



# Searches at HERA



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DESY

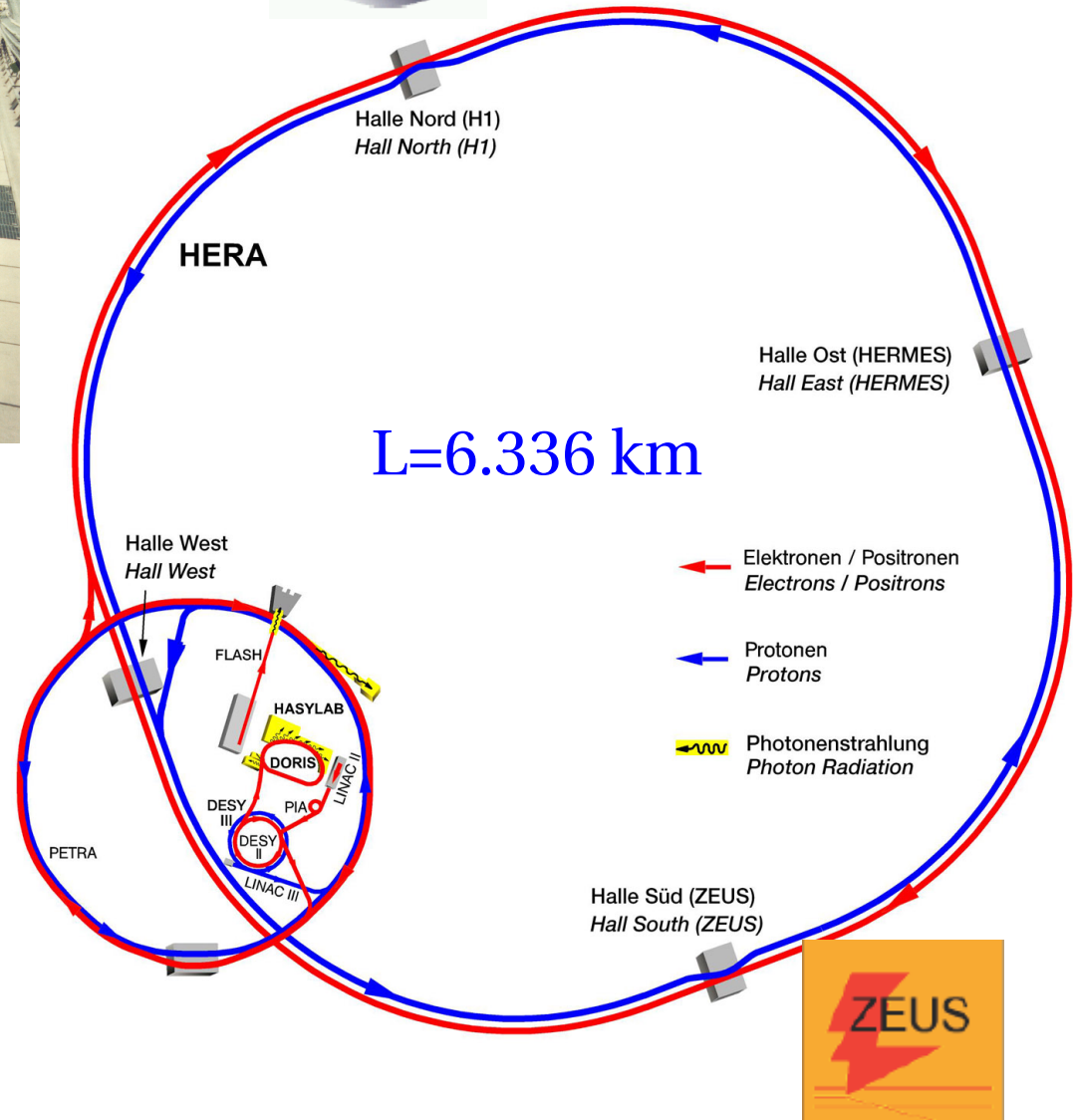
Aspen 2008 Winter Conference



- HERA
- Inclusive signatures
- Model-based searches
- Lepton signatures
- General search
- Summary



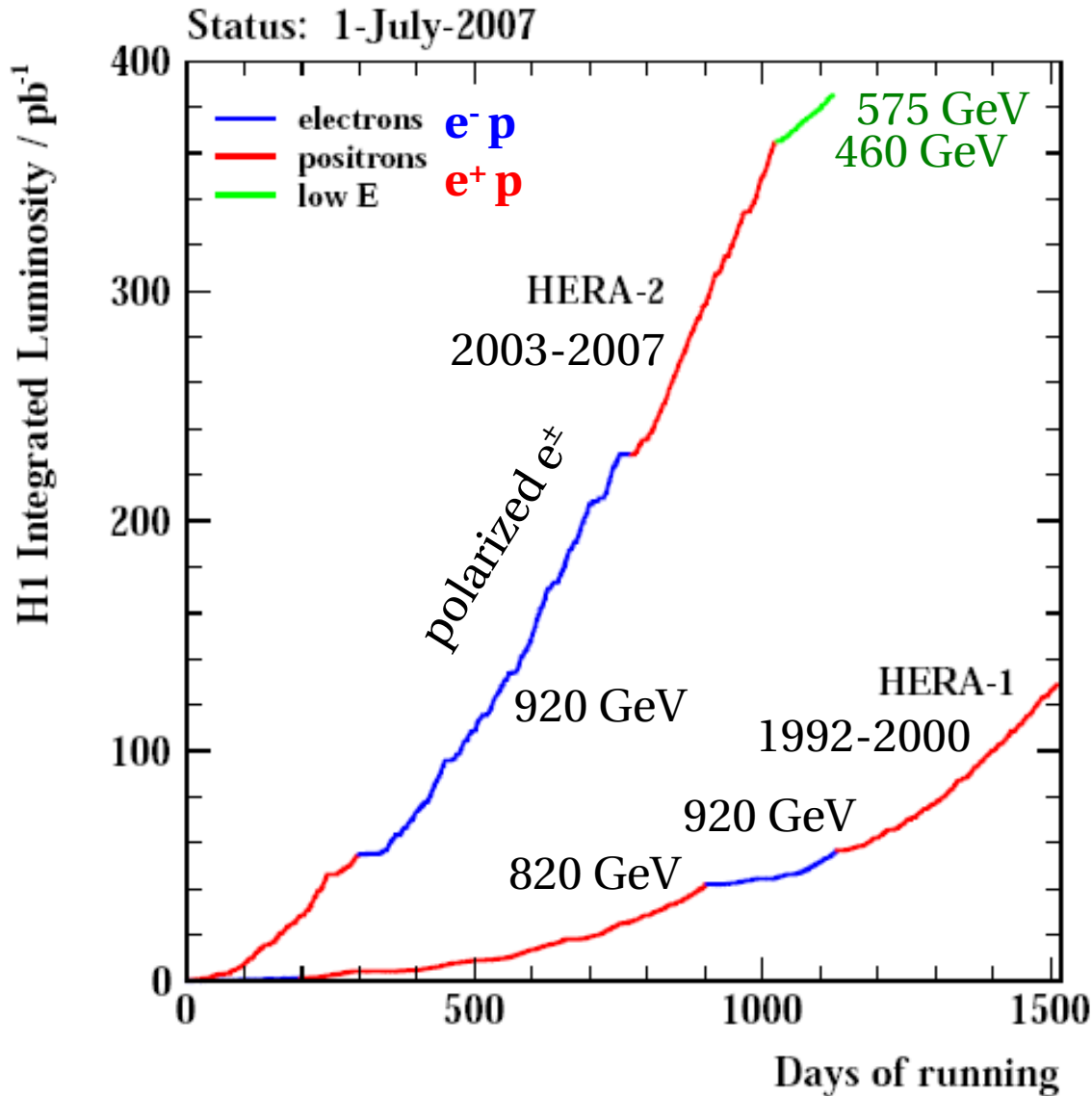
# Hadron Elektron Ring Anlage HERA



- World's only ep accelerator and collider
- Operated 1992 - 2007
- p: 460-920 GeV, 110 mA
- e: 27.6 GeV, 45 mA
- 2 ep collider experiments: H1 and ZEUS.



# Luminosity collection

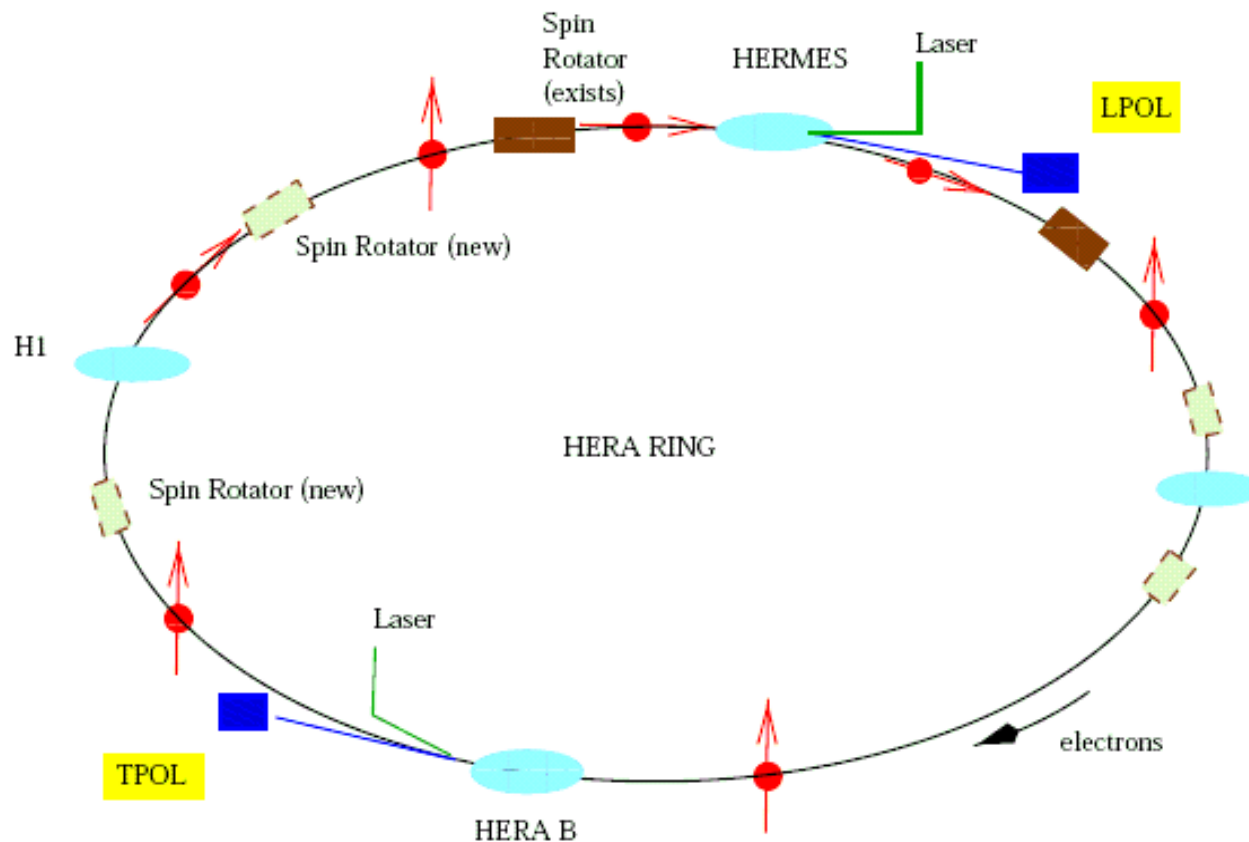


- H1 and ZEUS each have collected  $0.5 \text{ fb}^{-1}$  of high quality physics data, balanced in  $e^+$  and  $e^-$ .
- 72% of the luminosity is from HERA II, with longitudinally polarized  $e^\pm$  beams.
- The detectors have been operated successfully and efficiently, including all upgrades.

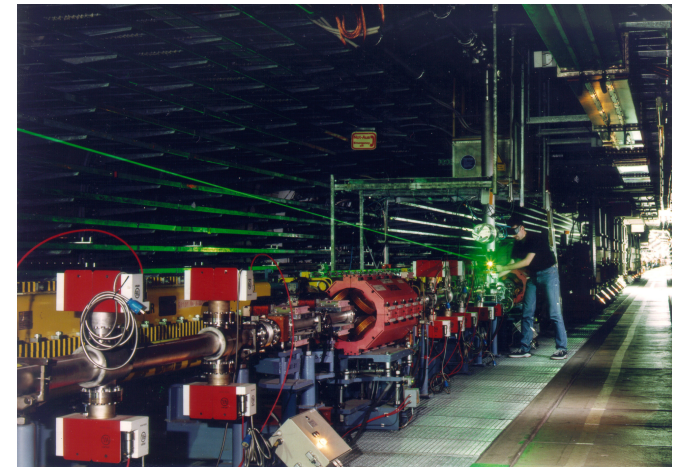
# Polarized $e^\pm$

$e$  beam acquires transverse polarization by the Sokolov-Ternov effect (magnetic moment couples to the dipole B field, spin flip by synchrotron radiation emission).

Spin rotators provide longitudinal polarization at the experiments (Hermes since 1995, H1 and ZEUS since 2003).



- Polarization typically 30-40%.
- Polarization monitored by Compton backscattering of laser beams.

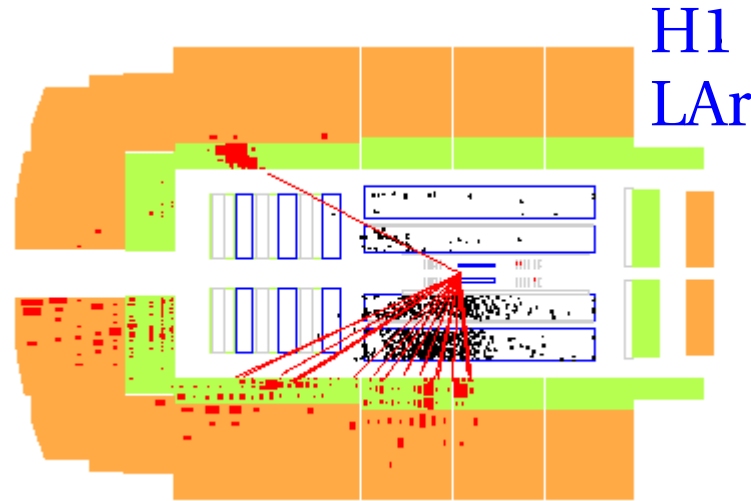
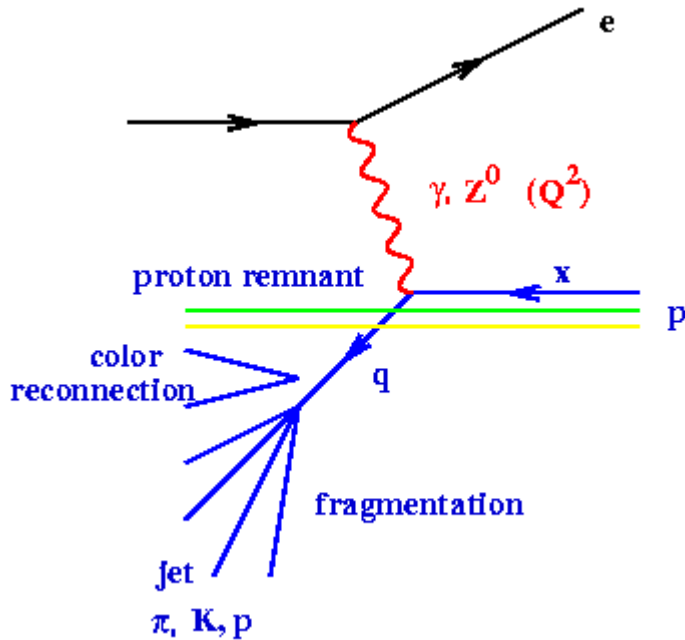




# Deep inelastic scattering



Neutral current:  $\gamma$  or Z exchange

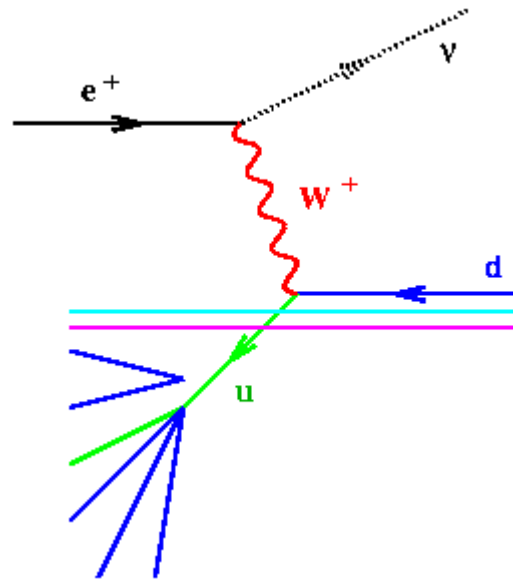


jet balanced by  $e$  in  $E_t$ : good for calibration.  
 1% jet energy scale uncertainty above 20 GeV.

- $Q^2$ : 4-momentum transfer from  $e$  to  $q$  by boson.
- $x$  = momentum fraction quark/proton.
- $s = 4E_e E_p = 101400 \text{ GeV}^2$ .
- $y = Q^2/sx = \text{inelasticity} = \frac{1}{2}(1 - \cos\theta^*)$  eq cms angle.

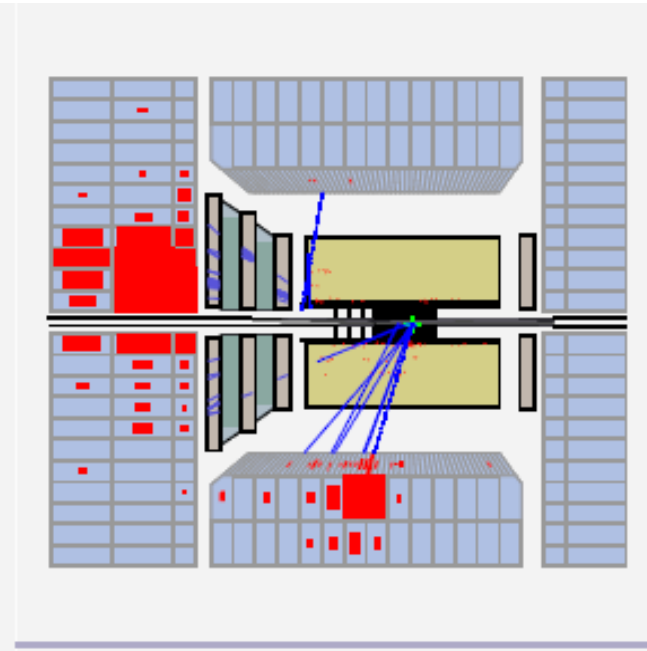
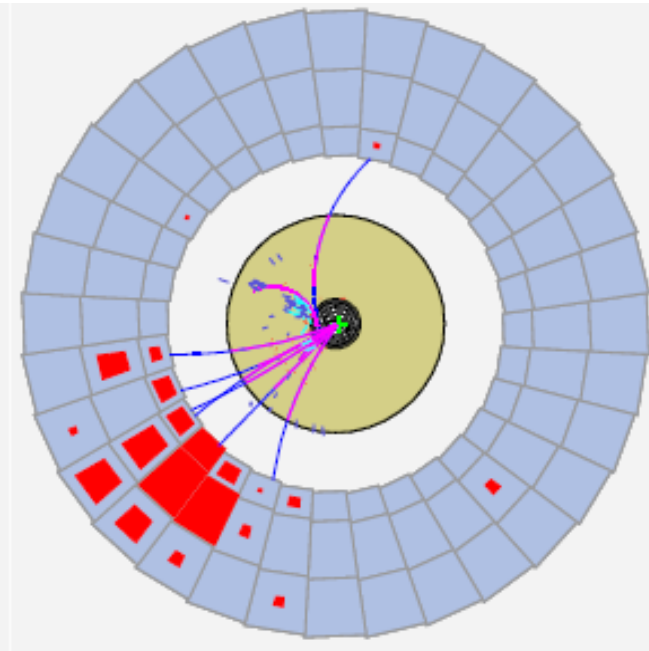


# Charged current: $W^\pm$ exchange



$Q^2, x, y$  can be reconstructed from the hadronic final state.

missing transverse momentum: neutrino



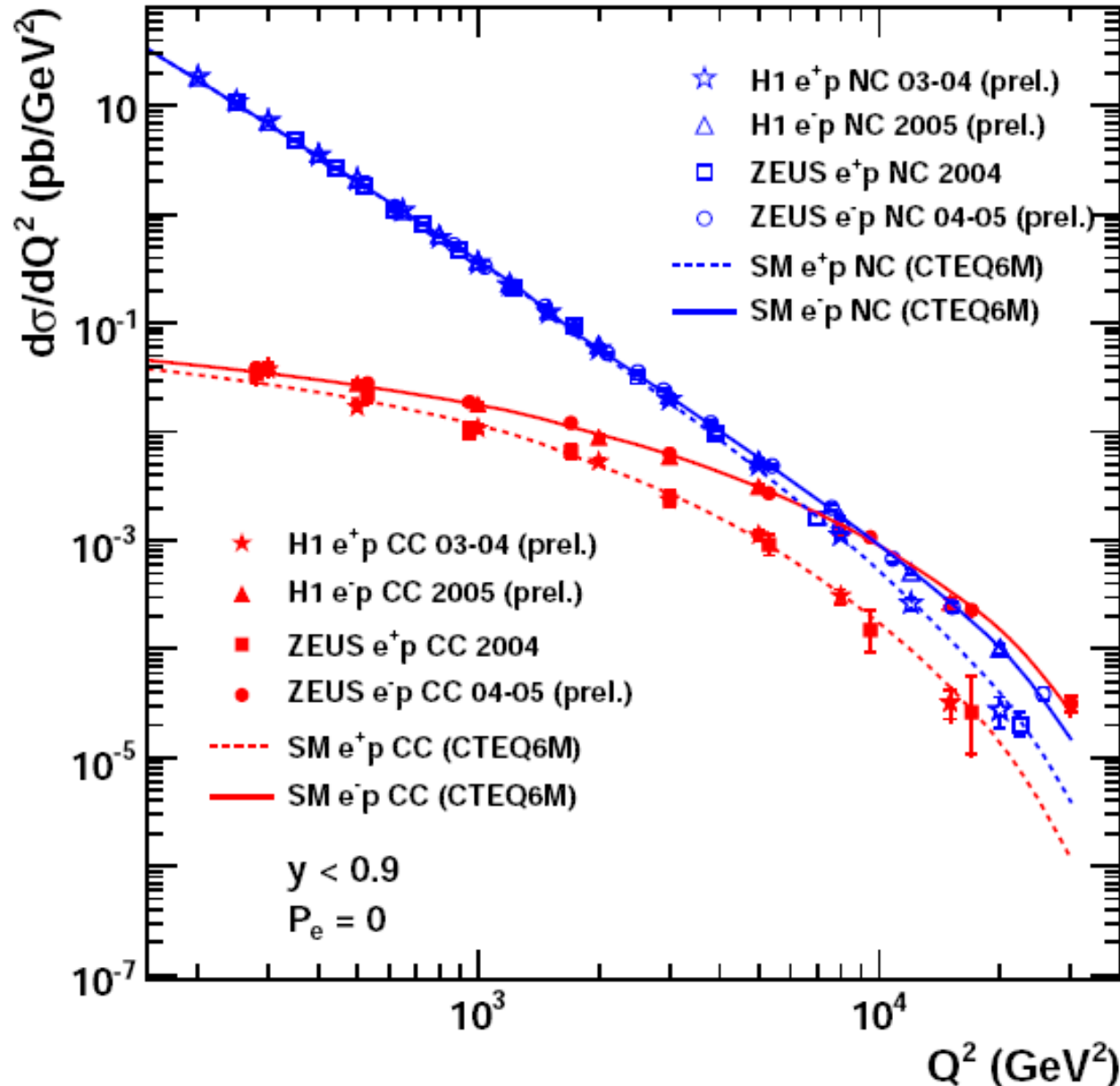
**ZEUS**  
compensating  
U-scintillator  
calorimeter



# $e^+ p$ and $e^- p$ cross sections vs $Q^2$



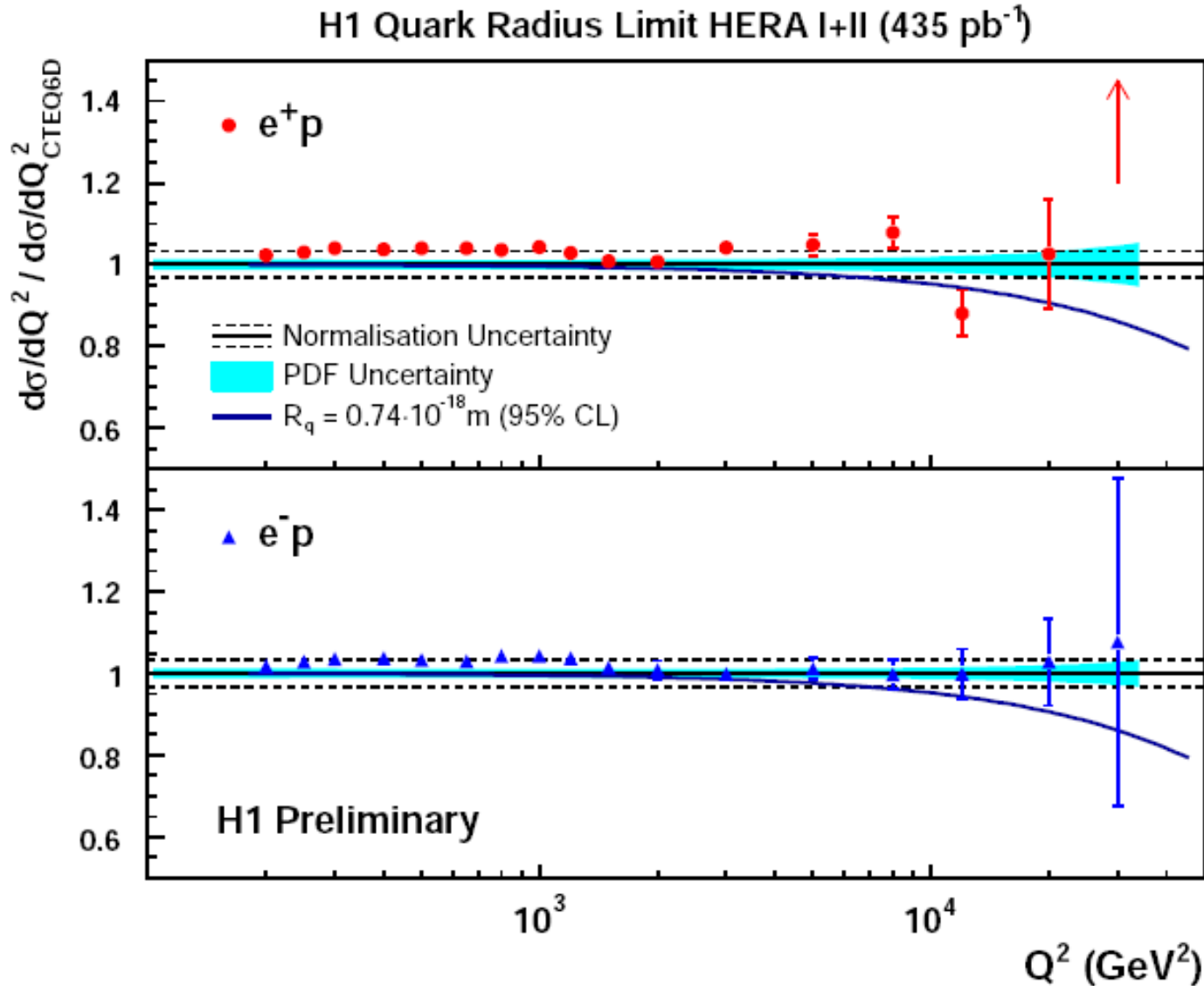
HERA II



- Destructive and constructive  $\gamma Z$  interference in Neutral Current.
- Charged Current:
  - $e^-u$  enhanced
  - $e^+d$  suppressed.
- Electroweak unification at  $Q^2 \sim m_W^2$ .
- A textbook measurement from HERA.



# Quark radius limit



Quark radius  
form factor:  
 $(1 - R_q^2 Q^2/6)$

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

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



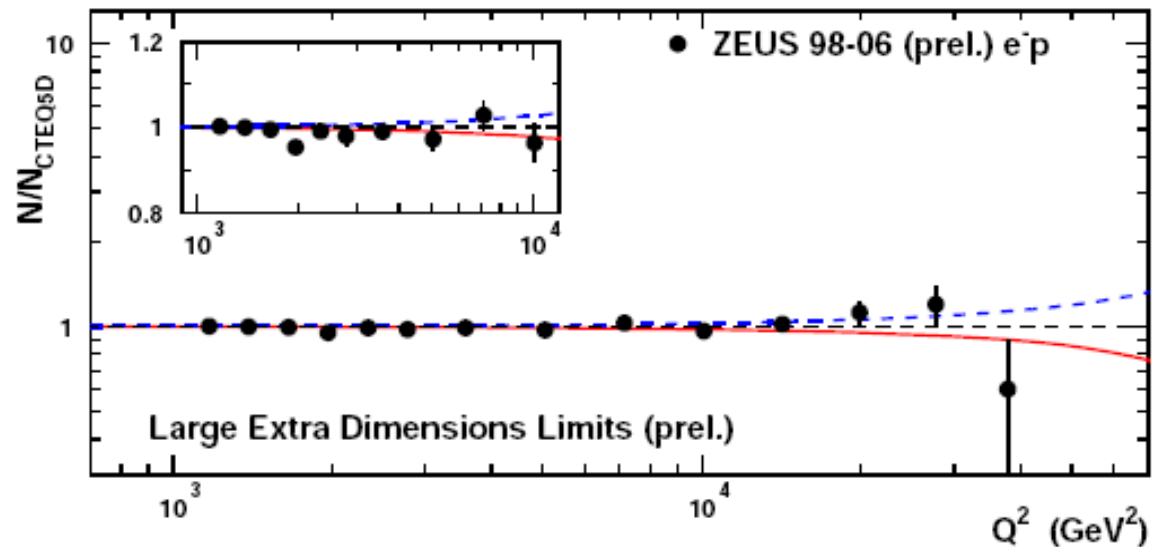
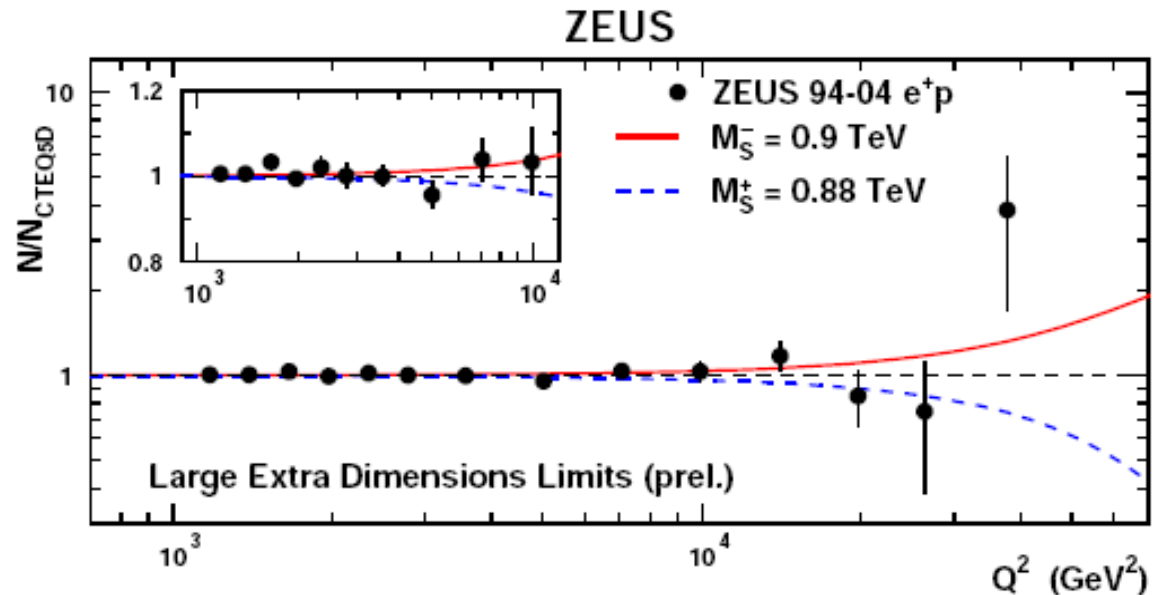
# Large extra dimensions?



Limit on the contribution of graviton exchange in theories with large extra dimensions at scale  $M_S^\pm$ ,  
 Destructive or constructive interference with standard model:

$$M_S^- > 0.9 \text{ TeV}$$

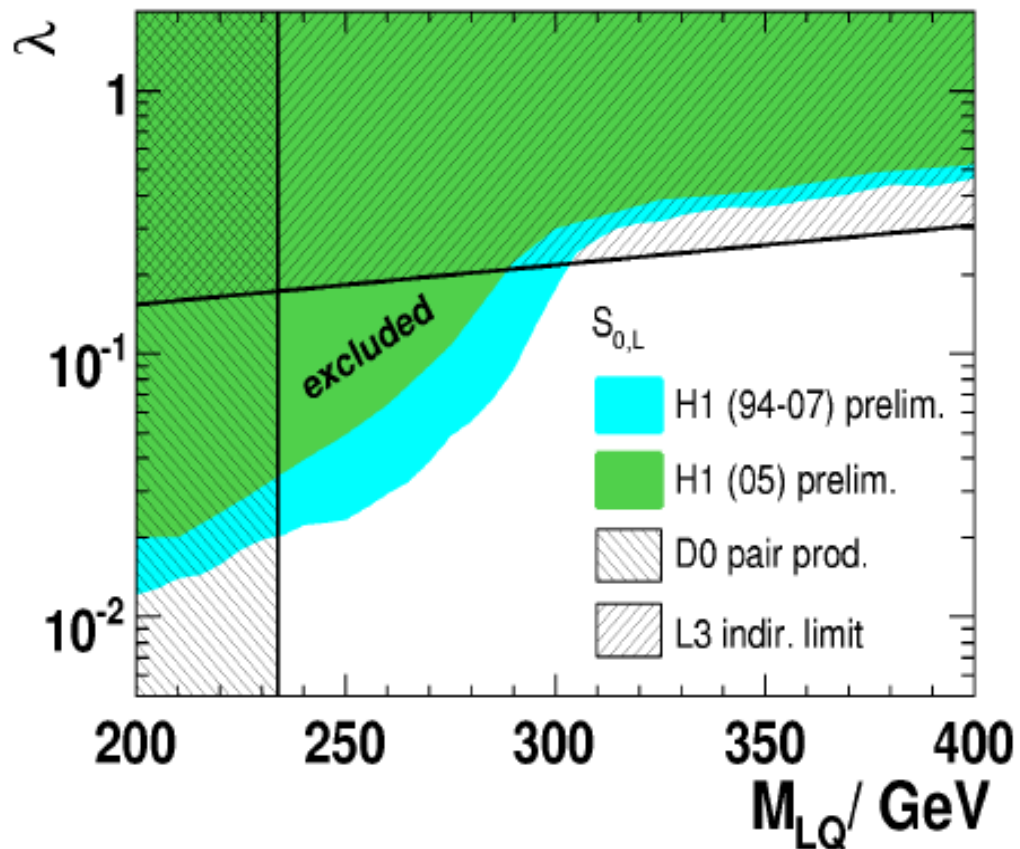
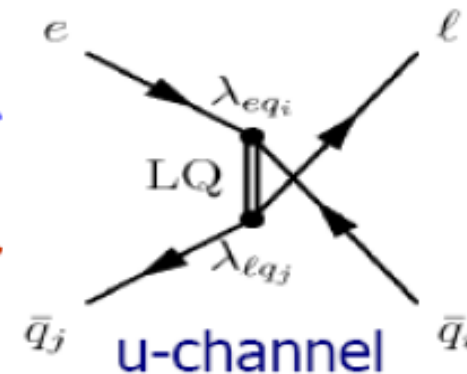
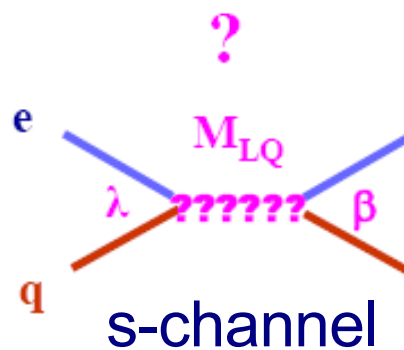
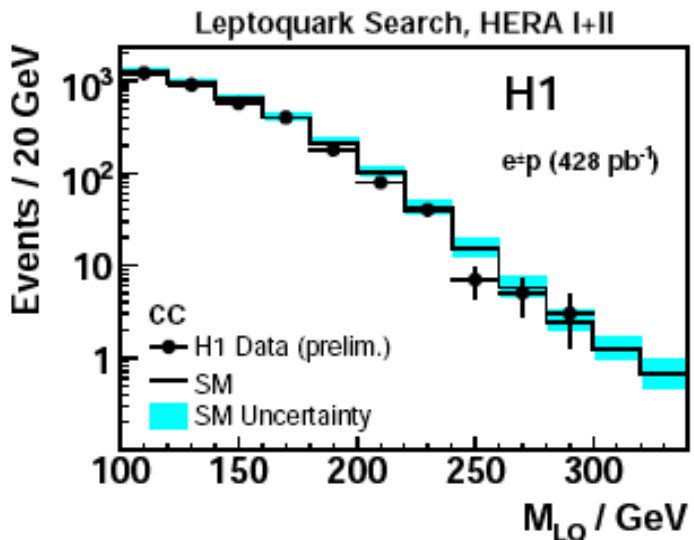
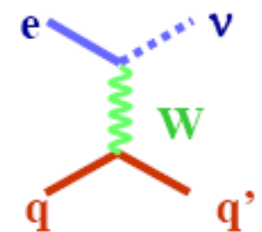
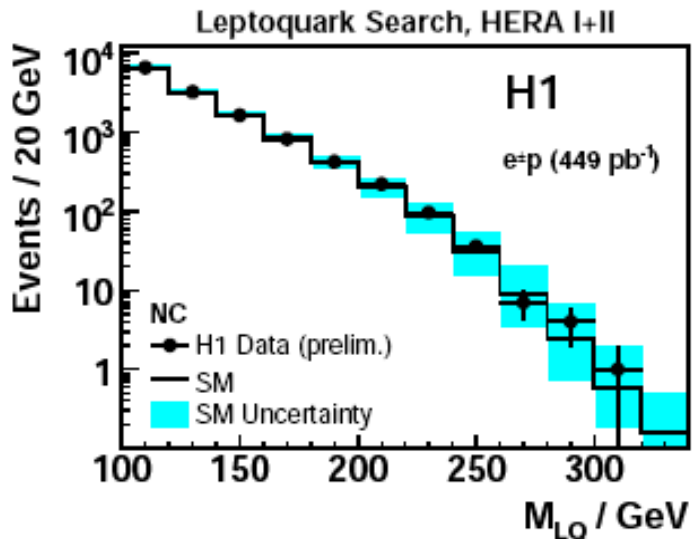
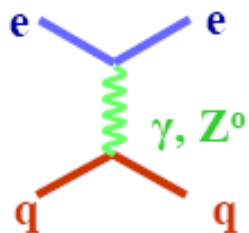
$$M_S^+ > 0.88 \text{ TeV}$$





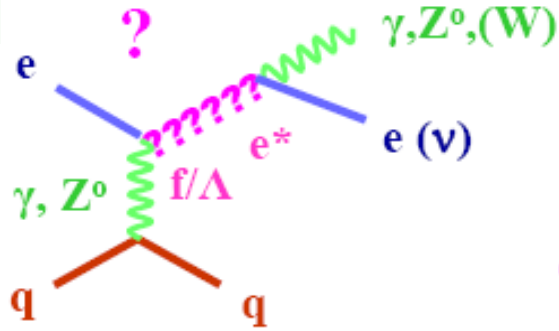
# 1<sup>st</sup> generation Leptoquarks?

Mass peak at  $\sqrt{x} \sqrt{s}$  ?



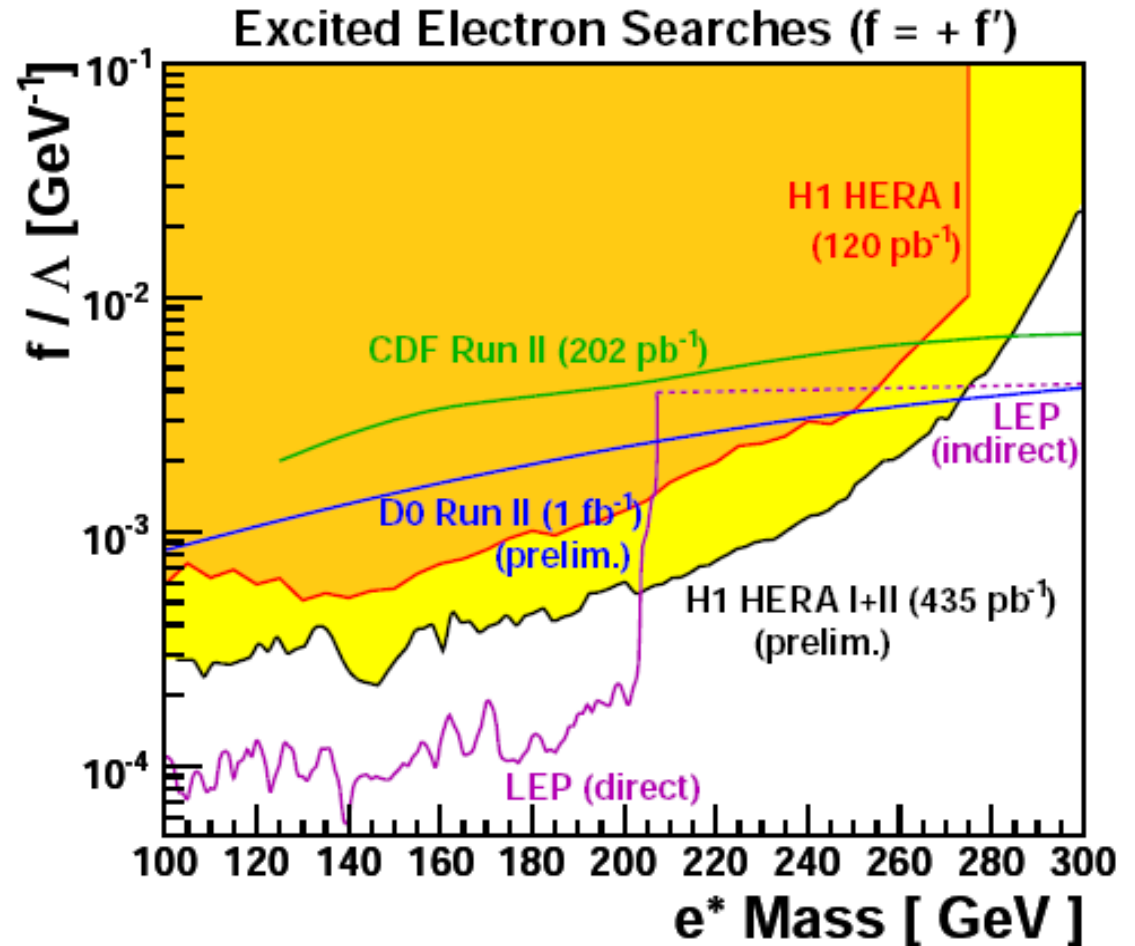
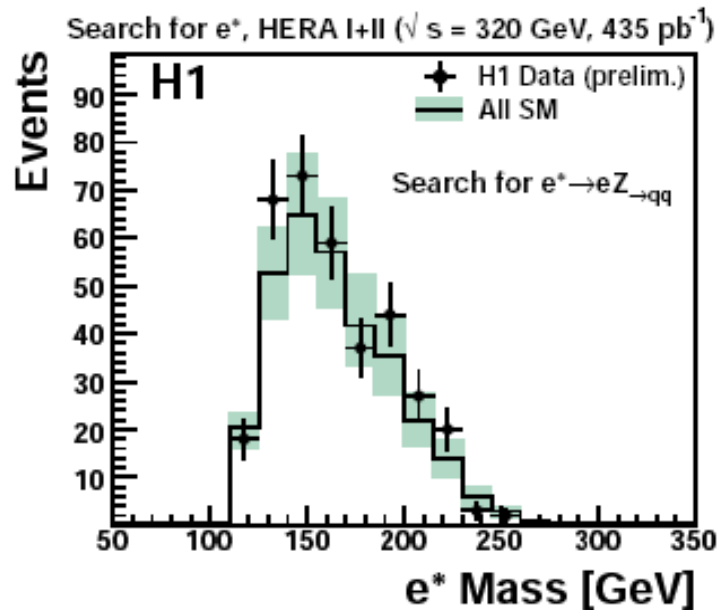


# Excited electrons?



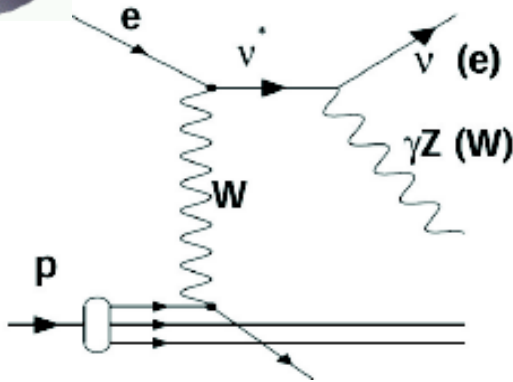
Hagiwara model of gauge mediation:  
 U(1) coupling  $f$   
 SU(2) coupling  $f'$ .

- $e^* \rightarrow e \gamma$
- $e^* \rightarrow e Z, Z \rightarrow q\bar{q}$
- $e^* \rightarrow \nu W, W \rightarrow qq'$



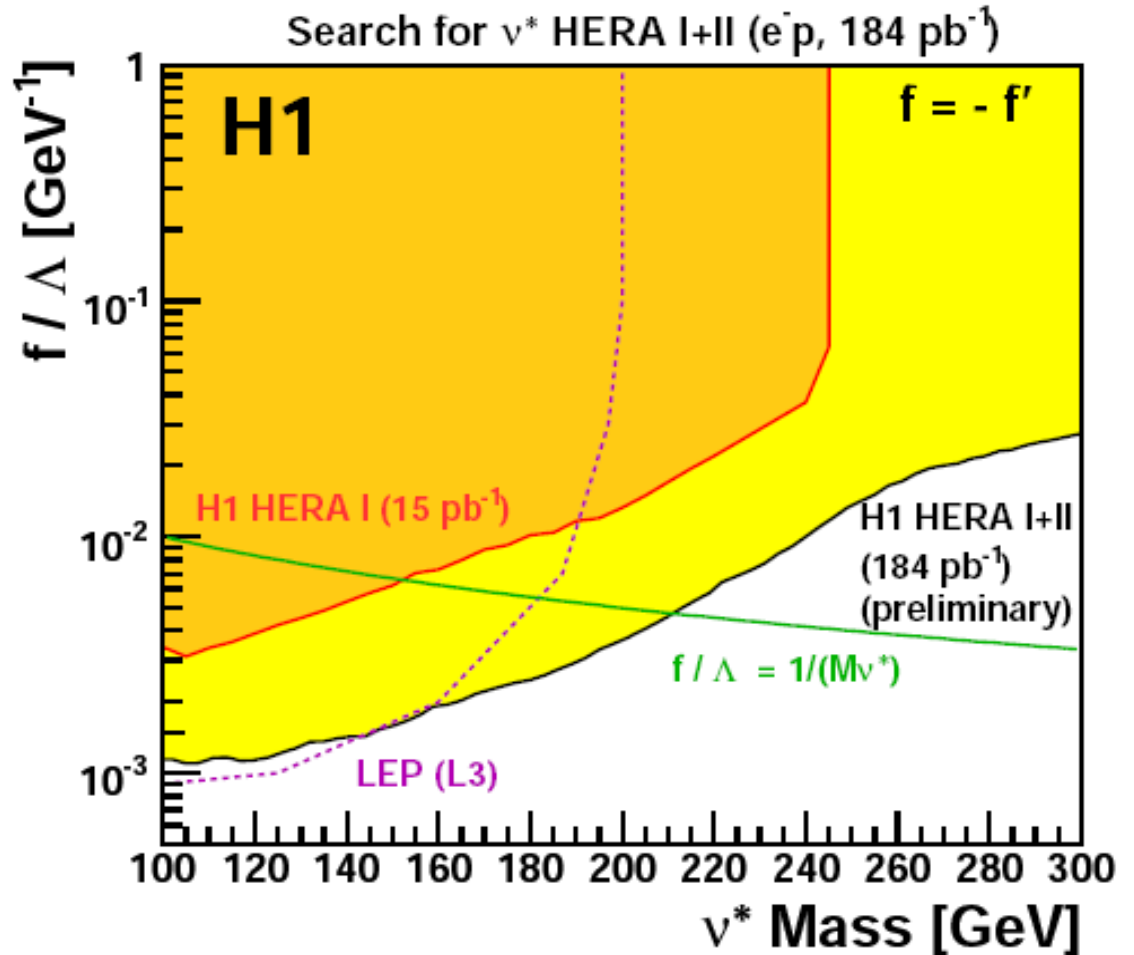
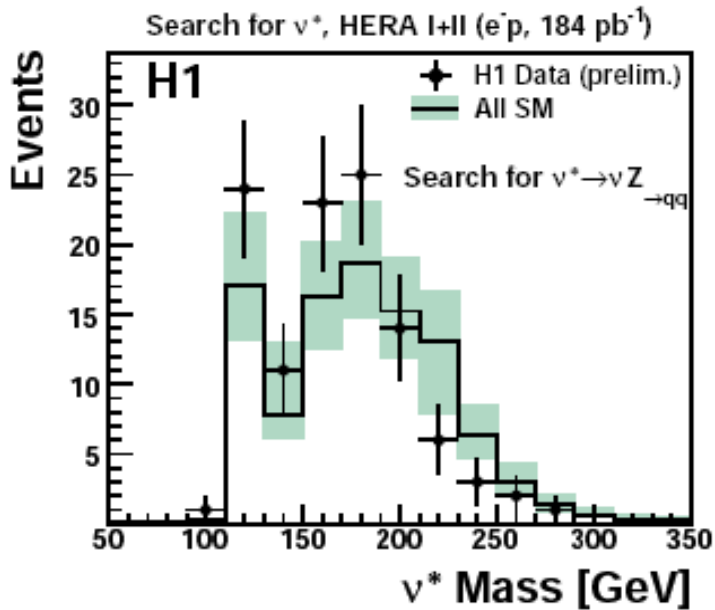


# Excited neutrinos?



$e^- p$  data used: enhanced charged current cross section.

- $\nu^* \rightarrow \nu \gamma$
- $\nu^* \rightarrow \nu Z, Z \rightarrow q\bar{q}$
- $\nu^* \rightarrow e W, W \rightarrow qq'$

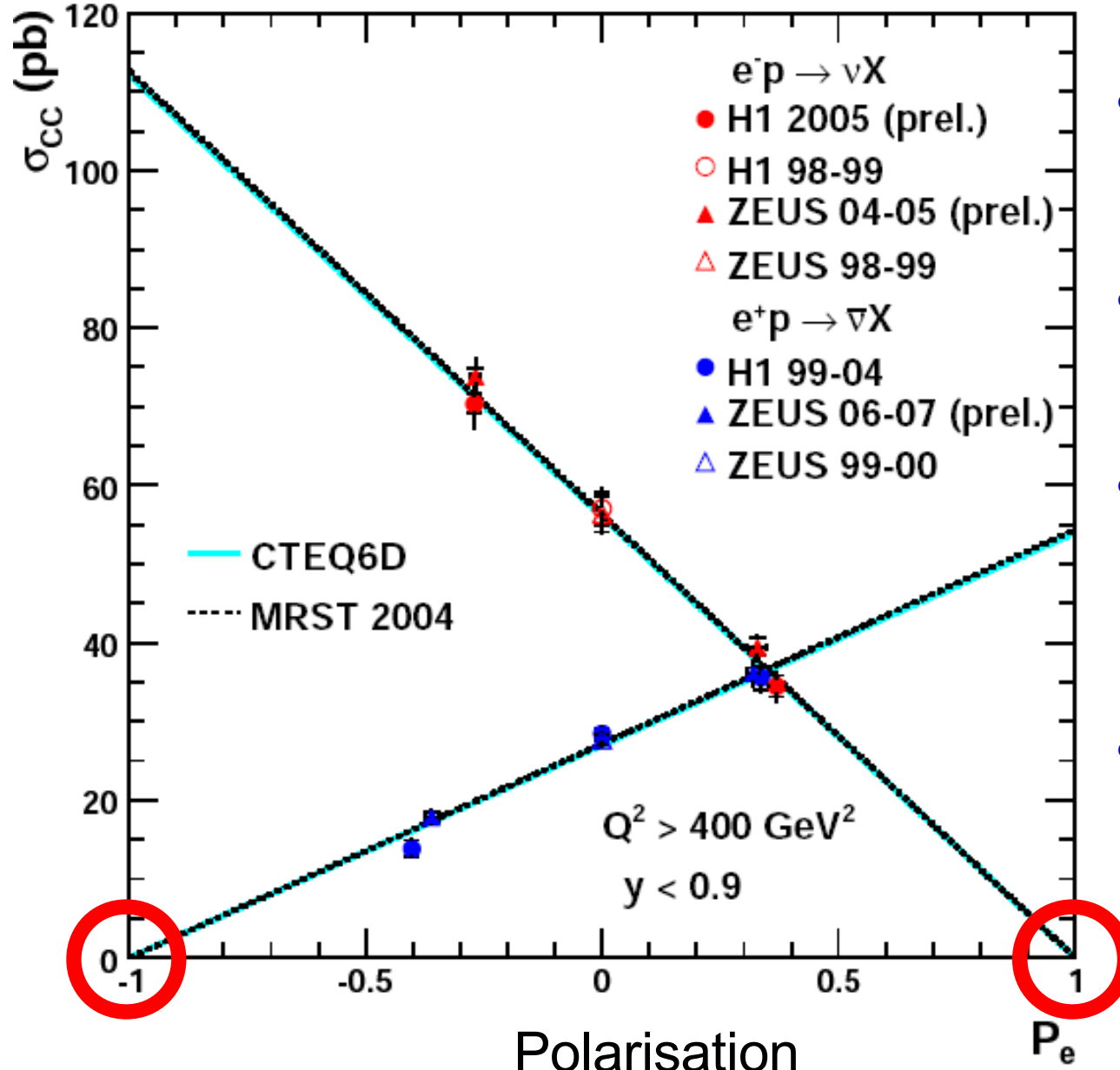




# Charged current with polarized $e^\pm$



## Charged Current $e^\pm p$ Scattering



- Standard model:  

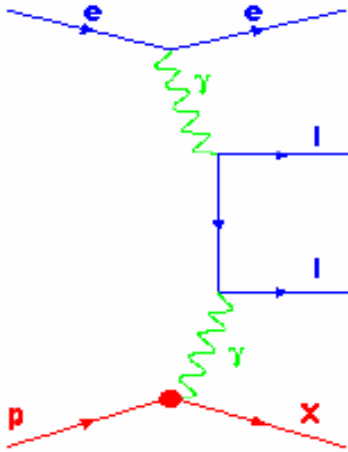
$$\sigma = (1 \pm P) \cdot \sigma_0$$
- Extrapolation to  $P = \pm 1$ :  
 $\sigma$  consistent with zero.
- limit on right-handed  $W$ :  
 $M(W_R) > 208 \text{ GeV}$ .
- CDF:  
 $M(W_R) > 790 \text{ GeV}$ .



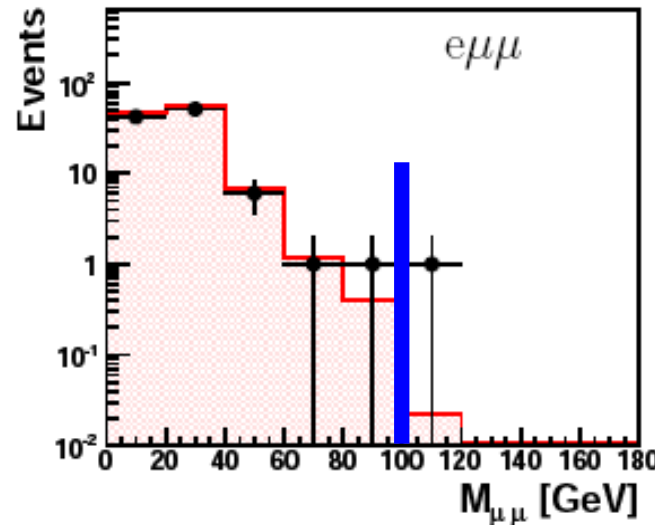
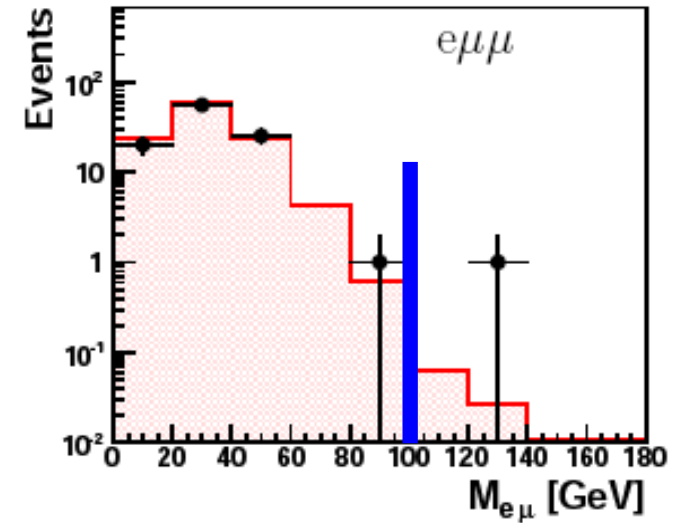
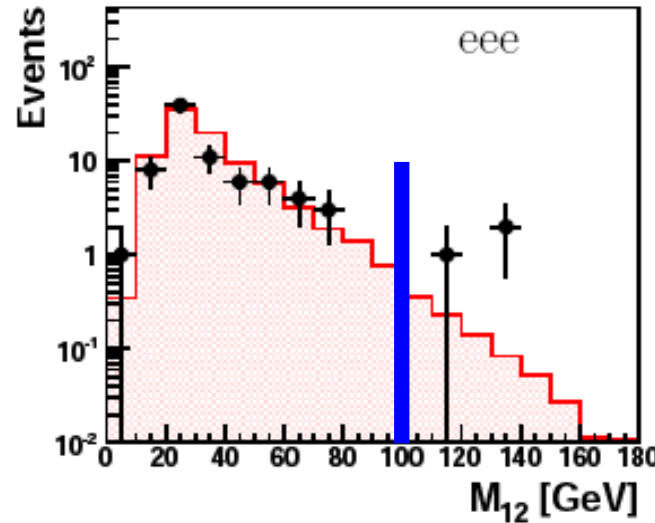
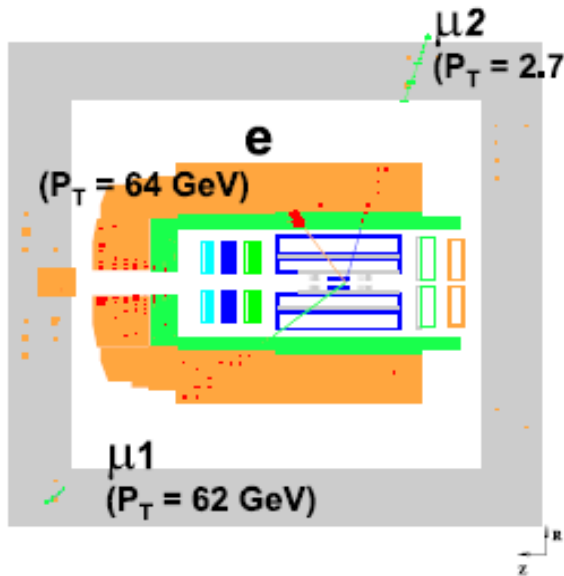
# Multi-leptons

example: tri-lepton mass spectra:

H1 Multi-lepton analysis HERA I+II (459 pb<sup>-1</sup>)



2 or 3 e/ $\mu$  observed



- H1 Data (prelim.)
- DIS+Compton
- Pair Production

H1 observes 9 events with  $M_{ij} > 100 \text{ GeV}$ , for 2.2 expected in  $e^+p$ .



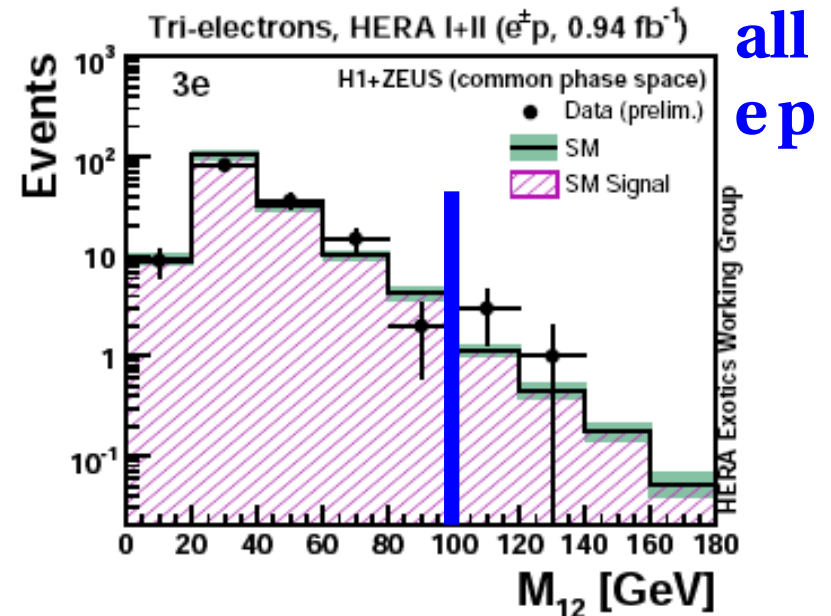
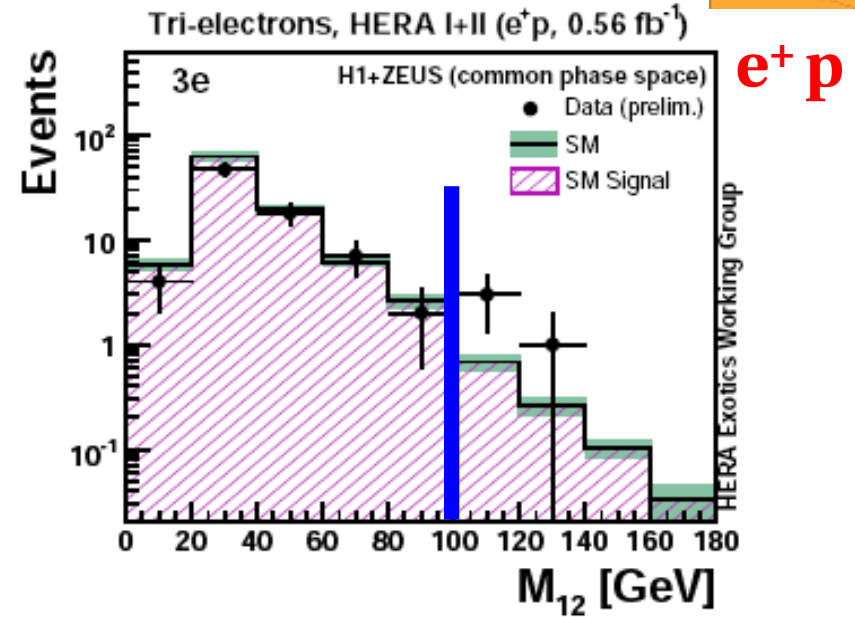
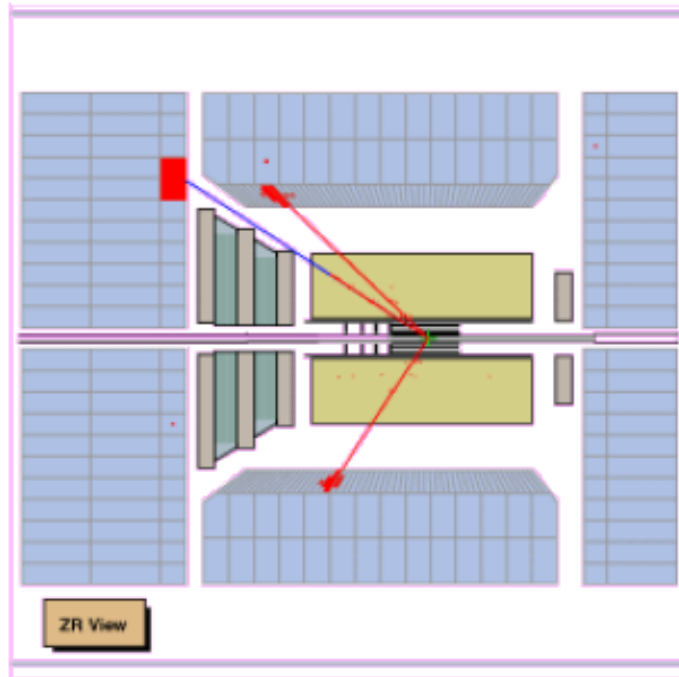
# Multi-electrons



H1 and ZEUS combined  
in common phase space  
for  $M_{12} > 100$  GeV:

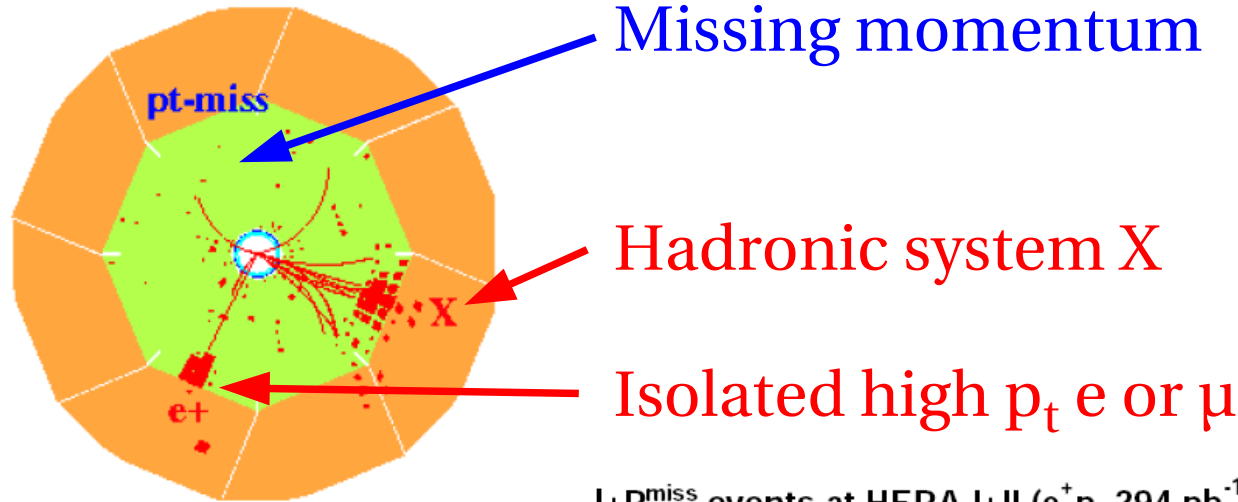
$e^+ p$ : 8 for 3.1 expected  
all ep: 9 for 5.3 expected.

A 3-electron event in ZEUS:

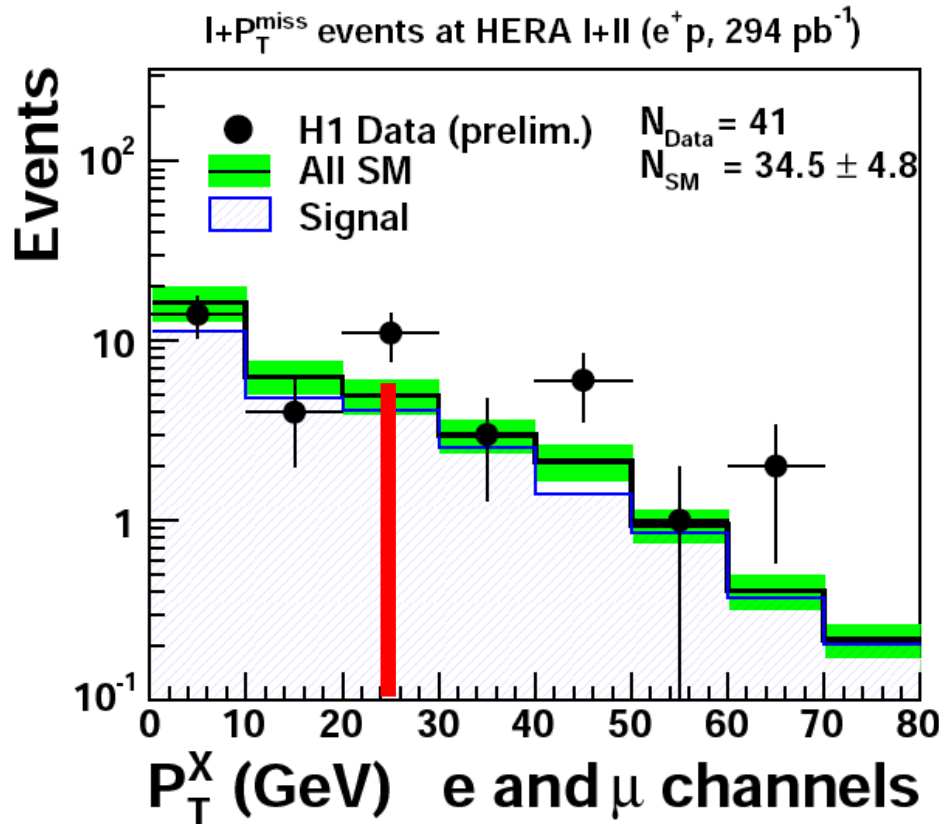
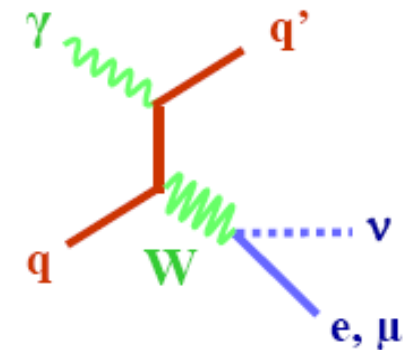




# High $p_t$ leptons and missing $p_t$



Standard model:  
W production,  $\sim 1$  pb.  
but: expect small  $P_T^X$



in  $e^+ p$ ,  
for  $P_T^X > 25$  GeV:  
H1 sees 21 events for  
 $9 \pm 1.5$  expected:  $3.0 \sigma$ .

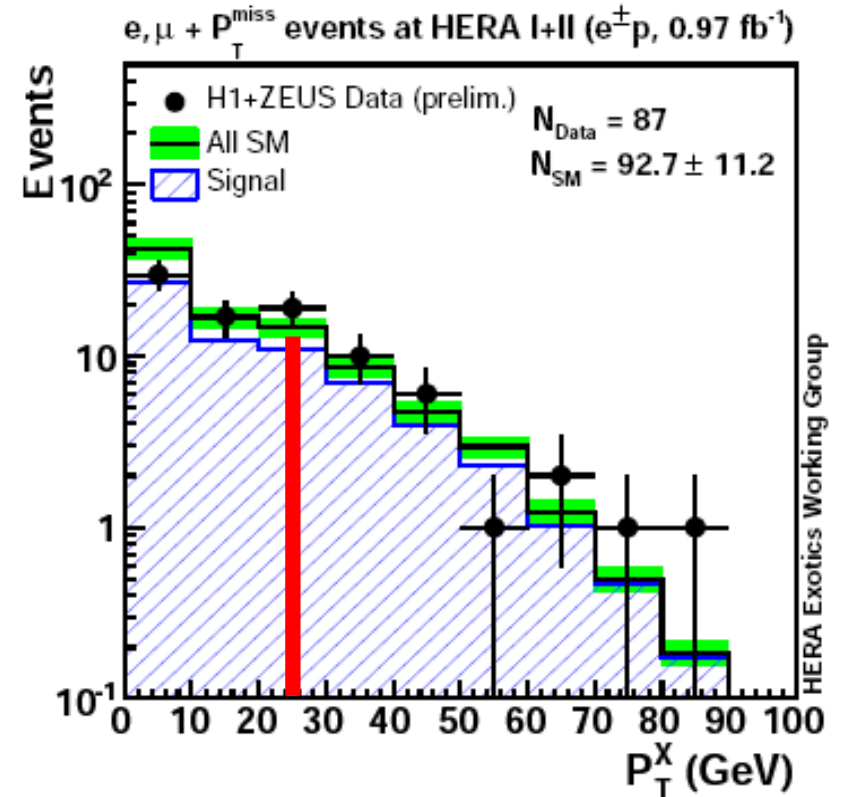
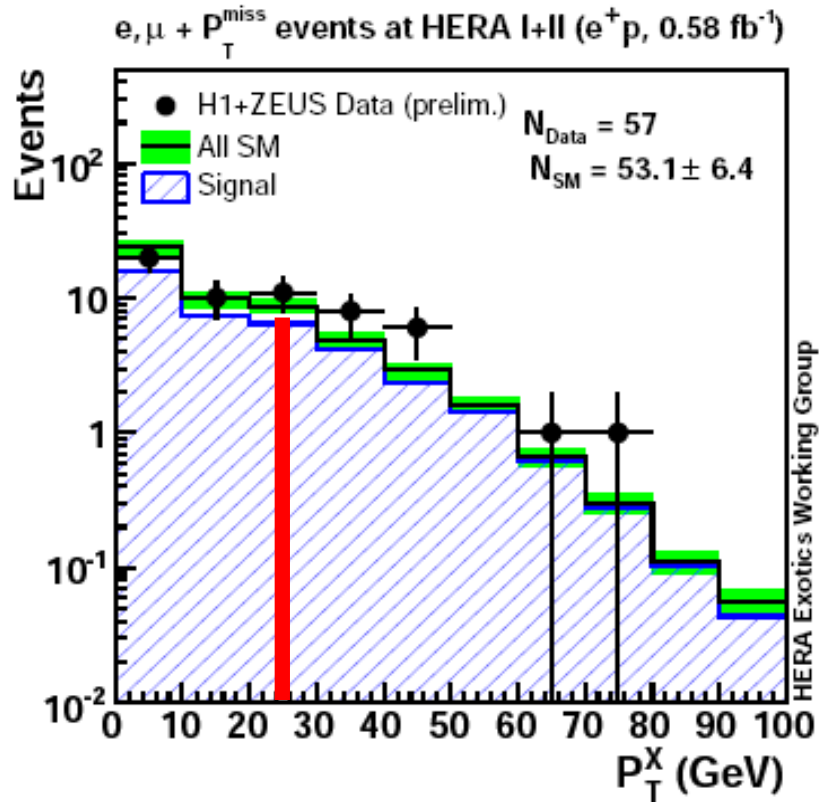




# High $p_t$ leptons and missing $p_t$



H1 and ZEUS combined in a common phase space:



in  $e^+p$ , for  $P_T^X > 25 \text{ GeV}$ :  
 H1 and ZEUS combined  
 see 23 events for  $15 \pm 2$   
 expected:  $1.8 \sigma$ .

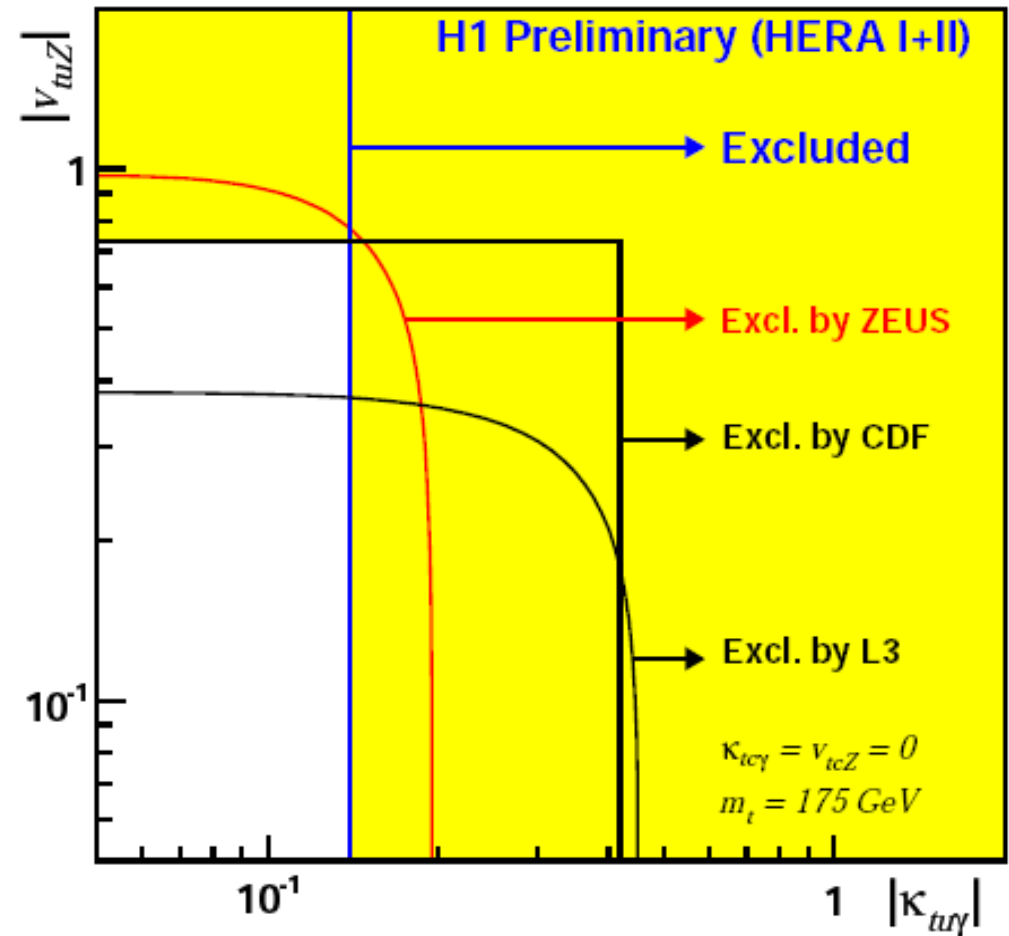
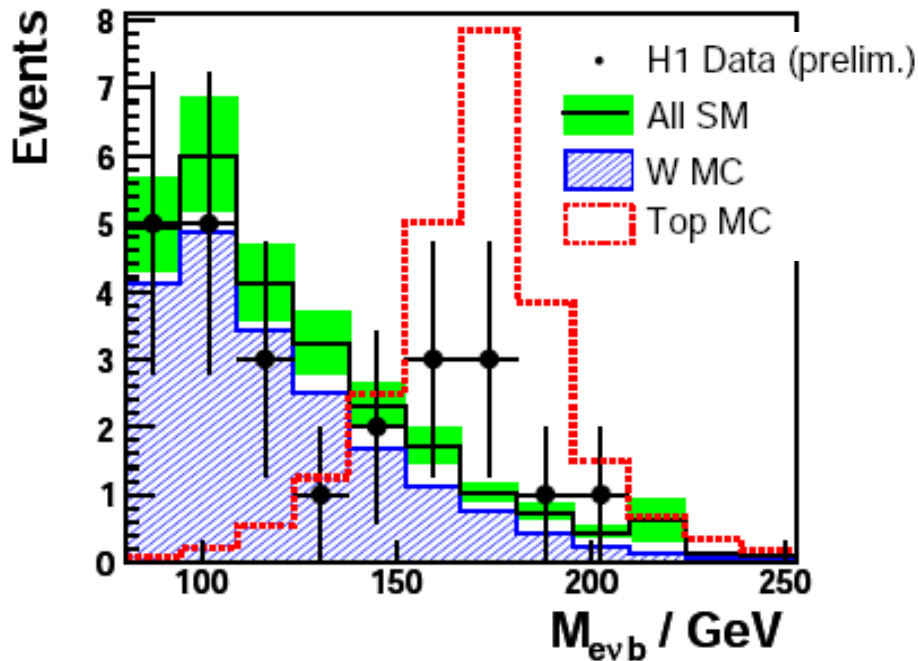
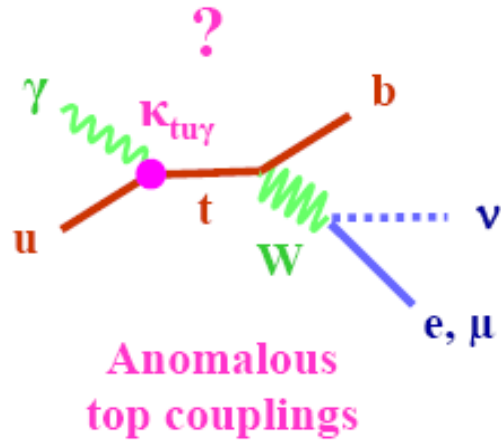
all  $ep$ , for  $P_T^X > 25 \text{ GeV}$ :  
 H1 and ZEUS combined  
 see 29 events for  $25 \pm 3$   
 expected.



# Anomalous top production?



Single top at HERA:  $\sim 1$  fb.

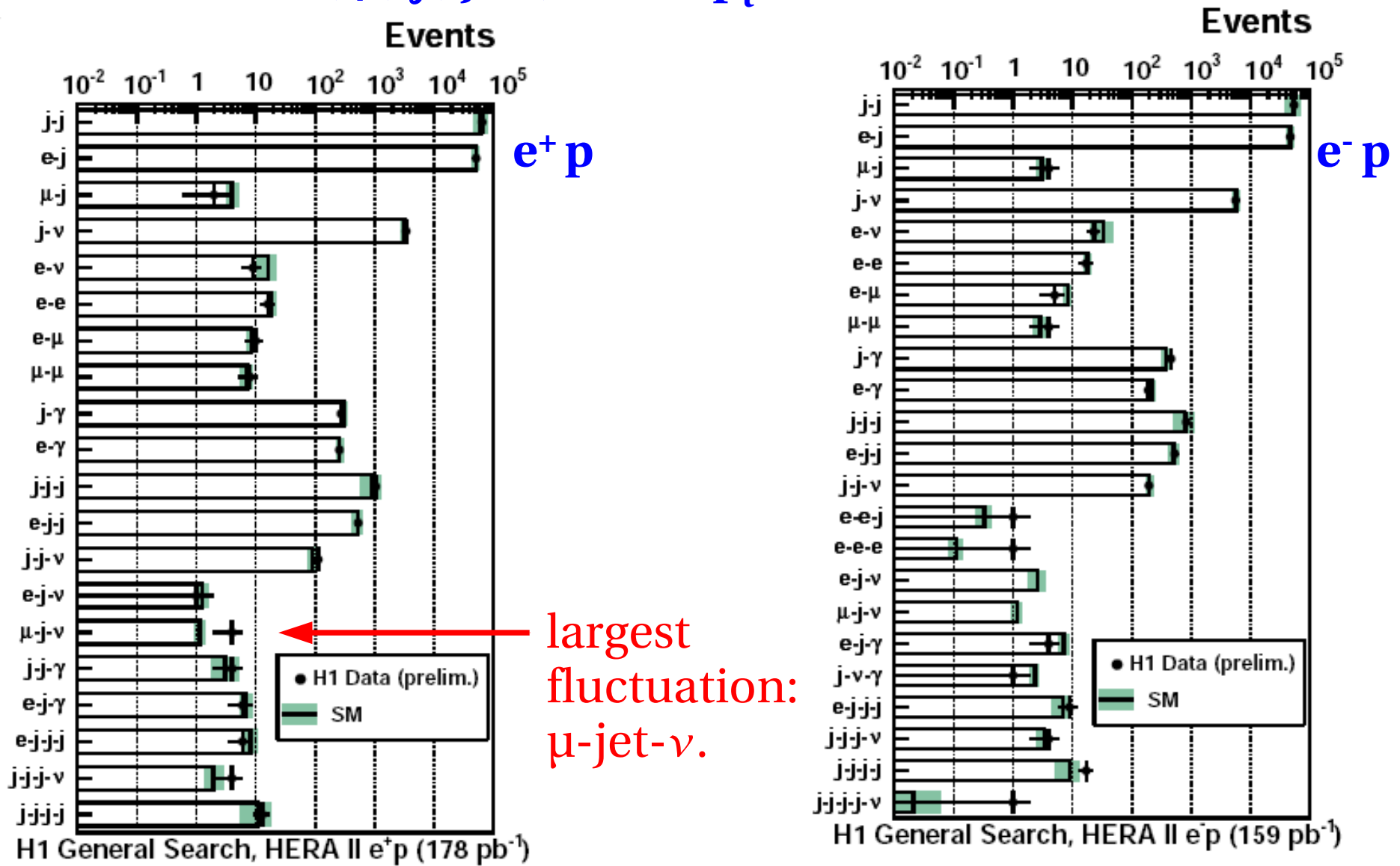


H1 has most stringent limit on t-u- $\gamma$  coupling.



# General search with high $p_t$ objects

$e, \mu, \gamma, \text{jets}, \nu$  with  $p_t > 20 \text{ GeV}$

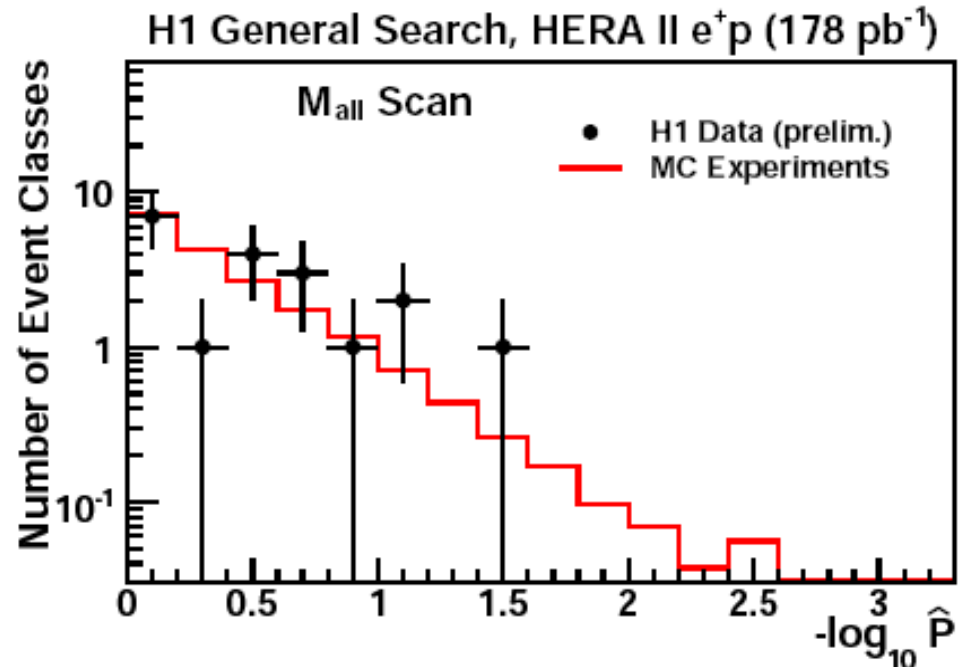
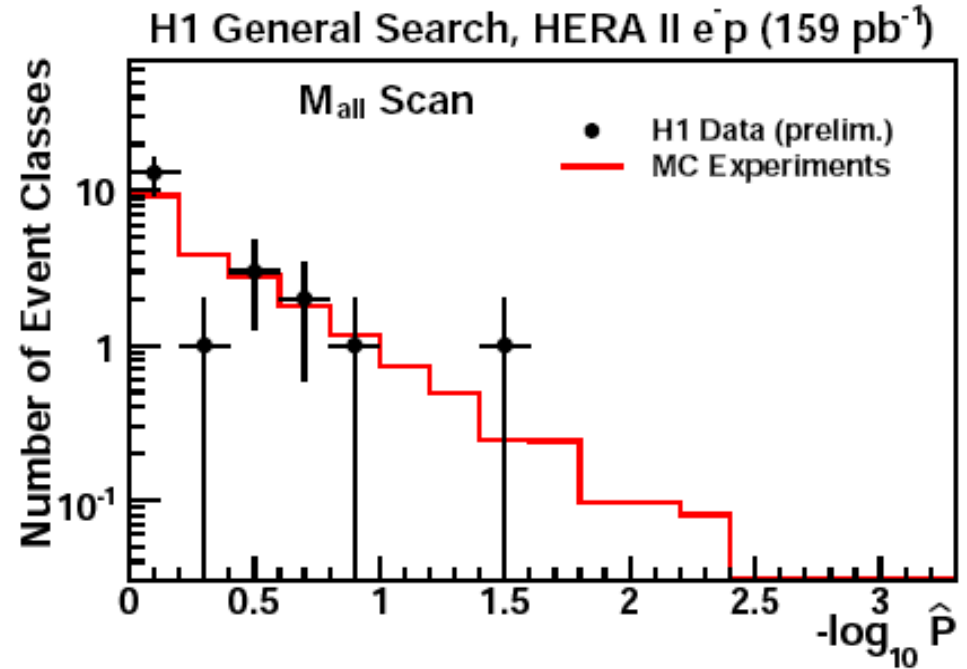
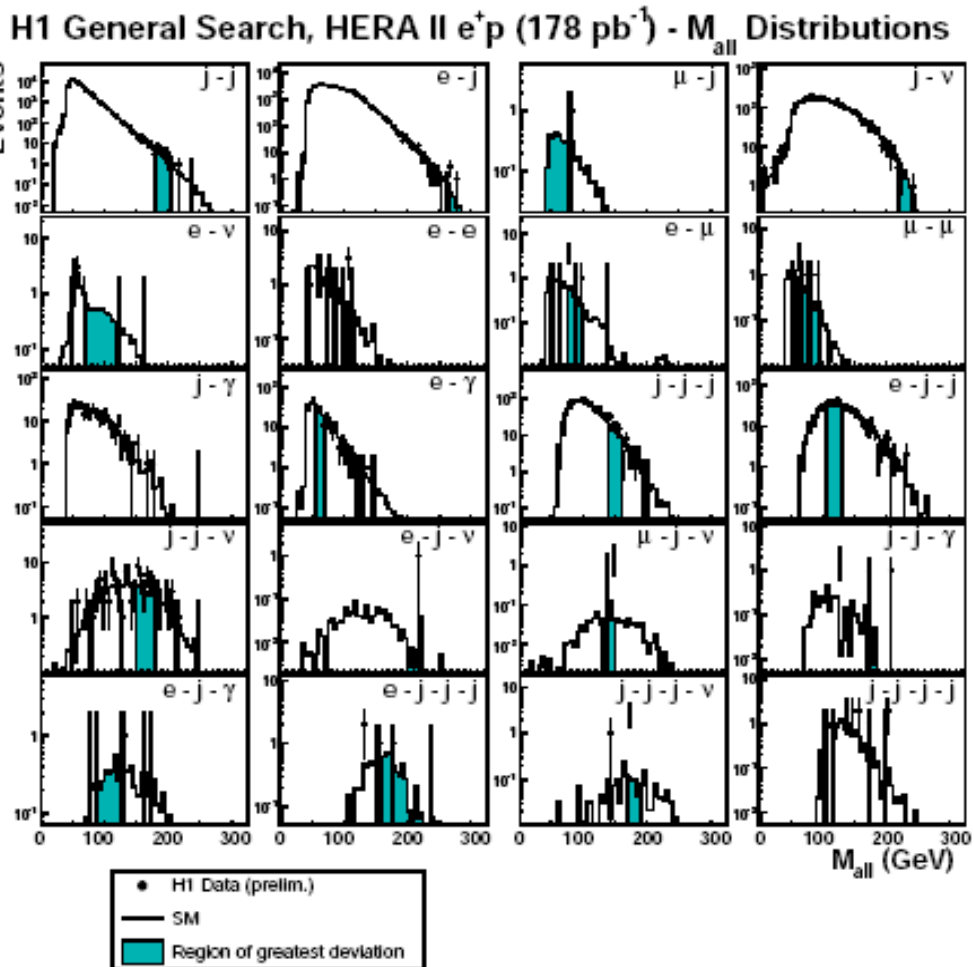


All channels described by Standard Model physics.



# General search with high $p_t$ objects

Search for largest deviation  
in mass spectra in each class,  
calculate P-values.





# Summary



- HERA ep beams ended on June 30, 2007, after 15 years of successful operation.
- Each collider experiment has collected close to  $0.5 \text{ fb}^{-1}$  of high quality data with precision detectors.
- A comprehensive search for new physics phenomena using all data and combining H1 and ZEUS is underway.
- Preliminary results show no significant deviation from the standard model.