Determination of top quark CP violating electroweak couplings at the ILC operating at 500 GeV

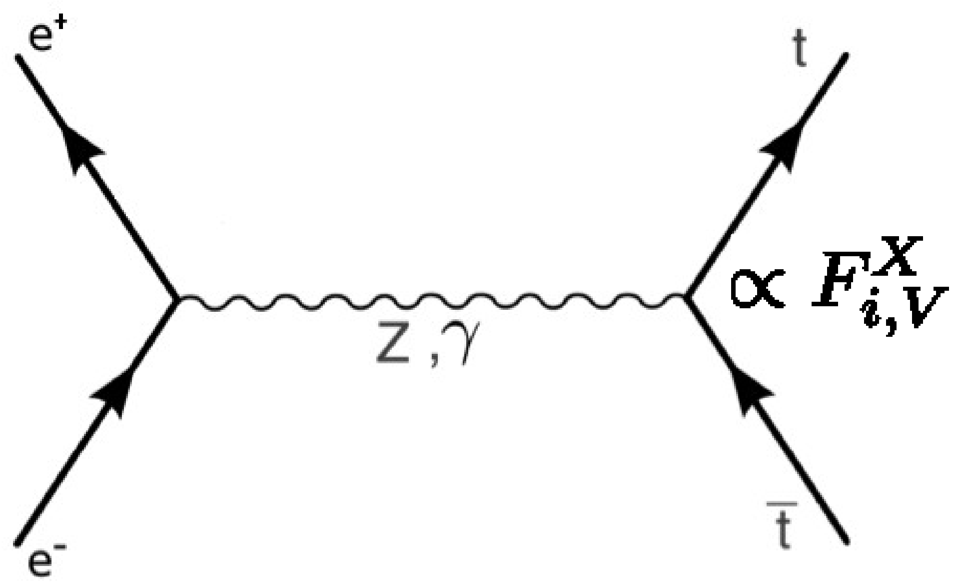
Roman Pöschl

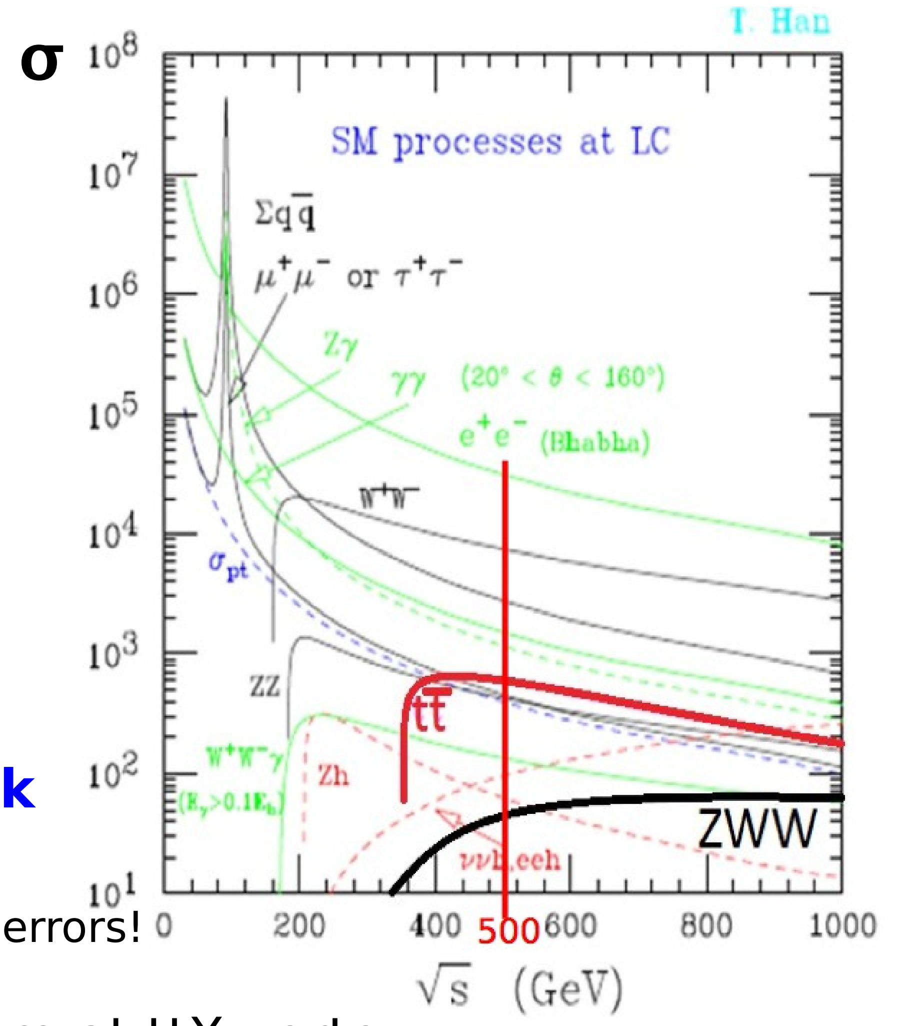
Based on work in the groups of

... and the theoretical foundation by
W. Bernreuther

Top LC Workshop - Paris March 2014

Top quark physics at (I)LC





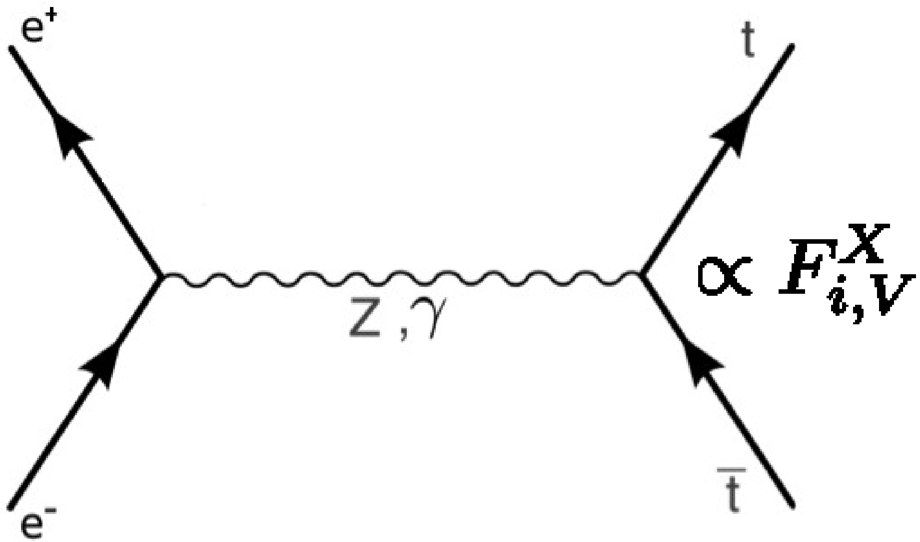
- Top quark production through **electroweak** processes,

  no competing QCD production => Small theoretical errors!

- Polarised beams allow to test chiral structure at ttX vertex
  => Precision on form factors F (this talk)

-ILC is promising for high precision top quark 'tomography'

Testing the chiral structure of the Standard Model



$$\Gamma^{ttX}_{\mu}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F^X_{1V}(k^2)+\gamma_5 F^X_{1A}(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF^X_{2V}(k^2)+\gamma_5 F^X_{2A}(k^2)\right)\right\}, \quad (2)$$

CP Violation through electric and weak dipole moment

$$d^X = (e/2m_t)F^X_{2A}, X = \gamma, Z$$

F2A is a complex number

$$F_{2A} = \lambda_{Re}Re(F_{2A}) + \lambda_{Im}Im(F_{2A})$$

Disentangling

ILC 'provides' two beam polarisations

$P(e^-) = \pm 80\%$ $\qquad$ $P(e^+) = \mp 30\%$

$$t\ \bar{t} \quad \rightarrow \quad \ell^+(\mathbf{q}_+) + \nu_\ell + b + \overline{X}_{\rm had}(\mathbf{q}_{\bar{X}}),$$

$$t\ \bar{t} \quad \rightarrow \quad X_{\rm had}(\mathbf{q}_X) + \ell^-(\mathbf{q}_-) + \bar{\nu}_\ell + \bar{b} \ ,$$

'Optimal' observables to measure F2A

$$O_+^{Re} = (\hat{k}_{\bar{t}} \times \hat{q}_+)\hat{e}_+ \qquad O_-^{Re} = (\hat{k}_t \times \hat{q}_-)\hat{e}_+$$

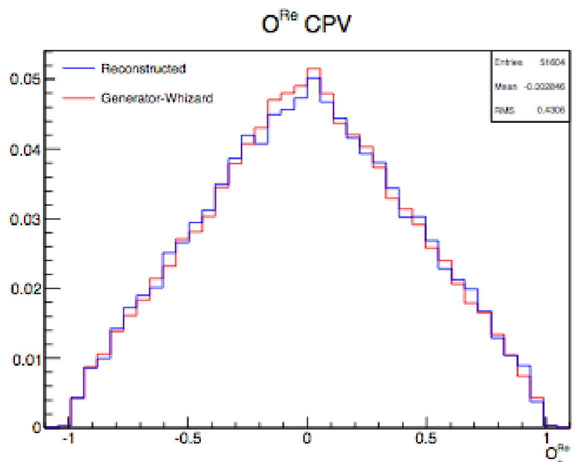
$$O_+^{Im} = -[1 + (\frac{\sqrt{s}}{2m_t} - 1)(\hat{q}_{\bar{X}} \times \hat{e}_+)^2]\hat{q}_+^* \cdot \hat{q}_{\bar{X}} + \frac{\sqrt{s}}{2m_t}\hat{q}_{\bar{X}} \cdot \hat{e}_+ \hat{q}_+^* \cdot \hat{e}_+$$

Extraction of four unknowns due to beam polarisation P

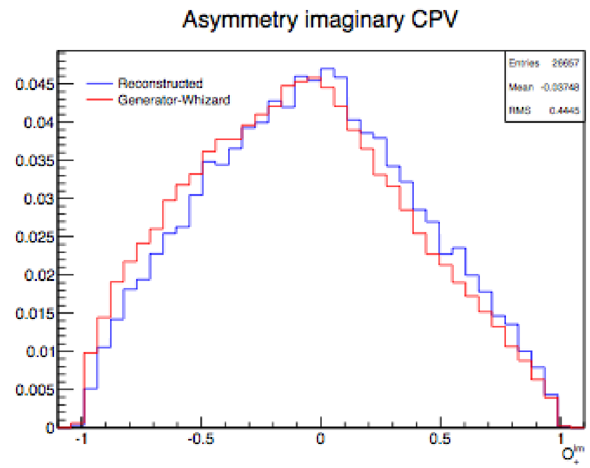
$$A_{\gamma,Z}^{Re} = \langle O_+^{Re} \rangle - \langle O_-^{Re} \rangle = c_\gamma[PRe(F_{2A}^\gamma) + KZRe(F_{2A}^Z)]$$

$$A_{\gamma,Z}^{Im} = \langle O_+^{Im} \rangle - \langle O_-^{Im} \rangle = d_\gamma[Im(F_{2A}^\gamma) + PKZIm(F_{2A}^Z)]$$

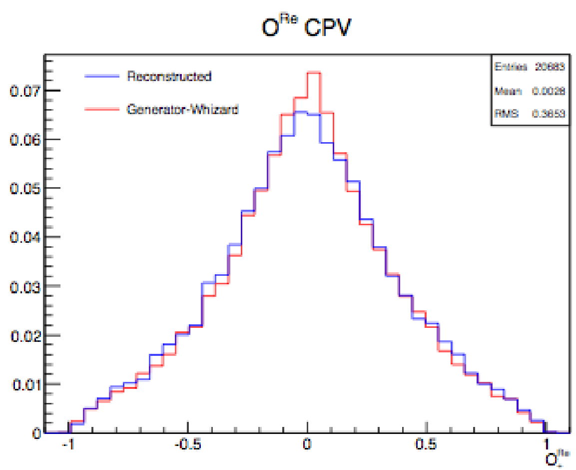
Distributions of O variables



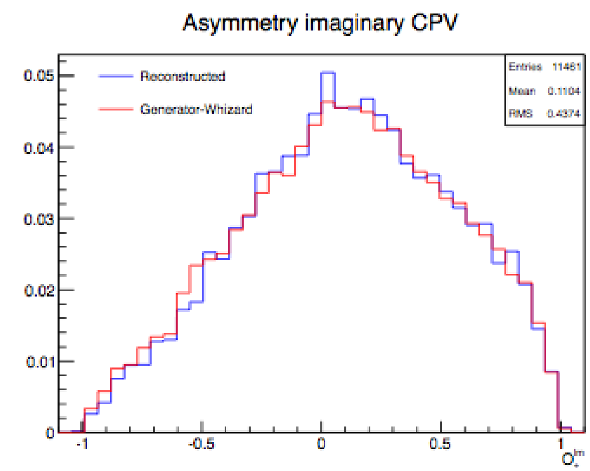
(a) O_+^{Re} P=-1



(b) O_+^{Im} P=-1



(c) O_+^{Re} P=1



(d) O_+^{Im} P=1

CPV obs	Generated	Reconstructed
$\langle O_+^{Re} \rangle$	-0.00285	-0.00206
$\langle O_-^{Re} \rangle$	0.00296	0.00116
$\langle O_+^{Im} \rangle$	-0.08922	-0.0375
$\langle O_-^{Im} \rangle$	-0.08654	-0.0341
$\bar{RMS}$	0.43	0.44
δ_{stat}	0.0014	0.002

	Generated	Reconstructed
$A_{\gamma,Z}^{Re}$	-0.0058 $\pm$ 0.002	-0.0032 $\pm$ 0.003
$A_{\gamma,Z}^{Im}$	-0.0027 $\pm$ 0.002	-0.0034 $\pm$ 0.003

Expected accuracies

Work in progress but ….

From above accuracies one can expect at ILC 500 ($500fb^{-1}$)

~0.0005 – 0.01 precision on F2A for both gamma and Z

With full disentangling of real and imaginary parts

To be compared with

~0.2 – 0.3 expected at LHC14 for 300 fb-1

Where only one factor at a time is varied

This is current knowledge and we are of course eagerly awaiting updates!

How can we benefit from these accuracies?

Further considerations

(by F. Richard)

If BSM contributions on Re(F2A) are independent of ECM then ECM=500 GeV is adequate

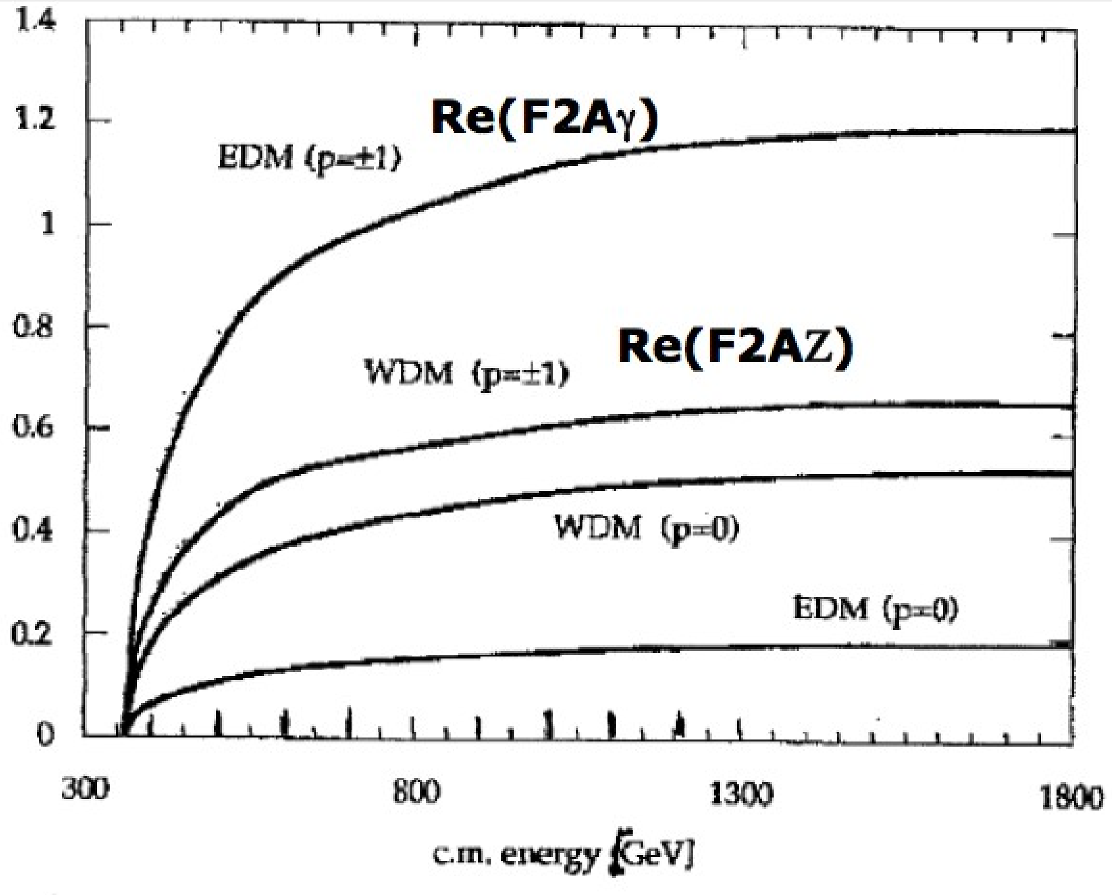
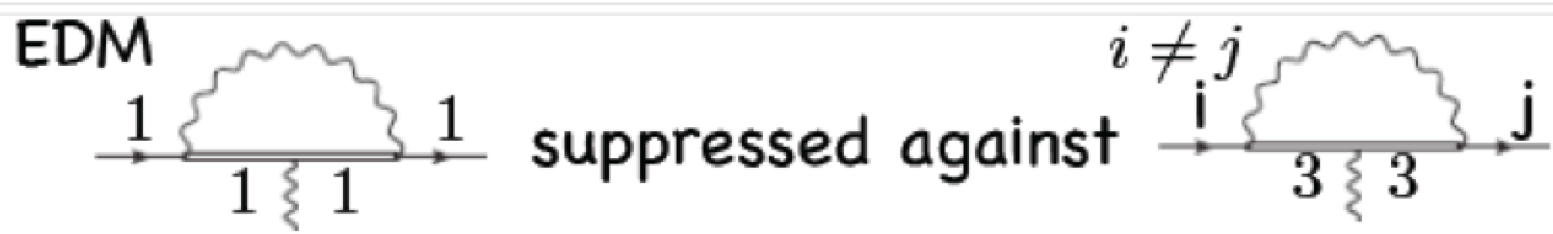


Figure 1: *The ratio* $r_1/2 = |c_\gamma|/\Delta\mathcal{O}_+(1)$ *as a function of* $\sqrt{s}$ *for several polarization degrees, and the corresponding ratio assocaited with the real part of the WDM.*

Further remarks

- On BSM models:
- Composite-like models (Barbieri et al):
- de<10-27 ecm dn<2.910-26 ecm
- At ILC dtop~few10-19 ecm modest unless the compositeness scale more favorable for the top quark
- 20-50 TeV for 1st generation, down to 10 TeV for top (from $\Delta F=2$ constraints) ? Does not seem to be sufficient ($1/\Lambda^2$) to regain 6 orders of magnitude !



Higgs sector

- It should be noted that for what concerns the Higgs sector (non-minimal) contribution there could be a much larger enhancement for the 3d generation **df~m³f** at one-loop
- Higgs exchange is larger near threshold and the sensitivity for Re(F2A) drops to 0 at 500 GeV

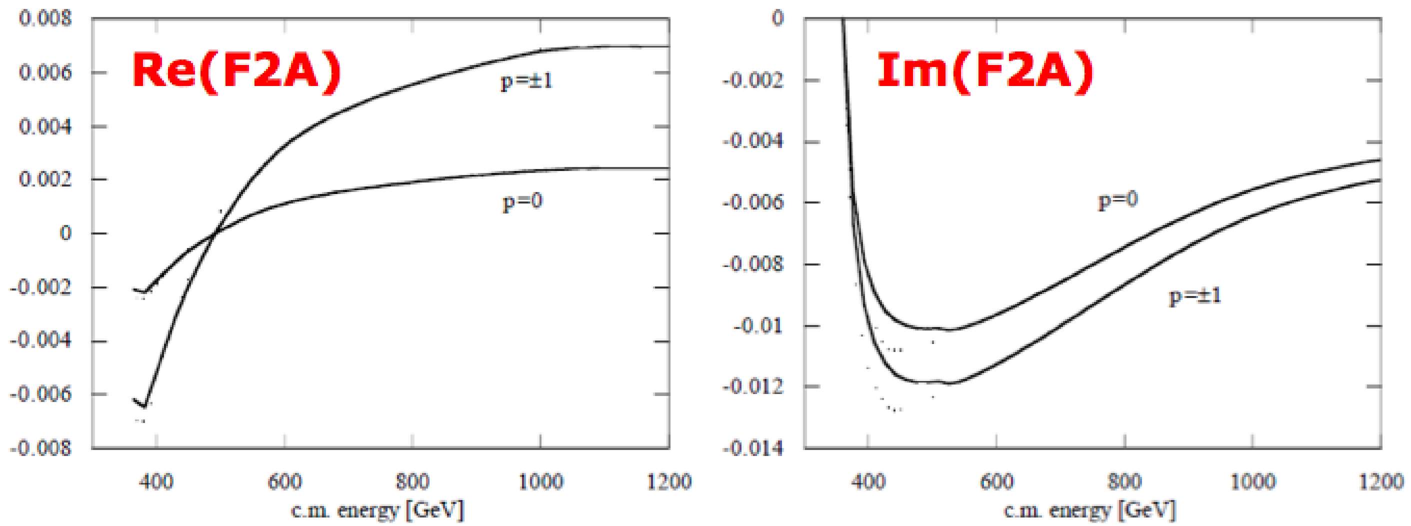
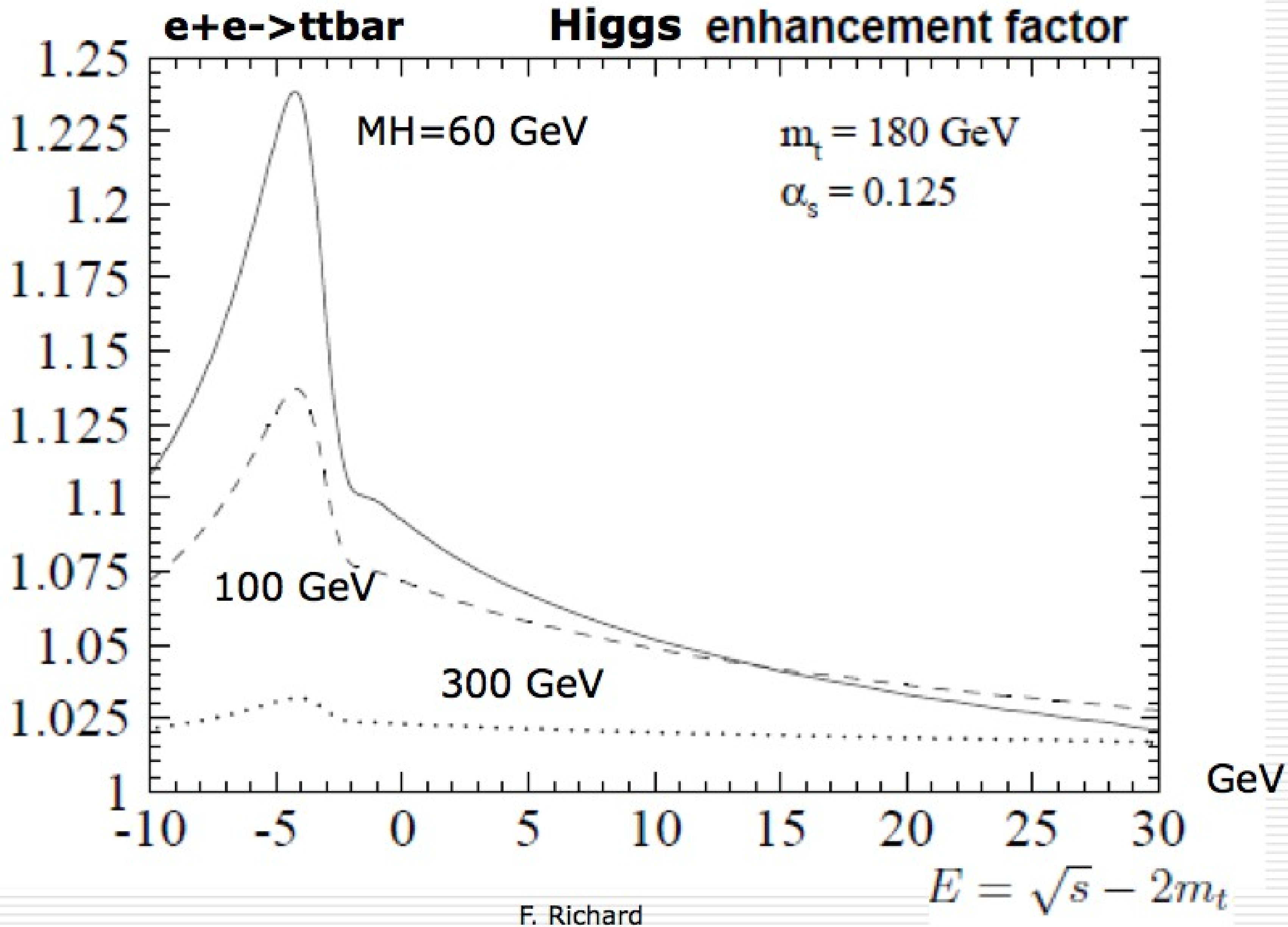


Fig 1: Ratios r_1 (left figure) and r_2 (right figure) for the optimized dispersive and absorptive observables $\mathcal{O}_{\pm}(i)$, $i = 1, 2$ defined in [6] for $m_t = 180$ GeV, $m_{\varphi_1} = 100$ GeV, and $\gamma_{CP} = 1$.

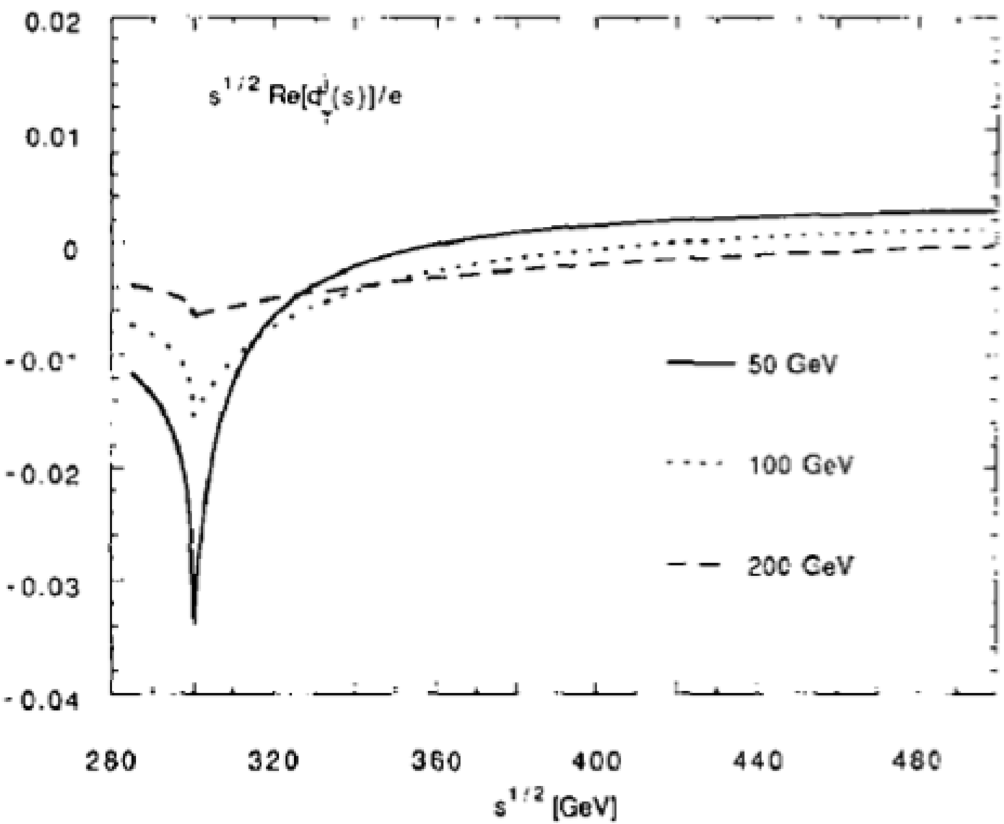
Harlander et al http://arxiv.org/pdf/hep-ph/9506292v1.pdf

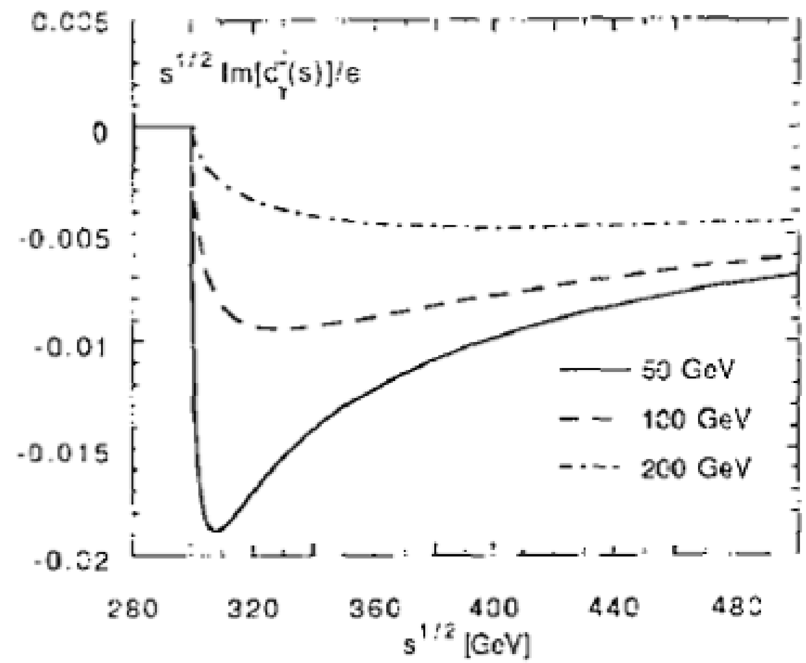


Expected effects

- Ref W. Bernreuther et al (Phys.Lett. B279 (1992) 389-396) quoted in TESLA TDR predicts **ReF2Aγ~ImF2Aγ ~2-3%** at **√s=370** GeV and F2AZ~0.34F2Aγ
- One should therefore evaluate which precisions can be achieved near threshold
- This work should be updated
- Also one should compare this approach to other possibilities using Higgs decays or B physics

Energy dependence (mt=150 GeV)





Conclusions

- CPV FF can be fully disentangled at ILC using optimized observables
- Beam polarization plays an essential part
- The accuracy is overwhelming with respect to LHC but is it sufficient to test BSM ?
- The Higgs sector with CPV seems the most promising meaning that ILC could not only measure (g-2)t but also dt (with some luck)
- Good progress so far but more experimental work needed