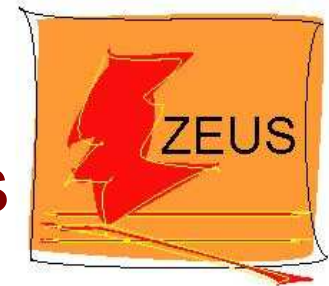


# Search for New Physics at HERA



Andrea Parenti (DESY)  
for the H1 and ZEUS collaborations



CIPANP 2009

S. Diego, 28/05/2009

# Outline

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- Introduction to HERA
- Model dependent searches
  - ★ Quark radius
  - ★ Excited fermions
  - ★ Leptoquarks
  - ★ Single top production
- Model independent searches
  - ★ Isolated lepton final states
  - ★ Multi-lepton final states
  - ★ General searches

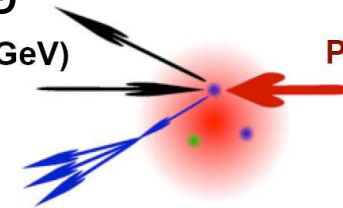
# The HERA Collider

- The world only  $ep$  collider, in DESY Hamburg

- Center-of-mass energy: up to 320 GeV

$e^\pm$  (27.6 GeV)

P (820/920 GeV)



- Two colliding, general purpose experiments, H1 and ZEUS

- Operations ended in Jun 2007

- Collected luminosity:

- HERA I, 1992-2000:

- ~0.1  $\text{fb}^{-1}/\text{exp}$

- HERA II, 2002-2007:

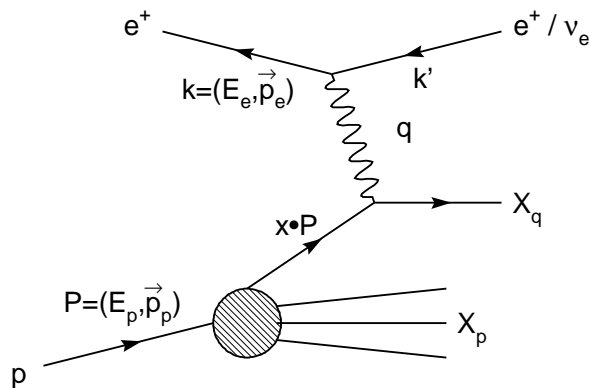
- ~0.4  $\text{fb}^{-1}/\text{exp}$

- (with polarized  $e^\pm$  beams)

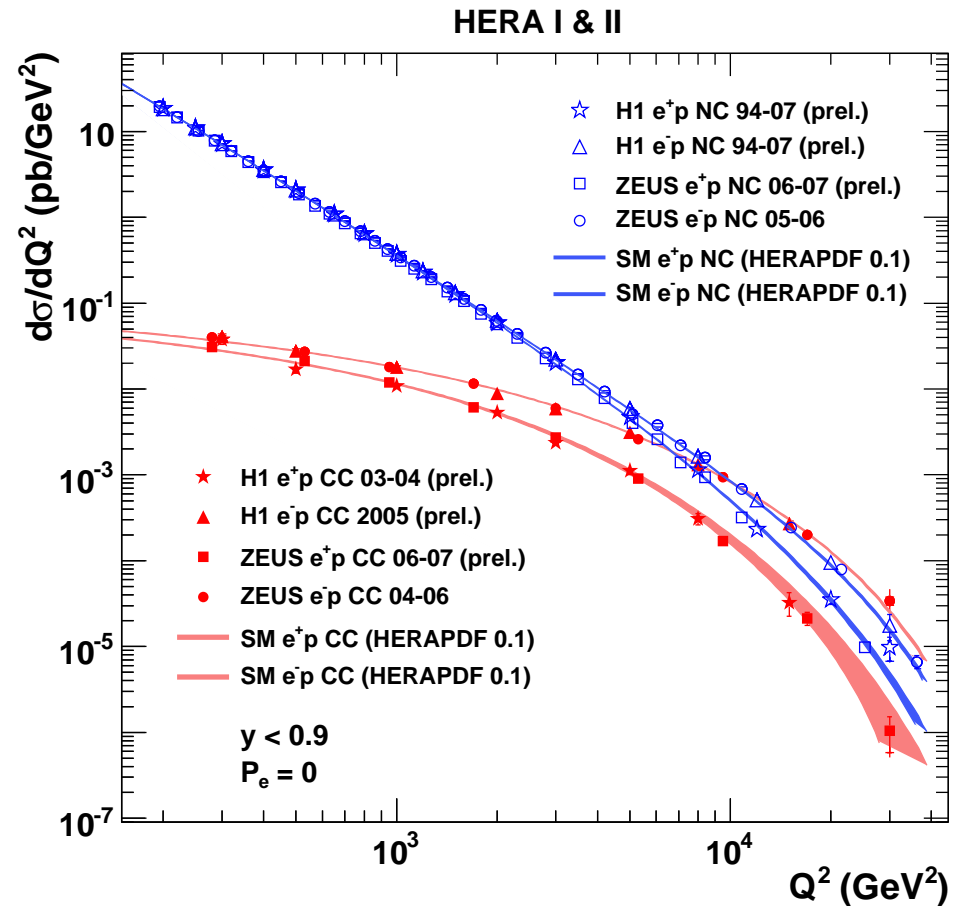


# Deep Inelastic Scattering at HERA

- HERA investigates  $ep$  collisions



- $Q^2 = -q^2$  gives the resolving power of the EW probe
- New physics would appear at high- $Q^2$ , ie small distance: at HERA down to  $10^{-18}\text{m}$





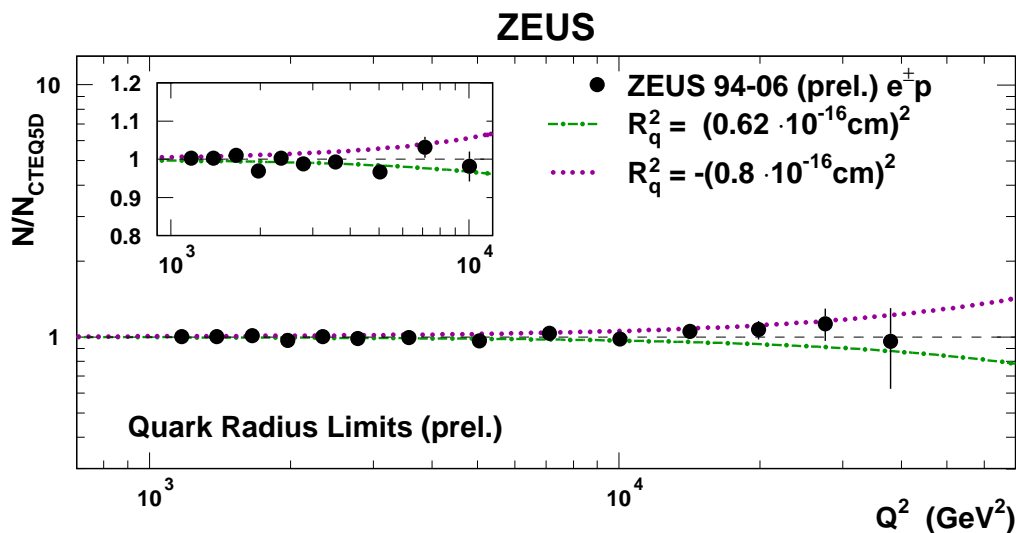
# Quark Radius

H1prelim-07-141

ZEUS-prel-07-028

- A decrease in the cross section at high- $Q^2$  is expected if quarks are not pointlike:

$$\sigma = \sigma_{\text{SM}} \times \left( 1 - \frac{\langle R_q \rangle^2 Q^2}{6} \right)^2$$



No deviation from SM  $\Rightarrow$   
 limits are set on  $R_q$  (95% CL):

- ★ ZEUS:  $R_q < 0.62 \cdot 10^{-3} \text{ fm}$
- ★ H1:  $R_q < 0.74 \cdot 10^{-3} \text{ fm}$

- With a similar fit we can also look for contact interactions ( $\rightarrow$  backup slides)



# Excited Fermions (1)

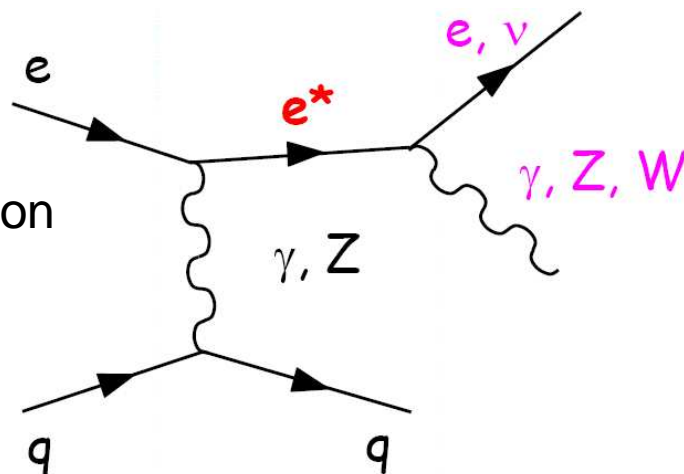
arXiv:0904.3392  
Phys.Lett.B666:131  
Phys.Lett.B663:382

- Excited fermions would be signature of compositeness
- Compositeness could explain 3 families and mass hierarchy
- Excitation/de-excitation described by effective Lagrangian:

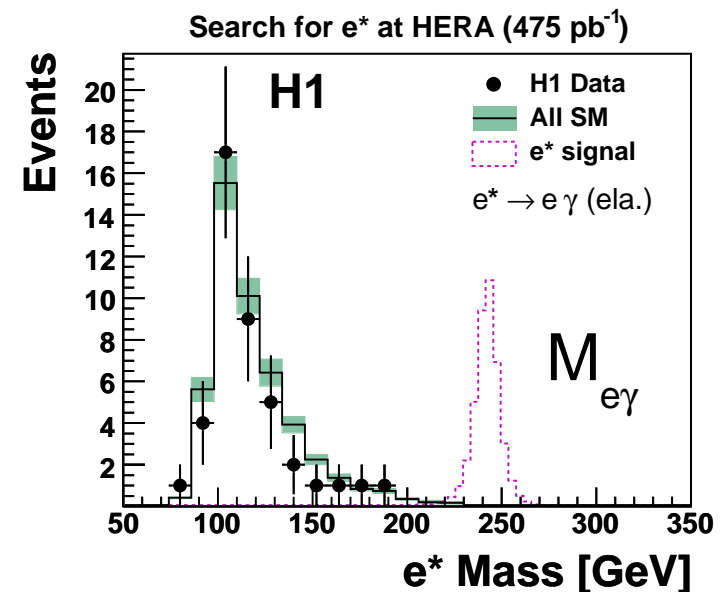
$$\mathcal{L}_{\text{GM}} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[ g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L$$

[f, f' and f<sub>s</sub> are the couplings to the SM gauge groups]

Example: production and decay of e\*

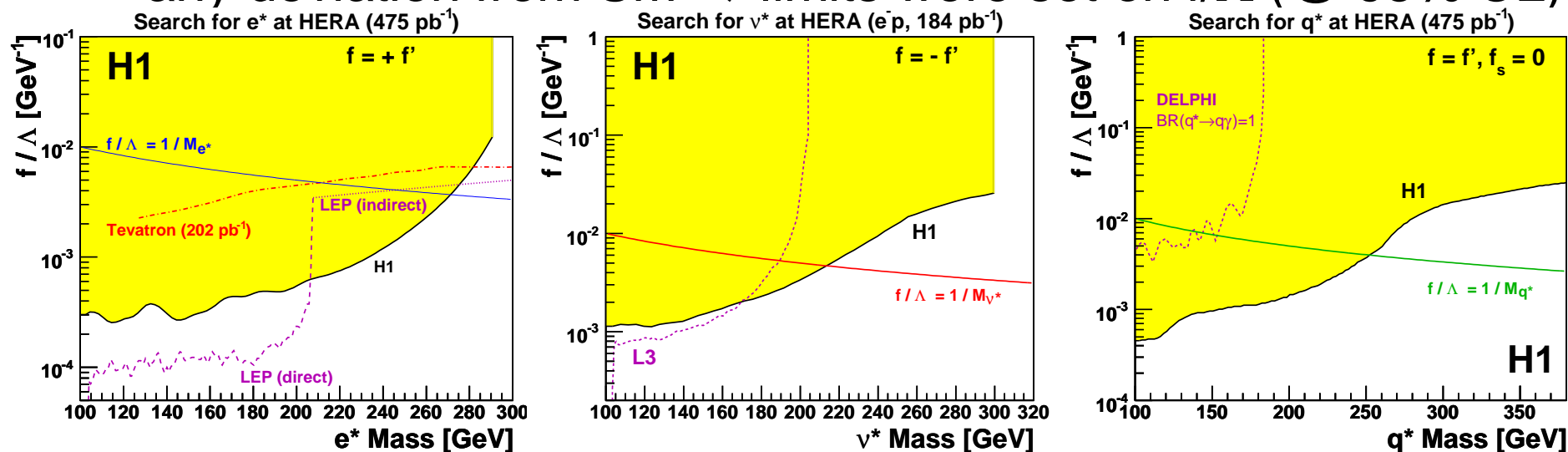


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# Excited Fermions (2)

- H1 looked for all possible decay channels and did not find any deviation from SM  $\Rightarrow$  limits were set on  $f/\Lambda$  (@ 95% CL)



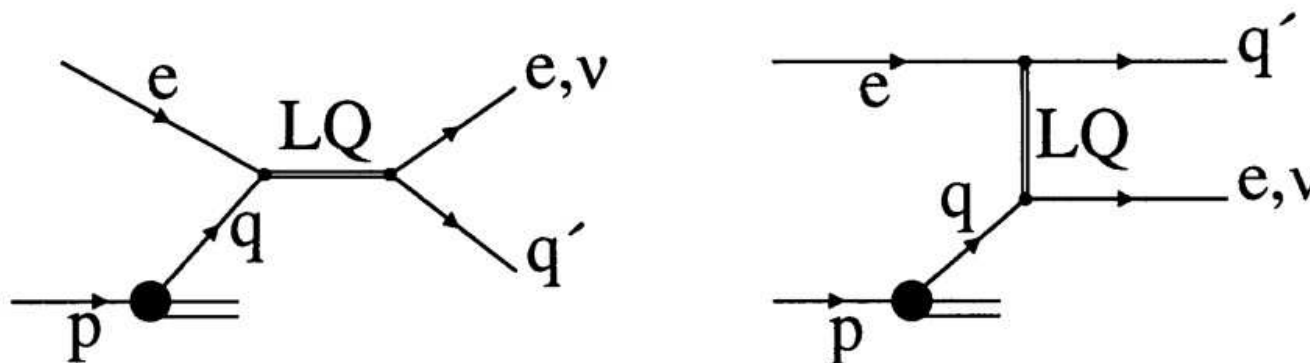
- $f/\Lambda$  limits can be translated into mass limits assuming  $f/\Lambda = 1/M_{f^*}$

- $M_{e^*} > 272 \text{ GeV}$
- $M_{\nu^*} > 213 \text{ GeV}$  [assuming  $f=-f'$ ]
- $M_{q^*} > 252 \text{ GeV}$  [assuming  $f_s=0$ ]

# Leptoquarks (1)

H1prelim-07-164

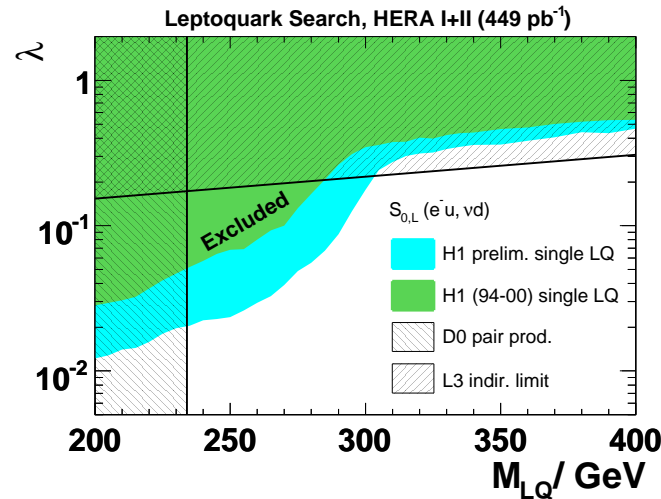
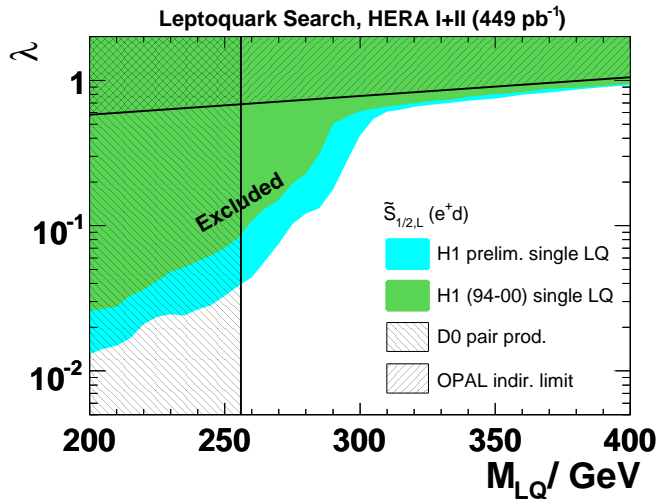
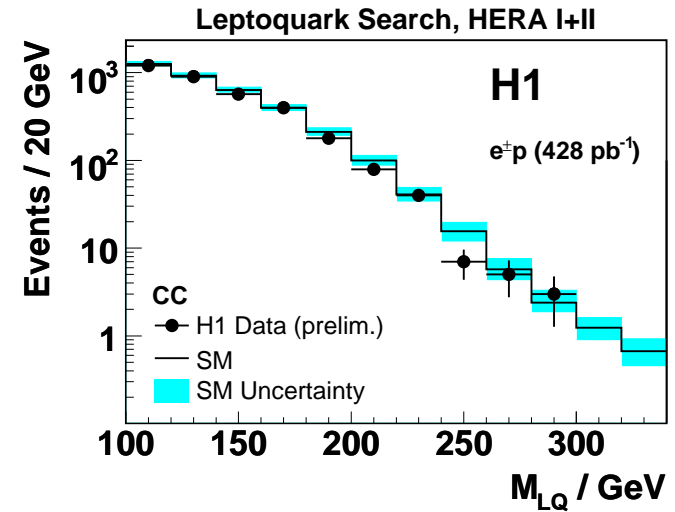
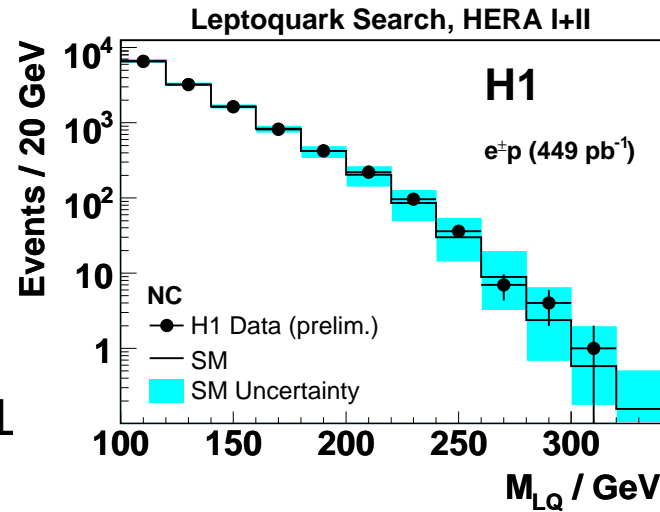
- LQs appear in many SM extensions
- Couple to both electrons and quarks and carry SU(3) color, fractional electric charge, baryon (B) and lepton (L) number
  - Fermion number:  $F = 3B + L = 0, 2$
- LQs model are explored in Buchmüller-Rückl-Wyler (BRW) framework (14 different LQ types)
- We search for LQ decaying into e-jet or  $\nu$ -jet:





# Leptoquarks (2)

- Full statistics analyzed by H1 (prel. results)
- No deviation from SM, so limits on coupling are derived @ 95% CL



- HERA limits are complementary to LEP and Tevatron

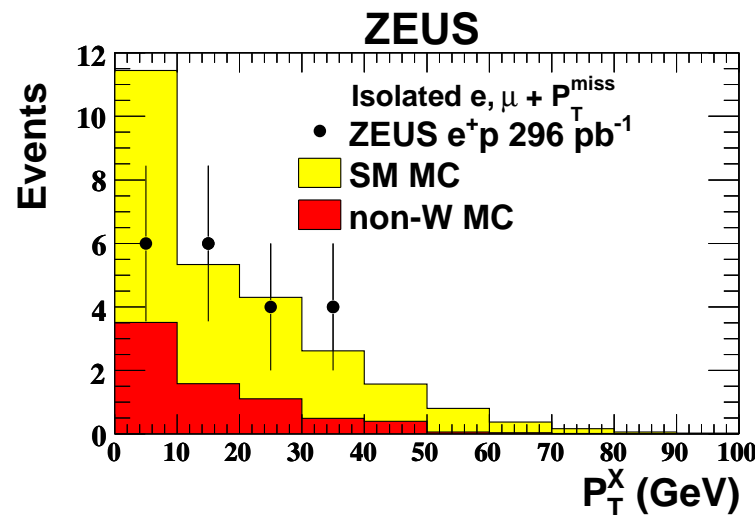
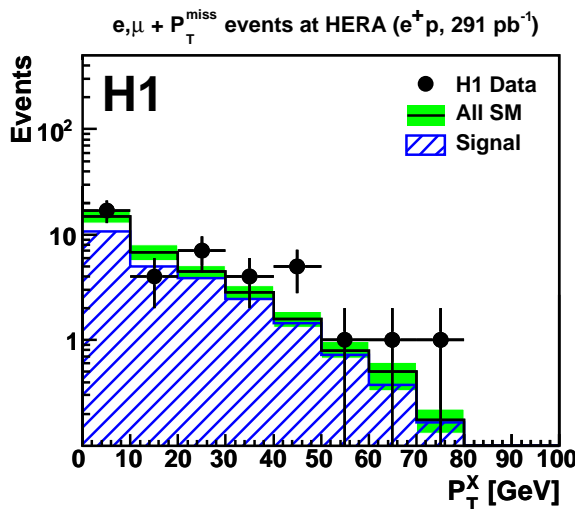
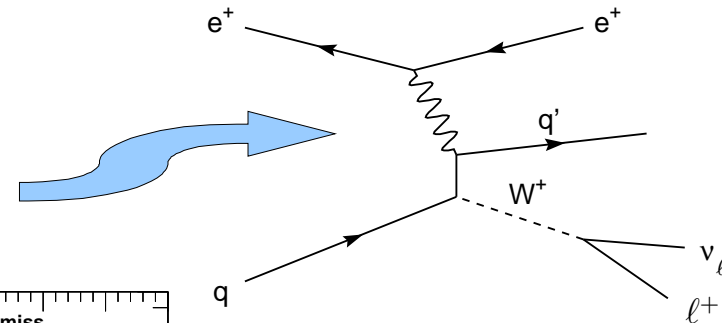


# Isolated Leptons

arXiv:0901.0488

Phys.Lett.B672:106

- Look for events with isolated, high- $P_T$  lepton ( $e, \mu$ ), missing  $P_T$  and hadronic system ( $P_T^X$ )
- SM production:  $ep \rightarrow eW^\pm X$  ( $\sigma \sim 1.3 \text{ pb}$ )



★ In H1  $e^+p$  data,  $P_T^X > 25 \text{ GeV}$ : 17 obs /  $8.0 \pm 1.3 \text{ exp}$  ( $2.4\sigma$  excess)

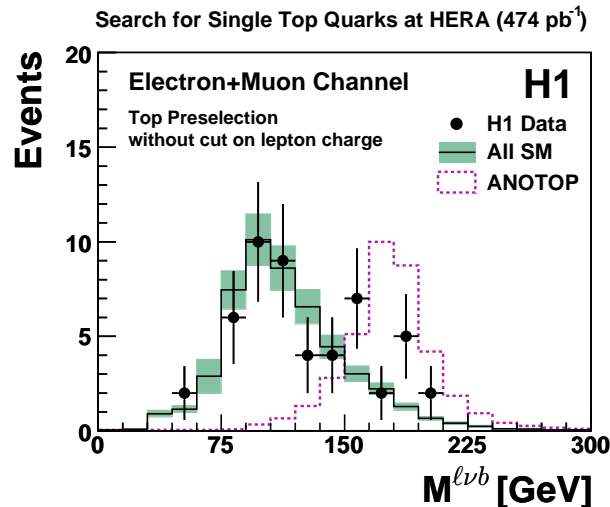
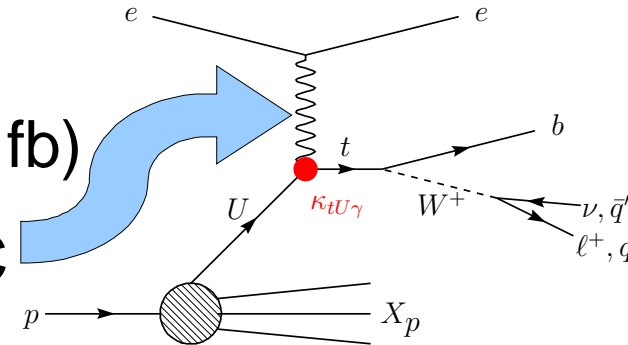
★ No excess seen in  $e^-p$ , also no excess observed by ZEUS



# Single Top production

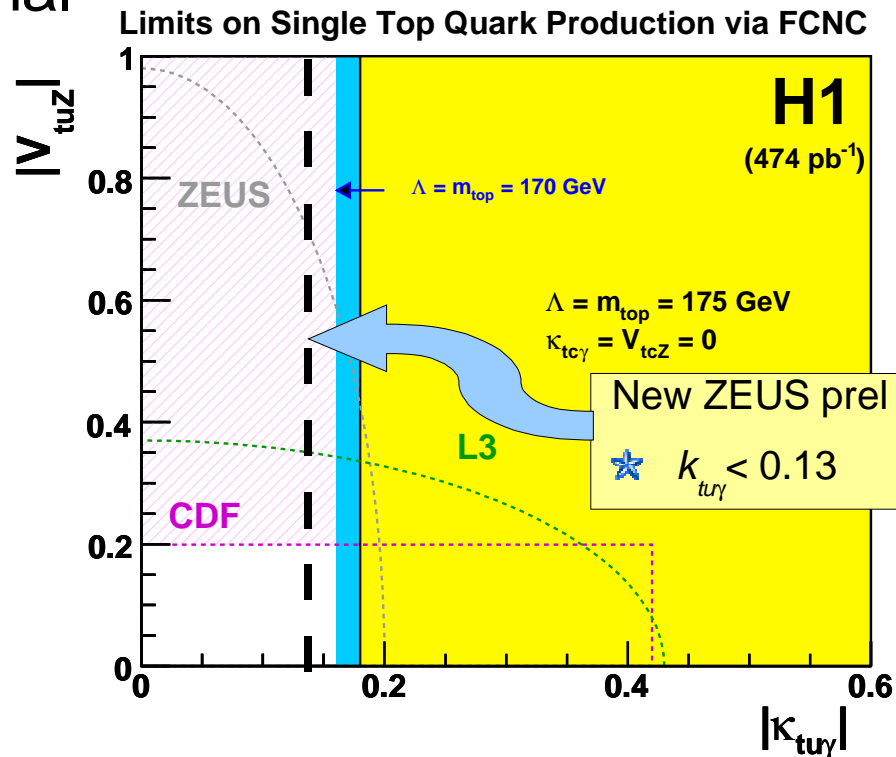
arXiv:0904.3876  
ZEUS-prel-09-009

- Produced in SM via CC interaction  
 $ep \rightarrow \nu tb X \dots$  but tiny cross section  $\sigma = O(1\text{fb})$
- BSM: production via Flavor Changing NC
- No significant excess in the signal region, limits are set on anomalous coupling  $k_{t\gamma}$



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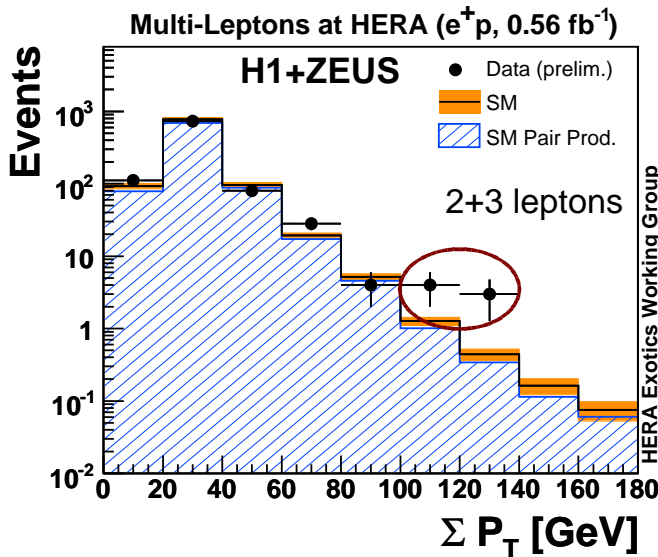
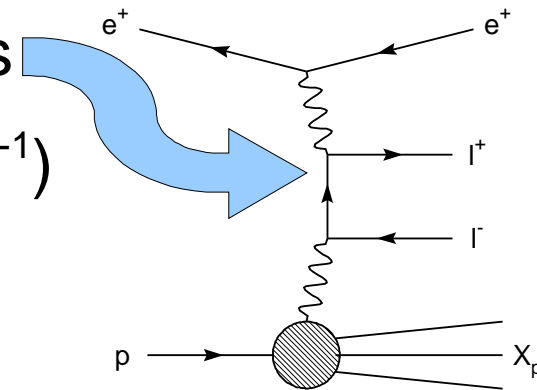
A. Parenti



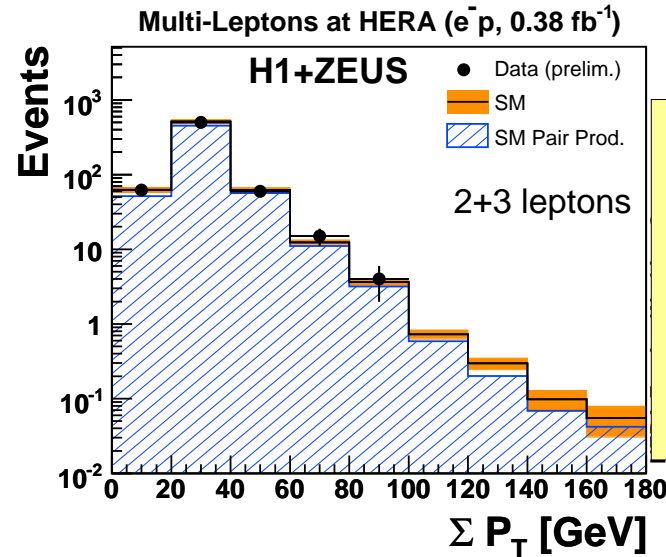
# Multi-Leptons

H1prelim-09-064  
ZEUS-prel-09-008

- Look for events with 2 or more isolated high- $P_T$  leptons ( $e, \mu$ )
- SM production via Bethe-Heitler process
- H1 and ZEUS combined results ( $0.94 \text{ fb}^{-1}$ )



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A. Parenti

★ In  $e^+p$  data,  $\Sigma P_T > 100 \text{ GeV}$ :  
7 obs/ $1.94 \pm 0.17$  exp  
(excess of  $2.6 \sigma$ )

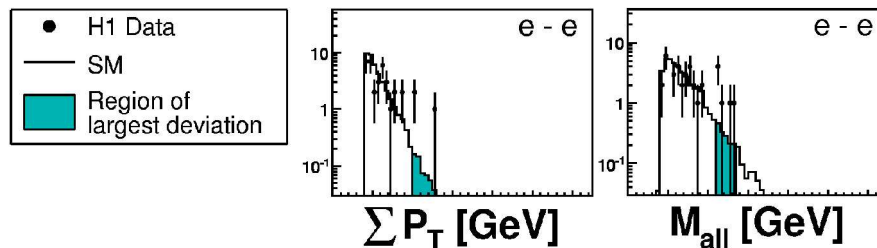
★ In  $e^-p$  data,  $\Sigma P_T > 100 \text{ GeV}$ :  
0 obs/ $1.19 \pm 0.12$  exp



# General Searches

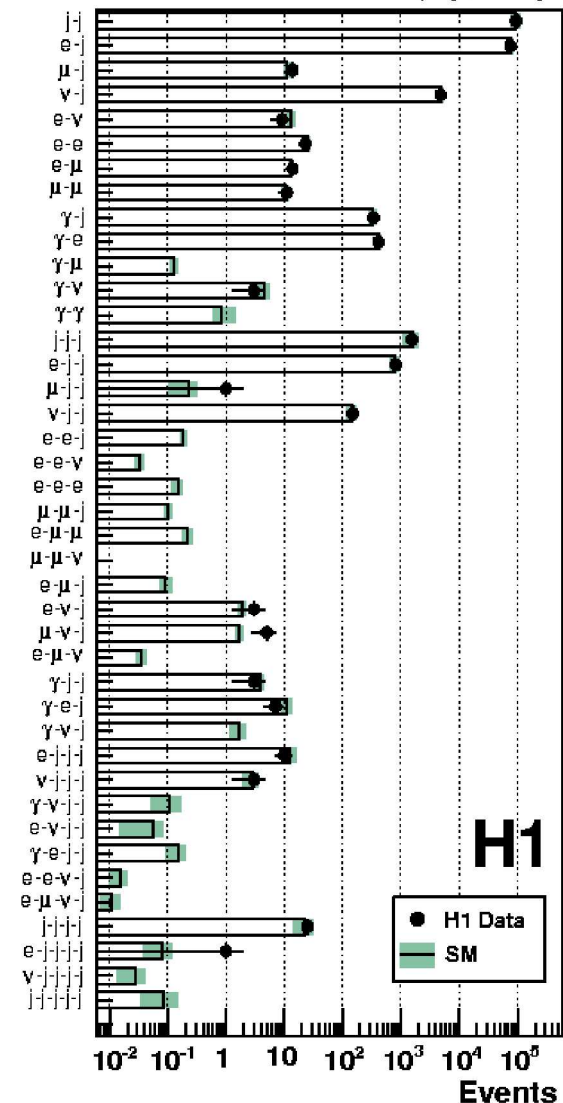
Phys.Lett.B674:257

- Look for events with isolated  $e, \gamma, \mu, \nu$ , jets having  $P_T > 20$  GeV
- Events are classified depending on the number and type of high- $P_T$  objects
  - at least one event in 27 topologies
- In general good agreement with SM
- Deviation from SM is searched for in distributions of  $\Sigma P_T$  and  $M_{\text{all}}$  with a statistical algorithm



- All deviations are compatible with statistical fluctuations

H1 General Search at HERA ( $e^+p$ , 285  $\text{pb}^{-1}$ )



# Summary

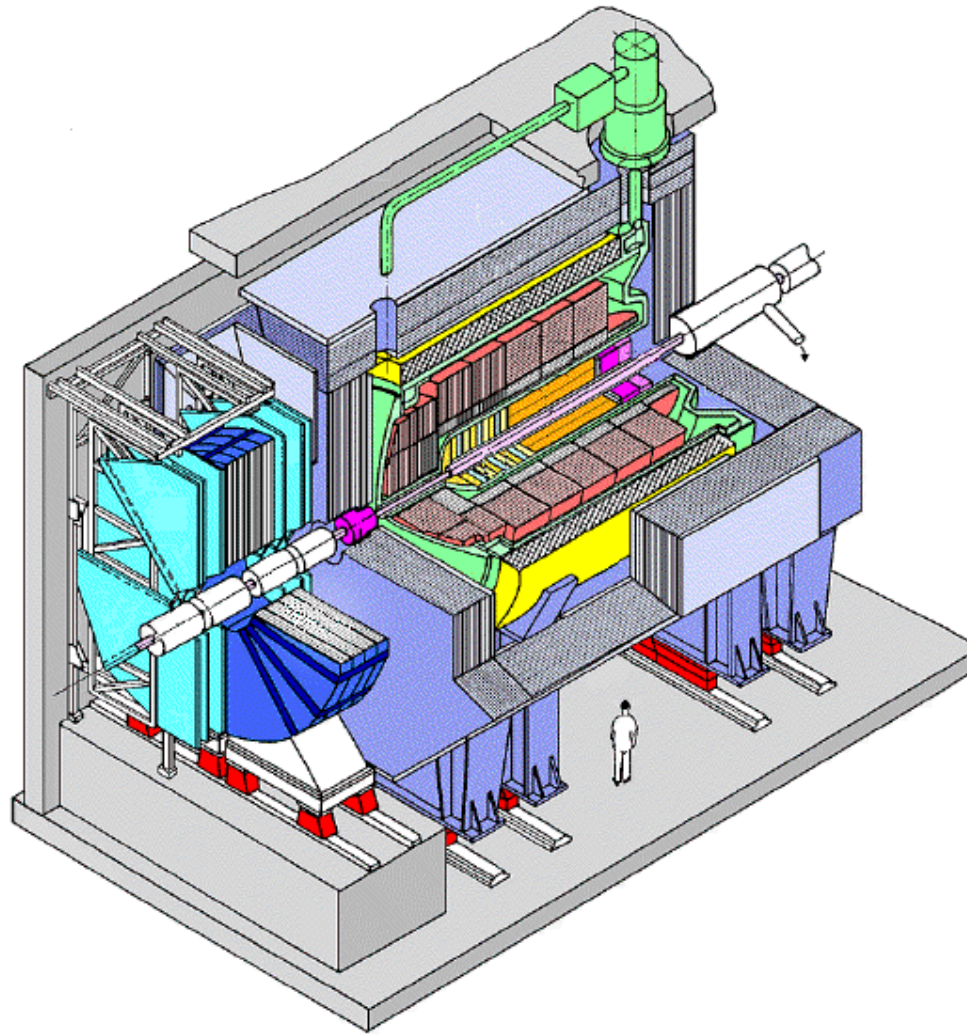
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- HERA collected  $\sim 0.5\text{fb}^{-1}$  per experiment
- Most analyses make use of the full statistics
- Overall good agreement with the SM:
  - Exclusion limits are set, competitive to LEP and TEVATRON
  - World's best limits on excited fermions, anomalous productions
- To reach the best sensitivity, H1 and ZEUS started combination

# Backup Slides

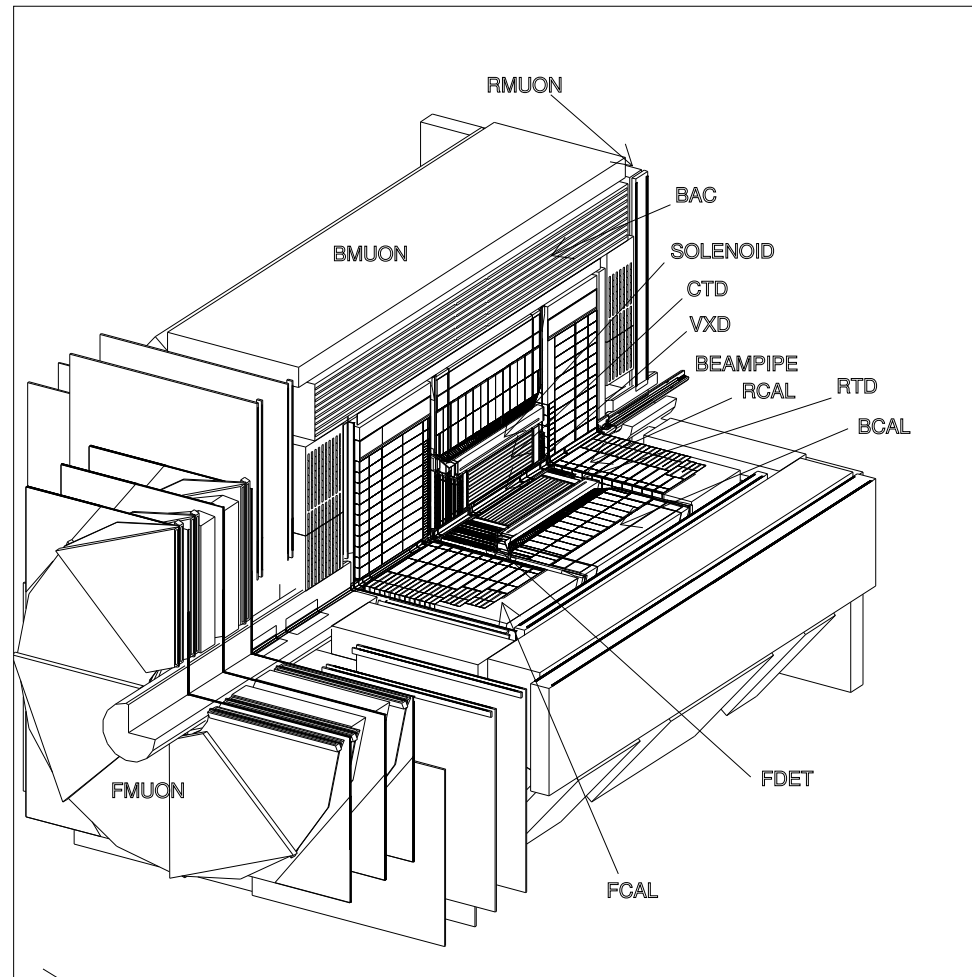
# The H1 Detector

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# The ZEUS Detector





# Contact Interactions (1)

Phys.Lett.B568:35  
ZEUS-prel-07-028

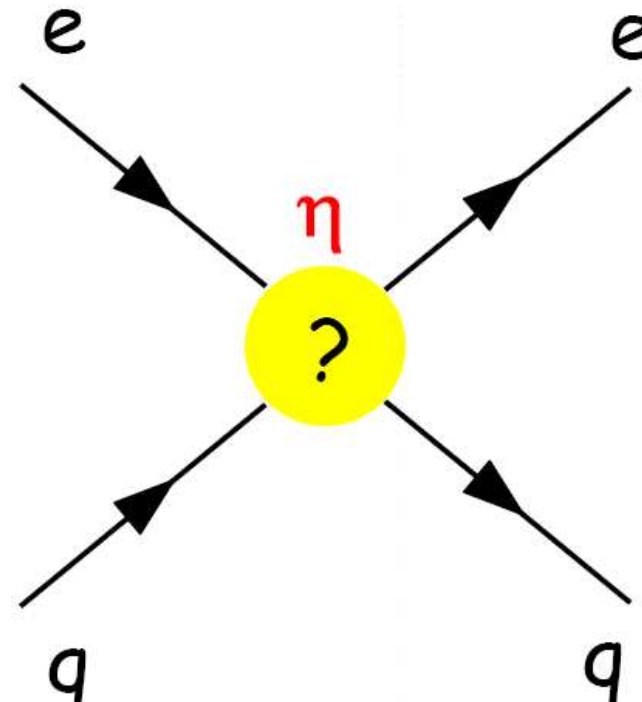
- Any interaction appearing at much higher energy than center-of-mass can be represented by an effective Lagrangian

$$\mathcal{L}_{CI} = \sum_{a,b=L,R}^{q=u,d} \eta_{ab}^q (\bar{e}_a \gamma_\mu e_a) (\bar{q}_b \gamma^\mu q_b)$$

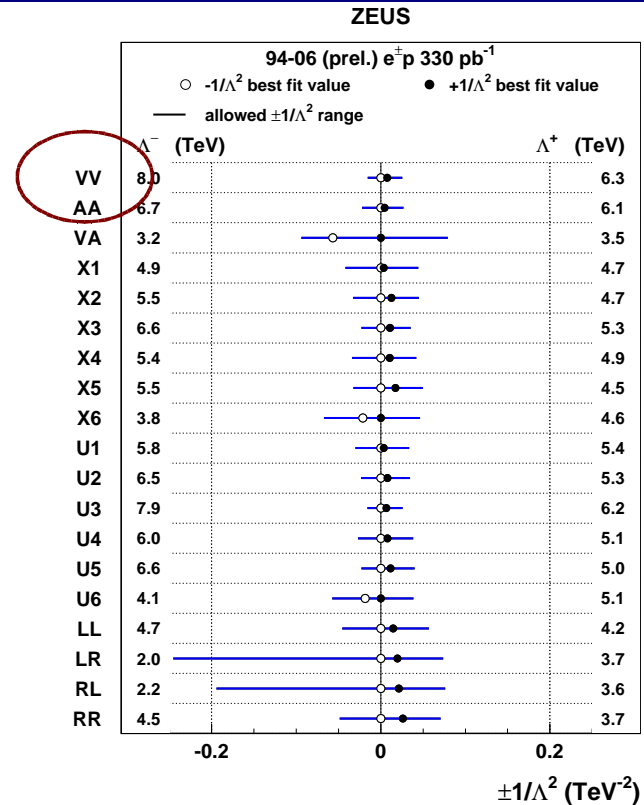
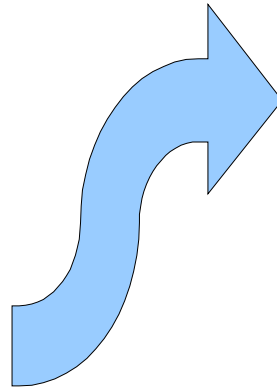
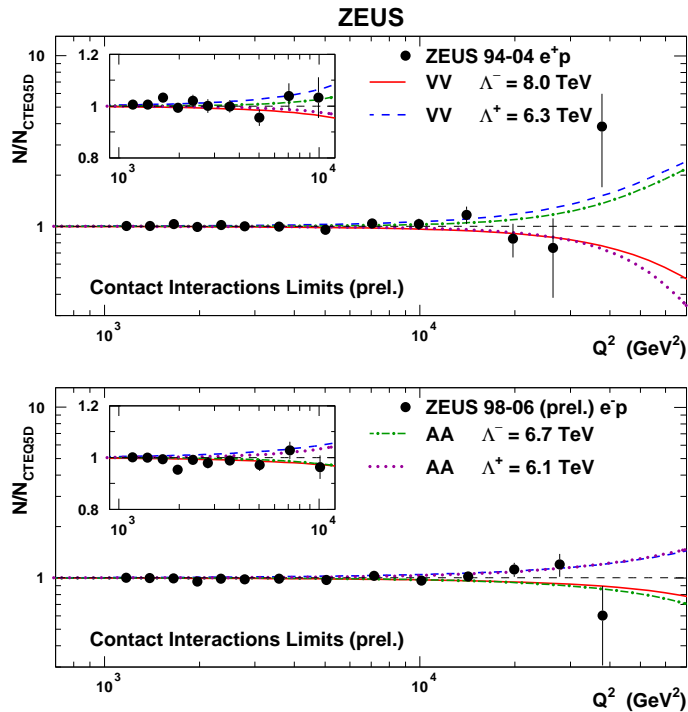
where

$$\eta_{ab}^q = \pm 4\pi / \Lambda^2$$

- $\Lambda$  is the new physics scale
- Many models are possible, depending on the chiral structure assumed



# Contact Interactions (2)



- No deviations from the SM. Limits are set on the scale  $\Lambda$  for each model:

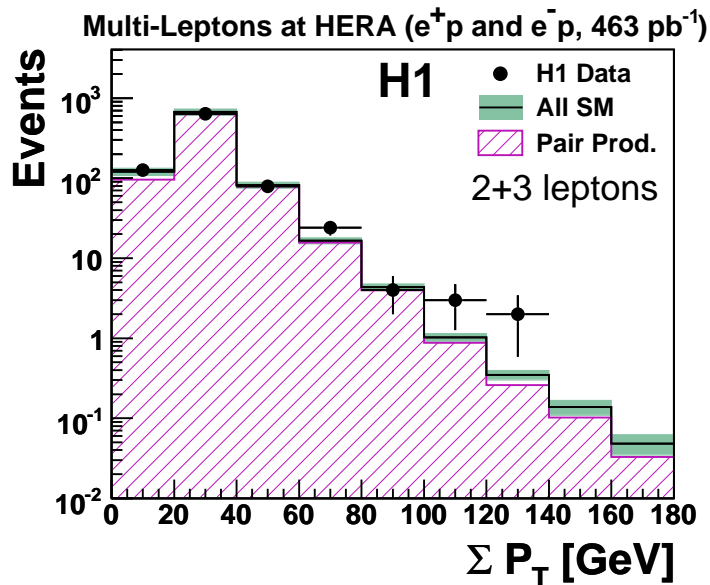
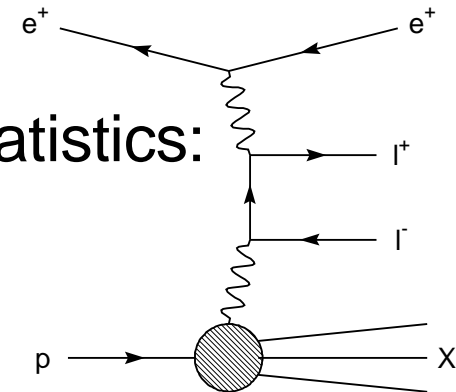
- ★ ZEUS (94-96):  $\Lambda > 2.0-8.0$  TeV
- ★ H1 (HERA I):  $\Lambda > 1.6-5.5$  TeV



# Multi-Leptons

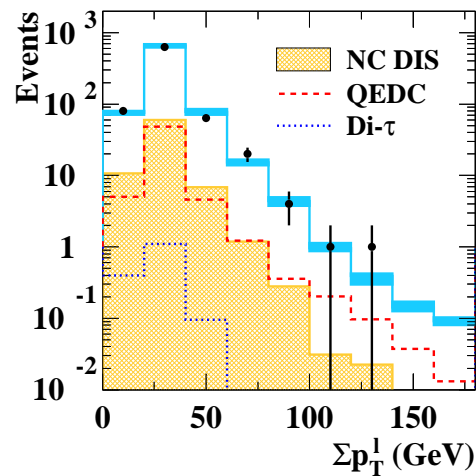
Phys.Lett.B668:268

- Look for events with 2 or more isolated high- $P_T$  leptons ( $e, \mu$ )
- SM production via Bethe-Heitler process
- Both H1 and ZEUS have results with full statistics:



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## ZEUS



A. Parenti

- ★ In H1  $e^+p$  data,  $\Sigma P_T > 100$  GeV: 5 obs/ $0.96 \pm 0.12$  exp
- ★ No excess in  $e^-p$  data
- ★ No excess seen by ZEUS

20

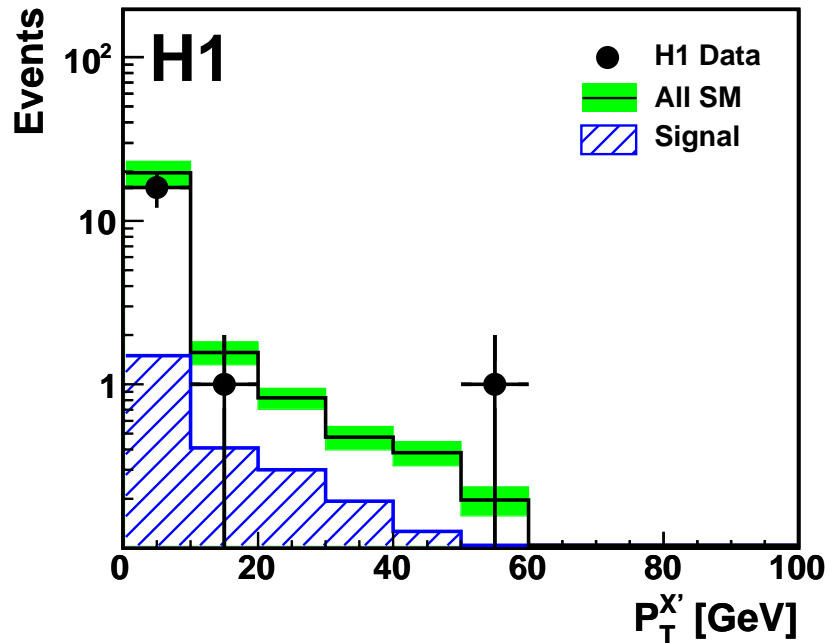


# Search for $\tau$ production

arXiv:0901.0488

Eur.Phys.J.C48:699  
ZEUS-prel-08-009

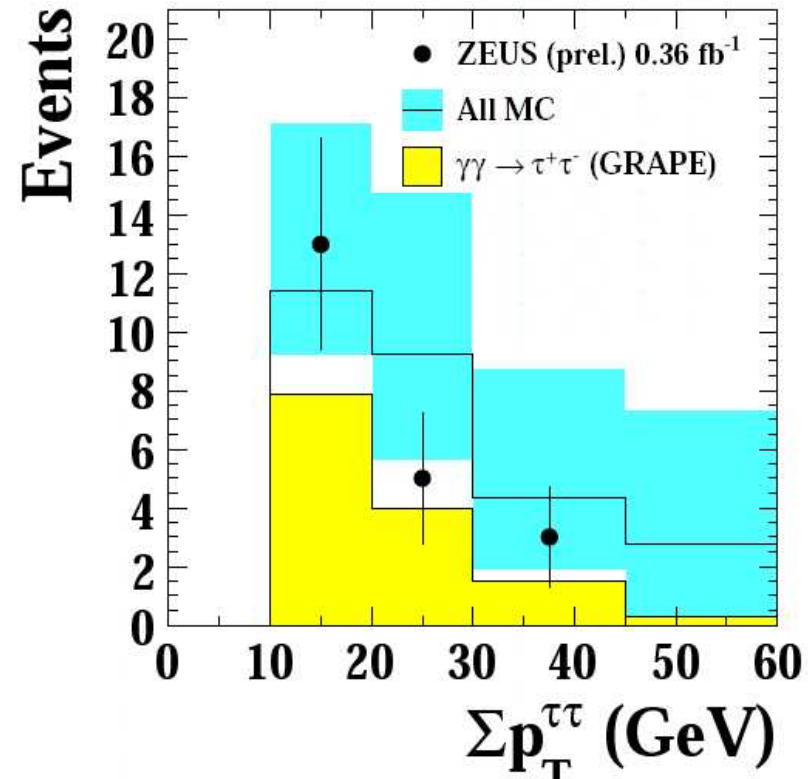
- Events with an isolated, high- $P_T$   $\tau$ , missing  $P_{\nu}$ , hadronic system



★ H1 analysis,  $P_T^X > 25$  GeV:  
1 obs /  $1.5 \pm 0.2$  exp

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- di- $\tau$  events



★ ZEUS prelim (HERA II):  
21 obs /  $27.2^{+7.1}_{-6.3}$  exp

★ H1 (HERA I data):  
30 obs /  $27.1 \pm 4.1$  exp

A. Parenti