Search for Leptoquarks and LFV at the H1 Experiment

Ana Dubak

on behalf of the

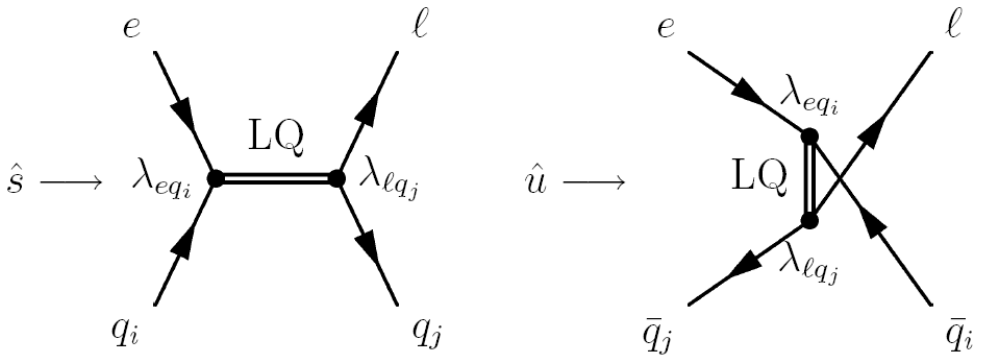
H1 Collaboration

- Leptoquarks at HERA
- Search for first generation LQs
- Search for Lepton Flavour Violation (LFV)
- Summary

Leptoquarks and LFV at HERA

Leptoquarks
colour triplet bosons
fractional charge
both lepton and baryon number

Parameters
mass
coupling
quantum numbers



s-channel $\sigma \sim \lambda^2$
$M_{LQ} \approx (sx)^{1/2}$
Specific angular distribution

u-channel $\sigma \sim \lambda^4$
$M_{LQ} > s^{1/2}$

Lepton Flavour Conservation (LFC) decays: LQ -> eq, νq (BRW)
Lepton Flavour Violation (LFV) decays: LQ -> μq, LQ -> τq

Buchmüller-Rückl-Wyler-Model

$F=2$	Prod./Decay	β_e	$F=0$	Prod./Decay	β_e
Scalar Leptoquarks					
$S_{0,L}$	$e_L^- u_L \to e^- u$	1/2	$S_{1/2,L}$	$e_R^+ u_R \to e^+ u$	1
	$\to \nu d$	1/2			
$S_{0,R}$	$e_R^- u_R \to e^- u$	1	$S_{1/2,R}$	$e_L^+ u_L \to e^+ u$	1
$\tilde{S}_{0,R}$	$e_R^- d_R \to e^- d$	1		$e_L^+ d_L \to e^+ d$	1
$S_{1,L}$	$e_L^- d_L \to e^- d$	1	$\tilde{S}_{1/2,L}$	$e_R^+ d_R \to e^+ d$	1
	$e_L^- u_L \to e^- u$	1/2			
	$\to \nu d$	1/2			
Vector Leptoquarks					
$V_{1/2,R}$	$e_R^- d_L \to e^- d$	1	$V_{0,R}$	$e_L^+ d_R \to e^+ d$	1
	$e_R^- u_L \to e^- u$	1	$V_{0,L}$	$e_R^+ d_L \to e^+ d$	1/2
				$\to \overline{\nu} u$	1/2
$V_{1/2,L}$	$e_L^- d_R \to e^- d$	1	$\tilde{V}_{0,R}$	$e_L^+ u_R \to e^+ u$	1
$\tilde{V}_{1/2,L}$	$e_L^- u_R \to e^- u$	1	$V_{1,L}$	$e_R^+ u_L \to e^+ u$	1
				$e_R^+ d_L \to e^+ d$	1/2
				$\to \overline{\nu} u$	1/2

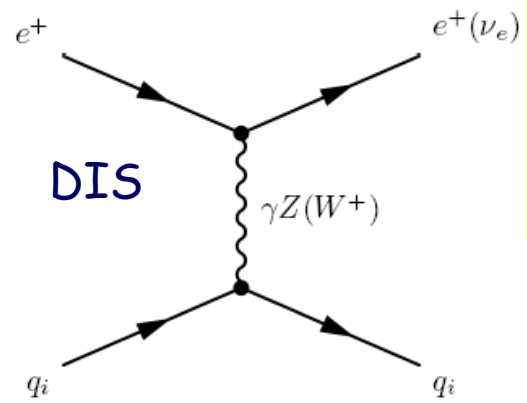
- 14 first generation LQs
- classied by Spin, Weak Isospin, e^- chirality
- Fermion number F=L+3B
  F = 2 (e^-q) or
  F = 0 (e^+q)
- **all** can decay into $e^{\pm}q$ **only 4** of them can also decay into νq
- branching ratio fixed to be β_e = 1 or 0.5
- two free parameters:
  - LQ mass M,
  - Yukawa coupling

New Leptoquark Searches

- Search for LQs with LQ -> eq, νq
  - full HERA I data published in '05 hep-ex/0506044v1
  - new e^-p polarised data from HERA II: L = 92 pb^{-1}

- Search for LFV via LQ -> μq, LQ -> τq
  - e^+p data from 1999-00: L = 65.5 pb^{-1}
  - e^-p data from 1998-99: L = 13.7 pb^{-1}

Search for LQ → eq,νq



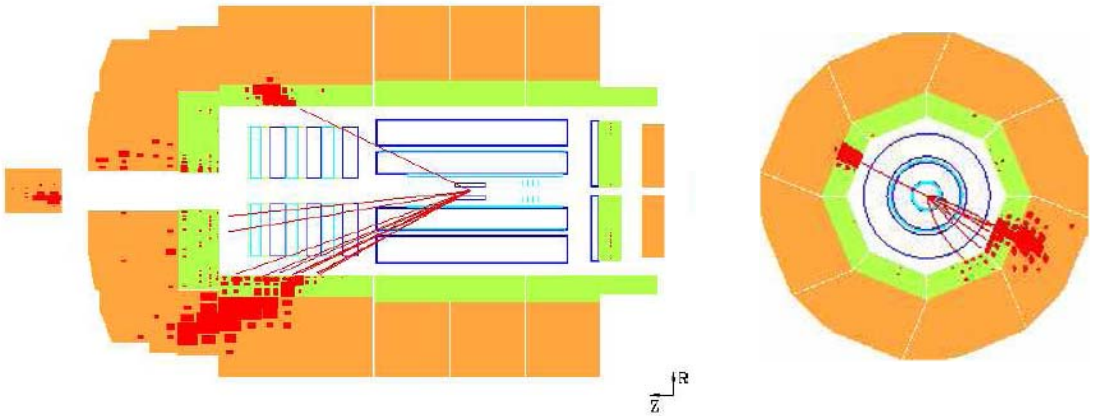
Standard NC/CC DIS selection cuts

$Q^2 > 500\ GeV^2$
$0.1 < y < 0.9$

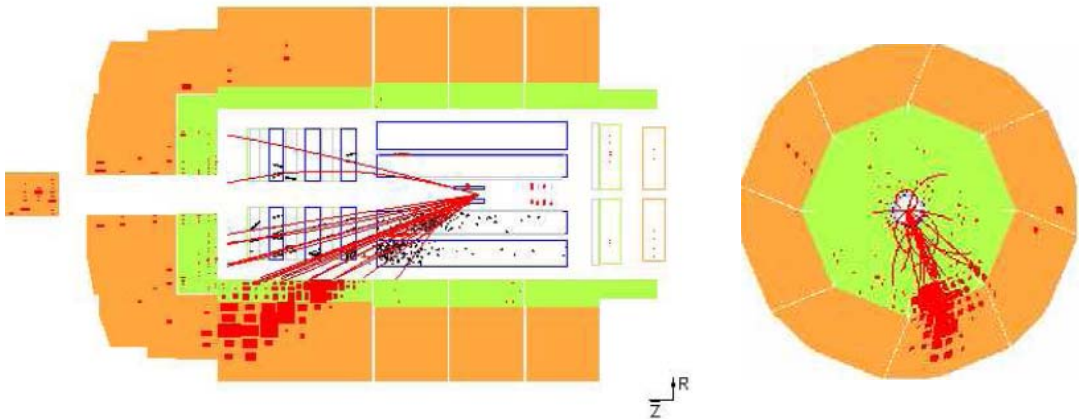
NC: $P_{Te} > 11\ GeV$

CC: $P_{Tmiss} > 12\ GeV$

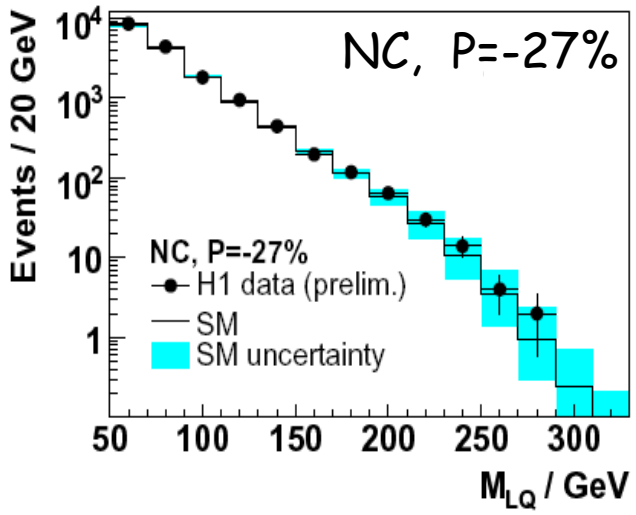
LQ → eq signature as NC DIS **eq → eX**

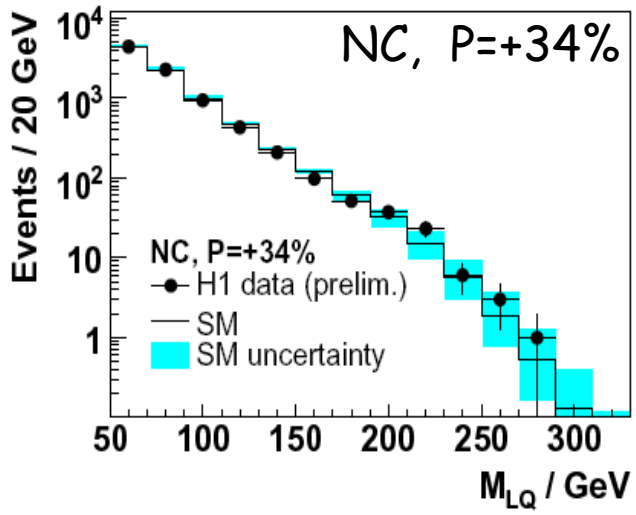


LQ → νq signature as CC DIS **eq → νX**

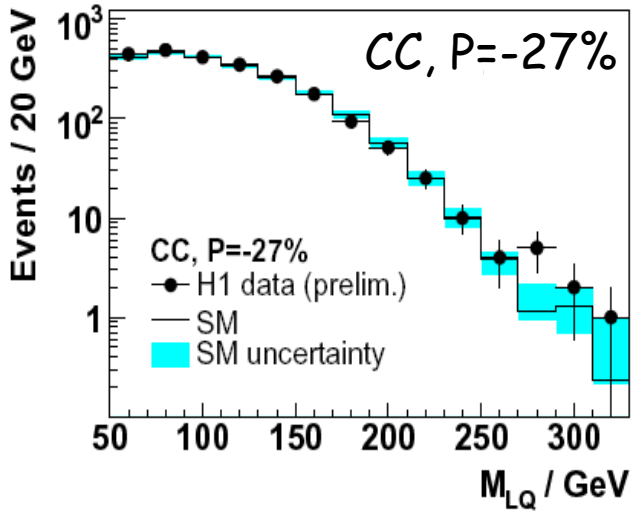


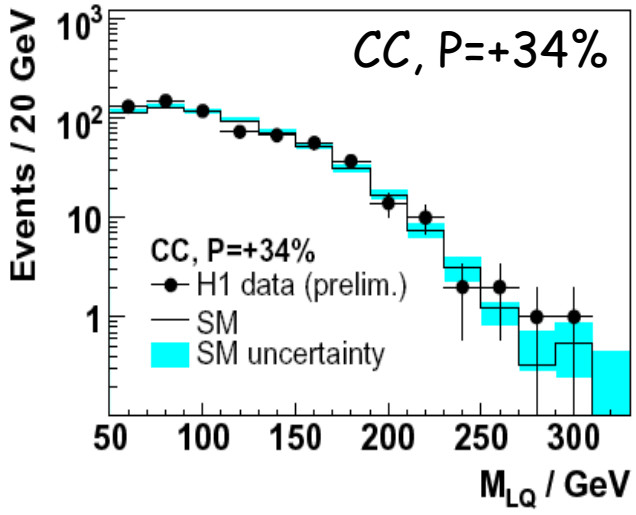
Search for LQ → eq,νq





- Look for enhancement in LQ mass spectra

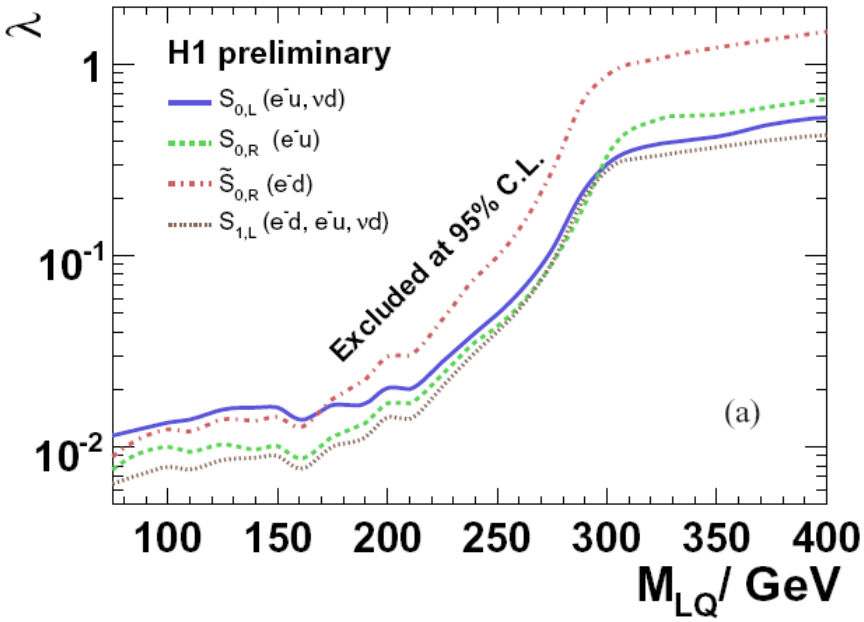




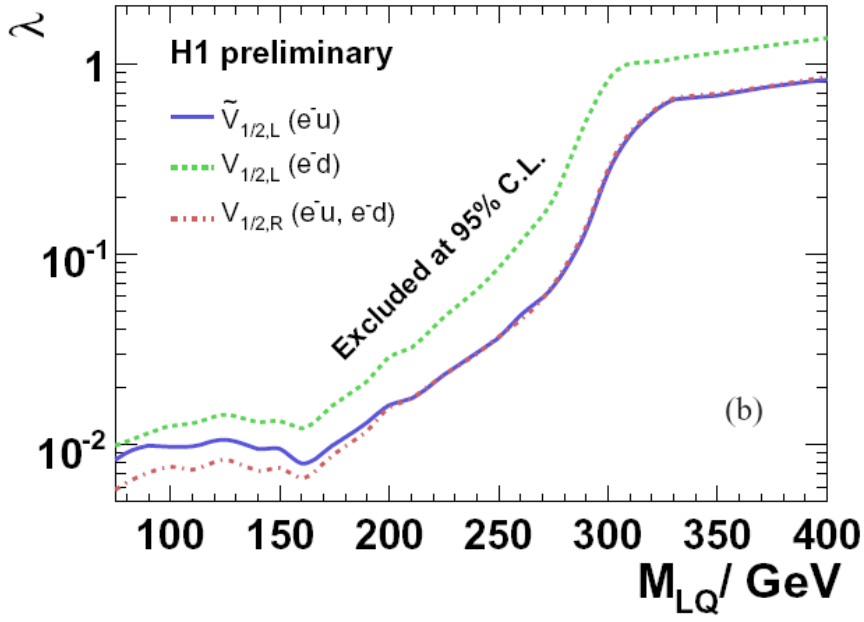
- No evidence for signal

Exclusion Limits for LQs with F=2

Scalar LQs

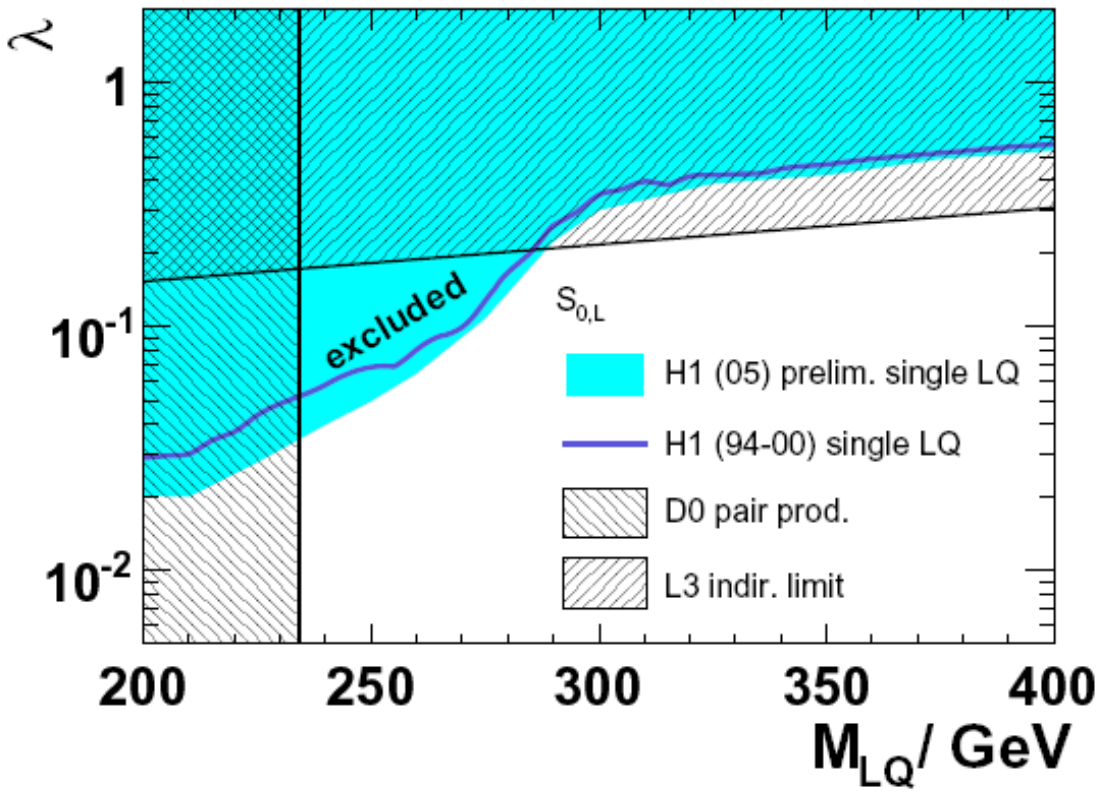


Vector LQs



- strongest constraint for resonant production, $M_{LQ} = (s_{ep}x)^{1/2}$
- at $\lambda = (4\pi\alpha)^{1/2} = 0.3$ lower limits on M_{LQ} : > 276 – 304 GeV

Comparison with LEP, Tevatron, HERA I

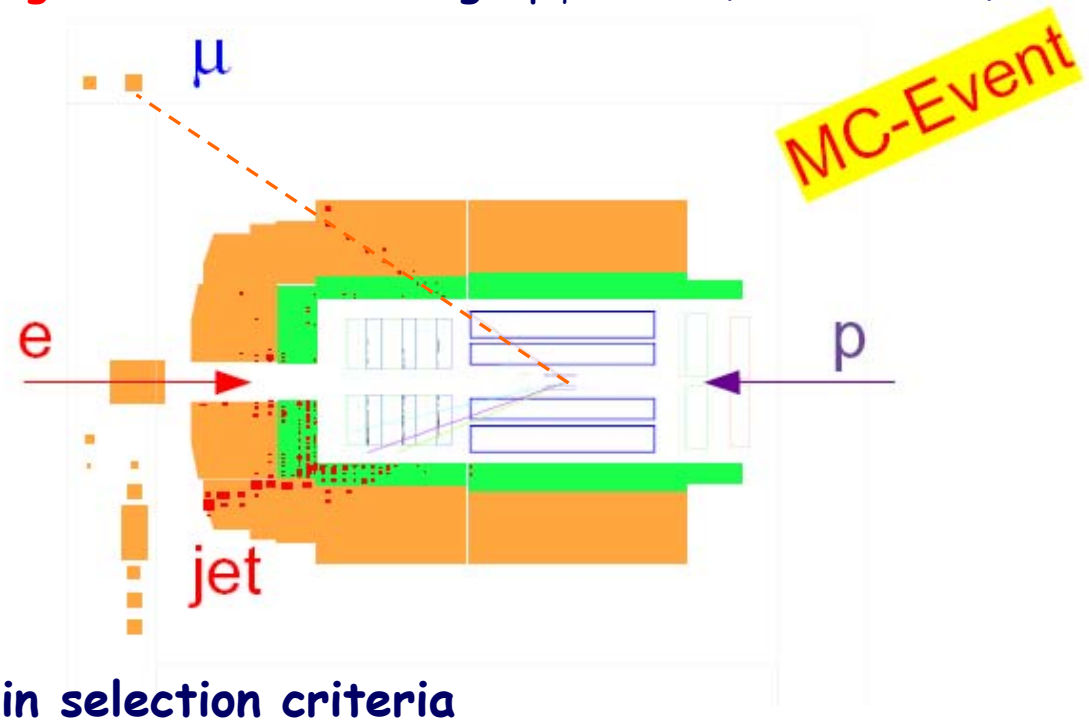


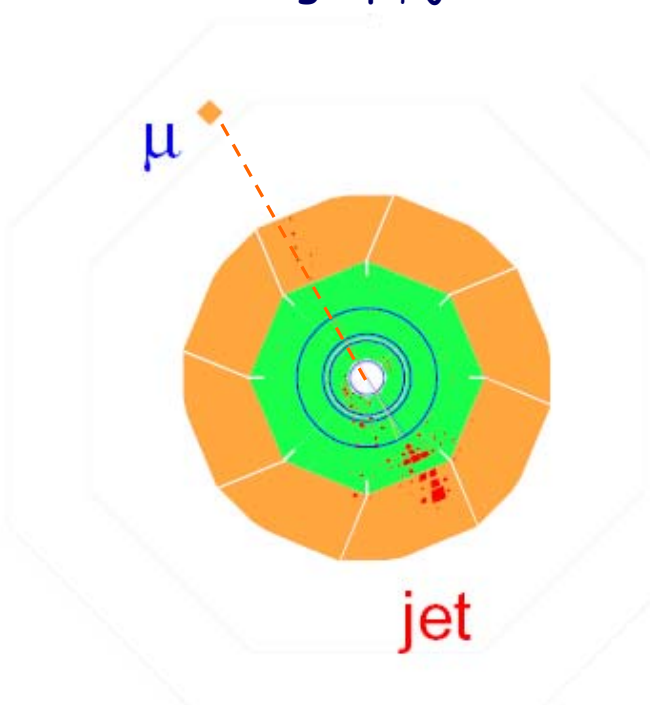
- Tevatron:
  LQ pair production - λ independent
- LEP – indirect constraints

Increased e^-p statistics (HERA II)
$\Rightarrow$ improvement in the resonant region

LFV: $ep \rightarrow \mu q$

Signature: isolated high p_T muon (no electron) back-to-back to high p_T jet

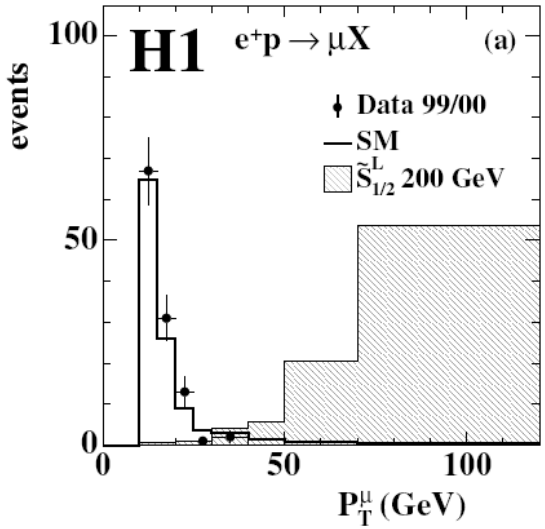


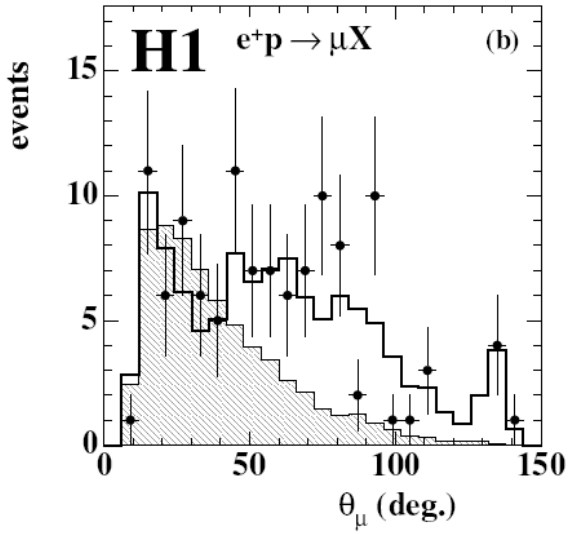


Main selection criteria

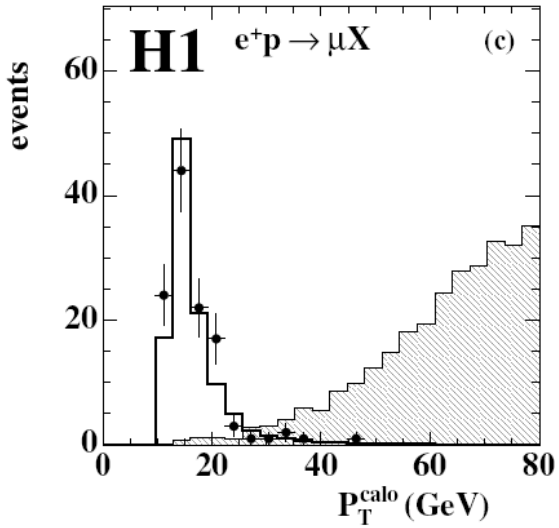
One muon with	$p_T > 10$ GeV
Muon escapes calorimeter	$P_T^{calo} > 25$ GeV
Back to back topology	$\Delta\phi_{\mu\text{-}X} > 170°$

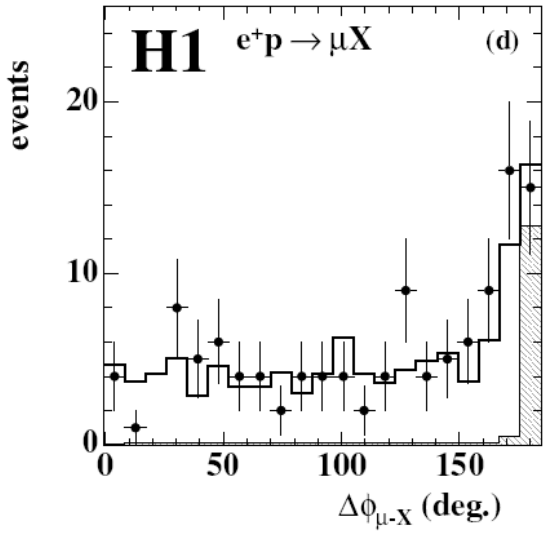
Control distributions of the μX sample





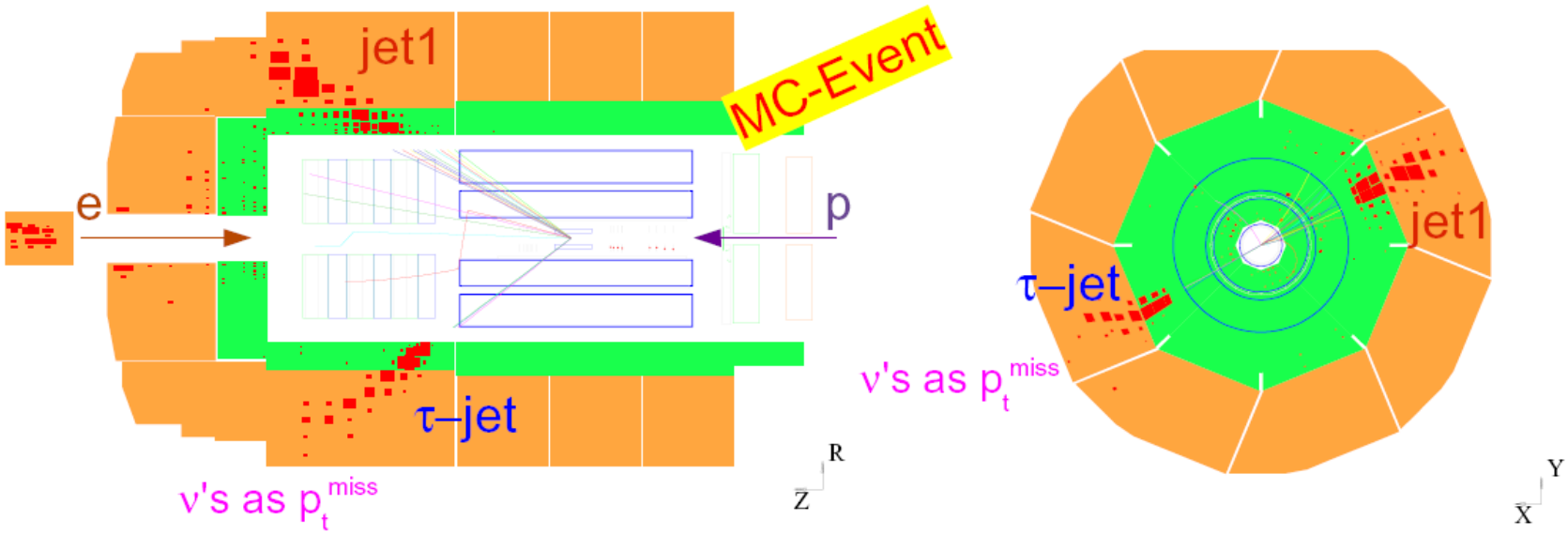
μ-channel:
no candidates found





In agreement with SM
No LQ signal observed

LFV: $ep \rightarrow \tau q$



Main selection criteria

Electronic τ decay

One jet with $p_T^{jet} > 25$ GeV

Electron with $p_T^{e} > 10$ GeV

$Q^2 > 1000$ GeV^2

Muonic τ decay

As for $ep \rightarrow \mu q$

Hadronic τ decay

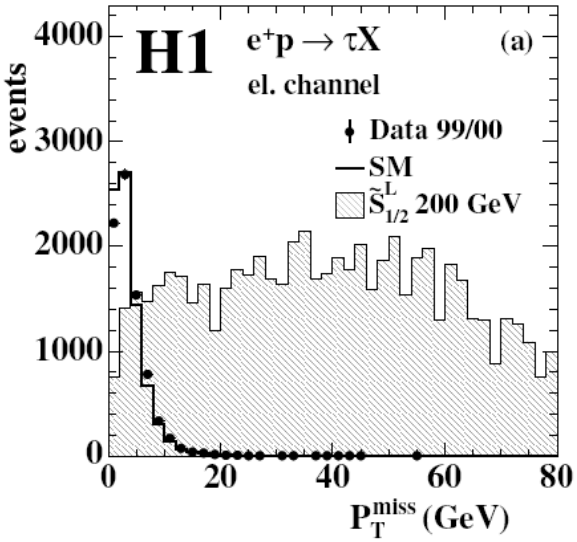
One jet (jet1) with $p_T^{jet1} > 20$ GeV

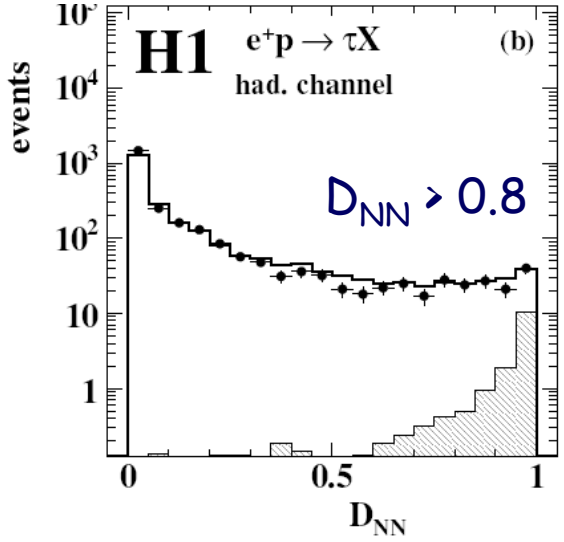
Pencil like jet (jet2) with low track multiplicity and $p_T^{jet2} > 15$ GeV

NN for identification of jet from τ

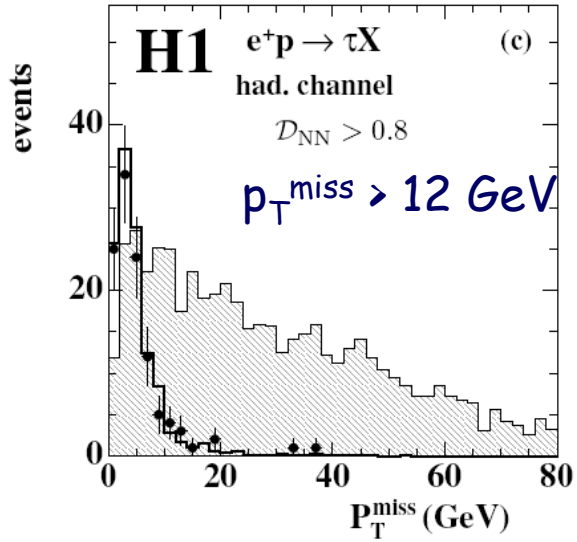
$P_T^{miss} > 12$ GeV

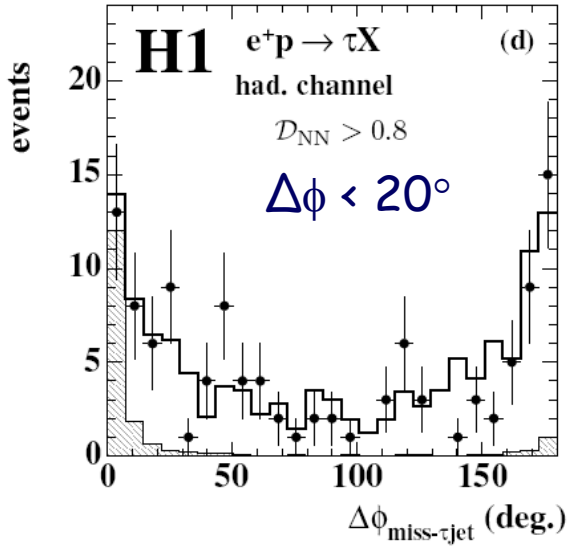
Control distributions of the τX sample





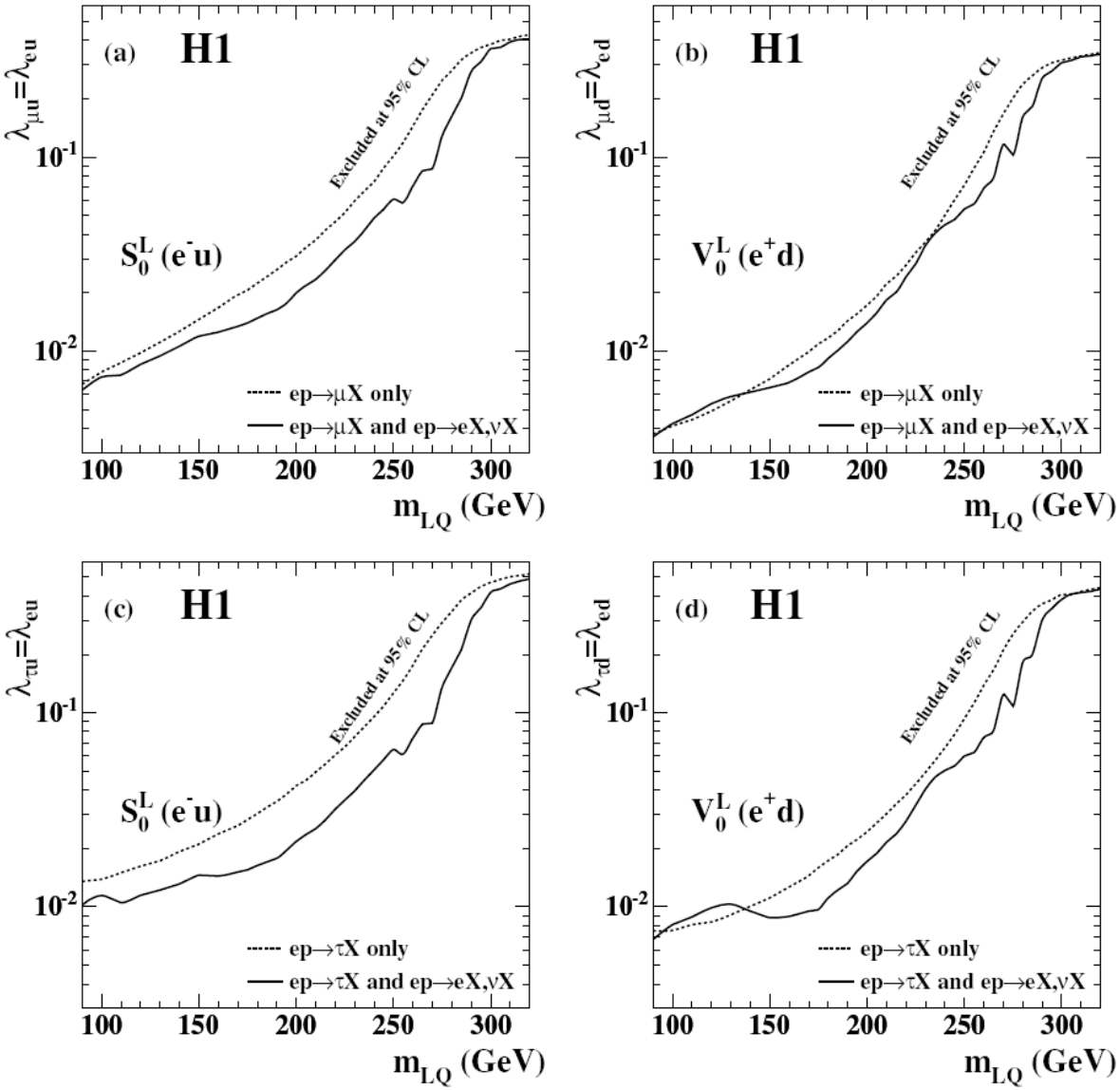
e-decay – no candidate
μ-decay – no candidate
hadronic decay – 1 candidate





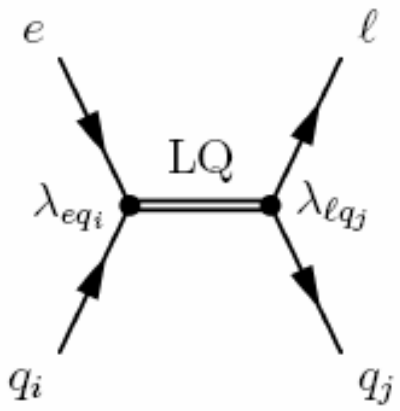
In agreement with SM
No LQ signal observed

Limits on the coupling constant

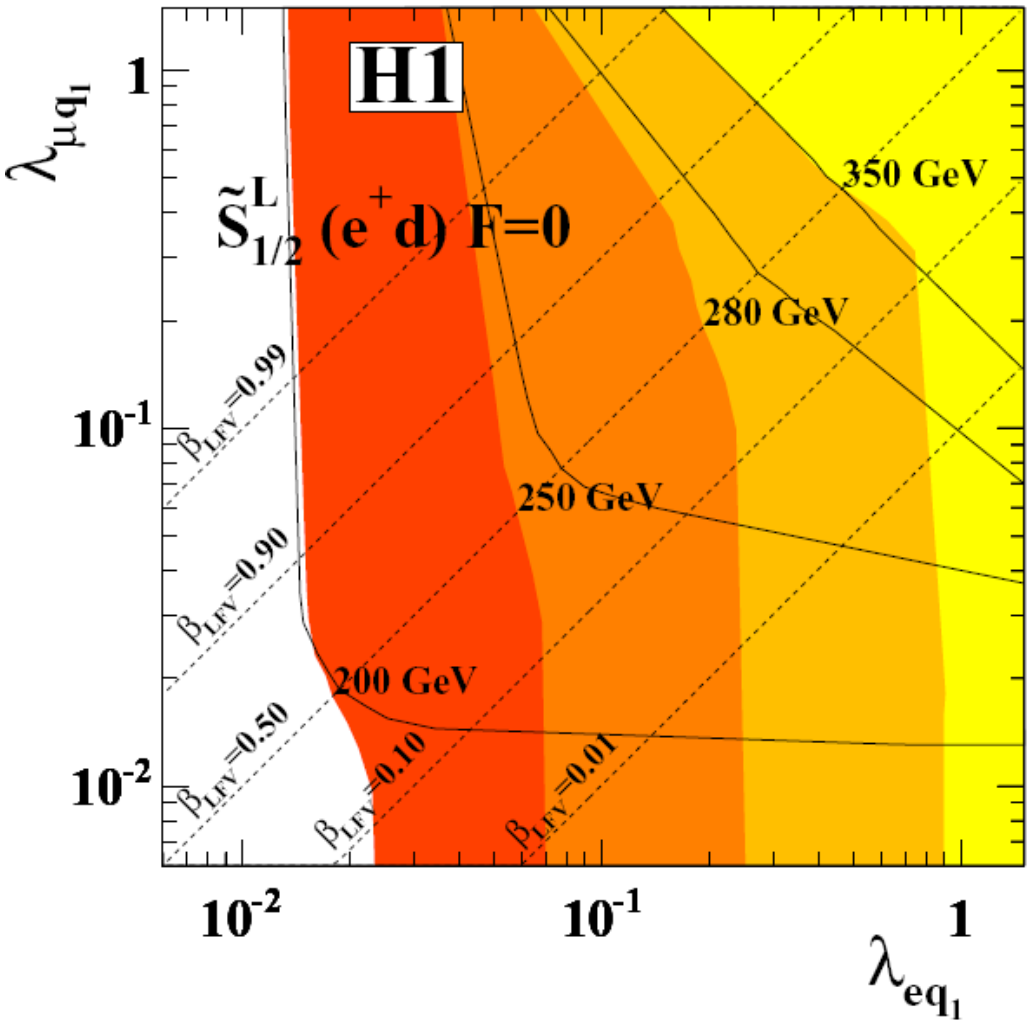


Limits derived

- assuming only one of the couplings $\lambda\mu q$, $\lambda\tau q$ non-zero
- Including published LFC channels from HERA I data

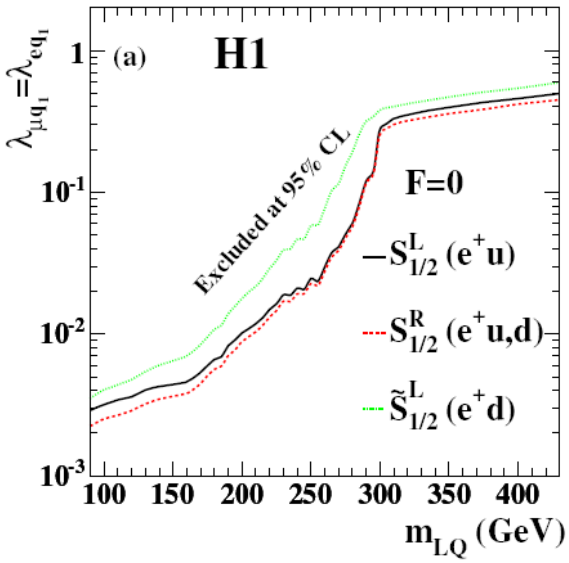


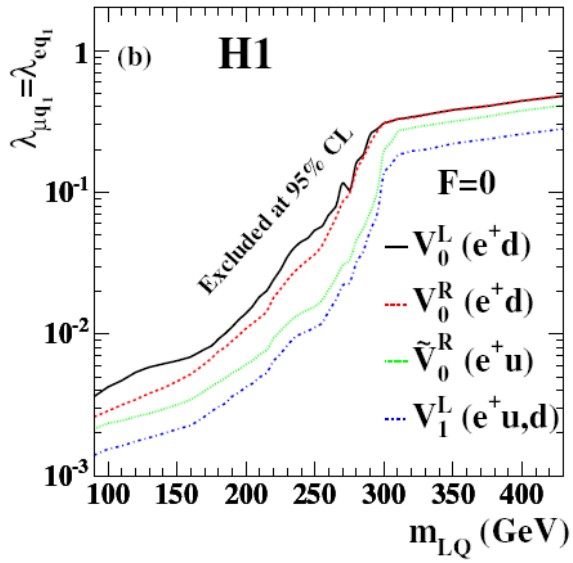
Limits with free β_{LFV}

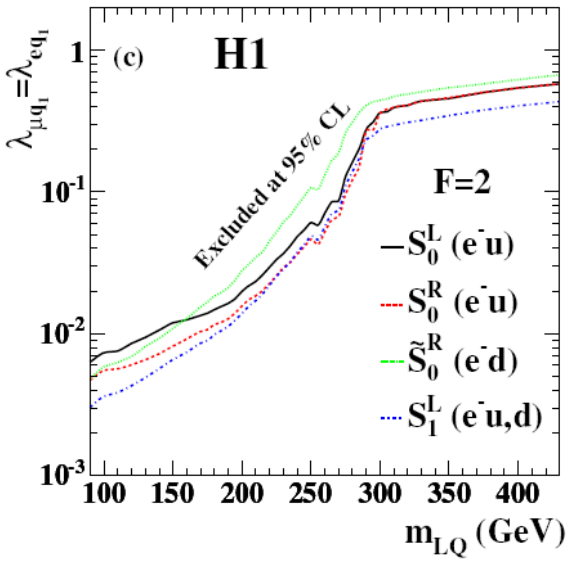


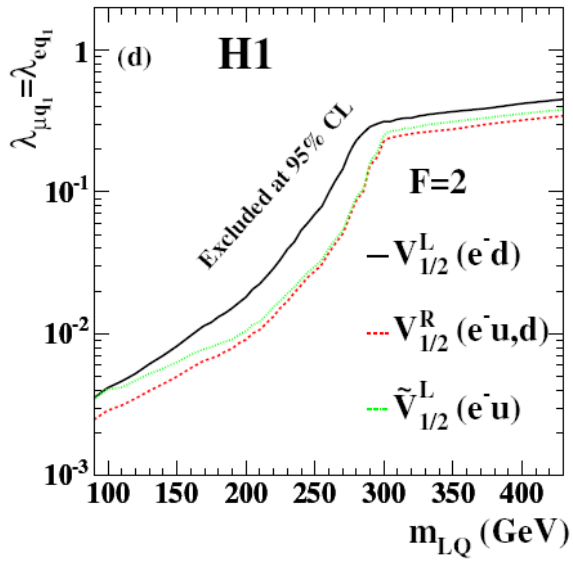
- First limits with free $\beta_{LFV} = \lambda_{\ell q}/(\lambda_{\ell q} + \lambda_{eq})$, $\ell = \mu, \tau$ i.e. independent λ_{eq}, $\lambda_{\ell q}$
- For $\beta_{LFV} \gg 0.5$ the analysis extends the published limits on λ_{eq} to lower values

Upper limits on $\lambda\mu q$





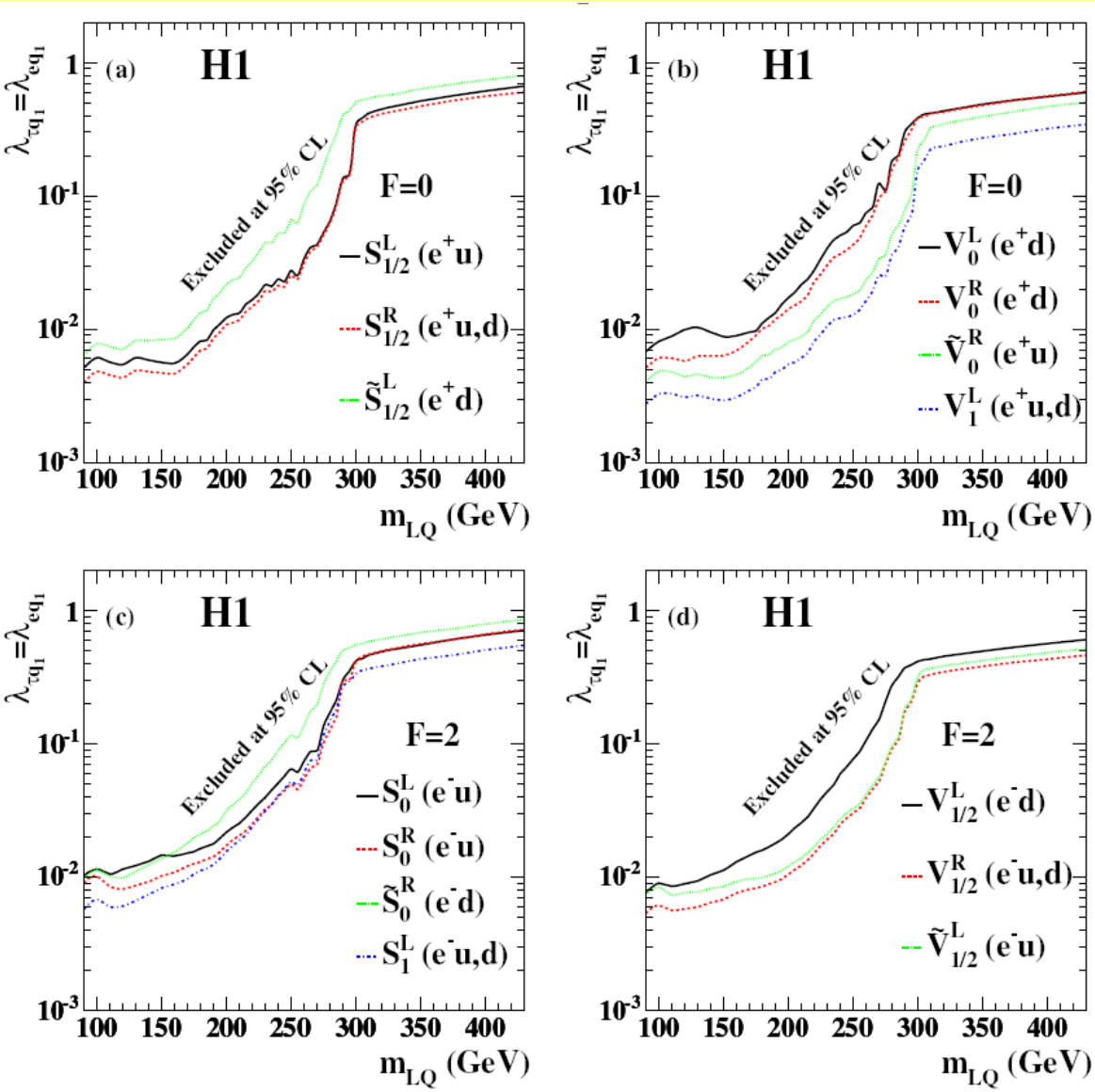




New limits

- extend to larger LQ mass
- For coupling of em strength, lower limit on M_{LQ} at 459 GeV

Upper limits on $\lambda\tau q$



New limits

- extend to larger LQ mass
- For coupling of em strength, lower limit on M_{LQ} at 379 GeV

Summary

- **Search for LQ coupling to first generation fermions using polarised e^-p HERA II data**
  - Increased sensitivity to F=2 LQs due to increased sample
  - No signal observed, limits on LQs set
  - For coupling of em strength lower limits on M_{LQ} 276-304 GeV

- **Search for LVF using full HERA I data**
  - No LFV process induced by LQ with F = 0, 2 found
  - For coupling of em strength LQs with $M_{LQ} < 459$ GeV (e->μ), $M_{LQ} < 379$ GeV (e->τ) ruled out

- **HERA II data to be fully exploited**
  - High luminosity
  - Polarised lepton beam

Backup slides

Leptoquarks

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
S_0^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	λ_L	1/2
				$\nu_\ell d$	$-\lambda_L$	1/2
S_0^R	0	2	$-1/3$	$e_R^- u_R \to \ell^- u$	λ_R	1
$\tilde{S}_0^R$	0	2	$-4/3$	$e_R^- d_R \to \ell^- d$	λ_R	1
S_1^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	$-\lambda_L$	1/2
				$\nu_\ell d$	$-\lambda_L$	1/2
			$-4/3$	$e_L^- d_L \to \ell^- d$	$-\sqrt{2}\lambda_L$	1
$V_{1/2}^L$	1	2	$-4/3$	$e_L^- d_R \to \ell^- d$	λ_L	1
$V_{1/2}^R$	1	2	$-1/3$	$e_R^- u_L \to \ell^- u$	λ_R	1
			$-4/3$	$e_R^- d_L \to \ell^- d$	λ_R	1
$\tilde{V}_{1/2}^L$	1	2	$-1/3$	$e_L^- u_R \to \ell^- u$	λ_L	1
V_0^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	λ_L	1/2
				$\bar{\nu}_\ell u$	λ_L	1/2
V_0^R	1	0	$+2/3$	$e_L^+ d_R \to \ell^+ d$	λ_R	1
$\tilde{V}_0^R$	1	0	$+5/3$	$e_L^+ u_R \to \ell^+ u$	λ_R	1
V_1^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	$-\lambda_L$	1/2
				$\bar{\nu}_\ell u$	λ_L	1/2
			$+5/3$	$e_R^+ u_L \to \ell^+ u$	$\sqrt{2}\lambda_L$	1
$S_{1/2}^L$	0	0	$+5/3$	$e_R^+ u_R \to \ell^+ u$	λ_L	1
$S_{1/2}^R$	0	0	$+2/3$	$e_L^+ d_L \to \ell^+ d$	$-\lambda_R$	1
			$+5/3$	$e_L^+ u_L \to \ell^+ u$	λ_R	1
$\tilde{S}_{1/2}^L$	0	0	$+2/3$	$e_R^+ d_R \to \ell^+ d$	λ_L	1

- The 14 leptoquark (LQ) types of the Buchm¨uller-R¨uckl-Wyler classication in the Aachen notation.
- The LQ subscripts refer to the weak isospin and the superscripts refer to the lepton chirality.
- Columns 2-4 display the spin J, fermion number F and electrical charge Q.
- The dominant resonant production process in ep scattering and the corresponding coupling is shown in columns 5 and 6 respectively.
- Leptoquarks which couple to a left-handed lepton doublet and can decay into a neutrino-quark pair, have a charged lepton decay branching ratio $\beta_l = \Gamma_{lq} / (\Gamma_{lq} - \Gamma_{\nu q})$.

Double differential cross section for the s-channel LQ process

$$\frac{d^2\sigma_s}{dxdy} = \underbrace{\frac{1}{32\pi\hat{s}}}_{\text{phase space}} \cdot \underbrace{\frac{\lambda_{eq}^2\lambda_{\ell q}^2\hat{s}^2}{(\hat{s}^2 - m_{\mathrm{LQ}}^2)^2 + m_{\mathrm{LQ}}^2\Gamma_{\mathrm{LQ}}^2}}_{\text{Breit-Wigner LQ propagator term}} \cdot \underbrace{q_i(x,\hat{s})}_{\text{parton density}} \times \begin{cases} \frac{1}{2} & \text{scalar LQ} \\ 2(1-y)^2 & \text{vector LQ} \end{cases}$$

Branching ratio for LQ -> μ(τ)q:

$$\mathrm{BR} = \beta_\ell \times \beta_{LFV} \text{ with } \beta_{LFV} = \frac{\Gamma_{\mu(\tau)q}}{\Gamma_{\mu(\tau)q} + \Gamma_e} \text{ and } \Gamma_{\ell q} = m_{\mathrm{LQ}}\lambda_{\ell q}^2 \times \begin{cases} \frac{1}{16\pi} & \text{scalar LQ} \\ \frac{1}{24\pi} & \text{vector LQ} \end{cases}$$

$\beta_\ell = \Gamma_{\ell q}/(\Gamma_{\ell q} + \Gamma_{\nu_\ell q})$ Fraction of decays into charged leptons

Angular distribution of LQ decays

- Angular distribution

$$y = 0.5(1 - cos\theta^{\star})$$

$\theta^{\star}$ - e scattering angle in $eq\ (\nu q)$ rest frame

Scalar Leptoquarks

$$\left.\frac{d\sigma}{dy}\right|_{scalar} \rightarrow flat$$

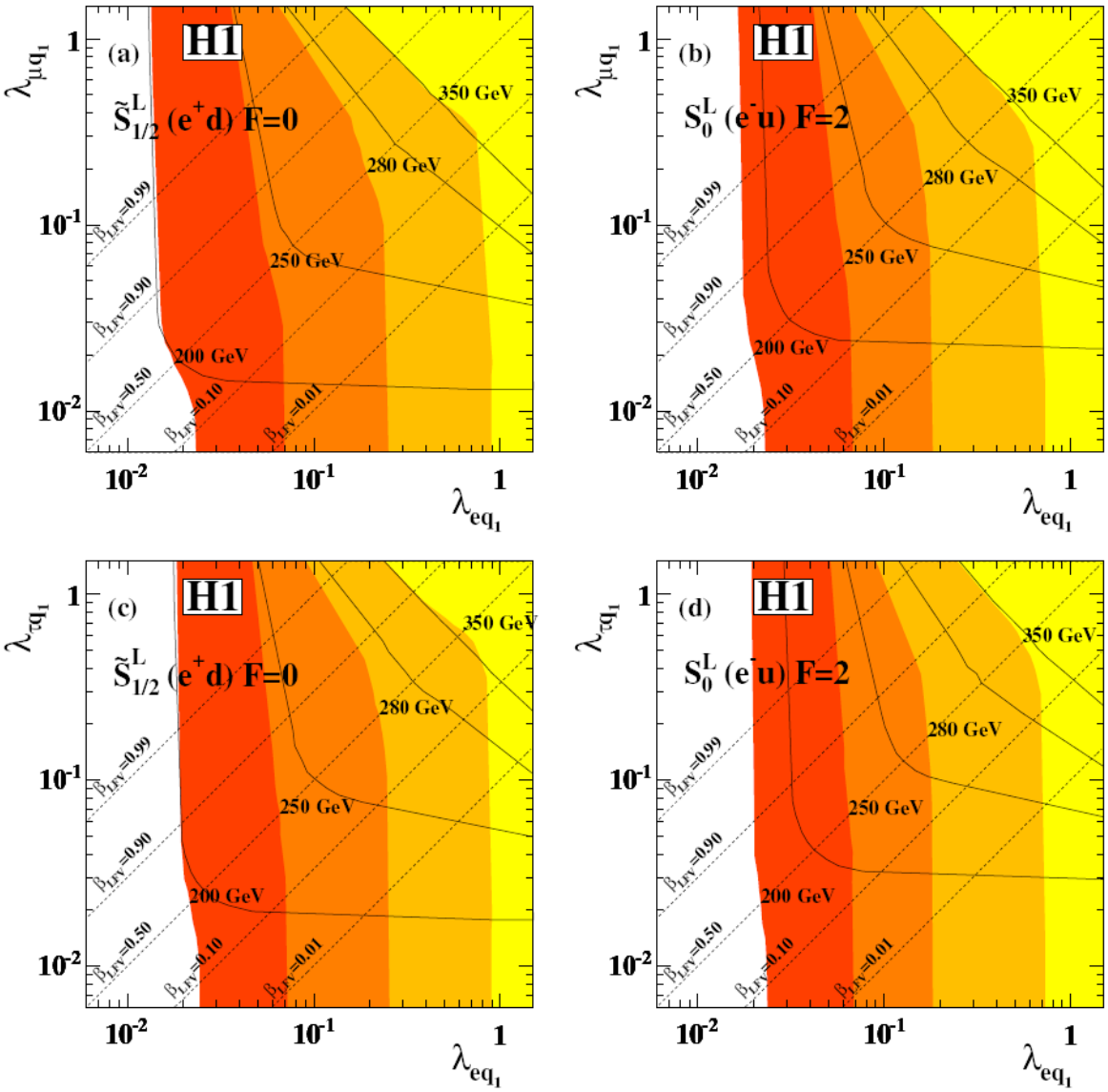
Vector Leptoquarks

$$\left.\frac{d\sigma}{dy}\right|_{vector} \sim (1-y)^2$$

NC DIS (Background)

$$\frac{d\sigma^{e^{\pm}p}}{dy} \sim \frac{1}{y^2}$$

Limits with free β_{LFV}



- For very low values of β_{LFV} ($\lambda_{eq} >> \lambda_{\mu\tau q}, \lambda_{\mu\tau q}$) reproduce published results
- For $\beta_{LFV} >> 0.5$ the analysis extends the published limits on λ_{eq} to lower values