Flavor Changing Neutral Higgs Boson meets the Top and the Tau at Hadron colliders

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Flavor changing in SM and Limits on Flavor anomalies

- In SM Flavor Changing neutral currents like $t \to c(u)V^0, (V^0 = \gamma, Z, h^0)$ or $h^0 \to \tau\bar{\mu}$ are absent at tree level.
- At one loop level,SM predicts $\mathcal{B}(t \to qh, Z, \gamma) \simeq 10^{-14}$ from [1] and $\mathcal{B}(h^0 \to f_i f_j)$ is highly suppressed at one loop level, where $i \neq j$.
- Current limits on some of the flavor anomalous searches are,
  - $\tau \to \mu\gamma \lesssim 4.5 \times 10^{-8}$ at 90% C.L (Belle-collaboration)
  - $\tau \to e\gamma \lesssim 1.1 \times 10^{-8}$ at 90 % C.L (BaBar Collaboration)
  - $t \to ch^0 \lesssim 1.1 \times 10^{-3}$ at 95 % C.L (ATLAS collaboration)

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[1] Aguilar-Saavedra arxiv:hep-ph/0409342

THDM and Corrections to Yukawa sector

- The mixing of the two doublets, induce corrections to Yukawa couplings. The effective yukawa lagrangian in General 2HDM is,

$$
\begin{aligned}
-\sqrt{2}\mathcal{L}_Y &= \bar{F}\left\{\left[\kappa^F s_{\beta-\alpha} + \rho^F c_{\beta-\alpha}\right] h + \left[\kappa^F c_{\beta-\alpha} - \rho^F s_{\beta-\alpha}\right] H^0\right\} P_R F \\
&\quad - \left\{ i\,\mathrm{sgn}(Q_F)\rho^F A^0 \right\} P_R F + \mathrm{H.c.}
\end{aligned}
$$

where $P_{L,R} \equiv (1 \mp \gamma_5)/2$, $c_{\beta-\alpha} = \cos(\beta-\alpha)$, $s_{\beta-\alpha} = \sin(\beta-\alpha)$, and α is the mixing angle between neutral Higgs scalars in the Type II (2HDM-II) notation[2], κ matrices are diagonal and fixed by fermion masses to $\kappa^F = \sqrt{2} m_F / v$ with $v \simeq 246$ GeV, while ρ matrices are free and have both diagonal and off diagonal term.

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[2] J. F. Gunion, H. E. Haber, G. L. Kane and S. Dawson, Front. Phys. **80**, 1 (2000).

THDM and Flavor Changing Neutral Currents

- With ρ matrix containing non diagonal terms, we have tree level FCNC's possible in gTHDM
- 2HDM-I,II,Lepton Specific, Flipped model preserves flavor symmetry by introducing additional ad-hoc symmetries.
- These models only effect the yukawa sector, Higgs couplings to bosons are independent of these model variations.

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Motivation for $t \to ch^0$

- $m_t > m_c + m_h$
- Current Experimental Limits are ~ 10 orders of magnitude higher than SM expectation
- If FCNH coupling $\rho_{tc} \sim \mathcal{O}(1)$, can drive Electroweak Baryogenesis[3].
- Promising results from previous phenomenological studies,
  - $t \to ch^0 \to cb\bar{b}$
    Kao,Cheng,Hou and Sayre (2012)
  - $t \to ch^0 \to cZZ^*$
    Chen,Hou,Kao and Kohda,(2013)
  - $t \to ch^0 \to cWW^*$
    Jain and Kao (2019)

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[3]Fuyuto.et.al doi:10.1016/j.physletb.2017.11.073

Translating Experimental Constraints

- The Branching Fraction for $t \to ch^0$ is given as, Using $m_t = 173.2$ GeV, $M_h = 125.1$ GeV and $m_c = 1.42$ GeV

$$\mathcal{B}_{t\to ch^0} = \frac{c_{\beta\alpha}^2 m_t}{32\pi\Gamma_t}\{0.48|\tilde{\rho}_{tc}|^2\} \times \lambda^{1/2}(1, x_c^2, x_h^2) \quad (1)$$

Where $\tilde{\rho}_{tc} = \sqrt{\frac{|\rho_{tc}|^2 + |\rho_{ct}|^2}{2}}$,

$\lambda(x,y,z) = x^2 + y^2 + z^2 - 2xy - 2xz - 2yz,\ x_i = m_i/m_t$

- Current limits $\mathcal{B}_{t\to ch^0} \lesssim 1.1 \times 10^{-3}$ gives $\lambda_{tc} = \tilde{\rho_{tc}} c_{\beta-\alpha} \lesssim 0.064$ [4]

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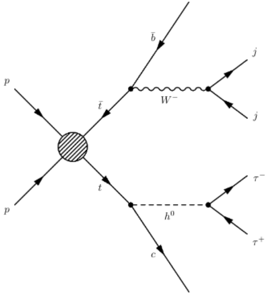
[4] doi 10.1007/JHEP05(2019)123, ATLAS Collaboration

Parameters and Channel of study

- Our production channel is top pair production at LHC. With the following following decay modes,
  - $t \rightarrow ch^0 \rightarrow c\tau^+\tau^-$, Other top decays via $t \rightarrow bjj$ $\Big[$ Work in progress $\Big]$



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Channel of Study and Important Backgrounds

- We are considering leptonic decays of τ letpons here.
- Important backgrounds are,
  - $t\bar{t} + 2j$
  - $t\bar{t}W^{\pm}$ and $t\bar{t}Z$
  - $b\bar{b}jjW^{+}W^{-}$,
  - $b\bar{b}jj\tau^{+}\tau^{-}$

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Event Generation and Selection

- Madgraph (tree level) → Pythia8 → Delphes
- We apply minimal cuts to get a stable cross section for event generation at tree-level and later use K-factor to scale them to NLO.
- We extract events from the samples which follows,
  - $P_T(b, j) \geq$ 20 GeV
  - $|\eta(b)| \leq$ 4.7 , $|\eta(j)| \leq$ 2.5
  - $P_T(\ell) \geq$ 10 GeV, and two OS leptons ,$|\eta(\ell)|$ ≤2.5
  - $E_T \geq$ 25 GeV, $(\ell\ell, jj, bj, bb, \ell j, \ell b) \geq$ 0.4
  - $P_T(leading\ell) \geq 20$ GeV
  - We also apply b veto. Remove all the event having more than one b with $P_T \geq 20$ GeV and $|\eta| < 4.7$

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Event Selection

- To reconstruct Higgs mass we apply collinear approximation to reconstruct τ momenta.
- Under collinear approximation[5], $P_{\tau_i} = P_{\ell_i}/x_i$
- We only select those event which satisfy $0 \leq x_i \leq 1$ Where i = 1,2.

Signal ($\lambda_{tc} = 0.064$)	$t\bar{t}$+ 2j	$b\bar{b}jj\tau\tau$	$t\bar{t}W$	$b\bar{b}jjWW$	$t\bar{t}Z$
0.18	147.1	1.9	0.57	0.47	0.34

Table: Background and Signal cross sections in fb

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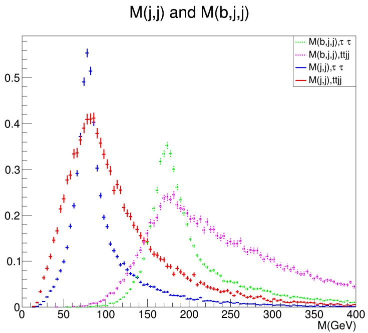
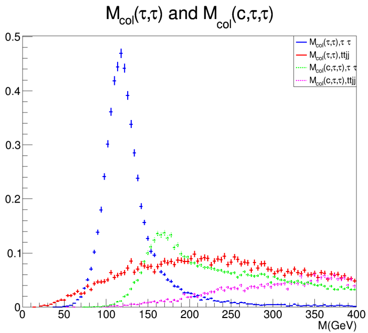
[5] Higgs decay to $\tau^+\tau^-$ a possible signature of intermediate mass higgs bosons at high energy hadron colliders. Nuclear Physics B, 297(2):221 – 243, 1988.

Training Variables





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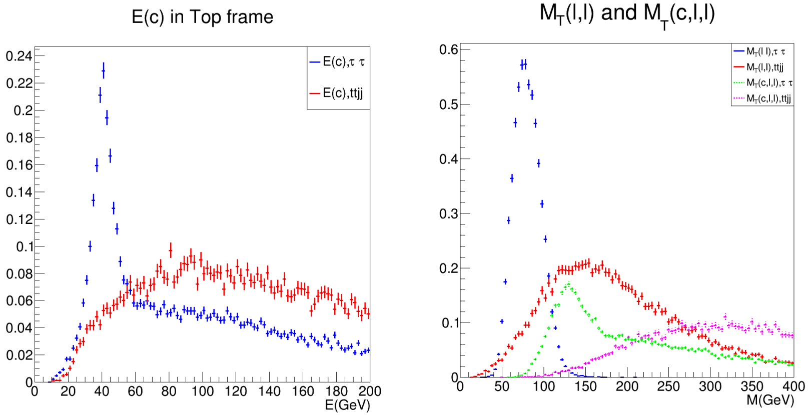
Training Variables



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Pre Selection cuts for Training

- As a case study we choose two sets of relaxed mass cuts, for Set-I,
  - $M(b, j_1, j_2) \leq$ 300 GeV and $M(j_1, j_2) \leq$ 150 GeV
  - $M(\ell, \ell) \leq$ 120 GeV and $M_T(\ell, \ell, E_T) \leq$ 180 GeV
  - $M_{col}(\tau, \tau) \leq$300 GeV and $M_{col}(c, \tau, \tau) \leq$ 400 GeV
  - Ec ≤ 120 GeV

Set-II is same, except for $M(\ell, \ell) \leq$ 100 GeV and $M_{j_1 j_2} \leq$ 120 GeV

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Process	After Selection Cuts	Set 1 Cuts	Set 2 Cuts
$t\bar{t}+$ 2j	147.1	12.9	9.3
$b\bar{b}jj\tau\tau$	1.9	0.51	0.47
$t\bar{t}W$	0.57	0.07	0.05
$b\bar{b}jjWW$	0.47	0.009	0.007
$t\bar{t}Z$	0.34	0.025	0.02
Total	150.4	13.6	9.9
Signal ($\lambda_{tc} = 0.064$)	0.18	9.5×10^{-2}	9×10^{-2}

Table: Cut flow for Background and Signal cross sections in fb

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Here we have used TMVA [6] for our BDT analysis,

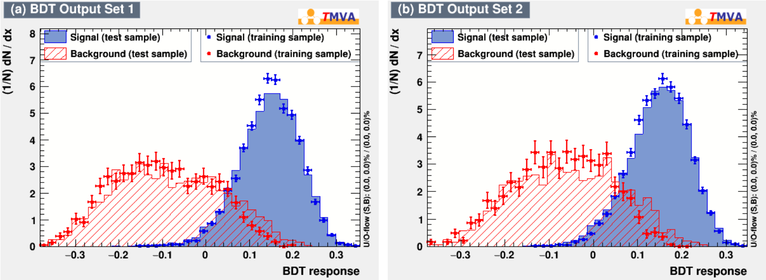

Figure: BDT discriminator from the two different Pre selection cuts

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[6] TMVA,arXiv:physics/0703039

Current Estimate of the Significance

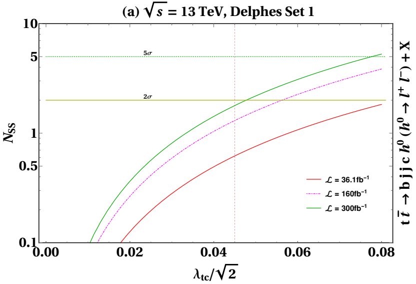

Figure: Preliminary Estimates of Significance

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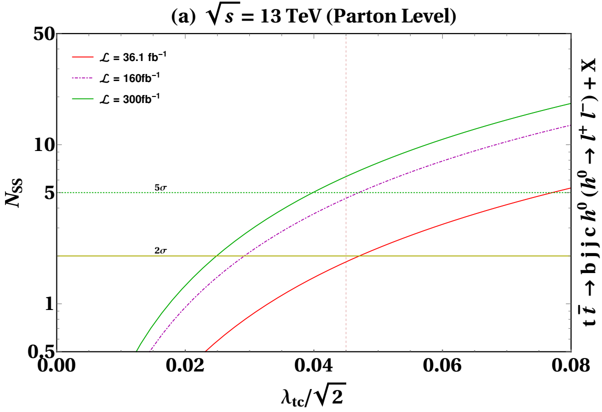
Discovery Potential at Parton Level



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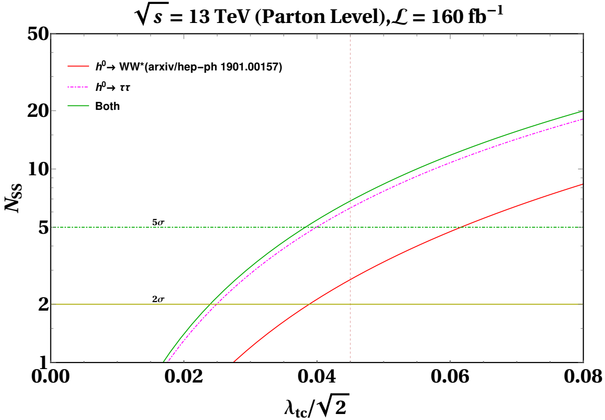
Discovery Potential at Parton Level



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Conclusion and Future Work

- FCNC's presents an exciting new physics channel to probe. If detected, can improve our understanding of the flavor structure of the nature.
- The $t \to ch^0$ also holds promising future. However the study we presented is limited for one τ decay modes. Including other decay modes for τ, can really improve the expectation for current and future hadron colliders.
- I have only presented estimates for 13 TeV, we are going to extend it to 14 and 27 TeV as well.
- Extra top coupling holds a very rich phenomenology, and In the future I would like work more on this, to find out what it can tell us about nature.

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thank
you!

Parton Level Mass cuts

- $|M(j_1, j_2) - m_W| \leq 0.15 \times m_W$ and $|M(b, j_1, j_2) - m_t| \leq 0.20 \times m_t$
- 40 GeV$\leq M_T(\ell, \ell, E_T)$ $\leq$140 GeV and 80 GeV $\leq M_T(c, \ell, \ell, E_T) \leq$ 180 GeV
- $|M_{col}(\tau, \tau) - m_h| \leq 0.35 \times m_h$ and $|M_{col}(c, \tau, \tau) - m_t| \leq 0.45 \times m_t$
- 32 GeV $\leq E_c \leq$ 52 GeV

Cross sections at Parton level

Process	SC	MRC
$t\bar{t}$+ 2j	617.76	0.96
$b\bar{b}jj\tau\tau$	4.32	0.06
$t\bar{t}W$	1.41	0.006
$b\bar{b}jjWW$	1.22	4.03×10^{-4}
$t\bar{t}Z$	0.76	3.3×10^{-4}
Total	625.5	1.03
Signal ($\lambda_{tc} = 0.064$)	0.51	0.39

Table: Cut flow for Background and Signal cross sections in fb