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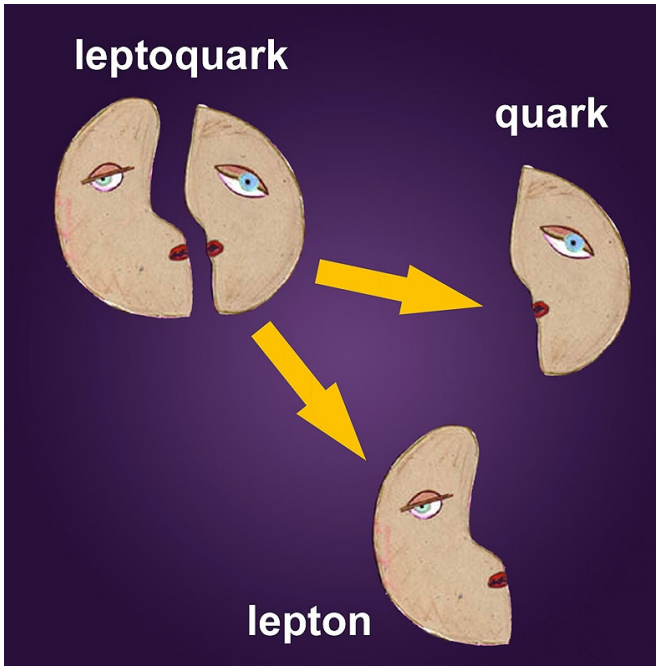
A search for resonance decays to lepton+jet at HERA and limits on leptoquarks

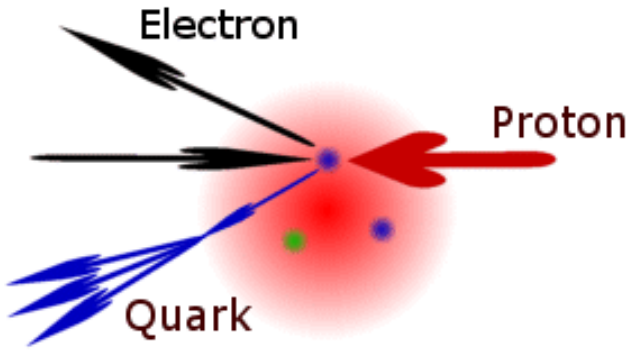
DESY-12-077

Katarzyna Wichmann on behalf of the ZEUS Collaboration

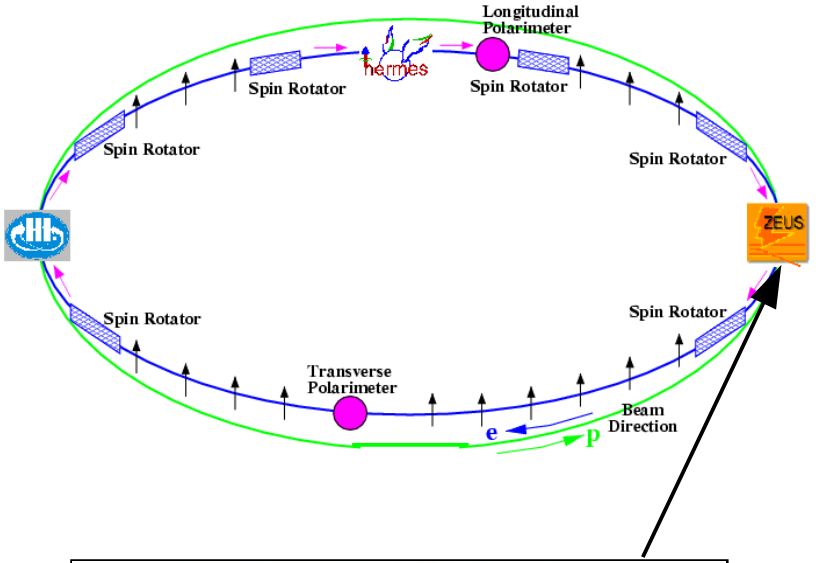
- HERA Accelerator & ZEUS Detector
- Search for leptoquarks at HERA
- Limits on leptoquarks
- Single top production: appetizer

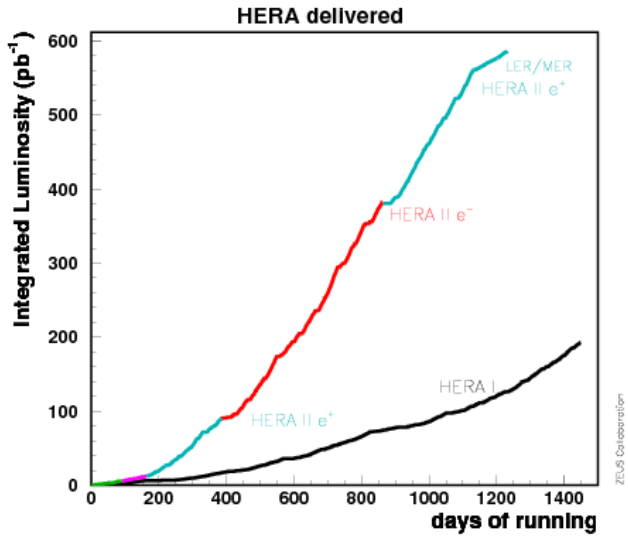


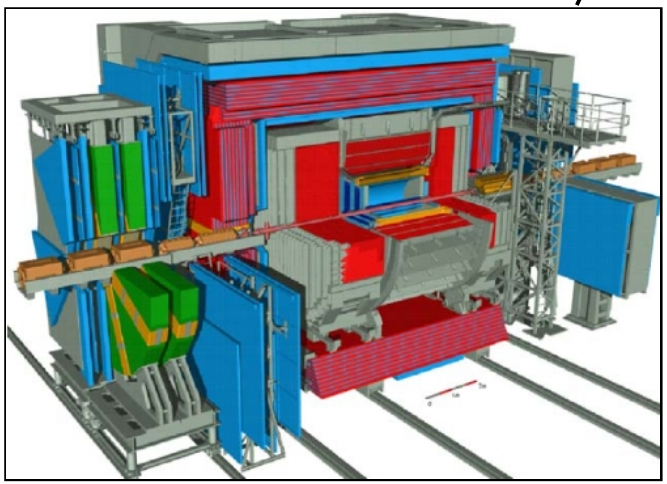
HERA Accelerator



- HERA: ep collider, $\sqrt{s}$ = 320 GeV
- From 2003 polarised lepton beam
- 2 colliding beams experiments: H1 & ZEUS
  - **collected 0.5 pb^{-1}/exp of luminosity in 1992-2007**

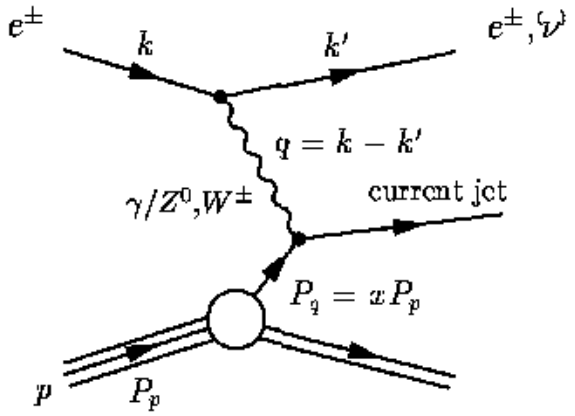






ZEUS: multi-purpose detector at HERA

Deep Inelastic Scattering



4-momentum transfer
$Q^2 = -q^2 = -(k - k')^2$

parton momentum fraction
$x = Q^2/(2p \cdot q)$

inelasticity
$y = p \cdot q/(p \cdot k)$

center of mass (cms) energy $\sqrt{s}$:
$s = (k + p)^2$

at fixed cms energy: $y = Q^2/xs$

neutral current (NC):
γ, Z^0 exchange

charged current (CC):
$W^{\pm}$ exchange

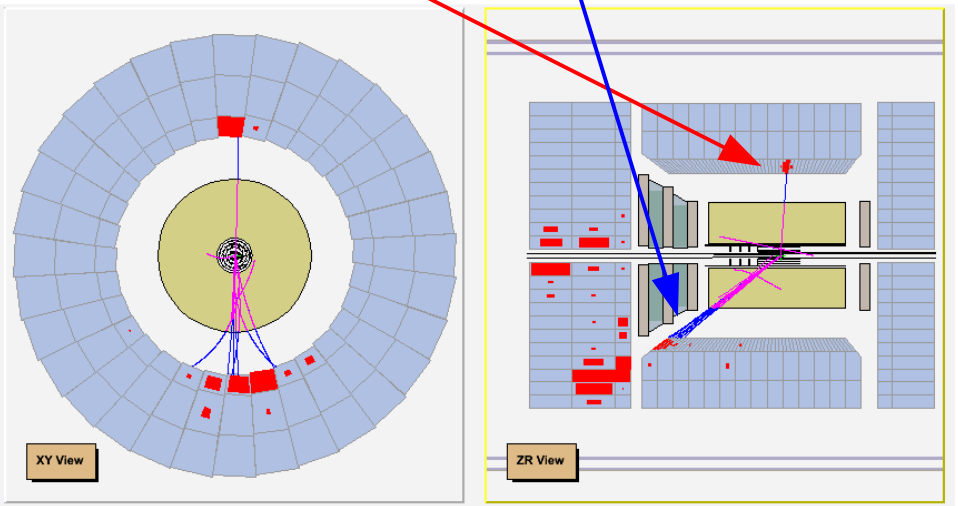
lepton vertex: pointlike particle,
determined by electroweak Standard Model (SM)

proton vertex: object with structure

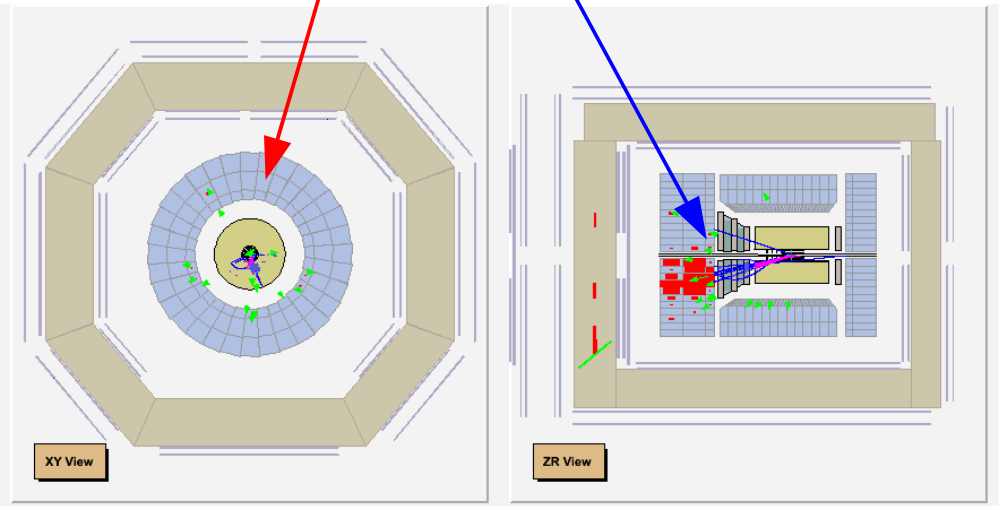
quark-parton-modell (QPM):
elastic scattering on pointlike parton (quark);
quark momentum distribution $xq(x)$ inside proton

Physics in ZEUS Detector

NC: electron + jet



CC: missing p_T + jet

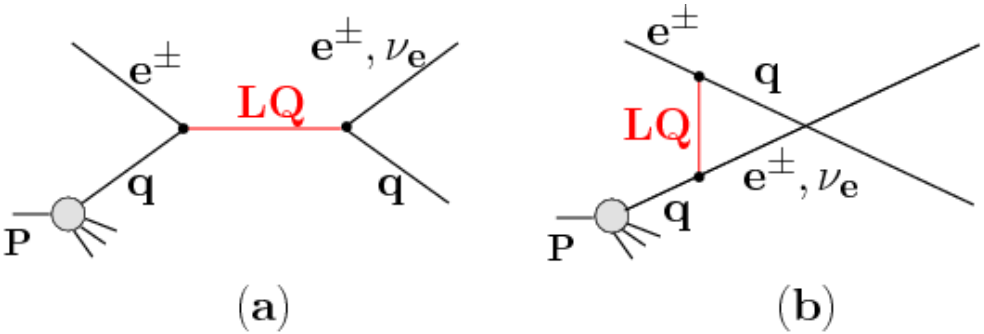


Leptoquarks @ HERA

- Leptoquarks - scalar or vector colour triplet bosons, carrying both lepton (L) and baryon (B) number
  - HERA is well suited for leptoquark searches
  - Fermion number: F=L+3B, (F=0,2)
  - spin: 0, 1

(a) @ HERA leptoquarks can be produced in s-channel for $M_{LQ} < \sqrt{s}$

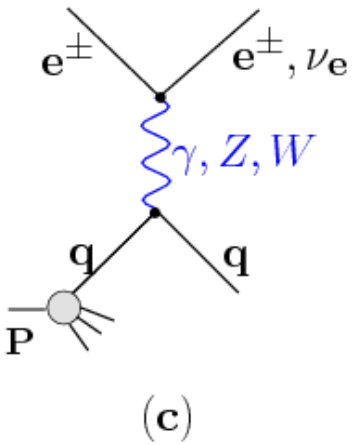
(b) ...or exchanged in u-channel



(c) LQs @ HERA have the same initial and final state as NC/CC DIS

- e-jet or υ-jet in the final state

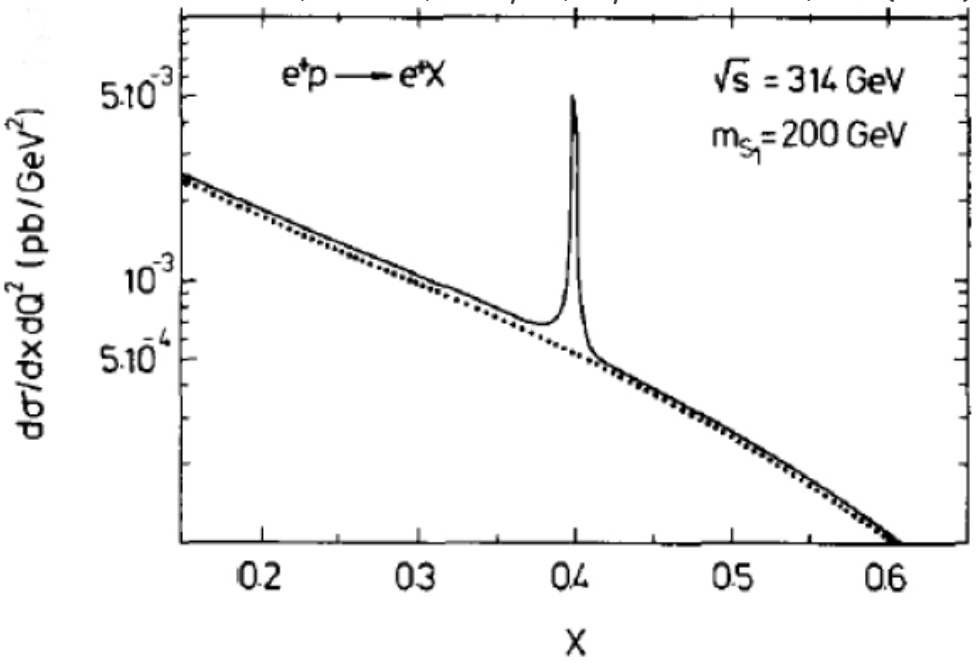
  → interfere with the SM



Search Strategy @ HERA

- Leptoquark events: the same signature as NC or CC events
- LQ contribution in SM: 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)

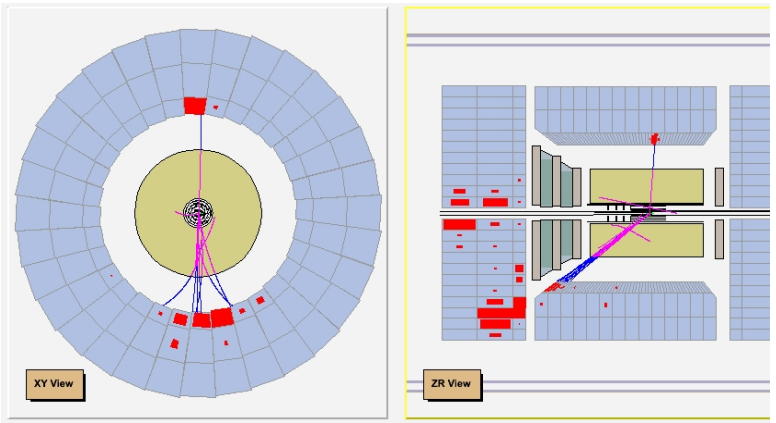


- Lepton scattering angle θ^* in the lepton-jets scattering frame can be used to reduce DIS background
  - leptoquarks have different distributions than NC DIS

Look for LQ-deviations from SM in NC & CC distributions

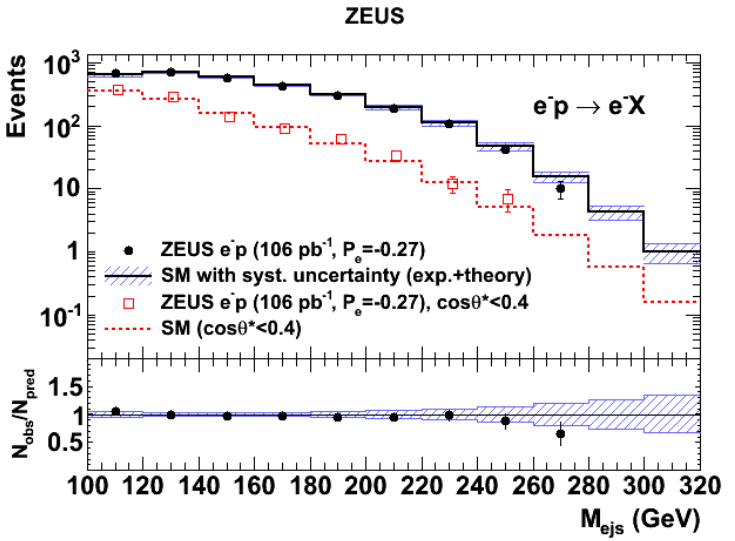
Leptoquarks in ZEUS Detector

Integrated luminosity of 366 pb^{-1} (2003-2007)

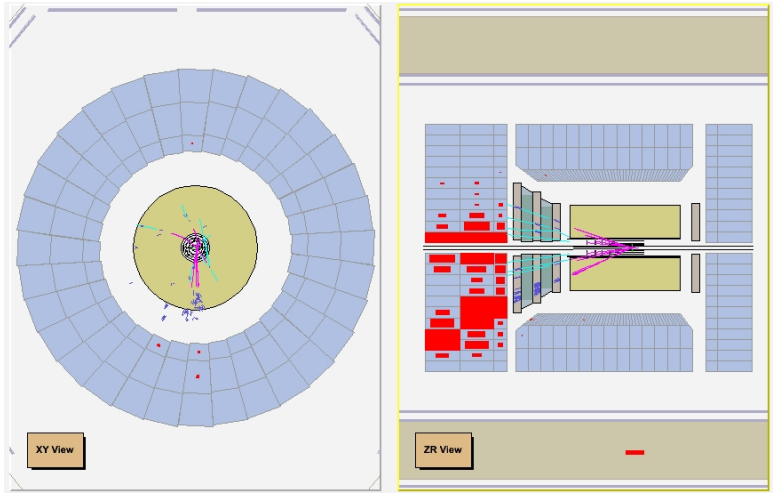


$M_{e\text{-}jet}$

e+jet final state

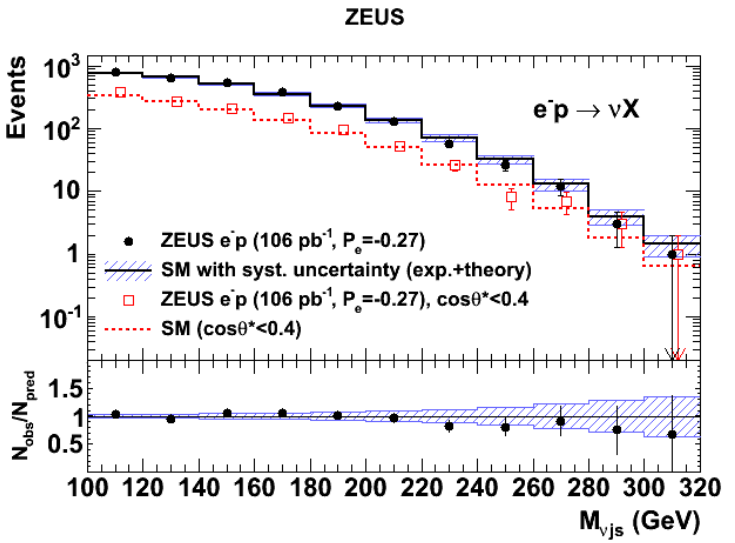


M_{ejs} (GeV)



$M_{\upsilon\text{-}jet}$

υ+jet final state



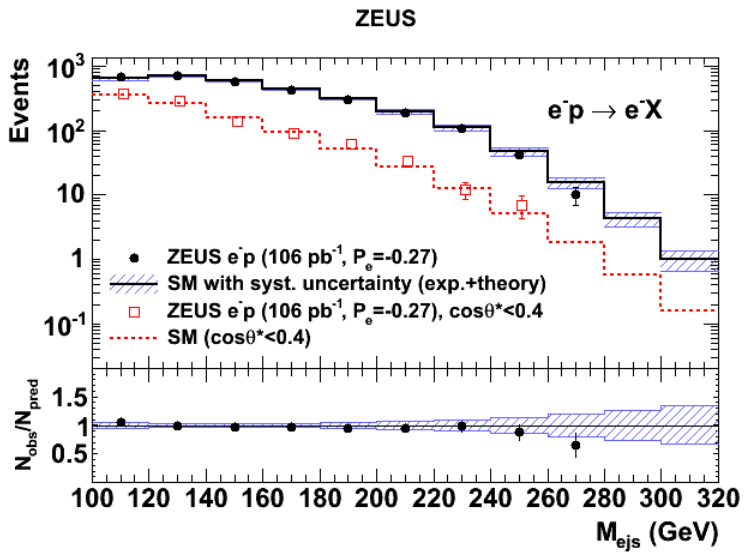
$M_{\upsilon js}$ (GeV)

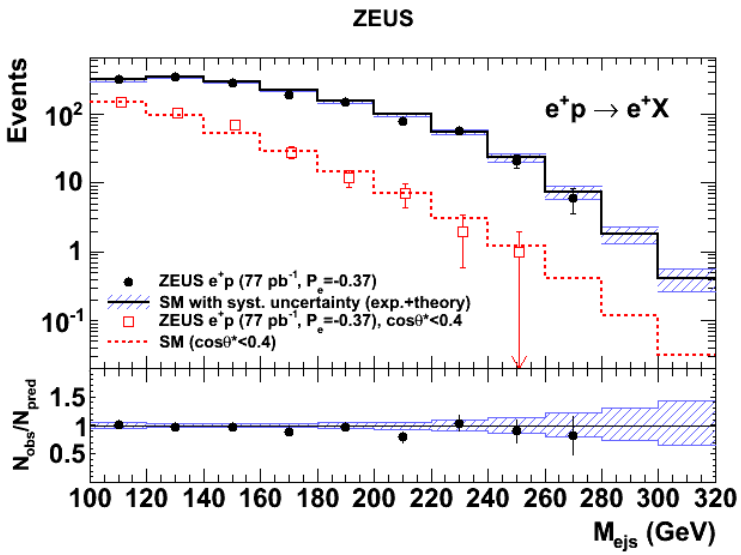
NC Invariant Mass Distribution

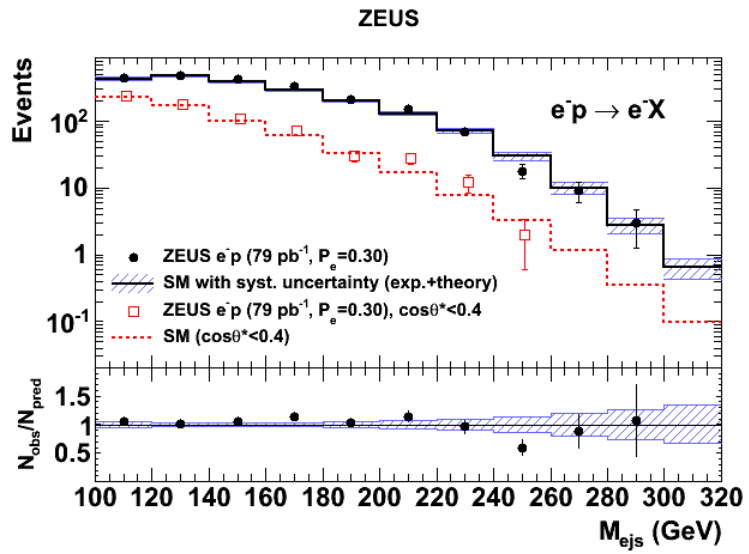
in red: with cut on $\cos\theta^* < 0.4$

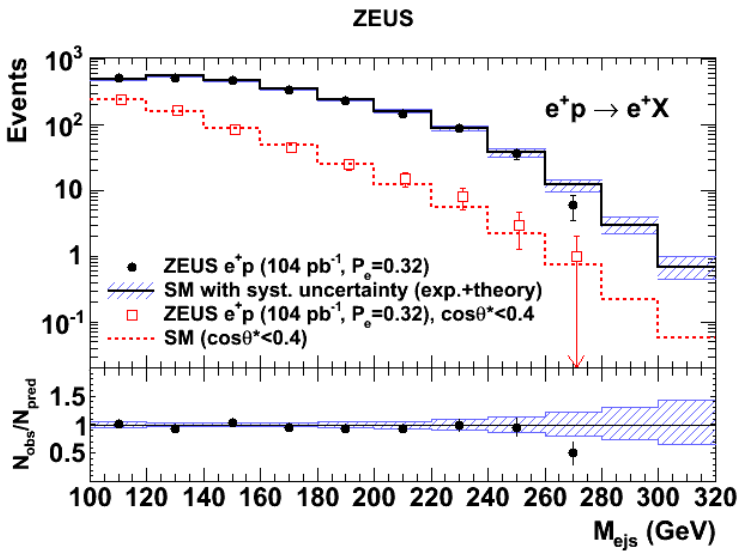
left-handed lepton

right-handed lepton









electrons M_{ejs} (GeV) **positrons** M_{ejs} (GeV)

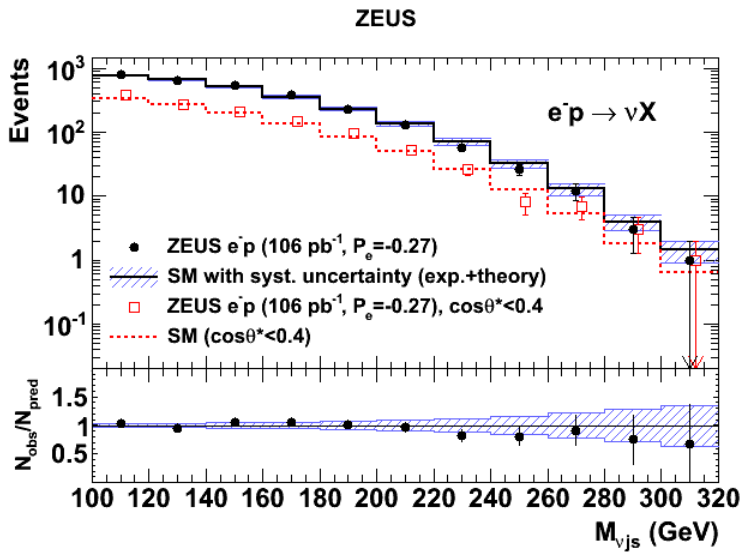
Good agreement between data and MC → no evidence for LQs

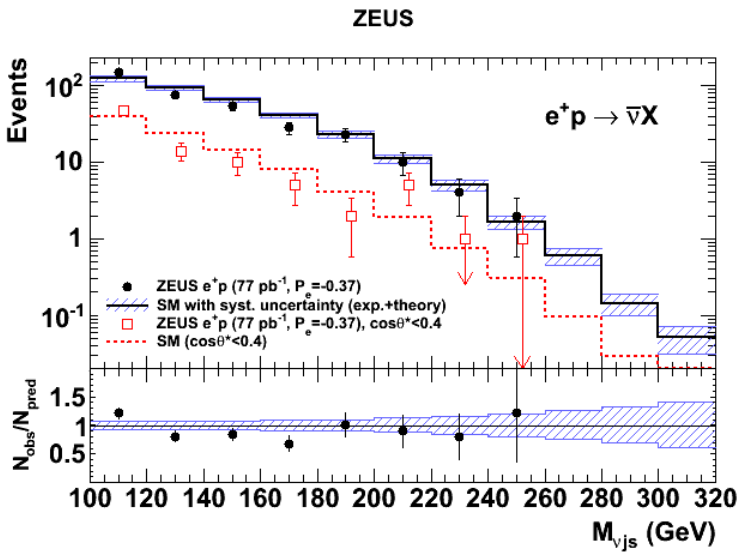
CC Invariant Mass Distribution

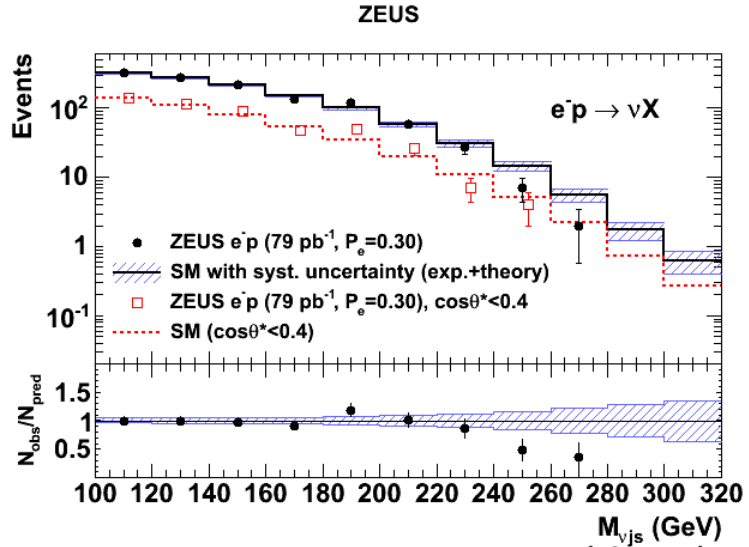
in red: with cut on cosθ* < 0.4

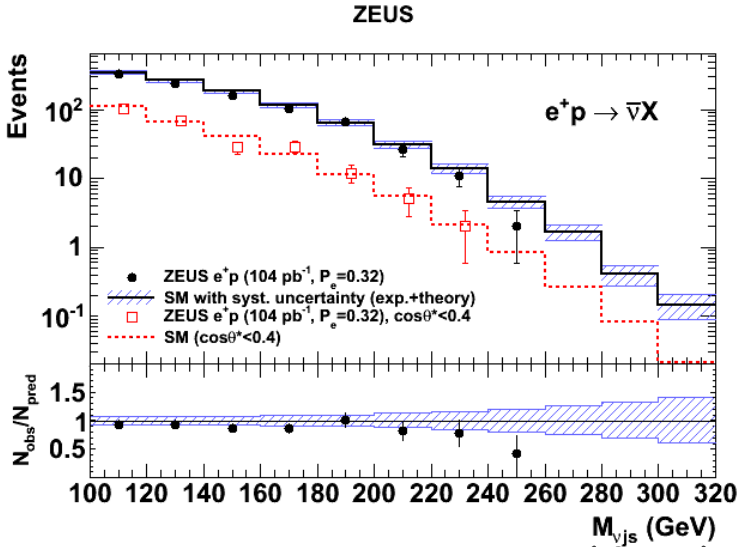
left-handed lepton

right-handed lepton









electrons M_{ejs} (GeV)

positrons M_{ejs} (GeV)

Good agreement between data and MC → no evidence for LQs

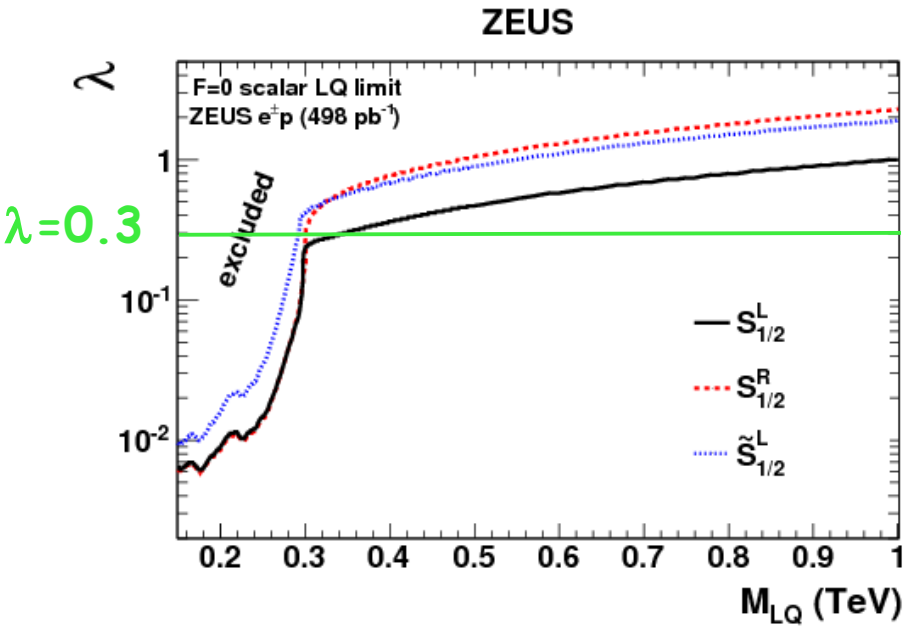
Leptoquark Limits

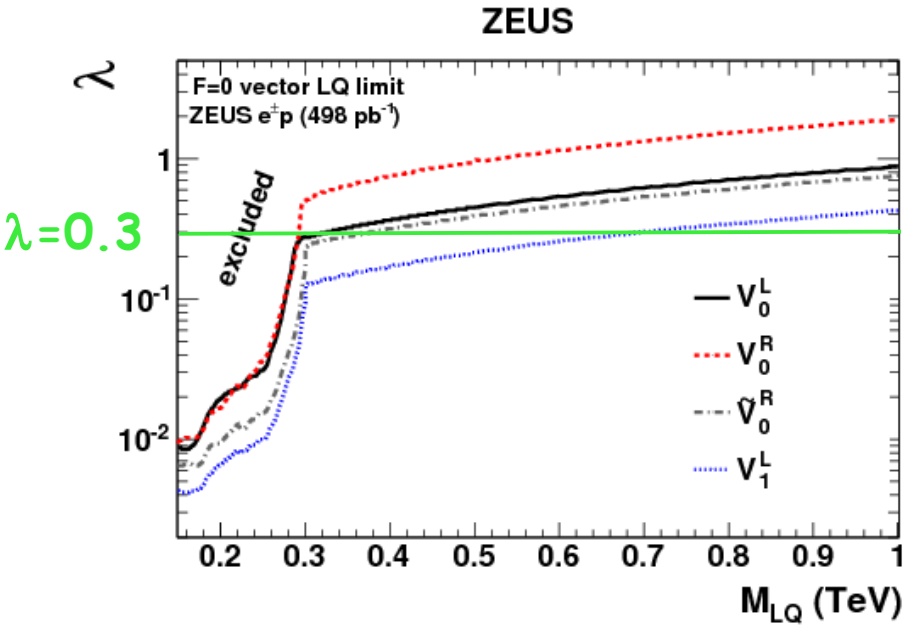
- **No evidence for LQs observed → limits set** within BRW model
- The Buchmüller-Rückl-Wyler model:
  - Standard Model symmetry conserved
  - Lepton and baryon number conserved
  - LQ resonance production
  - LQs couple either to right-handed or to left-handed leptons
  - No flavour-violating couplings

    → 7 scalar and 7 vector 1st generation leptoquarks
  - All 14 LQs couple to eq, 2 scalar and 2 vector LQs also to νq
- Limits are set on Yukawa coupling λ (e-q-LQ coupling) using Bayesian approach

Full HERA statistics of 0.5 fb^{-1} used for limit setting

Limits for Leptoquarks with F=0





Scalar LQs:

- Lower limit on M_{LQ} assuming $\lambda = 0.3$

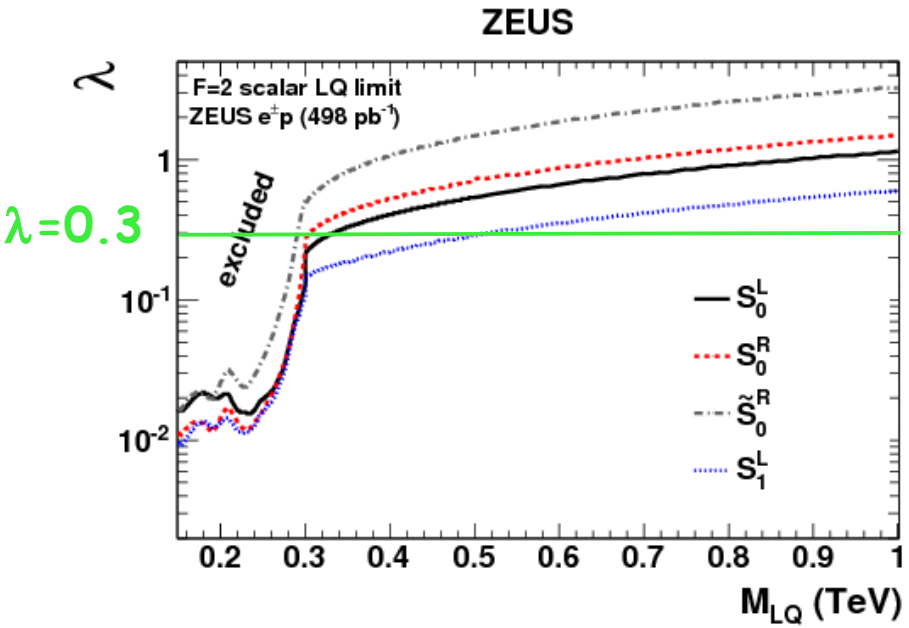
  292 GeV - 345 GeV

Vector LQs:

- Lower limit on M_{LQ} assuming $\lambda = 0.3$

  292 GeV - 699 GeV

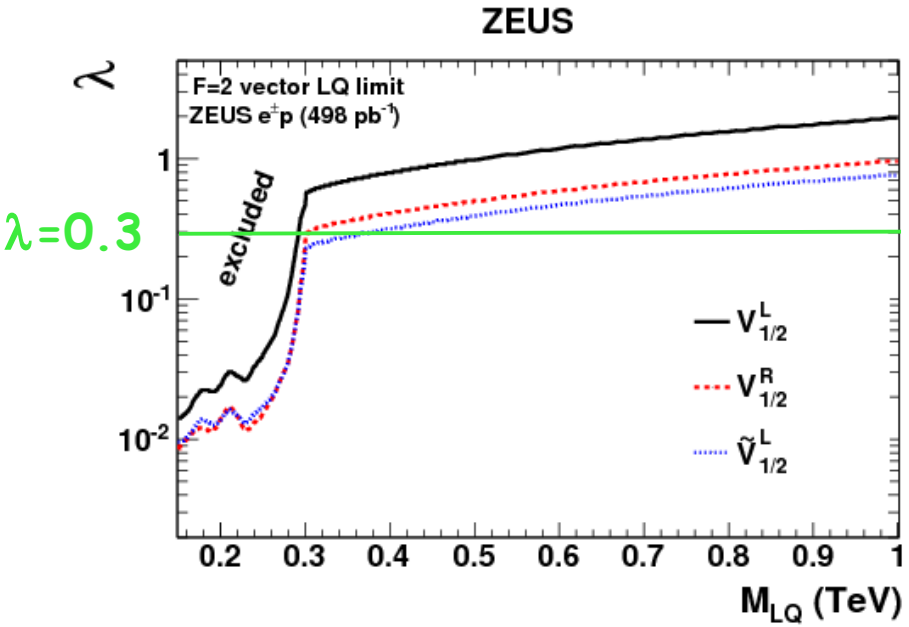
Limits for Leptoquarks with F=2



Scalar LQs:

- Lower limit on M_{LQ} assuming $\lambda = 0.3$

  290 GeV - 506 GeV



Vector LQs:

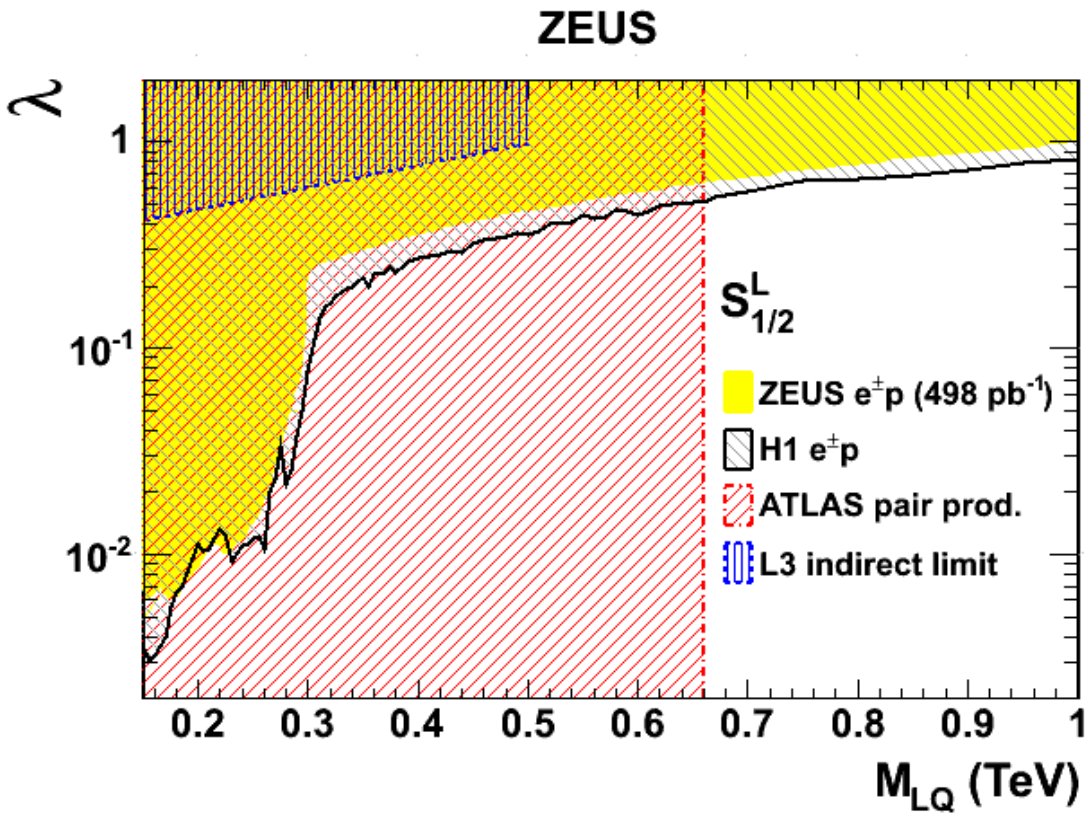
- Lower limit on M_{LQ} assuming $\lambda = 0.3$

  292 GeV - 376 GeV

Summary

- New results using full HERA luminosity of 0.5 fb^{-1} on LQs: DESY-12-077
- No evidence of leptoquarks observed

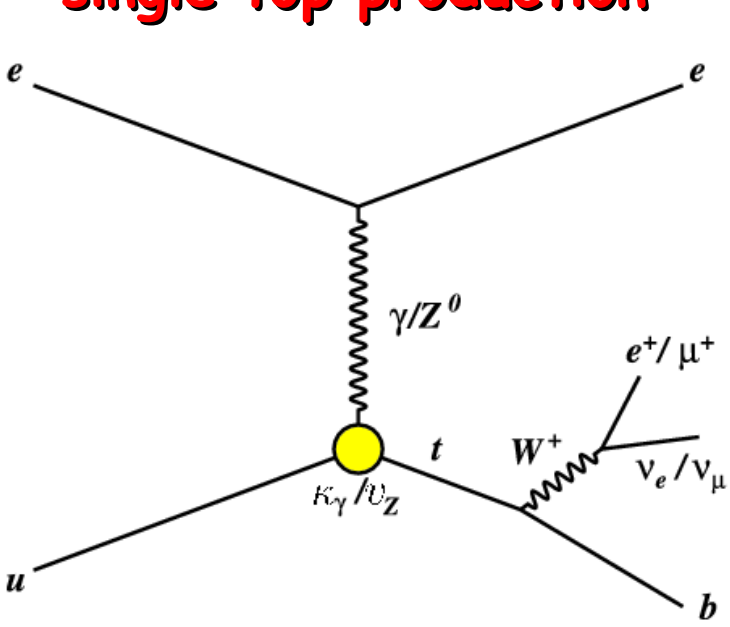
  → **Coupling limits set as function of LQ mass**
- Limits for some LQs similar to results from other experiments
- ZEUS results competitive and complementary to other experiments



HERA limits are the best to date at high masses

High-P_T Lepton and Missing E_T

- another example of similar topology:



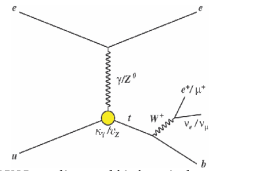
- no evidence of single top found
- limits set on anomalous single top production

Search for single top production in *ep* collisions at HERA

S. Antonelli (CNAF-INFN Bologna) on behalf of the ZEUS Collaboration

In *ep* (with *e* electron or positron) collisions at HERA, the production of single top quark is possible due to the large centre-of-mass energy $\sqrt{s}$ = 318 GeV. The dominant production process of single top quarks in the Standard Model (SM) is the charged current (CC) deep inelastic scattering (DIS) reaction $ep \to \nu tX$ [1], which has a cross section of less than 1 fb [2]. No sizeable production is hence expected in our data sample and any excess can be attributed to new physics. In several extensions of the SM, single top production can happen via a flavour changing neutral current (FCNC) process mediated by an effective coupling which allows a *u*-*t* or *c*-*t* transition via a neutral vector boson (γ or Z^0) [3]. The analysis has been performed with 0.37 fb^{-1} and extends the previously published ZEUS results [4] corresponding to 0.13 fb^{-1}. Limits for single top production via FCNC were computed combining this result with the previous ZEUS one [4], for a total luminosity of 0.50 fb^{-1}. The cross section upper limit at 95% Credibility Level (C.L.) was 0.13 pb at a centre-of-mass energy of $\sqrt{s}$ = 315 GeV. The results of this analysis have been published in [5].

Topology



The FCNC couplings could induce single-top production in *ep* collisions, $ep \to etX$, in which the incoming lepton exchanges a γ or Z with an up quark in the proton, yielding a top quark in the final state. Owing to the large Z mass, this process is more sensitive to a coupling of the type $tq\gamma$. Furthermore, large values of *x*, the fraction of the proton momentum carried by the struck quark, are needed to produce a top quark. Since the *u*-quark parton distribution function (PDF) of the proton is dominant at large *x*, the production of single top quark is most sensitive to the $tu\gamma$ coupling.

Event selection

The event selection was optimised for single-top production via photon exchange, looking for the dominant decay $t \to bW$ and subsequent *W* decay to *e* and μ and their respective neutrinos. The selection is based on requiring an isolated high-p_T lepton, large missing transverse momentum and high hadronic P_T.

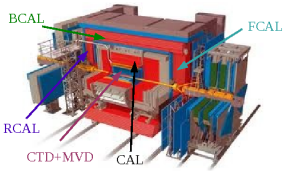
The main preselection cuts where the following:

- $P_{T,miss}$ > 10 (12) GeV μ- (*e*-) channel;
- leptonic p_T > 8 (10) GeV μ- (*e*-) channel;
- transverse mass M_T > 10 GeV *e*-channel only;

The main final cuts where the following:

- hadronic P_T > 40 GeV for both channels;
- $P_{T,miss}$ > 15 GeV *e*-channel.

ZEUS detector



Components of the detector that were more relevant for the analysis:

- central tracking detector (CTD) complemented by a silicon vertex detector (MVD)
- calorimeter, consisting of a forward (FCAL), rear (RCAL) and barrel (BCAL) parts
- Luminosity detector, consisting of a lead-scintillator calorimeter at z=107 m from the nominal interaction point along the outgoing e-beam direction

Systematic uncertainties

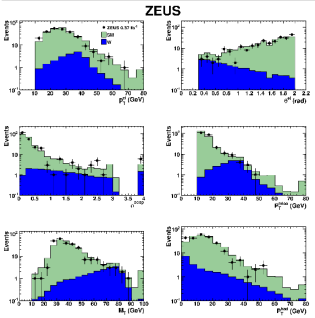
The main contribution to the systematical uncertainties on the predicted SM events is due to the following sources:

- the theoretical uncertainty on the W background normalisation ±15%;
- the statistical uncertainty on the total SM prediction after the final selection ±13% and ±9% for the e- and μ-channel respectively;
- the uncertainty on the NC DIS background ±15% for the preselection and ±6% for the final selection in the e-channel and negligible in the μ-channel.

	N_obs	N_pred	W [%]
e-channel	1	3.6±0.6	52±9
μ-channel	3	3.0±0.4	64±7

Table showing the number of events passing the final selection, N_obs, compared to the SM prediction, N_pred. The last column shows the *W* contribution as a percentage of the SM prediction. The uncertainties have been obtained by adding systematic and statistical contributions in quadrature

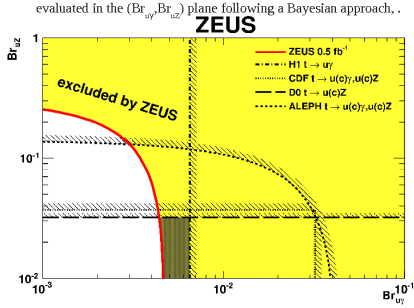
Preselection plots



Data-MC comparison at the preselection level for the e-channel; good agreement is observed.

Limits evaluation

Since no visible excess was found respect to the SM prediction, a limit, assuming a vanishing ν_z was evaluated on the signal cross section using a Bayesian approach, assuming a constant prior on the cross section σ. The result was σ < 0.24 (95 % C.L.) pb at $\sqrt{s}$ = 318 GeV. Such limit was converted into a limit on the coupling κ_γ: κ_γ < 0.18 (95 % C.L.). The result of this analysis was combined with the previous ZEUS result [4]: σ < 0.13 (95 % C.L.) pb at $\sqrt{s}$ = 315 GeV and κ_γ < 0.13 (95% C.L.). Constraints on the anomalous top branching ratios $t \to u\gamma$ ($Br_{u\gamma}$) and $t \to uZ$ (Br_{uZ}) were also evaluated assuming a non-zero coupling ν_z. Such limits were evaluated in the ($Br_{u\gamma}$,Br_{uZ}) plane following a Bayesian approach, .



This figure shows the ZEUS boundary in the ($Br_{u\gamma}$,Br_{uZ}) plane compared to limits from other experiments. The e^+e^- and hadron colliders, contrary to HERA, have similar sensitivities to *u*- and *c*-quarks; their limits are hence on both decays $t \to qV$ with $q = u,c$. The yellow area is excluded by ZEUS. The dark shaded region denotes the area uniquely excluded by ZEUS. The limits set by the ZEUS experiments in the region where Br_{uZ} is less than ~4% are the best to date.

References

[1] G.A.Schuler, Nucl.Phys. B 299, 21 (1988), U. Baur and J.J. van der Bij, Nucl. Phys. B 304, 451 (1988) J.J. van der Bij and G.J. van Oldenborgh, Z. Phys. C 51, 477 (1991)

[2] T. Stelzer, Z. Sullivan and S. Willenbrock, Phys. Rev. D 56, 5919 (1997) S. Moretti and K. Odagiri, Phys. Rev. D 57, 3040 (1998)

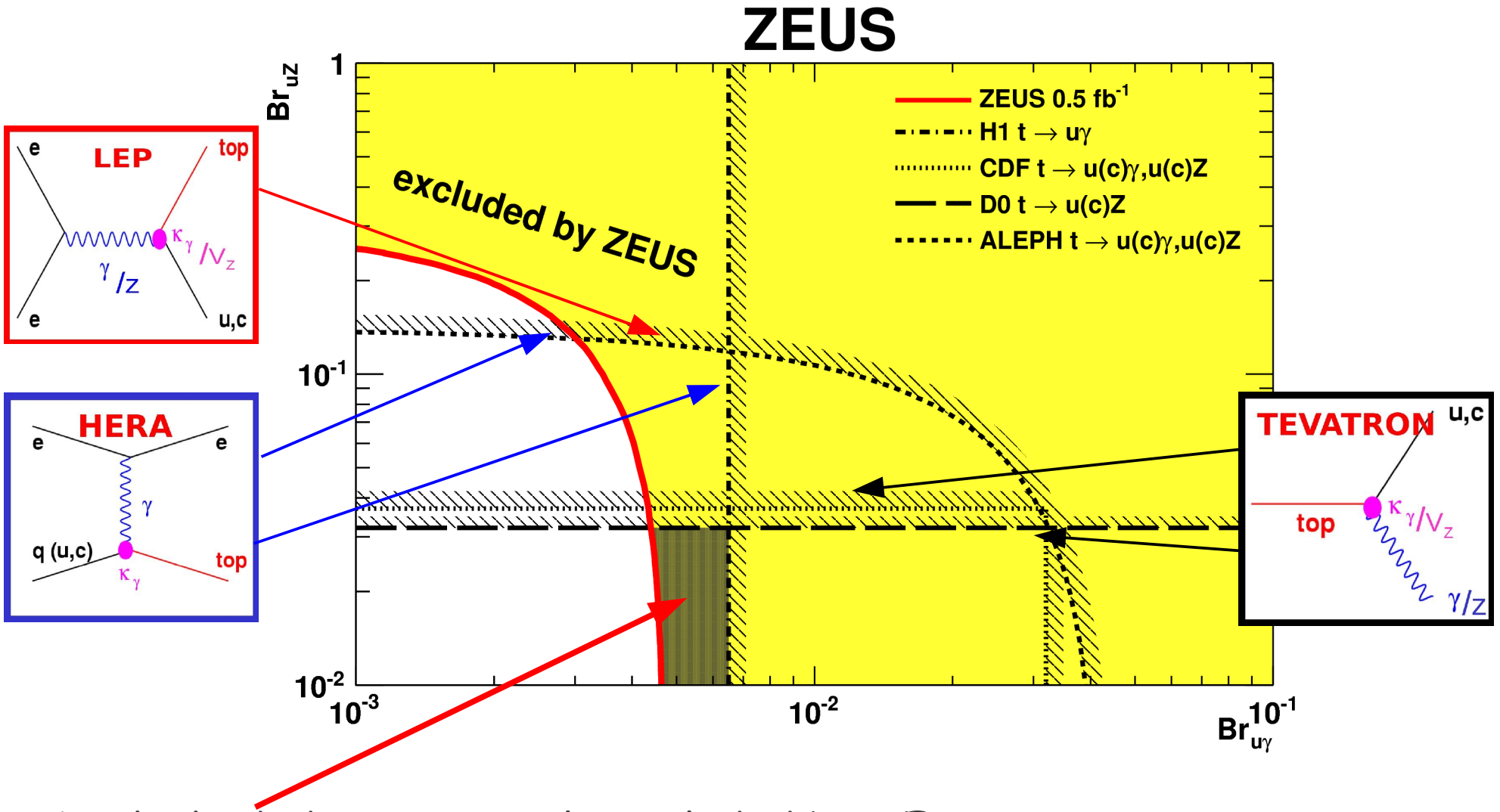
[3] H. Fritzsch, Phys. Lett. B 224, 423 (1989) T. Han, R.D. Peccei and X. Zhang, Nucl. Phys. B 454, 527 (1995)

[4] ZEUS Coll., S. Chekanov et al., Phys. Lett. B 559, 153 (2003)

[5] ZEUS Collaboration; H. Abramowicz et al., Phys. Lett. B 708 (2012) 27-36

[6] K. Nakamura et al. (Particle Data Group), J. Phys. G 37, 075021 (2010)

Single-top Production: Appetizer



- Dark shaded area uniquely excluded by ZEUS

For details see ZEUS Single-top Poster