Events with Isolated Leptons and Missing Transverse Momentum and Measurement of *W* Production at HERA

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On behalf of the H1 and ZEUS Collaborations

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Collider and Experiments

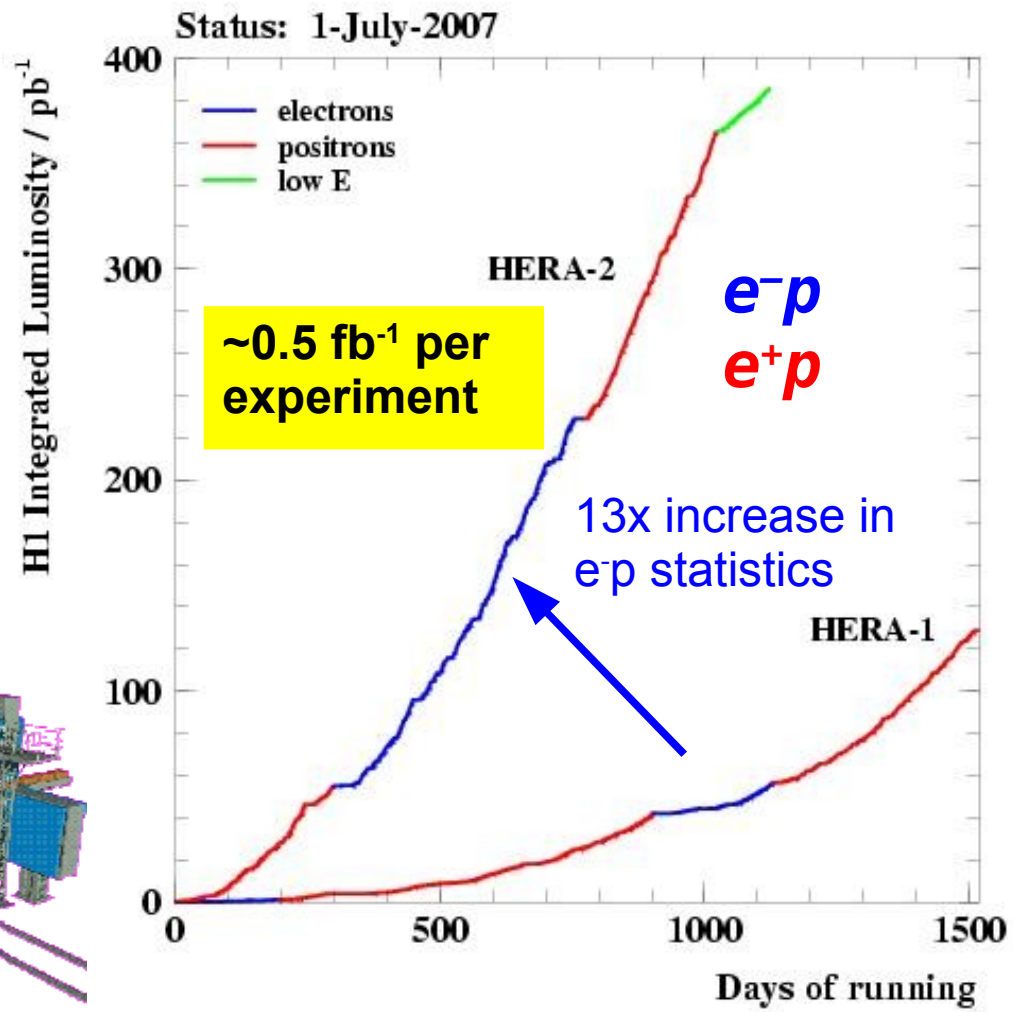
HERA

World's only *ep* Collider at DESY,Hamburg
Active 1991-2007
H1 and ZEUS Experiments

Asymmetric Desgin
4π Coverage
Excellent Lepton ID + HFS Reconstruction

HERA-I (1994-00)
~130 pb^{-1} per exp., (90% e^+p)

HERA-II (2003-07)
Luminosity upgrade
Long. *e* polarisation (avg. 40%)



Introduction: Isolated Lepton Events

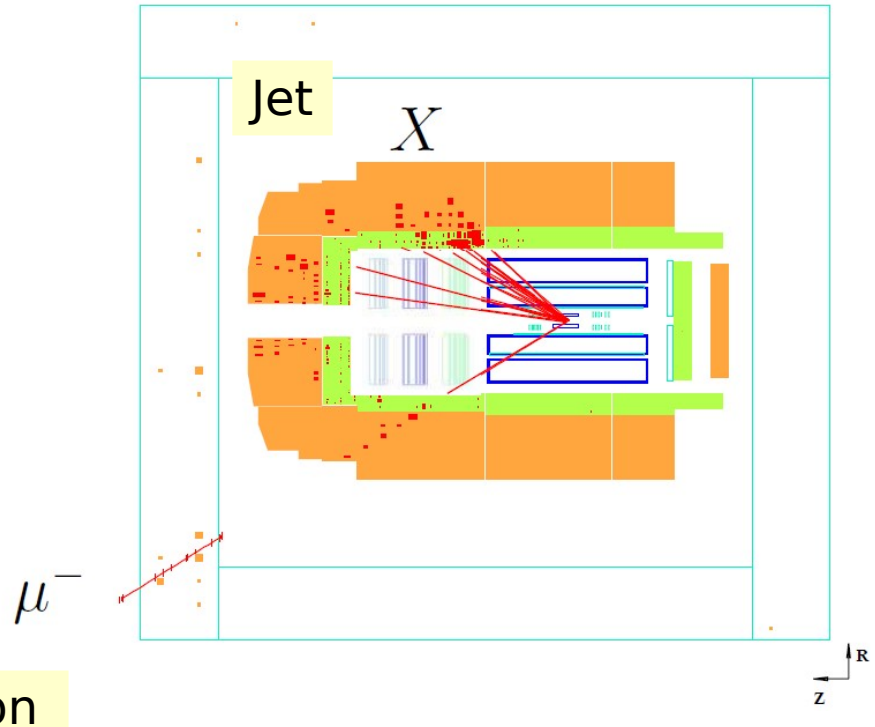
- Search for events with Isolated Leptons (Electrons or Muons, $P_T > 10$ GeV) and Missing Energy ($P_T > 12$ GeV)

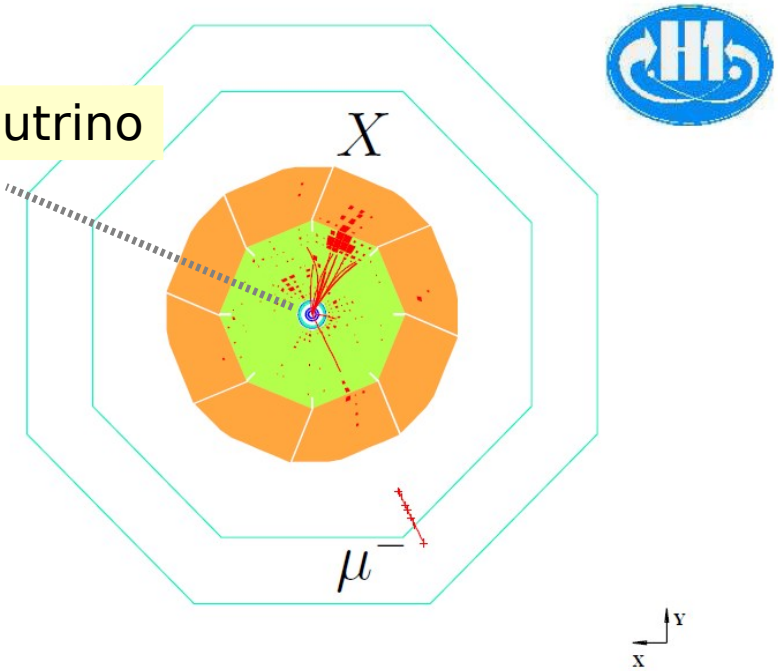
ZEUS [arXiv:0807.0589 Phys.Lett.B672:106-115,2009]

H1 [arXiv:0901.0488 Subm. to Eur.Phys.J **C**]

- Signature is sensitive to physics beyond the Standard Model (BSM) (appears in other analyses: SUSY, Lepto-Quarks, LFV, ...)

Example Event





High-P_T^X Isolated Lepton Events in HERA Data

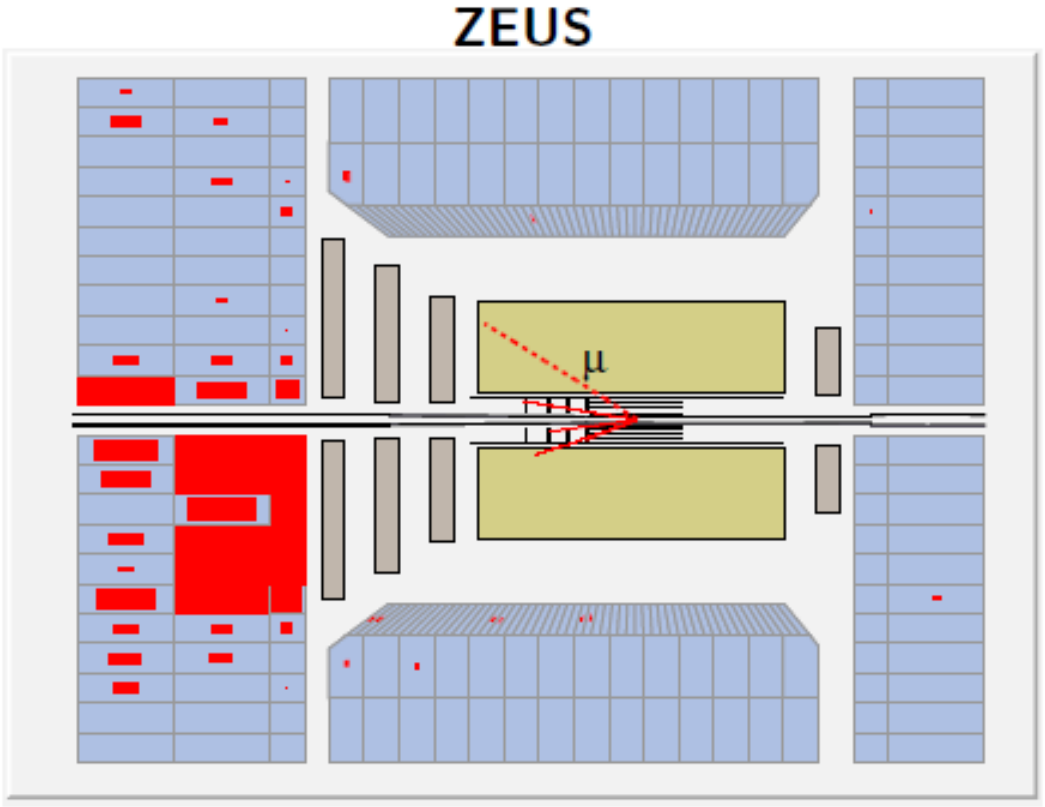
- H1 observed an excess of isolated lepton events over SM prediction in HERA-I data (mostly e^+p collisions)
- ZEUS did not confirm excess in similar analysis

1994-2000 $e^\pm p$		Electron obs./exp. ($W^\pm$ contribution)	Muon obs./exp. ($W^\pm$ contribution)
H1 118.4 pb^{-1}	Full sample	11 / 11.54 $\pm$ 1.50 (71%)	8 / 2.94 $\pm$ 0.50 (86%)
	$p_T^X > 25$GeV	5 / 1.76 $\pm$ 0.30 (82%)	6 / 1.68 $\pm$ 0.30 (88%)
	$p_T^X > 40$GeV	3 / 0.66 $\pm$ 0.13 (80%)	3 / 0.64 $\pm$ 0.14 (92%)

Another Example Event
(obs. by ZEUS in HERA-II data)

Muon Event

- High HFS $P_T^X > 80$ GeV
- High P_T^μ
- Signature untypical for a SM process

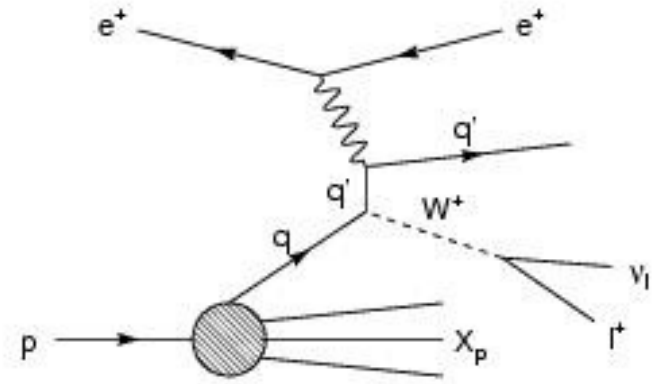


Single *W* Production: SM Signal

Signal with this signature in Standard Model:

Single *W* Production

$\sigma \sim 1.3$ pb



Jet / HFS

Missing Energy

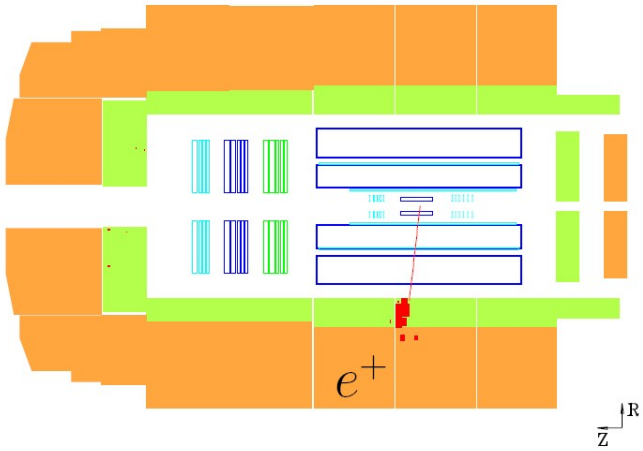
Electron or Muon

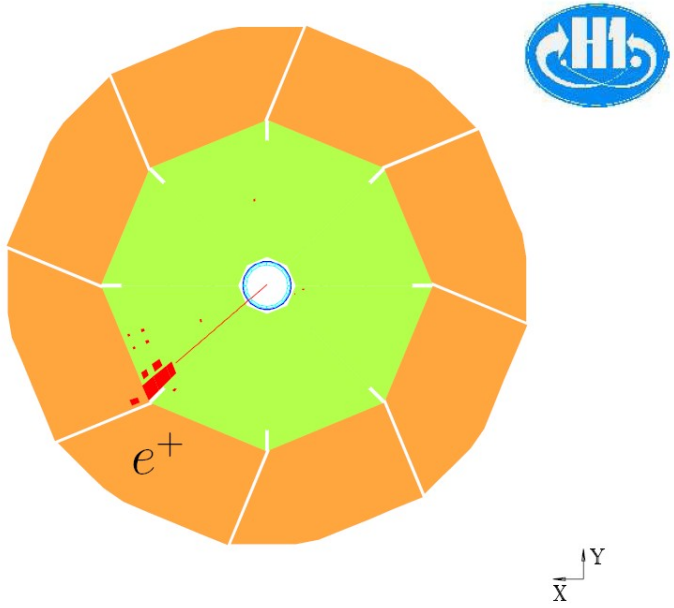
- Modelled in EPVEC Framework
- *W* Produced mostly in Photoproduction (HFS typically low P_T)
- With NLO Corrections 15% Th. Error

Example
Electron Event

- Typical for elastic SM Single *W* Production

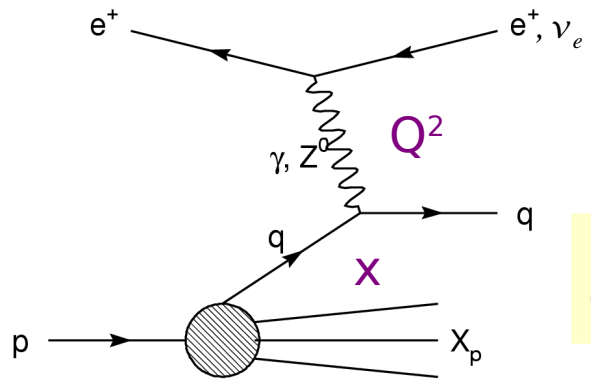
$P_T^X \sim 0$ GeV
$P_T^e = 46$ GeV
$M_T = 92$ GeV





Background from the SM: NC and CC in DIS

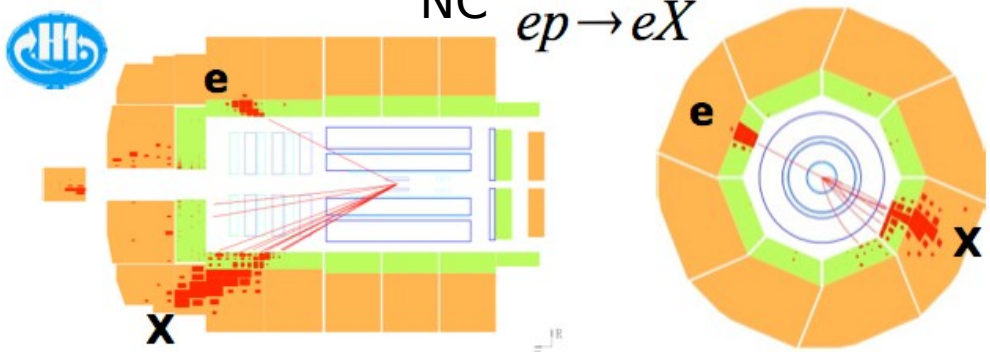
Main Standard Model Process at HERA:
Deep Inelastic Scattering



Electron or Missing Energy

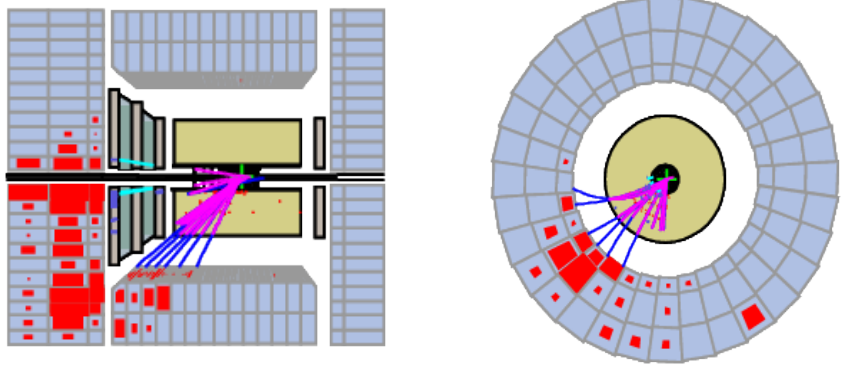
Hadronic final state

NC $ep \to eX$



- Neutral Current: Enters due to fake missing energy

CC $ep \to \nu X$



- Charged Current: Enters due to hadrons misidentified as leptons

Other Backgrounds

- Lepton-Pair Production *[→ see talk M. Turcato]*
- *Photoproduction*
- *Bremsstrahlung*

Enters if one lepton is not detected

Isolated Lepton Selection Criteria

Variable	Electron	Muon
P_T^{CAL}	$> 12\,\mathrm{GeV}$	$> 12\,\mathrm{GeV}$
P_T^{miss}	$> 12\,\mathrm{GeV}$	$> 12\,\mathrm{GeV}$
D_{track}	> 0.5 for $\theta_e > 45°$	> 0.5
P_T^l	$> 10\,\mathrm{GeV}$	$> 10\,\mathrm{GeV}$
θ_l	**H1: $5° < \theta_\mu < 140°$ / ZEUS: $15° < \theta_\mu < 120°$**	
δ	$5 < \delta < 50\,\mathrm{GeV}$	$< 70\,\mathrm{GeV}$
ϕ_{acop}	$> 20°$	$> 10°$
ξ_l^2	$> 5000\,\mathrm{GeV}^2$ for $P_T < 25\,\mathrm{GeV}$	—
$\frac{V_{\mathrm{ap}}}{V_p}$	< 0.5 (< 0.15 for $P_T^e < 25\,\mathrm{GeV}$)	< 0.5 (< 0.15 for $P_T^{\mathrm{CAL}} < 25\,\mathrm{GeV}$)
D_{jet}	implicit	> 1.0
# isolated μ	0	1
P_T^X	—	$> 12\,\mathrm{GeV}$

Missing Energy

Isolation
High Lepton P_T

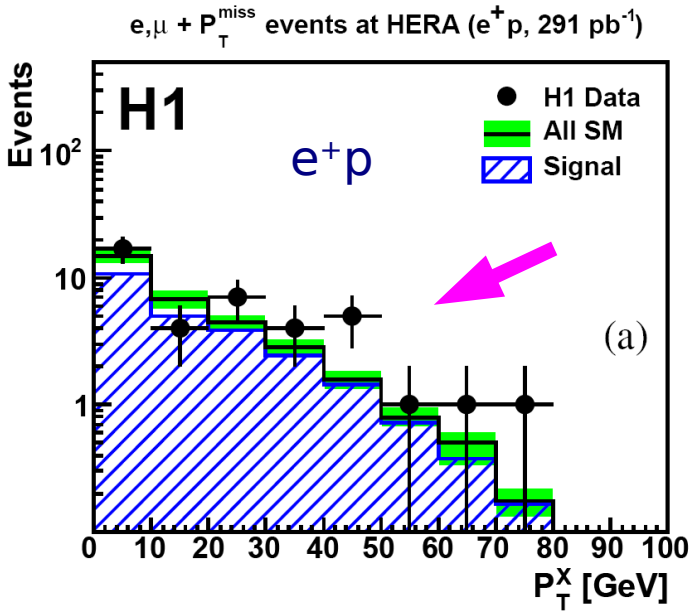
Polar Angle

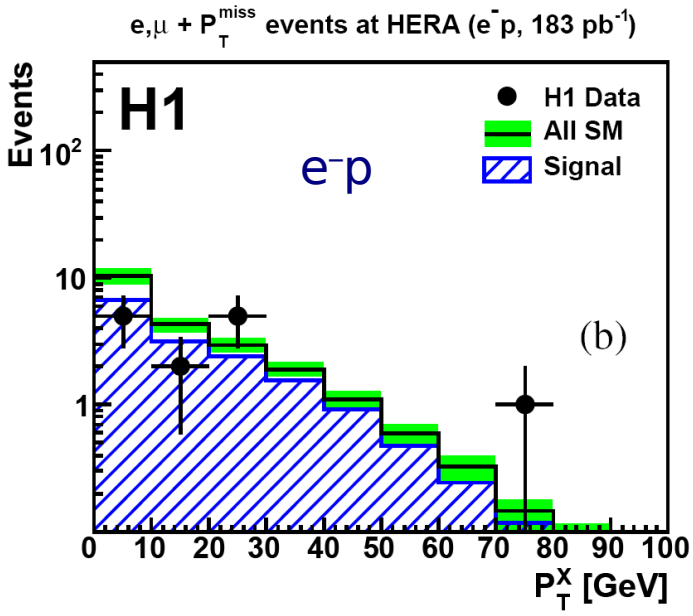
Anti-NC
Missing Energy
Anti-NC
Missing Energy

Isolation
Anti Lepton-Pair
Trigger Condition

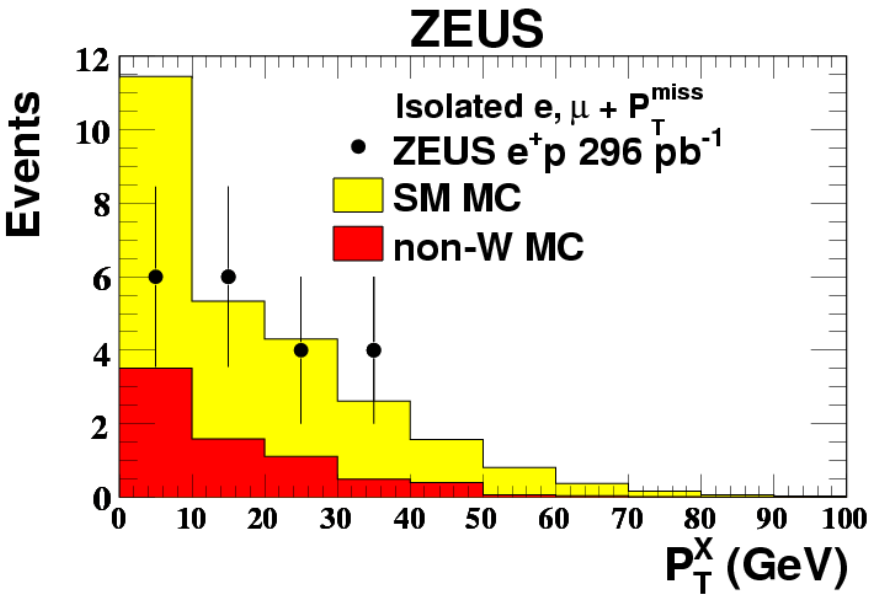
- H1 and ZEUS selection criteria largely the same (Result of parallel, on-going combination effort)
- Main difference:
  Larger polar angle range in H1 analysis

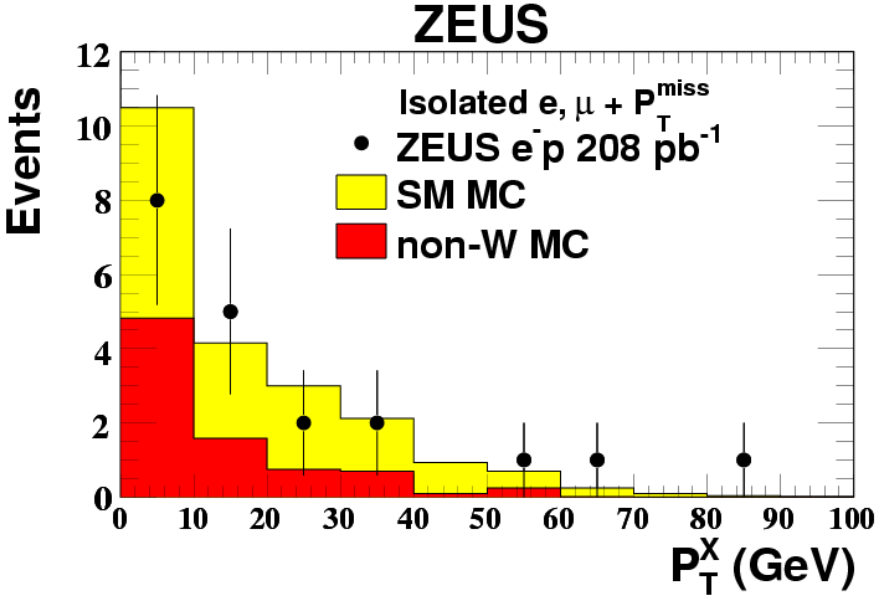
Isolated Leptons P_T^X Distributions





- Good overall agreement with Standard Model
- Interesting events at high hadronic P_T^X > 25 GeV observed in e^+p by H1





Isolated Lepton Event Yields

- H1: Good overall agreement of data and SM prediction, 18 / 13±2 at high P_T^X
- ZEUS: Good overall agreement of data and SM prediction, also at high $P_T X$

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

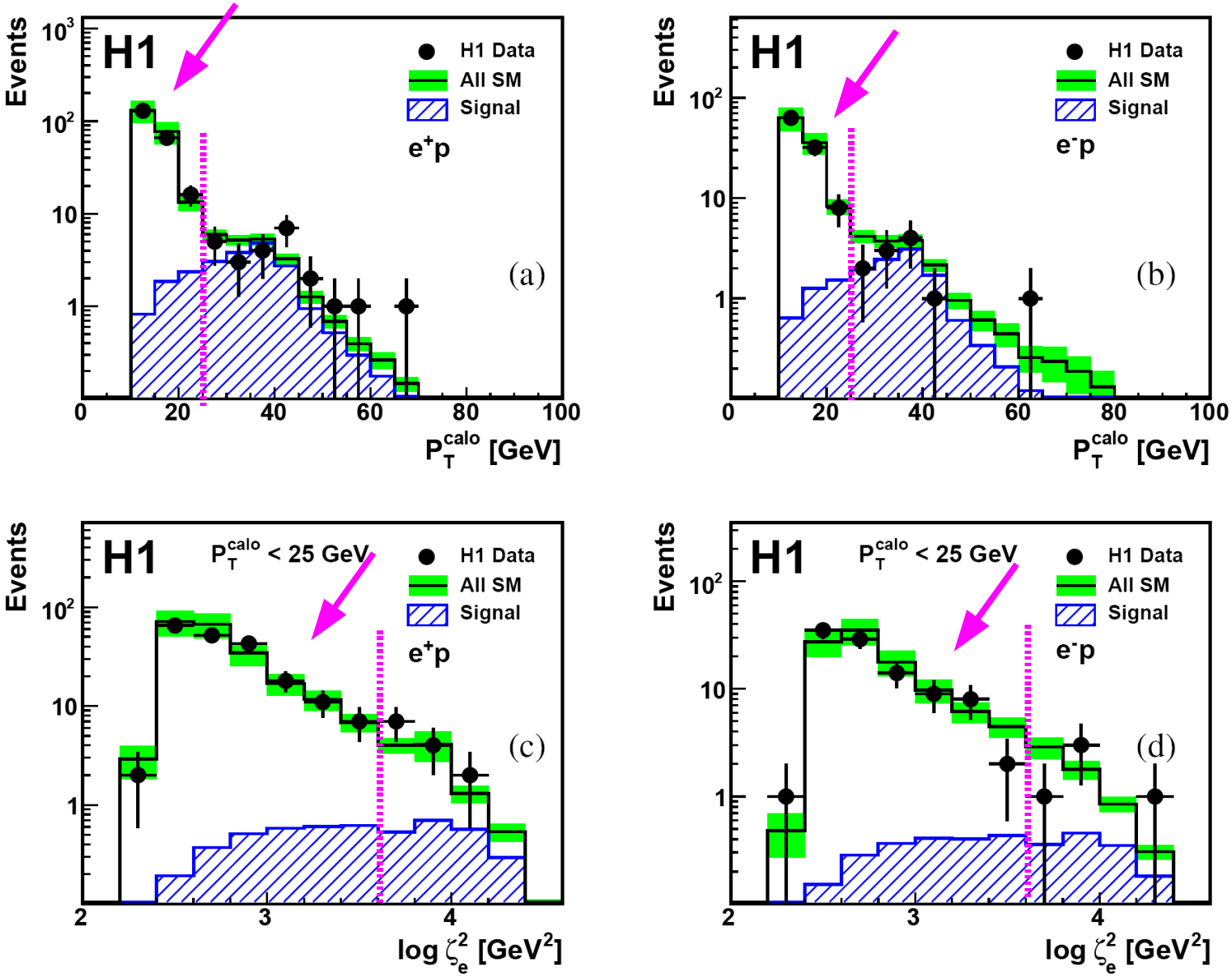
- What are those high-P_T^X events?
- Does H1 control their background?
- Study the main background contributions to the channels

➡

ZEUS 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 ± 1.5 (54%)	6/5.1 ± 0.7 (67%)	5/5.5 ± 0.8 (75%)
e^+p 296 pb^{-1}	7/12.6 ± 1.7 (68%)	7/6.2 ± 0.9 (75%)	6/7.4 ± 1.0 (79%)
$e^{\pm}p$ 504 pb^{-1}	16/23.9 ± 3.1 (61%)	13/11.2 ± 1.5 (71%)	11/12.9 ± 1.7 (77%)

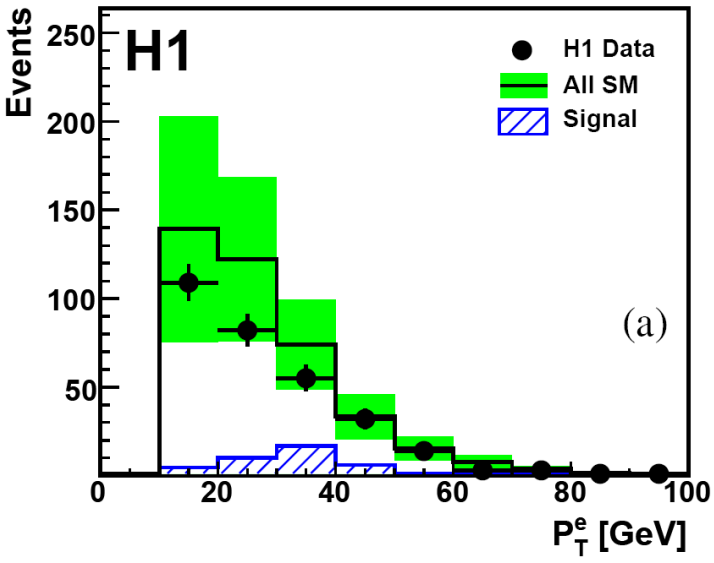
Electron Channel – NC Control

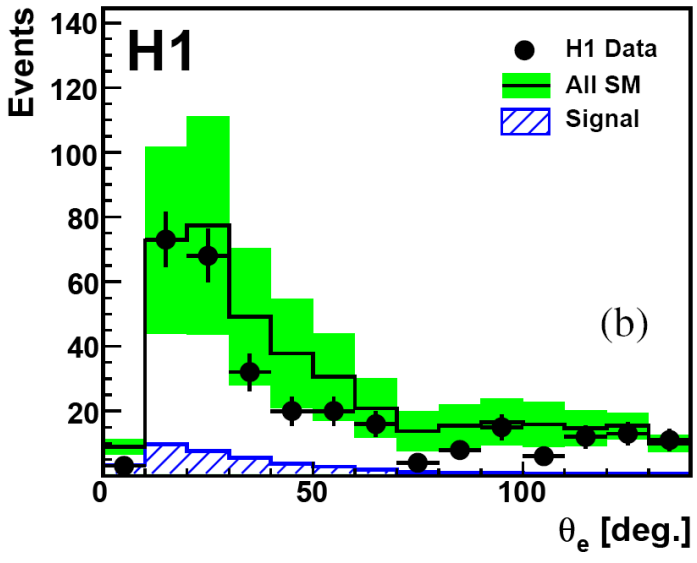
- Origin of isolated electron events NC background?
- Remove Anti-NC Cuts on P_T^{Calo}, Q^2_e
- NC background well described in enriched region

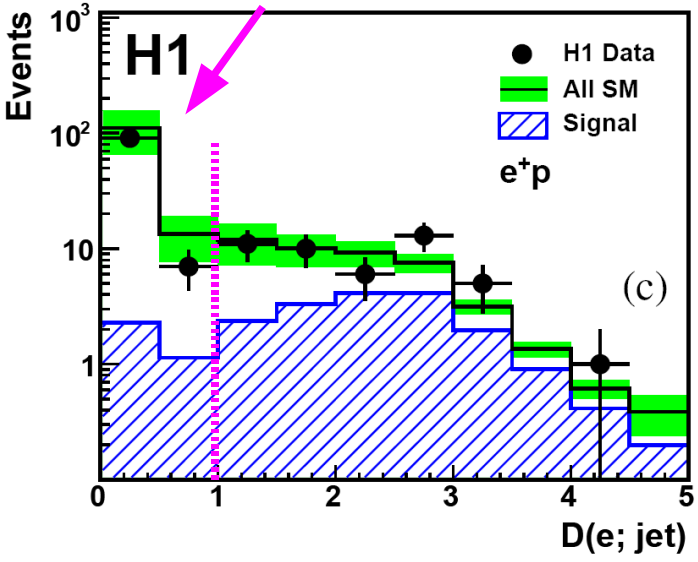


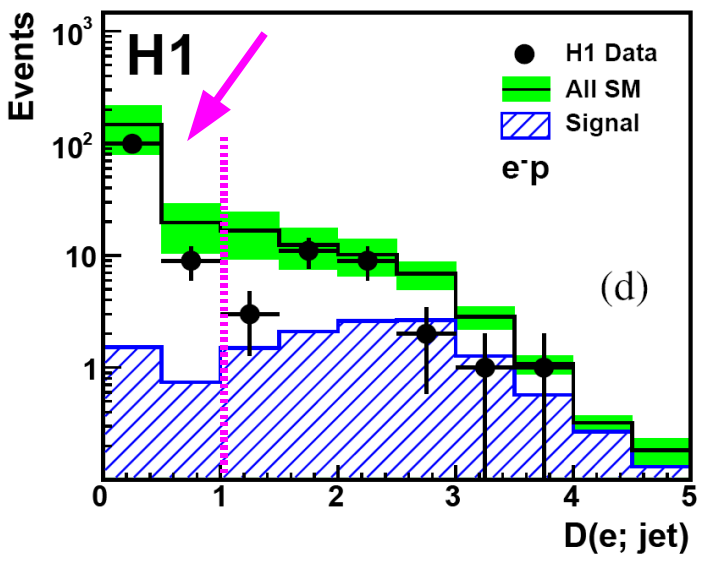
Electron Channel – CC Enriched Control Sample

- Origin of isolated electron events CC background?
- Remove anti-CC cuts on D_{jet}
- Fake electrons described within 50%



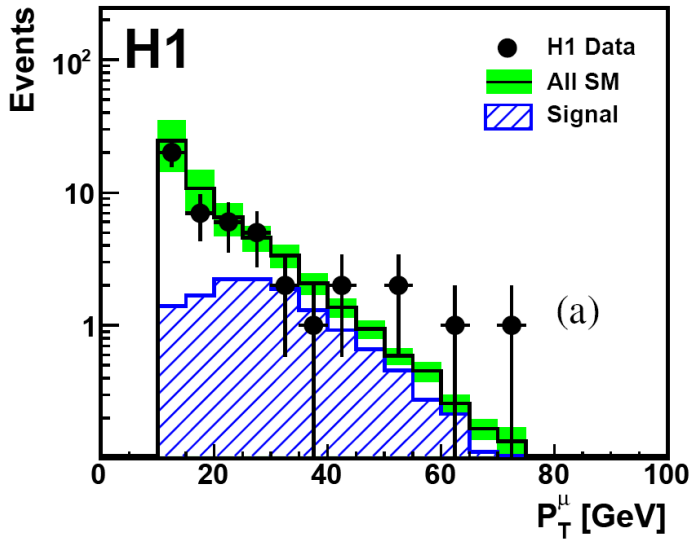


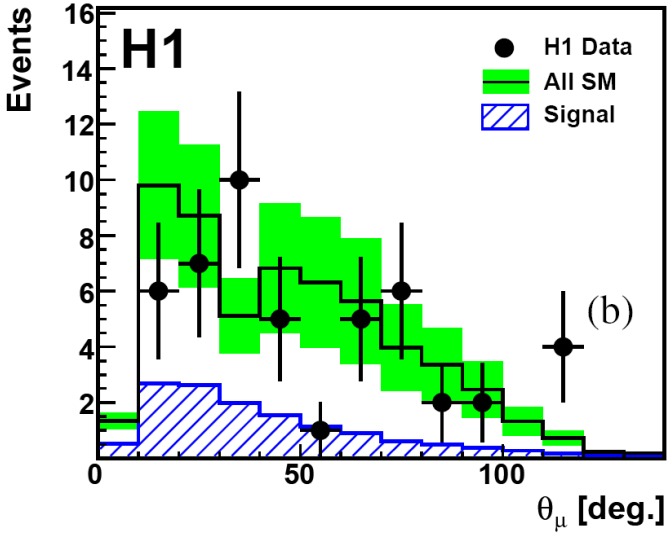


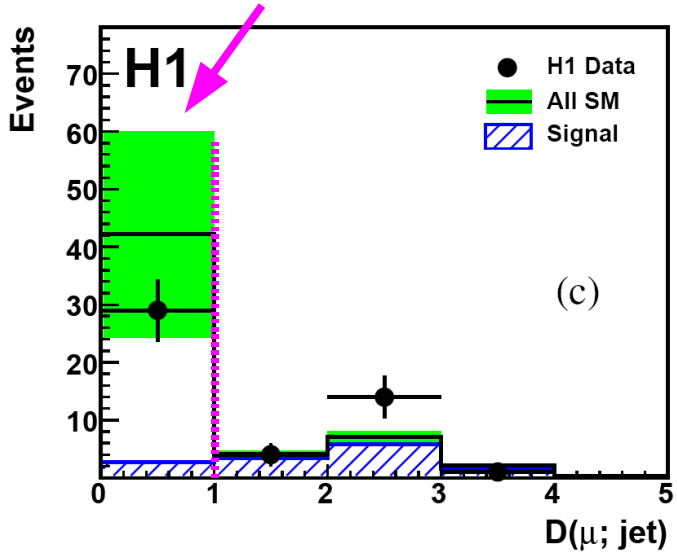


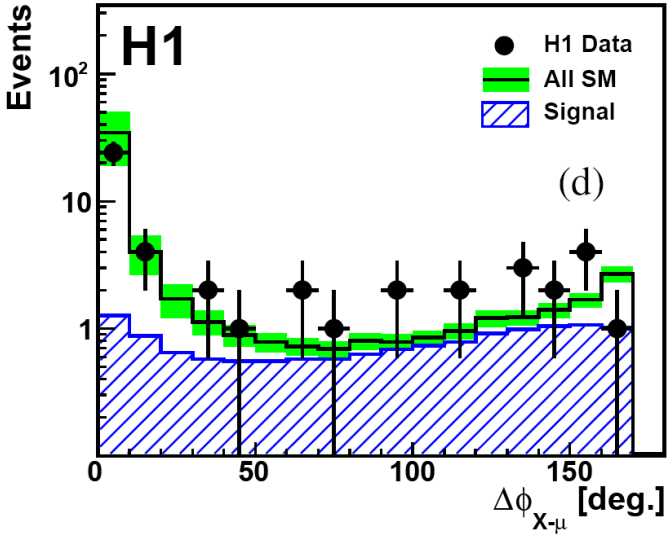
Muon Channel – CC Enriched Control Sample

- Origin of isolated muon events CC background?
- Remove anti-CC cuts (D_{jet})
- Fake or real muons in CC jets described within 50%



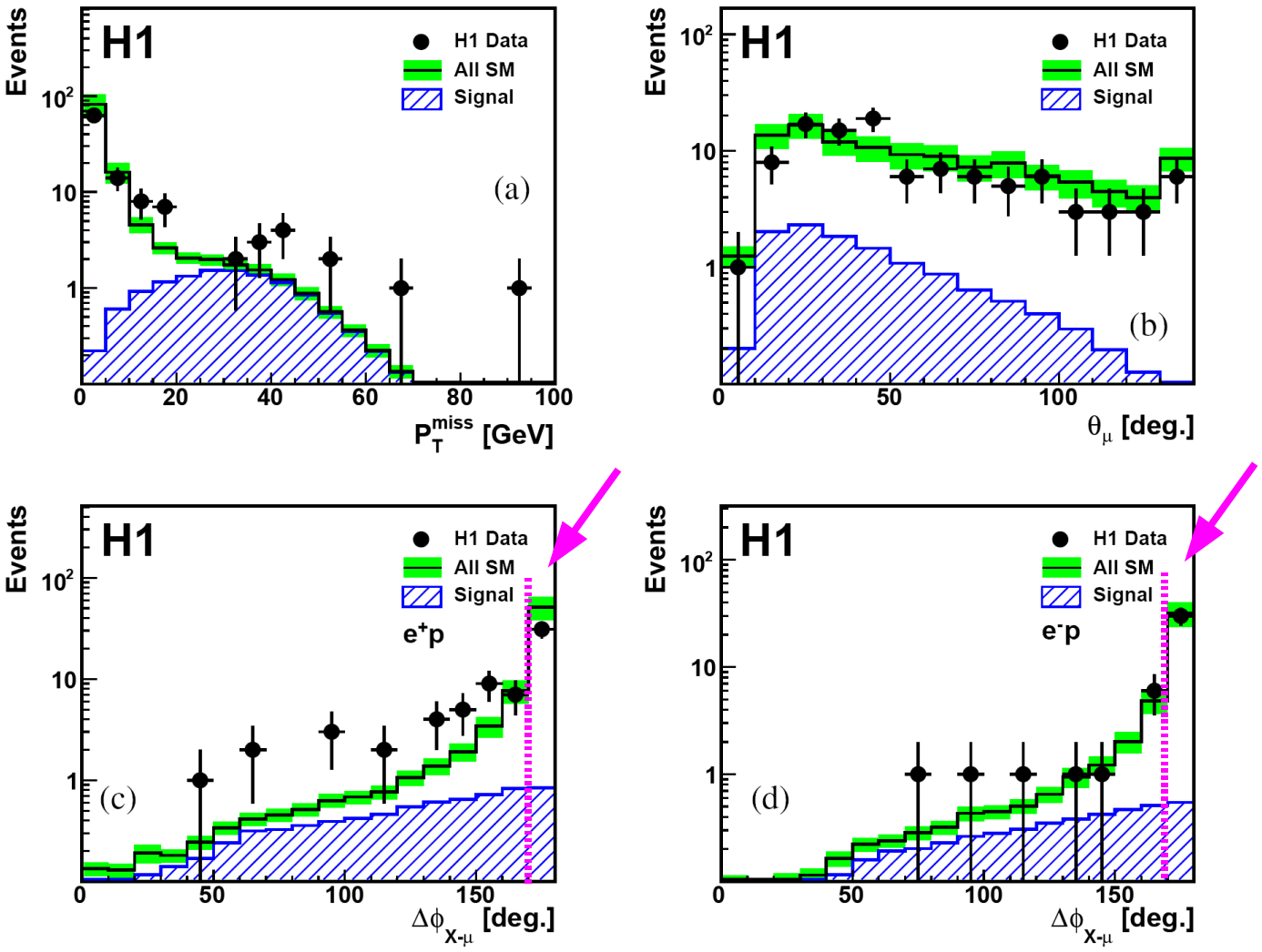






Muon Channel – Muon-Pair Control Sample

- Origin of muon events lepton-pair production? (One muon may not be detected)
- Remove Anti-lepton-pair cuts (P_T^{miss}, $\Delta\phi$)
- Lepton-Pair Production described in enriched region



H1 Isolated Leptons Production Cross Section

→ *Measure cross section of the isolated leptons events...*

- Treat SM prediction including SM as background
- Measure model-independent cross section
  (Estimate acceptance with SM EPVEC and BSM single top events)

$$\sigma = \frac{N_{\text{obs}} - N_{\text{bg}}^{\text{MC}}}{\mathcal{L}\mathcal{A}}$$

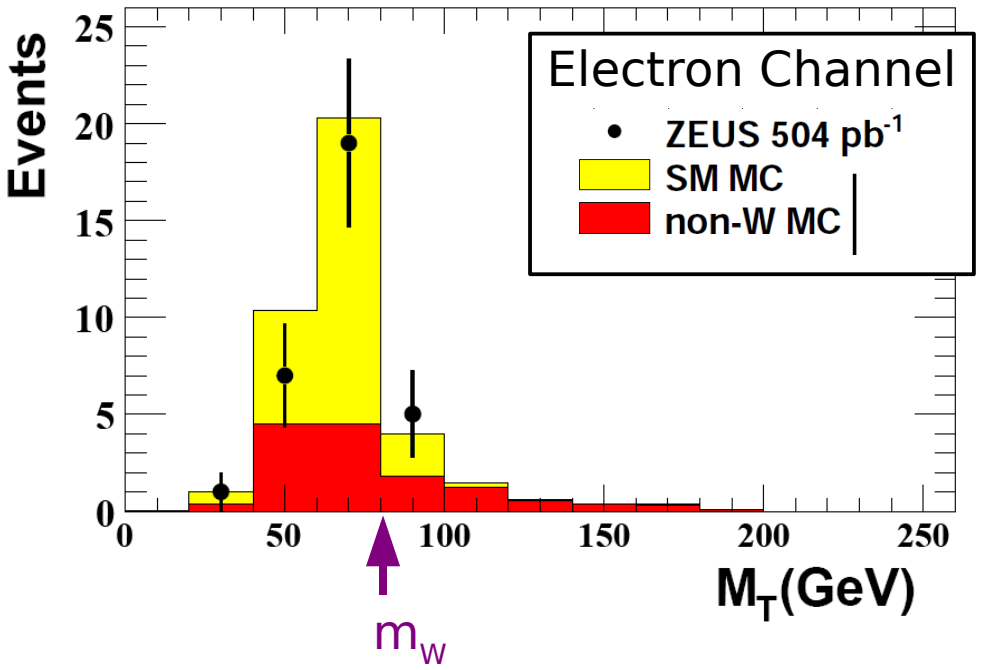
$$\sigma_{\ell+P_T^{\text{miss}}} = 0.23 \pm 0.05\ (\text{stat.}) \pm 0.04\ (\text{sys.})\ \text{pb}$$

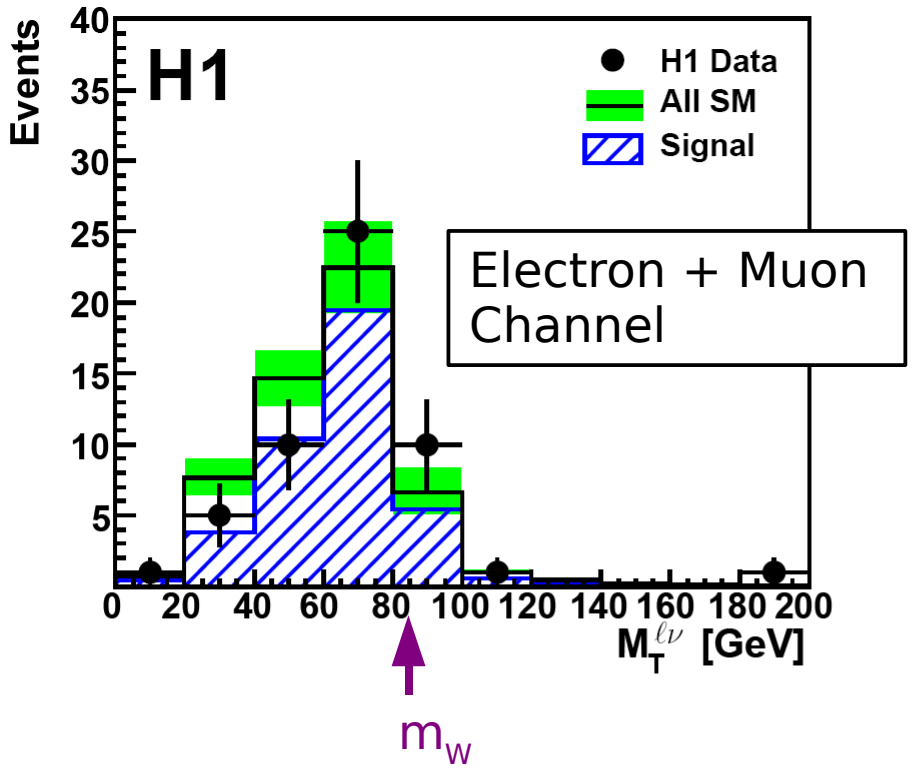
Differential breakdown [fb]:

H1 Isolated Lepton and P_T^{miss} Cross Section			
		Measured ± stat. ± sys. [fb]	SM NLO [fb]
Electron	$P_T^X \leq 12$ GeV	$63 \pm 22 \pm 13$	84 ± 13
	$P_T^X > 12$ GeV	$54 \pm 17 \pm 9$	49 ± 7
Muon	$P_T^X > 12$ GeV	$56 \pm 16 \pm 7$	44 ± 7
Combined	$P_T^X \leq 25$ GeV	$164 \pm 45 \pm 32$	207 ± 31
	$P_T^X > 25$ GeV	$64 \pm 18 \pm 10$	47 ± 7
	Total	$228 \pm 48 \pm 39$	253 ± 38

Transverse Mass Distributions

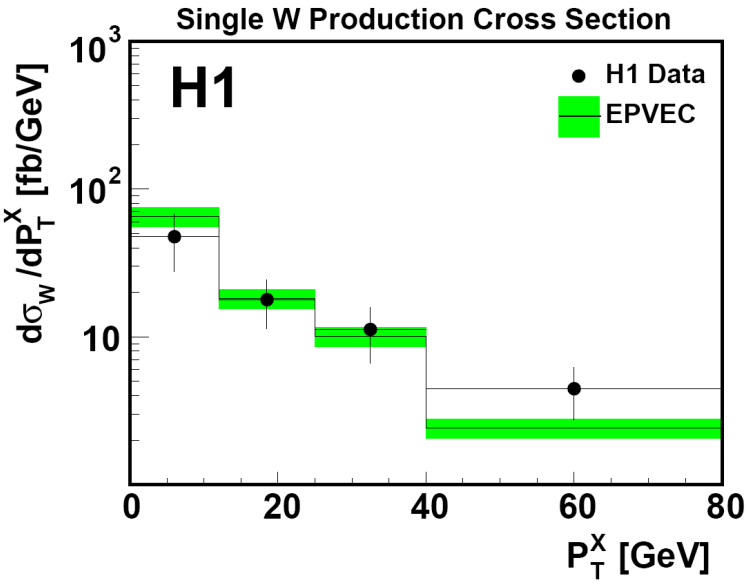
$$M_T^{\ell\nu} = \sqrt{(P_T^{\text{miss}} + P_T^{\ell})^2 - (\vec{P}_T^{\text{miss}} + \vec{P}_T^{\ell})^2}$$



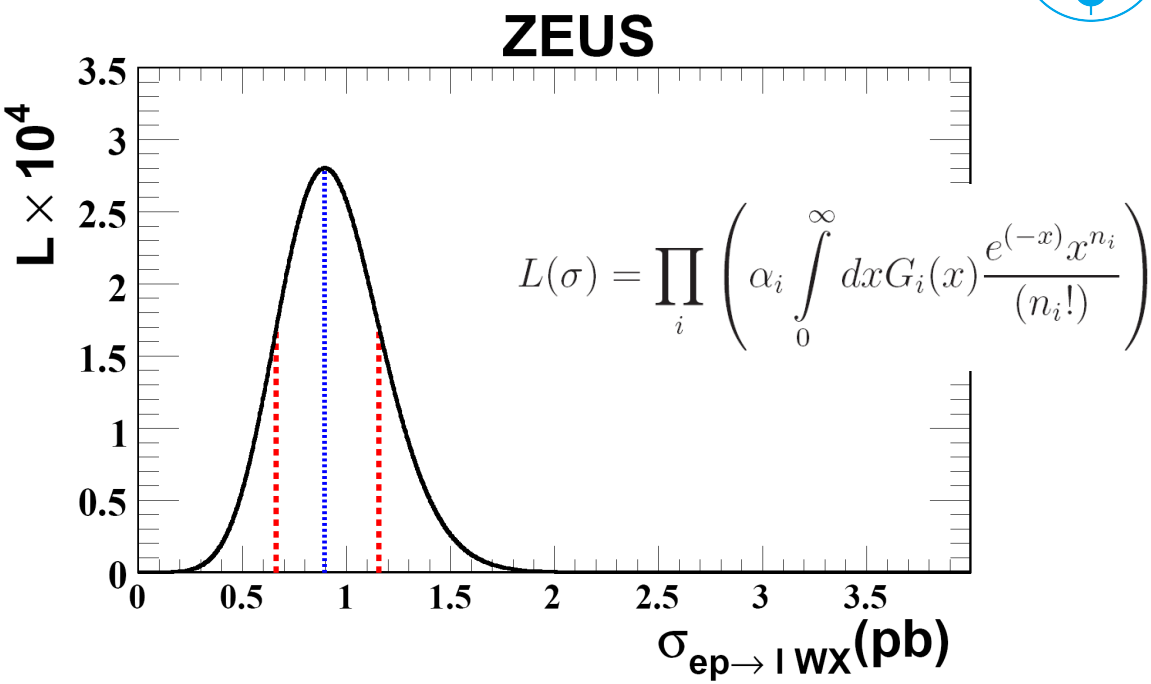


- High Purity of ~75% of *W* Prediction
- Clear Jacobian Peak
- Strong evidence for *W* Production at HERA
- Allows measurement of Single *W* Production Cross Section

W Production Cross Section Measurements



$$\sigma = \frac{N_{\rm obs} - N_{\rm bg}^{\rm MC}}{\mathcal{L}\mathcal{A}}$$



Likelihood Fit

ZEUS

$$0.89^{+0.25}_{-0.22}\,(\text{stat.}) \pm 0.10(\text{syst.})\,\text{pb},$$

H1

$$\sigma_W = 1.14 \pm 0.25\,(\text{stat.}) \pm 0.14\,(\text{sys.})\,\text{pb}$$

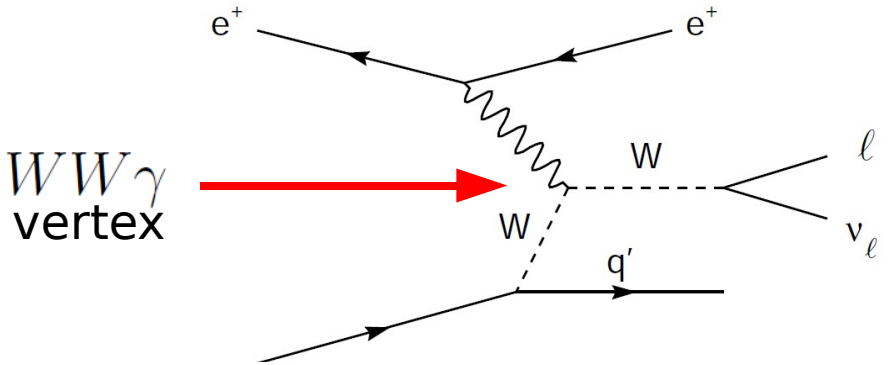
EPVEC

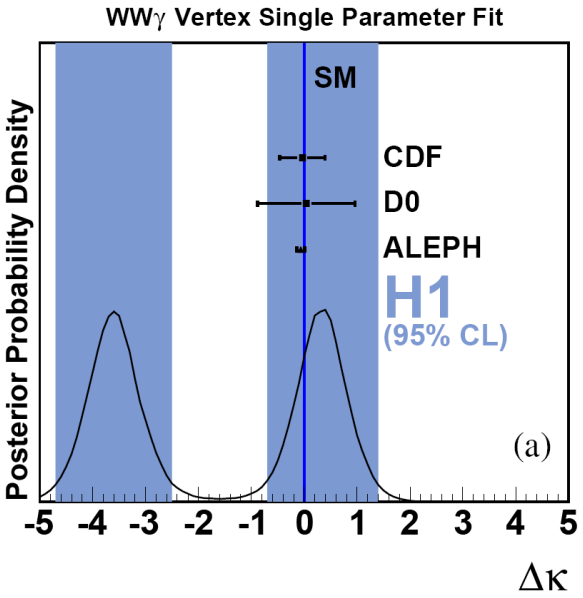
$$1.27 \pm 0.19\ \text{pb}$$

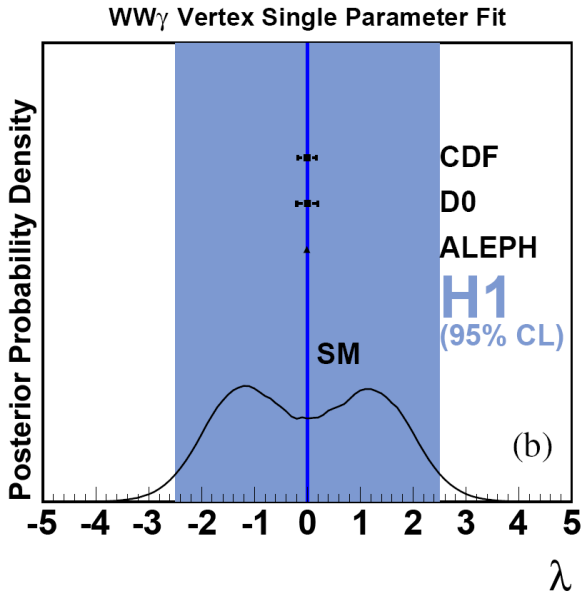
- *W* Cross Section Measurements compatible within errors

Measurement of $WW\gamma$ Vertex Parameters

- Production of W Bosons is sensitive to triple gauge couplings
- Attempt to provide complementary information to LEP, Tevatron on the $WW\gamma$ Vertex coupling parameters $\Delta\kappa$, λ
- H1 Measurements compatible to W production at other colliders







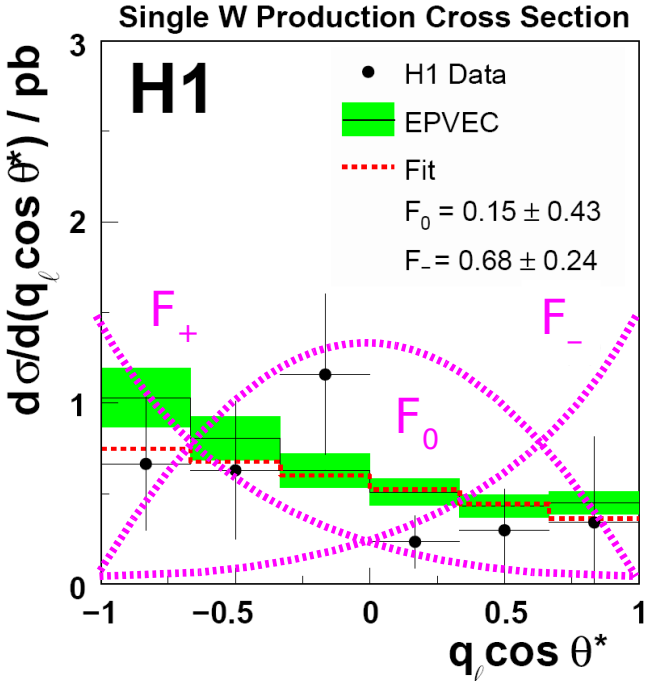
$$-4.7 < \Delta\kappa < -2.5 \quad \text{or} \quad -0.7 < \Delta\kappa < 1.4,$$

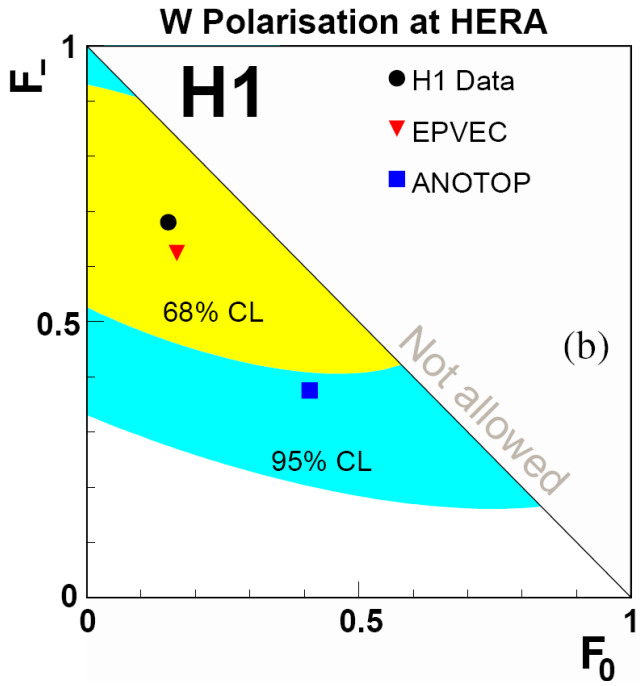
$$-2.5 < \lambda < 2.5.$$

H1 W Polarisation Fractions

- *W* polarisation fractions sensitive to angular properties of the decay
- May be different for SM and BSM contributions
- Measure for single *W* Production, and test with anomalous top production model
- Difference demonstrated, but sensitivity at 1σ level

Method:
Measure differential *W* cross section in $q_l^*(\cos\theta^*)$
Fit F- (LH), F+ (RH), F0 (longitudinal) *W* polarisation Fractions





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

Tau Channel

Tau Channel interesting addition to Electron / Muon Channels

SM - Lepton universality: tau leptons produced like e / μ

SUSY - non-zero RPV couplings connect different generations
- In many scenarios LSP $\tilde{\tau}_1 \longrightarrow \tau\nu_i$

Look for hadronic 1-prong tau-decays in events with P_T^{miss}

- *Tau Identification at HERA challenging business (small cross sections, difficult hadronic environment)*
- *Other HERA Tau Analyses – Full "lepton programme" covered*

HERA-I: Isolated Tau Leptons — 6 / 9.9±3.0 (0.9 from *W*)
Low-P_T Tau-Pairs — $\sigma_{\tau\tau}$ = 13.6±5.7 pb

HERA-I: Isolated Tau Leptons — 2 / 0.2±0.05 at $P_T X > 25$ GeV
HERA-II: High-P_T Tau-Pairs (prelim.)

Isolated Tau Leptons – Selection Details

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	$N_{\text{tracks}}^{D\text{jet}<1.0} = 1$ $N_{\text{NVtracks}}^{D\text{track}<0.3} = 1$

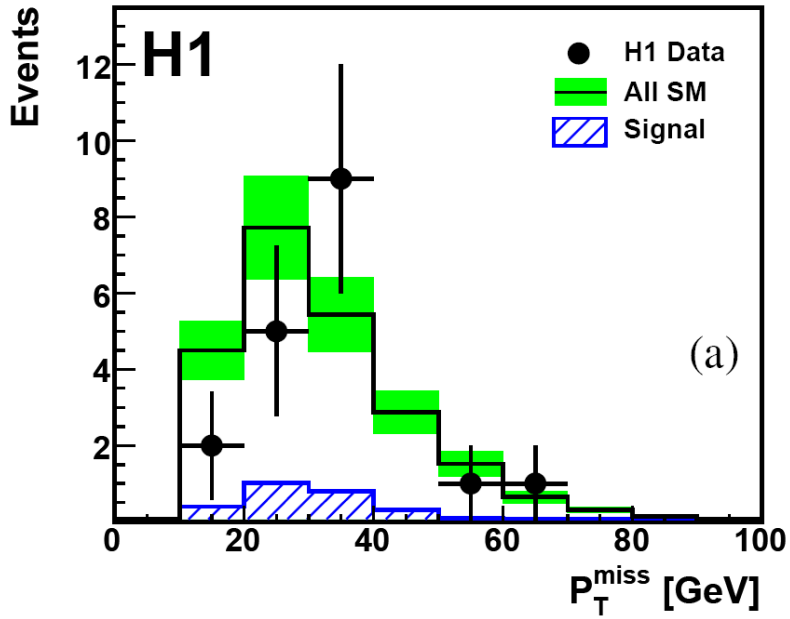
Missing Energy

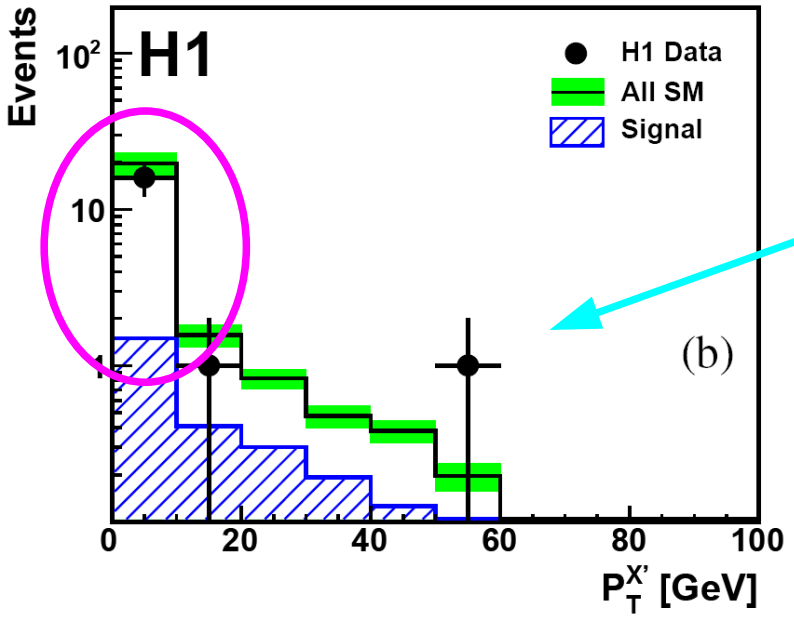
Narrow High-P_T Jet

Exactly one track in jet

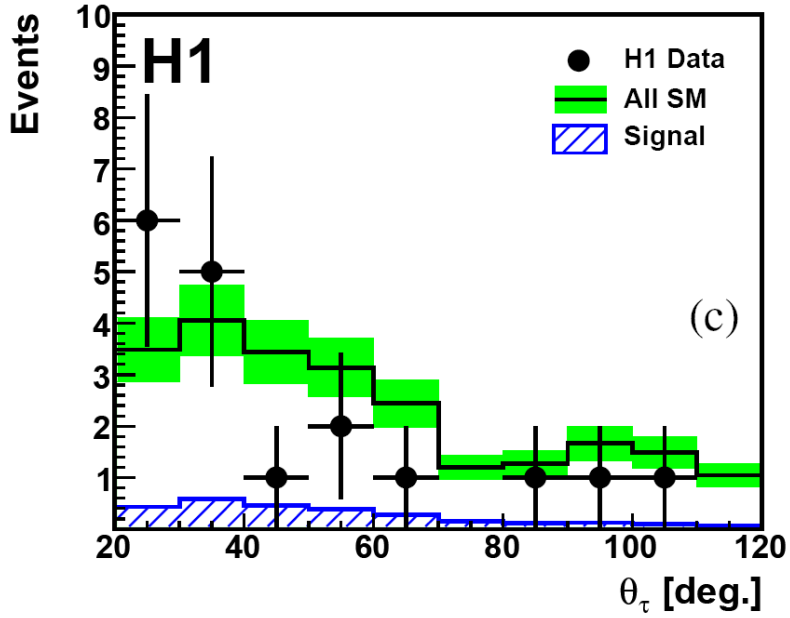
Isolated Tau Leptons – Kinematic Distributions

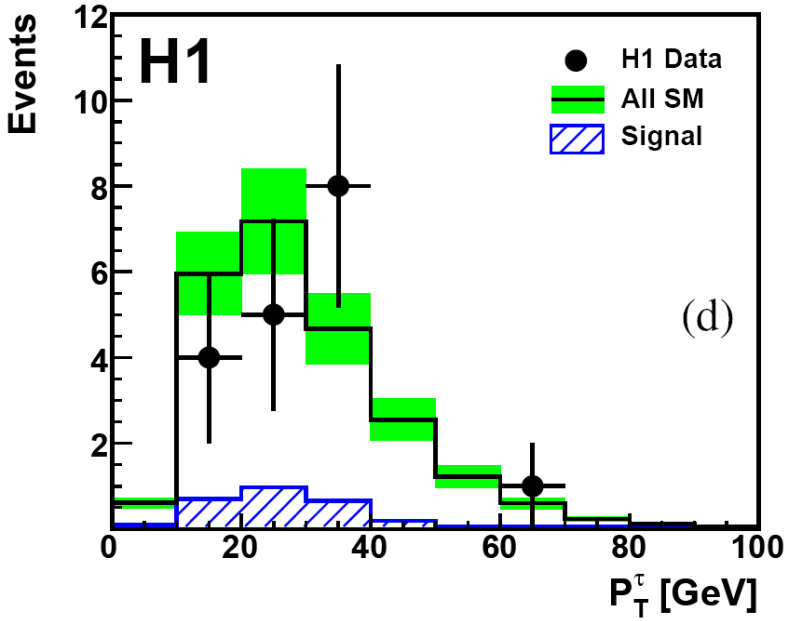
$\tau + P_T^{\text{miss}}$ events at HERA ($e^{\pm}p$, 474 pb^{-1})





Interesting Event at High P_T^X





Good overall agreement with SM (dominated by CC DIS)

H1 Tau Channel – Event Yields

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

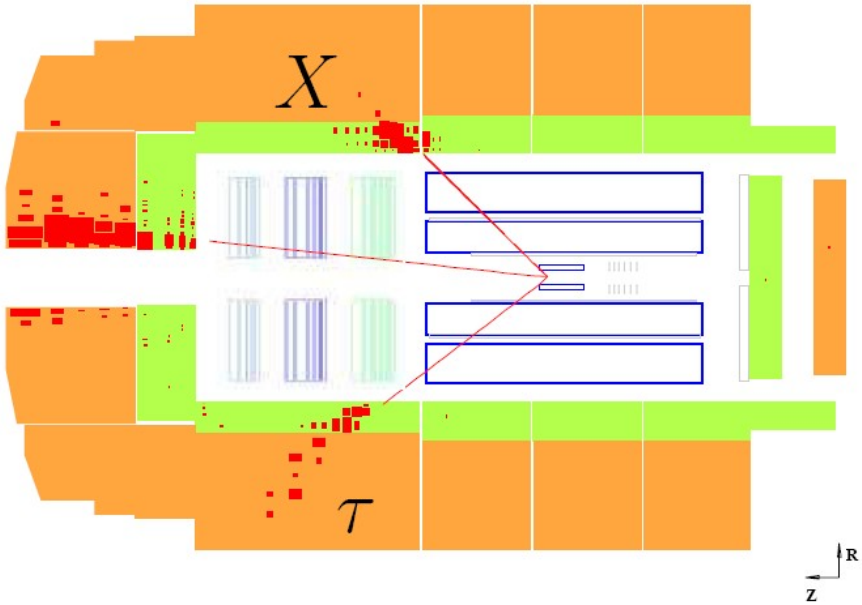
- Challenging hadronic environment
- Small tau production cross section in SM
- Expectation dominated by CC background

- H1 HERA I+II:

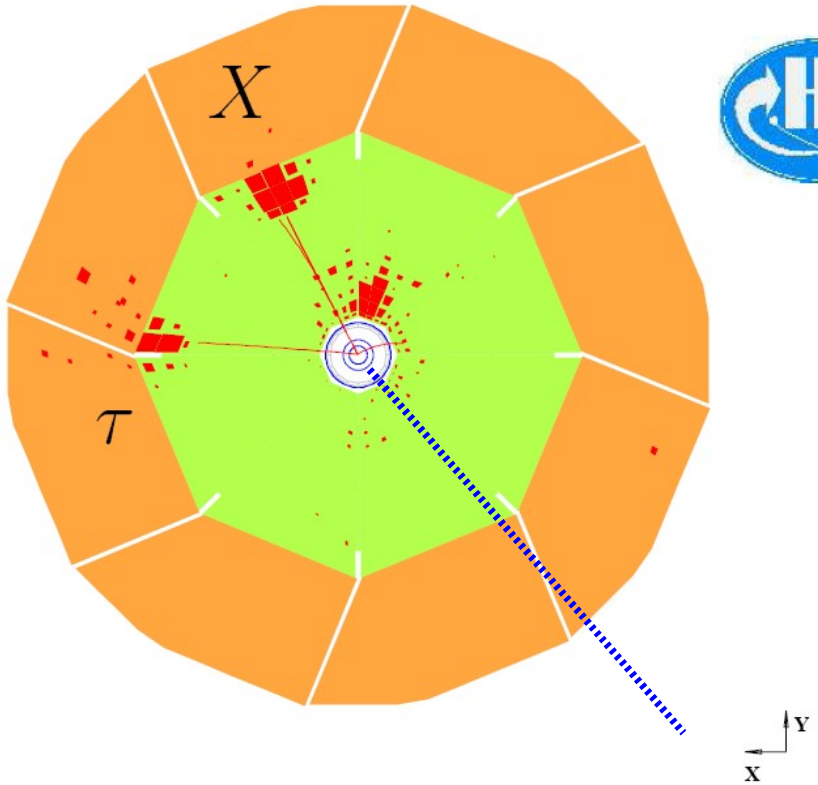
No signal for (enhanced) tau lepton production observed

Isolated Tau Lepton Candidate

$P_T^X = 56$ GeV



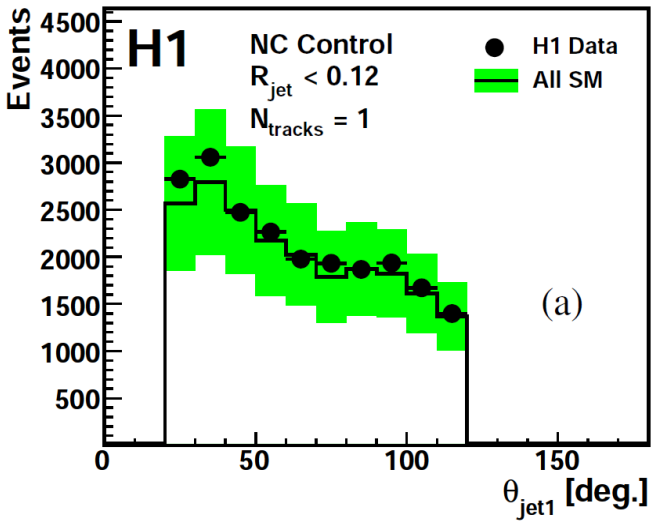
$P_T = 14$ GeV

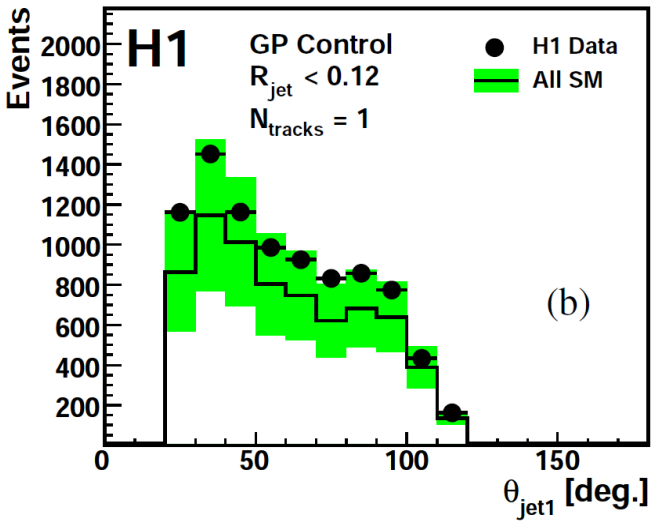


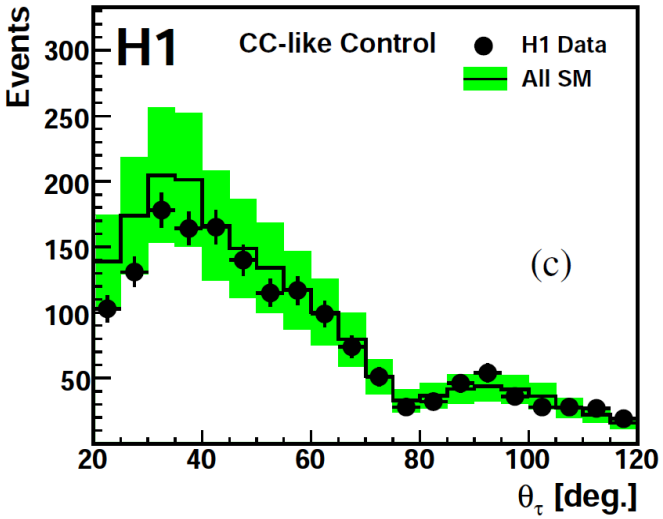
$P_T^{miss} = 60$ GeV

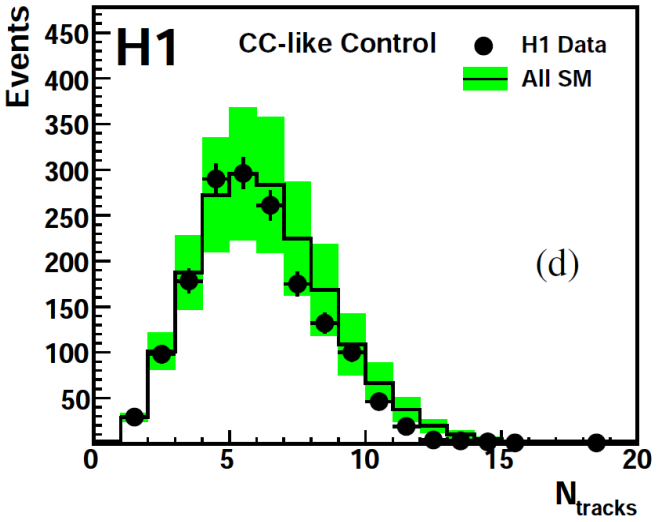
Tau Channel Control Samples

Look at narrow jets with 1 track in NC, γP samples









Track Multiplicity in narrow jets well described

Summary

- Full HERA data searched by the H1 and ZEUS Collaborations for Events with Isolated Leptons and Missing Transverse Momentum

Good overall agreement with the Standard Model

Interesting Events observed at high P_T^X by H1

- Single *W* Production Cross Section measured

- Dynamics of W production and decay probed

  $WW\gamma$ Vertex Coupling Parameters constrained

  W Polarisation Fractions probed

- Searched for Events with Isolated Tau Leptons + $P_T$miss
  Challenging background – no pure event sample selected

H1 Event Kinematics ($P_T^X > 25$ GeV)

H1 Isolated Lepton Events at High P_T^X							
Run	Event	Lepton $^{q(\sigma_q)}$	P_T^ℓ [GeV]	θ_ℓ [$^\circ$]	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

- Kinematics of high-P_T^X events published by H1

H1 W Cross Sections Results

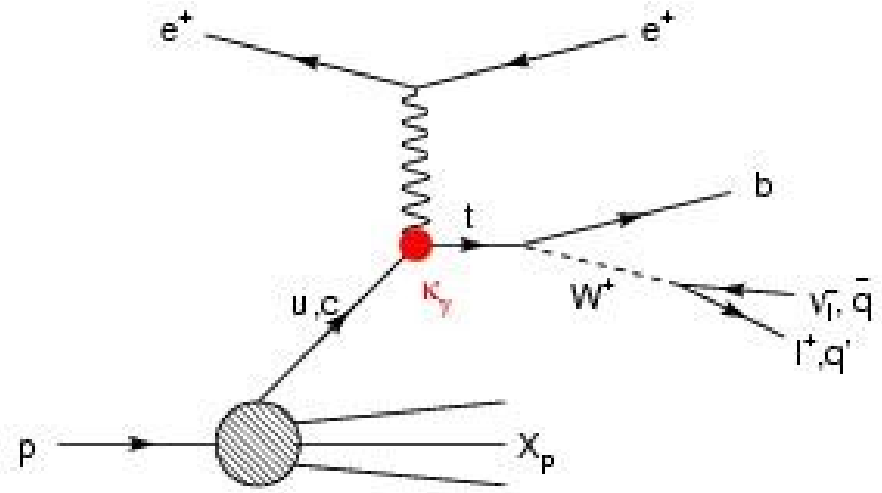
H1 Differential Single W Production Cross Section at $\sqrt{s} = 317$ GeV		
P_T^X [GeV]	Measured $\pm$ stat. $\pm$ sys. [fb / GeV]	SM NLO [fb / GeV]
$0 - 12$	$47.6 \pm 18.2 \pm 8.9$	65.2 ± 9.8
$12 - 25$	$17.4 \pm 6.3 \pm 1.7$	18.3 ± 2.7
$25 - 40$	$11.2 \pm 4.5 \pm 1.0$	10.1 ± 1.5
$40 - 80$	$4.5 \pm 1.7 \pm 0.6$	2.4 ± 0.4

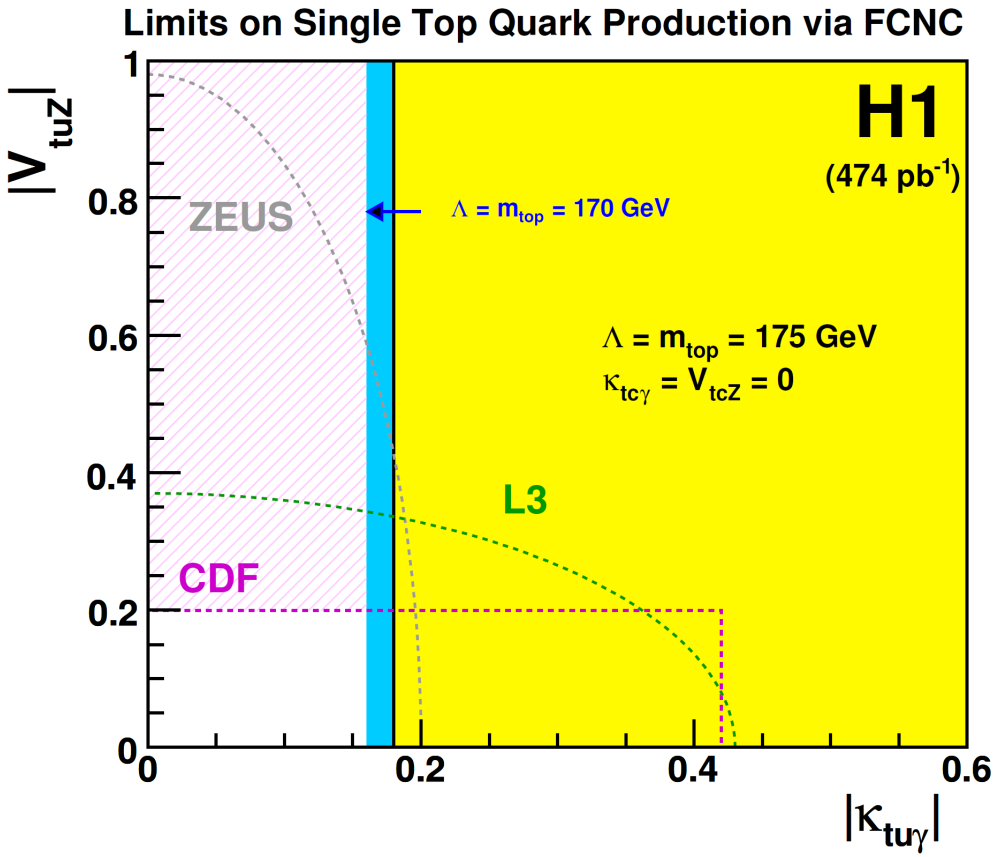
Search for Anomalous Single *top* Production

- At high P_T^X isolated leptons signature compatible to anomalous single top production via FCNC
- Study using effective couplings $\kappa_{tu\gamma}$, v_{tuZ}

- Reconstruct *top* in isolated leptons samples
- No significant excess observed
- Set limits

DESY09-050





HERA Limits on $\kappa_{tu\gamma}$ explore domain not covered by other colliders

H1 Isolated Leptons Selection Criteria

H1 Isolated Lepton $+P_T^{\text{miss}}$ Event Selection		
	Electron	Muon
Basic Event Selection	$5^\circ < \theta_\ell < 140^\circ$	
	$P_T^\ell > 10$ GeV	
	$P_T^{\text{miss}} > 12$ GeV	
	$P_T^{\text{calo}} > 12$ GeV	
Lepton Isolation	$D(\ell;\text{jet}) > 1.0$	
	$D(e;\text{track}) > 0.5$ for $\theta_e > 45^\circ$	$D(\mu;\text{track}) > 0.5$
Background Rejection	$V_{\text{ap}}/V_{\text{p}} < 0.5$	
	$V_{\text{ap}}/V_{\text{p}} < 0.2$ for $P_T^e < 25$ GeV	$V_{\text{ap}}/V_{\text{p}} < 0.2$ for $P_T^{\text{calo}} < 25$ GeV
	$\Delta\phi_{e-X} < 160^\circ$	$\Delta\phi_{\mu-X} < 170^\circ$
	$\delta_{\text{miss}} > 5$ GeV	–
	$\zeta_e^2 > 5000$ GeV^2 for $P_T^{\text{calo}} < 25$ GeV	–
	$M_T^{\ell\nu} > 10$ GeV	
	–	$P_T^X > 12$ GeV

H1 Isolated Leptons Event Yields

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

H1	1998-2006 e^-p 183 pb^{-1}	Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	11	17.5 ± 2.7	11.6 ± 1.8	5.9 ± 1.9
	$P_T^X > 25$ GeV	1	3.18 ± 0.58	2.23 ± 0.38	0.95 ± 0.41
Muon	Total	2	4.29 ± 0.69	3.96 ± 0.66	0.33 ± 0.11
	$P_T^X > 25$ GeV	0	2.40 ± 0.41	2.21 ± 0.39	0.19 ± 0.07
Combined	Total	13	21.8 ± 3.1	15.6 ± 2.4	6.2 ± 1.9
	$P_T^X > 25$ GeV	1	5.58 ± 0.91	4.45 ± 0.75	1.14 ± 0.44

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

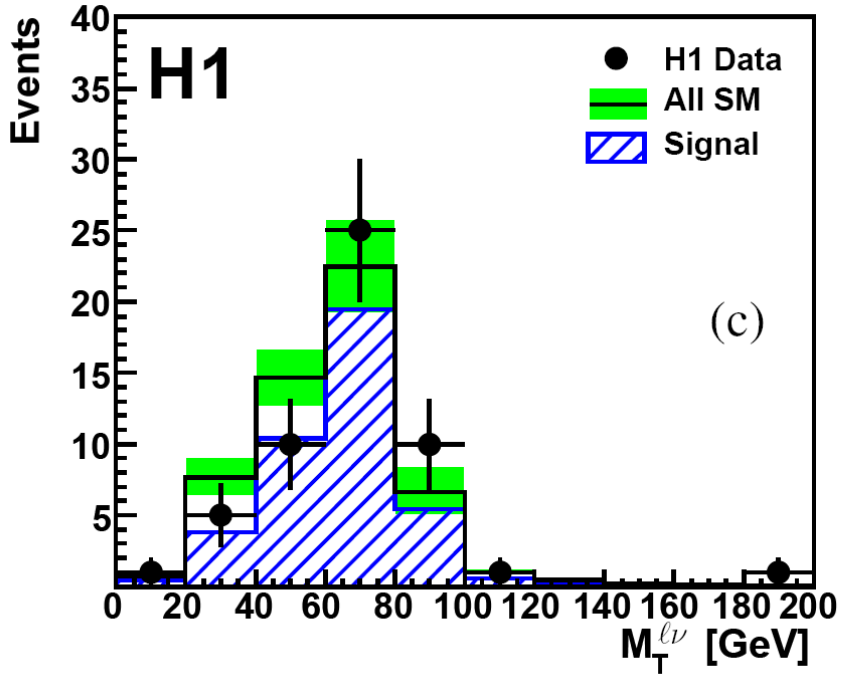
ZEUS Isolated Leptons Yield

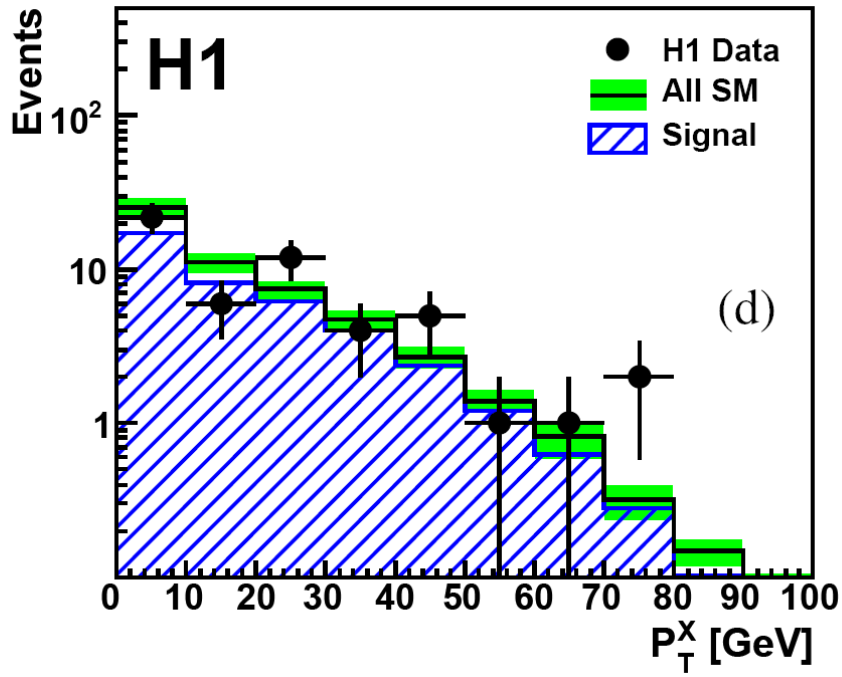
Isolated e Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb^{-1}	$9/11.3 \pm 1.5$ (54%)	$5/3.4 \pm 0.5$ (62%)	$3/3.2 \pm 0.5$ (69%)
e^+p 296 pb^{-1}	$7/12.6 \pm 1.7$ (68%)	$5/3.9 \pm 0.6$ (72%)	$3/4.0 \pm 0.6$ (77%)
$e^\pm p$ 504 pb^{-1}	$16/23.9 \pm 3.1$ (61%)	$10/7.4 \pm 1.0$ (67%)	$6/7.3 \pm 1.0$ (73%)

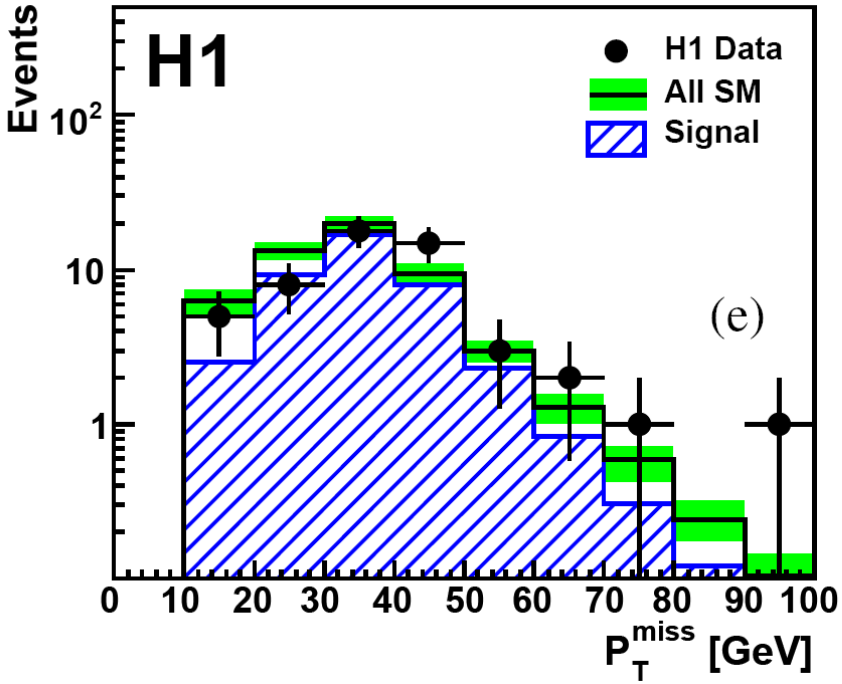
Isolated μ Candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb^{-1}	$1/1.6 \pm 0.3$ (77%)	$2/2.3 \pm 0.4$ (85%)
e^+p 296 pb^{-1}	$2/2.2 \pm 0.3$ (82%)	$3/3.4 \pm 0.5$ (81%)
$e^\pm p$ 504 pb^{-1}	$3/3.8 \pm 0.6$ (80%)	$5/5.7 \pm 0.8$ (83%)

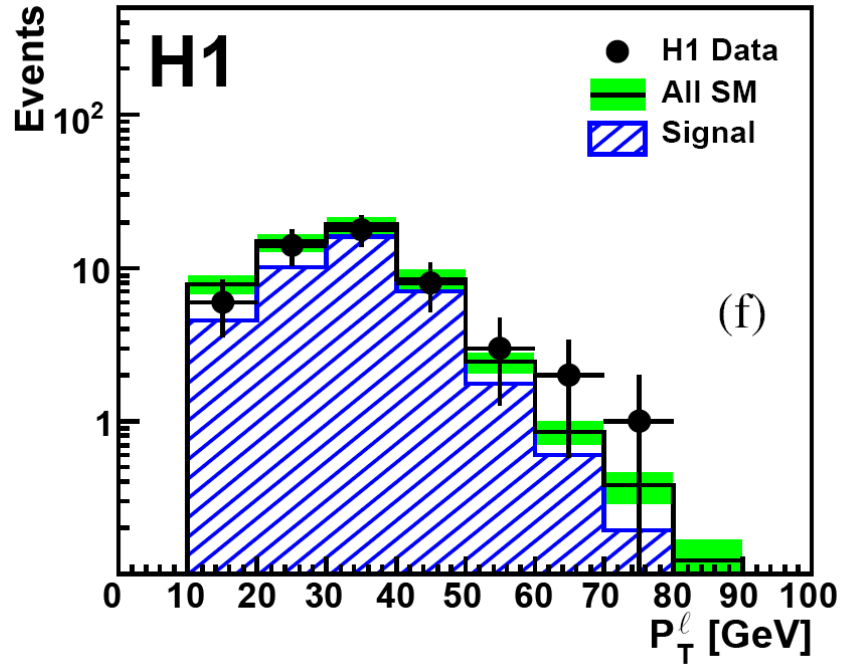
Isolated Lepton Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb^{-1}	$9/11.3 \pm 1.5$ (54%)	$6/5.1 \pm 0.7$ (67%)	$5/5.5 \pm 0.8$ (75%)
e^+p 296 pb^{-1}	$7/12.6 \pm 1.7$ (68%)	$7/6.2 \pm 0.9$ (75%)	$6/7.4 \pm 1.0$ (79%)
$e^\pm p$ 504 pb^{-1}	$16/23.9 \pm 3.1$ (61%)	$13/11.2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

H1 Kinematic Distributions

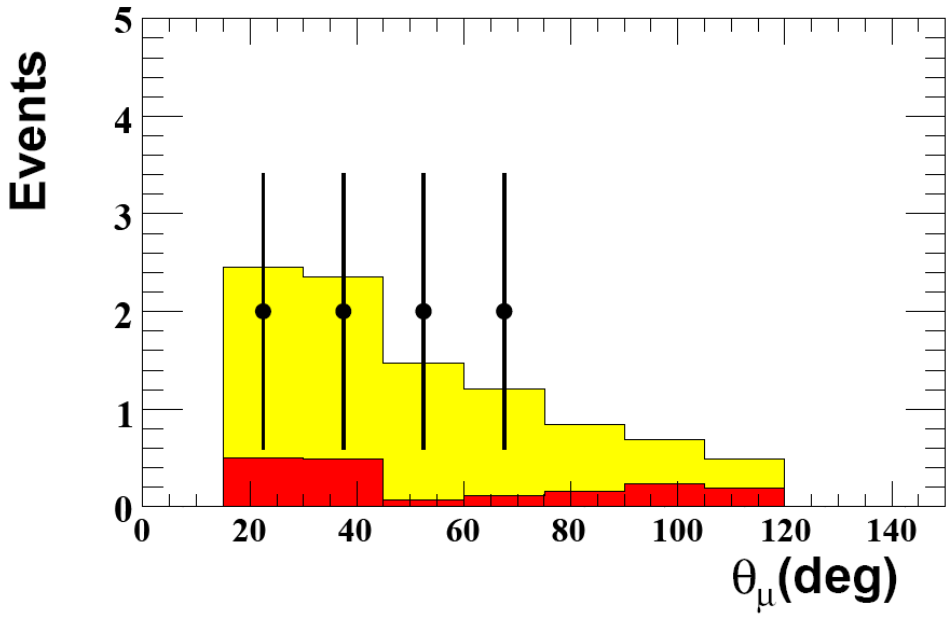


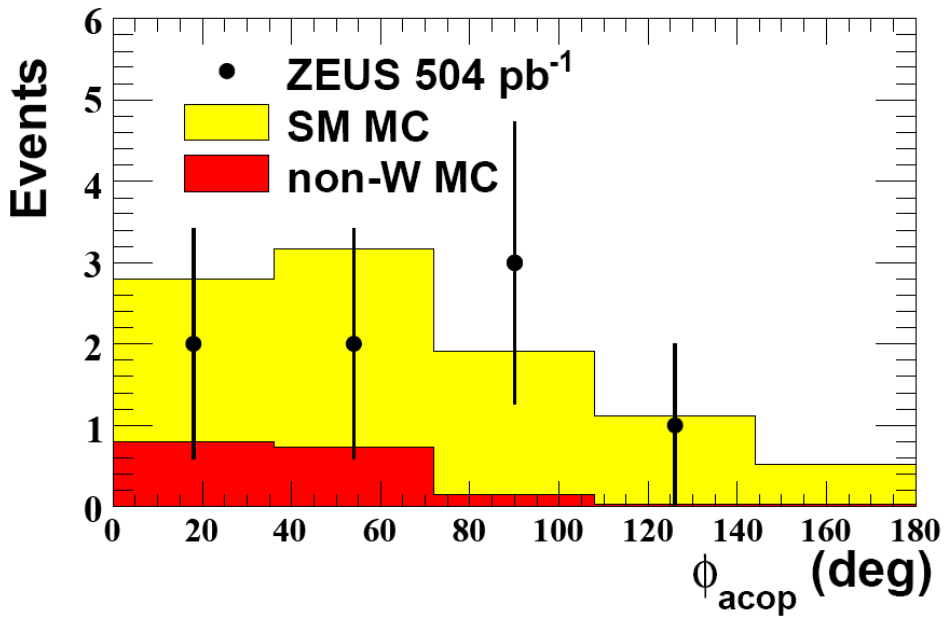


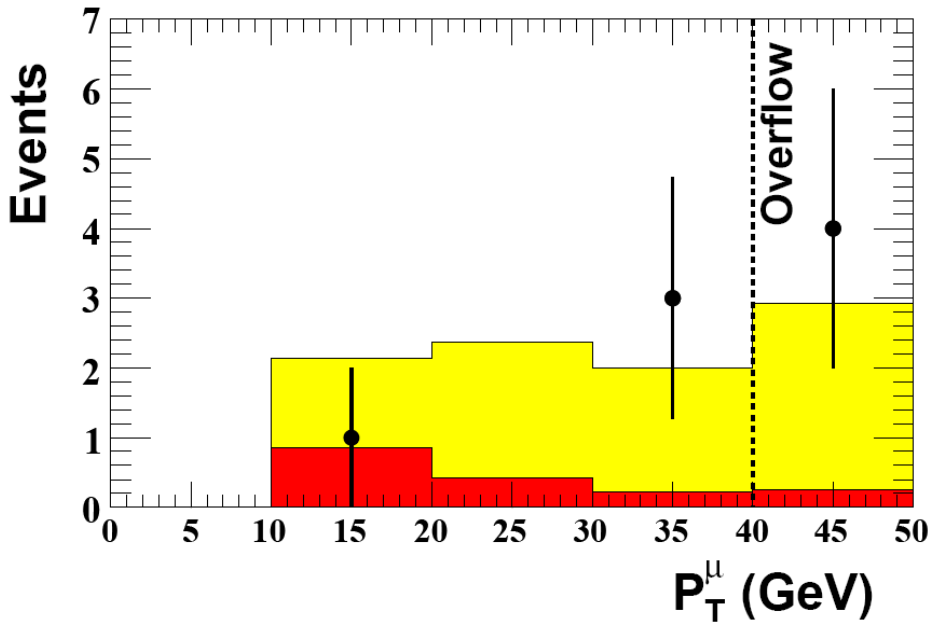


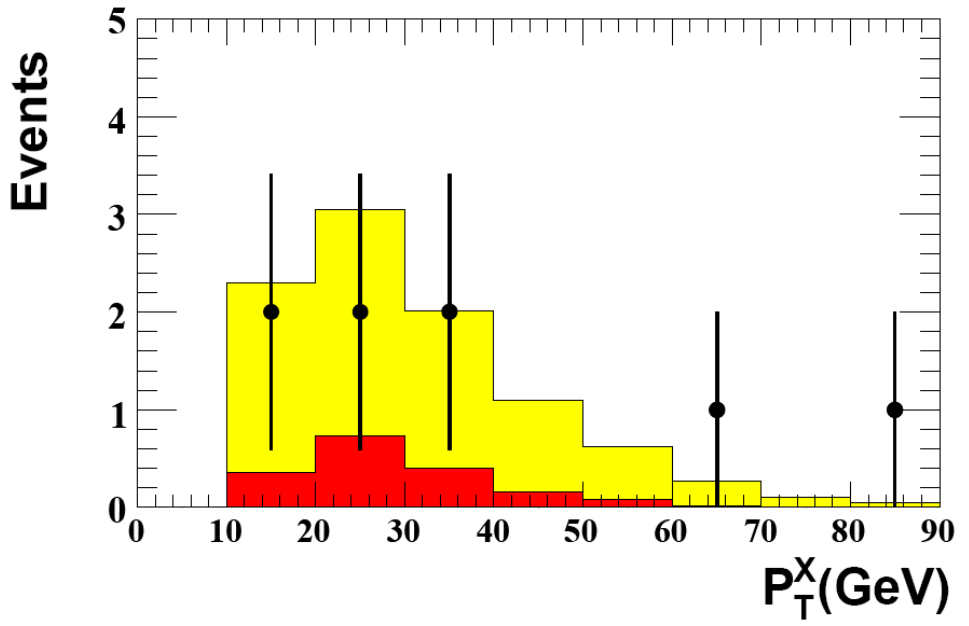


ZEUS Muon Channel – Kinematic Distributions

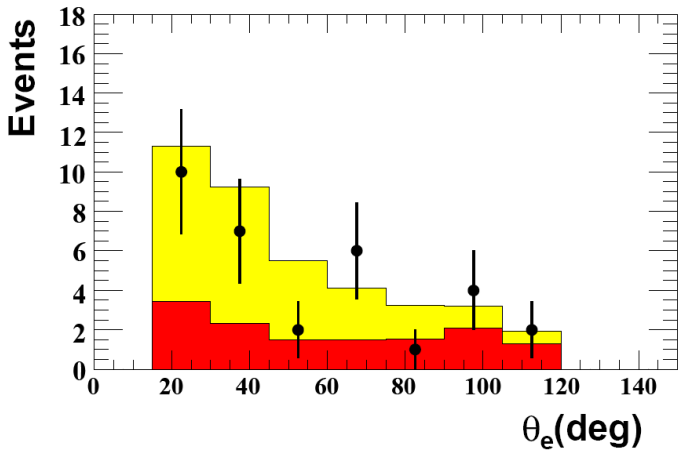


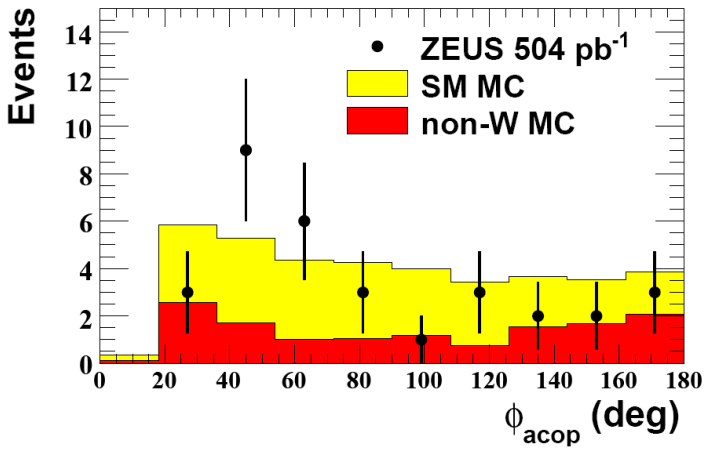


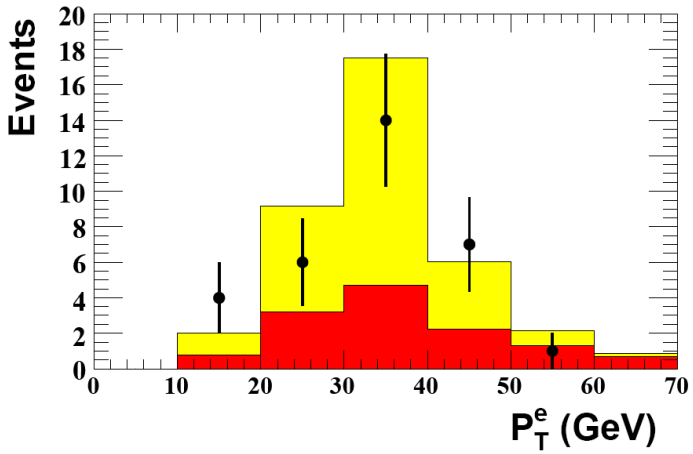


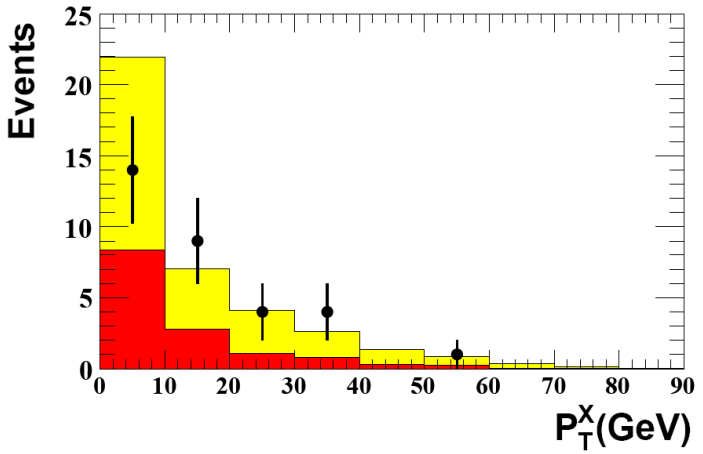


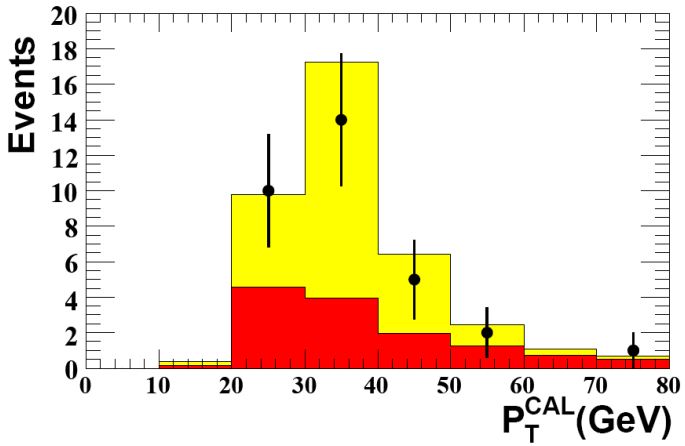
ZEUS Electron Channel – Kinematic Distributions

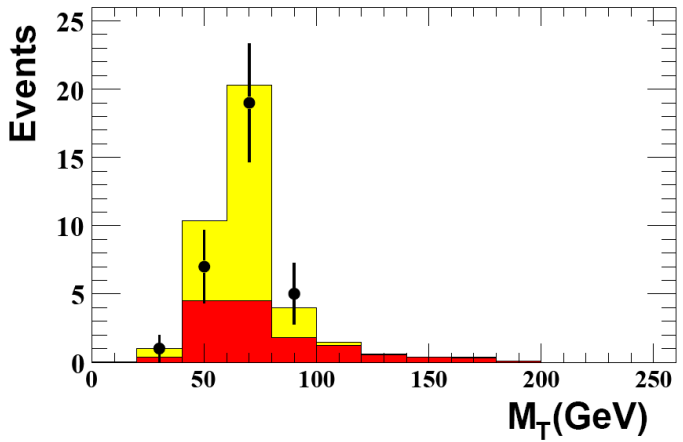












ZEUS *W* Production Cross Section Measurement

Process	$P_T^X >$ (GeV)	$\langle\sqrt{s}\rangle$ (GeV)	σ (pb)	σ_{SM} (pb)
$ep \to lWX$ $W \to e\nu_e$	0	316	$0.090^{+0.032}_{-0.028}$ (stat.) $^{+0.013}_{-0.013}$ (syst.)	0.13
$ep \to lWX$ $W \to \mu\nu_\mu$	12	316	$0.044^{+0.022}_{-0.018}$ (stat.) $^{+0.006}_{-0.006}$ (syst.)	0.05
$e^+p \to lWX$	0	315	$0.82^{+0.31}_{-0.26}$ (stat.) $^{+0.08}_{-0.08}$ (syst.)	1.2
$e^-p \to lWX$	0	318	$1.03^{+0.45}_{-0.38}$ (stat.) $^{+0.16}_{-0.16}$ (syst.)	1.3
$ep \to lWX$	0	316	$0.89^{+0.25}_{-0.22}$ (stat.) $^{+0.10}_{-0.10}$ (syst.)	1.2

$$\sigma_{ep\to lWX} = 0.89^{+0.25}_{-0.22}\,(\mathrm{stat.}) \pm 0.10(\mathrm{syst.})\,\mathrm{pb},$$