fcnc top quark rare decays

filipe veloso
filipe.veloso@coimbra.lip.pt

workshop valencia — coimbra — granada

26.nov.2009

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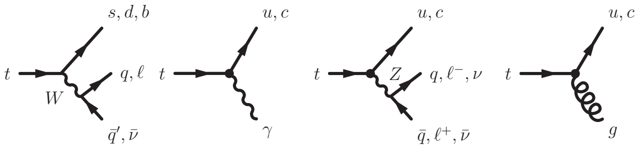
introduction

top quark decays



BR($t \to$ FCNC) in several models:

	SM	QS	2HDM	FC 2HDM	MSSM	$\not R$ SUSY	TC2
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$
$t \to qg$	$\sim 10^{-12}$	$\sim 10^{-7}$	$\sim 10^{-4}$	$\sim 10^{-8}$	$\sim 10^{-5}$	$\sim 10^{-4}$	$\sim 10^{-4}$

present experimental limits:

	LEP	HERA	Tevatron
$Br(t \to q\gamma)$	2.4 %	0.75 %	3.2 %
$Br(t \to qZ)$	7.8 %	49%	3.7 %
$Br(t \to qg)$	17 %	13 %	0.1 – 1 % (estimated)

c s c   a n a l y s e s

atlas csc study

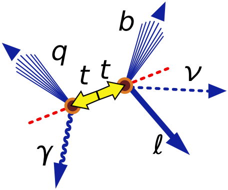
- preparing for first data samples
  - $L = 1\ \text{fb}^{-1}$
  - not using b-tag
- ATLAS full simulation samples:
  - ATLAS-CSC-01-02-00 detector geometry
  - TopView 12-14-03 common ntuples
  - luminosity per background sample: $0.02\ \text{fb}^{-1}$ – $14\ \text{fb}^{-1}$

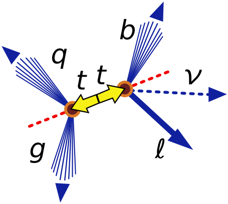
regular samples:

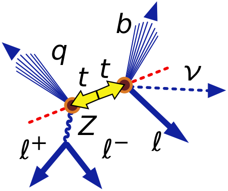
process	generator
$t\bar{t} \to bWq\gamma$	TopReX
$t\bar{t} \to bWqZ$	TopReX
$t\bar{t} \to bWqg$	TopReX
$t\bar{t} \to bWbW$	MC@NLO
single top	AcerMC
$Z \to \ell^+\ell^-$	HERWIG
$W \to \ell\nu + nj$	ALPGEN
$Wb\bar{b} + nj$	ALPGEN
$Wc\bar{c} + nj$	ALPGEN

Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics CERN-OPEN-2008-020 (2008)

event selection







$t\bar{t} \to bWq\gamma$	$t\bar{t} \to bWqg$	$t\bar{t} \to bWqZ$
$= 1\ell$ $p_T > 25$ GeV $\geq 2j$ $p_T > 20$ GeV $= 1\gamma$ $p_T > 25$ GeV $\not{p}_T > 20$ GeV	$= 1\ell$ $p_T > 25$ GeV $= 3j$ $p_T > 40, 20, 20$ GeV $= 0\gamma$ $\not{p}_T > 20$ GeV	$= 3\ell$ $p_T > 25, 15, 15$ GeV $\geq 2j$ $p_T > 30, 20$ GeV $= 0\gamma$ $\not{p}_T > 20$ GeV
$p_{T\gamma} > 75$ GeV	$E_{\mathrm{vis}} > 300$ GeV $p_{Tg} > 75$ GeV $m_{qg} > 125$ GeV $m_{qg} < 200$ GeV	2 ℓ same flavour, oppos. charge
e25i, mu20i or g60	e25i or mu20i	e25i or mu20i

kinematics reconstruction

method without jet tagging algorithms:

ν, m_t^{FCNC}, m_t^{SM}, etc. are determined by minimizing

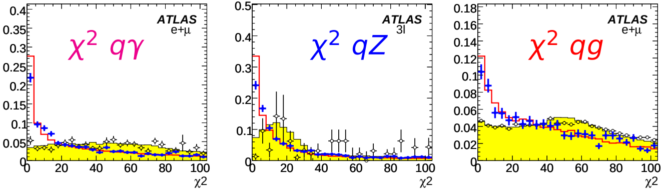
$$\chi^2 = \frac{\left(m_t^{FCNC} - m_t\right)^2}{\sigma_{m_t}^2} + \frac{\left(m_t^{SM} - m_t\right)^2}{\sigma_{m_t}^2} + \frac{\left(m_W^{SM} - m_W\right)^2}{\sigma_{m_W}^2} + \frac{\left(m_Z^{SM} - m_Z\right)^2}{\sigma_{m_Z}^2}$$

$$(b, q, g = j_1, j_2, j_3) \qquad (\ell, Z \to \ell^+\ell^- = \ell_1, \ell_2, \ell_3)$$

$m_t = 175$ GeV
$\sigma_t = 14$ GeV

$m_W = 80.42$ GeV
$\sigma_W = 10$ GeV

$m_Z = 91.19$ GeV
$\sigma_Z = 3$ GeV

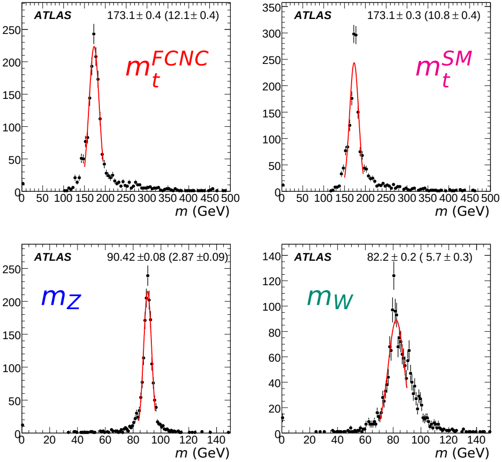


– Signal ATLFAST + Signal FullSim Backgr. ATLFAST + Backgr. FullSim

kinematics

example:
$t\bar{t} \rightarrow bWqZ$

m_t^{FCNC}	173.1±0.4
(σ)	(12.1±0.4)
m_t^{SM}	173.1±0.3
(σ)	(10.8±0.4)
m_W	82.2±0.2
(σ)	(5.7±0.3)
m_Z	90.42±0.08
(σ)	(2.87±0.09)



number of events

$L = 1\ \mathrm{fb}^{-1}$

	e	μ	ℓ
$t\bar{t} \to bWq\gamma$:			
Total	435 ± 63	216 ± 57	650 ± 66
Signal %	3.6 ± 0.2	4.1 ± 0.2	7.6 ± 0.2
$t\bar{t} \to bWqZ$:			
Total	28 ± 55	11 ± 55	125 ± 56
Signal %	1.4 ± 0.1	2.5 ± 0.1	7.6 ± 0.2
$t\bar{t} \to bWqg$:			
Total	10988 ± 308	8265 ± 193	19252 ± 359
Signal %	1.3 ± 0.1	1.5 ± 0.1	2.9 ± 0.1

trigger efficiencies were also studied:

	$t \to q\gamma$		$t \to qZ$		$t \to qg$	
	Sig.	Back.	Sig.	Back.	Sig.	Back.
trigger	99.6	99.5	99.2	95.0	83.2	82.2

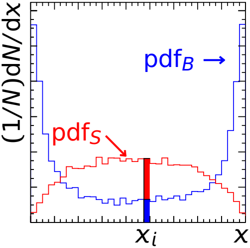
discriminant analysis

probabilistic analysis (after sequential)

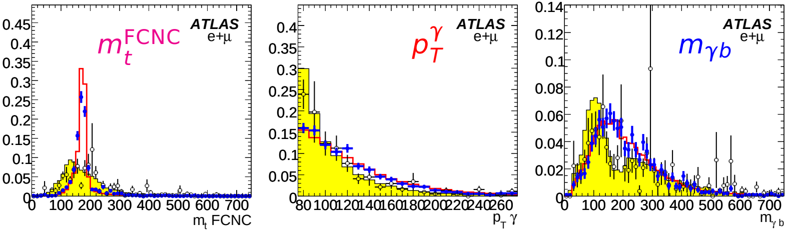
$$P_S = \Pi_{i=1}^{N} P_i^S(x_i)$$

$$P_B = \Pi_{i=1}^{N} P_i^B(x_i)$$

$$L_R = \ln(P_S/P_B)$$



example: $t\bar{t} \rightarrow \; bWq\gamma$



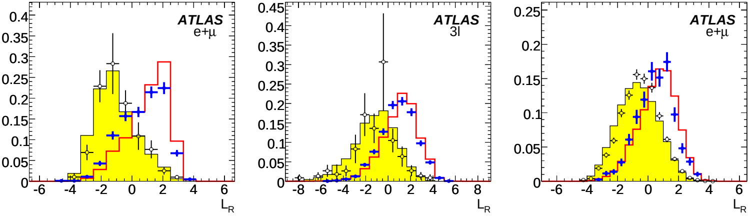
– Signal ATLFAST + Signal FullSim Backgr. ATLFAST + Backgr. FullSim

discriminant variables

FullSim statistics not enough
→ ATLFAST (with reco. eff.) pdf used

$$L_R = \ln\left(\frac{L_S}{L_B}\right)$$

− Signal ATLFAST + Signal FullSim Backgr. ATLFAST + Backgr. FullSim



$q\gamma$ qZ qg

results

$L = 1\ \mathrm{fb}^{-1}$

expected 95% CL limits (BR<):

	-1σ	expected	$+1\sigma$
$t\bar{t} \to bWq\gamma$:			
e	4.3×10^{-4}	1.1×10^{-3}	1.9×10^{-3}
μ	4.5×10^{-4}	8.3×10^{-4}	1.3×10^{-3}
ℓ	3.8×10^{-4}	6.8×10^{-4}	1.0×10^{-3}
$t\bar{t} \to bWqZ$:			
$3e$	5.5×10^{-3}	9.4×10^{-3}	1.4×10^{-2}
3μ	2.4×10^{-3}	4.2×10^{-3}	6.4×10^{-3}
3ℓ	1.9×10^{-3}	2.8×10^{-3}	4.2×10^{-3}
$t\bar{t} \to bWqg$:			
e	1.3×10^{-2}	2.1×10^{-2}	3.0×10^{-2}
μ	1.0×10^{-2}	1.7×10^{-2}	2.4×10^{-2}
ℓ	7.2×10^{-3}	1.2×10^{-2}	1.8×10^{-2}

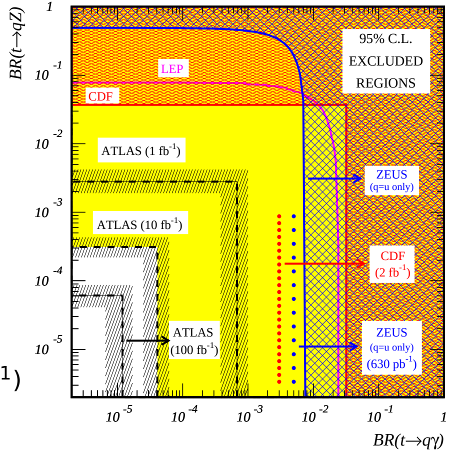
5σ discovery hipothesis (BR>) are on average 3.0 times larger

absolute value of the maximum relative changes on the 95% CL limits

source	$t \to q\gamma$	$t \to qZ$	$t \to qg$
systematic uncertainties:			
jet energy calibration	2%	5%	4%
luminosity	10%	6%	10%
top mass	6%	12%	5%
backgrounds σ	7%	12%	15%
ISR/FSR	17%	7%	9%
pile-up	22%	0%	13%
generator	4%	14%	4%
χ^2	4%	7%	9%
total	32%	25%	27%
analysis stability:			
selection criteria	3%	12%	5%

comparison of results

- ATLAS
  - $t \to q\gamma$: 3× better
  - $t \to qZ$: similar
  - $t \to qg$: one order mag. better/worst
- CMS
  - $t \to q\gamma$: 3× better
  - $t \to qZ$: similar
  - results from ATLAS and CMS were combined
- present limits
  - $t \to q\gamma$ and $t \to qZ$: one order mag. better (1 fb^{-1})
  - $t \to qg$: similar (1 fb^{-1})



data driven normalizations

data driven backgr. normalizations

dominant backgrounds for the FCNC analyses from the csc exercice:

channel	$Z+j$	$W+j$	dB	$t\bar{t}$	st
$t\bar{t} \to bWq\gamma$	30%	29%		38%	
$t\bar{t} \to bWqZ$	28%		13%	59%	
$t\bar{t} \to bWqg$		64%		25%	6%

event selection:
pre-selection:

- e20_loose or mu20 triggers
- FCNC signal veto:
  no events with ($N_\ell = 1$, $N_\gamma > 0$) or ($N_\ell = 3$, $N_\gamma = 0$)

5 orthogonal samples were defined after the pre-selection (no b-tag)

background composition per selection sample
assuming SM cross-sections

	background				
selection	$t\bar{t}$	st	$W+j$	$Z+j$	dB
$t\bar{t}$	72.8%	2.3%	23.1%	1.4%	0.3%
st	55.5%	8.8%	33.5%	1.8%	0.4%
$W+j$	1.2%	0.5%	95.8%	2.1%	0.5%
$Z+j$	0.0%	0.0%	0.0%	99.9%	0.1%
dB	21.5%	3.0%	71.0%	2.4%	2.1%

method

minimize this expression in order to determine the correction factors:

$$\sqrt{\sum_{h=1}^{\#\mathrm{sel.}} (1 - (N_{t\bar{t}} n_{t\bar{t}}^h + N_{st} n_{st}^h + N_{Wj} n_{Wj}^h + N_{Zj} n_{Zj}^h + N_{WZp} n_{WZp}^h)/n_d^h)^2}$$

eg.: n_d^h is the number of data events in selection h, $N_{t\bar{t}}$ is the $t\bar{t}$ background correction factor, etc...

error contributions:

- data statistical errors
- background statistical errors
- systematical errors from jes (±5% variations)

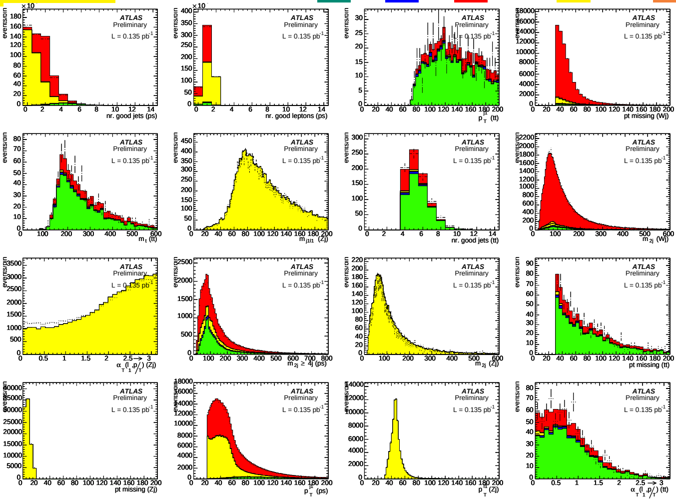
results for topmixing v2

$t\bar{t}$	st	$W+j$	$Z+j$	dB
with acermc; *st* and dB xs fixed to SM:				
0.98 ± 0.06	—	1.11 ± 0.01	1.12 ± 0.01	—
with acermc, *st* xs fixed to SM:				
0.98 ± 0.05	—	1.11 ± 0.01	1.12 ± 0.01	1.13 ± 0.85
with acermc:				
0.88 ± 0.08	0.10 ± 0.00	1.02 ± 0.05	1.11 ± 0.01	6.46 ± 2.45
with mc@nlo, *st* and dB xs fixed to SM:				
1.32 ± 0.08	—	1.10 ± 0.01	1.12 ± 0.01	—
with mc@nlo, *st* xs fixed to SM:				
1.32 ± 0.08	—	1.08 ± 0.01	1.12 ± 0.01	0.10 ± 0.00
with mc@nlo:				
0.92 ± 0.09	0.10 ± 0.00	1.05 ± 0.06	1.11 ± 0.01	4.66 ± 3.33

distributions after normalization

(with acermc; *st* and dB cross-sections fixed to SM)

$L = 135\ \mathrm{pb}^{-1}$ + topmixing $t\bar{t}$ st $W+j$ $Z+j$ dB

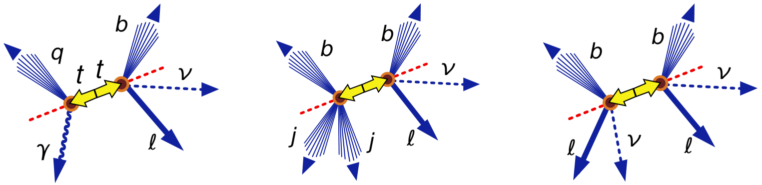


photon id studies

photon identification studies

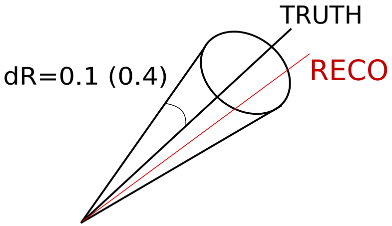
- γ identification is important for the top FCNC decays analysis

- samples:
  - 105510: TopRex, Pythia (20k $t\bar{t} \to bWq\gamma, W \to \ell\nu, \ell = e, \mu$)
  - 105200: MC@NLO, Herwig (1.48M $t\bar{t} \to bWbW$, no fully hadronic)
- tags:
  - 105510: e432, s495, r635 and t53
  - 105200: e357, s462, r635 and t53



definitions

- photons:
  - unconverted (`egammaParameters::AuthorPhoton`)
  - isEM tight (`egammaPID::PhotonTight`)
  - $p_T > 10$ GeV and $|\eta| < 2.47$ excluding $1.37 < |\eta| < 1.52$
- electrons:
  - isEM medium without isolation (`egammaPID::ElectronMediumNoIso`)
  - $p_T > 10$ GeV and $|\eta| < 2.47$ excluding $1.37 < |\eta| < 1.52$
- jets:
  - cone 0.4 and $p_T > 15$ GeV
- true objects:
  - γ from top quark decay
  - e from $t \to W \to \ell\nu$
  - jets from trujets
- true/reco match:
  - closest reco object (jet) with $\Delta R < 0.1$ (0.4)



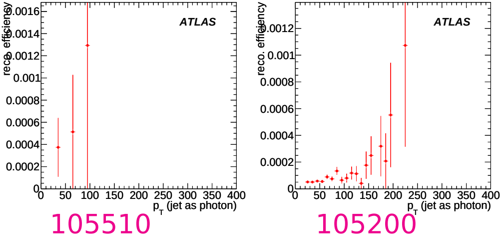
γ ID efficiencies

$p_T^{true} > 25$ GeV

$\varepsilon_{x \text{ as } y} = \frac{\text{no. } x \text{ as } y}{\text{total no. } x}$

true γ as γ:	64.4	$\pm$ 0.4	(105510)
true γ as e:	0.66	$\pm$ 0.06	(105510)
true γ as jet:	29.74	$\pm$ 0.34	(105510)
true e as γ:	5.23	$\pm$ 0.18	(105510)
	4.829	$\pm$ 0.026	(105200)
true jet as γ:	0.018	$\pm$ 0.009	(105510)
	0.0067	$\pm$ 0.0004	(105200)

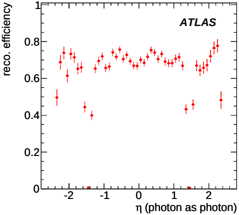
p_T (true jet as γ):



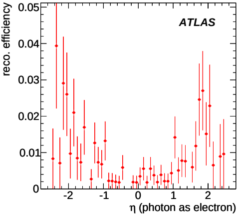
→ 105200 sample choosen for "true e as γ" and "true jet as γ"

γ ID efficiencies (η)

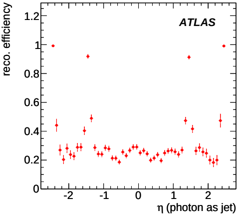
γ as γ



γ as e

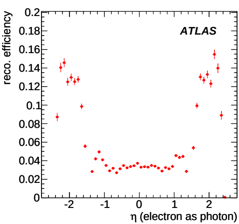


γ as jet

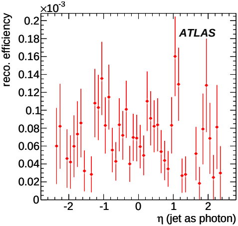


$p_T^{\text{true}} > 25$ GeV

$$\varepsilon_{x \text{ as } y} = \frac{\text{no. } x \text{ as } y}{\text{total no. } x}$$



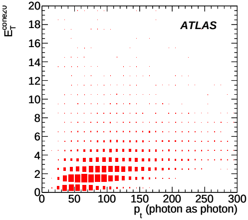
e as γ



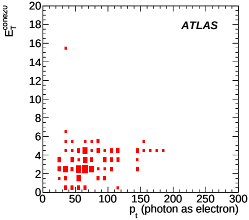
jet as γ

γ ID (E_T^{cone20} vs p_T)

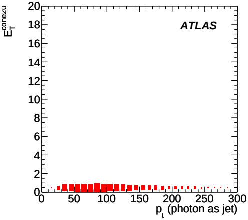
γ as γ



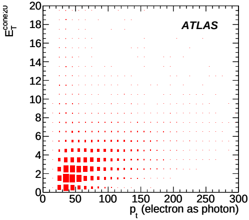
γ as e



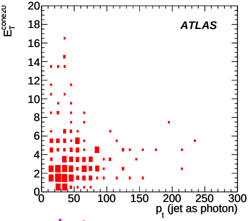
γ as jet



$p_T^{true} > 25$ GeV



e as γ



jet as γ

photon isolation ($p_T^{true} > 25$ GeV)

isolation cut	true γ as γ	true e as γ	$(S/\sqrt{B})$	true jet as γ	$(S/\sqrt{B})$
no cut	64.4 ± 0.4	4.830 ± 0.026	(29.3)	0.00665 ± 0.00043	(790)
EtCone20< 6 GeV	61.4 ± 0.4	4.574 ± 0.026	(28.7)	0.00592 ± 0.00041	(798)
EtCone20/Et < 0.06	60.4 ± 0.4	3.553 ± 0.023	(32.1)	0.00347 ± 0.00031	(1027)
EtCone20/Et < 0.08	62.5 ± 0.4	4.151 ± 0.025	(30.7)	0.00428 ± 0.00035	(955)
EtCone20/Et < 0.10	63.4 ± 0.4	4.449 ± 0.025	(30.0)	0.00482 ± 0.00037	(913)
EtCone20/Et < 0.12	63.8 ± 0.4	4.610 ± 0.026	(29.7)	0.00524 ± 0.00038	(881)
EtCone20/Et < 0.14	64.0 ± 0.4	4.691 ± 0.026	(29.6)	0.00547 ± 0.00039	(866)
EtCone20/Et < 0.16	64.1 ± 0.4	4.733 ± 0.026	(29.5)	0.00566 ± 0.00040	(852)
EtCone20/Et < 0.18	64.2 ± 0.4	4.760 ± 0.026	(29.4)	0.00583 ± 0.00041	(841)
EtCone30< 6 GeV	56.8 ± 0.4	4.148 ± 0.025	(27.9)	0.00493 ± 0.00037	(809)
EtCone30/Et < 0.06	53.9 ± 0.4	2.664 ± 0.020	(33.0)	0.00279 ± 0.00028	(1019)
EtCone30/Et < 0.08	58.6 ± 0.4	3.453 ± 0.023	(31.5)	0.00344 ± 0.00031	(999)
EtCone30/Et < 0.10	60.8 ± 0.4	3.932 ± 0.024	(30.6)	0.00395 ± 0.00033	(968)
EtCone30/Et < 0.12	62.0 ± 0.4	4.232 ± 0.025	(30.1)	0.00431 ± 0.00035	(944)
EtCone30/Et < 0.14	62.7 ± 0.4	4.410 ± 0.025	(29.8)	0.00471 ± 0.00036	(914)
EtCone30/Et < 0.16	63.2 ± 0.4	4.521 ± 0.026	(29.7)	0.00493 ± 0.00037	(900)
EtCone30/Et < 0.18	63.4 ± 0.4	4.591 ± 0.026	(29.6)	0.00524 ± 0.00038	(876)
EtCone40< 6 GeV	50.9 ± 0.4	3.608 ± 0.023	(26.8)	0.00426 ± 0.00035	(781)
EtCone40/Et < 0.06	46.6 ± 0.4	2.026 ± 0.017	(32.7)	0.00220 ± 0.00024	(994)
EtCone40/Et < 0.08	53.4 ± 0.4	2.817 ± 0.020	(31.8)	0.00279 ± 0.00028	(1010)
EtCone40/Et < 0.10	56.8 ± 0.4	3.392 ± 0.022	(30.9)	0.00355 ± 0.00032	(954)
EtCone40/Et < 0.12	58.9 ± 0.4	3.762 ± 0.024	(30.4)	0.00378 ± 0.00033	(959)
EtCone40/Et < 0.14	60.3 ± 0.4	4.024 ± 0.024	(30.0)	0.00409 ± 0.00034	(942)
EtCone40/Et < 0.16	61.0 ± 0.4	4.198 ± 0.025	(29.8)	0.00434 ± 0.00035	(927)
EtCone40/Et < 0.18	61.7 ± 0.4	4.320 ± 0.025	(29.7)	0.00468 ± 0.00036	(902)

protos validation for fcnc

protos

protos version 1.2:

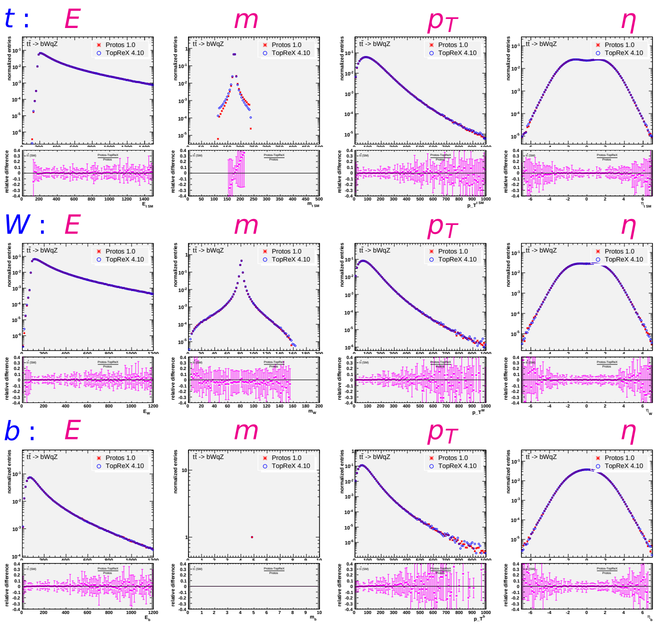
- $t\bar{t}$ and single top processes
- includes fcnc vertices with γ, Z, g and H

$$\mathcal{L}_{Htc} = -\frac{1}{\sqrt{2}}\,\bar{c}\left(\eta^L_{ct} P_L + \eta^R_{ct} P_R\right) t\,H + \mathrm{H.c.}$$

`arXiv:0904.2387v1 [hep-ph]`

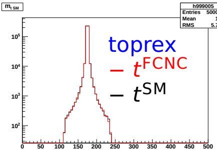
- the H decays are left to the parton shower monte carlo

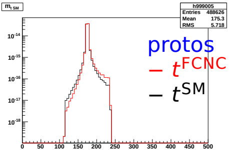
next page:
comparision between protos and toprex (for $t\bar{t} \to bWqZ$)

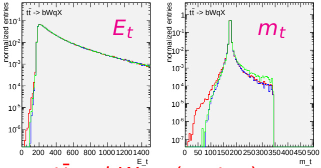

t : E
m
p_T
η
W : E
m
p_T
η
b : E
m
p_T
η
$t\bar{t}$ -> bWqZ
Protos 1.0
TopReX 4.10
normalized entries
relative difference
Protos-TopReX
Protos
$E_{t\ SM}$
$m_{t\ SM}$
$p\_T^{t\ SM}$
$\eta_{t\ SM}$
E_W
m_W
p_T^W
η_W
E_b
m_b
p_T^b
η_b

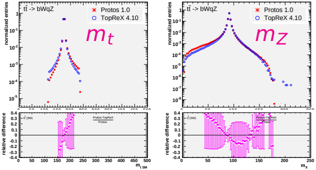
protos

- toprex gives the same m distributions for t^{FCNC} and t^{SM} (only Breit-Wigner)
- protos behaves better: gives different m distributions (accounts for phase space: $m_W \neq m_Z$; two body decay weight is proportional to W/Z momentum in t rest frame)









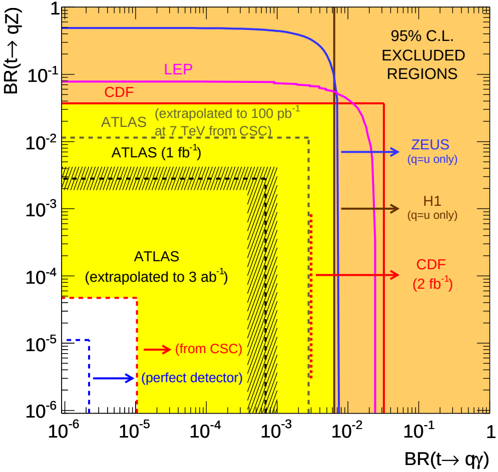
— $t\bar{t} \to bWq\gamma$ (protos)
— $t\bar{t} \to bWqH$ (protos)
— $t\bar{t} \to bWqZ$ (protos)

— $t\bar{t} \to bWqZ$ (protos)
— $t\bar{t} \to bWqZ$ (toprex)

e x t r a p o l a t i o n s

extrapolations

- competitive with 100 pb^{-1} at 7 TeV
- extrapolation to 3 ab^{-1}:
  $t\bar{t} \rightarrow bWq\gamma$:
  2.2×10^{-6} to
  1.0×10^{-5}
  $t\bar{t} \rightarrow bWqZ$:
  1.1×10^{-5} to
  4.7×10^{-5}
  $t\bar{t} \rightarrow bWqg$:
  7.7×10^{-5} to
  2.1×10^{-4}
- pile up at 3 ab^{-1} was not considered
- dedicated analyses would be better than projections



c o n c l u s i o n s

conclusions/final remarks

- data driven methods for background normalization:
- method without b-tag gives results compatible with previous ones
- considers *st* and dB although more work is needed
- add systematics (for example jes, m_t, distributions)

- photon identification studies:
- $E_T^{\mathrm{conex}}/p_T < y$ seems better than $E_T^{\mathrm{conex}} < 6$ GeV
- test other isolation cuts ($\neq$ values; (E_T^{coneX}, p_T) planes)
- converted photons
- performance of FCNC analysis

conclusions/final remarks

- protos:
- protos seems to behave better than toprex
- has the $t\bar{t} \rightarrow bWqH$ channel

- FCNC top quark decays can be studied with ATLAS:
- results with 1 fb^{-1} at 14 TeV will be one order of magnitude better than present BR limits
- the search for FCNC top quark decays gains significantly with luminosity

b a c k u p

dd: samples used

TopPhysDPDMaker:

- topmixing v2
  (108173; joined egamma and muon streams without double counting)
- topmixing v3
  (108175; joined egamma and muon streams without double counting)
- $t\bar{t}$ acermc (105205)
- $t\bar{t}$ mc@nlo with leptons (105200)
- $t\bar{t}$ mc@nlo without leptons (105204)
- single top (105500, 105502)
- W+jets 0-5 partons (107682 – 107705)
- Wbb (106280 – 106282)
- Z+jets (107650 – 107675)
- di-bosons (105985 – 105987)

dd: event selection

$Z + j$:

- $= 2$ leptons
- leptons with $p_T > 30$ GeV, same flavour, opp. charge
- $\not{p}_T < 20$ GeV
- 60 GeV$< m_{\ell\ell} < 120$ GeV

dd: event selection

$W + j$:

- $= 1$ lepton
- lepton with $p_T > 30$ GeV
- $\not{p}_T > 30$ GeV
- 1 to 3 jets
- leading jet with $p_T > 20$ GeV

dd: event selection

$t\bar{t}$:

- $=1$ lepton
- lepton with $p_T > 40$ GeV
- $\not{p}_T > 30$ GeV
- at least 4 jets
- $p_T^{j1} > 70$ GeV; $p_T^{j2} > 60$ GeV; $p_T^{j3} > 50$ GeV; $p_T^{j4} > 40$ GeV
- $|\eta^{j1-j4}| < 2.5$
- solution for reconstruction of $t \to Wb \to \ell\nu b$ (quad. eq.)

dd: event selection

single top:

- $= 1$ lepton
- lepton with $p_T > 30$ GeV
- $\not{p}_T > 30$ GeV
- at least 4 jets
- $p_T^{j1} > 60$ GeV; $p_T^{j2} > 50$ GeV; $p_T^{j3} > 40$ GeV; $p_T^{j4} > 30$ GeV
- one of the two leading jets with $|\eta| > 2.5$ and the other with $|\eta| < 2.5$
- $|\eta^{j3,j4}| < 2.5$
- solution for reconstruction of $t \to Wb \to \ell\nu b$ (quad. eq.)

dd: event selection

di-bosons:

- $= 1$ lepton
- lepton with $p_T > 30$ GeV
- $\not{p}_T > 30$ GeV
- at least 2 jets
- $p_T^{j1} > 40$ GeV; $p_T^{j2} > 30$ GeV; $p_T^{j4} < 35$ GeV
- 60 GeV$< m_{j1j2} < 100$ GeV

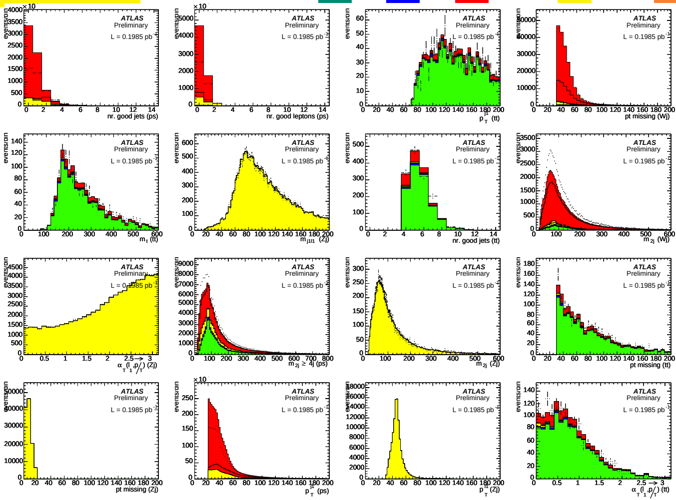
results for topmixing v3

$t\bar{t}$	st	$W+j$	$Z+j$	dB
with acermc; *st* and dB xs fixed to SM:				
1.24 ± 0.05	—	0.59 ± 0.01	0.92 ± 0.01	—
with acermc, *st* xs fixed to SM:				
1.23 ± 0.05	—	0.57 ± 0.01	0.91 ± 0.01	9.00 ± 0.00
with acermc:				
1.18 ± 0.05	2.13 ± 0.61	0.56 ± 0.01	0.91 ± 0.01	9.00 ± 0.00
with mc@nlo, *st* and dB xs fixed to SM:				
1.64 ± 0.06	—	0.59 ± 0.01	0.92 ± 0.01	—
with mc@nlo, *st* xs fixed to SM:				
1.61 ± 0.06	—	0.55 ± 0.01	0.91 ± 0.01	7.76 ± 1.25
with mc@nlo:				
1.50 ± 0.07	0.10 ± 0.00	0.56 ± 0.01	0.91 ± 0.01	9.00 ± 0.00

distributions after normalization

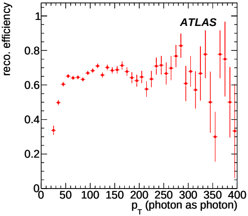
(with acermc; st and dB cross-sections fixed to SM)

$L = 198.5\ \text{pb}^{-1}$ + topmixing $t\bar{t}$ st $W+j$ $Z+j$ dB

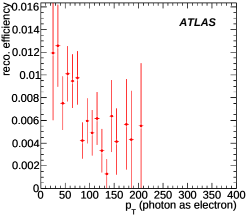


γ ID efficiencies (p_T)

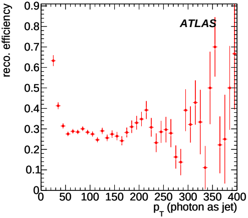
γ as γ



γ as e

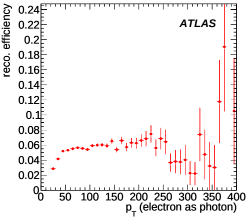


γ as jet

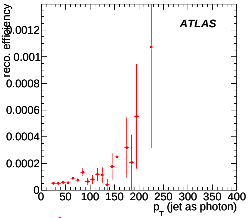


$$p_T^{\text{true}} > 25 \text{ GeV}$$

$$\varepsilon_{x \text{ as } y} = \frac{\text{no. } x \text{ as } y}{\text{total no. } x}$$



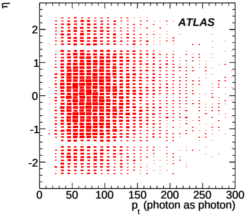
e as γ



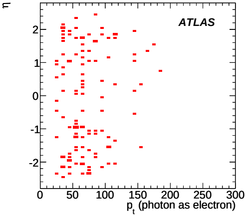
jet as γ

γ ID (η vs p_T)

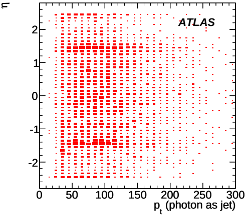
γ as γ



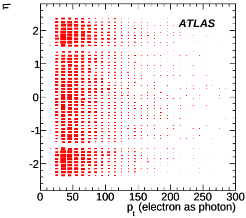
γ as e



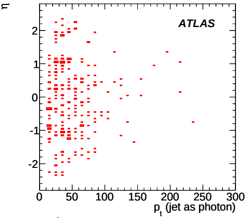
γ as jet



$p_T^{true} > 25$ GeV



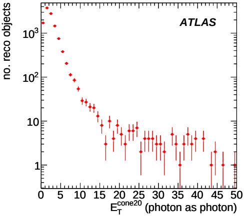
e as γ



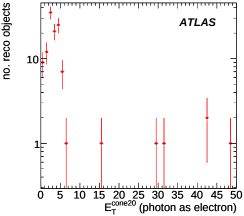
jet as γ

γ ID (E_T^{cone20})

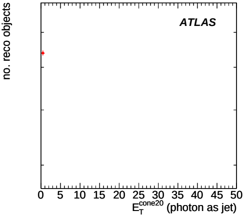
γ as γ



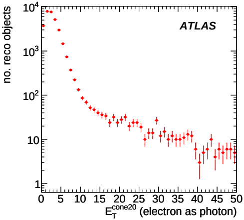
γ as e



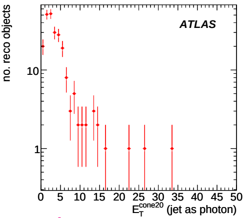
γ as jet



$p_T^{true} > 25$ GeV



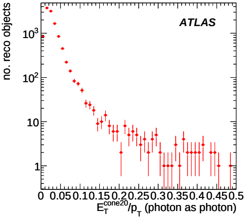
e as γ



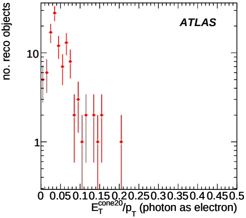
jet as γ

γ ID (E_T^{cone20}/p_T)

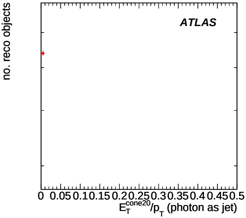
γ as γ



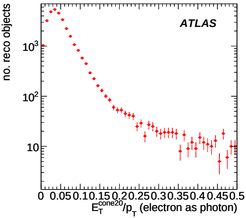
γ as e



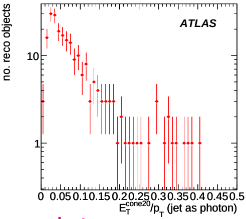
γ as jet



$p_T^{true} > 25$ GeV



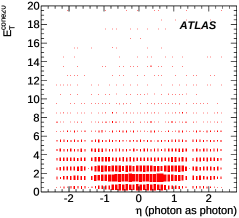
e as γ



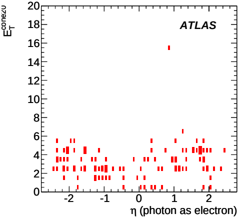
jet as γ

γ ID (E_T^{cone20} vs η)

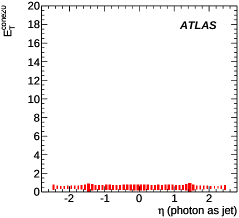
γ as γ



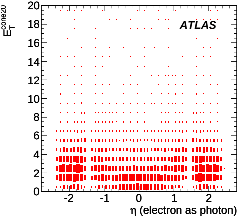
γ as e



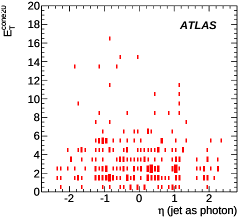
γ as jet



$p_T^{true} > 25$ GeV



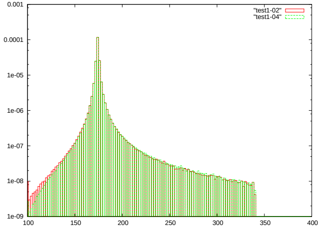
e as γ



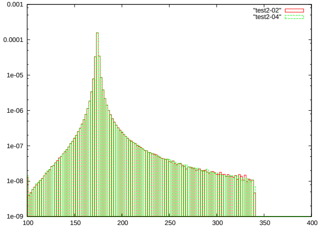
jet as γ

protos validation for fcnc

- protos: $m_W = m_Z \longrightarrow$ similar $m_{t^{\mathrm{FCNC}}}$ and $m_{t^{\mathrm{SM}}}$



with $m_W \neq m_Z$
– $m_{t^{\mathrm{FCNC}}}$ (protos)
– $m_{t^{\mathrm{SM}}}$ (protos)



with $m_W = m_Z$
– $m_{t^{\mathrm{FCNC}}}$ (protos)
– $m_{t^{\mathrm{SM}}}$ (protos)

extrapolations

values can be extrapolated from csc results to 3ab^{-1} using the expression for the estimation of the 5σ discovery limits:

$$BR = \frac{5\sqrt{B(\varepsilon_\ell, \varepsilon_\gamma)}}{2 \times L \times \sigma(t\bar{t}_{SM}) \times \varepsilon_S(\varepsilon_\ell, \varepsilon_\gamma)},$$

factors for extrapolation from 1 fb^{-1} to 3 ab^{-1} at 14 TeV:

$$f_{\text{lum}} = \sqrt{\frac{1}{3000}} \qquad f_{\varepsilon_\gamma} = \sqrt{\left(\frac{0.666}{0.9}\right)^{N_\gamma}} \qquad f_{\varepsilon_\ell} = \sqrt{\left(\frac{0.8535}{0.9}\right)^{N_\ell}}$$

$$f_{\text{tot}} = f_{\text{lum}} \times f_{\varepsilon_\gamma} \times f_{\varepsilon_\ell}$$

applying this to the CSC 95% CL limits gives:

$$t\bar{t} \to bWq\gamma\text{: } 1.0 \times 10^{-5} \qquad t\bar{t} \to bWqZ\text{: } 4.7 \times 10^{-5}$$