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

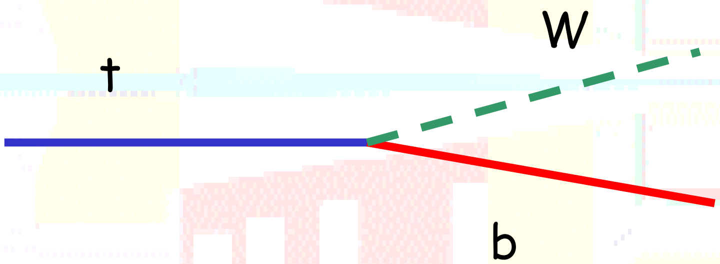
- Top remains bare

$\Gamma(t) >> \Lambda$, no time to hadronize before decay

- Top is heavy but point-like

→

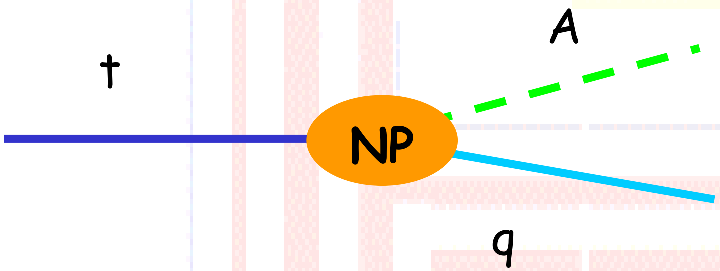
- it provides clean information on hard process
- it can be the main actor in BSM physics



The only decay seen today:

$t \to W\, b$

(Br > 99.9%)



Flavour Changing Neutral Current :

$t \to A\, q$,

where $q = u, c$, $A = Z, g, \gamma$

GIM suppressed: $A \approx SM \times m_b^2/M_W^2$

Introducing New Physics

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

- Exotic (vector-like) quark

FCNC decay	Br in SM	Br in SUSY	Br in R-parity violation	Exotic quark	Exp. limits (95% CL)
$t \to \gamma q$	$5\ 10^{-13}$	$<10^{-7}$	$<10^{-5}$	$<10^{-5}$	< 0.003 (HERA)
$t \to Zq$	$1.3\ 10^{-13}$	$<10^{-8}$	$<10^{-4}$	$<10^{-2}$	< 0.08 (LEP2)
$t \to g\,q$	$5\ 10^{-11}$	$<10^{-6}$	$<10^{-3}$	$<5\ 10^{-4}$	< 0.29 (CDF)

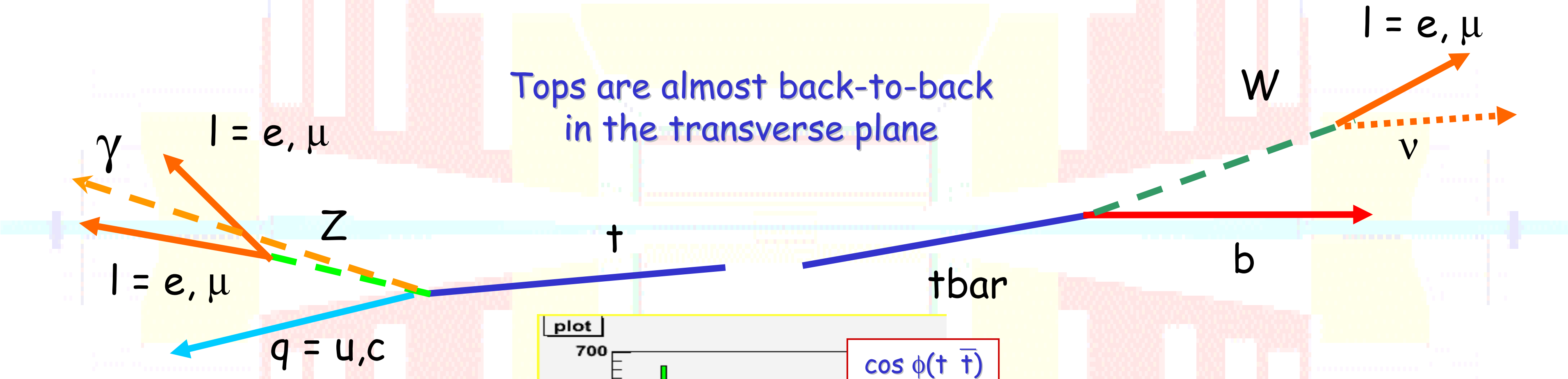
$t\ \bar{t}$ are produced at a rate $\approx 10^6$/year at $10^{33}/cm^2/s$

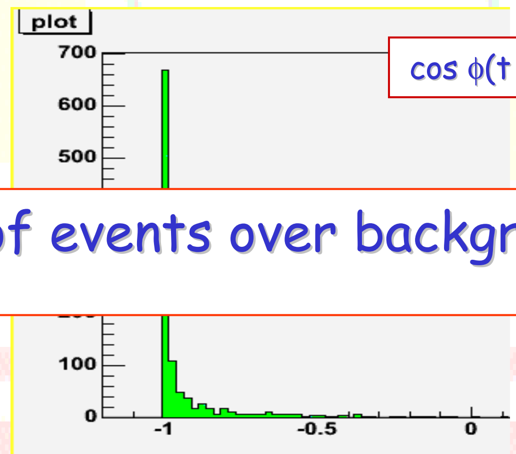
$\to$ FCNC Br might reach a detectable level

ANY OBSERVATION AT LHC WILL BE A SIGNAL OF NEW PHYSICS

The Signal topology

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





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

Relevant Backgrounds

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

Process	σ (pb)	comments	σ x Br (pb)
$t\bar{t} \rightarrow WbWb$	830	LO+NLO+NNLO	[illegible]
$WW \rightarrow 2l$	~100	NLO, CTEQ	4.9
Z+jets→ 2l+jets	12,528	P_0=20 [illegible]	830
$ZW \rightarrow 3l$	~19.5	[illegible]TEQ	0.3
$ZZ \rightarrow 4l$	1.247	[illegible]eX, P_0=20 GeV	0.009

GENERATED WITH PYTHIA AND TOPREX @ LO

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

$t\bar{t} \rightarrow WbWb$	[illegible]30	LO+NLO+NNLO	41
$W+c\bar{c} \rightarrow l$[illegible]	1079	$M(c\bar{c}) > 2m_c$	239.7
W+b[illegible]jets	294	$M(b\bar{b}) > 2m_b$	65.3
[illegible]$\gamma \rightarrow l+\gamma$	56.21	P_0=20 GeV, CTEQ	12.5
$WW \rightarrow 2l$	~100	NLO, CTEQ	4.9
$Z+\gamma \rightarrow 2l+\gamma$	46	P_0=20 GeV	3.0

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:

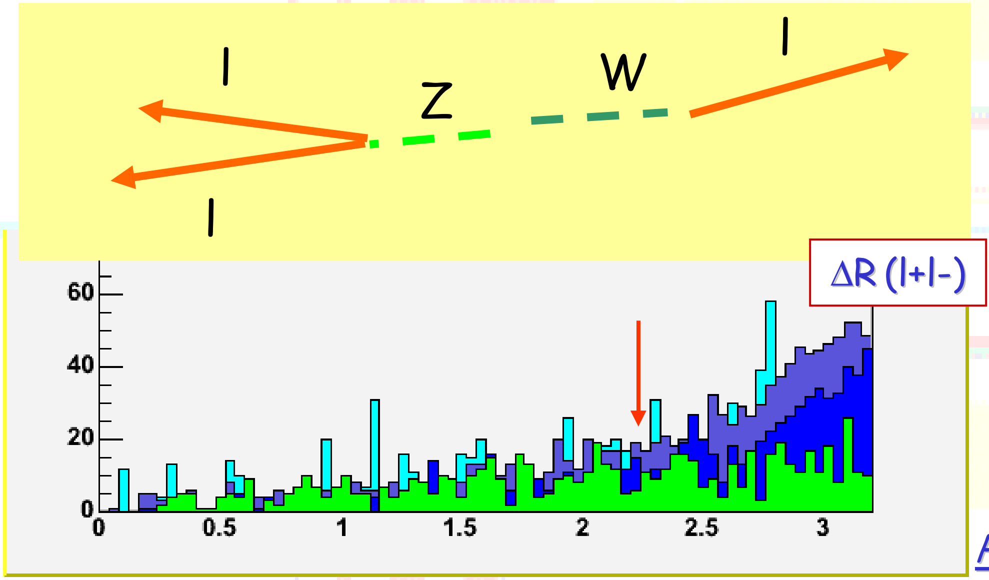
- estimate number of signal and background events for a given integrated luminosity
- derive a Br(FCNC) upper limit

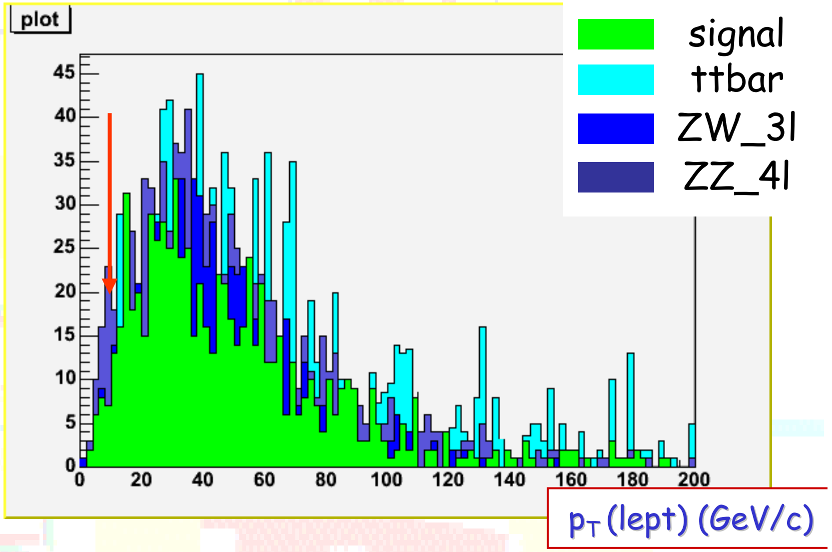
S and B are shown together, normalized to the same number

Rescaling for x-sections is performed only AFTER selection

Z reconstruction

- cut events with leptons outside CMS acceptance : $|\eta| < 2.4$
- p_T (l) cut can be quite soft
- cut on ΔR(l+l-) can be useful: Z and W in background are produced back-to-back, so ΔR(l+l-) is shifted to higher values





	Signal eff.	Relative purity
Before ΔR(νl) cut	89%	1
After ΔR(νl) cut	53%	3.1

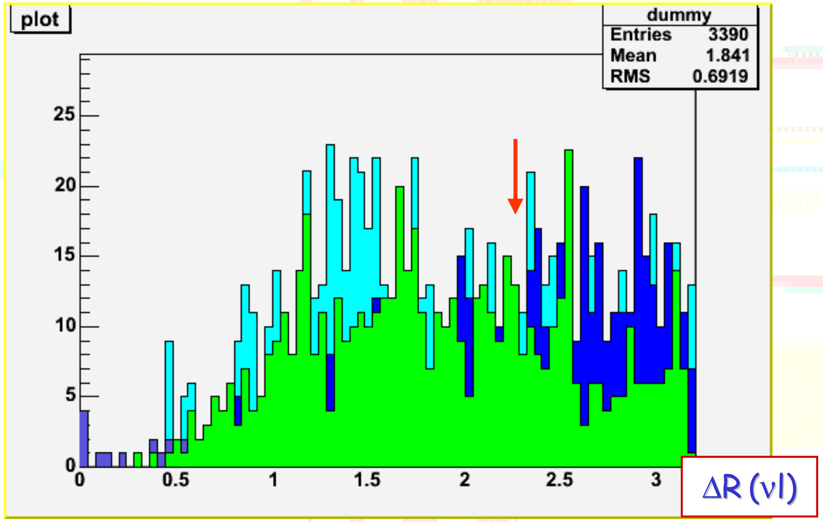
- a cut on invariant mass 91.19±10 GeV results in a reduction of continuous background down to 3%

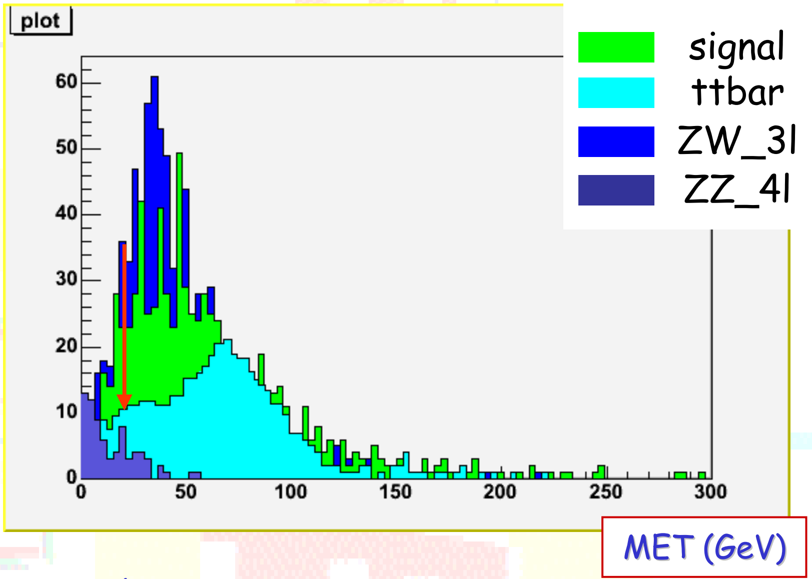
Proposed strategy:

- take two isolated, opposite signed and same flavou leptons cut p_T (l) > 10 (for e), 20 (for μ) GeV/c, $|\eta| < 2.4$
- cut ΔR(l+l-) < 2.0-2.5
- cut on Z mass window

W reconstruction

- cut events with leptons outside CMS acceptance : $|\eta| < 2.4$
- missing E_T (l) not less than 25 GeV to reduce ZZ and Zjets
- upper cut to missing E_T (l) cannot be performed
- cut on $\Delta R(\nu l)$ less effective wrt Z case





	Signal eff.	Relative purity
Before $\Delta R(\nu l)$ cut	79%	1
After $\Delta R(\nu l)$ cut	55%	1.8

Proposed strategy:

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

N.B. $p_Z(\nu)$ has two solutions, best solution has to be investigated case by case

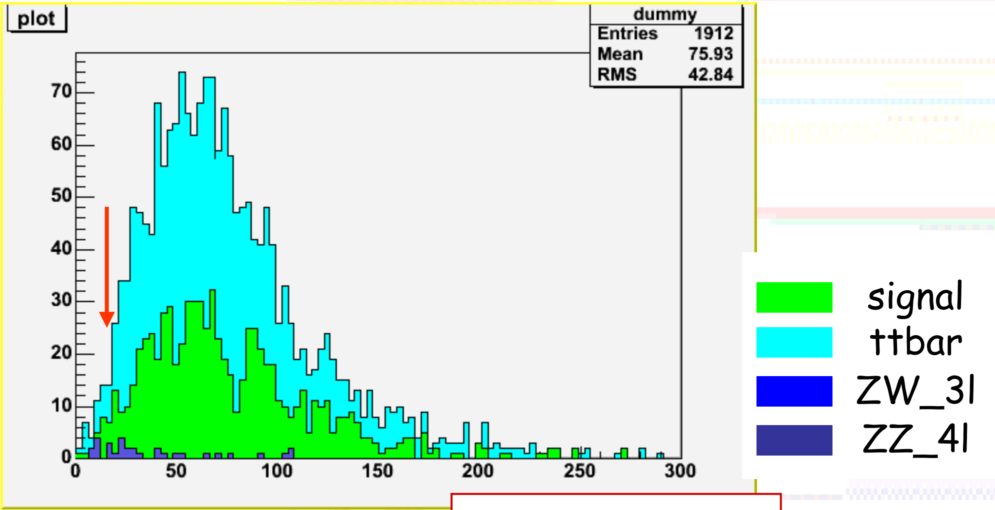
Light and b jet identification

b jet:

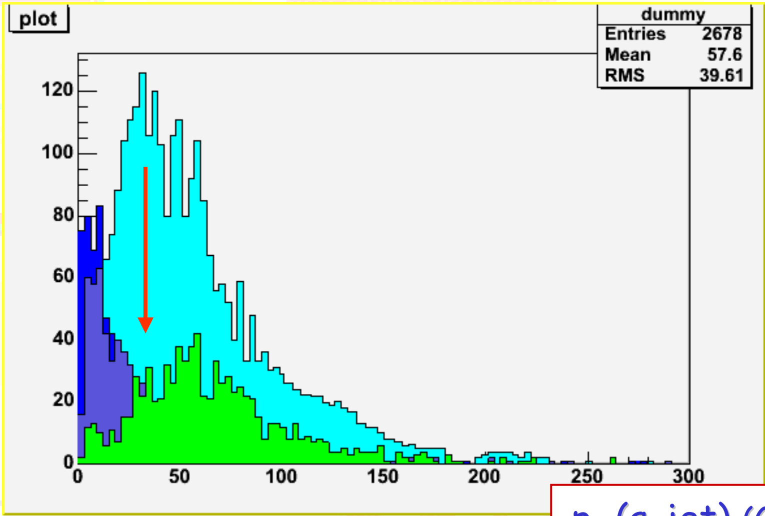
- contribution to b spectrum mostly from ttbar background
- cut on p_T (b-jet) to reject others backgrounds
- apply b-tagging algorithm (as secondary vertex, impact parameter etc.)
- counting b jets can be very effective

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



p_T (b-jet) (GeV/c)



p_T (q-jet) (GeV/c)

Proposed strategy:

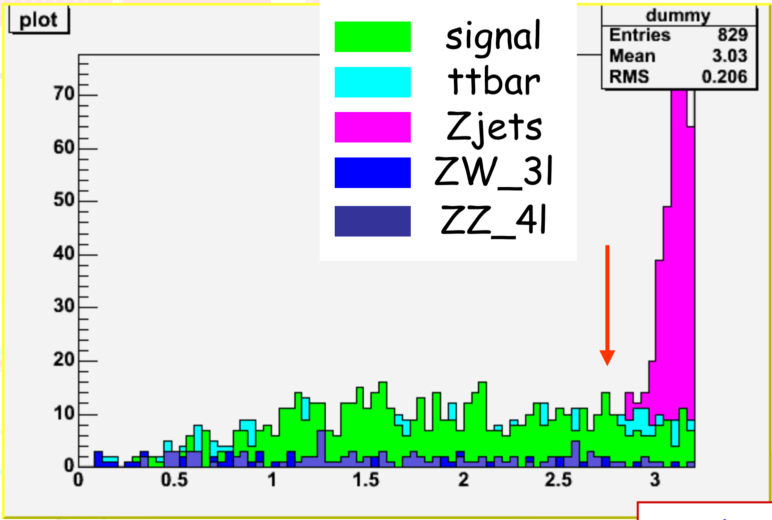
- take an isolated jet with p_T (light-jet) > 20-40 GeV/c
- tag i.e. with σ > 2.0
- constrained it to be ONE and ONLY ONE

Proposed strategy:

- take an isolated jet with p_T (light-jet) > 40 GeV/c, $|\eta|$ < 2.4
- constrained it to be ONE and ONLY ONE

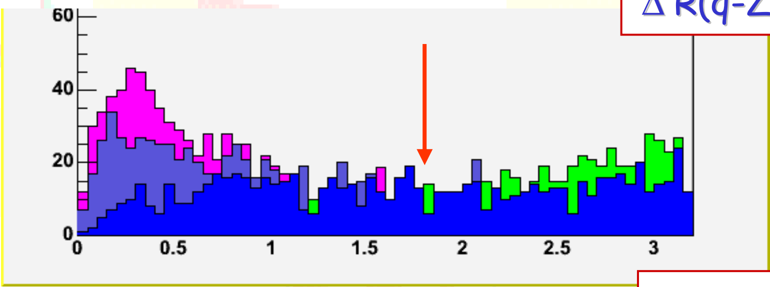
Building t_{SM} and t_{FCNC}

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



Δ R(q-Z)

→ *In analysis, keep ΔR(l-jet) > 0.5 to avoid l ← b,c jets*



Δ R(l-Z)

Proposed strategy:

- take the reconstructed and selected b and q jet
- take the reconstructed W, Z or γ
- choose a p_z (ν) solution (the one minimizing |M(Wb)-175| is a good choice)

→ *A cut on cosϕ(t $\bar{t}$) < -0.9 ÷-0.95 strongly suppress ZW, WW and Zjets backgrounds*

Final efficiency selection

Selections	SIGNAL	ttbar	ZZ	ZW	WW
Z selection	0.44	0.03	0.25	0.25	0.40
x W selection	0.15	0.01875	0.025	0.052	0.024
x b selection	0.14	0.01725	0.0005	0	0
x q selection	0.1151	17 10^{-5}	0.0001	0	0

Even without rescaling for x-sections, we see that ttbar 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 resolutions*

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

Reconstruction Efficiency

Lepton reconstruction :

➢ efficiency for μ 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, γ 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)

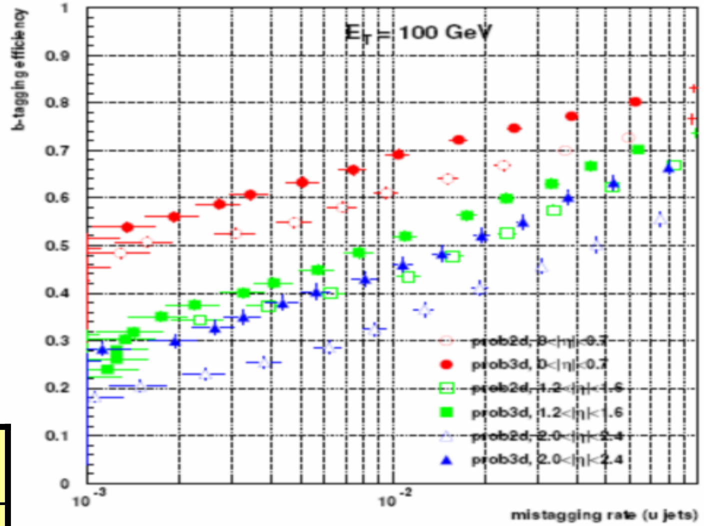
Trigger efficiency :

➢ very high (99% in CMS Note 2001-001)

High luminosity effects :

➢ Pile-up rises to 23 evs at $10^{34} cm^{-2} s^{-1}$

First studies with this scenario seem promising (no extra tracks or efficiency decrease)



Expected signal efficiency	3-5%
Expected surviving $t\bar{t}$ events @ 100 fb^{-1}	220÷310

Estimated Br_{FCNC} sensitivity

An evidence for a $t \to Zq$ can be claimed at 5σ (99% CL) if:
$S/\sqrt{(S+B)} > 5$

An FCNC signal with branching ratio $Br_{UPPER}(FCNC)$ is given by:

$$S = \sigma(t\bar{t})\ Br(W \to \nu l)\ Br(Z \to ll) * 2 * \int \mathcal{L}dt * \varepsilon * Br_{UPPER}(FCNC)$$

with $\int \mathcal{L}dt$ integrated luminosity and ε selection efficiency

Expected signal efficiency: 3-5%	$10\ fb^{-1}$	$100\ fb^{-1}$
Expected $t\bar{t}$ events	22÷31	220÷310
Expected S	39÷43	88÷101
Expected $Br_{UPPER}(FCNC)$	$(5.3 \div 11.4)\ 10^{-4}$	$(2.0 \div 4.1)\ 10^{-4}$

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→ qZ and t→ qγ signal. 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,η, 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!