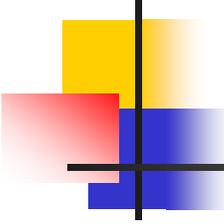


# Searches for New Physics in ep Collisions

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# Searches for New Physics at HERA

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## Recent results

### Model dependent searches

- **Leptoquarks**
- Lepton flavor violation
- **Excited fermions**
- Single top production
- Double charged Higgs
- Supersymmetry

### Limits from precision measurements

- NC DIS: contact interactions, extra large dimensions, **quark radius**
- CC DIS: right-handed weak currents

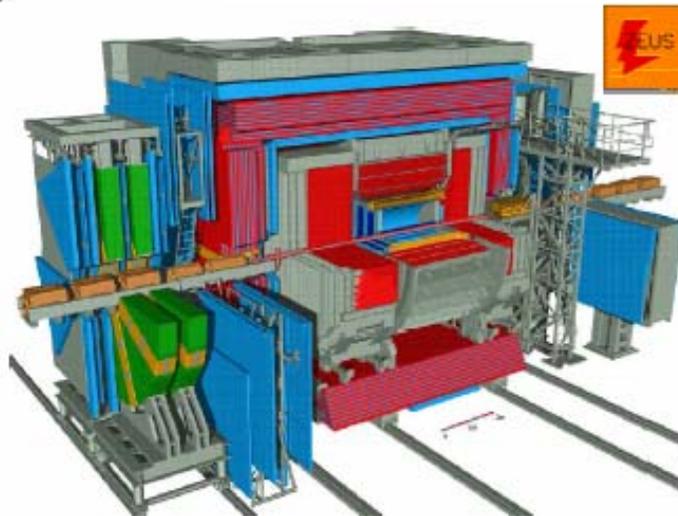
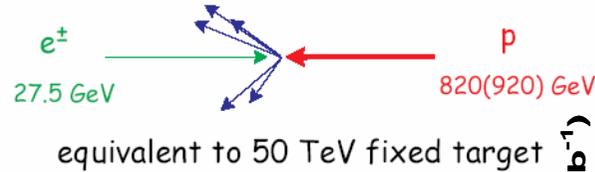
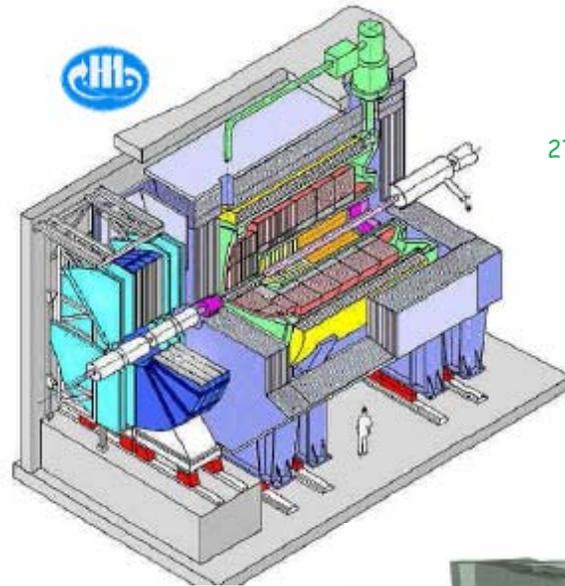
### Model independent searches

- **Events with isolated leptons and missing  $P_T$**
- **General searches**
- Tau production
- Multi-lepton production
- Magnetic monopoles

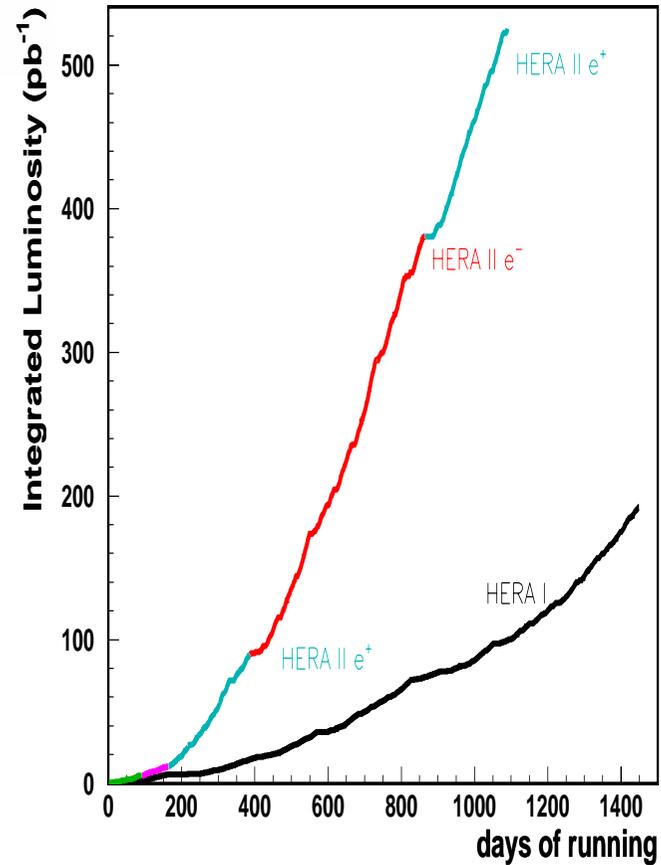
Topics in bold covered in this talk

# The HERA ep Collider at DESY

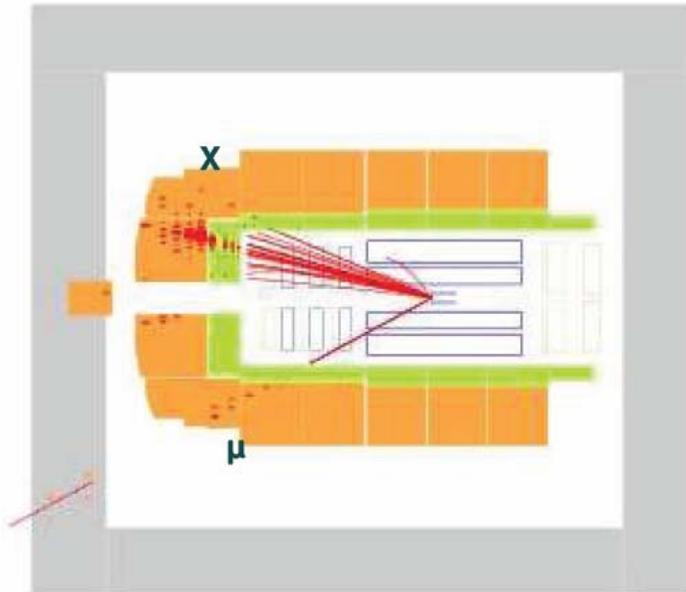
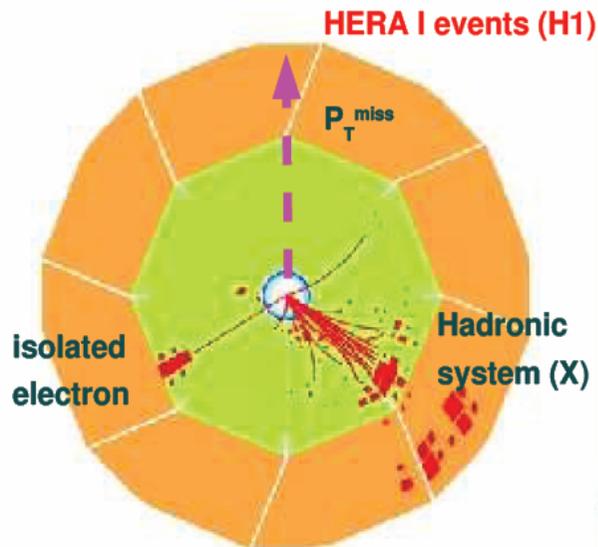
HERA - the world's only ep collider



HERA delivered



# Isolated Leptons and $p_T^{\text{miss}}$

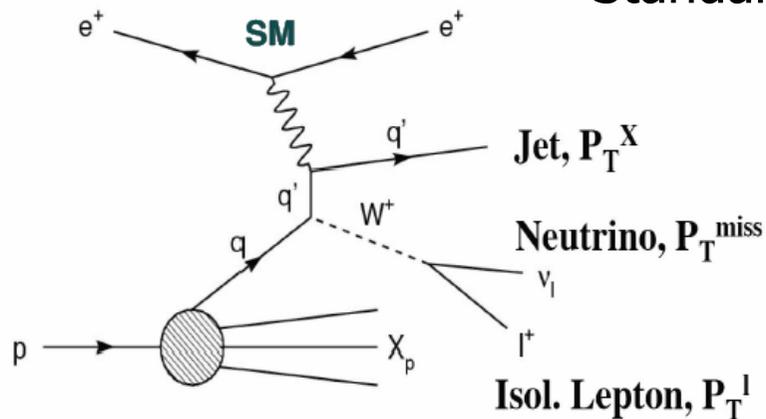


Excess of events with isolated leptons and large missing transverse momentum observed by H1 since 1993, mainly in  $e^+p$  collisions.

- HERA I data:  $p_T^{\text{miss}} > 25 \text{ GeV}$  11 events/ $3.5 \pm 0.6$  (standard model)
- Excess not observed by ZEUS
- Now almost final (HERA II) data set available.
- Common working group, detailed comparisons.

# Isolated Leptons and $p_T^{\text{miss}}$

Standard model process W photoproduction



- At HERA  $\sigma \sim 1.2 \text{ pb}$
- Important background to physics beyond the standard model

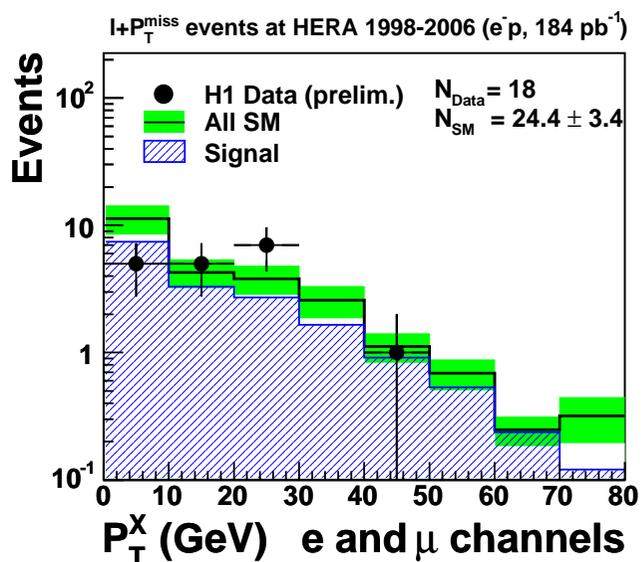
Event selection

- $P_T^l > 10 \text{ GeV}$ ,  $P_T^{\text{miss}} > 12 \text{ GeV}$
- Lepton isolation
- Event balance (acoplanarity)
- Kinematic and topological variables
- H1 and ZEUS slightly different  $\theta$  ranges

# Isolated Leptons and $p_T^{\text{miss}}$

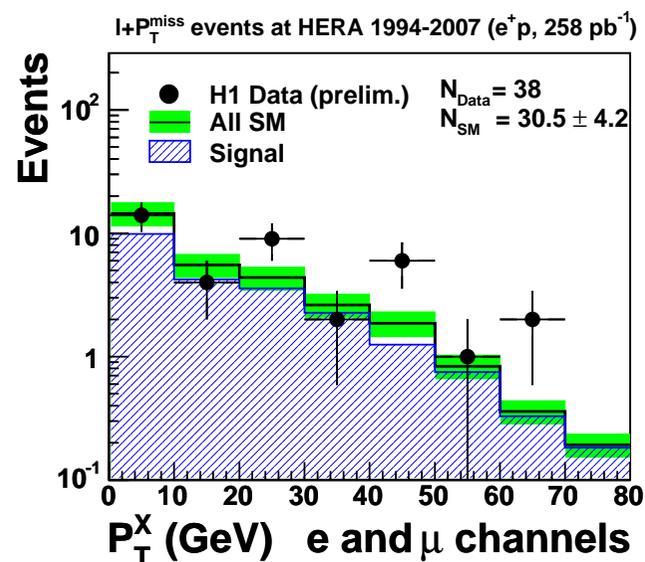
H1 results

$e^-p$  184  $\text{pb}^{-1}$



No excess in  $e^-p$  data

$e^+p$  258  $\text{pb}^{-1}$



2.7  $\sigma$  excess in  $e^+p$  data

$p_T^{\text{miss}} > 25 \text{ GeV}$ :

18 (obs.) /  $7.8 \pm 1.3$  (exp.)

# Isolated Leptons and $p_T^{\text{miss}}$

Comparison of H1 and ZEUS results (preliminary)

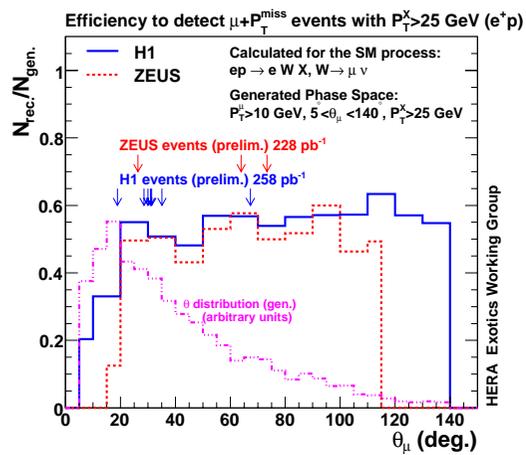
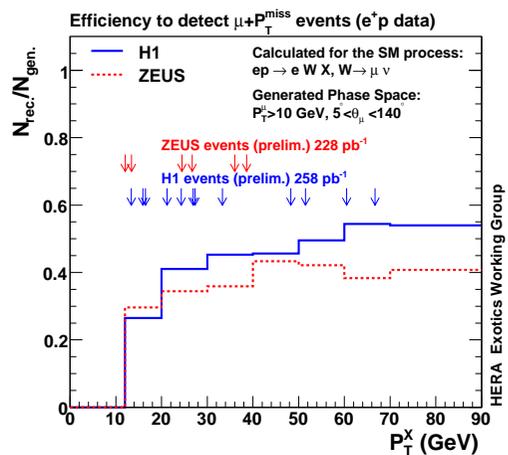
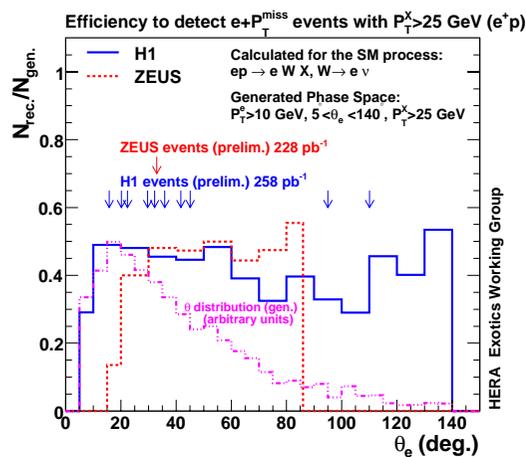
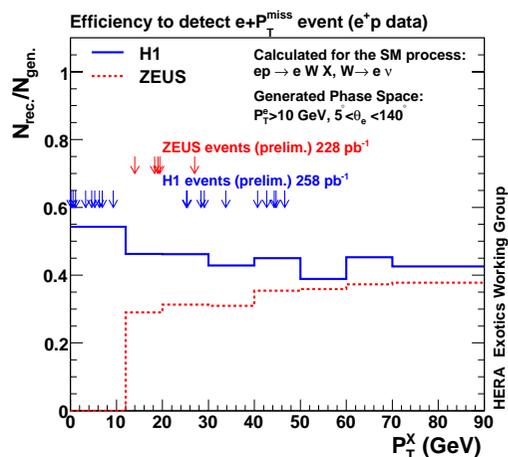
$p_T^X > 25 \text{ GeV}$	electron obs./exp.	muon obs./exp	Combined obs./exp
H1 e-p 1998-2006 184pb <sup>-1</sup>	3/3.8±0.6 (61%)	0/3.1±0.5 (74%)	3/6.9±1.0
H1 e+p 1994-2007 258pb <sup>-1</sup>	10/4.1±0.8 (75%)	8/3.7±0.6 I(85%)	18/7.8±1.3
ZEUS e-p 1998-2006 204pb <sup>-1</sup>	5/3.8±0.6 (55%)	2/2.2±0.3 (86%)	7/6.0±0.7
ZEUS e+p 1996-2006 228pb <sup>-1</sup>	1/3.2±0.4 (75%)	3/3.1±0.5 (80%)	4/6.3±0.6

Standard model W photoproduction is given in parentheses

- ZEUS in good agreement with Standard Model W production
- H1 some excess at large  $p_T^X$  in e+p data (2.7  $\sigma$ ).  
Excess slightly less significant than HERA I and earlier HERA II data

# Isolated Leptons and $p_T^{\text{miss}}$

## Comparison of efficiencies



- Similar efficiencies
- ZEUS slightly less efficient due to different tracking requirements
- Small difference for  $W$  photoproduction
- Small effect in high  $p_T^X$  region

# General Search for High- $P_T$ Phenomena

- H1 performed a model independent, generic search in final states with  $\geq 2$  high- $P_T$  objects:

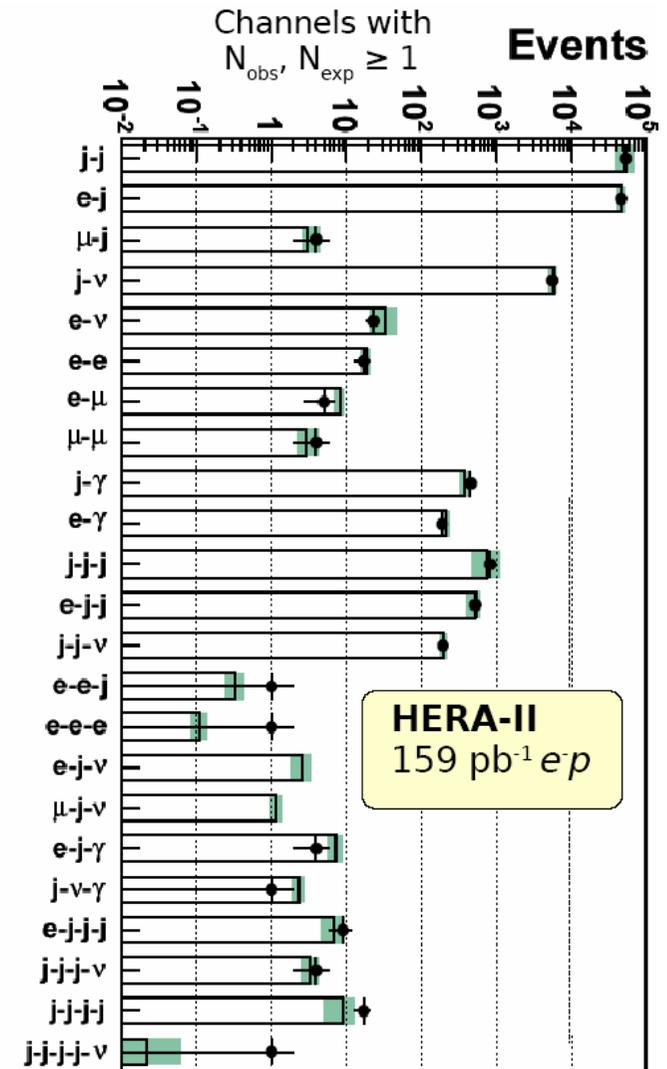
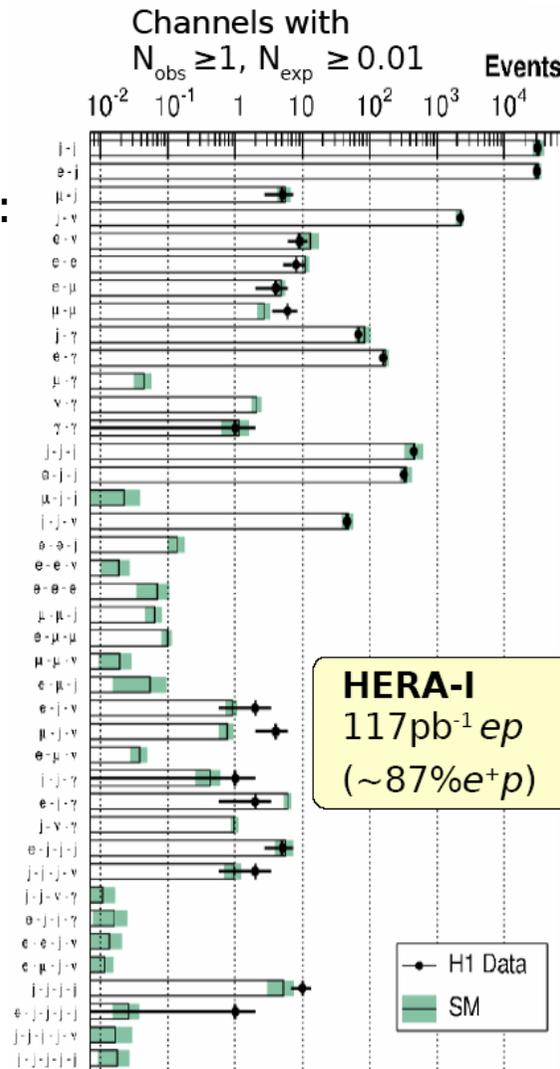
$e, \mu, \text{jets}, \gamma, \nu$

$P_T > 20\text{GeV}$

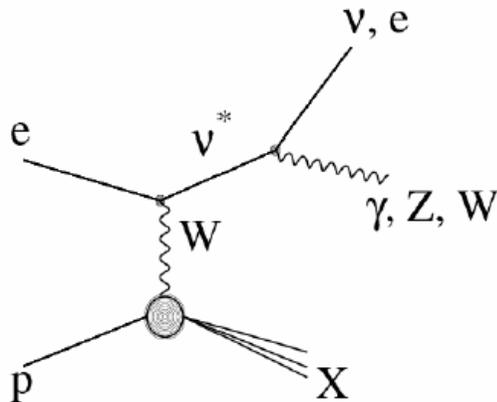
$10^\circ < \theta < 140^\circ$

- Classified by final state
- Standard model predictions for all HERA processes considered: NC and CC DIS, lepton-pairproduction, W-production, QEDC

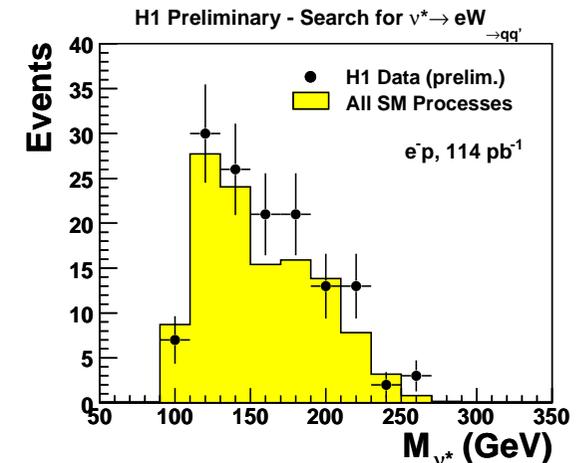
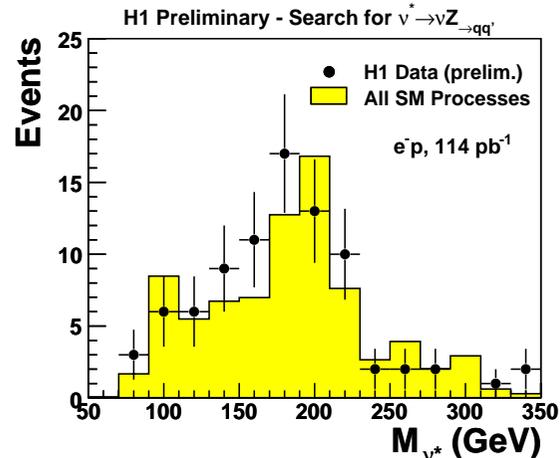
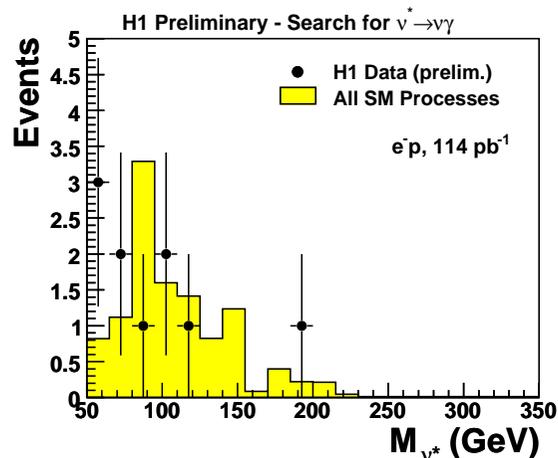
Good agreement of event yields with SM expectation for most classes



# Search for Excited Neutrinos

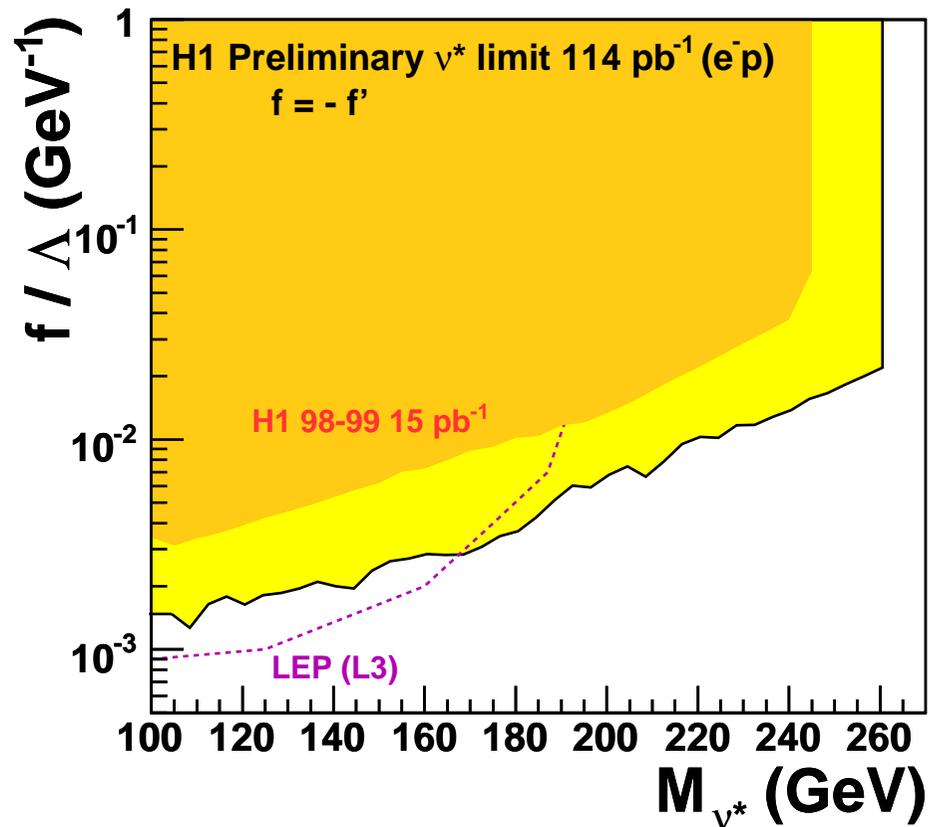


$\nu^*$  composite fermion at scale  $\Lambda$   
 Cross section proportional to couplings  $f$  and  $f'$  (electroweak)  
 $\sigma(e^-p) \approx 100 \times \sigma(e^+p)$   
 Improved sensitivity with HERA II data



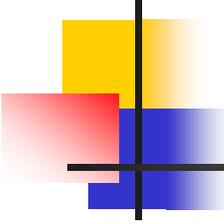
- Data well described by standard model predictions
- No evidence for excited neutrinos

# Search for Excited Neutrinos



Exclusion limits for  $f = -f'$   
(max. coupling to photon)  
Similar limits for  $f = +f'$

Assuming  $f/\Lambda = 1/M_{\nu}$ :  
 $M_{\nu} > 188 \text{ GeV}$  at 95% C.L.



# Contact Interactions

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- New interactions between electron and quarks involving mass scales above center-of-mass energy can modify cross section at high  $Q^2$  via virtual effects.
- Should observe deviations from Standard Model predictions.
- Many interactions, e.g. mediated by heavy leptoquarks, can be modeled as four-fermion contact interactions.
- Use SM predictions at high  $Q^2$  from evolution of accurate measurements of the proton structure functions made at lower  $Q^2$  for searches for:
  - four-fermion interactions,
  - graviton exchange in models with extra large dimensions or
  - finite charge radius of quarks (this talk).

# Are Quarks Elementary?

- Quark substructure can be detected by measuring spatial distribution of quark charge.
- If quark has finite radius, cross section will decrease as probe penetrates into it.

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \left( 1 - \frac{R_q^2}{6} Q^2 \right)$$

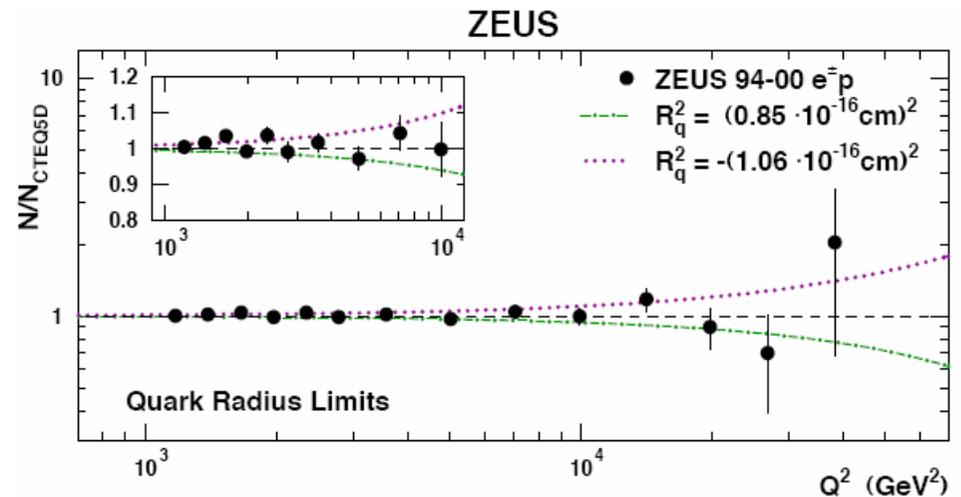
$R_q$  is rms of electroweak charge

- Limit on quark size (assuming point-like electron)

- $R_q < 0.85 \cdot 10^{-16} \text{ cm}$   
(95%CL)

- $R_q^2 < -(1.06 \cdot 10^{-16} \text{ cm})^2$   
If charge changes sign as  
function of radius

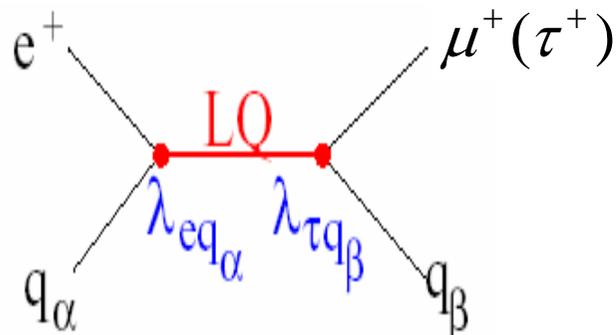
Similar limits by H1, CDF and L3.



# Search for Lepton-Flavor Violation

Motivation for search  $e^+p \rightarrow \mu^+(\tau^+)X$

- Many extensions of Standard Model allow lepton-flavor violation
- Lepton-flavor violation occurs in neutrino sector as shown by neutrino oscillation experiments



- Leptoquark (LQ): both lepton and baryon numbers and lepton-quark Yukawa couplings
- LFV if LQ couples to two different generations
- Mediated by squarks in R-parity-violation SUSY models

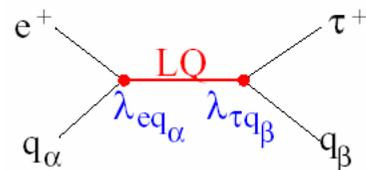
# Search for Leptoquarks

Buchmüller-Rückl-Wyler model: 14 LQ types,  
fermionic number (F=3B+L) 0 or 2

Narrow width approximation

$$(M_{LQ} < \sqrt{s})$$

$$\sigma^{NWA}(\lambda, M_{LQ}) \propto \lambda_{lq_i}^2 B_{lq_i}$$



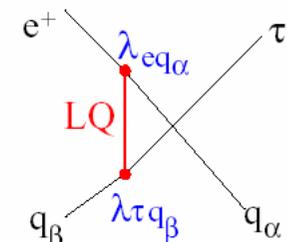
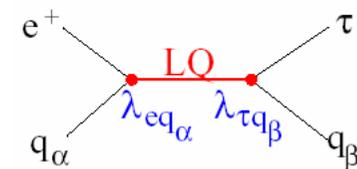
$\lambda_{eq_i}$  LQ coupling to electron and quark (generation i)

$B_{lq_i}$  Branching ratio to lepton and quark

High mass approximation

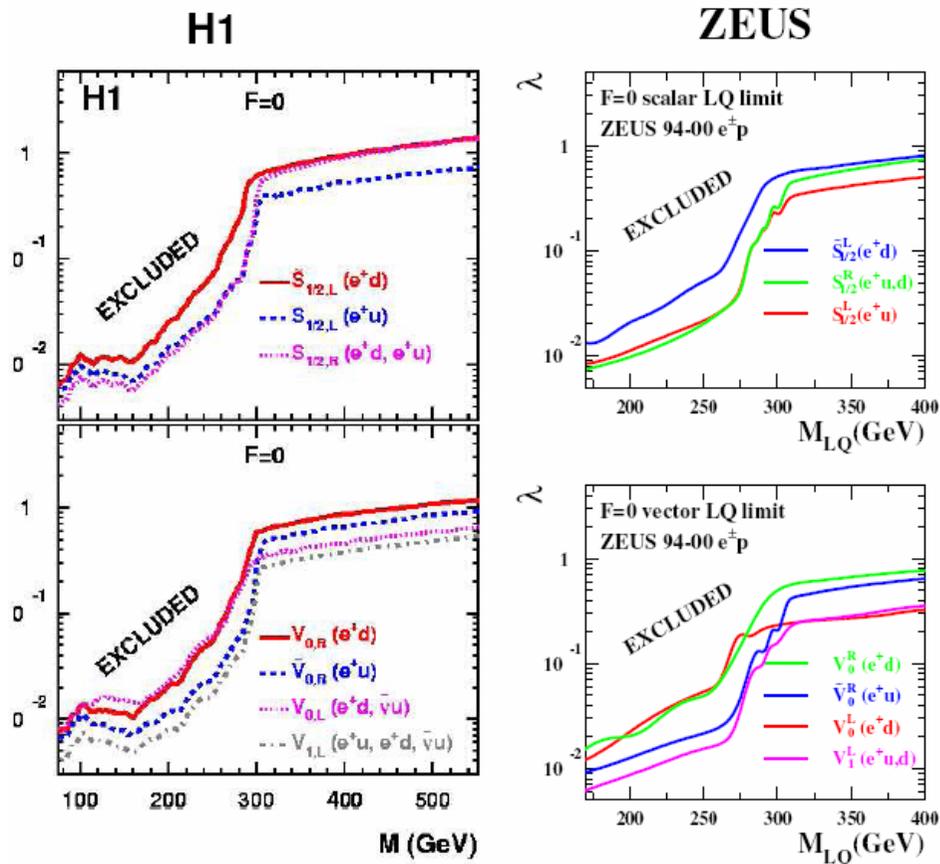
$$(M_{LQ} \gg \sqrt{s})$$

$$\sigma^{HMA}(\lambda, M_{LQ}) \propto \left[ \frac{\lambda_{eq_i} \lambda_{eq_j}}{M_{LQ}^2} \right]^2$$



# Search for Leptoquarks

Results: Limits on  $\lambda_{eq_1}$  as function of  $M_{LQ}$  for scalar and vector leptoquarks



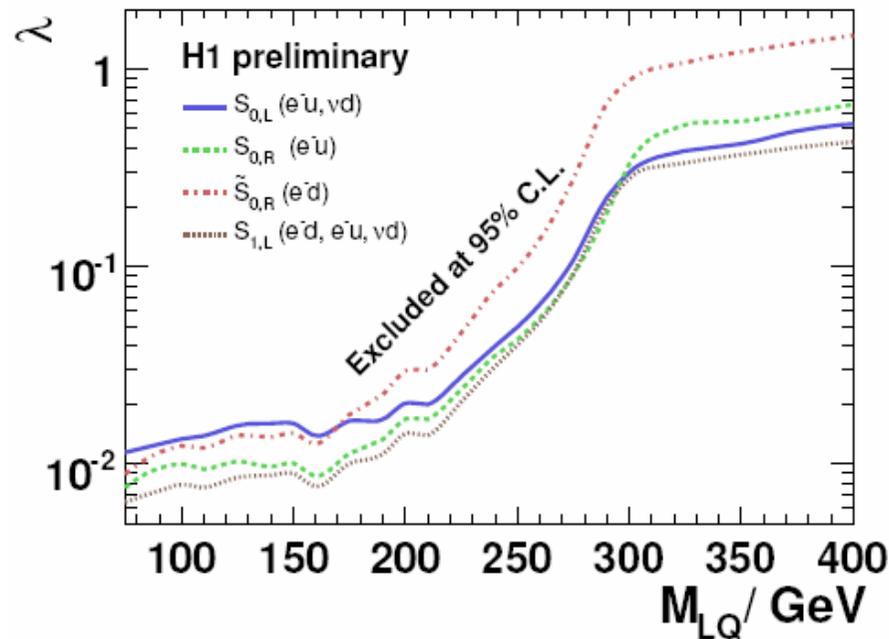
HERA I data

F=0 scalar BRW LQ  
Couples to eq only

F=0 vector BRW LQ  
eq and  $\nu q$  channels combined

# Search for Leptoquarks

Results: Limits on  $\lambda_{eq_1}$  as function of  $M_{LQ}$  for scalar and vector leptoquarks

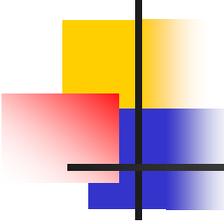


HERA II data

F=2 scalar BRW LQ  
e-p data more sensitive than  
e+p

Similar limits for vector LQ

Assuming  $\lambda = \sqrt{4\pi\alpha} \approx 0.3$  lower limits on  $M_{LQ}$  276 – 304 GeV



# Conclusions

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## Searches for New Physics at HERA

- Events with isolated leptons and missing  $P_T$ 
  - H1 still observing some excess at large  $p_T^X$  in  $e^+p$  data ( $2.7 \sigma$ )
  - Slightly less significant than in HERA I and earlier HERA II data
- General search for high- $P_T$  phenomena
  - Good agreement of event yields with standard model expectation for most classes of events
- Extended limits for mass of excited neutrinos with new  $e-p$  data
- Are quarks elementary?
  - New limits on quark radius
- New limits on leptoquark masses