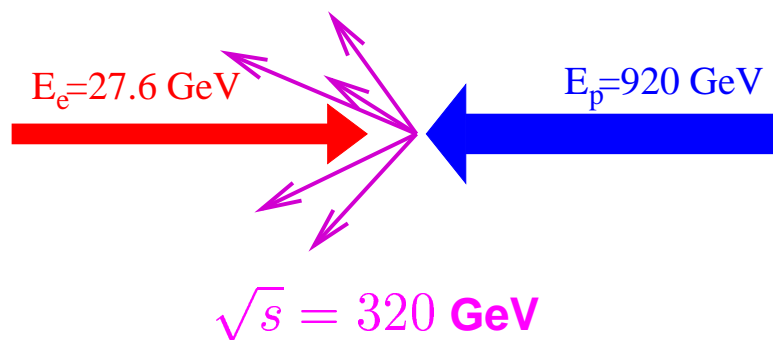


**Searches for Signatures of**  
**Physics Beyond the Standard Model**  
**with high- $P_T$  Leptons**  
**at HERA**



Jochen Dingfelder (Heidelberg)

On behalf of the H1 and ZEUS collaborations

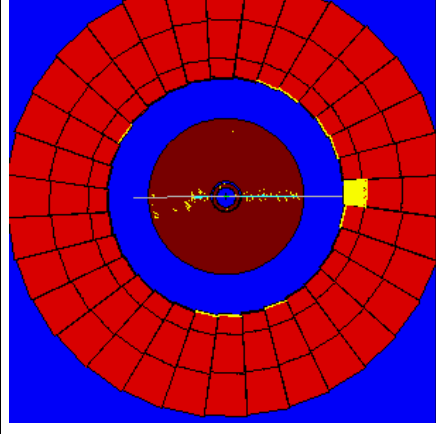
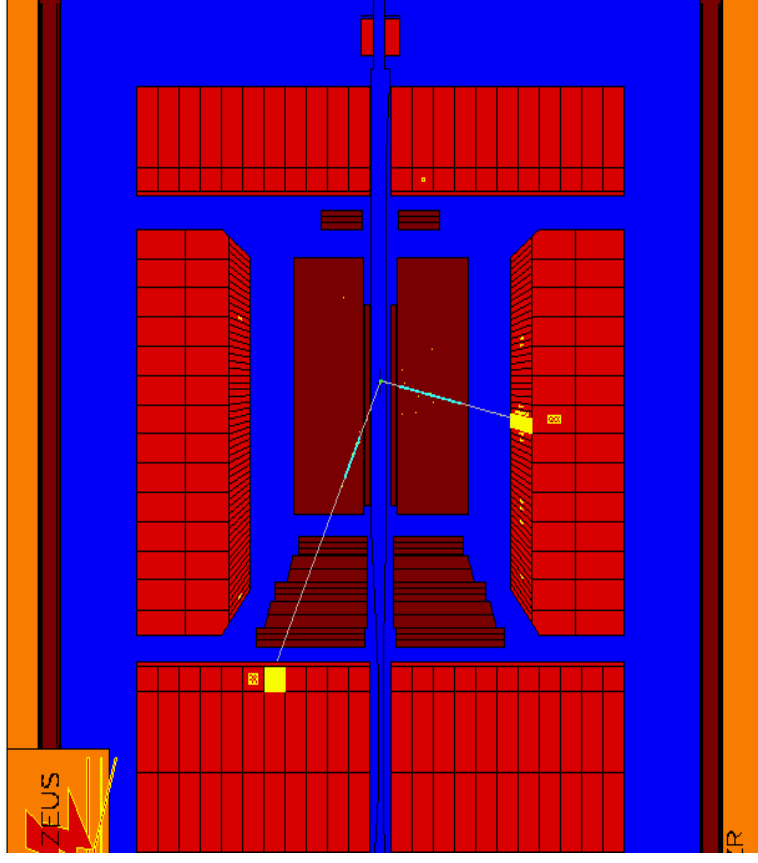
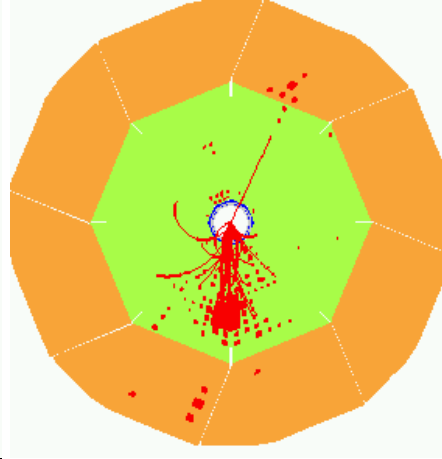
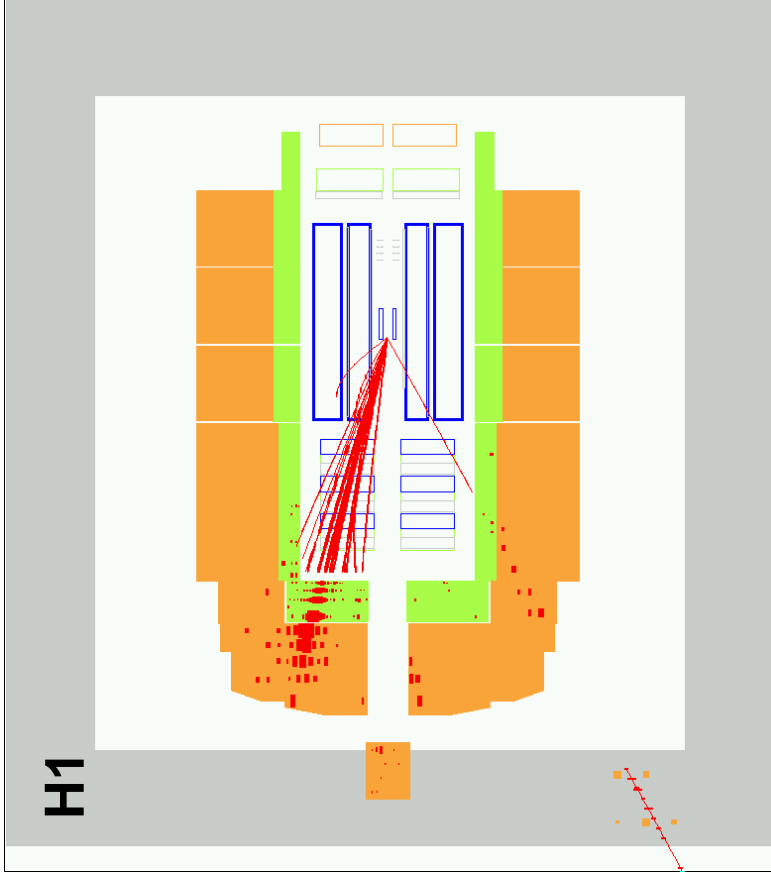


Results to be presented use the full HERA I data ( $\sim 130 \text{ pb}^{-1}$ )

**Contents:**

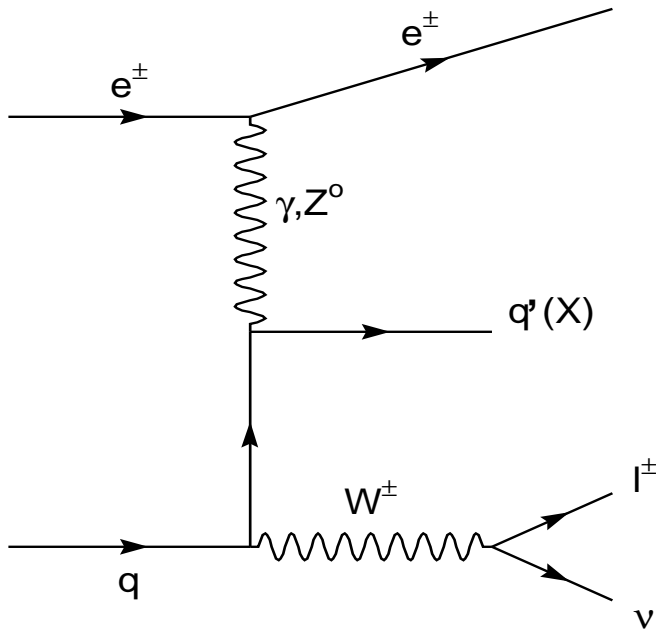
- ★ Isolated lepton events and W production
- ★ Single top quark production
- ★ Multi-lepton events
- ★ Search for doubly charged Higgs

# H1 and ZEUS Detectors: Outstanding Lepton Events



# Isolated Lepton Events with Missing $P_T$

Dominant SM process = Production of real W's



$$\sigma(ep \rightarrow eW^\pm X) \sim 1 \text{ pb}$$

⇒ hadronic jet

⇒ isolated lepton

⇒ missing  $P_T$

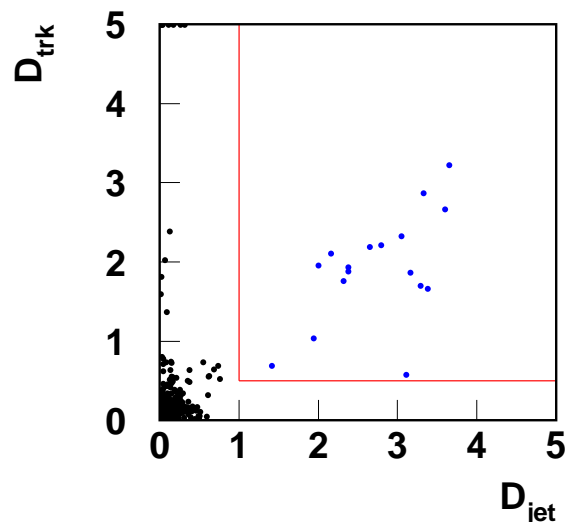
Main Selection Cuts	H1	ZEUS
Lepton $P_T$	> 10 GeV	> 10 GeV
Lepton polar angle	5° - 145°	17° - 115°
Calorimetric $P_T$	> 12 GeV	> 20 GeV
Acoplanarity (lepton - X)	> 20° (e), 10° (μ)	> 11.5°

Lepton Isolation (in  $\eta - \phi$ ):

$$D_{jet} > 1.0 \quad (\text{wrt. jets})$$

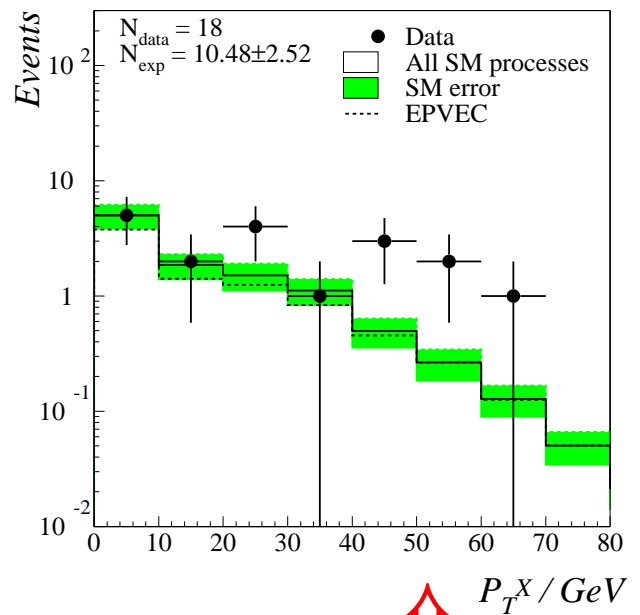
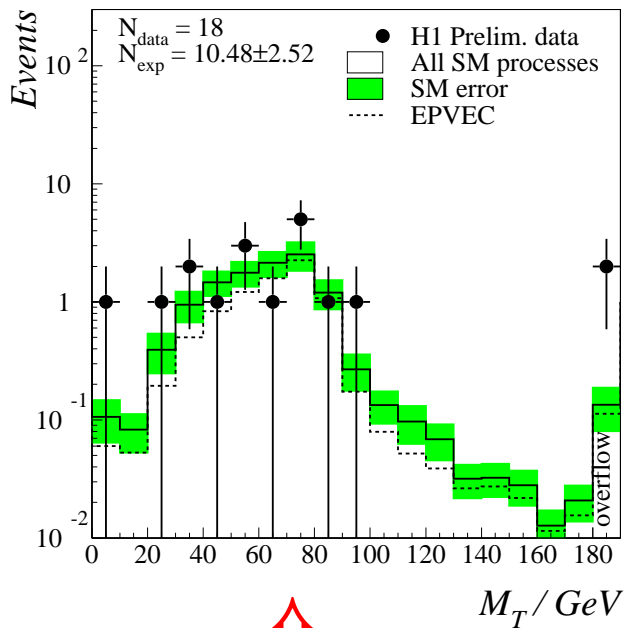
$$D_{track} > 0.5 \quad (\text{wrt. other tracks})$$

ZEUS 1994–2000 preliminary



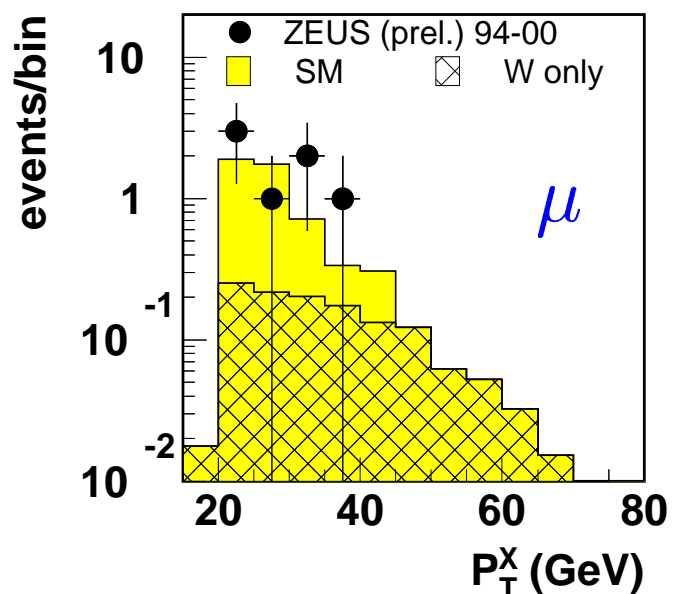
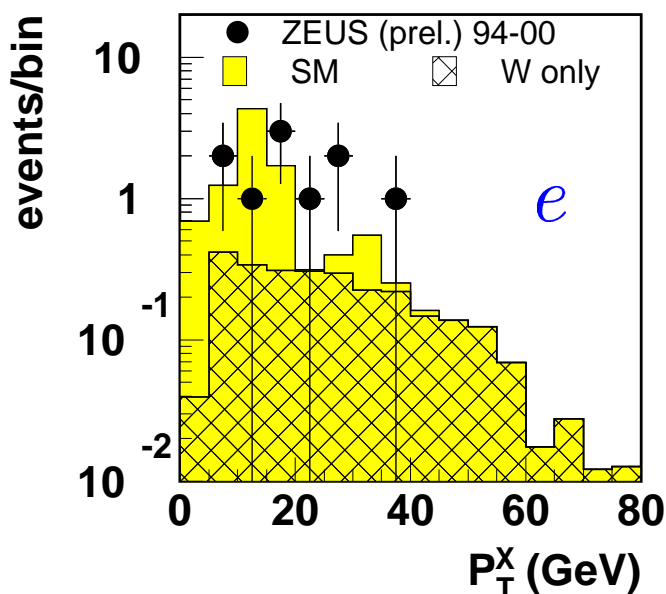
# Isolated Leptons and W Production

**H1:  $e + \mu$**  (after further cuts to enhance W component)



H1 observe no event in  $e^-p$  data (expect 1.46 (e) and 0.32 ( $\mu$ ))

**ZEUS:** (looser cuts than H1 → not yet final W selection)



# Results on Isolated Leptons at High $P_T(X)$

**H1:** (final W selection)

H1 preliminary $e^+p$ ( $101.6 \text{ pb}^{-1}$ )	Electrons obs./exp. (W)	Muons obs./exp. (W)
$P_T^X > 25 \text{ GeV}$	<b>4</b> / $1.29 \pm 0.33$ (1.05)	<b>6</b> / $1.54 \pm 0.41$ (1.29)
$P_T^X > 40 \text{ GeV}$	<b>2</b> / $0.41 \pm 0.12$ (0.40)	<b>4</b> / $0.58 \pm 0.16$ (0.53)

**Excess at high  $P_T^X$  in both 94-97  $e^+p$  and 99-00  $e^+p$  data**

**ZEUS:** (final W selection, similar to H1)

ZEUS preliminary $e^\pm p$ ( $130.5 \text{ pb}^{-1}$ )	Electrons obs./exp. (W)	Muons obs./exp. (W)
$P_T^X > 25 \text{ GeV}$	<b>1</b> / $1.14 \pm 0.06$ (1.10)	<b>1</b> / $1.29 \pm 0.16$ (0.95)
$P_T^X > 40 \text{ GeV}$	<b>0</b> / $0.46 \pm 0.03$ (0.46)	<b>0</b> / $0.50 \pm 0.08$ (0.41)

**Observed  $e, \mu$  events consistent with SM prediction**

**$\Rightarrow$  H1 and ZEUS background rates consistent,  
but discrepancy in observed event rates!**

**New analysis (ZEUS) in  $\tau$  decay channel  $\rightarrow$  see talk by L. Bellagamba**

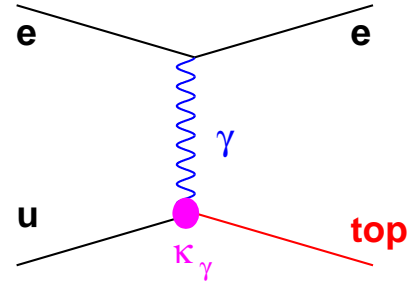


ZEUS preliminary $e^\pm p$ ( $130.5 \text{ pb}^{-1}$ )	Taus obs./exp. (W)
$P_T^X > 25 \text{ GeV}$	<b>2</b> / $0.12 \pm 0.02$ (0.10)
$P_T^X > 40 \text{ GeV}$	<b>1</b> / $0.06 \pm 0.01$ (0.05)

**$\Rightarrow$  Two new  $\tau$  events at high  $P_T^X$  complement H1  $e+\mu$  excess**

# Single Top Production at HERA

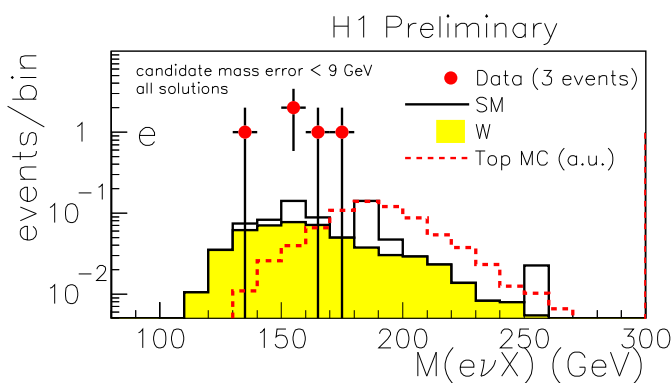
- Single top production in SM negligible  
 $\Rightarrow$  production in **FCNC** process  
 with **anomalous  $t\bar{u}\gamma$ -coupling**



- $t \rightarrow b + W \Rightarrow$  expect high  $P_T^X$  (b-quark)  
 $\Rightarrow$  Could the isolated lepton excess at high  $P_T^X$  come from single top?

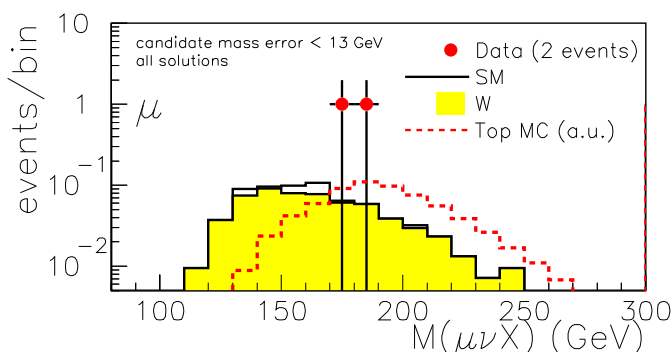
## Semi-Leptonic Top Decays ( $W \rightarrow \ell\nu$ )

- ZEUS see no isolated leptons at  $P_T^X > 40$  GeV
  - H1 apply further cuts to separate top from SM W:  
 $P_T^{jet} > 25$  GeV,  $M_T^{\ell,\nu} > 10$  GeV, only positive lepton charge  
**(hard b-jet)**                      **(real W's)**                      **( $\bar{t}$  prod. suppressed)**
- $\Rightarrow$  **H1 top candidates: 5 events (3 e, 2  $\mu$ ), expect:  $1.77 \pm 0.46$**



$W \rightarrow e\nu$

**W mass constraint imposed**  
 $\Rightarrow$  **2 possible solutions per event**



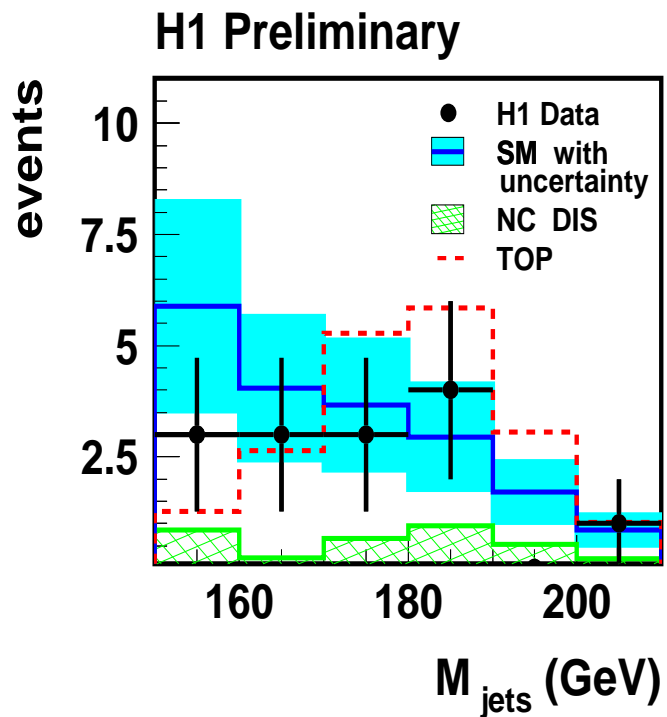
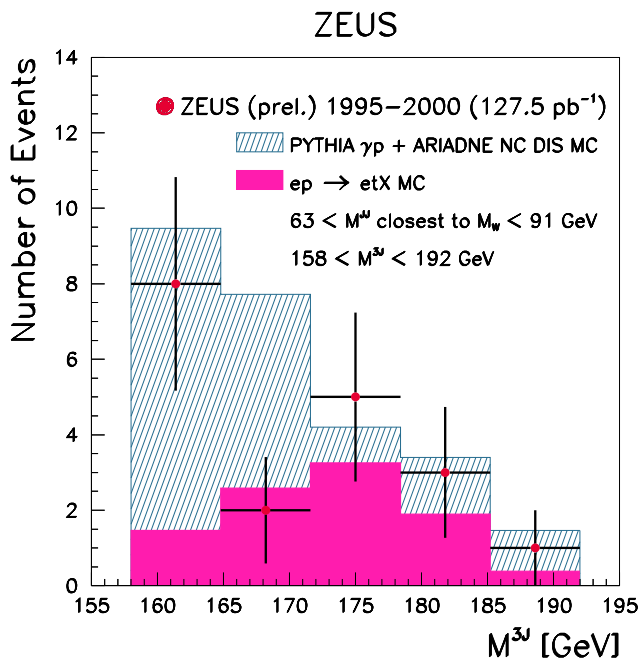
$W \rightarrow \mu\nu$

# Results on Single Top - Hadronic Decay

**Hadronic Top Decays:**  $t \rightarrow b W \rightarrow q\bar{q}' \Rightarrow 3 \text{ high-}P_T \text{ jets}$

	ZEUS	H1
$P_T^{\text{jet}}$	> 40, 25, 14	> 40, 25, 20
<b>W mass window</b>	$63 < M_{W\text{comb.}}^{2j} < 91$	$70 < M_{W\text{comb.}}^{2j} < 90$
<b>top mass window</b>	$158 < M_{3j} < 192$	$150 < M_{\text{jets}} < 210$

+ cut on decay angle (H1)



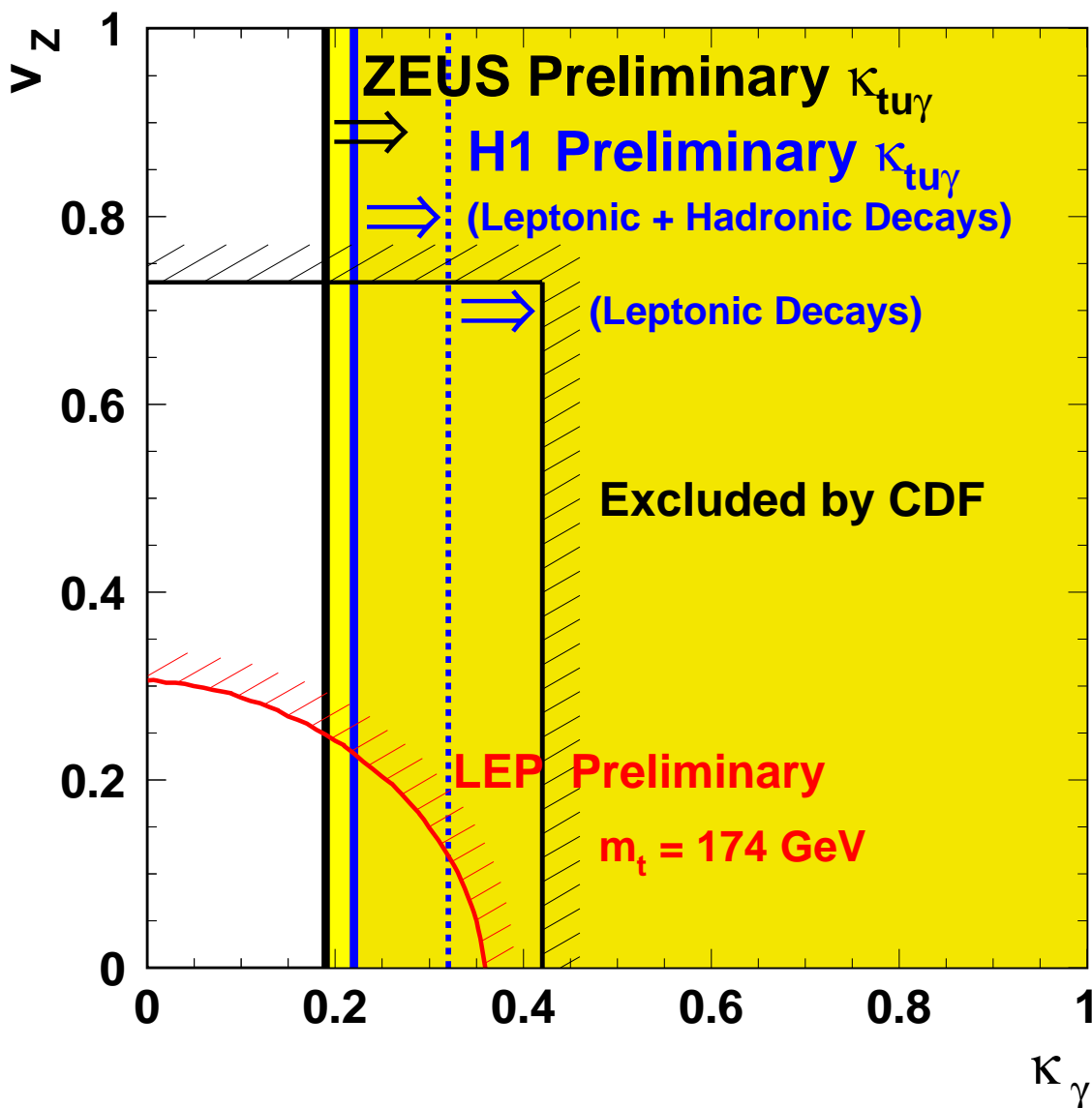
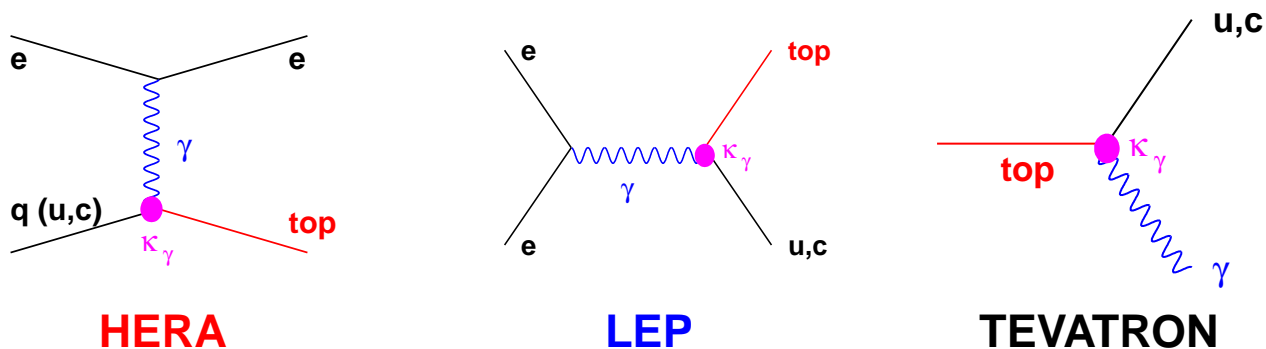
	DATA	Standard Model
ZEUS prelim.	19	20.0
H1 prelim.	14	$19.6 \pm 7.8$

**Comparison with semi-leptonic decays (H1):**

Starting from hadronic decays  $\Rightarrow$  expect for semi-leptonic decays at 95% CL < 5.4 top candidates (observe 5)

$\Rightarrow$  no contradiction within systematics

# Exclusion Limits on FCNC-Coupling



- HERA has large sensitivity to FCNC top production
- Set limits (combining leptonic and hadronic decays) :

$$\begin{aligned}
 \kappa_{tu\gamma} &< 0.19 \text{ (ZEUS)} \\
 &< 0.22 \text{ (H1)}
 \end{aligned}$$

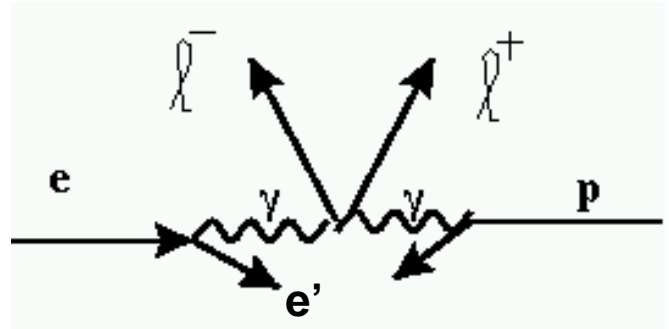


# Search for Multi-Lepton Events

$\ell$ -pair production cross-section at HERA falls off steeply with  $P_T^\ell$   
 $\Rightarrow$  multi-leptons at high  $P_T$  can be indication of new physics

## Main SM Background

$\gamma\gamma$  collisions  
(elastic + inelastic)



+ **fake leptons** (e.g. fake 2<sup>nd</sup> electron from  $\gamma$  or hadrons in NC DIS and QED Compton processes)

## Selection (Multi-Electrons)

### 2 e sample (central):

- 2 **isolated** electrons, one with  $P_T > 10$  GeV
- **H1:**  $20^\circ < \theta_e < 150^\circ$       **ZEUS:**  $17^\circ < \theta_e < 164^\circ$
- **track** associated to  $e$  shower

### 3 e sample:

- additional **3<sup>rd</sup> electron** ( $5^\circ < \theta_e < 175^\circ$ )

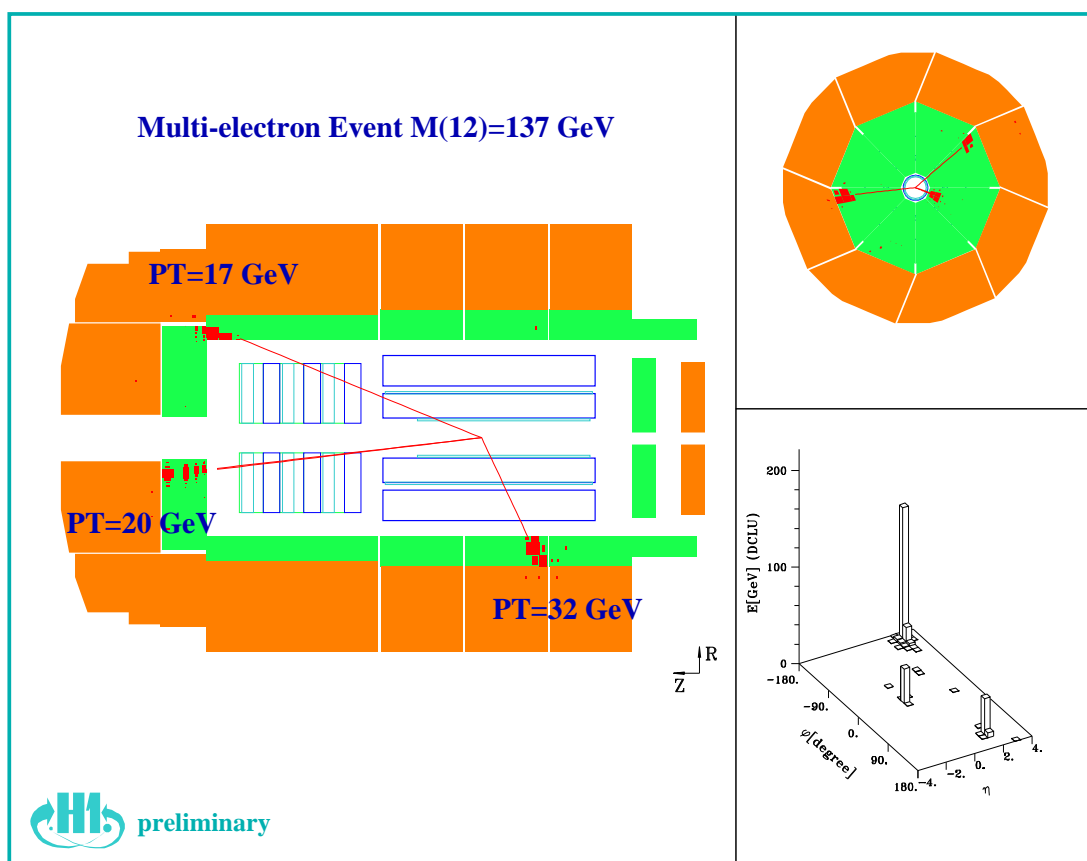
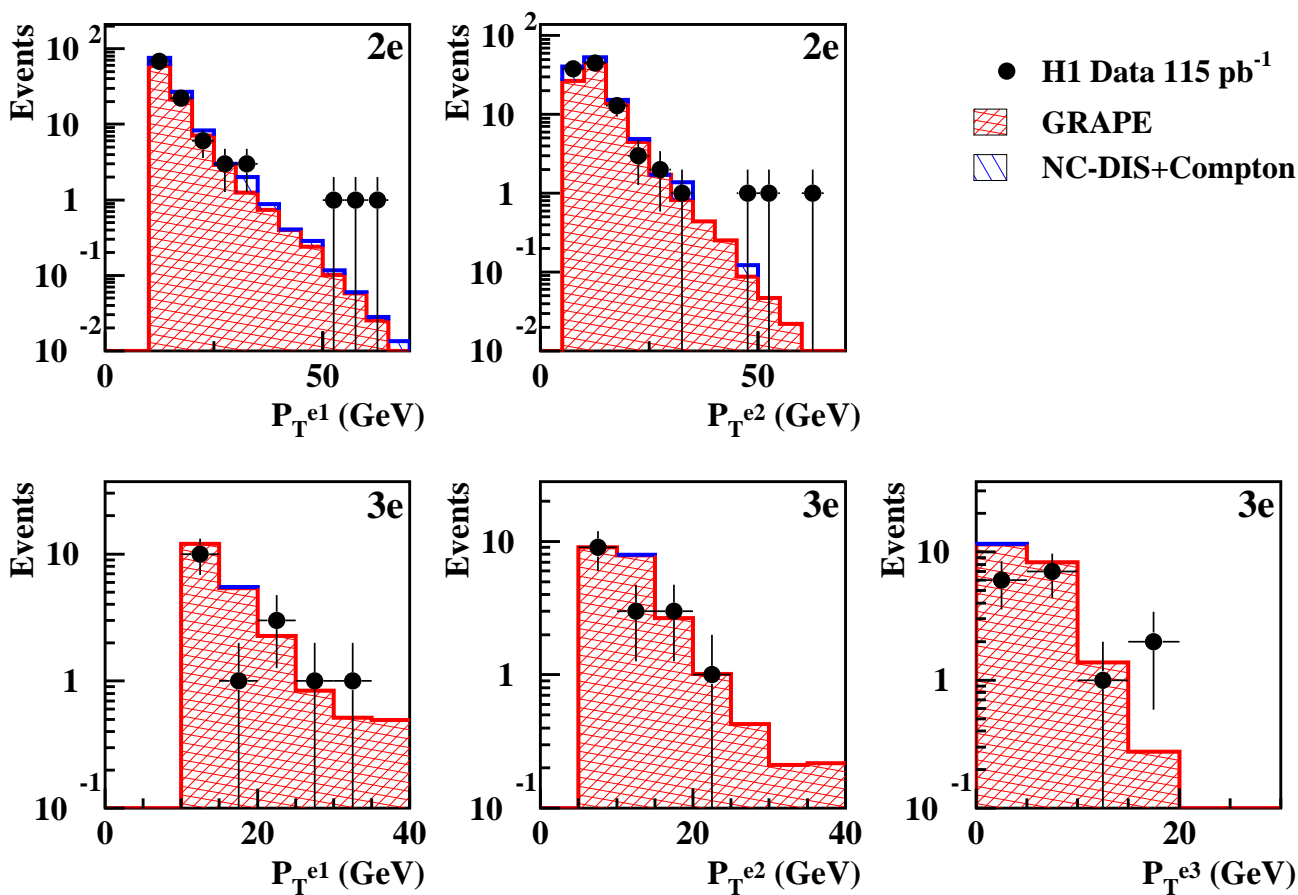
$\rightarrow$  no 4 electron event found by H1 or ZEUS

# H1 Multi-Electrons

## Electron Transverse Momenta

H1 Preliminary

Multi-electron Analysis

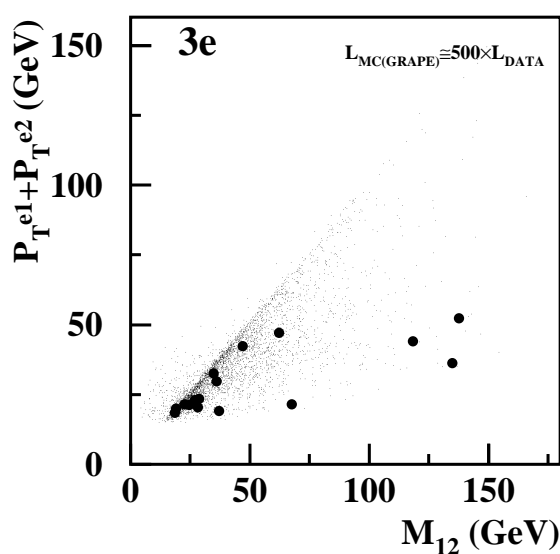
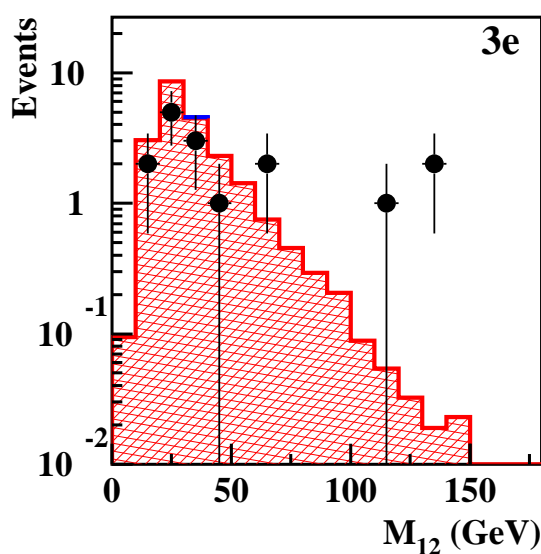
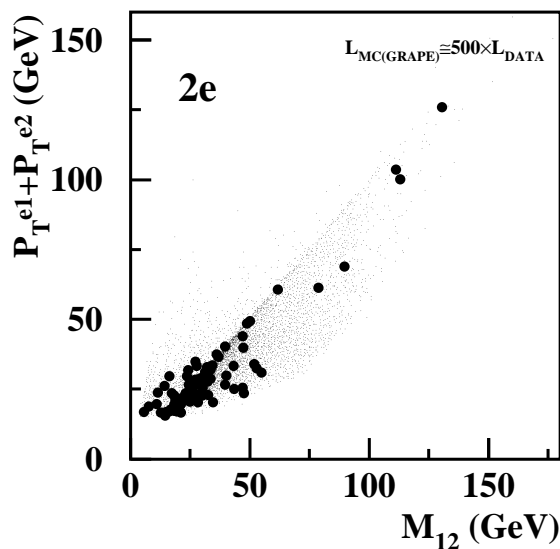
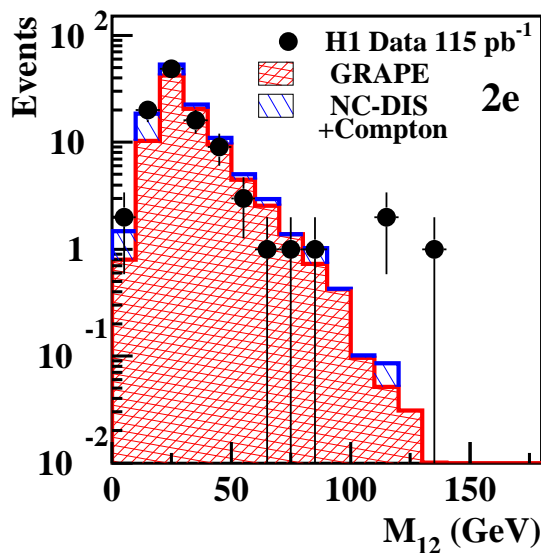


# H1 Multi-Electrons

## Mass of the Two Highest- $P_T$ Electrons

H1 Preliminary

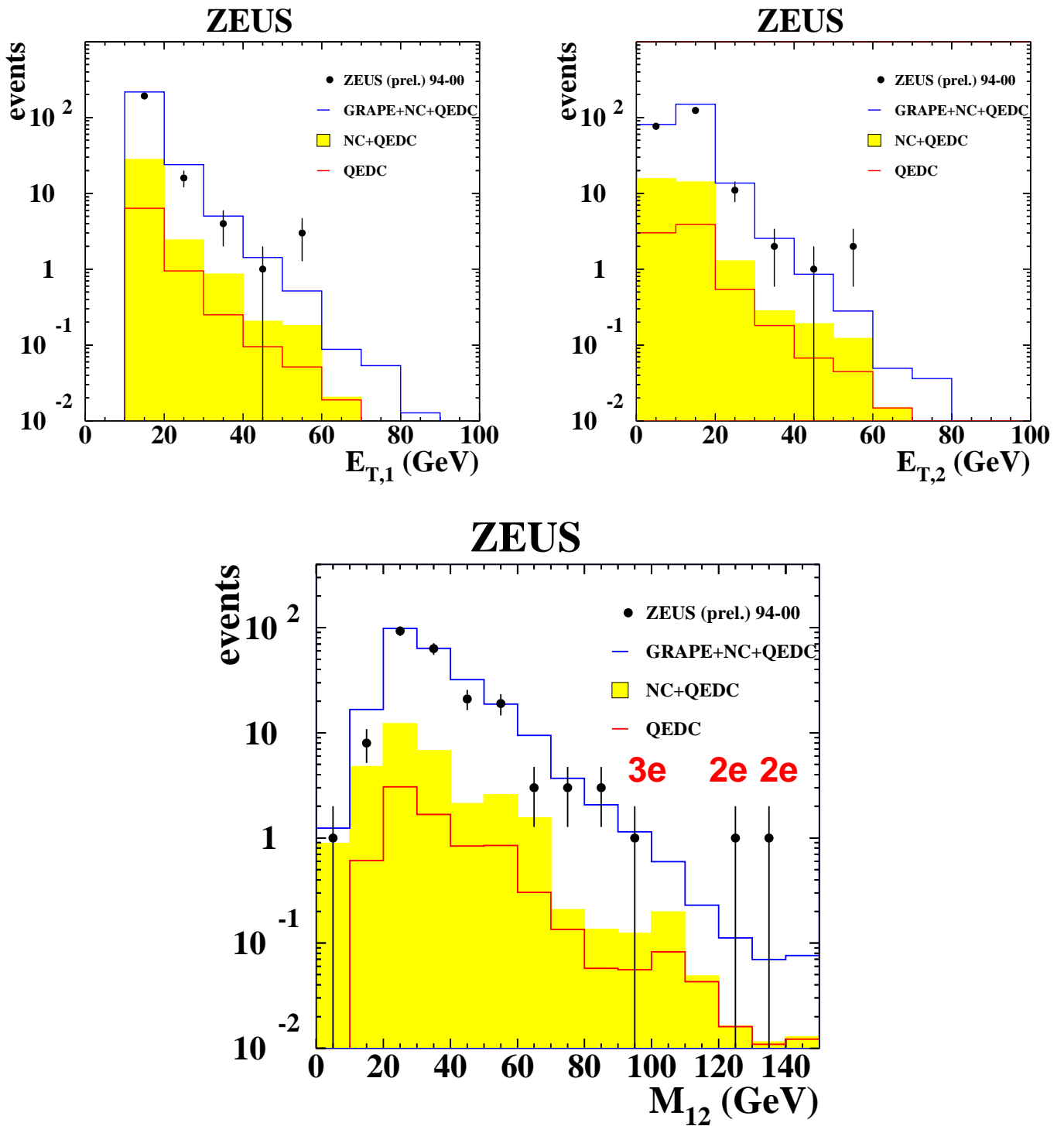
Multi-electron Analysis



H1 see 6 outstanding events with  $M_{12} > 100$  GeV

Selection	H1 Data (115 pb <sup>-1</sup> )	SM expectation
2 e $M_{12} > 100$	3	$0.25 \pm 0.05$
3 e $M_{12} > 100$	3	$0.23 \pm 0.04$

# ZEUS Multi-Electrons



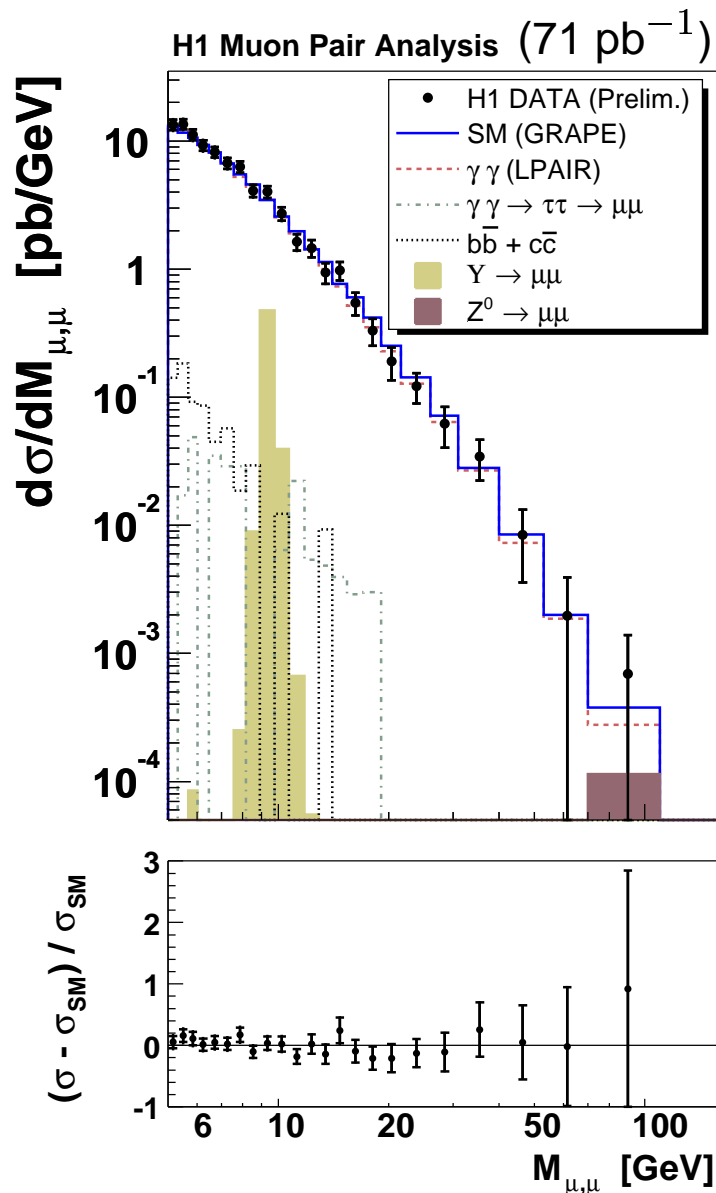
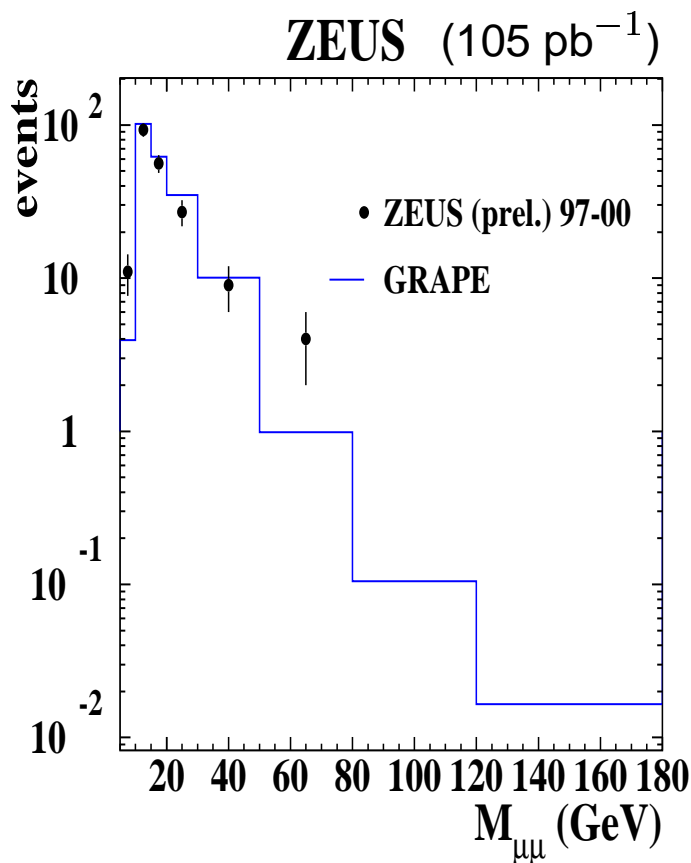
Selection	ZEUS Data (130 pb <sup>-1</sup> )	SM expectation
2 e $M_{12} > 100$	2	$0.77 \pm 0.08$
3 e $M_{12} > 100$	0	$0.37 \pm 0.04$

( H1 / ZEUS polar angle domains are different )

# Comparison to Di-Muon Production

What do we see in  $\mu\mu$ -production?

Angular range:  $20^\circ < \theta_\mu < 160^\circ$



**No  $\mu\mu$  event observed with  $M_{\mu\mu} > 100$  GeV**

Comparison  $2e \leftrightarrow \mu\mu$ :

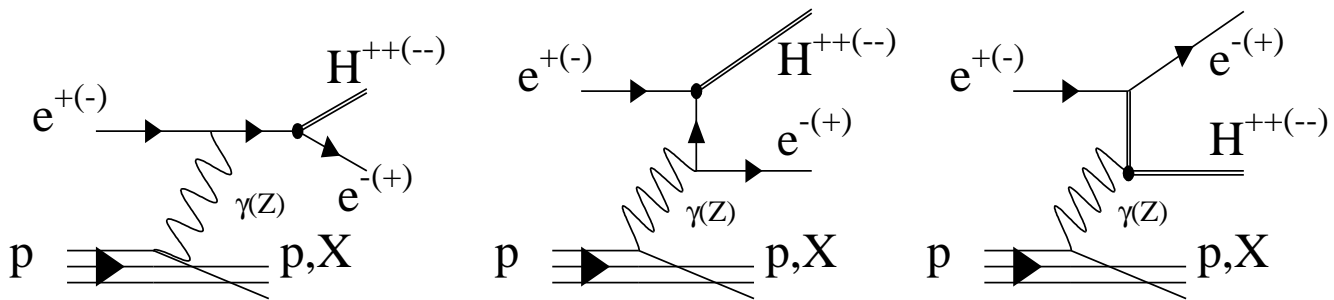
3 central  $2e$  events (H1)  $\rightarrow$  expect  $3 \cdot \frac{\mathcal{L}\epsilon(\mu\mu)}{\mathcal{L}\epsilon(2e)} \sim 1 \mu\mu$  event

$\Rightarrow$  **Comparison not yet conclusive !**

# Doubly Charged Higgs at HERA

- H1 analysis motivated by high mass multi-electron events !
- Attractive BSM interpretation:  $H^{\pm\pm}$  production (e.g. in left-right symmetric or Higgs triplet models)

**At HERA:**  $e^+p \rightarrow e^- H^{++} X$  and  $H^{++} \rightarrow \ell^+ \ell^+$



$\Rightarrow$  striking 3 (and 2) lepton topologies !

**H1 analysis:** (dedicated cuts on top of multi-electron selection)

- mass dependent cut on  $E_T(e1) + E_T(e2)$
- reject events with wrong lepton charges

What about the six H1 events at  $M_{12} > 100$  GeV ?

**No  $3e$  - event** passes cut on  $E_T(e1) + E_T(e2)$

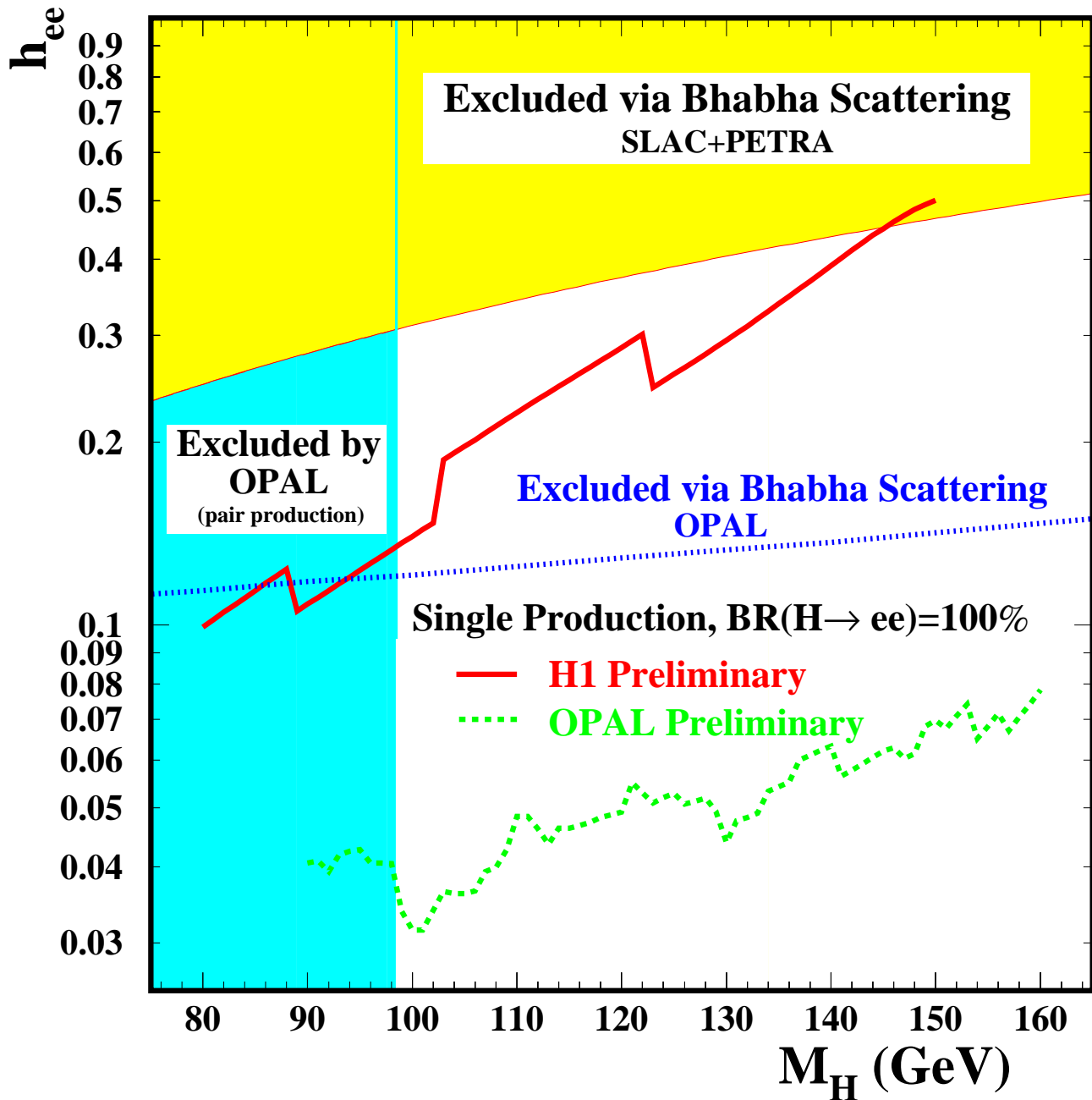
**One  $2e$  - event** fulfills charge requirement (++ charges)

$\Rightarrow$  This makes doubly charged Higgs interpretation very unlikely!

(Other possible interpretations: neutral bileptons, sneutrinos, ...

$\rightarrow$  to be investigated ...)

# Limits on Doubly Charged Higgs



- $H^{++}$  single production has recently been studied by OPAL
- $\Rightarrow$  Strong bounds on Yukawa coupling  $h_{ee}$  of Higgs to electrons
- $\Rightarrow$  Confirms that multi-electron excess not due to  $H^{++}$  decay

# Conclusions

HERA experiments have high sensitivity to rare heavy particle production

Intriguing excess of isolated electron and muon events with missing  $P_T$  seen by H1

ZEUS event rates in agreement with SM prediction

H1  $e + \mu$  excess complemented by new  $\tau$  candidates from ZEUS

Observation of several outstanding 2- and 3-electron events at high masses

Interpretation as doubly charged Higgs ruled out by H1 analysis and new OPAL limit

... We are eagerly awaiting HERA II data and more of those nice high- $P_T$  leptons ...

