

# Events with Isolated Leptons and Missing Transverse Momentum in $ep$ Collisions

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***“New Talents” Session, 30 August 2006***

*International School of Subnuclear Physics, Erice, Sicily 29 Aug – 7 Sep 2006*



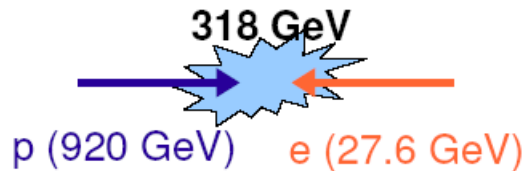
**ETTORE MAJORANA FOUNDATION AND  
CENTRE FOR SCIENTIFIC CULTURE**

TO PAY A PERMANENT TRIBUTE TO GALILEO GALILEI, FOUNDER OF MODERN SCIENCE  
AND TO ENRICO FERMI, "THE ITALIAN NAVIGATOR", FATHER OF THE WEAK FORCES



# The HERA Collider

World's only  $ep$  Collider  
at DESY, Hamburg



## HERA-I (1994-00)

~130  $\text{pb}^{-1}$  per exp., (90%  $e^+p$ )

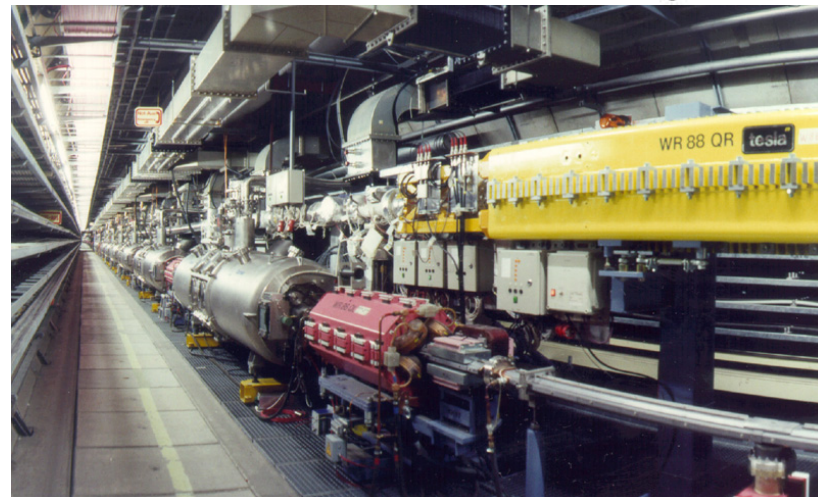
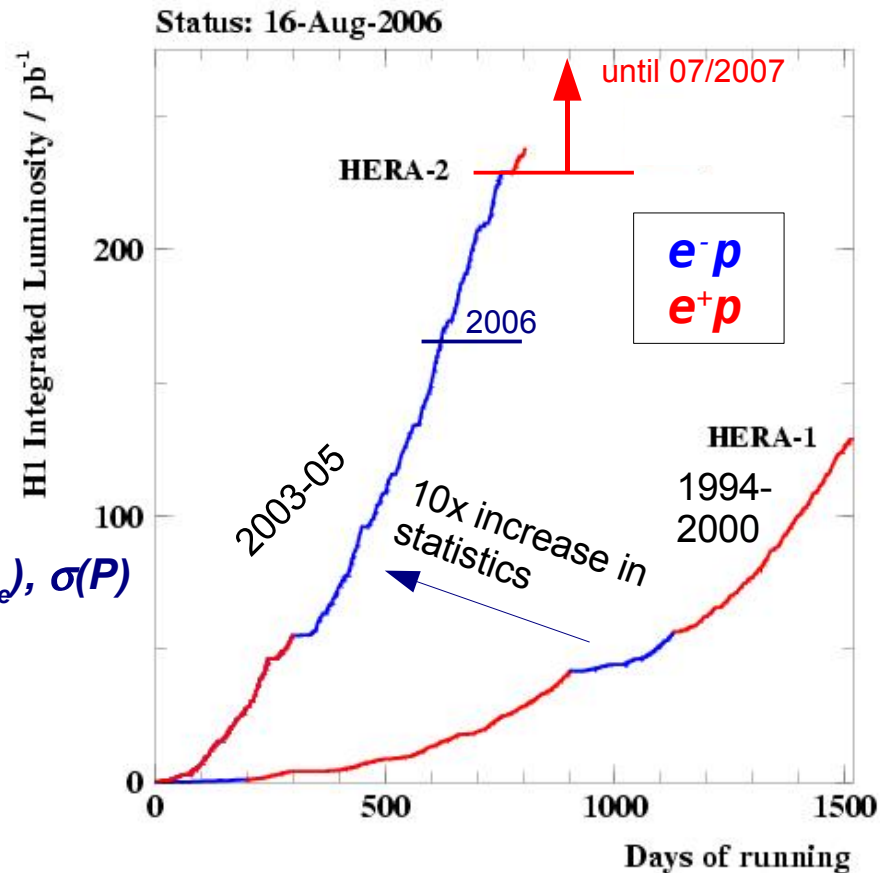
## HERA-II (2003-07)

Luminosity upgrade

Long. e polarisation (up to 50%)

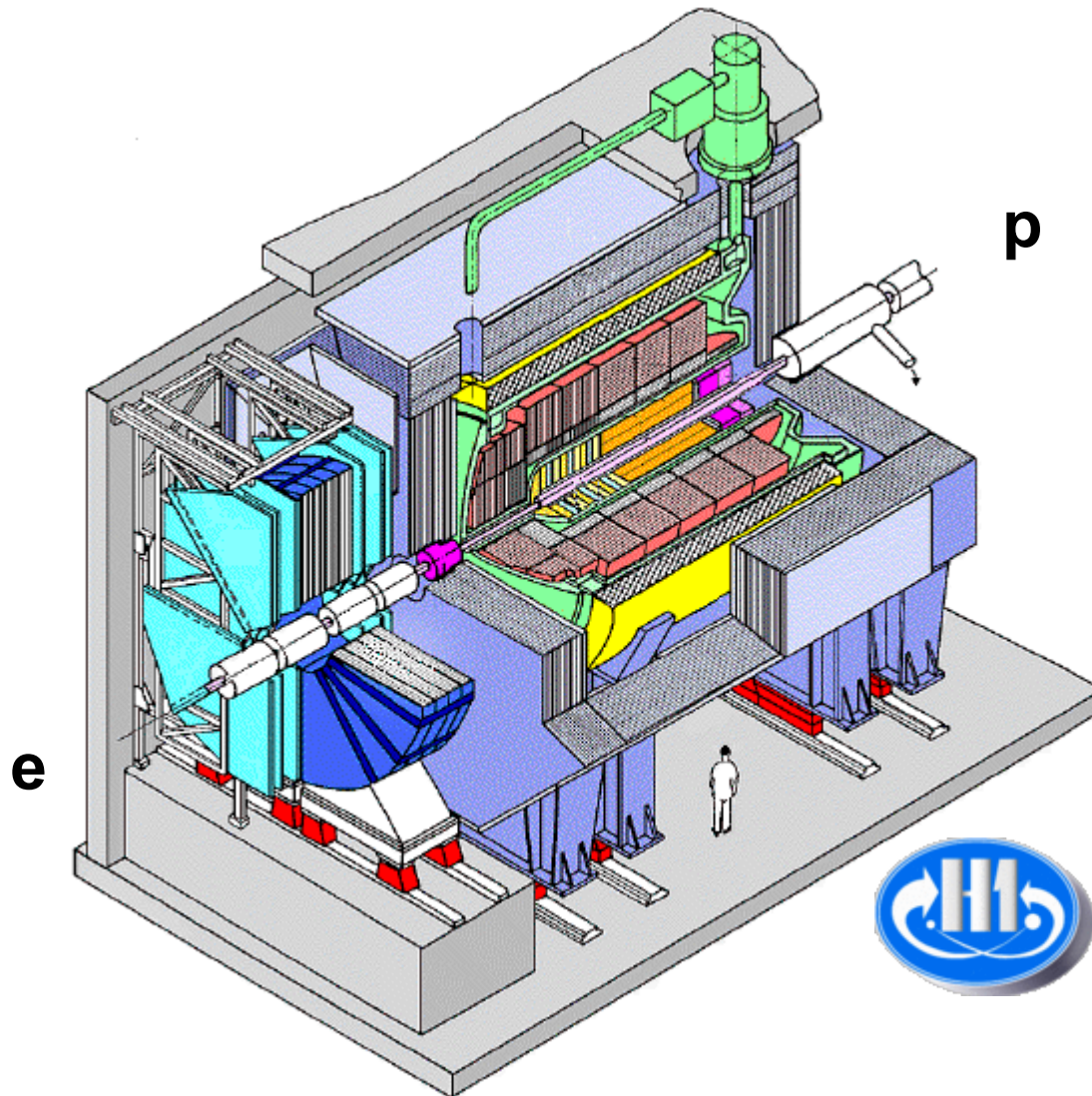
~240  $\text{pb}^{-1}$  per exp. so far

*Enough to see processes with small  $\sigma$  (~1pb), and/or  $\sigma(q_e)$ ,  $\sigma(P)$*



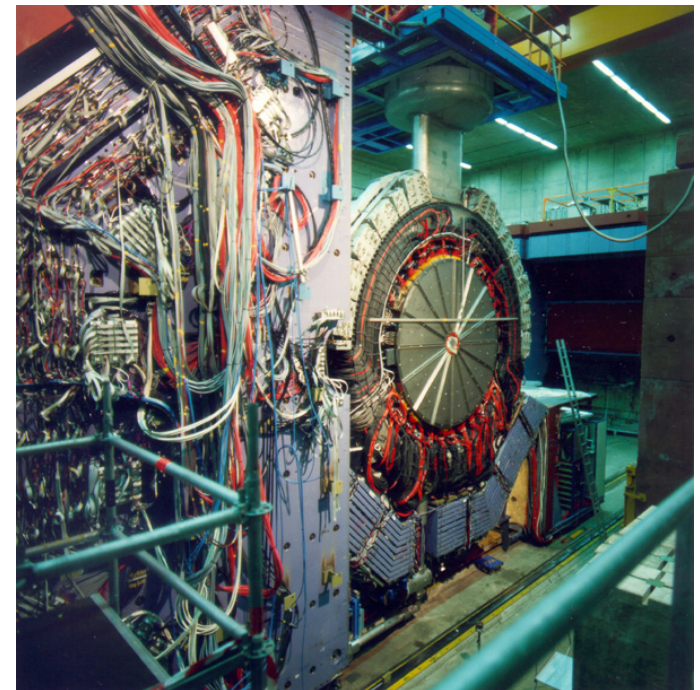
# The H1 Detector

- General Purpose Detector (for  $ep$ )
- $4\pi$  Coverage – Measure missing energy
- Excellent Lepton ID



## *Subdetectors*

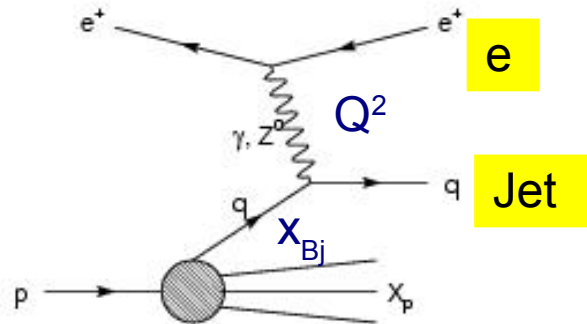
- Tracking
  - Central Jet Chambers
  - Forward and Vertex Detectors
- Calorimetry
  - LAr (forward, barrel)
  - Lead-Fiber (SpaCal, backward)
- Muon Detectors
  - Instrumented Iron (Streamer Tubes)
  - Forward Muon Chambers



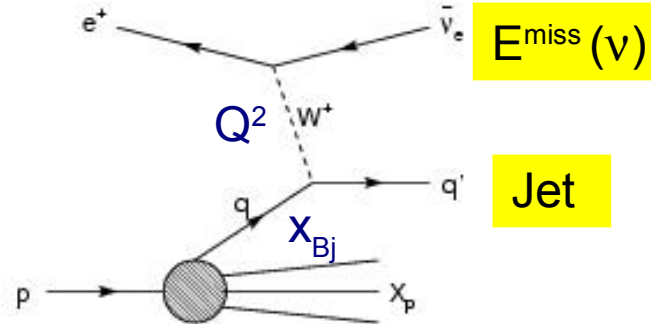
# Standard Model at HERA

## Deep Inelastic Scattering

Neutral Current

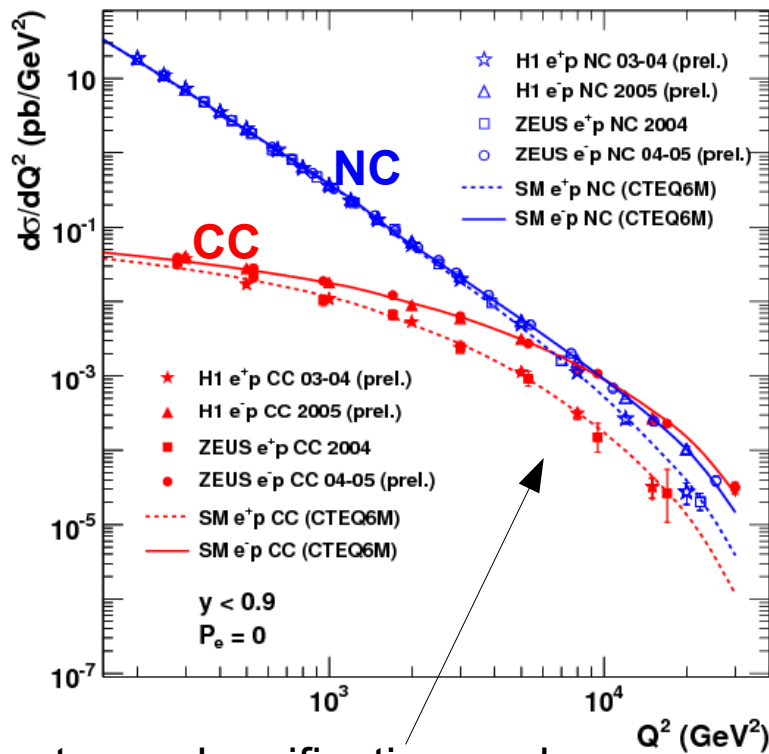


Charged Current



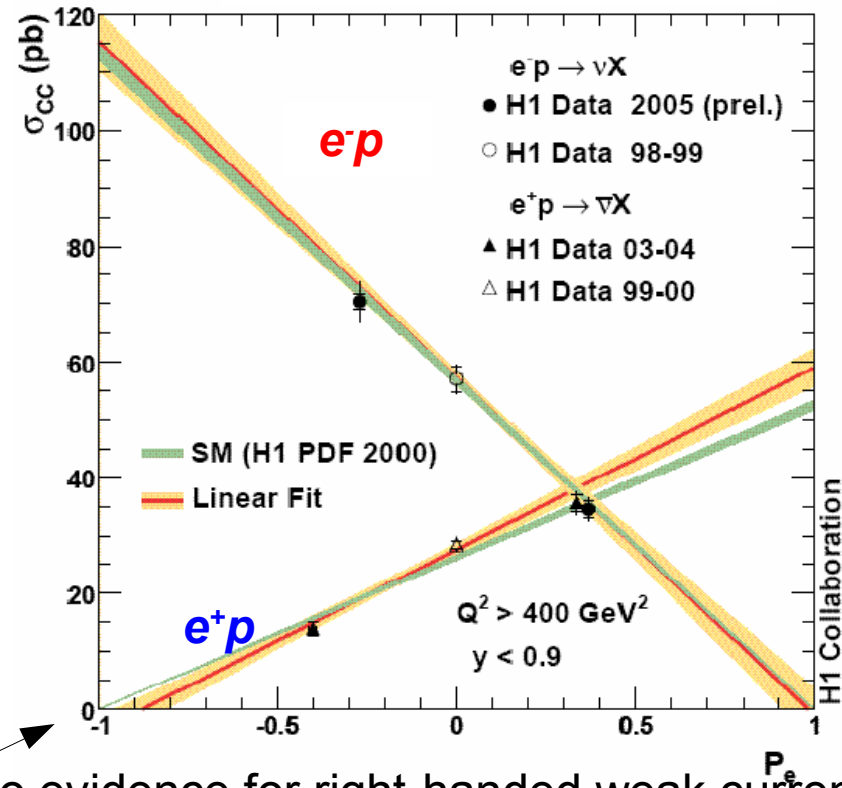
Important  
"textbook"  
measurements

## Unpolarised NC/CC x-sections



Electroweak unification works

## Polarised CC x-section

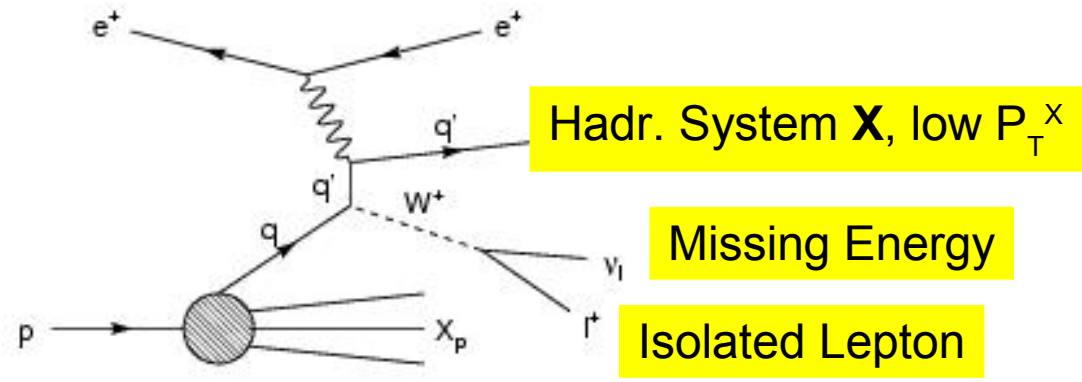


No evidence for right-handed weak currents

# Events with Isolated Leptons: Typical Example in SM

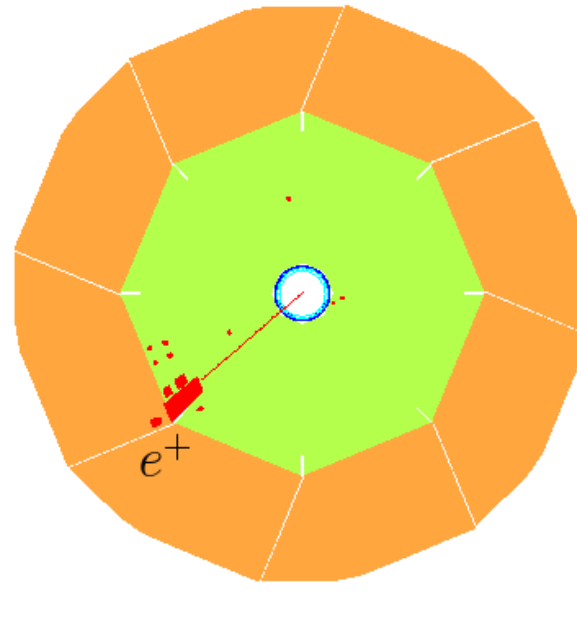
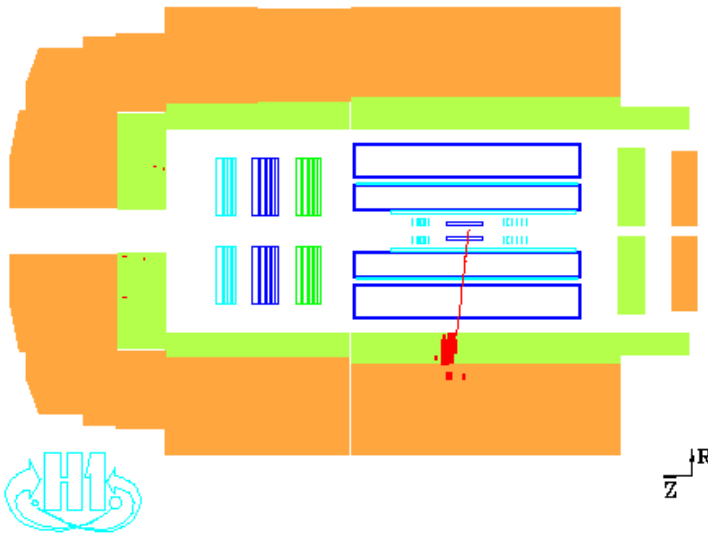
Typical Signature expected by Standard Model **W-Production**

( $\sigma \sim 1$  pb,  
with Efficiency 40% expect  
 $\sim 100$  events in  $250 \text{ pb}^{-1}$ )



**Event with  $e + P_T^{miss}$  in HERA II  $e^+p$  data**

$P_T^e = 47 \text{ GeV}, P_T^{miss} = 47 \text{ GeV}$



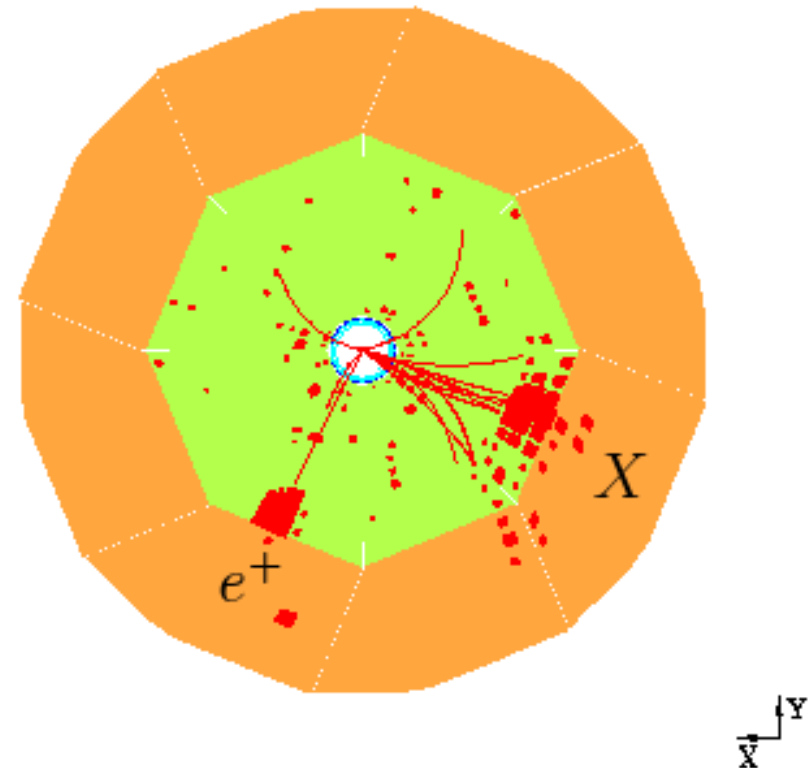
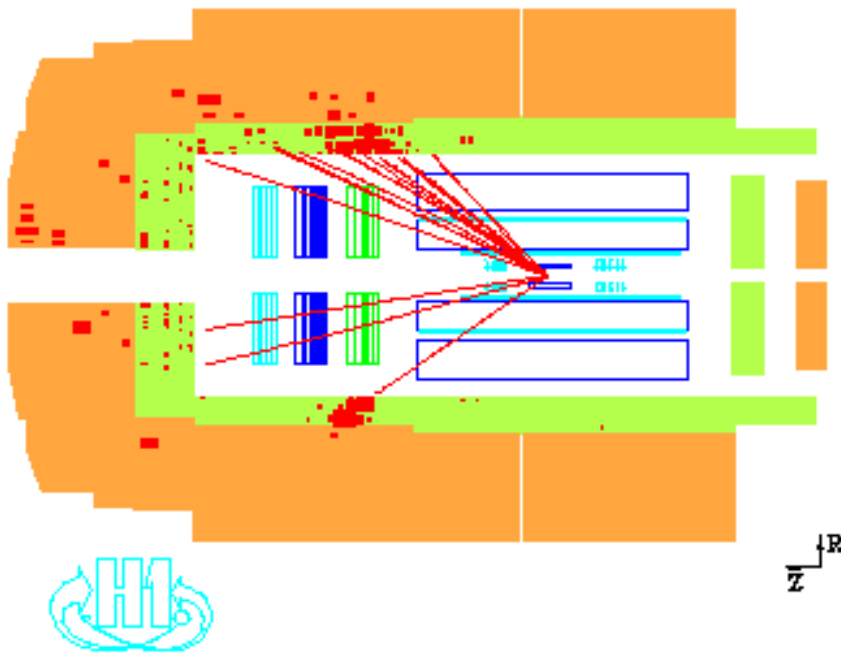
Isolated Electron  
+  $P_T^{miss}$ :  
Elastic W-Production?

# Events with Isolated Leptons: Example at High $P_T^X$

- $P_T$  of hadronic Rest-System X determines how “interesting” an event is
- High  $P_T^X$ : Low expectation in Standard Model

## Event with $e + P_T^{miss}$ in HERA II $e^+p$ data

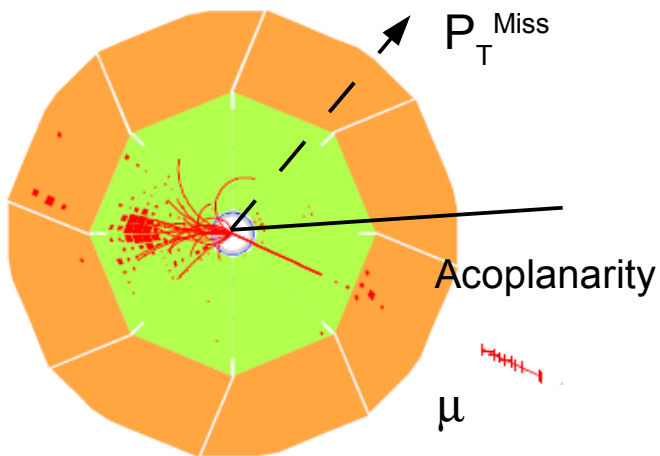
$$P_T^e = 37 \text{ GeV}, P_T^{miss} = 44 \text{ GeV}, P_T^X = 29 \text{ GeV}$$



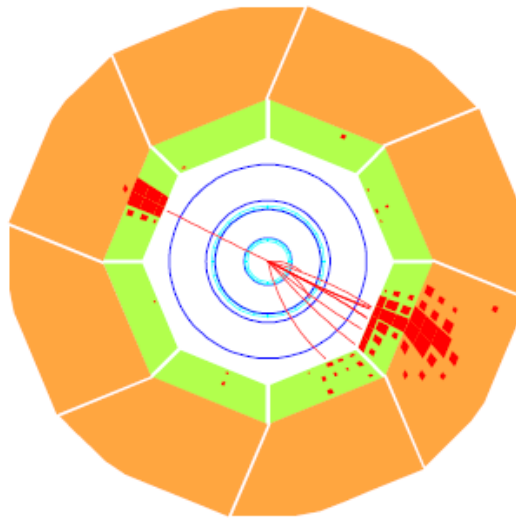
# Signal / Background Discrimination

- Lepton ID Phasespace:  
 $P_T > 10 \text{ GeV}$ ,  
 $5^\circ < \theta < 140^\circ$
- $P_T^{\text{Miss}} > 12 \text{ GeV}$
- Lepton Isolation against tracks, jets
- Event Balance + other topological variables

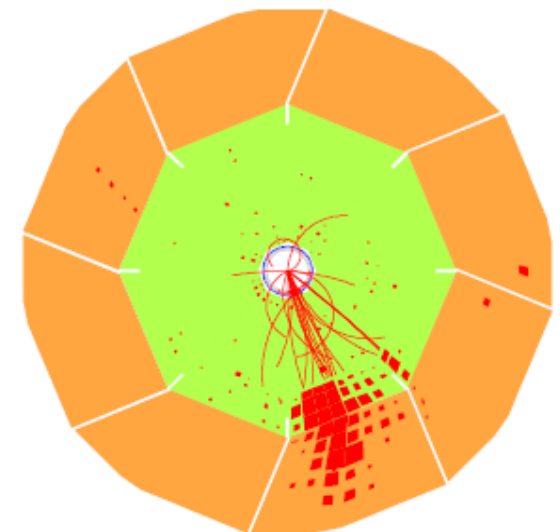
High lepton  $P_T$  and high  $P_T^{\text{Miss}}$  suppresses most background



**Signal ( $\mu$  Event)**

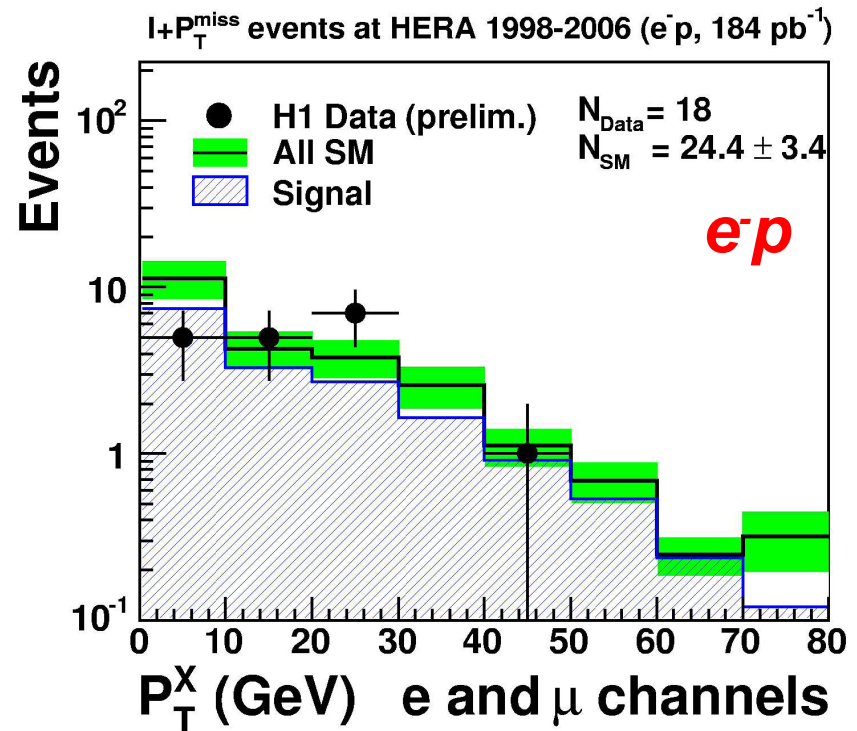
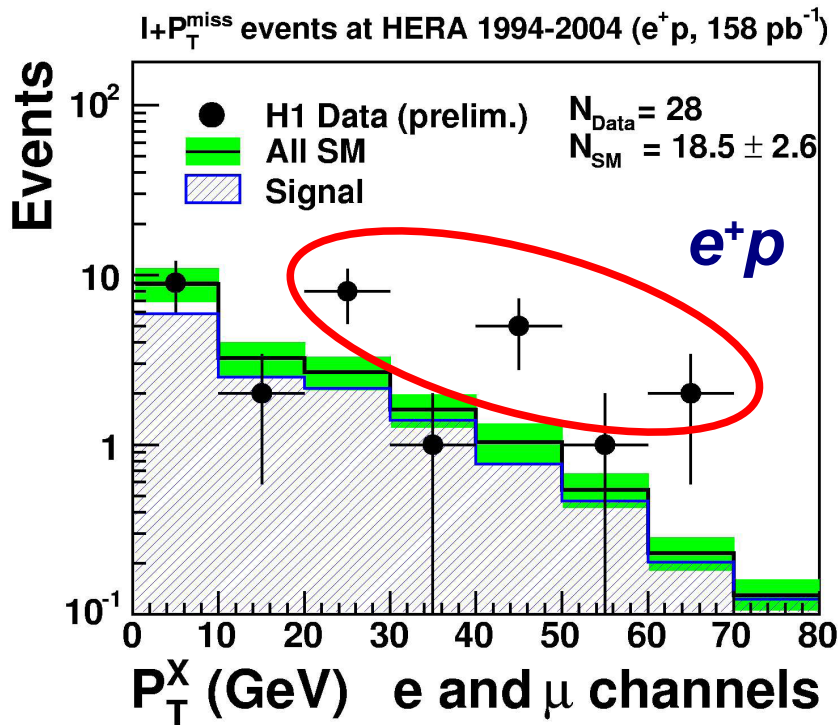


**Neutral Current**  
• back-to-back topology



**Charged Current**  
• no isolated leptons

# $e, \mu$ Results in $e^+p$ and $e^-p$ Data



- Clear Evidence for SM  $W$  Production
- Observe events at high  $P_T^X$

Yield at $P_T^X > 25 \text{ GeV}$	e Channel		$\mu$ Channel	
	obs. / exp.	(signal)	obs. / exp.	(signal)
$e^+p$ ( $158 \text{ pb}^{-1}$ )	9 / $2.3 \pm 0.4$	(80%)	6 / $2.3 \pm 0.4$	(84%)
$e^-p$ ( $184 \text{ pb}^{-1}$ )	3 / $3.8 \pm 0.6$	(61%)	0 / $3.1 \pm 0.5$	(74%)

- Excess a  $3.4\sigma$  effect in  $e^+p$
- Excess not seen in  $e^-p$

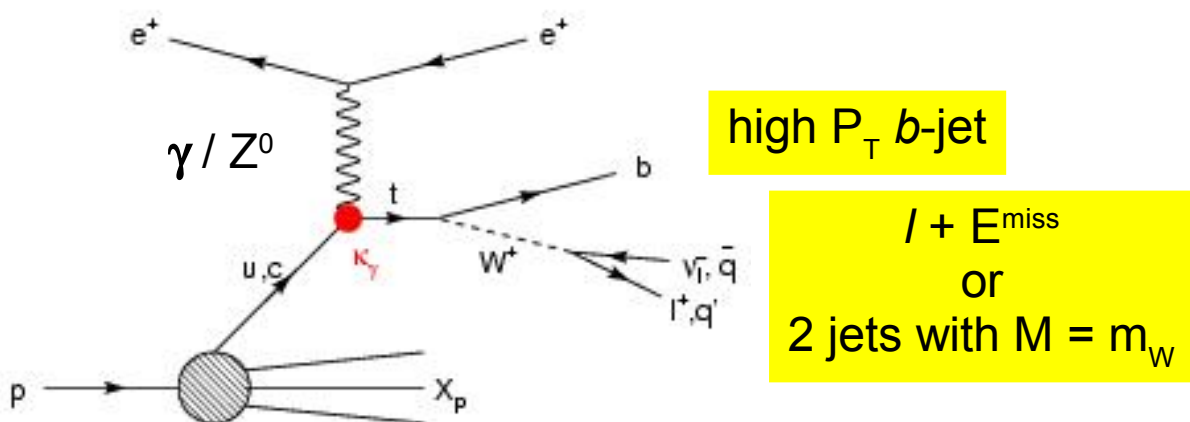
*HERA's best chance for a discovery!*

*What could it be ... ?*



# Anomalous Single Top Production?

- SM *top* Production possible, but  $\sigma_{\text{top}} < 1 \text{ fb}$
- BSM Template Model:  
FCNC *top* production with couplings  $\kappa_{\text{tu}\gamma}, \nu_{\text{tu}Z}$

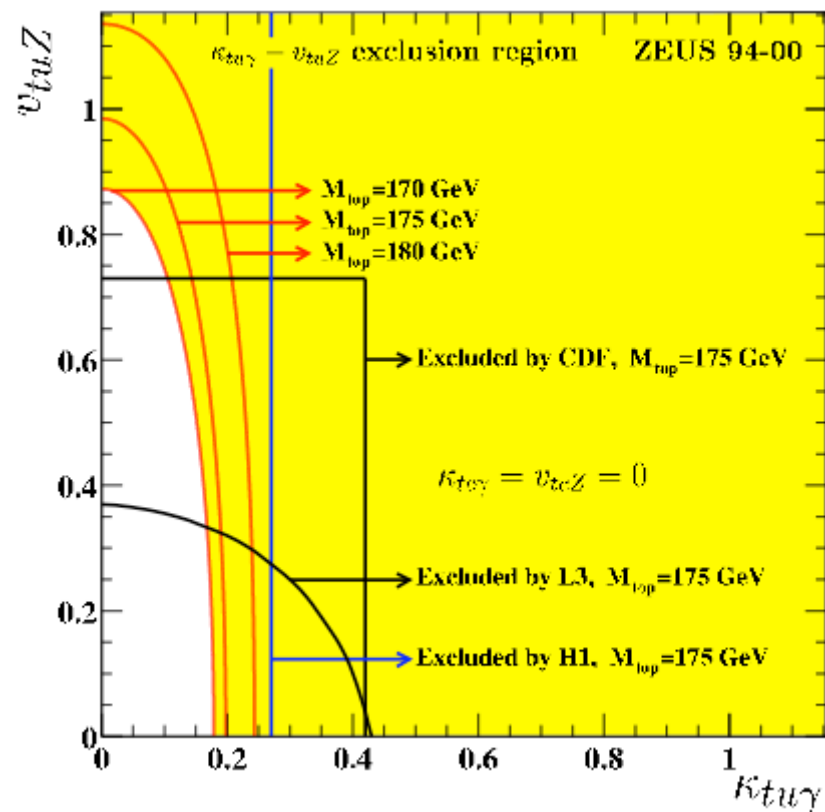


- Analysed at HERA-I

H1: 5 /  $1.31 \pm 0.22$  *top*-like events

Competitive limits set:  $\sigma_{\text{top}} < 0.55 \text{ pb}$

- Cannot explain  $e^+/e^-$  asymmetry

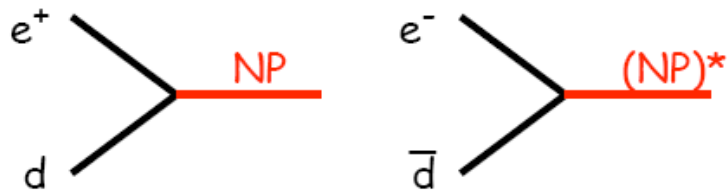


# Other Possible BSM Interpretations

Looking for models that explain difference in  $e^+ / e^-$

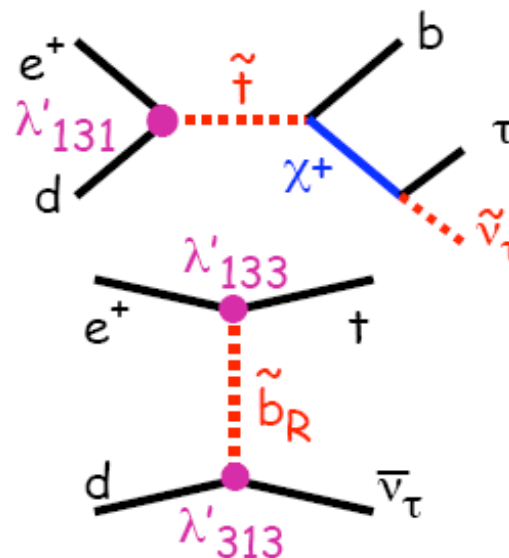
## Particle coupling to $e$ - $q$ with fermion number $F=0$ ?

- Resonant production and large mass  $M$ , i.e. large  $x_{Bj} = M^2/s$
- Then parton density  $d \gg \bar{d}$ , hence  $\sigma(e^+) \gg \sigma(e^-)$



## *R*-Parity violating SUSY ?

- Resonant *stop* squark Production
- t-Channel *sbottom* squark exchange



*Many ideas to be tested ...*

# Properties and Identification of Tau Leptons

Lepton Universality: Cross Check Results in e,  $\mu$  channel with  $\tau$  channel

## $\tau$ Leptons

Mass	$1777.0 \pm 0.3$ MeV
$c\tau$	$87.11 \pm 0.33$ $\mu\text{m}$

### Leptonic decay modes

$\tau \rightarrow e\nu$	17%
$\tau \rightarrow \mu\nu$	18%

covered inclusively  
in e,  $\mu$  channels

### Hadronic 1-prong decay modes

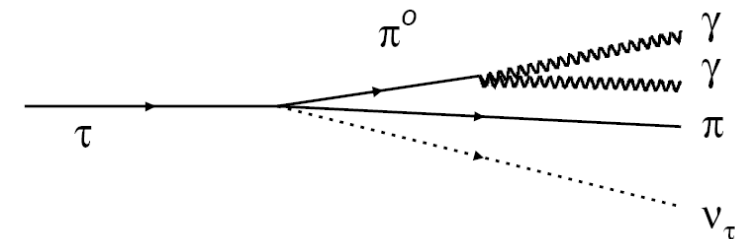
$\tau \rightarrow \pi^\pm \nu$	11%
$\tau \rightarrow \rho^\pm \nu \rightarrow \pi^\pm \pi^0 \nu$	25%
$\tau \rightarrow \pi^\pm \pi^0 \pi^0 \nu$	9%

covered here  
 $Br \sim 50\%$

### Hadronic 3-prong decay modes

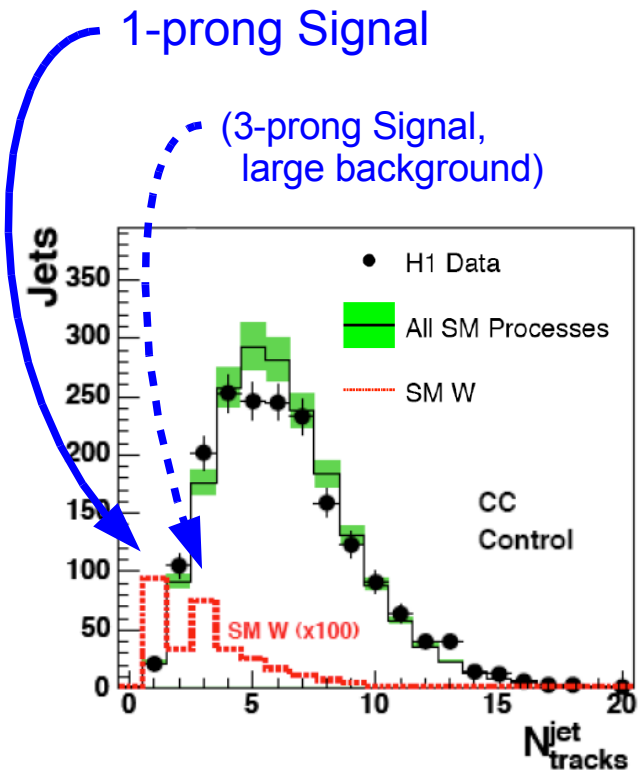
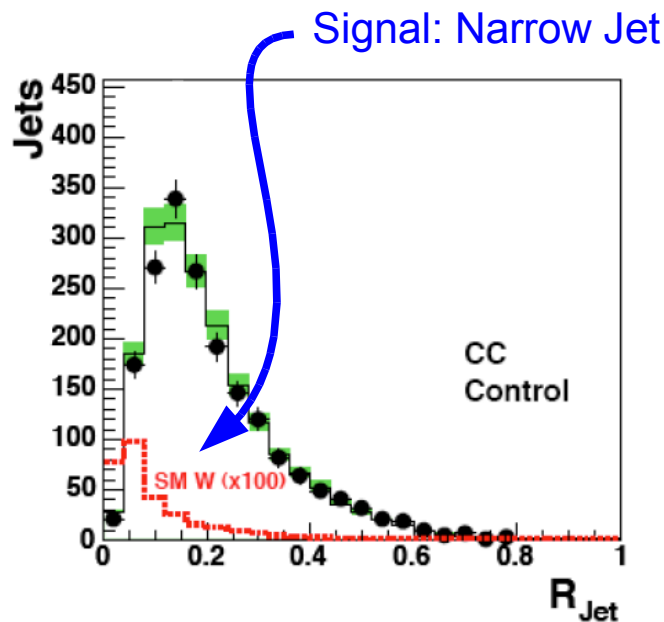
$\tau \rightarrow \pi^\pm \pi^\pm \pi^\pm \nu$	10%
$\tau \rightarrow \pi^\pm \pi^\pm \pi^\pm \pi^0 \nu$	4%

Typical  $\tau$  decay:



## Look for Tau Jets

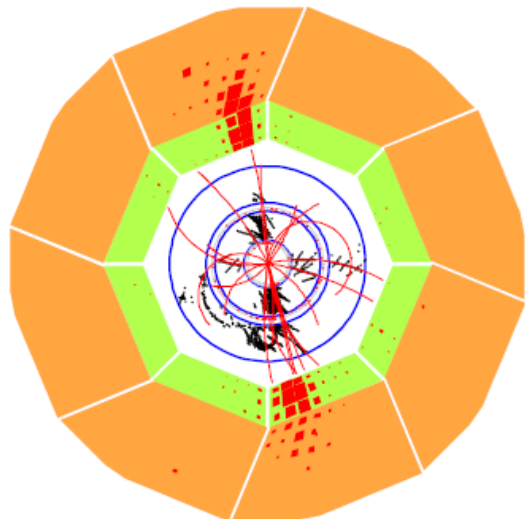
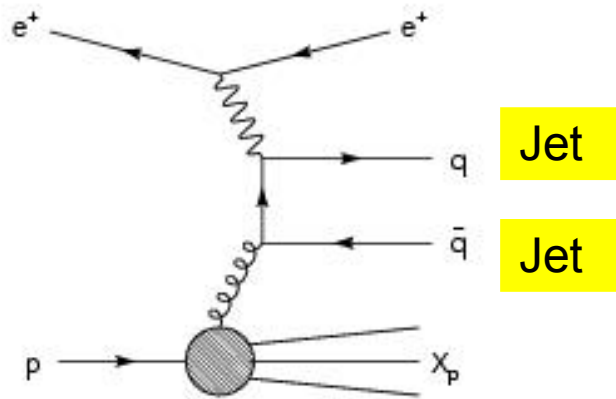
- Neutrino:  $P_T^{\text{Miss}} > 12$  GeV
- $P_T^{\text{Jet}} > 7$  GeV
- $20^\circ < \theta^{\text{Jet}} < 120^\circ$
- Narrow Jet:  $R^{\text{Jet}} < 0.12$
- "1-prong": 1 Isolated Track



# More Background for Tau Leptons

## Photoproduction ( $Q^2 < 1 \text{ GeV}$ )

- Enters because of fake  $E^{\text{miss}}$ , fake  $\tau$ -Jets
- Suppressed because of low Pt, back-to-back topology

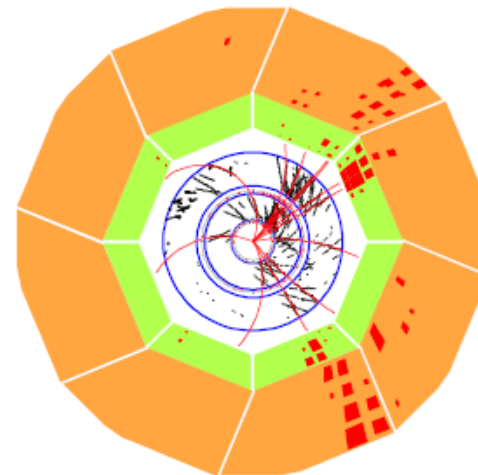
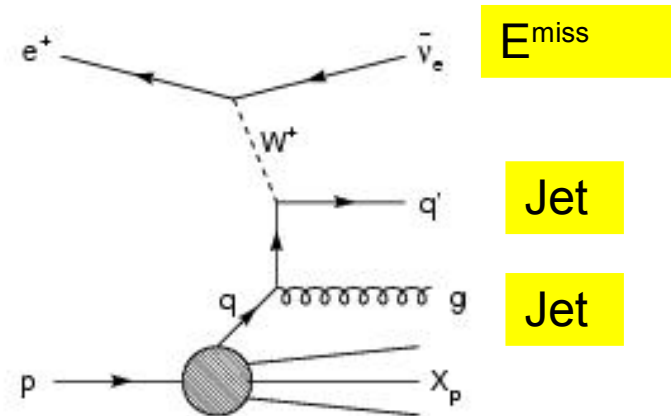


Jets not  $\tau$ -like:  
broad,  
many tracks

Jets  
back-to-back

## Charged Current

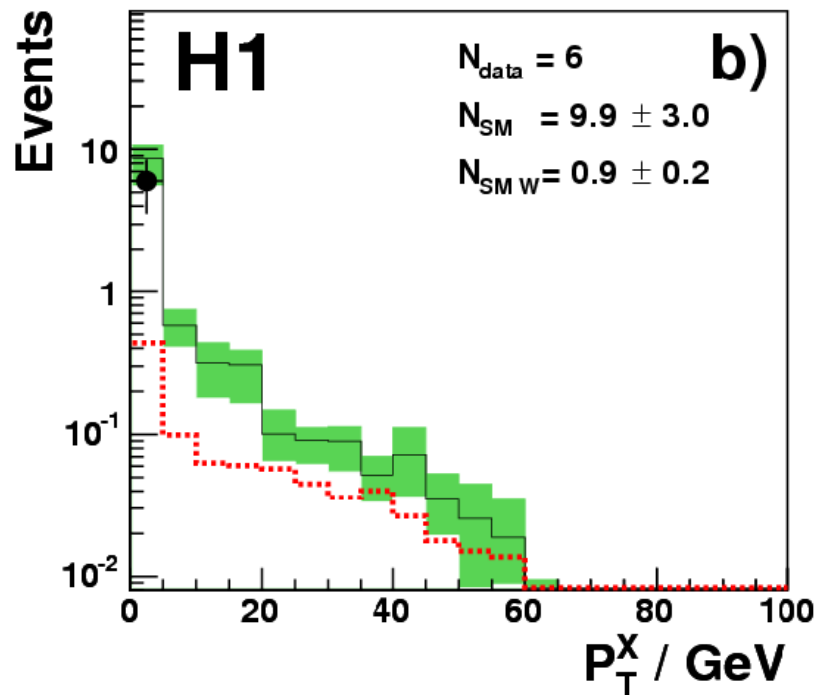
- Becomes very important w.r.t  $e/\mu$  Channel
- Even more at HERA-II:  $\sigma_{\text{CC}}(e^-) \sim 2 \sigma_{\text{CC}}(e^+)$
- Also, NLO in CC becomes important:  
CC Dijet Events



Jets not  $\tau$ -like:  
broad,  
many tracks

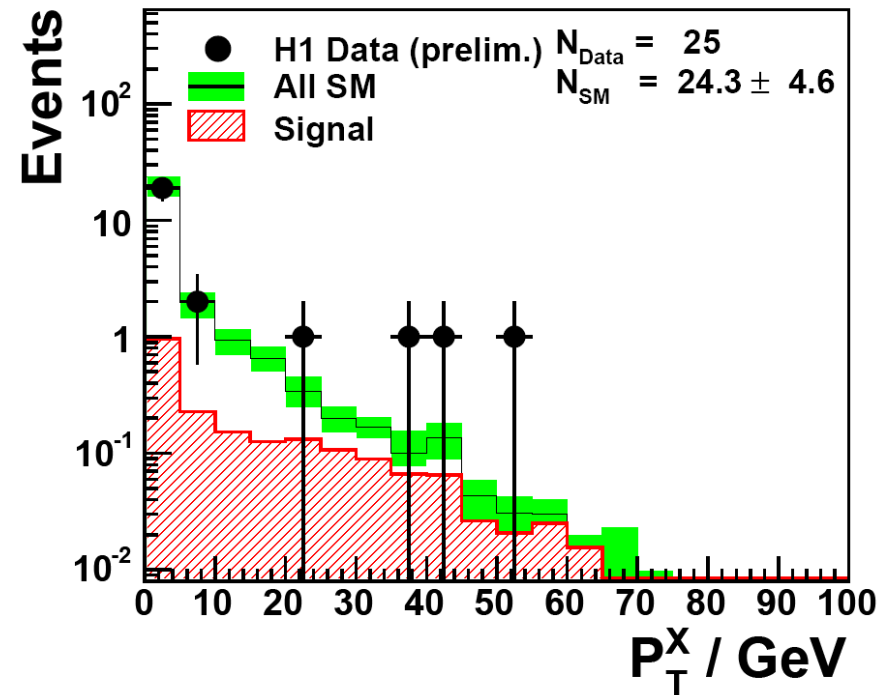
# Results for Tau Leptons

HERA-I Paper (115 pb<sup>-1</sup>, ~90% e<sup>+</sup>p)



HERA-I&II Combined Results (preliminary)

$\tau + P_T^{\text{miss}}$  events at HERA 1994-2005 (e<sup>±</sup>p, 278 pb<sup>-1</sup>)



H1 prelim 94-05	Obs.	SM expectation	Signal
All $P_T^X$	<b>25</b>	<b>24.3 ± 4.6</b>	<b>2.0 ± 0.4</b>
$P_T^X > 25$ GeV	<b>3</b>	<b>0.74 ± 0.15</b>	<b>0.43 ± 0.09</b>

Combined HERA yields for e<sup>+</sup> / e<sup>-</sup> differentially

1994-2004 e <sup>+</sup> p	Total	8	10.6 <sup>+2.2</sup> <sub>-3.5</sub>
153 pb <sup>-1</sup>	$P_T^X > 25$ GeV	0	0.40 <sup>+0.10</sup> <sub>-0.10</sub>
1998-2005 e <sup>-</sup> p	Total	17	13.5 <sup>+2.4</sup> <sub>-2.8</sub>
125 pb <sup>-1</sup>	$P_T^X > 25$ GeV	3	0.35 <sup>+0.10</sup> <sub>-0.08</sub>

- Overall good agreement with SM
- Has e<sup>+</sup>/e<sup>-</sup> yield opposite trend than in e,  $\mu$  Channels?
- Cannot decide now: Statistics limited / Background large
- Don't invent model yet ;-)

## ***Results***

- Excess of isolated Leptons observed in  $e+p$  data
- Excess not seen in  $e-p$  data
- Tau Channel analysed but difficult background conditions

## ***Data Taking + Analysis***

- Full HERA  $e-p$  Sample taken and being analysed
- Now running with  $e^+p$  until July 2007 –  
hoping to take another  $150 \text{ pb}^{-1}$  (~factor 2 increase in statistics)
- Will the yield and excess of isolated leptons in  $e^+p$  be sustained?

## ***Interpretation***

- Single top: Set stricter limits
- Other Models: Can they be ruled out or  
are they compatible with the observation?

*Looking forward to exciting final HERA running period*