Search for Flavor Changing Neutral Currents in Top Quark Decays

$t \to q\gamma$

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The Top Quark

- Heaviest fundamental particle, $172.5 GeV$
- Lifetime $5x10^{-25}s$, decays before hadronization
  - Allows us to study the decay of a single quark

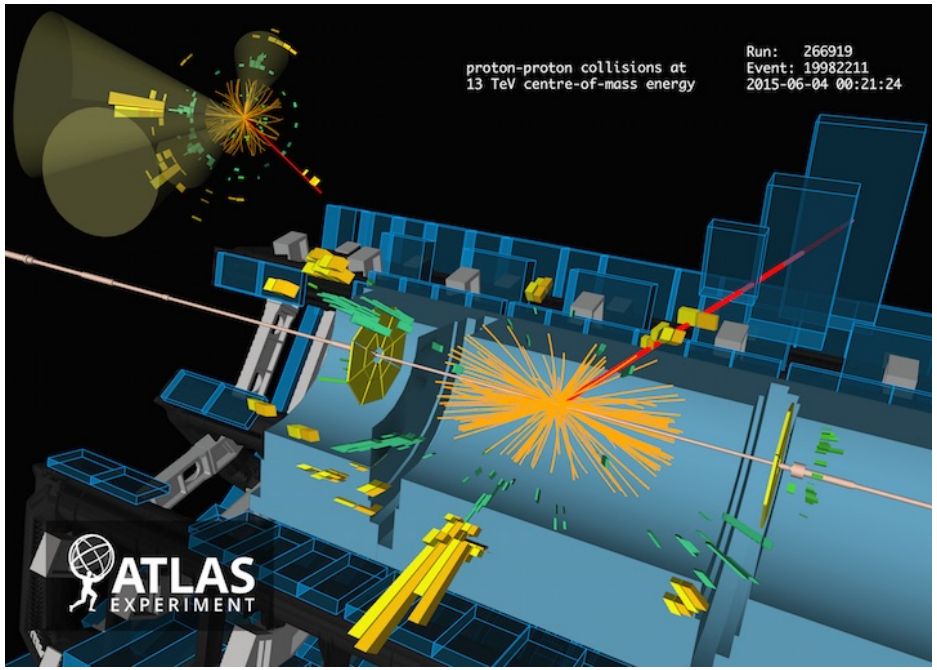


Figure: $t\bar{t}$ event in the ATLAS detector

Top Quark Pair Production

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

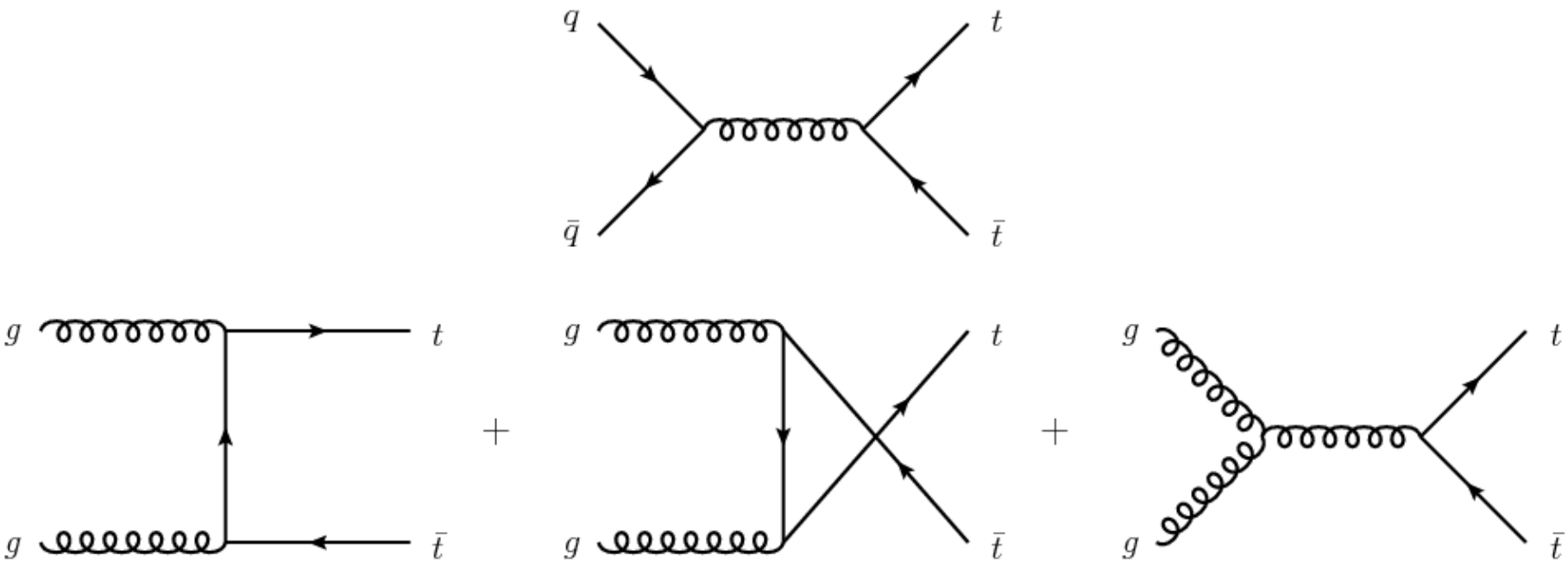


Figure: Leading order $t\bar{t}$ diagrams

Top Quark Pair Production

- At $\sqrt{s} = 13\,TeV$ for $m_t = 172.5\,GeV$, $\sigma_{t\bar{t}} = 831.76\,pb$

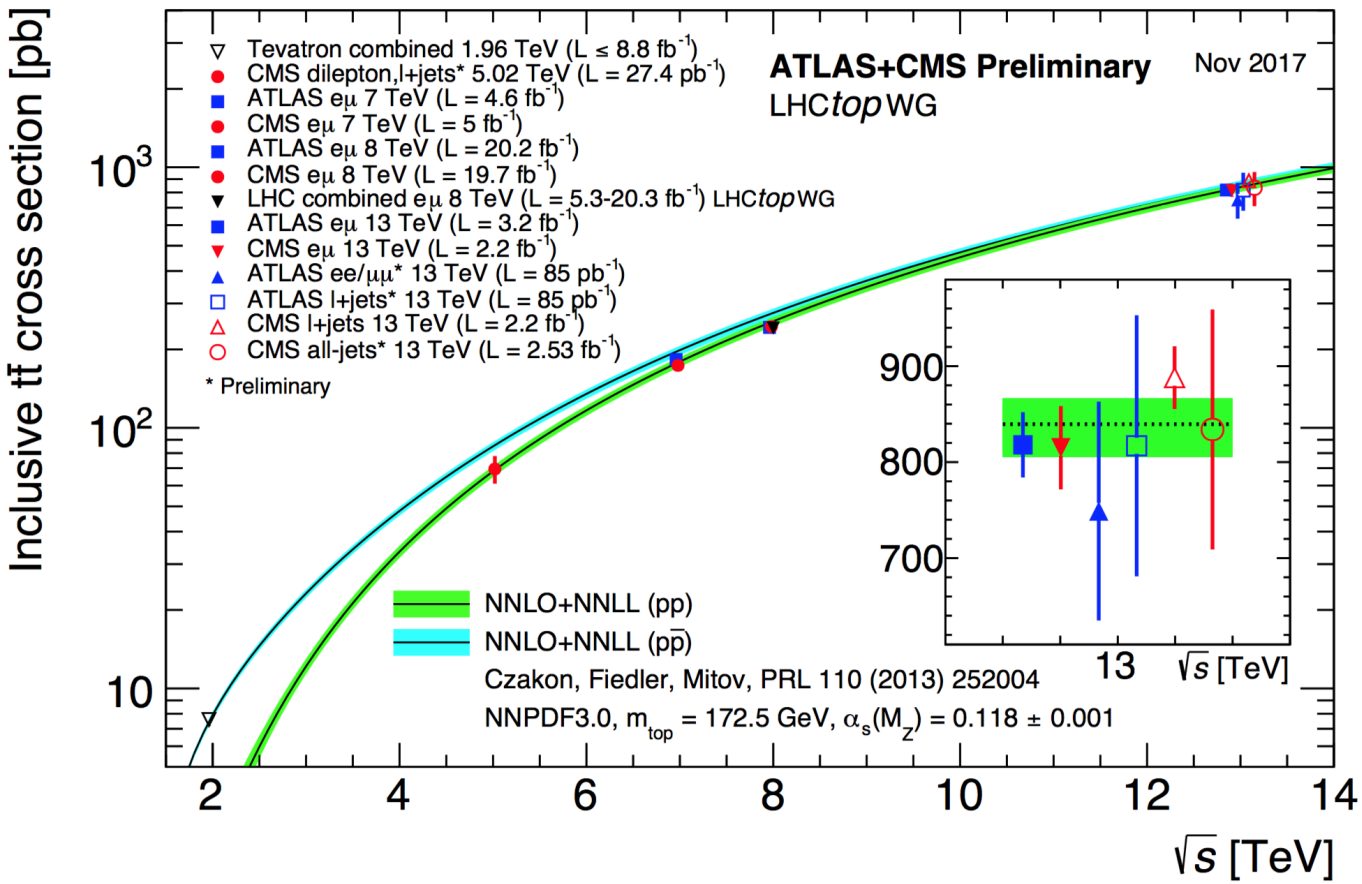


Figure: $t\bar{t}$ production cross section [TopWGSummaryPlots]

Top Quark Decays

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

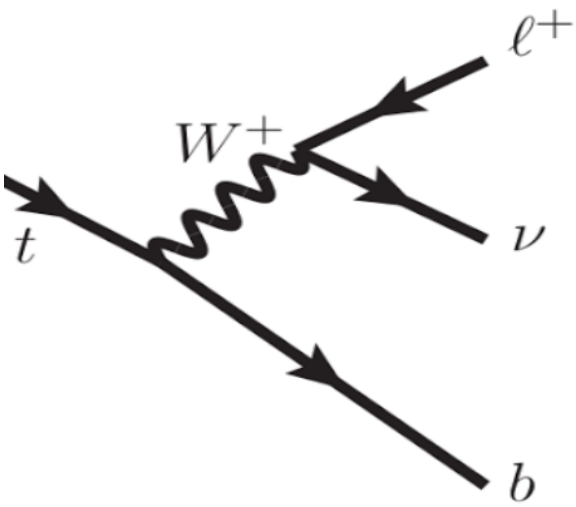


Figure: Leptonic final state diagram for a top decay

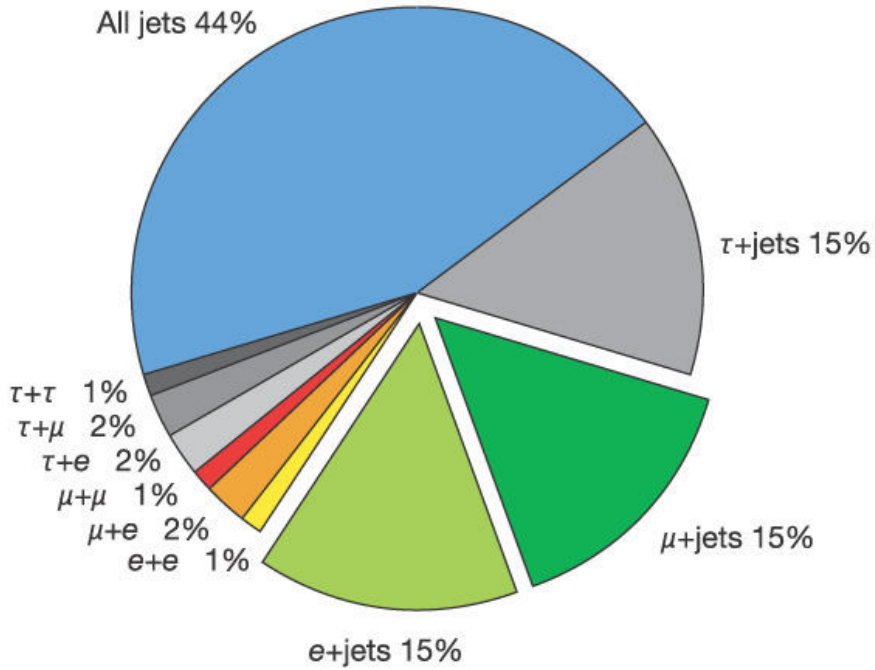
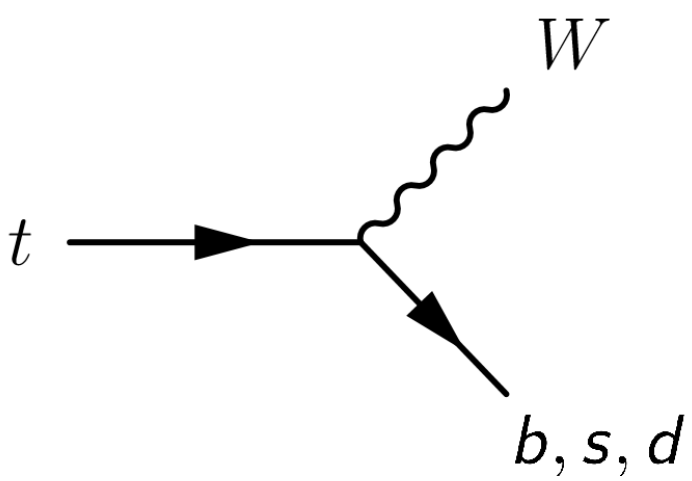
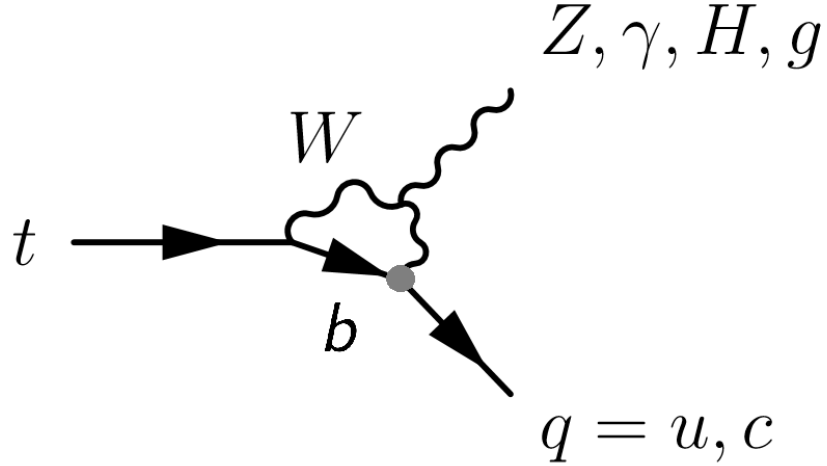


Figure: Top quark pair decay final states [Nature]

Top Quark Decays in the SM



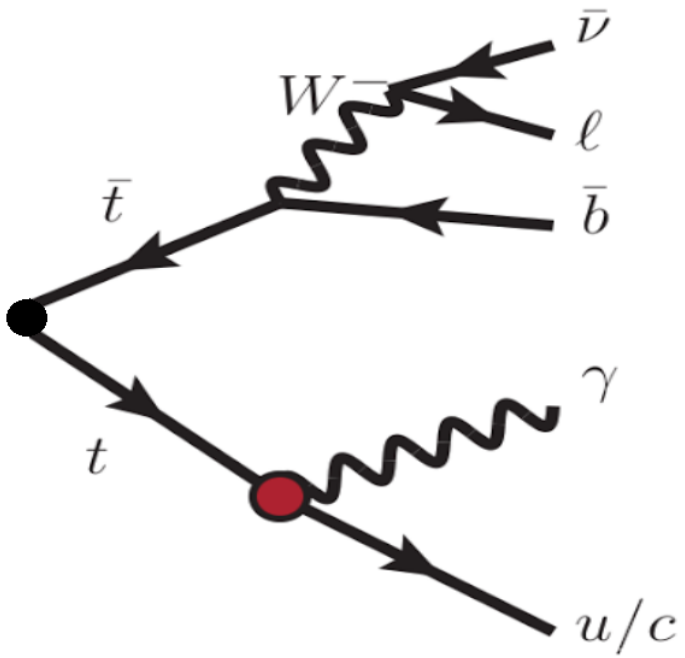


- $t \to bW \approx 99.83\%$
- $t \to sW \approx 0.16\%$
- $t \to dW \approx 0.01\%$

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

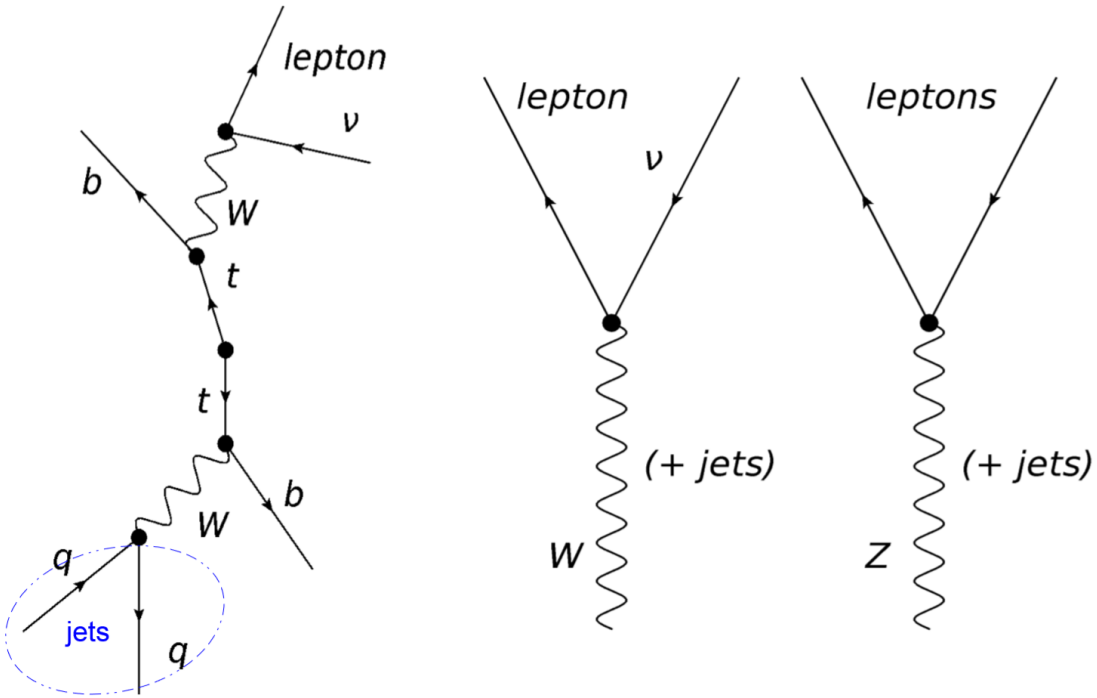
FCNC: What are we looking for? $t\bar{t} \rightarrow W(\rightarrow l\nu)b + q\gamma$

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



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



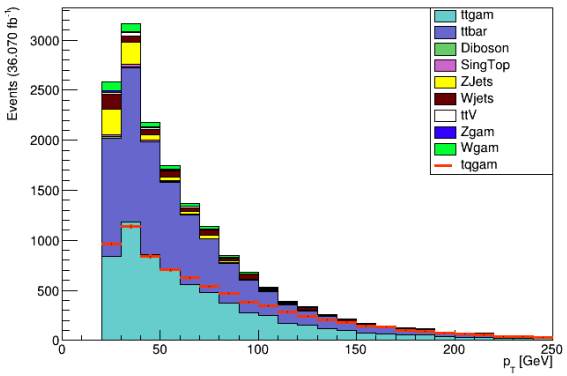
Object Preselection

- We preselect events with objects that look like our expected topology
- Require:
  - Exactly one lepton (e or μ) $\geq$ 28 GeV
  - Exactly one Good photon $\geq$ 25GeV
  - Missing Transverse Energy $\geq$ 30GeV
  - $\geq$ 2 Jets (at least one being b-tagged)
- All following plots will have signal scaled to 1% of $\sigma_{t\bar{t}}$, MC scaled to $36.07 fb^{-1}$

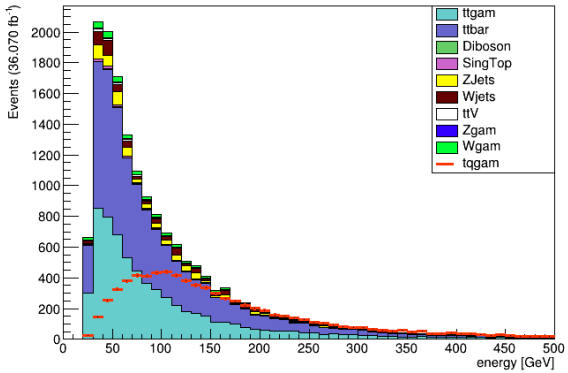
Preselection Objects

Electron Channel

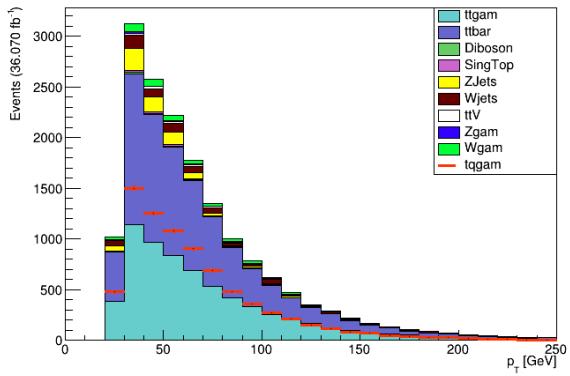
- Leading Jet p_T



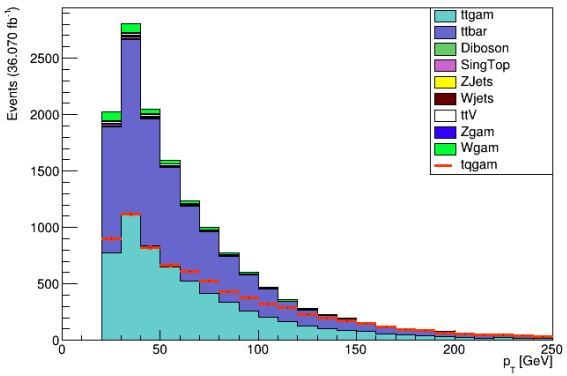
- Photons

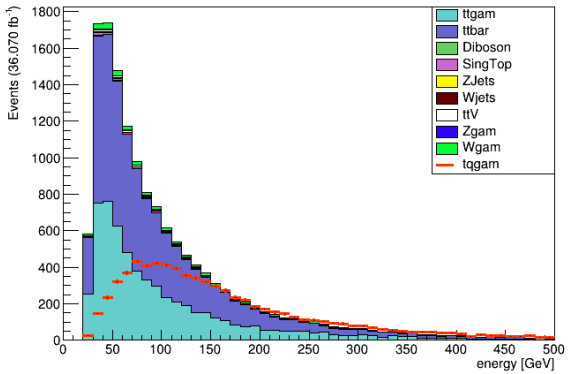


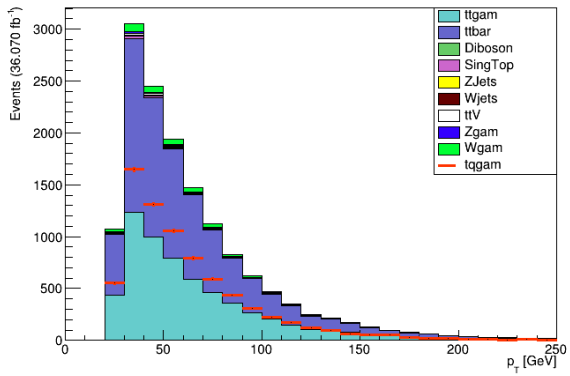
- Leptons



Muon Channel







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

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: $\chi^2 = \frac{(m_{b,l,\nu} - m_t)^2}{\sigma^2_{SMtop}} + \frac{(m_{l,\nu} - m_W)^2}{\sigma^2_W}$

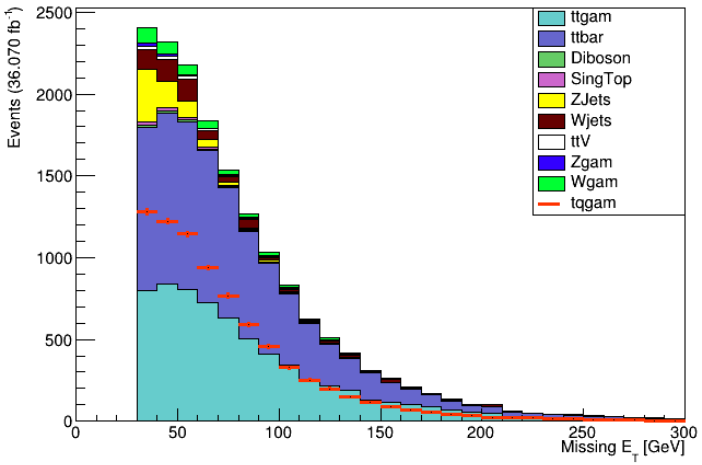


Figure: e-channel E_T^{miss} distribution

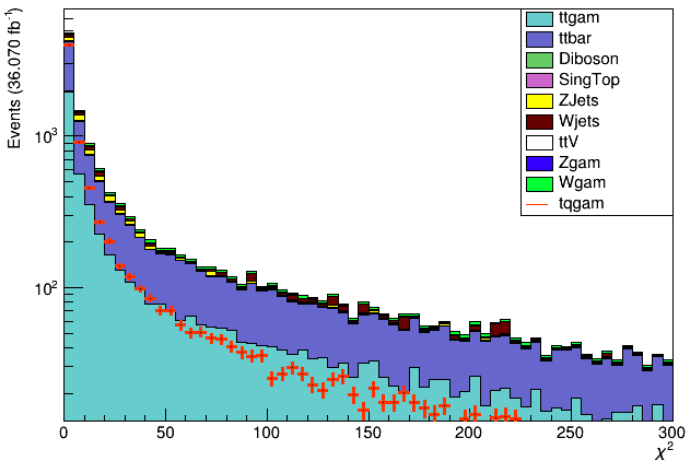
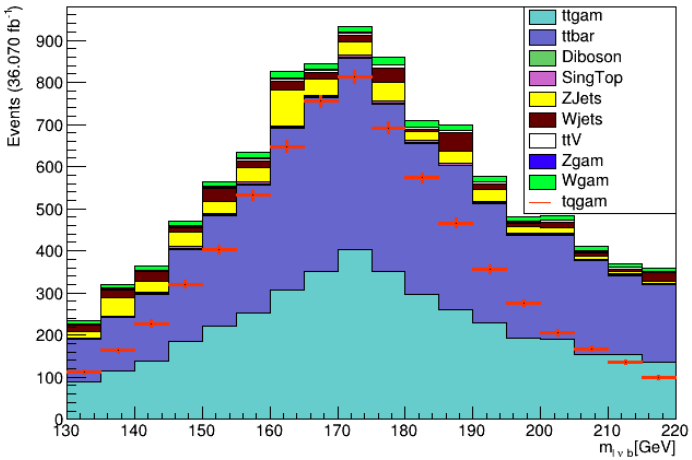


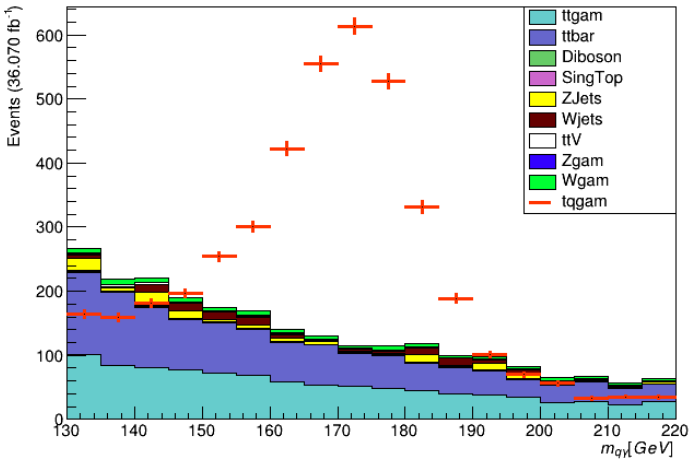
Figure: e-channel χ^2 distribution

Reconstructed Tops

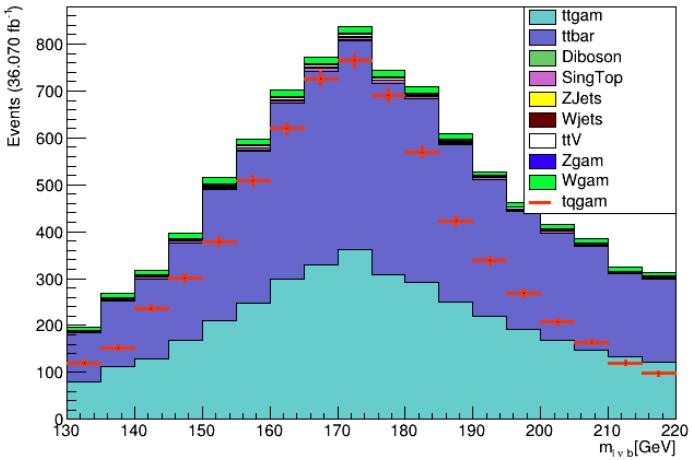
- SM Top
- FCNC Top

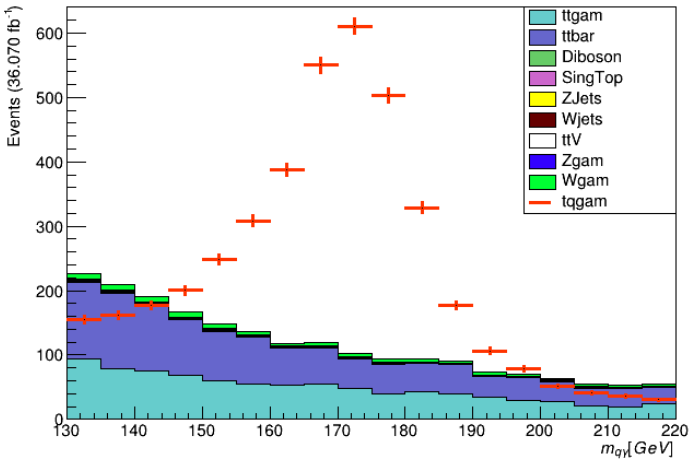
Electron Channel





Muon Channel

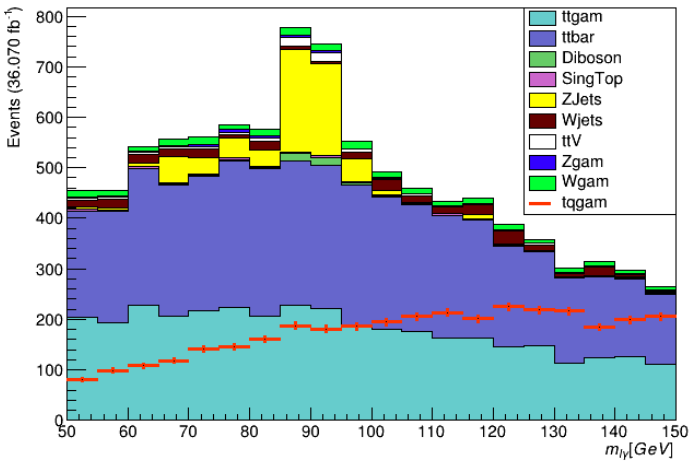


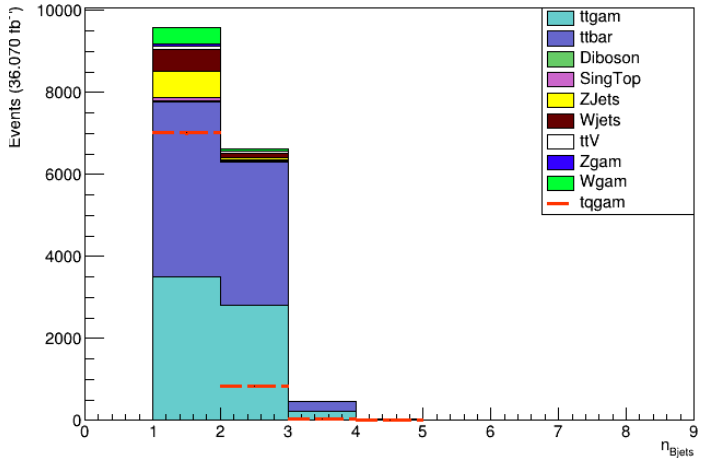


Thinning Out Backgrounds

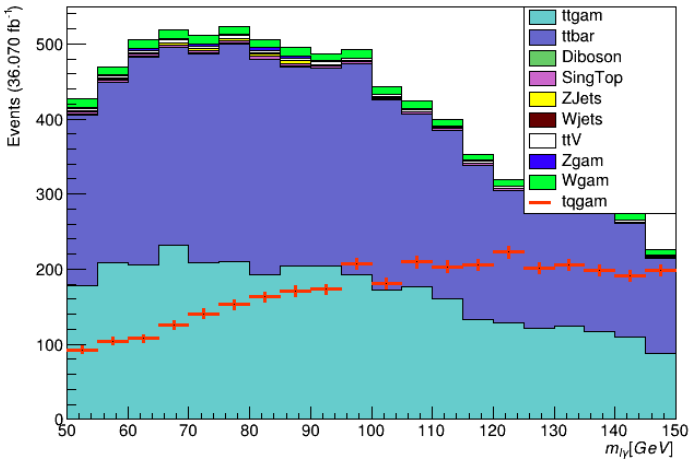
- Reconstructing Z mass
- Number of BJets

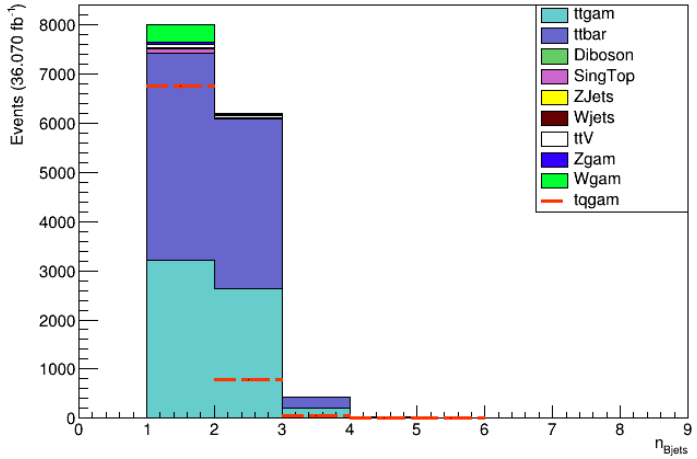
Electron Channel





Muon Channel

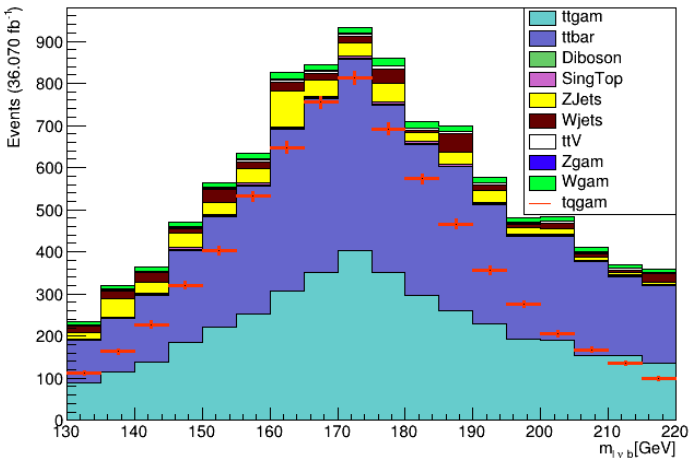


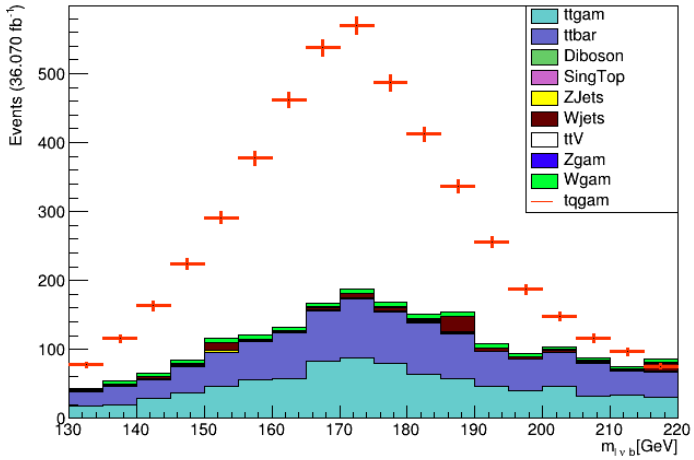


Thinning Out Backgrounds: SM Top ($m_{l\nu b}$)

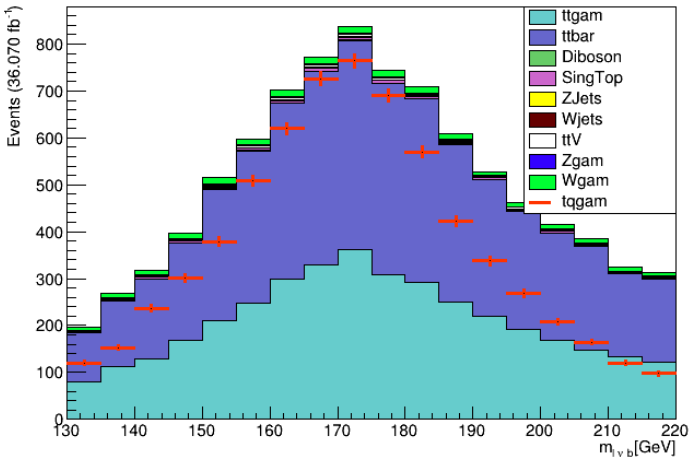
- Before Z-mass, Bjet cuts
- After Cuts

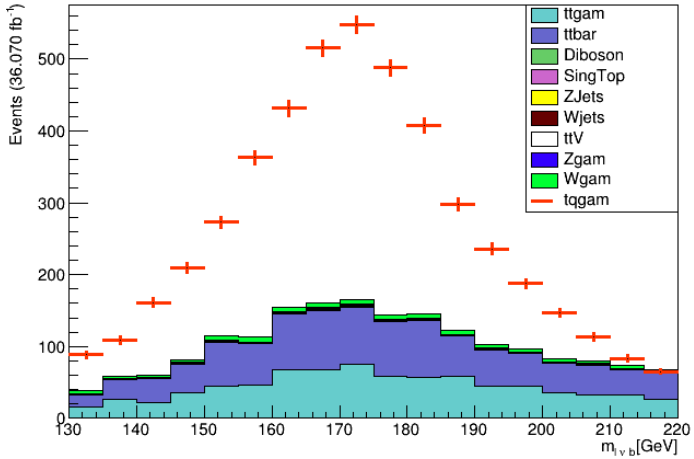
Electron Channel





Muon Channel

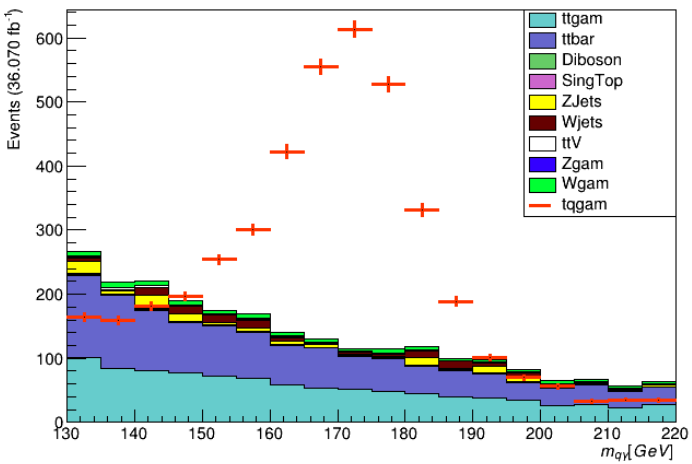


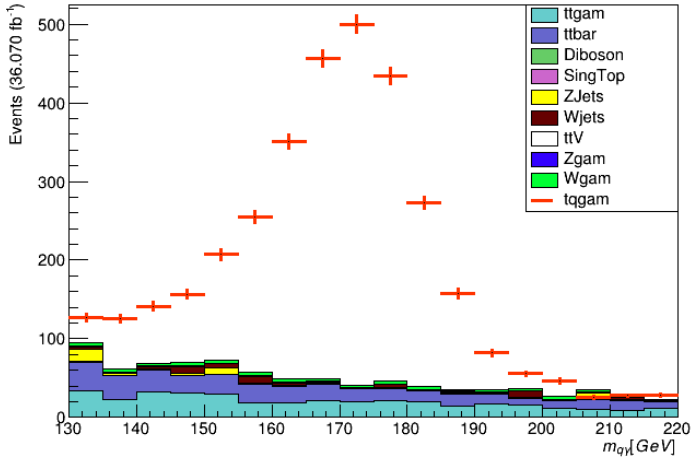


Thinning Out Backgrounds: FCNC Top ($m_{q\gamma}$)

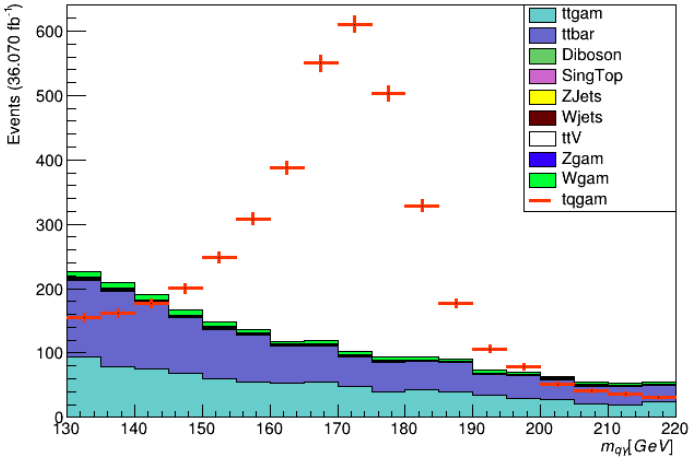
- Before Z-mass, Bjet cuts
- After Cuts

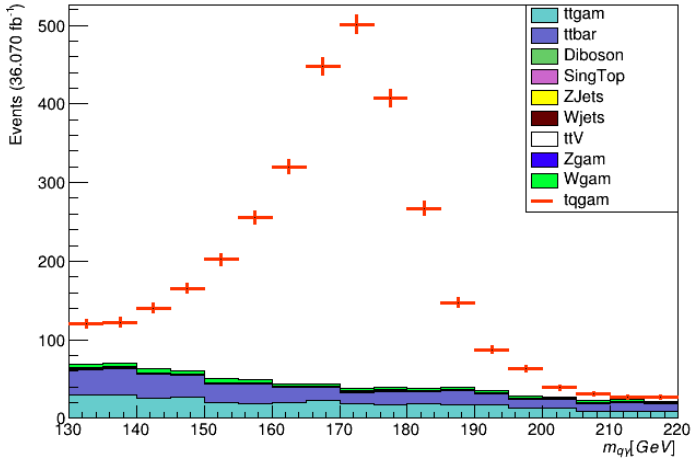
Electron Channel





Muon Channel





Current Investigation: χ^2

- Can χ^2 be used as a discriminating variable?
- $\chi^2 = \frac{(m_{b,l,\nu} - m_t)^2}{\sigma^2_{SMtop}} + \frac{(m_{l,\nu} - m_W)^2}{\sigma^2_W}$

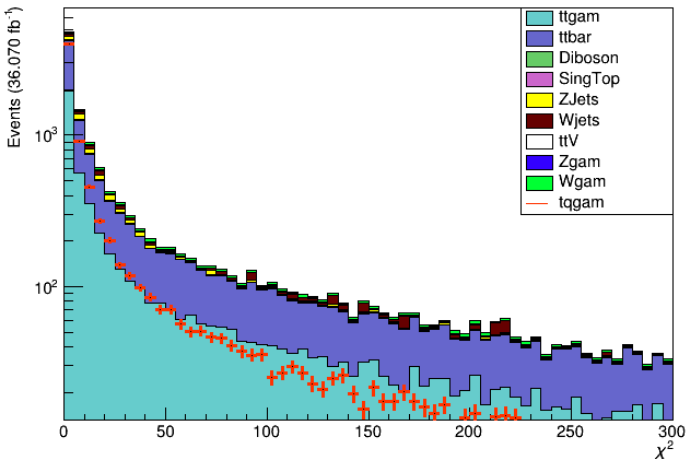


Figure: e-channel χ^2 before cuts

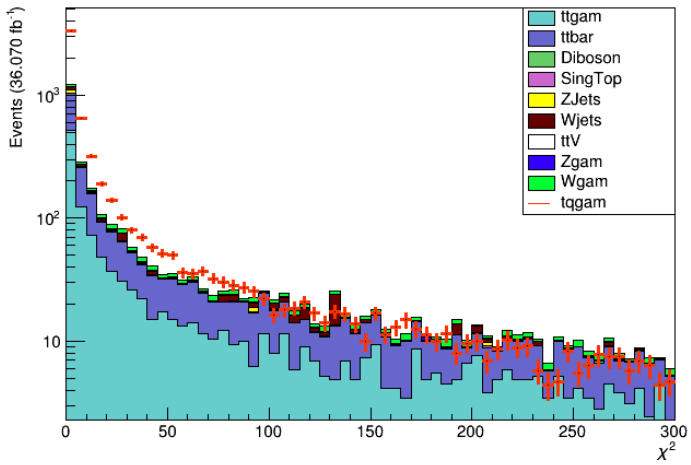
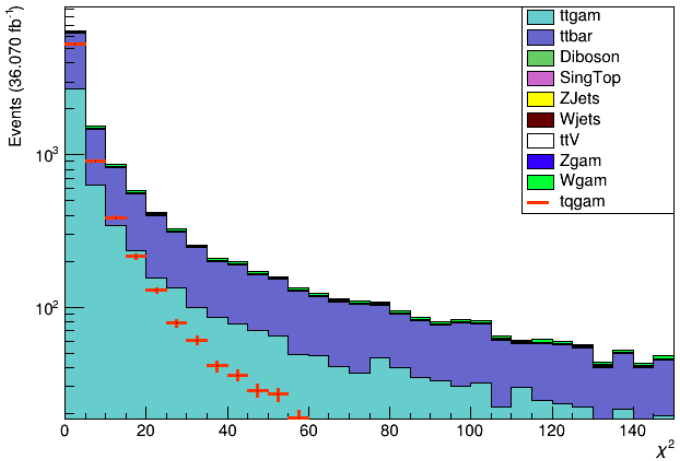


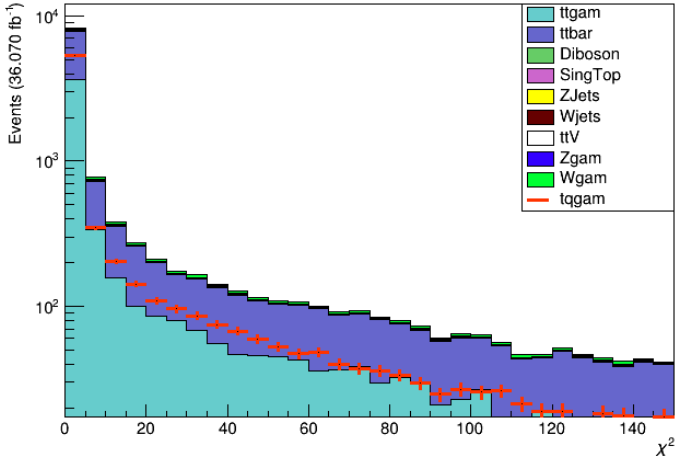
Figure: e-channel χ^2 after Z, Bjet cuts

Current Investigation: χ^2

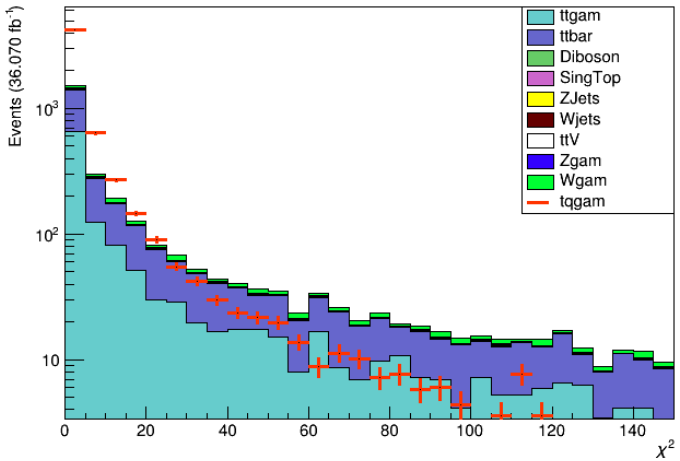
- $\frac{(m_{b,l,\nu} - m_t)^2}{\sigma^2_{SMtop}}$
- $\frac{(m_{l,\nu} - m_W)^2}{\sigma^2_W}$

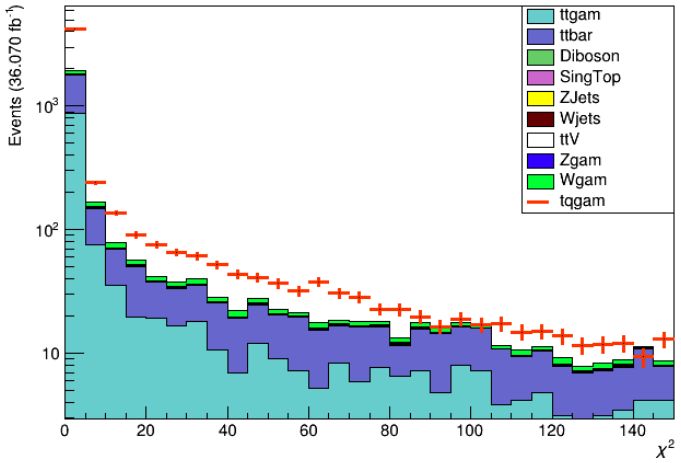
Before Cuts





After Cuts

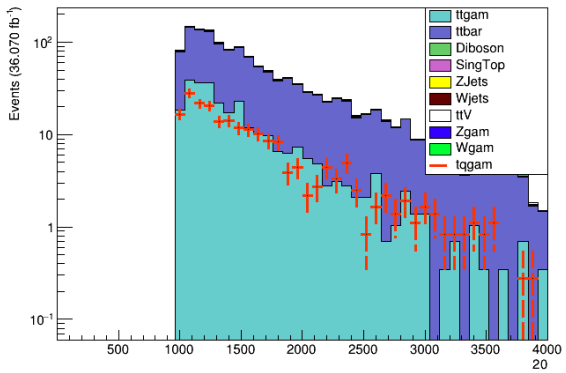


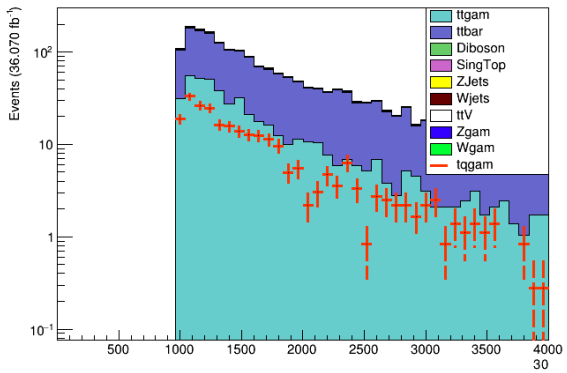


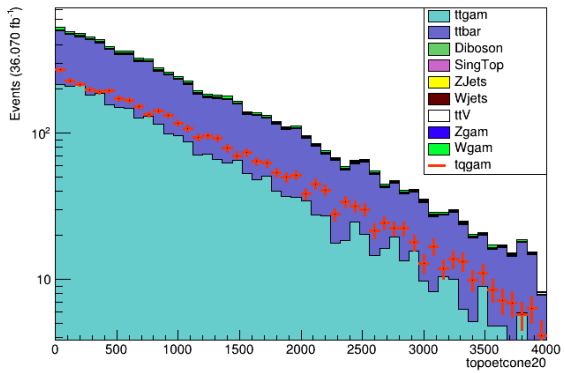
Current Investigation: Photon Isolation: μ-Channel

- ptvarcone20
- ptvarcone30
- topoetcone20

Before Cuts







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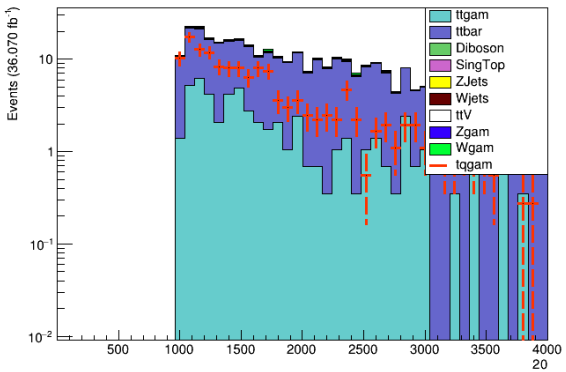
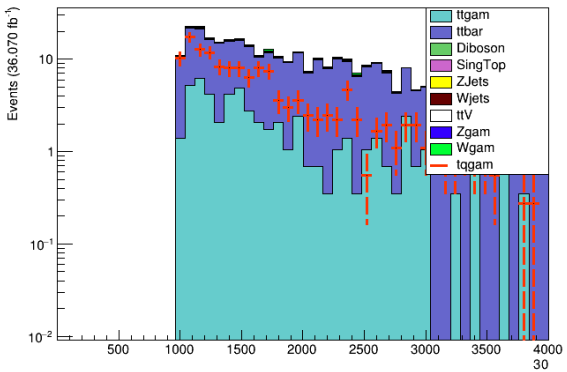
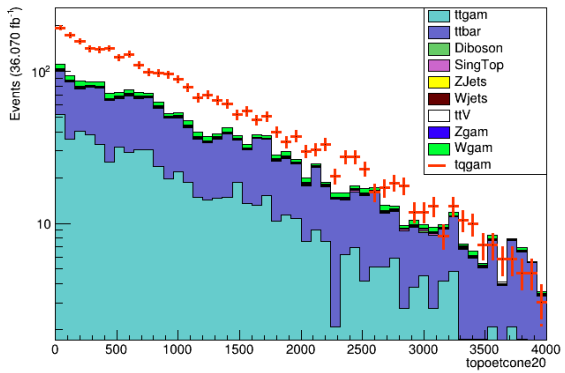


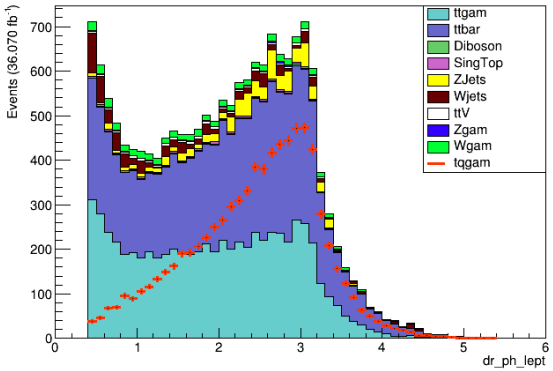


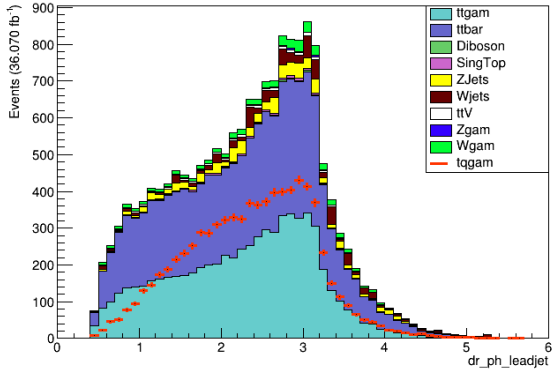


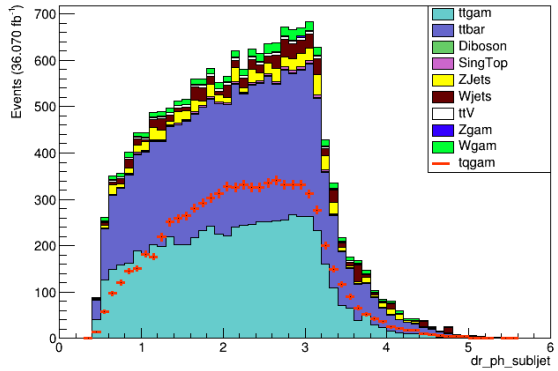
Current Investigation: Geometry ΔR to γ: e-channel

- $\Delta R_{\gamma l}$
- $\Delta R_{\gamma j_0}$
- $\Delta R_{\gamma j_1}$

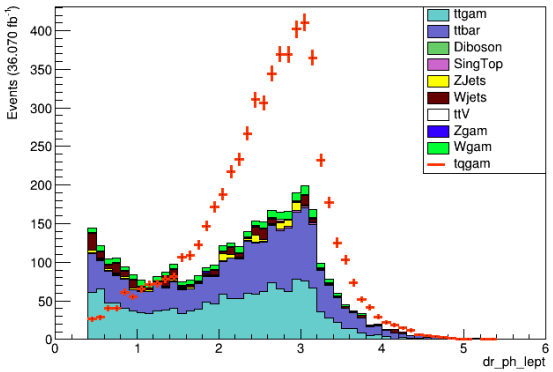
Before Cutsl

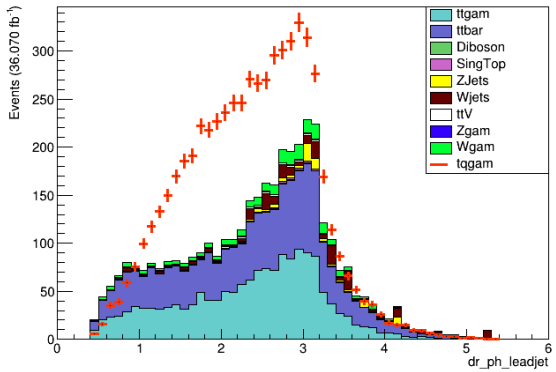


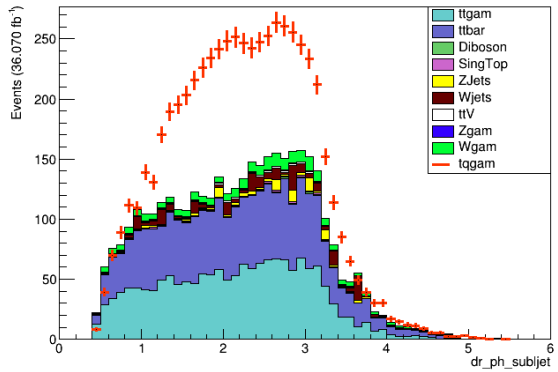




After Cuts







Outlook

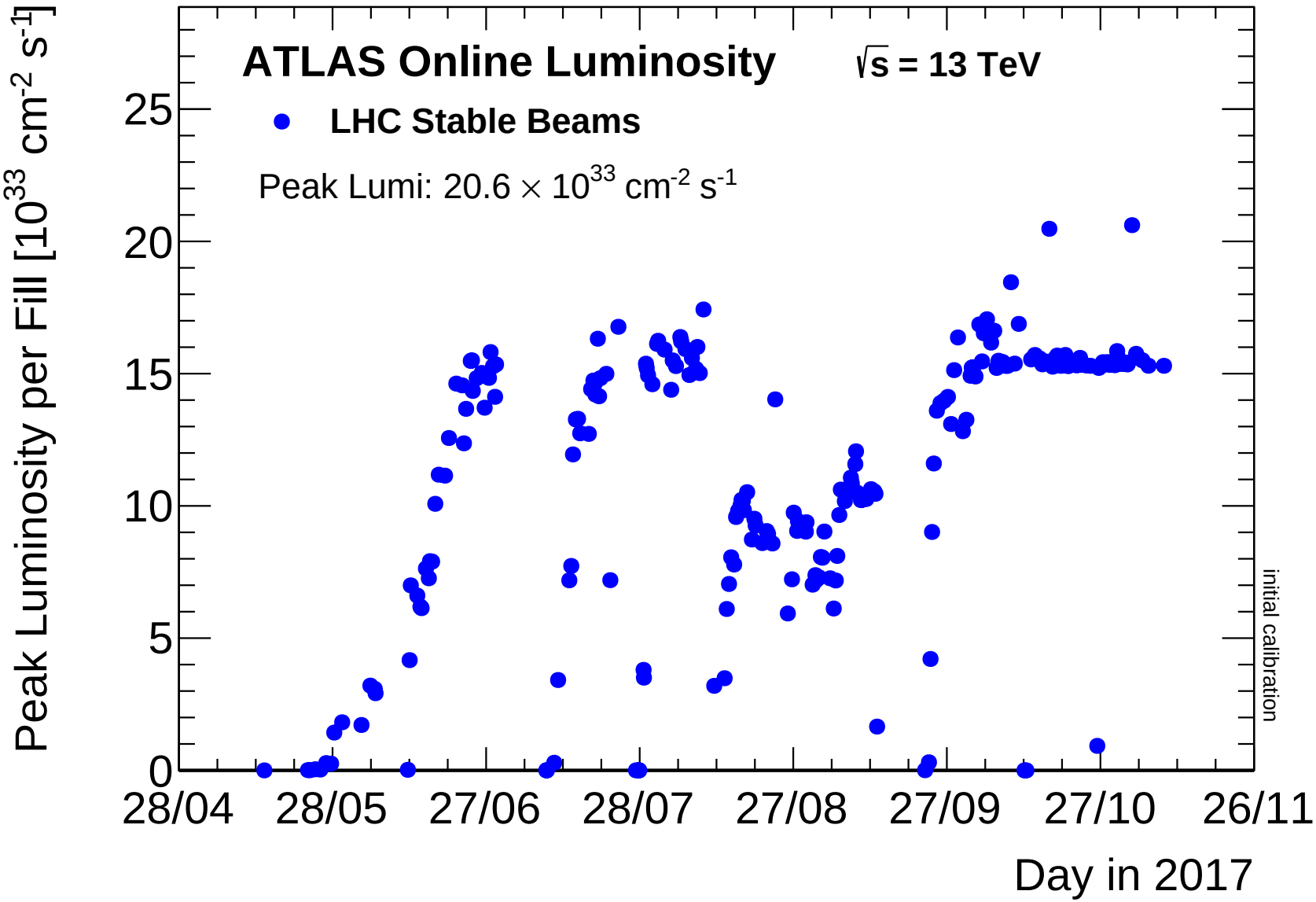
- Many improvements can be made to the analysis
  - Further investigation of χ^2 cuts
  - Inclusion of a new term in χ^2 to do with FC
  - Isolation cuts don't seem too promising for background reduction
  - $\Delta R_{\gamma l}$ could be useful
- Monte Carlo distributions can be used to set an expected limit on the Branching Ratio

Conclusion

- An excess signal would be indicative of some physics beyond the Standard Mode that couples strongly to the top sector
- The search for FCNCs with enhanced rates are important pieces of testing many new theories
- Barring any excess: with $\approx 150\text{fb}^{-1}$ data at $\sqrt{s} = 13\text{TeV}$ setting an upper limit of $\text{BR}(t \to q\gamma) < 3x10^{-5}$ is a reasonable goal, extrapolating from past results.

Backup

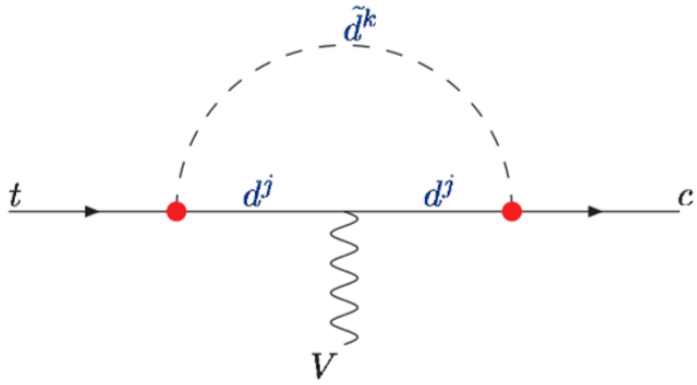
Integrated Luminosity



A Couple BSM Diagrams

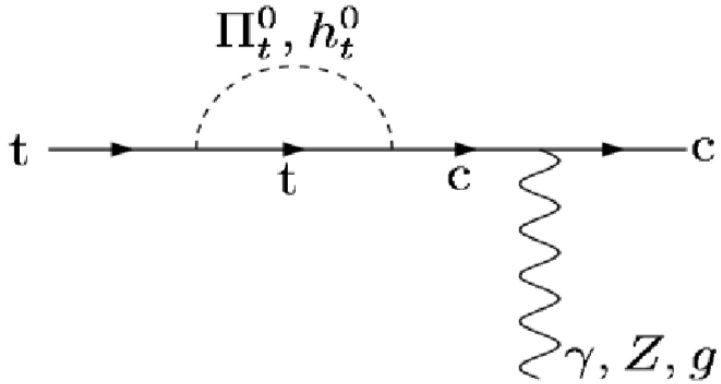
- R-parity-violating supersymmetric models

  [arXiv:hep-ph/9705341]



- Top-color-assisted technicolor models

  [arXiv:hep-ph/0303122]



Jets/AntiKT

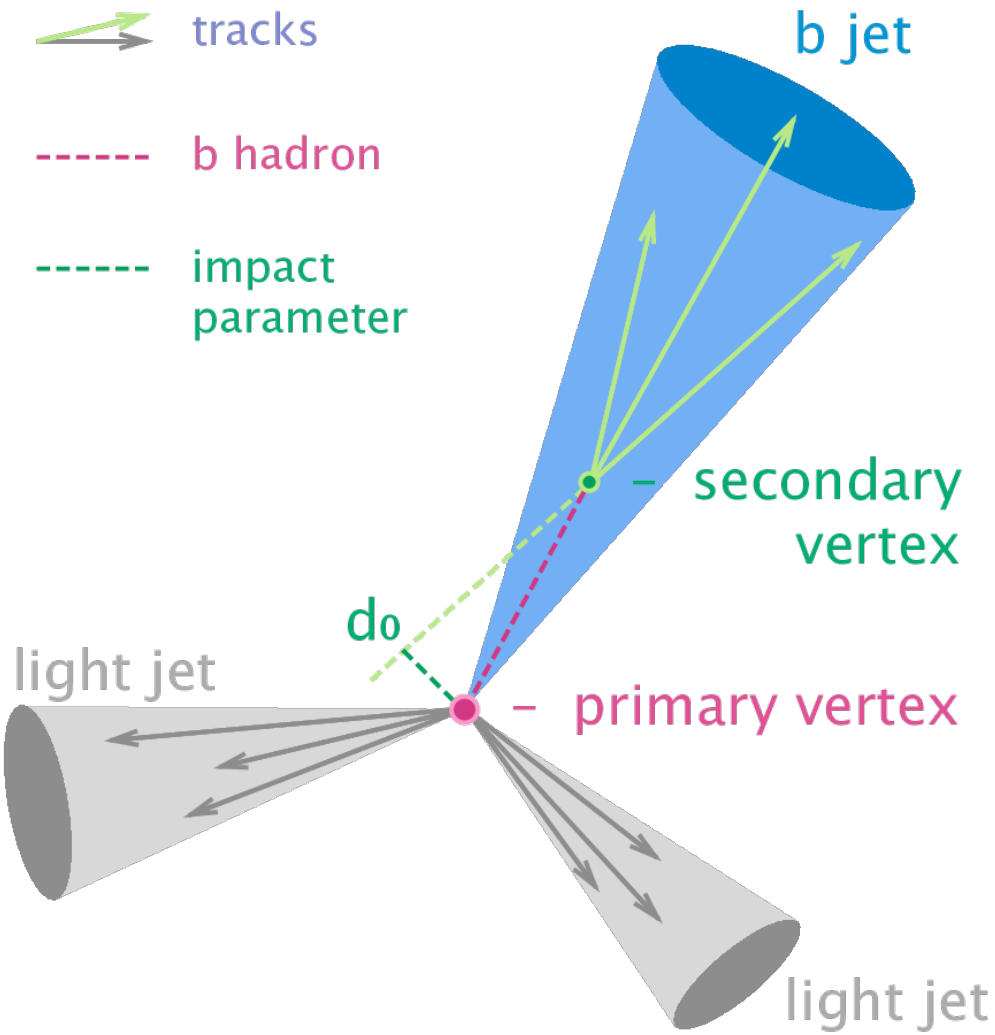
$$d_{ij} = min(\frac{1}{p_{ti}^2}, \frac{1}{p_{tj}^2})\frac{\Delta_{ij}^2}{R^2}$$

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

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

- 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


tracks
b hadron
impact parameter
b jet
secondary vertex
d0
primary vertex
light jet
light jet

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