Physics with Tau Leptons at HERA

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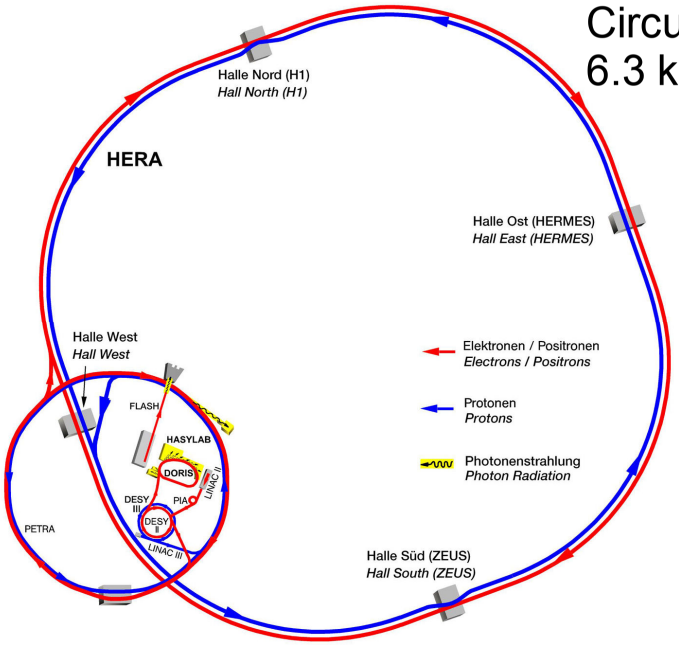
on behalf of
the Collaborations
H1 and ZEUS

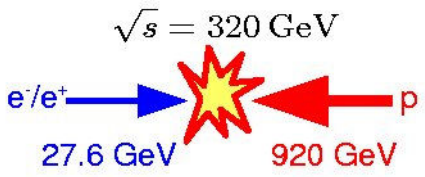
Tau06

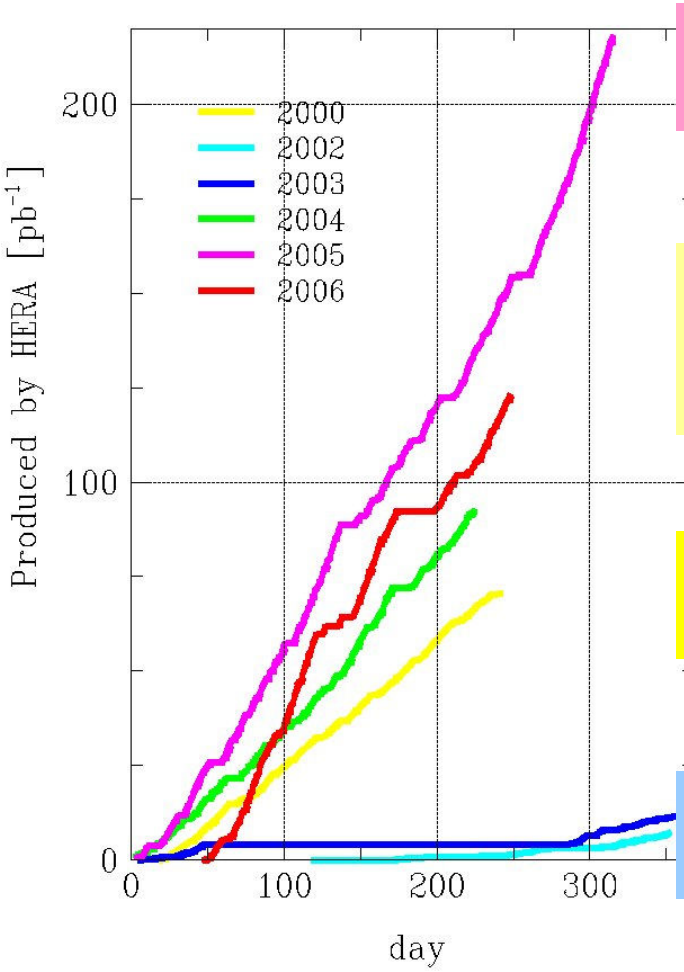
9th Int. Workshop on Tau Lepton Physics
September 19-22, 2006
Pisa (Italy)

The ep Collider HERA



Circumference
6.3 km





2005:
Luminosity Record

from 2003 on:
Longitudinally polarised
Lepton Beam

2000:
End of HERAI

2002-03:
HERAII Start-up

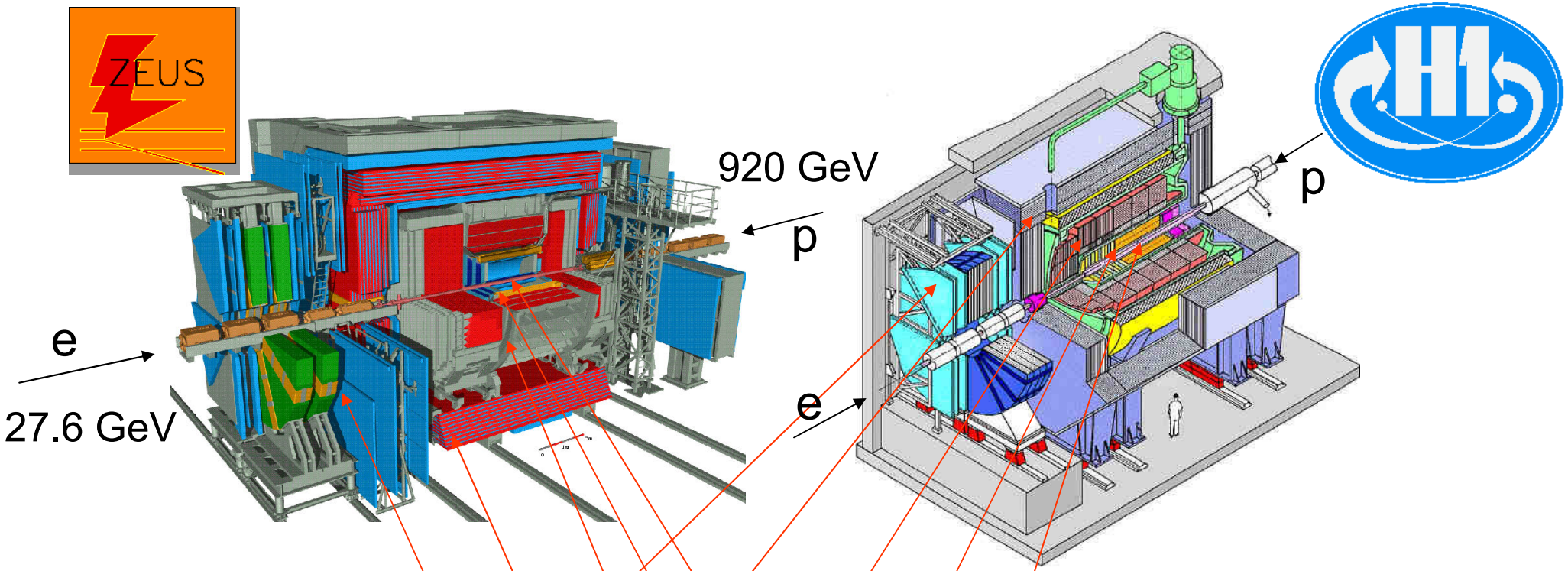
Luminosity seen by H1
(ZEUS similar):

HERAI (1994-2000)
e^+p: L ~ 115 pb^{-1}
e^-p: L ~ 15 pb^{-1}

HERAII (2003-now)
e^+p: L ~ 75 pb^{-1}
e^-p: L ~ 200 pb^{-1}

► **Now almost 400 pb^{-1} of Data for each Experiment !**

The Experiments ZEUS and H1

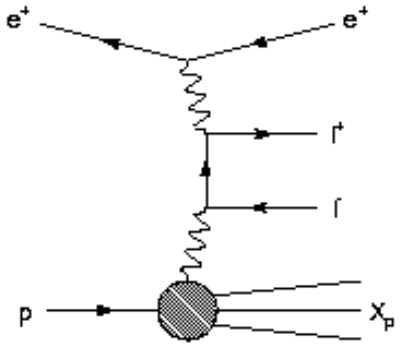


Main components:

- Forw. Muon detector
- Instr. Iron (Streamer tubes)
- Calorimeter
- Drift chambers
- Silicon Strip detectors

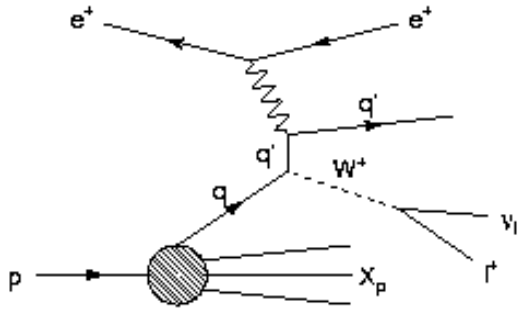
Tau Lepton Production at HERA

Standard Model



$\tau^+\tau^-$ Pair-Production

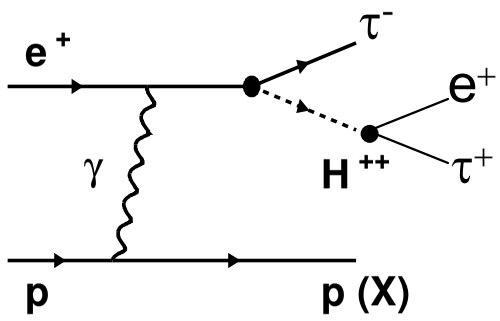
$\sigma \sim 20$ pb ($P_T^{\tau} > 2$ GeV)



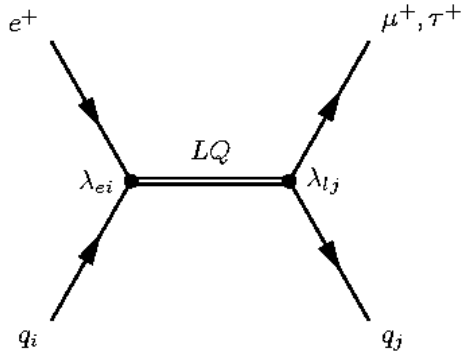
W Production with subsequent Decay $W \rightarrow \tau\, \nu$

$\sigma \bullet BR \sim 0.1$ pb

New Physics



Production of doubly charged Higgs Bosons



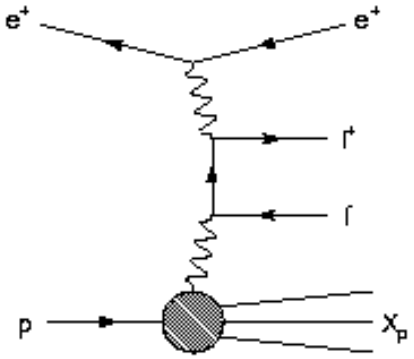
Production of heavy Resonances with subsequent Decay $LQ \rightarrow \tau q$

Lepton Flavour Violation

- Tau Lepton Production is a **rare** Process at HERA !
- Tau Lepton Channels are **important** in Searches for new Physics !

$\tau^+\tau^-$ Pair-Production at H1

$ep \rightarrow \tau^+\tau^-(ep)$

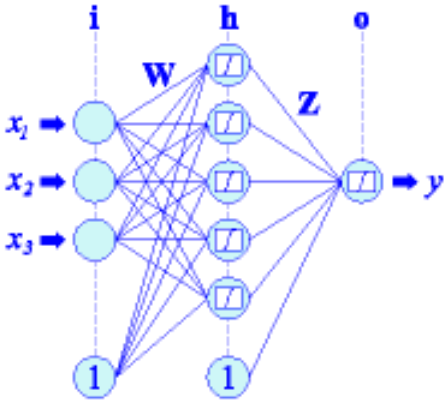


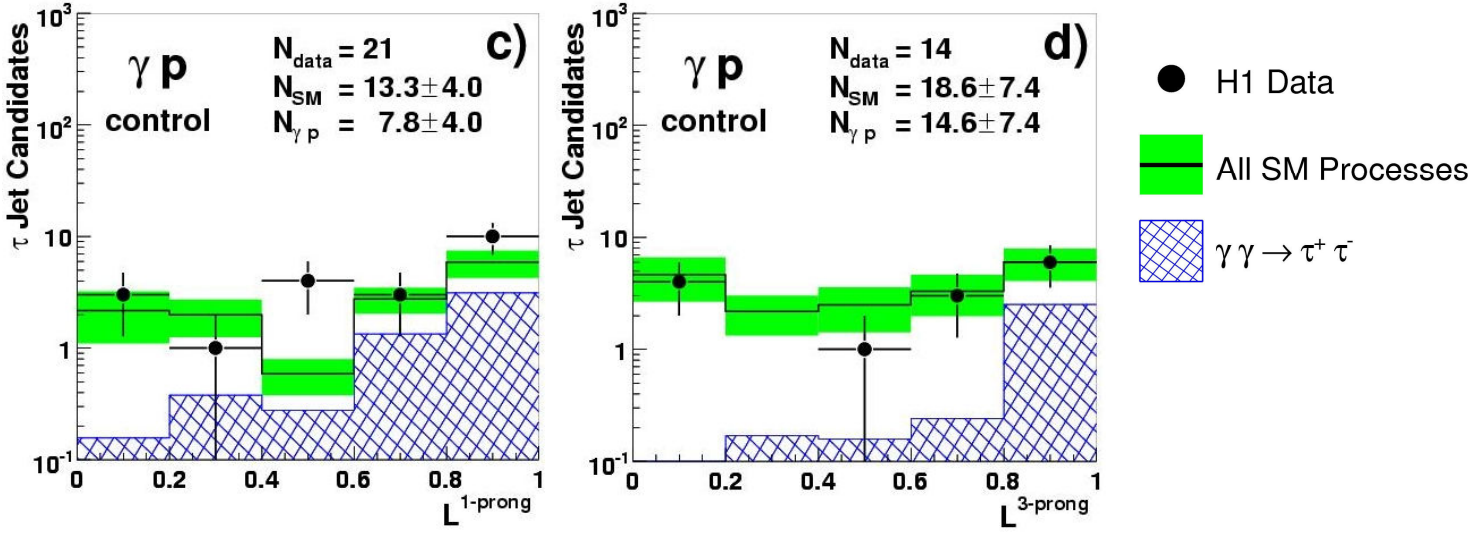
$\sigma \sim 20$ pb

e	μ	Jet
$E_e > 5$ GeV	$P_T^{\mu} > 2$ GeV	$P_T^{jet} > 2$ GeV
$P_T^e > 3$ GeV	$20^o < \theta_{\mu} < 140^o$	$P_T^{track} > 2$ GeV
$20^o < \theta_e < 140^o$		$20^o < \theta_{jet} < 120^o$
Isolation Criteria	Isolation Criteria	$L > 0.75$
Opposite Charges of Decay Products		
elastic No additional Particles (except scattered electron)		

Production

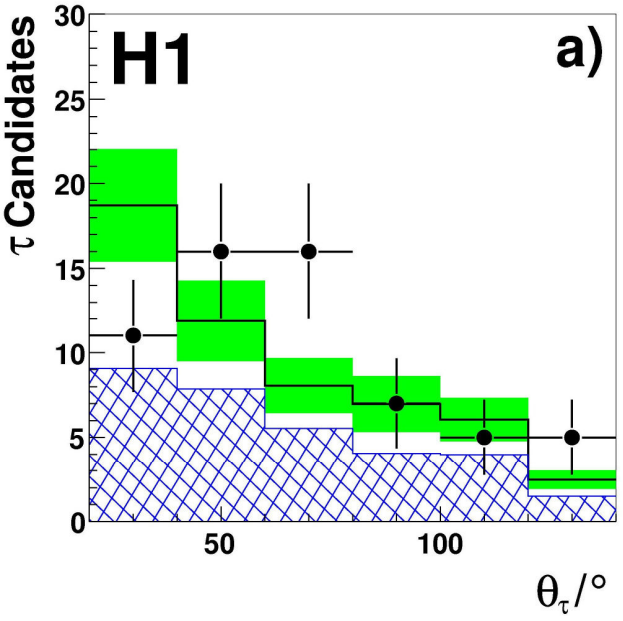
Neural Network based Identification of hadronic τ Decays

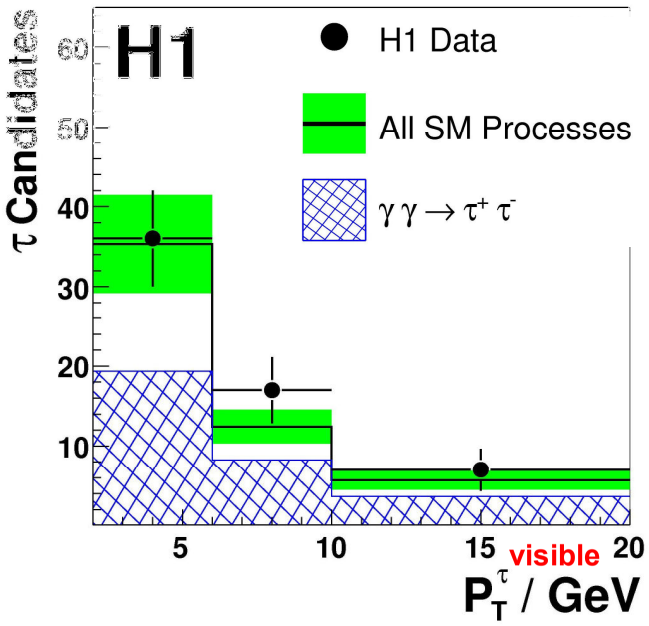


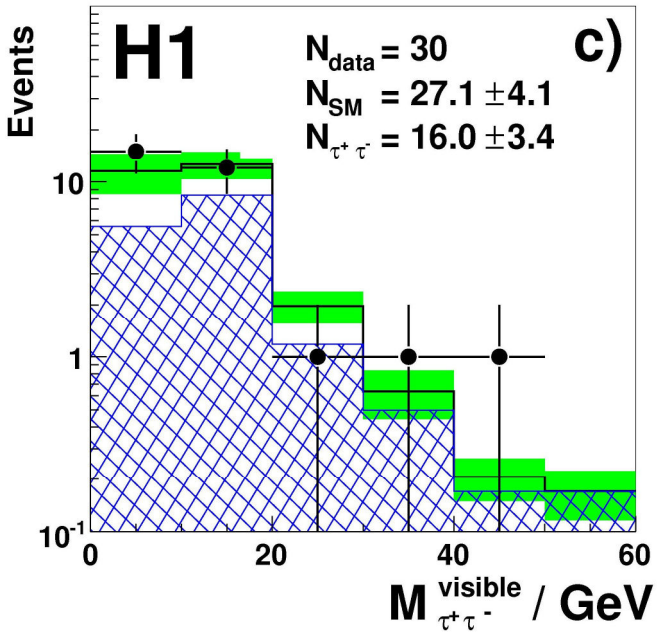


$\tau^+\tau^-$ Results of

HERAI $e^{\pm}p$ Data L = 106 pb^{-1}







$\tau^+\tau^-$ Results					
Decay Channel	**Leptonic**	**Semi–leptonic**		**Hadronic**	**Total**
	$e\ \mu$	$e\ \tau$–jet	$\mu\ \tau$–jet	τ–jet τ–jet	
H1 Data	7	2	10	11	30
SM	2.9 ± 0.4	6.3 ± 0.9	7.0 ± 1.3	11.0 ± 2.0	27.1 ± 4.1
$\tau^+\tau^-$	56%	47%	85%	50%	59%

► **Data in Agreement with SM Expectation !**

hep-ex/0604022, accepted by Eur. Phys. J. C

stat. sys.

$\sigma_{measured} = 13.6 \pm 4.4 \pm 3.7$ pb

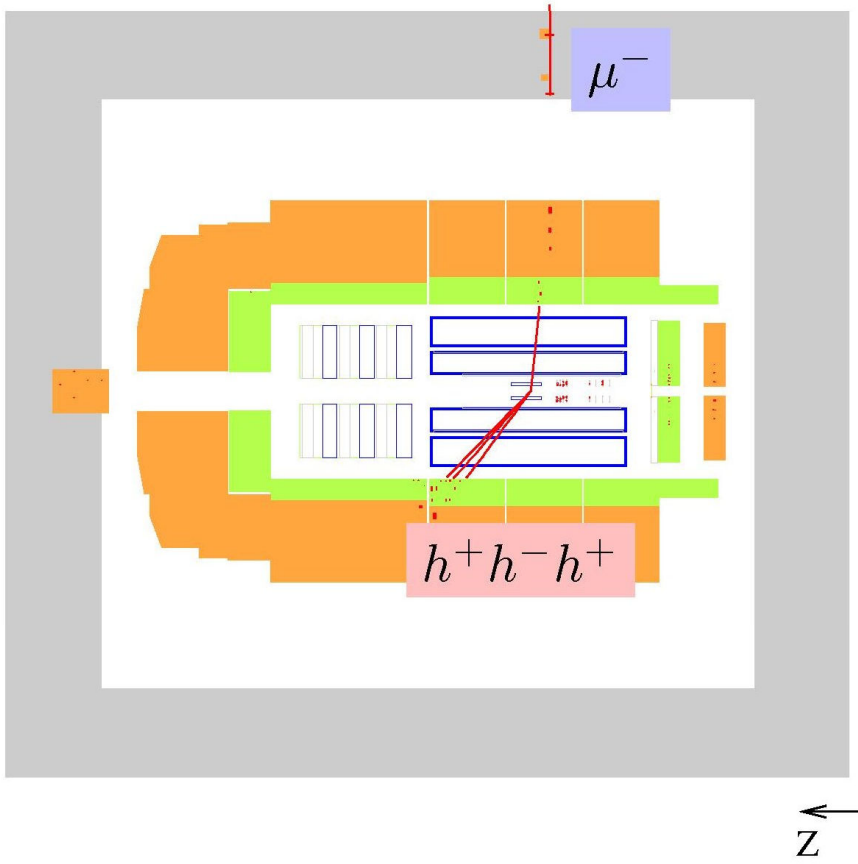
$\sigma_{theory} = 11.2 \pm 0.3$ pb (Grape)

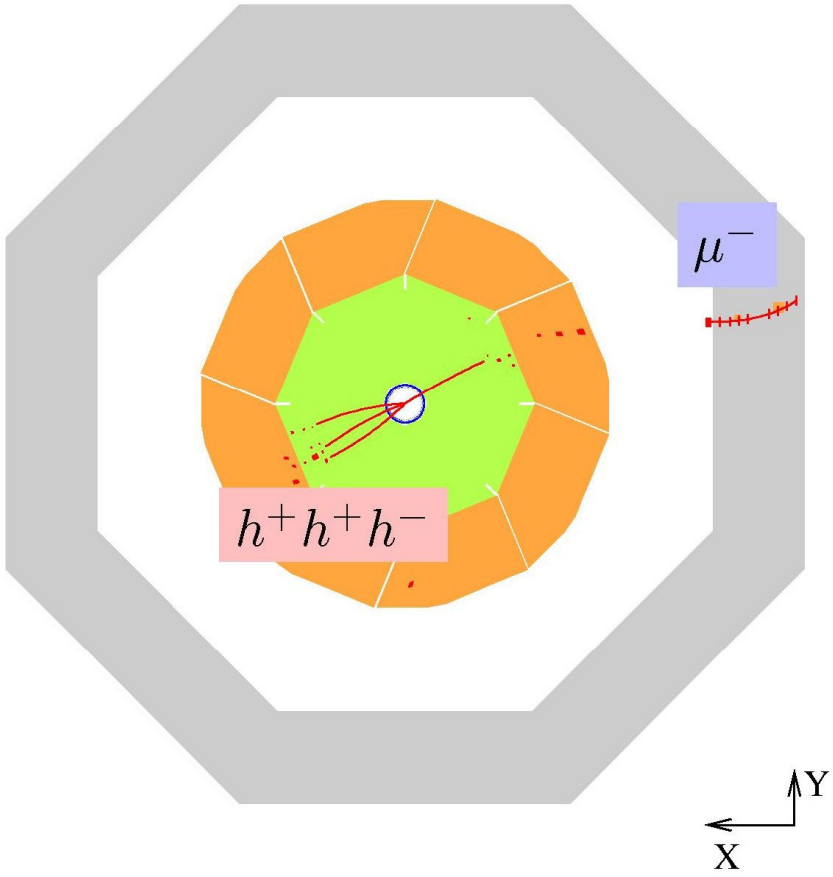
$\tau^+\tau^-$ Candidate Event

TAU PAIR CANDIDATE

$$e^+p \longrightarrow e^+ \; \tau^- \; \tau^+p$$

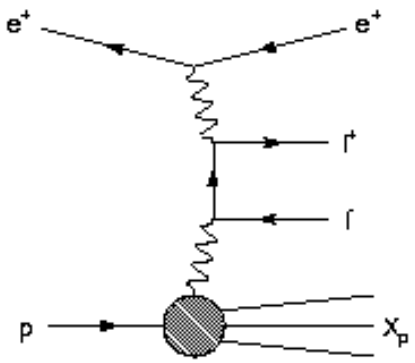
$$\tau^- \rightarrow \mu^- \; \bar{\nu}_\mu \nu_\tau \qquad \tau^+ \rightarrow h^+h^+h^- \; \bar{\nu}_\tau$$





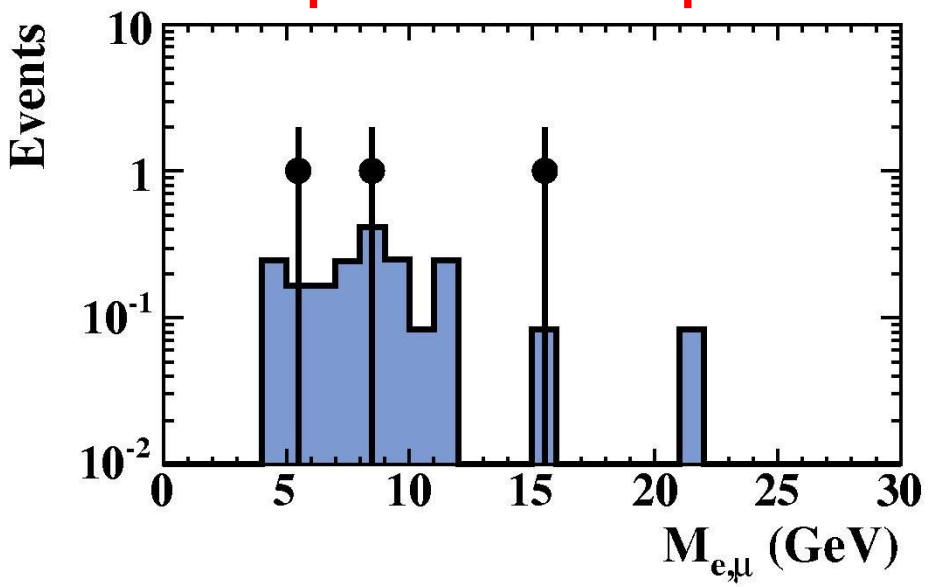
$\tau^+\tau^-$ Pair-Production at ZEUS

$ep \rightarrow \tau^+\tau^-(ep)$



e	μ
$E_e > 4$ GeV $\theta_e < 2.6$ rad Isolation Criteria	$P_T^{\mu} > 2$ GeV $17^o \lesssim \theta_{\mu} \lesssim 164^o$ (Acceptance of central Tracking Detector)
elastic Production	Number of Tracks in Event ≤ 3 No Activity in "forward" Calorimeter Region

HERAII e^-p Data L = 135 pb^{-1}



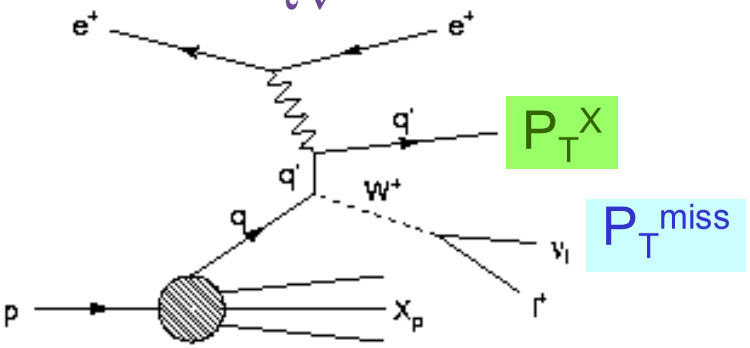
Decay Channel	Leptonic e μ
ZEUS Data	3
$\tau^+\tau^-$	2.0 ± 0.8
$\mu^+\mu^-$	< 0.2

► **Data in Agreement with SM Expectation**

ZEUS-prel-06-017

Analysis of $\tau + P_T^{miss}$ Events at

$ep \rightarrow W(eX)$
$\hookrightarrow \tau\nu$

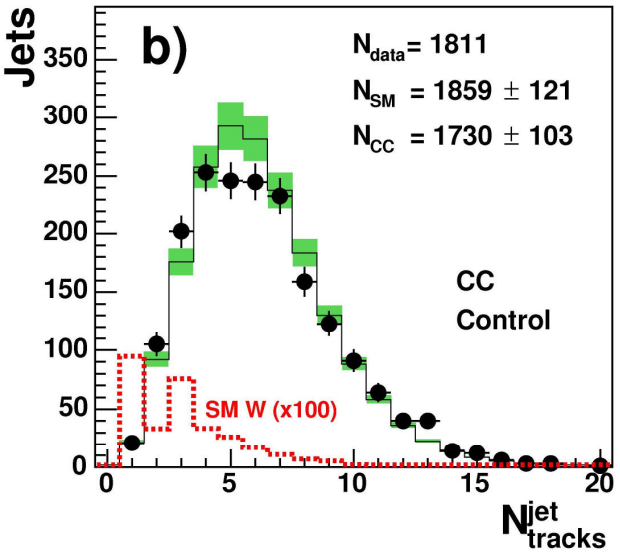


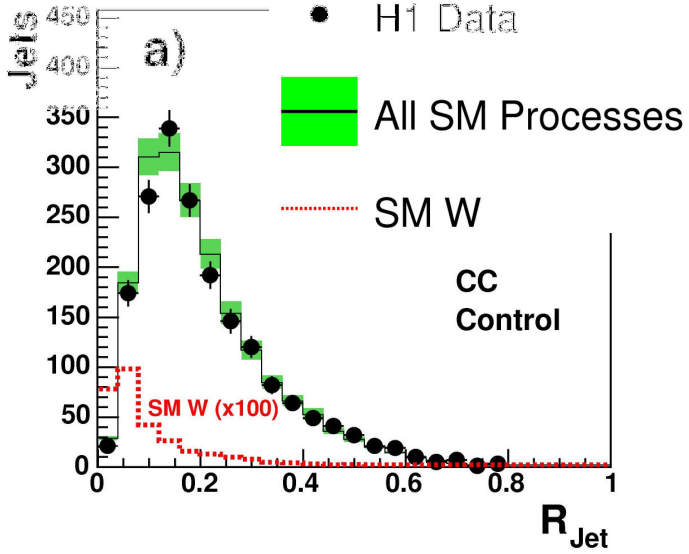
$\sigma \bullet BR \sim 0.1$ pb

Model-independent Analysis:

- SM Signal is Production of real W Bosons with subsequent Decay $W \rightarrow \tau\nu$
- Event Selection designed to be equally sensitive to New Physics

Cut based Identification of hadronic τ Decays



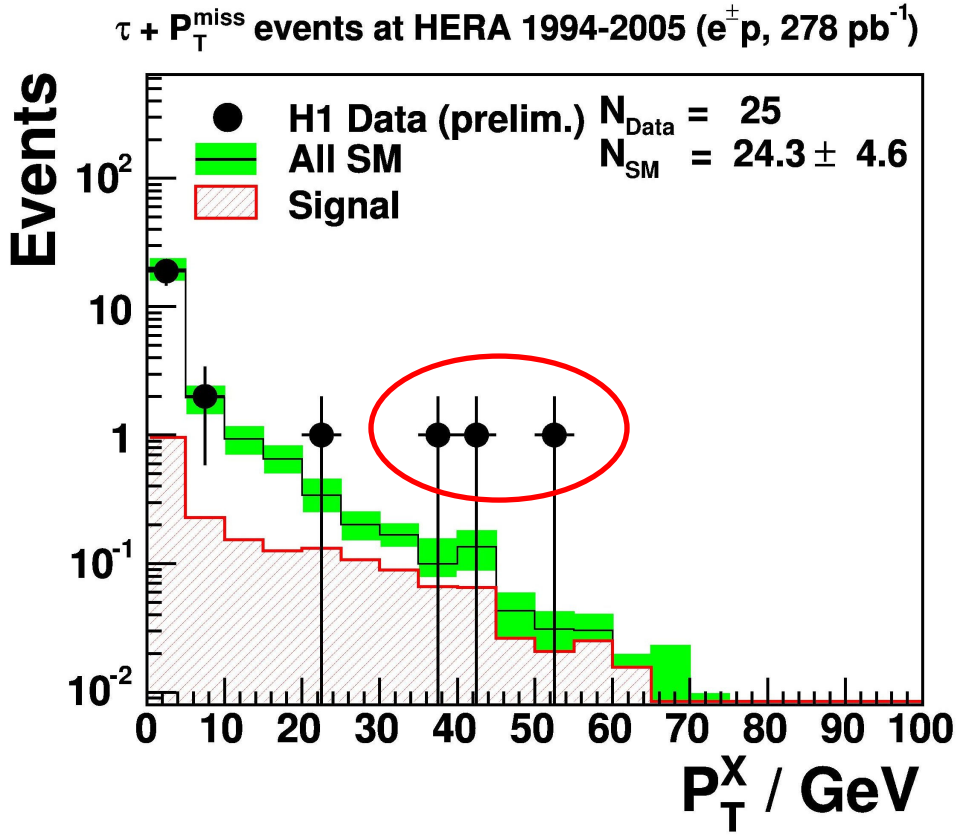


Jet
$P_T^{jet} > 7$ GeV
$P_T^{track} > 5$ GeV
$20^o < \theta_{jet} < 120^o$
$N_{jet}^{tracks} = 1$
$R_{jet} < 0.12$
$P_T^{miss} > 12$ GeV

$$R_{jet} = \frac{\Sigma E_i \bullet R_i}{\Sigma E_i}, \quad R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

Sum extends over all Particles i within Jet

$\tau + P_T^{miss}$ Results of

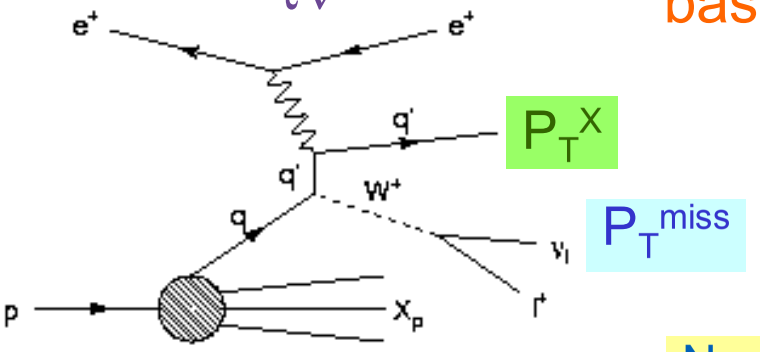


H1 Preliminary $\tau + P_T^{miss}$		H1 Data	SM Expectation	$W \to \tau\nu$ SM Signal	Other SM Processes
1994-2005 $e^{\pm}p$	Total	25	$24.2\ ^{+4.2}_{-5.8}$	$2.0\ ^{+0.33}_{-0.40}$	$22.2\ ^{+4.2}_{-5.8}$
278 pb^{-1}	$P_T^X > 25$ GeV	3	$0.74\ ^{+0.19}_{-0.16}$	$0.44\ ^{+0.07}_{-0.09}$	$0.31\ ^{+0.18}_{-0.13}$

▶ **Interesting $\tau + P_T^{miss}$ Events observed at large P_T^X !** hep-ex/0604022 H1-prelim-06-064

Analysis of $\tau + P_T^{miss}$ Events at ZEUS

$ep \rightarrow W(eX)$
$\hookrightarrow \tau\nu$



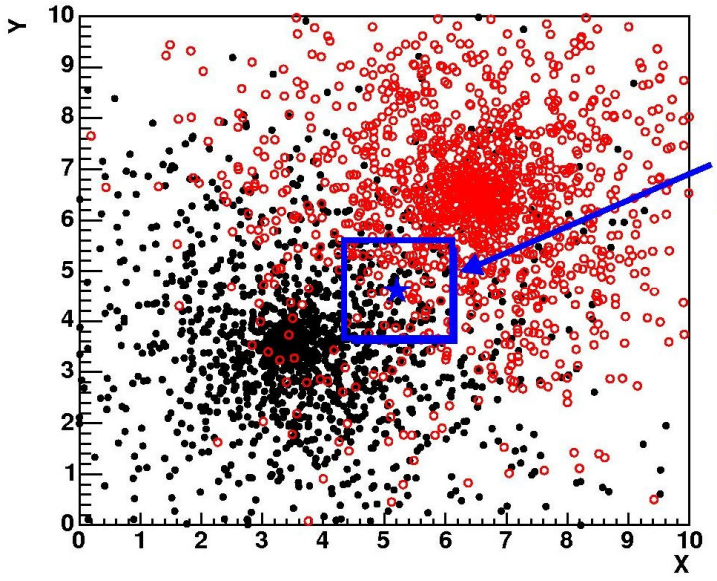
Identification of hadronic τ Decays based on Discriminant

$$D(\vec{x}) = \frac{\rho_{sig}(\vec{x})}{\rho_{sig}(\vec{x}) + \rho_{bg}(\vec{x})}$$

Nucl. Inst. Meth. A 501 (2003) 576
(R.O. Duda, P.E. Hart, D.G. Stork:
"Pattern Classification", Wiley, 2001)

Jet
$E_T^{jet} > 5$ GeV
$P_T^{track} > 5$ GeV
$-1.0 < \eta_{jet} < 2.5$
$D > 0.95$
$f_{EMC}^{jet} < 0.95$
$f_{EMC}^{jet} + f_{track}^{jet} < 1.6$
$P_T^{miss} > 20$ GeV

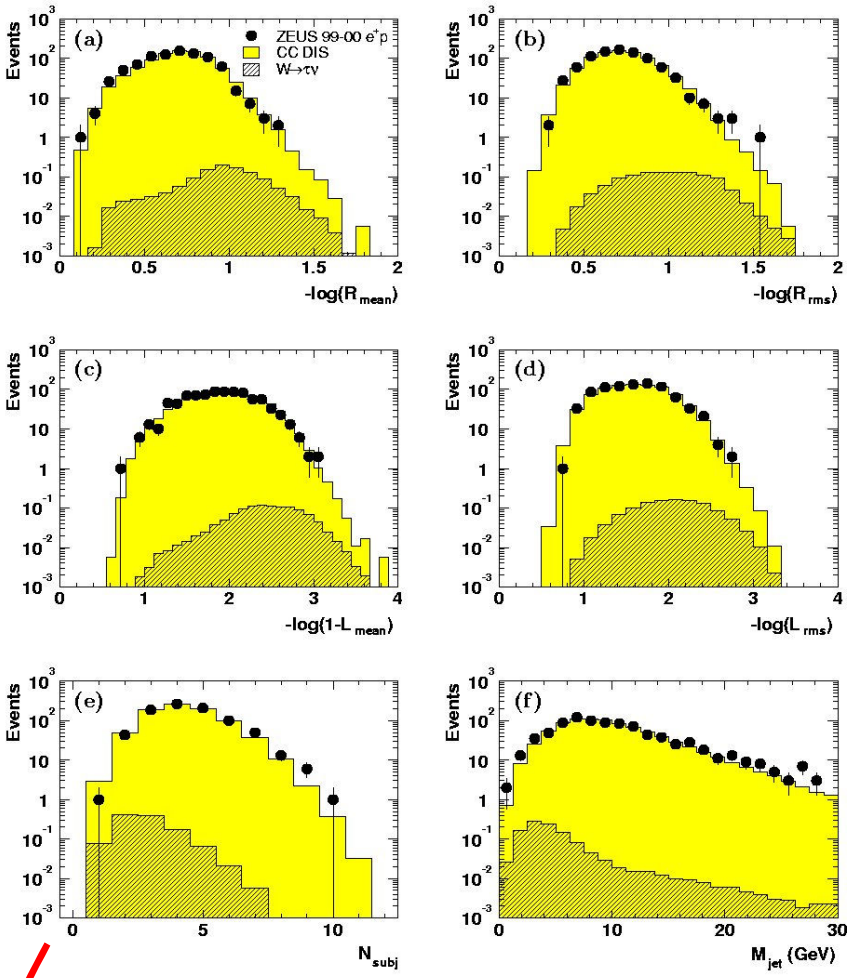
Rejection of unidentified electrons

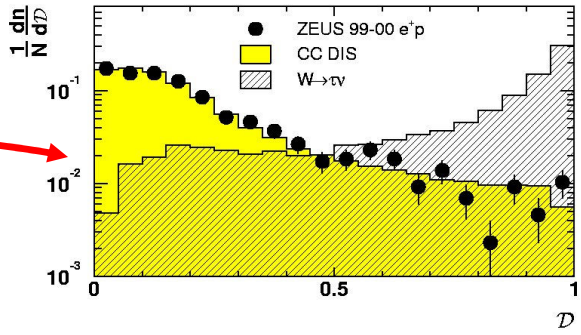


$$\mathcal{D}(\vec{x}) = \frac{\rho_{sig}}{\rho_{sig} + \rho_{bkg}}$$

For any jet with represented by vector $\vec{x}$ in jet-shape space to be classified, the signal and background densities are estimated from the number of simulated signal and background jets in a multi-dimensional box of fixed size around x

Identification of hadronic τ Decays at ZEUS





Discriminant based on 6 Features:

- 1st radial Moment

$$R_{\mathrm{mean}} = \langle R \rangle = \frac{\sum_i E_i \cdot R_i}{\sum_i E_i}$$

- 2nd radial Moment

$$R_{\mathrm{rms}} = \sqrt{\frac{\sum_i E_i (\langle R \rangle - R_i)^2}{\sum_i E_i}}$$

- 1st Moment of Projection onto Jet Axis

$$L_{\mathrm{mean}} = \langle L \rangle = \frac{\sum_i E_i \cdot \cos\alpha_i}{\sum_i E_i}$$

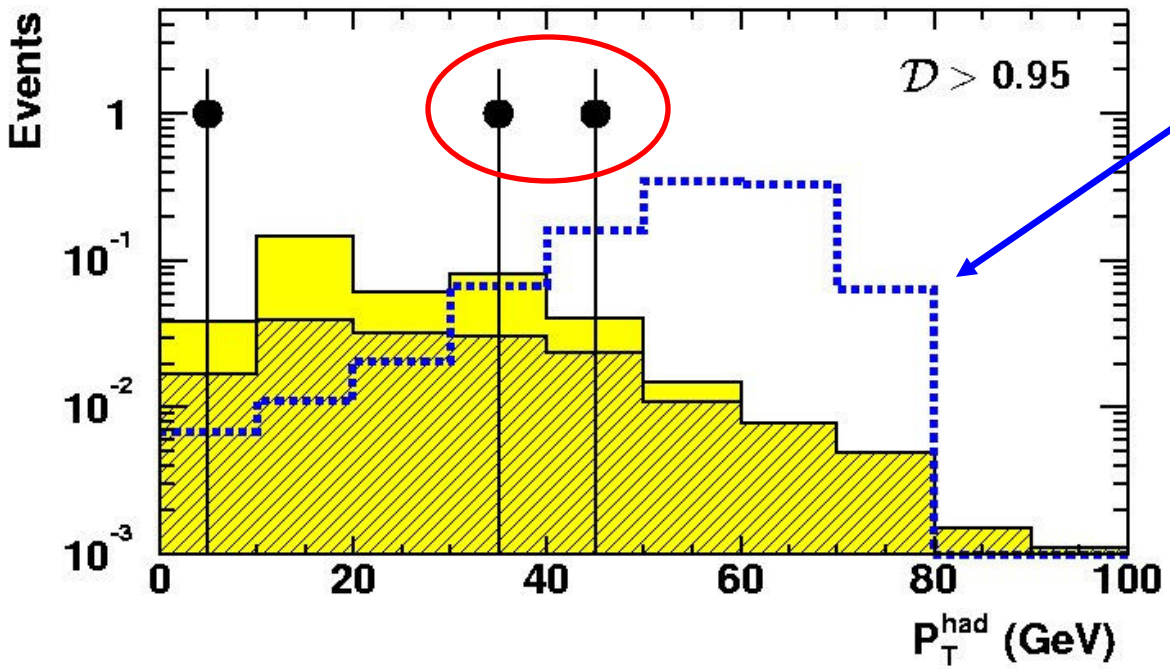
- 2nd Moment of Projection onto Jet Axis

$$L_{\mathrm{rms}} = \sqrt{\frac{\sum_i E_i (\langle L \rangle - \cos\alpha_i)^2}{\sum_i E_i}}$$

- Number of sub-Jets (for y-Cut of $5 \cdot 10^{-4}$)
- Invariant Mass of Jet reconstructed by summing over Calorimeter Cells
  massless Four-Vector defined by Energy measured in Cell and Position of Cell Centre

► **Good Separation of Signal from Background !**

$\tau + P_T^{miss}$ Results of ZEUS



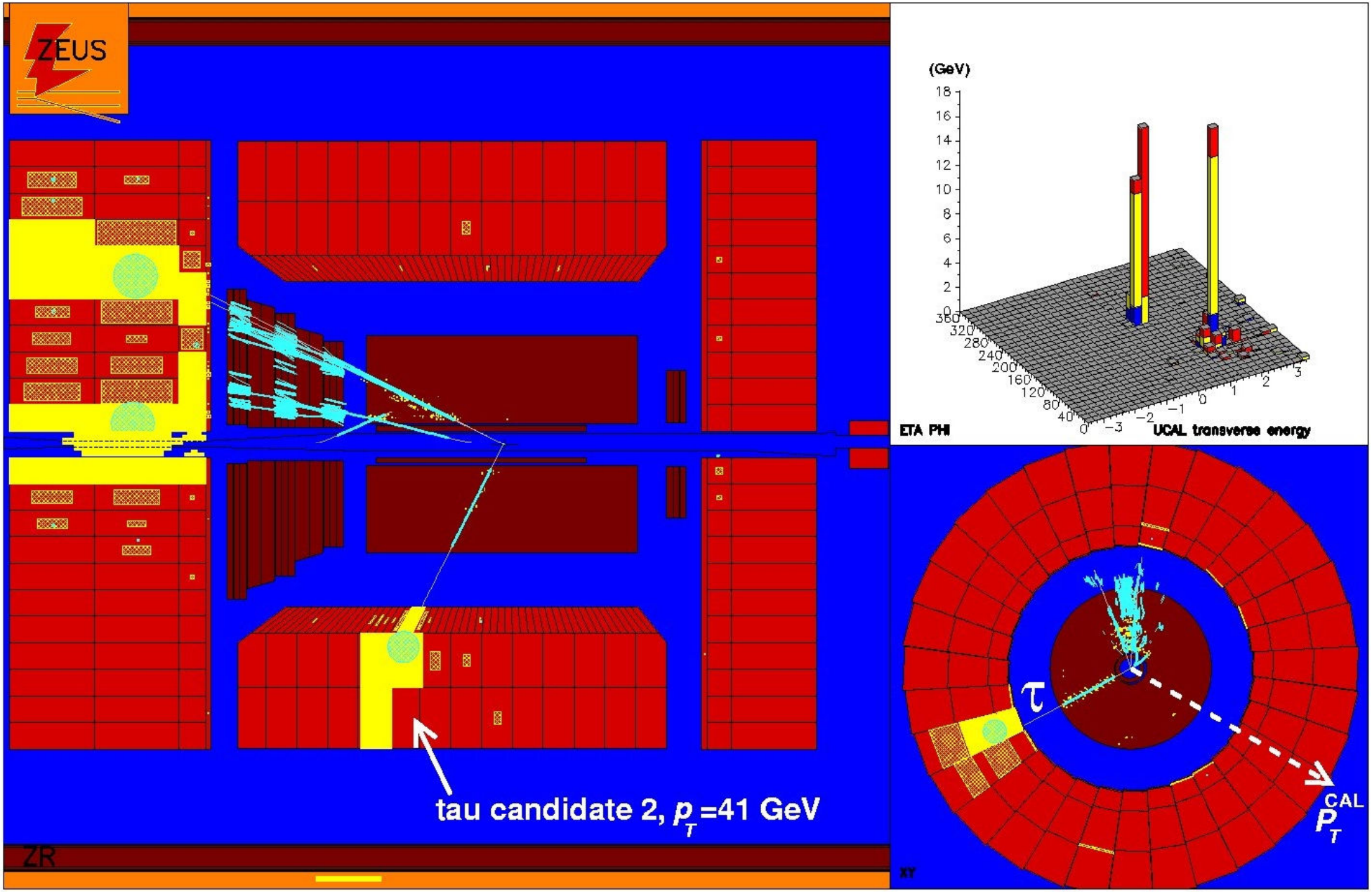
New Physics Signal
(Decay of heavy Resonance)

ZEUS $\tau + P_T^{miss}$		ZEUS Data	SM Expectation	$W \to \tau\nu$ Signal Contribution
1994-2000 $e^{\pm}p$	Total	3	$0.40\ ^{+0.12}_{-0.13}$	43%
$L = 130\ pb^{-1}$	$P_T^X > 25$ GeV	2	0.20 ± 0.05	49%

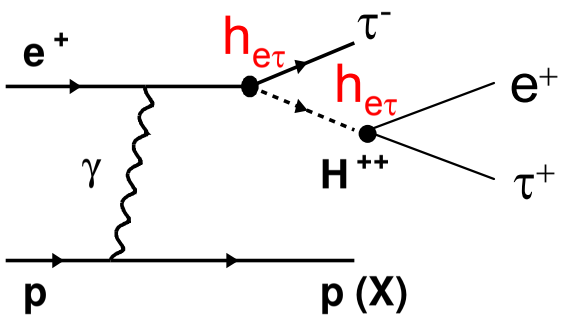
► **Interesting $\tau + P_T^{miss}$ Events at large P_T^X also observed in ZEUS Data !**

Phys. Lett. B 583 (2004) 41

$\tau + P_T^{miss}$ Candidate Event



Search for $H^{++} \rightarrow e^+\tau^+$ Decays

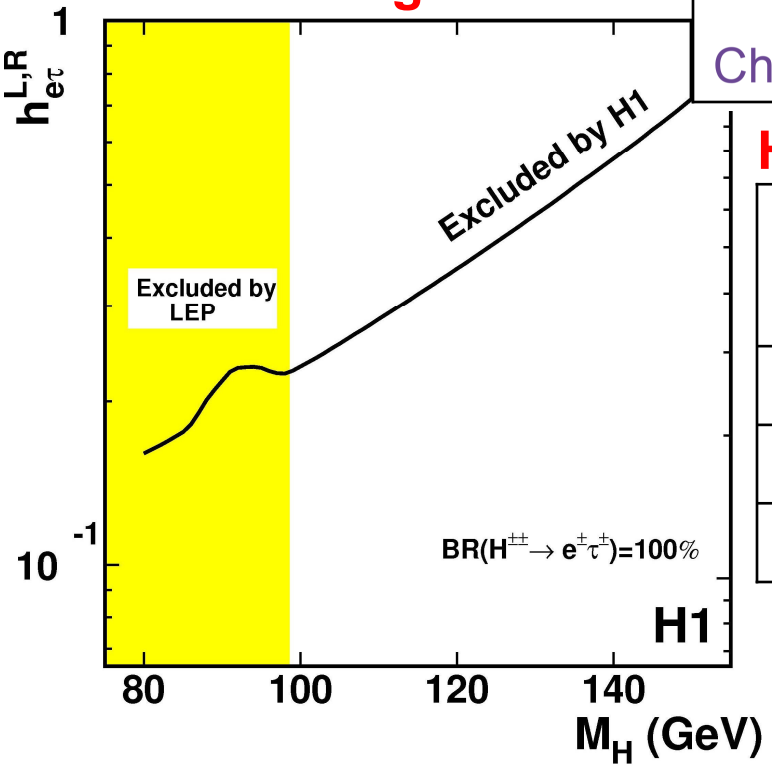


e	μ	Jet
$P_T^e > 5$ GeV	$P_T^\mu > 5$ GeV	$P_T^{jet} > 5$ GeV
$20^o < \theta_e < 140^o$	$20^o < \theta_\mu < 140^o$	$P_T^{track} > 5$ GeV
Isolation Criteria	Isolation Criteria	$20^o < \theta_{jet} < 120^o$
		No other Track within $0.15 < R < 1.5$

$P_T^{miss} > 8$ GeV (e + e) / > 11 GeV (e + Jet)

Charges of Decay Products matches Charge of Beam Lepton

resulting Limits



HERAI e^+p Data L = 88 pb^{-1}

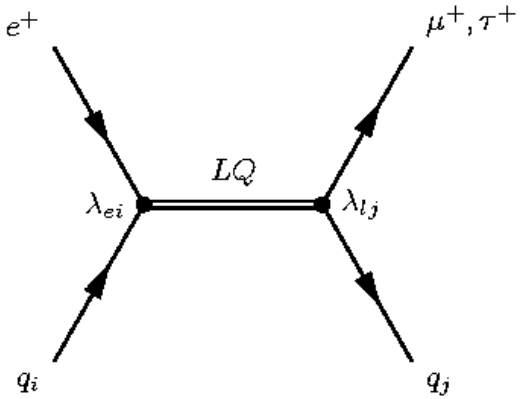
Decay Channel	e e	e μ	e Jet
H1 Data	0	0	1
SM	0.14 ± 0.04	0.27 ± 0.02	1.66 ± 0.48
$\varepsilon(H^{++})$	7%	6%	12%

► **Total Signal Efficiency 25%**

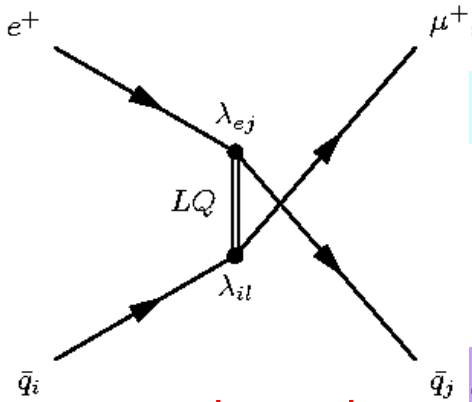
► **No Evidence for $H^{++} \rightarrow e^+\tau^+$ Decays found !**

Phys. Lett. B 638 (2006) 432

Search for Lepton Flavour Violation at



s-channel
$M_{LQ} < \sqrt{s}$



u-channel
$M_{LQ} > \sqrt{s}$

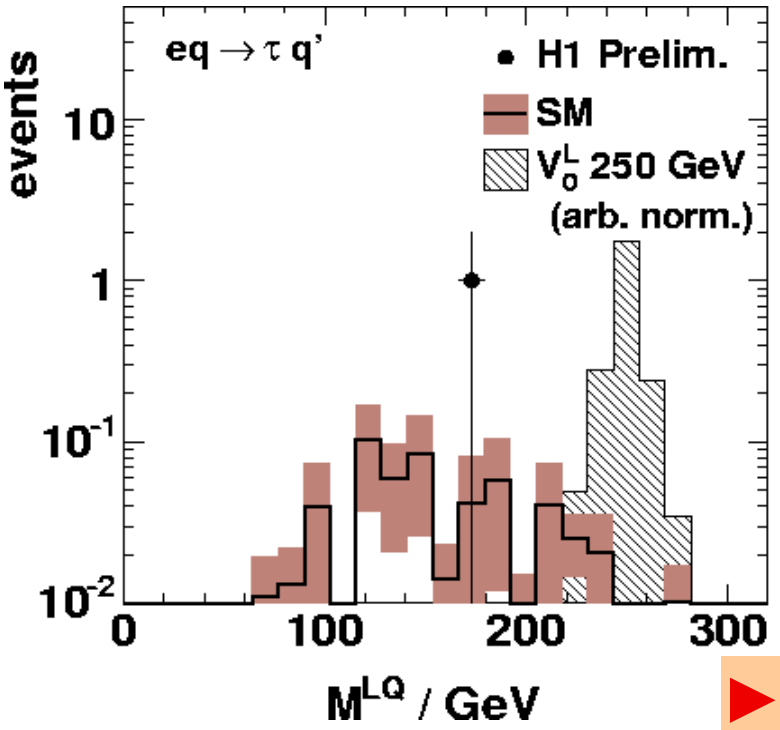
τJet

P_T^{miss}

~Jet1

Jet
$P_T^{jet1} > 25$ GeV, $P_T^{jet2} > 15$ GeV
$7^o < \theta_{jet1,2} < 145^o$
$f_{EMC}^{jet1,2} > 0.95$
$1 \leq N_{jet}^{tracks} \leq 3$
$R_{jet} < 0.12$
$M_{jet} < 7$ GeV
$P_T^{miss} > 20$ GeV
$\Delta\varphi_{miss\text{-}\tau Jet} < 30^o$

All within Cone of Radius 0.12



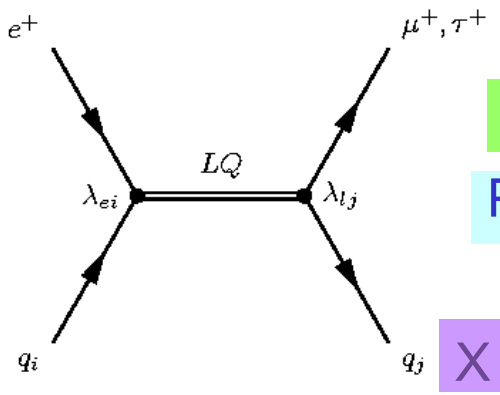
HERAI e^+p Data L = 66 pb^{-1}

H1 Data	1
SM	0.56 ± 0.16
ε(LQ)	~10 - 30%

H1prelim-04-162

► No Evidence for Lepton Flavour Violation found !

Search for Lepton Flavour Violation at ZEUS

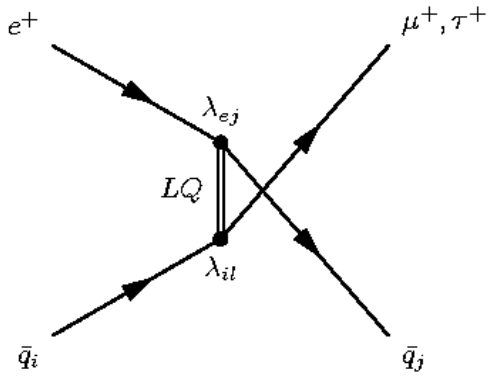


Jet

e μ

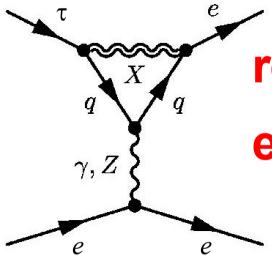
P_T^{miss}

X

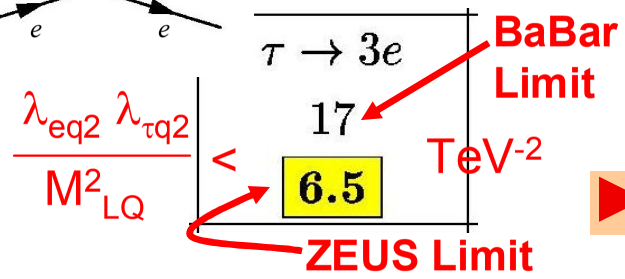


e	μ	Jet
$E_e > 20$ GeV	$P_T^{\mu} > 5$ GeV	$P_T^{jet} > 15$ GeV
$P_T^e > 3$ GeV	$8^o < \theta_\mu < 164^o$	$P_T^{track} > 2$ GeV
$20^o < \theta_e < 140^o$		$15^o < \theta_{jet} < 164^o$
Isolation Criteria	Isolation Criteria	$1 \le N_{jet}^{tracks} \le 3$
		$D > 0.90$
		$f_{EMC}^{jet} < 0.95$
		$f_{EMC}^{jet} + f_{track}^{jet} < 1.6$
$P_T^{miss} > 15$ GeV		
$\Delta\varphi_{e\text{-miss}} < 20^o$	$\Delta\varphi_{\mu\text{-miss}} < 20^o$	$\Delta\varphi_{jet\text{-miss}} < 20^o$

Same Discriminant as in $\tau + P_T^{miss}$ Search



resulting Limits e.g. on $\tilde{S}^L_{1/2}$:



HERAI $e^{\pm}p$ Data L = 130 pb^{-1}

ZEUS Data	0
SM	2.3 ± 0.5
ε(LQ)	~10 - 30%

► No Evidence for Lepton Flavour Violation found !

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Summary

- Tau Leptons are rare Particles at HERA
- It's interesting to look for Taus, as Observation of Excess over (small) SM Production Rate would immediately indicate New Physics
- A Variety of Tools for Identification of hadronic Tau Decays has been developed by H1 and ZEUS

- H1 and ZEUS Results for $\tau^+\tau^-$ Pair-Production in Agreement with SM Expectation
- No Evidence for $H^{++} \rightarrow e^+\tau^+$ Decays found in H1 Data
- No Evidence for Lepton Flavour Violation found by H1 and ZEUS
- Both H1 and ZEUS observe a (slight) Excess) of $\tau + P_T^{miss}$ Events ☞

(Isolated) Lepton + P_T^{miss} Events at HERA

H1 Preliminary		e obs. / exp. $W \to e\nu$ (Signal Contribution)	μ obs. / exp. $W \to \mu\nu$ (Signal Contribution)	τ obs. / exp. $W \to \tau\nu$ (Signal Contribution)
1994-2006 $e^{\pm}p$	Total	35 / 34.0 ± 4.7 (68%)	11 / 9.0 ± 1.4 (80%)	25 / 24.2 $^{+4.2}_{-5.8}$ (8%)
L = 341 pb^{-1}	P_T^X > 25 GeV	12 / 6.1 ± 1.1 (66%)	6 / 5.4 ± 0.9 (77%)	3 / 0.74 $^{+0.19}_{-0.16}$ (59%)

Tau Results based on L = 278 pb^{-1} of Data

Phys. Lett. B 561 (2003) 241
H1-prelim-06-162

ZEUS Preliminary		e obs. / exp. (Signal Contr.)	μ obs. / exp. (Signal Contr.)	τ obs. / exp. (Signal Contribution)
1994-2005 $e^{\pm}p$	Total	9 / 7.9 ± 0.7 (60%)	6 / 5.9 ± 0.4 (80%)	3 / 0.40 $^{+0.12}_{-0.13}$ (43%)
L = 250 pb^{-1}	P_T^X > 25 GeV	4 / 4.4 ± 0.5 (61%)	3 / 3.1 ± 0.3 (83%)	2 / 0.20 ± 0.05 (59%)

Tau Results based on L = 130 pb^{-1} of Data

ZEUS-prel-06-012

But: Results not conclusive yet

(Excess of $e + P_T^{miss}$ and $\mu + P_T^{miss}$ Events observed by H1 only in e^+p Collisions and not confirmed by ZEUS,
Excess of $\tau + P_T^{miss}$ Events observed in e^-p Collisions at H1 and in e^+p Collisions at ZEUS)

► **Need more Data !**

Outlook for Physics at HERA

- HERA Programme is coming to an End
- 2005 (e^-p Collisions) most successful Data Collection ever
- Very successful e^+p Running anticipated for 2006 and 2007
- HERA Shutdown scheduled for Summer 2007
- Expect to collect in total ~600 pb^{-1} per Experiment