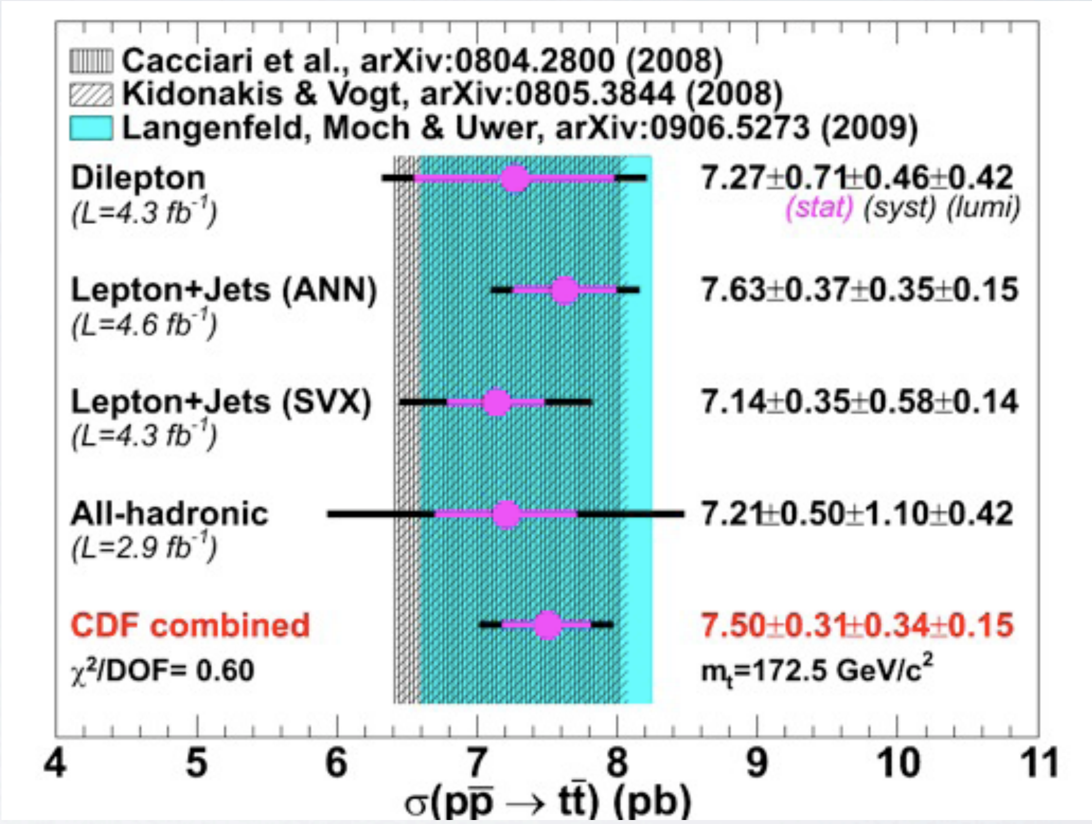


85% at TeV

VS



80% at LHC7



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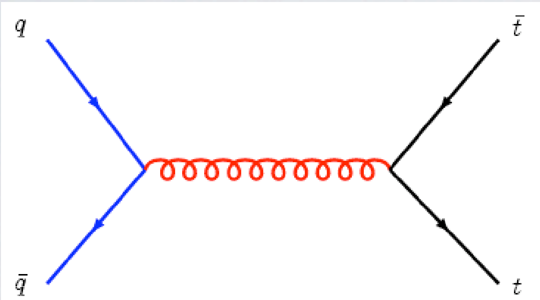
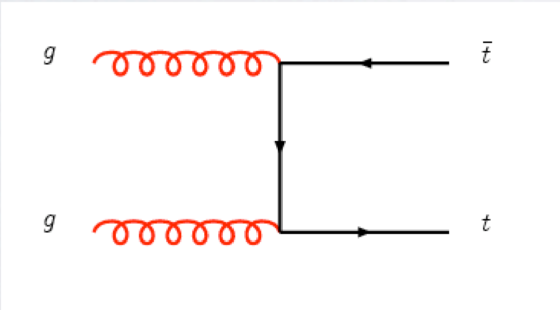
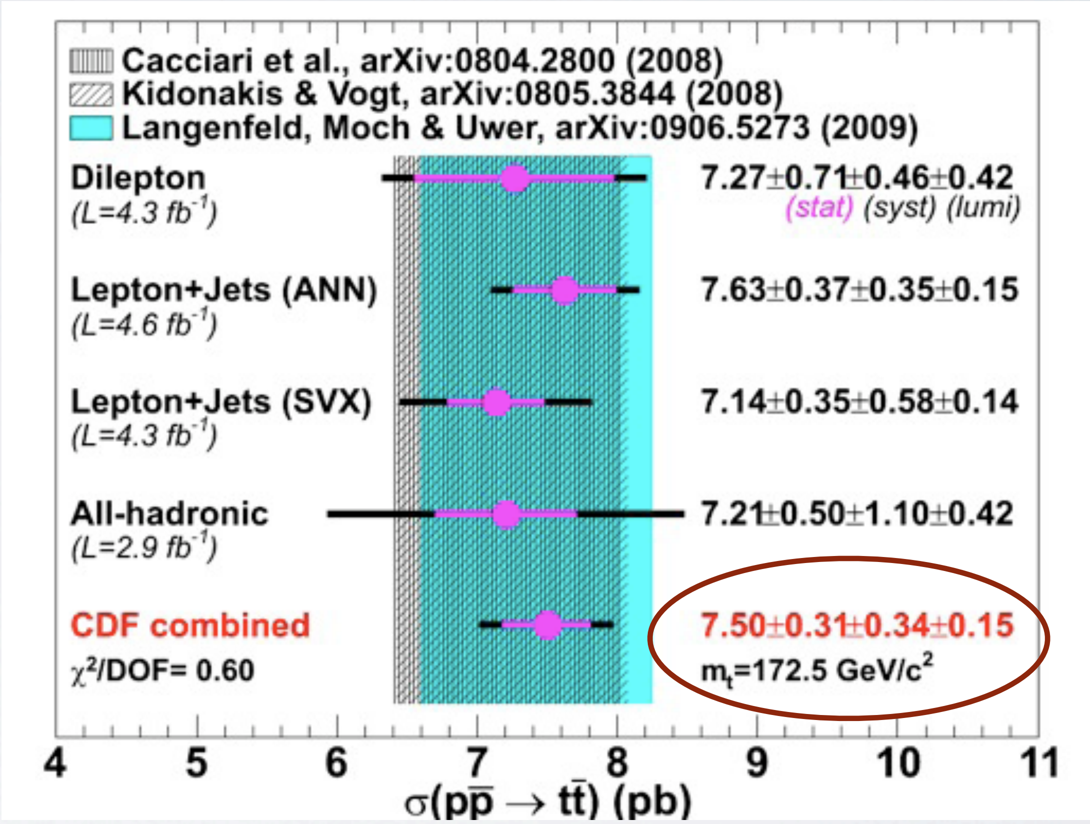


85% at TeV

VS



80% at LHC7



The gg channel is only very roughly constrained!!!
We might have missed some big and important NP effect connected with an gg initial state (such a scalar...).

EFT gives us the possibility of studying deviations in a model independent way.

Effective Field Theory Approach to t tbar production

$$\frac{d\sigma}{dt}(gg \to t\bar{t}) = \frac{d\sigma_{SM}}{dt} + \sqrt{2}\alpha_s g_s \frac{v m_t}{s^2}\frac{c_{hg}}{\Lambda^2}\left(\frac{1}{6\tau_1\tau_2} - \frac{3}{8}\right)$$

$$\frac{d\sigma}{dt}(q\bar{q} \to t\bar{t}) = \frac{d\sigma_{SM}}{dt}\left(1 + \frac{c_{Vv} \pm \frac{c'_{Vv}}{2}}{g_s^2}\frac{s}{\Lambda^2}\right) + \frac{1}{\Lambda^2}\frac{\alpha_s}{9s^2}\left(\left(c_{Aa} \pm \frac{c'_{Aa}}{2}\right) s(\tau_2 - \tau_1) + 4 g_s c_{hg}\sqrt{2} v m_t\right)$$

$$\tau_1 = \frac{m_t^2 - t}{s}, \quad \tau_2 = \frac{m_t^2 - u}{s}, \quad \rho = \frac{4m_t^2}{s} \qquad m_t^2 - t = \frac{s}{2}(1 - \beta\cos\theta)$$

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2. The operator O_{hg} can hardly be distinguished from the SM in gluon fusion

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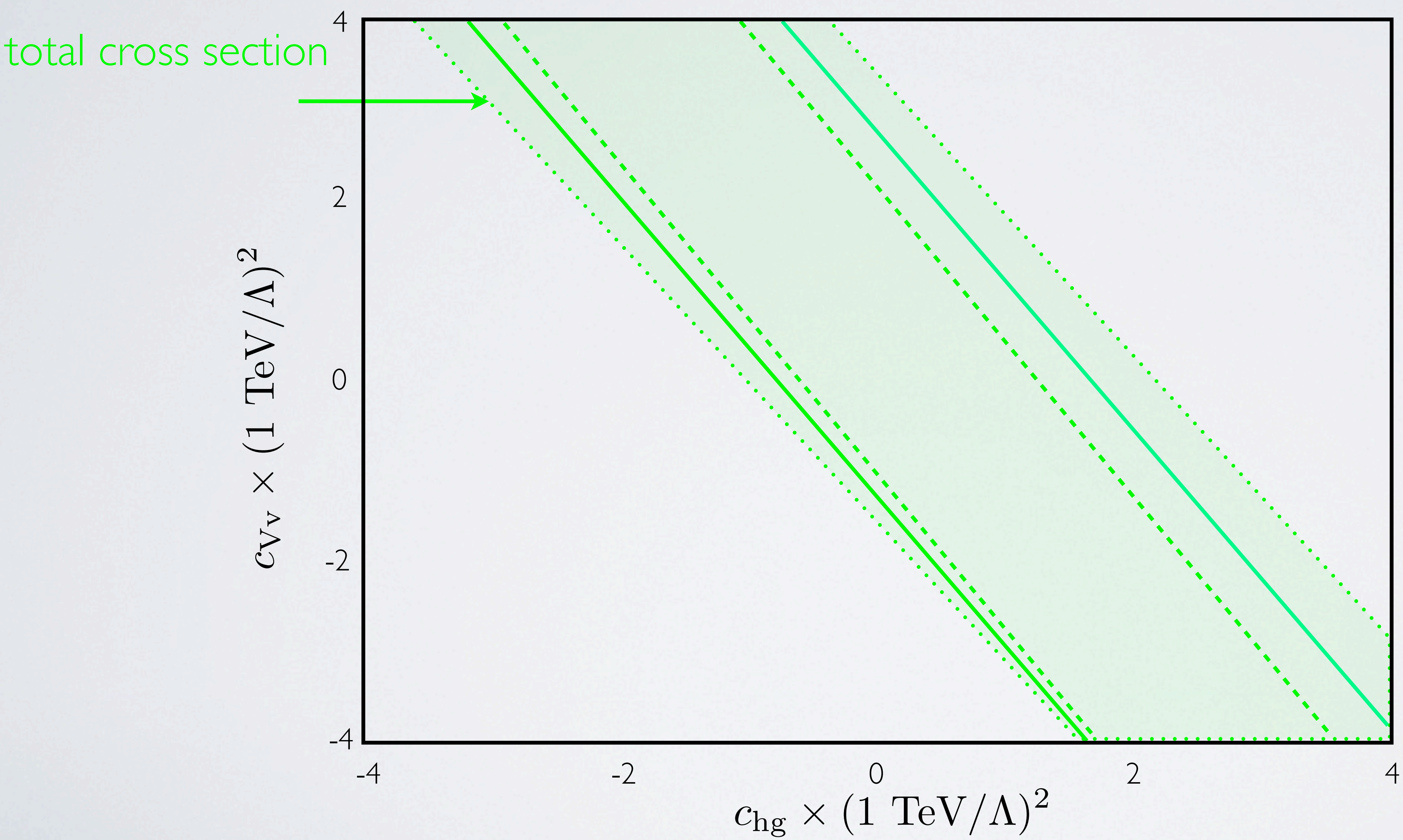
1. Extremely simple formulas!!
2. The operator O_{hg} can hardly be distinguished from the SM in gluon fusion
3. Distortions in the shape of the distributions can only come from qq annihilation ➙ small effects at LHC
4. Even and odd contributions for qq ➙ ttbar, the latter give rise to A_{FB}

Effective Field Theory Approach to t tbar production

- The pp → ttbar total cross section at Tevatron depends on both c_{hg} and c_{Vv} and constrains thus a combination of these parameters.



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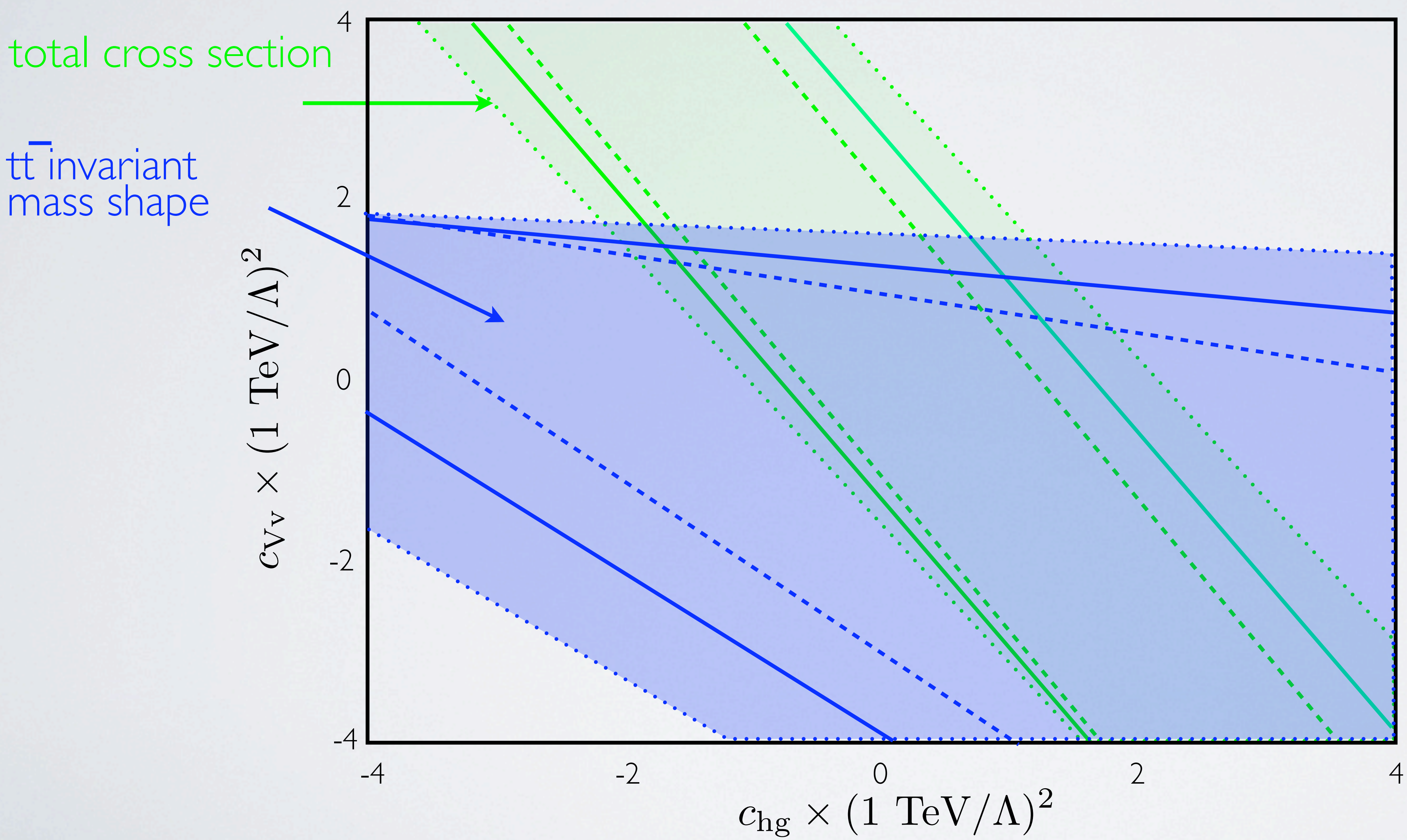
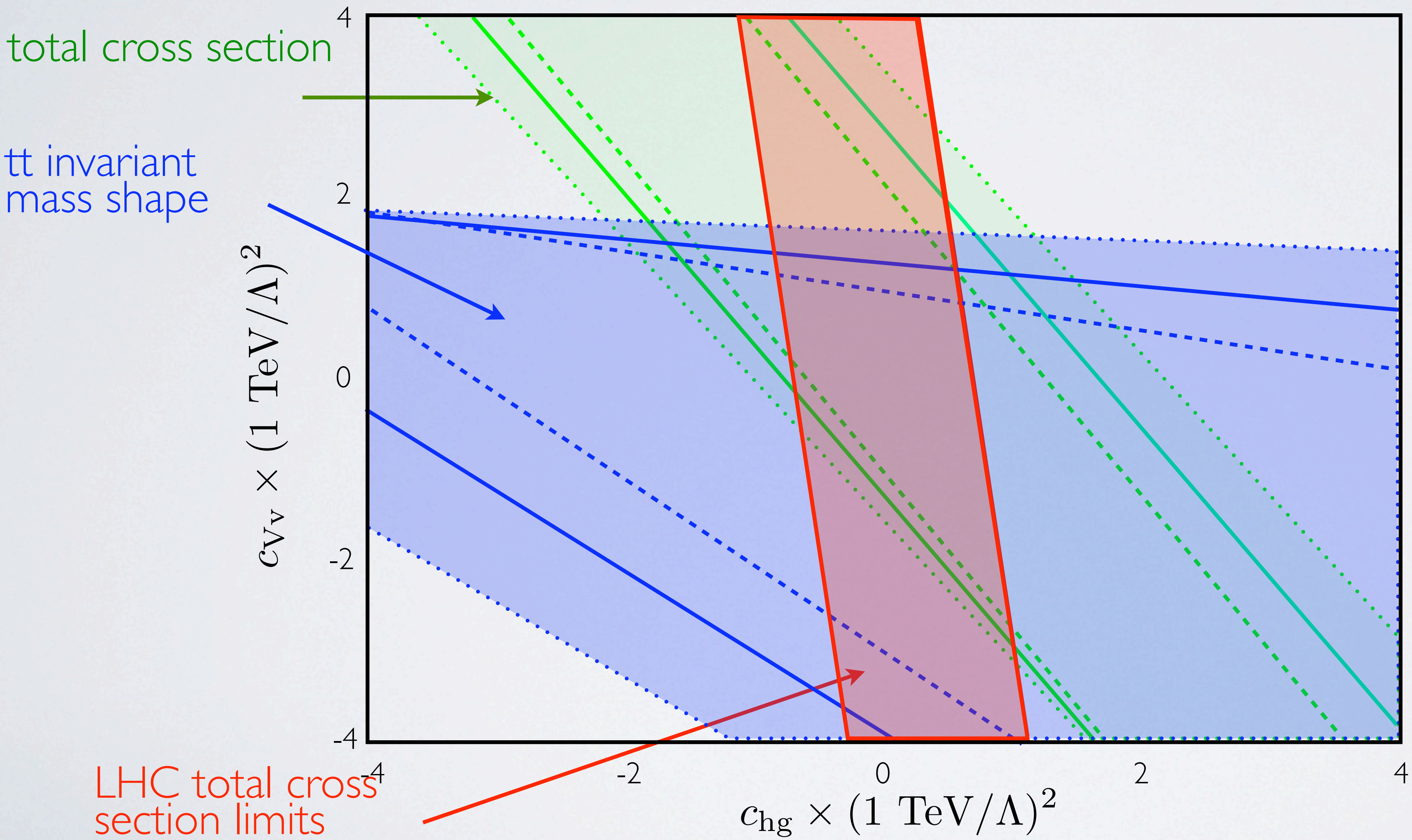
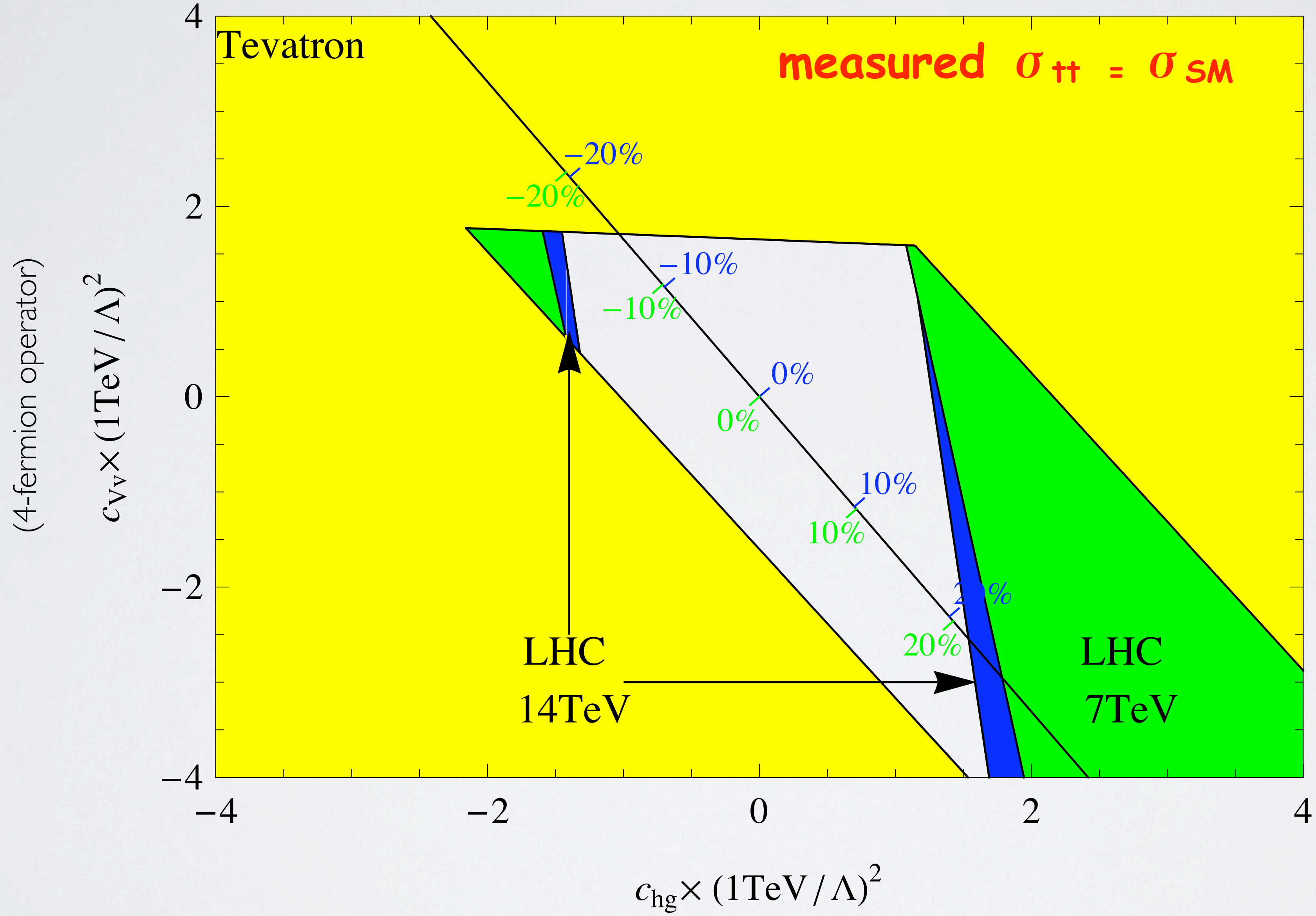


Effective Field Theory Approach to t tbar production

- The pp → ttbar total cross section at LHC strongly depends mostly on c_{hg} and can be directly used to constrain the allowed range for c_{hg}



Effective Field Theory Approach to t tbar production : constraints



(chromomagnetic moment operator)

Effective Field Theory Approach to t tbar production : A_{FB}

$$A_{FB} \equiv \frac{\sigma(\cos\theta_t > 0) - \sigma(\cos\theta_t < 0)}{\sigma(\cos\theta_t > 0) + \sigma(\cos\theta_t < 0)}$$ lab. frame

$$A_{FB}^{SM} = 0.05 \pm 0.015. \quad A_{FB}^{EXP} = 0.15 \pm 0.05(\mathrm{stat}) \pm 0.024(\mathrm{syst}),$$

$$\delta A_{FB}^{\dim 6} = \left(0.0342^{+0.016}_{-0.009}\, c_{Aa} + 0.0128^{+0.0064}_{-0.0036}\, c'_{Aa}\right) \times \left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2$$

C_{Aa} and C'_{Aa} are only constrained by the asymmetry and not by the total cross section or the invariant mass distribution

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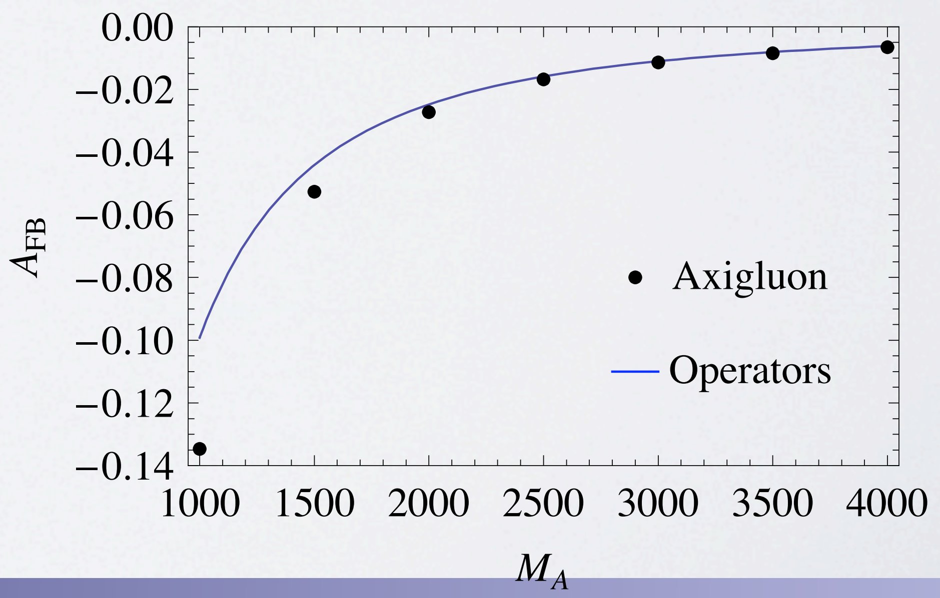
C $_{Aa}$ and C '$_{Aa}$ are only constrained by the asymmetry and not by the total cross section or the invariant mass distribution

Link to resonant models possible!
Example: axigluon

$$c_{Aa}/\Lambda^2 = -2 g_A^q g_A^t / m_A^2$$



Effective Field Theory Approach to t tbar production : Summary

Non-resonant top philic new physics can be probed using measurements in top pair production at hadron colliders

This model-independent analysis can be performed in terms of 8 operators.

Observables depend on different combinations of only 4 parameters:

$$\sigma(gg \to t\bar{t}), d\sigma(gg \to t\bar{t})/dt \quad \leftrightarrow \quad c_{hg}$$

$$\sigma(q\bar{q} \to t\bar{t}) \quad \leftrightarrow \quad c_{hg}, c_{Vv}$$

$$d\sigma(q\bar{q} \to t\bar{t})/dm_{tt} \quad \leftrightarrow \quad c_{hg}, c_{Vv}$$

$$A_{FB} \quad \leftrightarrow \quad c_{Aa}$$

$$\text{spin correlations} \quad \leftrightarrow \quad c_{hg}, c_{Vv}, c_{Av}$$

MODEL INDEPENDENT BSM SEARCHES: EXAMPLES

I. Search for resonances in m_{ttbar} (and boosted tops)

II. EFT approach to t tbar production

III. Exotic: same sign tops

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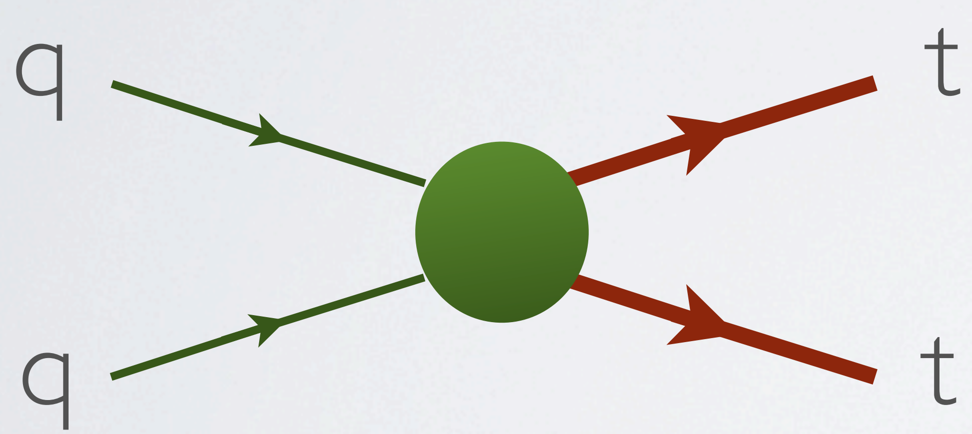
SAME SIGN TOPS

[Rajamaran et al., 2011][C. Degrande et al. , 2011], [Aguilar-Saavedra et al. 2011], [E. Berger et al. , 2011],[J. Cao et al., 2011] [Hao Zhang et al., 2010],[C. Bauer et al. 2010], [S. Jung et al. 2009] [J. Gao et al. 2009],[S. Bar-Shalom et al ,2008]....

Exotic signature : "easy" to identify in the same sign channel (double lepton decay) or in the charge asymmetry. (single lepton decay). At the LHC enhanced by PDF.



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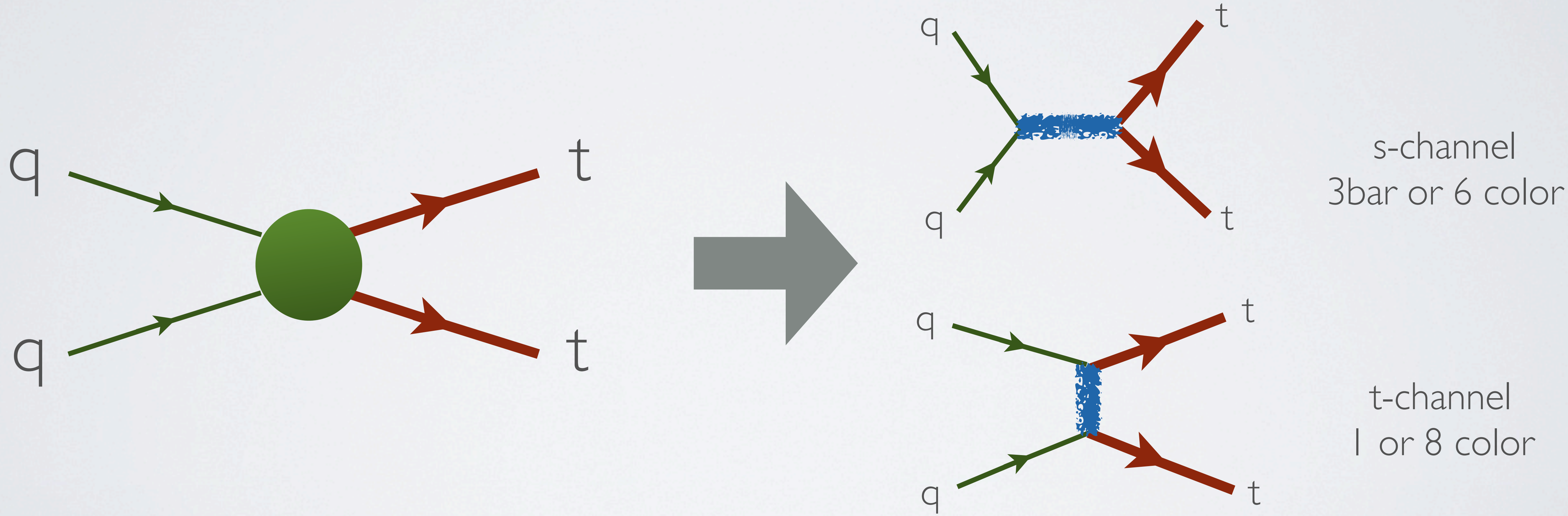

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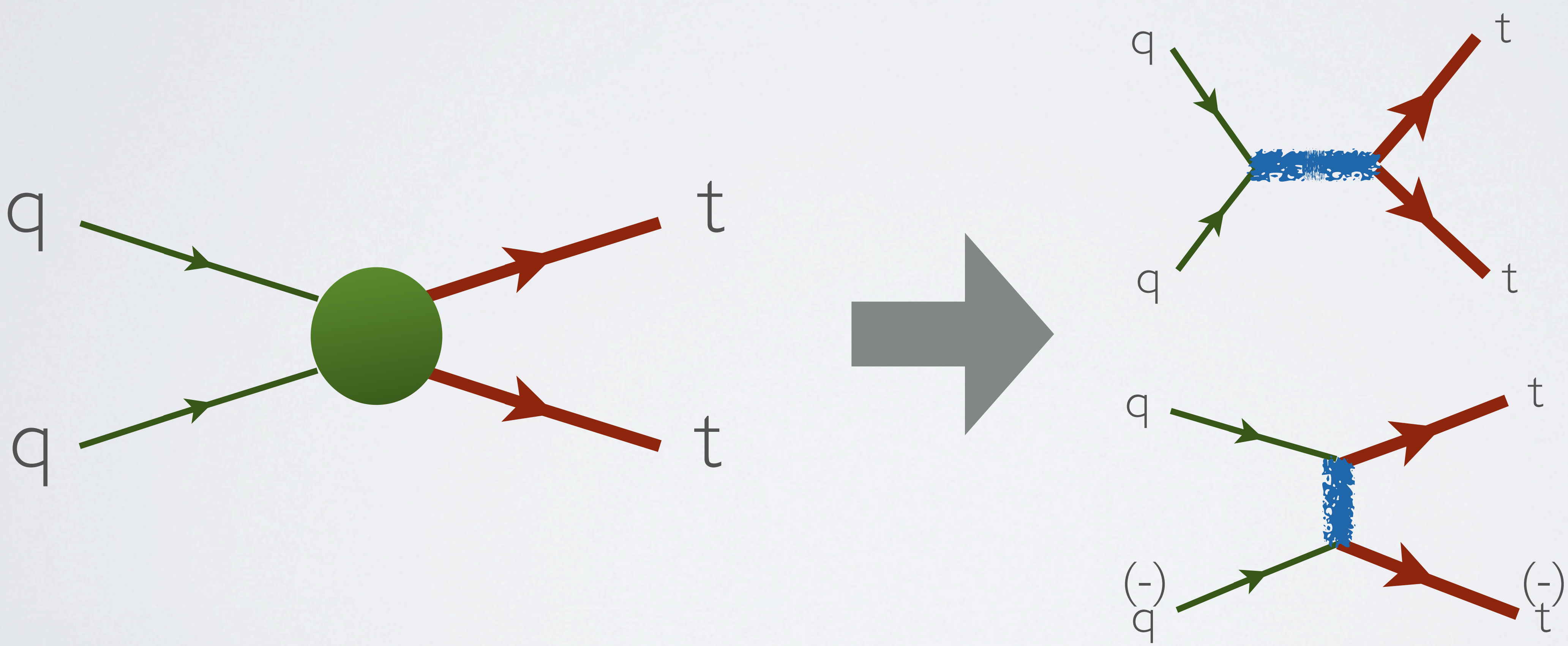

s-channel
3bar or 6 color

t-channel
1 or 8 color

The t-channel can be linked to the A_{FB} for neutral particle exchanges!

SAME SIGN TOPS

Resonant approach:

List all possible particles that can be exchanged either in the s-channel or in the t-channel

Symbol	Rep.	Interaction Lagrangian	Sym.
$\mathcal{B}_\mu$	$(1,1)_0$	$-\left(g^q_{ij}\bar{q}_{Li}\gamma^\mu q_{Lj} + g^u_{ij}\bar{u}_{Ri}\gamma^\mu u_{Rj} + g^d_{ij}\bar{d}_{Ri}\gamma^\mu d_{Rj}\right)\mathcal{B}_\mu$	$g = g^\dagger$
$\mathcal{W}_\mu$	$(1,\mathrm{Adj})_0$	$-g_{ij}\bar{q}_{Li}\gamma^\mu\tau^I q_{Lj}\,\mathcal{W}^I_\mu$	$g = g^\dagger$
$\mathcal{G}_\mu$	$(\mathrm{Adj},1)_0$	$-\left(g^q_{ij}\bar{q}_{Li}\gamma^\mu\frac{\lambda^a}{2}q_{Lj} + g^u_{ij}\bar{u}_{Ri}\gamma^\mu\frac{\lambda^a}{2}u_{Rj} + g^d_{ij}\bar{d}_{Ri}\gamma^\mu\frac{\lambda^a}{2}d_{Rj}\right)\mathcal{G}^a_\mu$	$g = g^\dagger$
$\mathcal{H}_\mu$	$(\mathrm{Adj},\mathrm{Adj})_0$	$-g_{ij}\bar{q}_{Li}\gamma^\mu\tau^I\frac{\lambda^a}{2}q_{Lj}\,\mathcal{H}^{aI}_\mu$	$g = g^\dagger$
$\mathcal{Q}^5_\mu$	$(3,2)_{-\frac{5}{6}}$	$-g_{ij}\varepsilon_{abc}\bar{u}_{Rib}\gamma^\mu\epsilon q^c_{Ljc}\,\mathcal{Q}^{5a\dagger}_\mu + \mathrm{h.c.}$	–
$\mathcal{Y}^5_\mu$	$(\bar{6},2)_{-\frac{5}{6}}$	$-g_{ij}\frac{1}{2}\left[\bar{u}_{Ria}\gamma^\mu\epsilon q^c_{Ljb} + \bar{u}_{Rib}\gamma^\mu\epsilon q^c_{Lja}\right]\mathcal{Y}^{5ab\dagger}_\mu + \mathrm{h.c.}$	–
ϕ	$(1,2)_{-\frac{1}{2}}$	$-g^u_{ij}\bar{q}_{Li}u_{Rj}\,\phi - g^d_{ij}\bar{q}_{Li}d_{Rj}\,\tilde{\phi} + \mathrm{h.c.}$	–
Φ	$(\mathrm{Adj},2)_{-\frac{1}{2}}$	$-g^u_{ij}\bar{q}_{Li}\frac{\lambda^a}{2}u_{Rj}\,\Phi^a - g^d_{ij}\bar{q}_{Li}\frac{\lambda^a}{2}d_{Rj}\,\tilde{\Phi}^a + \mathrm{h.c.}$	–
Ω^4	$(\bar{6},1)_{-\frac{4}{3}}$	$-g_{ij}\frac{1}{2}\left[\bar{u}_{Ria}u^c_{Rjb} + \bar{u}_{Rib}u^c_{Rja}\right]\Omega^{4ab\dagger} + \mathrm{h.c.}$	$g = g^T$
Σ	$(\bar{6},\mathrm{Adj})_{-\frac{1}{3}}$	$-g_{ij}\frac{1}{2}\left[\bar{q}_{Lia}\tau^I\epsilon q^c_{Ljb} + \bar{q}_{Lib}\tau^I\epsilon q^c_{Lja}\right]\Sigma^{Iab\dagger} + \mathrm{h.c.}$	$g = g^T$

[Aguilar-Saavedra et al. 2011]

SAME SIGN TOPS

Effective approach:

$$\mathcal{L}_{\rm dim=6}^{qq\to tt} = \frac{1}{\Lambda^2}\left(c_{RR}\mathcal{O}_{RR} + c_{LL}^{(1)}\mathcal{O}_{LL}^{(1)} + c_{LL}^{(3)}\mathcal{O}_{LL}^{(3)} + c_{LR}^{(1)}\mathcal{O}_{LR}^{(1)} + c_{LR}^{(8)}\mathcal{O}_{LR}^{(8)}\right) + h.c..$$

with:

$$\mathcal{O}_{RR} = [\bar{t}_R\gamma^\mu u_R]\,[\bar{t}_R\gamma_\mu u_R] \qquad \mathcal{O}_{LL}^{(1)} = [\bar{Q}_L\gamma^\mu q_L]\,[\bar{Q}_L\gamma_\mu q_L] \qquad \mathcal{O}_{LL}^{(3)} = [\bar{Q}_L\gamma^\mu\sigma^a q_L]\,[\bar{Q}_L\gamma_\mu\sigma^a q_L]$$

$$\mathcal{O}_{LR}^{(1)} = [\bar{Q}_L\gamma^\mu q_L]\,[\bar{t}_R\gamma_\mu\, u_R] \qquad \mathcal{O}_{LR}^{(8)} = [\bar{Q}_L\gamma^\mu T^A q_L]\,[\bar{t}_R\gamma_\mu\, T^A u_R]$$

All the effects given by the (heavy) resonances written before can be written in terms of the operators.

SAME SIGN TOPS

Effective approach:

$$\mathcal{L}^{qq\to tt}_{\text{dim}=6} = \frac{1}{\Lambda^2}\left(c_{RR}\mathcal{O}_{RR} + c^{(1)}_{LL}\mathcal{O}^{(1)}_{LL} + c^{(3)}_{LL}\mathcal{O}^{(3)}_{LL} + c^{(1)}_{LR}\mathcal{O}^{(1)}_{LR} + c^{(8)}_{LR}\mathcal{O}^{(8)}_{LR}\right) + h.c..$$

with:

$$\mathcal{O}_{RR} = [\bar{t}_R\gamma^\mu u_R]\,[\bar{t}_R\gamma_\mu u_R] \qquad \mathcal{O}^{(1)}_{LL} = [\bar{Q}_L\gamma^\mu q_L]\,[\bar{Q}_L\gamma_\mu q_L] \qquad \mathcal{O}^{(3)}_{LL} = [\bar{Q}_L\gamma^\mu\sigma^a q_L]\,[\bar{Q}_L\gamma_\mu\sigma^a q_L]$$

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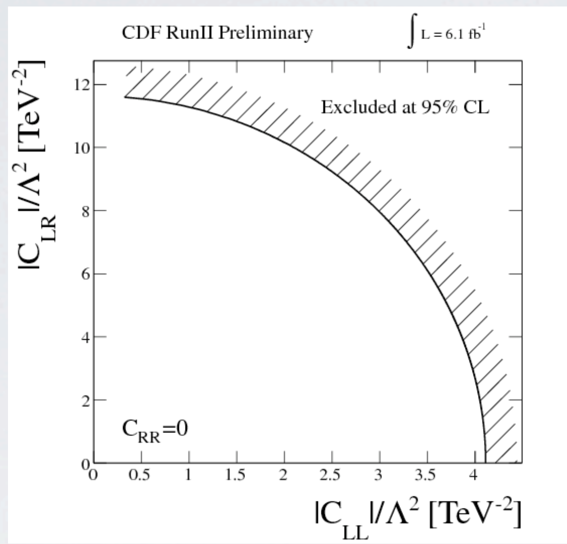
All the effects given by the (heavy) resonances written before can be written in terms of the operators.

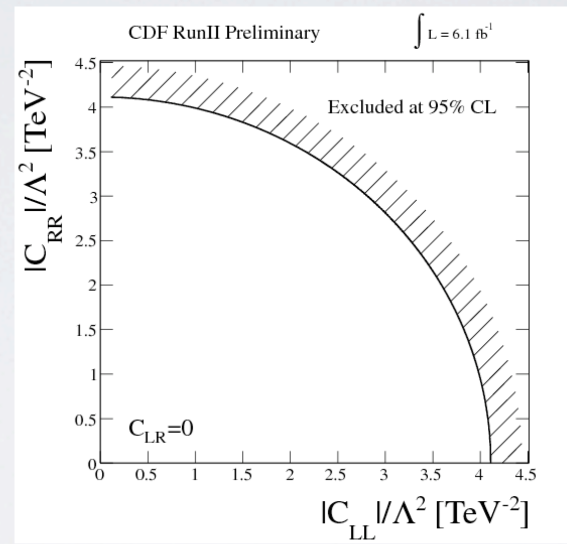
A very simple calculation leads to the differential cross section:

$$\frac{d\sigma}{dt} = \frac{1}{\Lambda^4}\Bigg[\left(|c_{RR}|^2 + |c_{LL}|^2\right)\frac{(s-2m_t^2)}{3\pi s} + \left(\left|c^{(1)}_{LR}\right|^2 + \frac{2}{9}\left|c^{(8)}_{LR}\right|^2\right)\frac{(m_t^2-t)^2 + (m_t^2-u)^2}{16\pi s^2} - \left(\left|c^{(1)}_{LR}\right|^2 + \frac{8}{3}\Re\left(c^{(1)}_{LR}c^{(8)\,*}_{LR}\right) - \frac{2}{9}\left|c^{(8)}_{LR}\right|^2\right)\frac{m_t^2}{24\pi s}\Bigg].$$

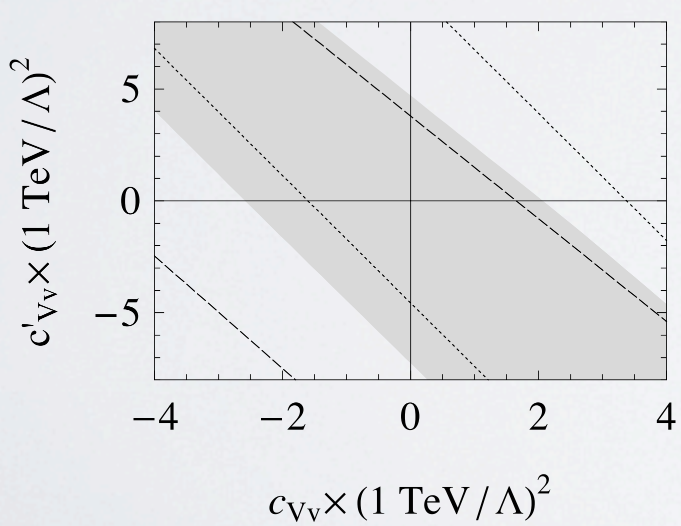
SAME SIGN TOPS

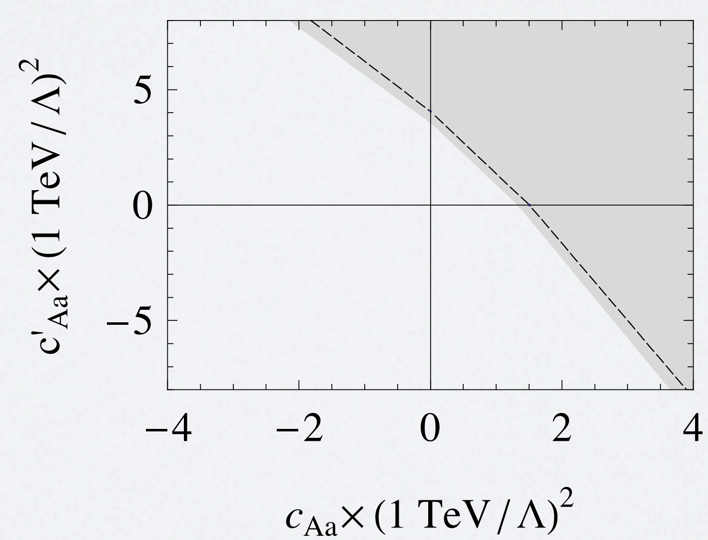
The Tevatron constraints on same-sign tops *[CDF/PHYS/EXO/PUBLIC/10466]* (pretty weak)

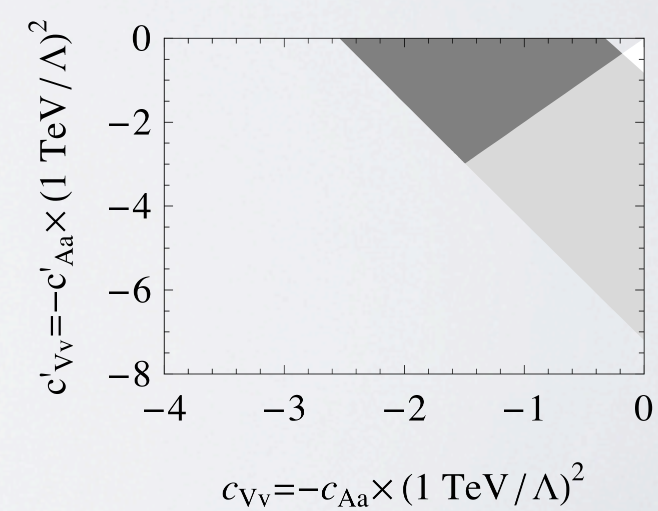




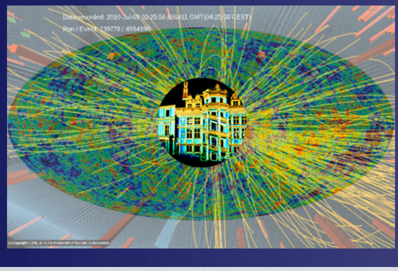
constraints from ttbar cross sections and invariant mass distributions and relations with the A_{FB} (assuming neutral t-channel physics)







Upshot: t-channel scenarios are disfavoured. No constraints for tt at the LHC.



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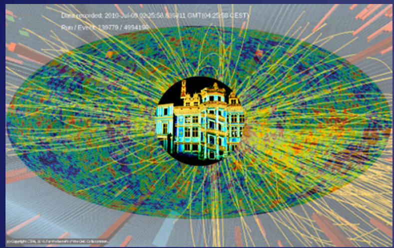

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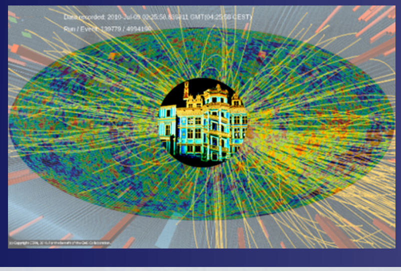

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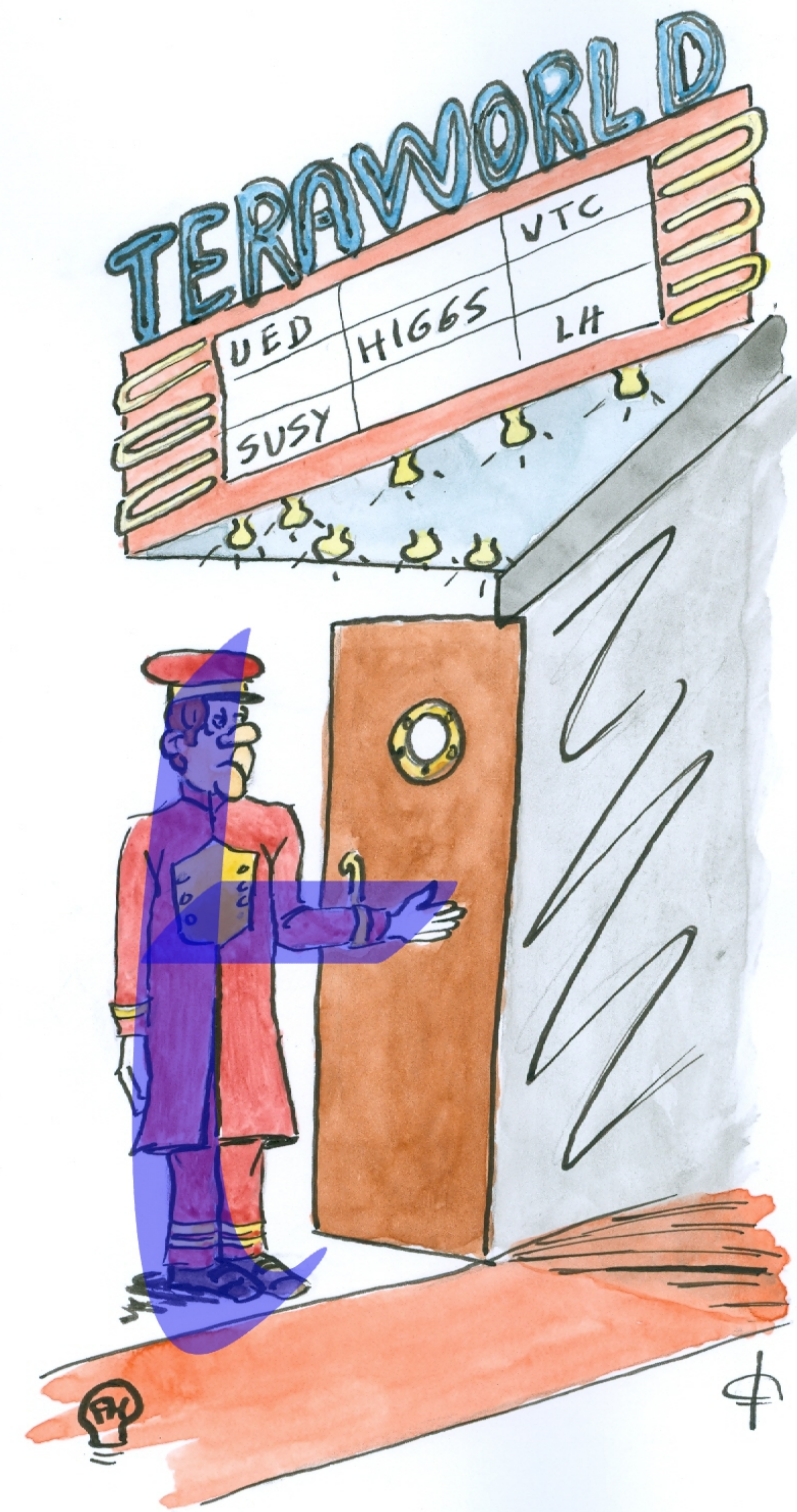

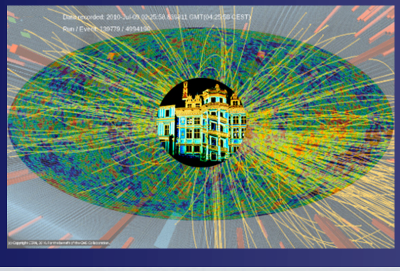

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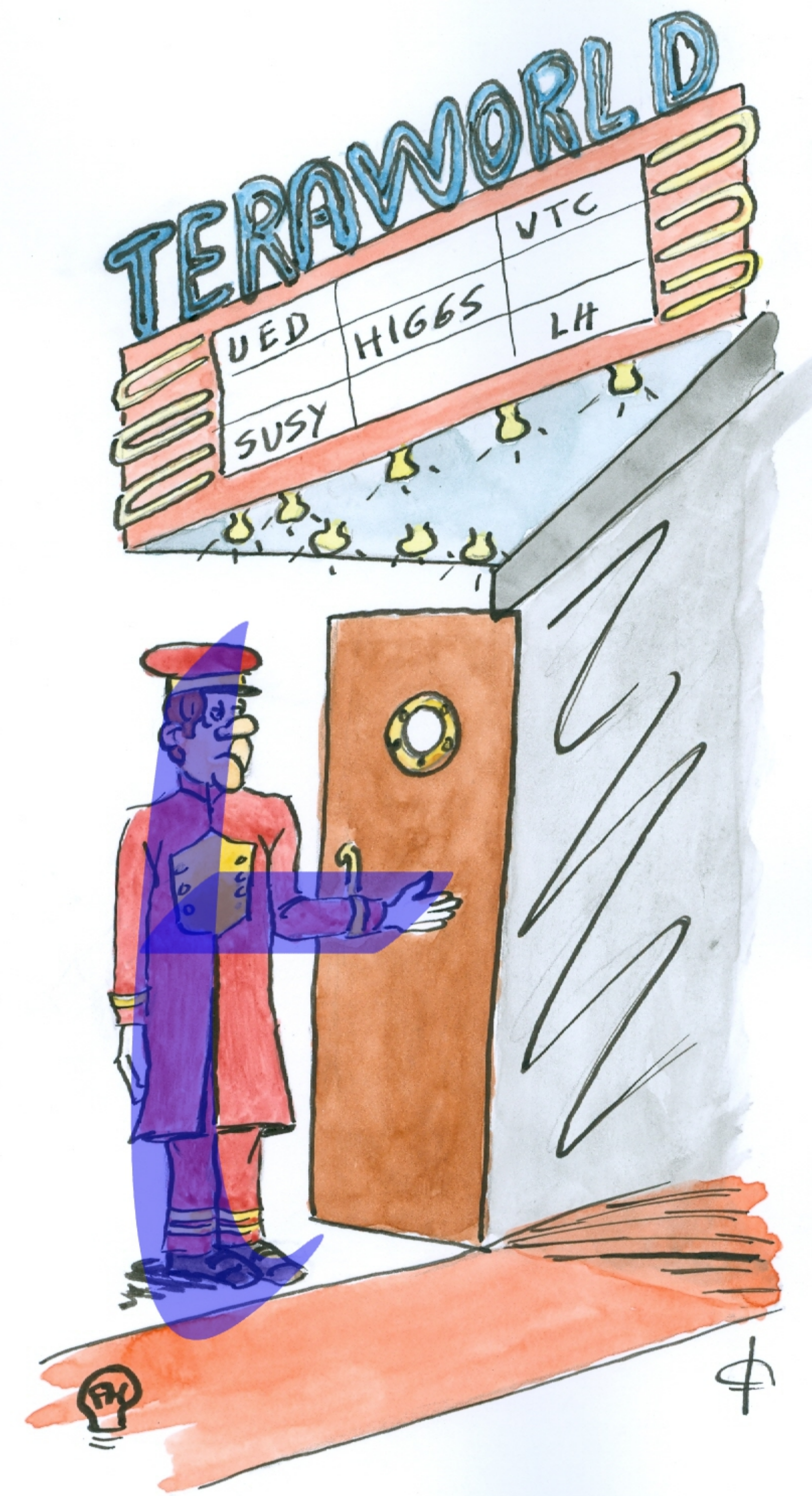
Enjoy this exciting 2011!



CREDITS

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(random order)

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