

Recent HERA Results Sensitive to SUSY

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(DESY)

On behalf of the H1 and ZEUS Collaborations



Topics

- Leptoquarks
- Isolated Leptons
- General Search

Not covered

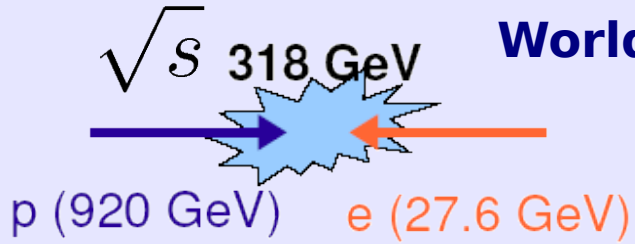
- Dedicated SUSY Parameter Scans

34th International Conference on High-Energy Physics

July 29th, 2008 - August 5th, 2008 Philadelphia, PA



HERA



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

Asymmetric Design
4 π Coverage
Excellent Lepton ID + HFS Reconstruction

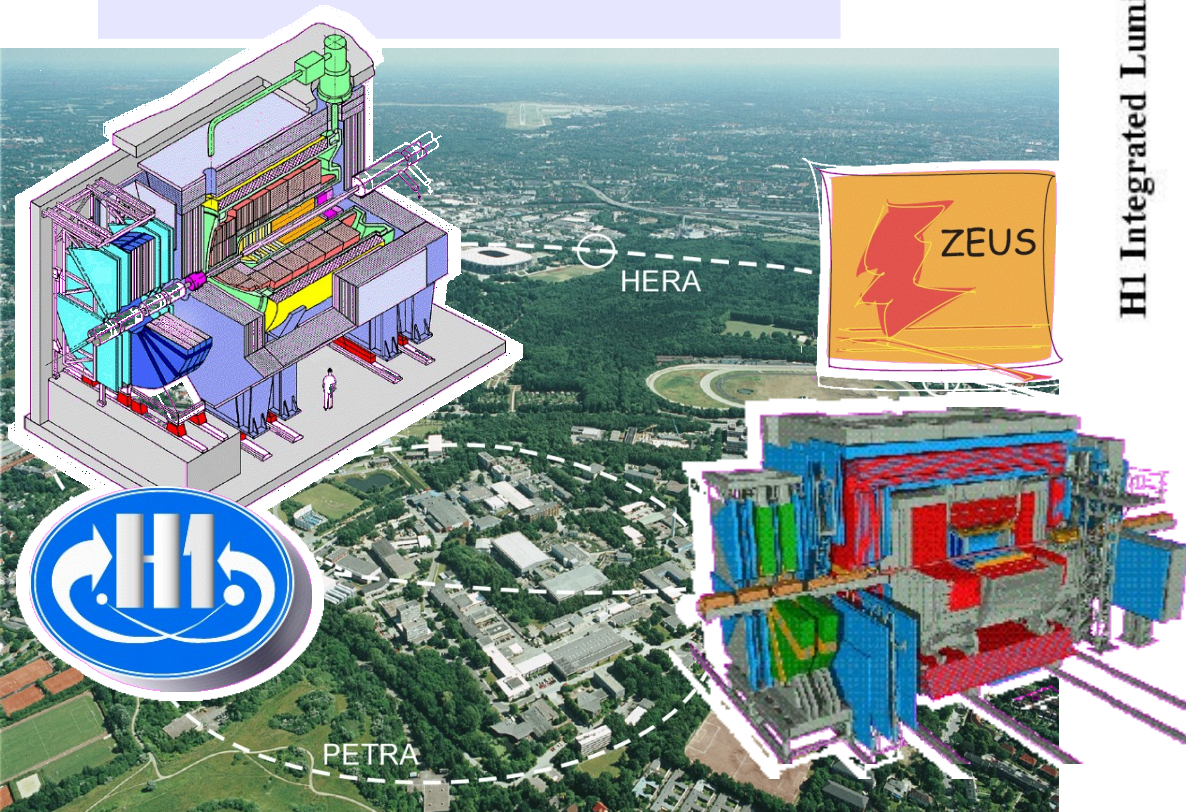
HERA-I (1994-00)

~130 pb⁻¹ per exp., (90% e⁺p)

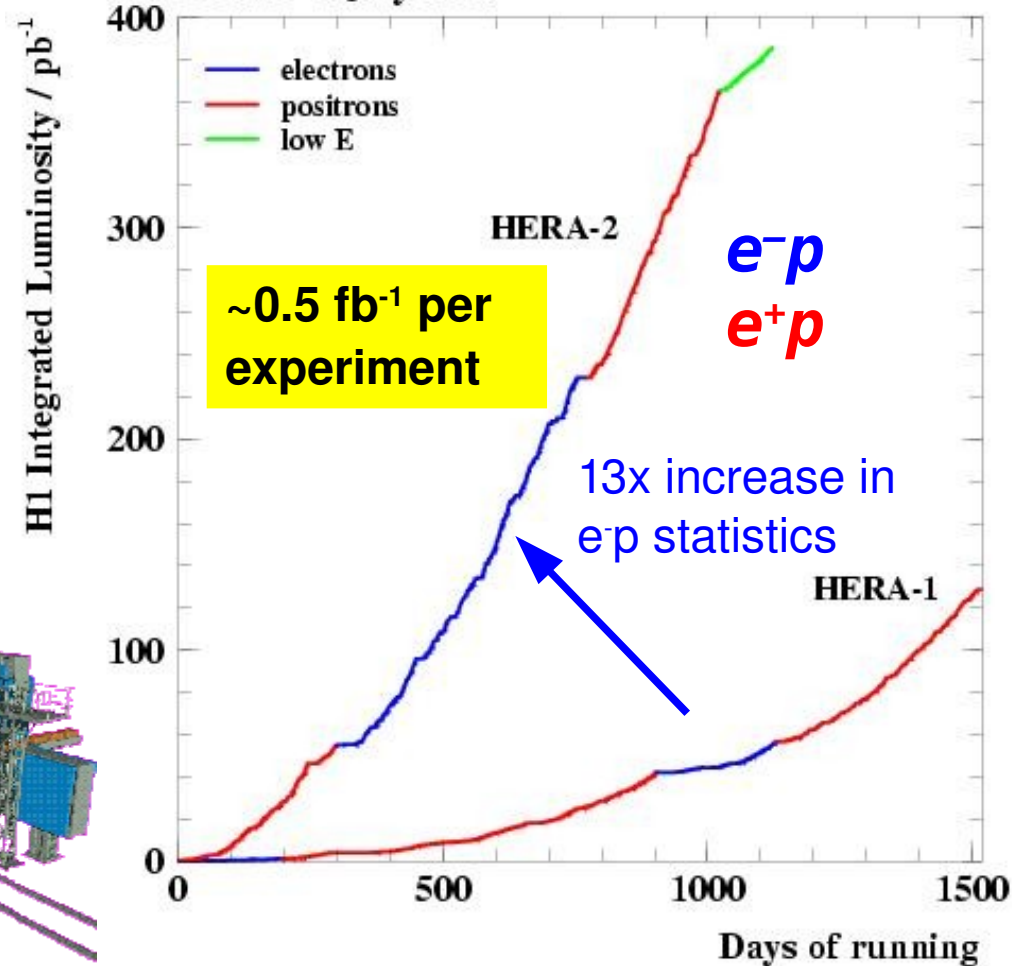
HERA-II (2003-07)

Luminosity upgrade

Long. e polarisation (avg. 40%)



Status: 1-July-2007



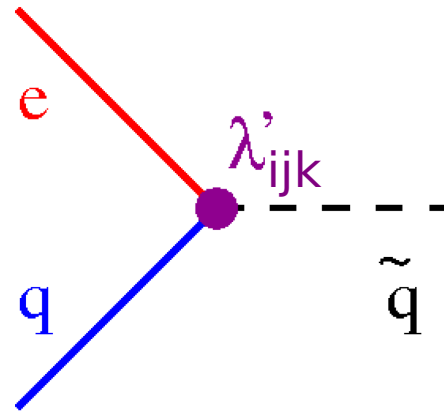


Squark Production at HERA

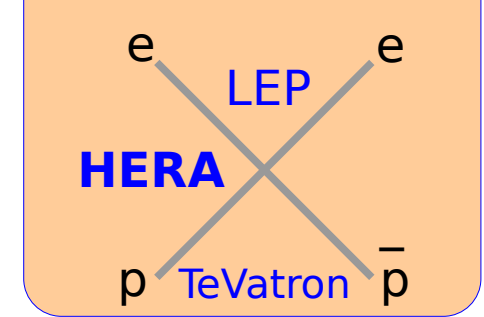
- ep initial state disfavours \tilde{q} pair production
- Sensitive to resonant \tilde{q} production with RPV coupling λ'_{ijk}

$$W_{RPV} = \lambda'_{ijk} L_i Q_j \bar{D}_k$$

- Unstable LSP



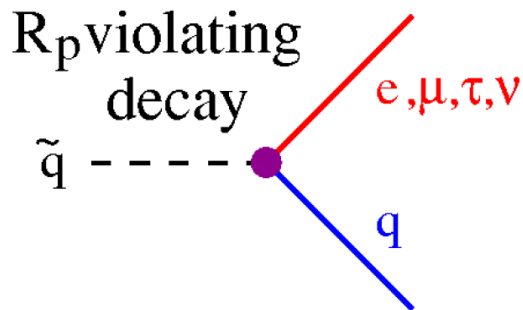
The energy frontier before LHC...



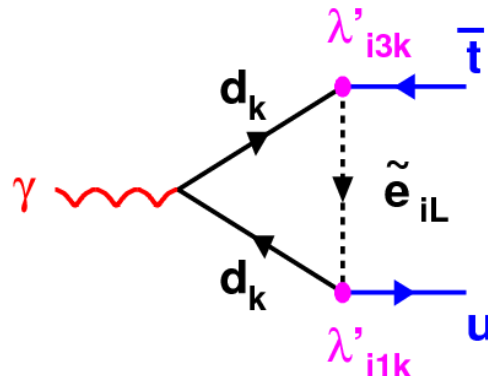
Final states with combinations of ...

- High- P_T Isolated Leptons
- High- P_T Jets
- Missing Energy

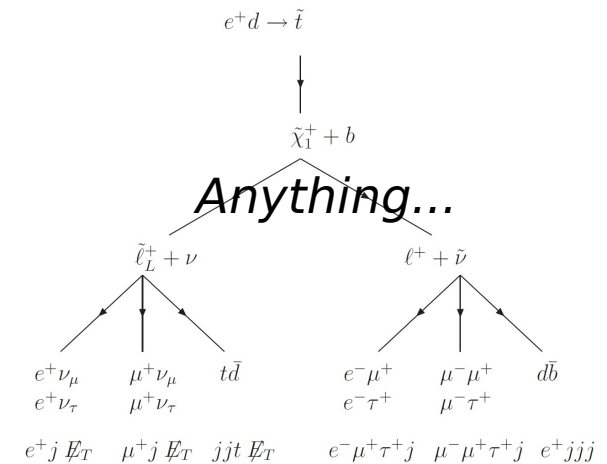
In this talk:



Leptoquarks



Single top Production



General Search



- Leptoquark Models explored in B-R-W Framework: 7 Scalar LQ, 7 Vector LQ
- Two 1. gen. leptoquarks compatible with squarks decaying via RPV

$$\tilde{S}_{1/2,L}$$

U-type squark

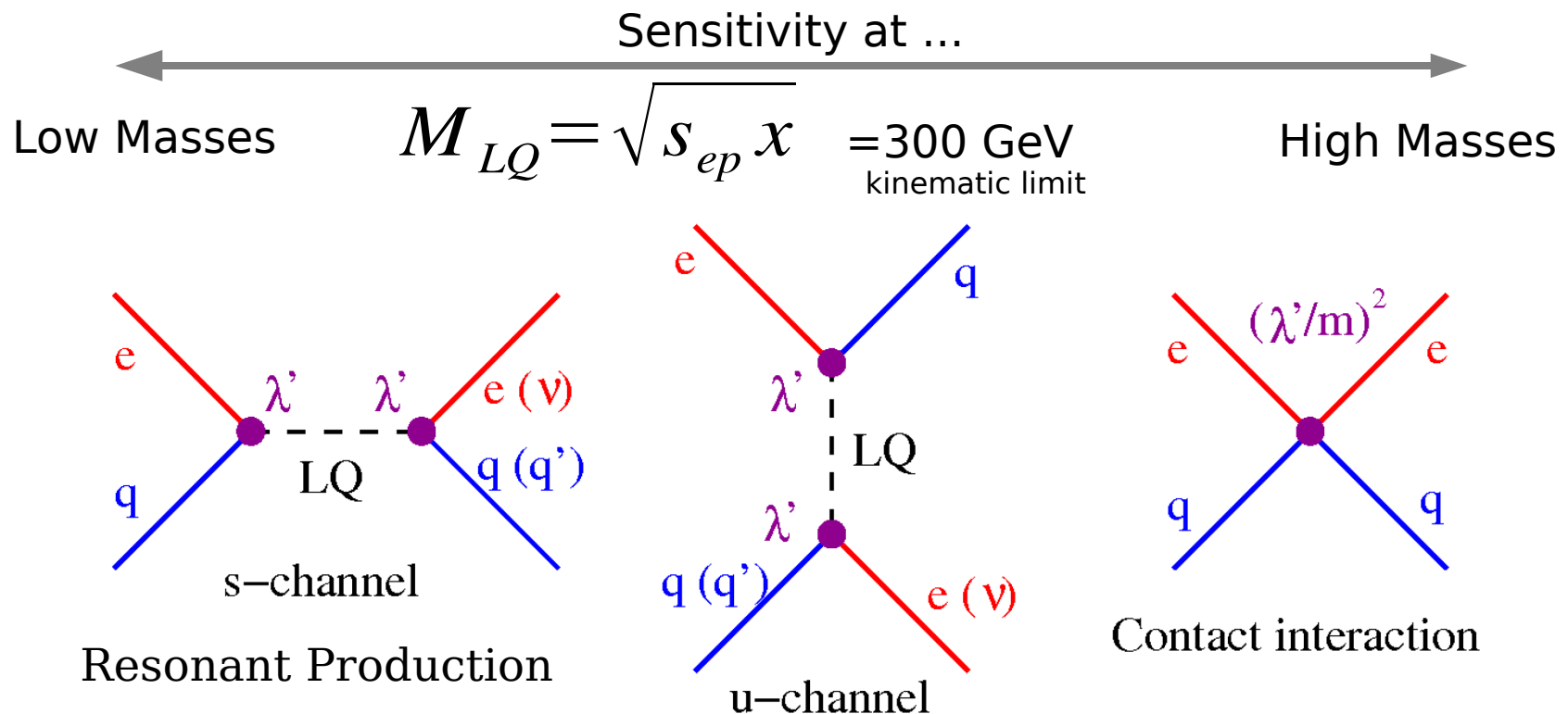
$$e^+ d \xrightarrow{\lambda'_{ij1}} \tilde{u}_{j,L} \rightarrow e^+ d$$

$$S_{0,L}$$

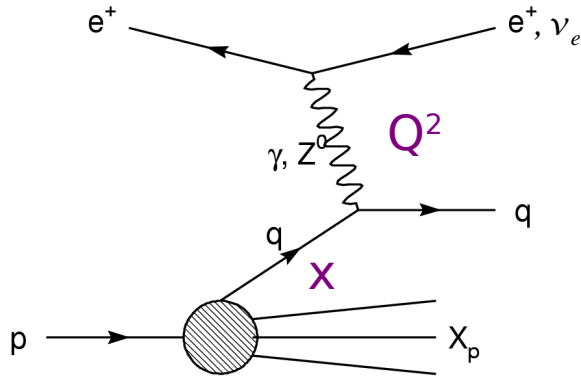
D-type squark

$$e^- u \xrightarrow{\lambda'_{11k}} \tilde{d}_{k,R} \rightarrow e^- u$$

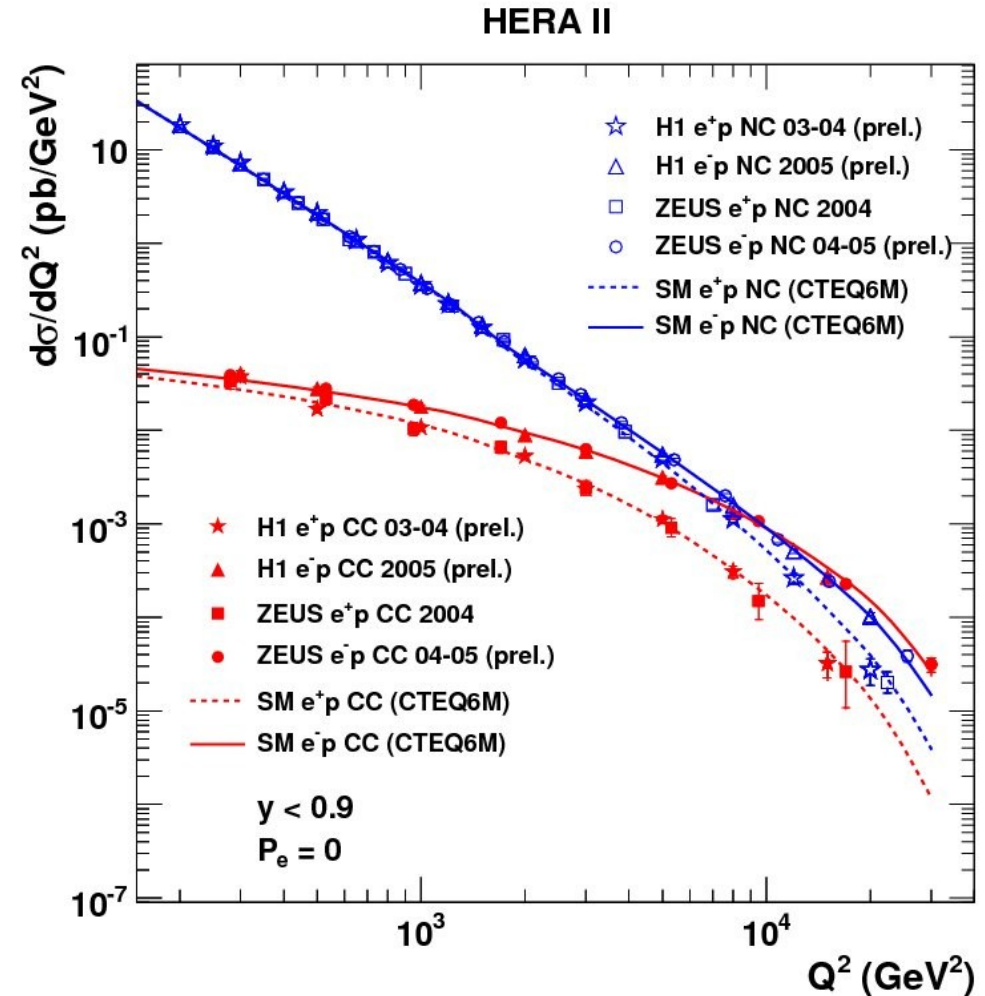
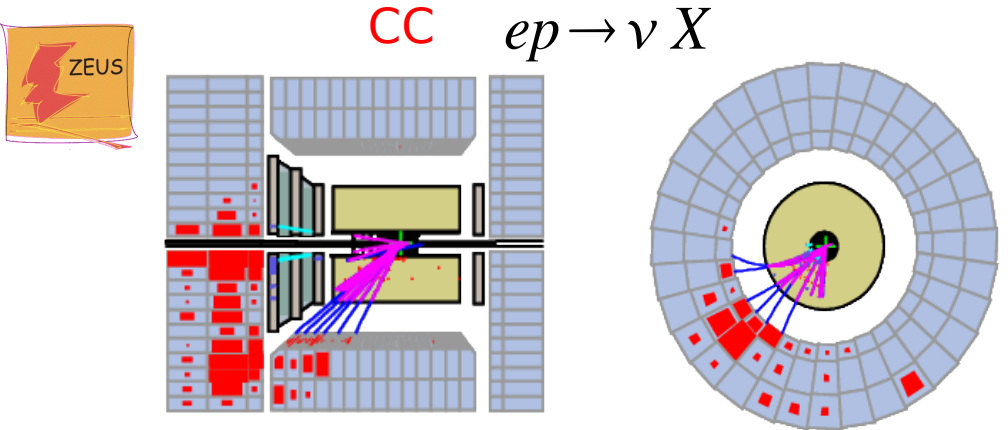
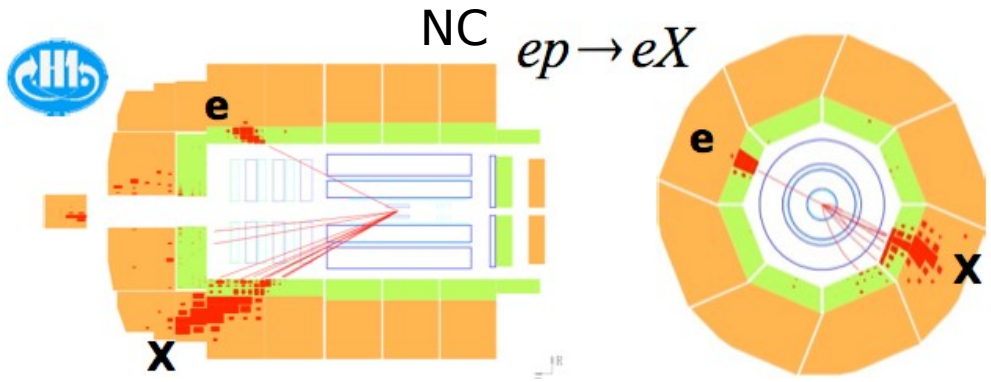
$$e^- u \xrightarrow{\lambda'_{11k}} \tilde{d}_{k,R} \rightarrow \nu d$$



Background from the SM: NC and CC in DIS



- Neutral Current and Charged Current described to very high Q^2
- Same signature as 1. gen. Leptoquarks
- Irreducible background
- Look for deviations from cross section



Limits on Squark Mass from Leptoquark Search

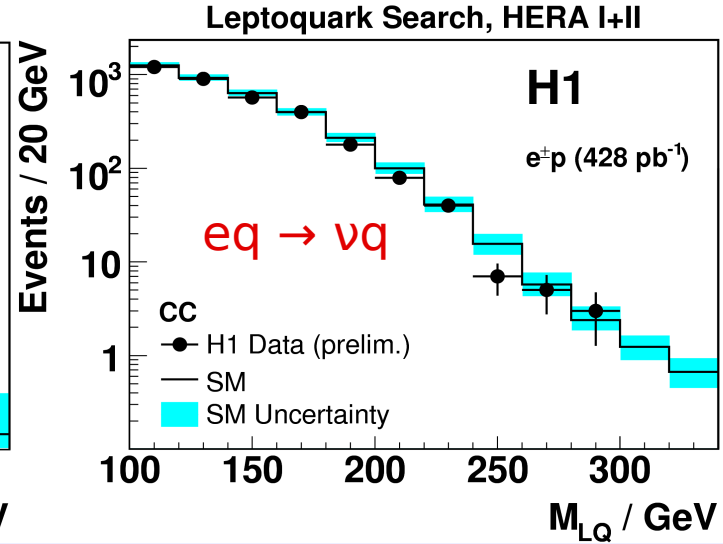
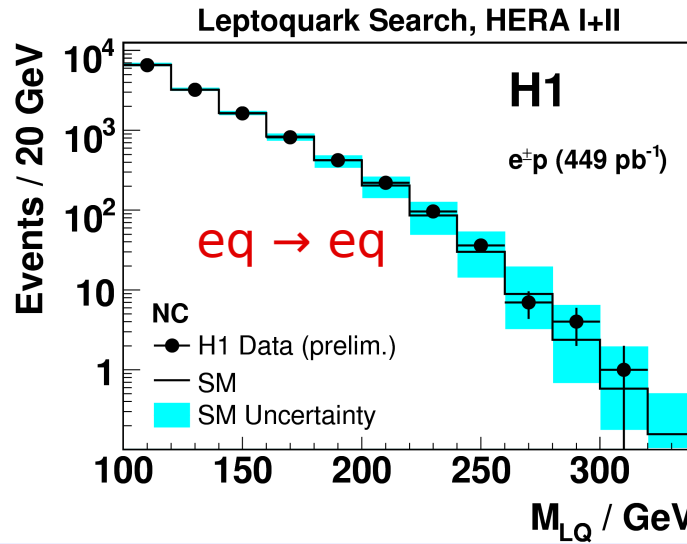


- Reconstruct

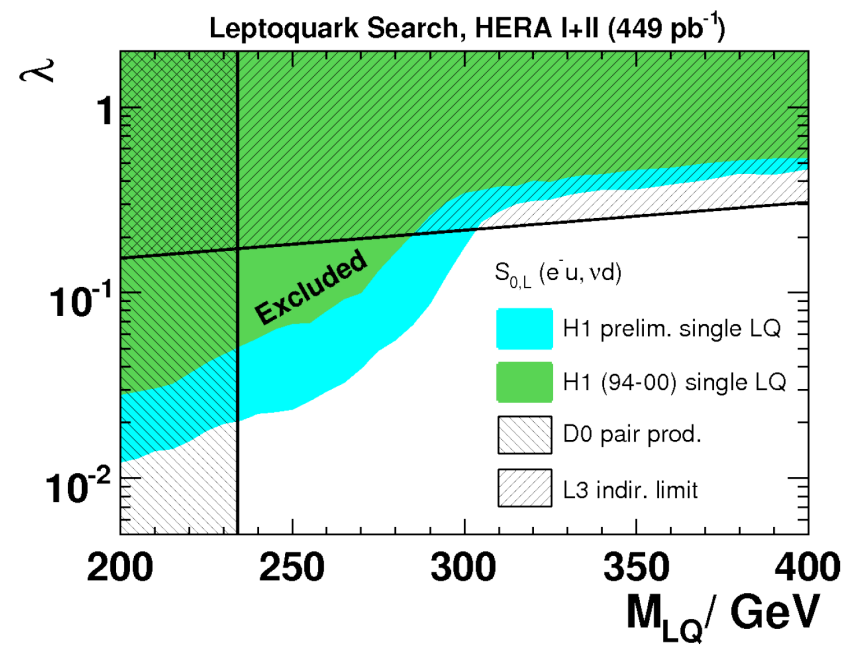
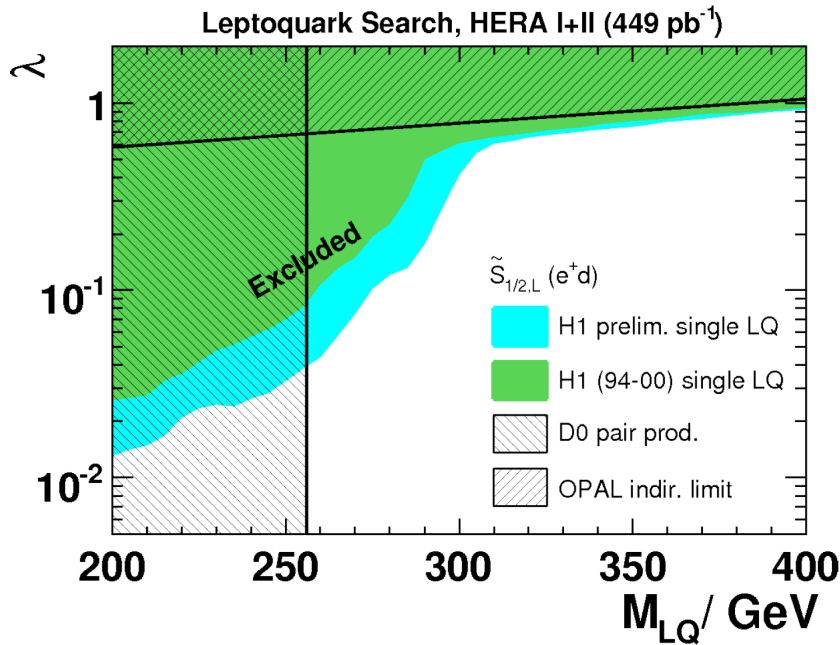
$$M_{LQ} = \sqrt{s_{ep} x}$$

- No deviations from SM

- Set limits



LQ limits valid for squarks if $Br(RPV) \approx 100\%$ or $M_{LQ} > 300$ GeV



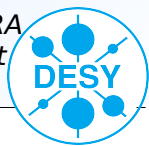
Similar constraints from fit to cross section (ZEUS)

$$M_{\tilde{S}_{1/2,L}} / \lambda_{LQ} \equiv M_{\tilde{u}_{j,L}} / \lambda'_{1j1} > 0.96 \text{ TeV}$$

$$M_{S_{0,L}} / \lambda_{LQ} \equiv M_{\tilde{d}_{k,R}} / \lambda'_{11k} > 0.44 \text{ TeV}$$

95%CL

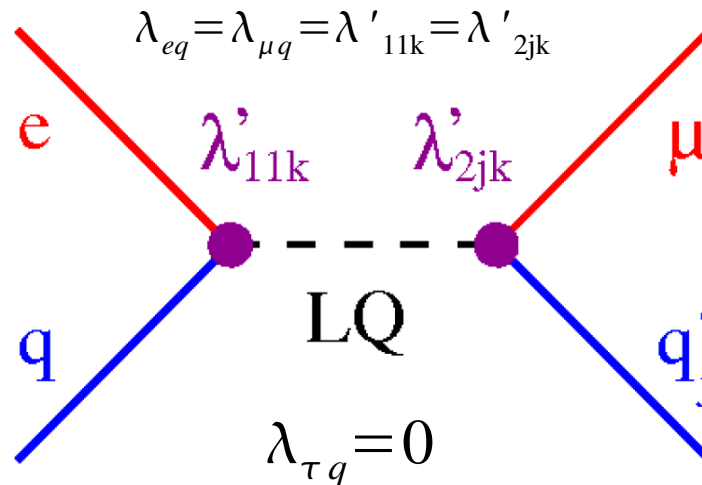
Lepton-Flavour Violating Leptoquarks



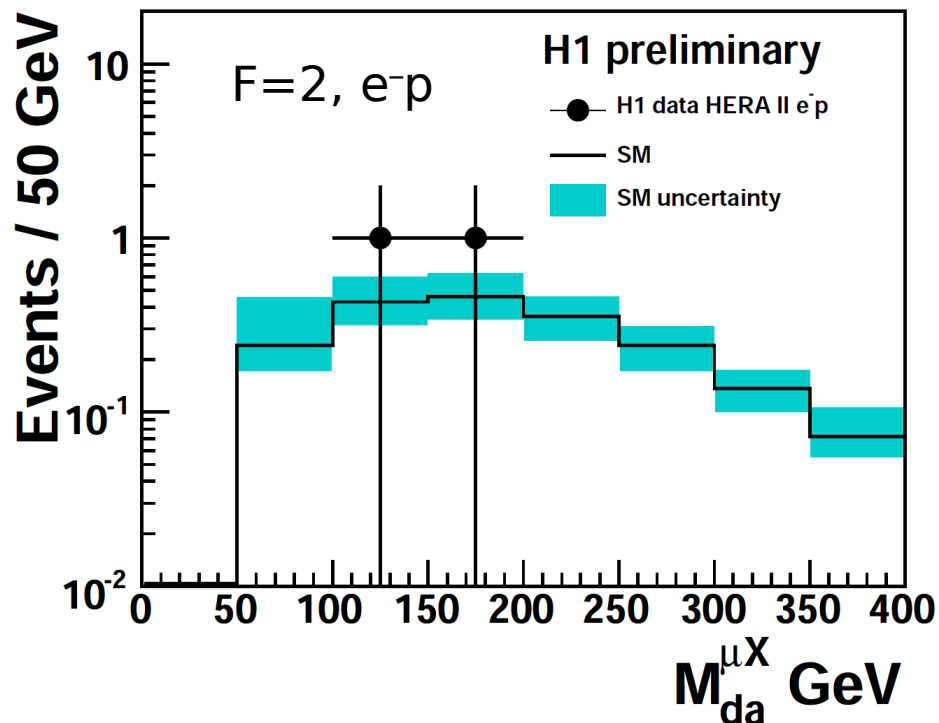
- Probe off-diagonal couplings
- Recent update for 2nd generation

$$\lambda_{\mu q} = \lambda'_{2jk}$$

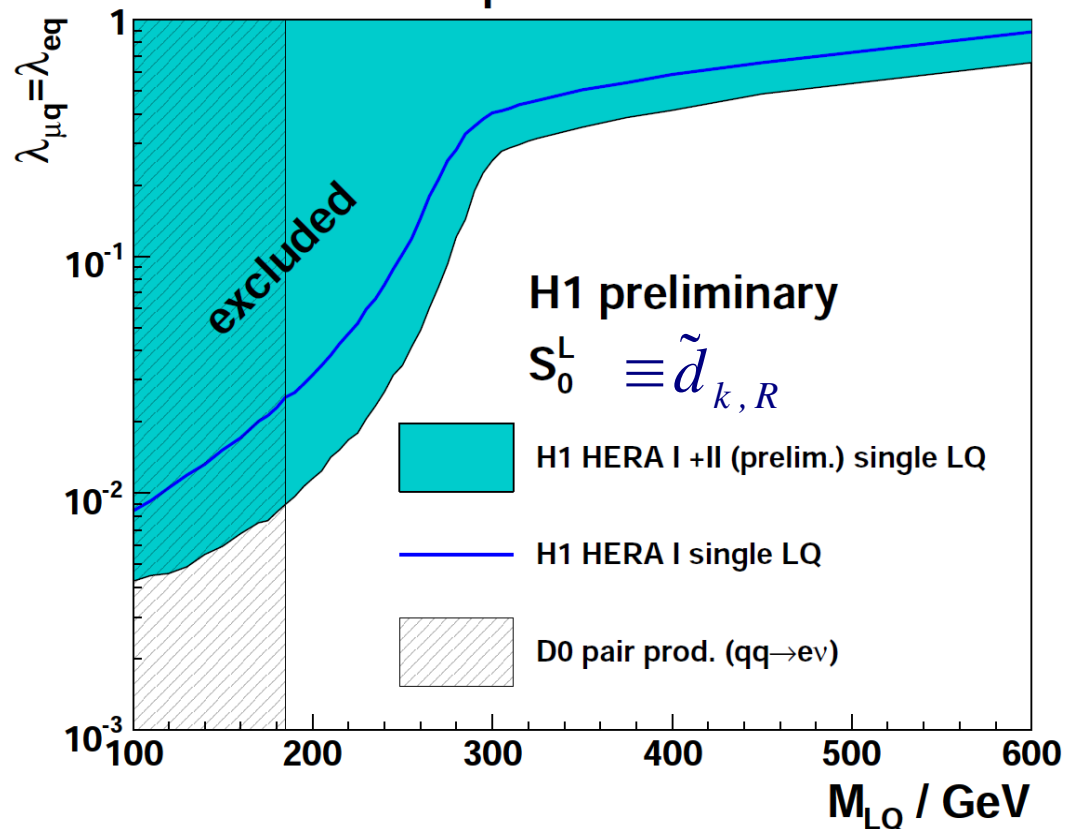
- Look for $ep \rightarrow \mu X$
- 2 obs. / 2.2 ± 0.6 exp.,
- Set limits



Search for Lepton Flavour Violation



Search for Lepton Flavour Violation

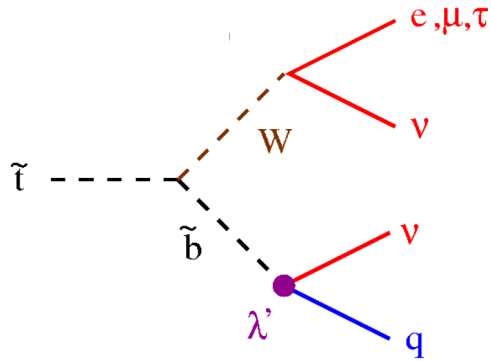




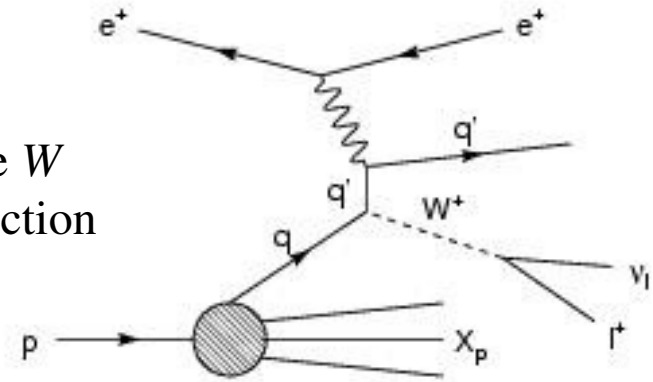
- Search for events with Isolated Leptons ($P_T > 10$ GeV) and Missing Energy ($P_T > 12$ GeV)

Many Ideas eg.: ~

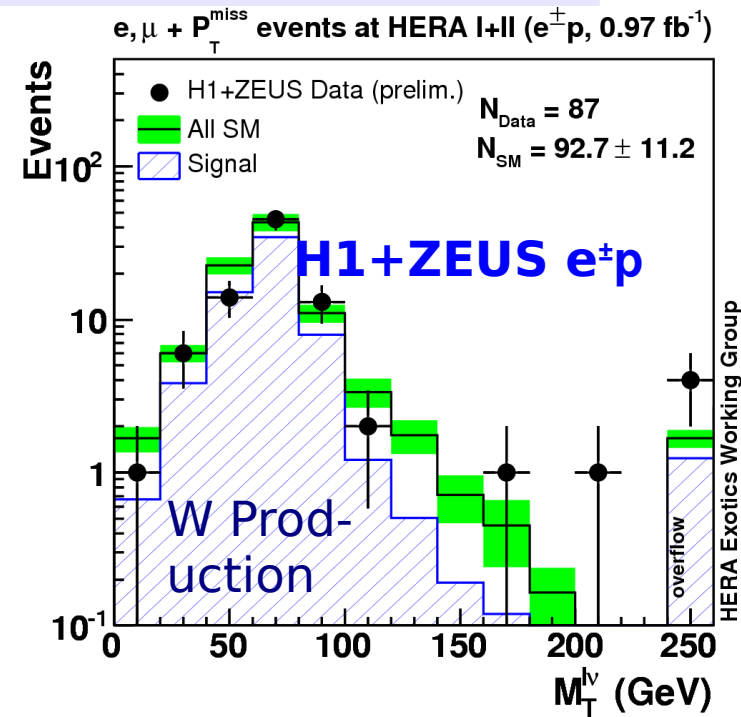
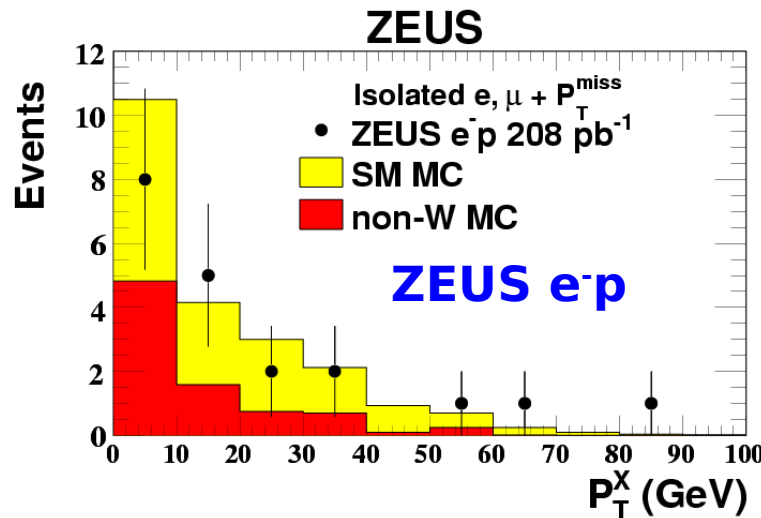
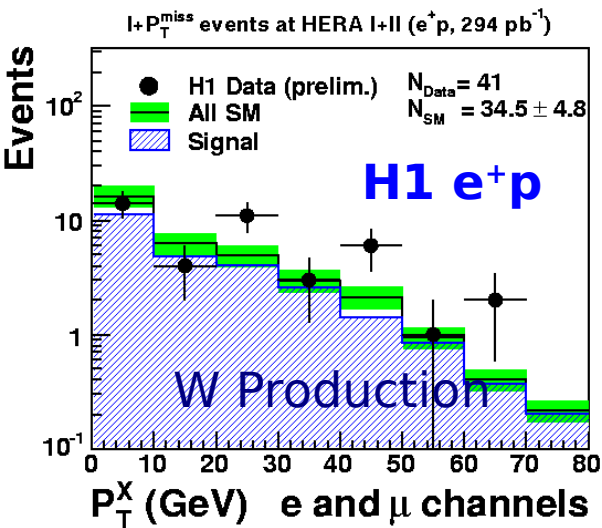
- bosonic t
- FCNC top



SM:
Single W
Production



- Interesting events at high hadronic $P_T^X > 25$ GeV observed
- Overall: Good agreement with SM, Measurement of Single W Production

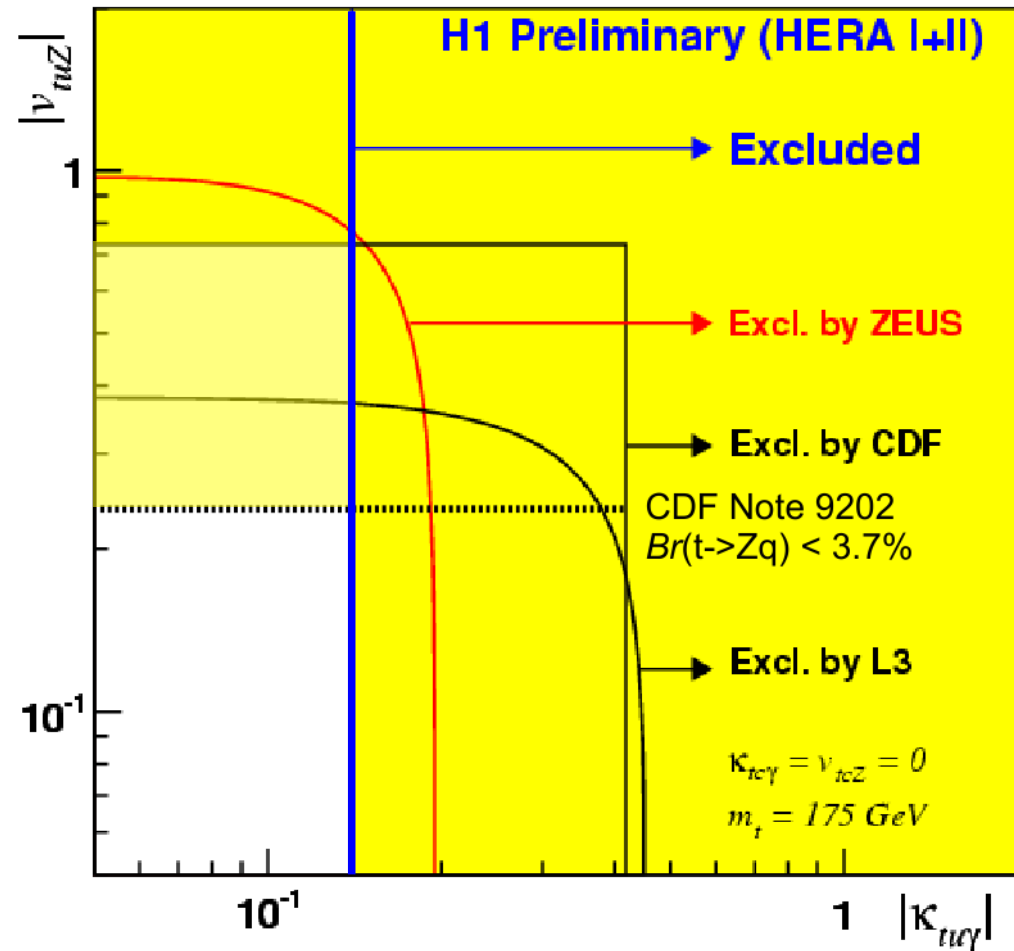
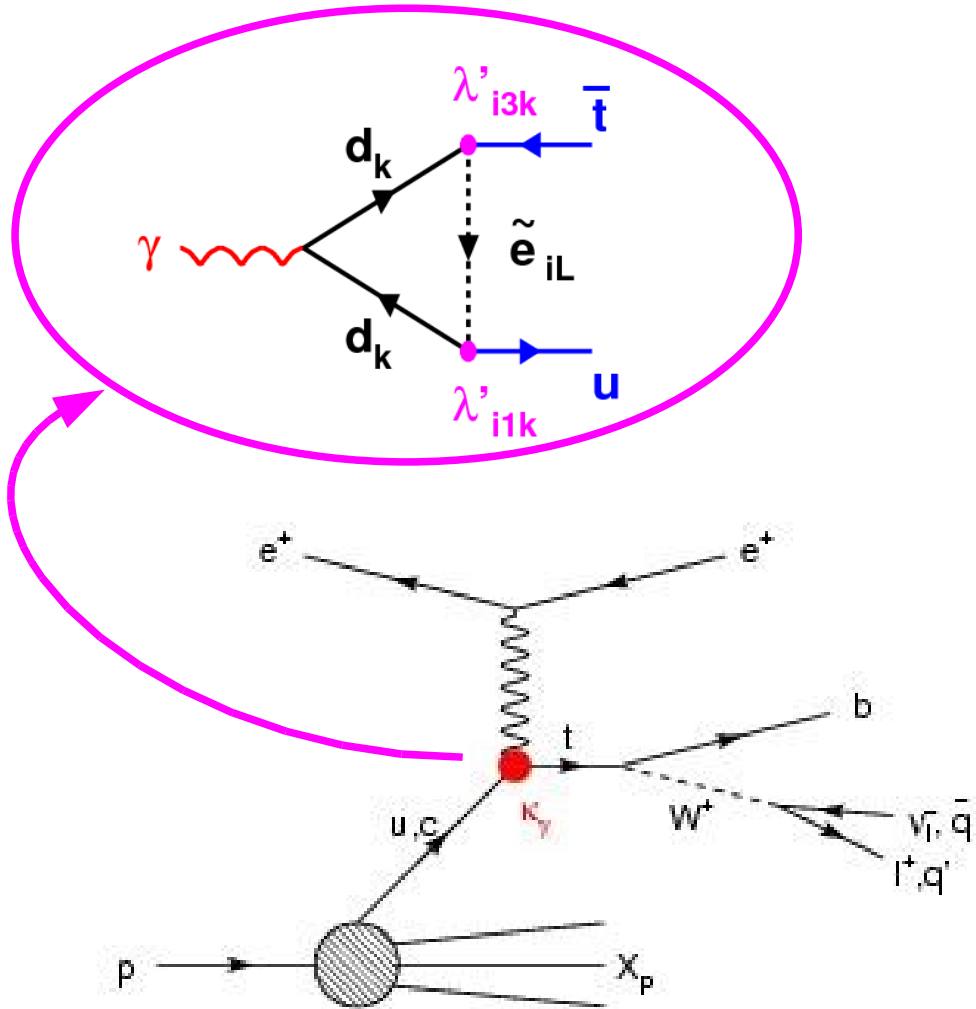


Search for Anomalous Single *top* Production

- At high P_T^X isolated leptons signature compatible to anomalous single top production via FCNC
- Study using effective couplings $K_{tu\gamma}$, V_{tuZ}
- SUSY one possibility

- Reconstruct *top* in isolated leptons samples
- No significant excess observed
- Set limits

Exchange of slepton?



HERA Limits on $K_{tu\gamma}$ explore new domain



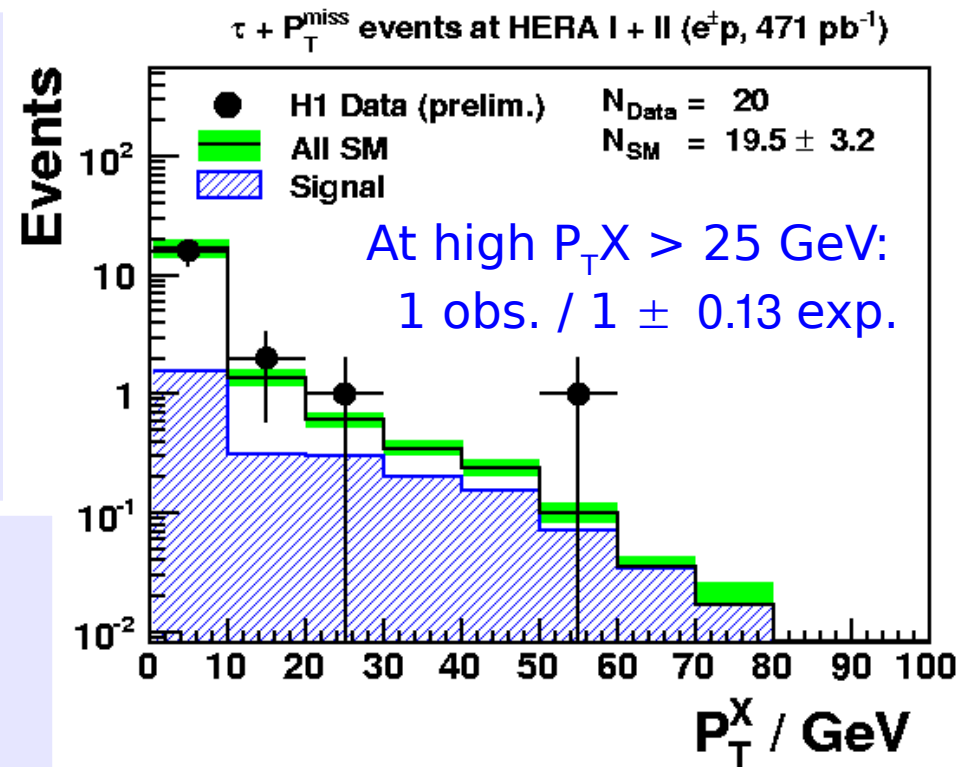
- SM** - Lepton universality: tau leptons produced like e / μ
- SUSY** - RPV couplings connect different generations
- In many scenarios LSP $\tilde{\tau}_1 \rightarrow \tau \nu_i$

Search for isolated tau leptons at HERA

Look for hadronic 1-prong tau-decays in events with P_T^{miss}

- High $P_T > 7 \text{ GeV}$
- Narrow Jet $R_{\text{jet}} < 0.12$
- Exactly one track

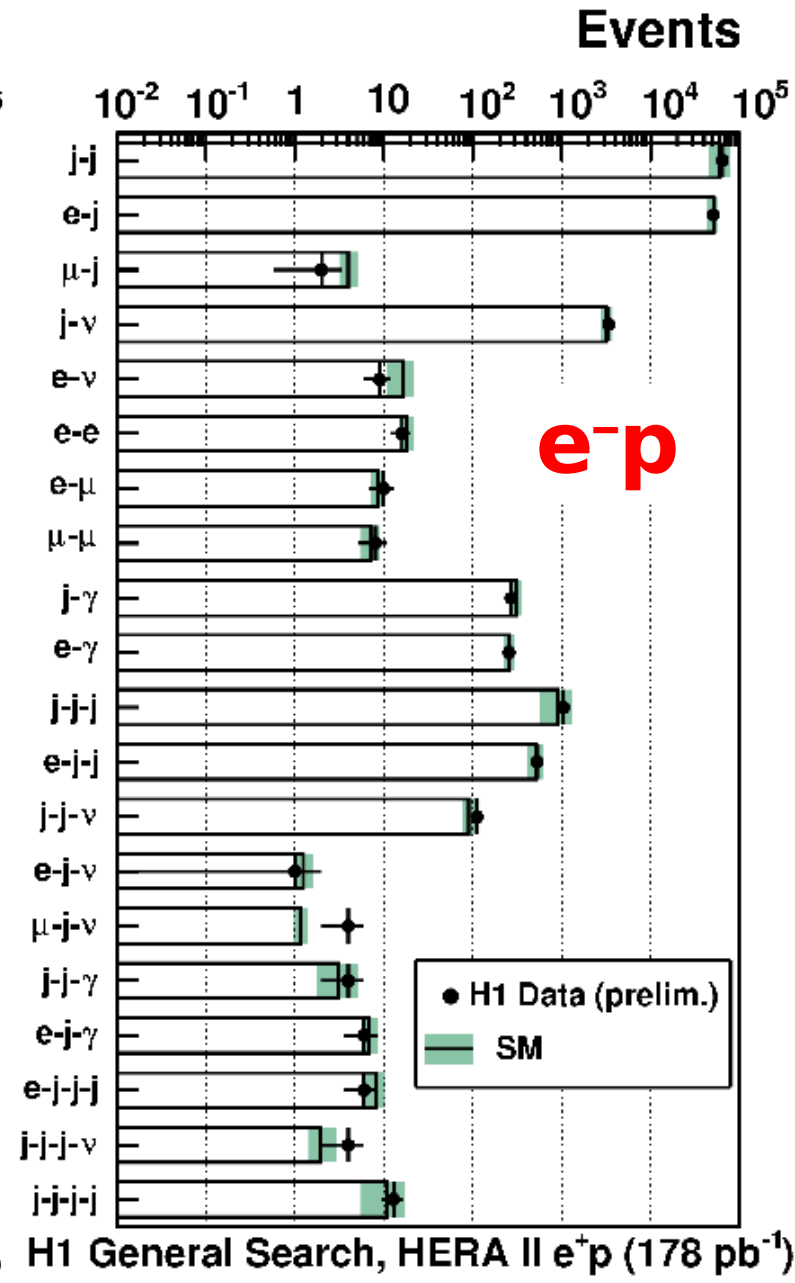
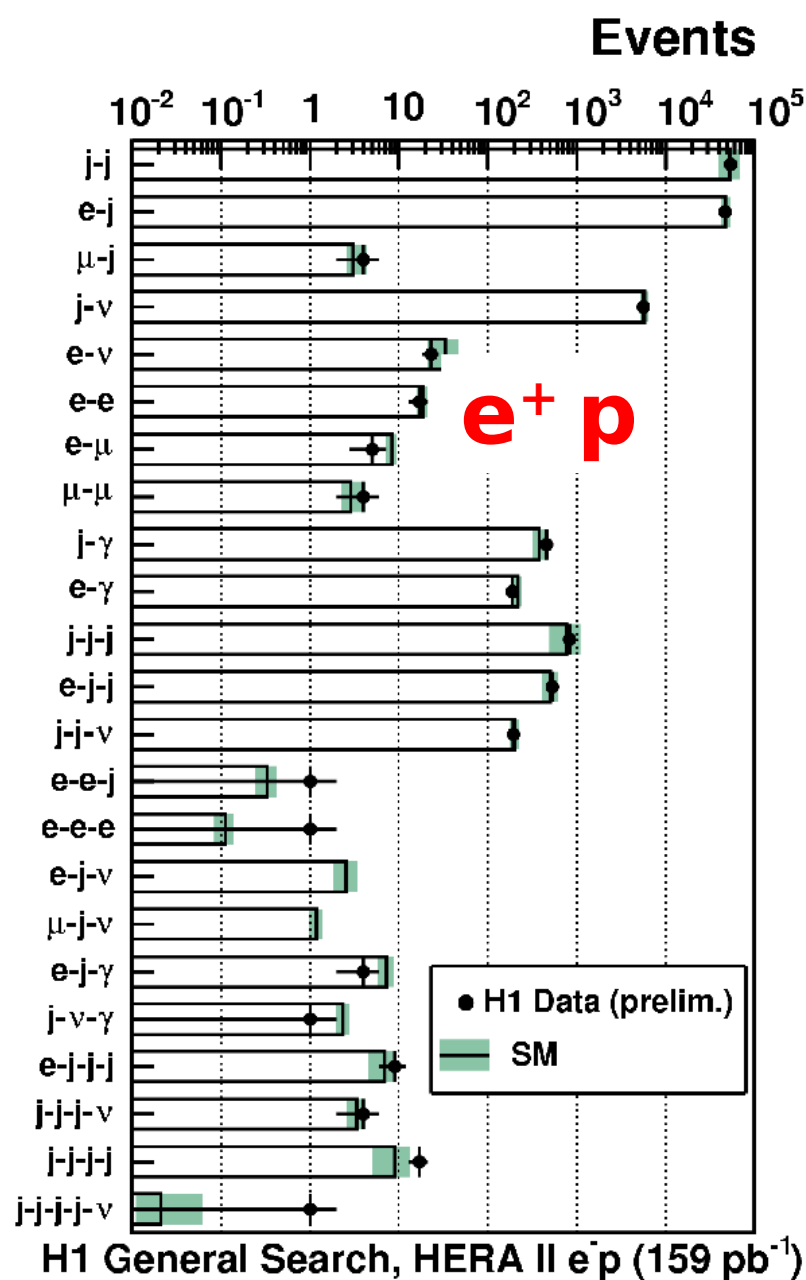
- Challenging hadronic environment
- Small tau production cross section in SM (W Production 1 pb^{-1})
- Expectation dominated by CC background
- H1 HERA I+II:
No sign for (enhanced) tau lepton production



ZEUS HERA-I:
2 / 0.2 ± 0.05 at $P_T^X > 25 \text{ GeV}$

Look at many final states with objects at high $P_T > 20$ GeV

- Good agreement in all channels
- Automatic scan to find deviations in all search channels
- Interesting events found again
- Data fluctuations compatible with expectations





Summary

- HERA – a unique testing ground for RPV SUSY at the energy frontier
- Look for deviations inclusively: *LQ, CI, ...*
- Many topologies covered: *Leptons (incl. Tau), Jets, MET, ...*
- Signature Searches or Phenomenological Models covered

Good agreement with the Standard Model

Outlook

- Dedicated SUSY Interpretations and Parameter Scans underway
- Exploit full HERA data and do H1/ZEUS combinations

SUSY Searches at HERA an active field

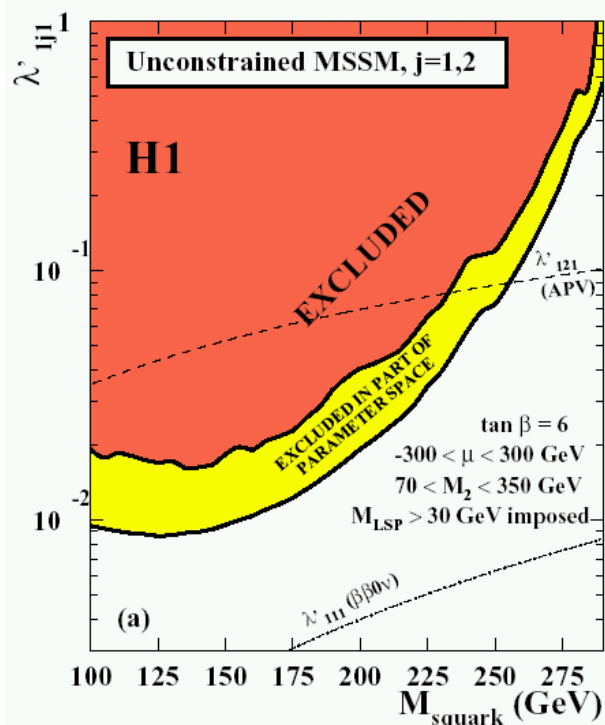
Expect improved, significant constraints on SUSY from HERA ...



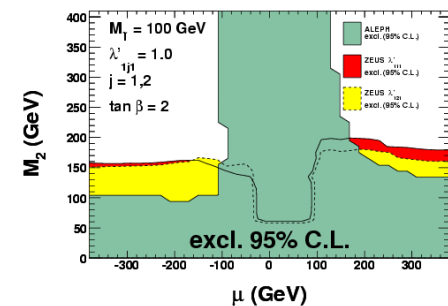
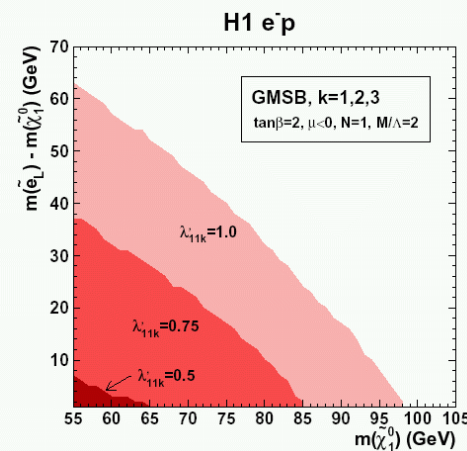
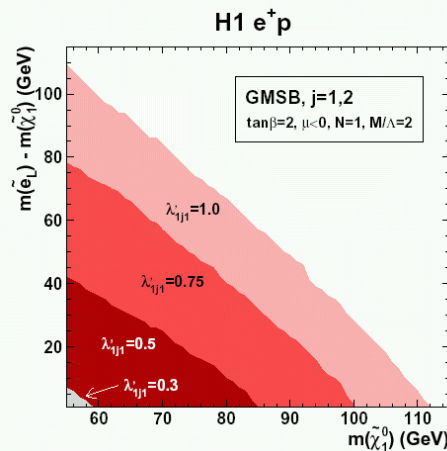
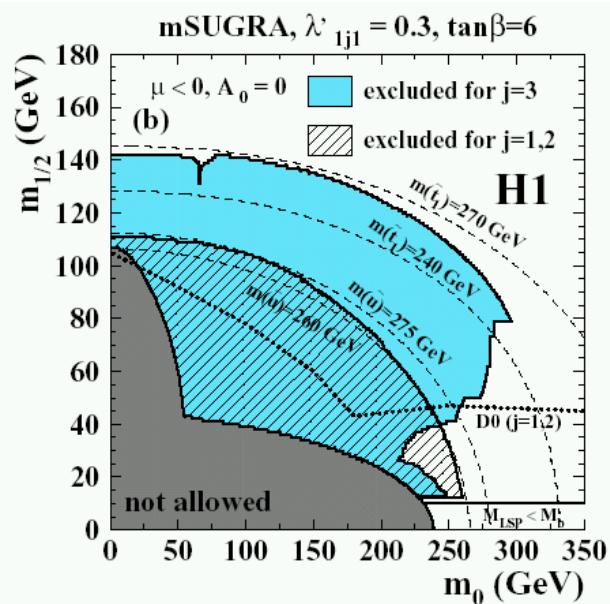
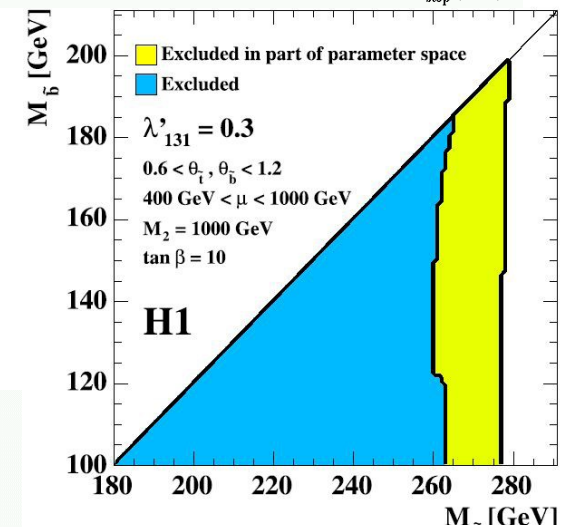
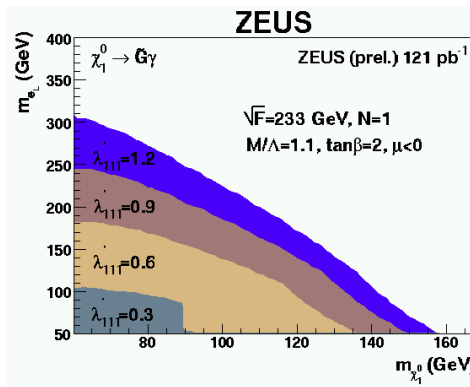
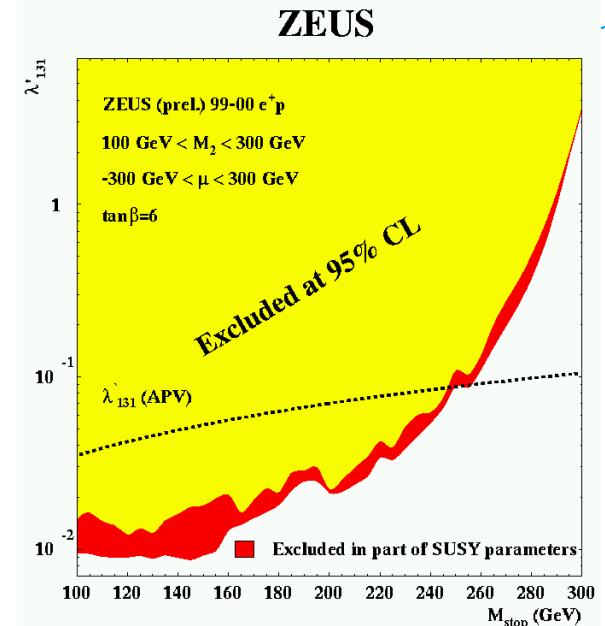
BACKUP

SLIDES

Reminder: SUSY Searches in HERA-I Data



- RPV SUSY Parameter Scan
- mSUGRA
- Stop decays
- Search for gauginos
- Search for gravitinos





- R-Parity $R_p = (-1)^{3B+L+3S}$ violated
- Unstable LSP
- Proton stable: One non-zero coupling λ'_{ijk}

$$W_{RPV} = \lambda'_{ijk} L_i Q_j \bar{D}_k$$

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks ($\times 3$ families)	Q	$(\tilde{u}_L \tilde{d}_L)$	$(u_L d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
	\bar{u}	\tilde{u}_R^*	u_R^\dagger	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	\bar{d}	\tilde{d}_R^*	d_R^\dagger	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons ($\times 3$ families)	L	$(\tilde{\nu} \tilde{e}_L)$	(νe_L)	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
	\bar{e}	\tilde{e}_R^*	e_R^\dagger	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H_u^+ H_u^0)$	$(\tilde{H}_u^+ \tilde{H}_u^0)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H_d^0 H_d^-)$	$(\tilde{H}_d^0 \tilde{H}_d^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$



Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	\tilde{g}	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\tilde{W}^\pm \tilde{W}^0$	$W^\pm W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	\tilde{B}^0	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0 H_d^0 H_u^+ H_d^-$	$h^0 H^0 A^0 H^\pm$
squarks	0	-1	$\tilde{u}_L \tilde{u}_R \tilde{d}_L \tilde{d}_R$	(same)
			$\tilde{s}_L \tilde{s}_R \tilde{c}_L \tilde{c}_R$	(same)
			$\tilde{t}_L \tilde{t}_R \tilde{b}_L \tilde{b}_R$	$\tilde{t}_1 \tilde{t}_2 \tilde{b}_1 \tilde{b}_2$
sleptons	0	-1	$\tilde{e}_L \tilde{e}_R \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L \tilde{\mu}_R \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L \tilde{\tau}_R \tilde{\nu}_\tau$	$\tilde{\tau}_1 \tilde{\tau}_2 \tilde{\nu}_\tau$
neutralinos	1/2	-1	$\tilde{B}^0 \tilde{W}^0 \tilde{H}_u^0 \tilde{H}_d^0$	$\tilde{N}_1 \tilde{N}_2 \tilde{N}_3 \tilde{N}_4$
charginos	1/2	-1	$\tilde{W}^\pm \tilde{H}_u^\pm \tilde{H}_d^\pm$	$\tilde{C}_1^\pm \tilde{C}_2^\pm$
gluino	1/2	-1	\tilde{g}	(same)
goldstino (gravitino)	1/2 (3/2)	-1	\tilde{G}	(same)



- BRW Models: 7 Scalar, 7 Vector LQs
- Certain Scalar LQs correspond to squarks

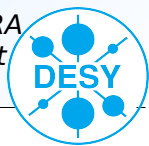
	e-p			e+p		
	$F = 2$	Prod./Decay	β_e	$F = 0$	Prod./Decay	β_e
	Scalar Leptoquarks					
$\tilde{d}_{k,R}$	$S_{0,L}$	$e_L^- u_L \rightarrow e^- u$ $\rightarrow \nu d$	1/2 1/2	$S_{1/2,L}$	$e_R^+ u_R \rightarrow e^+ u$	1
	$S_{0,R}$	$e_R^- u_R \rightarrow e^- u$	1	$S_{1/2,R}$	$e_L^+ u_L \rightarrow e^+ u$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

$$e u \xrightarrow{\lambda'_{11k}} \tilde{d}_{k,R} \rightarrow e^- u$$

$$e u \xrightarrow{\lambda'_{11k}} \tilde{d}_{k,R} \rightarrow \nu d$$

$$e u \xrightarrow{\lambda'_{1j1}} \tilde{u}_{j,L} \rightarrow e^+ d$$

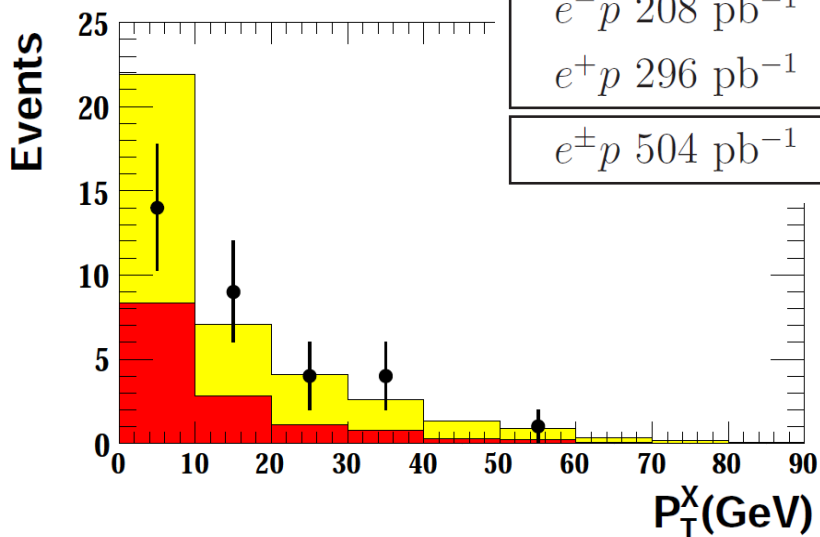
Generic LQ couplings λ'_{ij}
correspond to W_{RPV} couplings λ'_{ijk}



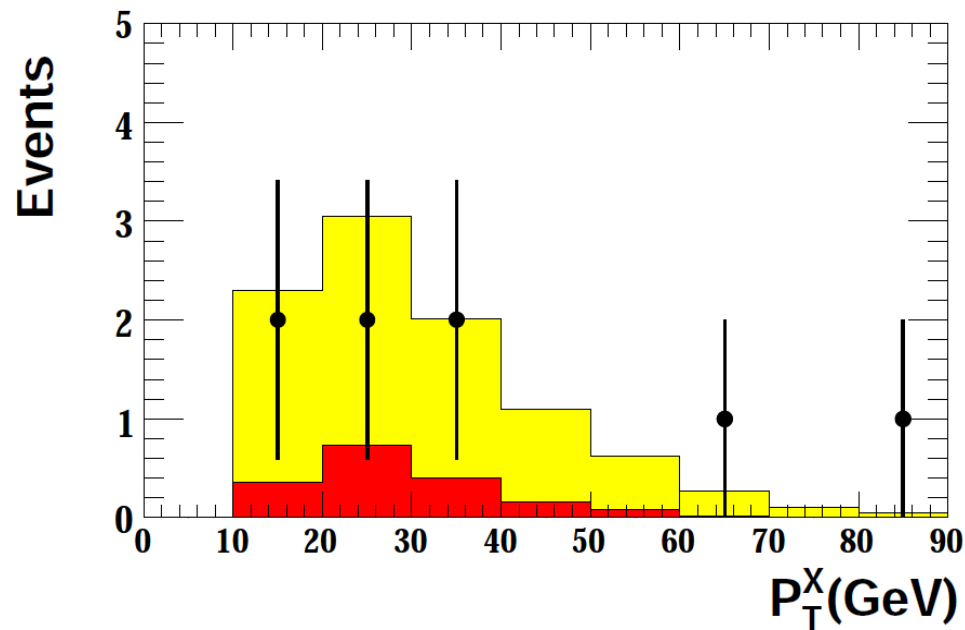
arXiv:0807.0589

Isolated Lepton Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb $^{-1}$	9/11.3 \pm 1.5 (54%)	6/5.1 \pm 0.7 (67%)	5/5.5 \pm 0.8 (75%)
e^+p 296 pb $^{-1}$	7/12.6 \pm 1.7 (68%)	7/6.2 \pm 0.9 (75%)	6/7.4 \pm 1.0 (79%)
$e^\pm p$ 504 pb $^{-1}$	16/23.9 \pm 3.1 (61%)	13/11.2 \pm 1.5 (71%)	11/12.9 \pm 1.7 (77%)

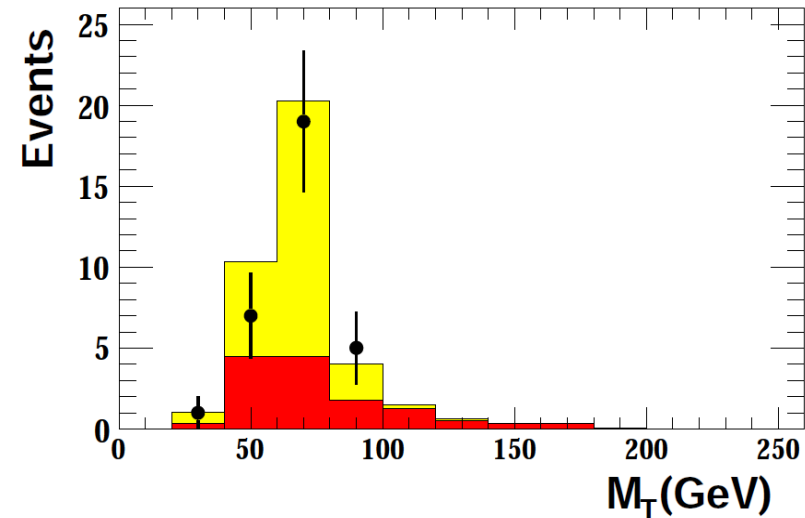
e Channel



μ Channel

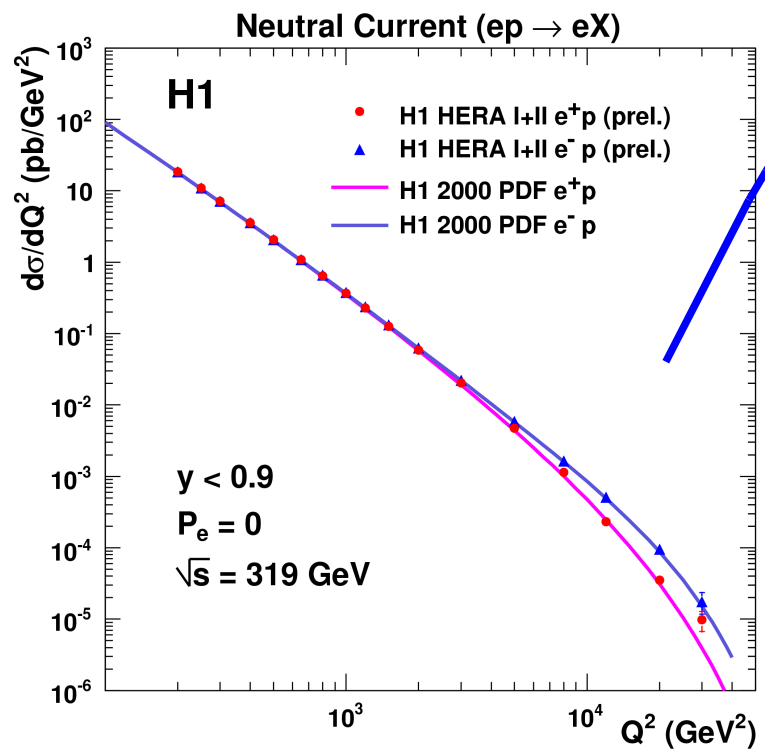
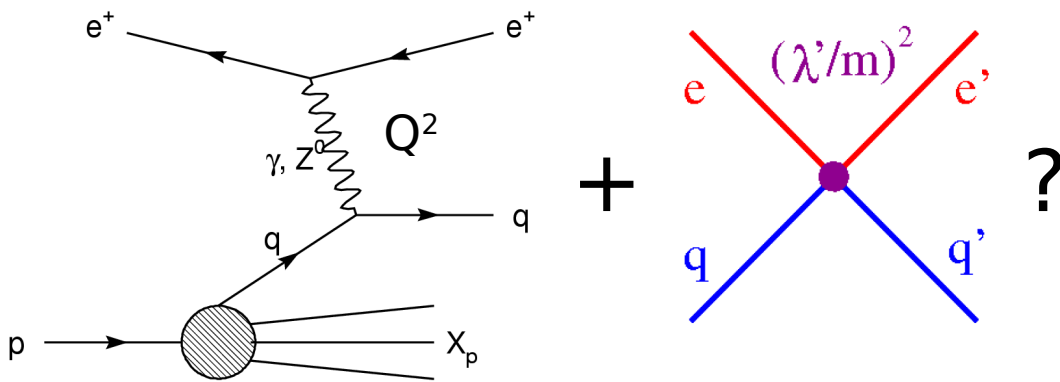


- ZEUS 504 pb $^{-1}$
- SM MC
- non-W MC

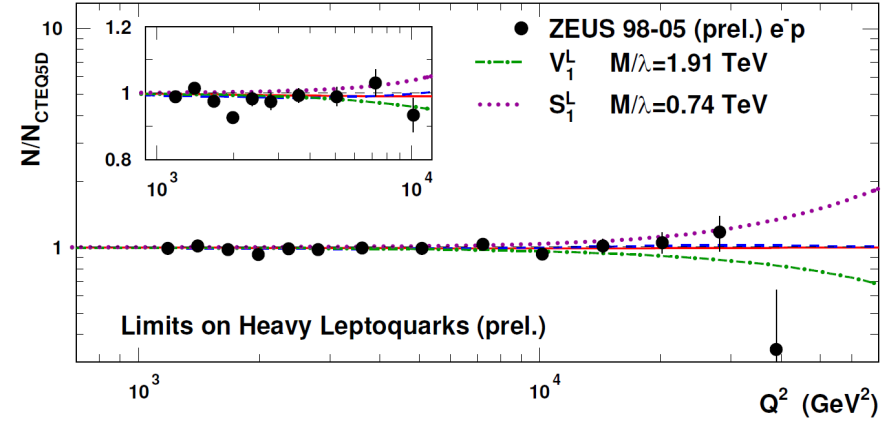
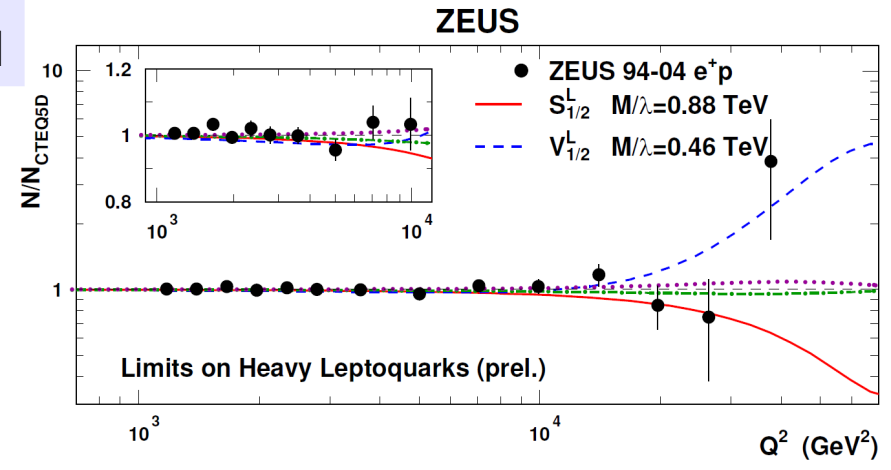


LQ/SUSY Limits from Contact Interactions

- Measure NC DIS Cross Section $d\sigma/dQ^2$
- Fit to extra terms on Lagrangian for LQ / CI



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



$$M_{\tilde{S}_{1/2,L}} / \lambda_{LQ} \equiv M_{\tilde{u}_{j,L}} / |\lambda'_{1j1}| > 0.96 \text{ TeV}$$

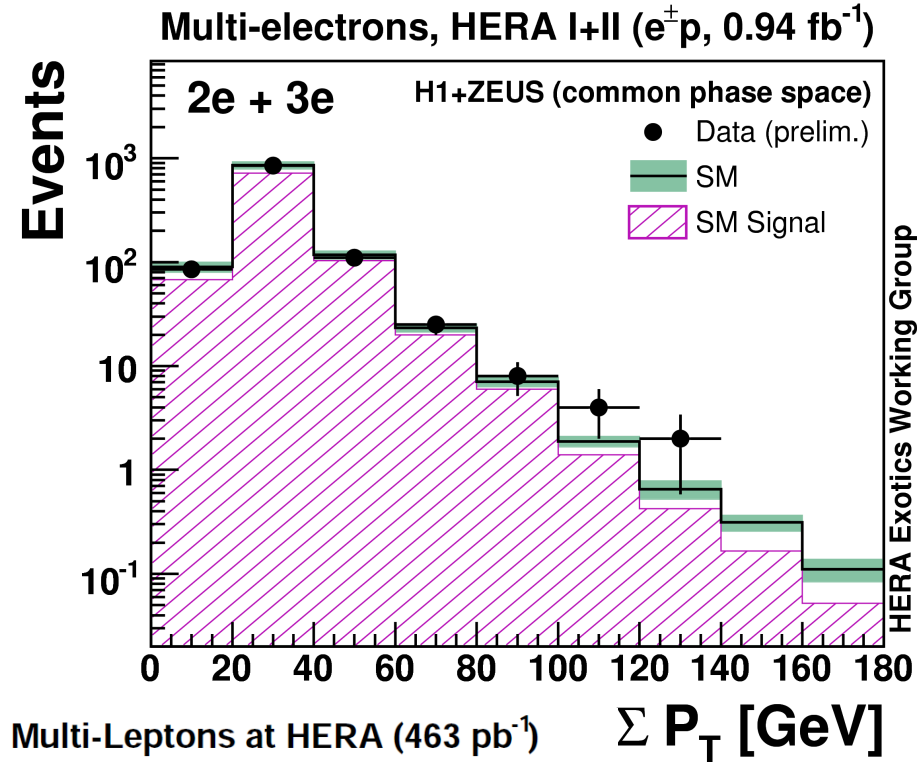
$$M_{S_{0,L}} / \lambda_{LQ} \equiv M_{\tilde{d}_{k,R}} / |\lambda'_{11k}| > 0.44 \text{ TeV}$$

95%CL

Study multitude of lepton topologies

$ee(e), \mu\mu(e), e\mu, ee\mu, \dots$

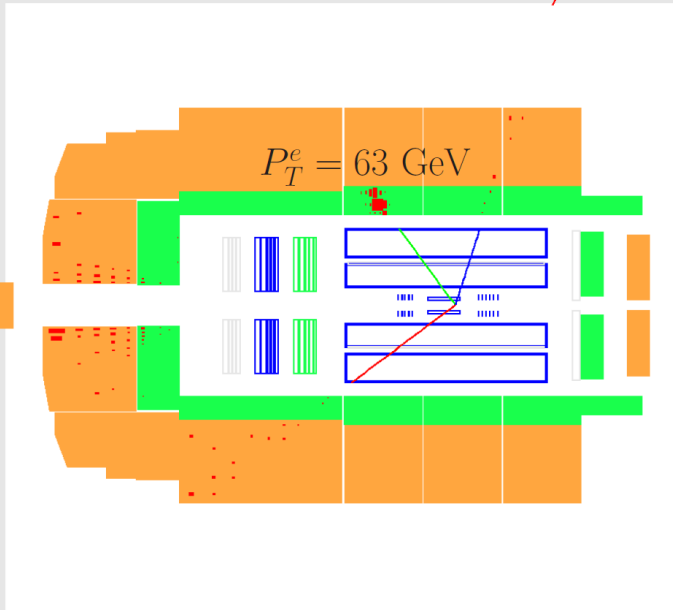
- Sensitive to exotic resonances like H^{++} in L—R symmetric models / SUSYLR
- Combined H1 and ZEUS results for $ee(e)$
- Overall good agreement with SM
- Some intriguing events observed at high P_T / high inv. mass



H1

$$P_T^\mu = 2.8 \text{ GeV}$$

$$P_T^e = 63 \text{ GeV}$$



$$P_T^\mu = 61 \text{ GeV}$$

Multi-Leptons at HERA (463 pb^{-1})

ΣP_T [GeV]

