

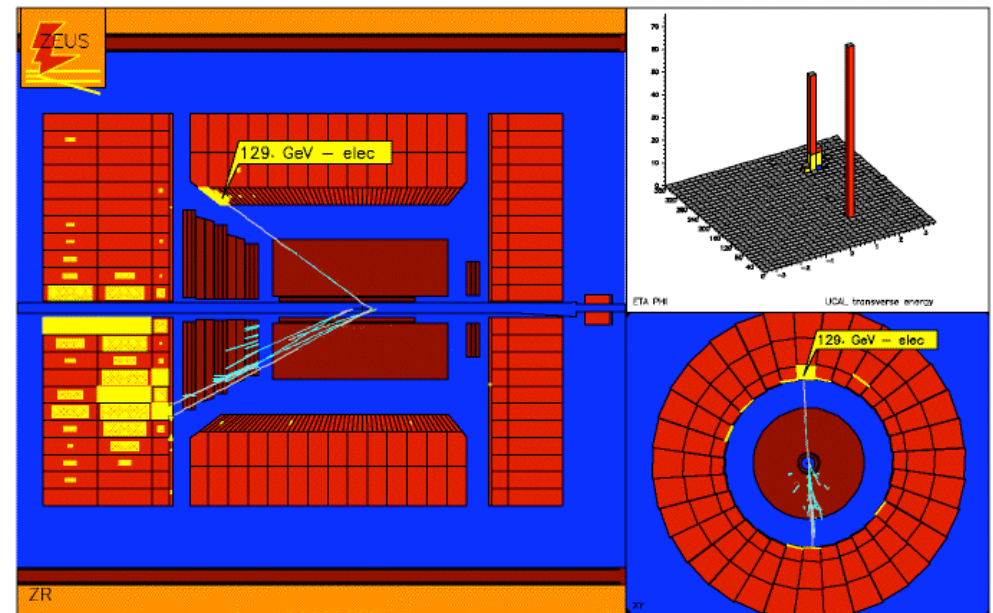
Search for Physics beyond Standard Model at HERA



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

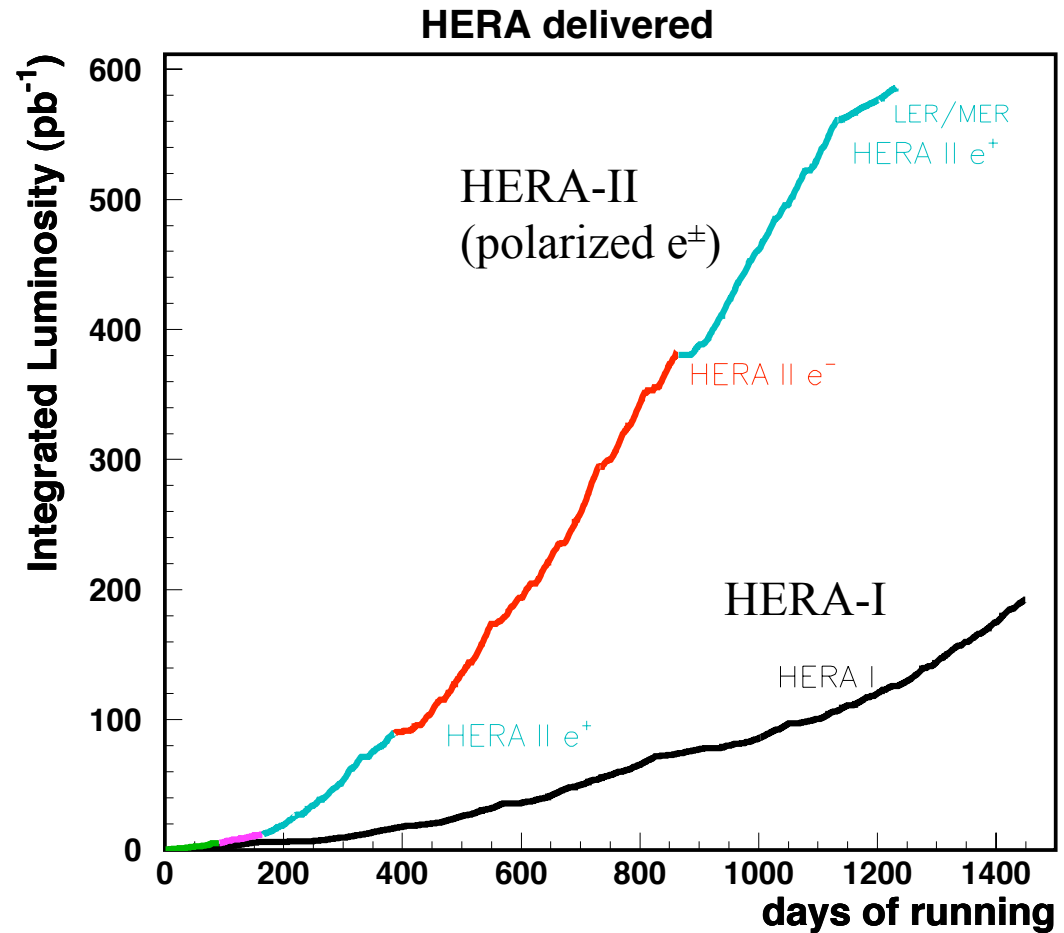


- HERA and experiments
- High- Q^2 DIS
- Contact Interactions
- Excited Fermions
- extra...



HERA collider at DESY/Hamburg

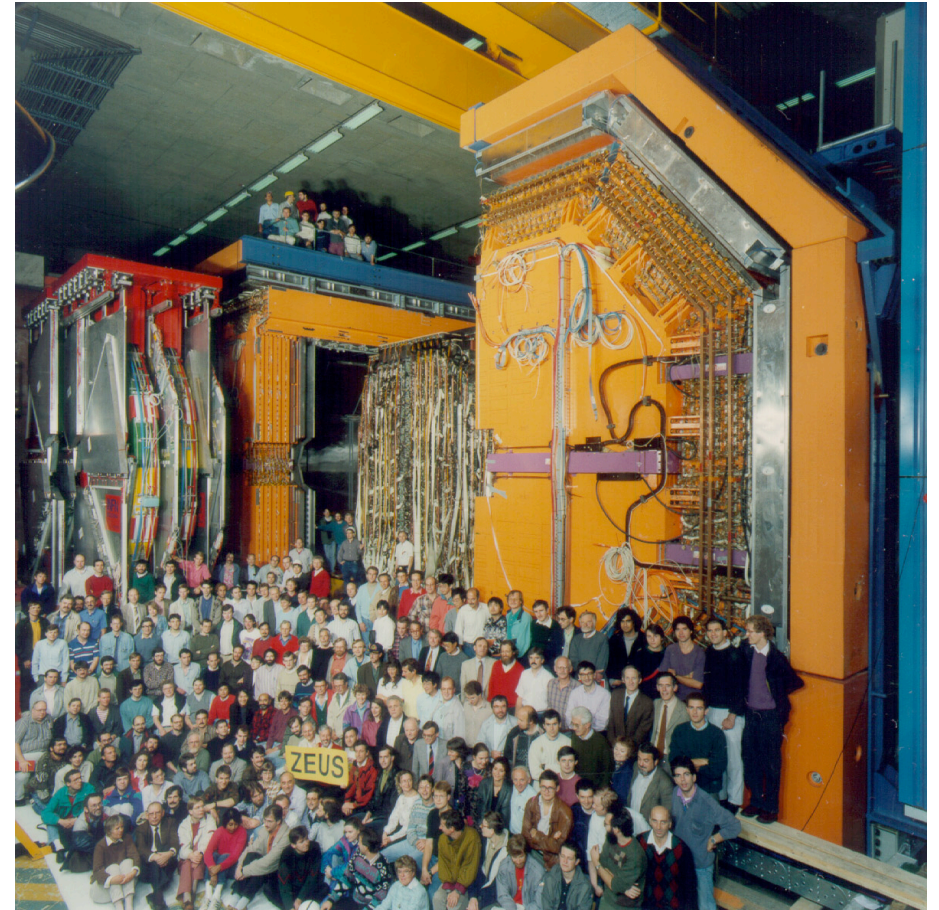
The only ep collider in the world!



- $920\text{GeV } p \otimes 27.5\text{GeV } e^\pm \Rightarrow \sqrt{s}=320 \text{ GeV}$
- Physics luminosity: $\sim 0.5 \text{ fb}^{-1} / \text{exp't.}$ ($\sim 0.3 \text{ fb}^{-1} e^+p$, $\sim 0.2 \text{ fb}^{-1} e^-p$)
- 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. $Q^2 \sim 40,000 \text{ GeV}^2 \rightarrow 0.001 \text{ fm}$.
Very short-distance eq interactions.
- Bjorken x : Parton Distribution Function (PDF) in proton.

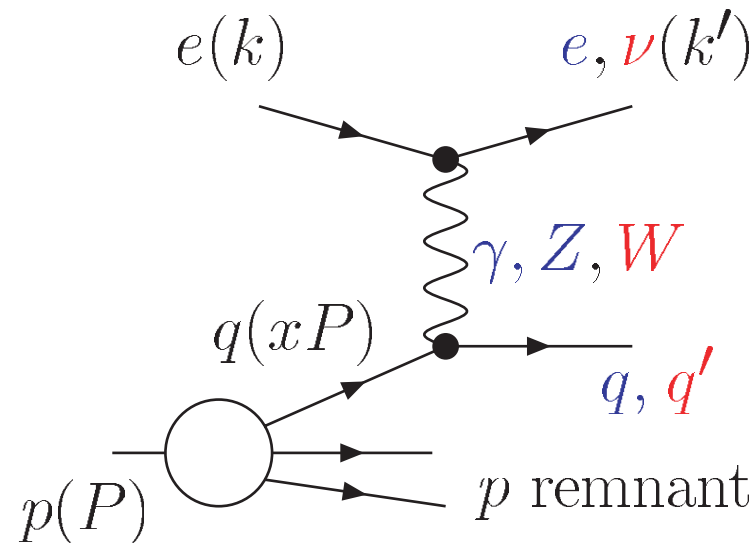
• Neutral (γ, Z)

or

Charged (W)

current

interactions.



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

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

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

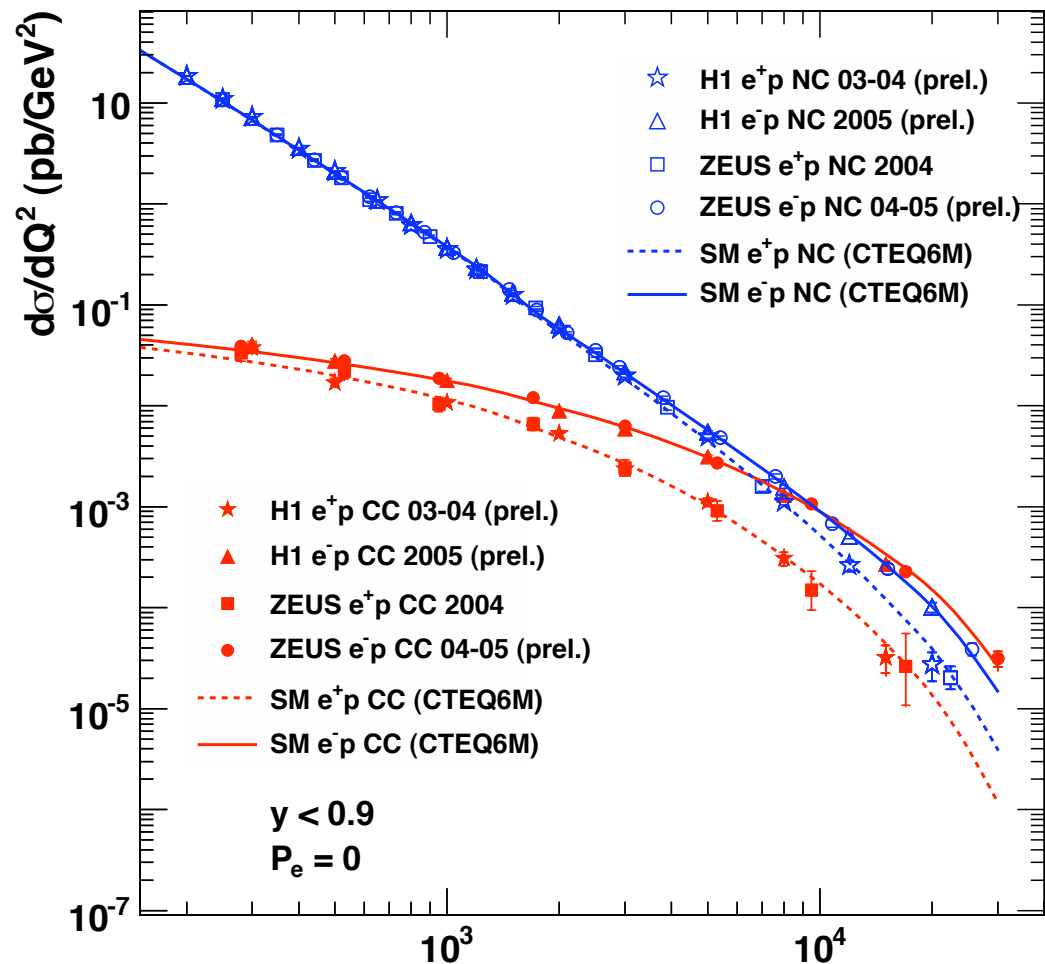
- $\sigma \approx (\text{coupling})^2 \otimes \text{propagator} \otimes \text{PDF}(x, Q^2) \quad \mathbf{EW} \otimes \mathbf{QCD}$

High- Q^2 NC/CC DIS cross sections

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

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

Unification of EW interactions



- short distance Q^2 (GeV²)
- high temperature
- early universe

First natural question: is quark elementary?

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

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

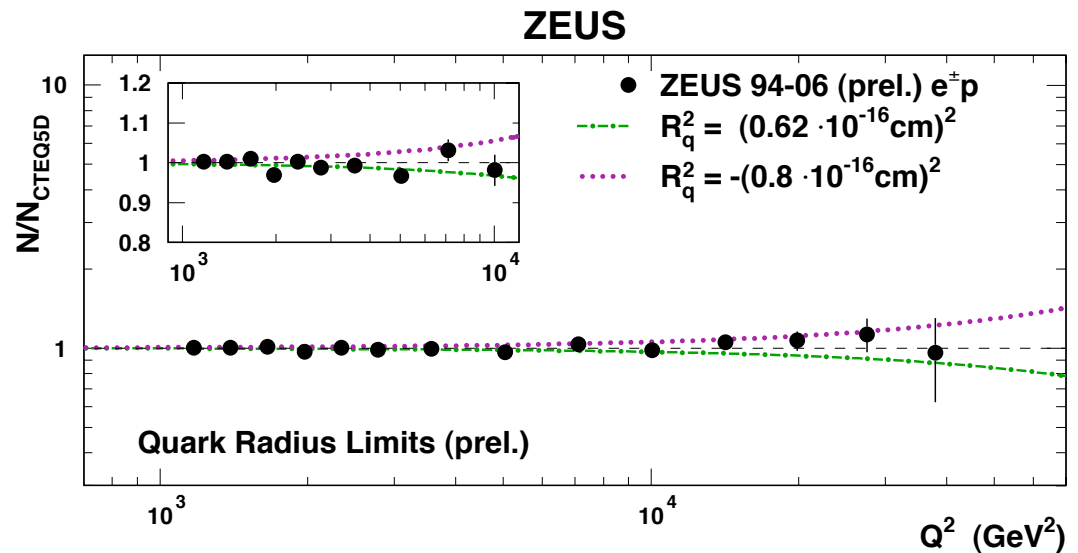
- **Limits on quark size**

(assuming electron is pointlike)

ZEUS: $R_q < 0.62 \cdot 10^{-16} \text{ cm}$

H1: $R_q < 0.74 \cdot 10^{-16} \text{ cm}$

(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:

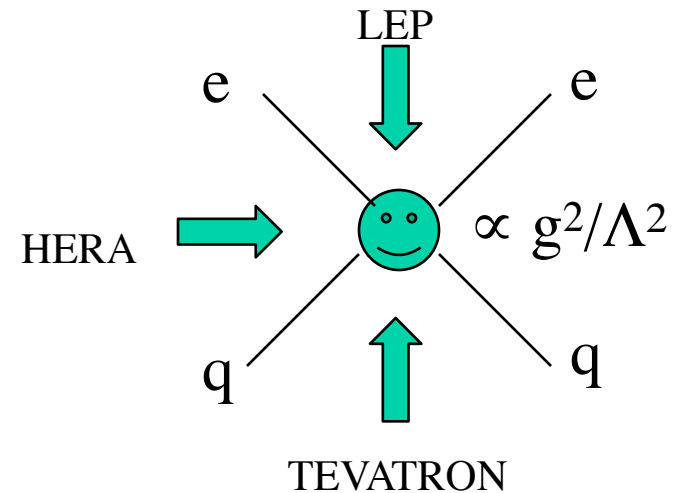
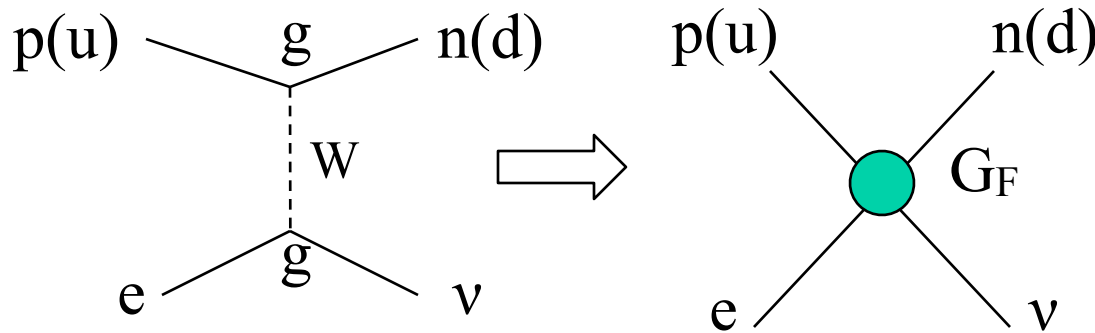
$$L_{CI} = \sum_{i,j=L,R}^{q=u,d} \eta_{ij}^q (\bar{e}_i \gamma^\mu e_i) (\bar{q}_j \gamma_\mu q_j)$$

i/j: lepton/quark chirality

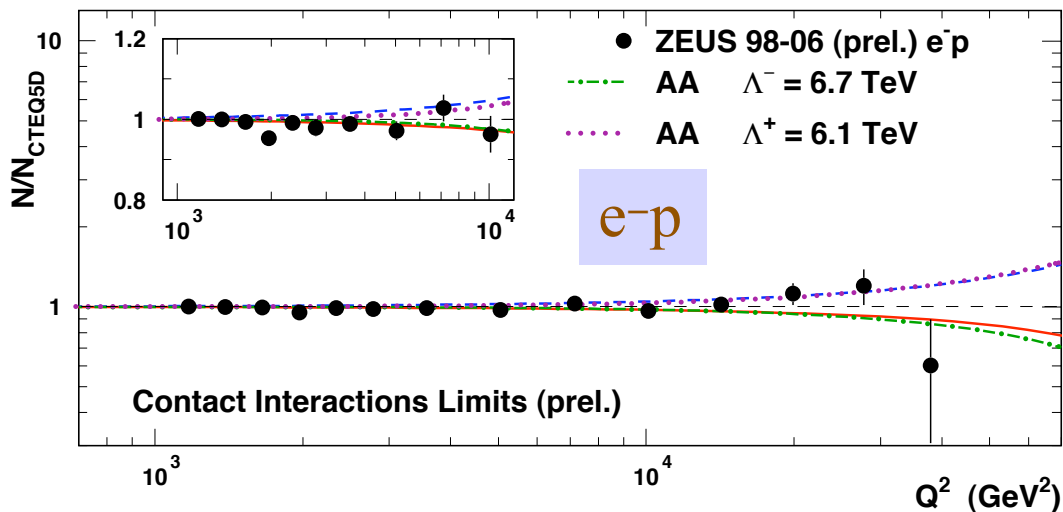
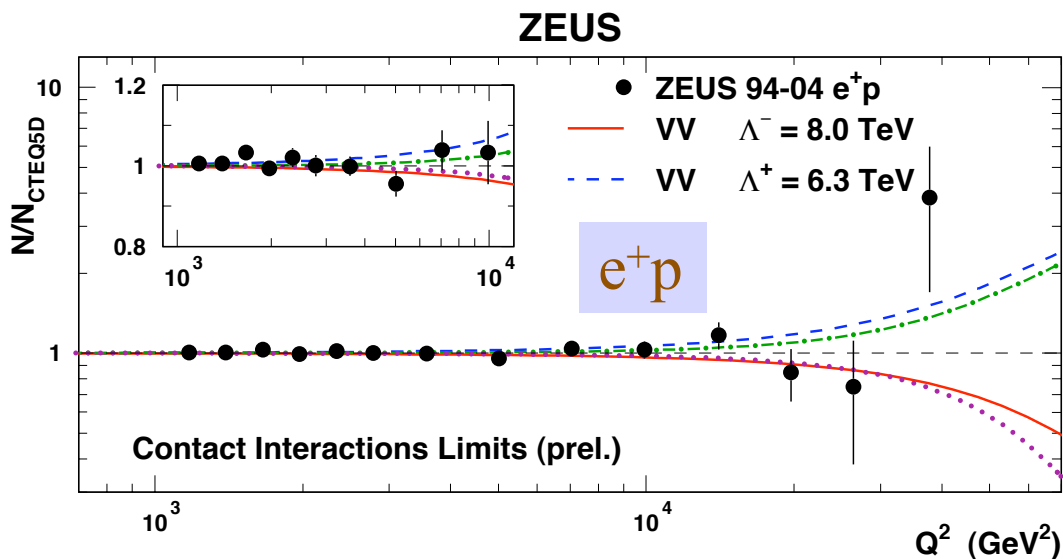
$\eta = g^2/\Lambda^2$ (g : unknown coupling, convention: $g^2 = 4\pi$; Λ : new physics scale)

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)



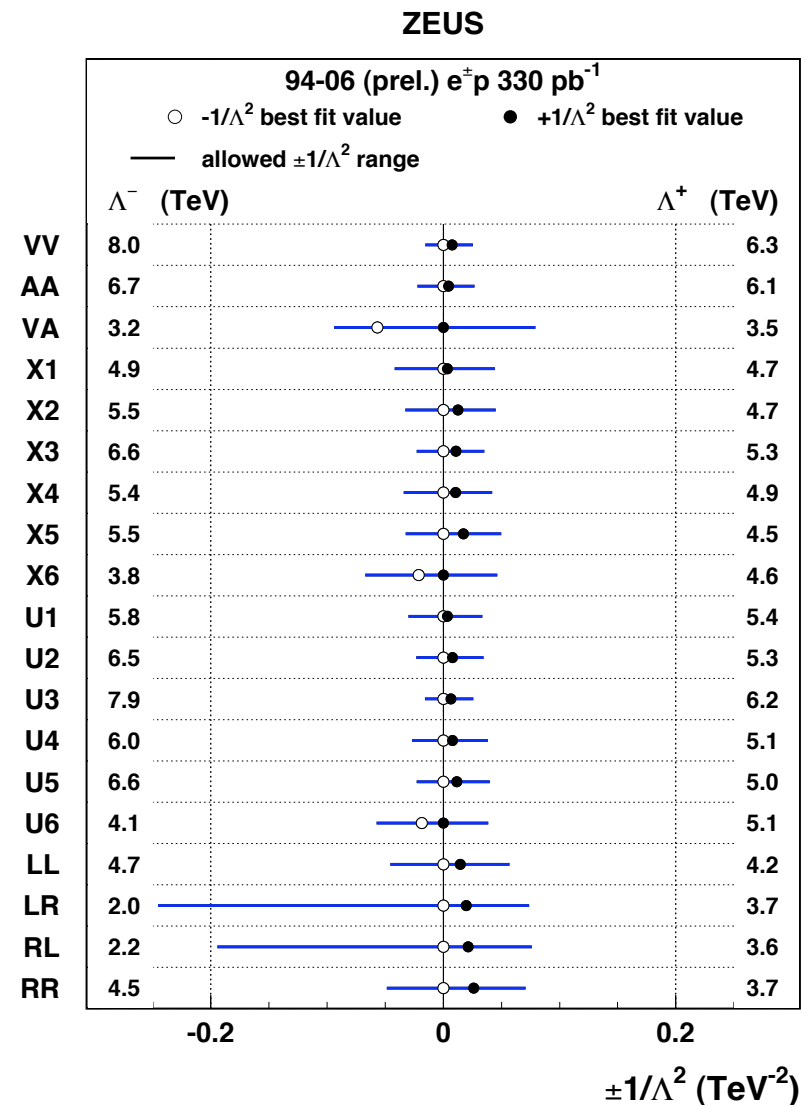
- Fit CI models to Q^2 dist. of data (example: AA=LL-LR-RL+RR)
- Different η sign \rightarrow different CI-SM interferences
- Limits on Λ on various models:
2.0 - 8.0 TeV (ZEUS)
1.6 - 5.5 TeV (H1/HERA-I)

Comparable to Tevatron/LEP limits on $eeqq$ CI

Contact Interactions (3)

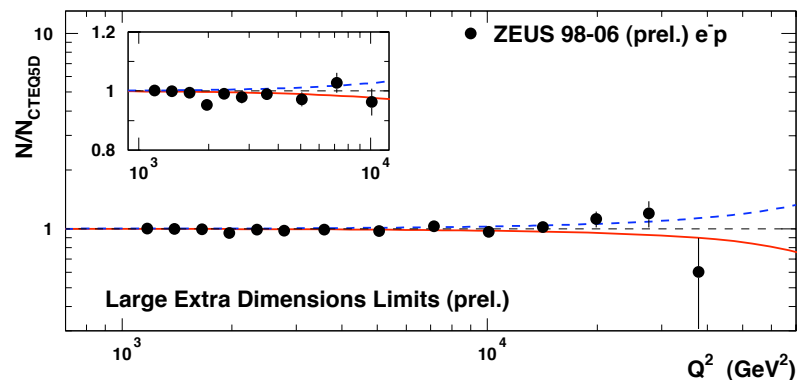
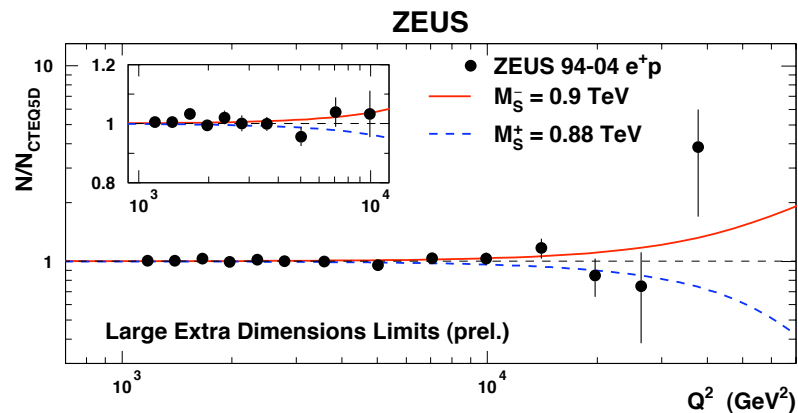
Results for models with various chirality

	Model	η_{LL}^{ed}	η_{LR}^{ed}	η_{RL}^{ed}	η_{RR}^{ed}	η_{LL}^{eu}	η_{LR}^{eu}	η_{RL}^{eu}	η_{RR}^{eu}
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 ($R^n M_s^{n+2} \sim M_{\text{Planck}}^2$)
- 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

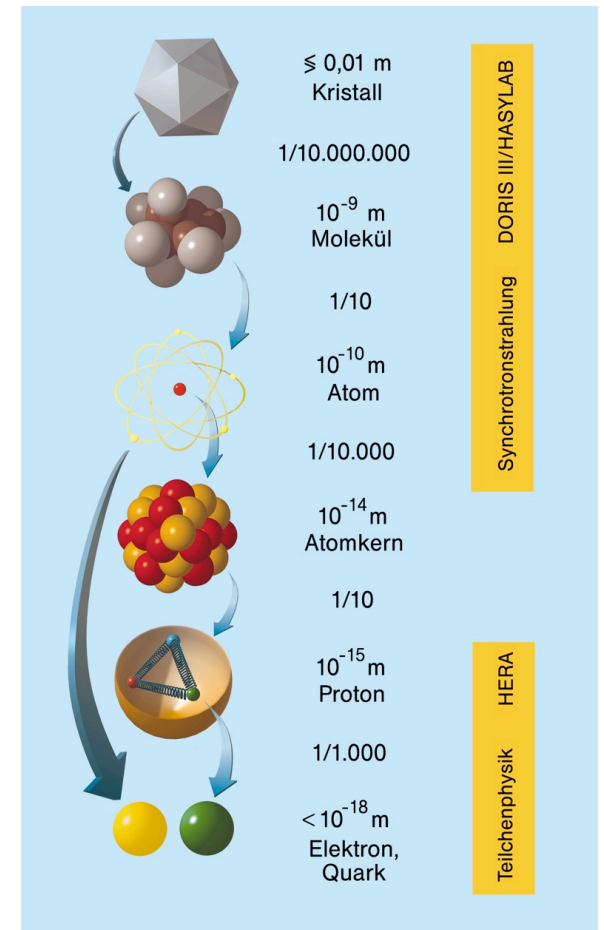
- ZEUS: $M_s > 0.88$ TeV ($\lambda=+1$)
 0.90 TeV ($\lambda=-1$)
- H1: $M_s > 0.82$ TeV ($\lambda=+1$)
 (HERA-I) 0.78 TeV ($\lambda=-1$)

Excited fermions

- **Compositeness**(structure) \Leftrightarrow excited states \Leftrightarrow 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 (0.1 GeV)
- **excited leptons/quarks**: radiate gauge bosons
 \rightarrow mass resonance in fermion+boson pair (0.1 TeV)



Excited leptons

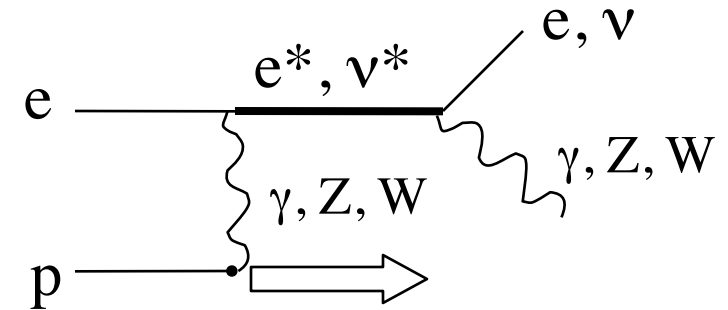
- Effective Lagrangian of f - f^* transition

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

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

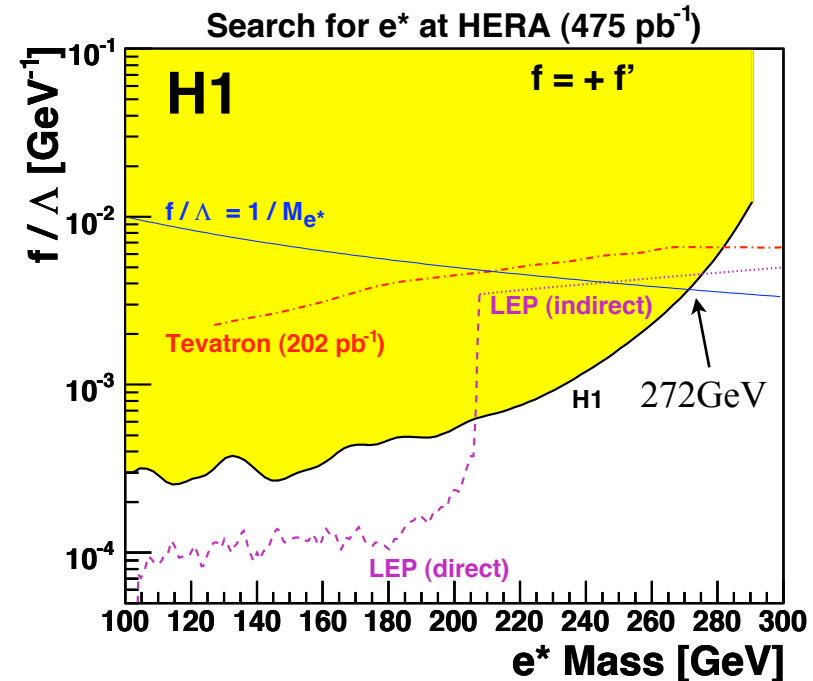
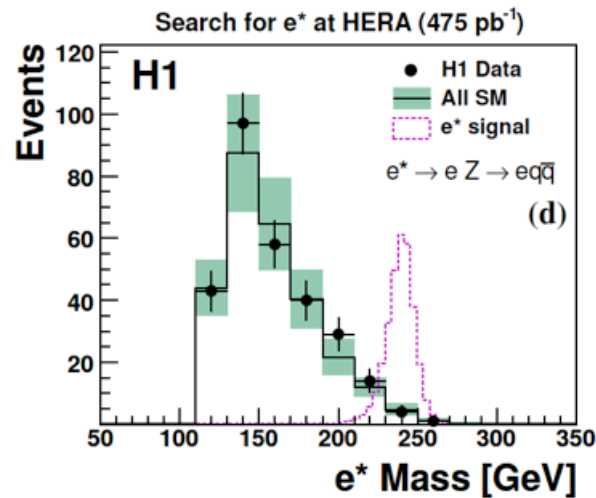
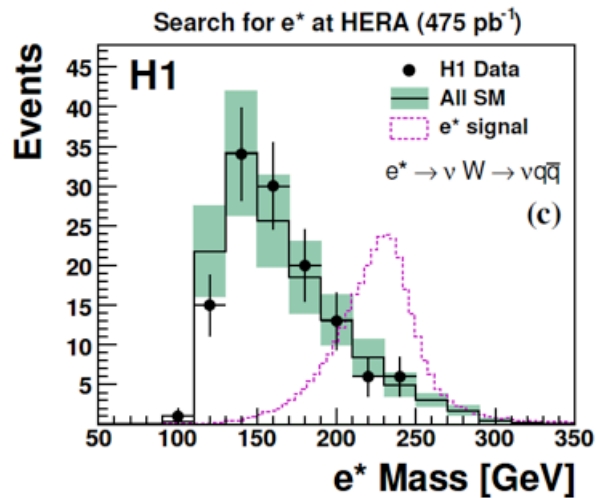
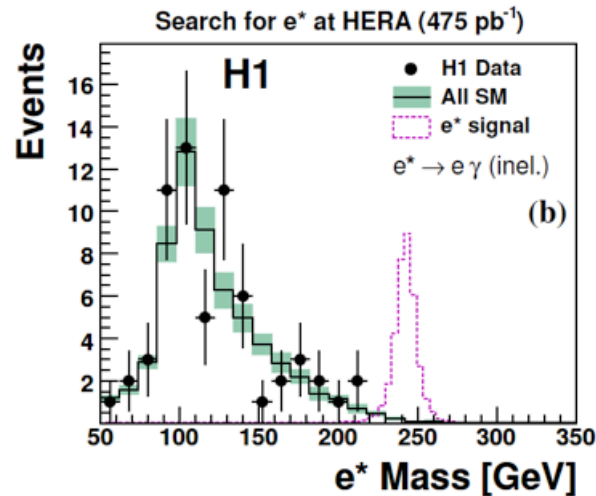
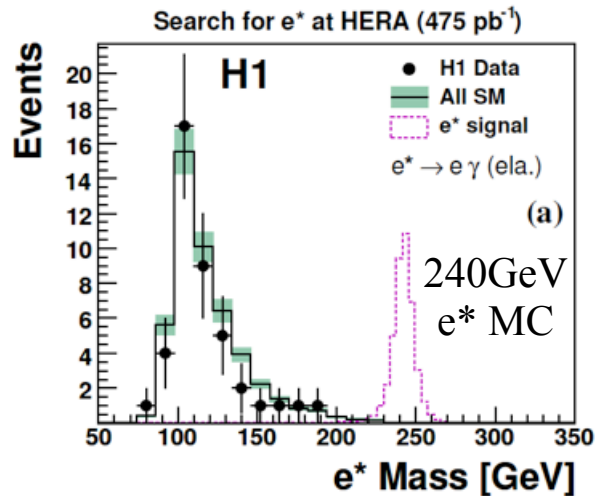
Search for ν^* at HERA (e^-p , 184 pb^{-1})

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

ν^* production is via CC

→ e^-p data have largest sensitivity

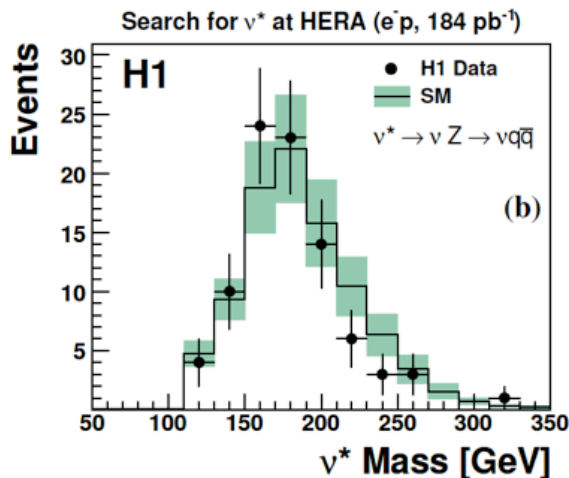
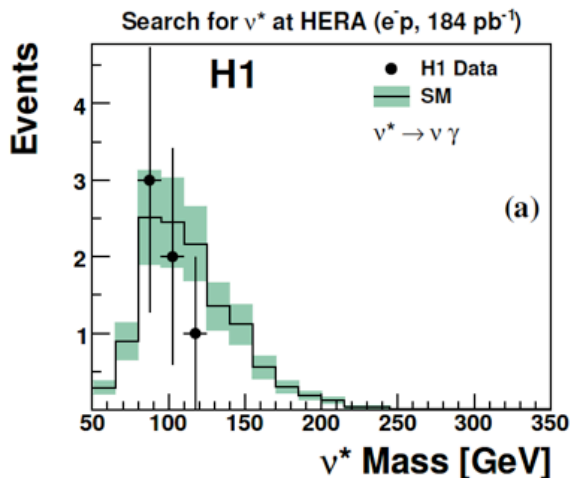
Excited electron search



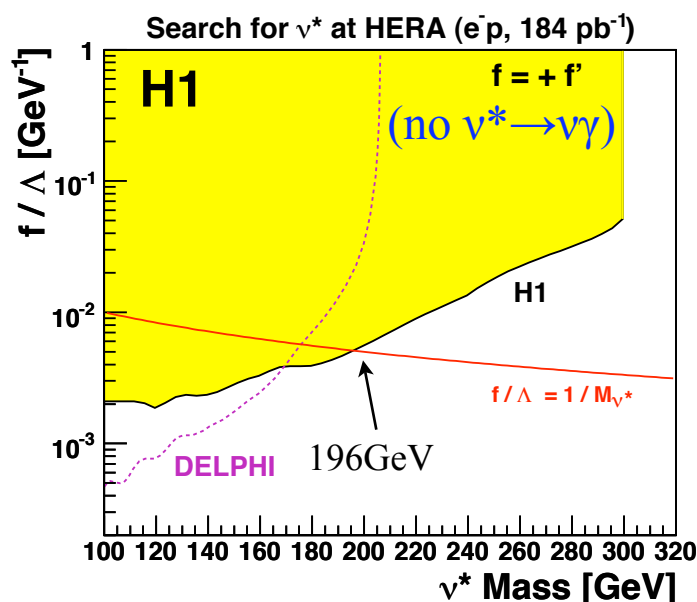
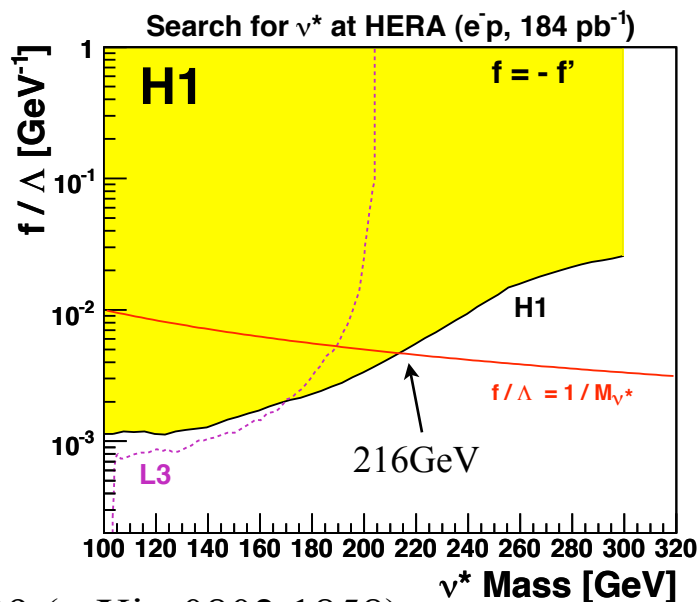
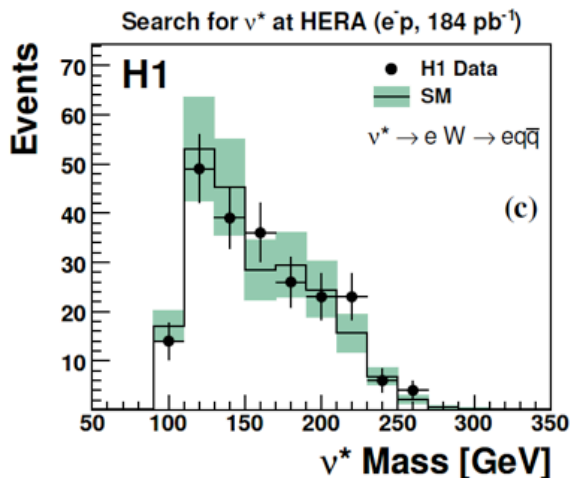
- Explores new domain above $M(e^*) > 200$ GeV
- LEP indirect limits from virtual effects in $e^+e^- \rightarrow \gamma\gamma$

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

Excited neutrino search



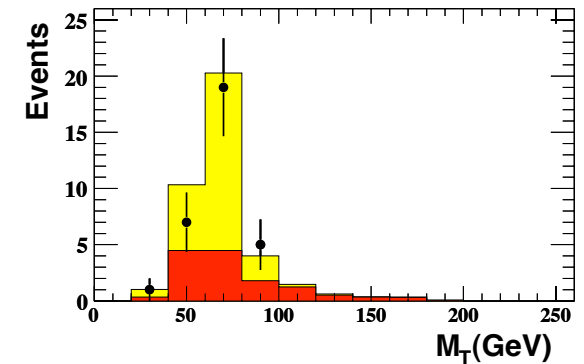
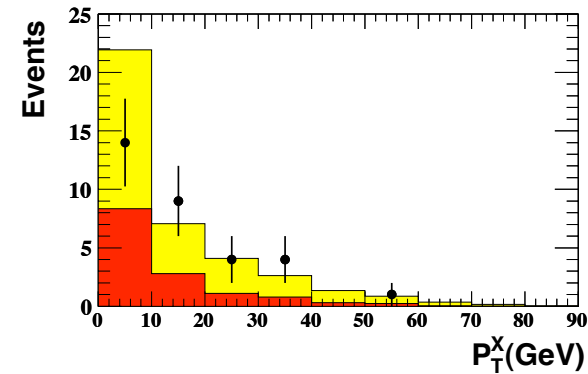
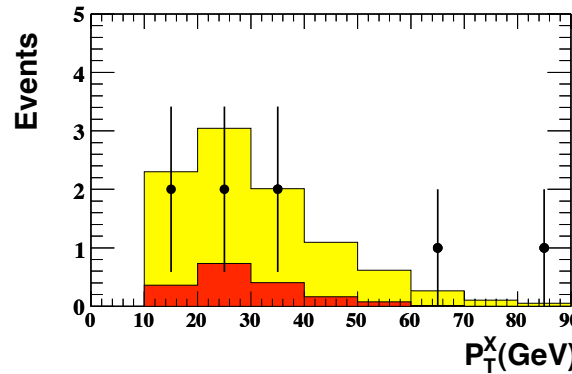
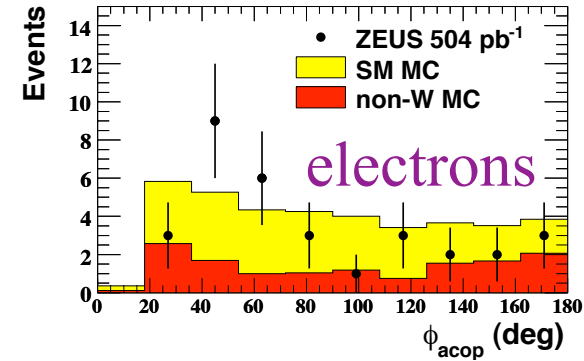
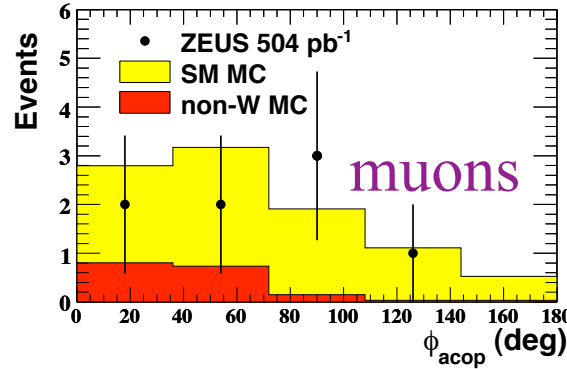
- HERA's unique sensitivity above $M(\nu^*) > 200 \text{ GeV}$



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%)

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

Summary

- HERA has ceased data-taking after ~ 15 years, with $\sim 0.5 \text{ fb}^{-1}$ 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.