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Lepton flavour violation and flavour changing neutral current at HERA

L. Bellagamba

ZEUS

INFN Sezione di Bologna

HERA: ep collisions @ $\sqrt{s} \sim 320$ GeV
Results presented collected during HERA I data taking
130 pb^{-1} during 1994-2000

This talk is about the study with the ZEUS detector at HERA of events involving high-pt isolated leptons. We'll focus in particular on:

- **single top production:** $e\ p \rightarrow e\ t\ X$ $(u \leftrightarrow t)$
- **lepton flavour violation:** $e\ p \rightarrow \mu\ (\tau)\ X$ $(e \leftrightarrow \mu,\ e \leftrightarrow \tau)$

Both processes involve FCNC transitions which are well suited to look for new physics:

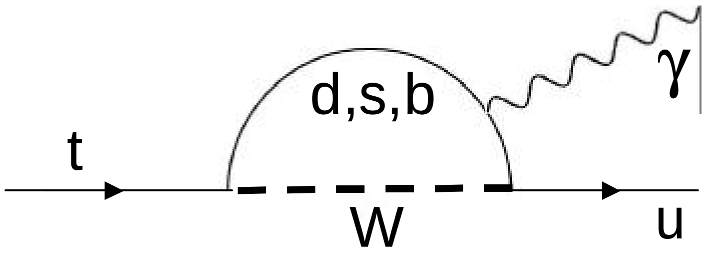
➡ **SM expectations negligibly small**
➡ **Striking topology allowing high efficiency detection**
➡ **Very low background from other SM processes**
➡ **Possible sizeable cross section from BSM sources**

FCNC transitions in the SM

The SM exhibits a remarkable symmetry between the lepton and the quark sector. The recent experimental results on solar and atmospheric neutrino, pointing towards neutrino masses and flavour mixing, give even more strength to this picture.

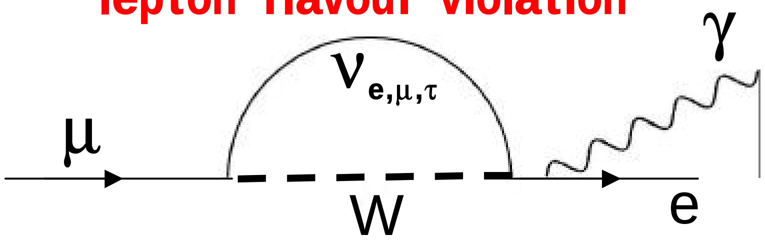
➡ The extension of the SM, required to account for this evidence, allows for one loop FCNC processes mediated by W-boson in the lepton sector analogue to the ones in the quark sector.

$u \leftrightarrow t$ transition



Br(SM) ~ 10^{-12}

$e \leftrightarrow \mu$ transition
lepton flavour violation



Br(SM) ~ 10^{-45}

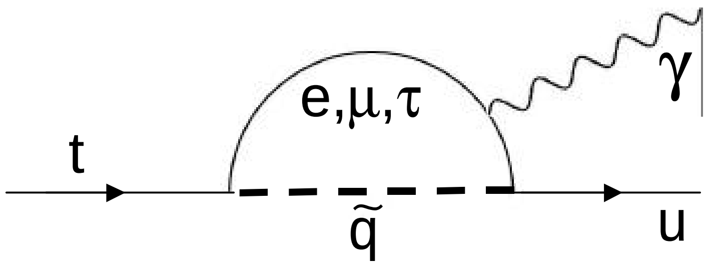
All these processes are strongly suppressed by the GIM mechanism. The only one with a sizeable rate is the process $b \rightarrow s\,\gamma$, due to the heavy top in the loop. For this process measurements are in good agreement with SM expectation.

FCNC transitions beyond the SM

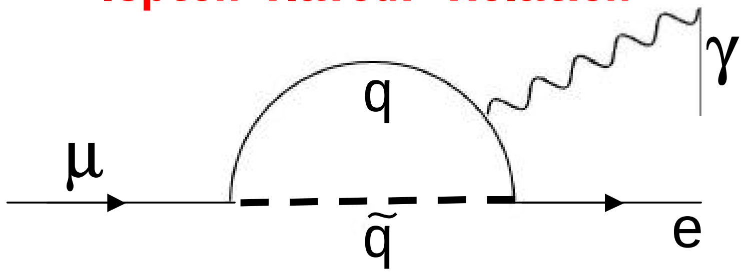
Many theories beyond the SM foresee new bosons linking quarks and leptons (leptoquarks in GUT theories or squarks in Rp violating SUSY models). HERA is the ideal place to study such exotic bosons since they can be directly produced via eq fusion.

Such new bosons or other SUSY particles can enter the loops enhancing FCNC process beyond SM predictions.

u $\leftrightarrow$ t transition



lepton flavour violation



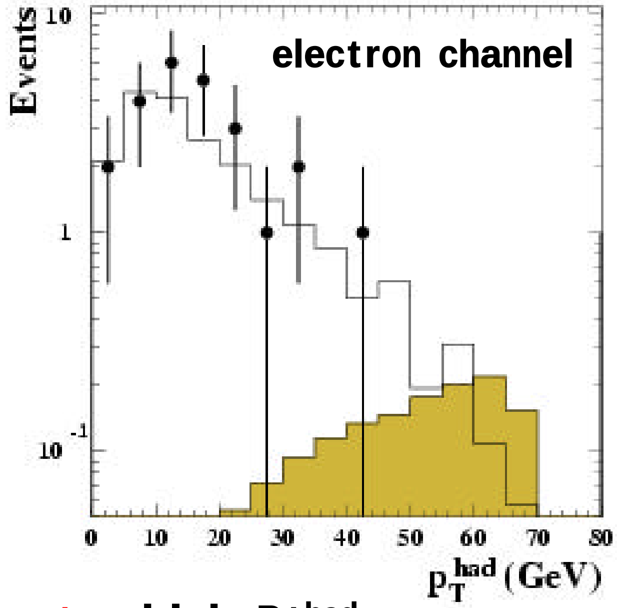
Search for events with high-pt isolated leptons large missing pt and large hadronic Pt

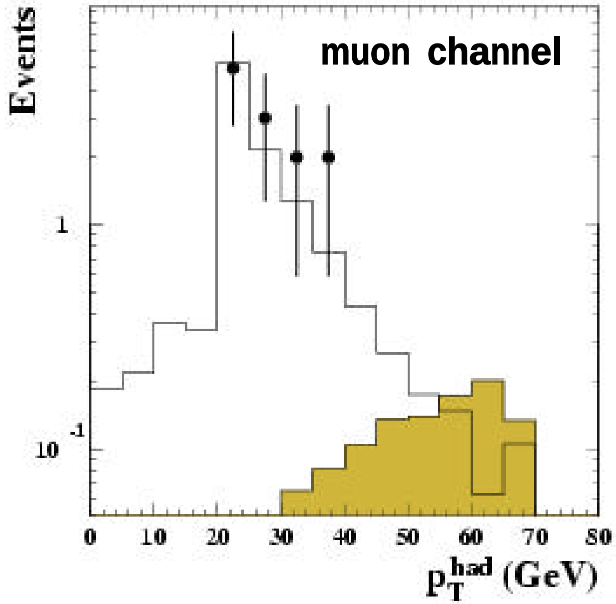
Such topologies can be produced by the decay of a heavy state involving charged leptons and neutrinos (i.e. single top productions)

Main selection cuts

- lepton pt > 10 GeV/c
- D_{jet} > 1, D_{trk} > 0.5 (distance respect to other tracks and jets in η-ϕ)
- calorimeter missing Pt > 20 GeV
- at least one jet with Et > 5 GeV
- in case of electron, acoplanarity angle $\Phi_{acop} > 8^{o}$ (NC DIS rejection)

SM W production ($\sigma \sim$ 1pb) is a source of background, but it steeply decreases with the hadronic Pt. Other sources are NC DIS for the electron channel and $\gamma\gamma \rightarrow \mu\mu, \tau\tau$ for other channels





Final cuts: **high Pt^{had} ,**

E-Pz < 47 GeV (electron), Pt^{tot} (CAL Pt + μ Pt) > 10 GeV (muon)

ZEUS 1994-2000 $e^{\pm}p$ $\mathcal{L} = 130.1\,\text{pb}^{-1}$	Electron obs./exp. ($W^{\pm}$ contribution)	Muon obs./exp. ($W^{\pm}$ contribution)	Tau obs./exp. ($W^{\pm}$ contribution)
$p_T^{\text{had}} > 25\,\text{GeV}$	$2\ /\ 2.90\ ^{+0.59}_{-0.32}$ (45%)	$5\ /\ 2.75\ ^{+0.21}_{-0.21}$ (50%)	$2\ /\ 0.20\ ^{+0.05}_{-0.05}$ (49%)
$p_T^{\text{had}} > 40\,\text{GeV}$	$0\ /\ 0.94\ ^{+0.11}_{-0.10}$ (61%)	$0\ /\ 0.95\ ^{+0.14}_{-0.10}$ (61%)	$1\ /\ 0.07\ ^{+0.02}_{-0.02}$ (71%)

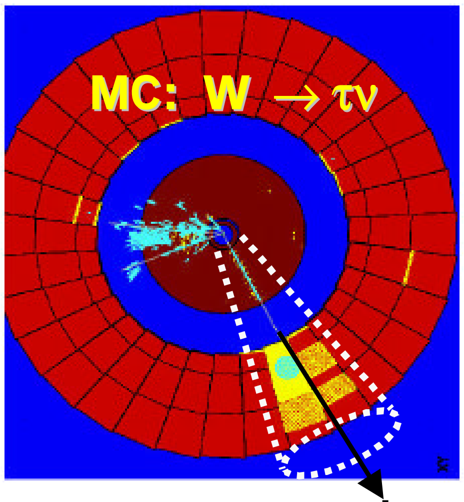
$\Rightarrow$ **Good agreement with SM, except for the tau channel**

τ- finder for the hadronic decay channel

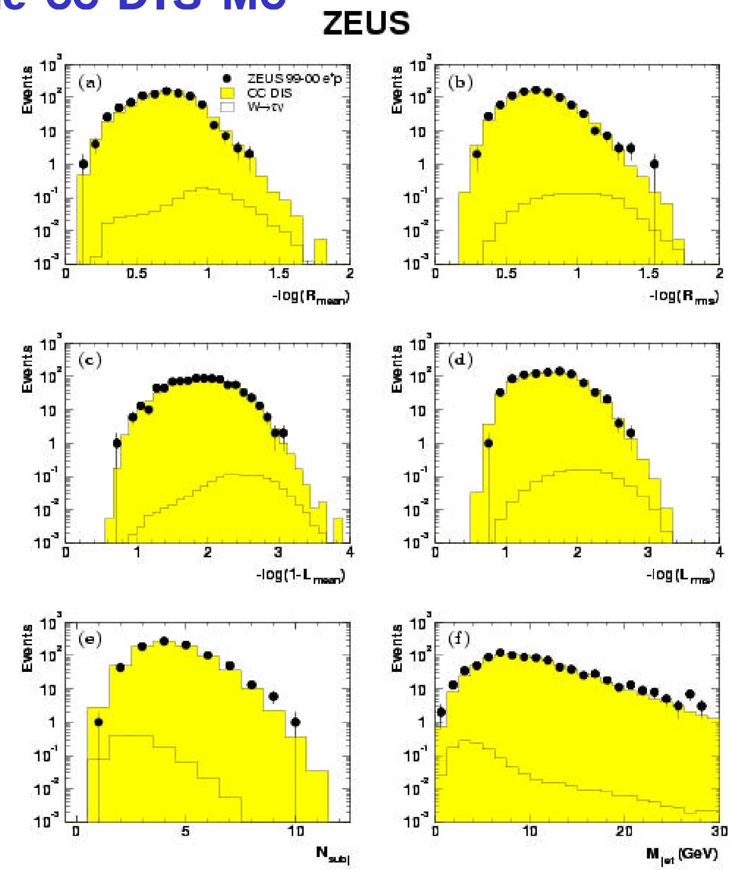
Multivariate technique to separate τ-jets from QCD-jets

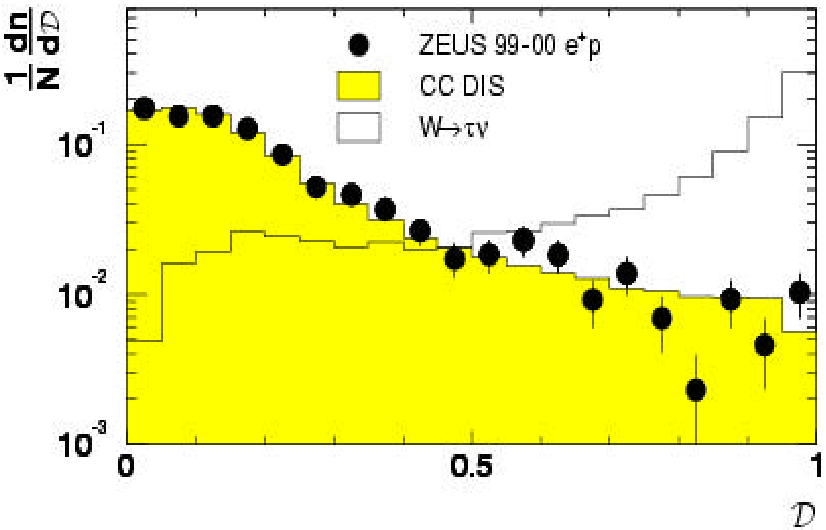
Observables used to characterize jet shape:

- radial jet energy distribution (mean and rms)
- longitudinal jet energy distribution (mean and rms)
- number of subjets
- jet mass



- Optimization done using standard inclusive CC DIS selection
- Internal jet shape well described by the CC DIS MC





Discriminant defined by the density of bg and signal event in the 6-dim phase space.

$D(\bar{x}) = \rho_{sig}(\bar{x}) \,/\, (\rho_{bg}(\bar{x}) + \rho_{sig}(\bar{x}))$

Each jet has a D value, evaluated in the vicinity of the point $\bar{x}$ that identify the jet. For each event the highest D is considered

DATA and CC DIS MC agree well

Requiring D>0.95 and 1 track for the τ jet → good separation between bg (CC DIS) and signal ($W \to \nu\tau$) and an acceptable efficiency (~24%) for the signal

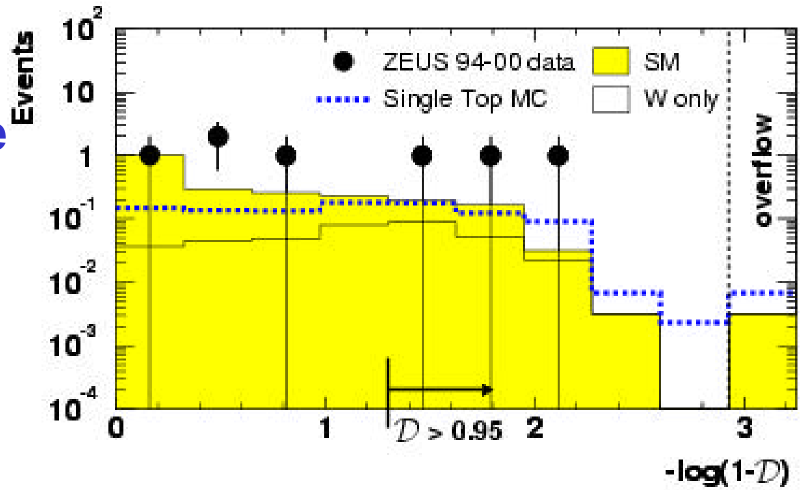
After the tuning on CC DIS τ identification is applied to the isolated high-pt lepton selection →

Isolated high-pt lepton selection:

- the same used for e and μ, D_{jet} cut increased (> 1.8)

Tau identification:

- Exclude tracks identified as μ or e
- D>0.95

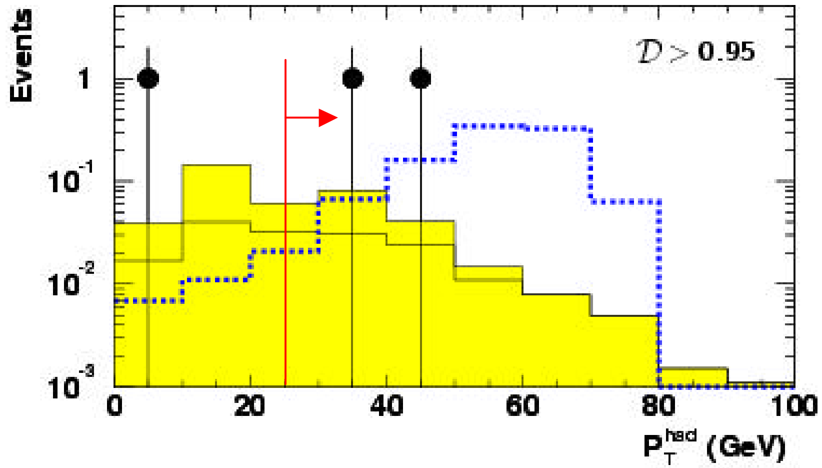


3 events observed

$0.40^{+0.12}_{-0.13}$ **expected**

Optimizing hadronic Pt cut for single top signal:

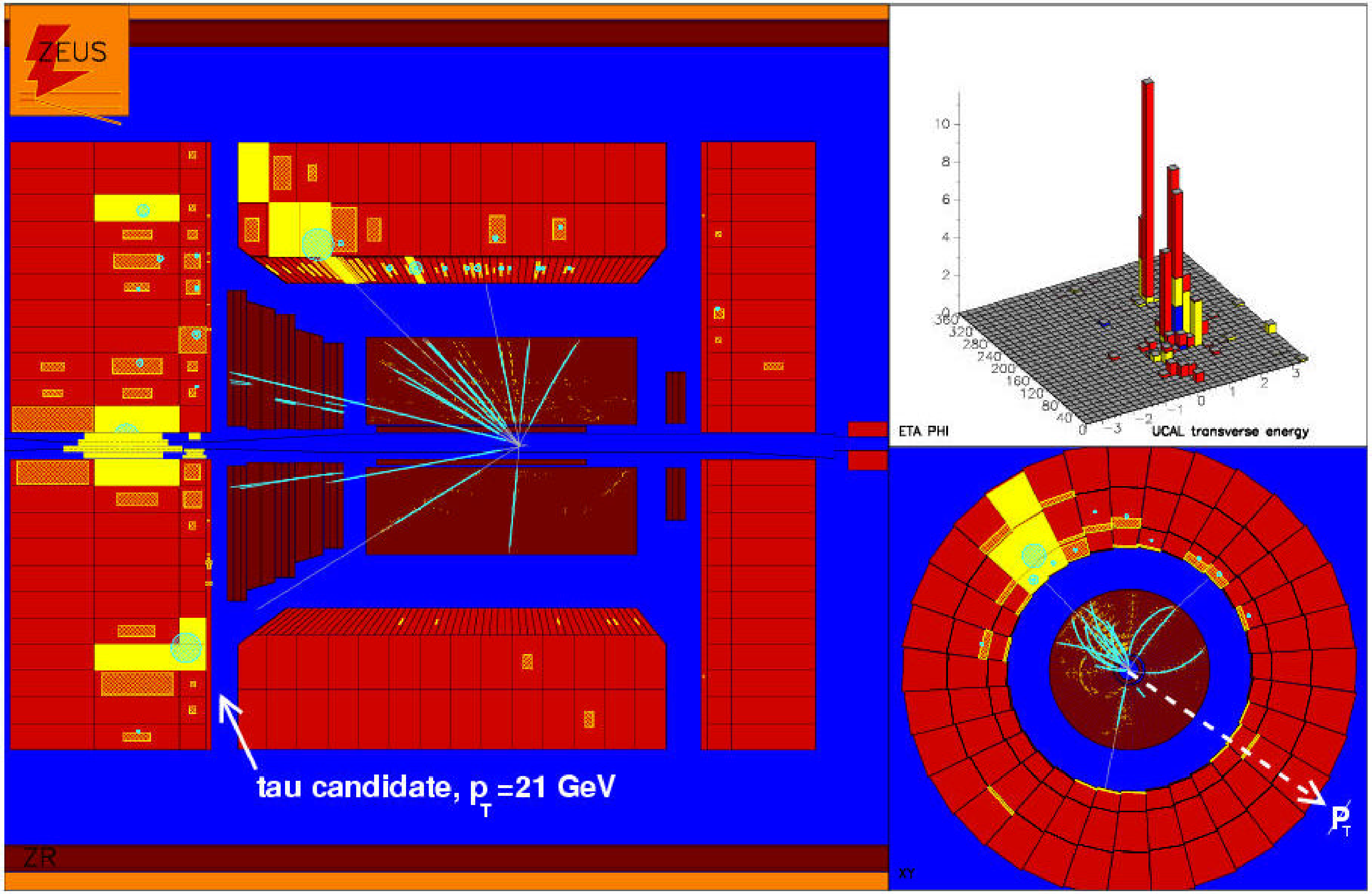
- $P_T^{had} > 25$ GeV



2 events observed
0.20 ± 0.05 expected

→ **Prob = 1.8%**

τ candidate 1 (1999 e^+ data)



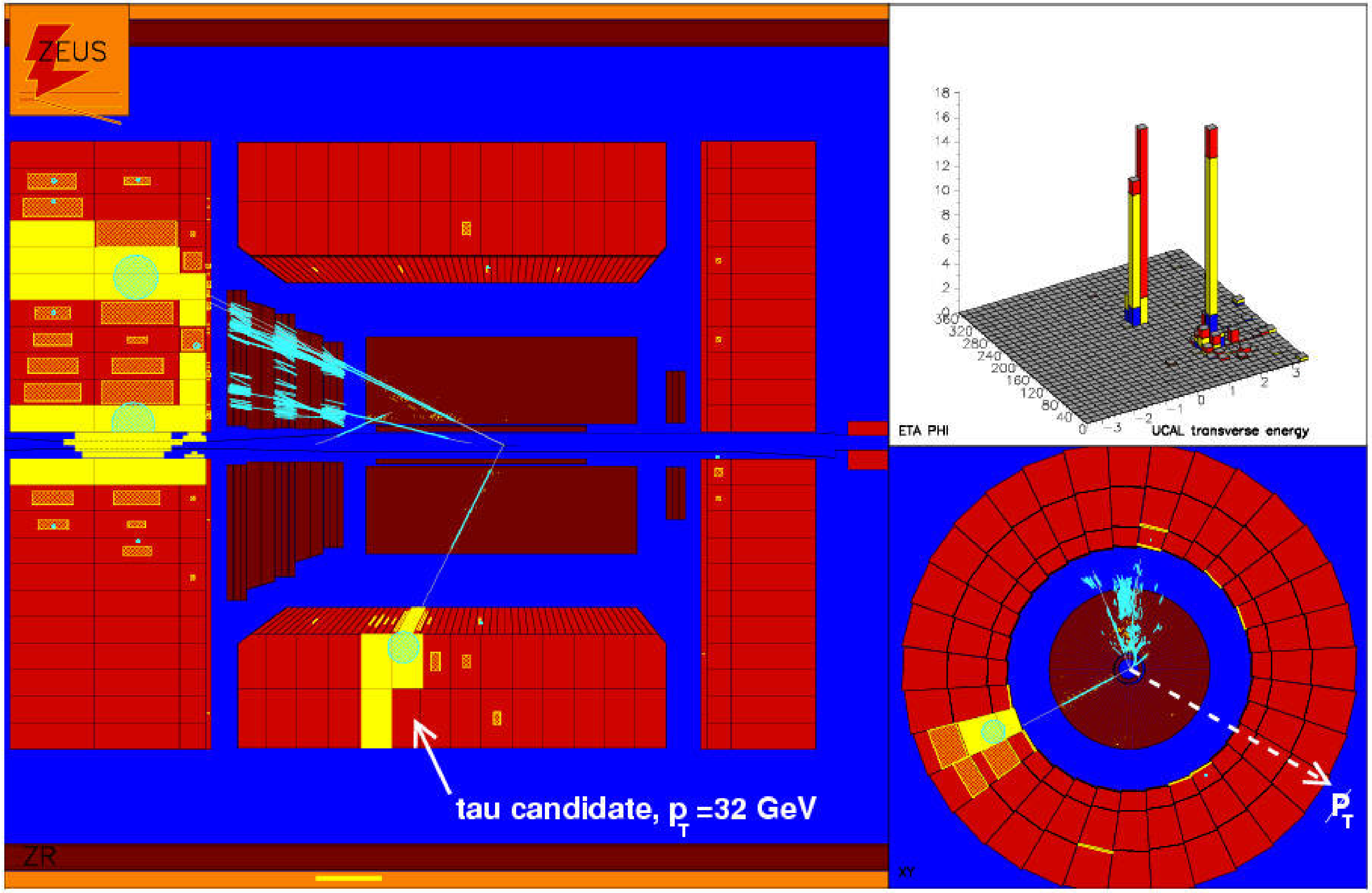
$P_{T,CAL}$ = 37 GeV

P_T^{had}= 48 GeV

$P_{T,\tau jet}$= 21 GeV

M_T = 32 GeV

τ candidate 2 (1999 e^+ data)



$P_{T,CAL}$ = 39 GeV

P_T^{had}= 38 GeV

$P_{T,\tau jet}$= 41 GeV

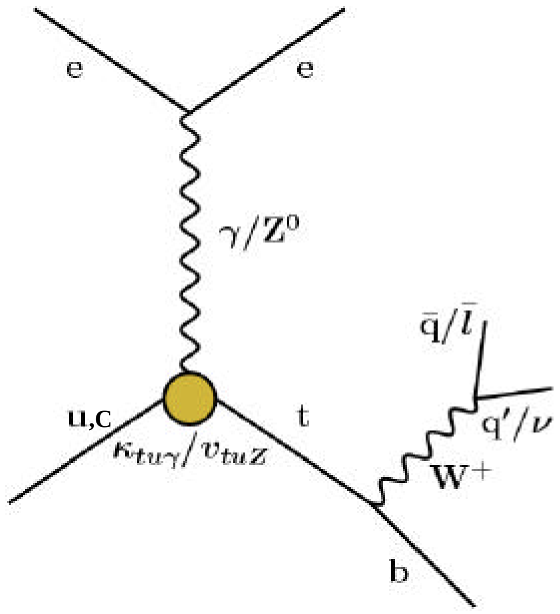
M_T= 70 GeV

Single top production at HERA

Results on electrons and muons can be used to constraint such process
Sensitivity of the tau channel is largely lower (not used)

HERA experiments sensitive to u (valence quark) and γ-exchange

➡ **sizeable production needs an anomalously large u-t-γ coupling**



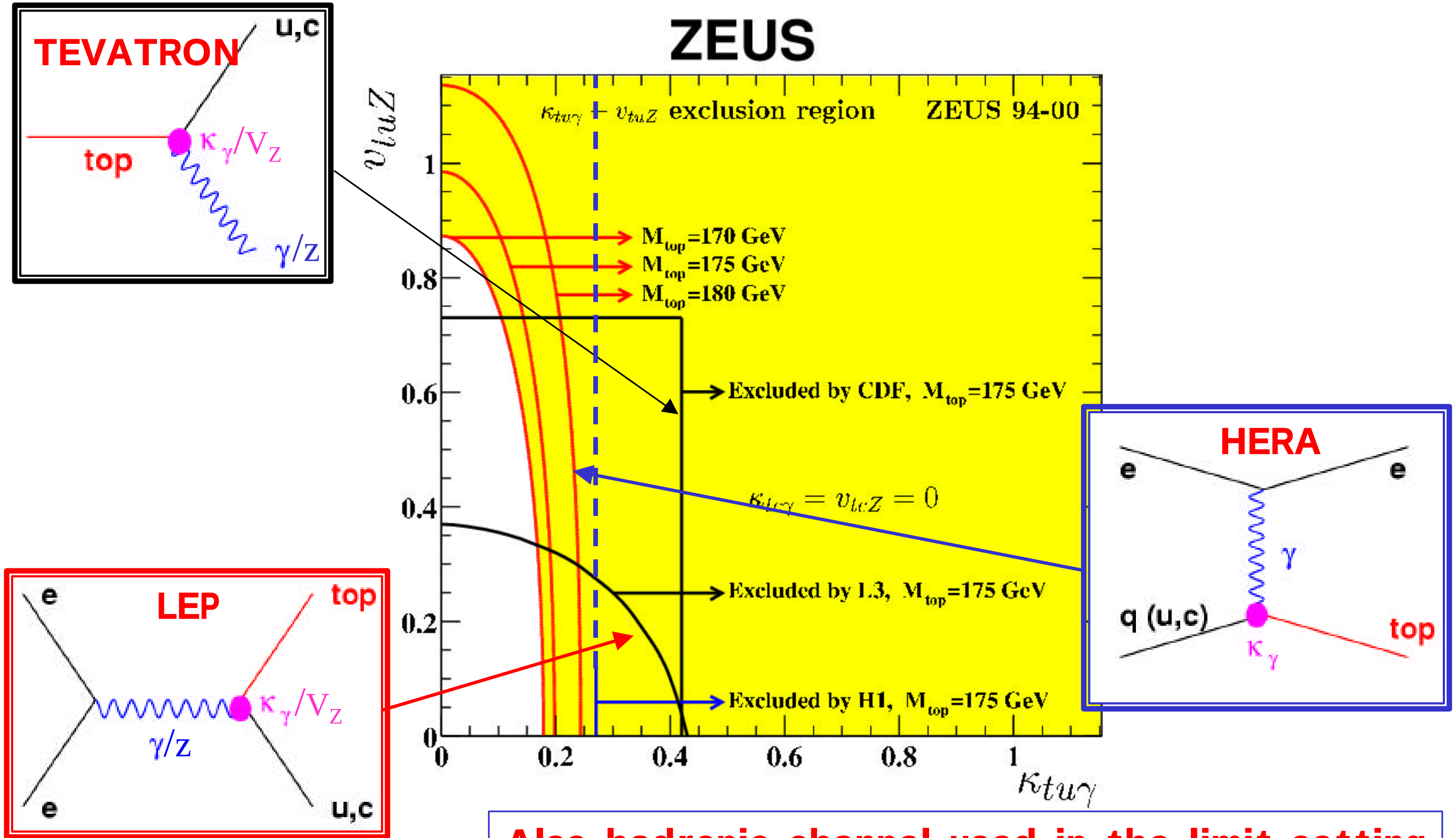
A Lagrangian involving a magnetic type coupling u-t-γ and a vector coupling u-t-Z is often used

γ-exchange   Z-exchange

$$\mathcal{L} = \boxed{\frac{ee_u}{\Lambda}\bar{t}\sigma_{\mu\nu}q^{\nu}k_{\gamma}cA^{\mu}} + \boxed{\frac{e}{2\sin\theta_W\cos\theta_W}\bar{t}\gamma_{\mu}k_{Z}cZ^{\mu}}$$

$$\sigma_{\mu\nu} = \frac{\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu}{2} \qquad e_u = \frac{2}{3}$$

Limits in the plane of the couplings



Also hadronic channel used in the limit setting

Summary and perspectives for high-pt leptons

- 2 interesting tau events in excess respect to SM exp. but:

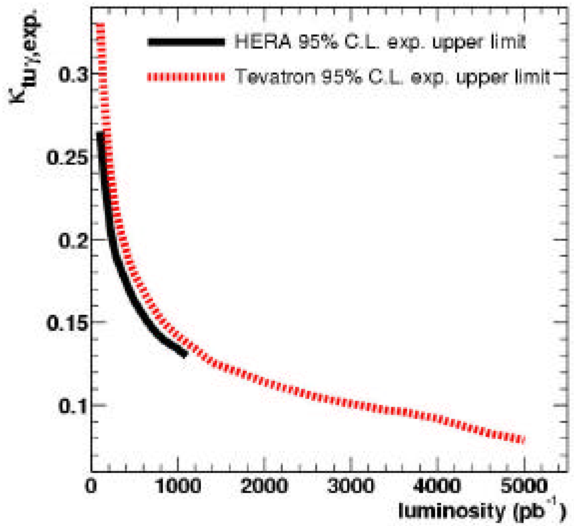
Single top hypothesis largely disfavoured by e/μ/jet ZEUS analysis

➡ any exotic explanation should produce excess in τ but not in μ or e

- H1 observes excess in e/μ, while ZEUS agrees with SM

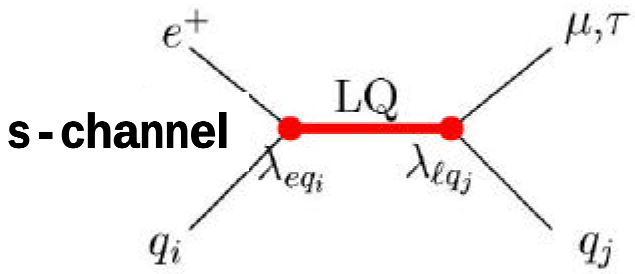
HERA II data needed to clarify the picture

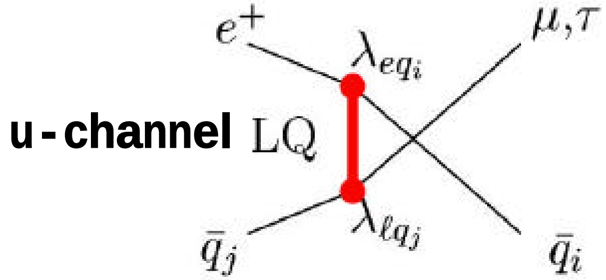
- In the next years HERA will continue to be competitive with Tevatron in studying the top anomalous FCNC couplings



LFV at HERA

Mediated by LQs or squarks in R_p violating SUSY models





Phenomenological model BRW:

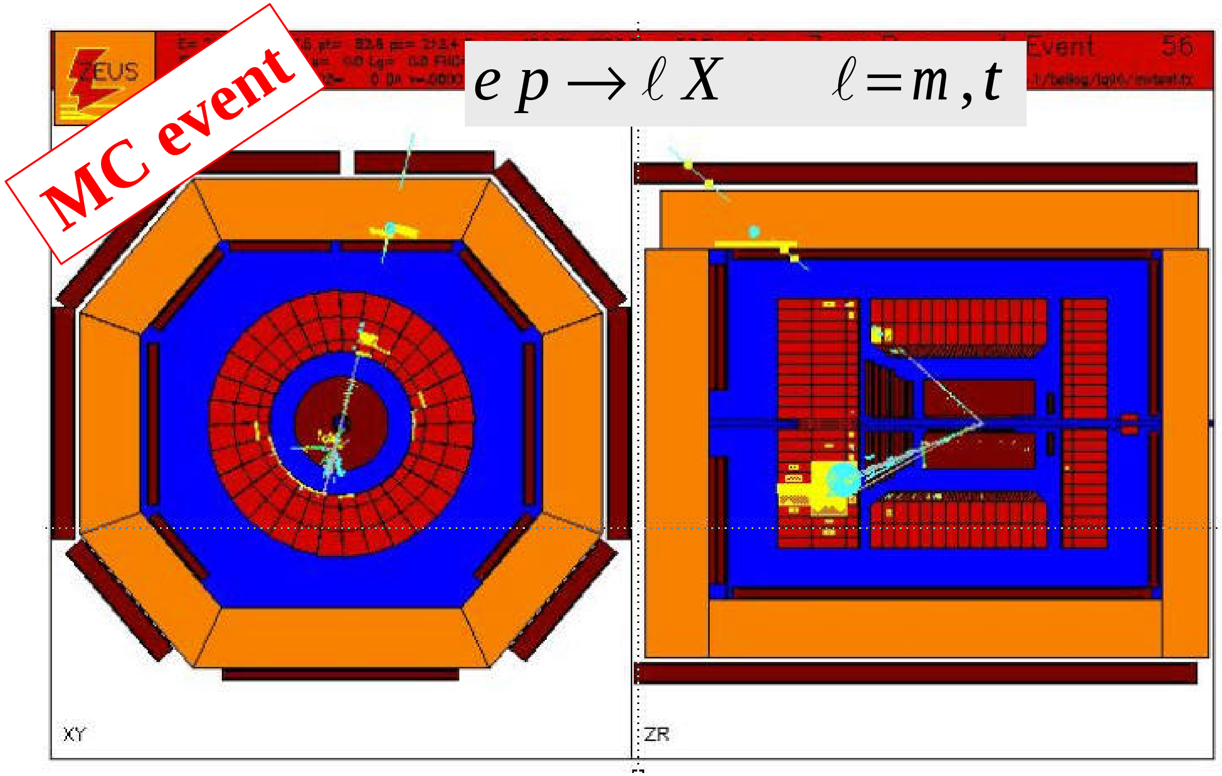
- Invariance under $SU(3)_C xSU(2)_L xU(1)_Y$
- Coupling to LH or RH leptons, not both
- Fixed branching ratio to eq, νq
- 14 LQ species (7 scalar: S_c^I , 7 vector: V_c^I) isospin I=0,1/2,1 helicity χ=L,R
- fermion number F=3B+L=0, |2|

F=0 (2) LQs better tested in e+(e-)p interactions (valence quarks involved)

If one LQ couples to different leptons $\longrightarrow$ LFV

Signature

Similar to a standard NC DIS with a μ or a τ replacing the scattered electron:



- **High Pt isolated μ or τ balanced by a jet in the transverse plane**
- **High missing calorimeter Pt**

$$M_{LQ} < \sqrt{s} \xrightarrow{\text{Narrow width approximation}} \sigma_{NWA} \propto \lambda^2_{eq_1} \, Br_{\ell q_j}$$

Dominated by s-channel resonance production

$$M_{LQ} >> \sqrt{s} \xrightarrow{\text{Contact int. approximation}} \sigma_{CI} \propto \frac{\lambda_{eq_i} \quad \lambda_{eq_j}}{M^2_{LQ}}$$

Both u- and s-channel contribute

HERA much more competitive in the tau-channel since the limits from low-energy experiments are much weaker respect to the muon-channel

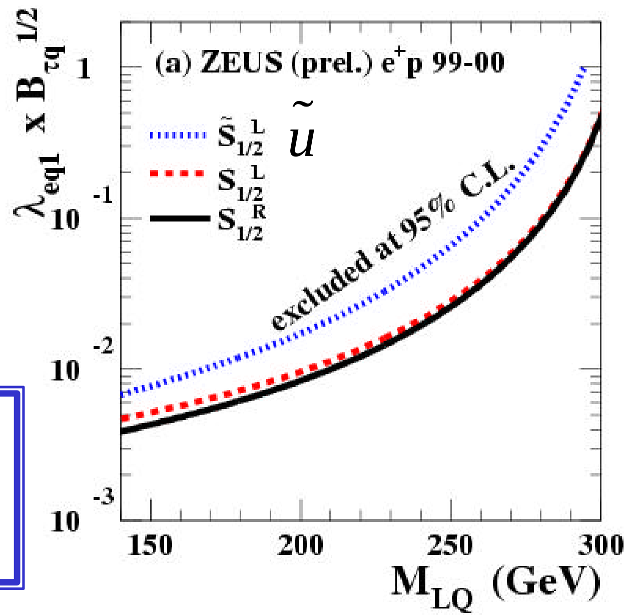
- **tau had. channel**: multivariate tecnique used in the isolated tau search, τ-jet was required to be in the missing Pt direction ($\Delta\phi<20^o$)
- **tau leptonic channel**: e or μ in the missing Pt direction ($\Delta\phi<20^o$)

Results for the tau channel using 65.5 pb^{-1} collected during 1999-2000

No event survive the final selection, 0.8 $\pm$ 0.3 expected from SM

$M_{LQ} < \sqrt{s}$ ⟶ limits on $l_{eq_1} \cdot \sqrt{B_{tq}}$

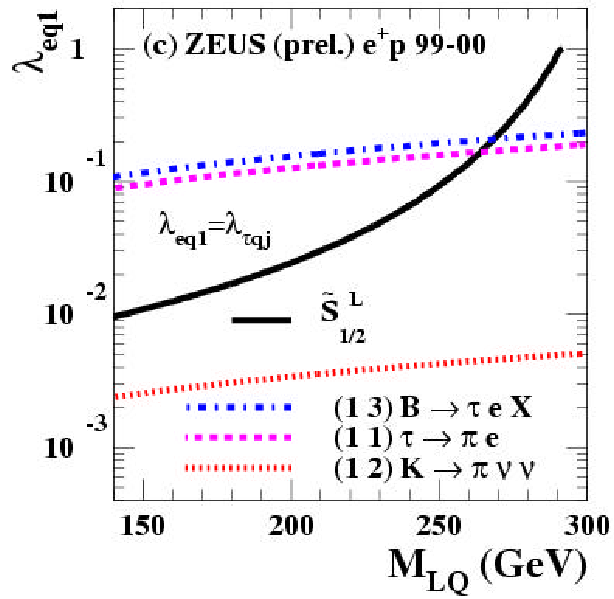
Limits for $\tilde{S}^{L}_{1/2}$ also interpretable as limit on $l'_{1j1} \cdot \sqrt{B_{tq}}$ for squark $\tilde{u}$ in Rp violating SUSY



Assuming a coupling of EW strength masses below 270-300 GeV (depending on LQ type) are escluded

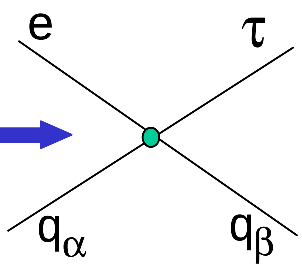
assuming $l_{eq_1} = l_{tq_b}$

The Br is fixed and limits can be compared with constraints from rare decays



As shown for $\tilde{S}^{L}_{1/2}$, HERA improve on indirect limits from rare decays for M_{LQ}<270 GeV when second or third generation quarks are involved

$M_{LQ} \gg \sqrt{s}$



Limits on the contact interaction term $\dfrac{l_{eq_a}\, l_{\ell q_b}}{M_{LQ}^2}$

In many cases, when second or third generation quarks are involved, HERA limits improve on constraints from rare decays

$e \to \tau$	ZEUS	$F=0$					
$\alpha\beta$	$S^L_{1/2}$ e^+u_α	$S^R_{1/2}$ $e^+(u+d)_\alpha$	$\tilde{S}^L_{1/2}$ e^+d_α	V^L_0 e^+d_α	V^R_0 e^+d_α	$\tilde{V}^R_0$ e^+u_α	V^L_1 $e^+(\sqrt{2}u+d)_\alpha$
1 1	$\tau \to \pi e$ 0.4 **2.2**	$\tau \to \pi e$ 0.2 **1.8**	$\tau \to \pi e$ 0.4 **3.2**	$\tau \to \pi e$ 0.2 **2.3**	$\tau \to \pi e$ 0.2 **2.3**	$\tau \to \pi e$ 0.2 **1.7**	$\tau \to \pi e$ 0.06 **0.8**
1 2	$\boxed{\mathbf{2.2}}$	$\tau \to K e$ 6.3 $\boxed{\mathbf{1.9}}$	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **3.4**	$\tau \to K e$ 3.2 $\boxed{\mathbf{2.6}}$	$\tau \to K e$ 3.2 $\boxed{\mathbf{2.6}}$	$\boxed{\mathbf{1.9}}$	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **0.9**
1 3	*	$B \to \tau\bar{e}$ 0.6 **3.8**	$B \to \tau\bar{e}$ 0.6 **3.8**	$B \to \tau\bar{e}$ 0.3 **3.2**	$B \to \tau\bar{e}$ 0.3 **3.2**	*	$B \to \tau\bar{e}$ 0.3 **3.2**
2 1	$\boxed{\mathbf{11}}$	$\tau \to K e$ 6.3 **6.4**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **7.8**	$\tau \to K e$ 3.2 **3.5**	$\tau \to K e$ 3.2 **3.5**	$\boxed{\mathbf{4.6}}$	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **1.9**
2 2	$\tau \to ee\bar{e}$ 20 $\boxed{\mathbf{13}}$	$\tau \to ee\bar{e}$ 30 $\boxed{\mathbf{7.3}}$	$\tau \to ee\bar{e}$ 66 $\boxed{\mathbf{8.9}}$	$\tau \to ee\bar{e}$ 33 $\boxed{\mathbf{4.4}}$	$\tau \to ee\bar{e}$ 33 $\boxed{\mathbf{4.4}}$	$\tau \to ee\bar{e}$ 10 $\boxed{\mathbf{7.1}}$	$\tau \to ee\bar{e}$ 6.1 $\boxed{\mathbf{2.7}}$
2 3	*	$B \to \tau\bar{e}X$ 14 $\boxed{\mathbf{11}}$	$B \to \tau\bar{e}X$ 14 $\boxed{\mathbf{11}}$	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{6.8}}$	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{6.8}}$	*	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{6.8}}$
3 1	*	$B \to \tau\bar{e}$ 0.6 **11**	$B \to \tau\bar{e}$ 0.6 **11**	V_{ub} 0.12 **4.0**	$B \to \tau\bar{e}$ 0.3 **4.0**	*	V_{ub} 0.12 **4.0**
3 2	*	$B \to \tau\bar{e}X$ 14 **14**	$B \to \tau\bar{e}X$ 14 **14**	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{5.2}}$	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{5.2}}$	*	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{5.2}}$
3 3	*	$\tau \to ee\bar{e}$ 30 $\boxed{\mathbf{19}}$	$\tau \to ee\bar{e}$ 66 $\boxed{\mathbf{19}}$	$\tau \to ee\bar{e}$ 33 $\boxed{\mathbf{10}}$	$\tau \to ee\bar{e}$ 33 $\boxed{\mathbf{10}}$	*	$\tau \to ee\bar{e}$ 6.1 **10**

Summary and perspectives for LFV

- HERA offers a unique environment to study non-flavour diagonal LQs. In particular when tau decays are involved, constraints are often better than limits from rare decays.

- Taking into account Tevatron limits for third generation LQs, ($\sim$100 GeV for Br(τ)=1) HERA have a unique sensitivity for LQs with a small Br in electron and large Br in tau.

- During future running the polarization of the electron beam will provide the possibility to selectively study chiral LQs