ee to tth as a probe of Higgs CP property

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Higgs as a probe of New Physics 2017
March 5, 2017

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

Outline

- Motivation
- Effective couplings for the CP-mixed Higgs state for tth in SM and 2HDM
- Current constraints from LHC data on htt coupling and CP mixing angle
- Production of e+e- to tth with tt decays semi-leptonically
- Distributions of CPV observables
- 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 and CP even Higgs.
- 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 target of ILC. We can study tth couplings at 500 GeV and 1000 GeV in the future.

effective htt coupling

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

g_{htt}: 125 $\cos\xi_{htt}$: CP-even $\sin\xi_{htt}\gamma_5$: CP-odd

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

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

$$h = O_{hH} \underbrace{H}_{\text{even}} + O_{hH'} \underbrace{H'}_{\text{even}} + O_{hA} \underbrace{A}_{\text{odd}}$$

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

typeII 2HDM:

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

H’ has no coupling to W/Z at tree level

constraints from LHC data

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

exp exp th th

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

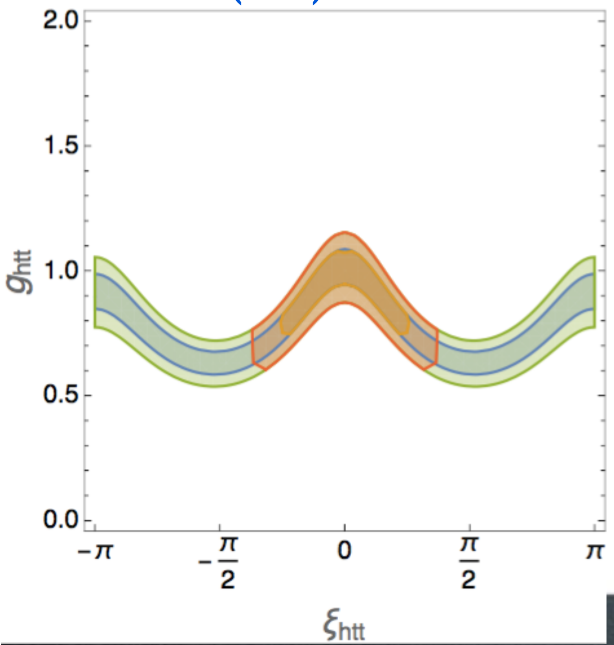
$$\frac{\Gamma[h\to WW^*]}{\Gamma_{SM}[H\to WW^*]} = \frac{\Gamma[h\to ZZ^*]}{\Gamma_{SM}[H\to ZZ^*]} = \cos^2\xi \qquad \frac{\Gamma[h\to f\bar{f}]}{\Gamma_{SM}[H\to f\bar{f}]} = A_f\cos^2\xi + B_f\sin^2\xi$$

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

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

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

if XS(tth) error±20% → ξ < 0.17 pi | Ellis, Hwang, Sakurai, Takeuchi JHEP (2014)



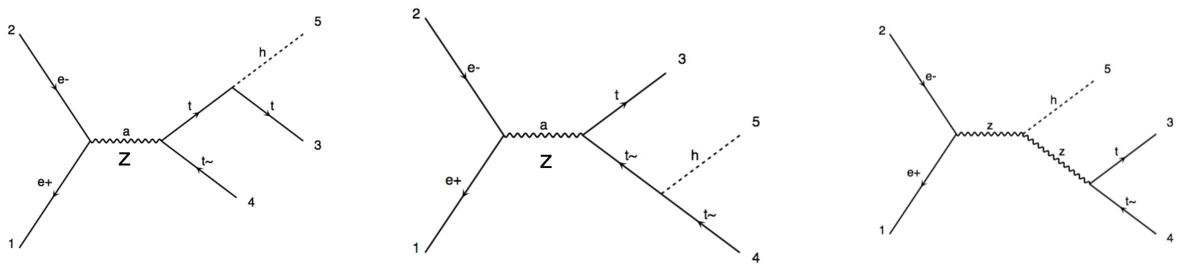
Cheung,Lee, Tseng PRD(2014), Bhattacharyya, Das,Pal PRD87(2013), Shu,Zhang PRL (2013), Inoue, Ramsey-Musolf, Zhang PRD89(2014), Bolognesi, Gao, Gritsan, Melnikov, Schulze, Tran, Whitbeck, PRD(2012), Englert, Goncalves-Netto, Mawatari,Plehn,JHEP(2013),...

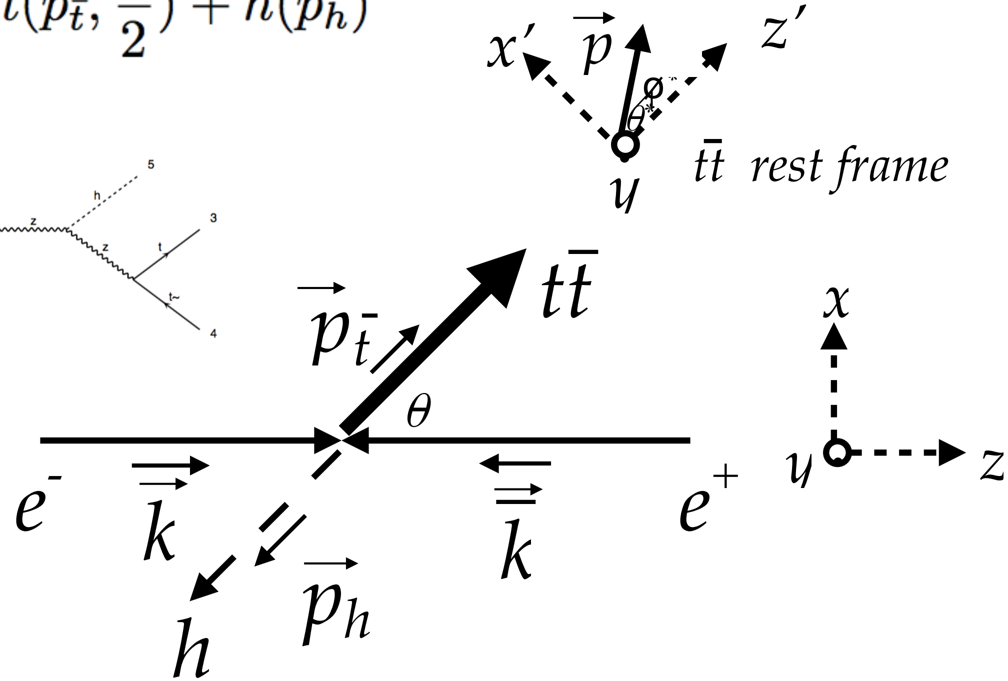
ATLAS+CMS, JHEP08(2016)045 signal strength of gg,rr

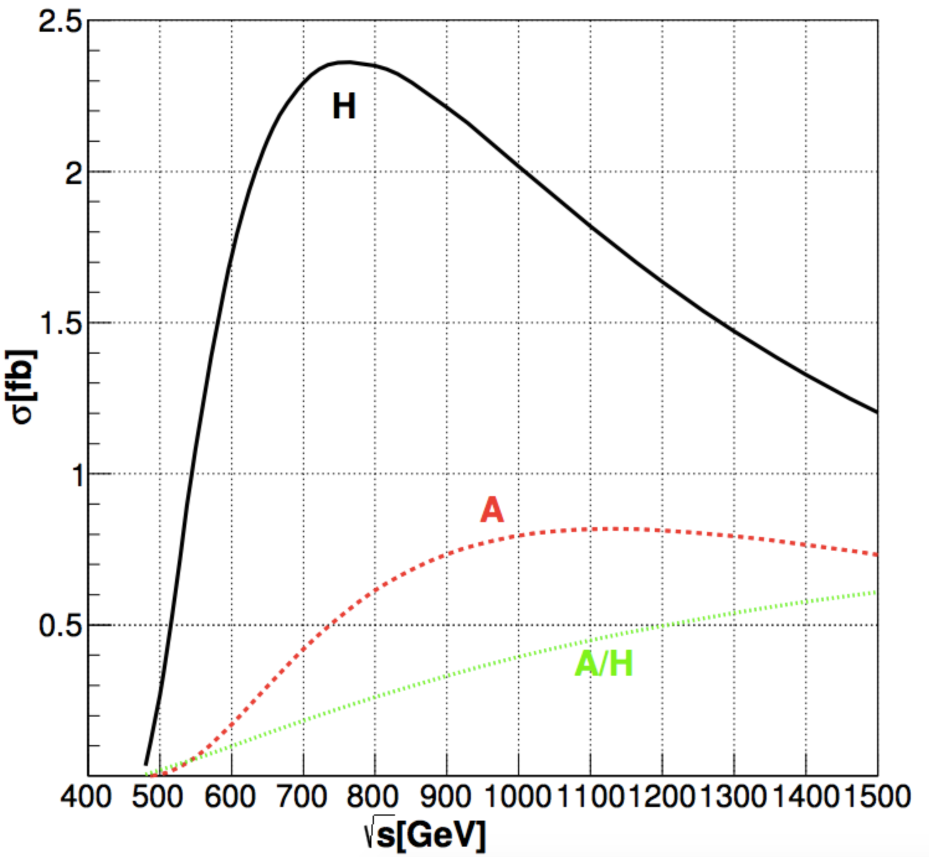
All the current bounds from LHC data on htt coupling and CP mixing angle are obtained by indirect observation and NP contribution is not included → Direct Observation

tth production at e+e- colliders

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





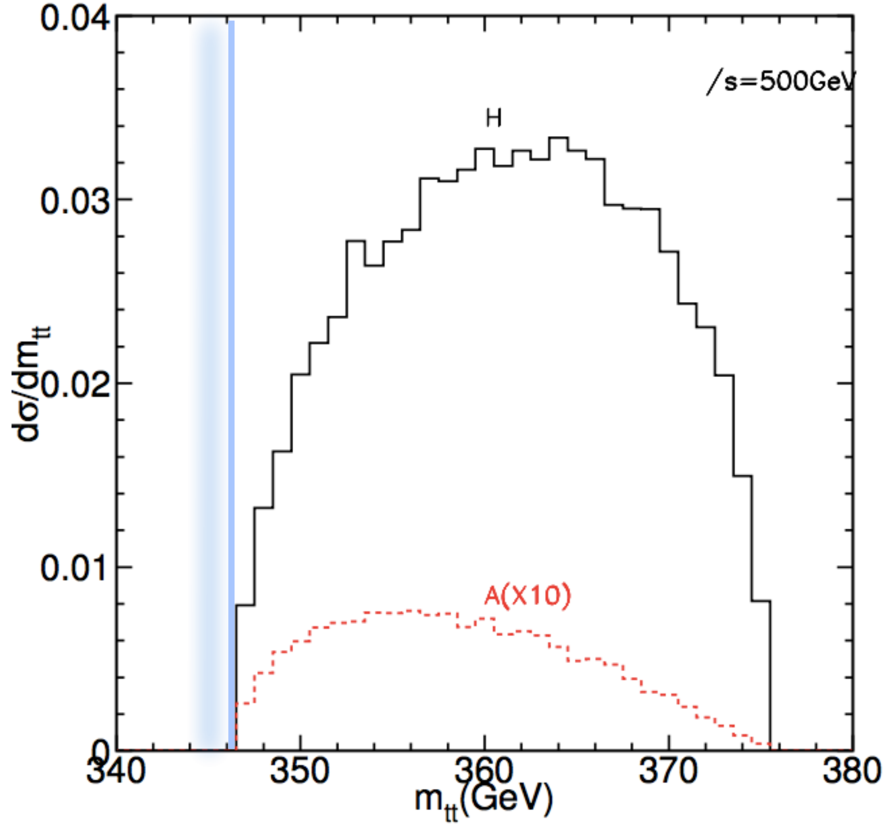


unpolarized beam $P(e^-)=P(e^+)=0$

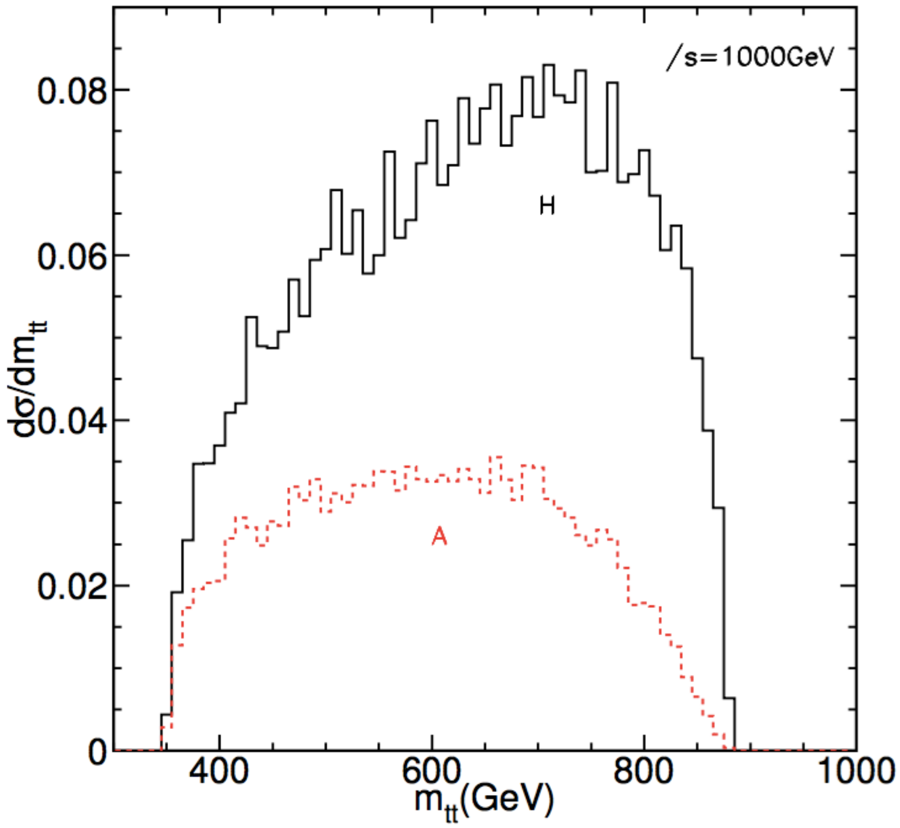
/s(GeV)	H(fb)	A(fb)	A/H
500	0.27	0.0053	0.020
550	1.1	0.063	0.058
600	1.7	0.17	0.10
1000	2.0	0.8	0.39

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)

In both cases, the sensitivity to CP phase and azimuthal angle distribution would remain the same.

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

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

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

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

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

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

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

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

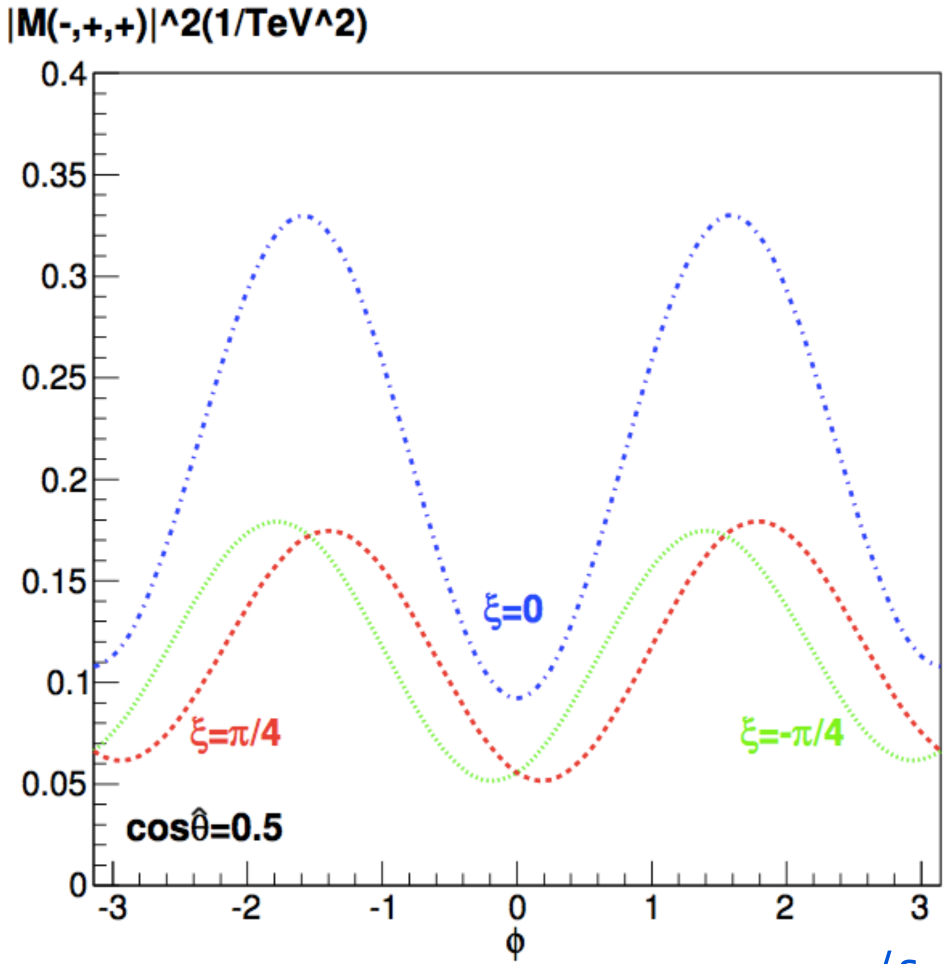
$$-2\left[\mathrm{Re}(M_{\alpha++}M^*_{\alpha--})\cos(\bar{\phi}^*+\phi^*) - \mathrm{Im}(M_{\alpha++}M^*_{\alpha--})\sin(\bar{\phi}^*+\phi^*)\right]\sin\bar{\theta}^*\sin\theta^*$$

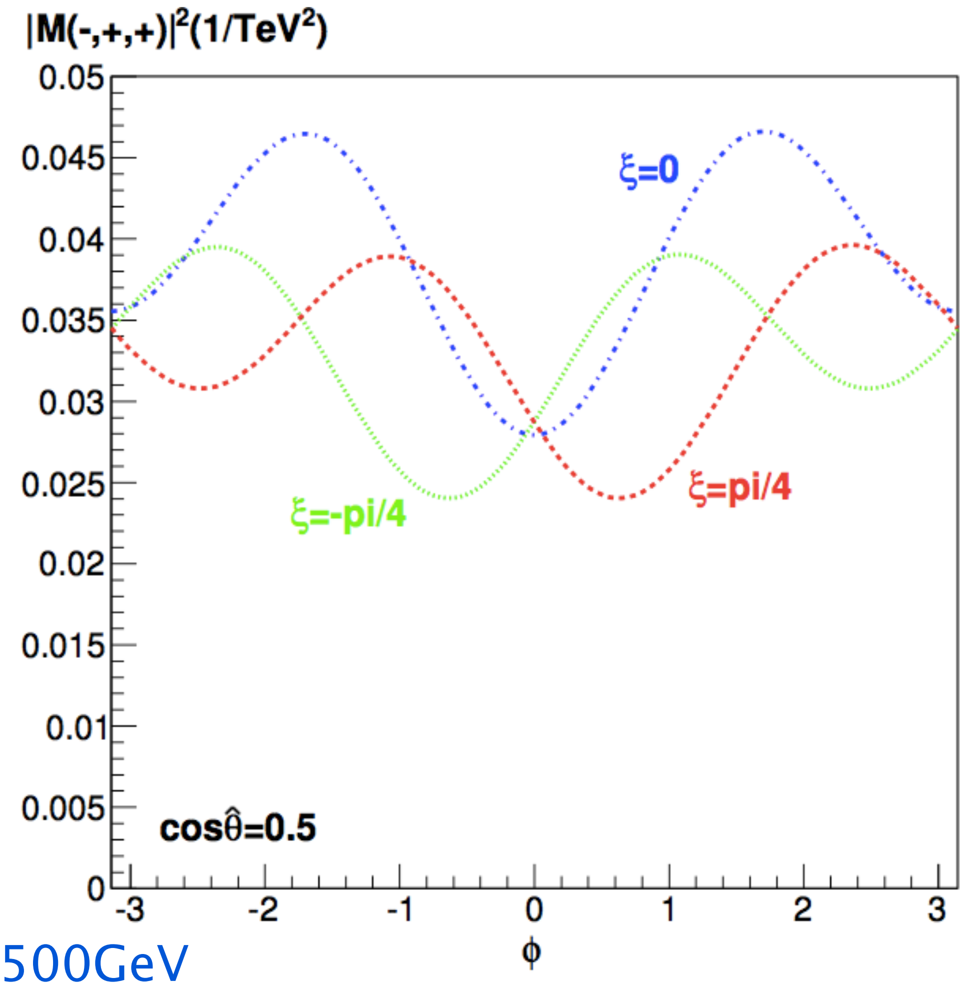
$$-2\left[\mathrm{Re}(M_{\alpha+-}M^*_{\alpha-+})\cos(\bar{\phi}^*-\phi^*) - \mathrm{Im}(M_{\alpha+-}M^*_{\alpha-+})\sin(\bar{\phi}^*-\phi^*)\right]\sin\bar{\theta}^*\sin\theta^*\Big\}$$

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 distribution



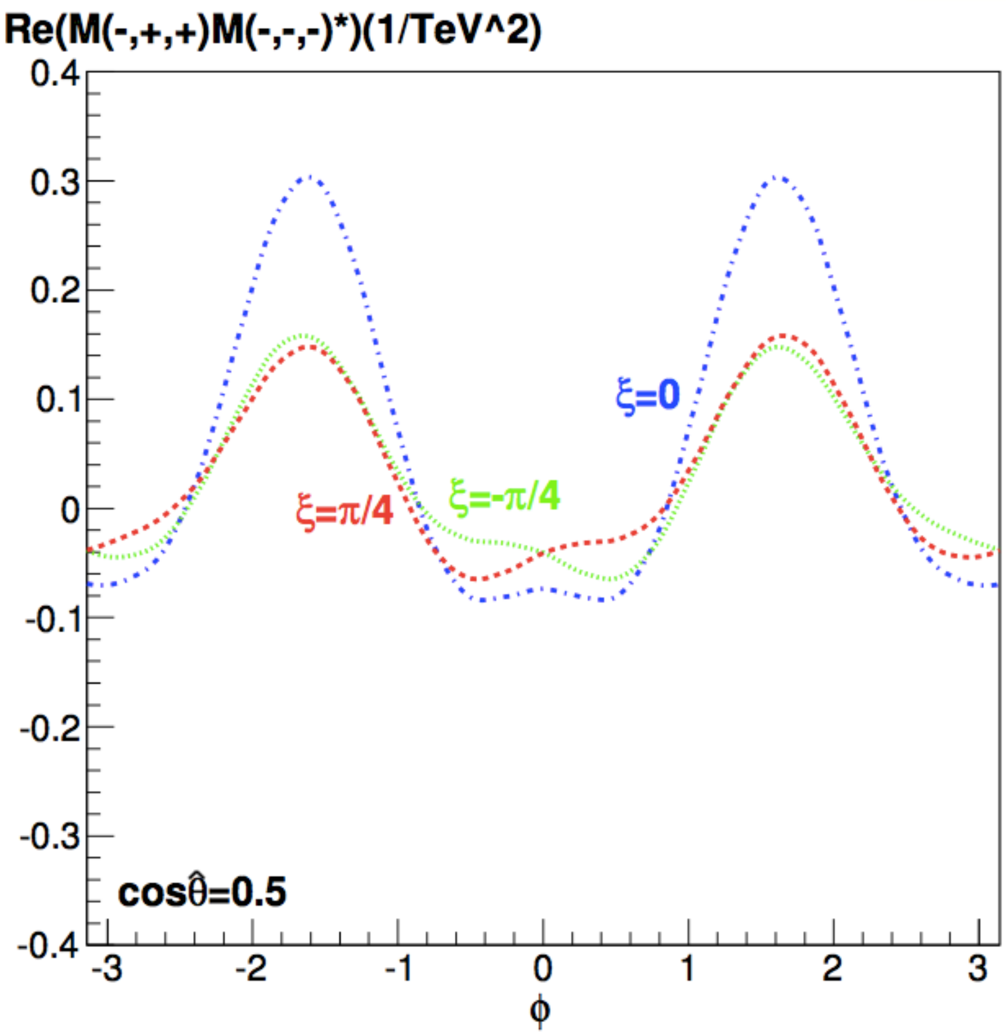


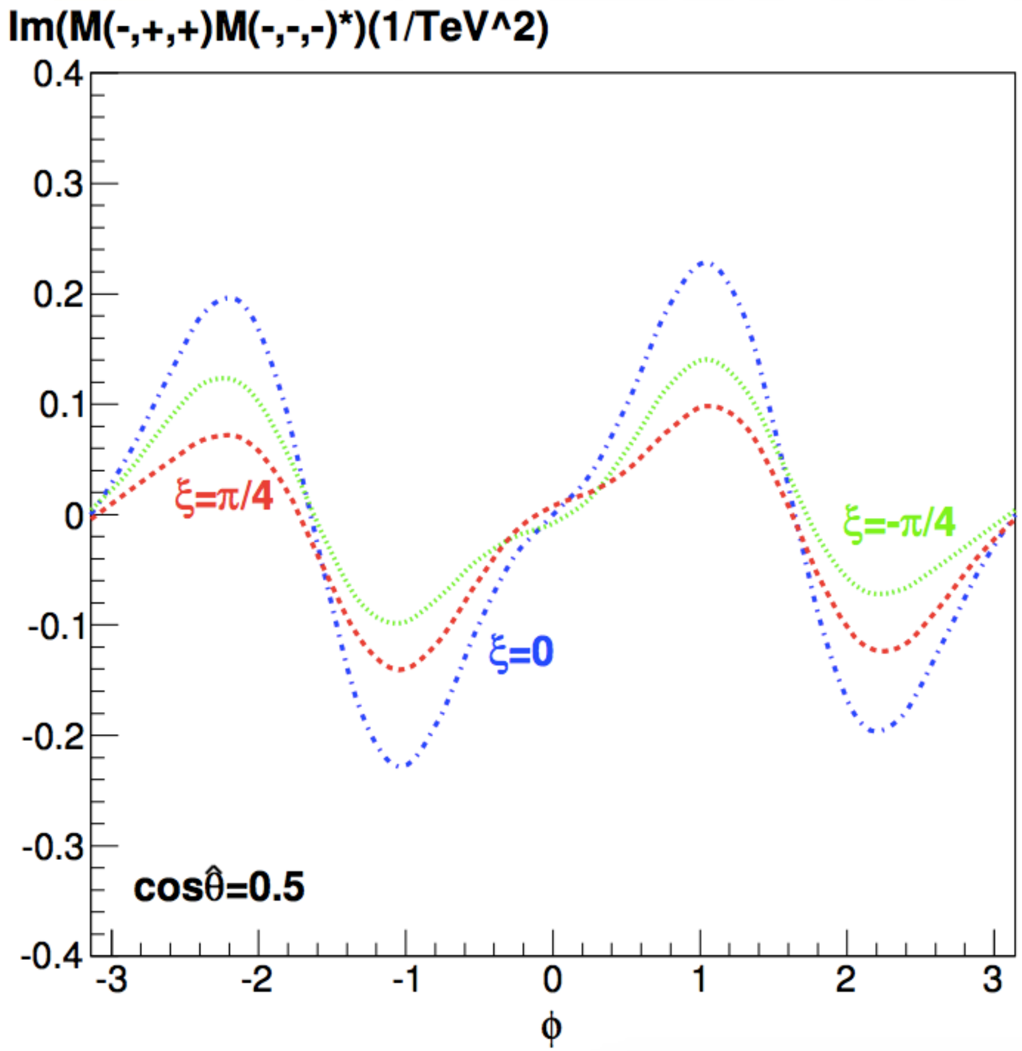
/s=500GeV

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

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

MM* distribution





- The above two distributions are the coefficients of $\cos(\bar{\phi}^* + \phi^*)$ and $\sin(\bar{\phi}^* + \phi^*)$ in the t and t bar decay lepton azimuthal angle distributions.
- The CP asymmetry (the difference between ξ_htt>0 and ξ_htt<0) is obtained as an asymmetry between φ>0 and φ<0 in real part

Summary

- The Higgs boson h has the largest coupling to the top quark t. The direct measurement of tth interaction can be sensitive to the investigation of 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 because of the production ratio of A/H, the sign of CPV mixing angle can be measured.

Thanks for your attention!