

# Exotic Physics at HERA

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*On behalf of the H1 and ZEUS collaborations*

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## **Topics**

- Search for Excited Neutrinos
  - Analysis of Multi-Lepton Events
  - Search for Doubly Charged Higgs
  - General Search for high- $P_T$  Phenomena
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*XXXIII International Conference on High Energy Physics,  
Moscow, July 26 - August 2, 2006*



# HERA Running and Data

- **HERA Collider**

$e^\pm p$  Collisions at  $\sqrt{s} = 320$  GeV

Running Periods:

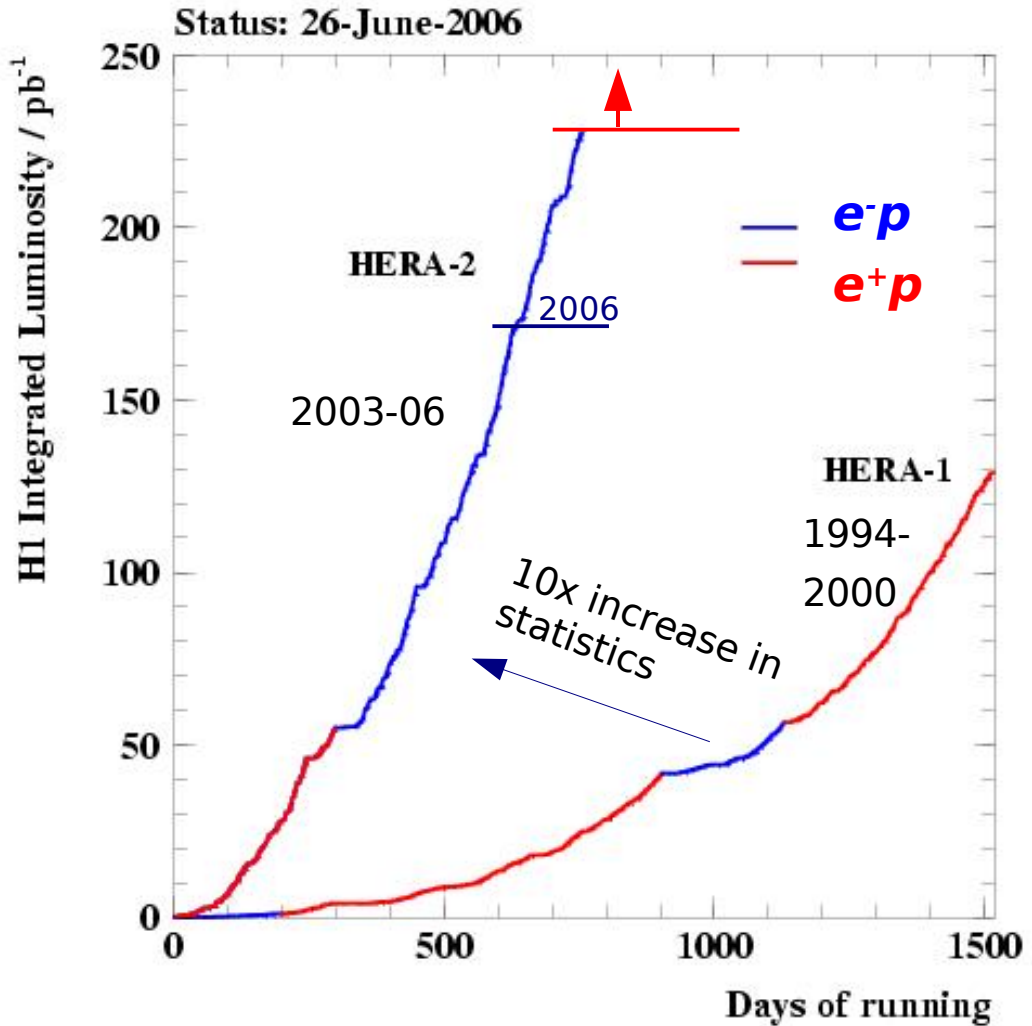
- HERA-I : 1994-00 ( $\sim 130$  pb<sup>-1</sup> per exp.)
- HERA-II: 2003-07 luminosity upgrade  
long. e polarisation

- Collider Experiments



Integrated Luminosities used for the analyses presented in this talk

	H1	ZEUS
$e^+p$	158 pb <sup>-1</sup>	144 pb <sup>-1</sup>
$e^-p$	184 pb <sup>-1</sup>	152 pb <sup>-1</sup>



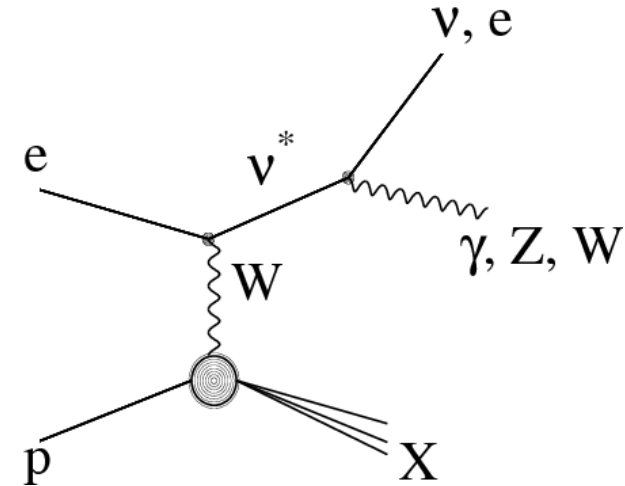
- Different sensitivity to  $e^+p$  /  $e^-p$  for some processes

# Search for Excited Neutrinos $\nu^*$

- Model: Fermions composite at Scale  $\Lambda$ , Cross-section and branching ratios described by  $f, f'$  (ew. sector)

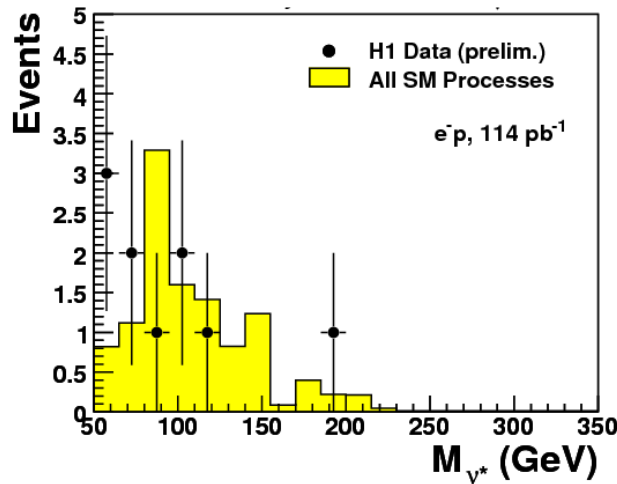
$$L_{F^*F} = \frac{1}{2\Lambda} \overline{F_R^*} \sigma^{\mu\nu} [gf \frac{\vec{\tau}}{2} \partial_\mu \vec{W}_\nu + g' f' \frac{Y}{2} \partial_\mu B_\nu] F_L + h.c.,$$

- $\sigma(e-p) \sim 100x \sigma(e^+p)$  at  $M_{\nu^*} > 200$  GeV ( $W$  exchange)
- Data Sample: 2005  $e-p$  114 pb<sup>-1</sup>



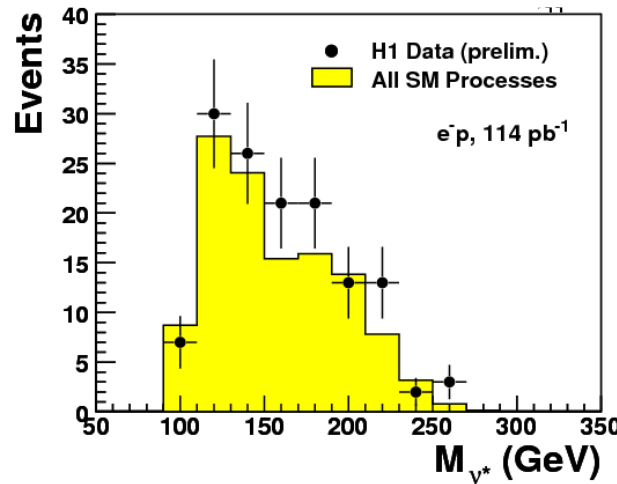
$$\nu^* \rightarrow \nu \gamma$$

Missing Pt + Photon



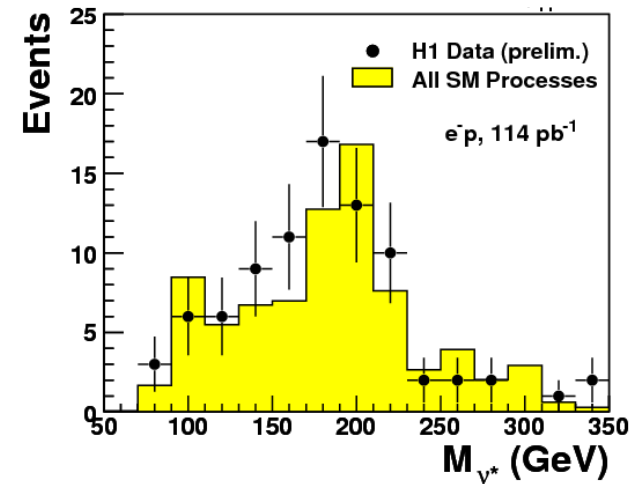
$$\nu^* \rightarrow \nu Z \rightarrow qq$$

Missing Pt + Jets



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

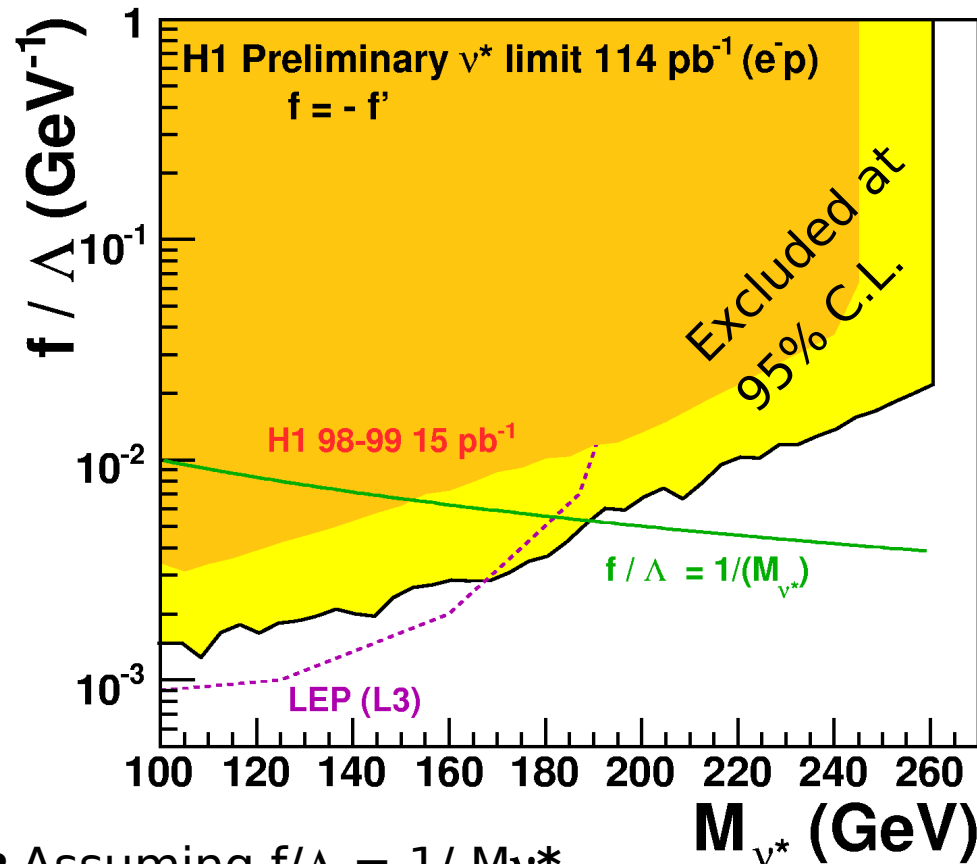
Electron + Jets



No evidence for Excited Neutrino Production found



- Scenario:  $f = -f'$  (max. coupling to photon)
- $\sigma_{\nu^*}(f/\Lambda, M_{\nu^*})$  in NWA



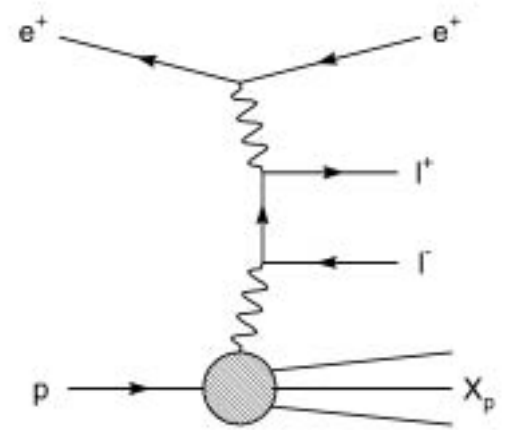
- Assuming  $f/\Lambda = 1/ M_{\nu^*}$

$M_{\nu^*} < 188 \text{ GeV}$  excl. at 95% C.L.

- Sensitivity extends beyond LEP reach

# Multi-Lepton Events

Analyses of Events with multiple  $e, \mu, \tau$



## SM Signal Processes

- Dominant:  $\gamma\gamma \rightarrow l^+ l^-$

## SM Background Processes

- NC-DIS, Compton (hadrons, photons misidentified as leptons)

Possible BSM Interpretation:  $H^{\pm\pm} \rightarrow \text{next topic}$

### Final states covered at HERA



Channel	Lumi	Lumi
$ee, eee$	$275 \text{ pb}^{-1}$	$296 \text{ pb}^{-1}$
$\mu\mu$	$275 \text{ pb}^{-1}$	$101 \text{ pb}^{-1}$
$e\mu, ee\mu$	$275 \text{ pb}^{-1}$	—
$\tau\tau$	$118 \text{ pb}^{-1}$	$135 \text{ pb}^{-1}$

# Multi-Lepton Selection (e, $\mu$ )



### Selection

- $P_{T,1(2)} > 10$  (5) GeV
- $20^\circ < \theta < 150^\circ$
- count all **e**,  $\mu$  and classify

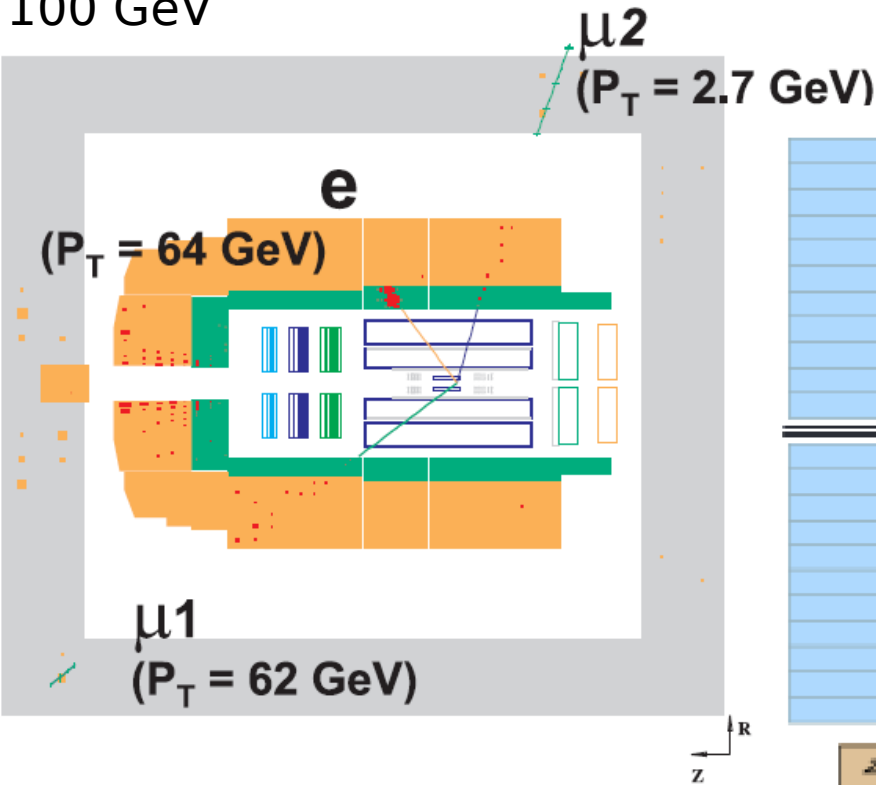


### Selection

- $P_{T,1(2)} > 10$  (5) GeV
- $17^\circ < \theta < 164^\circ$
- count **e** and classify

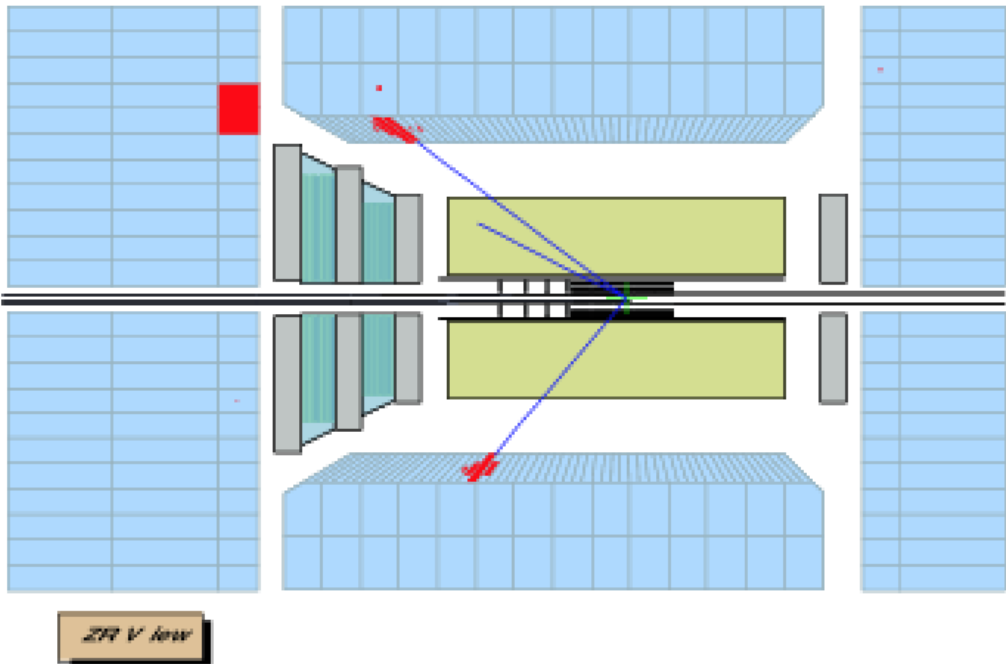
### Event in $e\mu\mu$ Sample

$M_{e\mu} > 100$  GeV



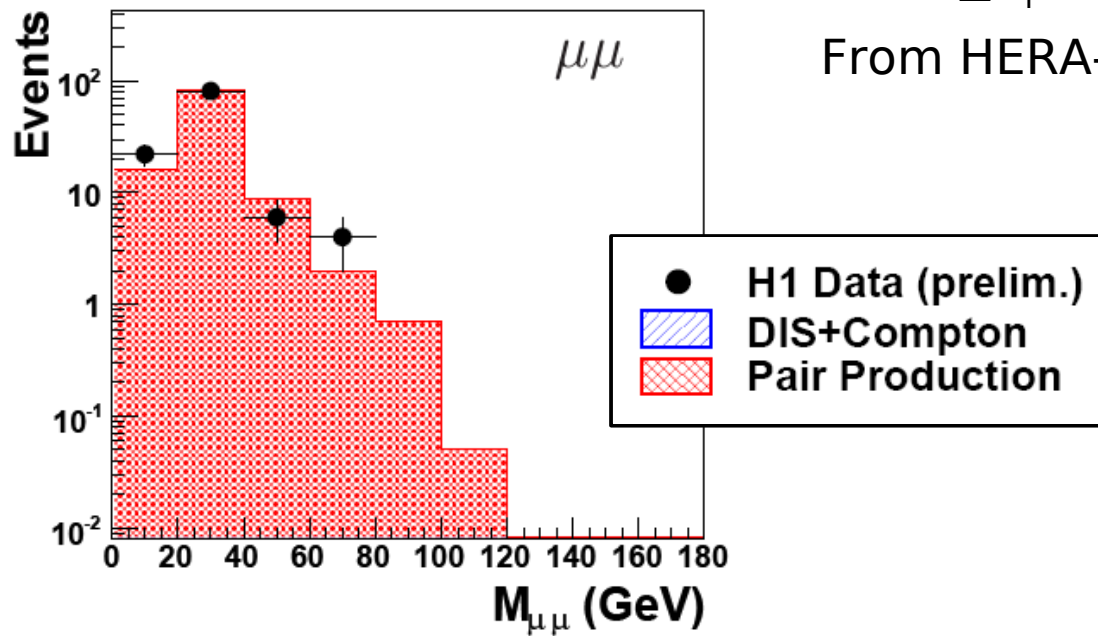
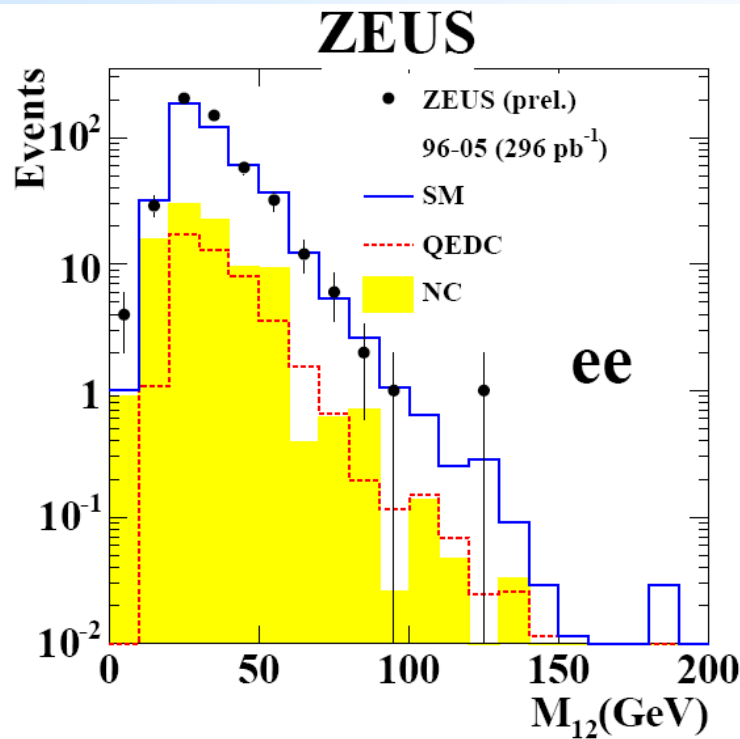
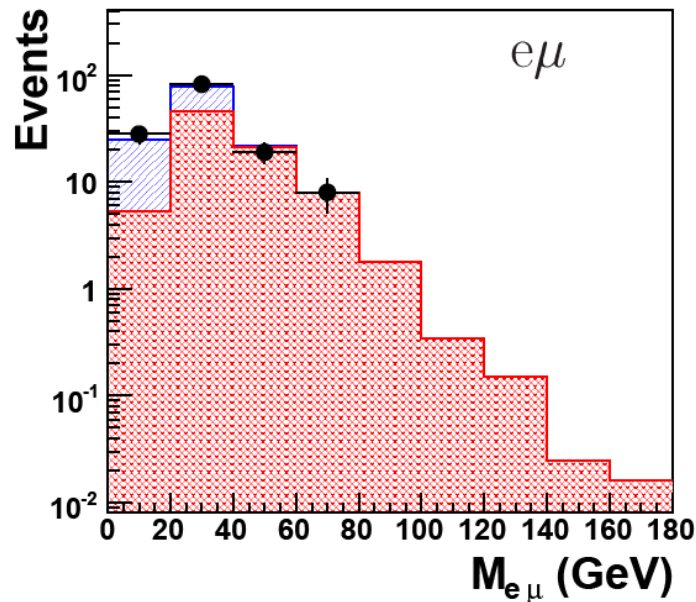
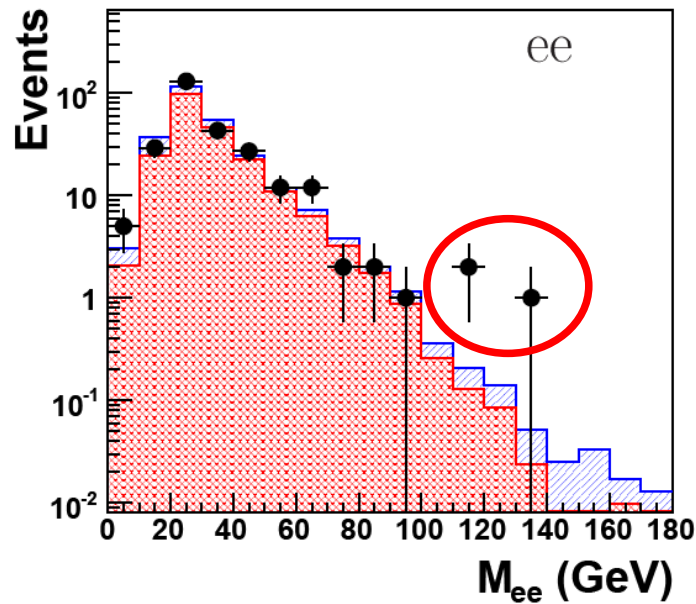
### Event in $eee$ Sample

$M_{12} = 103$  GeV



# Di-Lepton Results

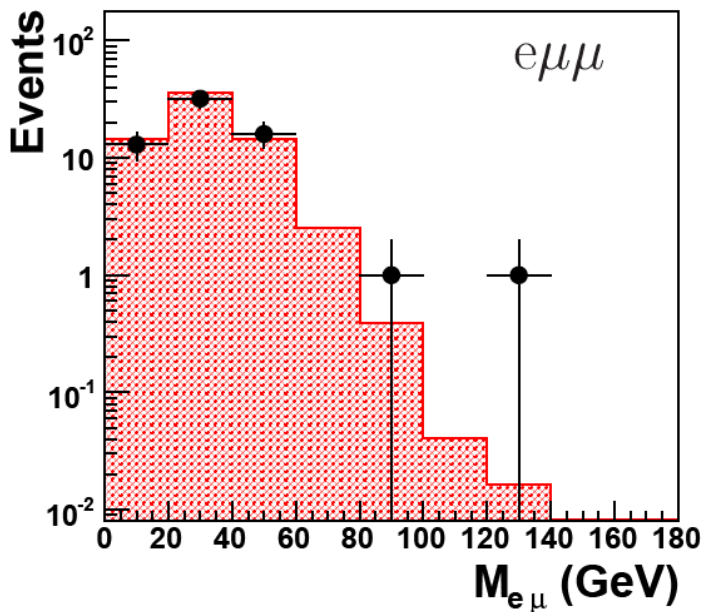
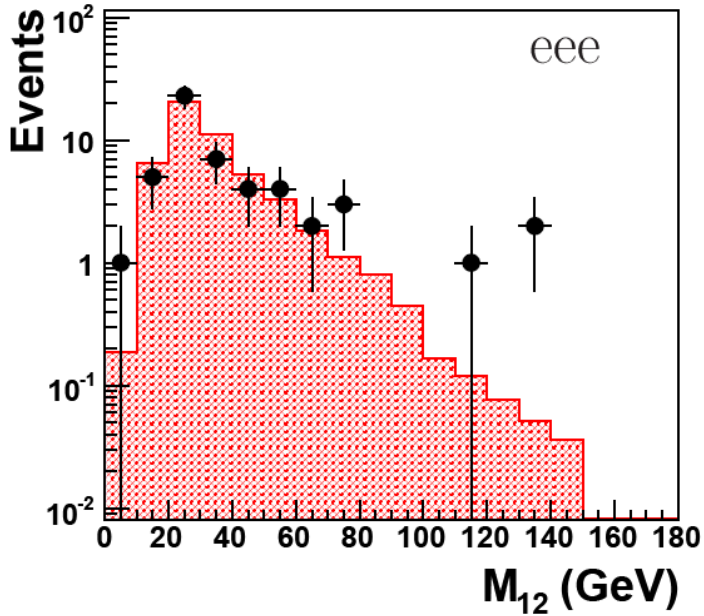
H1 Preliminary 275pb<sup>-1</sup>



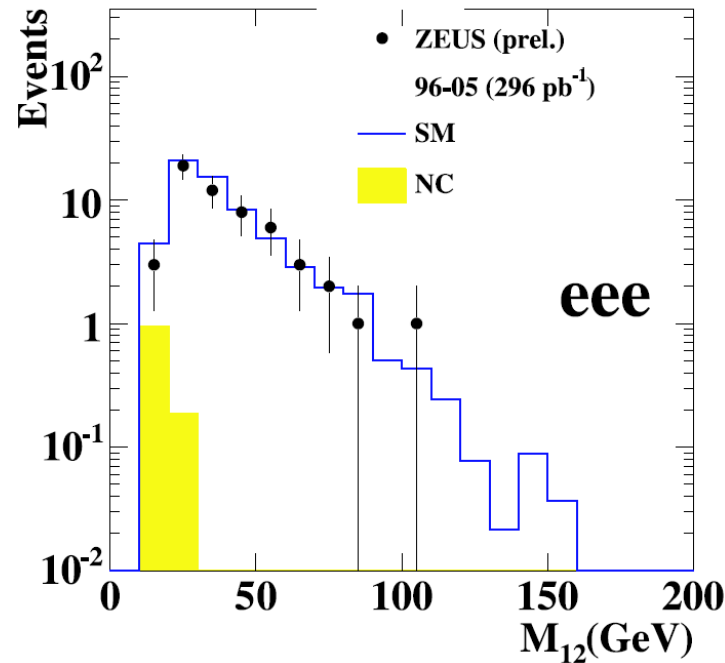
- Overall good agreement with the standard model
- Interesting events in H1 ee sample:  
At  $M_{ee} > 100$  GeV  
3 obs. / 0.86 exp.  
Have  $\sum P_T > 100$  GeV  
From HERA-I  $e^+p$

# Tri-Lepton Results

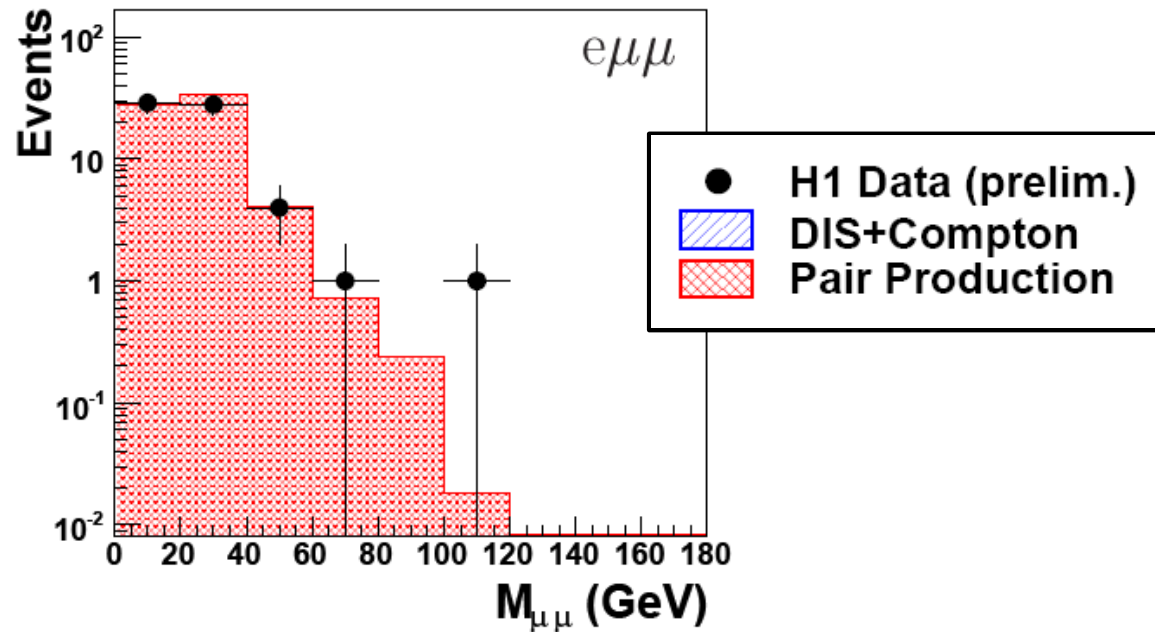
H1 Preliminary 275pb<sup>-1</sup>



## ZEUS

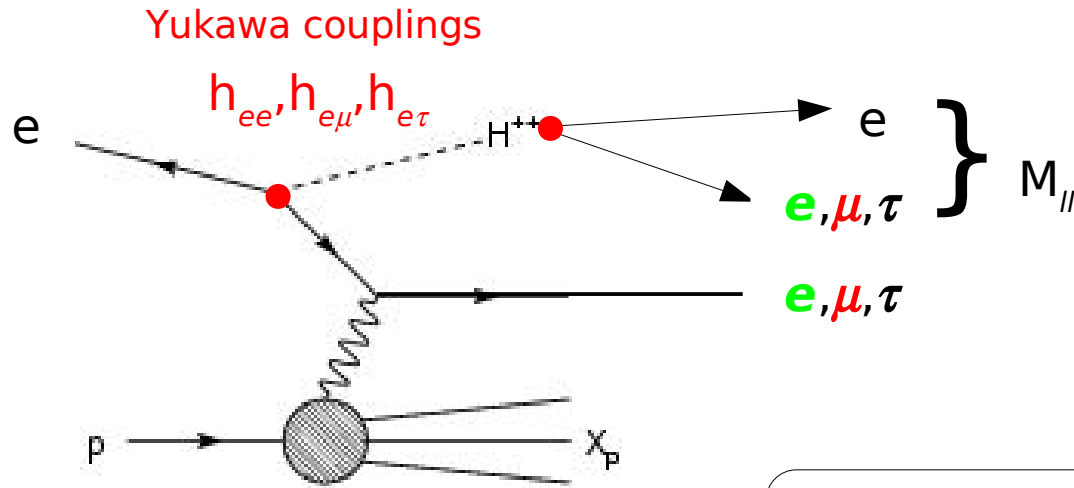


- Overall good agreement with the standard model



# Search for Doubly Charged Higgs $H^{\pm\pm}$

- Occur in extensions of the Higgs sector with  $H$  triplet(s) with  $Y \neq 0$
- Explanation for events at high  $M_{ee} / \sum P_T$  observed in HERA-I ee sample?



## Selection

- Sample: HERA-I ( $118 \text{ pb}^{-1}$ )
- $ee$ ,  $e\mu$  (based on Multi-Leptons)
- $e\tau$  with  $\tau \rightarrow e, \mu, \text{hadrons}$
- 2 high- $P_T$  leptons with same charge as beam lepton
- Reconstruct invariant mass  $M_{ll}$  of Higgs candidate

## $H^{\pm\pm}$ Analysis Results

At  $M_{ll} > 65 \text{ GeV}$ :

$ee$  3 obs. /  $2.45 \pm 0.11$  exp.

$e\mu$  1 obs. /  $4.17 \pm 0.44$  exp.

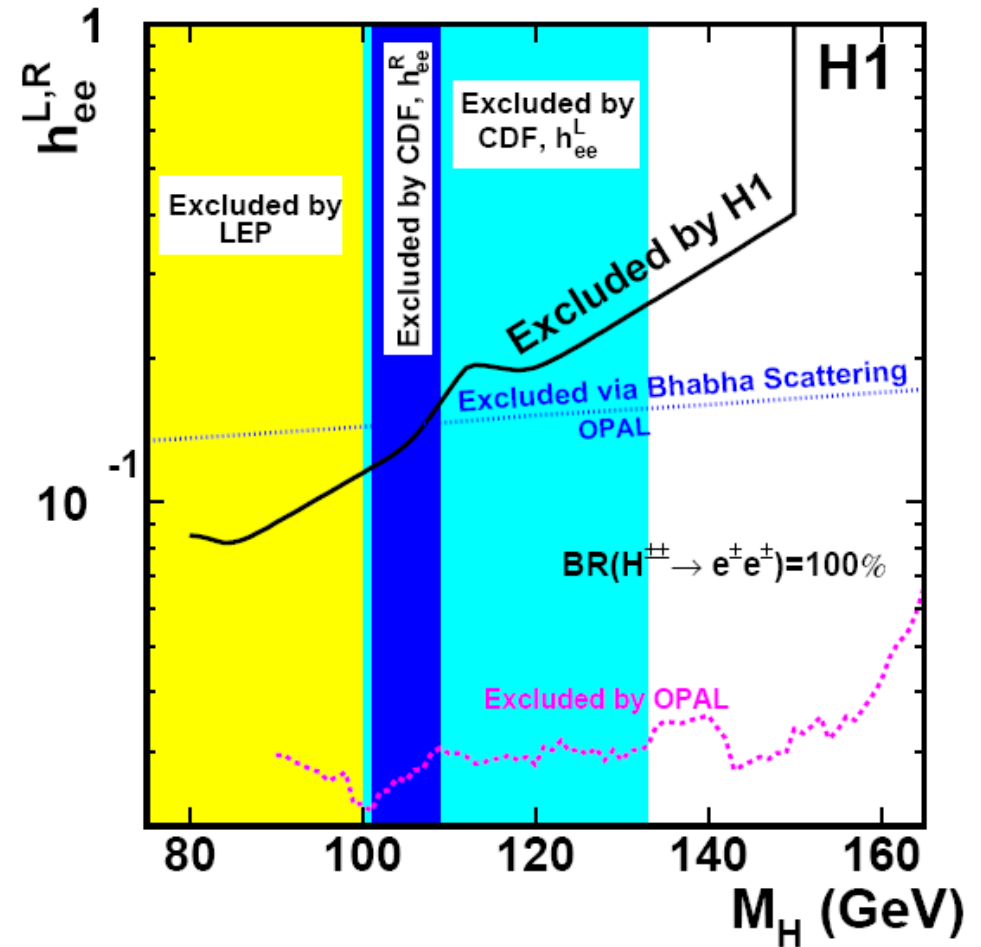
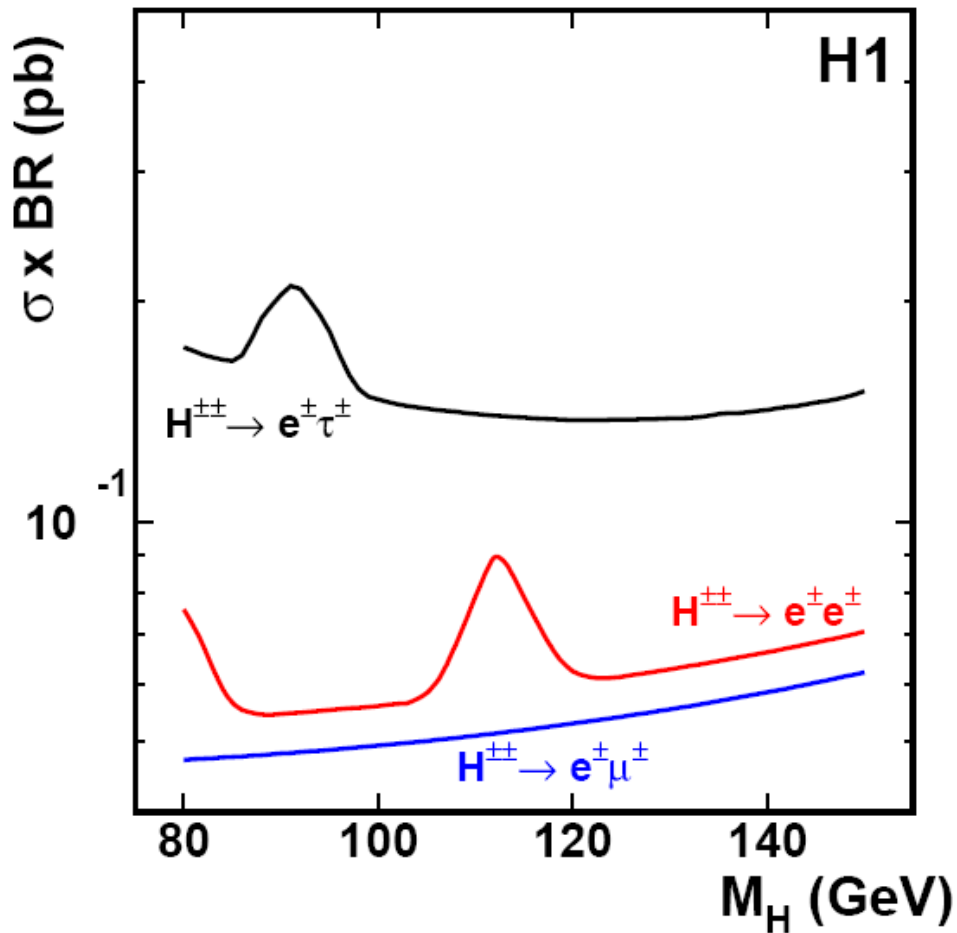
$e\tau$  1 obs. /  $2.07 \pm 0.54$  exp.

At  $M_{ll} > 100 \text{ GeV}$ :

Only 1  $ee$  event survives

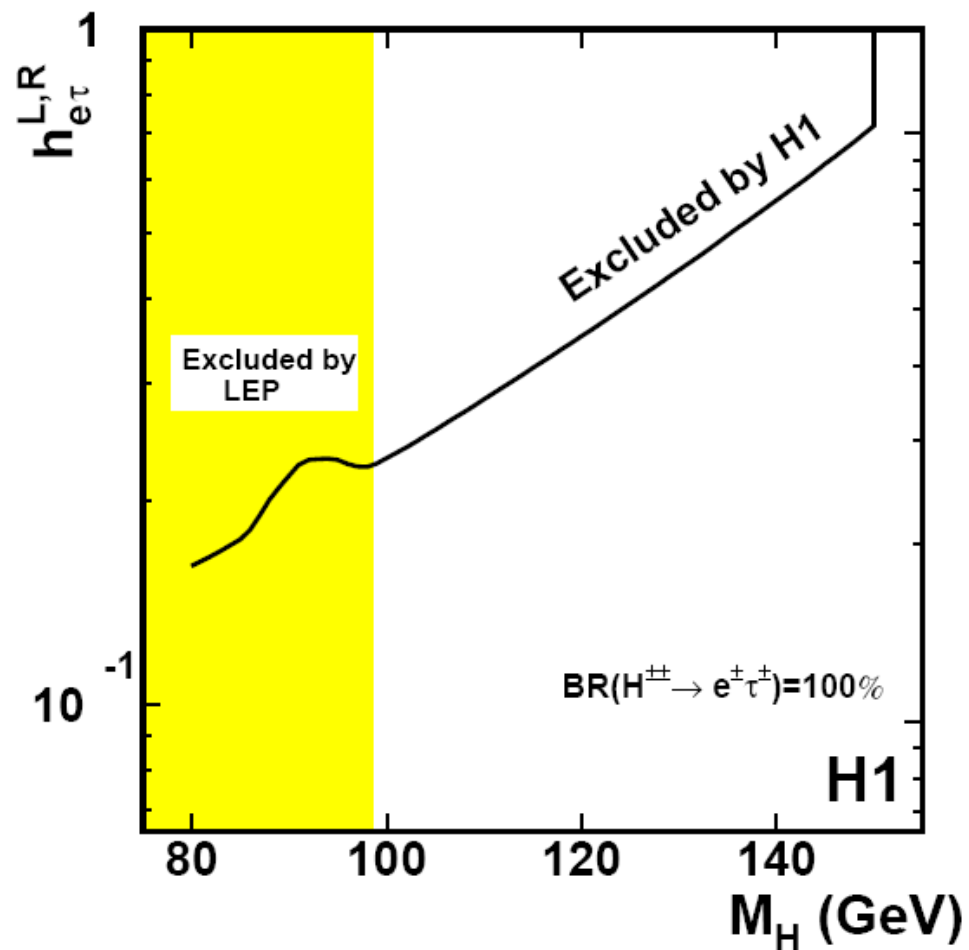
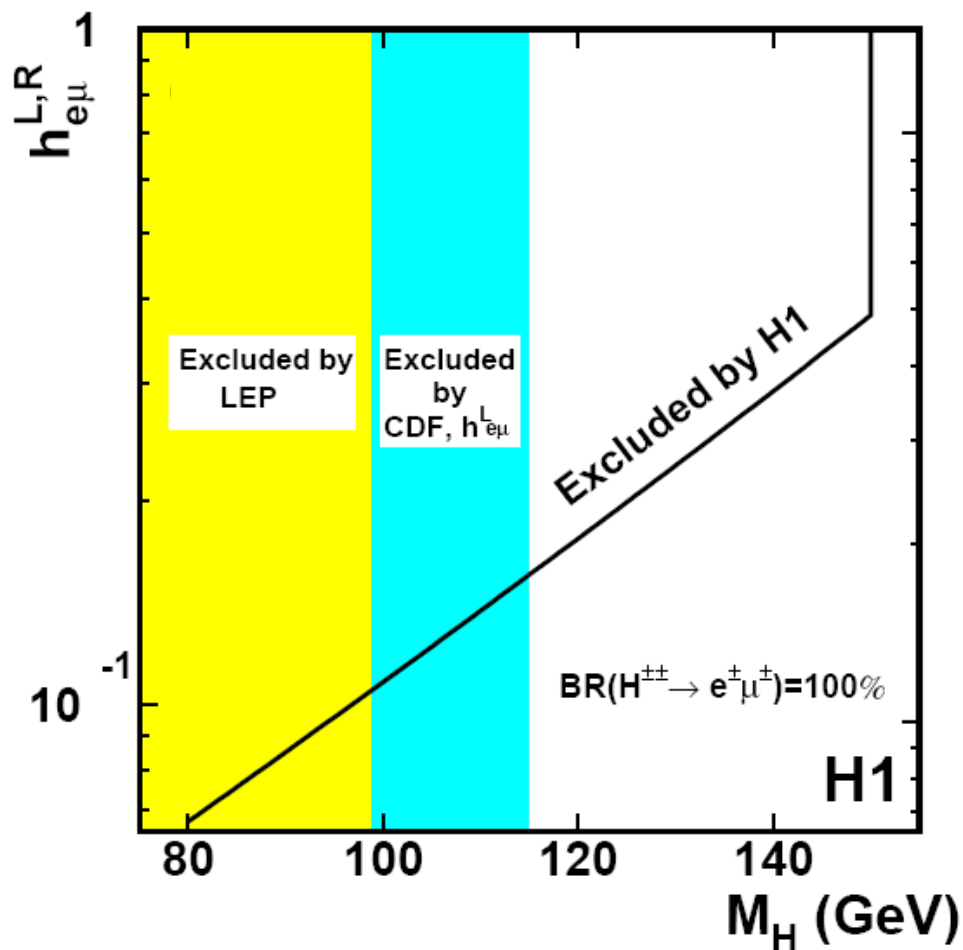
No excess – set limits

# $H^{\pm\pm}$ Limits for $\sigma \times Br$ and dominating $h_{ee}$ coupling



- Upper limits for  $H^{\pm\pm}$  production at 95% C.L. derived by modified frequentist method
- Best sensitivity:  $\sigma \times Br(h_{e\mu}) < 0.05$  pb

- $H^{\pm\pm}$  Interpretation for ee excess observed in HERA-I at H1 ruled out by **OPAL** ( $H^{\pm\pm}$  Single Production)
- LEP, TeVatron:  $H^{\pm\pm}$  Pair Production



- For  $h_{e\mu} = 0.3$  (em. strength):  $M_{H^{\pm\pm}} > 141$  GeV
- For  $h_{e\tau} = 0.3$ :  $M_{H^{\pm\pm}} > 112$  GeV
- HERA limits extend beyond LEP, TeVatron reach

# Tau Pair Events

## Measurement of $\sigma(\gamma\gamma \rightarrow \tau\tau)$

(HERA-I  $e^\pm p$ ,  $118 \text{ pb}^{-1}$ )

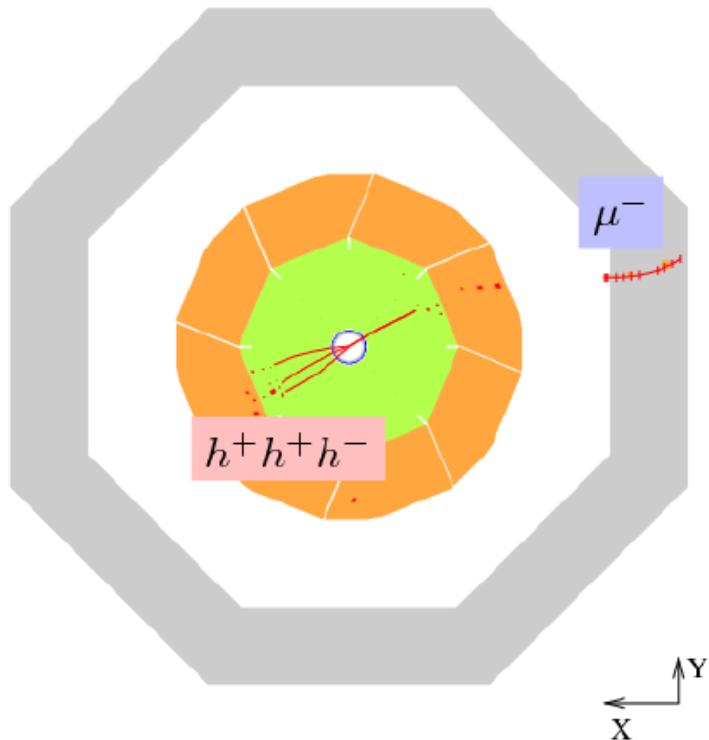
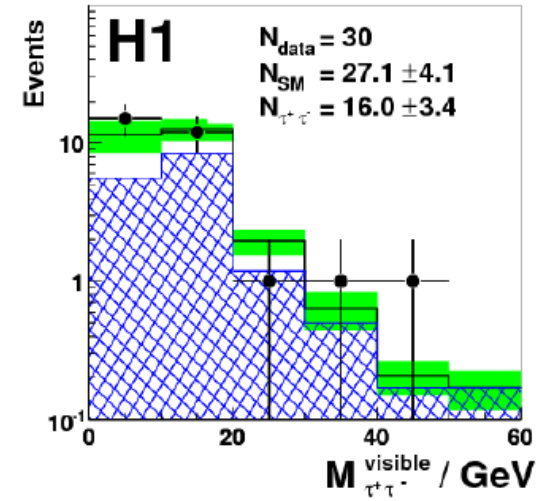
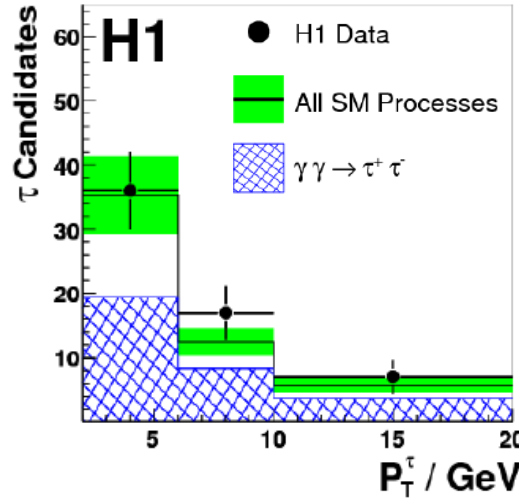


- Final states:  $e\text{-}\mu$ ,  $e\text{-jet}$ ,  $\mu\text{-jet}$ ,  $\text{jet-jet}$
- vis.  $P_T > 2 \text{ GeV}$ ,  $20^\circ < \theta < 140^\circ$

30 obs. /  $27.1 \pm 4.1 \text{ exp.}$  ( $\sim 60\% \tau\tau$ )

$$\sigma_{\text{measured}}^{\tau\tau} = 13.6 \pm 5.7 \text{ pb}$$

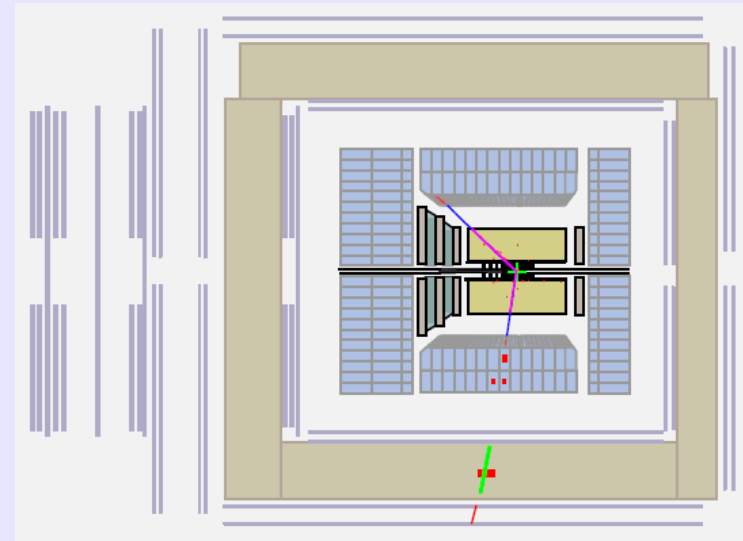
$$\sigma_{\text{expected}}^{\tau\tau} = 11.2 \pm 0.3 \text{ pb}$$



## Di-Tau Search (HERA-II $e\text{-}p$ $135 \text{ pb}^{-1}$ )

- Final state:  $e\text{-}\mu$
- vis.  $P_T > 2 \text{ GeV}$ ,  $17^\circ < \theta < 164^\circ$

3 obs. /  $2 \pm 0.8 \text{ exp.}$  ( $\sim 100\% \tau\tau$ )



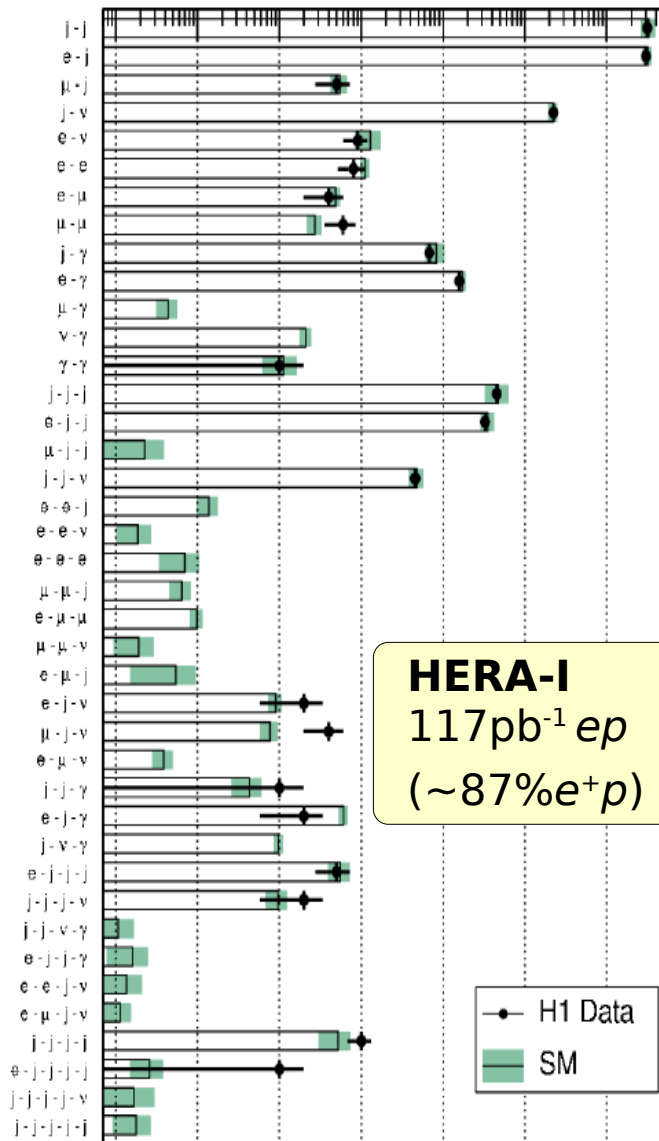


- Model independent, generic search in final states with  $\geq 2$  high- $P_T$  objects:

**$e, \mu, \text{jets}, \gamma, \nu$**   
with  
 $P_T > 20 \text{ GeV}$ ,  
 $10^\circ < \theta < 140^\circ$

- Classify by final state
- SM predictions for all HERA processes considered:  
NC DIS, CC DIS, Photoproduction, Lepton-Pairproduction,  $W$ -Production, QEDC

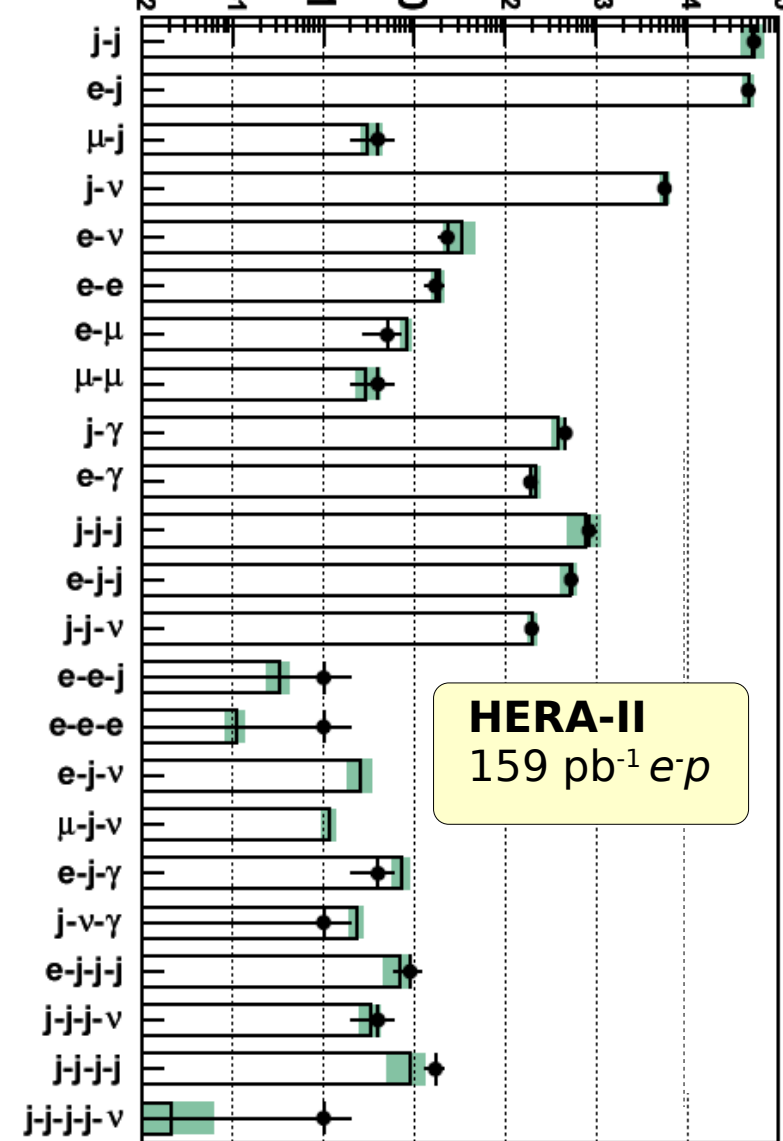
Channels with  
 $N_{\text{obs}} \geq 1, N_{\text{exp}} \geq 0.01$  Events



**HERA-I**  
 $117 \text{ pb}^{-1} ep$   
( $\sim 87\% e^+p$ )

● H1 Data  
■ SM

Channels with  
 $N_{\text{obs}}, N_{\text{exp}} \geq 1$  Events



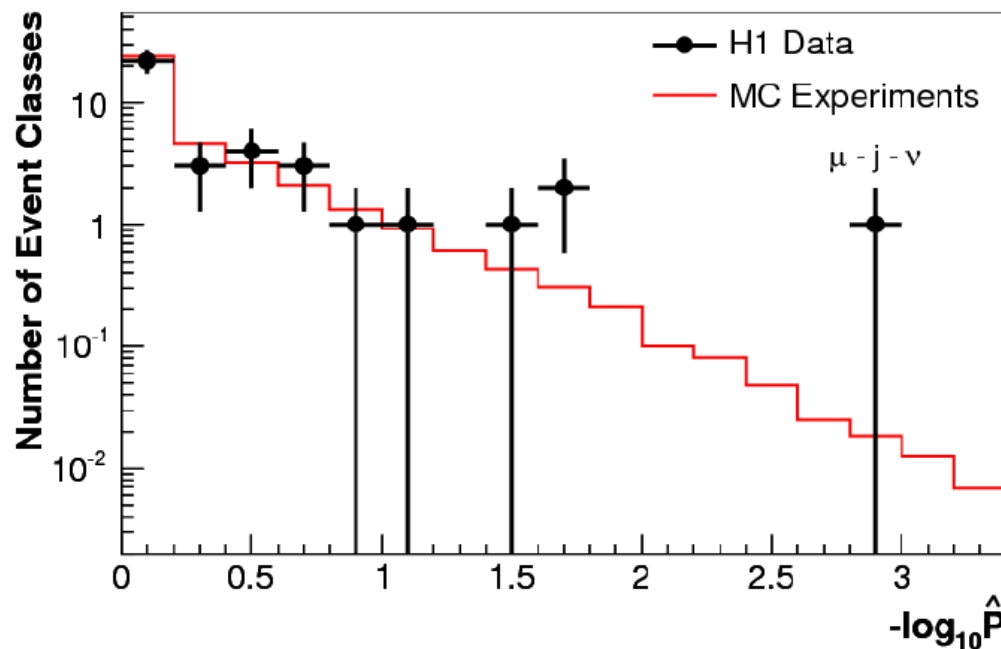
**HERA-II**  
 $159 \text{ pb}^{-1} e^+p$

Good description of total event yields by SM in most classes

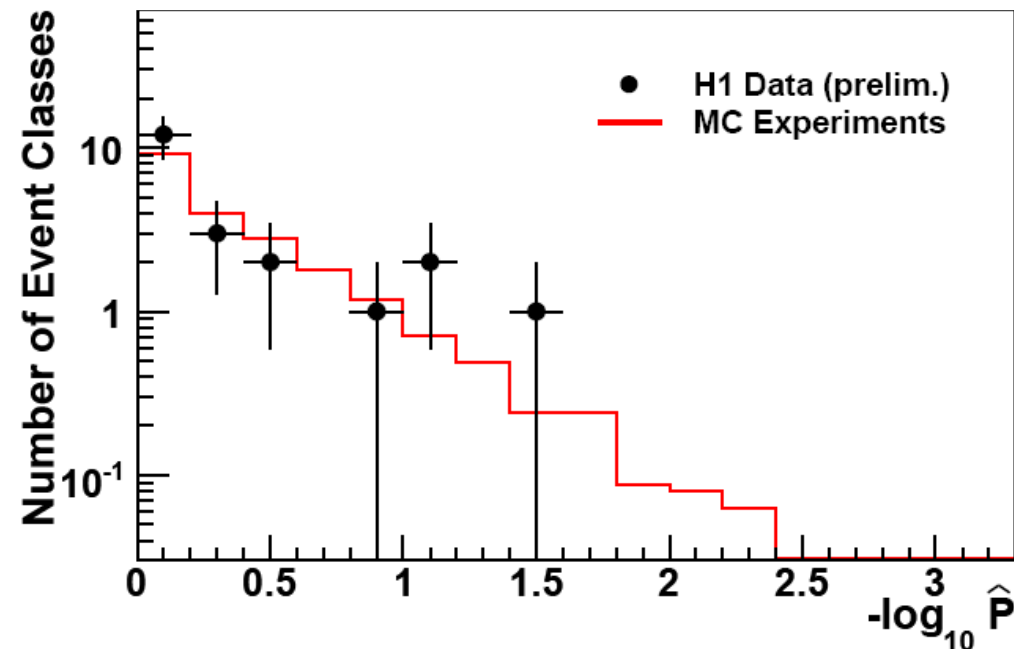
# General Search – Statistical Analysis

- Perform Statistical Analysis to find all possible deviations in channel spectra of  $M_{\text{all}}$  (total invariant mass) and  $\Sigma P_{\text{T}}$  of objects in class
- In each spectrum, find region with lowest probability  $p_{\text{min}}$
- Plot probability  $\hat{p}$  for deviation  $p < p_{\text{min}}$  anywhere in class  
 HERA-I : Significant channel  $\mu\text{-j-}\nu$  with  $\hat{p} \approx 0.1\%$  → see talk on Isolated Leptons  
 HERA-II:  $\hat{p} > 3\%$  for all channels

**HERA-I**  $117\text{pb}^{-1}e p$  ( $\sim 87\%e^+p$ )  $\Sigma P_{\text{T}}$  Scan



**HERA-II**  $159\text{pb}^{-1}e p$   $\Sigma P_{\text{T}}$  Scan



Statistical Analysis:  
 No significant deviation from the Standard Model observed in  $e p$

- Many different BSM channels and topologies have been searched at HERA
- No deviations from SM found so far

## Search for $\nu^*$

New domain explored

## Multi-Leptons

Interesting events observed at high mass

## Search for $H^{\pm\pm}$

HERA competitive at high  $M_{H^{\pm\pm}}$  for  $h_{e\mu}$ ,  $h_{e\tau}$

## General Search for high- $P_T$ Phenomena

No significant deviations from the SM found in  $e-p$  sample

- HERA competitive discovery machine on the energy frontier
- Full HERA  $e-p$  data sample collected
- Remaining  $e^+p$  data to be collected until June 2007 – 2x lumi expected
- Bright future for searches at HERA