

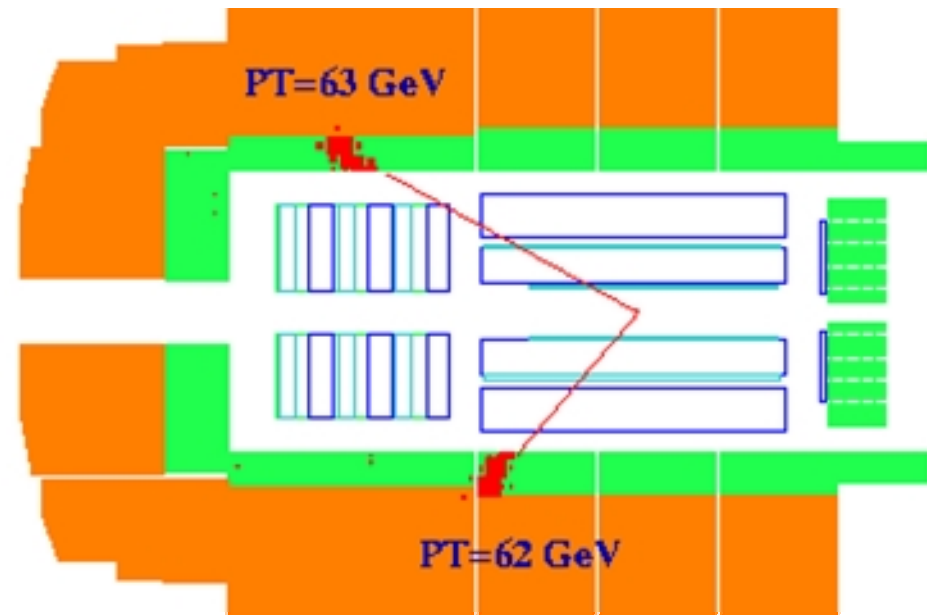
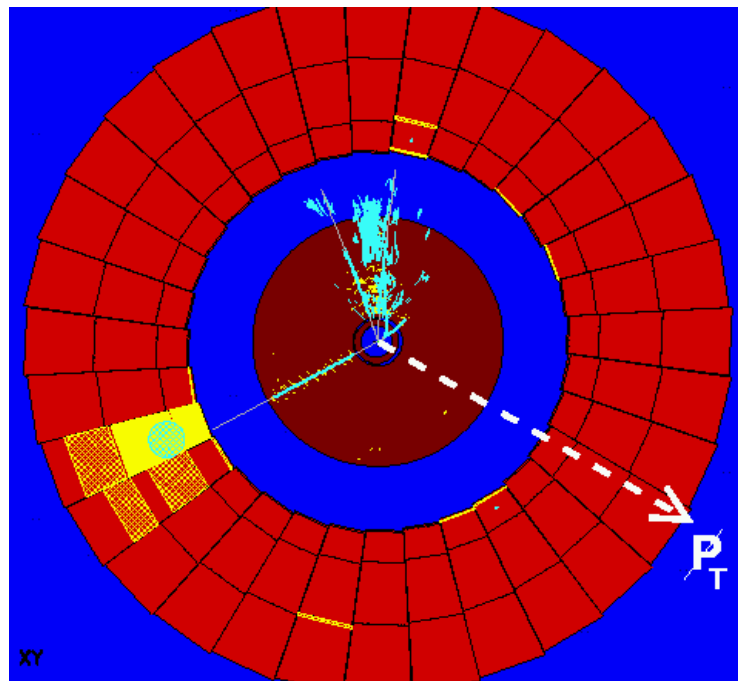
# Observation of Events with Isolated Leptons and Missing Transverse Momentum at Hera

## Observation of Multi-lepton Events at Hera

XXXVIIIth Recontres de Moriond

Tancredi.Carli@cern.ch

New experimental results on interesting events observed at HERA



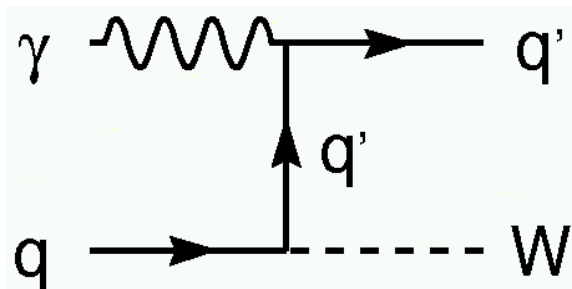
# Events with Isolated Leptons and $P_T^{\text{miss}}$ at HERA

Signature:

- isolated lepton
- large missing transverse momentum  $p_T^{\text{miss}}$
- large hadronic transverse momentum  $p_T^X$

Main background:

$W$  production, e.g.:

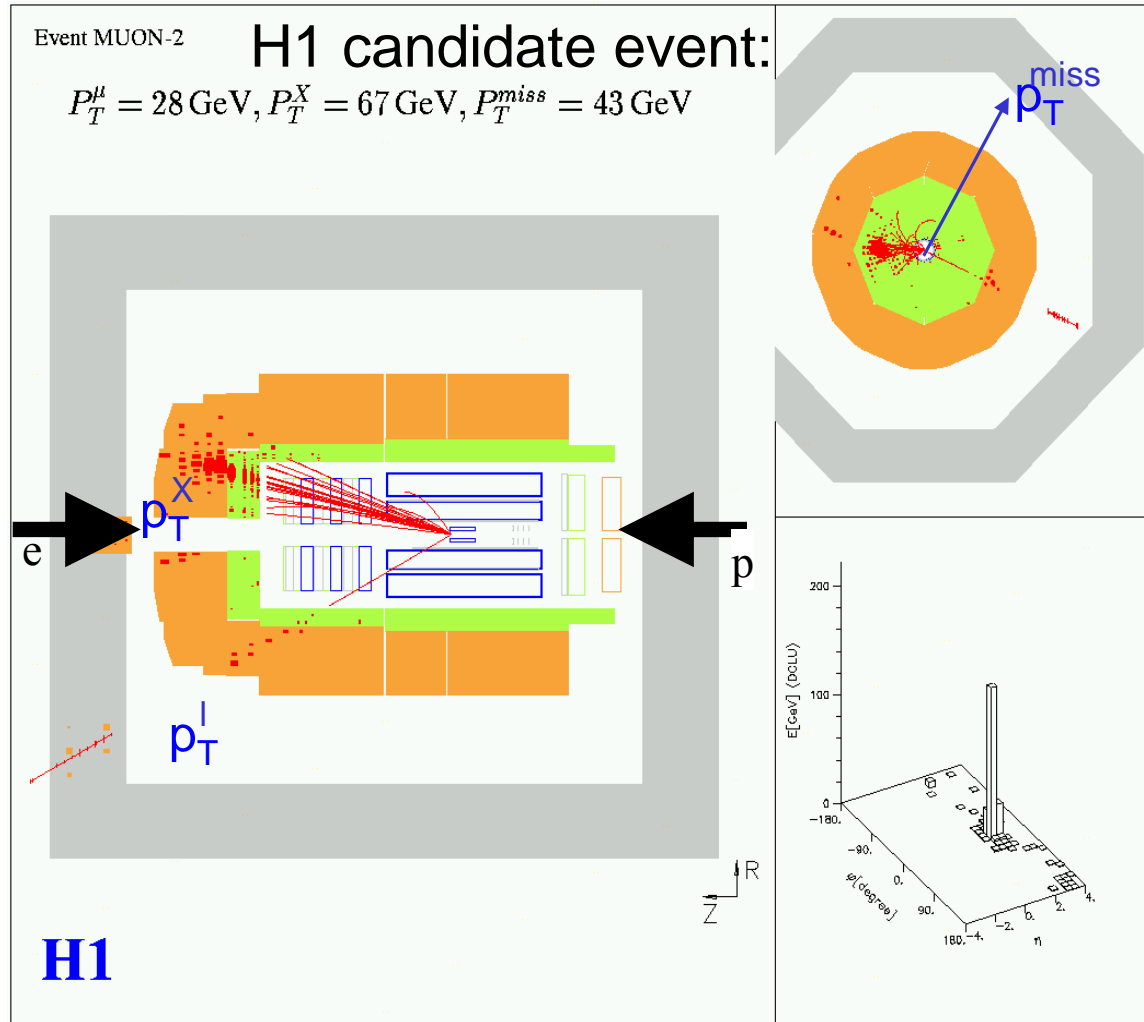


incl.  $\sigma(ep \rightarrow eW^{\pm}X) \approx 1\text{pb}$

for  $P_T^X > 25 \text{ GeV}$ :

$\sigma(W^+) = 0.15 \text{ pb}$

$\sigma(W^-) = 0.08 \text{ pb}$



- NLO correction 10-20%

- residual scale dependence: 5-20%

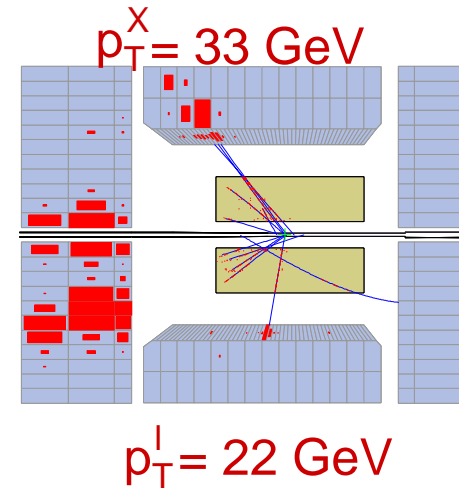
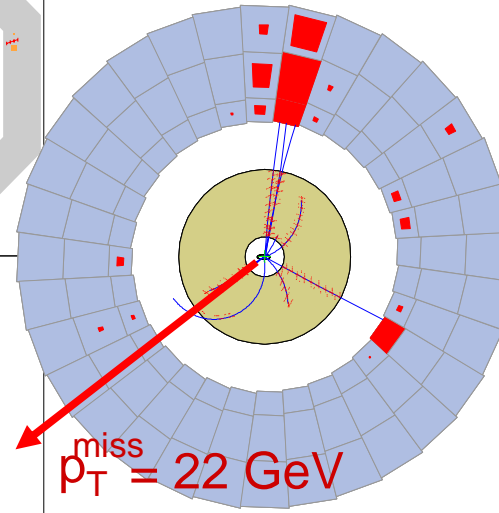
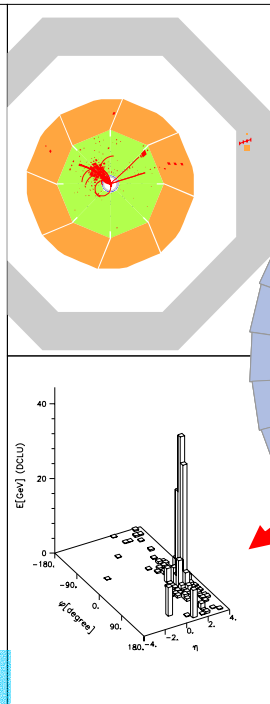
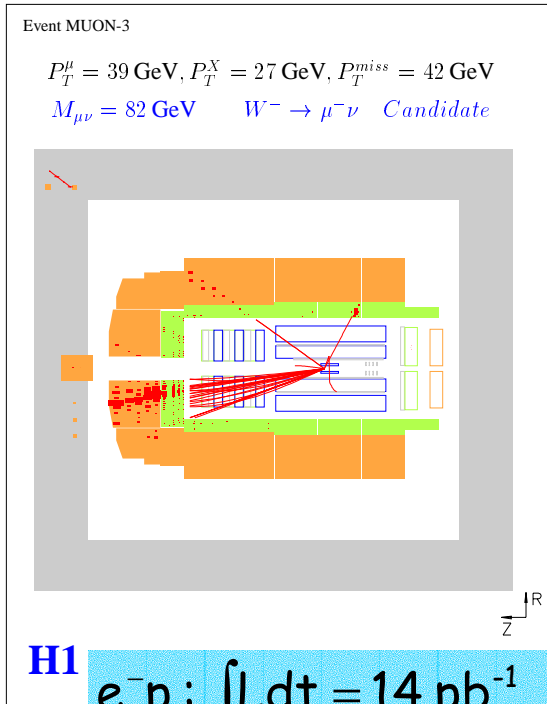
Diener, Spira, Schwanenberger: hep-ph/0203269

# Event (Pre)-Selection

H1

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

ZEUS



H1

$$e^-p: \int L dt = 14 \text{ pb}^{-1}$$

$$e^+p: \int L dt = 105 \text{ pb}^{-1}$$

$$\int L dt = 130 \text{ pb}^{-1}$$

$$5^\circ < \theta_l < 140^\circ, P_T^l > 10 \text{ GeV}$$

$$P_T^{\text{miss}} > 12 \text{ GeV}$$

$$D_{\text{jet}} = \sqrt{\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2} > 1, \Delta\phi_{l-X} < 160^\circ$$

“optimised for W-production”

$$17^\circ < \theta_l < 115^\circ, P_T^l > 5 \text{ GeV}$$

$$P_T^{\text{miss}} > 20 \text{ GeV}$$

$$D_{\text{jet}} = \sqrt{\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2} > 1, \Delta\phi_{l-X} < 172^\circ$$

“optimised for new particle searches”

0

50

100

0

50

100

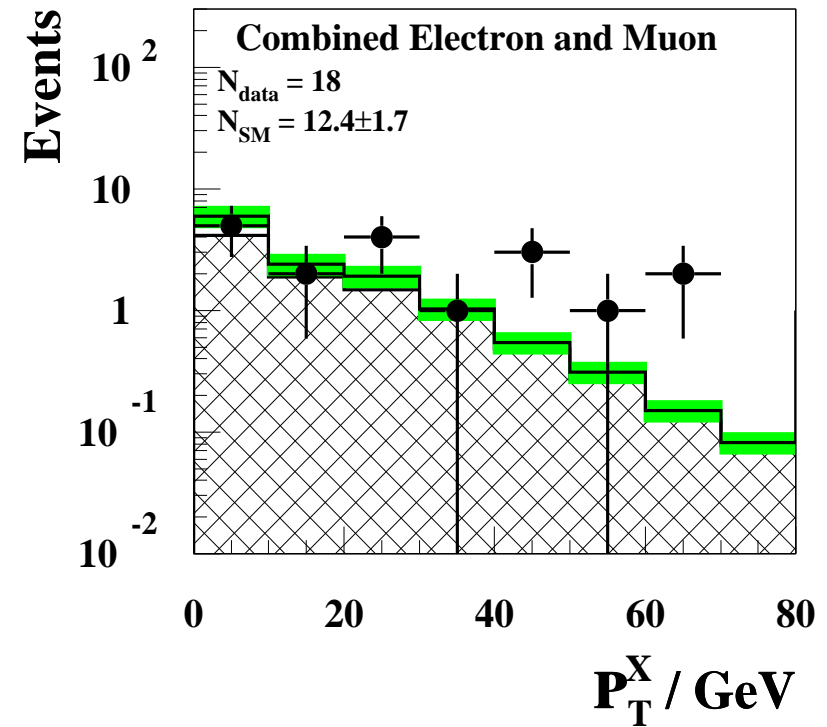
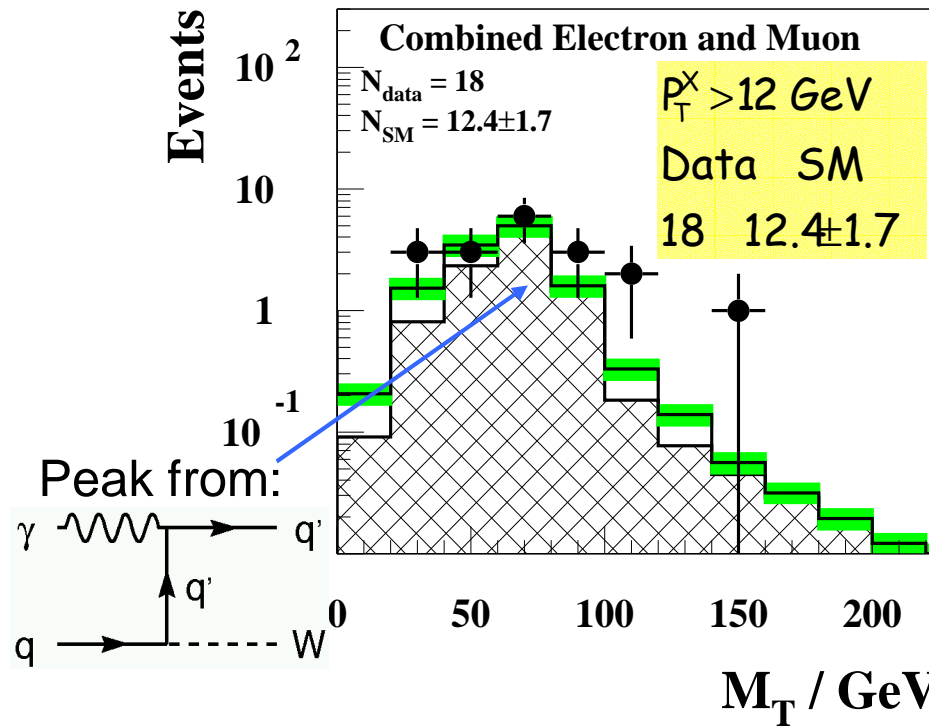
150

e+p final sample

hep-ex/0301030

Events with Isolated Leptons and  $P_T^{\text{miss}}$  in H1

0

 $P_T^X > 25 \text{ GeV}$ 

	Data	SM	W-contr.
electron	4	$1.5 \pm 0.3$	$0.8 \pm 0.1$
muon	6	$1.4 \pm 0.3$	$1.3 \pm 0.3$
combined	10	$3.0 \pm 0.5$	$2.6 \pm 0.5$

 $P_T^X > 40 \text{ GeV}$ 

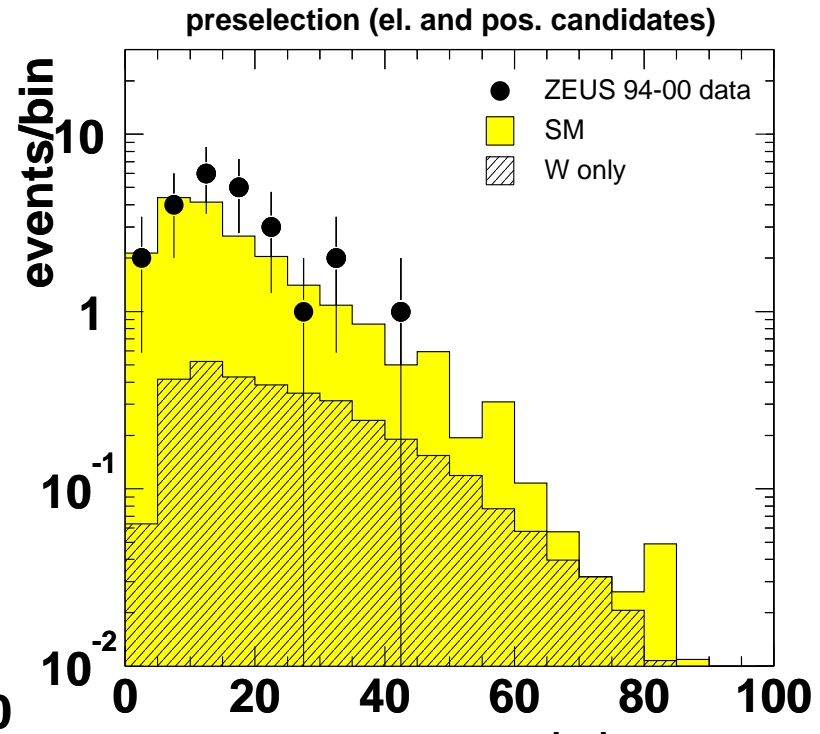
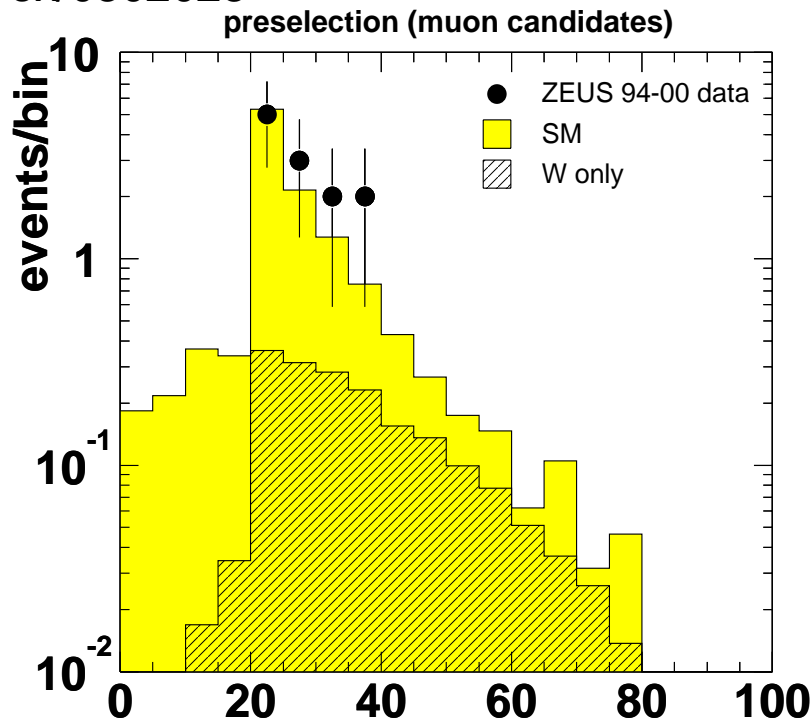
	Data	SM	W-contr.
electron	3	$0.5 \pm 0.1$	$0.45 \pm 0.1$
muon	3	$0.6 \pm 0.1$	$0.5 \pm 0.1$
combined	6	$1.1 \pm 0.2$	$1.0 \pm 0.2$

- .Excess of isolated lepton events above SM prediction.
- .Events have large hadronic momenta.

final sample

hep-ex/0302025

# Events with Isolated Leptons and $P_t^{\text{miss}}$ in ZEUS



$P_T^X > 25 \text{ GeV}$   $p_T^X = p_T^{\text{hadr}} \text{ (GeV)}$

	Data	SM	W-contr.
electron	2	$2.9 \pm 0.4$	1.3
muon	5	$2.8 \pm 0.2$	1.4
combined	7	$5.7 \pm 0.6$	2.7

$P_T^X > 40 \text{ GeV}$   $p_T^X = p_T^{\text{hadr}} \text{ (GeV)}$

	Data	SM	W-contr.
electron	0	$0.9 \pm 0.1$	0.5
muon	0	$1.0 \pm 0.1$	0.6
combined	0	$1.9 \pm 0.2$	1.1

In the above numbers a cut on

$E - P_z < 47 \text{ GeV}$  (electron)  $P_T^\mu > 10 \text{ GeV}$  (muon)

is included

**No Excess** of isolated lepton events above SM prediction in ZEUS

## H1/ZEUS: Isolated Leptons and $P_t^{\text{miss}}$ Summary I

Electron/muon combined:

	H1		ZEUS	
	Data	SM	Data	SM
overall	18	$12.4 \pm 1.7$	36	$32.6 \pm 3.8$
$p_T^X > 25 \text{ GeV}$	10	$2.9 \pm 0.5$	7	$5.7 \pm 0.6$
$p_T^X > 40 \text{ GeV}$	6	$1.1 \pm 0.2$	0	$1.9 \pm 0.2$

excess seen in H1 data:  $O(10^{-3})$ , no excess in ZEUS data

Combined (H1+ZEUS):  $O(10^{-2})$

H1 excess about equally shared in electron/muon channel

No conclusion possible from study of hadronic channel (background too large)

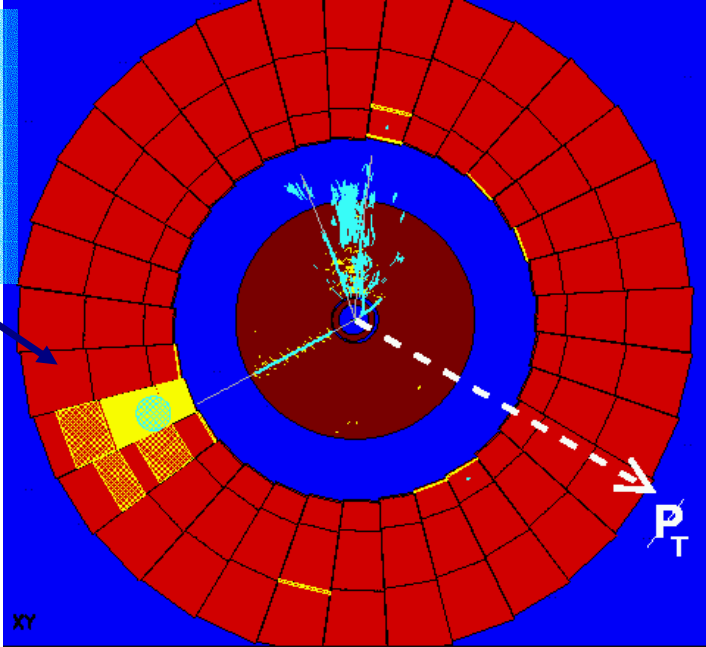
How to proceed ?

Wait for new data ? HERA-II

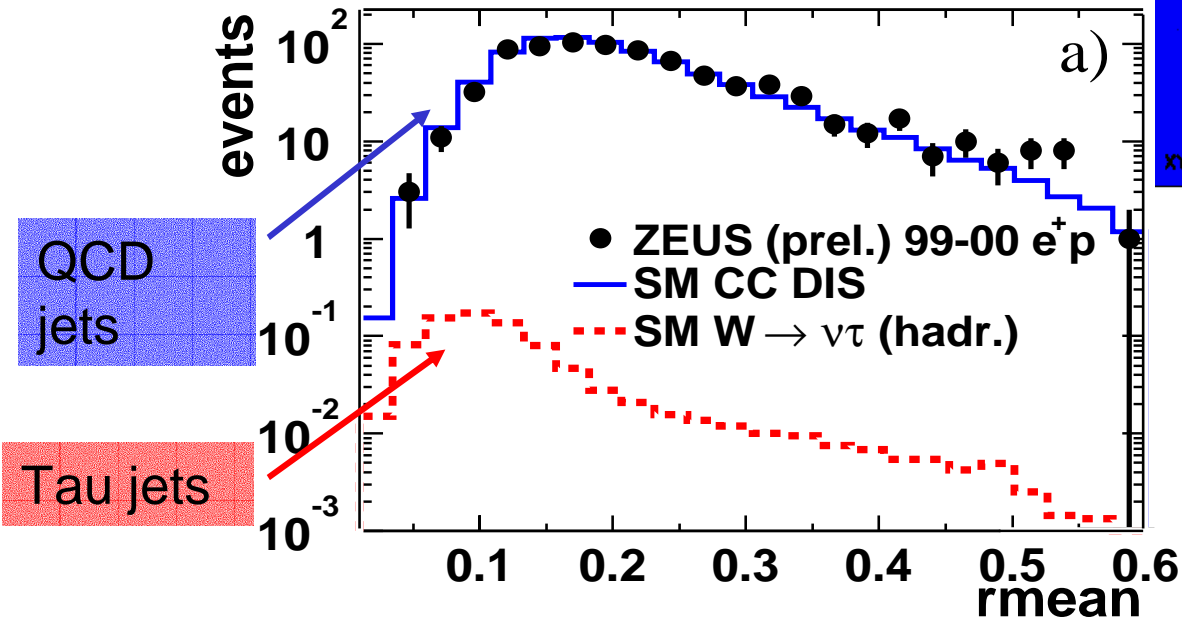
.....or look at Tau channel !

# Tau-Identification using Internal Jet Structure:

consider hadronic tau -decay based on internal jet structure: collimated (pencil-like) jets, only 1 track in Jet



One out of six estimators:



Note, Internal jet structure well modeled in ep, ee and pp collisions !

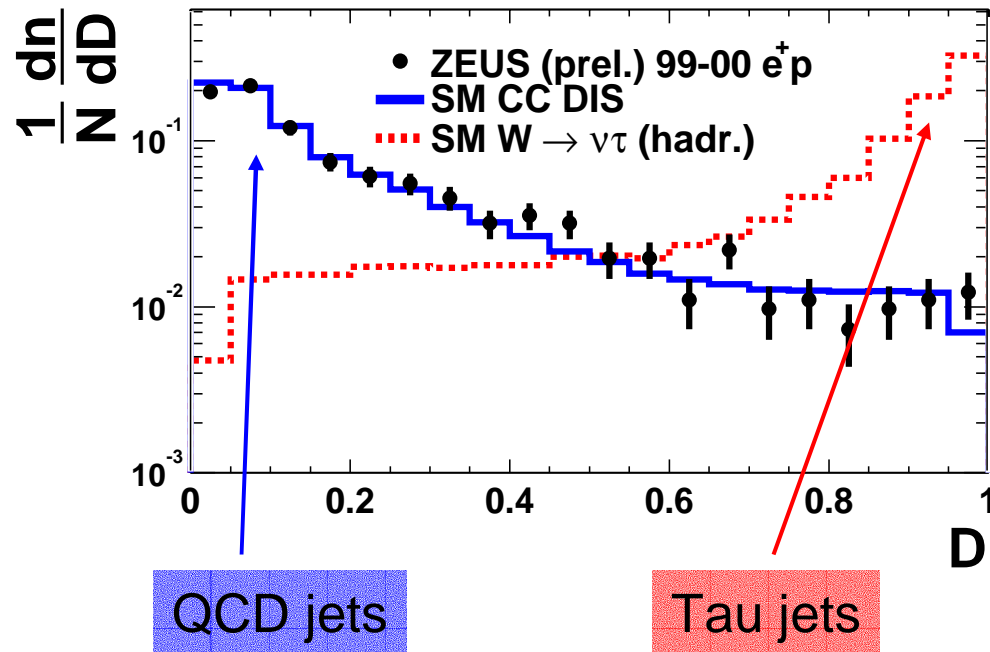
Needs reduction of QCD jet background by 1000 to see  $W \rightarrow \text{Tau} \rightarrow \text{hadrons}$

# Tau-Lepton Identification at ZEUS

Incl. charged current sample (only cut on missing  $P_T$ )

Shape:

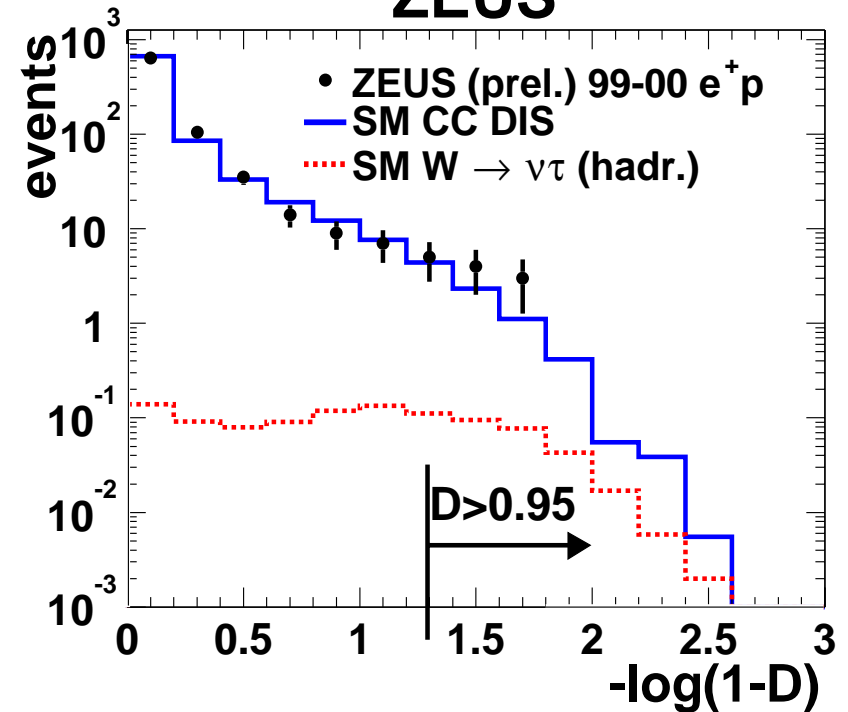
## ZEUS



Good separation  
tau efficiency  $\sim 25\%$   
bg rejection  $\sim 550$

Number of events:

## ZEUS



Good description of  
discriminant by MC simulation

Combine 6 estimators to one discriminant  $D$

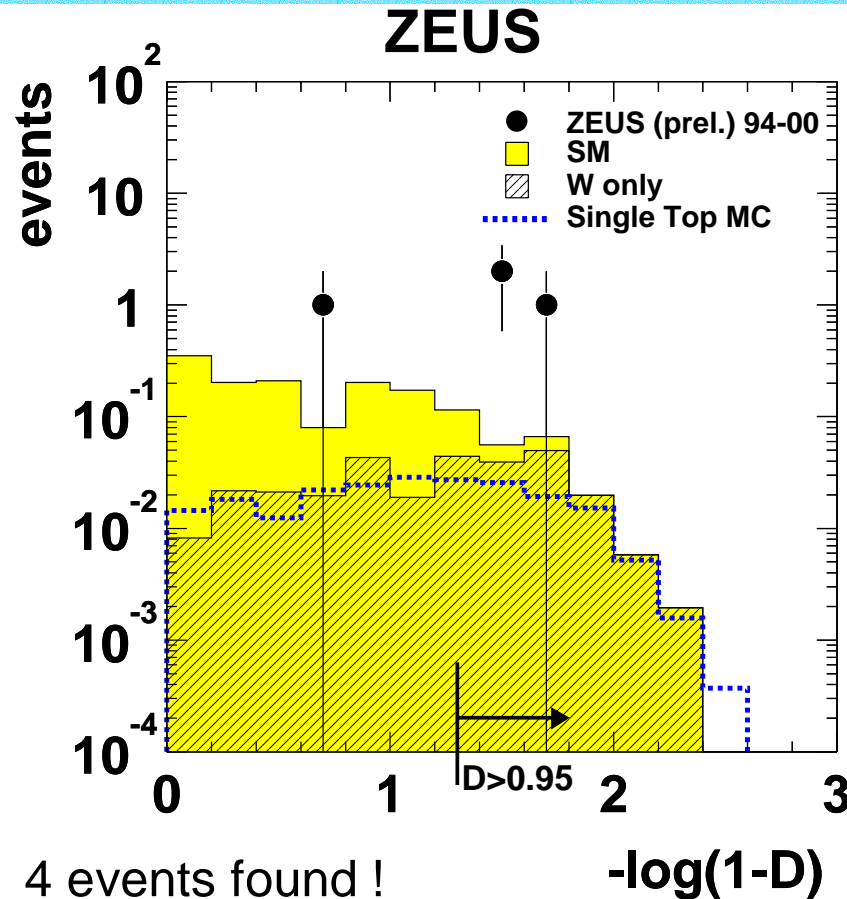
Probability density estimation based on range searching (hep-ph/0211019)

# Search for Isolated Tau-Leptons and Missing Pt

-  $p_T^{\text{miss}} > 20 \text{ GeV}$

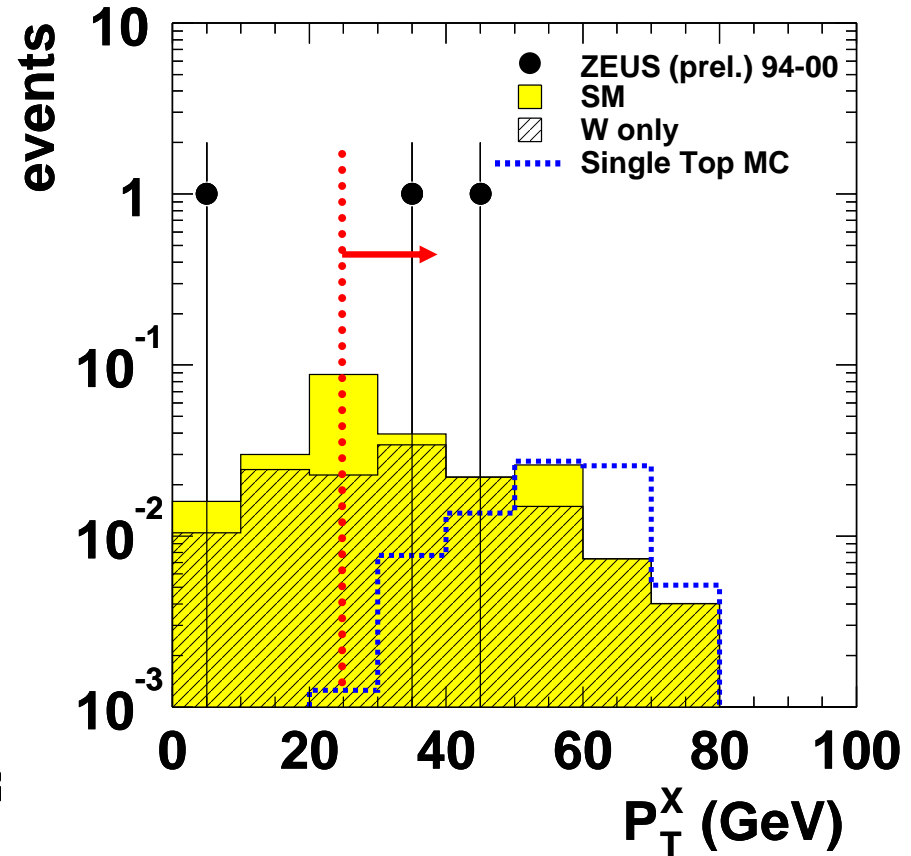
- isolated track with  $p_T > 5 \text{ GeV}$  ( $D_{\text{track,track}} > 0.5, D_{\text{track,jet}} > 1.8$ )

- not electron or muon      - not acoplanar



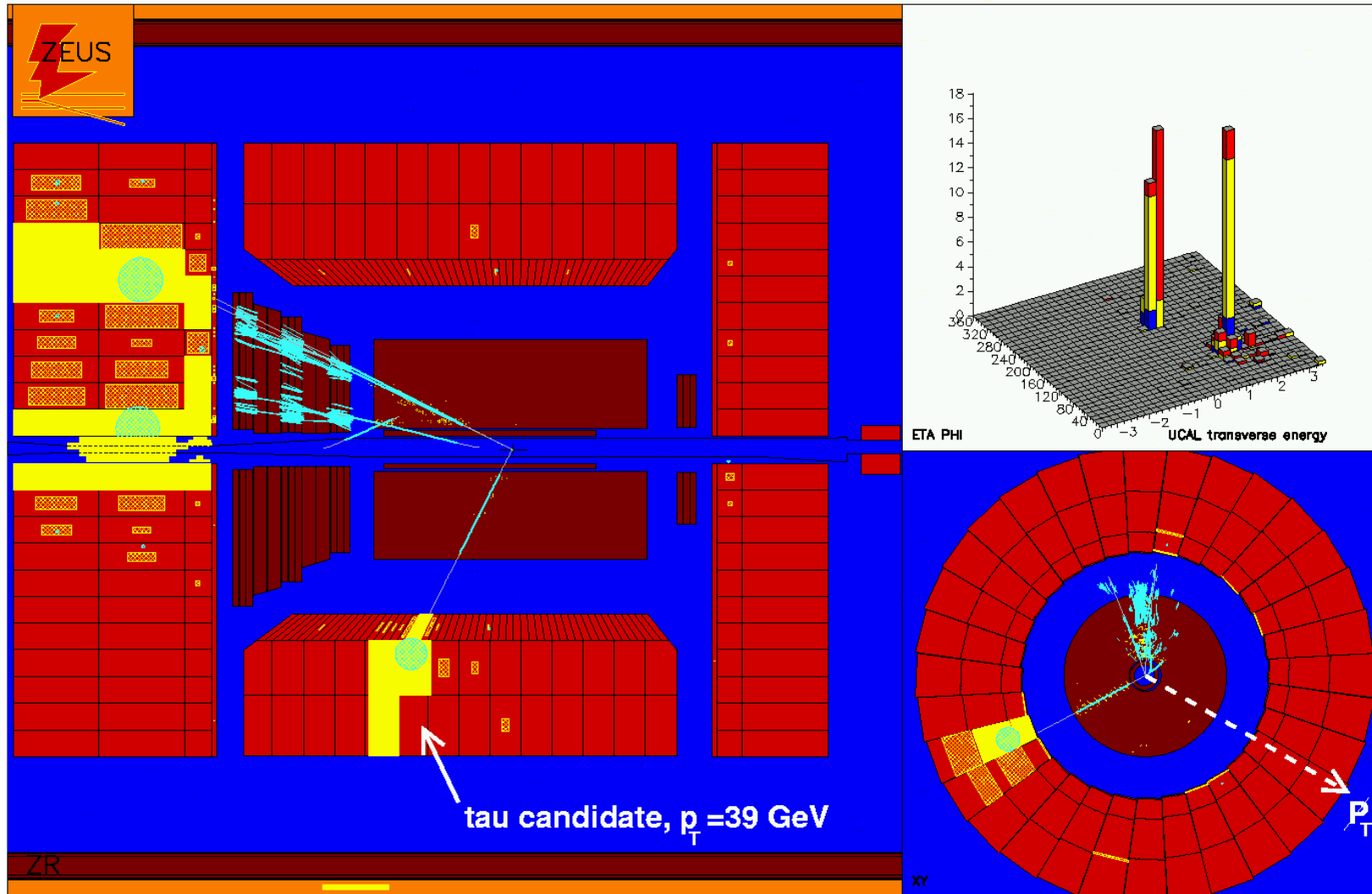
4 events found !  
3 are compatible with tau hypothesis, i.e. discriminant  $D > 0.95$

**ZEUS**



$D > 0.95$ :	data: 3	SM: $0.23 \pm 0.06$
and $P_T^X > 25 \text{ GeV}$ :	data: 2	SM: $0.12 \pm 0.02$ (0.1 $W^\pm$ )
$P_T^X > 40 \text{ GeV}$ :	data: 1	SM: $0.06 \pm 0.01$ (0.05 $W^\pm$ )
observed excess:	$O(10^{-3})$	

# Example of Tau Candidate



$$p_T^{CAL} = 39 \text{ GeV} \quad p_T^X = 37 \text{ GeV} \quad M_T = 68 \text{ GeV}$$

# Status: Isolated Lepton Events at HERA I

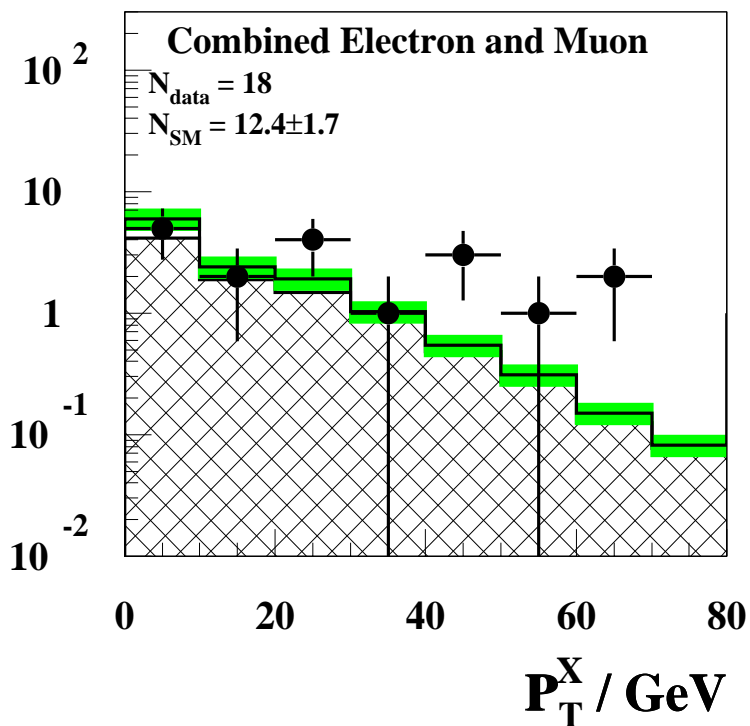
Electron/muon combined:

	H1		ZEUS	
	Data	SM	Data	SM
overall	18	$12.4 \pm 1.7$	36	$32.6 \pm 3.8$
$p_T^X > 25 \text{ GeV}$	10	$2.9 \pm 0.5$	7	$5.7 \pm 0.6$
$p_T^X > 40 \text{ GeV}$	6	$1.1 \pm 0.2$	0	$1.9 \pm 0.2$

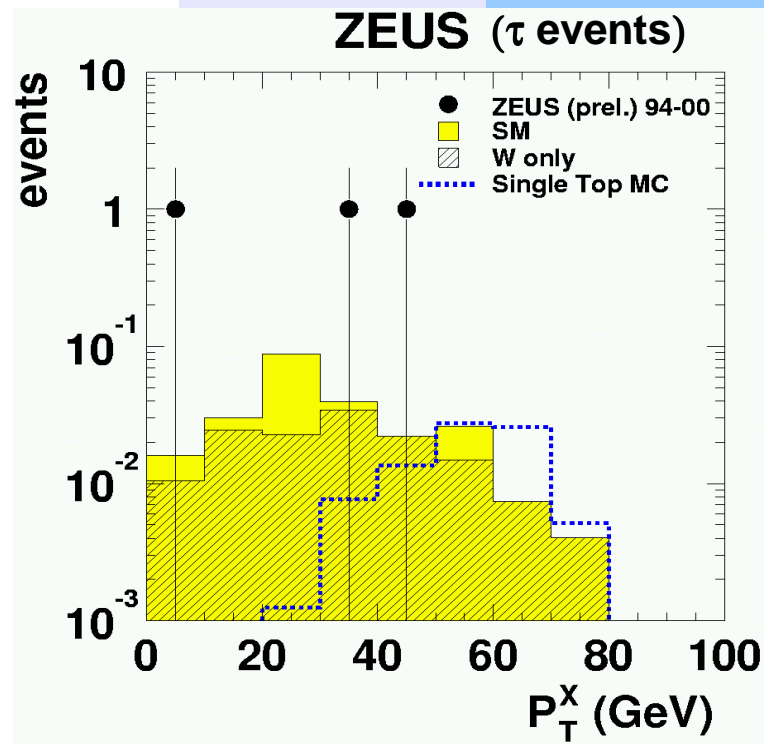
Tau Events:

	H1		ZEUS	
	Data	SM	Data	SM
overall	<i>Not yet</i>			
$p_T^X > 25 \text{ GeV}$			2	$0.12 \pm 0.02$
$p_T^X > 40 \text{ GeV}$			1	$0.06 \pm 0.01$

*preliminary*



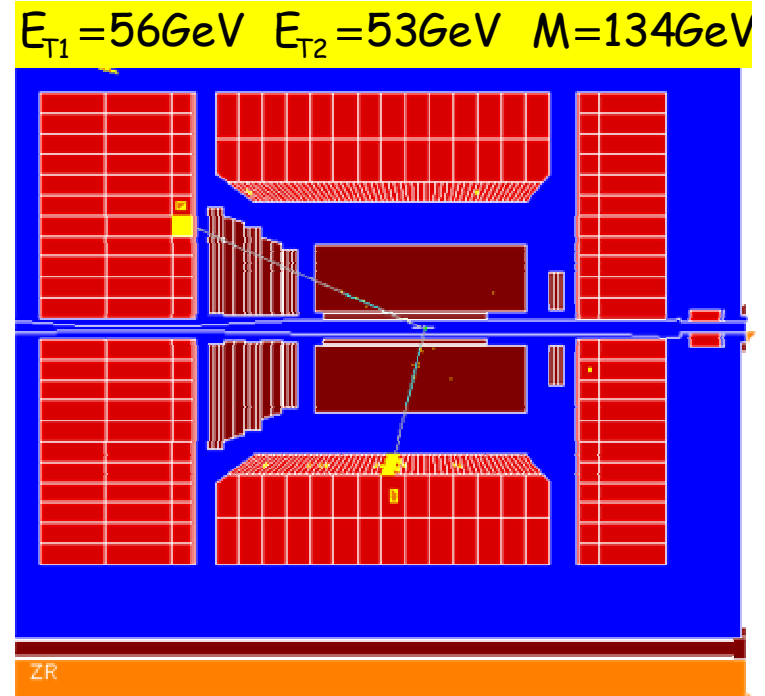
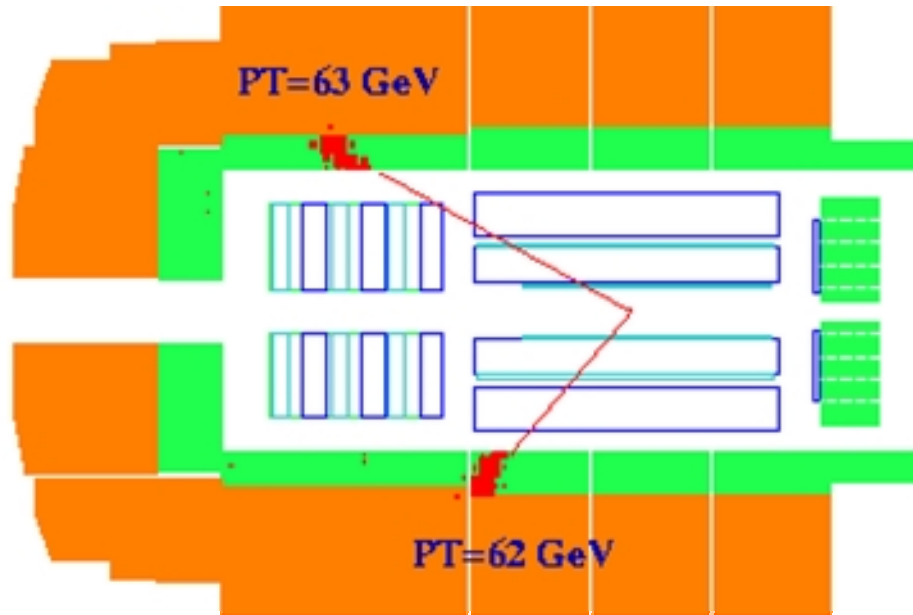
H1+ZEUS: Excess  $O(10^{-2}-10^{-3})$



Excess  $O(10^{-2}-10^{-3})$

# Multi-electron Events at Hera

Two isolated electrons, one with  $E_T > 10$  GeV



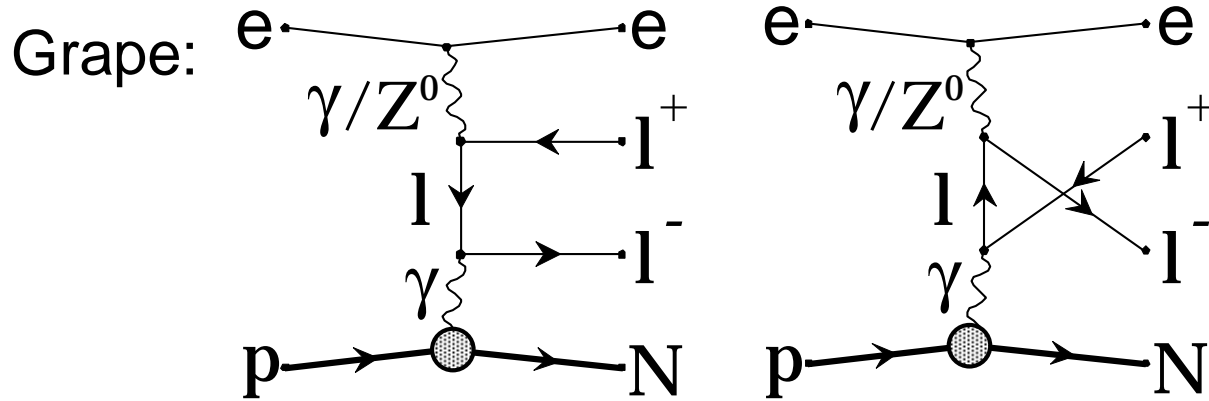
$$H1: 20^\circ < \theta_e < 150^\circ$$

$$Zeus: 17^\circ < \theta_e < 164^\circ$$

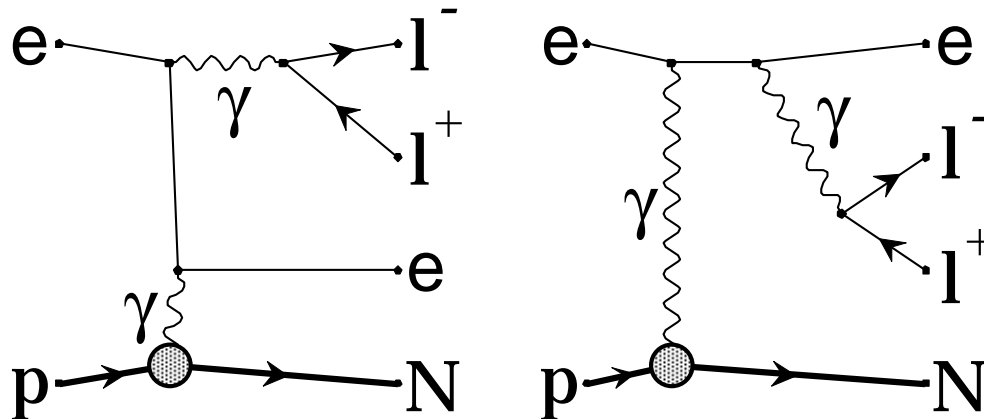
H1/Zeus: third electron allowed in:  $5^\circ < \theta_e < 175^\circ$

Different acceptances for SM expectation in the experiments

# SM Process: Multi-Electron Events



(a) Bethe-Heitler type diagrams

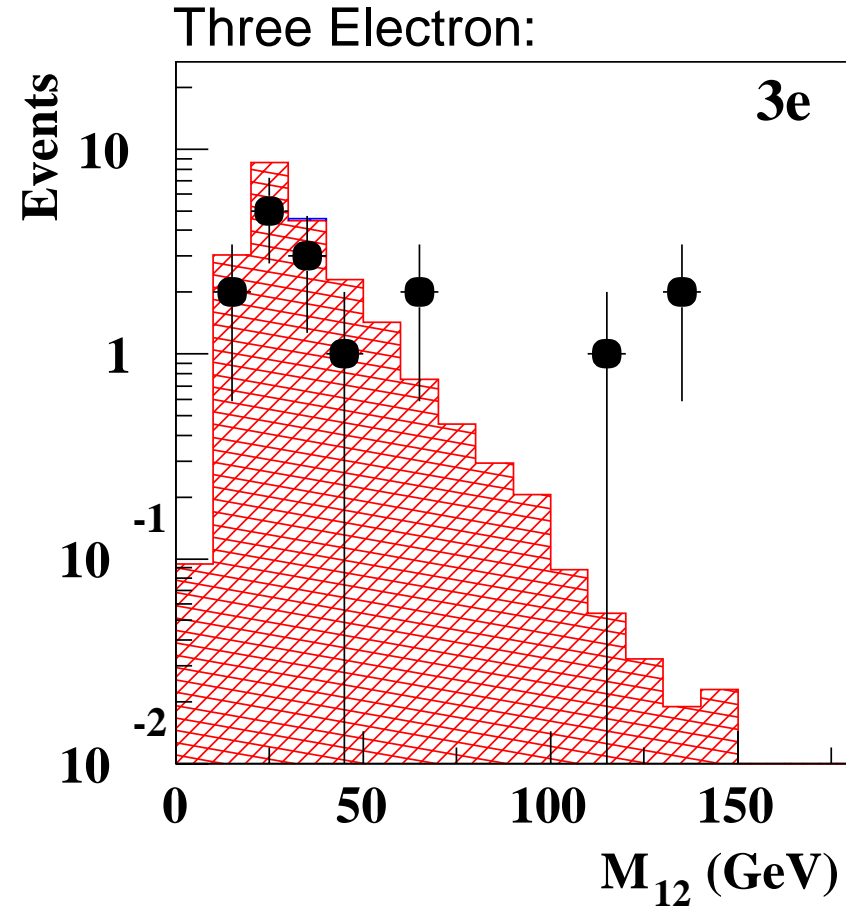
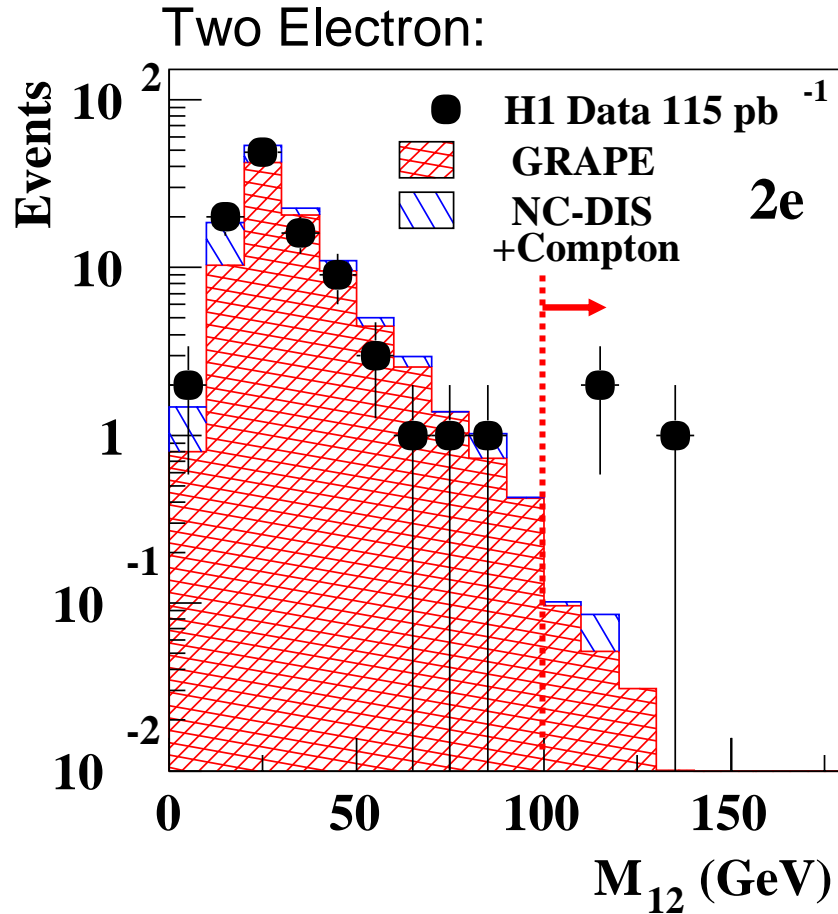


(b) QED-Compton type diagrams

+ electroweak diagrams

incl.  $\sigma(ep \rightarrow eeX) \approx$   
 200 - 300pb  
 depending on cuts

# H1 Two -and Three-electron Result



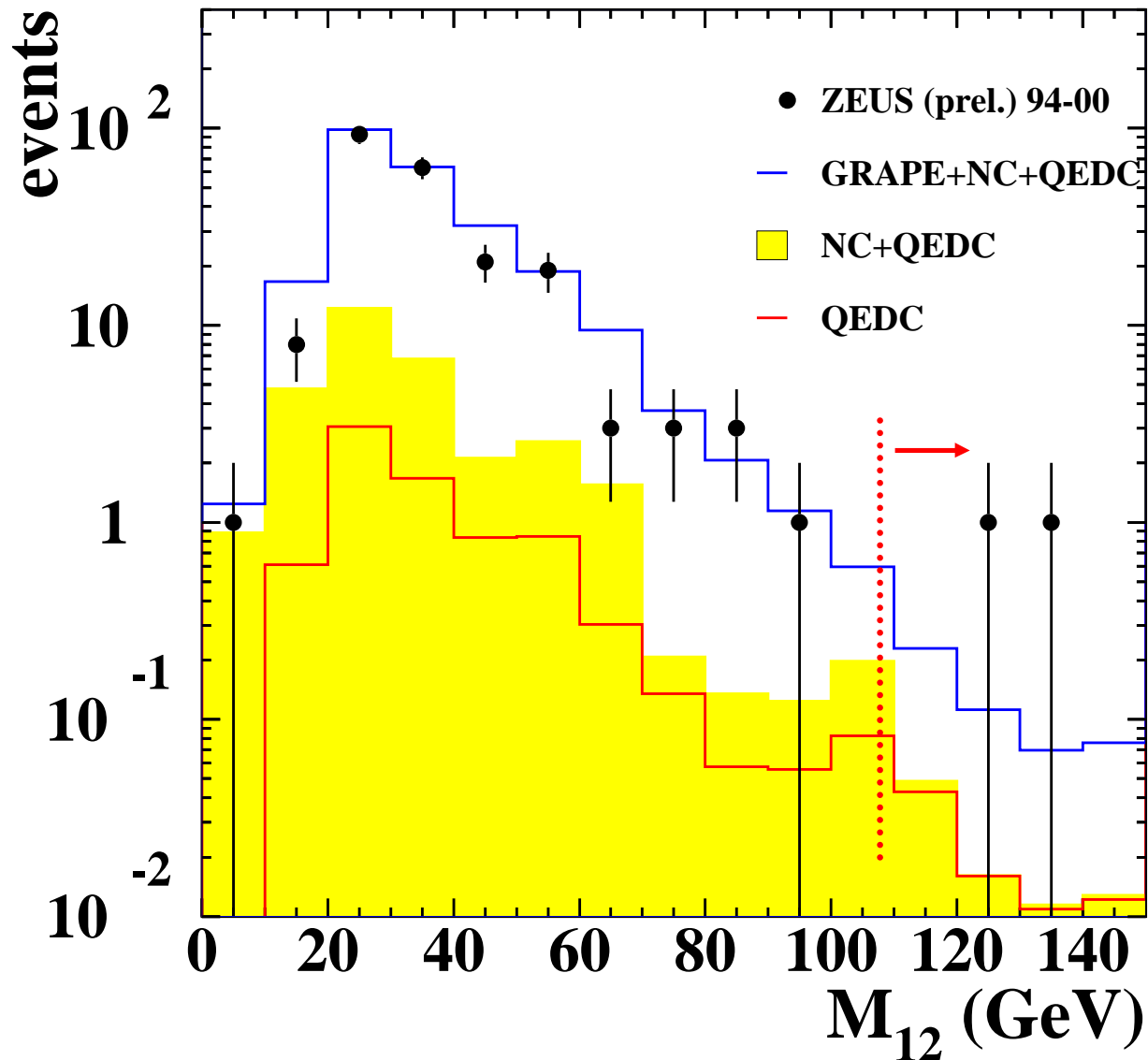
	Data	SM	(Grape	NC + QEDC)
	$M_{12} > 100$ GeV :			
$= 2 e^\pm$	3	$0.25 \pm 0.05$	$0.21 \pm 0.04$	$0.04 \pm 0.03$
$= 3 e^\pm$	3	$0.23 \pm 0.04$	$0.23 \pm 0.04$	$0.00 \pm 0.00$

Production of new particle ??  
 Muon channel also analysed,  
 but not conclusive

Excess  $O(10^{-5})$

# H1 Two -and Three -electron Result

Two or more electrons: **ZEUS**



Two electrons :  $M_{1,2} > 100 \text{ GeV}$  :

Data	SM	GRAPE
2	$0.8 \pm 0.1$	$0.5 \pm 0.1$

Three electrons :  $E_{T,1} > 30 \text{ GeV}$

Data	SM	GRAPE
2	$1.4 \pm 0.1$	$1.4 \pm 0.1$

Overall good agreement  
 no excess at high mass  
 in  $\mu$ -channel  
 no event  $M_{12} > 100 \text{ GeV}$

H1 excess not confirmed

H1+ZEUS Excess  $O(10^{-4})$

# Conclusions

Interesting events with isolated leptons and missing transverse energy observed

After final e/mu analysis situation remains unclear

H1 has a signal, ZEUS is compatible with SM

Preliminary analysis in Tau-Channel

Two interesting events, for the first time ZEUS “confirms” a signal

H1 observes 3 ee and 3 eee outstanding events with  $M_{ee} > 100$  GeV

ZEUS is compatible with SM

Hint for new physics or statistical fluctuation ?

Fully analysed HERA-I data give us puzzle

Needs HERA-II data to clarify situation

# Are the Tau-Data Compatible with e/mu-Data ?

Three different scenarios:

1) No signal, background fluctuates

2) strong anomalous W production  $\sigma_\tau=2/L$  (100%)

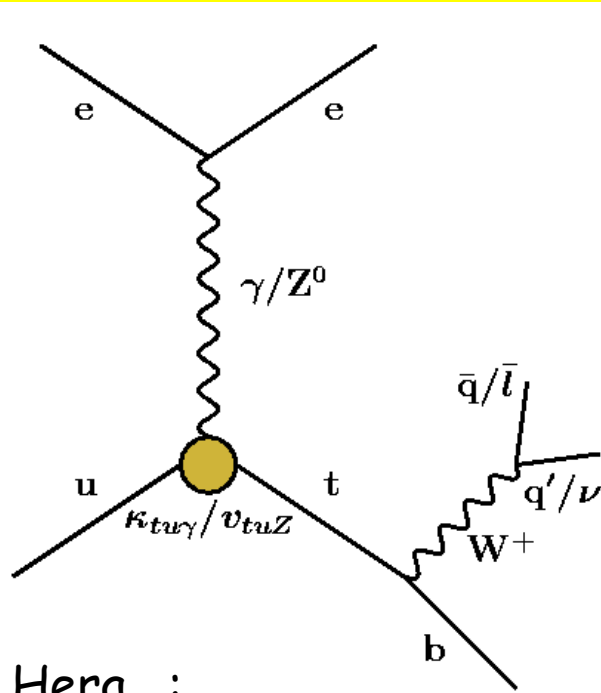
3) strong anomalous W production  $\sigma_\tau=0.2/L$  (5%)

Measurement	$N_{obs}$	$N_{exp}$	No signal		large W		small W	
			$N_{sig}$	$P(\frac{N_{obs}}{N_{exp}})$	$N_{sig}$	$P(\frac{N_{obs}}{N_{exp}})$	$N_{sig}$	$P(\frac{N_{obs}}{N_{exp}})$
ZEUS $\tau$ - search	2	0.2	0	0.7%	2	63%	0.2	4%
ZEUS $e/\mu$ $P_T^X > 25 GeV$	7	5.7	0	78%	56	$10^{-13}$	5.6	13%
ZEUS $e/\mu$ $P_T^X > 40 GeV$	0	1.9	0	15%	23	$10^{-7}$	2.3	1.5%
H1 $e/\mu$ $P_T^X > 25 GeV$	10	2.9	0	0.1%	51	$10^{-9}$	5.1	81%
H1 $e/\mu$ $P_T^X > 40 GeV$	6	1.1	0	0.1%	20	$10^{-4}$	2	96%

Small W signal in Tau-analysis is not excluded from e/mu analysis  
Need more data ! -> Hera-II

# Anomalous FCNC Single Top Production

# ZEUS



Hera :

very sensitive to  $\kappa_{tu\gamma}$   
 slightly sensitive to  $\kappa_{tuZ}$

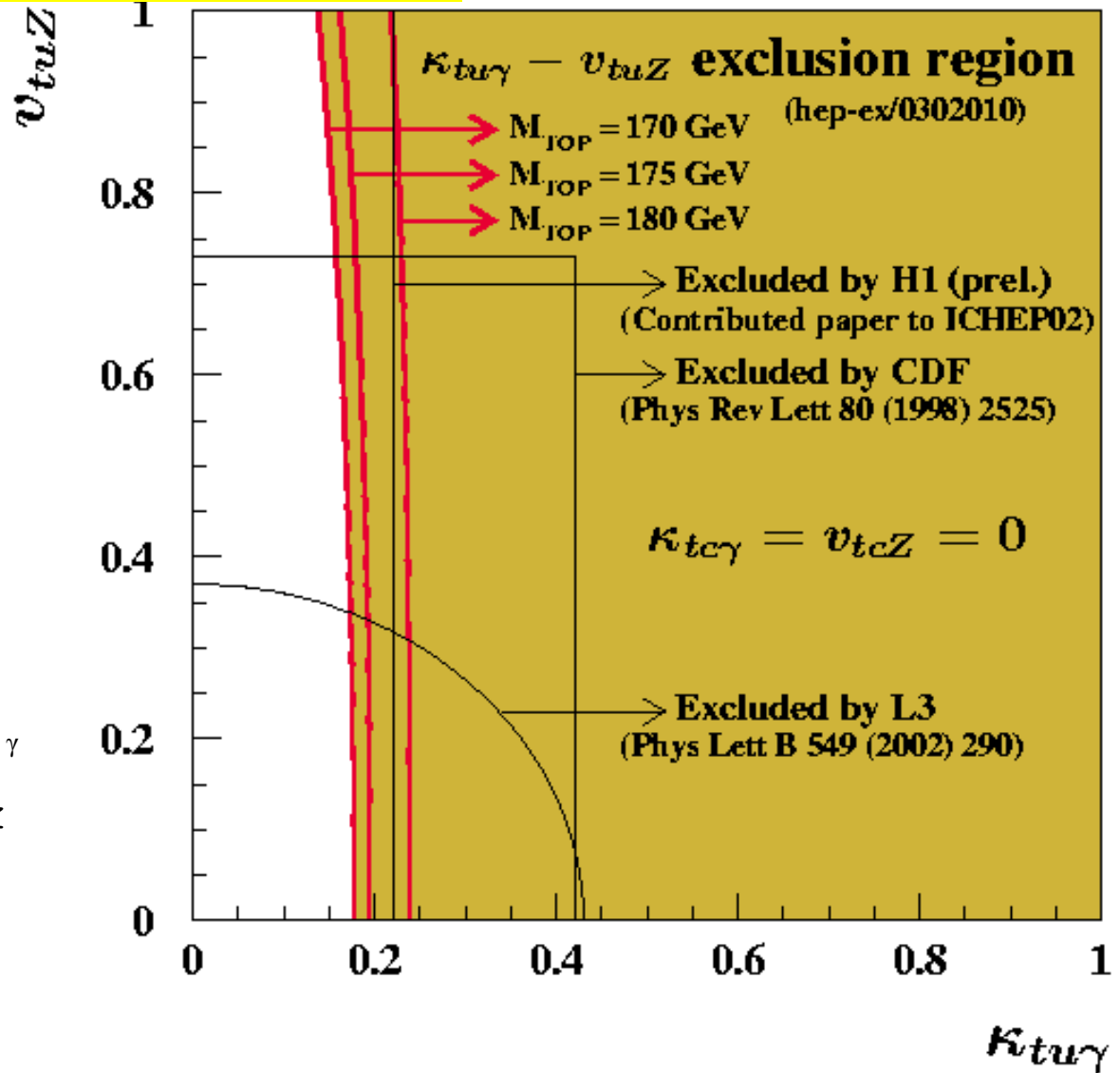
LEP :

$e^+e^- \rightarrow \gamma Z \rightarrow tu$

Tevatron :

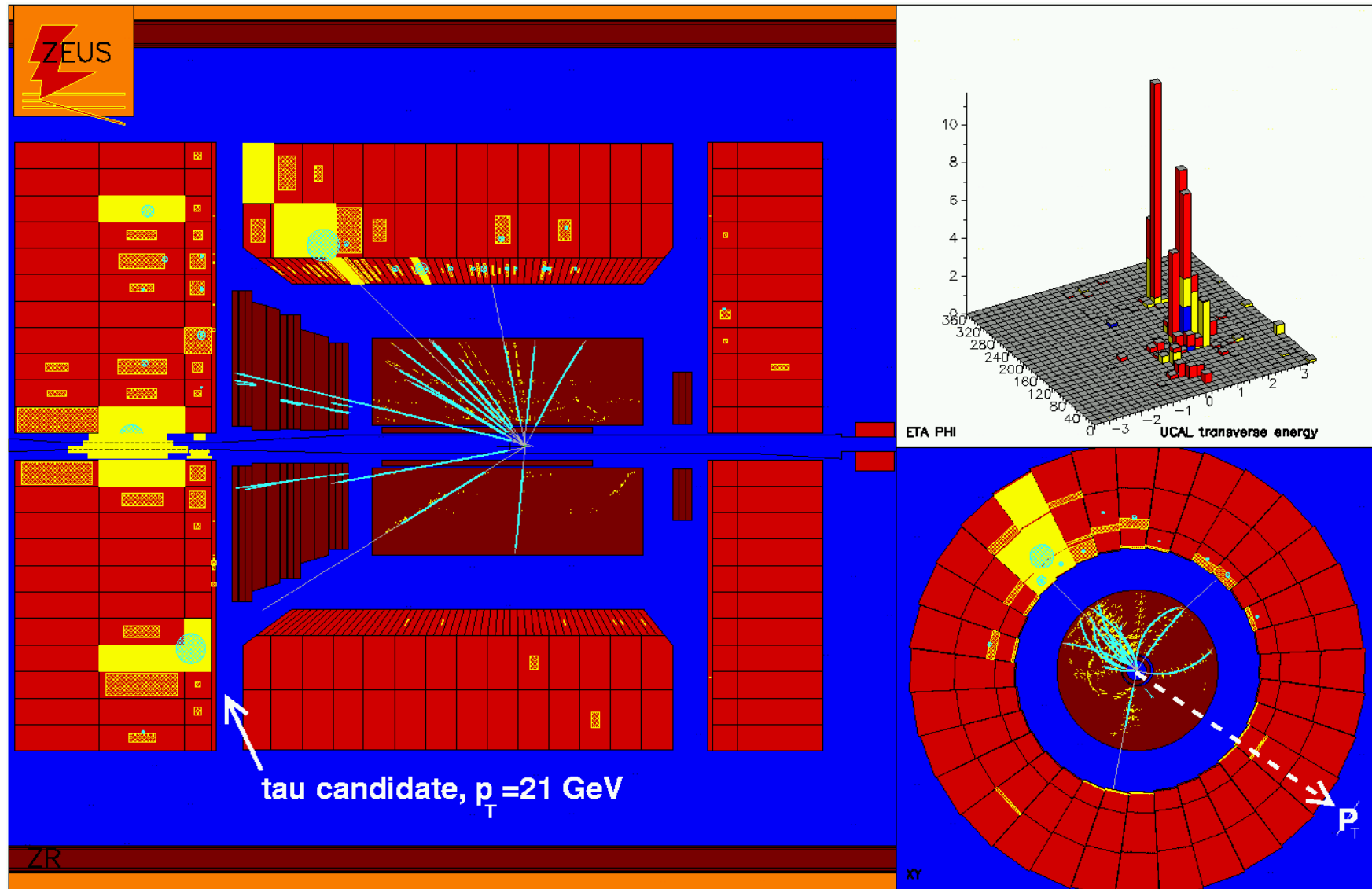
search for rare top decays

$t \rightarrow \gamma q, Zq$



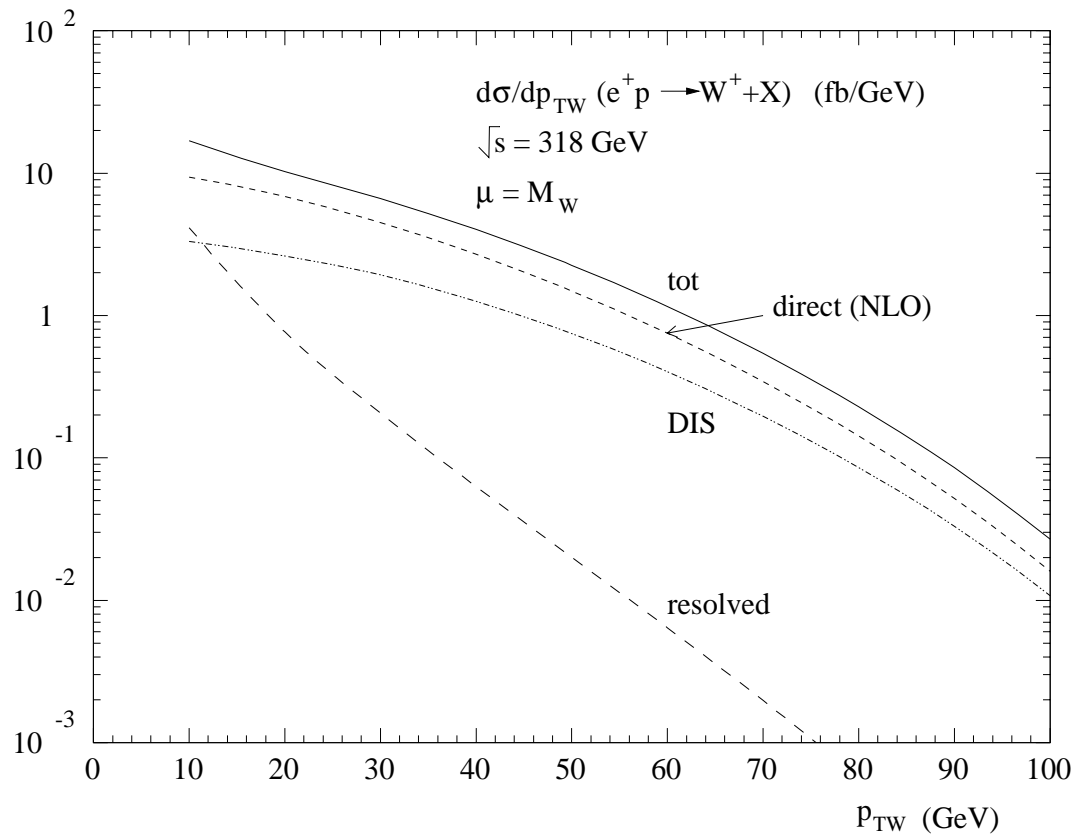
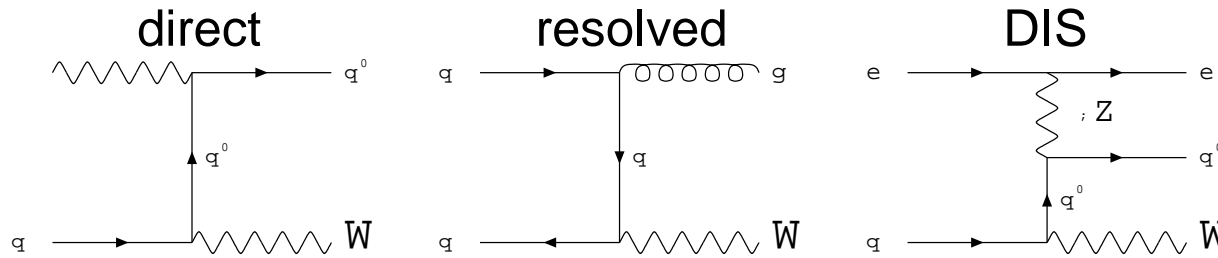
Had W decay also considered,  
 but no additional info (SM ok)

# Tau-1 Candidate



$$P_T^{CAL} = 37 \text{ GeV} \quad P_T^X = 48 \text{ GeV} \quad M_T = 32 \text{ GeV}$$

# Standard Model Processes: Isolated Leptons and $P_T^{\text{miss}}$



- 1) Direct contribution dominates
- 2) direct cross-section calculated in NLO
- 3) NLO correction 10-20%
- 4) residual scale dependence: 5-20%

$P_T^X > 25 \text{ GeV}$   
 $\sigma(W^+) = 0.15 \text{ pb}$   
 $\sigma(W^-) = 0.08 \text{ pb}$

## Details of H1 events

Run	Event	Lepton	$P_T^l$ /GeV	$P_T^X$ /GeV	$M_T$ /GeV	$M_{l\nu}$ /GeV	Charge
236176	3849	$e$	$10.1^{+0.4}_{-0.4}$	$25.4^{+2.8}_{-2.5}$	$26.1^{+1.1}_{-1.1}$		unmeasured
186729	702	$\mu^+$	$51^{+11}_{-17}$	$66.7^{+4.9}_{-4.9}$	$43^{+13}_{-22}$		+ (4.0 $\sigma$ )
188108	5066	$\mu^-$	$41.0^{+4.3}_{-5.5}$	$26.9^{+2.2}_{-2.3}$	$81.3^{+8.2}_{-11}$	$86.1^{+6.8}_{-8.7}$	- (8.3 $\sigma$ )
192227	6208	$\mu^-$	$73^{+9}_{-12}$	$60.5^{+5.5}_{-5.4}$	$74^{+20}_{-25}$		- (7.0 $\sigma$ )
195308	16793	$\mu^+$	$60^{+12}_{-19}$	$33.3^{+3.6}_{-3.6}$	$85^{+25}_{-37}$		+ (4.2 $\sigma$ )
248207	32134	$e^+$	$32.0^{+0.8}_{-0.9}$	$42.7^{+3.9}_{-4.1}$	$62.8^{+1.8}_{-1.8}$		+ (15 $\sigma$ )
252020	30485	$e^+$	$25.3^{+1.0}_{-1.0}$	$44.3^{+3.6}_{-3.6}$	$50.6^{+1.9}_{-2.0}$	$79^{+12}_{-12}$	+ (40 $\sigma$ )
266336	4126	$\mu^+$	$19.7^{+0.7}_{-0.8}$	$51.5^{+3.8}_{-4.0}$	$69.2^{+2.4}_{-2.6}$		+ (26 $\sigma$ )
268338	70014	$e^+$	$32.1^{+0.9}_{-0.8}$	$46.6^{+3.3}_{-3.3}$	$87.7^{+2.5}_{-2.4}$		+ (5.1 $\sigma$ )
270132	73115	$\mu$	$64^{+38}_{-55}$	$27.3^{+3.9}_{-3.9}$	$140^{+71}_{-83}$		- (0.6 $\sigma$ )
275991	29613	$e^+$	$37.7^{+1.0}_{-1.1}$	$28.4^{+5.7}_{-5.9}$	$74.7^{+2.3}_{-2.4}$		+ (37 $\sigma$ )

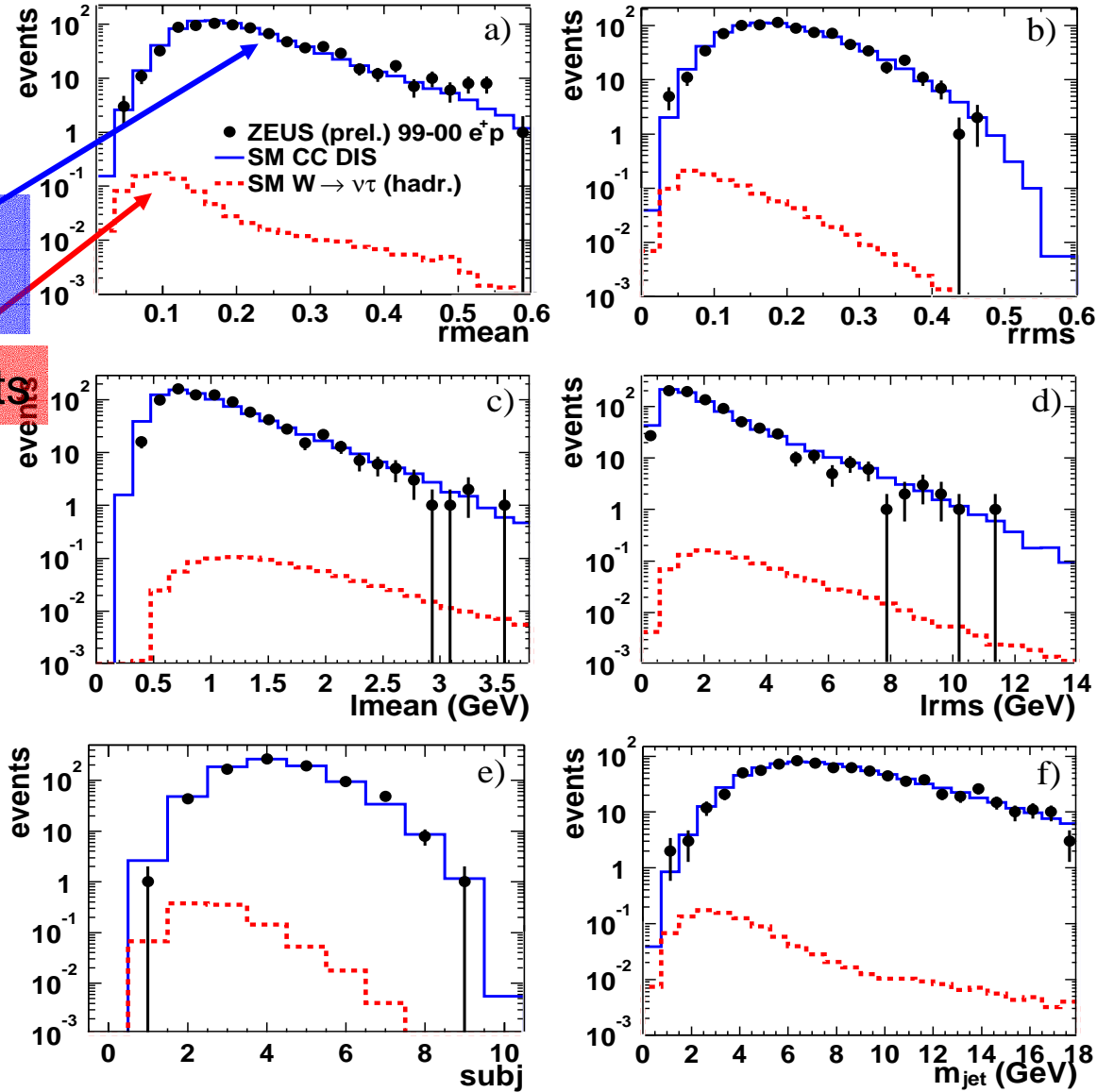
Table 1: Kinematics and lepton charges of the events at high  $P_T^X$  ( $> 25$  GeV). The invariant mass  $M_{l\nu}$  is only calculated for those events with an observed scattered electron. The significance of the charge measurement in numbers of standard deviations is given in brackets after the sign. The first event listed was observed in  $e^-p$  data. The rest were observed in  $e^+p$  data.

# Internal Jet Structure Observables

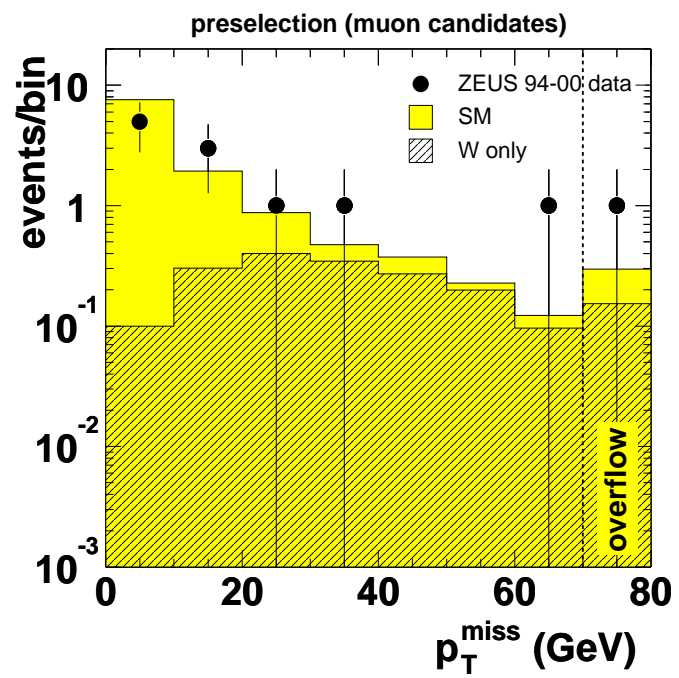
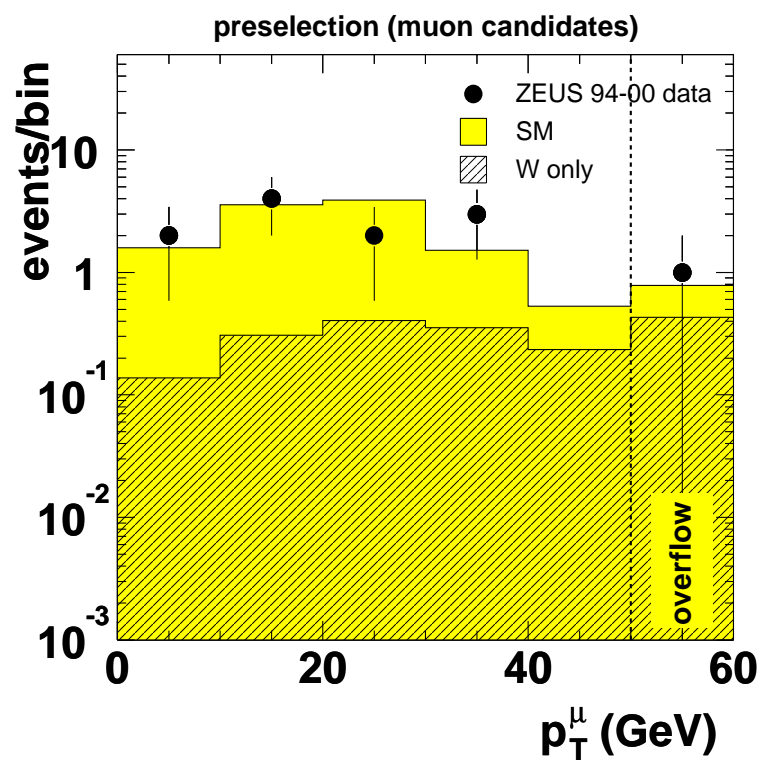
Incl. charged current sample: **ZEUS**

QCD jets

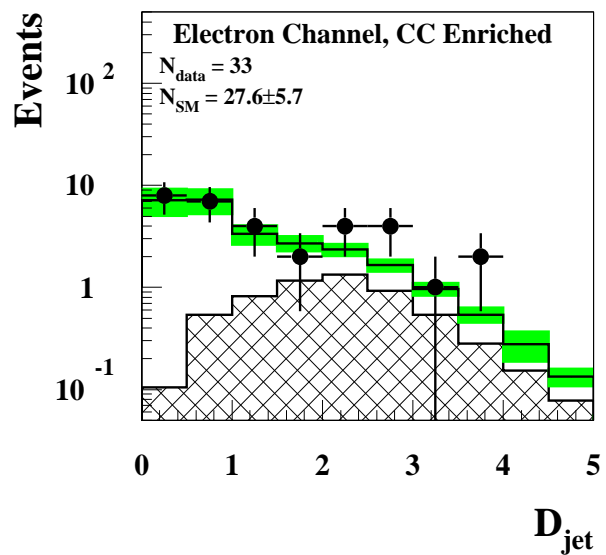
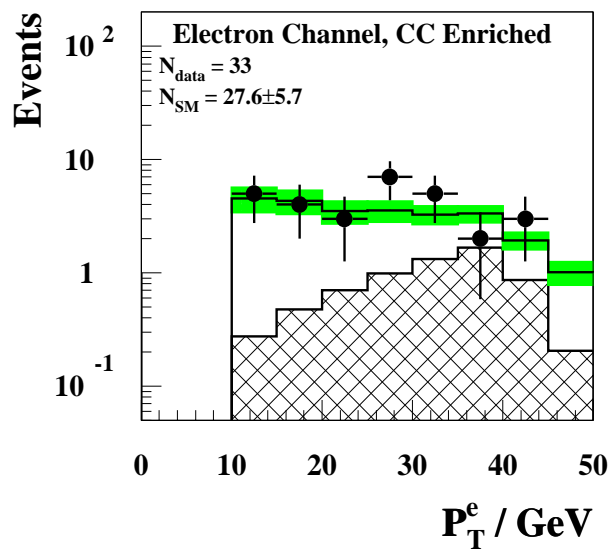
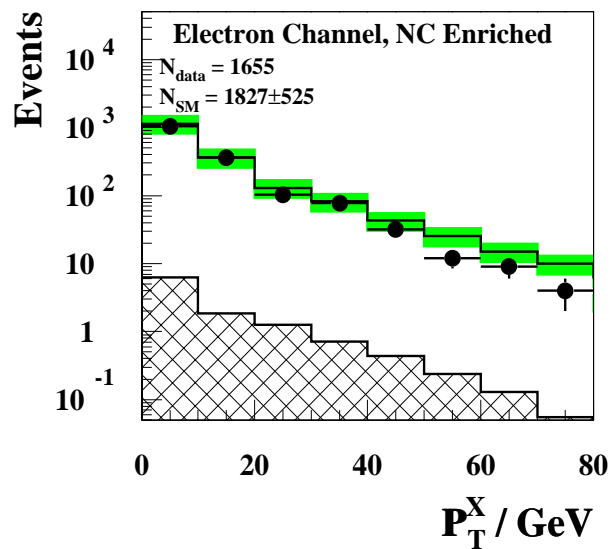
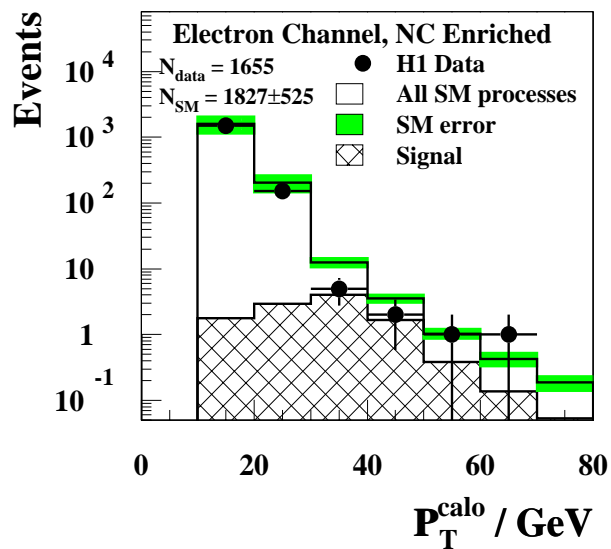
Tau jets



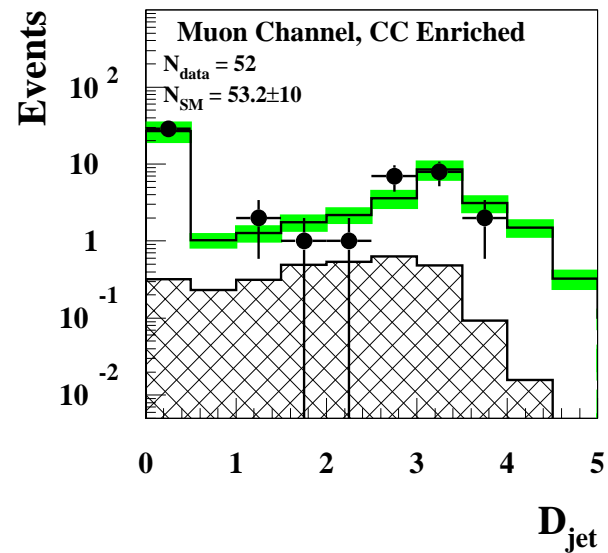
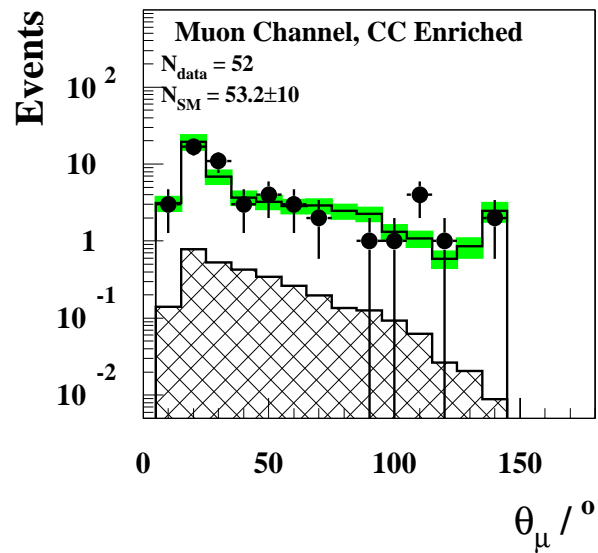
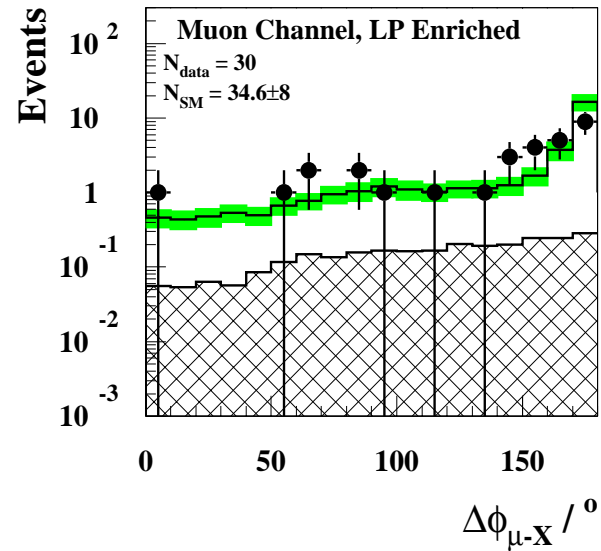
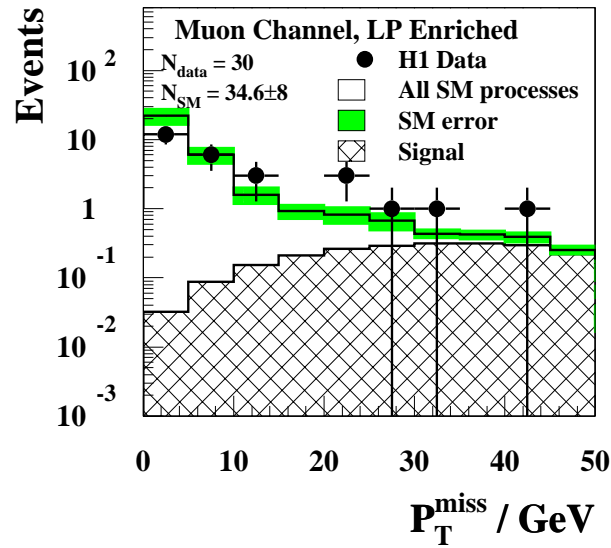
Needs reduction of QCD jet background by 1000 to see  $W \rightarrow \tau \rightarrow \text{hadrons}$



# H1 NC Background Sample



# H1 Lepton Pair Background Sample



# H1 Signal Sample

