ee to htt as a probe of Higgs CP property

Ya-Juan Zheng

Osaka University

Phenomenology 2017 Symposium
May 9, 2017

Based on collaboration with Kaoru Haigwara and Hiroshi Yokoya, work in progress

Outline

- Motivation
- Effective htt couplings for the CP-mixed Higgs state
- Current constraints from LHC data on htt coupling and CP mixing angle
- Production of e+e- to htt with tt decays semi-leptonically
- Distributions of CPV observables and chi-squared contour plot
- Summary

Motivation

- After the discovery of the Higgs boson, further precision measurement to study physics of symmetry breakdown and look for hints of BSM
- In the SM, the only fundamental neutral scalar is a spin 0, CP even Higgs boson.
- The spin of h(125) has been measured to be J=0 and CP of h(125) has been studied in h>4l decays and pure CP=-1 is excluded. h(125) interactions may violate CP.
- Higgs has the largest coupling to the top quark and top-Higgs interaction can be the best probe of BSM physics
- The precision measurements of Top mass and top Yukawa coupling are among the main targets of ILC. We can study htt couplings at 500 GeV and 1000 GeV in the future.

Effective htt coupling

effective Lagrangian: $\mathcal{L} = -g_{htt} h\bar{t}\left[\cos\xi_{htt} + i\sin\xi_{htt}\gamma_5\right]t$

h(125) CP-even CP-odd

SM: $\xi_{htt} = 0,\ g_{Htt} = m_t/v,\ \text{and}\ g_{Att} = 0$

In 2HDM, h(125) can be a mixture of 3 neutral scalar bosons

$$h = O_{hH}H + O_{hH'}H' + O_{hA}A$$

even even odd

In general, both H, H' and A couple to the top quark

e.g, typeII 2HDM:

$$g_{htt}\cos\xi_{htt} = \frac{m_t}{v}\left(O_{hH} + O_{hH'}\frac{1}{\tan\beta}\right), \quad g_{htt}\sin\xi_{htt} = \frac{m_t}{v}O_{hA}\frac{1}{\tan\beta}$$

ξ is model dependent and process dependent

Constraints from LHC data

Production rate: $\underset{\text{exp.}}{R(H\to ff)} = \underset{\text{exp.}}{\int Ldt} \cdot \underset{\text{th.}}{\sigma(pp\to H)} \cdot \underset{\text{th.}}{\frac{\Gamma_f}{\Gamma}}$

→ get partial decay width then $\Gamma_f \sim g_f^2$ → coupling

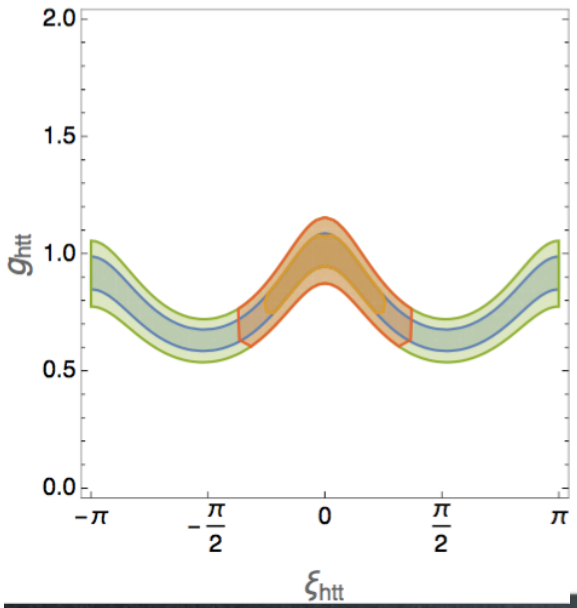
$$\frac{\Gamma[h\to WW^*]}{\Gamma_{\rm SM}[H\to WW^*]} = \frac{\Gamma[h\to ZZ^*]}{\Gamma_{\rm SM}[H\to ZZ^*]} = \cos^2\xi \qquad \frac{\Gamma[h\to f\bar{f}]}{\Gamma_{\rm SM}[H\to f\bar{f}]} = A_f\cos^2\xi + B_f\sin^2\xi$$

ATLAS, CMS, CDF/D0 → ξ < 0.35(0.22)pi @8(14)TeV LHC — Freitas,Schwaller,PRD(2013)

gg>h> rr → ξ < 0.64 pi — Kobakhidze,Wu,Yue, JHEP (2014)

ATLAS, CMS 7+8 (gg>H>VV,rr, tata, bb) → ξ < 0.75 pi — Djouadi,Moreau, EPJC (2013)

Future: if XS(htt) error±20% → ξ < 0.17 pi — Ellis, Hwang, Sakurai, Takeuchi JHEP (2014)



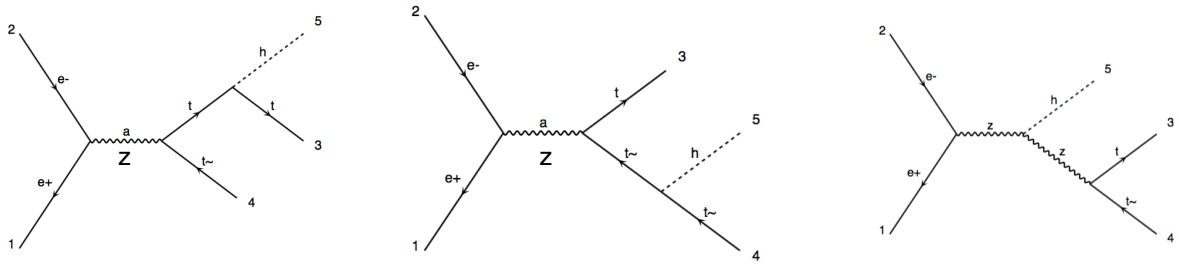
Cheung,Lee, Tseng PRD(2014), Bhattacharyya, Das,Pal PRD87(2013), Shu,Zhang PRL (2013), Inoue, Ramsey-Musolf, Zhang PRD89(2014), Bolognesi, Gao, Gritsan, Melnikov, Schulze, Tran, Whitbeck, PRD(2012), Englert, Goncalves-Netto, Mawatari,Plehn,JHEP(2013),...

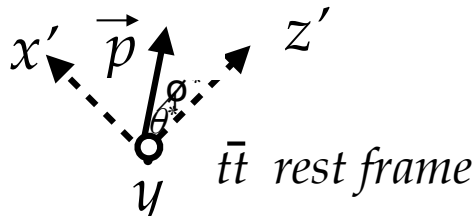
ATLAS+CMS, JHEP08(2016)045 — signal strength of gg,rr

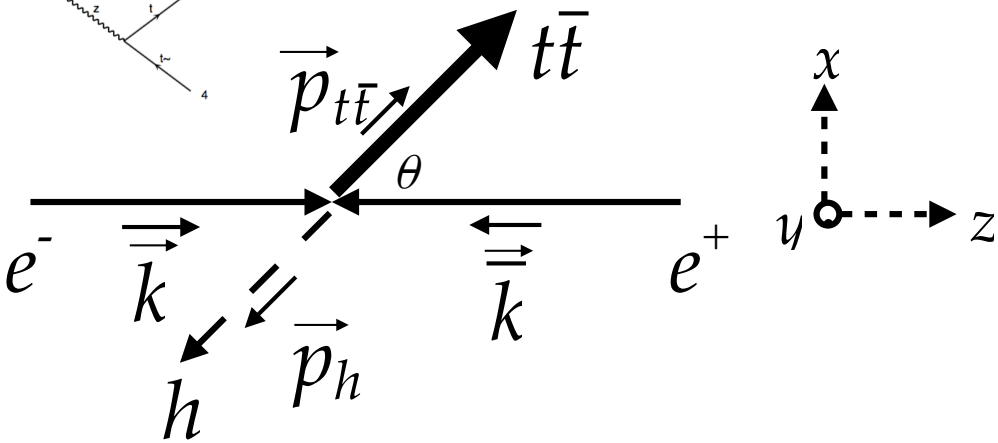
All the current bounds from LHC data on htt coupling and CP mixing angle are obtained by indirect observation and NP contribution is not included → Direct Observation

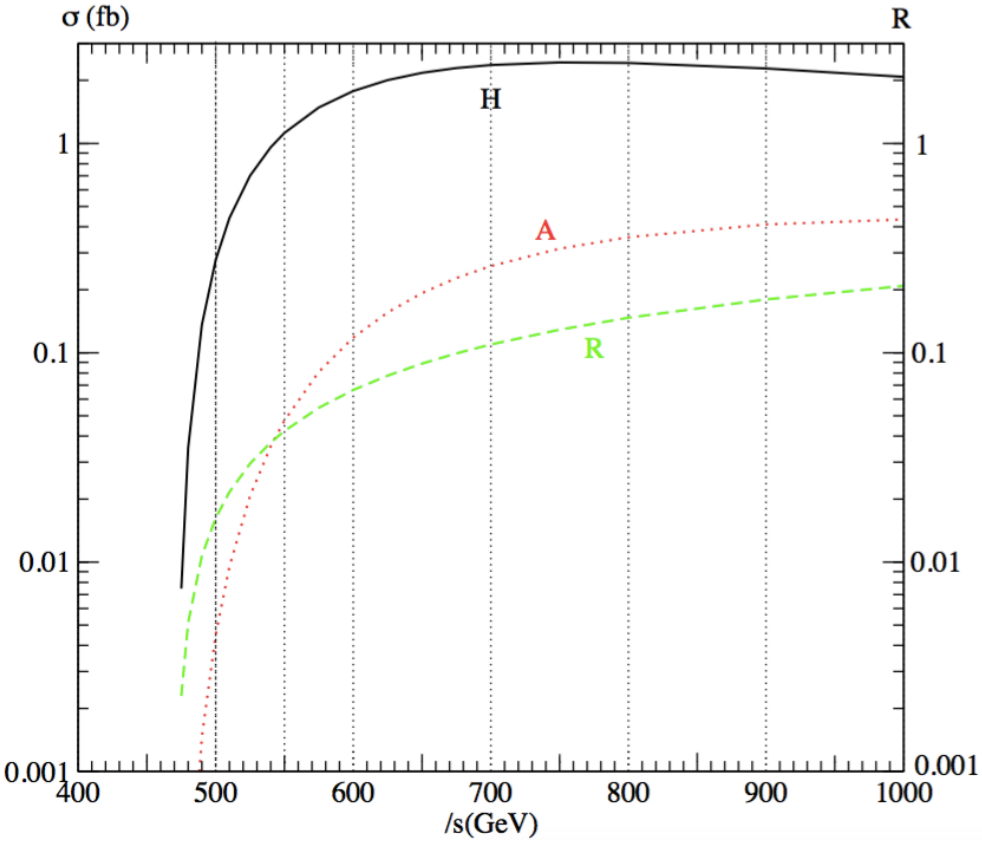
tth production at e+e- colliders

$$e^-(k_1, \frac{\alpha}{2}) + e^+(k_2, -\frac{\alpha}{2}) \to t(p_t, \frac{\sigma}{2}) + \bar{t}(p_{\bar{t}}, \frac{\bar{\sigma}}{2}) + h(p_h)$$







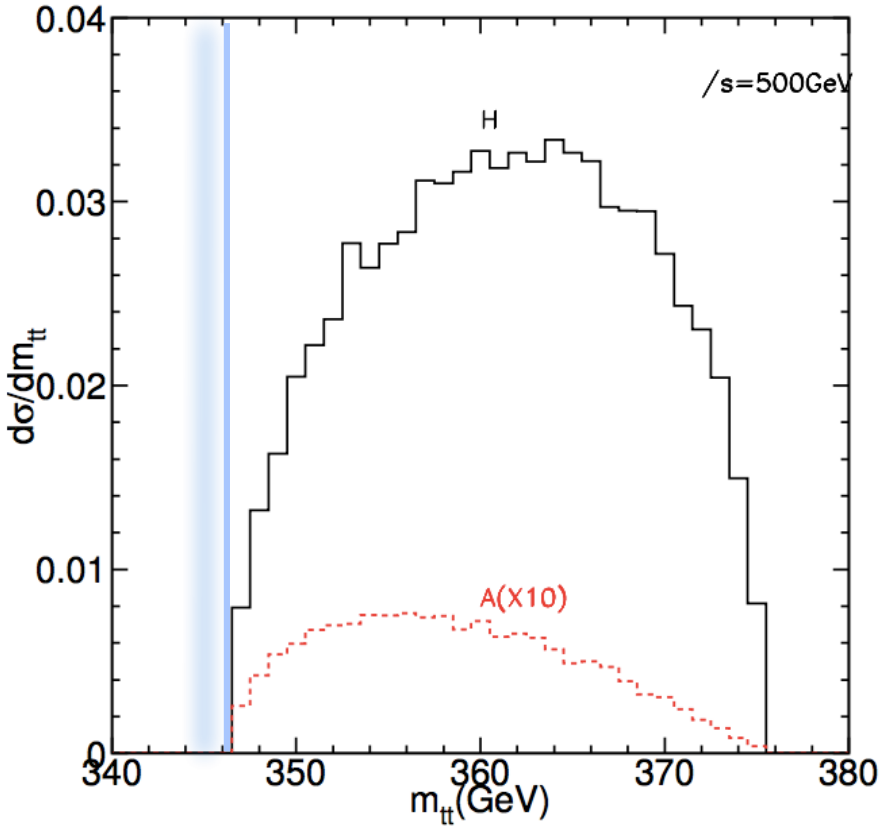


unpolarized beam $P(e^-)=P(e^+)=0$

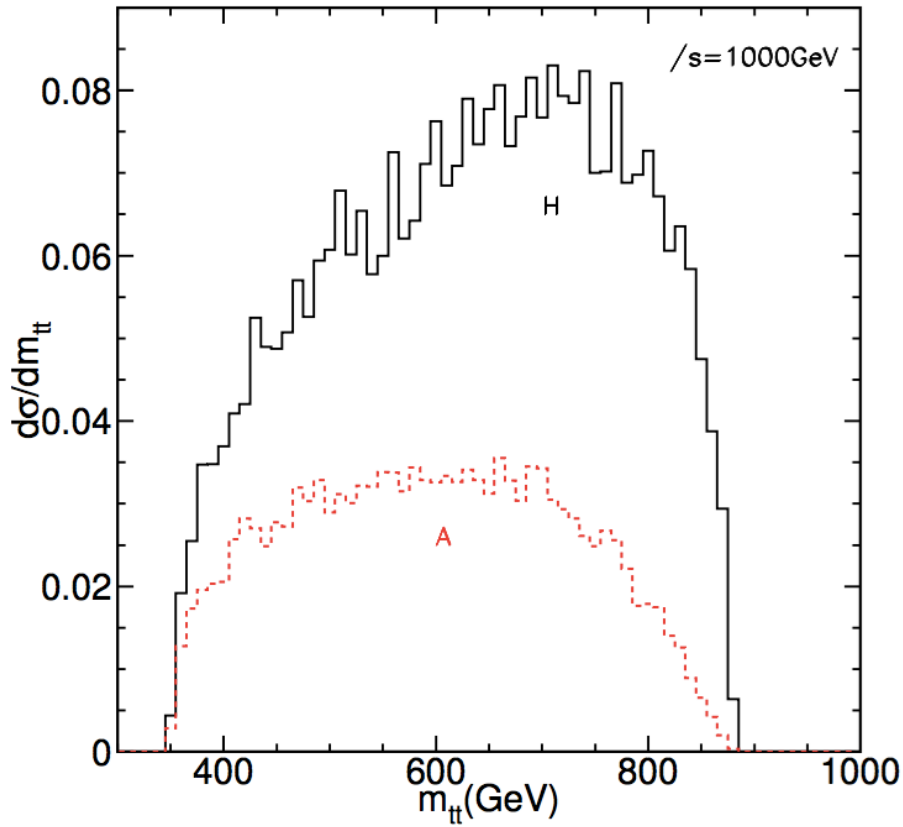
/s(GeV)	H(fb)	A(fb)	A/H
500	0.28	0.0049	0.018
550	1.1	0.052	0.047
1000	2.1	0.51	0.24

ratio of A/H is increased by more than two times from /s=500 GeV to 550 GeV

M_{tt} distribution



346 GeV < mtt <375 GeV



346 GeV < mtt <875 GeV

At /s=500 GeV, the cross section experiences large QCD corrections because of the tth production threshold. At /s=1000 GeV, QCD corrections are subleading.

e.g. K.Hagiwara, K.Ma, H.Yokoya, JHEP 1606 (2016)

with top pair decay

Differential cross section for

$$\mathcal{M}_{\alpha\sigma\bar{\sigma}} = \mathcal{M}\left(e^-(k_1, \frac{\alpha}{2}) + e^+(k_2, -\frac{\alpha}{2}) \to t(p_t, \frac{\sigma}{2}) + \bar{t}(p_{\bar{t}}, \frac{\bar{\sigma}}{2}) + h(p_h)\right)$$

when both top and anti top decays leptonically

$$(t \to \bar{l}(\bar{\theta}^*, \bar{\phi}^*))$$
$$(\bar{t} \to l(\theta^*, \phi^*))$$

$$\frac{d\sigma_\alpha}{dm_{tt} d\cos\theta d\cos\hat{\theta} d\phi d\cos\bar{\theta}^* d\bar{\phi}^* d\cos\theta^* d\phi^*} = \frac{B(t \to \ell\bar{\nu}b)^2}{64\pi^2 s} \times \Big\{$$

$$|M_{\alpha++}|^2(1+\cos\bar{\theta}^*)(1-\cos\theta^*) + |M_{\alpha+-}|^2(1+\cos\bar{\theta}^*)(1+\cos\theta^*)$$
$$+|M_{\alpha--}|^2(1-\cos\bar{\theta}^*)(1+\cos\theta^*) + |M_{\alpha-+}|^2(1-\cos\bar{\theta}^*)(1-\cos\theta^*)$$

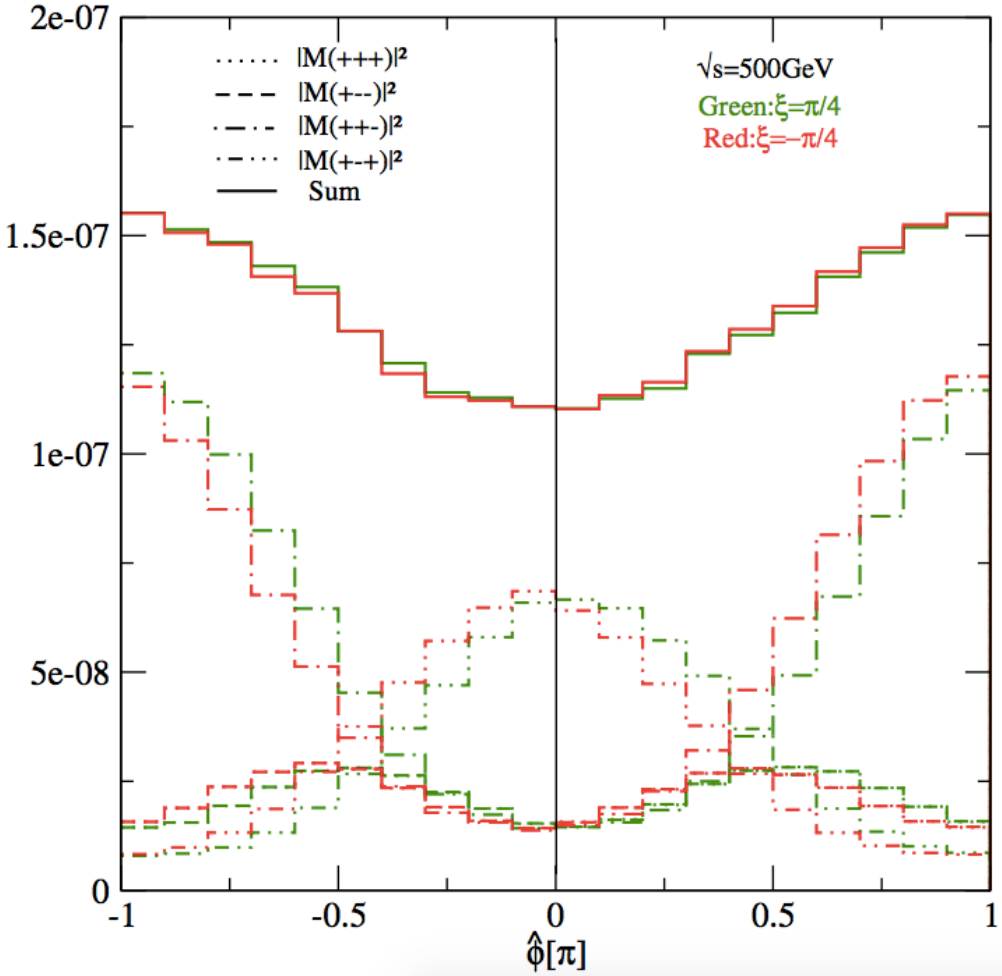
$$-2\left[\mathrm{Re}(M_{\alpha++}M^*_{\alpha+-})\cos\phi^* - \mathrm{Im}(M_{\alpha++}M^*_{\alpha+-})\sin\phi^*\right]\sin\theta^*(1+\cos\bar{\theta}^*)$$
$$-2\left[\mathrm{Re}(M_{\alpha-+}M^*_{\alpha--})\cos\phi^* - \mathrm{Im}(M_{\alpha-+}M^*_{\alpha--})\sin\phi^*\right]\sin\theta^*(1-\cos\bar{\theta}^*)$$
$$+2\left[\mathrm{Re}(M_{\alpha++}M^*_{\alpha-+})\cos\bar{\phi}^* - \mathrm{Im}(M_{\alpha++}M^*_{\alpha-+})\sin\bar{\phi}^*\right]\sin\bar{\theta}^*(1-\cos\theta^*)$$
$$+2\left[\mathrm{Re}(M_{\alpha+-}M^*_{\alpha--})\cos\bar{\phi}^* - \mathrm{Im}(M_{\alpha+-}M^*_{\alpha--})\sin\bar{\phi}^*\right]\sin\bar{\theta}^*(1+\cos\theta^*)$$

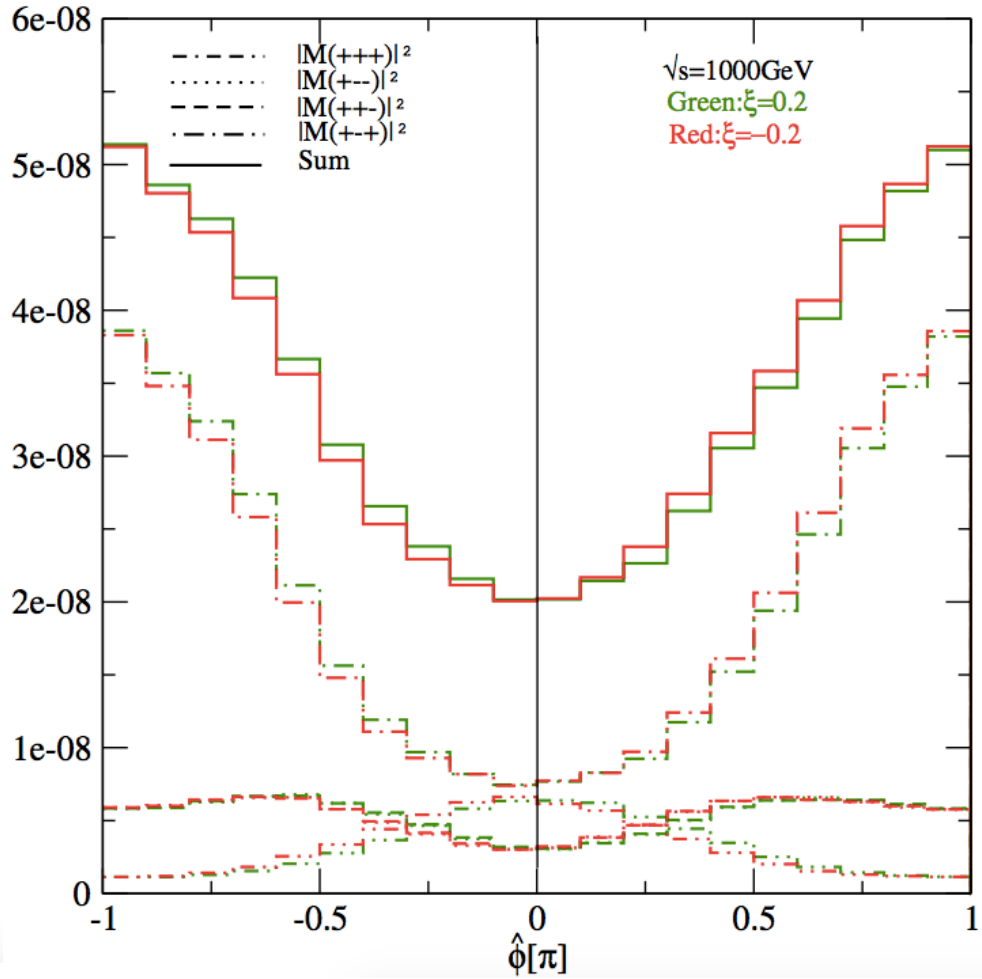
$$-2\left[\mathrm{Re}(M_{\alpha++}M^*_{\alpha--})\cos(\bar{\phi}^*+\phi^*) - \mathrm{Im}(M_{\alpha++}M^*_{\alpha--})\sin(\bar{\phi}^*+\phi^*)\right]\sin\bar{\theta}^*\sin\theta^*$$
$$-2\left[\mathrm{Re}(M_{\alpha+-}M^*_{\alpha-+})\cos(\bar{\phi}^*-\phi^*) - \mathrm{Im}(M_{\alpha+-}M^*_{\alpha-+})\sin(\bar{\phi}^*-\phi^*)\right]\sin\bar{\theta}^*\sin\theta^*\Big\}$$

8 dimensional distributions after integrating over vbbar and vbar b phase space

$$M_{\alpha,\sigma,\bar{\sigma}}(m_{tt}, \cos\theta, \cos\hat{\theta}, \phi)$$

M^2 distributions



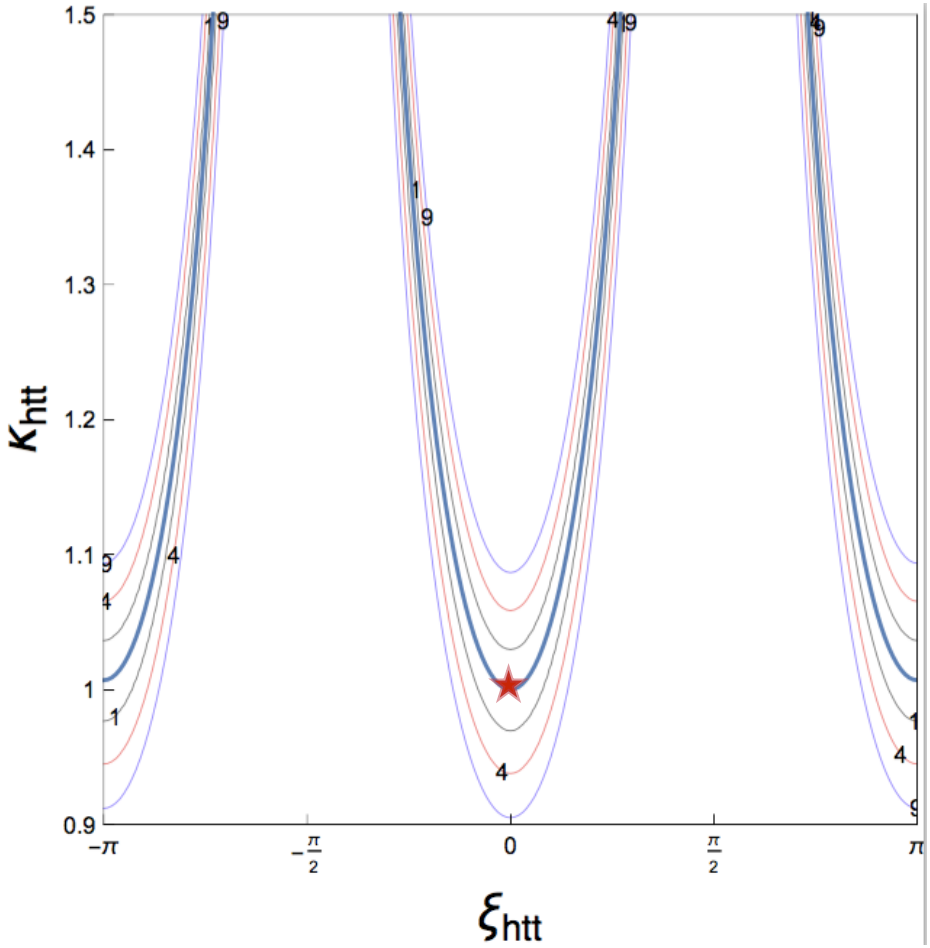


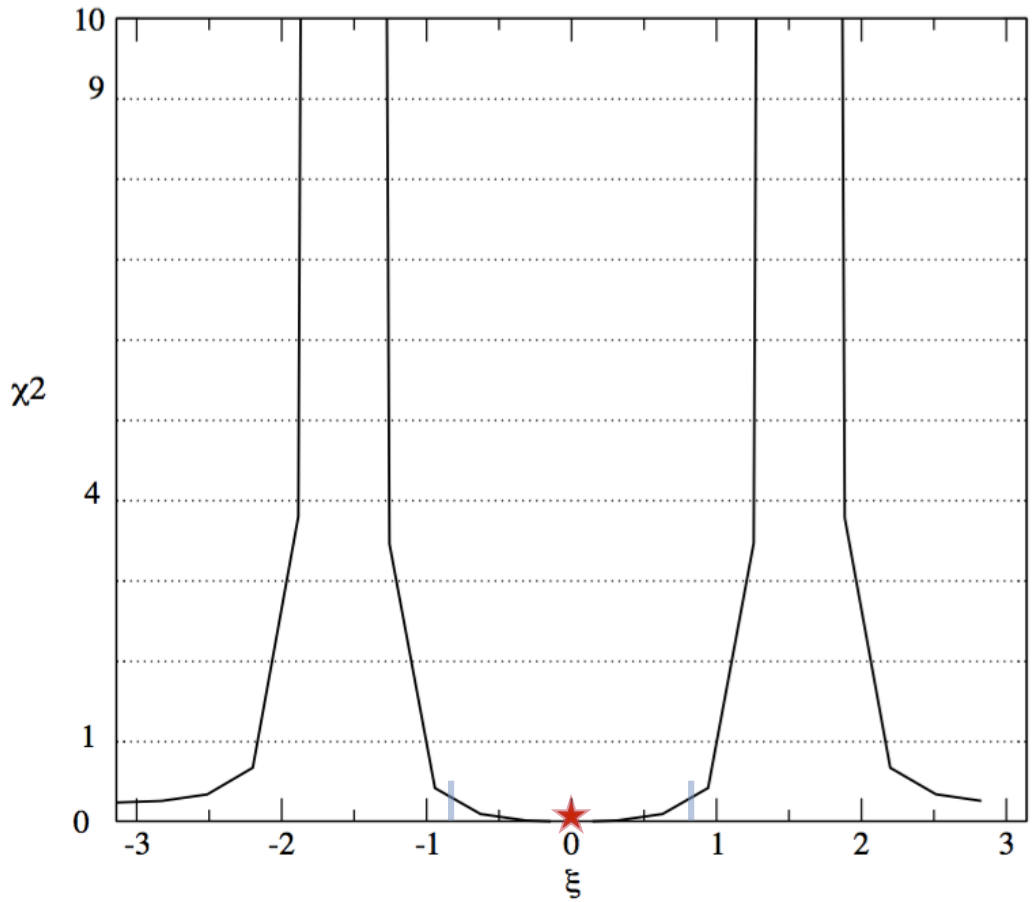
For $cos\theta = 0$,$m_{tt} = 350$GeV, $\sqrt{s} = 500$GeV in the left and $\sqrt{s} = 1000$GeV in the right.

- The sign of ξ can be determined by the asymmetry between φ>0 and φ<0

chi-squared contour plot

/s=500GeV, L=1000/fb





$$\chi^2(\kappa_{htt}, \xi_{htt}) = \left(\frac{\sigma_{ex} - \sigma_{th}(\kappa_{htt}, \xi_{htt})}{\sqrt{\sigma_{ex}/L}} \right)^2$$

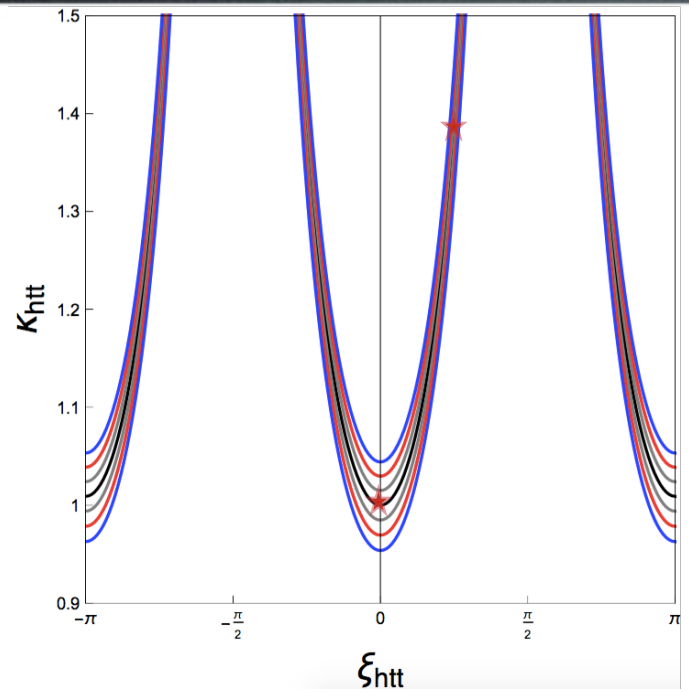
statistical error only

pure pseudoscalar excluded,
no sensitivity on CPV (e.g. pi/4) —>550GeV

$$\chi^2(\kappa_{htt}, \xi_{htt}) = \int d\Phi \left(\frac{d\sigma_{ex} - d\sigma_{th}(\kappa_{htt}, \xi_{htt})}{\sqrt{d\sigma_{ex}/L}} \right)^2$$

with decay angular correlations

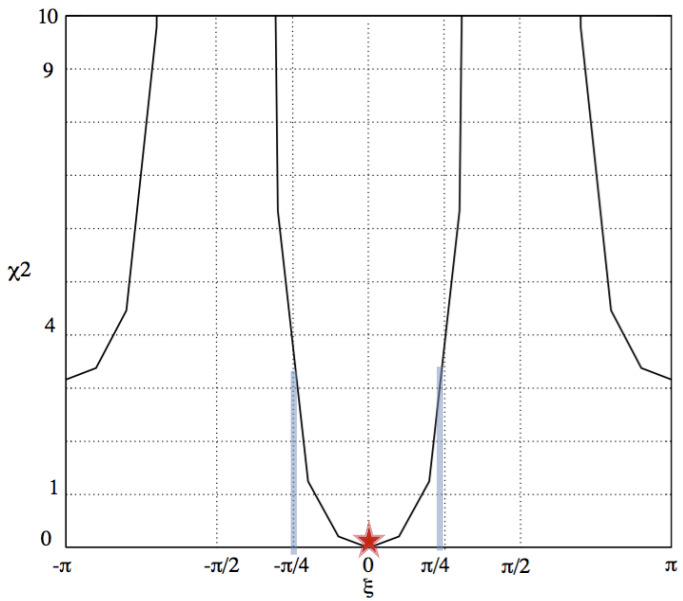
chi-squared contour plot



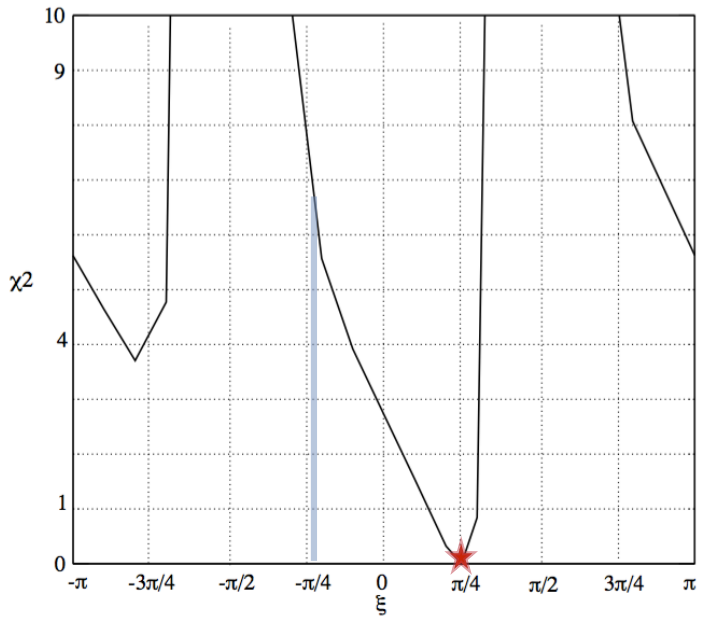
/s=550GeV, L=1000/fb

$$\chi^2(\kappa_{htt}, \xi_{htt}) = \int d\Phi \left(\frac{d\sigma_{ex} - d\sigma_{th}(\kappa_{htt}, \xi_{htt})}{\sqrt{d\sigma_{ex}/L}} \right)^2$$

★SM



★ ξ=pi/4



the sign of CP mixing angle can be measured

Summary

- The Higgs boson h has the largest coupling to the top quark t. The direct measurement of htt interaction can be sensitive to BSM physics. The precision measurements of top mass and Yukawa coupling are among the main targets of ILC.

- We study the CPV observables and present the complete distributions of ee to tth process with ttbar decays semi-leptonically.

- We find that the ILC1 target energy maybe increased to 550 GeV, the CPV sensitivity is high at low m_{tt} and high /s.

- At /s=500GeV, even with the decay angler distribution, we do not have sensitivity to CPV. At 550GeV, the sensitivity improves. With 1000/fb luminosity we can observe a CPV of ʒ=pi/4 at nearly 2sigma level, and the sign of CP mixing angle can be measured at more than 2sigma.

Thanks for your attention!