

Searches for New Physics at HERA

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DESY

on behalf of the H1 and ZEUS collaborations

La Thuile 2008

*For Prof. Dr. Beate Naroska, who offered me a home
when I thought of leaving particle physics*



- HERA
- New Physics in DIS?
- Model based searches
- Signature based searches
- Summary



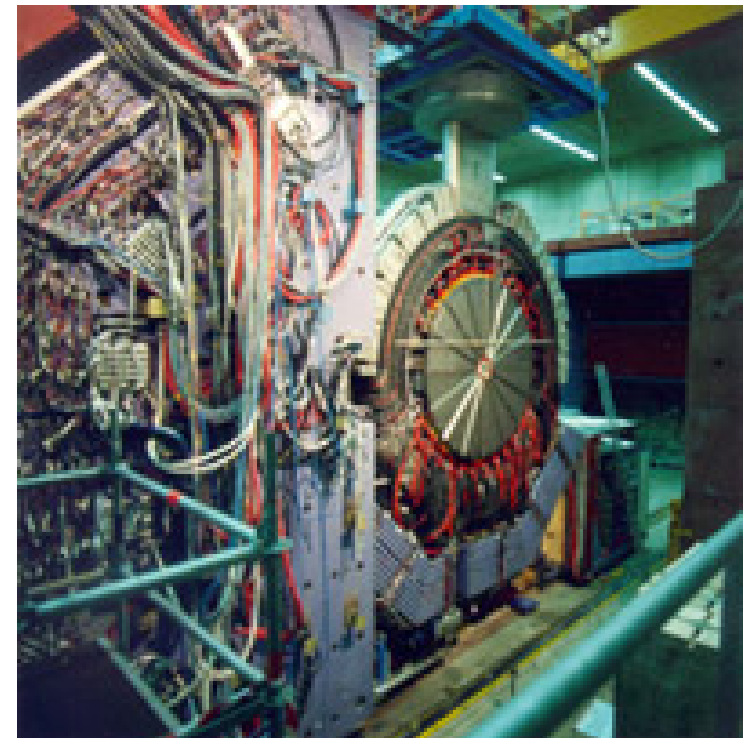
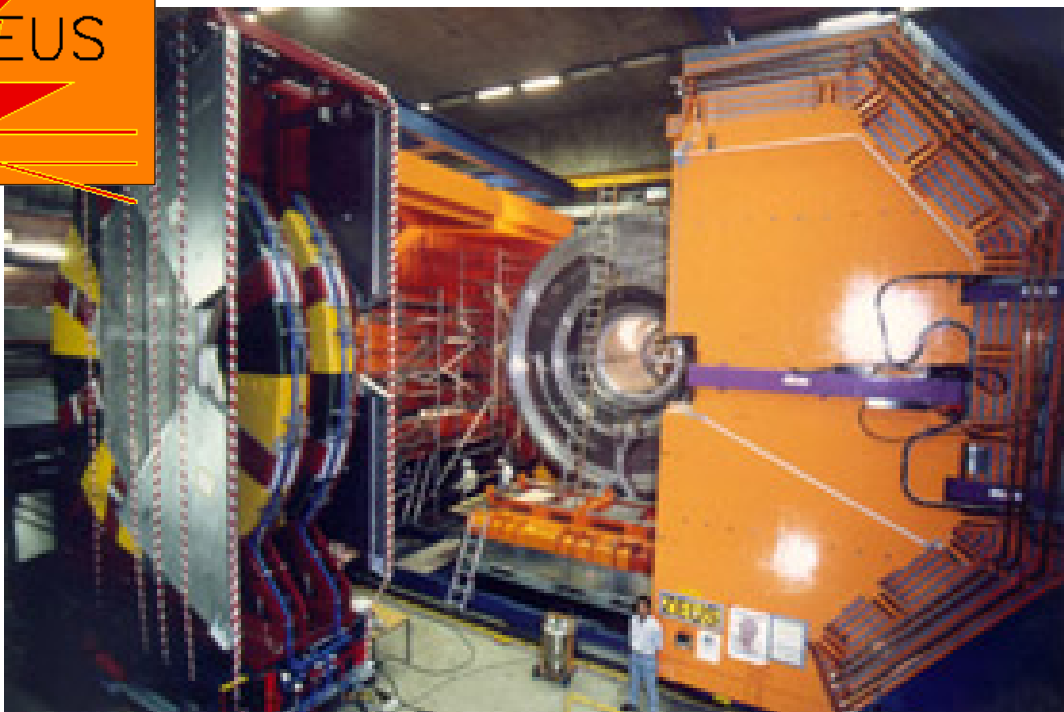
HERA and its Experiments

- World's only ep collider
- $E_p = 460 \dots 920 \text{ GeV}$, $E_e = 27.6 \text{ GeV}$
- running from 1994 to 2007
- 2 collider experiments:

<http://www-h1.desy.de>

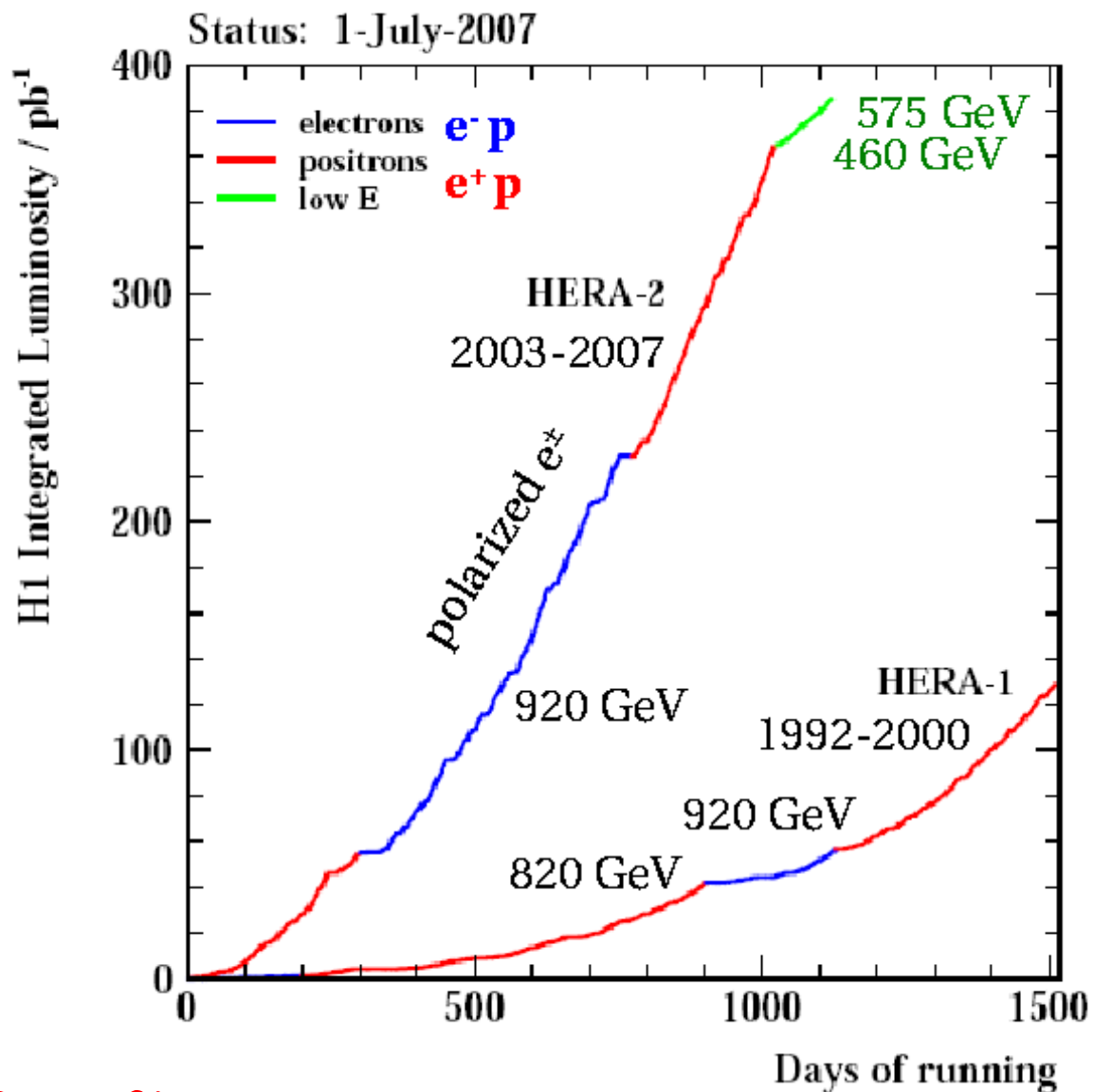


<http://www-zeus.desy.de>



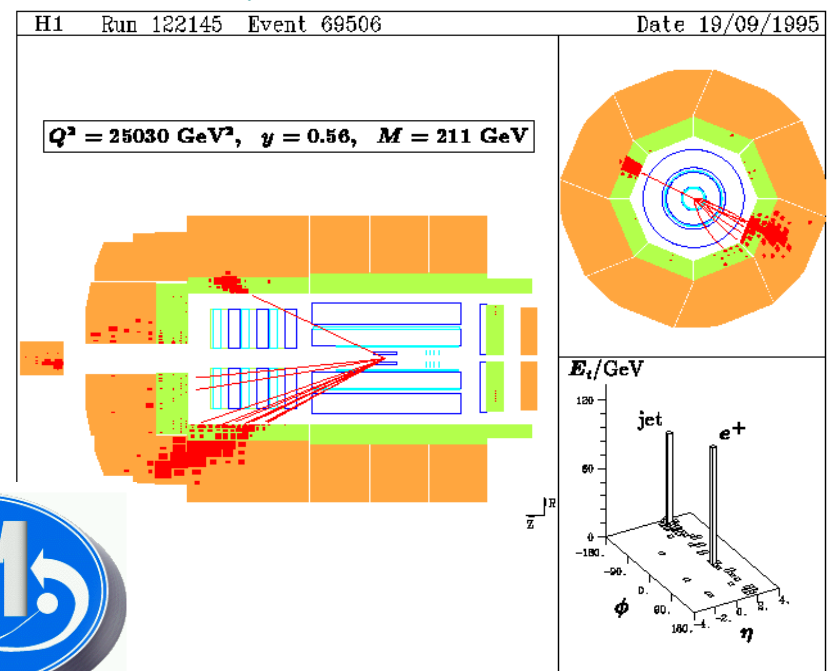
Data Collection

- $\sim 0.5 \text{ fb}^{-1} / \text{experiment}$
- $\sim 70\%$ taken during HERA II phase:
 - 30-40% longitudinal lepton polarisation
 - improved detectors
- data balanced between
 - e^+p / e^-p
 - left / right handed leptons
- **all limits in this talk @ 95% CL**

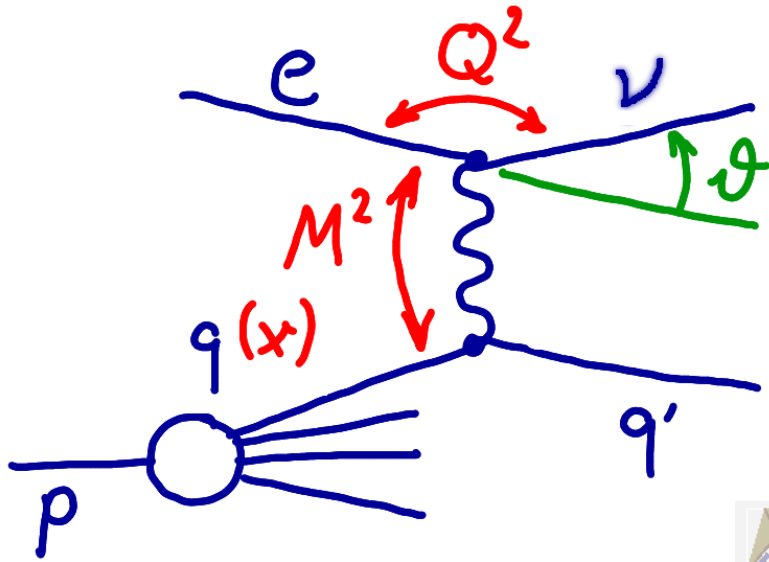


A hand-drawn Feynman diagram illustrating deep inelastic scattering (DIS). An incoming electron (e) and an incoming proton (p) interact via a virtual photon (wavy line). The electron is scattered (e') at an angle θ , and the proton is scattered (q') with a final state $q(x)$. The virtual photon has momentum Q^2 and the proton has mass M^2 .

- hadronic final state balanced by scattered electron
- E_+ balance allows calibration of jet energy scale to $\approx 1\%$ above $E_{\text{jet}} \approx 25 \text{ GeV}$

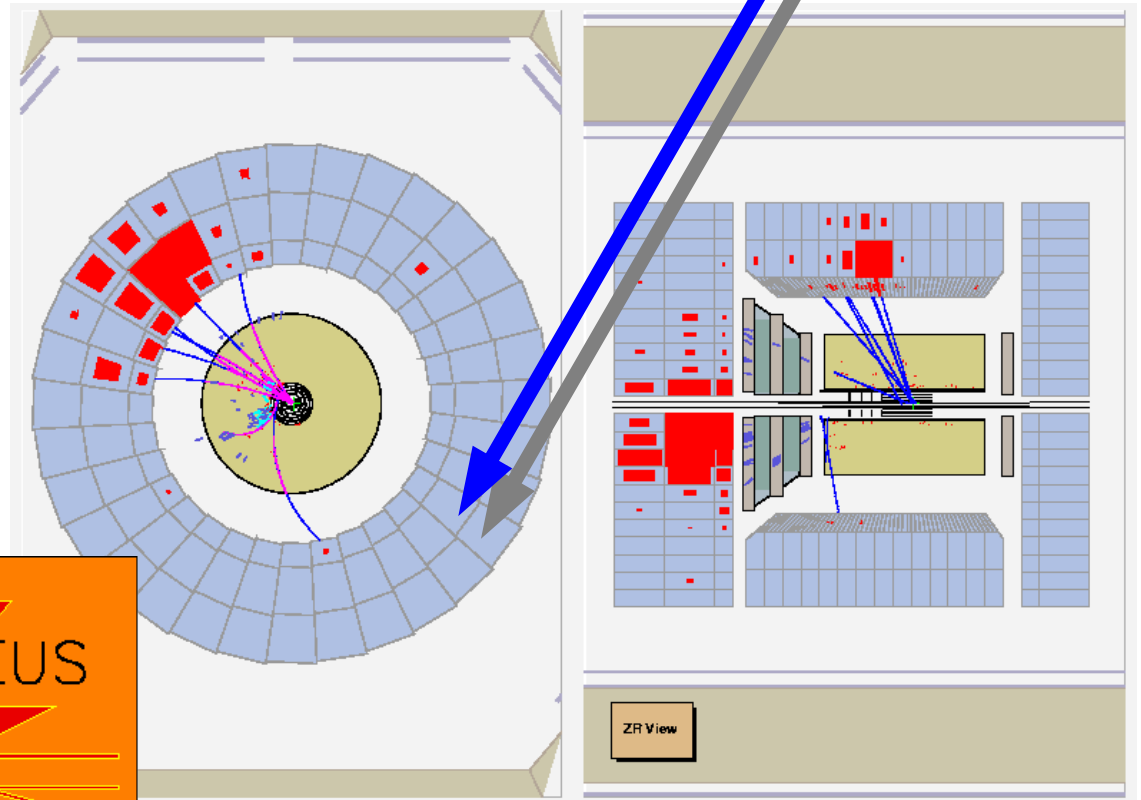


Deep Inelastic Scattering: Charged Current



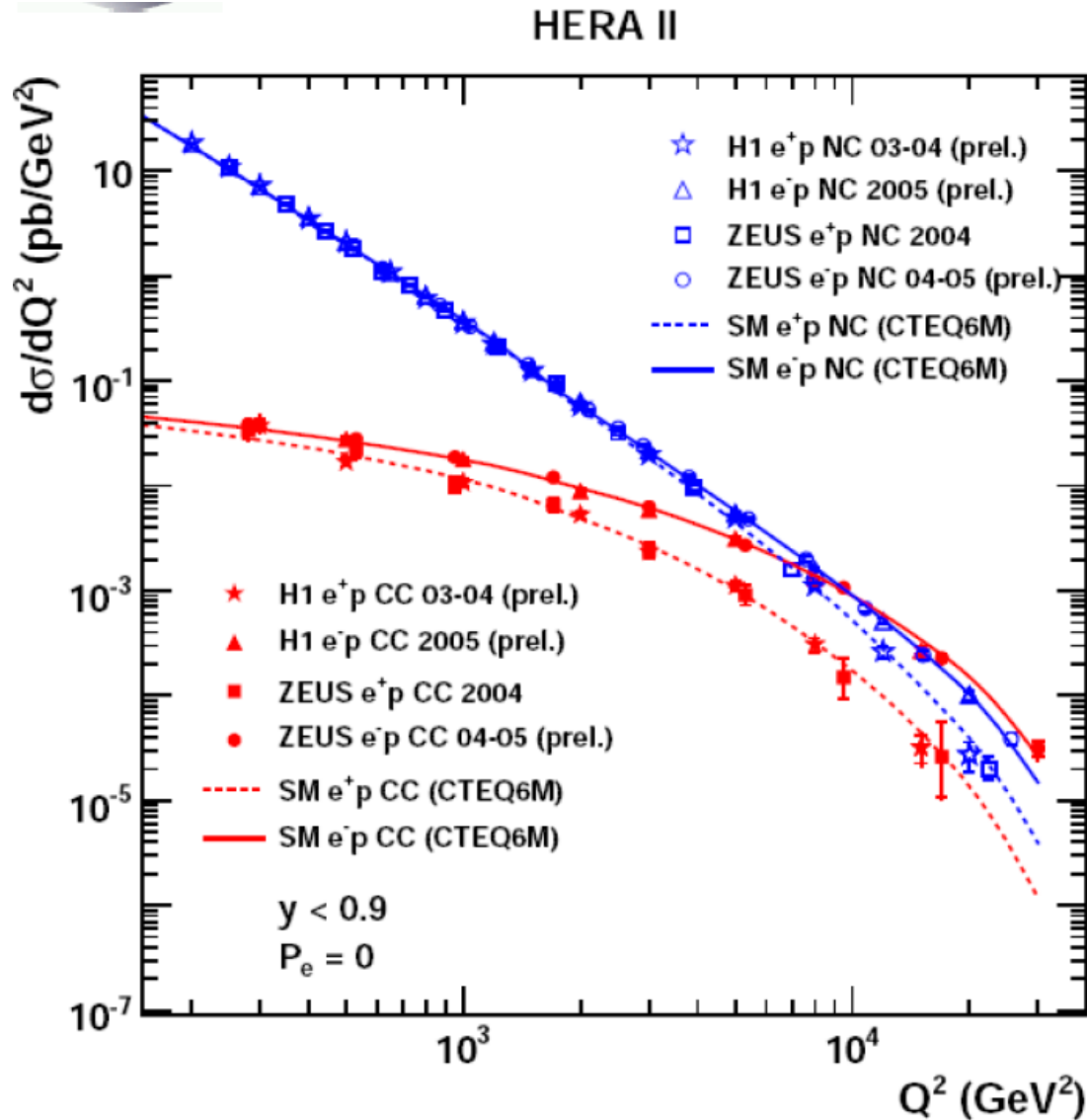
- W^\pm exchange
- neutrino instead of electron \Rightarrow missing E_+

- kinematic variables can be determined from hadronic final state alone
- SM x-section vanishes for righthanded e^- / lefthanded e^+



Deviations from SM at high Q^2 ?

Neutral Current and Charged Current for e^-p and e^+p vs Q^2

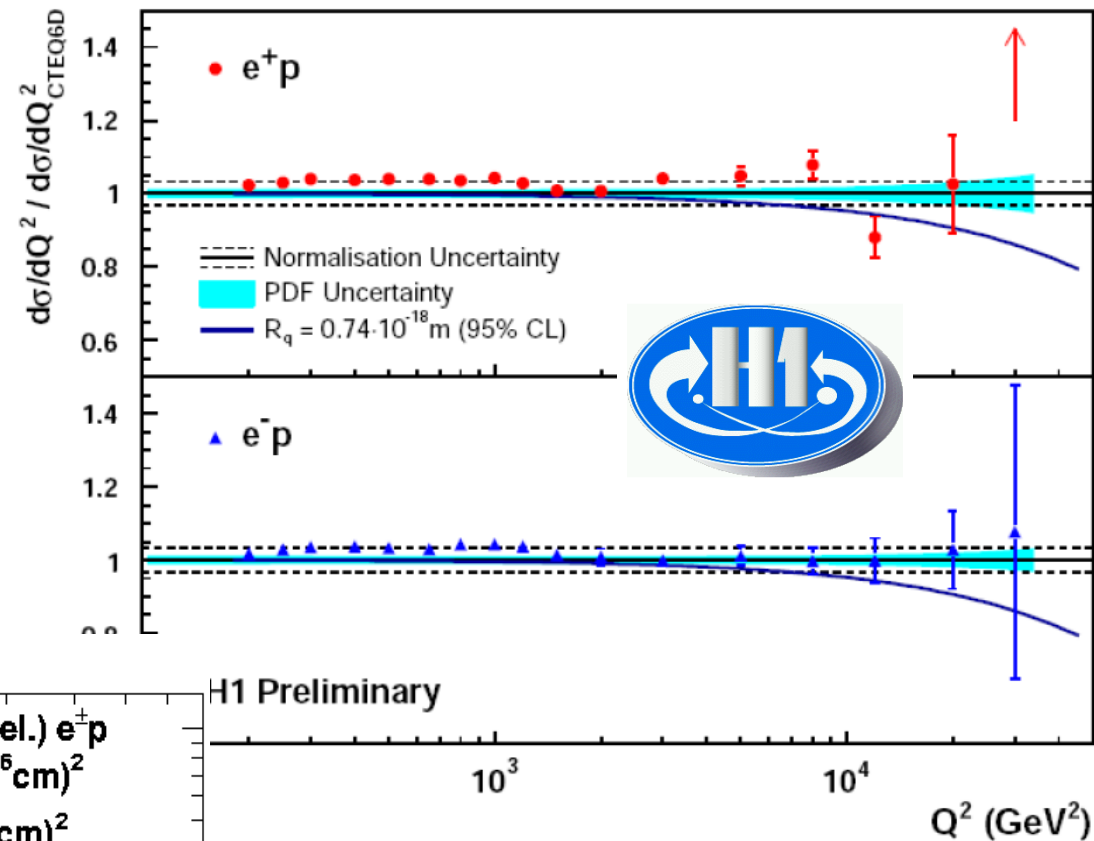


- NC: destructive and constructive γZ interference
- CC: $e^-u \approx 2 e^+d$ when in valence quark regime
- electroweak unification when $Q^2 \approx M_W^2$
- high precision measurements even at high Q^2 !

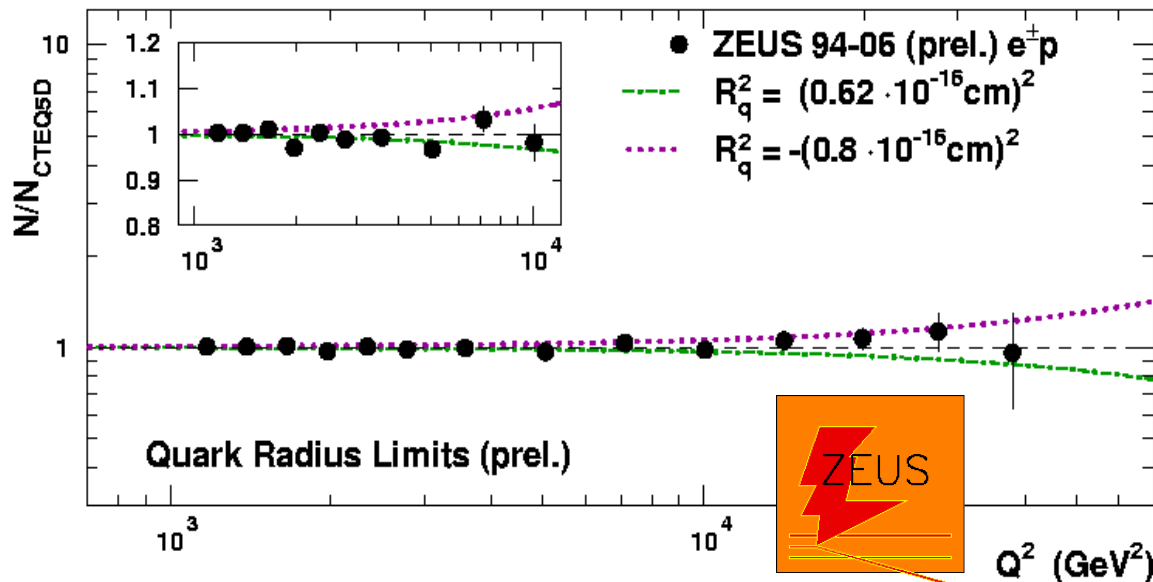
Quark Radius

- naïve expectation:
 $Q^2_{\max} \approx 100000 \text{ GeV}^2$
 $\Rightarrow r \approx \hbar c / Q \approx 10^{-18} \text{ m}$
- more sophisticated:
 fit quark radius form factor $(1 - R_q^2 Q^2 / 6)$

H1 Quark Radius Limit HERA I+II (435 pb⁻¹)



ZEUS

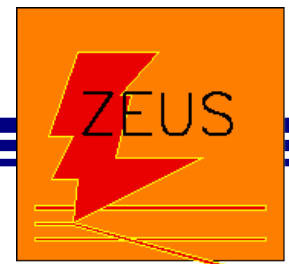


Results:

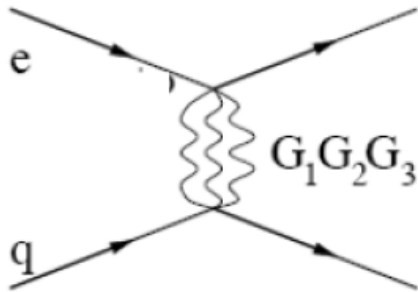
H1: $R_q < 0.74 \cdot 10^{-18} \text{ m}$

ZEUS: $R_q < 0.67 \cdot 10^{-18} \text{ m}$

Large Extra Dimensions?



- LED: contribution to DIS via Graviton exchange:

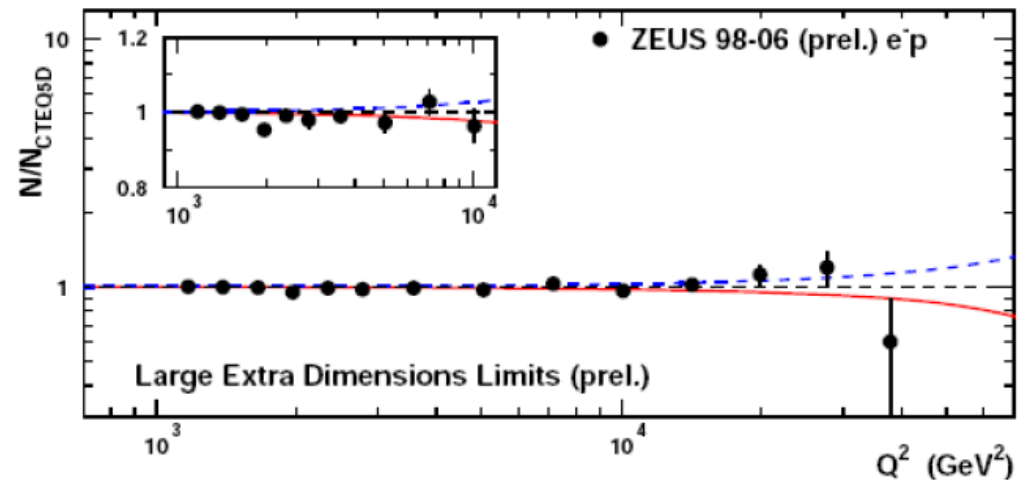
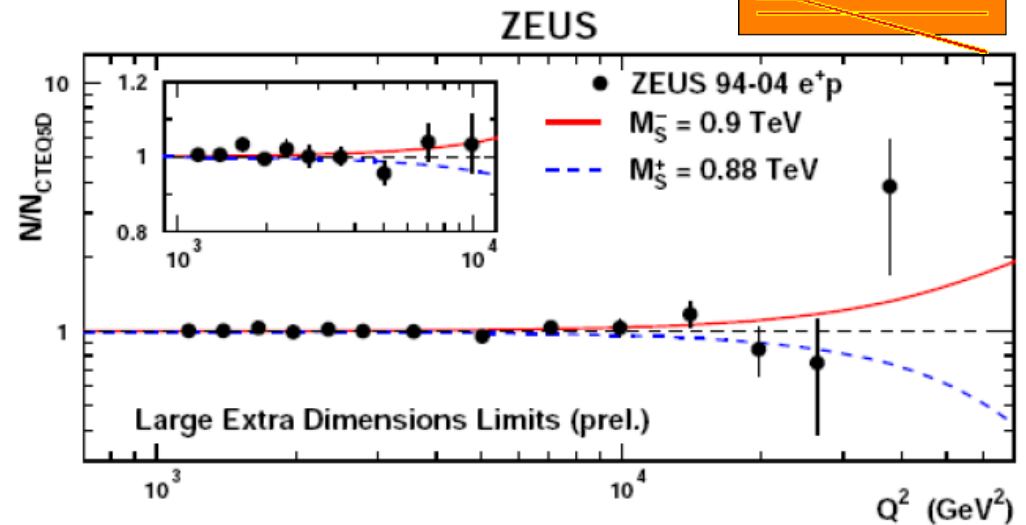


- limits on LED scale M_S :

- constructive interference

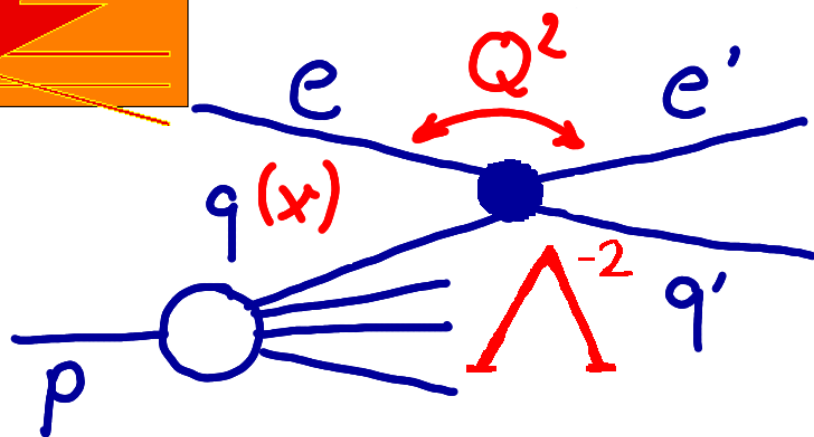
$$M_{S^+} > 0.88 \text{ TeV}$$

- destructive interference $M_{S^-} > 0.9 \text{ TeV}$



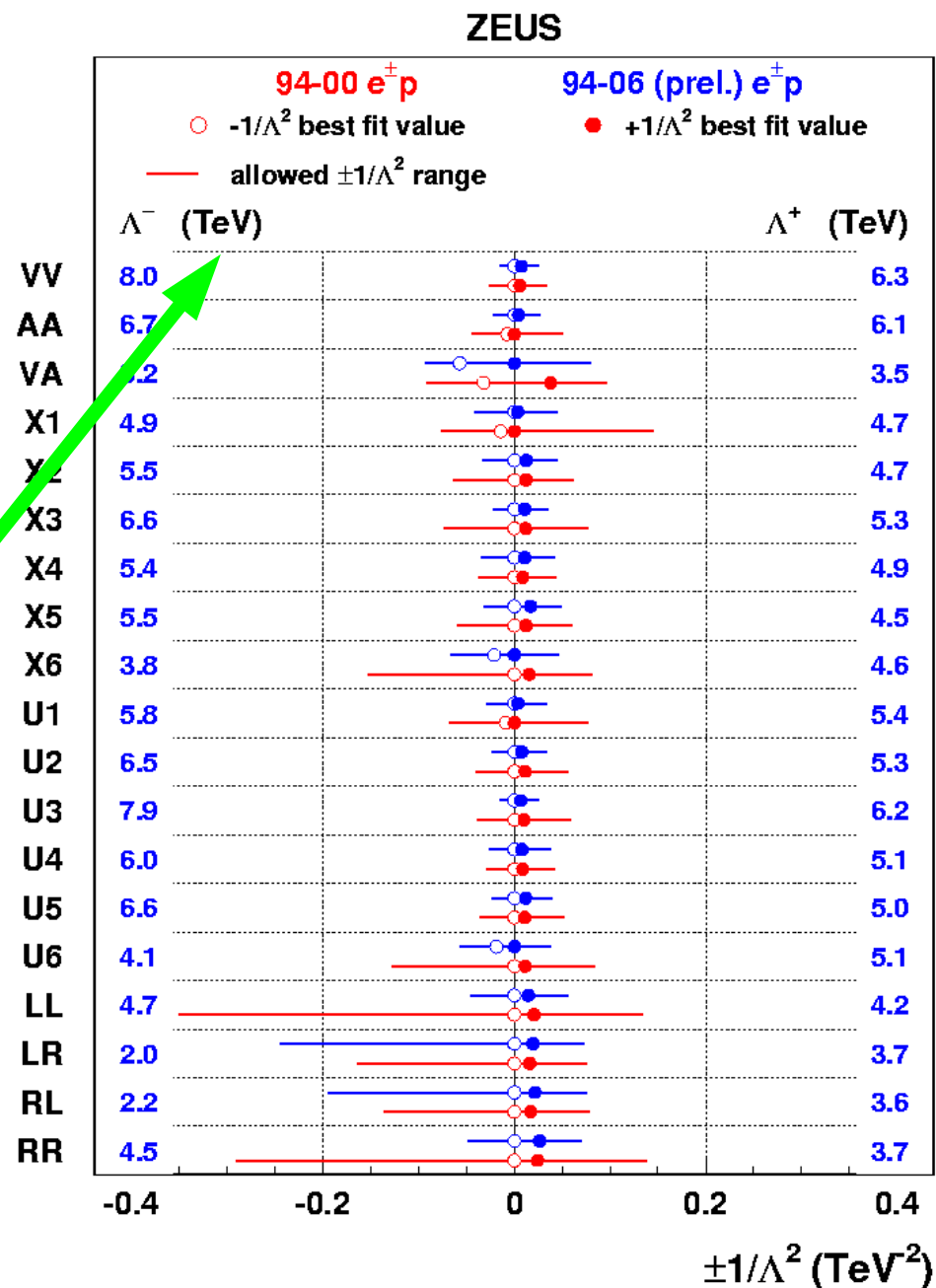
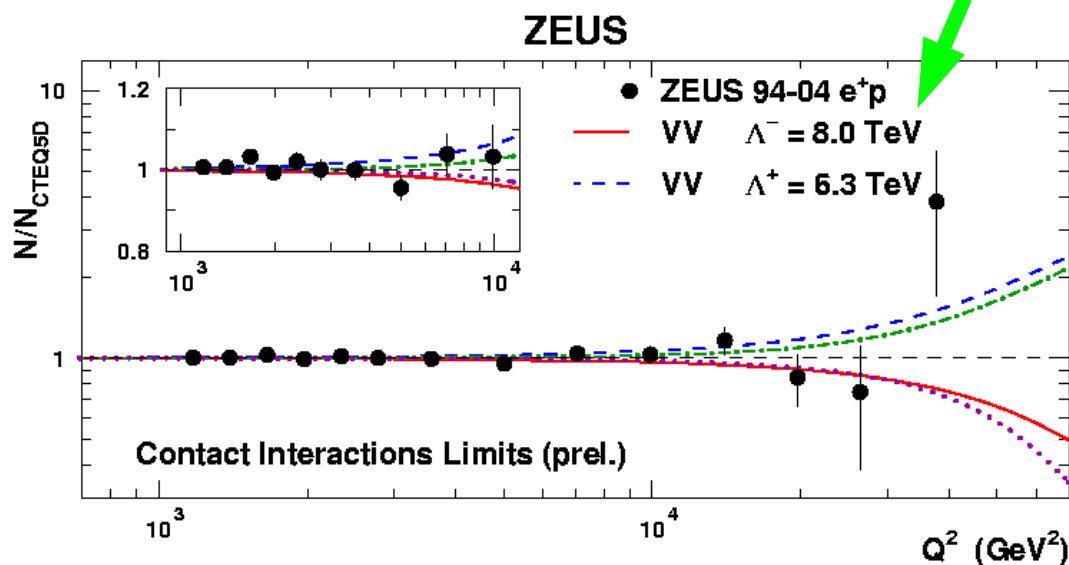


Contact Interactions?



effect of new physics at scale Λ
on DIS parametrised as CI

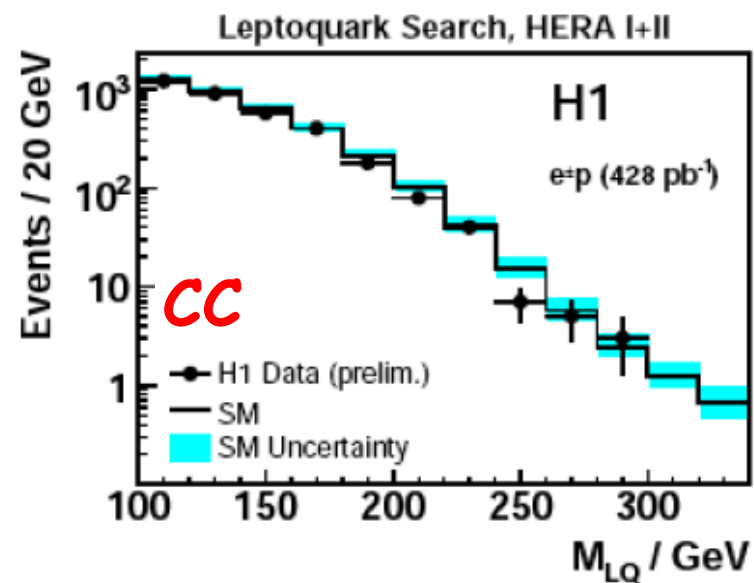
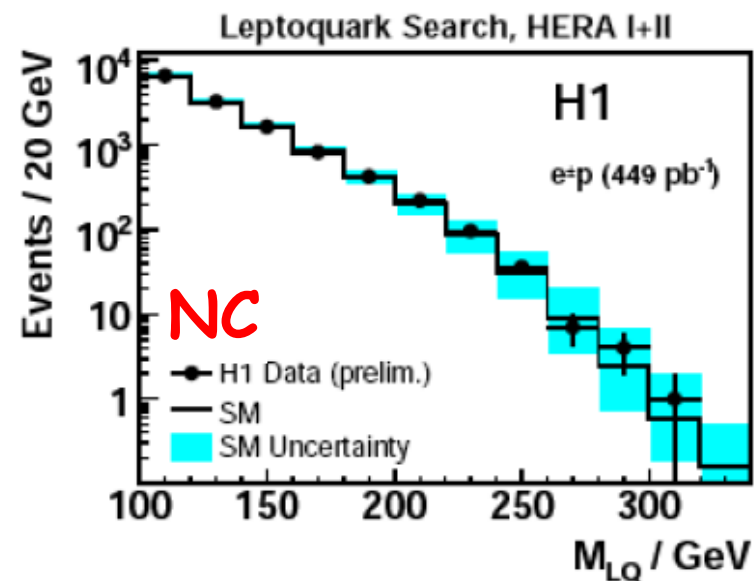
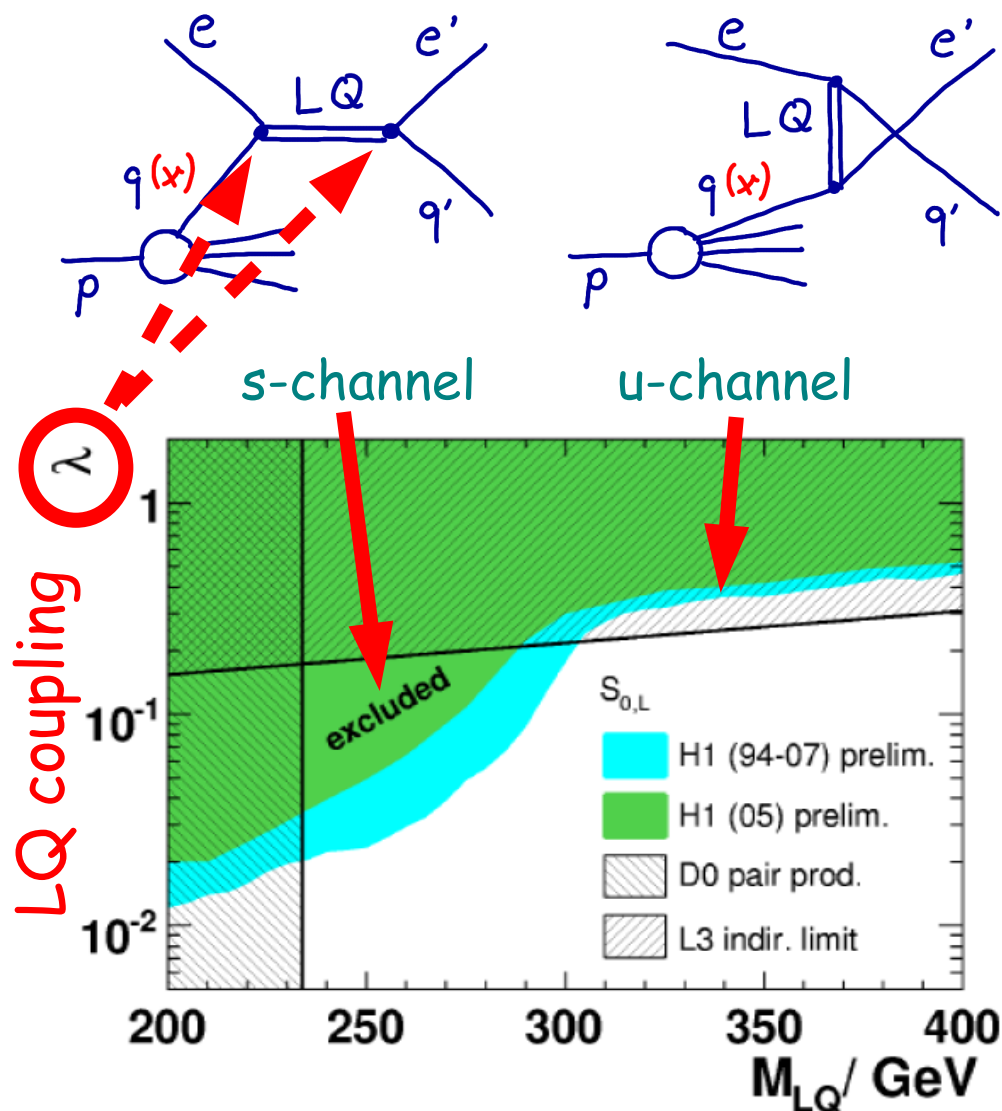
=> sensitive to several-TeV-range!





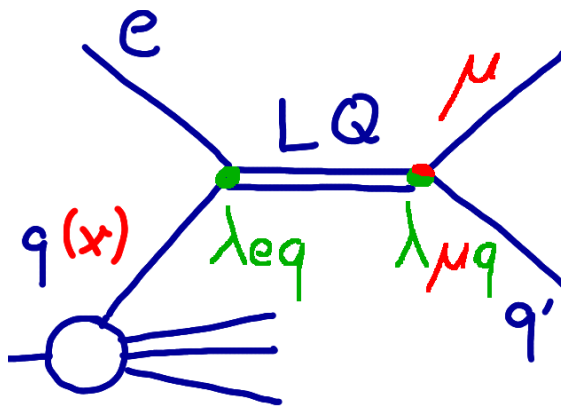
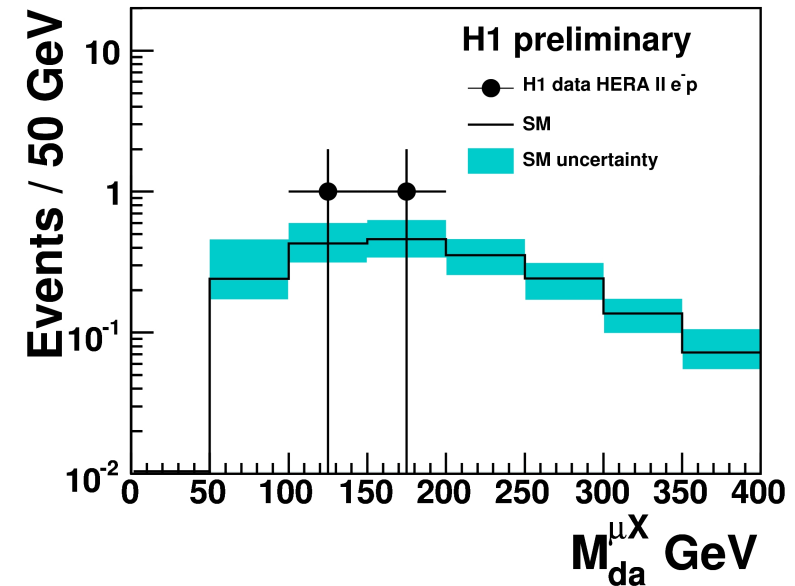
First Generation Leptoquarks?

constructive or destructive interference
with NC and CC DIS

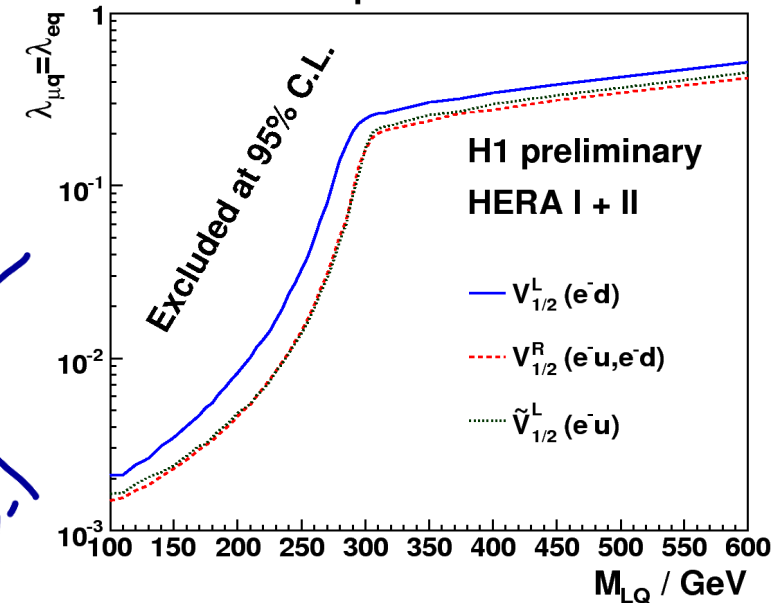


Lepton Flavour Violation?

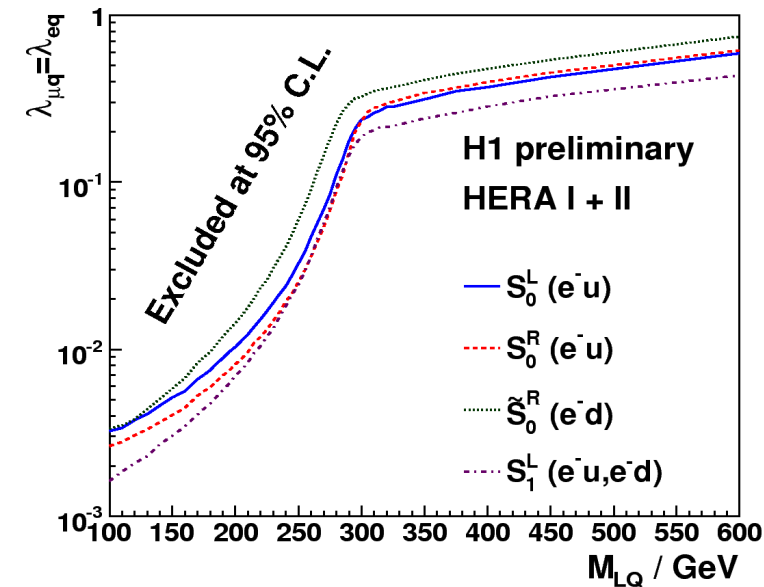
Search for Lepton Flavour Violation



Search for Lepton Flavour Violation



- e - p data, μq channel
- HERA: need λ_{eq} for production
=> Lepton Flavor Violation
- => different from 2. generation Leptoquark search at Tevatron
- here: assume $\lambda_{eq} = \lambda_{\mu q}$

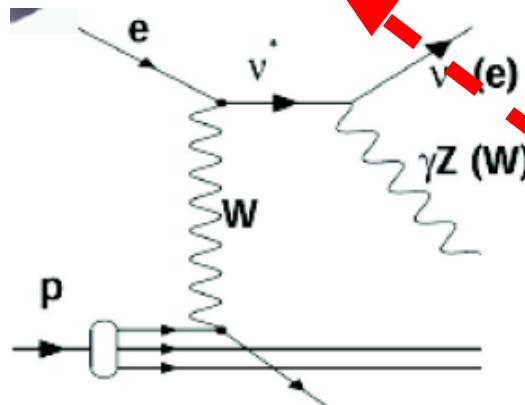


Excited Neutrinos?

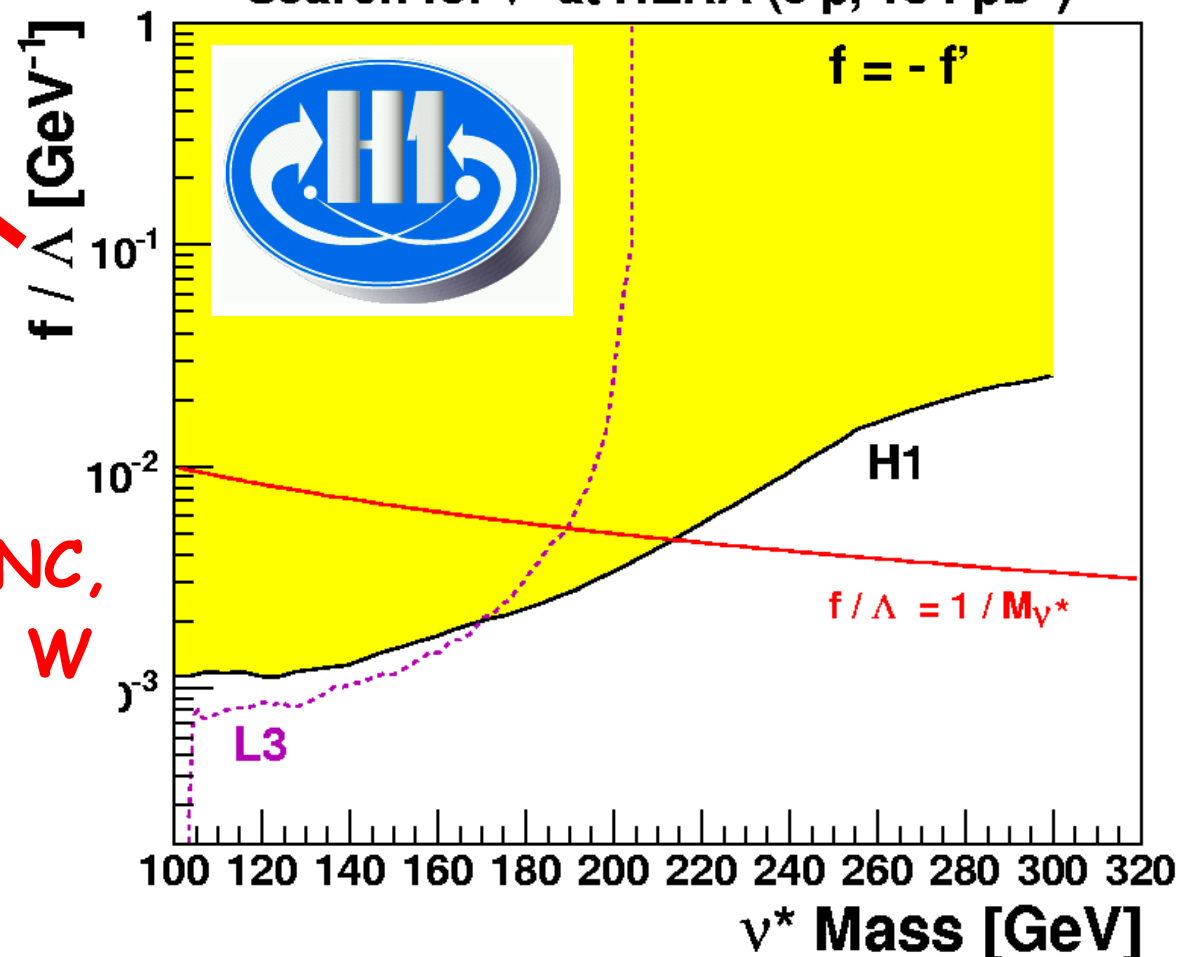
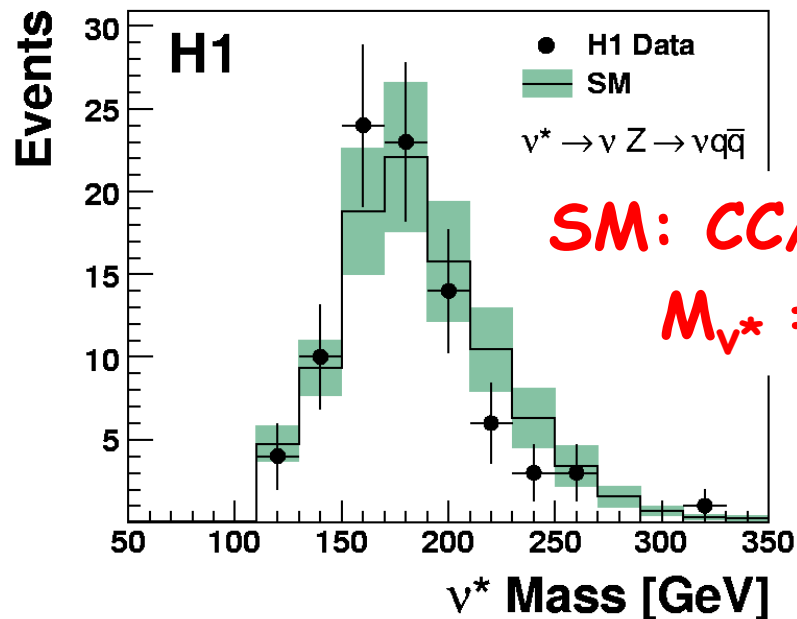
$$\mathcal{L}_{int.} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[g f \frac{\tau^a}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu} \right] F_L + h.c.$$

f U(1) related; f' : SU(2) related form factors

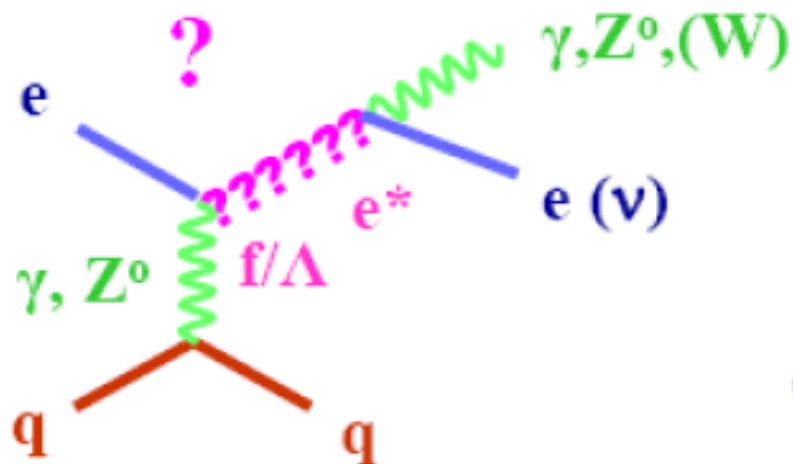
Search for ν^* at HERA (e^-p , 184 pb $^{-1}$)



Search for ν^* at HERA (e^-p , 184 pb $^{-1}$)



Excited Electrons?

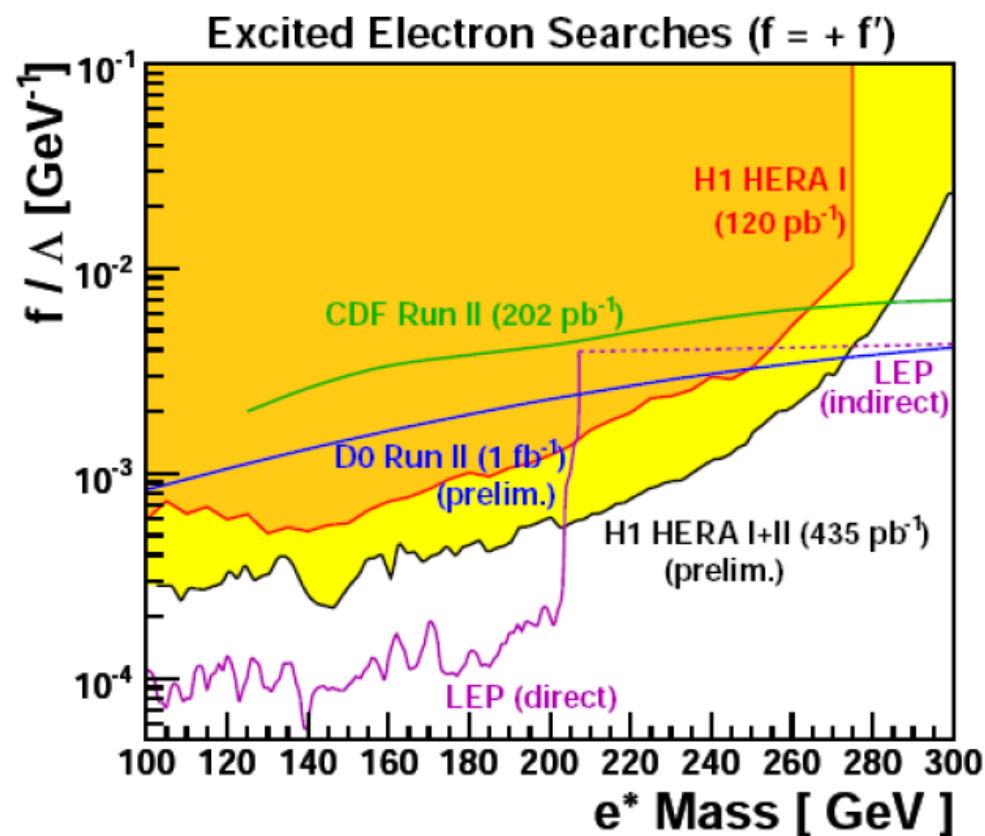
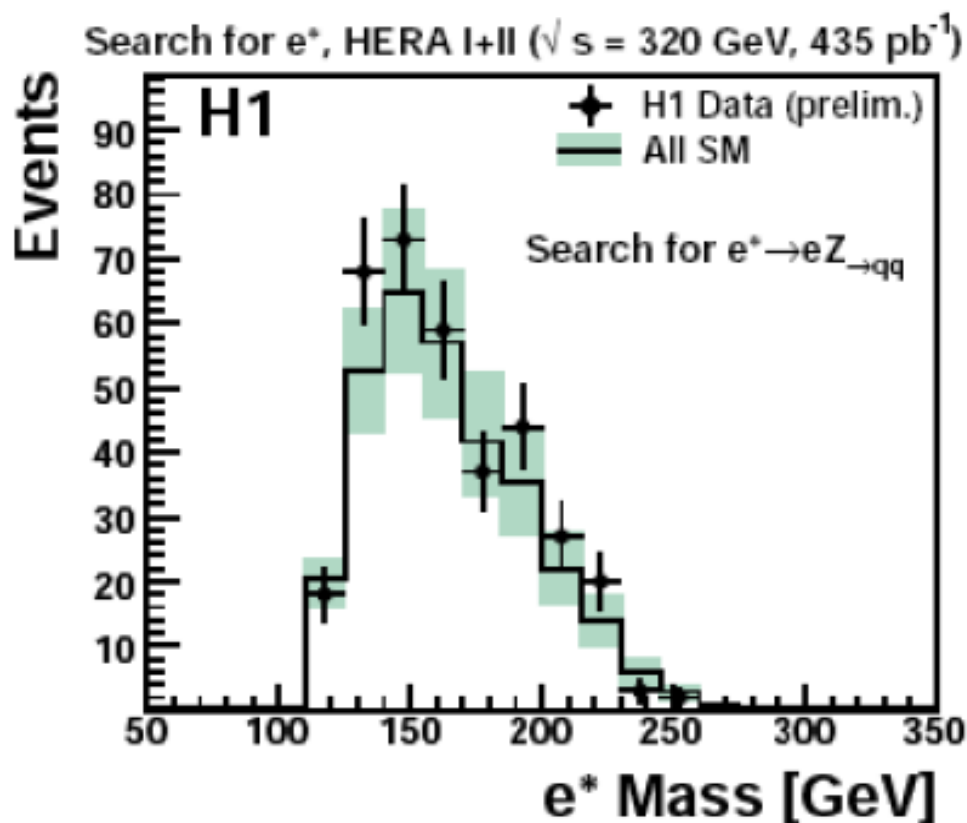


$$e\gamma/Z \rightarrow e^* \rightarrow \gamma e$$

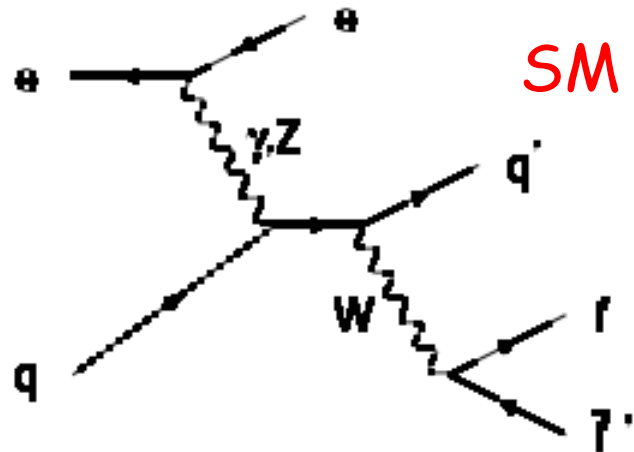
$$\rightarrow Ze \rightarrow f\bar{f}e$$

$$\rightarrow W\nu \rightarrow f\bar{f}'\nu$$

all HERA data combined

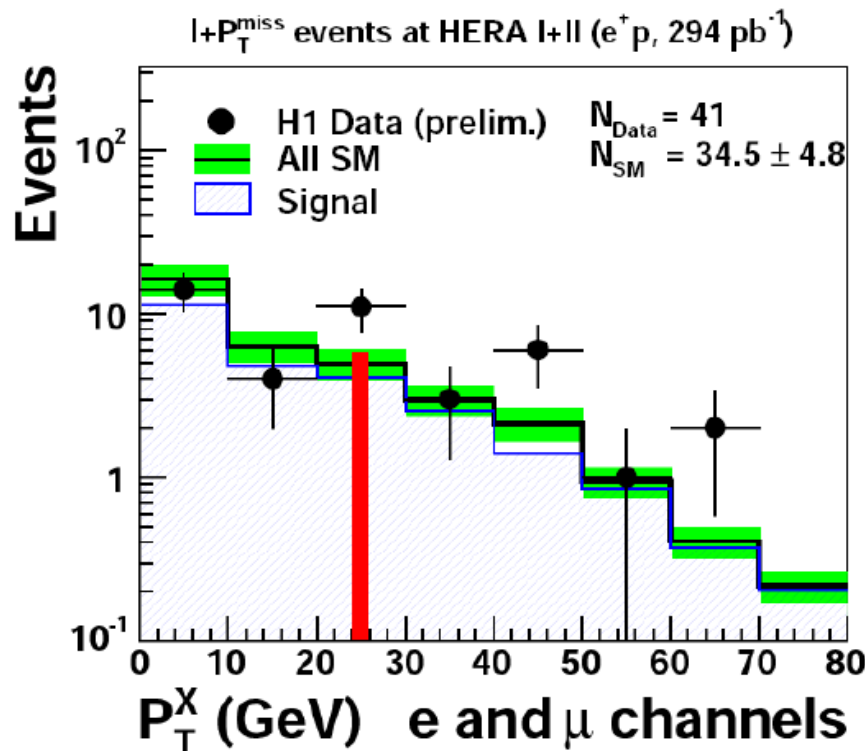
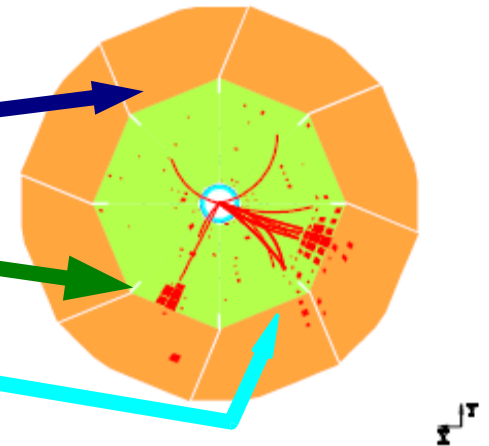


High p_T Leptons with missing p_T



SM process: single W production

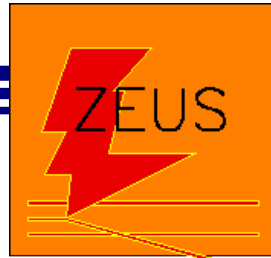
- large missing p_T
- isolated high p_T lepton
- high or low P_T hadronic final state



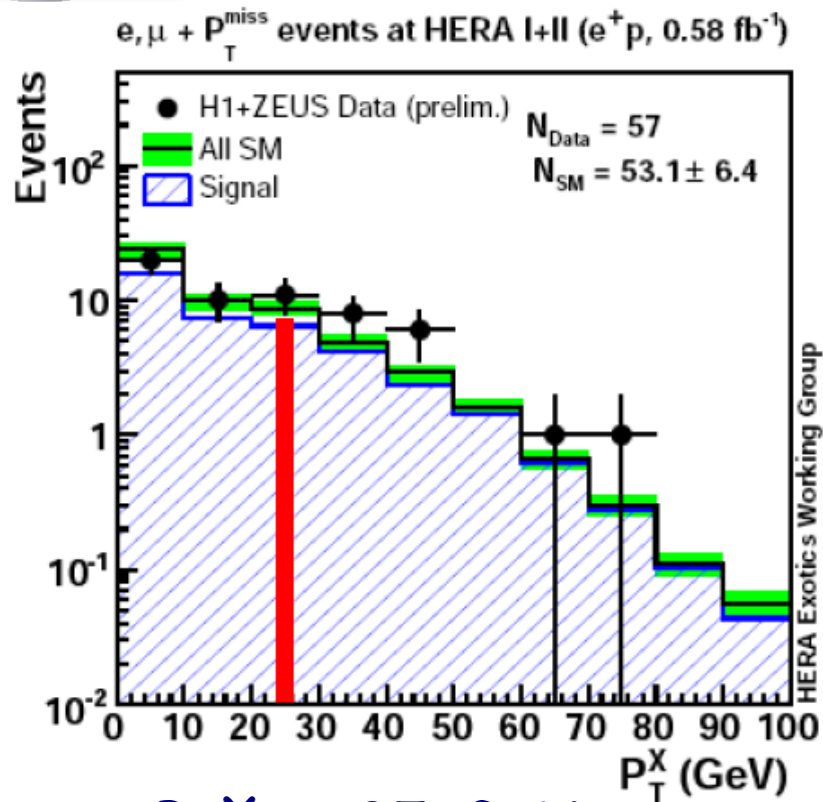
H1, e^+p , $P_T^X > 25 \text{ GeV}$:
 21 events observed vs
 9 ± 1.5 expected
 $\Rightarrow 3\sigma$ excess



High p_T Leptons with missing p_T



H1 and ZEUS analyses in **common phase space**

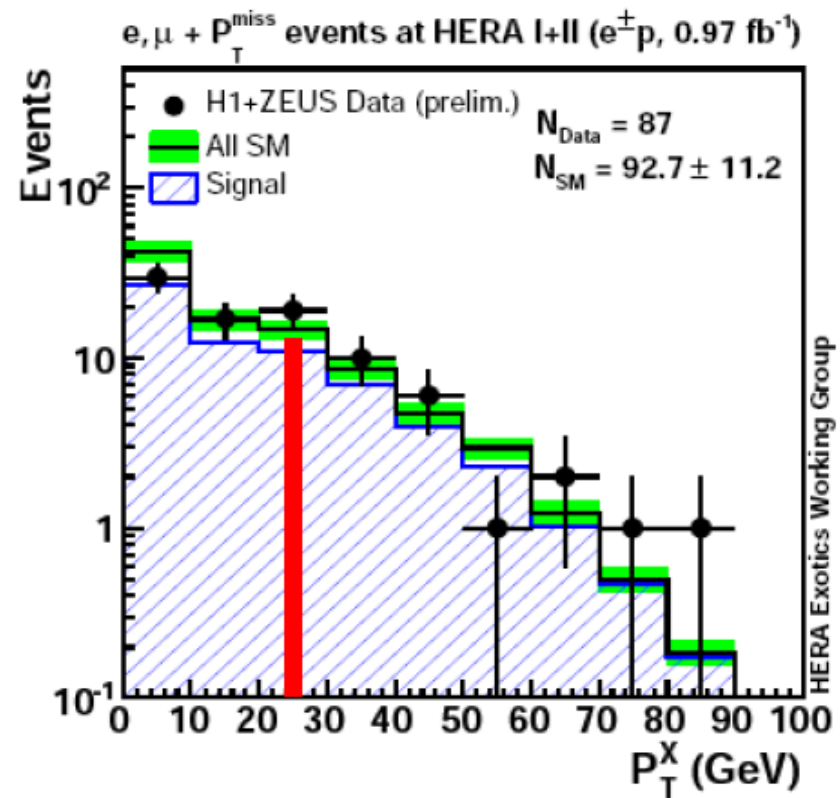


e^+p , $P_T^X > 25 \text{ GeV}$:

observed 23

expected 15 ± 2

$1.8\sigma \Rightarrow ?$ **H1 alone still 2.9σ ...**



$e^+p + e^-p$, $P_T^X > 25 \text{ GeV}$:

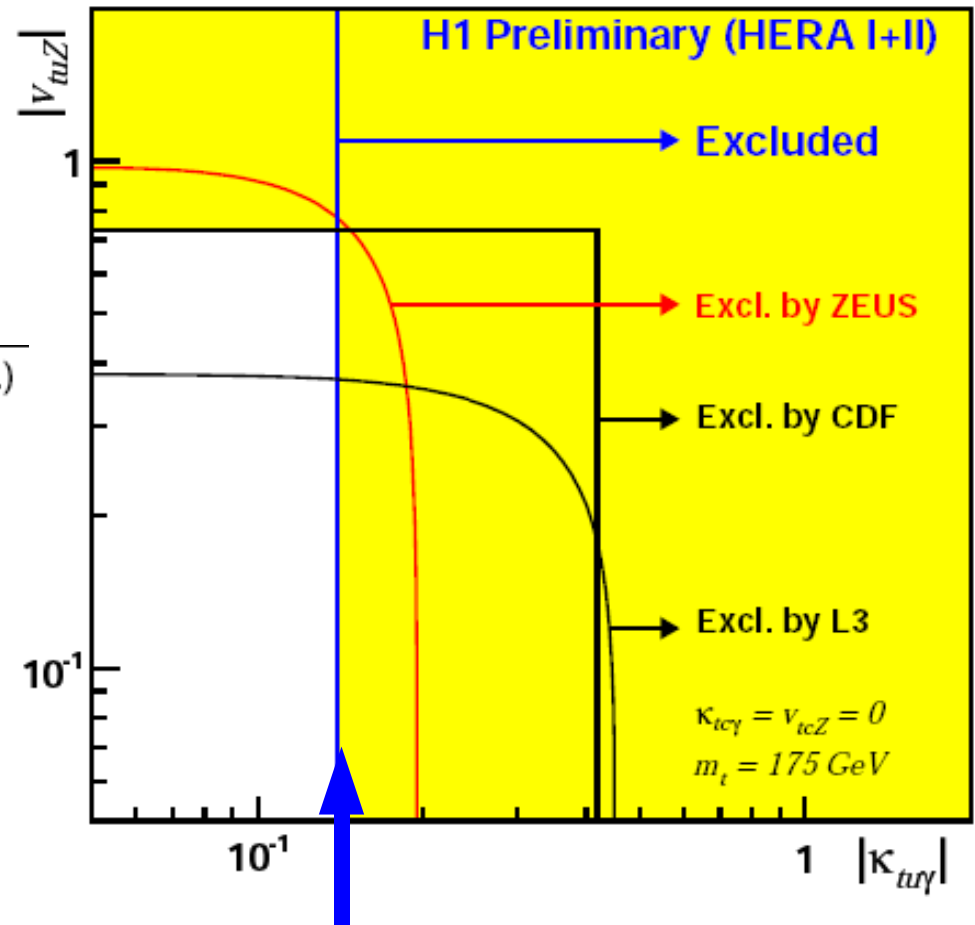
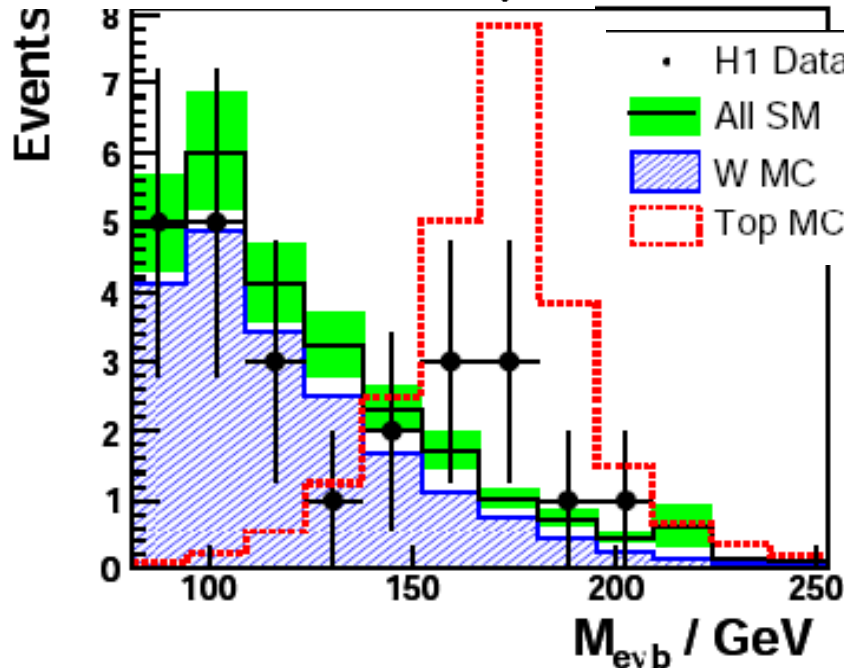
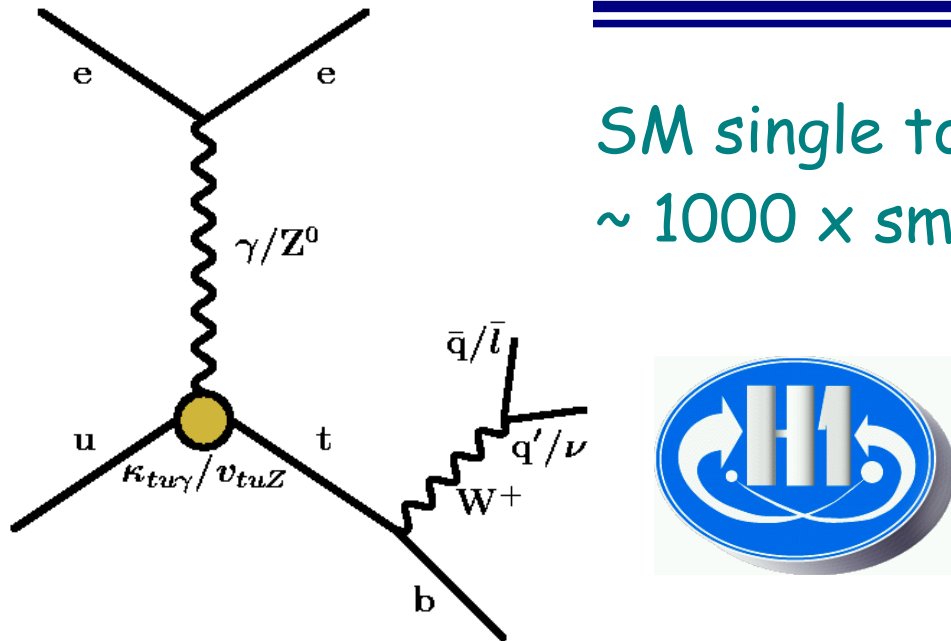
observed 29

expected 25 ± 3

$\Rightarrow \checkmark$

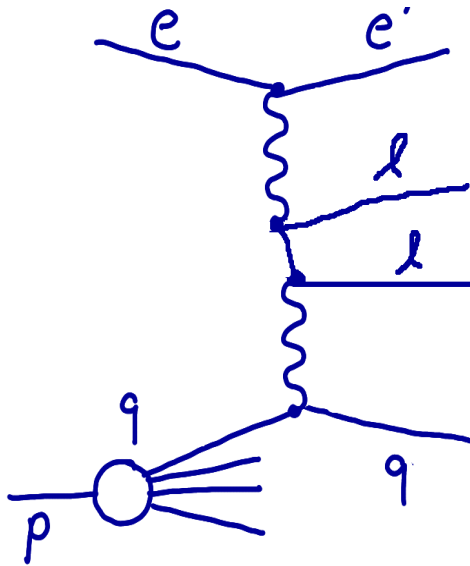
Anomalous Top Quark Production?

SM single top cross-section at HERA: $\sim 1 \text{ fb}$
 $\sim 1000 \times$ smaller than W production



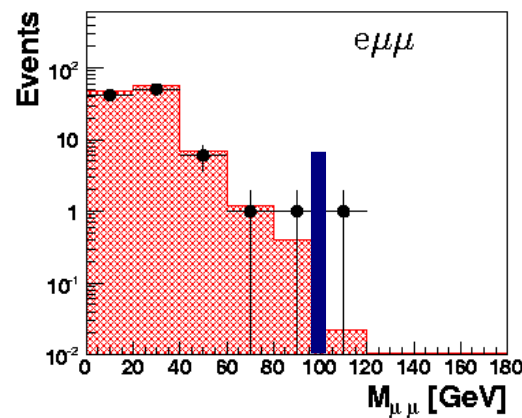
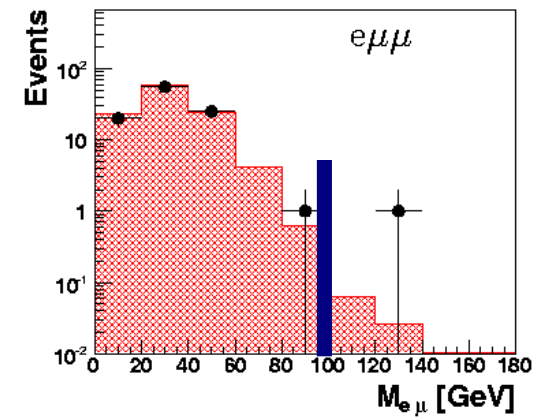
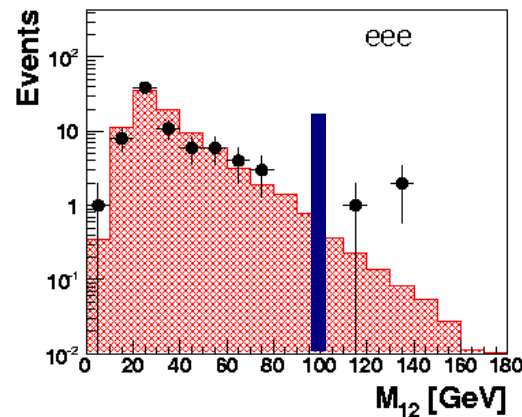
H1: most stringent limit on $\kappa_{tu\gamma}$!

Multi-Leptons

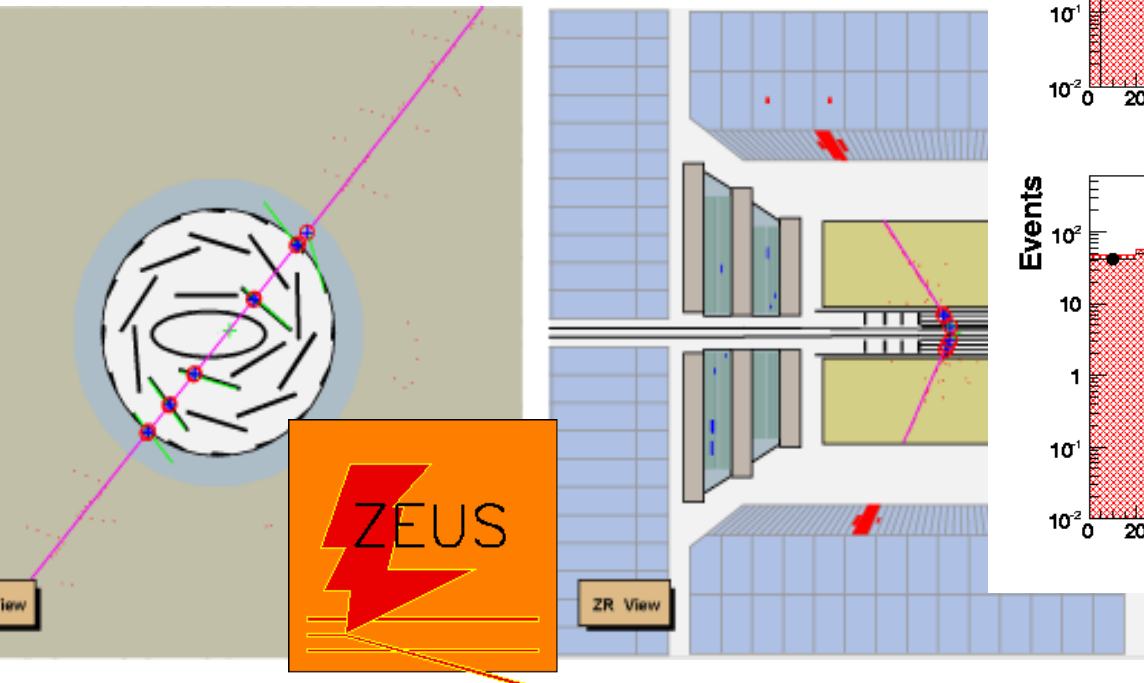


H1 e^+p , $M_{ij} > 100 \text{ GeV}$:
9 events observed, 2.2 expected

H1 Multi-lepton analysis HERA I+II (459 pb^{-1})

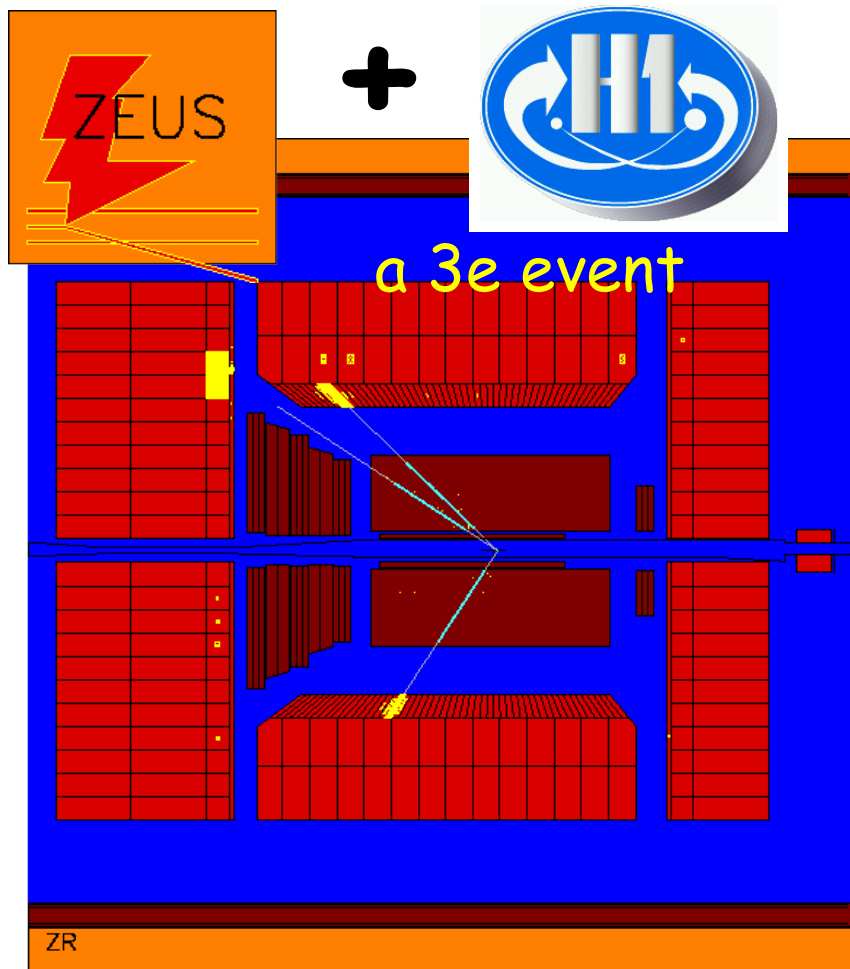


● H1 Data (prelim.)
▨ DIS+Compton
▨ Pair Production



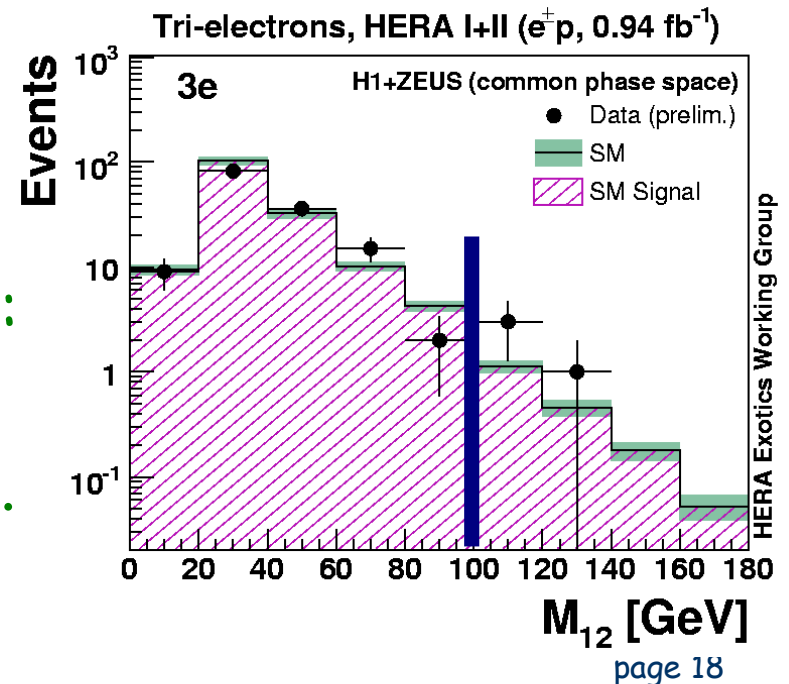
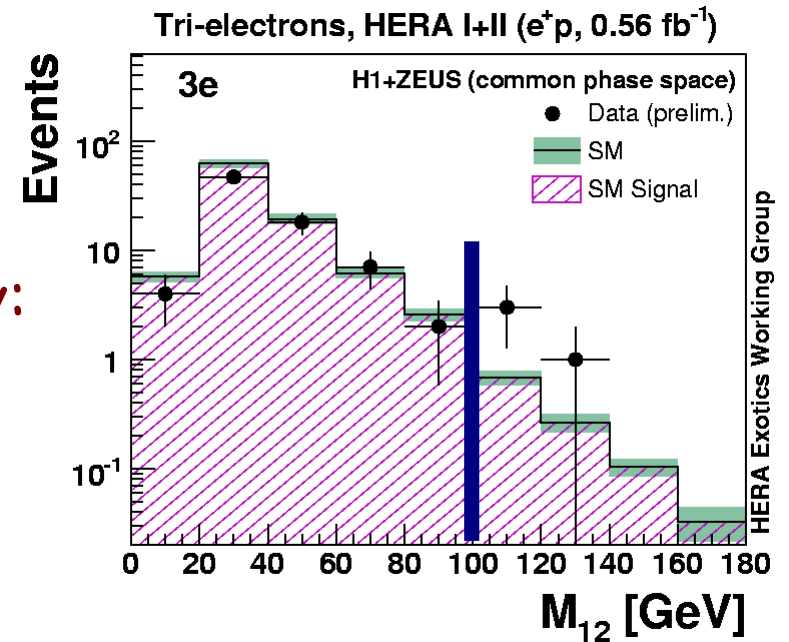
Multi-Electrons

H1 and ZEUS combined
inv. mass of highest p_T e 's
 $M_{12} > 100 \text{ GeV}$:

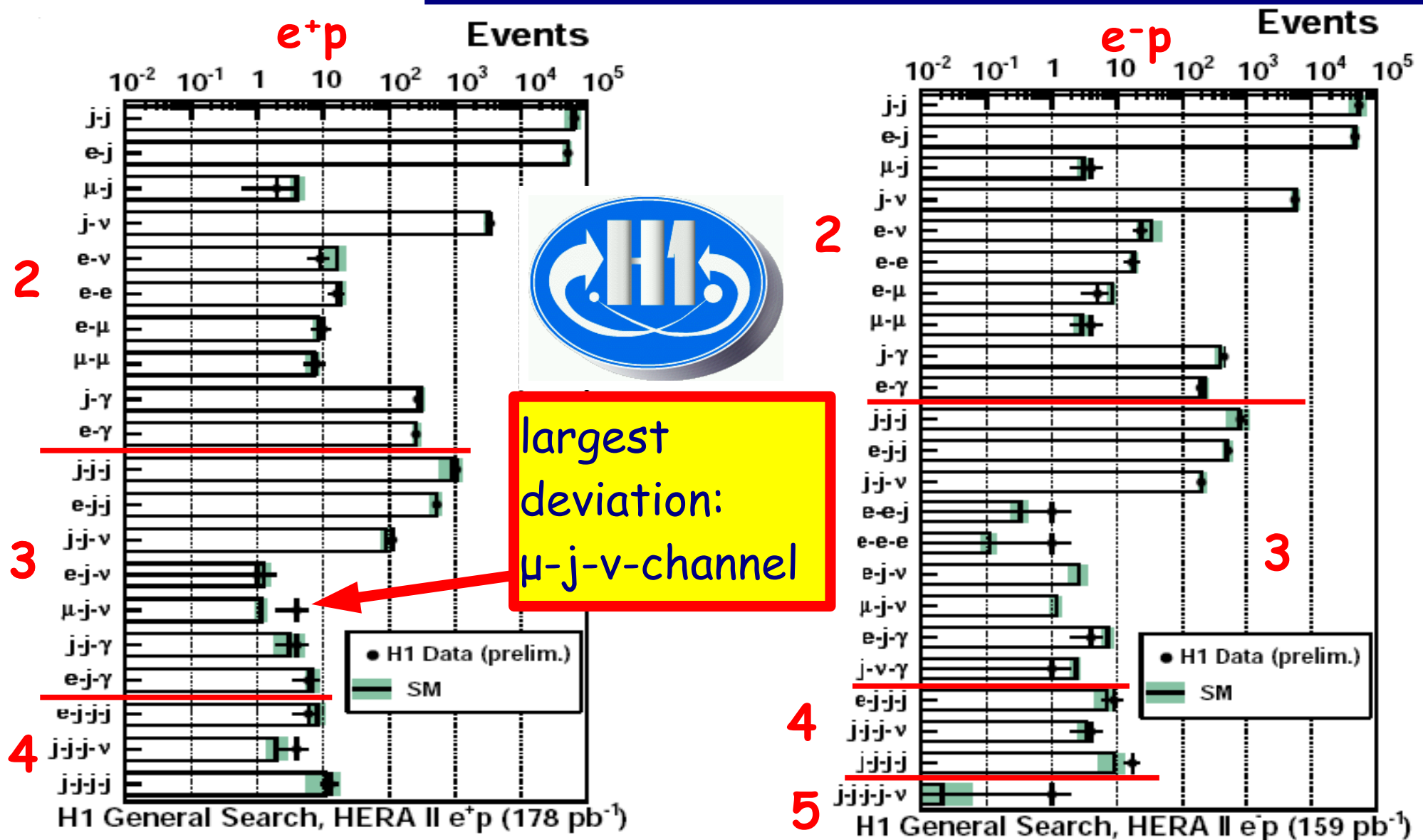


$e+p$ only:
8 obs.
3.1 exp.

all data:
9 obs.
5.3 exp.



General Search with $p_t > 20$ GeV-objects



all channels agree well with SM expectations!

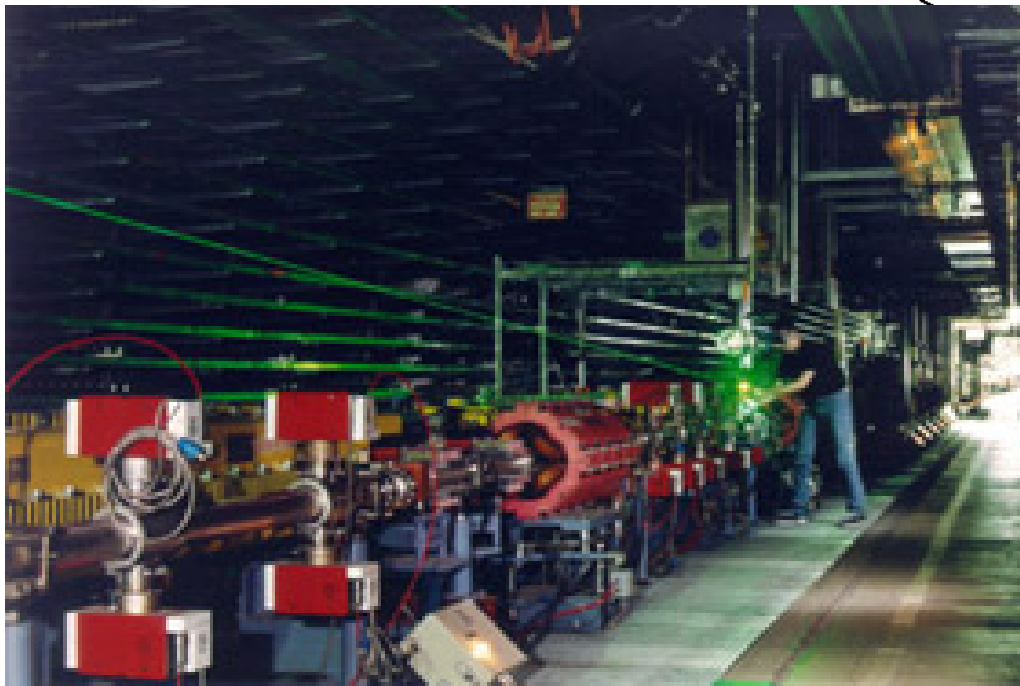
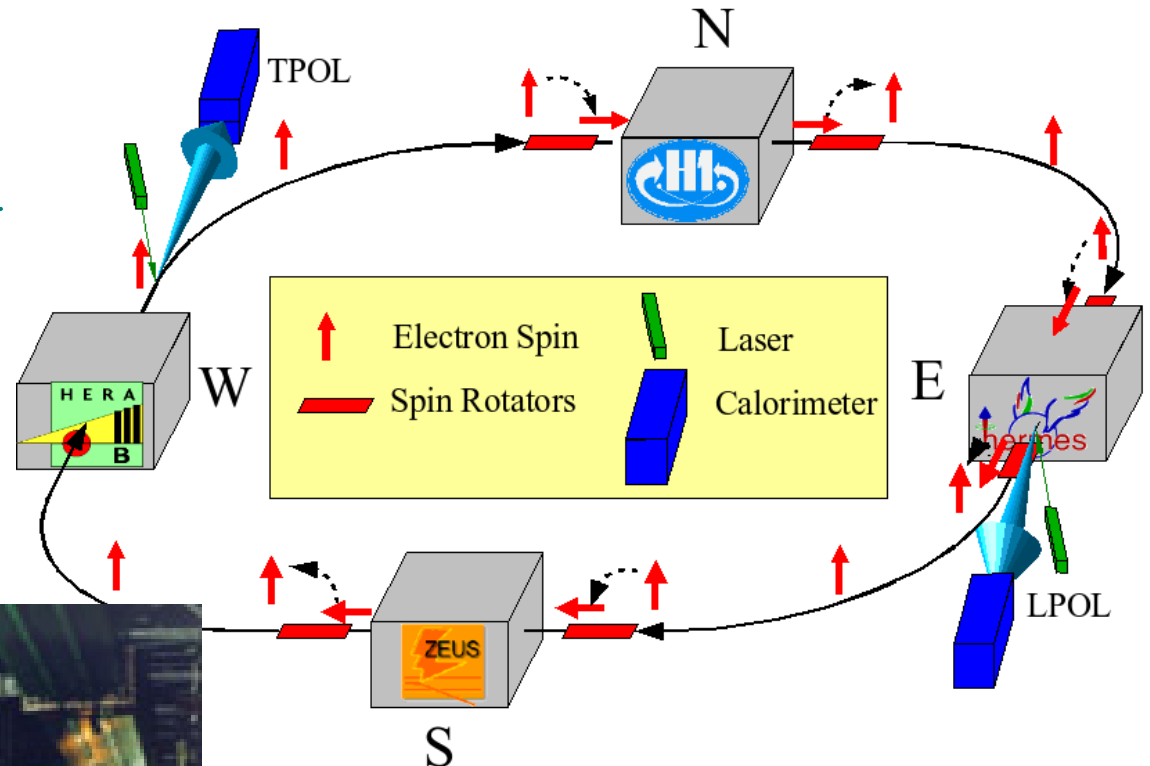


Summary

- HERA operation ended on June 30 2007
- nearly 0.5 fb^{-1} of high quality data were collected per experiment
- many analyses use already full dataset
- H1 and ZEUS started to perform common analyses $\Rightarrow \sim 1 \text{ fb}^{-1}$
- preliminary results show no hints of physics beyond the standard model
- ...but: HERA is competitive in setting limits!

Lepton Polarisation

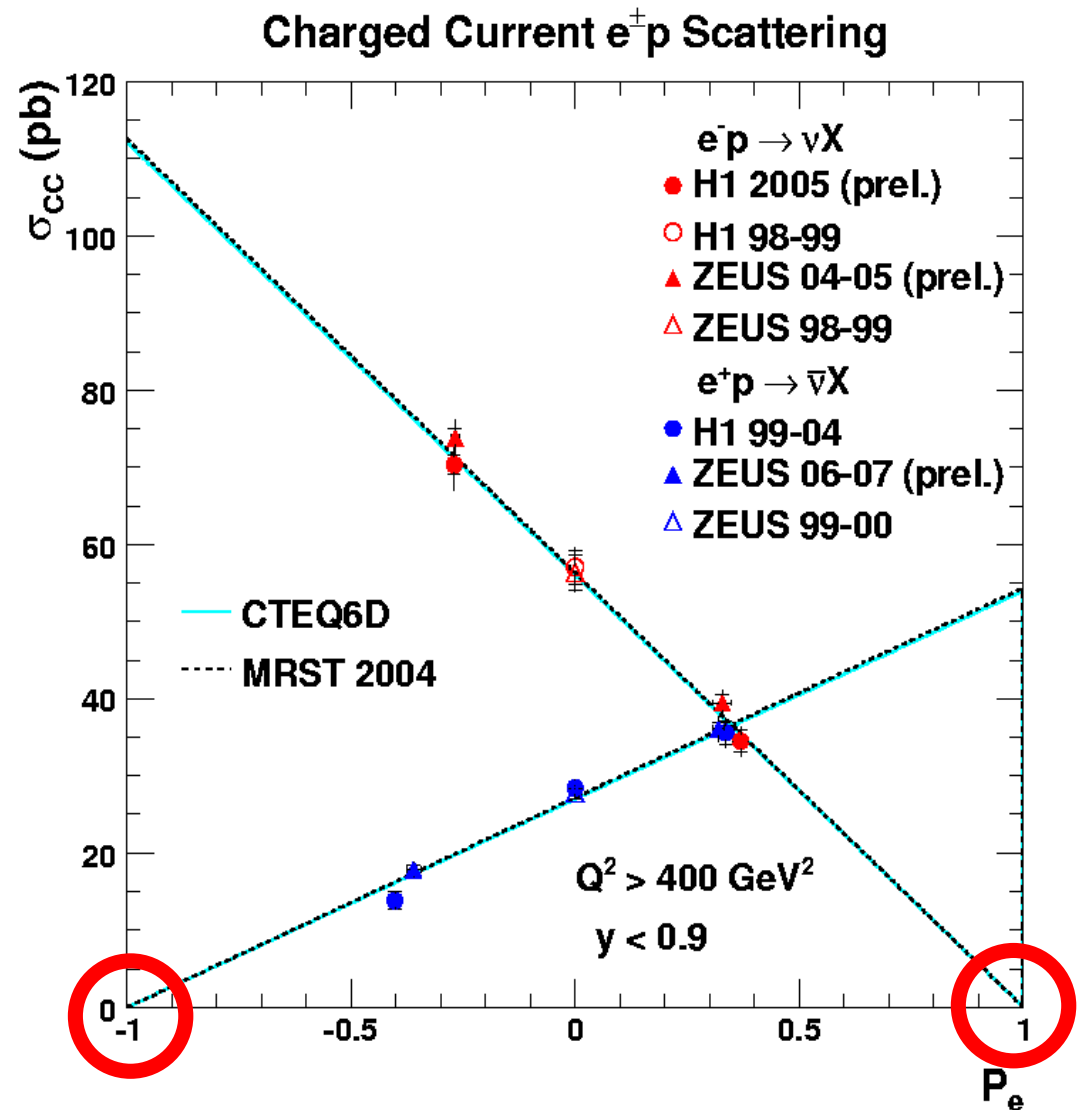
- synchrotron radiation leads to build-up of transverse polarisation due to Sokolov-Ternov effect
- spin rotators provide longitudinal polarisation in straight sections



- polarisation is measured by Compton backscattering of laser photons
- currently ~3% accuracy, improvement expected

Charged Current: Polarisation dependence

- SM: $\sigma(P) = (1 \pm P) \sigma_0$
- extrapolation to $P = \pm 1$:
consistent with $\sigma = 0$
- limit on righthanded W : $M(W_R) > 208 \text{ GeV}$
at 95% CL
- Tevatron:
 $M(W') > 790 \text{ GeV}$



General Search with $p_T > 20$ GeV-objects

Select regions with largest deviations from invariant mass spectra, calculate probabilities

