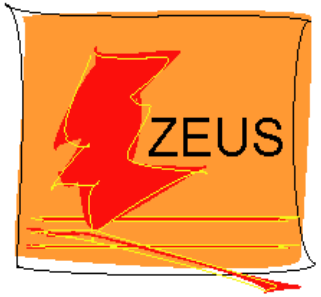
Searches for Physics beyond the Standard Model at ZEUS



Antje Hüttmann (DESY)
for the ZEUS collaboration

Hadron Structure and QCD
July ??, 2012

Outline

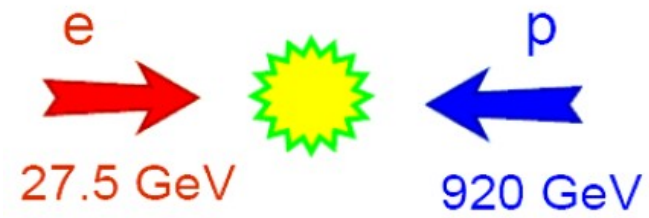
- The HERA collider
- Deep Inelastic Scattering (DIS)

- Search for leptoquarks
  - Introduction
  - Resonant searches
  - Limits

- Search for single top production
  - Introduction
  - Event selection
  - Limits

The HERA Collider

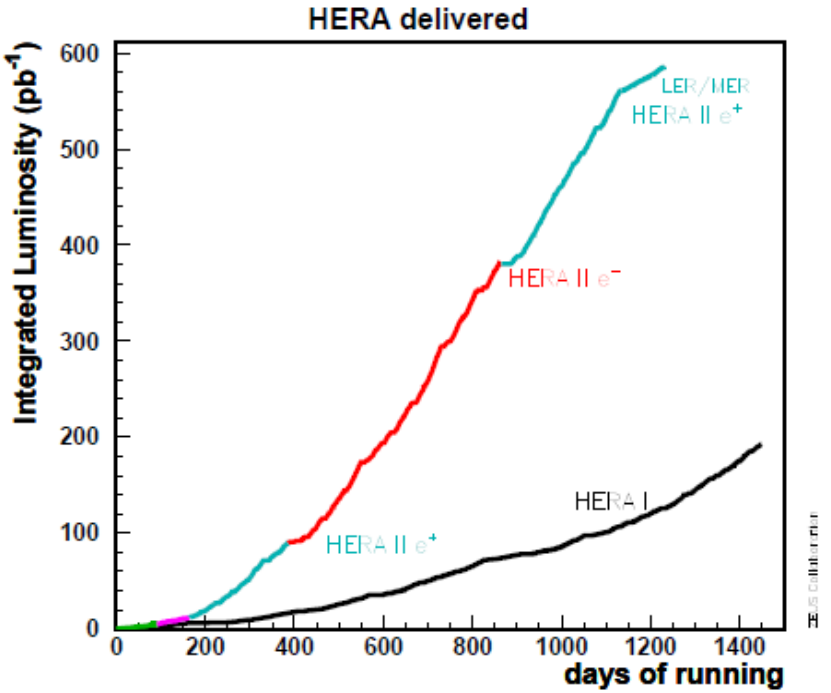
- World's only *ep* collider, located at DESY in Hamburg
- In operation from 1992-2007



Center of mass energy:

$$\sqrt{s} = 318 \text{ GeV}$$

- Two running periods:
  - HERA-I: 1992-2000, L=130 pb^{-1}
  - HERA-II: 2002-2007, L=370 pb^{-1} lepton beam longitudinally polarised (30-40%)
- Two general purpose collider experiments: ZEUS and H1



Deep Inelastic Scattering (DIS)

- ***Neutral current (NC):*** γ or Z exchanged, $e^{\pm}$ in final state
- ***Charged current (CC):*** $W^{\pm}$ exchanged, ν_e in final state
- Q^2: boson virtuality

$$Q^2 = -q^2 = -(k - k')^2$$

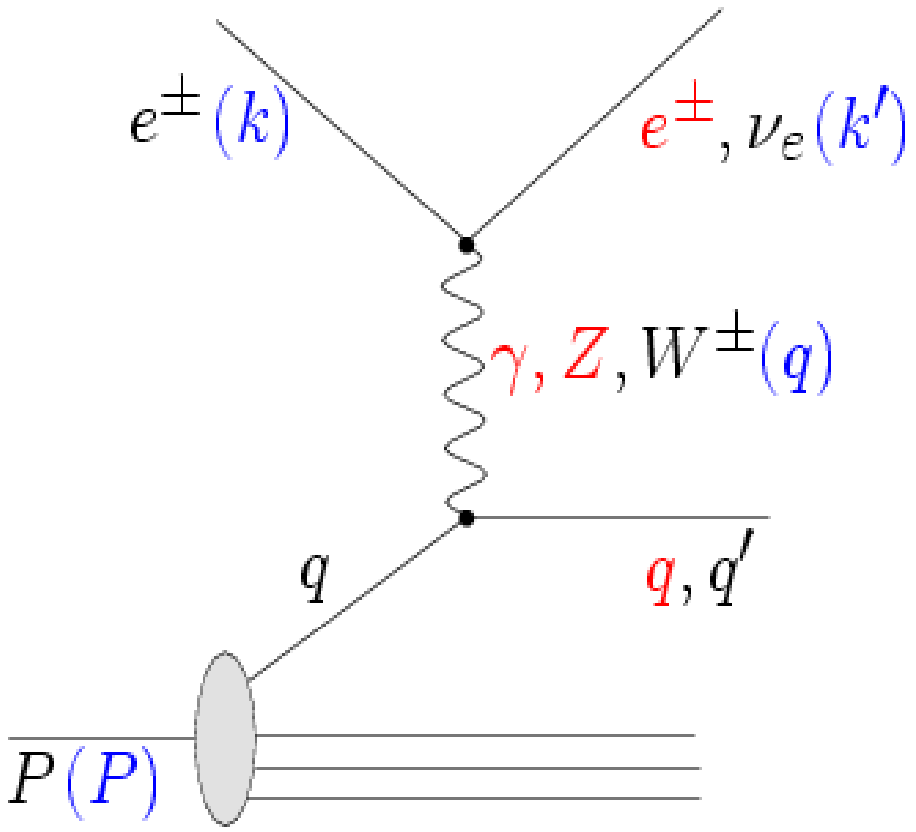
- x: proton momentum fraction carried by struck quark q

$$x = \frac{Q^2}{2P \cdot q}$$

- y: fractional energy loss of electron in rest frame of proton

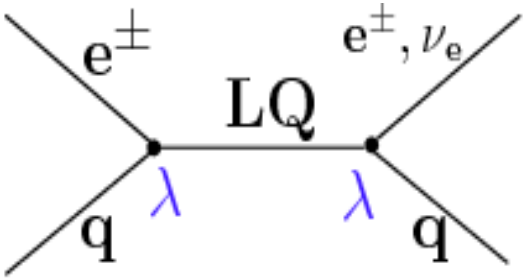
$$y = \frac{P \cdot q}{P \cdot k}$$

- $Q^2 = xys$ ($\sqrt{s}$ = center of mass energy)



The Leptoquark Model

- Leptoquarks are scalar or vector colour triplet bosons, carry both lepton and baryon number → HERA is well suited for leptoquark searches
- Fermion number: $F=L+3B$, ($F=0,2$)
- The Buchmüller-Rückl-Wyler model:
  - Standard Model symmetry conserved
  - Lepton and baryon number conserved
  - LQs couple either to right-handed or to left-handed leptons
  - No flavour-violating couplings
  - → 7 scalar and 7 vector 1st generation leptoquarks
  - All 14 LQs couple to eq, 2 scalar and 2 vector LQs also to νq
- LQ processes at HERA have the same initial and final state as NC/CC DIS → interfere with the SM

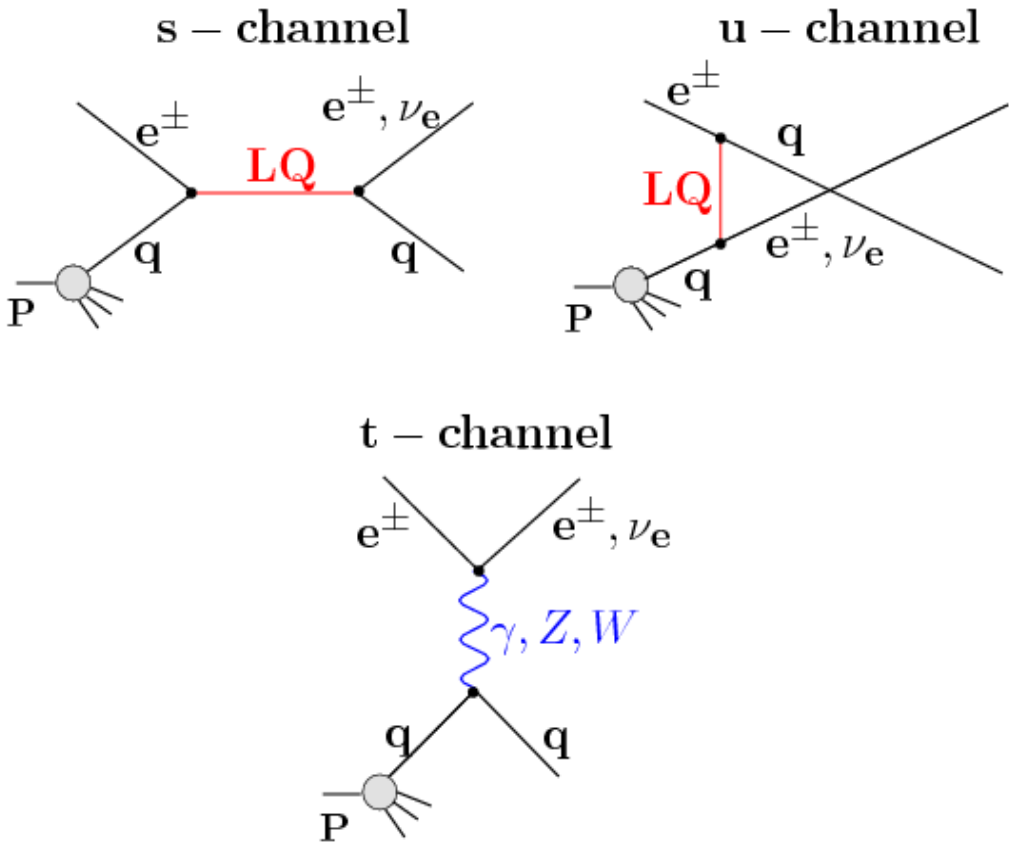


LQ resonance production

The Leptoquark Cross Section

Total cross section:

$$\sigma(e^{\pm}p) = \sigma_{SM} + \sigma^{Int}_{s/SM} + \sigma^{Int}_{u/SM} + \sigma_s + \sigma_u$$



- For $M_{LQ} \leq \sqrt{s}$, the *s*-channel dominates

Angular dependence:

$y = 0.5\,(1-\cos\theta^*)$

(θ^*: lepton scattering angle in the lepton-quark c.m.s.)

- scalar leptoquarks:

$$\left.\frac{d\sigma}{dy}\right|_{scalar} : \text{independent of } y$$

- vector leptoquarks:

$$\left.\frac{d\sigma}{dy}\right|_{vector} \sim (1-y)^2$$

s-channel

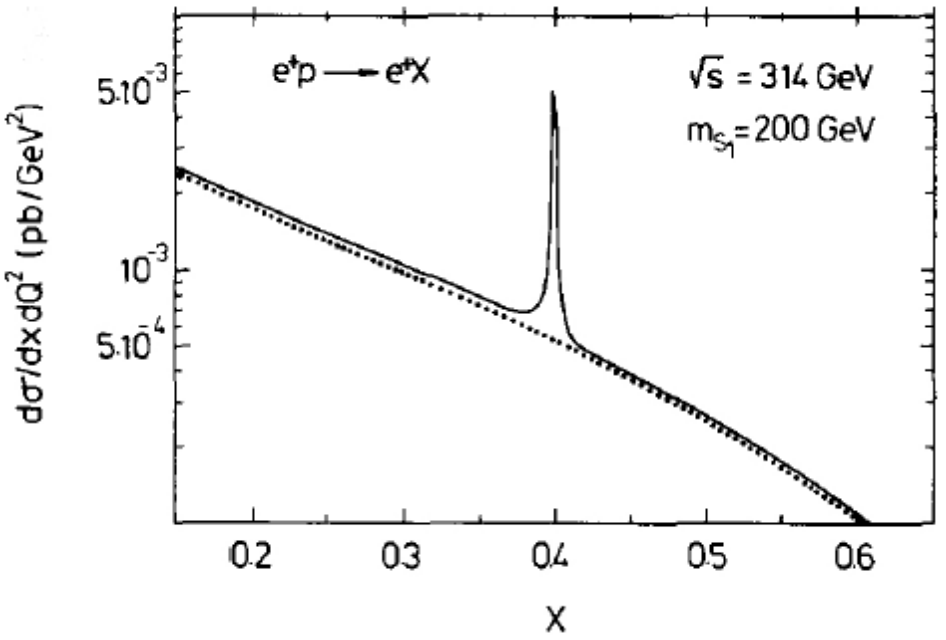
- NC DIS background:

$$\left.\frac{d\sigma}{dy}\right|_{SM} \sim \frac{1}{y^2}$$

→ signal-to-background ratio can be improved by restricting the search to the high-*y* region (negative $\cos\theta^*$)

Search Strategy

- Leptoquark events have the same signature as NC or CC events
- LQ contribution in addition to SM would lead to peak in invariant mass distribution (for $M_{LQ} < \sqrt{s}$)
- LQ cross section has different polarization dependence than NC (or CC) cross section → data samples with different polarization examined separately

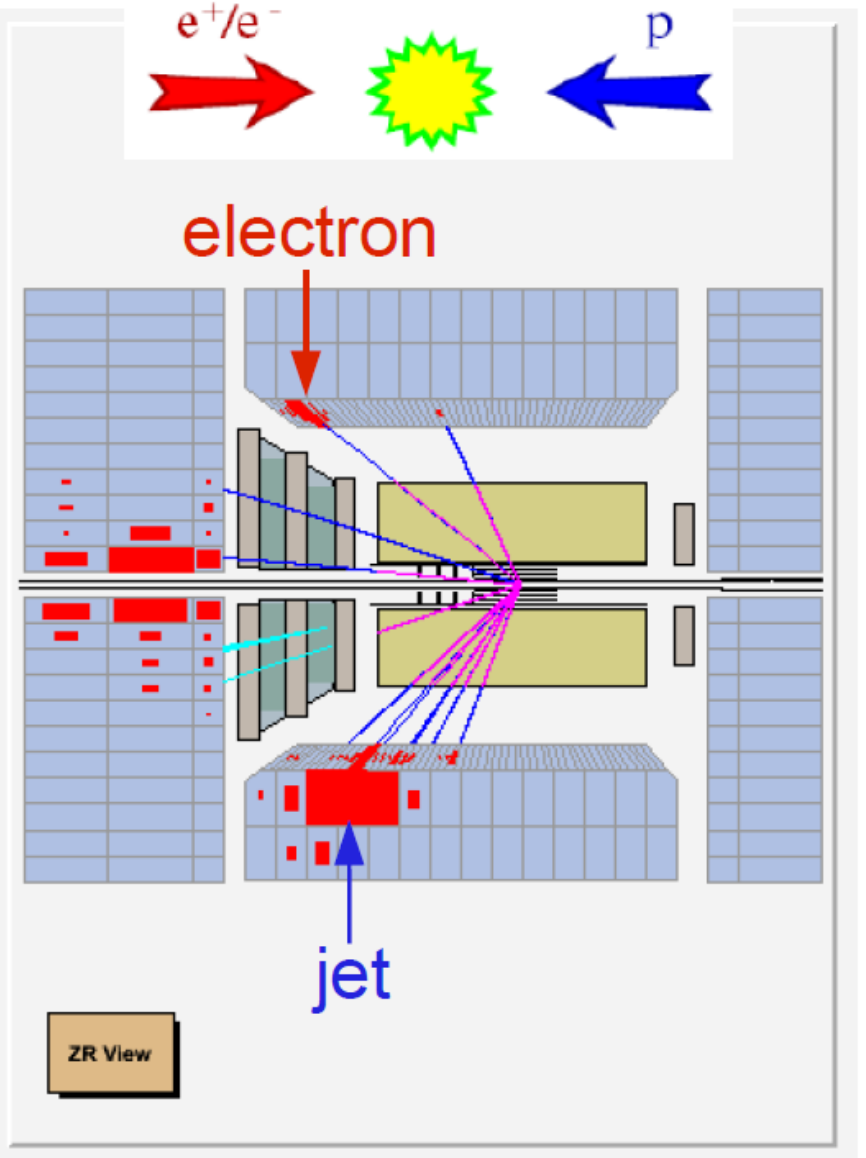


W. Buchmüller, R. Rückl, D. Wyler, Phys. Lett. B 191, 442 (1987)

$$M = \sqrt{xs}$$

Event Selection

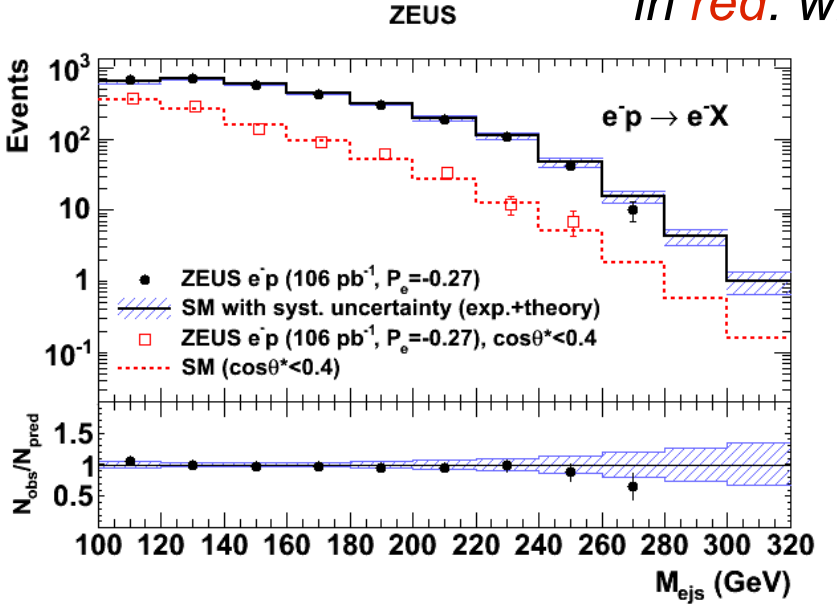
- All HERA-II data (0.37 pb^{-1}) were analysed
- NC DIS:
  - $Q^2 > 2500$ GeV^2
  - $x > 0.1$
  - isolated electron
  - ≥ 1 jet with $p_T > 15$ GeV
  - 9369 events selected, 9465±494 are expected
- CC DIS:
  - $Q^2 > 700$ GeV^2
  - Missing transverse momentum $p_T > 22$ GeV
  - ≥ 1 jet with $p_T > 10$ GeV
  - 8990 events selected, 9068±501 are expected
- The invariant mass is calculated from the lepton and all selected jets

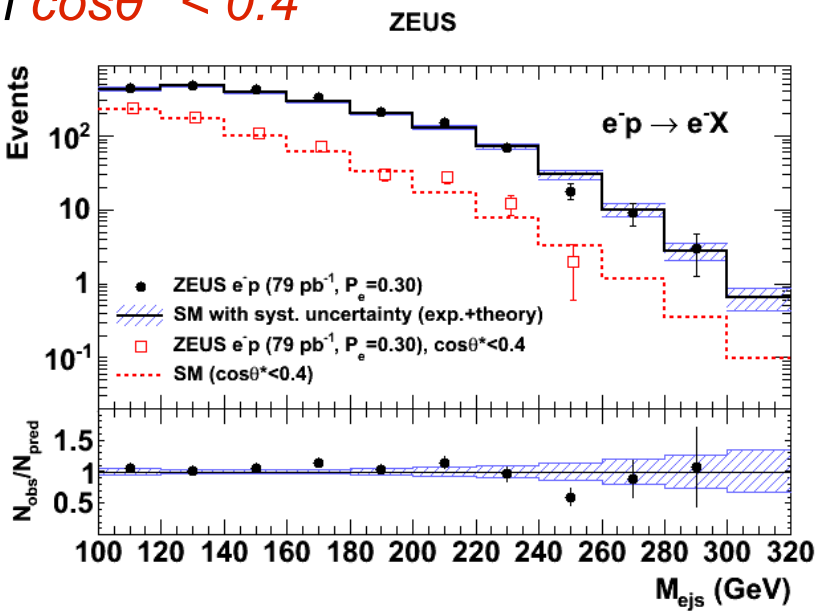


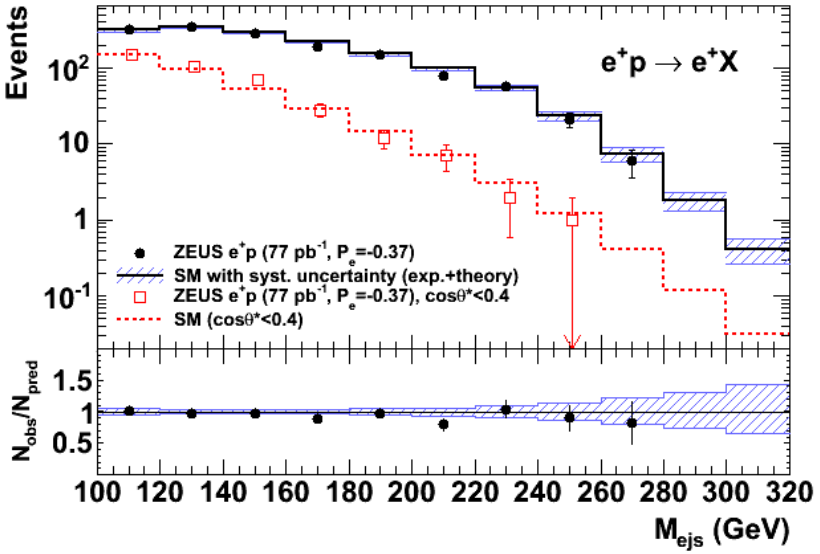
Neutral current DIS event

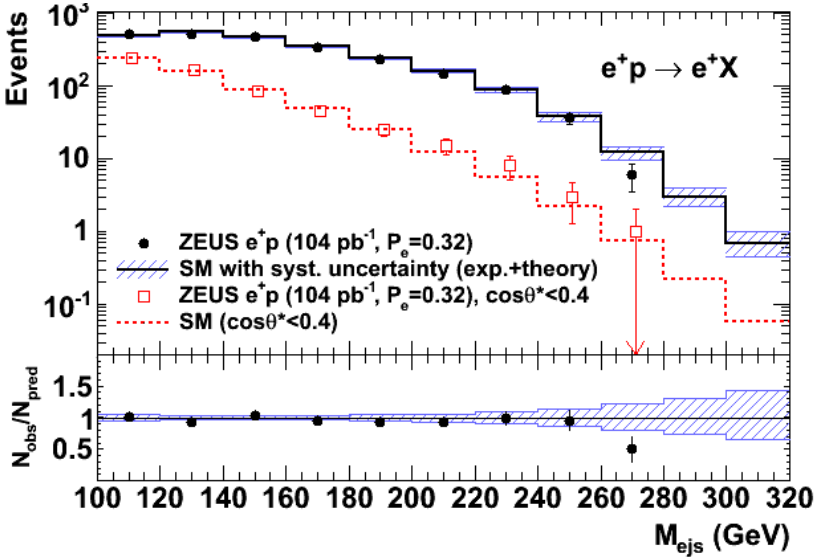
NC Invariant Mass Distributions

in red: with cut on $\cos\theta^* < 0.4$





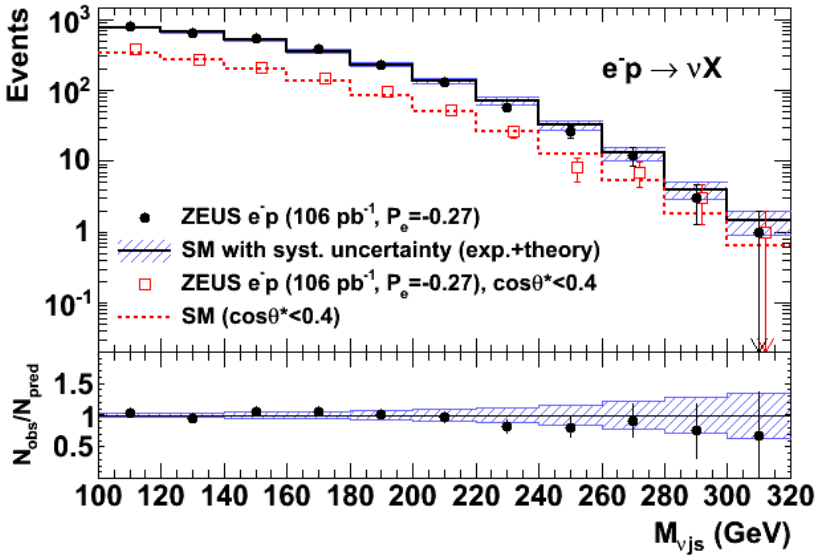


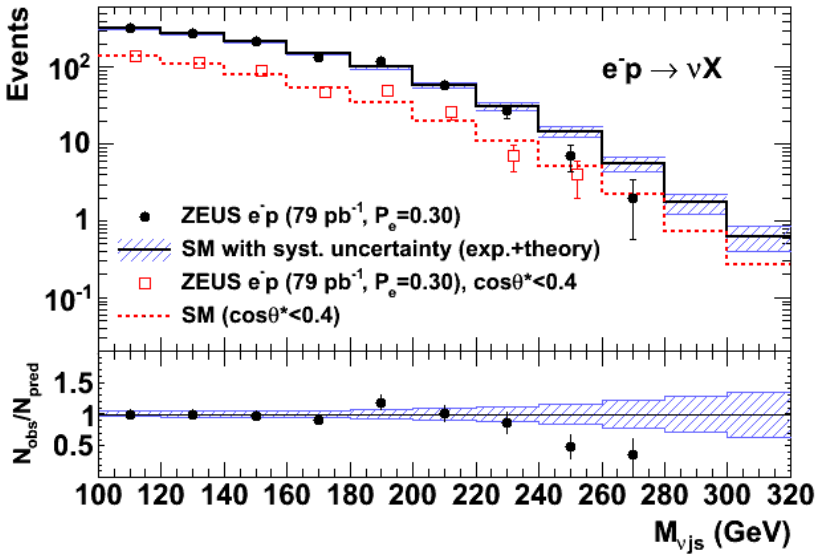


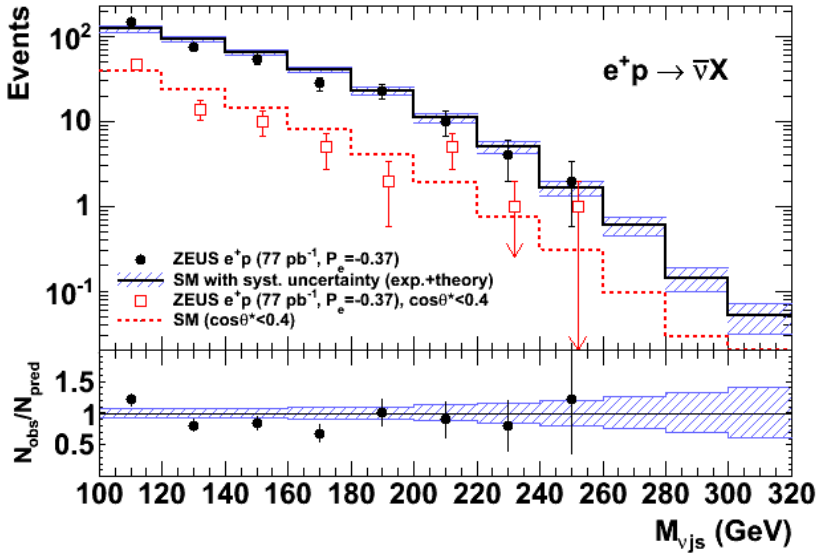
Good agreement between data and MC → no evidence for leptoquarks

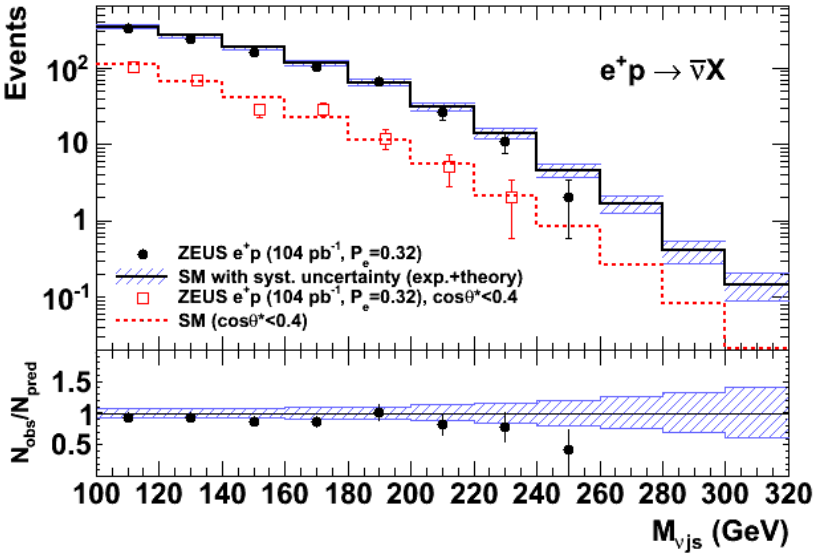
CC Invariant Mass Distributions

in red: with cut on $\cos\theta^* < 0.4$





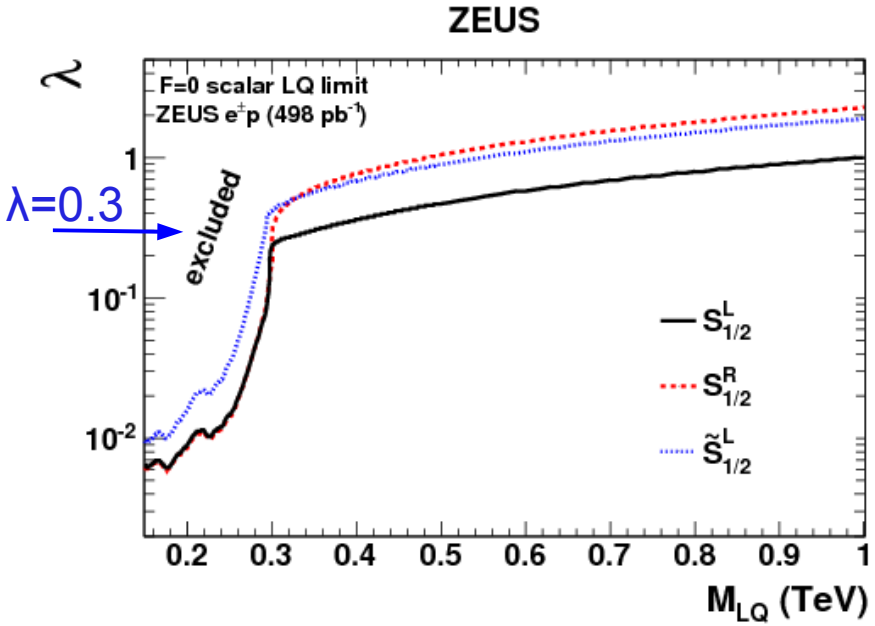


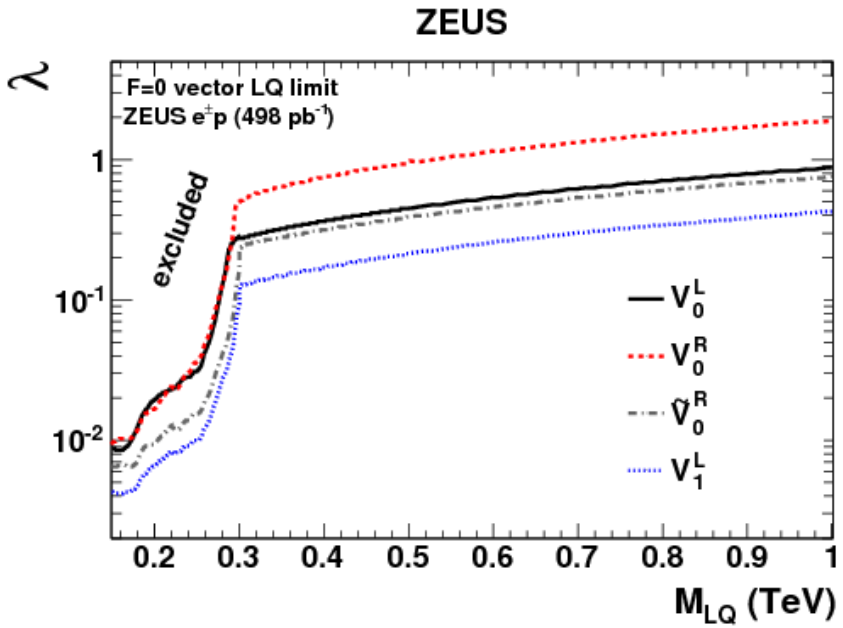


Good agreement between data and MC → no evidence for leptoquarks

Limits for Leptoquarks with *F=0*

- Limits are set on the Yukawa coupling λ (*e-q-LQ* coupling) using a Bayesian approach
- HERA-I data is included in the limit setting





Scalar LQs:

Lower limit on M_{LQ}

assuming $\lambda = \sqrt{4\pi\alpha} = 0.3$:

292 GeV $(\tilde{S}^L_{1/2})$ - 345 GeV $(S^L_{1/2})$

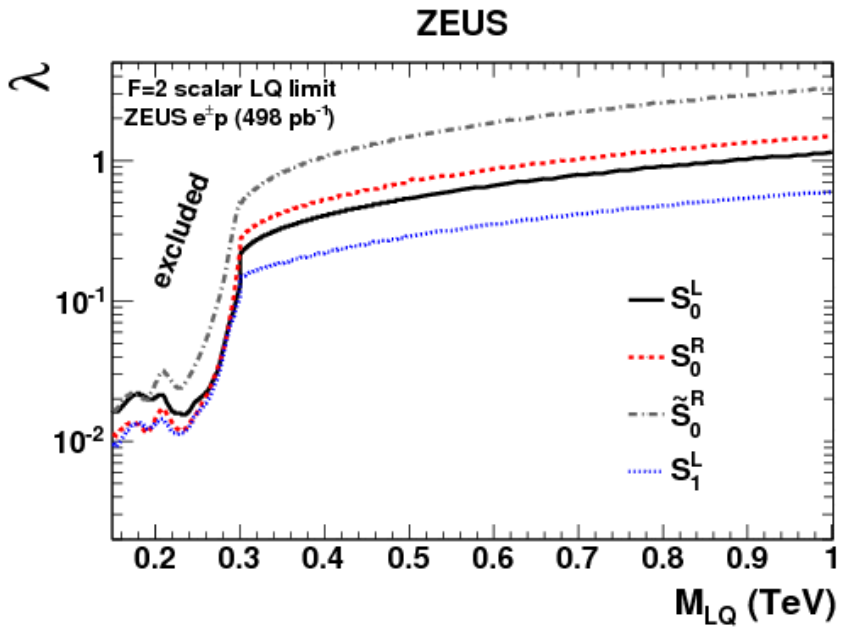
Vector LQs:

Lower limit on M_{LQ}

assuming λ=0.3:

292 - 699 GeV

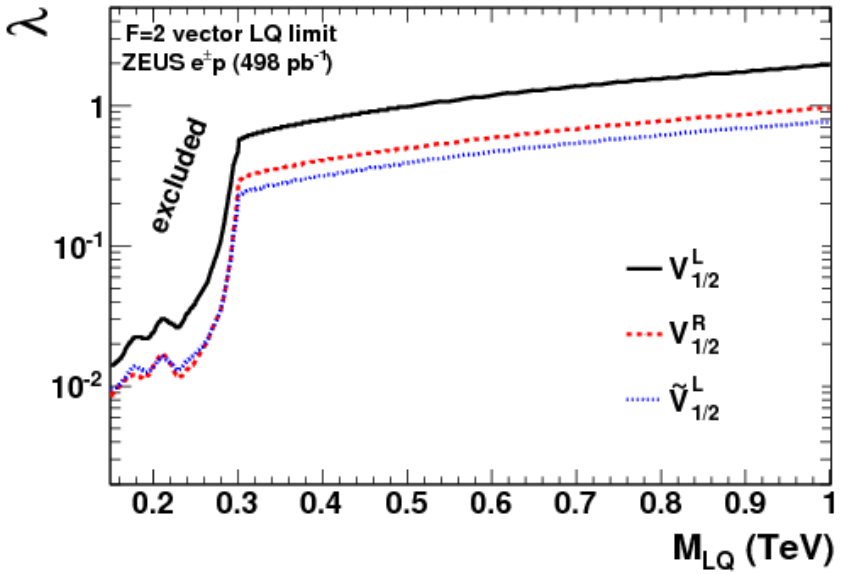
Limits for Leptoquarks with *F=2*



Scalar LQs:

Lower limit on M_{LQ} assuming λ=0.3:

290 - 506 GeV

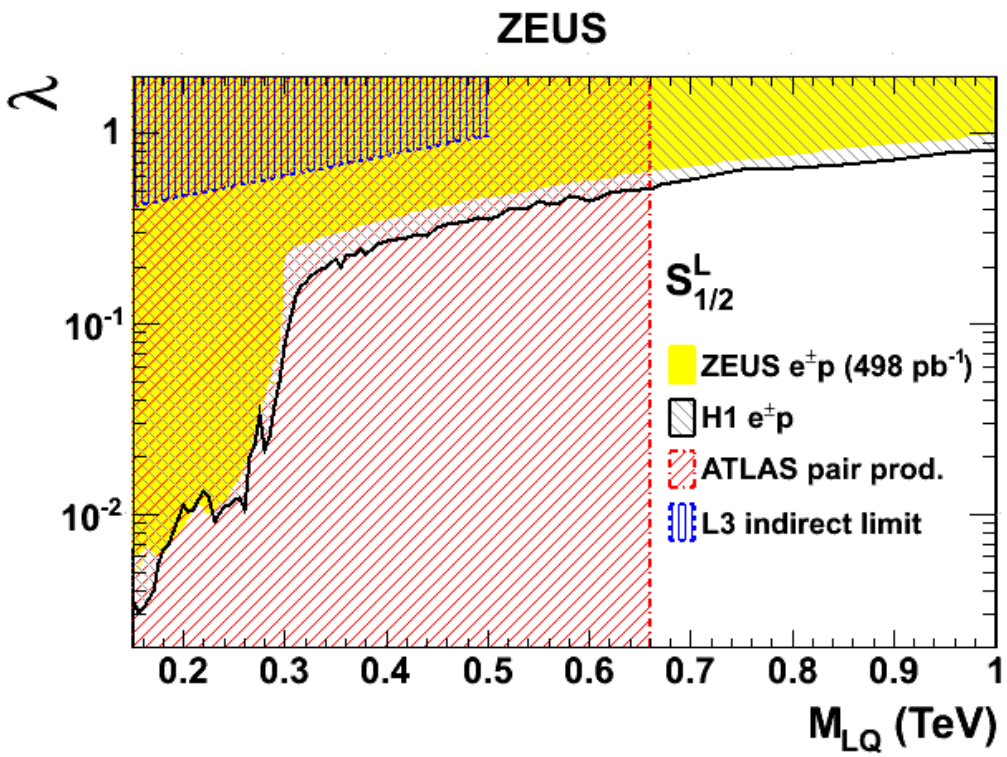


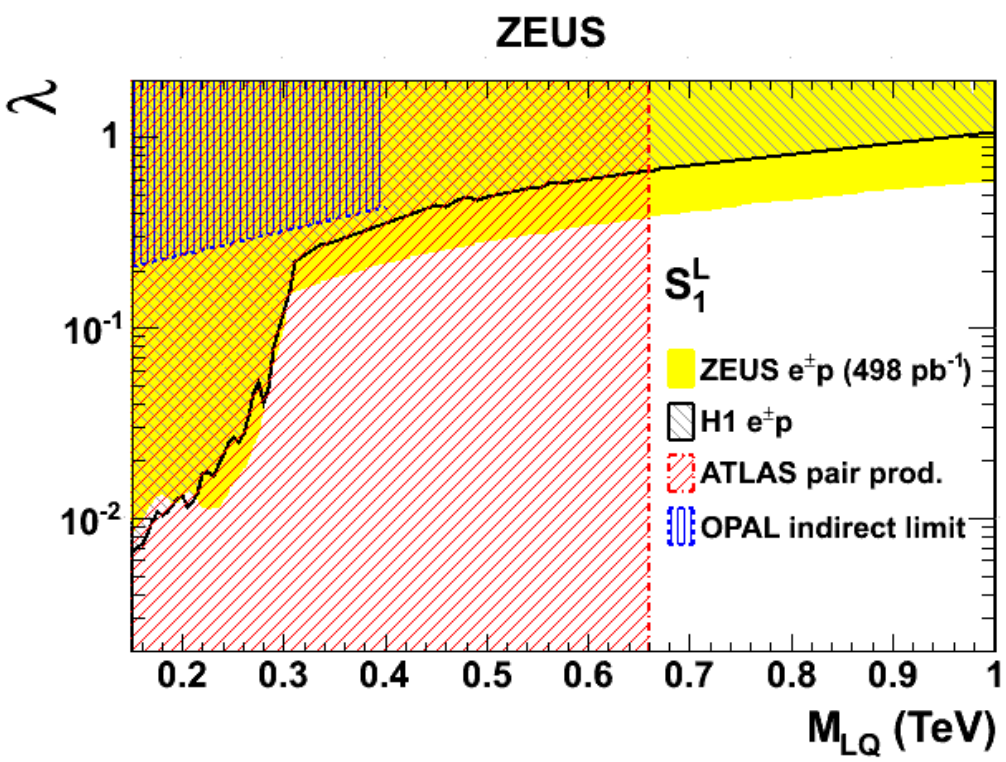
Vector LQs:

Lower limit on M_{LQ} assuming λ=0.3:

292 - 376 GeV

Comparison with Other Experiments

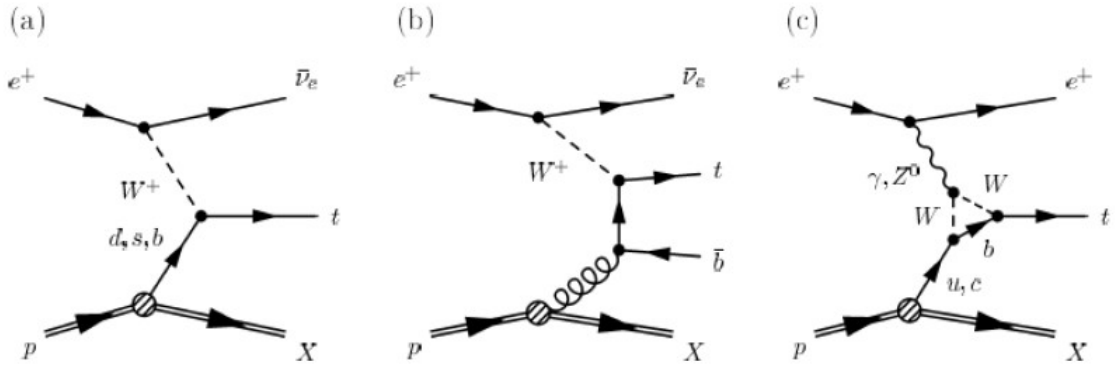




- ATLAS: leptoquark pair production → mass limits independent of λ
- L3/OPAL: indirect *t/u*-channel effects in $e^+e^- \rightarrow q\bar{q}$ → limits on λ as a function of the LQ mass
- HERA limits are the best to date at high masses

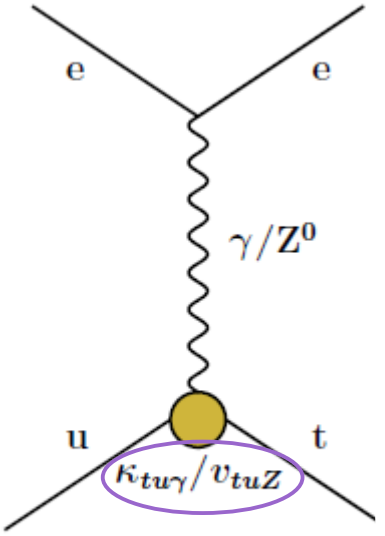
Single Top Production at HERA

- Top quarks at HERA can only be singly produced
- Production in the SM:



- Strongly suppressed by the GIM mechanism, σ < 1 fb
- Single top production at HERA via FCNC predicted by several BSM theories → observation would be clear indication of new physics
- FCNC transision induced by coupling *tuV* parametrised as:

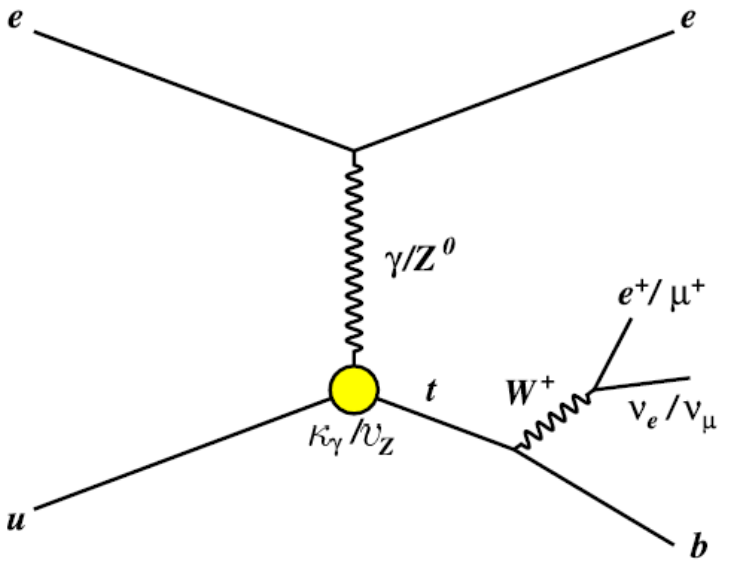
$$\Delta\mathcal{L}_{\text{eff}} = e\, e_t\, \bar{t}\frac{i\sigma_{\mu\nu}p^\nu}{\Lambda}\kappa_\gamma\, u\, A^\mu + \frac{g}{2\cos\theta_W}\,\bar{t}\gamma_\mu\, v_Z\, uZ^\mu + \text{h.c.}$$



- At HERA, most sensitive to coupling $\kappa_{tu\gamma}$

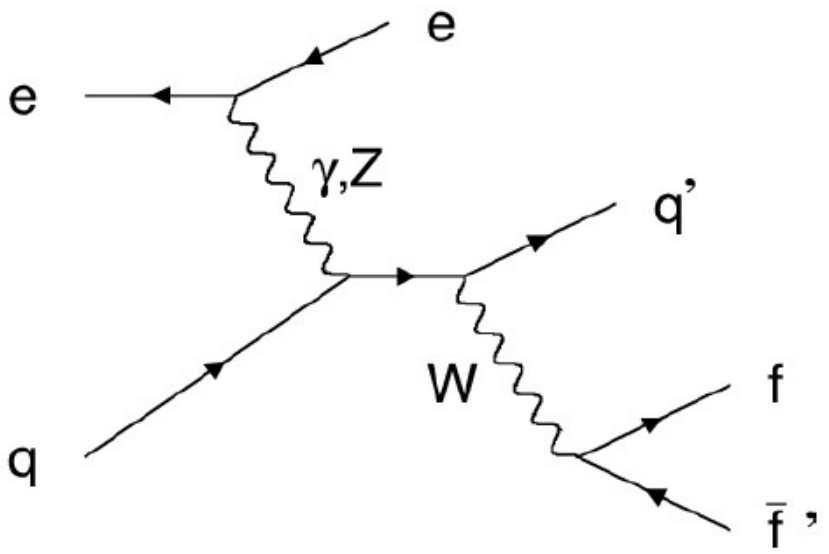
Event Topology

- Single top production was searched for in two channels:
  - muon channel: $t \rightarrow b\mu\nu_\mu$
  - electron channel: $t \rightarrow be\nu_e$
- Event topology:
  - 1 isolated lepton with high p_T
  - Large missing p_T
  - High hadronic transverse momentum $p_{T,had}$



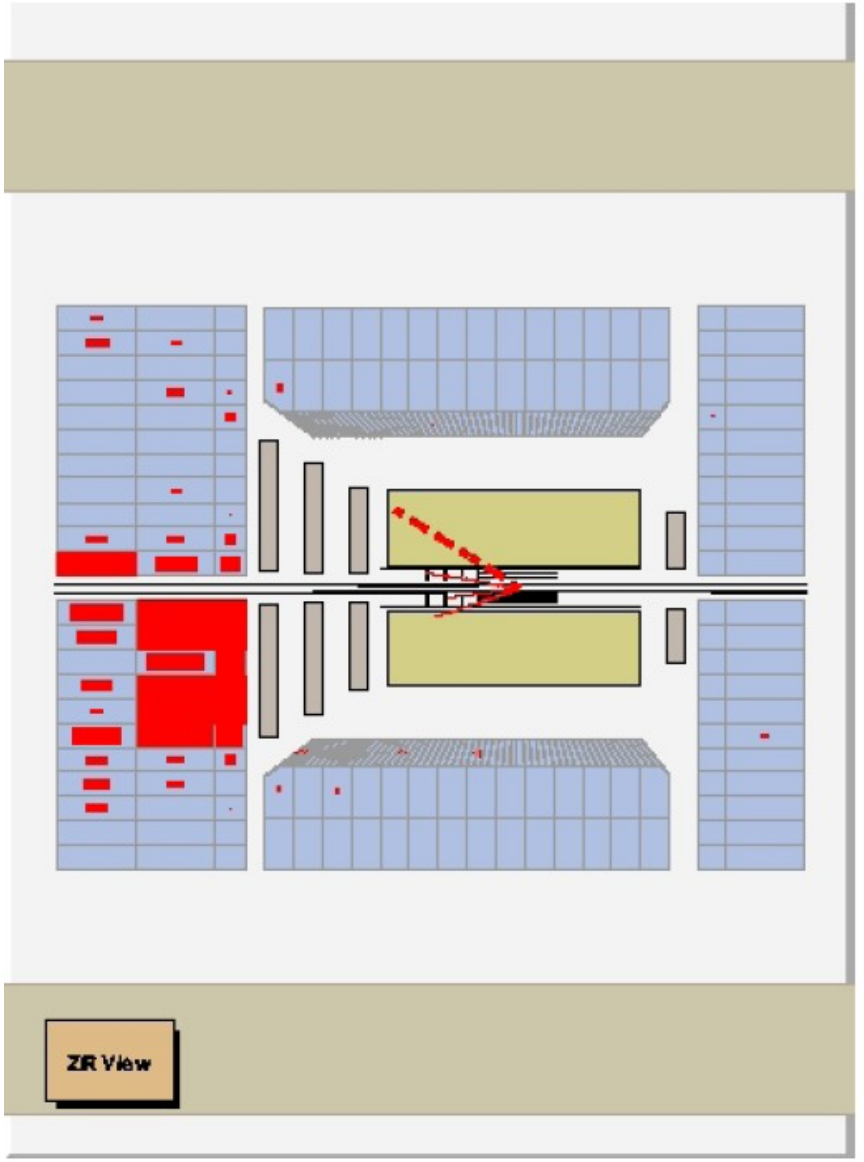
High-p_T isolated lepton events

- In the SM, events with high-p_T isolated leptons and large missing p_T are mainly due to single W production (σ~1 pb)
- In contrast to single top production, this process has low $p_{T,had}$ → $p_{T,had}$ can be used to discriminate the two processes
- Sources of background:
  - Dimuon production (muon channel)
  - NC DIS (electron channel)
  - CC DIS
  - Photoproduction
  - Cosmic background (muon channel)



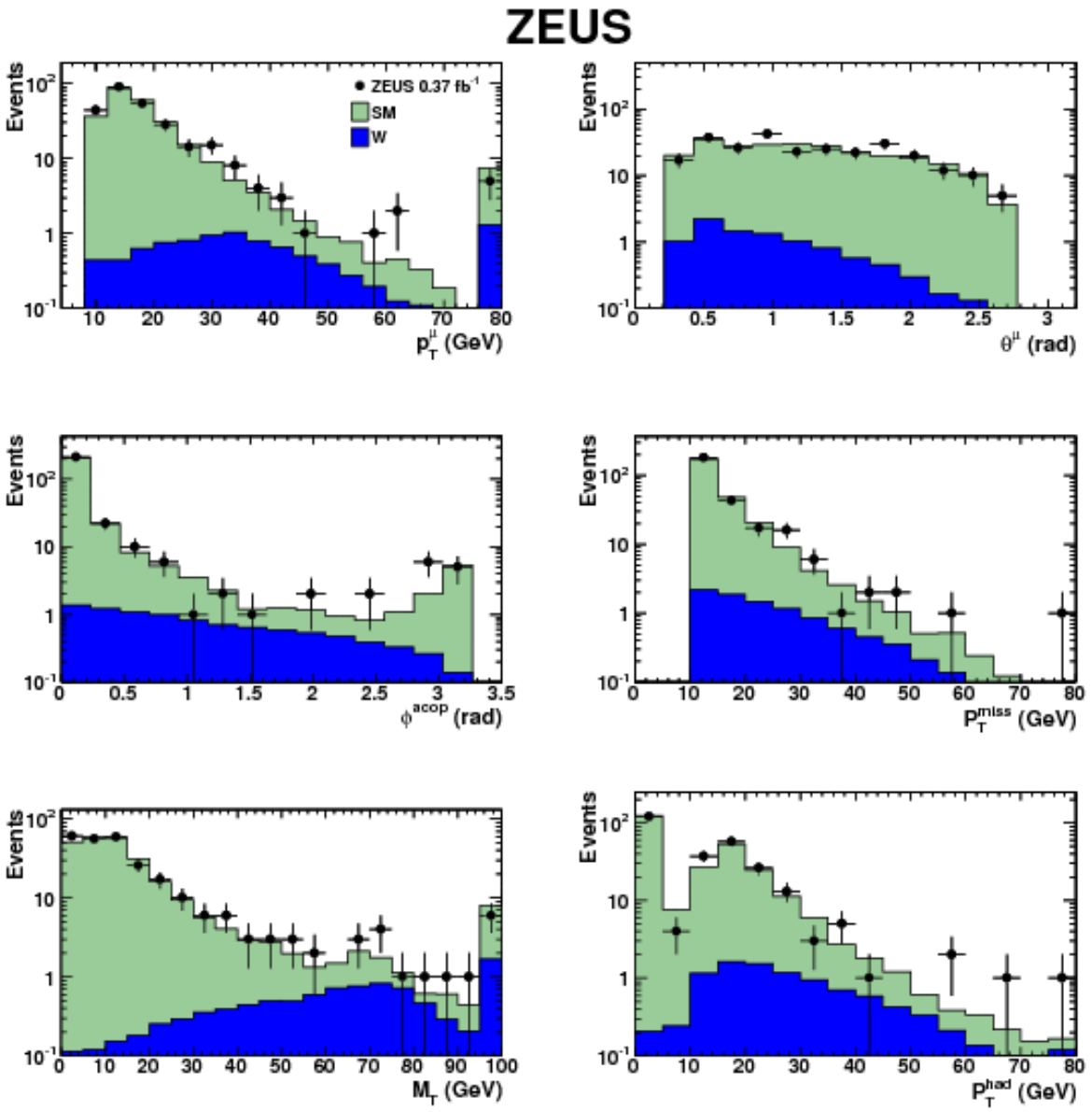
Event Selection

- All HERA-II data (0.37 pb^{-1}) were analysed
- Muon channel:
  - $|Z_{vtx}| < 30$ cm
  - $E\text{-}P_z > 10$ GeV
  - $P_{T,miss} > 10$ GeV
  - ≥1 muon candidate with an isolated track coming from the primary vertex, $p_T > 8$ GeV
- Electron channel:
  - $|Z_{vtx}| < 30$ cm
  - $5 < E\text{-}P_z < 50$ GeV
  - $P_{T,miss} > 12$ GeV
  - ≥1 electron candidate with an isolated track coming from the primary vertex, $p_T > 10$ GeV
  - $0.1 <$ acoplanarity $< (\pi\text{-}0.1)$ rad



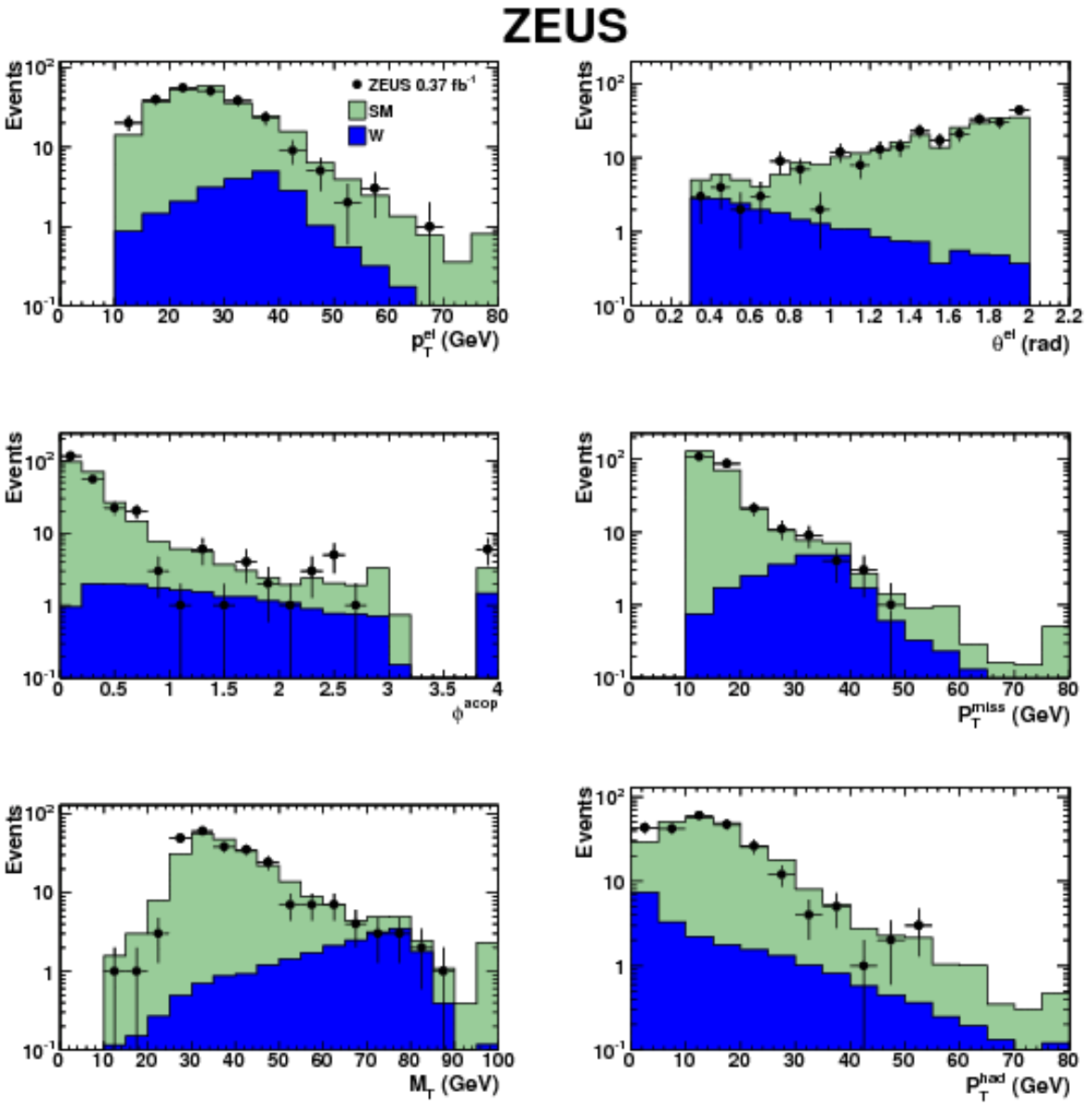
Selected event in the muon channel

Muon Channel



- Good agreement between data and MC
- 269 events selected, 260±3 are expected
- Dominated by dimuon production

Electron Channel

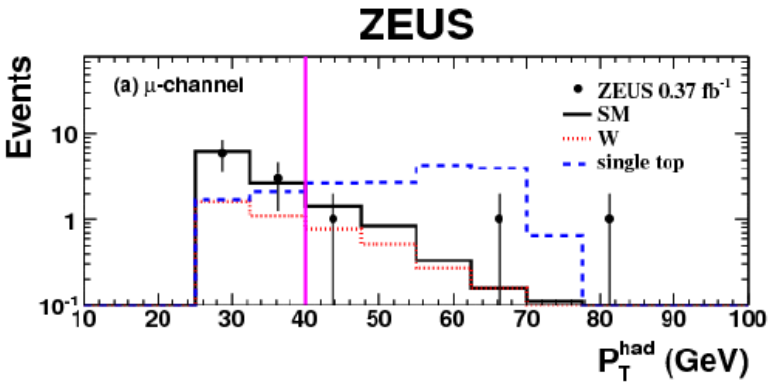


- Good agreement between data and MC
- 245 events selected, 253±6 are expected
- Dominated by NC DIS

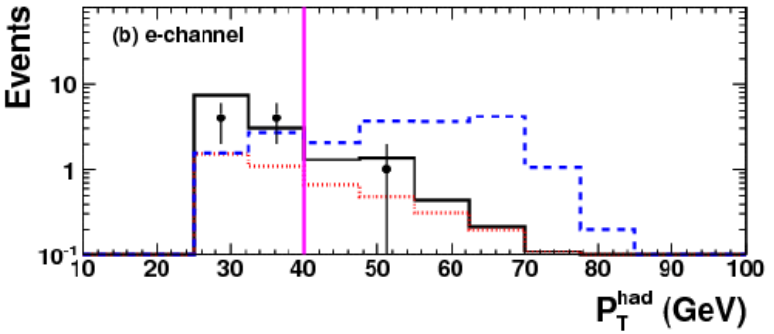
Selection of Single Top Candidates

- No excess above the SM is seen → further selection is made to maximise the sensitivity to a possible FCNC top signal:
- $p_{T,had}$ > 40 GeV for both channels

- Muon channel:
  - Acoplanarity > 0.05 rad
  - Events with more than one isolated muon are rejected



- Electron channel:
  - Acoplanarity > 0.15 rad
  - $p_{T,miss}$ > 15 GeV



- Good agreement between data and MC
- No discrepancy at high $p_{T,had}$

Limit Setting (I)

- Single top selection:

	N^{obs}	N^{pred}	W[%]
electron channel e^+p	0	1.7±0.4	53 ± 11
muon channel e^+p	1	1.5±0.2	64 ± 9
electron channel e^-p	1	1.9±0.4	51 ± 11
muon channel e^-p	2	1.5±0.3	63 ± 9
electron channel ep	1	3.6±0.6	52 ± 9
muon channel ep	3	3.0±0.4	64 ± 7

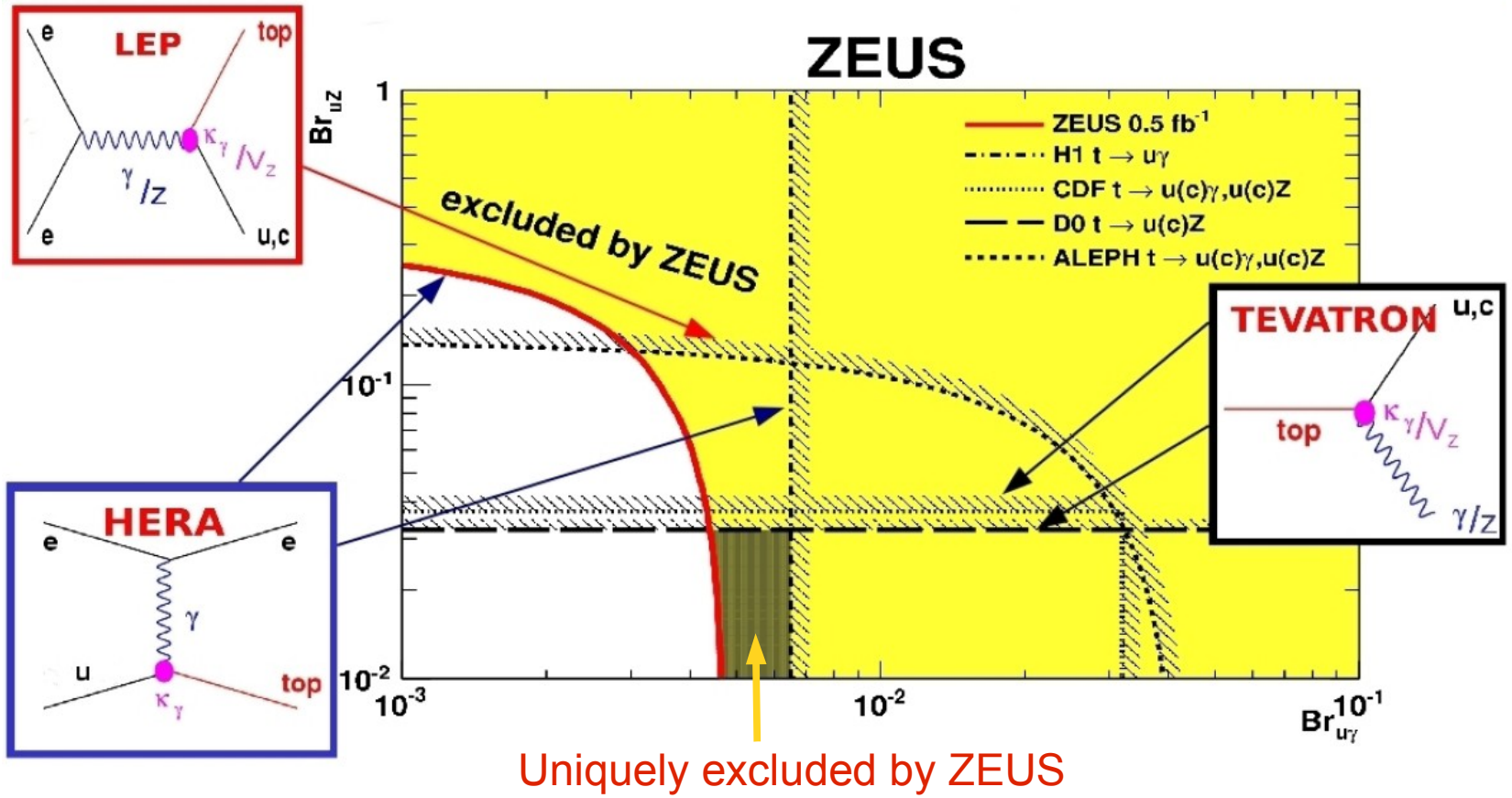
- No excess above SM → set limits on the *tuV* couplings
- HERA-I data is included in the limit setting
- First step: limit set on signal cross section and κ_γ assuming v_z=0
- Bayesian approach used assuming constant prior on σ

→ σ < 0.13 pb (95% CL) at $\sqrt{s}$=315 GeV

- Converts to limit on coupling: κ_γ < 0.12 (95% CL)

Limit Setting (II)

- Second step: assume $v_Z \neq 0$ and set limits in (BR($t \to u\gamma$), BR($t \to uZ$)) plane
- Same coupling was probed by LEP, Tevatron and H1



- In the region where BR($t \to uZ$) < 4%, the ZEUS limits are the best to date

Summary

- Recent searches for new physics at ZEUS have been presented
- No signs of new physics were observed
- Limits set on 1st generation leptoquarks and anomalous single top production
- ZEUS results are competitive and complementary to other experiments

Backup

Leptoquarks in Aachen Notation

Model	Fermion number F	Charge Q	$BR(LQ \to e^{\pm}q)$ β	Coupling		Squark type
S_0^L	2	$-1/3$	1/2	$e_L u$	νd	$\tilde{d}_R$
S_0^R	2	$-1/3$	1	$e_R u$		
$\tilde{S}_0$	2	$-4/3$	1	$e_R d$		
$S_{1/2}^L$	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	0		$\nu \bar{u}$	
$S_{1/2}^R$	0	$-5/3$	1	$e_R \bar{u}$		
		$-2/3$	1	$e_R \bar{d}$		
$\tilde{S}_{1/2}$	0	$-2/3$	1	$e_L \bar{d}$		$\overline{\tilde{u}_L}$
		$+1/3$	0		$\nu \bar{d}$	$\overline{\tilde{d}_L}$
S_1	2	$-4/3$	1	$e_L d$		
		$-1/3$	1/2	$e_L u$	νd	
		$+2/3$	0		νu	
V_0^L	0	$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
V_0^R	0	$-2/3$	1	$e_R \bar{d}$		
$\tilde{V}_0$	0	$-5/3$	1	$e_R \bar{u}$		
$V_{1/2}^L$	2	$-4/3$	1	$e_L d$		
		$-1/3$	0		νd	
$V_{1/2}^R$	2	$-4/3$	1	$e_R d$		
		$-1/3$	1	$e_R u$		
$\tilde{V}_{1/2}$	2	$-1/3$	1	$e_L u$		
		$+2/3$	0		νu	
V_1	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
		$+1/3$	0		$\nu \bar{d}$	