Single Top Production at LHeC

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contributions from
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- Anomalous FCNC *top* Production
  - Introduction
  - Existing Constraints
  - Expectations at LHC, ILC
- *W* Production at LHeC
- Single *top* Production at LHeC
- Expectations at LHeC

1st ECFA-CERN LHeC Workshop
1-3 September 2008,
Divonne-les-Bains, France

Motivation

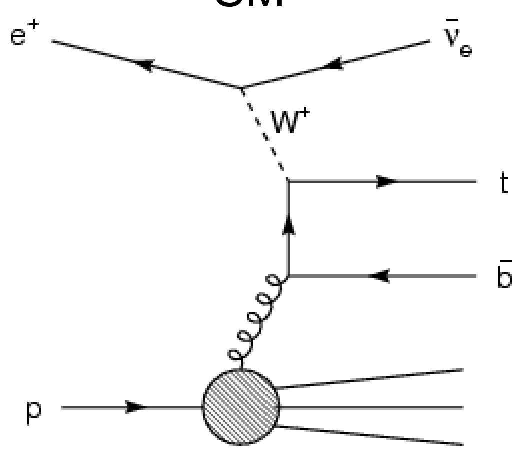
TeVatron LEP HERA	→	LHC ILC LHeC

- top Production (SM and FCNC) very interesting
  - M_{top} close to EWSB scale, sensitive to BSM
  - If BSM associated with mass generation, top especially sensitive

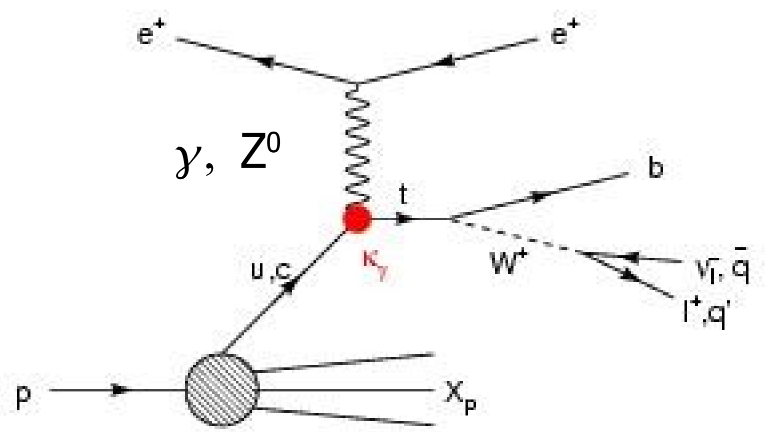
- Extensive top Programs at TeVatron, planned at LHC

- In *ep* collisions at HERA ($\sqrt{s}$ = 320 GeV)
  - SM: top production kinematically possible, but small cross section
  - FCNC: Excellent handle on anomalous tuγ coupling - competitive limits
  - What about LHeC?

SM



FCNC



Phenomenology

Following

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

Use effective Lagrangian

Simple story considered here:

$$\mathcal{L}_{eff}^{FCNC} = \sum_{U=u,c} \frac{e e_U}{2\Lambda} \kappa_{tU\gamma} \bar{t} \sigma_{\mu\nu} A^{\mu\nu} U$$

- Take care of different conventions used by different experiments / theorists
- Impact on coupling ~O(1), like e_U = 2/3, 1/√2 for q=u,c or u only
- Scale Λ = m_t = 175 GeV (in lit. sometimes 1 TeV used!)
- Assume V_{tuZ} = 0 for now
- Neglect c-quark for now: $\kappa_{tc\gamma} = \kappa_{tcZ} = 0$

Keep in mind the Full Story:

- Couplings of top to **q=u,c** and **V = γ, Z, g, H** possible
- Magnetic and (V-A) couplings for Z

$$\begin{aligned} -\mathcal{L}^{\rm eff} = & \frac{g}{2c_W} X_{qt}\, \bar q \gamma_\mu (x_{qt}^L P_L + x_{qt}^R P_R) t Z^\mu + \frac{g}{2c_W} \kappa_{qt}\, \bar q (\kappa_{qt}^v + \kappa_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t Z^\mu \\ & + e \lambda_{qt}\, \bar q (\lambda_{qt}^v + \lambda_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t A^\mu + g_s \zeta_{qt}\, \bar q (\zeta_{tq}^v + \zeta_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} T^a q G^{a\mu} \\ & + \frac{g}{2\sqrt{2}} g_{qt}\, \bar q (g_{qt}^v + g_{qt}^a \gamma_5) t H + \text{H.c.}\,, \end{aligned}$$

J.A. Aguilar-Saavedra, ActaPhys.Polon.B35:2695-2710,2004.

Top Decay Widths

- If Branching Fractions are measured, convert to coupling via decay widths

$$\mathrm{BR}(t \to bW^+) = \frac{\Gamma_{t\to bW^+}}{\Gamma_{t\to bW^+} + \Gamma_{t\to u\gamma} + \Gamma_{t\to uZ}}$$

$$\mathrm{BR}(t \to u\gamma) = \frac{\Gamma_{t\to u\gamma}}{\Gamma_{t\to bW^+} + \Gamma_{t\to u\gamma} + \Gamma_{t\to uZ}}$$

$$\mathrm{BR}(t \to uZ) = \frac{\Gamma_{t\to uZ}}{\Gamma_{t\to bW^+} + \Gamma_{t\to u\gamma} + \Gamma_{t\to uZ}}$$

with

$$\Gamma_{t\to bW^+} = w_{SM}$$

$$\Gamma_{t\to u\gamma} = w_\gamma \cdot \kappa^2_{tu\gamma}$$

$$\Gamma_{t\to uZ} = w_Z \cdot v^2_{tuZ},$$

- For small values of the anomalous couplings use $\Gamma_{\mathrm{tot}} = \Gamma_{t\text{->}bW+}$

Thesis D. Dannheim (2003)

M_{top} (GeV)	w_{SM} (MeV)	w_γ (MeV)	w_Z (MeV)
170	1404	293	1297
175	1554	302	1449
180	1713	310	1610

- Analytical expressions for decay widths given in literature
- Dependencies the same, conventions mostly different
- Use values used by H1/ZEUS for the HERA-1 Papers

FCNC top Production Cross Sections in *ep*

- Cross section for anomalous top production in *ep* collisions can be expressed as

$$\sigma_{\text{single top}} = c_\gamma \cdot \kappa_{tu\gamma}^2 + c_Z \cdot v_{tuZ}^2 + c_{\gamma Z} \cdot \kappa_{tu\gamma} \cdot v_{tuZ}.$$

Interference term small
(~ 1% of total cross section at HERA),
neglected here

	c_γ [pb]	c_Z [pb]	using
HERA (this study)	6.4	0.25	LO, ANOTOP (2->4)
ZEUS (D. Dannheim)	6.1	0.23	LO, CompHEP
LHeC (70x7000) (Ee x Ep)	152	16.8	LO, ANOTOP (2->4)
LHeC (140x7000)	207	23.	LO, ANOTOP (2->4)
γP at LHC	368		
THERA (E. Perez) (500x920)	336		

- Factors c_γ , c_Z contain all conventions, NLO corrections, different cme

- If $k_{tu\gamma} = v_{tuZ}$ Z, Z relatively more important at LHeC (11% vs. 4% at HERA)

Uncertainties on FCNC top Production in *ep*

- NLO Corrections of ~20% at HERA energies (H1 HERA-1 Paper: 17%)
- Cross Section ± 25% with m_{top} = 175 GeV ± 5 GeV
- Pdfs – impact at LheC? (*x-distribution shown later*)
- Use of correct conventions...

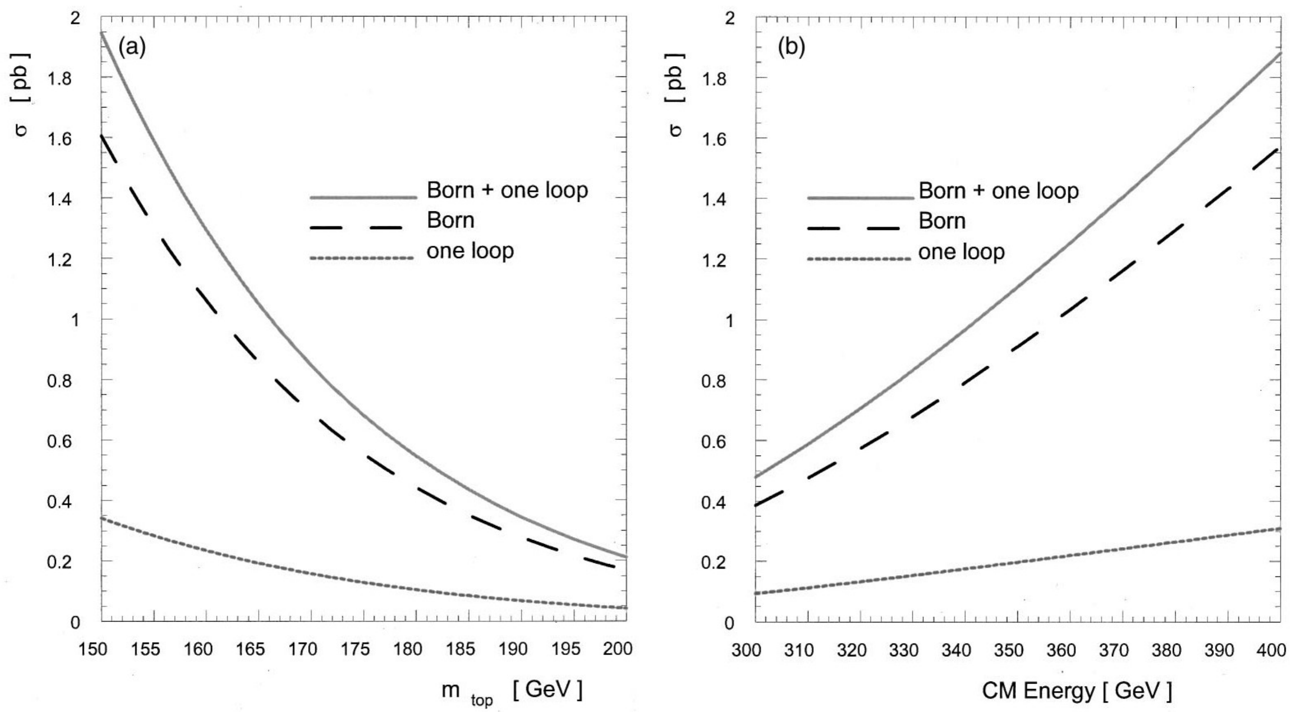


FIG. 3. Born, one-loop, and Born plus one-loop cross section for the FCNC single top-quark production at the DESY HERA collider with $Q=m_{\rm top}$ and $\kappa_{tu\gamma}=0.1$ vs (a) the top-quark mass with $\sqrt{S}=318$ GeV and (b) the c.m. energy with $m_{\rm top}=175$ GeV.

Belyaev, Kidonakis

Existing Limits on $\kappa_{tq\gamma}$

CDF

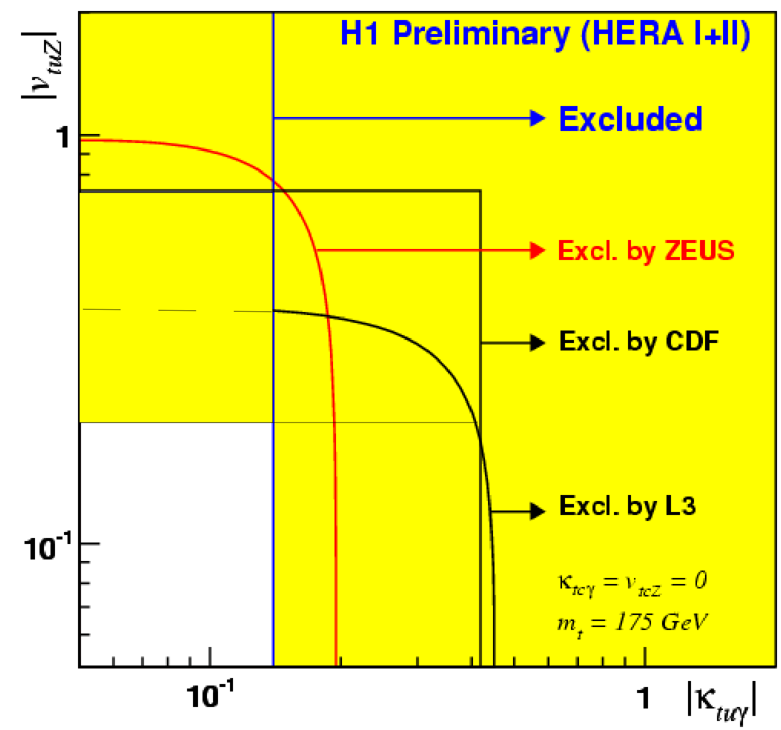
(Run I, $110pb^{-1}$) tt-> bW qγ $\kappa_{tq\gamma}$ B(t -> qγ) < 3.2%

(Run II, $1.9fb^{-1}$) tt-> bW qZ (qqqqll) V_{tqZ} B(t -> qZ) < 3.7% 95% CL

HERA

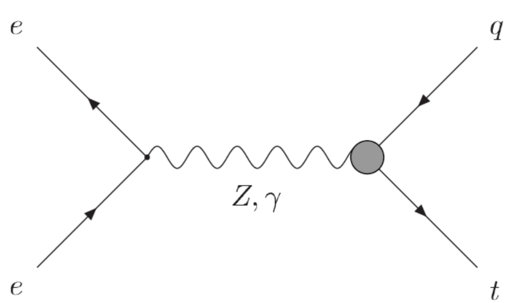
σ(p -> etX) < 0.16 pb

$\kappa_{tu\gamma}$ < 0.14



LEP

- $\sqrt{s}$ = 188.6 – 206.6 GeV
  - Single top kinematically possible
  - top Pair-Production not possible
- Look at decays only
- Cannot discern γ,Z



B(t->qZ) < 13.7%
B(t->qγ) < 4.1%

- Branching Fractions are the Measured observables
- L3 method to convert to coupling gives slightly stricter results
- Here use our own method to ensure consistency

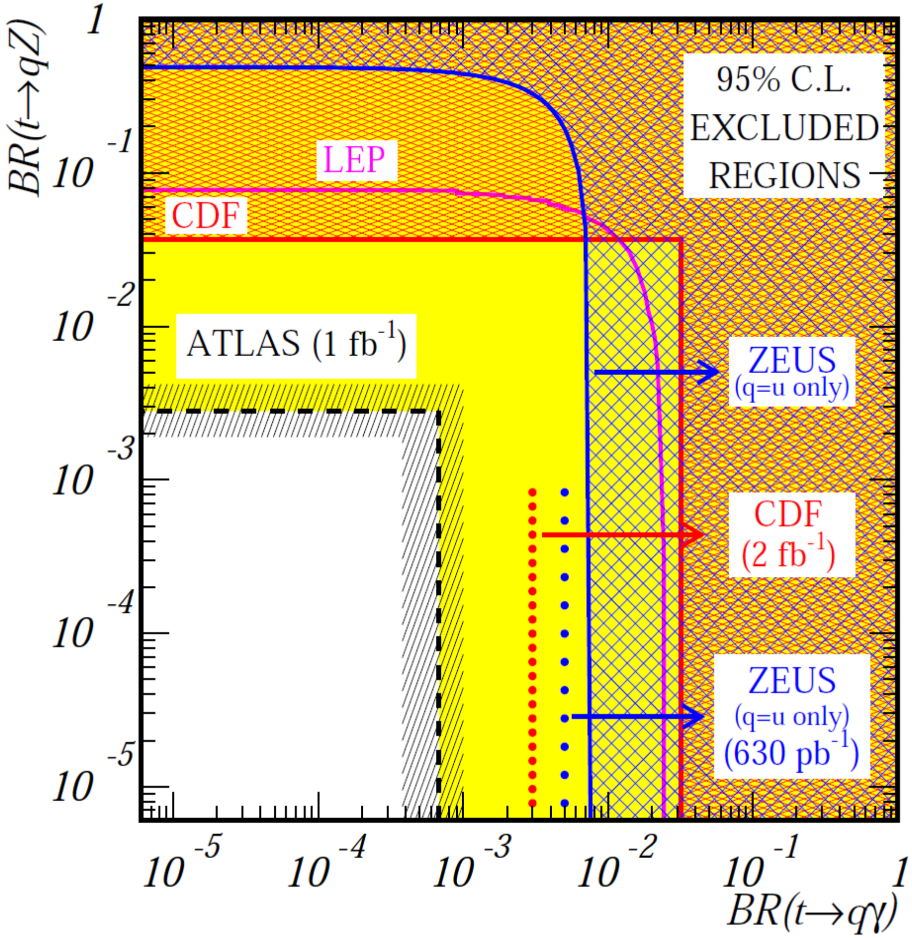
Study of ATLAS Sensitivity to FCNC top decays

Taken from
Top Quark Physics at ATLAS CSC Note (Draft!)

Scenario: 1 fb^{-1}, 95% CL

	-1σ	Expected	$+1\sigma$
$t\bar{t} \to bWq\gamma$:			
e	4.3×10^{-4}	1.1×10^{-3}	1.9×10^{-3}
μ	4.5×10^{-4}	8.3×10^{-4}	1.3×10^{-3}
ℓ	3.8×10^{-4}	6.8×10^{-4}	1.0×10^{-3}
$t\bar{t} \to bWqZ$:			
3e	5.5×10^{-3}	9.4×10^{-3}	1.4×10^{-2}
3μ	2.4×10^{-3}	4.2×10^{-3}	6.4×10^{-3}
3ℓ	1.9×10^{-3}	2.8×10^{-3}	4.2×10^{-3}
$t\bar{t} \to bWqg$:			
e	1.3×10^{-2}	2.1×10^{-2}	3.0×10^{-2}
μ	1.0×10^{-2}	1.7×10^{-2}	2.4×10^{-2}
ℓ	7.2×10^{-3}	1.2×10^{-2}	1.8×10^{-2}

Previous version available:
Eur. Phys. J. C 52, 999-1019 (2007)
arXiv:0712.1127v1 [hep-ex]



CMS

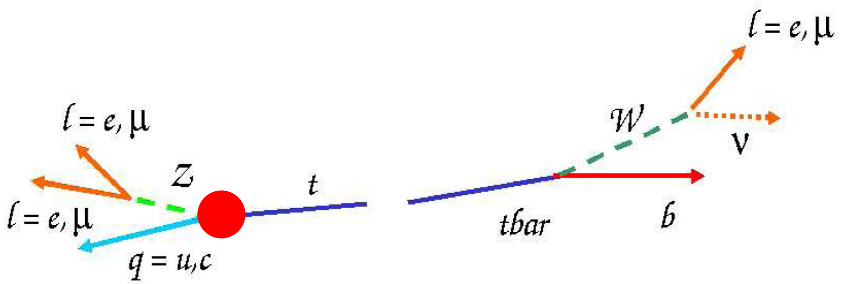
CMS TDR Vol. 2
CMS Note 2006/093

"5-sigma discovery limits" at L=10 fb^{-1}
-> difficult to compare

Br(t->qZ) < 11.4 x 10^{-4} (w/o syst.)
Br(t->qγ) < 5.7 x 10^{-4}

SM:

Br(t->sW)=10^{-3}
Br(t->dW)=10^{-4} – 10^{-5}



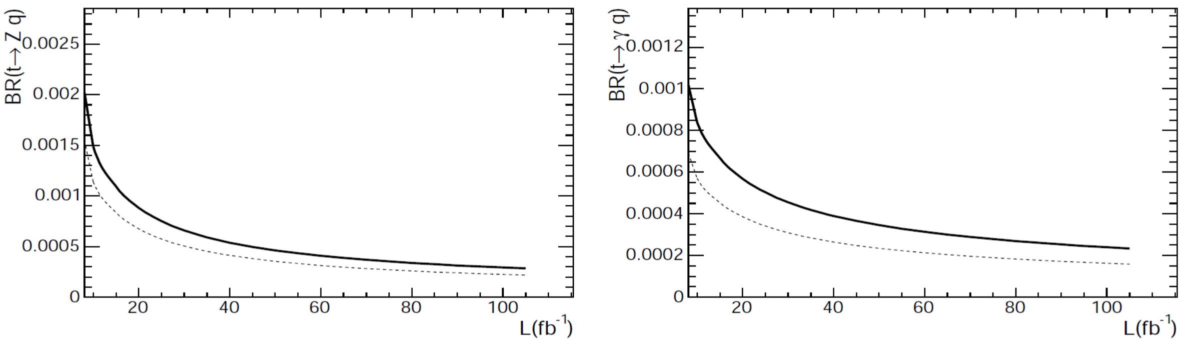
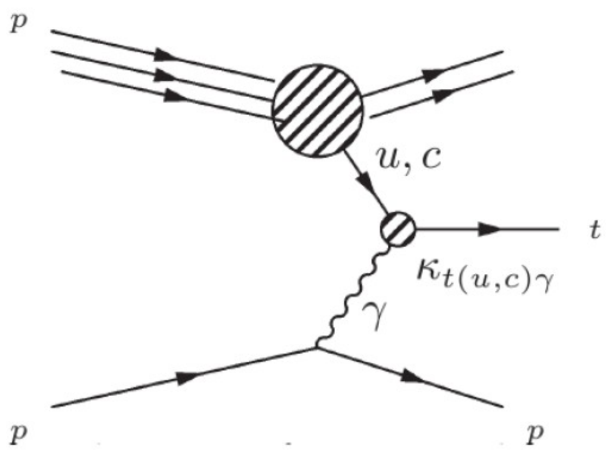


Figure 25: The branching ratios of FCNC top decays as a function of integrated luminosity, for $t \to qZ$ (left) and $t \to q\gamma$ (right), assuming a 5-sigma discovery level. These curves are based on the values given in the text, which correspond to an integrated luminosity of L=10 fb^{-1}. The two curves represent the branching ratios including (solid line) and excluding (dashed line) the contribution from systematic uncertainties.

Photoproduction at LHC

- Idea to exploit Photoproduction at the LHC
- Measure Production, similar to HERA

S. Ovyn, J.d.Favereau (U.C.Louvain)
Arxiv 0806.4841 (hep-ph), 0806.4886 (hep-ph)



Tag with LRG (very low lumi)
Large Rapidity Gap

Tag intact proton with VFD (low lumi)

Prospects for 1 fb^{-1} 95% CL

$$\text{Very low luminosity} : k_{tu\gamma} < 0.044,\ k_{tc\gamma} < 0.077,$$
$$\text{Low luminosity} : k_{tu\gamma} < 0.029,\ k_{tc\gamma} < 0.050.$$

Convenient to compare (same conventions like HERA)

$$\sigma_{pp\to t} = 368 \text{ pb} \times k^2_{tu\gamma} + 122 \text{ pb} \times k^2_{tc\gamma}.$$

ILC (TESLA)

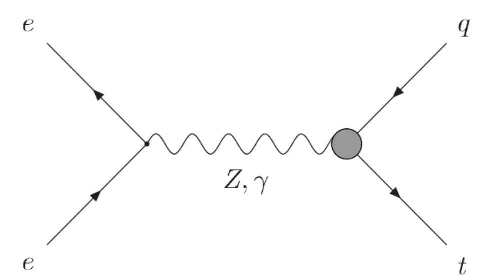
Latest Study:
J.A.Aguilar-Saavedra, T.Riemann, arXiv:hep-ph/0102197.

Many scenarios considered, shown here:
- L = 300 fb-1 (1 year)
- √s = 500 GeV
- no polarisation
- Limits @ 95%CL

At ILC:

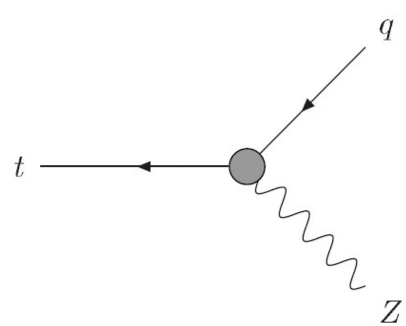
Sigma($t\bar{t}$) = 0.52 pb

FCNC *top* Production
- Higher cross section
- See only B(t->Vq)

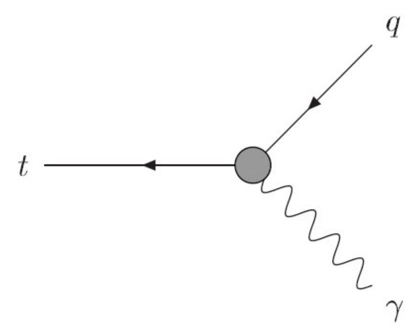


B(t->Zq) (γ_μ)	4.4 x 10^{-4}
B(t->Zq) ($\sigma_{\mu\nu}$)	3.5 x 10^{-5}
B(t ->γq)	2.2 x 10^{-5}

- Decay
  - Cleaner
  - can diff. Gamma, Z



B(t->qZ) < 1.8 x 10^{-3}



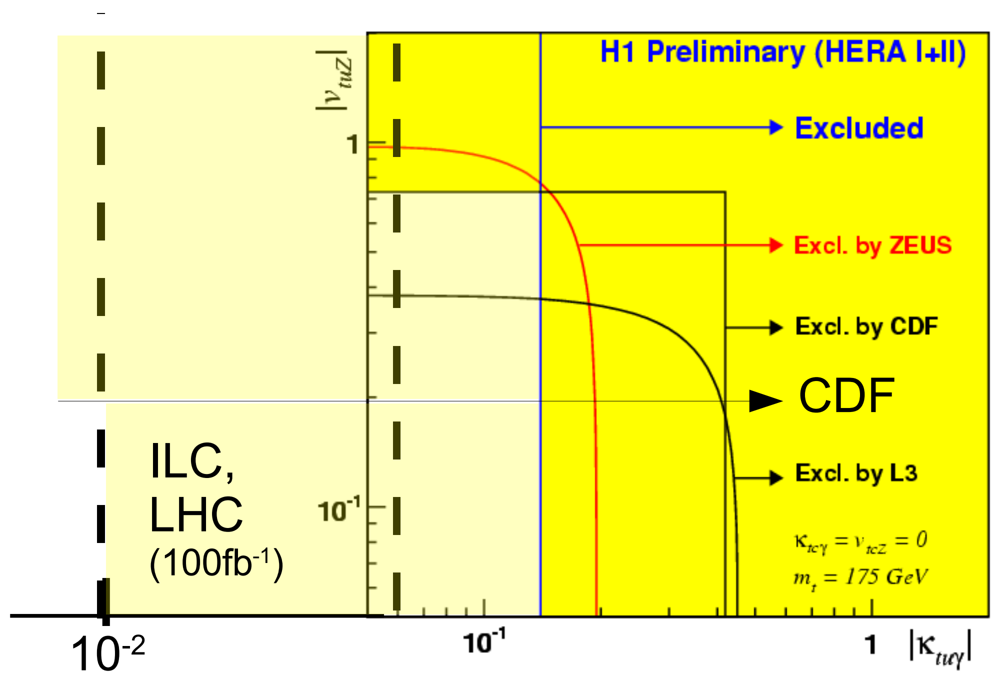
B(t->γq) < 9.9 x 10^{-5}

Summary of Limits on $\kappa_{tu\gamma}$

Experiment	$\kappa_{tu\gamma}$	$Br(t \to u\gamma)$
L3	0.43	4.1e-2
CDF	0.41	3.2e-2
ZEUS	0.17	5.9e-3
H1	0.14	3.8e-3
ATLAS	0.059	6.8e-4
γP@LHC	0.029	1.6e-4
ILC (TESLA)	0.011	2.2e-5
LHC ($100 fb^{-1}$)	0.007	1.2e-5
SM	-	3.7e-16

measured

Use $\kappa_{tu\gamma} = 0.01$ to estimate what happens at LHeC



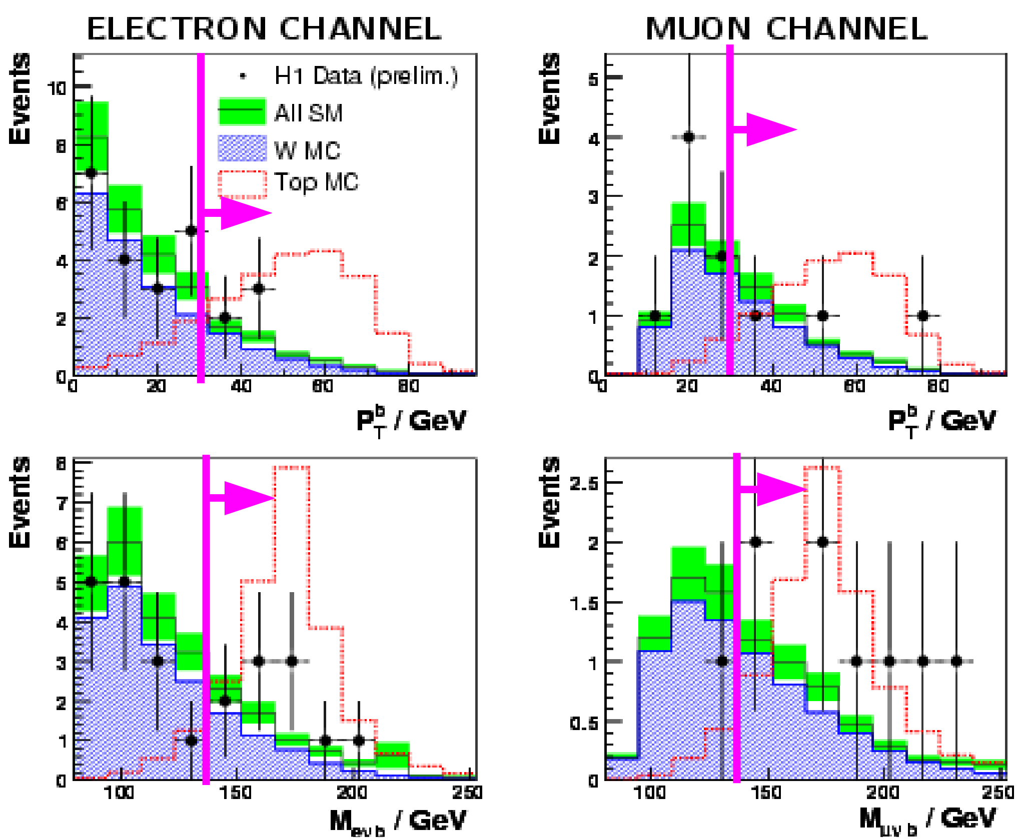
Reminder: Background to FCNC top at HERA

HERA

Semi-Leptonic Channels (e, mu)

- Main Background from SM W Production
- Top in region $P_T b$ > 30 GeV, M_{top} > 140 GeV

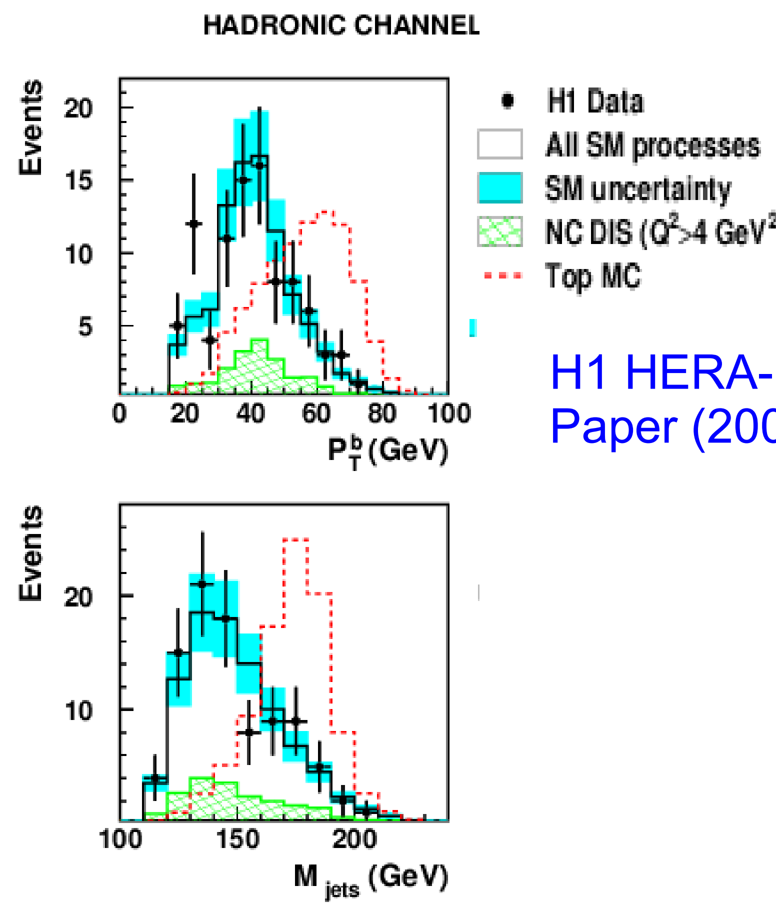
Cut based top selection: $\varepsilon \approx 40\%$



Search for Anomalous Top Production
H1 Preliminary (DIS'07)

Hadronic Channel

- Main Background from Jets in Photoproduction and DIS
- *Not considered for now*



H1 HERA-1
Paper (2003)

SM *W* Production in *ep* Collisions

- Use EPVEC Generator
- Th. Error 30% (NLO Corrections not applied)
- CC and Z Production not considered

LHeC (E_{e+} = 70 GeV, E_p = 7000 GeV)

$W \rightarrow e\nu$

DIS W+	1.38 pb
DIS W-	1.10 pb
RES W+	0.38 pb
RES W-	0.28 pb

$\sigma(W^+ \rightarrow l\nu)$ = 9.42 pb

σ_W = 31.4 pb

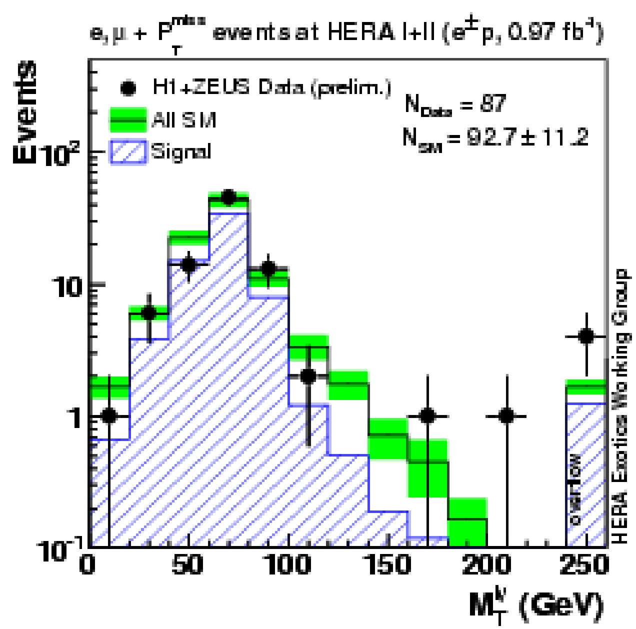
3.1×10^6 W's produced at LHeC in 100 fb^{-1}

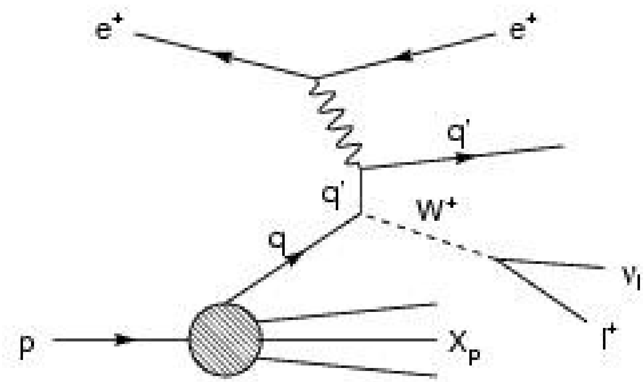
HERA

$\sigma(W^+ \rightarrow l\nu)$ = 0.4 pb

$\sigma(W^+ \rightarrow qq)$ = 1.0 pb

σ_W = 1.4 pb



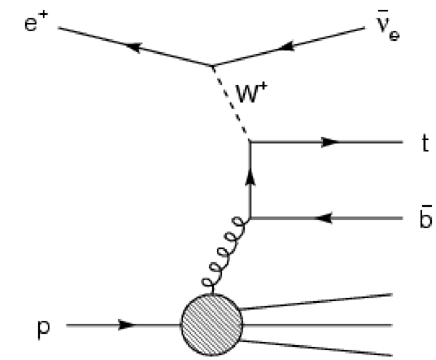


Dominating diagram (at HERA)

SM Single top Cross Sections in *ep* Collisions

	HERA [fb]	LHeC [pb]
PYTHIA 6.4		
CTEQ6l	0.39	1.62
CTEQ6m	1.19	
GRV98 (lo)	0.02	
MRST2002nlo	0.86	
PYTHIA 6.1		
GRV LO	0.97	
CompHEP		
CTEQ6L	0.42	1.93
CTEQ6D	2.13	2.40
CTEQ6M	1.27	2.3
CTEQ5L	0.71	2.0

LHeC (E_e=70 x E_p=7000)



dominating

- Use PYTHIA with Process
  $q_i + f_j \to Q_k + f_l$

HERA
- $\sigma \sim 1\ fb^{-1}$ – not observable in $\sim 1\ fb^{-1}$
- Sensitive to "*b*-density" in *p* at x > 0.3
- Not well constrained
  (but chance for measuring this quantity?)

LHeC
- $\sigma \sim 2\ pb^{-1}$

THERA
(E_e=500 x E_p=920)
(E. Perez)
$\sigma \sim 1\ pb^{-1}$

LHC
Single top production
(M. Beneke et al, 1999)

t-channel	245	± 27 pb
s-channel	10.2	± 0.7pb
Wt	51	± 9 pb

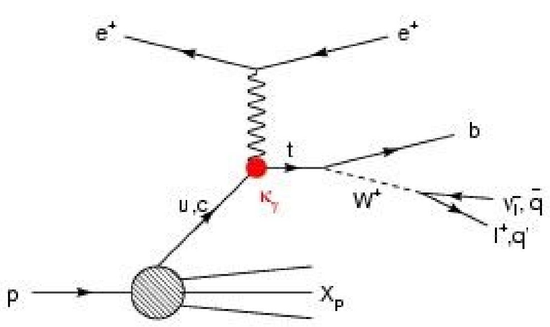
Top pair production
Sigma (pp->tt) 833 pb

Kinematics Comparisons HERA / LHeC

A very brief look at kinematics to estimate efficiencies

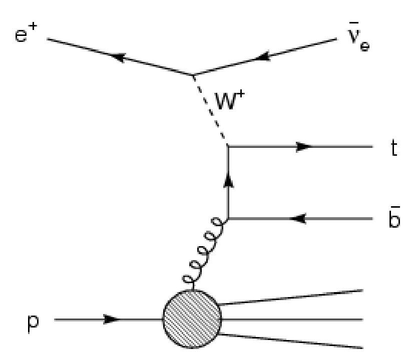
- Use Generator files only
- Assume we are looking for anomalous top production
- Look at $W \to e\nu$ channel only
- Generous acceptance for stable particles: $-3.0 < \eta < 5.0$
- Smear generated particles
  - Had. Energy: $50\%/\sqrt{E} \oplus 4\%$ (Jets, Neutrino)
  - Em. Energy: $10\%/\sqrt{E} \oplus 1\%$ (Electron)
- Take sum of gen. Jets (= Total HFS) as *b*-jet Candidate
- No isolation / distances required
- No *b*-tagging used
- Look at shapes only

ANOTOP



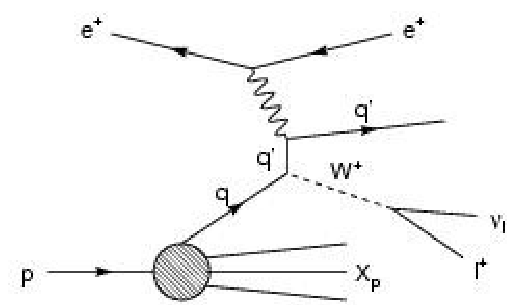
X ν e

PYTHIA



X ν e

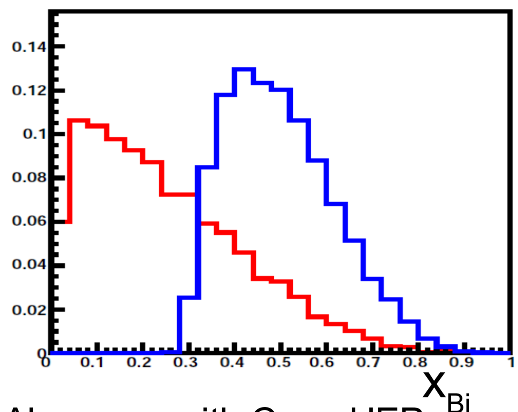
EPVEC



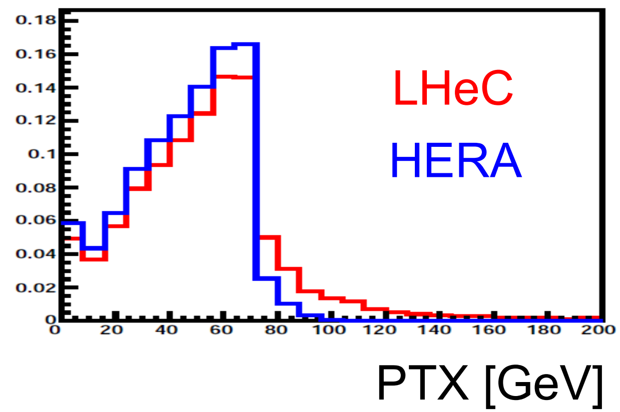
X ν e

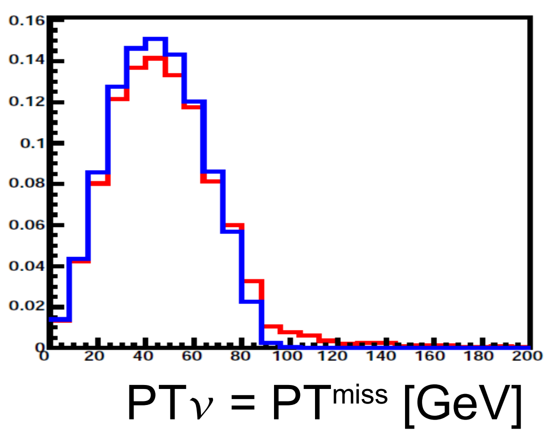
ANOTOP Kinematics HERA / LHeC

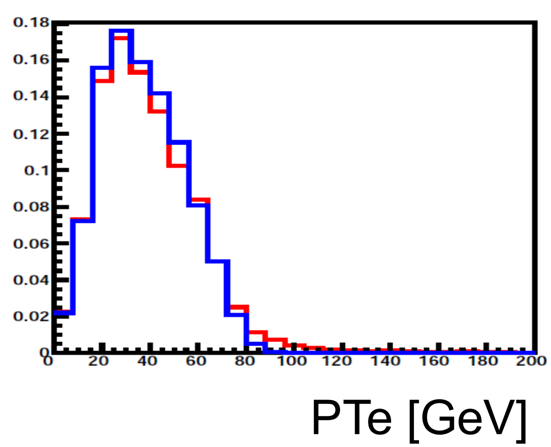
- Top probes lower x_{Bj} at LHeC (*c*-density should not be neglected)
- In transverse plane very similar kinematics for top at HERA and LheC ($P_T^{top} \approx 0$)
- Electron, X more forward at LheC: Lower acceptance?
  - Assume LHeC detector can measure down to η = 5.0 ...
  - For now use same efficiency for HERA / LHeC of **40%** (in $W \rightarrow e\nu$)

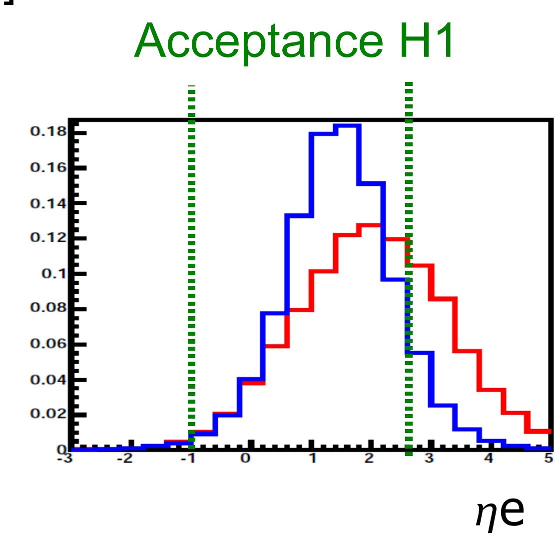


Also seen with CompHEP
(C. Diaconu)





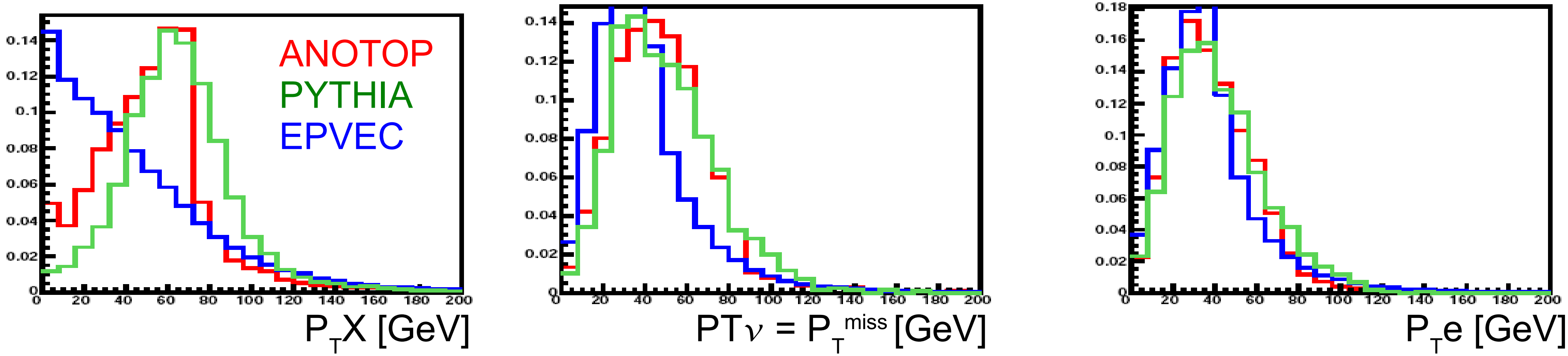


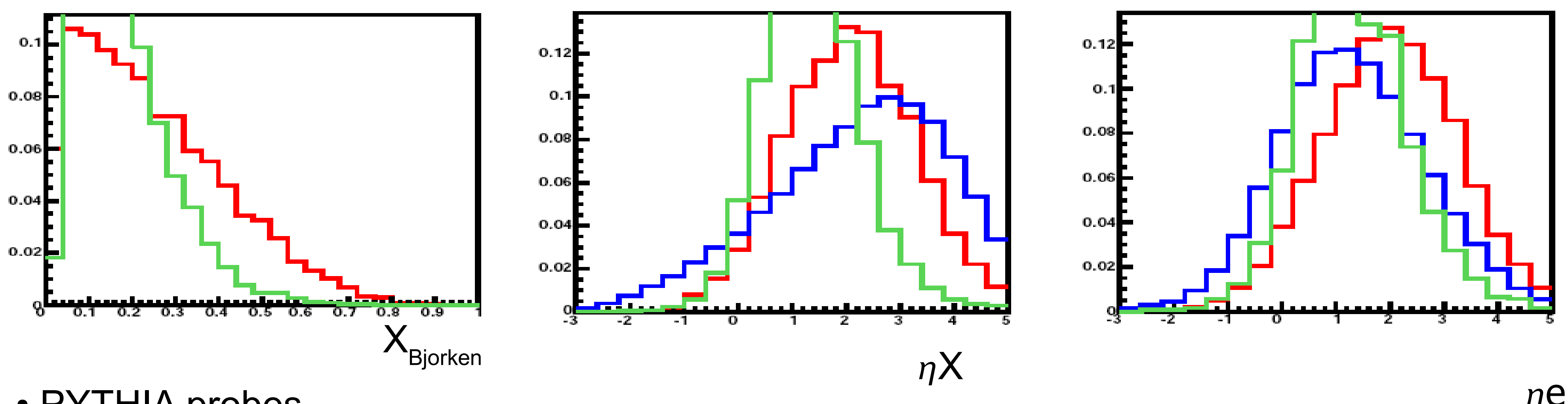


Kinematics of FCNC top, SM top, SM W at LHeC

- PTX main discriminant between W and *top*, like at HERA

- ANOTOP and PYTHIA kinematically similar
- X in PYTHIA more central, assume efficiency of **50%**





- PYTHIA probes even “lower” x

- SM W Production boosted very forward
- Assume lower efficieny than at HERA: ~ **30 %** (in $W \rightarrow e\nu$)

Finally: Estimations at LHeC

$$N = \underbrace{c_\gamma \cdot \kappa_{tu\gamma}^2}_{\sigma} \cdot L \cdot Br \cdot \varepsilon$$

Option	Ee [GeV]	Ep [GeV]	Int. Lumi [fb]	$\sigma(\kappa_{tu\gamma}=0.01)$ [pb]	N_{obs}	
LHeC (RR)	70	7000	100	0.0152 31.4 2	760 94000 10000	FCNC top SM W SM top
LHeC (LR)	140	7000	10	0.0207 pb	103	

- Very difficult to help with FCNC top production at LHeC
- Large W sample, can measure cross-section, Mass, polarisations, WWγ, ...
- Large SM single top sample, nice top program possible -> *ideas in backup*
- If FCNC has strength of current HERA limit,
  SM and FCNC are of the same order of magnitude at LHeC:
  FCNC top $\sigma(\kappa_{tu\gamma}=0.14) = 3.0\ \mathrm{pb}^{-1}$
- Higher energy LHeC LR option would not compensate lower lumi
  (Estimates for W, SM top not done...)

BACKUP
/
NOTES

Models giving Rise to Anomalous Couplings

2HDM

MSSM with RPV

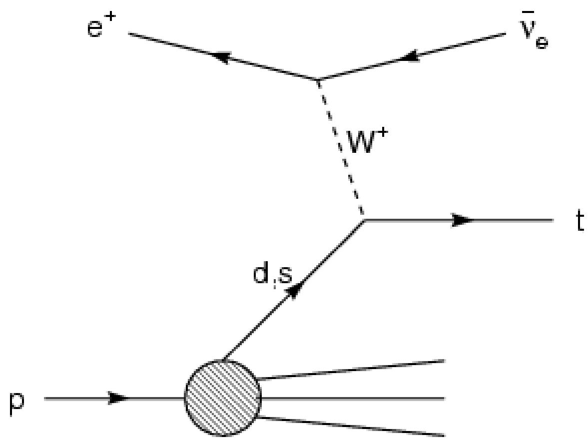
Exotic extra quarks

Unparticles

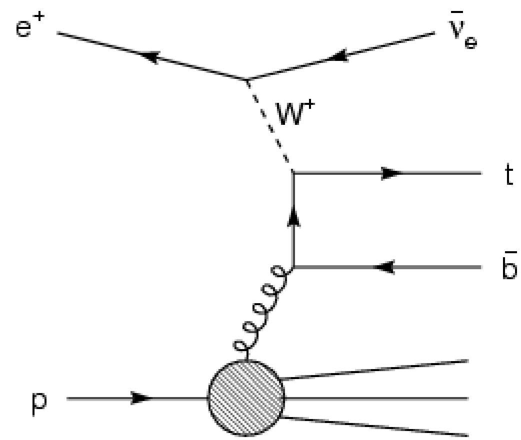
Table 1: Branching ratio predictions for FCNC top quark decays from the SM and from four SM extensions, with the corresponding current experimental limits.

	SM	2HDM	SUSY	SUSY with $\not{R}$	Exotic quarks	Exp. Limits (95% CL)
$\mathrm{BR}(t \to qg)$	5×10^{-11}	$\sim 10^{-5}$	$\sim 10^{-6}$	$\sim 10^{-3}$	$\sim 5 \times 10^{-4}$	0.29 (CDF)
$\mathrm{BR}(t \to q\gamma)$	5×10^{-13}	$\sim 10^{-7}$	$\sim 10^{-8}$	$\sim 10^{-5}$	$\sim 10^{-5}$	0.0059 (ZEUS)
$\mathrm{BR}(t \to qZ)$	$\sim 10^{-13}$	$\sim 10^{-6}$	$\sim 10^{-8}$	$\sim 10^{-4}$	$\sim 10^{-2}$	0.14 (LEP2)

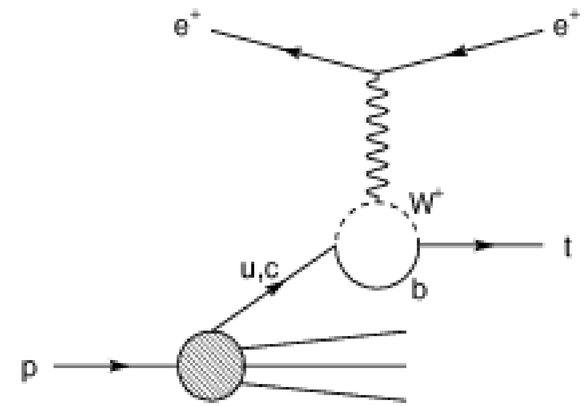
SM Top Production in *ep* Collisions



Probe V_{td}, V_{ts}

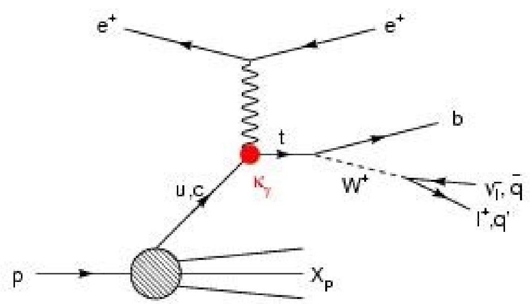


Probe b-quark density

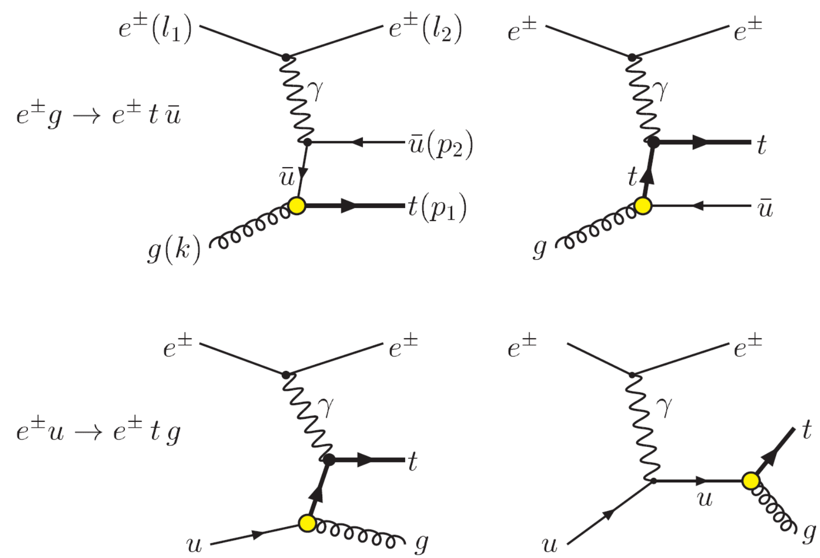


from ktγ

- Possible to interpret FCNC top production via ktγ as FCNC via ktg
- Set limits on ktg
- HERA: Br(t->gq) < 13%, ktg/lambda < 0.4 TeV^{-1}



e-Print: hep-ph/0604119



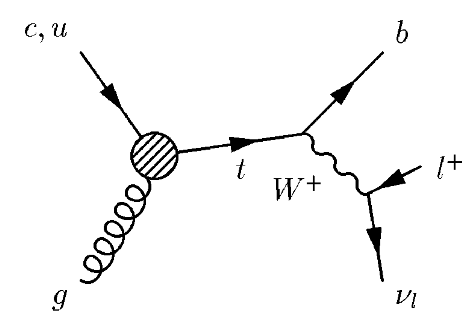
At TeVatron

D0 Phys.Rev.Lett.99:191802,2007. hep-ex/0702005

Using single top Analysis

kcg\Λ < 0.15 TeV^{-1}

kug\Λ < 0.037 TeV^{-1}



M. Hosch et al.
Phys. Rev. D 56, 5725 - 5730 (1997)

Phenomenology of Anomalous top Couplings

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

Use effective Lagrangian

$$\mathcal{L}_{eff}^{FCNC} = \sum_{U=u,c} \frac{e e_U}{2\Lambda} \kappa_{tU\gamma} \bar{t} \sigma_{\mu\nu} A^{\mu\nu} U + \frac{g}{2\cos\theta_W} \bar{t} \left[\gamma_\mu (v_{tUZ} - a_{tUZ}\gamma^5) U Z^\mu + \frac{1}{2\Lambda} \kappa_{tUZ} \sigma_{\mu\nu} Z^{\mu\nu} U \right] + \text{h.c.}$$

- Take care of different conventions used
- Impact would be factors ~O(1), like e_U = 2/3, on coupling

ZEUS (D. Dannheim)

$$\Delta\mathcal{L}_{\text{eff}} = e\ e_t\ \bar{t}\ \frac{i\sigma_{\mu\nu}q^\nu}{\Lambda}\ \kappa_{tu\gamma}\ u\ A^\mu + \frac{g}{2\cos\theta_W}\ \bar{t}\ \gamma_\mu\ v_{tuZ}\ u\ Z^\mu\ + \text{h.c.},$$

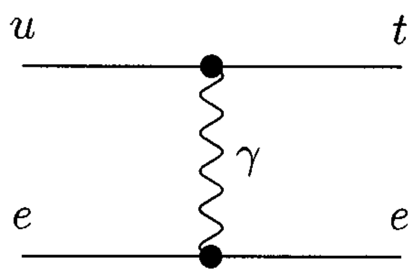
- Most general effective Lagrangian
- Couplings of **q=u,c** to **V = γ, Z, g, H**

J.A. Aguilar-Saavedra, ActaPhys.Polon.B35:2695-2710,2004.

$$\begin{aligned} -\mathcal{L}^{\text{eff}} = & \frac{g}{2c_W} X_{qt}\, \bar{q}\gamma_\mu (x_{qt}^L P_L + x_{qt}^R P_R) t Z^\mu + \frac{g}{2c_W} \kappa_{qt}\, \bar{q}(\kappa_{qt}^v + \kappa_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu}q^\nu}{m_t} t Z^\mu \\ & + e\lambda_{qt}\, \bar{q}(\lambda_{qt}^v + \lambda_{qt}^a\gamma_5) \frac{i\sigma_{\mu\nu}q^\nu}{m_t} t A^\mu + g_s \zeta_{qt}\, \bar{q}(\zeta_{tq}^v + \zeta_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu}q^\nu}{m_t} T^a q G^{a\mu} \\ & + \frac{g}{2\sqrt{2}} g_{qt}\, \bar{q}(g_{qt}^v + g_{qt}^a\gamma_5) t H + \text{H.c.}\,, \end{aligned}$$

Lagrangian Collection ...

$$\Delta\mathcal{L}^{eff} = \frac{1}{\Lambda}\left[\kappa_{tq\gamma} e \bar{t} \sigma_{\mu\nu} q F^{\mu\nu} + \kappa_{tqg} g_s \bar{t} \sigma_{\mu\nu} \frac{\lambda^i}{2} q G^{i\mu\nu} \right] + \text{H.c.},$$



ILC

$$-\mathcal{L} = \frac{g_W}{2c_W} X_{tq} \bar{t}\gamma_\mu (x_{tq}^L P_L + x_{tq}^R P_R) q Z^\mu + \frac{g_W}{2c_W} \kappa_{tq} \bar{t}(\kappa_{tq}^v - \kappa_{tq}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} q Z^\mu + e\,\lambda_{tq} \bar{t}(\lambda_{tq}^v - \lambda_{tq}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} q A^\mu ,$$

Decay Width Collection

$$\Gamma(t \to qg) = \left(\frac{\kappa_{tq}^g}{\Lambda}\right)^2 \frac{8}{3}\alpha_s m_t^3,$$

$$\Gamma(t \to q\gamma) = \left(\frac{\kappa_{tq}^\gamma}{\Lambda}\right)^2 2\alpha m_t^3,$$

$$\Gamma(t \to qZ)_\gamma = \left(|v_{tq}^Z|^2 + |a_{tq}^Z|^2\right) \alpha m_t^3 \frac{1}{4M_Z^2 \sin^2 2\theta_W} \left(1 - \frac{m_Z^2}{m_t^2}\right)^2 \left(1 + 2\frac{m_Z^2}{m_t^2}\right) \text{ and}$$

$$\Gamma(t \to qZ)_\sigma = \left(\frac{\kappa_{tq}^Z}{\Lambda}\right)^2 \alpha\, m_t^3 \frac{1}{\sin^2 2\theta_W} \left(1 - \frac{m_Z^2}{m_t^2}\right)^2 \left(2 + \frac{m_Z^2}{m_t^2}\right),$$

- Different Results in Literature!
- Compare to:

J.A. Aguilar-Saavedra, ActaPhys.Polon.B35:2695-2710,2004

Using $m_t = 178$ GeV, $\Gamma_{tot} = \Gamma_{t\to bW+} = 1.61$ GeV

$$\text{Br}(t \to qZ)_\gamma = 0.472\, X_{qt}^2,$$ $\Gamma_{t\to qZ} = 760$ MeV

$$\text{Br}(t \to qZ)_\sigma = 0.367\, \kappa_{qt}^2,$$

$$\text{Br}(t \to q\gamma) = 0.428\, \lambda_{qt}^2,$$ $\Gamma_{t\to q\gamma} = 690$ MeV

$$\text{Br}(t \to qg) = 7.93\, \zeta_{qt}^2,$$

$$\text{Br}(t \to qH) = 3.88 \times 10^{-2}\, g_{qt}^2.$$

$$\Gamma(t \to c\gamma) = \kappa_\gamma^2 \frac{\alpha\, e_q^2}{4}\left(\frac{m_t^2}{\Lambda^2}\right) m_t,$$

$$\Gamma(t \to cZ) = \kappa_Z^2 \frac{\alpha}{8\sin^2 2\vartheta_W\, M_Z^2} m_t^3 \left(1 - \frac{M_Z^2}{m_t^2}\right)^2 \left(1 + 2\frac{M_Z^2}{m_t^2}\right)$$

Obraztsov et al., Physics Letters B Volume 426, Issues 3-4, 7 May 1998, Pages 393-402

- SM Single Top
  - Cross Sections + Kinematics
    - HERA, LHC, ILC
    - LHeC
- Theory for anomalous couplings
  - 2HDM
  - MSSM (RPV)
  - Unparticles
  - Effective L
- Conversion coupling <-> Br
- FCNC in production (coupling)
  - HERA
  - LHC in Photoproduction
- FCNC in decay (Br)
  - CDF, D0
  - ATLAS, CMS

SM

$$BR(t \to c\gamma) = 4.6 \times 10^{-14}$$
$$BR(t \to u\gamma) = 3.7 \times 10^{-16}.$$

J. A. Aguilar-Saavedra, B. M. Nobre (IST Lisbon)
Phys.Lett. B553 (2003) 251-260

ATLAS Note Conversions

	LEP	HERA	Tevatron
$BR(t \to qZ)$	7.8% [36–40]	49% [41]	3.7% [42]
$BR(t \to q\gamma)$	2.4% [36–40]	0.75% [41]	3.2% [43]
$BR(t \to qg)$	17% [44]	13% [41, 45, 46]	0.1 – 1 % (estimated from [45, 47])

Initially stressed by
Fritzsch, Holtmannspoetter
Phys.Lett. B457 (1999) 186-192

Conversion Br <-> Couplings <-> Widths <-> XSec

- FCNC top Production: Measure Cross Section

  Xsec -> Coupling -> Decay Width -> Br

- FCNC Top Decays: Measure Branching Ratio

  Br -> Width -> Coupling -> Xsec

- For comparable Results, all assumptions / conventions must be the same
- Strategy:
  - Take measured quantities
  - Do conversions ourselves using our conventions