Events with isolated leptons and missing transverse momentum at HERA

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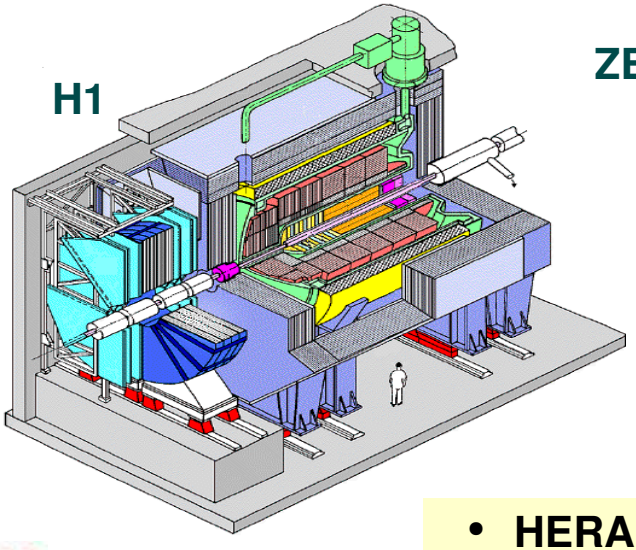
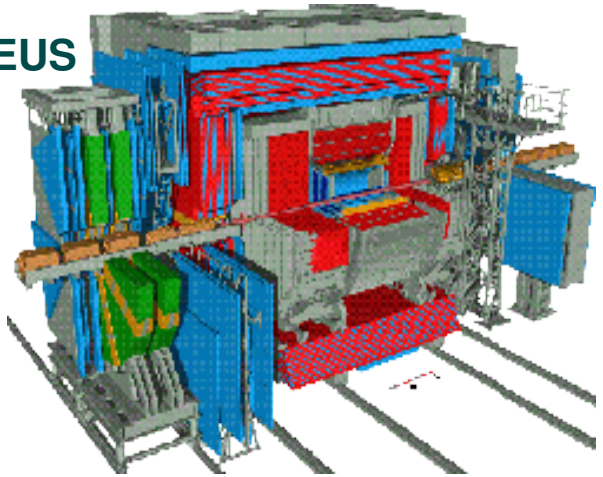
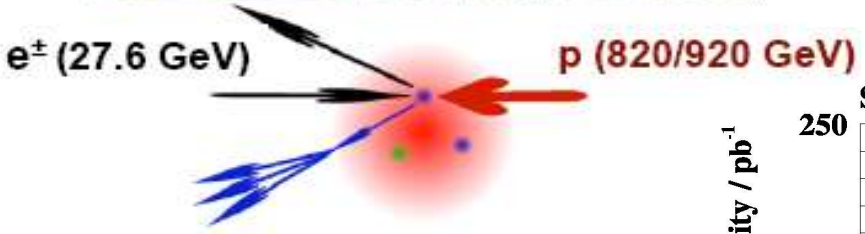
on behalf of H1 and ZEUS collaborations

- Introduction
- Selection of events with e or μ and P_T^{miss}
- Results
- H1/ZEUS comparison
- Search for events with τ+P_T^{miss}
- Conclusions and outlook

HERA 1992-2006

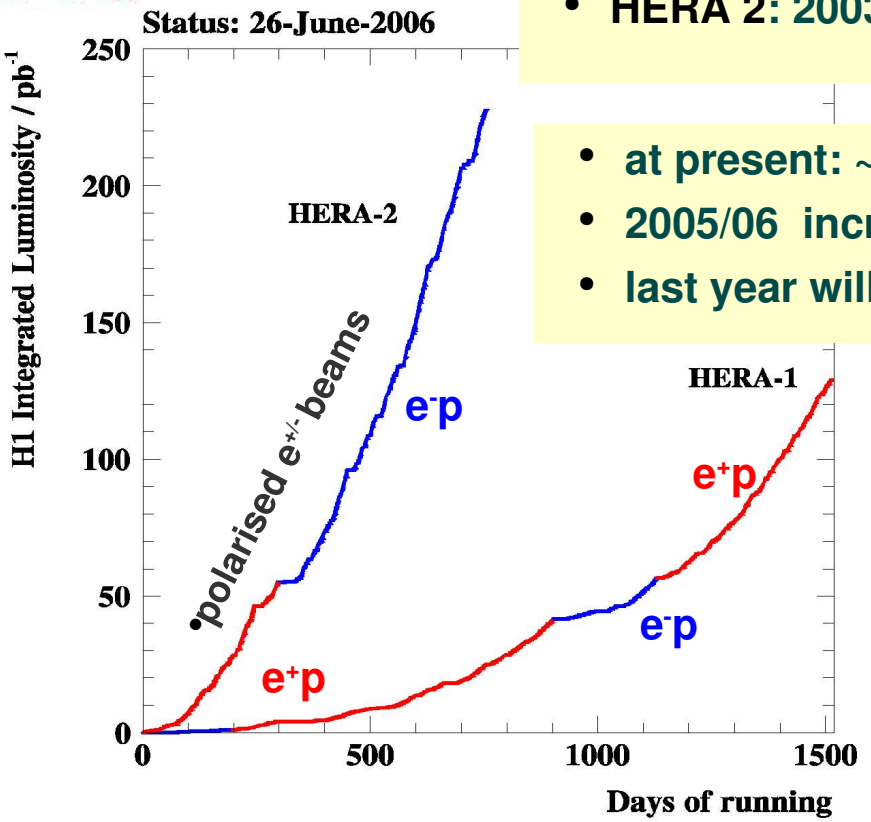






- **HERA 1**: 1992-2000 ~130 pb^{-1}/expt
- **HERA 2**: 2003-2007 luminosity upgrade

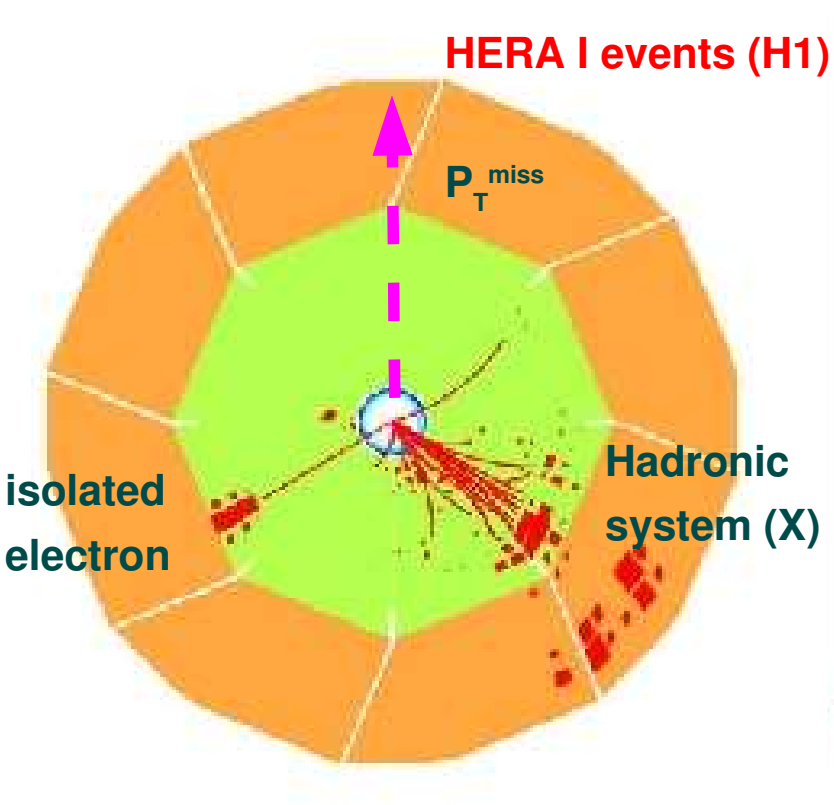
- at present: ~160 pb^{-1} e+p ~200 e$^-$p
- 2005/06 increase >10x L(e-p)
- last year will collect e+p :2xL(e+p)

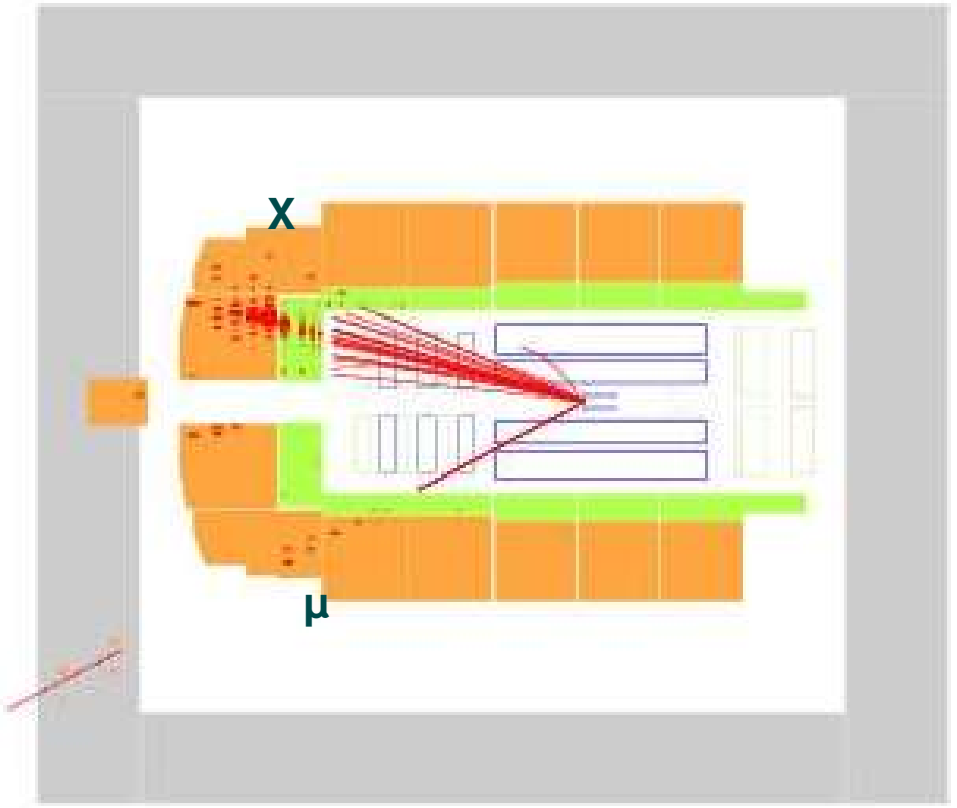


- **Collision mode: H1 and ZEUS**
- **Hermetic, multi-purpose detectors**
- **Calorimetry and tracking in both central and forward region**
  - **Excellent lepton identification**
  - **Excellent e.m./hadronic energy measurement**

Rare phenomena σ~ 1pb may become visible at HERA

Event with isolated leptons and P_T^{miss}





Observation by H1: L=118 pb^{-1} (mainly e^+p, first events in 1994)

Spectacular events at large PTX in excess (still consistent with a stat. fluct.)

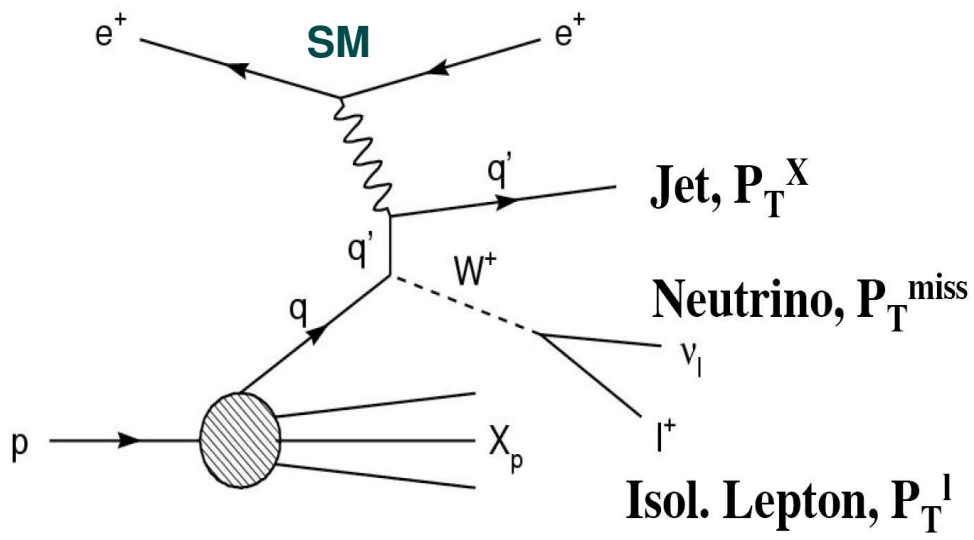
P_T^X>25 GeV 11 (Data) / 3.5±0.6 (SM) Phys.Lett.B561:241-257,2003

Not supported by ZEUS (search for top, higher P_T) Phys.Lett.B559:153-170,2003

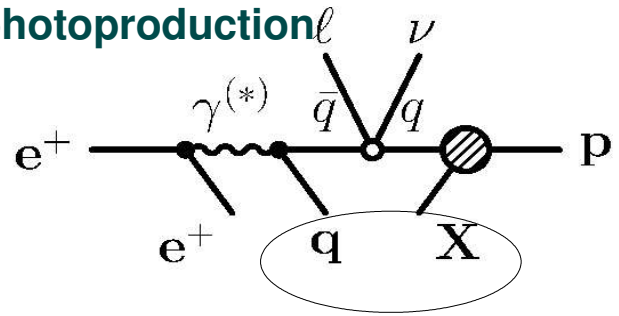
H1 analysis using new data : L=341 pb^{-1}

New preliminary ZEUS analysis : L=249 pb^{-1}

Events with isolated leptons and P_T^{miss}



Mostly W photoproduction



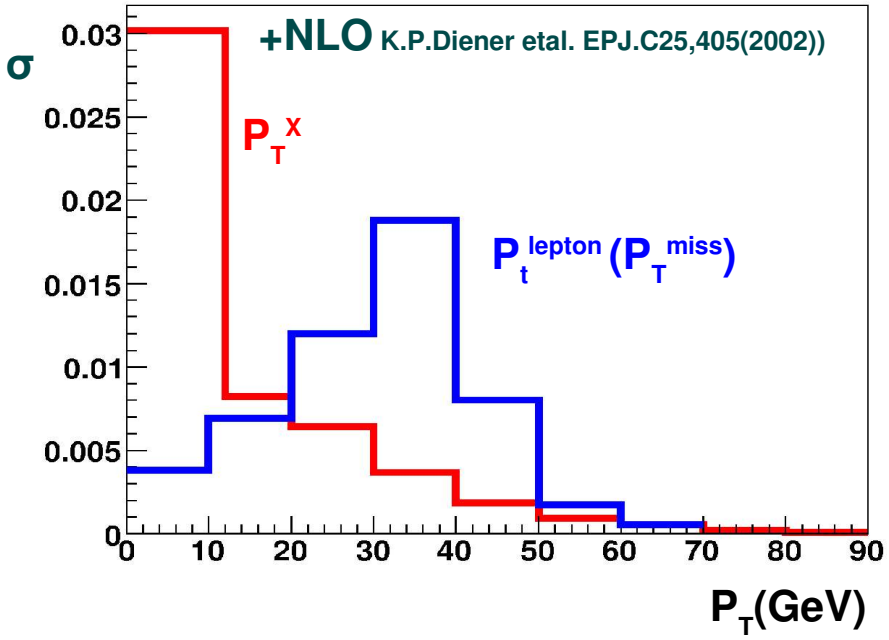
hadronic system
typically "quiet"

Total Cross Section ~1.3 pb

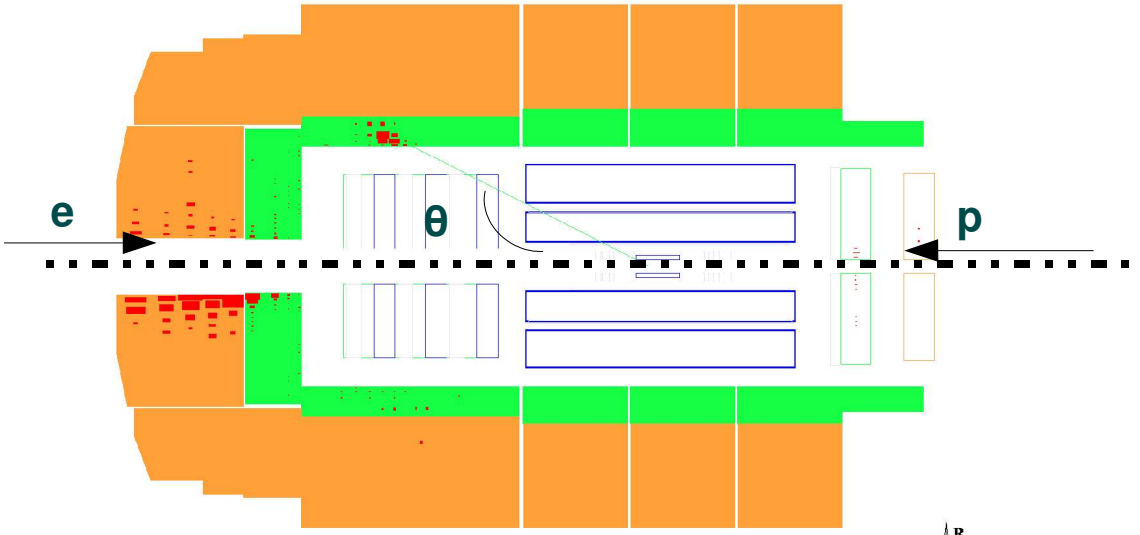
=> ~5 events/100pb^{-1}with e or μ

[Hadronic channel is difficult, due to QCD background.]

EPVEC Generator U.Baur at al., Nucl.Phys.B375:3(1992

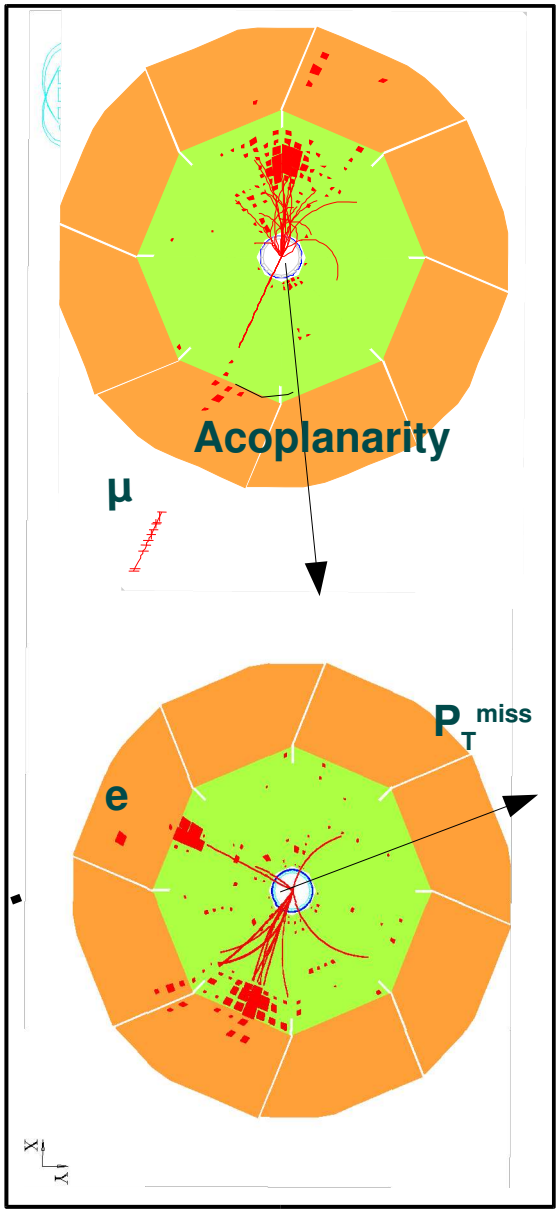


Typical W→e+P_T^{miss} event (Monte Carlo)

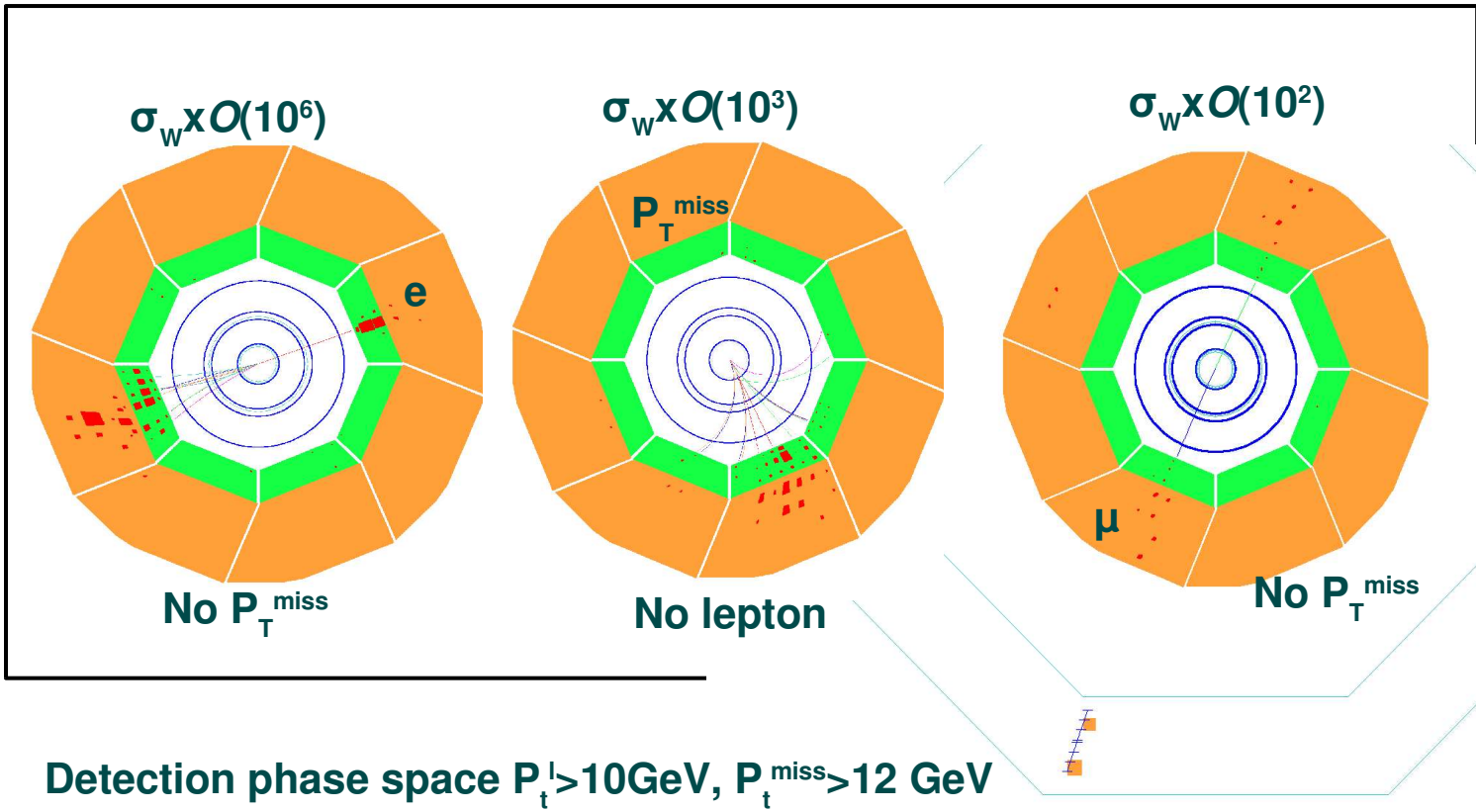


Signal/Background Discrimination

Signal



Backgrounds



Detection phase space P_t^l>10GeV, P_t^{miss}>12 GeV

reduce most of the background

Further background supression using:

- -lepton isolation D_{track} , D_{Jet}
- -event balance (Acoplanarity)
- -extra-kinematics (M_T^{lv}) + other topological variables

Selection of e+P_T^{Miss}

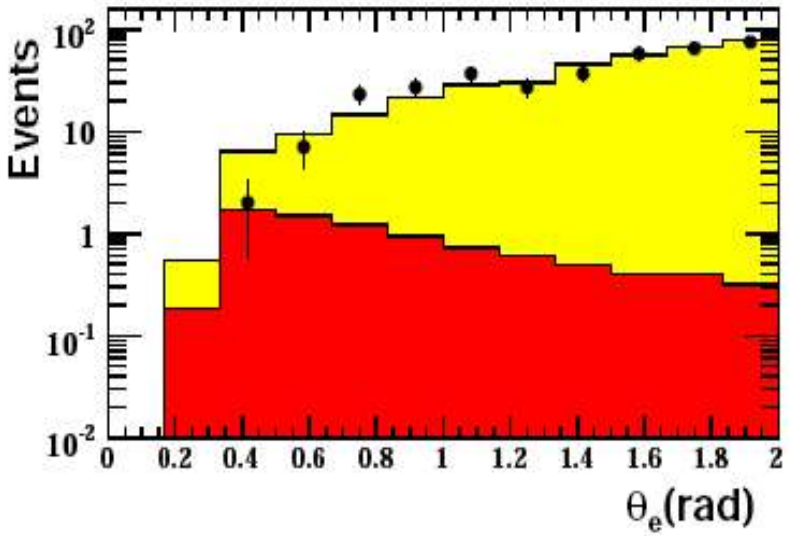
H1	ZEUS	
Detection phase space		
$P_T^e > 10$ GeV	$P_T^e > 10$ GeV	
$P_T^{miss} > 12$ GeV	$P_T^{miss} > 12$ GeV	
$5° < \theta_e < 140°$	$17° < \theta_e < 86°$	(*)
	$P_T^X > 12$ GeV	(*)

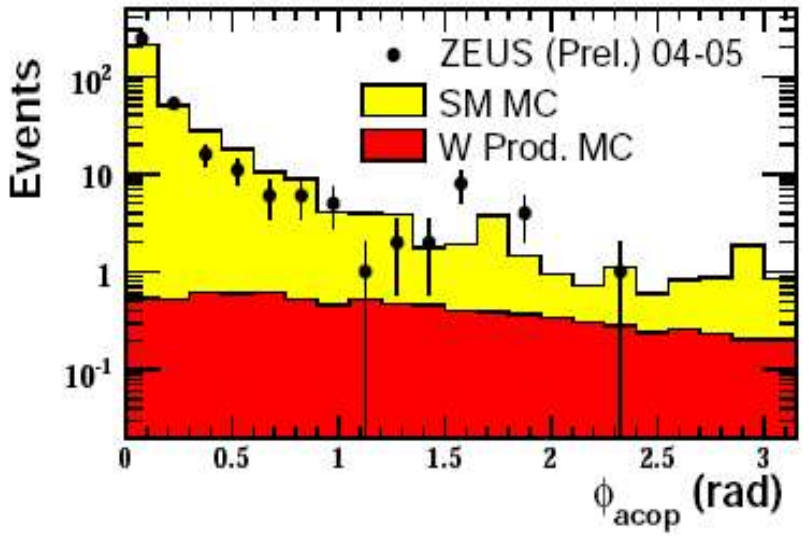
+Background Supression criteria based on topology & kinematics

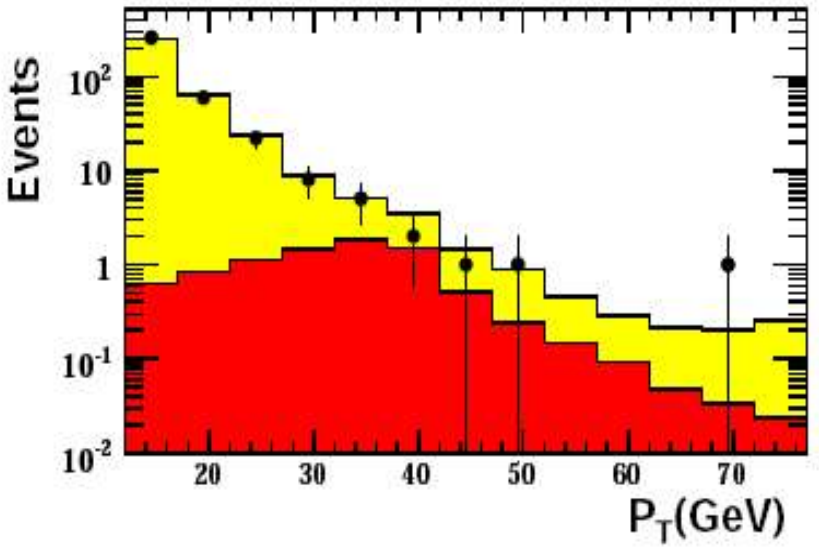
(*)Main differences: angular range, restricted PTX domain (ZEUS)

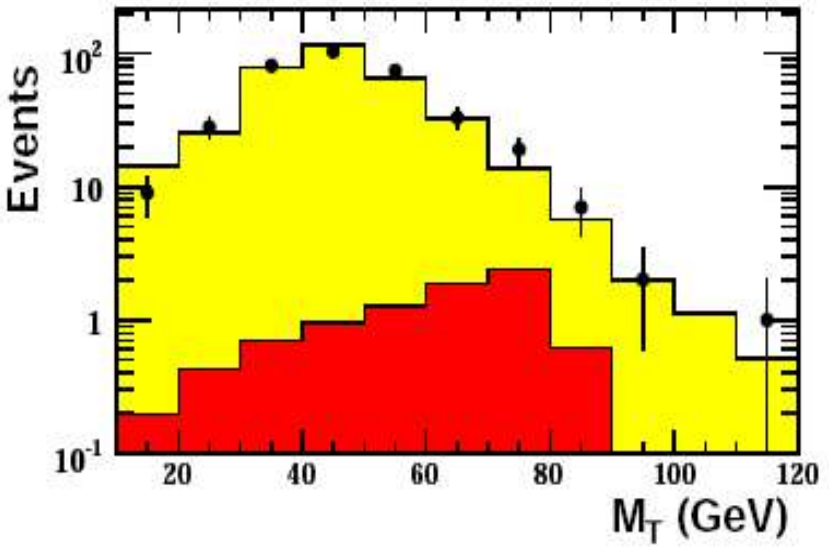
Control sample e+P_T^{Miss} (ZEUS)

- Before final cuts, sample dominated by NC (P_T^{miss} from fluctuations)









Selection μ+P_T^{Miss}

H1 **ZEUS**

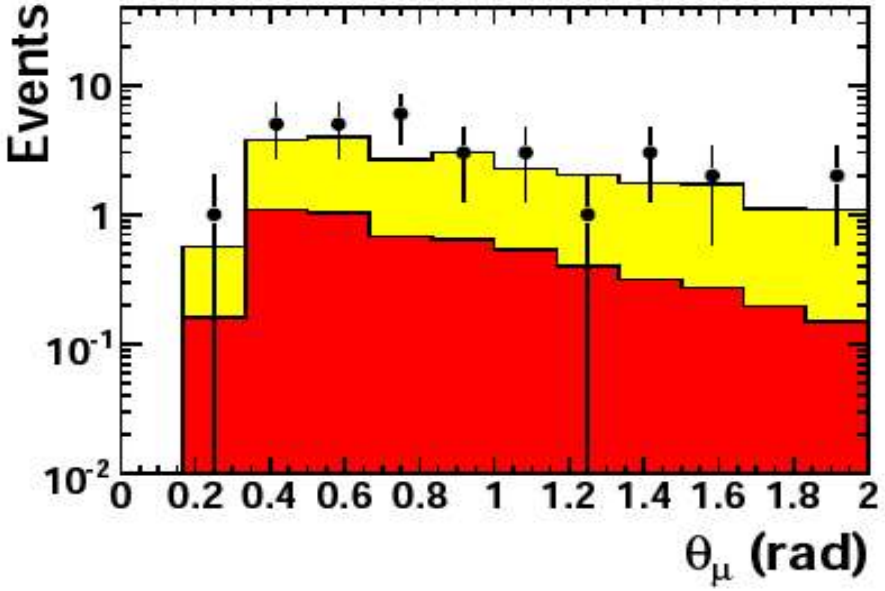
Detection phase space

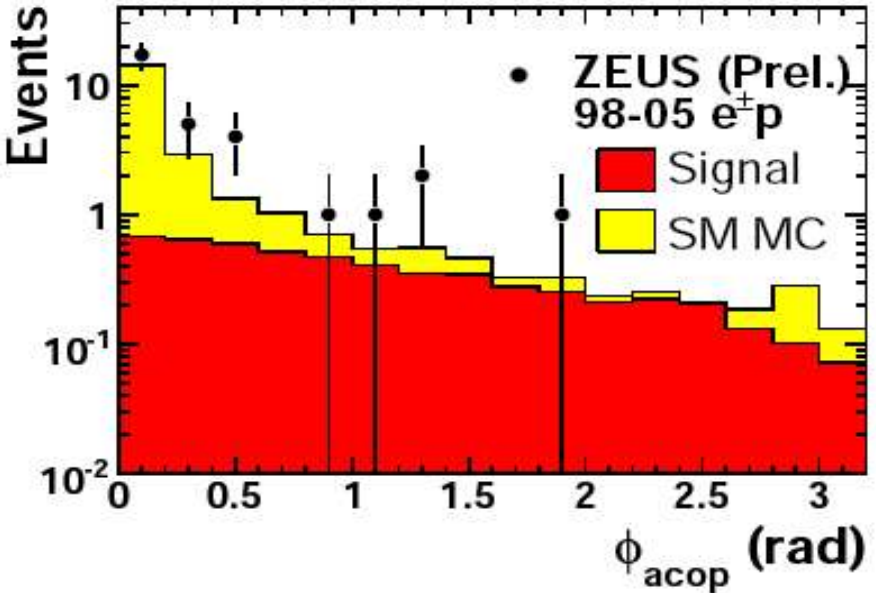
H1	ZEUS	
$P_T^\mu > 10$ GeV	$P_T^\mu > 10$ GeV	
$5^\circ < \theta_\mu < 140^\circ$	$17^\circ < \theta_\mu < 115^\circ$	(*)
$P_T^{miss} > 12$ GeV	$P_T^{miss} > 12$ GeV	
$P_T^X > 12$ GeV	$P_T^X > 12$ GeV	

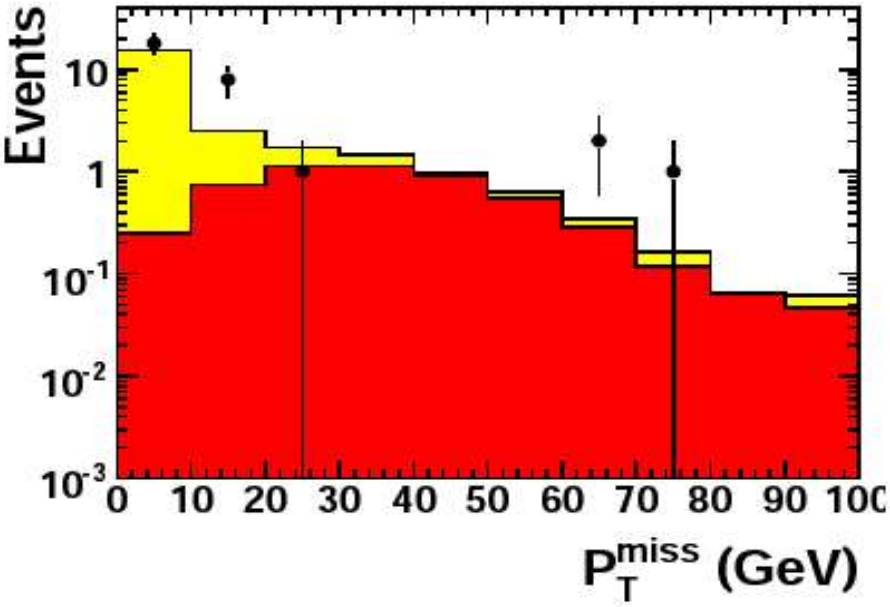
+Background Supression criteria based on topology & kinematics

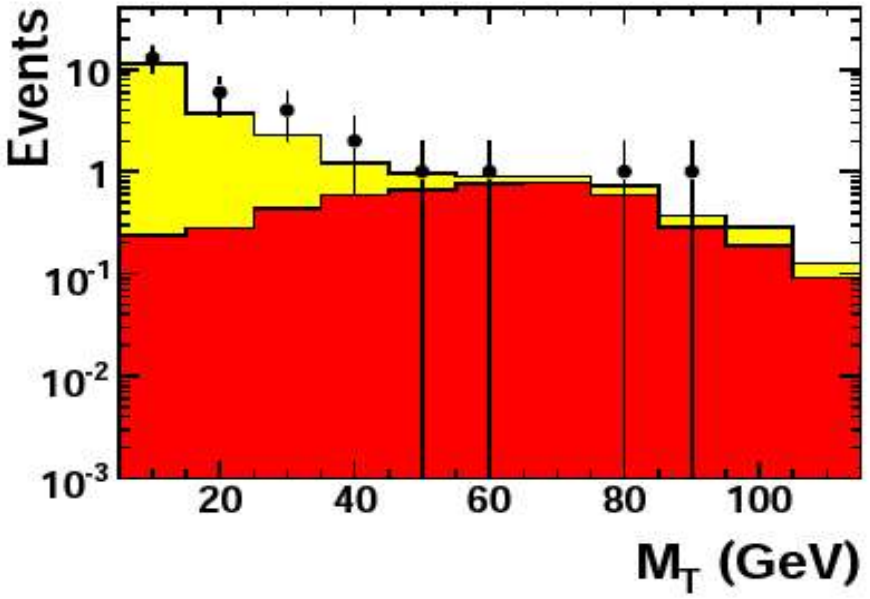
(*) Main Difference: restricted angular range (ZEUS)

Control sample: muon channel



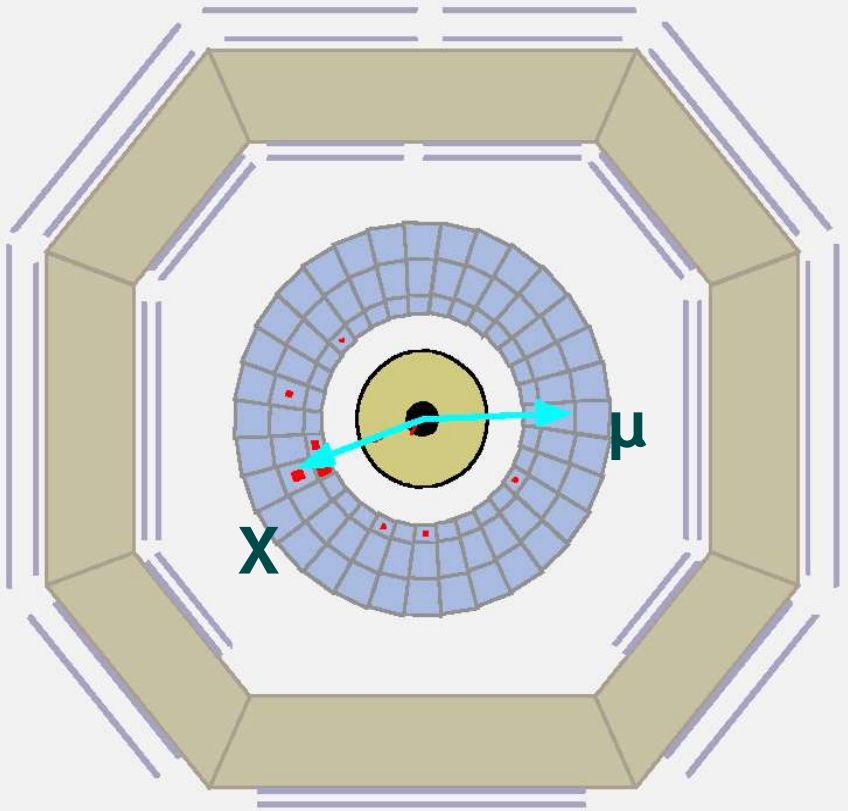




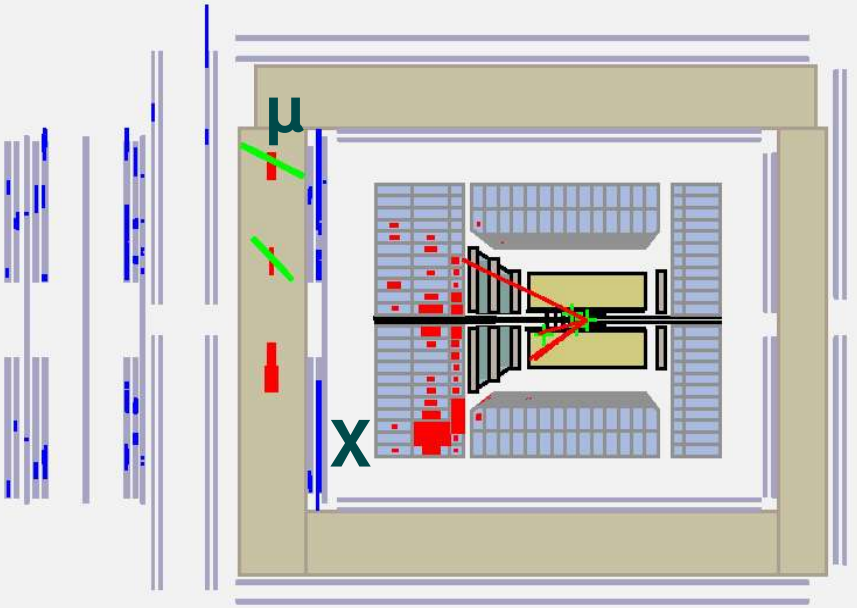


Background at low P_t^{miss}, small Acoplanarity(back-to-back) and low M_T

ZEUS μ candidate at large P_T^X



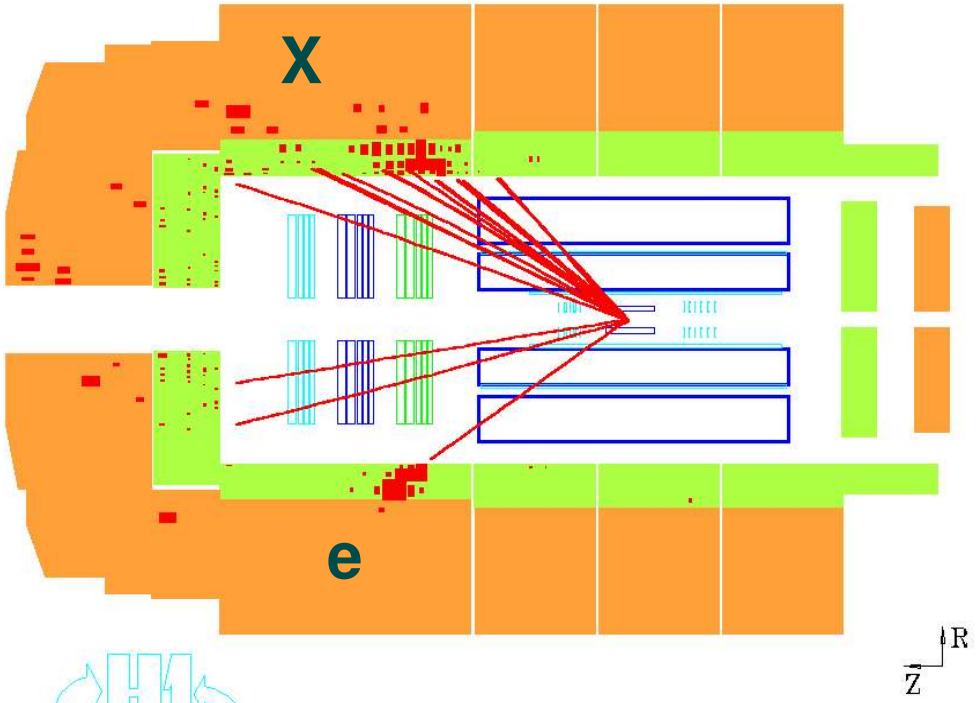
XY View

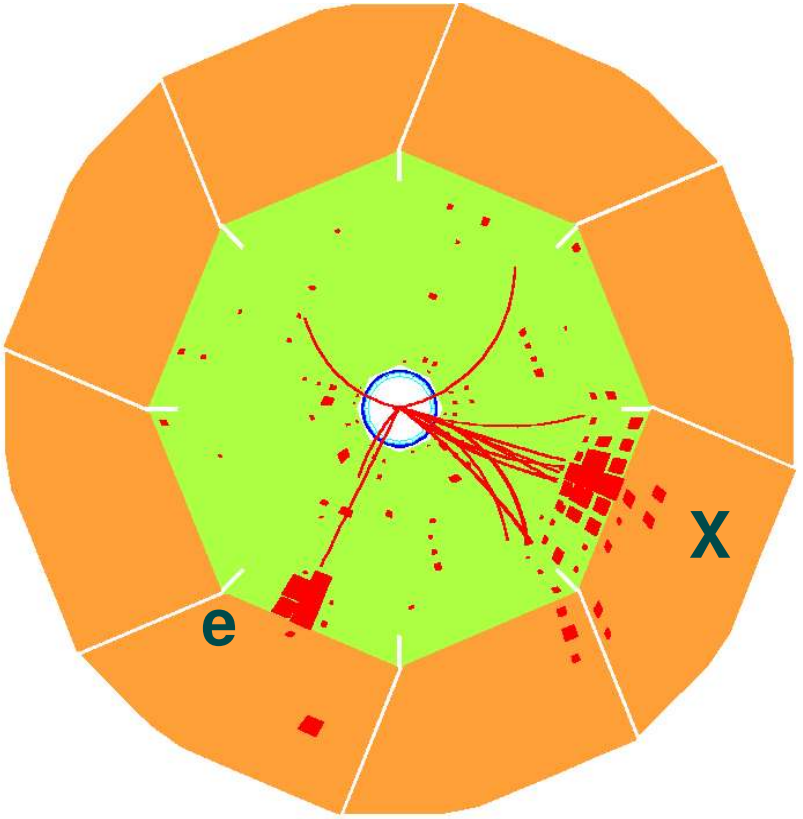


P_T^X=66 GeV

ZR View

H1 candidate from e^+p HERA 2 data





$$\mathbf{P}_T^e = 37 \text{ GeV}, \mathbf{P}_T^{miss} = 44 \text{ GeV}, \mathbf{P}_T^X = 29 \text{ GeV}$$

Results with full data sample

Preliminary $e^{\pm}p$ Data		Electron	Muon	Combined
H1	1994-2006 341 pb^{-1}	obs./exp.	obs./exp.	obs./exp.
ZEUS	1998-2005 249 pb^{-1}			
H1	e:Full Sample/μ : $P_T^X > 12$ GeV	35 / 34.0 $\pm$ 4.7	11 / 9.0 $\pm$ 1.4	46 / 43.0 $\pm$ 6.0
ZEUS	$P_T^X > 12$ GeV	9 / 7.8 $\pm$ 0.6	6 / 5.9 $\pm$ 0.4	15 / 13.7 $\pm$ 0.7
H1	$P_T^X > 25$ GeV	12 / 6.1 $\pm$ 1.1	6 / 5.4 $\pm$ 0.9	**18 / 11.5 $\pm$ 1.8**
ZEUS	$P_T^X > 25$ GeV	4 / 4.4 $\pm$ 0.5	3 / 3.1 $\pm$ 0.3	**7 / 7.5 $\pm$ 0.6**

signal purities e: 60-68% μ:76-83%

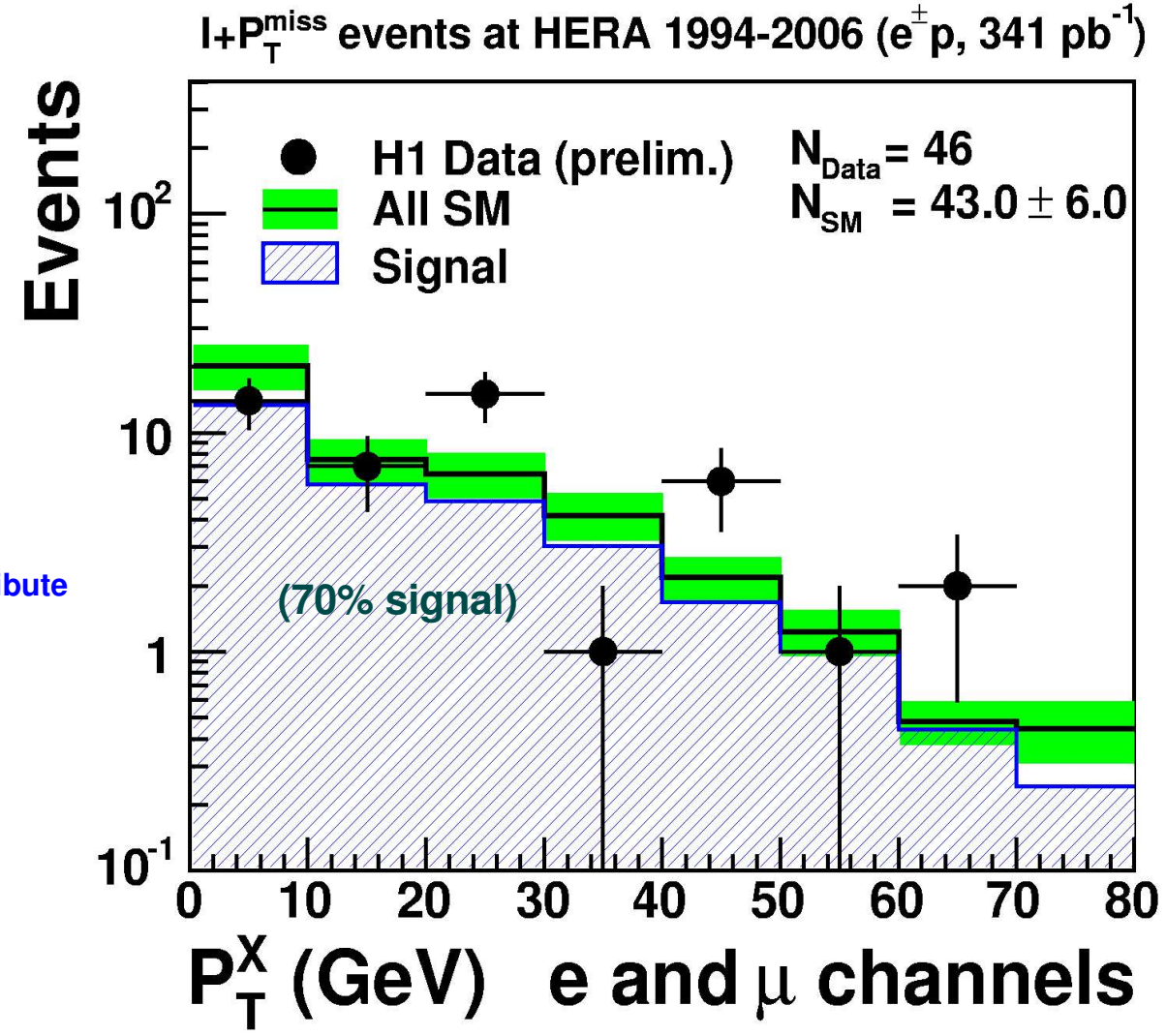
ZEUS errors do not include theory error (W:15%)

-large yield in e-channel (H1) due to full PTX spectrum detected

-ZEUS : good agreement

-H1 : more events detected at large P_T^X

H1 result (e and μ)



Only electrons contribute

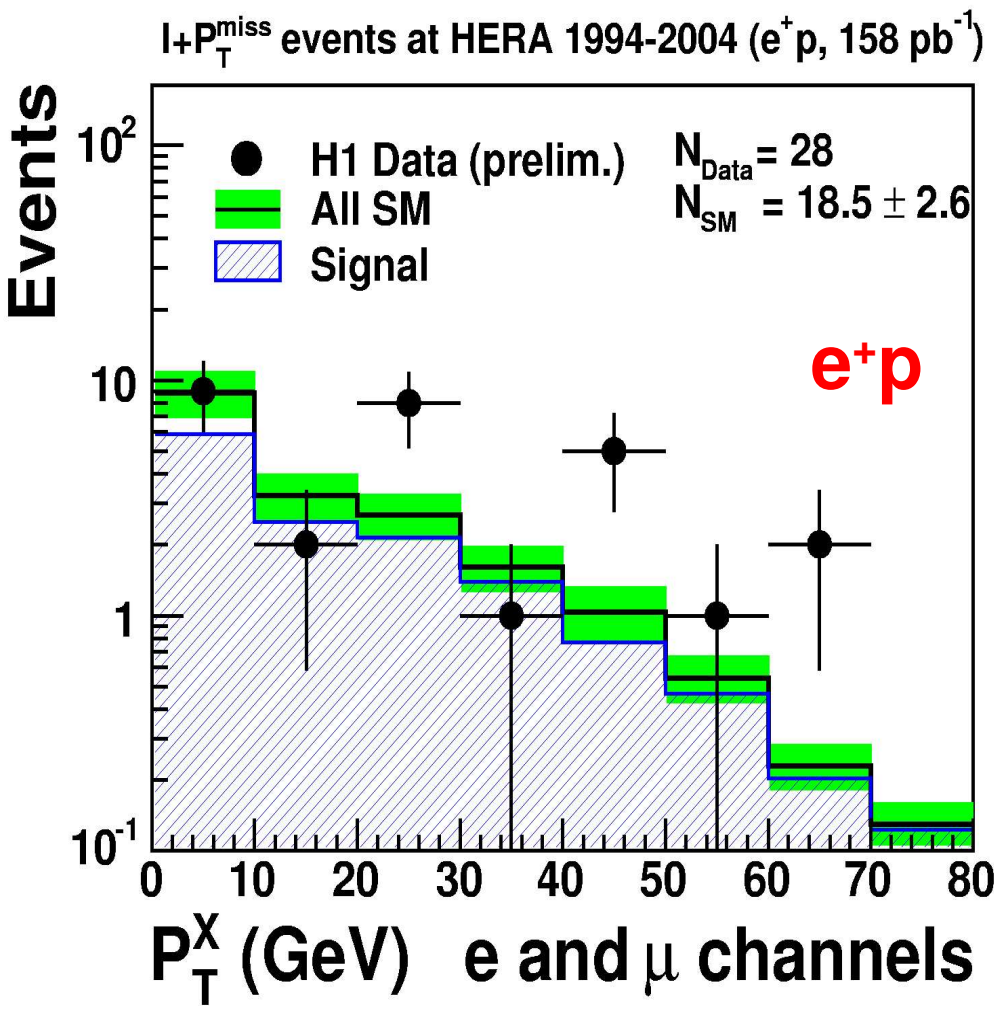
$0<P_T^X<12$ GeV

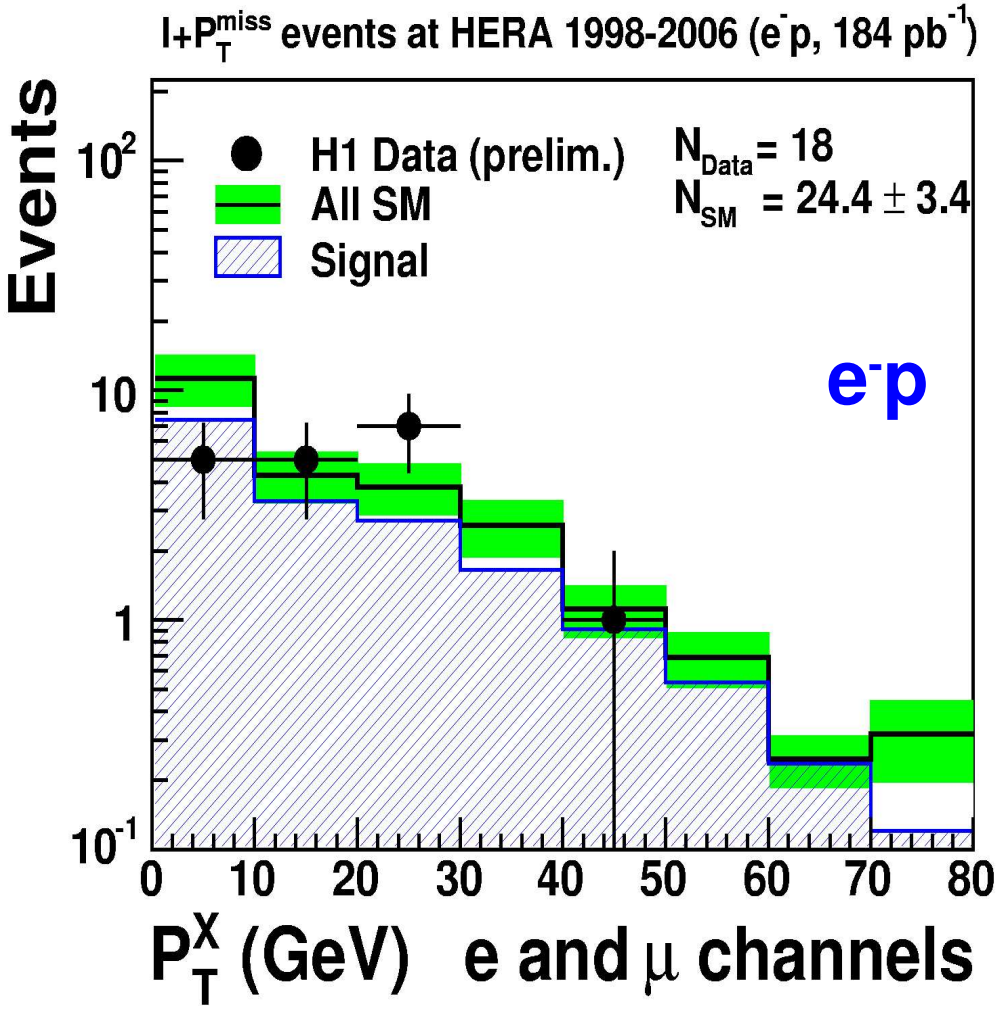
Clear evidence for W production at HERA

Observe Events at high PTX

=>Look more differentially in e+p/e-p data samples

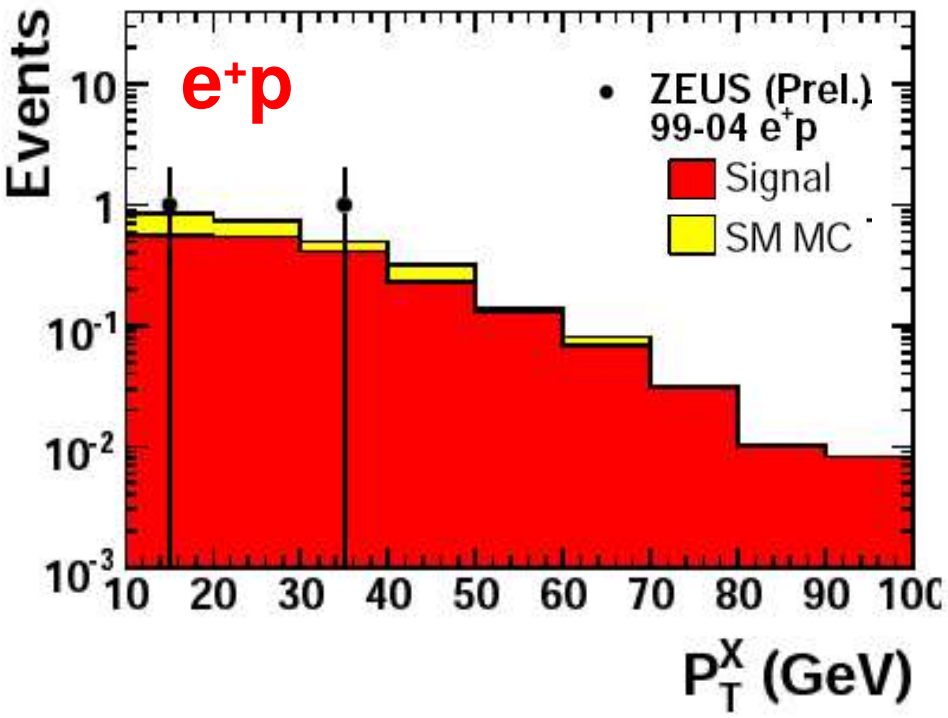
H1 Results (e and μ) e^+p vs. e^-p data

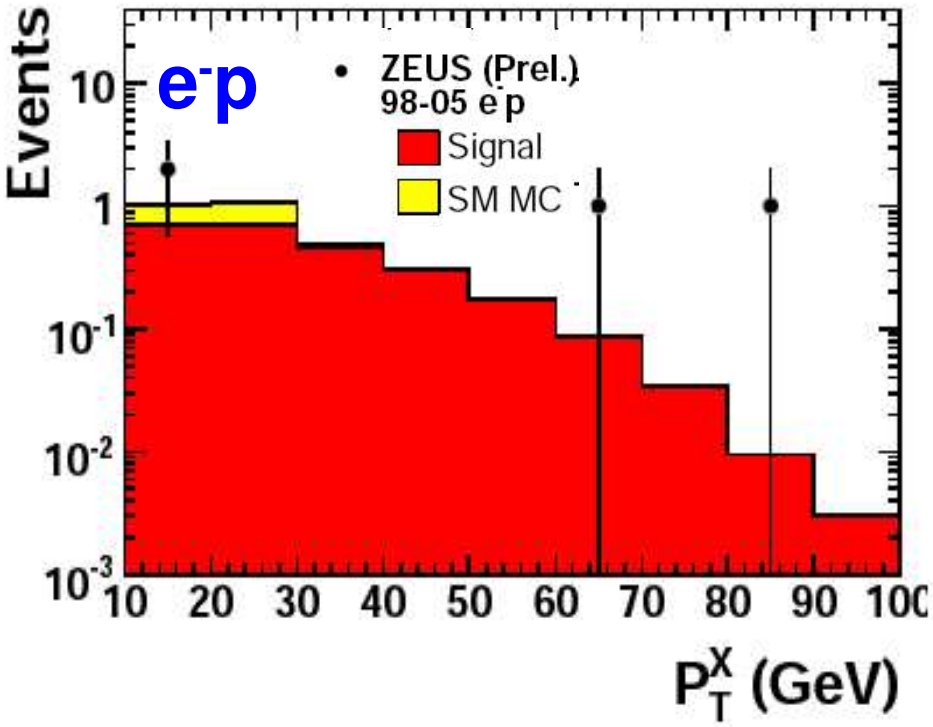




- Different observations in e^+p and e^-p.

ZEUS μ channel





- Overall agreement with the SM
- No e^+p/e^-p feature at high P_T^X (same for e-channel)

H1/ZEUS results at large hadronic transverse momentum

P_T^X> 25 GeV	electrons Data/SM	(signal)	muons Data/SM	(signal)
H1 (e^+p) **158 pb^{-1}**	9/2.3±0.4	(80%)	6/2.3±0.4	(84%)
ZEUS(e^+p)106 pb^{-1}	1/1.5±0.1	(78%)	1/1.5±0.2	(80%)
H1(e^-p) 184 pb^{-1}	3/3.8±0.6	(61%)	0/3.1±0.5	(74%)
ZEUS(e^-p) 143 pb^{-1}	3/2.9±0.5	(53%)	2/1.6±0.2	(86%)

e^+p Data: excess observed by H1 15/4.6±0.8 (3.4σ)

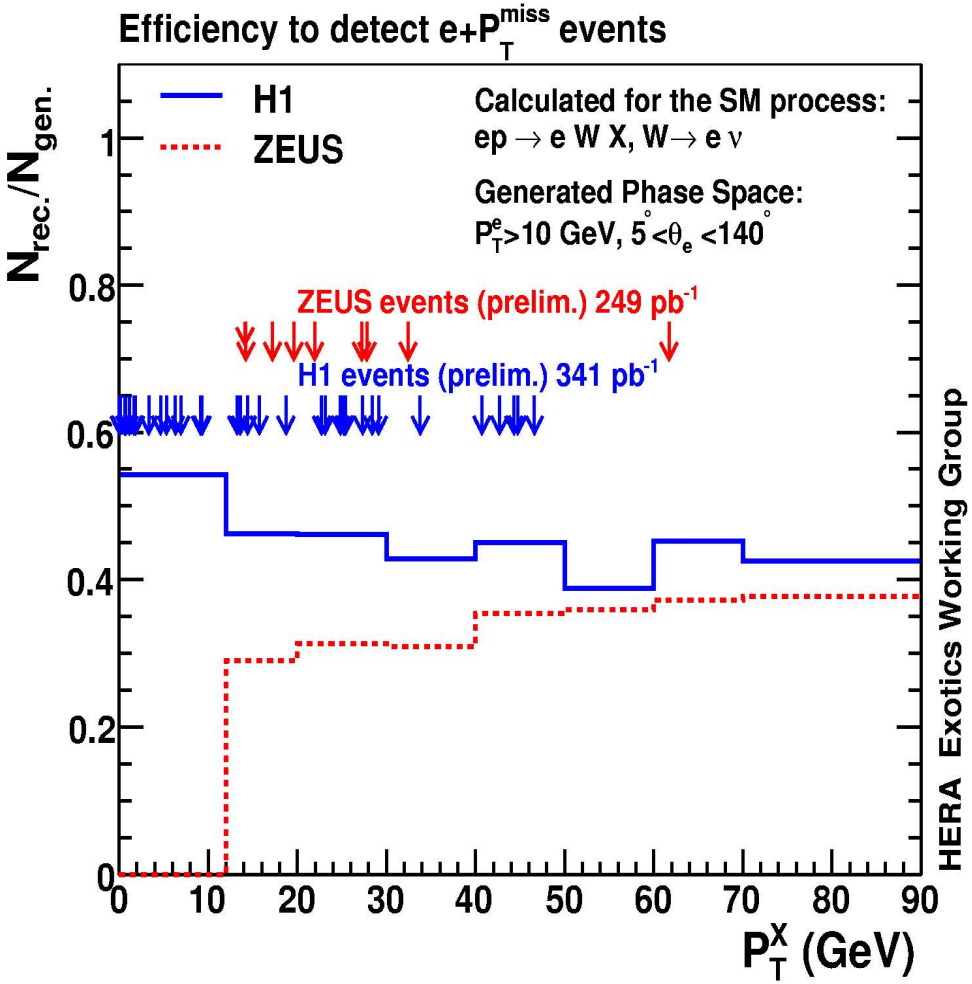
no events in excess observed by ZEUS

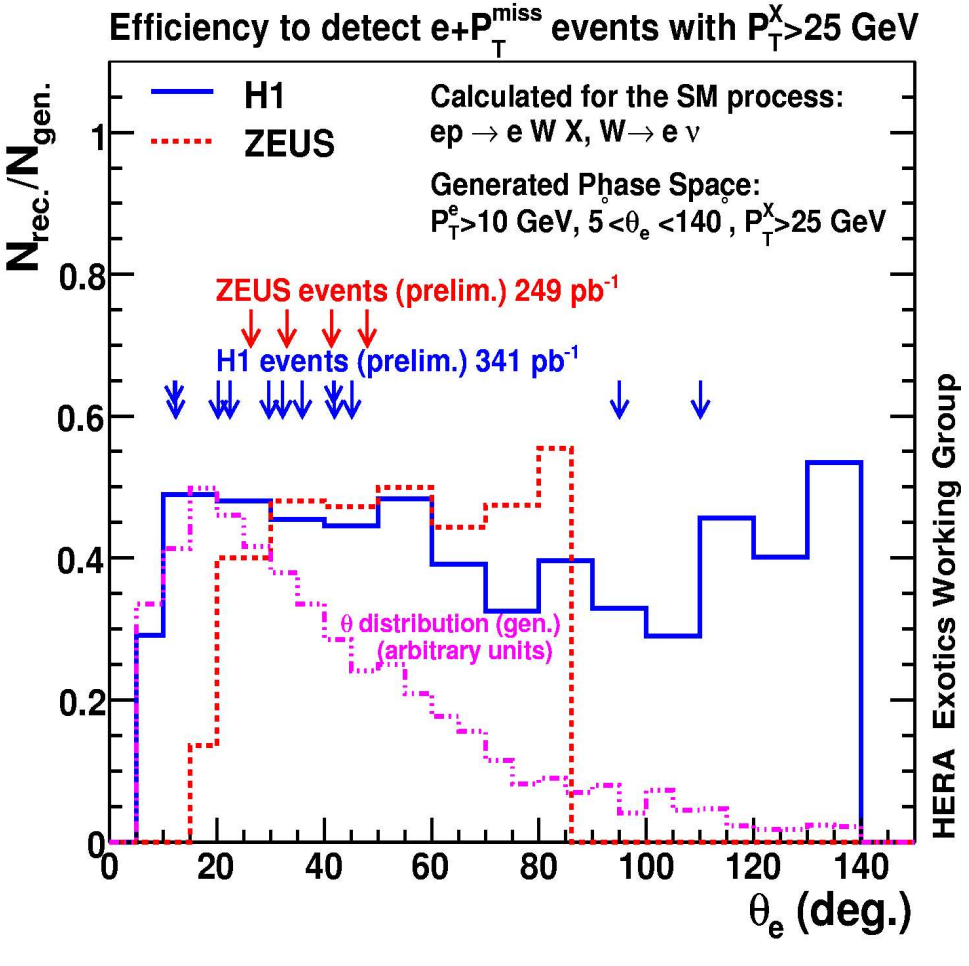
e^-p Data: Agreement with SM (H1 and ZEUS)

H1+ZEUS(P_T^X> 25 GeV)	e	μ	e+μ
e^+p Data (264 pb-1)	10/3.8±0.5	7/3.8±0.6	17/7.6±1.1 (2.6σ)
e^-p Data (327 pb-1)	6 /6.7±1.1	2/4.7±0.7	8 /11.4±1.8

H1/ZEUS Compare acceptance : e-channel

Signal Prototype: W production





Events with PTX up to ~45/60 detected in H1/ZEUS

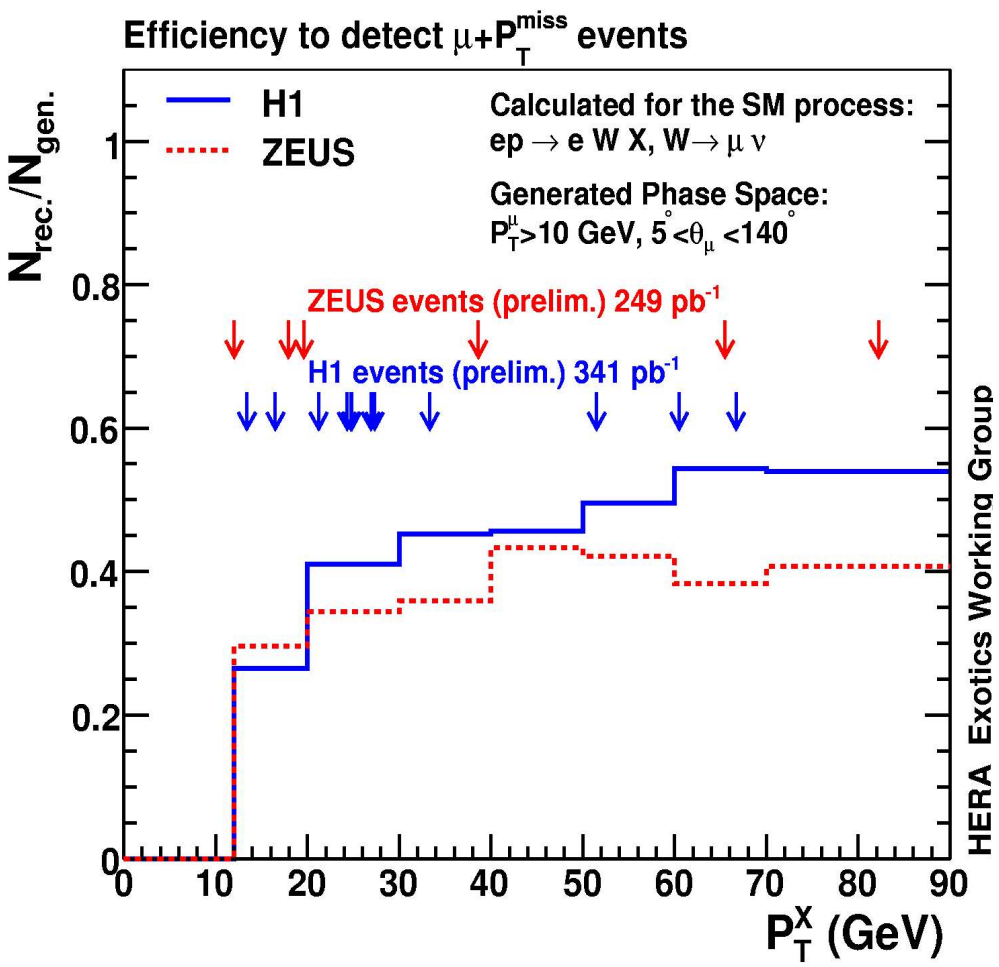
Acceptance to lowest PTX in H1, at large PTX more similar H1 higher due to wider θ range

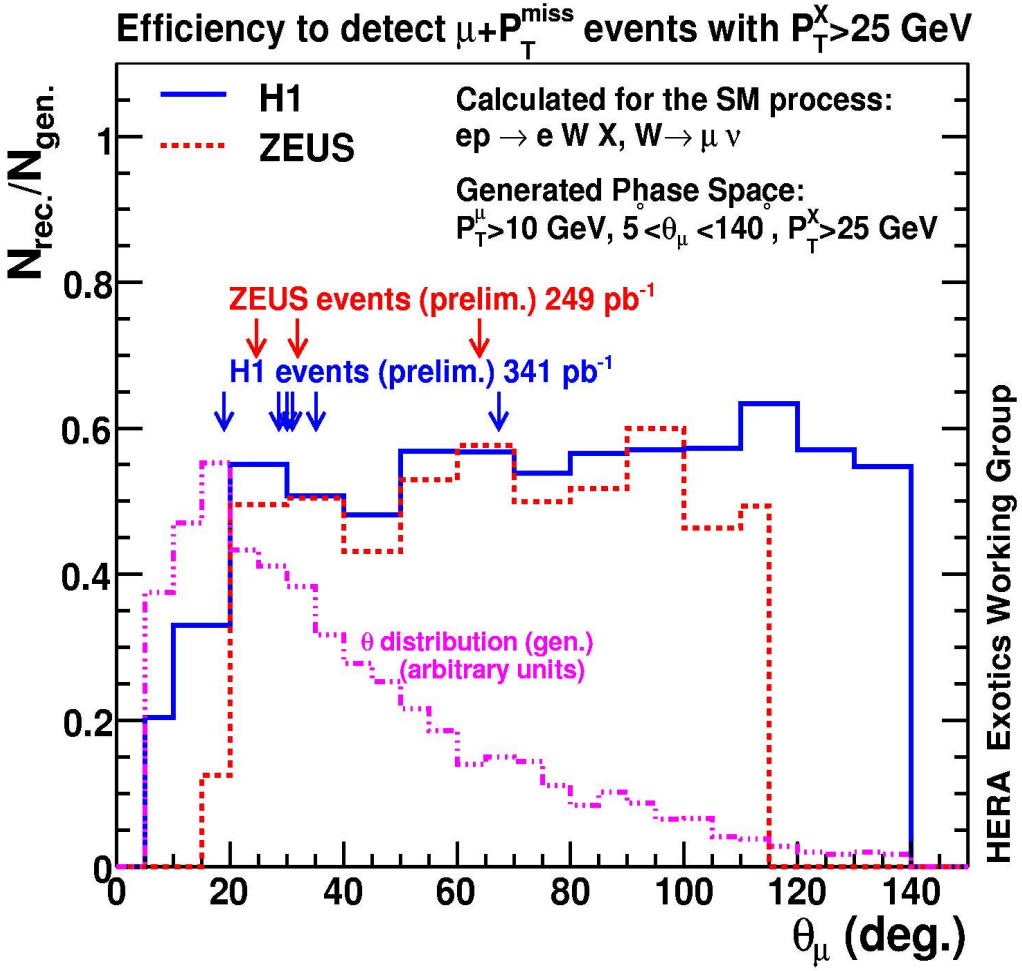
Similar event detection capabilities in the common polar angle range

Most (but not all) H1 events in ZEUS acceptance

Compare acceptance : e-channel

Signal Prototype: W production





Events with PTX up to 65/83 GeV detected in H1/ZEUS

Similar acceptances in PTX (H1 higher due to θ range)

In common θ range, very similar detection capabilities

Most H1 events are in ZEUS detection region

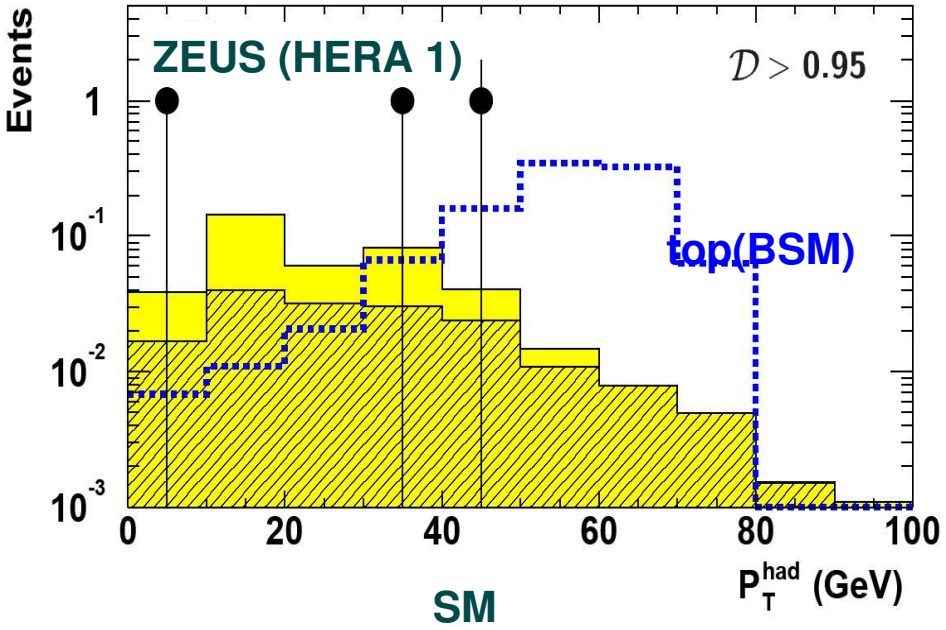
Search for events with $\tau + P_T^{miss}$

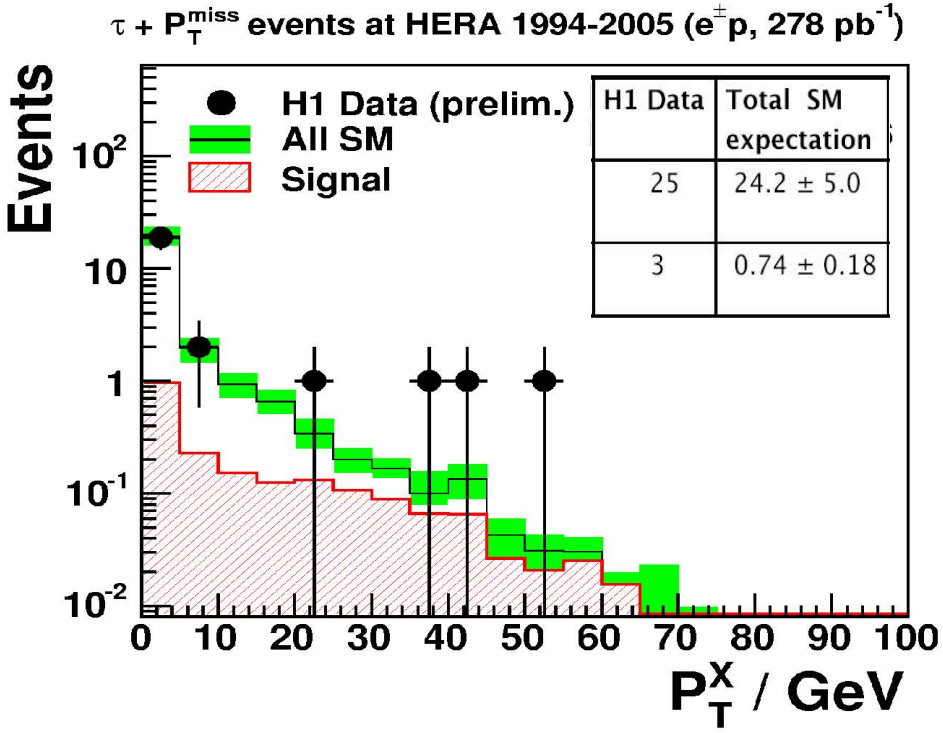
- Use 1-prong hadronic channel
  - remaining hadrons -> X
- Large background from CC-jets
- ZEUS HERA 1(mainly e+p data)

$P_T(\tau\text{-jet})>7$ GeV

$20<\theta<140$

anti-CC/NC cuts





	H1 e^+p 158 pb^{-1}	H1 e^-p 121 pb^{-1}	ZEUS $e^{\pm}p$ 130 pb^{-1}
All	$8/10.6 \pm 2.9$	$17/13.5 \pm 2.6$	$3/0.40 \pm 0.12$
$P_T^X > 25$ GeV	$0/0.40 \pm 0.10$	$3/0.35 \pm 0.09$	$2/0.20 \pm 0.05$

Conclusions and Outlook

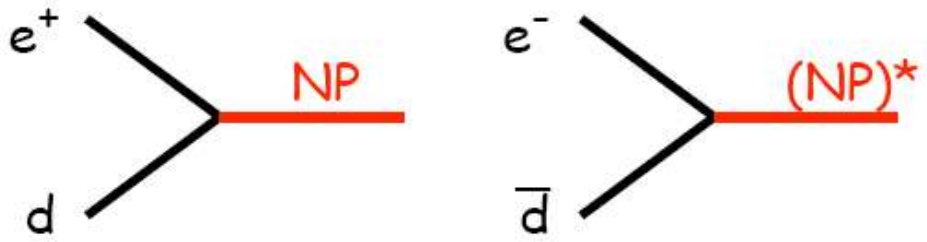
- Events with isolated leptons and missing transverse momentum are detected at HERA
- Clear evidence for W production, but an anomaly:
  - P_T^X>25 GeV
    - e^+p Data: Fluctuation at large transverse momentum observed by H1 (3.4σ) not confirmed by ZEUS
      - H1+ZEUS: 17 / 7.6±1.1
    - e^-p Data: good agreement :
      - H1+ZEUS: 8 / 11.4±1.8
- Tau channel investigated, interesting events (lower rate/larger backgrounds)
- Last data taking period (2006/2007) started in july : e^+p collisions
  - $L^{HERAtotal}(e^+p)$~factor 2 w.r.t. present analysis
  - Surprises still possible, H1/ZEUS common work ongoing

We look forward for an exciting end of run at HERA with e^+p collisions!

Backup Slides

e^+p/e^-p new physics

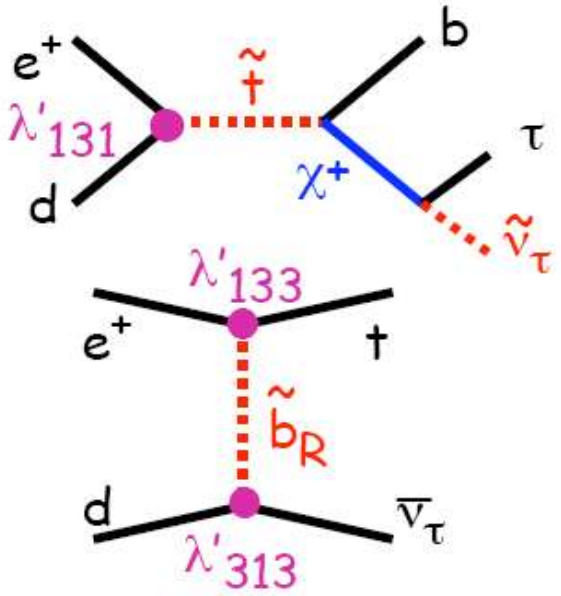
- Particle coupling to e-q with fermion number F=0 :



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 $M_{top} \rightarrow$ large x_{Bj}

Selection of e+P_T^{Miss}

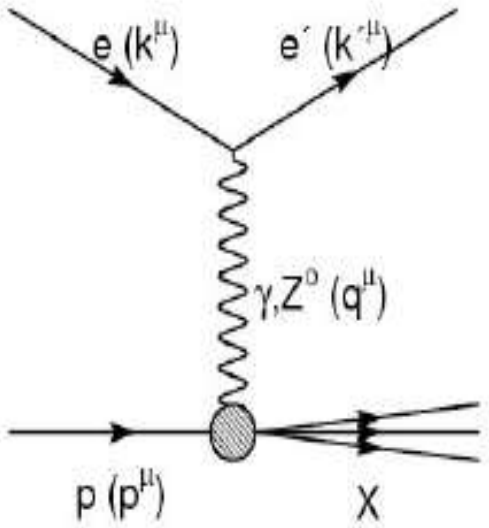
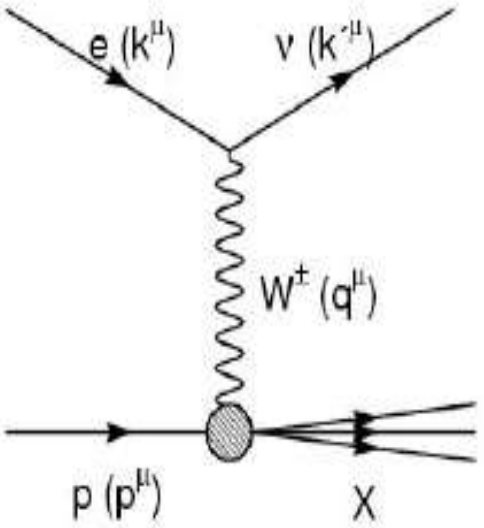
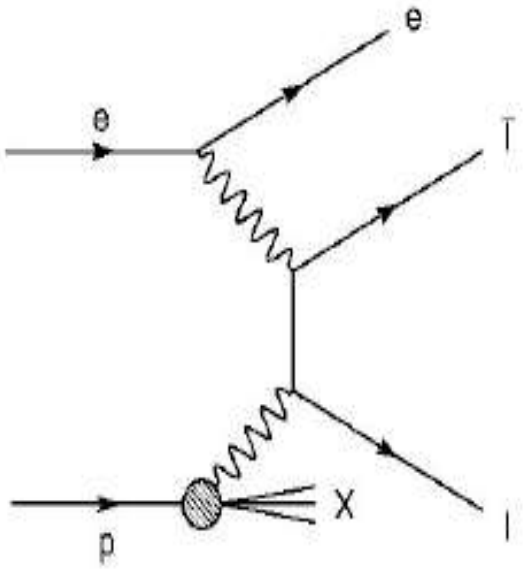
	H1	ZEUS
Detection phase space	$P_T^e > 10\text{GeV}$	$P_T^e > 10\text{GeV}$
	$P_T^{miss} > 12$	$P_T^{miss} > 12$
	$5^\circ < \theta_e < 150^\circ$	$17^\circ < \theta_e < 86^\circ$ (*)
	-	$P_T^X > 12$ (*)
Background supression	$P_T^{miss} > 25$ or $Q^2 > 5000\ \text{GeV}^2$	$P_T^{miss} > 25$ or $Q^2 > 5000\ \text{GeV}^2$
	$\frac{V_{ap}}{V_p} < 0.5$ (< 0.15 for $P_T^e < 25$ GeV)	$M_T^{e\nu} > 10$ GeV
	Acoplanarity $> 20^\circ$	Acoplanarity $> 17^\circ$
	$E - P_z < 50$ GeV	$5 < E - P_z < 50$ GeV
	$D_{jet} > 1.0$	$D_{jet} > 1.0$
	$D_{track} > 0.5$ ($\theta_e > 45^\circ$)	$D_{track} > 0.5$

(*)Main differences: angular range, restricted PTX domain (ZEUS)

Selection μ+P_T^{Miss}

H1	ZEUS
$P_T^\mu > 10\text{GeV}$	$P_T^\mu > 10\text{GeV}$
$5^\circ < \theta_\mu < 140^\circ$	$17^\circ < \theta_\mu < 120^\circ$
$P_T^{miss} > 12$	$P_T^{miss} > 12$
$P_T^X > 12$	$P_T^X > 12$
$\frac{V_{ap}}{V_p} < 0.5$	$M_T^{\mu\nu} > 5$ GeV
$(< 0.15$ for $P_T^{\text{calo}} < 25$ GeV)	$5 < E - P_z < 50$
Acoplanarity $> 10^\circ$	Acoplanarity $> 11^\circ$
$D_{jet} > 0.5$	$D_{jet} > 0.5$
$D_{track} > 0.5$	$D_{track} > 0.5$

Main Difference: restricted angular range (ZEUS)

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