Top couplings: ILC-B physics interplay

TYL-FKKPL Top physics

March 2, 2015 LAL

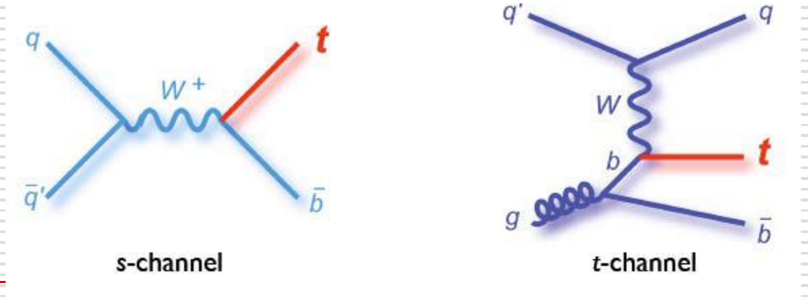
François Richard LAL/Orsay

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Introduction

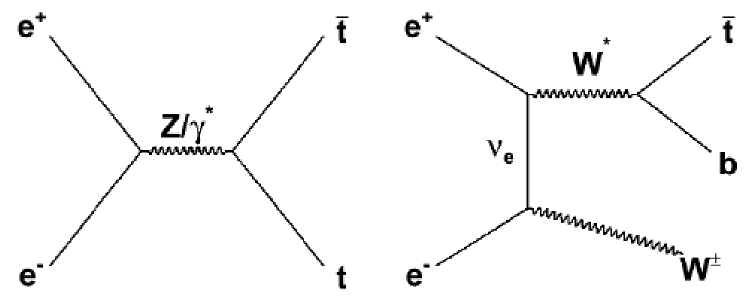
- Top EW couplings **direct** measurements can only be carried at HE colliders like **ILC** and **LHC**
- This talk discusses **indirect** measurements at **B factories** and at **LEP1/SLC** (T observable)
- I will compare the accuracies which are reachable with these various set ups
- If time is available, I will give a short status report on CPV at ILC

LHC



- ATLAS and CMS are reaching an accuracy of a few % on Vtb e.g. CMS gives $\mathbf{|V_{tb}|=0.998\pm0.0038(exp.)\pm0.016(theo.)}$
- If one assumes a SM CKM with $V_{tb}\sim1$ this is translated into a constraint on the **WbLtL** coupling which, under mild assumptions, can be related to **gL=ZtLtL** and **ZbLbL** (measured precisely at LEP1)
- Knowing ZtLtL one can use the **ttZ cross section** to extract **gR=ZtRtR** $\sigma_{ttZ} \sim g_R^2 + g_L^2$
- Unfortunately this cross section is known to ±35% and since **gR²/gL²~0.2**, this measurement is insensitive to ZtRtR and this will remain true for long since this measurement is systematics limited to ~5% which corresponds to an error of ~15% on ZtRtR

ILC

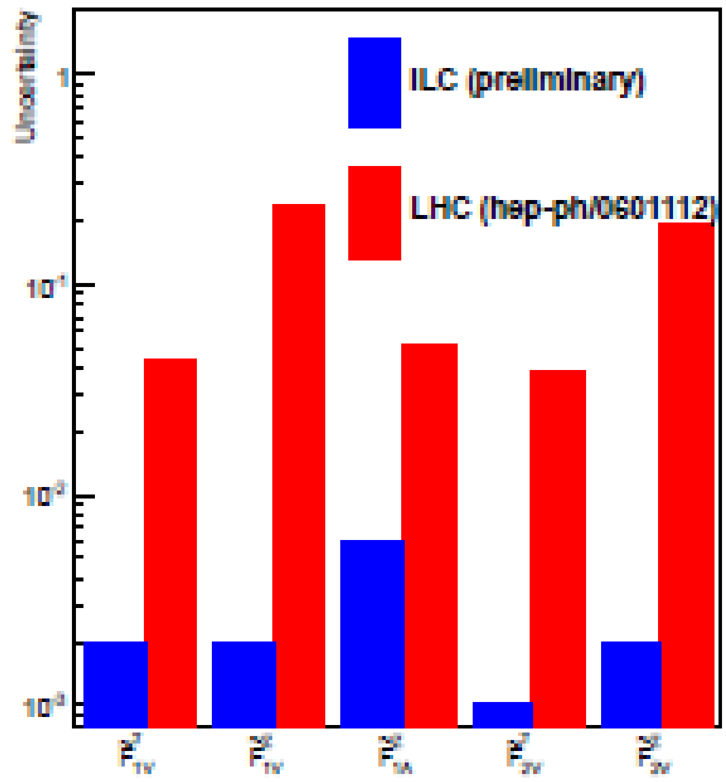


- ILC produces top quarks through γ and Z exchange
- Single top can be best measured using **e^-_L** 1411.2355
- Using **polarized beams** one can separately extract Z axial and vector couplings and the photon coupling (neglecting tensorial terms)

- 4 observables are available : $\boldsymbol{\sigma_{tt}}$ and **AFBt** for the two polarisations
- ILC operates at 500 GeV centre of mass well above tt threshold to avoid large coulombic QCD corrections and to keep good sensitivity to the axial term
- Statistical accuracies are overwhelmingly good, beyond theoretical present uncertainties, specially EW corrections

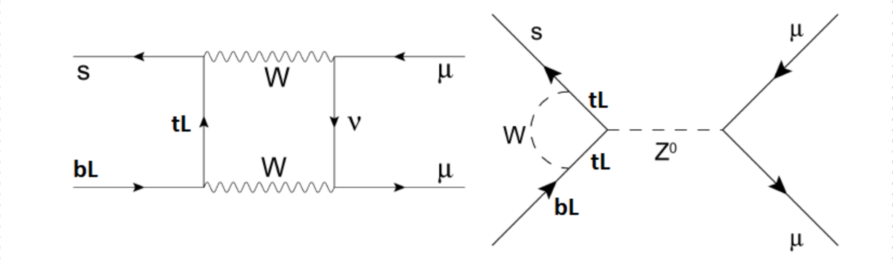
Comparisons LHC ILC

- The very large errors at LHC are due to the **sign** uncertainty which is absent at ILC due to Z-γ interference
- The tensorial terms F2V is obtained assuming SM vectorial terms
- F2A can be independently measured by measuring CPV distributions (see backup)
- I will concentrate on Z couplings

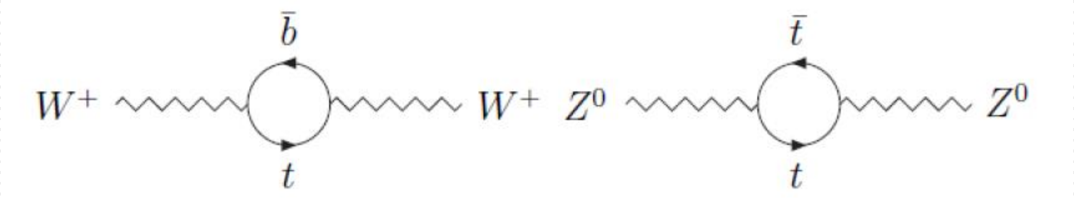


Top coupling through loops

- The B factory cleanest mode seems to be:



- Depends on **WbLtL** and **ZtLtL**
- The T parameter also depends on top loops



- In both cases beware that **additional BSM loops** (heavy quarks, Z') can also contribute

EFT

- From 1408.0792 one writes

$$\mathcal{L}_Z^{\rm diag} = \frac{e}{2 s_w c_w} Z_\mu \Big[\big(C^{(3)}_{\phi q,33} - C^{(1)}_{\phi q,33} \big)\, \bar{t}_L \gamma^\mu t_L - C_{\phi u,33}\, \bar{t}_R \gamma^\mu t_R$$

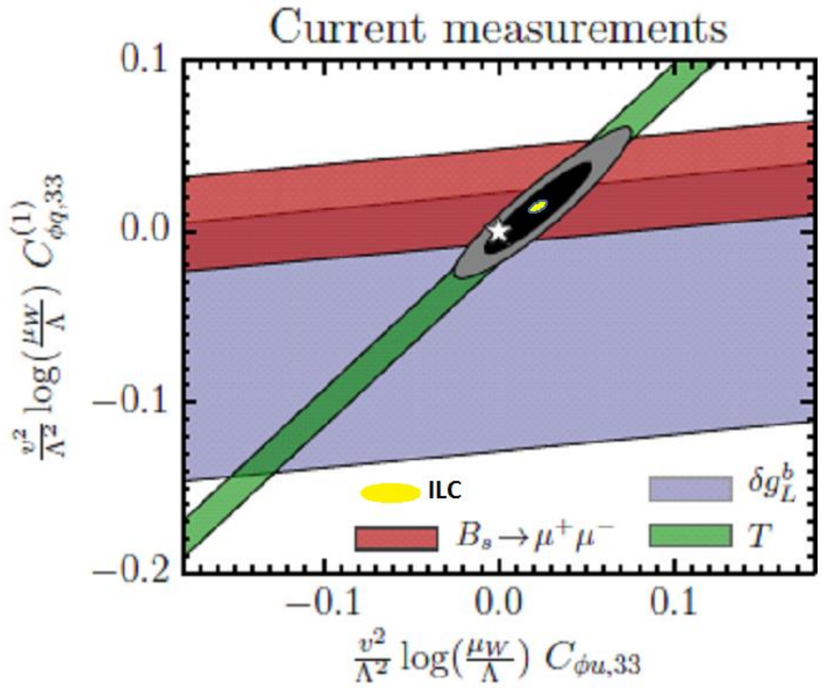
$$\delta g_L^t = \frac{v^2}{2\Lambda^2} \big(C^{(3)}_{\phi q,33} - C^{(1)}_{\phi q,33} \big)\,, \qquad \delta g_R^t = -\frac{v^2}{2\Lambda^2} C_{\phi u,33}$$

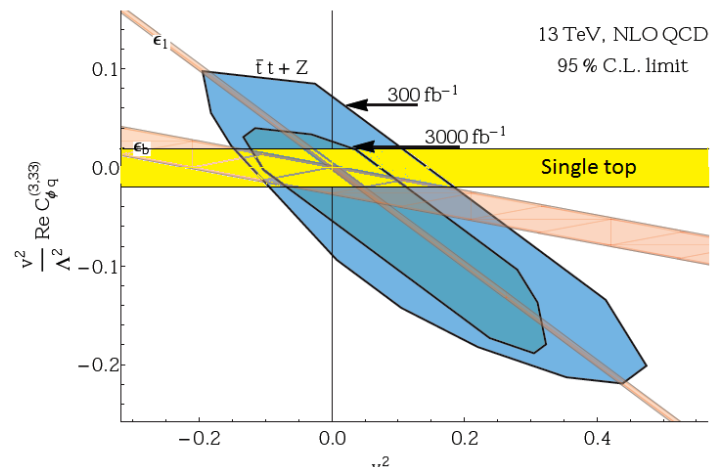
- T= $-\frac{v^2}{\Lambda^2} \left[\frac{1}{3\pi c_w^2} \left(C^{(1)}_{\phi q,33} + 2 C_{\phi u,33} \right) + \frac{3 x_t}{2\pi s_w^2} \left(C^{(1)}_{\phi q,33} - C_{\phi u,33} \right) \right] \log \frac{\mu_W}{\Lambda}$

- SU(2)L gives $C^{(3)}_{\phi q,33} \sim -C^{(1)}_{\phi q,33}$
- There are only **2 EFT parameters** simply related to gL and gR **Truly most general ?**
- Looking at concrete BSM models, I believe that this not the case

Results

- As expected B physics red band is almost horizontal
- The black ellipse is due to the **very tight T constraint**
- ILC errors which correspond to **dgL/gL=1%** and **dgR/gR=2%** are correlated (-0.8)
- Systematics are ignored so far
- LHC and B physics are inaccurate for gR (ignoring the T constraint)





1404.1005

T~ε_1/α counterexample

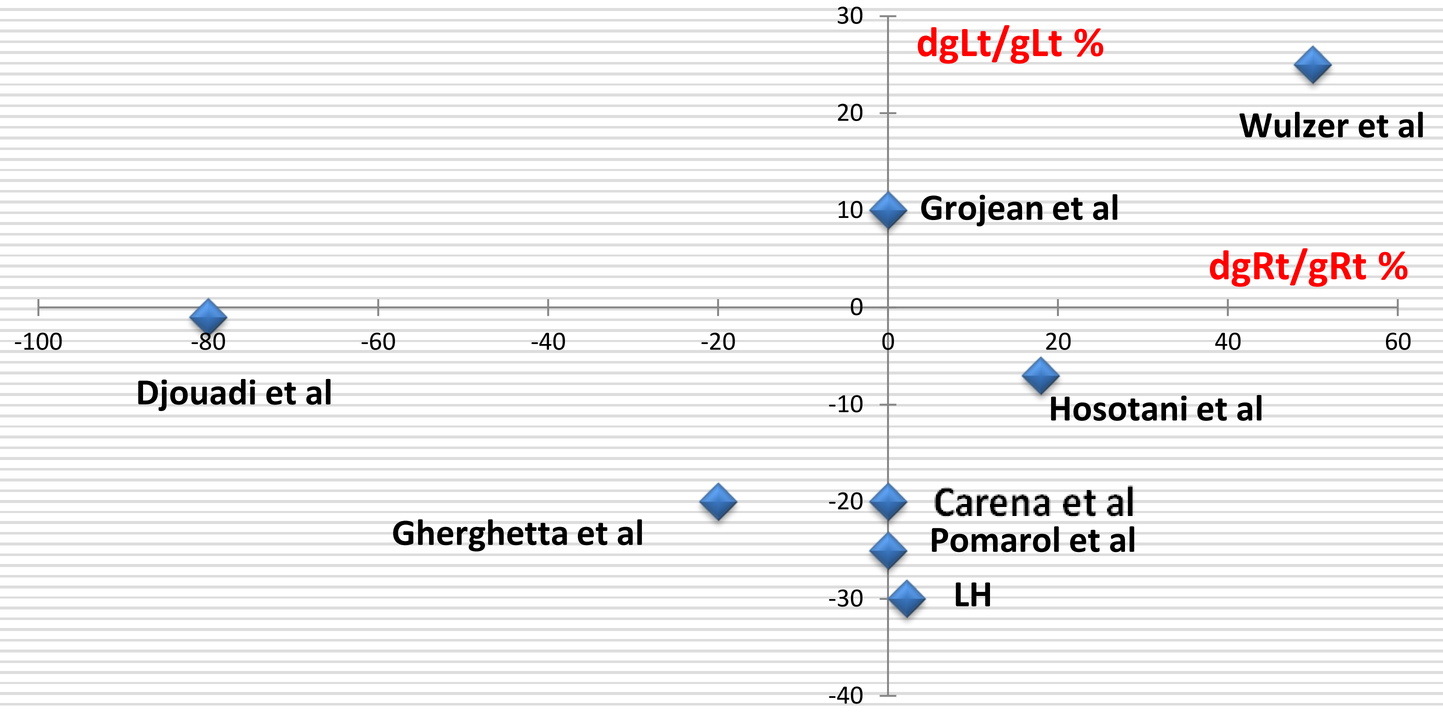
$$\mathcal{L} = \frac{g}{2c_W}\left(1 - \frac{4s_W^2}{3} + \kappa_L^{NC}\right)\overline{t_L}\gamma^\mu t_L Z_\mu + \frac{g}{2c_W}\left(-\frac{4s_W^2}{3} + \kappa_R^{NC}\right)\overline{t_R}\gamma^\mu t_R Z_\mu$$

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

- Djouadi et al: δT=0 for κ_R^{NC} □ 1 κ_L^{NC} □ 0
- This type of solution (see 1403.2893) falls outside the EFT prediction
- Not experimentally excluded as many others

http://arxiv.org/abs/arXiv:1403.2893

Expected deviations



Comments

- It can be shown that the SMALL residual sensitivity of B physics to **ZtRtR** is due to the large top mass
- The EFT approach is useful to evaluate the **sensitivity** of the various set ups but does not give the whole picture
- New physics can provide additional diagrams which can influence differently the **direct** and **indirect** measurements
- As an example one can have a Z′ which is not flavor diagonal and contributes to B->μμ but not to ILC couplings
- At ILC a Z′ can be observed through its propagator with an effect going like $\sim s/M^2_{Z'}$ (energy dependent) as discussed in 1403.2893
- The latter example shows the need for **energy flexibility in e+e-**

Conclusions

- A precise and **model independent** determination of top EW couplings requires ILC with polarised beams
- The high accuracy achievable allows to reach very large **BSM scales, beyond LHC** (e.g. KK exchange in RS) but beware the **theory errors**
- The **T parameter** seems to play a crucial part but this constraint has to be taken with a grain of salt given that it is far from clear that the **EFT** formalism covers all **BSM** scenarios (**counterexample** in Djouadi et al. scenario)
- **B factories** can add a crucial piece of information since these results also depend on loops which can be affected differently by BSM exchanges (e.g. flavour non diagonal Z' in Bs->$\mu\mu$)

Prunus Sato-Zakura 'Shirotae'

Jardin des Plantes Paris March 2011

BACK UP SLIDES

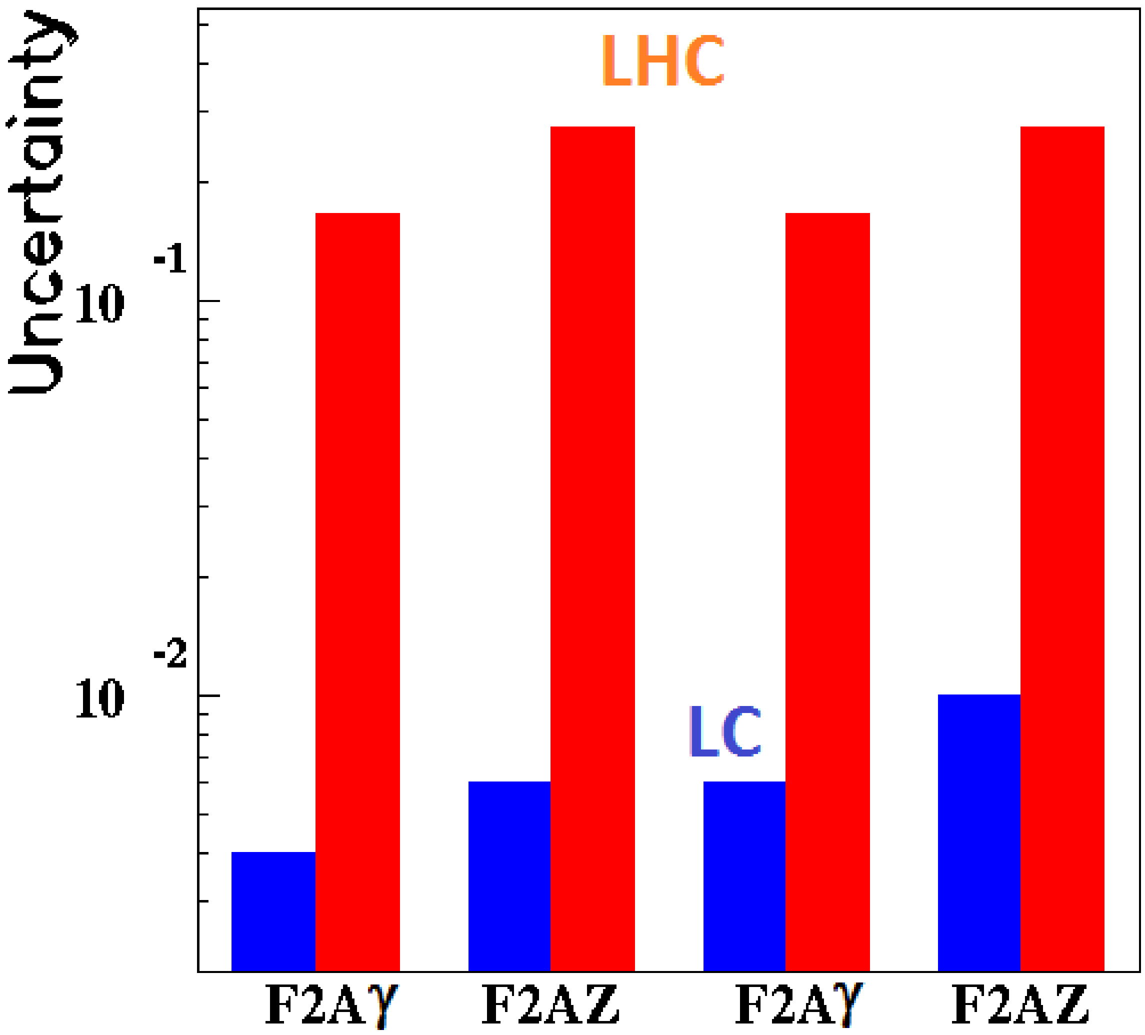
CPV status

- Studies have been performed by the Orsay-Valencia collaboration
- Did not go beyond ppt presentation from FR and internal note from Valencia
- Results are also available in the PhD Thesis of J. Rouene: https://tel.archives-ouvertes.fr/tel-01062136/document
- The method uses W. Bernreuther & P. Overmann http://arxiv.org/abs/hep-ph/9602273
- Accuracies are much better than at LHC
- Their relevance to explicit models are still unclear

Final table (Preliminary !)

Coupling	SM Value	LHC 300 fb-1	e+e- TDR TESLA 300 fb-1	e+e- ILC 500 GeV 500 fb-1
ReF^{γ}_{2A}	0	±0.17	±0.007	±0.004
ReF^{Z}_{2A}	0	±0.28	±0.008	±0.006
ImF^{γ}_{2A}	0	±0.17	±0.008	±0.006
ImF^{Z}_{2A}	0	±0.28	±0.010	±0.010

- In terms of dipole moment:
- **δRe(dγ)=±2.210-19ecm**
- **~10-18ecm** with two doublet models

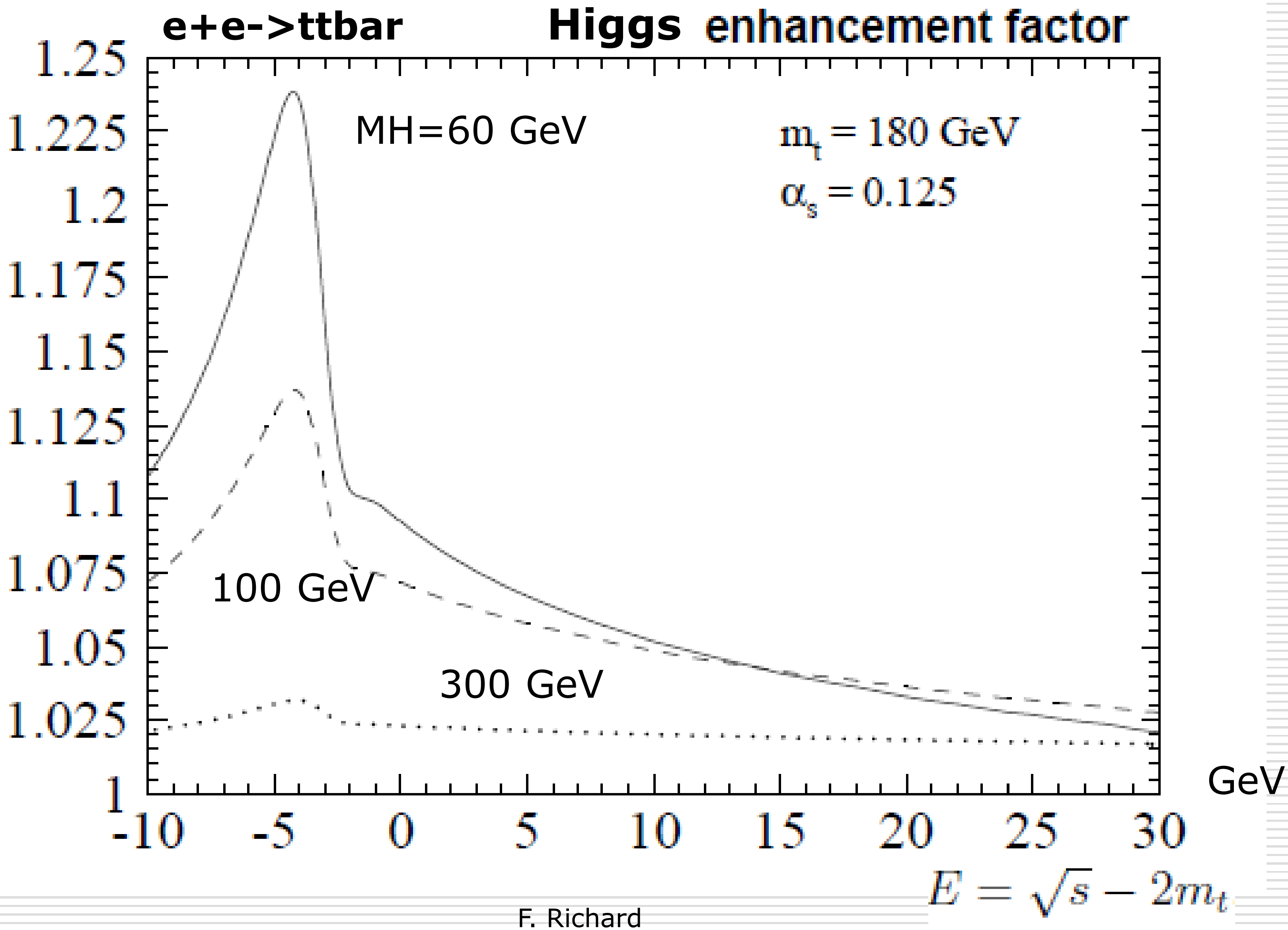


Uncertainty
LHC
LC
10^-1
10^-2
F2Aγ
F2AZ
F2Aγ
F2AZ

Things to do

- Check the validity of this approach (Benreuther et al) done by Valencia and J. Rouene
- Can one improve by using a more complete set of observables (seems the case for Im(F2A))
- Check for migration effects for Im(F2A)
- Investigate BSM models
- Look into the Higgs sector
- Write a note : started by Valencia

Harlander et al http://arxiv.org/pdf/hep-ph/9506292v1.pdf



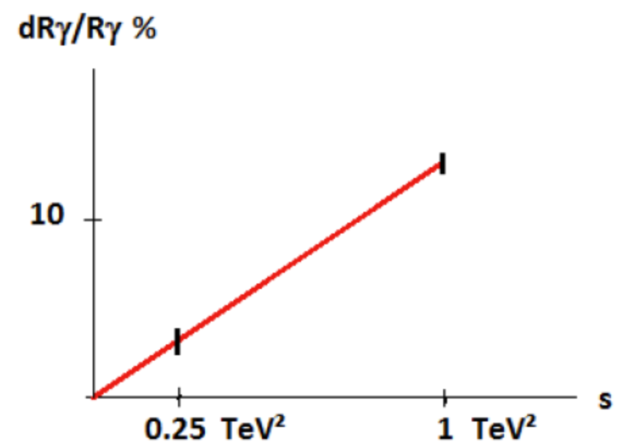
An example of RS 1403.2893

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

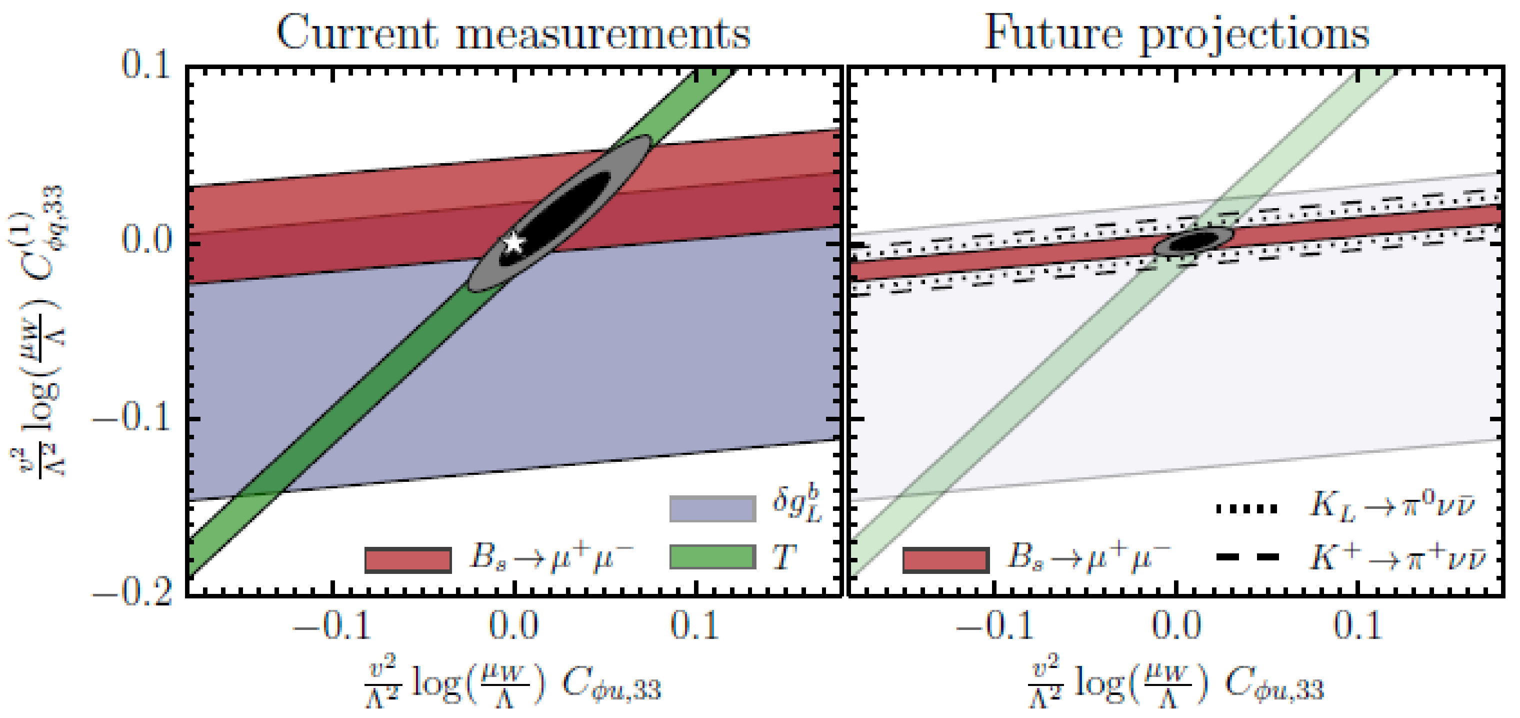
$$\frac{dL_Z}{L_Z}=\left(\frac{M_Z}{0.4M_{KK}}\right)^2\left[1-\frac{1}{4\cos^2\theta'}\right]F(c_{tL})+\frac{s}{s-M_{KK}^2}Q(e)Q(c_{tL})$$

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

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



Future accuracy with flavour



T~ε_1/α ε_b

$$\mathcal{L} = \frac{g}{2c_W}\left(1 - \frac{4s_W^2}{3} + \kappa_L^{NC}\right)\overline{t_L}\gamma^\mu t_L Z_\mu + \frac{g}{2c_W}\left(-\frac{4s_W^2}{3} + \kappa_R^{NC}\right)\overline{t_R}\gamma^\mu t_R Z_\mu$$

$$+\frac{g}{\sqrt{2}}\left(1+\kappa_L^{CC}\right)\overline{t_L}\gamma^\mu b_L W_\mu^+ + \frac{g}{\sqrt{2}}\left(1+\kappa_L^{CC*}\right)\overline{b_L}\gamma^\mu t_L W_\mu^-$$

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

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

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

EFT

$$Q^{(3)}_{\phi q,33} \equiv (\phi^\dagger i \overleftrightarrow{D}^a_\mu \phi)(\bar{Q}_{L,3}\gamma^\mu \sigma^a Q_{L,3}) \, ,$$
$$Q^{(1)}_{\phi q,33} \equiv (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{Q}_{L,3}\gamma^\mu Q_{L,3}) \, ,$$
$$Q_{\phi u,33} \equiv (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{t}_R\gamma^\mu t_R) \, .$$

$$\delta Y^{\rm NP} = \delta X^{\rm NP} = \frac{x_t}{8}\left(C_{\phi u}(\Lambda) - \frac{12+8x_t}{x_t} C^{(1)}_{\phi q,33}\right)\frac{v^2}{\Lambda^2}\log\frac{\mu_W}{\Lambda}$$