Lepton Flavour Violating Higgs decays at LHC and CEPC/SppC

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Why $h \to \tau\mu$?

- SM forbids Lepton Flavour Violating(LFV) decays of the Higgs
- Beyond SM with one Higgs doublet there are higher dimensional operators, $[H^{\dagger}H][\bar{\ell}_{Li}H]\tau_R$
- Extended Higgs sector models may induce Flavour changing Higgs interactions

Example Models

- 2HDM *[Diaz, Martinez, Rodriguez 2000]*
- NMSSM *[Ellwanger, Hugonie, Teixeira 2009]*
- MSSM + ν_R *[Brignole, Rossi 2004]*
- RPV-SUSY *[Arhrib, Cheng, Kong 2012]*
- …….

Predict $\mathrm{B}r(h \to \tau\mu) \sim 10^{-5} - 10^{-2}$

Constraints from data

- Relatively weak constraints from low energy data
- Tree-level: $\tau \to 3\mu, \tau \to e\bar{\mu}\mu$ give order 1 constraint on $y_{\tau\mu}$
- Radiative: $\tau \to \mu\gamma$ gives order y_τ constraint

[Harnik, Kopp, Zupan 2012, and many others]

Collider searches

Assume 125 GeV Higgs with SM-like production via gluon-fusion and study the sensitivity at:

- LHC@8TeV
- LHC@13TeV
- CEPC@240GeV
- SppC@100TeV

Using packages: MadGraph5, Pythia8, PGS
Also MadEvent Analysis Routines by David Curtin
Based on Chameleon

LHC @ 8(13) TeV

- Signal: $gg \to h \to \tau^{\pm}\mu^{\mp} \to e^{\pm}\mu^{\mp}\bar{\nu}\nu$

$\sigma(gg \to h) \sim 21(48)pb$

- Backgrounds:

$pp \to Z/\gamma^{*} \to \tau^{+}\tau^{-} \to e^{\pm}\mu^{\mp}\bar{\nu}\nu\bar{\nu}\nu, \quad \sigma \sim 4(6)pb$

$pp \to W^{+}W^{-} \to e^{\pm}\mu^{\mp}\bar{\nu}\nu, \quad \sigma \sim 0.5(0.8)pb$

$$gg \to h \to W^{+}W^{-}, \tau^{+}\tau^{-}, ZZ^{*}$$

Basic event selection for LHC

- At least one muon(electron) with $p_T > 30(15)GeV$ and $|\eta| < 2.1(2.5)$
- Exactly 2 Opposite Sign leptons
- No jets with $p_T > 30GeV$ and $|\eta| < 2.5$
- $\Delta\varphi(e,\mu) > 2.7, \text{and } \Delta\varphi(e, MET) < 0.3$

MET reconstruction

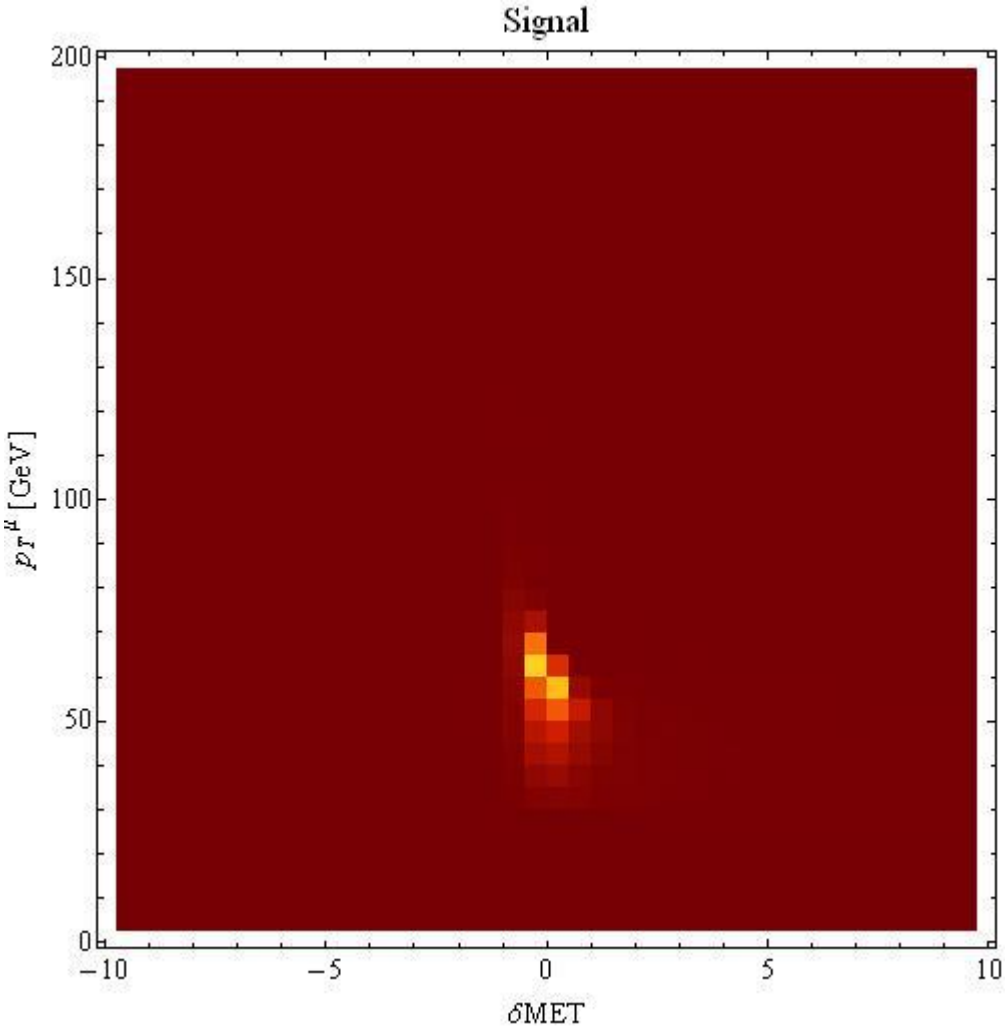
- $gg \to h \to \tau^{\pm}\mu^{\mp} \to e^{\pm}\mu^{\mp}\bar{\nu}\nu$ the tau is highly boosted, so assume decay to $e^{\pm}\bar{\nu}\nu$ is collinear $p_{\tau} = \alpha p_e$ and $p_{2\nu} = (\alpha - 1)p_e$
- $\alpha\, p_{\mu}.p_e = p_{\mu}.p_{\tau} = \frac{{m_h}^2}{2}$ such that,

$$\alpha = \frac{{m_h}^2}{4E_e E_{\mu} \sin^2 \frac{\theta_{e\mu}}{2}}$$

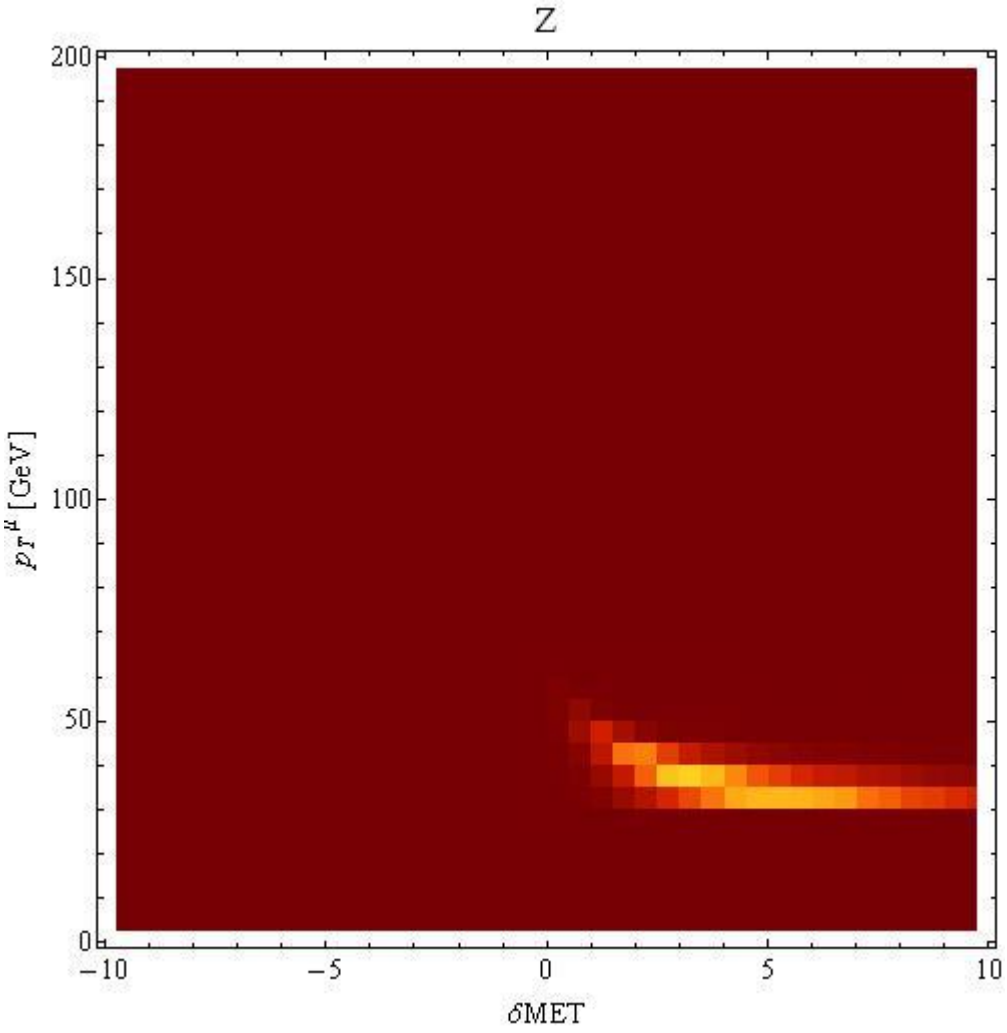
and define:

$$\delta MET = \frac{(\alpha-1){p_T}^e - MET}{MET}$$

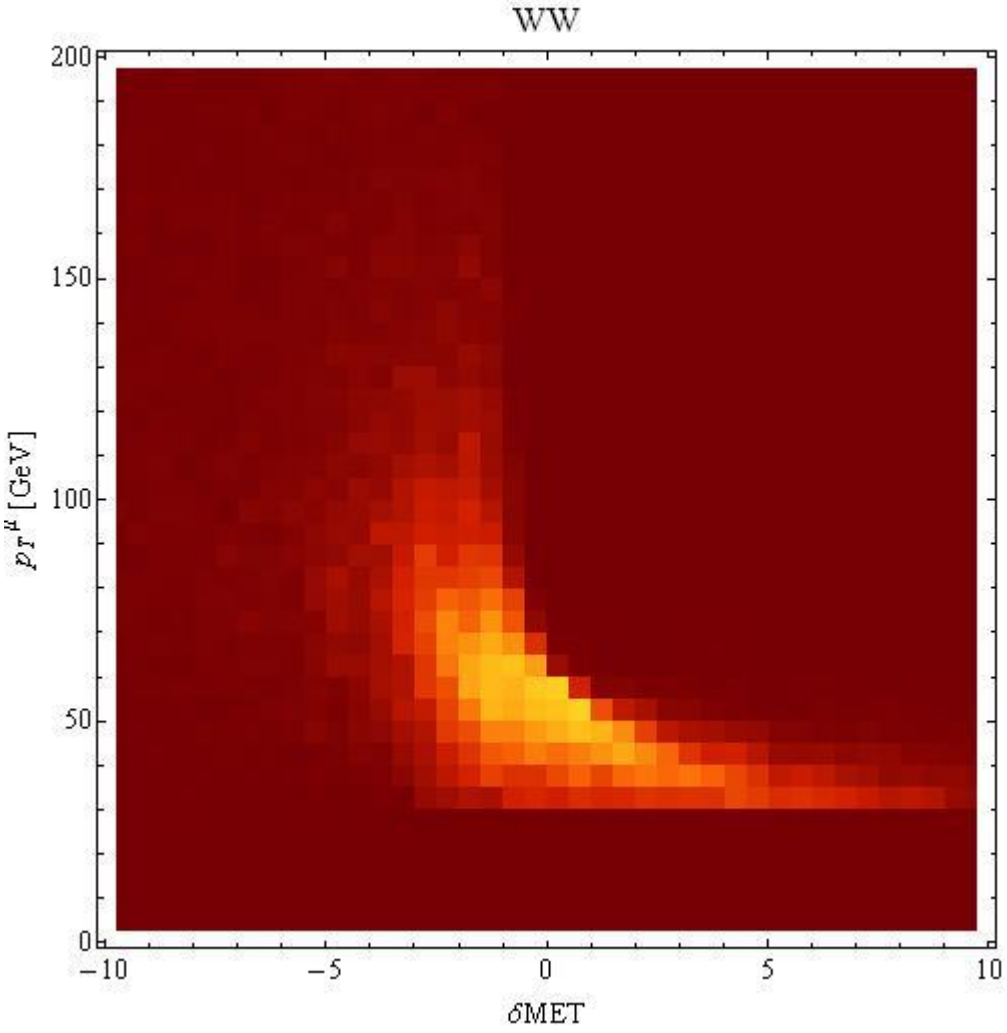
δMET-$p_T{}^{\mu}$ plot



δMET-$p_T{}^{\mu}$ plot



δMET-$p_T{}^{\mu}$ plot



2-D cut

- Muon p_T tends to be higher for the signal than background, so we make a 2-D cut,

$$\left(\frac{{p_T}^{\mu} - 60}{25}\right)^2 + \left(\frac{\delta MET}{0.25}\right) < 1$$

[Davidson, Verdier 2012]

Very Preliminary

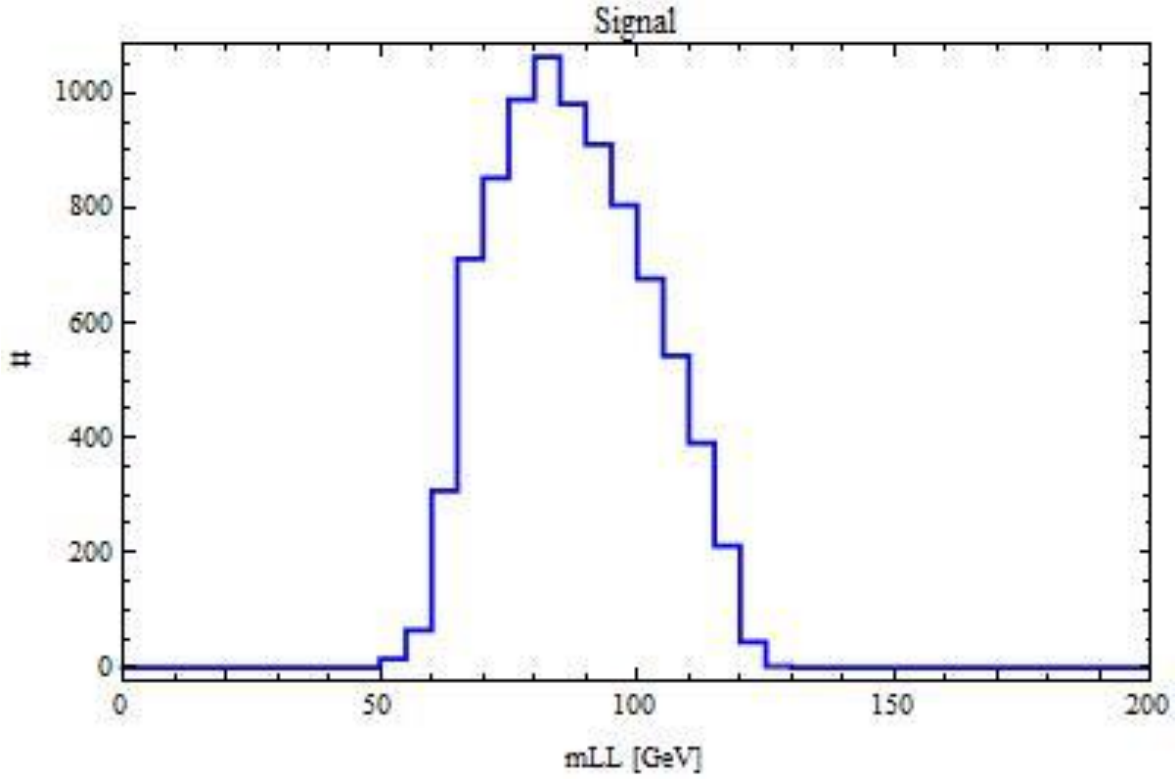
Results for LHC at 8(13) TeV

- Here we assume: $Br(h \to \tau\mu) \equiv Br(h \to \tau\bar{\tau})$ $\sqrt{s} = 8(13)TeV$ and $\mathcal{L} = 20\ (100)fb^{-1}$

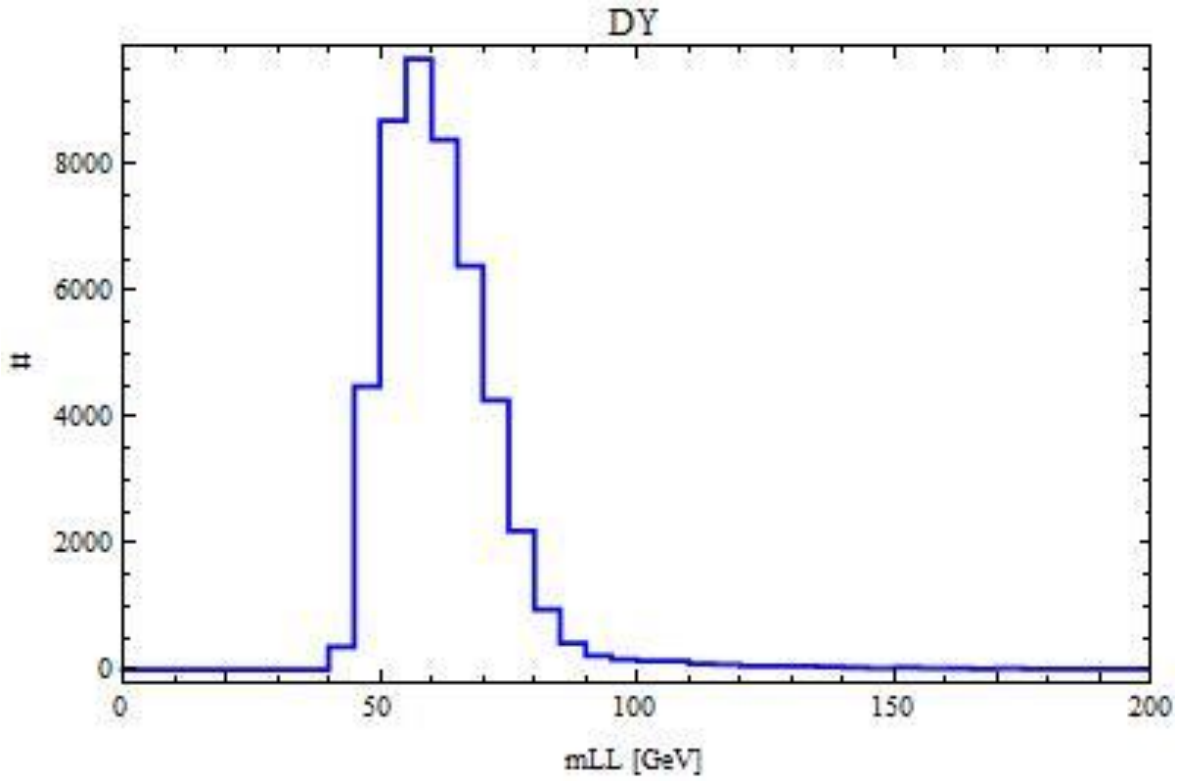
Process	# of events
$Z/\gamma \to \tau\tau$	117±5 (889±27)
WW $\to e\mu\nu\nu$	284±4 (2165±21)
Total	401±9 (3054±48)
$h \to \tau\mu$	226±3 (960±12)

- 2σ exclusion: $Br(h \to \tau\mu) < 0.0013\ \ (0.0004)$
- 5σ discovery: $Br(h \to \tau\mu) > 0.0034\ \ (0.0010)$

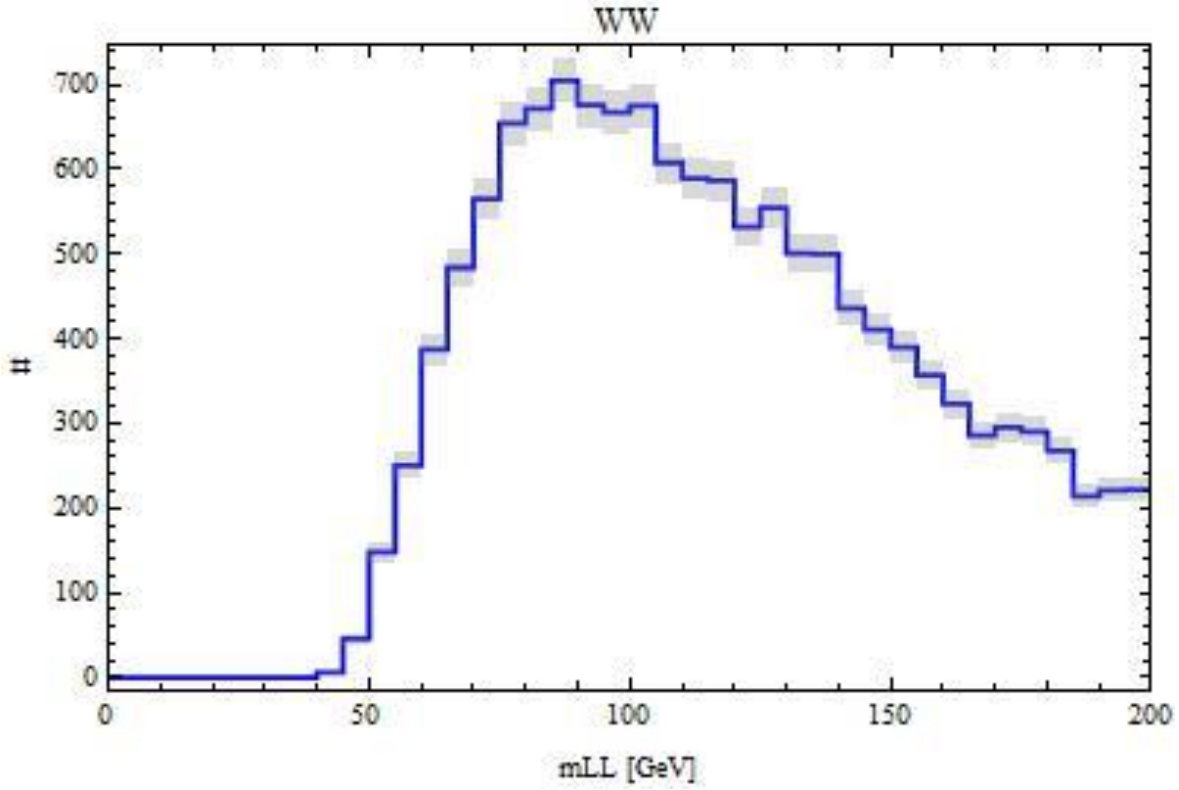
Invariant Mass



Invariant Mass



Invariant Mass



Very Preliminary

Results for LHC at 8(13) TeV

- Here we assume: $Br(h \to \tau\mu) \equiv Br(h \to \tau\bar{\tau})$ $\sqrt{s} = 8(13)TeV$ and $\mathcal{L} = 20\ (100) fb^{-1}$
- Add Inv Mass cut $50\ GeV < m_{LL}{}^{e\mu} < 130\ GeV$

Process	# of events
$Z/\gamma \to \tau\tau$	86±4 (650±23)
WW $\to e\mu\nu\nu$	87±2 (638±11)
Total	173±6 (1288±34)
$h \to \tau\mu$	226±3 (960±12)

- 2σ exclusion: $Br(h \to \tau\mu) < 0.001\ \ (0.0002)$
- 5σ discovery: $Br(h \to \tau\mu) > 0.002\ \ (0.0006)$

CEPC/TLEP

	CEPC	TLEP-HZ
Beam energy [GeV]	120	120
Circumference [km]	53.6	80
Luminosity [$10^{34} cm^{-2} s^{-1}$]	1.82	5
# Higgs/yr/IP [10^5]	0.4	1.2
# IP	2	4
Int. Lum. [$ab^{-1} yr^{-1} IP^{-1}$]	0.182	0.5

CEPC/TLEP

- Signal:
  $e^+e^- \to Z^* \to Zh \to Z\tau\mu \to \bar{\mu}\mu\, e^{\pm}\mu^{\mp}\bar{\nu}\nu$
- Background:
  $e^+e^- \to Z^* \to Zh \to ZWW^* \to \bar{\mu}\mu\, e^{\pm}\mu^{\mp}\bar{\nu}\nu$
  $e^+e^- \to ZZ \to \bar{\mu}\mu\, \bar{\tau}\tau \to \bar{\mu}\mu\, e^{\pm}\mu^{\mp}\bar{\nu}\nu\bar{\nu}\nu$
  $e^+e^- \to \bar{\mu}\mu W^+W^- \to \bar{\mu}\mu\, e^{\pm}\mu^{\mp}\bar{\nu}\nu$
- $\sigma(Zh) \sim 0.25pb$
  $\sigma(ZZ) \sim 1pb$
  $\sigma(\bar{\mu}\mu W^+W^-) \sim 0.1fb$

Selection for CEPC/TLEP

- Just use basic event selection
- At least 3 muon (1 electron) with $p_T > 30(15)GeV$ and $|\eta| < 2.1(2.5)$
- Exactly 2 pairs Opposite Sign leptons
- No jets with $p_T > 30GeV$ and $|\eta| < 2.5$
- Reconstruct Higgs mass to ± 25 GeV and Z mass to ± 20 GeV

Very Preliminary

Results for CEPC/TLEP

- Here we assume: $Br(h \to \tau\mu) \equiv Br(h \to \tau\bar{\tau})$
  $\sqrt{s} = 240\ GeV$ and $\mathcal{L} = 0.364\ (2.0)\ ab^{-1}$

Process	# of events
$Zh \to ZWW^*$	~0 .1 (0.5)
$ZZ \to Z\tau\bar{\tau}$	~0.1 (0.5)
$\bar{\mu}\mu WW$	~0
Total	~0.2 (1)
$h \to \tau\mu$	~7 (37)

- 2σ exclusion: $Br(h \to \tau\mu) < 0.006\ \ (0.002)$
- 5σ discovery: $Br(h \to \tau\mu) > 0.014\ \ (0.006)$

So far

LHC @ 8TeV (13 TeV) and $\mathcal{L} = 20\ (100) fb^{-1}$

- 2σ exclusion: $Br(h \to \tau\mu) < 0.001\ \ (0.0002)$
- 5σ discovery: $Br(h \to \tau\mu) > 0.002\ \ (0.0006)$

CEPC/TLEP with $\mathcal{L} = 0.364\ (2.0)\ ab^{-1}$

- 2σ exclusion: $Br(h \to \tau\mu) < 0.006\ \ (0.002)$
- 5σ discovery: $Br(h \to \tau\mu) > 0.014\ \ (0.006)$

Only one Z decay channel

Not yet considered

- CEPC including all Z decay channels, $e\bar{e}$, jj, $v\bar{v}$
- HL-LHC
- SppC @ 100 TeV

Thank you