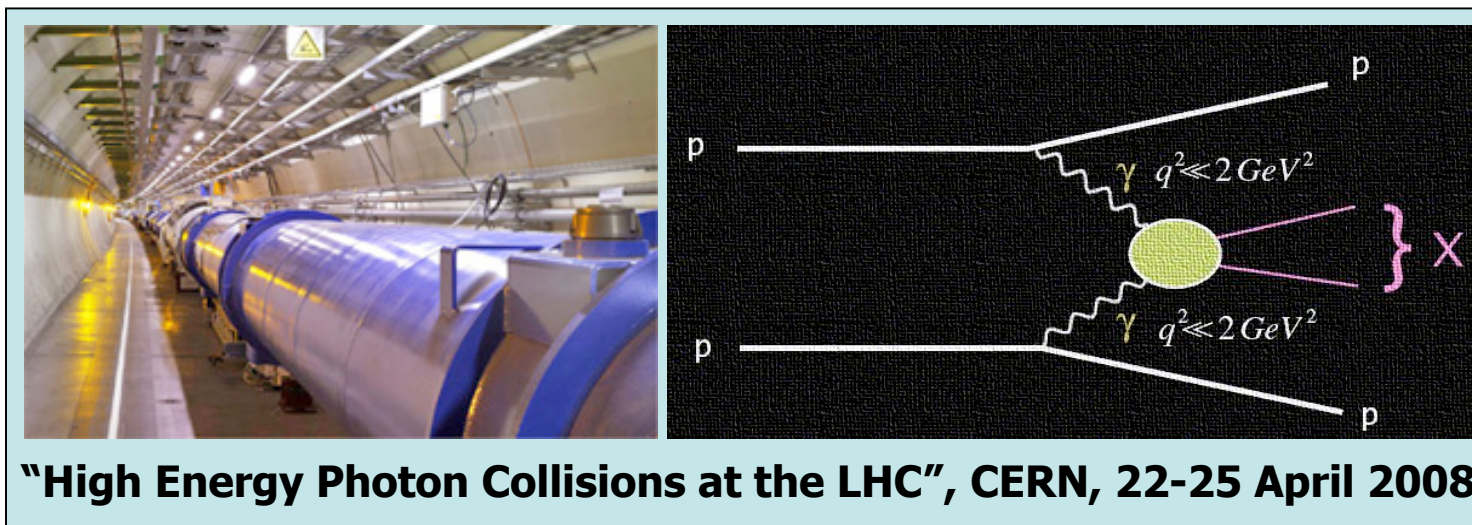




Single W and Anomalous Single Top Production at HERA

David South (Technische Universität Dortmund)

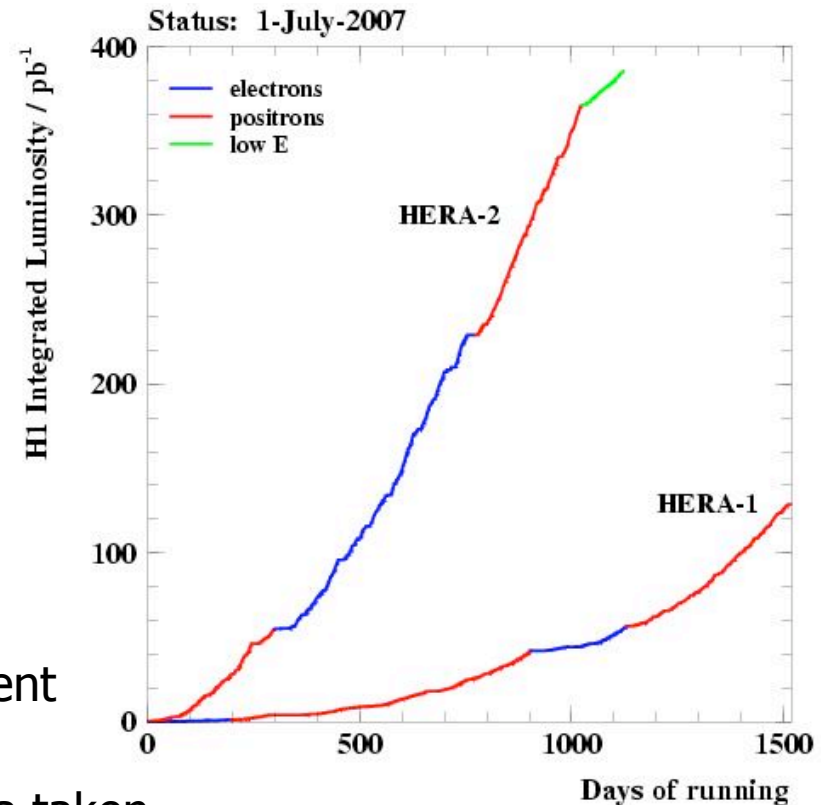
on behalf of the H1 and ZEUS Collaborations



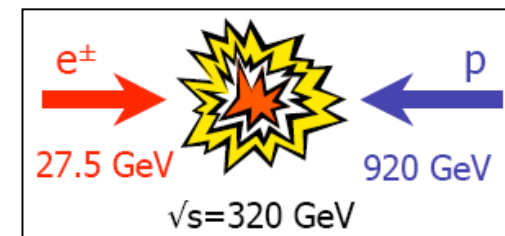
Contents

- Introduction to HERA and Isolated Leptons
- Standard Model Signal Processes
- Search for Isolated Leptons and P_T^{Miss} at H1 and ZEUS
- Combined H1 and ZEUS Results
- Cross Section and W Polarisation Measurements
- Search for Anomalous Single Top Production
- Summary and Conclusions

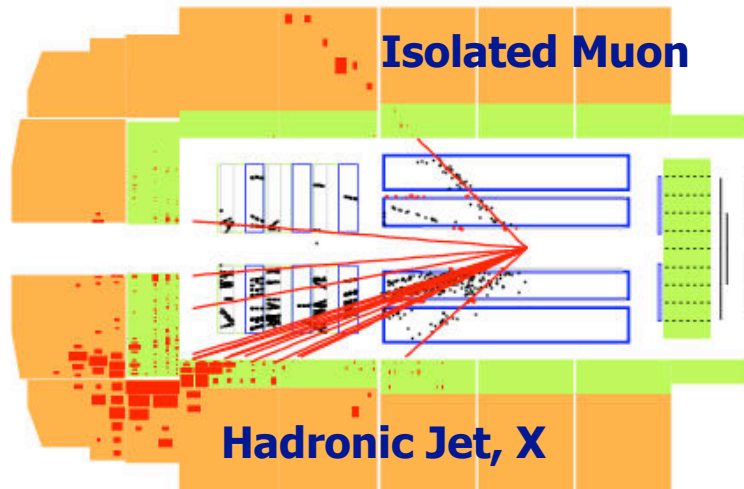
H1 and ZEUS at HERA 1994-2007



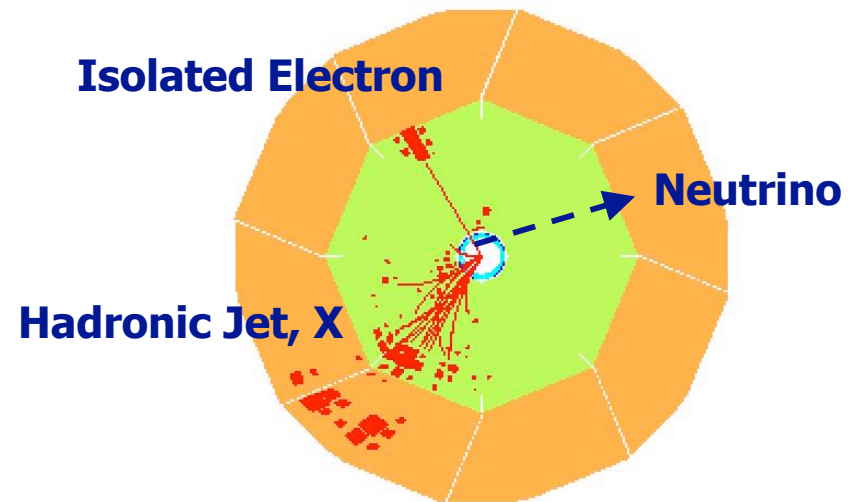
- Large increase in data per experiment from HERA II (factor of 3)
- Large increase (factor of 12) in data taken from e⁻p collisions
 - HERA I mostly e⁺p data
- **Final combined HERA dataset ~ 1 fb⁻¹**



Introduction to Isolated Leptons



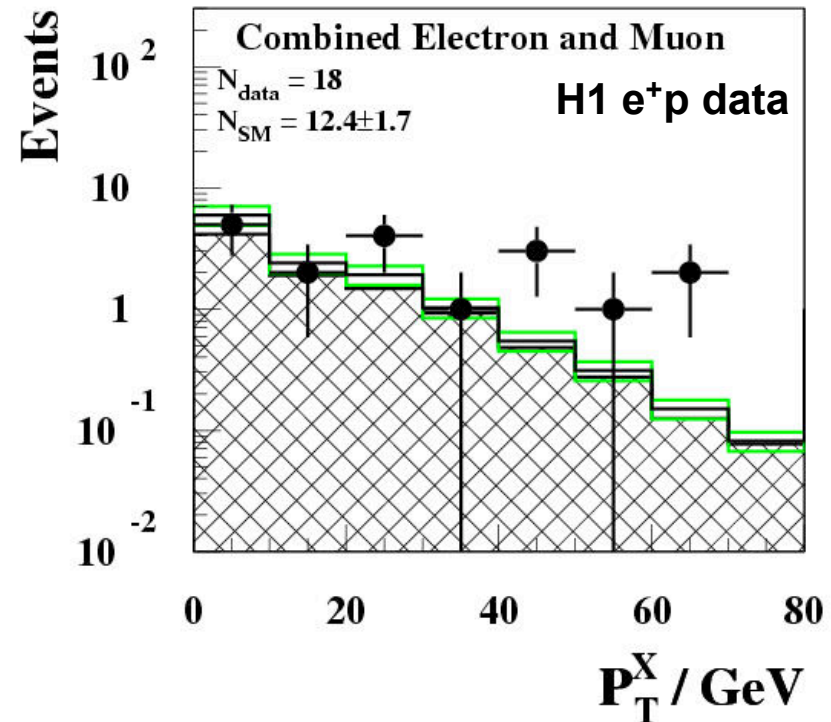
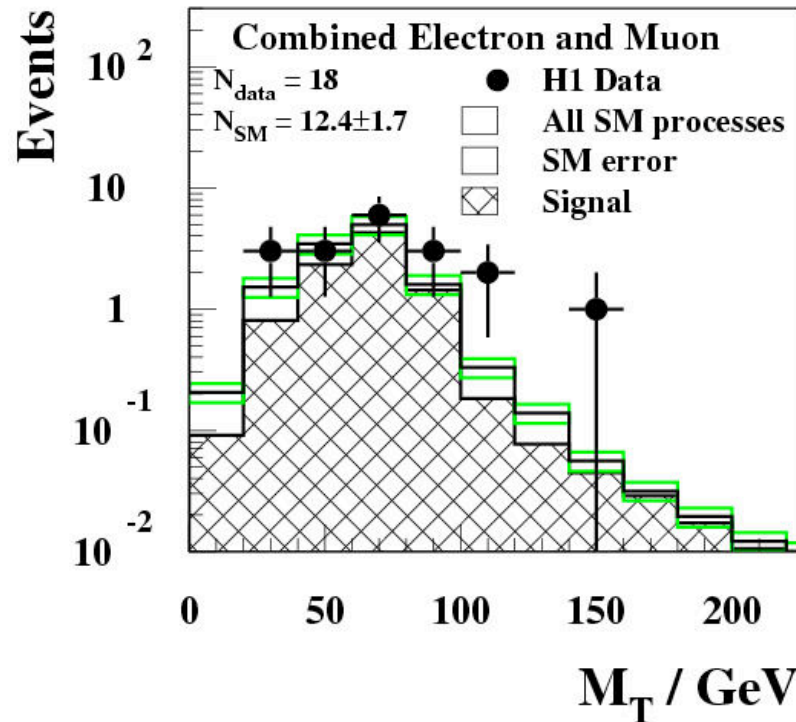
H1 HERA I $\mu + P_T^{\text{miss}}$ event



H1 HERA I $e + P_T^{\text{miss}}$ event

- H1 observation of events containing P_T^{Miss} and high P_T leptons (electron or muon) in the HERA I analysis (118 pb^{-1}):
 - 19 events in the data (1 in e-p) compared to SM expectation of 14.5 ± 2.0
 - Excess of data events observed at large hadronic transverse momentum, P_T^X
 - Result not confirmed by ZEUS HERA I analysis (more limited phase space)

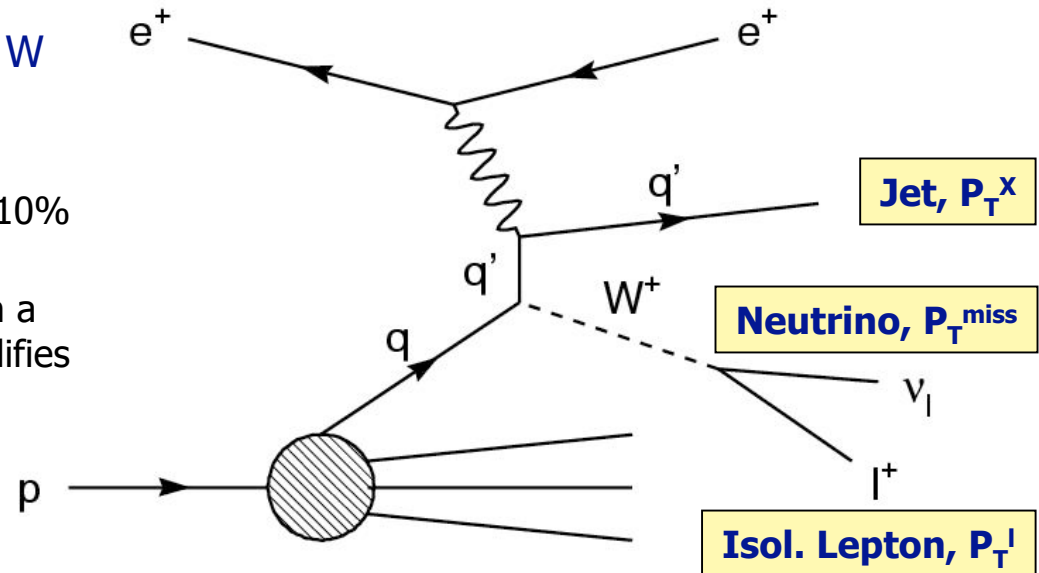
H1 Results from HERA I Analysis



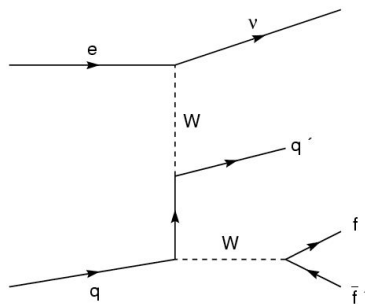
H1 e^+p data HERA I (118 pb^{-1})	e channel obs. / exp.	μ channel obs. / exp.	e and μ channels obs. / exp.
Full sample	11 / 11.5 ± 1.5	8 / 2.9 ± 0.5	19 / 14.5 ± 2.0
$P_T^X > 25 \text{ GeV}$	5 / 1.8 ± 0.3	6 / 1.7 ± 0.3	11 / 3.5 ± 0.6

Standard Model Signal Processes

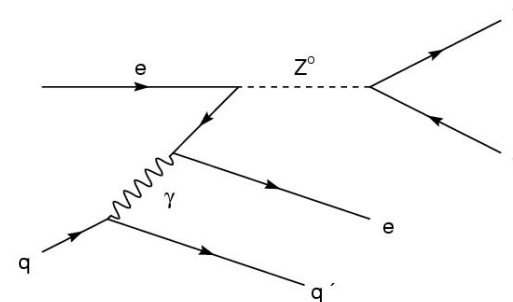
- Main SM contribution to signal from **real W production via photoproduction** with subsequent decay to leptons
 - Total cross section of order **1.3 pb**, with 10% of W decays to each lepton flavour
 - Modelled using the **EPVEC** generator with a **NLO QCD correction** (Diener et. al.): modifies LO cross section by about 10%, reduces theoretical error to 15%
 - Hadronic system of **typically low P_T^X**



- Two additional processes included that contribute to the signal topology:



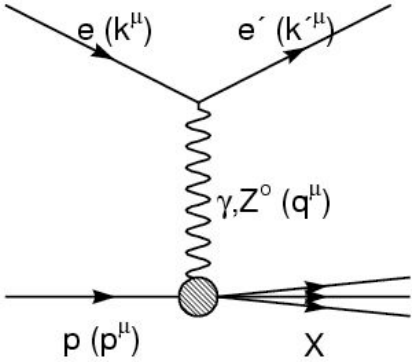
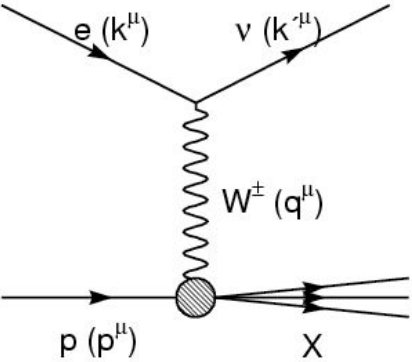
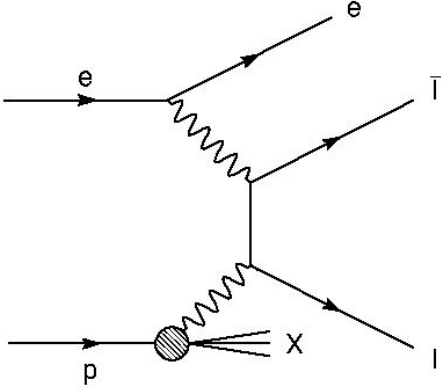
CC W Production (~7%)




Cabibbo-Parisi Z^0 production (~3%, e channel only)

Standard Model Background

- Main SM Background processes:
 - Neutral and Charged Current and lepton pair production (also photoproduction)

e: Neutral Current	e, μ : Charged Current	μ : Lepton Pair Production
		
<p>real electron and fake missing P_T from mismeasurement</p>	<p>misidentified electron or muon and real missing P_T</p>	<p>real muon and fake missing P_T from mismeasurement</p>


Isolated Lepton Event Selection

Variable	Electron	Muon
θ_1	$5^\circ < \theta_1 < 140^\circ$ (H1), $15^\circ < \theta_1 < 120^\circ$ (ZEUS)	
P_T^1	> 10 GeV	
P_T^{calo}	> 12 GeV	
P_T^{miss}	> 12 GeV	
P_T^X	-	> 12 GeV
D_{jet}	> 1.0	
D_{track}	> 0.5 for $\theta_e \geq 45^\circ$	> 0.5
ξ_1^2	> 5000 GeV ² for $P_T^{\text{calo}} < 25$ GeV	-
$V_{\text{ap}}/V_{\text{p}}$	< 0.5 (< 0.15 for $P_T^e < 25$ GeV)	< 0.5 (< 0.15 for $P_T^{\text{calo}} < 25$ GeV)
$\Delta\phi_{l-X}$	$< 160^\circ$	$< 170^\circ$
δ_{miss}	> 5 GeV 	-
# isolated μ	0	1

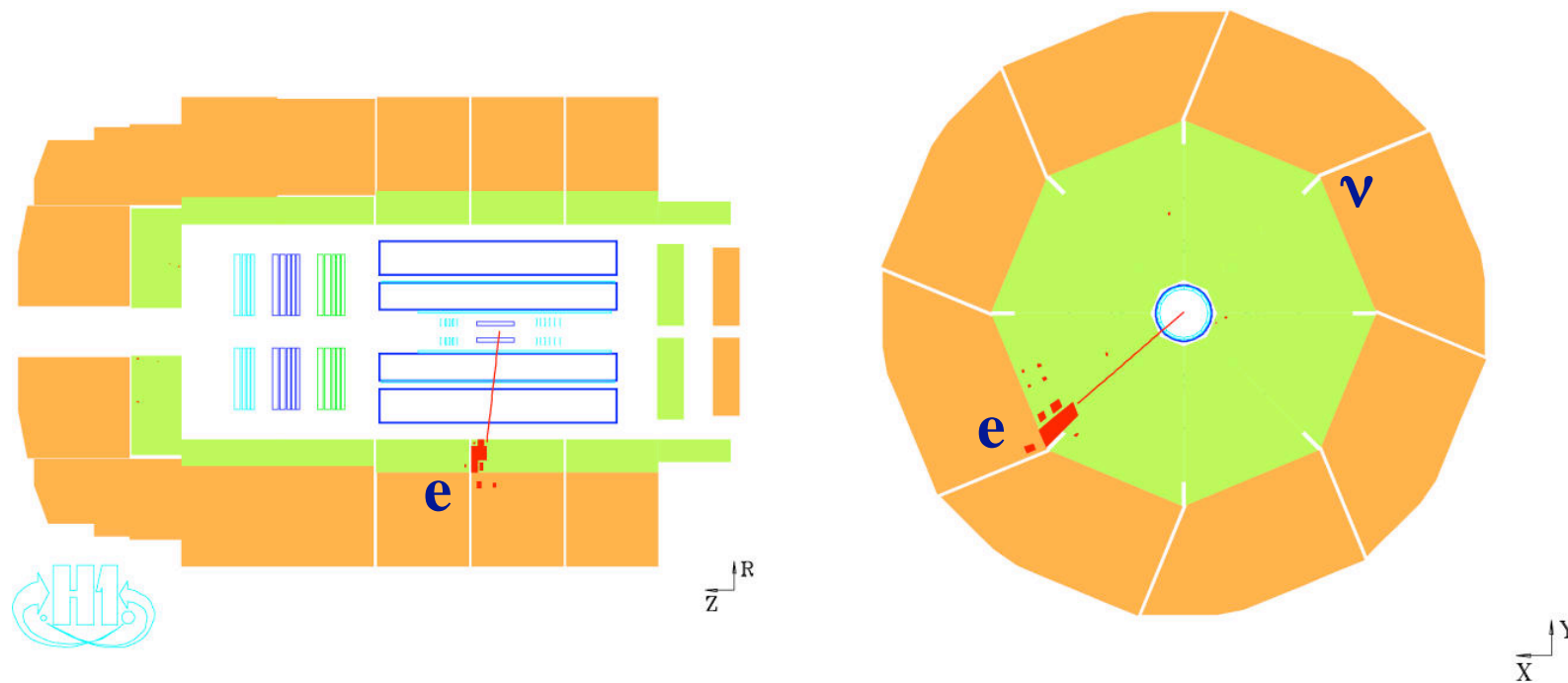
} Analysis phase space selection.
H1: extended polar angle range

} Isolation of lepton

} Cuts designed to reduce SM background, whilst preserving large signal purity

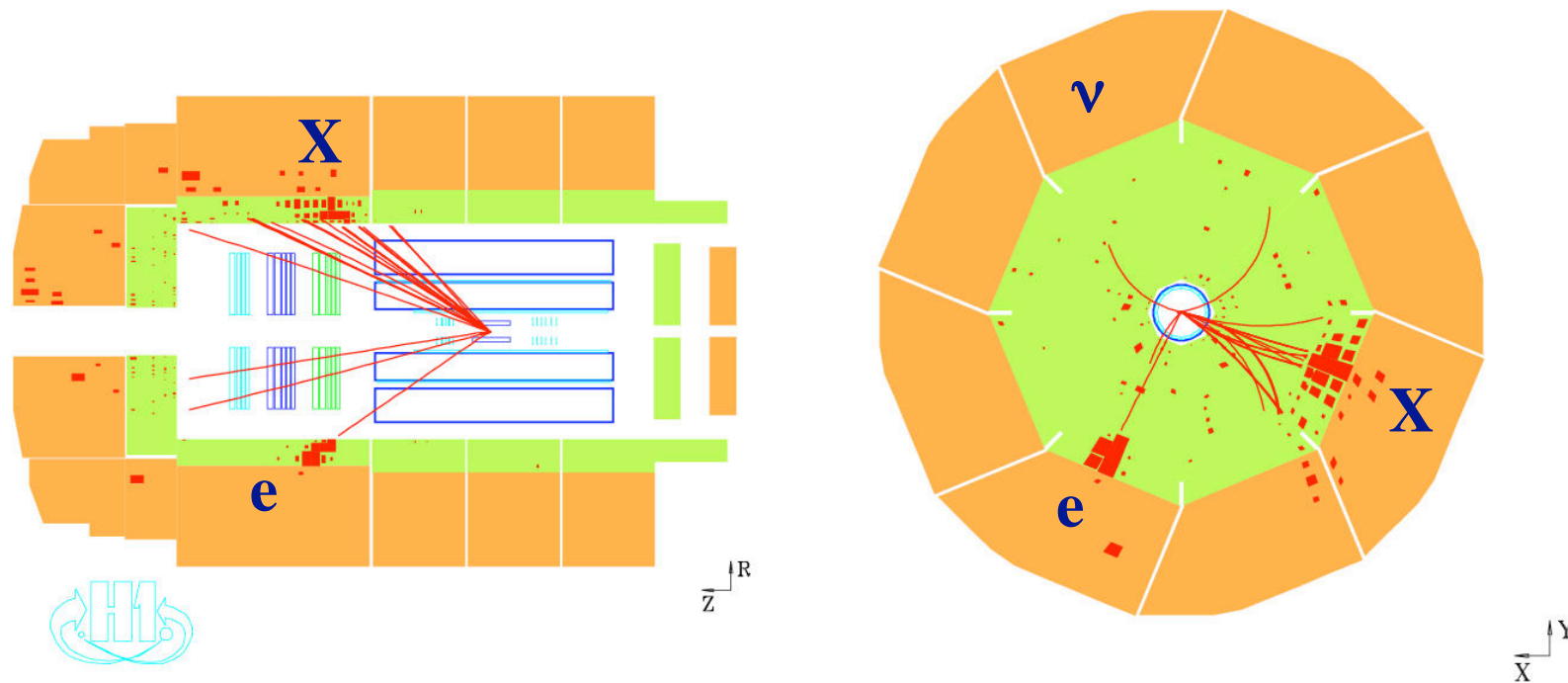
 **H1:** only if one e candidate is detected, with the same charge as the beam lepton

Display of an Isolated Electron Event



- Elastic $e + P_T^{\text{Miss}}$ event in the H1 HERA II e^+p data
- $P_T^e = 47 \text{ GeV}$, $P_T^{\text{Miss}} = 47 \text{ GeV}$, $P_T^X = 0 \text{ GeV}$

Display of an Isolated Electron Event

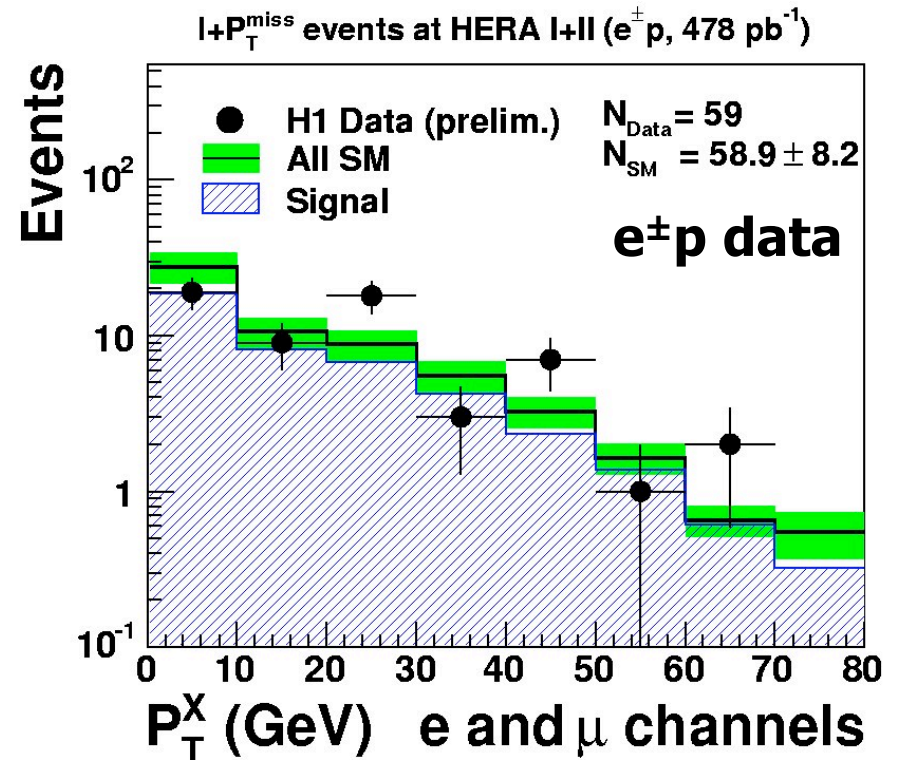


- High P_T^X e + P_T^{Miss} event in H1 HERA II e+p data
- $P_T^e = 37$ GeV, $P_T^{\text{Miss}} = 44$ GeV, $P_T^X = 29$ GeV

H1 Results from HERA I+II

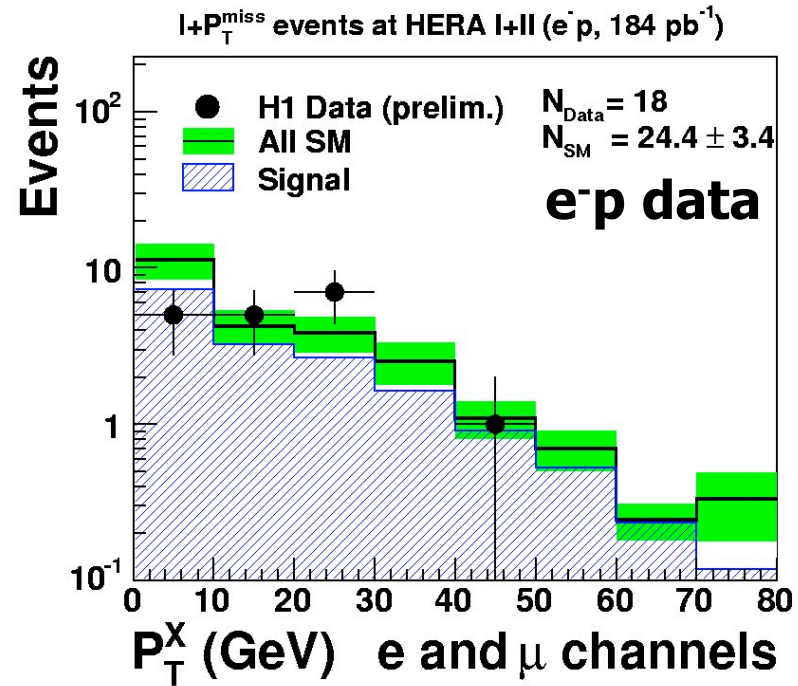
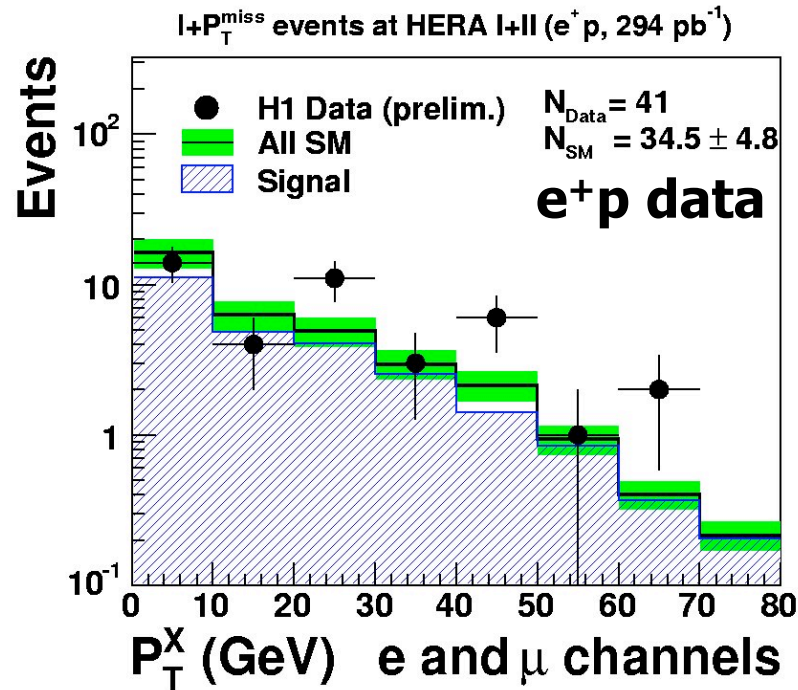
Analysis lepton polar angle range $5^\circ < \theta_1 < 140^\circ$

- Total H1 luminosity from HERA I and II datasets: 478 pb^{-1}
- Significant increase in statistics of e^-p data compared to HERA I
- An overall excess still visible at large values of hadronic transverse momentum



H1 $e^\pm p$ data HERA I+II (478 pb^{-1})	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
Full sample	42 / 46.7 ± 6.5 (69%)	17 / 12.2 ± 1.8 (82%)	59 / 58.9 ± 8.2 (72%)
$P_T^X > 25 \text{ GeV}$	14 / 8.5 ± 1.5 (68%)	10 / 7.3 ± 1.2 (79%)	24 / 15.8 ± 2.3 (73%)

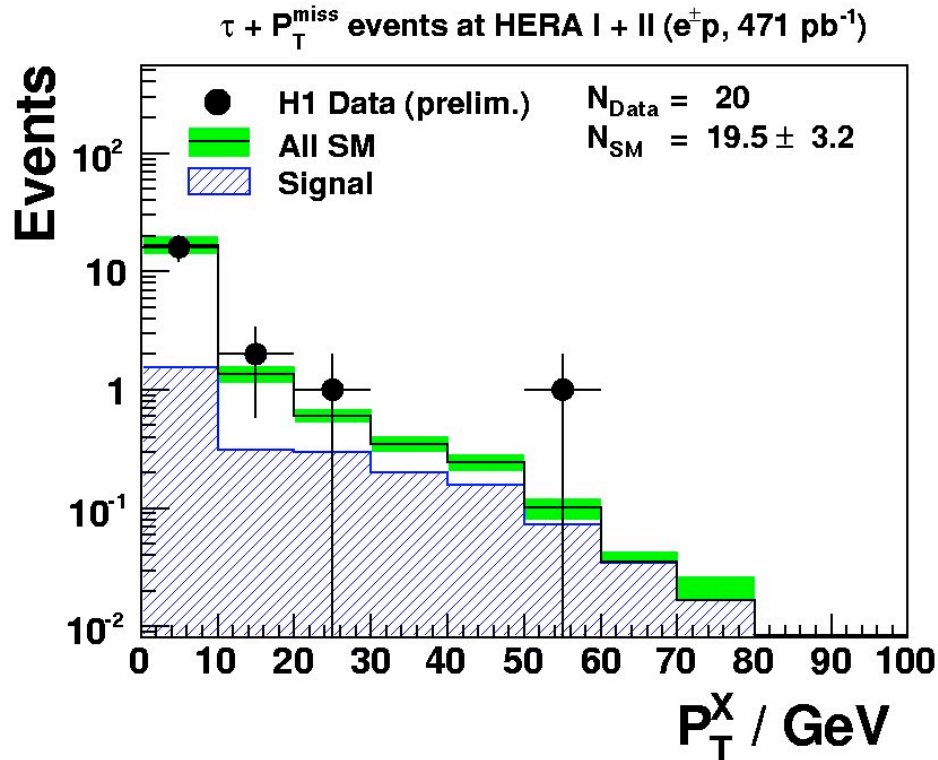
H1 Results from e^+p and e^-p Data



H1 HERA I+II $P_T^X > 25$ GeV	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
e^+p data (294 pb^{-1})	11 / 4.7 ± 0.9 (75%)	10 / 4.2 ± 0.7 (85%)	21 / 8.9 ± 1.5 (80%)
e^-p data (184 pb^{-1})	3 / 3.8 ± 0.6 (61%)	0 / 3.1 ± 0.5 (74%)	3 / 6.9 ± 1.0 (67%)

- **Excess at 3.0σ level in e^+p data only** - difference between data sets

H1 Tau Results from HERA I+II

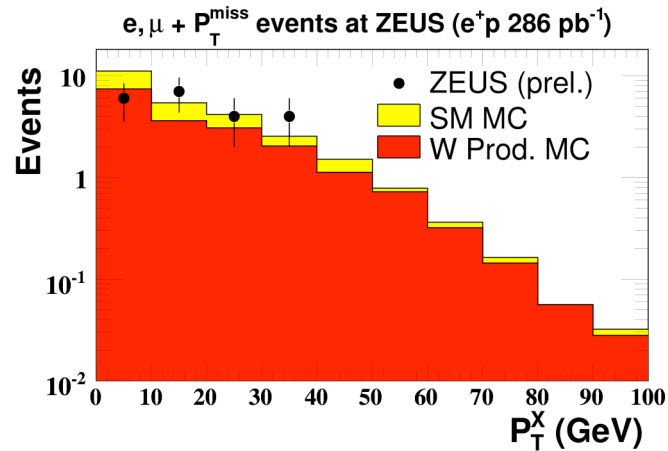
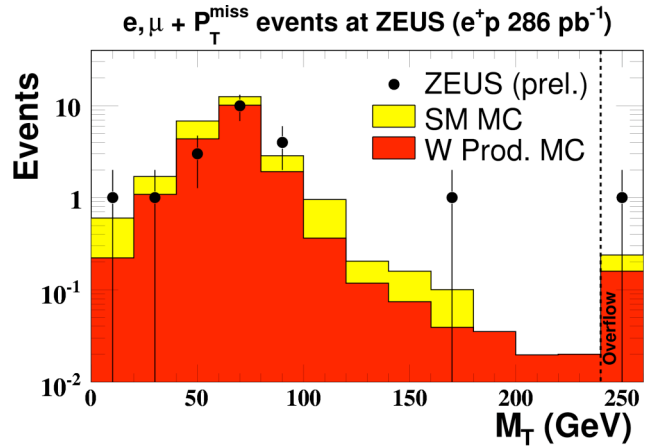


- Complementary results to the electron and muon channels
- Signature of 1-prong tau decay (45% branching ratio)
 - 1 charged track (the “prong”) giving a narrow, pencil like jet
- Good agreement seen of complete H1 data with the SM prediction
- Dominated by background processes, only 14% signal (other channels up to 85%)
 - Main source of background: CC events with narrow jets

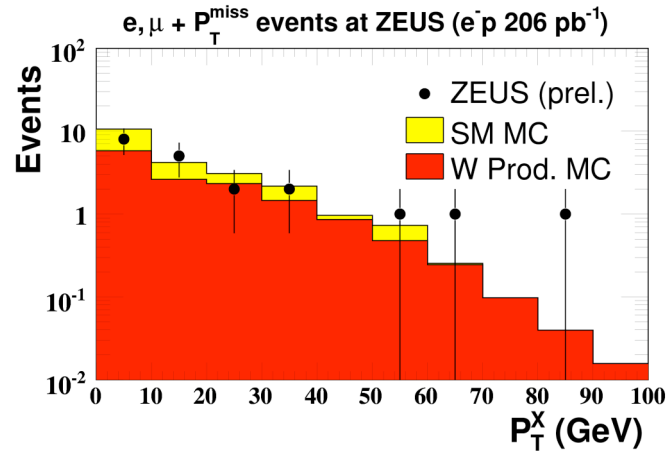
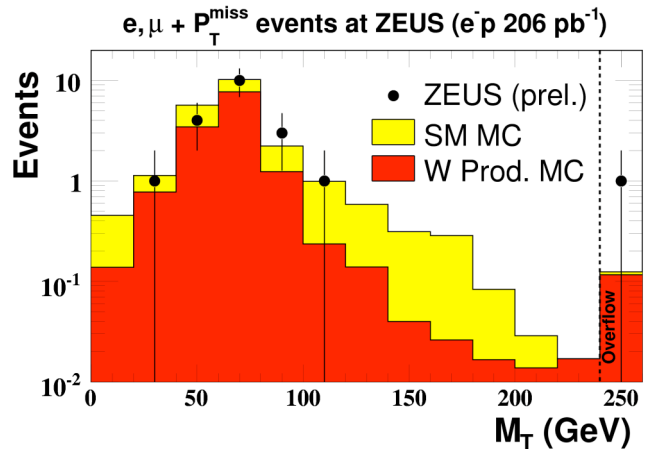
H1 e^+p data HERA I+II (471 pb^{-1})	τ channel obs. / exp. (signal)
Full sample	20 / 19.5 ± 3.2 (14%)
$P_T^X > 25$ GeV	1 / 0.99 ± 0.13 (63%)

ZEUS Results from HERA I+II

Analysis lepton polar angle range: $15^\circ < \theta_l < 120^\circ$

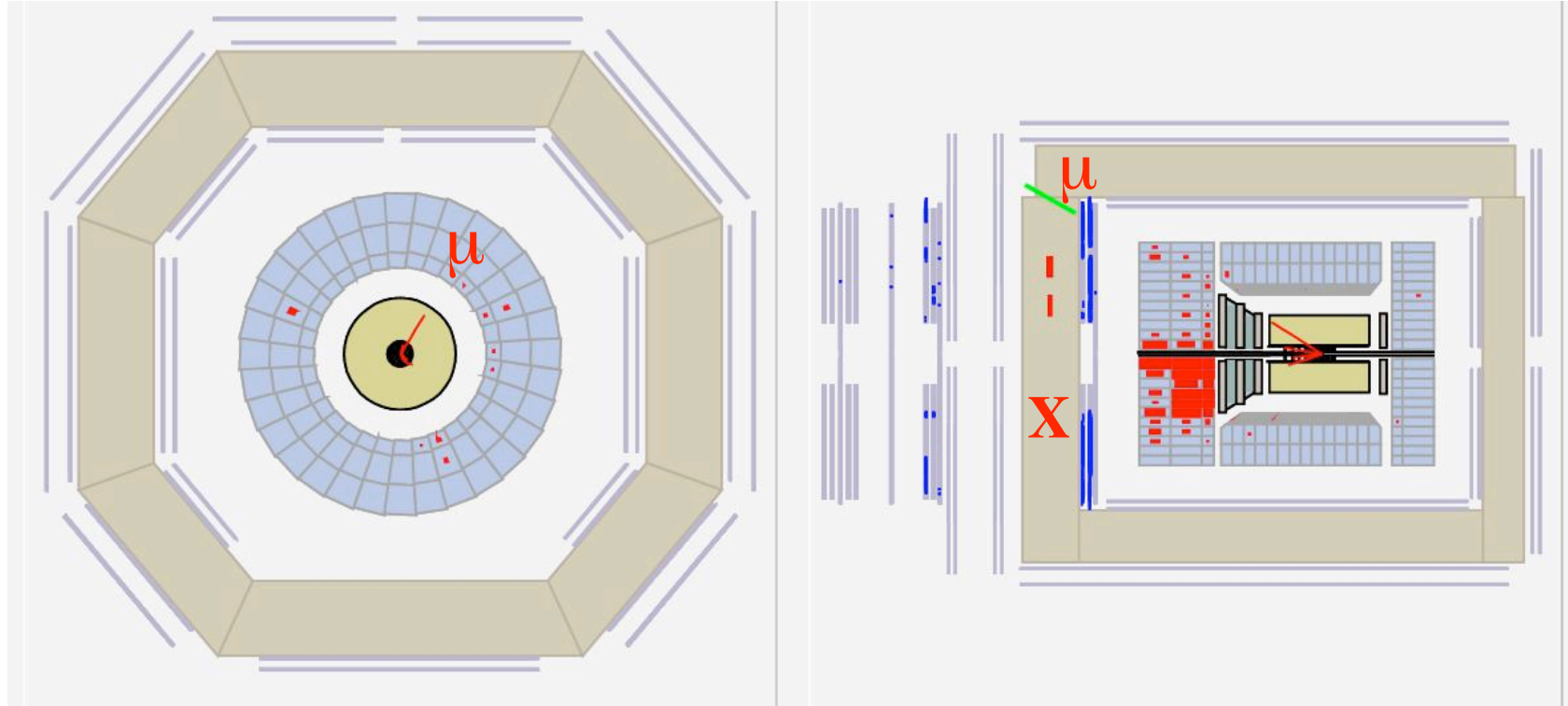


- ZEUS e^+p data
1996-2007
286 pb^{-1}



- ZEUS e^-p data
1998-2006
206 pb^{-1}

Display of an Isolated Muon Event



- High $P_T^X \mu + P_T^{\text{Miss}}$ event in the ZEUS $e-p$ HERA II data
- $\theta^\mu = 32^\circ$, $M_T^{\mu\nu} = 79 \text{ GeV}$, $P_T^X = 82 \text{ GeV}$

ZEUS Results from HERA I+II

Isolated e Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) e^-p 206 pb $^{-1}$	9/11.3 \pm 2.0 (55%)	5/3.4 \pm 0.8 (62%)	3/3.2 \pm 0.6 (69%)
ZEUS (prel.) e^+p 286 pb $^{-1}$	7/12.3 \pm 1.9 (66%)	5/4.1 \pm 0.7 (67%)	3/3.9 \pm 0.6 (76%)
ZEUS (prel.) $e^\pm p$ 492 pb $^{-1}$	16/23.6 \pm 3.8 (60%)	10/7.5 \pm 1.4 (65%)	6/7.1 \pm 1.1 (73%)



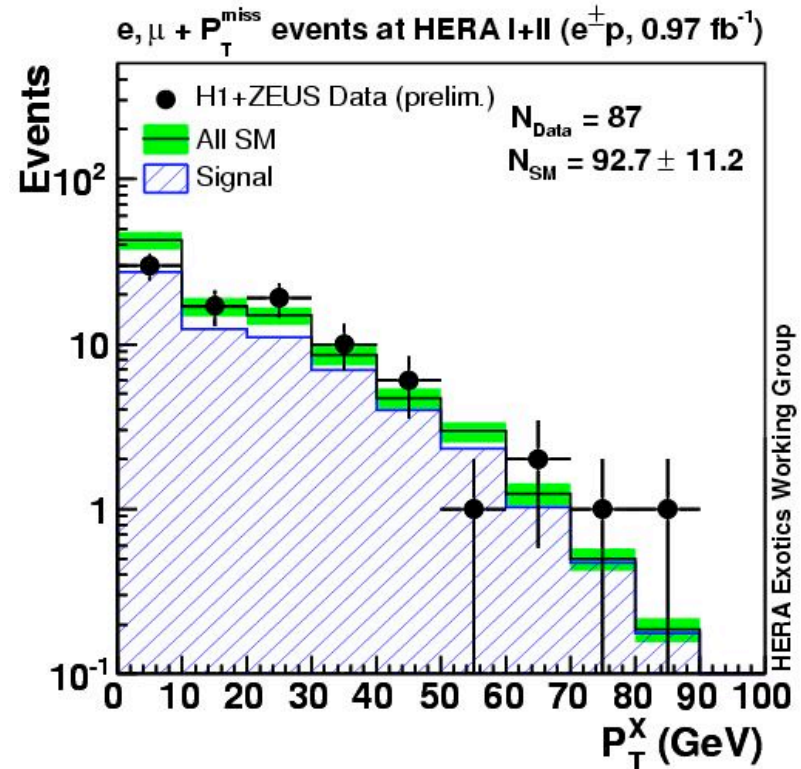
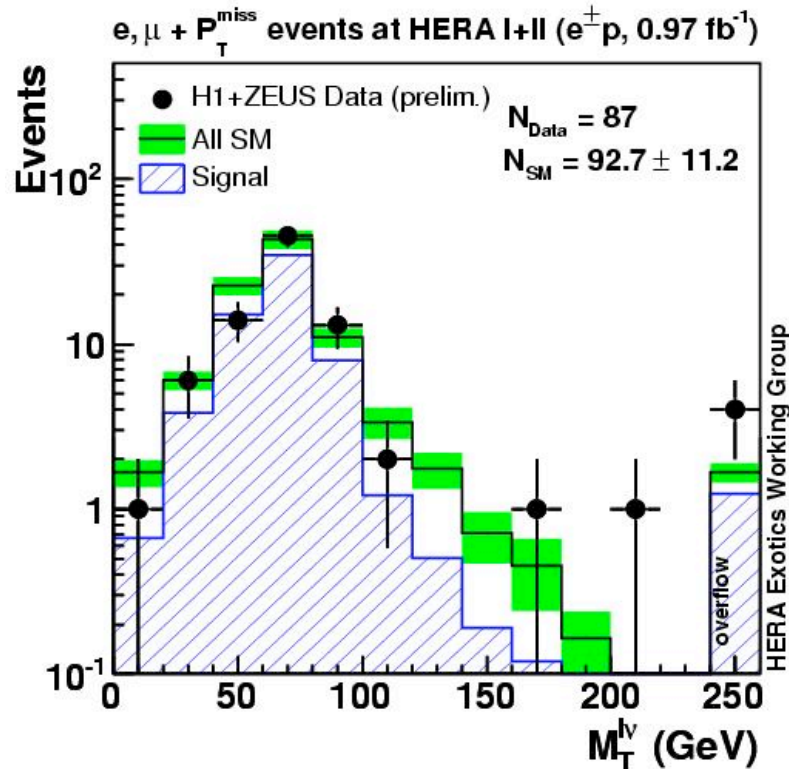
Isolated μ Candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) e^-p 206 pb $^{-1}$	1/1.7 \pm 0.3 (77%)	2/2.4 \pm 0.4 (85%)
ZEUS (prel.) e^+p 286 pb $^{-1}$	3/2.3 \pm 0.3 (82%)	3/3.6 \pm 0.5 (81%)
ZEUS (prel.) $e^\pm p$ 492 pb $^{-1}$	4/4.1 \pm 0.6 (80%)	5/6.0 \pm 0.8 (82%)

- Like H1, full HERA I+II data set has been analysed
 - 41 events observed in 492 pb $^{-1}$ of data
- Good agreement between data and SM in both lepton channels and in all data sets
- No excess seen at high P_T^X in the e^+p data as seen by H1

Combining H1 and ZEUS Results

- The H1 analysis is redone using the ZEUS event selection
 - Few changes to the H1 selection: a more restricted polar angle range: $15^\circ < \theta_1 < 120^\circ$, as well as relaxing of the condition on δ_{miss}
- This common phase space was studied using HERA II samples
 - Excellent agreement found between signal rates of the experiments
 - Some background is still higher in the ZEUS analysis, but within reasonable level of agreement
- H1 and ZEUS signal contributions added together and 15% correlated systematic (theory error) applied
- All others added separately in quadrature with individual (level of agreement) uncorrelated systematic error

H1+ZEUS Results from HERA I+II

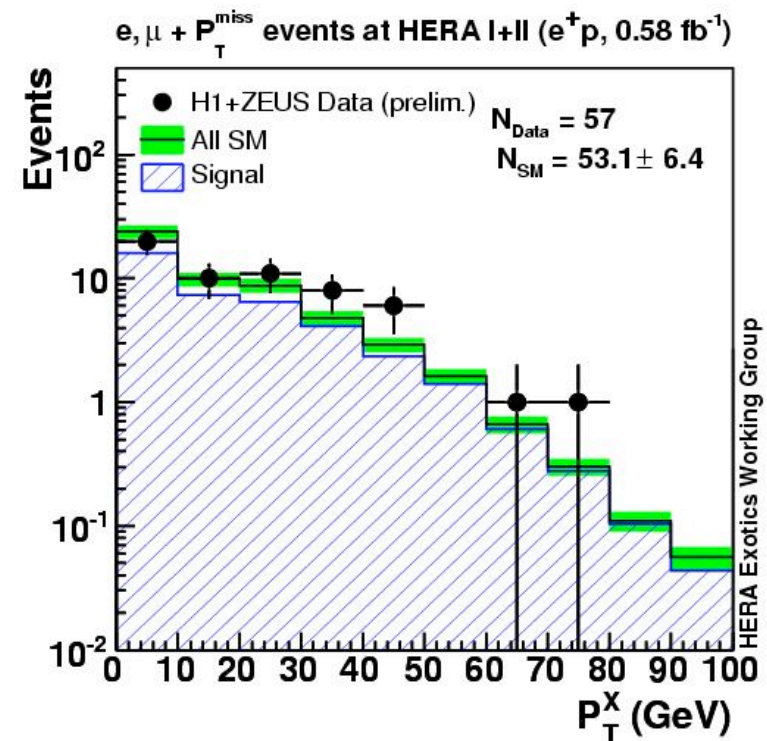


H1+ZEUS e^+p data HERA I+II (0.97 fb^{-1})	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
Full sample	64 / 72.9 ± 8.9 (67%)	23 / 19.9 ± 2.6 (85%)	87 / 92.7 ± 11.2 (71%)
$P_T^X > 25 \text{ GeV}$	16 / 13.3 ± 1.7 (73%)	13 / 12.0 ± 1.6 (86%)	29 / 25.3 ± 3.2 (79%)

H1+ZEUS: Results at High P_T^X

H1+ZEUS HERA I+II $P_T^X > 25$ GeV	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
e^+p data (0.58 fb^{-1})	12 / 7.4 ± 1.0 (70%)	11 / 7.2 ± 1.0 (85%)	23 / 14.6 ± 1.9 (81%)
e^-p data (0.39 fb^{-1})	4 / 6.0 ± 0.8 (67%)	2 / 4.8 ± 0.7 (87%)	6 / 10.6 ± 1.4 (76%)

- High P_T^X excess in e^+p data remains, even after inclusion of the ZEUS data, with a lower significance of 1.8σ
- For the H1 contribution in this phase space: $17 / 7.1 \pm 0.9$, the significance is 2.9σ



H1 Cross Section Measurements

- H1 selection results in the electron and muon channels are used to calculate production cross sections (excess only at high P_T^X)
- Two cross section definitions: I) topology based and ii) for W production

$$\sigma_{IsoLep} = \frac{N_d - N_{bg}^{MC}}{\mathcal{L}\epsilon} \quad \sigma_W = \frac{N_d - N_{bg}^{MC}}{\mathcal{L}\Gamma\epsilon} \quad \epsilon = \frac{N_{rec}^{MC}}{N_{gen}^{MC}}$$

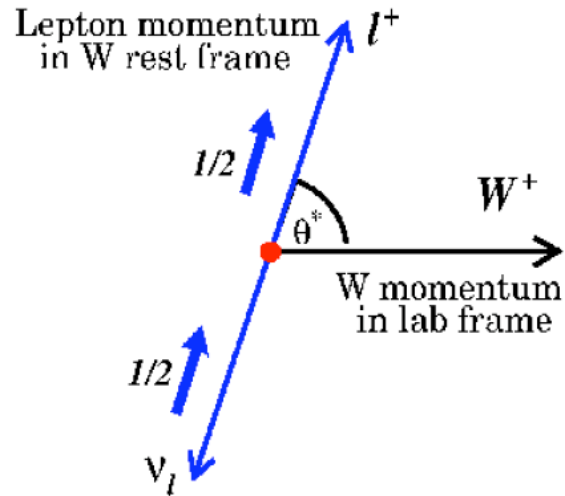
Isolated Lepton Cross Section

Total Single W Cross Section

H1	HERA I+II Data	SM
$\sigma_{\sigma_{\ell+p_T}}$	0.24 ± 0.05 (stat) ± 0.05 (sys)	0.26 ± 0.04 (th.sys)
σ_W	1.23 ± 0.25 (stat) ± 0.22 (sys)	1.31 ± 0.20 (th.sys)

- Both measured cross sections in good agreement with the SM predictions

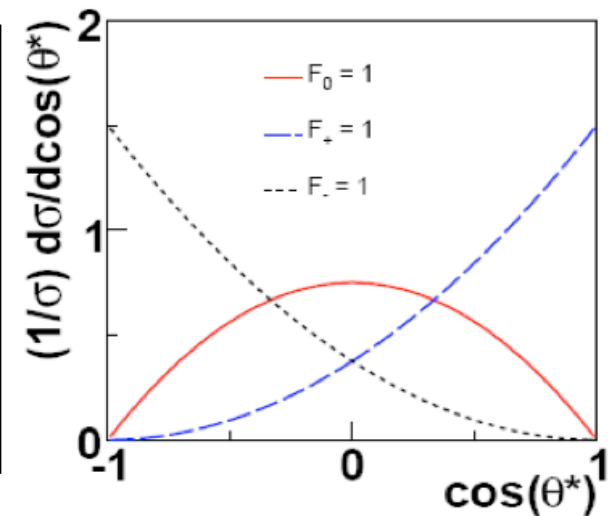
H1 Measurement of W Polarisation Fractions



- Measurement makes use of the $\cos \theta^*$ distributions in the decay $W \rightarrow l + \nu$
- Cross section can be expressed in three terms of the polarisation fractions, with $F_+ \equiv 1 - F_- - F_0$

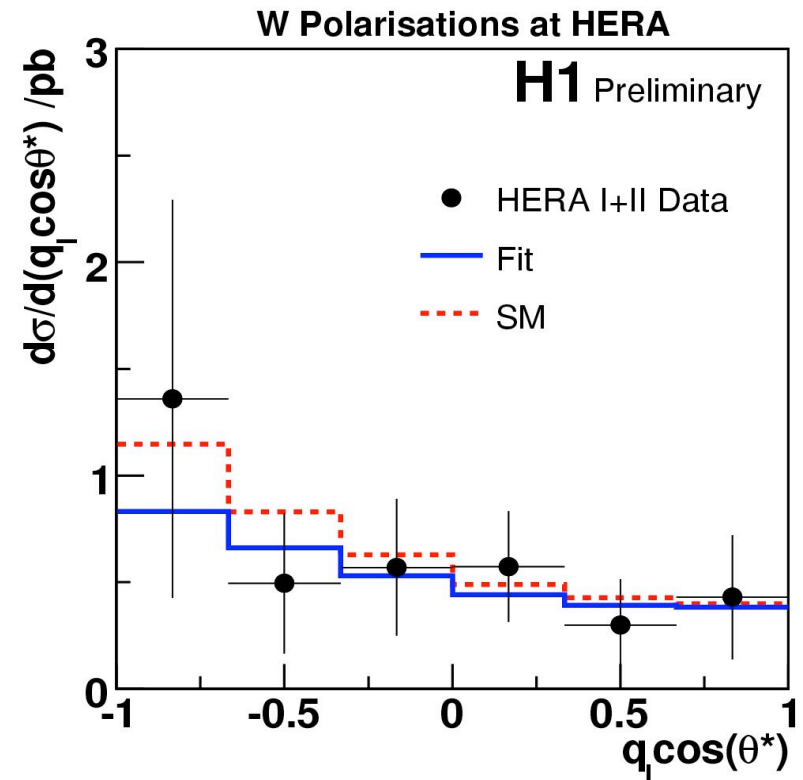
$$\begin{aligned}
 \frac{d\sigma_W}{d\cos\theta^*} &\propto (1 - F_- - F_0) \cdot \frac{3}{8} (1 + \cos\theta^*)^2 \quad \text{left} \\
 &+ F_0 \cdot \frac{3}{4} (1 - \cos^2\theta^*) \quad \text{longitudinal} \\
 &+ F_- \cdot \frac{3}{8} (1 - \cos\theta^*)^2. \quad \text{right}
 \end{aligned}$$

(for W^+)



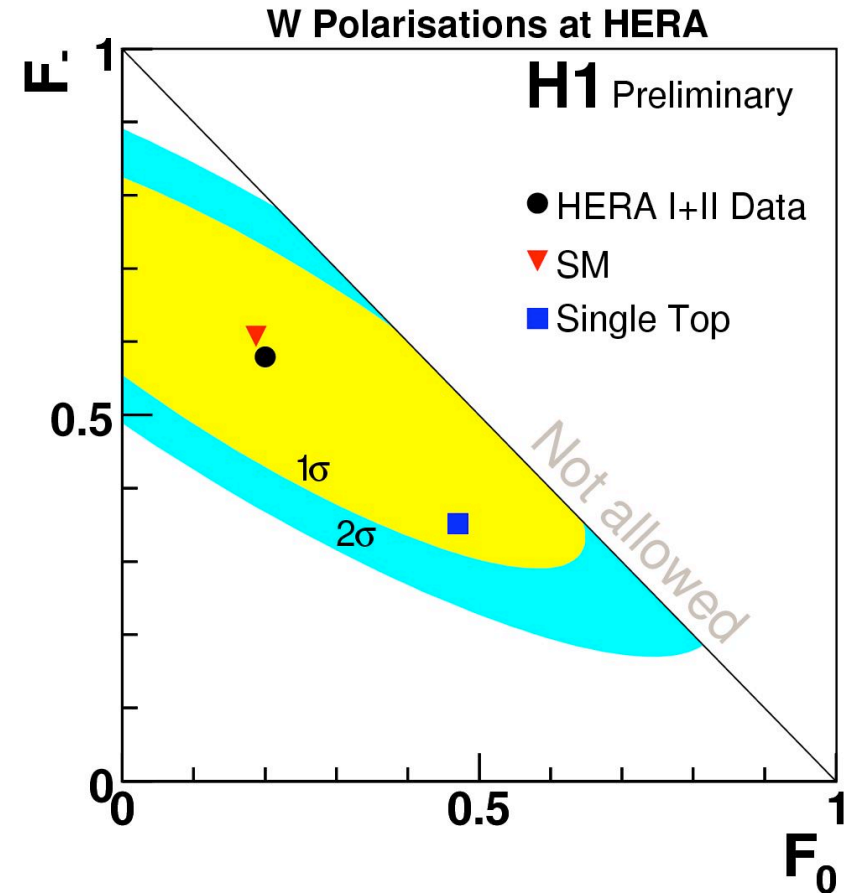
H1 Measurement of W Polarisation Fractions

- Additional selection criteria employed to reconstruct W and neutrino
- Most events have two neutrino solutions: forward / backward
 - For events with $\theta_{lepton} < 35^\circ$, choose forward solution
- Require $\theta > 20^\circ$ and lepton charge
 - $\cos \theta^*$ is weighted with the sign of the charge of the identified lepton q_l
- Charge from track with > 1 curvature significance
 - Results in $< 1\%$ charge miss-ID
- The measured H1 cross section is fit using the 2 parameter W helicity model



H1 Measurement of W Polarisation Fractions

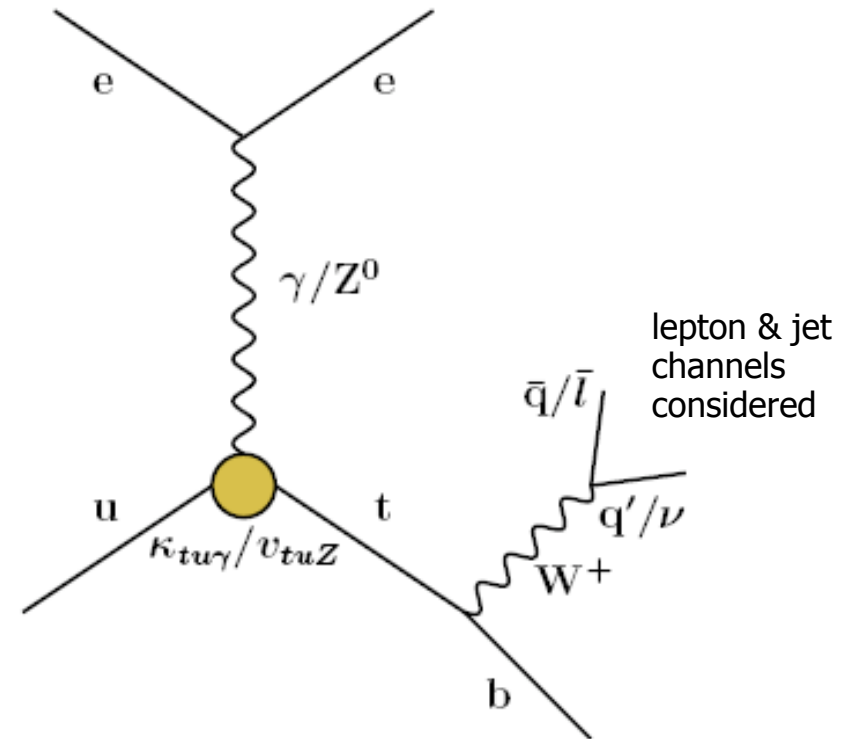
- F_0 and F_- simultaneously extracted (2D fit)
- Result in agreement with the SM prediction and compatible with Single Top production
- Polarisation fractions also extracted in 1D fits where one parameter is fixed to the SM



H1	HERA I+II Data	SM
F_-	0.58 ± 0.15 (stat) ± 0.12 (sys)	0.61 ± 0.01 (stat)
F_0	0.15 ± 0.21 (stat) ± 0.09 (sys)	0.19 ± 0.01 (stat)

Single Top Production at HERA

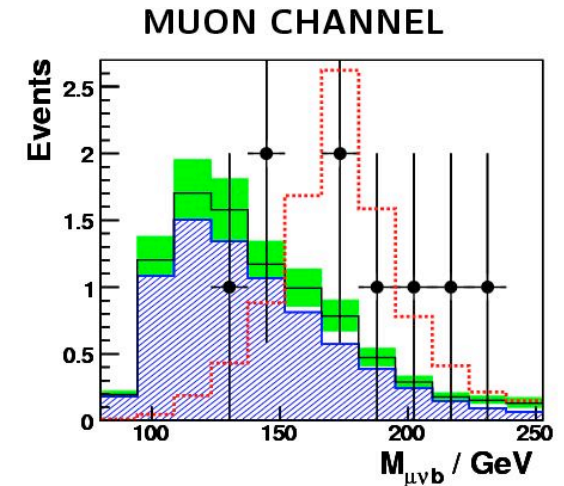
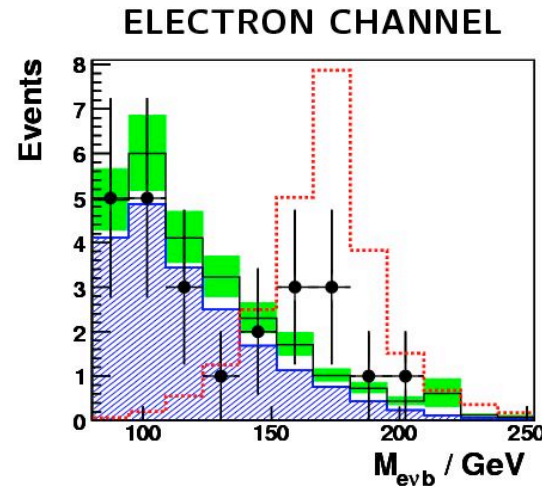
- Excess of observed events at high P_T^X unlikely to be due to W production (typically low P_T^X)
 - But! Observed topology is typical signature of top decay $t \rightarrow bW$
 - Tiny SM top production cross section < 1 fb
 - Anomalous top production via Flavour Changing Neutral Current ?
 - However: This process cannot explain asymmetry between datasets
- HERA I analyses:
 - H1: $\sigma(ep \rightarrow etX) < 0.55$ pb
 - ZEUS: $\sigma(ep \rightarrow etX) < 0.23$ pb



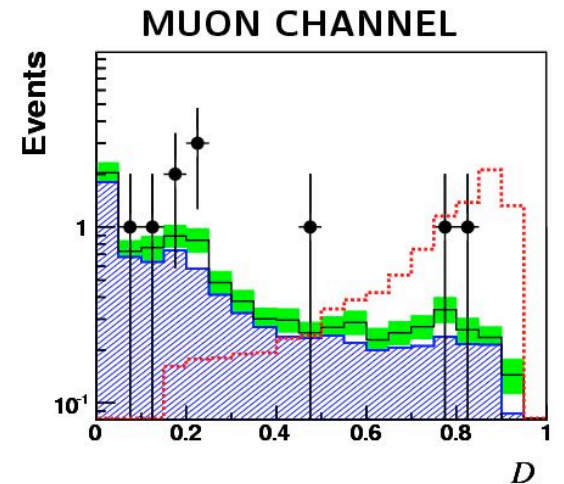
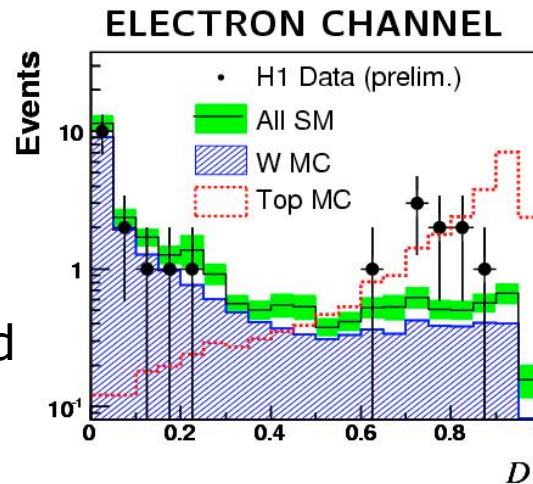
$\kappa_{tu\gamma}$: Anomalous γ magnetic coupling
 V_{tuZ} : Anomalous Z vector coupling

H1: Single Top using HERA I+II Data

- Top pre-selection is subset of the $l + P_T^{\text{Miss}}$ selection
 - Good top quark reconstruction required
 - Positive charge of lepton, where possible

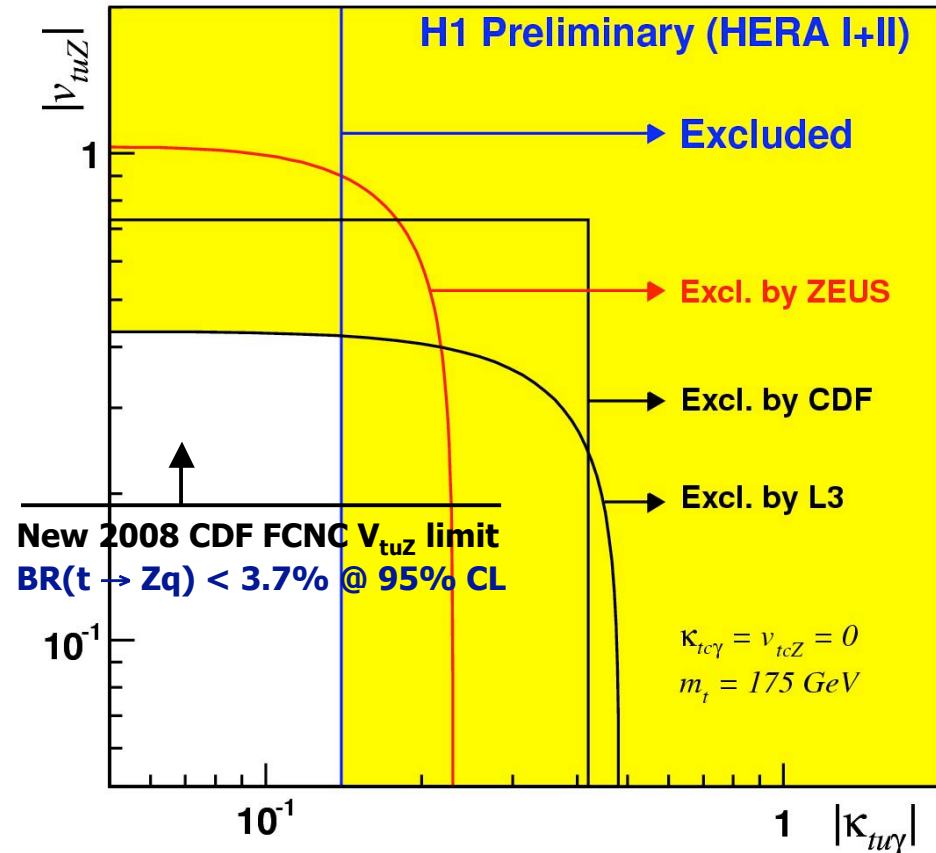


- Multivariate discriminator then used to separate signal and background
 - P_T^b , $M_{l\nu b}$ and θ_W^l
 - Top:signal, W:background



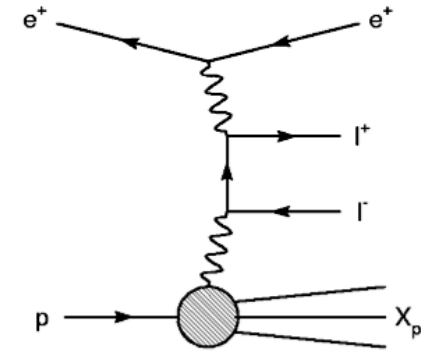
H1: HERA I+II Exclusion Limits

- Cross section limits on FCNC single top extracted from discriminator using a maximum likelihood method
- New H1 upper bound on the cross section at 95% CL:
 - $\sigma(ep \rightarrow etX) < 0.16 \text{ pb}$
- Upper bound on the anomalous coupling
 - $\kappa_{t\gamma} < 0.14$
- New limit extends into region of phase space uncovered by other colliders: H1 ($\kappa_{t\gamma}$) and CDF (V_{tuZ}) best limits on FCNC couplings

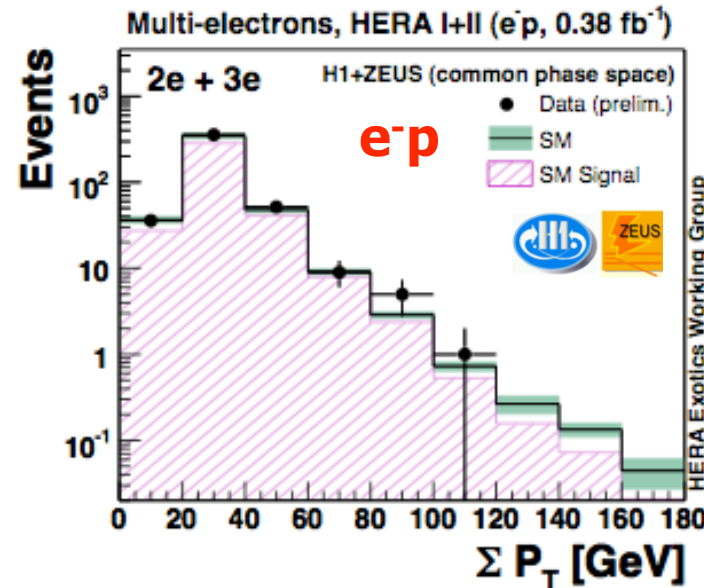
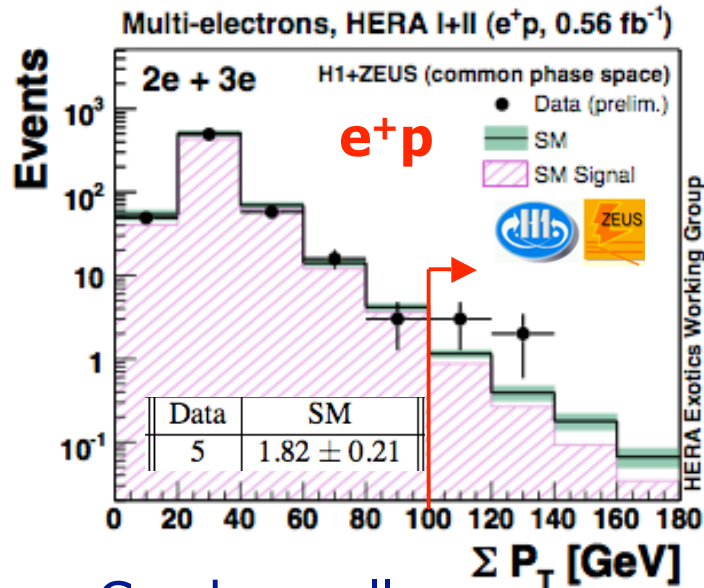


A quick mention: Multi-leptons at HERA

- Multi electron (2e, 3e) events studied in combined H1 and ZEUS analysis, using full HERA I+II data
- Electrons at high P_T , in central region of detectors



Main process at HERA is two photon Bethe-Heitler



- Good overall agreement between data and SM
- H1 also studies combinations of electron and muon final states

H1+ZEUS Multi-electron analysis HERA I+II (0.94 fb^{-1} , preliminary)

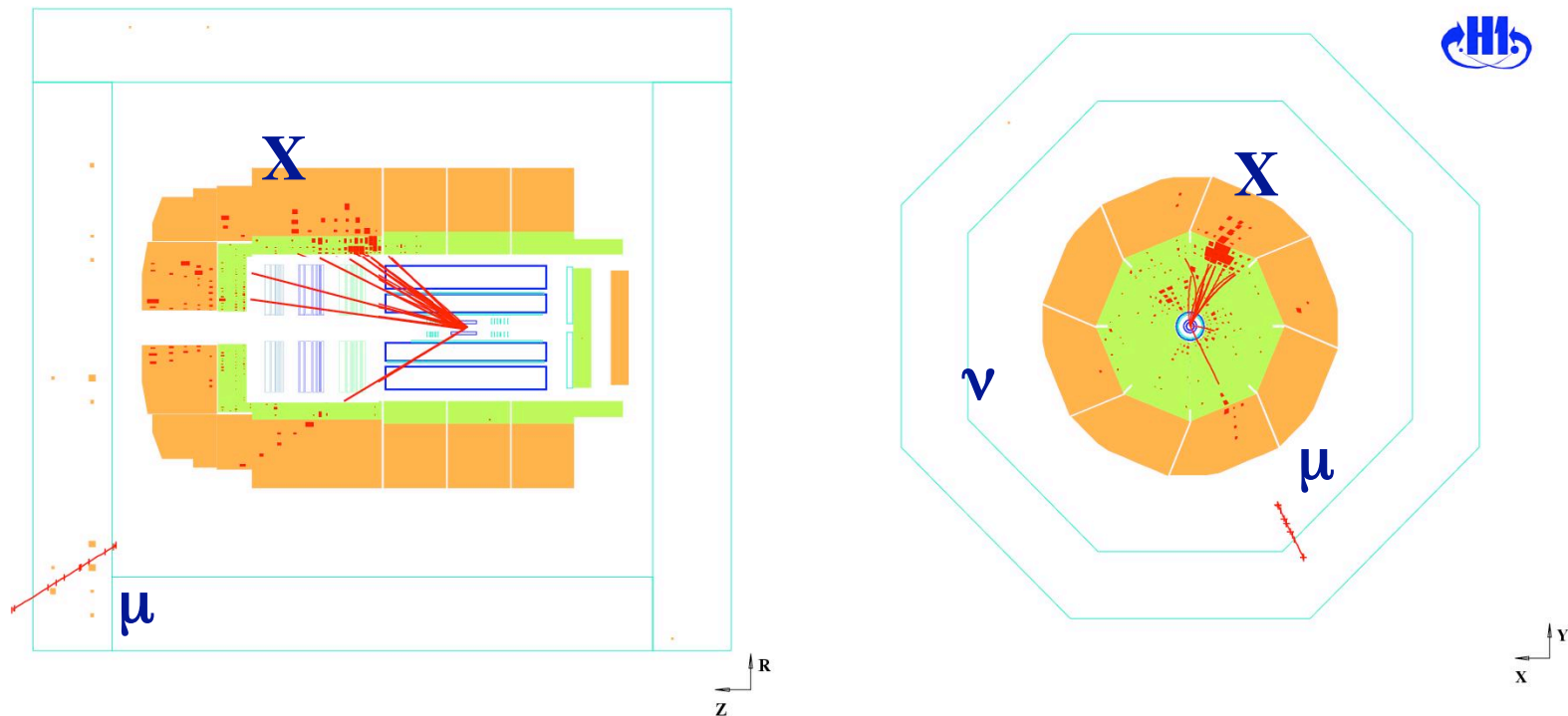
Selection	Data	SM	Pair Production	NC-DIS + Compton
2e	937	937 ± 67	756 ± 48	181 ± 39
3e	148	161 ± 10	160 ± 10	0.4 ± 0.01
All	1085	1098 ± 75	916 ± 58	182 ± 39

Summary

- A search for events with isolated leptons and missing P_T performed by H1 and ZEUS using the **full HERA I+II dataset, luminosity $\sim 1 \text{ fb}^{-1}$**
 - *Measurement of W production at HERA*
- The H1 and ZEUS analyses are coherently combined for the first time
- H1 excess at large P_T^X in e^+p data persists in full HERA I+II data set
 - *Excess drops to 1.8 sigma significance with full H1+ZEUS data*
- Cross section and W Helicity measurements performed by H1
- Exclusion limit on anomalous top cross section extended to $\sigma < 0.16 \text{ pb}$
 - *Currently the best limit on the anomalous magnetic coupling: $\kappa_{t\gamma} < 0.14$*

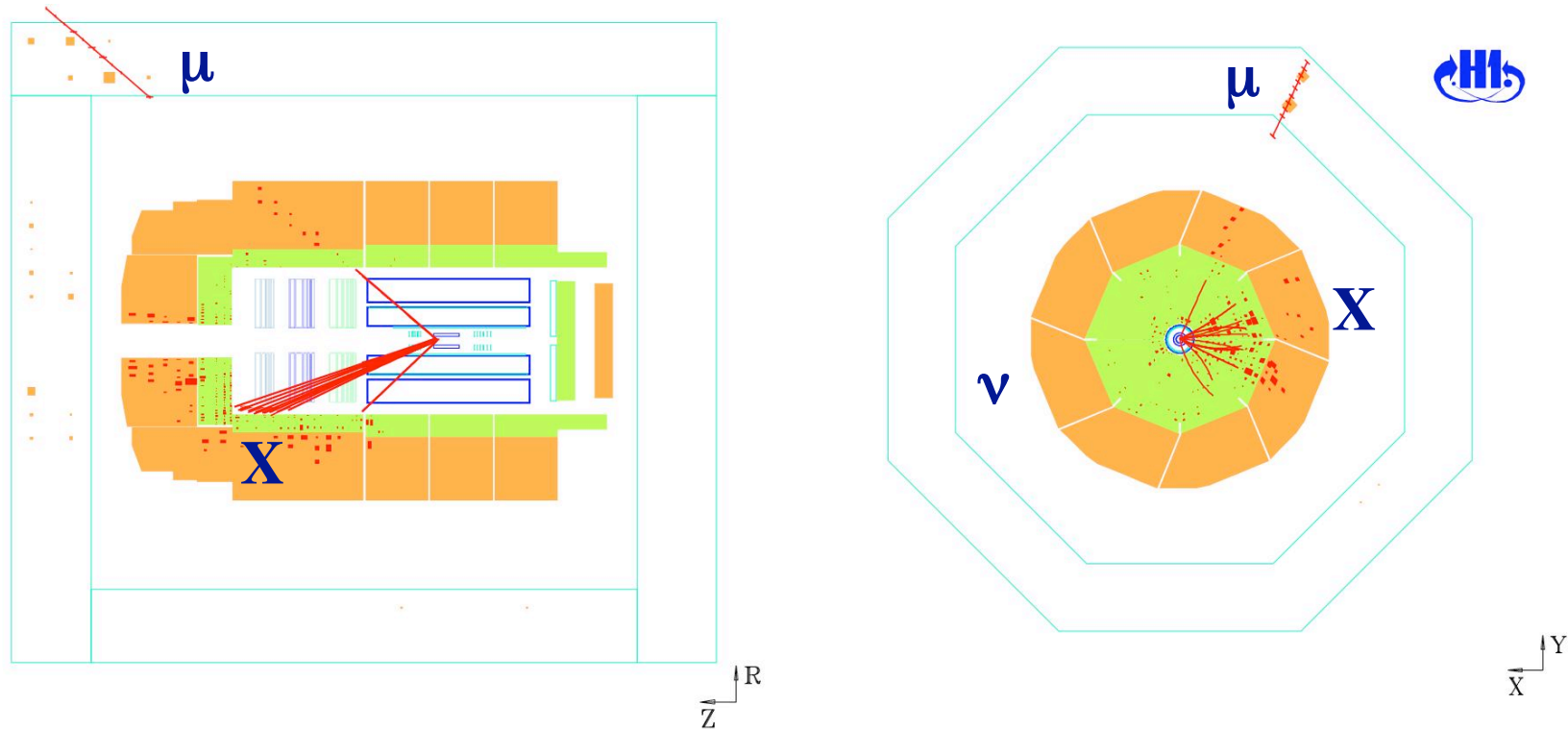
Extras

Display of an Isolated Muon Event



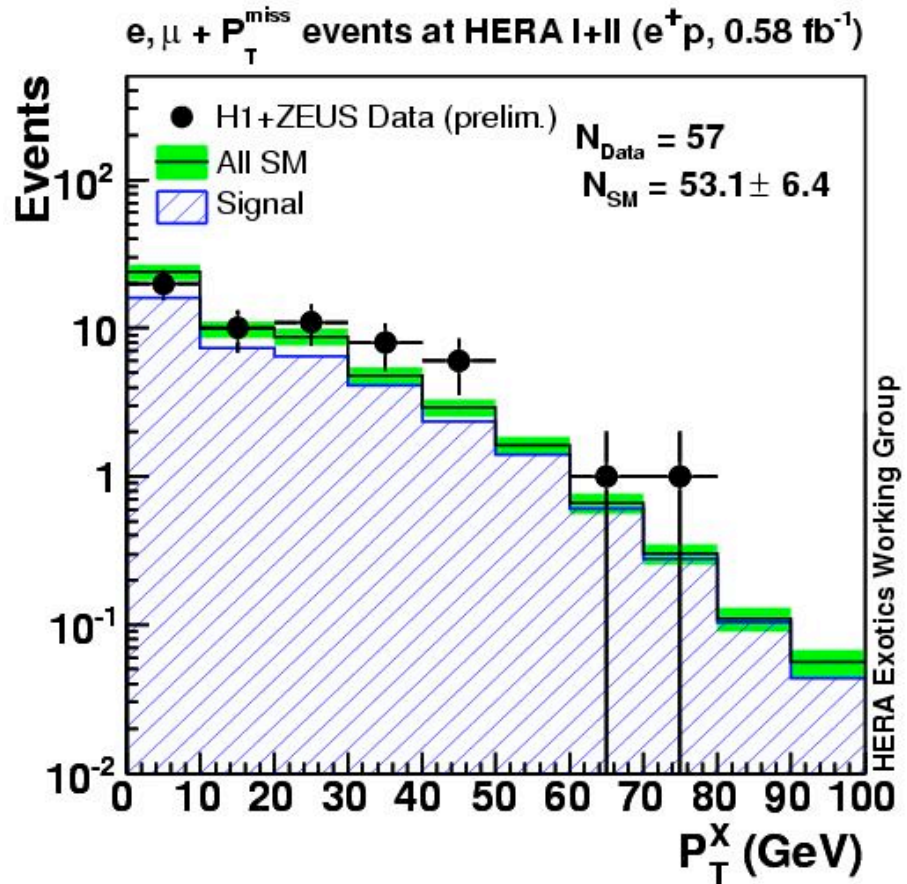
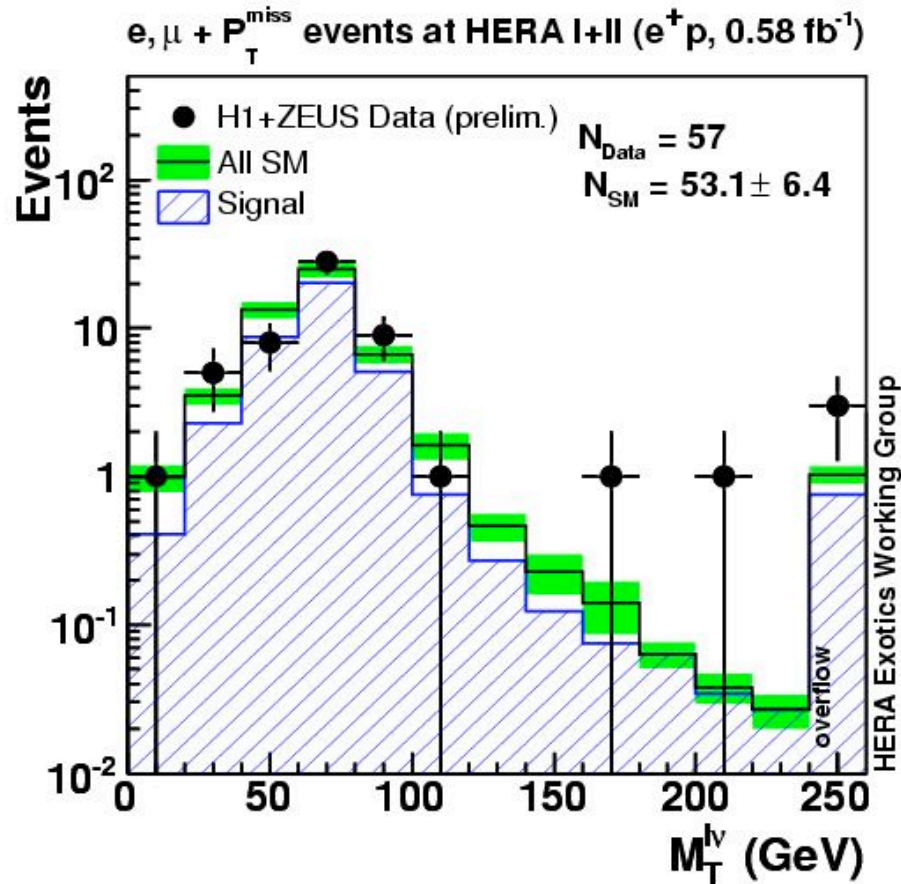
- High $P_T^X \mu + P_T^{\text{Miss}}$ event in H1 HERA II e^+p data
- $P_T^\mu = 51 \text{ GeV}$, $P_T^{\text{Miss}} = 39 \text{ GeV}$, $P_T^X = 48 \text{ GeV}$

Display of an Isolated Muon Event

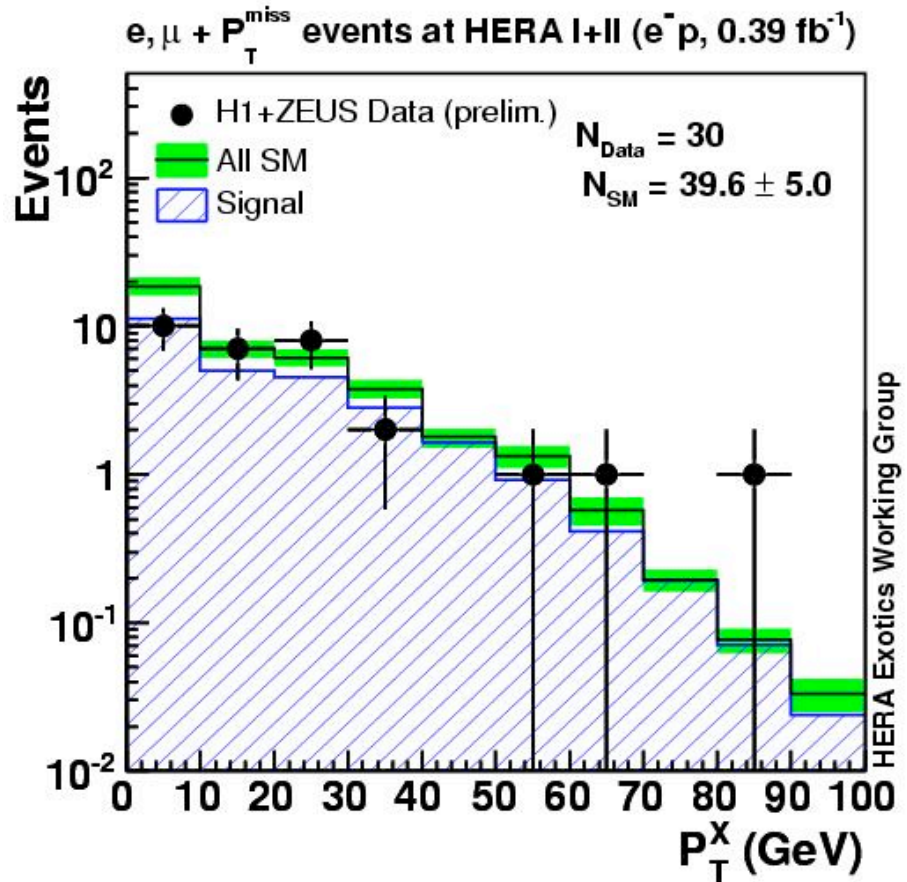
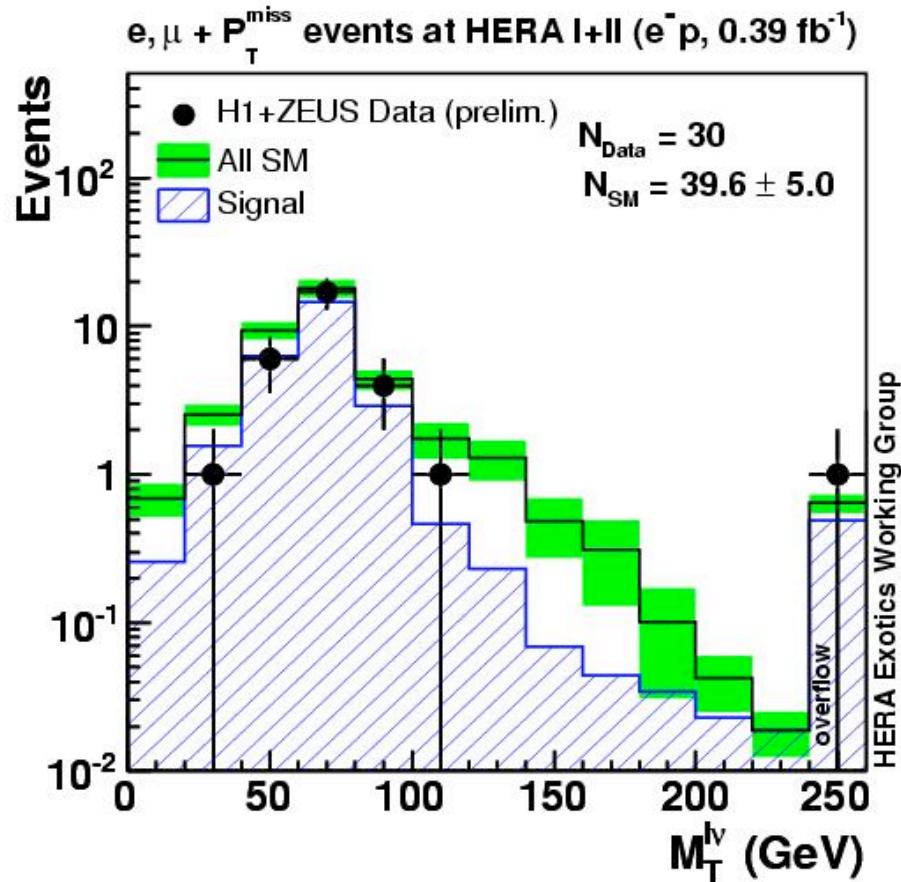


- High $P_T^X \mu + P_T^{\text{Miss}}$ event in H1 HERA II e-p data
- $P_T^\mu = 38 \text{ GeV}$, $P_T^{\text{Miss}} = 51 \text{ GeV}$, $P_T^X = 24.7 \text{ GeV}$

H1+ZEUS: HERA I+II e^+p Data



H1+ZEUS: HERA I+II e⁻p Data



H1+ZEUS: HERA I+II Data

H1+ZEUS Preliminary $l+P_T^{\text{miss}}$ events at HERA I+II		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2007 e^+p 0.58 fb ⁻¹	Full Sample	39 / 41.3 ± 5.0 (70%)	18 / 11.8 ± 1.6 (85%)	57 / 53.1 ± 6.4 (73%)
	$P_T^X > 25$ GeV	12 / 7.4 ± 1.0 (78%)	11 / 7.2 ± 1.0 (85%)	23 / 14.6 ± 1.9 (81%)
1998-2006 e^-p 0.39 fb ⁻¹	Full Sample	25 / 31.6 ± 4.1 (63%)	5 / 8.0 ± 1.1 (86%)	30 / 39.6 ± 5.0 (68%)
	$P_T^X > 25$ GeV	4 / 6.0 ± 0.8 (67%)	2 / 4.8 ± 0.7 (87%)	6 / 10.6 ± 1.4 (76%)
1994-2007 $e^\pm p$ 0.97 fb ⁻¹	Full Sample	64 / 72.9 ± 8.9 (67%)	23 / 19.9 ± 2.6 (85%)	87 / 92.7 ± 11.2 (71%)
	$P_T^X > 25$ GeV	16 / 13.3 ± 1.7 (73%)	13 / 12.0 ± 1.6 (86%)	29 / 25.3 ± 3.2 (79%)