Overview on Top Physics

Fabio Maltoni

Center for Cosmology, Particle Physics and Phenomenology (CP3)
Universitè catholique de Louvain, Belgium

OUTLINE

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- The importance of being Top

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- Top as tool for BSM: strategies with examples

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

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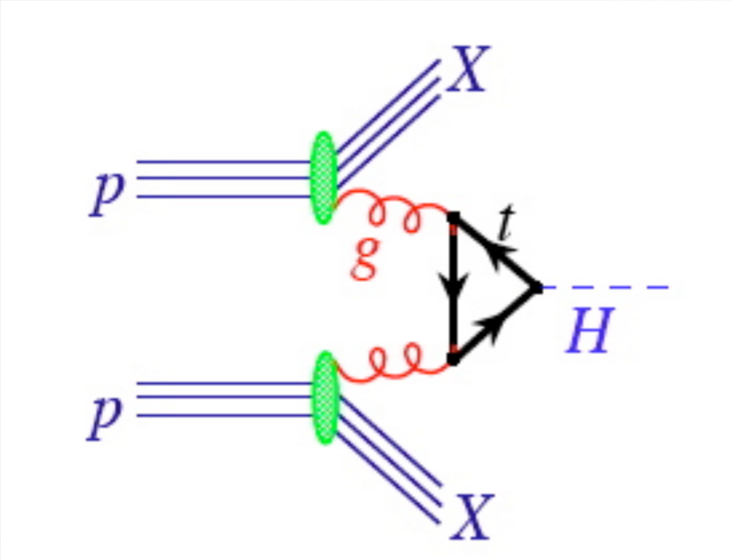
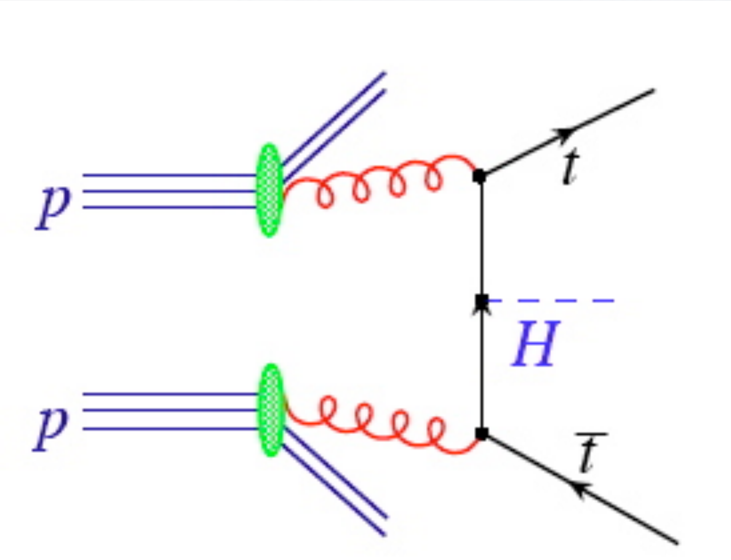


It can easily excite the Higgs



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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)

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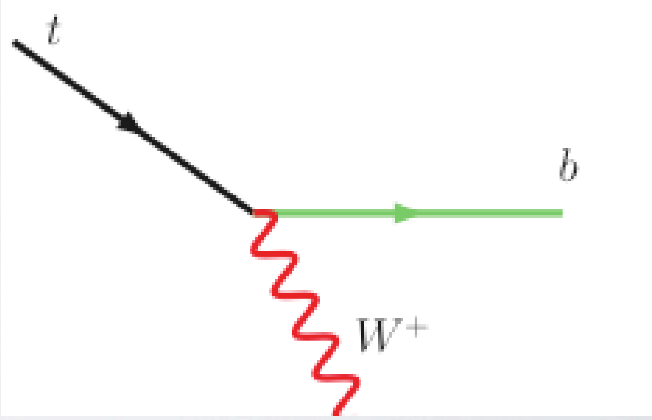

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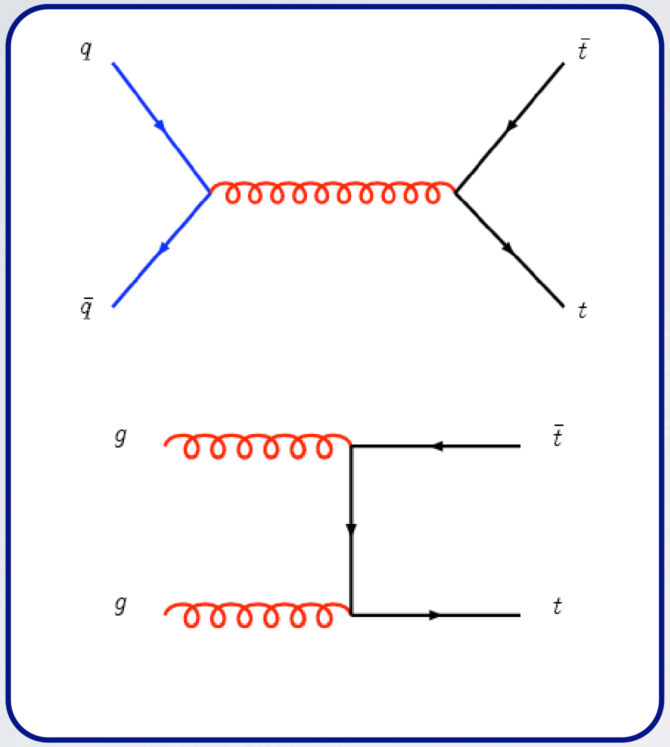


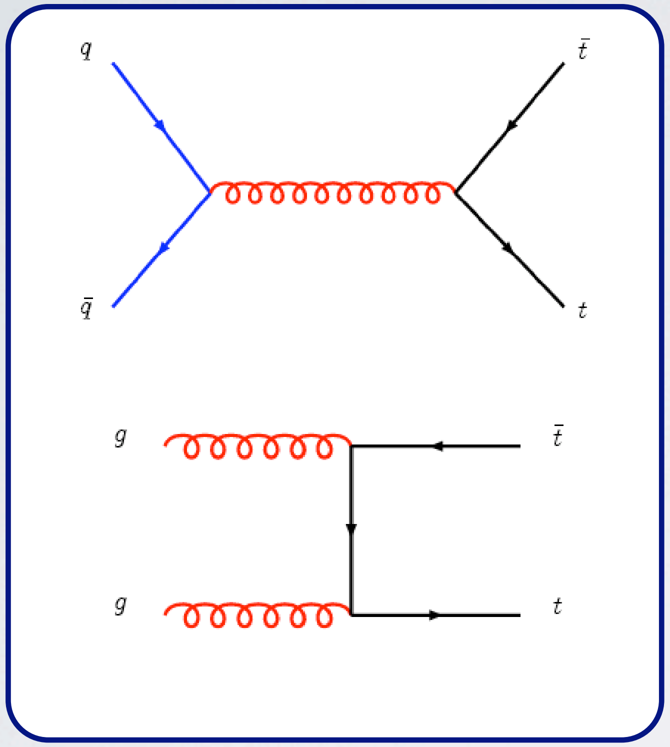
Largest cross section (LO at α_S^2):

~ 7 pb at Tevatron
~ 150 pb at LHC7

Precision physics studies

Top is special

Strong



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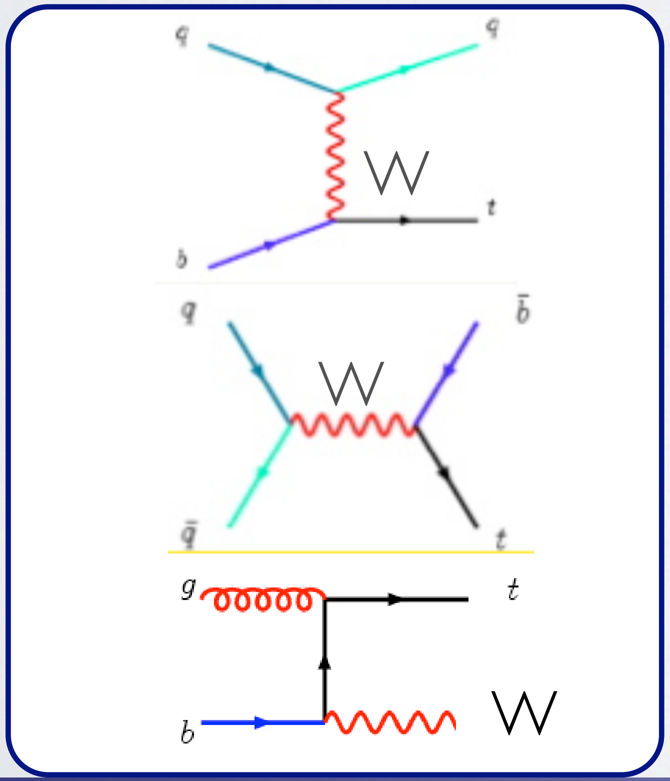
Precision physics studies

Weak



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.

We know a lot already from the Tevatron...

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- Top quark mass: 173.3 ± 1.1 GeV
- 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:
  $(t \to W^+b)/(t \to W^+q) > 0.61$ at 95% C.L.
- Electric charge: $Q_t = -4/3$ excluded at 87% C.L
- Single top production cross section
- Measurement of $|V_{tb}| = 0.88 \pm 0.07$
- Discrimination between t- and s-channel production

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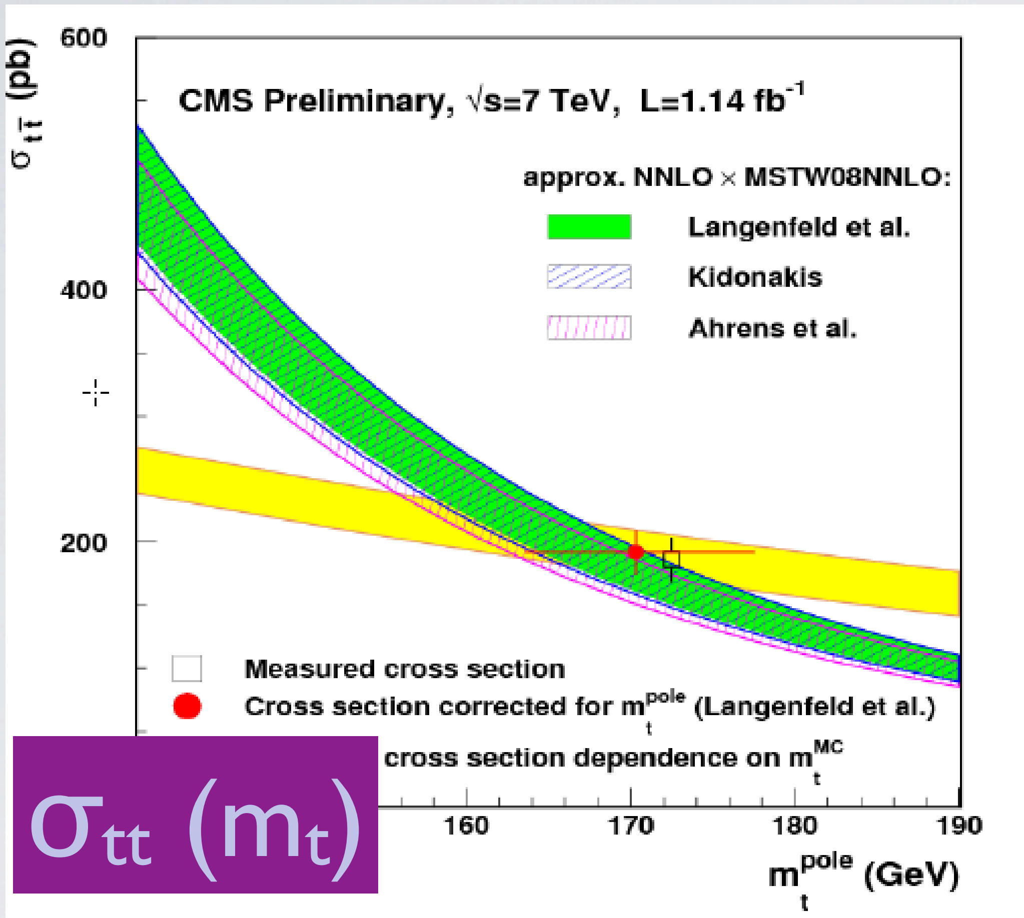

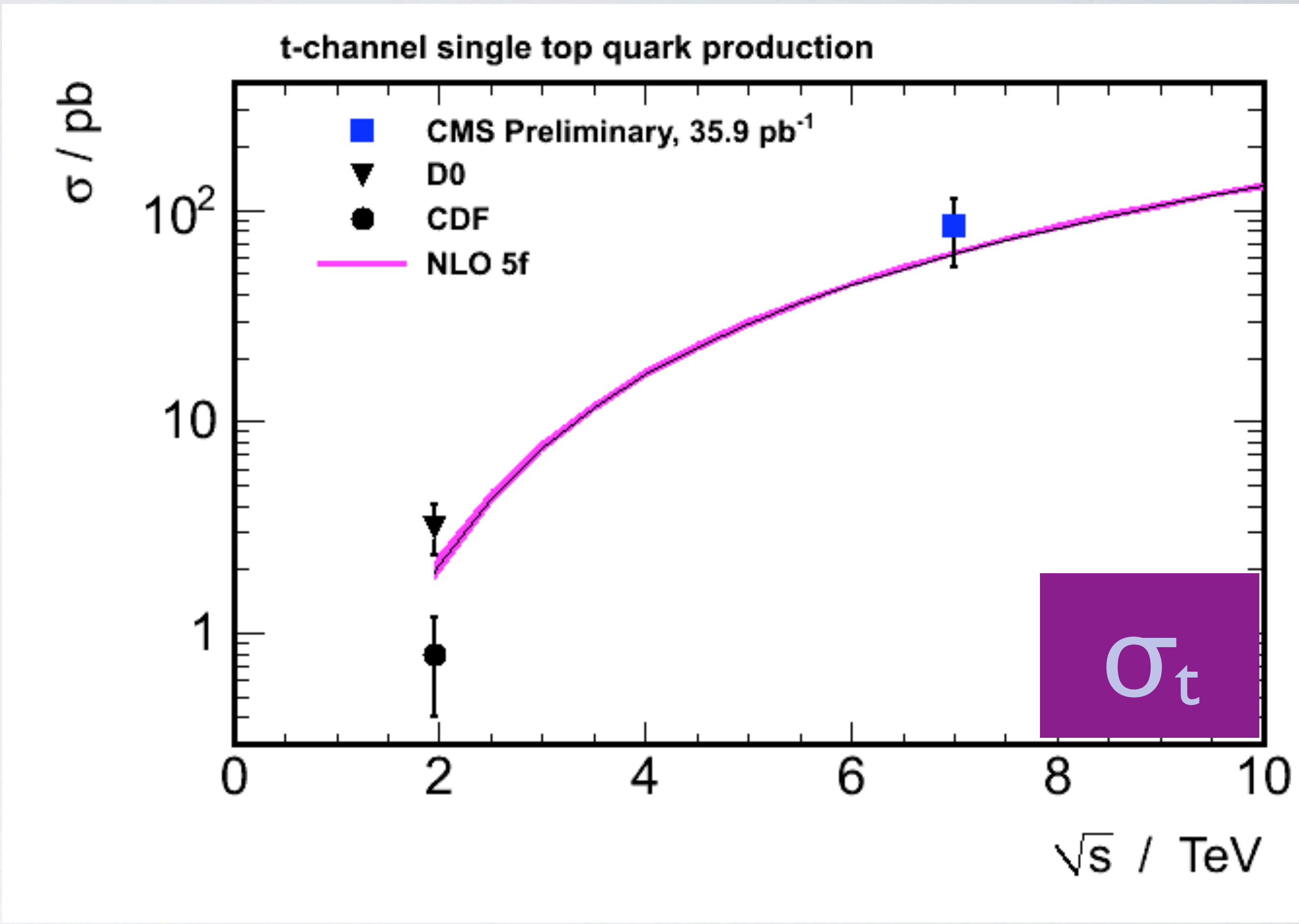

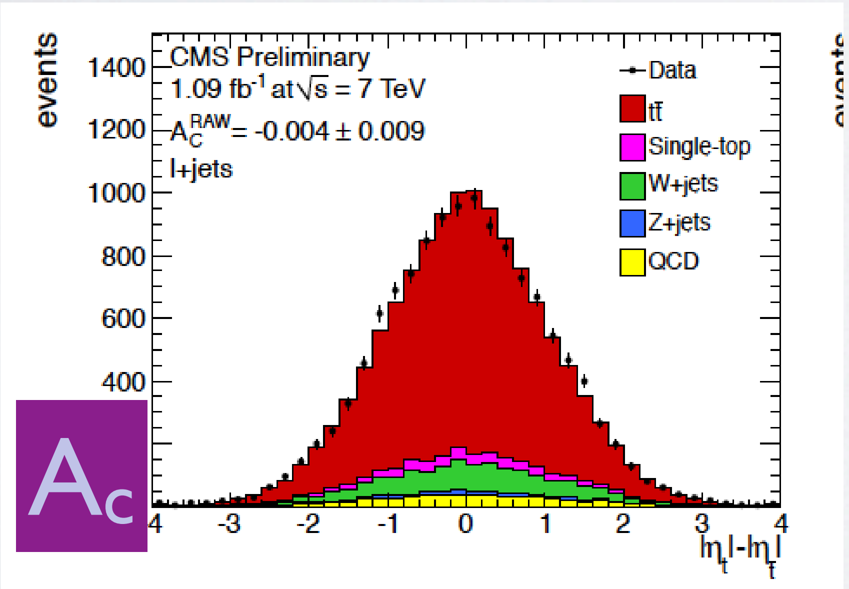

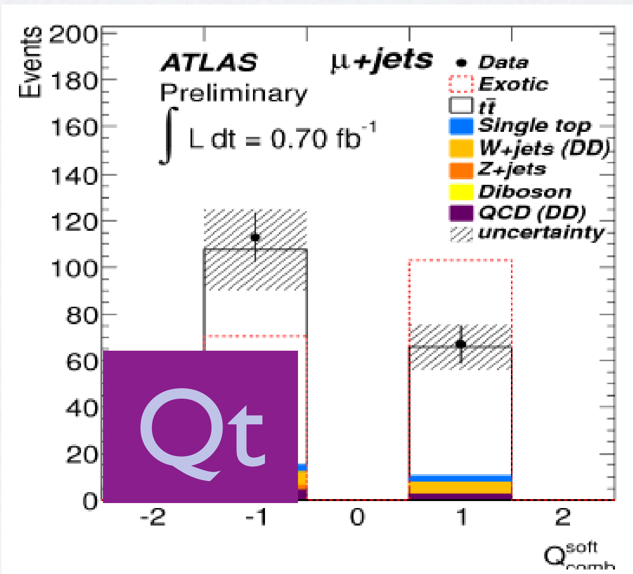

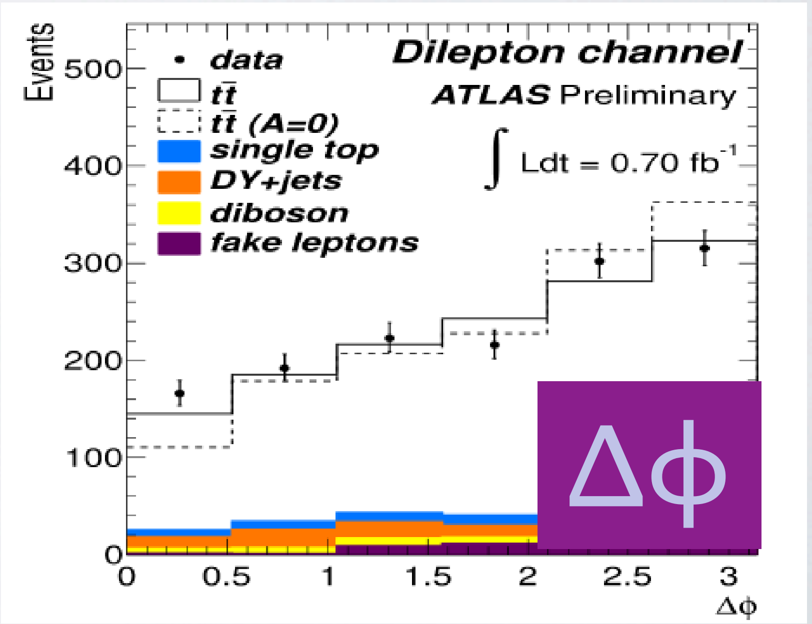

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modified by the speaker

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PROGRESS IN SM TOP PREDICTIONS

Top pair cross section and distributions:

- Updates of total top pair cross section (NLO QCD + threshold res. (NLL)) *Moch, Uwer; Cacciari et al; Kidonakis, Vogt*
- NNLL extensions *Czakon et al.; Beneke et al.; Ahrens et al., Cacciari et al.*
- Forward-Backward asymmetry from threshold resummation *Almeida et al; Ahrens et al.; Antunano et al.; Kidonakis;*
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- Partial results towards top pair total rate at NNLO QCD *Czakon; Bonciani et al. ...*

Top pair + jets: top as a background to Higgs searches: $H \to W^+W^-$ and ttH

- pp → tt+jet *Dittmaier et al.; Melikov, Schulze*
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- tt(+jet) production including decay at NLO QCD *Melnikov, Schulze, Melnikov et al.*; including weak interference corrections *Bernreuther, Si*
- tt spin correlations revisited *Mahlon, Parke; Bernreuther, Si*

Single-top:

- Single top t-channel production at NLO QCD in 5 and 4 flavor schemes *Campbell, Frederix, FM, Tramontano*
- Single top including decay at NLO QCD *Falgari et al.*

Monte Carlo at NLO:

- Wt production at NLO QCD in MC@NLO *Frixione et al.; White 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]

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Beware: NNLO corrections not known exactly yet!!

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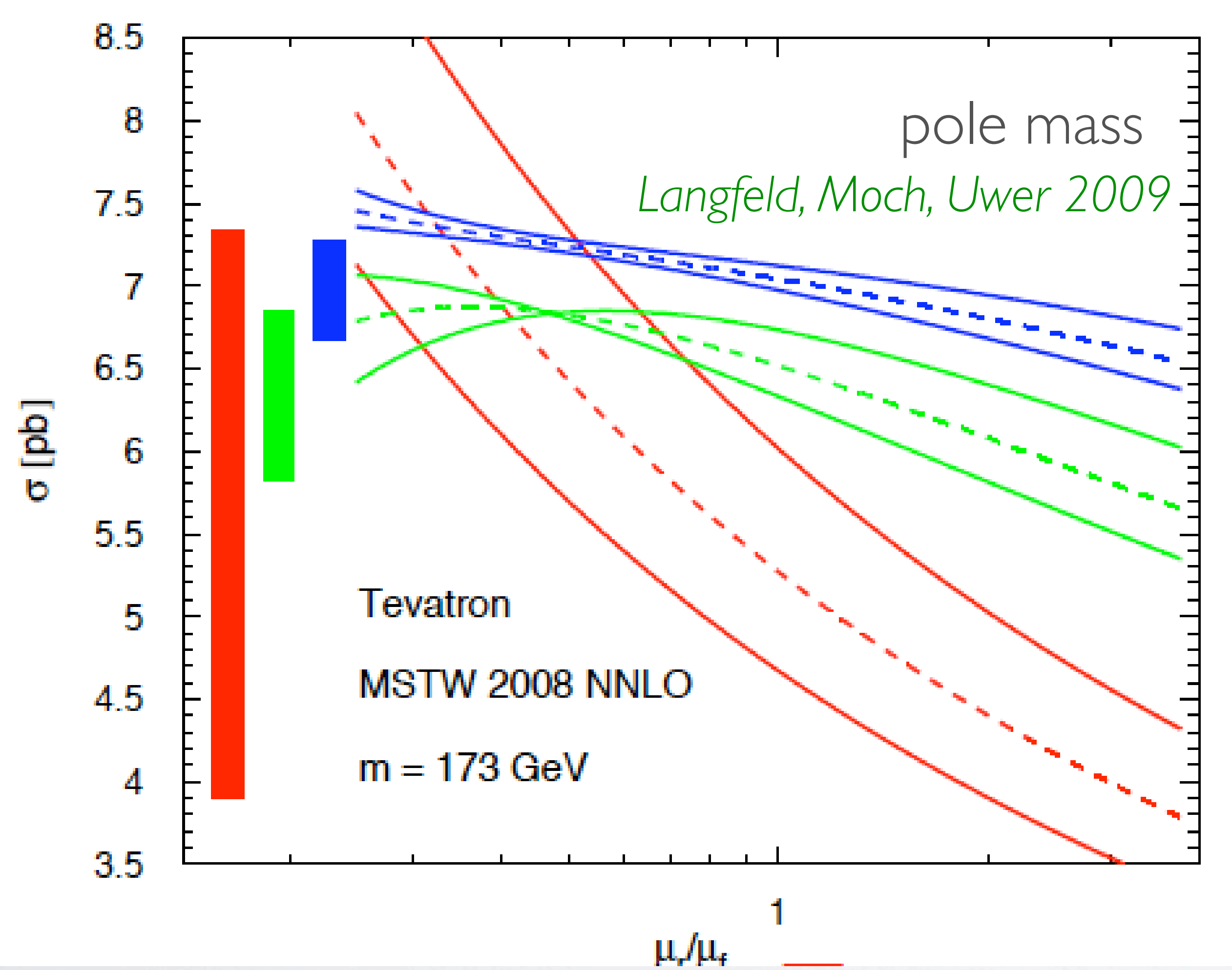

Approximated NNLO results:
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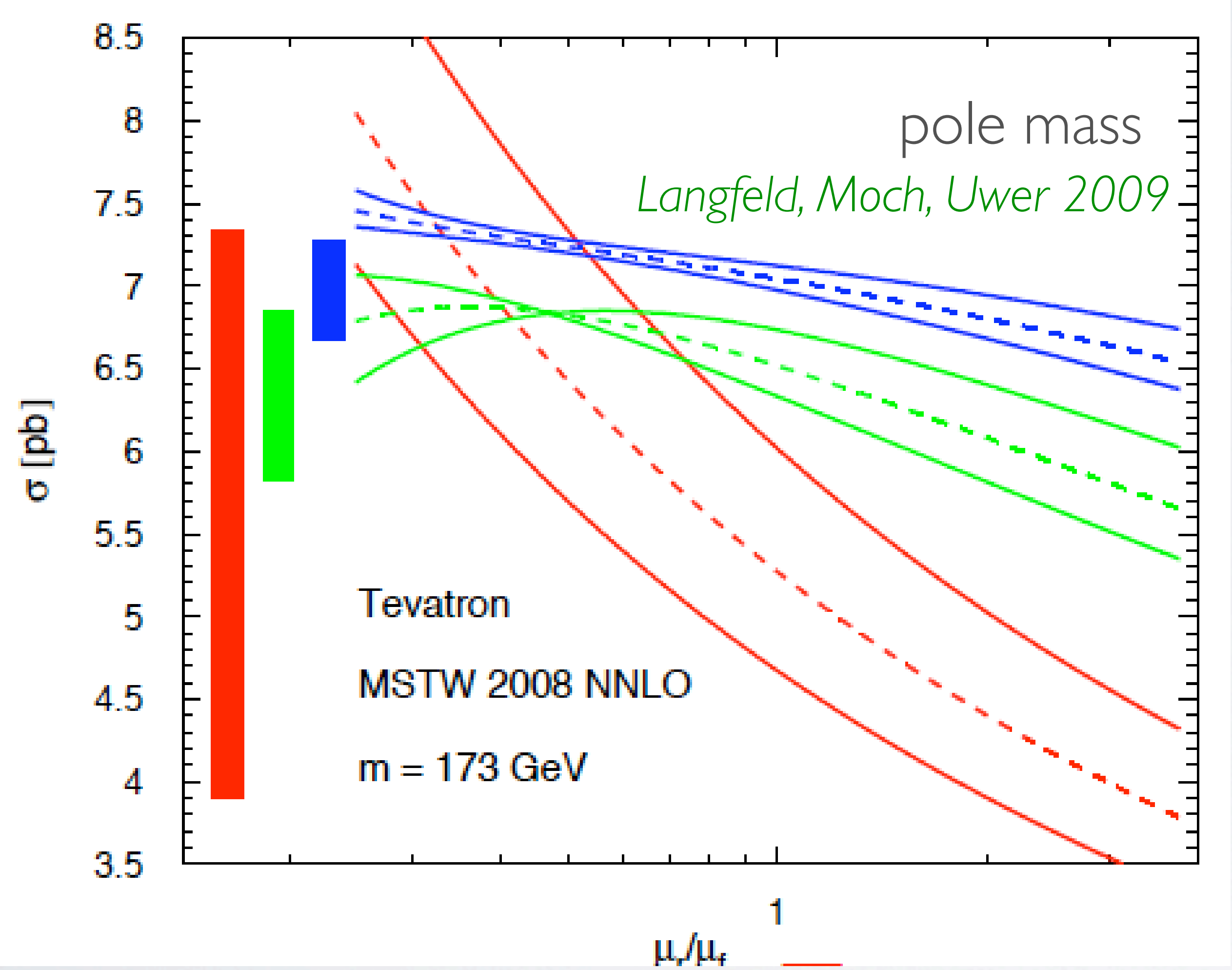

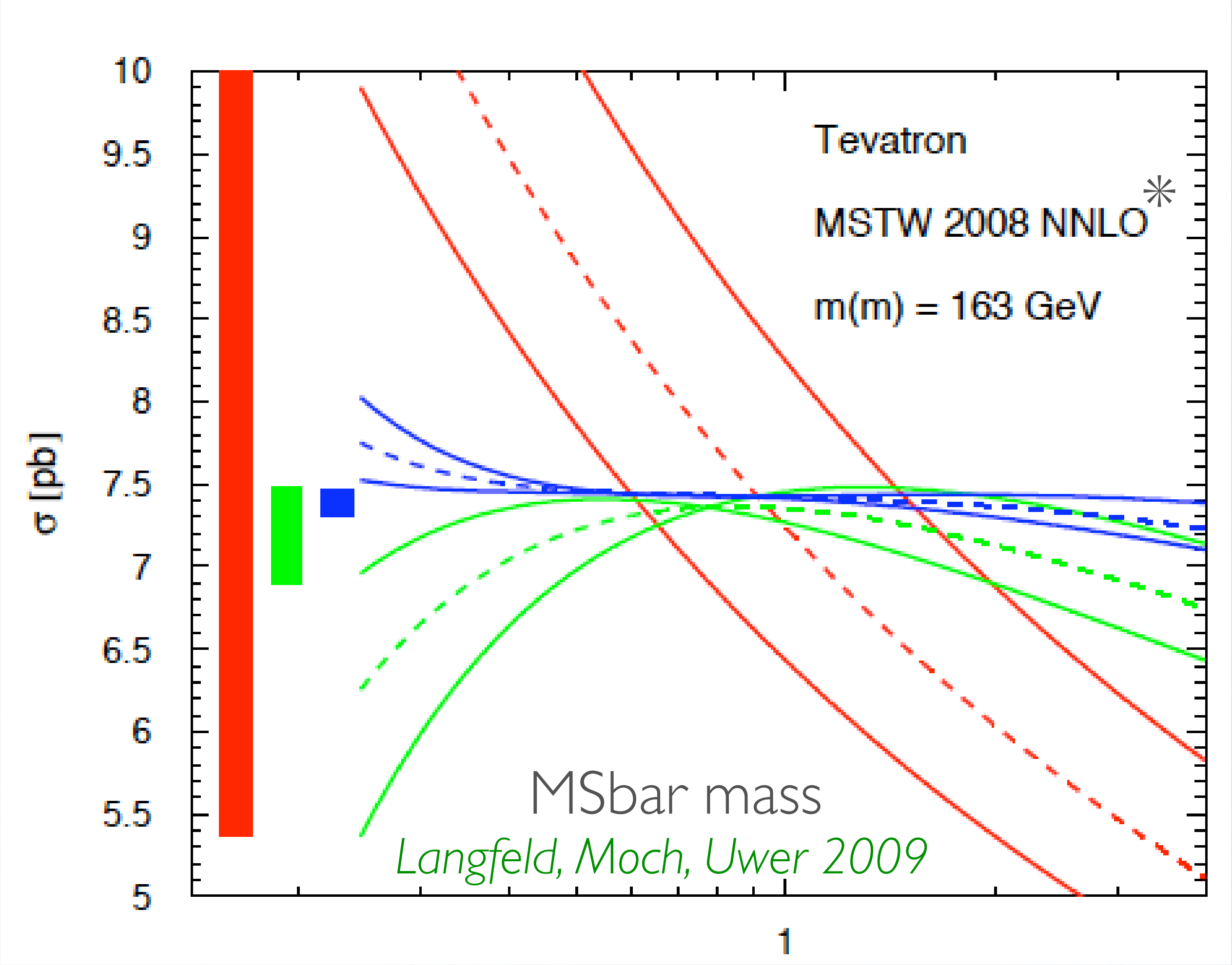

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Even better if the MSbar mass is used as a parameter in the calculation : possibility of extracting the mass from the cross section.

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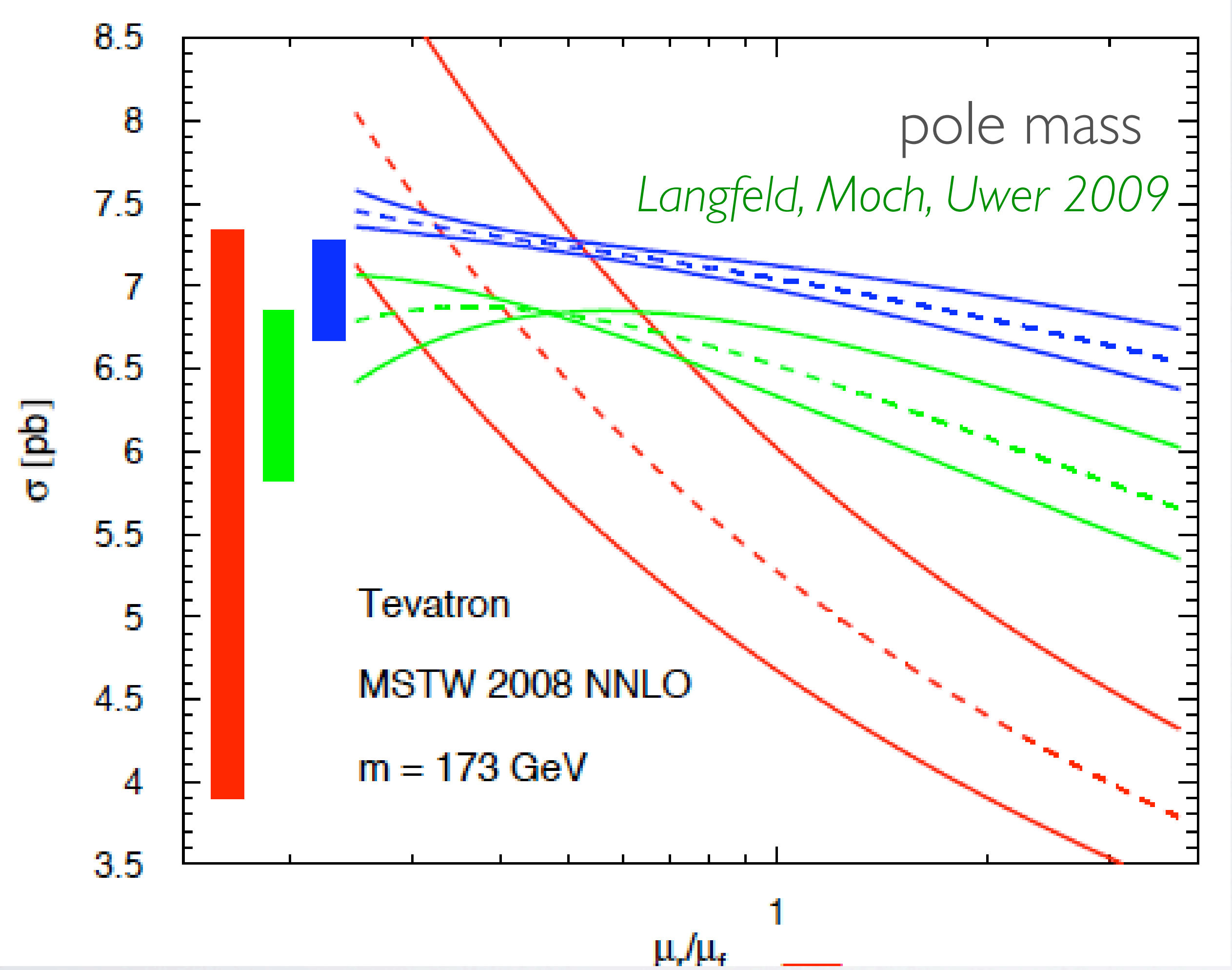

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[Cacciari, Czakon, Mangano, Mitov, Nason, 2011]

Last results at NLO+NNLL:

Tevatron

	Approximation	$\sigma_{\rm tot}$ [pb]	PDF	A	2-loop Coulomb
1	NLO	$6.681^{+0.363\,(5.4\%)}_{-0.752\,(11.3\%)}$	NLO	–	–
2	NLO+NLL	$7.070^{+0.212\,(3.0\%)}_{-0.432\,(6.1\%)}$	NLO	0	–
3	NLO+NLL	$6.930^{+0.278\,(4.0\%)}_{-0.496\,(7.2\%)}$	NLO	2	–
4	NNLO_β, $C_{ij}^{(2,0)}=0$	$7.062^{+0.240\,(3.4\%)}_{-0.334\,(4.7\%)}$	NNLO	–	–
5	NNLO_β, $C_{ij}^{(2,0)}=\overline{C}_{ij}^{(2,0)}$	$6.853^{+0.268\,(3.9\%)}_{-0.386\,(5.6\%)}$	NNLO	–	–
6	NLO+NNLL	$6.844^{+0.197\,(2.9\%)}_{-0.353\,(5.2\%)}$	NNLO	0	NO
7	NLO+NNLL	$6.722^{+0.212\,(3.2\%)}_{-0.391\,(5.8\%)}$	NNLO	2	NO
8	NLO+NNLL	$6.844^{+0.215\,(3.1\%)}_{-0.377\,(5.5\%)}$	NNLO	0	YES
9	NLO+NNLL	$6.722^{+0.243\,(3.6\%)}_{-0.410\,(6.1\%)}$	NNLO	2	YES

LHC

	Approximation	$\sigma_{\rm tot}$ [pb]	PDF	A	2-loop Coulomb
1	NLO	$158.1^{+19.5\,(12.3\%)}_{-21.2\,(13.4\%)}$	NLO	–	–
2	NLO+NLL	$174.8^{+17.6\,(10.1\%)}_{-15.3\,(8.8\%)}$	NLO	0	–
3	NLO+NLL	$167.1^{+14.3\,(8.6\%)}_{-15.4\,(9.2\%)}$	NLO	2	–
4	NNLO_β, $C_{ij}^{(2,0)}=0$	$161.2^{+11.3\,(7.0\%)}_{-10.8\,(6.7\%)}$	NNLO	–	–
5	NNLO_β, $C_{ij}^{(2,0)}=\overline{C}_{ij}^{(2,0)}$	$154.0^{+12.0\,(7.8\%)}_{-8.6\,(5.6\%)}$	NNLO	–	–
6	NLO+NNLL	$161.5^{+14.5\,(9.0\%)}_{-12.3\,(7.6\%)}$	NNLO	0	NO
7	NLO+NNLL	$155.9^{+11.5\,(7.4\%)}_{-13.0\,(8.3\%)}$	NNLO	2	NO
8	NLO+NNLL	$164.7^{+15.0\,(9.1\%)}_{-12.8\,(7.8\%)}$	NNLO	0	YES
9	NLO+NNLL	$158.7^{+12.2\,(7.7\%)}_{-13.5\,(8.5\%)}$	NNLO	2	YES

* Best improved results basically the same as those from standard NLO both Tevatron and LHC

* Nothing more to squeeze out from improved, partial, resummed results. The only improvement now can come from the true NNLO corrections which should be expected soon.

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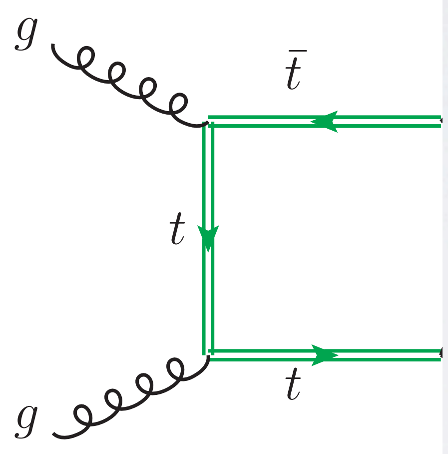

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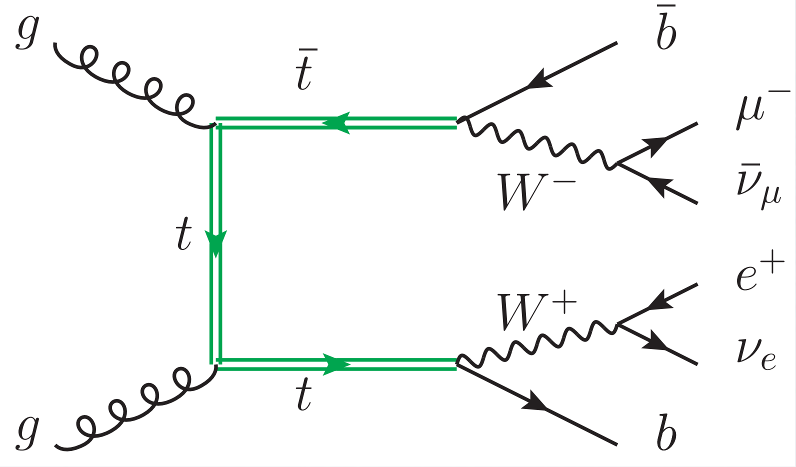
- However, top quarks decay, so the true LO diagram is this one



PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 2: WWBB

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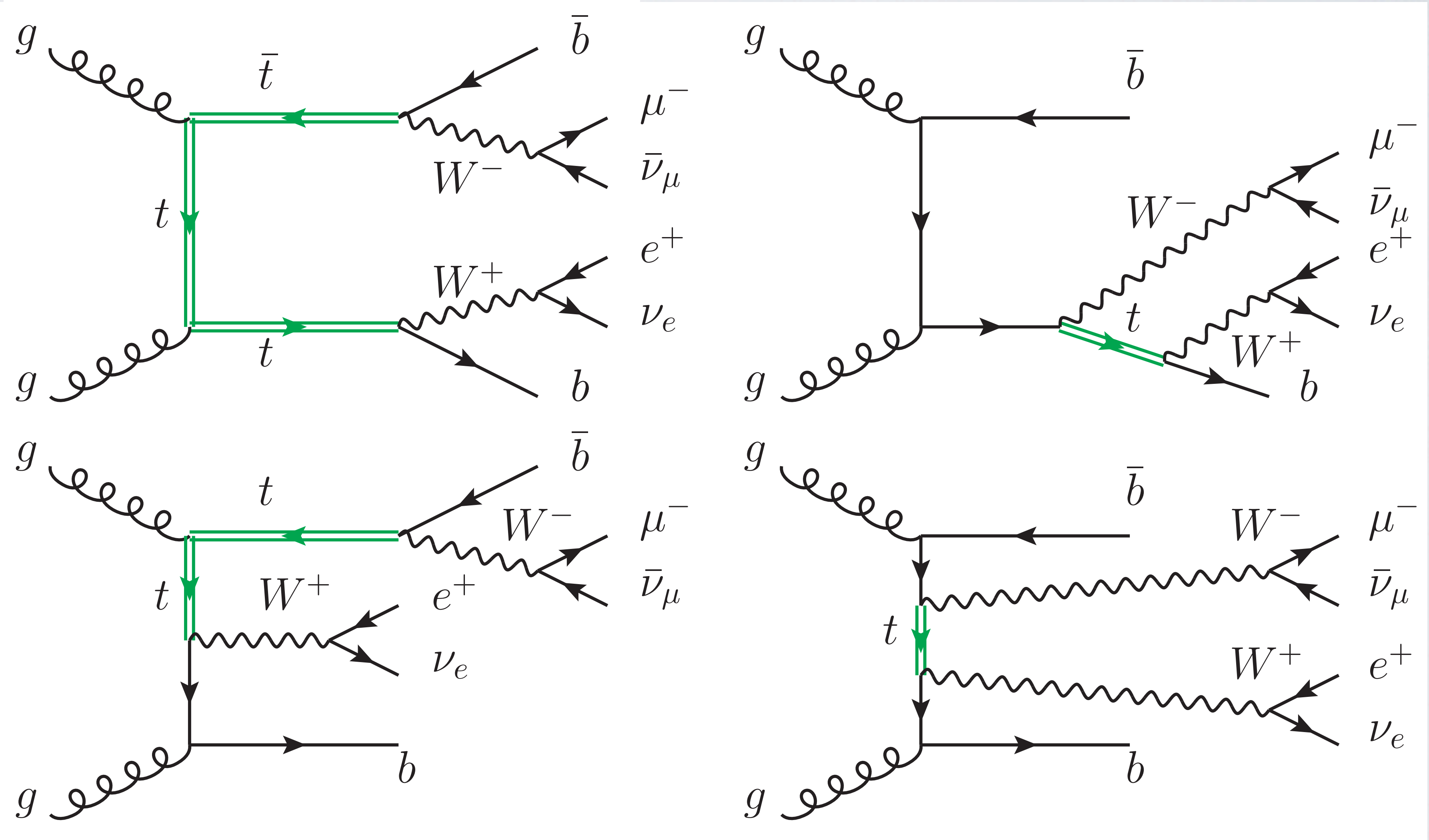
- In fact, there are quite a few more diagrams of the same order...



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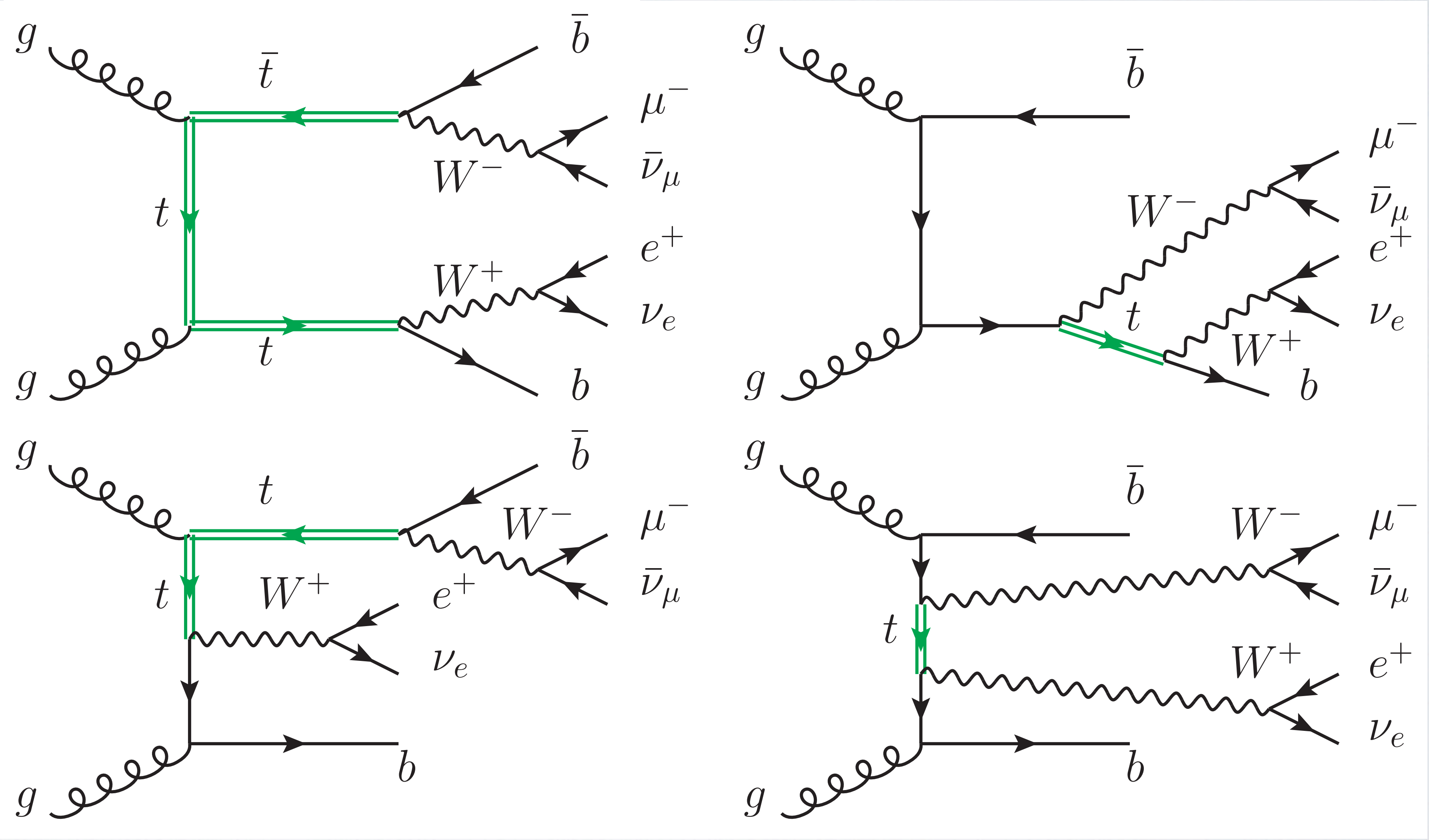
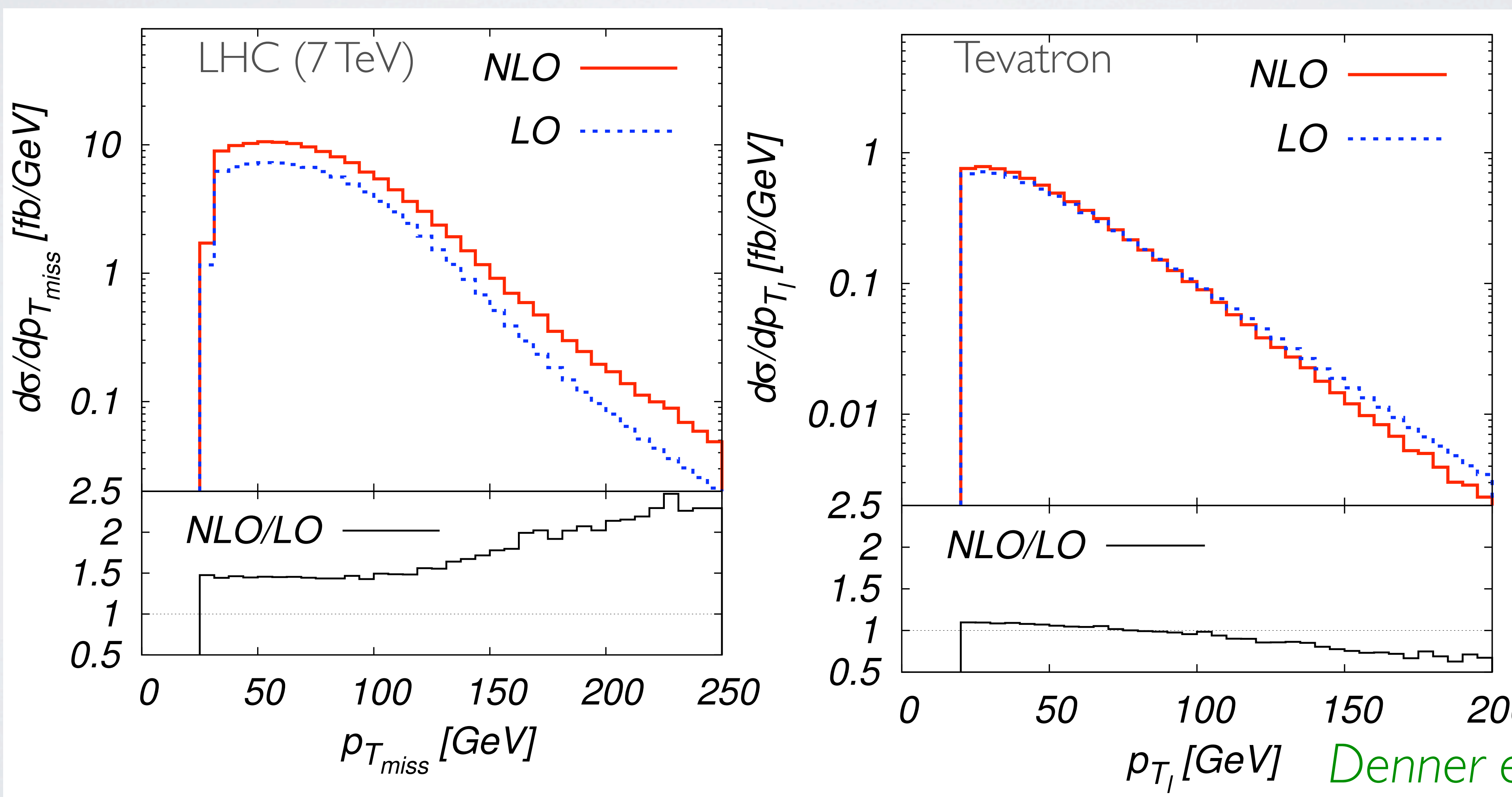


- Gauge invariance guides us to include also single-resonant and non-resonant production. Note that there is interference between the diagrams above

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 2: WWBB

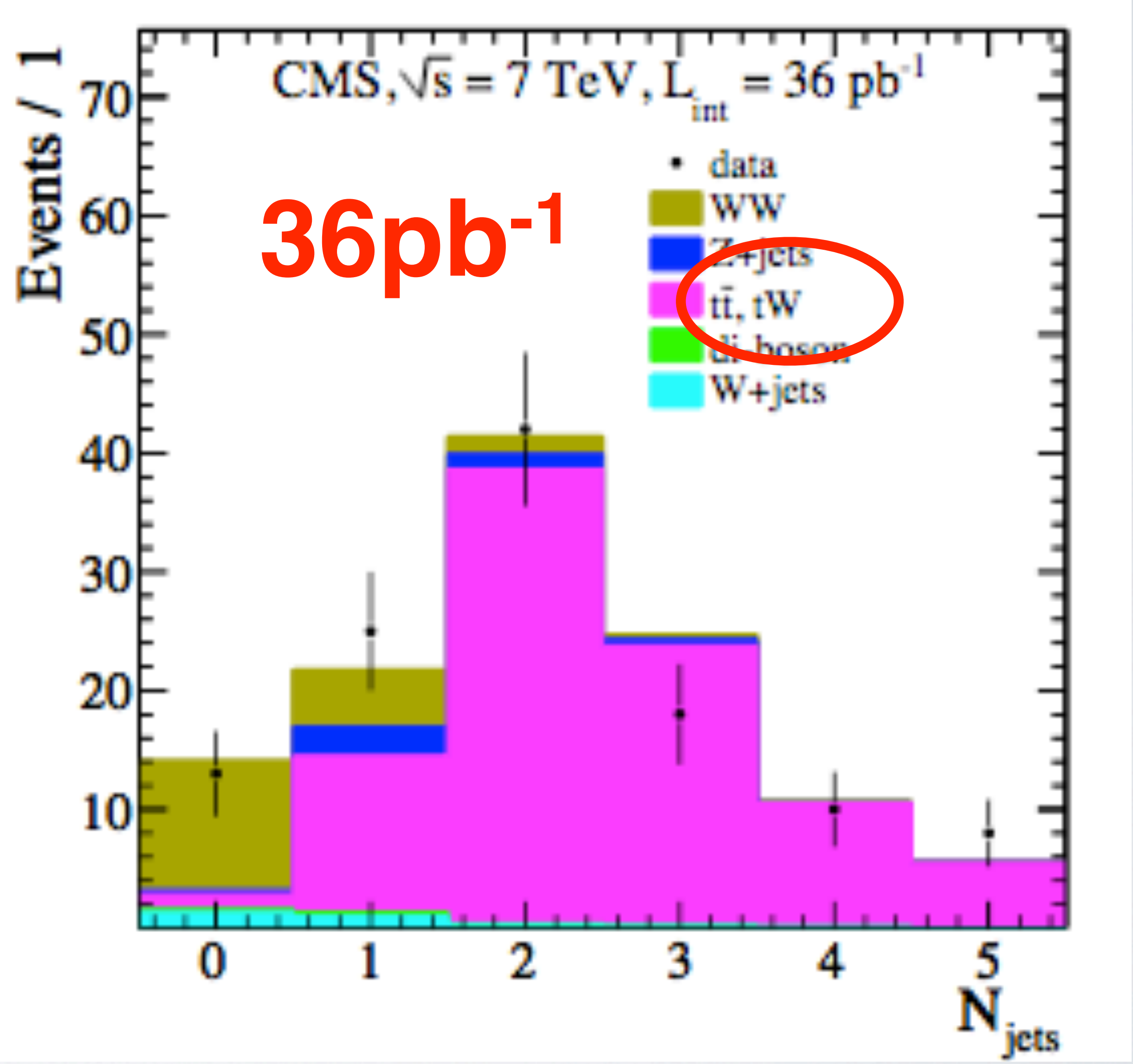
- Recently, the full NLO computations to the WWbb process **(with mb=0)** were calculated by two independent groups. [Denner et al.; Bevilacqua et al.]
- Compared to the LO WWbb production, the NLO corrections do **not** lead to an overall change in normalization:



Denner et al.

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 2: WWBB

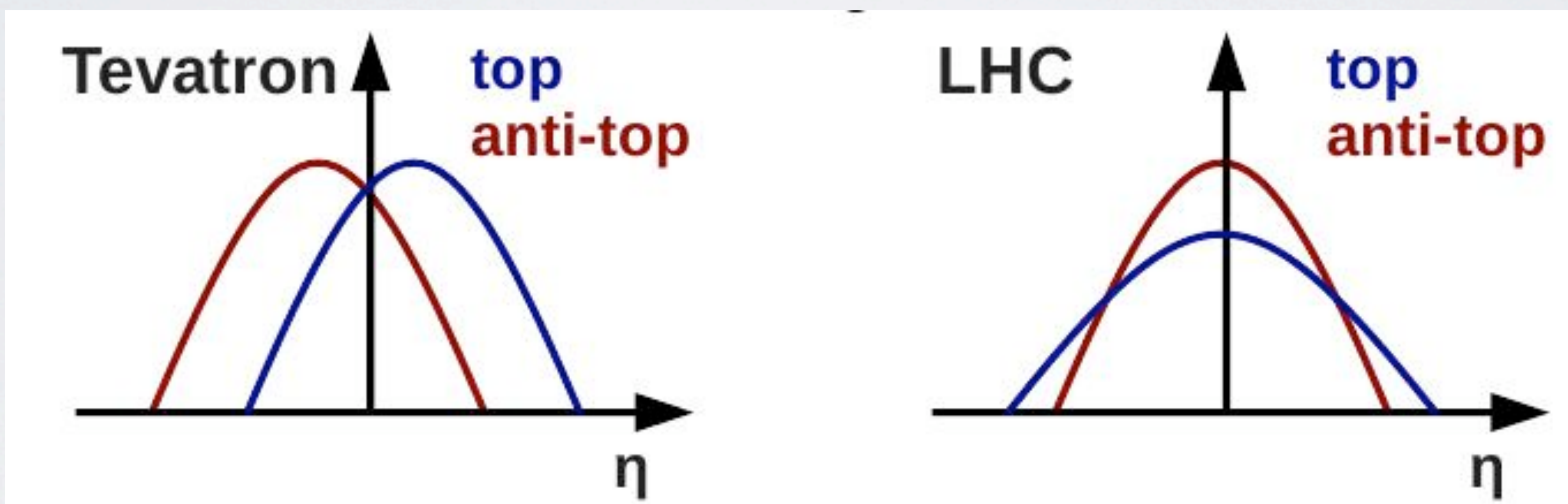
- A full calculation **with $m_b \neq 0$** would have a much larger phenomenological impact
- Consistent description of top pair, single top and non-resonant contributions at NLO
- Particularly important when cuts require tops to be off-shell
- No need to disentangle top pair and Wt and apply separate K-factors when studying the "top" background to e.g. H → WW.



Add it to the desiderata...

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

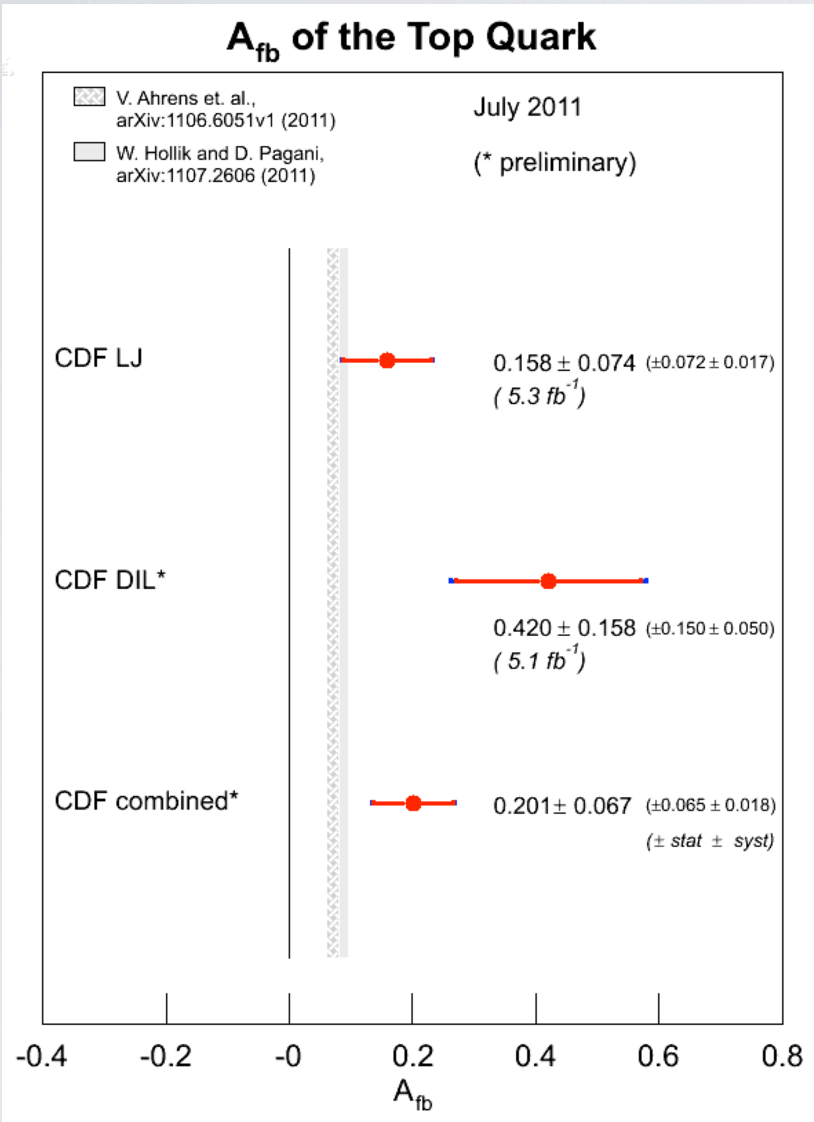
$$A_{CC}^{t\bar{t}} = \frac{\sigma(\Delta y > 0) - \sigma(\Delta y < 0)}{\sigma(\Delta y > 0) + \sigma(\Delta y < 0)}$$



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

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.]

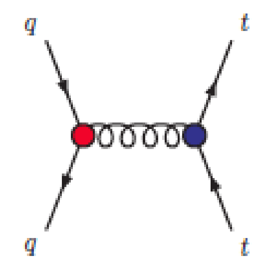
PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: COLOR CHARGE ASYMM.



	$M_{t\bar{t}} < 450$ 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

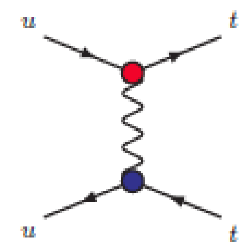
Most popular models

[Aguilar-Saavedra, top2011]



s channel:

$\mathcal{G}_\mu \sim (8,1)_0$ 0809.3354 , 0906.0604 , 0911.2955 , 1007.0243 , 1011.6380 , 1011.6557 , 1101.2902 , 1101.5203 , 1103.0956 1104.1917 , 1105.3158 , 1105.3333 , 1106.0529 , 1106.4054 , 1107.0978 , 1107.1473 , 1107.2120 , 1107.5769 , 1109.0648

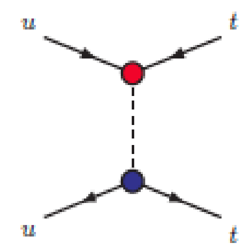


t channel:

$Z' \sim (1,1)_0$ 0907.4112 , 1101.4456 , 1101.5625 , 1102.0545 , 1103.1266 1103.4835 , 1104.1385 , 1104.3139 , 1106.5982 , 1108.0350 , 1108.1802

$W' \sim (1,1)_1$ 0908.2589 , 1002.1048 , 1003.3461 , 1101.1445 , 1101.5392 , 1102.0279 1104.0083 , 1105.4606

$\phi \sim (1,2)_{-\frac{1}{2}}$ 1104.4782 , 1107.0841 , 1107.4350 , 1108.4005



u channel:

$\omega^4 \sim (3,1)_{-\frac{4}{3}}$

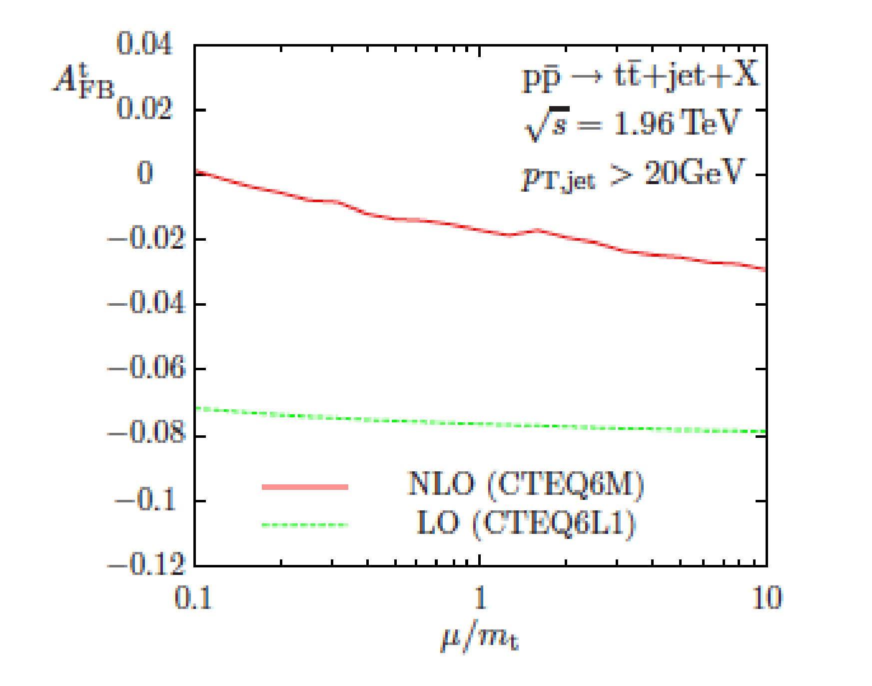
$\Omega^4 \sim (\bar{6},1)_{-\frac{4}{3}}$

0911.3237 , 0911.4875 , 0912.0972 , 1007.2604 , 1102.3374 , 1102.4736 , 1103.2757 , 1108.4027

PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: 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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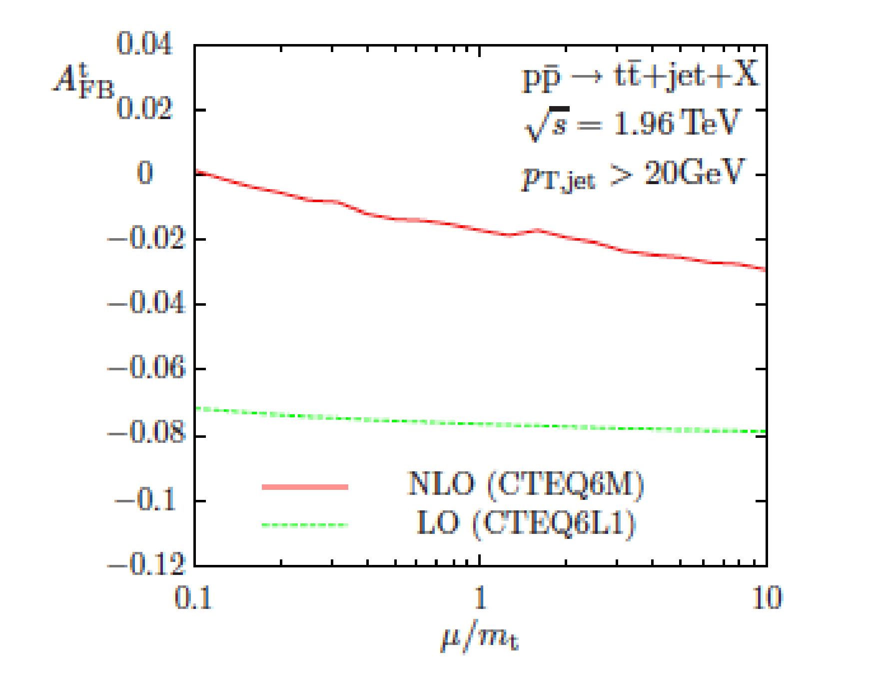
α_S^4 (NNLO) calculation for the sigma(ttbar) not available yet.

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. (?) *[Melnikov & Schulze, 2010]*

3. EW corrections are small *[Kuhn & Pagani 2011]*



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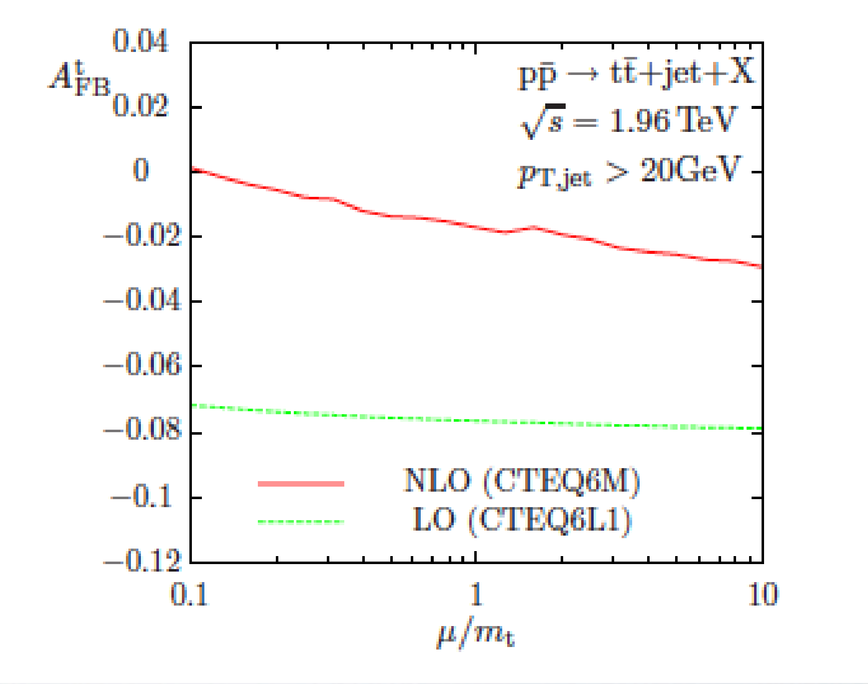
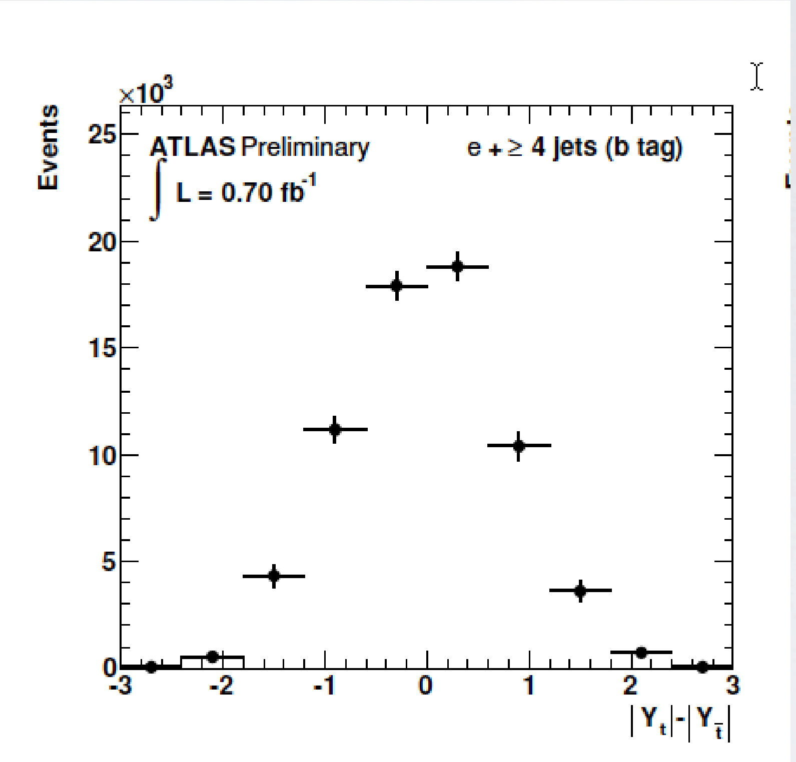
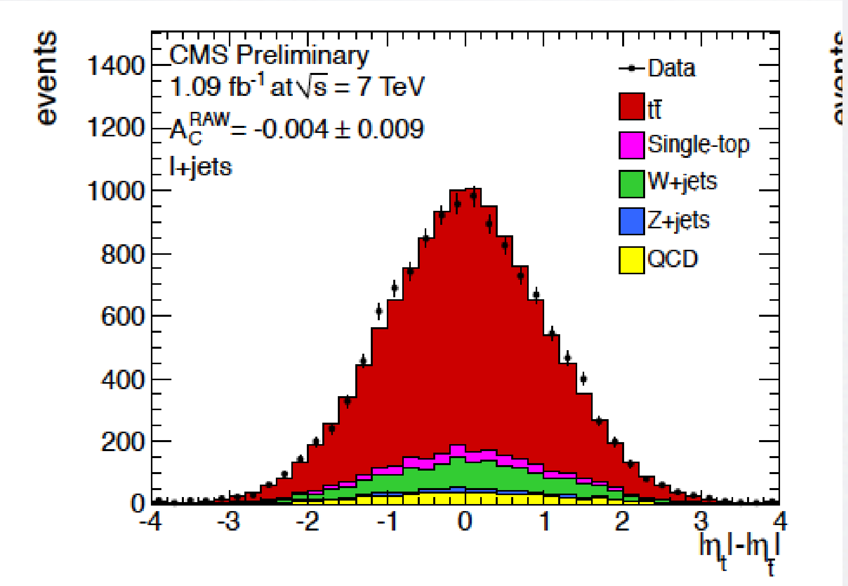


Note, on the other hand, the interesting pattern:
t tbar : LO=0 + Virtual>0 (large) + Real<0 (small) = 0.05
t tbar j : LO<0 (-0.08) + Virtual>0 (large) + Real<0 (small) = -0.02
t tbar jj : LO <0
Virtuals always dominate : what about the two-loop contributions? to be seen...

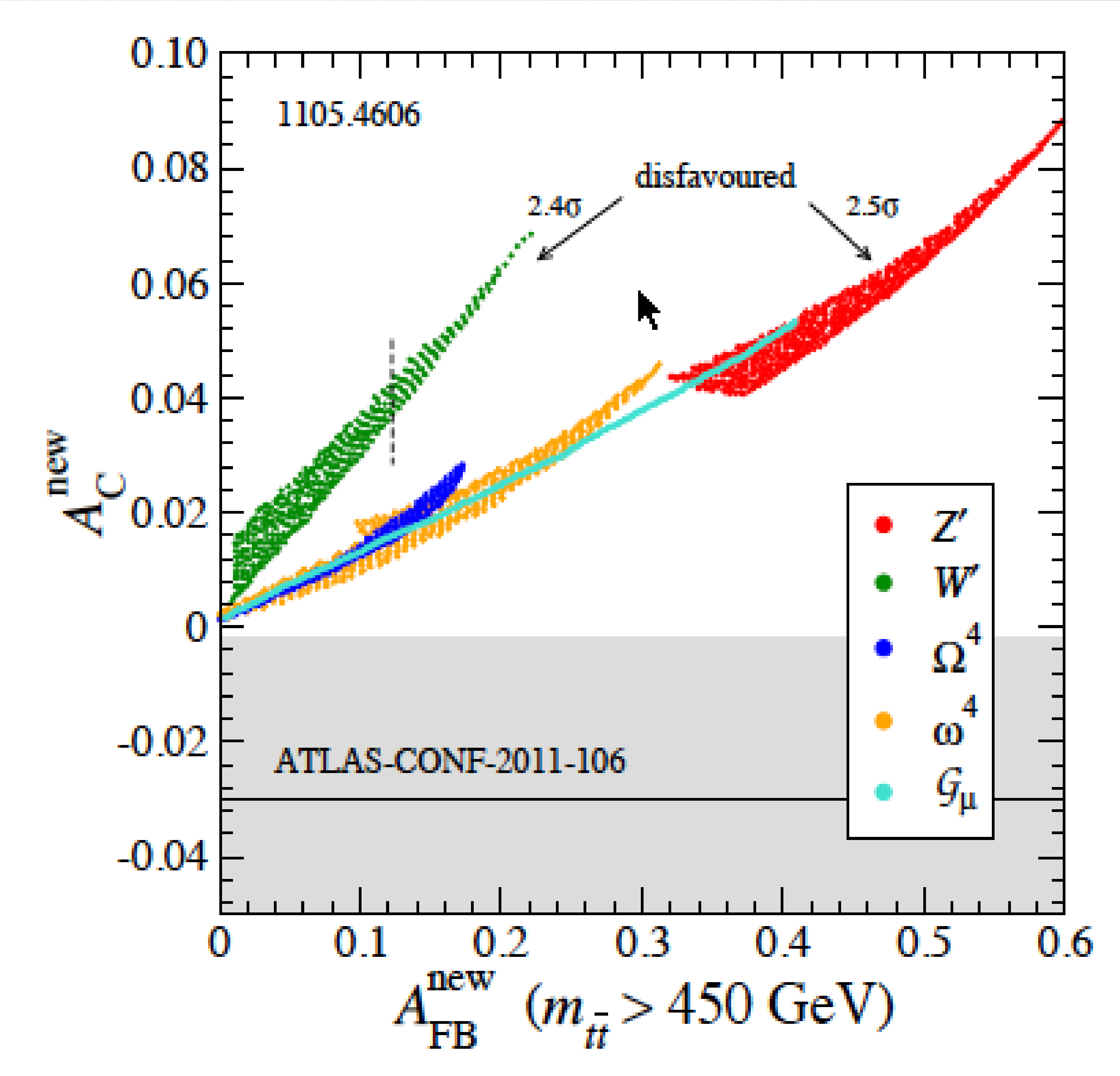
PROGRESS IN SM TOP PREDICTIONS: EXAMPLE 3: COLOR CHARGE ASYMM.



$A_C = -0.024 \pm 0.016\ (\mathrm{stat}) \pm 0.023\ (\mathrm{syst}),$



$A_C^{\eta} = -0.016 \pm 0.030\ (\mathrm{stat.})^{+0.010}_{-0.019}\ (\mathrm{syst.})$



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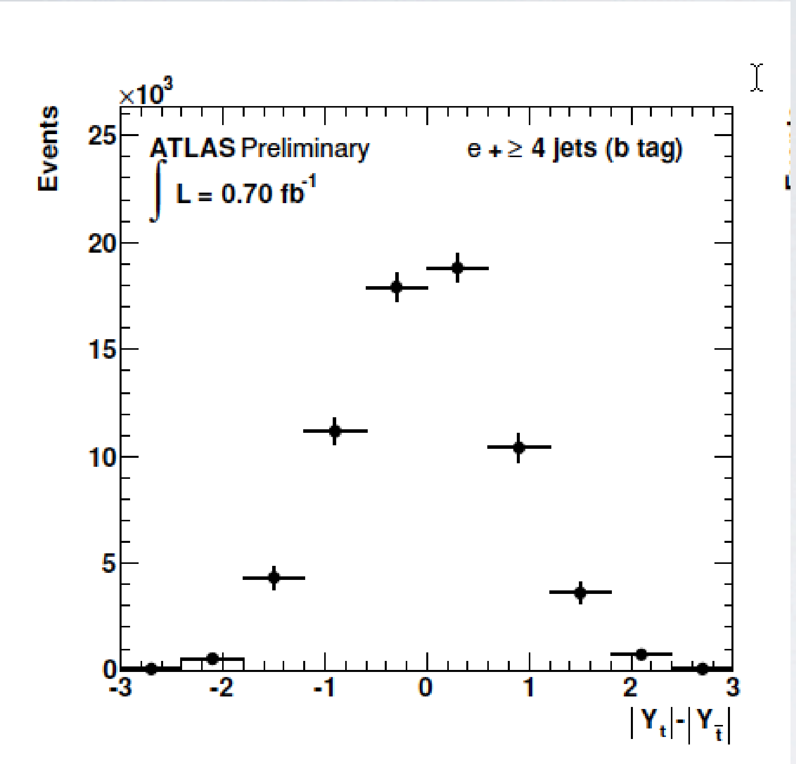

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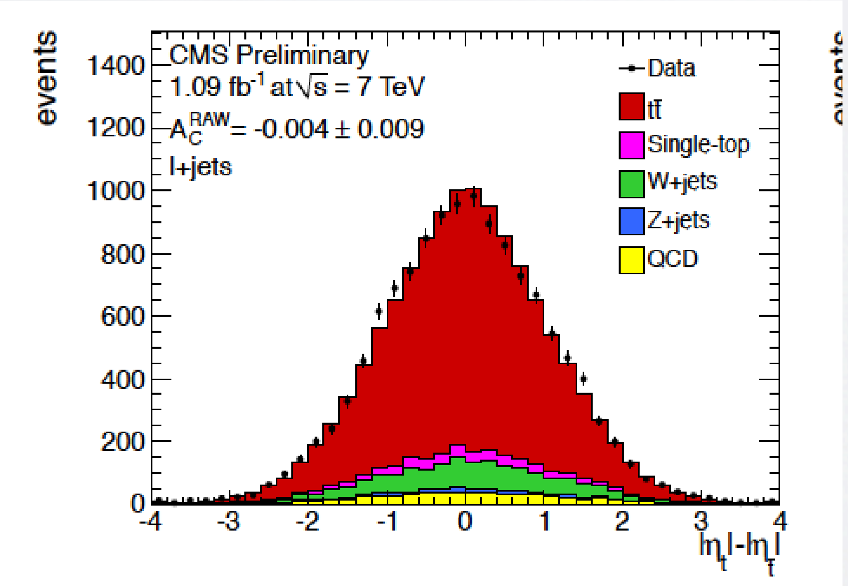

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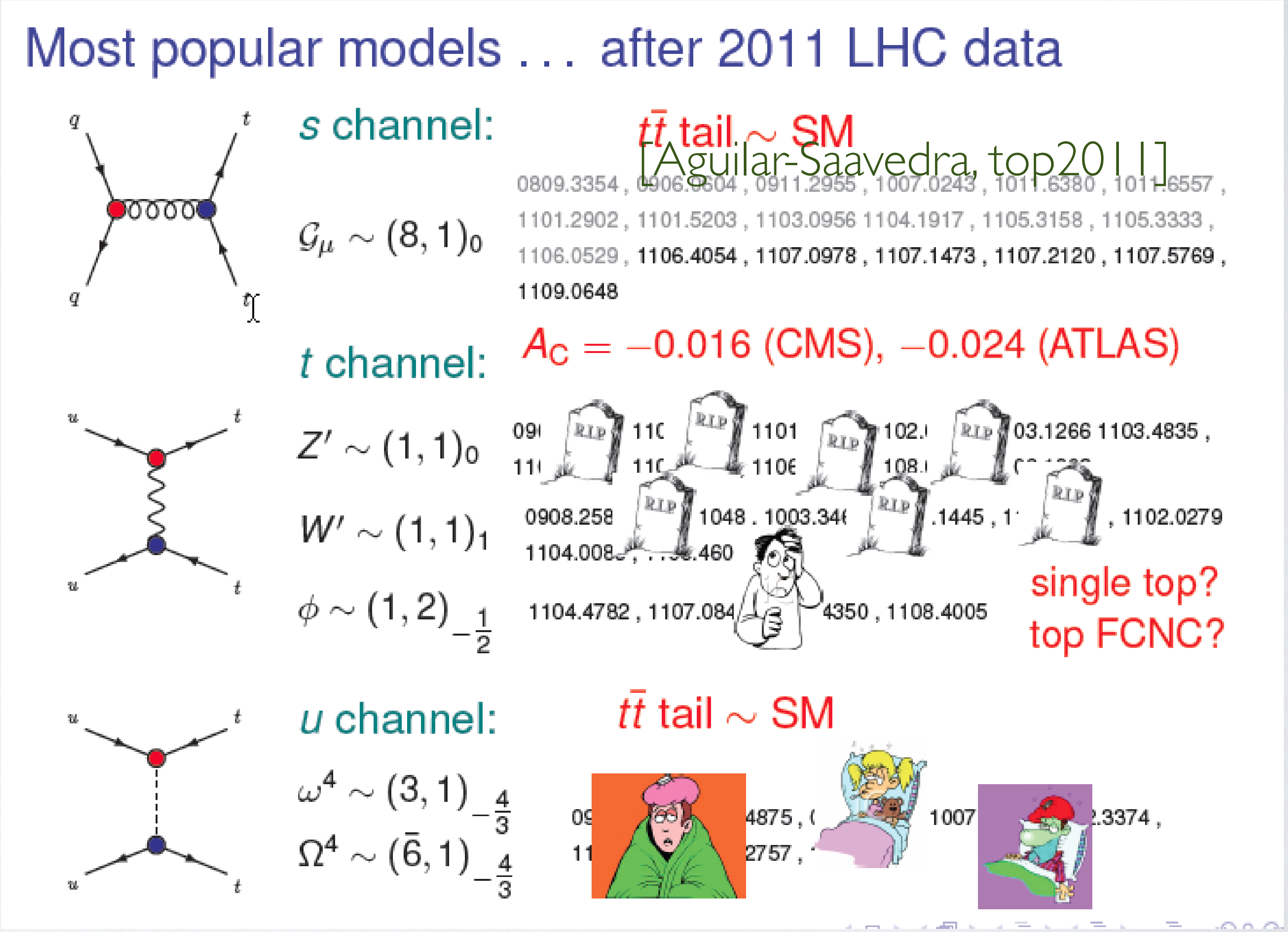

OUTLINE

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

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

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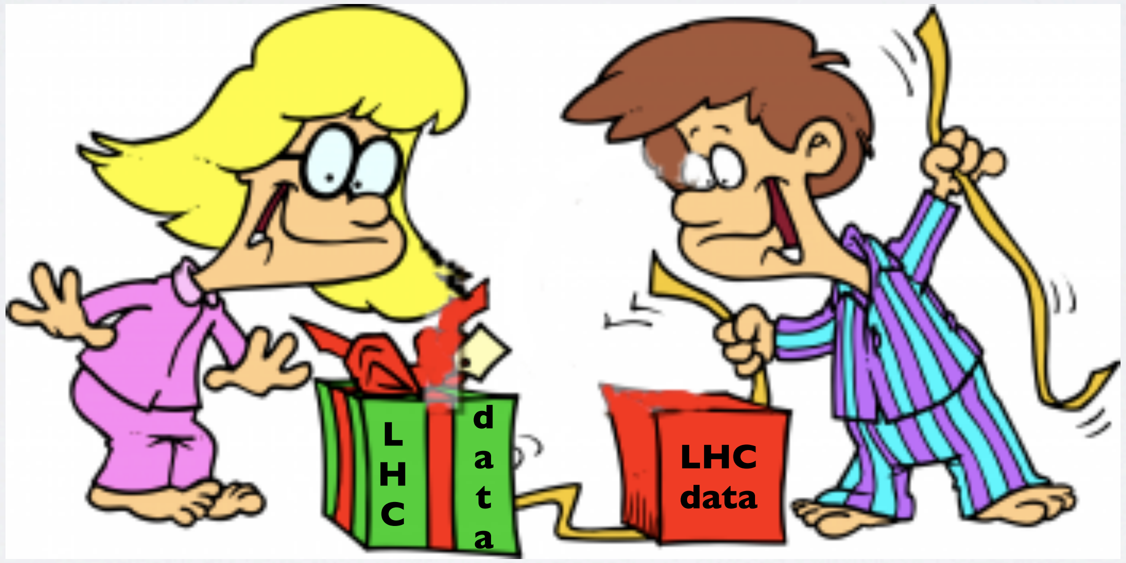


BSM : TOP-DOWN APPROACH

New Physics

Signatures/Observables

BSM : TOP-DOWN APPROACH

New Physics

↓

Signatures/Observables

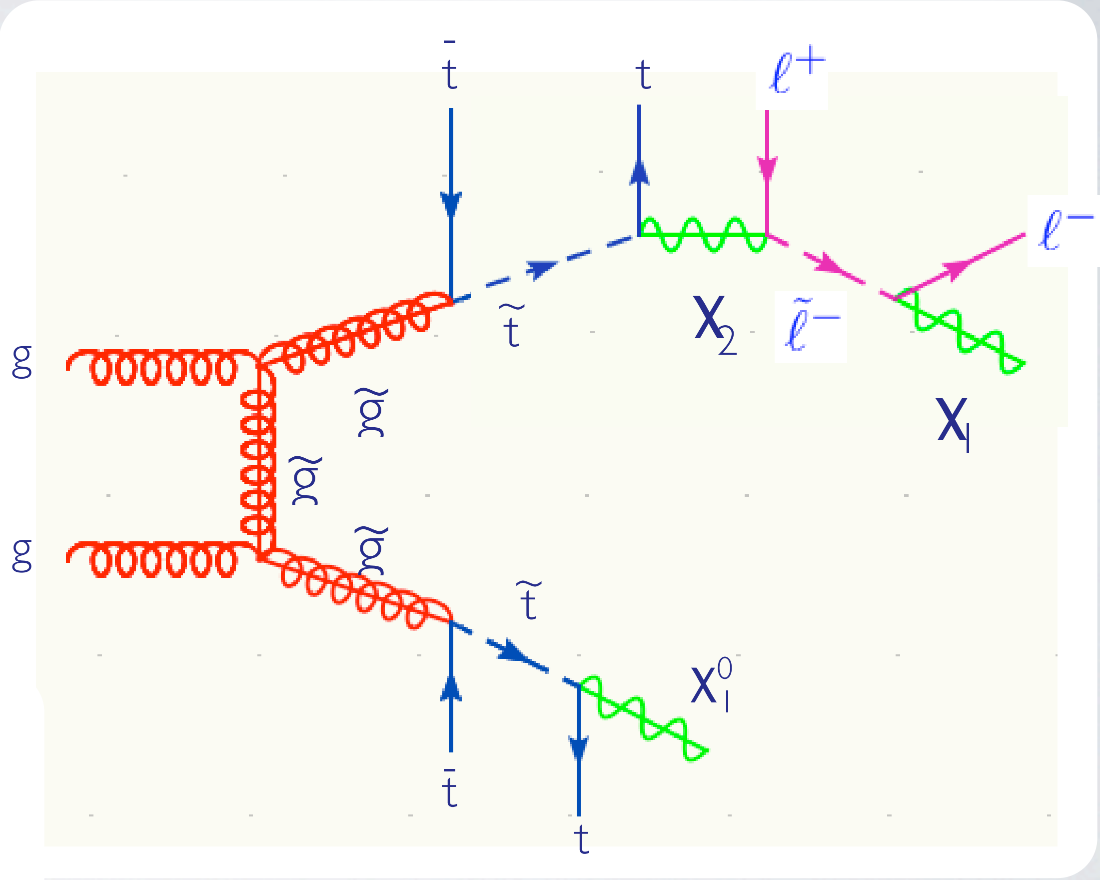
BSM : TOP-DOWN APPROACH

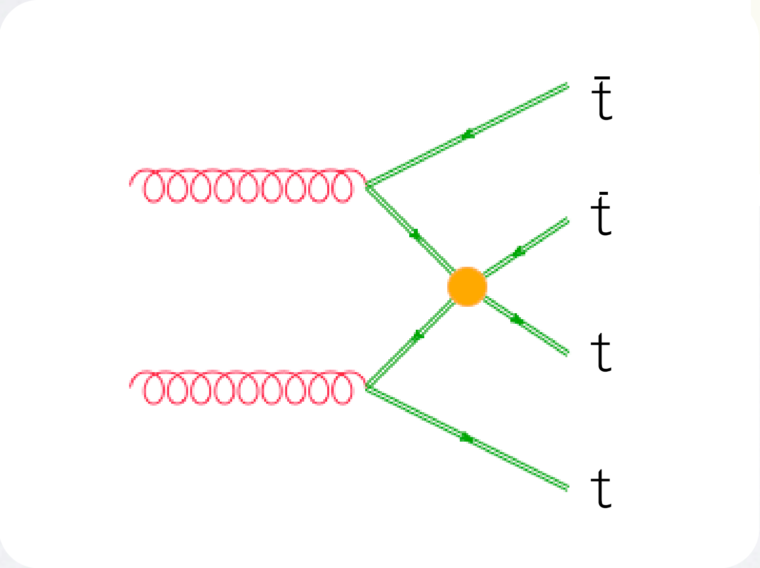
* New Physics model with top partners (SUSY, UED, LH, 4th Gen..)
* Consider viable benchmark points.
* Identify the signatures with top.
* Set exclusion limits on the model parameters
* Optional : learn "model independent" lessons...

BSM : TOP-DOWN APPROACH

Examples: signatures with top:

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

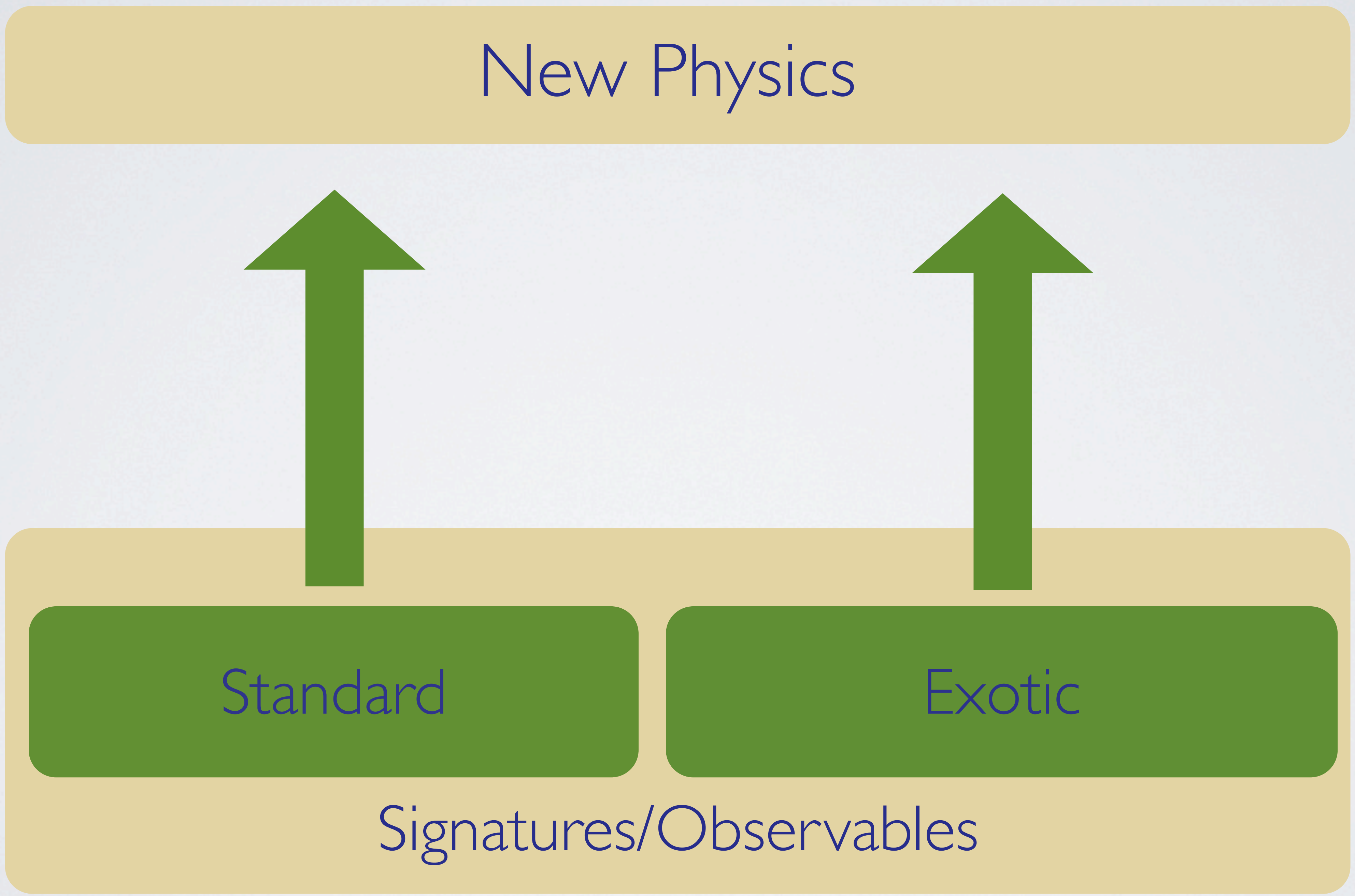
New Physics

Standard

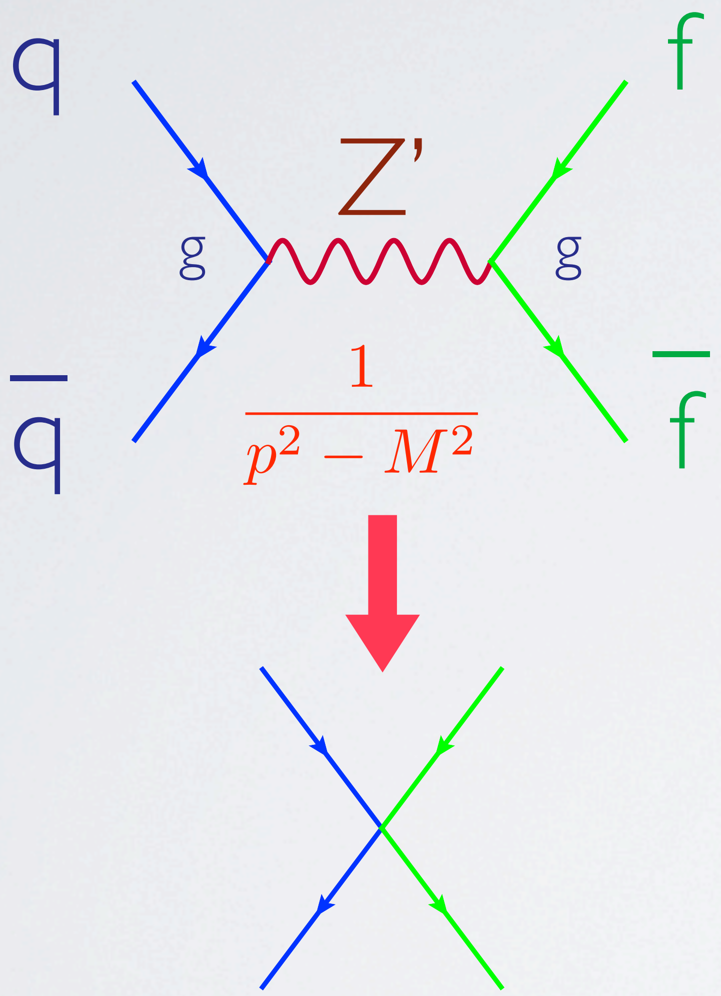
Exotic

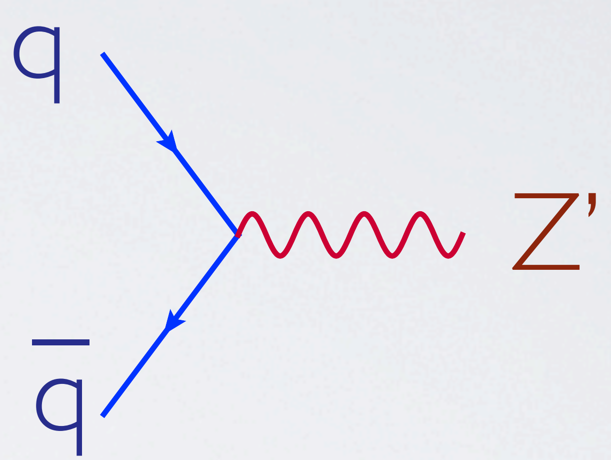
Signatures/Observables

Bottom-up approach



New Physics : Two possibilities





New Physics

Energy

$\Lambda = M$

New Physics : Two possibilities

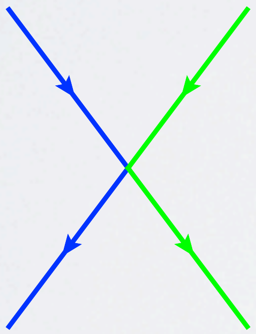
$$\hbar = c = 1$$

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

$$\dim \phi = 1$$

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

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



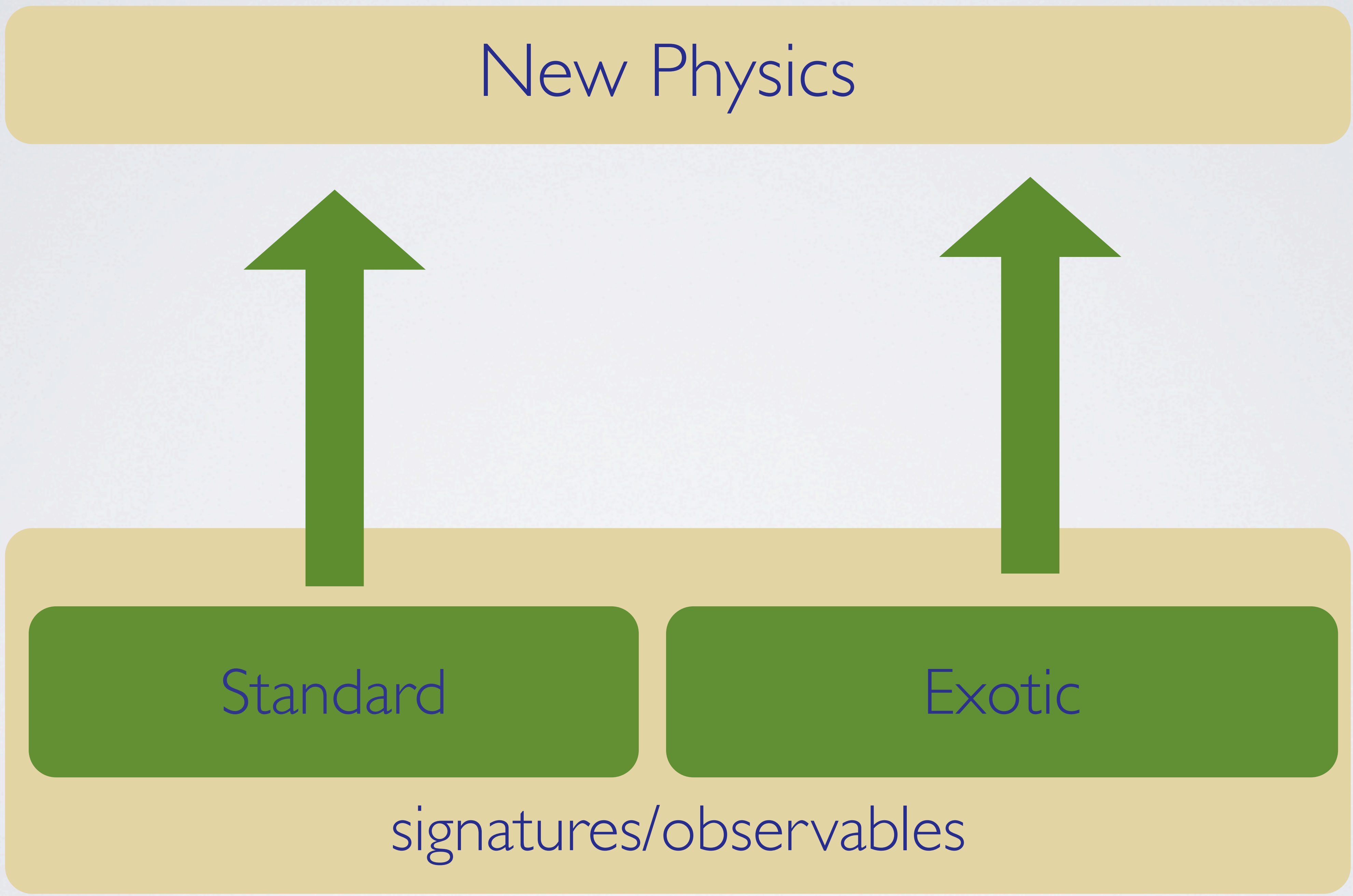
$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{\mathrm{dim}=6}$$

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

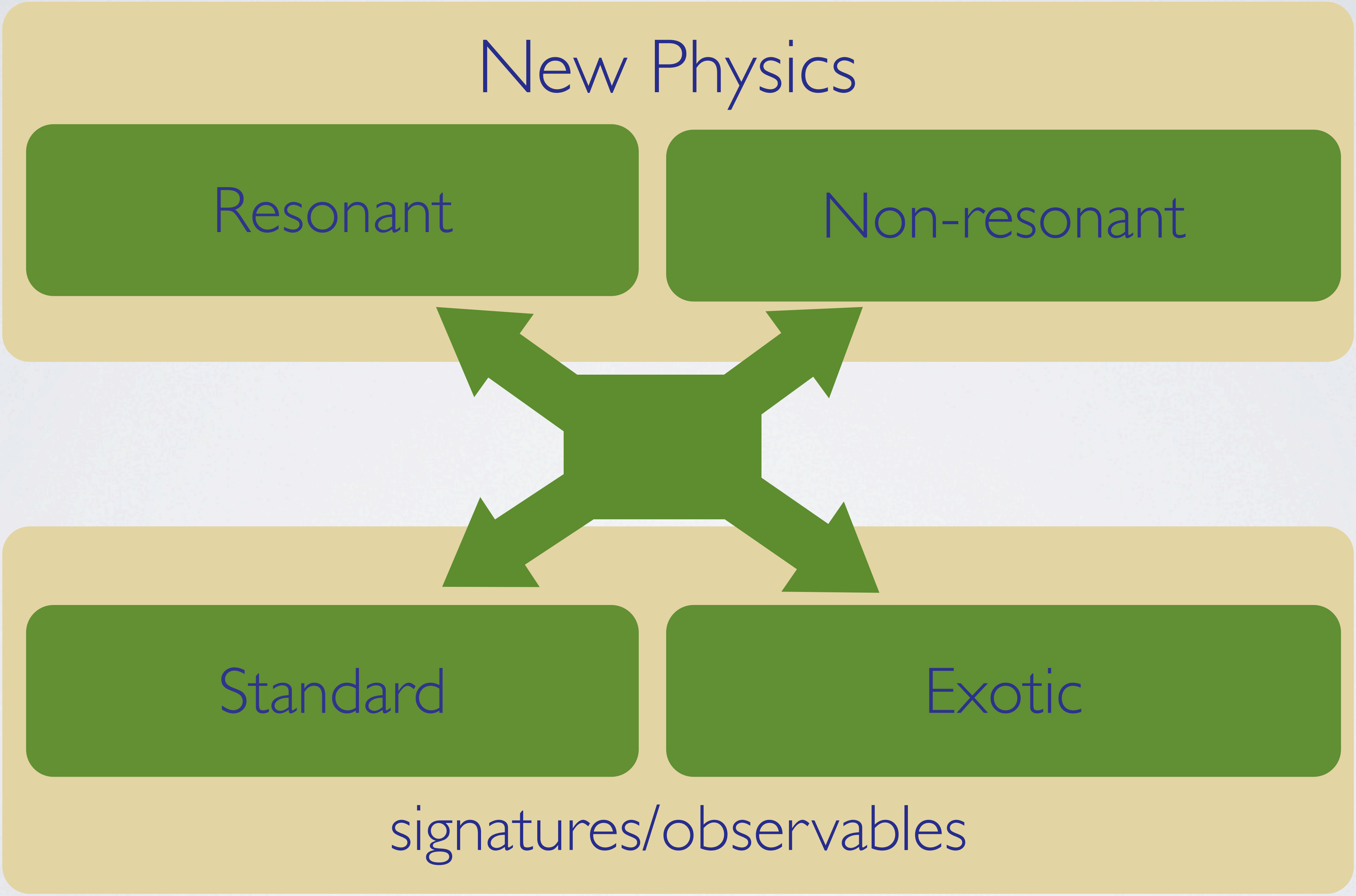
Bottom-up approach

New Physics

Resonant	Non-resonant
Standard	Exotic

signatures/observables

Bottom-up approach



MODEL INDEPENDENT BSM SEARCHES: EXAMPLES

I. EFT approach to ttbar

II. Exotic

  A. Same sign tops

  B. Monotops

  C. BNV

MODEL INDEPENDENT BSM SEARCHES: EXAMPLES

I. EFT approach to ttbar $\Rightarrow 2\mathrm{Re}(A_{SM} \cdot A^{\dagger}_{BSM})$

II. Exotic

A. Same sign tops

B. Monotops $\Rightarrow |A_{BSM}|^2$

C. BNV

MODEL INDEPENDENT BSM SEARCHES: EXAMPLES

I. EFT approach to ttbar

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MODEL INDEPENDENT BSM SEARCHES: EXAMPLES

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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)

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

CP-even

operator	process
$O^{(3)}_{\phi q} = i(\phi^+ \tau^I D_\mu \phi)(\bar{q}\gamma^\mu \tau^I q)$	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
$O^{(1,3)}_{qq} = (\bar{q}^i \gamma_\mu \tau^I q^j)(\bar{q}\gamma^\mu \tau^I q)$	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

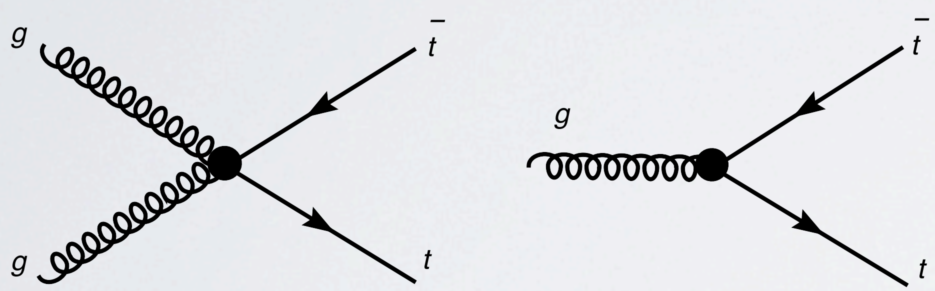
operator	process
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu}$ (with imaginary coefficient)	top decay, single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi}G^A_{\mu\nu}$ (with imaginary coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_{\tilde{G}} = f_{ABC}\tilde{G}^{A\nu}_\mu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

TTBAR PRODUCTION

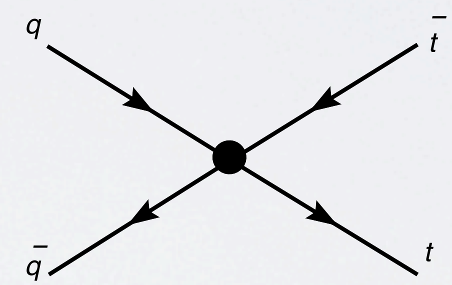
One can show that you end up with five main operators,

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

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 $a_A = a_R - a_R$

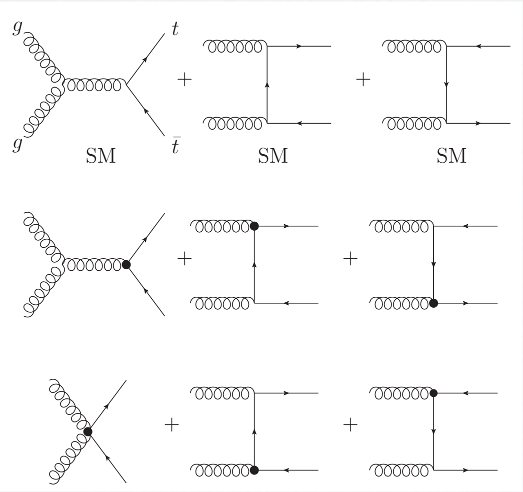


Chromomagnetic operator $\mathcal{O}_{hg} = (H\bar{Q})\sigma^{\mu\nu}T^A t\; G^A_{\mu\nu}$

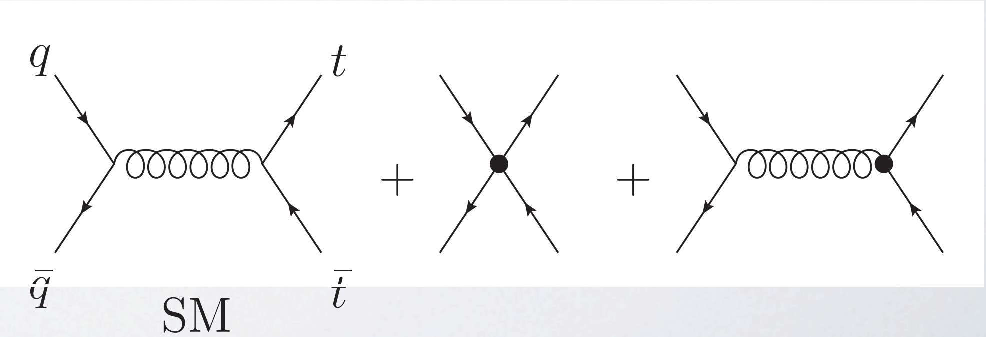


Four-fermion operators

gluon fusion
corrections from c_{hg} only



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



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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1. Extremely simple formulas!!

Effective Field Theory Approach to t tbar production

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

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

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

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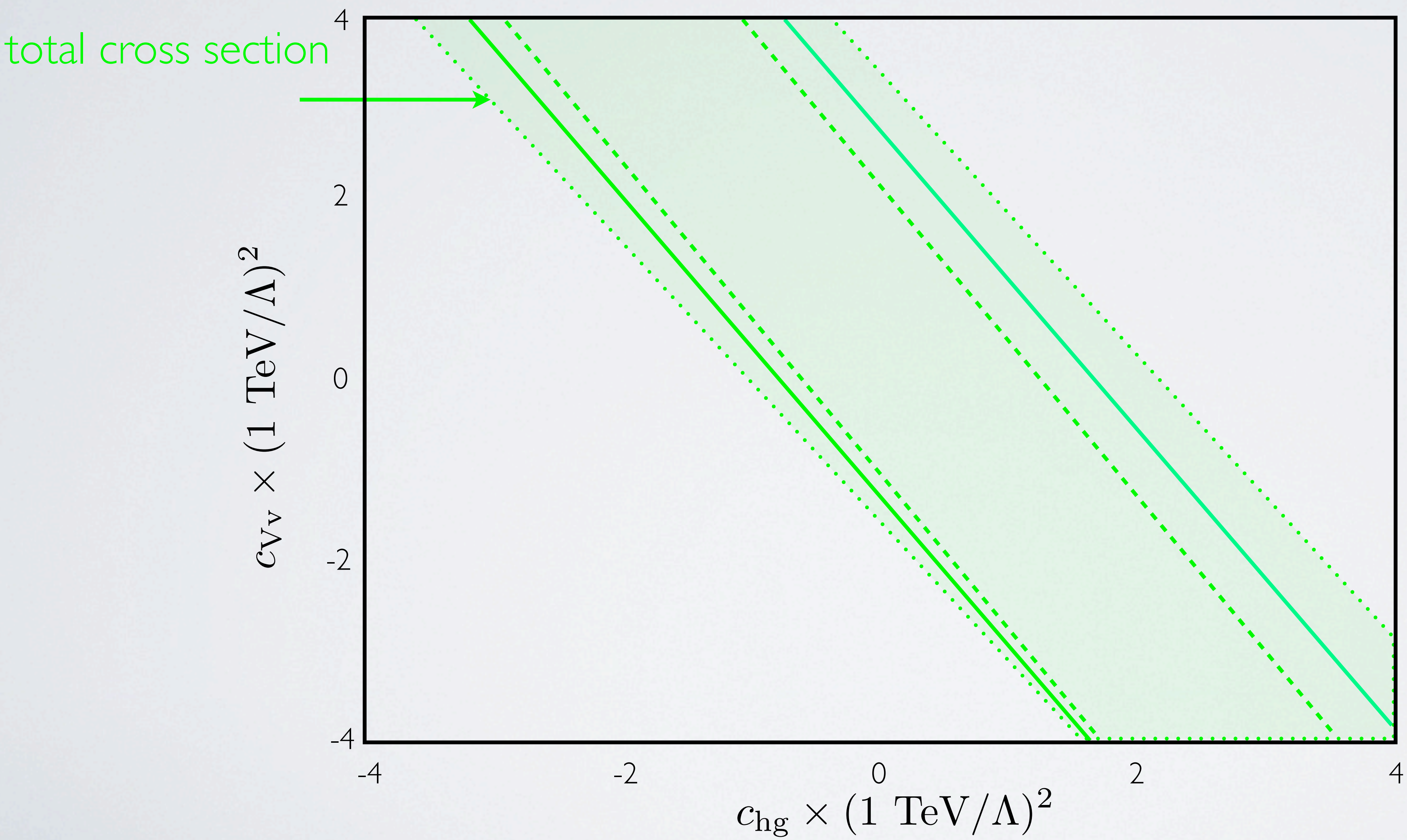
1. Extremely simple formulas!!
2. The operator O_{hg} can hardly be distinguished from the SM in gluon fusion
3. Distortions in the shape of the distributions can only come from qq annihilation ➞ small effects at LHC
4. Even and odd contributions for qq ➞ ttbar, the latter give rise to A_{FB}

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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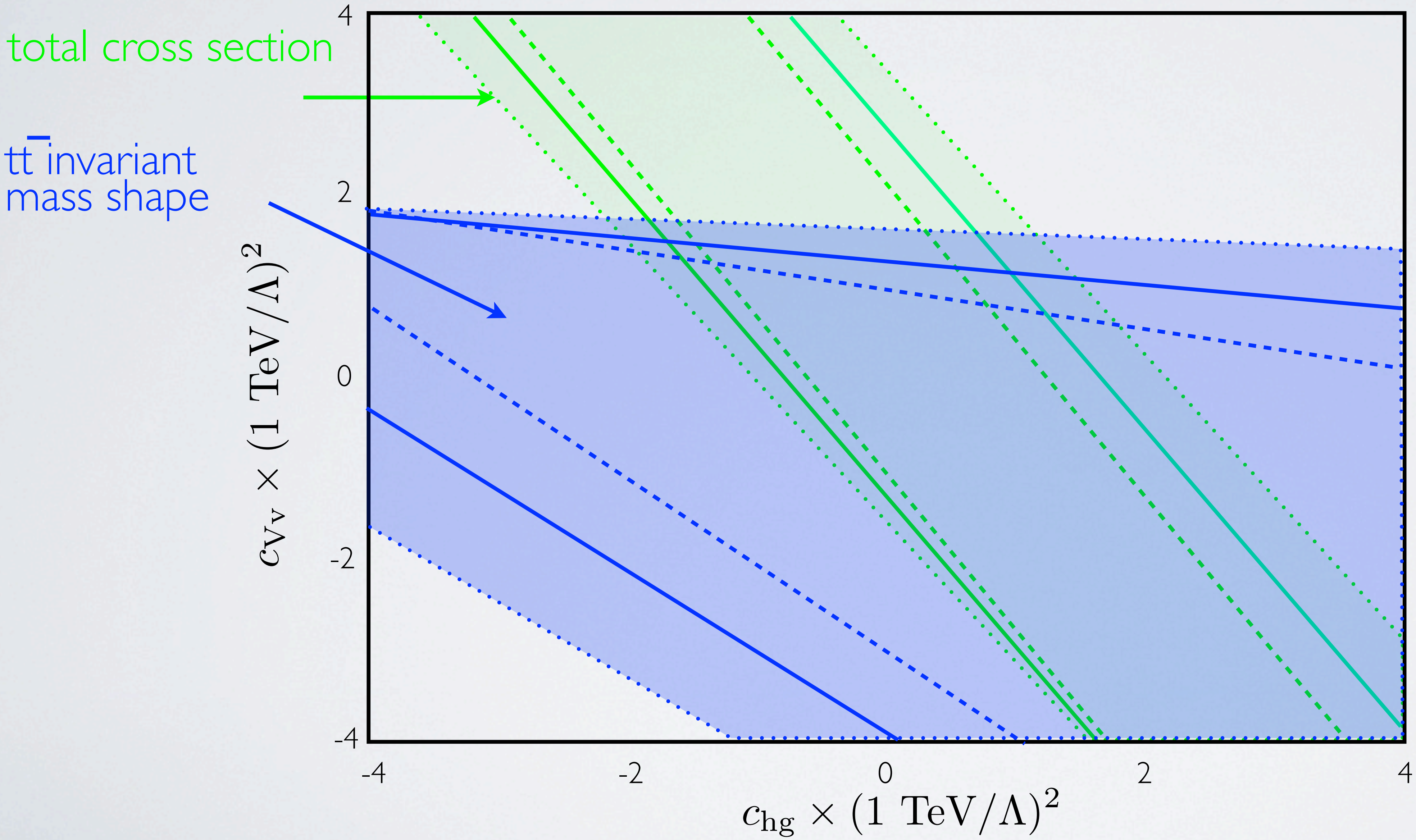
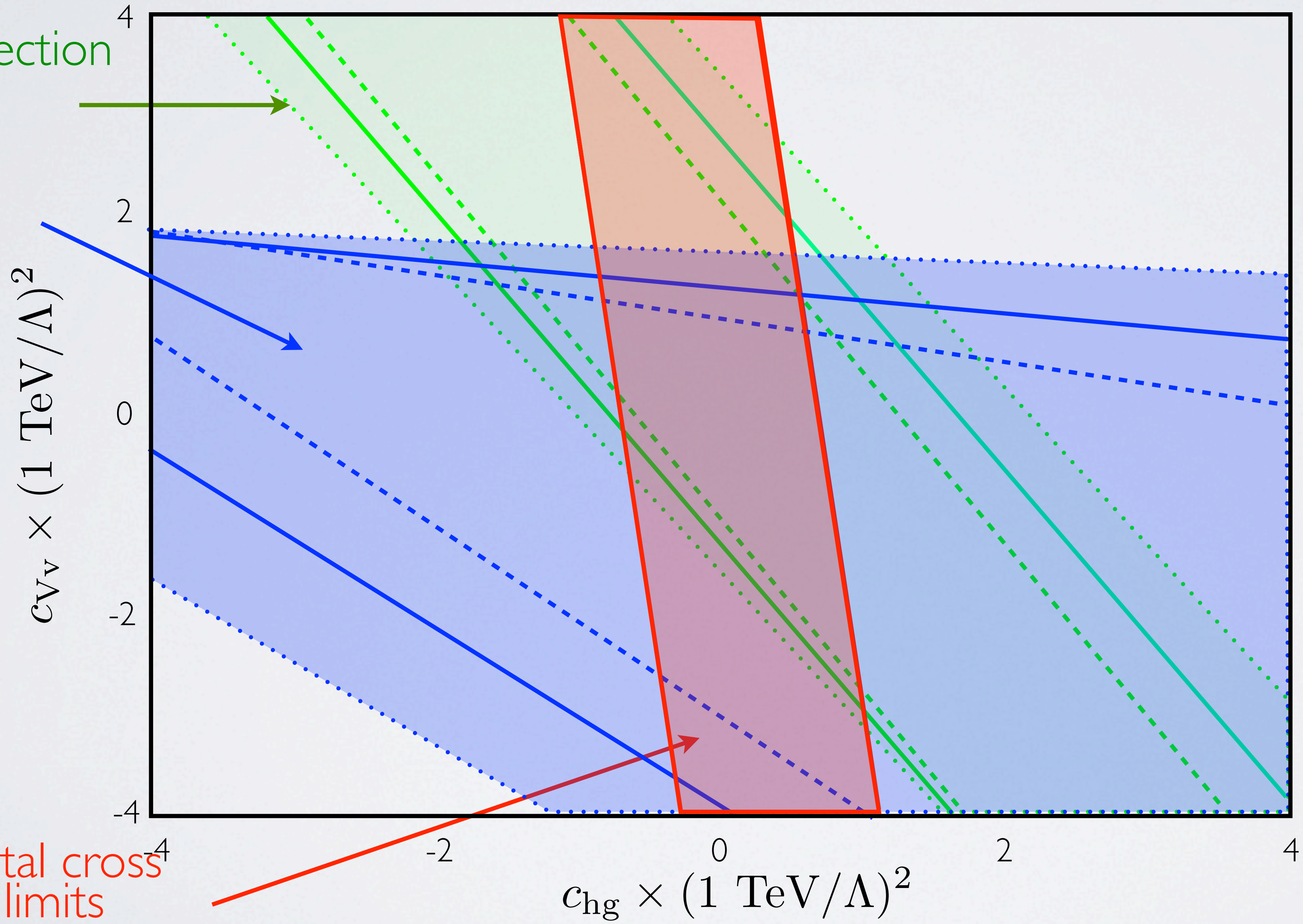


Effective Field Theory Approach to t tbar production

- 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}

total cross section

tt invariant mass shape



LHC total cross section limits

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

II. Exotic

A. Same sign tops

B. Monotops

C. BNV

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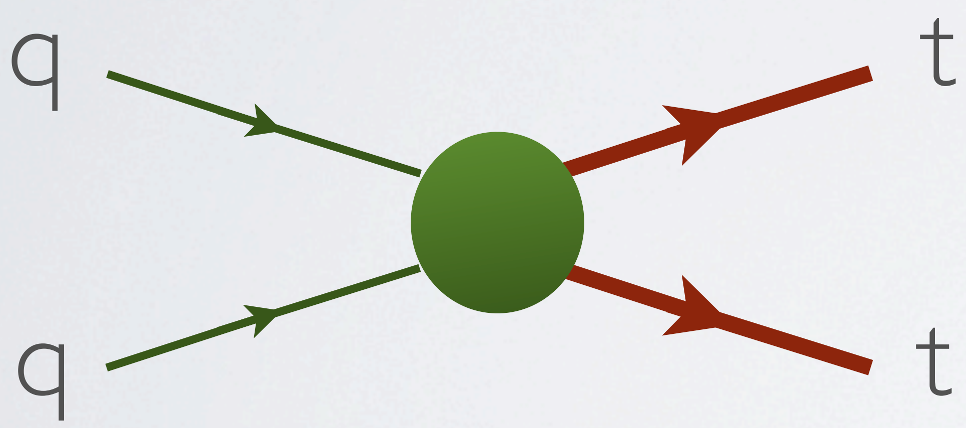
SAME SIGN TOPS

[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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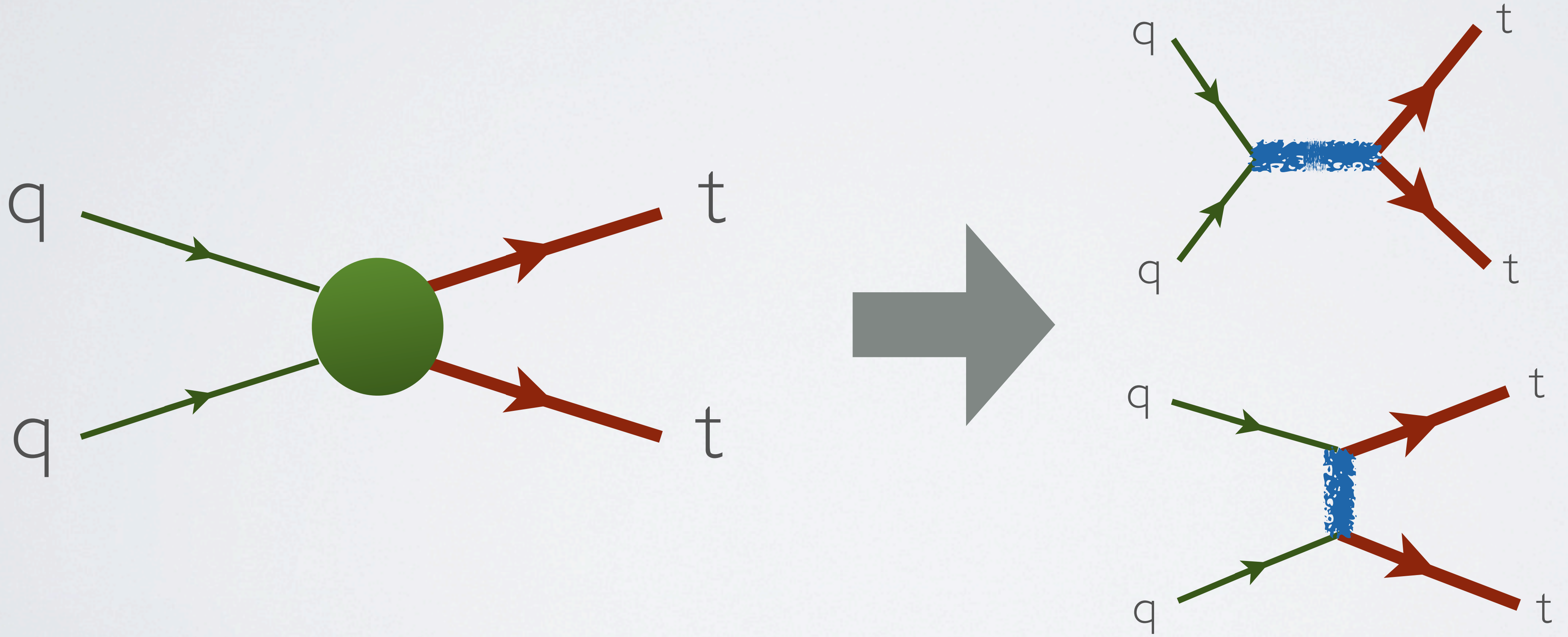

s-channel
3bar or 6 color

t-channel
1 or 8 color

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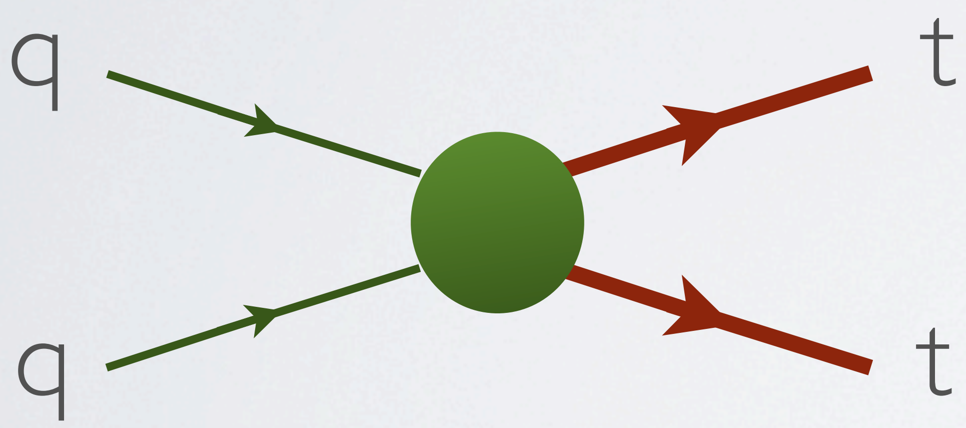
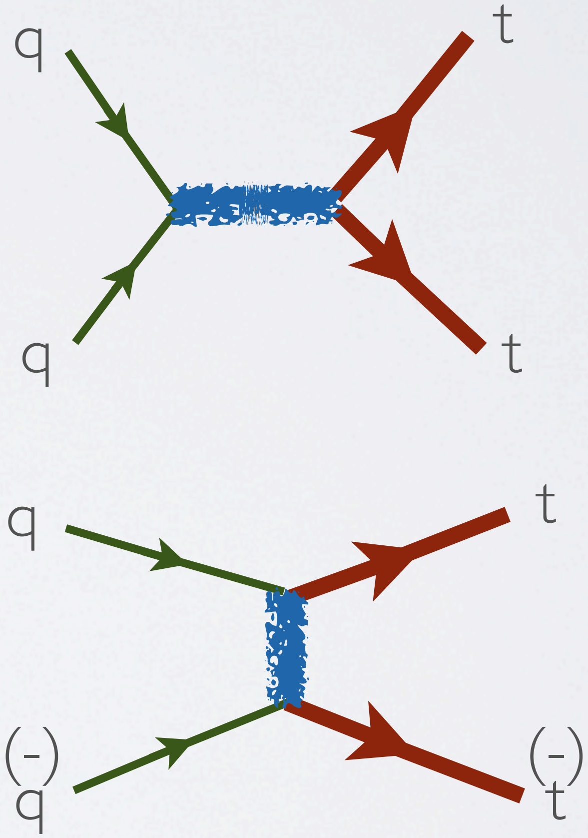




s-channel
3bar or 6 color

t-channel
1 or 8 color

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

[Degrande, Gerard, Grojean, FM, Servant, 2011]

SAME SIGN TOPS

Effective approach:

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

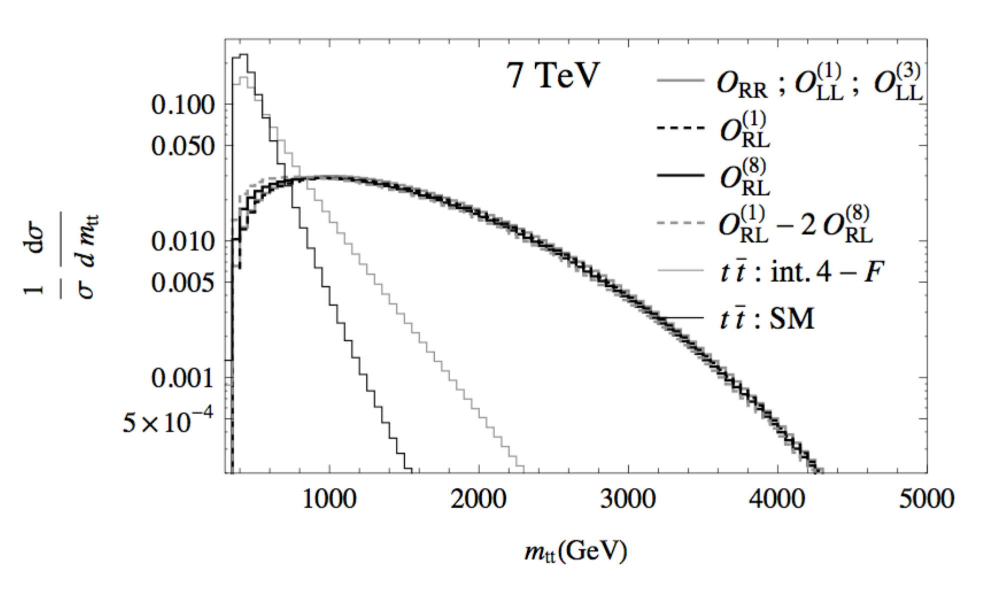
with:

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

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

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

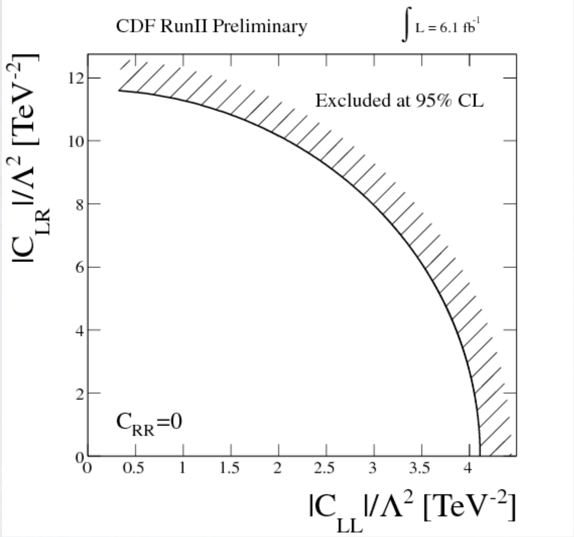
$$\frac{d\sigma}{dt} = \frac{1}{\Lambda^4}\Bigg[\left(|c_{RR}|^2 + |c_{LL}|^2\right)\frac{(s-2m_t^2)}{3\pi s} + \left(\left|c^{(1)}_{LR}\right|^2 + \frac{2}{9}\left|c^{(8)}_{LR}\right|^2\right)\frac{\left(m_t^2-t\right)^2 + \left(m_t^2-u\right)^2}{16\pi s^2} - \left(\left|c^{(1)}_{LR}\right|^2 + \frac{8}{3}\Re\left(c^{(1)}_{LR}c^{(8)\,*}_{LR}\right)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

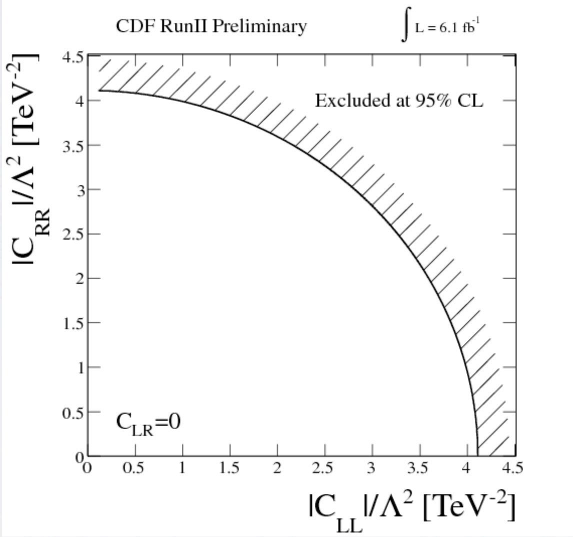


[Degrande, Gerard, Grojean, FM, Servant, 2011]

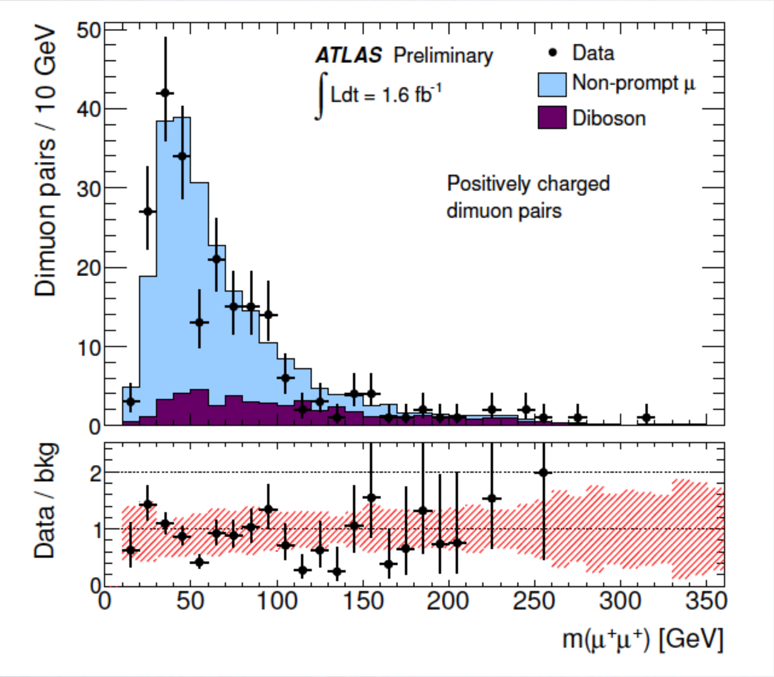
SAME SIGN TOPS

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





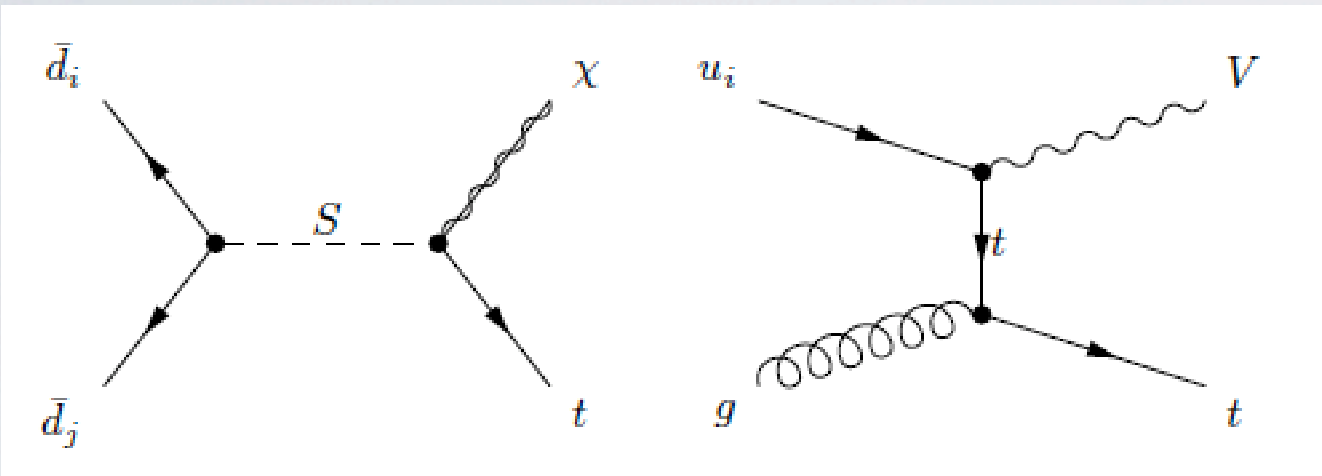
LHC start to put limits on same sign tops, but using a model...:



Mass range [GeV]	$\sigma_{95}(tt)$ (pb) $m(Z')$ = 100 GeV exp.	obs.	$m(Z')$ = 150 GeV exp.	obs.	$m(Z')$ = 200 GeV exp.	obs.	$m(Z') \gg 1$ TeV exp.	obs.
$m(\mu^+\mu^+) > 15$ GeV	24.8	21.8	23.0	20.3	22.4	19.7	36.6	32.2
$m(\mu^+\mu^+) > 100$ GeV	5.4	3.6	4.7	3.1	4.4	2.9	6.1	4.1
$m(\mu^+\mu^+) > 200$ GeV	4.1	4.1	3.3	3.3	3.0	3.0	2.9	2.9
$m(\mu^+\mu^+) > 300$ GeV	5.5	5.5	4.1	4.1	3.7	3.7	2.8	2.8

[J. Andrea, B. Fuks, F.M., 2011]

MONOTOPS



Very unique signature.
Two types of physics involved:
R parity violation (RPV) and/or FCNC.

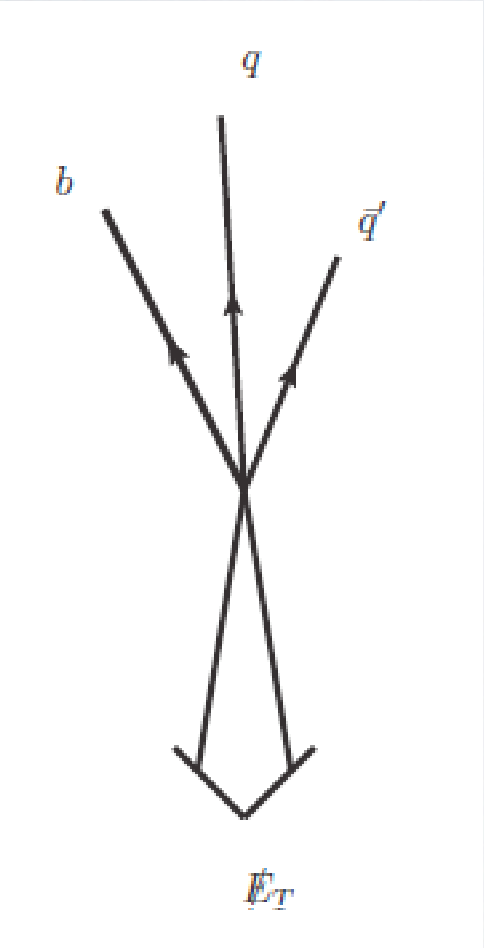
Most general simplified model leading to monotops:

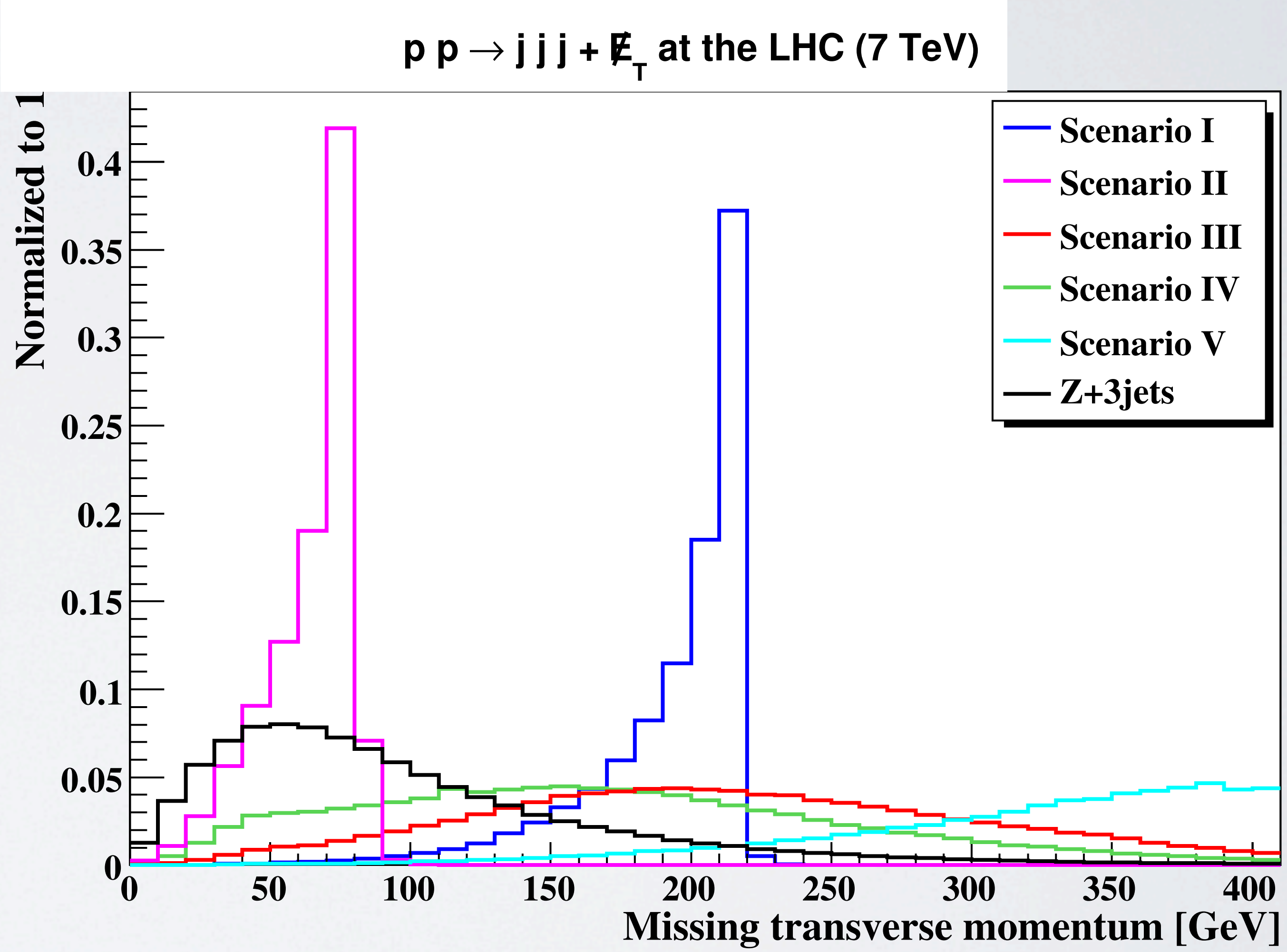
$$\begin{aligned}\mathcal{L} = \; & \mathcal{L}_{SM} \\ & + \phi \bar{u} \left[a^0_{FC} + b^0_{FC} \gamma_5 \right] u + V_\mu \bar{u} \left[a^1_{FC} \gamma^\mu + b^1_{FC} \gamma^\mu \gamma_5 \right] u \\ & + \epsilon^{ijk} \varphi_i \bar{d}^c_j \left[a^q_{SR} + b^q_{SR} \gamma_5 \right] d_k + \varphi_i \bar{u}^i \left[a^{1/2}_{SR} + b^{1/2}_{SR} \gamma_5 \right] \chi \\ & + \epsilon^{ijk} \tilde{\varphi}_i \bar{d}^c_j \left[\tilde{a}^q_{SR} + \tilde{b}^q_{SR} \gamma_5 \right] u_k + \tilde{\varphi}_i \bar{d}^i \left[\tilde{a}^{1/2}_{SR} + \tilde{b}^{1/2}_{SR} \gamma_5 \right] \chi \\ & + \epsilon^{ijk} X_{\mu,i} \; \bar{d}^c_j \left[a^q_{VR} \gamma^\mu + b^q_{VR} \gamma^\mu \gamma_5 \right] d_k \\ & + X_{\mu,i} \; \bar{u}^i \left[a^{1/2}_{VR} \gamma^\mu + b^{1/2}_{VR} \gamma^\mu \gamma_5 \right] \chi + \text{h.c.},\end{aligned}$$

[J. Andrea, B. Fuks, F.M., 2011]

MONOTOPS

Study of the simplest signature: 3jets (and/or 1 boosted top)+nothing.





Models implemented in FeynRules + MG5. Pheno ready to go.

[Z. Dong, G. Durieux, JM Gerard, T. Han, F.M., 2011]

TOP & BARYON NUMBER VIOLATION

$$\mathcal{L}_{\rm BNV}^{\rm dim=6} = \frac{1}{\Lambda^2}\sum_{i=1}^{5} c_i\, O^{(i)}$$

Weinberg's dimension-6 operator basis reduce in case of top to only 2 independent ones:

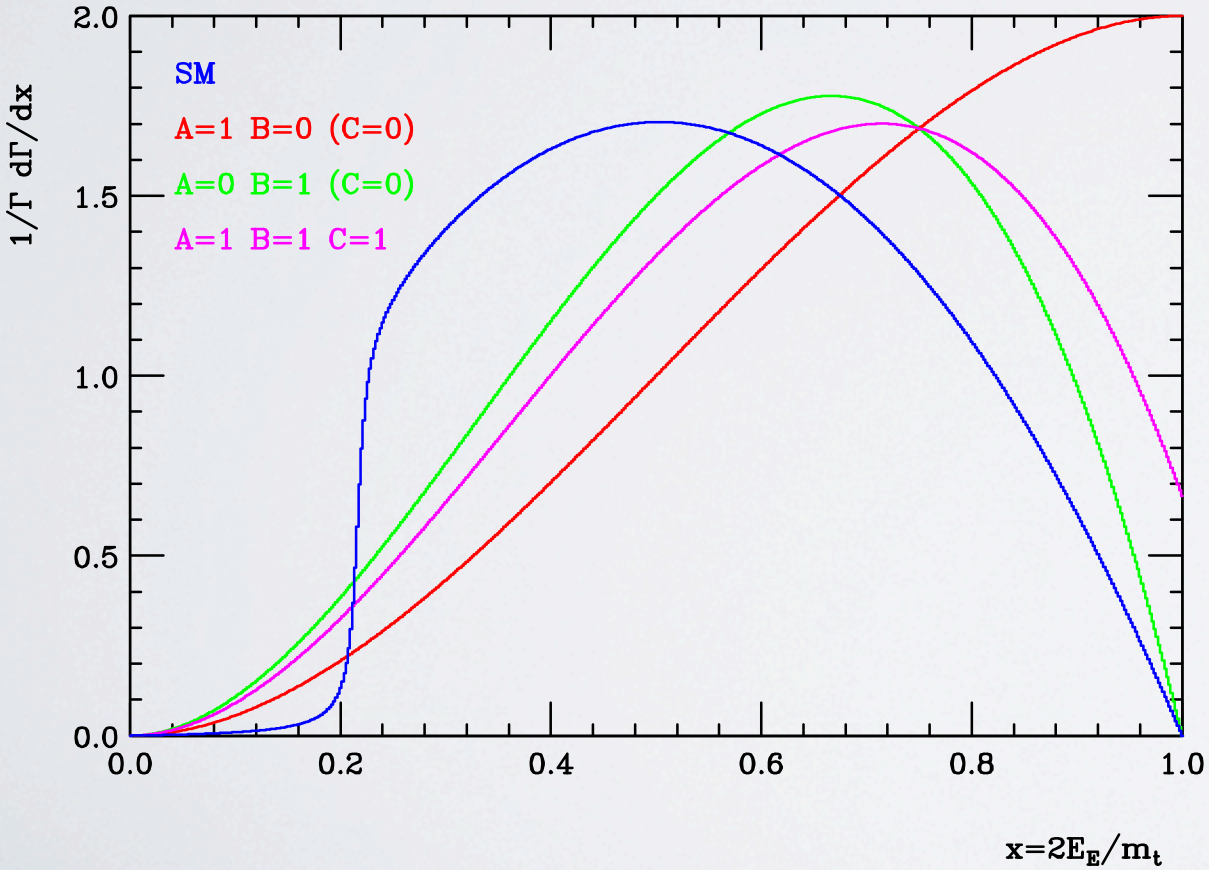
$$O^{(s)} \equiv \epsilon^{\alpha\beta\gamma}[\overline{t^c_\alpha}(aP_L + bP_R)D_\beta][\overline{U^c_\gamma}(cP_L + dP_R)E]$$
$$O^{(t)} \equiv \epsilon^{\alpha\beta\gamma}[\overline{t^c_\alpha}(a'P_L + b'P_R)E][\overline{U^c_\beta}(c'P_L + d'P_R)D_\gamma]$$

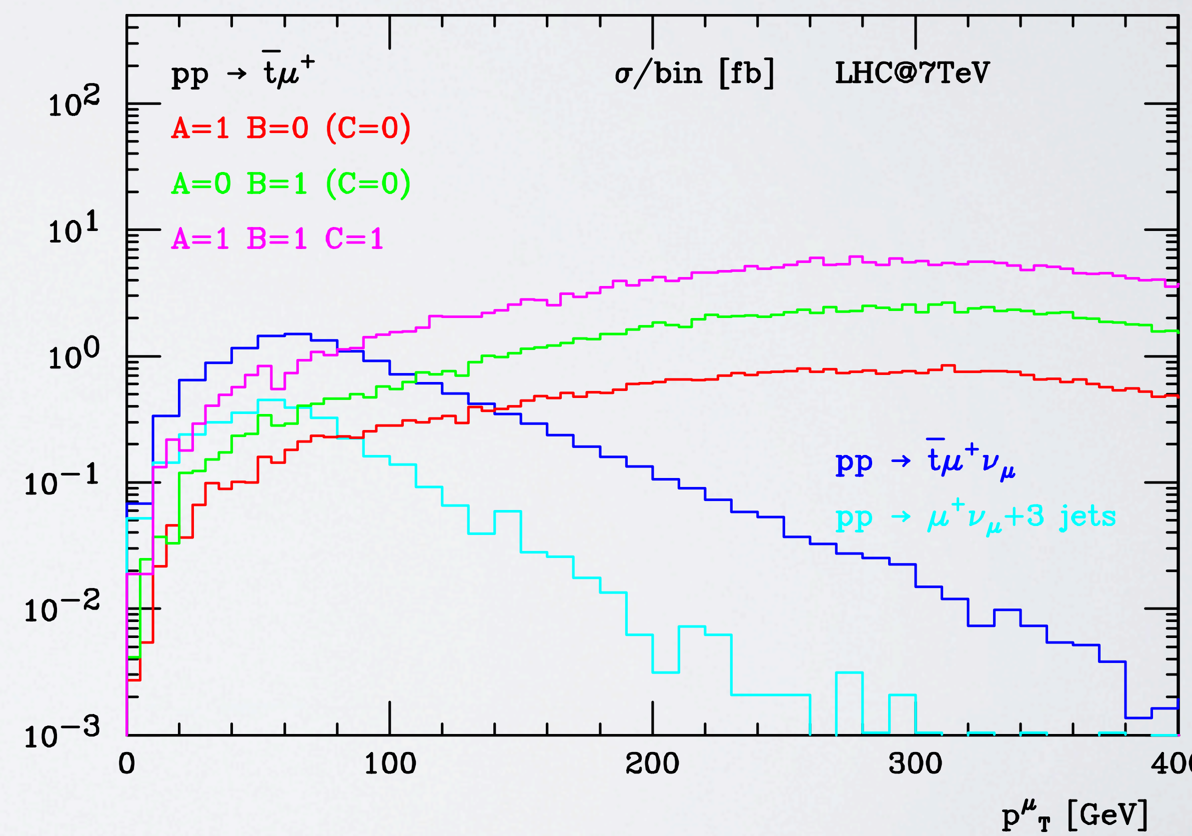
[Z. Dong, G. Durieux, JM Gerard, T. Han, F.M., 2011]

TOP & BARYON NUMBER VIOLATION

$$t \xrightarrow{\text{BNV}} \overline{U}\,\overline{D}\,E^+ \qquad\qquad U\,D \xrightarrow{\text{BNV}} \bar{t}\,E^+$$

$$\Gamma_t^{\text{BNV}} = \frac{m_t^5}{192\pi^3}\frac{1}{16\Lambda^4}[A+B+C] \qquad \hat{\sigma}_t^{\text{BNV}} = \frac{\hat{s}}{96\pi\Lambda^4}\left(1-\frac{m_t^2}{\hat{s}}\right)^2\left[\left(\frac{A}{3}+B+C\right)+\frac{m_t^2}{\hat{s}}\frac{A}{6}\right]$$





Strongly constrained by proton decay due to two-loop contributions. Theory of flavor needed...

OUTLOOK

Celine Degrande

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- Top-quark physics *is still crazy after all these years*.

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CREDITS

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(random order)

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