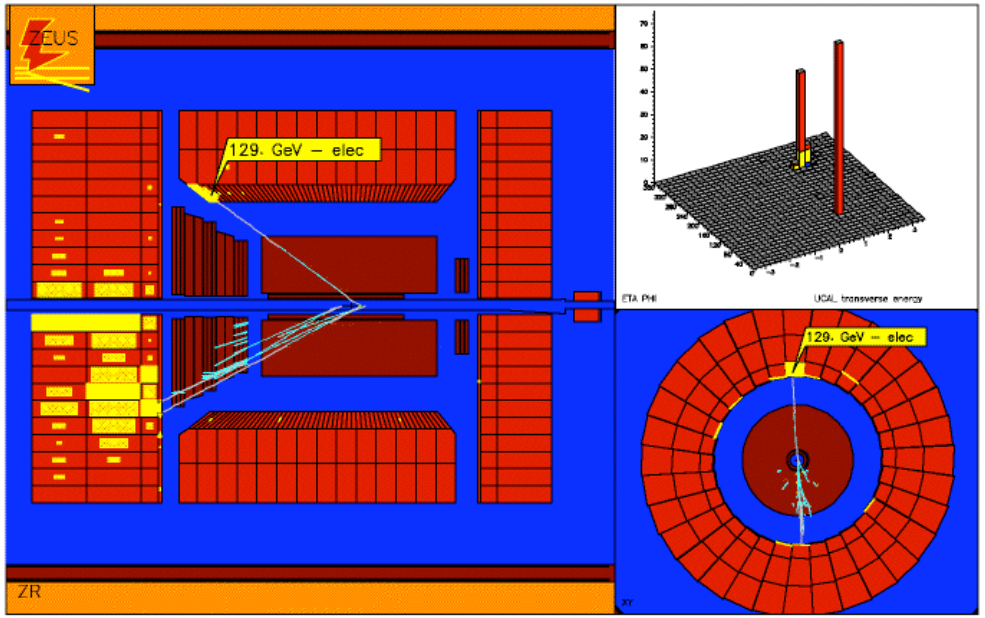
Search for Physics beyond Standard Model at HERA

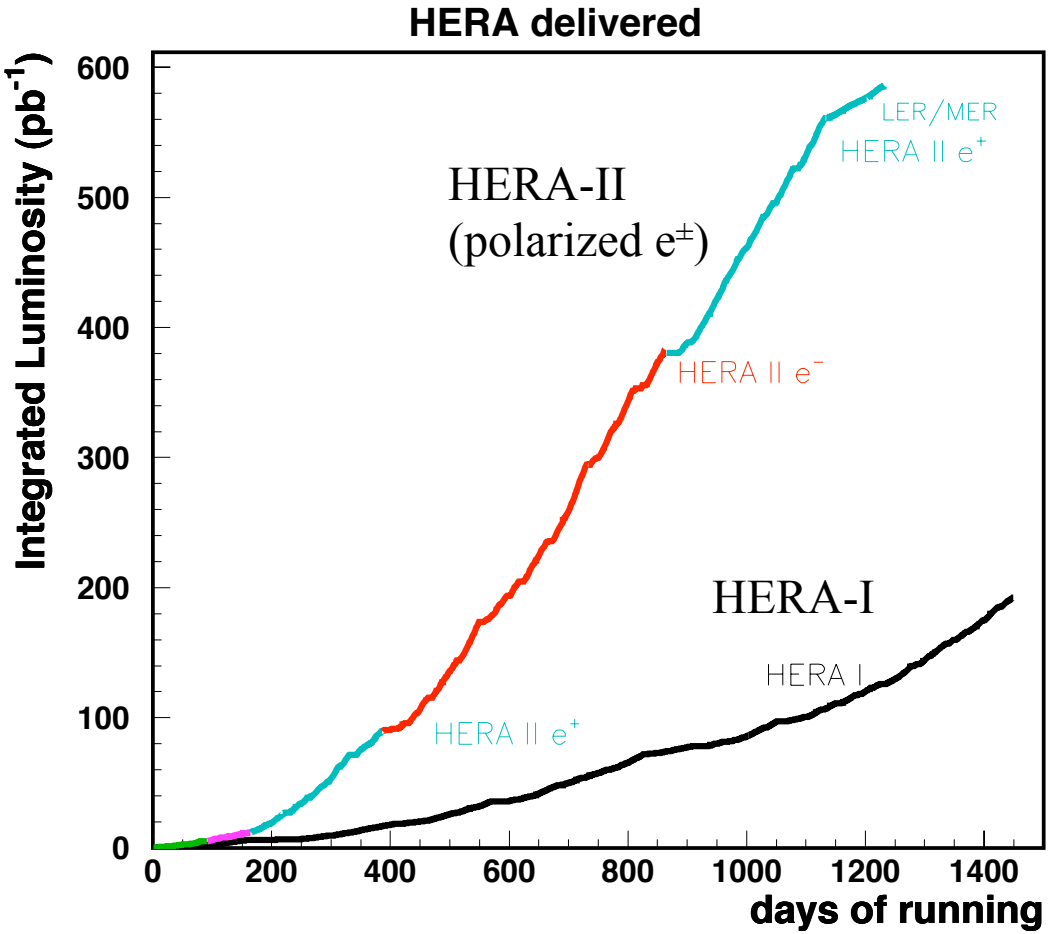
Masahiro Kuze
(Tokyo Institute of Technology)
On behalf of H1 and ZEUS collaborations

- HERA and experiments
- High-Q^2 DIS
- Contact Interactions
- Excited Femions
- extra...



HERA collider at DESY/Hamburg

The only *ep* collider in the world!

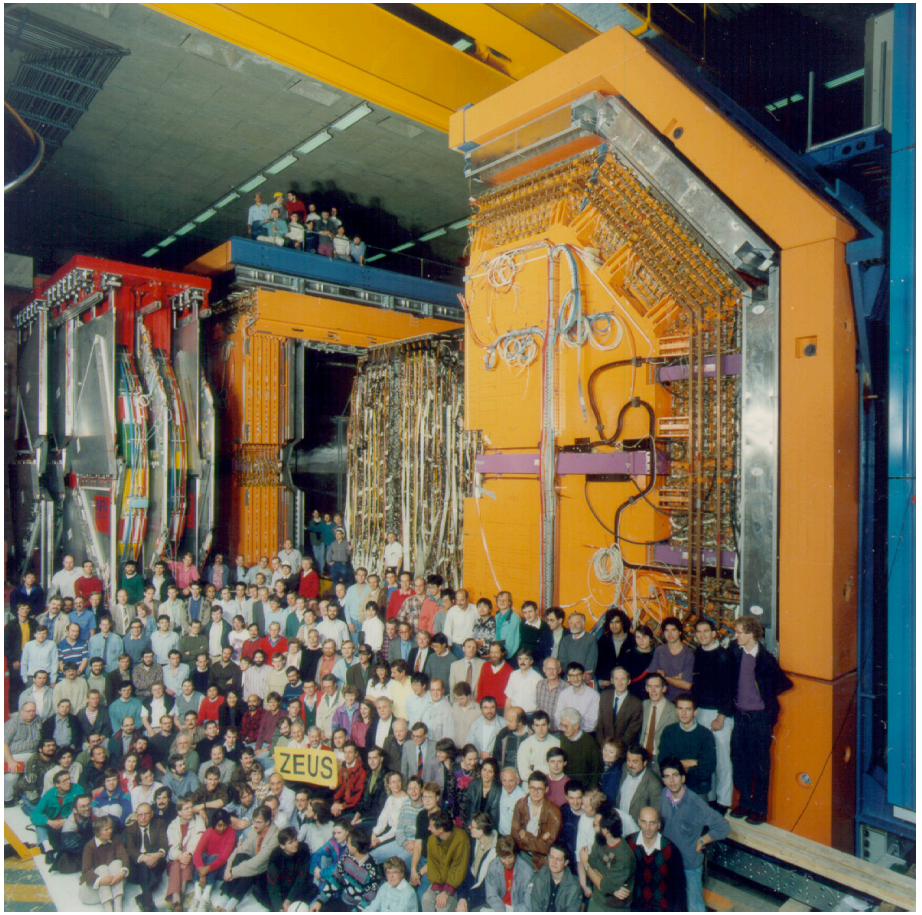


- 920GeV p ⊗ 27.5GeV $e^\pm \Rightarrow \sqrt{s}$=320 GeV
- Physics luminosity: ~0.5 fb^{-1} / exp't. (~0.3 fb^{-1} e^+p, ~0.2 fb^{-1} e^-p)
- Operation terminated in June 2007.

The Detectors

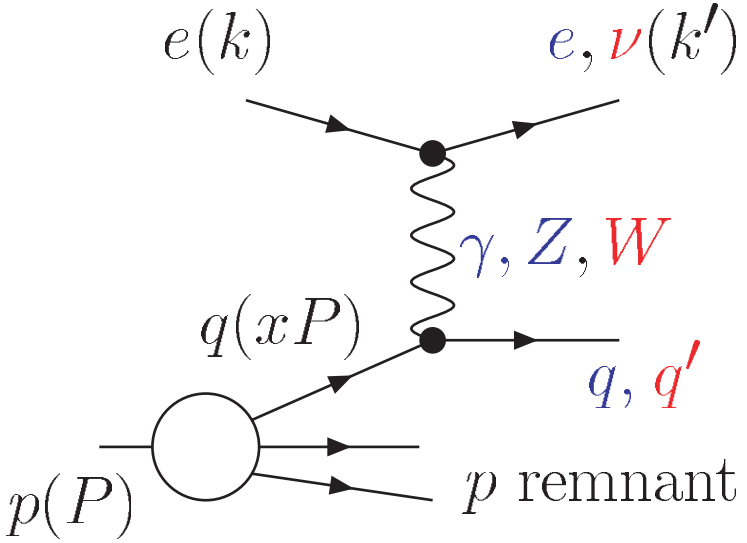
- ZEUS Detector
  - Uranium-Scintillator calorimeter
    - $\sigma(E)/E = 18\%/\sqrt{E}$ for electrons
    - $\sigma(E)/E = 35\%/\sqrt{E}$ for hadrons
  - Central tracking detector
    - $\sigma(p_T)/p_T =$

      $0.0058\,p_T \oplus 0.0065 \oplus 0.0014/p_T$
- H1 Detector
  - Liquid-Ar calorimeter
    - $\sigma(E)/E = 12\%/\sqrt{E}$ for electrons
    - $\sigma(E)/E = 50\%/\sqrt{E}$ for hadrons
  - Central tracking detector



Lepton-Hadron scattering (DIS)

- t-channel (space-like) propagator boson.
- Virtuality Q^2= resolving power. Q^2~40,000 GeV^2→0.001 fm. Very short-distance *eq* interactions.
- Bjorken *x*: Parton Distribution Function (PDF) in proton.
- Neutral (γ, Z)
  or
  Charged (W)
  current
  interactions.



$$Q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P \cdot (k - k')}$$

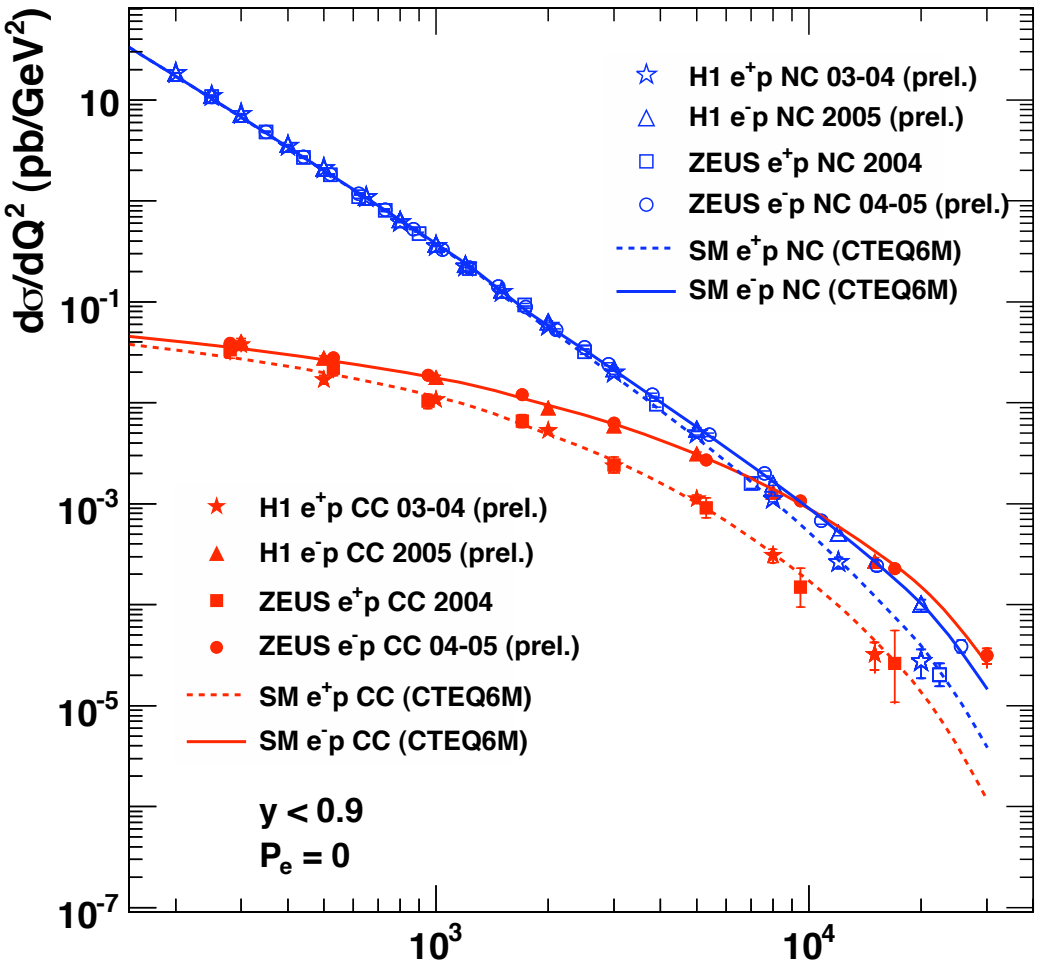
$$y = \frac{P \cdot (k - k')}{P \cdot k}$$

- $\sigma \approx (\text{coupling})^2 \otimes \text{propagator} \otimes \text{PDF}(x, Q^2)$ ***EW*** ⊗ ***QCD***

High-Q^2 NC/CC DIS cross sections

Unification of EW interactions

- At low Q^2:
  NC ~ $1/Q^4$ (EM current)
  CC ~ G_F^2 (Weak current)
- At high Q^2 ($> M_z^2, M_W^2$):
  Both NC and CC mediated by unified EW current. $\sigma_{NC} \sim \sigma_{CC}$
- Measure PDF at low Q^2 (non-perturbative QCD)
  Extrapolate to high Q^2 (SM DGLAP equations)
  →
  Search for signatures of BSM physics



→ short distance
→ high temperature
→ early universe

See also S.Schmitt's talk in SUSY parallel session

First natural question: is quark elementary?

- Repeat 'form-factor measurement' as Hofstadter, but at $Q^2 \sim 40{,}000$ GeV^2 instead of 1 GeV^2.
  - Resolution = $1/Q \sim 10^{-16}$cm = 0.001 proton radius
- Finite quark radius → cross section decreases as the probe 'penetrates' into it (sees less EW charge).

  $\sigma = \sigma_{SM}(1-\langle R_q^2\rangle Q^2/6)^2$

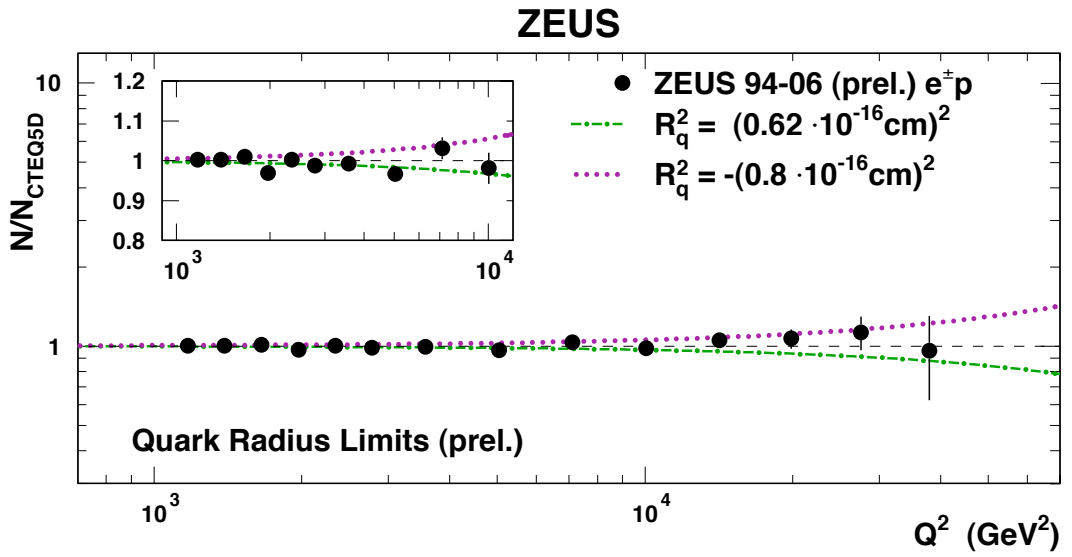
- Limits on quark size

  (assuming electron is pointlike)

  ZEUS: $R_q < 0.62*10^{-16}$ cm

  H1: $R_q < 0.74*10^{-16}$ cm

  (95% CL)



Contact Interactions

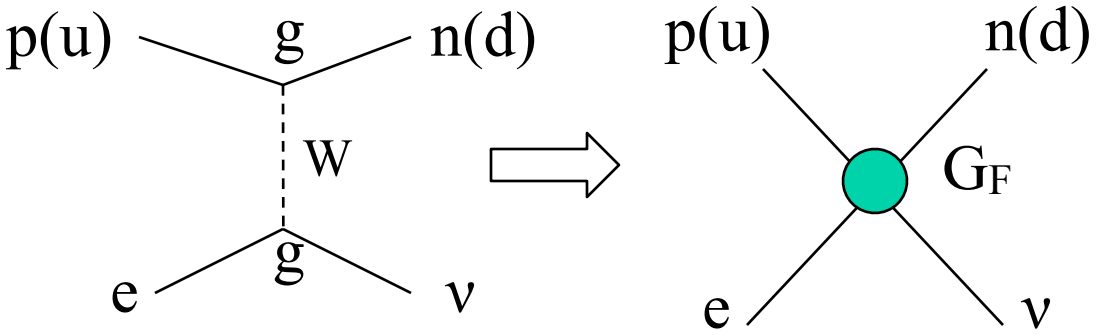
- Physics at very high mass-scale 'felt' at lower energies via virtual effects. e.g. new gauge bosons, composite fermions, …

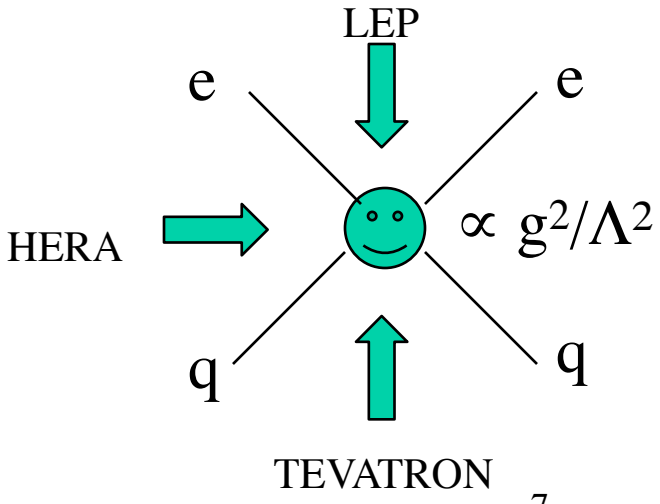
- Generically described as CI Lagrangian

eeqq vector CI: $$L_{CI} = \sum_{i,j=L,R}^{q=u,d} \eta_{ij}^{q} (\bar{e}_i \gamma^{\mu} e_i)(\bar{q}_j \gamma_{\mu} q_j)$$ i/j: lepton/quark chirality

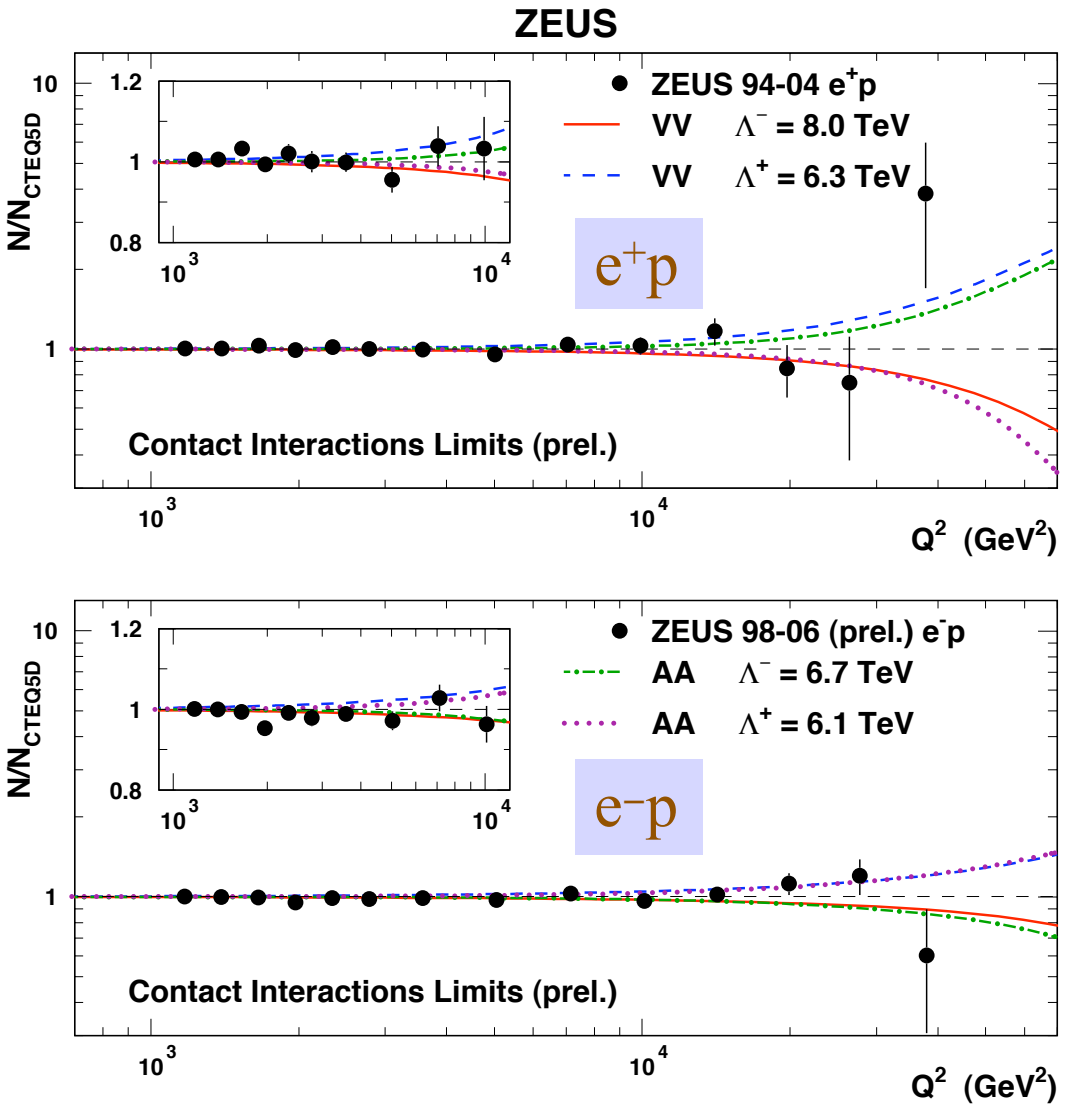
$\eta = g^2/\Lambda^2$ (g: unknown coupling, convention: $g^2 = 4\pi$; Λ: new physics scale)

Analogy: early days of weak int. ('large' M_W)
= 4-fermion CI. $G_F \sim e^2/\sin^2\theta_W M_W^2$





Contact Interactions (2)



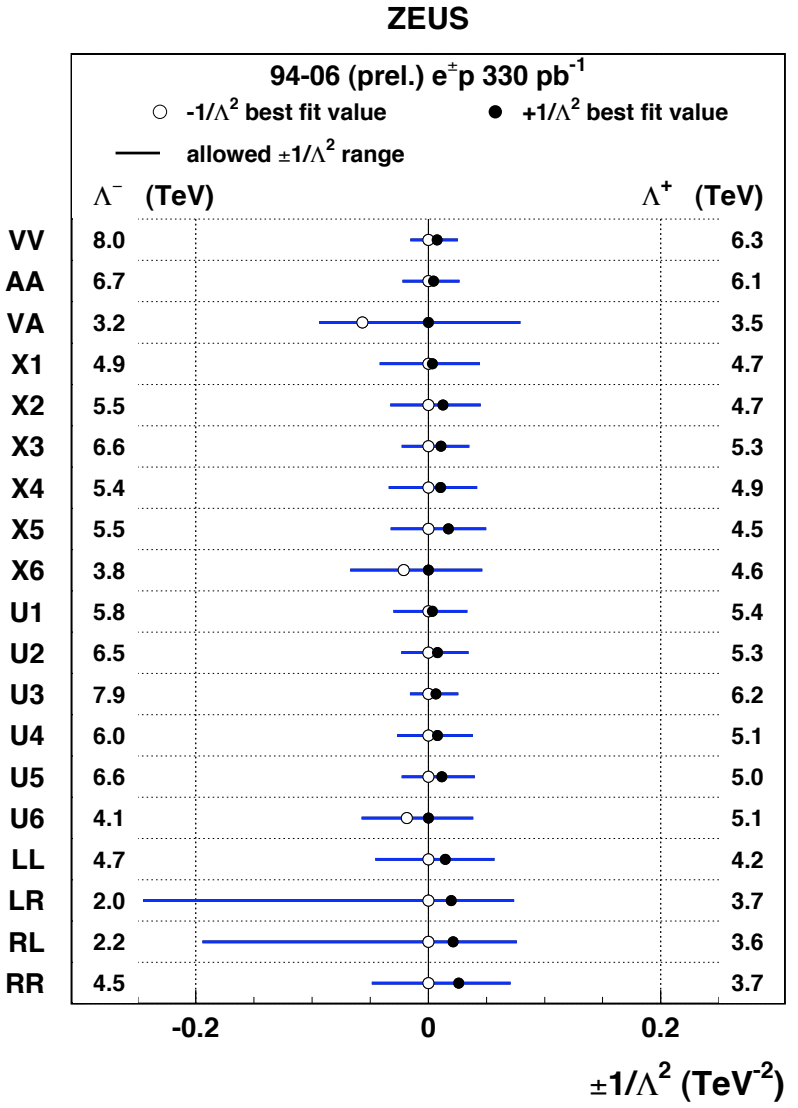
- Fit CI models to Q^2 dist. of data (example: AA=LL−LR−RL+RR)
- Different η sign → different CI–SM interferences
- Limits on Λ on various models:
  2.0 - 8.0 TeV (ZEUS)
  1.6 - 5.5 TeV (H1/HERA-I)

Comparable to Tevatron/LEP limits on eeqq CI

Contact Interactions (3)

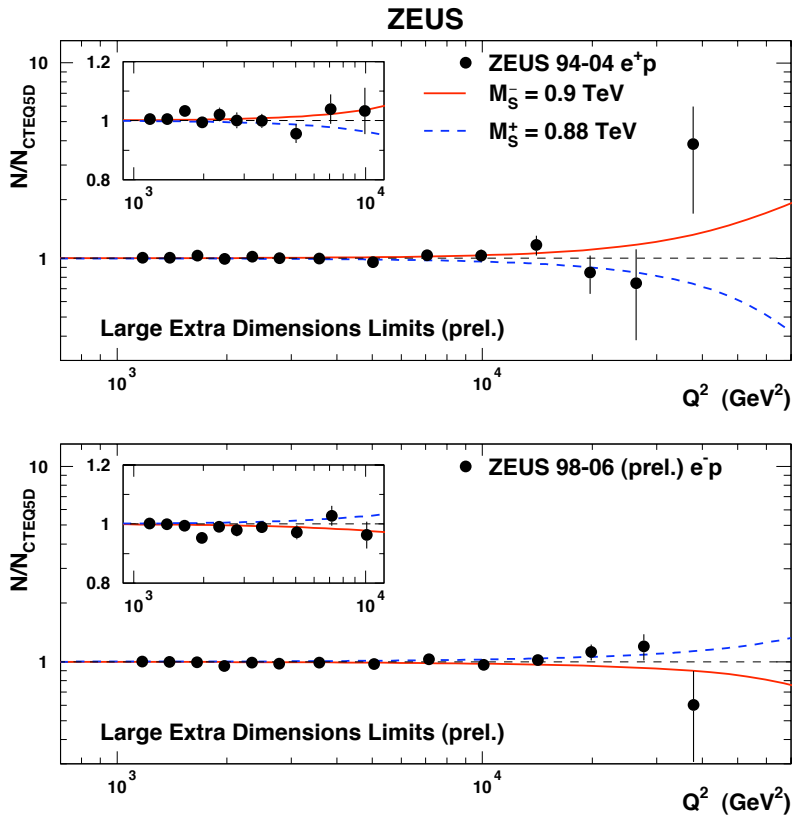
Results for models with various chirality

	Model	η^{ed}_{LL}	η^{ed}_{LR}	η^{ed}_{RL}	η^{ed}_{RR}	η^{eu}_{LL}	η^{eu}_{LR}	η^{eu}_{RL}	η^{eu}_{RR}
vector/axial	VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
	AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
	VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
other parity-conserving models	X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$		
	X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$	
	X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$
	X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$	
	X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$
	X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$
u-quark only	U1					$+\eta$	$-\eta$		
	U2					$+\eta$		$+\eta$	
	U3					$+\eta$			$+\eta$
	U4						$+\eta$	$+\eta$	
	U5						$+\eta$		$+\eta$
	U6							$+\eta$	$-\eta$
purely chiral	LL	$+\eta$				$+\eta$			
	LR		$+\eta$				$+\eta$		
	RL			$+\eta$				$+\eta$	
	RR				$+\eta$				$+\eta$



Large Extra Dimensions

- Arkani-Hamed, Dimopoulos and Dvali:
  n extra dimensions compactified to scale R, where only gravity propagates.
  Real GUT scale as low as TeV ($R^n M_s^{n+2} \sim M^2_{Planck}$)
- Collider consequence: exchange of Kaluza-Klein excitations of gravitons modifies SM-particle scattering at high energy.



- HERA: eeqq CI formalism with λ/M_s^4 as a parameter

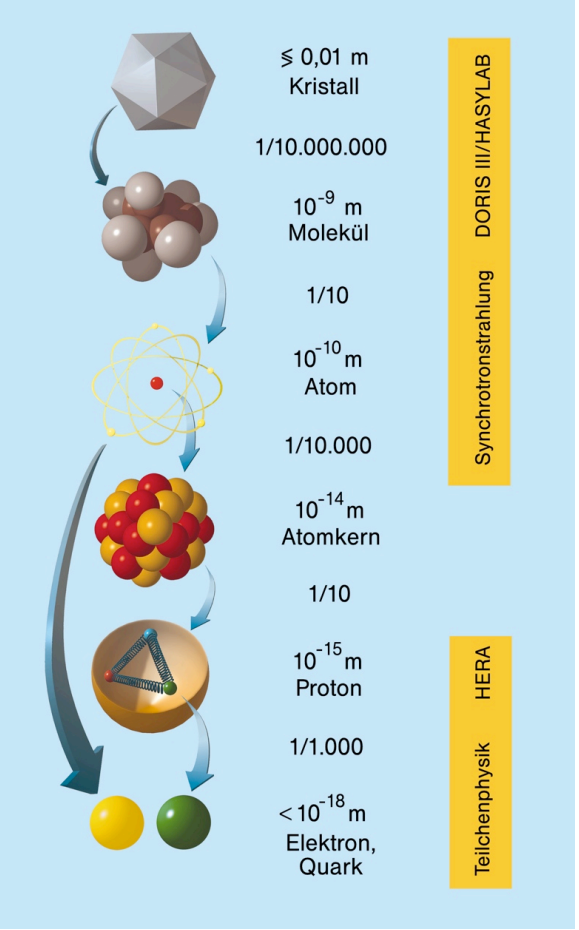
- ZEUS: $M_s > 0.88$ TeV ($\lambda=+1$)
  0.90 TeV ($\lambda=-1$)
  H1: $M_s > 0.82$ TeV ($\lambda=+1$)
  (HERA-I) 0.78 TeV ($\lambda=-1$)

Excited fermions

- Compositeness(structure) ⇔ excited states ⇔ emission(radiation)

  Can be seen at each scale of Nature.

- excited molecule: light emission
  (eV)
- excited atom: X-ray
  (keV)
- excited nucleus: γ-ray
  (MeV)
- excited nucleon (resonances): decay with pion
  (0.1GeV)
- excited leptons/quarks: radiate gauge bosons
  → mass resonance in fermion+boson pair
  (0.1 TeV)



Excited leptons

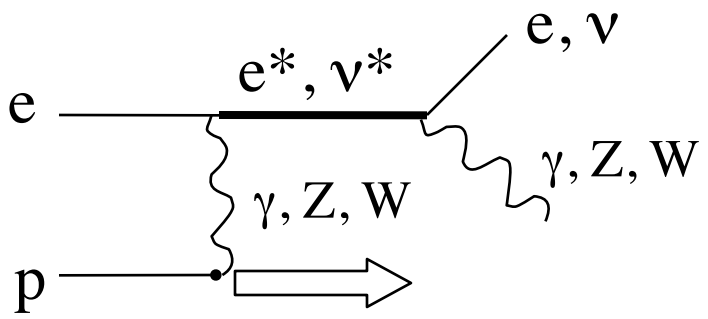
- Effective Lagrangian of *f-f** transition

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

SU(2) U(1) SU(3)

f, f', f_s - weight factors determined by composite dynamics

Λ - compositeness scale



- Explored channels and number of events

Search for e^* at HERA (475 pb^{-1})

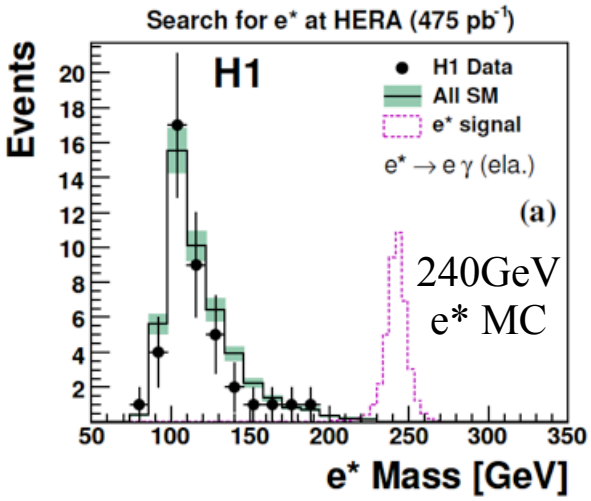
Channel	Data	SM	Signal Efficiency [%]
$e^*\to e\gamma$ (ela.)	42	48 ± 4	60–70
$e^*\to e\gamma$ (inel.)	65	65 ± 8	60–70
$e^*\to \nu W\to \nu q\bar{q}$	129	133 ± 32	20–55
$e^*\to \nu W\to \nu e\nu$	4	4.5 ± 0.7	60
$e^*\to eZ\to e\nu\nu$			35
$e^*\to eZ\to eq\bar{q}$	286	277 ± 62	20–55
$e^*\to eZ\to eee$	0	0.72 ± 0.06	60
$e^*\to eZ\to e\mu\mu$	0	0.52 ± 0.05	40–15

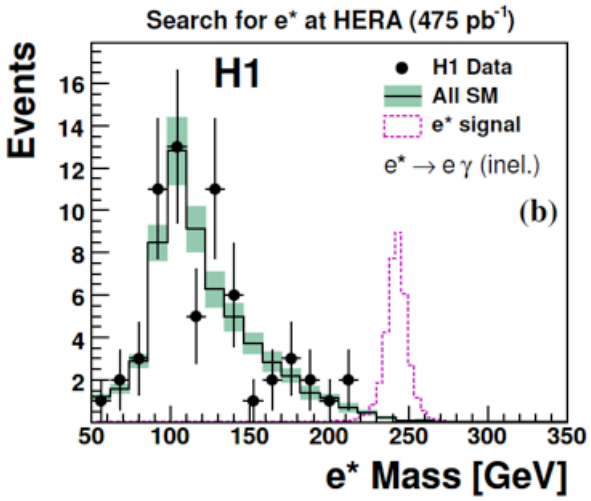
Search for ν^* at HERA (e^-p, 184 pb^{-1})

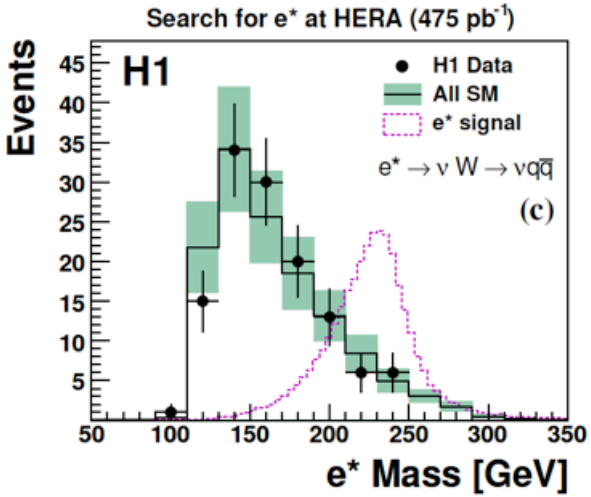
Channel	Data	SM	Signal Efficiency [%]
$\nu^*\to \nu\gamma$	7	12.3 ± 3.0	50–55
$\nu^*\to eW\to eq\bar{q}$	220	223 ± 47	40–65
$\nu^*\to eW\to e\nu\mu$	0	0.40 ± 0.05	35
$\nu^*\to eW\to e\nu e$	0	0.7 ± 0.1	45
$\nu^*\to \nu Z\to \nu q\bar{q}$	89	95 ± 21	25–55
$\nu^*\to \nu Z\to \nu ee$	0	0.19 ± 0.05	45

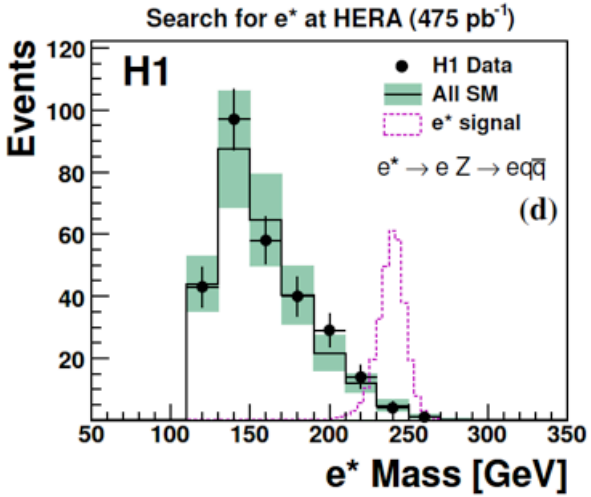
ν* production is via CC
→ e⁻p data have largest sensitivity

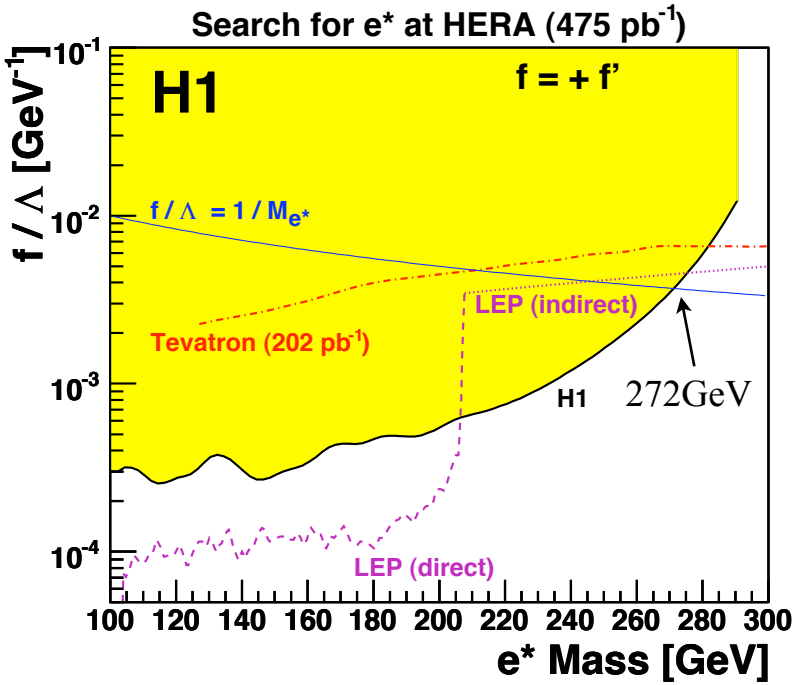
Excited electron search







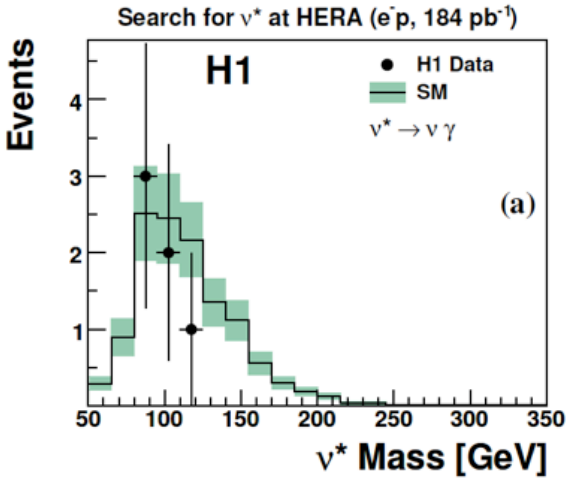


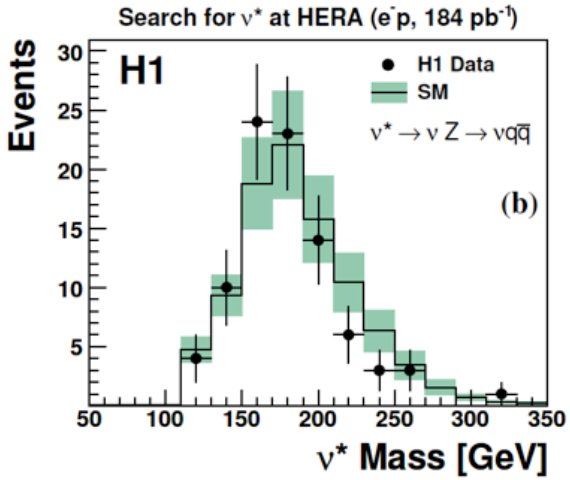


- Explores new domain above M(e*) > 200 GeV
- LEP indirect limits from virtual effects in $e^+e^- \rightarrow \gamma\gamma$

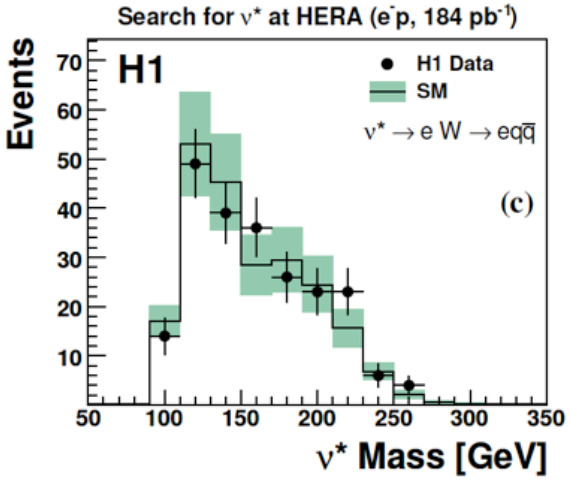
New publication DESY-08-052 (arXiv:0805.4530)

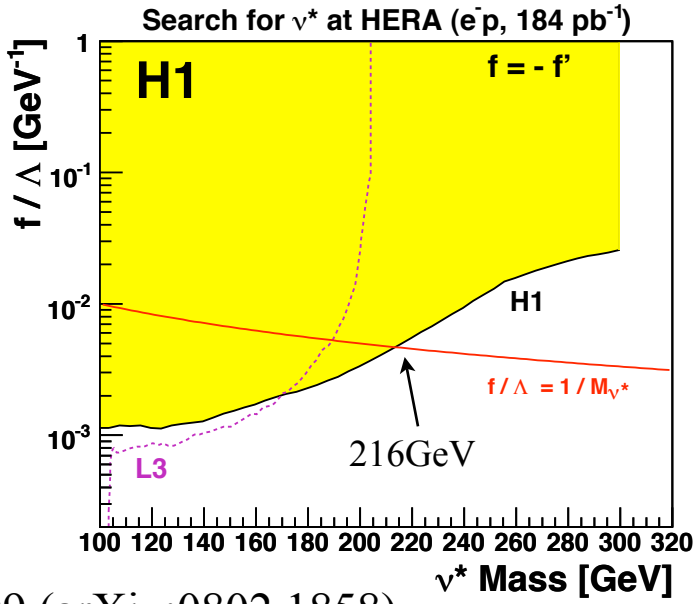
Excited neutrino search

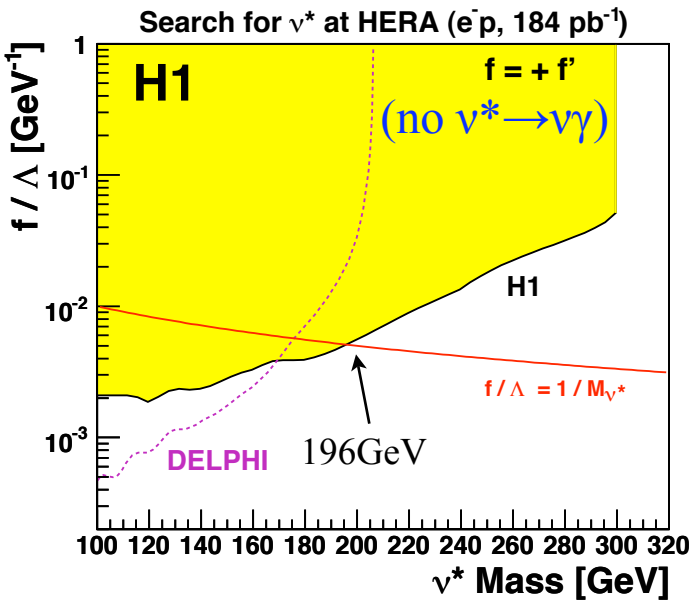




- HERA's unique sensitivity above M(ν*) > 200 GeV



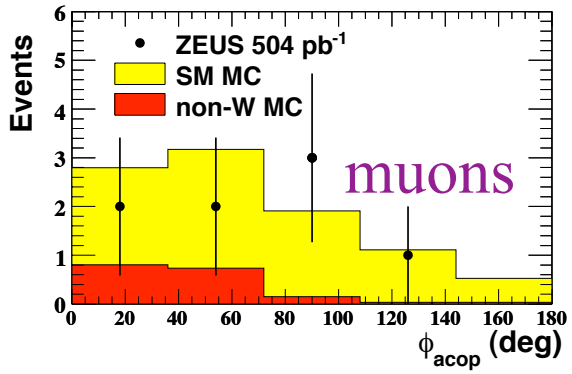


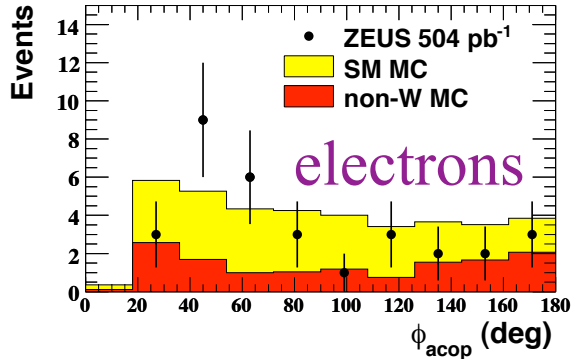


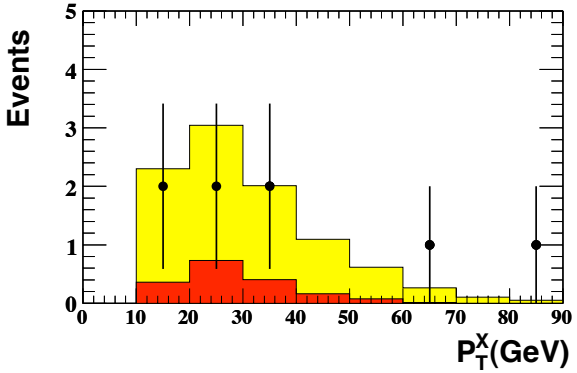
New publication DESY-08-009 (arXiv:0802.1858)

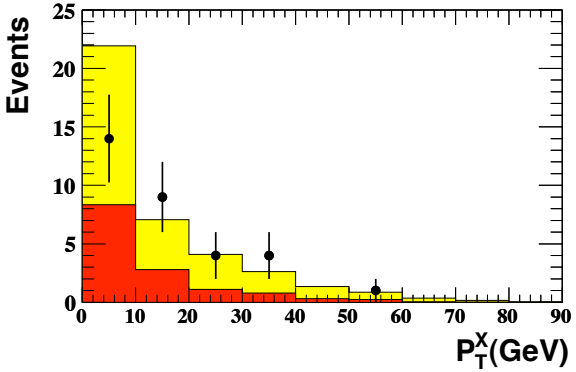
Hottest paper (released this week): ZEUS-pub-08-005

- Final ZEUS results on "high-Pt lepton + missing Pt" events and measurement of *W* cross sections
- Data show clear *W* component, consistent with SM prediction.

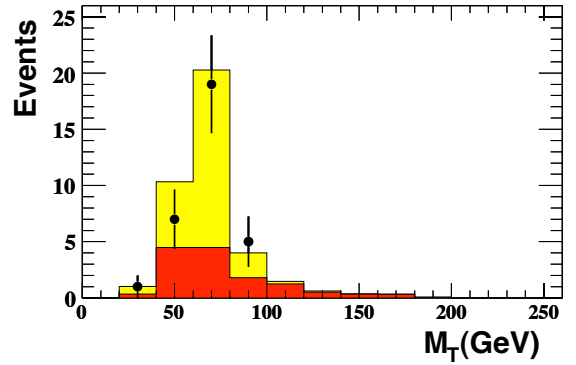








Isolated Lepton Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
$e^- p$ 208 pb^{-1}	$9/11.3 \pm 1.5$ (54%)	$6/5.1 \pm 0.7$ (67%)	$5/5.5 \pm 0.8$ (75%)
$e^+ p$ 296 pb^{-1}	$7/12.6 \pm 1.7$ (68%)	$7/6.2 \pm 0.9$ (75%)	$6/7.4 \pm 1.0$ (79%)
$e^\pm p$ 504 pb^{-1}	$16/23.9 \pm 3.1$ (61%)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



- $\sigma_{ep \to lWX} = 0.89^{+0.25}_{-0.22}\,(\text{stat.}) \pm 0.10(\text{syst.})\,\text{pb}$
  smallest total cross section measured at HERA

Summary

- HERA has ceased data-taking after ~15 years, with ~0.5 fb^{-1} per experiment of high-energy *ep* collision data.
  - Solid confidence on perturbative QCD.
  - Indispensable PDF inputs to LHC physics.
- Short-distance *eq* interaction: unique opportunity to search for particles and forces beyond SM.
  - Contact interactions, quark radius, large extra dimensions.
  - Excited electrons, excited neutrinos.
  - Many results competitive/complementary with other colliders.
- The search lists are not yet exhaustive.
  - More results from whole HERA data to come.
  - H1+ZEUS combined results WG under work.