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Search for single-top production with the ZEUS detector at HERA

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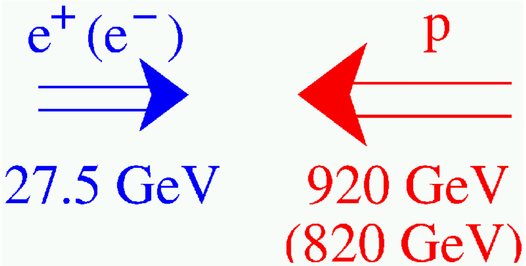
Outline:
- Single-top production at HERA
- Isolated leptons
- 3-jet events
- Exclusion limits
- Summary/Outlook

Single-top production at HERA

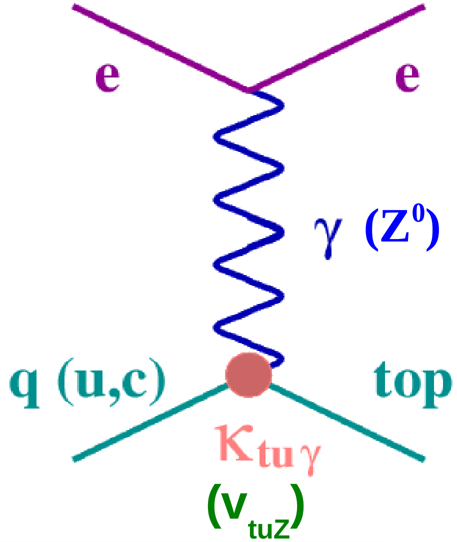
HERA:



$\sqrt{s} = 318\,GeV\ (300\,GeV)$

ZEUS: L_{int} = 130 pb^{-1}

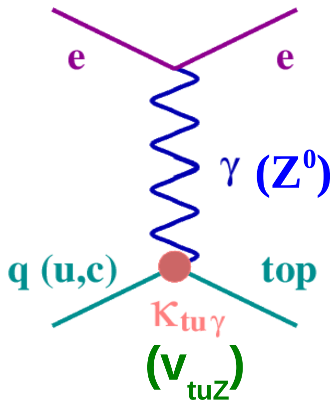
- **production of single top quarks through quark-flavour changing neutral currents (FCNC)**
- **SM contribution <1 fb (GIM suppression)**
- **several BSM theories (e.g. SUSY models) predict sizeable FCNC rates**
- **effective anomalous coupling at t-u-γ- or t-u-Z^0 vertex:**



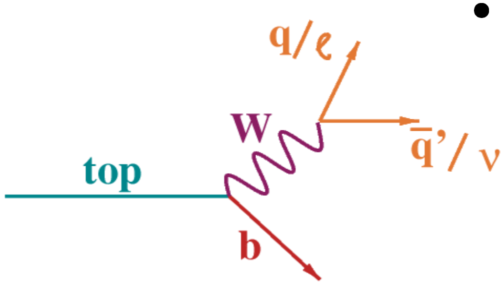
$$\Delta\mathcal{L}_{\text{eff}} = e\ e_t\ \bar{t}\ \frac{i\sigma_{\mu\nu}q^{\nu}}{\Lambda}\kappa_{tu\gamma}\,u\ A^{\mu} + \frac{g}{2\cos\theta_W}\ \bar{t}\ \gamma_{\mu}\,v_{tuZ}\,u\ Z^{\mu} + \text{h.c.}$$

- **differences w.r.t LEP/Tevatron analyses:**
  - **we neglect c-coupling (u dominant at large x>0.3)**
  - **$\kappa_{t\text{-}u\text{-}\gamma}^{LEP} = \sqrt{2}\kappa_{t\text{-}u\text{-}\gamma}^{ZEUS}$ and $v_{t\text{-}u\text{-}\gamma}^{LEP} = \sqrt{2}v_{t\text{-}u\text{-}\gamma}^{ZEUS}$**

Experimental signature

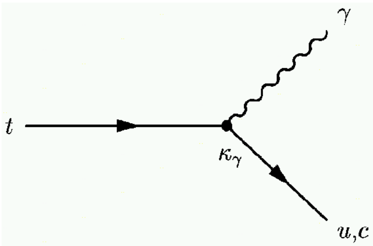


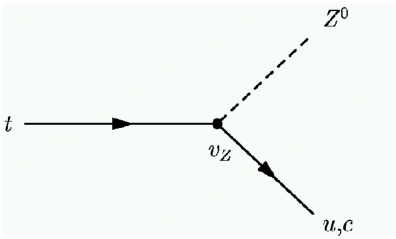
- Production modes:
  - γ–exchange: scattered el. not in detector ~65%
  - Z-exchange: scattered el. in detector ~100%



- Decay modes:
  - SM:
    - leptonic (BR~32%): $t \to bW,\ W \to l\nu$ isol. e/μ,b-jet,missing p_T
    - hadronic (BR=68%): $t \to bW,\ W \to q\bar{q}'$ 3 jets, inv.mass~m_{top}
  - FCNC:
    - $\kappa_{t\text{-}u\text{-}\gamma}$: $t \to u\gamma$
    - $v_{t\text{-}u\text{-}Z}$: $t \to uZ^0$

    n-jets (+ lepton pairs)





- Search strategy:
  - optimize acceptance for
    - γ–exchange (highest sensitivity at HERA)
    - SM decay modes (existing constraints on FCNC decay)
  - consider also other production and decay modes

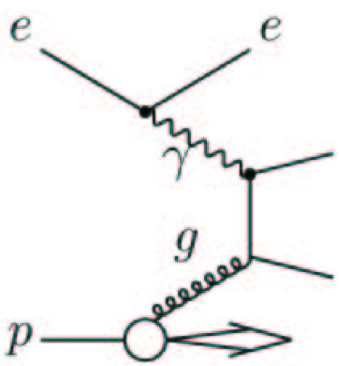
MC Simulation for signal process

- Two generators used:
  - HEXF (modified version)
    - produce excited u* with $m_{u*}=m_{top}$
    - Only SM decay: u* $\rightarrow$ bW
    - uses Hagiwara model (only right-handed top quarks)
    - ISR according to Weizsäcker-William-approximation
  - CompHEP + PYTHIA
    - LO calculation for single-top Lagrangian
    - samples for all combinations of production and decay modes
    - no ISR

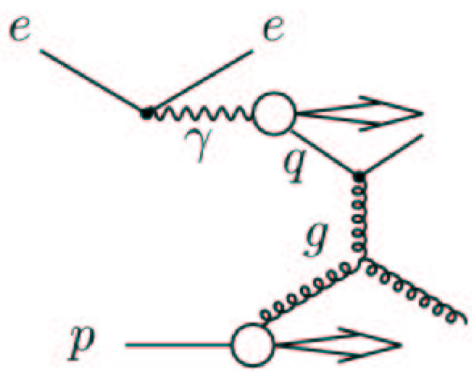
- Good agreement between both generators (<10% difference in efficieny)
  - ➔ use HEXF as default, CompHEP for anomalous decays
- single top efficiencies from samples for
  - all combinations of production and decay modes
  - m_{top}=170, 175, 180 GeV (main systematic uncertainty)

Standard Model Background

direct PhP

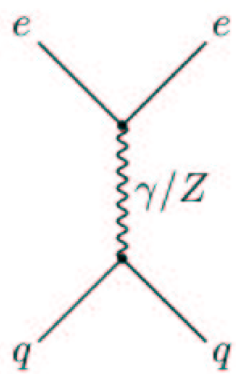


resolved PhP



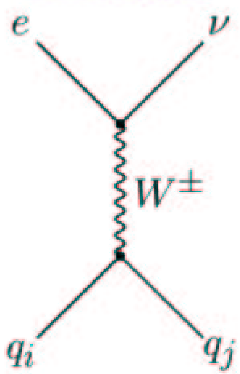
contribute to hadr. channel

NC DIS

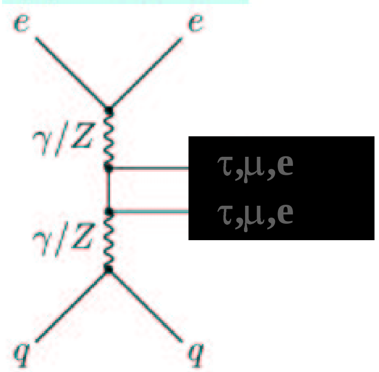


contributes to e-channel

CC DIS

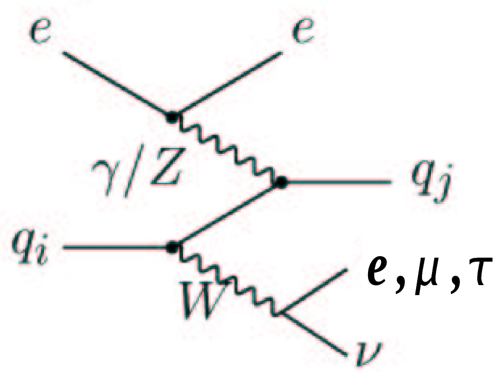


$\gamma\gamma \rightarrow \ell^+\ell^-$



contributes to μ-channel

W production



contributes to e/μ channel

$\sigma(ep \rightarrow eW^{\pm}X) \approx 1pb$

EPVEC LO MC, reweighted with recent NLO calculations for PhP part (Diener, Schwanenberger, Spira: *hep-ex/0302040*),
→talk by Chr. Schwanenberger

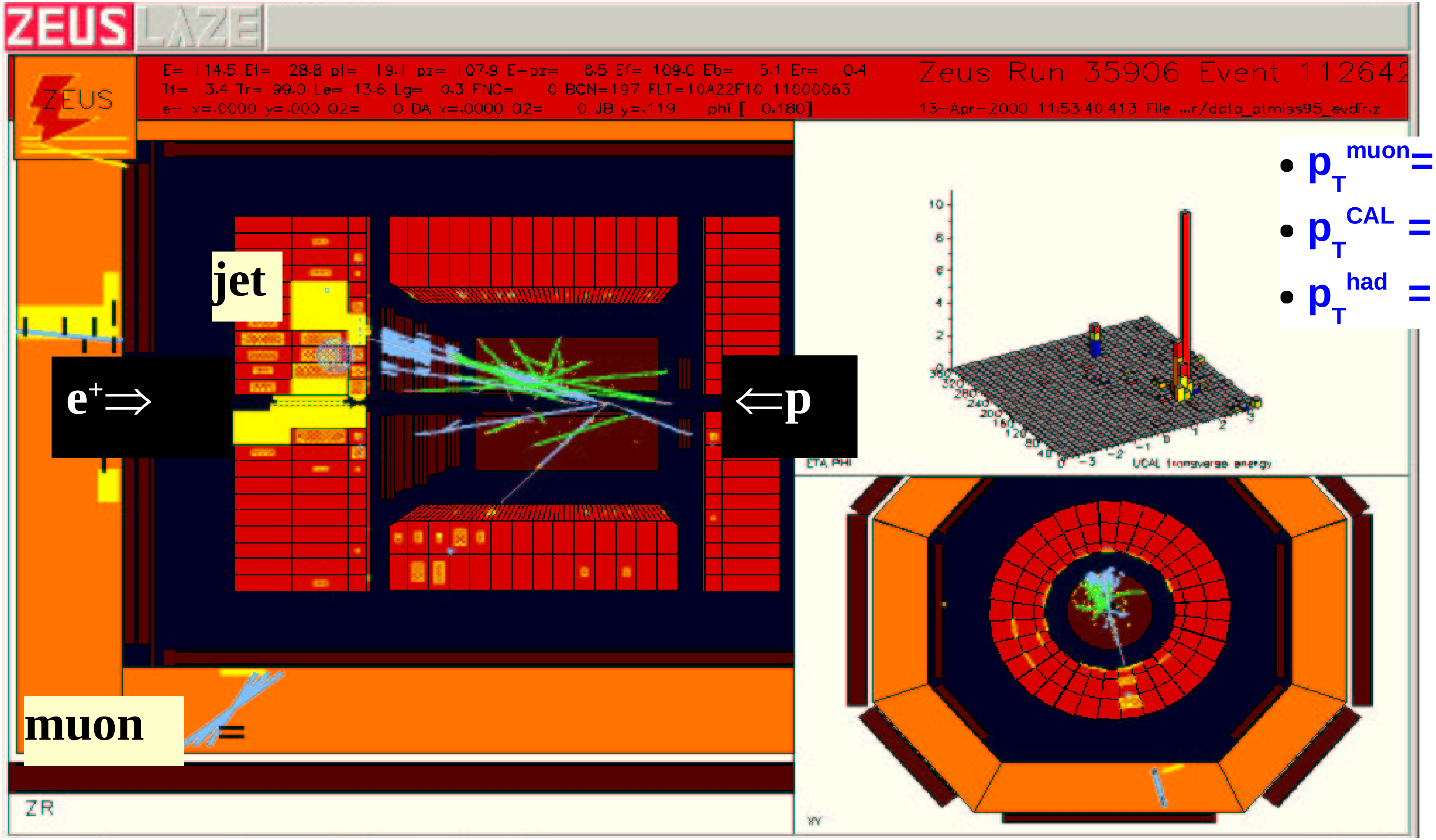
Preselection leptonic channel: isolated electrons/muons

$$ep \to e\,t\,X$$
$$\quad\hookrightarrow b\,W$$
$$\qquad\hookrightarrow e\nu\;(\mu\nu)$$

- Missing transverse momentum p_T^{CAL} > 20 GeV
- ≥ 1 jet with p_T^{jet} > 5 GeV, 9°<θ<140°
- ≥ 1 track with:
  - p_T^{track} > 5 GeV, 17°<θ< 115°
  - Isolation to other tracks/jets:
    - distance to closest track in η−φ-plane: D_{trk} > 0.5
    - distance to closest jet in η−φ-plane: D_{jet} > 1.0
- Lepton identification:
  - electron or muon
  - (tau →*talk by Damir Lelas tomorrow*)
- ϕ_{acopl}>8° for el. (NC DIS rejection)

$$D_{trk,jet} = \sqrt{(\Delta\eta_{trk,jet})^2 + (\Delta\phi_{trk,jet})^2}$$

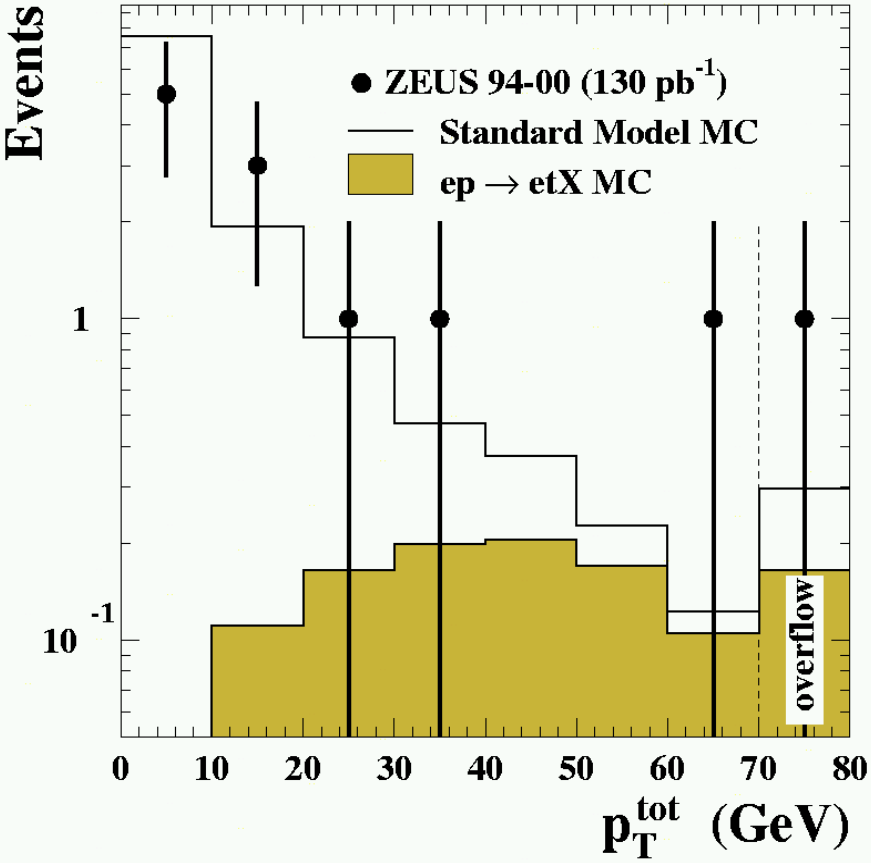
Muon candidate event

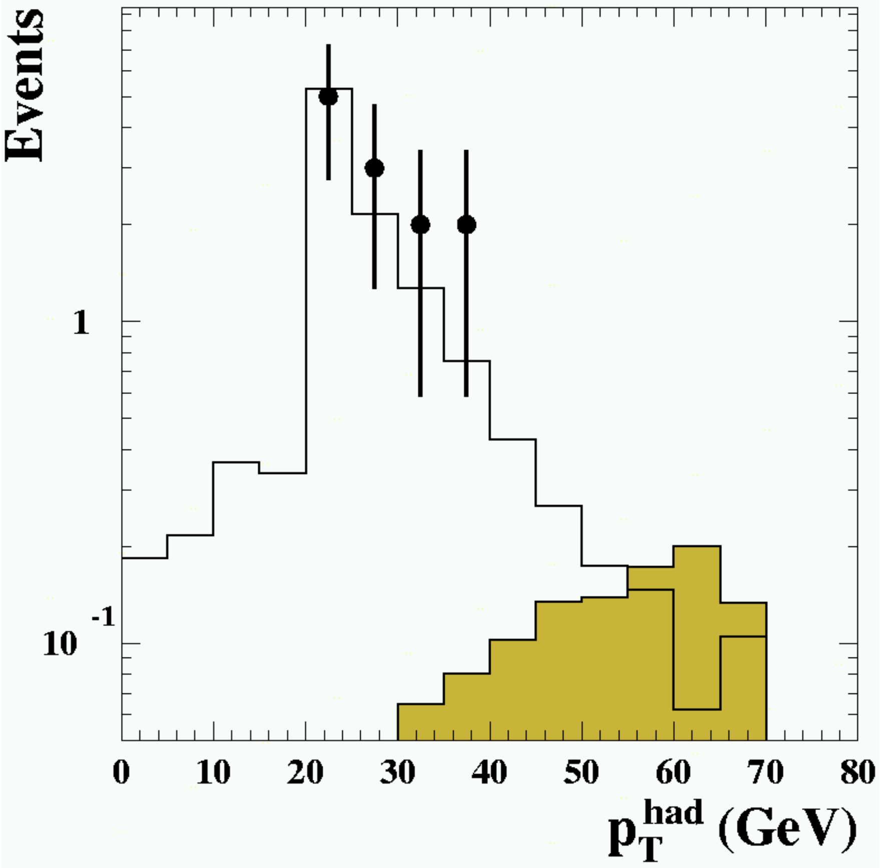


- p_T^{muon} = 30 GeV
- p_T^{CAL} = 23 GeV
- p_T^{had} = 23 GeV

- **striking signature**
- **main motiviation for this search:**
  H1 sees excess at large p_T^{had} (→*following talk by Andre Schöning*)

preselection of isolated muons

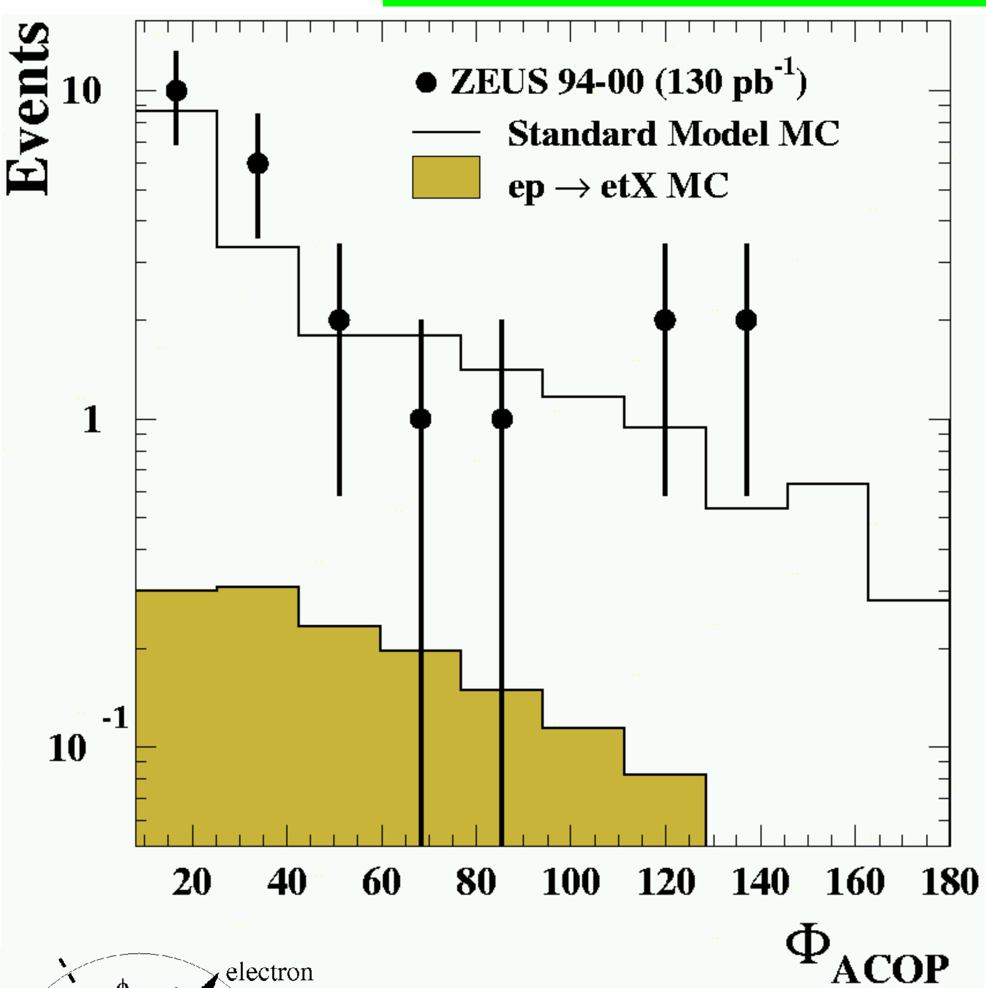


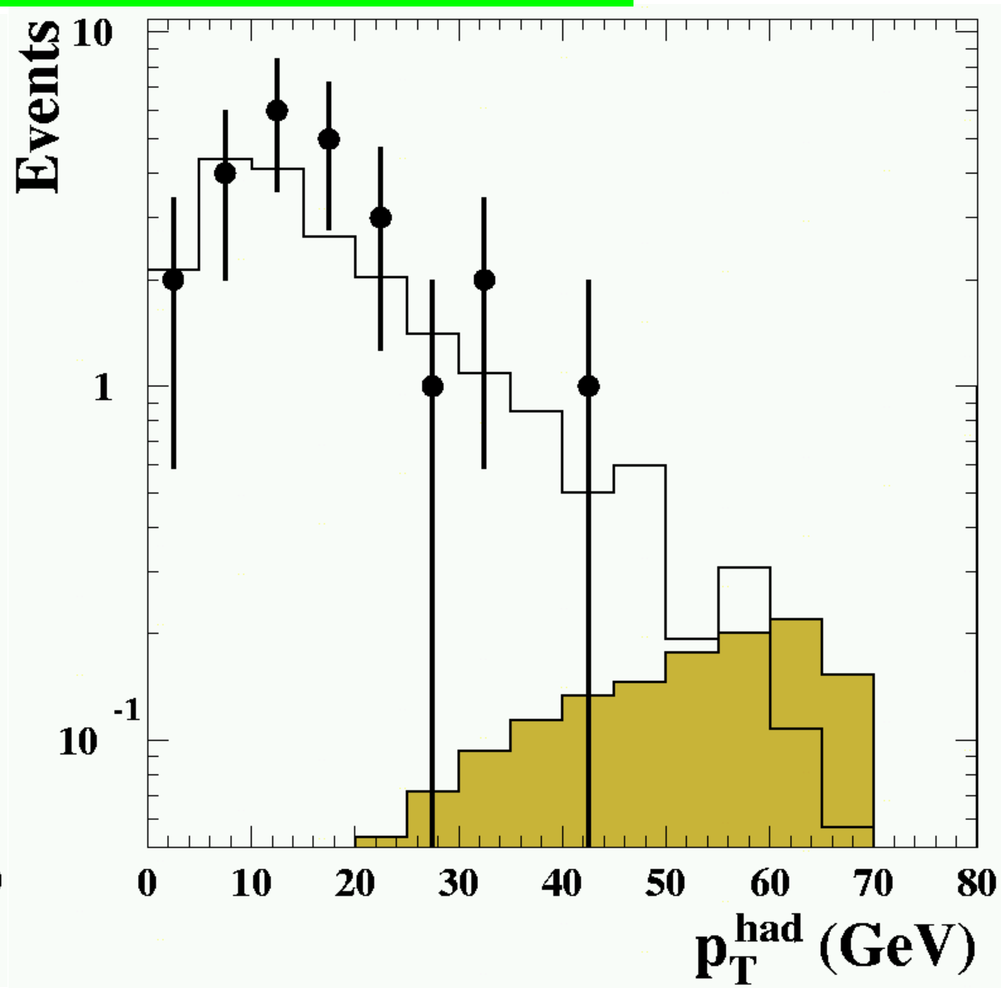


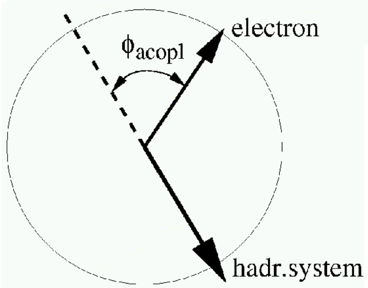
$$p_T^{tot} = \sqrt{(p_x^{CAL} + p_x^{\mu})^2 + (p_y^{CAL} + p_y^{\mu})^2}$$

- **12 events observed, $11.9^{+0.6}_{-0.7}$ expected from SM background**
- **SM background dominated by $\gamma\gamma \rightarrow \mu\mu$ (low p_T^{tot})**
- **large p_T^{had} for signal MC**
- **good agreement between data and SM MC**

preselection of isolated electrons







p_T^{had}

- 24 events observed, $20.6^{+1.7}_{-4.6}$ expected from SM background
- SM background dominated by NC DIS (low acoplanarity)
- good agreement between data and SM MC
- large p_T^{had} for signal MC

Final selection of single-top candidates

- optimize selection for single-top signal:
  - minimize expected Bayesian upper limit on signal in the presence of background
  - ➔ additional selection cuts:
    - $E-p_z<47$ GeV (only electron candidates)
    - $p_T^{tot} > 10$ GeV (only muon candidates)
    - $p_T^{had} > 40$ GeV

Leptonic channel	Positron channel obs./expected (W)	Muon channel obs./expected (W)
Preselection	$24 \;/\; 20.6^{+1.7}_{-4.6}$ (17%)	$12 \;/\; 11.9^{+0.6}_{-0.7}$ (16%)
Final selection ($p_T^{had} > 25$ GeV)	$2 \;/\; 2.90^{+0.59}_{-0.32}$ (45%)	$5 \;/\; 2.75^{+0.21}_{-0.21}$ (50%)
Final selection ($p_T^{had} > 40$ GeV)	$0 \;/\; 0.94^{+0.11}_{-0.10}$ (61%)	$0 \;/\; 0.95^{+0.14}_{-0.10}$ (61%)

- No top candidate in HERA I dataset observed
- 1.9 events expected from SM background
- SM background dominated by direct W production
- signal efficiency: 33% el. channel, 34% muon channel

Hadronic channel

$$ep \rightarrow e\, t\, X$$
$$\hookrightarrow b\, W$$
$$\hookrightarrow q\bar{q}'$$

- Signature: 3 jets with invariant mass M^{jj}~M_W, M^{3j}~M_{top}
- main SM background: QCD multi-jet production

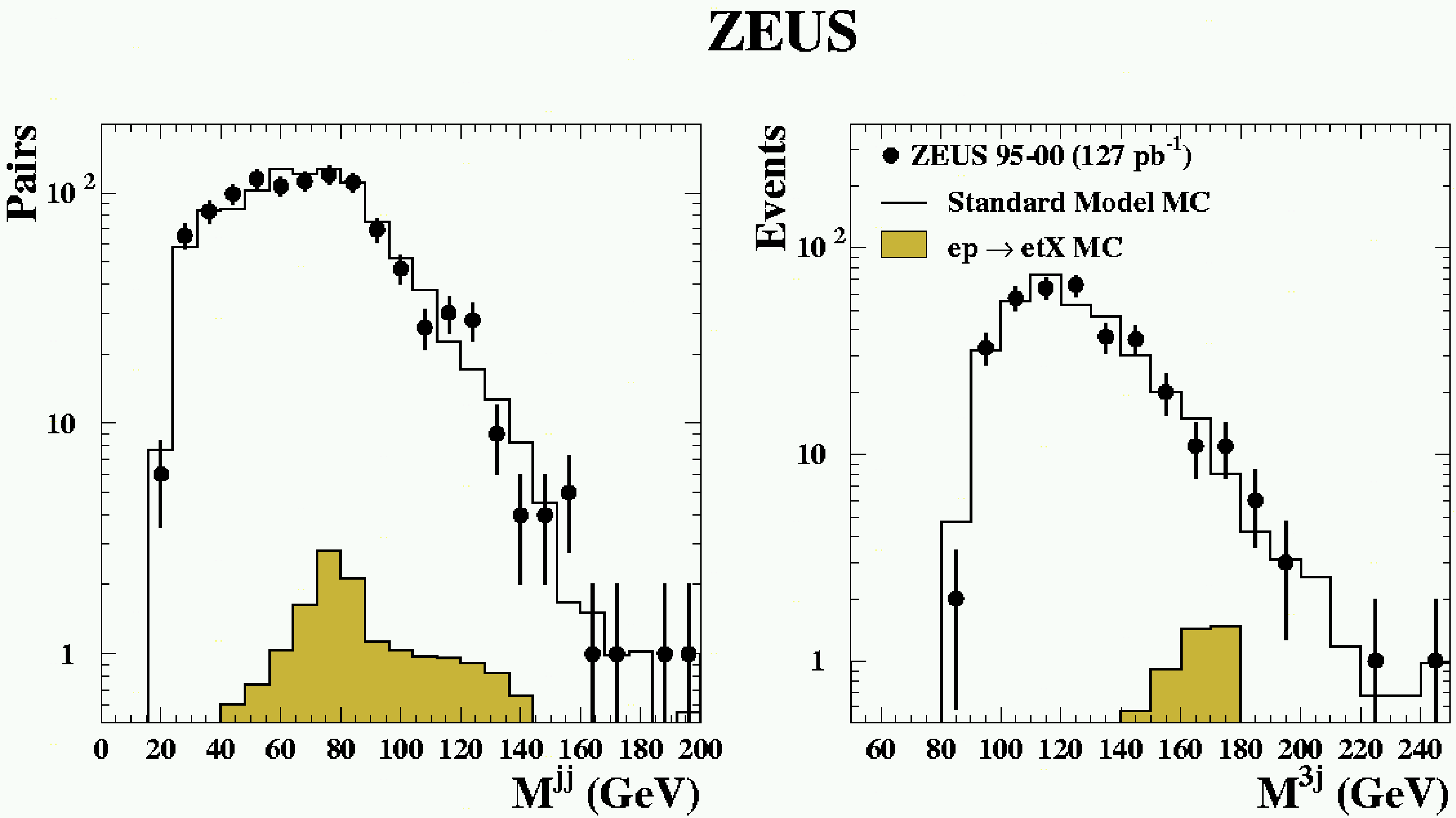
- Preselection:
  - $\geq$ 3 jets $-1<\eta<2.5$
  - $E_T^{jet(1,2,3)}$ > 40, 25, 14 GeV
  - N_{el}=0 (NC DIS rejection)
  - $p_T^{CAL}/\sqrt{E_T^{tot}}$ < $2\sqrt{GeV}$ (CC DIS rejection)
  - 8.8<E-p_Z<52.2 GeV (NC DIS and p-beam-gas rejection)

$$M^{jj} = \sqrt{2E_T^{\text{jet,k}} E_T^{\text{jet,l}}[\cosh(\eta^{\text{jet,k}} - \eta^{\text{jet,l}}) - \cos(\varphi^{\text{jet,k}} - \varphi^{\text{jet,l}})]}$$

$$M^{3j} = \sqrt{\sum_{k<l} 2E_T^{\text{jet,k}} E_T^{\text{jet,l}}[\cosh(\eta^{\text{jet,k}} - \eta^{\text{jet,l}}) - \cos(\varphi^{\text{jet,k}} - \varphi^{\text{jet,l}})]}$$

- resolution:
  - M^{jj}~8% for M^{jj}>50 GeV
  - M^{3j}~4% for M^{3j}>80 GeV

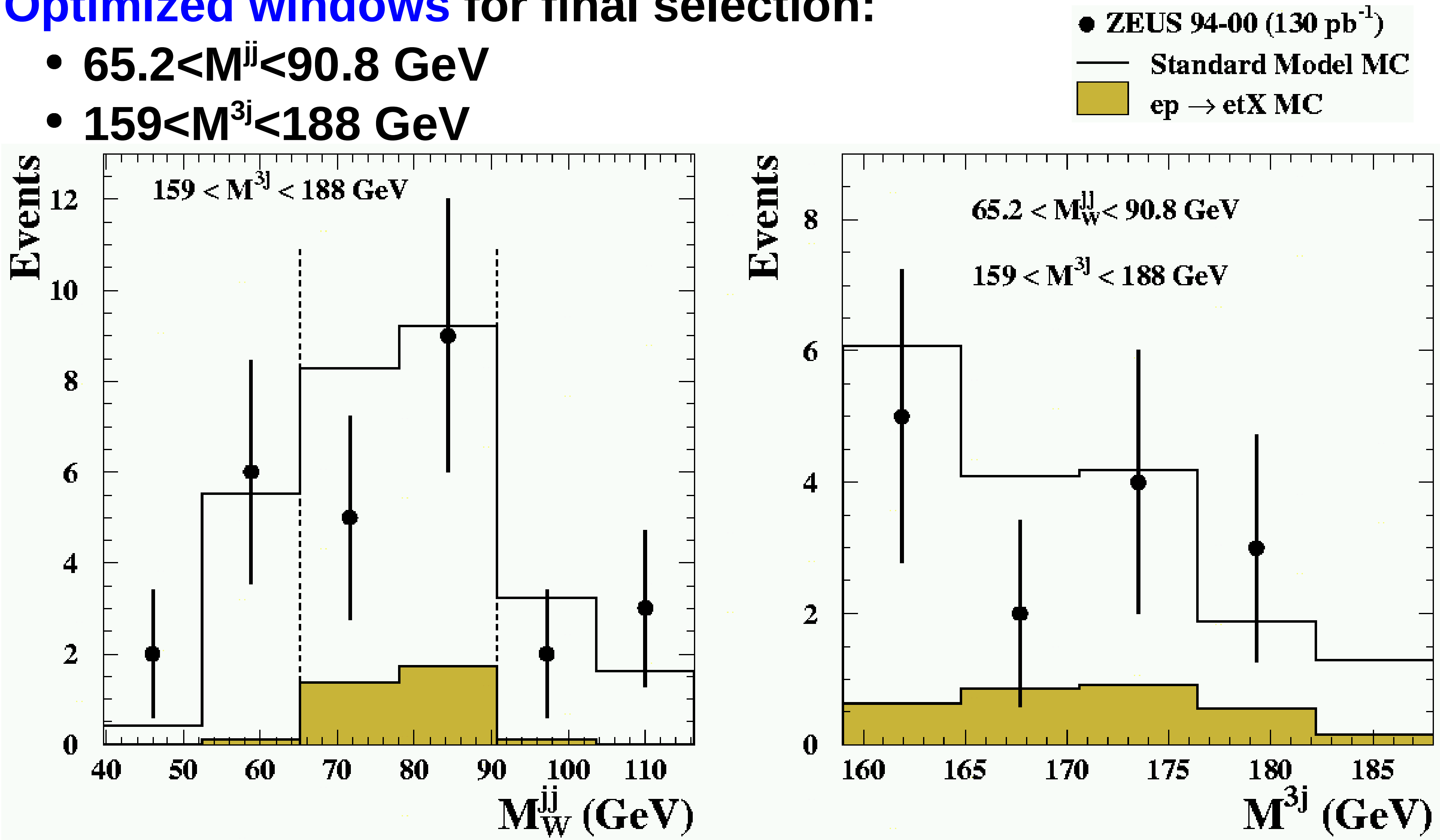
preselection hadronic channel



- background dominated by low Q^2 QCD Multi-jet production
- PYTHIA PhP MC normalised to data for M^{3j}<159 GeV
- good agreement with SM expectations

final selection hadronic channel

- **Optimized windows for final selection:**
  - **$65.2 < M^{jj} < 90.8$ GeV**
  - **$159 < M^{3j} < 188$ GeV**

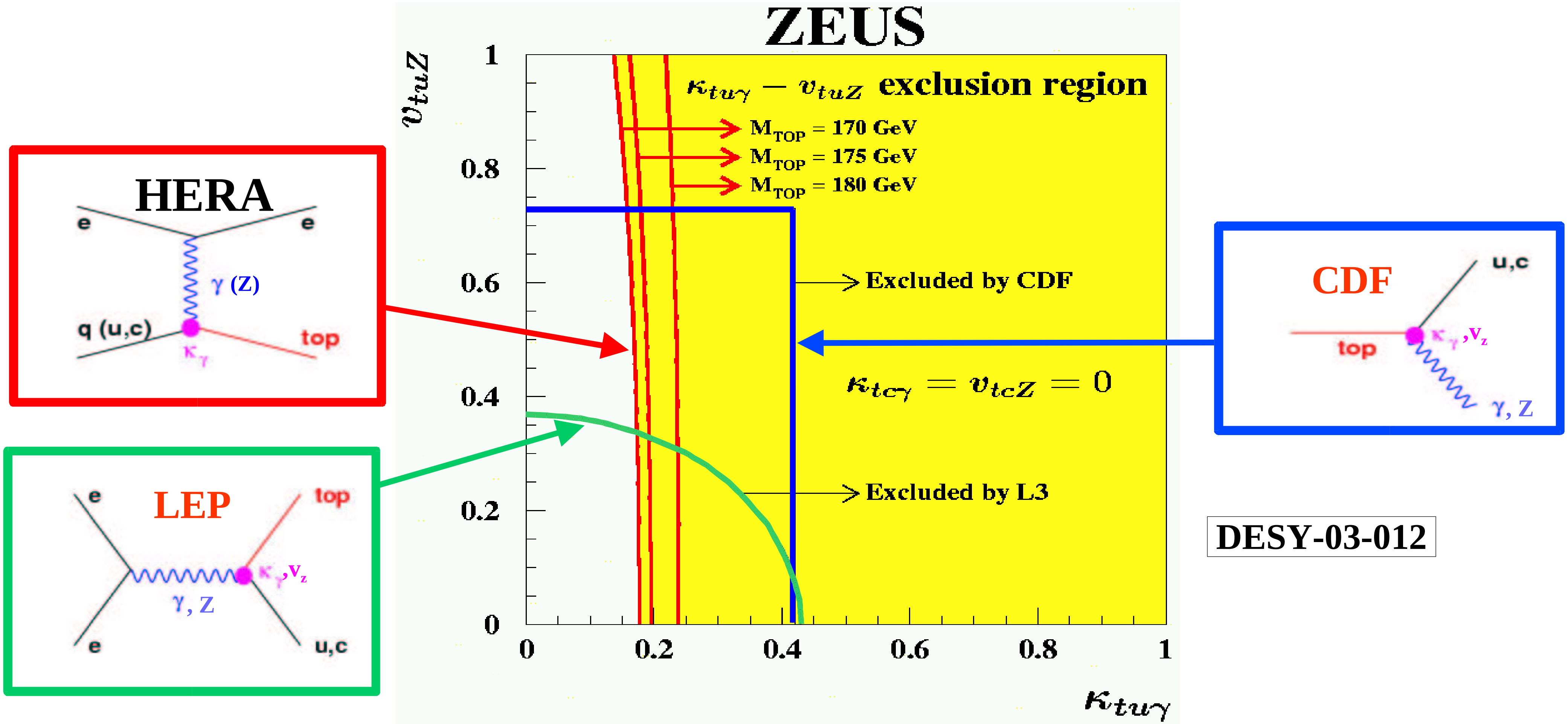


- **14 events selected, 17.6 expected from SM background**
- ➔ **good agreement with SM expectations**
- ➔ **signal efficiency ~24% for $t \rightarrow bW$, $W \rightarrow qq'$**

Exclusion limits on $\kappa_{t\text{-}u\text{-}\gamma}$

- **NLO QCD corrections for $\sigma(\kappa_{t\text{-}u\text{-}\gamma})$:**
  - **calculations by Belyaev and Kidonakis (*PRD 65(2002) 037501*)**
  - $\mu_R=\mu_F=m_{top}$
  - **reduced scale-dependence:** $\mu_R=\mu_F=m_{top}/2$ .. $2m_{top}$ $\rightarrow \Delta\sigma<\pm4\%$
  - **systematic uncertainties:**
    - $m_{top}=\pm5$ **GeV** $\rightarrow \Delta\sigma=\pm25\%$ **($\pm$20%) for $\sqrt{s}$=318 (300) GeV**
    - $\alpha_s(M_Z) \rightarrow \Delta\sigma=\pm2\%$
    - **proton PDF** $\rightarrow \Delta\sigma=\pm4\%$
- **95% C.L. on $\kappa_{t\text{-}u\text{-}\gamma}$, assuming $v_{t\text{-}u\text{-}Z}=0$:**
  - m_{top}**=170 GeV:** $\kappa_{t\text{-}u\text{-}\gamma}<0.158$
  - m_{top}**=175 GeV:** $\kappa_{t\text{-}u\text{-}\gamma}<0.174$ **(σ<0.225 pb at $\sqrt{s}$=318 GeV)**
  - m_{top}**=180 GeV:** $\kappa_{t\text{-}u\text{-}\gamma}<0.210$

2-dimensional exclusion limits



- LEP and Tevatron limits displayed for HERA Lagrangian convention and assuming no charm contribution
- highest sensitivity for $\kappa_{t\text{-}u\text{-}\gamma}$
- significant region excluded by ZEUS limit

Summary/Outlook

- search for single-top production through FCNC
- full HERA I dataset covered, L_{int} = 130 pb^{-1}
- search in leptonic and hadronic W decay channels
- no signal observed
- constraints on anomalous couplings $\kappa_{t-u-\gamma}$ and v_{t-u-Z}
- limits competitive with other colliders:

$\kappa_{t-u-\gamma}$ <0.174 $\Leftrightarrow$ σ<0.225 pb at $\sqrt{s}$=318 GeV

Future data from HERA II:

- 5x higher int. luminosity $\rightarrow$ 2x higher sensitivity to couplings
- improved detector, in particular forward tracking