Study of Top Quark Rare Decays Via FCNC at LHC

L.Chikovani
Institute of Physics of GAS, Tbilisi

T.Djobava
High Energy Physics Institute of Tbilisi State University

T.Grigalashvili
Institute of Physics of GAS, Tbilisi

Introduction

- **LHC can be considered as a "top factory", producing about 10^8 $t\bar{t}$ pair per year at luminosity L=100 fb^{-1} .**
- **The decays (FCNC) $t \to Zq$ (q=u,c), $t \to Hq$ (q=u,c) is strongly suppressed (loop suppression, heaviness of gauge bosons) in SM. The SM predicts :**

  $Br(t \to Zq) \sim 1.3 \times 10^{-13}$

  $Br(t \to Hq) \sim 0.9 \times 10^{-13}$ (4×10^{-15}) for m_H = 100(160) GeV

- **Observation of significantly larger Br's will be a clear signal of new physics (new dynamical interactions of top quark, multi-Higgs doublets, exotic fermions or other possibilities).**
- **The recent theoretical (MSSM, 2HDM II, Technicolor TC2) estimations:**

  $Br(t \to Zq) \sim 10^{-5} \div 10^{-4}$

  (J.Yang, B..L.Young and X.Zhang, Phys Rev., D58 (1998) 055001)

  $Br(t \to Hq) \leq 5 \times 10^{-4}$

  (J.Guasch and J.Sola, Nucl. Phys., B562 (1999) 3: hep/ph/9906268, 1999)

- **The analysis presented here focus on the following final state topology of**

  $t\bar{t} \to HqWb \to W\,W^*\,q\,W\,b \to l\nu l\nu\,j,\ l^{\pm}\nu\,b$ ($l=e,\mu$).

FCNC Decay $t \to Zq$ (q=u,c)

- **The sensitivity of the ATLAS experiment to the $t \to Zq$ decay has been studied in two decay modes:**

  $t\bar{t} \to ZqWb \to l^+ l^- j, l^\pm \nu b$ ($l=e, \mu$) – leptonic final state topology

  $t\bar{t} \to ZqWb \to l^+ l^- j, jjb$ ($l=e, \mu$) --- hadronic final state topology

  For $t \to Zq$ decay the following SM backgrounds has been considered:

- **Z+jets $\to l^+ l^- +$ jets**
- **$t\bar{t} \to WbWb \to l^+ \nu b\, l^- \nu\, b$**
- **pp $\to$ WZ + X $\to l^\pm \nu\, l^+ l^- +X$**

It has been obtained that, the Br ($t \to Zq \to l^+ l^- q$) as low as 2.0×10^{-4} for the leptonic mode and as low as 5.9×10^{-4} for the hadronic mode could be discovered at the 5σ level with an integrated luminosity of 100 fb^{-1}.

Monte Carlo Events Generation

The signal $t \to Hq$ has been implemented in the PYTHIA 5.7. The following SM backgrounds has been considered:

- $t\bar{t} \to W^{+}bW^{-}b \to l^{+}\nu b\ l^{-}\nu b$
- $t\bar{t}H \to W^{+}bW^{-}b,\ WW^{*} \to l^{+}\nu b\ ,\ l^{-}\bar{\nu}\bar{b}\ ,\ l^{+}\nu l^{-}\bar{\nu}\ ;\ l^{\pm}\nu b, jjb,\ l^{+}\nu l^{-}\bar{\nu}\ ;\ l^{+}\nu b\ ,\ l^{-}\bar{\nu}\bar{b}\ ,\ jj\ l\ \nu$
- $WZ \to l^{\pm}\nu\ l^{+}\ l^{-} + X$
- $WH \to l^{\pm}\nu\ WW^{*} \to l^{\pm}\nu,\ l^{+}\nu\ l^{-}\bar{\nu} + X$

- All backgrounds were generated by PYTHIA 5.7 at $\sqrt{s} = 14$ TeV , m_{top}=175 GeV for two masses of Higgs m_H = 150 GeV and m_H = 160 GeV, with proton strucrure function CTEQ2L. Initial and final state QED and QCD (ISR, FSR) radiation, multiple interactions, fragmentations and decays of unstabled particles were enabled. The cross-section for $t\bar{t}$ production was assumed to be σ_{tt}= 833 pb.

- The events were simulated using the detector fast simulation package ATLFAST 2.51. The b-tagging performance was simulated assuming the nominal efficiencies of ε_b=50 %, ε_c=10 % , ε_j=1 % .

- The branching ratios of the $H \to WW^{*}$ decays have been estimated by the Fortran code HDECAY (a. Djouadi, J.Kalinovski and M.Spira, hep-ph/9704448,1997) $Br(H \to WW^{*})$=0.68 for m_H = 150 GeV and $Br(H \to WW^{*})$=0.92 for m_H = 160 GeV .

Event Analysis

- **Preselection cuts: the presence of at least 3 charged leptons (electron with P_T > 5 GeV, $|\eta| < 2.5$ and muon with P_T > 6 GeV, $|\eta| < 2.4$); the number of jets with P^{jet}_T >15 GeV, $|\eta^{jet}| < 5$ at least 2. The preselection cuts reduce backgrounds up to 2÷14%, meanwhile ~ 50% of signal events are survived.**

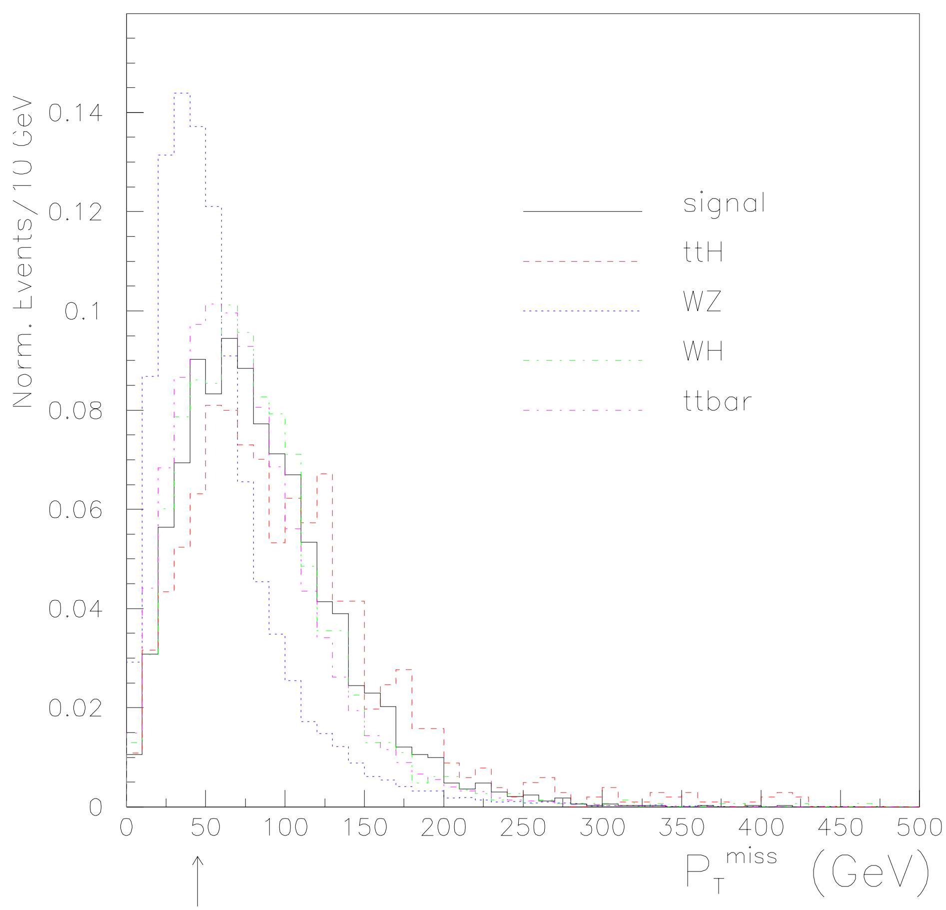
- **The requirement of 3 isolated leptons with high P^l_T > 30 GeV certainly includes the presence of one opposite charged lepton. This cut affects significantly $t\bar{t}$ dangerous background, while keeping still a significant fraction of the signal.**

- **The next requirement of the missing transverse momentum in event with P^{miss}_T > 45 GeV is a powerful cut for reduction of WZ background, though other backgrounds are less sensitive to this cut.**

- **We demand the presence of at least 2 jets with high P^{jet}_T >30 GeV in the region $|\eta^{jet}| < 2.5$. Among the isolated high P_T jets is required the presence at least of one tagged b-jet. This cut significantly suppresses WZ background and vanishes WH, the acceptance for them is (~0.01 ÷ 0.05 %).**

Cuts for m_H=150,160 GeV	t→Hq Signal		Background Processes ttH		Background Processes WH	
	Nevt	Eff(%)	Nevt	Eff(%)	Nevt	Eff(%)
Nevt gen.	10401 8805		110000 32800		300000 15000	
Expected events			12950 15020		430 480	
Preselection	5012 3943	48.00 45.00	395 475	3.05 3.16	56 66	13.07 13.70
P^{miss}_T > 45 GeV P^l_T > 30 GeV P^{jet}_T > 30 GeV $N_{b\text{-}jet} \geq 1$	249 218	2.39 2.48	48 76	0.38 0.51	0 0	5.13×10^{-2} 5.33×10^{-2}
m_{ll} < 80 GeV $\Delta\eta$ < 1.5, $\Delta\varphi$ < 1.0	186 170	1.79 1.93	22 35	0.17 0.24	0 0	4.03×10^{-2} 4.67×10^{-2}
t→Hq, m_{llj}< 110 GeV P^j_T > 30 GeV	87 60	0.84 0.68	6 12	5.1×10^{-2} 8.5×10^{-2}	0 0	7.30×10^{-3} 6.70×10^{-3}
t→Wb, m_{lb}< 140 GeV P^{bjet}_T > 40 GeV	78 59	0.75 0.67	6 11	4.6×10^{-2} 7.6×10^{-2}	0 0	6.70×10^{-3} 5.10×10^{-3}

Cuts for m_H=150,160 GeV	$t\rightarrow Hq$ Signal		Background Processes			
			$t\bar{t}$		WZ	
	Nevt	Eff(%)	Nevt	Eff(%)	Nevt	Eff(%)
Nevt gen.	10401 8805		4.0×10^6		2×10^5	
Expected events			3.8×10^6		39040	
Preselection	5012 3943	48.00 45.00	93611	2.41	3552	9.10
P^{miss}_T > 45 GeV P^l_T > 30 GeV P^{jet}_T > 30 GeV $N_{b\text{-}jet} \geq 1$	249 218	2.39 2.48	152	3.91×10^{-3}	5	1.28×10^{-2}
m_{ll} < 80 GeV $\Delta\eta < 1.5$, $\Delta\varphi < 1.0$	186 170	1.79 1.93	38	9.78×10^{-4}	0	1.00×10^{-3}
$t\rightarrow Hq$, m_{llj}< 110 GeV P^j_T > 30 GeV	87 60	0.84 0.68	7	1.80×10^{-4}	0	5.00×10^{-4}
$t\rightarrow Wb$, m_{lb}< 140 GeV P^{bjet}_T > 40 GeV	78 59	0.75 0.67	3	7.72×10^{-5}	0	5.00×10^{-4}


Norm. Events/10 GeV
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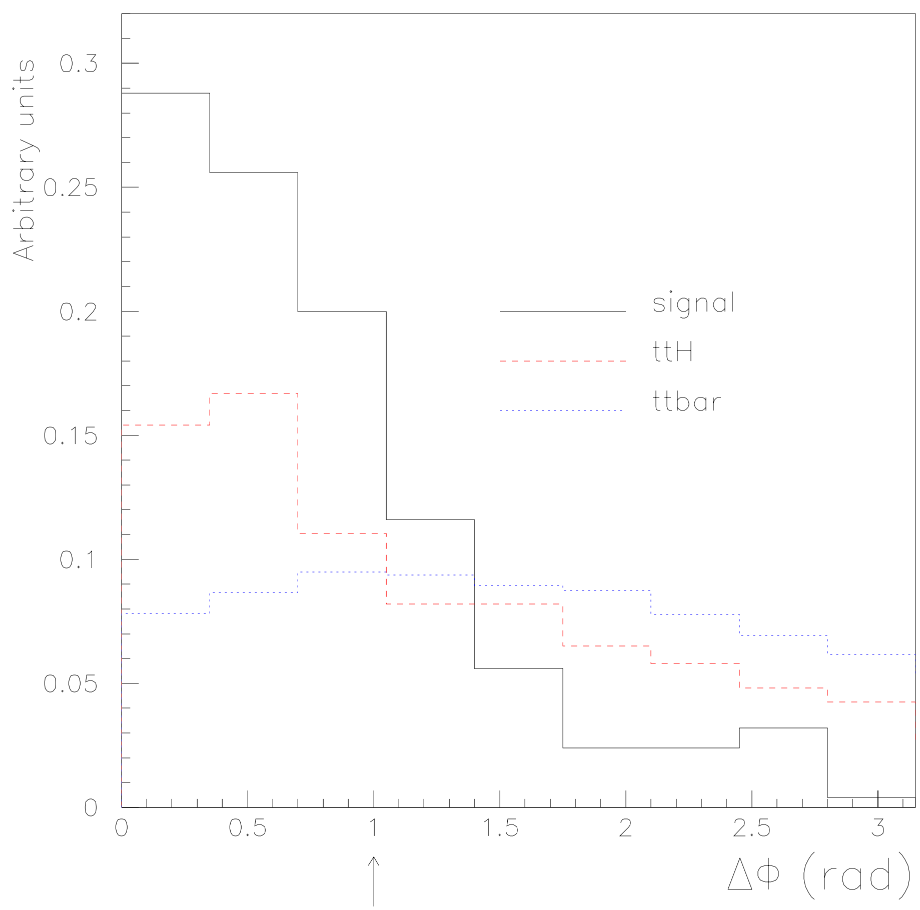
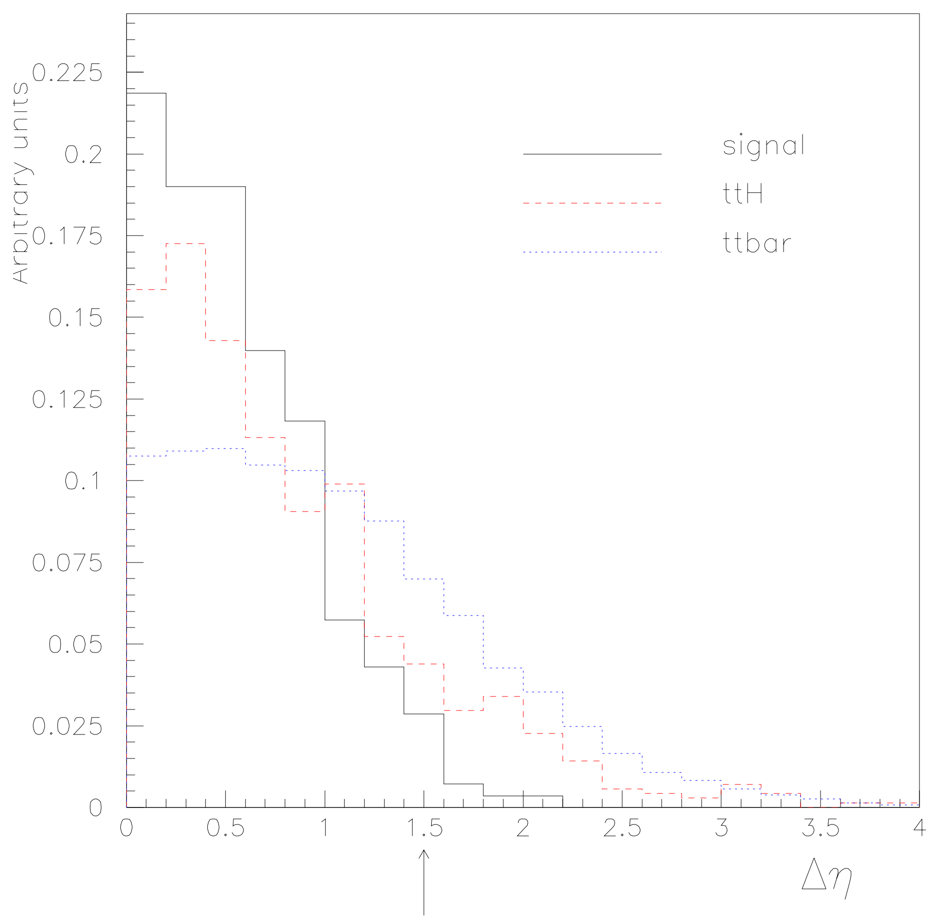
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
250
300
350
400
450
500
P_T^{miss} (GeV)
signal
ttH
WZ
WH
ttbar


Arbitrary units
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
1
1.5
2
2.5
3
signal
ttH
ttbar
ΔΦ (rad)

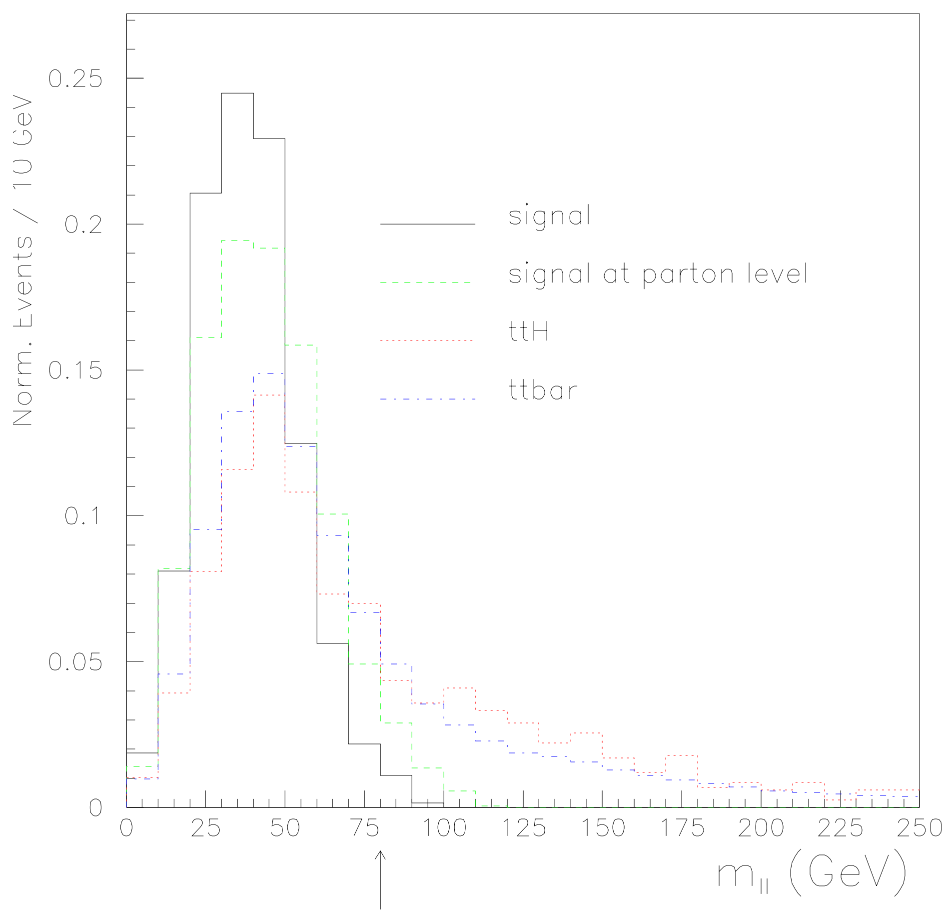

Arbitrary units
0.225
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0
0.5
1
1.5
2
2.5
3
3.5
4
signal
ttH
ttbar
Δη

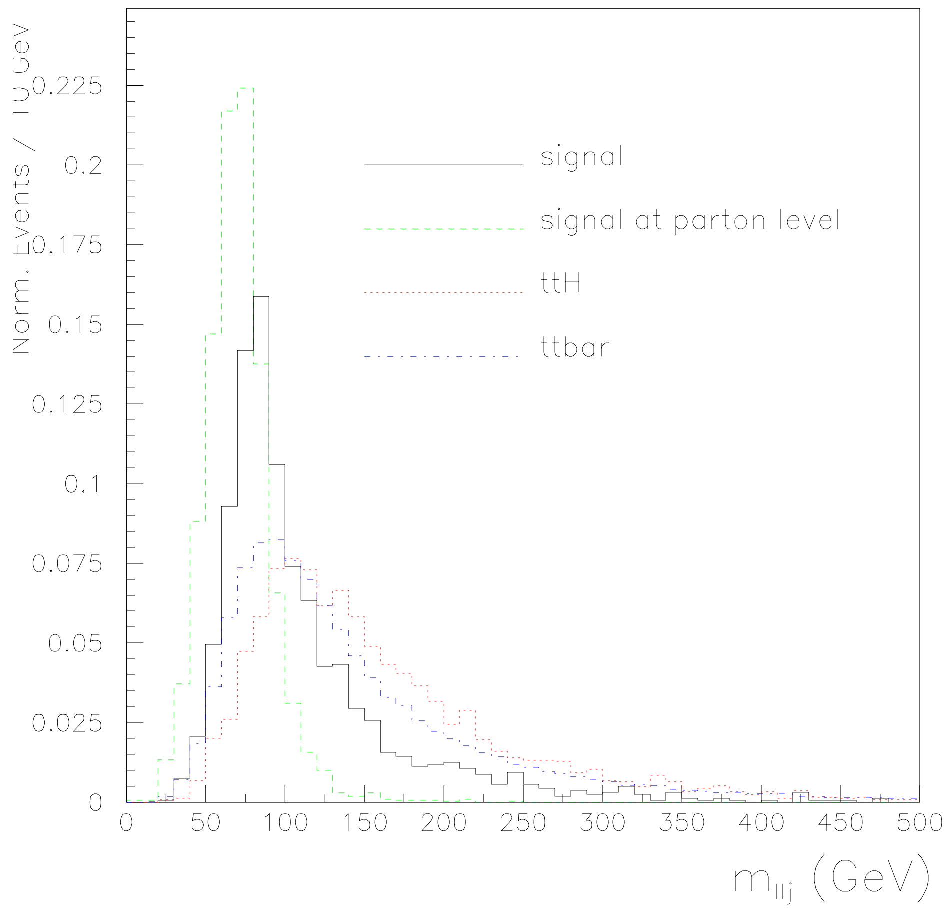
- For the dilepton (coming from H decay) m_{ll} mass reconstruction it have been required opposite charged lepton pairs with $\Delta\varphi < 1.0$ (the opening angle between the two leptons in the transverse plane, measured in rad.), $\Delta\eta < 1.5$ (the absolute values of the pseudorapidity difference between the two leptons) and an invariant dilepton mass smaller than 80 GeV. These cuts sufficiently reduce $t\bar{t}$ background and WZ background is vanished.

- Then two kinematical cuts have been applied on:

1. Invariant masses of $m_{llj} < 110$ GeV with light jets $P^{j}_{T} > 30$ GeV and
2. $m_{lb} < 140$ GeV with light jets $P^{bjet}_{T} > 40$ GeV

- It should be noted, that for m_{ll} and m_{llj} pairs the best combinations are defined as the closest values to the average numbers of ll and llq invariant mass distributions at parton level.


Norm. Events / 10 GeV
0.25
0.2
0.15
0.1
0.05
0
0
25
50
75
100
125
150
175
200
225
250
m_ll (GeV)
signal
signal at parton level
ttH
ttbar


Norm. Events / 10 GeV
signal
signal at parton level
ttH
ttbar
m_{llj} (GeV)

$t\bar{t} \rightarrow HqWb \rightarrow WW^{*}qWb \rightarrow l\nu l\nu j,\ l\pm\nu b\ (l = e, \mu)$

- $S = 2. \times \sigma_{tt} \times Br(t\rightarrow Hq) \times Br(t\rightarrow Wb) \times Br(H\rightarrow W^{+}W^{-}) \times$
  $\times Br(W\rightarrow l\nu)^{3} \times (\varepsilon^{l})^{3} \times A^{s} \times L$

  $\varepsilon^{l} = 0.9$ – lepton identification efficiency
  A^{s} -- Signal Acceptance
  L -- Luminosity

- $S/\sqrt{(Bg \times (\varepsilon^{l})^{3})} = 5.$
  Bg -- The sum of background events

- $Br(t\rightarrow Hq) = K \times 1/A^{s} \times \sqrt{Bg}$

$K = 5./(2. \times \sigma_{tt} \times Br(t\rightarrow Wb) \times Br(H\rightarrow W^{+}W^{-}) \times Br(W\rightarrow l\nu)^{3} \times L \times$
$\times \sqrt{(\varepsilon^{l})^{3}})$

$K_{150} = 5./(2. \times 833. \times 0.9982 \times 0.6852 \times 0.2163^{3} \times 100000. \times$

$\times \sqrt{0.729})$

$K_{150} = 5.1 \times 10^{-6}$

$K_{160} = 3.8 \times 10^{-6}$

Summary of the results at L= 100 fb^{-1}

Cuts	Sensitivity to Br ($t \to Hq$)	
	m_H = 150 GeV	m_H = 160 GeV
$t \to Hq$, m_{llj}< 110 GeV P^j_T > 30 GeV	2.19×10^{-3}	2.43×10^{-3}
$t \to Wb$, m_{lb}< 140 GeV P^{bjet}_T > 40GeV	2.03×10^{-3}	2.12×10^{-3}

The Br($t \to Hq \to WW^* q$) as low as 2.0×10^{-3} for m_H=150 GeV and as low as 2.1×10^{-3} for m_H=160 GeV could be discovered at the 5σ level with an integrated luminosity of 100 fb^{-1}.

Summary

- We have studied the ATLAS sensitivity to FCNC top quark rare decay $t \rightarrow Hq$ (q=u,c) with $H \rightarrow WW^*$ at $\sqrt{s} = 14$ TeV for an intergrated luminosity of 100 fb^{-1}.

- The results demonstrate that, a branching ratio as low as 2.0×10^{-3} for $m_H = 150$ GeV and as low as 2.1×10^{-3} for $m_H = 160$ GeV could be discovered at the 5σ level with an integrated luminosity of of 100 fb^{-1}.

Preliminary results for $t\bar{t} \rightarrow HqWb \rightarrow b\bar{b}j, l^{\pm}\nu b, (l=e,\mu)$ decays

- Study of the sensitivity of the ATLAS experiment to the top quark rare decay via FCNC $t \rightarrow Hq$ $(q=u,c)$ at $\sqrt{s}$ = 14 TeV in the decay mode of $t\bar{t} \rightarrow HqWb \rightarrow b\bar{b}j, l^{\pm}\nu b, (l=e,\mu)$ is underway.

- The Standard Model backgrounds $t\bar{t}$, $t\bar{t}H$, W_jets, WZ, WH and $Wb\bar{b}$ have been analysed. The signal and backgrounds were generated via PYTHIA 5.7 and HERWIG and simulated and analysed using ATLFAST 2.51. The preliminary result for the brahcning ratio $t \rightarrow Hq \rightarrow b\bar{b}j$ as low as 4.5×10^{-3} is obtained at 5σ level with an integrated luminosity of 100 fb^{-1} for m_H =115 GeV.