

# Events with High $P_T$ Leptons and Missing $P_T$ and Anomalous Top at HERA

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On Behalf of the H1 Collaboration



**XIIIth International Workshop on Deep Inelastic Scattering (DIS 2004)**

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# Outline

## Introduction

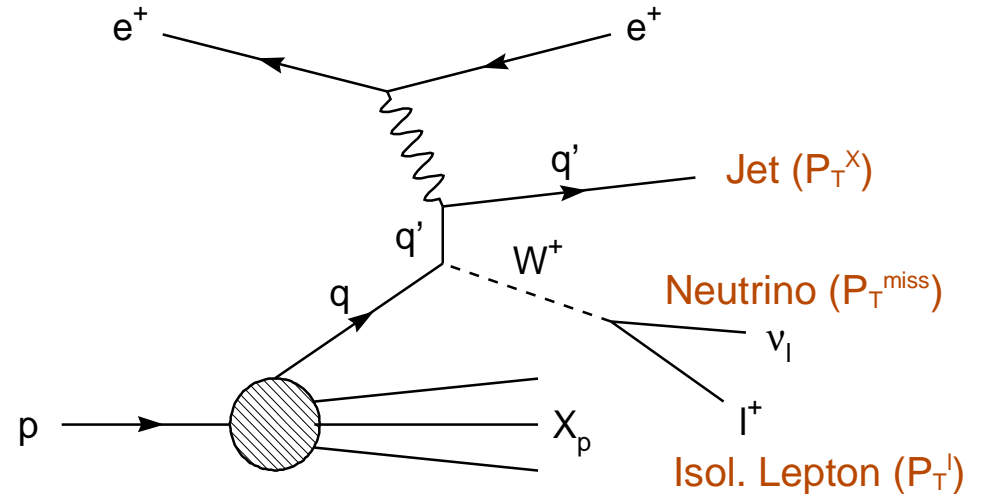
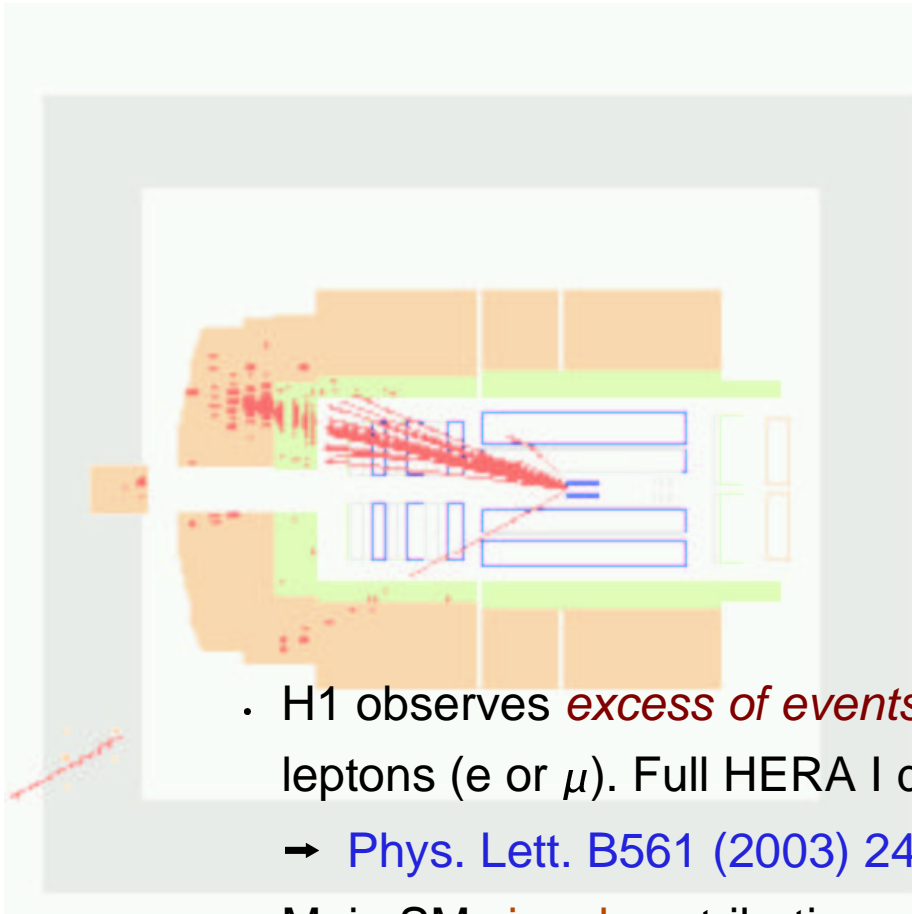
## H1 Events with Missing $P_T$ and High $P_T$ Leptons at HERA I

## Search for Single Top Quark Production

## Latest H1 Results from HERA II Data

## Summary and Outlook

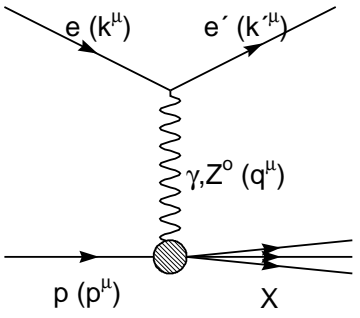
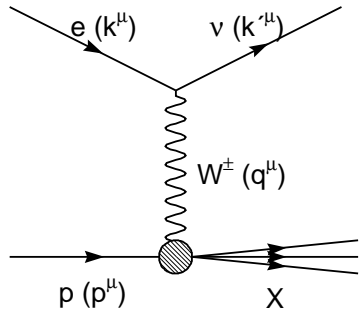
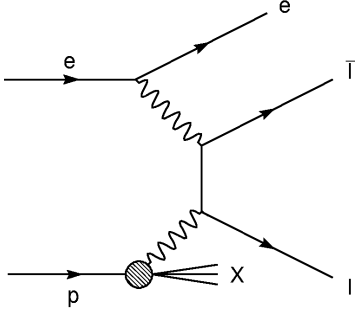
# Introduction to the “Isolated Lepton” Analysis



- H1 observes *excess of events* containing missing  $P_T$  and high  $P_T$  leptons (e or  $\mu$ ). Full HERA I data set now published  
→ [Phys. Lett. B561 \(2003\) 241](#).
- Main SM **signal** contribution comes from the production of real W bosons via photoproduction, with subsequent leptonic decay
- LO Cross section at HERA,  $\sigma(ep \rightarrow eW^\pm X) \approx 1$  pb; NLO SM W calculations performed by [Schwanenberger et. al](#) now included

# Isolated Lepton Analysis – SM Background

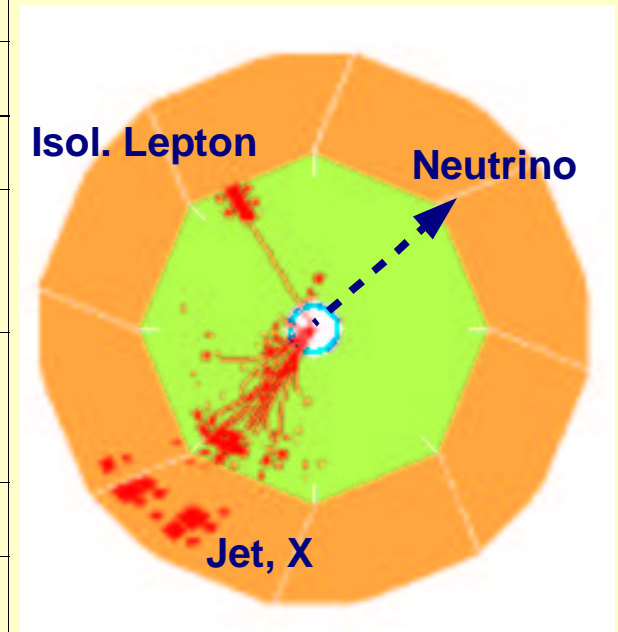
- SM **signal** processes modelled by **EPVEC** Monte Carlo, including additional contributions from CC W production and Cabibbo-Paresi  $Z^0$  production
- SM **background** processes include Neutral Current, Charged Current, Lepton Pair and Photoproduction – dedicated study samples of main backgrounds performed

e: Neutral Current	e, $\mu$ : Charged Current	$\mu$ : Lepton Pair
		
<p>real electron &amp; fake <math>P_T^{\text{miss}}</math> from mismeasurement</p>	<p>misidentified electron/ real muon &amp; real <math>P_T^{\text{miss}}</math></p>	<p>real muon &amp; fake <math>P_T^{\text{miss}}</math> from mismeasurement</p>

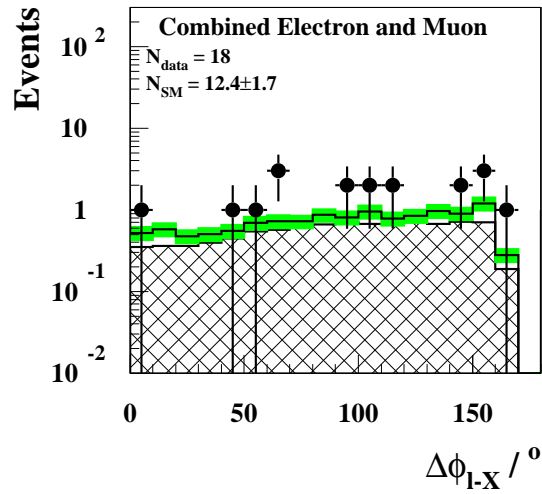
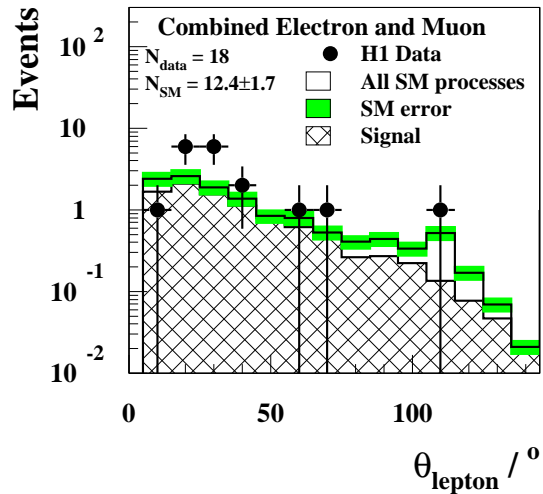
# Isolated Lepton Analysis – Event Selection

Main Selection requirements include:

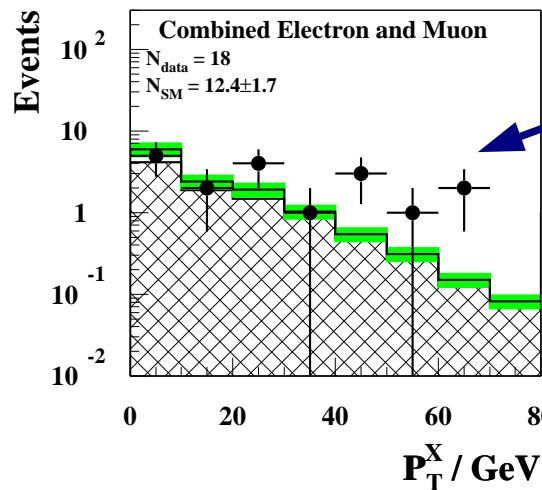
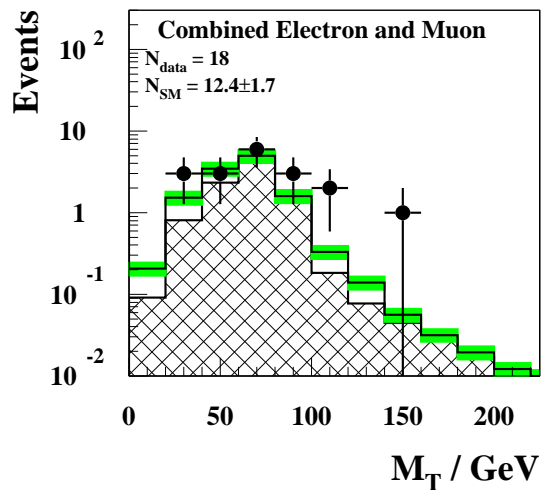
Lepton in central region of detector	$5^\circ < \theta_l < 140^\circ$
High lepton transverse momentum	$P_T^l > 10 \text{ GeV}$
Large missing transverse momentum	$P_T^{\text{miss}} > 12 \text{ GeV}$
Overall direction of event : calorimetric energy sums	$V_{\text{ap}} / V_{\text{p}} < 0.5$
Azimuthal imbalance, acoplanarity	$\Delta\phi_{e-X} < 160^\circ$ ( $\Delta\phi_{\mu-X} < 170^\circ$ )
Longitudinal imbalance	$\delta_{\text{miss}} > 5 \text{ GeV}$
Lepton Isolation w.r.t. other parts of the event	$D_{\text{jet}} > 1,$ $D_{\text{track}} > 0.5$



# HERA I Isolated Lepton Analysis – Results



Final  $e^+p$  Data Selection in the combined electron & muon channels



$P_T^X > 25$  GeV:

$N_{\text{data}} = 10$

$N_{\text{SM}} = 2.92 \pm 0.49$

# HERA I Isolated Lepton Analysis – Results

## H1 e<sup>+</sup>p data (1994-2000), 104.7 pb<sup>-1</sup>

Electron and Muon	H1 Data	SM Total	Signal (EPVEC)	Other SM Processes
$P_T^X < 12$ GeV	5	$6.40 \pm 0.79$	$4.45 \pm 0.70$	$1.95 \pm 0.36$
$12 < P_T^X < 25$ GeV	3	$3.08 \pm 0.43$	$2.40 \pm 0.40$	$0.68 \pm 0.14$
$25 < P_T^X < 40$ GeV	4	$1.83 \pm 0.27$	$1.59 \pm 0.26$	$0.24 \pm 0.06$
$P_T^X > 40$ GeV	6	$1.08 \pm 0.22$	$0.96 \pm 0.22$	$0.12 \pm 0.04$

## H1 e<sup>-</sup>p data (1998-1999), 13.6 pb<sup>-1</sup>

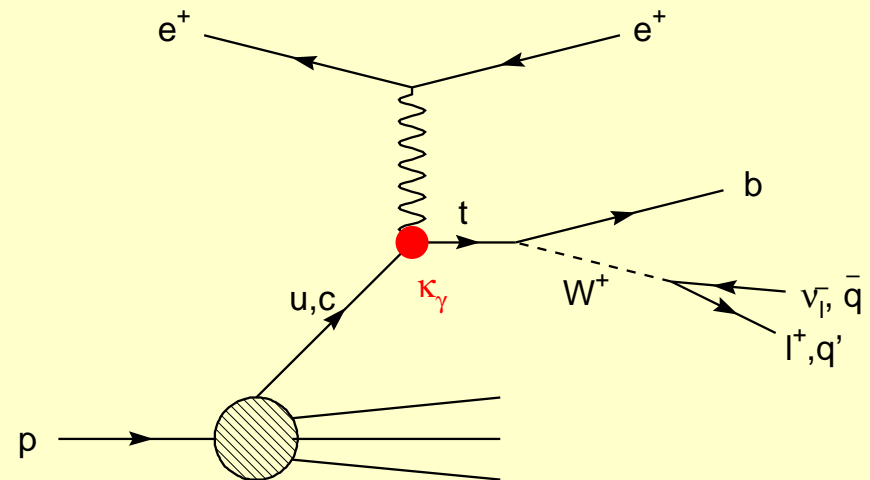
$P_T^X < 25$ GeV	0	$1.54 \pm 0.20$	$0.93 \pm 0.16$	$0.61 \pm 0.13$
$P_T^X > 25$ GeV	1	$0.52 \pm 0.08$	$0.37 \pm 0.07$	$0.15 \pm 0.04$

- Excess observed at large values of  $P_T^X$  in e<sup>+</sup>p data
- Analysis of tau channel now [H1 Preliminary](#) → see talk by *G.Brandt*

# Search for Single Top Production - Introduction

- Motivated by observed excess at high  $P_T^X$  of events in Isolated Lepton analysis  
 → The production of single top quarks with decay to **b** and a **W boson** may provide a possible explanation

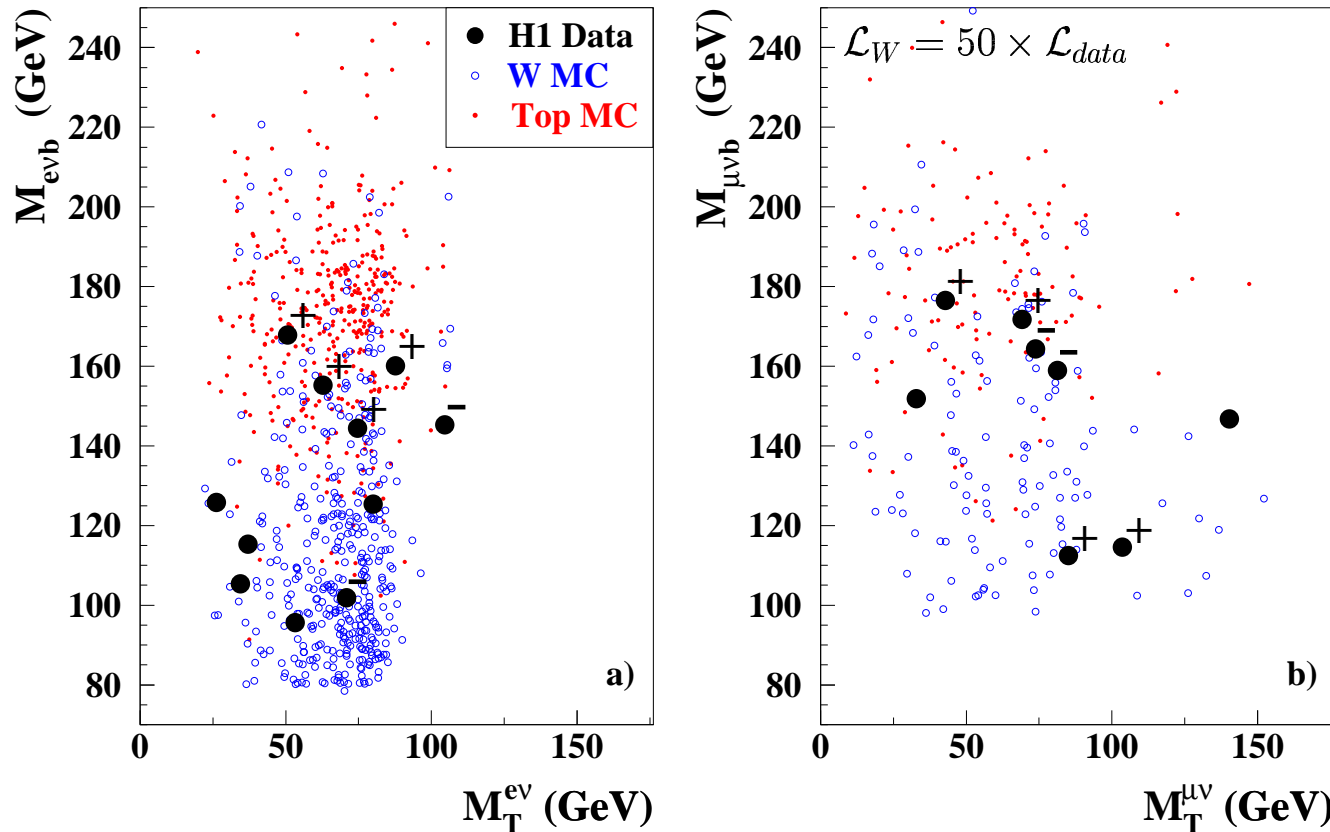
- SM single top **highly suppressed**
- Search for **anomalous top production** via **FCNC** interaction
- SM W production is dominant at low values of  $P_T^X$ , whereas the b-jet has large transverse momentum



- Study coupling between up and top quarks,  $K_{tuy}$  (neglect  $Z^0$  boson exchange)
- Search covers the leptonic ( $W \rightarrow l\nu$ ) and hadronic ( $W \rightarrow qq'$ ) decays of the W.



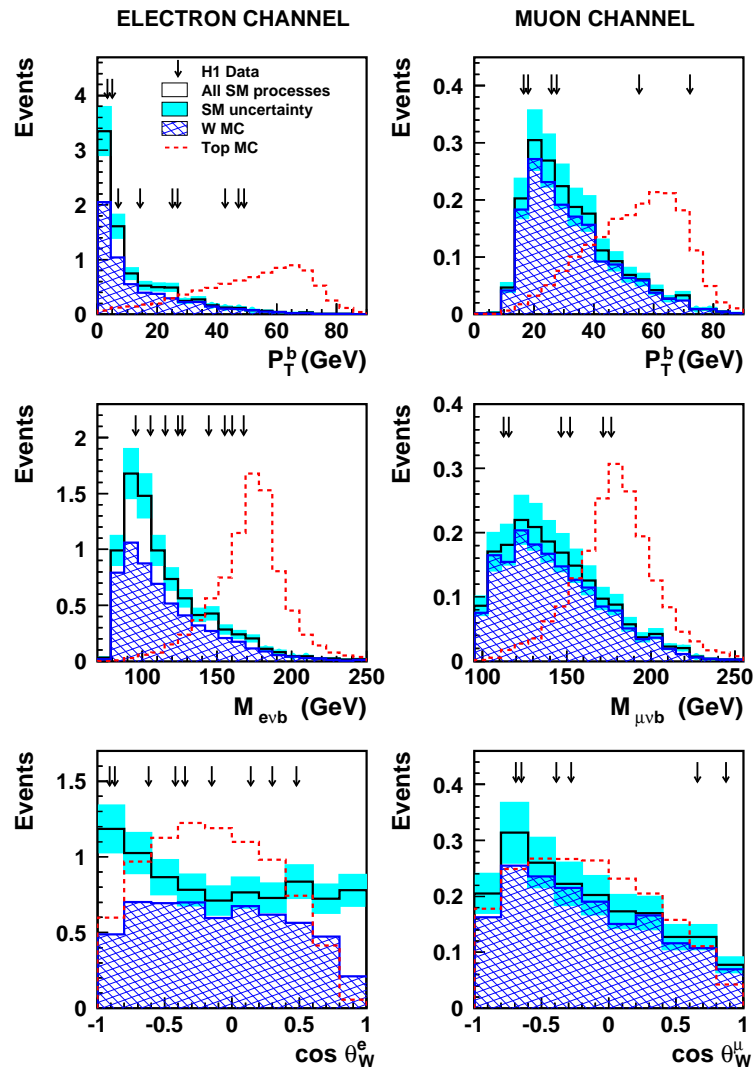
# Search for Single Top in the Leptonic Channel



## Kinematic Reconstruction of the top quark decay

- **b quark** reconstruction: b-jet not tagged, but reconstructed from sum of all jets
- **neutrino** reconstruction: apply constraint on W mass,  $M_{l\nu} = \sqrt{P_l^2 + P_\nu^2 + 2 P_l P_\nu} \approx \sqrt{2 P_l P_\nu} = M_W$
- Examine invariant mass of top system,  $M_{\text{l}\nu\text{b}}$  versus the lepton-neutrino transverse mass,  $M_{\text{T}}^{\text{l}\nu}$

# Search for Single Top in the Leptonic Channel



## Top Preselection

- Isolated lepton events + neutrino reconstruction
- Rejection of leptons with negative charge:

$$t \rightarrow bW^+ \rightarrow bl^+\nu_l$$

top decay produces only positively charged leptons

- 9 electron events and 6 muon events
- Three discriminatory observables:  $P_T^b$ ,  $M_{l\nu b}$  and  $\theta_W^l$

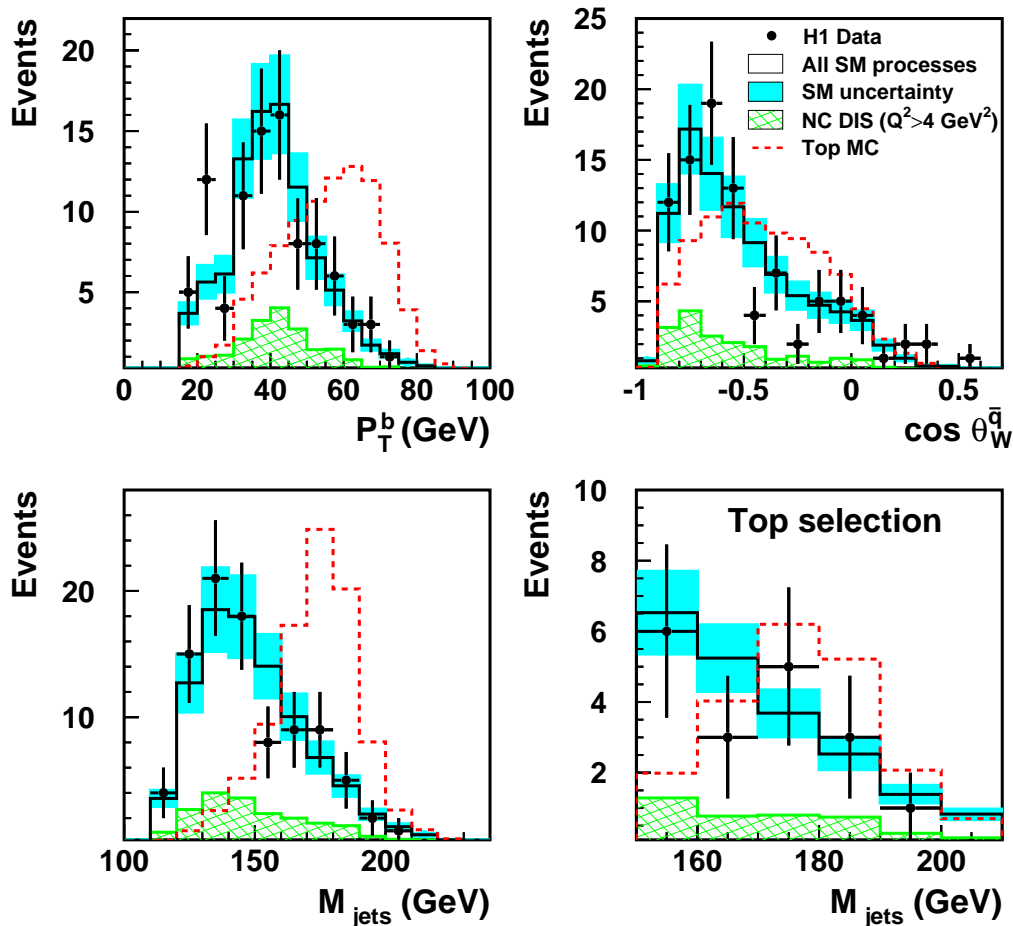
## Cut-based Top Selection in Leptonic Channel

- $P_T^b > 30$  GeV and  $M_{l\nu b} > 140$  GeV
- Main contribution to SM prediction from **W production**

	Data	Standard Model
Electron Channel	3	$0.65 \pm 0.10$
Muon Channel	2	$0.66 \pm 0.12$
Total	5	$1.31 \pm 0.22$

# Search for Single Top in the Hadronic Channel

## HADRONIC CHANNEL - TOP PRESELECTION



## Top Preselection

- High transverse momentum multi-jet events,  $P_T^{\text{jet}1} > 40 \text{ GeV}$ ,  $P_T^{\text{jet}2} > 30 \text{ GeV}$ ,  $P_T^{\text{jet}3} > 15 \text{ GeV}$
- Large total transverse energy,  $E_T^{\text{tot}} > 110 \text{ GeV}$
- One pair of jets with  $65 \text{ GeV} < M_l < 95 \text{ GeV}$
- 92 data events,  $92.4 \pm 16.6$  expected from SM
- Discriminatory observables analogous to leptonic channel:  $P_T^b$ ,  $M_{\text{jets}}$  and  $\theta_W^q$

## Cut-based Top Selection in Hadronic Channel

- $P_T^b > 40 \text{ GeV}$ ,  $150 \text{ GeV} < M_{\text{jets}} < 210 \text{ GeV}$   
and  $\cos \theta_W^q > -0.75$
- Less sensitive to W Production than leptonic channel, main SM contribution from **NC DIS**

	Data	Standard Model
Hadronic Channel	18	$20.6 \pm 3.6$

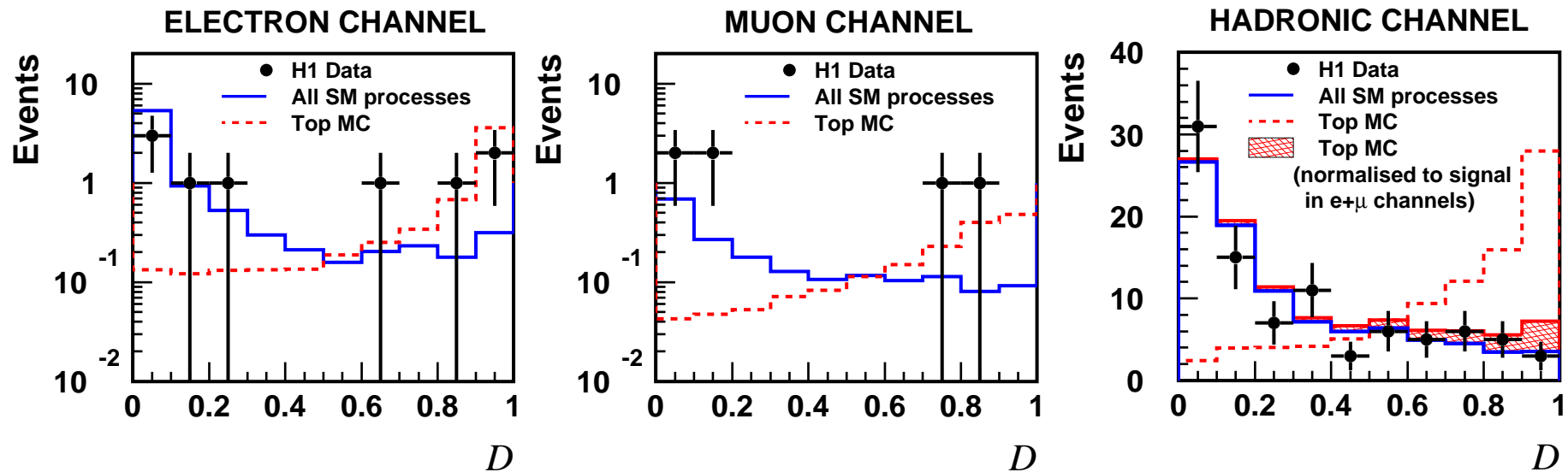
# Multivariate Analysis

- Set of observables,  $V = \{V_i\}$  with probability densities  $p_i^{signal}$  and  $p_i^{background}$  calculated from MC

**leptonic channel:**  $V = \{P_T^b, M_{l\nu b}, \cos \theta_W^l\}$  , **hadronic channel:**  $V = \{P_T^b, M_{jets}, \cos \theta_W^q\}$

- Observables combined to calculate a Discriminator  $D(V)$  for each event, given by:

$$D(V) = \frac{P^{signal}}{P^{signal} + P^{background}} \quad \text{where} \quad P = C(V) \prod_i p_i$$



- Leptonic channel:** 5 data events in cut-based analysis found in top-like region ( $D = 1$ )
- Hadronic channel:** data and QCD background in good agreement
- Results in hadronic channel not in contradiction with single top hypothesis in leptonic channel*

# Maximum Likelihood Fit – Cross Sections

- A **maximum likelihood fit** is performed of the top contribution, using likelihood discriminator distributions as input

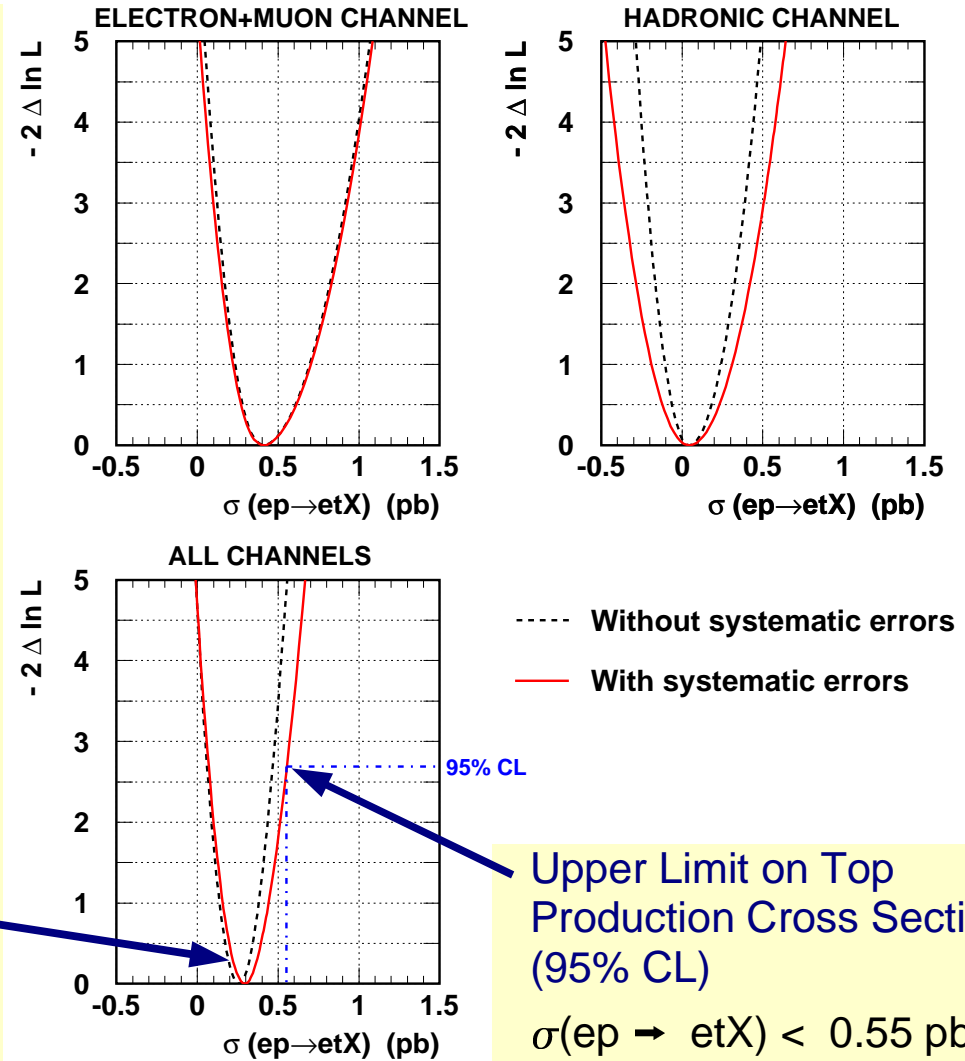
- Likelihood function:

$$L = \prod_{k=1}^n e^{-\mu_k} \frac{\mu_k^{n_k}}{n_k!}$$

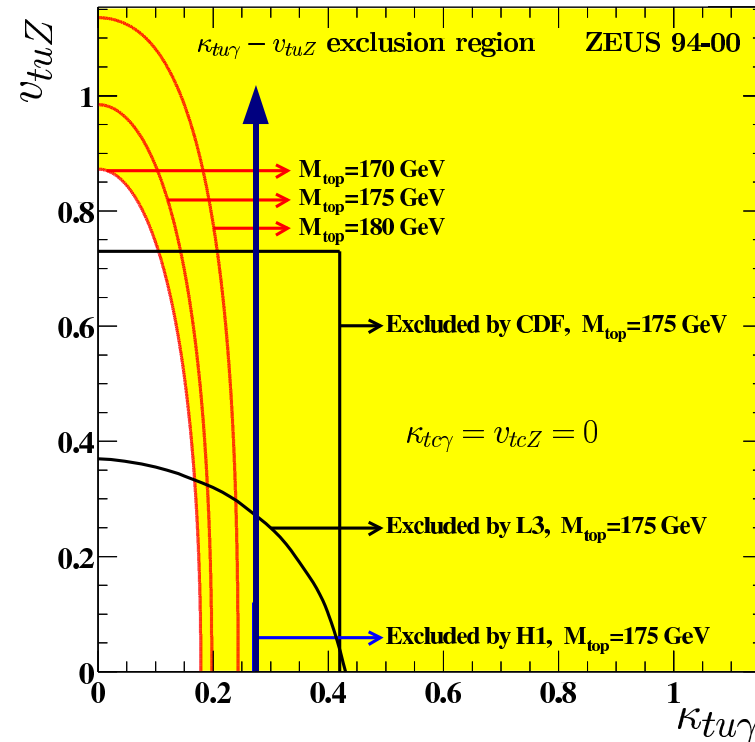
- $\mu_k$  is the sum of signal and background in bin  $k$
- Look for **minimum** in negative log likelihood function  $-2\Delta/\ln L$  as a function of top production cross section
- Leptonic and Hadronic channels found to be compatible at  $1.1\sigma$  level, including systematic errors (dominant in hadronic channel)

## Measured Top Production Cross Section

$$\sigma(ep \rightarrow etX) = 0.29^{+0.15}_{-0.14} \text{ pb}$$



# Single Top Production – Exclusion Limit



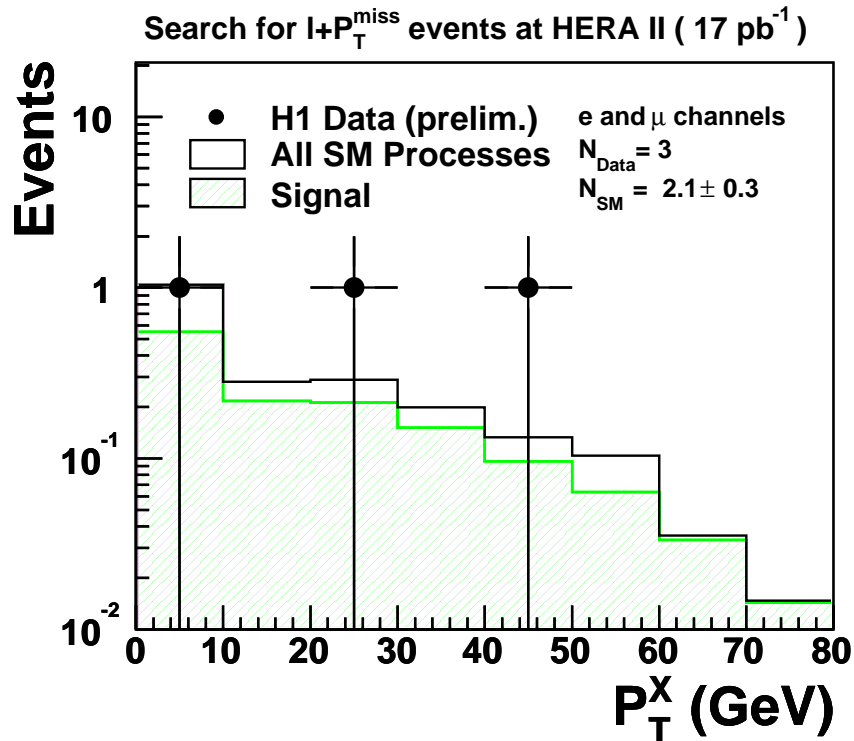
- Bound on top production cross section transformed into upper limit on anomalous  $t\gamma$  coupling at NLO, assuming  $v_{t\gamma}Z = 0$ :  $|\kappa_{t\gamma}| < 0.27$  (95% CL)
- This limit is **competitive** with ZEUS analysis ( $Z^0$  contribution evaluated at LO) and with results from the LEP and CDF experiments
- H1 Single Top Analysis now published → *Eur. Phys. J. C33 (2004) 9*

# H1 and HERA II Upgrade

- Extensive upgrade to HERA to deliver factor of 10 more luminosity - H1 also upgraded
- HERA II major data taking period underway since autumn 2003
- First HERA II analyses made **preliminary** for this conference, using **17 pb<sup>-1</sup>** of data
- The Isolated Lepton analysis has been performed on the new HERA II data

→ See talks by: [O. Henshaw](#), [E. Sauvan](#) and [M. Peetz](#)

# HERA II Isolated Lepton Analysis – Results



## H1 $e^+p$ data (2003-2004), $17 \text{ pb}^{-1}$

	H1 Data	SM Expectation	SM Signal
Electron			
Total	3	$1.61 \pm 0.29$	$0.97 \pm 0.29$
$P_T^X > 25 \text{ GeV}$	2	$0.34 \pm 0.07$	$0.22 \pm 0.05$

Muon			
Total	0	$0.44 \pm 0.32$	$0.39 \pm 0.08$
$P_T^X > 25 \text{ GeV}$	0	$0.29 \pm 0.11$	$0.26 \pm 0.05$

Electron & Muon			
Total	3	$2.05 \pm 0.32$	$1.36 \pm 0.27$
$P_T^X > 25 \text{ GeV}$	2	$0.63 \pm 0.11$	$0.48 \pm 0.10$

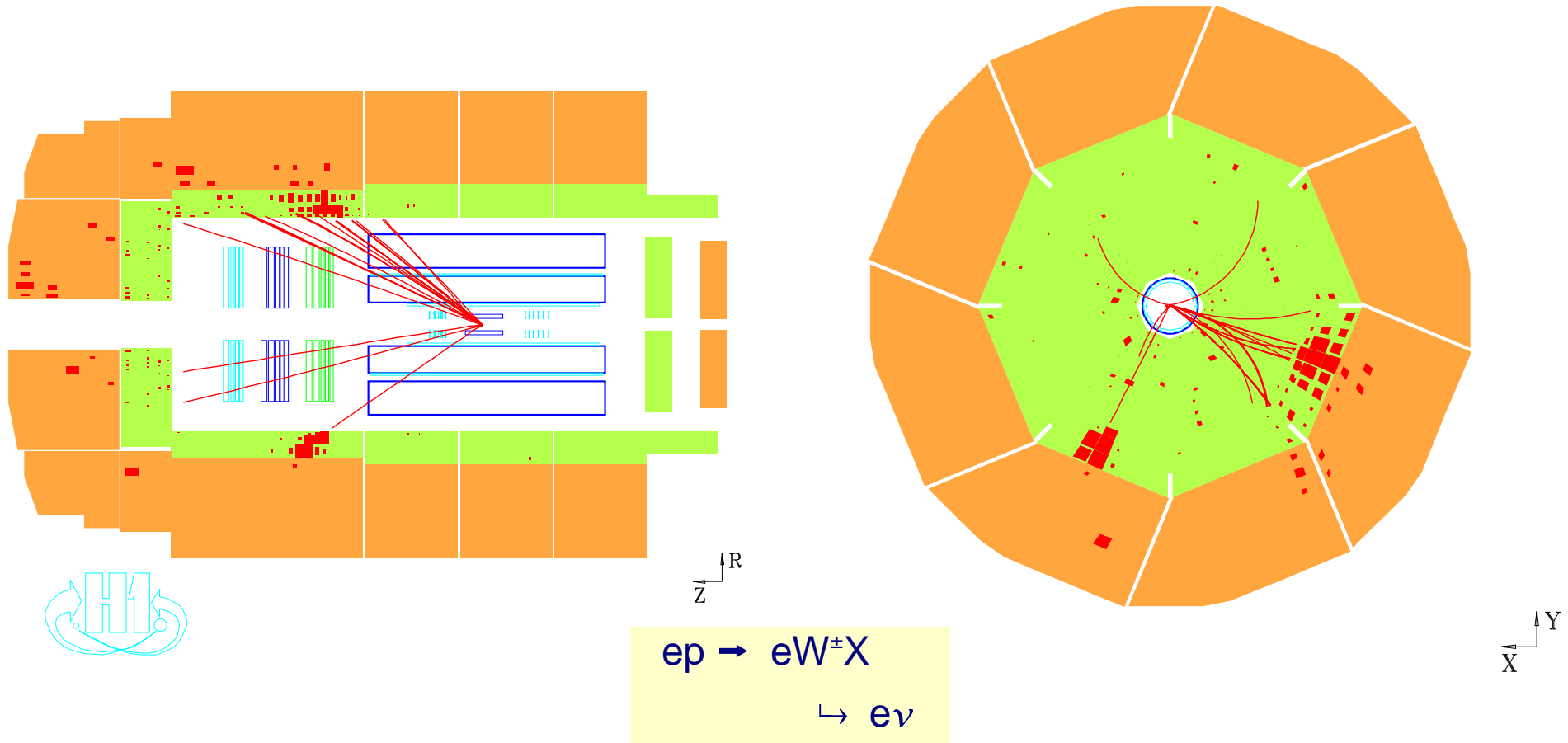
- Three new electron candidate events observed in HERA II data (No muons yet...)
- Two events are at high values of  $P_T^X$ , where the excess was observed in HERA I data
- The higher luminosity provided by HERA II will help to clarify the origin of these events



# HERA II Isolated Lepton Event Display

New High  $P_T^X$  Event with  $e + P_T^{\text{miss}}$  in HERA II data:

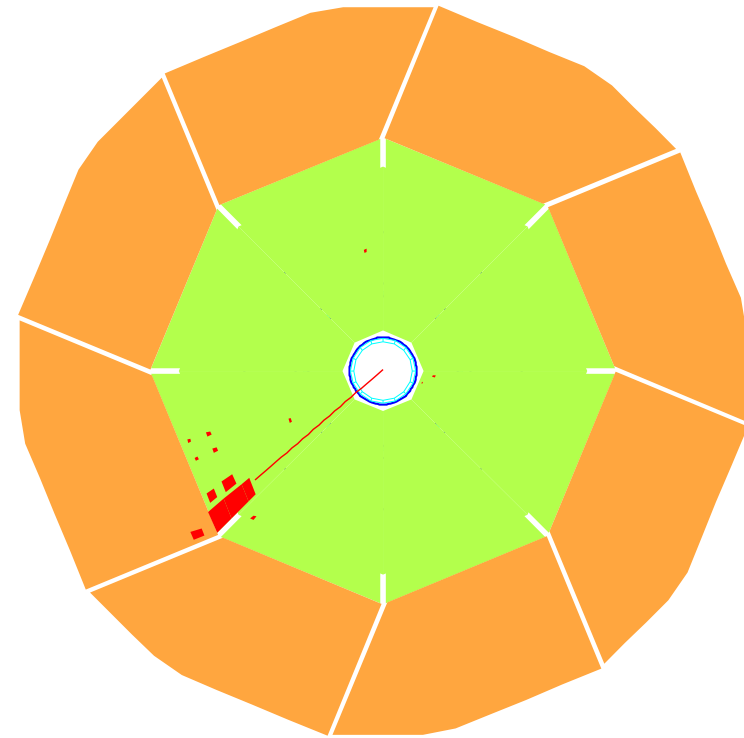
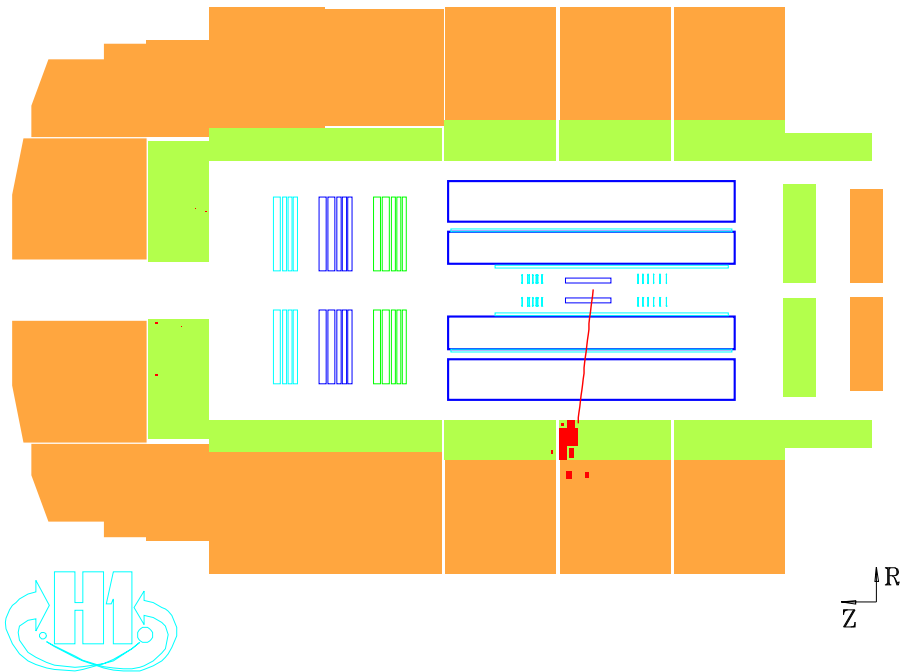
$$P_T^e = 37 \text{ GeV}, P_T^{\text{miss}} = 44 \text{ GeV}, P_T^X = 29 \text{ GeV}$$



# HERA II Isolated Lepton Event Display

New Elastic Event with  $e + P_T^{\text{miss}}$  in HERA II data:

$$P_T^e = 47 \text{ GeV}, P_T^{\text{miss}} = 47 \text{ GeV}, P_T^X = 0 \text{ GeV}$$



$ep \rightarrow eW^\pm X$

$\hookrightarrow e\nu$

# Summary & Outlook

- Full H1 HERA I data sample analysed for events containing high  $P_T$  leptons and missing  $P_T$ , **excess observed** at high  $P_T^X$
- Cut-based search for single top production yields **5 ( $1.31 \pm 1.22$ )** events in the leptonic channel and **18 ( $20.6 \pm 3.6$ )** in the hadronic channel
- Derived upper limits on the top production cross section and the anomalous coupling  $t_{uy}$  are **competitive** with other experiments
- The first new data from HERA II have been analysed and **new isolated lepton candidates** have been observed
- The **increased luminosity** of HERA II ( $1 \text{ fb}^{-1}$ ) is necessary to clarify the origin of the isolated lepton events and provide increased sensitivity to the production of single top quarks