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Lepton flavour violation and flavour changing neutral current at HERA

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Topic: search for events with high-pt isolated leptons and large missing pt with the ZEUS detector at HERA

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

Such topologies can be originated by:

- $u \leftrightarrow t$ $\quad$ $e\,p \rightarrow e\,t\,X$ (single top production)

- $e \leftrightarrow \mu$, $e \leftrightarrow \tau$ $\quad$ $e\,p \rightarrow \mu\,(\tau)\,X$ (lepton flavour violation)

→ **FCNC** transitions which are well suited to look for new physics:

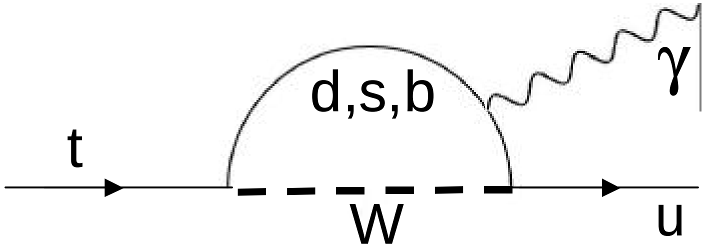
→ SM expectations negligibly small
→ Possible sizeable cross section from BSM sources
→ Very low background from other SM processes
→ Striking topology allowing high efficiency detection

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.

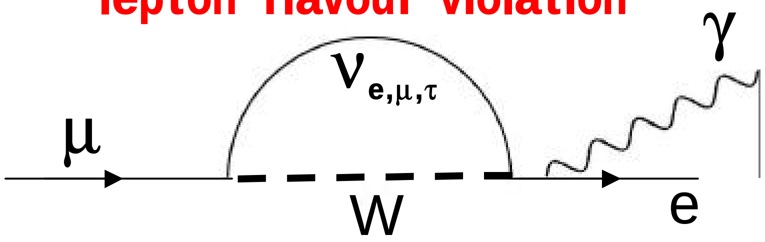
➡ The extension of the SM, required to account for this evidence, allows for one loop FCNC processes mediated by W-boson in the lepton sector analogue to the ones in the quark sector.

$u \leftrightarrow t$ transition



Br(SM) ~ 10^{-12}

$e \leftrightarrow \mu$ transition
lepton flavour violation



Br(SM) ~ 10^{-45}

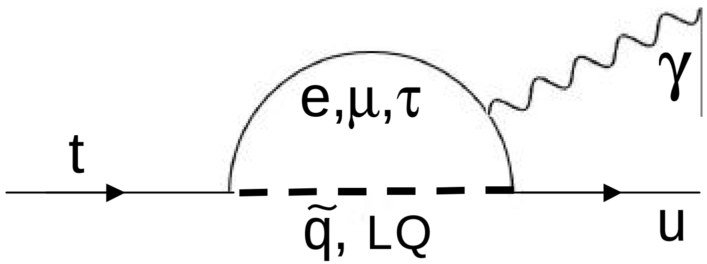
All these processes are strongly suppressed by the GIM mechanism. The only one with a sizeable rate is the process $b \to s\,\gamma$, due to the heavy top in the loop. For this process measurements are in good agreement with SM expectation.

FCNC transitions beyond the SM

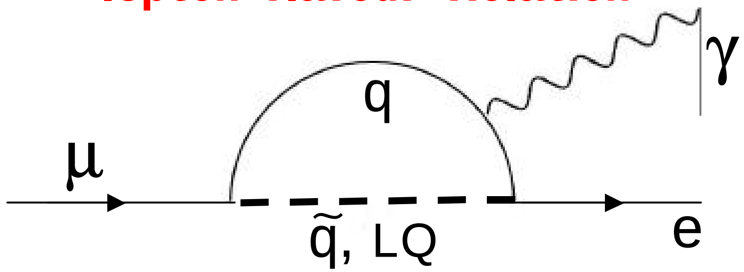
Many theories beyond the SM foresee new bosons linking quarks and leptons (leptoquarks in GUT theories or squarks in Rp violating SUSY models). HERA is the ideal place to study such exotic bosons since they can be directly produced via eq fusion.

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

u ↔ t transition



lepton flavour violation



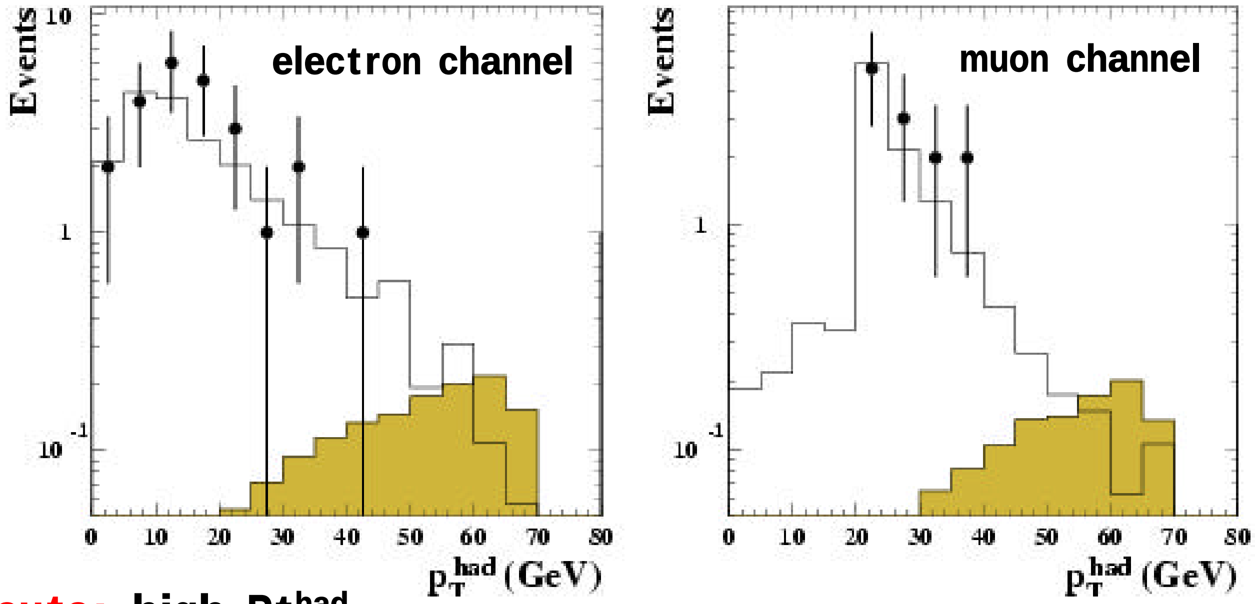
Search for events with high-pt isolated leptons large missing pt and large hadronic Pt

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 > 5 GeV/c, 17 < θ < 115**
- **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 Φ_{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 $e^{\pm}p$ $\mathcal{L} = 130.1\,\mathrm{pb}^{-1}$	Electron obs./exp. ($W^{\pm}$ contribution)	Muon obs./exp. ($W^{\pm}$ contribution)	Tau obs./exp. ($W^{\pm}$ contribution)
$p_T^{had} > 25$ 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%)
$p_T^{had} > 40$ 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%)

μ channel: [ZEUS, Phys. Lett. B559, 153, 2003, Addendum DESY-03-188]
τ channel: [ZEUS, Phys. Lett. B583, 41, 2004]

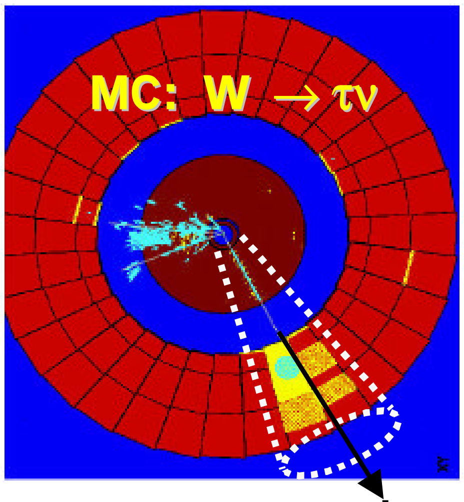
→ **Good agreement with SM, except for the tau channel**

τ-finder for the hadronic decay channel

Multivariate technique to separate τ-jets from QCD-jets

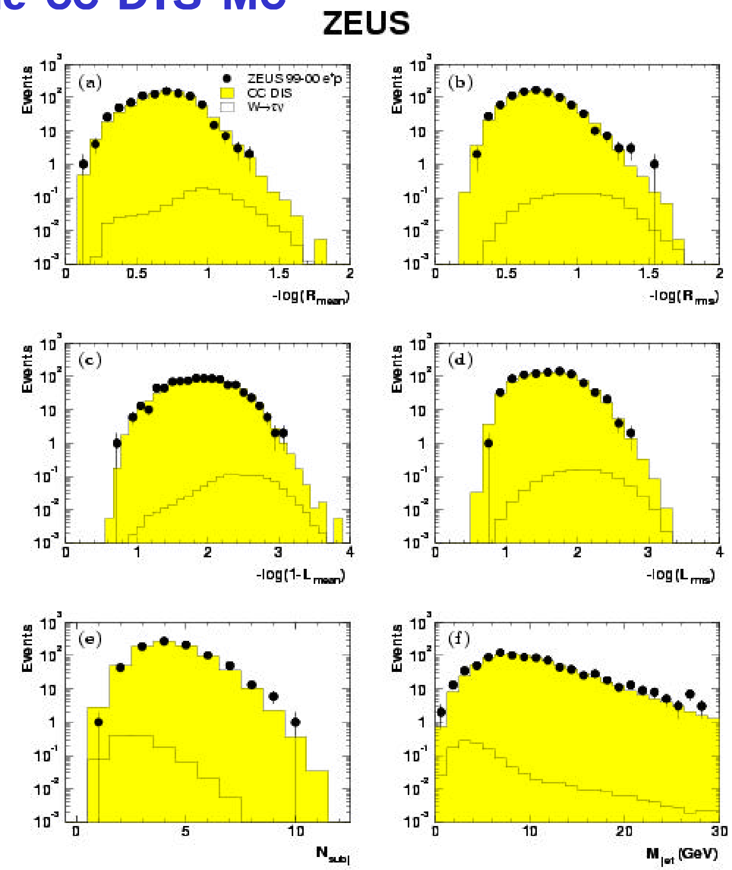
Observables used to characterize jet shape:

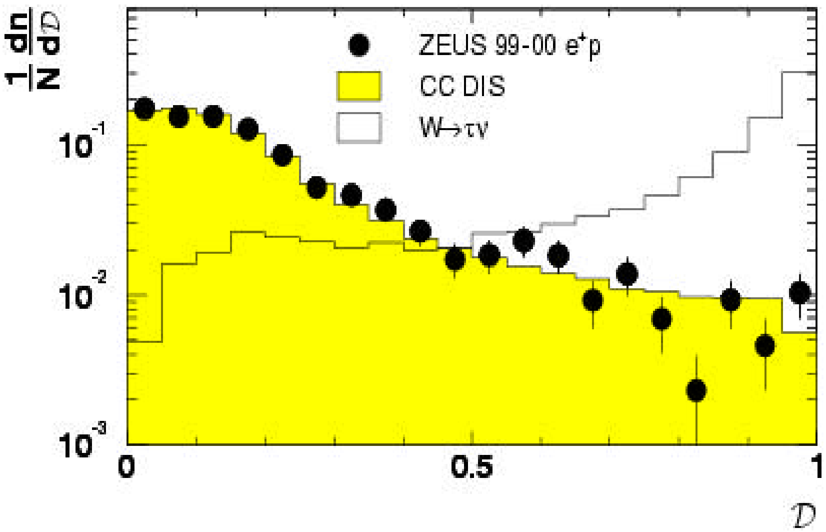
- radial jet energy distribution (mean and rms)
- longitudinal jet energy distribution (mean and rms)
- number of subjets
- jet mass



tau-jet axis

- 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 1 track for the τ jet optimal separation between bg (CC DIS) and signal ($W \to \nu\tau$) for D>0.95
efficiency ~22% for the signal

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

tau channel results

Isolated high-pt lepton selection:

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

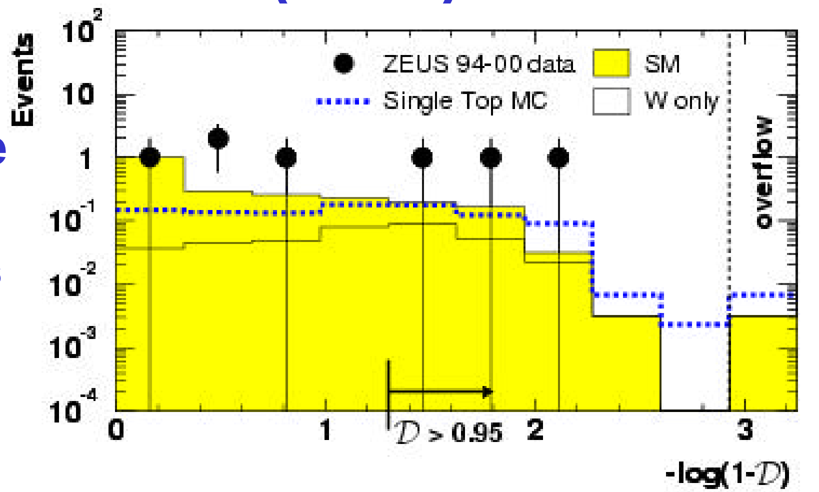
Tau identification:

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

  discriminant from the 6 jet shape variables

3 events observed

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



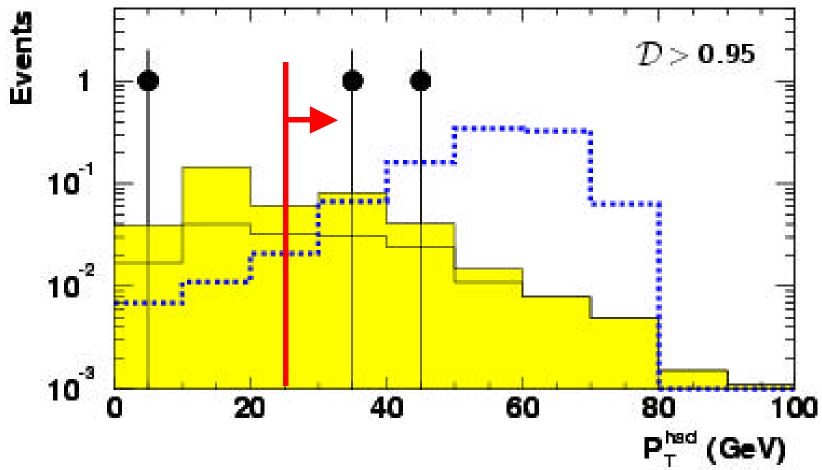
Optimizing hadronic Pt cut for single top signal:

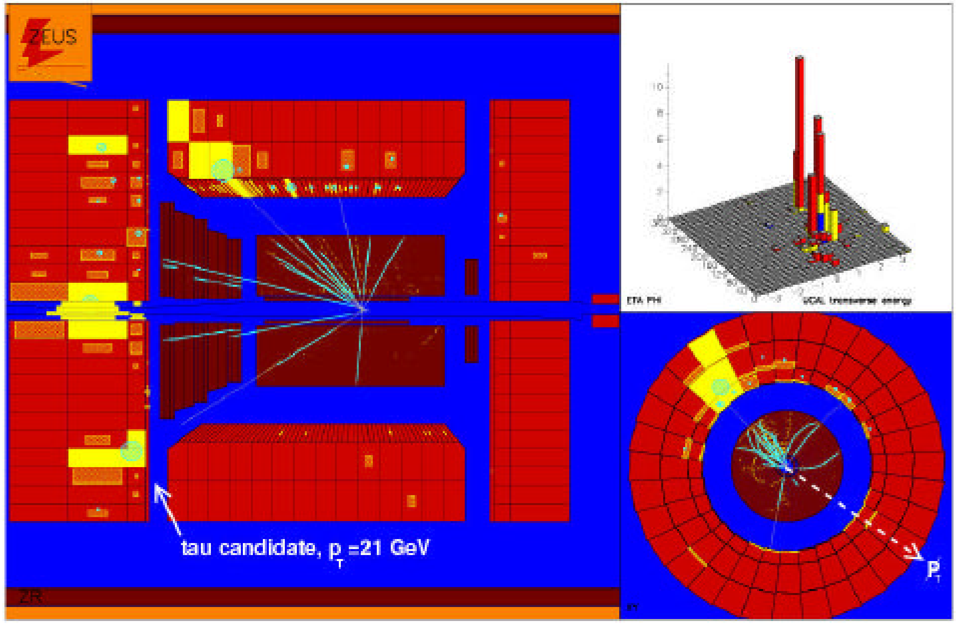
- P_T^{had} > 25 GeV

2 events observed

0.20 ± 0.05 expected

→ Prob = 1.8%





τ candidate 1

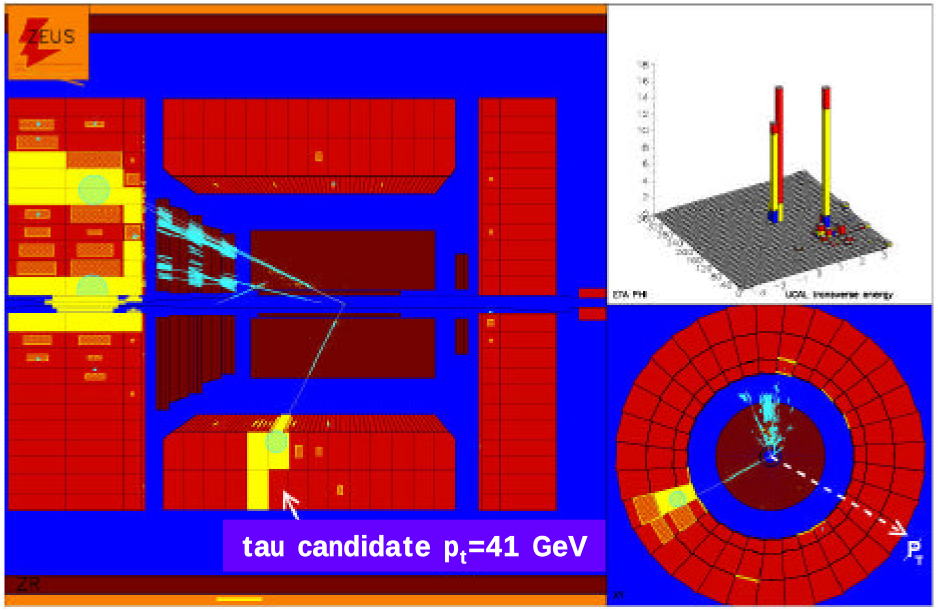
$P_{T,CAL}$ = 37 GeV
P_T^{had}= 48 GeV

$P_{T,\tau jet}$= 21 GeV
M_T = 32 GeV

τ candidate 2

$P_{T,CAL}$ = 39 GeV
P_T^{had}= 38 GeV

$P_{T,\tau jet}$= 41 GeV
M_T= 70 GeV



Single top production at HERA

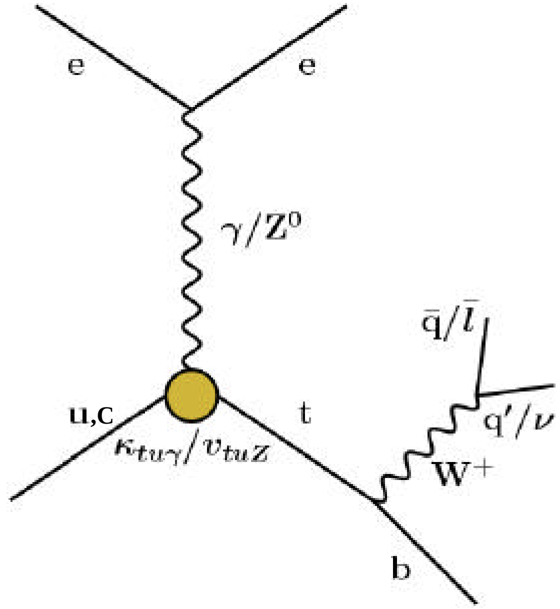
Results on electrons and muons can be used to constraint such process
Sensitivity of the tau channel is largely lower (not used)

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

γ-exchange | Z-exchange

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

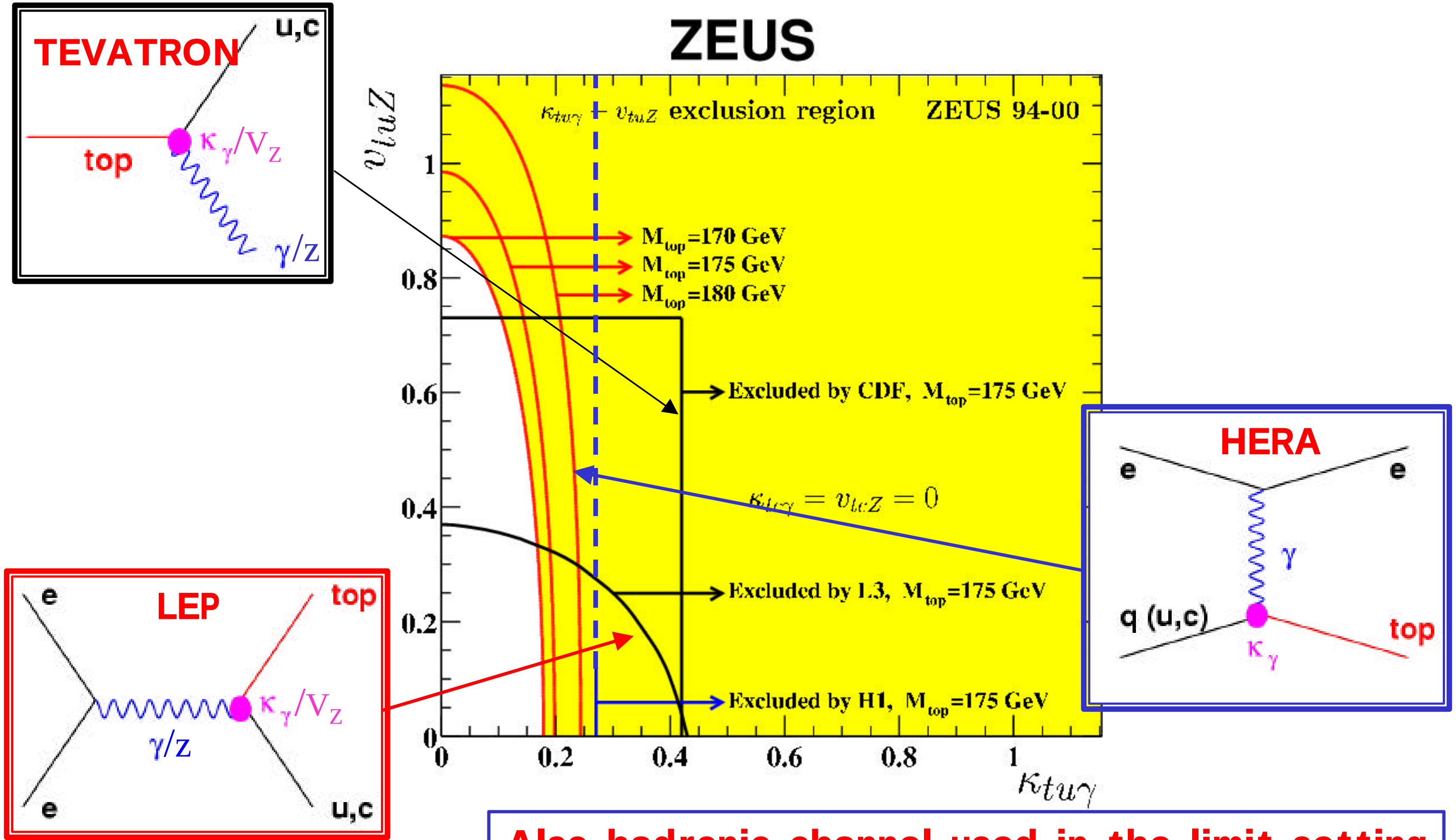
$$\sigma_{\mu\nu} = \frac{\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu}{2} \qquad e_u = \frac{2}{3}$$



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

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

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:

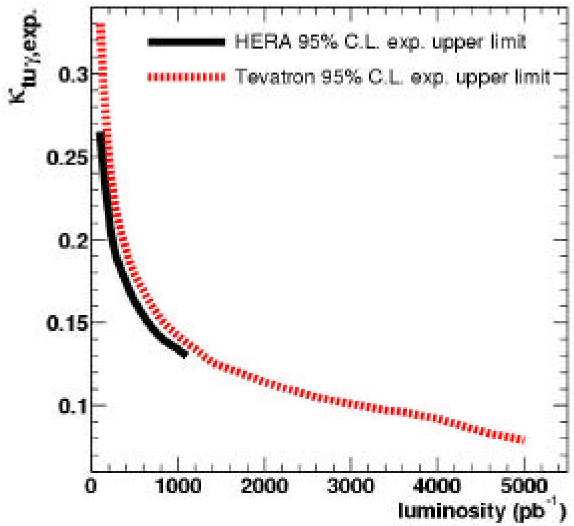
Single top hypothesis largely disfavoured by e/μ/jet ZEUS analysis

➡ **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

[T.Carli et al., hep-ph/0402012]



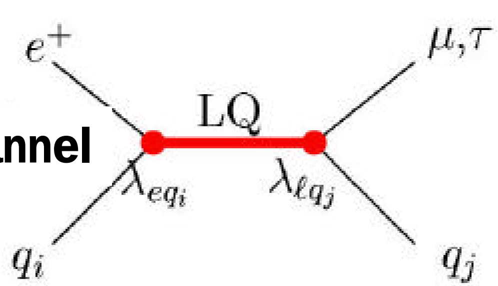
- In the next years HERA will continue to be competitive with Tevatron in studying the top anomalous FCNC couplings

500 pb^{-1} ⟶ $k_{tu\gamma}$<0.16

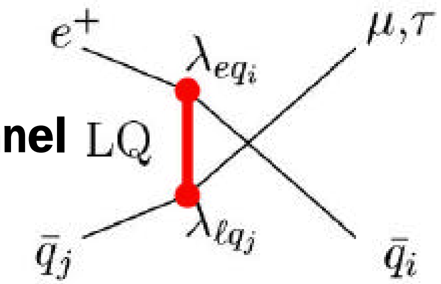
LFV at HERA

Mediated by LQs or squarks in R_p violating SUSY models

s-channel



u-channel



Phenomenological model BRW:

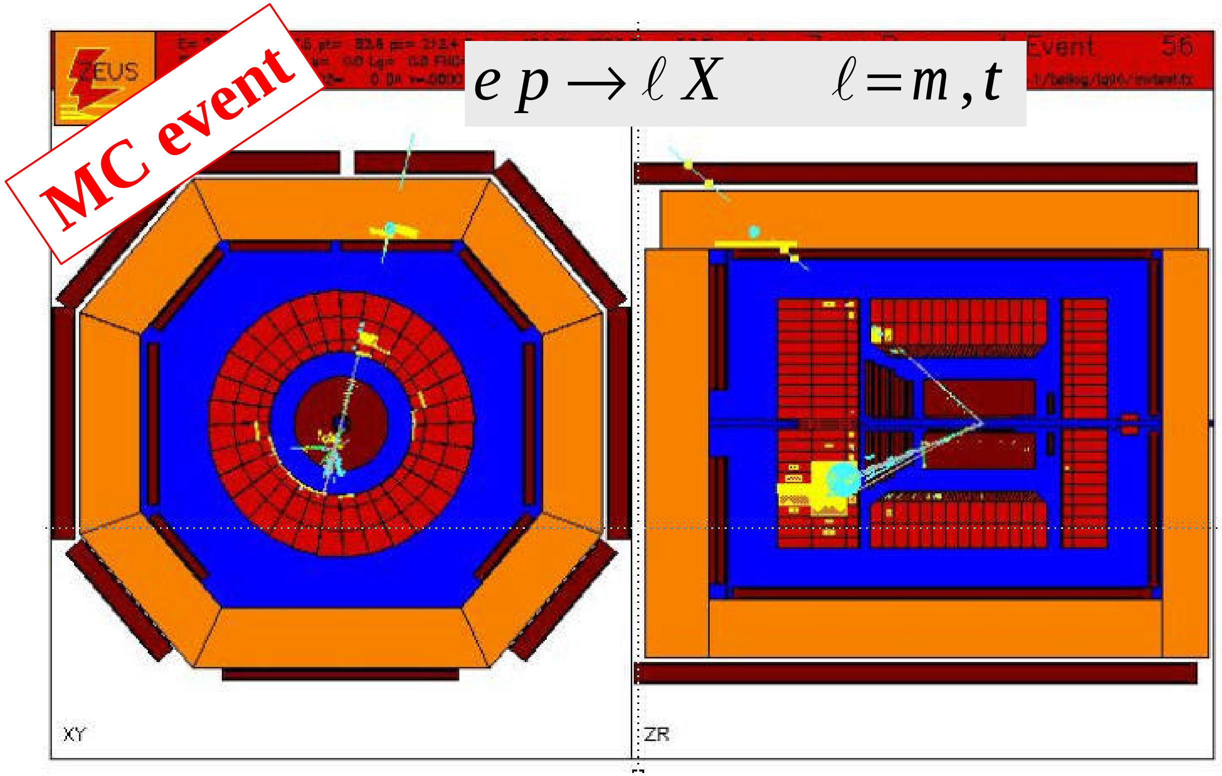
- Invariance under $SU(3)_C \times SU(2)_L \times U(1)_Y$
- Coupling to LH or RH leptons, not both
- Fixed branching ratio to eq, νq
- 14 LQ species (7 scalar: S_c^I , 7 vector: V_c^I) — isospin I=0,1/2,1; helicity χ=L,R
- fermion number F=3B+L=0, $\pm$2

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

If one LQ couples to different leptons ⟶ 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**

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

Dominated by s-channel resonance production at $x=M^2_{LQ}/s$

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

Both u- and s-channel contribute

HERA much more competitive in the tau-channel since existing limits from rare decays are much weaker respect to the muon-channel

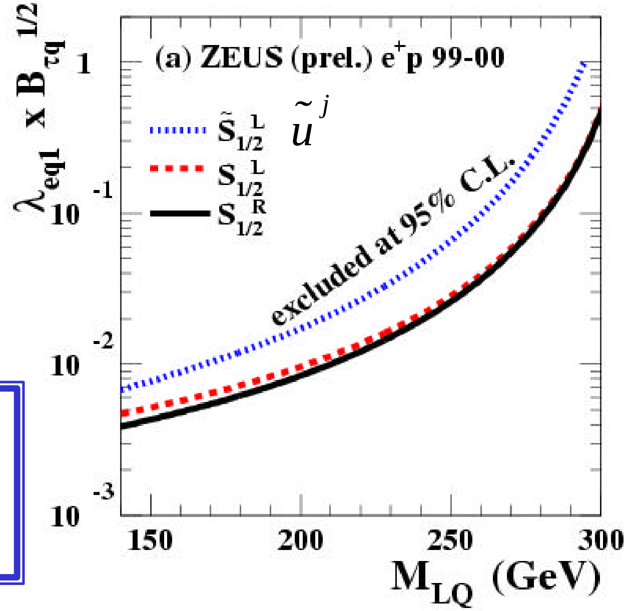
- **tau had. channel**: multivariate tecnique used in the isolated tau search, τ-jet was required to be in the missing Pt direction ($\Delta\phi<20^o$)
- **tau leptonic channel**: e or μ in the missing Pt direction ($\Delta\phi<20^o$)

Preliminary results for the tau channel (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 $l_{eq_1} \cdot \sqrt{B_{tq}}$

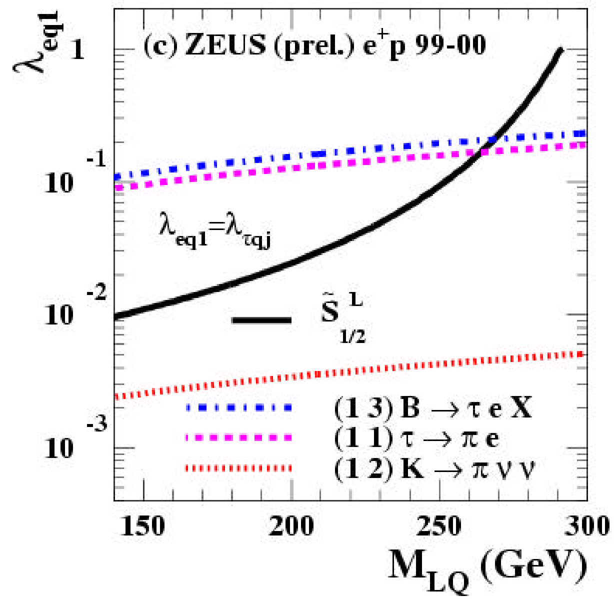
Limits for $\tilde{S}^{L}_{1/2}$ also interpretable as limit on $l'_{1j1} \cdot \sqrt{B_{tq}}$ for squark $\tilde{u}^{j}$ in Rp violating SUSY



Assuming a coupling of EW strength masses below 275-300 GeV (depending on LQ type) are excluded

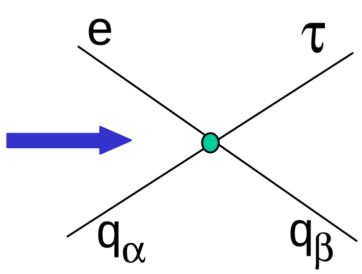
assuming $l_{eq_1} = l_{tq_b}$

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 $\frac{l_{eq_a}\, l_{\ell q_b}}{M_{LQ}^2}$

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	**2.2**	$\tau \to K e$ 6.3 **1.9**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **3.4**	$\tau \to K e$ 3.2 **2.6**	$\tau \to K e$ 3.2 **2.6**	**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	**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**	**4.6**	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **1.9**
2 2	$\tau \to e e\bar{e}$ 20 **13**	$\tau \to e e\bar{e}$ 30 **7.3**	$\tau \to e e\bar{e}$ 66 **8.9**	$\tau \to e e\bar{e}$ 33 **4.4**	$\tau \to e e\bar{e}$ 33 **4.4**	$\tau \to e e\bar{e}$ 10 **7.1**	$\tau \to e e\bar{e}$ 6.1 **2.7**
2 3	*	$B \to \tau\bar{e}X$ 14 **11**	$B \to \tau\bar{e}X$ 14 **11**	$B \to \tau\bar{e}X$ 7.2 **6.8**	$B \to \tau\bar{e}X$ 7.2 **6.8**	*	$B \to \tau\bar{e}X$ 7.2 **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 **5.2**	$B \to \tau\bar{e}X$ 7.2 **5.2**	*	$B \to \tau\bar{e}X$ 7.2 **5.2**
3 3	*	$\tau \to e e\bar{e}$ 30 **19**	$\tau \to e e\bar{e}$ 66 **19**	$\tau \to e e\bar{e}$ 33 **10**	$\tau \to e e\bar{e}$ 33 **10**	*	$\tau \to e e\bar{e}$ 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, (~100 GeV for scalar LQs with Br(τ)=1) HERA have a unique sensitivity for LQs with a small Br in electron and a large Br in tau.

- During future running the polarization of the positron/electron beam will provide the possibility to selectively study LH or RH LQs.

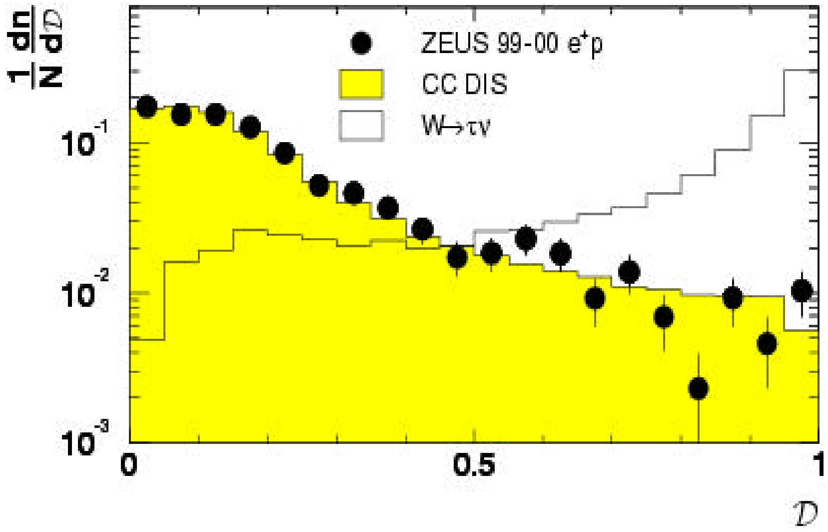
Conclusions

We expect few years of exciting data from HERA II running

- main issue: understand the H1/ZEUS discrepancy in high-pt leptons

- but also competitive/complementary with Tevatron in many aspects of BSM physics

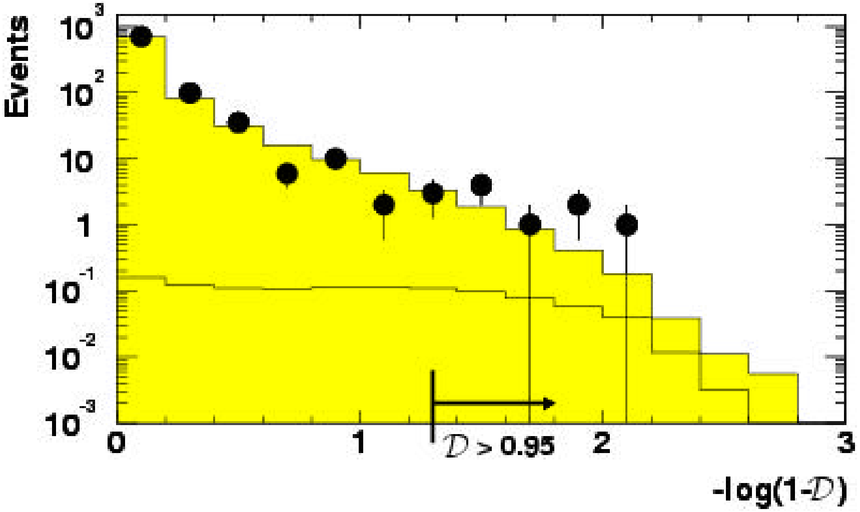
Should we really wait for LHC to discover first signals of BSM physics ?



Shape comparison

Absolute normalization

- W signal two order of magnitude lower
- x-axis stretched to emphasize large D region



Signature

Leptonic channel:

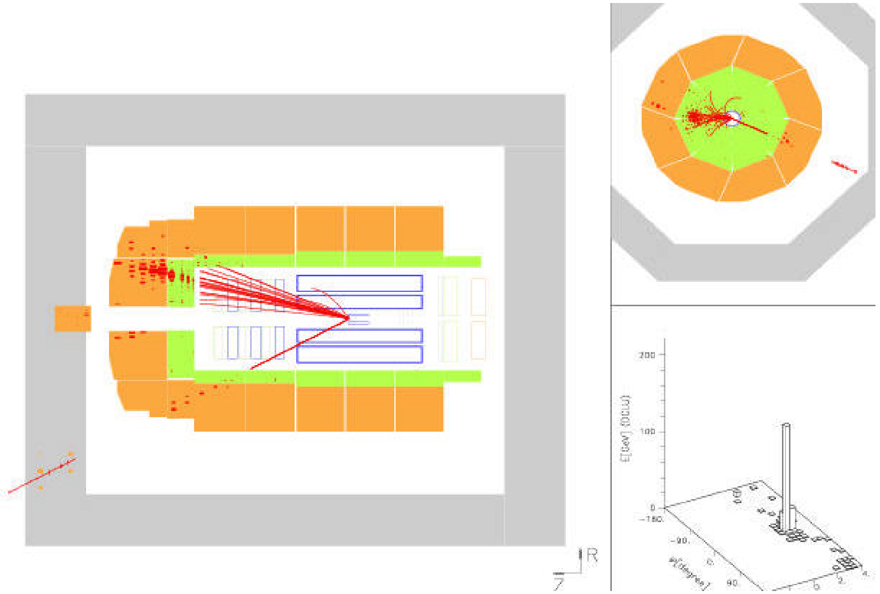
- high pt lepton
- high missing Pt
- high Pt^{had} (Pt of the hadronic state)
- acoplanarity between lepton and jet

SM W production ($\sigma \sim$ 1pb) is a source of background, but it steeply decreases with Pt^{had}

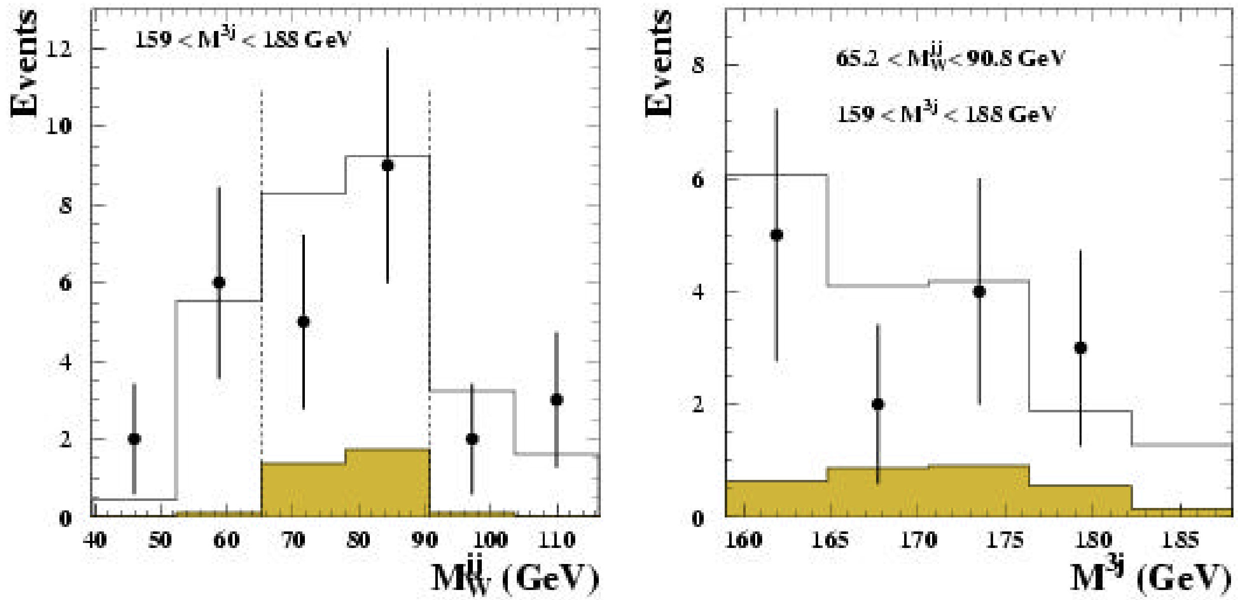
Hadronic channel:

- three jets with high Et
- two jet invariant mass compatible with W-mass
- three jet invariant mass compatible with top-mass

Larger background respect to leptonic channel, dominated by multi-jet photoproduction events



Hadronic channel



Observed: 14

SM Expected: $17.6^{+1.8}_{-1.2}$

Good agreement with SM expectations