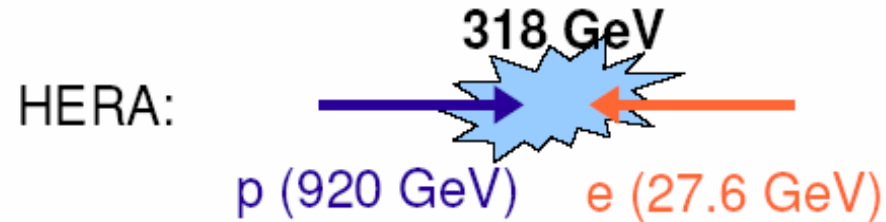
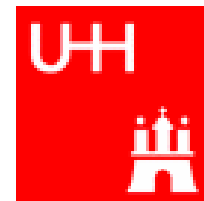


# Non-SUSY Searches at HERA



- HERA Performance
- Model –independent Search
- Contact Interactions
- Excited Fermions

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Hamburg University  
SUSY07  
July 27, 2007



# 1. HERA Performance

## HERA-I : 1992 - 2000

- $\sim 120 \text{ pb}^{-1}$  per experiment, mostly  $e^+p$

## HERA-II: 2003 - 2007

Upgrade: luminosity & polarisation:  $e_L^-$ ,  $e_R^-$ ,  $e_L^+$ ,  $e_R^+$

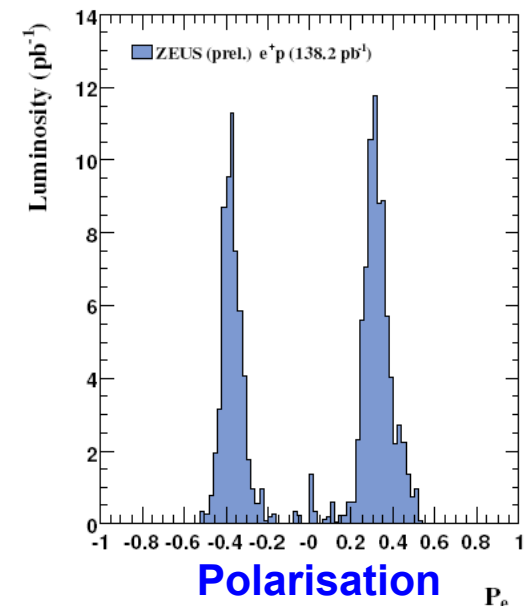
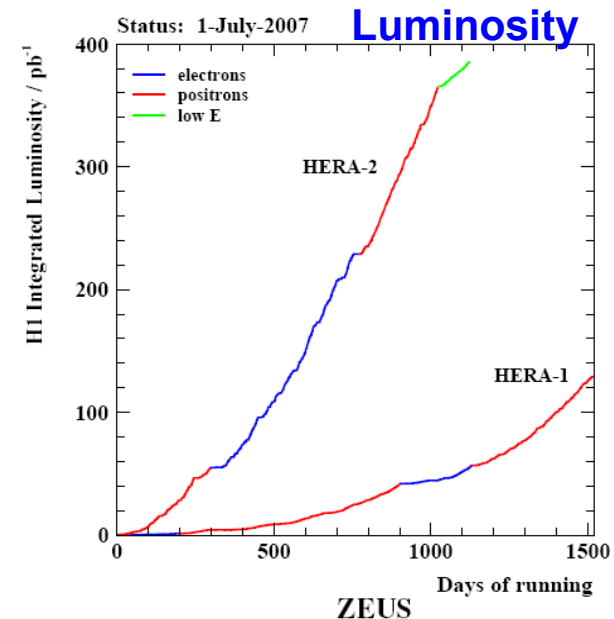
Recently: very good conditions

→ low background, stable beam conditions

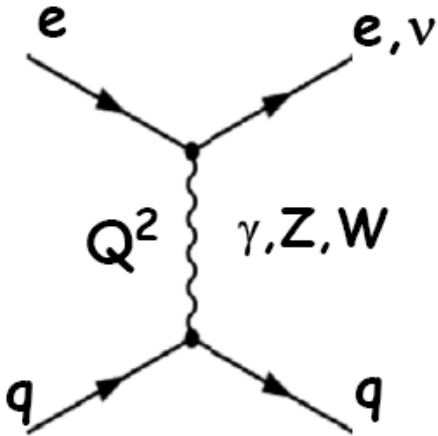
→ high data taking efficiencies, low thresholds

→ no major problems on central detectors

- **polarisation**
  - average  $\sim 40\%$
- **electron & positron running**
  - $\sim 184 \text{ pb}^{-1} e^-p$
  - $\sim 294 \text{ pb}^{-1} e^+p$
- **Luminosity HERA I & II**
  - $\sim 478 \text{ pb}^{-1}$  per experiment,  $\sim 90\%$  at 320 GeV
- End of HERA running in June, 2007 → final data set



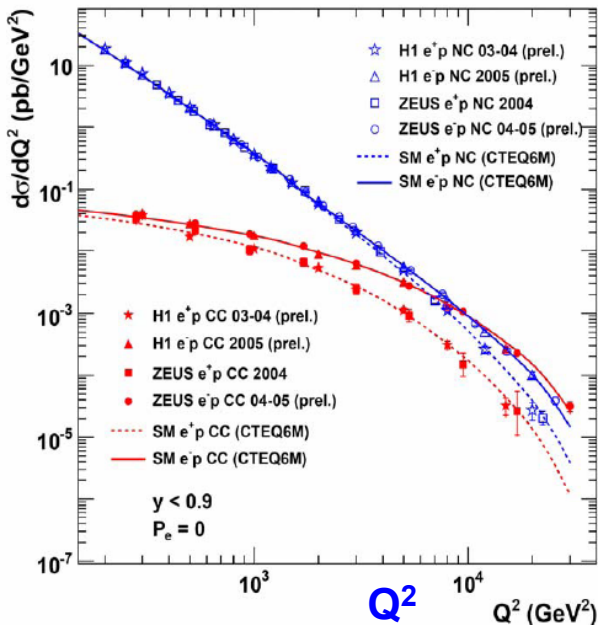
# HERA Data



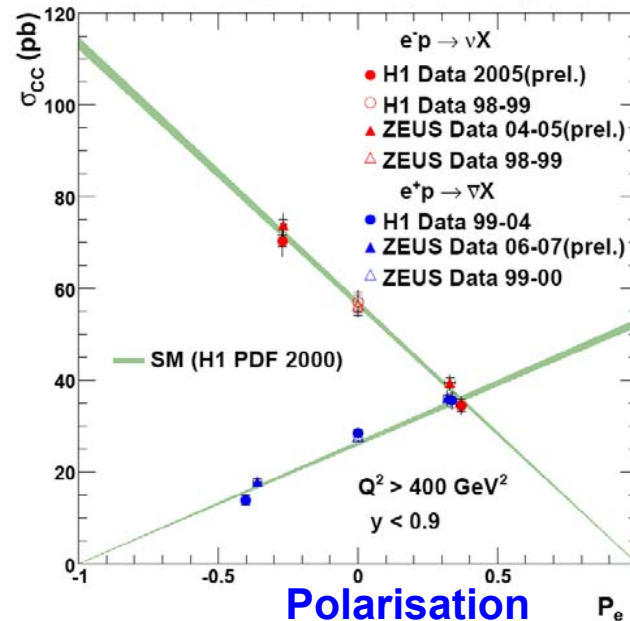
~ few  $10^8$  ep collisions triggered by H1 & ZEUS

- Thresholds: 5 ... 10 GeV for electrons and jets
- Luminosity: ~ 1.6 ... 3.5 % precision
- Polarisation: ~ 3 ... 5 % precision
- Calorimeters E-scales: 1 ... 3 % for e, jets from kin. Constr.

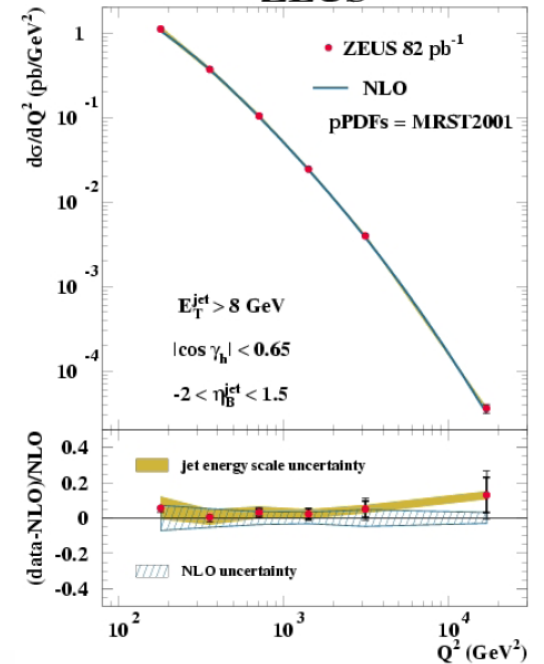
## Neutral Current HERA II



## Charged Current Charged Current $e^+p$ Scattering



## Inclusive Jet Production ZEUS



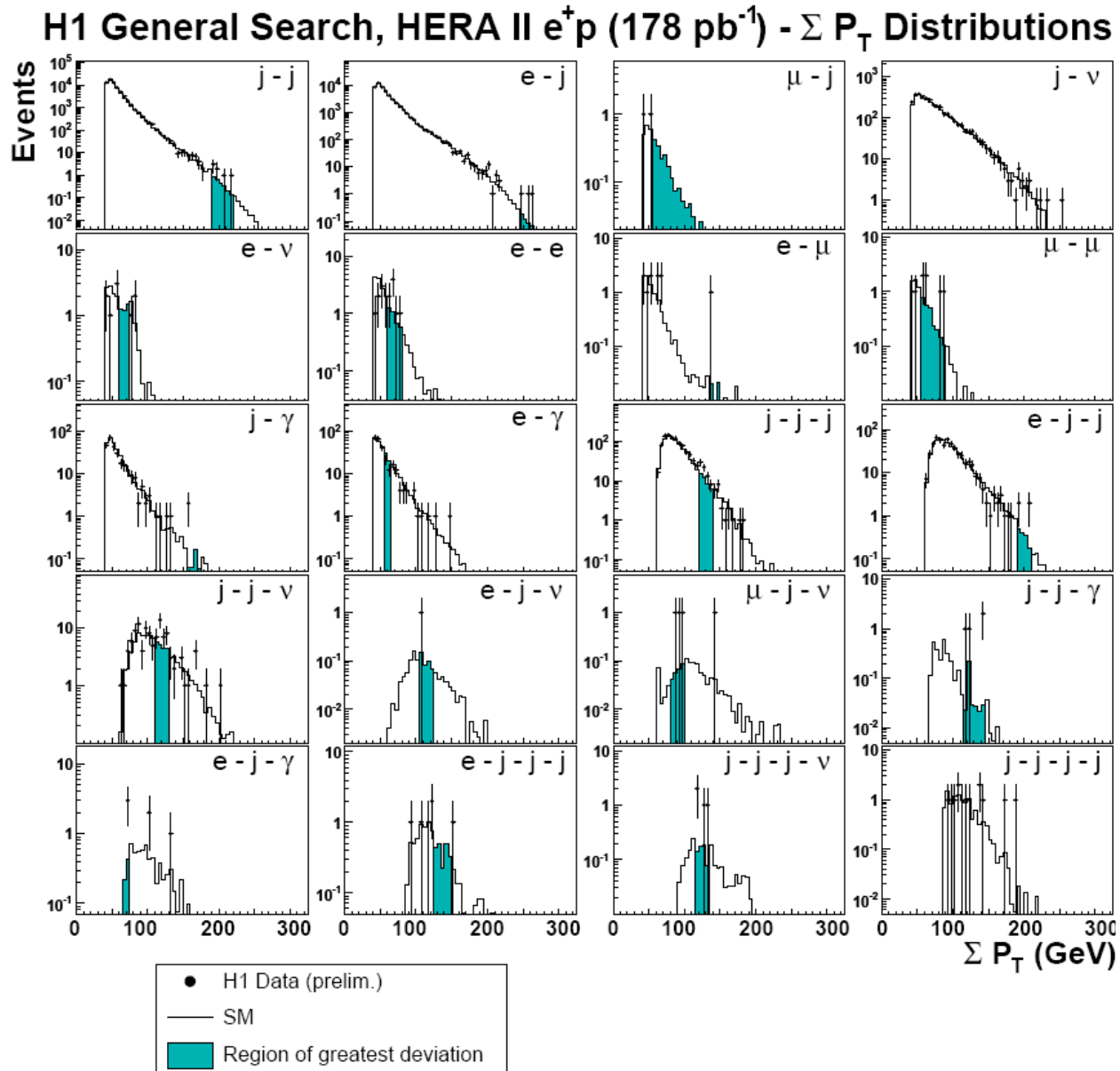
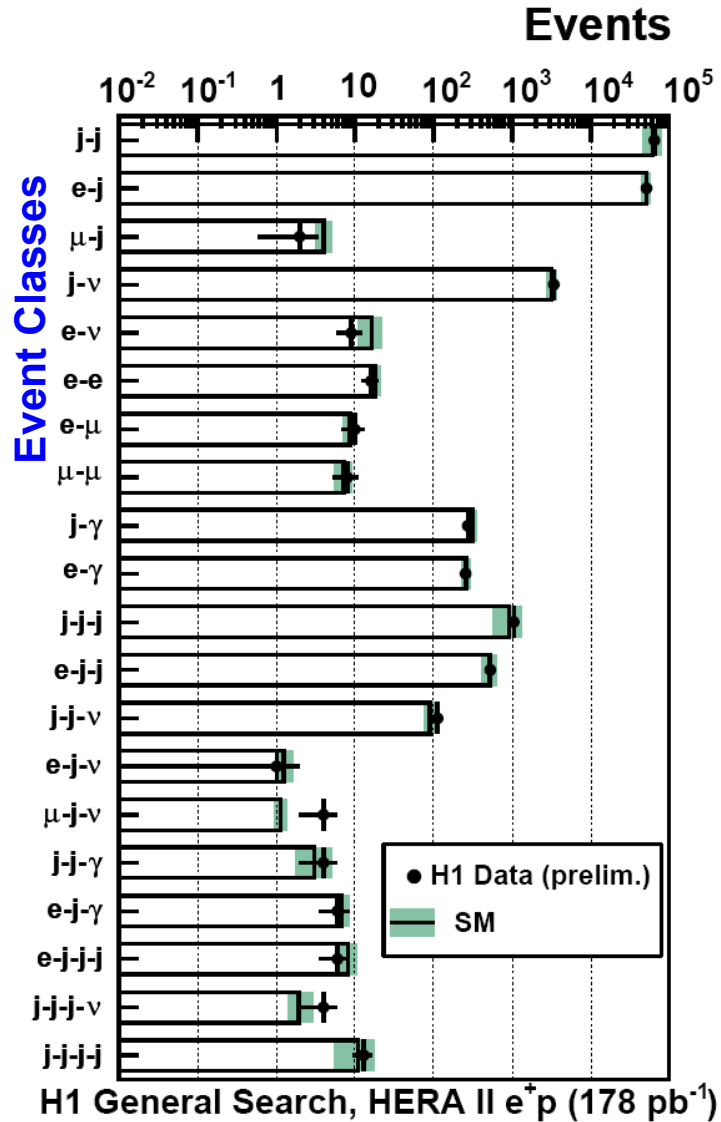
**HERA combined (new analysis):**

$$\alpha_s(M_Z) = 0.1198 \pm 0.0019 \text{ (exp.)} \pm 0.0026 \text{ (th.)}$$

## 2. Model – independent Search (H1)

- Inclusive search for particles at high  $P_T$
- **Electrons ,Photons, Muons, Hadronic Jets, Neutrinos (PTmiss)**
- phase space for all:
  - $P_T > 20 \text{ GeV}$
  - $10^\circ < \theta < 140^\circ$
- All combinations: ee, e $\gamma$ , e $\mu$ , ej, .....jj, ejj, ejv  $\rightarrow$  event classes
- **Mass** and  $\sum P_T$  (Jacobi-peak)
- Comparison to SM (LO)  
 $\rightarrow$  look for deviations (max. deviations)
- Statistical interpretation via monte carlo experiments  $\rightarrow$  probability

# Model – independent Search



# Model – independent Search

Precision :

→ Systematics: few %

→ Statistically limited at large M, PT  
and large multiplicity

→ Theory: uncertainty large for  
multi-jet channel

Distribution for data follows  
expectation

→ Excellent understanding  
of most final states at HERA

Exception: Largest deviation for  $\mu j \nu$  channel

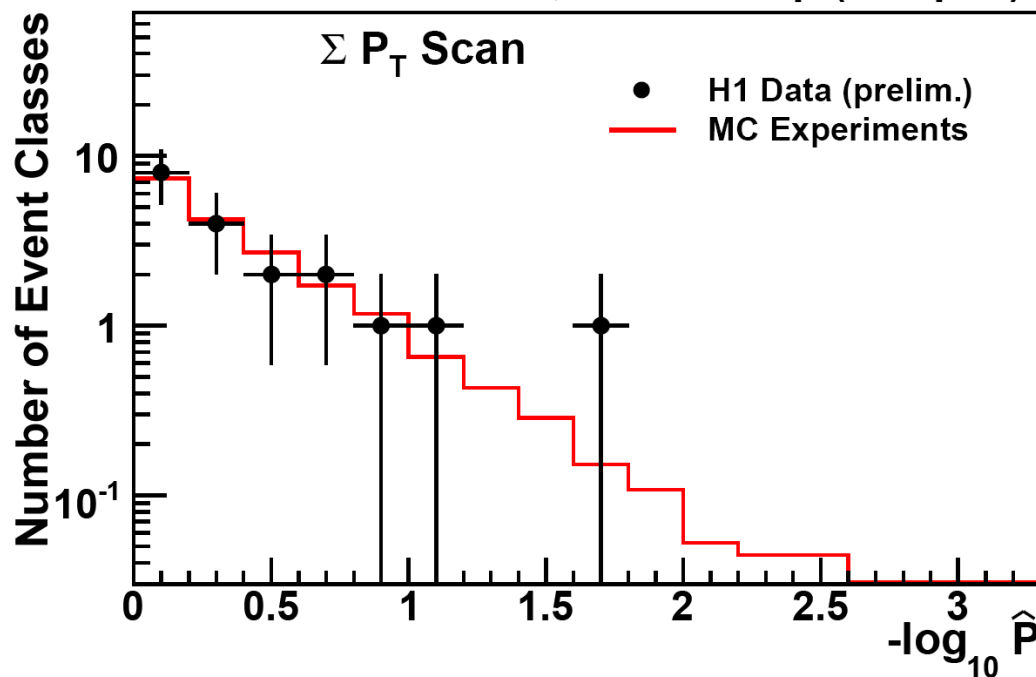
$e^+p$ : H1 observation: 21 /  $8.9 \pm 1.5$  events ( $3.0\sigma$ )

ZEUS: no events in excess of SM

$e^-p$ : H1 and ZEUS: Agreement with SM

Probability of max. deviation for event classes

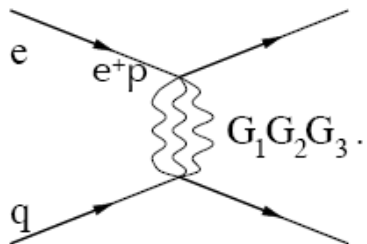
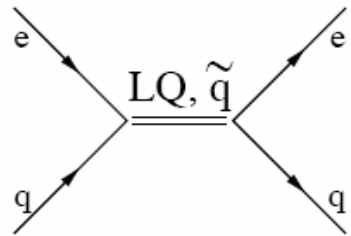
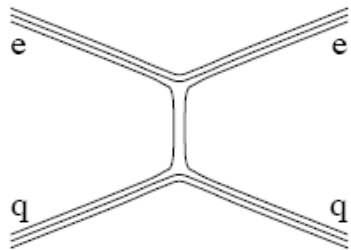
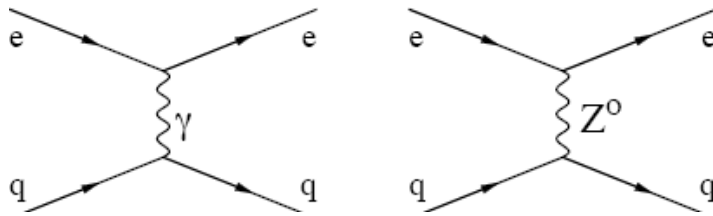
H1 General Search, HERA II  $e^+p$  ( $178 \text{ pb}^{-1}$ )



→ Dedicated search: talk by J. Katzy

# 3. Contact Interactions (ZEUS)

## Standard Model



## + 4-Fermion interaction

$$\mathcal{L}_{CI} = \sum_{i,j=L,R; q=u\dots b} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i) (\bar{q}_j \gamma_\mu q_j)$$

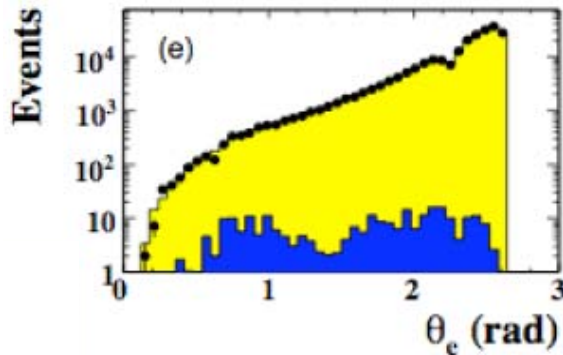
$$\eta_{ij} = \epsilon_{i,j} \frac{4\pi}{\Lambda^2} \quad \text{Compositeness}$$

$$\left(1 - \frac{R_q^2}{6} Q^2\right) \quad \text{Quark radius}$$

$$\eta \sim (\lambda/M_{LQ})^2 \quad \begin{array}{l} \text{Leptoquark (M} > E_{\text{CMS}}) \\ \text{Squarks in R}_p\text{-viol.} \end{array}$$

$$\eta_G \sim 1/M_S^4 \quad \begin{array}{l} \text{Large Extra} \\ \text{Dimensions} \end{array}$$

# Contact Interactions

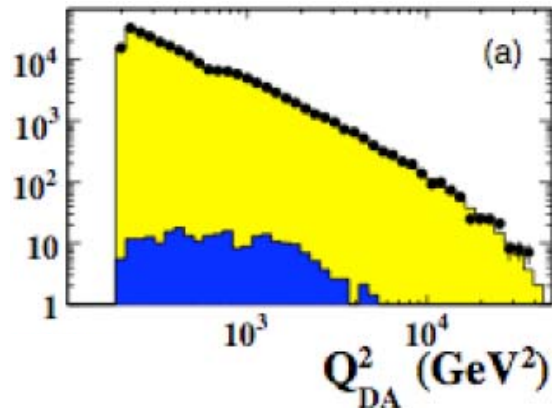
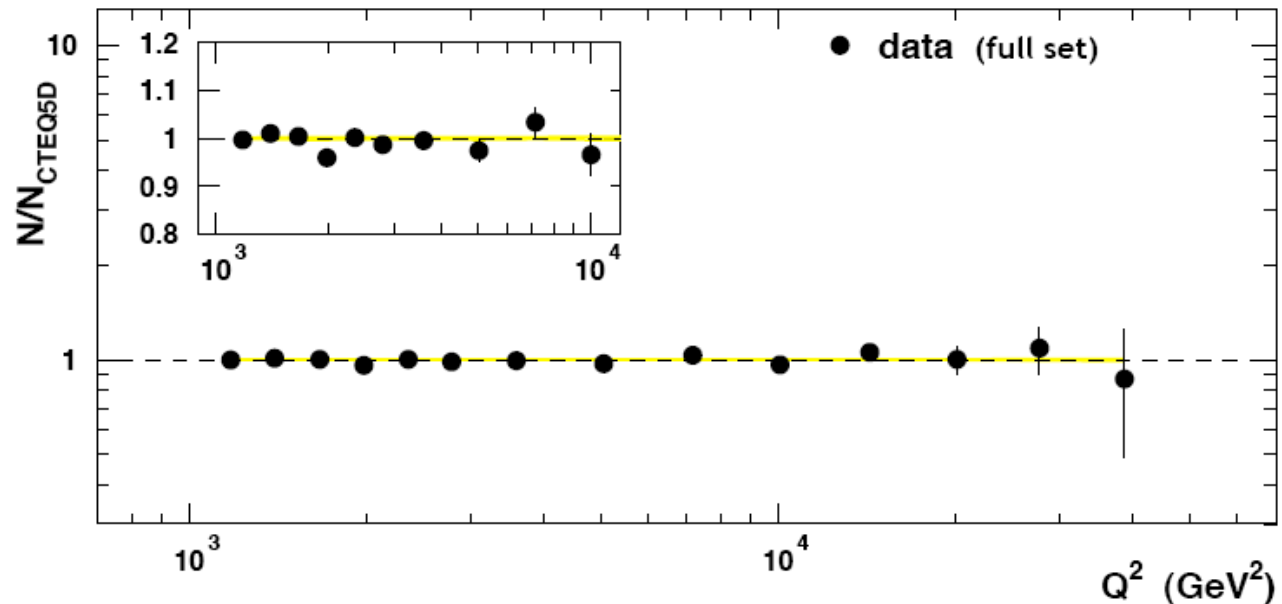
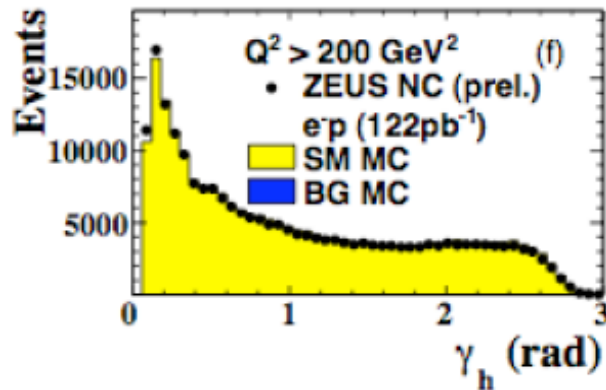


## ZEUS ep data

- HERA I  $\sqrt{s} = 300$  GeV 1994-2000 128 pb<sup>-1</sup>
  - unpolarized e<sup>+</sup> (112 pb<sup>-1</sup>) and e<sup>-</sup> data sets
- HERA II  $\sqrt{s} = 318$  GeV 2003-2005 146 pb<sup>-1</sup>
  - polarization e<sup>-</sup> -0.27, +0.33, e<sup>+</sup> -0.41, +0.32

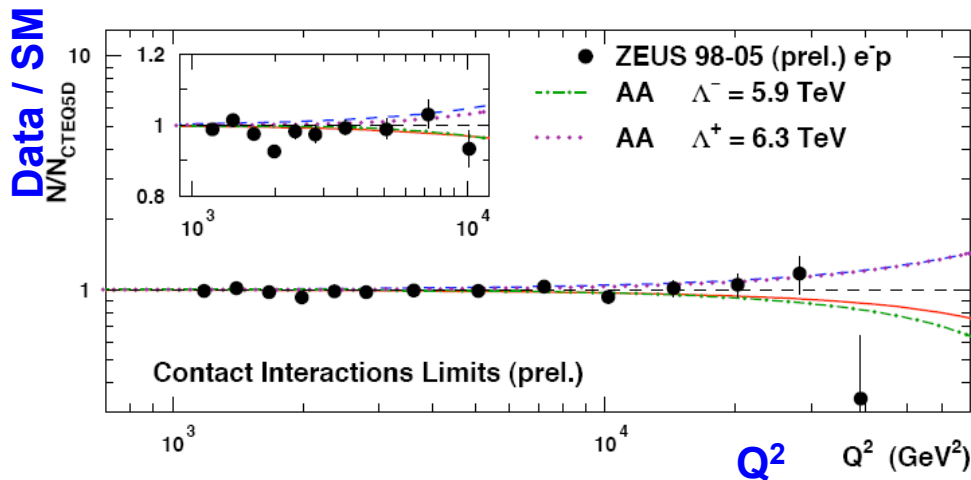
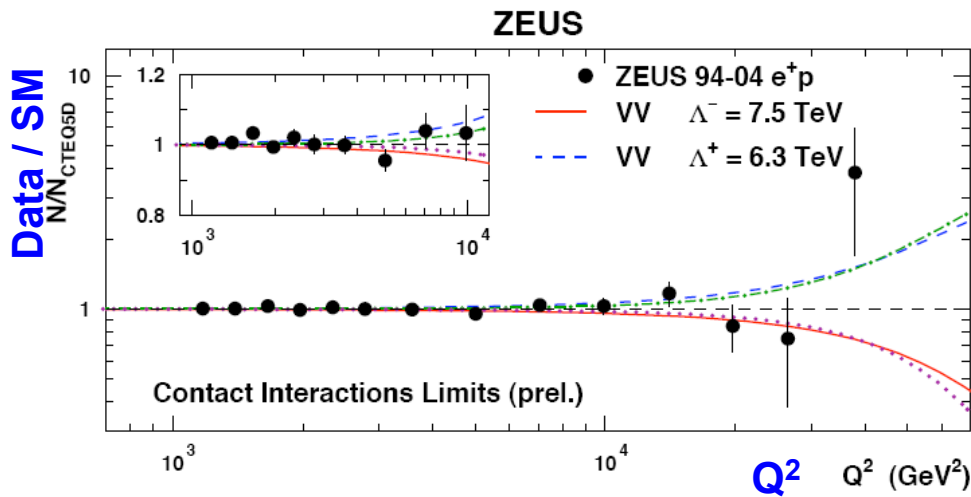
## Measurement via 2-angle method:

- Resolution  $\ll$  Binning
- Results limited by statistics

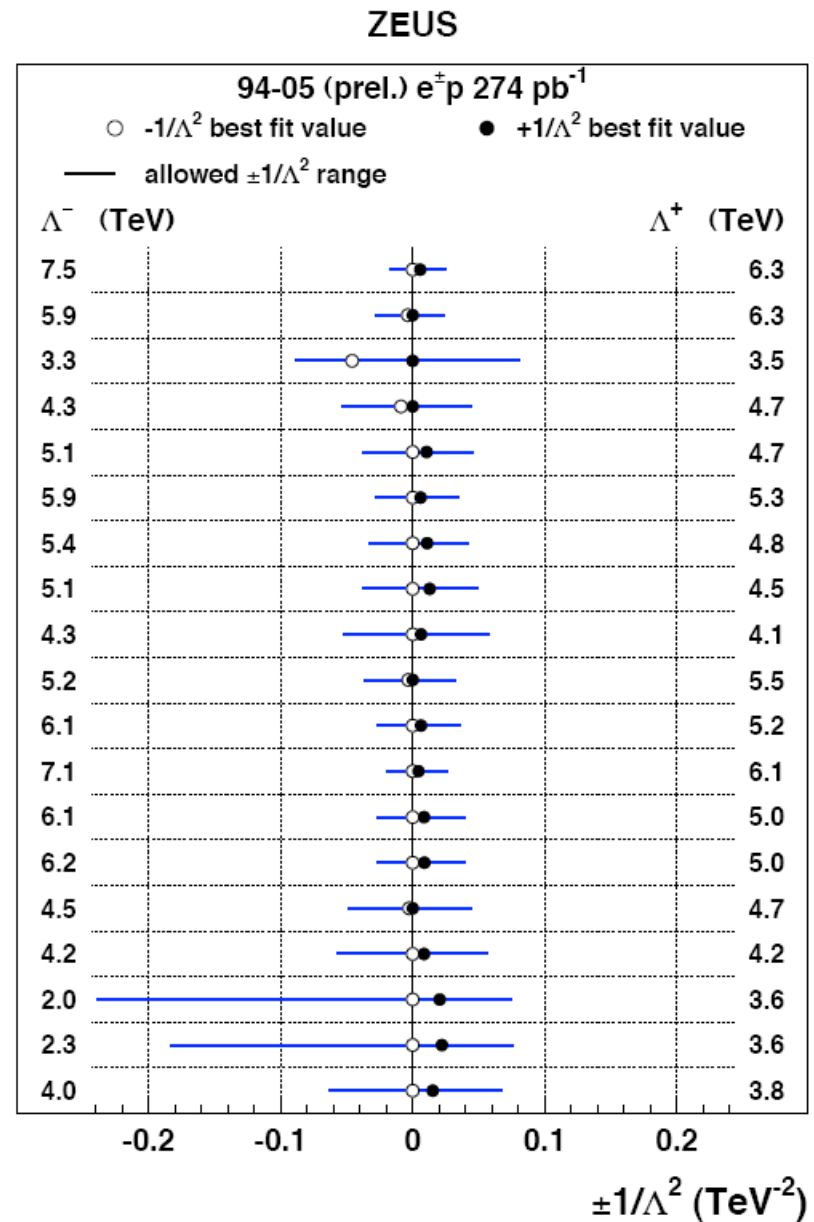




# Contact Interactions



**Helicity Combinations**



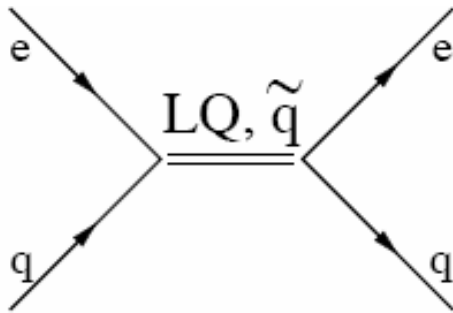
Typical Range of Contact Interaction scales:

**2 ... 7.5 TeV**

Improvements: **Luminosity: factor 2**

**Polarisation**

# Leptoquarks (indirect)



Leptoquark masses excluded for:

- Indirect search

$$M / \lambda' > 0.3 \dots 2 \text{ TeV}$$

- Direct searches for peak in  $M_{eq}$

$$M < 300 \text{ GeV} \rightarrow \lambda < 0.01$$

Squarks in R-parity viol. SUSY:

$\lambda'_{ijk} L_i Q_j D_k$  coupling

$\tilde{u}$  has same coupling as  $\tilde{S}_{1/2}$

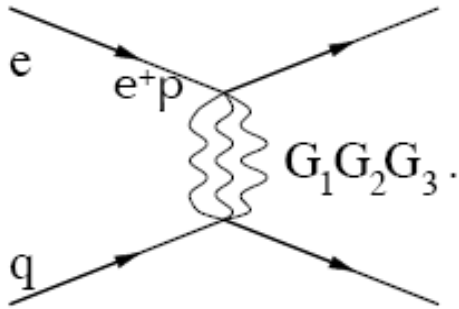
same limit applies

scalar

vector

ZEUS 1994-2005 (prel.) $e^\pm p$		
Model	Coupling Structure	95% C.L. (TeV) $M_{LQ}/\lambda_{LQ}$
$S_\circ^L$	$a_{LL}^{eu} = +\frac{1}{2}$	0.96
$S_\circ^R$	$a_{RR}^{eu} = +\frac{1}{2}$	0.82
$\tilde{S}_\circ^R$	$a_{RR}^{ed} = +\frac{1}{2}$	0.32
$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	0.88
$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.46
$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	0.44
$S_1^L$	$a_{LL}^{ed} = +1, a_{LL}^{eu} = +\frac{1}{2}$	0.74
$V_\circ^L$	$a_{LL}^{ed} = -1$	0.80
$V_\circ^R$	$a_{RR}^{ed} = -1$	0.62
$\tilde{V}_\circ^R$	$a_{RR}^{eu} = -1$	1.33
$V_{1/2}^L$	$a_{LR}^{ed} = +1$	0.46
$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	1.00
$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	1.10
$V_1^L$	$a_{LL}^{ed} = -1, a_{LL}^{eu} = -2$	1.91

# Large Extra Dimension

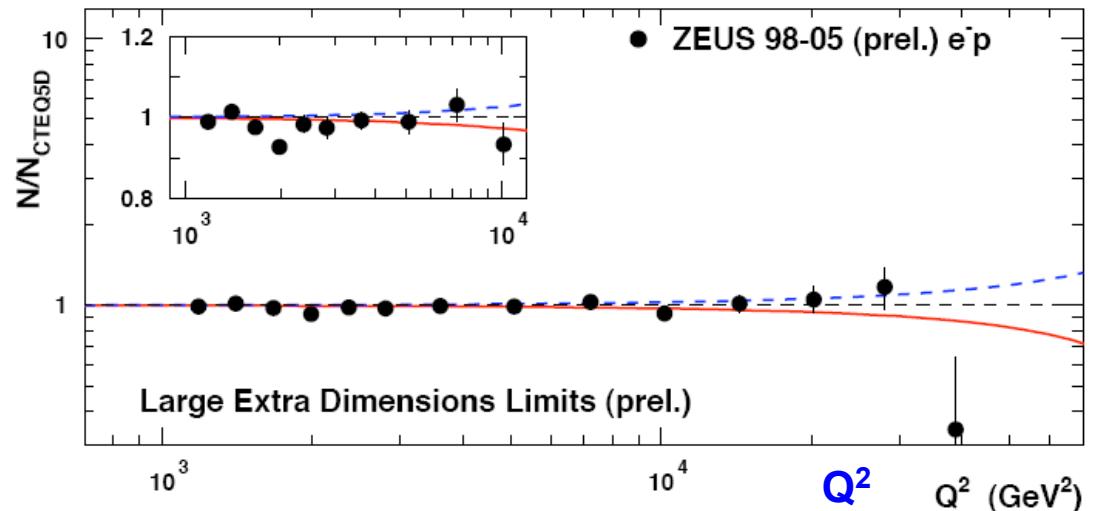
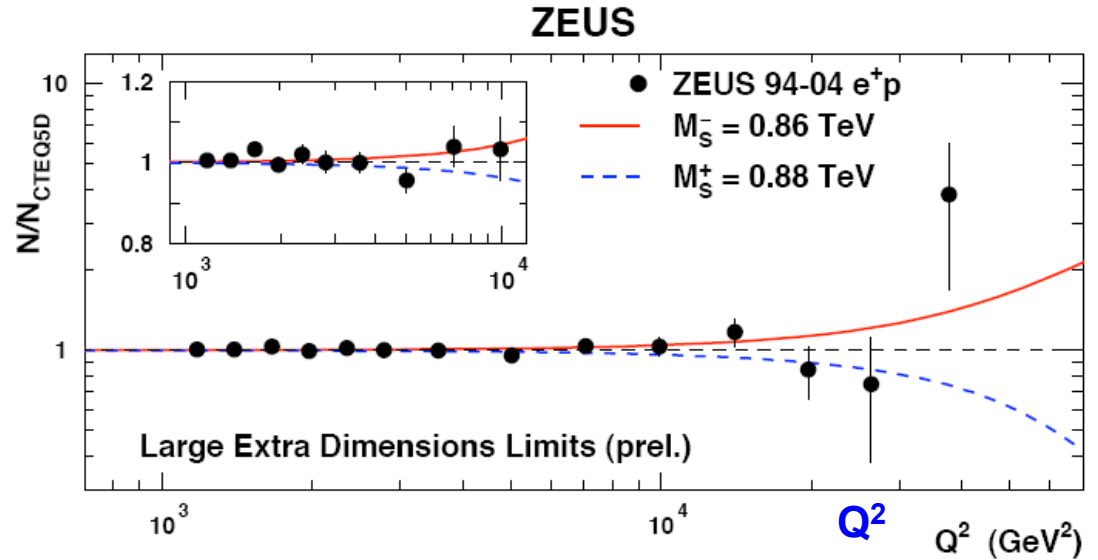


LED's limited to

- $M_S > 0.88 \text{ TeV}$

Quark Radius limited to

- $R_q < 0.67 \times 10^{-18} \text{ m}$

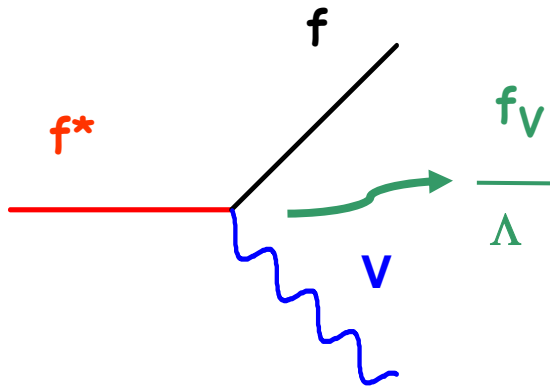


# 4. Excited Leptons (H1)

Effective lagrangian to parameterize compositeness:

- Spin 1/2, isospin 1/2, vector currents as SM leptons

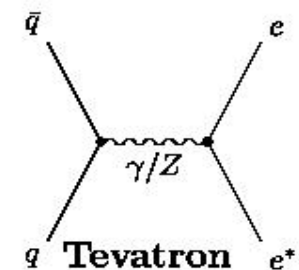
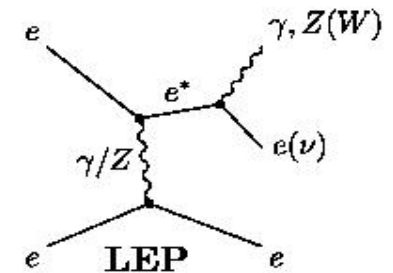
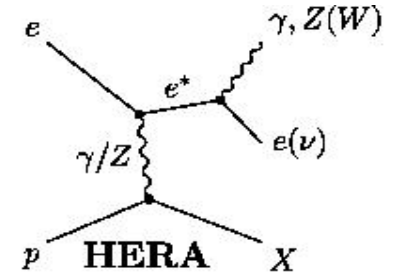
$$L_{F^*F} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[ g f \frac{\vec{T}}{2} \partial_\mu \vec{W}_\nu + g' f' \frac{Y}{2} \partial_\mu B_\nu \right] F_L + h.c.$$



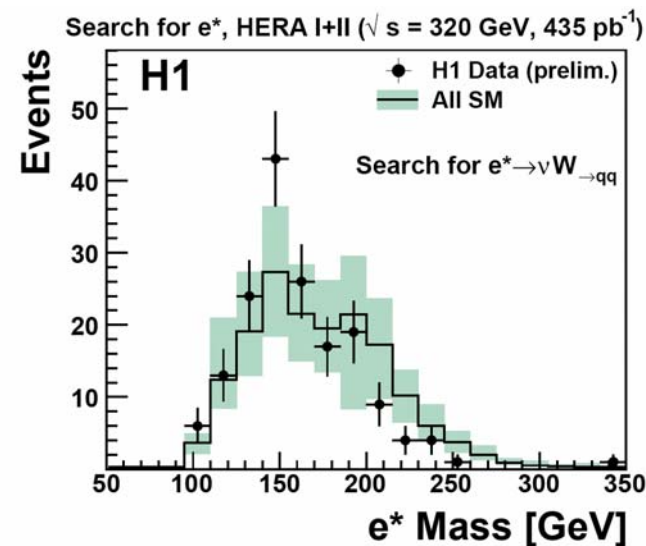
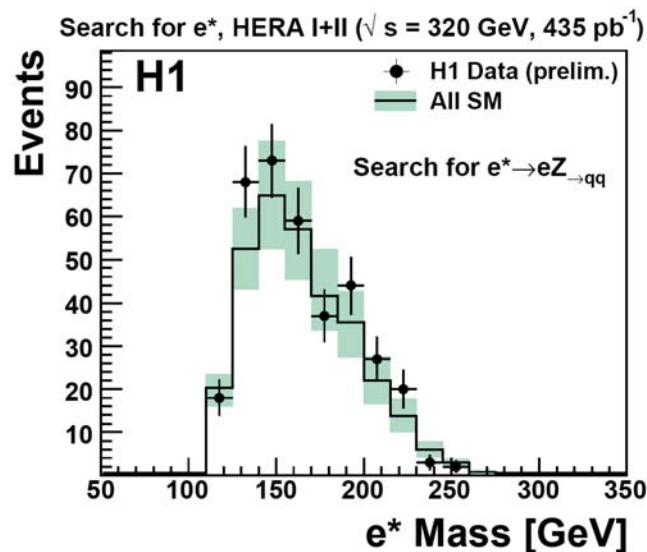
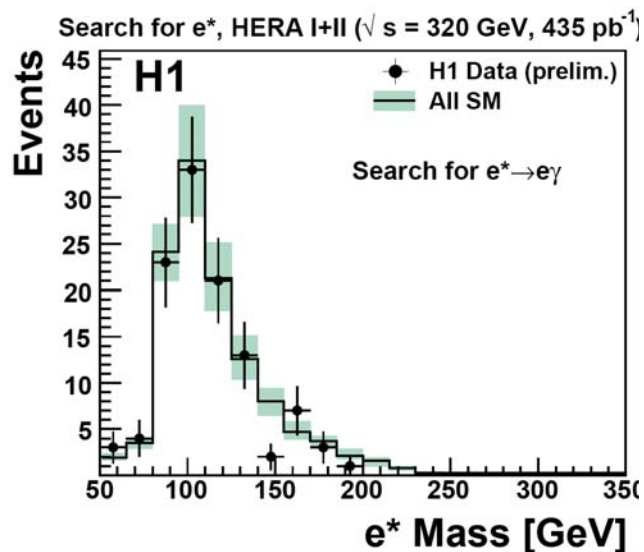
$\Lambda$  compositeness scale

$f, f'$  relative strength  
for  $W_\mu, B_\mu \rightarrow \gamma, Z$

Resonance production for masses  $< E_{\text{CMS}}$



# Excited electrons

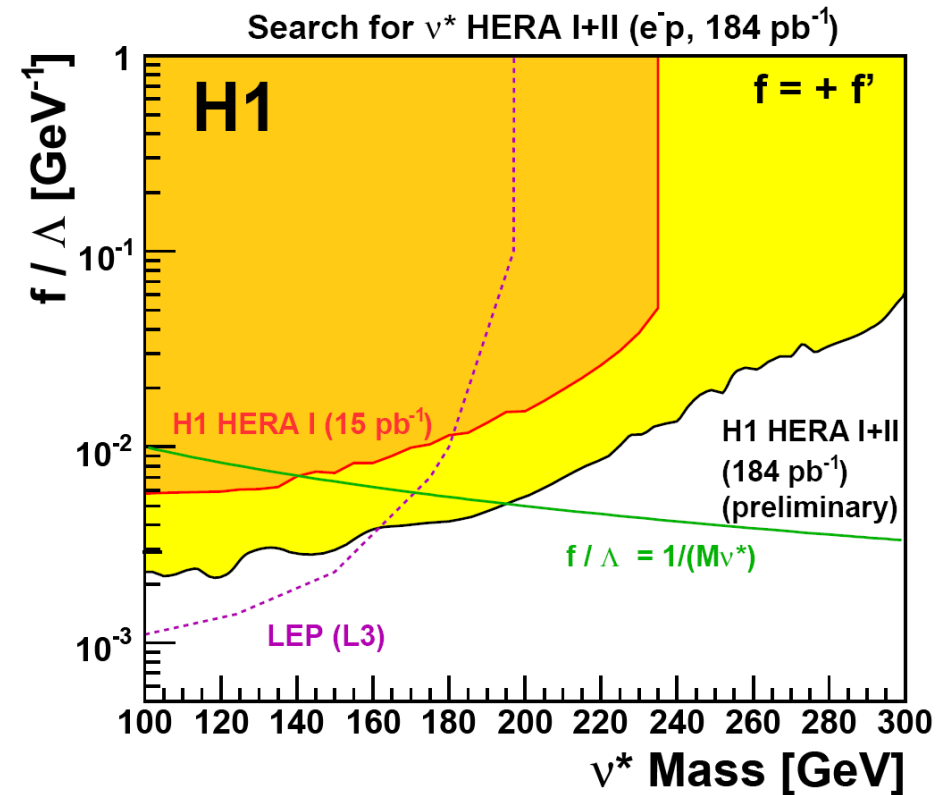
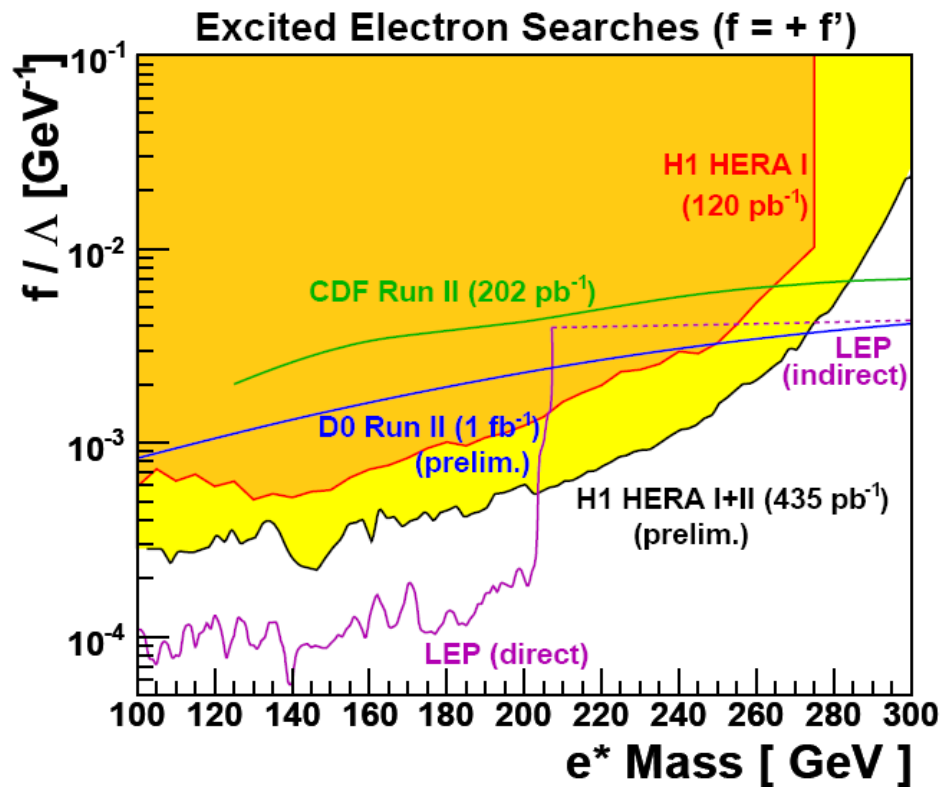


Search for  $e^*$  HERA I+II ( $\sqrt{s} = 320 \text{ GeV}$ ,  $435 \text{ pb}^{-1}$ , preliminary)

Selection	Data	SM	Efficiency $\times$ BR
$e^* \rightarrow \nu W \rightarrow qq$	172	$175 \pm 39$	$\sim 40 \%$
$e^* \rightarrow eZ \rightarrow qq$	351	$318 \pm 64$	$\sim 45 \%$
$e^* \rightarrow e\gamma$	112	$125 \pm 19$	60–70 %

**Full statistics: No excess seen**

# Excited Electrons and Neutrinos



**HERA: Limits typically 220 ... 280 GeV for  $M \sim \Delta / f$**

**LEP:  $M > 208 \text{ GeV}$  direct search**

**LEP/Tevatron: indirect limits for  $M > 280 \text{ GeV}$**

# 5. Conclusion

**HERA: final statistics available → 0.5 fb<sup>-1</sup> per experiment**

**Precision limited by**

- Luminosity for indirect searches: Contact interactions
- Beam energies for direct searches
- Experimental errors small in most cases

**Model –independent search (H1 full statistics):**

- **Few % level of understanding of ~ ALL final states at HERA**
- Exception: H1:  $\mu\nu$  channel for  $e^+$  scattering  
ZEUS: not confirmed

**Contact interactions (ZEUS 285 pb<sup>-1</sup>):**

- limits on scale  $\sim 10 \times E_{\text{CMS}} \dots$  **up to 7.5 TeV**
- Improvements from luminosity and polarisation still to come

**Excited Leptons (H1 full statistics):**

- Mass limit  **$\sim 220 \dots 280 \text{ GeV}$**