



Universität Hamburg



BMBF - Förderschwerpunkt

Elementarteilchenphysik

Großgeräte der physikalischen
Grundlagenforschung

New Physics Searches at HERA

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on behalf of



and



Outline:

- **H1 and ZEUS at HERA**
- **Searches in inclusive DIS**
- **Model based searches**
- **Model independent searches**
- **Summary**

HERA ep collider



➤ HERA-I: 1992-2000 $L \sim 120 \text{ pb}^{-1}/\text{exp.}$

➤ HERA-II 2002-2007 $L \sim 350 \text{ pb}^{-1}/\text{exp.}$

-Luminosity upgrade:

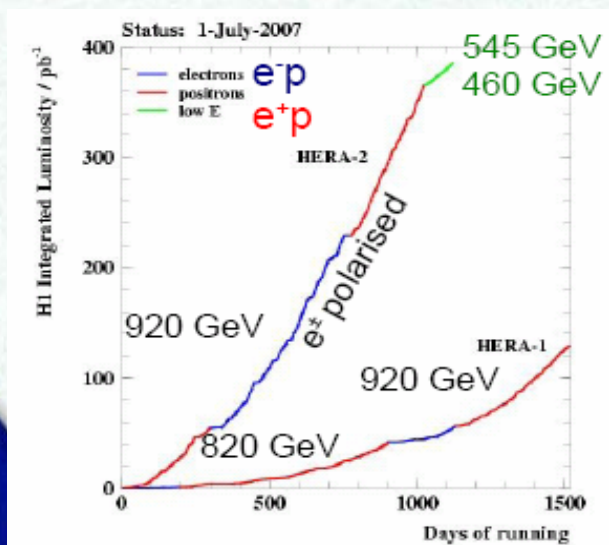
~10x more e-p data than in HERA-I

-Longitudinally polarized lepton beam



▪ ep collision at H1 and ZEUS

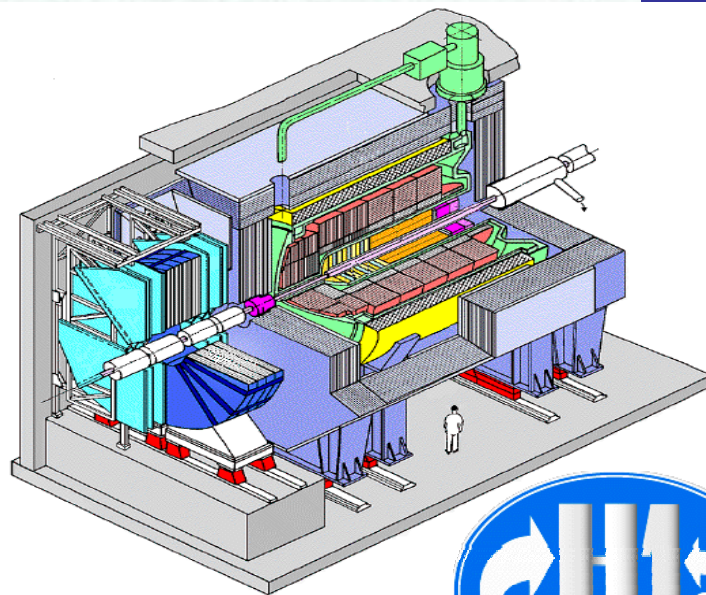
Presented results:



	H1	ZEUS
<i>e+p</i>	<i>294 pb⁻¹</i>	<i>272 pb⁻¹</i>
<i>e-p</i>	<i>184 pb⁻¹</i>	<i>206 pb⁻¹</i>
<i>Total</i>	<i>478 pb⁻¹</i>	<i>479 pb⁻¹</i>

Total luminosity ~ 1fb⁻¹

H1 and ZEUS hermetic multi-purpose detectors

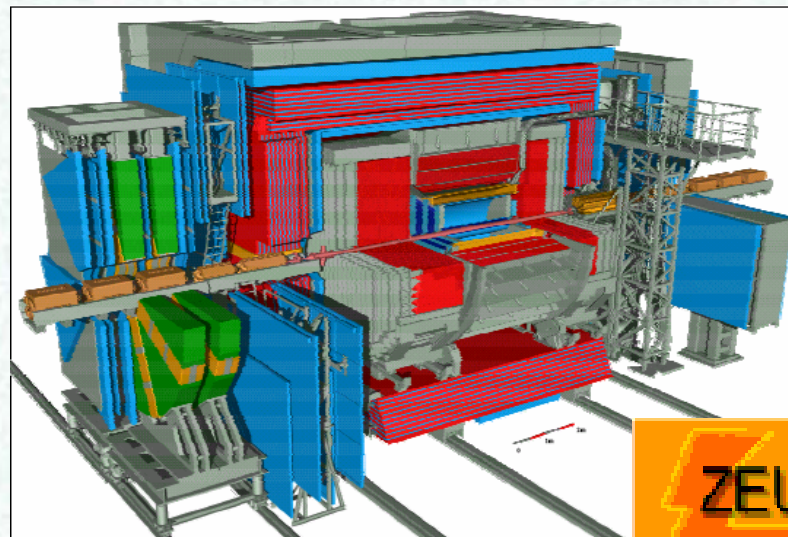


Liquid Argon Calorimeter

optimized for precision measurement of the scattered lepton

$$\sigma_E/E = 12\%/\sqrt{E} \quad (\text{ele})$$

$$\sigma_E/E = 50\%/\sqrt{E} \quad (\text{had})$$



Uranium-scintillator Calorimeter

optimized for precision measurement of the hadronic final state

$$\sigma_E/E = 18\%/\sqrt{E} \quad (\text{ele})$$

$$\sigma_E/E = 35\%/\sqrt{E} \quad (\text{had})$$

Beyond Standard Model searches at HERA

Searches in inclusive DIS

- ✓ NC: Quark Radius, Contact Interaction , Extra Dimensions
- ✓ CC: Polarization dependence

Model based searches

Test models and verify predicted signatures

- ✓ Leptoquarks and LFV
- ✓ Excited Leptons
- ✓ Single Top production
- ✓ Doubly Charged Higgs
- ✓ Supersymmetry

Model-independent searches

Compare data vs SM, reveal anomalies above small SM contribution

- ✓ Isolated leptons and missing P_T
- ✓ High- P_T multi-leptons
- ✓ General searches
- ✓ Magnetic monopoles

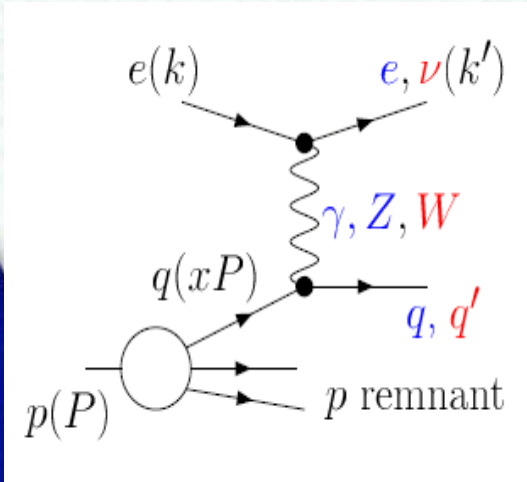
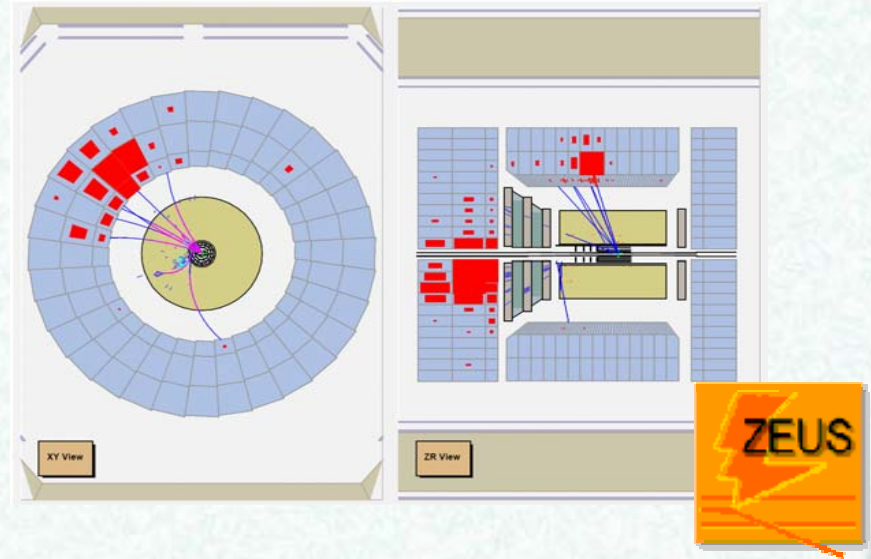
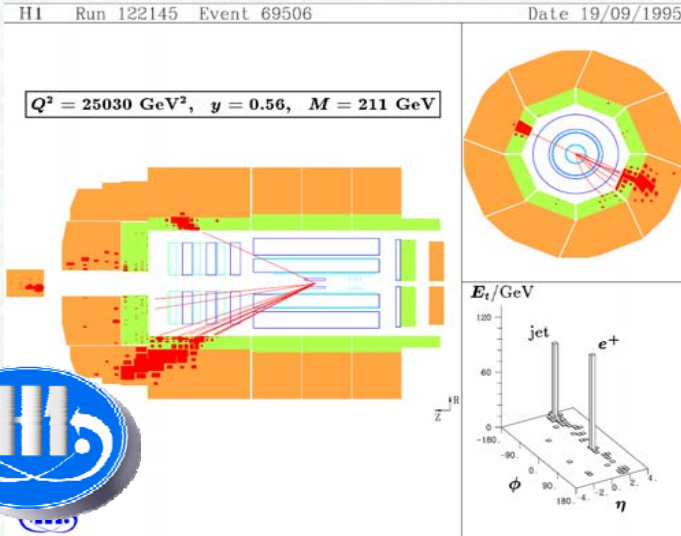
Topics in **red** covered in this talk

Deep Inelastic $e^\pm p$ Scattering

Main processes studied at H1 and ZEUS:

Neutral Current

Charged Current



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

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

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

$Q^2 = -(\text{4-momentum of propagator})^2$ - the virtuality of the exchanged boson.

x - fractional momentum of proton carried by struck quark q

y - fractional energy of the incoming lepton transferred to the proton in the proton's rest frame

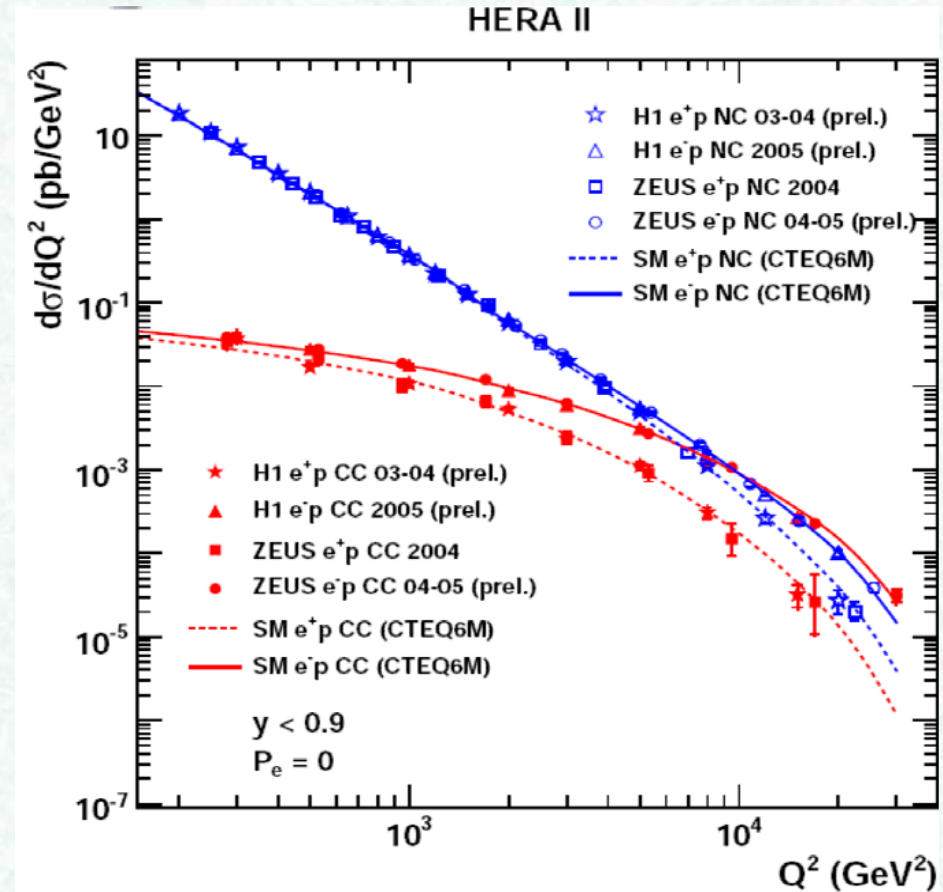
DIS at high- Q^2

Neutral Current and Charge Current cross-sections for e+p and e-p

➤ NC DIS at highest $Q^2 \Rightarrow$
 Z^0 contribution significant!

➤ CC DIS: e⁻u enhanced
e⁺d suppressed

➤ Excellent agreement of
precise data with Standard
Model over many order of
magnitude \Rightarrow testing ground
for SM and QCD



New Physics would create deviations from SM at high- Q^2 !

Quark (sub)structure

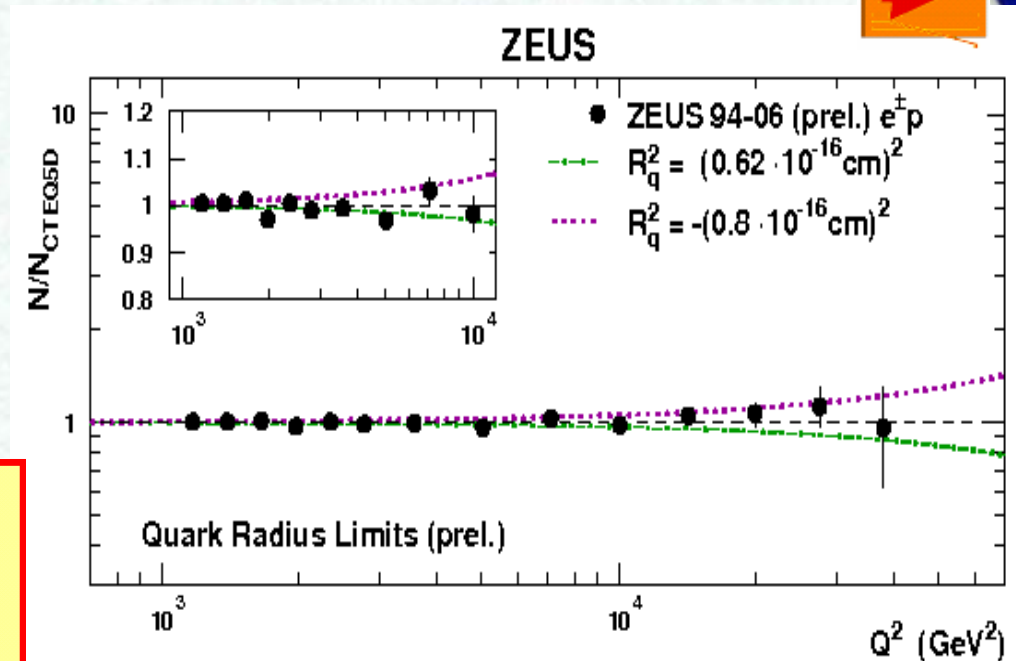


Quark radius form factor

If a quark has **finite size** =>
SM cross-section decreases
at high momentum transfer:

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

where R_q is the root mean square radius of the electroweak charge distribution in the quark



95% CL limit:

H1: $R_q < 0.74 \times 10^{-18} \text{ m}$

ZEUS: $R_q < 0.62 \times 10^{-18} \text{ m}$

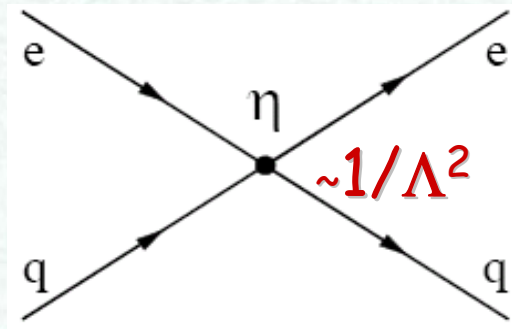
Limit below 1/1000 of the proton radius!

Contact Interactions

General models:

If the **scale Λ** of new interactions is **large**:

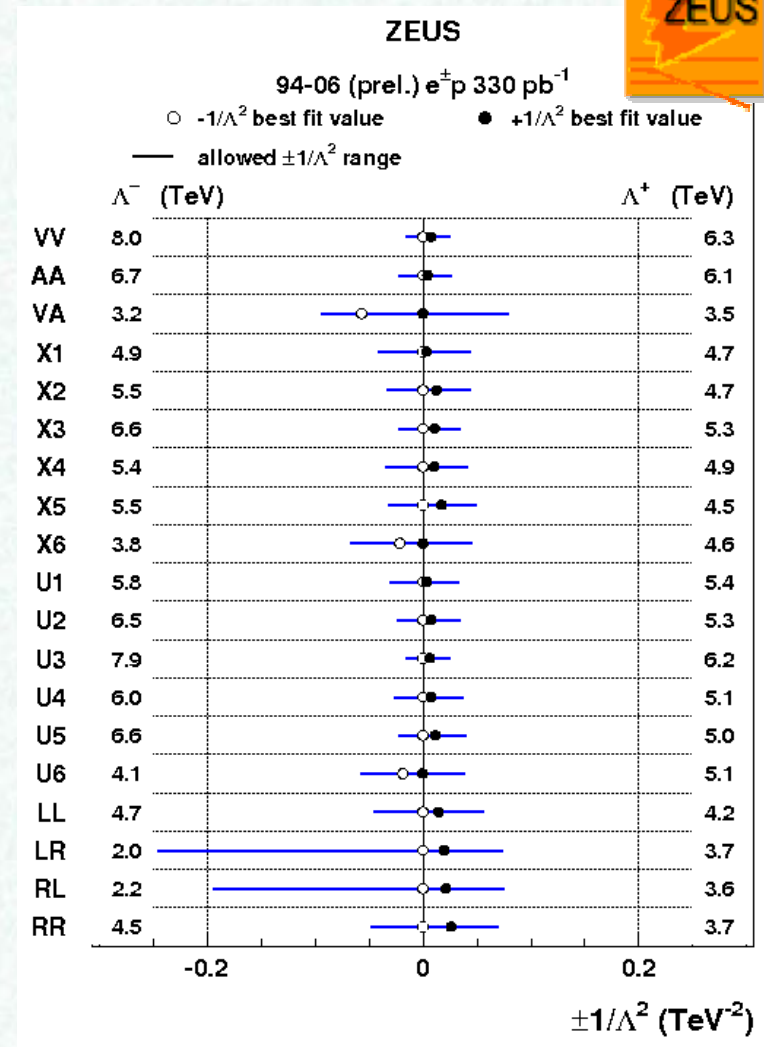
➤ Effective **contact interaction** parameterization



Modification of DIS cross-section at high- Q^2

Different models with different helicity structure =>

95% CL limits : $\Lambda > 2.0-8.0$ TeV



Sensitive to several TeV range !



Large Extra Dimensions

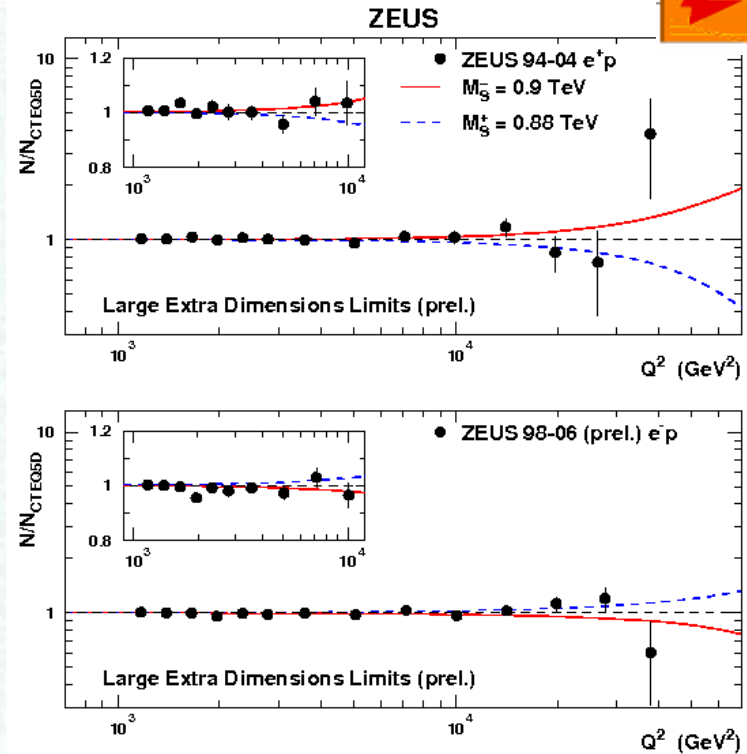
Arkani-Hamed-Dimopoulos-Dvali Model

If gravity propagates in the $4+\delta$ dimensions
 the effective mass scale M_S can be as low as 1TeV
 \Rightarrow Gravitational interactions become comparable
 in strength to electroweak interactions

The contribution of graviton exchange to
 the ep NCDIS \Rightarrow effective CI type coupling:

$$\eta_G = \pm \lambda \cdot \frac{\epsilon^2}{M_S^4}$$

where: λ is the coupling strength
 and ϵ is related to the energy scale
 of hard interaction (\sqrt{s} , Q^2)



95% CL limits on LED
 scale M_S :

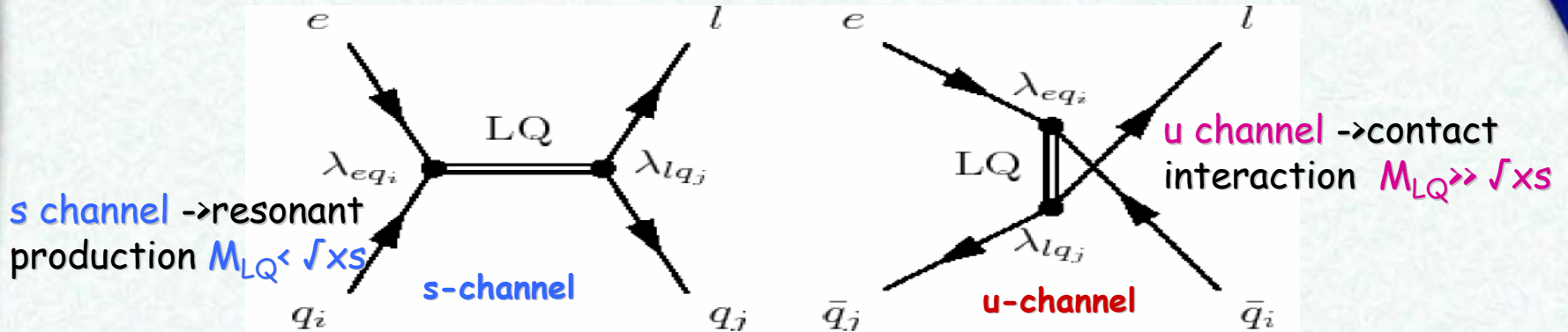
$M_{S+} > 0.88$ TeV

$M_{S-} > 0.90$ TeV

1st generation of Leptoquarks

Scalar or vector color triplet bosons carrying **L** and **B** numbers

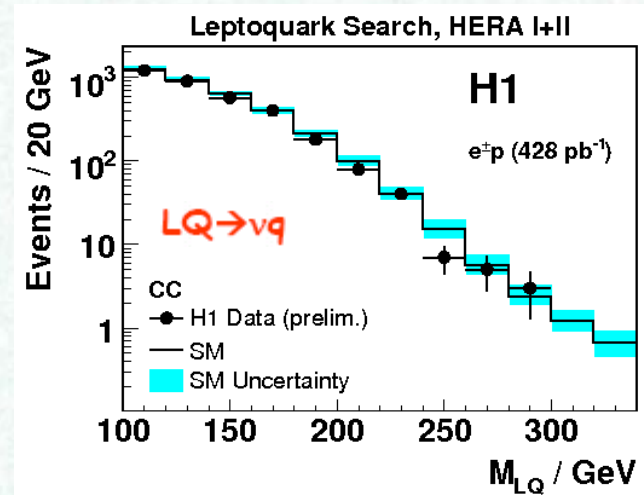
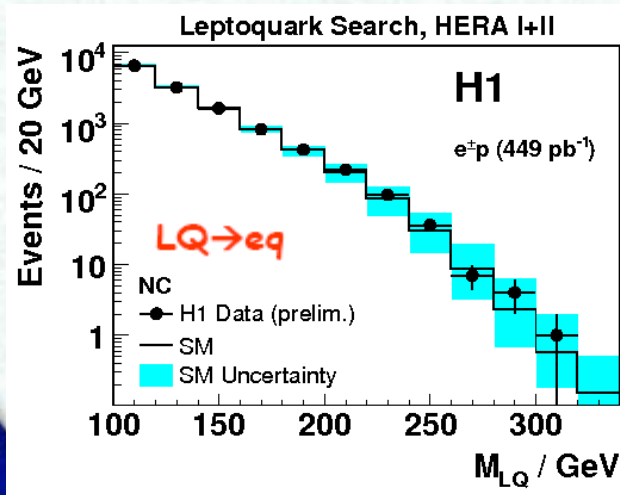
=> Fermion number $F = 3B + L = 0, 2$



Buchmuller-Ruckl-Wyler (BRW) model => 7 scalar and 7 vector LQs:

✓ All 14 LQs => $LQ \rightarrow eq'$

✓ 2 scalar & 2 vector LQ couple to both eq & vq



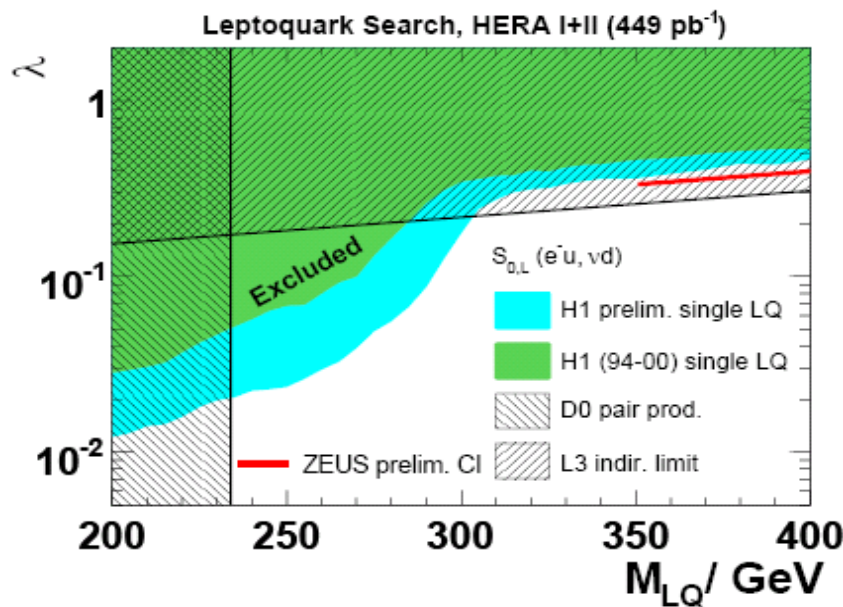
1st generation of Leptoquarks



Limit on LQ Yukawa coupling λ as a function of M_{LQ} :

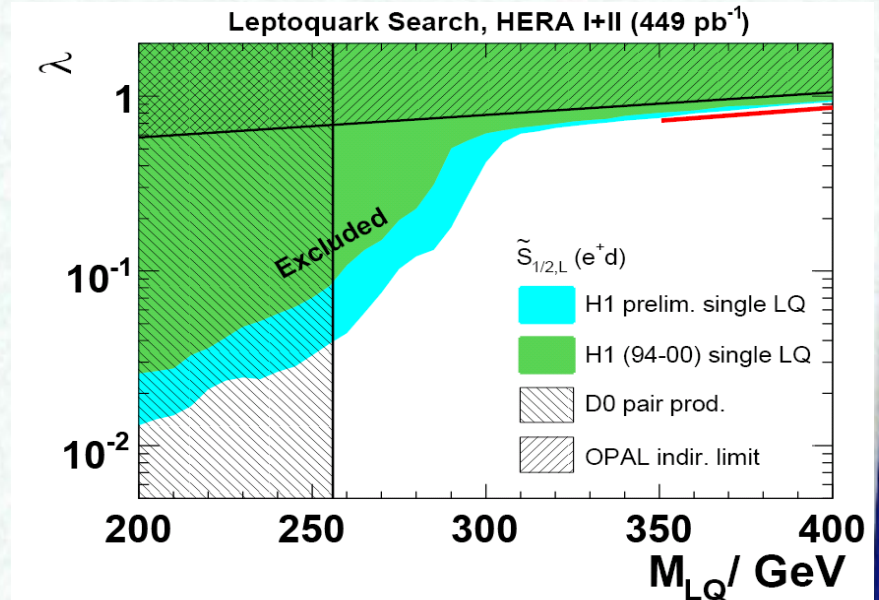
F=2 BRW LQ model

=> e-p data more sensitive than e+p



F=0 BRW LQ model

=> e+p data more sensitive than e-p



For electromagnetic strength $\lambda \approx 0.3$:
 $M_{LQ} < 291\text{-}330 \text{ GeV}$ can be ruled out

Limits comparable to those obtained by LEP and Tevatron 11

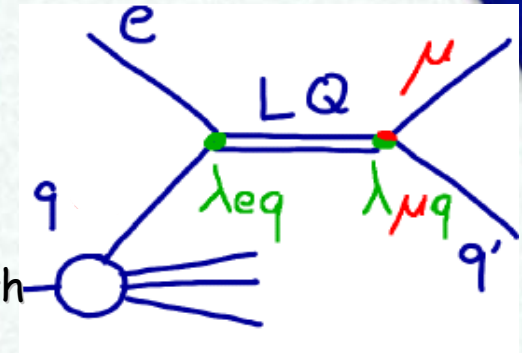
Or..Lepton Flavour Violation

LFV can be mediated by LQ in family non-diagonal models

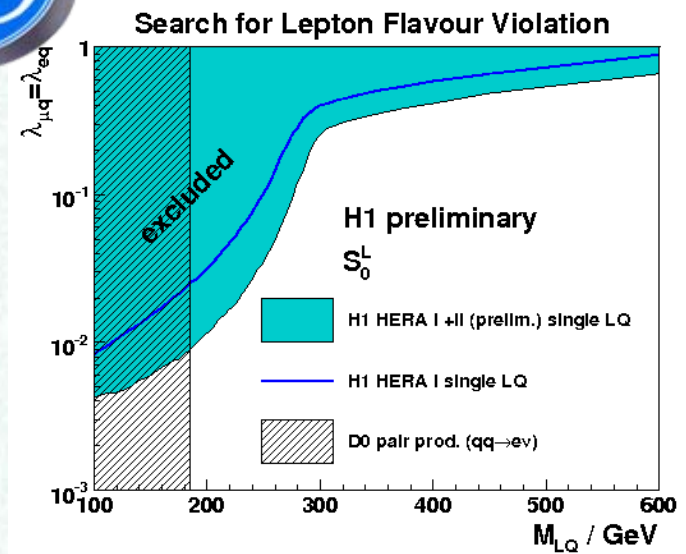
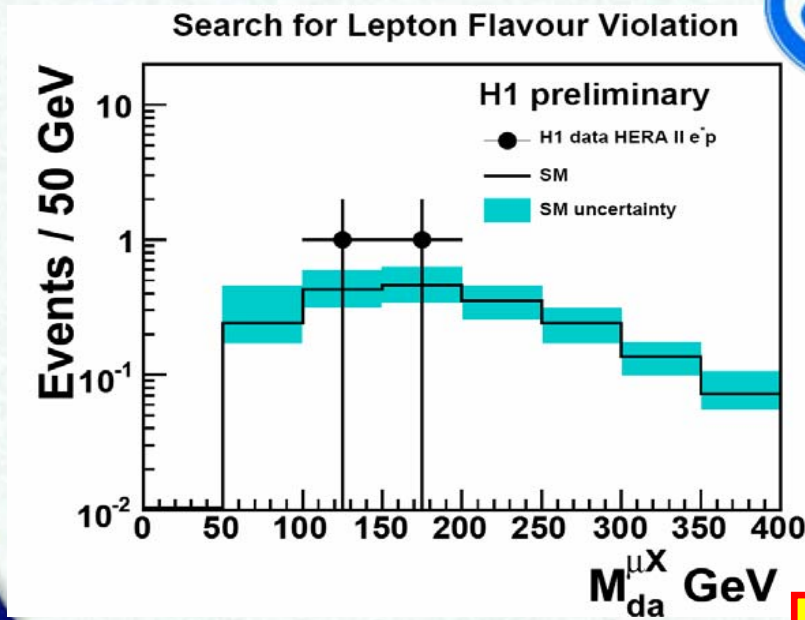
Incoming $e \rightarrow \mu$ or τ in the final state

Process: $e-p \rightarrow \mu-X$ mediated by $F=2$ LQ in $e-p$ data

Signature: isolated muon and jet, back to back in events with high missing P_t



Assumption: $\lambda_{eq} = \lambda_{\mu q}$



For a coupling of $\lambda \approx 0.3$:
 $F=2$ LQs with M_{LQ} up to
433 GeV can be ruled out

Excited Leptons

Gauge mediated model for compositeness of fermions (Hagiwara et al.):

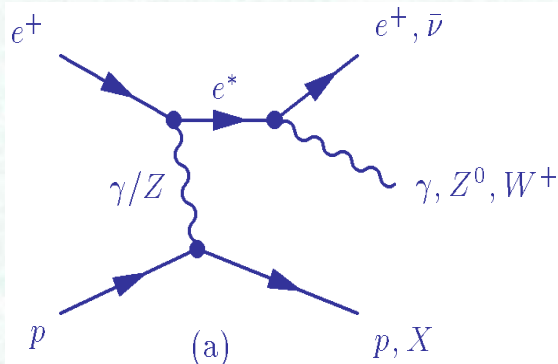
Excited leptons: spin $\frac{1}{2}$, isospin $\frac{1}{2}$ and the same currents as SM leptons

Effective Lagrangian to parameterize compositeness

$$L_{F^*F} = \frac{1}{2\Lambda} \overline{F_R^*} \sigma^{\mu\nu} \left[gf \frac{\tau}{2} \partial_\mu W_\nu + g'f' \frac{Y}{2} \partial_\mu B_\nu \right] F_L + h.c.$$

Λ compositeness scale

f, f' weight factors of the gauge groups (U(1), SU(2))

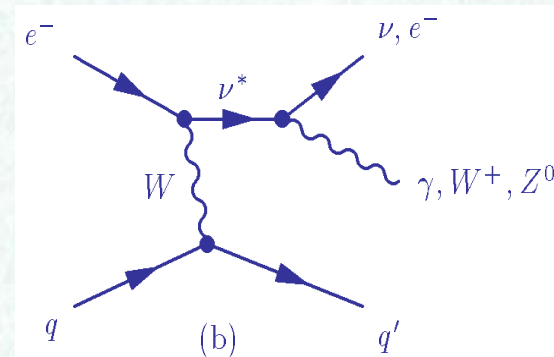


Investigated channels:

$e^* \rightarrow e\gamma$

$e^* \rightarrow eZ$ with $Z \rightarrow qq$

$e^* \rightarrow \nu W$ with $W \rightarrow qq'$



Investigated channels:

$\nu^* \rightarrow \nu\gamma$

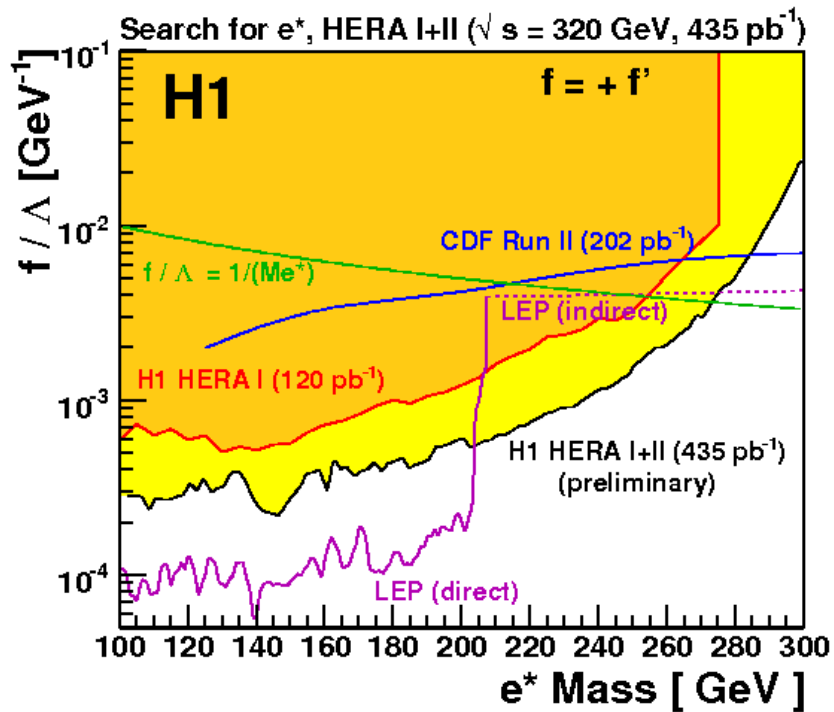
$\nu^* \rightarrow \nu Z$ with $Z \rightarrow qq$

$\nu^* \rightarrow eW$ with $W \rightarrow qq'$

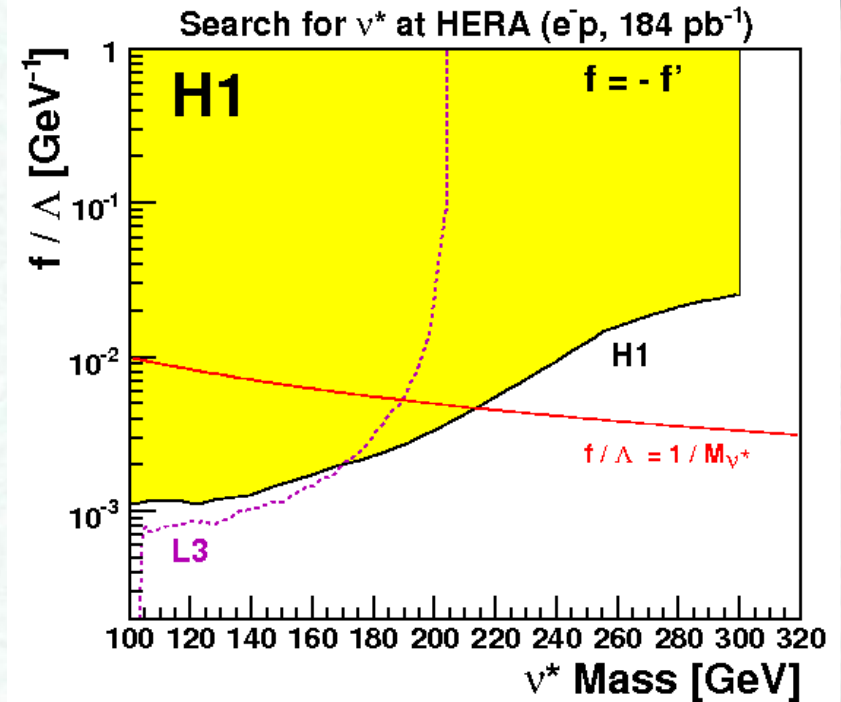
Excited Leptons



Excited electrons



Excited neutrinos

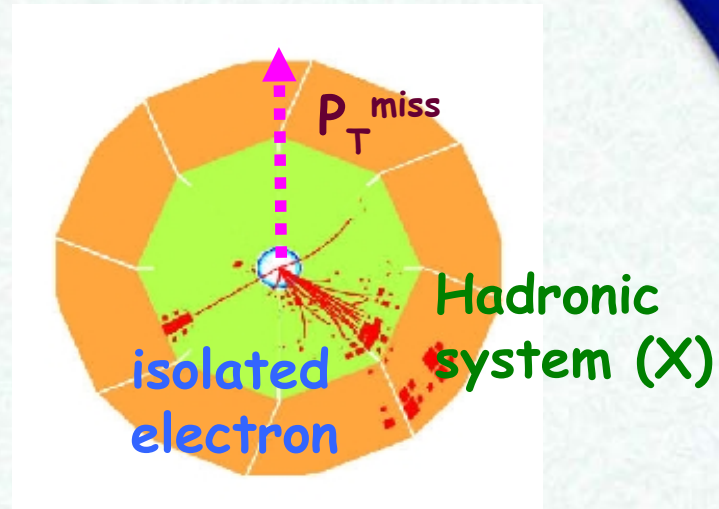
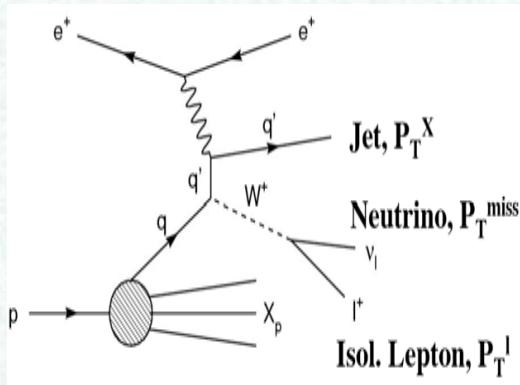


for ν^* , e^-p much more sensitive than e^+p

For $f/\Lambda = 1/M_{P^*}$, 95% upper limits:
 e^* 273 ($f=+f'$), GeV
 ν^* 196 ($f=f'$), 213 ($f=-f'$) GeV

High- P_T leptons with missing P_T

In the SM, isolated leptons are produced by **single W production ($\sigma \sim 1\text{pb}$)**



Signature:

Jet hadronic system with large transverse momentum

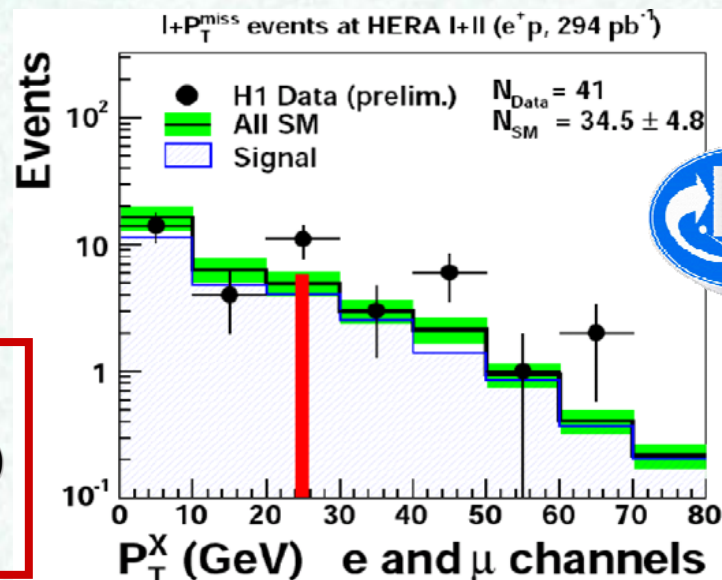
Isolated lepton

Large missing transverse momentum

e+p data: $P_T^X > 25 \text{ GeV}$

H1: 21 events for 9 ± 1.5 expected ($\sim 3\sigma$)

ZEUS: no events in excess of SM



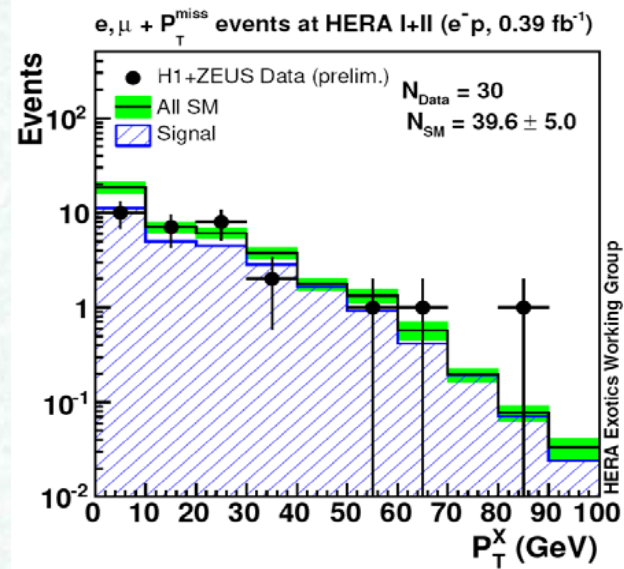
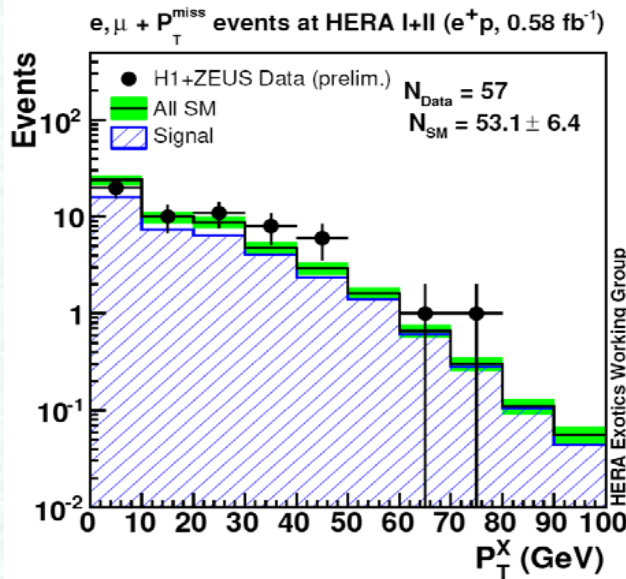
High- P_T leptons with missing P_T



H1 and ZEUS results combined in common phase-space



Total luminosity $L = 0.97 \text{ fb}^{-1}$



Good agreement with the SM

Excess observed in H1 $e+p$ $P_T^X > 25 \text{ GeV}$ sample is reduced ($\sim 1.8 \sigma$)

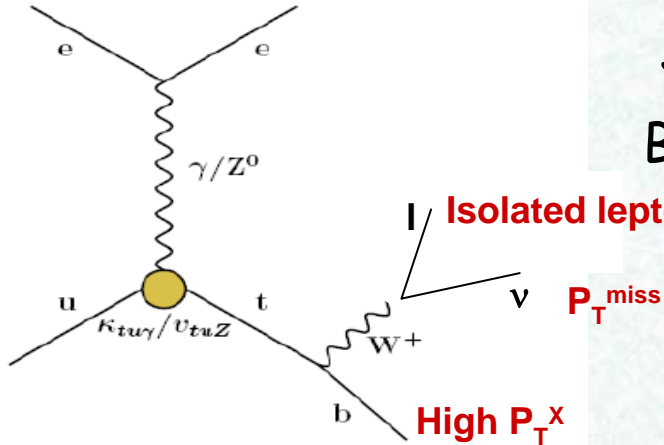
Single W production is observed at HERA

Anomalous Single Top production



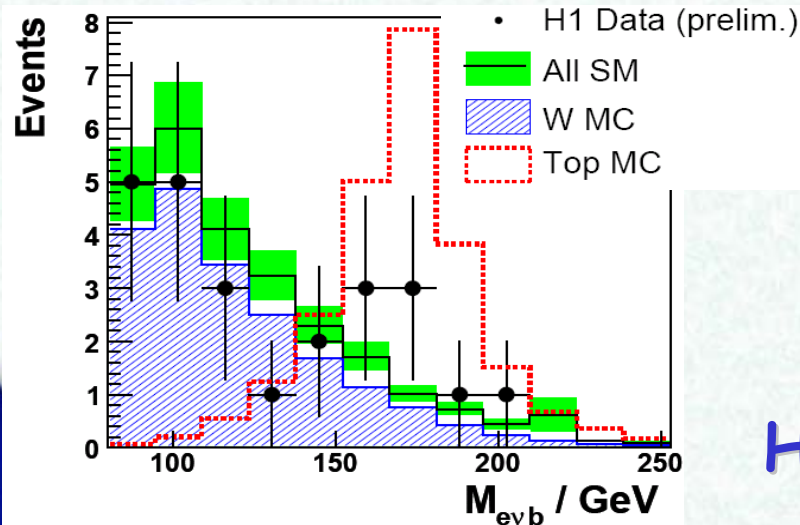
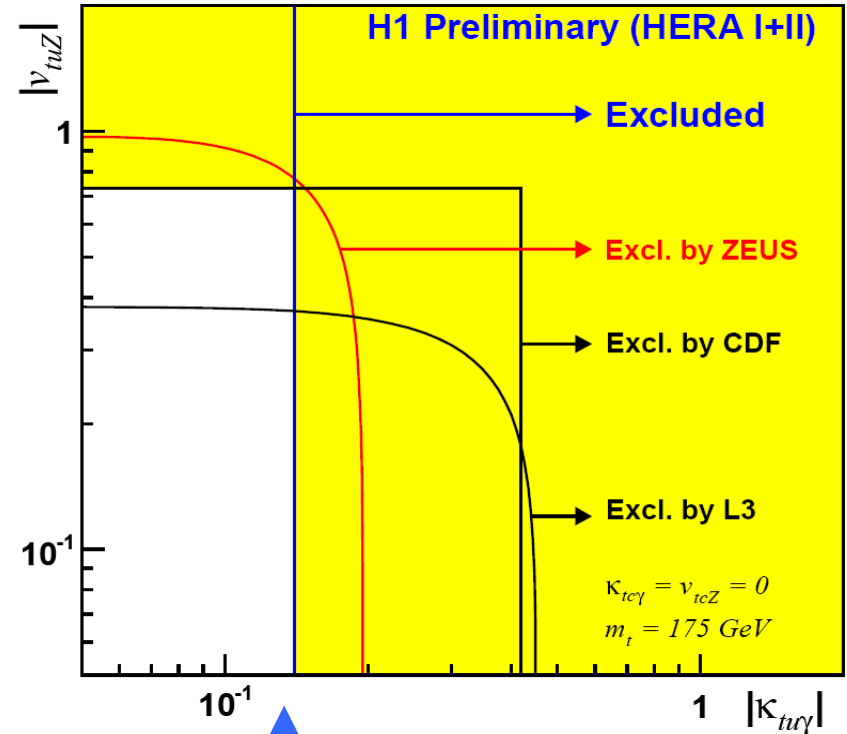
SM: single top production $\sigma < 1 \text{ fb}$

BSM: top production via flavor changing NC



$\kappa_{t\gamma}$: Anomalous γ magnetic coupling

V_{tuZ} : Anomalous Z vector coupling

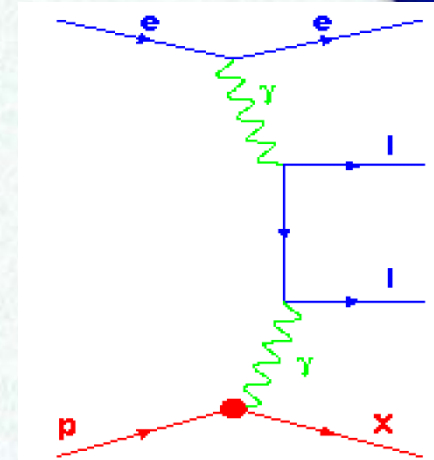


H1: most stringent limit on $\kappa_{t\gamma}$

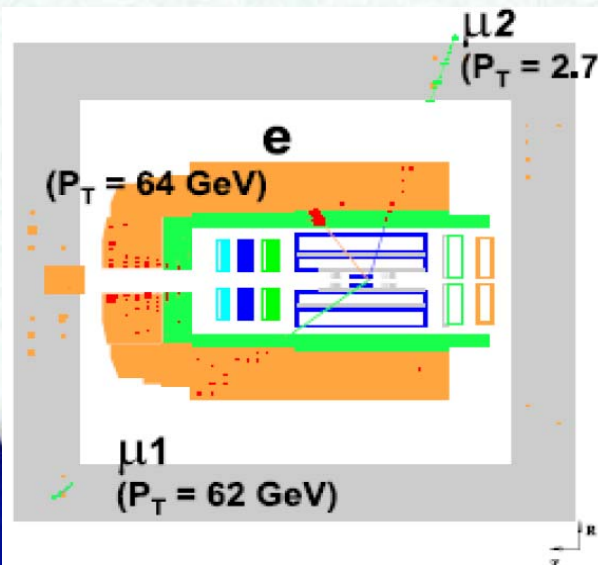
High Pt multi-leptons

Small and very precisely known SM contribution

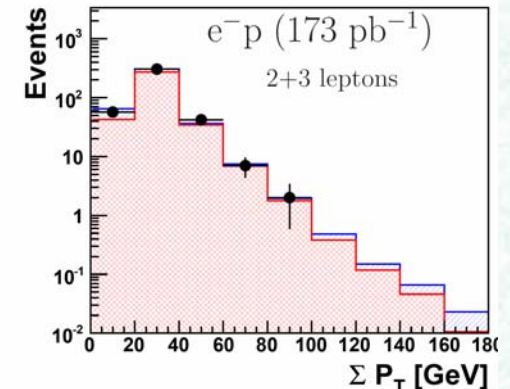
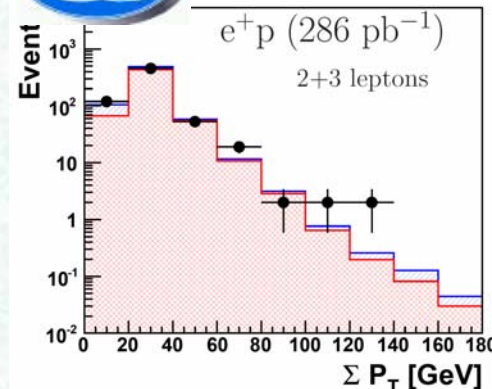
- ✓ Mainly produced via $\gamma\gamma$ in SM
- ✓ Look for events with **at least 2 high-Pt isolated leptons** (e or μ)
- ✓ Topologies: ee , eee , $e\mu$, $\mu\mu$, $e\mu\mu$



Scalar sum of transverse momentum ($L \sim 0.5 \text{ fb}^{-1}$)



H1 Multi-lepton analysis HERA I+II (459 pb^{-1})



H1 e+p data, $\Sigma P_T > 100 \text{ GeV}$:
4 obs. vs. $1.2 \pm 0.2 \text{ exp.}$

- H1 Data (prelim.)
- ▨ DIS+Compton
- ▤ Pair Production

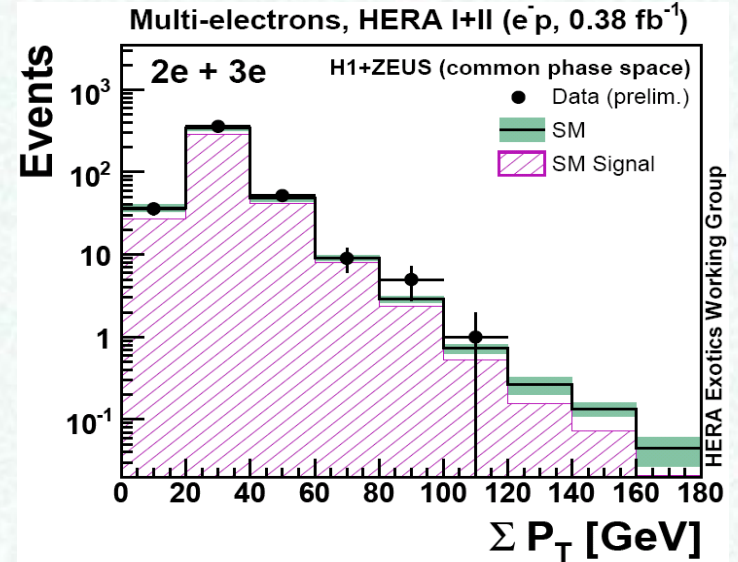
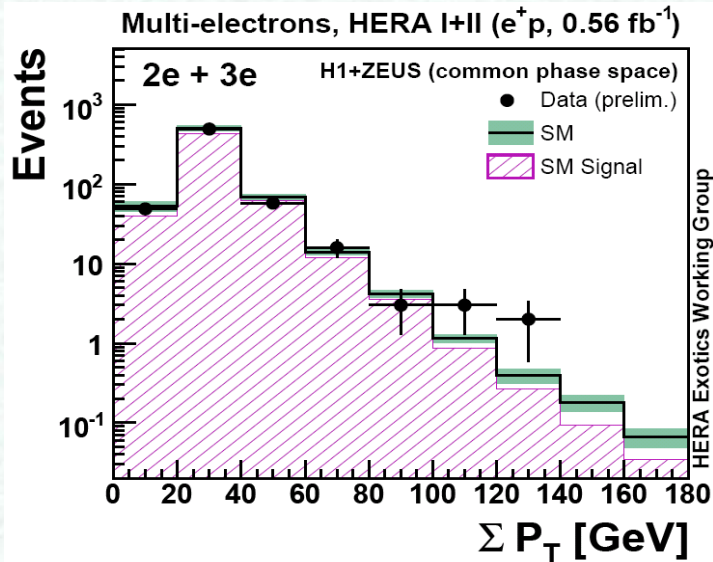
Multi-electrons H1 and ZEUS combined



H1 and ZEUS results combined in common phase-space



Total luminosity $L=0.94 \text{ fb}^{-1}$



$\Sigma P_T > 100 \text{ GeV}$:

High Pt events
mainly in e+p data

Data sample	Data	SM
e^+p (0.56 fb^{-1})	5	1.82 ± 0.21
e^-p (0.38 fb^{-1})	1	1.19 ± 0.14
$e^\pm p$ (0.94 fb^{-1})	6	3.00 ± 0.34

General searches



A model independent search for deviation from the SM prediction

HERA II data ($L=337 \text{ pb}^{-1}$)

HERA I ($L=117 \text{ pb}^{-1}$) published

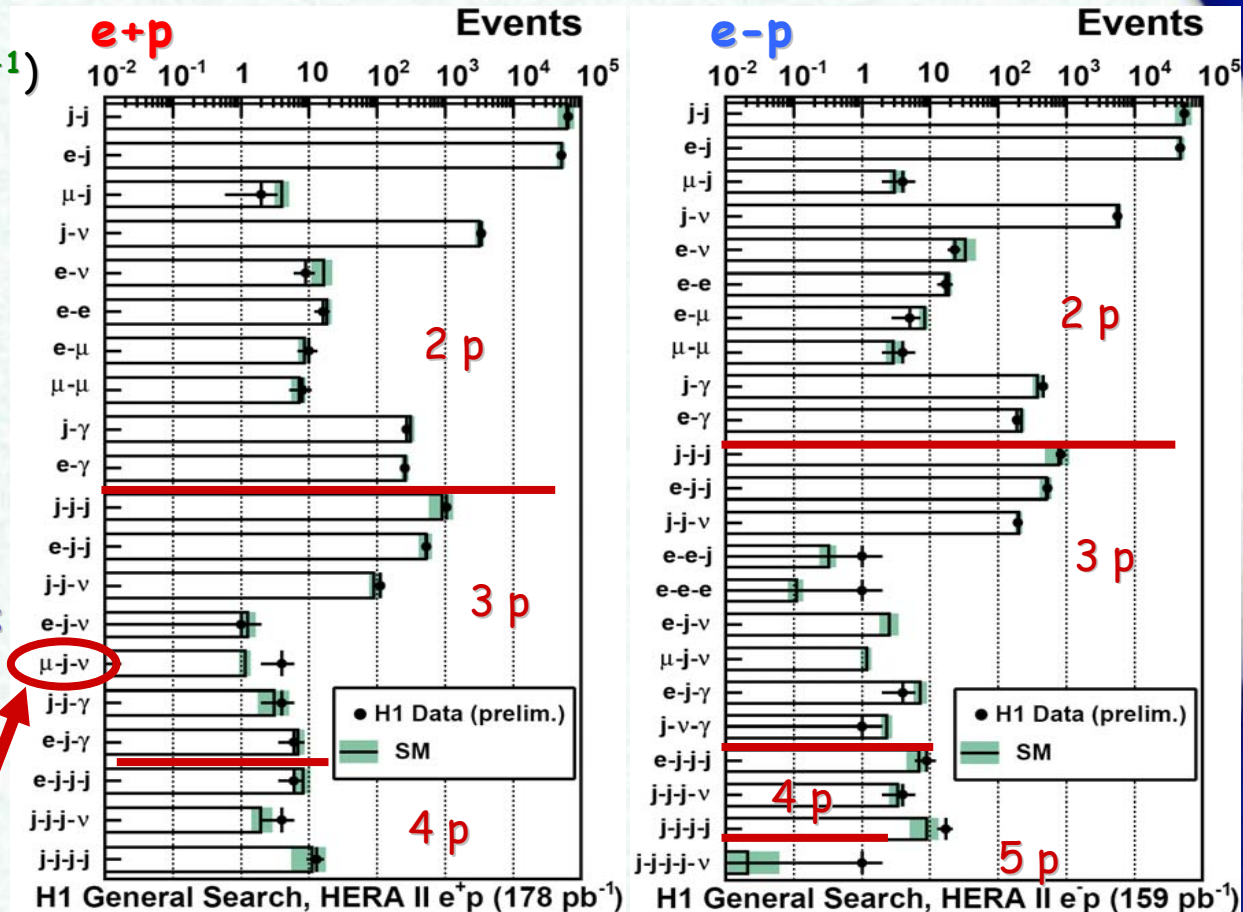
[PLB 602(2004)14]

All topologies with ≥ 2 isolated particle:
 $e, \gamma, \mu, \text{jet}, \nu$

A common phase space:

$P_T > 20 \text{ GeV}$

$10 < \theta < 140 \text{ deg.}$



The largest deviation from SM in μ -j- ν ($e+p$)

Good agreement between data and SM predictions

Summary

- ✓ HERA data taking ended on June 30 2007 after 15 years successful operation:
=>the two experiments combined have collected $\sim 1\text{fb}^{-1}$ data
- ✓ Many analyses use already **full dataset**
- ✓ H1 +ZEUS started to perform **common analyses**
- ✓ Results show no significant deviations from the Standard Model
- ✓ HERA provides strong results in searches beyond SM

Extra-slides

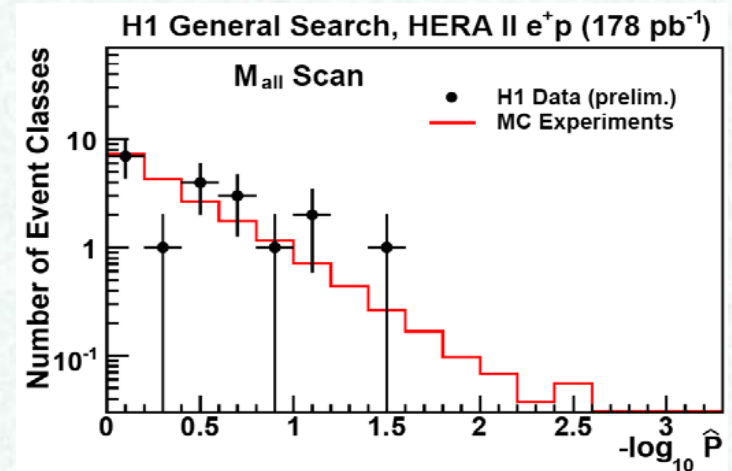
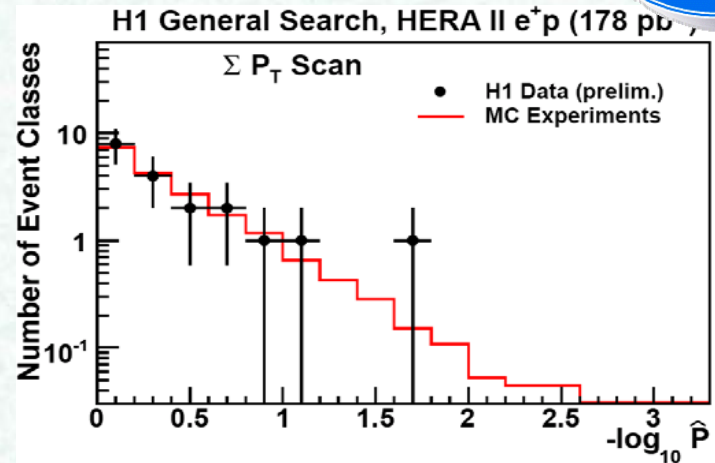
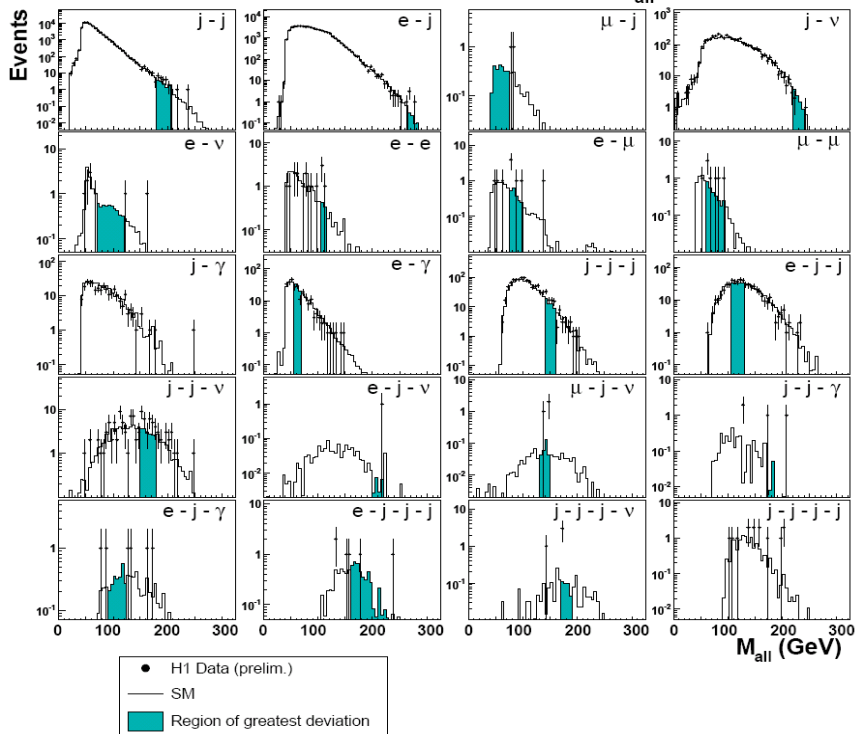
General searches



Agreement to SM quantified by looking for maximum deviation in ΣP_T and M_{all} distributions

=> Statistical analysis to quantify the **significance of deviations (P)**

H1 General Search, HERA II e^+p (178 pb^{-1}) - M_{all} Distributions



Observed fluctuations compatible with the SM prediction

General Models

Coupling structure

Couplings $\eta_{\alpha\beta}^{eq}$ are related to the “new physics” mass scale Λ by the formula:

$$\eta = \frac{\varepsilon \cdot g_{CI}^2}{\Lambda^2}$$

where g_{CI} is the coupling strength of new interactions and $\varepsilon = \pm 1$.

$$g_{CI}^2 = 4\pi$$

Different models assume different helicity structure of new interactions \Rightarrow

Also referred to as **compositeness models** (Λ - compositeness scale)

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}
LL	$+\eta$				$+\eta$			
LR		$+\eta$				$+\eta$		
RL			$+\eta$				$+\eta$	
RR				$+\eta$				$+\eta$
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
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			$+\eta$	$-\eta$			$+\eta$	$-\eta$
U1					$+\eta$	$-\eta$		
U2					$+\eta$		$+\eta$	
U3					$+\eta$			$+\eta$
U4						$+\eta$	$+\eta$	
U5						$+\eta$		$+\eta$
U6							$+\eta$	$-\eta$

Contact Interactions

Cross-section

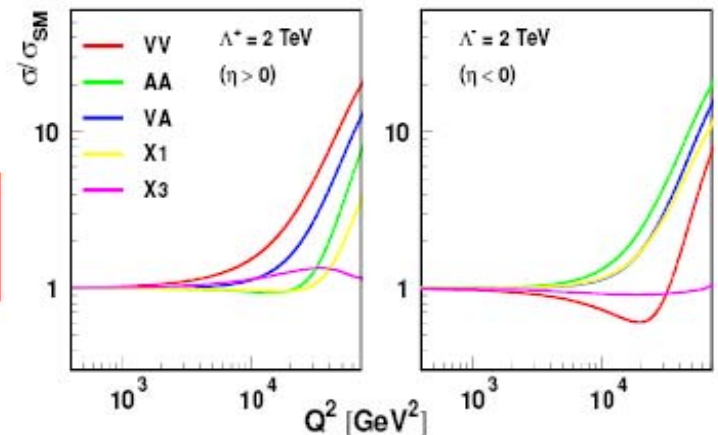
Contact Interactions modify tree level $eq \rightarrow eq$ scattering amplitudes $M_{\alpha\beta}^{eq}$:

$$M_{\alpha\beta}^{eq}(Q^2) = \underbrace{\frac{e^2 e_q}{Q^2}}_{\gamma} - \frac{e^2}{\sin^2\theta_W \cdot \cos^2\theta_W} \cdot \frac{g_{\alpha}^e g_{\beta}^q}{Q^2 + m_Z^2} + \eta_{\alpha\beta}^{eq} \quad ?$$

Resulting contribution to the differential NC DIS cross-section:

$$\frac{d\sigma}{dx dQ^2}(\eta) = \frac{d\sigma^{SM}}{dx dQ^2} \cdot [1 + A(x, Q^2)\eta + B(x, Q^2)\eta^2]$$

General formula for all CI type models



Models

Leptoquarks

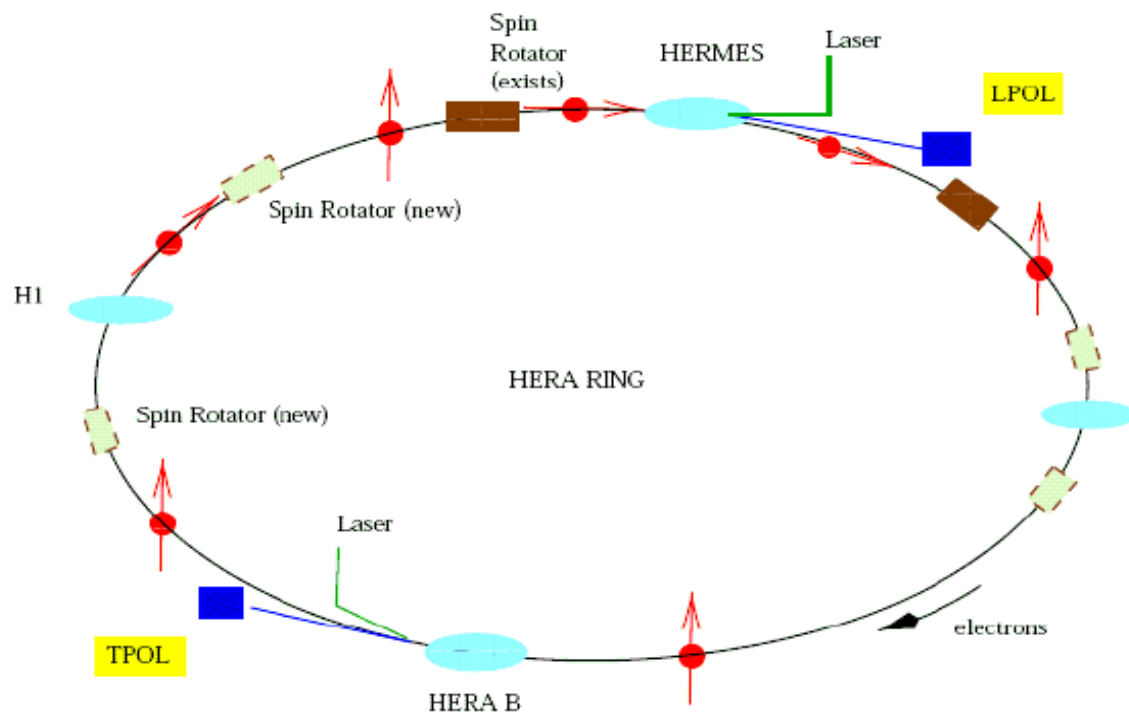
Aachen notation

Model	Fermion number F	Charge Q	$BR(LQ \rightarrow e^\pm q)$ β	Coupling	Squark type
S_0^L	2	-1/3	1/2	$e_{LU} \quad \nu d$	\tilde{d}_R
S_0^R	2	-1/3	1	e_{RU}	
\tilde{S}_0	2	-4/3	1	e_{RD}	
$S_{1/2}^L$	0	-5/3	1	$e_{L\bar{u}}$	
		-2/3	0		$\nu\bar{u}$
$S_{1/2}^R$	0	-5/3	1	$e_{R\bar{u}}$	
		-2/3	1	$e_{R\bar{d}}$	
$\tilde{S}_{1/2}$	0	-2/3	1	$e_{L\bar{d}}$	$\overline{\tilde{u}_L}$
		+1/3	0		$\overline{\tilde{d}_L}$
S_1	2	-4/3	1	e_{Ld}	
		-1/3	1/2	e_{LU}	νd
		+2/3	0		νu
V_0^L	0	-2/3	1/2	$e_{L\bar{d}}$	$\nu\bar{u}$
V_0^R	0	-2/3	1	$e_{R\bar{d}}$	
\tilde{V}_0	0	-5/3	1	$e_{R\bar{u}}$	
$V_{1/2}^L$	2	-4/3	1	e_{Ld}	
		-1/3	0		νd
$V_{1/2}^R$	2	-4/3	1	e_{Rd}	
		-1/3	1	e_{RU}	
$\tilde{V}_{1/2}$	2	-1/3	1	e_{LU}	
		+2/3	0		νu
V_1	0	-5/3	1	$e_{L\bar{u}}$	
		-2/3	1/2	$e_{L\bar{d}}$	$\nu\bar{u}$
		+1/3	0		$\nu\bar{d}$

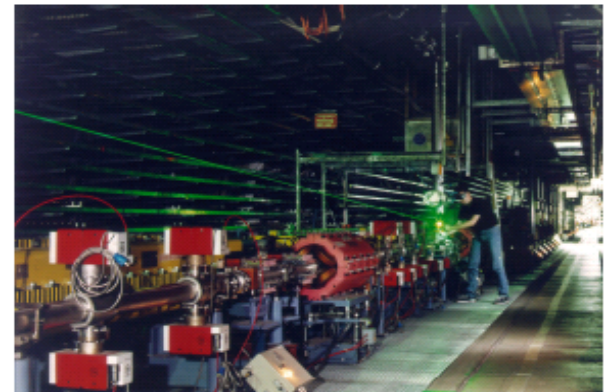
Polarized e^\pm

e beam acquires transverse polarization by the Sokolov-Ternov effect (magnetic moment couples to the dipole B field, spin flip by synchrotron radiation emission).

Spin rotators provide longitudinal polarization at the experiments (Hermes since 1995, H1 and ZEUS since 2003).



- Polarization typically 30-40%.
- Polarization monitored by Compton backscattering of laser beams.



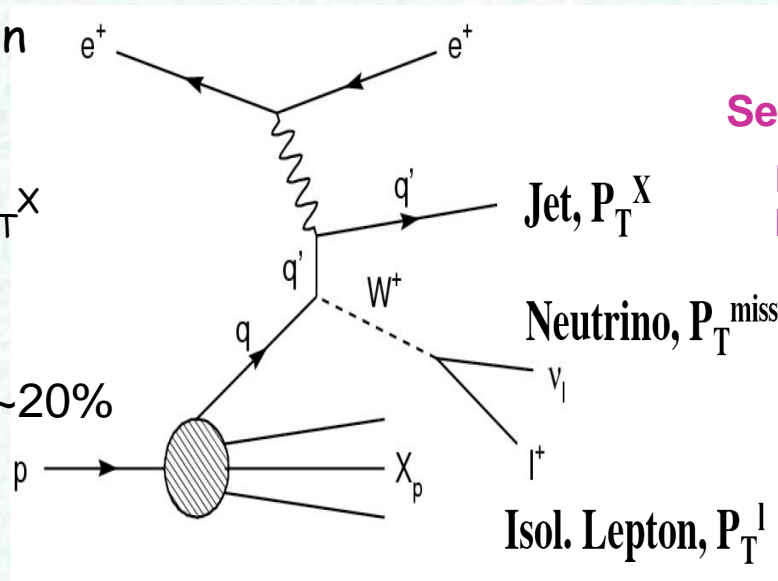
Standard Model prediction

Real W production in photoproduction
with W decay into leptons
main process for this event topology
Hadronic system with typically low p_T^X

$\sigma_W \sim 1.3 \text{ pb}^{-1}$
W decay branching ratio into e or $\mu \sim 20\%$

Other signal processes:
CC W production $\sim 7\%$
Cabbibo-Parisi Z0 production $\sim 3\%$ (only e channel)

Modeled using EPVEC generator with NLO QCD correction:
Modifies cross section by $\sim 10\%$, reduces theoretical uncertainty to $\sim 15\%$



Selection cuts

For μ only:
 $P_T^X > 12 \text{ GeV}$

$> 12 \text{ GeV}$

$\text{Isol. Lepton}, P_T^l > 10 \text{ GeV}$

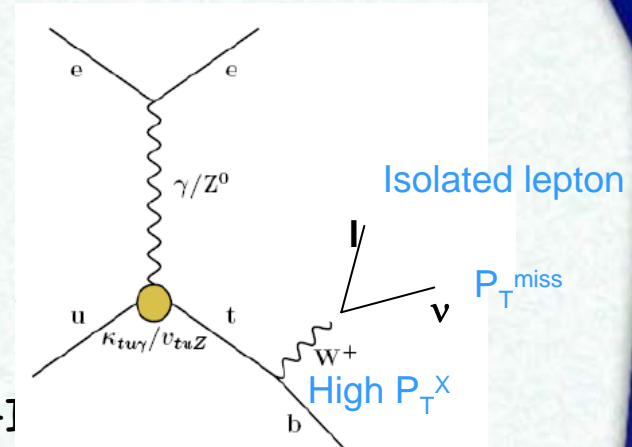
Anomalous single top production

SM single top production $\sigma < 1 \text{ fb}^{-1}$

Top production via **flavor changing NC** in BSM

Candidate process for excess

But: same rate for e^+ and e^-

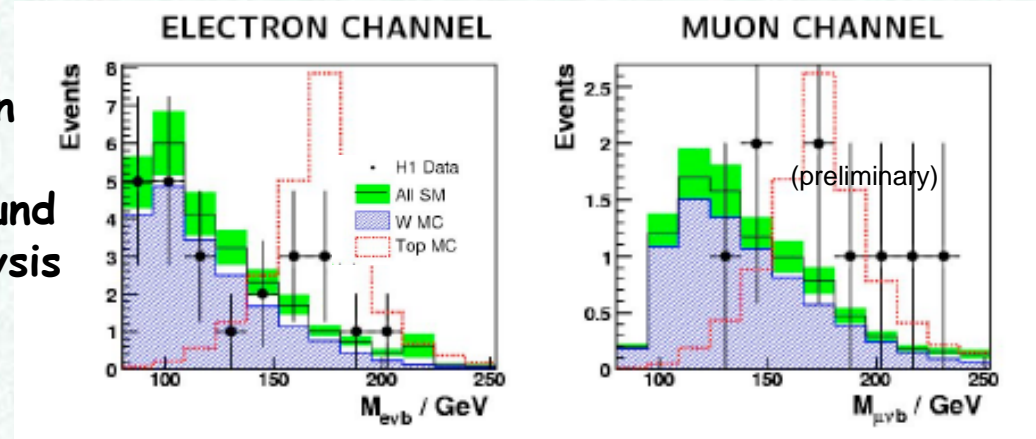


Search for FCNC based on isolated lepton events of HERAI+]
 additional good top quark reconstruction and positive lepton
 charge requirement (if possible)

$\kappa_{tu\gamma}$: Anomalous γ magnetic coupling
 V_{tuZ} : Anomalous Z vector coupling

24 events selected,
 26 events SM prediction

No significant signal found
 using multi variant analysis



Single top results

Limits on FCNC cross section derived using maximum likelihood:

$$\sigma(ep \rightarrow etX) < 0.16 \text{ (95\% CL)}$$

HERA 1 results:

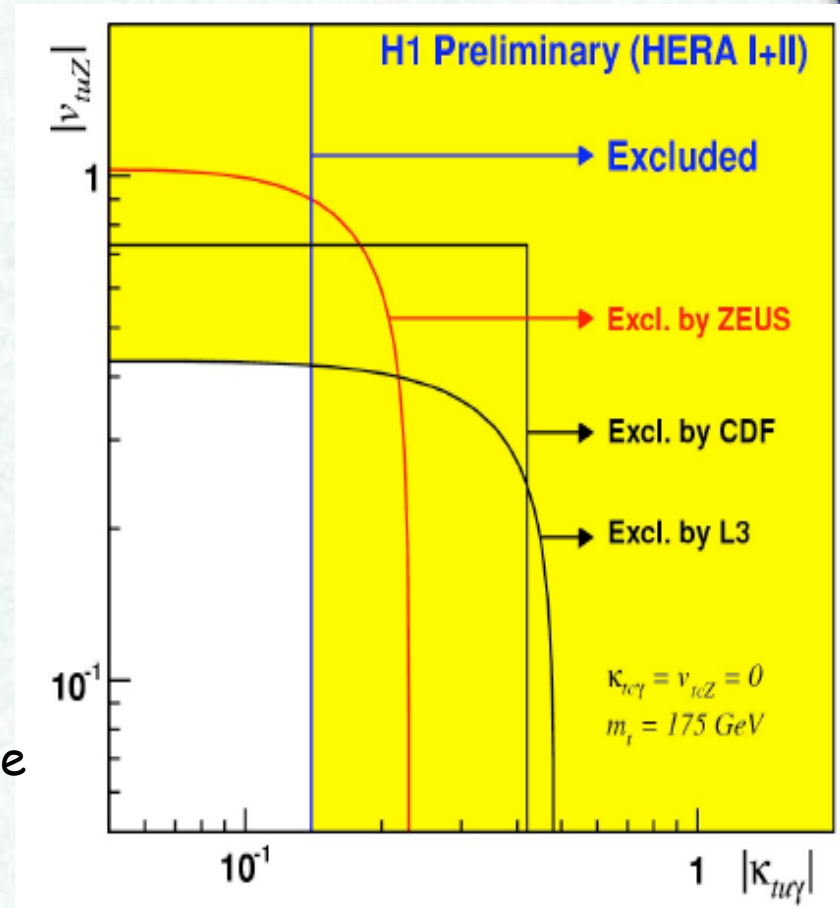
$$\text{H1: } \sigma(ep \rightarrow etx) < 0.55 \text{ pb}$$

$$\text{Zeus: } \sigma(ep \rightarrow etX) < 0.23 \text{ pb}$$

Upper bound on the anomalous coupling:

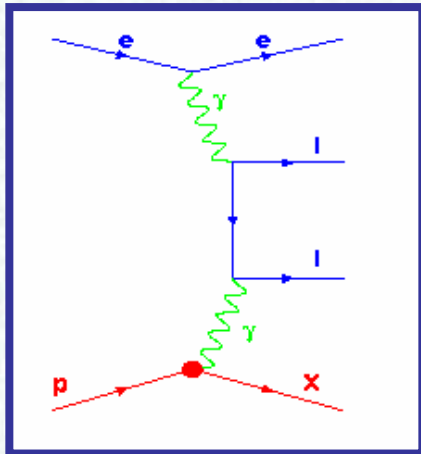
$$k_{\tau\nu\gamma} < 0.14$$

New limit extends into region of phase space uncovered by other colliders

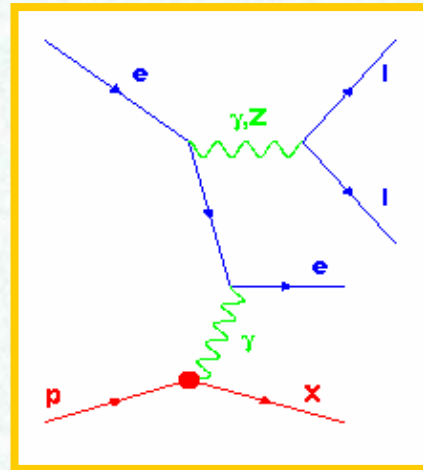


Multi-lepton events at HERA

How are lepton pairs produced ?

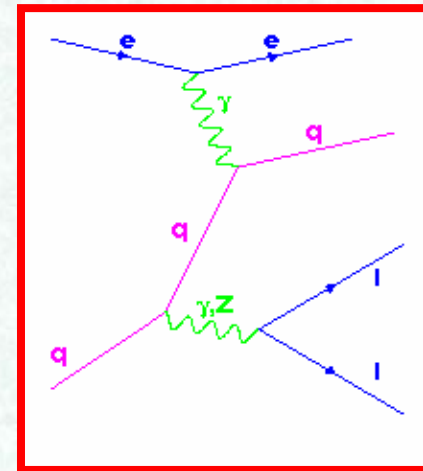


$\gamma\gamma$ process dominant



Cabbibo-Parisi

- $ee \rightarrow ee$ annihilation & Scattering
- $ee \rightarrow \mu\mu$ annihilation



Drell-Yan negligible

Multi-lepton production is a QED process

-very well understood in the Standard Model

Any excess over SM prediction at high mass region is sensitive to new phenomena (e.g. $H^{\pm\pm}$)

Multi-lepton events at high mass

Selection:

- Look for events with **at least 2 high Pt leptons**:
- $P_{\tau}^{l1} > 10$ and $P_{\tau}^{l2} > 5$ GeV and $20^{\circ} < \theta_l < 150^{\circ}$
- Additional lepton: $E_e > 5$ GeV or $P_{\tau}^{\mu} > 2$ GeV ($5^{\circ} < \theta_l < 175^{\circ}$)
- Covered topologies:
 - * **H1**: $ee, e\mu, \mu\mu$ and $eee, e\mu\mu$
 - * **ZEUS**: ee, eee

Dominant background:

- **NC DIS**: DIS e + fake electron
- **QED Compton**: γ misidentified as e

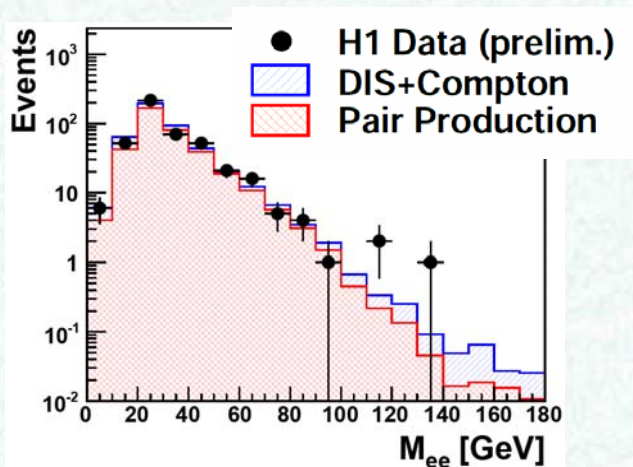
Invariant mass M_{ll} :

- Reconstructed using **2 highest Pt leptons**

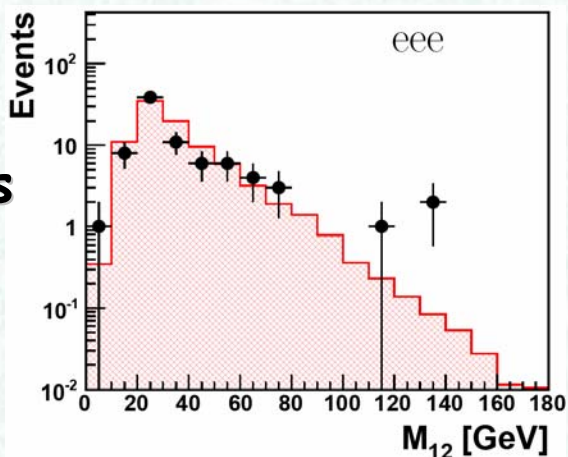
Multi-electron mass

H1: $L = 459 \text{ pb}^{-1}$

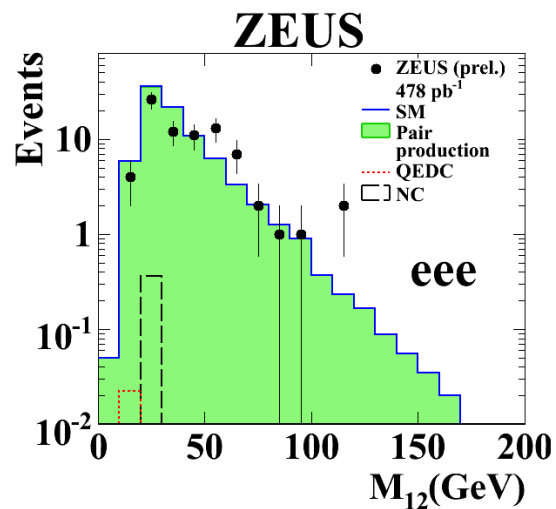
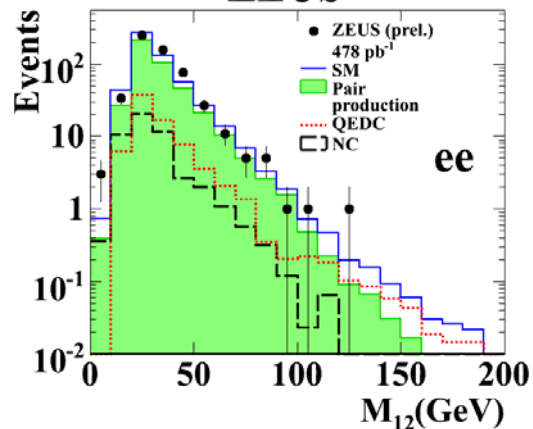
ee events



eee events



ZEUS: $L = 478 \text{ pb}^{-1}$

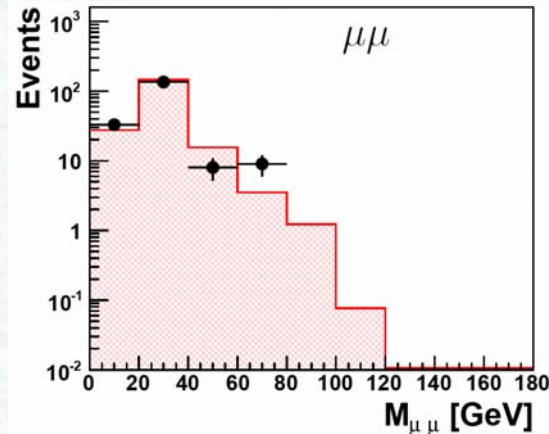
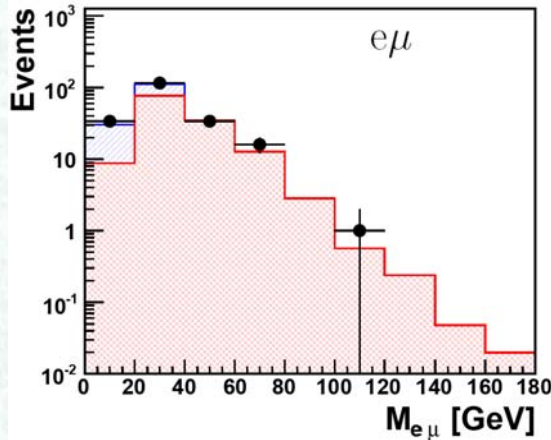


Overall good agreement with the Standard Model

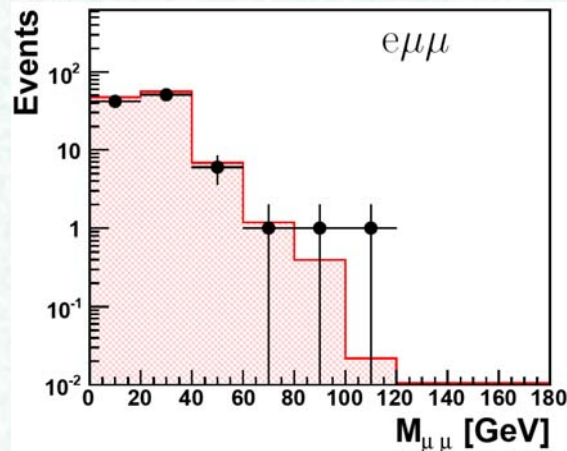
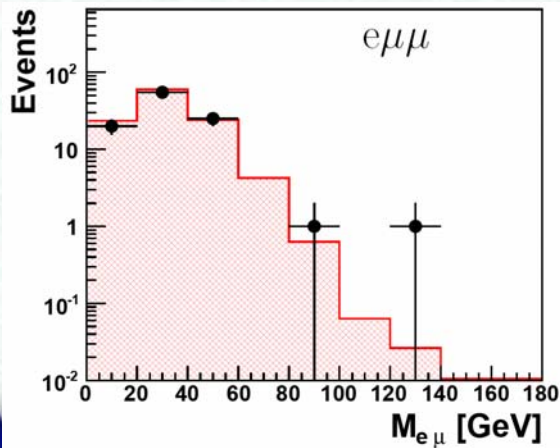
Topologies with $\mu(s)$

H1: $L = 459 \text{ pb}^{-1}$

- H1 Data (prelim.)
- ▨ DIS+Compton
- ▨ Pair Production



Di-lepton topology



Tri-lepton topology

Overall good agreement with the Standard Model

Event yields at high $M_{ll} > 100$ GeV

H1 Preliminary: $L = 459 \text{ pb}^{-1}$

	Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (286 pb^{-1})					
e^+p	$ee M_{12} > 100 \text{ GeV}$	3	1.0 ± 0.2	0.6 ± 0.2	0.4 ± 0.1
	$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.06 ± 0.03	0.06 ± 0.03	—
	$e\mu M_{e\mu} > 100 \text{ GeV}$	1	0.53 ± 0.05	0.53 ± 0.05	—
	$eee M_{12} > 100 \text{ GeV}$	3	0.6 ± 0.1	0.6 ± 0.1	—
	$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	1	0.04 ± 0.02	0.04 ± 0.02	—
	$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	1	0.007 ± 0.005	0.007 ± 0.005	—
e^-p collisions (173 pb^{-1})					
e^-p	$ee M_{12} > 100 \text{ GeV}$	0	0.55 ± 0.1	0.3 ± 0.1	0.25 ± 0.07
	$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.03 ± 0.02	0.03 ± 0.02	—
	$e\mu M_{e\mu} > 100 \text{ GeV}$	0	0.3 ± 0.05	0.3 ± 0.05	—
	$eee M_{12} > 100 \text{ GeV}$	0	0.32 ± 0.06	0.32 ± 0.06	—
	$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	0	0.04 ± 0.01	0.04 ± 0.01	—
	$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.006 ± 0.004	0.006 ± 0.004	—

All high mass events
 $M_{ll} > 100 \text{ GeV}$ from
 e^+p data

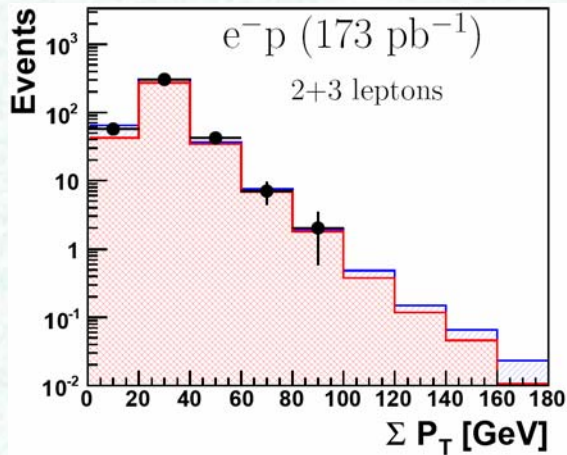
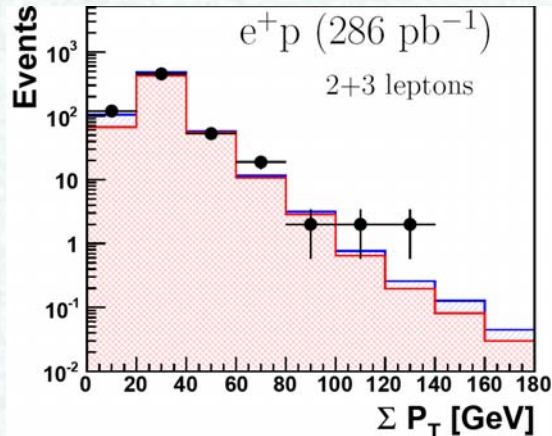
ZEUS Preliminary: $L = 478 \text{ pb}^{-1}$

e^+p ($L = 272 \text{ pb}^{-1}$) e^-p ($L = 206 \text{ pb}^{-1}$)

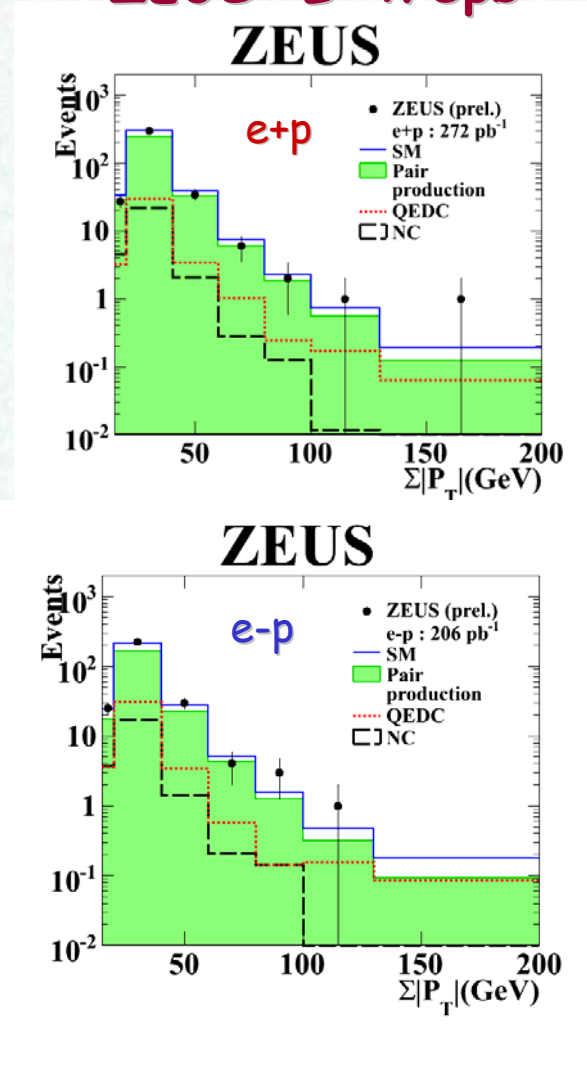
	Data sample	Data	SM	Pair Production	Compton	NC DIS
e^+p	ee	1	0.9 ± 0.1	0.5 ± 0.07	0.4 ± 0.12	0.07 ± 0.03
	eee	2	$0.6^{+0.5}_{-0.07}$	0.6 ± 0.07	< 0.01	< 0.5
e^-p	ee	1	0.8 ± 0.08	0.4 ± 0.04	0.4 ± 0.1	0.04 ± 0.01
	eee	0	$0.4^{+0.5}_{-0.05}$	0.4 ± 0.05	< 0.01	< 0.5

Multi-leptons: scalar ΣP_T distribution

H1: $L = 459 \text{ pb}^{-1}$



ZEUS: $L = 478 \text{ pb}^{-1}$



Good agreement with SM

Event yields at scalar $\Sigma P_t > 100 \text{ GeV}$

H1 Preliminary: $L = 459 \text{ pb}^{-1}$ Multileptons: electrons and muons

Data sample	Data	SM	Pair Production	NCDIS + Compton
e+p L=286pb	4	1.2 ± 0.2	1.0 ± 0.2	0.2 ± 0.1
e-p L=173pb	0	0.8 ± 0.2	0.6 ± 0.2	0.2 ± 0.1
All L=459pb	4	1.9 ± 0.4	1.5 ± 0.3	0.4 ± 0.1

H1: All events at high ΣP_t come from e+p data

ZEUS Preliminary: $L = 478 \text{ pb}^{-1}$ Multileptons: electrons only

Data sample	Data	SM	Pair Production	Compton	NC DIS
e+p L=272pb	2	$0.95^{+0.10}_{-0.09}$	0.67 ± 0.07	$0.26^{+0.07}_{-0.06}$	0.02 ± 0.01
e-p L=206pb	1	$0.68^{+0.08}_{-0.07}$	0.41 ± 0.04	$0.27^{+0.07}_{-0.06}$	0.01 ± 0.01
All L=478pb	3	$1.63^{+0.16}_{-0.12}$	1.08 ± 0.11	$0.53^{+0.15}_{-0.11}$	0.03 ± 0.01

Search for doubly charged Higgs

In extension to SM:

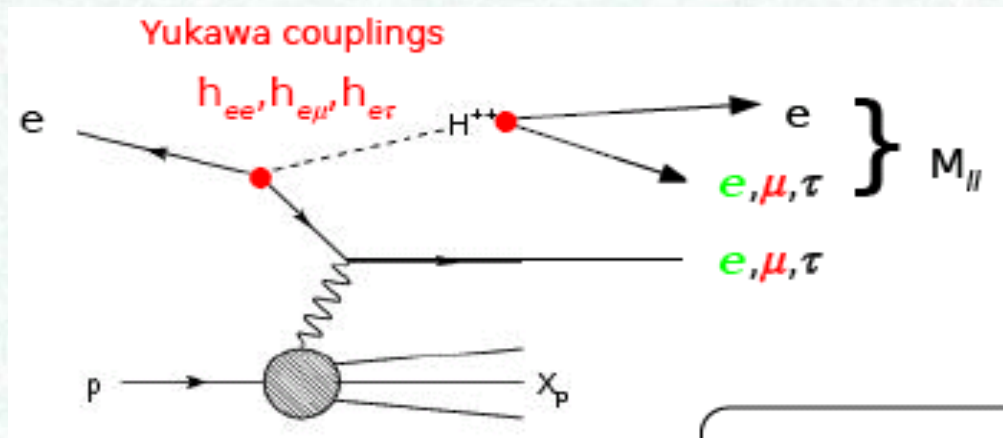
- $H^{\pm\pm}$ appears in Higgs triplet(s) of non-zero hypercharge
- Left-right symmetries: $SU(2)_R \times SU(2)_L \times U(1)_{B-L}$
- provides mass to Majorana neutrinos
- Couplings to leptons $h_{ll}^{R,L}$ unknown

Democratic scenario: $h_{ee} = h_{e\mu} = h_{e\tau}$

One dominant coupling $h_{e_l} \gg 0$, others ~ 0

HERA: $e^\pm p \rightarrow l^\pm H^{\pm\pm} X$

where $H^{\pm\pm} \rightarrow e^\pm l^\pm$



Double charged Higgs

Selection:

- ✓ Data: HERA-I $L=118 \text{ pb}^{-1}$
- ✓ ee , $e\mu$: based on multi-lepton analysis
- ✓ $e\tau$ with $\tau \rightarrow e, \mu$ and hadrons
- ✓ 2 high-Pt leptons with the same charge as a beam lepton
- ✓ Reconstruct inv. mass Higgs candidates - $M_{H^{\pm\pm}}$

Results:

$M_{H^{\pm\pm}} > 65 \text{ GeV}$

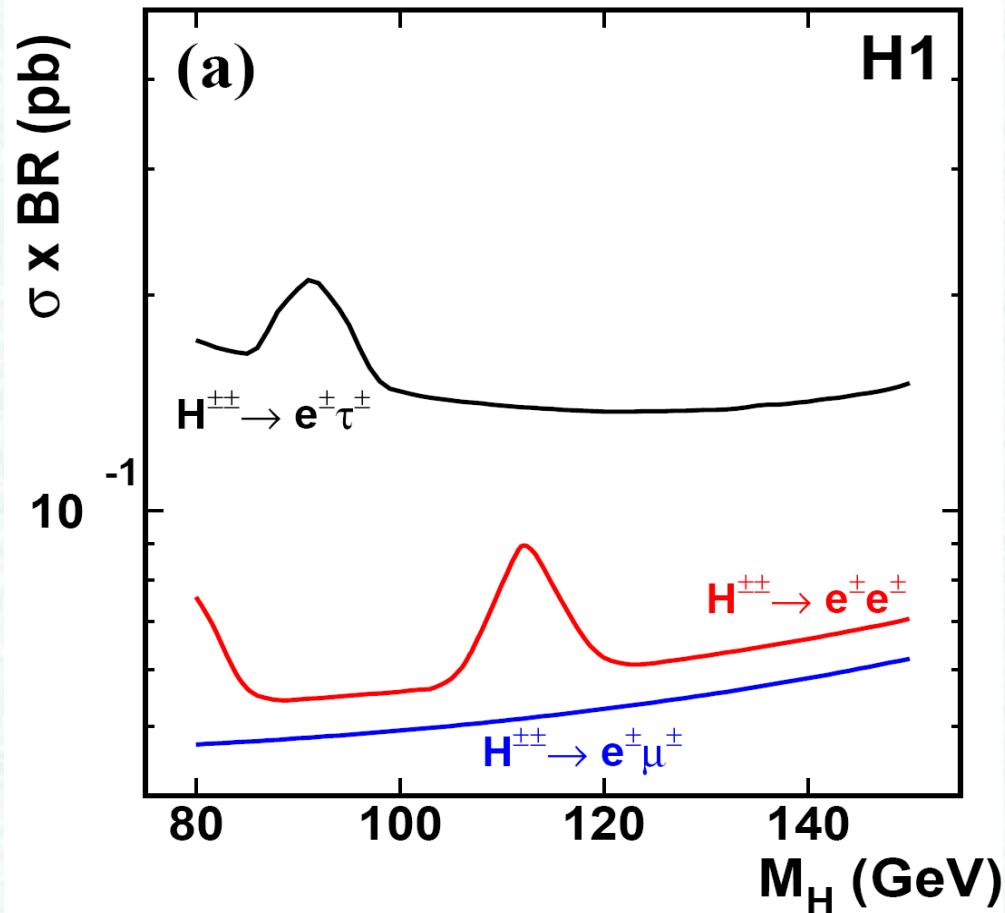
	Obs	SM exp.
ee	3	2.45 ± 0.11
$e\mu$	1	4.17 ± 0.44
$e\tau$	1	2.1 ± 0.5

$M_{H^{\pm\pm}} > 100 \text{ GeV}$

Only one ee event satisfies
the final selection criteria

No evidence for $H^{\pm\pm} \Rightarrow$ set limits

Double charged Higgs: results



Upper limits for H^{++} production at 95% C.L. derived by modified frequentist method

$$H^{++} \rightarrow e^+ \tau^+$$

$$H^{++} \rightarrow e^+ e^+$$

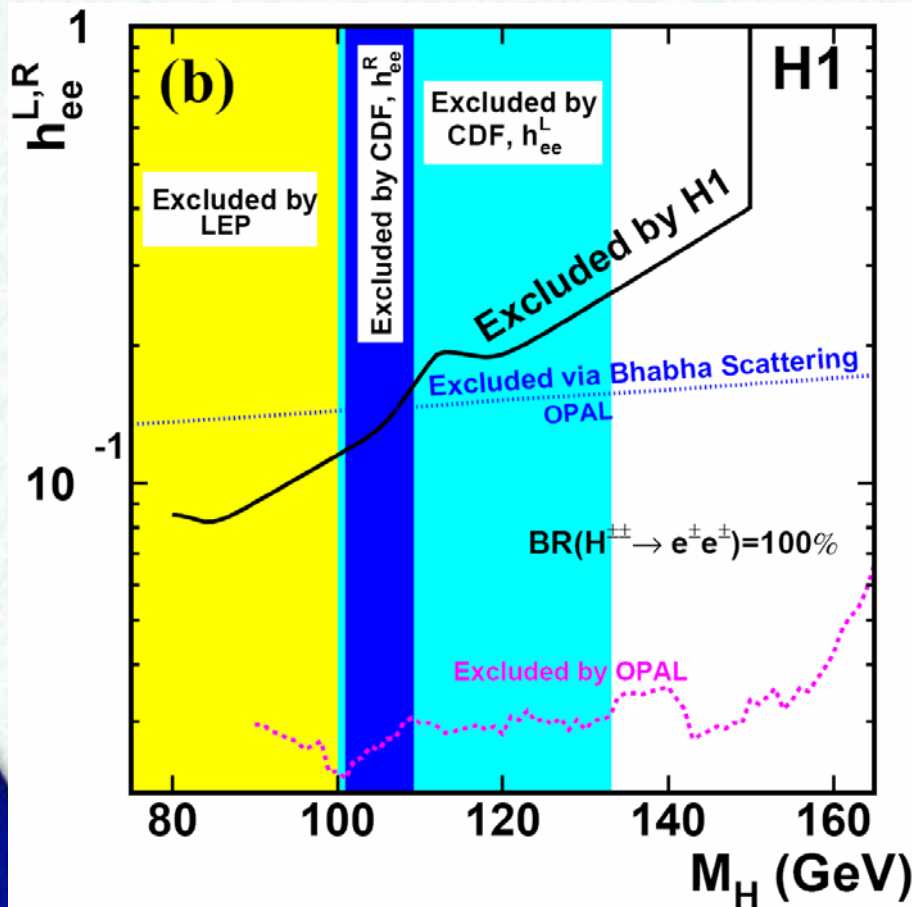
$$H^{++} \rightarrow e^+ \mu^+$$

Best sensitivity:
 $\sigma \times \text{Br}(h_{e\mu}) < 0.05 \text{ pb}$

Double charged Higgs: upper limits on h_{ee}

$H^{\pm\pm}$ boson couples to **electron-electron pair** only

Topologies: ee and eee (excess was observed in HERA I data)



LEP, TeVatron:

- $H^{\pm\pm}$ Pair Production: h_{ei} independent

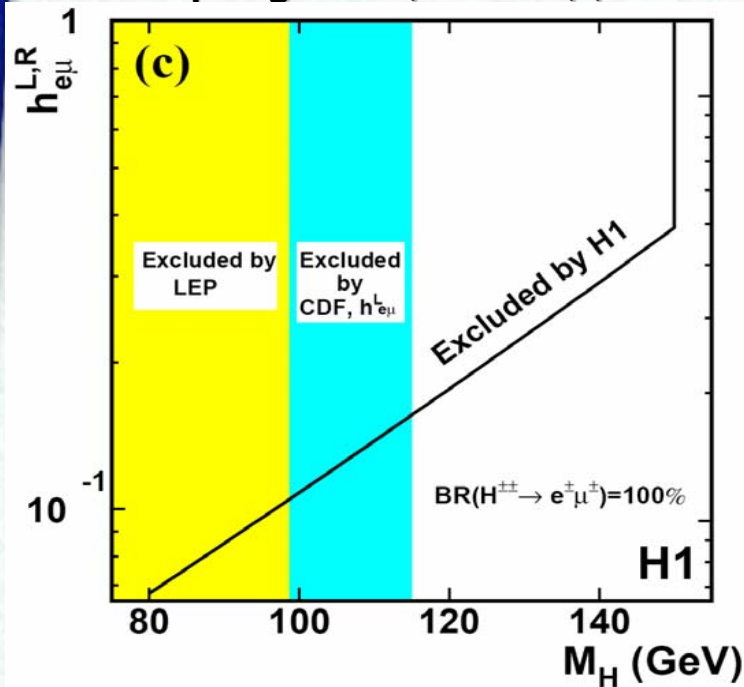
OPAL:

- $H^{\pm\pm}$ single production

Limits are set for left- and right-handed h_{ee} couplings

Doubly charged Higgs: upper limits on $h_{e\mu}$ and $h_{e\tau}$

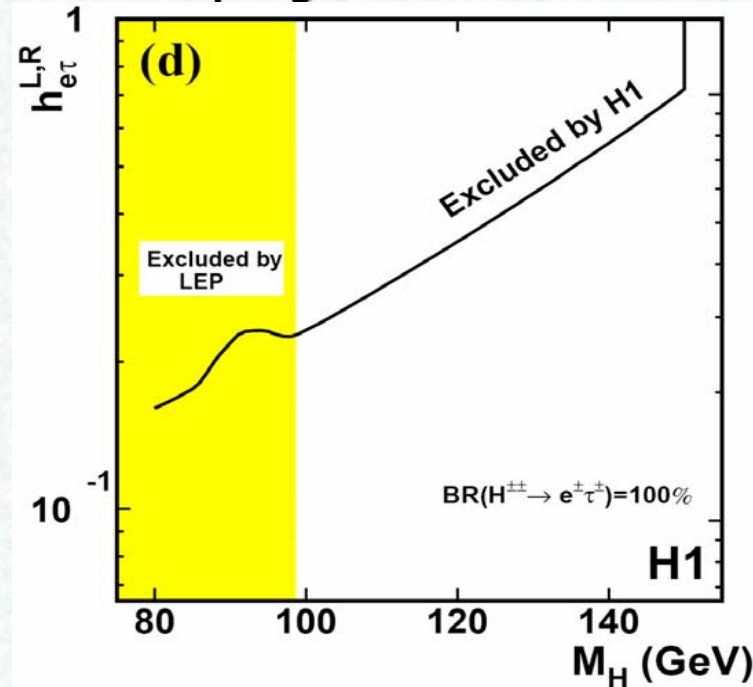
- $H^{\pm\pm}$ boson couples to **electron-muon pair** only
- Topologies: $e\mu$ and $e\mu\mu$



For couplings of em. strength $h_{e\mu} \sim 0.3$: mass exclusion $M_{H^{\pm\pm}} > 141 \text{ GeV}$

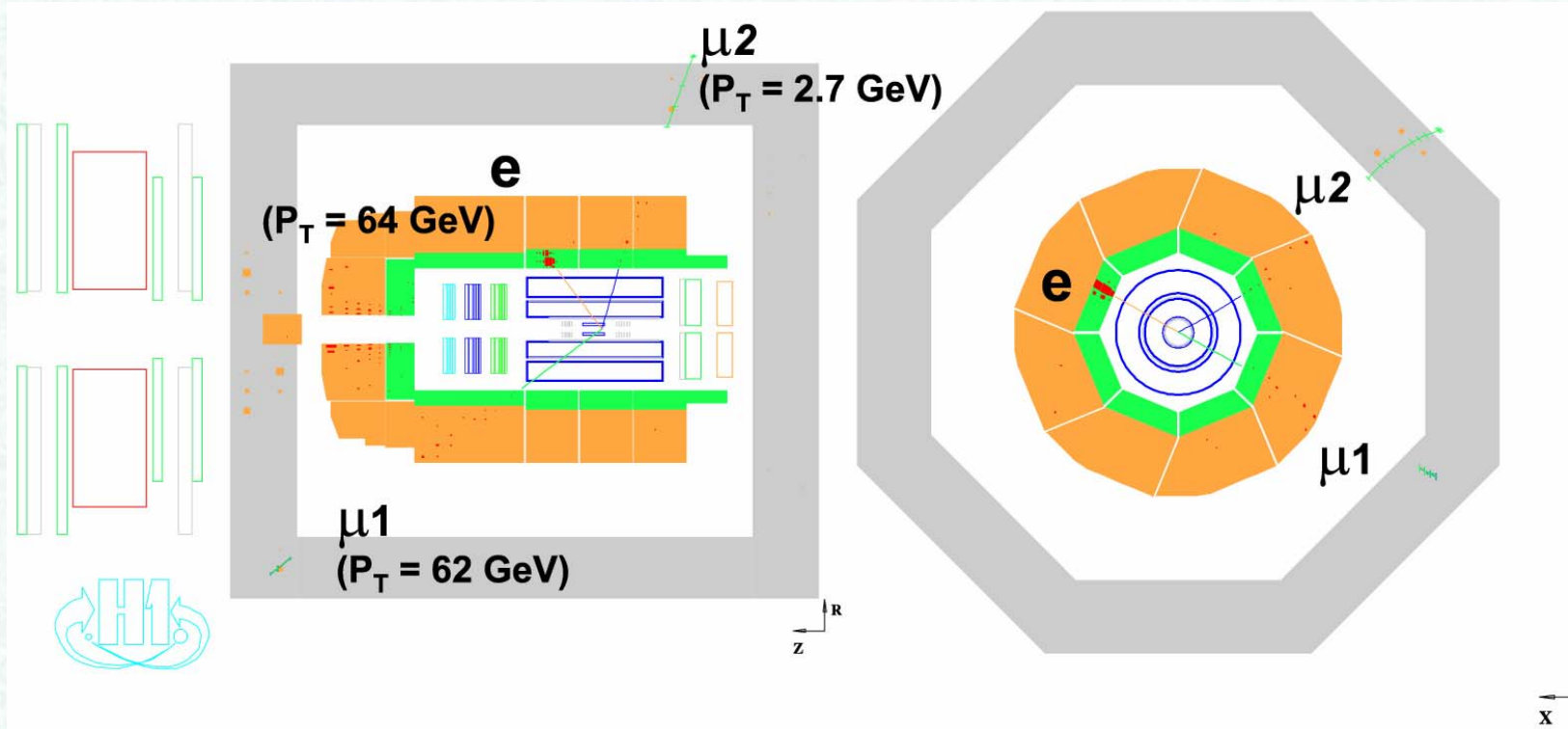
$h_{e\tau} \sim 0.3$: mass exclusion $M_{H^{\pm\pm}} > 112 \text{ GeV}$

- $H^{\pm\pm}$ boson couples to **electron-tau pair** only
- Topologies: $e\tau$ and $e\tau\tau$

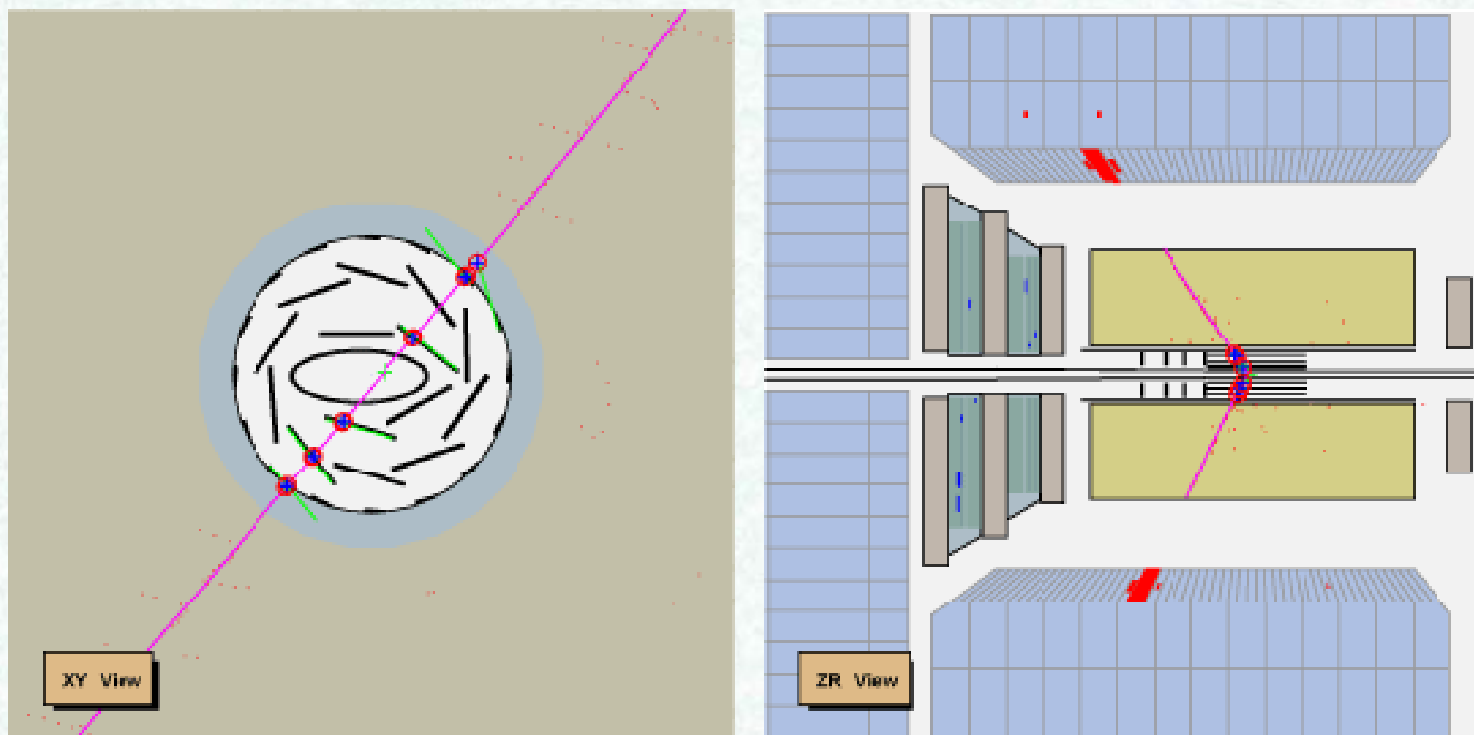


HERA limits extend beyond LEP, TeVatron reach

High mass events H1



High mass events ZEUS

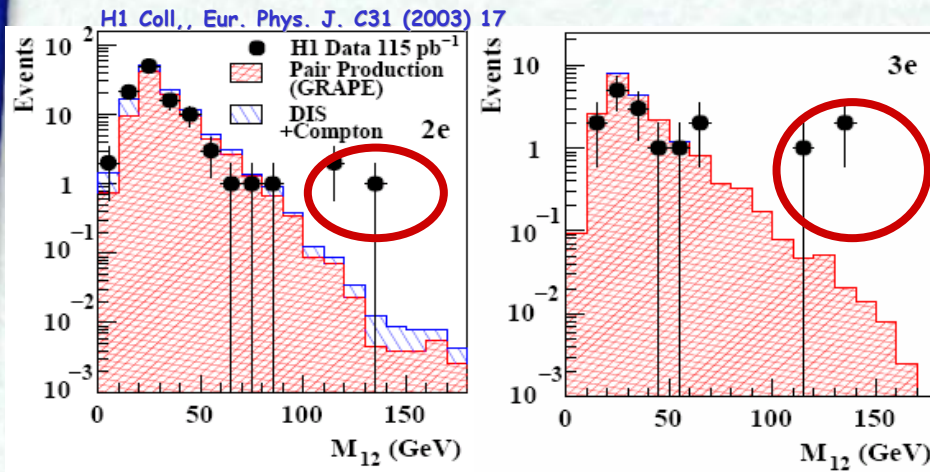


**Mass = 100.8 GeV, $P_{t^{e1}} = 50.4$ GeV, $P_{t^{e2}} = 50.0$ GeV,
 $\theta_{e1} = 1.12(\text{rad})$, $\theta_{e2} = 0.97(\text{rad})$.**

Motivation

➤ H1 results for ee and eee channels (HERA-I data)

Distribution of inv. Mass of 2 highest Pt electrons



- General good agreement with SM
- Interesting events at $M_{ee} > 100 \text{ GeV}$

Selection	Data	SM	Pair Production (GRAPE)	DIS + Compton
"2e" $M_{12} > 100 \text{ GeV}$	3	0.30 ± 0.04	0.21 ± 0.03	0.09 ± 0.02
"3e" $M_{12} > 100 \text{ GeV}$	3	0.23 ± 0.04	0.23 ± 0.03	< 0.02 (95% C.L.)



H^{\pm} production?