ATLAS dilepton searches for fourth generation quarks

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IPPP Flavour and the Fourth Family Workshop

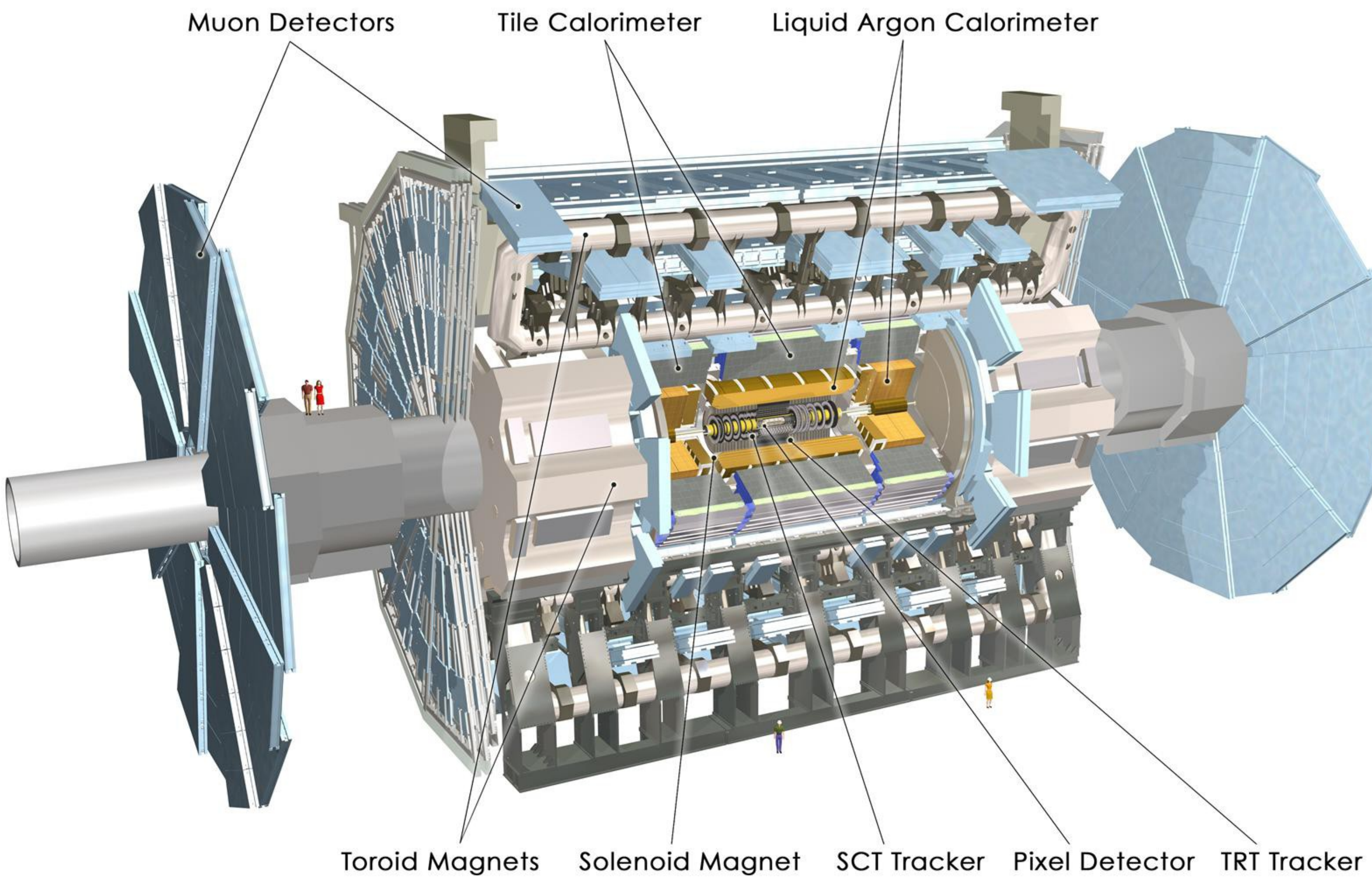
14 September 2011

Outline

- Search for Q4 (heavy quark with top-like decay) in the opposite sign dilepton channel
  - Motivation
  - Event Selection
  - Mass reconstruction
  - Limit setting
  - Conclusions

- Search for d4 in the same sign dilepton channel
  - Motivation
  - Event Selection
  - Limit setting
  - Conclusions

The ATLAS detector

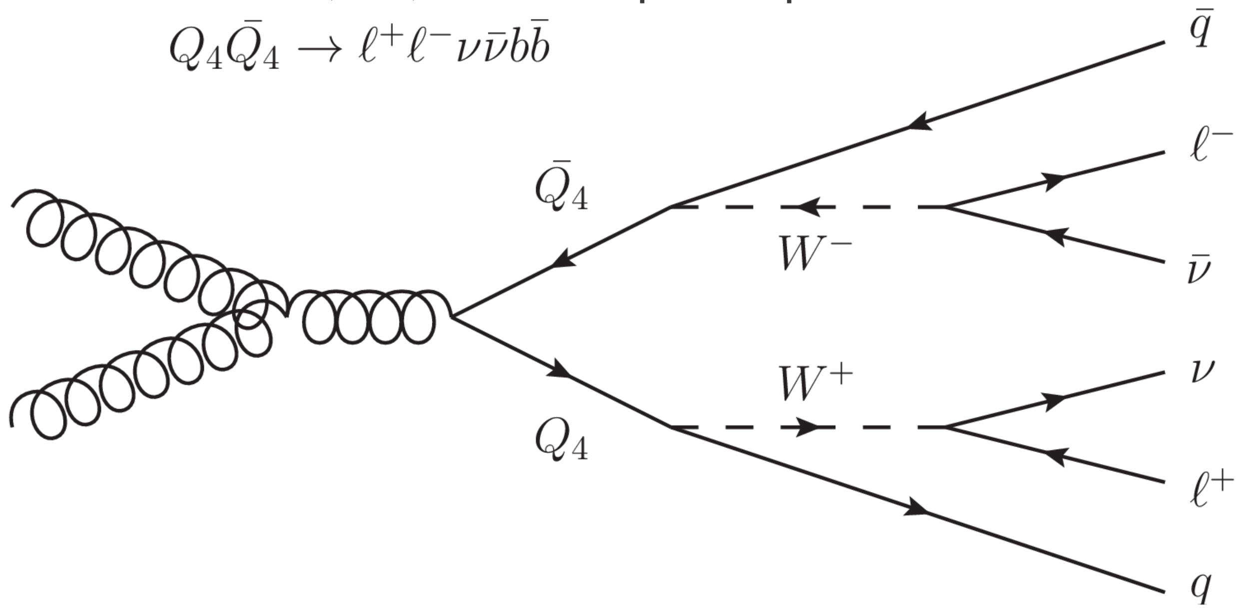


Search for Q4 with top-like decay in the dilepton channel at ATLAS

Generic Q4 → Wq Motivation

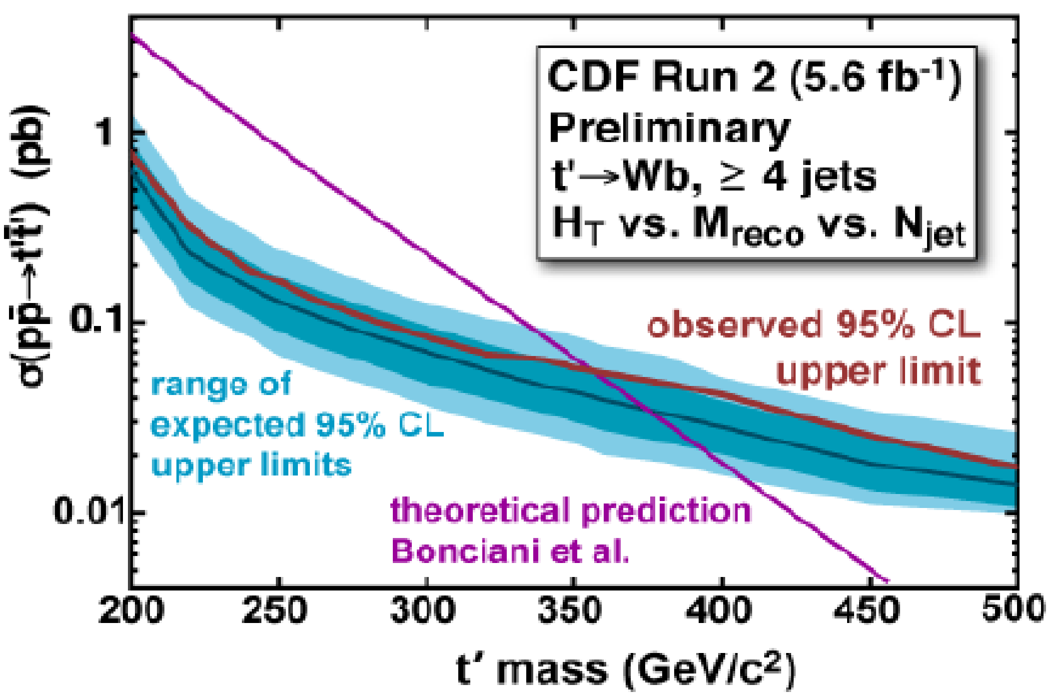
- Seek fourth generation quarks with top-like decay
  - Simple extension to the Standard Model
  - Benefits from the work going into $t\bar{t}$ studies
  - Checking generic dilepton signature with no b-tagging
    - Q4Q4 → qq WW → qq ll νν, where q can be a jet from any quark lighter than top
      - Sensitive to u4, d4, or new top-like quarks with exotic charges (4/3)

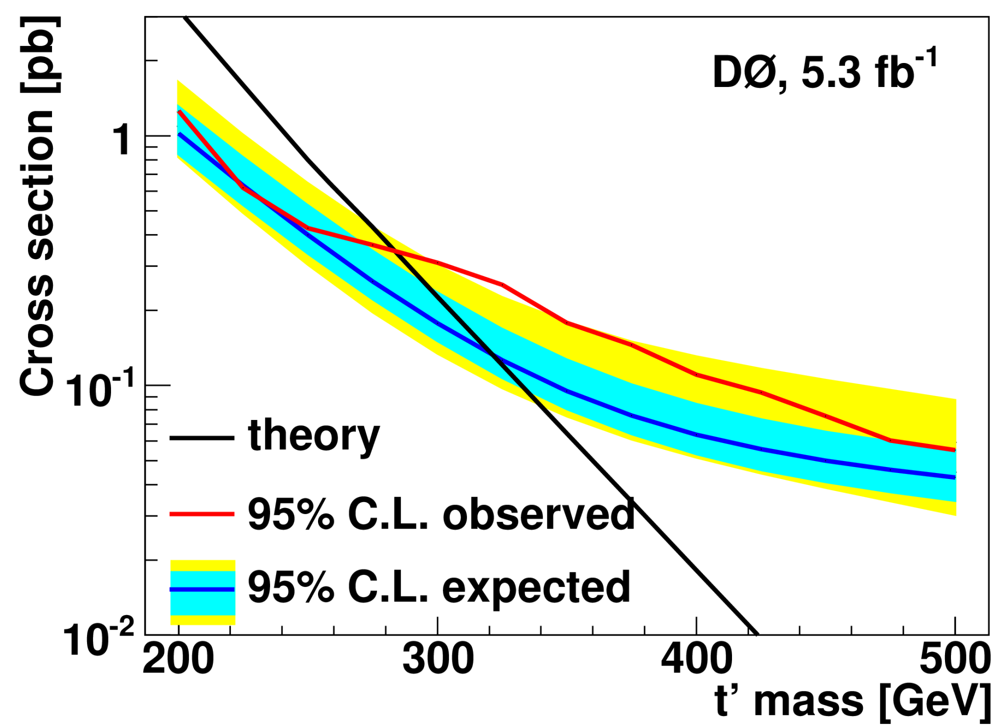
$Q_4\bar{Q}_4 \rightarrow \ell^+\ell^-\nu\bar{\nu}b\bar{b}$



Some Tevatron top-like Q4 Limits

- Most recent CDF limit: Exclude M < 358 GeV
  - l+jets channel, 5.6/fb
- Most recent D0 limit: Exclude M < 285 GeV
  - l+jets channel, 5.3/fb





NOTE: There has been no published Q4 dilepton search at Tevatron

Procedure

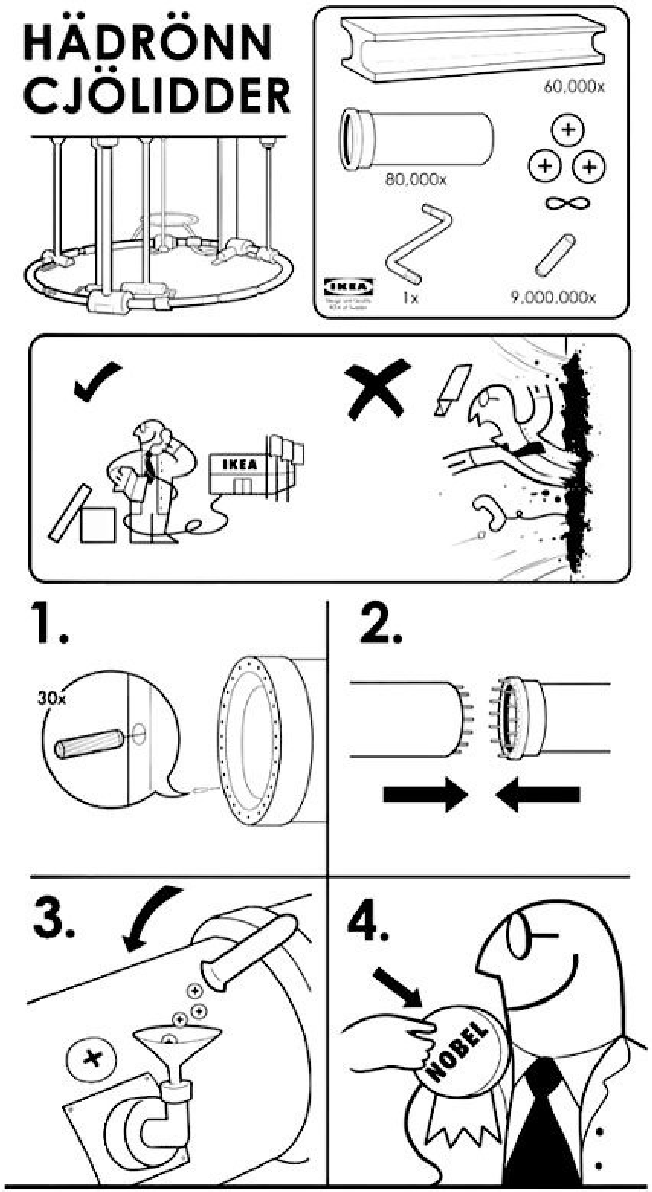
1) Apply $t\bar{t}$ event selection

2) Mass reconstruction

3) Apply additional cuts to suppress backgrounds and enhance signal

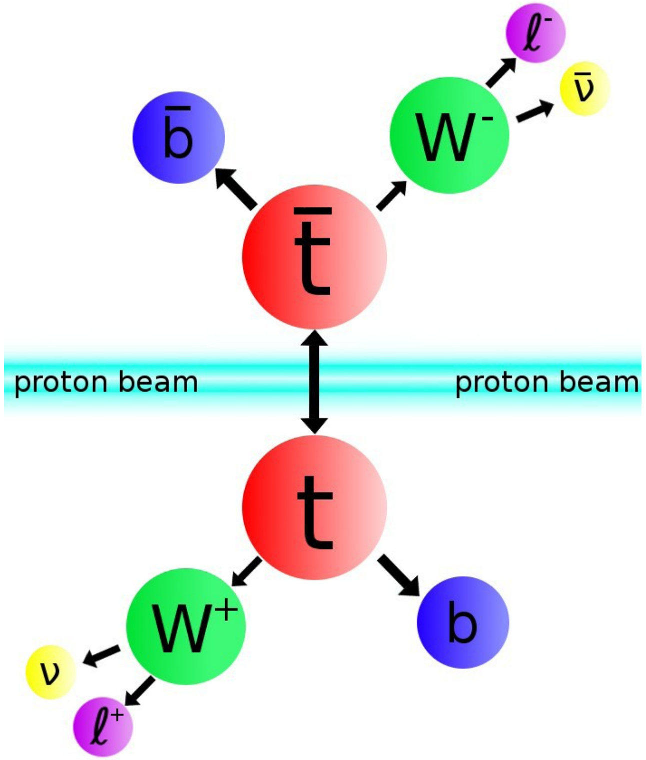
4) Template analysis using reconstructed mass

5) Set limits



Event Selection

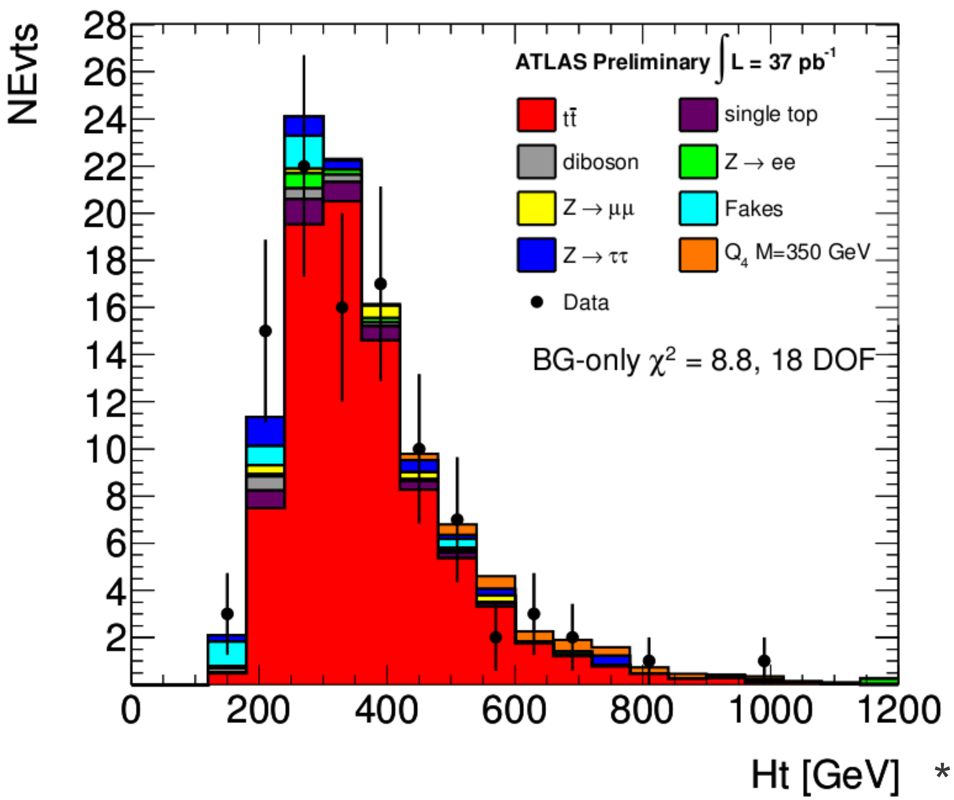
- Start with a generic top analysis, use top selections
  - Apply event cleaning and trigger requirements
  - Require two isolated leptons and at least two jets
  - Require large missing transverse energy (two neutrinos)
  - Remove Z-window (where 2 leptons make a Z mass within 81-101 GeV)



- For details on this selection, see the following notes:
  - Dilepton Top CONF note: ATLAS-CONF-2011-034
  - Dilepton Q4 CONF note: ATLAS-CONF-2011-022

Dominant Backgrounds

- MC-based
  - $t\bar{t}$ (dominant)
  - Single top
  - Drell-Yan
  - Diboson



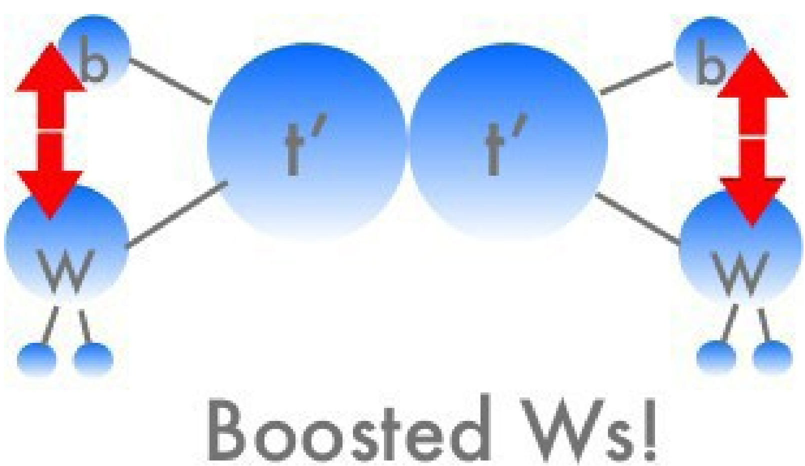
- Data-driven
  - Jets misidentified as leptons ("Fakes")
    - Primarily come from W+jets and single lepton $t\bar{t}$ events
    - Estimate in data by calculating the probability of measuring a jet as a lepton, the "matrix method", see backups

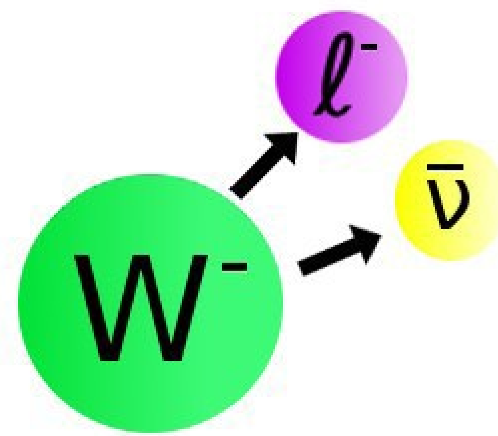
* Ht = Scalar sum of Et of all kept leptons and jets

Mass Reconstruction?

- We lack enough information to fully reconstruct the Q4 mass in dilepton events
  - Because the neutrinos go undetected!

- Heavy quarks should provide a boost to the W bosons, making the W decay products more collinear in the lab frame

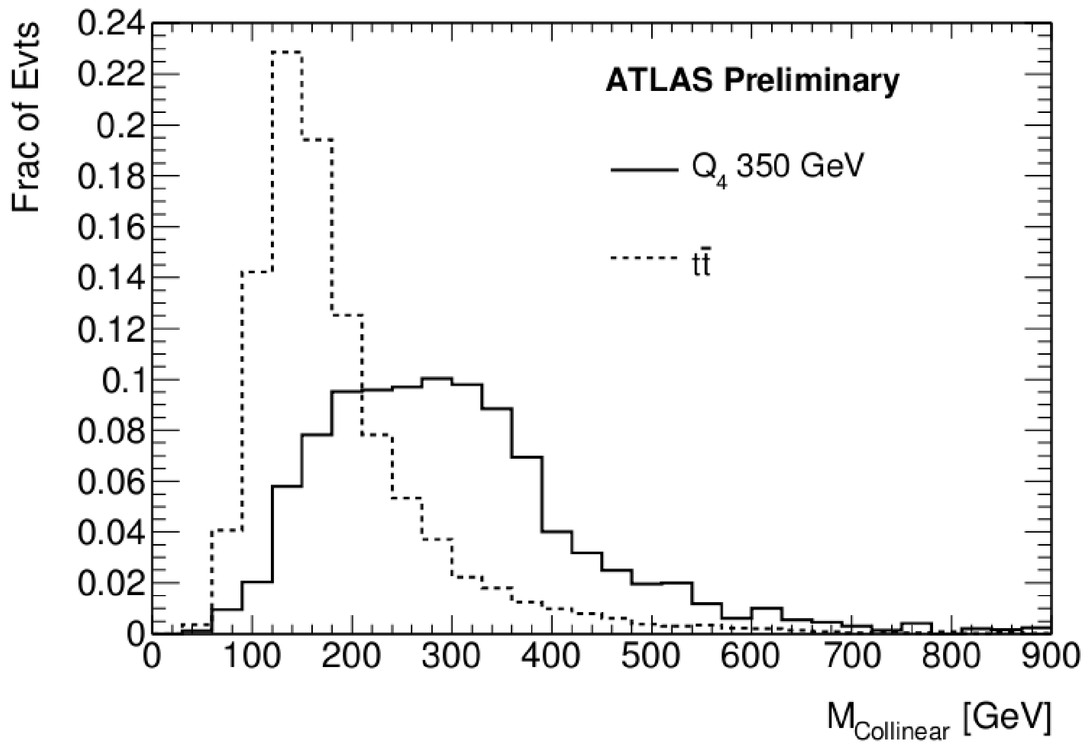




Boosted W decay products are collinear in the lab frame

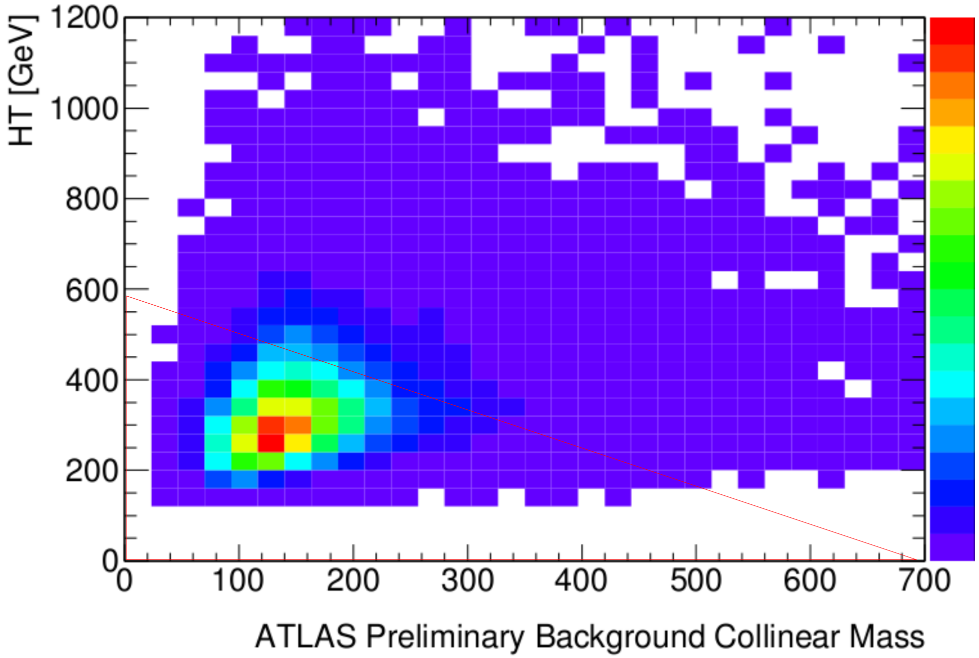
Collinear Mass Reconstruction

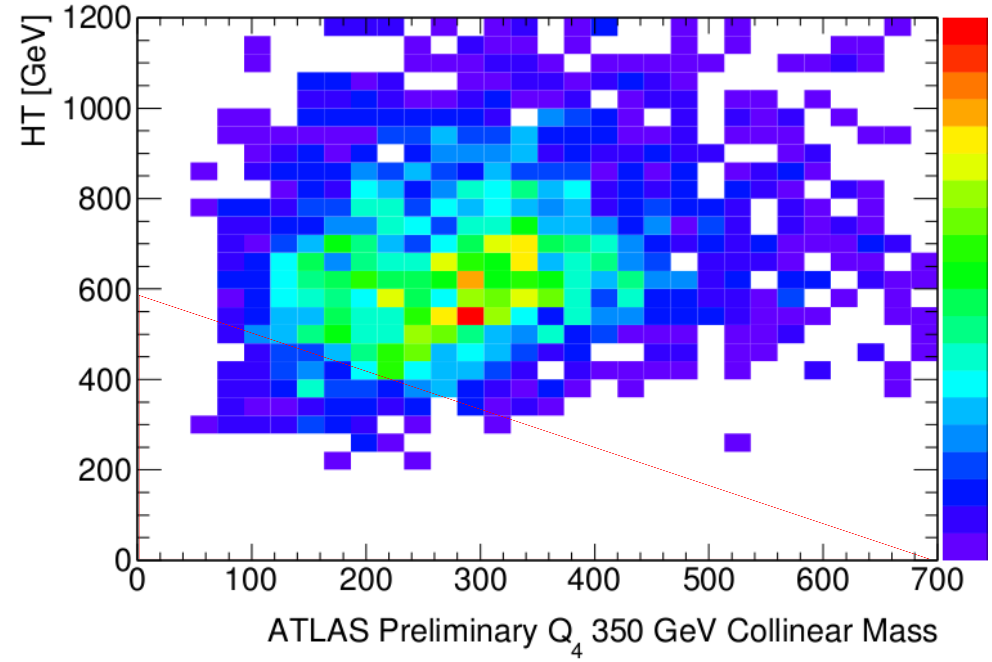
- Assume two neutrinos are in every selected event and that they are the dominant contributors to the EtMiss
- Assume each neutrino has an eta, phi close to its sister lepton
- These assumptions allow us to solve for the neutrino 4-vectors
  - 6 unknowns: Px, Py, Pz of each neutrino
  - 6 knowns: Eta and Phi of two leptons plus two components of EtMiss



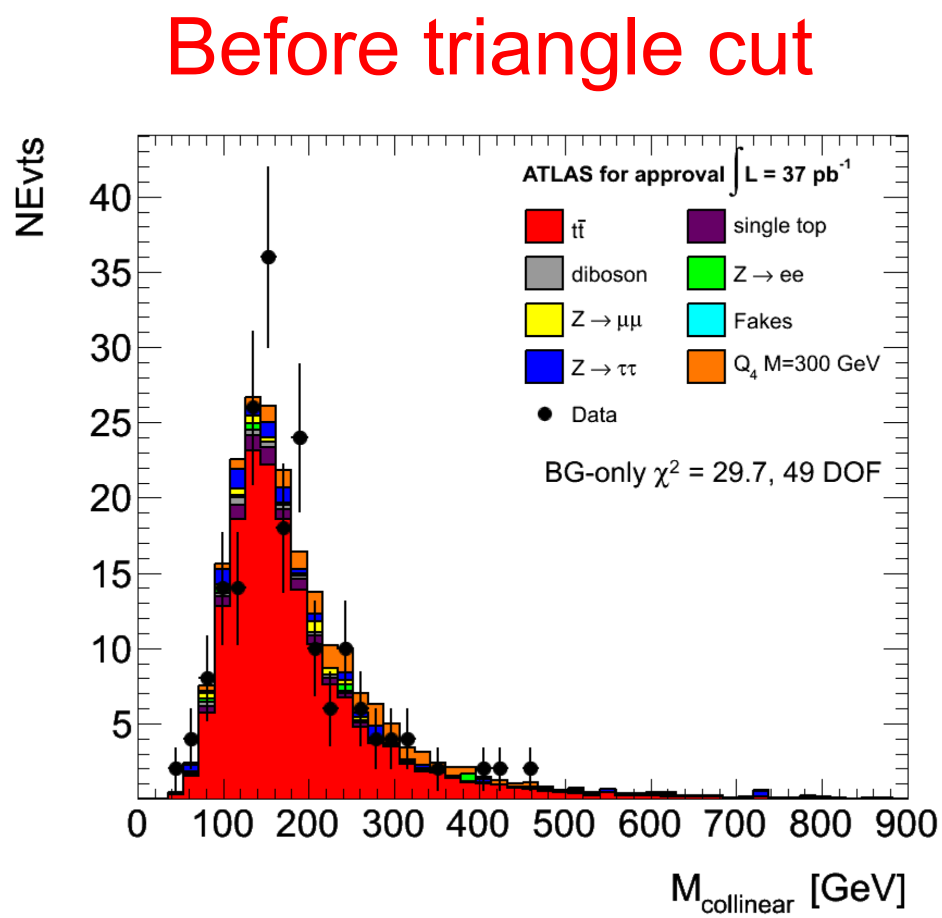
Additional Cuts

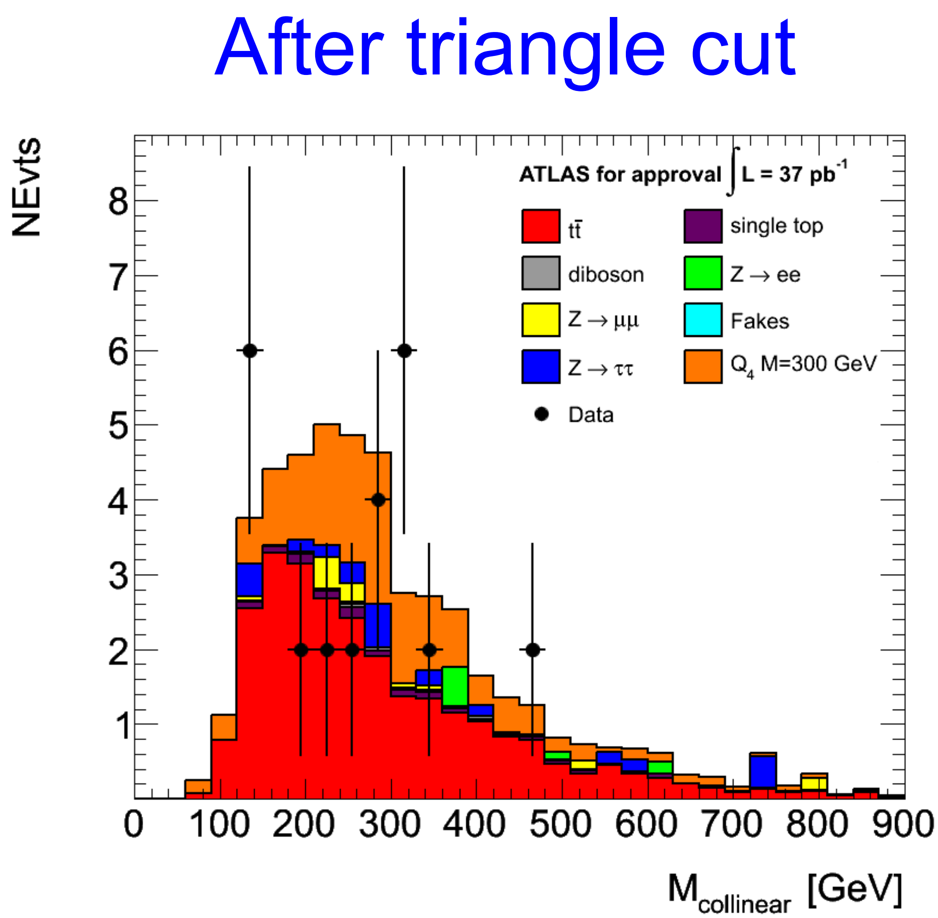
- We apply a cut between Ht and Collinear Mass to further suppress background
  - Ht: Sum of Et from good leptons and jets
  - Cut is optimized for each hypothetical signal mass: 250 – 400 GeV in 50 GeV steps





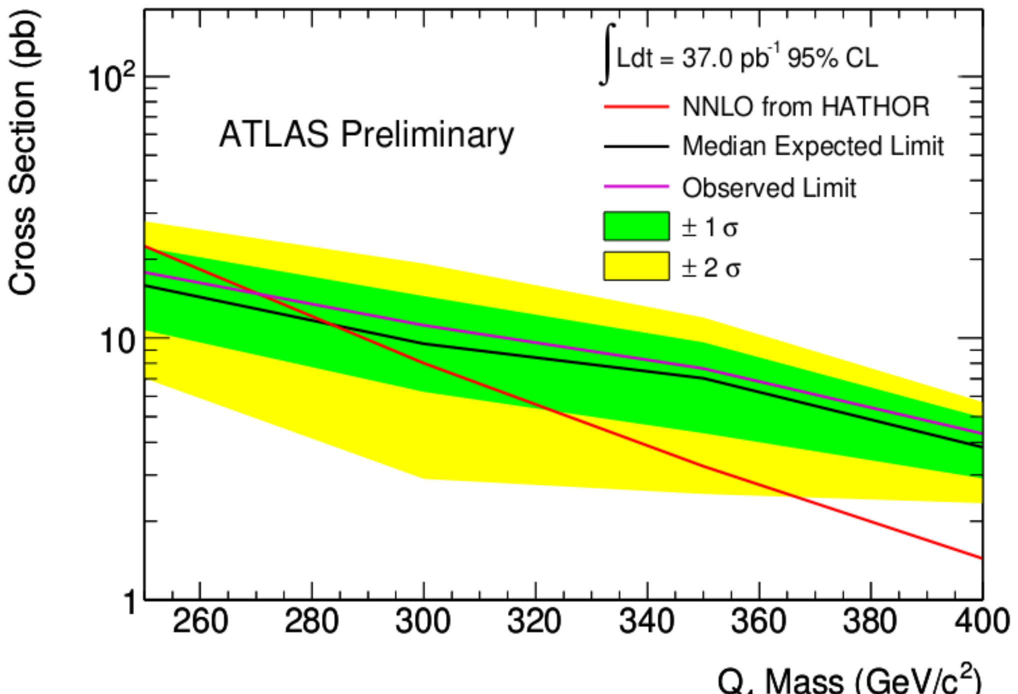
Triangle cut comparison





Dilepton Q4 Limit Setting

- We apply a binned maximum likelihood fit and extract observed and median expected limits
- We exclude M_{Q4} < 270 GeV at 95% confidence in L = 37/pb
  - Observation consistent with null hypothesis



Q4 Conclusions

- Set a limit on a generic new quark with a top-like dilepton final state in 37/pb at ATLAS
  - Q4 $\rightarrow$ qW, q is any b, s, d, c, u
  - Quark charges unchecked, sensitive to exotic Q4 charges (4/3)
- First LHC fourth generation quark limit
- First dilepton fourth generation quark limit
- Plans: repeat analysis with greater luminosity and update results, also examine L+Jets channel

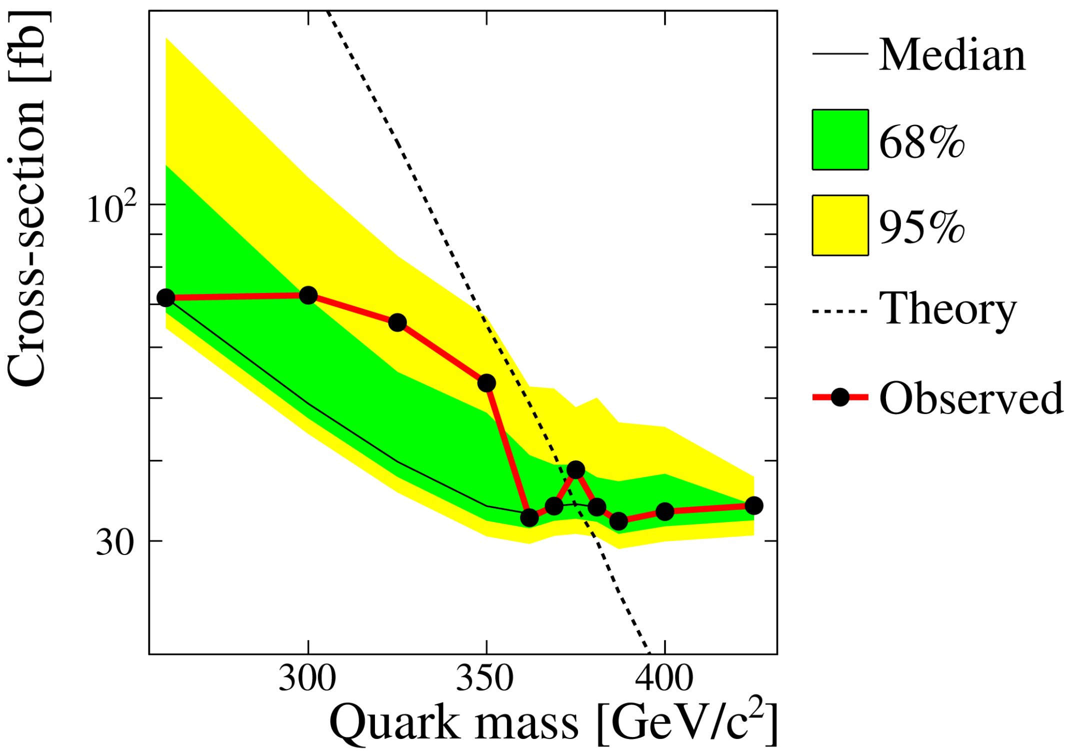
Search for d4 in the same-sign dilepton channel at ATLAS

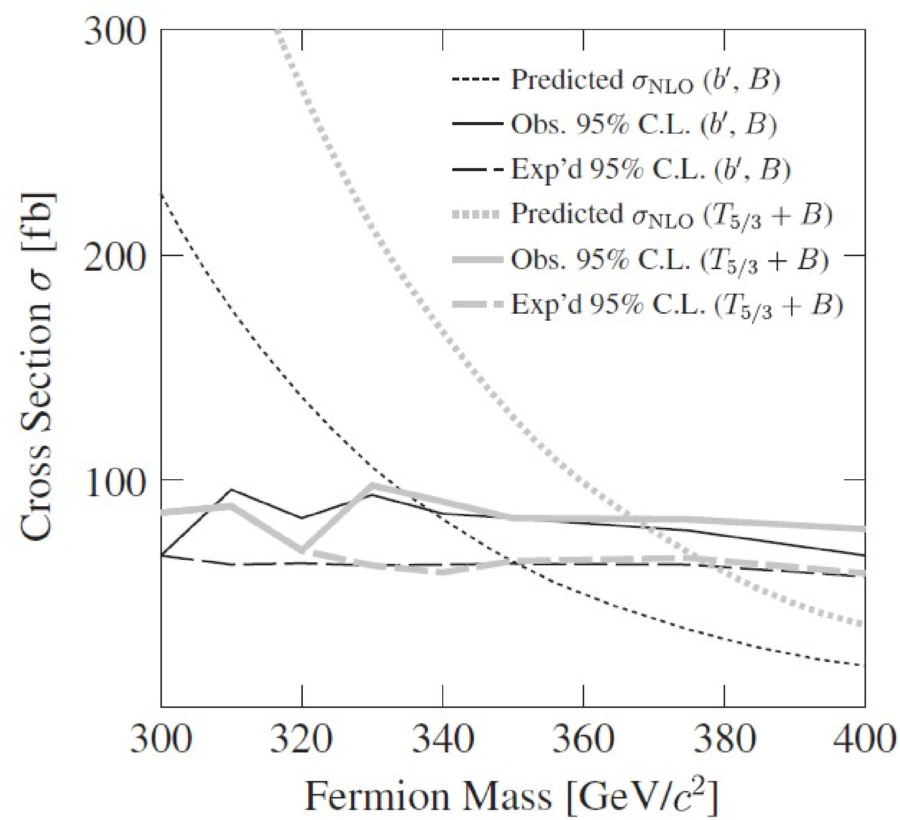
d4 → Wt Motivation

- Seek fourth generation d-type quark decaying to tW
  - Checking same sign dilepton signature with no b-tagging
    - d4d4 → tt WW → bb W W W W → ll νν jjjjjj
    - Cut by requiring large missing transverse energy
    - Template fit to jet multiplicity
- Paper is part of a generic same-sign dilepton search
  - Limits on multiple models, including SUSY, UED, Majorana neutrinos, etc.

Some Tevatron d4 Limits

- Most recent CDF l+jets limit:
  Exclude M < 372 GeV
  - l+jets channel, 4.8/fb
- Most recent CDF same-sign dilepton limit:
  Exclude M < 338 GeV
  - SS dil. channel, 2.7/fb





d4 → Wt Event Selection

- Apply same sign dilepton event selection
  - Apply event cleaning and trigger requirements
  - Require two isolated same charge leptons
  - Require large missing transverse energy
- Leaves very few remaining backgrounds
  - Dibosons, fake leptons, electron charge misID
- For additional details, please refer to the paper submitted to JHEP
  - *Inclusive search for same-sign dilepton signatures* CERN-PH-EP-2011-094

Jet Multiplicity Search for d4

- From CERN-PH-EP-2011-094

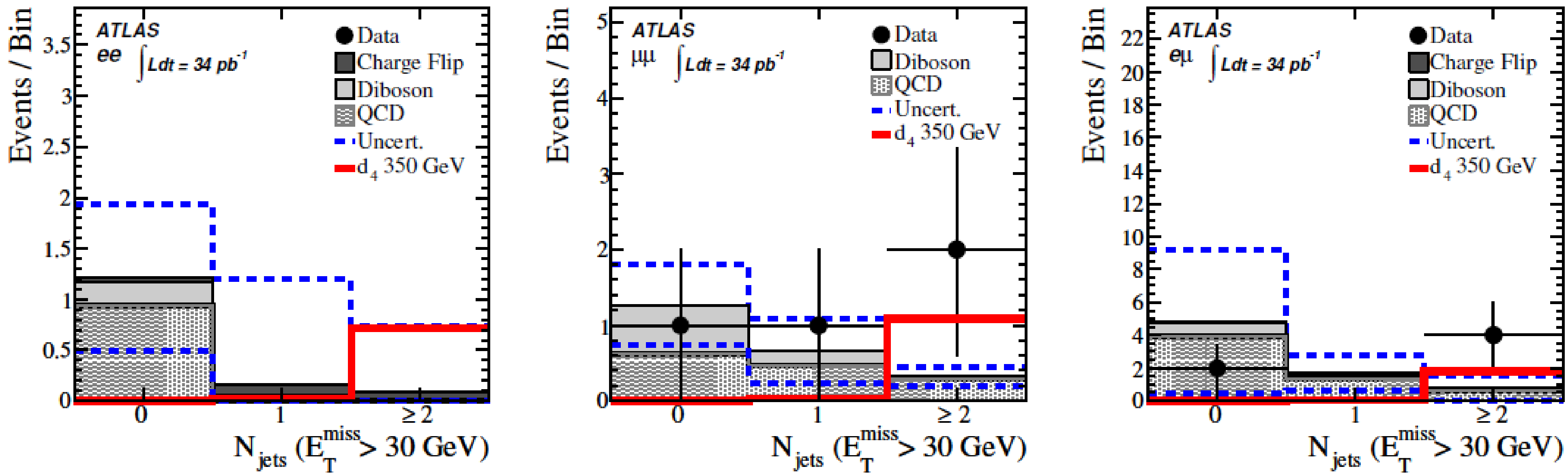
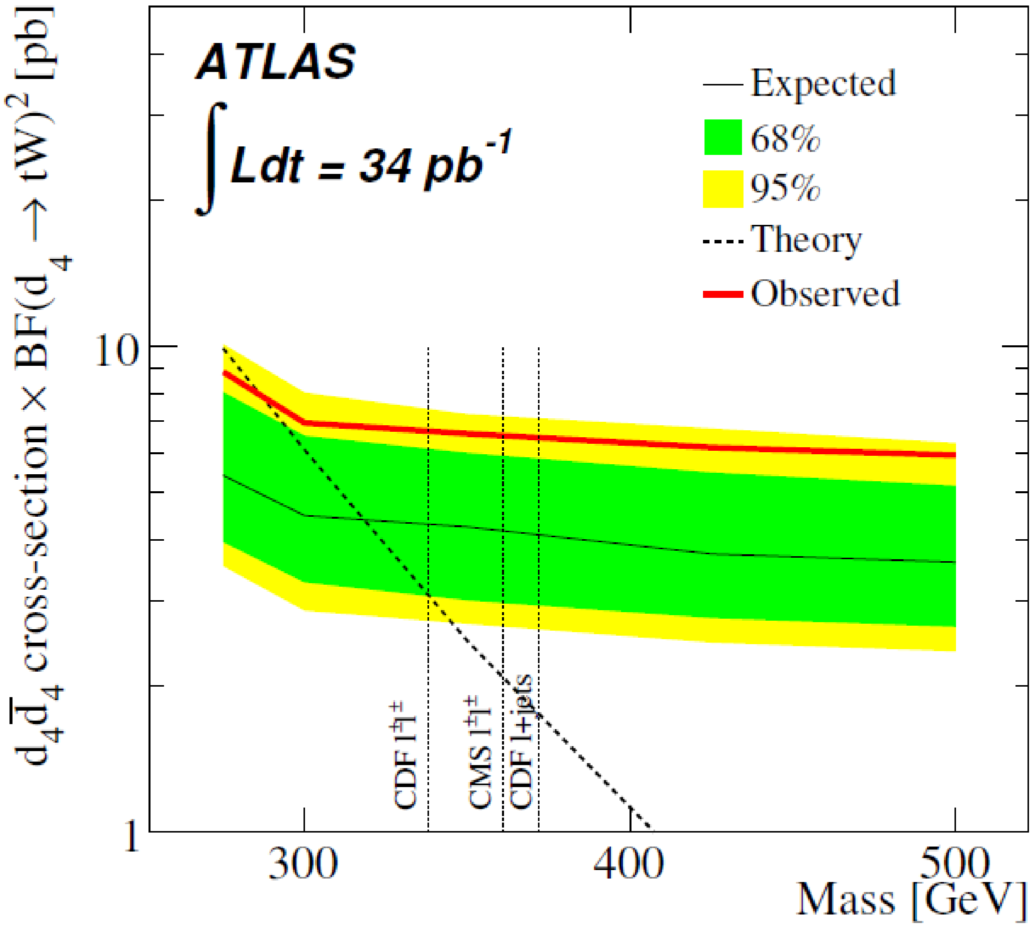


Figure 11. Distributions of jet multiplicity with $E_T^{miss} > 30$ GeV in ee (left), $\mu\mu$ (center) and $e\mu$ (right) channels. The final bin includes events with two or more jets. Shown are data (points) and backgrounds (solid stacked histograms). The combined statistical and systematic uncertainty is shown as a dashed blue line. Overflow events are included in the final bin. In the ee channel, the Z reflection is suppressed by excluding $80 < m_{\ell\ell} < 95$ GeV.

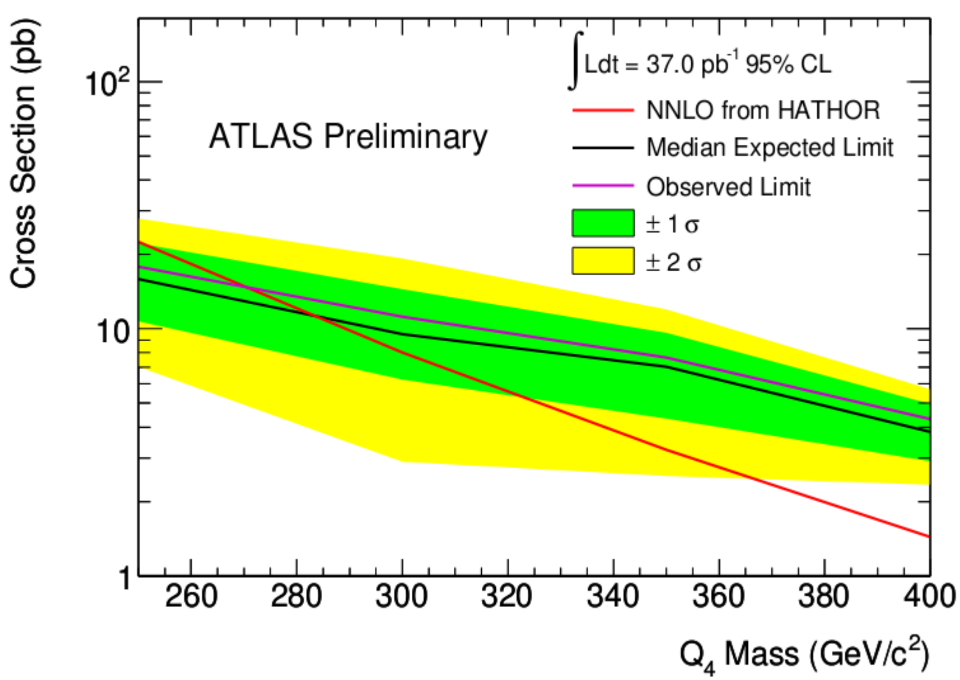
Same-sign Dilepton d4 Limit

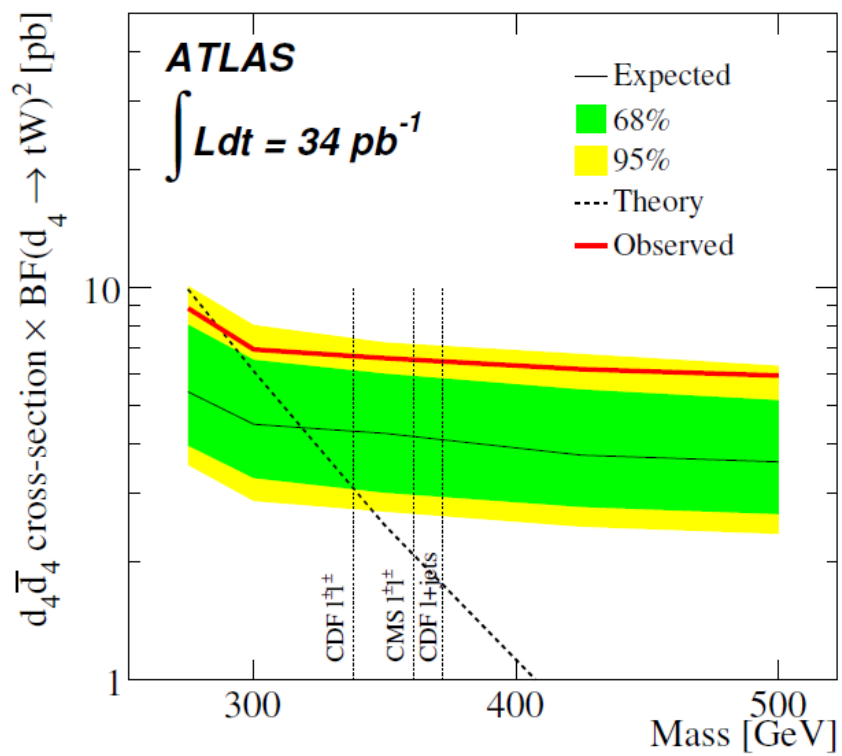
- Binned max likelihood fit with jet multiplicity
- We exclude M_{d4} < 290 GeV at 95% confidence in L = 34/pb



Summary

- Exclude Q4 < 270 GeV
  - Q4 → Wq (Top-like decay)
  - Opposite-sign dilepton search
- Exclude d4 < 290 GeV
  - d4 → tW
  - Same-sign dilepton search





BONUS SLIDES

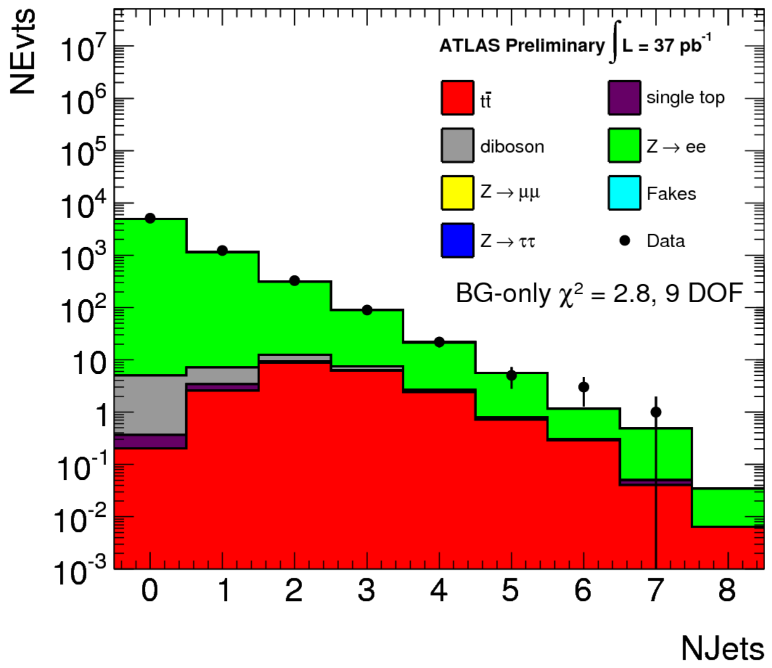
Q4 Fake Leptons

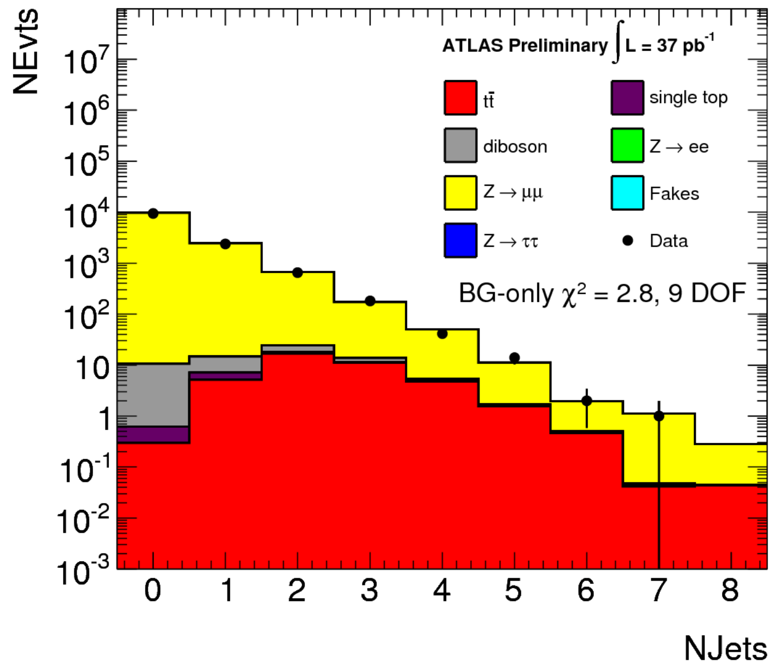
- Fake leptons (jets misidentified as leptons) are estimated using a Matrix Method
  - Define a Loose (L) and Tight (T) lepton selection
  - Using tag and probe Drell-Yan events, measure the rate at which Real Loose leptons pass theTight selection (r)
  - Using tag and probe QCD multijet events, measure the rate at which Fake (f) Loose leptons pass the Tight selection (f)
  - Measure the number of events with two (Pt ordered) tight, one tight and one loose, one loose and one tight, or two loose leptons (N_{TT}, N_{TL}, N_{LT}, N_{LL})
  - Use the matrix below to solve for the number of events with one or more fake leptons (N_{RF}, N_{FR}, N_{FF})

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

Q4 Background Validation

- We ensure the quality of our background modeling by examining the data in signal-depleted regions
  - Drell-Yan dominated events
  - Events with low HT
  - Events where leptons or jets have low Pt, or low EtMiss





Q4 Systematic Uncertainty

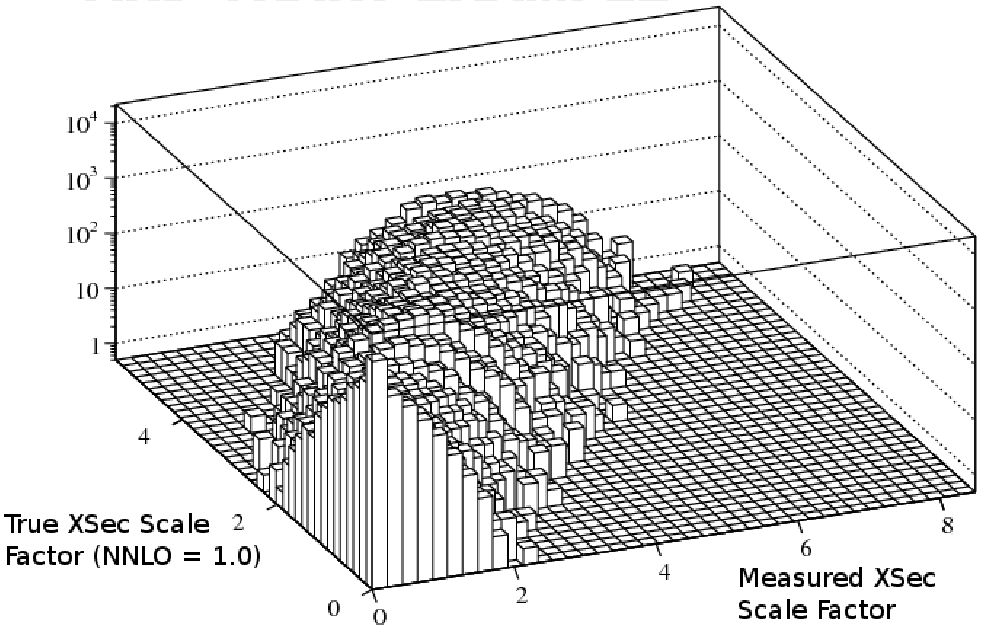
Source	Effect	Size [%]
Electron trigger and reconstruction	Yield	1.6%
Electron ID	Yield	2-9%
Muon ID and reconstruction	Yield	0.3%
Muon trigger	Yield	0.1-1.3%
Electron energy scale	Shape	0.6%
Muon momentum scale	Shape	0.1%
Jet energy scale	Shape and Yield	12%
Gluon radiation	Shape and Yield	15%
Signal cross-section	Yield	14%
Background cross-sections	Yield	5-30%
Fake lepton background	Shape and Yield	50%
Luminosity	Yield	11%

Size[%] reflects only overall scale uncertainty

Q4 Fitting / Limit Setting

- Consider range of hypothetical cross sections, draw pseudoexperiments from combined (Monte Carlo) shape
- We use a binned maximum likelihood fit on a plot of Collinear Mass after triangle cuts
  - Float the background rates within uncertainties
  - Allow variation due to systematic uncertainties, such as luminosity, energy scale, resolution, etc.
  - Simultaneously fit for the signal and background rates
- Use Feldman-Cousins method to extract 95% Neyman confidence intervals from measured Xsec distributions
  - Phys. Rev. D 57: 3873-3889
- Fit for signal fraction in data

ARBITRARY EXAMPLE



d4 Systematic Uncertainty

Table 2. Sources and estimated sizes of systematic uncertainties, for data-driven predictions and for Monte Carlo predictions of background and hypothetical signals, shown as a fraction of the event yield or of the electron and muon efficiencies (ϵ^e and ϵ^μ, respectively).

Source of uncertainty	Size
Data-driven predictions	
Category transformation, yield and shape	25% of yield
Monte Carlo predictions	
Luminosity	3.4% of yield
Jet-energy calibration	$\leq$ 2% of yield
E/p requirement ($E_T^e < 150$ GeV)	3% of ϵ^e
E/p requirement ($E_T^e \geq 150$ GeV)	12% of ϵ^e
Electron charge misidentification	1.5% of ϵ^e
Muon momentum resolution	$<$ 1% of ϵ^μ
Electron energy resolution	$<$ 1% of ϵ^e