Flavor changing neutral currents (FCNC) in $t\bar{t}$ decays at DZero

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University of Kansas
On behalf of the DZero Collaboration

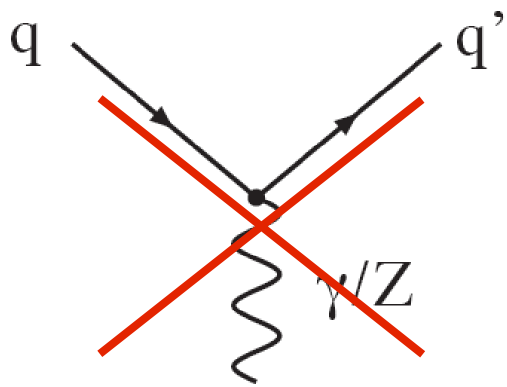
Supersymmetry 2011, Aug. 29, 2011

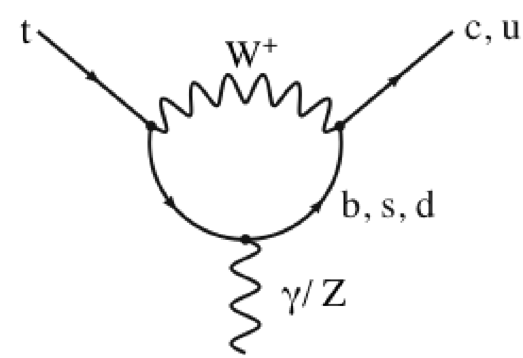
Outline

- Motivation
- DZero detector
- Event selection
- FCNC signal modeling
- Limits on branching ratio B(t→Zq) and v_{tqZ} coupling
- Summary

FCNC Motivation

- The standard model (SM) has been found to be in excellent agreement with experimental results
- SM Lagrangian does not contain flavor changing neutral currents terms
  - $t \rightarrow c,u$ quarks transitions only possible through radiative corrections





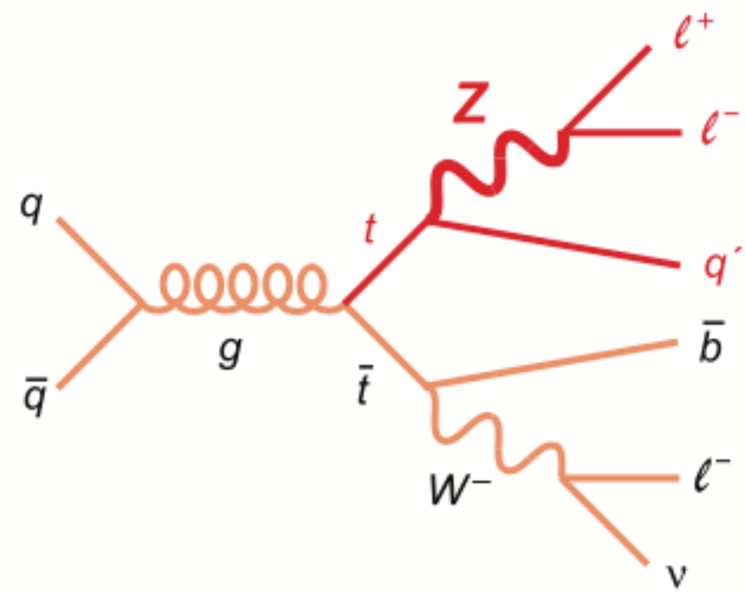
- Expected branching ratio of $t \rightarrow Zc$ is $\sim 10^{-14}$, while $t \rightarrow Zu$ is $\sim 10^{-17}$
- Some theories beyond SM predict $B \sim 10^{-4}$
- Observation would certainly point to physics beyond the SM

FCNC Motivation

- Use a previous analysis of trilepton + imbalance in transverse momentum for WZ cross section : Physics Letters B **695**, 67 (2011)
- Search for signal using new final state : X is any number of jets

$$p\bar{p} \to t\bar{t} \to ZqWb \to \ell\ell\ell\nu + X$$

- Extract or set limits on branching ratio of t→Zq (q = u, c)



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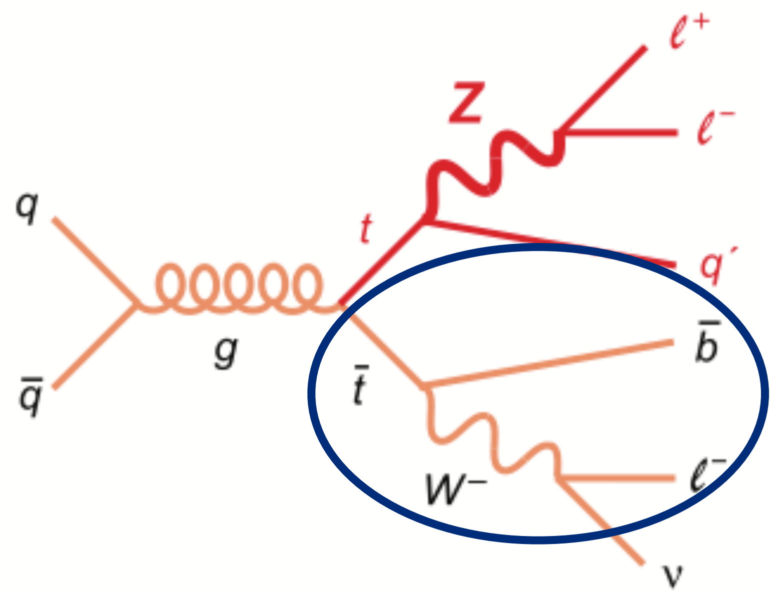

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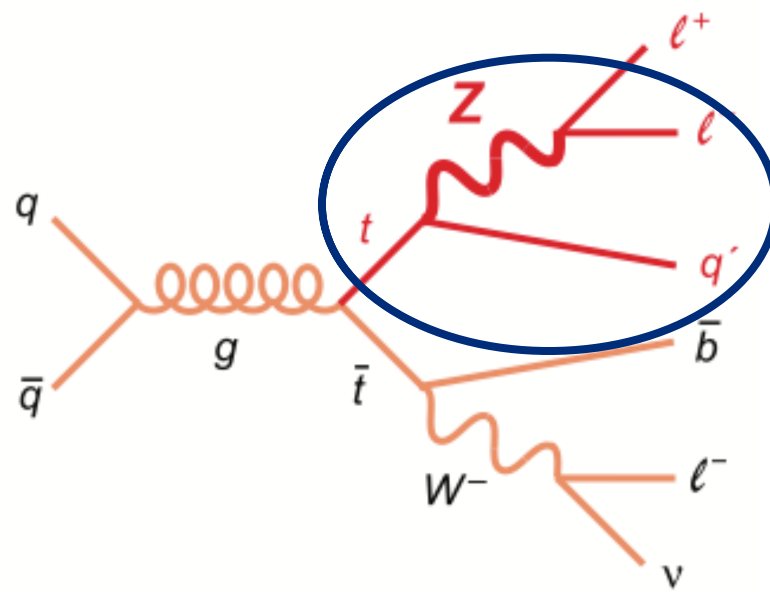

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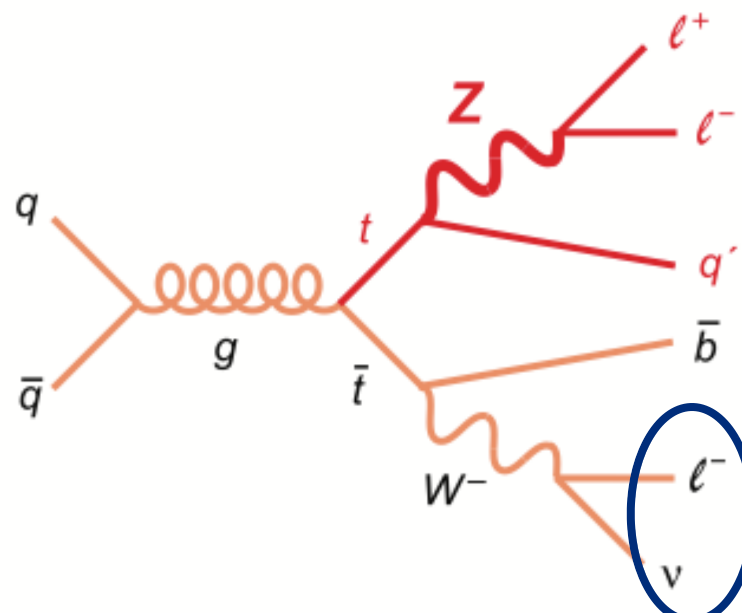

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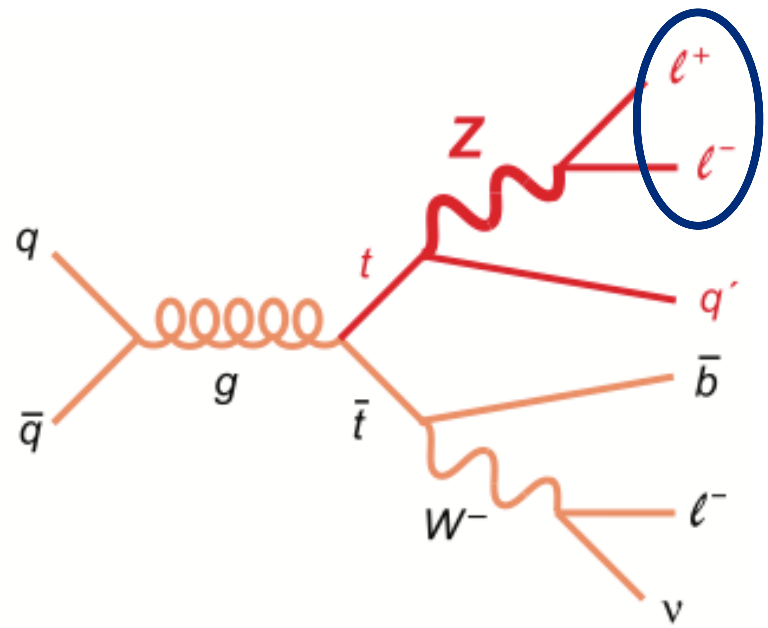

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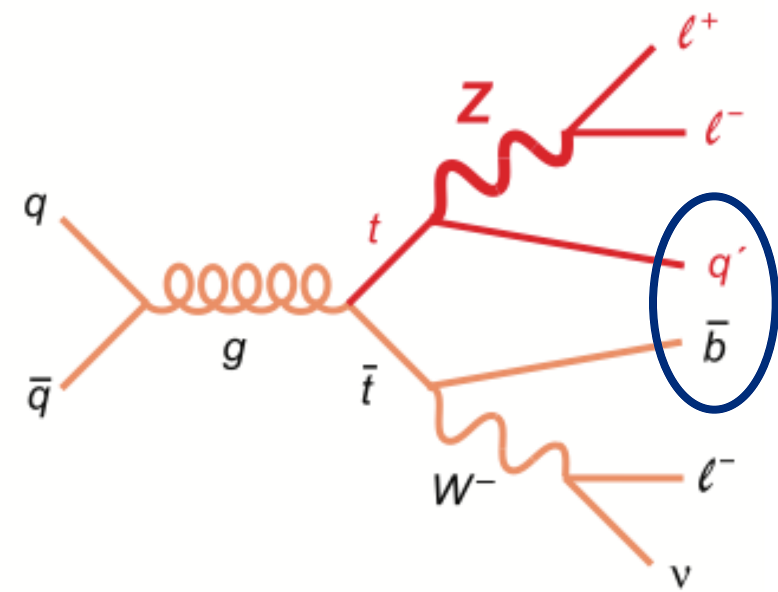

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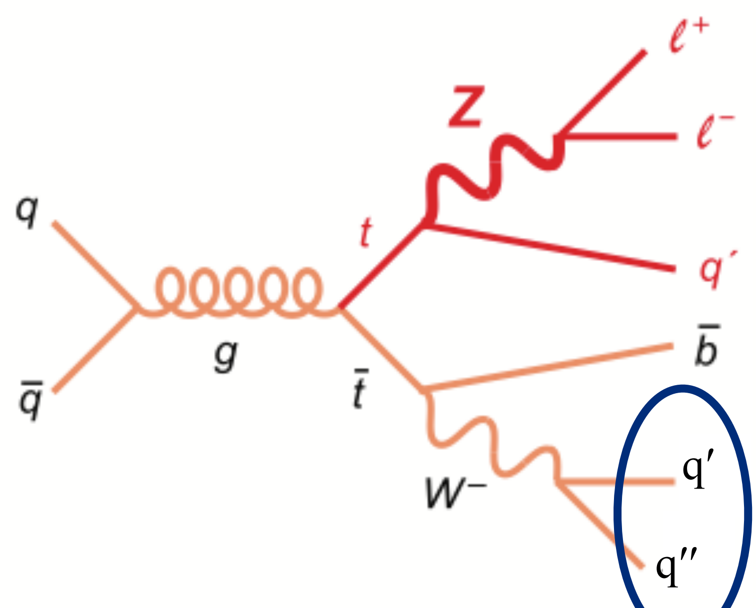
- Extract or set limits on branching ratio of t→Zq (q = u, c)

- CDF results : B(t→Zq) < 3.7% (observed) with a < 5.0% (expected) at 95% C.L. using 1.9 fb^{-1} T. Aaltonen et al. [CDF Collaboration], Phys. Rev. Lett.101, 192002 (2008)
  - $Z \to \ell\ell + \geq 4$ jets
  - Complementary search



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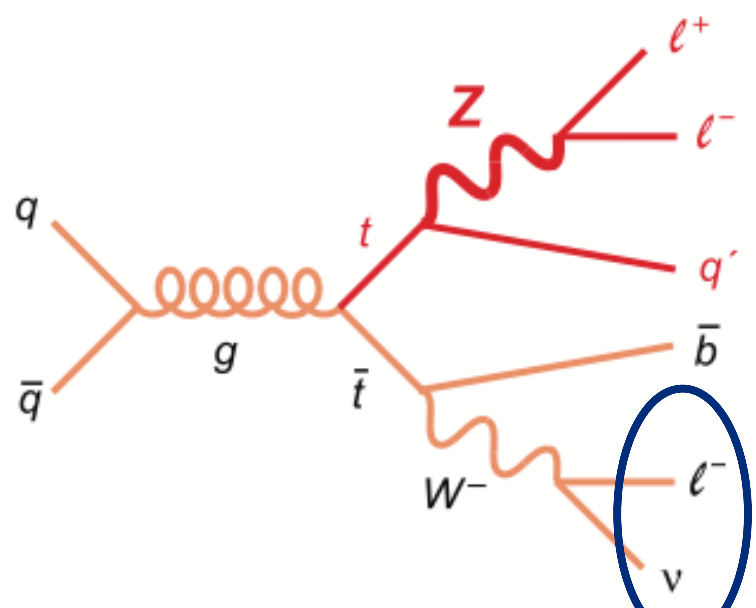
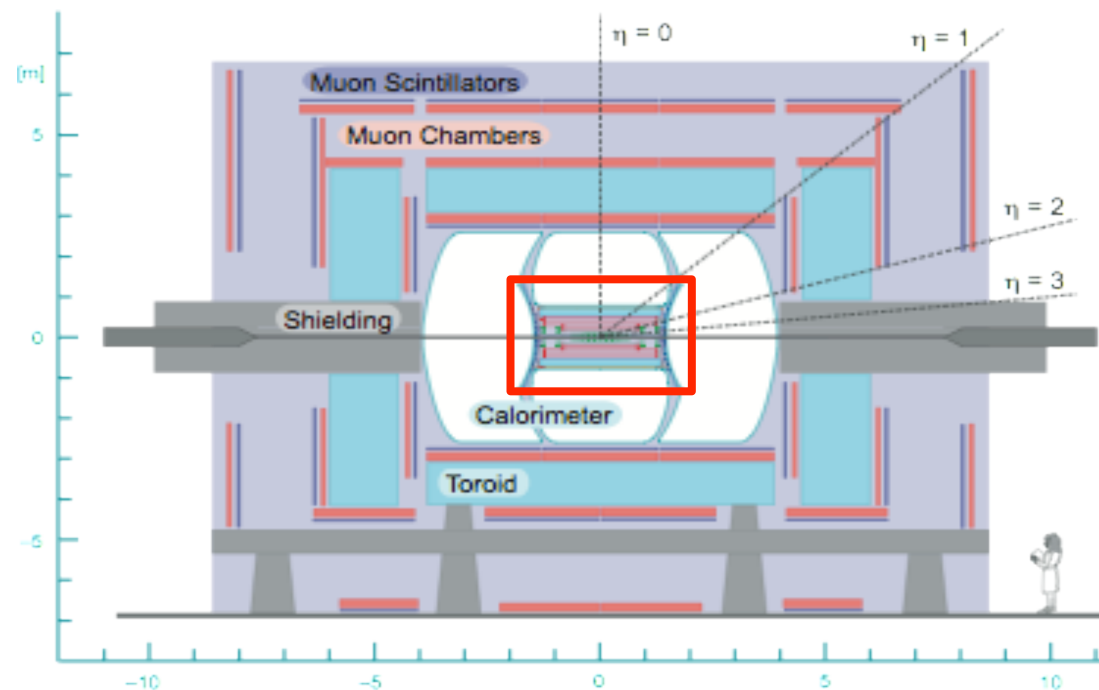
- Extract or set limits on branching ratio of t→Zq (q = u, c)

- ATLAS results : B(t→Zq) < 17% (observed) with a < 12% (expected) at 95% C.L. using 35 pb^{-1} ATLAS-CONF-2011-061
  - Three leptons + MET + 2 jets



DZero Detector

- Consists of three sub-detectors :
  - Tracking : Reconstruct interaction vertices and measure momenta of charged particles, enclosed in a 1.9 T solenoid field
  - Calorimeter : EM and Hadronic calorimeters measure energies of hadrons, electrons and photons
  - Muon : consists of three layers of drift tubes and scintillation counters (one layer inside a 1.8 T toroidal magnet)



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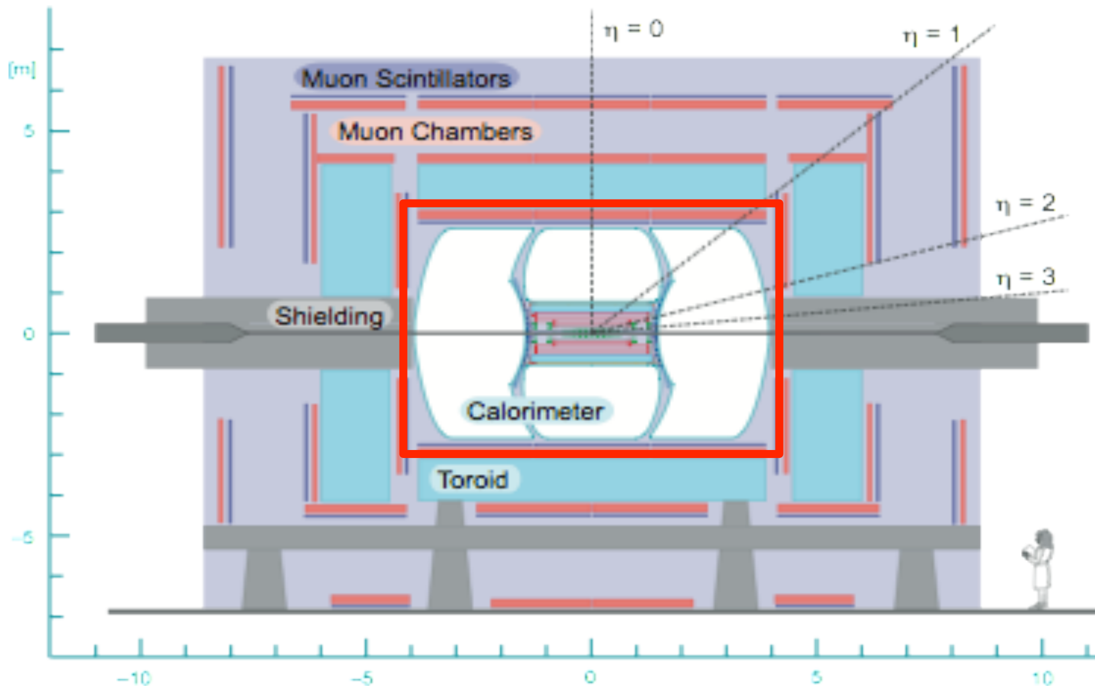

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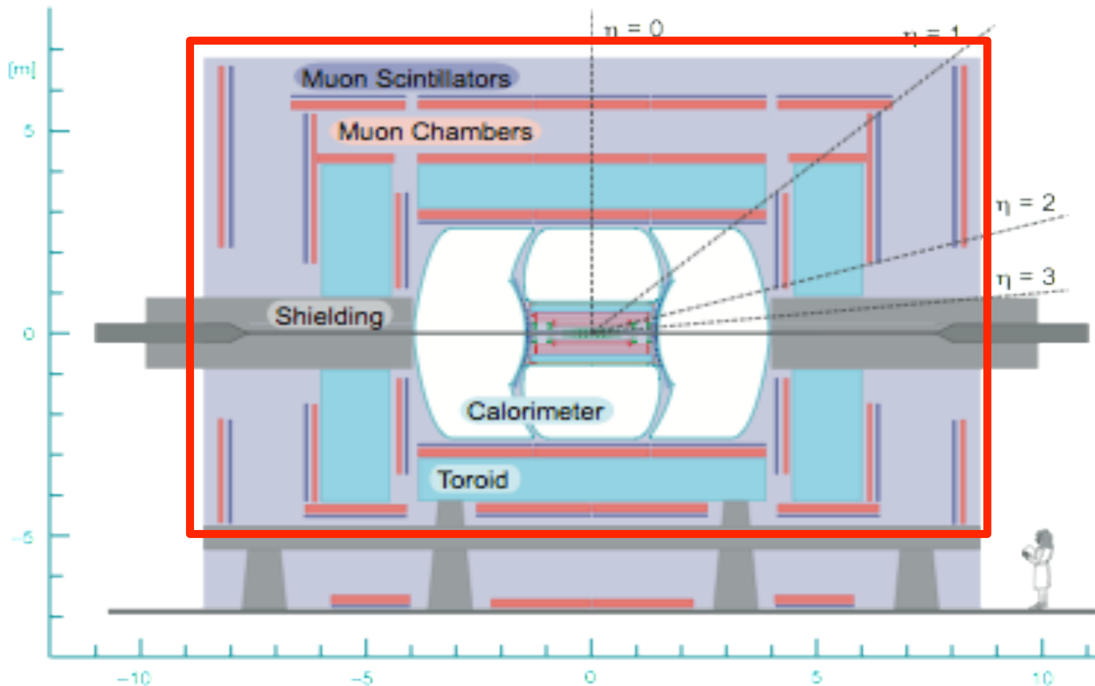
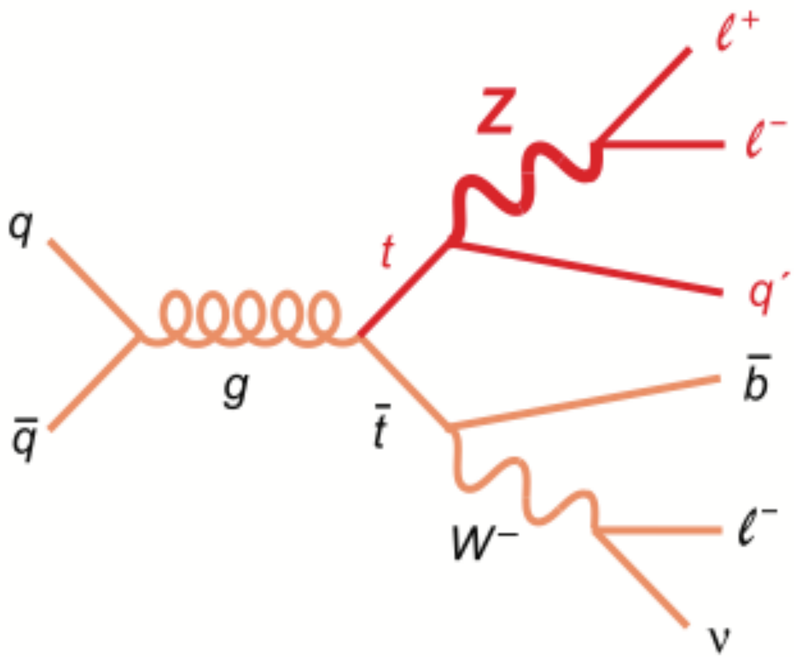


Event Selection



$\geq$ 3 isolated leptons, with high p_T, separated in $\Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$

Imbalance in transverse momentum (MET)

Three jet multiplicity bins; 0, 1, $\geq$ 2

All from same vertex

Invariant dilepton mass within Z window

- Use 4.1 fb^{-1} of integrated luminosity collected in Tevatron Run II, with selection criteria optimized for $s/\sqrt{(s+b)}$.
- Signal : FCNC $t\bar{t}$, Main Backgrounds: WZ, ZZ, Zγ, Z/W+Jets, SM $t\bar{t}$
  - Determined using MC Simulations and Data

FCNC Signal Modeling

- Use CompHEP to generate the signal at the parton level (to correctly model the helicity structure) and PYTHIA for jet development and hadronization
  - Modified to include the following FCNC Lagrangian

$$\mathcal{L}_{FCNC} = \frac{e}{2\sin\theta_W \cos\theta_W} \bar{t}\gamma_\mu (v_Z - a_Z \gamma_5) c Z^\mu + h.c.$$

T. Han and J. L. Hewett, Phys. Rev. D 60, 074015 (1999).

- Assume SM neutral current couplings (Z→$q\bar{q}$ for up-type quarks) : $v_{tuZ} = 1/2 - 4/3 \sin^2\theta_W = 0.192\,,\ a_{tuZ} = 1/2$

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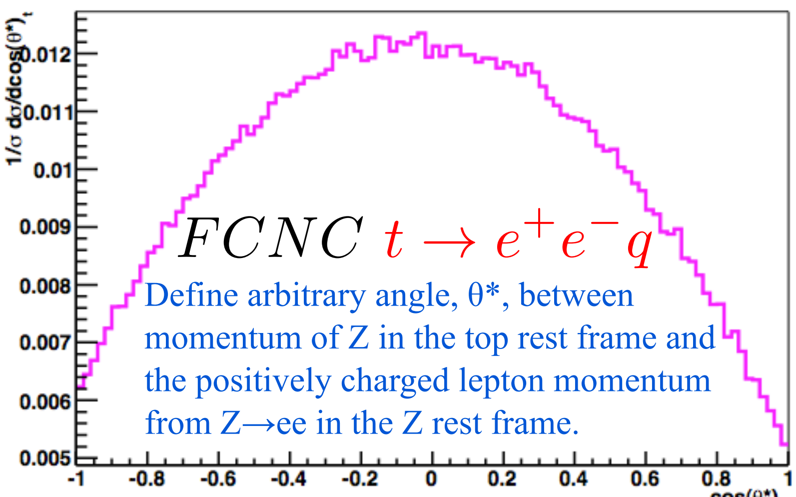
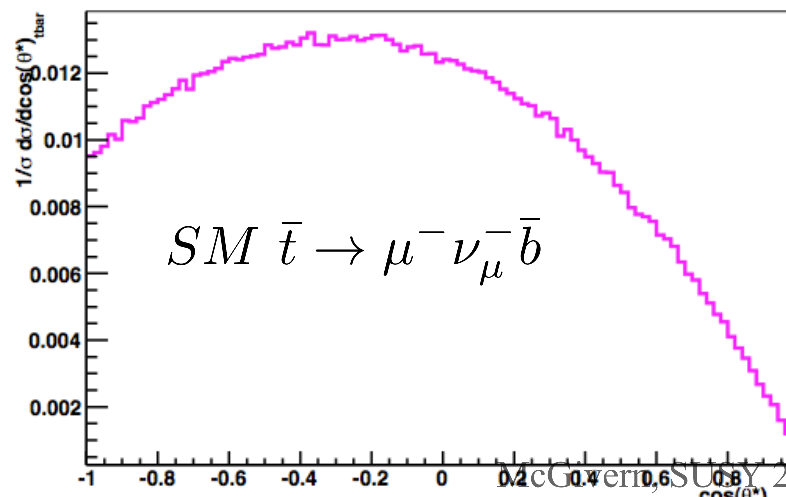
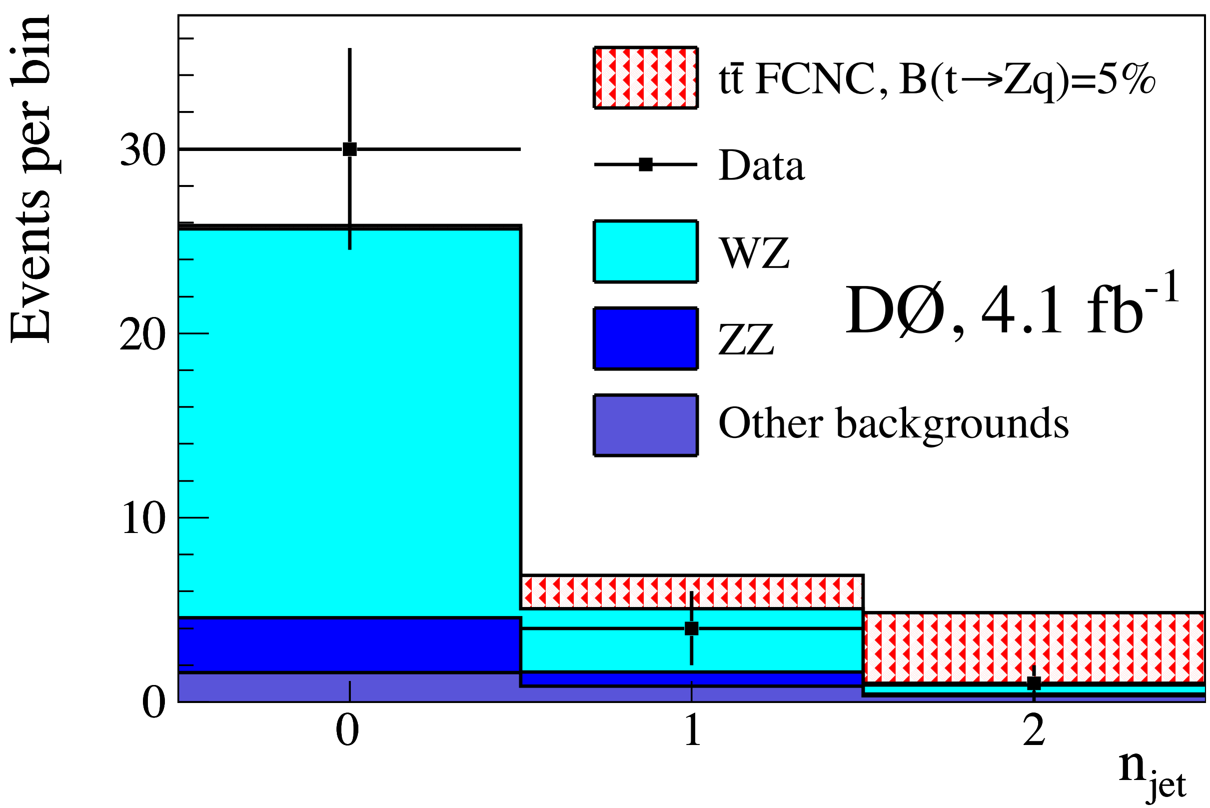
From CompHEP: $p\bar{p} \rightarrow t\bar{t} \rightarrow ZqW^-\bar{b} \rightarrow e^+e^-q\mu^-\nu_\mu^-\bar{b}$





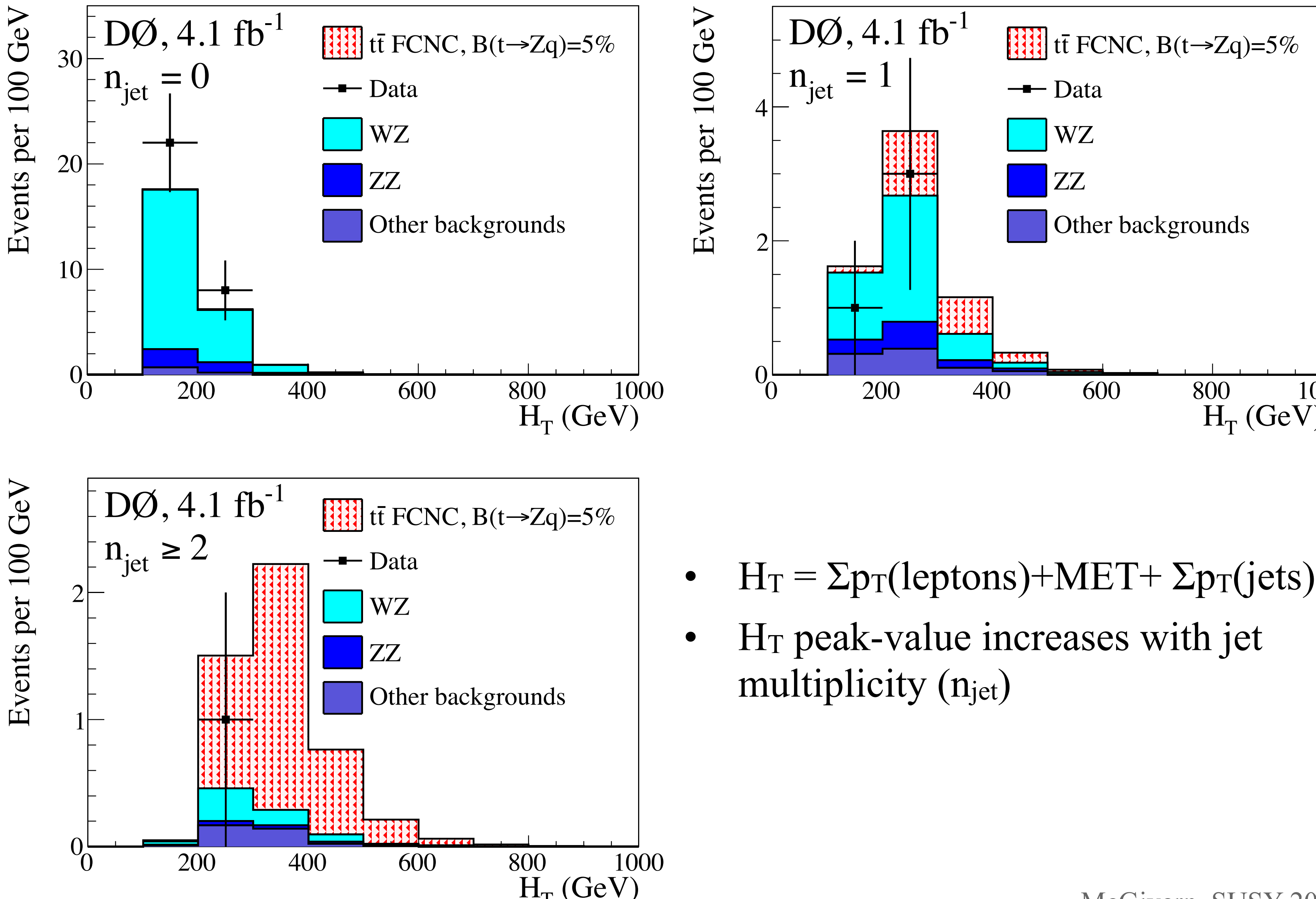
Yields and Jet Distribution

- 35 candidate events
  - Expected background = 31.8 ± 0.3(stat) ± 3.9(syst) events
- Dominant Systematic Uncertainties : Lepton ID, Theoretical Cross Sections (including FCNC $t\bar{t}$ signal), Jet Energy Scale (JES), Jet Energy Resolution (JER)



All distributions are shown with B(t→Zq) = 5%

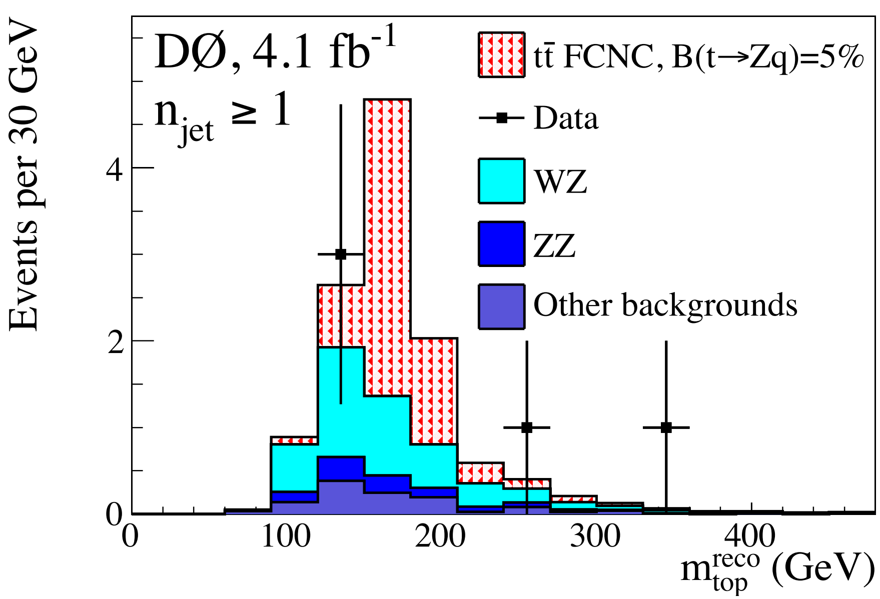
Scalar H_T Distributions

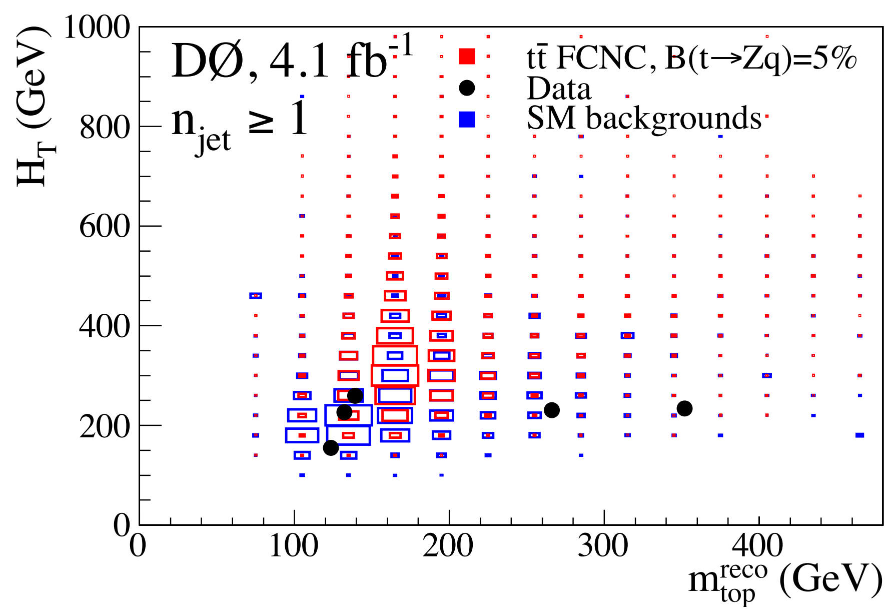


- $H_T = \Sigma p_T$(leptons)+MET+ Σp_T(jets)
- H_T peak-value increases with jet multiplicity (n_{jet})

Limits on B(t→Zq)

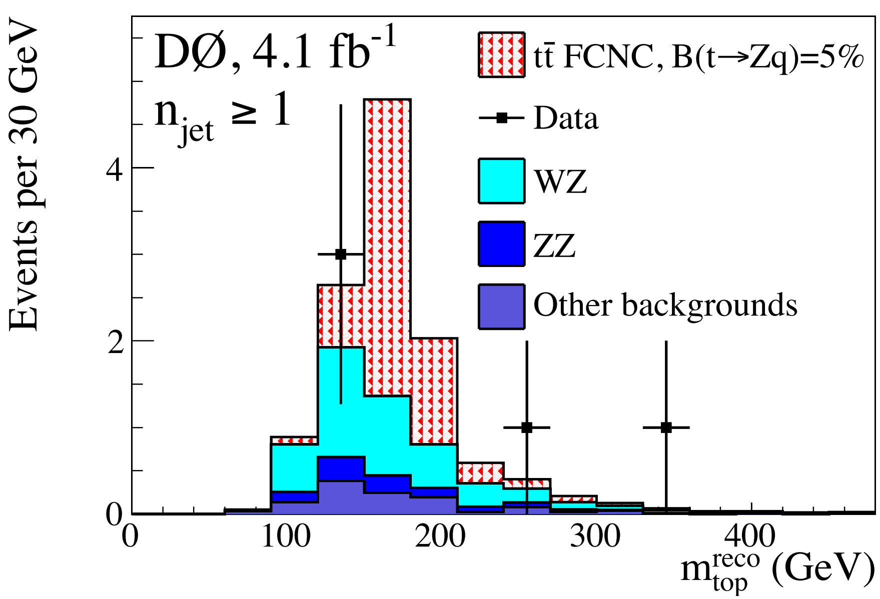
- Use n_{jet}, H_T, and reconstructed top quark mass (m_t^{reco}) (from the two Z leptons and jets) to separate signal from background
- Good separation is observed between signal and background using these three variables

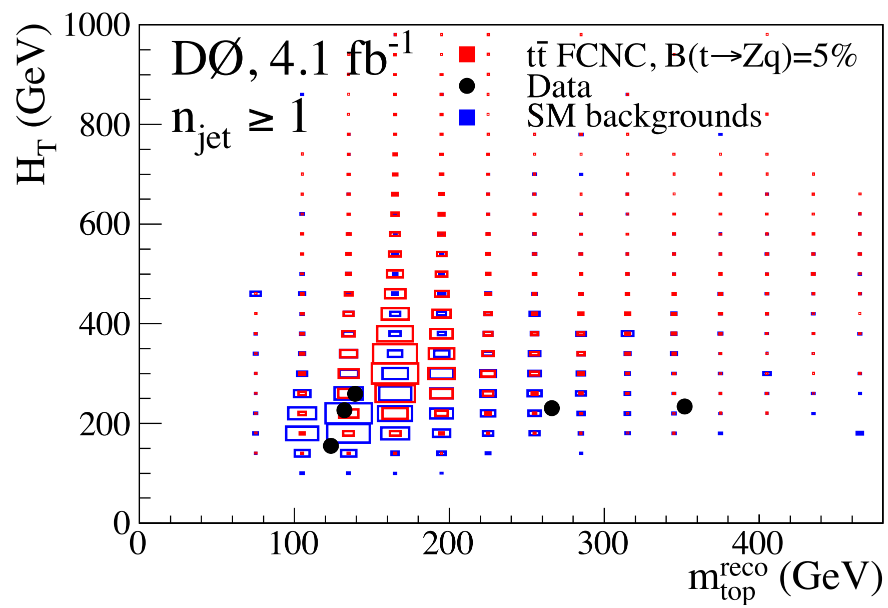




Limits on B(t→Zq)

- Use Poisson probabilities, with systematic uncertainty parameterized through Gaussian smearing, to extract the limits
- B(t→Zq) < 3.2% (observed), < 3.8% (expected) at 95% C.L.

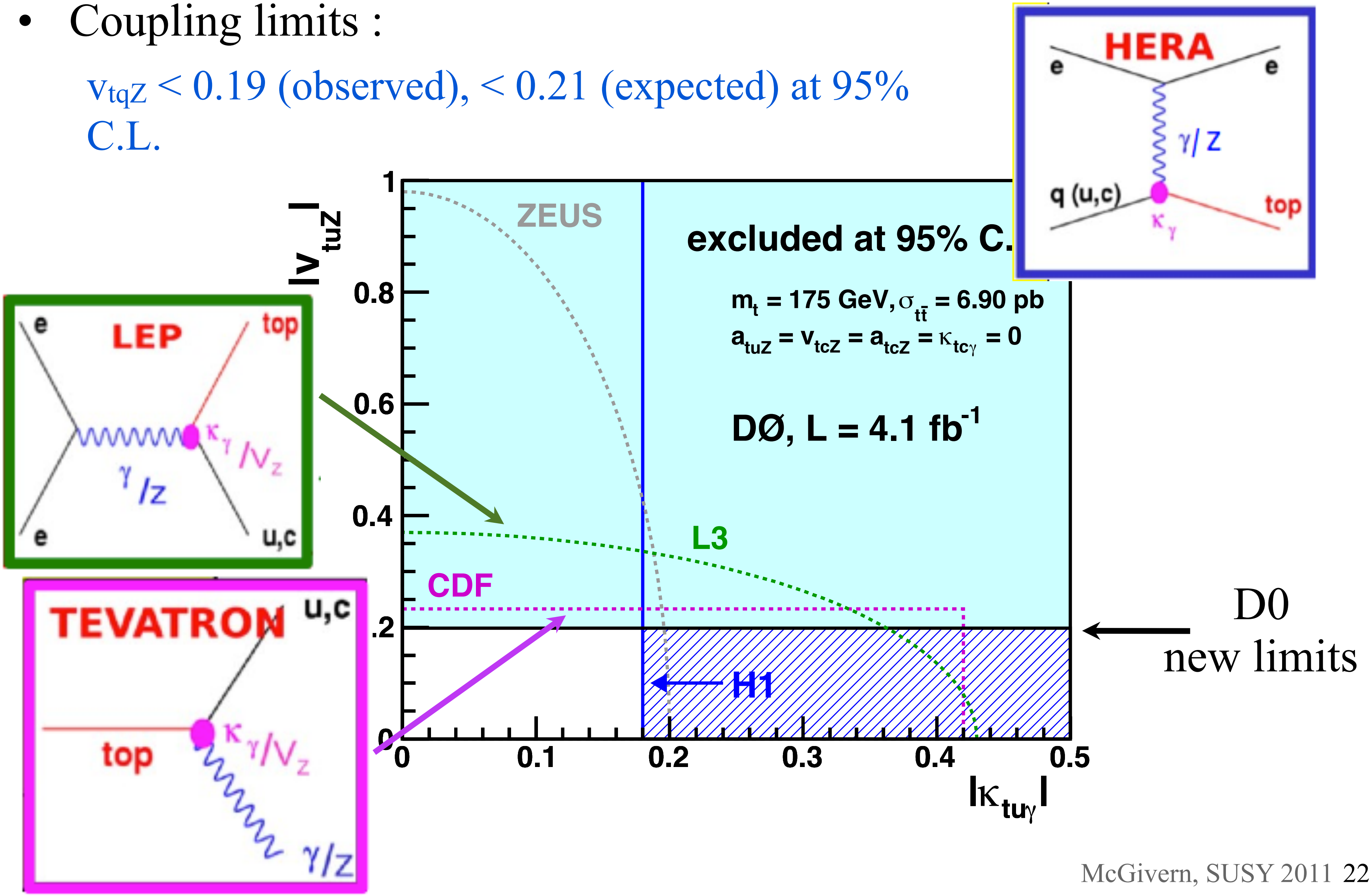




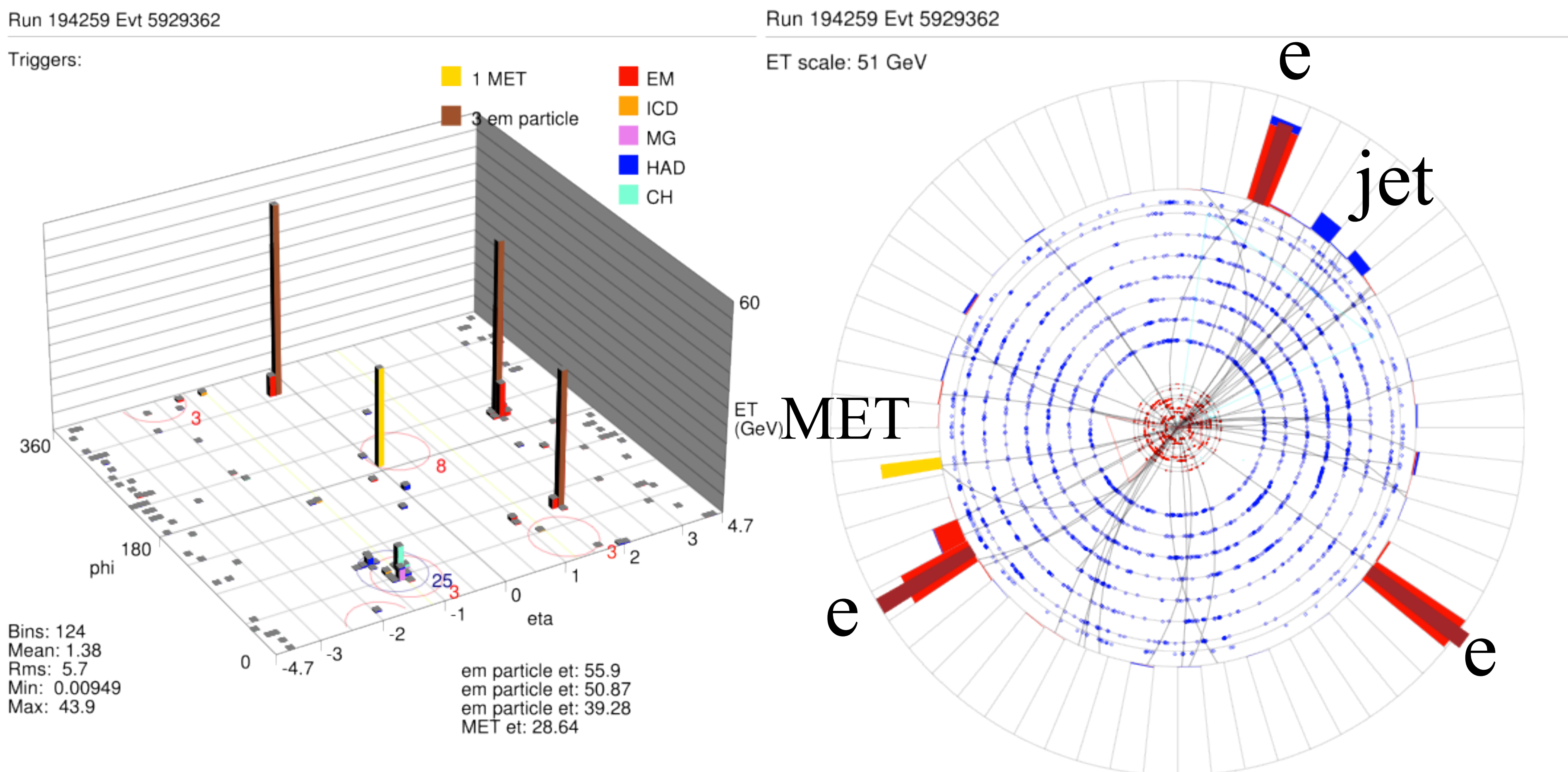
Limits on v_{tqZ} Coupling

- Coupling limits :

  $v_{tqZ} < 0.19$ (observed), < 0.21 (expected) at 95% C.L.



Candidate eee+1jet Event



- eee + 1 jet candidate event, with m_t^{reco} = 351 GeV

Summary

- No indication of new physics at this level of statistics
- Recently published in Physics Letters B **701**, 313 (2011)
- $B(t \rightarrow Zq) < 3.2\%$ (observed), $< 3.8\%$ (expected) at 95% C.L.
- Coupling limits $v_{tqZ} < 0.19$ (observed), < 0.21 (expected) at 95% C.L.
  - World's best limits on v_{tqZ}!

Long Live

Backup Slides

Detailed Event Selection

- Look for a signal with 3 or more isolated leptons and an imbalance in transverse momentum (MET)
- Use 4.1 fb^{-1} of integrated luminosity collected from the Tevatron Run II, selection criteria optimized with $s/\sqrt{(s+b)}$.
- Main Backgrounds: WZ, ZZ, $Z\gamma$, V+Jets, SM ttbar
  - Determined using MC Simulations and Data
- General selection criteria for all leptons :
  - Invariant dilepton mass (74 GeV $< M_{ee} <$ 104 GeV, 65 GeV $< M_{\mu\mu} <$ 115 GeV, 60 GeV $< M_{eeICR} <$ 120 GeV)
  - Missing Transverse Energy > (20 - 30) GeV
  - Lepton p_T > (15 - 30) GeV
  - Lepton ΔR ($=\sqrt{(\Delta\phi^2 + \Delta\eta^2)}$) > 0.5 - 0.6
  - Δz_{DCA} (between any two lepton tracks) < 3 cm
  - Jet E_T > 20 GeV

FCNC Event Yields

Jet Inclusive

Source	eee	$ee\mu$	$e\mu\mu$
WZ	$5.17 \pm 0.06 \pm 0.97$	$5.72 \pm 0.07 \pm 0.89$	$4.76 \pm 0.06 \pm 0.70$
ZZ	$0.25 \pm 0.03 \pm 0.05$	$1.35 \pm 0.06 \pm 0.21$	$0.52 \pm 0.04 \pm 0.08$
$V + jets$	$0.42 \pm 0.11 \pm 0.08$	$0.14 \pm 0.04 \pm 0.06$	$0.48 \pm 0.11 \pm 0.01$
$Z\gamma$	$0.18 \pm 0.05 \pm 0.07$	< 0.001	$0.66 \pm 0.07 \pm 0.38$
$t\bar{t}$	$0.04 \pm 0.01 \pm 0.01$	$0.013 \pm 0.004 \pm 0.002$	$0.05 \pm 0.01 \pm 0.01$
Total bkg.	$6.05 \pm 0.14 \pm 0.98$	$7.22 \pm 0.10 \pm 0.92$	$6.43 \pm 0.15 \pm 0.71$
Observed	7	10	9
Source	$\mu\mu\mu$	$ee_{ICR}e$	$ee_{ICR}\mu$
WZ	$6.09 \pm 0.07 \pm 1.00$	$1.46 \pm 0.03 \pm 0.24$	$1.78 \pm 0.04 \pm 0.25$
ZZ	$1.31 \pm 0.06 \pm 0.22$	$0.08 \pm 0.01 \pm 0.02$	$0.46 \pm 0.03 \pm 0.07$
$V + jets$	$0.18 \pm 0.05 \pm 0.03$	$0.18 \pm 0.07 \pm 0.08$	$0.26 \pm 0.18 \pm 0.16$
$Z\gamma$	< 0.001	$0.10 \pm 0.01 \pm 0.03$	< 0.001
$t\bar{t}$	$0.04 \pm 0.01 \pm 0.01$	$0.010 \pm 0.003 \pm 0.002$	$0.022 \pm 0.004 \pm 0.003$
Total bkg.	$7.75 \pm 0.13 \pm 1.02$	$1.83 \pm 0.08 \pm 0.26$	$2.52 \pm 0.19 \pm 0.31$
Observed	5	1	3

0^{th} Jet Bin

Source	eee	$ee\mu$	$e\mu\mu$
WZ	$4.40 \pm 0.06 \pm 0.83$	$4.80 \pm 0.06 \pm 0.75$	$3.92 \pm 0.05 \pm 0.58$
ZZ	$0.17 \pm 0.02 \pm 0.03$	$1.02 \pm 0.06 \pm 0.16$	$0.33 \pm 0.03 \pm 0.05$
$V + jets$	$0.16 \pm 0.07 \pm 0.08$	$0.05 \pm 0.02 \pm 0.03$	$0.23 \pm 0.07 \pm 0.01$
$Z\gamma$	$0.11 \pm 0.04 \pm 0.04$	< 0.001	$0.43 \pm 0.06 \pm 0.25$
$t\bar{t}$	$0.001 \pm 0.001 < 0.001$	$0.001 \pm 0.001 < 0.001$	< 0.001
Total bkg.	$4.84 \pm 0.10 \pm 0.84$	$5.87 \pm 0.09 \pm 0.77$	$4.68 \pm 0.08 \pm 0.63$
Observed	6	7	8
Source	$\mu\mu\mu$	$ee_{ICR}e$	$ee_{ICR}\mu$
WZ	$5.02 \pm 0.06 \pm 0.83$	$1.23 \pm 0.03 \pm 0.20$	$1.52 \pm 0.03 \pm 0.22$
ZZ	$0.99 \pm 0.05 \pm 0.17$	$0.05 \pm 0.01 \pm 0.01$	$0.38 \pm 0.03 \pm 0.05$
$V + jets$	$0.12 \pm 0.04 \pm 0.03$	$0.07 \pm 0.05 \pm 0.04$	$0.25 \pm 0.18 \pm 0.16$
$Z\gamma$	< 0.001	$0.09 \pm 0.01 \pm 0.03$	< 0.001
$t\bar{t}$	$0.002 \pm 0.001 < 0.001$	< 0.001	$0.003 \pm 0.001 < 0.001$
Total bkg.	$6.01 \pm 0.08 \pm 0.85$	$1.44 \pm 0.06 \pm 0.21$	$2.15 \pm 0.19 \pm 0.28$
Observed	4	1	3

FCNC Event Yields

Source	eee	$ee\mu$	$e\mu\mu$
WZ	$0.69 \pm 0.02 \pm 0.14$	$0.80 \pm 0.03 \pm 0.14$	$0.73 \pm 0.02 \pm 0.13$
ZZ	$0.07 \pm 0.02 \pm 0.01$	$0.28 \pm 0.03 \pm 0.05$	$0.16 \pm 0.02 \pm 0.03$
$V + jets$	$0.21 \pm 0.08 \pm 0.04$	$0.06 \pm 0.03 \pm 0.02$	$0.21 \pm 0.06 \pm 0.01$
$Z\gamma$	$0.04 \pm 0.03 \pm 0.02$	< 0.001	$0.17 \pm 0.04 \pm 0.10$
$t\bar{t}$	$0.012 \pm 0.004 \pm 0.002$	$0.006 \pm 0.002 \pm 0.001$	$0.009 \pm 0.002 \pm 0.001$
Total bkg.	$1.02 \pm 0.09 \pm 0.15$	$1.15 \pm 0.05 \pm 0.15$	$1.09 \pm 0.05 \pm 0.17$
Observed	1	2	1

Source	$\mu\mu\mu$	$ee_{ICR}e$	$ee_{ICR}\mu$
WZ	$0.93 \pm 0.03 \pm 0.19$	$0.20 \pm 0.01 \pm 0.04$	$0.24 \pm 0.01 \pm 0.05$
ZZ	$0.28 \pm 0.03 \pm 0.06$	$0.02 \pm 0.01 \pm 0.01$	$0.08 \pm 0.01 \pm 0.01$
$V + jets$	$0.07 \pm 0.03 \pm 0.03$	$0.04 \pm 0.03 \pm 0.04$	< 0.001
$Z\gamma$	< 0.001	$0.016 \pm 0.004 \pm 0.005$	< 0.001
$t\bar{t}$	$0.013 \pm 0.004 \pm 0.002$	$0.008 \pm 0.003 \pm 0.001$	$0.008 \pm 0.002 \pm 0.001$
Total bkg.	$1.24 \pm 0.04 \pm 0.20$	$0.29 \pm 0.03 \pm 0.06$	$0.33 \pm 0.01 \pm 0.05$
Observed	1	0	0

← 1st Jet Bin

≥ 2 Jets Bin →

Source	eee	$ee\mu$	$e\mu\mu$
WZ	$0.08 \pm 0.01 \pm 0.02$	$0.12 \pm 0.01 \pm 0.03$	$0.11 \pm 0.01 \pm 0.04$
ZZ	$0.0108 \pm 0.005 \pm 0.003$	$0.04 \pm 0.01 \pm 0.02$	$0.03 \pm 0.01 \pm 0.02$
$V + jets$	$0.06 \pm 0.04 \pm 0.08$	$0.04 \pm 0.03 \pm 0.01$	$0.03 \pm 0.03 \pm 0.01$
$Z\gamma$	$0.03 \pm 0.02 \pm 0.01$	< 0.001	$0.05 \pm 0.02 \pm 0.03$
$t\bar{t}$	$0.011 \pm 0.004 \pm 0.002$	$0.006 \pm 0.003 \pm 0.001$	$0.03 \pm 0.01 \pm 0.01$
Total bkg.	$0.19 \pm 0.05 \pm 0.08$	$0.21 \pm 0.03 \pm 0.04$	$0.65 \pm 0.11 \pm 0.06$
Observed	0	1	0

Source	$\mu\mu\mu$	$ee_{ICR}e$	$ee_{ICR}\mu$
WZ	$0.14 \pm 0.01 \pm 0.04$	$0.03 \pm 0.01 \pm 0.01$	$0.03 \pm 0.01 \pm 0.01$
ZZ	$0.04 \pm 0.01 \pm 0.02$	$0.004 \pm 0.003 \pm 0.004$	$0.008 \pm 0.004 \pm 0.002$
$V + jets$	< 0.001	$0.07 \pm 0.04 \pm 0.04$	< 0.001
$Z\gamma$	< 0.001	$0.001 \pm 0.001 \pm 0.001$	< 0.001
$t\bar{t}$	$0.018 \pm 0.004 \pm 0.003$	$0.002 \pm 0.002 < 0.001$	$0.011 \pm 0.003 \pm 0.002$
Total bkg.	$0.50 \pm 0.09 \pm 0.05$	$0.11 \pm 0.04 \pm 0.04$	$0.05 \pm 0.01 \pm 0.01$
Observed	0	0	0