Study of FCNC top decay $t \to ch$: an update

Aleksander Filip Żarnecki

Faculty of Physics, University of Warsaw

ILD Analysis/Software Meeting
June 10, 2015

Large enhancement of 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}

For details see presentation at Analysis/Software Meeting on March 25th

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):

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

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

WHIZARD

Dedicated implementation of 2HDM(III) prepared by Florian Straub.
Many thanks are also due to Juergen Reuter and Wolfgang Kilian...

Test configuration of the model:

- $m_{h_1} = 125$ GeV
- $\mathrm{BR}(t \to ch_1) = 10^{-3}$
- $\mathrm{BR}(h \to b\bar{b}) = 100\%$

Generated samples

- $e^+e^- \longrightarrow t\bar{t}$ (2HDM/SM)
- $e^+e^- \longrightarrow ch_1\bar{t},\ t\bar{c}h_1$ (2HDM)
- $e^+e^- \longrightarrow cb\bar{b}\bar{t},\ t\bar{c}b\bar{b}$ (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
Only t, W and h defined to be unstable. No hadronization/decays.

For details see presentation at Analysis/Software Meeting on April 15th

Detector description

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

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

with S = 30% (presented previously) ⇒ also 50% and 80% [GeV$^{1/2}$]

- *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%

Signal selection

Main background to top FCNC decay $t \rightarrow ch$ from SM top decays.
Hadronic (6 jet) and semi-leptonic (4 jet + $l + \not{p}_T$) final states considered

Background reduction by comparison of two hypothesis:

- background

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

- signal

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

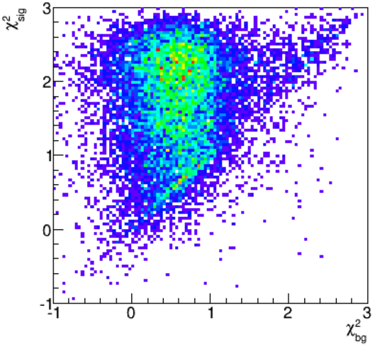
Width parameters depending on the assumed resolution and beam energy

Jet energy resolution

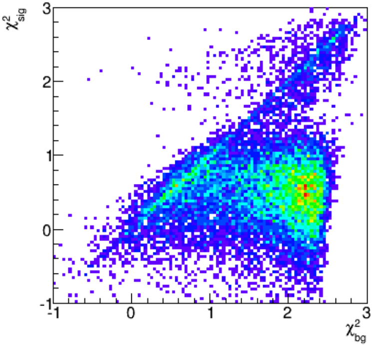
Correlation of $\log_{10}\chi^2$ for two hypothesis for hadronic events @ 500 GeV

Jet energy resolution 30%

SM background



Signal events

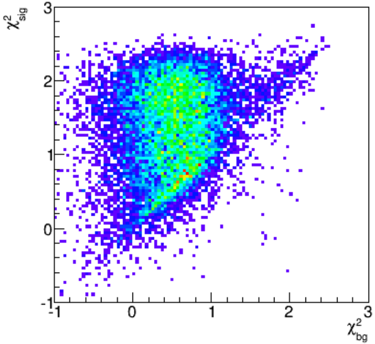


Jet energy resolution

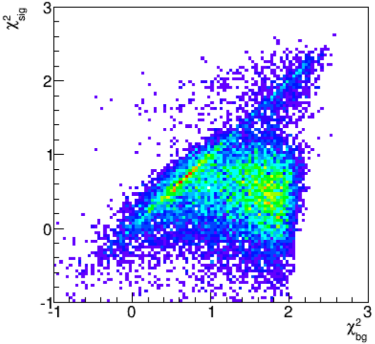
Correlation of $\log_{10} \chi^2$ for two hypothesis for hadronic events @ 500 GeV

Jet energy resolution 50%

SM background



Signal events

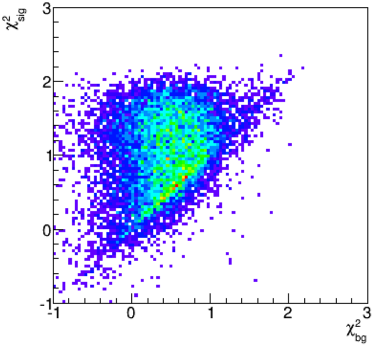


Jet energy resolution

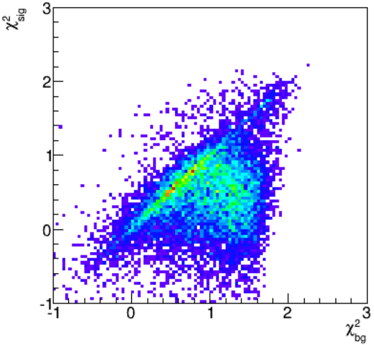
Correlation of $\log_{10}\chi^2$ for two hypothesis for hadronic events @ 500 GeV

Jet energy resolution 80%

SM background



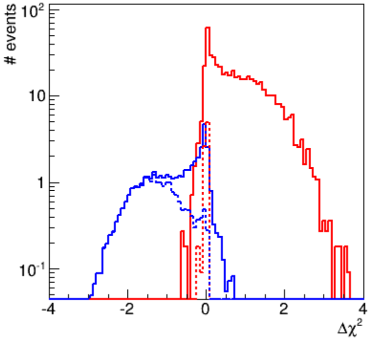
Signal events



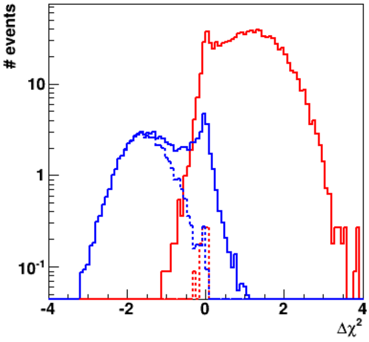
Difference of $\log_{10}\chi^2$ for two hypothesis, for signal and background events
Before (solid) and after (dashed) other selection cuts

Jet energy resolution 30%

Semi-leptonic events



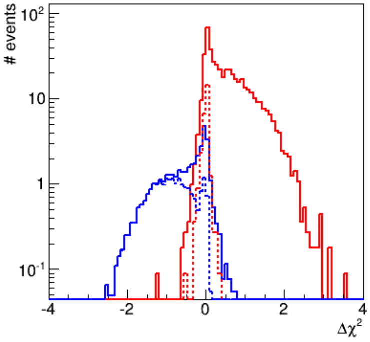
Fully hadronic events



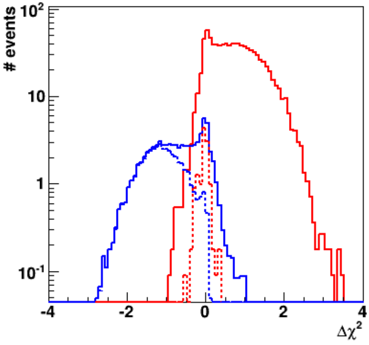
Difference of $\log_{10}\chi^2$ for two hypothesis, for signal and background events
Before (solid) and after (dashed) other selection cuts

Jet energy resolution 50%

Semi-leptonic events



Fully hadronic events

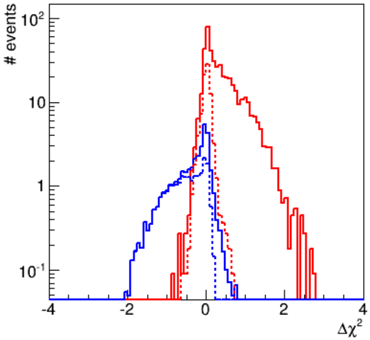


Jet energy resolution

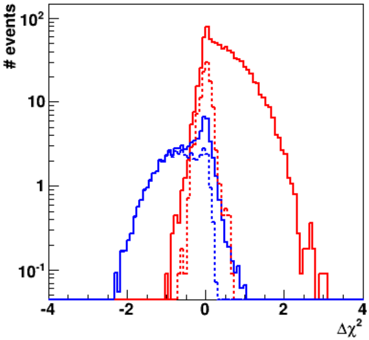
Difference of $\log_{10}\chi^2$ for two hypothesis, for signal and background events
Before (solid) and after (dashed) other selection cuts

Jet energy resolution 80%

Semi-leptonic events



Fully hadronic events

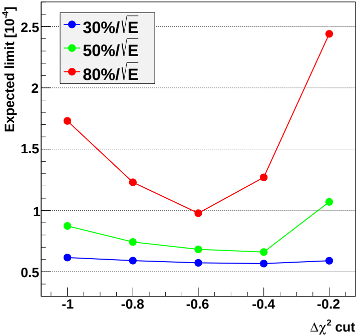


Signal - background separation still possible, but with decreasing efficiency

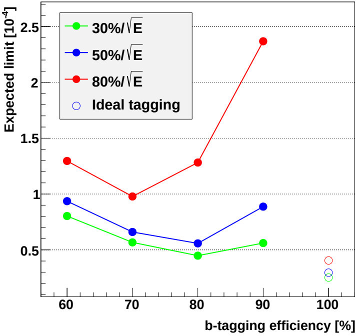
Jet energy resolution

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$
for 500 fb^{-1} @ 500 GeV and different jet energy resolutions assumed

For b-tagging efficiency of 70%



For optimized $\Delta\chi^2$ cut

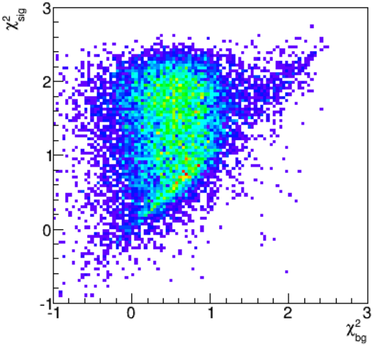


Worsening jet energy resolution $\Rightarrow$ tighter cuts & b-tagging required

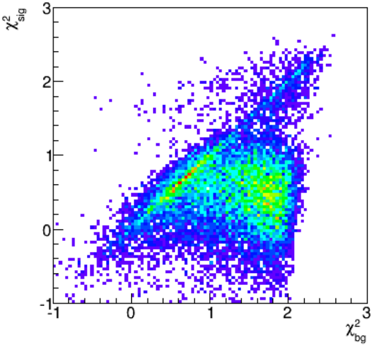
Correlation of $\log_{10} \chi^2$ for hadronic events, 50% resolution, 70% b-tagging

Collision energy 500 GeV

SM background



Signal events

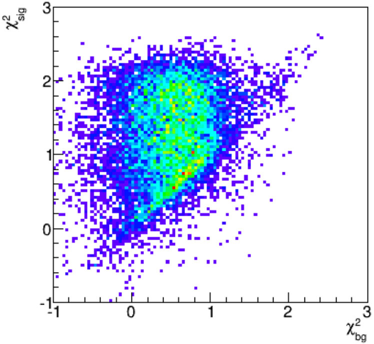


Collision energy

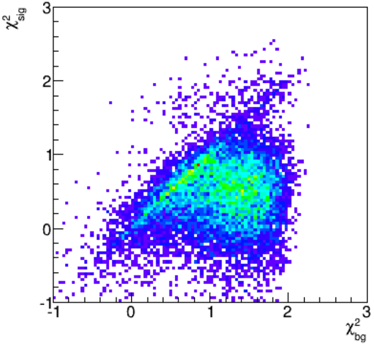
Correlation of $\log_{10} \chi^2$ for hadronic events, 50% resolution, 70% b-tagging

Collision energy 380 GeV

SM background



Signal events

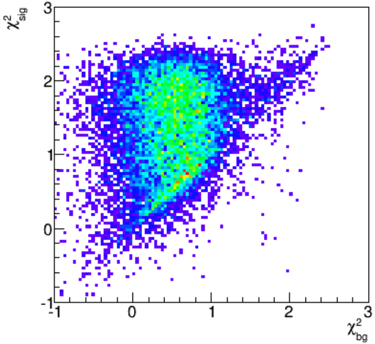


Collision energy

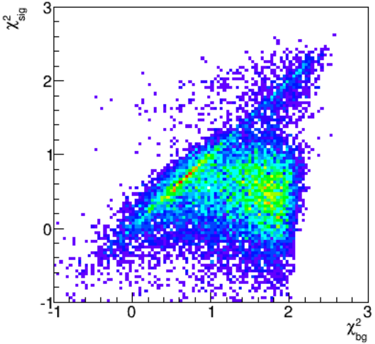
Correlation of $\log_{10}\chi^2$ for hadronic events, 50% resolution, 70% b-tagging

Collision energy 500 GeV

SM background



Signal events

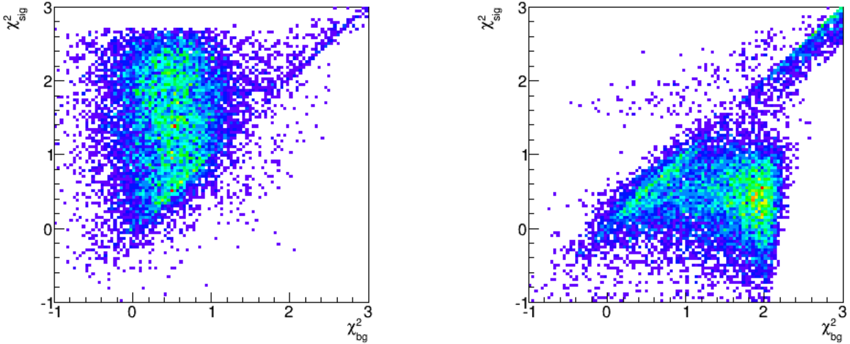


Correlation of $\log_{10}\chi^2$ for hadronic events, 50% resolution, 70% b-tagging

Collision energy 1000 GeV

SM background

Signal events

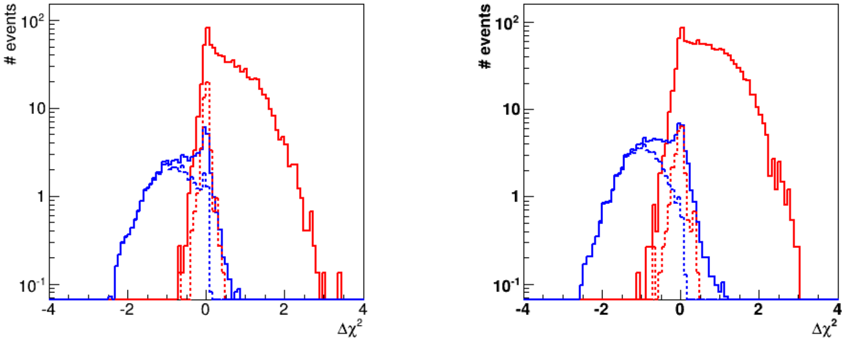


Collision energy

Difference of $\log_{10} \chi^2$ (signal - background) 50% resolution, 70% b-tagging
Before (solid) and after (dashed) additional selection cuts

Collision energy 380 GeV

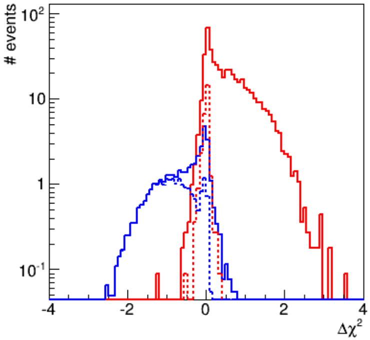
Semi-leptonic events | Fully hadronic events



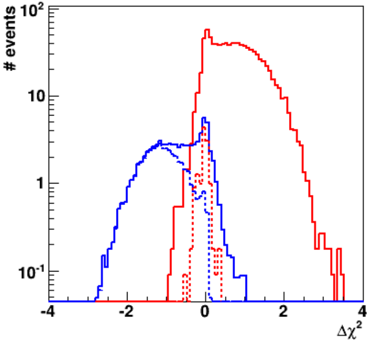
Difference of $\log_{10}\chi^2$ (signal - background) 50% resolution, 70% b-tagging
Before (solid) and after (dashed) additional selection cuts

Collision energy 500 GeV

Semi-leptonic events



Fully hadronic events

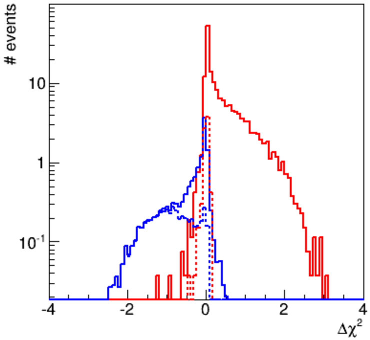


Collision energy

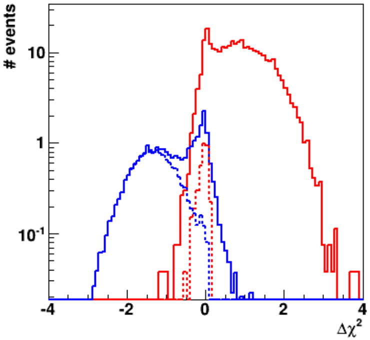
Difference of $\log_{10} \chi^2$ (signal - background) 50% resolution, 70% b-tagging
Before (solid) and after (dashed) additional selection cuts

Collision energy 1000 GeV

Semi-leptonic events



Fully hadronic events

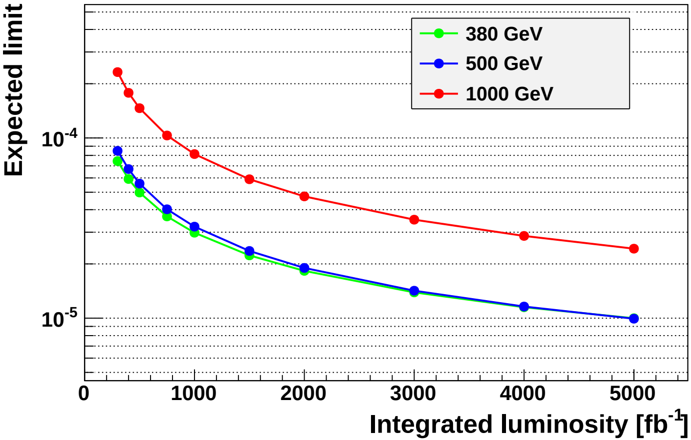


Signal - background separation improves slightly for hadronic events.
Visible loss of efficiency in semi-leptonic channel.

Collision energy and luminosity

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

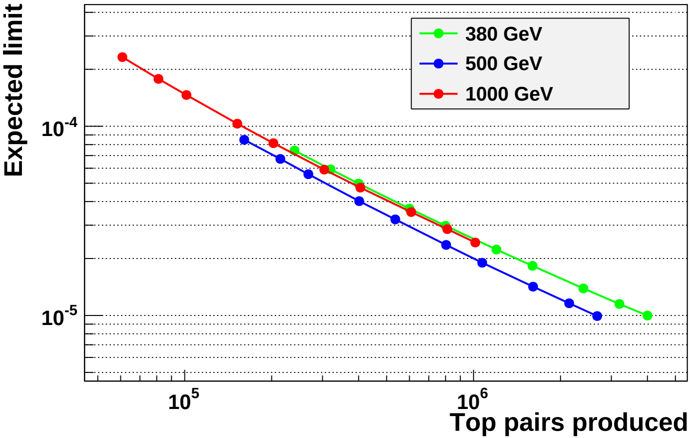
Jet energy resolution 50%



Collision energy and statistics

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

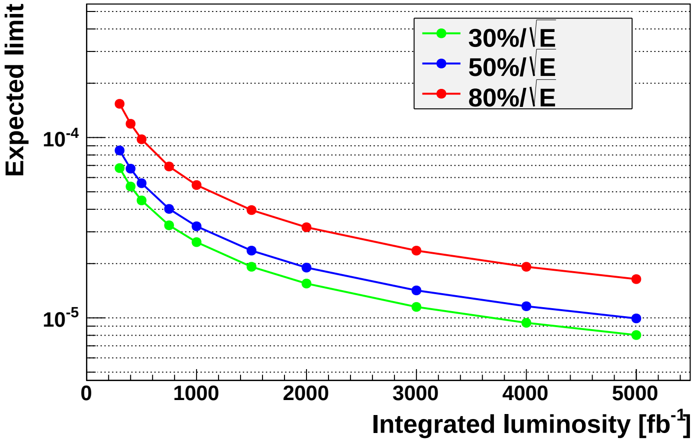
Jet energy resolution 50%



Jet energy resolution and luminosity

Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Collision energy 500 GeV



Conclusions

Measurement of FCNC top decays is statistics limitted.

In most cases, optimal selection cuts give less than 1 expected bg event.

Similar sensitivity at different collision energies,
expected limits depend mainly on the number of produced $t\bar{t}$ pairs...

Conclusions

Measurement of FCNC top decays is statistics limitted.
In most cases, optimal selection cuts give less than 1 expected bg event.

Similar sensitivity at different collision energies,
expected limits depend mainly on the number of produced $t\bar{t}$ pairs...

Selection efficiency strongly depends on the jet energy resolution.
At 500 GeV, $30\%/\sqrt{E}$ require 25% less luminosity than $50\%/\sqrt{E}$,
$80\%/\sqrt{E}$ require twice as much luminosity as $50\%/\sqrt{E}$ (for same limit)
Largest impact observed when running at 380 GeV

Conclusions

Measurement of FCNC top decays is statistics limitted.
In most cases, optimal selection cuts give less than 1 expected bg event.

Similar sensitivity at different collision energies,
expected limits depend mainly on the number of produced $t\bar{t}$ pairs...

Selection efficiency strongly depends on the jet energy resolution.
At 500 GeV, $30\%/\sqrt{E}$ require 25% less luminosity than $50\%/\sqrt{E}$,
$80\%/\sqrt{E}$ require twice as much luminosity as $50\%/\sqrt{E}$ (for same limit)
Largest impact observed when running at 380 GeV

Expected limits on $BR(t \to ch)$ below $\sim 10^{-4}$

Limits on $BR(t \to ch) \times BR(h \to b\bar{b})$, at 500 GeV, vary
from $\sim 10^{-4}$ for $80\%/\sqrt{E}$ jet energy resolution and 500 fb^{-1}
to $\sim 10^{-5}$ for $30\%/\sqrt{E}$ jet energy resolution and 3500 fb^{-1}

Limits scale with integrated luminosity approximately as $\mathcal{L}^{-0.8}$

Conclusions

Sensitivity to $BR(t \rightarrow ch)$ estimated with parton level simulation

- only $t\bar{t}$ background considered
- no effects of hadronization/decays (τ, B...)
- very simplified description of detector effects

Conclusions

Sensitivity to $BR(t \to ch)$ estimated with 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
- angurlar distributions not taken into account
- polarization not taken into account
- selection cuts not optizmized (except for $\Delta\chi^2$)

Sensitivity to $BR(t \to ch)$ estimated with 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
- angurlar distributions not taken into account
- polarization not taken into account
- selection cuts not optizmized (except for $\Delta\chi^2$)

Results are just estimates!

Conclusions

Sensitivity to $BR(t \to ch)$ estimated with 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
- angurlar distributions not taken into account
- polarization not taken into account
- selection cuts not optizmized (except for $\Delta\chi^2$)

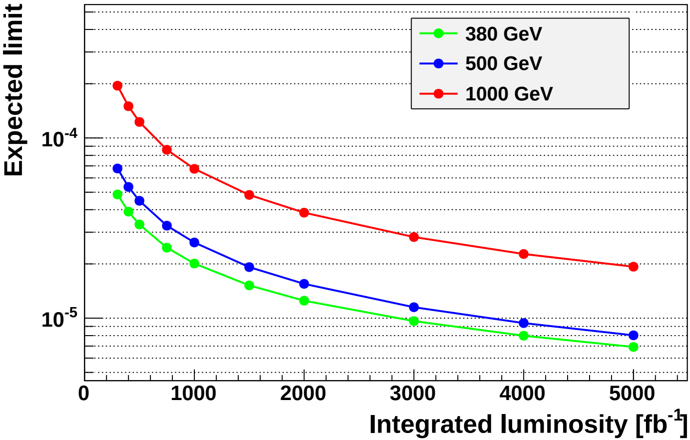
Results are just estimates!

Plans for the next months:

- Prepare signal event samples for full simulation
- Look at available $t\bar{t}$ and background samples
- Consider other decay channels

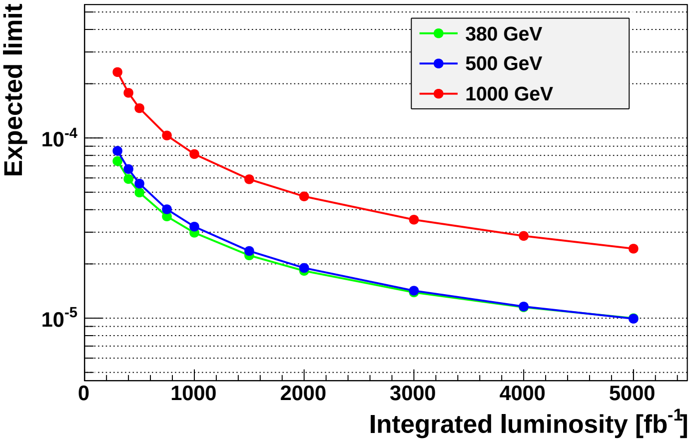
Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Jet energy resolution 30%



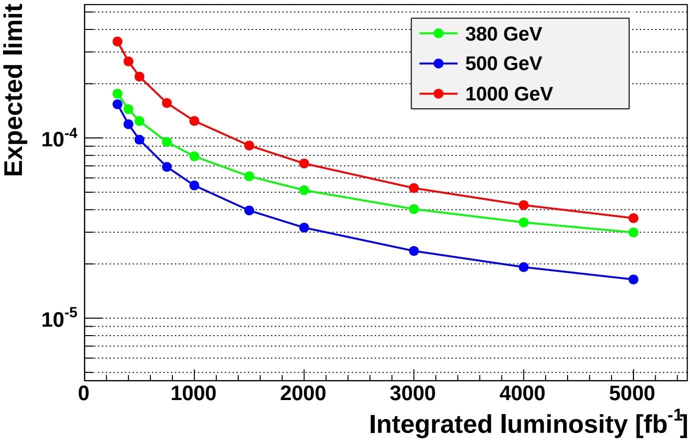
Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Jet energy resolution 50%



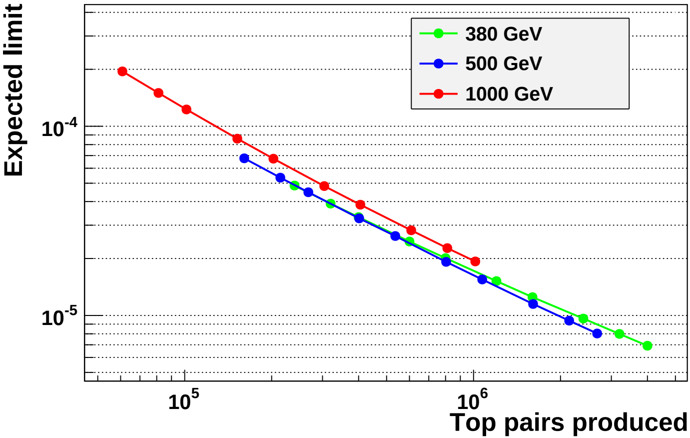
Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Jet energy resolution 80%



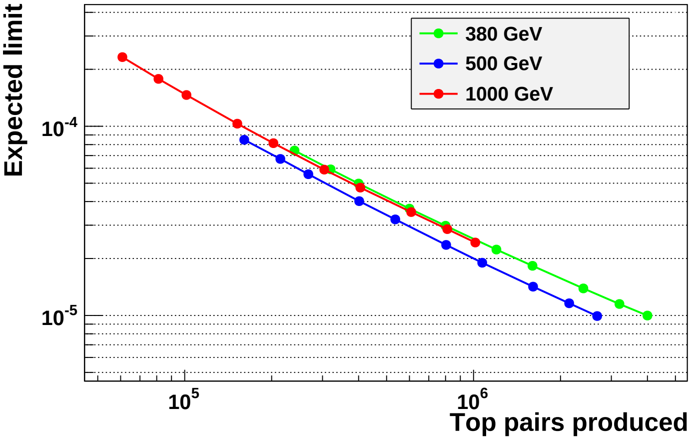
Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Jet energy resolution 30%



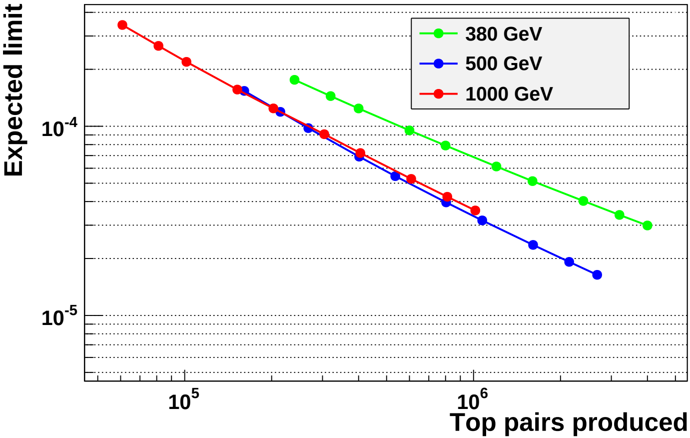
Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Jet energy resolution 50%



Expected limits on $BR(t \to ch) \times BR(h \to b\bar{b})$

Jet energy resolution 80%



Expected limit

Expected 95% C.L. limit on the number of signal events calculated as an average limit from multiple "background only" experiments, with number of observed events generated from Poisson distribution.