Prospect of top EW coupling measurements at CEPC

Hongbo Liao (IHEP)

On behalf of

Gang Li, Jiabao Gong, Lei Zhang, Mustapha Biyabi, Shudong Wang, Xiaoxu Zhang, Yaquan Fang,

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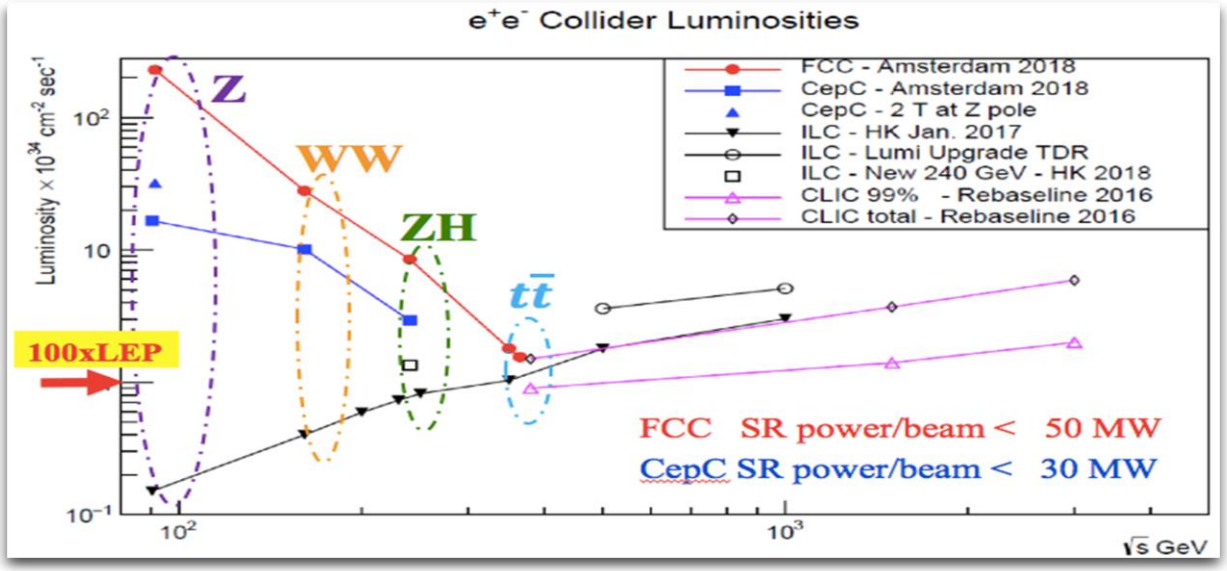
Introduction

- CEPC will be a versatile machine with many opportunities
  - ✓ Higgs factory @~240 GeV
  - ✓ Diboson factory @~160 GeV
  - ✓ Z factory @~90 GeV

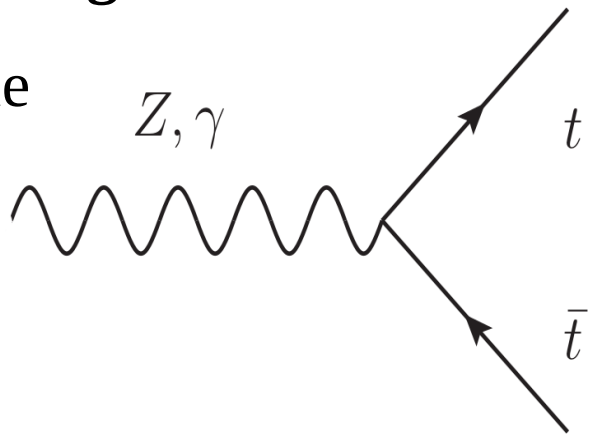


- @~360 GeV it can also be a playground for Top precision measurements, Higgs complementary measurements and also BSM searches

Top electroweak couplings

Why should we study the Top EW couplings?

- ✓ Set constraints on new physics scale
- ✓ Very sensitive to BSM Physics
- ✓ Test of composite Higgs models



JHEP 08 (2015), arXiv:1403.2893 …

A brief introduction to CEPC

- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ≥1 M Higgs; at the **Z** pole for ~Tera Z; at the **W⁺W⁻** pair and then $t\bar{t}$ pair production thresholds.
- Higgs, EW, flavor physics & QCD, probes of physics BSM.
- Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the far future.

Yuhui Li

→ **a great opportunity to measure the Top EW couplings**

Top electroweak couplings

- ✓ **At the CEPC, the ttV (V = γ, Z) couplings could be probed directly through the top pair production process.**
- ✓ **The most general Lorentz-invariant vertex function describing the interaction of a neutral vector boson V with two on-shell top quarks can be written:**

$$\Gamma^{\mu}_{ttV} = \frac{g}{2}\left[\gamma^{\mu}\{(A_V + \delta A_V) - \gamma_5(B_V + \delta B_V)\} + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}(\delta C_V - \delta D_V \gamma_5)\right]$$

- Anomalous couplings δX_V describe: (X=A,B,C,D and V=γ, Z)

$\delta A_\gamma \rightarrow$ Electric charge $\neq \frac{2}{3}$

$\delta B_\gamma \rightarrow$ Parity violation in the γ coupling

δA_Z, $\delta B_Z \rightarrow$ Deviation from the SM in the Z coupling

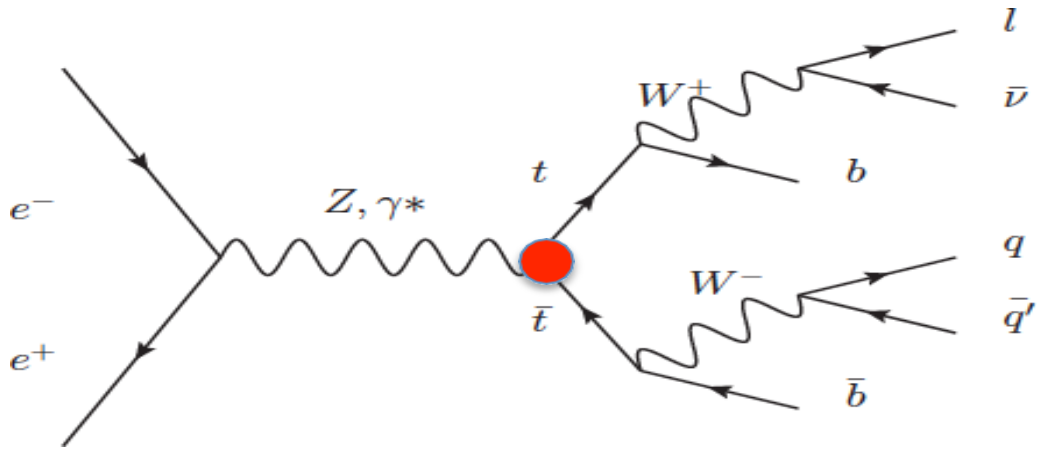
$\delta C_V \rightarrow$ Deviation from the SM in both the Z and γ coupling

$\delta D_V \rightarrow$ CP violation in both the Z and γ coupling

At tree level in the SM, $\delta A_V = \delta B_V = \delta C_V = \delta D_V = 0$

Top electroweak couplings

The energy and the angular distributions of the decay products, in particular, the charged lepton and the b-quark,… are powerful tools to disentangle and access different components of the ttZ and ttγ.



measure

$\sigma(+)$ $A_{FB}(+)$

$\sigma(-)$ $A_{FB}(-)$

$\Rightarrow$ **extract**

$(+=e_R^-)$, $(-=e_L^-)$ $\Rightarrow$ F_{1V}^{γ} * F_{2V}^{γ}; F_{1V}^{Z} F_{1A}^{Z} F_{2V}^{Z}

Measure 2 observables:

-- x-section

-- FB asymmetry

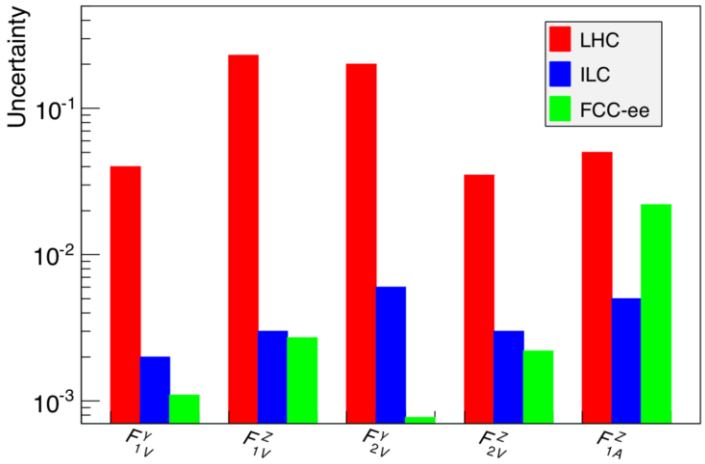
Extract form factors in groups

(assuming SM for remaining groups)

Top electroweak couplings at FCC-ee

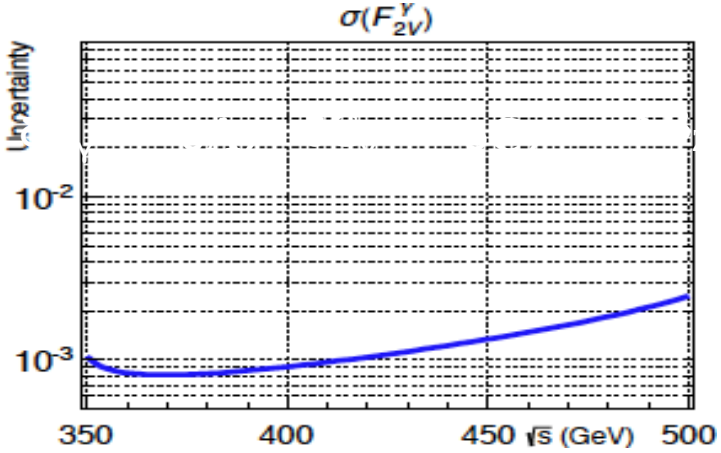
- ✓ **The present LHC precision is not very constraining**
- ✓ **FCC-ee could reduce the statistical uncertainties by orders of magnitude**

LHC: Snowmass study 2005 $\sqrt{s}$=14TeV,300pb^{-1}
ILC: $\sqrt{s}$=500GeV, 500fb^{-1}polarized beams
FCC-ee = $\sqrt{s}$=365 GeV, 2.4 ab^{-1}



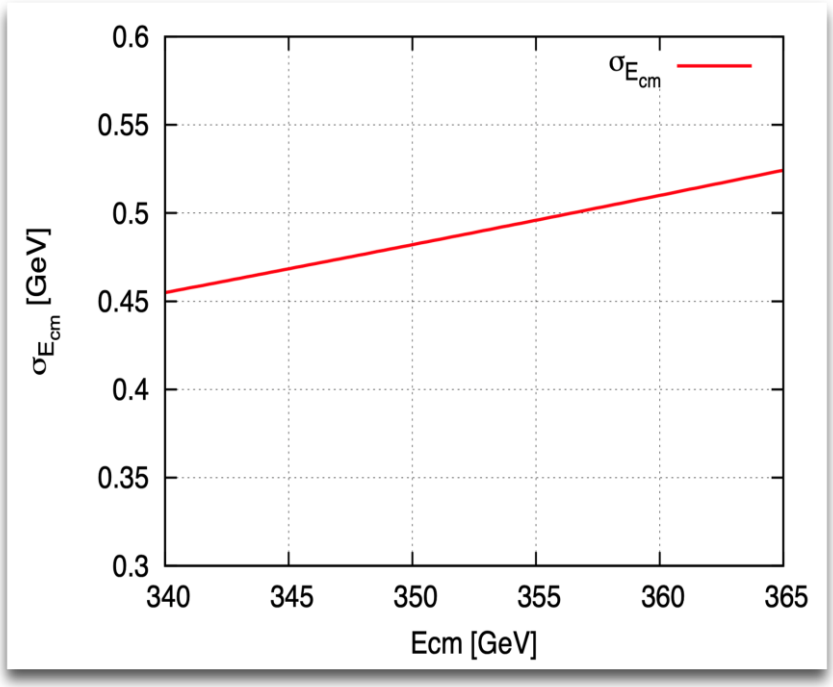
- ✓ With conservative assumptions on lepton identification, b-tagging efficiencies, and lepton angular and momentum resolutions
- ✓ The estimated precisions at FCC-ee are at the order of: 10^{-2} to 10^{-3}

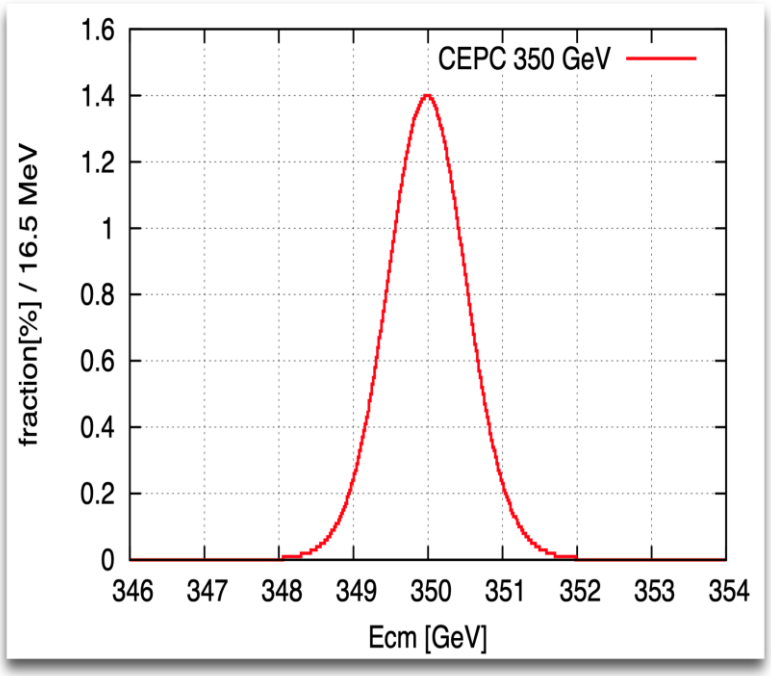
-- Optimal at the energy of 365 GeV.



--Not necessary for high energy runs above the threshold.

Luminosity spectrum @ CEPC





- The beam energy resolution increases as a function of $\sqrt{s}$
- The luminosity spectrum is shown for $\sqrt{s} = 350$ GeV with a width of ~480 MeV
- Similar to the FCC-ee scenario

-- Prospect of similar precision on top EW coupling at CEPC

Analysis at CEPC

Regular discussion since 2 months ago

- ✓ **The Top EW couplings are being probed**
- ✓ **We can measure the EW coupling by studying the energy-angle distribution of the lepton from the semileptonic decay:**

$$e^+e^- \to t\bar{t} \to b\bar{b}q\bar{q}'\ell\nu_\ell \ (\ell = e, \mu)$$

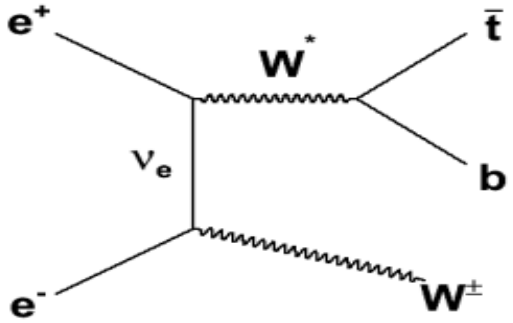
- Tagging of the semileptonic tt events
- Background rejection using discriminating variables
- Muons and electrons coming from the tau decay will be excluded
- Fully leptonic tt events are rejected as a first step

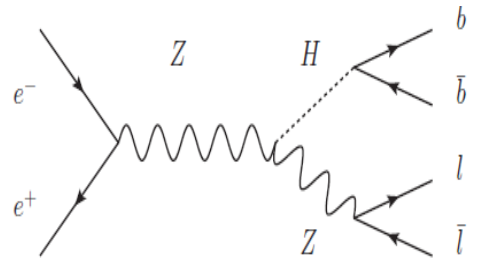
Samples

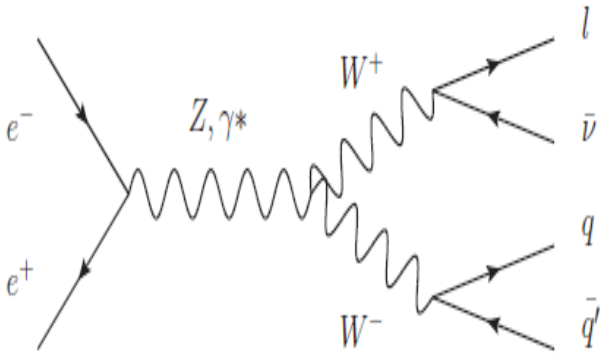
- ✓ Signal samples are ready based on CEPC-V4

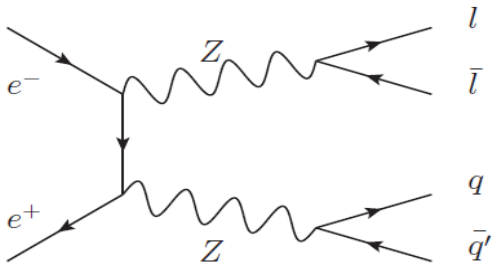
```
/cefs/higgs/wangshudong/top_coupling/reconstruction/output/signal/sm_em
ep_ttbar_*/DST_DATA
```

- ✓ Background samples (diboson and single top) are in production



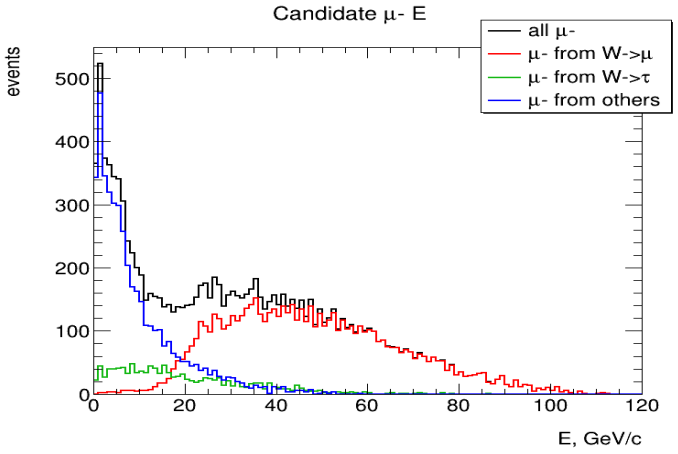


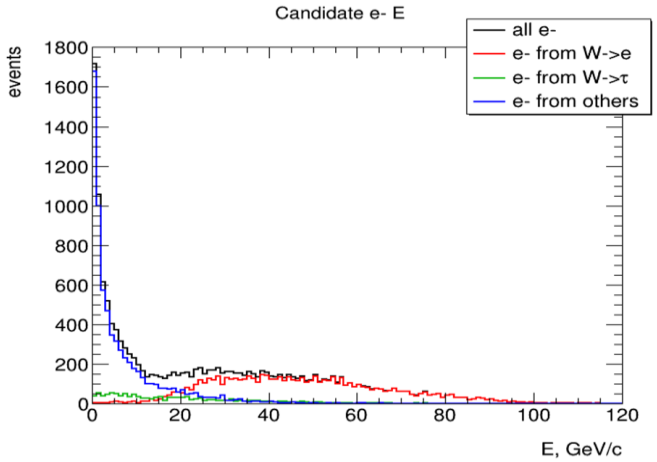




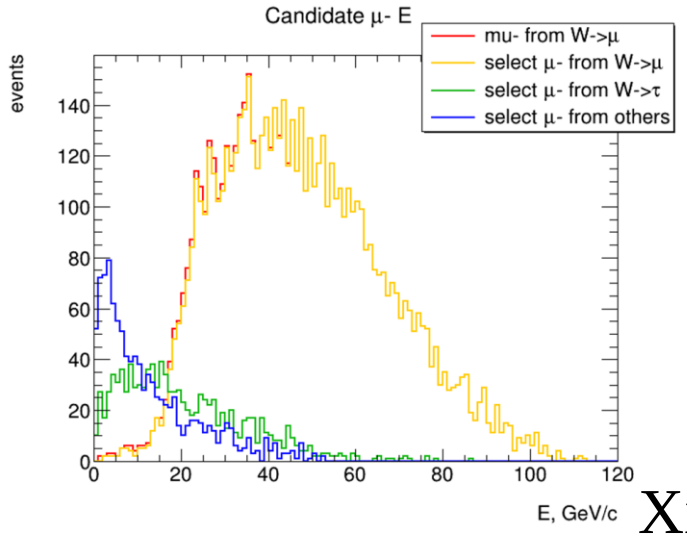
Lepton selection

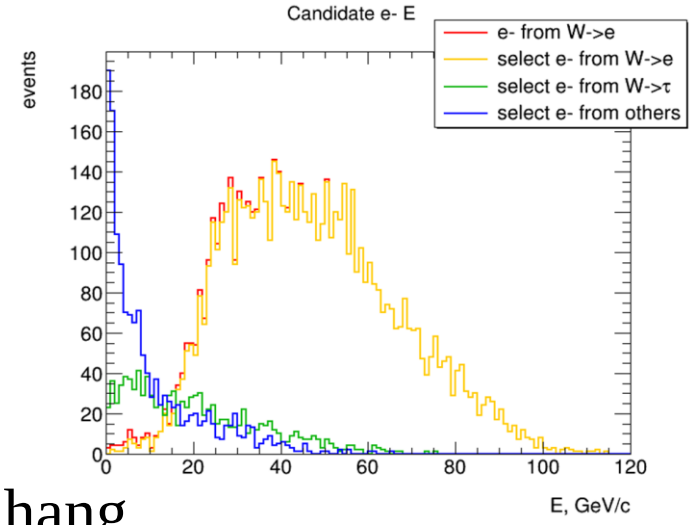
✓ Muons and electrons coming from the tau decay will be excluded





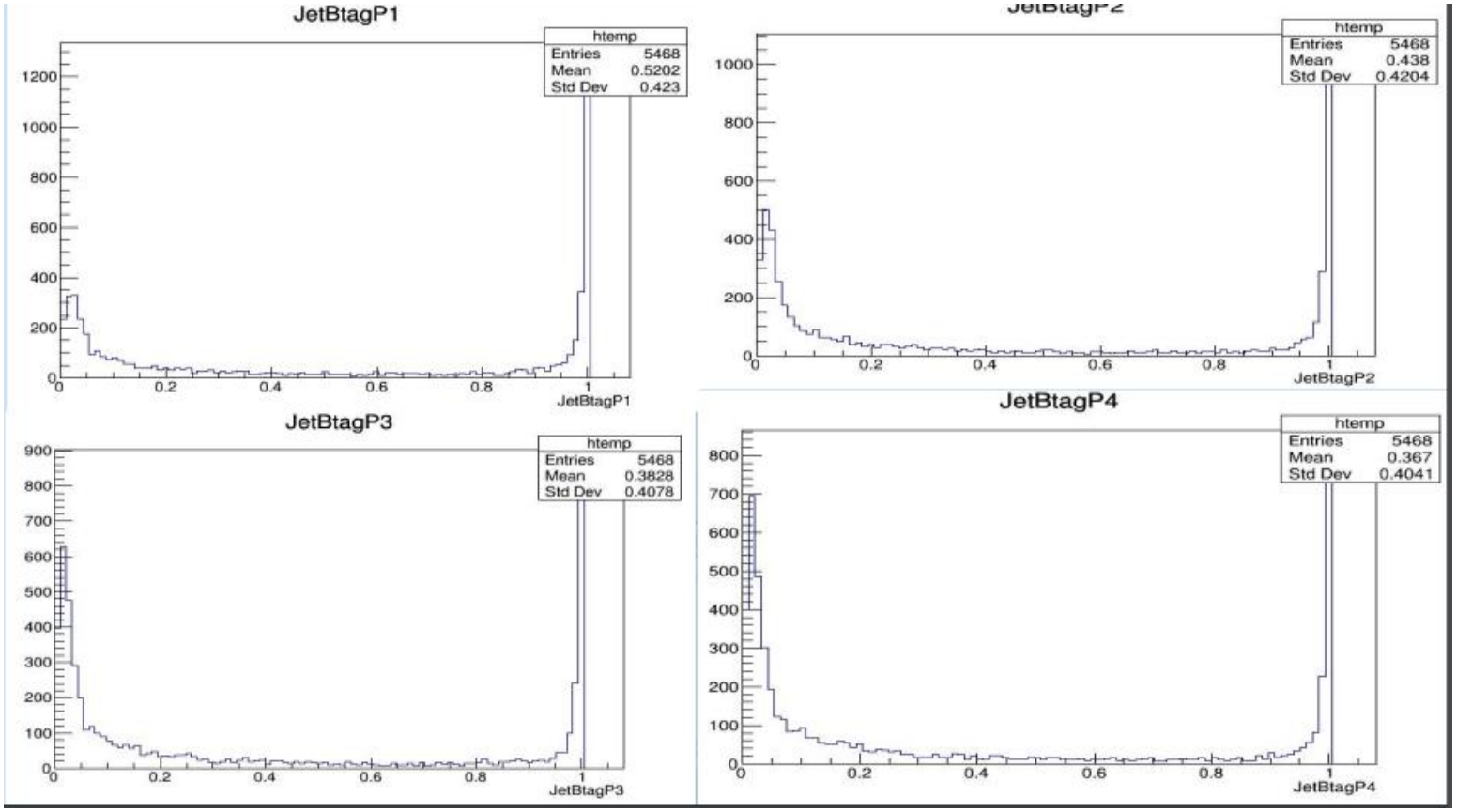
✓ Select lepton with largest energy in the event





B-tag WP

✓ b-tag WP → reject events without 2 b-jets

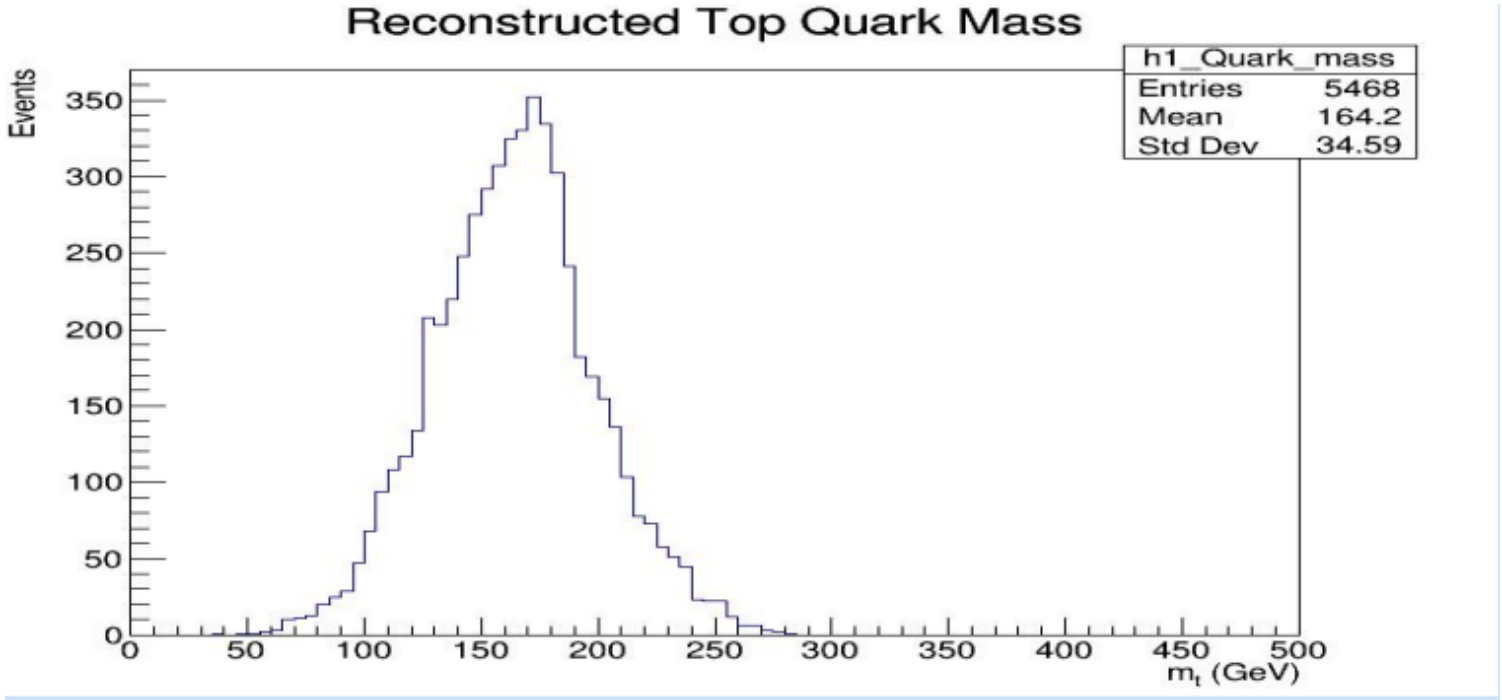


Mustapha Biyabi

Hadronic top mass

- ✓ Hadronic top mass window → reject events with multiple jets without top, such as hadronic ZZ and WW

Mustapha Biyabi



B-tag and correct association are important

- ✓ **First time to select and reconstruct ttbar events at CEPC**
- ✓ **Detailed studies are in progress**

- ✓ Missing Energy range → reject events with Z → invisible in the final state
- ✓ Top and W mass constraint: further backgrounds rejection
- ✓ Study of b (and c)-tagging: except background rejection and also to exploit using the b-jet as observable as well (in addition to the lepton)
- ✓ Optimizing for the correct association: $\chi 2$ method, kinematical fit, ML….

$$\chi^2 = \frac{(m^{rec}_{t-lep} - m_{t-lep})^2}{\sigma^2_{t-lep}} + \frac{(m^{rec}_{t-had} - m_{t-had})^2}{\sigma^2_{t-had}} +$$

$$+ \frac{(m^{rec}_{W-lep} - m_{W-lep})^2}{\sigma^2_{W-lep}} + \frac{(m^{rec}_{W-had} - m_{W-had})^2}{\sigma^2_{W-had}}$$

Summary and future perspectives

- ✓ **Studying the Top EW couplings is very important because of the sensitivity to new physics**
- ✓ **It is possible to perform this measurement at CEPC**
- ✓ **It is expected that we could reach a satisfactory precision in this measure at CEPC**

- ✓ **Optimize event selection and reconstruction to improve the analysis**

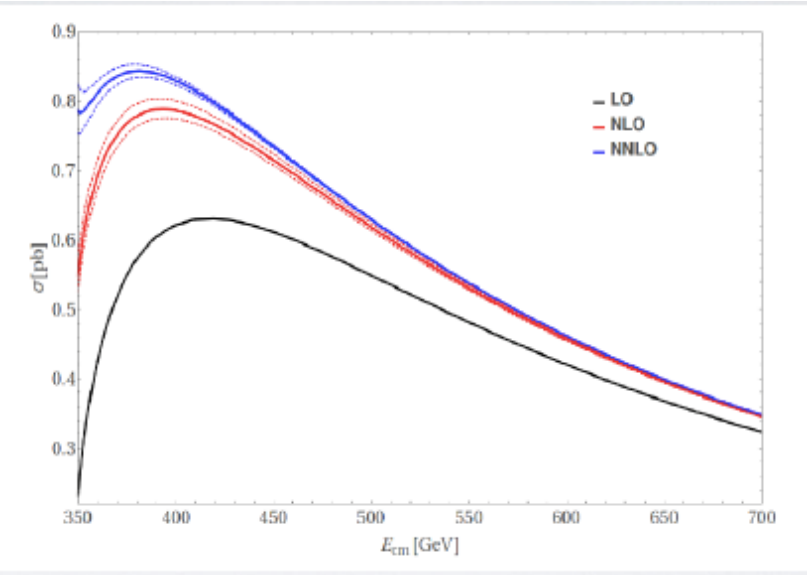
- ✓ **Improve the analysis including fully leptonic final states**

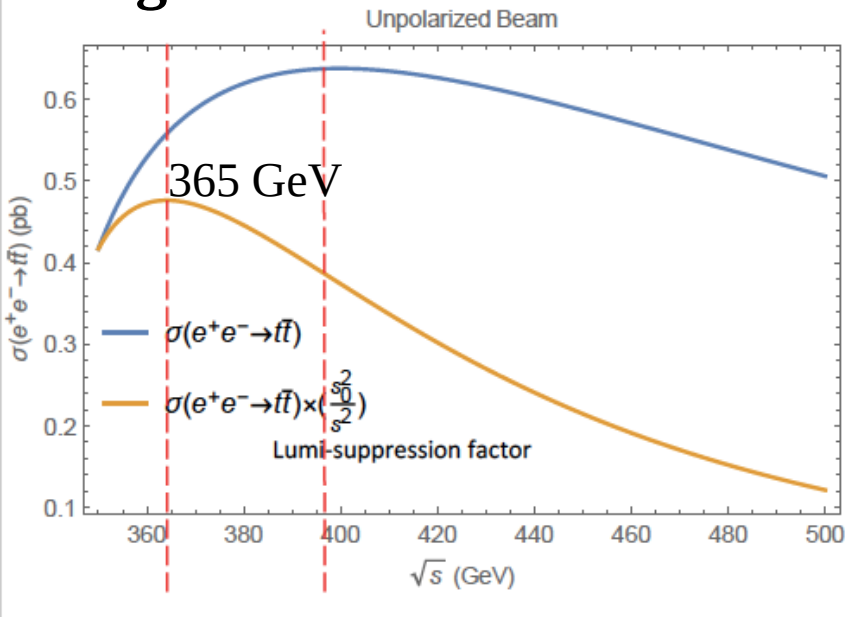
- ✓ **Improve the analysis including b quark energy-angle distribution**

Backup

Top electroweak couplings

Why FCC-ee choosing 365 GeV?



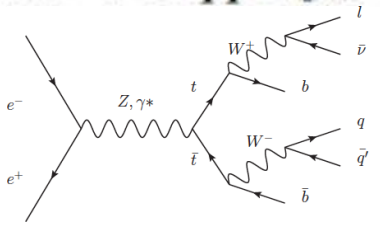


- ✓ With the NNLO calcuation, the highest XS is at the energy of 381.3 GeV
- ✓ Considering the Lumi-suppression factor when going to higher energy, the effective highest XS is around 365 GeV.
- ✓ The effective XS from 360 GeV is not much different from that of 365 GeV.
- ✓ If we choose higher order correction, It could be even lower than 360 GeV.

Top EW couplings

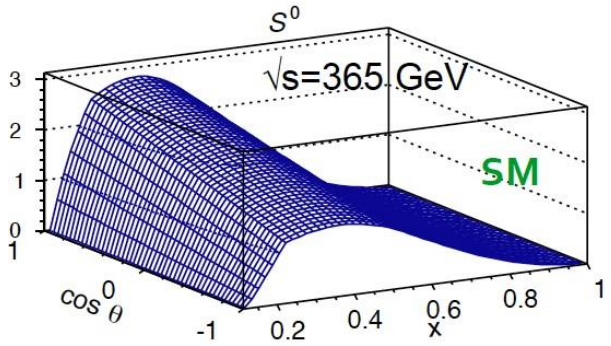
The differential production cross section $d^2\sigma/d\cos\theta dx_f$ for $e^+e^- \to t\bar{t} \to b\bar{b}q\bar{q}'\ell\nu_\ell$ $(\ell = e, \mu)$

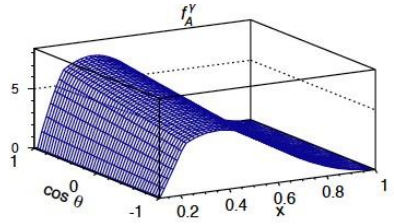
$$\Gamma^{\mu}_{ttV} = \frac{g}{2}\left[\gamma^{\mu}\{(A_V + \delta A_V) - \gamma_5(B_V + \delta B_V)\} + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}(\delta C_V - \delta D_V \gamma_5)\right]$$

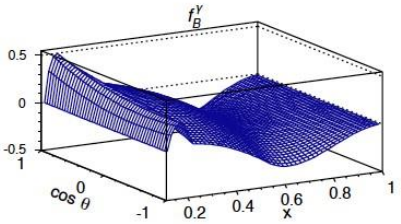


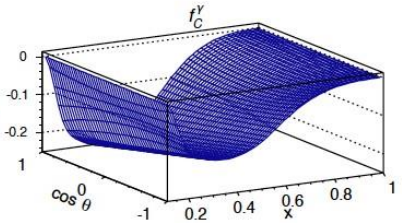
arXiv:1510.09056, P.Janot.

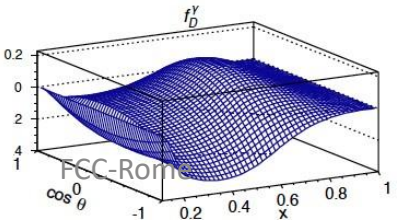
$$\frac{d^2\sigma}{dx\,d\cos\theta} =$$

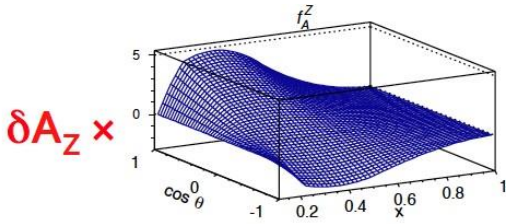


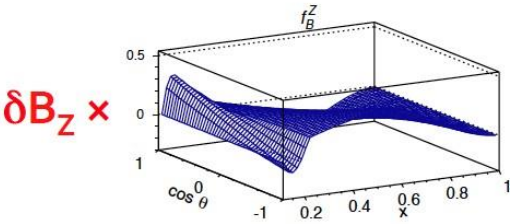
+ $\delta A_\gamma \times$ 

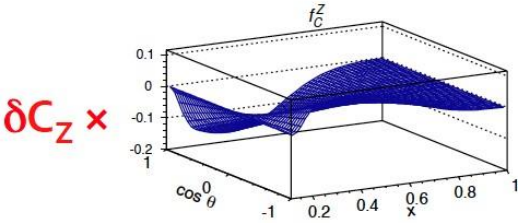
+ $\delta B_\gamma \times$ 

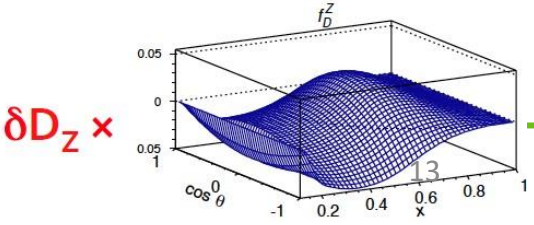
+ $\delta C_\gamma \times$ 

+ $\delta D_\gamma \times$ 

+ $\delta A_Z \times$ 

+ $\delta B_Z \times$ 

+ $\delta C_Z \times$ 

+ $\delta D_Z \times$ 

$\delta A_V = \delta B_V = \delta C_V = \delta D_V = 0$

$$x_f \equiv \frac{2E_f}{m_t}\sqrt{\frac{1-\beta}{1+\beta}}$$

$$\beta\left(\equiv\sqrt{1-4m_t^2/s}\right)$$

Reduced charged lepton energy