Lepton production in ep collisions

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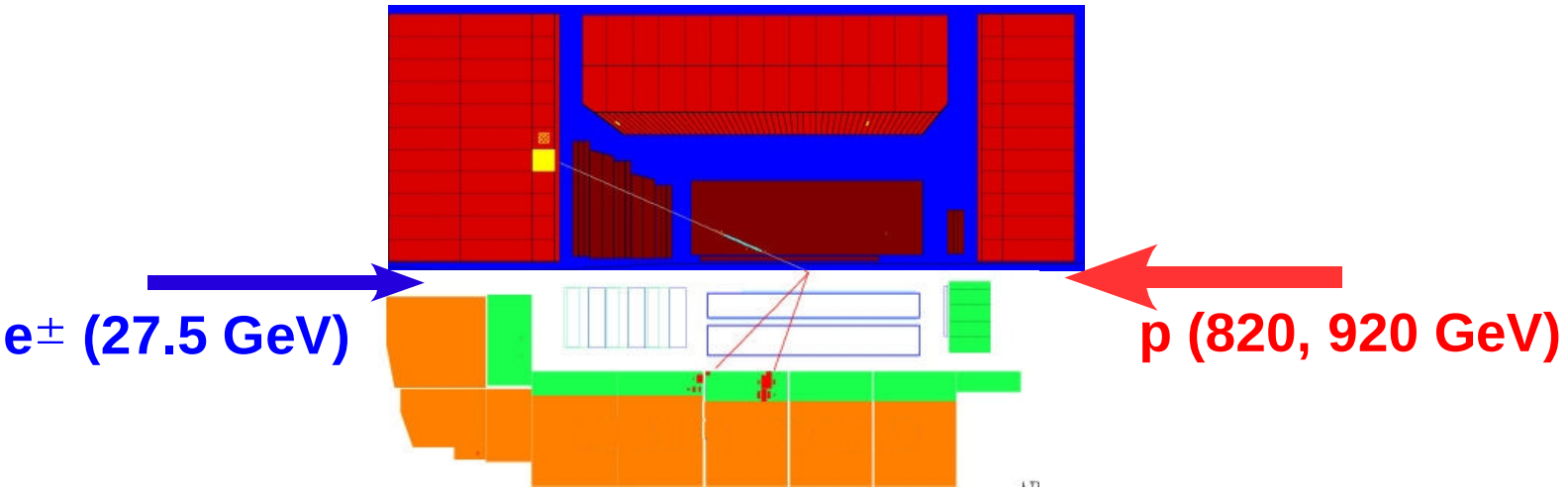
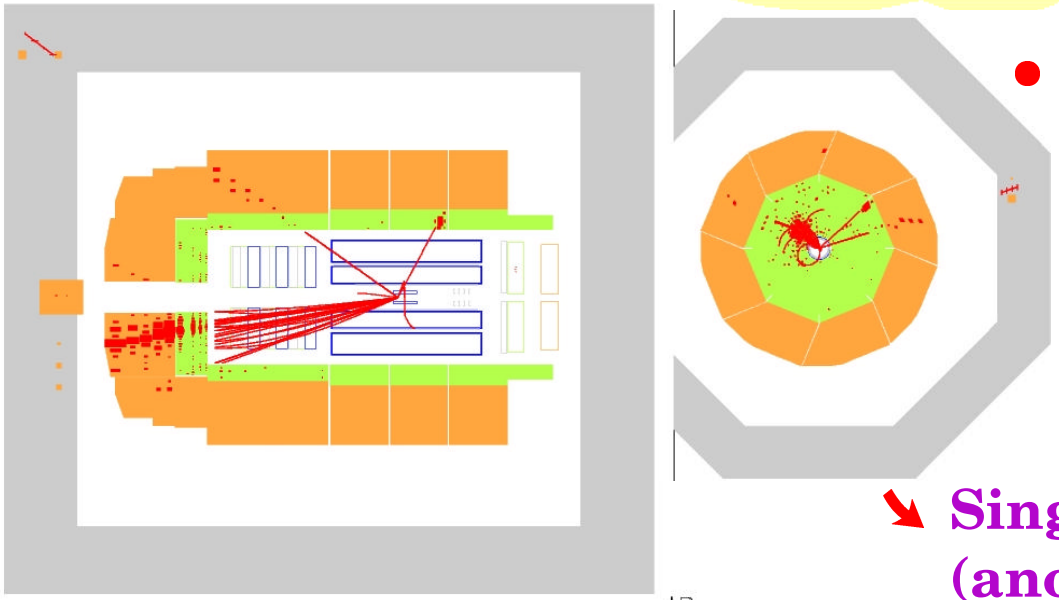
On behalf of H1 and ZEUS collaborations



- HERA : $e^{\pm}$ p collider $\sqrt{s}$ = 300-320 GeV
- HERA I : H1 / ZEUS ~120 pb^{-1}

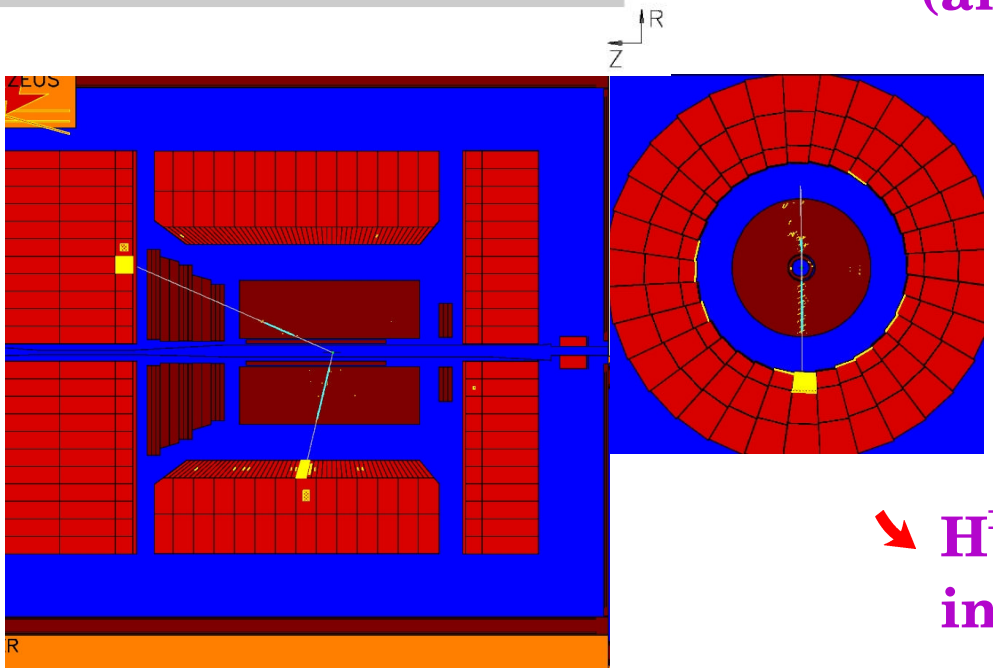
→ **Outstanding high P_T lepton events observed**

Introduction



- **Isolated lepton events:**
  - ➔ High P_T lepton (e, μ, τ)
  - ➔ missing P_T
  - ➔ Jet

➘ **Single top quark production ? (anomalous FCNC coupling)**

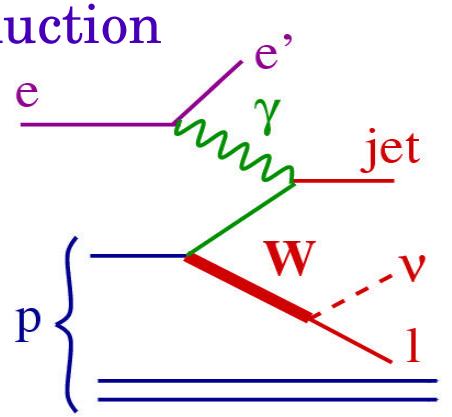


- **Multi-lepton events:**
  - ➔ 2 or 3 e at high P_T
  - ➔ 2 μ

➘ **$H^{\pm\pm}$ as possible BSM interpretation ?**

Isolated lepton events with missing P_T

- Dominant SM process: W production
  (σ (ep $\rightarrow$ eW$^{\pm}$ X) ~ 1pb)



➔ Hadronic jet

➔ Missing P_T

➔ Isolated lepton

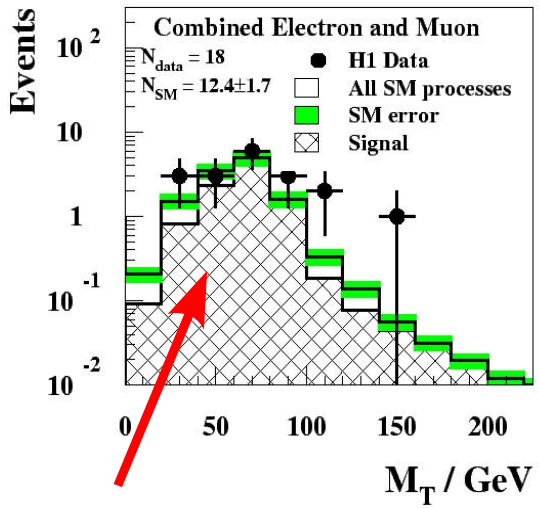
- Main selection cuts:

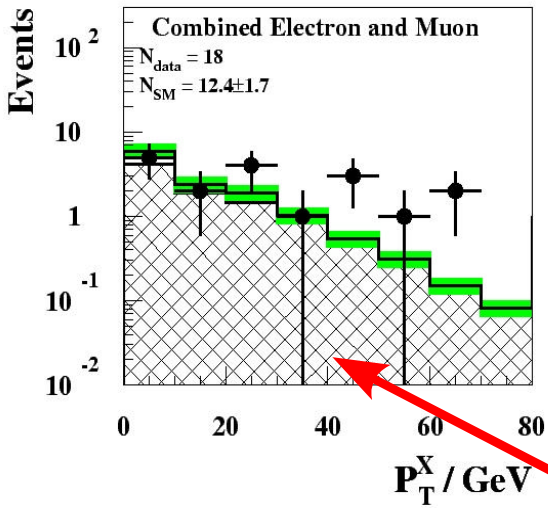
	H1	ZEUS
Lepton P_T	> 10 GeV	> 5 GeV
Lepton polar angle	5° - 140°	17° - 115°
Calorimetric P_T	> 12 GeV	> 20 GeV
Acoplanarity (lepton - X)	> 20° (e), 10° (μ)	> 8°

- Lepton isolation (in η - ϕ):
  - ➔ D_{jet} > 1.0 (wrt. jets)
  - ➔ D_{tracks} > 0.5 (wrt.other tracks)
- H1: further cuts to enhance W component

Isolated leptons: W production

- **H1: e + μ**

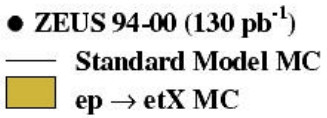


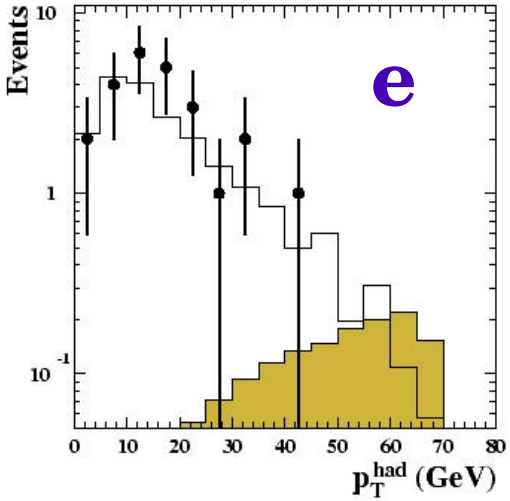


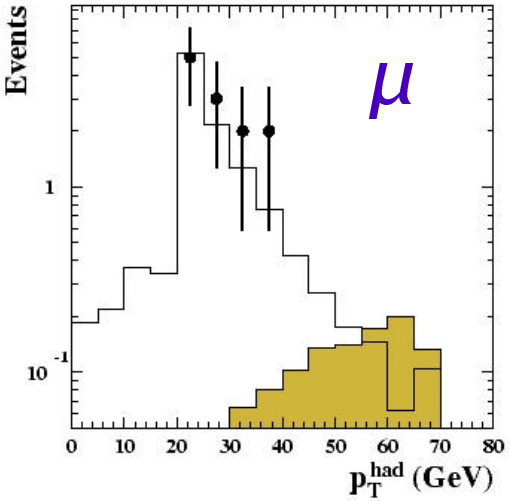
Compatible with W hypothesis

Excess at high P_T^X

- **Zeus:**







Isolated leptons: results at high P_T^X

H1 $e^+ p$ (101.6 pb-1)	Electrons obs. / exp. (W)	Muons obs. / exp. (W)
$P_T^X > 25$ GeV	4 / 1.29 $\pm$ 0.33 (81 %)	6 / 1.54 $\pm$ 0.41 (84 %)
$P_T^X > 40$ GeV	2 / 0.41 $\pm$ 0.12 (97 %)	4 / 0.58 $\pm$ 0.16 (91 %)

➔ Excess at high P_T^X in both 94-97 and 99-00 data

➔ No events in e^- p (expect 1.46 (e) and 0.32 (μ))

ZEUS $e^\pm p$ (130 pb-1)	Electrons obs. / exp. (W)	Muons obs. / exp. (W)
$P_T^X > 25$ GeV	2 / 2.90 $^{+\ 0.59}_{-\ 0.32}$ (45 %)	5 / 2.75 $\pm$ 0.21 (50 %)
$P_T^X > 40$ GeV	0 / 0.94 $^{+\ 0.11}_{-\ 0.10}$ (61 %)	0 / 0.95 $^{+\ 0.14}_{-\ 0.10}$ (61 %)

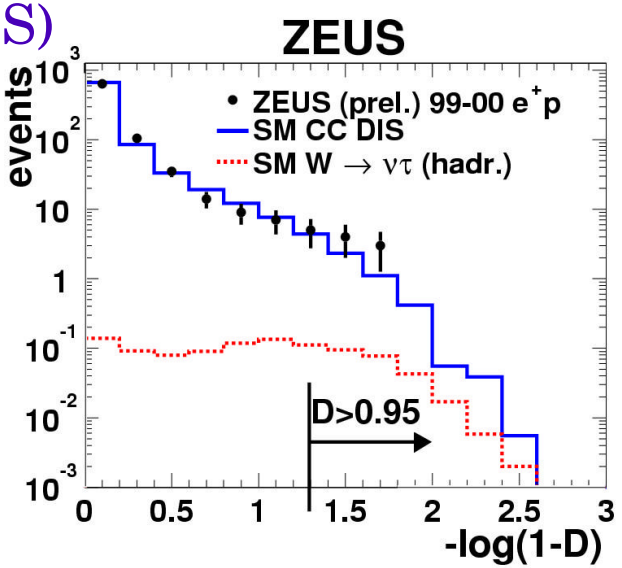
➔ Yields consistent with SM prediction

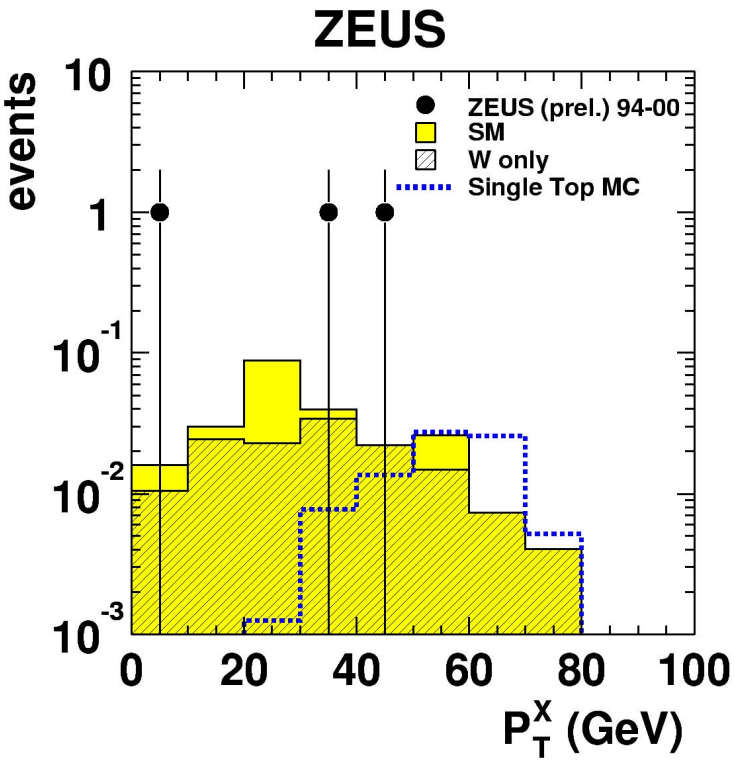
➔ **H1: purer W sample**

➔ **Discrepancy in observed event yields** ($P_T^X > 40$GeV)

Isolated leptons: τ decay channel

- Isolated high P_T lepton selection
- Multi-variables technique: discriminate τ hadronic jet (1-prong decay) from QCD jets (CC-DIS)
- 24 % signal efficiency

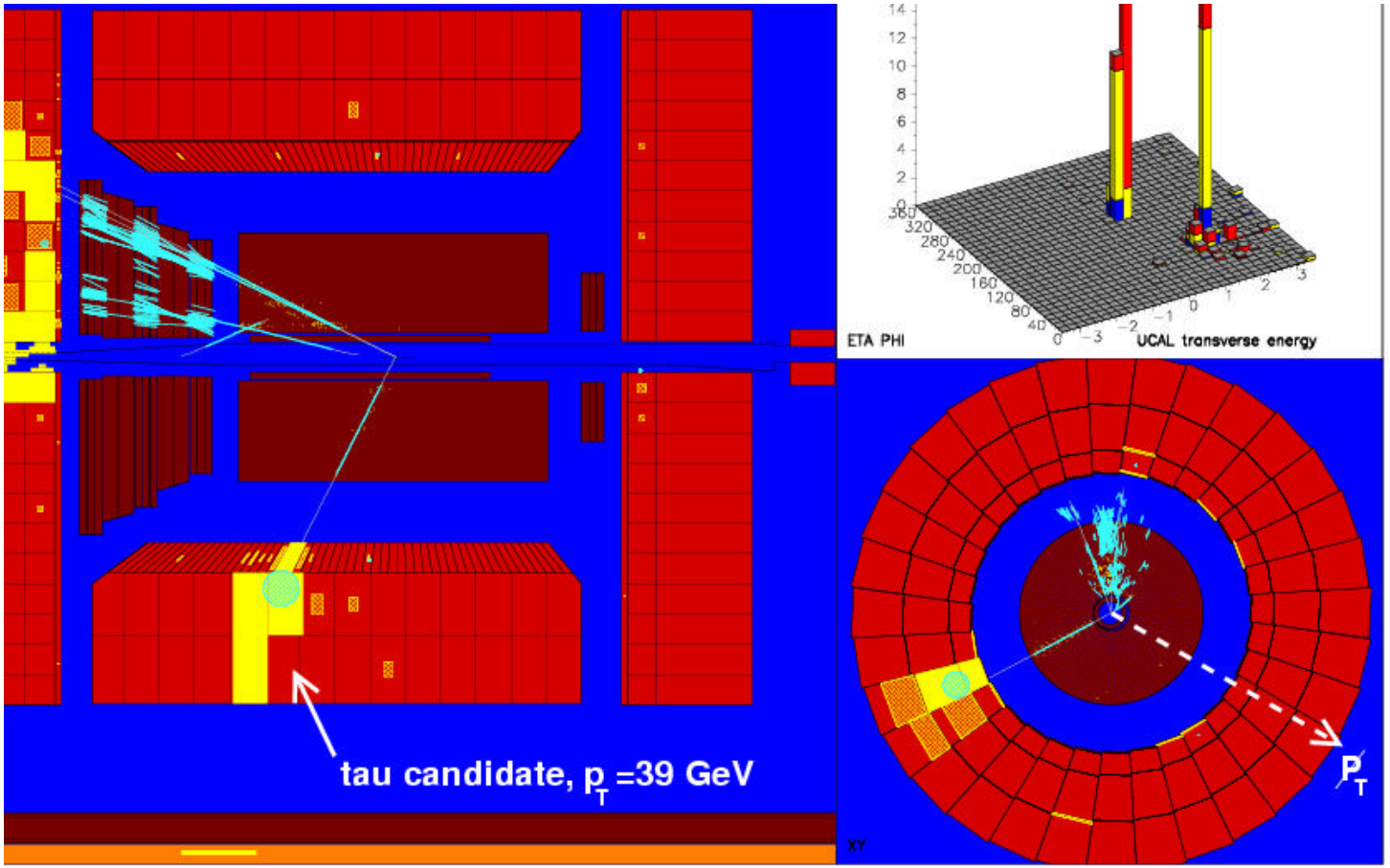




ZEUS preliminary e^+p (130.5 pb-1)	Taus obs. / exp. (W)
$P_T^X > 25$ GeV	2 / 0.12 ± 0.02 (0.10)
$P_T^X > 40$ GeV	1 / 0.06 ± 0.01 (0.05)

→ **2 new τ events at high P_T^X**

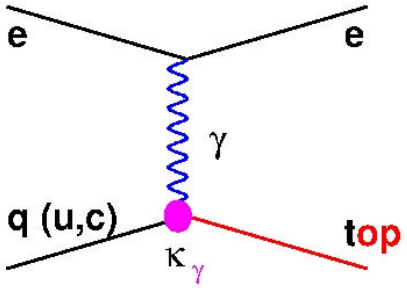
τ candidate



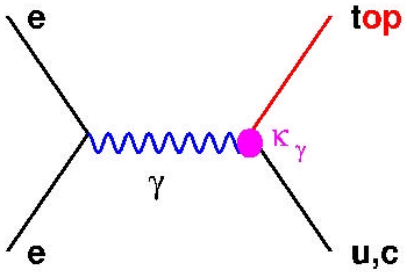
- $P_{T,cal}$ = 39 GeV
- P_T^X = 37 GeV
- $P_{T,\tau\ jet}$ = 39 GeV
- M_T = 68 GeV

Single top production at HERA

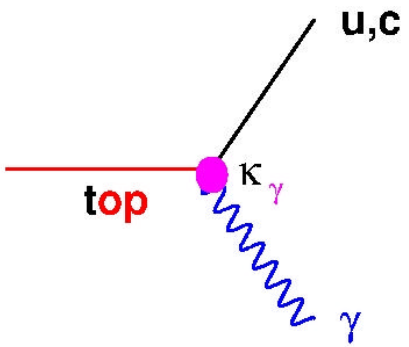
- Single top production in SM negligible (< 1 fb)
  - ➔ production in FCNC process with anomalous $tu\gamma$ coupling



HERA



LEP

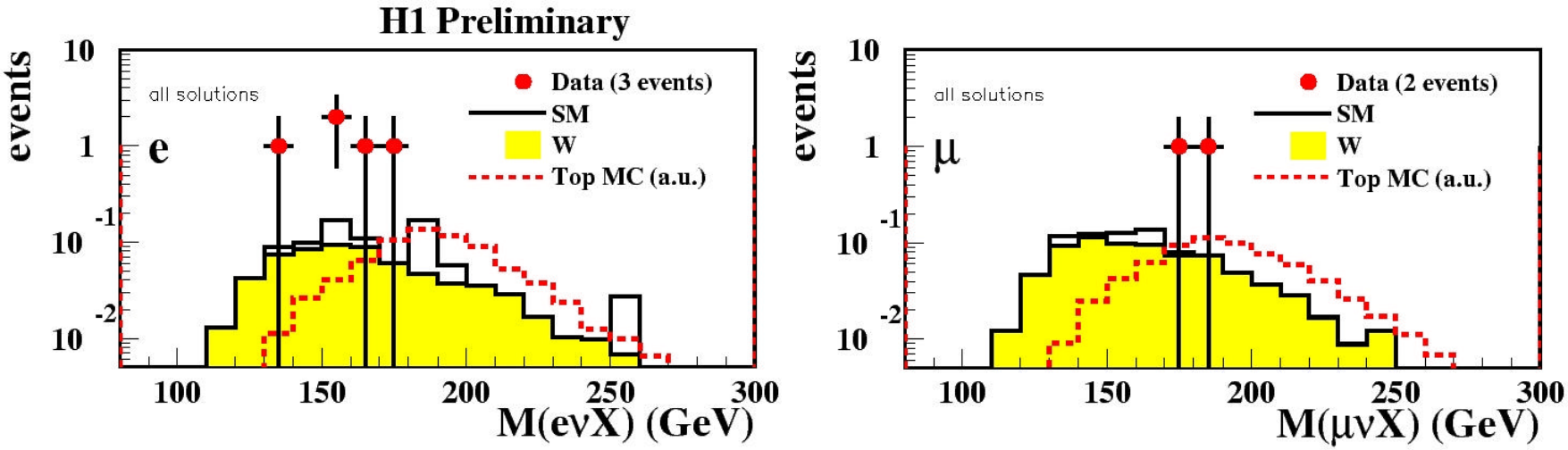


TEVATRON

➔ $t \rightarrow b + W \rightarrow$ high P_T^X + l ν or q $\bar{q}'$

Semi-leptonic top decays

- $t \rightarrow b\ W \rightarrow$ l(e or μ) + ν
- **ZEUS : no events $P_T^X > 40$ GeV**
- H1: further cuts to separate top from SM W
  - ➔ $P_T^{jet} > 25$ GeV $M_T^{l,\nu} > 10$ GeV
  - ➔ only + lepton charge

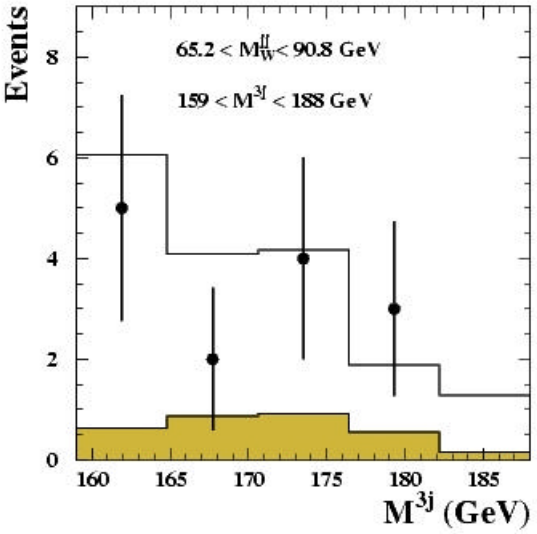


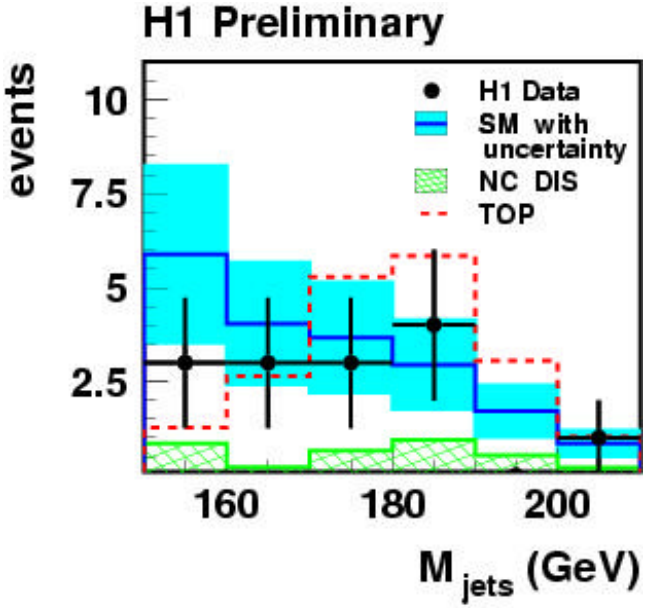
- ➔ **H1: 5 events (3e, 2μ) / 1.77 ± 0.46 expected**

Single top: hadronic decay

- $t \rightarrow bW \rightarrow q\,\bar{q}' \Rightarrow$ 3 high P_T jets

	ZEUS	H1	
P_T jet	$> 40, 25, 14$	$> 40, 25, 20$	
W mass window	$65 < M_{2j} < 91$	$70 < M_{2j} < 90$	
top mass window	$159 < M_{3j} < 188$	$150 < M_{3j} < 210$	+ cut on decay angle (H1)

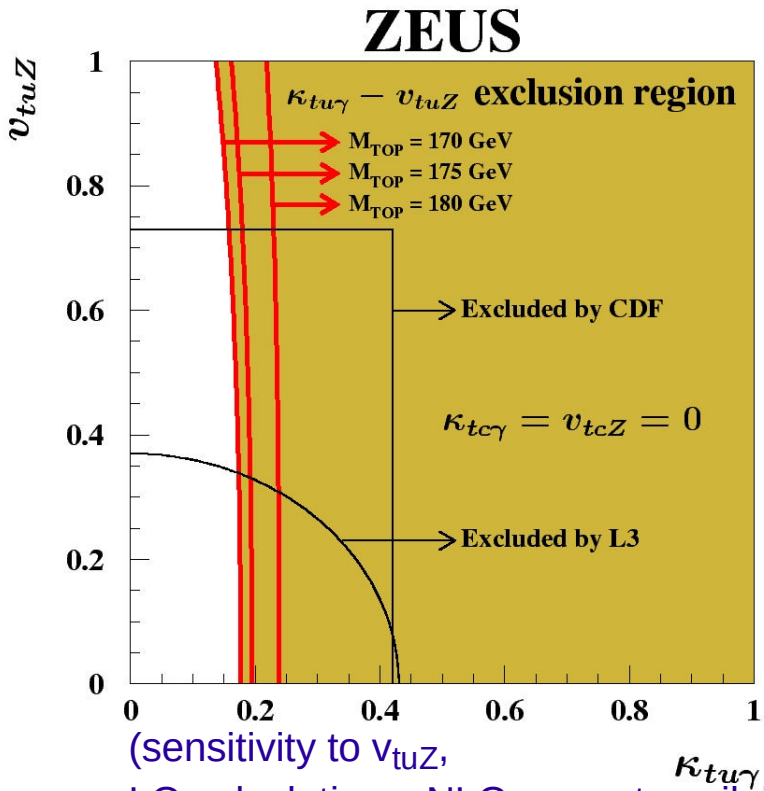




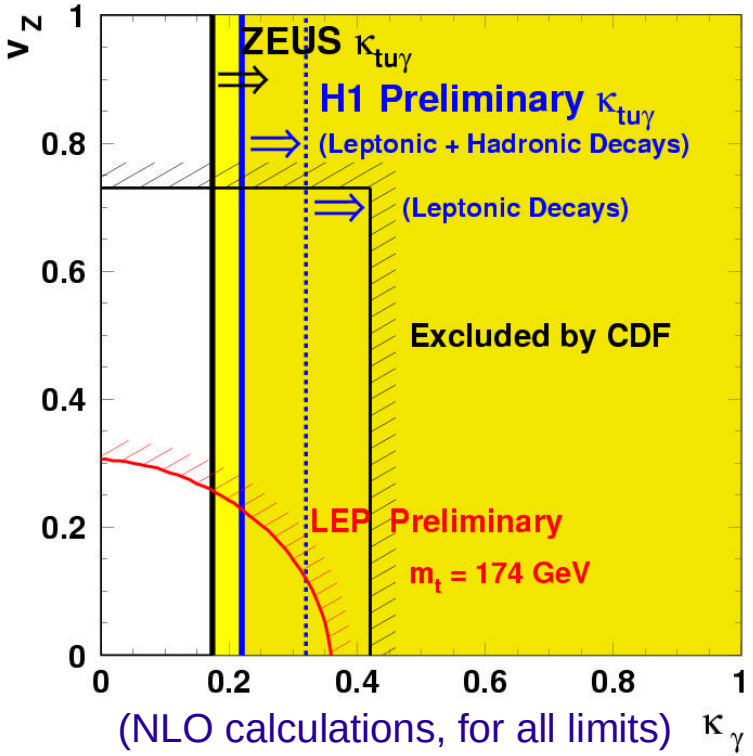
ZEUS	$14 / 17.6\ ^{+\ 2.5}_{-\ 1.5}$
H1 prelim.	$14 / 19.6 \pm 7.8$

- Comparison to semi-leptonic decay (H1):
  - ➔ < 5.4 expected (95 % CL) ⇔ 5 observed
  - ➔ no contradiction within systematics

Exclusion limits on FCNC coupling



(sensitivity to v_{tuZ}, LO calculations, NLO are not available)



(NLO calculations, for all limits)

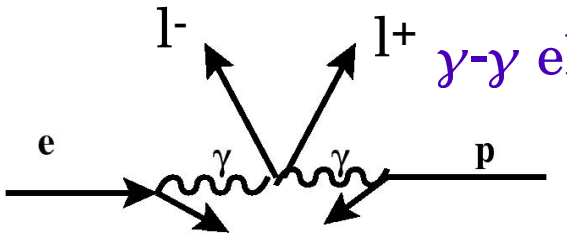
- Large sensitivity at HERA on FCNC top production
- Limits (leptonic + hadronic decays):

  Ktuγ < 0.174 (ZEUS)

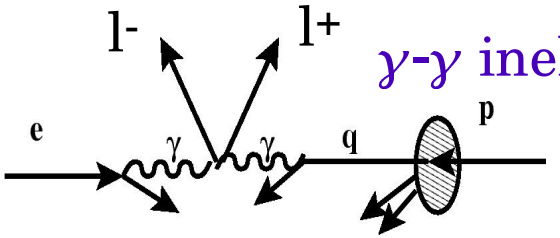
  < 0.22 (H1) (fluctuations in leptonic channel)

Lepton pair production

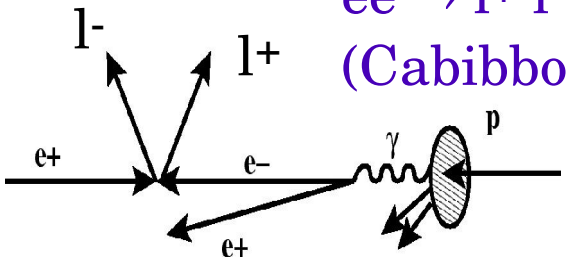
- Mainly via γ-γ collisions:



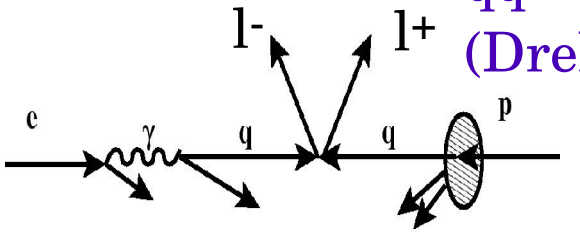
γ-γ elastic



γ-γ inelastic



ee → l+ l-
(Cabibbo-Parisi)
(small at HERA)



qq → l+ l-
(Drell-Yan)
(small at HERA)

➔ **e - e or μ - μ pairs**

- Background: fake leptons
  - ➔ NC-DIS: fake 2nd electron from radiation or mis-identification
  - ➔ Compton: eγ(p) → e + γ (→ fake 2nd e)

Multi-electron selection

- 2 e sample: 2 central isolated electrons

	H1	ZEUS
P_T	> 10, 5 GeV	> 10, E > 10 GeV
Lepton polar angle	20° - 150°	17° - 164°

+ good track associated to e shower

- 3 e sample: any 3rd electron ($5° < \theta < 175°$)

➔ no 4 electron found by H1 or ZEUS

H1 (115 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	105	118.2 ± 12.8	93.3 ± 11.5	25.0 ± 5.5
3 e	16	21.6 ± 3.0	21.5 ± 3.0	0.1 ± 0.0

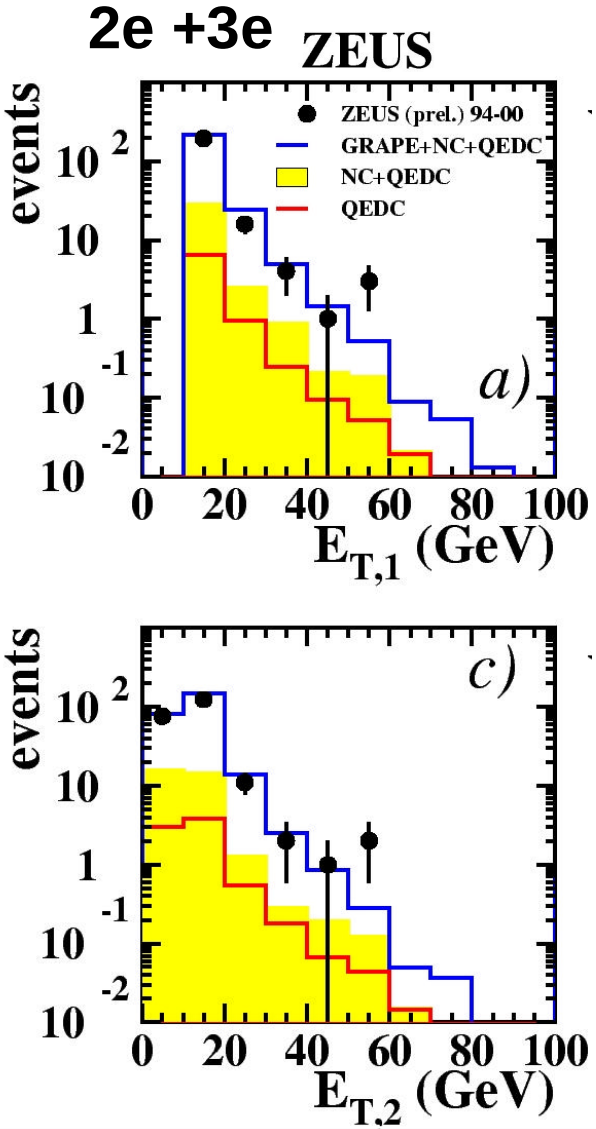
(statistical and systematical errors)

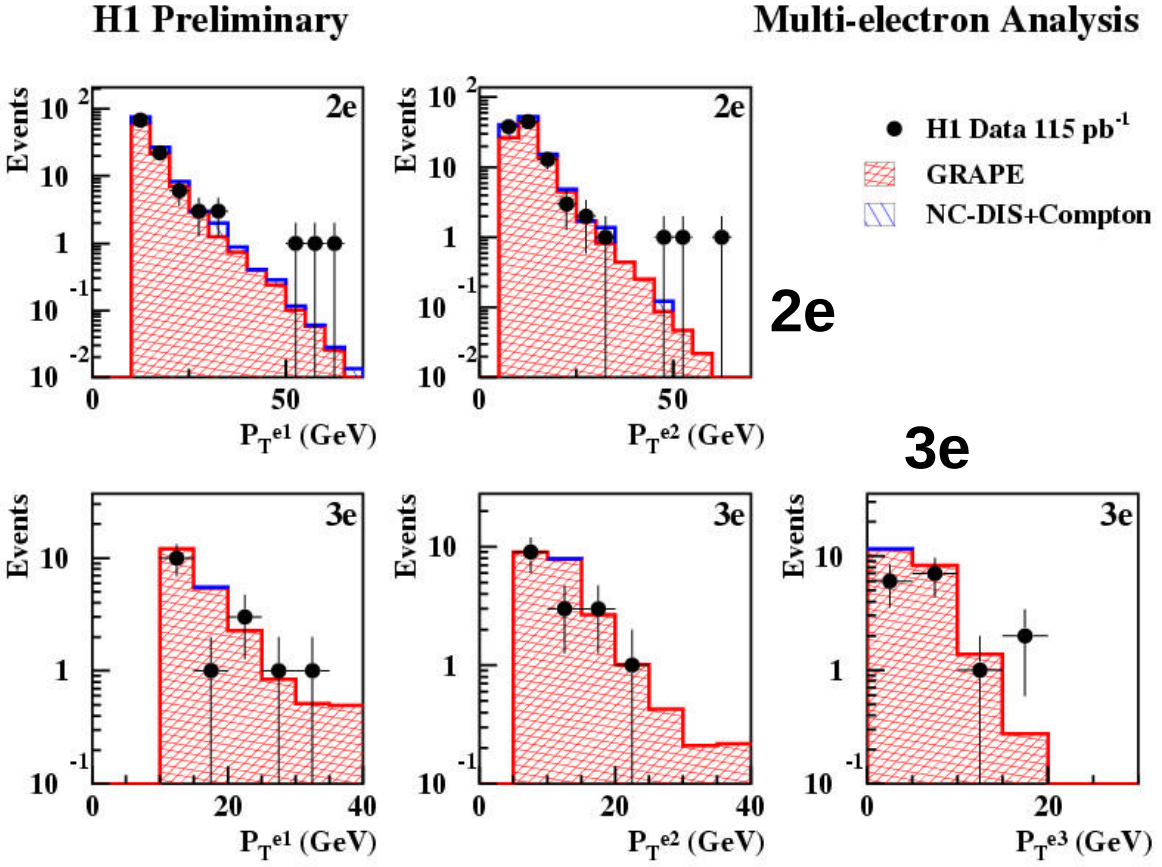
ZEUS (130 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	191	213.9 ± 3.9	182.2 ± 1.2	31.7 ± 3.7
3 e	26	34.7 ± 0.5	34.7 ± 0.5	--

(statistical errors)

Multi-electrons: transverse momenta

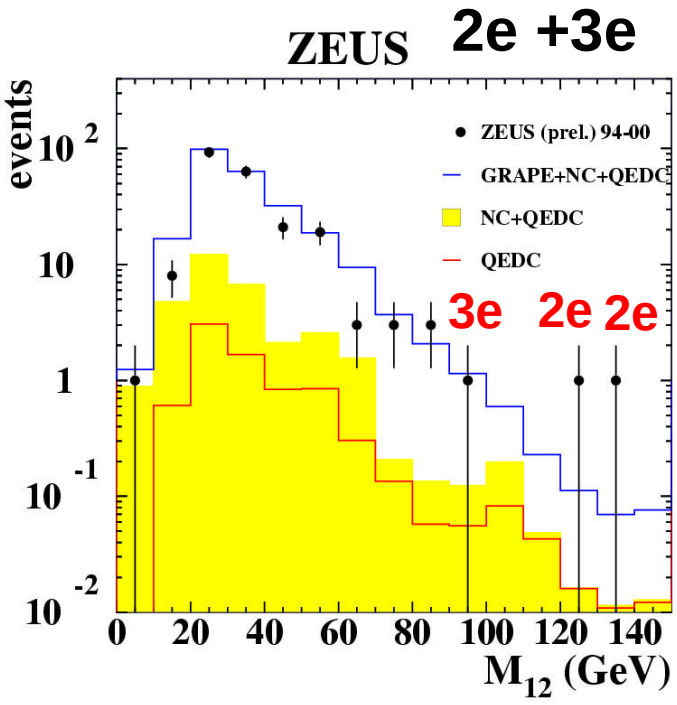
- Good overall agreement
- ZEUS: 2 events $P_T > 50$ GeV
- H1: 3 2e events $P_T > 50$ GeV

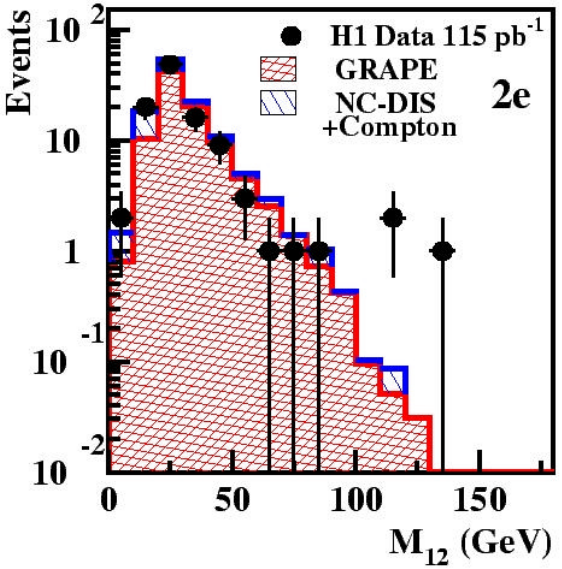


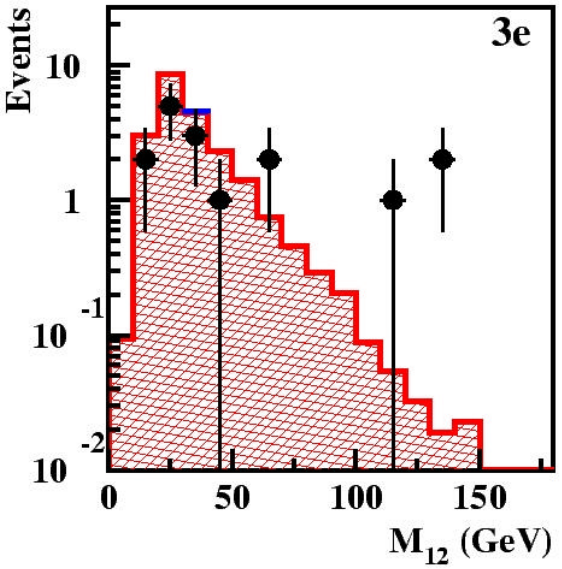


Multi-electrons: Mass distribution

- Mass of 2 highest P_T electrons in the event:







➔ Good overall agreement

➔ **Several events at high mass M_{12} > 100 GeV**

Multi-electrons: events at $M_{12} > 100$ GeV

H1 (115 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	3	0.25 ± 0.05	0.21 ± 0.04	0.04 ± 0.03
3 e	3	0.23 ± 0.04	0.23 ± 0.04	0.0 ± 0.0

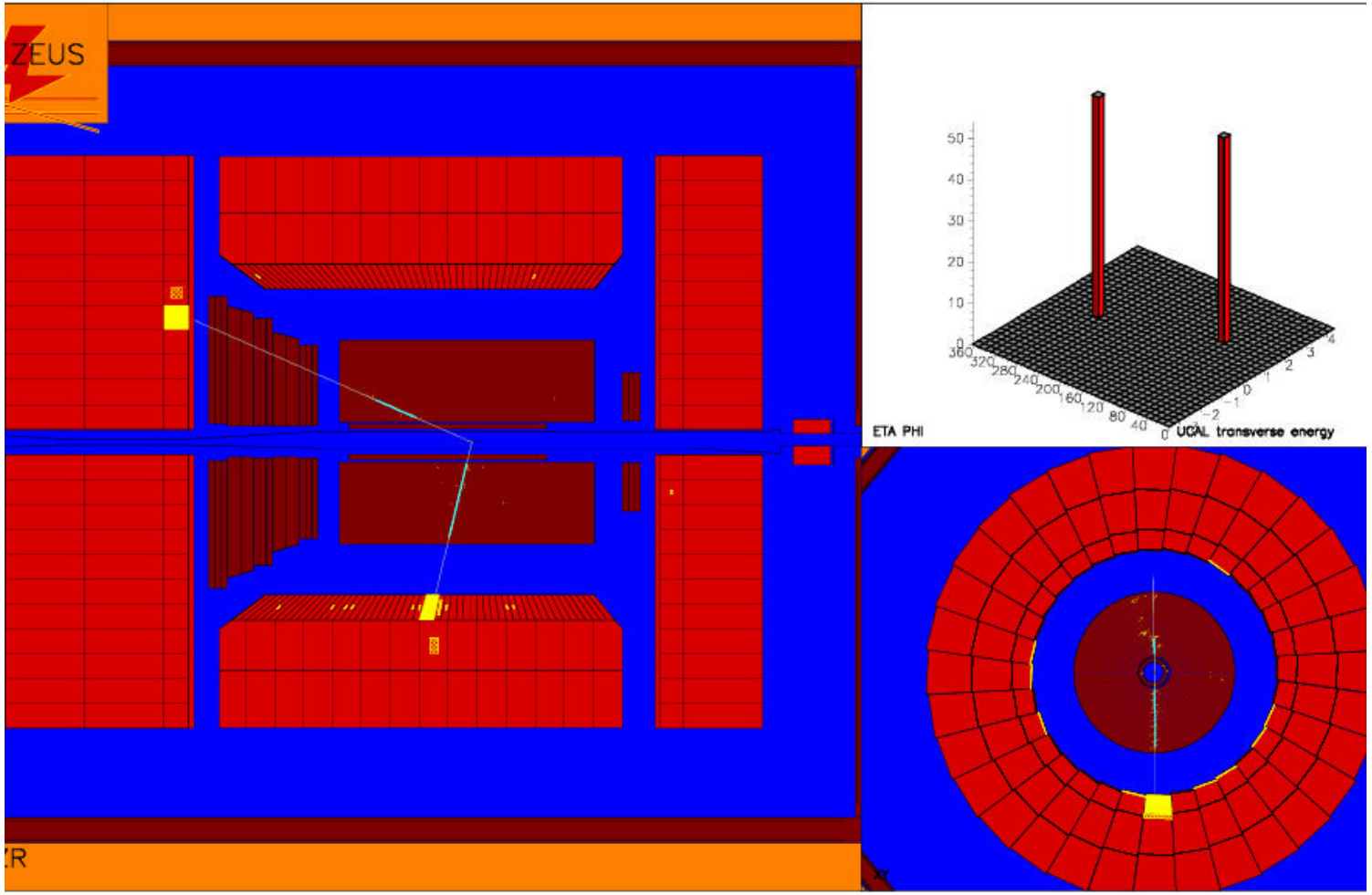
(statistical and systematical errors)

ZEUS (130 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	2	0.77 ± 0.08	0.47 ± 0.05	0.30 ± 0.07
3 e	0	0.37 ± 0.04	0.37 ± 0.04	--

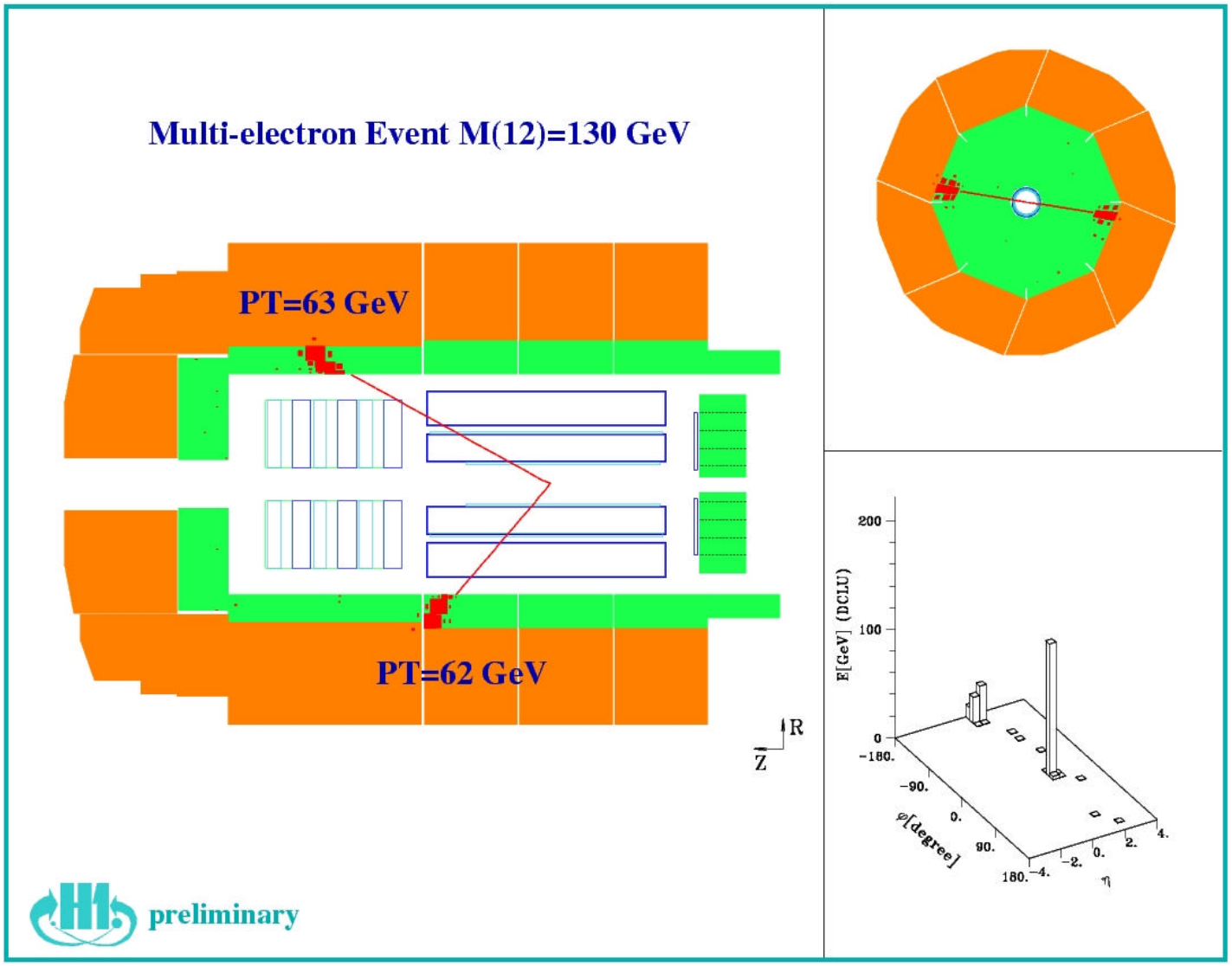
(statistical errors)

(different polar angle domains for H1 / ZEUS)

2e event (ZEUS) M_{12} = 134 GeV

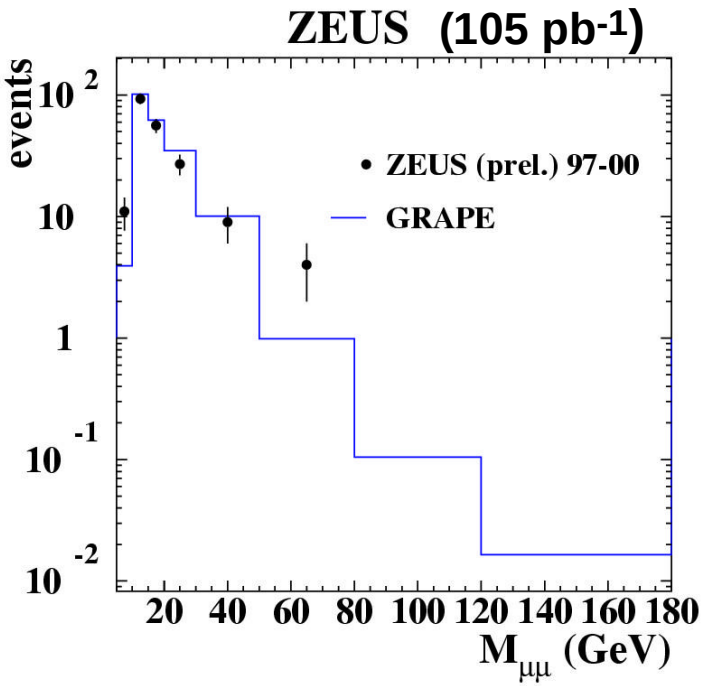


2e event (H1) M_{12} = 130 GeV

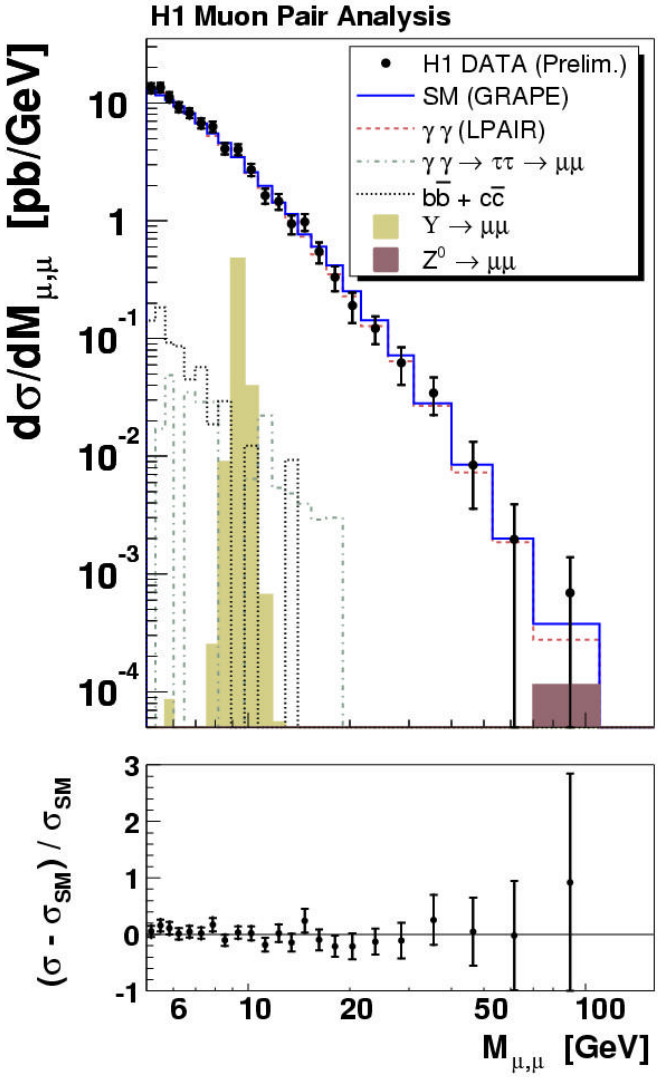


Di-muon events

- μ identified in central tracker, calorimeter and external muon chambers ($20° < \theta < 160°$)
  - ➔ No μ-μ event observed with $M_{\mu\mu} > 100$ GeV
  - ➔ Comparison 2e $\leftrightarrow \mu\mu$: 1 $\mu\mu$ expected (H1)

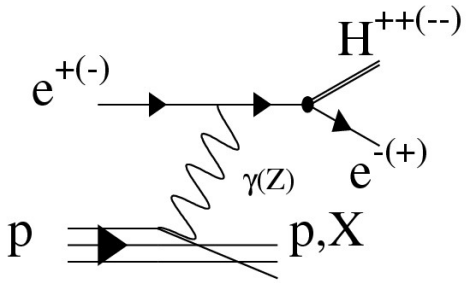


H1: (71 pb^{-1})



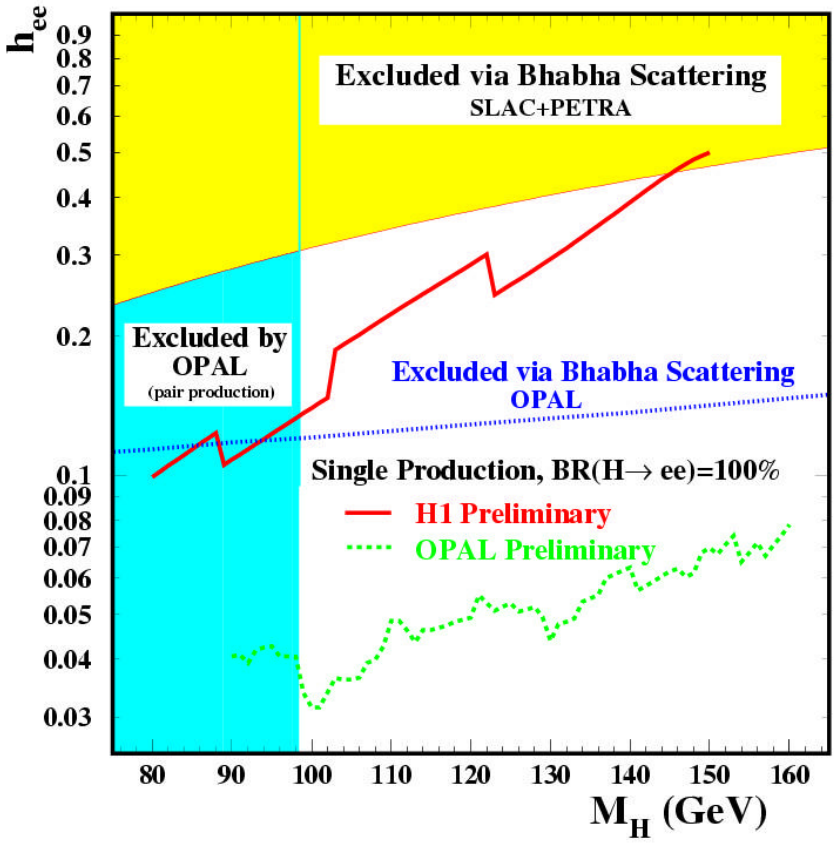
Doubly charged Higgs at HERA ?

- at HERA : $e^+ p \rightarrow e^- H^{++} X$, $H^{++} \rightarrow l^+ l^+$, sensitivity to h_{ee} coupling



➔ H1: on top of multi-electron selection, combines e and μ channels

- Only 1 2e fulfils charge requirements
  - ➔ Doubly charged Higgs very unlikely
  - ➔ Strong bounds on Yukawa coupling h_{ee} by OPAL



➔ **Multi-electron events not due to H^{++} decay**

Conclusions ...

- H1: Intriguing isolated electron/muon events with missing P_T
- ZEUS event yields in agreement with SM but ...
  2 τ interresting events !

➔ HERA has the sensitivity to set limits on anomalous top couplings

- Several outstanding 2 and 3 electron events observed by H1 and ZEUS
- No deviations seen in the μ-μ channel

➔ **need of HERA II data !**
(x10 more luminosity)