

Tau Leptons at HERA

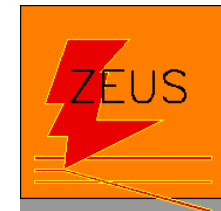
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Int. Workshop on Tau Lepton Physics, Nara, Japan

September 14-17, 2004

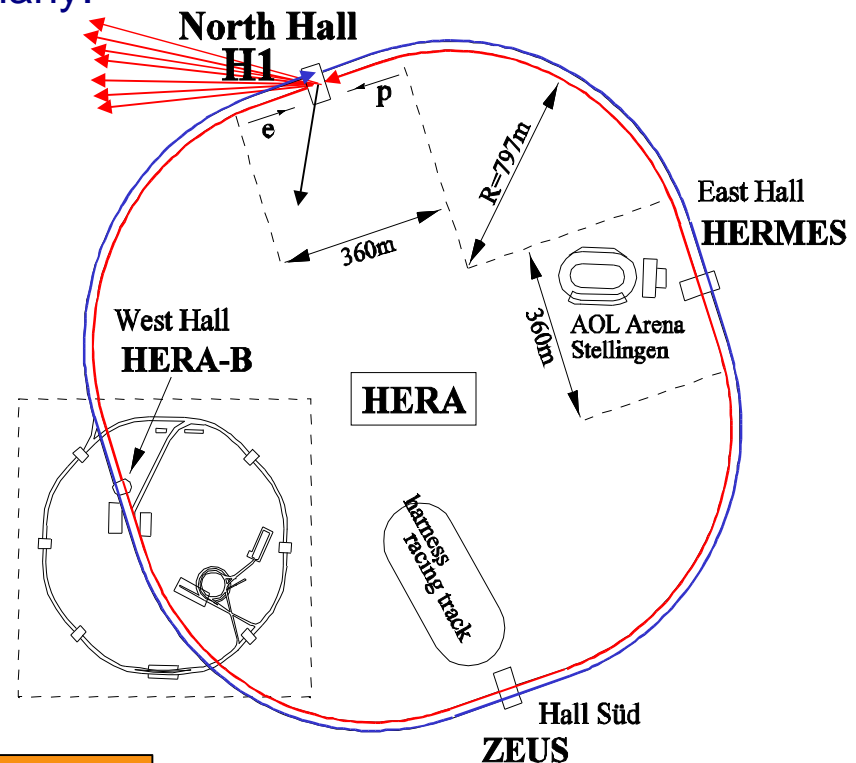
- Introduction
- Isolated taus + P_t^{miss} at ZEUS
- Tau pairs at H1
- Isolated taus at H1
- Search for $H^{++} \rightarrow \tau^+\tau^+$
- Search for LFV LQ decays into taus



The ep-collider HERA

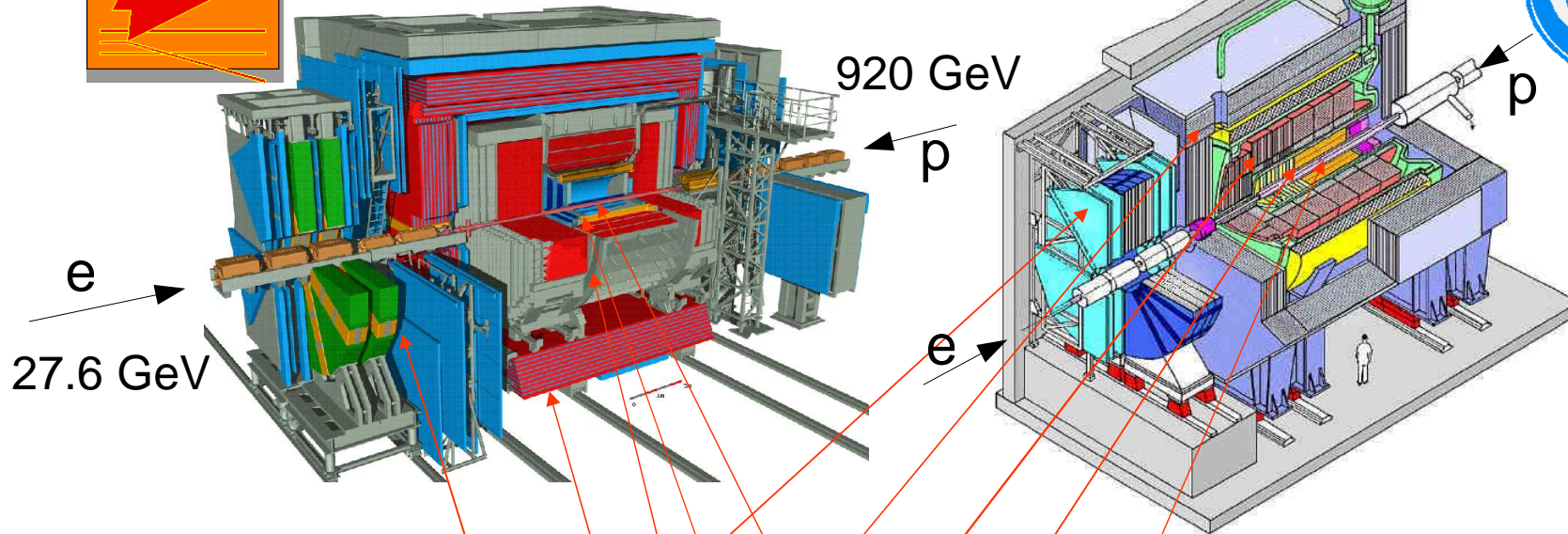
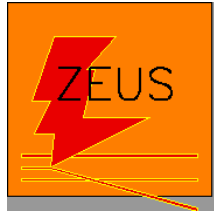
Hadron Electron Ring Accelerator (HERA):

- Two storage rings each with 6,3 km circumference in opposite direction for **protons** ($E=920 \text{ GeV}$, $I_p=100 \text{ mA}$) and **electrons/positrons** ($E=27.6 \text{ GeV}$, $I_e=50 \text{ mA}$), supported by DESY in Hamburg, Germany.
- Two interaction points where electrons and protons collide
- Detectors around interaction point to reconstruct event (H1, ZEUS)
- Interaction rate 10.4 MHz , every 96 ns
- Center-of-mass energy: $\sqrt{s} \approx 320 \text{ GeV}$



Integrated ep -luminosity up to now $\sim 200 \text{ pb}^{-1}$

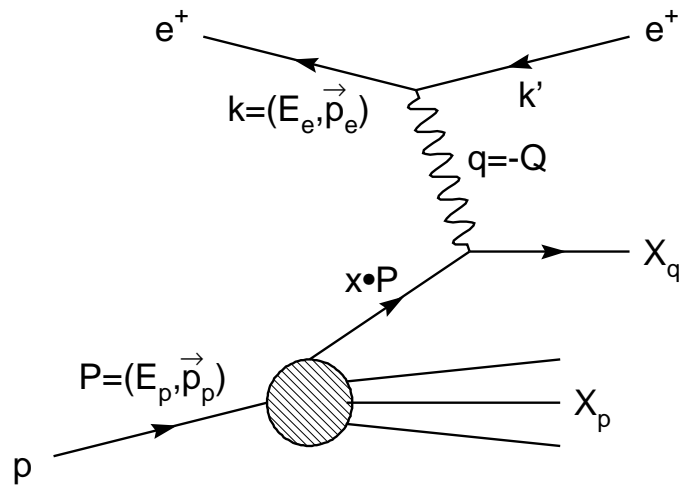
The experiments ZEUS and H1



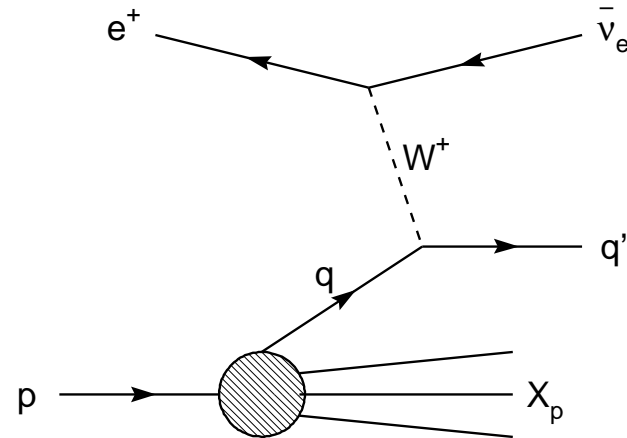
Main components:

- Muon chambers
- Instr. iron (streamer tubes)
- Calorimeter
- Drift chambers
- Silicon strip detectors

ep-collisions



Neutral Current (NC)



Charged Current (CC)

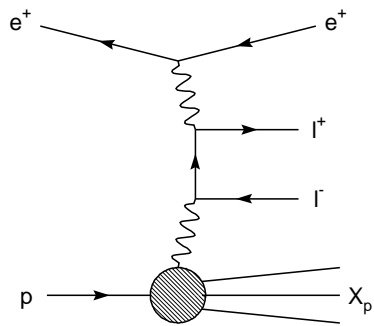
SM Photoproduction ($Q^2 \sim 0$) and Deep-Inelastic Scattering (DIS) ($Q^2 > 4 \text{ GeV}^2$):

- $Q^2 = -(k-k') = -q^2$ four momentum transfer squared
- $x = -q^2 / (2Pq)$ Bjorken scaling variable
- $y = (qP) / (kP)$ inelasticity, i.e. energy loss of electron in proton rest frame
- $s = 2kP = Q^2 / (xy)$ electron-proton center of mass energy squared

ep-collisions with tau leptons

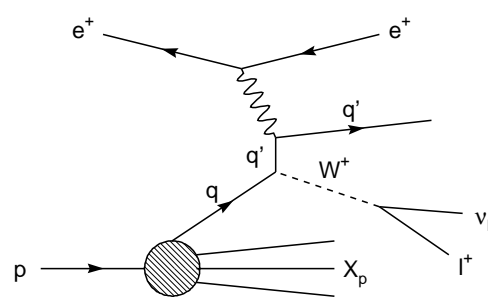
Tau Processes at HERA:

Standard Model



Lepton-Pair-Production
via Photon-Photon-Fusion

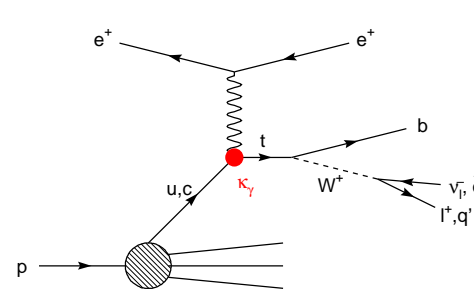
$\sigma \sim 10 \text{ pb}$ ($P_t^\tau > 8 \text{ GeV}$)
hidden in large background



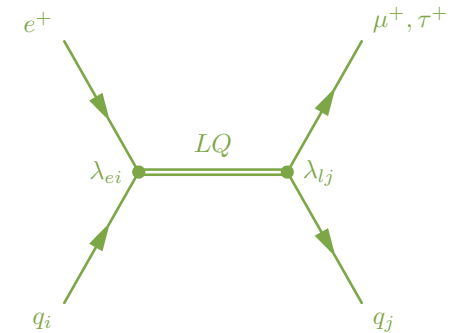
W-Production
with $W \rightarrow \tau \nu$

$\sigma < 0.1 \text{ pb}$, i.e.
less than 20 events!

New Physics



Anomalous top-Production
via FCNC



Resonant Leptoquark
production with LFV
decay to tau

and more ...

► Tau lepton important in searches for new physics

Signature of a tau lepton

tau almost decays at vertex ($c_{\tau} \sim 88 \mu\text{m}$)

decay modes:

τ^+	\longrightarrow	$e^+ \nu_e \bar{\nu}_{\tau}$	17.9%
τ^+	\longrightarrow	$\mu^+ \nu_{\mu} \bar{\nu}_{\tau}$	17.6%
τ^+	\longrightarrow	$h^+ \bar{\nu}_{\tau} + \text{neutrals}$	50.3%
τ^+	\longrightarrow	$2h^+ h^- \bar{\nu}_{\tau} + \text{neutrals}$	14.0%
τ^+	\longrightarrow	$\geq 5h^{\pm} \bar{\nu}_{\tau} + \text{neutrals}$	0.1%

Characteristic for hadronic decay:

- tau jet has low mass
- "pencil-like" jet with low charged multiplicity
- narrow cluster
- 1-3 tracks to narrow cluster

Strategy:

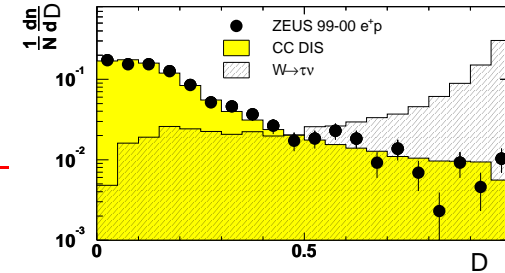
- high- p_{T} electron in direction of $p_{\text{T}}^{\text{miss}}$
- high- p_{T} muon in direction of $p_{\text{T}}^{\text{miss}}$ (calo.)
- narrow high- p_{T} jet in direction of $p_{\text{T}}^{\text{miss}}$

Isolated tau leptons + P_T^{miss} at ZEUS

Jet-Shape observables combined with a probability-density-estimation method to a discriminant variable:

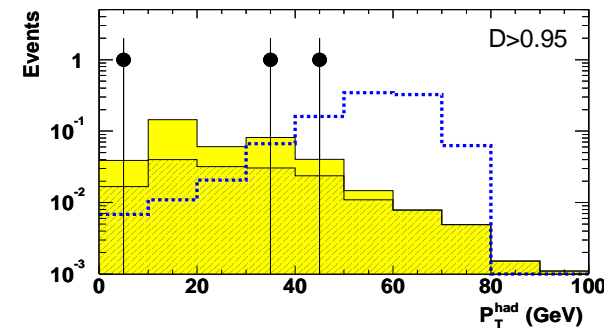
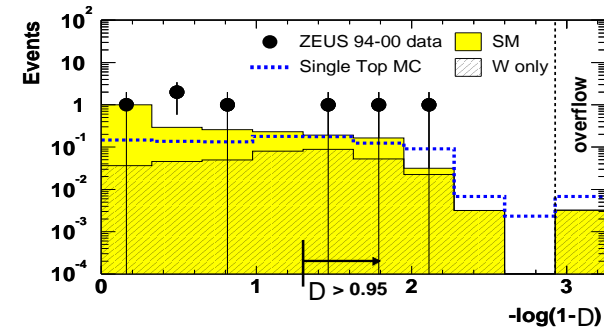
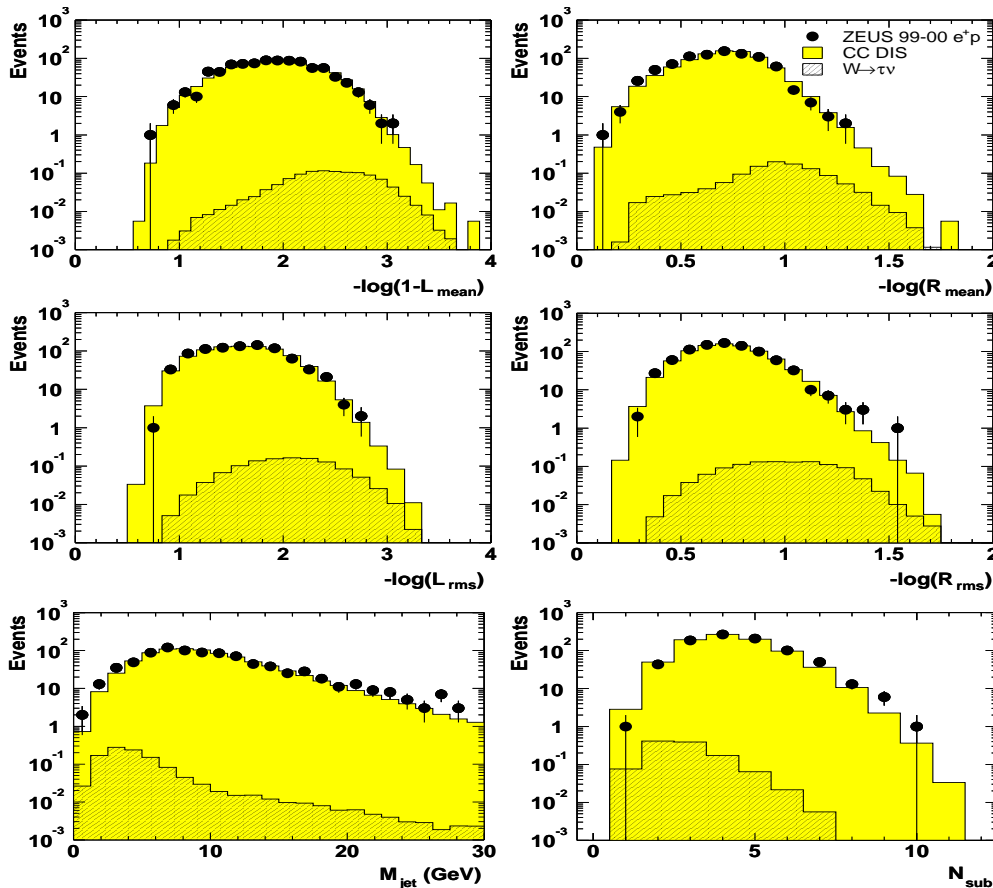
$$L_{\text{int}} = 130 \text{ pb}^{-1}$$

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

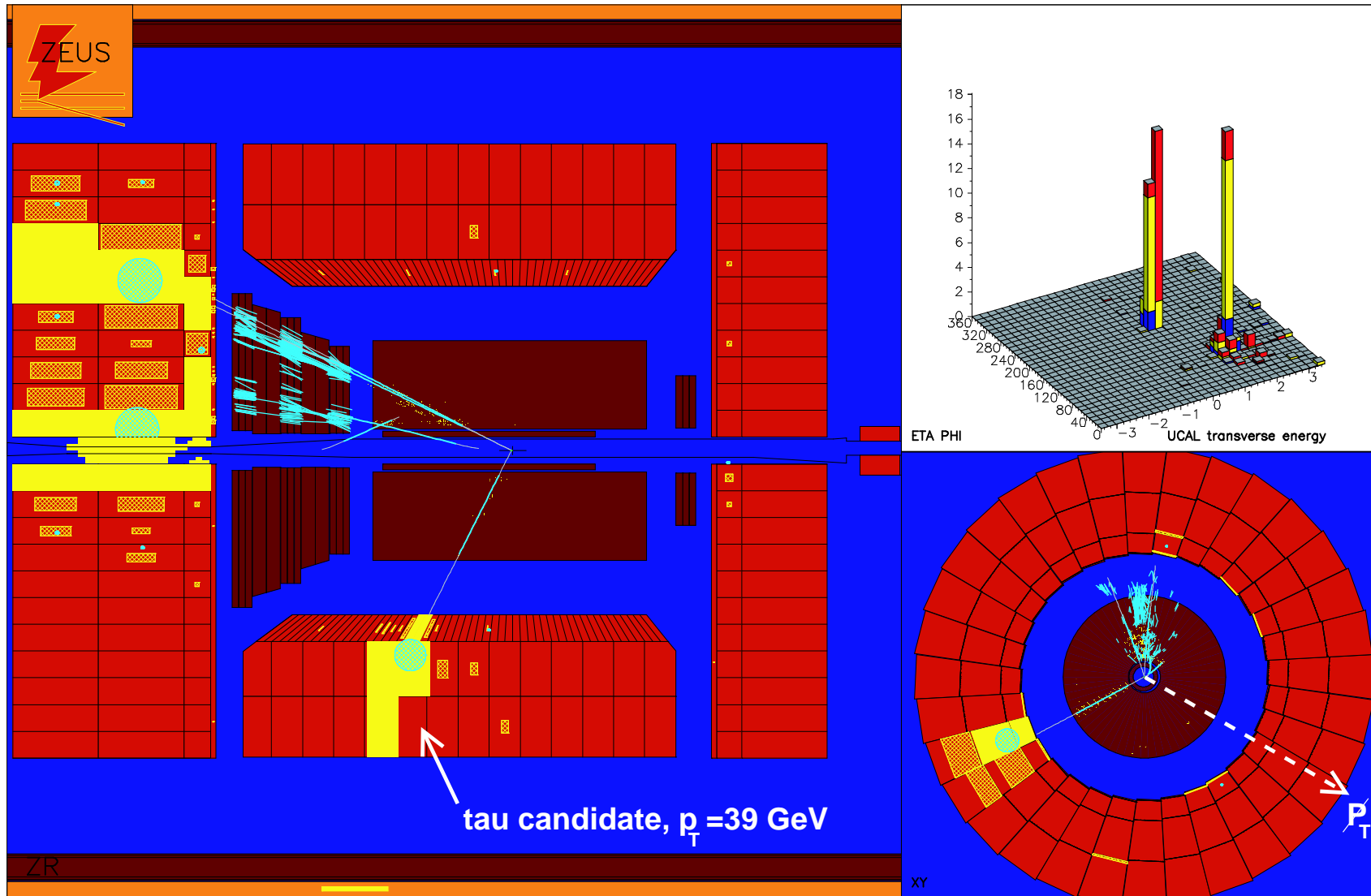


Preselection: $7 / 2.2^{+0.39}_{-0.58}$ events (obs. / exp.)

$D > 0.95$: $3 / 0.4^{+0.12}_{-0.13}$
 $P_t^{\text{had}} > 25 \text{ GeV}$: $2 / 0.2^{+0.05}_{-0.05}$
 $P_t^{\text{had}} > 40 \text{ GeV}$: $1 / 0.07^{+0.02}_{-0.02}$



Isolated tau leptons + P_t^{miss} at ZEUS



Tau pairs at H1

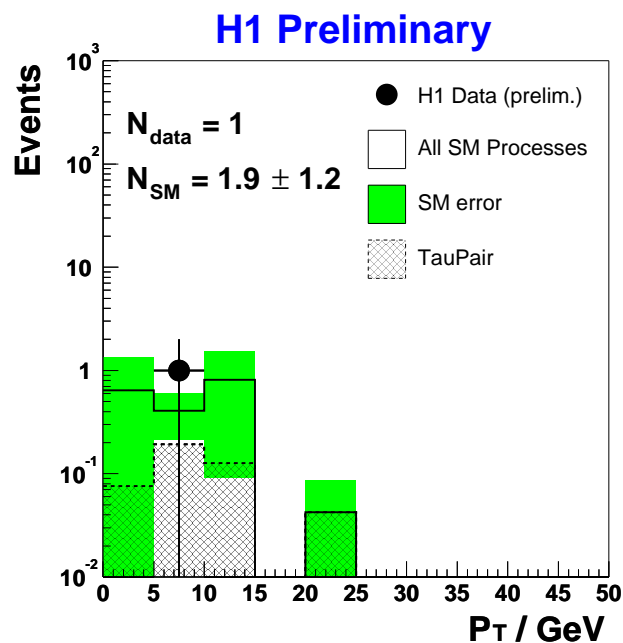
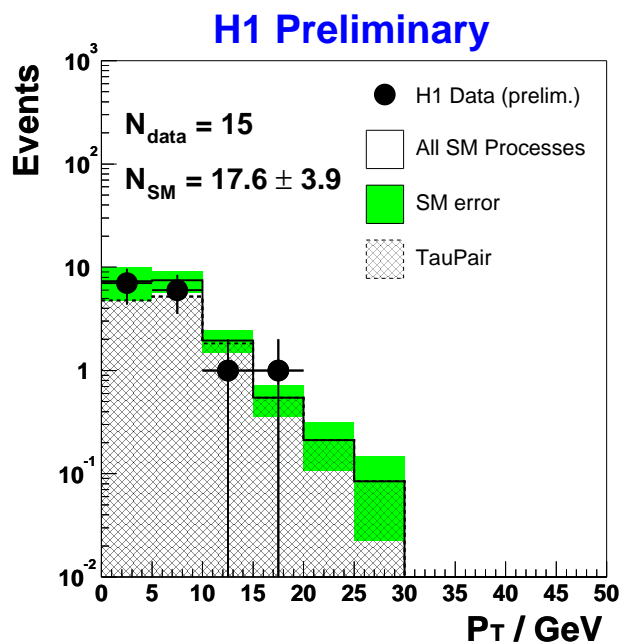
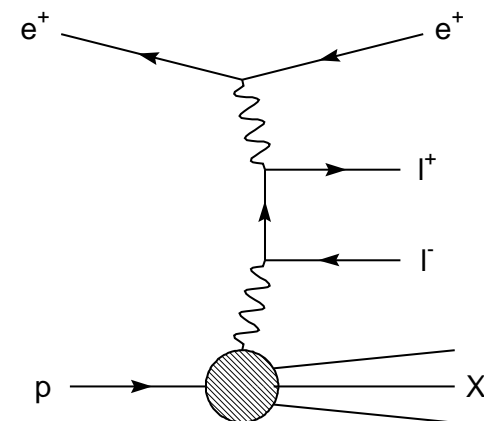
Search for hadronic „one-prong“ and „three-prong“ tau decays with a **neural network algorithm** based on **hadronic jet-shape variables** yields:

15 / 17.6 ± 3.9 unlike-sign events (obs. / exp.)

1 / 1.9 ± 1.2 like-sign event (obs. / exp.)

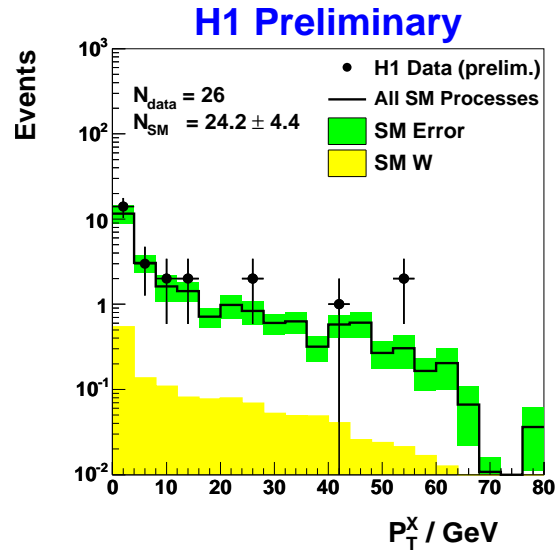
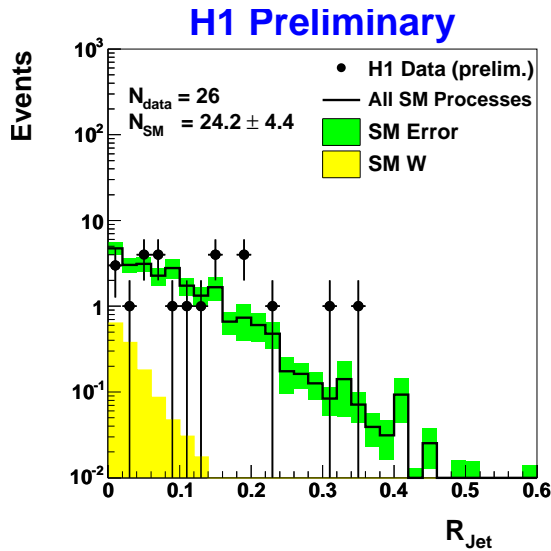
unlike-sign

like-sign



$L_{\text{int}} = 108 \text{ pb}^{-1}$

Isolated tau leptons + P_t^{miss} at H1

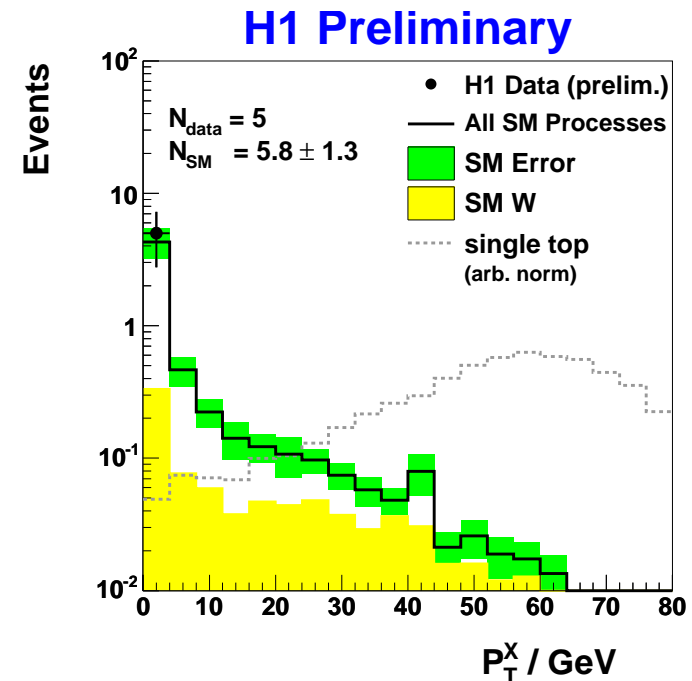


Cut-based analysis is restricted to hadronic „one-prong“ tau decays:

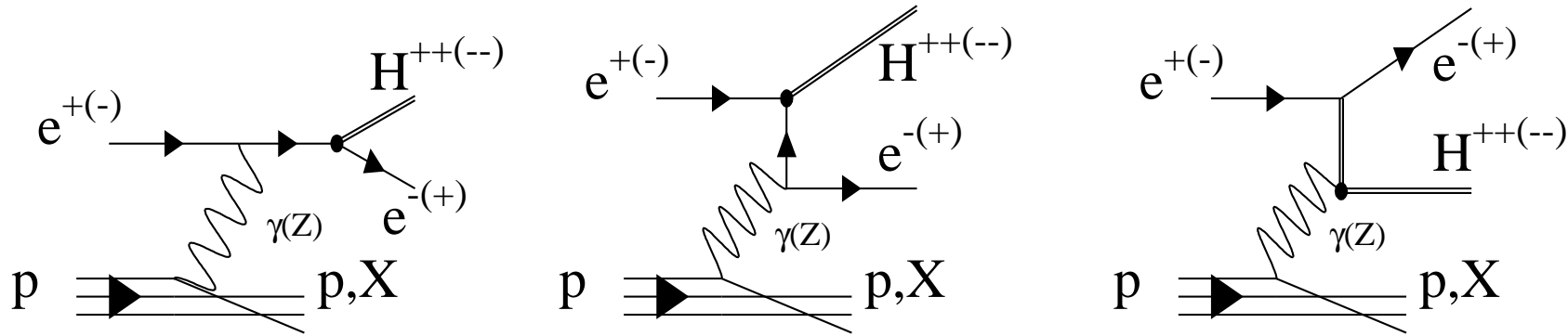
A jet with one isolated track pointing to a typical narrow hadronic energy depositon

$$L_{\text{int}} = 108 \text{ pb}^{-1}$$

Preselection:	26	events (obs. / exp.)
$R_{\text{Jet}} < 0.12$:	5	5.81 ± 1.36
$P_t^X > 25 \text{ GeV}$:	0	0.53 ± 0.10
$P_t^X > 40 \text{ GeV}$:	0	0.22 ± 0.05



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

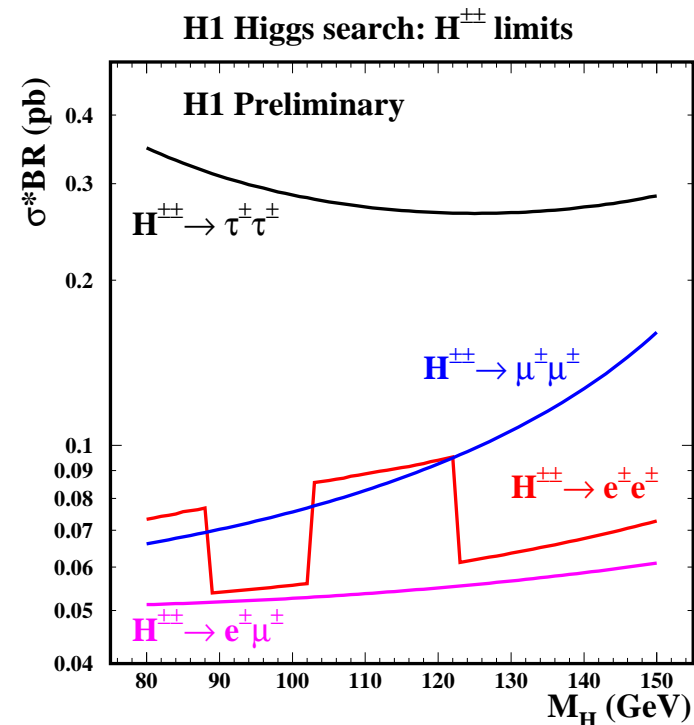


$$L_{\text{int}} = 65 \text{ pb}^{-1}$$

Search for like-sign tau pairs is based on two isolated high P_T tracks and includes **leptonic** and **hadronic** decays of the tau shows:

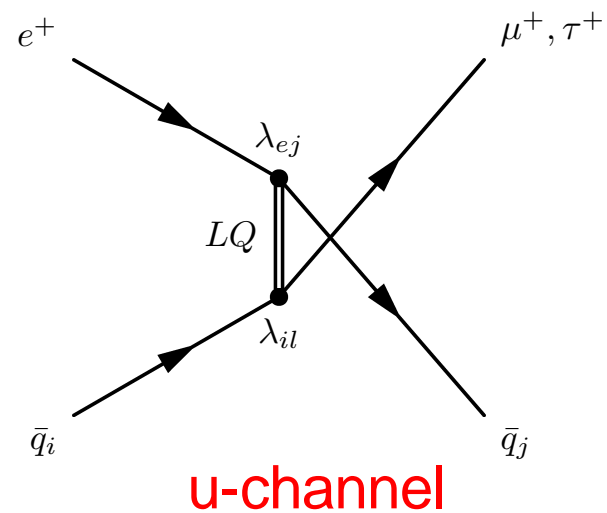
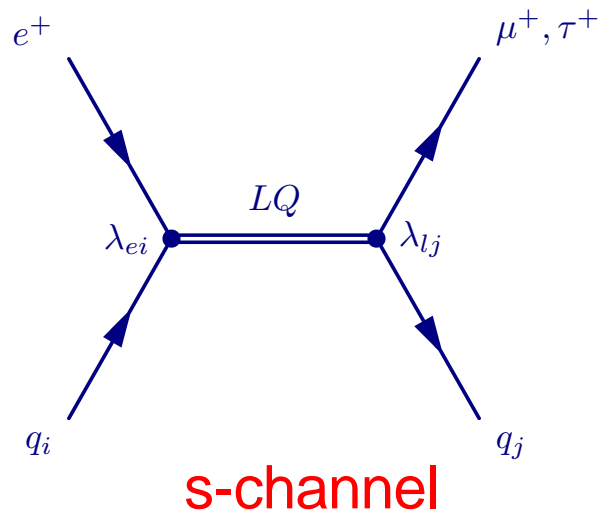
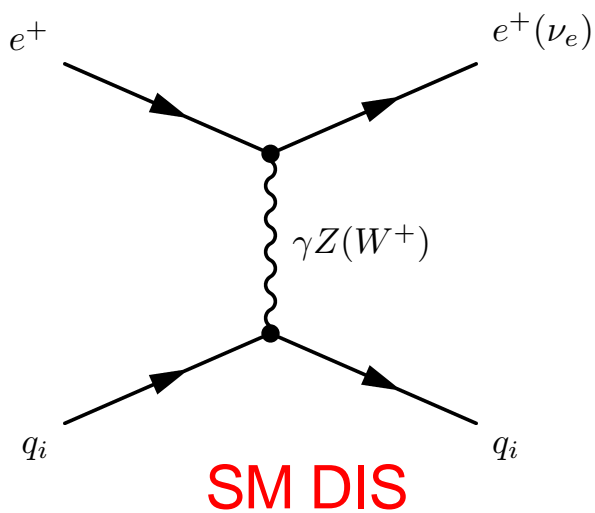
1 / 2.12 ± 0.32 unlike-sign events (obs. / exp.)

0 / 1.03 ± 0.19 like-sign events (obs. / exp.)



Search for LFV LQ decays into taus

Leptoquarks couple to both quarks and leptons:



narrow resonance in x at:

$$x_0 = \frac{M_{LQ}^2}{s}$$

Leptoquarks

color triplet bosons

fractional charge

Both lepton and baryon number $\neq 0$

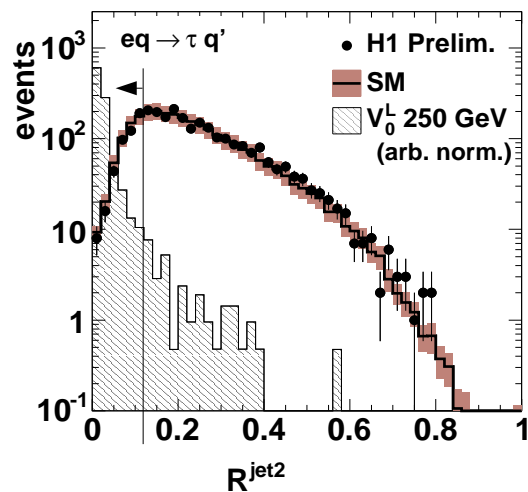
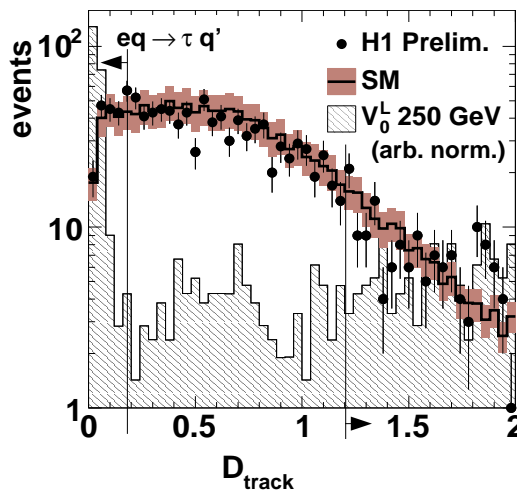
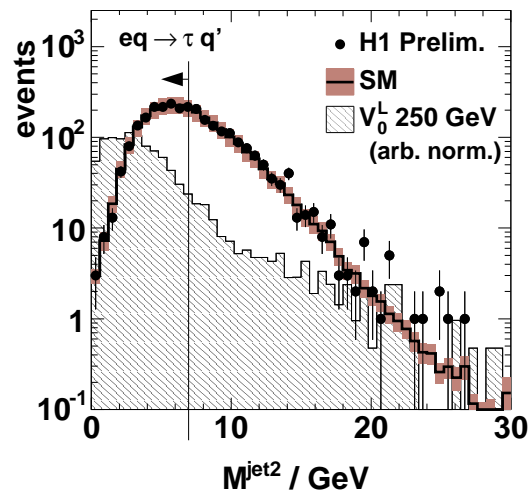
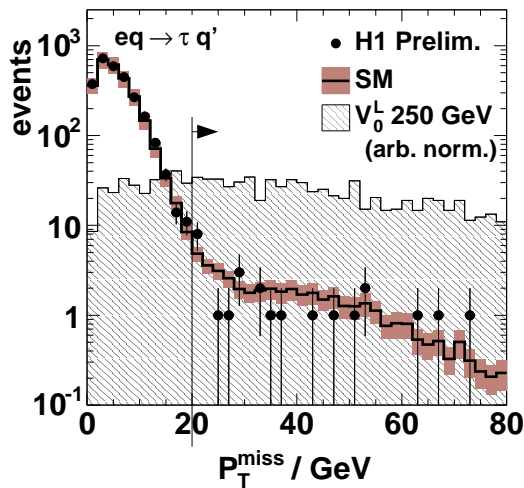
Parameters

mass

coupling

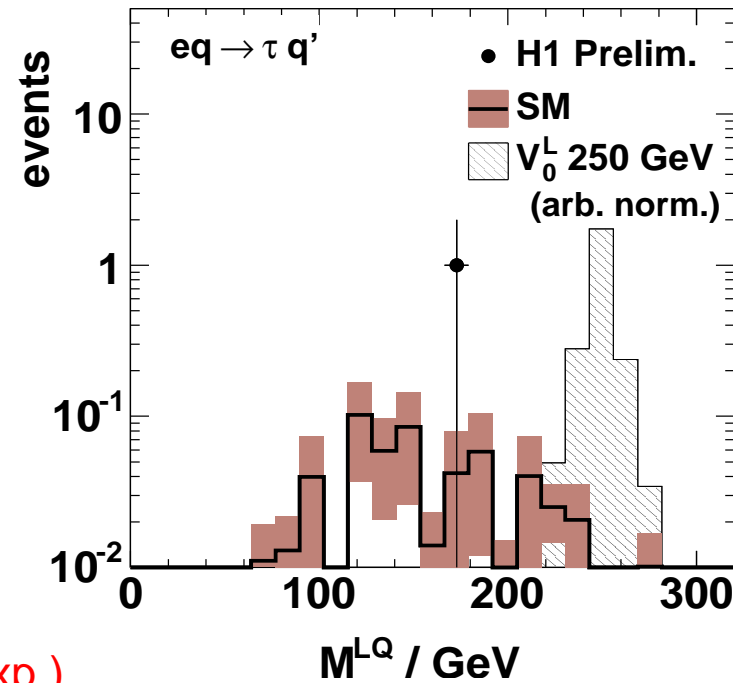
quantum numbers

Search for LFV LQ decays into taus at H1



Cut-based analysis is restricted to hadronic tau decays:

A jet with one to three isolated tracks pointing to a typical narrow hadronic energy depositon. The missing energy (neutrinos from tau decay) is aligned with the tau-jet.



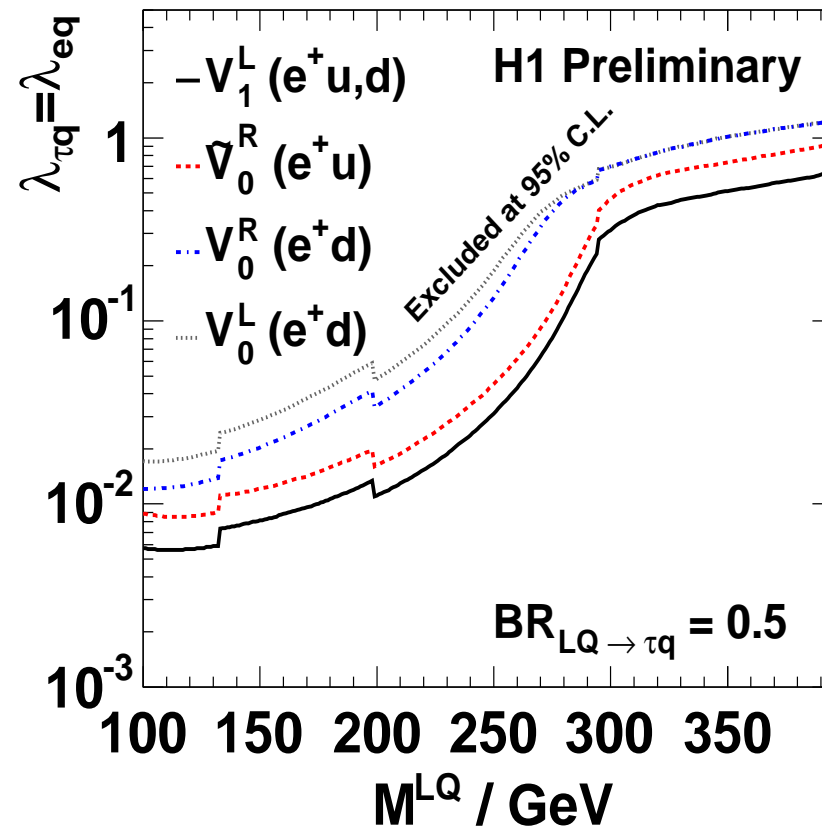
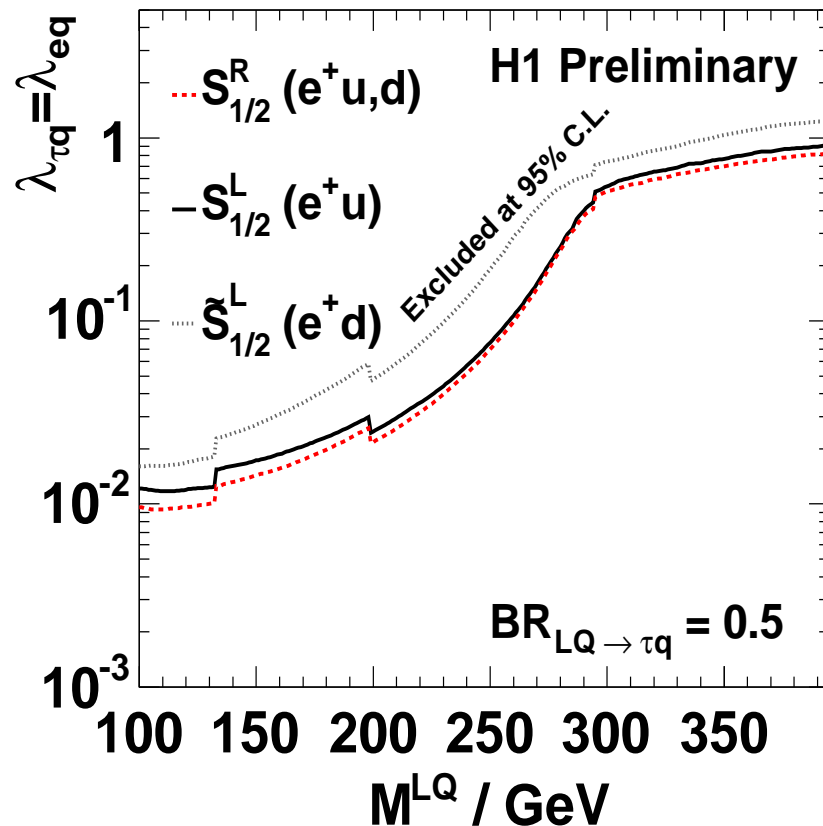
Final selection yields:

$$L_{\text{int}} = 66 \text{ pb}^{-1}$$

1 / 0.56 ± 0.16 events (obs. / exp.)

Search for LFV LQ decays into taus at H1

- No significant deviation from SM found
- Limits are set on couplings to Leptoquarks mediating lepton flavor violation



Search for LFV LQ decays into taus at ZEUS

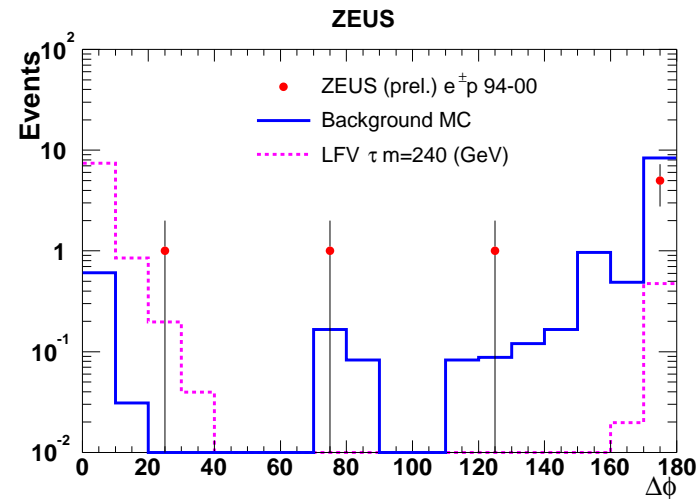
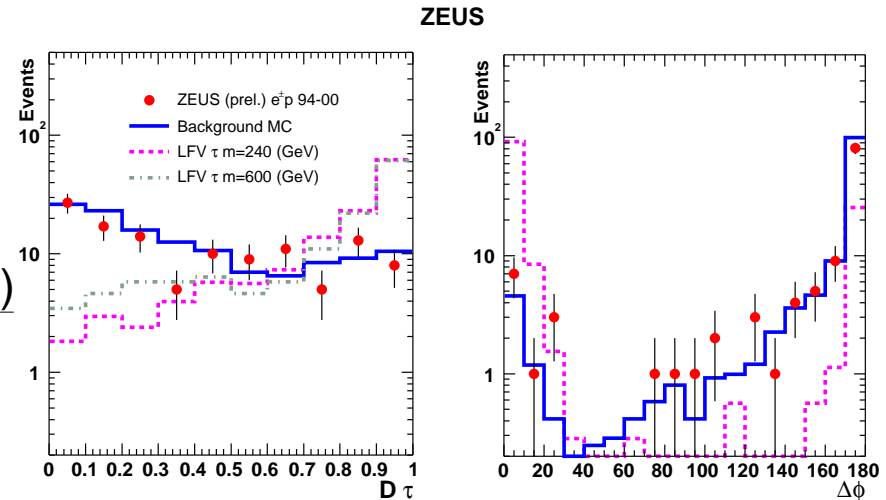
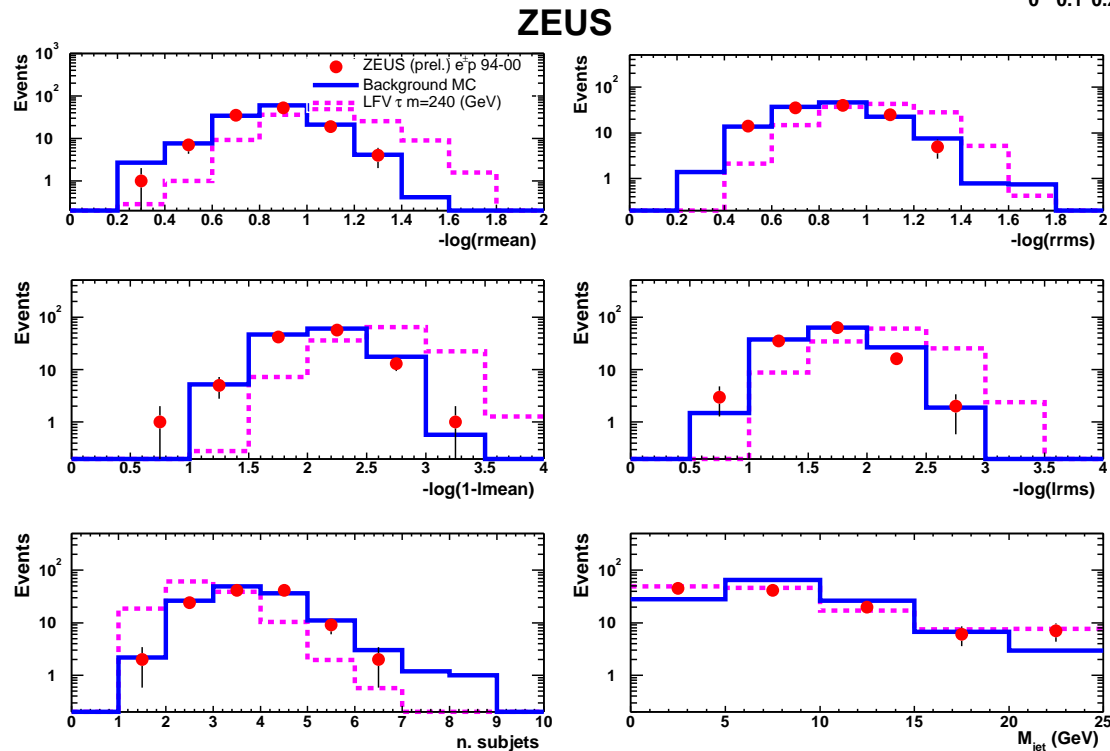
Search for **hadronic** tau decays with a discriminant variable **D** based on **hadronic jet-shape variables** yields:

$$L_{\text{int}} = 130 \text{ pb}^{-1}$$

Preselection: 119 / 131.2 ± 4 events (obs. / exp.)

$D > 0.9$: 8 / 11.2 ± 1.5

$\Delta\phi < 20^\circ$: 0 / 1.7 ± 0.4



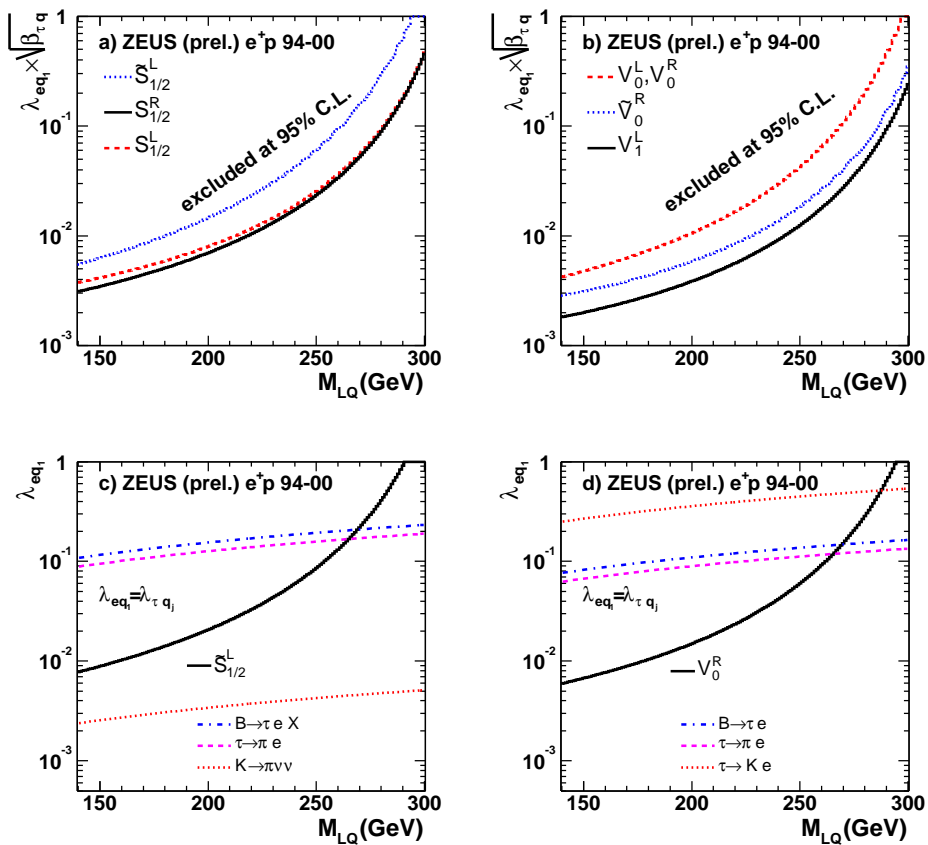
A cut-based selection for **leptonic decays** reveals no candidate and is combined for exclusion limits

Search for LFV LQ decays into taus at ZEUS

No candidate event was found and limits on LQ are set

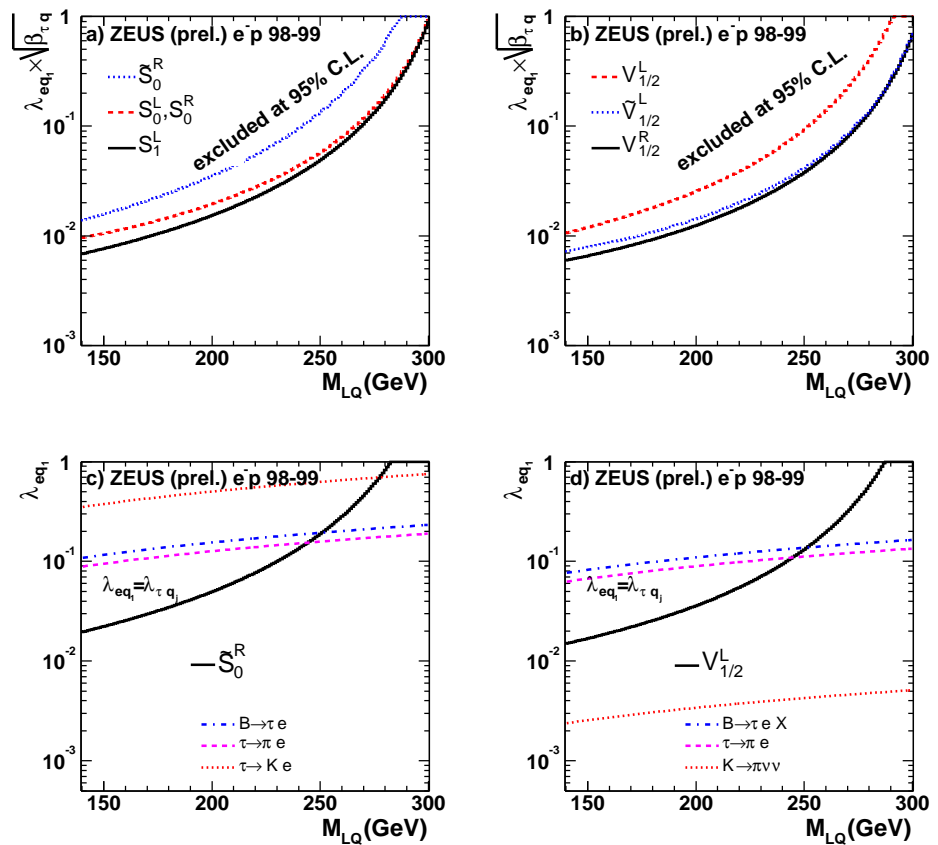
e^+p -collisions

ZEUS



e^-p -collisions

ZEUS



Summary

- The tau lepton appears rarely in SM ep-collisions at HERA
- Detecting taus at HERA is a difficult business
- It's worth looking for taus, because a significant excess would immediately indicate new physics
- Recent analyses searching for new physics in ep-collisions succeeded in developing tools to detect taus efficiently
- 3 outstanding tau events seen with the ZEUS detector might already reveal new physics
- The searches for tau leptons help to set exclusion limits on new phenomena like FCNC, doubly charged Higgs or Leptoquarks