Higgs: the view from the Top

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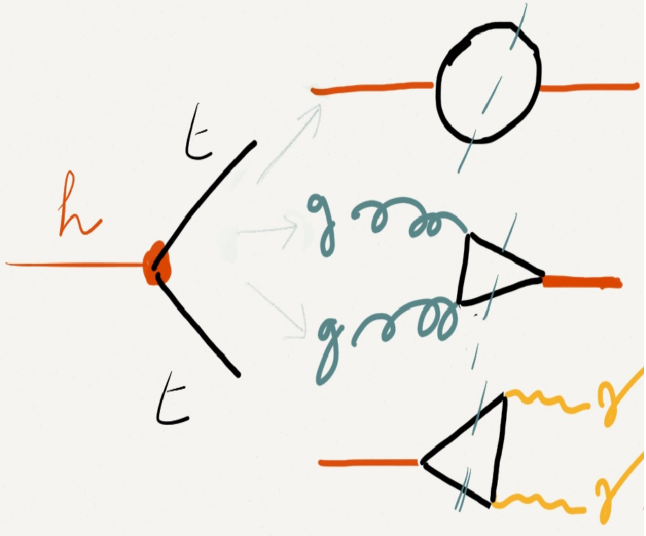
Work done with Rohini Godbole, Diego Guadagnoli and Kirtimaan Mohan

Preliminary results, Les Houches Proceedings, in arXiv: 1405.1617

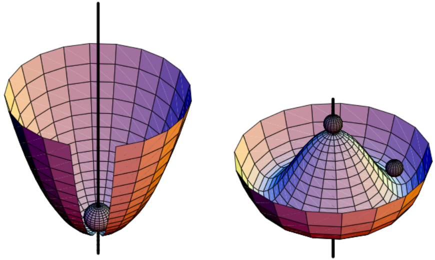
some analysis in arXiv: 1312.5736 (J. Ellis, D.S. Hwang, K. Sakurai, M. Takeuchi)

The Higgs and the Top



Higgs-Kibble in the SM model

Higgs Kibble Mechanism



$$V = \lambda(|\Phi|^2 - v^2/2)^2$$

$$\boxed{(\lambda > 0)}$$

$$\langle 0|\phi|0\rangle = v/\sqrt{2}$$

$$Q_{em}|0\rangle = |0\rangle$$

$$y_\Phi = Y_\Phi = \frac{1}{2}$$

$$\Phi = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(v+H) \end{pmatrix} e^{i\frac{\omega^j \tau^j}{2v}}$$

$$\mathcal{L}_{\text{Higgs}} = (D^\mu\Phi)^\dagger(D_\mu\Phi) - V(\Phi^\dagger\Phi), \quad V(\Phi^\dagger\Phi) = \lambda\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)^2$$

$$\mathcal{L}_{m_f} = -\left(y_u \bar{u}_R \tilde{\Phi}^\dagger Q_L + {}^{y}_{d}\, \bar{d}_r \Phi^\dagger Q_L\right) + h.c, \quad \tilde{\Phi} = i\tau_2\Phi^* \quad m_{d,u} = y_{d,u}\frac{v}{\sqrt{2}}$$

in the SM, Higgs and Mass are "ONE"

- Goldstones ω^i and H combine to form a linear representation of $SU(2) \times U(1)$

in the SM, Higgs and Mass are "ONE"

- Goldstones ω^i and H combine to form a linear representation of $SU(2) \times U(1)$
- $\hat{H} = H + v = v(1 + H/v)$, coupling of H is to the mass. Factor the mass out, the coupling is *universal* (tree-level). This must be verified precisely

Mass and the Higgs, mass without a Higgs

$$\hat{H} \neq H + v$$

- Dynamical mass from strong dynamics

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Mass and the Higgs, mass without a Higgs

$$\hat{H} \neq H + v$$

- Dynamical mass from strong dynamics
- naive prototype: technicolour (3GB and no Higgs)
- Technicolour revamped, larger symmetries (modern parlance Composite Higgs)

Masses in a Gauge Invariant Way without Higgs

The W, Z, γ kinetic pure gauge term still of the same origin but

mass and longitudinals through a system of Goldstones without the Higgs (still gauge invariant): Non-Linear realisation of SB

$$\Sigma = exp(\frac{i\omega^i\tau^i}{v}) \;(v = 246\; GeV \text{ is the vev}) \;\text{ and }\; \mathcal{D}_\mu\Sigma = \partial_\mu\Sigma + \frac{i}{2}\left(g\boldsymbol{W}_\mu\Sigma - g'B_\mu\Sigma\tau_3\right)$$

$$\mathcal{L}_M = \frac{v^2}{4}\mathrm{Tr}(\mathcal{D}^\mu\Sigma^\dagger\mathcal{D}_\mu\Sigma) \equiv -\frac{v^2}{4}\mathrm{Tr}\left(\mathcal{V}_\mu\mathcal{V}^\mu\right) \quad \text{with } \; \mathcal{V}_\mu = (\mathcal{D}_\mu\Sigma)\,\Sigma^\dagger$$

Replaces all of the Higgs sector, potential and all.

Not renormalisable? and so what...!

The "chirally coupled" Higgs, composite Higgs

Chivukula and Koulovassilopoulos ('93,94)

FB+Chopin, '95

Grojean et al.

Coupling the Higgs X, to the chiral Lagrangian

$$
\begin{aligned}
\Sigma &= exp(\frac{i\omega^i\tau^i}{v}) \\
\mathcal{L}_{M,X} &= \frac{1}{2}(\partial_\mu X)^2 - \frac{1}{2}M_X^2 X^2 \\
&+ \frac{v^2}{4}\mathrm{Tr}(\mathcal{D}^\mu\Sigma^\dagger\mathcal{D}_\mu\Sigma)\left(1+2a\frac{X}{v}+b\frac{X^2}{v^2}+\cdots\right) - Y_{ij}\overline{\psi}^i_L\Sigma\psi^j_R(1+c_{ij}\frac{X}{v}+\cdots) \\
&- \frac{1}{2}M_X^2 X^2\frac{X}{v}\left(h_3+h_4\frac{X}{4v}\right)+\cdots \\
\text{for}\quad X &= H, \qquad a=b=c=1, \qquad h_3=h_4=1 \\
\text{Composite } X & \qquad \text{better have } c_{ij}=c \text{ else FCNC}
\end{aligned}
$$

The Chiral Higgs

$$W^+W^- \to W^+W^- \Longrightarrow \mathcal{A} = \frac{1}{v^2}\left(s - \frac{a^2 s^2}{s - M_X^2}\right) \to a = \pm 1$$

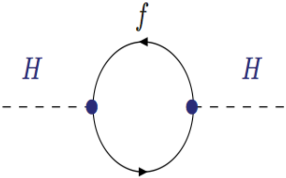
The Chiral Higgs

$$\boxed{W^+W^- \to t\bar{t} \Longrightarrow ac = 1}$$

The Chiral Higgs

$$W^+W^- \to XX \Longrightarrow b = a^2$$

Unnaturalness and fine-tuning



Take a fermion f with Yukawa coupling $\lambda_f = \sqrt{2} m_f / v$. (Assume for simplicity that the fermion is very heavy so that one can neglect the external Higgs momentum)

$$\Delta M_H^2 = \frac{\lambda_f^2}{8\pi^2}\left[-\Lambda^2 + 6 m_f^2 \log\frac{\Lambda}{m_f} - 2 m_f^2 \right] + \mathcal{O}(1/\Lambda^2)$$

$\Delta M_H^2 \propto \Lambda^2$

if $\Lambda = \Lambda_P$ tuning of contributions at the level of 30 digits

The potential: Stability up to which scale

the Higgs boson self-coupling $\lambda = M_H^2/2v^2$

$\lambda = M_H^2/2v^2 = 0.118(M_H = 125GeV) \quad \lambda^2/4\pi \sim 1/900 \ll \alpha_{\rm em}$

$\lambda = M_H^2/2v^2 = 4.9(M_H = 800GeV).$

$\lambda > 0.$

Behaviour of $\lambda(Q^2)$?

Running of couplings in the SM

At M_Z $g_i = \{0.46, 0.65, 1.2\}$

$$\begin{aligned} g_1 &= \sqrt{\frac{5}{3}}\frac{\sqrt{4\pi\alpha(m_Z)}}{\cos\theta_W} \simeq 0.46 \\ g_2 &= \frac{\sqrt{4\pi\alpha(m_Z)}}{\sin\theta_W} \simeq 0.65 \\ g_3 &= g_s = \sqrt{4\pi\alpha_3(m_Z)} \simeq 1.2 \end{aligned}$$

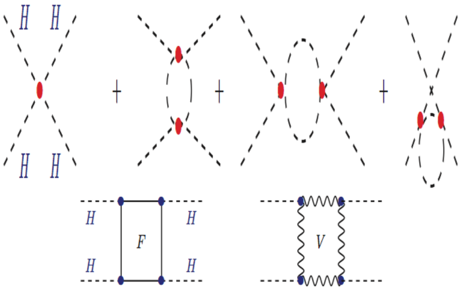
the top Yukawa coupling $y_t = \sqrt{2}m_t/v \simeq 1$,

$$\begin{aligned} \frac{dg_1}{dt} &= \frac{41}{10}\frac{g_1^3}{16\pi^2}, \quad \frac{dg_2}{dt} = -\frac{19}{6}\frac{g_2^3}{16\pi^2}, \quad \frac{dg_3}{dt} = -7\frac{g_3^3}{16\pi^2} \\ \frac{dy_t}{dt} &= \frac{y_t}{16\pi^2}\left(-\frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 - 8g_s^2 + \frac{9}{2}y_t^2\right) \end{aligned}$$

$$t \equiv \ln(Q/Q_0)$$

Running of the quartic coupling (one-loop)

$$\frac{d\lambda}{dt} = \frac{1}{16\pi^2}\left\{ +24\lambda^2 - \lambda\left(\frac{9}{5}g_1^2 + 9g_2^2 + 12y_t^2\right) \right.$$
$$-6y_t^4$$
$$\left. +\frac{9}{8}\left(\frac{3}{25}g_1^4 + \frac{2}{5}g_1^2 g_2^2 + g_2^4\right)\right\}$$



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$+ \Rightarrow$ Coupling will increase until very large values and will no longer be perturbative.

$+ \Rightarrow$ like with em coupling, breaks at the Landau pole, Q_{LP}

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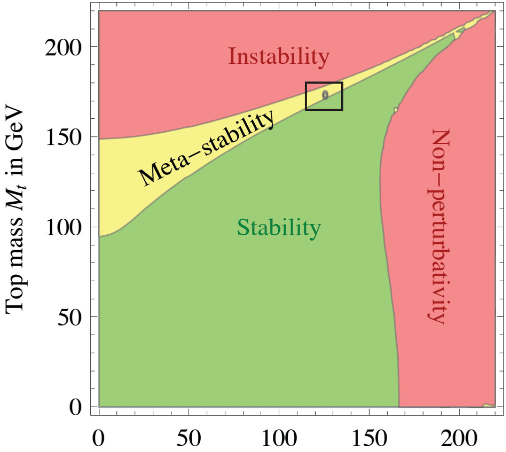
– ⇒ Coupling will decrease and may turn negative!

– ⇒ the Higgs potential will be unbounded from below: vacuum is no longer stable

Stability: The Miracle (Strumia et al.,), 2loop,..



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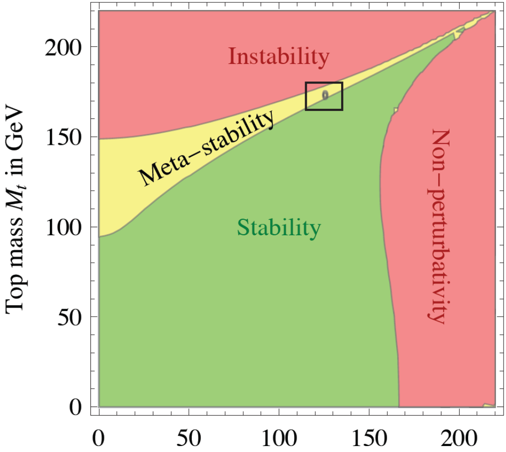

some new physics contribution could easily move us to a stable region

m_t essential (which m_t?)

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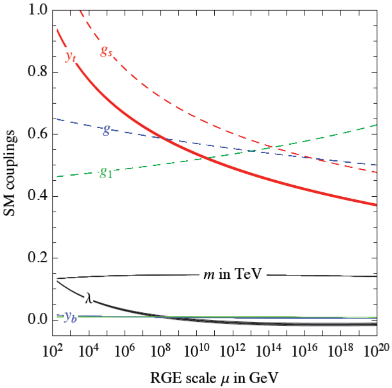

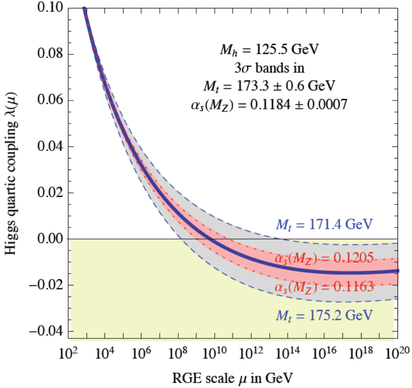

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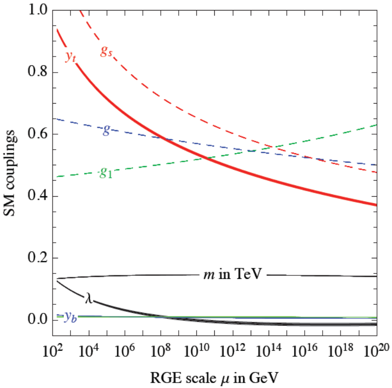
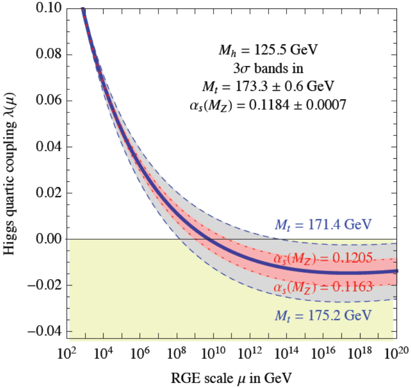
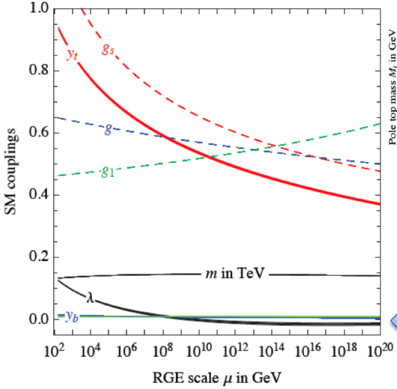
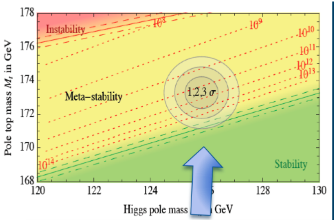




some new physics contribution could easily move us to a stable region and perhaps give gauge coupling unification

Vanishing of λ and its β function?

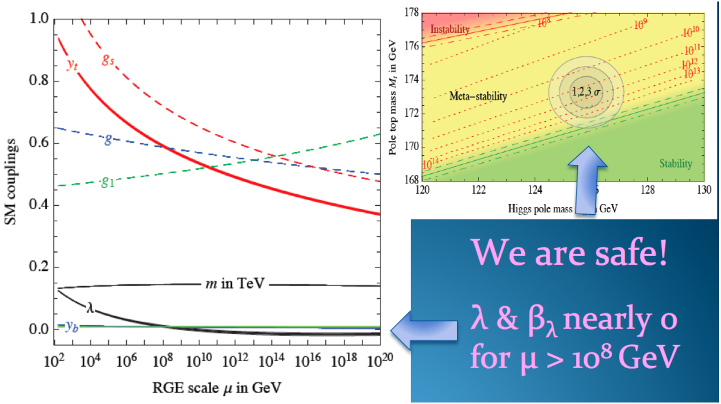




We are safe!

λ & β_λ nearly o for $\mu > 10^8$ GeV

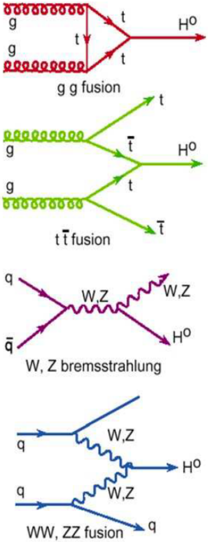
Vanishing of λ and its β function?

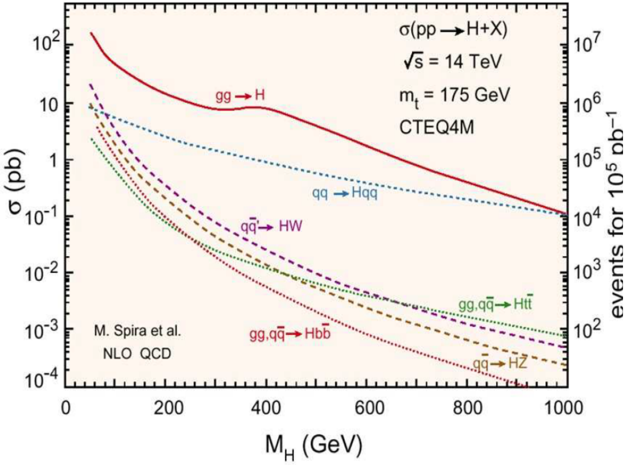


Is there any meaning in this? M_h *vs* Planck Scale. Not to me. Let alone that λ and β_λ vanish over a wide range, starting from $\mu > 10^8$GeV.

Production at LHC

Production mechanisms





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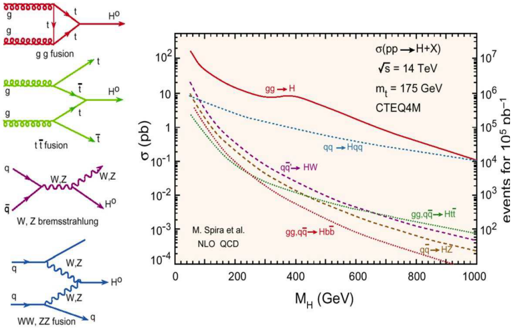

The largest cross section is the loop induced channel $gg \to h$

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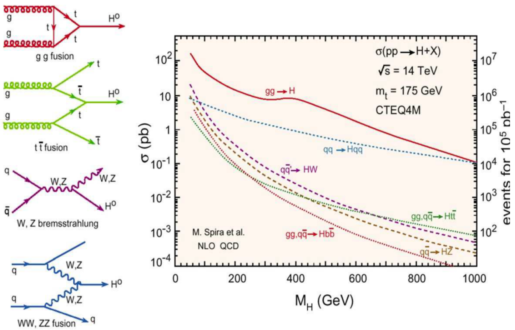

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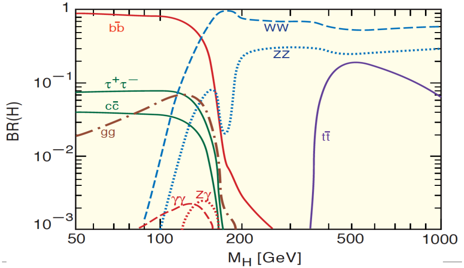
This *presumably* goes through tops

Signatures



Though very small, $H \to \gamma\gamma$ is an essential signature

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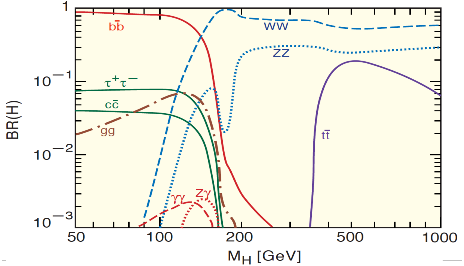

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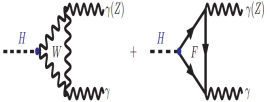

$$\mathcal{L}_{H\gamma\gamma} = c\frac{\alpha}{4\pi} F_{\mu\nu}F^{\mu\nu}\frac{H}{v}$$

$$\Gamma(H \to \gamma\gamma) = \frac{G_\mu M_H^3}{\sqrt{2}} \frac{\alpha^2}{128\pi^3} \sum_i |Q_i^2 N_{C,i} F_i|^2, \qquad F_i = \begin{cases} +7 \ (W^\pm) \\ -\frac{4}{3} \ \text{fermion} \\ -\frac{1}{3} \ \text{scalar} \end{cases}$$

Related to the β function.
4th generation reduces the rate by 15%.

Again $h \to \gamma\gamma$ is loop induced, the top plays a crucial role

What do we know about the $t\bar{t}h$ vertex ?

$t\bar{t}H$ vertex and " parity"

$$\mathcal{L}_{tth} = -g_{tth}\,\bar{t}\,(\mathbf{a_t} + i\mathbf{b_t}\,\gamma_5)\,H\,t\,,$$

where $g_{tth} = m_t/v$ normalizes the coupling to the SM strength.

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one can also check

$$\mathcal{L}_{hVV} = \frac{g}{2}\kappa_V m_W h\left(W^{\mu}W_{\mu} + \frac{1}{\cos\theta_W^2}Z^{\mu}Z_{\mu}\right).$$

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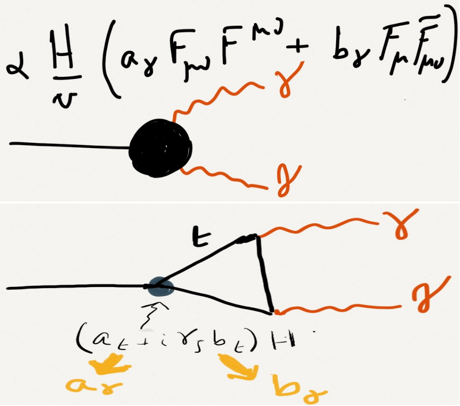
$$\mathcal{L}_{tth} \;=\; -g_{tth}\,\bar{t}\,(\mathbf{a_t} \,+\, i\mathbf{b_t}\,\gamma_5)\,H\,t\;,$$

where $g_{tth} = m_t/v$ normalizes the coupling to the SM strength.

Not multiHiggs exactly but certainly multi-couplings of the Higgs !


$\propto \frac{H}{v}\left(a_\gamma F_{\mu\nu}F^{\mu\nu} + b_\gamma F_{\mu}\tilde{F}_{\mu\nu}\right)$
γ
γ
t
γ
γ
$(a_t + i\gamma_5 b_t)\,H$
a_γ
b_γ

$$\frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)^{\rm SM}} = \frac{|\kappa_V A^a_W(\tau_W) + a_t \frac{4}{3} A^a_t(\tau_t)|^2 + |b_t \frac{4}{3} A^b_t(\tau_t)|^2}{|A^a_W(\tau_W) + \frac{4}{3} A^a_t(\tau_t)|^2} \, .$$

For $\tau = m_h^2/4M^2 \ll 1$ $(M = m_t, M_W, ..)$

$$\begin{aligned}
A^a_t(\tau) &= 4/3\,(1 + \tau/4 + \cdots) \\
A^a_W(\tau) &= -7\,(1 + \tau/5 + \cdots) \\
A^b_t(\tau) &= 2\,(1 + \tau/3 + \cdots)
\end{aligned}$$

$$\begin{aligned}
\frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)^{\rm SM}} &\sim 1.6\left((\kappa_W - a_t/5)^2 + (b_t/3)^2\right) \\
\frac{\sigma(gg \to h)}{\sigma(gg \to h)^{\rm SM}} &= \frac{\Gamma(h \to gg)}{\Gamma(h \to gg)^{\rm SM}} \sim a_t^2 + b_t^2 \frac{|A^b_t(\tau_t)|^2}{|A^a_t(\tau_t)|^2} \simeq a_t^2 + (3b_t/2)^2 \, .
\end{aligned}$$

Fits from Higgs observables

ATLAS and CMS have preformed an analysis to measure a_t:

$$a_t \in [-1.2, -0.6] \cup [0.6, 1.3] \qquad \text{ATLAS}$$

$$a_t \in [0.3, 1.0] \qquad \text{CMS} .$$

Fits from Higgs observables

We extend the analysis to include b_t, combine both ATLAS and CMS data, making sure we recover (for $b_t = 0$, both ATLAS and CMS data).

As customary, the signal strength measured in a particular channel i at the LHC

$$\hat{\mu}_i = \frac{n^i_{\rm exp}}{(n^i_S)^{\rm SM}}$$

where $n^i_{\rm exp}$ is the number of events observed in the channel i and $(n^i_S)^{\rm SM}$ is the expected number of events as predicted in the SM.

For specific models, define

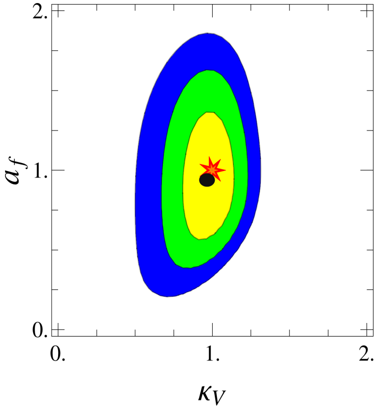
$$\mu_i = \frac{n^i_S}{(n^i_S)^{\rm SM}} = \frac{\Sigma_p \sigma_p \epsilon^i_p}{\Sigma_p \sigma^{SM}_p \epsilon^i_p} \times \frac{{\rm BR}_i}{{\rm BR}^{\rm SM}_i} \, .$$

The fit is performed by minimizing the χ^2 function

$$\chi^2 = \sum_i \left(\frac{\mu_i - \hat{\mu}_i}{\sigma^{\rm exp}_i} \right)^2 ,$$

When correlations are given, we modify the χ^2 function to take correlations into account.

Fits from Higgs observables

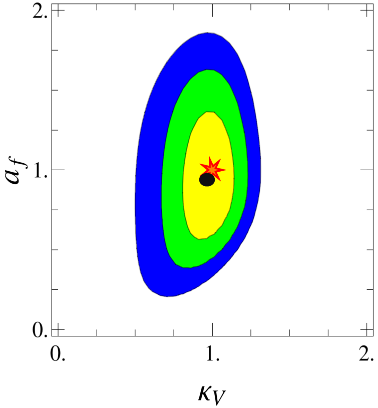


The ● indicates the best-fit value.

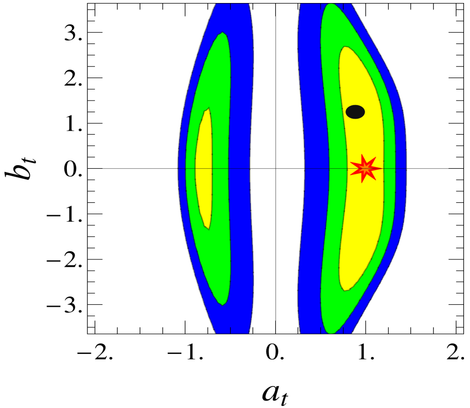
68% , 95%, 99.7% CL

$\star$ SM, $(\kappa_V, a_f) = (1, 1)$.

Fits, $\kappa_V, a_f, b_f = 0$: P Properties



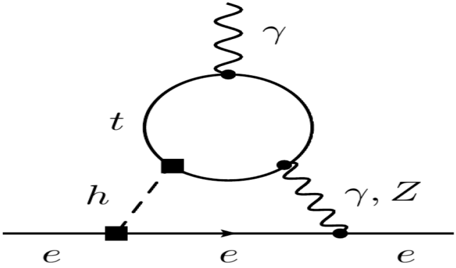
If parity of Higgs measured as $\kappa_{\rm CP} = 1 - \kappa_V^2$, then very little is left for a parity-odd Higgs. (Djouadi-Moreau 1303.6591)



The ● indicates the best-fit value $(a_t, b_t) = (0.93, 1.17)$.
68% , 95%, 99.7% CL
⋆ SM

Indirect constraints, low energy CP violation

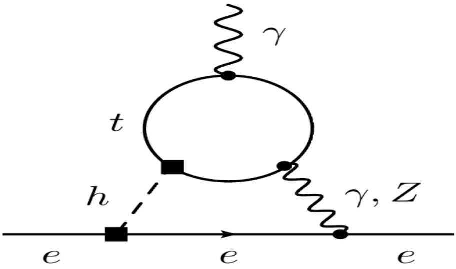
edm of the electron



$$
\begin{aligned}
\mathcal{L}^{e}_{\mathrm{EDM}} &= -d_e \, \frac{i}{2} \, \overline{e} \, \sigma^{\mu\nu} \gamma_5 \, e \, F_{\mu\nu} \\
d_e &\propto b_t a_e f_1(m_t^2/m_h^2) + b_e a_t f_2(m_t^2/m_h^2) \\
|d_e/e| &< 8.7 \cdot 10^{-29} \mathrm{cm}(90\% \mathrm{CL}) \Longrightarrow b_t < 0.01
\end{aligned}
$$

Indirect constraints, low energy CP violation

edm of the electron



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\end{aligned}
$$

Very model dependent, again an indirect loop induced argument: assumes we know *hee* coupling very well and that *hee* has both a scalar and a pseudo-scalar component

Direct Probe of the $t\bar{t}h$ coupling

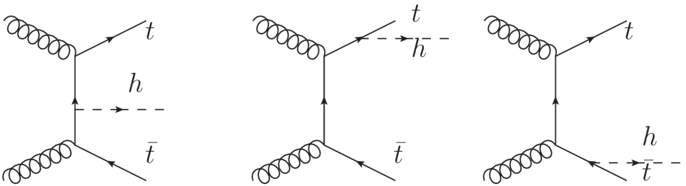
$$pp \to t\bar{t}h$$

Feynman diagrams

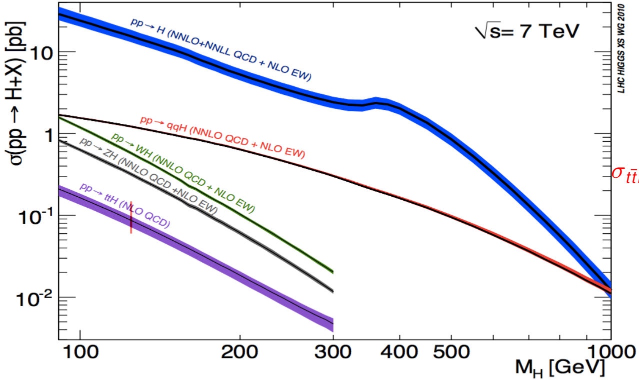
$a)$

$b)$

$c)$



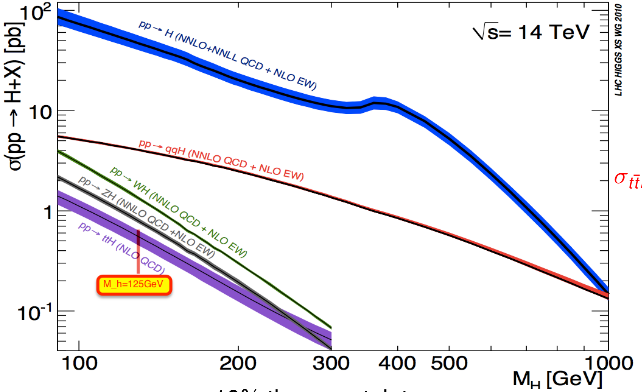
$t\bar{t}H$ SM cross sections



$\sigma_{t\bar{t}H}$(@7TeV)=137fb

10% th. uncertainty on $\sigma_{t\bar{t}H}$

$t\bar{t}H$ SM cross sections



$\sigma_{t\bar{t}H}$(@14TeV)=630fb

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process	incl. σ	efficiency	$\sigma^{\rm rec}$
$t\bar{t}h$, single-lepton	111 fb	0.0485	5.37 fb
$t\bar{t}h$, di-lepton	17.7 fb	0.0359	0.634 fb
$t\bar{t}$+jets, single-lepton	256 pb	0.463×10^{-3}	119 fb
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Artoisenet *et al.*, arXiv: 1304.6414

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● Difficult, but the 3 body final state with each state decaying offers a large number of observables to study

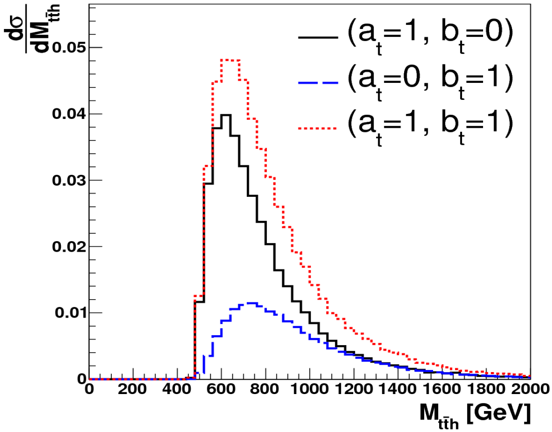
$t\bar{t}H$ SM cross sections: difficult but a lot of progress

ATLAS and CMS have performed searches in this channel even in the rarest channel $H \to \gamma\gamma$ with present data, this help set a limit (with $\sim$ 25fb^{-}1) $\sigma_{tth}^{\text{obs.}} < 5\sigma_{tth}^{SM}$ (assuming SM branching ratios!),

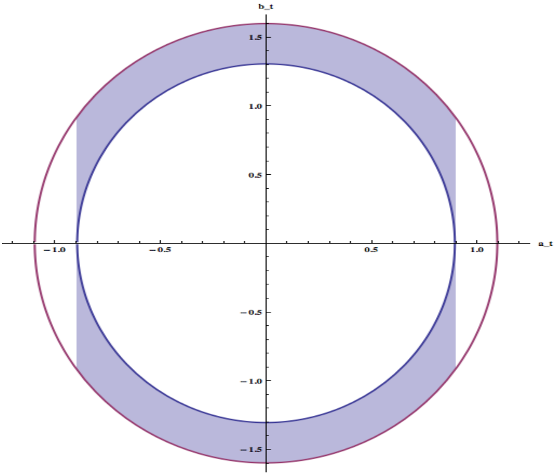
CMS has even newer results combining $H \to b\bar{b}, \tau\tau, \gamma\gamma$ $\sigma_{tth}/\sigma_{tth}^{SM} = 2.5^{+1.1}_{-1.0}$

Total cross sections

$$\frac{\sigma_{t\bar{t}H}}{\sigma^{\rm SM}_{t\bar{t}H}} \sim a_t^2 + 0.47 b_t^2$$

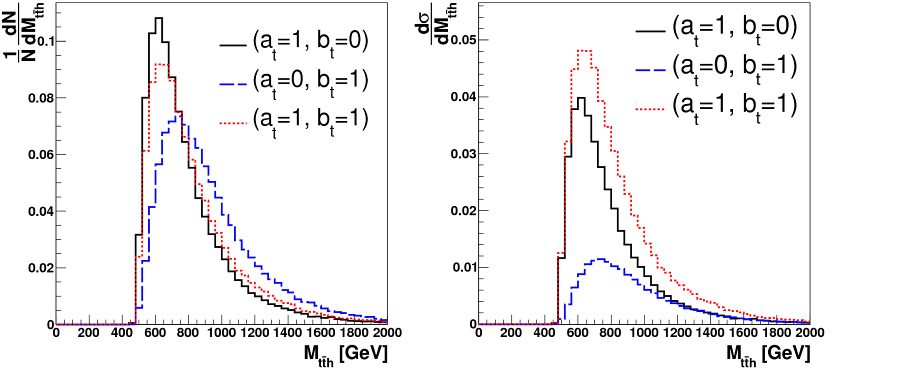


Total cross sections, direct constraint



If $\sigma_{tth}/\sigma_{tth}^{\mathrm{SM}} = 1 \pm 0.2$

$\hat{s}$ distributions or $M_{t\bar{t}h}$



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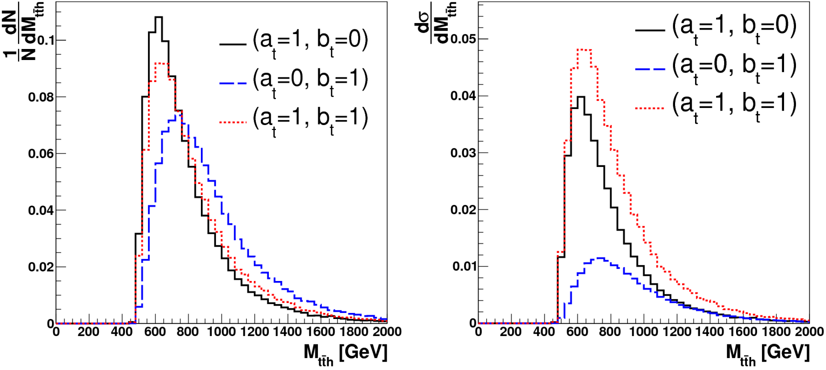

This is the key observation that was made in e^+e^-. More rapid increase with energy ($\hat{s}$) in the case of the scalar

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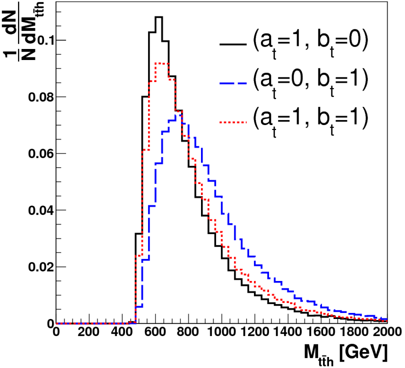
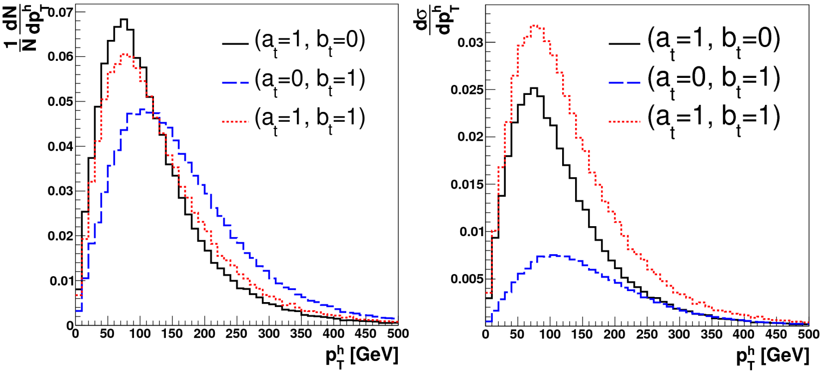


This is the key observation that was made in e^+e^-. More rapid increase with energy ($\hat{s}$) in the case of the scalar

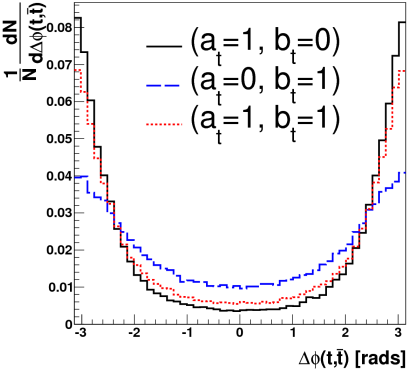
One must reconstruct $M_{t\bar{t}h}$ meaning $t, \bar{t}$ and h momenta. May prove to be difficult.

p_t^h distributions



p_T^h is a good discriminating variable. Easier to measure, requires to determine p_T^h, ($h \to b\bar{b}$, beware of combinatorics though ($4b$)).

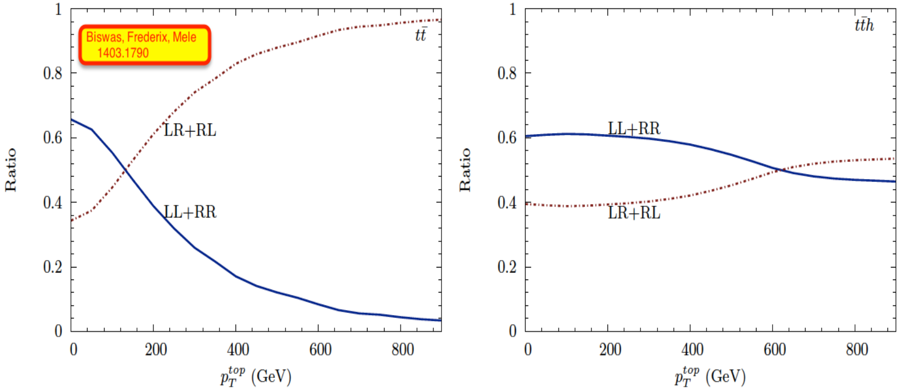
Azimuthal angle between the 2 tops



$$\cos(\Delta\phi(t\bar{t})) = \frac{(\hat{z}\times\vec{p}^{\,\bar{t}})\cdot(\hat{z}\times\vec{p}^{\,t})}{|\vec{p}^{\,\bar{t}}|\;\;|\vec{p}^{\,t}|}$$

Does not require charge identification but still we need reconstruct both the top and anti-top direction. May not be easy.

$t\bar{t}h$ vs $t\bar{t}$ at LHC, SM

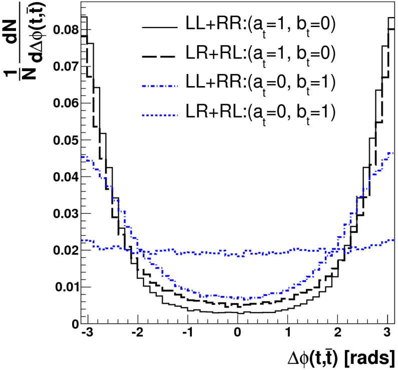


from arXiv: 1403.1790 (S. Biswas, R. Frederix, E. Gabrielli and B. Mele)

Polarised tops

A measure of the spin correlations can be defined through the following spin-correlation asymmetry in the lab frame

$$\begin{aligned}\zeta_{\mathrm{lab}} &= \frac{\sigma(pp\to t_L\bar{t}_L h)+\sigma(pp\to t_R\bar{t}_R h)-\sigma(pp\to t_L\bar{t}_R h)-\sigma(pp\to t_R\bar{t}_L h)}{\sigma(pp\to t_L\bar{t}_L h)+\sigma(pp\to t_R\bar{t}_R h)+\sigma(pp\to t_L\bar{t}_R h)+\sigma(pp\to t_R\bar{t}_L h)}\\ &= \frac{0.21\ (1+1.03\ b_t^2/a_t^2)}{1+0.47\ b_t^2/a_t^2}\end{aligned}$$



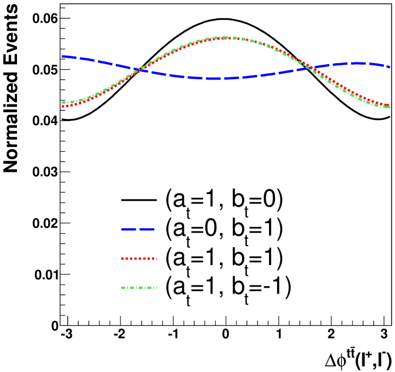
$\frac{1}{N}\frac{dN}{d\Delta\phi(t,\bar{t})}$
LL+RR:(a_t=1, b_t=0)
LR+RL:(a_t=1, b_t=0)
LL+RR:(a_t=0, b_t=1)
LR+RL:(a_t=0, b_t=1)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-3
-2
-1
0
1
2
3
$\Delta\phi(t,\bar{t})$ [rads]

Spin correlations, density matrix

Using correlations with the final decay products

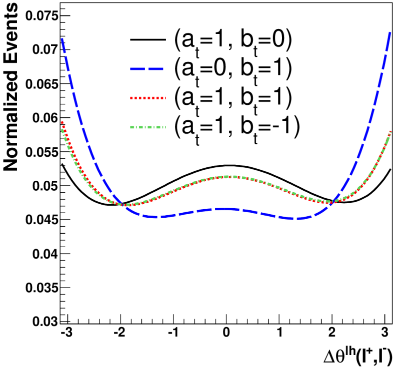
distributions for $\Delta\phi^{t\bar{t}}(\ell^+,\ell^-)$, $t,\bar{t}$ rest frames

- Dileptonic decay of the top. Beware cross section small...
- But it is also known that the lepton angular distribution in the decay of the top is not affected but non SM effect in the decay vertex. Hence all happens at production.
- Try to reconstruct observables as if we were in $t\bar{t}$production: observables **in rest frame** of the tops for example. This requires reconstruction of the top momenta, difficult with the missing enegy/$p_T$from the 2 neutrinos.



$$\cos(\Delta\phi^{t\bar{t}}(\ell^+,\ell^-)) = \frac{(\hat{z}\times\vec{p}^{\,\bar{t}}_{\ell-})\cdot(\hat{z}\times\vec{p}^{\,t}_{\ell+})}{|\vec{p}^{\,\bar{t}}_{\ell-}|\,|\vec{p}^{\,t}_{\ell+}|},$$

$\Delta\theta^{\ell h}(\ell^-, \ell^+)$, substitute in lab. frame



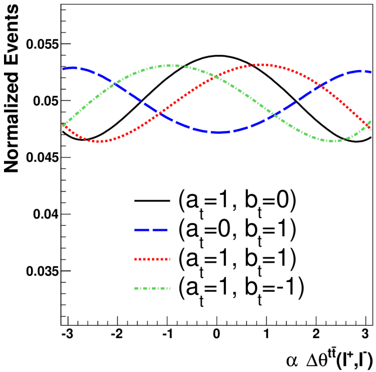
$$\cos(\Delta\theta^{\ell h}(\ell^-, \ell^+)) = \frac{(\vec{p}_h \times \vec{p}_{\ell-}) \cdot (\vec{p}_h \times \vec{p}_{\ell+})}{|\vec{p}_h \times \vec{p}_{\ell-}| \; |\vec{p}_h \times \vec{p}_{\ell+}|} \; .$$

Now all momenta in lab. frame. (could have used p_W instead of p_l and use the full hadronic samples).

CP-violating observables, 1-$t\bar{t}$ rest frame (Ellis et al.;)

$$\alpha \equiv \mathrm{sgn}\left(\vec{p}_t^{\,t\bar{t}} \cdot (\vec{p}_{\ell^-}^{\,t\bar{t}} \times \vec{p}_{\ell^+}^{\,t\bar{t}})\right).$$

$\Delta\theta^{t\bar{t}}(\ell^+, \ell^-)$ is the angle between the two lepton momenta projected onto the plane perpendicular to the t direction in the center-of-mass frame of the $t\bar{t}$ system.

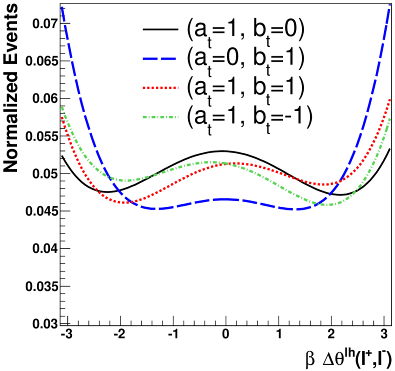


distributions for $\alpha \times \Delta\theta^{t\bar{t}}(\ell^+, \ell^-)$

CP-violating observables, 2- lab. frame

take the b's from the quark decays. One of these must be tagged (reconstruct either t or $\bar{t}$)

$$\beta \equiv \mathrm{sgn}\left((\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_{\ell^-} \times \vec{p}_{\ell^+})\right).$$



distributions for $\beta \times \Delta\theta^{\ell h}(\ell^-, \ell^+)$

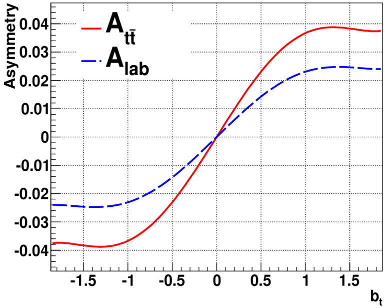
Asymmetries

$\alpha \times \Delta\theta^{t\bar{t}}(\ell^+,\ell^-)$ and $\beta \times \Delta\theta^{\ell h}(\ell^-,\ell^+)$ it is useful to define CP asymmetries as follows:

$$A_{t\bar{t}} = \frac{\sigma(\alpha \times \Delta\theta^{t\bar{t}}(\ell^+,\ell^-) > 0) - \sigma(\alpha \times \Delta\theta^{t\bar{t}}(\ell^+,\ell^-) < 0)}{\sigma(\alpha \times \Delta\theta^{t\bar{t}}(\ell^+,\ell^-) > 0) + \sigma(\alpha \times \Delta\theta^{t\bar{t}}(\ell^+,\ell^-) < 0)}$$

and

$$A_{\mathrm{lab}} = \frac{\sigma(\beta \times \Delta\theta^{\ell h}(\ell^-,\ell^+) > 0) - \sigma(\beta \times \Delta\theta^{\ell h}(\ell^-,\ell^+) < 0)}{\sigma(\beta \times \Delta\theta^{\ell h}(\ell^-,\ell^+) > 0) + \sigma(\beta \times \Delta\theta^{\ell h}(\ell^-,\ell^+) < 0)}.$$



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- useful studies are already being used
- $pp \to t/\bar{t}h$ may be another handle, but cross sections even smaller