



# Rare and Exotic Studies in H1

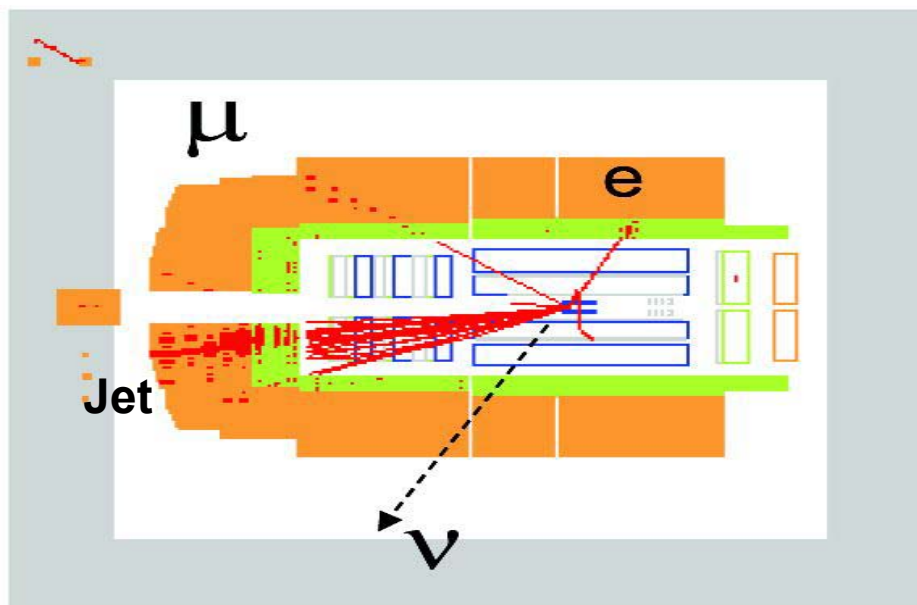


**Marina Rotaru**

Horia Hulubei National Institute of Physics and Nuclear Engineering - IFIN HH  
Particle Physics Department

**First High Energy School in Măgurele**  
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 **$e^\pm$  (27.5 GeV)**



  
**p (820, 920 GeV)**

**Topics:**

- Search for Excited Quarks in ep Collisions
- A Generic Search for Exotic Processes
- Search for RPV SUSY
- Contact Interactions
- Conclusions

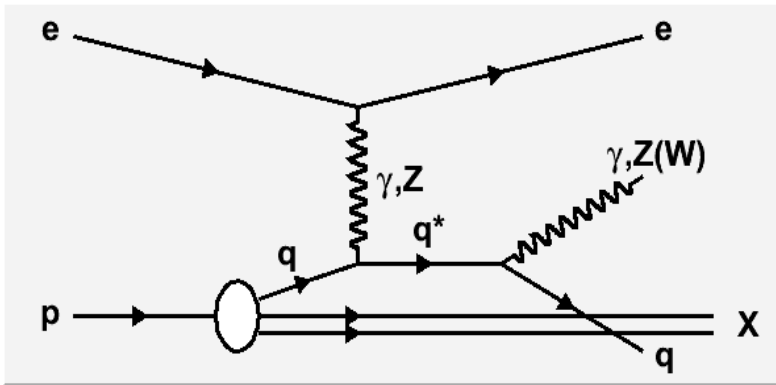
# Search for Excited Quarks in ep Collisions at HERA

- In the '70s, scientists started to consider the idea that *quarks and leptons* are composed of some subconstituents ( S. Weinberg, L. Susskind, H. Harari etc.)
- Excited states of quarks and leptons would provide convincing evidence of a new scale matter
- $q^*$  is assumed to have spin 1/2 and isospin 1/2
- Lagrangian proposed by Hagiwara, Komamiya and Zeppenfeld:

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

- $\Lambda$  is the compositeness scale (energy units)
- $Y$  is the weak hypercharge;  $g_s$ ,  $g$  and  $g'$  are the strong and electroweak gauge couplings
- $f_s$ ,  $f$  and  $f'$  are the coupling constants associated to each gauge field

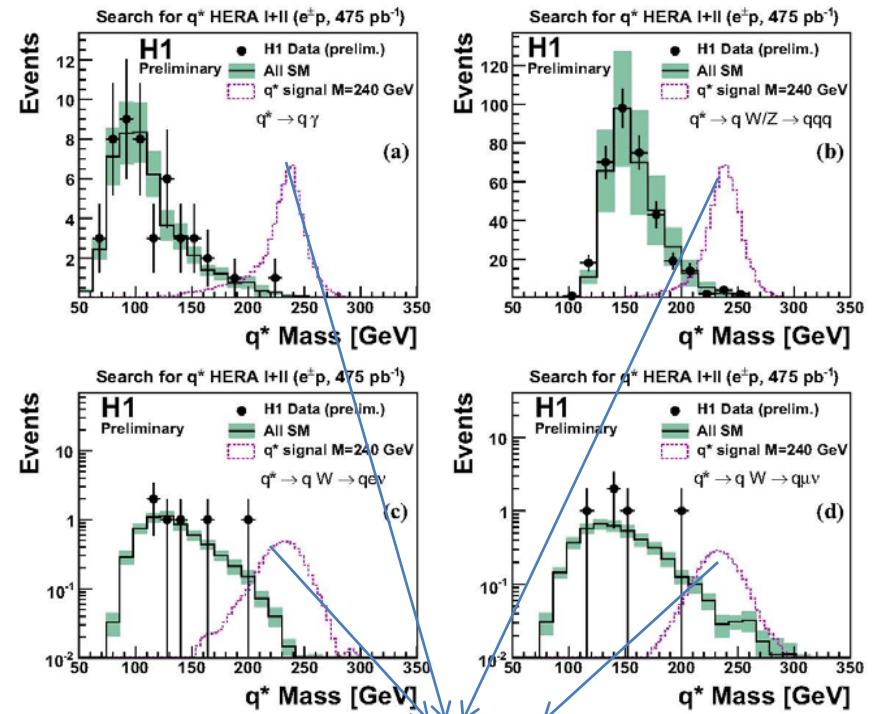
# Search for Excited Quarks in ep Collisions at HERA



- The electroweak decays of excited quarks
  - $q^* \rightarrow q\gamma$
  - $q^* \rightarrow qZ$  (with hadronic or leptonic decays of the Z bosons)
  - $q^* \rightarrow qW$  (with hadronic or leptonic decays of the W bosons)
- The distributions of the invariant mass of the data events are in agreement with those of the expected SM background
- No evidence for the production of excited quarks is observed

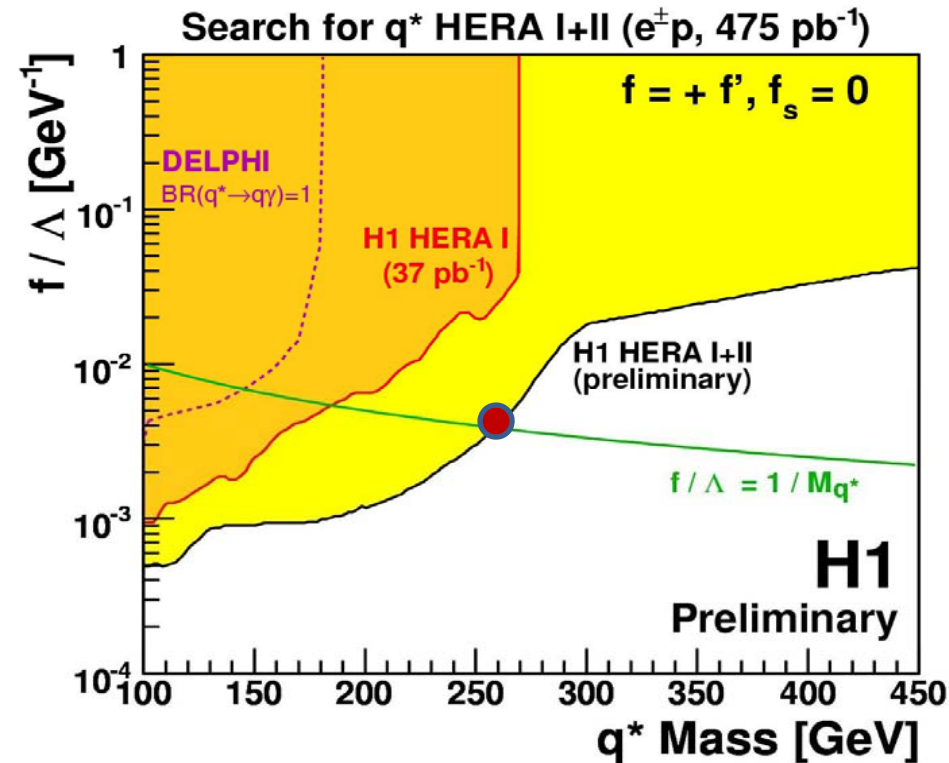
Search for  $q^*$ , HERA I+II ( $475 \text{ pb}^{-1}$ , preliminary)

Channel	Data	SM	Signal Efficiency [%]
$q^* \rightarrow q\gamma$	47	$47 \pm 7$	35–45
$q^* \rightarrow qW/Z \rightarrow qq\bar{q}$	346	$338 \pm 137$	5–60
$q^* \rightarrow qW \rightarrow qe\nu$	6	$6.0 \pm 0.8$	25–40
$q^* \rightarrow qW \rightarrow q\mu\nu$	5	$4.4 \pm 0.7$	25–50
$q^* \rightarrow qZ \rightarrow qee$	0	$0.44 \pm 0.08$	35
$q^* \rightarrow qZ \rightarrow q\mu\mu$	0	$0.87 \pm 0.08$	35



mass distribution of  $q^*$  events with  $M_{q^*} = 240 \text{ GeV}$  (an arbitrary normalization)

# Search for Excited Quarks in ep Collisions at HERA



- Considering the assumption  $f/\Lambda = 1/M_{q^*}$  excited quarks with masses up to 259 GeV are excluded (at 95% CL)
- Excited quarks with masses below 500 GeV are excluded for coupling values  $f/\Lambda > 0.05$
- These results extend previously excluded domains at HERA and LEP and are complementary to  $q^*$  searches performed at the Tevatron

# A Generic Search for Exotic Processes at HERA

- search for deviations from the SM in a model independent way

Select event sample at high  $P_T$ :

- investigate all final state configurations of ep interactions with  $\geq 2$  particles

- considered particles

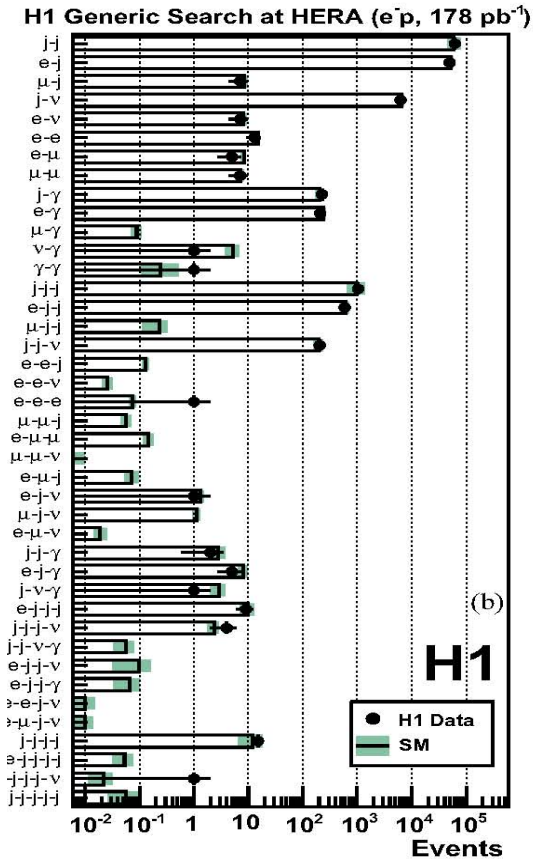
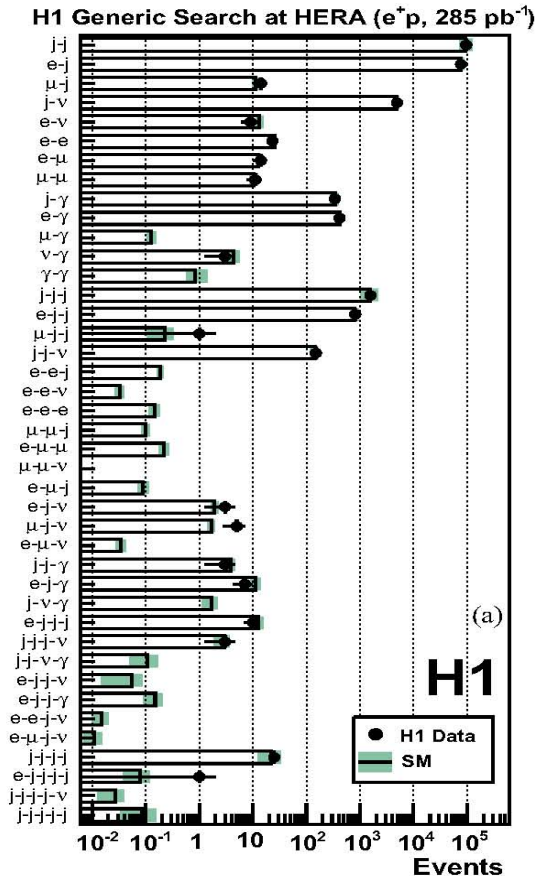
**electron, muon, jet, photon, neutrino**

- phase space

**$P_T > 15 \text{ GeV}$   $10^\circ < \theta < 140^\circ$**

- classification of events into exclusive classes

**e-j-j or j-j or j-j-j**

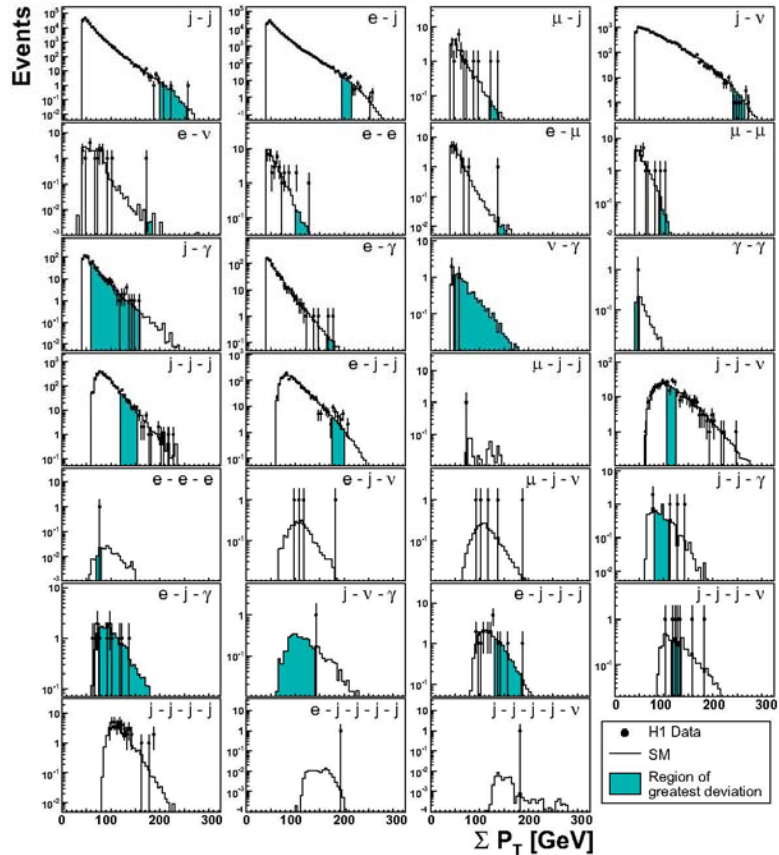


The event yields are presented for the data and SM expectation for  $e^+p$  and  $e^-p$  collisions  
In most channels good agreement between data and SM

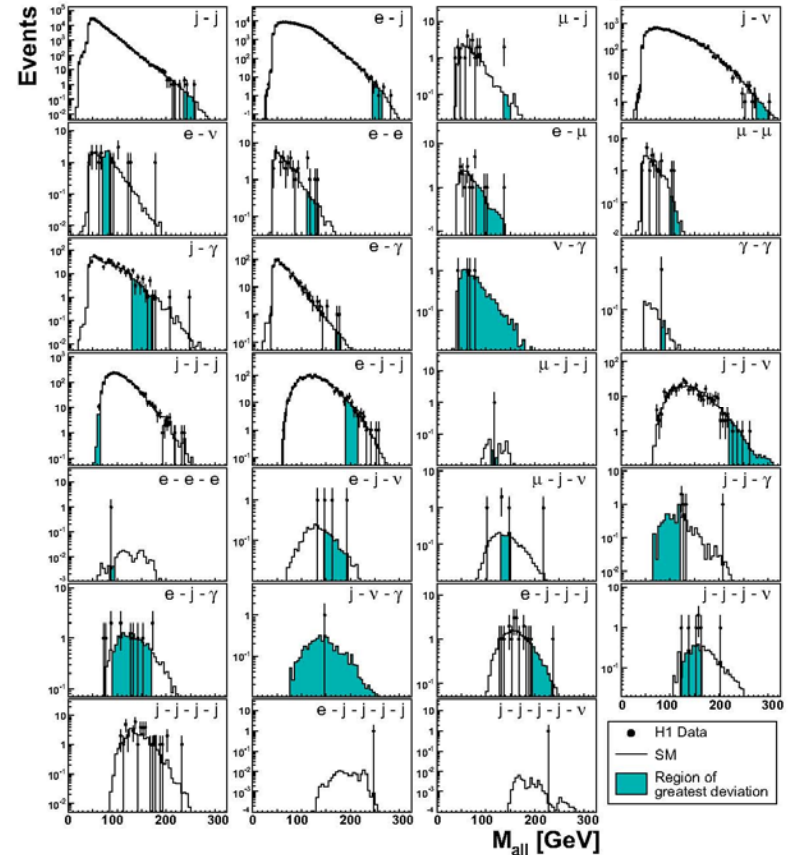
# A Generic Search for Exotic Processes at HERA

- look for possible deviations in  $\Sigma P_T$ ,  $M_{all}$
- find the regions in the distribution with the largest deviation (deficit or excess)

H1 Generic Search at HERA ( $e^\pm p$ , 463  $\text{pb}^{-1}$ ) -  $\Sigma P_T$  Distributions



H1 Generic Search at HERA ( $e^\pm p$ , 463  $\text{pb}^{-1}$ ) -  $M_{all}$  Distributions



A good agreement between data and SM distributions is observed

# A Generic Search for Exotic Processes at HERA

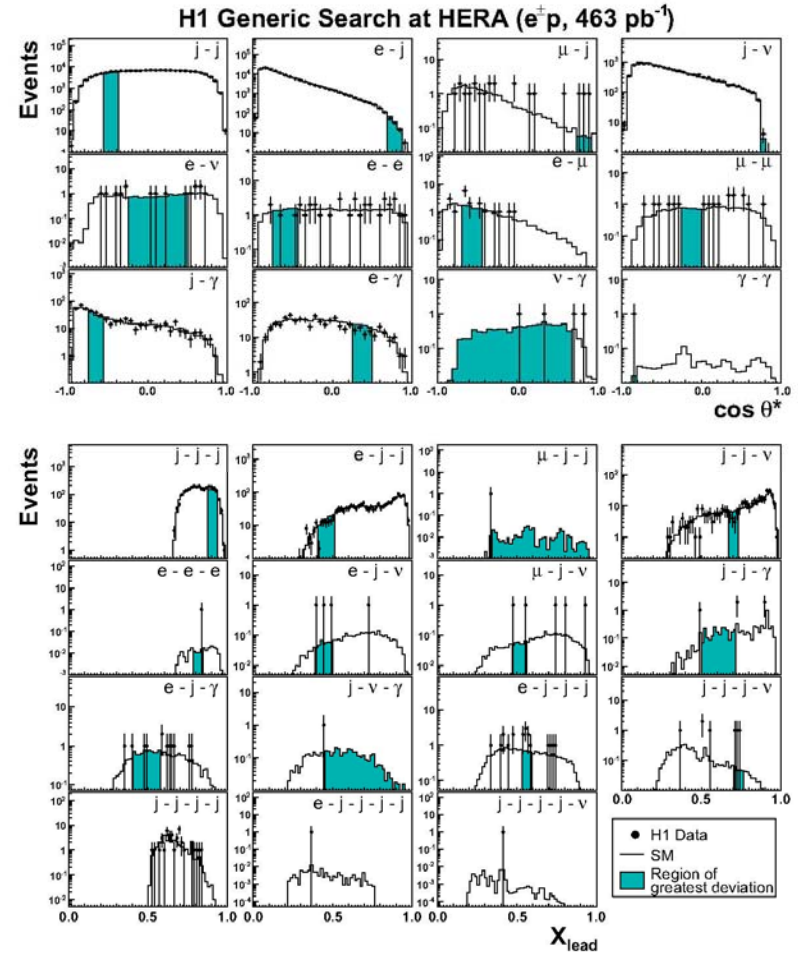
- look for possible deviations in angular distributions and energy ratios (are sensitive to spin and decay properties of the hypothetical high mass particles)

$\cos\theta^*$  - cosine of the polar angle of the leading body relative to the incident proton in the centre-of-mass frame defined by all bodies

$$X_{lead} = \frac{2E_{lead}^*}{\sum_i E_i^*} \quad \text{Dalitz variable}$$

$E_{lead}^*$  and  $E_i^*$  are calculated in the centre of mass frame of all bodies

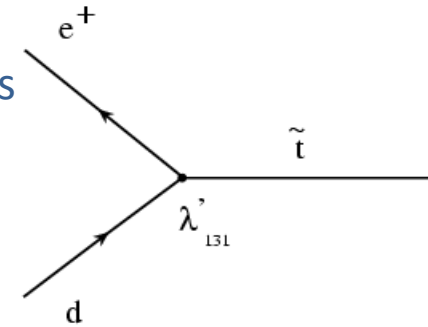
A good overall agreement with the SM prediction is observed in all cases



# Search for RPV SUSY at HERA

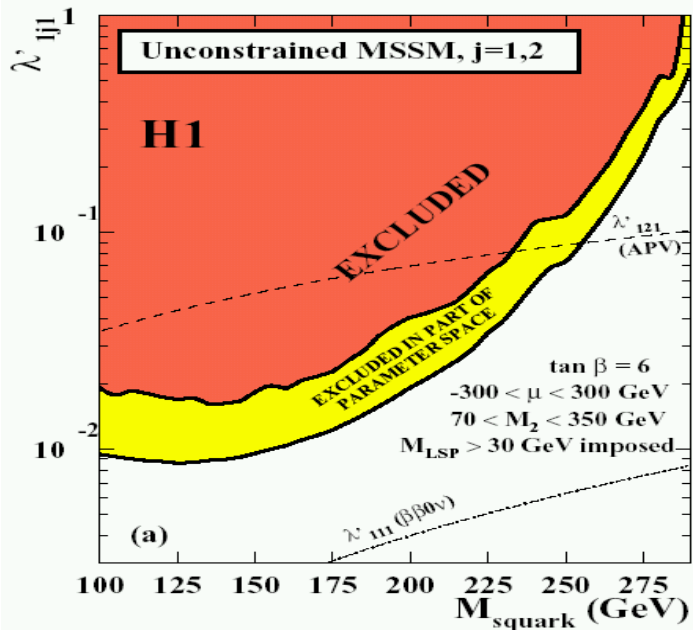
- Multiplicative, discrete Symmetry:  $R_p = (-1)^{3B+L+2S}$ 
  - B-baryon number
  - L-lepton number
  - S-the spin of a particle

+1 for SM particles  
-1 for SUSY particles



Squark production

- RPV: Allows single sparticle production
- Large number of free parameters in the theory
- Squark search and parameter scan of RPV MSSM on full H1 data
- Many final states considered:  $eq, nq, eMJ, eeMJ, emMJ, neMJ, nMJ, nmMJ$   $\Sigma BR \sim 100\%$



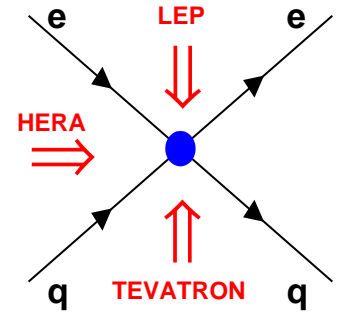
- exclusion limits for  $\tan\beta = 6$
- continue lines – maximal and minimal values obtained for  $\lambda'$  within the parameter space investigated
- the red region is excluded in the full parameter space
- the yellow region is ruled out in parts of the SUSY parameter space

$\tan\beta$  – ratio of the two vacuum expectation values  
 $\mu$  – corresponds to the Higgs mass parameter in SM  
 $M_2$  – wino mass parameter



# Contact Interactions

- Possible new interactions between e and q can modify DIS cross section at high  $Q^2$  via virtual effects
- Four fermion eeqq contact interactions  $\rightarrow$  convenient method to investigate these interferences
- Effective Lagrangian for vector eeqq contact interactions:  
(Scalar and tensor CI constrained beyond HERA sensitivity)

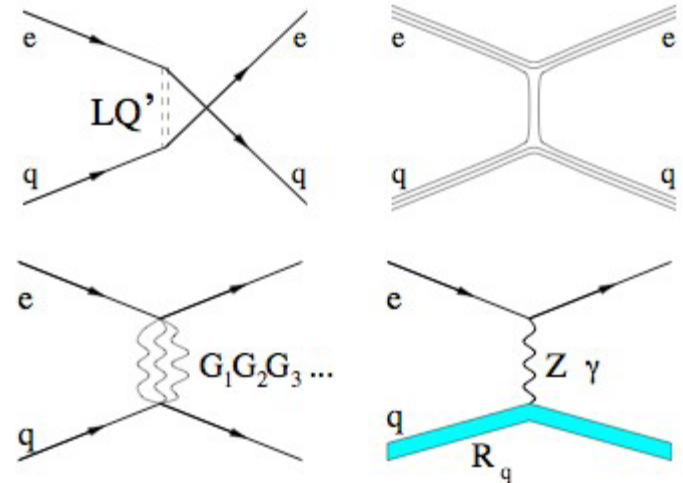


$$\mathcal{L}_{CI} = \sum_{\substack{\alpha, \beta=L,R \\ q}} \eta_{\alpha\beta}^{eq} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha) (\bar{q}_\beta \gamma_\mu q_\beta)$$

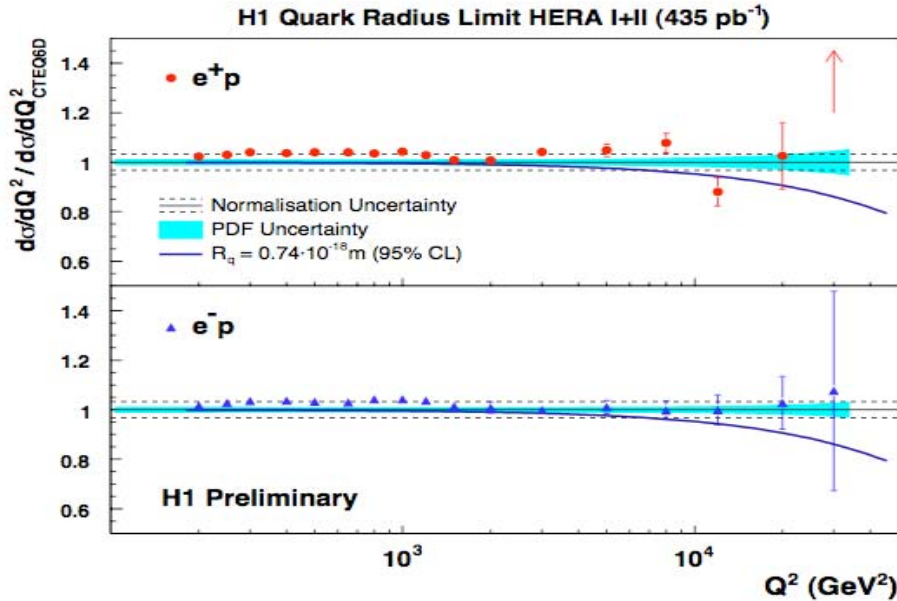
$\eta_{\alpha\beta}^{eq}$  - 4 possible couplings for every flavor q

- Certain models can be constructed by appropriate choice of the couplings  $\eta_{\alpha\beta}^{eq}$
- General models considered:

- Quark Form Factor
- Compositeness
- Heavy Leptoquarks
- Large Extra Dimensions



# Contact Interactions



$$R_q < 0.74 \times 10^{-16} \text{ cm at 95\% CL}$$

No evidence for New Physics

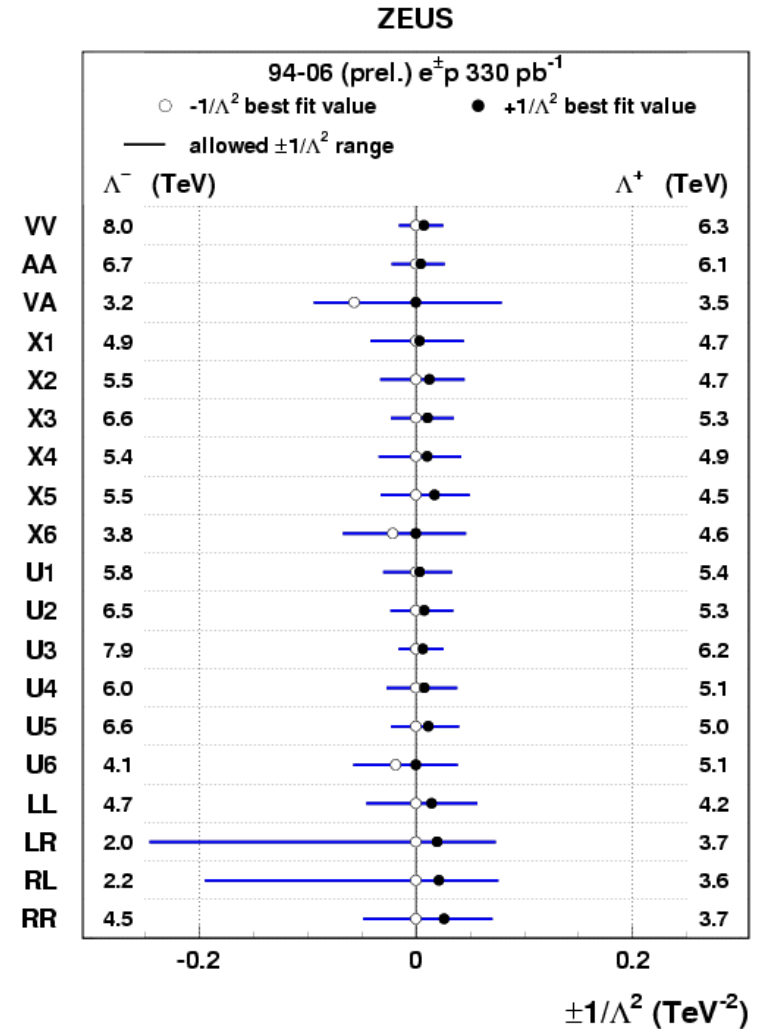
- LQ limits from H1 using HERA II  $e^-p$  data:  
 $M_{LQ} > 276-304 \text{ GeV}$  for  $\lambda=0.3$
- CI limits from ZEUS using all HERA I+II data:

Compositeness scale:  $\Lambda = 2-8 \text{ TeV}$

Heavy LQ:  $M_{LQ} / \lambda > 0.32-1.9 \text{ TeV}$

Quark radius:  $R_q < 0.67 \times 10^{-16} \text{ cm}$

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



Limits on the compositeness scale  $\Lambda$ , for different CI models (at 95% CL)

## Summary & Outlook

**Excited Quarks** - all HERA Data (I+II) analyzed  
- no evidence found for excited quarks  
- excited quarks with a mass lower than 259 GeV are excluded

**Generic Search** - full  $e^\pm p$  data sample is investigated for deviations from the SM prediction  
- no significant deviation is found

**Search for RPV SUSY** – large variety of SUSY scenario assuming  $R_p$  violation  
- HERA particularly well suited to study squark production but also for scenarios where squarks are much heavier than sleptons

**New interesting results from HERA expected soon!**

**Contact Interactions** - analysis including HERA I+II data → significant improvement of limits  
- more data HERA I+II and possible H1 + ZEUS data combination

**Improvements are expected!**