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Universität Dortmund

Isolated Leptons + P_T^{Miss} at HERA

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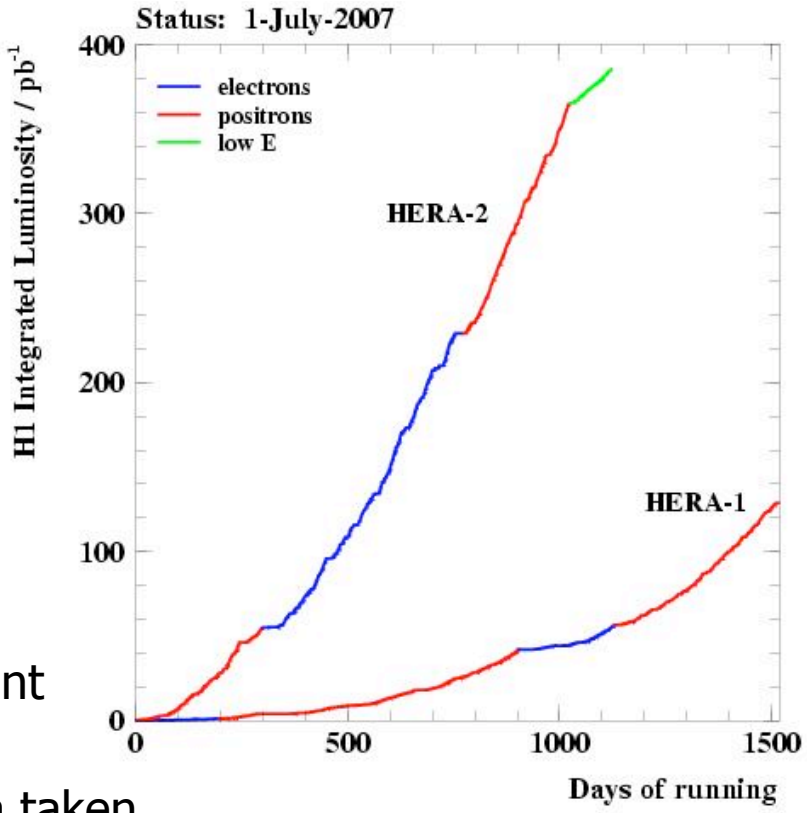
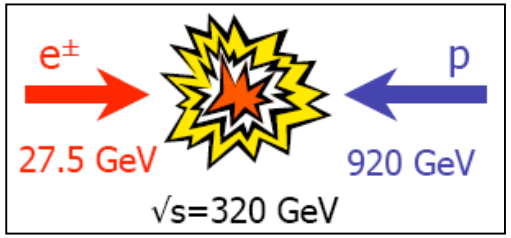
on behalf of the H1 and ZEUS collaborations

- 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

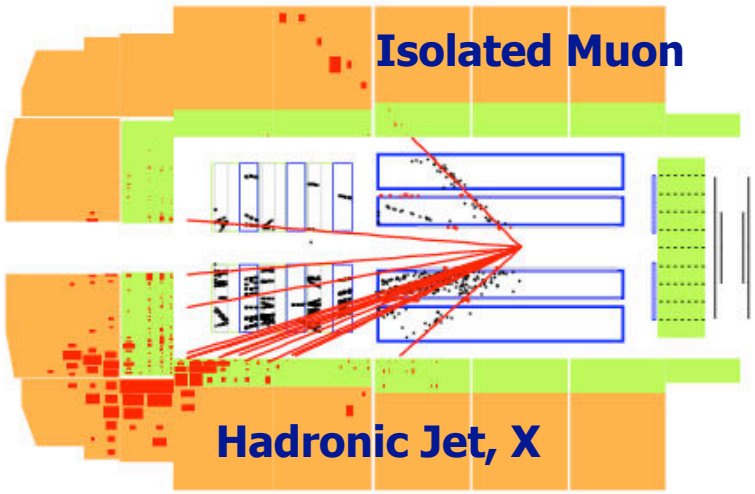
H1 and ZEUS at HERA 1994-2007



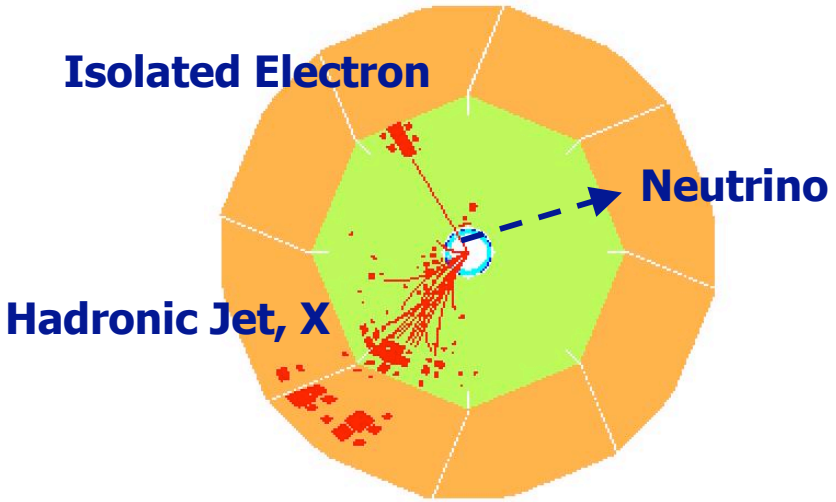
- Large increase in data per experiment from HERA II (factor of 3)
- Large increase (factor of 12) in data taken from $e^{-}p$ collisions
  - HERA I mostly $e^{+}p$ data
- **Final combined HERA dataset ~ 1 fb^{-1}**



Introduction to Isolated Leptons



H1 HERA I μ + P_T^{miss} event

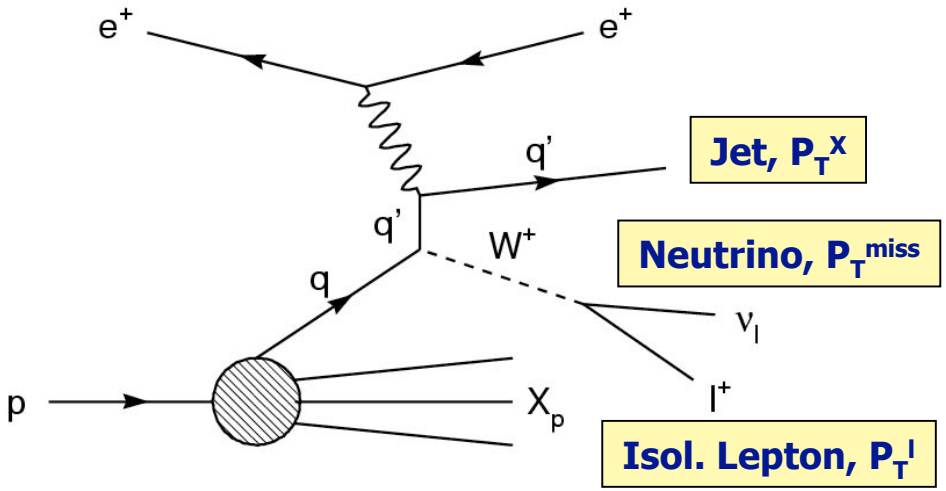


H1 HERA I e + P_T^{miss} event

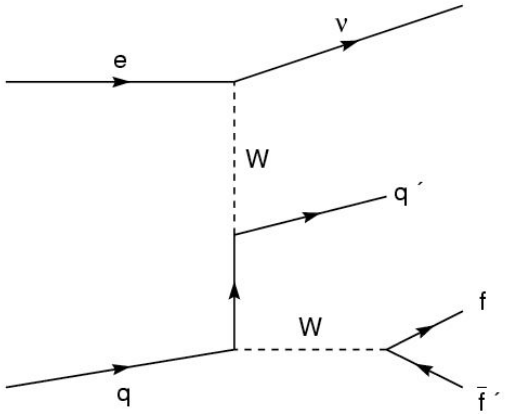
- H1 observation of events containing P_T^{Miss} and high P_T leptons (electron or muon) in the HERA I analysis (118 pb^{-1}):
  - 19 events in the data (1 in e^-p) compared to SM expectation of 14.5 ± 2.0
  - Excess of data events observed at large hadronic transverse momentum
  - Result not confirmed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

Standard Model Signal Processes

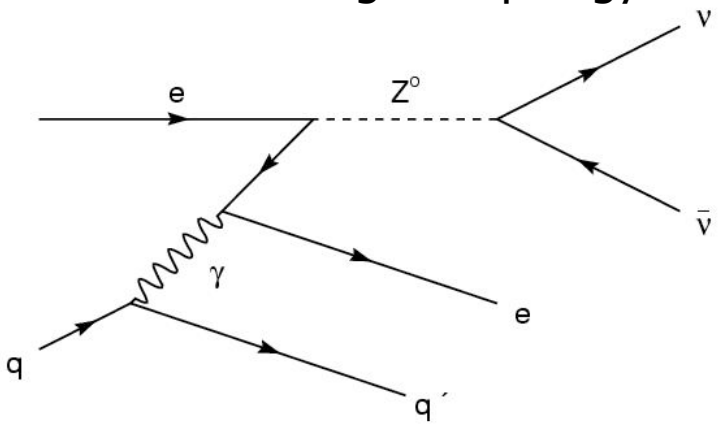
- Main SM contribution to signal from real W production via photoproduction with subsequent decay to leptons
  - Total cross section of order 1.3 pb, with 10% of W decays to each lepton flavour
  - Modelled using the EPVEC generator with a NLO QCD correction (Diener et. al.): modifies LO cross section 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)

Isolated Lepton Event Selection

Variable	Electron	Muon
θ_l	**$5^o < \theta_l < 140^o$ (H1), $15^o < \theta_l < 120^o$ (ZEUS)**	
P_T^l	> 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 $\theta_e \geq 45^o$	> 0.5
ζ_l^2	> 5000 GeV^2 for $P_T^{calo} < 25$ GeV	-
V_{ap}/V_p	< 0.5 (< 0.15 for $P_T^e < 25$ GeV)	< 0.5 (< 0.15 for $P_T^{calo} < 25$ GeV)
$\Delta\phi_{l\text{-}X}$	$< 160^o$	$< 170^o$
δ_{miss}	> 5 GeV	-
# isolated μ	0	1

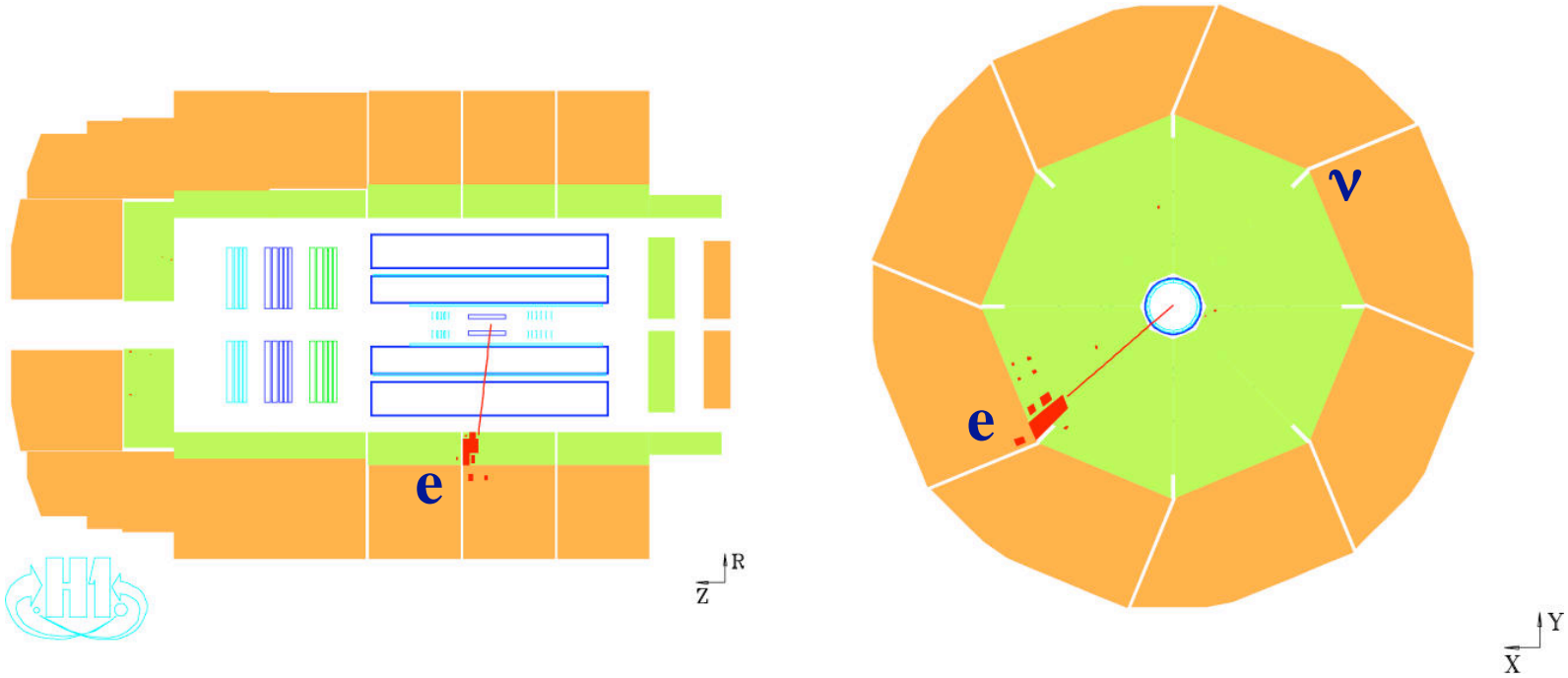
Analysis phase space selection. H1: extended polar angle range

Isolation of lepton

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

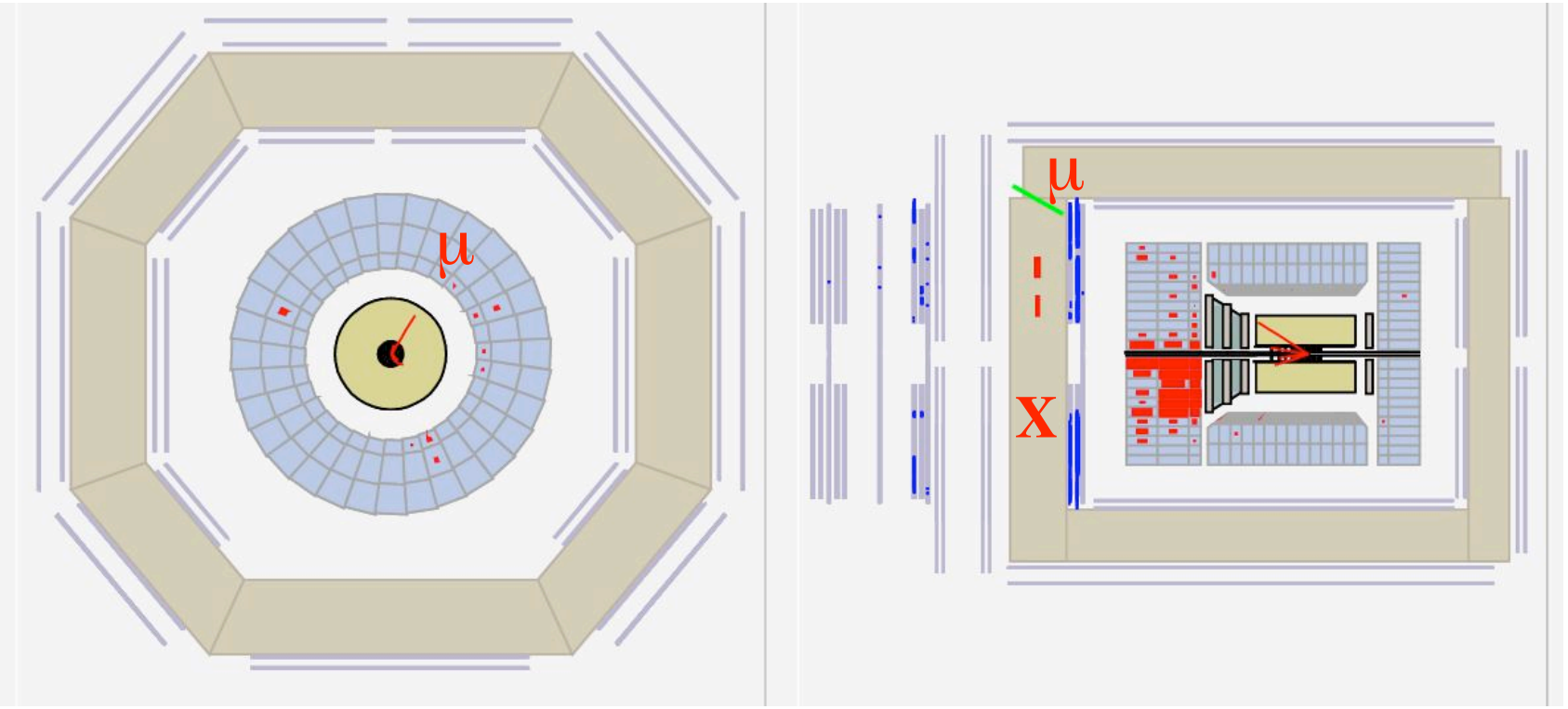
H1: *only if one e candidate is detected, with the same charge as the beam lepton*

Display of an Isolated Electron Event



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

Display of an Isolated Muon Event

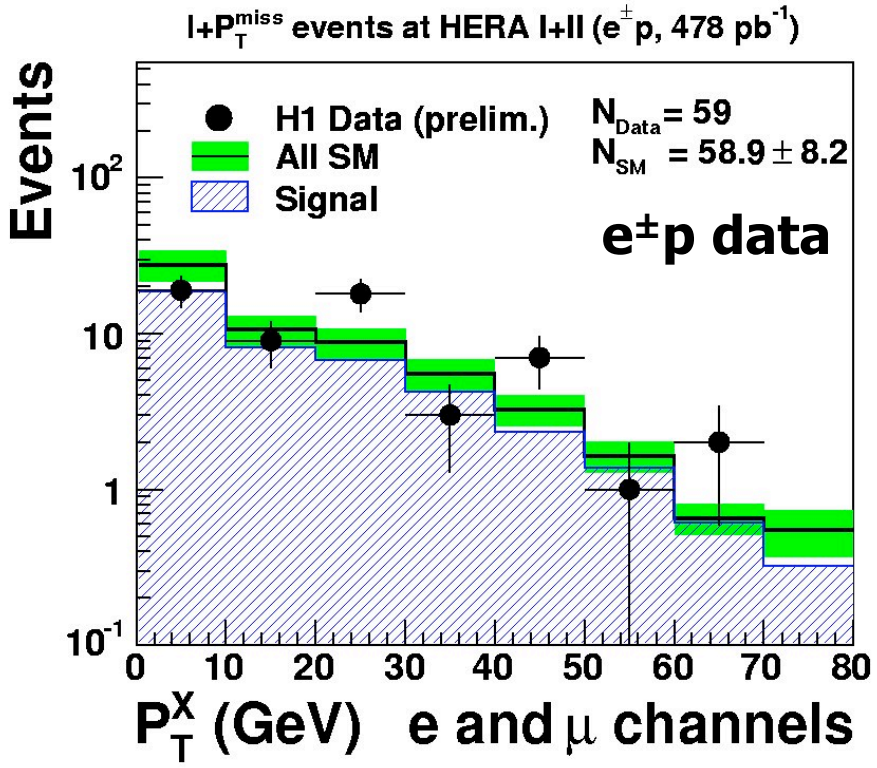


- High P_T^X μ + P_T^{Miss} event in the ZEUS e^-p HERA II data
- θ^μ = 32°, $M_T^{\mu\nu}$ = 79 GeV, P_T^X = 82 GeV

H1 Results from HERA I+II

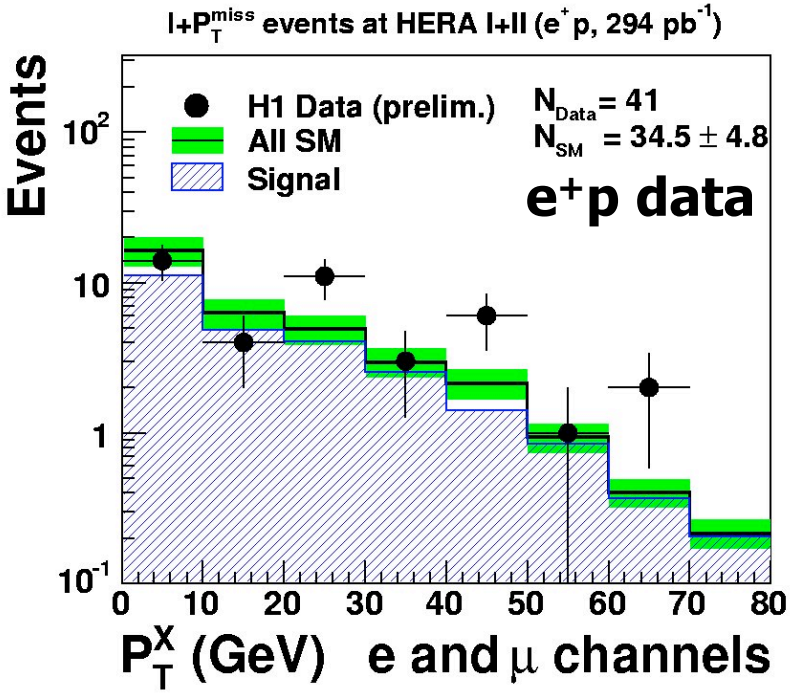
Analysis lepton polar angle range $5^o < \theta_l < 140^o$

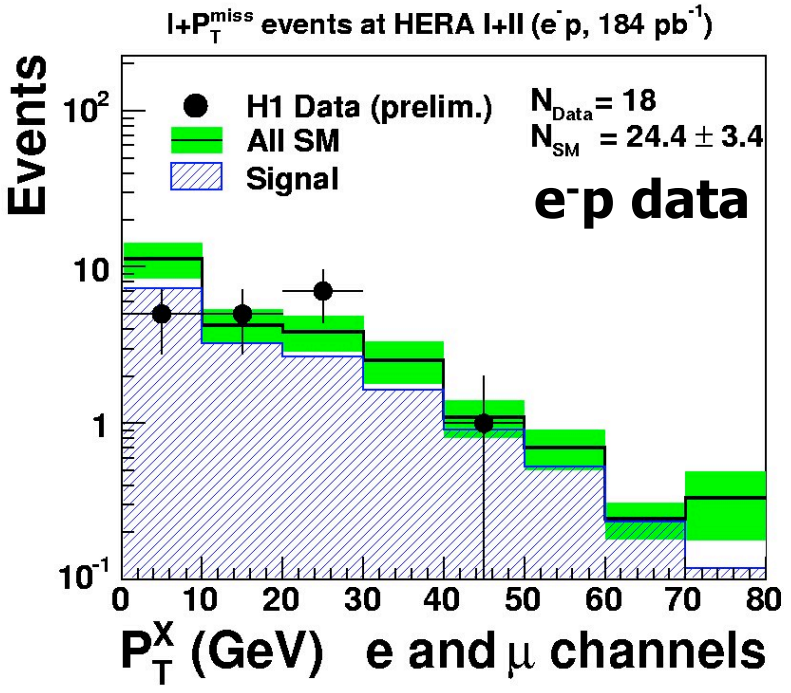
- Total H1 luminosity from HERA I and II datasets: 478 pb^{-1}
- Significant increase in statistics of e^-p data compared to HERA I
- An overall excess still visible at large values of hadronic transverse momentum



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%)
$P_T^X > 25$ 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

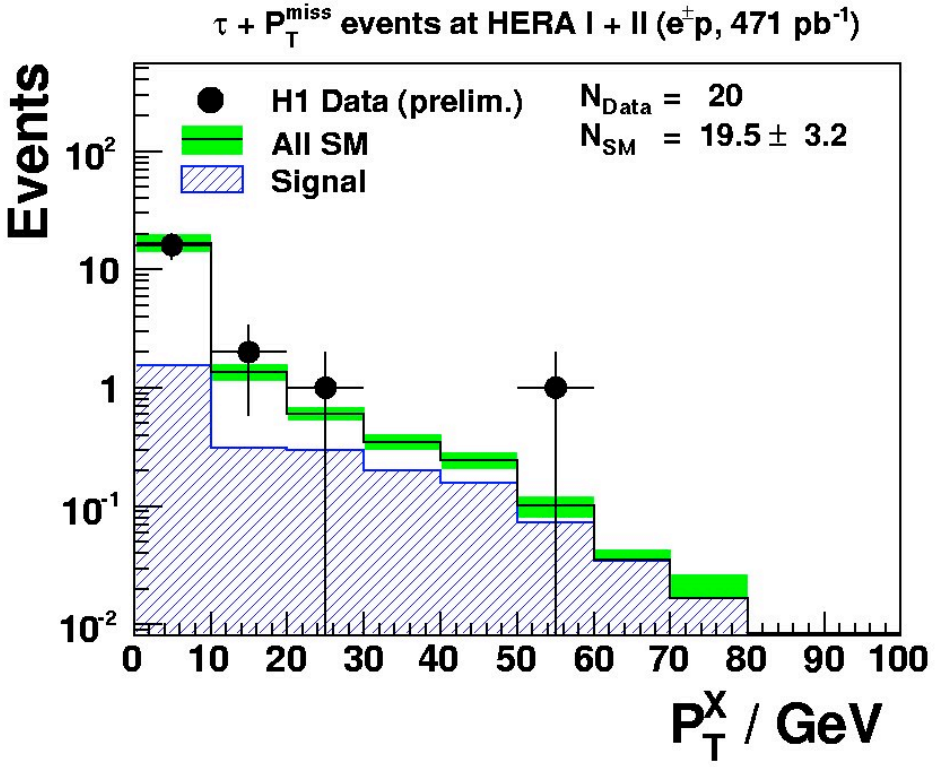




H1 HERA I+II P_T^X > 25 GeV	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
e^+p data (294 pb^{-1})	11 / 4.7 ± 0.9 (75%)	10 / 4.2 ± 0.7 (85%)	21 / 8.9 ± 1.5 (80%)
e^-p data (184 pb^{-1})	3 / 3.8 ± 0.6 (61%)	0 / 3.1 ± 0.5 (74%)	3 / 6.9 ± 1.0 (67%)

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

H1 Tau Results from HERA I+II

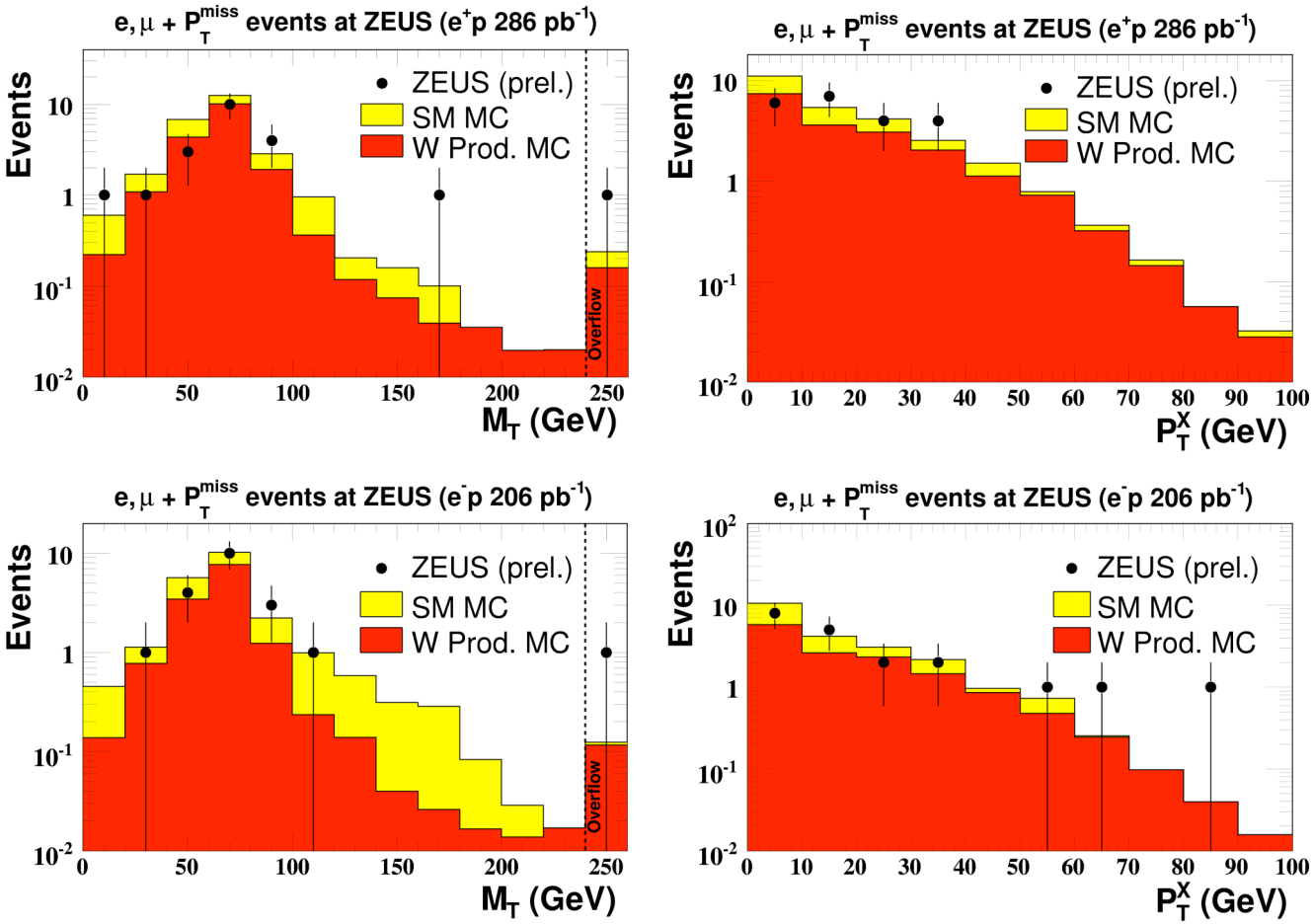


H1 $e^{\pm}p$ data HERA I+II (471 pb^{-1})	τ channel obs. / exp. (signal)
Full sample	20 / 19.5 ± 3.2 (14%)
P_T^X > 25 GeV	1 / 0.99 ± 0.13 (63%)

- 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

ZEUS Results from HERA I+II

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



- ZEUS e^+p data 1996-2007 286 pb^{-1}
- ZEUS e^-p data 1998-2006 206 pb^{-1}

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%)

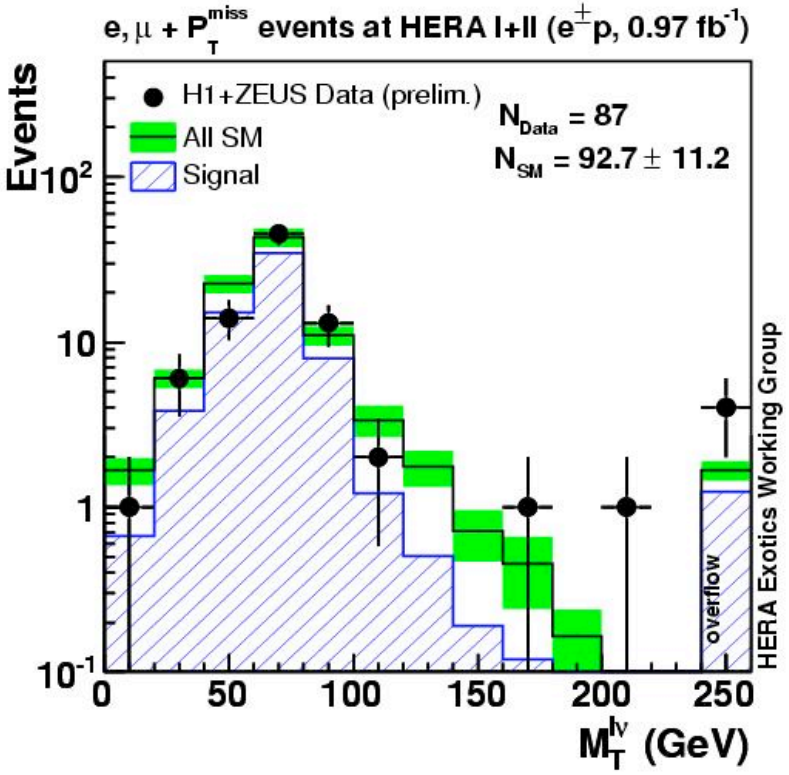
Isolated μ Candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) $e^- p$ 206 pb^{-1}	$1/1.7 \pm 0.3$ (77%)	$2/2.4 \pm 0.4$ (85%)
ZEUS (prel.) $e^+ p$ 286 pb^{-1}	$3/2.3 \pm 0.3$ (82%)	$3/3.6 \pm 0.5$ (81%)
ZEUS (prel.) $e^\pm p$ 492 pb^{-1}	$4/4.1 \pm 0.6$ (80%)	$5/6.0 \pm 0.8$ (82%)

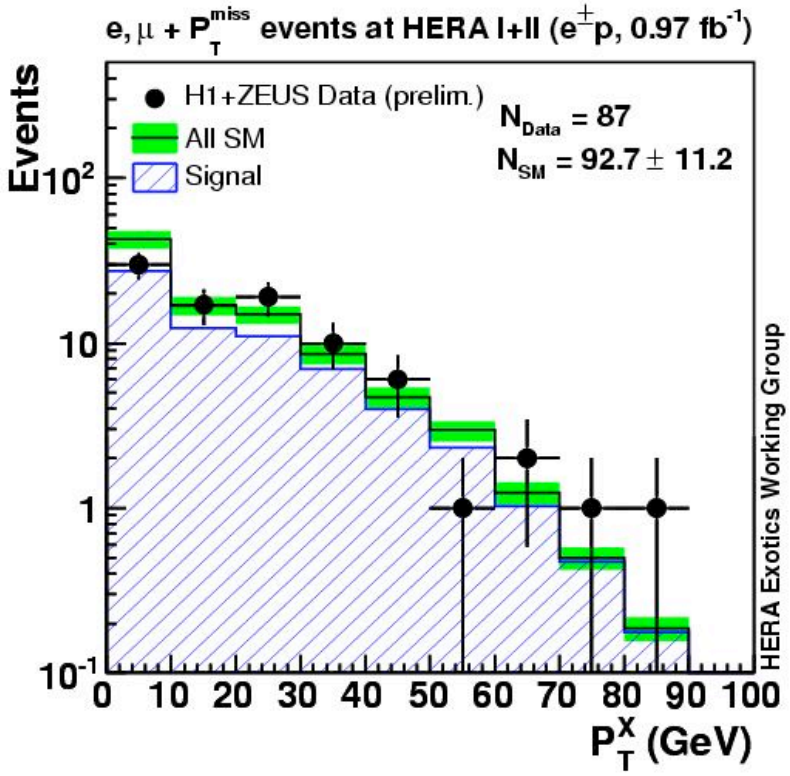
- Like H1, full HERA I+II data set has been analysed
  - 41 events observed in 492 pb^{-1} of data
- Good agreement between data and SM in both lepton channels and in all data sets
- No excess seen at high P_T^X in the e^+p data as seen by H1

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: $15^o < \theta_l < 120^o$, 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



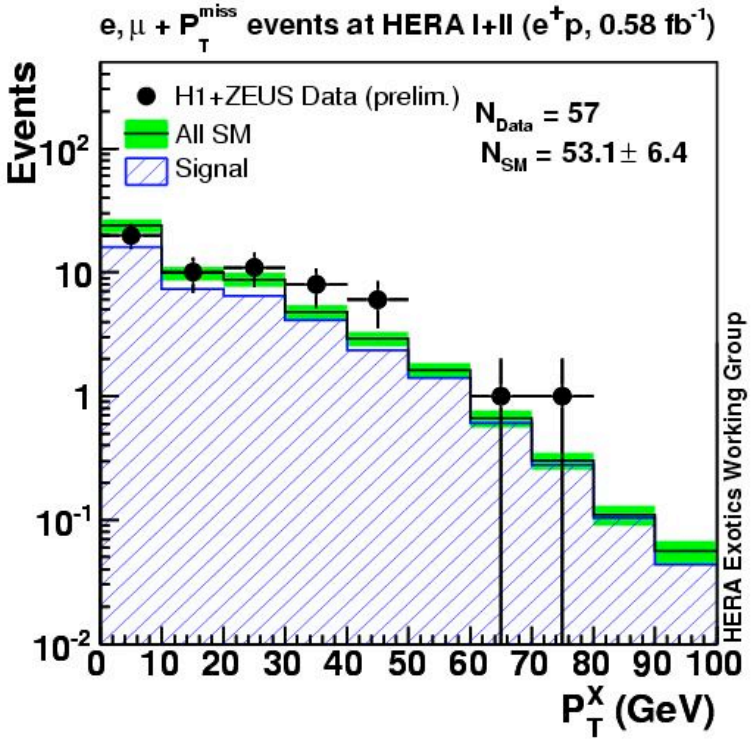


H1+ZEUS $e^{\pm}p$ data HERA I+II (0.97 fb^{-1})	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
Full sample	64 / 72.9 ± 8.9 (67%)	23 / 19.9 ± 2.6 (85%)	87 / 92.7 ± 11.2 (71%)
P_T^X > 25 GeV	16 / 13.3 ± 1.7 (73%)	13 / 12.0 ± 1.6 (86%)	29 / 25.3 ± 3.2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

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

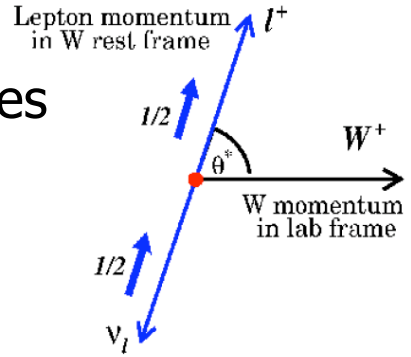
Isolated Lepton Cross Section | Total Single W Cross Section

H1	HERA I+II Data	SM
$\sigma_{\sigma_{\ell+\not{p}_T}}$	$0.24 \pm 0.05\,(\text{stat}) \pm 0.05\,(\text{sys})$	$0.26 \pm 0.04\,(\text{th.sys})$
σ_W	$1.23 \pm 0.25\,(\text{stat}) \pm 0.22\,(\text{sys})$	$1.31 \pm 0.20\,(\text{th.sys})$

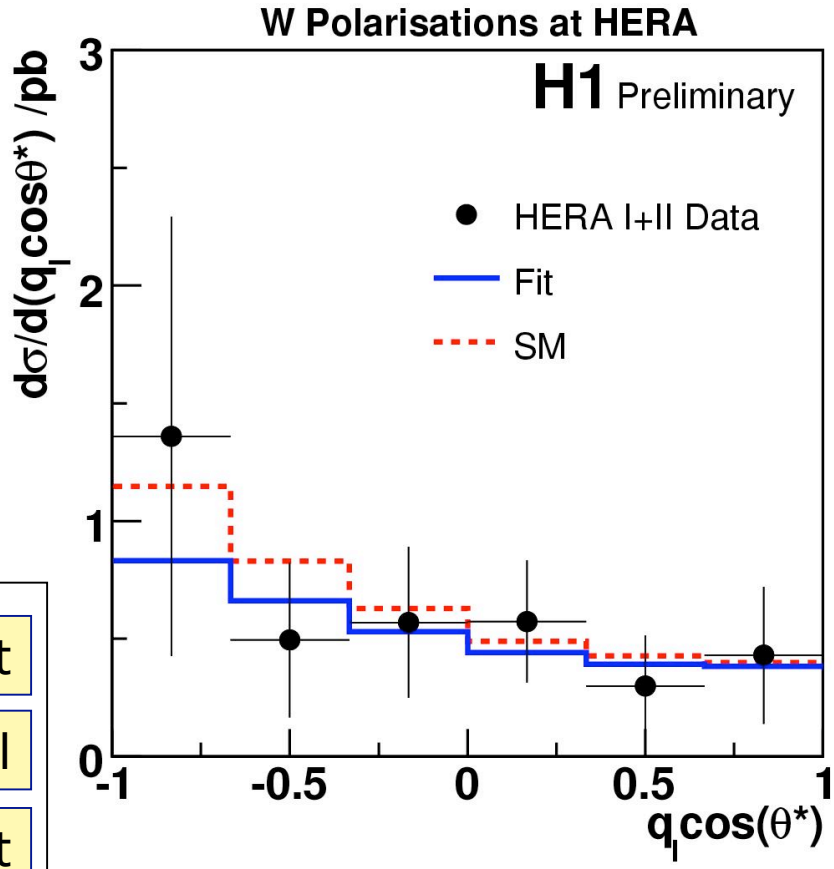
- Both measured cross sections in good agreement with the SM predictions

H1 Measurement of W Polarisation Fractions

- Measurement makes use of the cos θ^* distributions in the decay $W \rightarrow l + \nu$



- Require $\theta > 20^o$ and lepton charge
  - cos θ^* is weighted with the sign of the charge of the identified lepton q_l



W pol. fractions

$$\frac{dN}{d\cos\theta^*} \propto (1 - F_- - F_0) \cdot \frac{3}{8}(1 + \cos\theta^*)^2 \quad \text{left}$$

$$+ \; F_0 \cdot \frac{3}{4}(1 - \cos^2\theta^*) \quad \text{longitudinal}$$

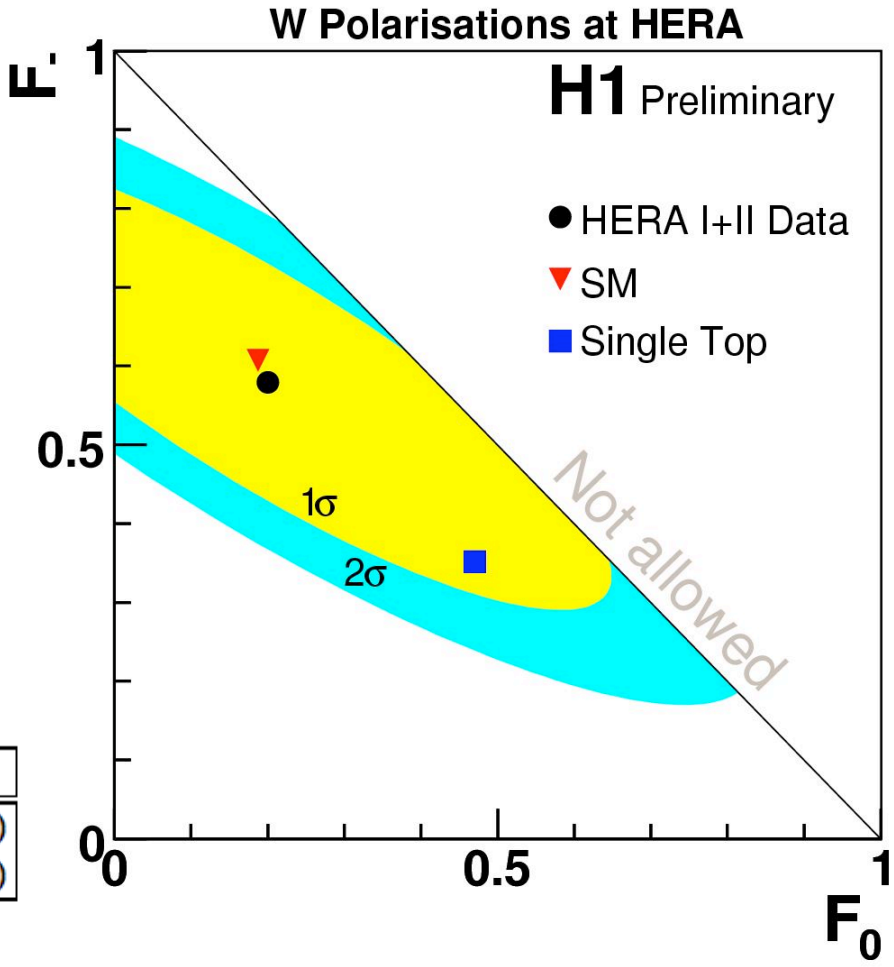
$$+ \; F_- \cdot \frac{3}{8}(1 - \cos\theta^*)^2 . \quad \text{right}$$

- The measured H1 cross section is fit to the above W helicity model

H1 Measurement of W Polarisation Fractions

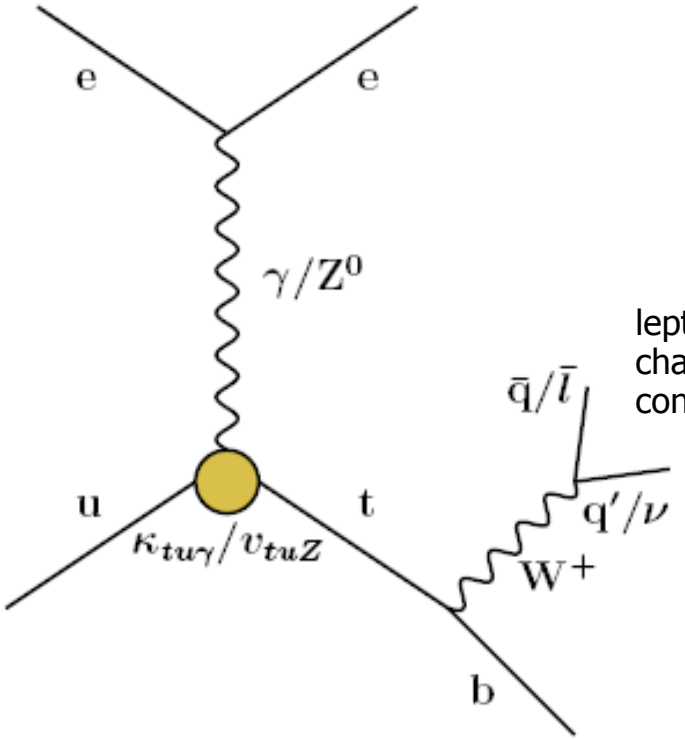
- F_0 and F_- simultaneously extracted (2D fit)
- Result in agreement with the SM prediction and compatible with Single Top production
- Polarisation fractions also extracted in 1D fits where one parameter is fixed to the SM

H1	HERA I+II Data	SM
F_-	$0.58 \pm 0.15\,(\text{stat}) \pm 0.12\,(\text{sys})$	$0.61 \pm 0.01\,(\text{stat})$
F_0	$0.15 \pm 0.21\,(\text{stat}) \pm 0.09\,(\text{sys})$	$0.19 \pm 0.01\,(\text{stat})$



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 → 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



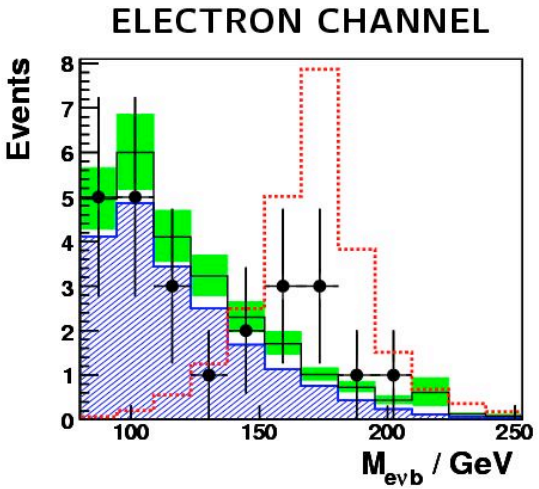
lepton & jet channels considered

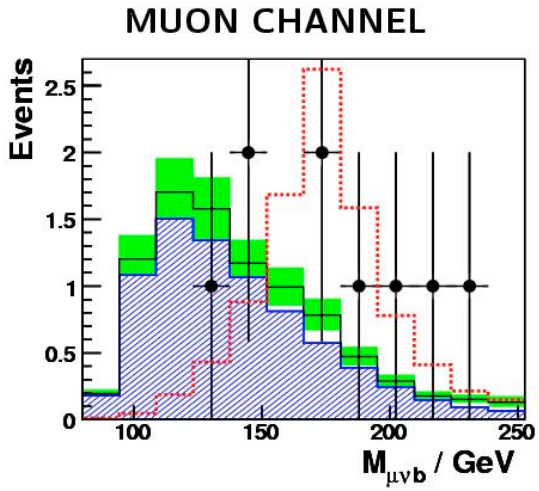
- HERA I analyses:
  - H1: $\sigma(ep \rightarrow etX) < 0.55$ pb
  - ZEUS: $\sigma(ep \rightarrow etX) < 0.23$ pb

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

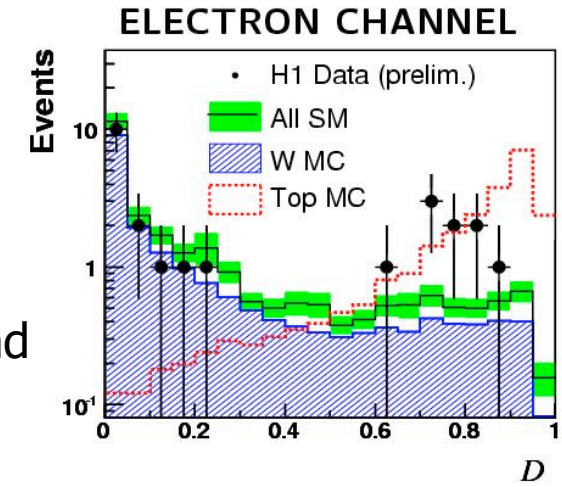
H1: Single Top using HERA I+II Data

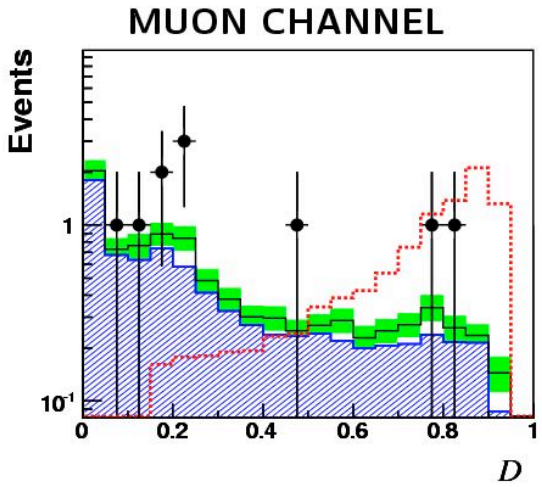
- Top pre-selection is subset of the l + P_T^{Miss} selection
  - Good top quark reconstruction required
  - Positive charge of lepton, where possible





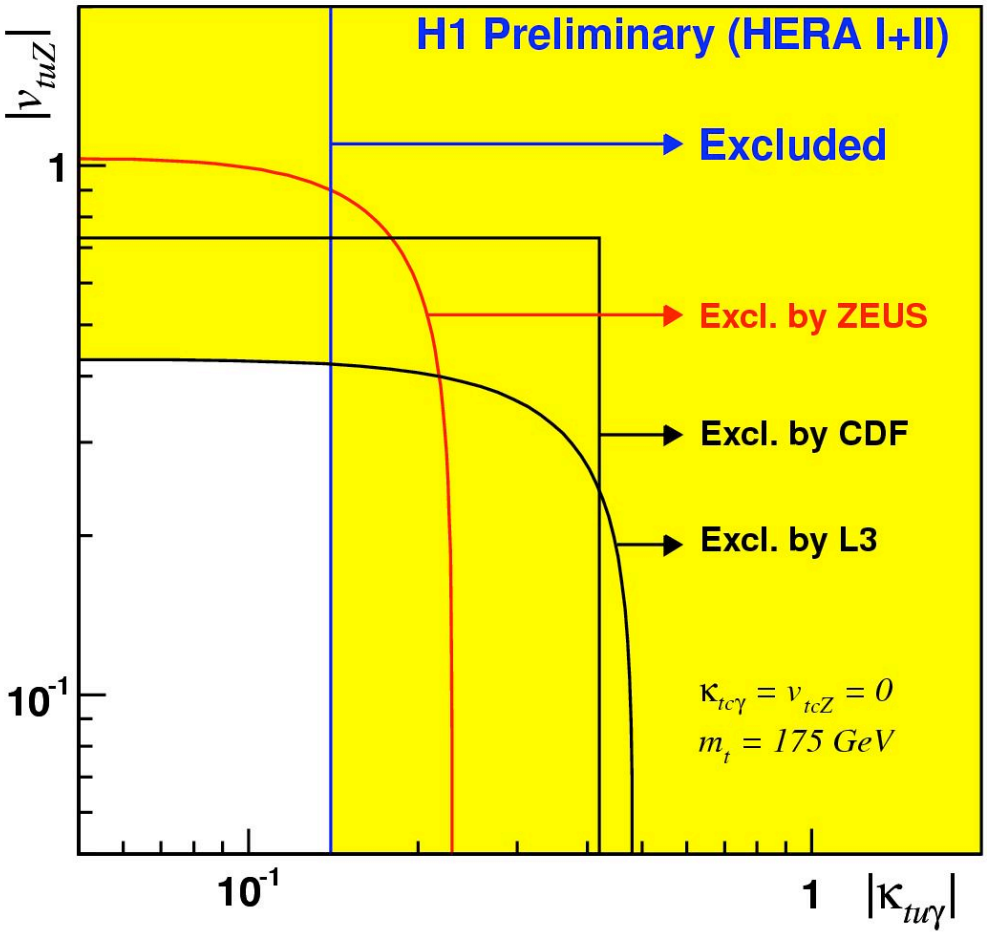
- Multivariate discriminator then used to separate signal and background
  - P_T^b , $M_{l\nu b}$ and θ^l_W
  - Top:signal, W:background





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:
  - $\sigma(ep \rightarrow etX) < 0.16$ pb
- Upper bound on the anomalous coupling
  - $\kappa_{tu\gamma} < 0.14$



- New limit extends into region of phase space uncovered by other colliders

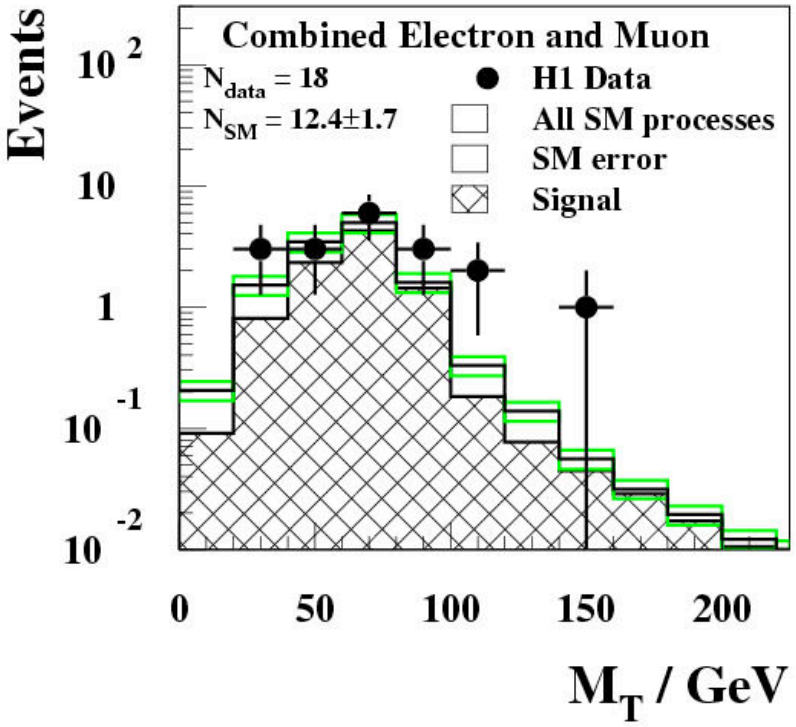
Summary

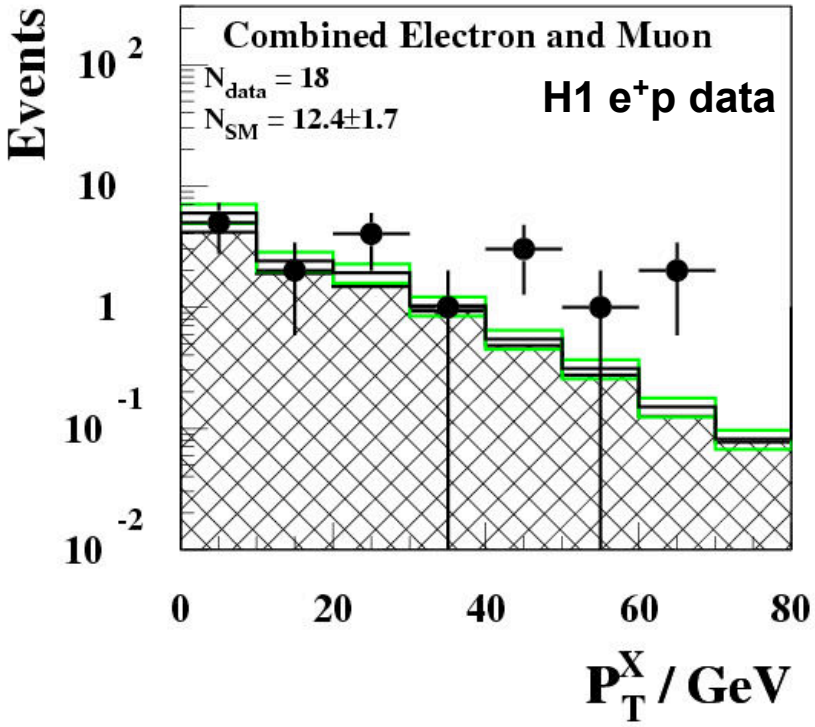
- A search for events with isolated leptons and missing P_T performed by H1 and ZEUS using the **full HERA I+II dataset, luminosity ~ 1 fb^{-1}**
  - *Measurement of W production at HERA*
- The H1 and ZEUS analyses are coherently combined for the first time
- H1 excess at large P_T^X in e^+p data persists 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 $\sigma < 0.16$ pb
  - *Currently the best limit on the anomalous magnetic coupling: $\kappa_{tu\gamma} < 0.14$*

Extras

Phys. Lett. B 561 (2003) 241

H1 Results from HERA I Analysis

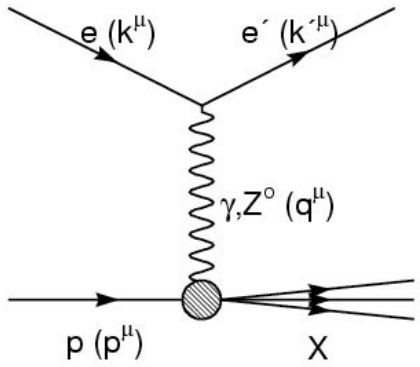
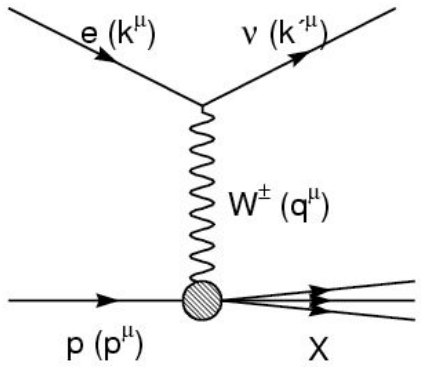
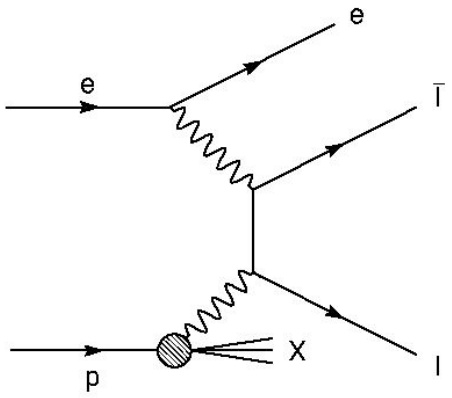




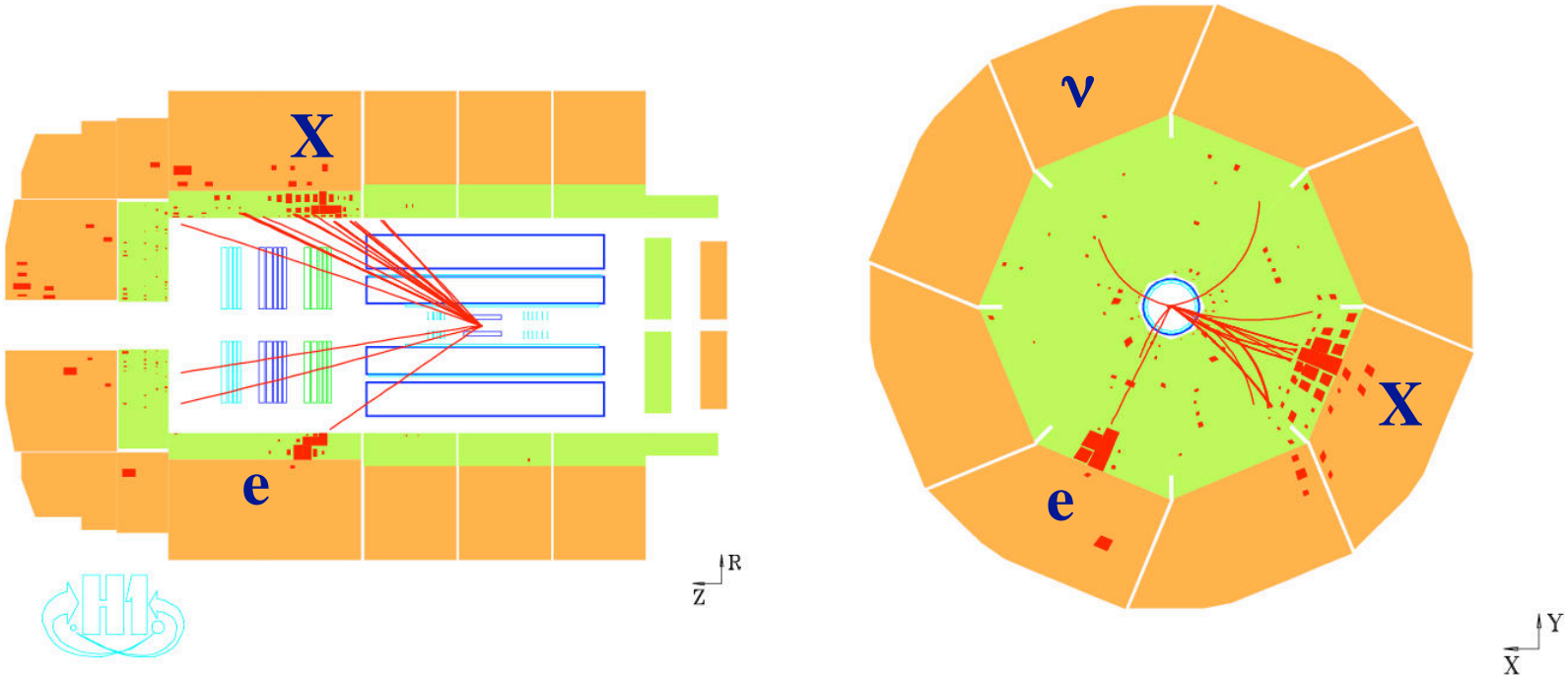
H1 $e^{\pm}p$ data HERA I (118 pb^{-1})	e channel obs. / exp.	μ channel obs. / exp.	e and μ channels obs. / exp.
Full sample	11 / 11.5 ± 1.5	8 / 2.9 ± 0.5	19 / 14.5 ± 2.0
P_T^X > 25 GeV	5 / 1.8 ± 0.3	6 / 1.7 ± 0.3	11 / 3.5 ± 0.6

Standard Model Background

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

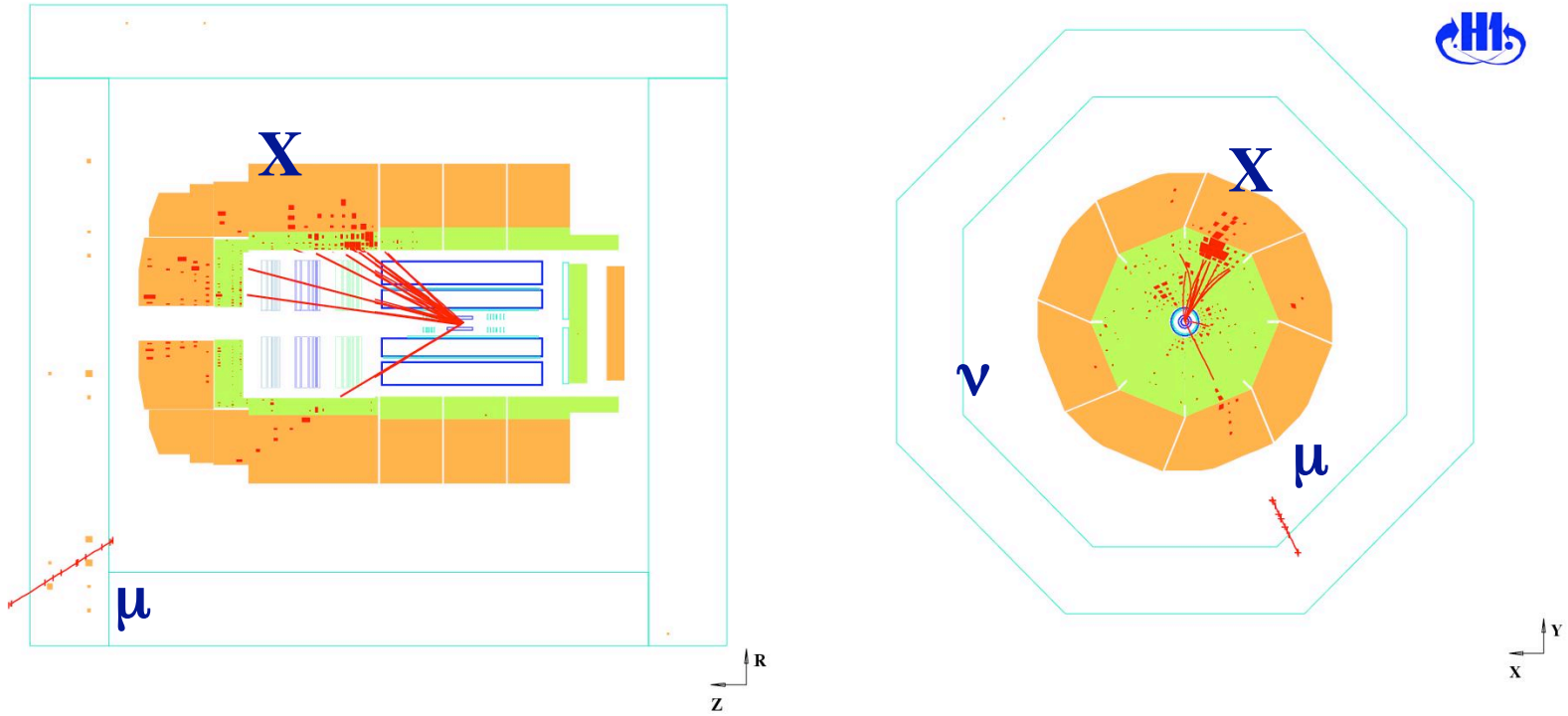
e: Neutral Current	e,μ: Charged Current	μ: Lepton Pair Production
		
real electron and fake missing P_T from mismeasurement	misidentified electron or muon and real missing P_T	real muon and fake missing P_T from mismeasurement

Display of an Isolated Electron Event



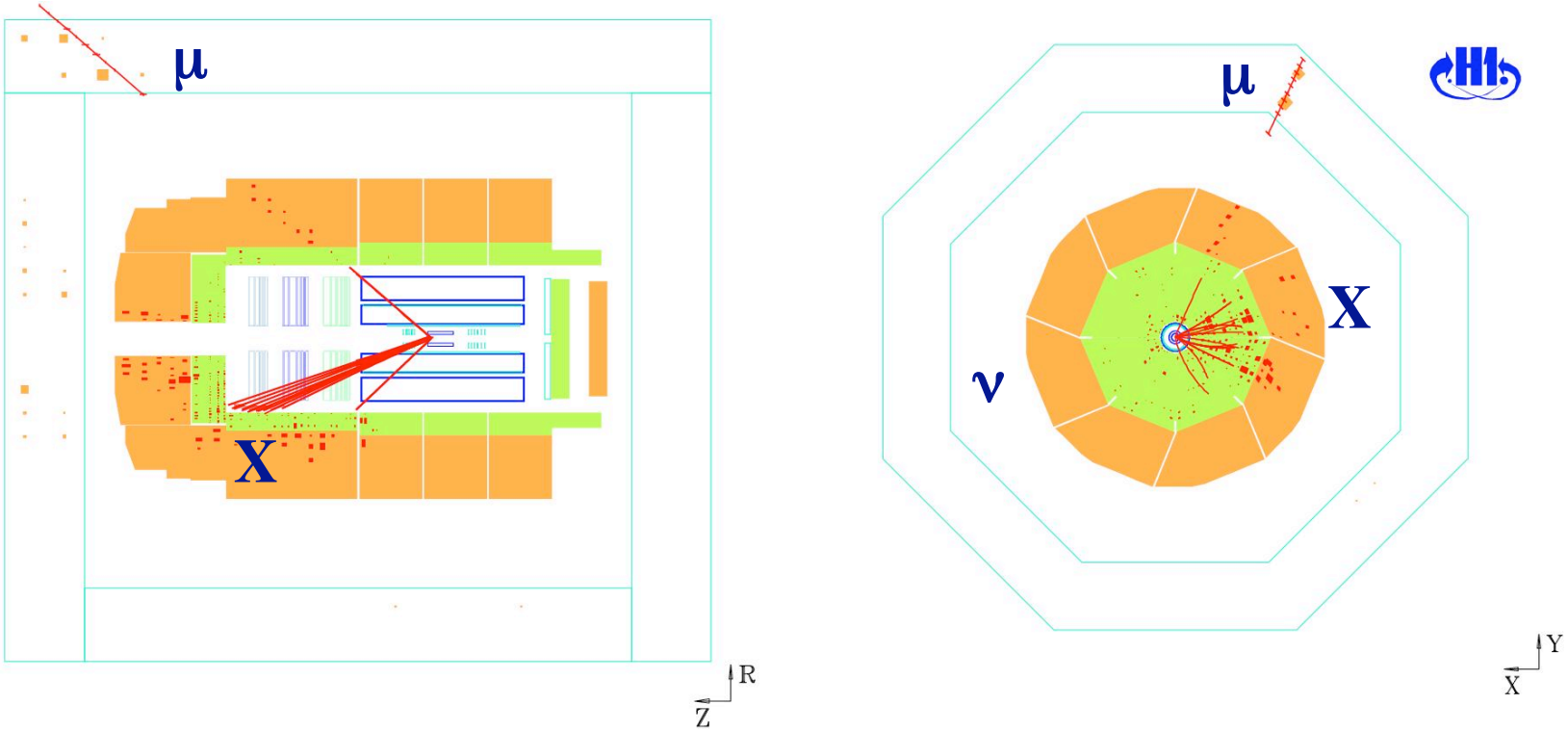
- High P_T^X e + P_T^{Miss} event in H1 HERA II e^+p data
- P_T^e = 37 GeV, P_T^{Miss} = 44 GeV, P_T^X = 29 GeV

Display of an Isolated Muon Event



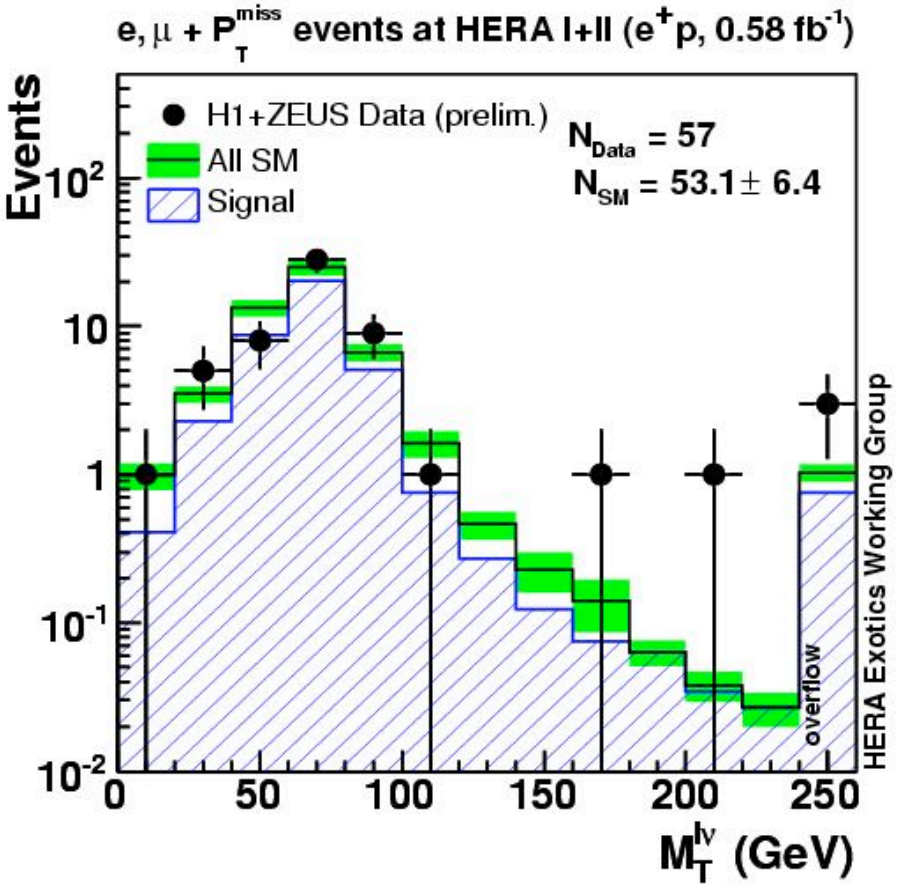
- High P_T^X μ + P_T^{Miss} event in H1 HERA II e^+p data
- P_T^{μ} = 51 GeV, P_T^{Miss} = 39 GeV, P_T^X = 48 GeV

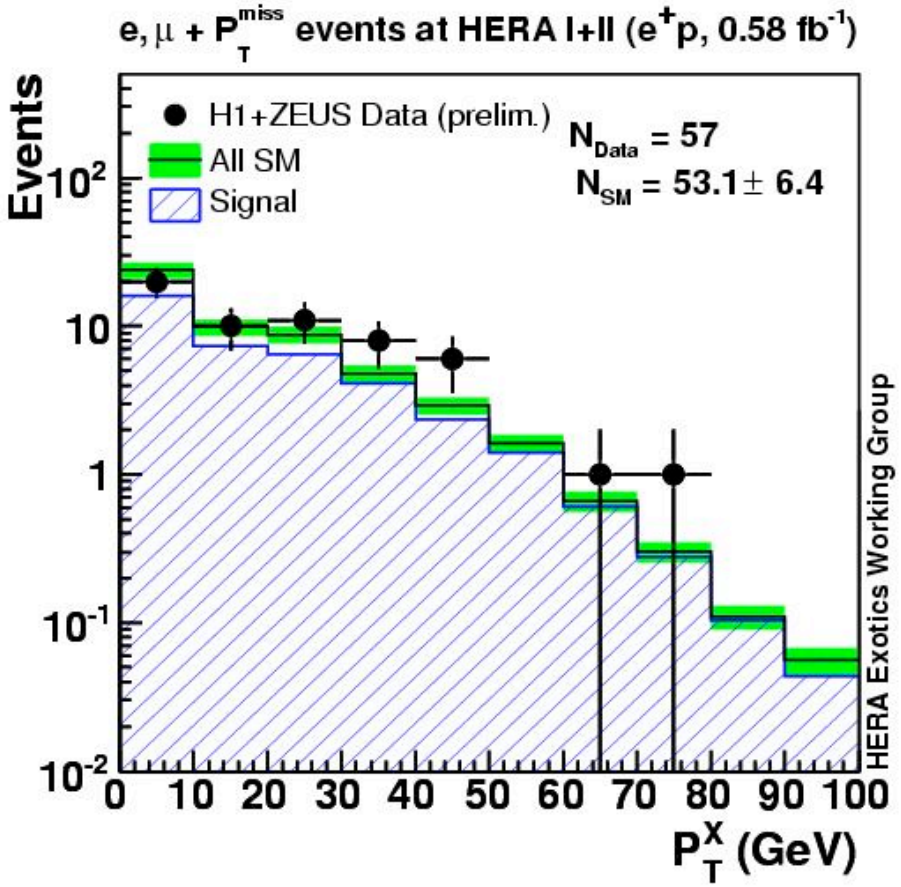
Display of an Isolated Muon Event



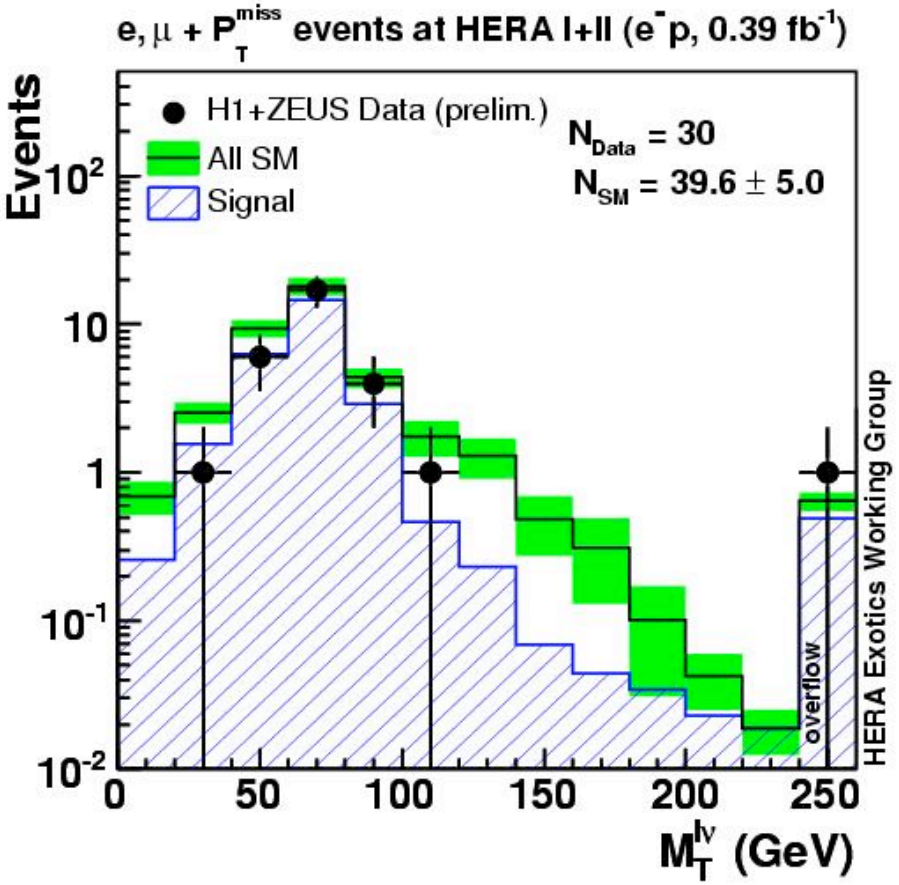
- High P_T^X μ + P_T^{Miss} event in H1 HERA II e^-p data
- P_T^{μ} = 38 GeV, P_T^{Miss} = 51 GeV, P_T^X = 24.7 GeV

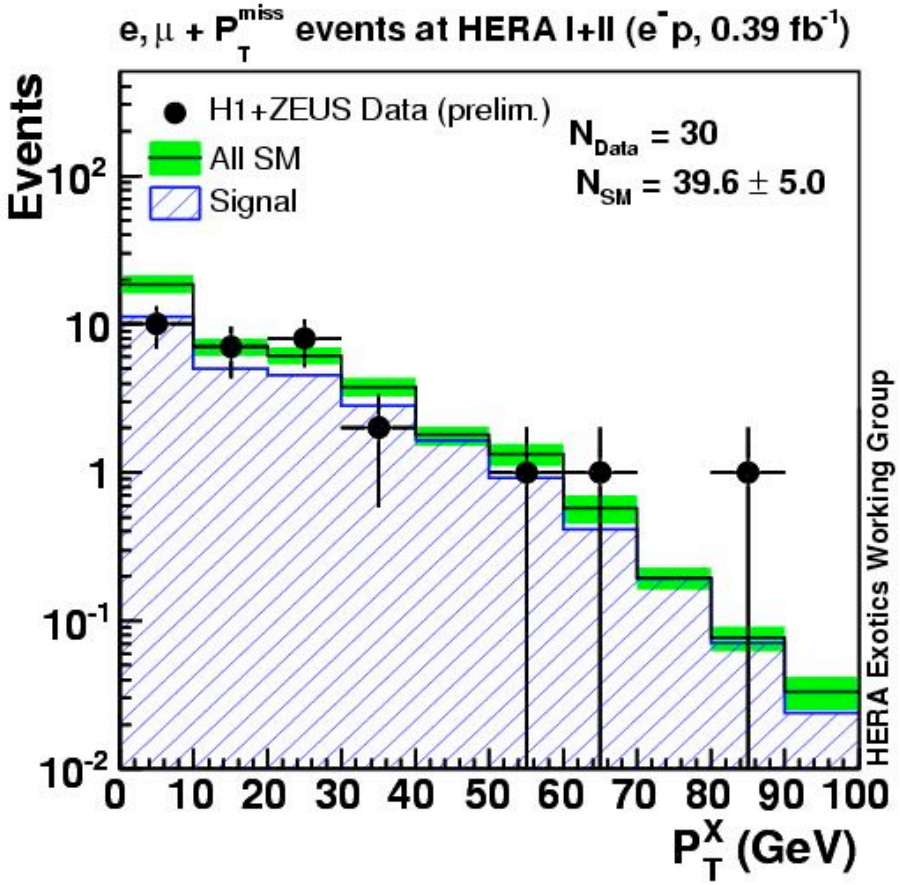
H1+ZEUS: HERA I+II e^+p Data





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



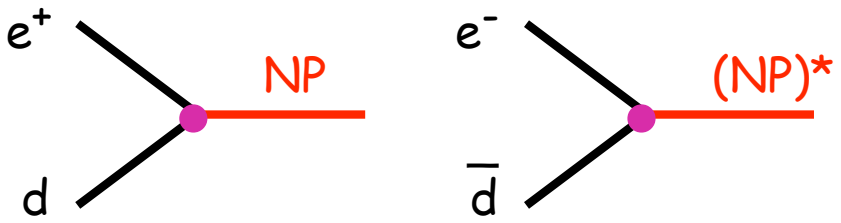


H1+ZEUS: HERA I+II Data

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

A BSM Model favouring e^+p over e^-p

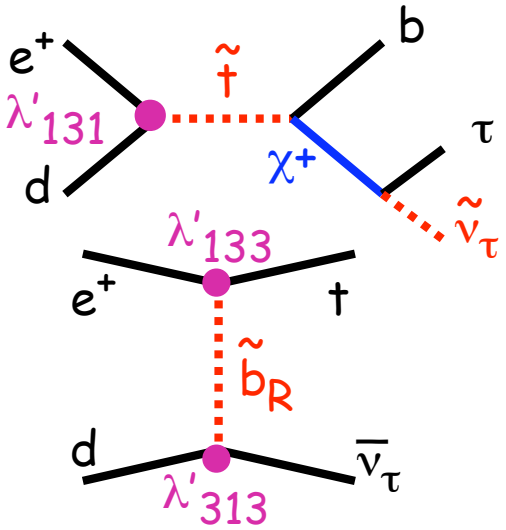
- Particle coupling to e-q with fermion number F=0 ?



Large mass i.e. large x_{Bj}

d >> $\bar{d}$, hence $\sigma(e+) >> \sigma(e-)$

- Another example : Squarks in R-parity violating SUSY ?



If LSP is $\tilde{\nu}_\tau$ and no large RpV coupling involving the τ : $\tilde{\nu}_\tau$ could be long-lived

RpV via couplings involving two 3rd generation fields, light sbottom. Large M_{top} → large x_{Bj}