The Search for New Physics at HERA

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On behalf of the H1 and ZEUS Collaborations

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BSM – Talk 1112 – 24 July 2010

HERA Collider and Experiments

HERA $\sqrt{s}$ HERA: 318 GeV

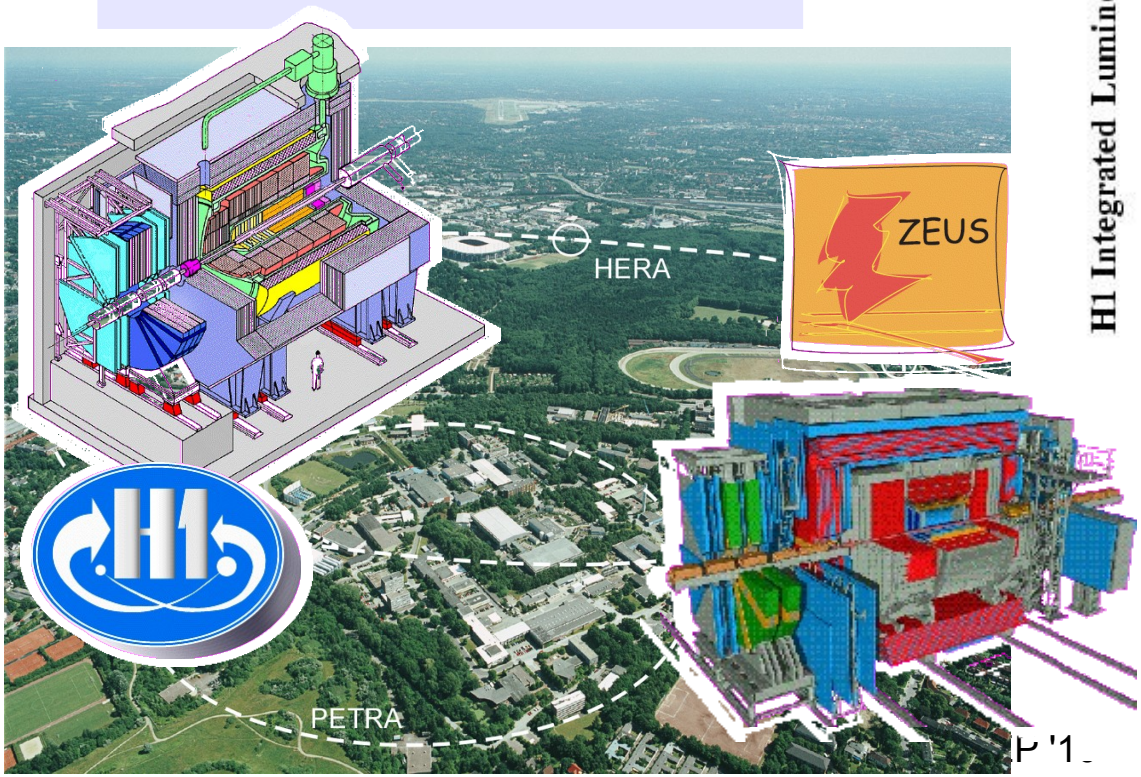
p (920 GeV) e (27.6 GeV)

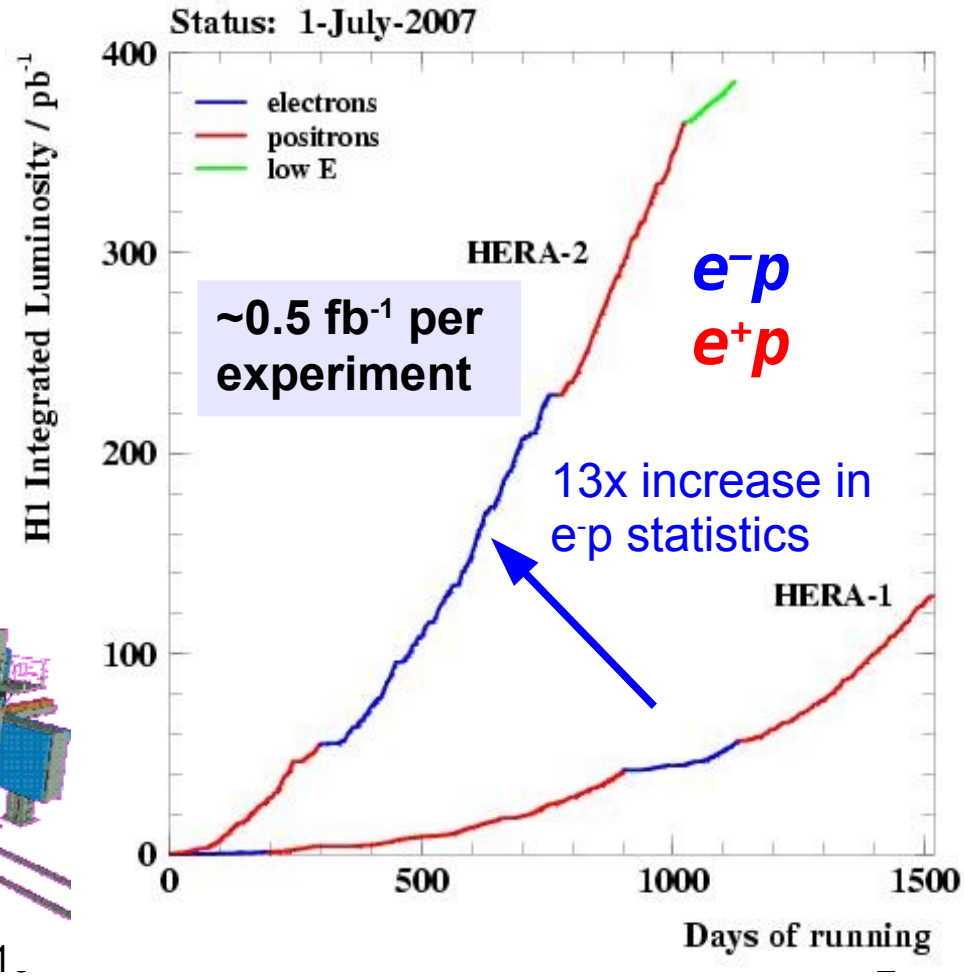
World's only *ep* Collider at DESY,Hamburg
Active 1991-2007
H1 and ZEUS Experiments

Asymmetric Design
4π Coverage
Excellent Lepton ID + HFS Reconstruction

HERA-I (1994-00)
~130 pb^{-1} per exp., (90% e^+p)

HERA-II (2003-07)
Luminosity upgrade
Long. *e* polarisation (avg. 40%)





Searches for New Physics at HERA since ICHEP 2008

A General Search for New Phenomena at HERA
H1 Collaboration, DESY-08-173, Phys.Lett.B674:257-268,2009

Search for contact interactions in ep collisions with the ZEUS experiment at HERA
ZEUS Collaboration, ZEUS-prel-09-013

Search for Excited Quarks in ep Collisions at HERA
H1 Collaboration, DESY-09-040, Phys.Lett.B678:335-343,2009

Search for Single Top Quark Production at HERA
H1 Collaboration, DESY-09-050, Phys.Lett.B678:450-458,2009

Search for Squarks in R-Parity Violating Supersymmetry with the H1 Experiment at HERA
H1 Collaboration, H1prelim-10-063

Search for Lepton Flavour Violation at HERA
H1 Collaboration, H1prelim-10-061

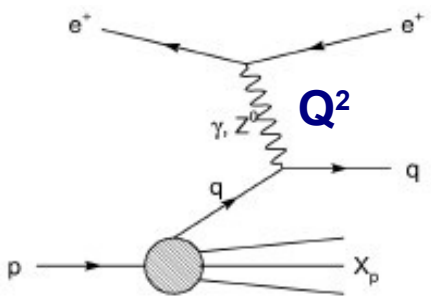
Search for Contact Interactions at HERA
H1 Collaboration, H1prelim-10-062

Searches using …

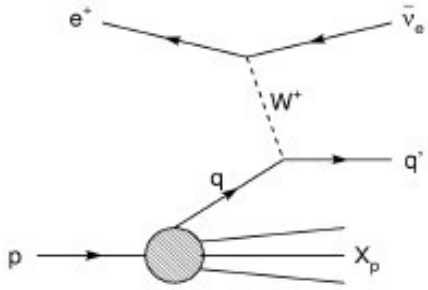
- Inclusive Measurement
- Exclusive Final States

Deep-Inelastic Scattering at high Q^2

- Main Standard Model processes in *ep* collisions



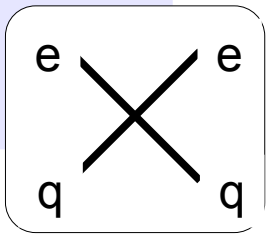
Neutral Current

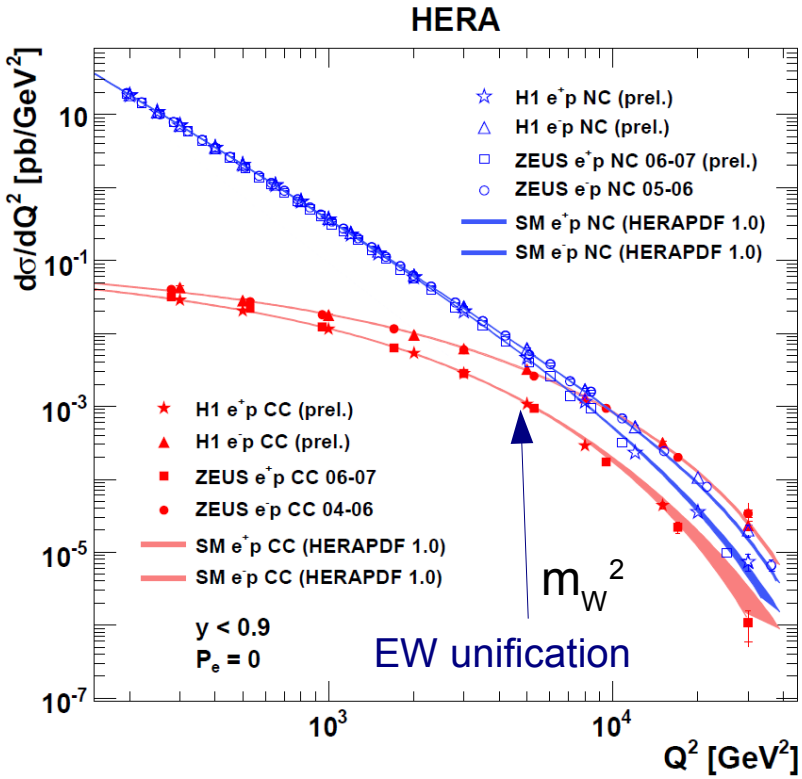


Charged Current

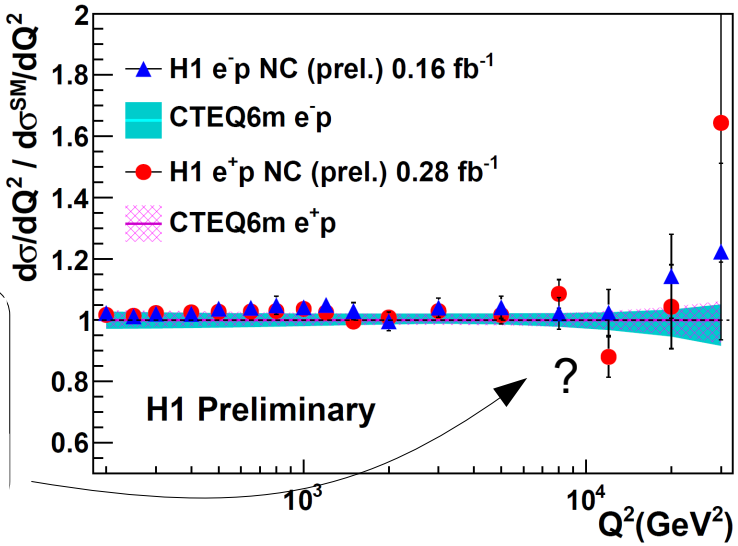
- Sq. Momentum transfer Q^2 up to 40.000 GeV^2
- Spatial resolution ~ $1/Q^2 = 10^{-18}$ m
- Can probe small distances

- Deviation from SM prediction may indicate new physics
  → can appear like effective contact interaction
- Investigated by
  - ZEUS using events + Likelihood method
  - H1 using χ^2 –fit to cross sections





compare H1 to CTEQ6m



Search for Contact Interactions

- Consider vector currents as additional term to SM Lagrangian

$$\mathcal{L}_V = \sum_q \sum_{a,b=L,R} \eta^q_{ab} (\bar{e}_a \gamma_\mu e_a)(\bar{q}_b \gamma^\mu q_b)$$

General Compositeness

- Models defined by coefficients $\epsilon_{ab} = \pm 1, 0$

$$\eta^q_{ab} = \epsilon_{ab} \frac{4\pi}{\Lambda^2}.$$

- Limits on effective mass scale Λ:
  Λ > 3.7 – 8.9 [TeV]

Quark Radius

- Formfactor f_q modifies cross section
- Assuming point-like leptons (f_e=0)

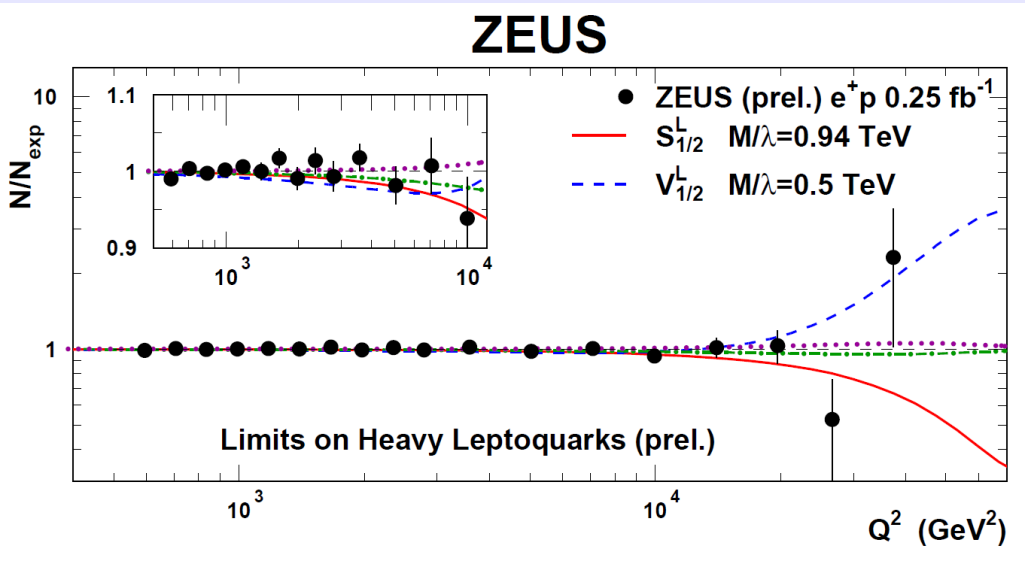
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2}\left(1 - \frac{1}{6} R_q^2 Q^2\right)$$

- R_q<0.63 – 0.65 [10^{-18} m]

Heavy Leptoquarks

- BRW-framework
- M_{LQ}/λ_{LQ}> 0.63 – 1.94 [TeV]

$$\eta^q_{ab} = \epsilon^q_{ab} \frac{\lambda^2}{M^2_{LQ}}$$



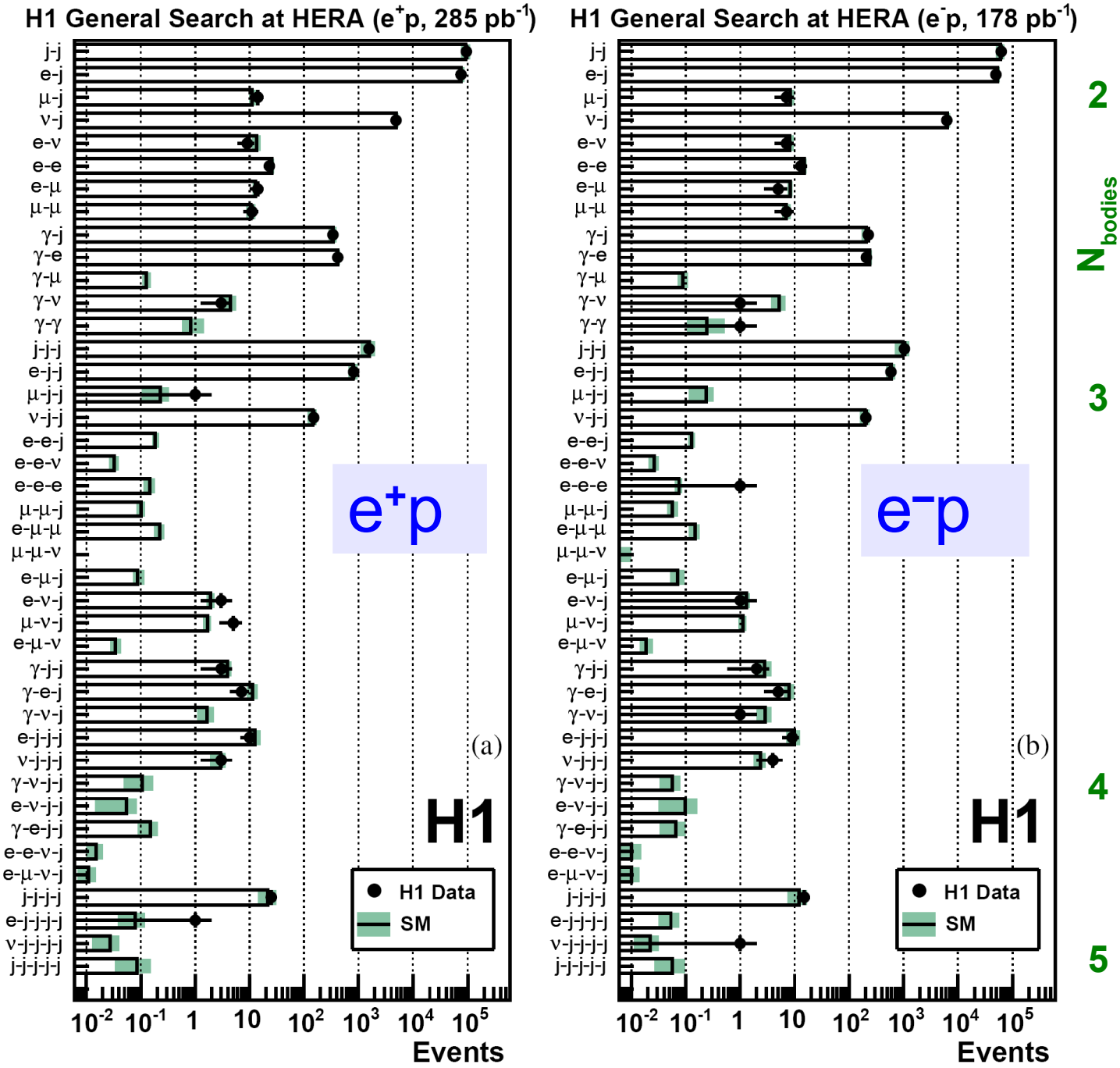
Large Extra Dimensions

- ADD model: 4+n dimensions leads to effective CI with scale M_s

$$\eta_G = \frac{\lambda}{M_S^4}$$

- M_s > 0.90 – 0.94 [TeV]

General Search



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5

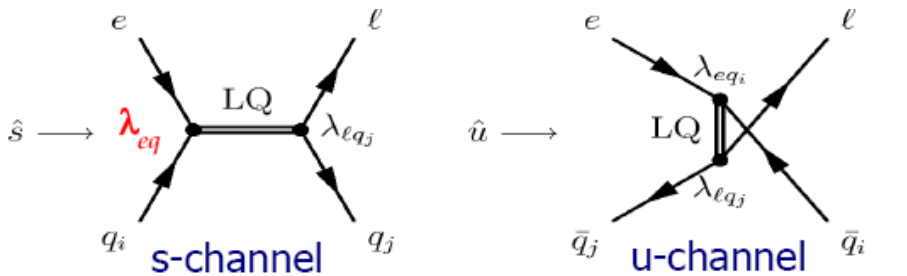
N_{bodies}

- Select all combinations of γ, e, μ, jets, ν with $P_T > 20$ GeV
- Stat. algorithm to look for deviations from SM
- Good overall agreement of of yields and shapes between data and MC
- Shown are the **41** channels with $N_{obs} > 0$ or prediction $N_{SM} > 0.01$
- Many topologies appear also in specific analyses

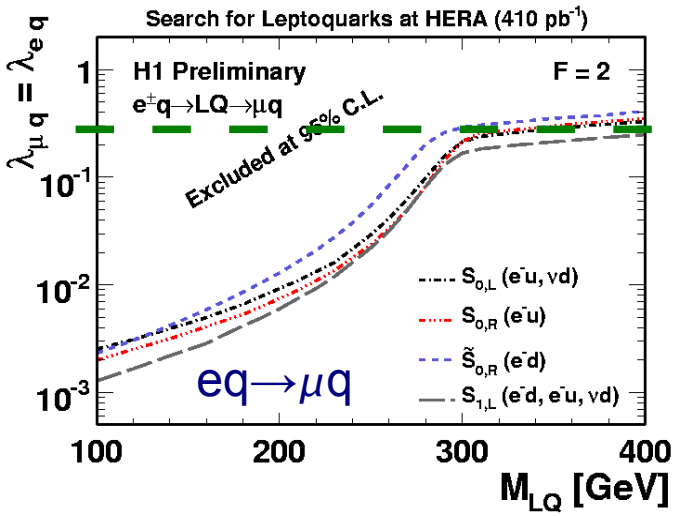
This talk:
- Lepton Flavor Violation
- Isolated Leptons
- Excited fermions
- Squarks
- *Multi-Leptons*

Search for Lepton Flavor Violation

- Search for Production of Lepton Flavor Violating Leptoquarks in 0.41 fb^{-1}



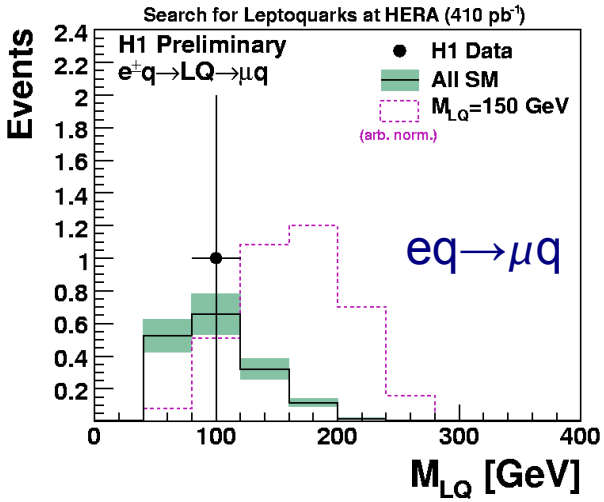
For scalar LQ β=0.5 Tevatron limit M_{LQ}>259 GeV



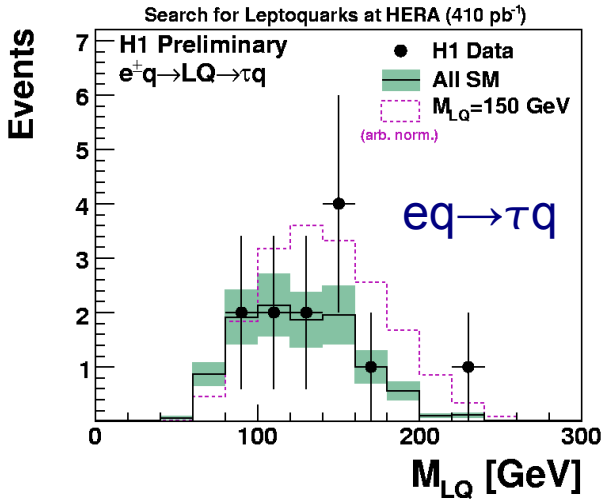
- Final state similar to NC, replacing *e* with μ, τ
- Limits on couplings set on 14 LQ types of BRW framework assuming non-zero 2nd/ 3rd gen. coupling:

$\lambda_{\mu q} = \lambda_{eq}$, $\lambda_{\tau q} = 0$ $\quad$ $\lambda_{\tau q} = \lambda_{eq}$, $\lambda_{\mu q} = 0$

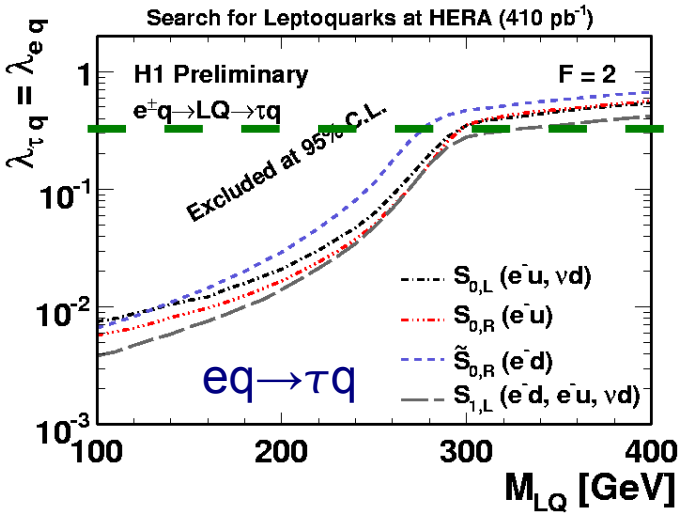
For λ=0.3 (em. strength)
M_{LQ}>304-530 GeV



1 obs. / 1.6±0.5 exp.



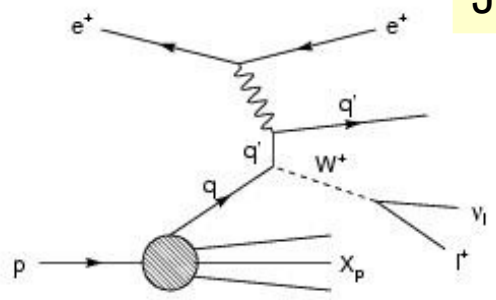
12 obs. /10.6 exp.



For λ=0.3 (em. strength)
M_{LQ}>272-450 GeV

Isolated Leptons in Events with Missing P_T

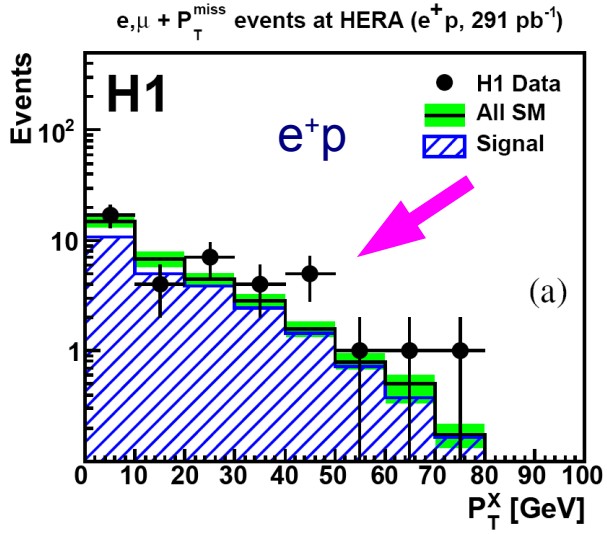
- Select isolated p_T>10 GeV electrons or muons in events with P_T^{miss} > 12 GeV
- Good overall agreement with Standard Model (*W-Production*)
- Interesting **events** at high hadronic P_T^X > 25 GeV observed in e^+p by H1

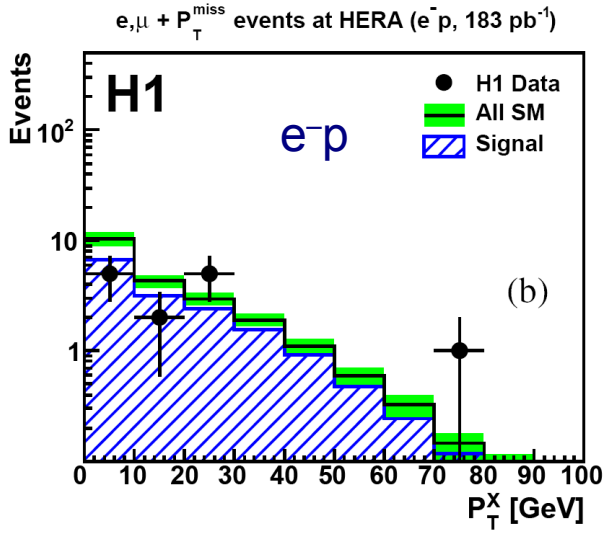


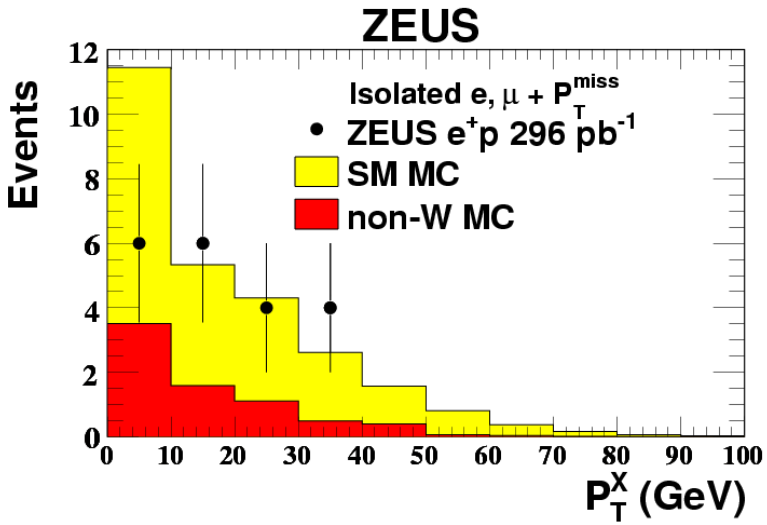
Jet / HFS

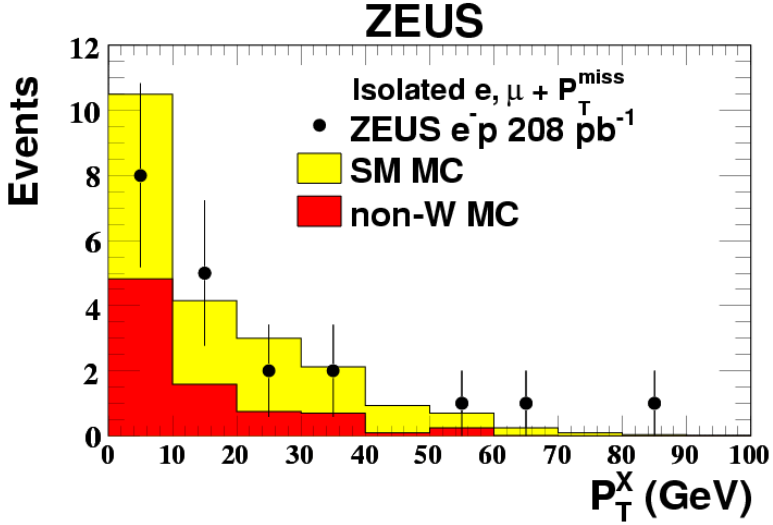
Missing Energy

Electron/ Muon



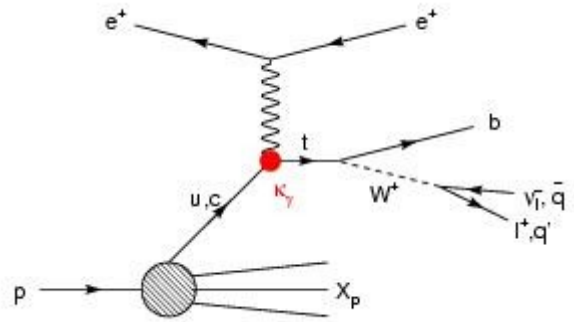




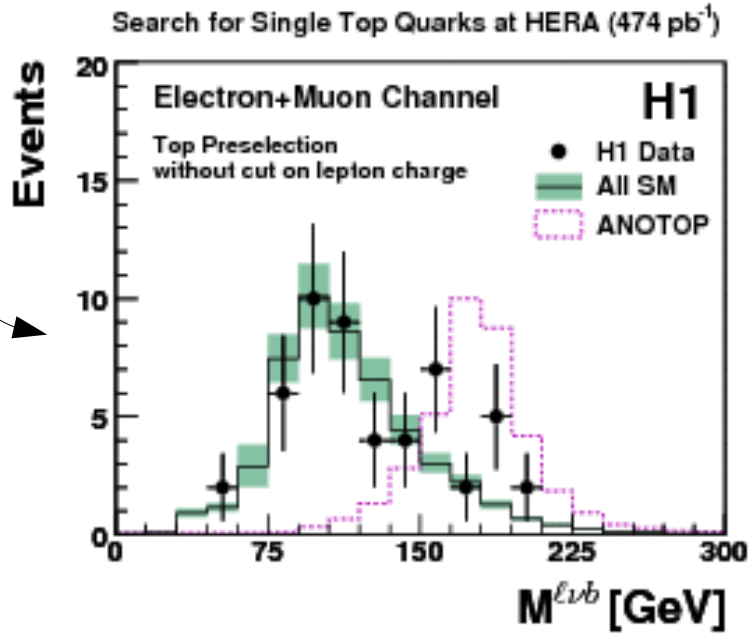


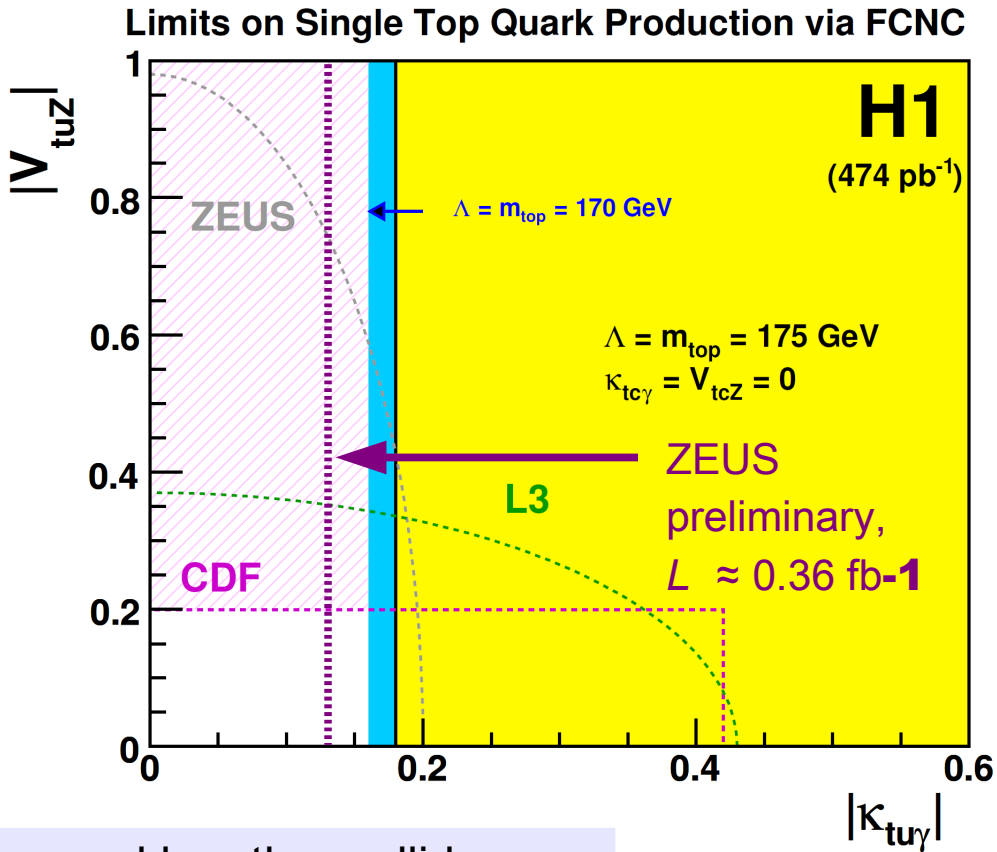
Anomalous Single Top Production

- At high P_T^X isolated leptons signature compatible to **anomalous single top production via FCNC**
- Study using effective couplings v_{tuZ} $\kappa_{tu\gamma}$



- Reconstruct *top* in isolated leptons sample
- Also include hadronic channel (3j)
- Some interesting events remain, but no significant excess observed
- Set limits on $\kappa_{tu\gamma}$, v_{tuZ} (95% CL)



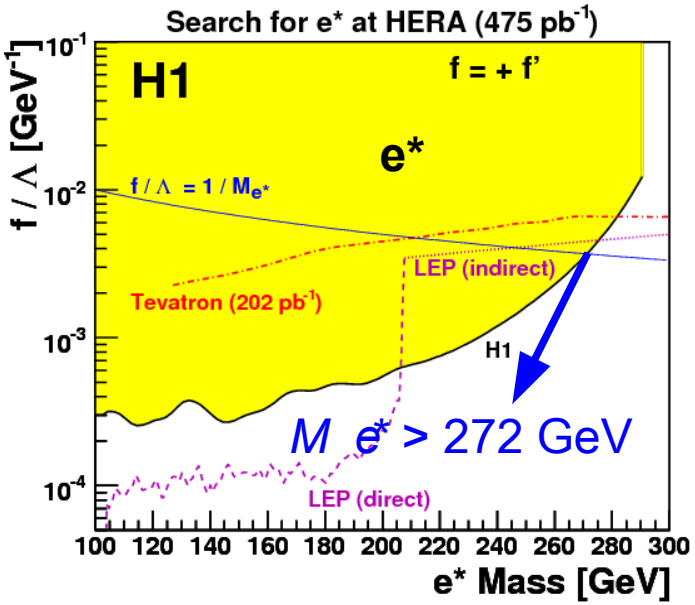


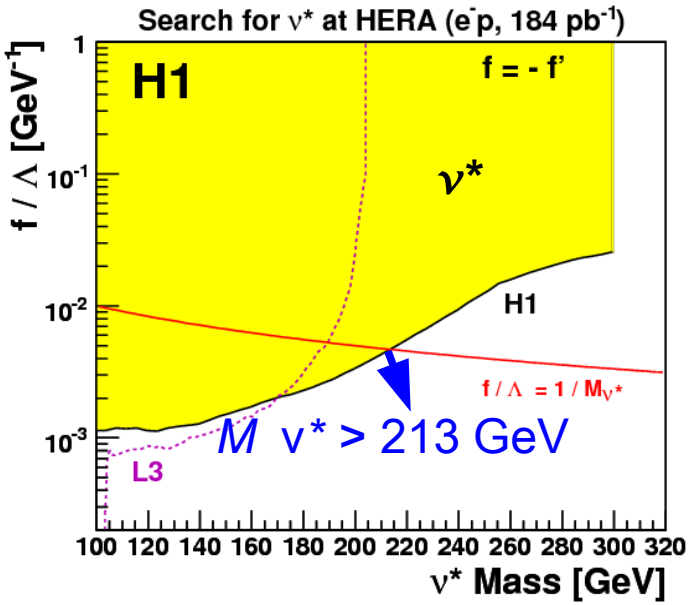
- HERA Limits on $\kappa_{tu\gamma}$ explore domain not covered by other colliders
- H1 limits weaker than ZEUS preliminary due to events in signal region

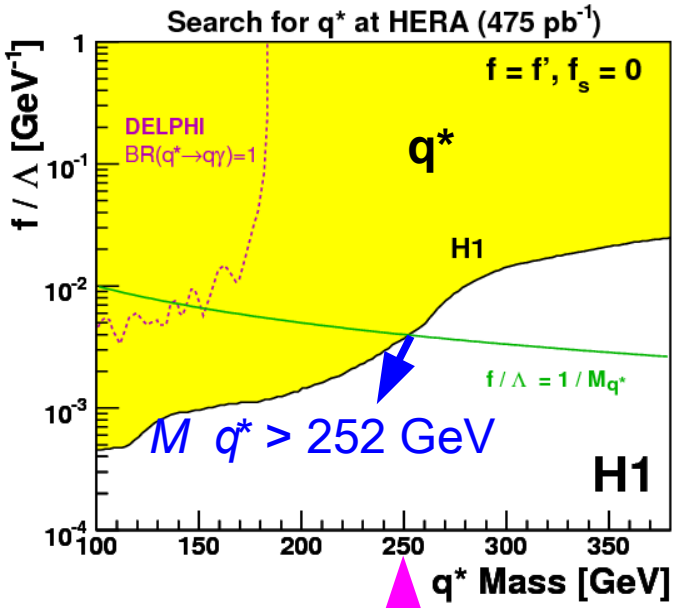
Search for Excited Fermions

- Search for direct production of excited fermions – evidence for compositeness
- Use effective Lagrangian to describe excitation/deexcitation

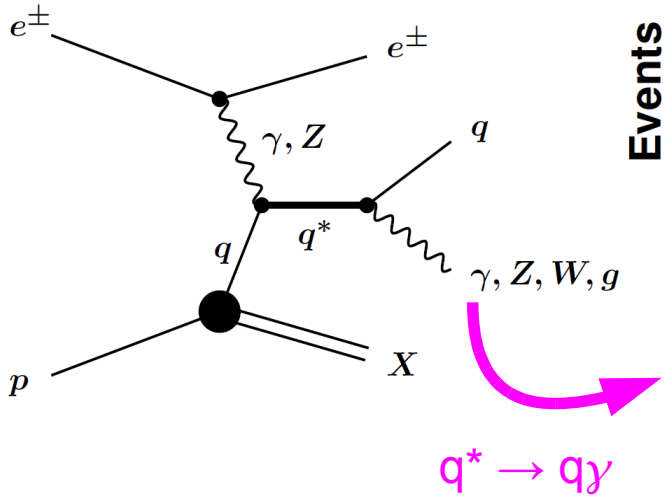
(Tevatron q* limits not shown, assume f_s=1)

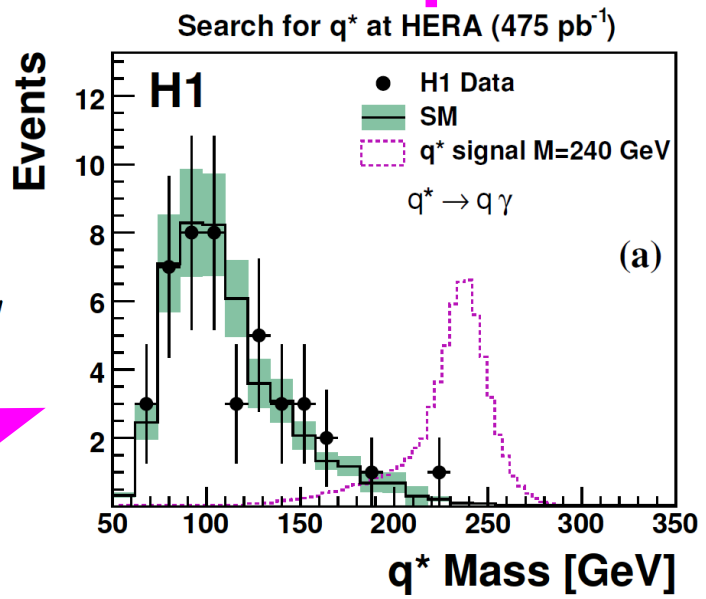






- Excited fermions decay to SM fermions and gauge bosons
- Leptonic and hadronic decay channels of gauge bosons
- No deviation from SM found – set limits f/Λ (m_{f^*}) at 95%CL
- f,f',f_s: couplings to gauge groups
- Λ: effective scale





Search for Squark Production at HERA

Resonant production of single squarks in *ep*-collisions possible with *R*-Parity **Violating** Superpotential

$$R_P = (-1)^{3B+L+2S}$$

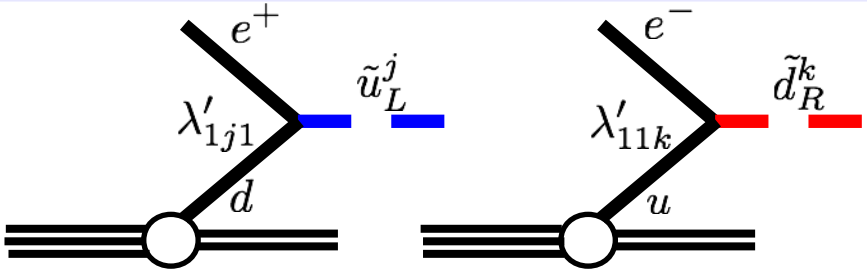
SUSY: R_P = **-1**

SM: R_P = 1

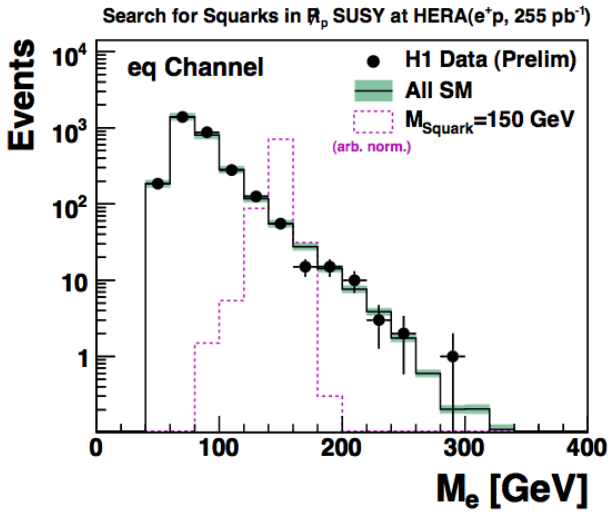
$$W_R = \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

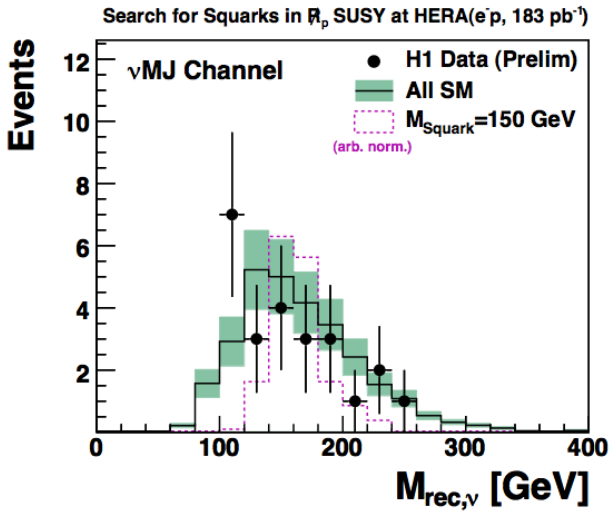
L: LH (s)leptons, **Q**: LH (s)quarks, **D**: RH down-type (s)quarks

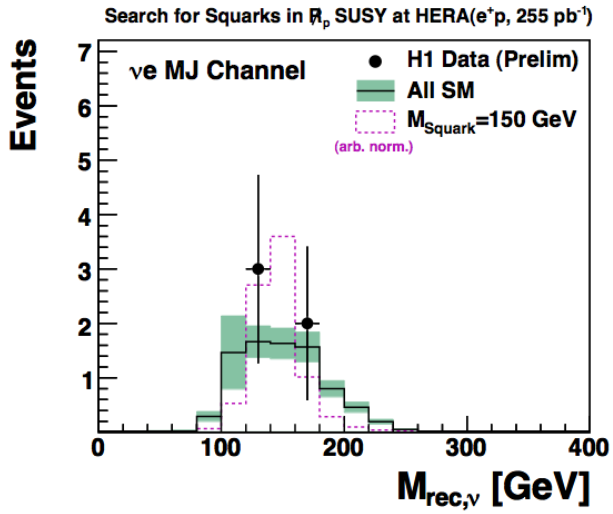
i,*j*,*k* generation indices (27 couplings)



- Many decay modes possible (direct, cascade)
- All relevant 17 final states investigated
- Selections optimized to minimize expected limit
- Some examples for rec. inv. mass spectra:



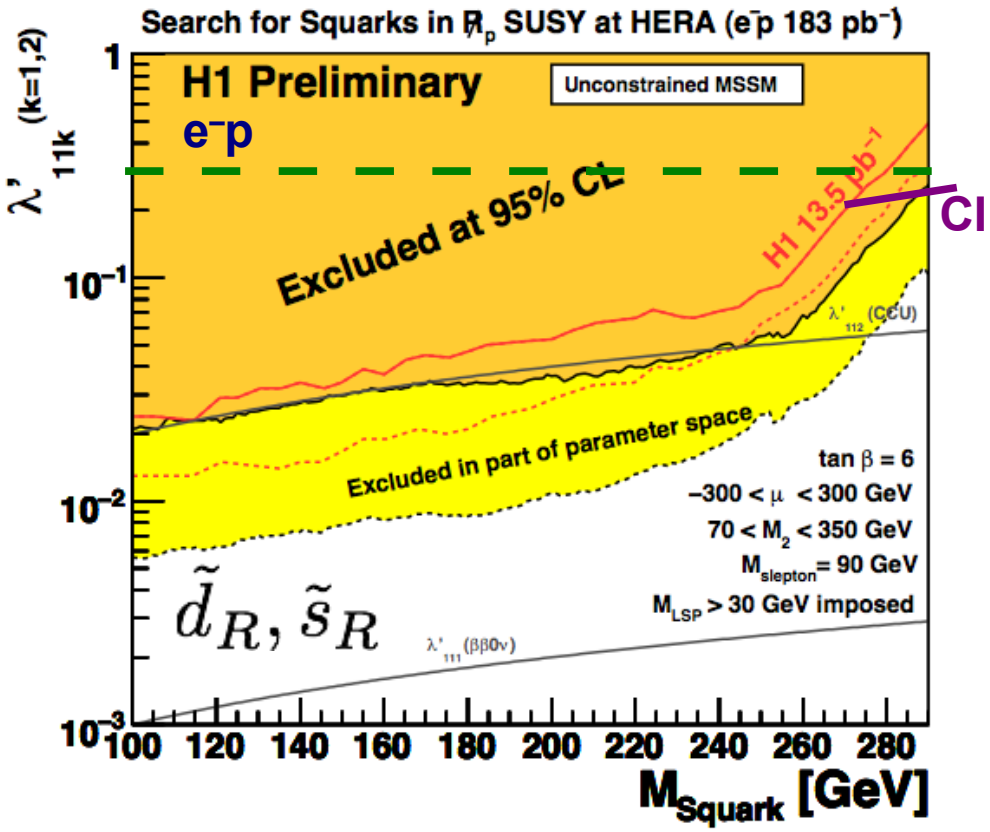


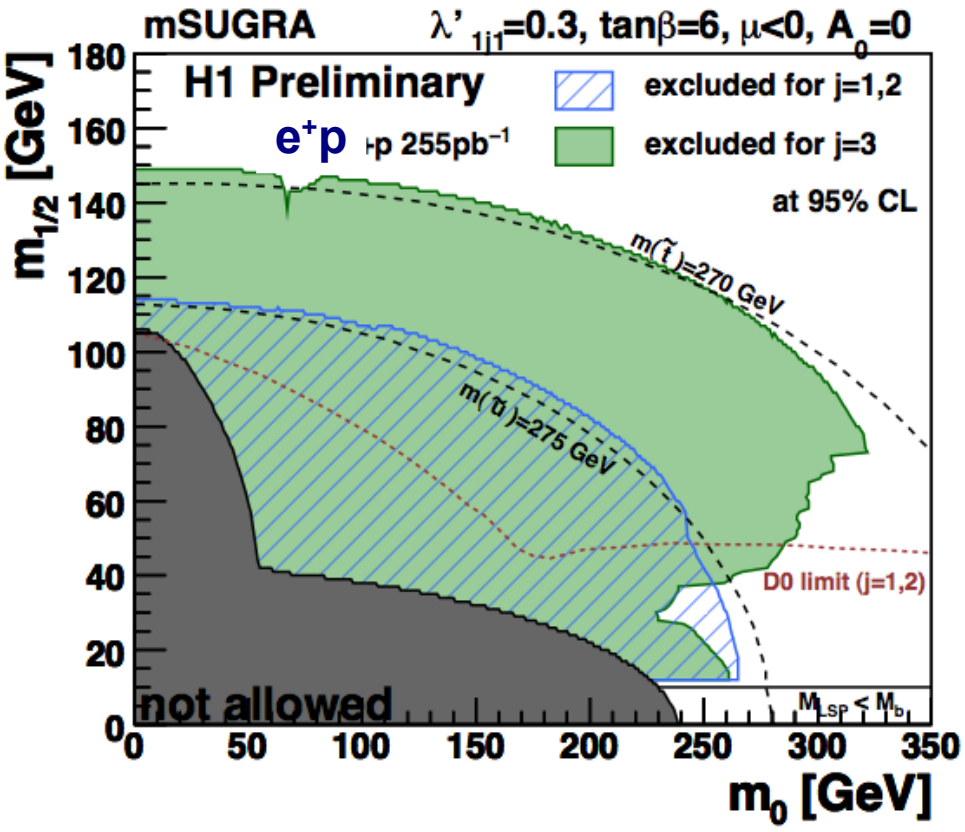


All investigated topologies in good agreement with SM exp.! → Set limits on *R*pV SUSY models

Constraints on MSSM and mSUGRA

Scan of accessible MSSM parameter space





- For a Yukawa coupling $\lambda'_{11k} = 0.3$ (em. strength):
- Down-type squarks up to **290 GeV** excluded at 95%CL
- Complementary to indirect limits from CCU, $\beta\beta0\nu$
- Similar results for $\tilde{u}_L, \tilde{c}_L\ \tilde{b}_R\ \tilde{t}_L$

- Assuming mSUGRA () with coupling $\lambda'_{1j1} = 0.3$ (em. strength)
  indicated region excluded at 95% CL
- HERA limits at tanβ=6 extend beyond D0 limits

Summary

- Searches for deviations from the SM in $e^{\pm}p$ data performed by H1 and ZEUS based on the full HERA dataset (~0.5 fb-1 per experiment)

- Good description of NC DIS at high Q^2 allows to constrain many CI models inclusively and estimate a quark radius $Rq < 0.63*10^{-18}$ m

- Most accessible final states investigated by the experiments
  - General Search and many optimised searches
  - Intriguing events observed, but overall no significant deviation from SM prediction

- Many models excluded up to (and beyond for CI-like interactions) center-of-mass energy:

• Anomalous single top production	
• Excited Fermions	$M_{e^*} > 272$ GeV, $M_{\nu^*} > 213$ GeV, $M_{q^*} > 252$ GeV
• Lepton-flavor violating Leptoquarks	$M_{LQ} > 272$-530 GeV
• Squarks in RPV SUSY	*u*-type $M_{sq}>275$GeV, *d*-type $M_{sq}>290$GeV

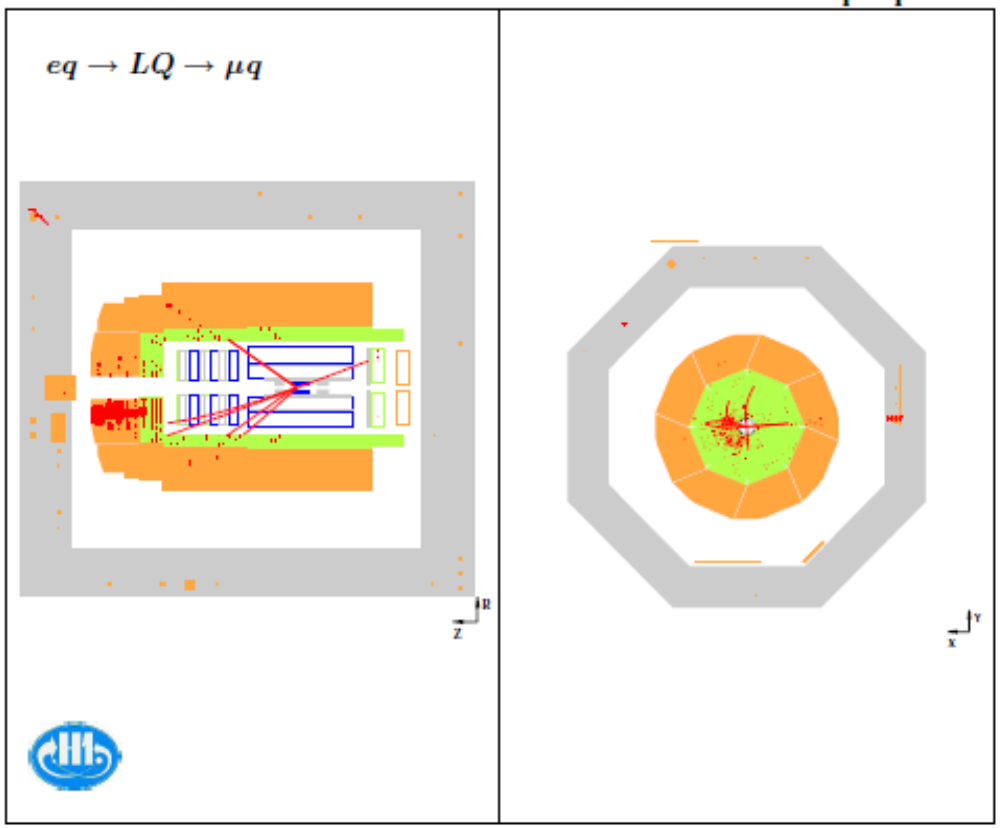
$\lambda'_{1j1}, \lambda'_{11k} = 0.3$

- Excellent understanding of *ep* physics at $\sqrt{s}$=320 GeV
- HERA limits remain competitive in regions not accessible at LEP, Tevatron (and not *yet* at LHC)

b a c k u p

Event Displays: LFV Candidates

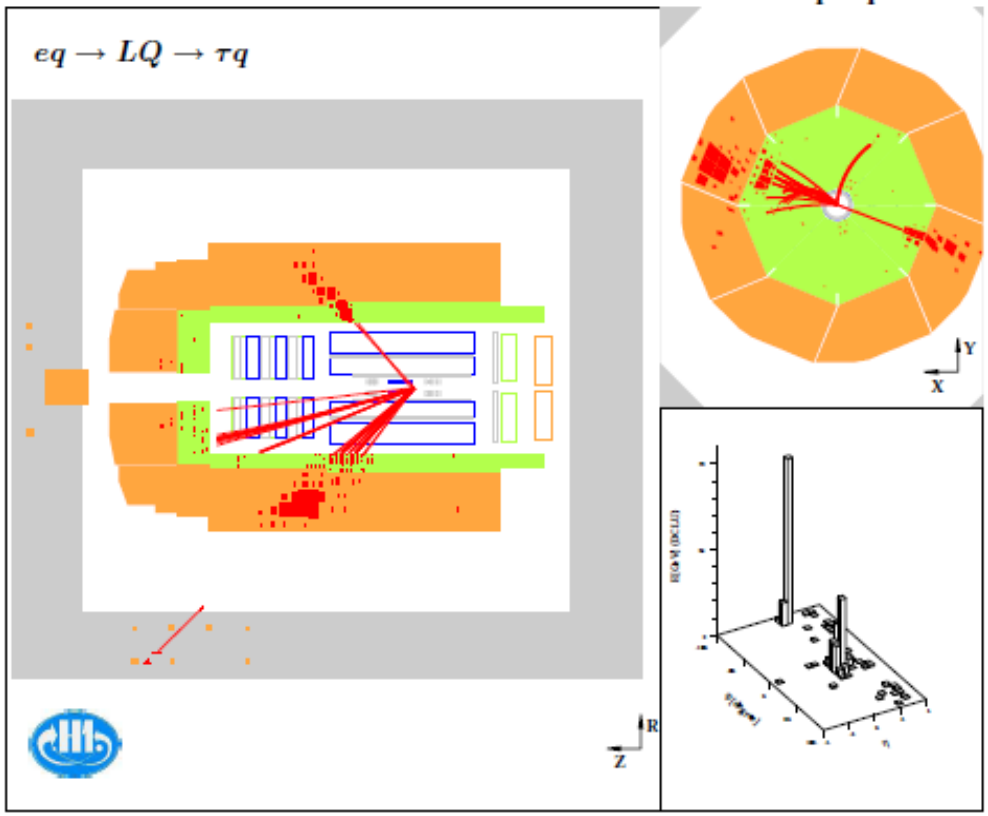
H1 Candidate Event in the Search for Second Generation Leptoquarks



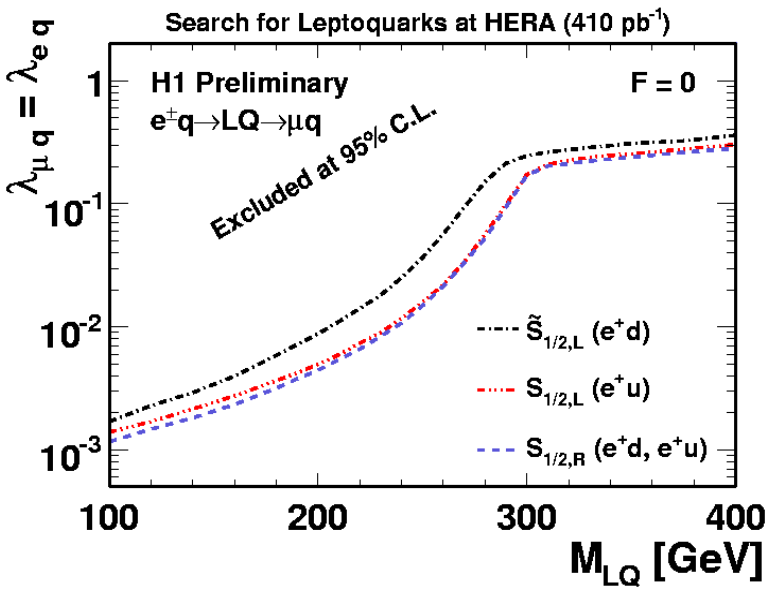
ep → μX

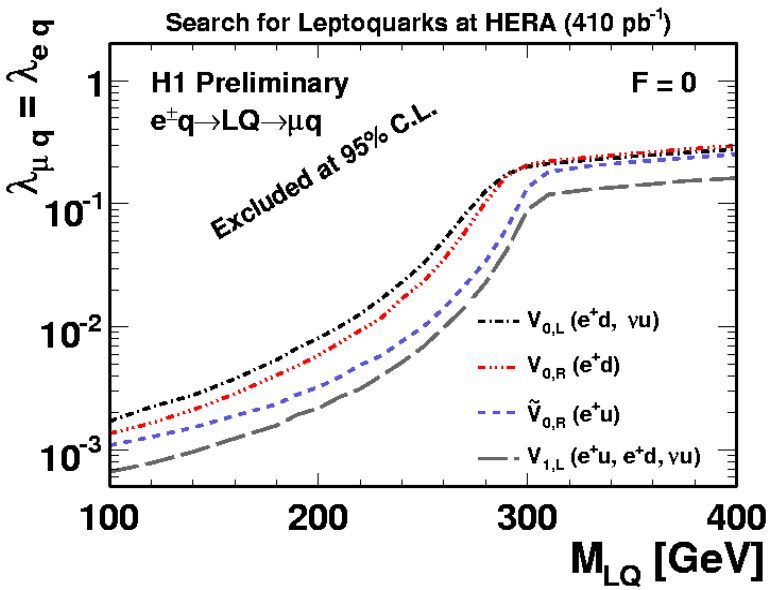
ep → τX

H1 Candidate Event in the Search for Third Generation Leptoquarks

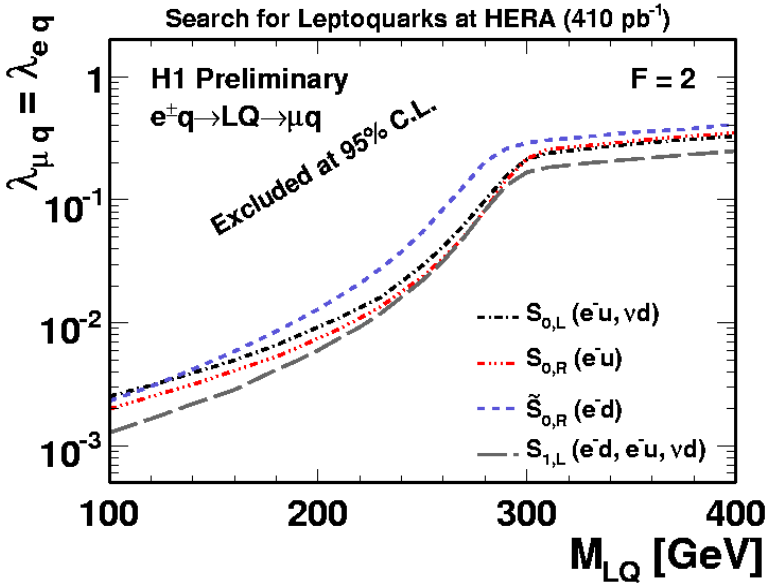


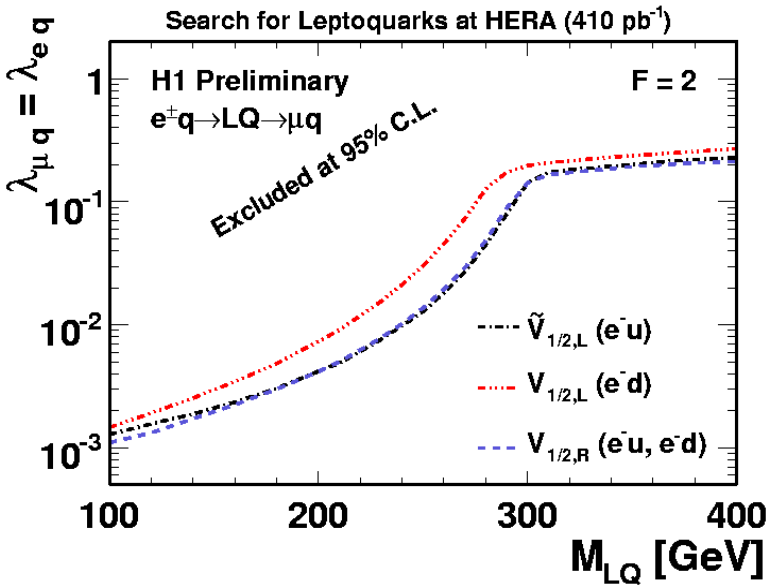
Search for 2nd generation Leptoquarks





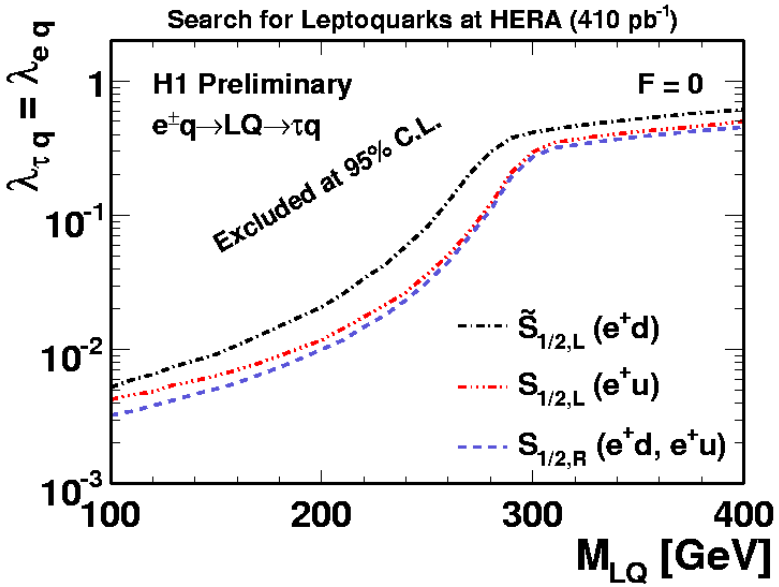
For electromagnetic strength λ=0.3 M_{LQ}<304-530 GeV can be ruled out

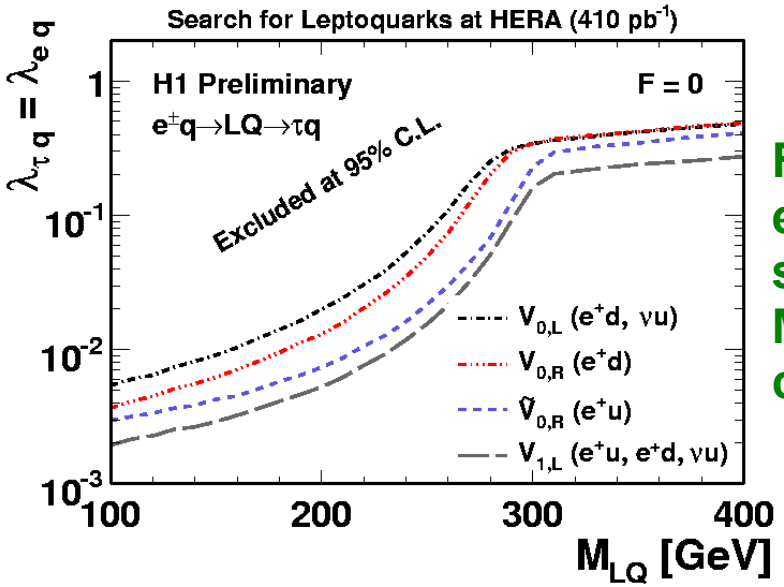




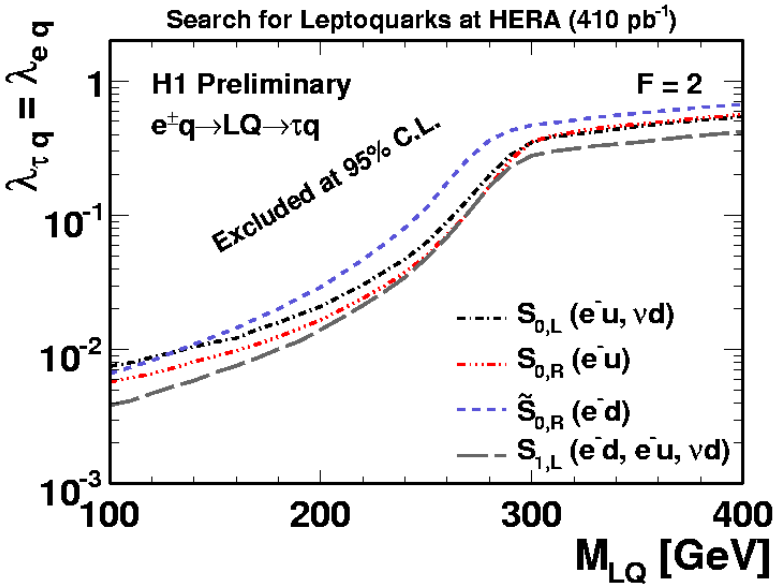
For scalar LQ, β=0.5 Tevatron limit M_{LQ}>259 GeV

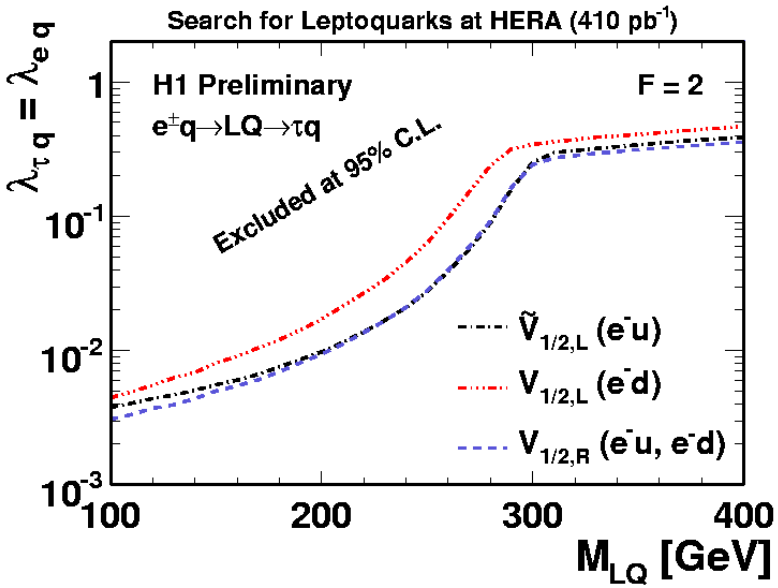
Search for 3rd generation Leptoquarks





For electromagnetic strength λ=0.3 MLQ<272-450 GeV can be ruled out



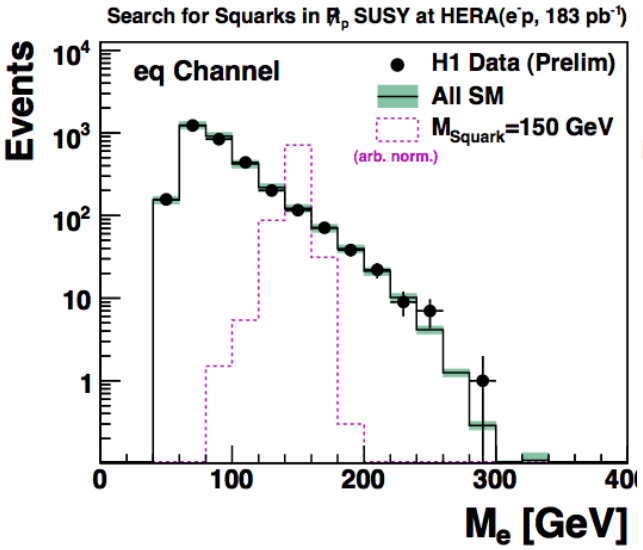


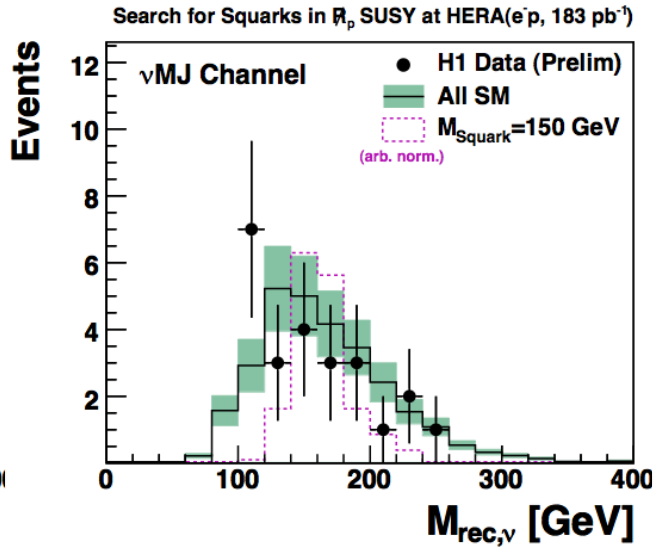
For scalar LQ, β=0.5 Tevatron limit **M_{LQ}>207 GeV**

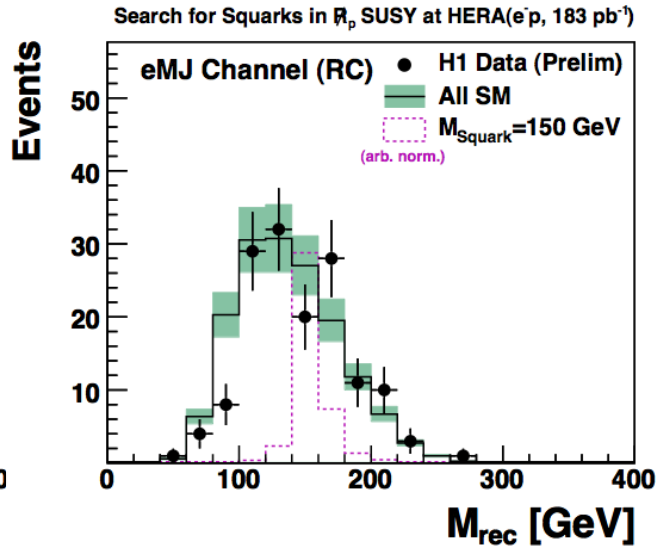
Search for RPV SUSY – Selection Results

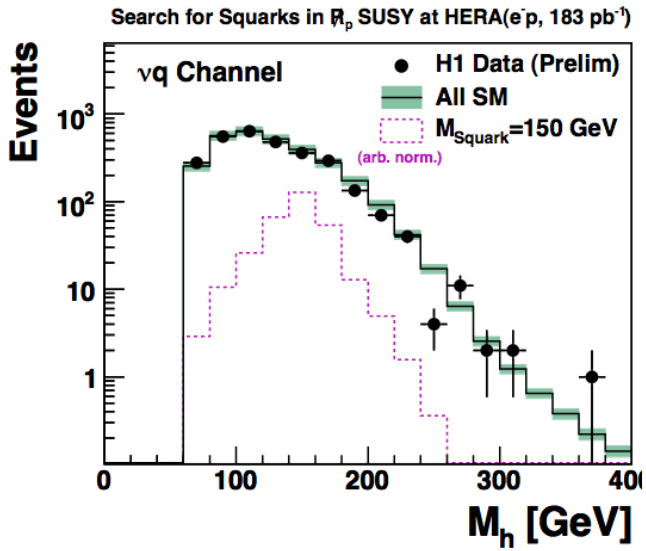
Search for Squarks in RPV SUSY with H1 (Preliminary)					
	e^+p (255 pb^{-1})		e^-p (183 pb^{-1})		Signal
Channel	Data	SM Expectation	Data	SM Expectation	Efficiency
eq	2946	2899 ± 302	3121	3215 ± 336	$30 - 40\%$
νq	-	-	2858	2983 ± 358	$50 - 60\%$
eMJ (RC)	140	145.6 ± 21.3	147	157.7 ± 23.8	$10 - 40\%$
eMJ (WC)	1	0.58 ± 0.36	0	1.3 ± 0.3	$5 - 20\%$
νMJ	19	23.4 ± 5.8	24	28.9 ± 7.2	$5 - 15\%$
$eeMJ$	2	1.7 ± 0.5	0	1.5 ± 0.5	$5 - 35\%$
$e\mu MJ$	0	0.03 ± 0.03	0	0.03 ± 0.02	$5 - 15\%$
νeMJ	5	8.2 ± 2.0	3	5.6 ± 1.2	$5 - 40\%$
$\nu\mu MJ$	0	0.06 ± 0.03	0	0.04 ± 0.02	$5 - 20\%$

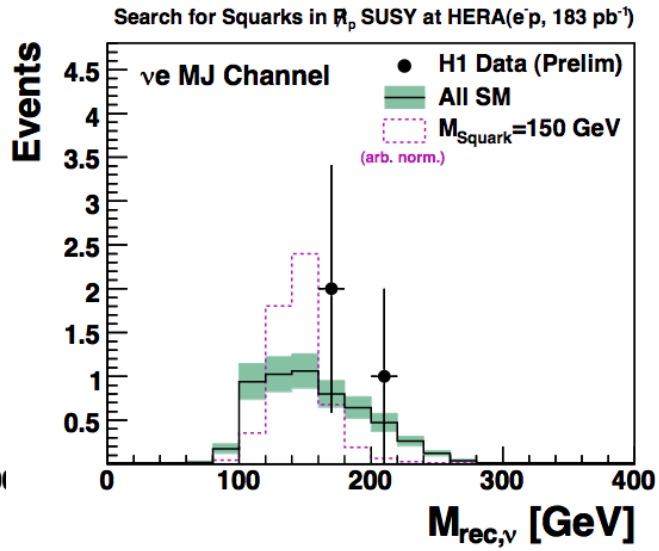
Mass Distributions (e^-p, 183 pb^{-1})





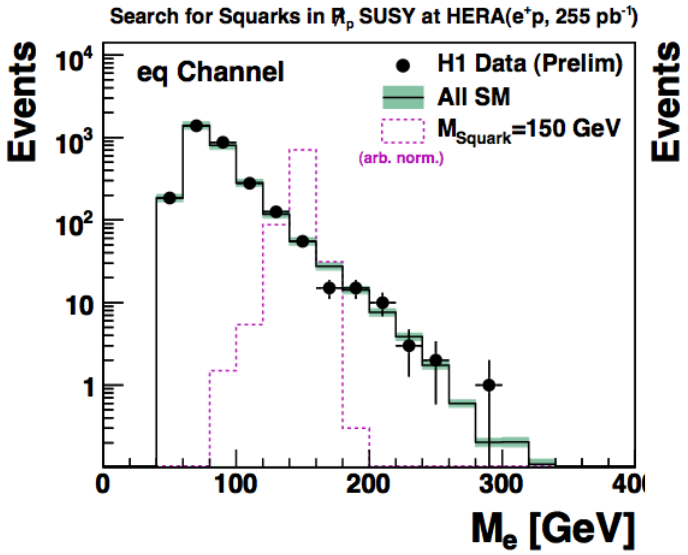


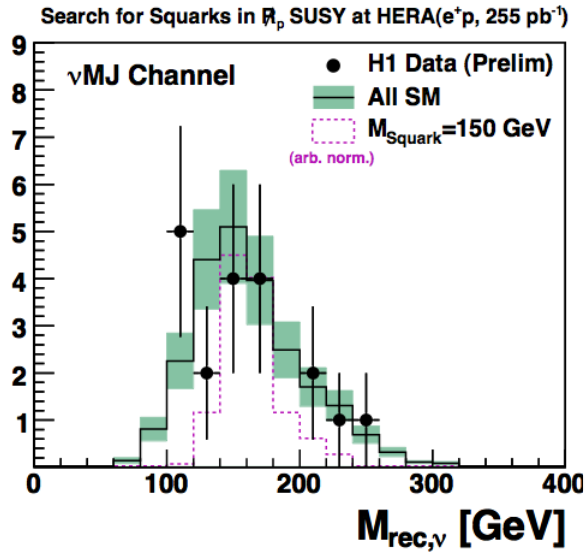


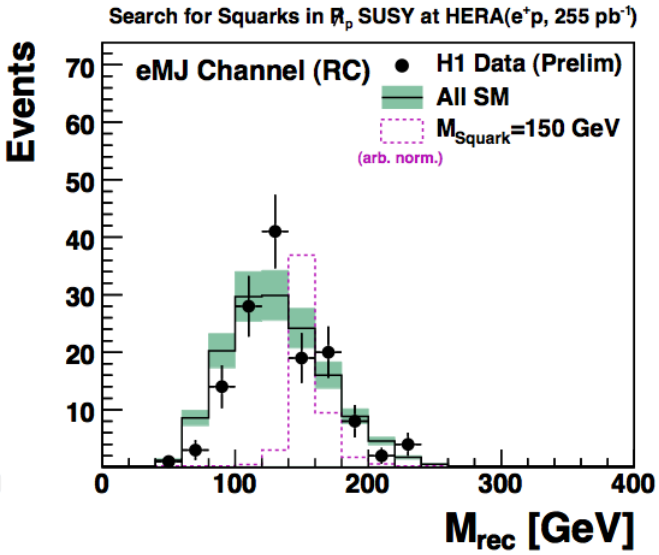


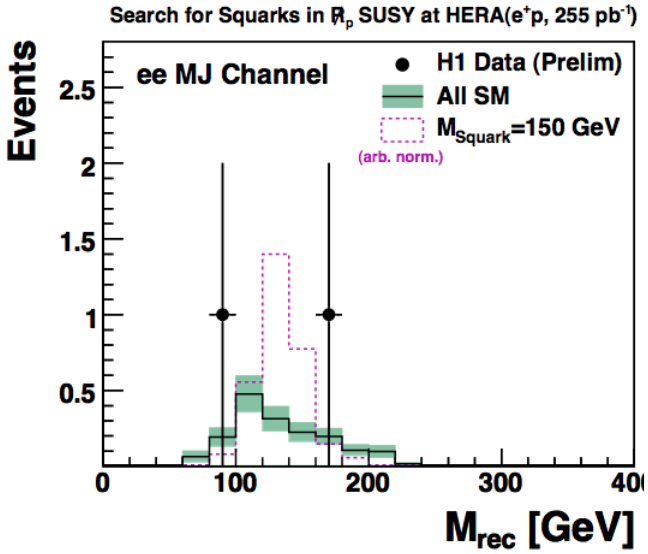
In e-p and e+p data no significant deviation from SM background observed

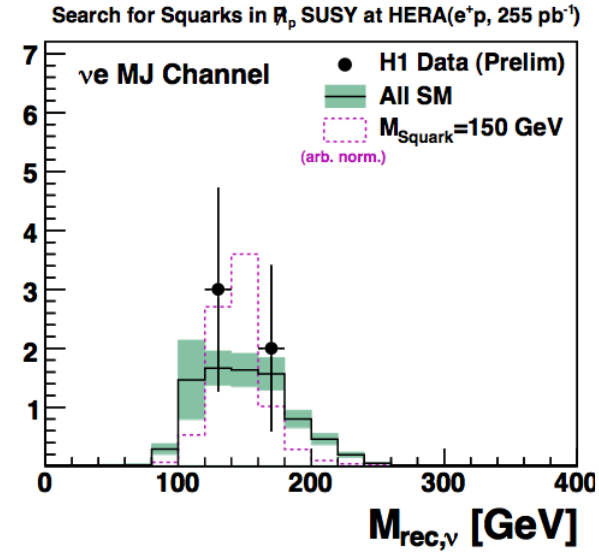
Mass Distributions (e^+p 255pb^{-1})

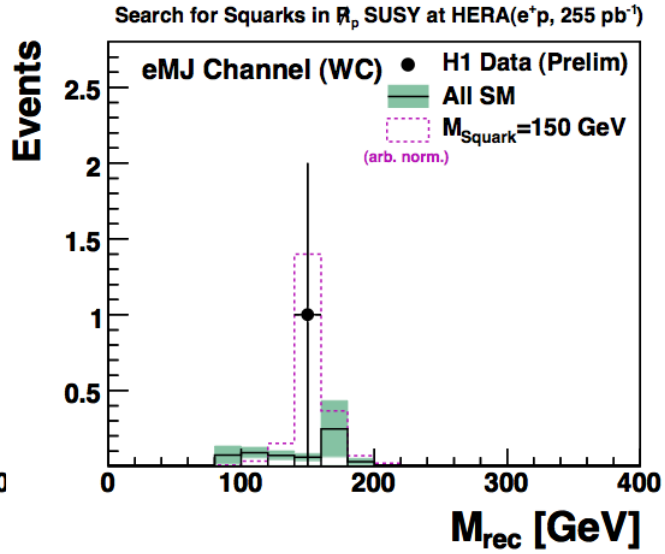




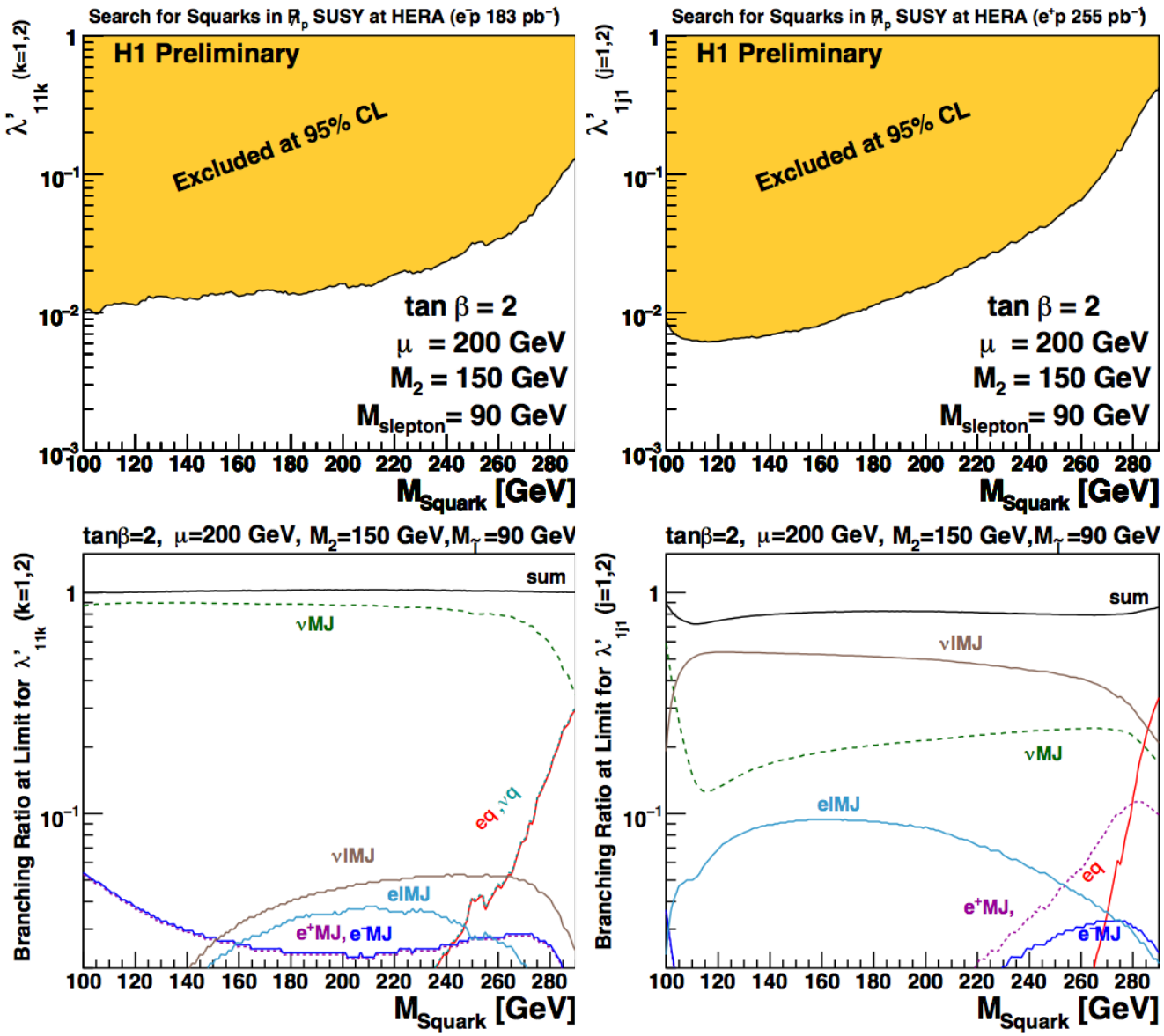








zino dominated neutralino

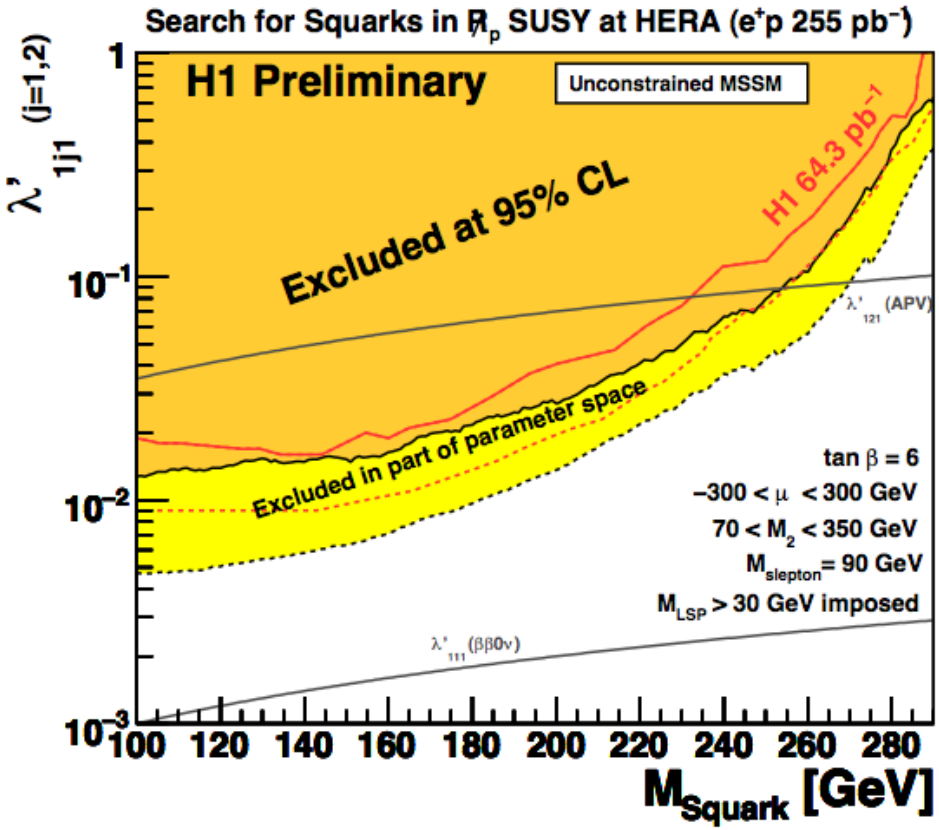


$\mu, \tan\beta, M_2$

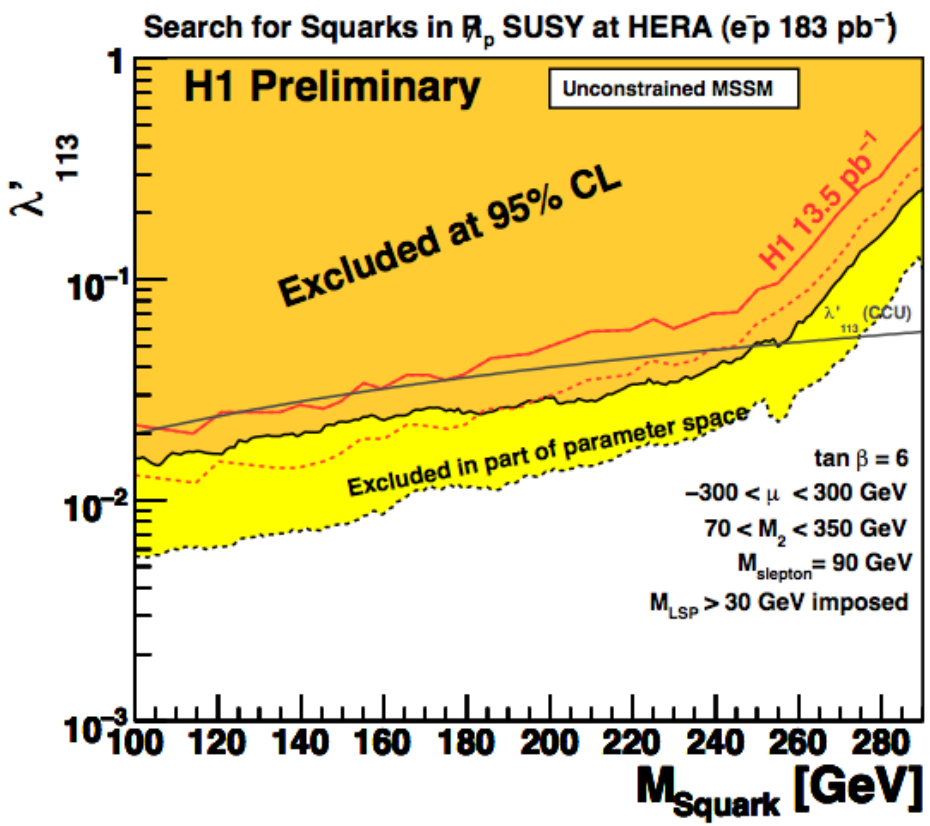
determine REWSB

SUSY RPV Parameter Scan

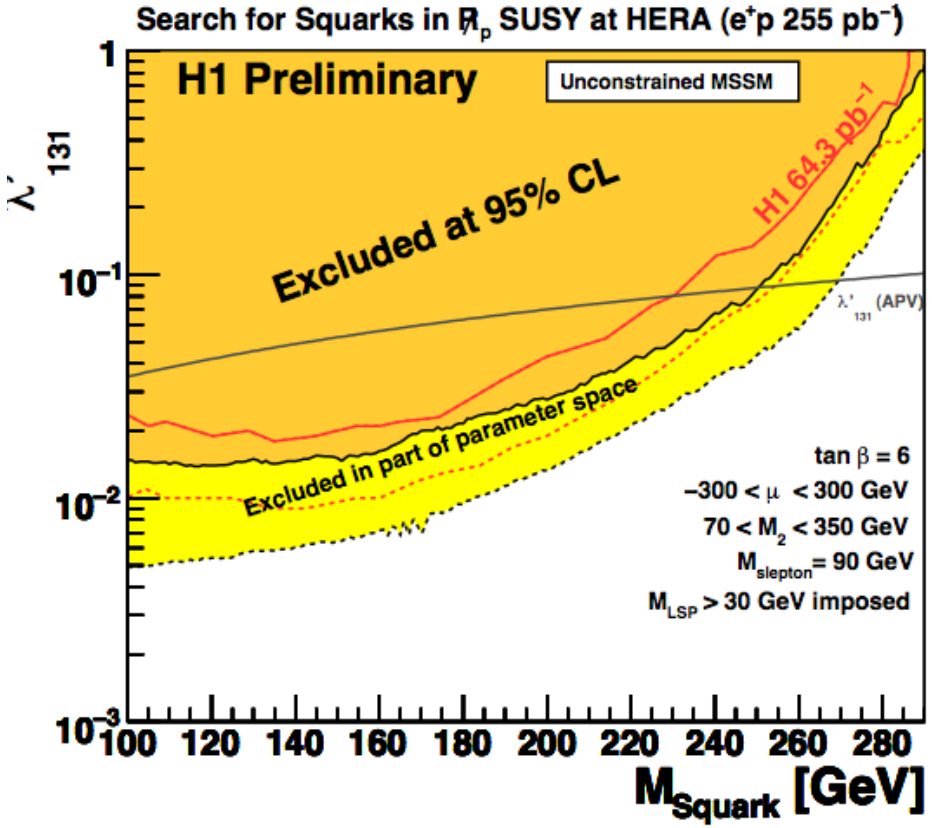
$\tilde{u}_L, \tilde{c}_L$



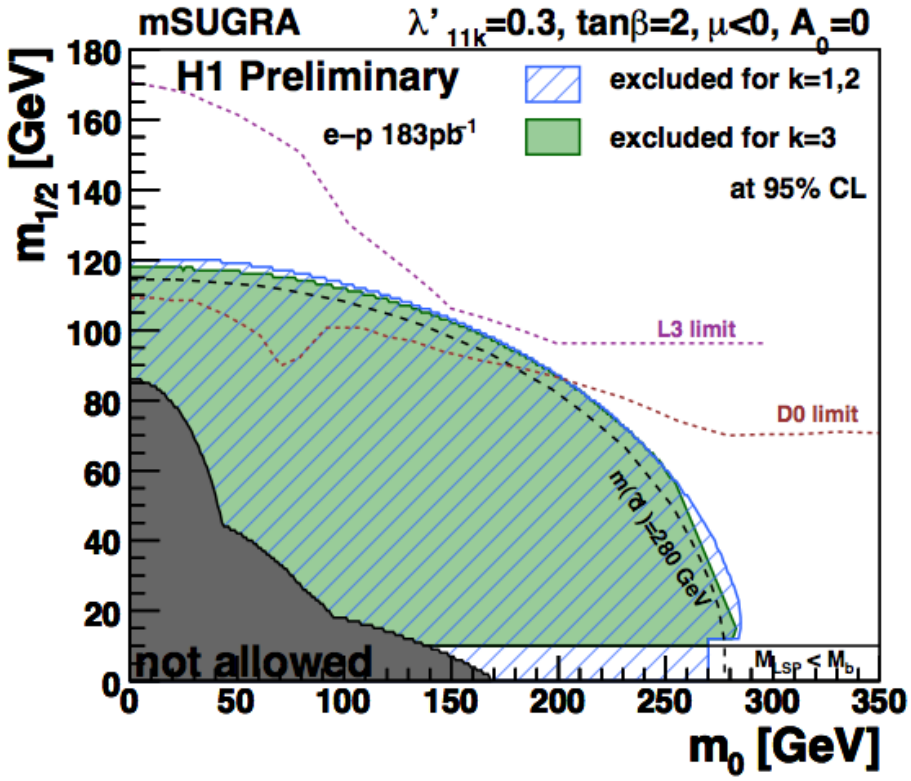
$\tilde{b}_R$

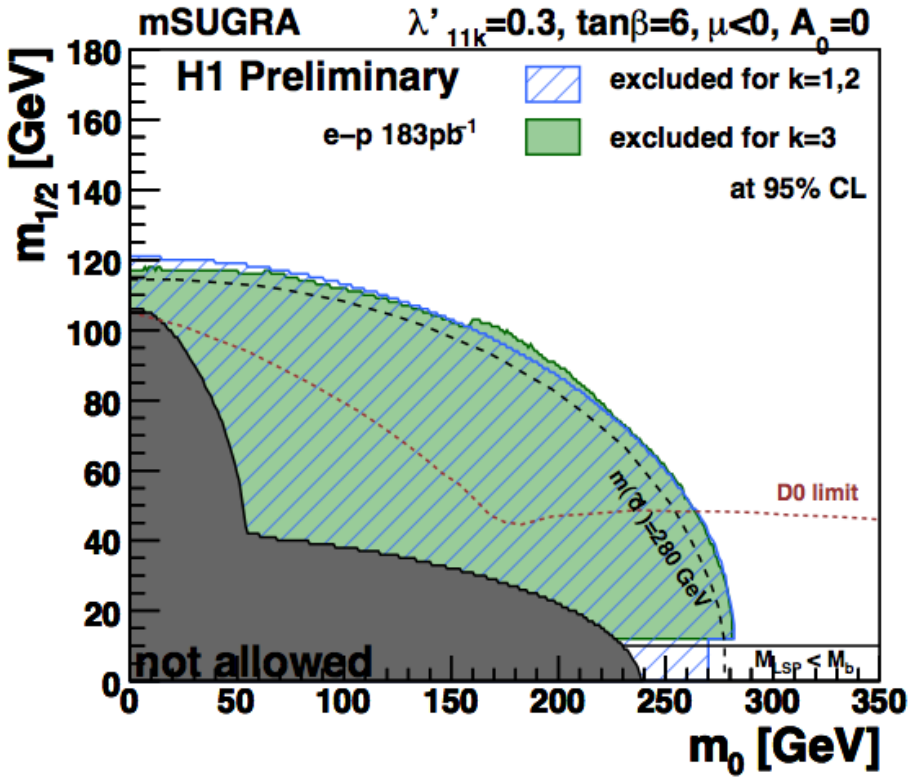


$\tilde{t}_L$



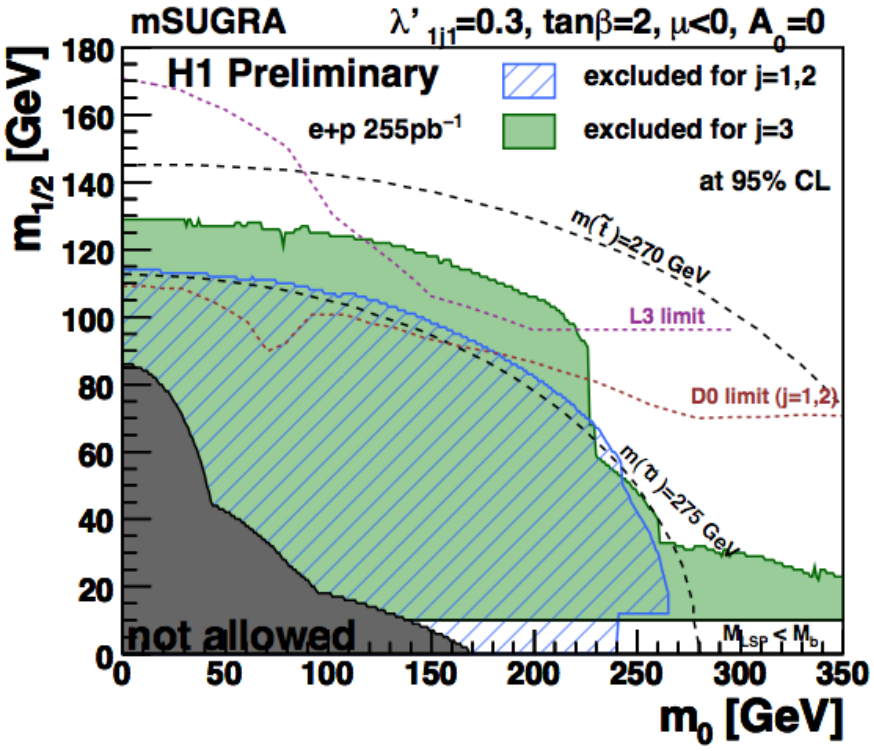
mSUGRA - Down-type Squarks

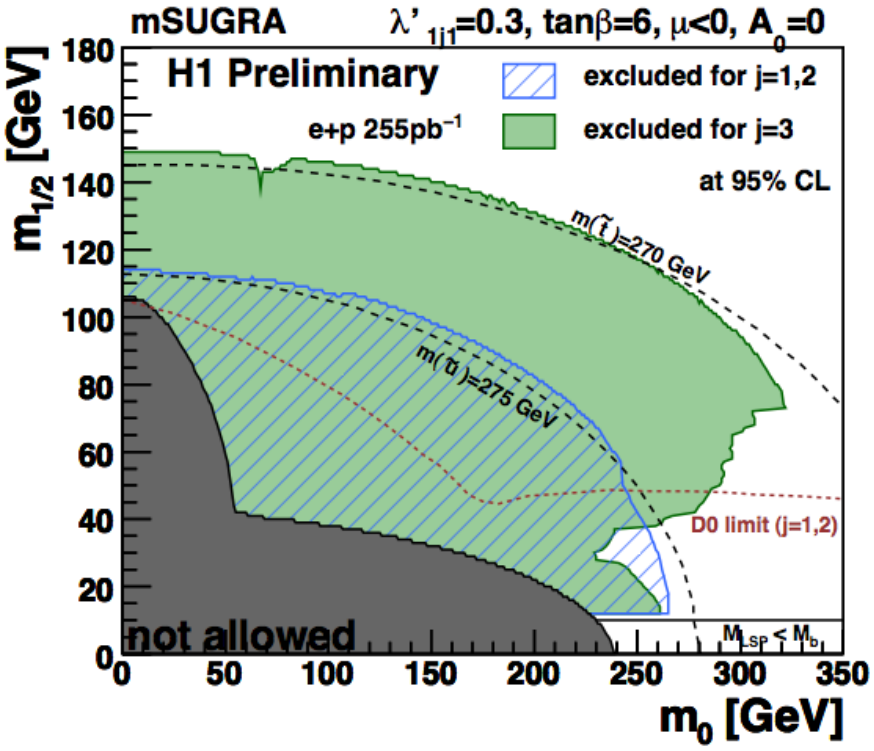




assuming a coupling strength: $\lambda'_{11k}=0.3$
the indicated region can be excluded at 95% CL

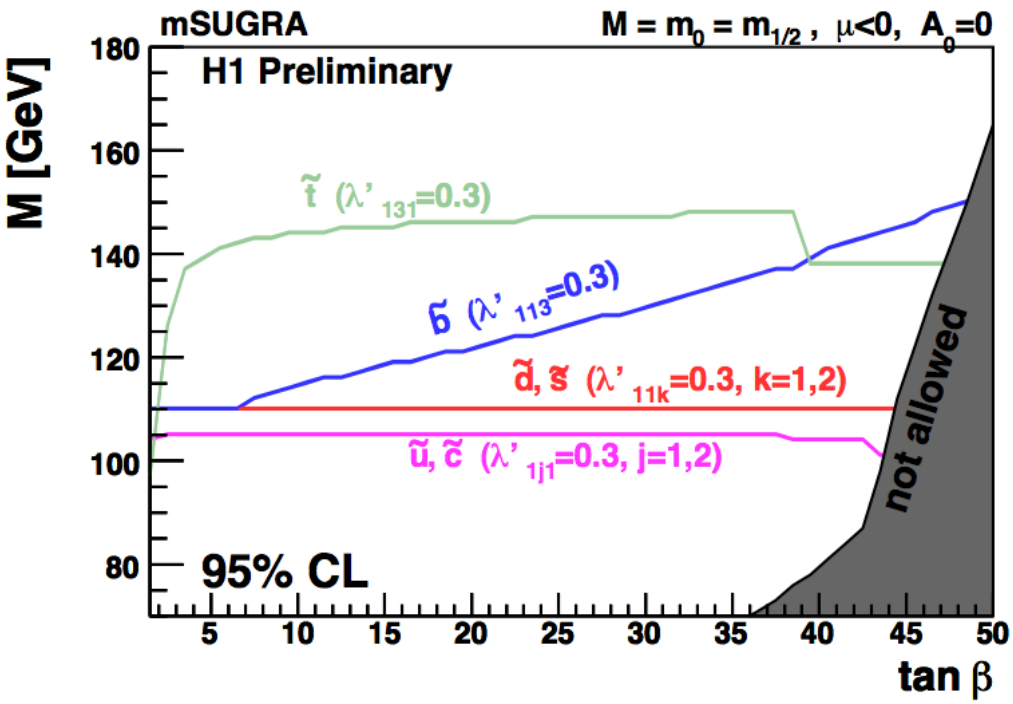
mSUGRA - Up-type Squarks





assuming a coupling strength: $\lambda'_{1j1}=0.3$
the indicated region can be excluded at 95% CL

Dependence of mSUGRA limits on tan β



Strong mixing between stop (sbottom) states at higher tan **β** leads to dependence for third generation squarks.