Flavor changing neutral Higgs meet top and tau at Hadron colliders

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Energy Frontiers in Particle Physics: LHC and Future Colliders

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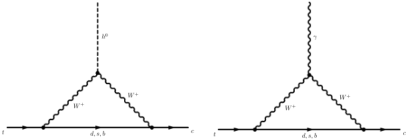
Outline

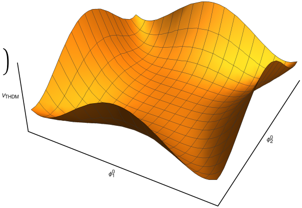
- In SM, there are no tree level flavor violating neutral Higgs decays.
- At one loop, CKM Unitarity suppresses channels like $t \to ch^0 \propto 10^{-15}$.(Aguilar-Saavedra (2004))



- $\sum_j V_{ij} V_{jk}^* = 0$ (Dattoli.et.al (1996))

Higgs potential(Gunion and Haber, 2002)

$$
\begin{aligned}
& m_{11}^2 \phi_1^\dagger \phi_1 + m_{22}^2 \phi_2^\dagger \phi_2 \\
- & [m_{12}^2 \phi_1^\dagger \phi_2 + h.c] \\
+ & \frac{1}{2}\lambda_1 (\phi_1^\dagger \phi_1)^2 + \frac{1}{2}\lambda_2 (\phi_2^\dagger \phi_2)^2 \\
+ & \lambda_3 (\phi_1^\dagger \phi_1)(\phi_2^\dagger \phi_2) + \lambda_4 (\phi_1^\dagger \phi_2)(\phi_1^\dagger \phi_2) \\
+ & \left\{ \frac{1}{2}\lambda_5 (\phi_1^\dagger \phi_2)^2 + [\lambda_6 (\phi_1^\dagger \phi_1) \right. \\
+ & \lambda_7 (\phi_2^\dagger \phi_2)] \phi_1^\dagger \phi_2 + h.c
\end{aligned}
$$



(1)

Extra Yukawa's in general THDM

$$\frac{-1}{\sqrt{2}} \sum_{F=U,D,E} \bar{F}\Big\{ \left[\kappa^F s_{\beta-\alpha} + \rho^F c_{\beta-\alpha}\right] h^0 + \left[\kappa^F c_{\beta-\alpha} - \rho^F s_{\beta-\alpha}\right] H^0 - i\,\mathrm{sgn}(Q_F)\rho^F A^0 \Big\} P_R F + \mathrm{H.c.}$$

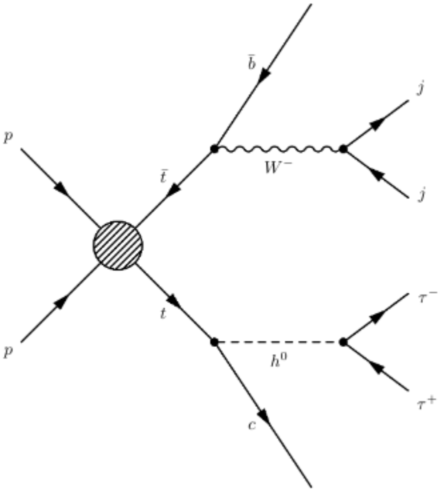
- κ_F is the SM like Yukawa matrix = $\sqrt{2}m_F/v$, hence diagonal. (v = vev = 246 GeV)
- ρ_F is the Extra Yukawa matrix, with a possibility for off diagonal terms and a CP phase.

- This model leads to CP violation and can potentially enhance tree level flavor changing neutral Higgs currents at LHC.
- Current results favor mostly SM results, but Higgs-top flavor changing can potentially give new physics signature at LHC
  - $t \rightarrow ch^0, \lambda_{tc} = \rho_{tc} \cos(\beta - \alpha)$ (Hou 1991)
  - $H \rightarrow tc, \lambda_{tcH} = \rho_{tc} \sin(\beta - \alpha)$ (Altunkaynak.et.al 2015)

Constraint on FCNH coupling

- Recent experiemental results from ATLAS (2019) put a tight constraint on λ_{tc} and λ_{ct}.
  - $\mathcal{B}(t \to ch^0) < 0.011$
  - $\sqrt{\lambda_{tc}^2 + \lambda_{ct}^2} < 0.064$
- If we choose ρ^F matrix to be hermitian, then $b \to s\gamma$ and $B - \bar{B}$ mixing requires $|\rho_{ct}| < 0.1$
- If we choose ρ^F matrix to be non hermitian then we must have $|\rho_{ct}| < 0.1$, where ρ_{tc} can be close to 1.

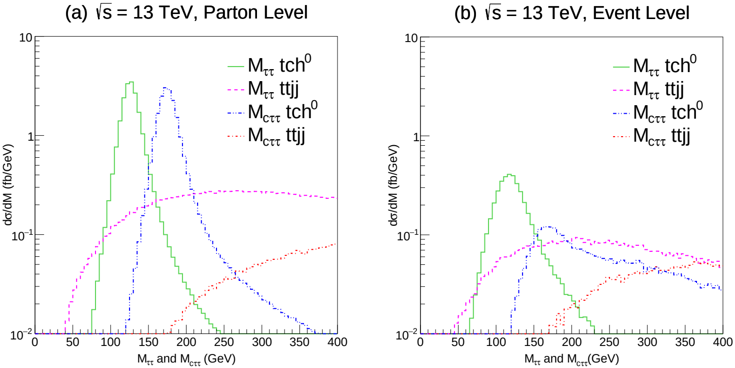
Channel of Interest



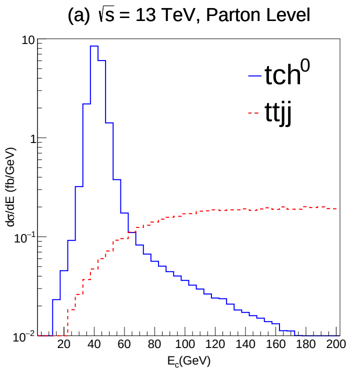
Other Studies

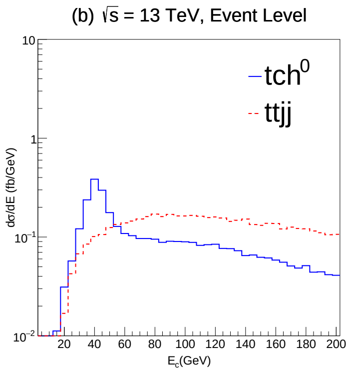
- **X.Chen and L.Xia, Phys Rev. D 93, no 11, 113010 (2016)**
- **M. Aaboud *et al.* [ATLAS Collaboration], JHEP 1905, 123 (2019)**
- **In this study we have done Parton level, and event level study with BDT.**
- **We have only considered leptonic channel with $e\mu$ state only.**

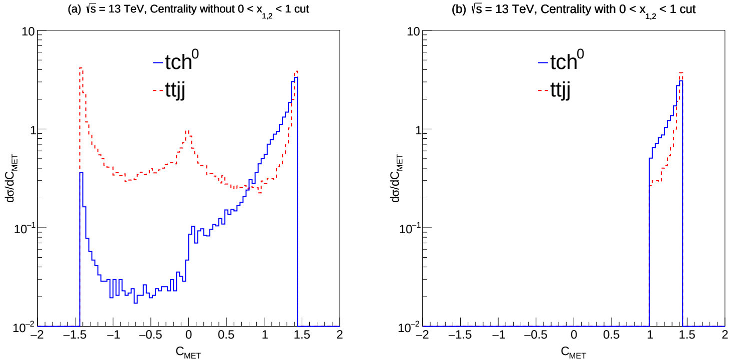
Mass Reconstruction with Collinear Approximation



Power of Collinear Approximation, Energy of Charm







$$C_{MET} = \frac{x+y}{\sqrt{x^2+y^2}}$$

$$x = \frac{\sin(\phi_{MET}-\phi_{\ell_1})}{\sin(\phi_{\ell_1}-\phi_{\ell_2})}, y = -\frac{\sin(\phi_{MET}-\phi_{\ell_2})}{\sin(\phi_{\ell_1}-\phi_{\ell_2})}$$

Important Selection Cuts

- $|M(j_1, j_2) - m_W| \leqslant 0.20 \times m_W$ and $|M(b, j_1, j_2) - m_t| \leqslant 0.25 \times m_t$
- 40 GeV$\leqslant M_T(\ell, \ell, E_T) \leqslant$140 GeV and 80 GeV $\leqslant M_T(c, \ell, \ell, E_T) \leqslant 180$ GeV
- $|M_{col}(\tau, \tau) - m_h| \leqslant 0.20 \times m_h$ and $|M_{col}(c, \tau, \tau) - m_t| \leqslant 0.25 \times m_t$
- 29 GeV $\leqslant E_c \leqslant$ 54 GeV

Parton Level Estimates

$\sqrt{s}$	$t\bar{t}$ jj	$b\bar{b}jj\tau\tau$	$b\bar{b}jjWW$	$t\bar{t}$V	Total
13	0.67	0.021	3.2×10^{-4}	3.5×10^{-3}	0.69
14	0.78	0.025	3.8×10^{-4}	3.8×10^{-4}	0.8
27	2.91	0.074	1.3×10^{-3}	9.8×10^{-3}	2.99

Table: Background Cross sections after applying the mass cuts, in fb at PL.

Parton Level Estimates

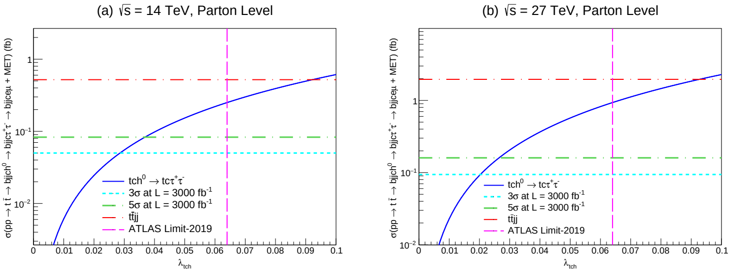
$\sqrt{s}(TeV)$	$h \to WW^*$	$h^0 \to \tau^+\tau^-$
13	0.127	0.073
14	0.123	0.069
27	0.09	0.049

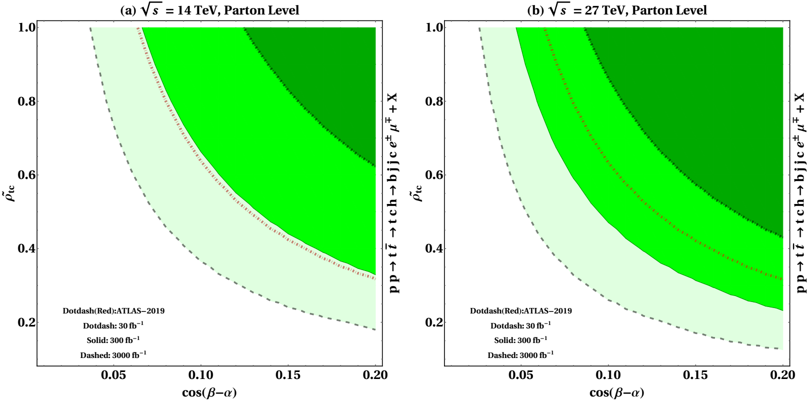
Table: Minimum λ_{tc} at $\mathcal{L} = 139 fb^{-1}$ for 5 σ.

$\sqrt{s}(TeV)$	$h \to WW^*$	$h^0 \to \tau^+\tau^-$
13	0.06	0.033
14	0.057	0.031
27	0.041	0.023

Table: Minimum λ_{tc} at $\mathcal{L} = 3000 fb^{-1}$ for 5 σ.

Parton Level Estimates



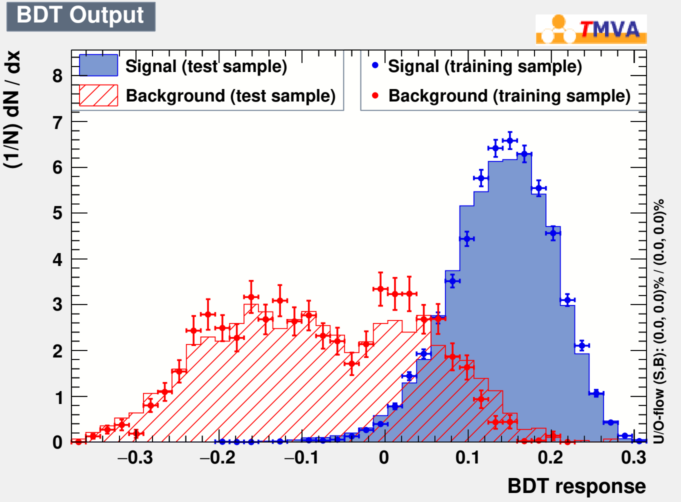

(a) $\sqrt{s}$ = 14 TeV, Parton Level
(b) $\sqrt{s}$ = 27 TeV, Parton Level
$\tilde{\rho}_{tc}$
cos($\beta-\alpha$)
$p\,p \to t\,\bar{t} \to t\,c\,h \to b\,j\,j\,c\,e^{\pm}\mu^{\mp} + X$
Dotdash(Red):ATLAS−2019
Dotdash: 30 fb^{-1}
Solid: 300 fb^{-1}
Dashed: 3000 fb^{-1}
1.0
0.8
0.6
0.4
0.2
0.05
0.10
0.15
0.20

Event Level Estimates

$\sqrt{s}$	$t\bar{t}$ jj	$b\bar{b}jj\tau\tau$	$b\bar{b}jjWW$	$t\bar{t}$V	Total
13	0.14	0.004	6.7×10^{-5}	7.1×10^{-4}	0.15
14	0.21	0.007	9.9×10^{-5}	9.9×10^{-5}	0.22
27	0.71	0.02	3.1×10^{-4}	2.4×10^{-3}	0.74

Table: Background Cross sections after applying the mass cuts, in fb at PL.

BDT response



BDT vs Cut Based (Event Level)

$\sqrt{s}$(TeV)	Cut-Based	BDT
13	1.2	2.7
14	1.3	3.2
27	2.2	5.5

Table: Comparison between the statistical significance at $\lambda_{tc} \sim 0.064$ and $\mathcal{L} = 3000 fb^{-1}$ for cut-based and BDT .

Event Level estimates

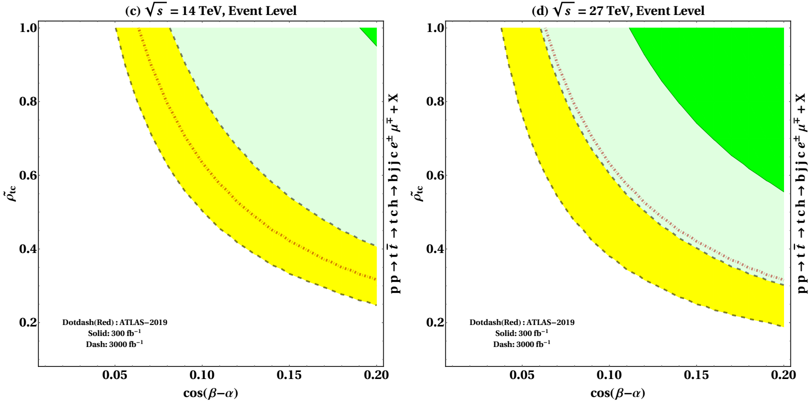
$\sqrt{s}$(TeV)	$\mathcal{L} = 300fb^{-1}$	$\mathcal{L} = 3000fb^{-1}$
13	0.099	0.055
14	0.092	0.051
27	0.068	0.038

Table: 95 % C.L Limits on λ_{tc} at different center of mass energies and Integrated Luminosities.

$\sqrt{s}$(TeV)	$\mathcal{L} = 300fb^{-1}$	$\mathcal{L} = 3000fb^{-1}$
13	0.21	0.088
14	0.16	0.082
27	0.11	0.061

Table: Minimum λ_{tc} for discovery at different center of mass energies and Integrated Luminosities.

Event level estimates



Conclusion

- The $t \to ch^0$ decay is an exciting new physics mode to study extra Yukawa couplings.
- We have studied $h^0 \to \tau^+\tau^- \to e^\pm\mu^\mp + MET$ decay of SM-Higgs. We find that $\tau\tau$ holds a very promising study channel and with the inclusion of Energy of Charm variable we can really improve the reach for the LHC. Same can be repeated for $h^0 \to \gamma\gamma, ZZ^* \to 4\ell$.
- Here we have constrained ourself just $e\mu$, but remaining leptonic modes and hadronic modes of tau decay can further improve the reach of this channel.
- We also just used the traditional collinear approximation for tau reconstruction, with more powerful method like Missing Mass calculator can also improve the search.

THANK YOU FOR
YOUR LİSTENİNG

DO YOU HAVE
ANY QUESTİONS?