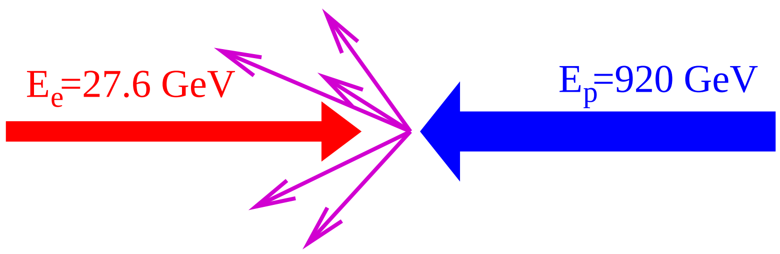
Searches for Signatures of Physics Beyond the Standard Model with high-P_T Leptons at HERA



$\sqrt{s} = 320$ GeV

Jochen Dingfelder (Heidelberg)

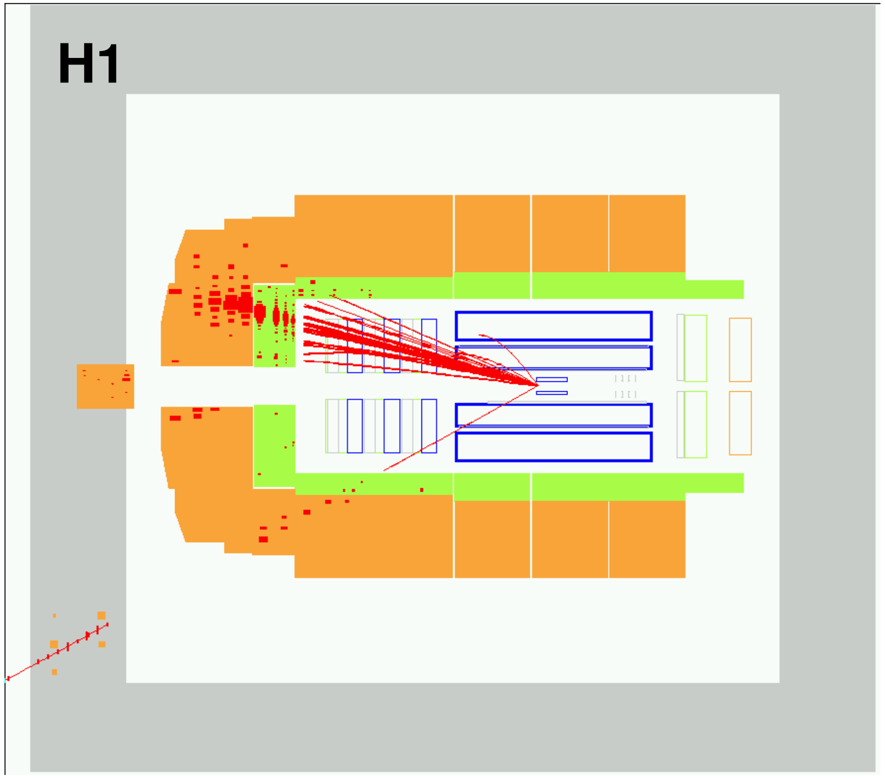
On behalf of the H1 and ZEUS collaborations

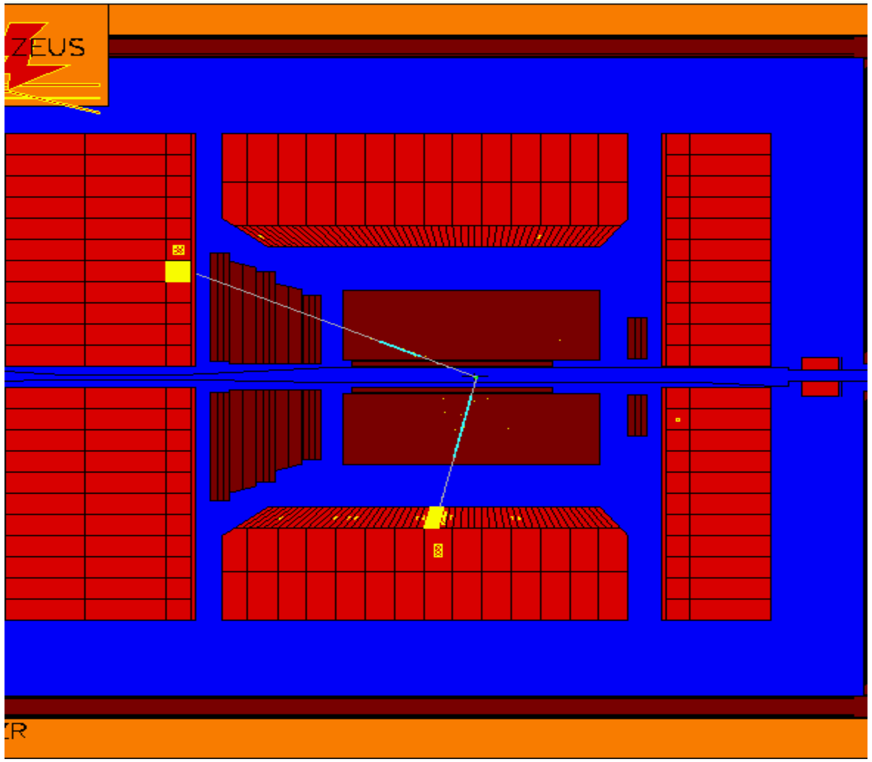
Results to be presented use the full HERA I data (~ 130 pb $^{-1}$)

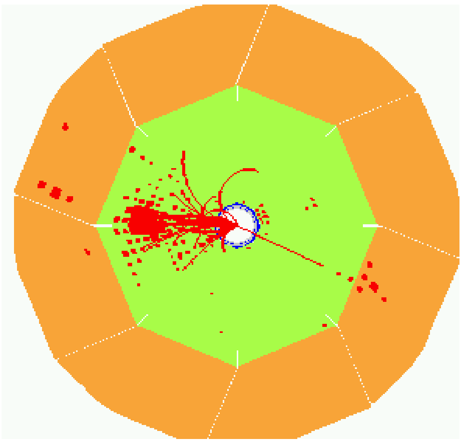
Contents:

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

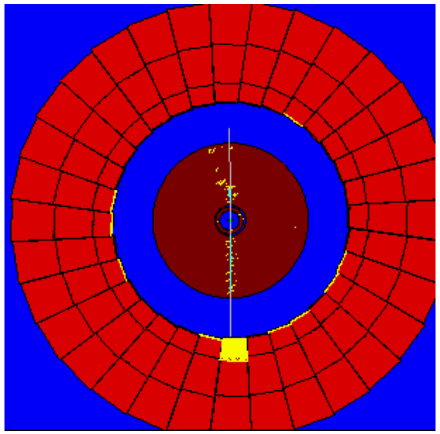
H1 and ZEUS Detectors: Outstanding Lepton Events







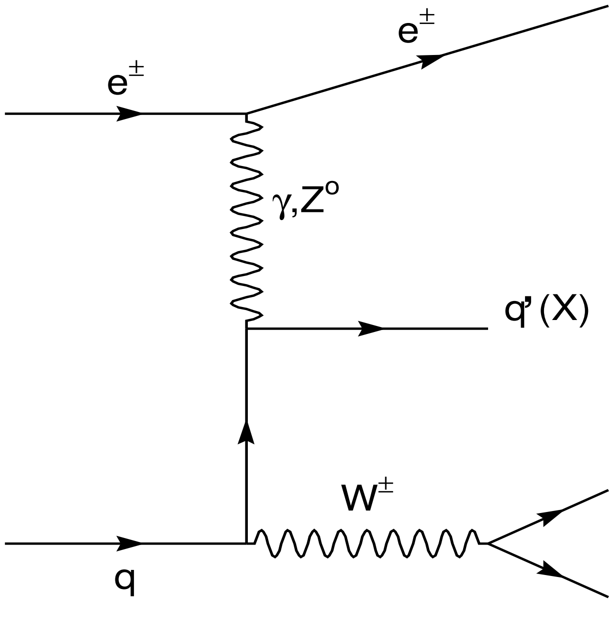
Event with high-P_T muon, jet, and P_T^{miss}



Event with two high-P_T electrons

Isolated Lepton Events with Missing P_T

Dominant SM process = Production of real W's



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

$\Rightarrow$ **hadronic jet**

$\Rightarrow$ **isolated lepton**

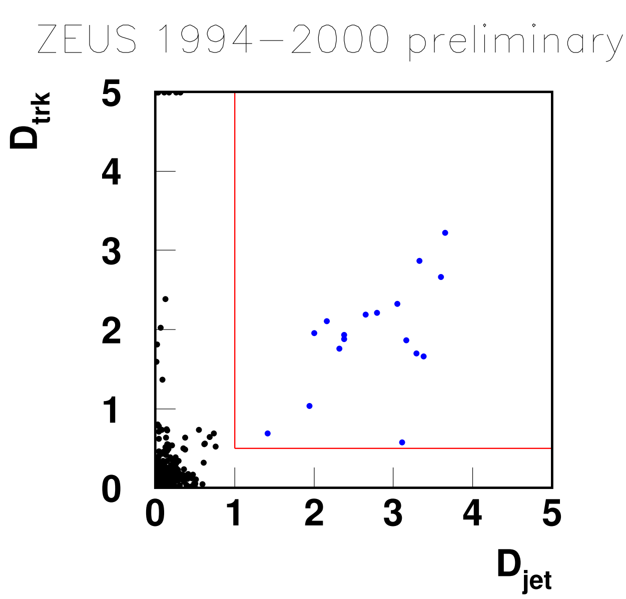
$\Rightarrow$ **missing P_T**

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)	$> 20^\circ$ (e) , 10° (μ)	$> 11.5^\circ$

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

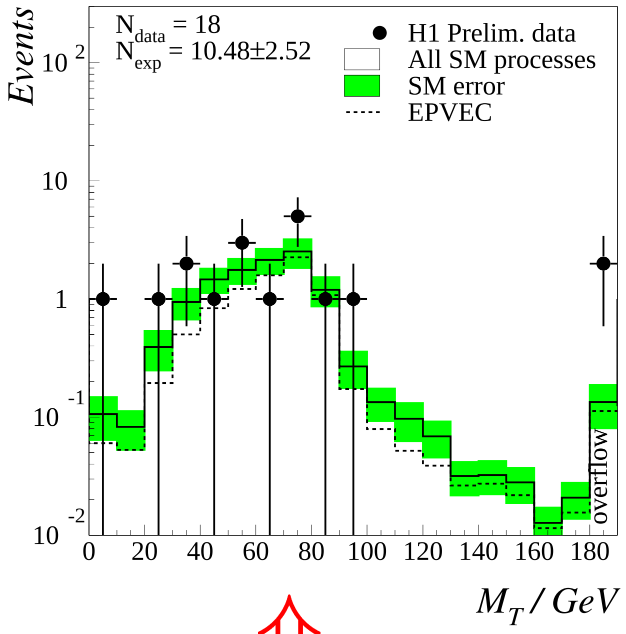
$D_{jet} \quad > 1.0$ **(wrt. jets)**

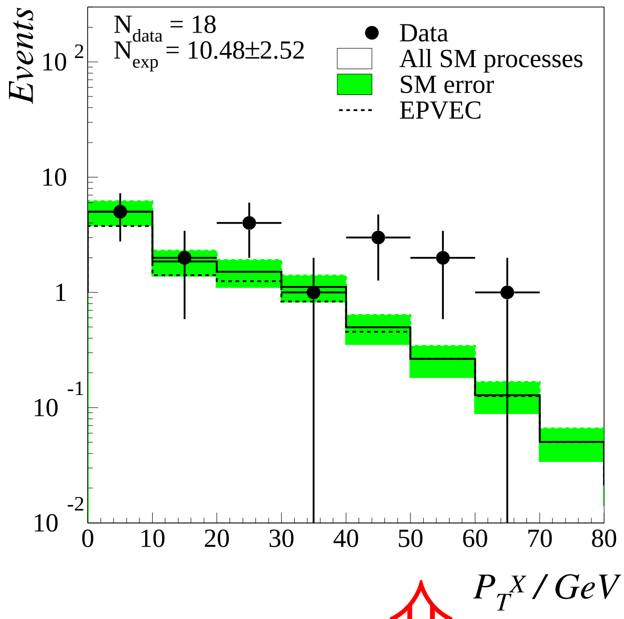
$D_{track} > 0.5$ **(wrt. other tracks)**



Isolated Leptons and W Production

H1: e + μ (after further cuts to enhance W component)



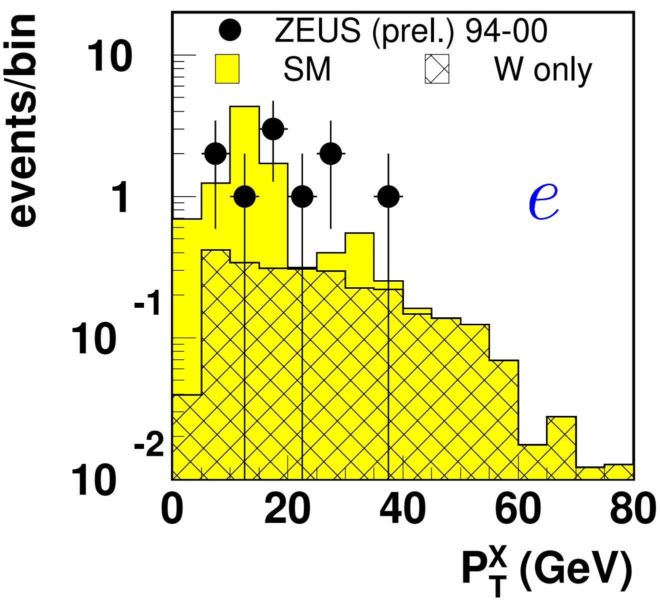


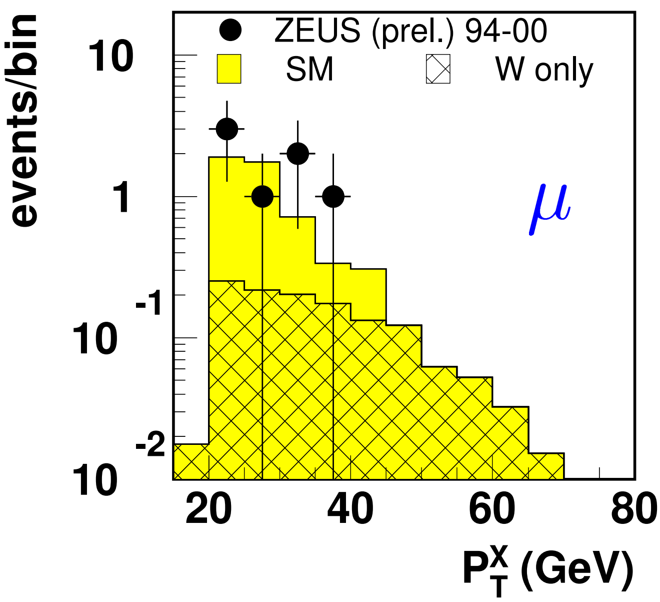
Compatible with W hypothesis

Excess at high P_T^X

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

ZEUS: (looser cuts than H1 $\rightarrow$ not yet final W selection)





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

H1: (final W selection)

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

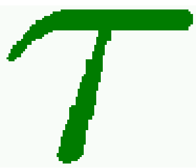
ZEUS preliminary $e^\pm$p (130.5 pb^{-1})	Electrons obs./exp. (W)	Muons obs./exp. (W)
$P_T^X > 25$ GeV	1 / 1.14 $\pm$ 0.06 (1.10)	1 / 1.29 $\pm$ 0.16 (0.95)
$P_T^X > 40$ GeV	0 / 0.46 $\pm$ 0.03 (0.46)	0 / 0.50 $\pm$ 0.08 (0.41)

Observed e, μ events consistent with SM prediction

$\Rightarrow$ H1 and ZEUS background rates consistent,

but discrepancy in observed event rates!

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

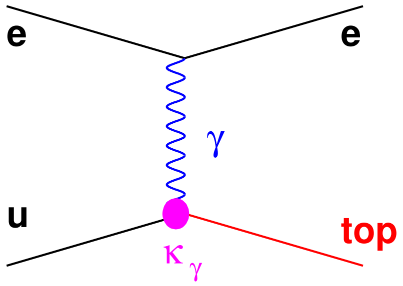


ZEUS preliminary $e^\pm$p (130.5 pb^{-1})	Taus obs./exp. (W)
$P_T^X > 25$ GeV	2 / 0.12 $\pm$ 0.02 (0.10)
$P_T^X > 40$ GeV	1 / 0.06 $\pm$ 0.01 (0.05)

$\Rightarrow$ Two new τ events at high P_T^X complement H1 e+μ excess

Single Top Production at HERA

- **Single top production in SM negligible**
  $\Rightarrow$ **production in FCNC process**
  with anomalous $tu\gamma$-coupling



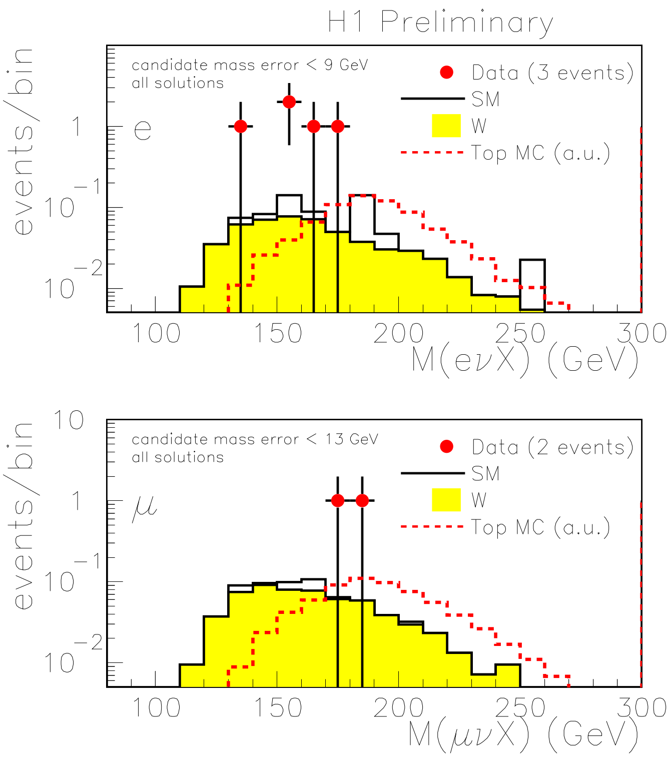
- $t \to b + W$ $\Rightarrow$ **expect high P_T^X (b-quark)**
  $\Rightarrow$ **Could the isolated lepton excess at high P_T^X come from single top?**

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

- **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 μ) , expect:** 1.77 ± 0.46



$W \to e\nu$

$W \to \mu\nu$

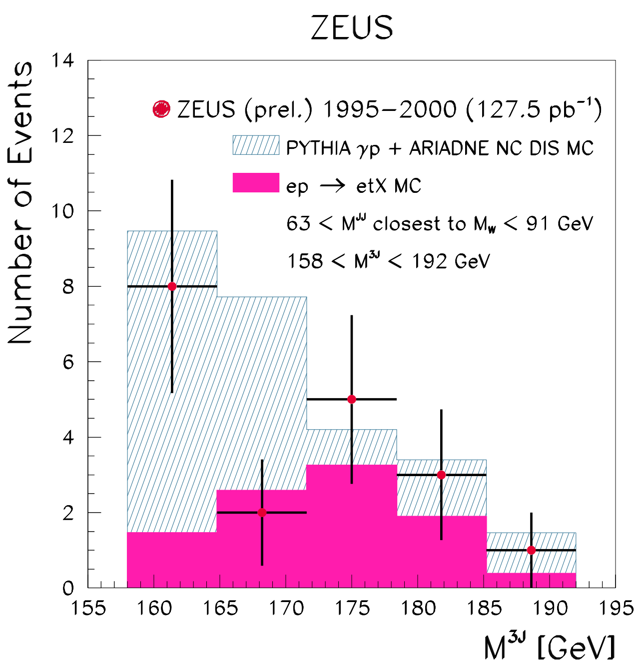
W mass constraint imposed
$\Rightarrow$ **2 possible solutions per event**

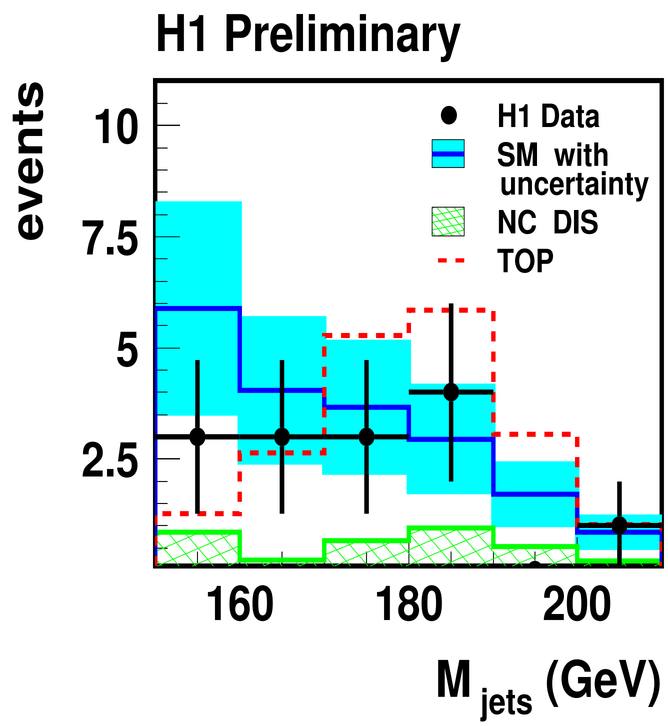
Results on Single Top - Hadronic Decay

Hadronic Top Decays: $t \to b\,W$, $\hookrightarrow q\bar{q}'$ $\Rightarrow$ 3 high-P_T jets

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

+ cut on decay angle (H1)





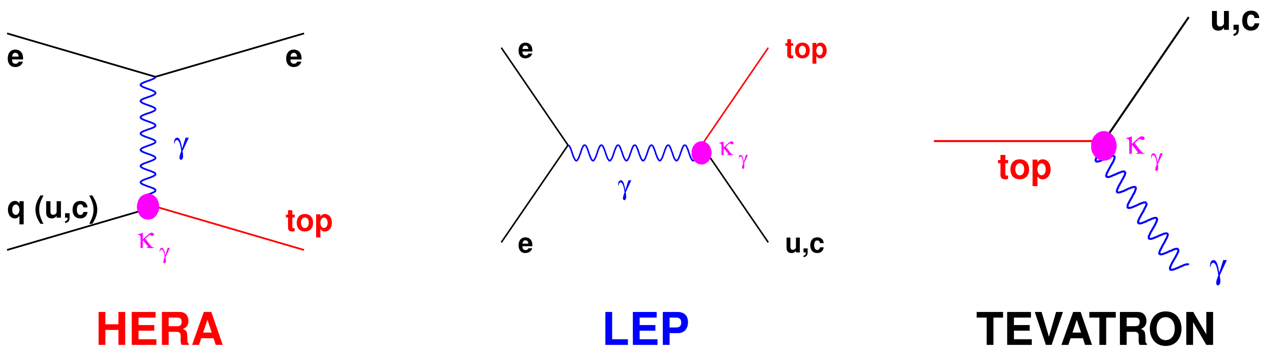
	DATA	Standard Model
ZEUS prelim.	19	20.0
H1 prelim.	14	19.6 ± 7.8

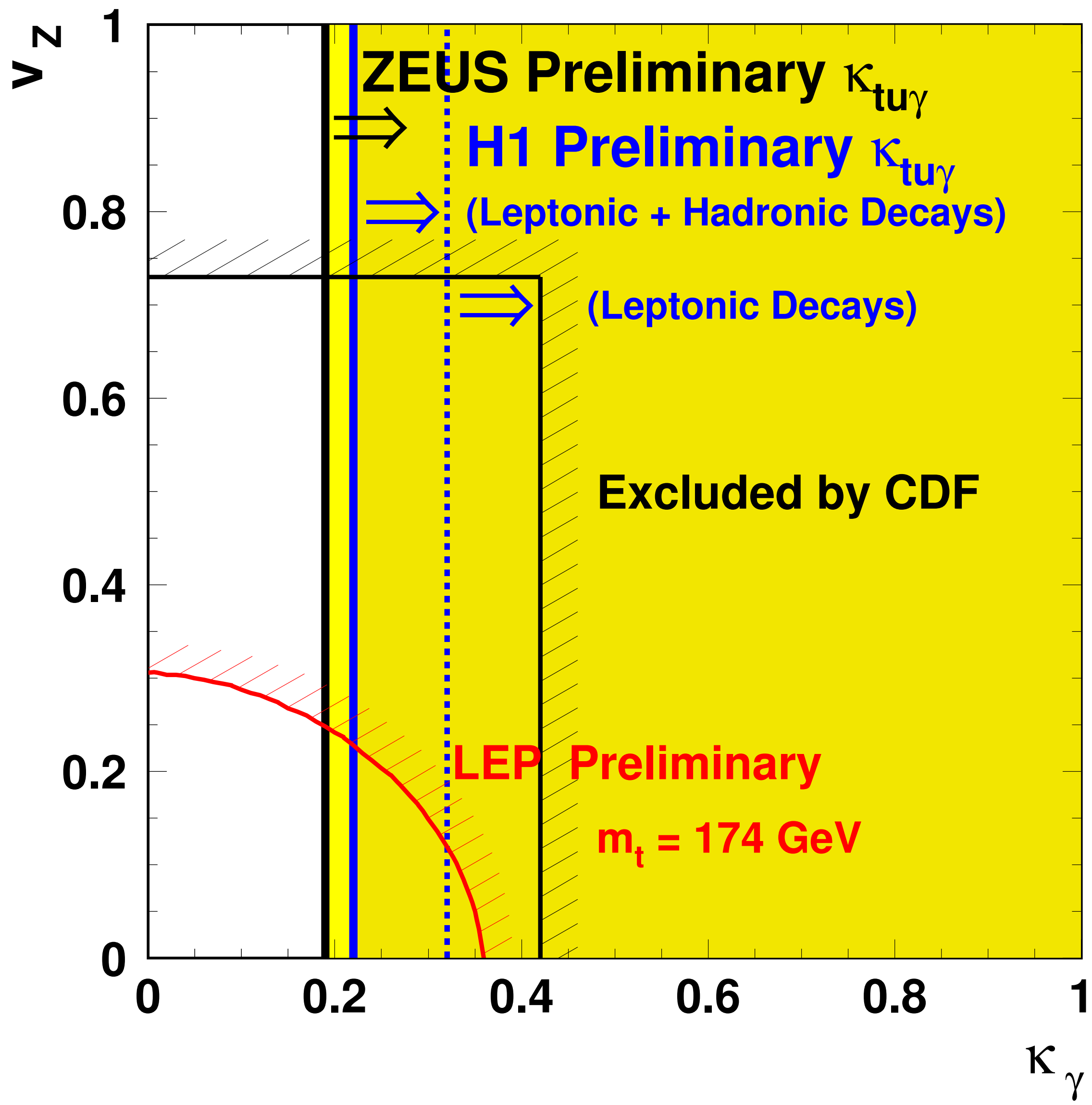
Comparison with semi-leptonic decays (H1):

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) :**

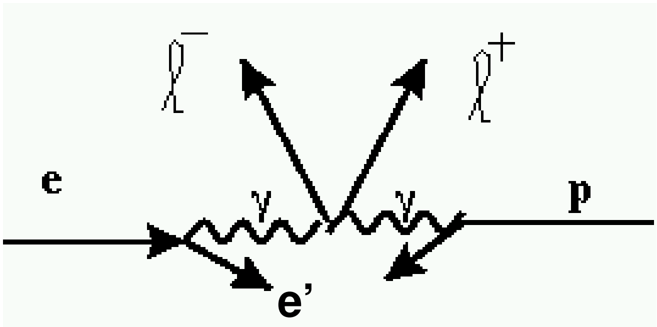
$$\kappa_{tu\gamma} < 0.19 \quad \textbf{(ZEUS)}$$
$$< 0.22 \quad \textbf{(H1)}$$

Search for Multi-Lepton Events

ℓ-pair production cross-section at HERA falls off steeply with P_T^ℓ
$\Rightarrow$ 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^{nd} electron from γ 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: $20° < \theta_e < 150°$ ZEUS: $17° < \theta_e < 164°$
- track associated to e shower

$3\ e$ sample:

- additional 3^{rd} electron ($5° < \theta_e < 175°$)

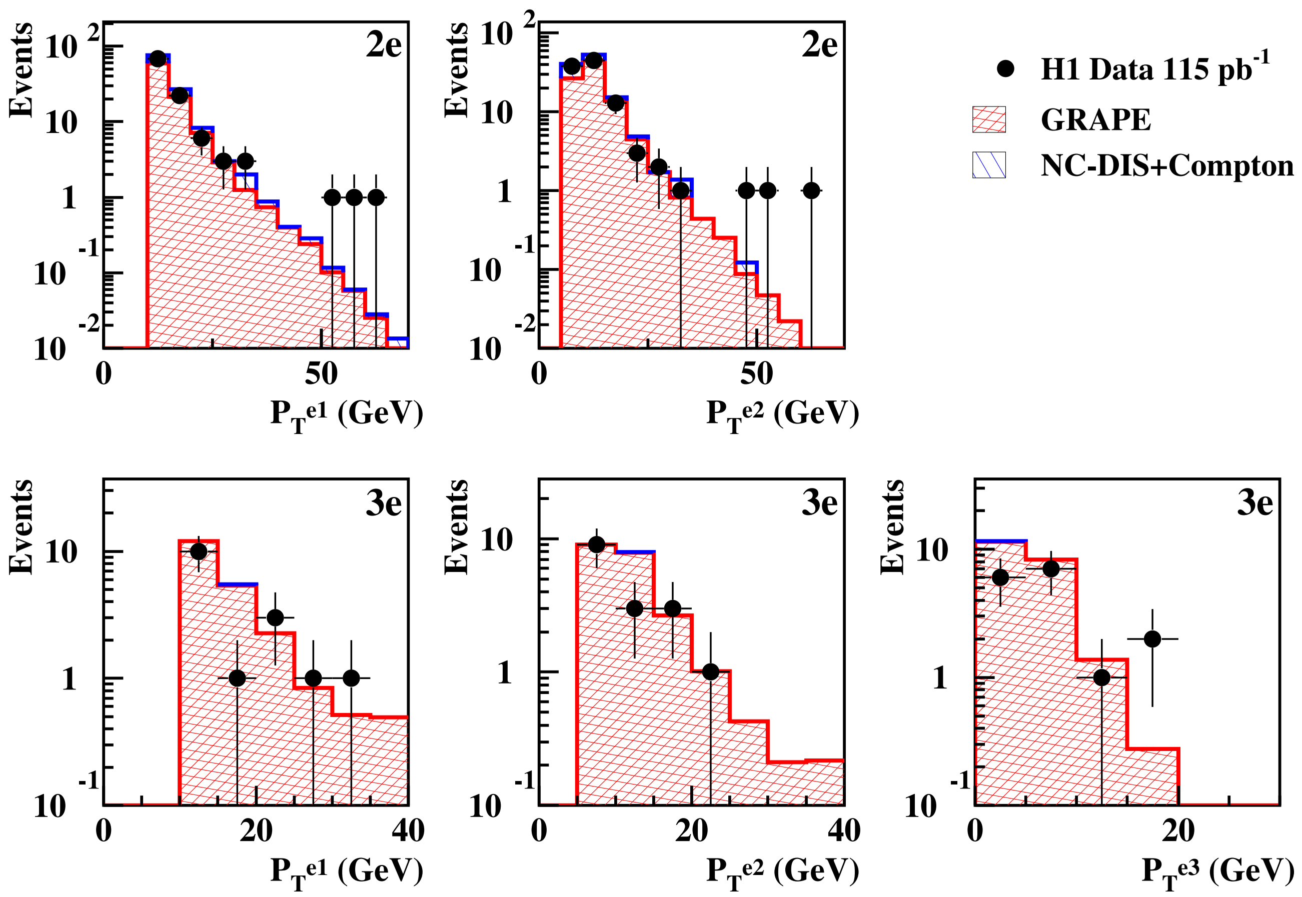
$\rightarrow$ no 4 electron event found by H1 or ZEUS

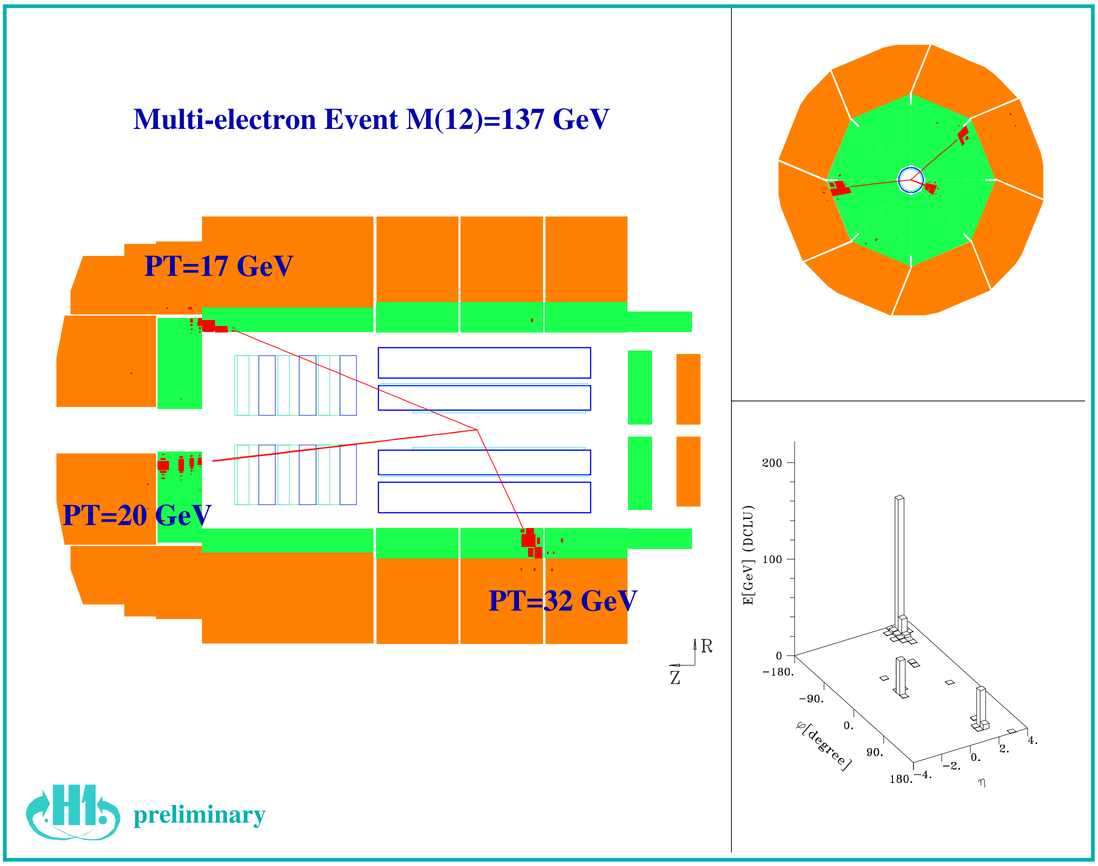
H1 Multi-Electrons

Electron Transverse Momenta

H1 Preliminary

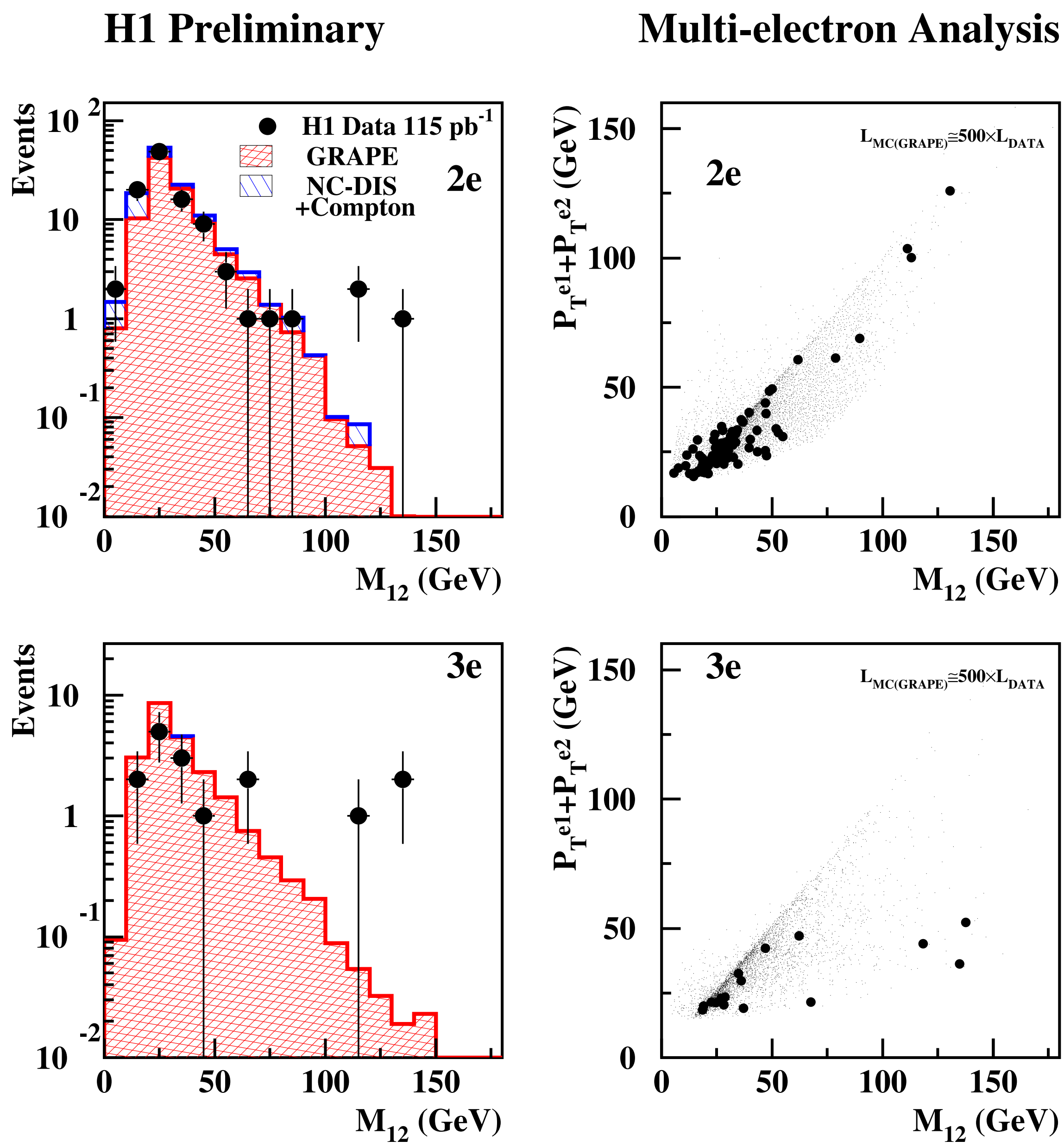
Multi-electron Analysis





H1 Multi-Electrons

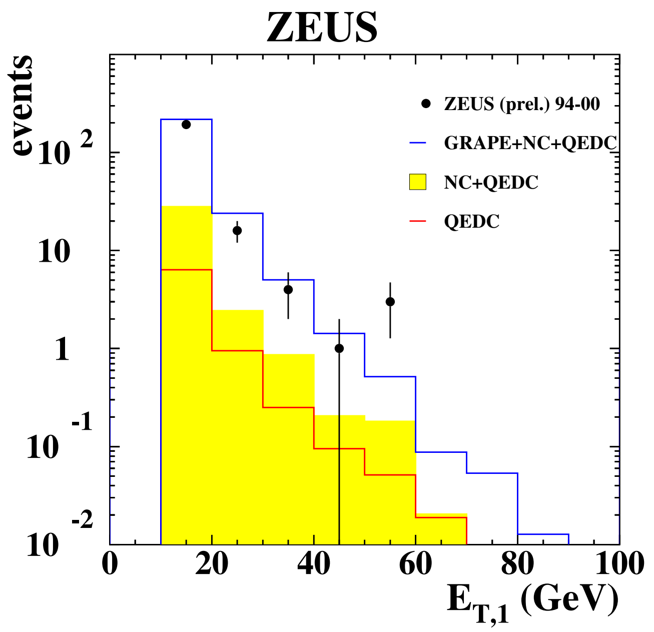
Mass of the Two Highest-P_T Electrons

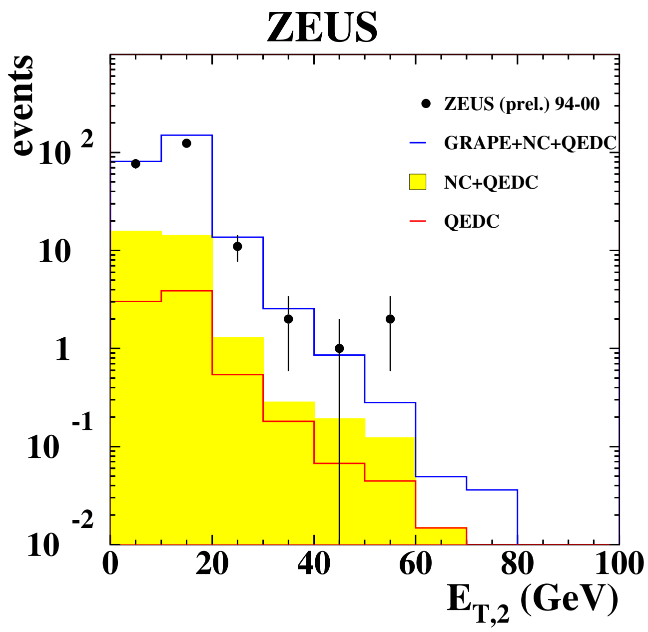


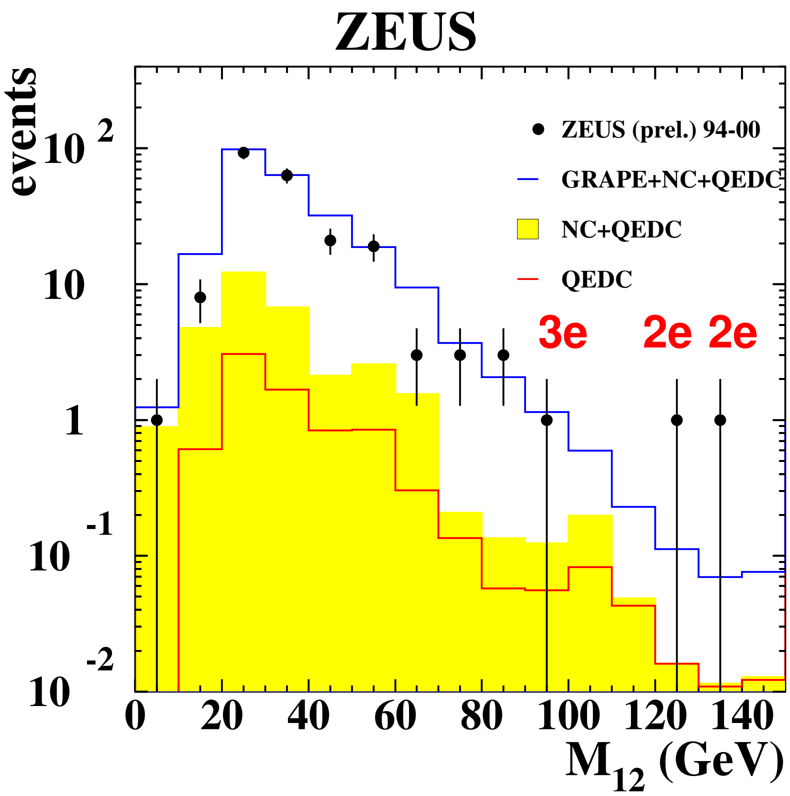
H1 see 6 outstanding events with $M_{12} > 100$ GeV

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

ZEUS Multi-Electrons







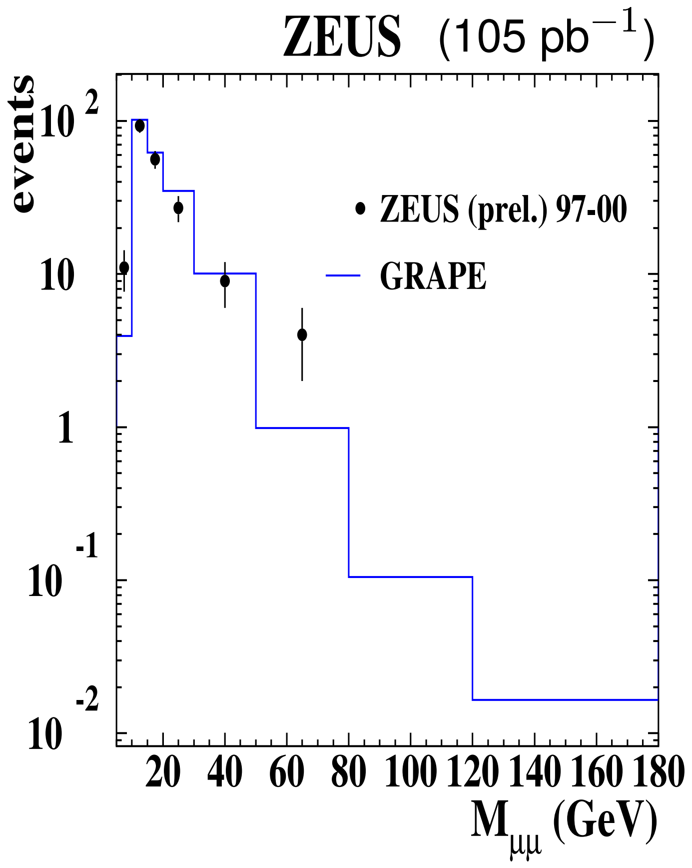
Selection	ZEUS Data (130 pb^{-1})	SM expectation
$2\ e \quad M_{12} > 100$	2	0.77 ± 0.08
$3\ e \quad M_{12} > 100$	0	0.37 ± 0.04

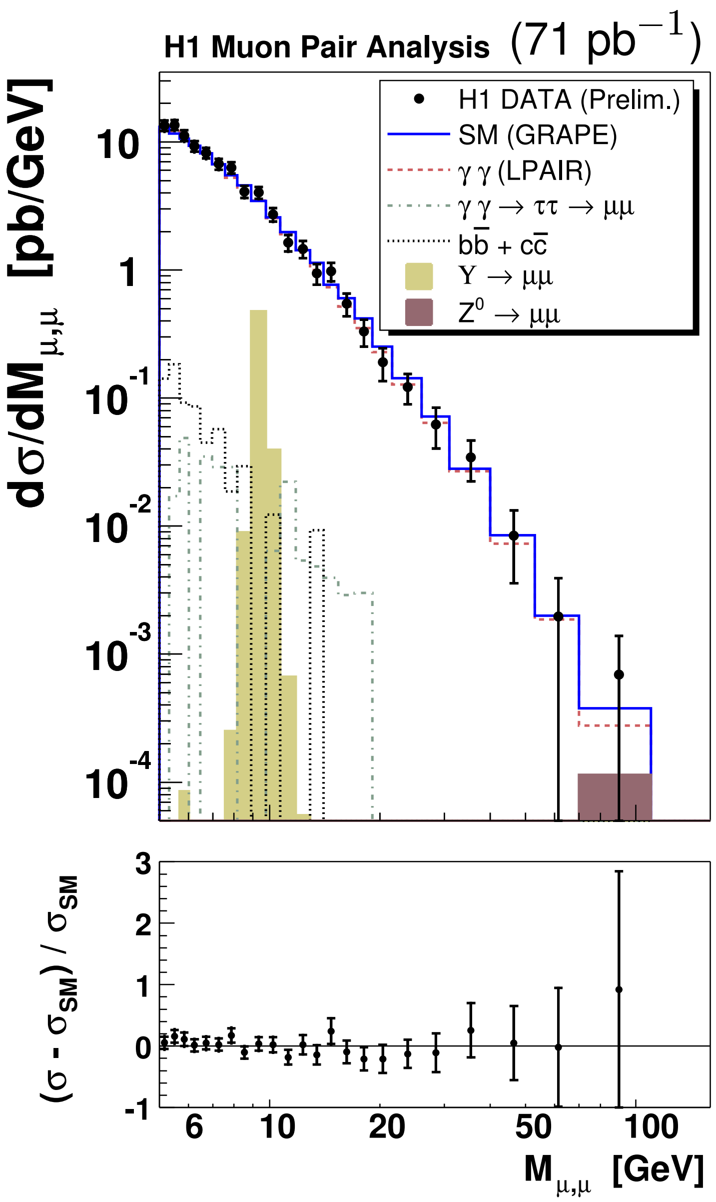
(H1 / ZEUS polar angle domains are different)

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 $2e \leftrightarrow \mu\mu$:

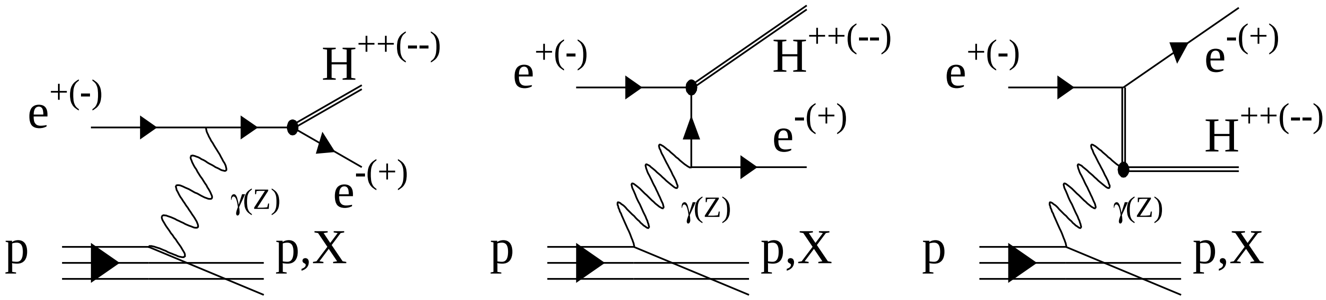
3 **central** $2e$ **events (H1)** $\rightarrow$ **expect** $3 \cdot \dfrac{\mathcal{L}\epsilon(\mu\mu)}{\mathcal{L}\epsilon(2e)} \sim 1\ \mu\mu$ **event**

$\Rightarrow$ **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: $e^+p \to e^-H^{++}X$ **and** $H^{++} \to \ell^+\ell^+$



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

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

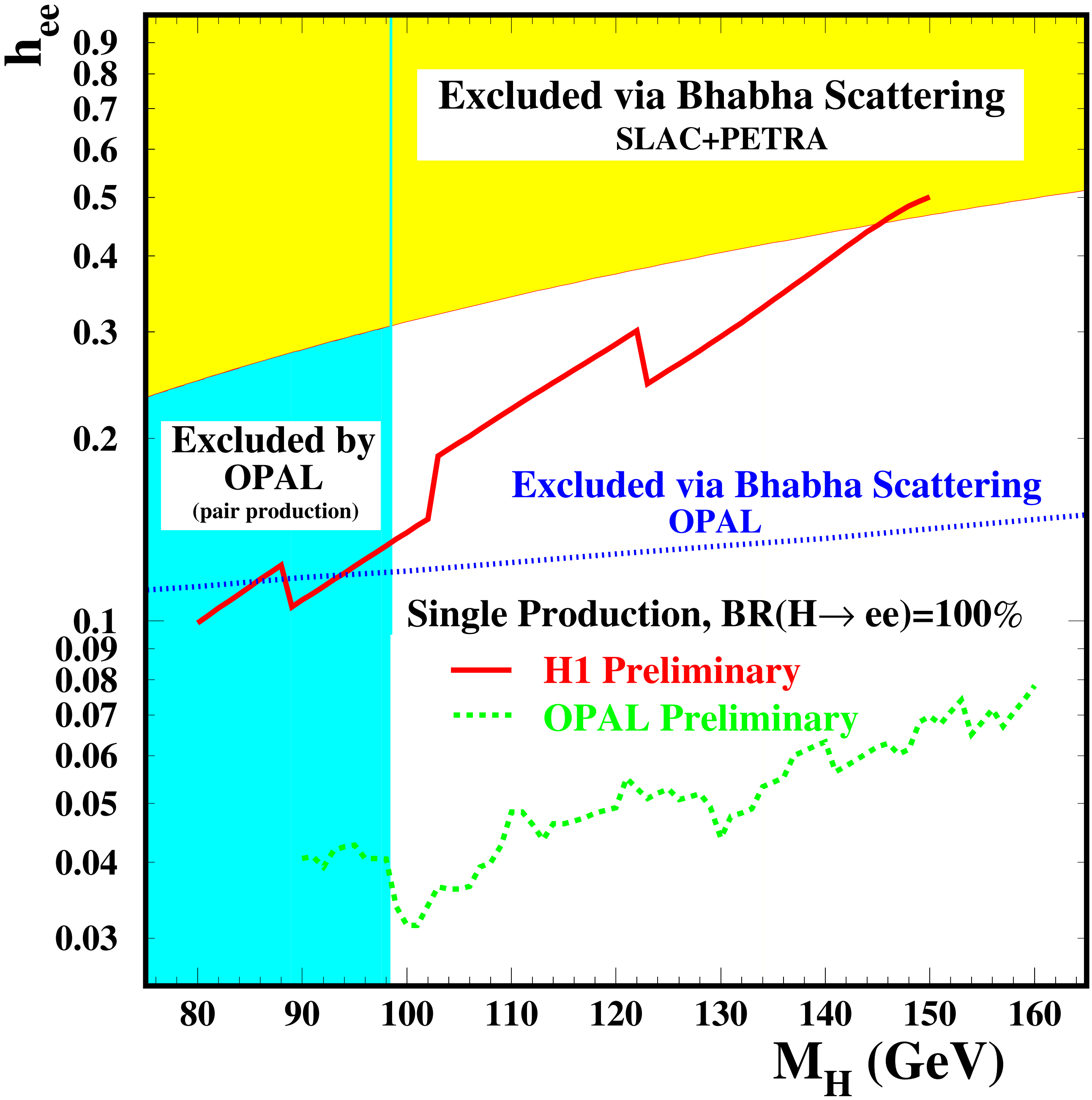
- **mass dependent cut on** $E_T(e1) + E_T(e2)$
- **reject events with wrong lepton charges**

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 unlikey!**
(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 + μ excess complemented by new τ 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 ...