Present and future constraints on top EW couplings

Workshop on Top physics at the LC

5-6 March 2014 LPNHE Paris

IFIC
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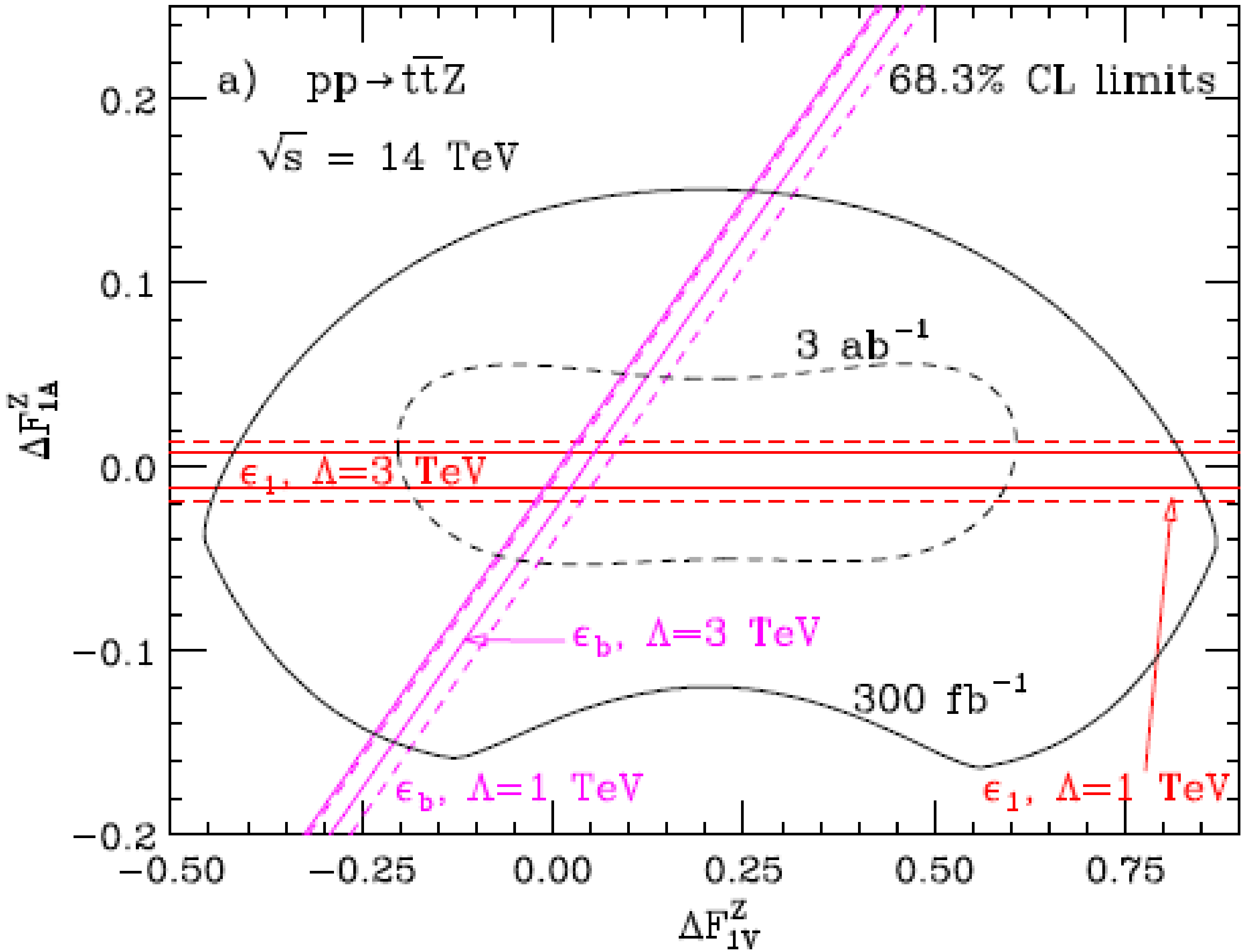
Introduction

- In **composite mode**ls which comprise e.g. extra-dimensions (RS), Little Higgs (LH), one expects a proeminent part for the top quarks
- Predictions on possible deviations for **top EW couplings** span a large range from a few %, only visible with ILC, up more to several 10% observable at LHC
- In this talk, I will indicate how LEP/Tevatron/ SLC constraints already tell us what one can realistically expect to observe

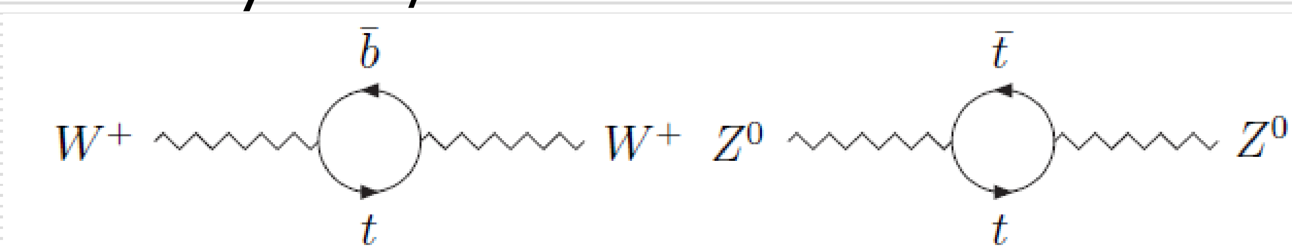
A. Juste et al.
hep-ph/0601112

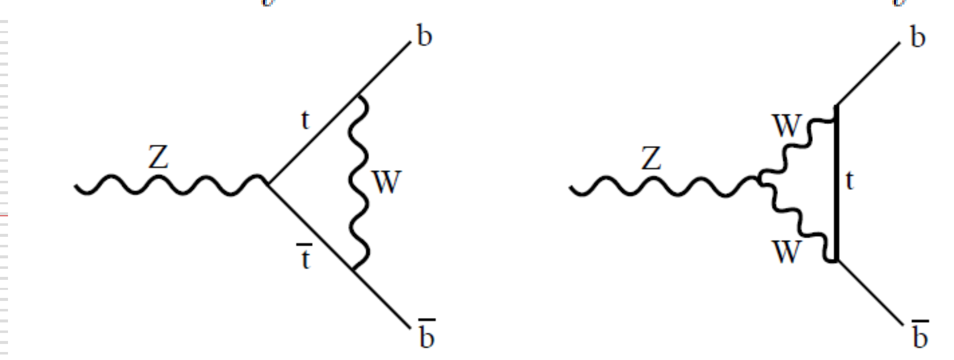
A surprising plot



Origin of these constraints

- Recall that if one modifies the fermion EW couplings the SM loops becomes UV divergent and this requires introducing a **cutoff Λ~TeV** to compute these contributions
- Given this cutoff the top EW **couplings anomalies** are limited by LEP/SLD measurements





Explicit formulae

A. Larios et al.
hep-ph/9704288

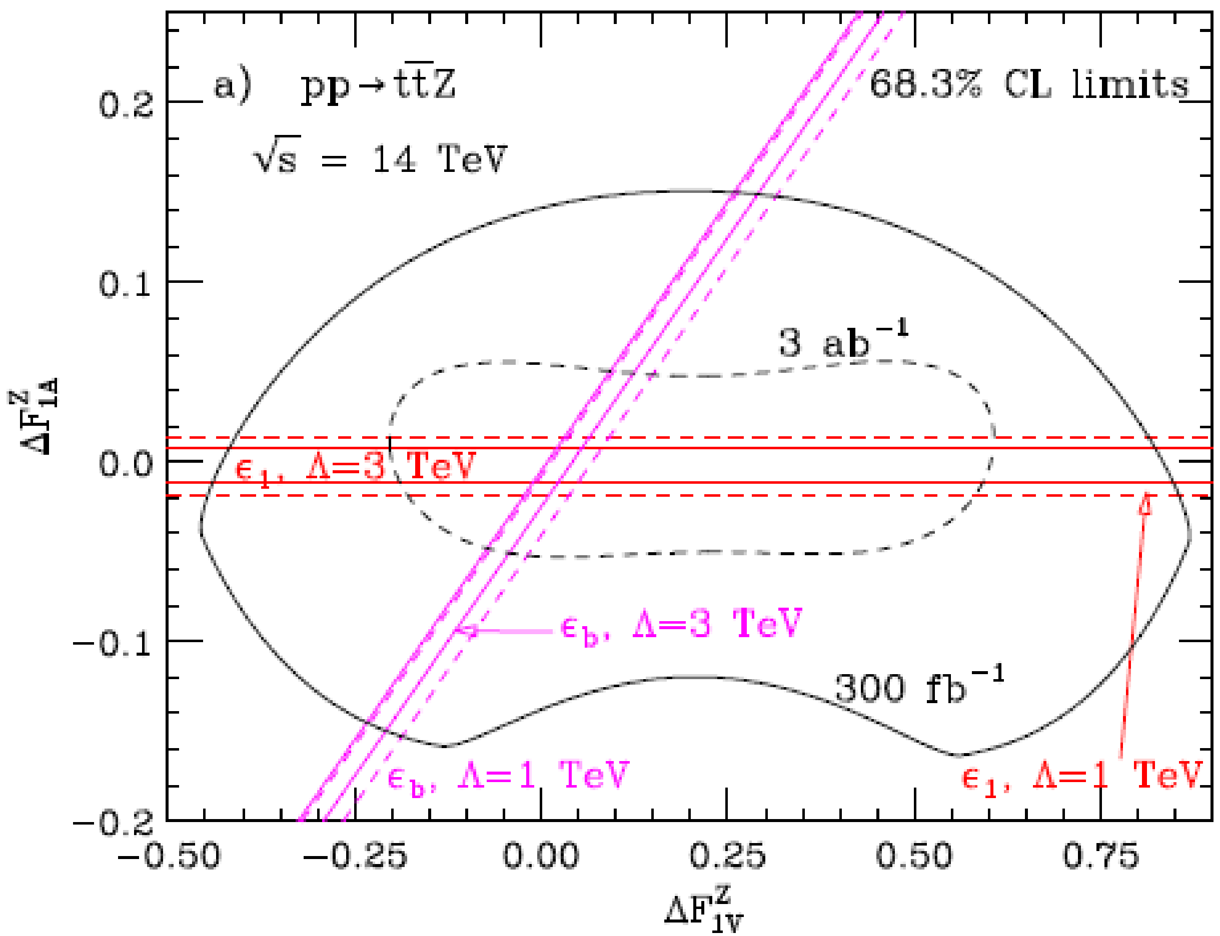
$$\delta\epsilon_1 = \frac{3m_t^2 G_F}{2\sqrt{2}\pi^2}\left[\kappa_R^{NC} - \kappa_L^{NC} + \kappa_L^{CC} - \left(\kappa_R^{NC}\right)^2 - \left(\kappa_L^{NC}\right)^2 + \left(\kappa_L^{CC}\right)^2 + 2\kappa_R^{NC}\kappa_L^{NC}\right]\ln\frac{\Lambda^2}{m_t^2}$$

$$\delta\epsilon_b = \frac{m_t^2 G_F}{2\sqrt{2}\pi^2}\left(\kappa_L^{NC} - \frac{1}{4}\kappa_L^{NC}\right)\left(1 + 2\kappa_L^{CC}\right)\ln\frac{\Lambda^2}{m_t^2}$$

$$\begin{aligned} L \equiv\ & \frac{g}{2c_W}\left(1 - \frac{4s_W^2}{3} + \kappa_L^{NC}\right)\overline{t_L}\gamma^\mu t_L Z_\mu + \frac{g}{2c_W}\left(-\frac{4s_W^2}{3} + \kappa_R^{NC}\right)\overline{t_R}\gamma^\mu t_R Z_\mu \\ & + \frac{g}{\sqrt{2}}\left(1 + \kappa_L^{CC}\right)\overline{t_L}\gamma^\mu b_L W_\mu^+ + \frac{g}{\sqrt{2}}\left(1 + \kappa_L^{CC*}\right)\overline{t_L}\gamma^\mu b_L W_\mu^- \end{aligned}$$

- If one assumes that charged currents are SM $\kappa^{CC}=0$ then at lowest order $\epsilon_1 \sim \kappa^{NC}_R - \kappa^{NC}_L$ ~axial term for Ztt **F1AZ** is tightly constrained

A not surprising plot



Gauge invariance

JA Aguilar et al.
hep-ph/012037

- Gauge invariance relates ZtLtL to WtLbL and ZbLbL

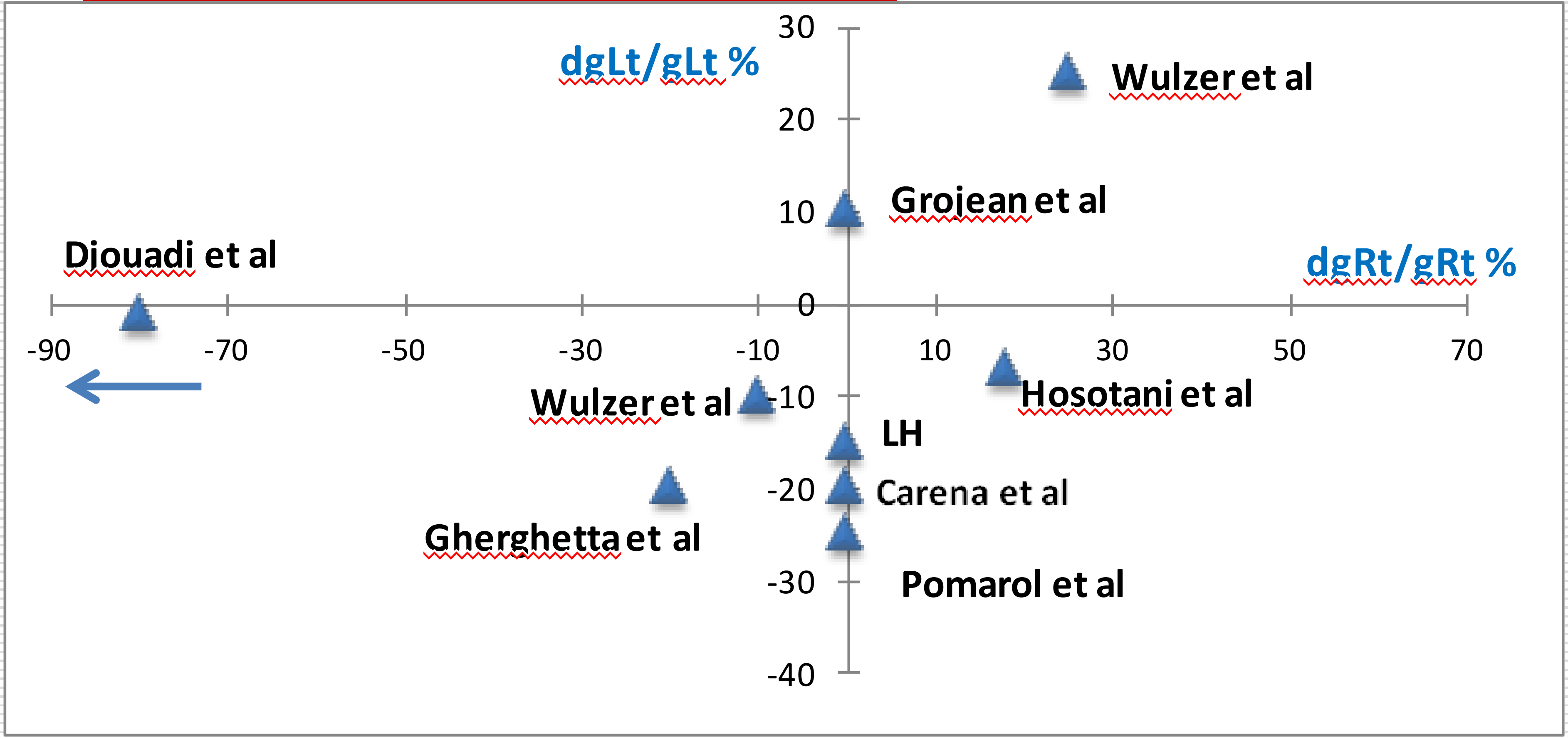
$$\kappa_{bL}^{NC} + \kappa_{tL}^{NC} \square \kappa_{tL}^{NC} = 2\kappa_{tLbL}^{CC}$$

- From LEP1 we know that ZbLbL has no anomaly meaning that

$$\frac{\delta WtLbL}{WtLbL} \square 0.72 \frac{\delta ZtLtL}{ZtLtL}$$

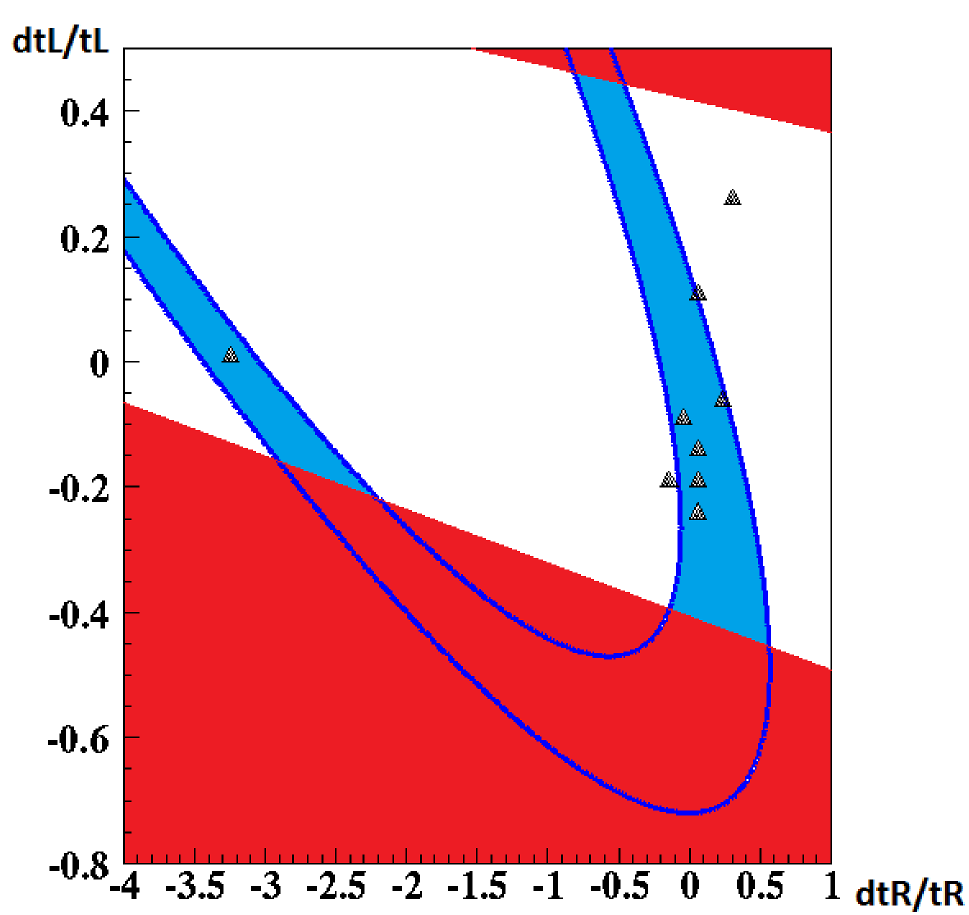
- $\delta\square_1$ and $\delta\square_b$ only depend on neutral couplings ZbLbL and ZbRbR
- Loop contributions therefore fully constrain ZtLtL and ZtRtR and the only freedom left comes from BSM compensating contributions to $\square_1$ and $\square_b$

Example of models

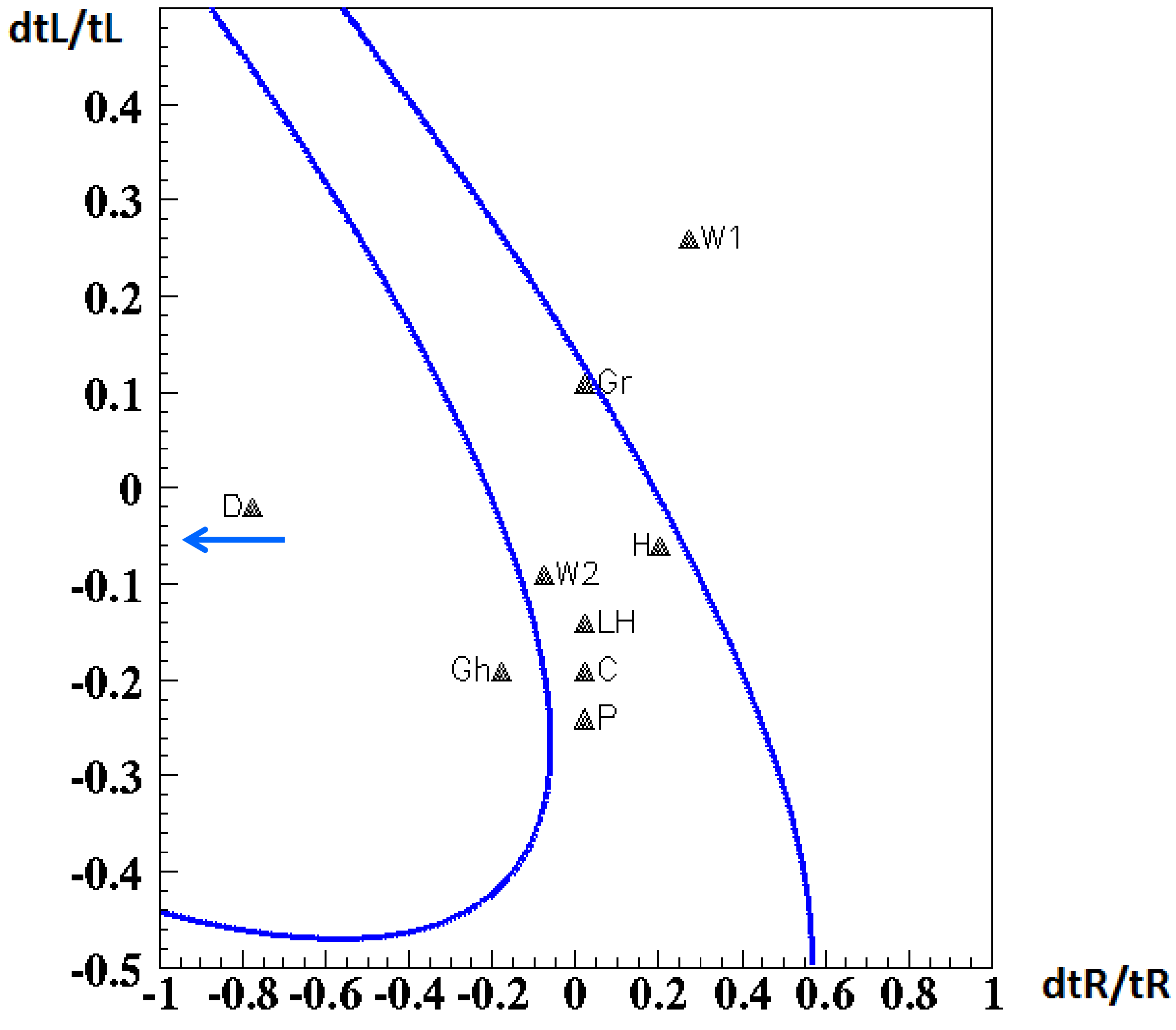


Constraints

- Take $|\delta\square_1/\square_1|$ and $|\delta\square_b/\square_b|$ <1.5 and Λ=1 TeV
- A wide range is allowed for dtR/tR while dtL/tL is restricted
- Most models (after some ‘educated choices’) are consistent with these constraints
- A few are at the edge meaning that they need a **large BSM compensating loop** contribution

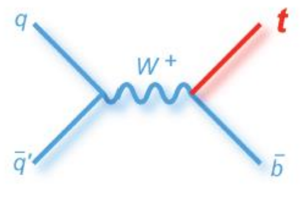


Close up

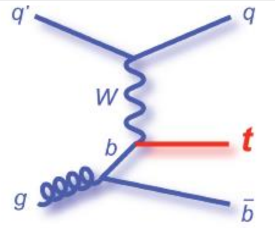


dtL/tL
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
dtR/tR
W1
Gr
D
H
W2
LH
Gh
C
P

In detail



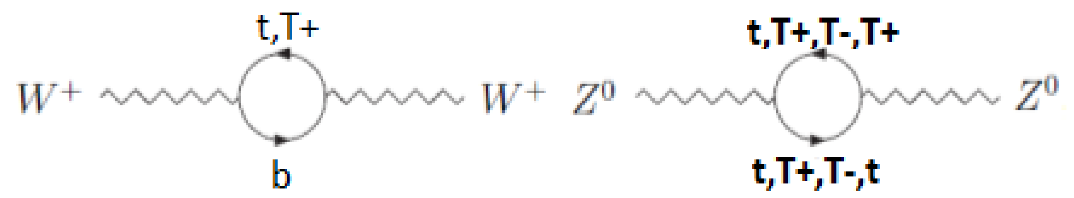
s-channel



t-channel

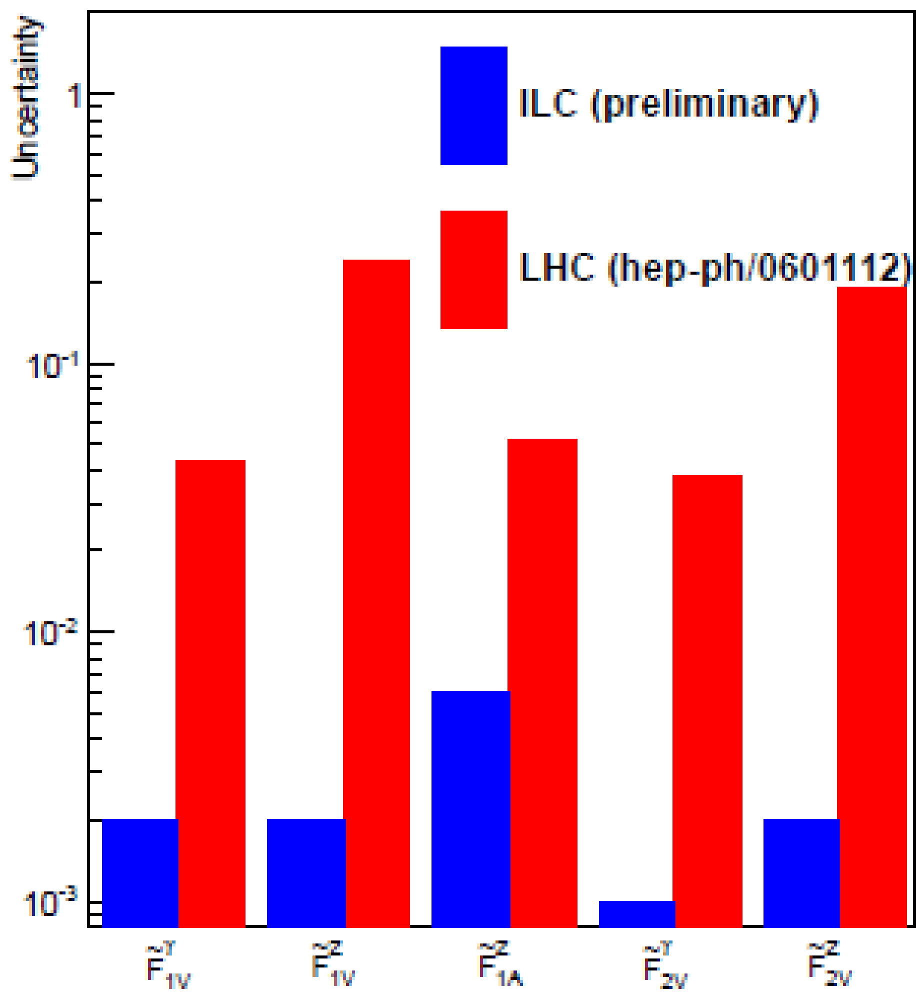
Model	dtR/tR %	dtL/tL %	dtLbL/tLbL %	$d\square_b/\square_b$	$d\square_{1}/\square_1$	dσZtt/σZtt %
Carena	0	-20	-14	0.8	1.1	-30
Djouadi	-330	0	0	-1.4	1.1	70
Gherghetta	-20	-20	-14	0.7	2.1	-36
Grojean	0	10	7	-0.4	-1.0	17
Hosotani	18	-7	-5	-0.4	-0.8	-5
Little Higgs	0	-15	-10	0.6	1.0	-23
Pomarol	0	-25	-17	1.0	1.2	-37
Wulzer 1	25	25	17	-1.1	5.8	56
Wulzer 2	-10	-10	-7	0.4	1.3	-20

Lessons



- Loop constraints have allowed to trim most of the models (Djouadi and LH had a priori a wide range)
- Most of the proposed models need large **BSM** contributions to compensate loop contributions meaning, e.g. for LH, that new particles like heavy vector quarks could be discovered at LHC14
- While some of these models could be tested at LHC by measuring **single top** production or the **Ztt** production, it will take ILC for a conclusive test of the various scenarios
- Disentangling of tL and tR is essential to separate models (difficult at LHC)

Comparisons



Coupling errors	ILC	LHC 300 fb-1
δZtLtL/ZtLtL	0.6%	-66% 15%
δZtRtR/ZtRtR	1.4%	-100% 148%
δγtLtL/γtLtL	0.24%	-7% 12%
δγtRtR/γtRtR	0.24%	-7% 12%

Conclusions

- **Loop contributions** + **gauge invariance** allows to put very useful restrictions on Wtb and Ztt coupling deviations
- Some models require large compensating loops which implies light vector quarks
- **Single top** and σ_{Ztt} from LHC still in infancy but in the future could indicate significant deviations
- The same mechanisms operate for the **Higgs sector**
- ILC will be a key instrument to fully elucidate the underlying **top and Higgs** physics and reach the highest sensitivity

BACK UPS

Higgs sector

- The same mechanism is at work when Higgs couplings deviate from SM, compensating contributions are needed to satisfy the LEP/SLC constraints
- Without these compensations **hZZ** coupling could not give significant deviations measurable at LHC or even at ILC
- Quantatively one can write:

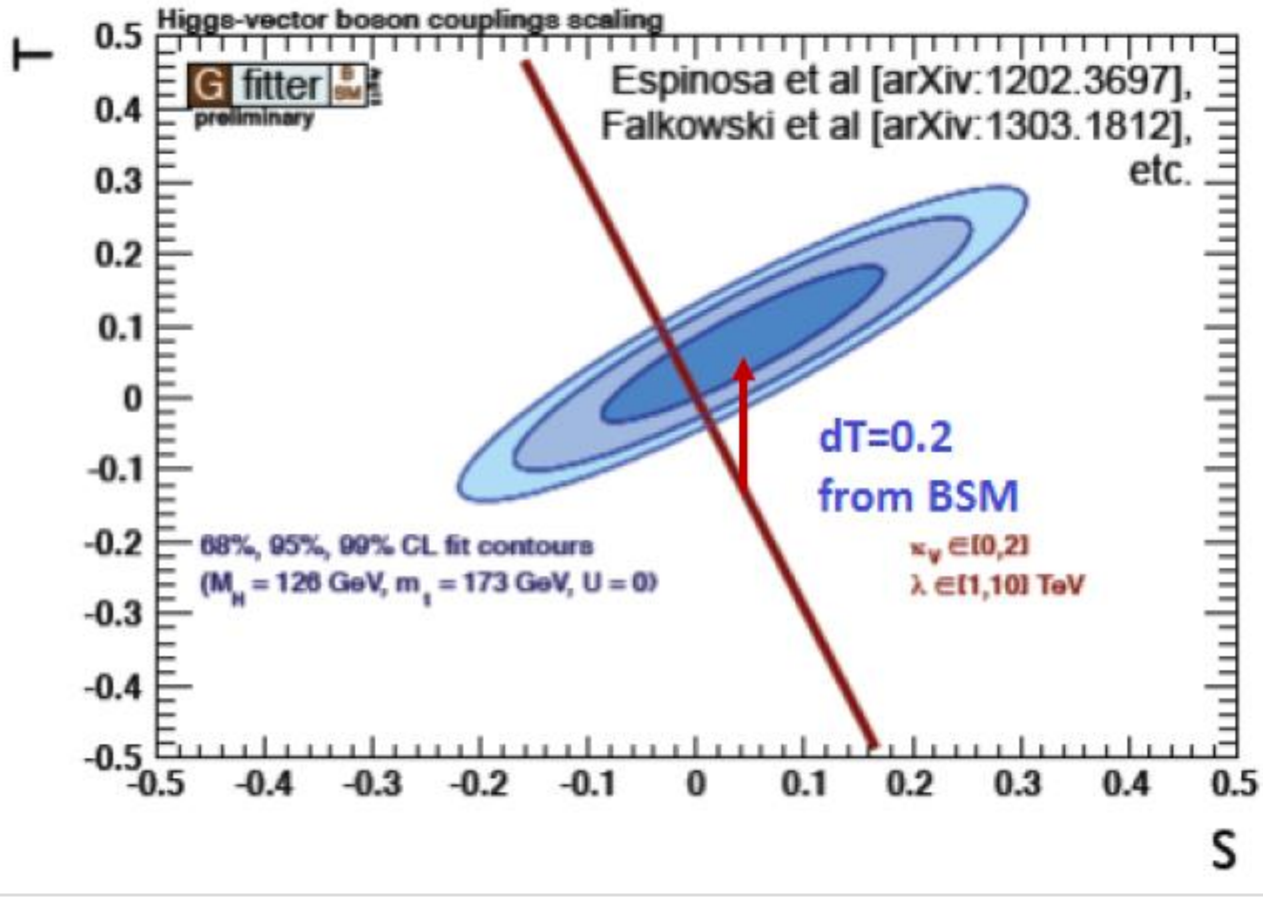
$$T = -\frac{3}{16\pi c_W^2}(1-\kappa_V^2)\log\frac{\Lambda^2}{M_H^2} \qquad S = \frac{1}{12}(1-\kappa_V^2)\log\frac{\Lambda^2}{M_H^2}$$

with $\kappa_V=1$ for the SM case

- A compensating term dT=0.2 allows to have $\kappa^2_V=0.7$ perfectly measurable at a LC

Higgs couplings

$$T = -\frac{3}{16\pi c_W^2}(1-\kappa_V^2)\log\frac{\Lambda^2}{M_H^2} \qquad S = \frac{1}{12}(1-\kappa_V^2)\log\frac{\Lambda^2}{M_H^2}$$



The RS solution for AFBb

- Main formulas

$$\frac{dR_Z}{R_Z}=\left(\frac{M_Z}{0.4M_{KK}}\right)^2\left[1+\frac{\frac{3}{4}\left(1-\frac{4}{3}\sin^2\theta'\right)}{\sin^2\theta'\cos^2\theta'}\right]\mathrm{F}\left(\mathrm{c_{tR}}\right)+\frac{s}{s-M_{KK}^2}Q(\mathrm{e})Q\left(\mathrm{c_{tR}}\right)$$

$$\frac{dL_Z}{L_Z}=\left(\frac{M_Z}{0.4M_{KK}}\right)^2\left[1-\frac{1}{4\cos^2\theta'}\right]\mathrm{F}\left(\mathrm{c_{tL}}\right)+\frac{s}{s-M_{KK}^2}Q(\mathrm{e})Q\left(\mathrm{c_{tL}}\right)$$

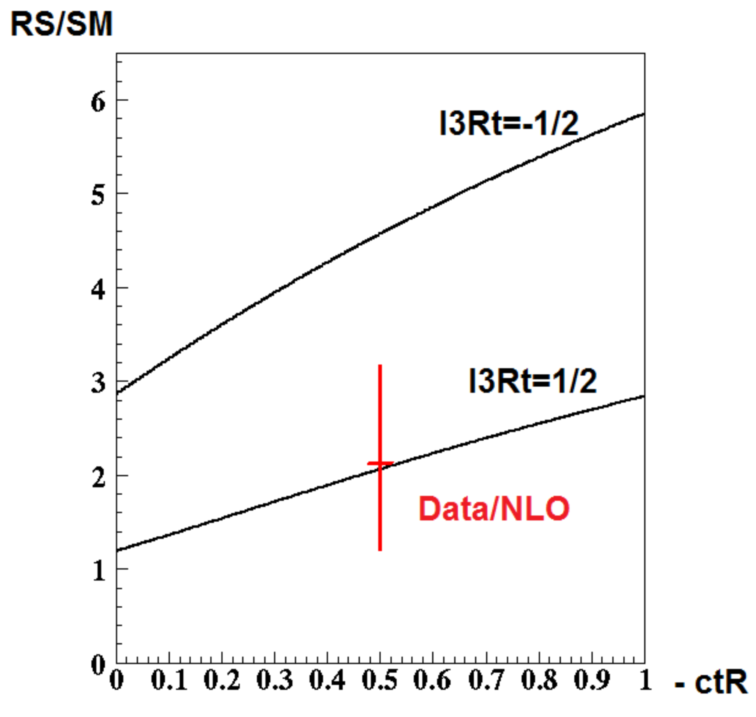
$$\frac{dR_\gamma}{R_\gamma}=\frac{s}{s-M_{\gamma KK}^2}Q(\mathrm{e})Q\left(\mathrm{c_{tR}}\right)$$

$$\frac{dL_\gamma}{L_\gamma}=\frac{s}{s-M_{\gamma KK}^2}Q(\mathrm{e})Q\left(\mathrm{c_{tL}}\right)$$

- Can be fully solved with ILC measurements
- Determining Mkk requires running at 2 energies
- F(ctR)/F(cbR)~30 close to mt/mb as one would expect in RS
- Possibly additional terms due to quark mixing

arXiv:1304.3594

CMS result on ttZ



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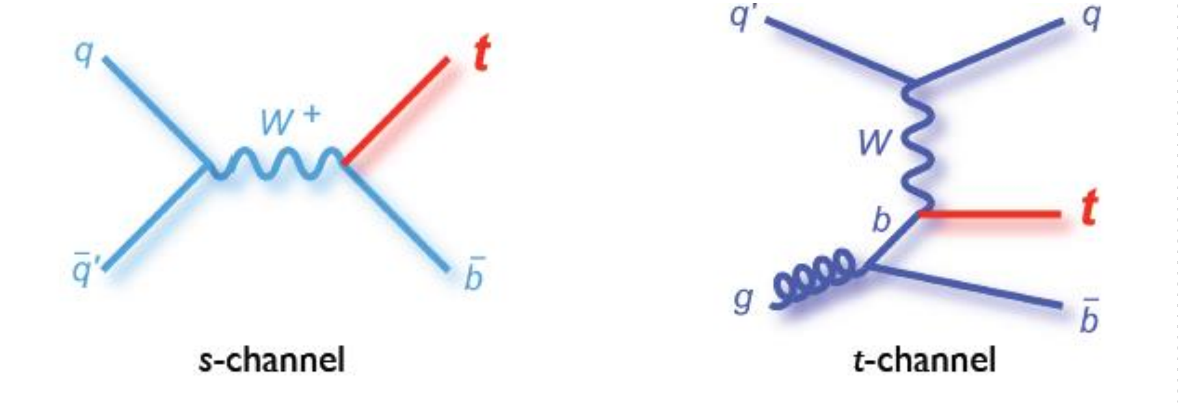
Single top



experiment	Vtb
CDF	0.92+0.10-0.08
D0	1.12+009-0.08
CMS	1.03+-0.12±0.04(th)
ATLAS	1.04+.10-0.11