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dortmund

Isolated Leptons and Single Top at HERA

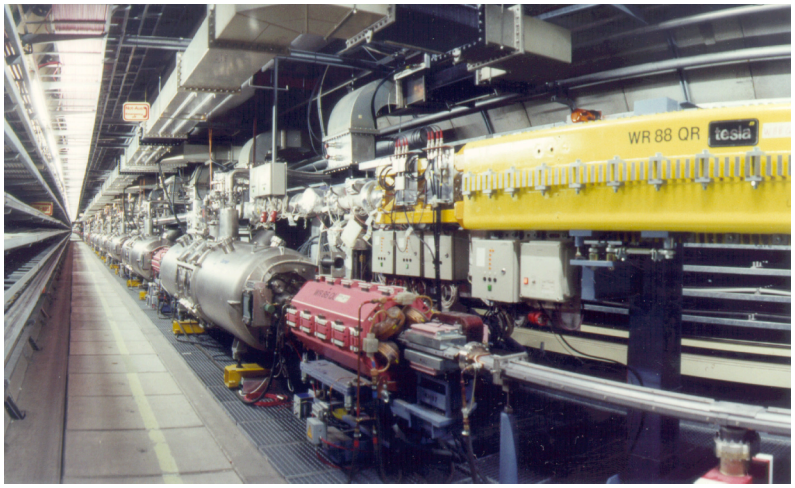
David South (Technische Universität Dortmund)

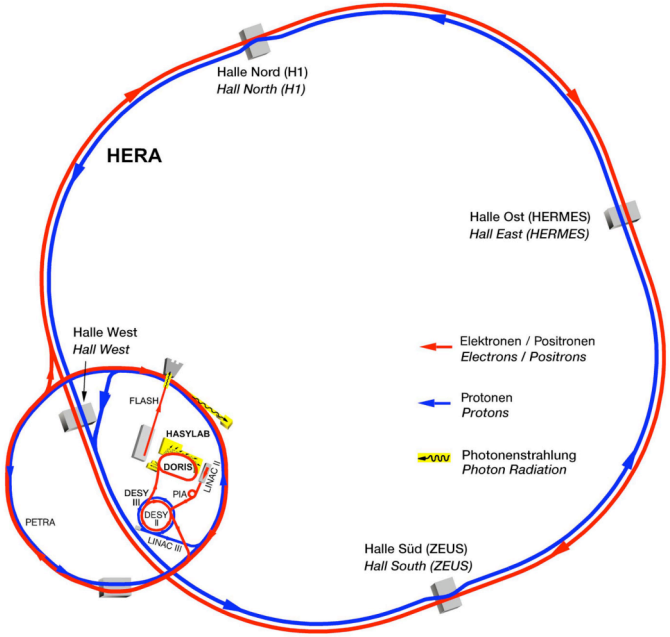
Contents

- Introduction to HERA, H1 and ZEUS
- A little early history about Isolated Leptons at HERA
- Search for Isolated Leptons and P_T^{miss} by H1 and ZEUS
- Combined H1 and ZEUS Results using full 1 fb^{-1} of data: the final word
- Searches for Single Top Production
- (A few other things along the way)
- Summary

ZEUS Isolated Leptons: Phys. Lett. **B672** (2009) 106
H1 Isolated Leptons: Eur. Phys. J. **C64** (2009) 251
H1 Single Top: Phys. Lett. **B678** (2009) 450
ZEUS Single Top: ZEUS-prel-09-009
H1+ZEUS Isolated Leptons: JHEP **03** (2010) 35

The HERA Collider

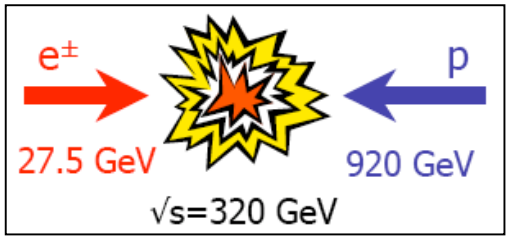




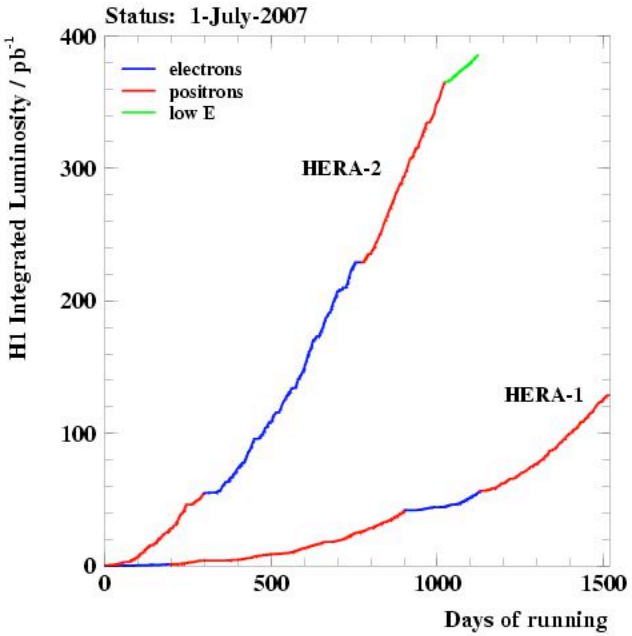
- Two counter-rotating 6.3 km long accelerators:

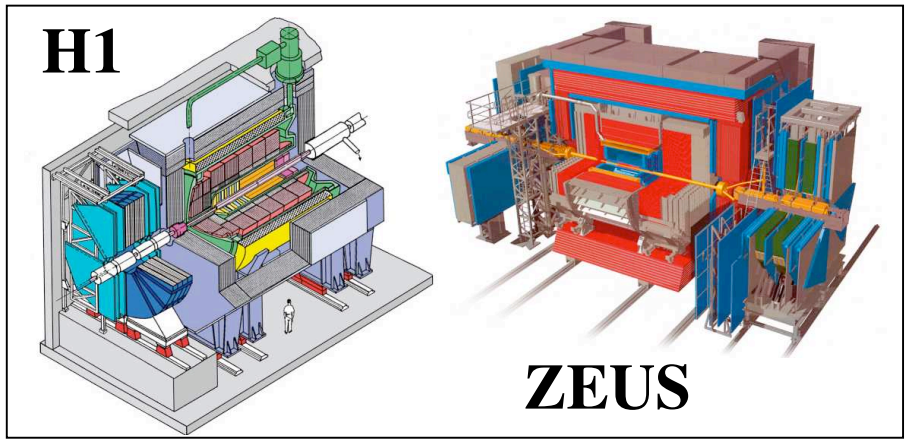
- Collisions every 96ns, √s = 320 GeV

The H1 and ZEUS Experiments at HERA



Data taking
1994 - 2007



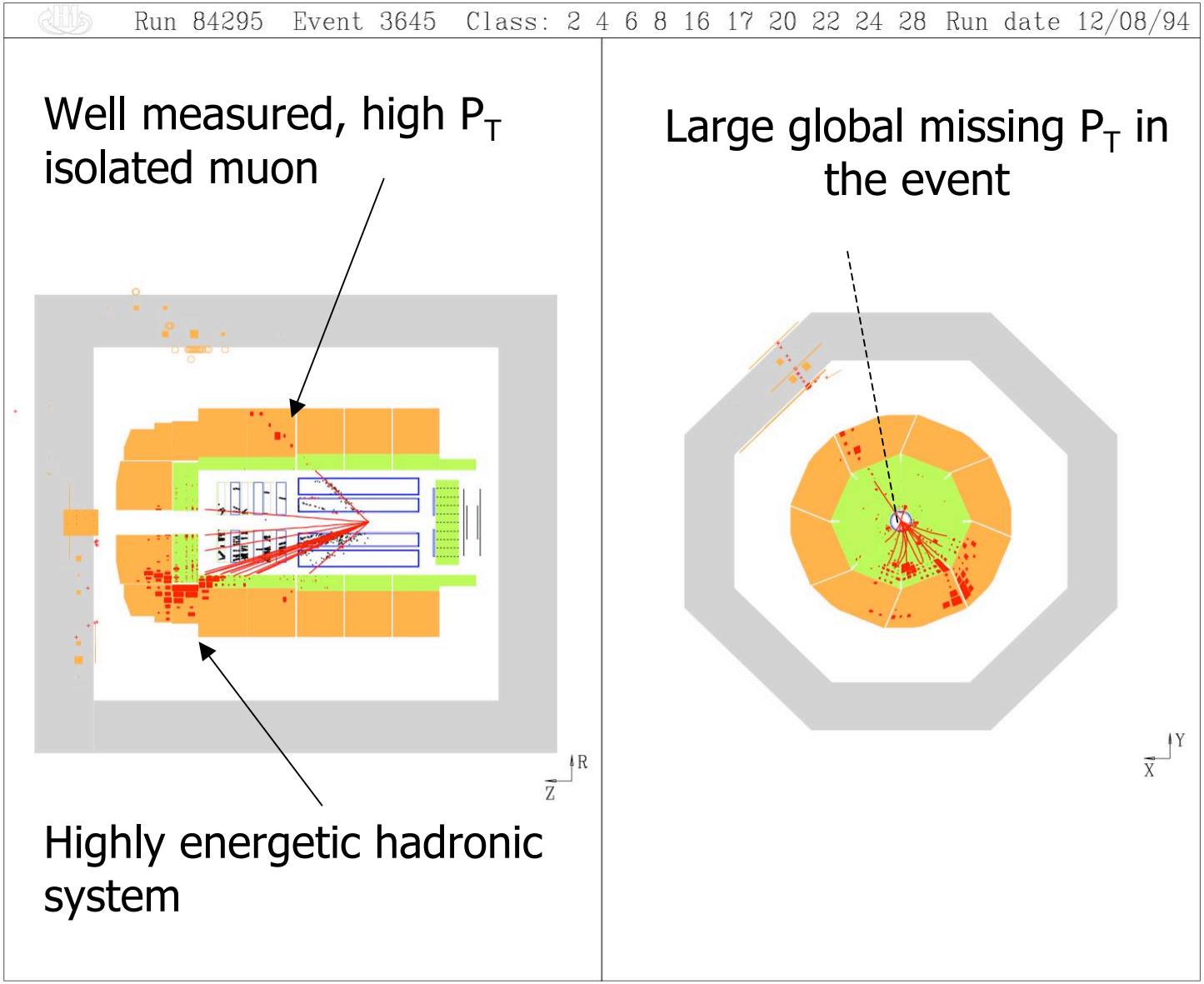


Two multi-purpose experiments
located at the ep interaction points

- Large increase in data per experiment from HERA II (x3)
- Large increase (x12) in data taken from e^-p collisions; HERA I mostly e^+p data

Final combined HERA dataset ~ 1 fb^{-1}

An Event Observed by H1 in 1994



Described in a Dedicated Paper

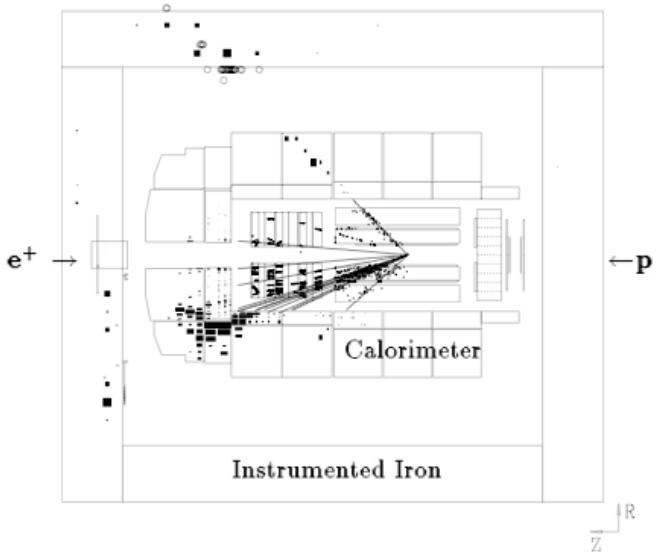
DESY 94-248
December 1994
ISSN 0418-9833

Observation of an $e^+p \to \mu^+X$ Event with High Transverse Momenta at HERA

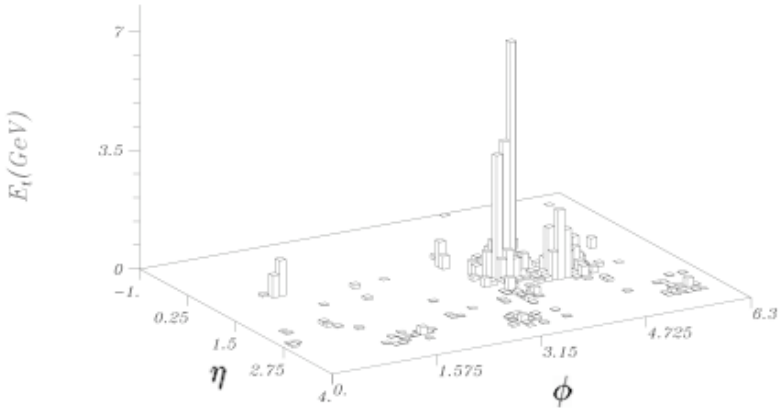
H1 Collaboration

Abstract

At the HERA electron-proton collider an event has been observed in the H1 detector which shows an isolated muon recoiling against a hadronic system, both of high transverse momentum. The event was registered in a total integrated luminosity of 4 pb^{-1}.



Analysis used the first 4 pb^{-1} of H1 data

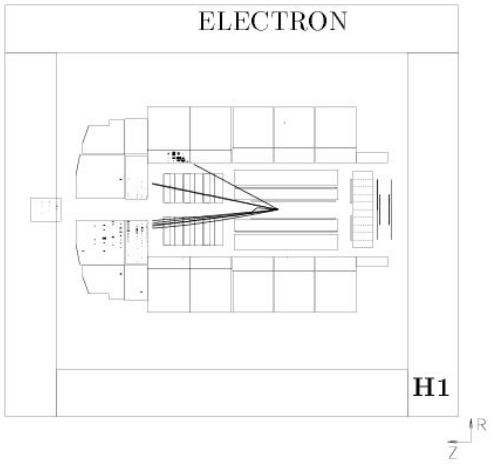


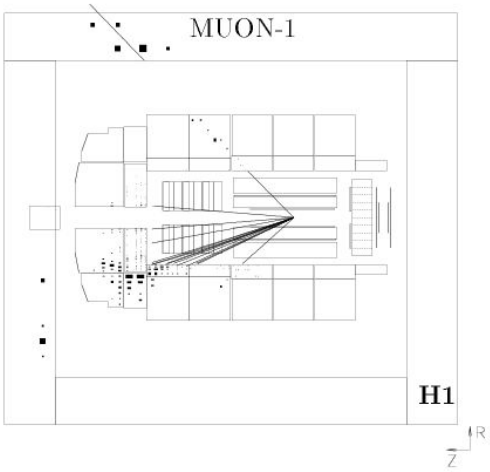
The isolated track :	
Charge	Positive
Transverse momentum	$23.4 \pm 2.4^{+7}_{-5}$ GeV
Polar angle	$46.2 \pm 1.3°$
Azimuthal angle	$57.4 \pm 0.1°$
The total hadronic system :	
Transverse momentum	42.1 ± 4.2 GeV
Average azimuthal angle	$240 \pm 1°$
Hadronic cluster 1:	
Transverse momentum	25.3 ± 3.0 GeV
Polar angle	$22.3 \pm 0.5°$
Azimuthal angle	$227 \pm 1°$
Hadronic cluster 2 :	
Transverse momentum	15.2 ± 1.9 GeV
Polar angle	$16.5 \pm 0.5°$
Azimuthal angle	$270 \pm 1°$
Global event properties :	
Missing transverse momentum	$18.7 \pm 4.8^{+5}_{-7}$ GeV
$\delta = \sum E(1 - \cos\theta)$	$19.2 \pm 1.6^{+3.0}_{-2.1}$ GeV
$\Delta\phi$ muon-hadronic system	$183 \pm 1°$

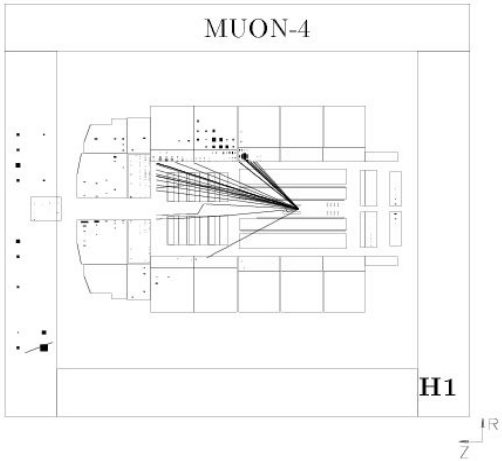
Including some possible Interpretations

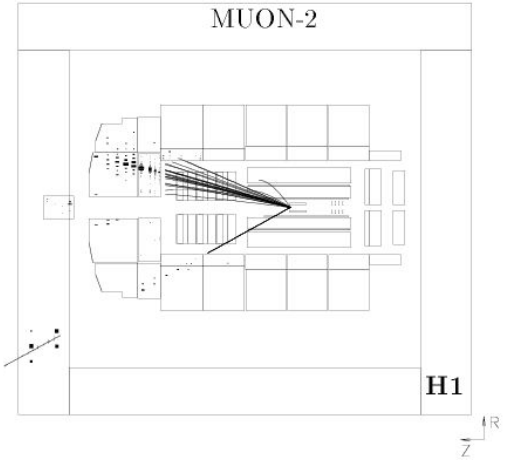
- Production of two high P_T jets, where one jet contains a single particle (a pion) which fakes the muon signature
  - Interpretation unlikely, probability calculated to be less than 0.001
- A flavour changing NC process $e^+ + p \rightarrow \mu^+ + X$, topologically identical to the production of a leptoquark
  - Large missing momentum makes this unlikely
- A background event due to (e.g.) a halo muon
  - The E_T in the event is too large, also ruled out (the muon also points to the vertex..)
- *Production of W bosons with leptonic decay*
  - OK, maybe, but the hadronic jet should have low P_T..

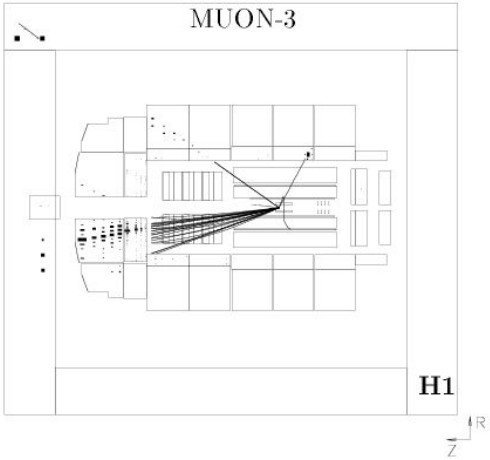
1998: Now 37 pb^{-1} of H1 e^+p data

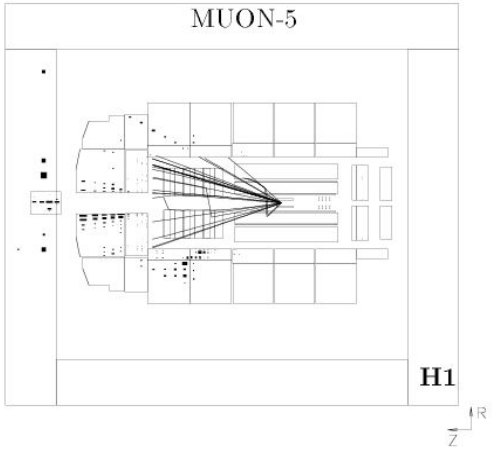






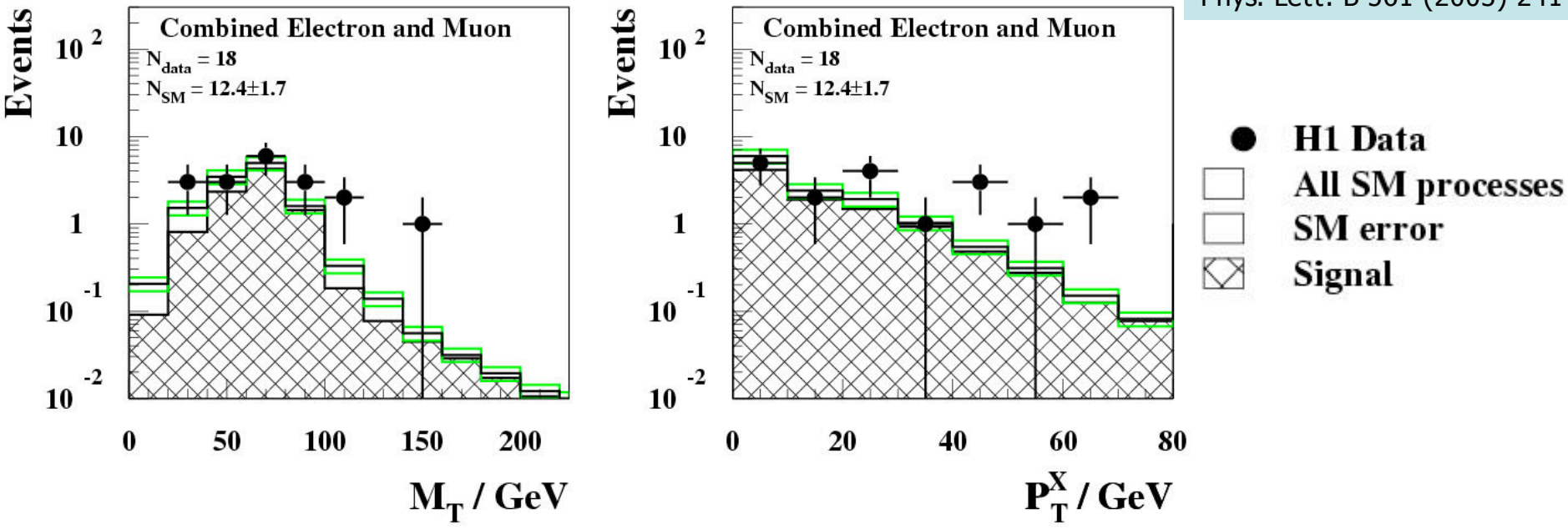






Results from H1 HERA I e^+p Data: 106 pb^{-1}

Phys. Lett. B 561 (2003) 241



- Significant excess observed by H1 at large hadronic momentum $P_T^X > 25$ GeV

H1 e^+p data HERA I (106 pb^{-1})	e channel obs. / exp.	μ channel obs. / exp.	e and μ channels obs. / exp.
Full sample	10 / 9.9 ± 1.3	8 / 2.6 ± 0.4	18 / 12.4 ± 1.7
$P_T^X > 25$ GeV	4 / 1.5 ± 0.3	6 / 1.4 ± 0.3	10 / 2.9 ± 0.5

3.0σ excess

- *Result not confirmed by ZEUS HERA I analysis (in a more limited phase space)*

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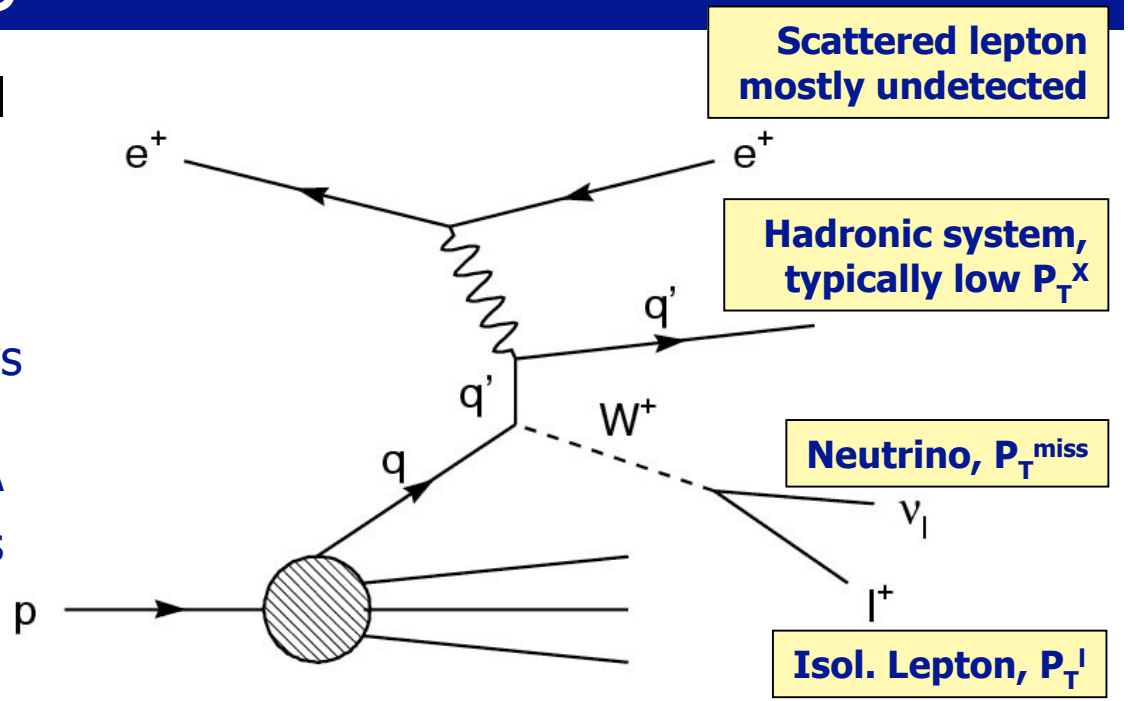
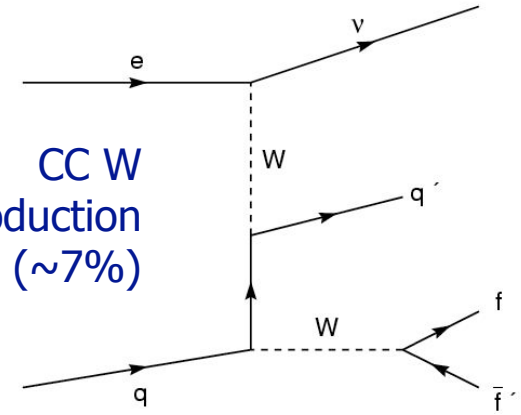
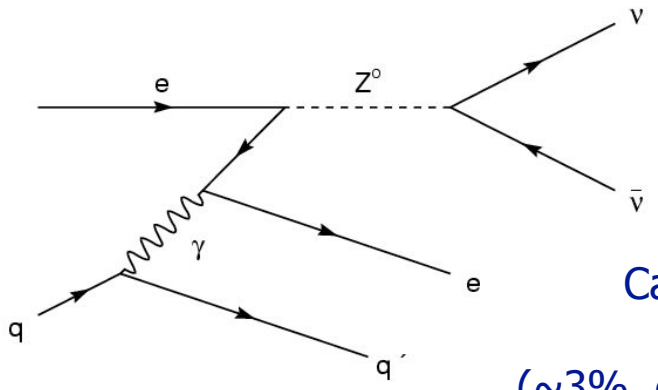
SM Signal Processes

- Main SM contribution to signal from *real W production* with subsequent decay to leptons
  - Total cross section of order 1.3 pb, with 10% of W decays to each lepton flavour: very few events expected at HERA
  - Hadronic system typically has ***low*** transverse momentum



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

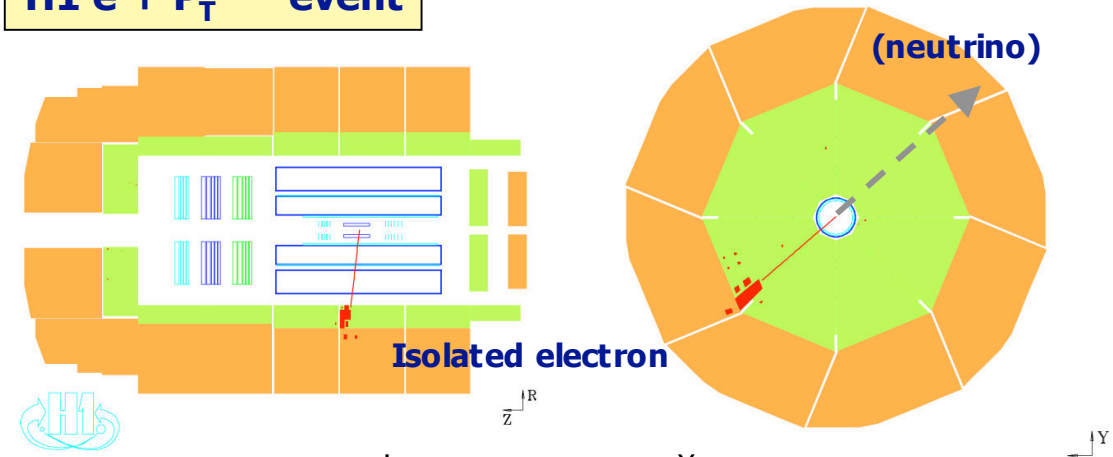




Cabibbo-Parisi Z^0 production (~3%, e channel only)

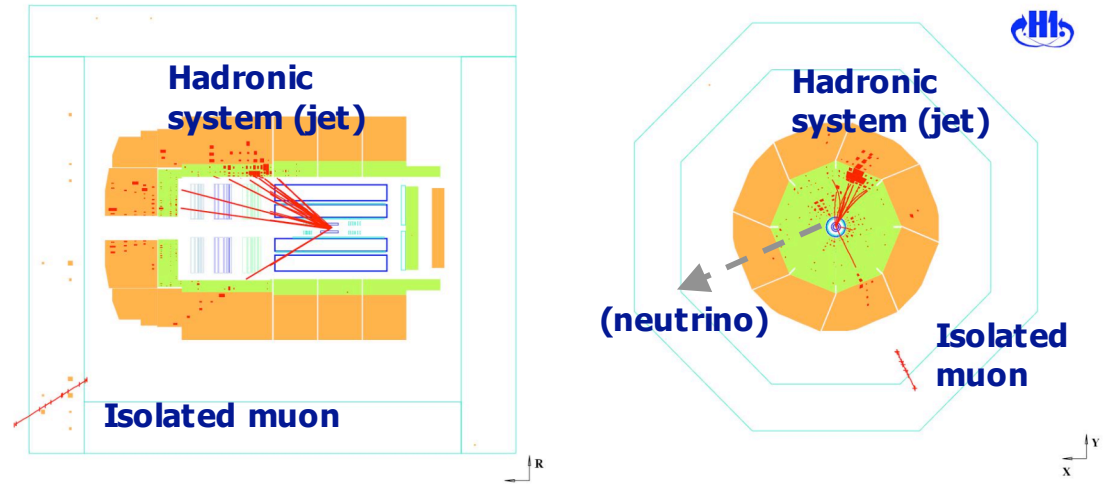
Signal Event Characteristics

H1 e + P_T^{miss} event



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

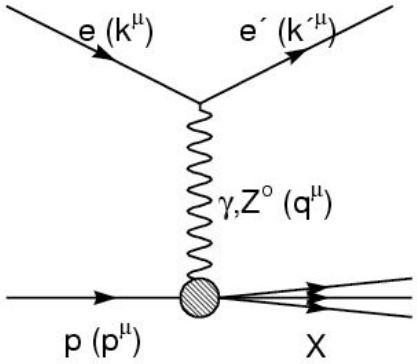
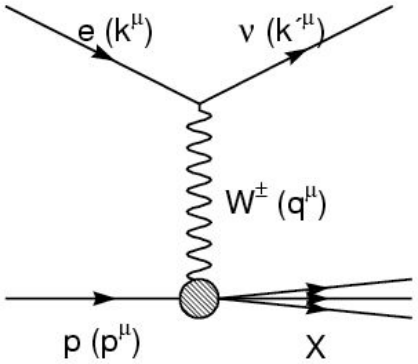
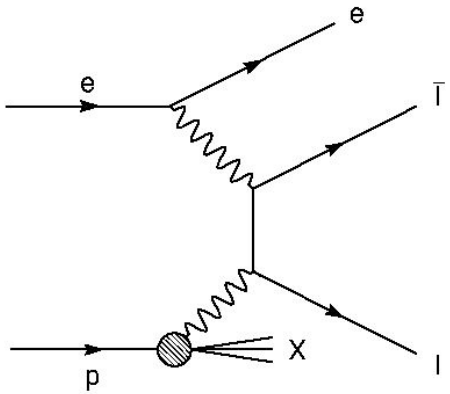
H1 μ + P_T^{miss} event



P_T^μ = 51 GeV, P_T^{miss} = 39 GeV, P_T^X = 48 GeV

- Electron or muon with high transverse momentum, isolated from other parts of the event
  - *H1:* $5^o < \theta_l < 140^o$
  - *ZEUS:* $15^o < \theta_l < 120^o$
  - $P_T^l > 10$ GeV
  - $D_{l\text{-jet}} > 1.0$, $D_{l\text{-track}} > 0.5$
- Large missing global transverse momentum
  - $P_T^{miss} > 12$ GeV
- Sometimes with a hadronic system, sometimes at large transverse momentum

Standard Model Background

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

- Further topological cuts are applied to reduce SM background
  - Acoplanarity, longitudinal and transverse balance of the event
- Dedicated control samples used in both the H1 and ZEUS analyses to estimate the uncertainties on these processes in the analysis phase space
  - Control samples formed by removing cuts from final sample

H1+ZEUS Isolated Lepton Event Selection

	Variable	Electron	Muon
	θ_l	$15^o < \theta_l < 120^o$	
	P_T^l	> 10 GeV	
	P_T^{calo}	> 12 GeV	
*	M_T	> 10 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 < δ_{miss} < 50 GeV	
	# isolated μ	0	1
*	# electrons	< 3	-

Major difference between H1 and ZEUS: H1 nominal analysis: $5^o < \theta_l < 140^o$

Analysis phase space selection

Isolation of lepton

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

** Other small differences between H1 and ZEUS analyses*

Electron and muon channels are exclusive and can therefore be combined

H1 Analysis with full $e^{\pm}p$ Data, 474 pb^{-1}

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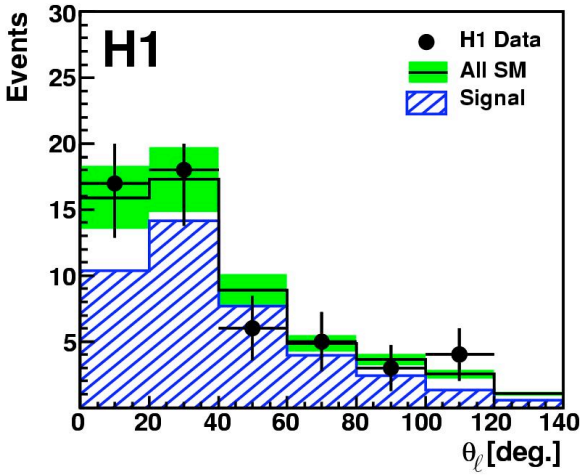

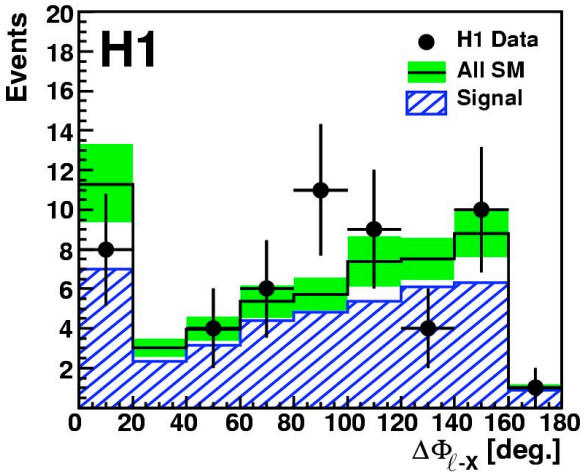

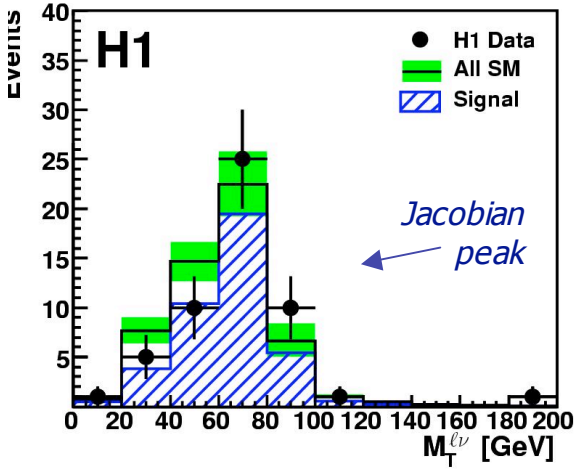

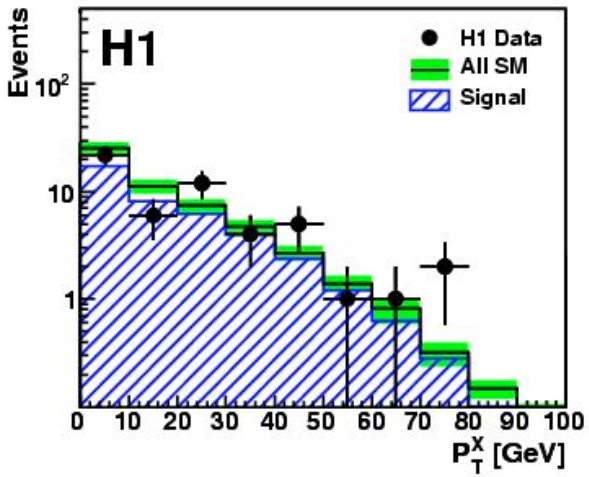

H1	1994-2007 $e^{\pm}p$ 474 pb^{-1}	Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	39	43.1 ± 6.0	30.3 ± 4.8	12.9 ± 3.4
	$P_T^X > 25$ GeV	10	7.5 ± 1.3	5.79 ± 0.99	1.71 ± 0.71
Muon	Total	14	11.0 ± 1.8	10.1 ± 1.7	0.88 ± 0.29
	$P_T^X > 25$ GeV	8	6.1 ± 1.0	5.64 ± 0.99	0.47 ± 0.15
Combined	Total	53	54.1 ± 7.4	40.4 ± 6.3	13.7 ± 3.5
	$P_T^X > 25$ GeV	18	13.6 ± 2.2	11.4 ± 1.9	2.18 ± 0.80

Good overall agreement with the Standard Model: W Production

H1 Analysis with full e^+p Data 291 pb^{-1}

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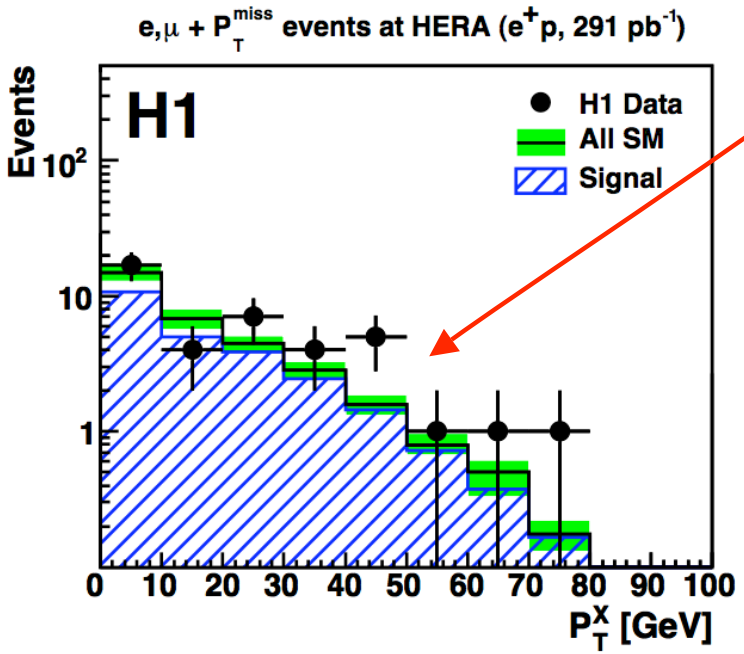
H1	1994-2007 e^+p 291 pb^{-1}	Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	28	25.6 ± 3.5	18.6 ± 2.9	6.9 ± 1.7
	$P_T^X > 25$ GeV	9	4.32 ± 0.71	3.56 ± 0.61	0.76 ± 0.32
Muon	Total	12	6.7 ± 1.1	6.2 ± 1.0	0.55 ± 0.18
	$P_T^X > 25$ GeV	8	3.70 ± 0.63	3.42 ± 0.60	0.28 ± 0.09
Combined	Total	40	32.3 ± 4.4	24.8 ± 3.9	7.5 ± 1.8
	$P_T^X > 25$ GeV	17	8.0 ± 1.3	7.0 ± 1.2	1.04 ± 0.37

- Excess of data events H1 analysis at large P_T^X persists
  - Significance less than in HERA I data alone
  - Also still not confirmed in the ZEUS analysis



ZEUS Analysis with full $e^{\pm}p$ Data, 504 pb^{-1}

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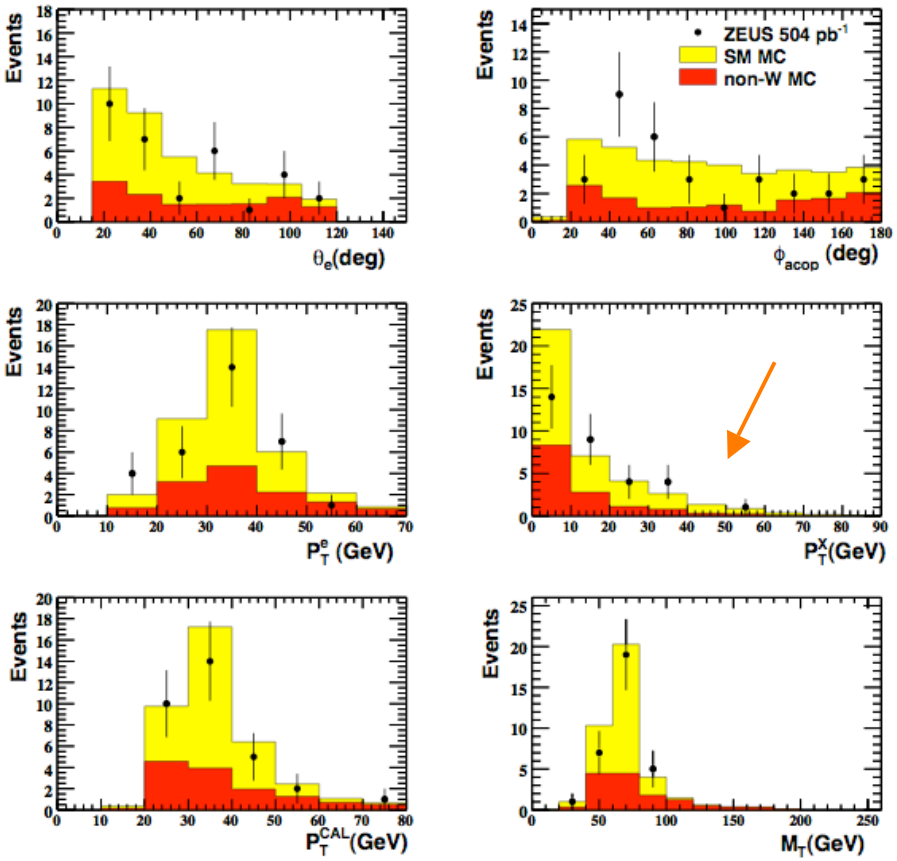
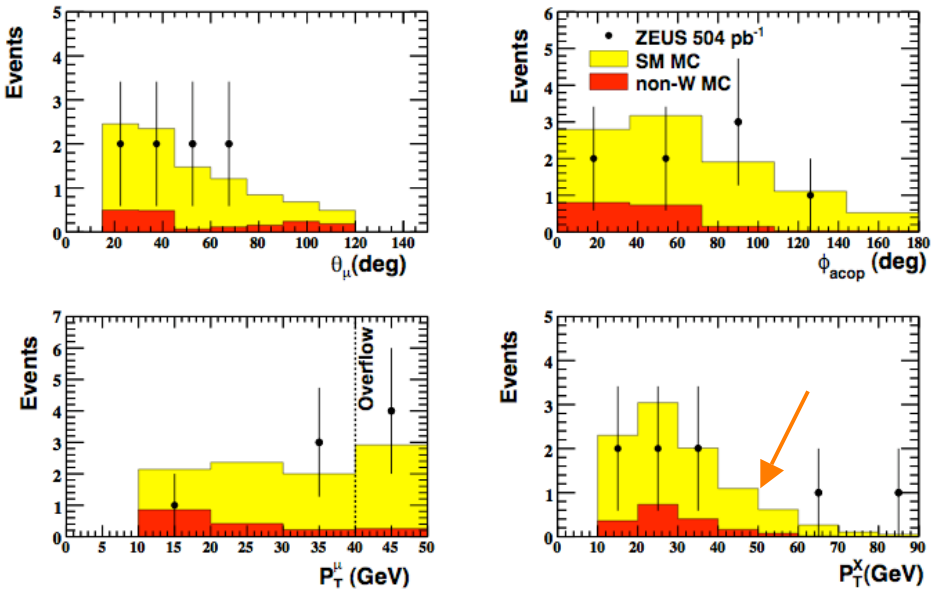
electron channel

muon channel



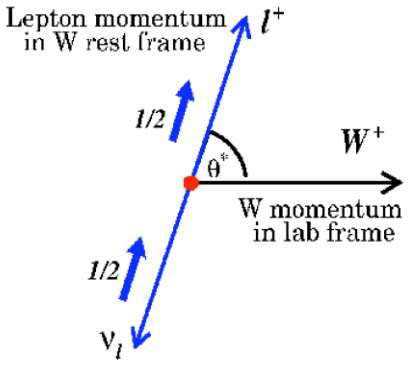


Isolated Lepton Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb^{-1}	$9/11.3 \pm 1.5$ (54%)	$6/5.1 \pm 0.7$ (67%)	$5/5.5 \pm 0.8$ (75%)
e^+p 296 pb^{-1}	$7/12.6 \pm 1.7$ (68%)	$7/6.2 \pm 0.9$ (75%)	$6/7.4 \pm 1.0$ (79%)
$e^{\pm}p$ 504 pb^{-1}	$16/23.9 \pm 3.1$ (61%)	$13/11.2 \pm 1.5$ (71%)	$11/12.9 \pm 1.7$ (77%)

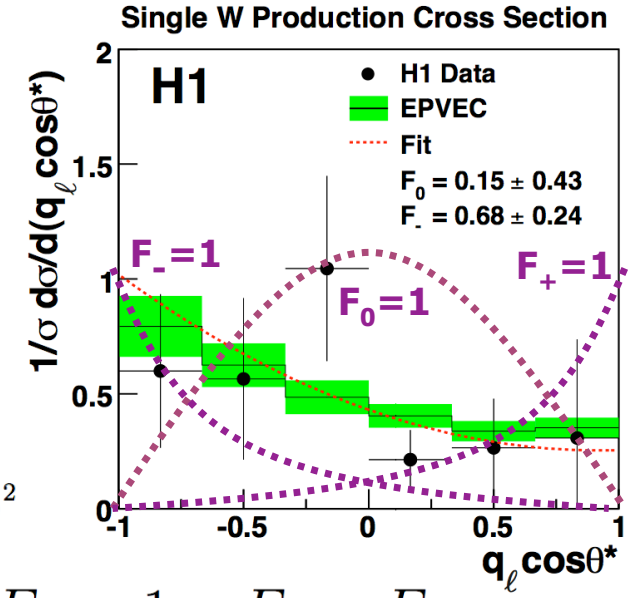
Total ZEUS rates	
e^-p (208 pb^{-1})	20 / 21.8 ± 2.7
e^+p (296 pb^{-1})	20 / 26.2 ± 3.2
$e^{\pm}p$ (504 pb^{-1})	40 / 48.0 ± 5.9

Good agreement with the Standard Model, no excess at high P_T^X

H1 Measurement of W Polarisation Fractions

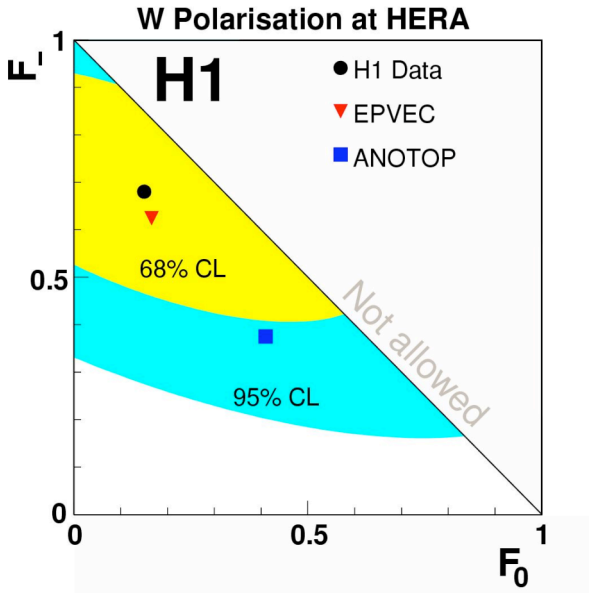


- Cross section can be expressed in terms of W polarisation fractions: *sensitive to angular properties of the decay*
- Measure cross section as a function of cos θ^*



$$\frac{1}{\sigma_{W\to\ell+\nu}}\frac{d\sigma_{W\to\ell+\nu}}{d\cos\theta^*} = \frac{3}{4}F_0\left(1-\cos^2\theta^*\right) + \frac{3}{8}F_-\left(1-\cos\theta^*\right)^2 + \frac{3}{8}F_+\left(1+\cos\theta^*\right)^2$$

$$F_+ \equiv 1 - F_- - F_0$$



- F_0 and F_- simultaneously extracted in a fit
- Measure for single W Production, and test with anomalous top production model
  - May be different for SM and BSM contributions
- Difference demonstrated, but sensitivity only at the 1 sigma level

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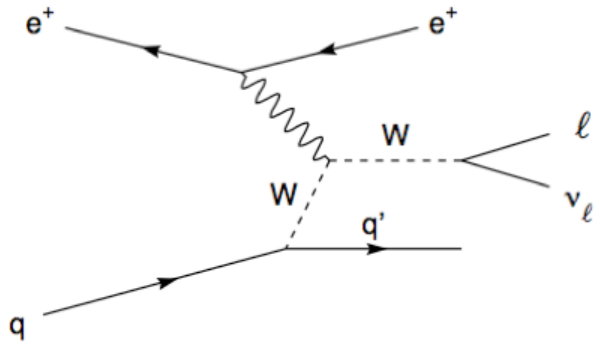
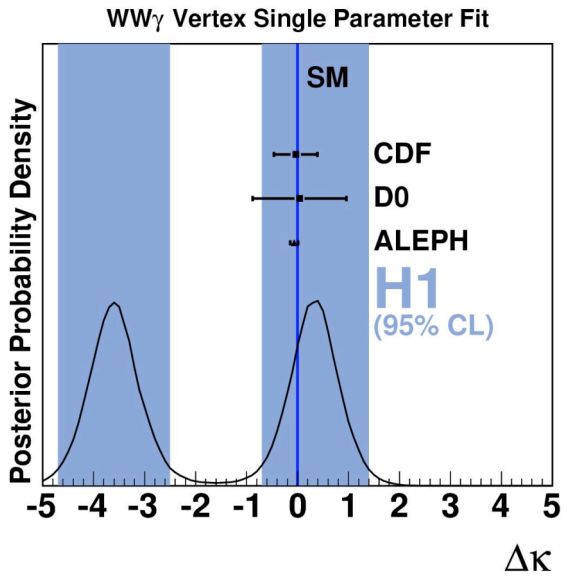
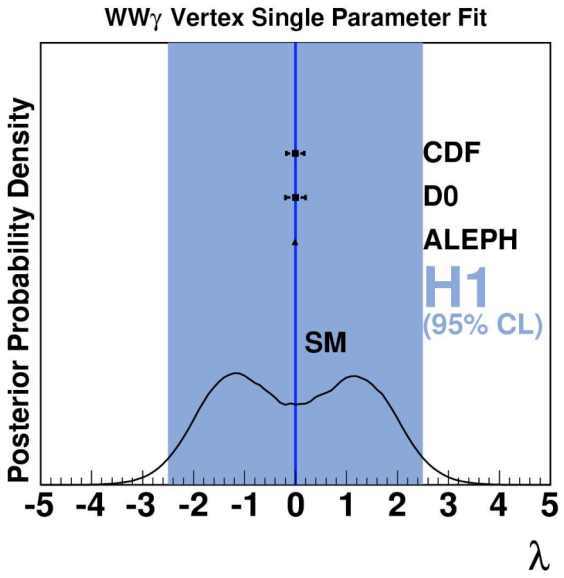
H1 Limits on WWγ Coupling Parameters



- Production of W Bosons is sensitive to triple gauge couplings
- Attempt to provide complementary information to LEP, Tevatron on the WWγ vertex coupling parameters $\Delta\kappa$, λ using maximum likelihood analysis
- H1 measurements compatible to W production at other colliders





$-4.7 < \Delta\kappa < -2.5 \quad \text{or} \quad -0.7 < \Delta\kappa < 1.4$

$-2.5 < \lambda < 2.5$

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A Combined H1 and ZEUS Analysis

- The SM expectation for signal events at HERA is low, so the analysis benefits from the combination of the full 1 fb^{-1} of H1 and ZEUS data in a common phase space
  - Cross sections measured with better statistical precision
  - Increase sensitivity to possible new phenomena

- The individual analyses are similar in their selections due to initial comparison work
  - Combined selection very close to the nominal ZEUS analysis selection
  - Limited polar angle range of ZEUS analysis is main change to H1

- Common phase space was studied individually in H1 and ZEUS
  - Excellent agreement found between signal rates and acceptances
  - Some background still higher in ZEUS analysis, within reasonable level of agreement

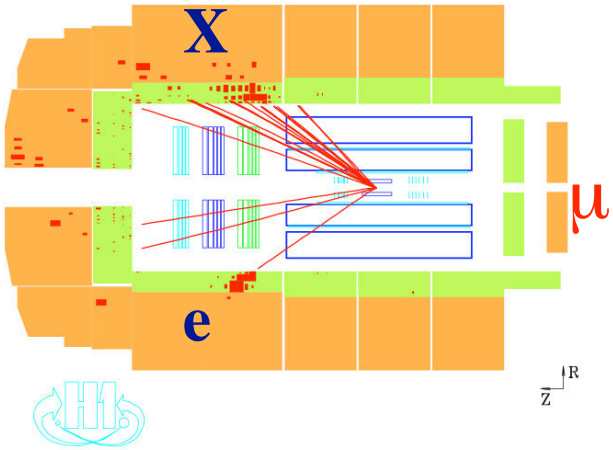
- H1, ZEUS SM signal contributions added together with 15% correlated systematic
- All others errors treated uncorrelated and use individual (level of agreement) errors

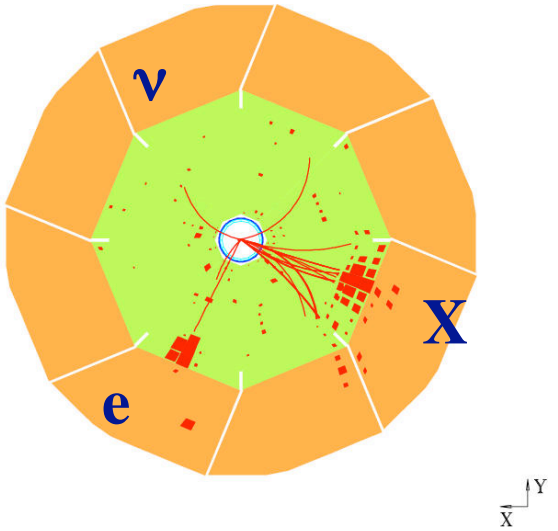
- Effect of common phase space on data events:
  - 11/53 H1 events not in common phase space (mainly due to polar angle)
  - 1/40 ZEUS events not in common phase space (low transverse mass)

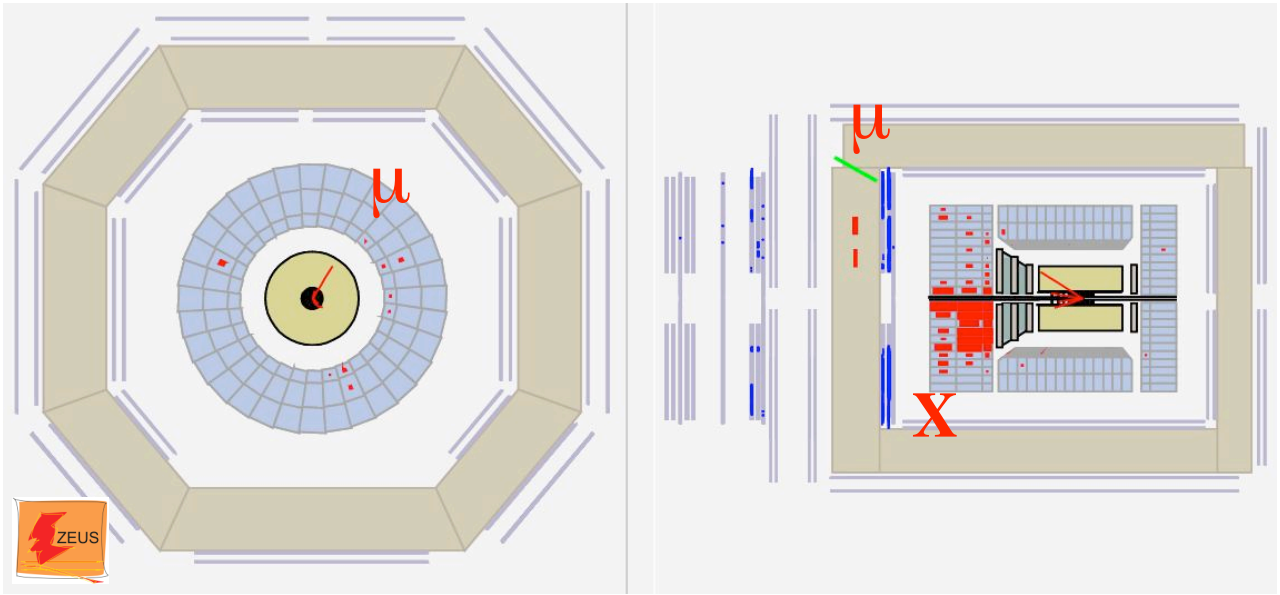
More Selected Events

High P_T^X e + P_T^{miss} event in H1 e^+p data

P_T^e = 37 GeV
P_T^{Miss} = 44 GeV
P_T^X = 29 GeV







High P_T^X μ + P_T^{miss} event in ZEUS e^-p data

θ^μ = 32°
$M_T^{\mu\nu}$ = 79 GeV
P_T^X = 82 GeV

H1+ZEUS Isolated Leptons: Results

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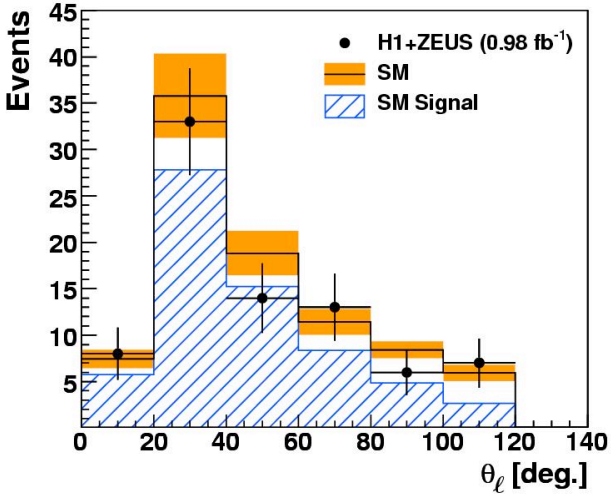
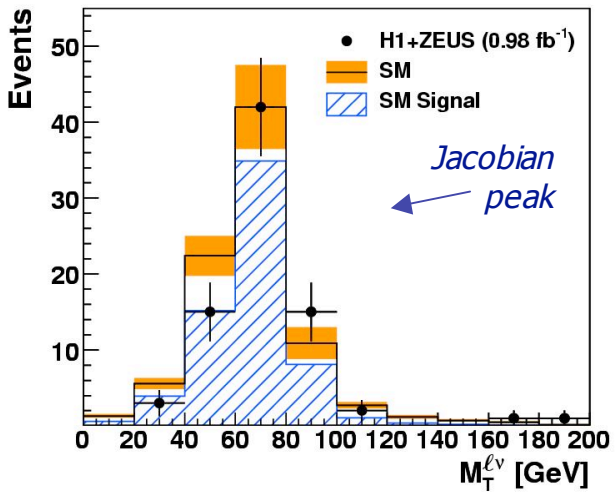
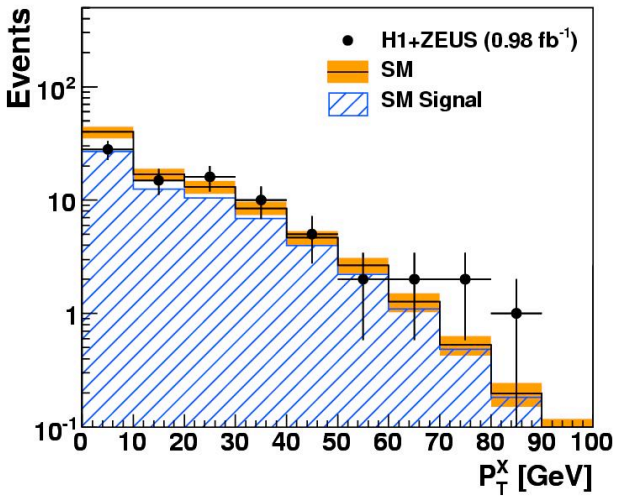




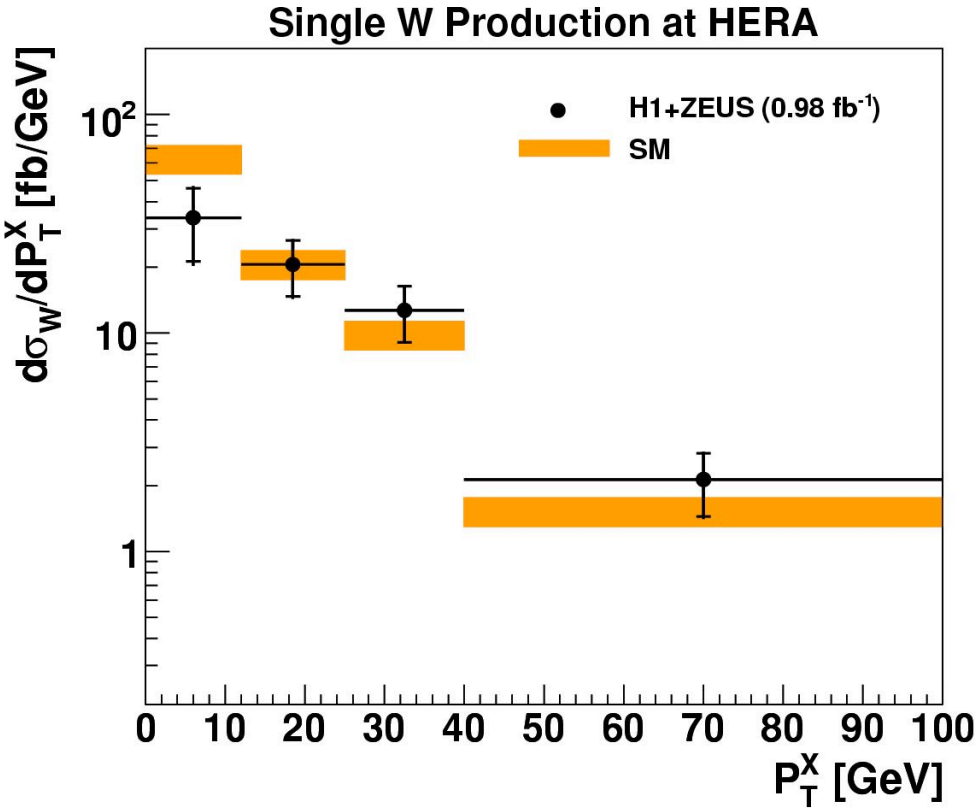


H1+ZEUS 1994–2007 $e^{\pm}p$ 0.98 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	61	69.2 ± 8.2	48.3 ± 7.4	20.9 ± 3.2
	$P_T^X > 25$ GeV	16	13.0 ± 1.7	10.0 ± 1.6	3.1 ± 0.7
Muon	Total	20	18.6 ± 2.7	16.4 ± 2.6	2.2 ± 0.5
	$P_T^X > 25$ GeV	13	11.0 ± 1.6	9.8 ± 1.6	1.2 ± 0.3
Combined	Total	81	87.8 ± 11.0	64.7 ± 9.9	23.1 ± 3.3
	$P_T^X > 25$ GeV	29	24.0 ± 3.2	19.7 ± 3.1	4.3 ± 0.8

SM expectation dominated W production
→ *Cross section*

Good overall agreement with the Standard Model

Single W Production Cross Section



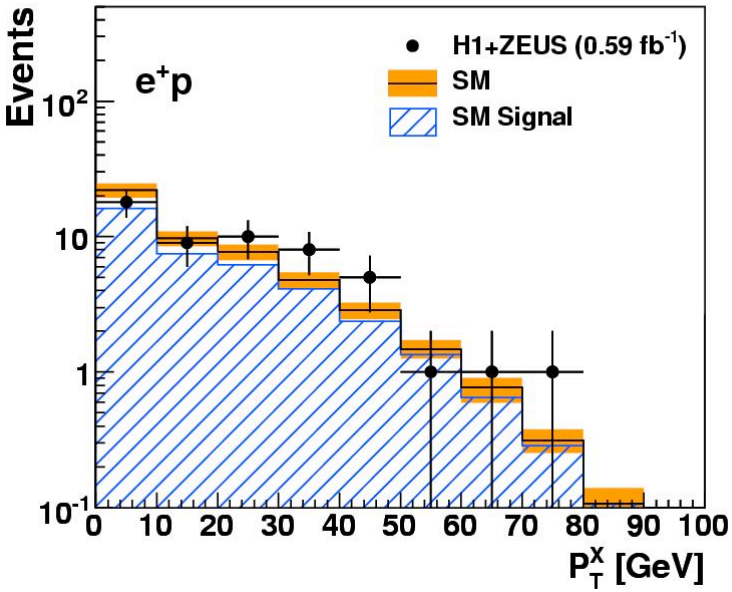
- Inclusive single W cross section measured 1.06 ±0.16 (stat.) ± 0.07 (sys.) pb in good agreement with the SM prediction of 1.26 ± 0.19 pb from EPVEC at NLO
- Good agreement also with the individual cross section measurements by H1 and ZEUS

H1: 1.14 ±0.25 (stat.) ± 0.14 (sys.) pb

ZEUS: $0.89\ ^{+0.25}_{-0.22}$ (stat.) ± 0.10 (sys.) pb

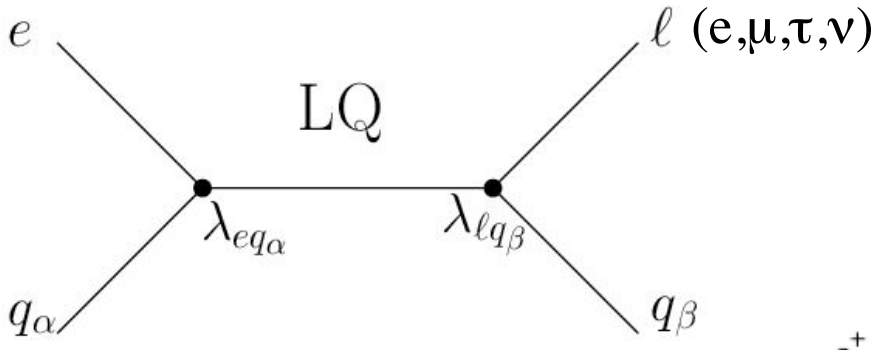
H1+ZEUS Isolated Leptons: Positron Data

H1+ZEUS 1994–2007 e^+p 0.59 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	37	38.6 ± 4.7	28.9 ± 4.4	9.7 ± 1.4
	$P_T^X > 25$ GeV	12	7.4 ± 1.0	6.0 ± 0.9	1.5 ± 0.3
Muon	Total	16	11.2 ± 1.6	9.9 ± 1.6	1.3 ± 0.3
	$P_T^X > 25$ GeV	11	6.6 ± 1.0	5.9 ± 0.9	0.8 ± 0.2
Combined	Total	53	49.8 ± 6.2	38.8 ± 5.9	11.1 ± 1.5
	$P_T^X > 25$ GeV	23	14.0 ± 1.9	11.8 ± 1.9	2.2 ± 0.4

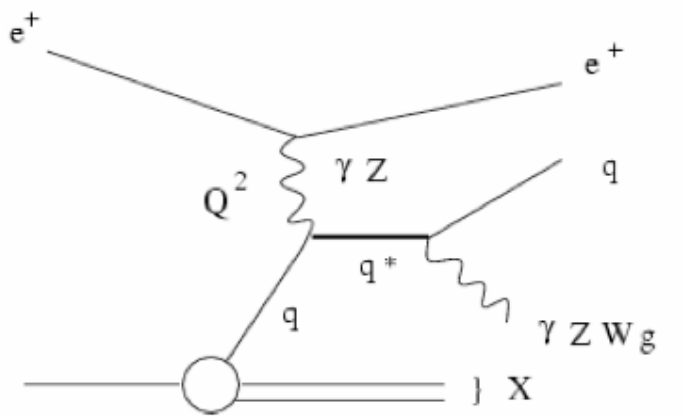


- Excess at large P_T^X in the e^+p data remains in the common phase space of the combined analysis but is less significant, around 1.9σ
  - Still driven by the H1 data

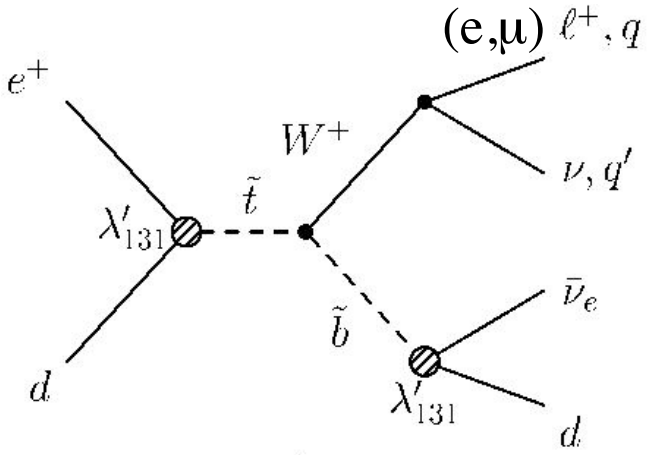
What could the high P_T^X events be?



Leptoquarks ?



Excited Fermions ?

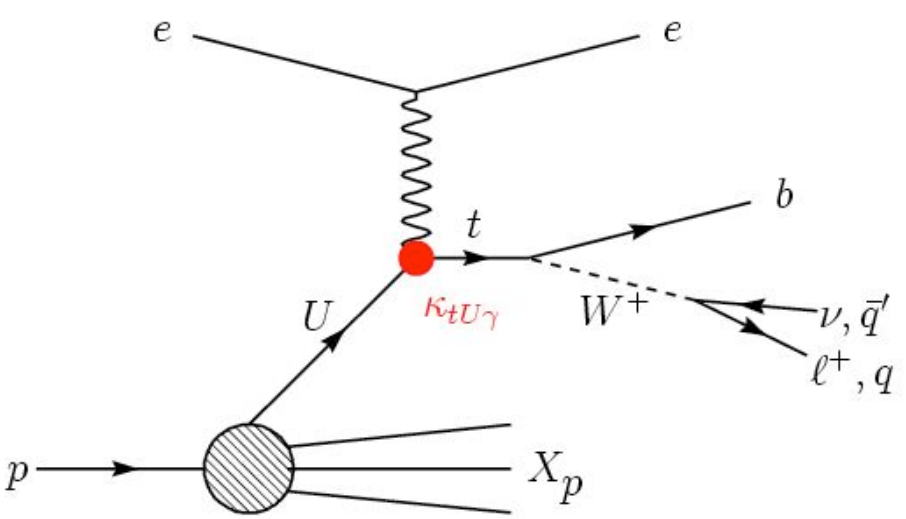


Bosonic Stop Production ?

Ruled out in dedicated analyses…

What about Single Top Production?

- Excess of observed events at high P_T^X unlikely to be due to W production (typically low P_T^X)
  - 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 the e^+p and e^-p datasets..

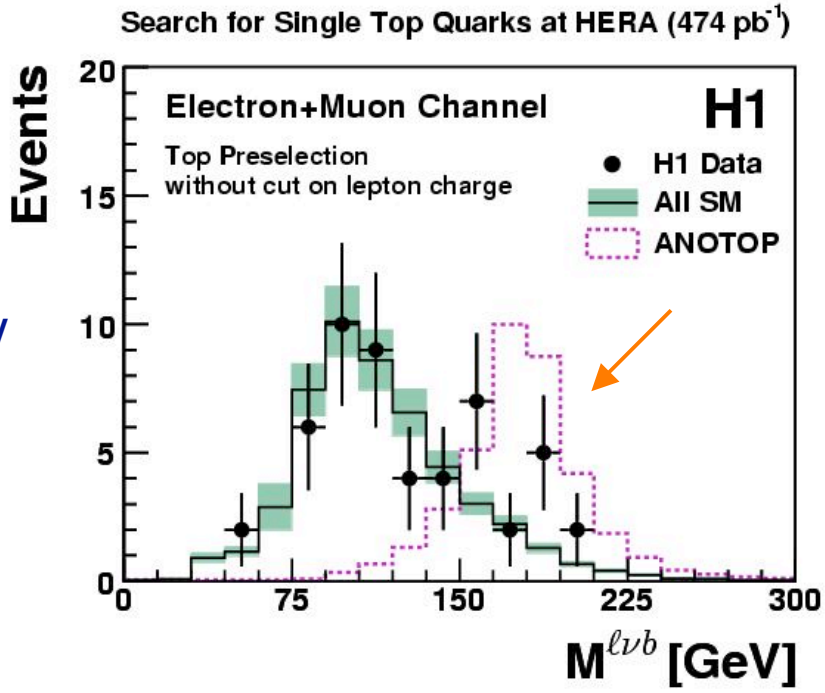


$\kappa_{tu\gamma}$: Anomalous γ magnetic coupling

H1 Single Top Analysis

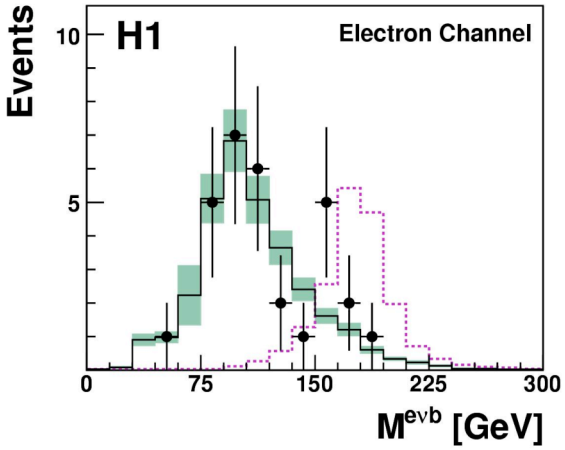
Phys. Lett. B678 (2009) 450

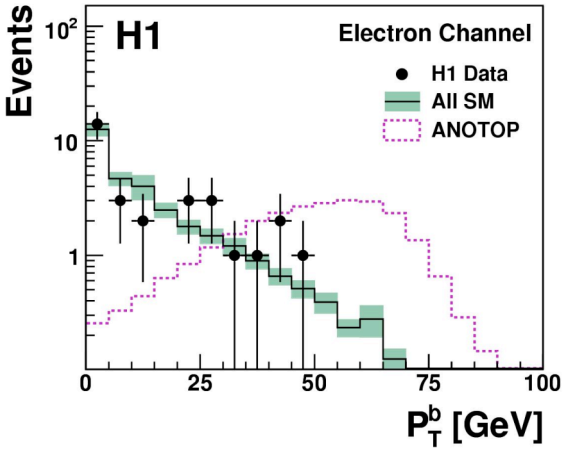
- Leptonic channels:
  - Top pre-selection is subset of the isolated lepton selection
  - Add good neutrino reconstruction
  - Require positively charged lepton
- Hadronic channel:
  - 3 jet selection $P_T^{jet1,2,3} > 40, 30, 15$ GeV
  - Pair of jets with $65 < M^{i,j} < 95$ GeV
- Multivariate discriminator then used to separate signal (Single Top) and background (W production)
  - Used as input: P_T^b , $M^{l\nu b\ (jets)}$ and $\theta_W{}^{l\ (q)}$
  - Cut-based analysis used as cross check

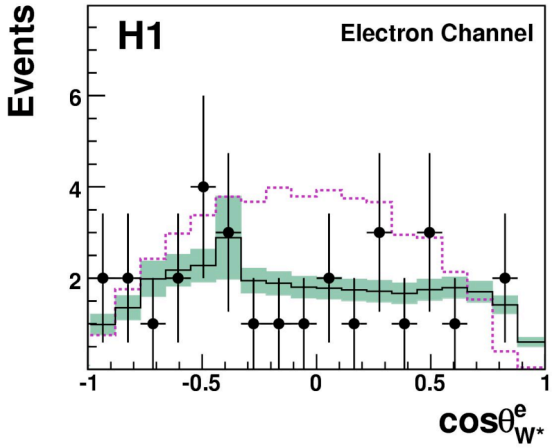


H1 Single Top Analysis: Discriminator Output

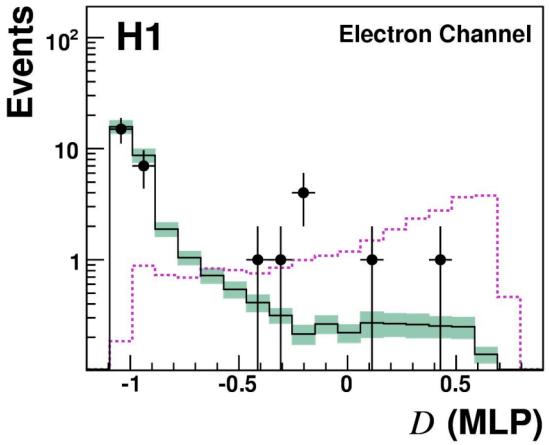
Discriminator input variables (electron channel):

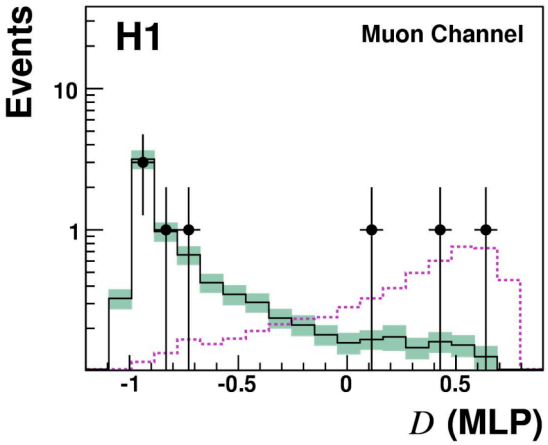


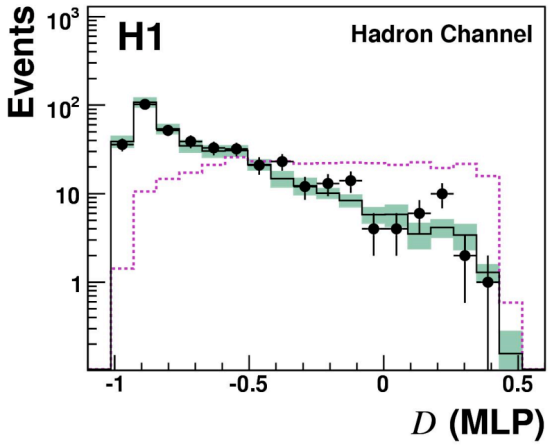




Discriminator output (separation) of all three channels:





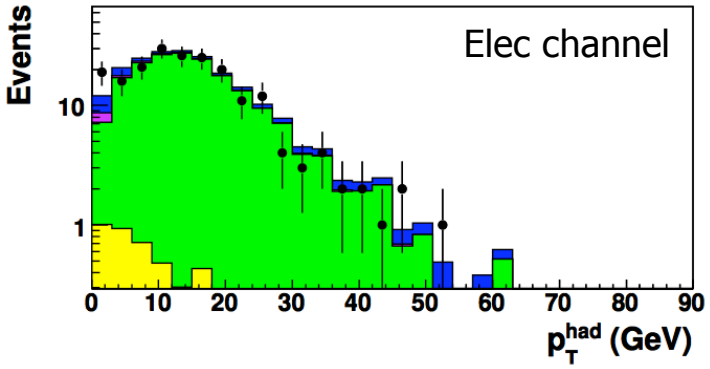


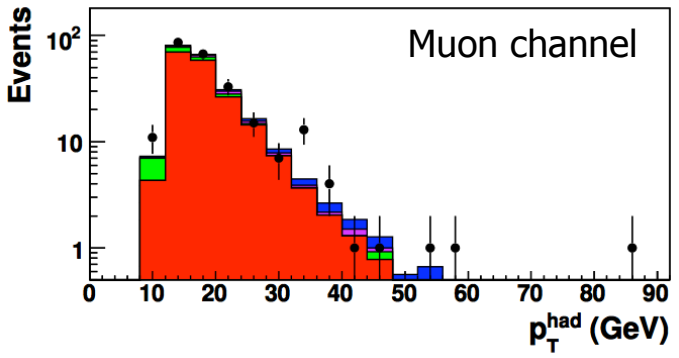
No significant deviation from the SM →*Derive limit.*.

ZEUS Single Top Analysis

ZEUS-prel-09-009

- Investigate leptonic channels in a dedicated analysis
  - Similar to ZEUS isolated lepton selection, but optimised for single top

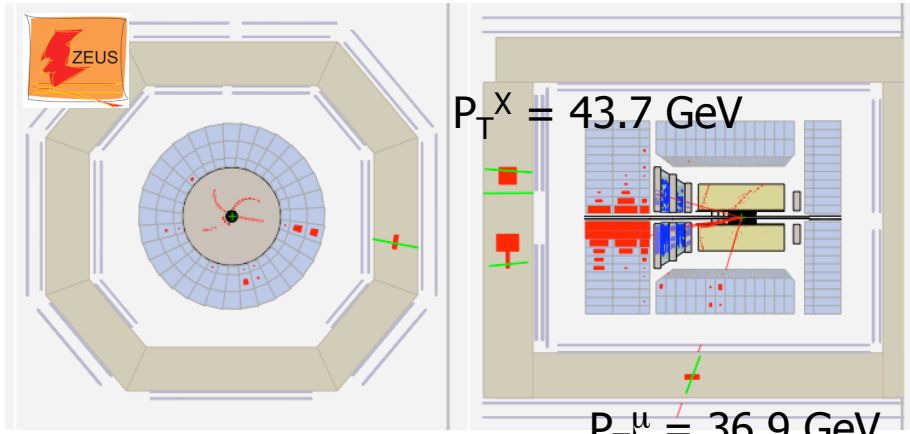




- No large deviation at high P_T^X, further topological cuts added to remove SM background (acoplanarity, missing transverse momentum)
- No significant deviation from the SM observed, two high P_T data events in the muon channel →*Limit*

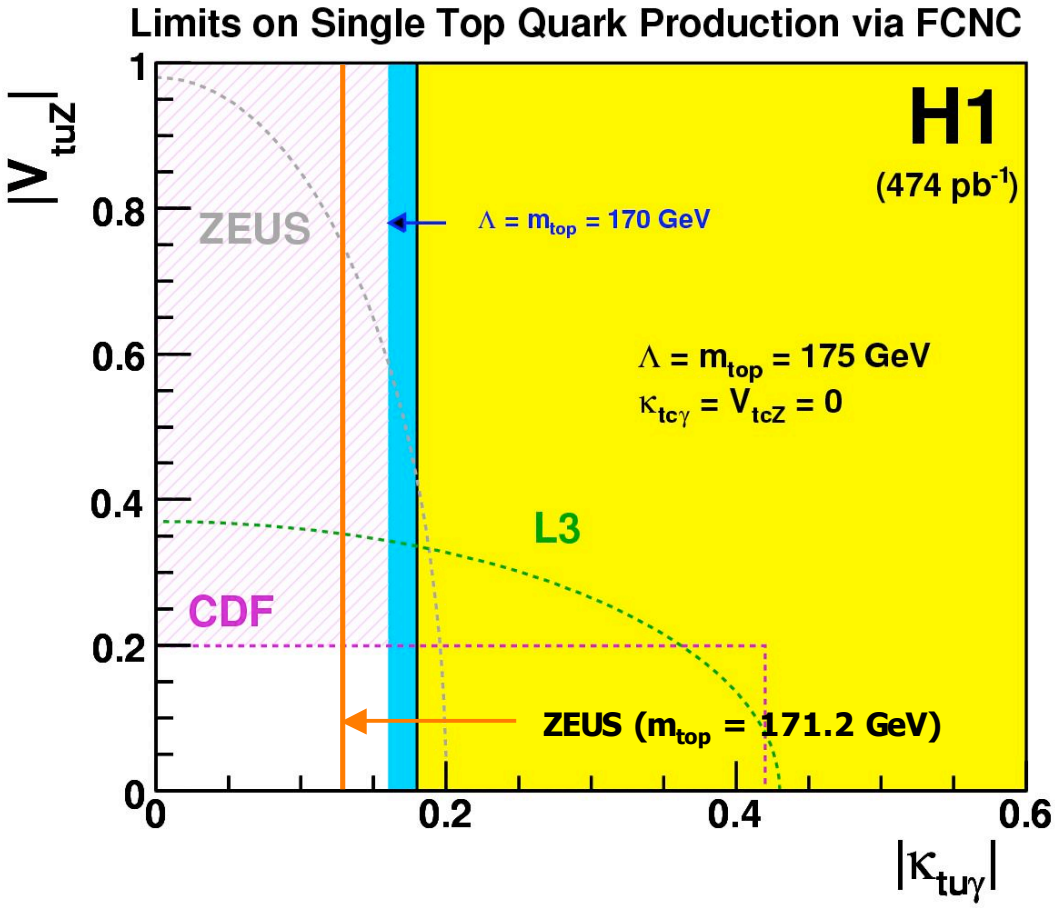
Single Top Selection

	N_{obs}	N_{pred}	W%	Efficiency
Electron Channel 04-05 e-p	0	2.1±0.6	38	0.033
Muon Channel 04-05 e-p	1	1.5±0.4	47	0.026
Electron Channel 06-07 e+p	0	0.9 ±0.3	78	0.033
Muon Channel 06-07 e+p	1	1.4±0.4	50	0.026



Limits on FCNC Single Top Cross Section

- Upper bounds at 95% CL:
  - H1: $\sigma(ep \to etX) < 0.25$ pb
  - ZEUS: $\sigma(ep \to etX) < 0.13$ pb
- Upper bounds on the anomalous coupling
  - H1: $\kappa_{tu\gamma} < 0.18$
  - ZEUS: $\kappa_{tu\gamma} < 0.13$



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

What about the Tau Channel?

Eur. Phys. J. C64 (2009) 251

- Look for events with P_T^{miss} and narrow jets from hadronic decay
- Complementary results to those in the electron and muon channels

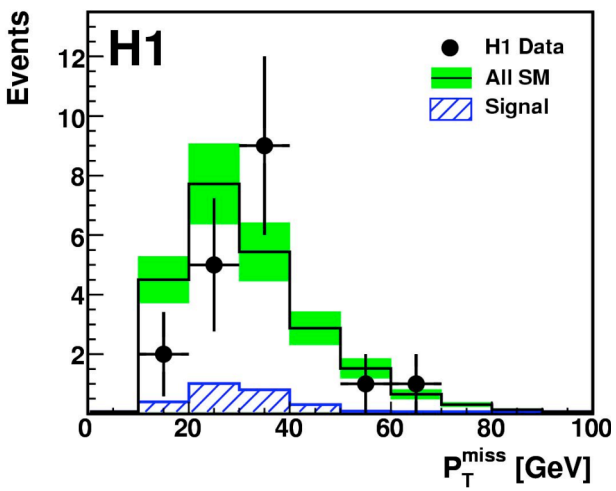
- Signature of 1-prong tau decay (45% branching ratio)
  - One charged track (the "prong"): narrow, pencil like jet

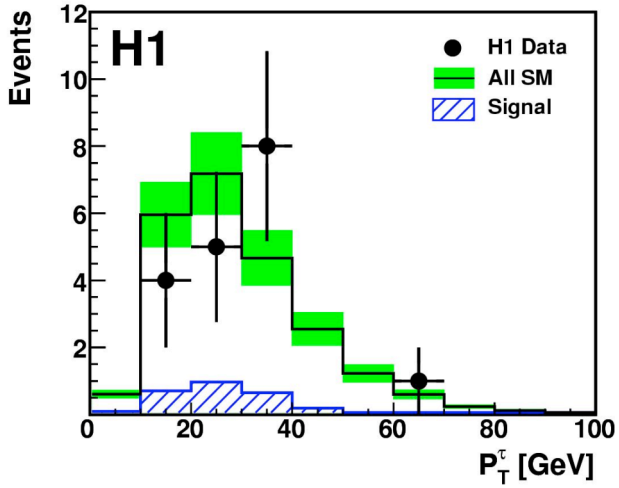
- H1 analysis using full HERA statistics: 474 pb^{-1}
  - Good overall agreement with the SM prediction
  - Expectation dominated by CC background
  - Challenging hadronic environment

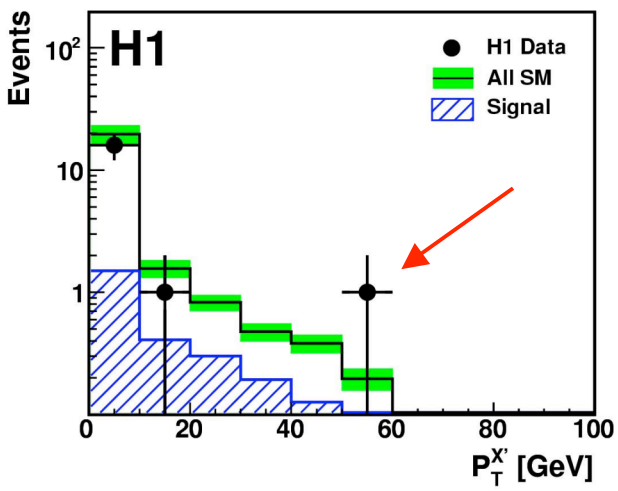
ZEUS HERA-I:
Isolated Tau Leptons
2 / 0.2 ± 0.05 at $P_T^X > 25$ GeV

H1	Tau Channel	Data	SM Expectation	SM Signal	Other SM Processes
1994-2007 e^+p	Total	9	12.3 ± 2.0	1.66 ± 0.25	10.6 ± 1.8
291 pb^{-1}	$P_T^X > 25$ GeV	0	0.82 ± 0.12	0.38 ± 0.06	0.44 ± 0.06
1999-2006 e^-p	Total	9	11.0 ± 1.9	1.00 ± 0.15	10.0 ± 1.8
183 pb^{-1}	$P_T^X > 25$ GeV	1	0.68 ± 0.11	0.21 ± 0.03	0.47 ± 0.07
1994-2007 $e^{\pm}p$	Total	18	23.2 ± 3.8	2.66 ± 0.40	20.6 ± 3.4
474 pb^{-1}	$P_T^X > 25$ GeV	1	1.50 ± 0.21	0.59 ± 0.09	0.91 ± 0.12

Tau Channel Distributions

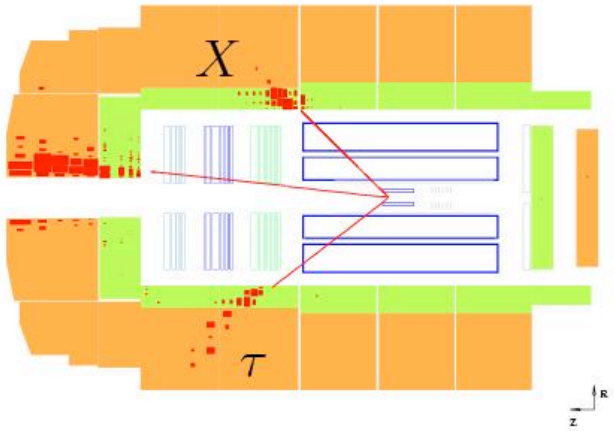


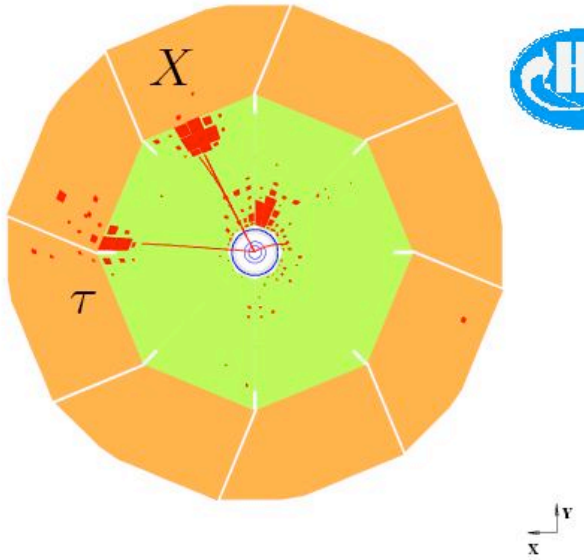




Good overall agreement with the SM prediction

One interesting event observed at high P_T^X (compared to 1.5 ± 0.2 SM)

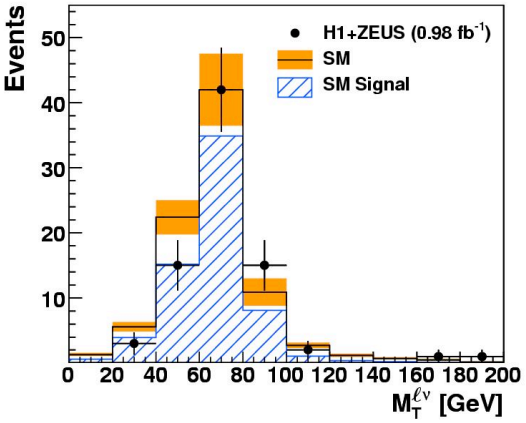


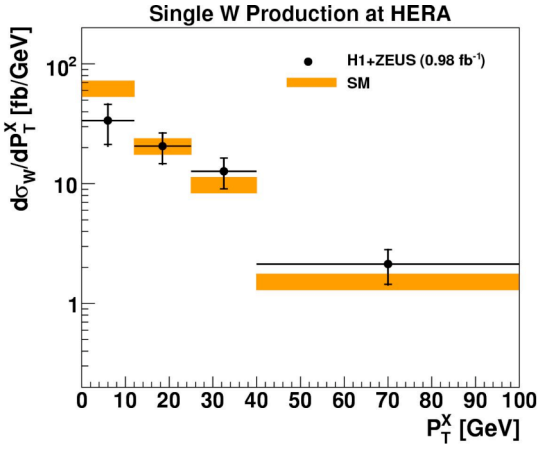


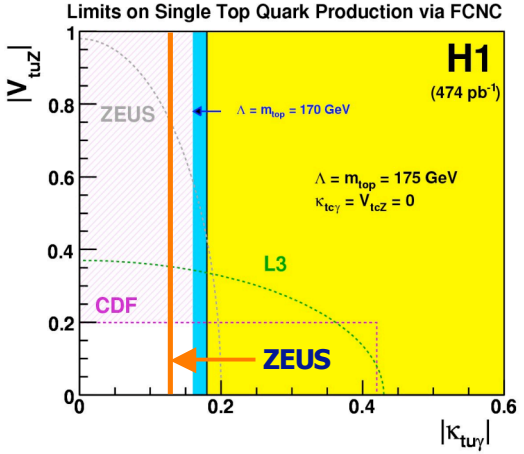
P_T^{τ} = 14 GeV, P_T^{miss} = 60 GeV, P_T^X = 56 GeV

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}
- H1 excess at large P_T^X in e^+p data persists in full HERA I+II data set
  - Data excess drops to 1.8 sigma significance with full H1+ZEUS data
- Single W cross section measured with greater statistical precision
  - σ_W = 1.06 ±0.16 (stat.) ± 0.07 (sys.) pb, cf 1.26 ± 0.19 pb from SM
- Exclusion limit on anomalous top cross section extended to σ < 0.13 pb
  - Best limit on the anomalous magnetic coupling: $\kappa_{tu\gamma}$ < 0.13 (for M_{top}=171.2 GeV)







Extras

List of Relevant Publications

- H1 Collaboration, *T. Ahmed et al.*, Observation of an $e^+p \rightarrow \mu^+X$ Event with High Transverse Momenta at HERA, unpublished, DESY-94-248
- H1 Collaboration, *C. Adloff et al.*, Observation of Events with an Isolated High Energy Lepton and Missing Transverse Momentum at HERA, Eur. Phys. J. C5 (1998) 575
- ZEUS Collaboration, *J. Breitweg et al.*, W Production and the Search for Events with an Isolated High-Energy Lepton and Missing Transverse Momentum at HERA, Phys. Lett. B471 (1999) 411
- ZEUS Collaboration, *S. Chekanov et al.*, Search for Single-top Production in ep Collisions at HERA, Phys. Lett. B559 (2003) 153
- H1 Collaboration, *V. Andreev et al.*, Isolated Electrons and Muons in Events with Missing Transverse Momentum at HERA, Phys. Lett. B561 (2003) 241
- H1 Collaboration, *A. Aktas et al.*, Search for Single Top Quark Production in ep Collisions at HERA, Eur. Phys. J. C 33 (2004) 9
- ZEUS Collaboration, *S. Chekanov et al.*, Search for events with an Isolated Lepton and Missing Transverse Momentum and a Measurement of W production at HERA, Phys. Lett. B672 (2009) 106
- H1 Collaboration, *F. D. Aaron et al.*, Events with Isolated Leptons and Missing Transverse Momentum and Measurement of W Production at HERA, Eur. Phys. J. C64 (2009) 251
- H1 Collaboration, *F. D. Aaron et al.*, Search for Single Top Quark Production at HERA, Phys. Lett. B678 (2009) 450
- H1 Collaboration and ZEUS Collaboration, *F. D. Aaron et al.*, Events with an Isolated Lepton and Missing Transverse Momentum and Measurement of W Production at HERA, JHEP 1003 (2010) 35

Kinematics of H1 High P_T^X Events

H1 Isolated Lepton Events at High P_T^X							
Run	Event	Lepton $^{q(\sigma_q)}$	P_T^ℓ [GeV]	θ_ℓ [°]	P_T^X [GeV]	$M_T^{\ell\nu}$ [GeV]	P_T^{miss} [GeV]
186729	702	μ	> 42.5	30.0 ± 0.4	75.3 ± 5.5	> 33.7	> 40.0
188108	5066	$\mu^{-\,(8.3\sigma)}$	$40.9\,^{+5.6}_{-4.4}$	35.1 ± 0.4	29.4 ± 2.4	$79.2^{+8.0}_{-10.1}$	$43.7^{+3.3}_{-4.2}$
192227	6208	$\mu^{-\,(7.0\sigma)}$	$73.3\,^{+12.2}_{-9.2}$	28.6 ± 0.3	63.9 ± 5.9	$67.8^{+19.8}_{-24.9}$	$19.8^{+5.4}_{-6.8}$
195308	16793	$\mu^{+\,(4.2\sigma)}$	$60.1\,^{+18.6}_{-11.5}$	30.9 ± 0.4	30.1 ± 2.6	$88.7^{+23.5}_{-37.0}$	$33.5^{+10.6}_{-15.8}$
248207	32134	$e^{+\,(15\sigma)}$	32.1 ± 1.3	32.2 ± 0.3	42.0 ± 3.9	62.7 ± 2.3	43.4 ± 2.8
252020	30485	$e^{+\,(40\sigma)}$	25.6 ± 1.2	110.2 ± 0.3	39.1 ± 3.3	48.6 ± 2.1	35.5 ± 2.5
266336	4126	$\mu^{+\,(26\sigma)}$	$19.7\,^{+0.8}_{-0.7}$	67.3 ± 0.4	50.0 ± 3.8	$69.8^{+2.4}_{-2.5}$	66.6 ± 3.7
268338	70014	$e^{+\,(1.6\sigma)}$	33.8 ± 1.3	29.7 ± 0.2	45.2 ± 3.2	90.3 ± 3.1	67.2 ± 3.0
275991	29613	$e^{+\,(37\sigma)}$	37.8 ± 1.5	41.7 ± 0.3	27.1 ± 1.8	73.3 ± 2.8	40.3 ± 1.4
369241	6588	e	29.2 ± 1.1	20.3 ± 0.2	40.5 ± 4.8	74.3 ± 3.0	55.5 ± 4.2
385422	76666	$e^{+\,(22\sigma)}$	28.1 ± 1.3	96.1 ± 0.3	25.9 ± 2.8	63.1 ± 2.8	40.0 ± 2.3
389826	2783	$e^{-\,(10\sigma)}$	62.0 ± 2.2	45.6 ± 0.3	45.3 ± 4.5	79.7 ± 6.0	30.3 ± 2.1
391884	49715	e	38.2 ± 1.4	22.7 ± 0.2	32.4 ± 2.6	48.5 ± 3.0	20.1 ± 0.8
473929	107593	$\mu^{-\,(9.6\sigma)}$	$53.5\,^{+6.2}_{-5.1}$	31.4 ± 0.4	49.1 ± 4.5	$80.6^{+8.7}_{-10.7}$	$40.9^{+2.8}_{-3.4}$
494115	121996	$\mu^{+\,(22\sigma)}$	$22.6\,^{+1.0}_{-1.0}$	61.5 ± 0.4	37.0 ± 3.7	$45.2^{+1.8}_{-1.9}$	$35.8^{+3.0}_{-3.0}$
495399	85500	$\mu^{-\,(32\sigma)}$	$29.4\,^{+0.9}_{-0.8}$	62.4 ± 0.4	29.6 ± 2.8	$63.1^{+1.7}_{-1.8}$	$40.3^{+2.0}_{-2.0}$
498117	316609	$e^{+\,(9.8\sigma)}$	27.4 ± 1.1	30.7 ± 0.3	26.7 ± 1.8	72.5 ± 2.5	49.9 ± 2.0
433051	64528	$e^{-\,(24\sigma)}$	26.2 ± 1.3	69.9 ± 0.3	72.9 ± 5.6	71.3 ± 2.9	75.8 ± 5.2

Different Isolated Lepton Event Selections

	Variable	Electron	Muon
1.	θ_l	$15^o < \theta_l < 120^o$	
	P_T^l	> 10 GeV	
	P_T^{calo}	> 12 GeV	
2.	M_T	> 10 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	-
3.	V_{ap}/V_p	< 0.5 (< 0.15(0.20) for $P_T^e <$ 25 GeV)	< 0.5 (< 0.15(0.20) for P_T^{calo} < 25 GeV)
	$\Delta\phi_{l\text{-}X}$	$< 160^o$	$< 170^o$
4.	δ_{miss}	5 GeV$^{\text{apple}}$ $< \delta_{miss}$ (< 50 GeV)	
	# isolated μ	0	1
5.	# electrons	< 3	-

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

- Five cut differences between the nominal H1 and ZEUS selections
- The preliminary CPS selection is still based on the ZEUS nominal selection

M_T and # electrons cuts adopted by ZEUS

V (the 2D part) and δ_{miss} cuts adopted by H1

- The more limited polar angle range is needed

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

$$\sigma_{IsoLep} = \frac{N_d - N_{bg}^{MC}}{\mathcal{L}\epsilon}$$

$$\epsilon = \frac{N_{rec}^{MC}}{N_{gen}^{MC}}$$

$$\sigma_W = \frac{N_d - N_{bg}^{MC}}{\mathcal{L}\Gamma\epsilon}$$

Isolep

$P_{T,\ell} > 10$ GeV
$5^o < \theta_\ell < 140^o$
$D_{\text{jet}} > 1$ (in $\eta - \phi$)

Here just look in this phase space (include all signal processes)

W

Lepton from W (TRUTH)

Here specifically leptons produced in W decays

H1	HERA I+II Data	SM
$\sigma_{\ell+P_T^{\text{miss}}}$	0.23 ± 0.05 (stat.) ± 0.04 (sys.) pb	0.25 ± 0.04 pb
σ_W	1.14 ± 0.25 (stat.) ± 0.14 (sys.) pb	1.27 ± 0.19 pb

Both measured H1 cross sections in good agreement with the SM predictions

H1 and ZEUS Analysis Details

- Analysis uses full HERA data set: 978 pb^{-1}
  - 474 pb^{-1} H1 and 504 pb^{-1} ZEUS data
  - 587 pb^{-1} of e^+p data, 391 pb^{-1} of e^-p data
  - 84 pb^{-1} of data at 301 GeV, 894 pb^{-1} of data at 319 GeV
- Large MC samples used in each analysis, simulated for the different running conditions

Process	H1	ZEUS
Signal (W, Z0*)	EPVEC NLO	EPVEC NLO
NC	RAPGAP	DJANGO
Lepton Pair	GRAPE	GRAPE
Photoproduction	PYTHIA	-
Compton	WABGEN	(included in NC)
Charged Current	DJANGO	DJANGO

*not ZEUS

- Average HERA II beam polarisation taken into account in CC

Full Treatment of Systematic Errors

Systematics taken from H1 and ZEUS nominal analyses

H1 Experimental Systematics

Source	Systematic
E_e	LAr : z < 20 cm 0.7% LAr : 20 < z < 100 cm 1.5% LAr : 100 cm < z 2.0% Spacal: 0.5%
θ_e	LAr : 3 mrad Spacal: 1 mrad
ϕ_e	1 mrad
P_T^μ θ_μ ϕ_μ	2.5% 3 mrad 1 mrad
E_{had} θ_{had} ϕ_{had}	2% (5% if $P_T^X < 8$ GeV) 10 mrad 10 mrad
$\frac{V_{ap}}{V_p}$ Muon ID Electron ID Electron track-clus linking CC trigger	± 0.02 5% if $\theta_\mu > 12.5^o$ else 15% 2% 3% $2\% \oplus 30\%(1-\epsilon_{CC})$
$\mathcal{L}$	1994-2000 $e^\pm p$: 1.5% 2003-2006 $e^\pm p$: 2.5% 2006-2007 $e^+ p$: 5.0%

ZEUS experimental systematics

- Muon ID: 5%
- EM calo: 2%
- HAD calo: 3%
- Lumi (e^+p): 2.9%
- Lumi (e^-p): 3.4%

SM Signal model uncertainty

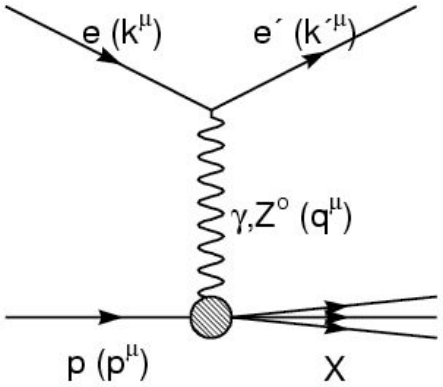
- EPVEC: 15% (NLO model error)

SM Background uncertainties from agreement in control samples

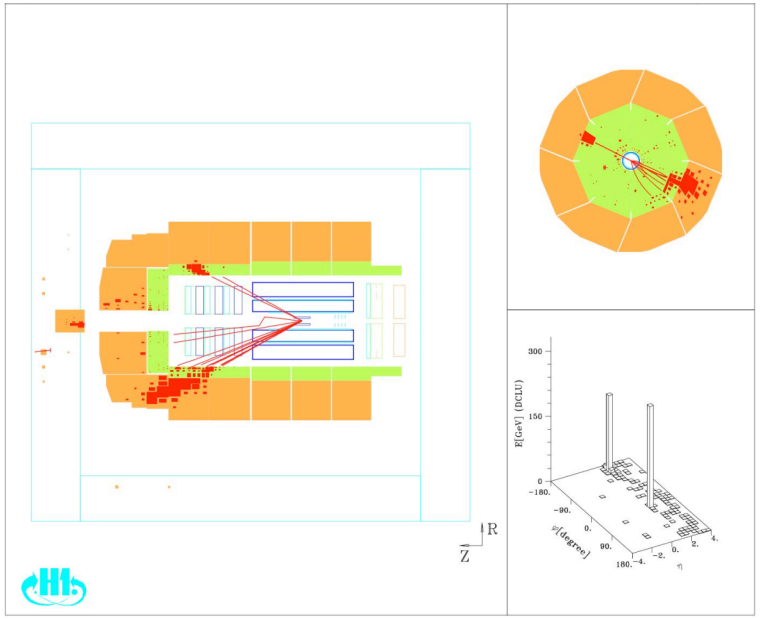
- NC: 30% (15%) H1 (ZEUS)
- LPAIR: 30% (25%) H1 (ZEUS)
- CC: 50% (25%) H1 (ZEUS)
- COMPTON, GAMMAP: 30% *(H1)*

All errors treated uncorrelated between H1 and ZEUS except EPVEC

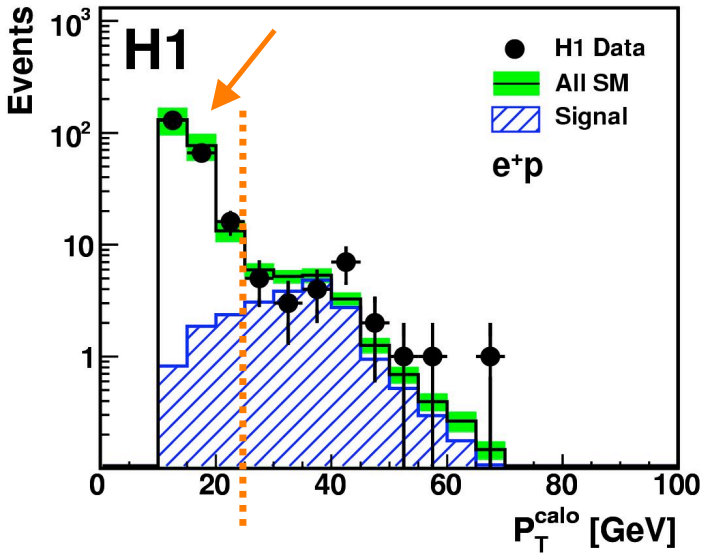
SM Background: Neutral Current

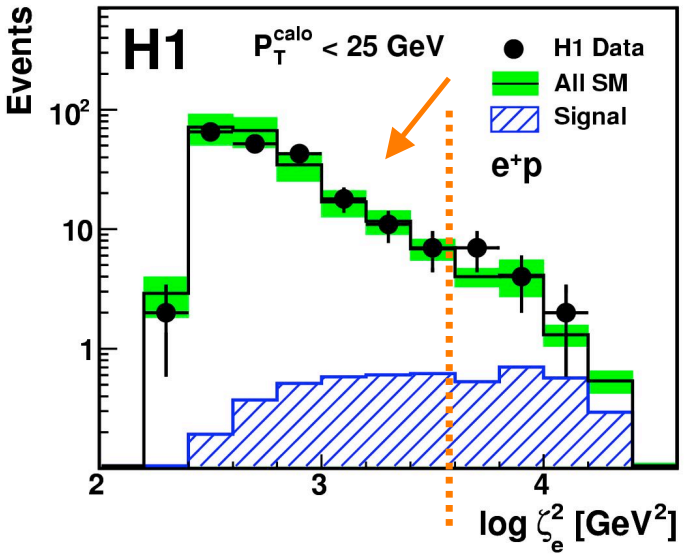


Real electron and fake missing P_T from mismeasurement

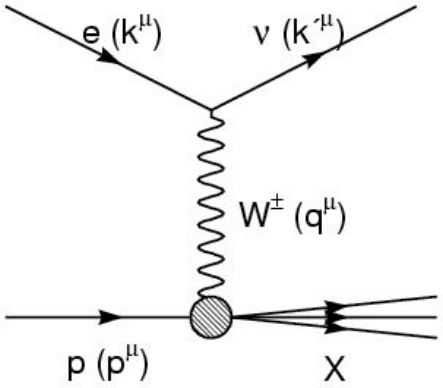


- Origin of isolated electron events NC background?
- Remove Anti-NC Cuts on P_T^{miss}, Q^2
- NC background well described in enriched region

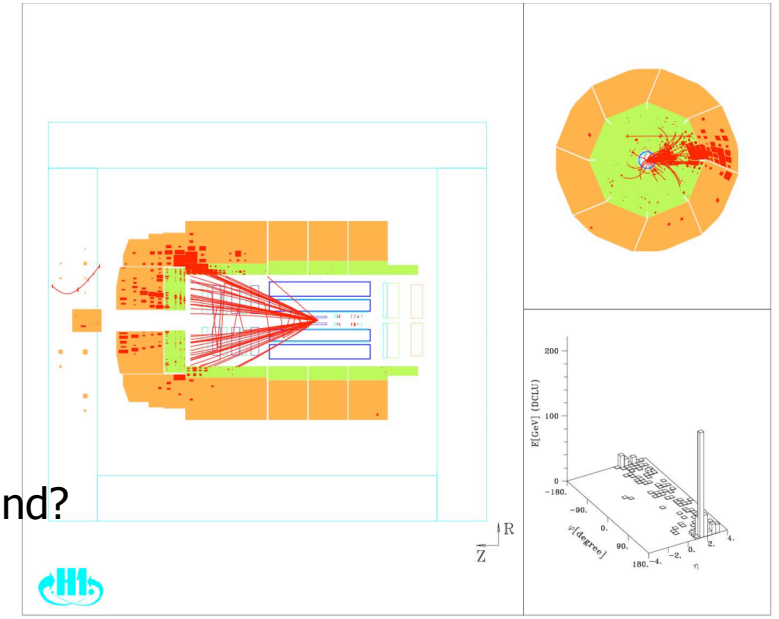




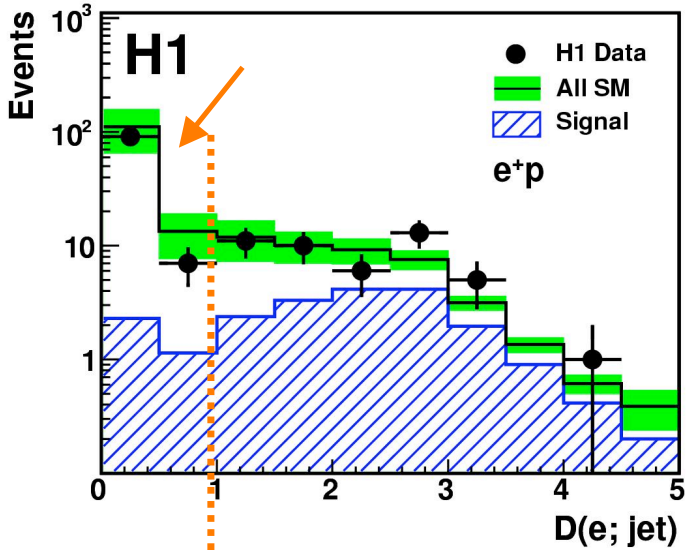
SM Background: Charged Current

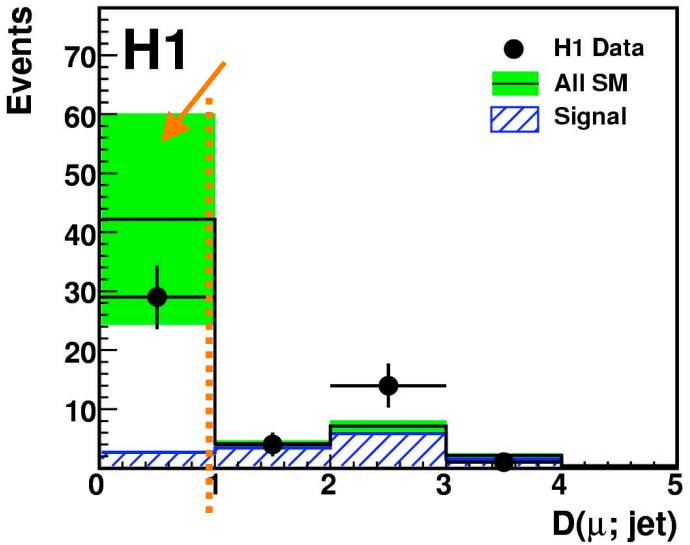


Misidentified electron or muon and real missing P_T

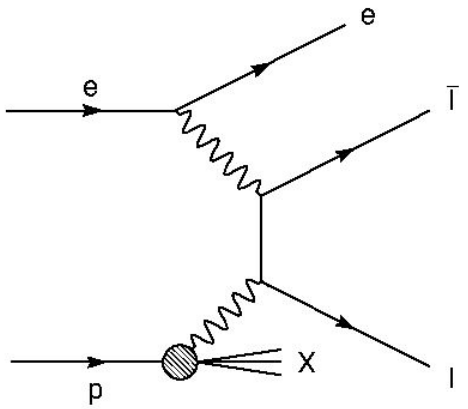


- Origin of electron or isolated muon events: CC background?
- Remove Anti-CC cuts (D jet)
- Electrons and muons in CC jets described within 50%

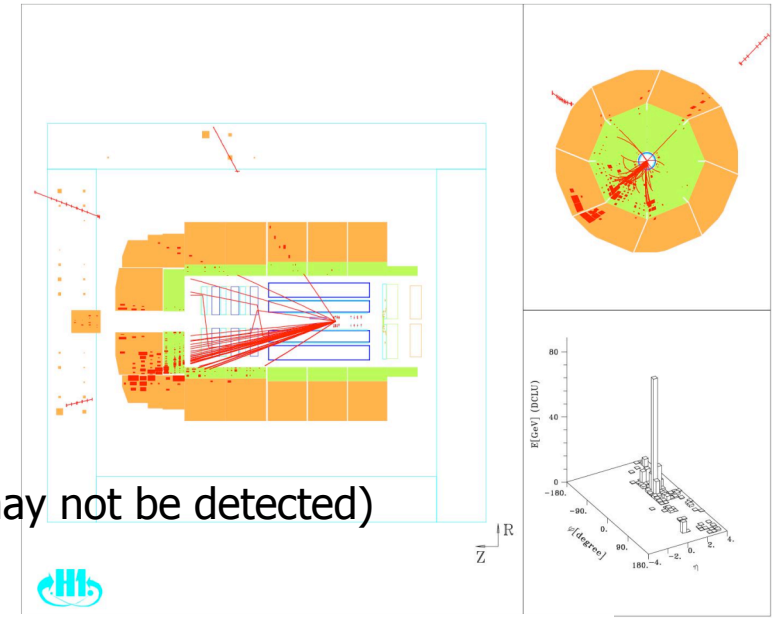




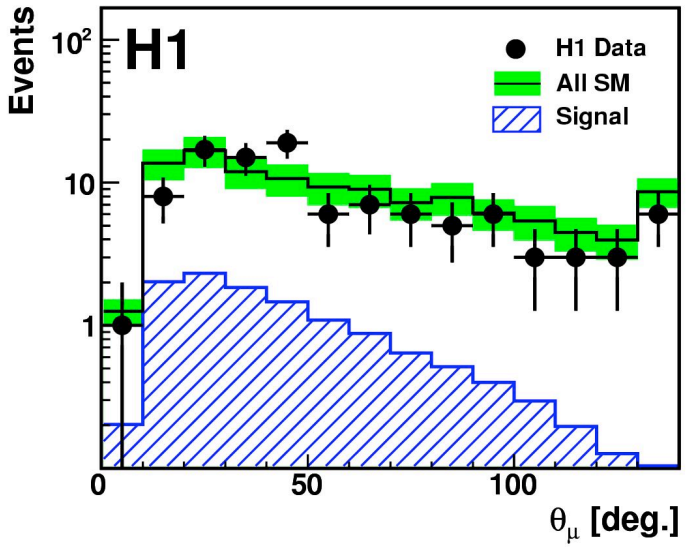
SM Background: Pair Production

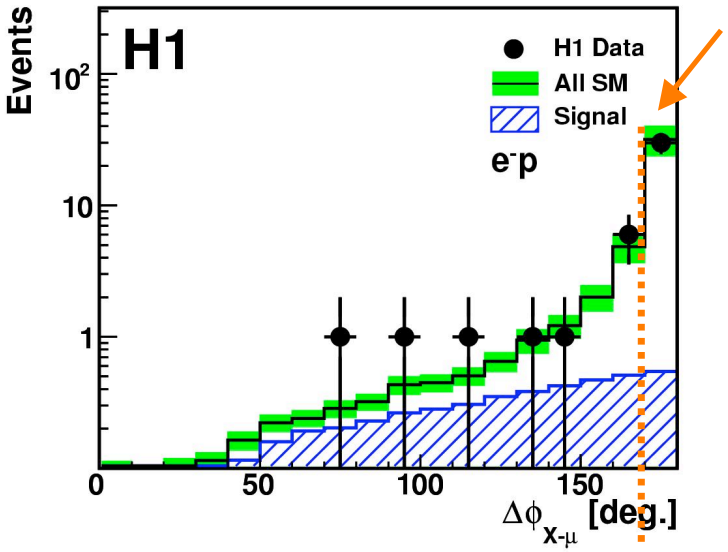


Real muon and fake missing P_T from mismeasurement

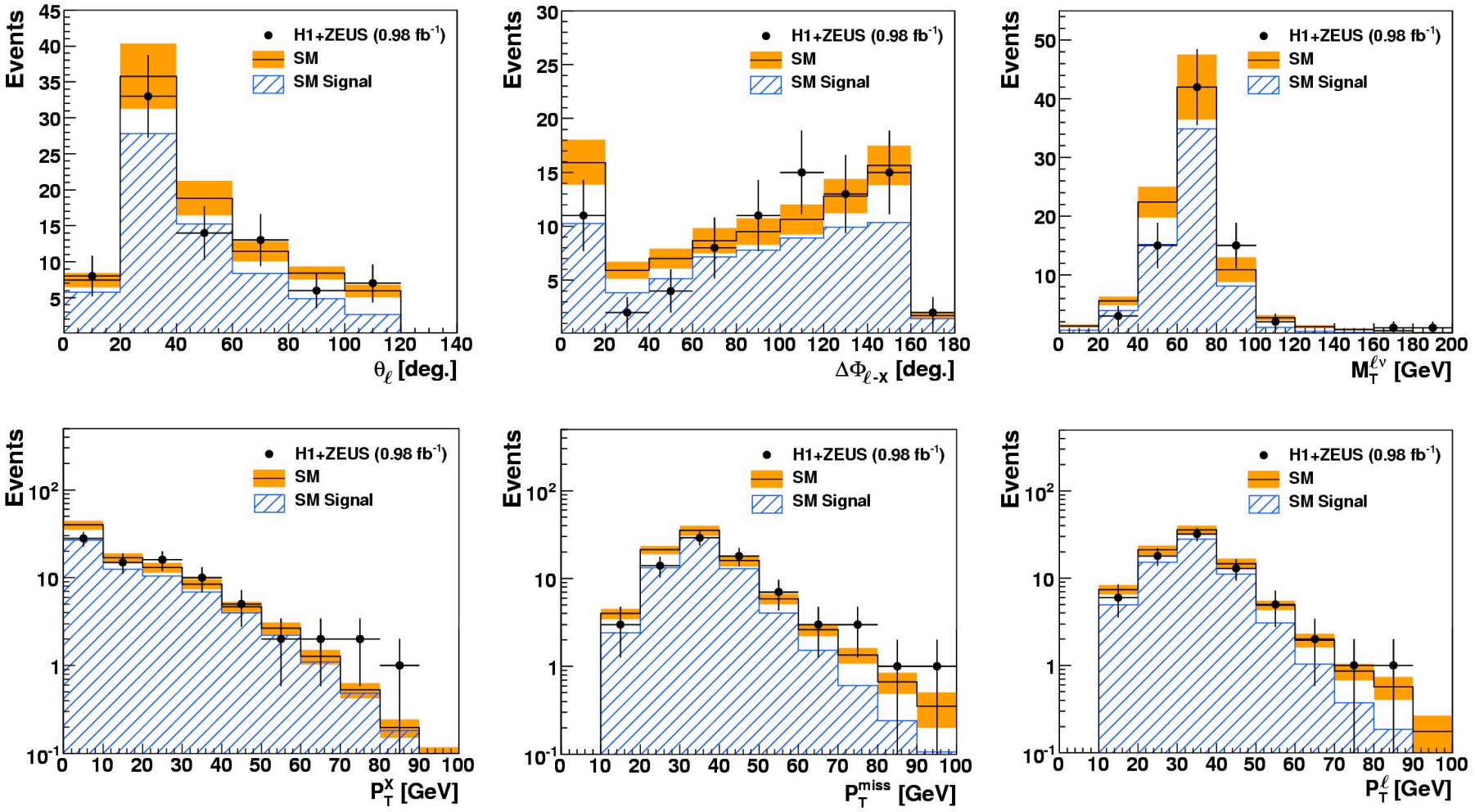


- Muon events from lepton-pair production? (One muon may not be detected)
- Remove Anti-lepton-pair cuts (P_T^{miss}, acoplanarity)
- Lepton-pair Production described in enriched region

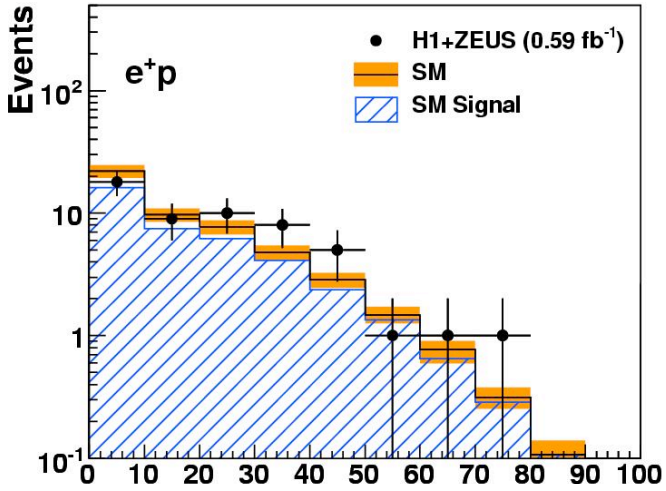




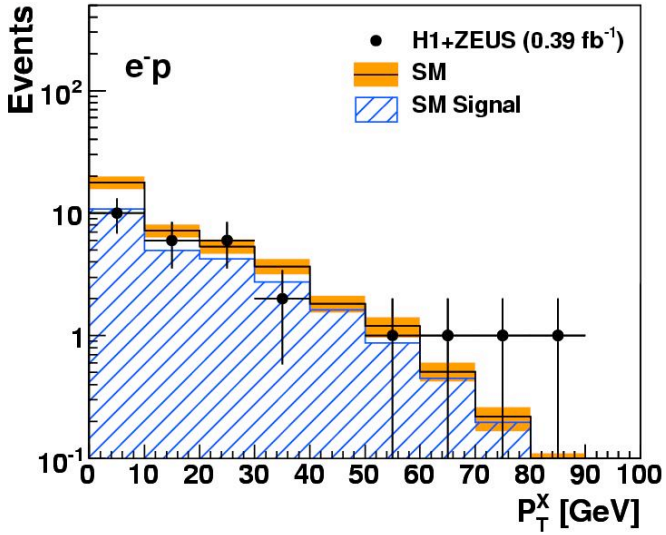
H1+ZEUS Isolated Leptons: All Distributions



H1+ZEUS Isolated Leptons: e^+p and e^-p



H1+ZEUS 1994–2007 e^+p 0.59 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	37	38.6 ± 4.7	28.9 ± 4.4	9.7 ± 1.4
	$P_T^X > 25$ GeV	12	7.4 ± 1.0	6.0 ± 0.9	1.5 ± 0.3
Muon	Total	16	11.2 ± 1.6	9.9 ± 1.6	1.3 ± 0.3
	$P_T^X > 25$ GeV	11	6.6 ± 1.0	5.9 ± 0.9	0.8 ± 0.2
Combined	Total	53	49.8 ± 6.2	38.8 ± 5.9	11.1 ± 1.5
	$P_T^X > 25$ GeV	23	14.0 ± 1.9	11.8 ± 1.9	2.2 ± 0.4



H1+ZEUS 1998–2006 e^-p 0.39 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	24	30.6 ± 3.6	19.4 ± 3.0	11.2 ± 1.9
	$P_T^X > 25$ GeV	4	5.6 ± 0.8	4.0 ± 0.6	1.6 ± 0.4
Muon	Total	4	7.4 ± 1.1	6.6 ± 1.0	0.9 ± 0.3
	$P_T^X > 25$ GeV	2	4.3 ± 0.7	3.9 ± 0.6	0.4 ± 0.2
Combined	Total	28	38.0 ± 3.4	26.0 ± 3.4	12.0 ± 2.0
	$P_T^X > 25$ GeV	6	10.0 ± 1.3	7.9 ± 1.2	2.1 ± 0.5

Single W Production Cross Section

$$\sigma = \frac{N_{data} - N_{bg}^{MC}}{\mathcal{L} \cdot Br \cdot \mathcal{A}}$$

N_{bg}^{MC} : Number of background events from MC
L : Luminosity of full HERA data
Br : Branching ratio of decay channels included
A : Acceptance calculated in full phase space

- Acceptance defined as: $\mathcal{A} = \frac{\mathrm{N_{rec}}}{\mathrm{N_{gen}}}$
  - N_{gen} : Number of generated W events decaying to the electron and muon channel
  - Leptonic tau decays included in N_{gen} and therefore also in the branching ratio, Br
- Measure inclusive cross section and also in 4 bins in P_T^X
- There is no measurement in the $P_T^X < 12$ GeV bin in the muon channel, so the electron channel is used under the assumption of lepton universality:

$$\sigma_\ell^{All P_T^X} = \sigma_e^{P_T^X > 12} + \sigma_\mu^{P_T^X > 12} + 2\sigma_e^{P_T^X < 12}$$

  - This is valid if SM cross sections agree in this bin: $\frac{\sigma\mu^{SM}}{\sigma e^{SM}}|_{P_T^X<12} = 1.0092$

H1+ZEUS Isolated Leptons: Cross Section

H1+ZEUS Differential Single W Production Cross Section		
P_T^X [GeV]	Measured $\pm$ stat. $\pm$ sys. [fb / GeV]	SM NLO [fb / GeV]
$0 - 12$	$33.6 \pm 12.3 \pm 5.0$	62.7 ± 9.4
$12 - 25$	$20.6 \pm 6.0 \pm 1.9$	20.7 ± 3.1
$25 - 40$	$12.7 \pm 3.6 \pm 1.0$	9.8 ± 1.5
$40 - 100$	$2.1 \pm 0.7 \pm 0.2$	1.5 ± 0.2

H1 Isolated Tau Selection

H1 Isolated Tau Lepton $+P_T^{\text{miss}}$ Event Selection	
CC–like Sample	$P_T^{\text{miss}} > 12$ GeV $P_T^{\text{calo}} > 12$ GeV $P_T^X > 12$ GeV $\delta_{\text{miss}} > 5$ GeV $V_{\text{ap}}/V_{\text{p}} < 0.5$ $V_{\text{ap}}/V_{\text{p}} < 0.15$ for $P_T^{\text{miss}} < 25$ GeV
Tau–like Jets	$P_T^{\text{jet}} > 7$ GeV $20^\circ < \theta_{\text{jet}} < 120^\circ$ $R_{\text{jet}} < 0.12$ $N_{\text{tracks}}^{\text{jet}} \geq 1$ for $P_T^{\text{track}} > 5$ GeV
Isolation	$D(\tau; e, \mu, \text{jet}) > 1.0$
Acoplanarity	$\Delta\phi_{\tau-X'} < 170^\circ$ for $P_T^{X'} > 5$ GeV
One–prong	$N_{\text{tracks}}^{D\text{jet}<1.0} = 1$ $N_{\text{NVtracks}}^{D\text{track}<0.3} = 1$

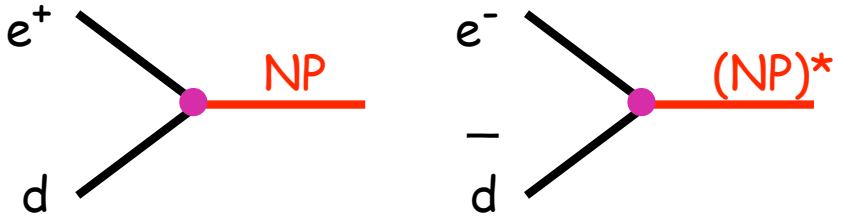
Missing Energy

Narrow, high P_T jet

Exactly one track in the jet

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

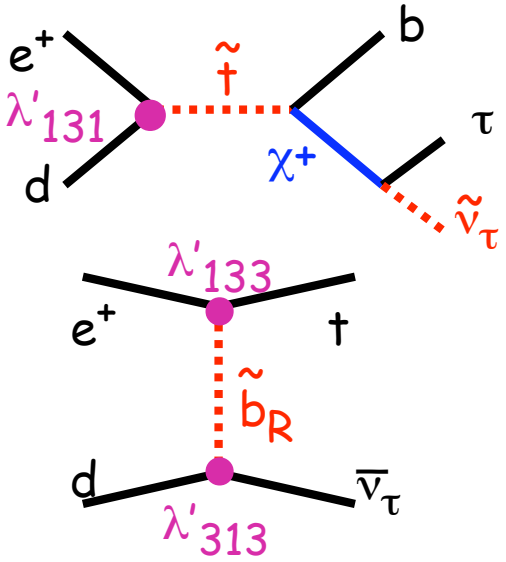
- Particle coupling to e-q with fermion number F=0 ?



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}