rare top decays and FCNC at ATLAS

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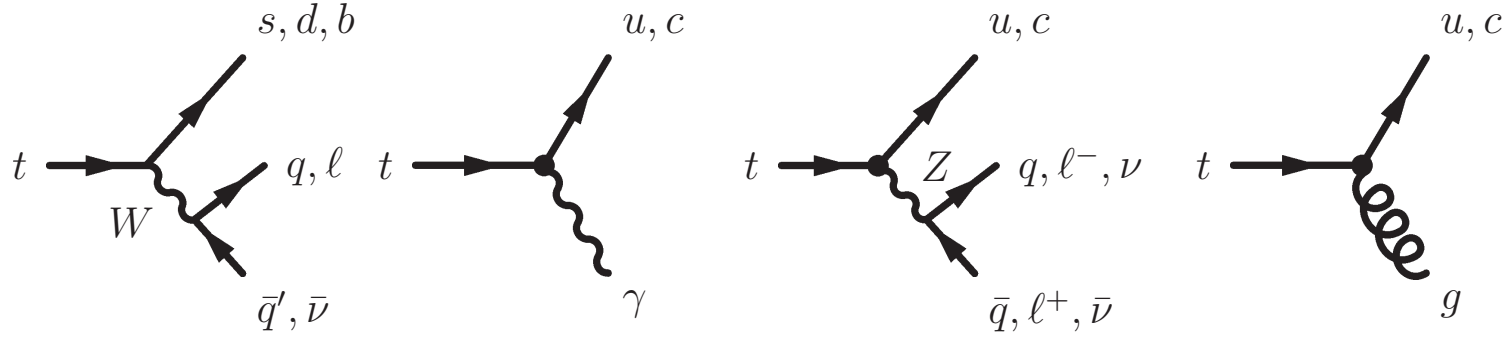
workshop on top physics at the LHC
13.mar.2009

top quark decays



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

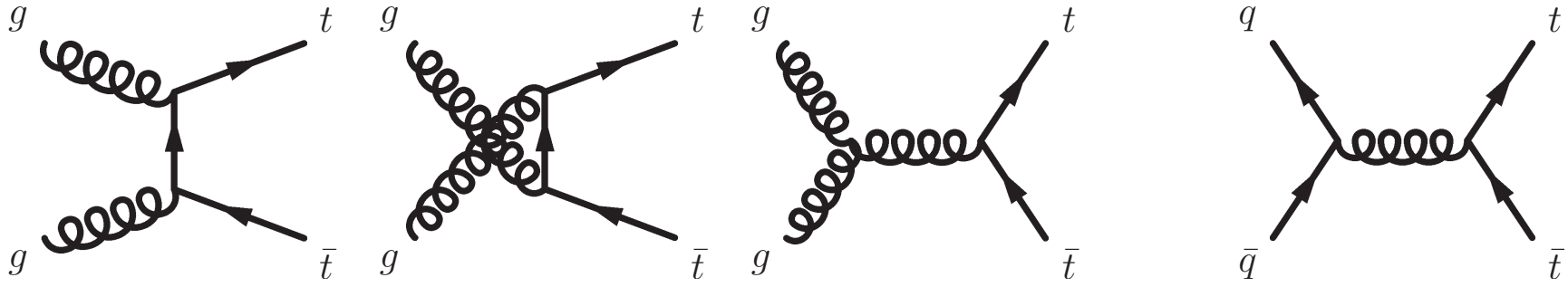
	SM	QS	2HDM	FC 2HDM	MSSM	$\not R$ SUSY	TC2
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$
$t \to qg$	$\sim 10^{-12}$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

present experimental limits:

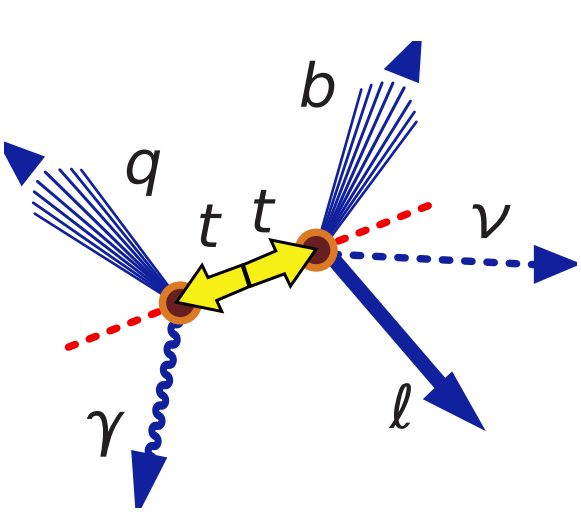
	LEP	HERA	Tevatron
$Br(t \to q\gamma)$	2.4 %	0.75 %	3.2 %
$Br(t \to qZ)$	7.8 %	49%	3.7 %
$Br(t \to qg)$	17 %	13 %	0.1 – 1 % (estimated)

expected signals at the LHC

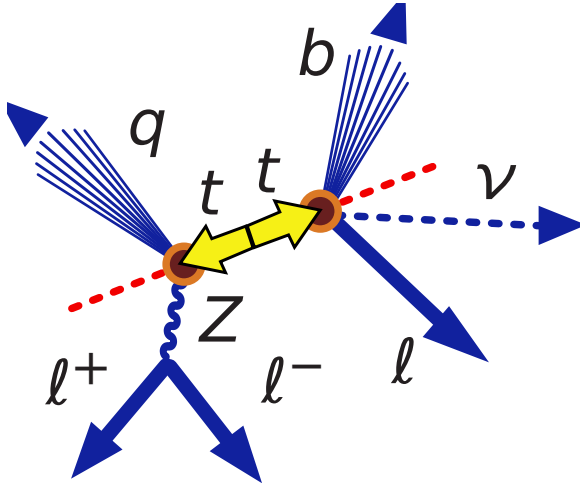
top quark pair production:



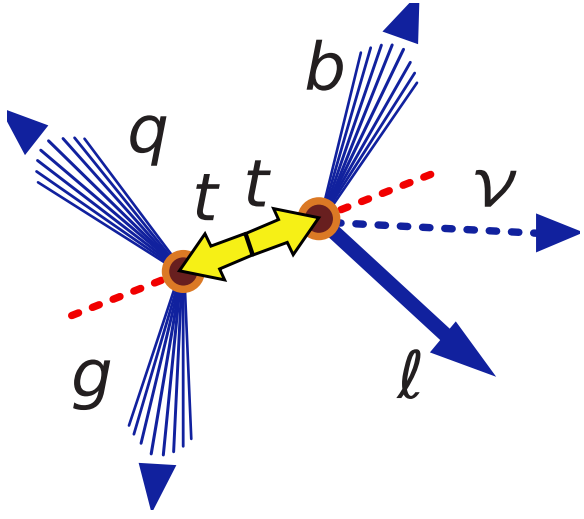
$$\sigma = 833 \pm 100 \text{ pb}$$



$t\bar{t} \to bWq\gamma$



$t\bar{t} \to bWqZ$



$t\bar{t} \to bWqg$

ATLAS CSC study

- preparing for first data samples
- $L = 1$ 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 fb^{-1} – 14 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)

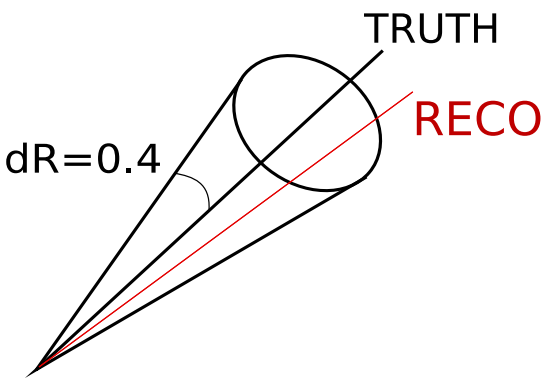
reconstruction efficiencies

reconstruction efficiencies (%):

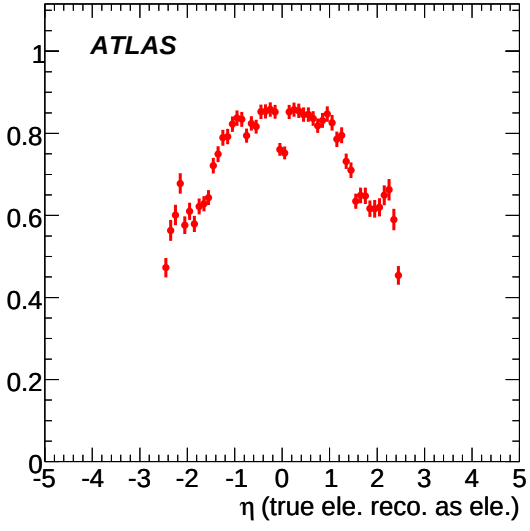
- e = 76.8 ± 0.3
- μ = 93.9 ± 0.3
- γ = 66.6 ± 0.8
- q/g = 92.7 ± 0.1

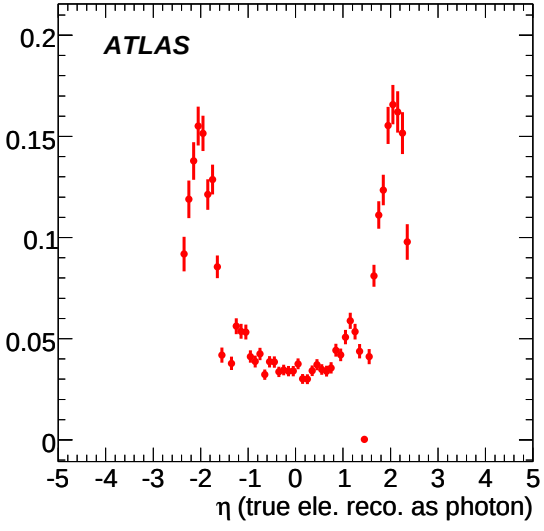
mistag was also studied, eg (%):

- γ as jet = 31.2 ± 0.5
- q/g as γ = 0.176 ± 0.003
- e as μ = 0.005 ± 0.002

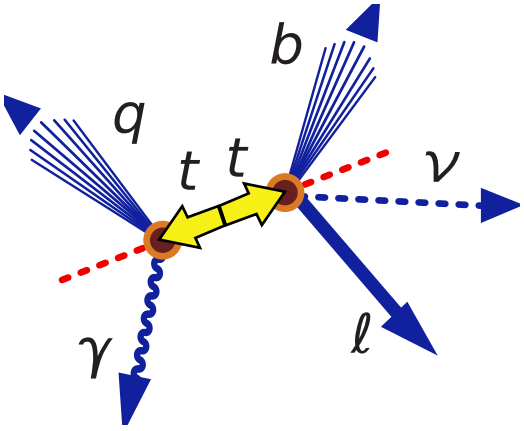


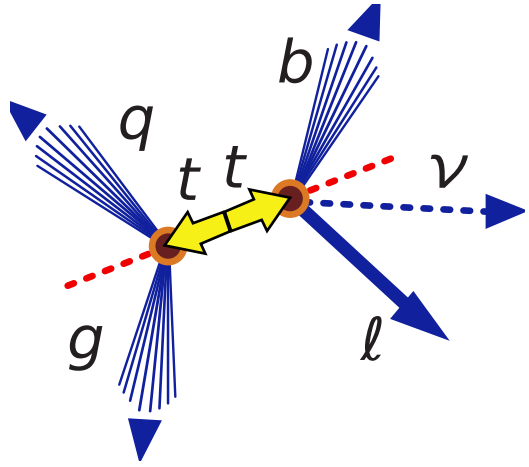
$p_T^{\text{true}} > 25$ GeV

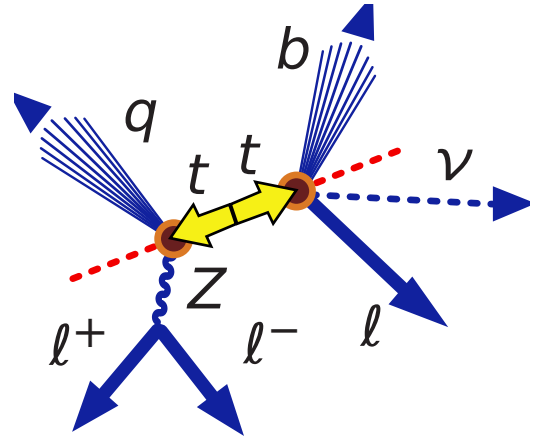




event selection







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

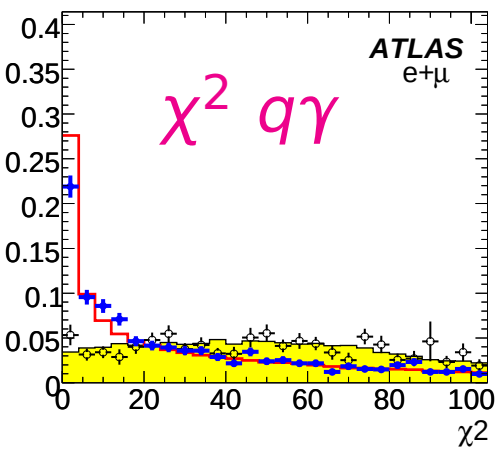
$$\chi^2 = \frac{\left(m_t^{FCNC} - m_t\right)^2}{\sigma_{m_t}^2} + \frac{\left(m_t^{SM} - m_t\right)^2}{\sigma_{m_t}^2} + \frac{\left(m_W^{SM} - m_W\right)^2}{\sigma_{m_W}^2} + \frac{\left(m_Z^{SM} - m_Z\right)^2}{\sigma_{m_Z}^2}$$

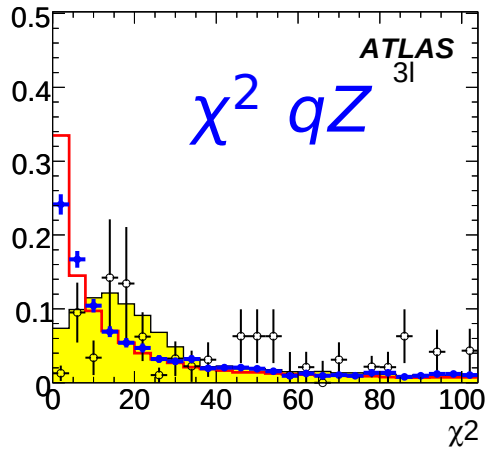
$$(b, q, g = j_1, j_2, j_3) \qquad (\ell, Z \to \ell^+\ell^- = \ell_1, \ell_2, \ell_3)$$

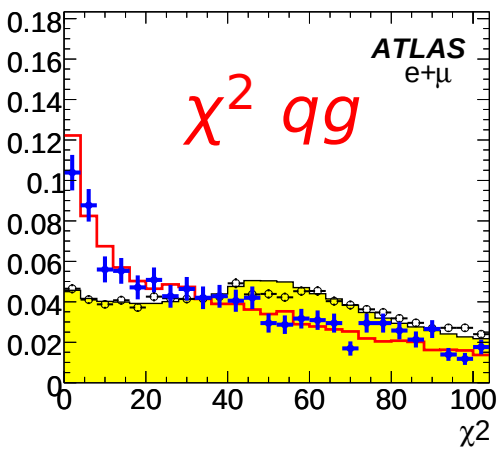
$m_t = 175$ GeV
$\sigma_t = 14$ GeV

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

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





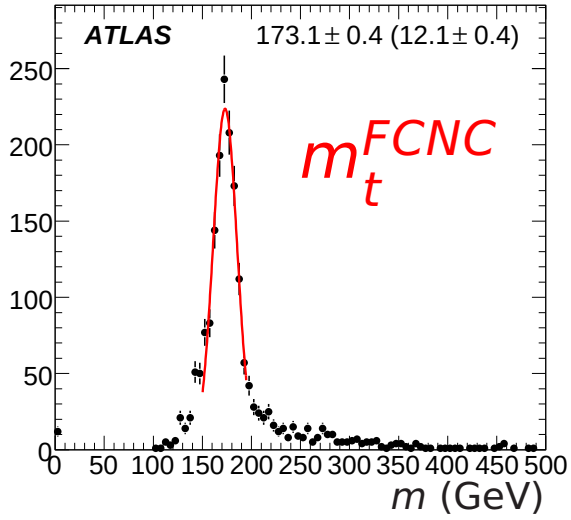


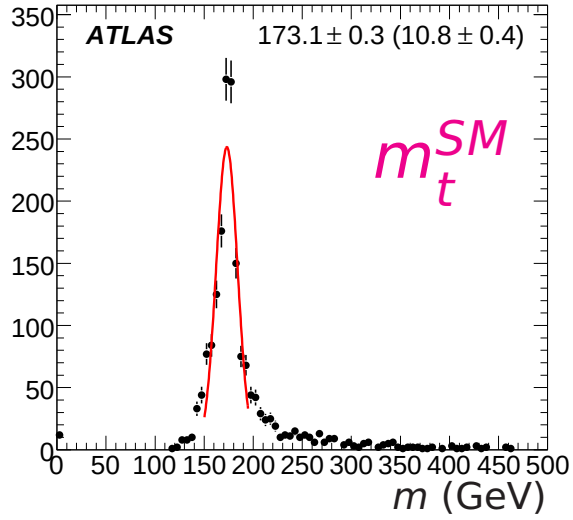
– Signal ATLFAST + Signal FullSim Backgr. ATLFAST ⊹ Background FullSim

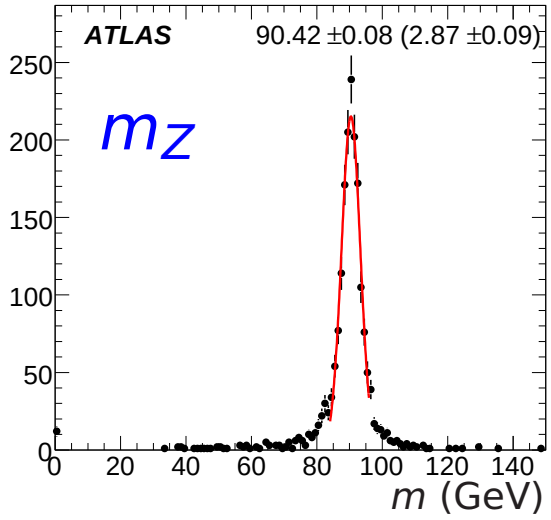
kinematics

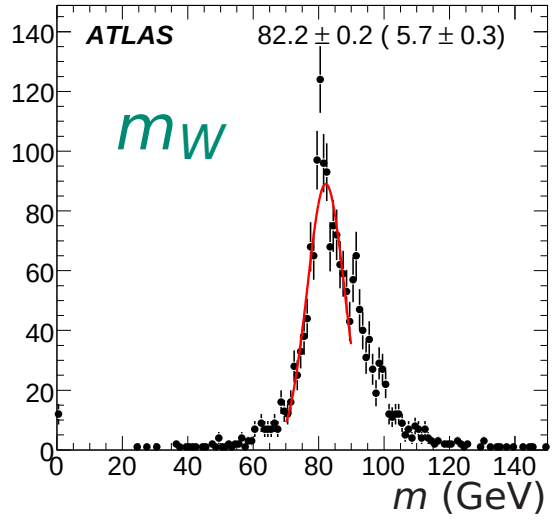
example:
$t\bar{t} \rightarrow bWqZ$

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

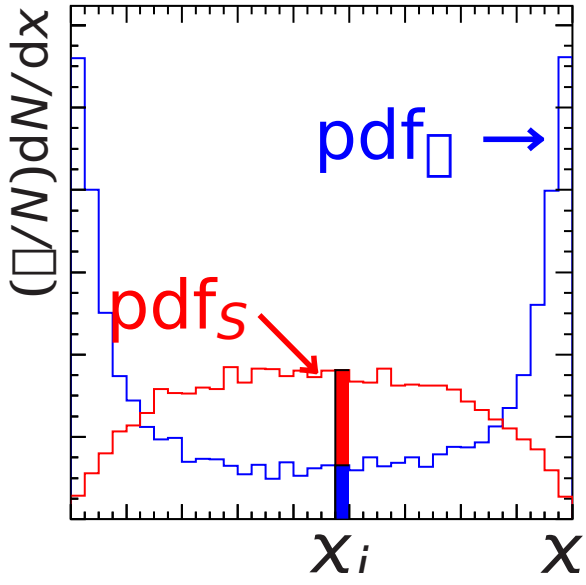
discriminant analysis

probabilistic analysis (after sequential)

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

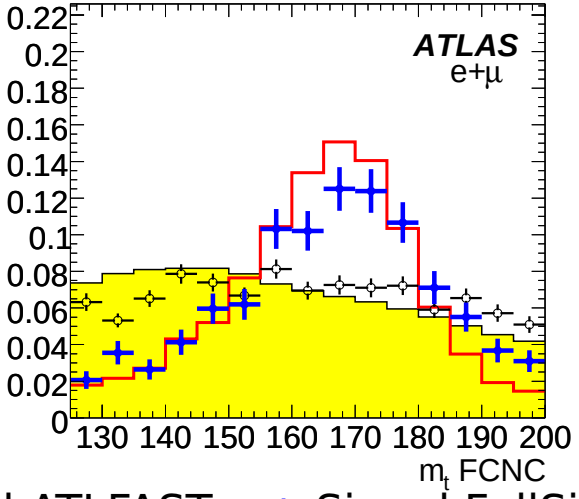
$$P_B = \Pi_{i=1}^{N} P_i^B(x_i)$$

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

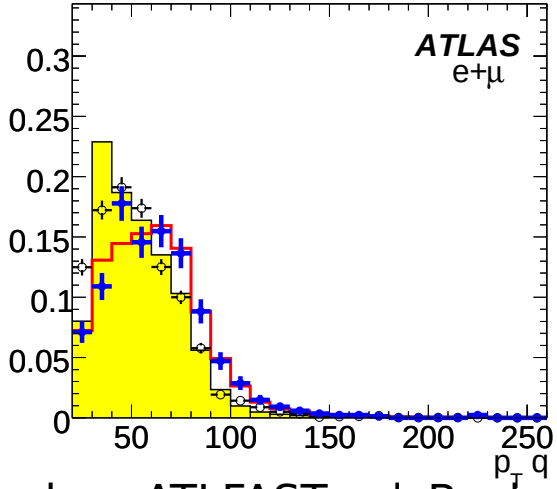


Typical distributions used as pdf:

masses



momenta

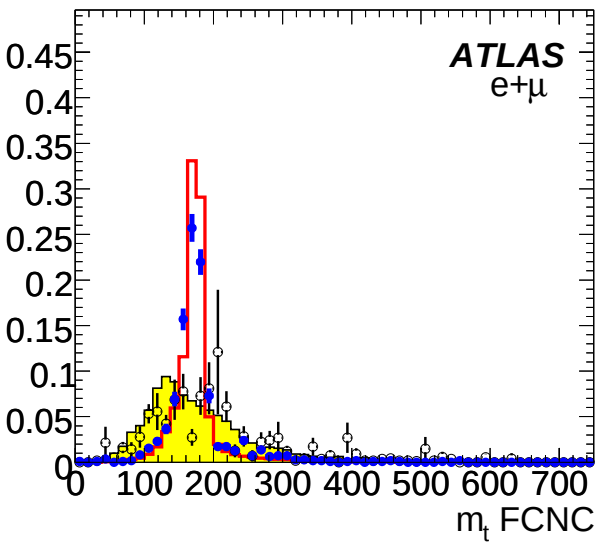


– Signal ATLFAST + Signal FullSim Backgr. ATLFAST Background FullSim

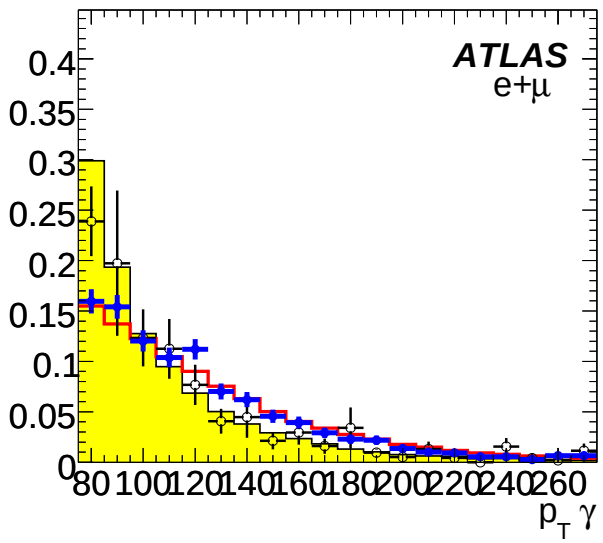
probability density functions

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

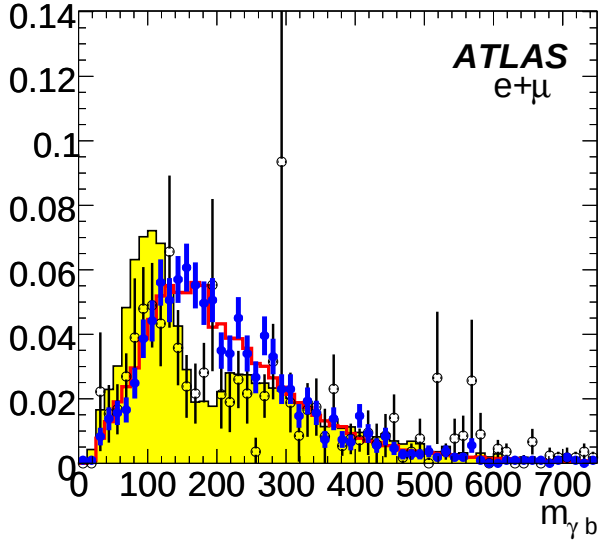
− Signal ATLFAST + Signal FullSim Backgr. ATLFAST ⟡ Background FullSim



m_t^{FCNC}



p_T^{γ}



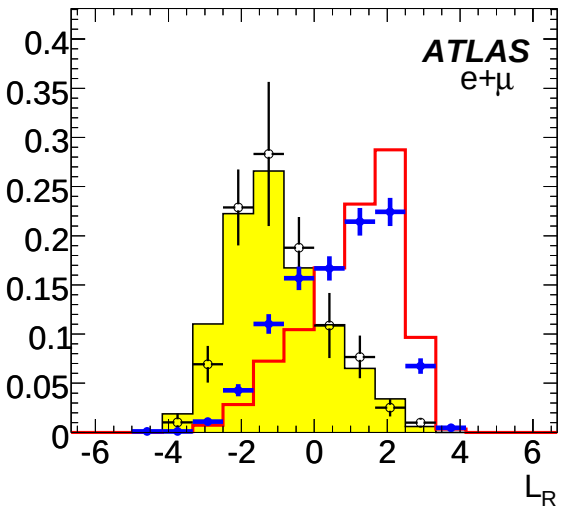
$m_{\gamma b}$

discriminant variables

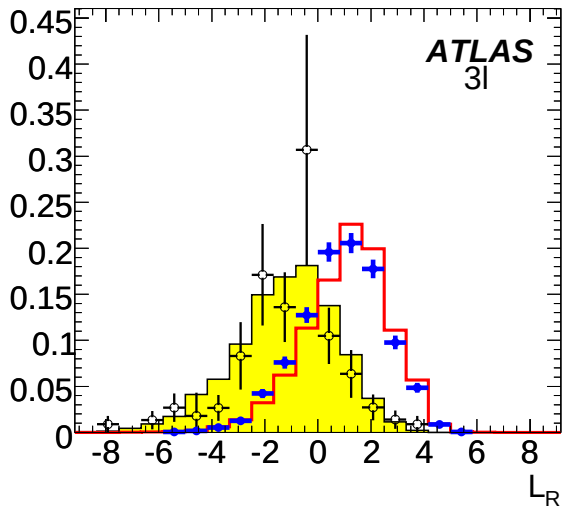
FullSim statistics not enough
→ ATLFAST (with reco. eff.) pdf used

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

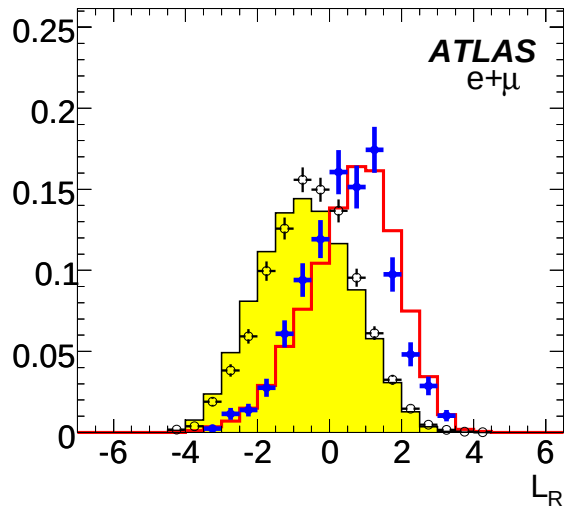
– Signal ATLFAST + Signal FullSim Backgr. ATLFAST ⟡ Background FullSim



$q\gamma$



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}

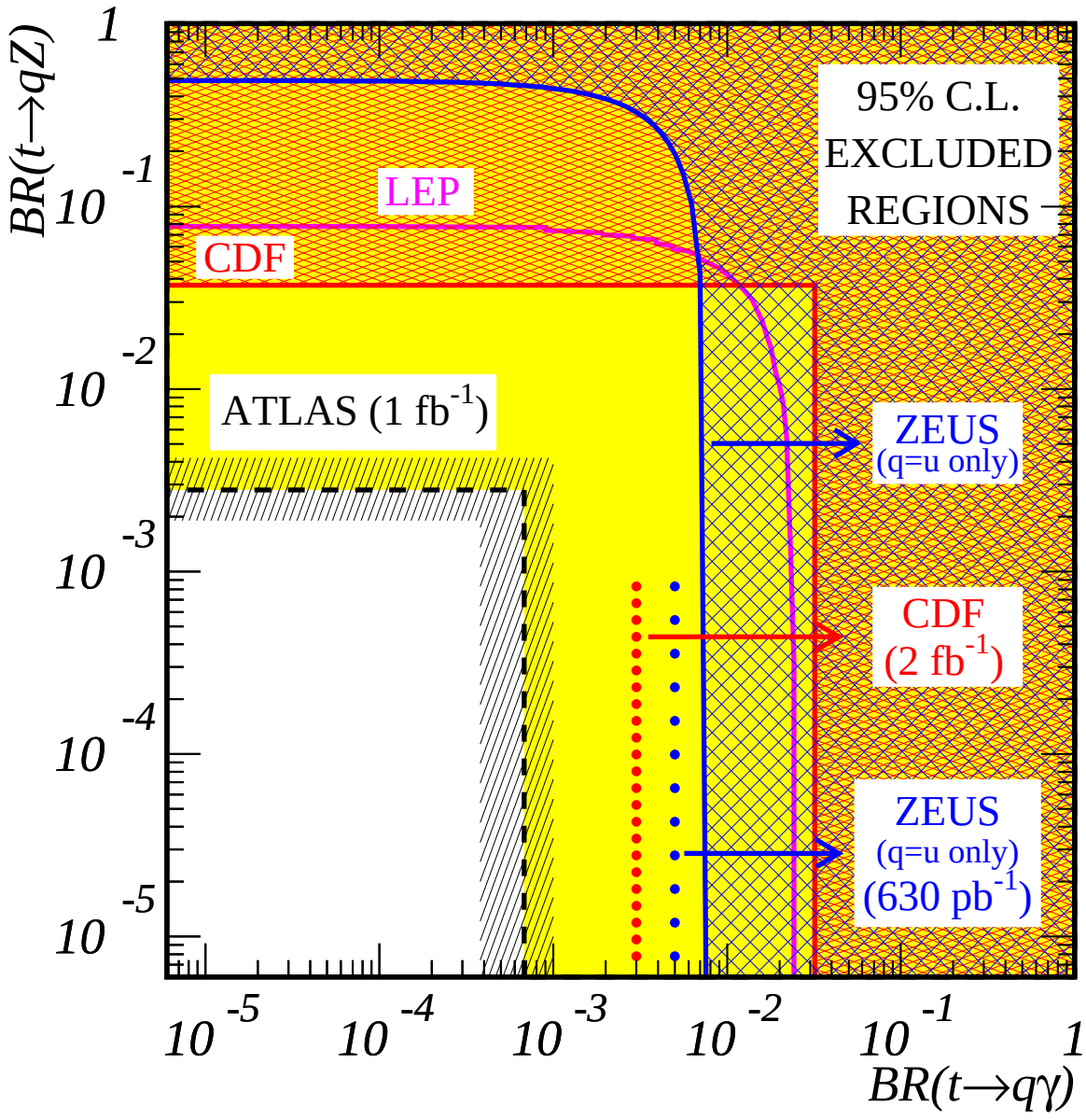
5σ discovery hipothesis (BR>) are on average 3.0 times larger

systematic uncertainties

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

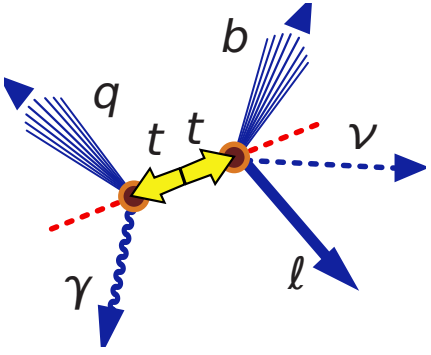
source	$t \to q\gamma$	$t \to qZ$	$t \to qg$
systematic uncertainties:			
jet energy calibration	2%	5%	4%
luminosity	10%	6%	10%
top mass	6%	12%	5%
backgrounds σ	7%	12%	15%
ISR/FSR	17%	7%	9%
pile-up	22%	0%	13%
generator	4%	14%	4%
χ^2	4%	7%	9%
total	32%	25%	27%
analysis stability:			
selection criteria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

comparison of results

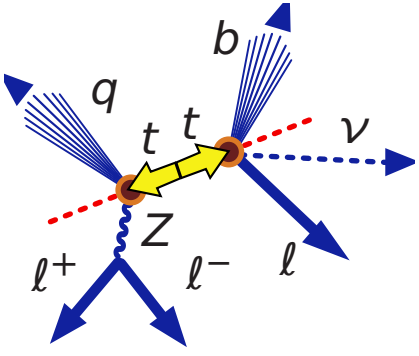


rescaling to 10 TeV

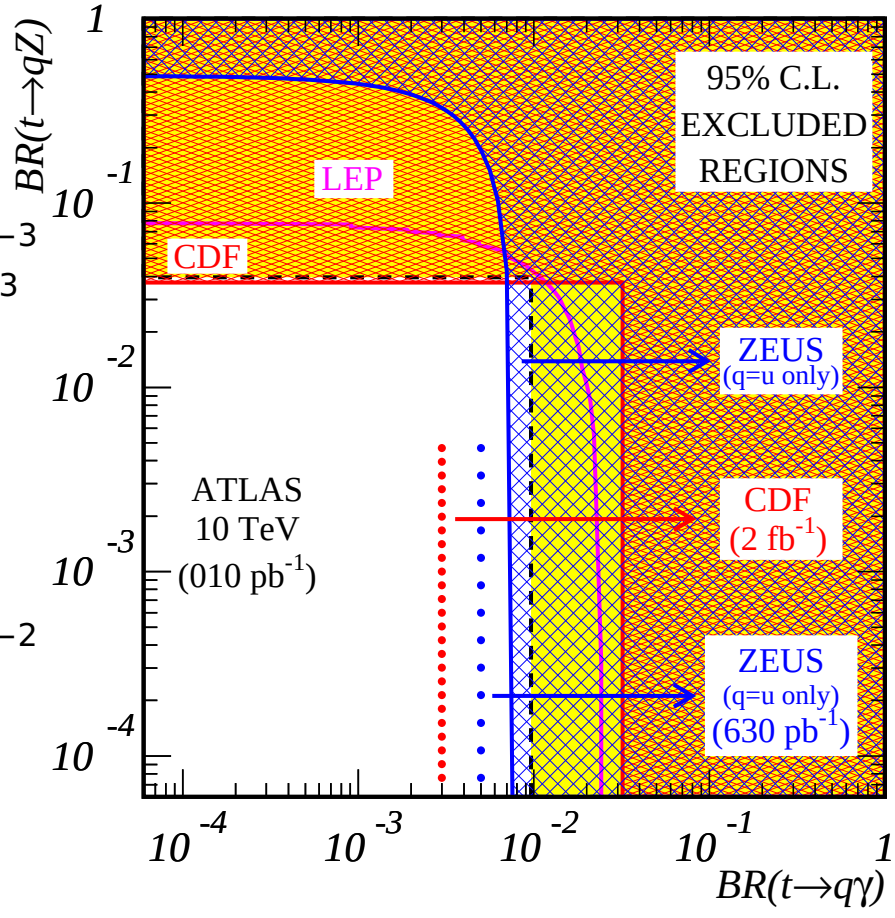
at 10 TeV ATLAS might be competitive with just 10–50 pb^{-1}
(CSC 95% CL limits rescaled)



$t\bar{t} \to bWq\gamma$
ATLAS = 9.6×10^{-3}
ZEUS = 7.5×10^{-3}



$t\bar{t} \to bWqZ$
ATLAS = 4.0×10^{-2}
CDF = 3.7×10^{-2}



conclusions and outlook

- FCNC top quark decays can be studied with ATLAS
  - 3 decay channels were studied
  - results with 1 fb^{-1} will be one order of magnitude better than present BR limits
- future improvements
  - 10 TeV analyses
  - study other multivariate data analysis methods
  - include jet tagging in χ^2 reconstruction
  - data driven analyses