Search for Flavor Changing Neutral Currents in Top Quark Decays

Fake Rates and Initial Asimov Fits

Jason Barkeloo

February 20, 2020

Overview

Brief Background
    The Top Quark
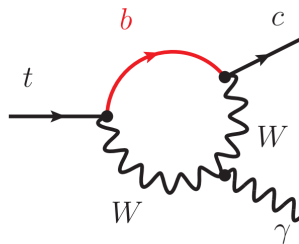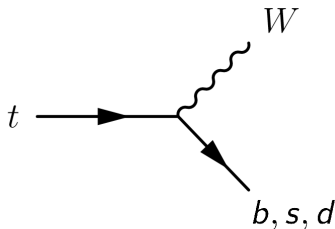   FCNC at the LHC

Fake Rate Studies
    $e \to \gamma$ Fake Rate Studies
    $j \to \gamma$ Fake Rate Studies: ABCD Method

Asimov Data Initial Fits
    Asimov Fit, e+jets channel MC16a

Outlook and Conclusions

Brief Background
Fake Rate Studies
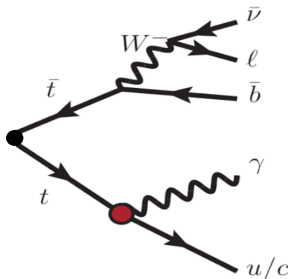Asimov Data Initial Fits
Outlook and Conclusions

The Top Quark
FCNC at the LHC

Top Quark Decays in the SM

- $t \to bW \approx 99.83\%$
- $t \to sW \approx 0.16\%$
- $t \to dW \approx 0.01\%$

- $t \to q_{u,c}X \approx 10^{-17} - 10^{-12}$
- Limits on $t \to \gamma q$ processes:
  [Phys.Lett. B800 135082]
  - $t \to \gamma u < 2.8x10^{-5}$
  - $t \to \gamma c < 18x10^{-5}$

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

The Top Quark
FCNC at the LHC

FCNC: What are we looking for? $t\bar{t} \rightarrow W(\rightarrow l\nu)b + q\gamma$
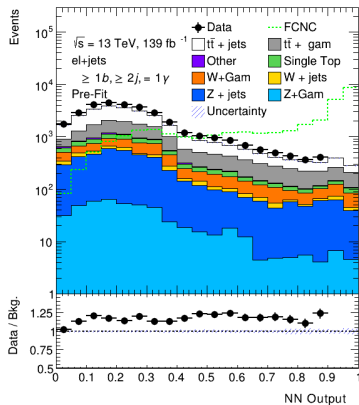
Will further investigate BJets here.

▶ Final state topology

   ▶ One Neutrino, from W
   ▶ One Lepton, from W
   ▶ One B-jet, SM Top
   ▶ One Photon, FCNC Top
   ▶ One Jet, FCNC Top
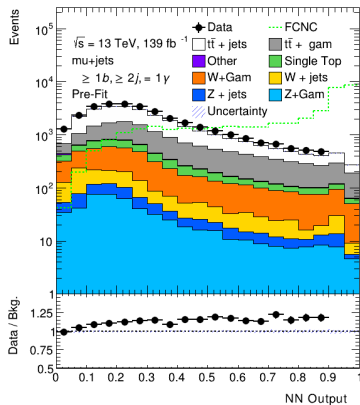
Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

The Top Quark
FCNC at the LHC

Preselection NN Outputs

▶ $e+$jets

▶ $\mu+$jets

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \rightarrow \gamma$ Fake Rate Studies
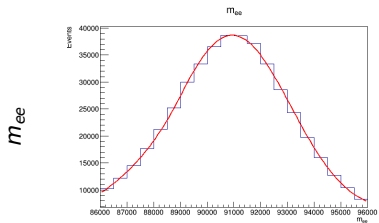$j \rightarrow \gamma$ Fake Rate Studies: ABCD Method

Fake Rate Object Selection

▶ Want to calculate fake rate in events which could enter the signal region.

▶ Create 2 control regions: $Z \rightarrow ee$ and $Z \rightarrow e\gamma$

▶ Require:
  ▶ Common Object Selection (MET,Jets,Triggers, etc.)
  ▶ Exactly 1Bjet
  ▶ $Z \rightarrow ee$: 2 Opposite Sign Electrons, 86.1 GeV $< m_{e^+e^-} <$ 96.1 GeV
  ▶ $Z \rightarrow e\gamma$:1 Electron, $\geq$1 Photon, 86.1 GeV $< m_{e\gamma} <$ 96.1 GeV

▶ Tag and Probe Method used

▶ Systematic determined by varying tail size and other parameters

Brief Background
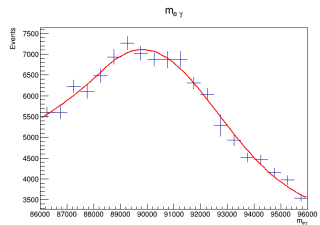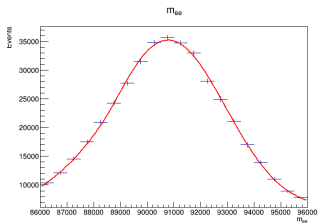Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \longrightarrow \gamma$ Fake Rate Studies
$j \longrightarrow \gamma$ Fake Rate Studies: ABCD Method

$m_{ee}, m_{e\gamma}$

Data and MC

▶ Data

▶ Monte Carlo

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \rightarrow \gamma$ Fake Rate Studies
$j \rightarrow \gamma$ Fake Rate Studies: ABCD Method
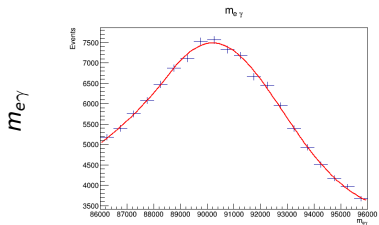
Scale Factor

$$FR^{e\text{-fake}} = \frac{N_{e,\gamma}}{N_{e,e}}$$

$$SF_{FR}^{e\text{-fake}} = \frac{FR_{data}^{e\text{-fake}}}{FR_{MC}^{e\text{-fake}}}$$

Basic Scale Factor can be calculated for the entire spectrum:
$SF_{FR}^{e\text{-fake}} = 0.97 \pm 0.01$

In practice this scale factor is calculated for converted and unconverted photons as well as in bins of η and ϕ

▶ Converted photons pair produce before the ECAL leaving tracks in the Inner Detector

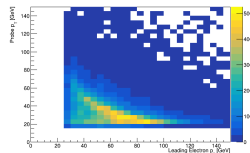▶ Unconverted photons only pair produce inside of the ECAL

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \rightarrow \gamma$ Fake Rate Studies
$j \rightarrow \gamma$ Fake Rate Studies: ABCD Method

Data and MC Distributions

▶ Probe e ▶ Converted γ ▶ Unconverted γ

Data

MC

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \longrightarrow \gamma$ Fake Rate Studies
$j \longrightarrow \gamma$ Fake Rate Studies: ABCD Method

2D Fake Rates

▶ Converted γ

▶ Unconverted γ

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions
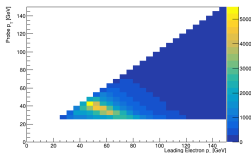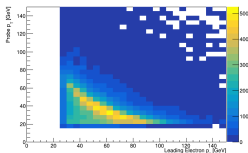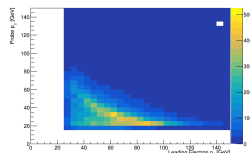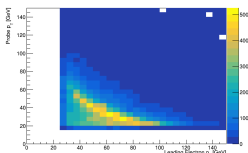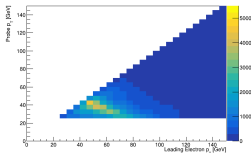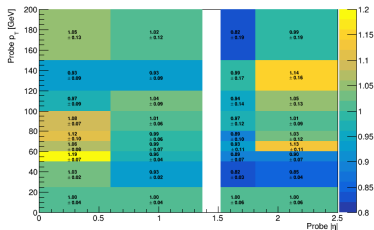
$e \rightarrow \gamma$ Fake Rate Studies
$j \rightarrow \gamma$ Fake Rate Studies: ABCD Method
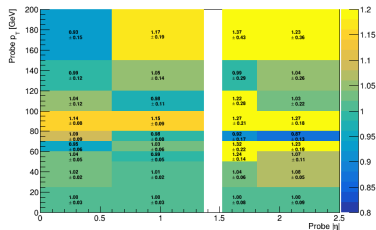
$j \rightarrow \gamma$ Fake Rate Studies

Majority of hadronic fake photons from from $t\bar{t}$ events where a final state jet radiates a non-prompt photon. Similarly radiated photons for W+jets and single top processes can enter the signal region through the radiation of a non-prompt photon.

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \rightarrow \gamma$ Fake Rate Studies
$j \rightarrow \gamma$ Fake Rate Studies: ABCD Method
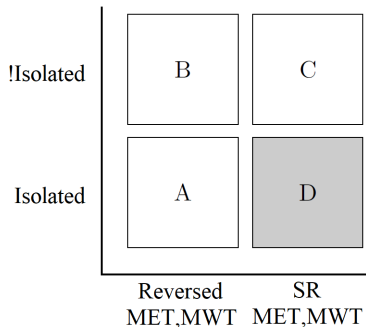
ABCD Method

$$\frac{N_D^{\text{h-fake}}}{N_C^{\text{h-fake}}} = \frac{N_A^{\text{h-fake}}}{N_B^{\text{h-fake}}} \text{ and } \frac{N_D^{\text{h-fake}}}{N_A^{\text{h-fake}}} = \frac{N_C^{\text{h-fake}}}{N_B^{\text{h-fake}}}$$

Want uncorrelated variables, use a correction factor to account to ensure closure

$$\theta_{\text{MC}} = \frac{N_{D,\text{MC}}^{\text{h-fake}} / N_{C,\text{MC}}^{\text{h-fake}}}{N_{A,\text{MC}}^{\text{h-fake}} / N_{B,\text{MC}}^{\text{h-fake}}}$$

$$N_{D,\text{est.}}^{\text{h-fake}} = \frac{N_{A,\text{data}}^{\text{h-fake}} \times N_{C,\text{data}}^{\text{h-fake}}}{N_{B,\text{data}}^{\text{h-fake}}} \times \theta_{\text{MC}}$$

	!Isolated	
	B	C
Isolated	A	D
	Reversed MET,MWT	SR MET,MWT
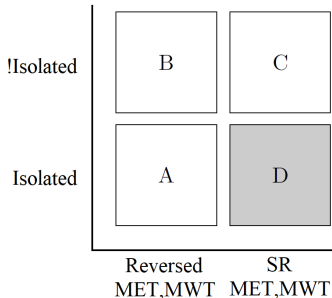
$$\text{SF}^{\text{h-fake}} = \frac{N_{D,\text{est.}}^{\text{h-fake}}}{N_{D,\text{MC}}^{\text{h-fake}}}$$

Brief Background
Fake Rate Studies
Asimov Data Initial Fits
Outlook and Conclusions

$e \rightarrow \gamma$ Fake Rate Studies
$j \rightarrow \gamma$ Fake Rate Studies: ABCD Method

▶ Converted Photons

▶ Unconverted Photons

e channel
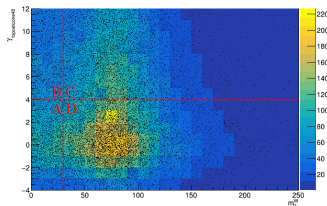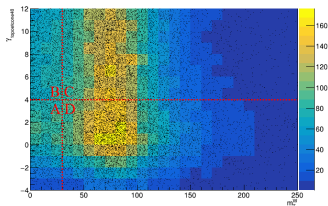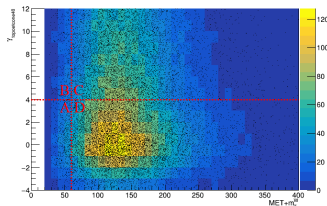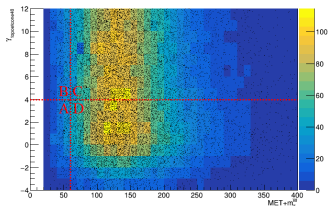
μ channel

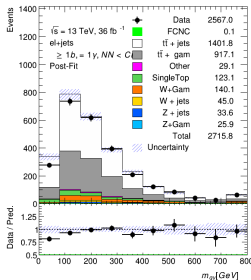| Channel:	Converted	Unconverted
Electron Channel	1.28 ± 0.34	1.99 ± 0.52
Muon Channel	1.23 ± 0.50	2.27 ± 0.92

Asimov Data Post-Fit
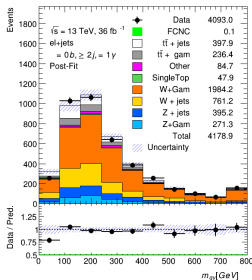
▶ VR1, W+γ ▶ VR2: $t\bar{t} + \gamma$ ▶ Signal Region
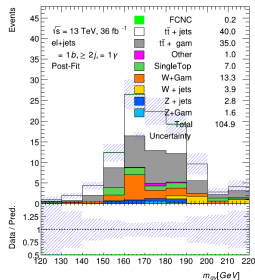
Nominal signal strength $\mu = 1.0 \Rightarrow$ Branching Ratio $= 10^{-3}$
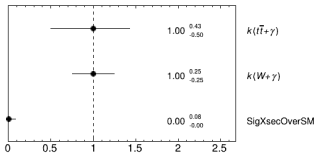
Statistical Limit from Asimov Fit

▶ Expected signal strength $\mu = 0.13^{+0.05}_{-0.04}$

▶ Corresponds to BR$(t \rightarrow q\gamma) = 13 \times 10^{-5}$

▶ Extrapolation to full data set limit: BR$(t \rightarrow q\gamma) \approx 4 \times 10^{-5}$

Outlook

- ▶ Fake rates calculated
- ▶ Full systematics samples almost done, one major sample being run locally
- ▶ Fitting machinery in place
- ▶ Internal note draft started, complete first draft expected by end of February
    - ▶ Will be hosted here: gitlab:fcnc-tqgam-decay-intnote
- ▶ New post-doc joining the project to help push toward publication either alone or in combination with production mode

Backup

FCNC Diagrams
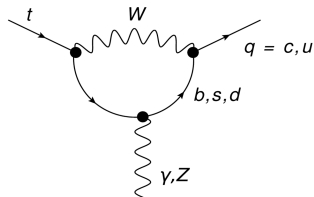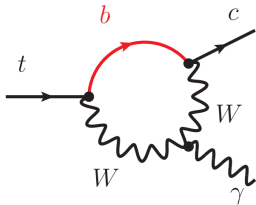
No Photon Scale Factors
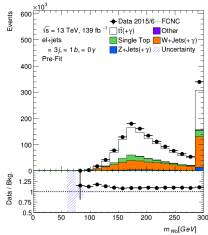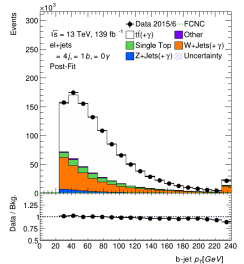
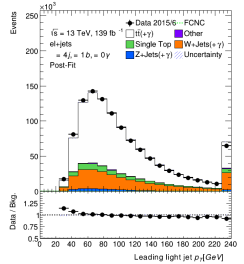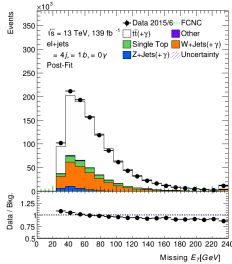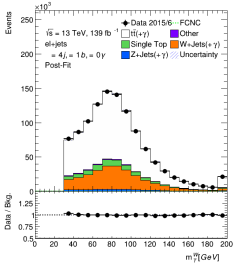▶ W+jets Rich   ▶ $t\bar{t}$+jets Rich   ▶ Validation Region
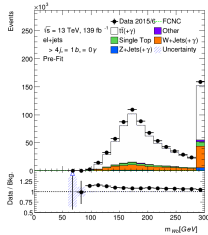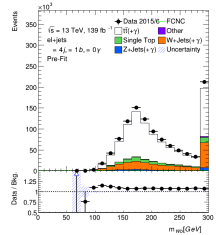
Before SF
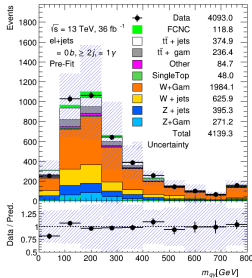

SF Applied
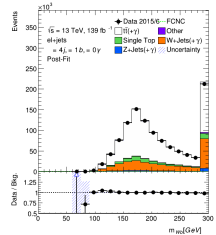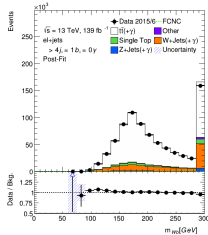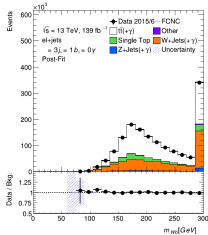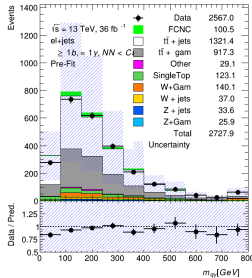
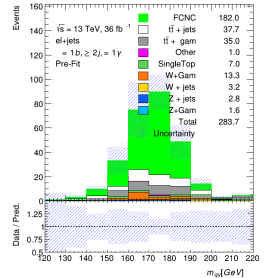# No Photon Region SF Applied in Val Region
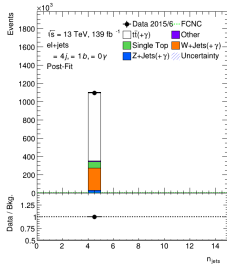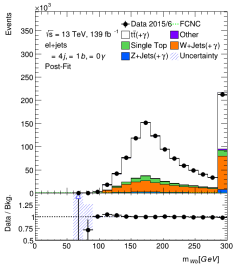
Asimov Data Pre-Fit

▶ VR1, W+γ ▶ VR2: $t\bar{t} + \gamma$ ▶ Signal Region

Jets/AntiKT

$$d_{ij} = min(\frac{1}{p_{ti}^2}, \frac{1}{p_{tj}^2})\frac{\Delta_{ij}^2}{R^2}$$

$$d_{iB} = \frac{1}{p_{ti}^2}$$

$$\Delta_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$$

▶ Find minimum of entire set of $\{d_{ij}, d_{iB}\}$

▶ If d_{ij} is the minimum particles i,j are combined into one particle and removed from the list of particles

▶ If d_{iB} is the minimum i is labelled as a final jet and removed from the list of particles

▶ Repeat until all particles are part of a jet with distance between jet axes Δ_{ij} is greater than R

$$\mathcal{L}_{tq\gamma}^{eff} = -e\bar{c}\frac{i\sigma^{\mu\nu}q_\nu}{m_t}(\lambda_{ct}^L P_L + \lambda_{ct}^R P_R)tA_\mu + H.c.$$