Search for Flavor Changing Neutral Currents in Top Quark Decays

$t \rightarrow q\gamma$

Jason Barkeloo

November 15, 2018

ATLAS EXPERIMENT

UNIVERSITY OF OREGON

Overview

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Top Quark Pair Production

▶ Leading order processes for top quark production
  ▶ Quark-antiquark annihilation $\approx 10\%$
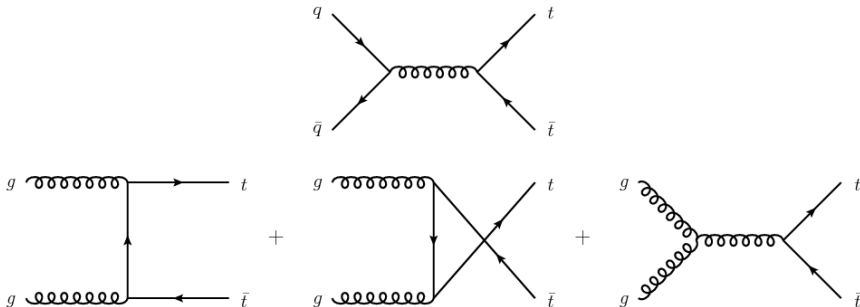 ▶ Gluon-gluon fusion $\approx 90\%$

Figure: Leading order $t\bar{t}$ diagrams

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Top Quark Pair Production

▶ At $\sqrt{s} = 13\,TeV$ for $m_t = 172.5\,GeV$, $\sigma_{t\bar{t}} = 831.76\,pb$
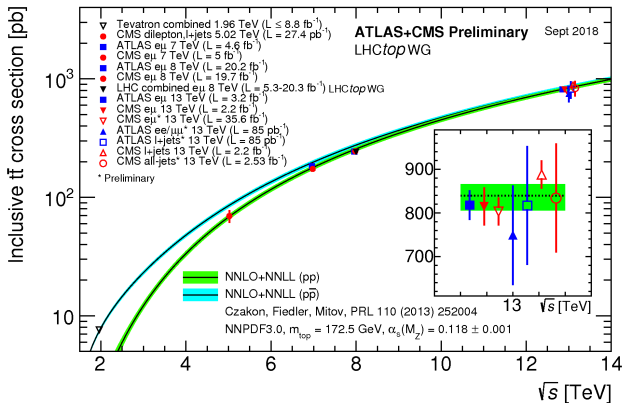
Figure: $t\bar{t}$ production cross section [TopWGSummaryPlots]

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Top Quark Decays

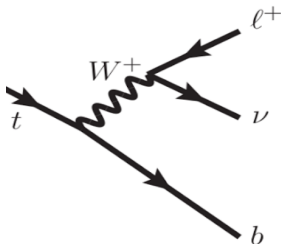▶ Standard model top branching
ratio to bW $\simeq 100\%$

Figure: Leptonic final state diagram for
a top decay

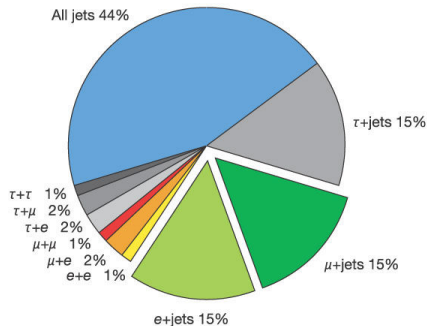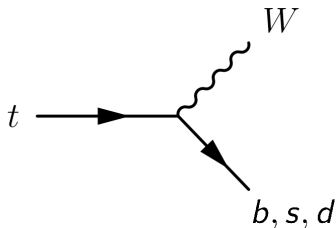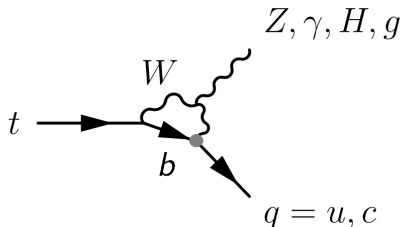Figure: Top quark pair decay final
states [Nature]

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
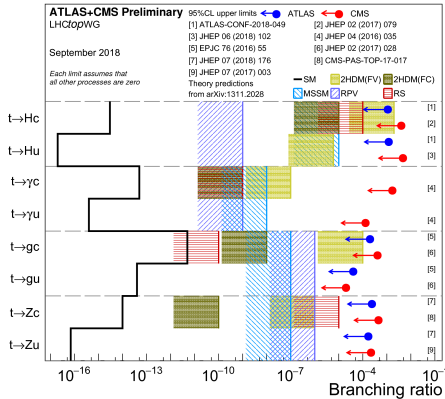Duplicate Event Removal

Top Quark Decays in the SM

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

- $t \rightarrow q_{u,c}X \approx 10^{-17} - 10^{-12}$

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Top Flavor Changing Neutral Currents

▶ Current Limits on FCNC Decays
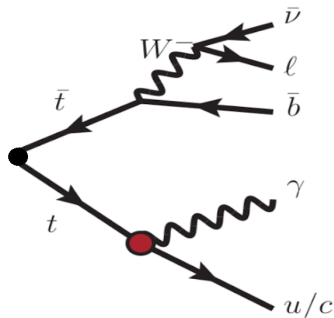

▶ Limits on $t \to \gamma q$ processes: [JHEP 04 (2016) 035]
  ▶ $t \to \gamma u < 1.3 \times 10^{-4}$
  ▶ $t \to \gamma c < 1.7 \times 10^{-3}$

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

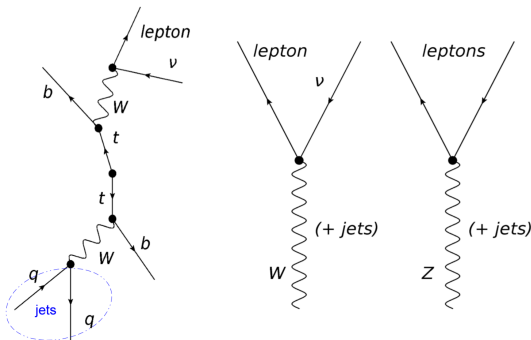# FCNC: What are we looking for? $t\bar{t} \to W(\to l\nu)b + q\gamma$

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

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
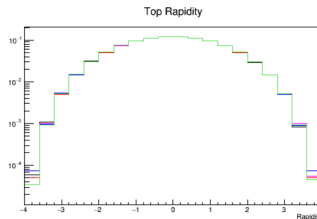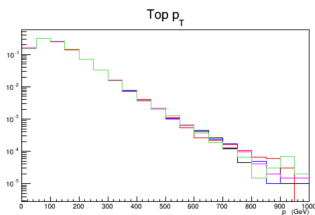Duplicate Event Removal

Background Processes

▶ Due to all of the processes at hadron colliders it is important to model similar event topologies well.

▶ Major backgrounds include $t\bar{t}$, W+Jets, Z+Jets, + processes with an associated photon

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Migration to Release 21

- ▶ AnalysisTop2.X → AnalysisTop21.X
- ▶ Underlying architechture similar, setup/use slightly different (i.e. git, CMake instead of svn, rootcore)
- ▶ Updates to FastSim means more and more samples are being produced with AFII, bigger MC sets
- ▶ Revalidation of UFO Model, Recreation of signal events
- ▶ Previous use of tt+γ group ntuple maker, no longer usable with r21
- ▶ Transition to new ntuple builder → new duplicate event removal based on MCTruthClassifier

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Top FCNC Signal Creation - Kinematic Checks

Top p_T

Top Rapidity

t Mass

$<p\_T>$ = 121.1GeV

$<m\_t>$ =172.7
official σ= 2.79
FCNC σ= 3.46

Consistent to official production
Difference in top mass
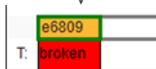width obvious, not large
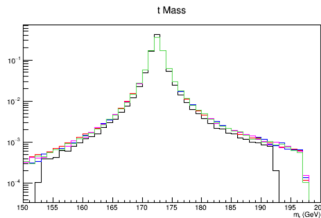
-----: Official MC Production
-----: $t\bar{t} \to bW(\to l\nu)c\gamma$
-----: $t\bar{t} \to bW(\to jj)c\gamma$
-----: $t\bar{t} \to bW(\to l\nu)u\gamma$
-----: $t\bar{t} \to bW(\to jj)u\gamma$

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

MadGraph Issues May-October

▶ Solved Issue in: [Production Request - ATLMCPROD-6008]
▶ Local (lxplus) version of MCProd19.2.5.33.4 had MadGraphControl-00-05-79, worked locally, not on grid
▶ MadGraph version included in cache of MCProd19.2.5.34.1 with MadGraphControl-00-05-82 crashes locally, and on grid
▶ Use of MCProd19.2.5.34.1 with correct MadGraph production runs locally and on grid
▶ Pointed to MadGraphControl issue, something was rolled back or not changed when rolled out to grid sites, not seen until my production

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Duplicate Event Removal

▶ Due to the large influence of photons on this analysis special
  samples are used for major backgrounds
  ▶ $t\bar{t} + \gamma$ and V+jets+γ
  ▶ Increases MC statistics for samples with prompt photons from the
    hard interation

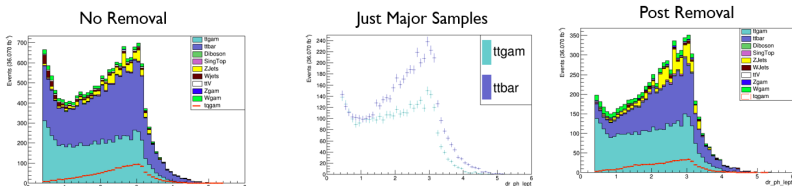Figure: Schematic of how this worked with older samples, similar algorithm
different implementation

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

The Top Quark
FCNC at the LHC
Transitioning to r21, New Ntuple Production
Duplicate Event Removal

Duplicate Event Removal cont.

▶ Release 21: Use MCTruthClassifier to determine origin of photons in event and directly determine if the photons are a result of an electron or jet faking a photon

▶ The removal ensure events from $t\bar{t} + \gamma$ and V+jets$+\gamma$ only contribute events from the hard scattering process and $t\bar{t}$, W+jets,Z+Jets only contribute events with a photon faked by an electron or a jet.

▶ This hard scatter truth origin forces orthogonality and prevents duplicate events entering the selections

▶ Currently nontrivial to update $N_{MCevents}$ during event removal due to parallelization

$$w = \frac{\mathcal{L}.\sigma}{N_{MCevents}}$$

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
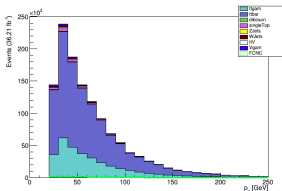Top and Neutrino Reconstruction
Region Creation

Object Preselection

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

▶ Require:
  ▶ Exactly one lepton (e or μ) $\geq$ 28 GeV
  ▶ Exactly one Good photon $\geq$ 15GeV
  ▶ Missing Transverse Energy $\geq$ 30GeV
  ▶ $\geq$ 2 Jets

▶ All following plots will have signal scaled to 1% of inclusive $\sigma_{t\bar{t}}$, MC scaled to $36.21 fb^{-1}$

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
Top and Neutrino Reconstruction
Region Creation

Preselection Objects with $N_{BJet} \geq 1$
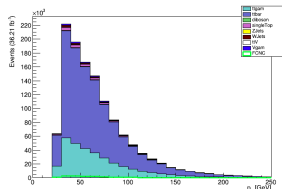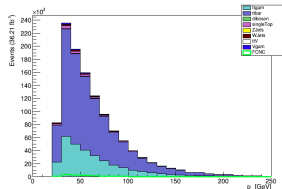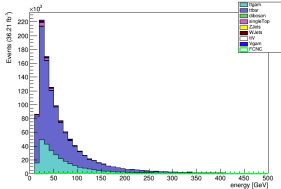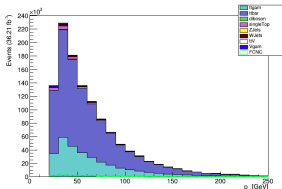
Electron Channel

► Leading Jet p_T ► Photons   ► Leptons
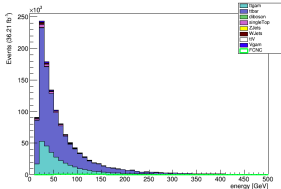
Muon Channel

Bug with Normalization Factor that had been working for previous athena release, $t\bar{t}$ and $t\bar{t} + \gamma$ weights too large

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
Top and Neutrino Reconstruction
Region Creation

Where are the Tops?

▶ Must be 'reconstructed' from these objects as well as b-jets and E_T^{miss}

▶ E_T^{miss} is calculated to balance the event energy in the transverse plane of the detector

▶ The other particles are combined in the only way the signal topology would allow two top quark candidates

    ▶ Standard model top candidate: b-jet + lepton + neutrino

    ▶ FCNC Top: Photon + Light Jet

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
Top and Neutrino Reconstruction
Region Creation

Neutrinos

▶ All missing energy in signal topology is from neutrino
▶ We have E_T^{miss} and its' direction
  ▶ Can calulate E_{Tx}^{miss} and E_{Ty}^{miss} easily
  ▶ Ambiguous direction along the z-axis
▶ A minimization of this χ^2 will allow us to determine the z momentum of the neutrino: $\chi^2 = \frac{(m_{b,l,\nu} - m_t)^2}{\sigma_{SMtop}^2} + \frac{(m_{l,\nu} - m_W)^2}{\sigma_W^2}$
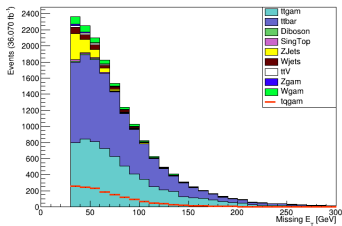
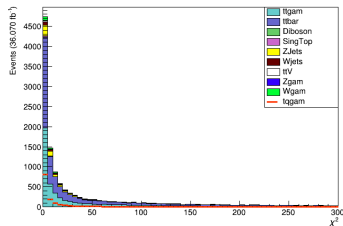Figure: e-channel E_T^{miss} distribution

Figure: e-channel χ^2 distribution

*Plots from previous release, same methodology used, same results

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
Top and Neutrino Reconstruction
Region Creation

Validation Region - With Real Photons
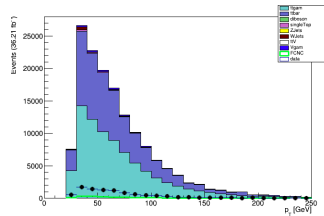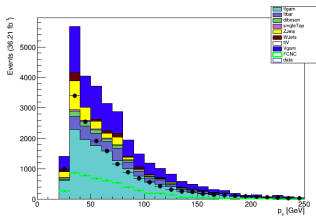
▶ Validation and Control Regions are created orthogonal to Signal Region for large backgrounds

▶ VR for $(t\bar{t} + \gamma)$
  ▶ Same preselection and isolation cuts as SR
  ▶ > 4 jets
  ▶ Reverse FCNC top mass cut $|m_{q\gamma} - m_{top}| > 50 GeV$: Gaurantees orthogonality

▶ VR for $W + \gamma$
  ▶ Similar preselection and isolation cuts to SR
  ▶ $= 0$ BJets (orthogonal cut)

▶ Similar regions have been created for regions without real photons - haven't included in grid runs yet for ease/size
  ▶ These regions include $t\bar{t}$ and W rich samples with 0 good photons and different amounts of jets.

Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
Top and Neutrino Reconstruction
Region Creation

Example VR Plots - lepton p_T
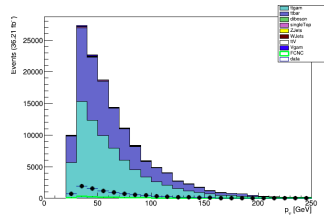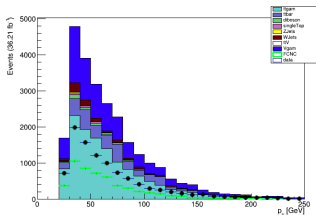
▶ VR1 - $W(V) + \gamma$ enriched

▶ VR2 - $t\bar{t} + \gamma$ enriched

Electron Channel

Muon Channel

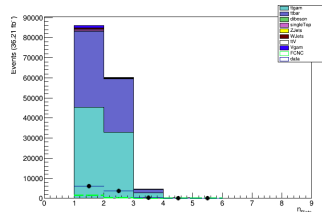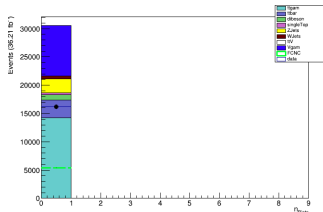Brief Background
Searching for Flavor Changing Neutral Current Signatures
Outlook and Conclusions

Object Preselection Cuts
Top and Neutrino Reconstruction
Region Creation

Example VR Plots - n$_{Jets}$, n$_{BJets}$

► Slightly more obvious to see problem with $t\bar{t}(+\gamma)$ samples

► VR1 - $W(V) + \gamma$ enriched

► VR2 - $t\bar{t} + \gamma$ enriched

Outlook

- ▶ Still lots to be done
  - ▶ Bug fixes on event normalizations
  - ▶ New duplicate event removal is most likely culprit at this point - nontrivial fix to implement
  - ▶ Further investigation into SR optimization with cuts on other variables such as $\Delta R_{\gamma, closejet}$ l
- ▶ Fake Rates $e \to \gamma$ and $k \to \gamma$ will be investigated soon
  - ▶ MCTruthClassifier implemented already, should be straight forward
- ▶ A new grid run will be done soon with MC16a and MC16d samples
  - ▶ Inclusion of 0 photon events in grid sample for remaining control/validation regions
- ▶ Full Analysis transitioned to be able to run on condor nodes
  - ▶ Capable of handling much larger samples by directly using grid output files
  - ▶ Necessary to look at MC16a/d/e samples and full 2018 data set in a reasonable amount of time

Conclusion

- ▶ Any excess signal would be indicative of some physics beyond the Standard Model that couples strongly to the top sector
- ▶ The search for FCNCs with enhanced rates are important pieces of testing many new theories
- ▶ Hopefully no one else has to deal with a multimonth debugging process to get MC samples produced with MadGraph again
- ▶ Now that I have my new samples the analysis can once again move forward
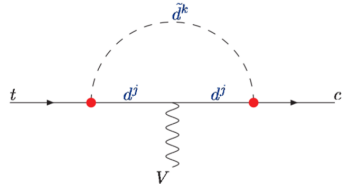- ▶ Thank you!

Backup

Integrated Luminosity
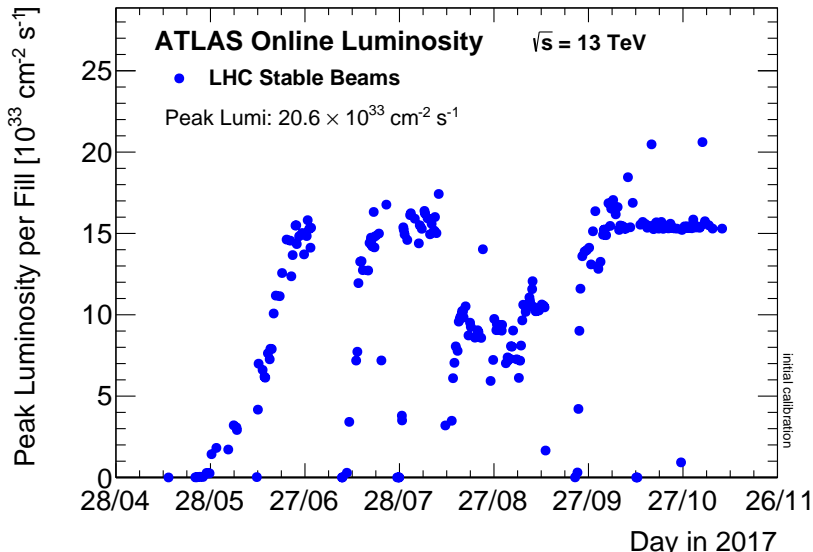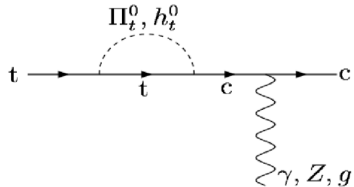
A Couple BSM Diagrams

- R-parity-violating supersymmetric models

  [arXiv:hep-ph/9705341]

- Top-color-assisted technicolor models

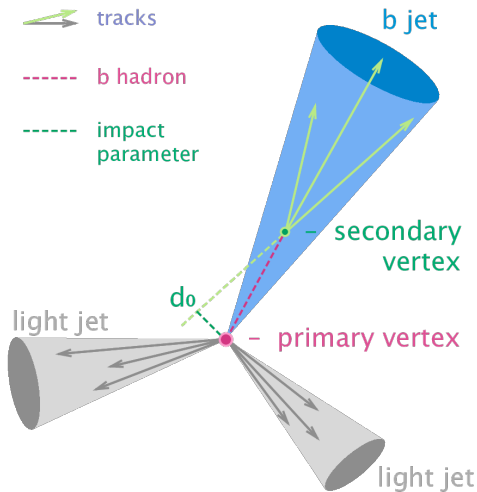 [arXiv:hep-ph/0303122]

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

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