Search for Flavor Changing Neutral Currents in Top Quark Decays

$t \rightarrow q\gamma$

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July 11, 2019

Overview

Brief Background
Neural Network
Continuing Analysis
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Object Preselection Cuts

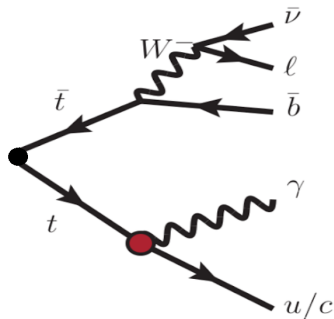# Top Quark Decays in the SM
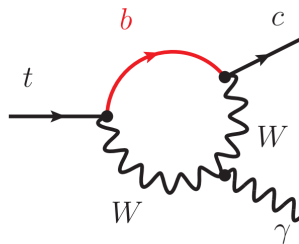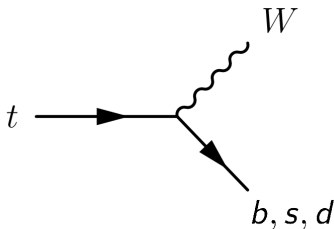
- ▶ $t \to bW \approx 99.83\%$
- ▶ $t \to sW \approx 0.16\%$
- ▶ $t \to dW \approx 0.01\%$

- ▶ $t \to q_{u,c}X \approx 10^{-17} - 10^{-12}$
- ▶ Limits on $t \to \gamma q$ processes: [JHEP 04 (2016) 035]
  - ▶ $t \to \gamma u < 1.3 \times 10^{-4}$
  - ▶ $t \to \gamma c < 1.7 \times 10^{-3}$

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

▶ Final state topology
  ▶ One Neutrino, from W
  ▶ One Lepton, from W
  ▶ One B-jet, SM Top
  ▶ One Photon, FCNC Top
  ▶ One Jet, FCNC Top

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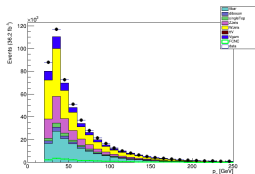Object Preselection Cuts

Object Preselection

▶ We preselect events with objects that look like similar to our expected topology

▶ Require:
  ▶ Exactly one lepton (e or μ) $\geq$ 25 GeV
  ▶ Exactly one good photon $\geq$ 15GeV
  ▶ Missing Transverse Energy $\geq$ 30GeV
  ▶ $\geq$ 1 Jets

▶ Plots shown will be with MC16a and Data15/16 (36.2 fb^{-1}) for quicker turnaround

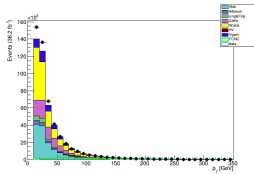▶ N.B. we expect slightly higher MC values - $t\bar{t} + \gamma$ sample not finished in time

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Preselection Objects

Signal MC Scaled to 1% $\sigma_{t\bar{t}}$

Electron Channel

- ▶ Leading Jet p_T

- ▶ Lead Photon

- ▶ Lepton E

Muon Channel

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Neural Network Studies
Neural Network Cut Applied
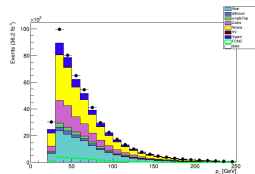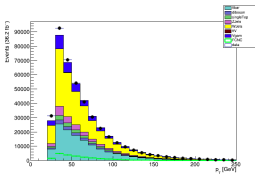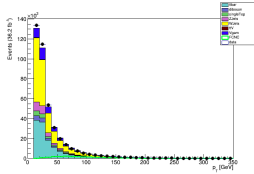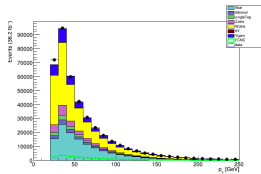
Neural Network Architecture

▶ Using Keras on top of Tensorflow various input parameters are tested for model behavior

▶ A Dense Neural Network with variable number of input variables and hidden layers are explored

▶ Cut optimization has been performed with full Run 2 luminosity for potential reach of the search
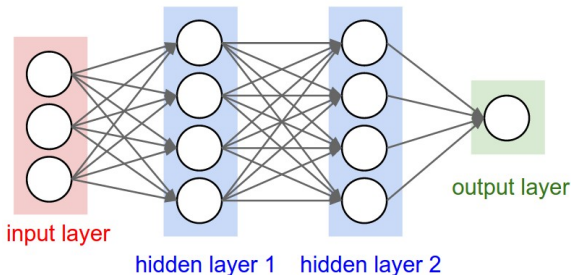

input layer

hidden layer 1   hidden layer 2

output layer

Figure: [Ref: Neural Network]

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Neural Network Model Inputs

▶ Using keras on top of tensorflow various input parameters are tested for model behavior

▶ Networks are set up with 1 input layer, 2 hidden layers with 10 nodes ($+1$ bias node) [Ref: Bias], and 1 output node

▶ Each hidden layer has 20% dropout to prevent overtraining by removing codependency between nodes

▶ Batch size of 100 used and each network is allowed 200 epochs (with patience=50), all models converge and end early with reasonable batch sizes

▶ Optimizer: Adam

▶ Loss Function: Binary Cross Entropy

▶ Many sets of input variables tested, best results from follow-up studies shown

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Cut Optimization

▶ Follow up changes allow a better limit with a cut that is slightly less harsh (0.96/0.95 instead of 0.98)

▶ Estimated limit reduced by a factor of 2 by reweighting the number of events the model saw by taking advantage of the loss function
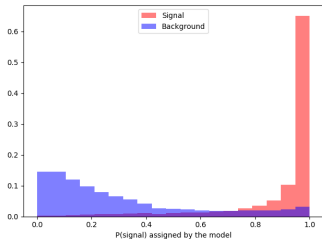
$$\text{Loss} = -\frac{1}{N} \sum_{i=1}^{N} y_i \log(p(y_i)) + (1 - y_i) \log(1 - p(y_i))$$

▶ y - binary indicator (0 or 1) if class label is the correct classification for observation

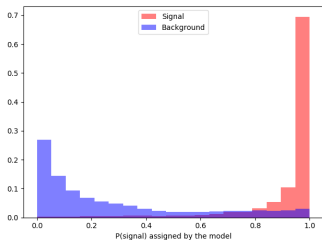▶ p - predicted probability observation is the class label (0 or 1)
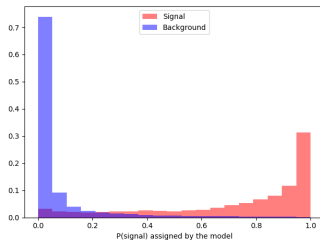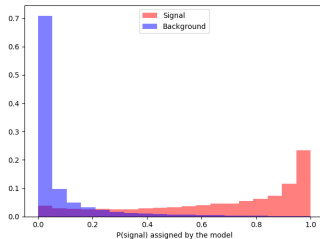
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Neural Network Separation

▶ Previous

▶ Current

Electron Channel

Muon Channel

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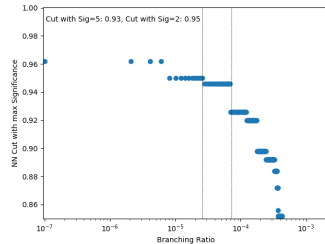# Significance Plots, Electron Channel

Branching ratio with Significance = 2: 2.4e-5

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Neural Network Cut Applied
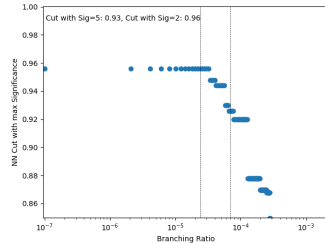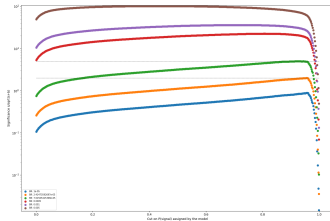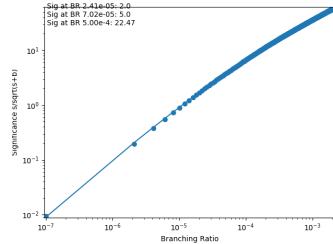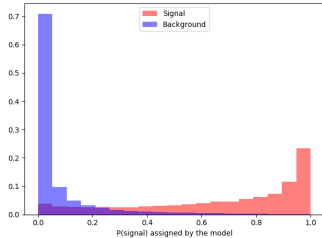
Significance Plots, Muon Channel

Branching ratio with Significance = 2: 2.5e-5

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Neural Network Studies
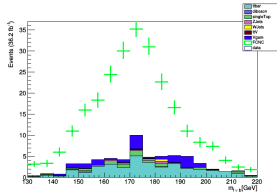Neural Network Cut Applied
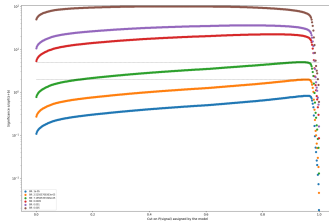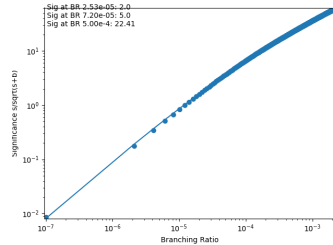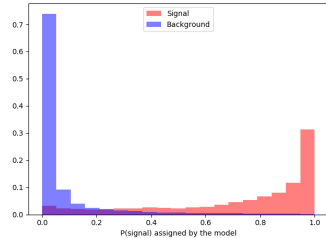
Neural Network Cut Application Electron Channel
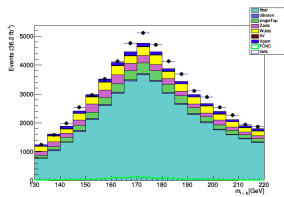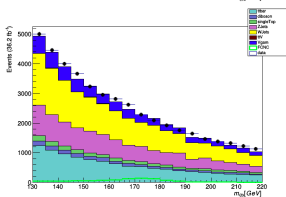
Signal MC Scaled to .1% $\sigma_{t\bar{t}}$

► $m_{q\gamma}$

► $m_{l\nu b}$
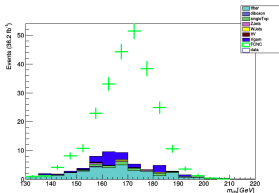
Binning becomes more of an issue with such few events in SR. Should improve with stats from further MC campaigns. Missing sample very evident here.

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Region Creation
New Ntuple Production

Control and Validation Regions

▶ Validation and Control Regions are created orthogonal to Signal
Region for large backgrounds

▶ VR for $(t\bar{t} + \gamma)$, $(W + \gamma)$

▶ CRs for regions without real photons

    ▶ These regions include $t\bar{t}$ and W rich samples with 0 good photons,
so many events new regions should probably be created

▶ Previous cuts to make these regions make less sense to do now with
NN Cuts since NN contains information on all of these cuts

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New Ntuple Production

- ▶ New tools have been recently developed in the Top Group (Ref:VGammaORTool, Duplicate Event Removal,etc.)
- ▶ Replacing Custom Event Saver with that of tt+gamma group, more support and faster integration of new tools
- ▶ Custom post-grid local processing code developing
- ▶ Will transition with the currently running ntuples to local mini-ntuple creation
- ▶ Beginning to work with TRExFitter to push toward the statistical part of the analysis

Outlook

- ▶ As always, still lots to be done
- ▶ Fake Rates $e \to \gamma$ and $j \to \gamma$ to be investigated
- ▶ Using full MC16a/Data15,16 for quick iterations, have access to full MC/Data sets
- ▶ Happy with the state of the neural network studies, any further reduction would require significant time for insignificant gain, factor 2 improvement thanks to feedback I got during this meeting
- ▶ Questions?

Backup

FCNC Diagrams
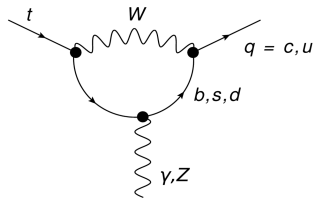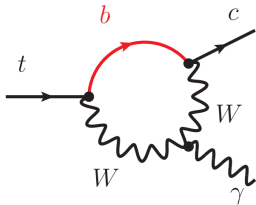
NN Input Variable Correlations
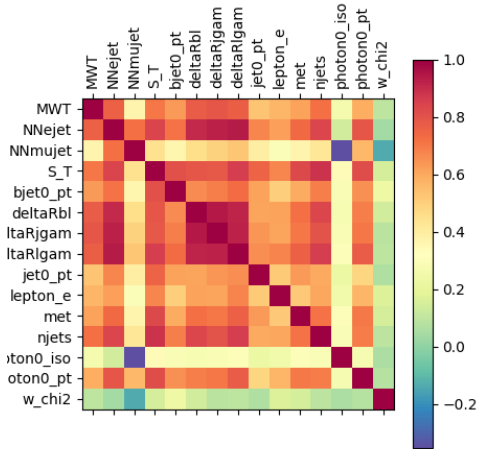
Neural Network Model Inputs

$$\text{Separation} = \sum_i^{bins} \frac{n_{si} - n_{bi}}{n_{si} + n_{bi}}$$

mu+jets channel

Variable	Separation
photon0iso	41.18
mqgam	28.27
photon0pt	24.07
mtSM	11.60
mlgam	7.56
deltaRjgam	5.64
deltaRbl	4.42
MWT	3.34
ST	3.30
nuchi2	3.12
jet0pt	2.81
njets	2.07
smchi2	1.89
wchi2	1.87
jet0e	1.52
deltaRlgam	1.17
leptone	0.87
deltaRjb	0.86
met	0.68
bjet0pt	0.52
leptoniso	0.27

e+jets channel

Variable	Separation
photon0pt	23.14
mqgam	22.73
photon0iso	18.70
mtSM	11.02
mlgam	9.53
deltaRbl	5.00
deltaRjgam	4.60
ST	3.83
MWT	3.16
jet0pt	2.47
njets	1.70
nuchi2	1.59
deltaRlgam	1.40
wchi2	1.33
smchi2	1.09
deltaRjb	0.88
leptone	0.85
leptoniso	0.56
bjet0pt	0.50
met	0.47

Input Variables

['photon0iso','photon0pt','mqgam','mlgam','mtSM','deltaRjgam','deltaRbl',
'MWT','ST','njets','wchi2','jet0pt','deltaRlgam','leptone','met','bjet0pt']
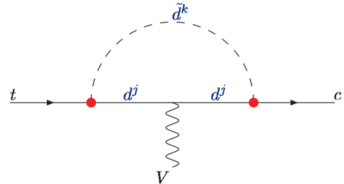
Integrated Luminosity
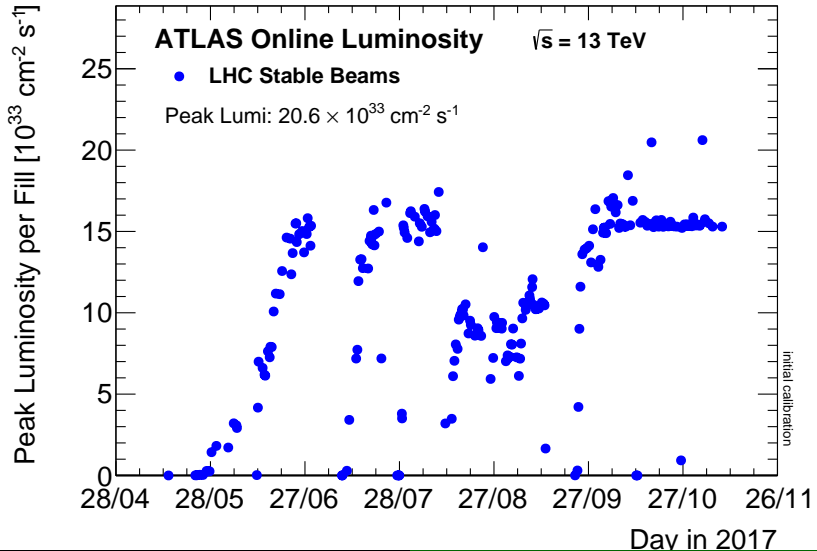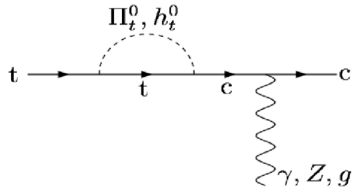
A Couple BSM Diagrams

- R-parity-violating supersymmetric models

  [arXiv:hep-ph/9705341]

- Top-color-assisted technicolor models
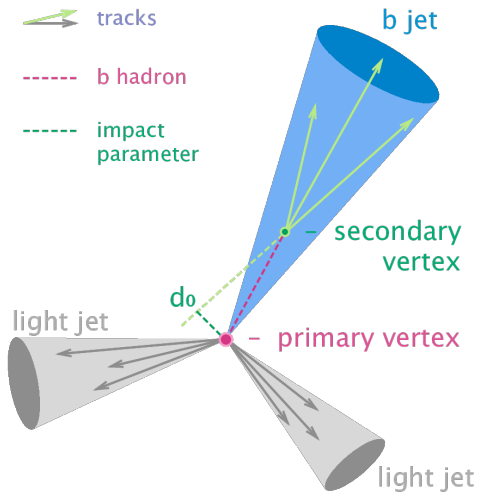
  [arXiv:hep-ph/0303122]

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

B-tagging

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