Top FCNC: preliminary studies in CMS

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Outline

- Why FCNC of top quark?
- The signal we would like to discover
- Relevant Backgrounds
- Analysis at Generator Level: useful variables
- Analysis at Generator Level: proposed strategy and acceptances
- Detectors simulations and foreseen efficiencies
- Guidelines for the near future
Top decays at LHC

- Top remains bare
  \( \Gamma(t) \gg \Lambda \), no time to hadronize before decay
- Top is heavy but point-like

- It provides clean information on hard process
- It can be the main actor in BSM physics

The only decay seen today:
\[ t \rightarrow W b \]
\( (\text{Br} > 99.9\%) \)

Flavour Changing Neutral Current:
\[ t \rightarrow A q, \]
where \( q = u, c \), \( A = Z, g, \gamma \)

GIM suppressed:
\[ A \approx SM \times \frac{m_b^2}{M_W^2} \]

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Introducing New Physics

- Introducing SUSY: significant increase in Br
- R-parity violating models in MSSM (with B non-conservation)
- Exotic (vector-like) quark

<table>
<thead>
<tr>
<th>FCNC decay</th>
<th>Br in SM</th>
<th>Br in SUSY</th>
<th>Br in R-parity violation</th>
<th>Exotic quark</th>
<th>Exp. limits (95% CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \rightarrow \gamma q$</td>
<td>$5 \times 10^{-13}$</td>
<td>$&lt;10^{-7}$</td>
<td>$&lt;10^{-5}$</td>
<td>$&lt;10^{-5}$</td>
<td>$&lt;0.003$ (HERA)</td>
</tr>
<tr>
<td>$t \rightarrow Zq$</td>
<td>$1.3 \times 10^{-13}$</td>
<td>$&lt;10^{-8}$</td>
<td>$&lt;10^{-4}$</td>
<td>$&lt;10^{-2}$</td>
<td>$&lt;0.08$ (LEP2)</td>
</tr>
<tr>
<td>$t \rightarrow g q$</td>
<td>$5 \times 10^{-11}$</td>
<td>$&lt;10^{-6}$</td>
<td>$&lt;10^{-3}$</td>
<td>$&lt;5 \times 10^{-4}$</td>
<td>$&lt;0.29$ (CDF)</td>
</tr>
</tbody>
</table>

$t \bar{t}$ are produced at a rate $\approx 10^6$/year at $10^{33}$/cm$^2$/s

$\rightarrow$ FCNC Br might reach a detectable level

ANY OBSERVATION AT LHC WILL BE A SIGNAL OF NEW PHYSICS
The Signal topology

$\bar{t} - \bar{t}$ production $\rightarrow \bar{t}$ decays SM, $t$ decays FCNC

Tops are almost back-to-back in the transverse plane

Try to find an excess of events over background in 150-200 GeV region
## Relevant Backgrounds

### On $t \bar{t} \rightarrow Zq$ Wb signal:

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma$ (pb)</th>
<th>comments</th>
<th>$\sigma \times Br$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \bar{t} \rightarrow WbWb$</td>
<td>830</td>
<td>LO+NLO+NNLO</td>
<td></td>
</tr>
<tr>
<td>$WW \rightarrow 2l$</td>
<td>$\sim 100$</td>
<td>NLO, CTEQ</td>
<td>4.9</td>
</tr>
<tr>
<td>$Z+\text{jets} \rightarrow 2l+\text{jets}$</td>
<td>12,528</td>
<td>$P_0=20$ GeV</td>
<td>830</td>
</tr>
<tr>
<td>$ZW \rightarrow 3l$</td>
<td>$\sim 19.5$</td>
<td>NLO, CTEQ</td>
<td>0.3</td>
</tr>
<tr>
<td>$ZZ \rightarrow 4l$</td>
<td>1.247</td>
<td>TeX, $P_0=20$ GeV</td>
<td>0.009</td>
</tr>
</tbody>
</table>

### On $t \bar{t} \rightarrow \gamma q$ Wb signal:

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<th>$\sigma$ (pb)</th>
<th>comments</th>
<th>$\sigma \times Br$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \bar{t} \rightarrow WbWb$</td>
<td>830</td>
<td>LO+NLO+NNLO</td>
<td>41</td>
</tr>
<tr>
<td>$W+c\bar{c} \rightarrow l\gamma$</td>
<td>1079</td>
<td>$M(c\bar{c}) &gt; 2m_c$</td>
<td>239.7</td>
</tr>
<tr>
<td>$W+\text{jets} \rightarrow l\gamma$</td>
<td>294</td>
<td>$M(b\bar{b}) &gt; 2m_b$</td>
<td>65.3</td>
</tr>
<tr>
<td>$\gamma \rightarrow l+\gamma$</td>
<td>56.21</td>
<td>$P_0=20$ GeV, CTEQ</td>
<td>12.5</td>
</tr>
<tr>
<td>$WW \rightarrow 2l$</td>
<td>$\sim 100$</td>
<td>NLO, CTEQ</td>
<td>4.9</td>
</tr>
<tr>
<td>$Z+\gamma \rightarrow 2l+\gamma$</td>
<td>46</td>
<td>$P_0=20$ GeV</td>
<td>3.0</td>
</tr>
</tbody>
</table>

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*FLAVOUR IN THE ERA OF THE LHC - Cern Workshop, 7th-10th November 2005*
A study for selection strategy

We present a preliminary study at Generator Level:

- identify quarks, leptons and γ by their MC code
- build real particle as W, Z and t
- analyze kinematical (p_T, η, etc.) and geometrical (ΔR, angles, etc) variables for signal and background
- define cuts in order to reject background
- estimate efficiencies of selections

Afterwards, efficiencies at generator level have to be convoluted with effects from detector simulation (reconstruction, b-tagging, misidentification etc.)

Actually:

- estimate number of signal and background events for a given integrated luminosity
- derive a Br(FCNC) upper limit

S and B are shown together, normalized to the same number
Rescaling for x-sections is performed only AFTER selection

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Z reconstruction

- cut events with leptons outside CMS acceptance: $|\eta| < 2.4$
- $p_T(l)$ cut can be quite soft
- cut on $\Delta R(l+l^-)$ can be useful: Z and W in background are produced back-to-back, so $\Delta R(l+l^-)$ is shifted to higher values
- a cut on invariant mass $91.19\pm10$ GeV results in a reduction of continuous background down to 3%

**Proposed strategy:**
- take two isolated, opposite signed and same flavour leptons cut $p_T(l) > 10$ (for $e$), 20 (for $\mu$) GeV/c,
  $|\eta| < 2.4$
- cut $\Delta R(l+l^-) < 2.0-2.5$
- cut on Z mass window

<table>
<thead>
<tr>
<th>Signal eff.</th>
<th>Relative purity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before $\Delta R(vl)$ cut</td>
<td>89%</td>
</tr>
<tr>
<td>After $\Delta R(vl)$ cut</td>
<td>53%</td>
</tr>
</tbody>
</table>

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Proposed strategy:

- take an isolated lepton with $p_T(l) > 20$ GeV/c, $|\eta| < 2.4$
- skip leptons used for Z
- choose $\text{MET} > 25-30$ GeV
- cut $\Delta R(l, v) < 2.3$

**N.B.** $p_Z(v)$ has two solutions, best solution has to be investigated case by case
**Light and b jet identification**

**b jet:**
- contribution to b spectrum mostly from ttbar background
- cut on p_T (b-jet) to reject others backgrounds
- apply b-tagging algorithm (as secondary vertex, impact parameter etc.)
- counting b jets can be very effective

**Light jet:**
- even at parton level, there is a significant fraction of light jets in all sample
- in real life, things are much more complicated (direct production, ISR, gluon splitting etc.)
- cut on p_T (light-jet) has to be high
- counting not-b jets can be very effective

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**Proposed strategy:**
- take an isolated jet with p_T (light-jet) > 20-40 GeV/c
- tag i.e. with σ > 2.0
- constrained it to be ONE and ONLY ONE

**Proposed strategy:**
- take an isolated jet with p_T (light-jet) > 40 GeV/c, |n| < 2.4
- constrained it to be ONE and ONLY ONE
Building $t_{SM}$ and $t_{FCNC}$

- $q-Z$ combinations from Zjets can be reduced by cutting on $\Delta R(qZ)$
- a cut on cone between lepton from $W$ and $Z$
  $\Delta R(lZ) > 1.5 \div 2$ could improve selection of $W-Z$ opposite in transverse plane

→ In analysis, keep $\Delta R(l-jet) > 0.5$ to avoid $l \leftarrow b,c$ jets

**Proposed strategy:**
- take the reconstructed and selected $b$ and $q$ jet
- take the reconstructed $W, Z$ or $\gamma$
- choose a $p_z (v)$ solution (the one minimizing $|M(Wb)|-175$ is a good choice)

→ A cut on $\cos \phi(\bar{t} t) < -0.9 \div -0.95$ strongly suppress $ZW, WW$ and Zjets backgrounds
### Final efficiency selection

<table>
<thead>
<tr>
<th>Selections</th>
<th>SIGNAL</th>
<th>$t\bar{t}$</th>
<th>$ZZ$</th>
<th>$ZW$</th>
<th>$WW$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z selection</td>
<td>0.44</td>
<td>0.03</td>
<td>0.25</td>
<td>0.25</td>
<td>0.40</td>
</tr>
<tr>
<td>$xW$ selection</td>
<td>0.15</td>
<td>0.01875</td>
<td>0.025</td>
<td>0.052</td>
<td>0.024</td>
</tr>
<tr>
<td>$xb$ selection</td>
<td>0.14</td>
<td>0.01725</td>
<td>0.0005</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$xq$ selection</td>
<td>0.1151</td>
<td>17 $10^{-5}$</td>
<td>0.0001</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Even without rescaling for $x$-sections, we see that $t\bar{t}$ is the only relevant background.
Introducing CMS simulation

Full/Fast simulations tool are under development
- reconstruct tracks using combinatorial Track-finder
- identify isolated muons and electrons
- match tracks with clusters in ECAL
  ➔ *a lepton reconstruction efficiency is introduced*

- build jets using an Iterative Cone Algorithm
- implement a b-tag algorithm (Combined BTag)
  ➔ *a b-tagging efficiency and a mis-tagging are introduced*

- evaluate missing $E_T$ from jets in calorimeters
  ➔ *missing $E_T$ has a finite resolution*

Fast simulation package includes Pile-up tuning for high luminosity studies
Reconstruction Efficiency

**Lepton reconstruction:**
- Efficiency for $\mu$ is high (90-95%, see e.g. CMS Note 2001-054)
- For $e$, many parameters have to be optimized ($E/p$, $E_h/E_e$, $\gamma$ conversions, match between TK and ECAL etc.): ~80% in preliminary studies

**Jet reconstruction:**
- B-tagging capabilities significantly reduce efficiency: 40-50% in 100 GeV region if we want to contain mis-tagging under 2% (CMS Note 2002-046)

**Trigger efficiency:**
- Very high (99% in CMS Note 2001-001)

**High luminosity effects:**
- Pile-up rises to 23 evs at $10^{34} \text{cm}^{-2}\text{s}^{-1}$
- First studies with this scenario seem promising (no extra tracks or efficiency decrease)

<table>
<thead>
<tr>
<th>Expected signal efficiency</th>
<th>3-5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected surviving $t\bar{t}$ events @ 100 fb$^{-1}$</td>
<td>220÷310</td>
</tr>
</tbody>
</table>
An evidence for a \( t \to Zq \) can be claimed at \( 5\sigma \) (99% CL) if:

\[
\frac{S}{\sqrt{S+B}} > 5
\]

An FCNC signal with branching ratio \( \text{Br}_{\text{UPPER}}(\text{FCNC}) \) is given by:

\[
S = \sigma (t \bar{t}) \text{Br}(W \to \nu l) \text{Br}(Z \to ll) \times 2 \times \int L \, dt \times \varepsilon \times \text{Br}_{\text{UPPER}}(\text{FCNC})
\]

with \( \int L \, dt \) integrated luminosity and \( \varepsilon \) selection efficiency.

<table>
<thead>
<tr>
<th>Expected signal efficiency: 3-5%</th>
<th>10 fb(^{-1})</th>
<th>100 fb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected ( t \bar{t} ) events</td>
<td>22±31</td>
<td>220±310</td>
</tr>
<tr>
<td>Expected ( S )</td>
<td>39±43</td>
<td>88±101</td>
</tr>
<tr>
<td>Expected ( \text{Br}_{\text{UPPER}}(\text{FCNC}) )</td>
<td>((5.3 \div 11.4) \times 10^{-4})</td>
<td>((2.0 \div 4.1) \times 10^{-4})</td>
</tr>
</tbody>
</table>

significant improvement to existent limit - close to exotic models predictions
Conclusion and outlook

Two groups are working on top FCNC inside CMS community. Parallel work is performed, analyzing both $t \rightarrow qZ$ and $t \rightarrow q\gamma$ signals. Fast and full simulations results are regularly compared.

At the present, quite promising results:
- large statistic of signal and background is under production
- signal is clearly understood and quite clean selections are defined
- nice agreement in full/fast comparison in most variables ($p_T, \eta, \cos$ etc.)

To do in the very next future:
- several optimization needed: $b$-tagging algorithms, light jet mistagging etc.
- increase statistic as much as possible to approach to a HL environment
- include study of effect of systematics uncertainties (pile-up, UE, jet fragmentation, PDF etc, see CMS Note 2005-013)
- include full simulation in all analyses
- CMS official results with full simulation and systematics will be ready by April 2006

...Intensive work is ongoing!