search for multilepton final states in top rare decays

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workshop on ”multi-lepton final states in search of new physics at the LHC”
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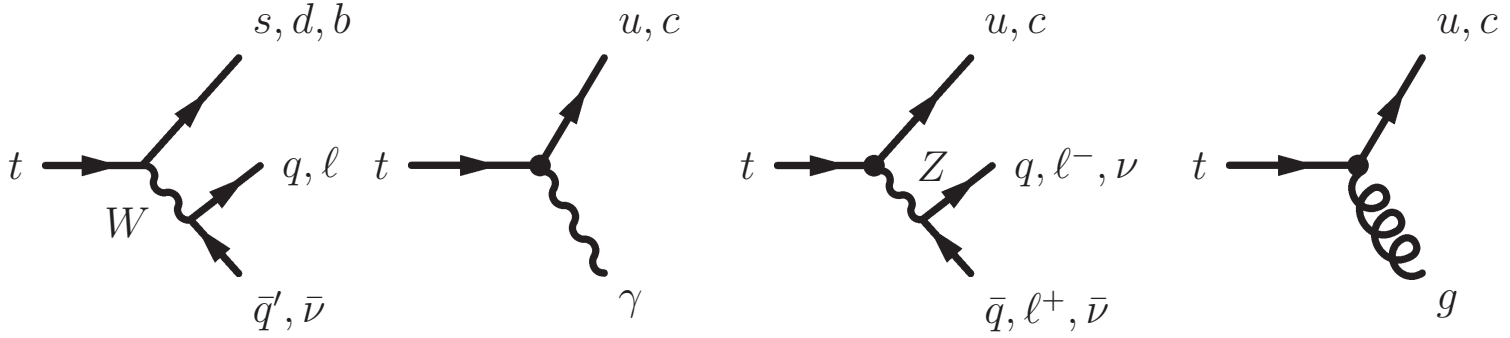
top quark decays



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

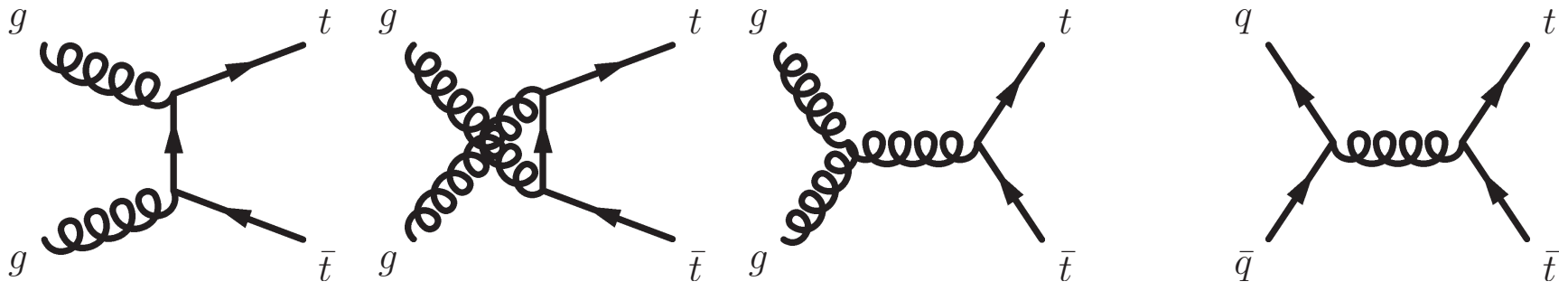
	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	TC2
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$
$t \to qg$	$\sim 10^{-12}$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

present experimental limits:

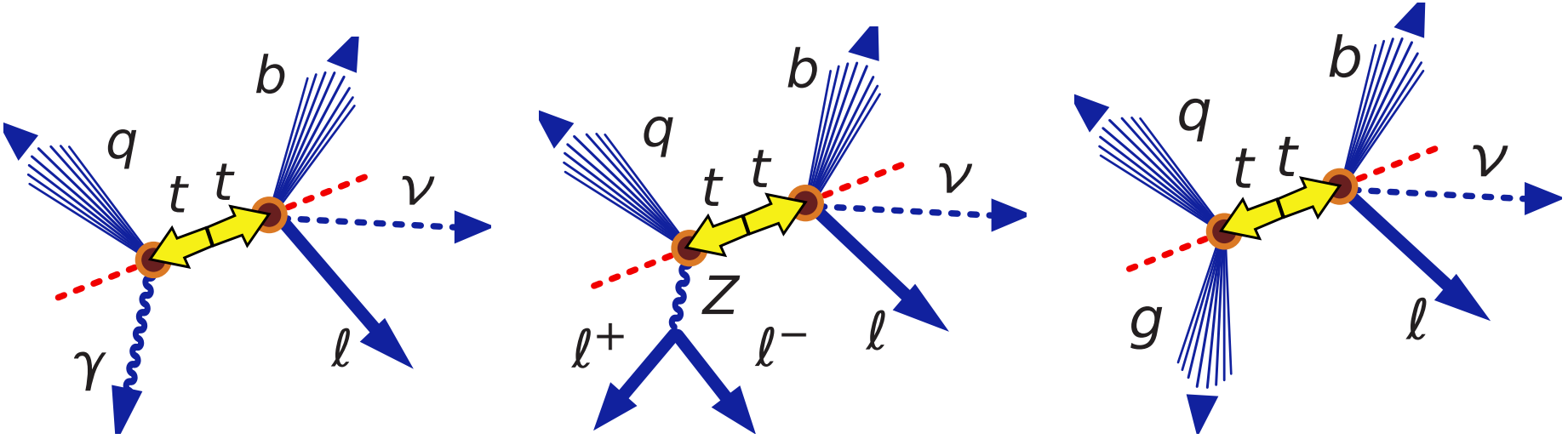
	LEP	HERA	Tevatron
$Br(t \to q\gamma)$	2.4 %	0.75 %	3.2 %
$Br(t \to qZ)$	7.8 %	49%	3.7 %
$Br(t \to qg)$	17 %	13 %	0.1 – 1 % (estimated)

expected signals at the LHC

top quark pair production:



final states with leptons:



$t\bar{t} \to bWq\gamma$ $\quad$ $t\bar{t} \to bWqZ$ $\quad$ $t\bar{t} \to bWqg$

$\downarrow$

multilepton final state

ATLAS CSC study

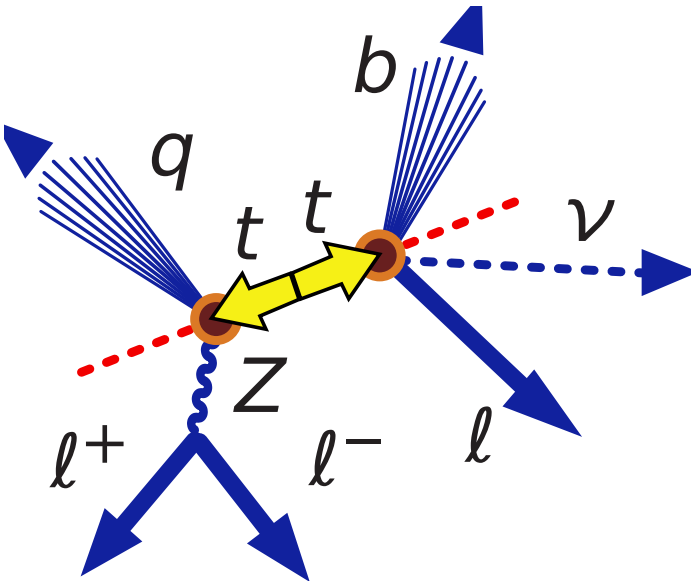
- preparing for first 14 TeV data samples
  - L =1 fb^{-1}
  - no b-tag
- ATLAS full simulation samples:
  - luminosity per background sample: 0.02 fb^{-1} – 14 fb^{-1}

regular samples:

process	generator
$t\bar{t} \rightarrow bWqZ$	TopReX
$t\bar{t} \rightarrow bWbW$	MC@NLO
single top	AcerMC
$Z \rightarrow \ell^+\ell^-$	HERWIG
$W \rightarrow \ell\nu + nj$	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



$t\bar{t} \rightarrow bWqZ$

topology selection:

- $= 3\ell$ ($p_T > 25, 15, 15$ GeV)
- $\geq 2j$ ($p_T > 30, 20$ GeV)
- $= 0\gamma$ ($p_T > 15$ GeV)
- $\not{p}_T > 20$ GeV

background rejection:

- 2 ℓ same flavour and opposite charge

trigger menus:

- e25i or mu20i

$\ell = e$ or μ

kinematics reconstruction

method without jet tagging algorithms:

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

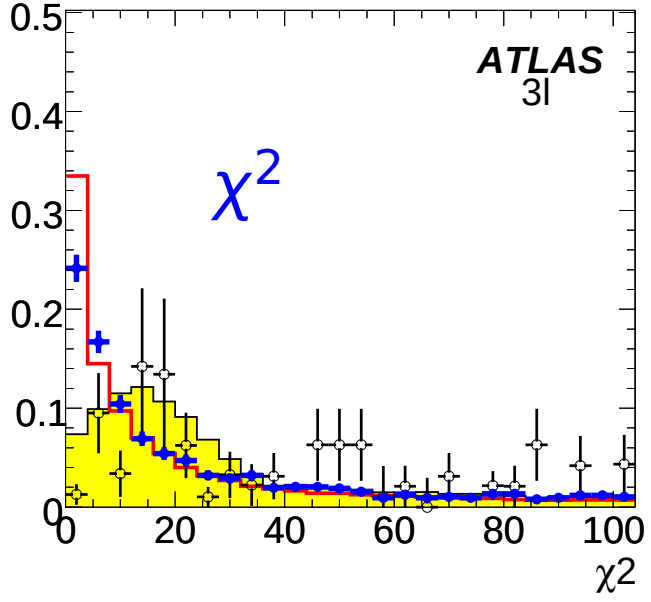
$$\chi^2 = \frac{\left(m_t^{FCNC} - m_t\right)^2}{\sigma_{m_t}^2} + \frac{\left(m_t^{SM} - m_t\right)^2}{\sigma_{m_t}^2} + \frac{\left(m_W^{SM} - m_W\right)^2}{\sigma_{m_W}^2} + \frac{\left(m_Z^{SM} - m_Z\right)^2}{\sigma_{m_Z}^2}$$

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

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

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

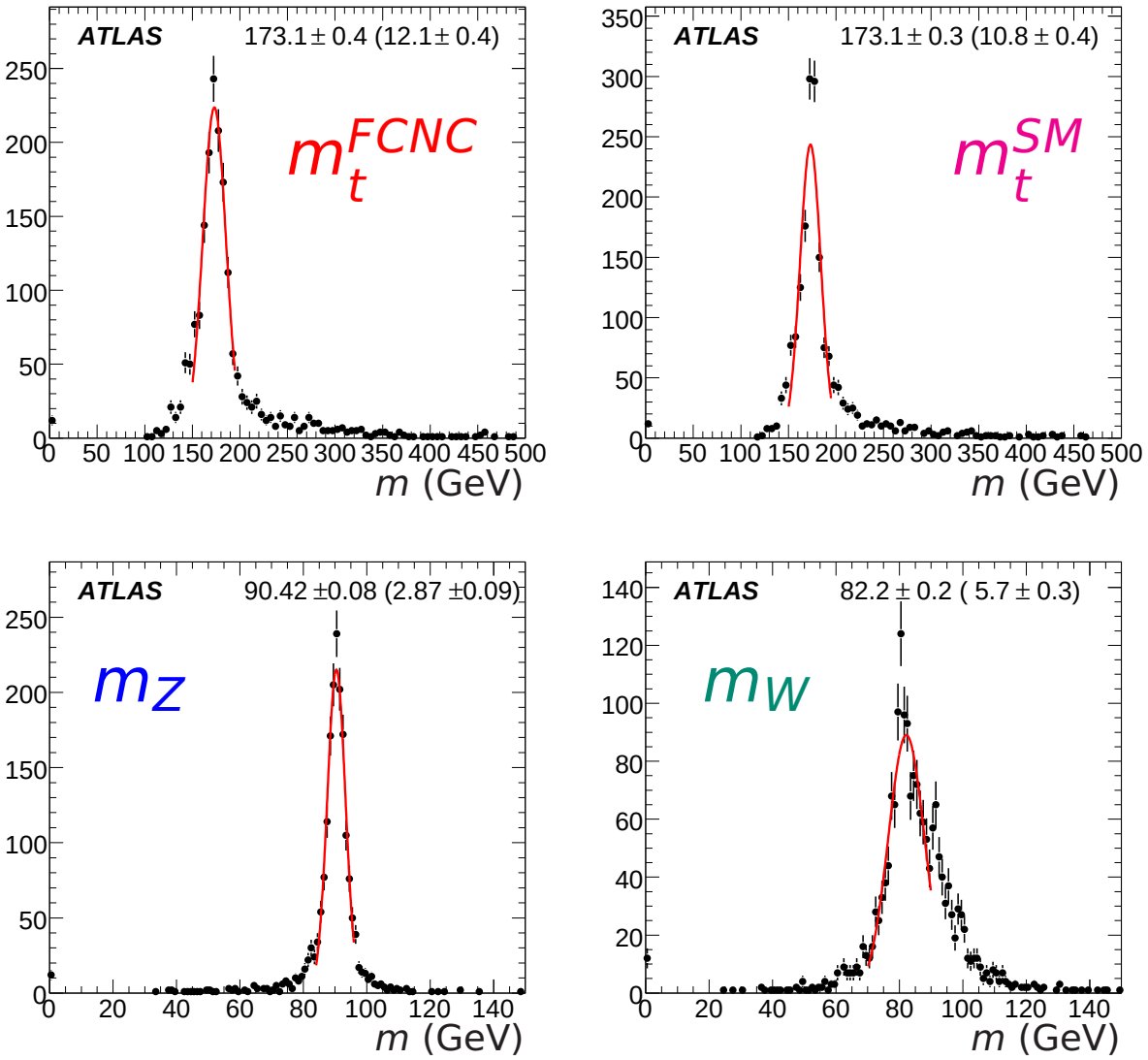
$m_Z = 91.19$ GeV
$\sigma_Z = 3$ GeV



− Signal ATLFAST + Signal FullSim Backgr. ATLFAST Background FullSim

kinematics

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

14 TeV, $L = 1\ \mathrm{fb}^{-1}$

number of events after cut based selection:

	e	μ	ℓ
$t\bar{t} \to bWqZ$:			
Total	28 ± 55	11 ± 55	125 ± 56
Signal %	1.4 ± 0.1	2.5 ± 0.1	7.6 ± 0.2

single lepton trigger efficiencies were also studied:

	Sig.	Back.
L1	99.9	100.0
L2	99.5	96.9
trigger	99.2	95.0

dominant backgrounds:

$t\bar{t}$	$Z+j$	dB
59%	28%	13%

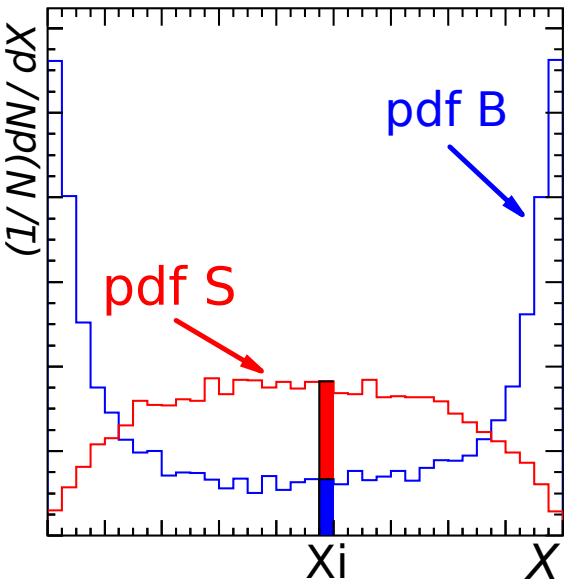
discriminant analysis

probabilistic analysis (after cut based selection)

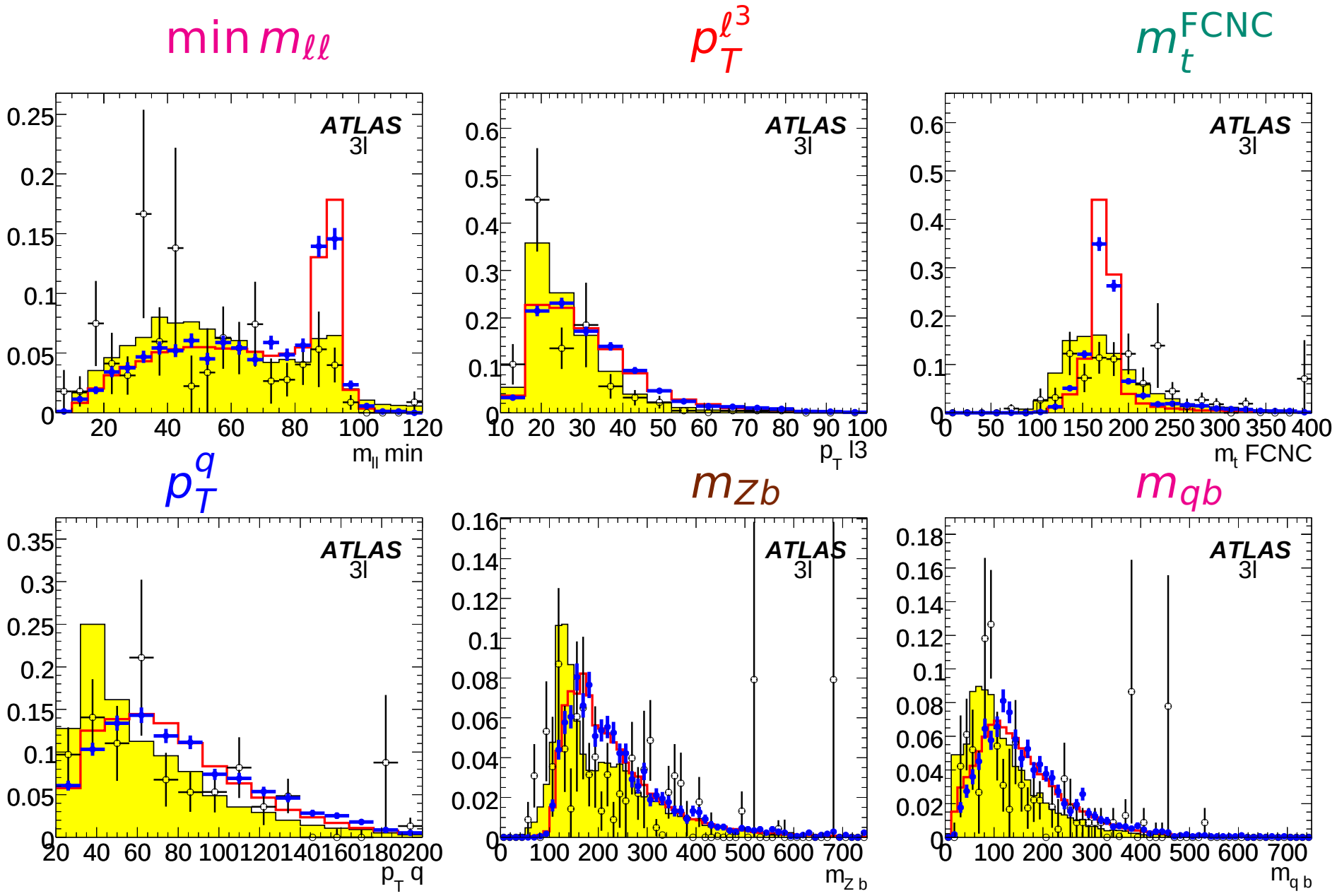
$$P_S = \Pi_{i=1}^{N} P_i^S(x_i)$$

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

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



probability density functions

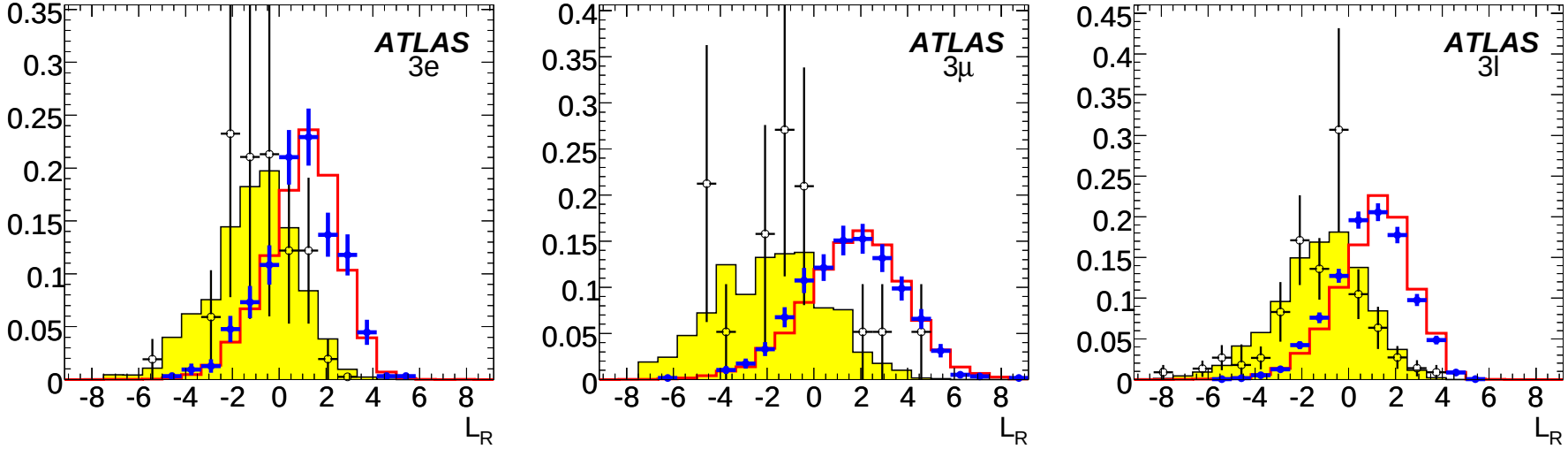


discriminant variables

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



e μ ℓ

results

14 TeV, $L = 1\ \mathrm{fb}^{-1}$

expected 95% CL limits (BR<):

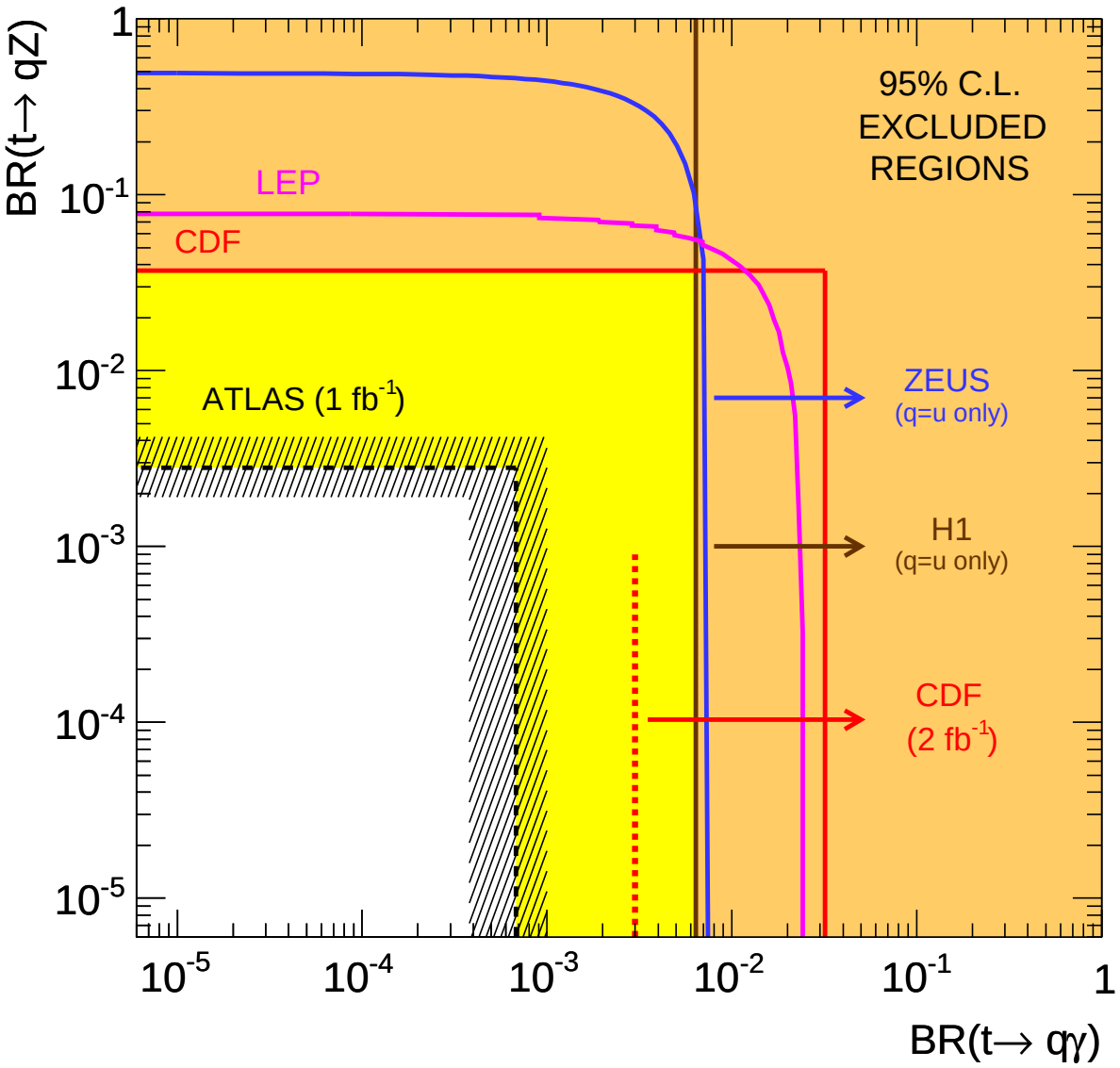
	-1σ	expected	$+1\sigma$
$3e$	5.5×10^{-3}	9.4×10^{-3}	1.4×10^{-2}
3μ	2.4×10^{-3}	4.2×10^{-3}	6.4×10^{-3}
3ℓ	1.9×10^{-3}	2.8×10^{-3}	4.2×10^{-3}

systematic uncertainties

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

source	
systematic uncertainties:	
jet energy calibration	5%
luminosity	6%
top mass	12%
backgrounds σ	12%
ISR/FSR	7%
pile-up	0%
generator	14%
χ^2	7%
total	25%
analysis stability:	
selection criteria	12%

comparison of results



extrapolation to 7 TeV

values can be extrapolated from previous results using the expression for the estimation of the 5σ discovery limits:

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

factors for extrapolation from 14 TeV to 7 TeV with 1 fb^{-1}:

$$f_\sigma^{\text{signal}} = \frac{833\ \text{pb}}{160\ \text{pb}} \qquad f_\sigma^{\text{back.}} = \sqrt{\frac{160\ \text{pb}}{833\ \text{pb}}}$$

$$f_{\text{tot}} = f_\sigma^{\text{signal}} \times f_\sigma^{\text{back.}}$$

applying this to the CSC 95% CL limits gives:

$$t\bar{t} \rightarrow bWqZ\text{: } 6.4 \times 10^{-3}$$

conclusions and outlook

- FCNC top quark decays can be studied with ATLAS
  - multilepton signature
  - results with 1 fb^{-1} will be one order of magnitude better than present BR limits
- future improvements
  - dedicated 7 TeV analyses
  - study other multivariate data analysis methods
  - include jet tagging in χ^2 reconstruction
  - data driven analyses

b a c k u p

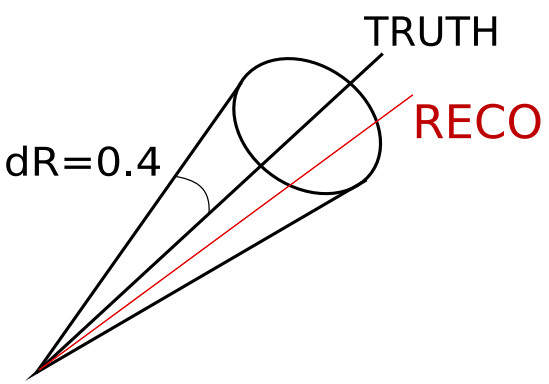
reconstruction efficiencies

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