The Search for New Physics at HERA
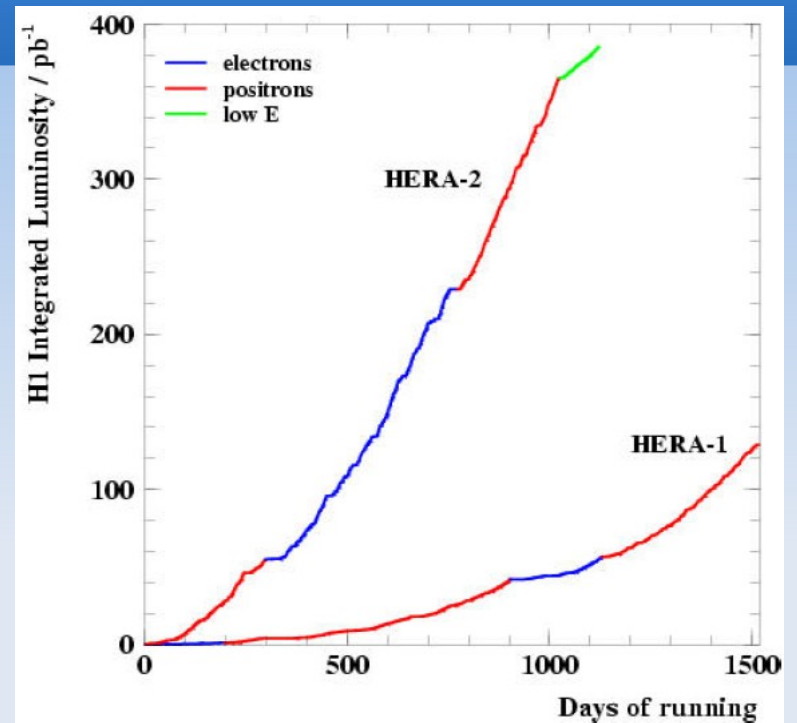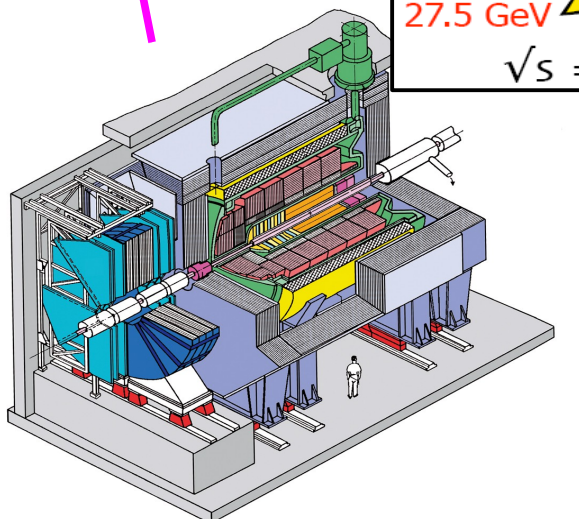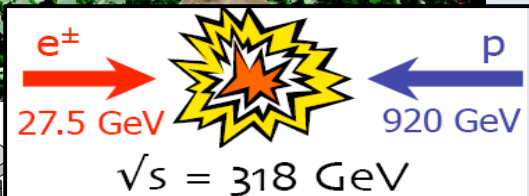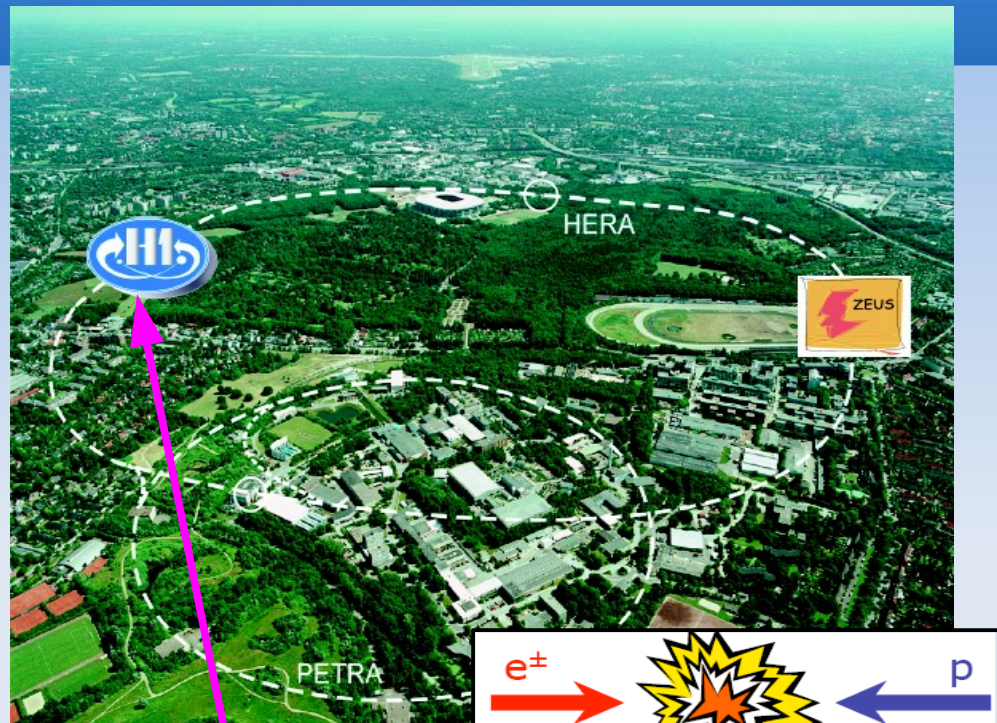
Hayk Pirumov (PI Heidelberg)
On behalf of the H1 Collaboration

➔ Introduction
➔ Search for Contact Interactions in ep Collisions at HERA *(CI)*
➔ Search for First Generation Leptoquarks in ep Collisions at HERA *(LQ)*
➔ Search for Lepton Flavor Violation at HERA *(LFV)*
➔ Search for R-parity Violating Supersymmetry in ep Collisions at HERA *(RPV SUSY)*
➔ Summary

EPS 2011, Grenoble, 20-27 July 2011

HERA Collider and H1 Experiment

$e^{\pm} \rightarrow \quad \leftarrow p$

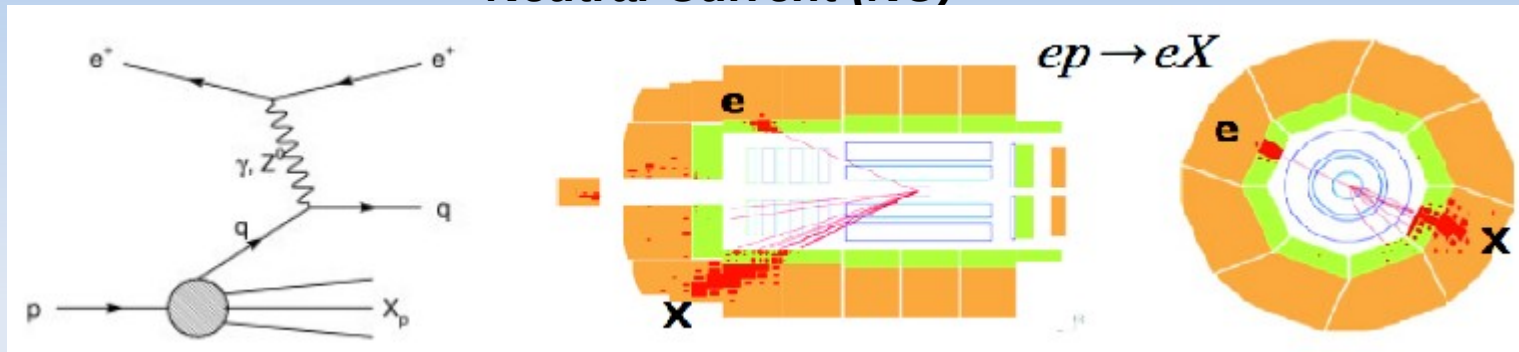27.5 GeV $\qquad$ 920 GeV

$\sqrt{s} = 318$ GeV

- World's only electron proton collider, at DESY, Hamburg.

- 1992 – 2000: HERA I period.

- 2003 – 2007: HERA II period (luminosity upgrade, longitudinally polarised lepton).

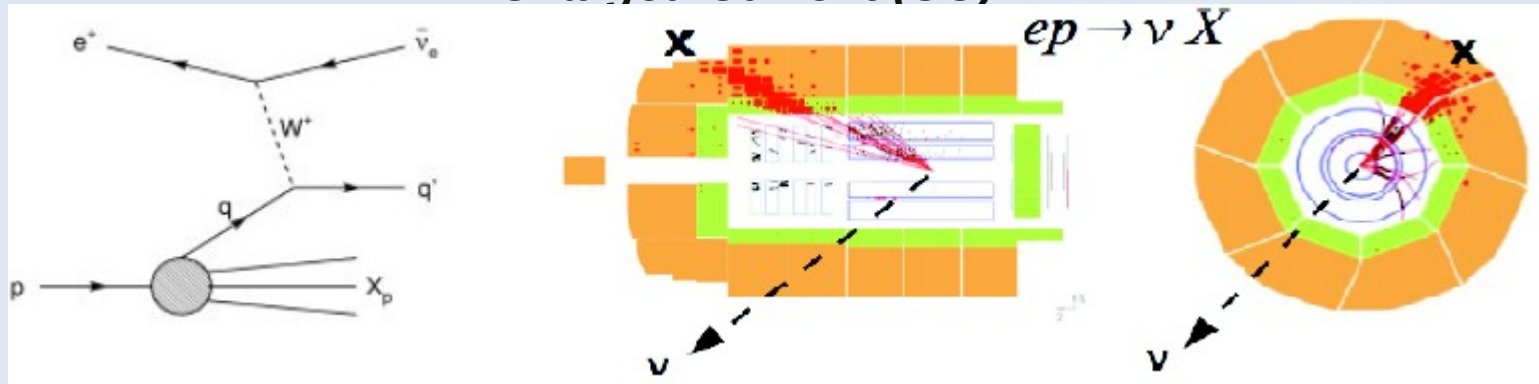- H1 detector operated 1992-2007, collected about *0.5 fb⁻¹* of data.

Deep Inelastic ep Scattering

- Main Standard Model processes in *ep* collisions:
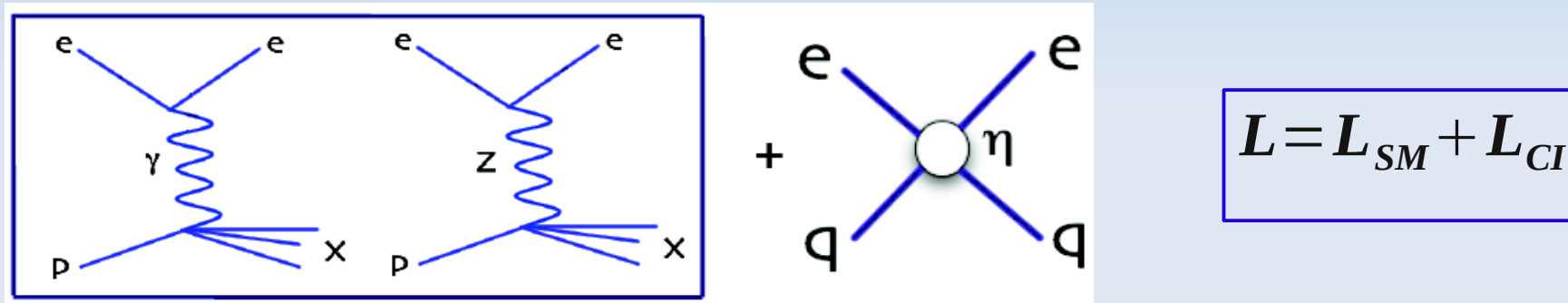
Neutral Current (NC)

Charged Current (CC)

- NC and CC data are investigated for deviations from Standard Model predictions

Contact Interactions

- Possible new interactions between *e* and *q* could modify the DIS cross section at high Q² via virtual effects.

- ***Four-fermion eeqq contact interactions (CI)*** → convenient method to investigate the interference of new fields.

$$L = L_{SM} + L_{CI}$$

- Effective Lagrangian for neutral current vector-like contact interactions:

$$L_{CI} = \sum_{i,j=L,R} \eta_{ij}^{eq} (\overline{e}_i \gamma_\mu e_i)(\overline{q}_j \gamma^\mu q_j)$$

4 possible couplings for each q flavor

- Various models can be constructed by appropriate choice of the coupling *η*

Search for Contact Interactions at HERA

Full H1 neutral current data are used to set constraints at 95% CL on various CI models.
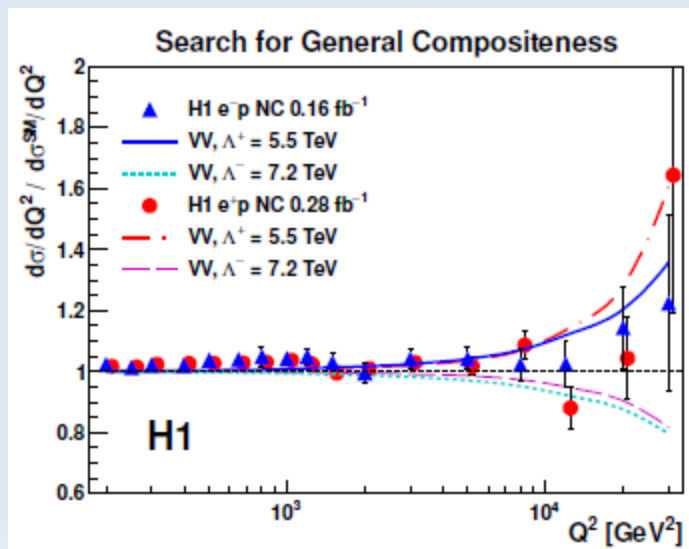
General Compositeness

- Contact interactions coupling are related to the mass scale via:

$$\eta_{ab}^{eq} = \frac{\pm 4\pi}{\Lambda^2}$$

- Different models assume different helicity structure of new interactions, given by a set of η couplings

- Limit on effective mass scale:
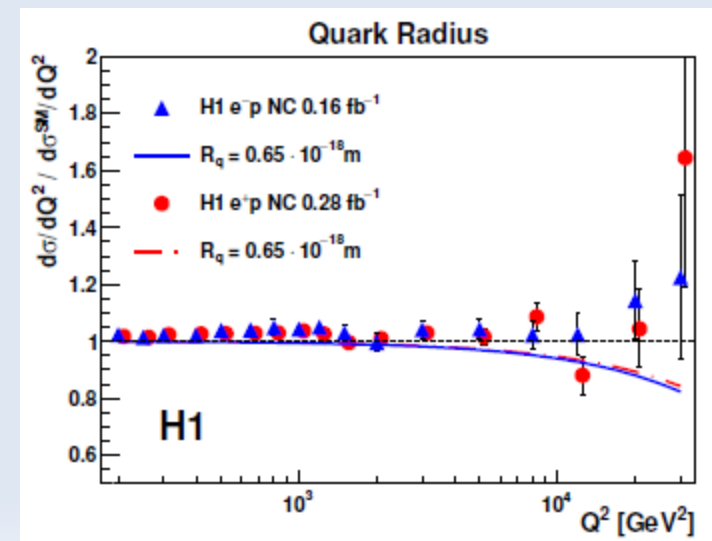
$$\Lambda > 3.2 - 7.2 \, TeV$$

Quark Radius

- Finite size of the quark can be defined by introducing spatial distribution of the electroweak charge:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma_{SM}}{dQ^2} \cdot \left(1 - \frac{R^2}{6} \cdot Q^2\right)^2$$

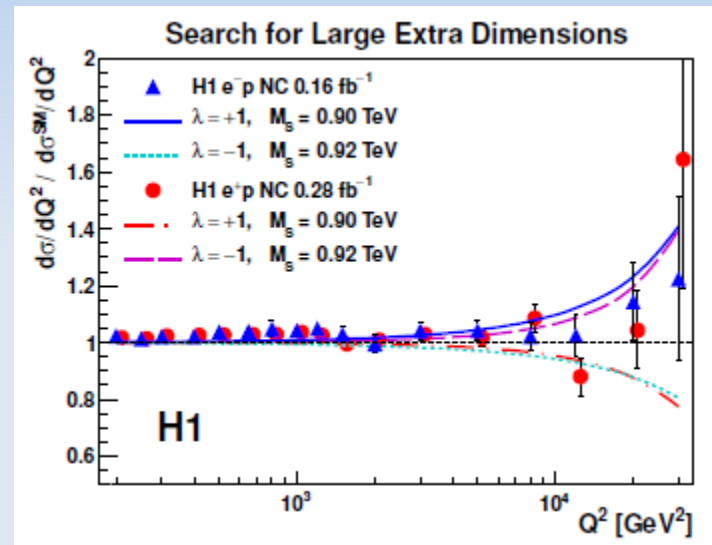- Upper limit on quark radius:

$$R < 0.65 \cdot 10^{-18} \, m$$

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Large Extra Dimensions

- Arkani-Hamed-Dimopoulos-Dvali (ADD) model assumes that space-time has 4+n dimensions.

- Gravity can propagate into the extra dimensions

- Contribution of graviton exchange to neutral current DIS cross section can be described by an effective contact interaction type coupling:

$$\eta_G \sim \lambda / M_S^4$$

- Limit on gravitational scale

$$M_S > 0.90 - 0.91 \, TeV$$

Leptoquarks at HERA

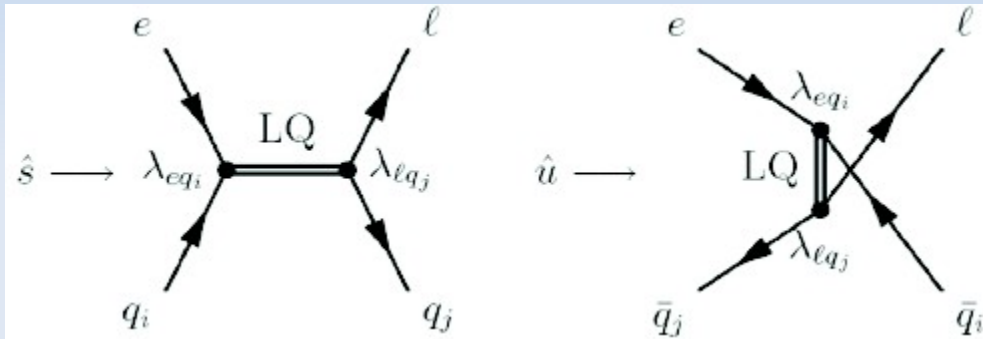- Leptoquarks **(LQ),** compound states of leptons and quarks

  Fermion number **F = L+3B**   **F = 2 (e^-p)**   **F = 0 (e^+p)**

- **Buchmüller-Rückl-Wyler** framework: 14 different types (7 scalar, 7 vector)

- LQ at HERA:

1st gen: eq $\rightarrow$ LQ $\rightarrow$ e(ν)q   **(LFC)**

2nd gen: eq $\rightarrow$ LQ $\rightarrow$ μ(ν)q **(LFV)**

3rd gen: eq $\rightarrow$ LQ $\rightarrow$ τ(ν)q **(LFV)**

s-channel:	u-channel:
(resonant production)	(LQ exchange)

- Leptoquarks are chiral particles $\rightarrow$ additional
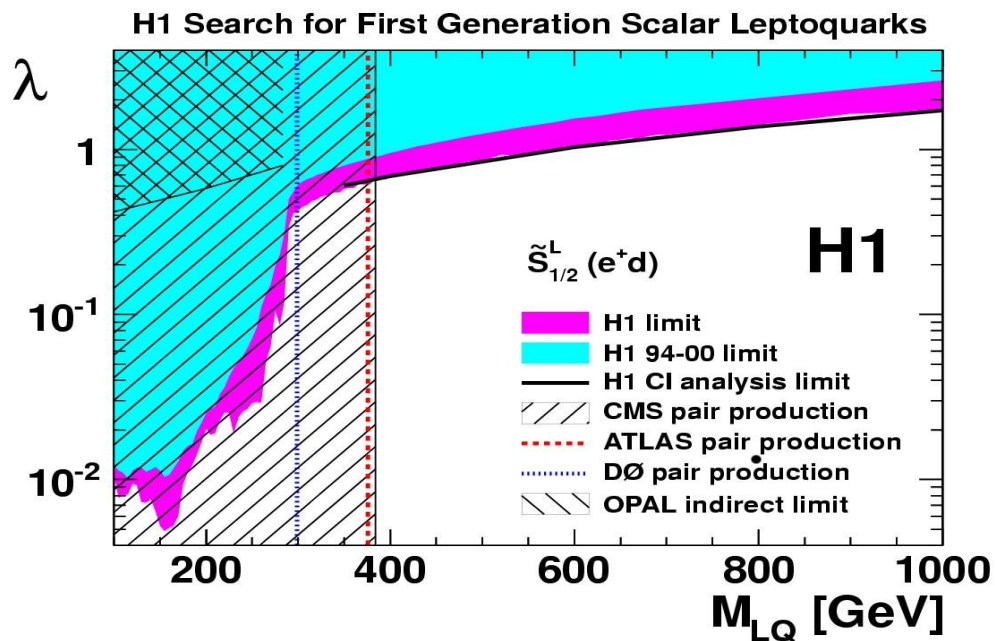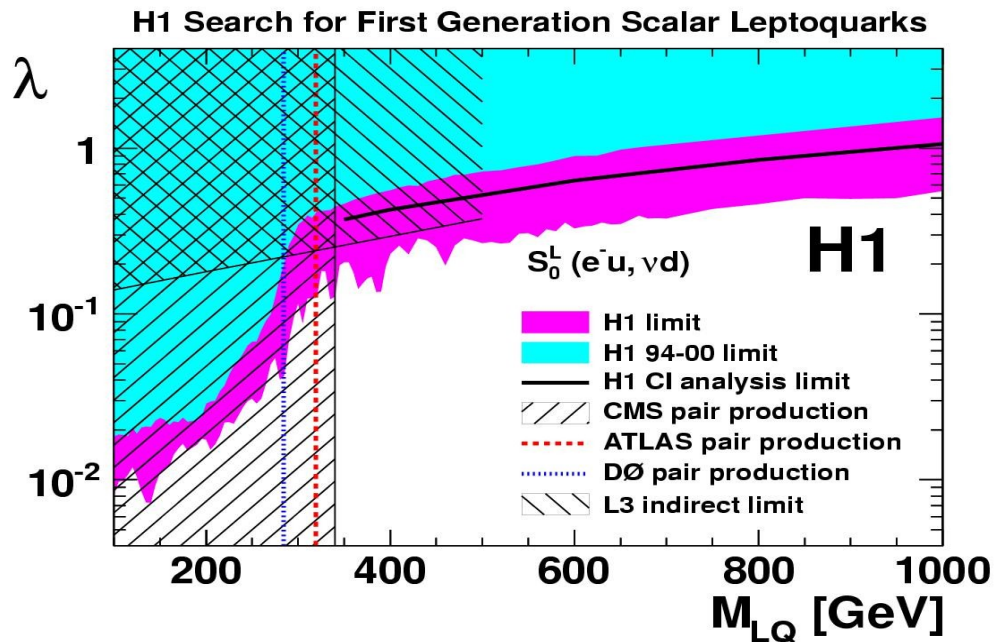 sensitivity at HERA due to polarised lepton beam

H1 Search for First Generation Leptoquarks
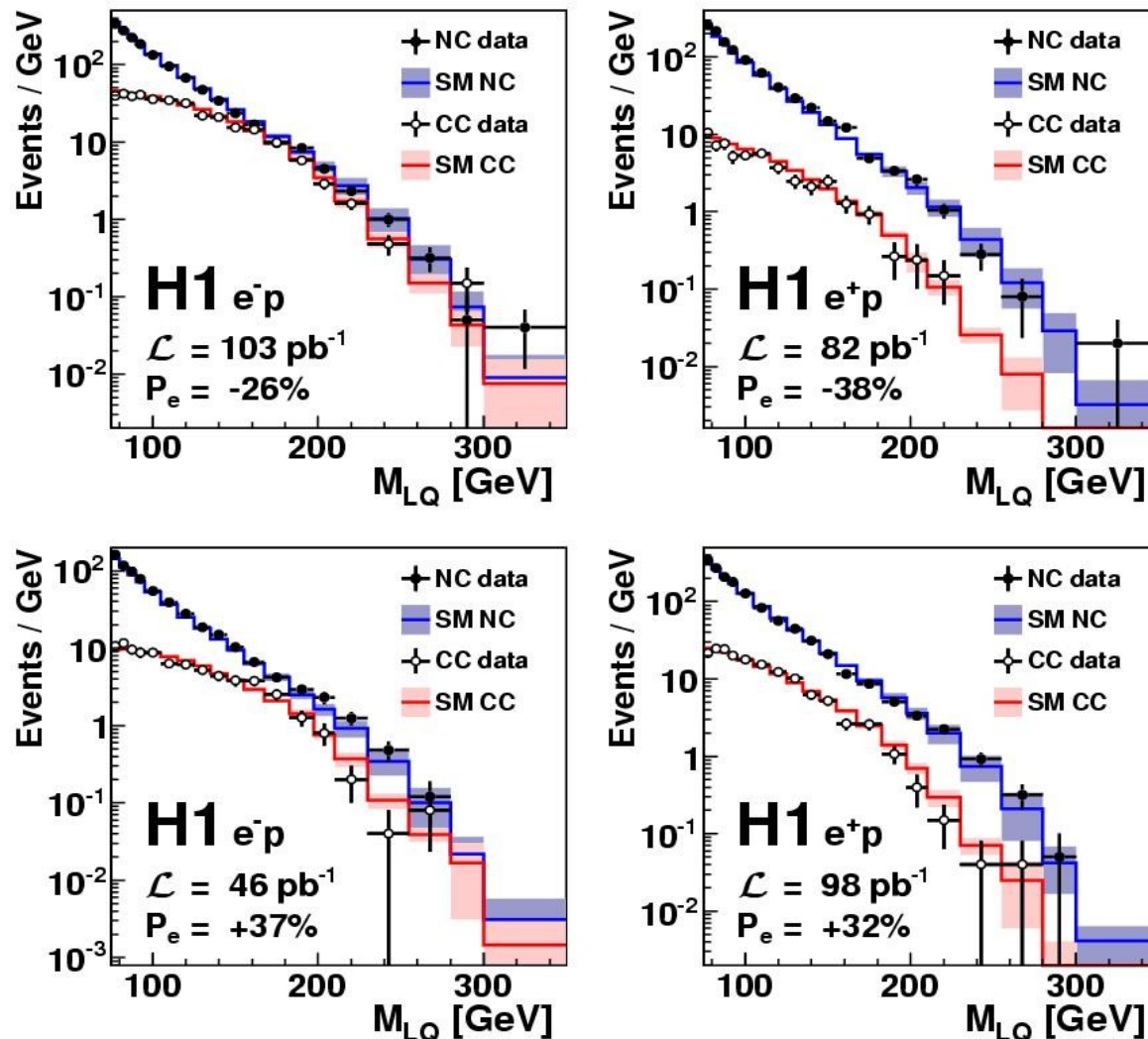
- Mass plots of first Generation LQs.

- The two upper plots correspond to the data with left-handed polarisation of the lepton beam.

- The two lower plots correspond to the data with right-handed polarisation of the lepton beam.

- No evidence for LQ signal found → results are interpreted in terms of exclusion limits.

Search for First Generation LQs

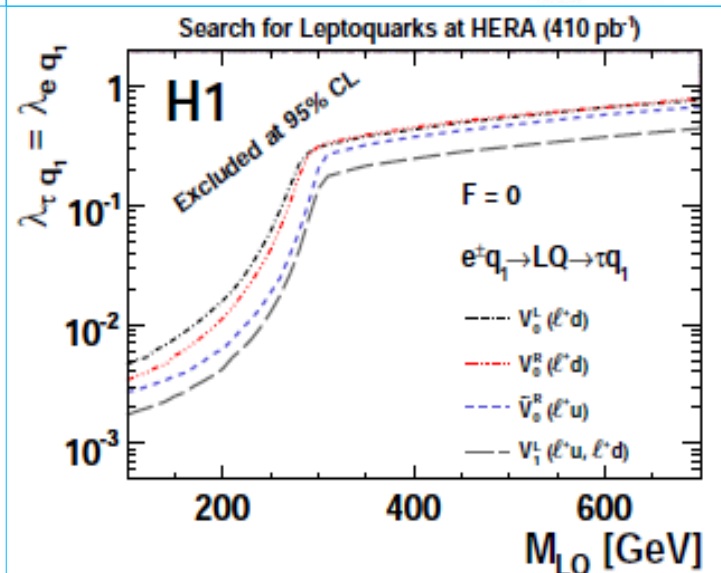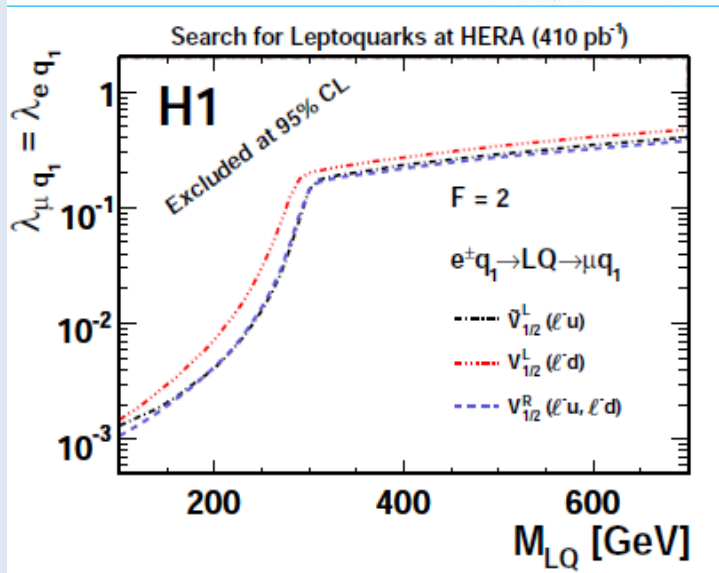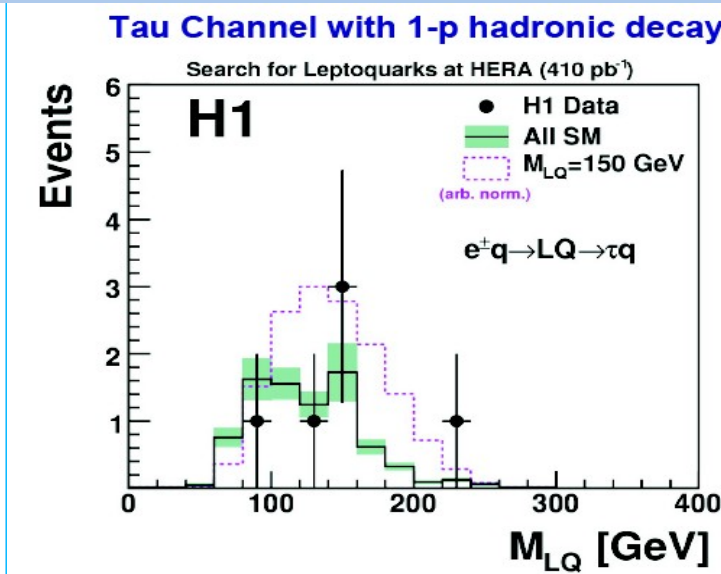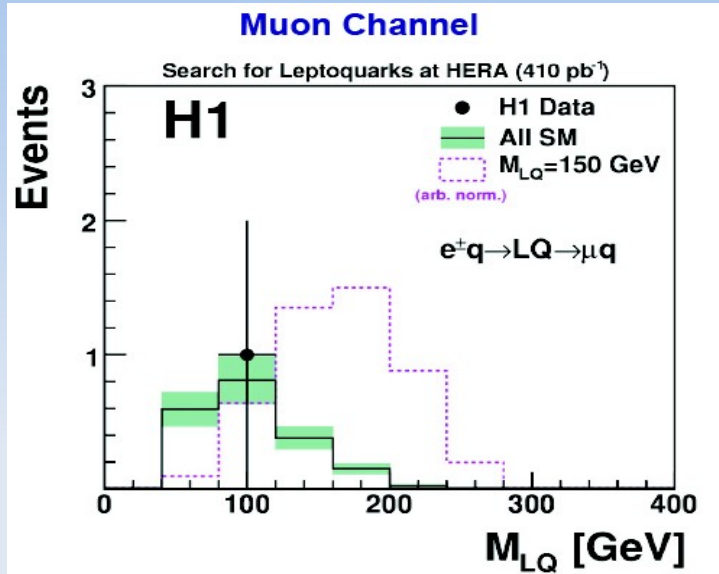H1 Search for First Generation Scalar Leptoquarks

$S_0^L (e^- u, \nu d)$

H1

- H1 limit
- H1 94-00 limit
- H1 CI analysis limit
- CMS pair production
- ATLAS pair production
- DØ pair production
- L3 indirect limit

H1 Search for First Generation Scalar Leptoquarks

$\tilde{S}_{1/2}^L (e^+ d)$

H1

- H1 limit
- H1 94-00 limit
- H1 CI analysis limit
- CMS pair production
- ATLAS pair production
- DØ pair production
- OPAL indirect limit

- The exclusion ranges for two scalar type leptoquarks.

- The results from H1 CI analysis as well as from other experiments are also indicated in the plots.

- eq → LQ → e(ν)q excluded up to 800 *GeV* for λ = 0.3 *(EM coupling strength)*.

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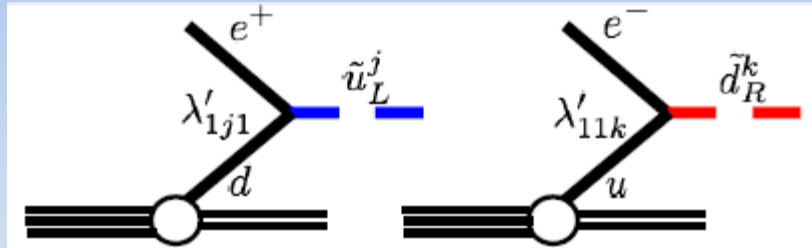- Mass plots of second and third Generation LQs

- No evidence for LQ signal found → results are interpreted in terms of exclusion limits.

- eq → LQ → $\mu(\nu)q$ excluded up to *712 GeV* for $\lambda = 0.3$.

- eq → LQ → $\tau(\nu)q$ excluded up to *479 GeV* for $\lambda = 0.3$.
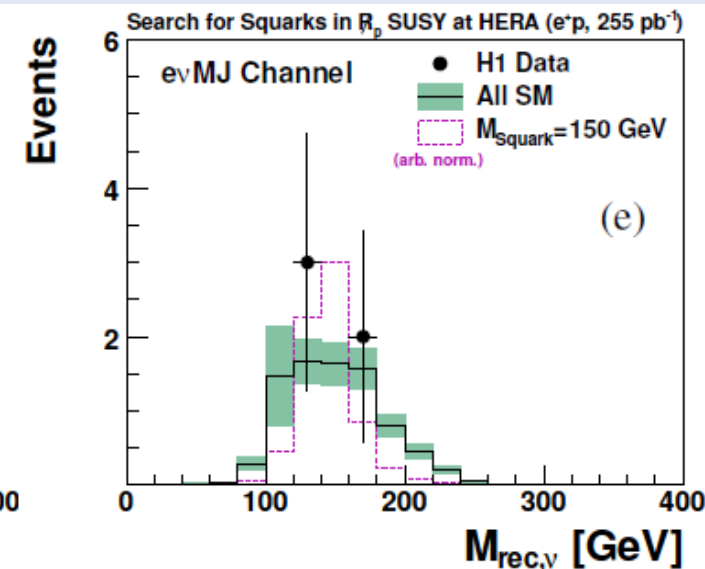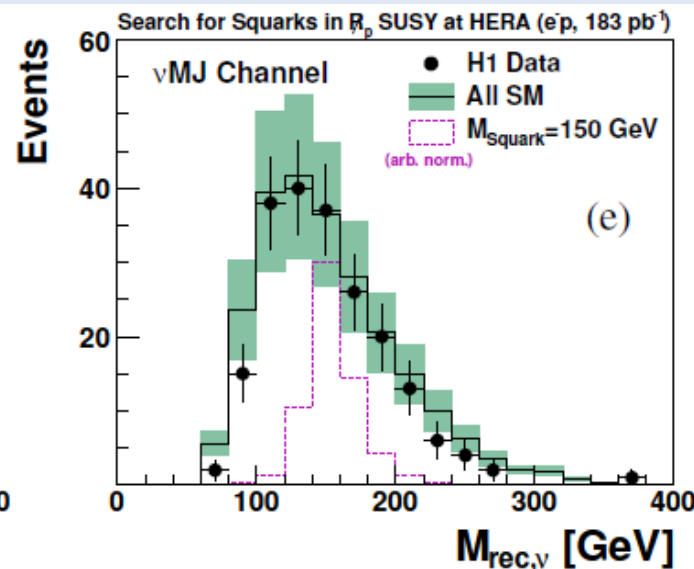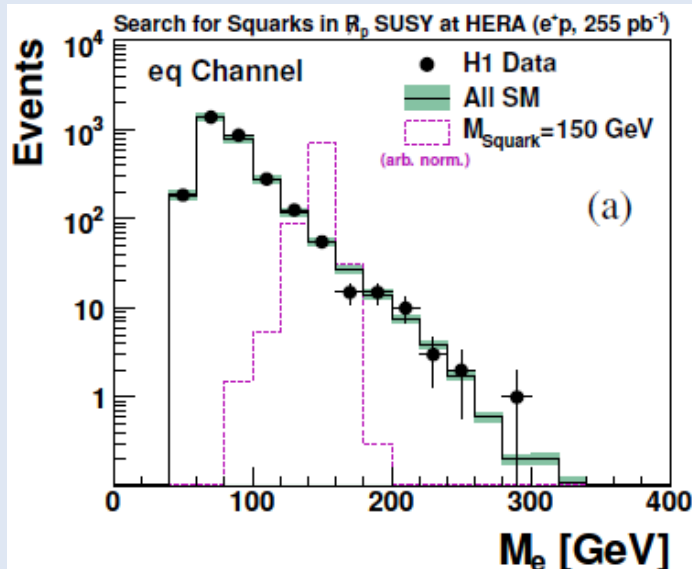
Squarks Production in RPV SUSY at HERA

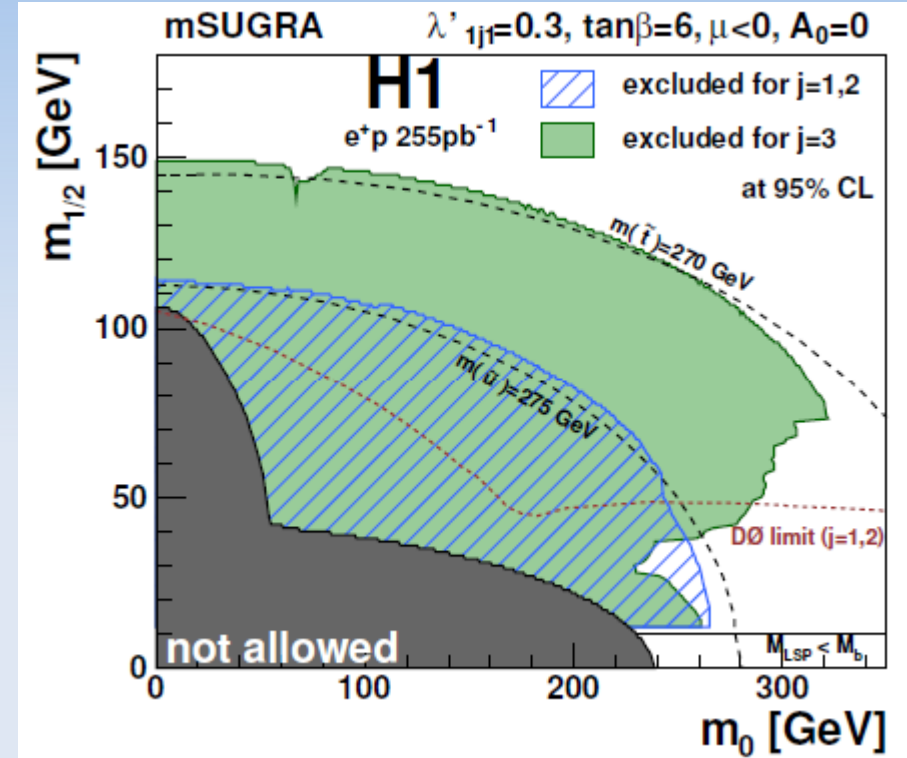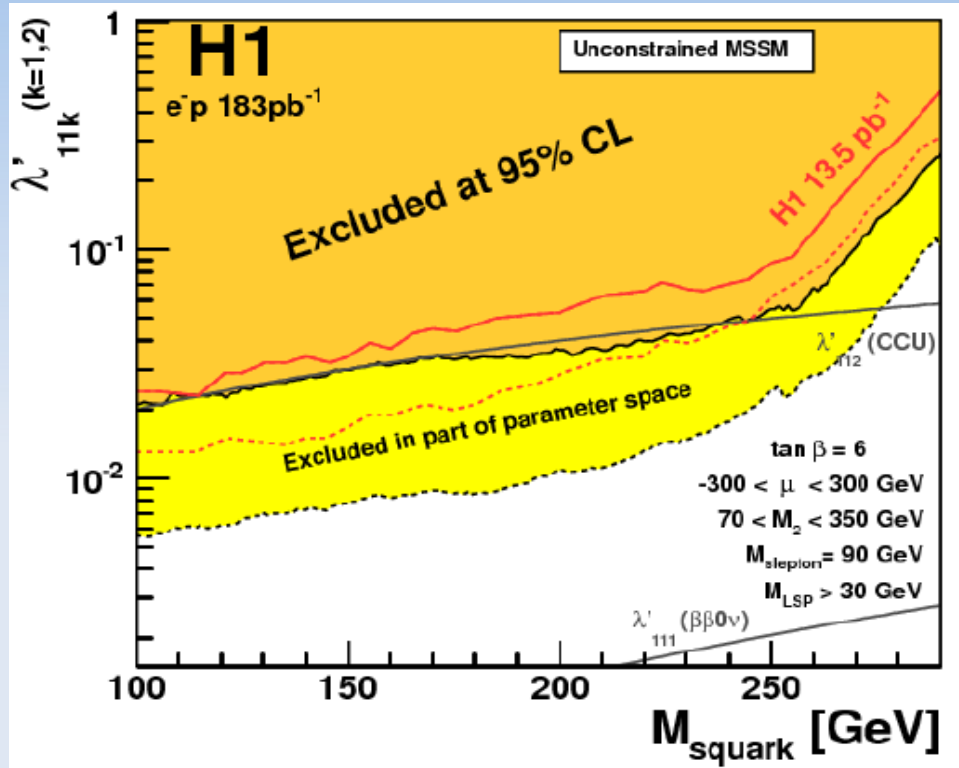Resonant production of squarks in ep-collisions is possible with *R*-Parity violation.

- Possible decay modes:
  - Direct (production and decay via same **RPV** coupling)
  - Cascade (**R$_p$** conserving decay, followed by RPV χ^0/χ^{+-})

Data show a good agreement with the Standard Model predictions!

- All relevant 17 final states were investigated.

Constraints on MSSM and mSUGRA

- Scan of MSSM parameter space
- For Yukava coupling $\lambda'_{1j1} = 0.3$:
  - Up-type squarks excluded up to *275 GeV*
  - Down type squarks excluded up to *290 GeV*

- Assuming mSUGRA with coupling $\lambda'_{1j1} = 0.3$, indicated region is excluded

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Summary

- Search for deviations from the Standard Model in *ep* performed by H1 based on the full HERA data.

- Data show **good agreement** with the Standard Model predictions.

- Exclusion limits at *95% CL* are determined for

  - **Compositeness (*3.2 - 7.2 TeV*)**

  - **Large Extra dimensions (*0.90 - 0.91 TeV*)**

  - **Quark Radius (*$0.65 * 10^{-18}$ m*)**

  - **First Generation LQs (up to *800 GeV*)**

  - **LFV LQs (up to *712 GeV*)**

  - **MSSM, mSUGRA (up to *290 GeV*)**

- HERA provides **competitive** limits compared to the Tevatron and the LHC.

Backup

Search for Contact Interactions at HERA

Heavy Leptoquarks

- For high mass leptoquarks
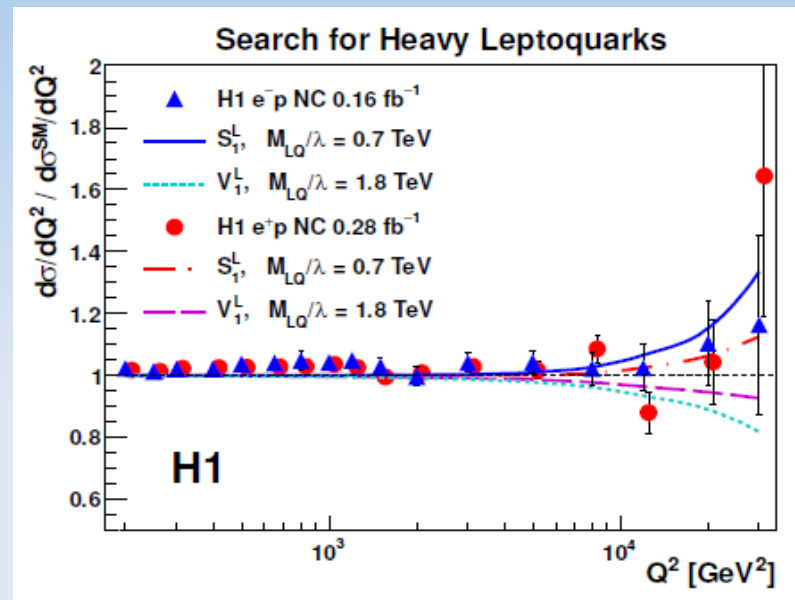
$$M_{LQ} \gg \sqrt{s}$$

virtual leptoquark production (exchange) results in an effective contact interaction type coupling:
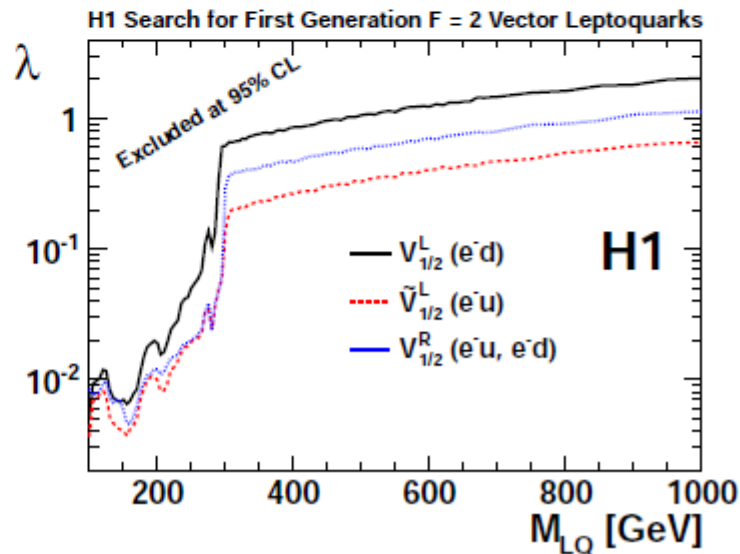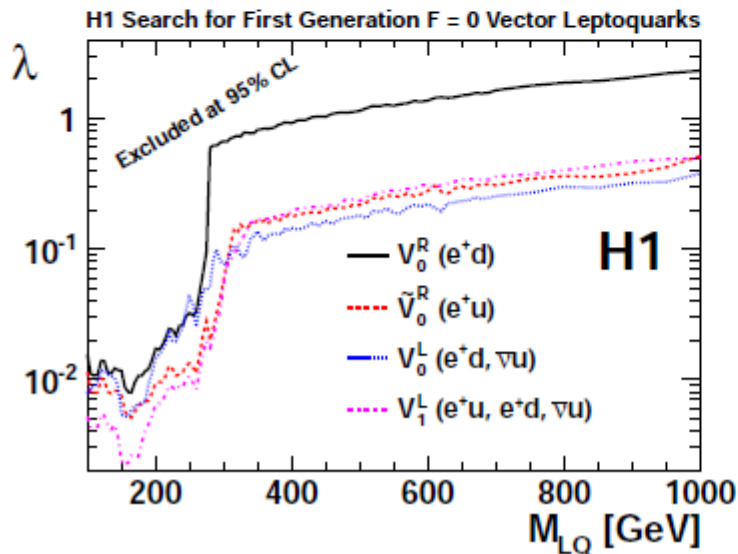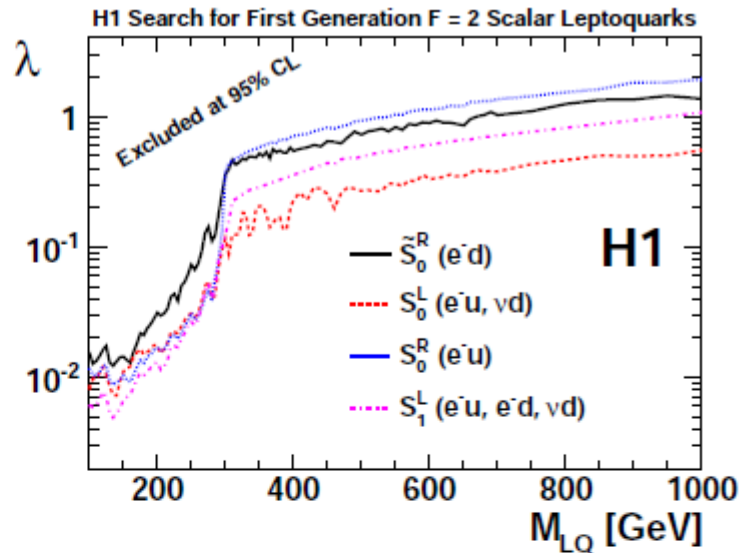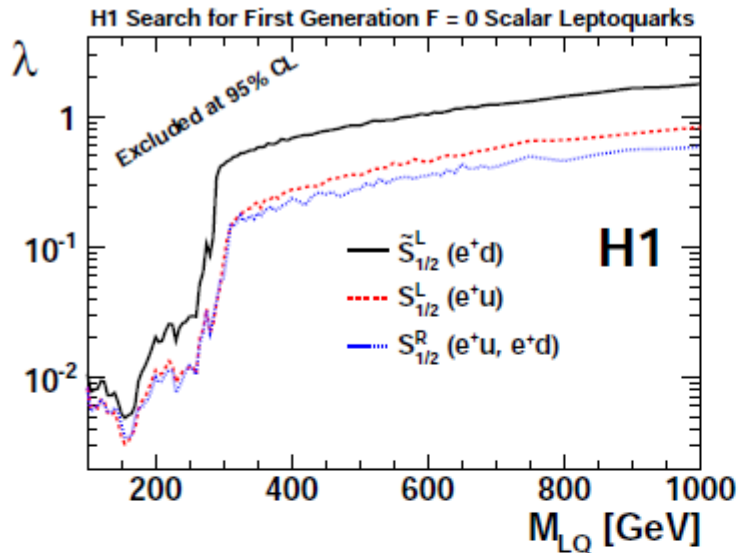
$$\eta_{LQ} \sim \left(\lambda / M_{LQ}\right)^2$$

- Limits on mass to coupling ratio

$$M_{LQ}/\lambda_{LQ} > 0.4 - 1.9 \, TeV$$

Search for First Generation LQs

- Exclusion ranges for 7 scalar and 7 vector type leptoquarks.

- Masses excluded up to between **277 Gev** and **800 GeV** for $\lambda = 0.3$.
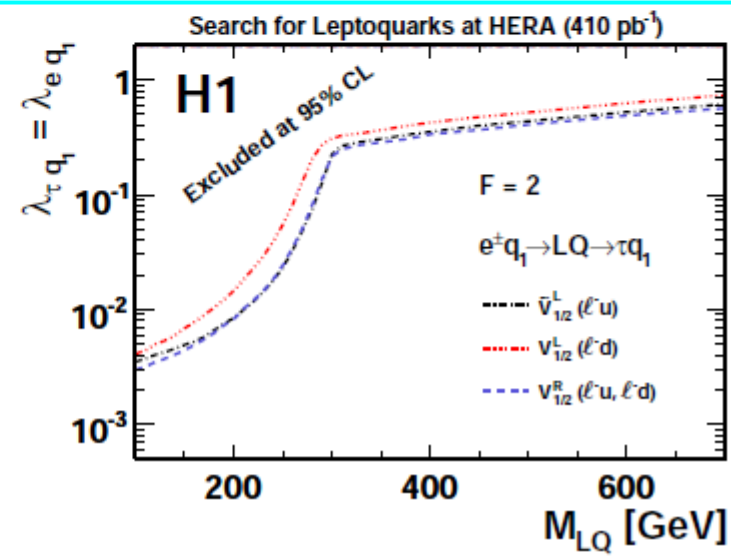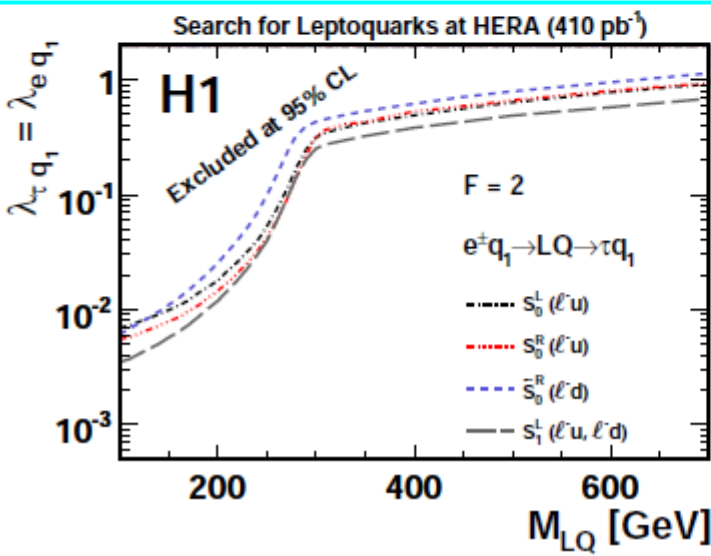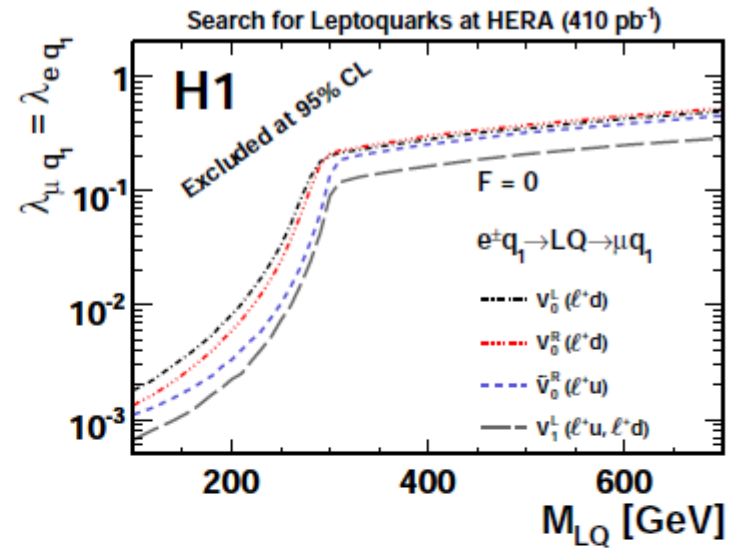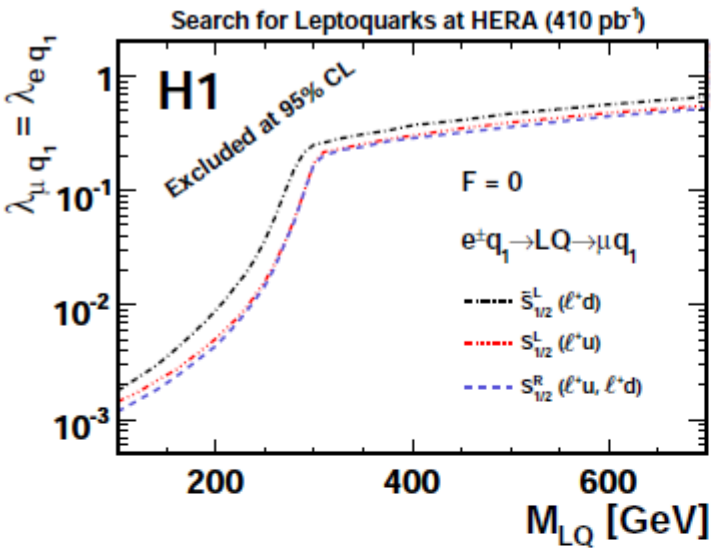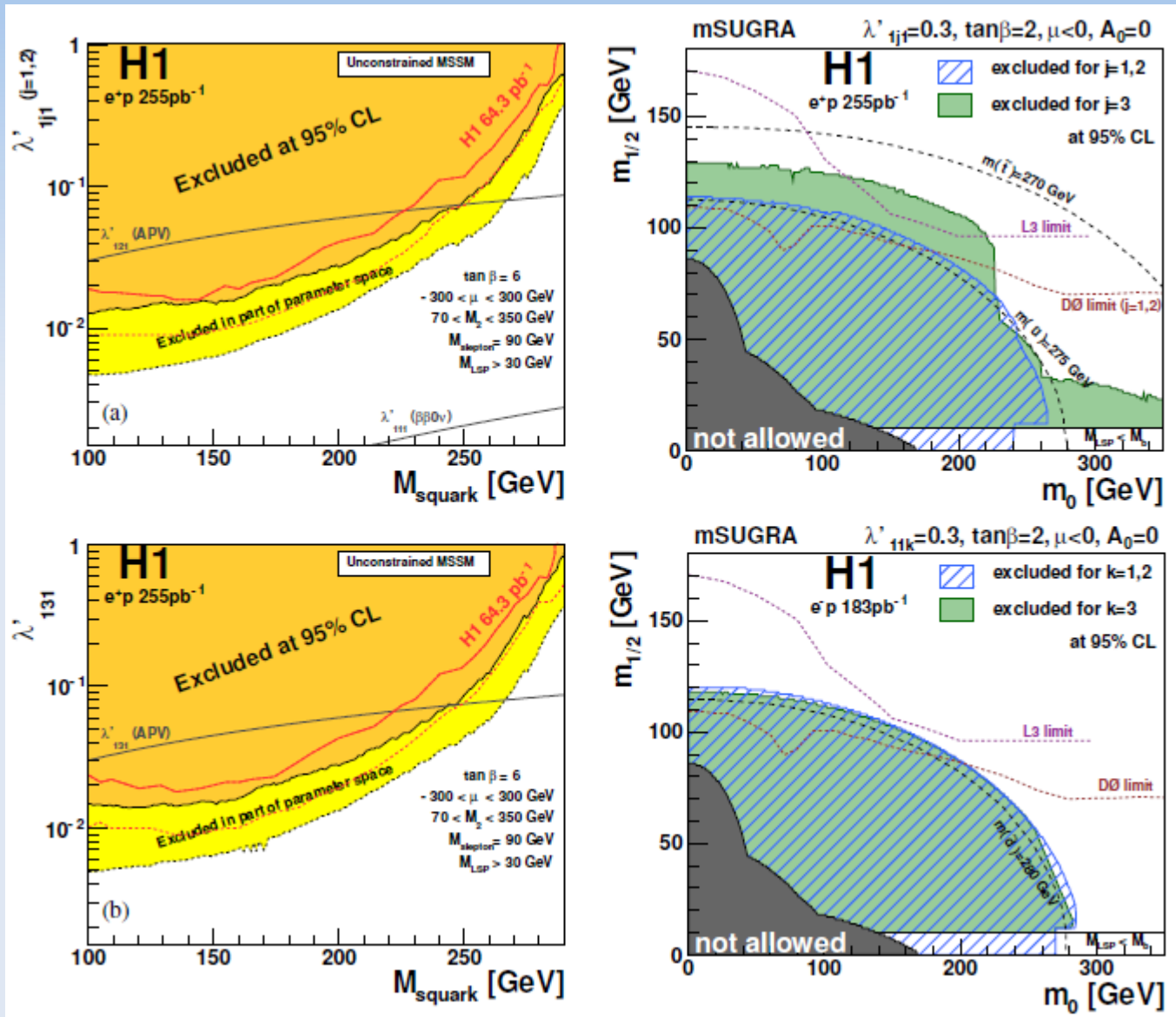
Search for LFV: Second and Third Generation LQs

- Exclusion ranges for 7 scalar and 7 vector type leptoquarks.

- Two upper plots correspond to the second generation:

  $eq \rightarrow LQ \rightarrow \mu(\nu)q$

- Two lower plots correspond to the third generation:

  $eq \rightarrow LQ \rightarrow \tau(\nu)q$
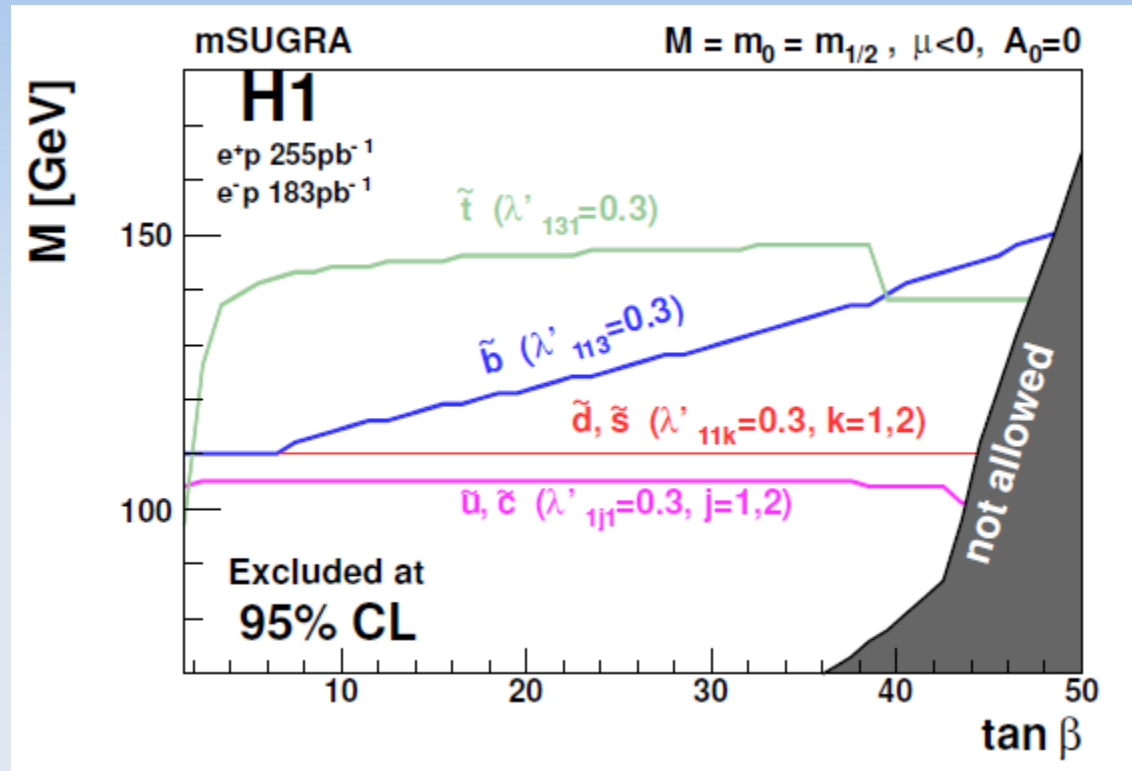
Squarks Production in RPV SUSY at HERA

- *95% CL exclusion limits on λ' as a function of the squark mass from a scan of the MSSM parameter space (left two plots).*

- *95% CL exclusion limits in m_0, $m_{1/2}$ plane assuming λ'_{1j1} = 0.3 in mSUGRA parameter space (right two plots).*

Squarks Production in RPV SUSY at HERA

- *95% CL* exclusion domains as function of *tan β*.

- No dependence from *tan β* for the first and second generations

- Dependence for the third generation due to mixing between states at higher *tan β* .

- The area below the curves is excluded.