

# Study of Rare Exclusive EW Processes at HERA



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On behalf of

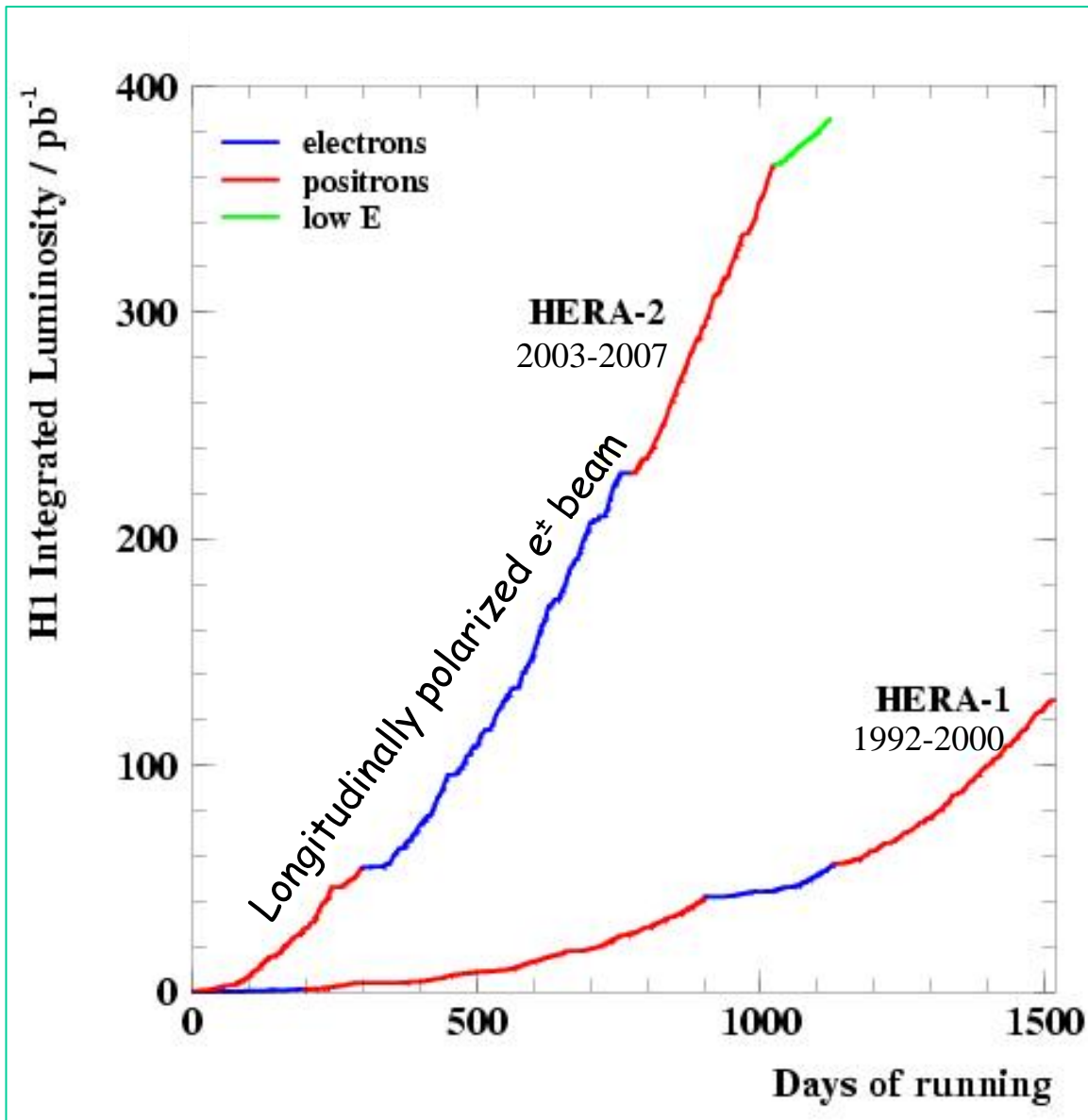


## OUTLINE

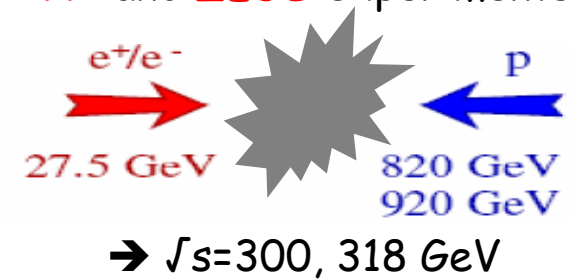
- Introduction
- 1 Multi-lepton events at high  $P_T$
- 2 Isolated lepton events with large missing  $P_T$
- 3 Single W production
- Summary

Covered abstracts: 100, 101, 823, 824 825, 831, 626 and 627  
                                ZEUS                                H1                                H1 & ZEUS

# Introduction: HERA-1+2 Data Sample



Unique **ep collider** for  
**H1** and **ZEUS** experiments



|                | HERA-1               | HERA-2               |
|----------------|----------------------|----------------------|
| e <sup>-</sup> | ~20pb <sup>-1</sup>  | ~200pb <sup>-1</sup> |
| e <sup>+</sup> | ~100pb <sup>-1</sup> | ~200pb <sup>-1</sup> |

→ H1/ZEUS: 0.5fb<sup>-1</sup>/exp

→ H1+ZEUS: ~1fb<sup>-1</sup>

Study rare SM or new  
exotic processes with  
cross-sections down to 1pb

# 1. Multi-Lepton Events @ High $P_T$

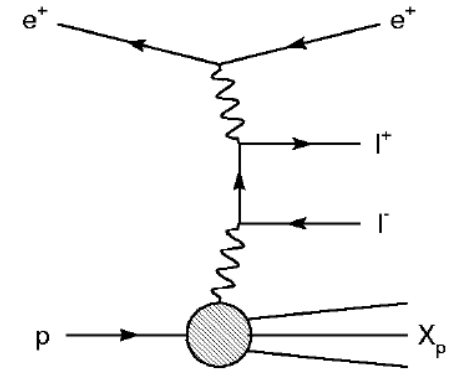
- Excess reported in 2003 by H1 in  $2e$ ,  $3e$  modes

(H1 Collab., Eur. Phys. J. C31 (2003) 17)

- Dominant SM processes:

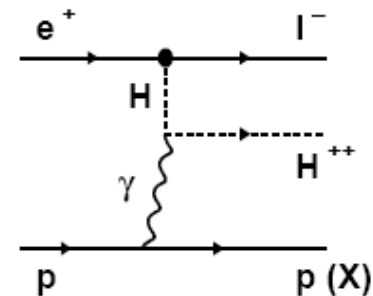
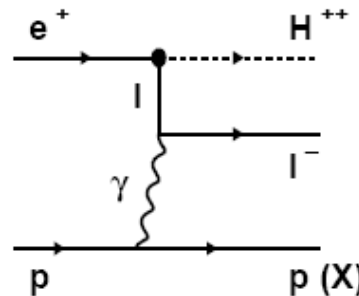
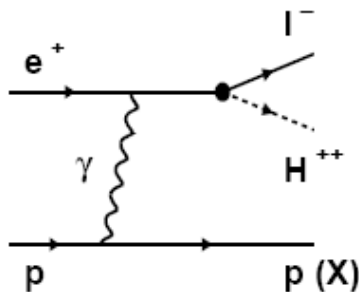
Signal (Grape):  $\gamma\gamma \rightarrow ll$  ( $l=e, \mu, \tau$ )

Background: NC DIS, QED Compton



- Sensitive to new phenomena at large invariant masses

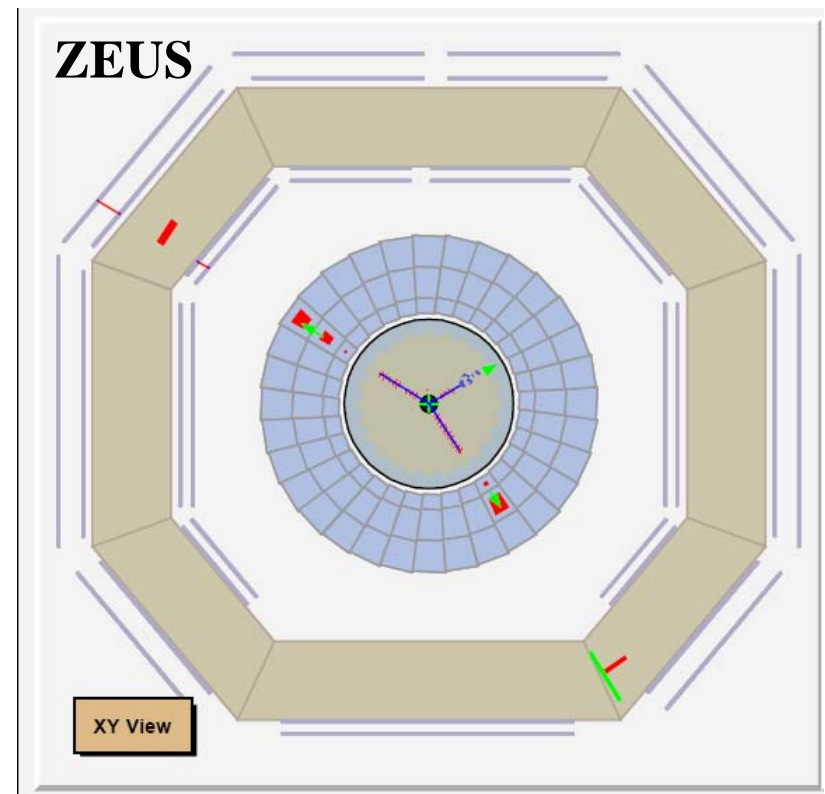
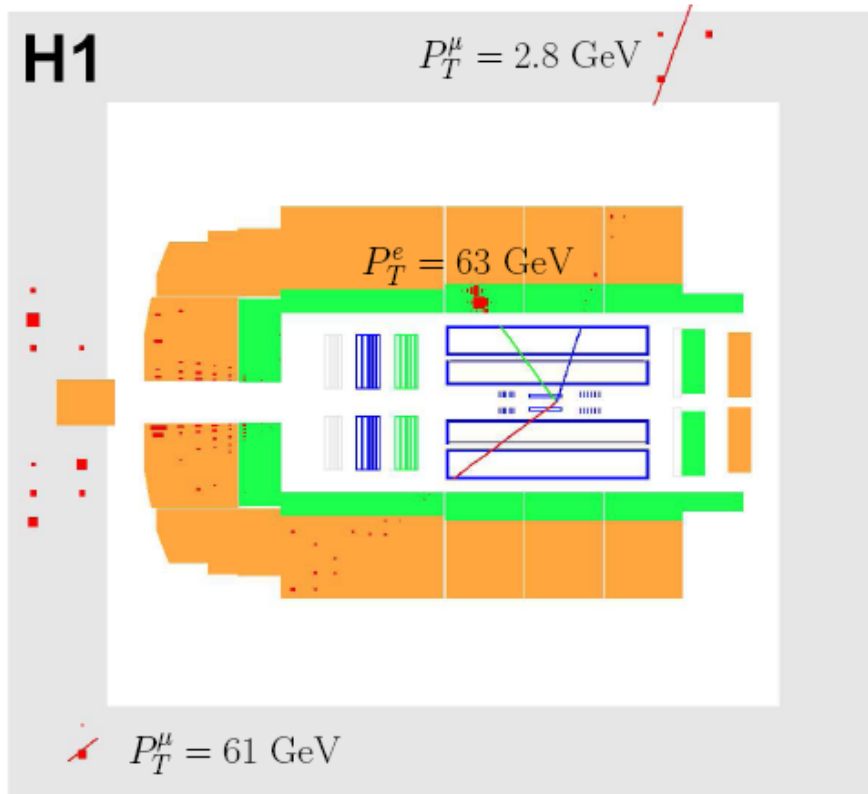
(e.g. Doubly-charged Higgs boson  $H^{++} \rightarrow e^+ l^+$ ):



# 1. Two Examples of Observed Events

Model independent analysis with main selection cuts:

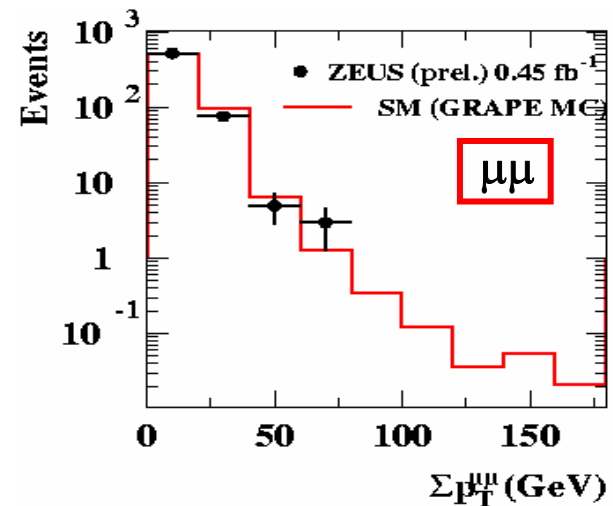
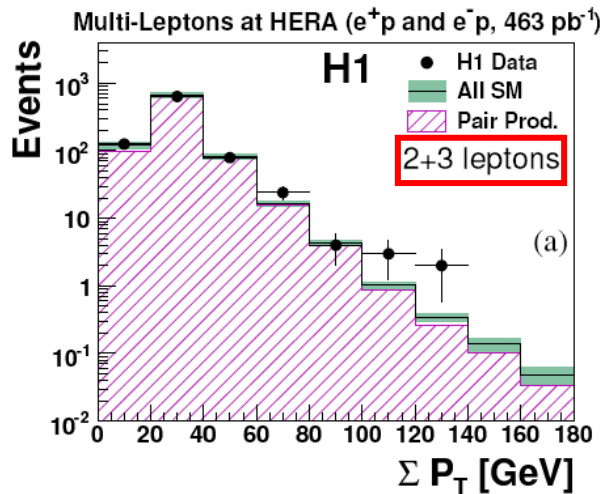
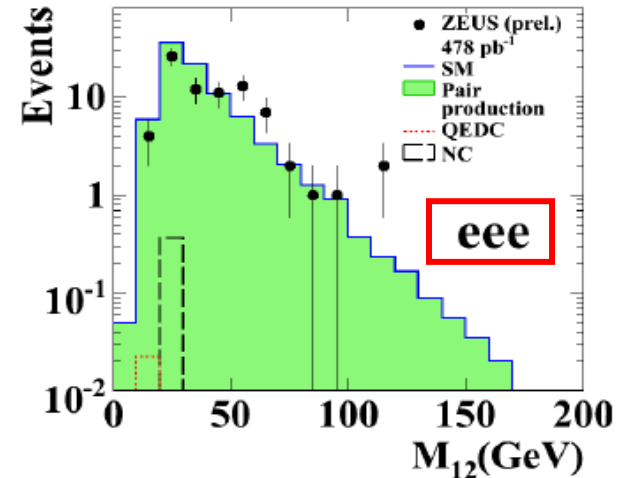
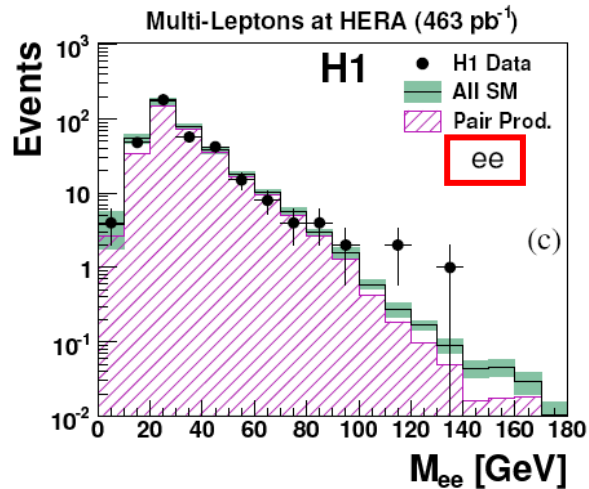
- at least two leptons ( $e, \mu$ ):  $20^\circ < \theta < 150^\circ$ ,  $P_{T1} > 10 \text{ GeV}$ ,  $P_{T2} > 5 \text{ GeV}$
- additional  $e$ :  $5^\circ < \theta < 175^\circ$ ,  $P_T > 5 \text{ GeV}$
- additional  $\mu$ :  $20^\circ < \theta < 160^\circ$ ,  $P_T > 2 \text{ GeV}$



# 1. Mass and $P_T$ Distributions

H1 publication (arxiv:0806.3987 [hep-ex])  
covers  $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$ ,  $e\mu\mu$ ,  $ee\mu$ ,  $eeee$

ZEUS preliminary covers  $ee$ ,  $eee$ ,  $(e)\mu\mu$



# 1. Event Yields at High Mass and $P_T$

➤ At high mass ( $M_{ll} > 100 \text{ GeV}$ ):

| Topology   | H1 publication |                        | ZEUS preliminary |                     |
|------------|----------------|------------------------|------------------|---------------------|
|            | Data           | SM (pair)              | Data             | SM (pair)           |
| ee         | 3              | $1.34 \pm 0.20$ (0.83) | 2                | $1.7 \pm 0.2$ (0.9) |
| e $\mu$    | 1              | $0.59 \pm 0.06$ (0.59) |                  |                     |
| eee        | 3              | $0.66 \pm 0.09$ (0.66) | 2                | $1.0 \pm 0.1$ (1.0) |
| $\mu\mu$   | 1              | $0.17 \pm 0.07$ (0.17) |                  |                     |
| e $\mu\mu$ | 2              | $0.16 \pm 0.05$ (0.16) |                  |                     |

➤ At high  $P_T$  (scalar sum  $> 100 \text{ GeV}$ ):

| Data set         | H1 publication |                        |
|------------------|----------------|------------------------|
|                  | Data           | SM (pair)              |
| e <sup>+</sup> p | 5              | $0.96 \pm 0.12$ (0.78) |
| e <sup>-</sup> p | 0              | $0.64 \pm 0.09$ (0.51) |
| All              | 5              | $1.60 \pm 0.20$ (1.29) |

➔ H1 excess observed only in e<sup>+</sup> data sample

H1+ZEUS combination being performed

# 1. Cross Section Measurement

H1 phase space:

$$e p \rightarrow e \ell^+ \ell^- X$$

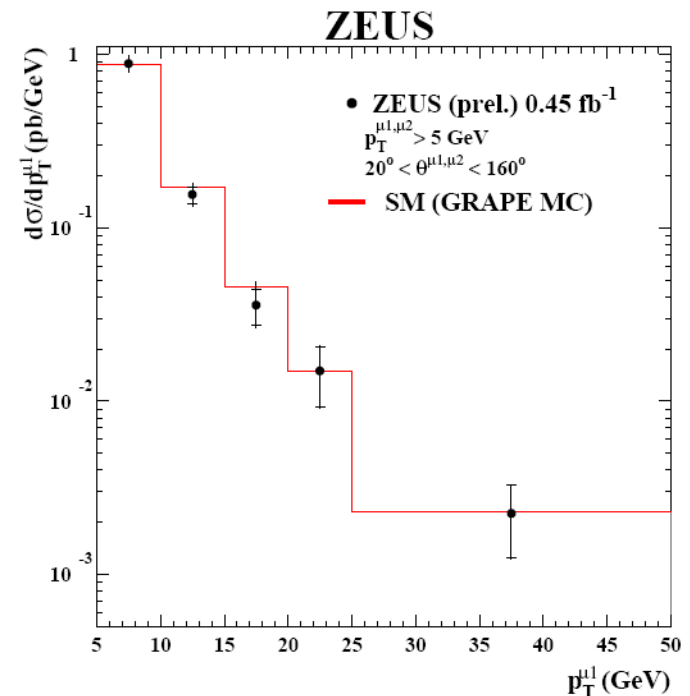
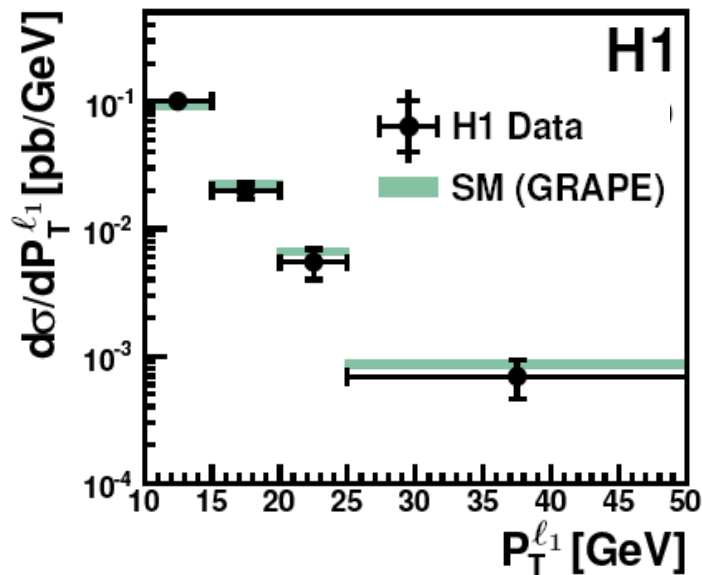
$$P_T^{\ell_1} > 10 \text{ GeV}, P_T^{\ell_2} > 5 \text{ GeV}$$

$$20^\circ < \theta^{\ell_1, \ell_2} < 150^\circ$$

$$y < 0.82, Q^2 < 1 \text{ GeV}^2$$

Whereas H1 is the averaged cross section for e and mu samples, ZEUS is for di-mu sample only

Multi-Leptons at HERA (463 pb<sup>-1</sup>)



→ Steeply falling cross section in agreement with the expectation

## 2. Isolated Lepton Events with Large Missing $P_T$

### ➤ 1<sup>st</sup> excess seen by H1 & published in 1998

(H1 Collab., Eur. Phys. J. C5 (98) 575)

### ➤ Main SM processes:

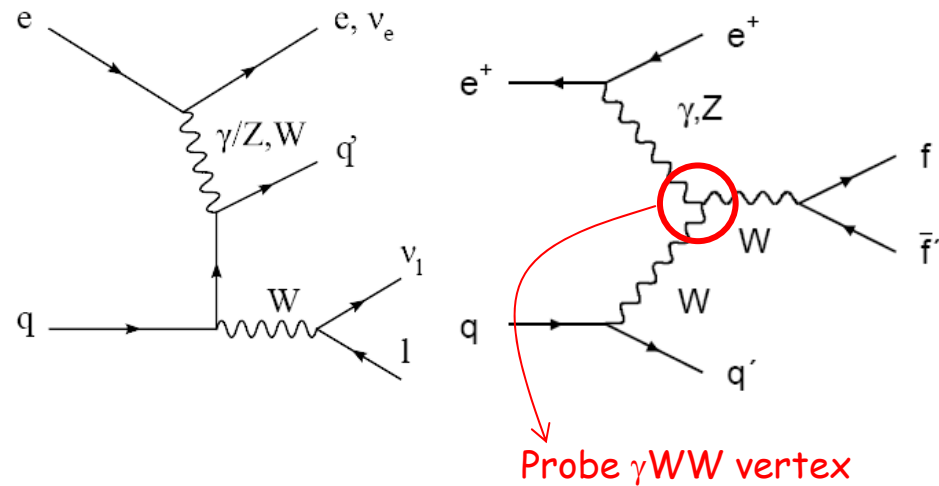
Signal (Epvec):  $\gamma p$  production

NLO correction has 15% uncertainty

Background: NC, CC DIS

pair production

$\gamma p \rightarrow X$

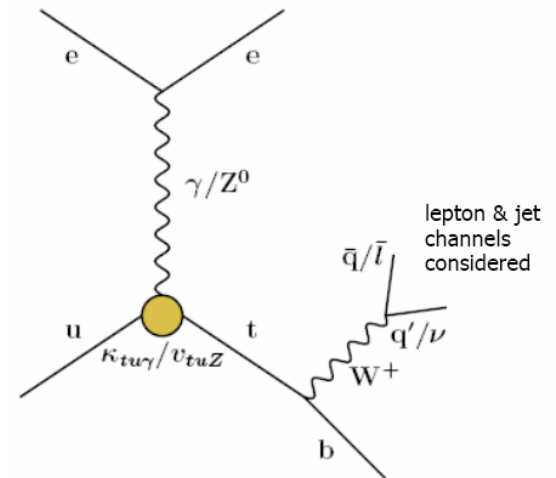


### ➤ Exotic models:

e.g. single top production via  
Flavor Changing Neutral Current

$\kappa_{tu\gamma}$ : anomalous  $\gamma$  magnetic coupling

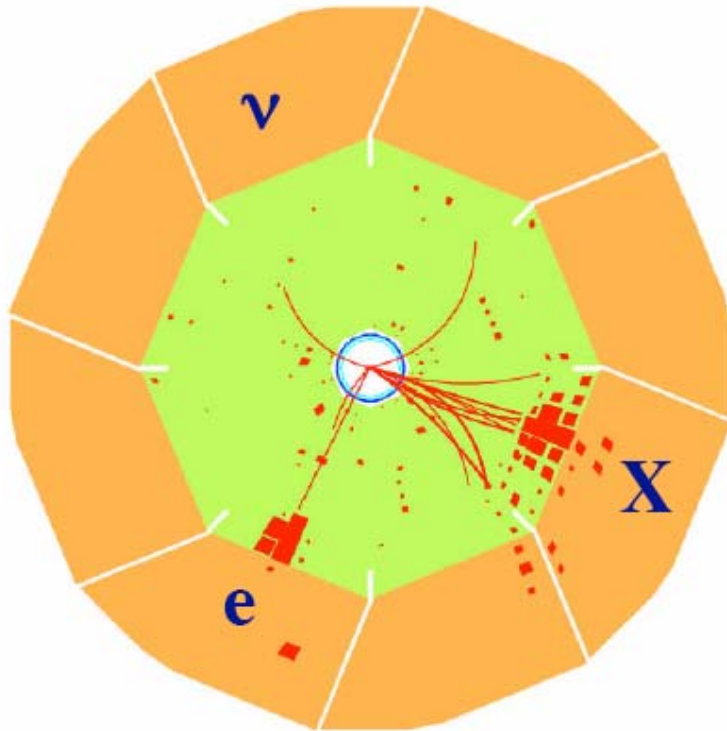
$v_{tuZ}$ : anomalous  $Z$  vector coupling



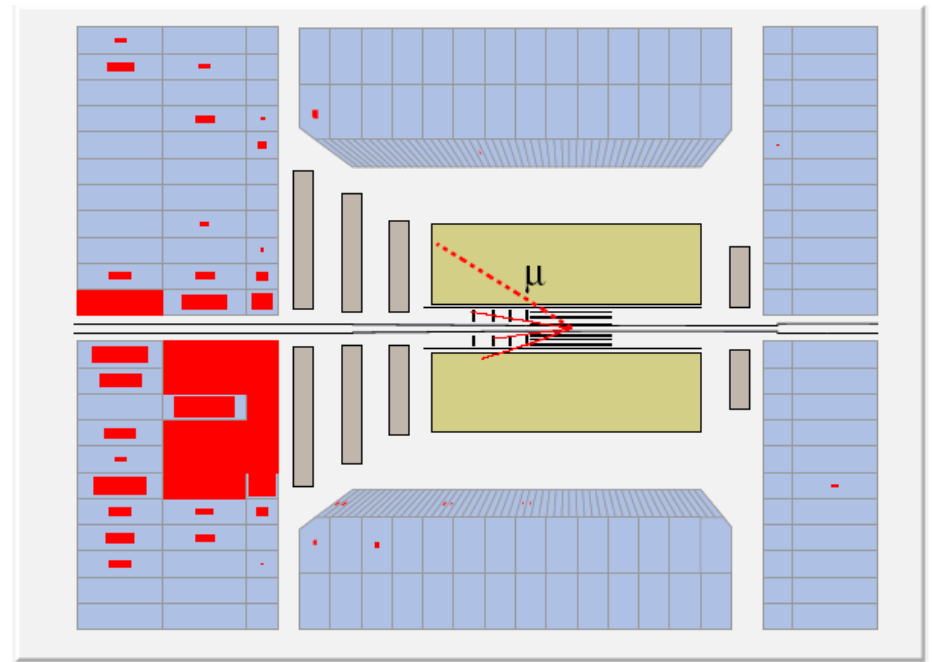
## 2. Two Examples of Observed Events

Model independent analysis ( $e, \mu$  phase space cuts):

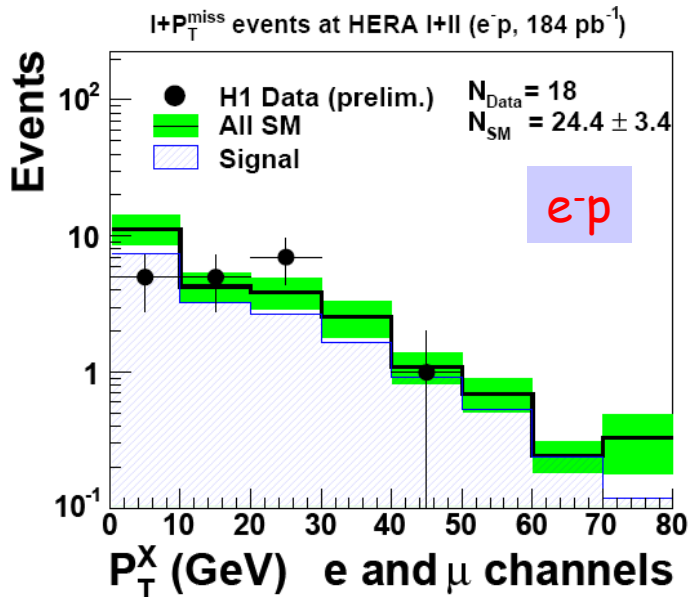
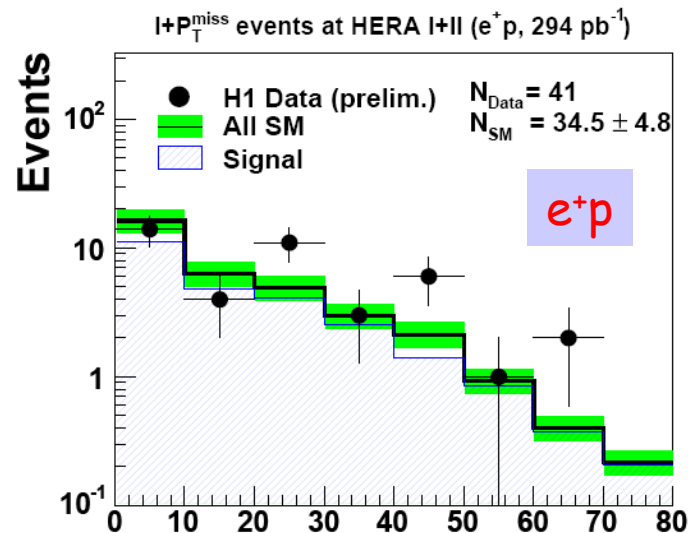
**H1:**  $5^\circ < \theta_f < 140^\circ$ ,  $P_{Tf} > 10 \text{ GeV}$   
 $P_{T\text{calo}} > 12 \text{ GeV}$ ,  $P_{TX} > 12 \text{ GeV}$



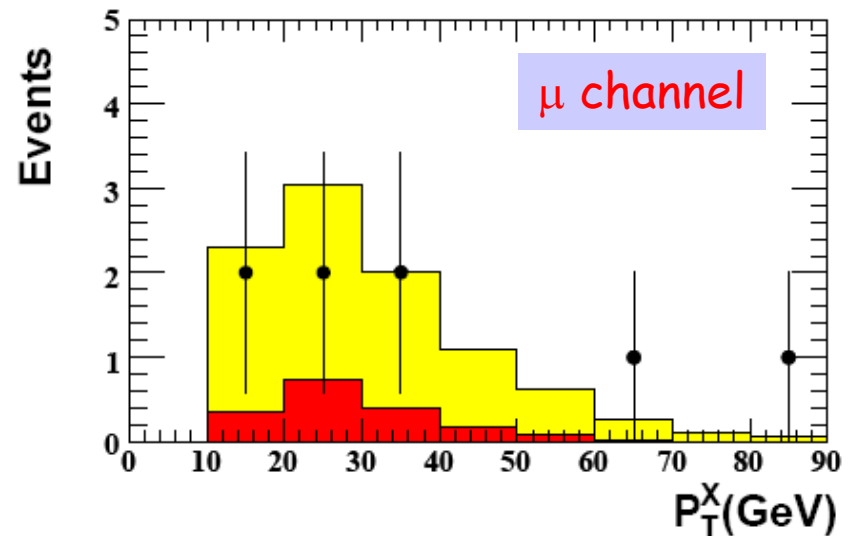
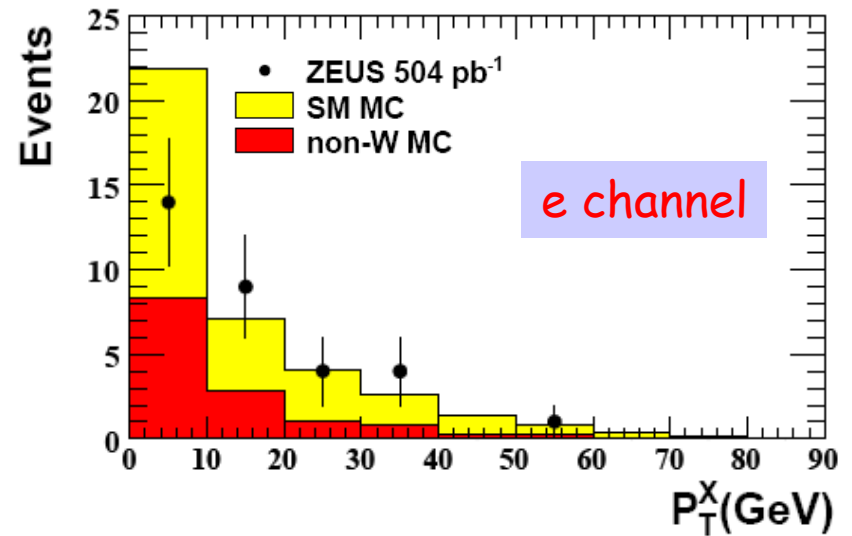
**ZEUS:**  $15^\circ < \theta_f < 120^\circ$ ,  $P_{Tf} > 10 \text{ GeV}$   
 $P_{T\text{calo}} > 12 \text{ GeV}$ ,  $P_{TX} > 12 \text{ GeV}$



## 2. Missing $P_{TX}$ Distributions



ZEUS publication (arxiv: 0807.589)



## 2. Event Yields and Cross Section

➤ Event yields at high  $P_{TX}$  ( $> 25$  GeV):

| Data set | Channel | H1 preliminary |                     | ZEUS publication |                     |
|----------|---------|----------------|---------------------|------------------|---------------------|
|          |         | Data           | Exp (signal)        | Data             | Exp (signal)        |
| $e^+p$   | $e$     | 11             | $4.7 \pm 0.9$ (75%) | 3                | $4.0 \pm 0.6$ (77%) |
|          | $\mu$   | 10             | $4.2 \pm 0.7$ (85%) | 3                | $3.4 \pm 0.5$ (81%) |
|          | $\tau$  | 0              | $0.5 \pm 0.1$ (72%) |                  |                     |
| $e^-p$   | $e$     | 3              | $3.8 \pm 0.6$ (61%) | 3                | $3.2 \pm 0.5$ (69%) |
|          | $\mu$   | 0              | $3.1 \pm 0.5$ (74%) | 2                | $2.3 \pm 0.4$ (85%) |
|          | $\tau$  | 1              | $1.0 \pm 0.1$ (63%) |                  |                     |

➤ Cross section at high  $P_T$  ( $5^\circ < \theta_l < 140^\circ$ ,  $P_{Tl} > 10$  GeV and  $P_{Tmiss} > 12$  GeV):

H1 preliminary:  $\sigma_{l+P_{Tmiss}} = 0.24 \pm 0.05$  (stat)  $\pm 0.05$  (syst) [pb]

SM expectation:  $0.26 \pm 0.04$  [pb]

### 3. W Production Cross Section

The isolated lepton with large missing  $P_T$  is dominated by SM W production

→ This same sample is used to measure the W production cross section

ZEUS:

$$\sigma_{ep \rightarrow lWX} = 0.89^{+0.25}_{-0.22} \text{ (stat)} \pm 0.10 \text{ (syst)} [\text{pb}] @ \sqrt{s}=316 \text{ GeV}$$

H1 (preliminary):

$$\sigma_{ep \rightarrow lWX} = 1.23 \pm 0.25 \text{ (stat)} \pm 0.22 \text{ (syst)} [\text{pb}] @ \sqrt{s}=320 \text{ GeV}$$

In agreement with the SM expectation:

$$\begin{aligned} \sigma_{ep \rightarrow lWX} &= 1.2 \pm 0.2 [\text{pb}] @ \sqrt{s}=316 \text{ GeV} \\ &= 1.3 \pm 0.2 [\text{pb}] @ \sqrt{s}=320 \text{ GeV} \end{aligned}$$

→ Both measurements have a significance of ~5 standard deviations

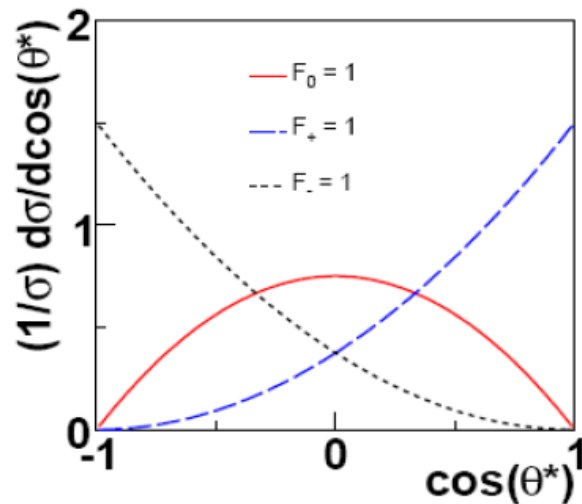
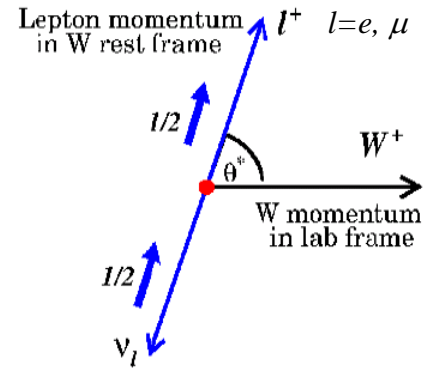
# 3. W Polarization Fractions @ HERA

Restricted to the isolated lepton sample in which a W is reconstructed

Angular distribution and polarization fractions:

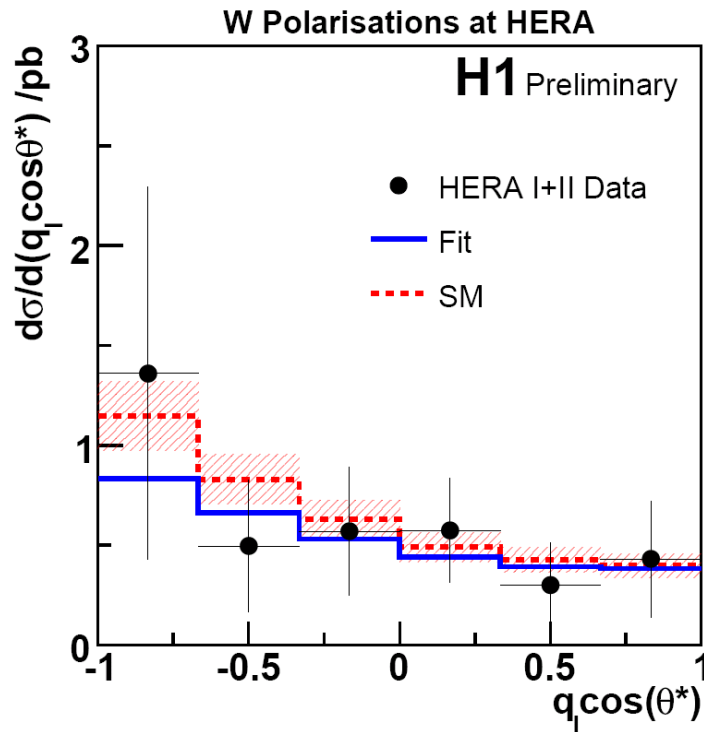
$$\frac{dN}{d \cos \theta^*} = \underbrace{F_-}_{\text{left}} \frac{3}{8} (1 - \cos \theta^*)^2 + \underbrace{F_0}_{\text{longitudinal}} \frac{3}{4} \sin^2 \theta^* + \underbrace{F_+}_{\text{right}} \frac{3}{8} (1 + \cos \theta^*)^2$$

$F_+ = 1 - F_- - F_0$



→ Three components  
 left ( $F_- = 1$ )  
 right ( $F_+ = 1$ )  
 longitudinal ( $F_0 = 1$ )  
 have well distinct distributions

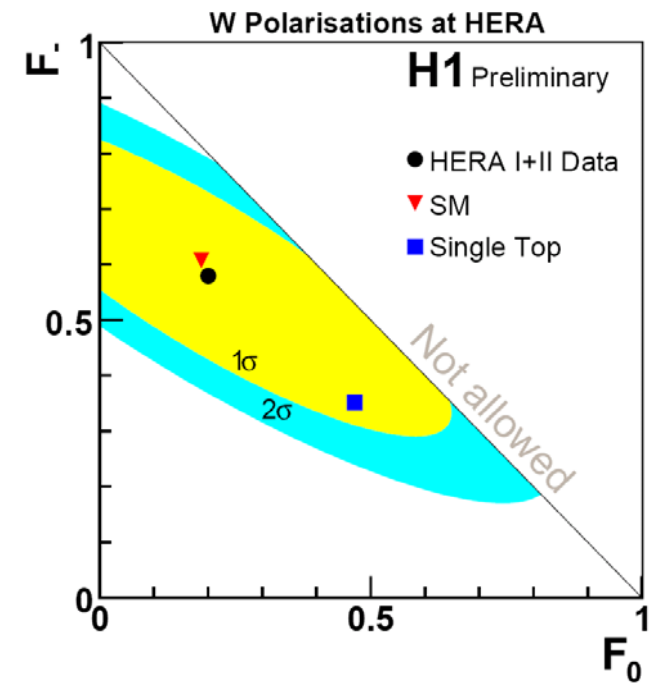
# 3. W Polarization Fractions @ HERA



One parameter fit

Two parameter fit

| Fraction | H1 result   | SM                            |
|----------|---|-------------------------------|
| $F_0$    | $0.15 \pm 0.21_{\text{stat}} \pm 0.09_{\text{sys}}$ | $0.19 \pm 0.01_{\text{stat}}$ |
| $F_-$    | $0.58 \pm 0.15_{\text{stat}} \pm 0.12_{\text{sys}}$ | $0.61 \pm 0.01_{\text{stat}}$ |



# Summary

- ❑ Full HERA 1+2 data analyzed
- ❑ H1+ZEUS combinations are/being performed
- ❑ In all results, general agreement between data and the SM, some interesting excess at high mass/ $P_T$  observed

More information is available at H1 and ZEUS working group web page:

<http://www.desy.de/h1zeus/exotics/index.html>