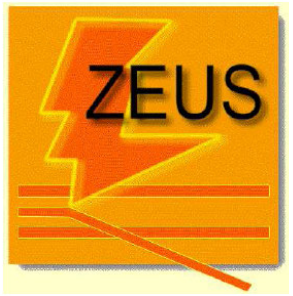
HSQCD 2008



Search for new physics at HERA

L.Bellagamba
INFN Bologna
on behalf of the H1 and ZEUS collaborations

HERA history and outline

15 years of succesful operations !!

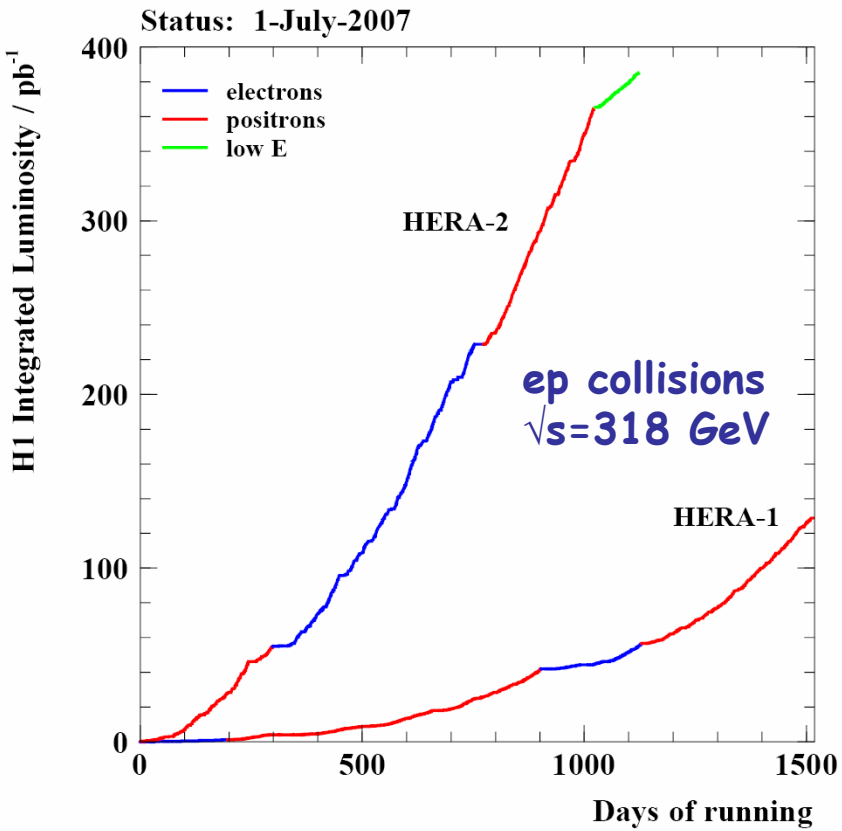
Data taking ended last summer:

- 1992-2000 (HERA I) L~120 pb^{-1} (mostly e+p)
- 2002-2007 (HERA II) L~360 pb^{-1} (polarization ~30-40%, e+/e-p balanced)

Many results produced on searches:
Leptoquarks, LFV, excited fermions, FCNC, SUSY ,monopoles, contact interactions, double charged Higgs…..
⇨ competitive with other colliders or precise low energy experiments

I summarize recent update, using full statistics, of some of the mainstream searches at HERA:

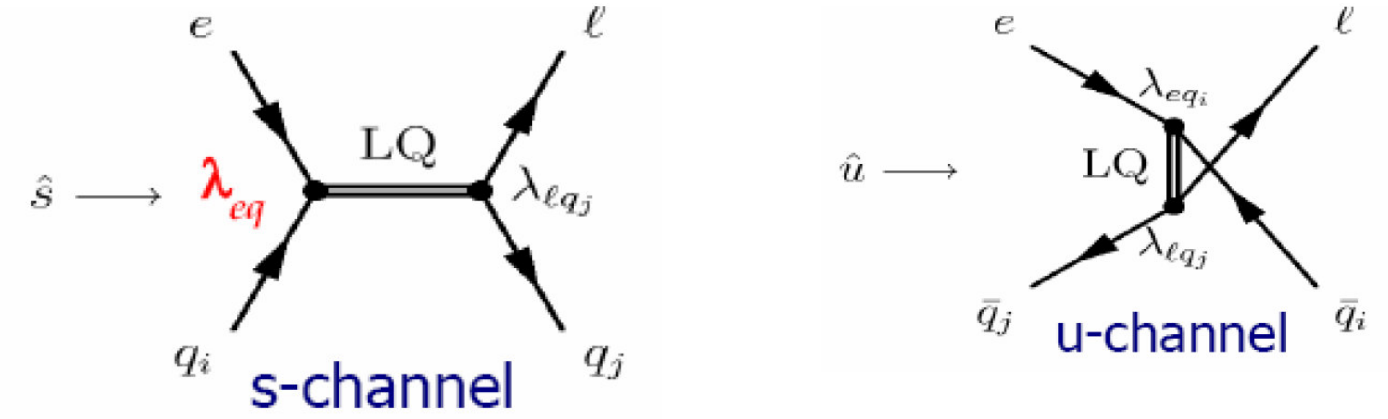
- Leptoquarks
- Contact Interactions
- High-pt leptons
- Single top



Leptoquarks

- Hypothetical bosons connecting the quark and the lepton sectors.
- Naturally arise in unified models where quarks and leptons are arranged in common multiplets.
- Carry SU(3) colour, fractional elecric charge and both lepton (L) and baryon (B) number: fermion number F = 3B + L = 0,2

At HERA can be resonantly produced in the s-channel for $M_{LQ} < \sqrt{s}$ or exchanged in the u-channel, then can decay to eq or νq

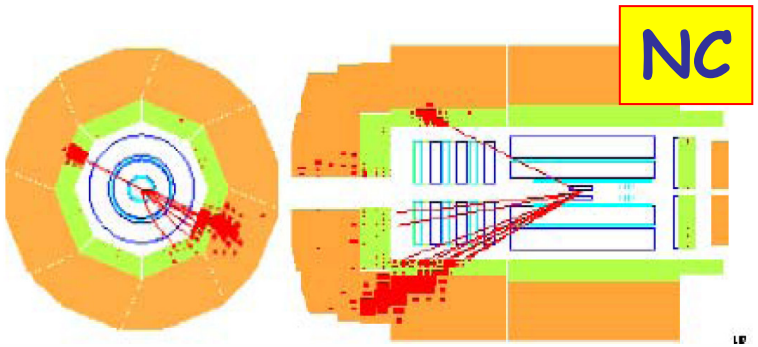


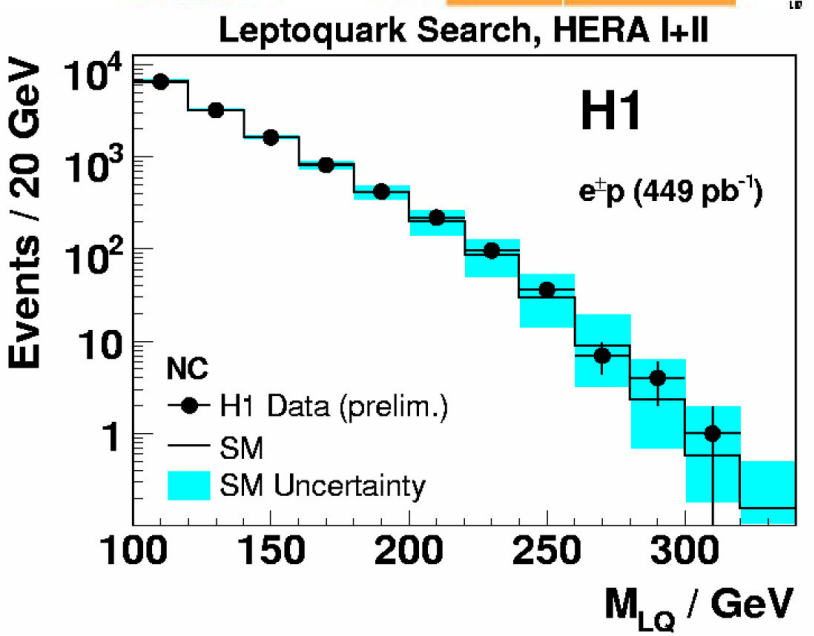
Signature identical to NC or CC DIS

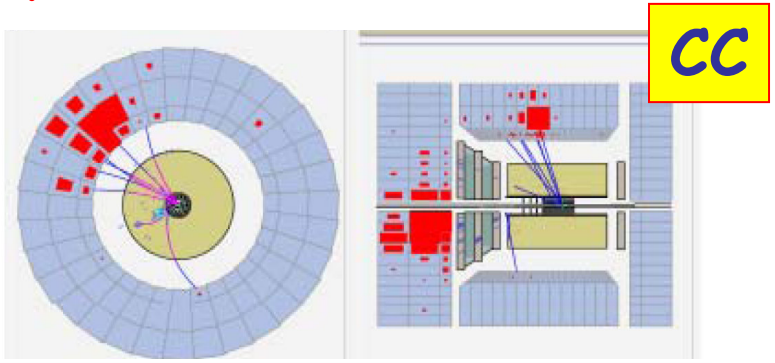
Analysis look for possible deviations in e-jet or ν-jet invariant mass

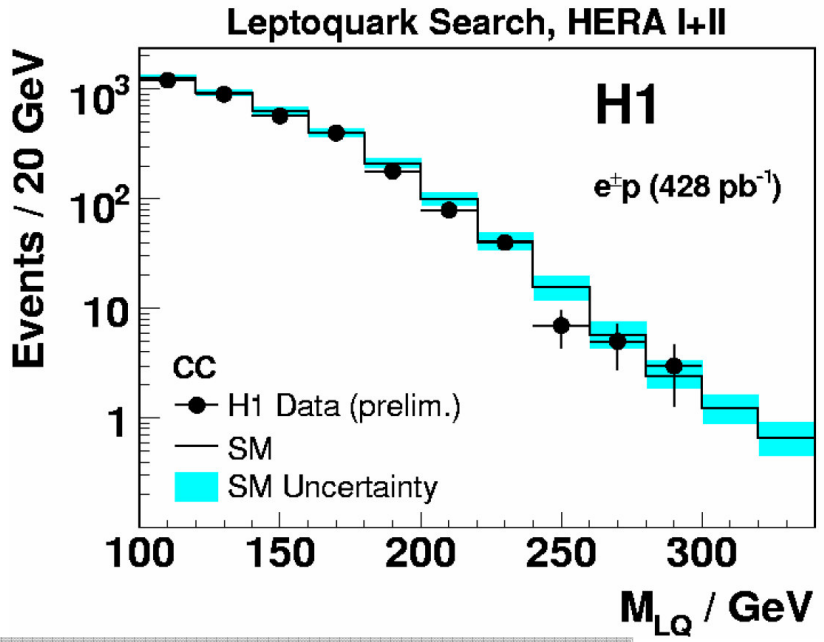
Leptoquarks results

Complete H1 data set both e^+p and e^-p L~0.5 fb^{-1}









Good agreement between data and SM predictions

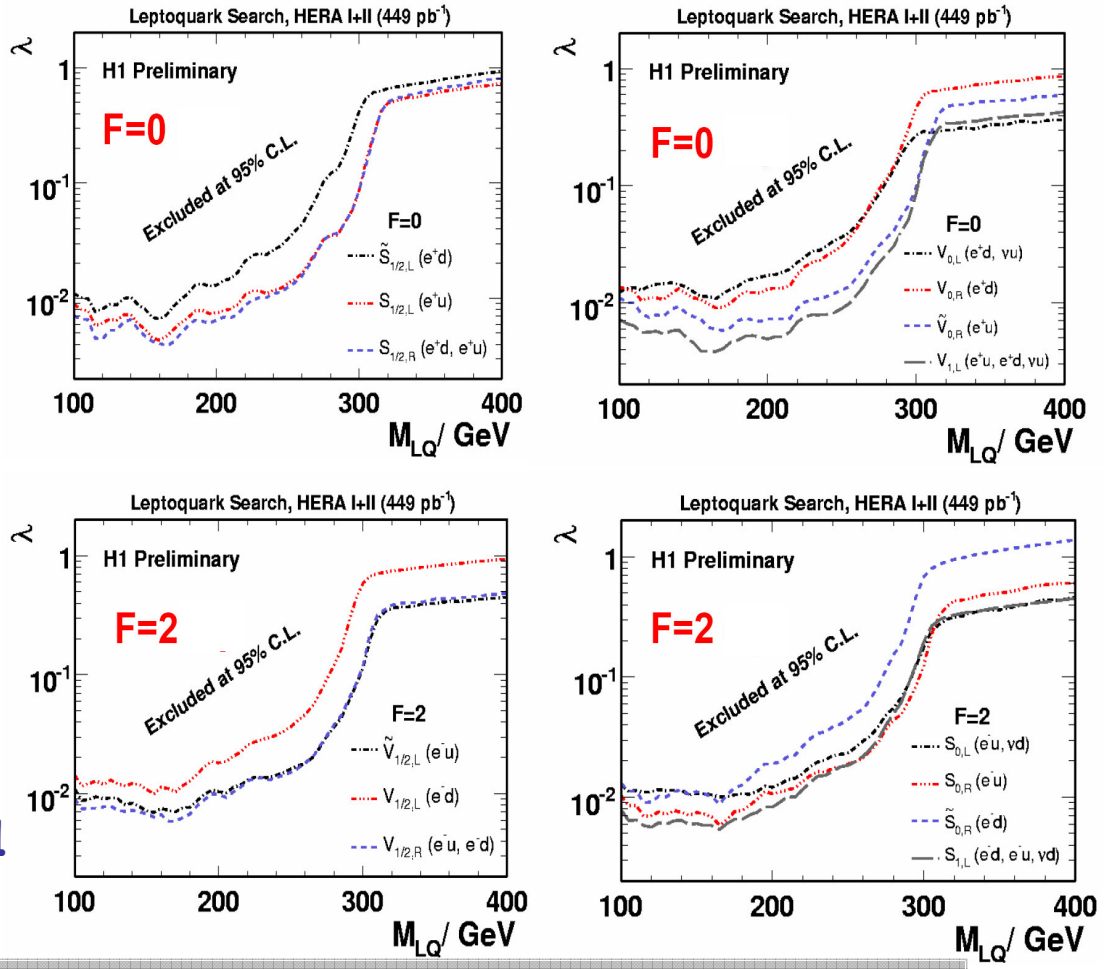
Leptoquarks results

Phenomenological model of Buchmuller-Ruckl-Wyler used in limit setting:

- $U(1)_Y \times SU(2)_L \times SU(3)_c$ invariance
- lepton and baryon number conservation
- either left- or right-handed coupling to lepton but not both (bounds from rare decays)

⇒

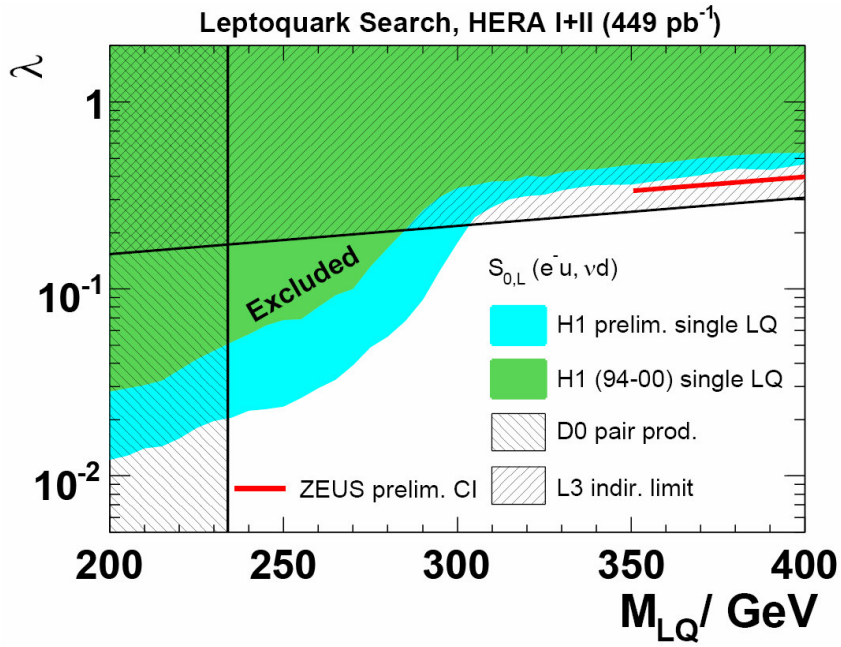
- 7 scalar + 7 vector states
- decay to eq or νq with $\beta=0,\frac{1}{2},1$

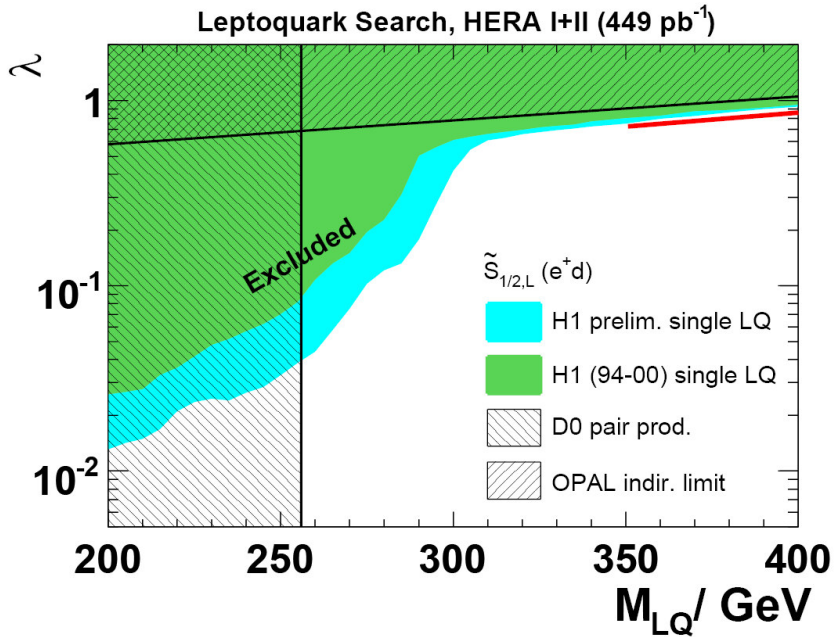


M < 300 GeV resonant production ⇒ stronger limits
For a coupling of EM strength λ=0.3, M<291-300 GeV @ 95%CL

Leptoquarks results

Comparison with other colliders:





LEP (OPAL, L3): indirect constraints from $ee \rightarrow qq$

TEVATRON (D0): pair production via qq annhilation or gg fusion

⇒ limit independent of λ

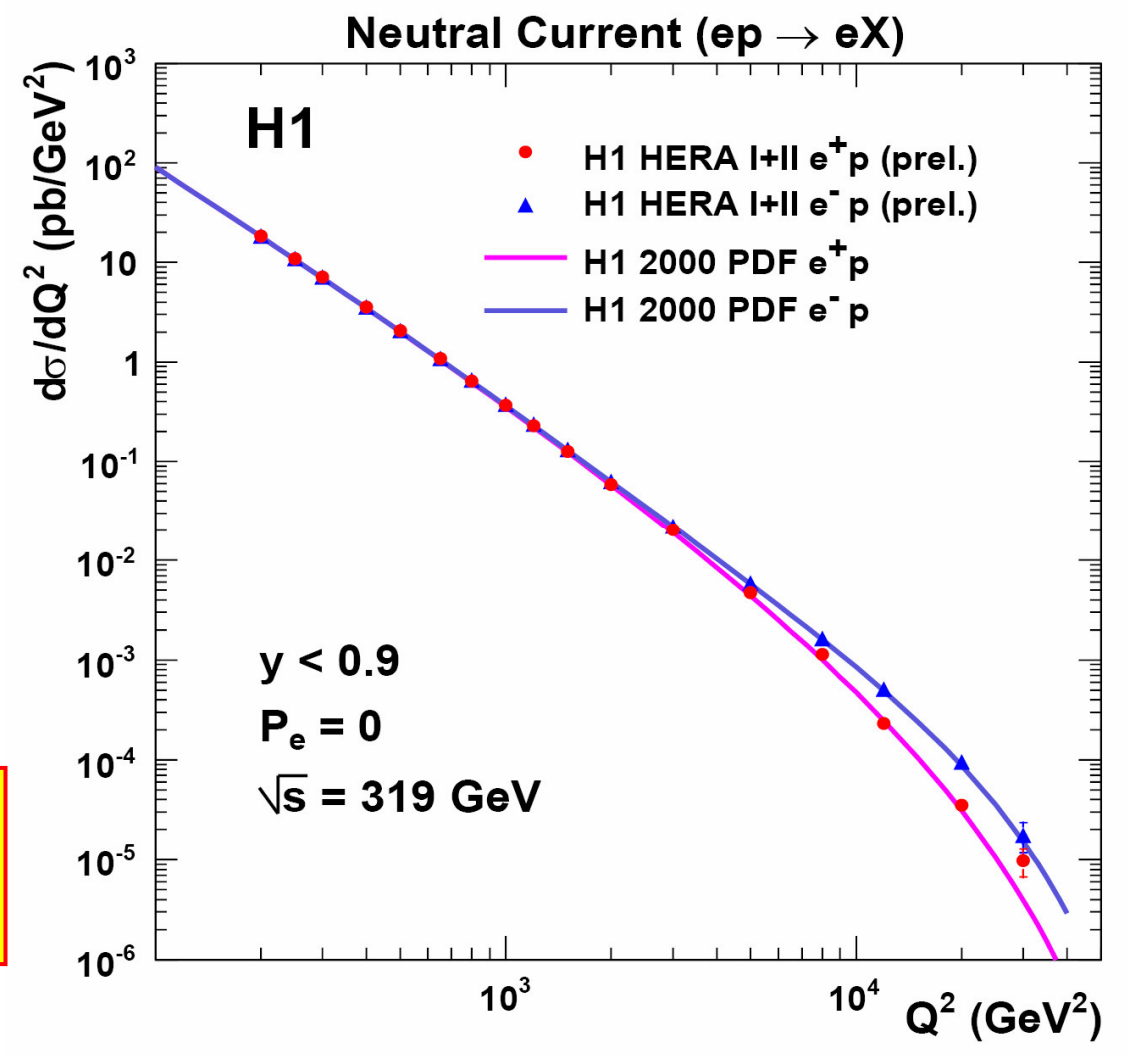
HERA extends the excluded domain for masses beyond the TEVATRON limit

Contact interactions

- Neutral current DIS data: excellent agreement between data and predictions over many orders of magnitude.

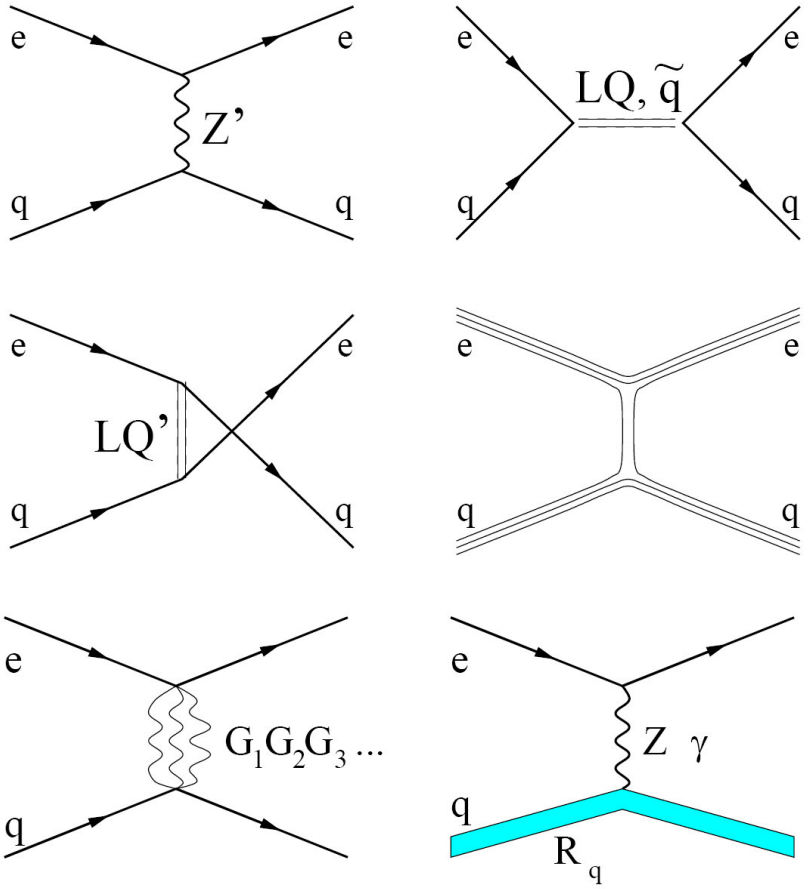
- Precise test for SM and QCD looking at possible deviations at high Q^2 due to CI induced by virtual effects of new physics at much higher scale.

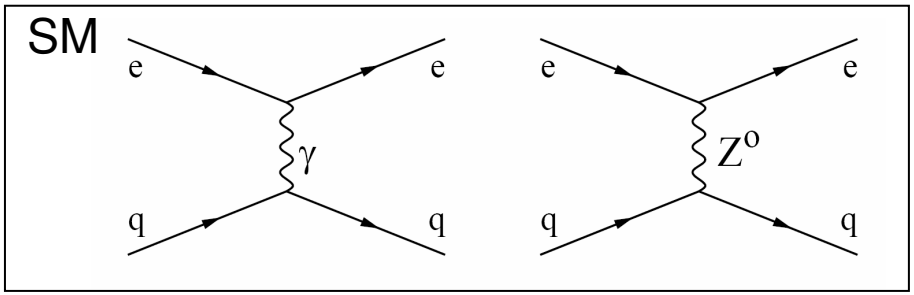
Q^2 up to 40000 GeV^2
Resolution = 1/Q ~10^{-16} cm
1/1000 of proton radius



Contact interactions

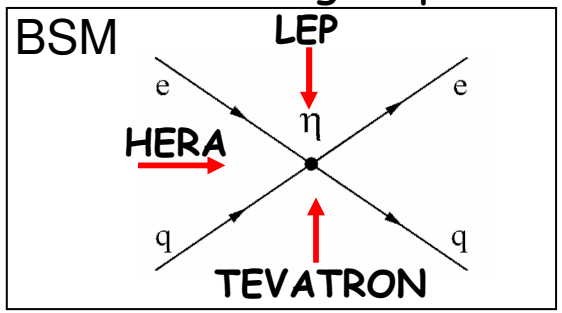
Possible scenarios:





CI modifies eq → eq tree level scattering amplitude

$\sqrt{s} << \Lambda$



Effective lagrangian for vector eeqq coupling (scalar and tensor couplings constrained beyond HERA sensitivity)

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

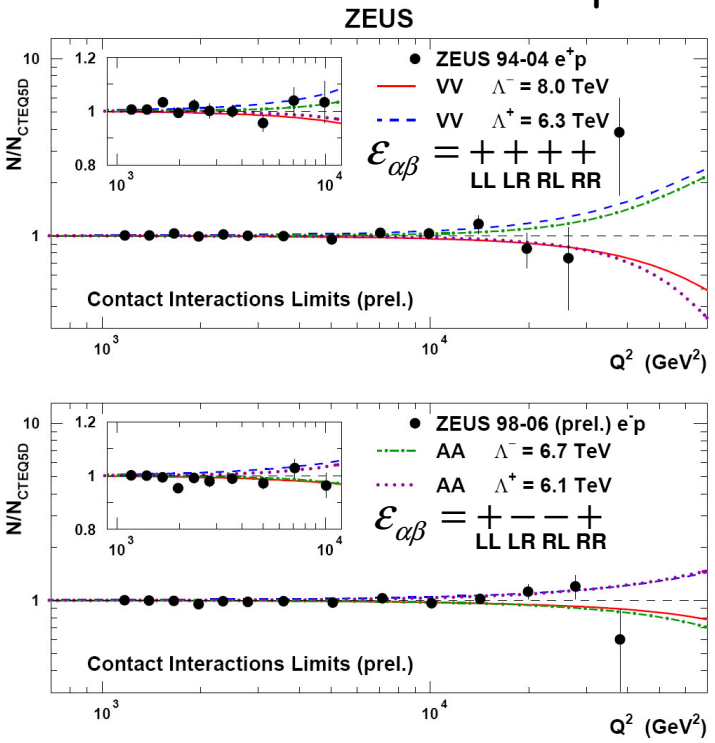
α,β give the helicity structure of new interactions (4 for each q flavor)

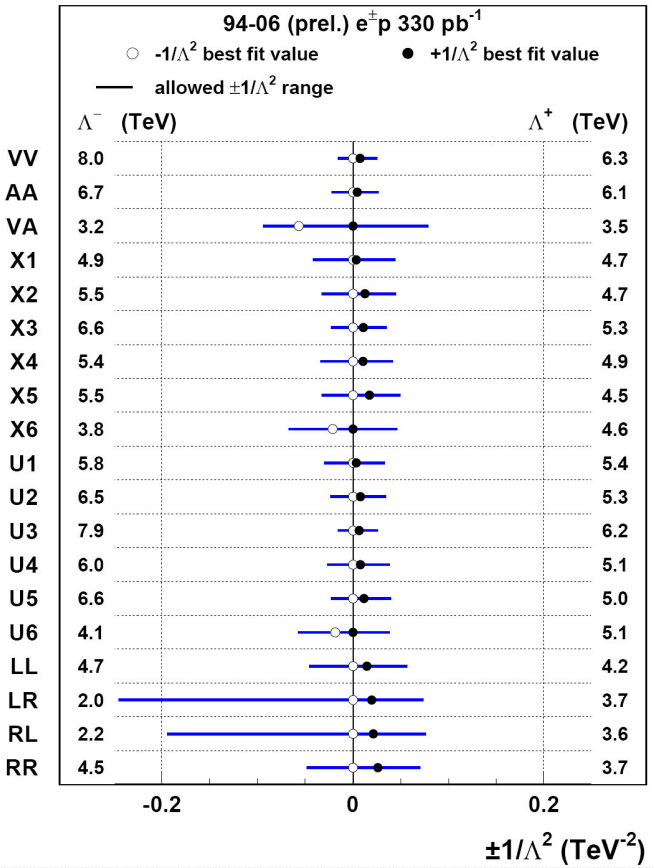
Contact interactions results

General models:

Couplings related to the mass scale of new physics Λ by $\eta_{\alpha\beta} = \varepsilon_{\alpha\beta} 4\pi / \Lambda^2 \quad \varepsilon_{\alpha\beta} = 0, \pm 1$

Zeus data 1994-2006 / SM predictions





ZEUS 95%CL limits: Λ>2.0 – 8.0 TeV
H1 95% CL limits: Λ>1.6 – 5.5 TeV (HERA I Phys. Lett. B568(2003)35-47)

Contact interactions results

Large extra dimensions

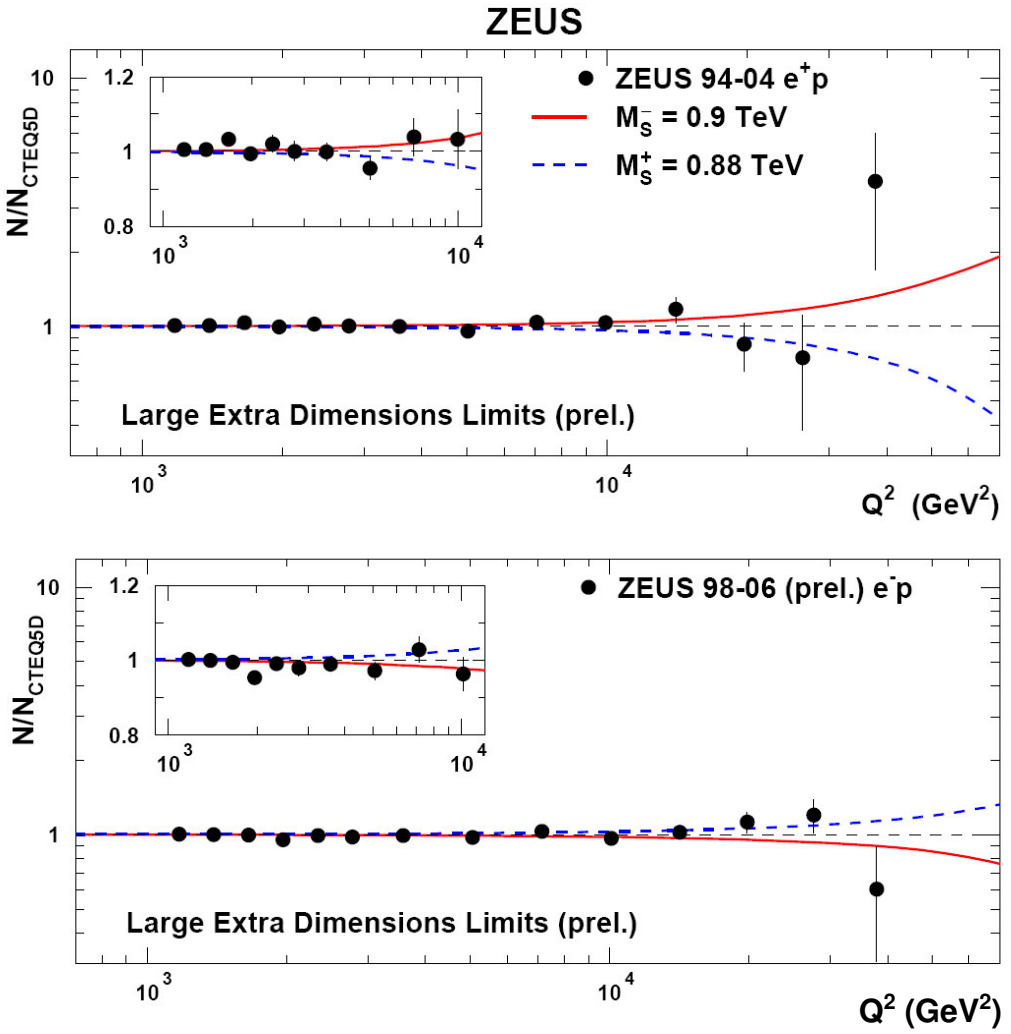
(Arkani-Ahmed-Dimopulos-Dvali)

If gravity propagates in 4+δ dim., effective gravity mass scale M_S can be as low as 1 TeV comparable to EW interactions

Contribution of gravity exchange to ep NC DIS via the effective CI coupling:

$$\eta_G = \frac{\lambda}{M_S^4}$$

Where λ is the coupling (positive or negative) and M_s the effective gravity scale



ZEUS 95% CL limits: M^-_S>0.90 TeV, M^+_S > 0.88 TeV
H1 (HERA I): M^-_S>0.78TeV, M^+_S >0.82 TeV

Contact interactions results

High mass Leptoquarks

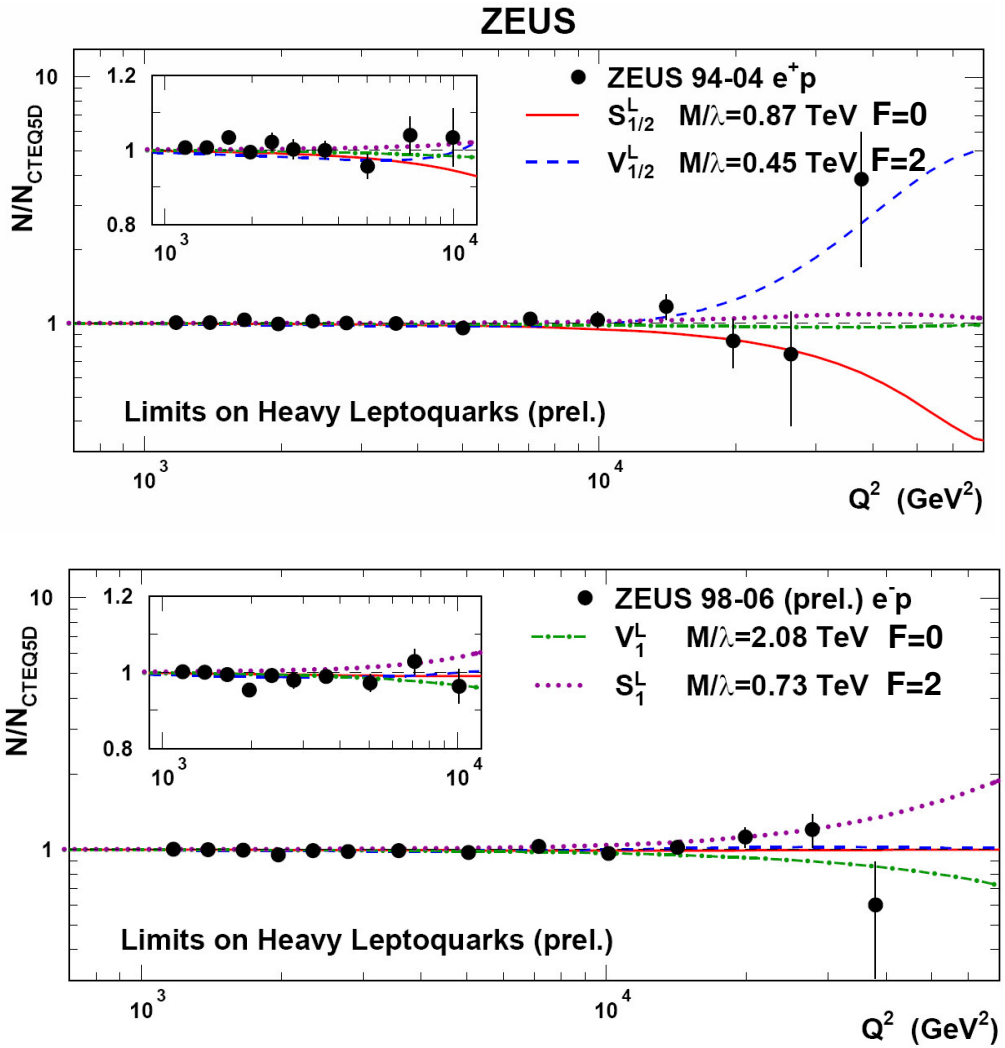
$$M_{LQ} >> \sqrt{s}$$

Virtual production/exchange of such state results in an effective CI coupling

$$\eta_{CI} \sim \left(\frac{\lambda}{M_{LQ}} \right)^2$$

λ LQ Yukawa coupling

Both s- and u- channel important



ZEUS 95% CL limits: M_{LQ}/λ_{LQ} > 0.29-2.08 TeV

Contact interactions results

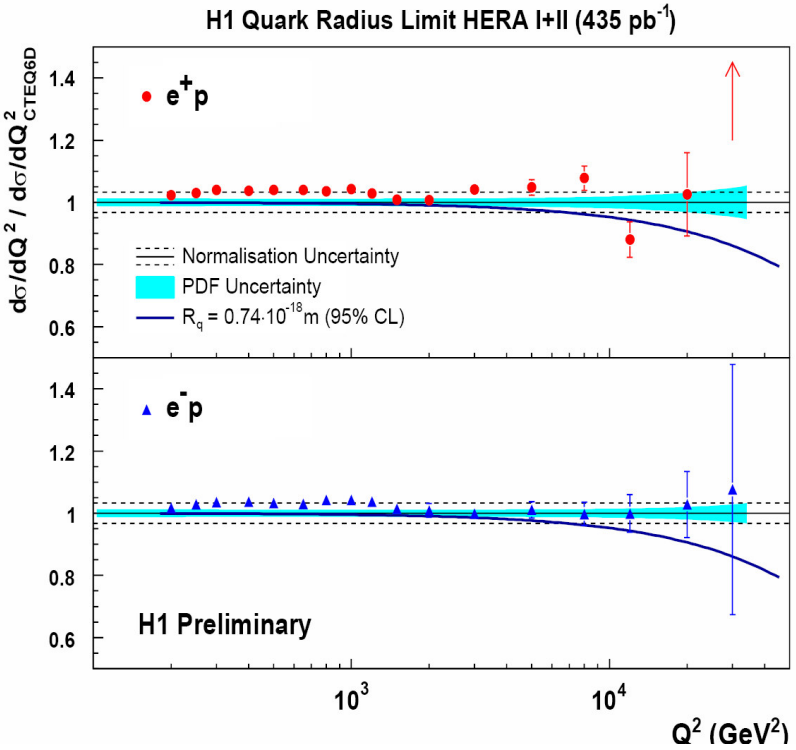
Quark form factor

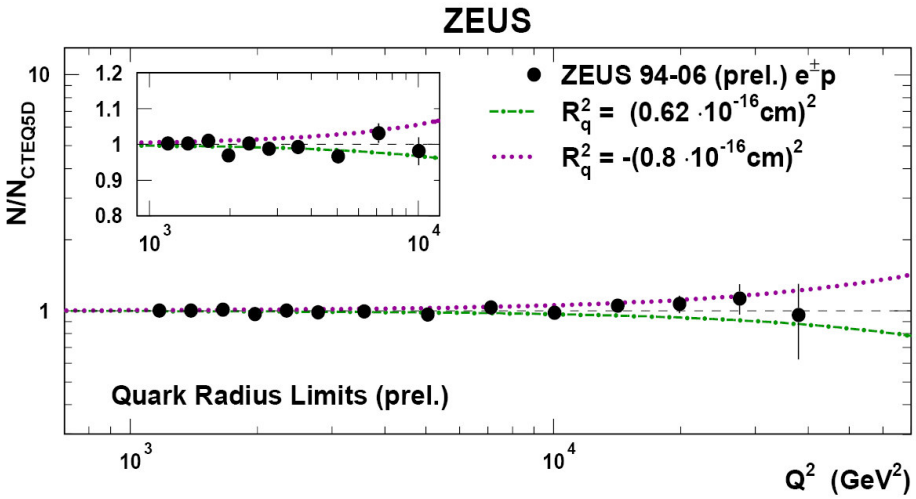
If the colliding particles have finite size the SM cross-section is expected to decrease at large momentum transfer:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot \left[1 - \frac{R_q^2}{6} Q^2\right]^2 \cdot \left[1 - \frac{R_e^2}{6} Q^2\right]^2$$

← Elecron term not considered

R_q is the root mean-sqaure radius of the EW charge distribution of the quark



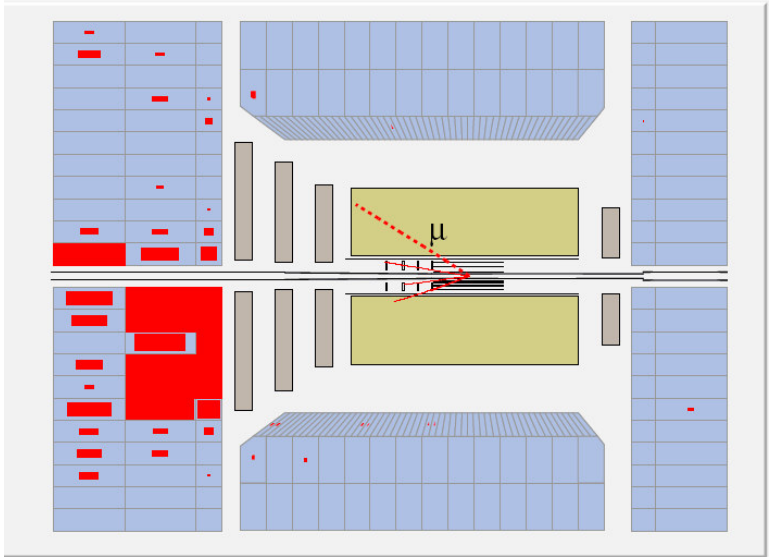


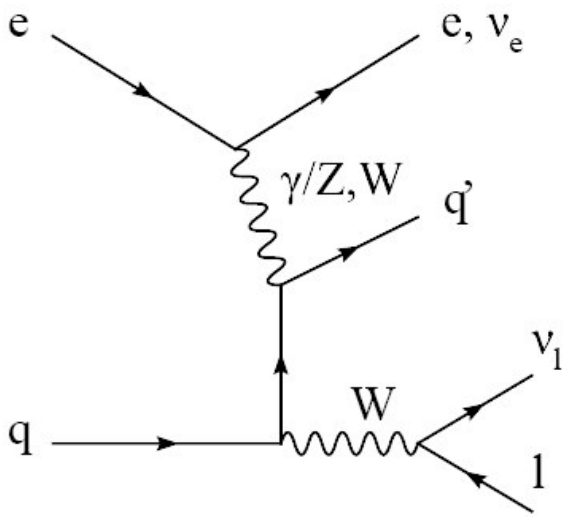
ZEUS 95% CL limit: R_q < 0.62 10^{-16} cm
H1 95% CL limit: R_q < 0.74 10^{-16} cm
(H1 preliminary 07-141 for LP2007)

Isolated leptons

High-pt leptons + missing Pt

low Background environment, well suited to look for new physics effect





At HERA main SM source of isolated high-pt leptons and missing transverse momentum is W production via γp interactions with σ≈1pb

Cross section evaluated at NLO, theoretical uncertainty ~15%

W predominantly produced at low transverse momentum

⟹ **low transverse momentum of the hadronic system (P_T^X)**

Isolated leptons: HERA I results

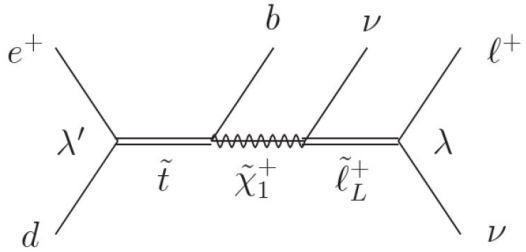
Excess over the SM predictions observed by H1 in both electron and muon channel not confirmed by ZEUS

1994-2000 $e^{\pm}p$		Electron obs./exp. ($W^{\pm}$ contribution)	Muon obs./exp. ($W^{\pm}$ contribution)
H1 118.4 pb^{-1}	Full sample	11 / 11.54 $\pm$ 1.50 (71%)	8 / 2.94 $\pm$ 0.50 (86%)
	$p_T^X > 25$GeV	5 / 1.76 $\pm$ 0.30 (82%)	6 / 1.68 $\pm$ 0.30 (88%)
	$p_T^X > 40$GeV	3 / 0.66 $\pm$ 0.13 (80%)	3 / 0.64 $\pm$ 0.14 (92%)

In the τ channel ZEUS observed 2/0.2 $\pm$ 0.05 (45%) at P_T^X>25 GeV

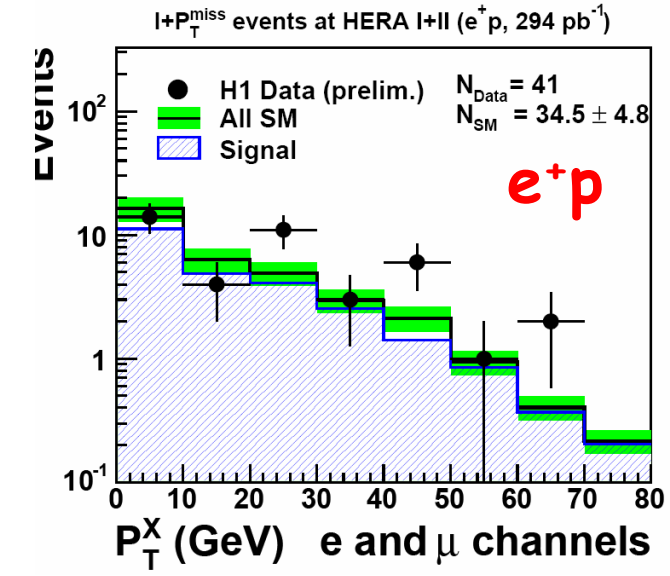
A lot of interest triggered by these results in the HEP community

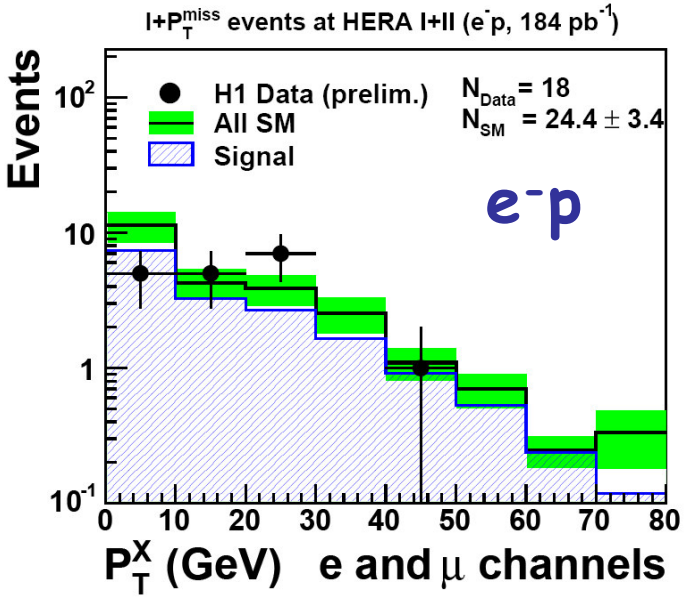
Attempts to explain the possible excess in term of Rp-violating SUSY models (Eur. Phys. J C51 543 (2007))



A joint group was created to ensure the compatibility of the analysis and to produce combined results for HERA II data

Isolated leptons: H1 HERA I+II results





$P_t^l > 10GeV$ + **well isolated from other jets and tracks**

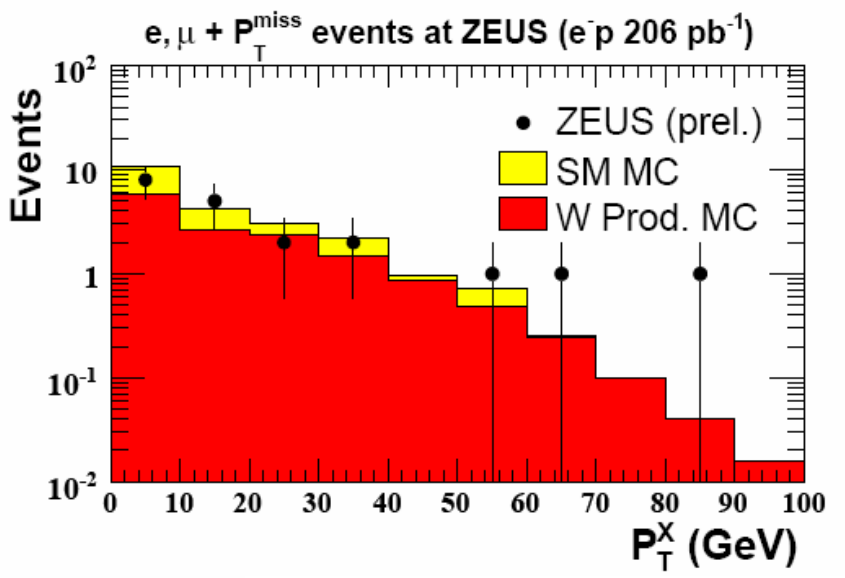
$5^o < \vartheta_\ell < 140^o$ $\qquad$ $P_t^{miss} > 12GeV$

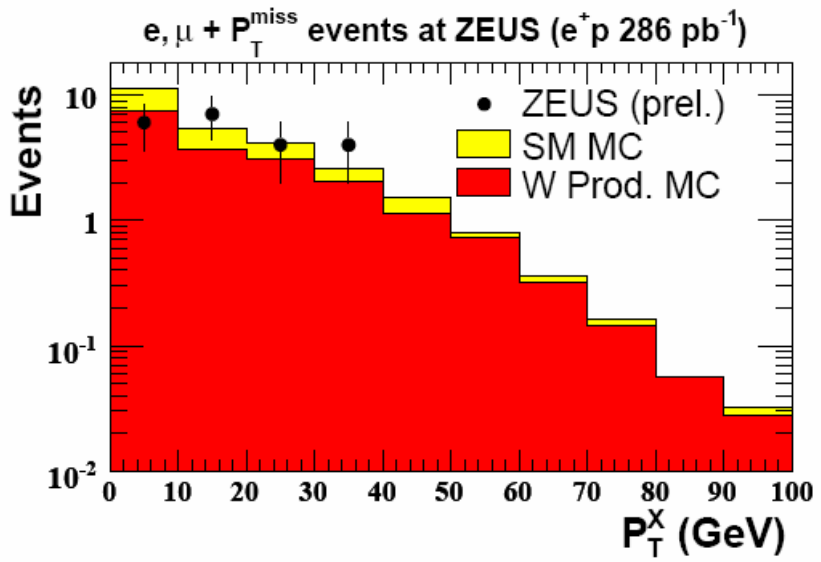
H1 Preliminary l+$P_T^{\rm miss}$ events at HERA I+II		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
e^+p	Full Sample	26 / 27.3 ± 3.8 (71%)	15 / 7.2 ± 1.1 (85%)	41 / 34.5 ± 4.8 (74%)
294 pb^{-1}	$P_T^X > 25$ GeV	11 / 4.7 ± 0.9 (75%)	10 / 4.2 ± 0.7 (85%)	21 / 8.9 ± 1.5 (80%)
e^-p	Full Sample	16 / 19.4 ± 2.7 (65%)	2 / 5.1 ± 0.7 (78%)	18 / 24.4 ± 3.4 (68%)
184 pb^{-1}	$P_T^X > 25$ GeV	3 / 3.8 ± 0.6 (61%)	0 / 3.1 ± 0.5 (74%)	3 / 6.9 ± 1.0 (67%)
$e^\pm p$	Full Sample	42 / 46.7 ± 6.5 (69%)	17 / 12.2 ± 1.8 (82%)	59 / 58.9 ± 8.2 (72%)
478 pb^{-1}	$P_T^X > 25$ GeV	14 / 8.5 ± 1.5 (68%)	10 / 7.3 ± 1.2 (79%)	24 / 15.8 ± 2.5 (73%)

H1 excess observed in HERA I data confirmed in HERA II e+p data:
e^+p excess~3σ
e^-p agreement with SM

Isolated leptons: ZEUS HERA I+II results

Selection very similar to H1 except reduced angular acceptance for leptons: $15^o < \vartheta_\ell < 120^o$ **(Combined analysis use this range)**

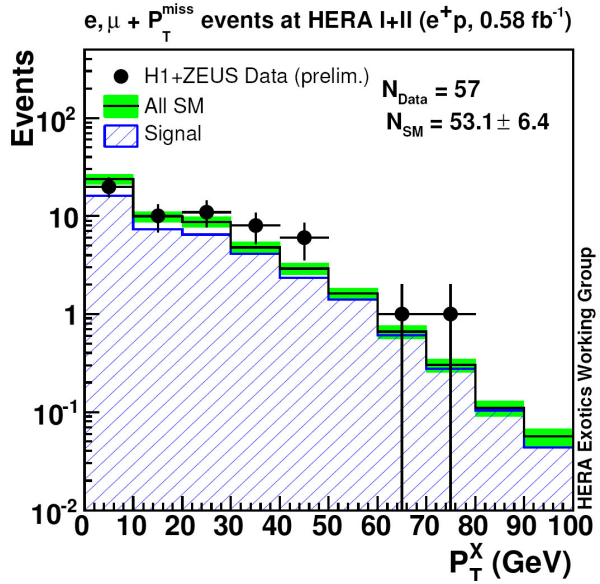


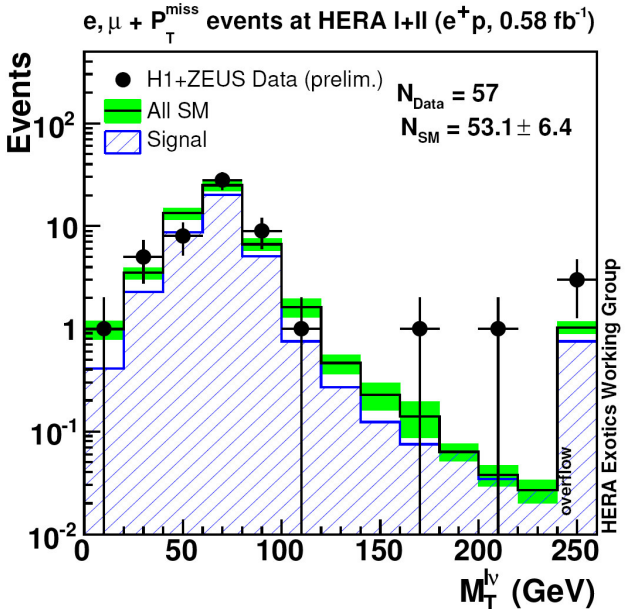


Isolated Lepton Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb^{-1}	$9/11.3 \pm 1.5$ (54%)	$6/5.1 \pm 0.7$ (67%)	$5/5.5 \pm 0.8$ (75%)
e^+p 296 pb^{-1}	$7/12.6 \pm 1.7$ (68%)	$7/6.2 \pm 0.9$ (75%)	$6/7.4 \pm 1.0$ (79%)
$e^\pm p$ 504 pb^{-1}	$16/23.9 \pm 3.1$ (61%)	$13/11.2 \pm 1.5$ (71%)	$11/12.9 \pm 1.7$ (77%)

ZEUS results:
agreement with SM both for e+p and e-p

Isolated leptons: comb. HERA I+II results





Both analysis restricted to a common phase space region

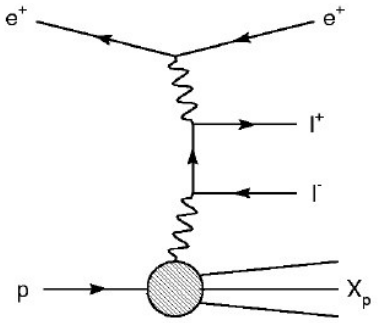
H1+ZEUS Preliminary l+$P_T^{\rm miss}$ events at HERA I+II		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2007 e^+p 0.58 fb^{-1}	Full Sample	39 / 41.3 ± 5.0 (70%)	18 / 11.8 ± 1.6 (85%)	57 / 53.1 ± 6.4 (73%)
	$P_T^X > 25$ GeV	12 / 7.4 ± 1.0 (78%)	11 / 7.2 ± 1.0 (85%)	23 / 14.6 ± 1.9 (81%)
1998-2006 e^-p 0.39 fb^{-1}	Full Sample	25 / 31.6 ± 4.1 (63%)	5 / 8.0 ± 1.1 (86%)	30 / 39.6 ± 5.0 (68%)
	$P_T^X > 25$ GeV	4 / 6.0 ± 0.8 (67%)	2 / 4.8 ± 0.7 (87%)	6 / 10.6 ± 1.4 (76%)
1994-2007 $e^\pm p$ 0.97 fb^{-1}	Full Sample	64 / 72.9 ± 8.9 (67%)	23 / 19.9 ± 2.6 (85%)	87 / 92.7 ± 11.2 (71%)
	$P_T^X > 25$ GeV	16 / 13.3 ± 1.7 (73%)	13 / 12.0 ± 1.6 (86%)	29 / 25.3 ± 3.2 (79%)

e^+p excess

- H1 only → 3σ
- H1 comm. ph. sp. → 2.9σ
- H1+ZEUS comb. → 2σ

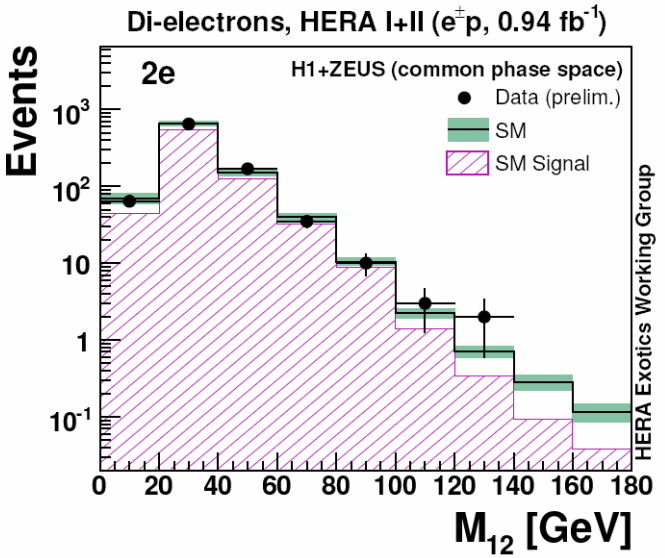
Multi-electrons: comb. HERA I+II results

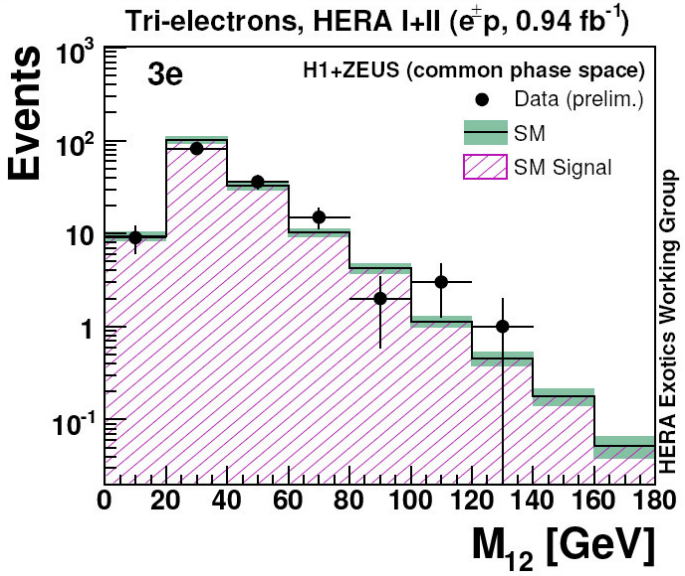
- Main SM production $\gamma\gamma \rightarrow ee$
- QED process theoretically very well known
- Production falls steeply with the lepton pt



H1+ZEUS Multi-electron analysis HERA I+II (preliminary)

M_{12} >100 GeV				
Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (0.56 fb^{-1})				
2e	4	1.97 ± 0.22	1.10 ± 0.21	0.87 ± 0.18
3e	4	1.10 ± 0.12	1.10 ± 0.12	—
e^-p collisions (0.38 fb^{-1})				
2e	1	1.44 ± 0.15	0.77 ± 0.10	0.67 ± 0.12
3e	0	0.75 ± 0.08	0.75 ± 0.08	—
$e^\pm$ collisions (0.94 fb^{-1})				
2e	5	3.41 ± 0.37	1.87 ± 0.25	1.54 ± 0.29
3e	4	1.85 ± 0.24	1.85 ± 0.24	—





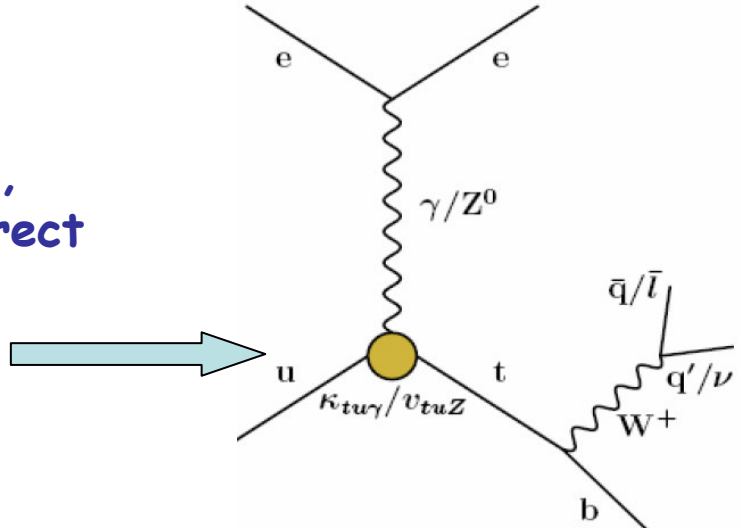
Few events at large mass in e+p collisions
Overall acceptable agreement with SM predictions

Single top

SM cross section at HERA < 1fb

Topology: high pt leptons, high-ptmiss, large hadronic Pt (differently from direct W production)

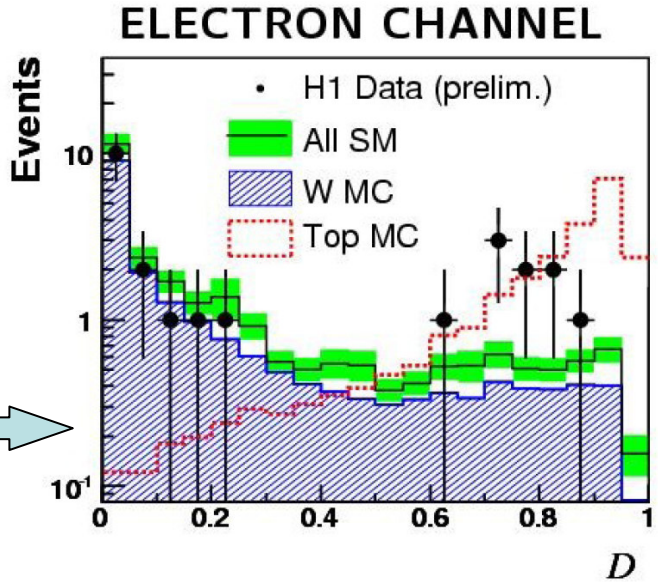
Possible anomalous production due to FCNC couplings tuV



Selection:

- Standard high-pt lepton selection + good lepton charge and top mass reconstruction M_{lvl}
- Multivariate discriminant based on M_{lvb}, $\theta(W)$, Pt^X

Few events compatible with top, no large significance



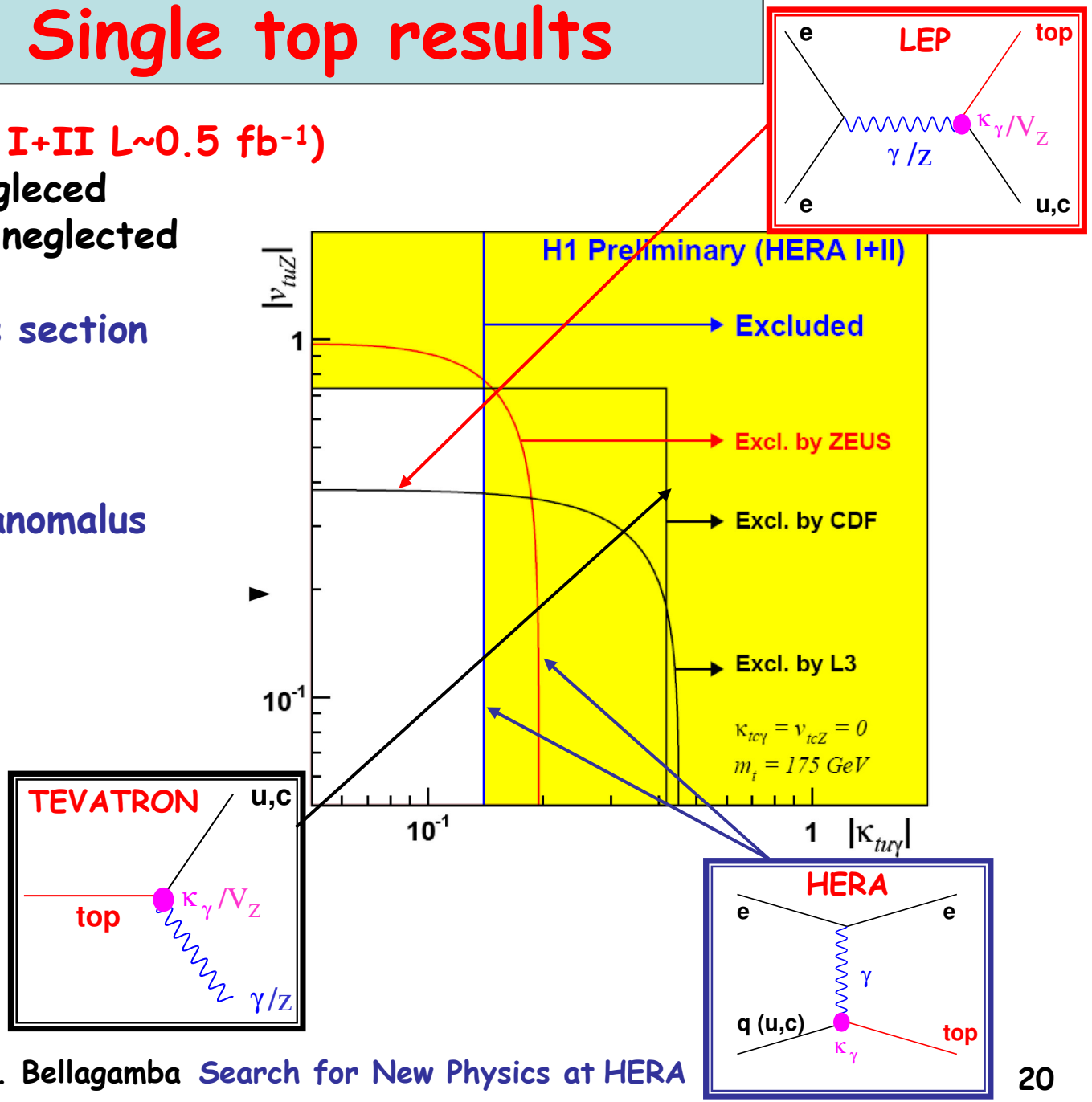
Single top results

New H1 result (HERA I+II L~0.5 fb^{-1})
Charm contribution negleced
Vector coupling to Z0 neglected

upper bound on cross section at 95%CL:
$\sigma_{ep\to etX} < 0.16$ pb

upper bound on the anomalus coupling:
$K_{tu\gamma} < 0.14$

HERA limits for $k_{tu\gamma}$ more stringent than TEVATRON and LEP



Conclusions

HERA ceased data taking after 15 years of honoured activity

Each experiment collected ~ 0.5 fb^{-1} of ep data

HERA valuable legacy:

- A deeper understanding of the proton structure

⇒ Indispensable input to LHC physics

- Study of short distance eq interactions, unique opportunity to search for BSM particles and interactions

⇒ Lot of results spread over the whole spectrum of interests of the HEP community

⇒ Many constraints competitive or complementary with other colliders

Activity is ongoing

- Further searches are going to be updated using the whole HERA data
- H1+ZEUS WG is working to produce further combined results