Estimate of ILC sensitivity to FCNC top decay $t \to ch$ at $\sqrt{s} = 500$ GeV

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Motivation

Large FCNC top decays expected in many BSM scenarios

Model	BR($t \to c\ h$)	BR($t \to c\ \gamma$)	BR($t \to c\ g$)	BR($t \to c\ Z$)
SM	$3 \cdot 10^{-15}$	$5 \cdot 10^{-14}$	$5 \cdot 10^{-12}$	10^{-14}
2HDM	10^{-5} - 10^{-4}	10^{-9}	10^{-8}	10^{-10}
2HDM (FV)	10^{-3} - 10^{-2}	10^{-6} - 10^{-7}	10^{-4}	10^{-6}
MSSM	10^{-5} - 10^{-4}	10^{-8} - 10^{-6}	10^{-7} - 10^{-4}	10^{-8} - 10^{-6}
$\not{R}$ SUSY	10^{-9} - 10^{-6}	10^{-9} - 10^{-5}	10^{-5} - 10^{-3}	10^{-6} - 10^{-4}
Little Higgs	10^{-5}	$1.3 \cdot 10^{-7}$	$1.4 \cdot 10^{-2}$	$2.6 \cdot 10^{-5}$
Quark Singlet	$4.1 \cdot 10^{-5}$	$7.5 \cdot 10^{-9}$	$1.5 \cdot 10^{-7}$	$1.1 \cdot 10^{-4}$
Randal-Sundrum	10^{-4}	10^{-9}	10^{-10}	10^{-3}

Please refer to my talk given on March 25, 2015.

Motivation

Decay $t \to c\ h$ in 2HDM is an interesting scenario:

- large enhancement both on tree and loop level
- well constrained kinematics
- seems to be most difficult for LHC

Limits on top FCNC decays from LHC (Moriond 2015):

$$
\begin{aligned}
BR(t \to qZ) &< 0.05\% \quad \text{(CMS)} \\
BR(t \to c\gamma) &< 0.18\% \quad \text{(CMS)} \\
BR(t \to u\gamma) &< 0.016\% \quad \text{(CMS)} \\
BR(t \to cg) &< 0.016\% \quad \text{(ATLAS)} \\
BR(t \to ug) &< 0.0031\% \quad \text{(ATLAS)}
\end{aligned}
$$

$$
\begin{aligned}
BR(t \to ch) &< 0.56\% \quad \text{(CMS, 20 fb}^{-1}\text{)} \\
BR(t \to ch) &< 0.79\% \quad \text{(ATLAS, 25 fb}^{-1}\text{)}
\end{aligned}
$$

Model

Dedicated implementation of 2HDM(III) prepared by Florian Straub.
Many thanks also due to Juergen Reuter and Wolfgang Kilian, for their help in solving different problems...

Test configuration of the model:

- $m_{h_1} = 125$ GeV
- $\mathrm{BR}(t \to c h_1) = 10^{-3}$
- $\mathrm{BR}(h \to b\bar{b}) = 100\%$

Generated samples at $\sqrt{s}$=500 GeV

- $e^+e^- \longrightarrow t\bar{t}$ (2HDM/SM)
- $e^+e^- \longrightarrow ch_1\bar{t},\ t\bar{c}h_1$ (2HDM)
- $e^+e^- \longrightarrow cb\bar{b}\bar{b}l^+\nu$ ... (SM)

Assume that we can select high purity $t\bar{t}$ sample
$\Rightarrow$ main background to FCNC decays from standard decay channels

All events generated with CIRCE1 spectra + ISR (2HDM problem solved)
Only t, W and h defined to be unstable. No hadronization/decays.
No generator-level cuts imposed.

Very simplified detector description

- detector acceptance for leptons: $|\cos\theta_l| < 0.995$
- detector acceptance for jets: $|\cos\theta_j| < 0.975$
- jet energy smearing:

$$\sigma_E = \begin{cases} \frac{30\%}{\sqrt{E}} & \text{for} \quad E < 100\,GeV \\ 3\% & \quad\quad E > 100\,GeV \end{cases}$$

- b tagging (misstagging) efficiencies: (LCFI+ presentation, Dec. 2013)

Scenario	b	c	uds
Ideal	100%	0%	0%
A	90%	30%	4%
B	80%	8%	0.8%
C	70%	2%	0.2%
D	60%	0.4%	0.08%

$t\bar{t}$ final state selection

"Signal" top: $t \rightarrow ch_1$ + higgs decay to $b\bar{b}$ $\Rightarrow$ 2 b tags
"Spectator" top: SM top decay $\Rightarrow$ 1 b tag

Considered final states (resulting from $W^{\pm}$ decay channels):

- semileptonic: 4 jets + lepton + missing p_t
- fully hadronic: 6 jets, no leptons, no missing p_t (new)

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Semileptonic:

- Missing $p_t > 20$ GeV
- Single lepton with $p_t > 15$ GeV
- 4 jets with $p_t > 15$ GeV
- 3 jets b-tagged

Fully hadronic:

- Missing $p_t < 10$ GeV
- No lepton with $p_t > 10$ GeV
- 6 jets with $p_t > 15$ GeV
- 3 jets b-tagged

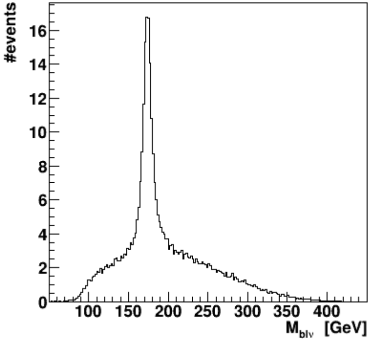
Top reconstruction

Try to group final state objects into two tops

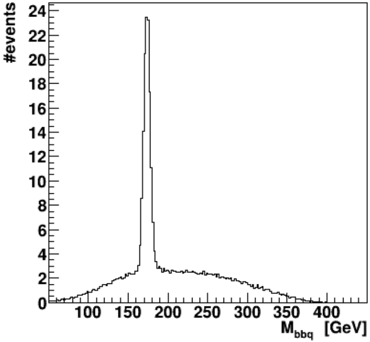
Check invariant mass distributions for all considered combinations

Semileptonic events (signal sample):

Semileptonic "spectator" top decay



Fully hadronic "signal" top decay



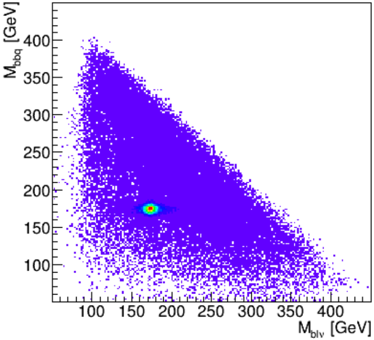
Top reconstruction

Try to group final state objects into two tops

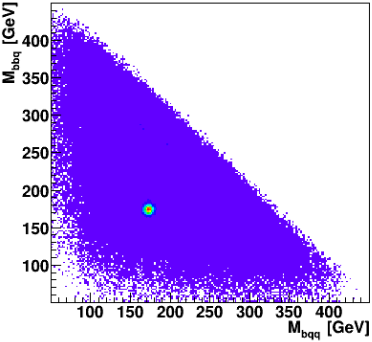
Check invariant mass distributions for all considered combinations

Proper combination can be easily identified

Semileptonic events



Fully hadronic events

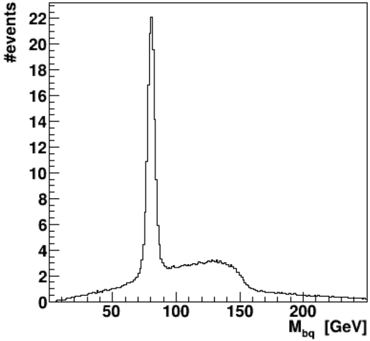


Signal selection

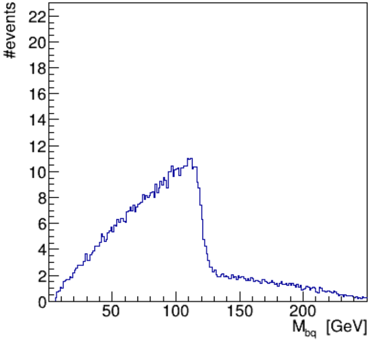
Cut based approach: $W^{\pm}$ veto

Irreducible SM background can be suppressed by reconstructing second W

Invariant mass of two jets from "signal" top - all bq combinations



$$e^+e^- \longrightarrow cb\bar{b}\bar{b}l^+\nu \text{ (SM)}$$

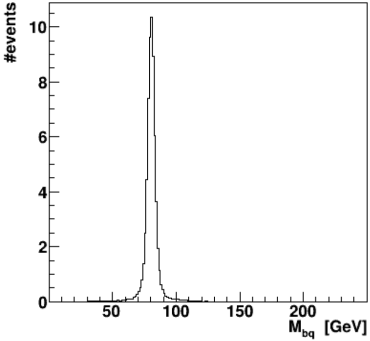


$$e^+e^- \longrightarrow ch_1\bar{t},\ t\bar{c}h_1 \text{ (2HDM)}$$

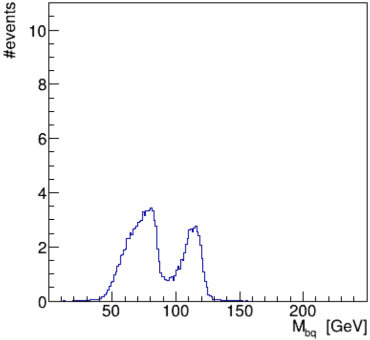
Cut based approach: $W^{\pm}$ veto

Irreducible SM background can be suppressed by reconstructing second W

Invariant mass of two jets from “signal” top - best background fit



$e^+e^- \longrightarrow cb\bar{b}\bar{b}l^+\nu$ (SM)

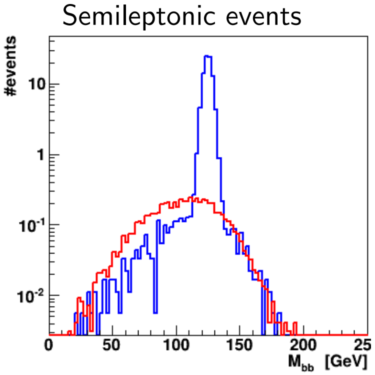


$e^+e^- \longrightarrow ch_1\bar{t},\ t\bar{c}h_1$ (2HDM)

Cut based approach: Higgs candidate events

$W^{\pm}$ veto used: events with $73.5 < M_{bq} < 87.3$ GeV rejected ($\pm 3\sigma$)

Invariant mass of two b-jets jets after $W^{\pm}$ veto: signal vs background



Look for events in the Higgs mass window...

Alternative approach - compare two hypothesis:

- background hypothesis

$$\chi^2_{bg} = \left(\frac{M_{bl\nu} - m_t}{\sigma_{t,lep}}\right)^2 + \left(\frac{M_{l\nu} - m_W}{\sigma_{W,lep}}\right)^2 + \left(\frac{M_{bbq} - m_t}{\sigma_{t,had}}\right)^2 + \left(\frac{M_{bq} - m_W}{\sigma_{W,had}}\right)^2$$

- signal hypothesis

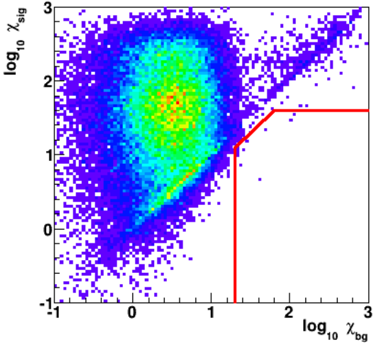
$$\chi^2_{sig} = \left(\frac{M_{bl\nu} - m_t}{\sigma_{t,lep}}\right)^2 + \left(\frac{M_{l\nu} - m_W}{\sigma_{W,lep}}\right)^2 + \left(\frac{M_{bbq} - m_t}{\sigma_{t,had}}\right)^2 + \left(\frac{M_{bb} - m_h}{\sigma_h}\right)^2$$

Independent search for best background and signal combinations

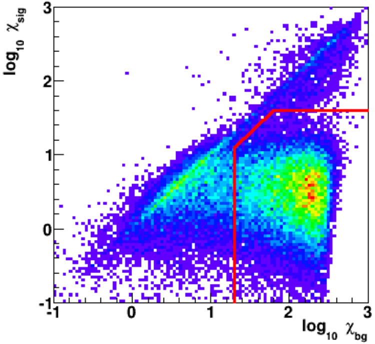
Hypothesis comparison

Correlation of $\log_{10}\chi^2$ for two hypothesis (cut used indicated)

SM background



Signal events

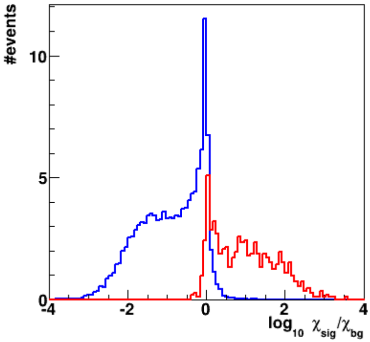


b-tagging scenario B

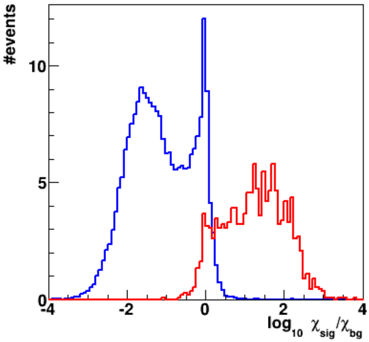
Hypothesis comparison

Difference of $\log_{10}\chi^2$ for two hypothesis: signal vs background

Semileptonic channel



Fully hadronic channel



Ideal *b*-tagging

Very efficient background rejection possible

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Difference of $\log_{10}\chi^2$ for two hypothesis: signal vs background

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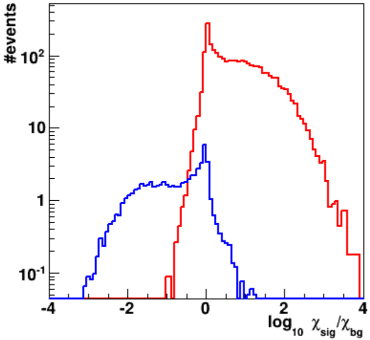

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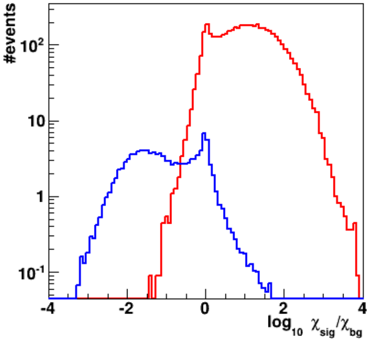

b-tagging scenario B

Very efficient background rejection possible

Expected events

For 500 fb^{-1}, assuming $BR(t \to ch) \times BR(h \to b\bar{b}) \approx 10^{-3}$ for signal

Semileptonic	Ideal b-tagging		Scenario B	
	$t\bar{t}$ (SM)	Signal	$t\bar{t}$ (SM)	Signal
All	268'000	548	268'000	548
Single lepton + $\not{p}_t$	102'000	149	102'000	149
4 jets	75'700	122	75'700	122
3 b-tags	64.3	122	2'480	61.3
W veto	6.4	88.8	25.7	45.4
h mass window	1.1*	82.5	4.1	39.7
χ^2 cut	0.82	67.7	0.89	32.5
h mass window	0.43*	64.9	0.71	30.8

* dominated by nonresonant bg.

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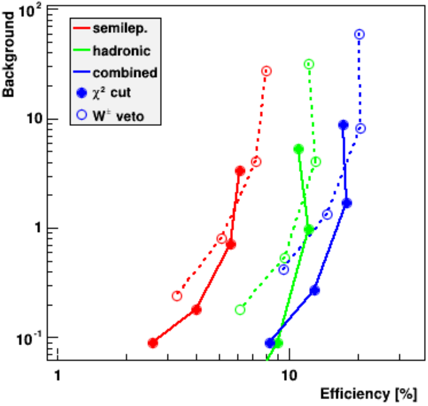
Fully hadronic	Ideal b-tagging		Scenario B	
	$t\bar{t}$ (SM)	Signal	$t\bar{t}$ (SM)	Signal
All	268'000	548	268'000	548
No leptons, no $\not{p}_t$	116'000	343	116'000	343
6 jets	73'200	237	73'200	237
3 b-tags	130.1	236	4'680	118
W veto	0.4	162	37.4	79.7
h mass window	0.1	154	4.1	71.7
χ^2 cut	< 0.3	152	1.3	70.2
h mass window	< 0.3	146	1.0	66.6

non-resonant contribution not included

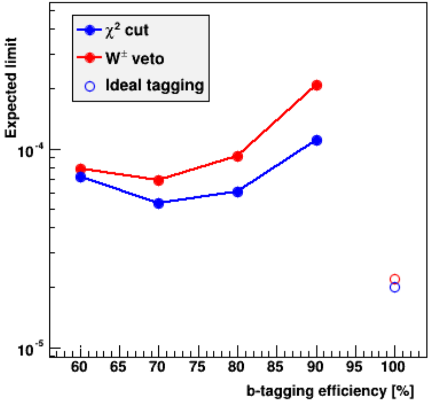
Selection efficiencies

Background level vs signal selection efficiency (including $W^{\pm}$ BRs)
for different *b*-tagging scenarios



Expected limits

Limits on $BR(t \to ch) \times BR(h \to b\bar{b})$ expected for 500 fb^{-1} from combined analysis (semileptonic+hadronic channels)



Summary

Estimate of sensitivity to $BR(t \to ch)$ based on parton level simulation

- only $t\bar{t}$ background considered
- no effects of hadronization/decays (τ, B...)
- very simplified description of detector effects
- final state reconstruction and b-tagging not optimized
- selection cuts not optizmized

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SM background can be very strongly suppressed using the available kinematic constraints $\Rightarrow$ irreducible background under control

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$\Rightarrow$ up to 50% of signal events look "background-like"

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Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$ reach $\sim 5 \cdot 10^{-5}$
$\sim 10^{-4}$ for $BR(t \to ch)$, assuming SM Higgs decays

Conclusions

FCNC decay $t \to c\ h$ should be measurable down to $BR \sim 10^{-4}$

Results have to be verified with full background and detector simulation.

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New requirements (to be optimized!):

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Background samples already generated for $t\bar{t}$ study can be used.
Large signal sample needs to be generated...