Up-down asymmetry for $t\bar{t}H$ CP studies at 1.4TeV

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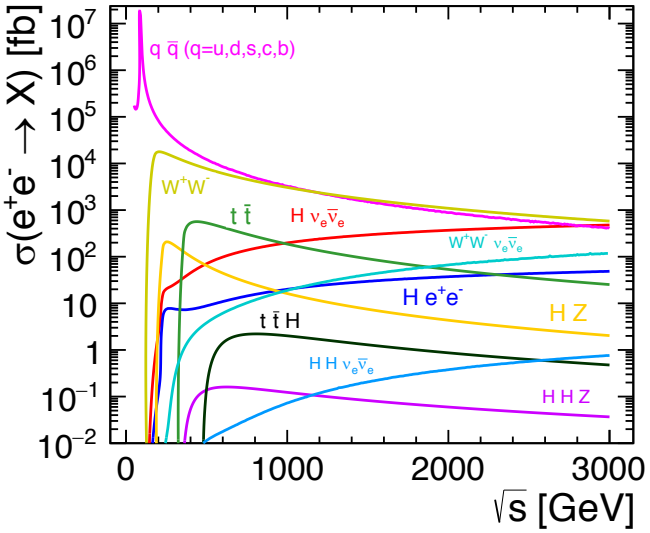
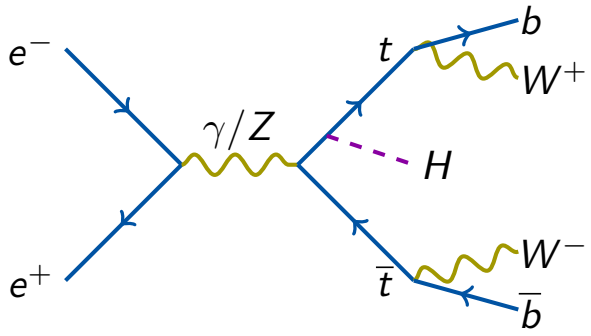
Outline

- Previous results recap
  - Top-Yukawa coupling
  - Precision measurement on CP mixing using cross section
- Up-down asymmetry
  - Improvement on Rec vs MC
  - Chi-square template fit
  - Preliminary result
- Summary

Motivation



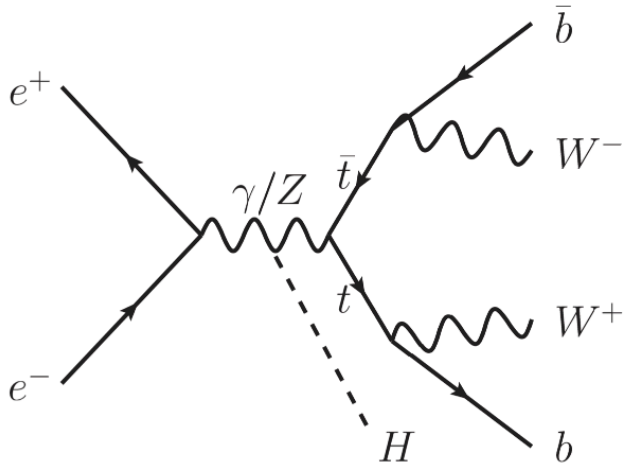


$e^+ + e^- \rightarrow t\bar{t}H$ at 1.4 TeV with integrated luminosity of 1.5 ab^{-1}.

$t\bar{t}H$ decay	$BR \times BR(H \rightarrow b\bar{b} \approx 58\%)$	No. Leptons	Channel classification
$t\bar{t} \rightarrow 6jets, H \rightarrow bb$	46%	0	**Hadronic**
$t\bar{t} \rightarrow 4jets + 1l + 1\bar{\nu}_l, H \rightarrow bb$	45%	1	**Semi-leptonic**
$t\bar{t} \rightarrow 2jets + 2l + 2\bar{\nu}_l, H \rightarrow bb$	9%	>1	Not analysed further

*The top-Yukawa analysis is a refinement of previous analysis CLICdp-Note-2014-001

Result on top-Yukawa coupling



To translate the cross-section measurement into top Yukawa coupling at 1.4TeV, a linear approximation is used:

$$\frac{\Delta g_{ttH}}{g_{ttH}} = 0.53 \frac{\Delta\sigma(t\bar{t}H)}{\sigma(t\bar{t}H)}$$

	Significance	$\Delta\sigma/\sigma$	$\Delta g_{ttH}/g_{ttH}$
Hadronic	10.44	7.30%	3.86%
Semi-leptonic	9.00		

(4.27% from previous analysis [1])

[1] CLICdp-Note-2014-001

Intro on CP violation in Higgs

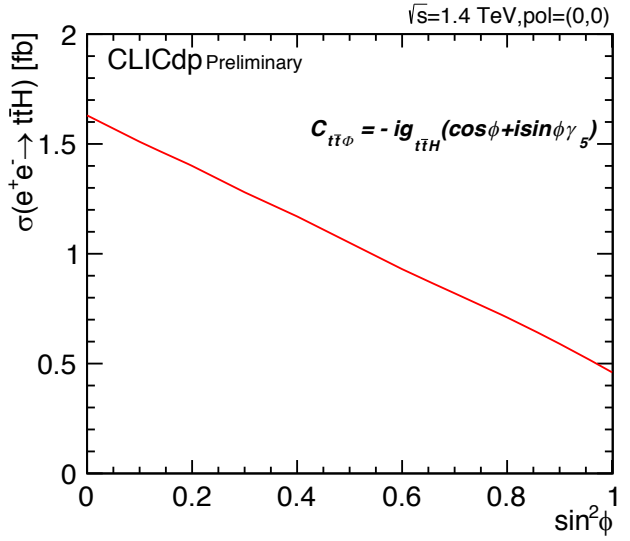
A model-independent way of parameterising the CP mixing in Higgs:

- $C_{t\bar{t}\Phi} = -ig_{t\bar{t}H}(a + ib\gamma_5)$
- SM: a = 1, b = 0 ; pure CP-odd: a = 0, b ≠ 0.

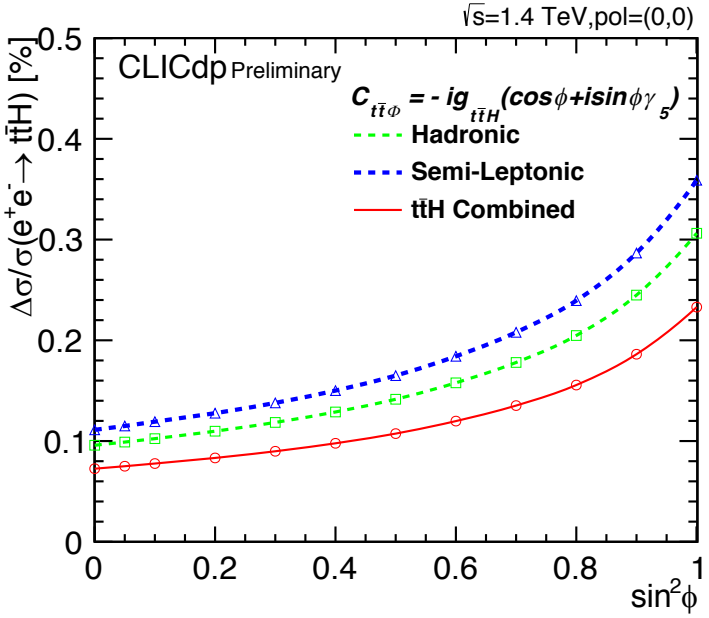
By assuming $a^2 + b^2 = 1$, $a = \cos(\phi)$ and b= $\sin(\phi)$, then a measure of mixing angle ϕ would indicate the CP properties of Higgs.

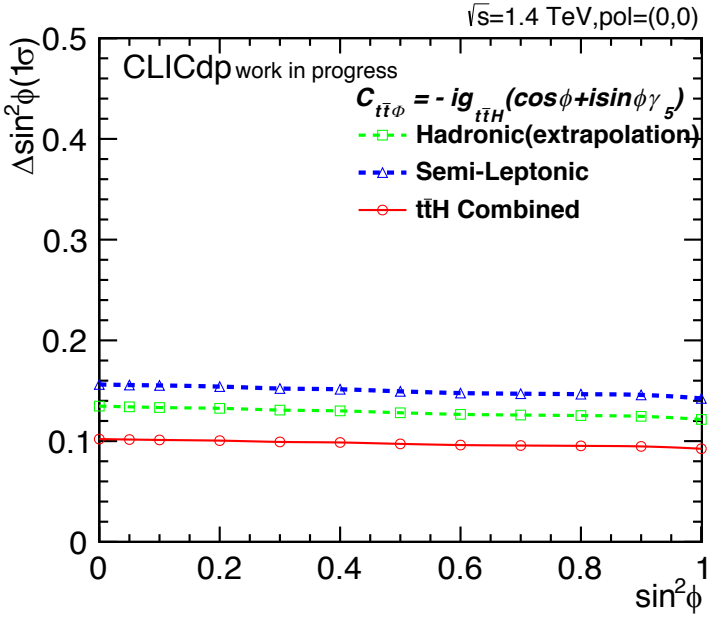
Physsim calculation (by Philipp Roloff):

- $\sqrt{s}$ = 1.4 TeV
- Polarisation = (0,0)
- ISR included
- CLIC luminosity spectrum
- M_H=125GeV
- M_t=174GeV



Sensitivity to CP mixing





$$\sigma = k \sin^2\phi$$

$$\Rightarrow \Delta\sin^2\phi = \frac{1}{k}\frac{\Delta\sigma}{\sigma}\sigma$$

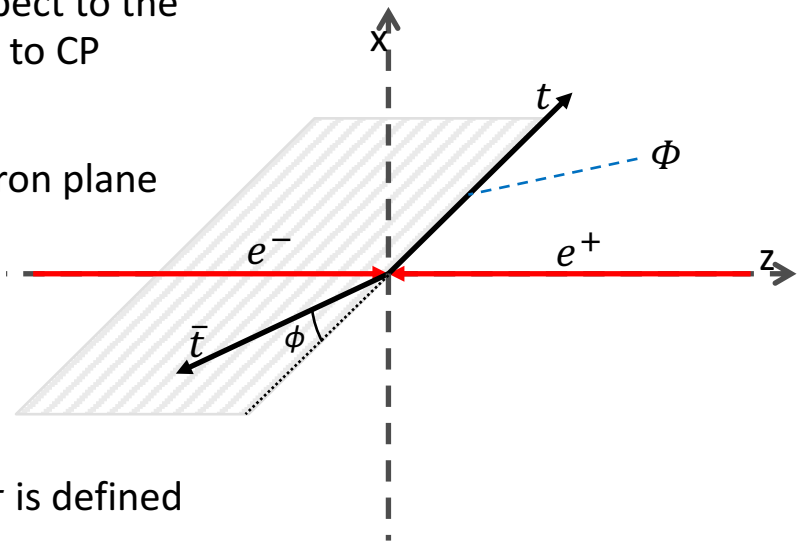
$$\Rightarrow \Delta\sin^2\phi \simeq 0.1$$

The up-down asymmetry

The up-down asymmetry A_ϕ of an antitop with respect to the top-electron plane is an observable that is sensitive to CP violation.

The angle ϕ between the antitop and the top-electron plane is given by

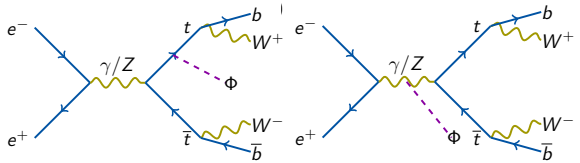
$$\sin(\phi) = \frac{\vec{p}_{\bar{t}}(\vec{q}_{e^-} \times \vec{p}_t)}{|\vec{p}_{\bar{t}}||(\vec{q}_{e^-} \times \vec{p}_t)|}$$



The up-down asymmetry of the $t\bar{t}\Phi$ cross section σ is defined as

$$A_\phi = \frac{\sigma(\sin\phi > 0) - \sigma(\sin\phi < 0)}{\sigma(\sin\phi > 0) + \sigma(\sin\phi < 0)}$$

$\sigma = \sigma(up) + \sigma(down)$ where 'up' ('down') denotes the cross section integrated over $\phi \in [0, \pi)$ ($\phi \in [\pi, 2\pi)$).



Interference between $t\bar{t}\Phi$ and $ZZ\Phi$!

[1] arXiv:1103.5404v1

$\sin(\phi)$ calculation

Top/anti-top identification (semi-leptonic):

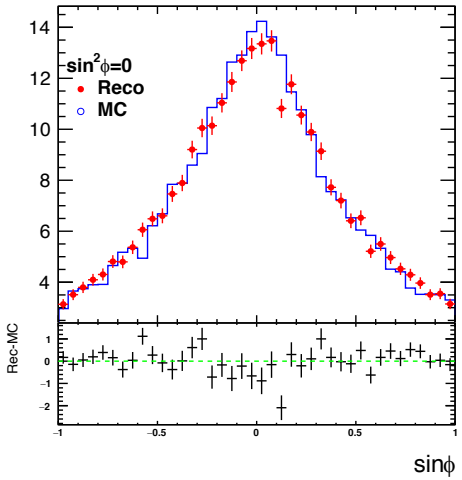
1. Find the charge of the identified lepton ($e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$),
2. If charge<0, the leptonic reconstructed $t/\bar{t}(blnu)$ is a top and $t/\bar{t}(bqq)$ is antitop, vice versa.

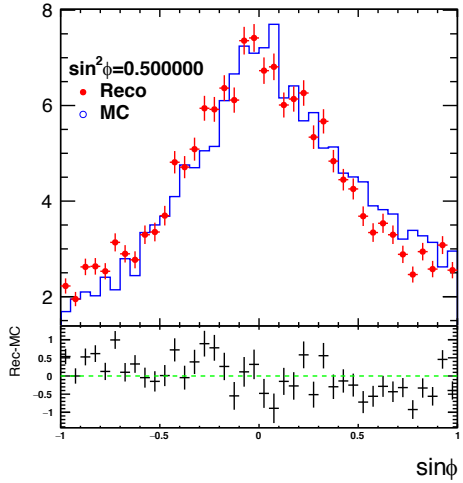
Calculation procedure:

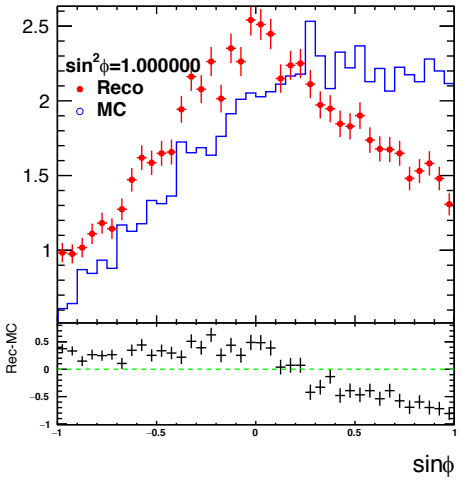
1. Obtain the 4-momentum of the reconstructed top and antitop in their rest frames,
2. Assume electron 4-momentum $p_{e^-} = (0,0,7000,7000)$,
3. Boost e^-, t and $\bar{t}$ to $t\bar{t}\Phi$ rest frame,
4. Calculate the vector of electron-top plane,
5. Calculate $\sin\phi$.

MC: use top, anti-top and electron 4-momentum from generator level

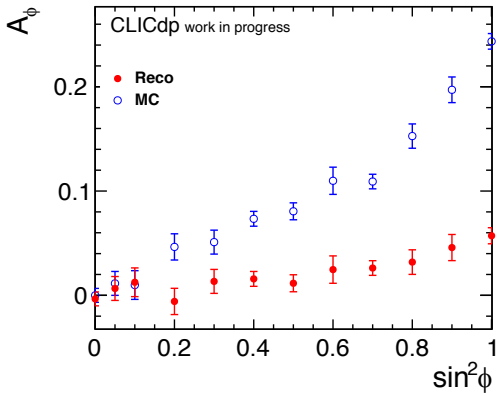
Up-down asymmetry distribution (Lepton cut + MVA cut)





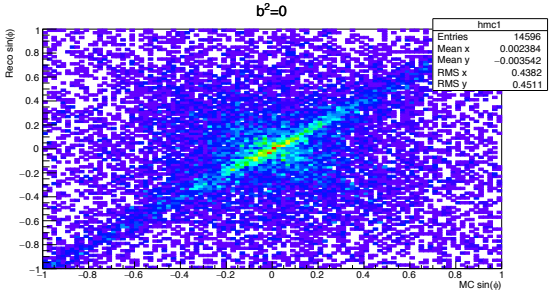


$$A_\phi = \frac{\sigma(\sin\phi > 0) - \sigma(\sin\phi < 0)}{\sigma(\sin\phi > 0) + \sigma(\sin\phi < 0)}$$

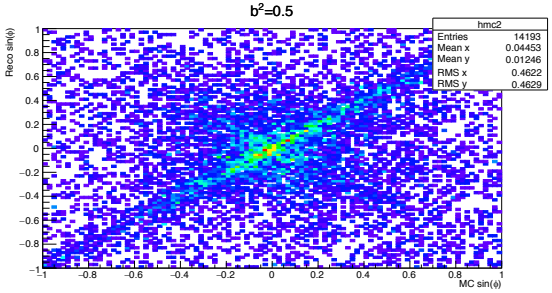


MC vs Rec (investigation)

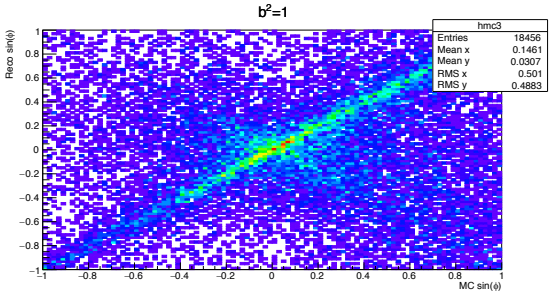
$\sin^2\phi = 0$



$\sin^2\phi = 0.5$



$\sin^2\phi = 1$



Correlation of $\sin\phi$ between MC and Rec:

- A lot of background
- Opposite diagonal line
  - Mis-identification of top

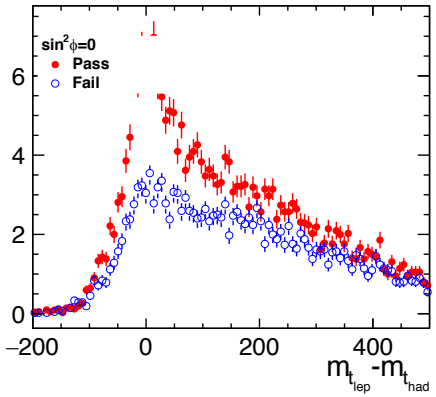
How to cut away mis-identified top?

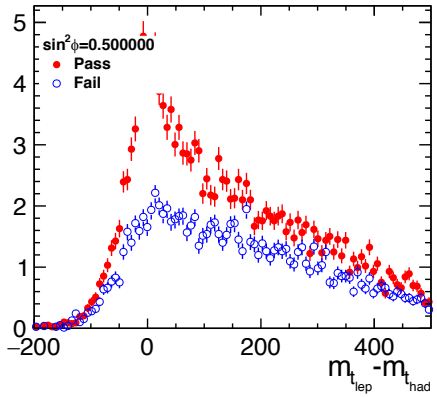
- Choose suitable cuts by looking at events passing or failing:

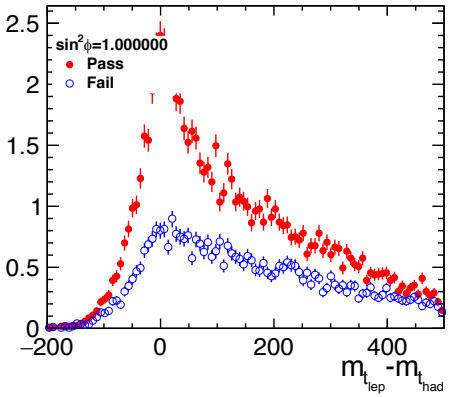
$$|\sin(\phi_{rec}) - \sin(\phi_{mc})| < 0.05:$$

$|\sin(\phi_{rec}) - \sin(\phi_{mc})| < 0.05$

$m_{t_{lep}} - m_{t_{had}}$ from reconstruction:



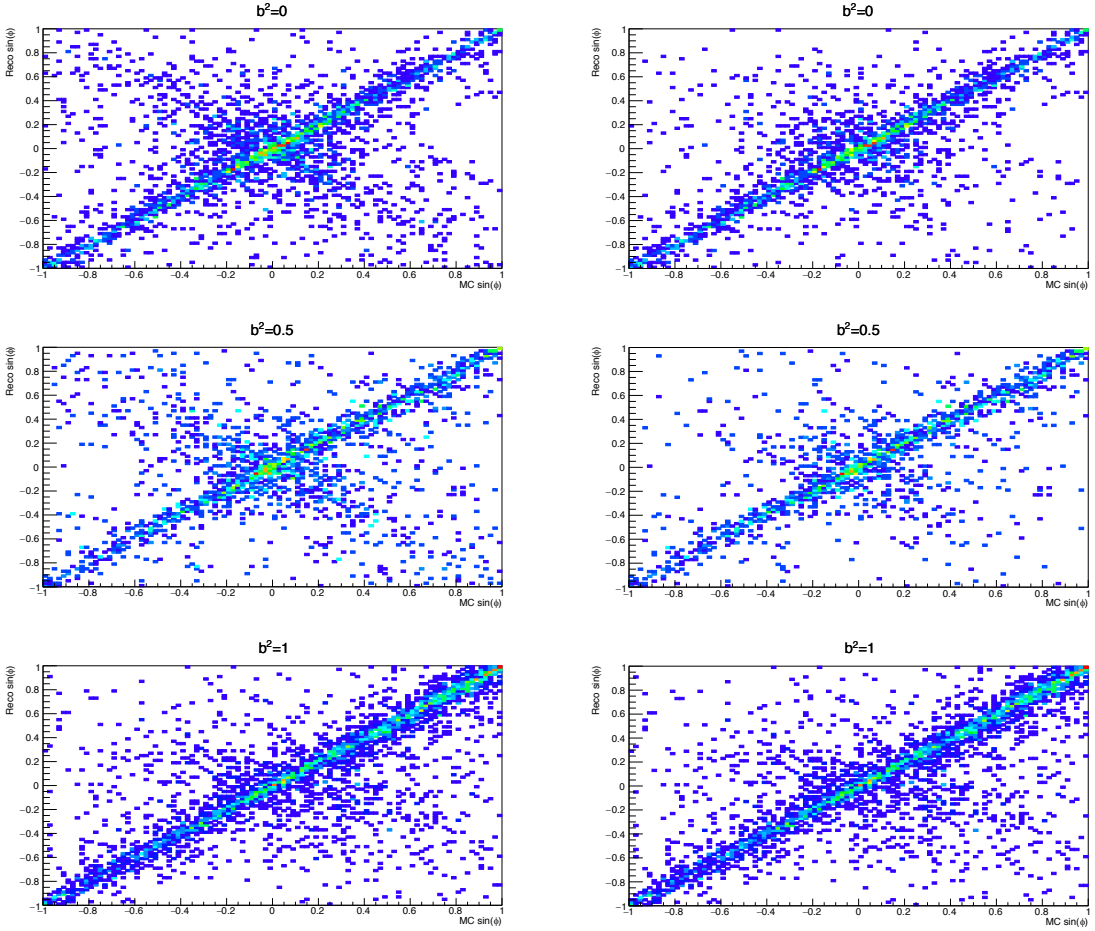




$\rightarrow m_{t_l} - m_{t_q} < 100$

$\rightarrow$ jetmatch $\chi^2 < 10$

Remove poor reconstructed top

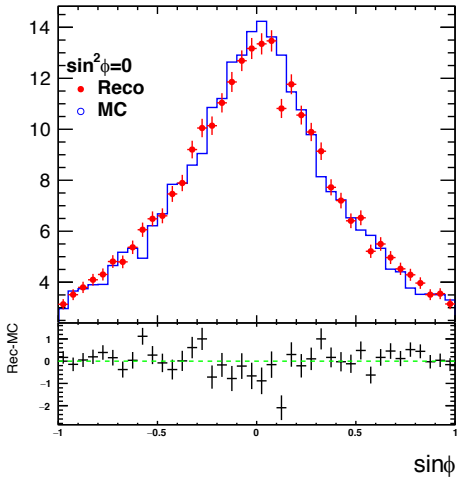


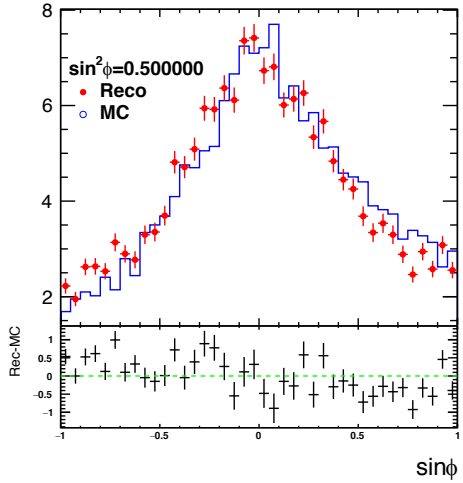
- $m_{t_l} - m_{t_q} < 100$
- jetmatch $\chi^2 < 10$

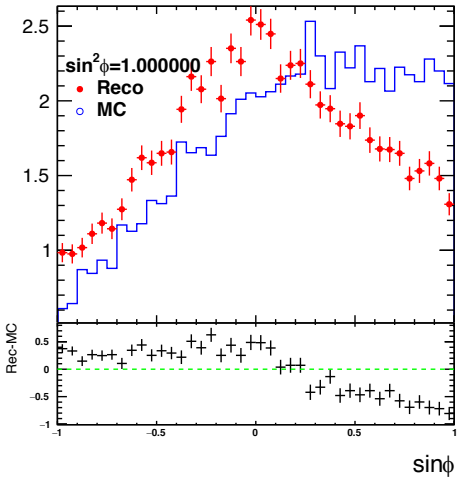
- Remove taus

(hadronic tau will have a mis-reconstructed charge)

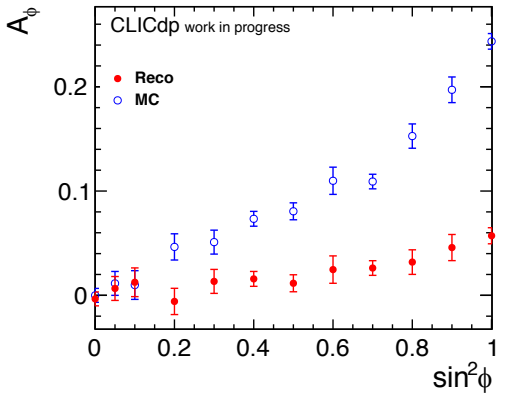
Lepton cut + MVA cut



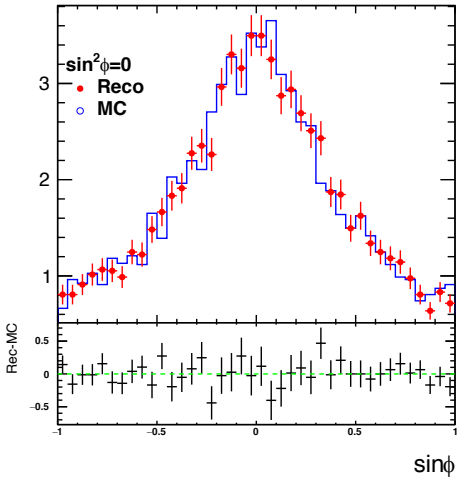


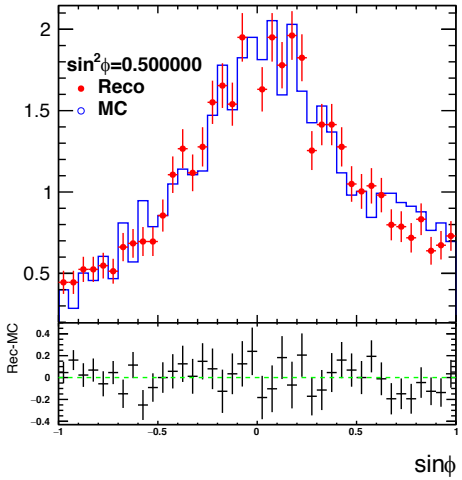


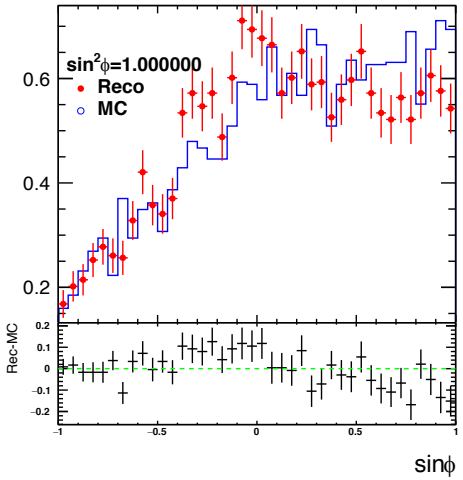
A_ϕ measurements:



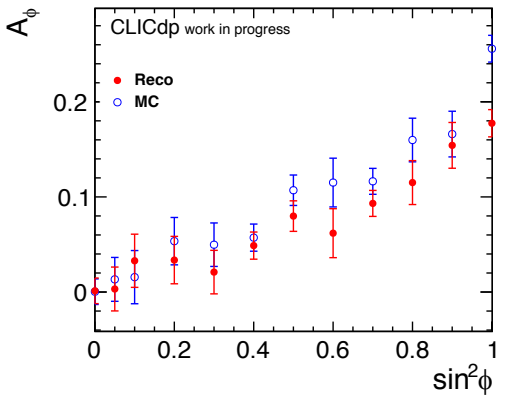
Lepton cut + MVA cut + New cuts







A_ϕ measurements:

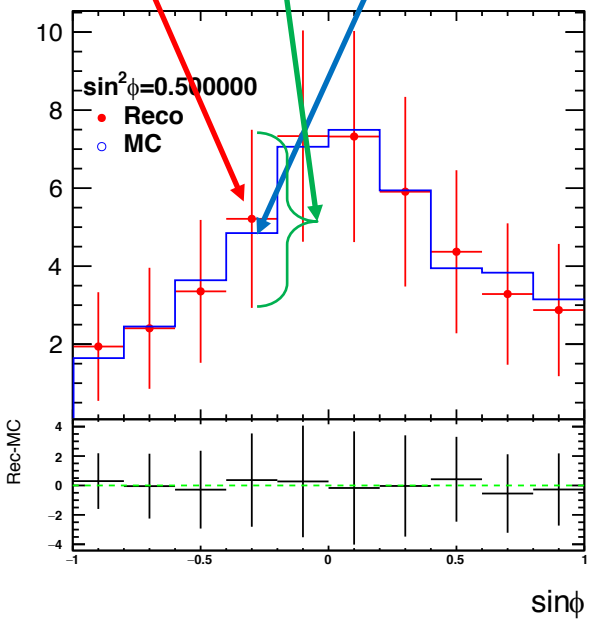


Chi-square template fit

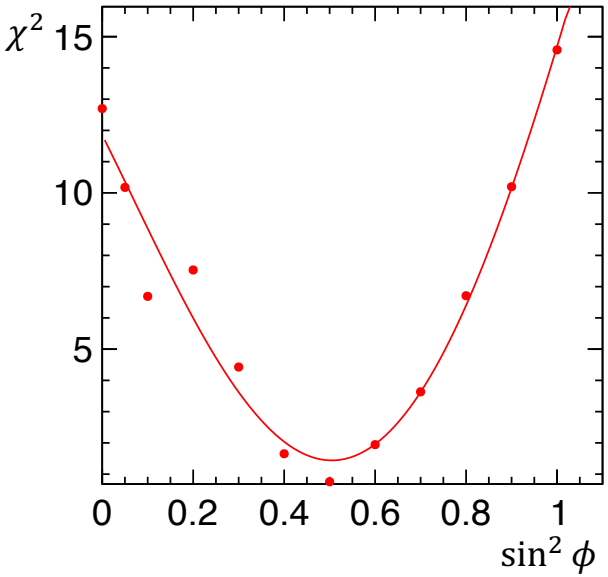
$$\chi^2_n(\sin^2\phi = 0.5) = \sum_{i=1}^{nbins} \left(\frac{O_{data(\sin^2\phi=0.5)} - O_{MC(n)}}{\sigma_{data}} \right)^2$$

- n is the different $\sin^2\phi$ samples.
- $O_{MC(n)}$ is the number of events in the same bin of different $\sin^2\phi$ samples.

Errors in each bin are recalculated as $\sqrt{O_{data}}$ after weighted.



Chi-square curve fitting



χ_n^2 is calculated for different $\sin^2\phi$ with $\sin^2\phi = 0.5$ as input data.

A parabola function is fitted to the χ^2 distribution:

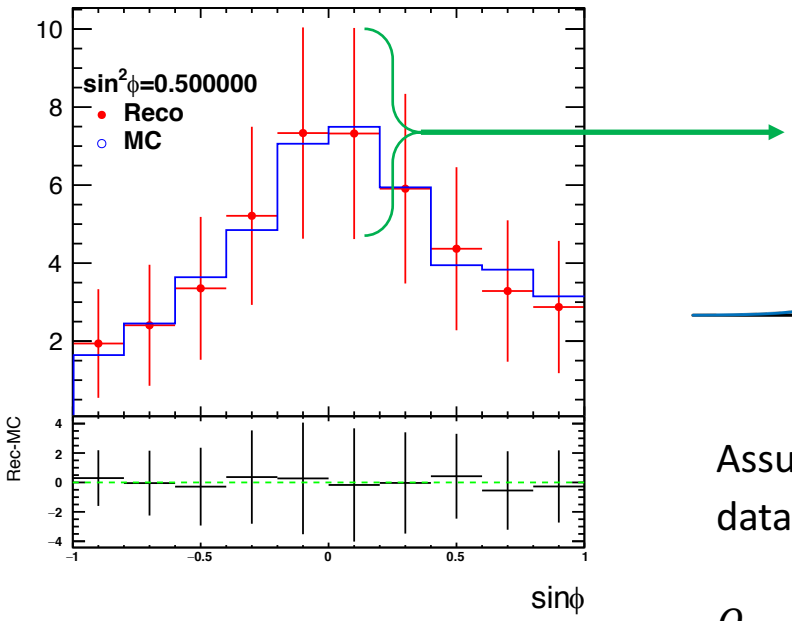
$$y = a + bx + cx^2$$

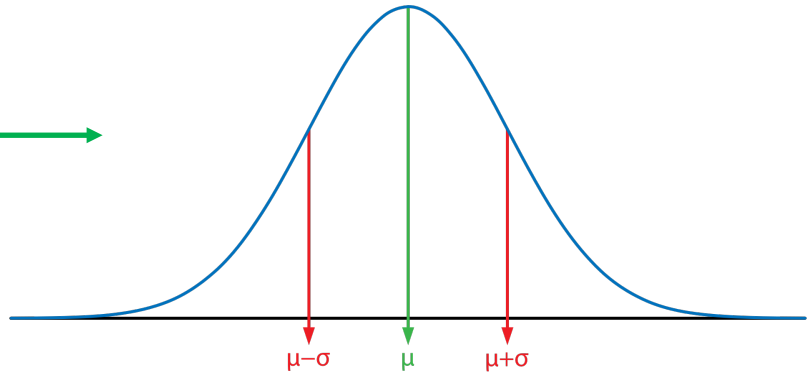
And the minimum point of the function is determined, e.g. $\sin^2\phi$ =0.509 in this plot.

Improvement:

- Self-defined function to constraint the fitting parameters and range.

Smearing data point



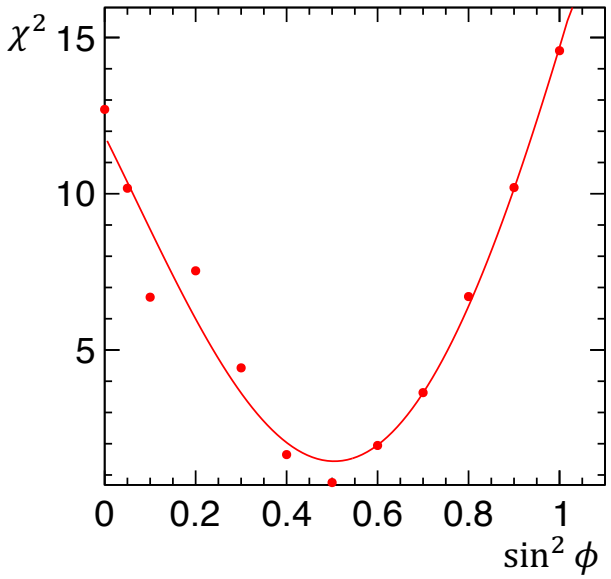


Assume to be gaussian distribution for each data point, $Gaus(O_{data}, \sqrt{O_{data}})$.

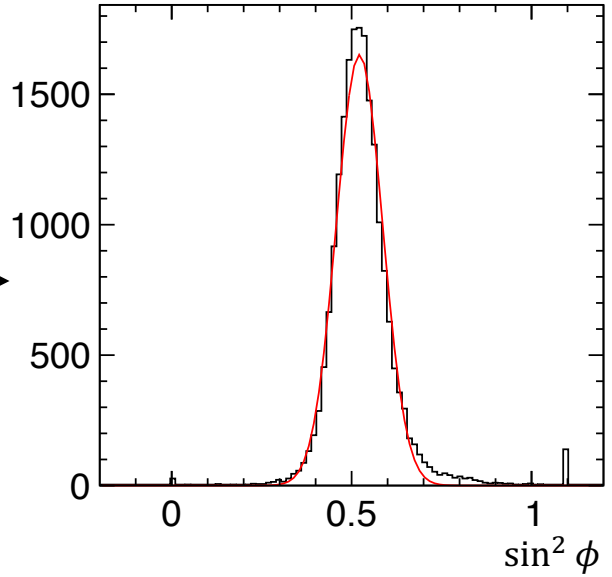
O_{data} is randomly smeared within the gaussian distribution.

χ^2 calculation is repeated many times to obtain $\sin^2\phi$ measurements.

Fitting $\sin^2\phi$ distribution



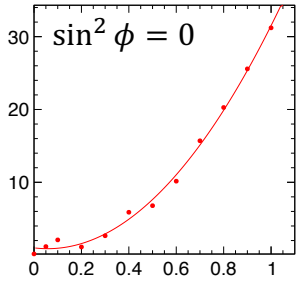
× N times

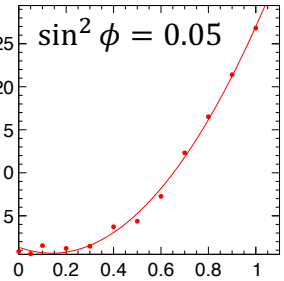


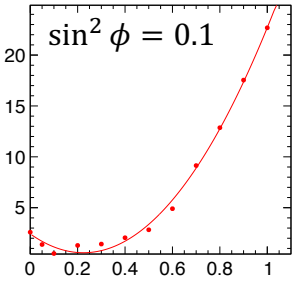
Fitted using gaussian for $\sin^2\phi = 0.5$:

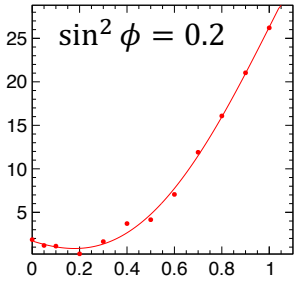
$\rightarrow \sin^2\phi = 0.52 \pm 0.06$

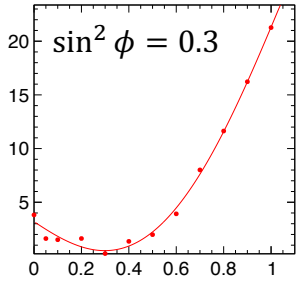
Fitting χ^2 curves for all

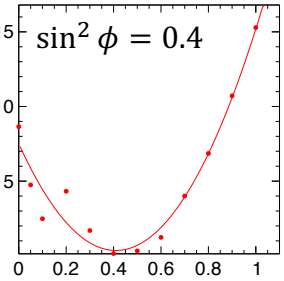


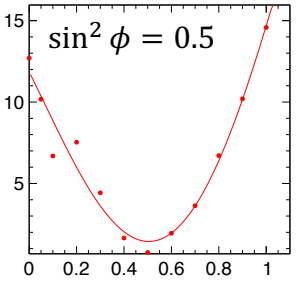


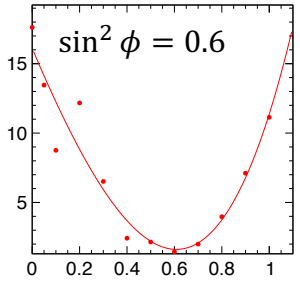


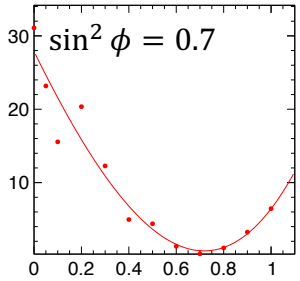


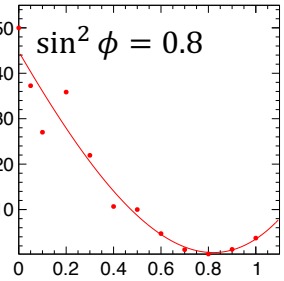


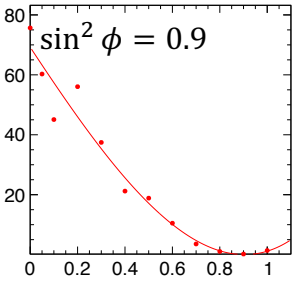


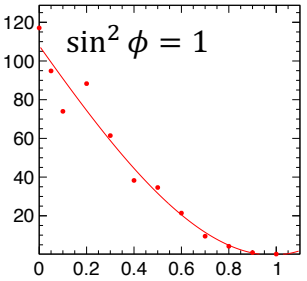




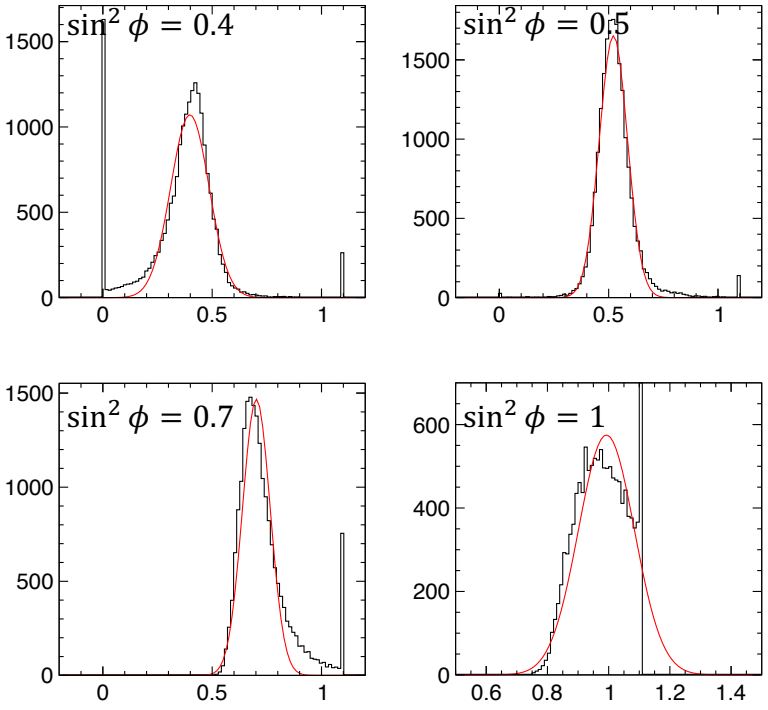








Fitting $\sin^2\phi$ distribution for all



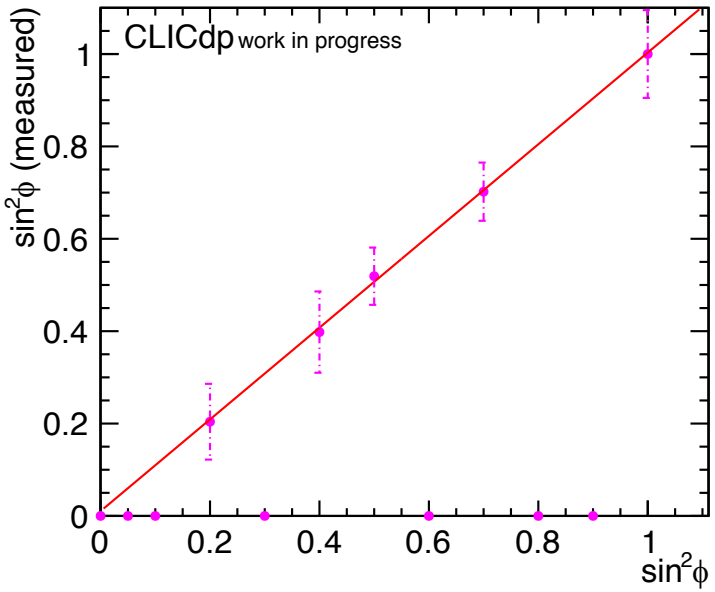
- The $\sin^2\phi$ distributions are fitted using gaussian,
- The mean and sigma are obtained for $\sin^2\phi$ measurements.

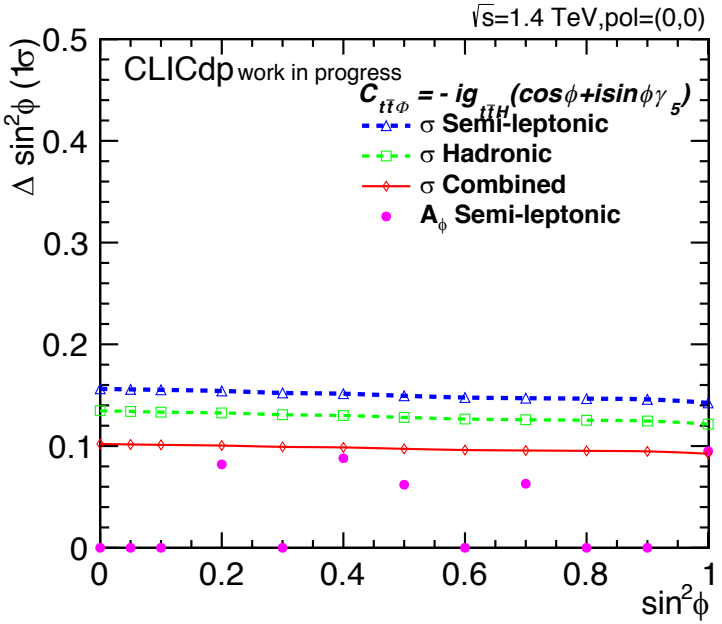
- The fittings are just for demonstration of the chi-square template method to obtain very preliminary results.

Improvements:

- Fitting χ^2 curves with self-defined parabola function,
- Solve the problem with fitting range exceeding $\sin^2\phi = 0$ and $\sin^2\phi = 1.1$
- Fitting $\sin^2\phi$ using double gaussian,
- Optimise $\sin\phi$ bin size.

Preliminary results





Summary

- Expected precision of the CP mixing angles with cross section measurement is $\Delta \sin^2 \phi \simeq 0.1$.
- Up-down asymmetry is extracted in semi-leptonic channel.
- Optimised by using additional cuts to match reconstructed events with MC.
- Chi-square template fitting is performed to extract the measurements on $\sin^2 \phi$

To do …

- Improvements for fittings for various steps,
- Fix fitting range bug,
- Obtain full results for all $\sin^2 \phi$.

Thank you !

Backup Slides

CP observables

An observable sensitive to CP violation must be odd under CP transformation. There are couple of variables that we can measure to investigate the CP violation [1]:

- Up-down asymmetry
  - → directly test CP violation
- The polarisation asymmetry of the top quark
  - → distinguish between CP even and CP odd Higgs

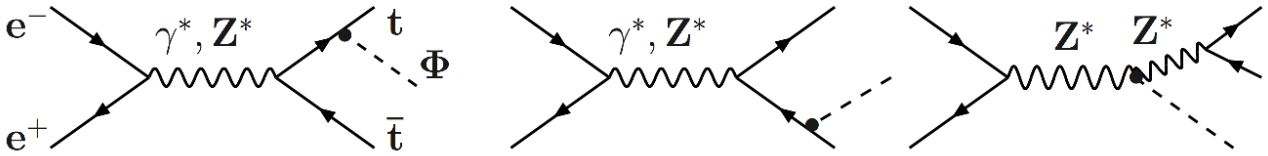


Figure: Feynman diagrams of ttH production.

[1] Reference: R.M. Godbole, C. Hangst, M. Mu¨hlleitner, S.D. Rindani and P. Sharma, "Model-independent analysis of Higgs spin and CP properties in the process $e^+e^- \rightarrow t\bar{t}\Phi$", arXiv:1103.5404v1 [hep-ph] 28 Mar 2011