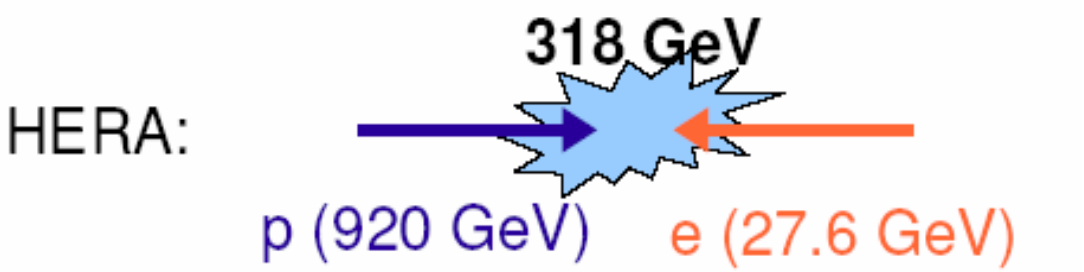
Searches for new Physics at HERA

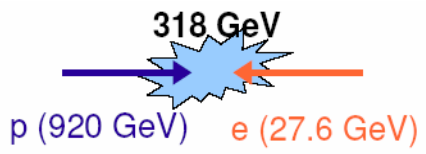


- HERA data & experiments
- Model – independent Search
- Single top & lepton + $P_{T,miss}$
- Supersymmetry
- Contact Interactions
- Excited Fermions

Peter Schleper
Hamburg University
Physics at LHC
Split, 30. Sept. 2008

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

HERA Perfomance



HERA– I : 1992 - 2000

- ~ 120 pb^{-1} per experiment, mostly e^+p

HERA– II: 2003 - 2007

Upgrade: luminosity & polarisation: e_L^-, e_R^-, e_L^+, e_R^+

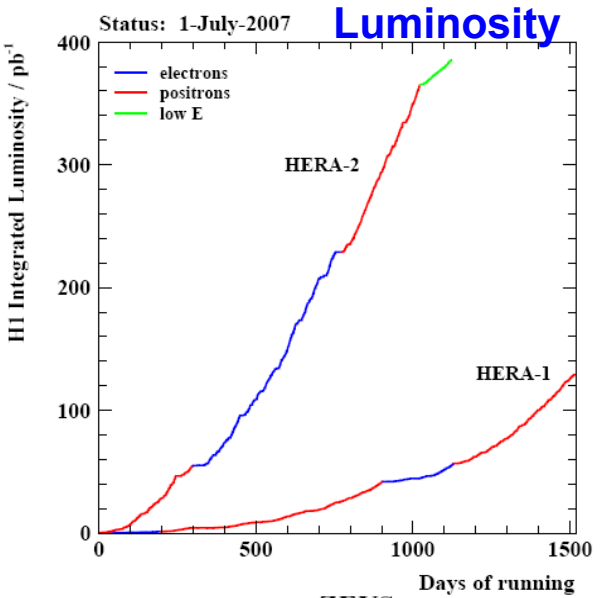
Recently: very good conditions

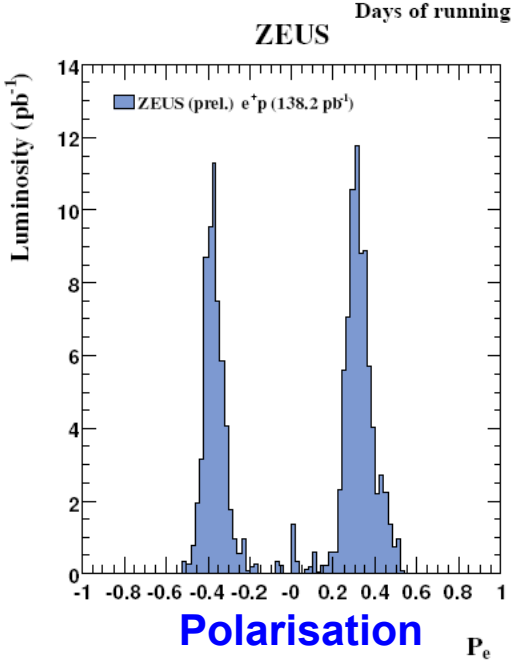
→ low background, stable beam conditions

→ high data taking efficiencies, low thresholds

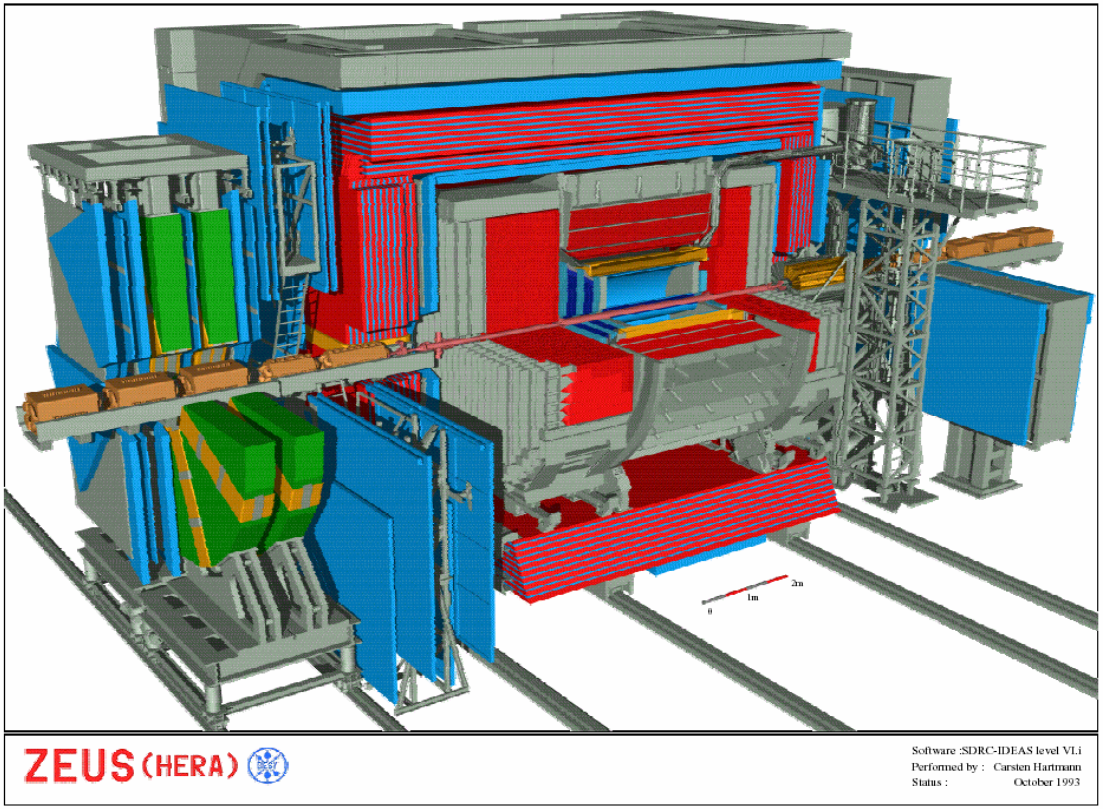
→ no major problems on central detectors

- polarisation
  - average ~ 40%
- electron & positron running
  - ~184 pb^{-1} e^-p
  - ~294 pb^{-1} e^+p
- luminosity HERA I & II
  - ~ 478 pb^{-1} per experiment, ~ 90 % at 320 GeV
- end of HERA running in June, 2007 → final data set





HERA Experiments: H1 & ZEUS



multi-purpose detectors

Tracking (B-Feld: 1.15 … 1.5 Tesla)

- 3 layers silicon vertex detectors
- central driftchambers (~60 hits)
- forward straw tubes or drift chambers

Calorimeters: hermetic up to $\eta < 3.5..4$

ZEUS: Uran-Szint. → compensating

- electrons: 18%/sqrt(E)
- hadrons: 35%/sqrt(E),

H1: Liquid Argon → high granularity

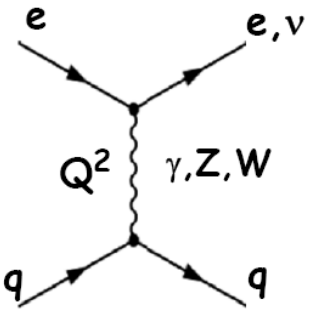
- electrons: 11%/sqrt(E)
- hadrons: 50%/sqrt(E)

Jets from tracks + calor. for $\eta < 1.5$

Muon chambers in return yoke

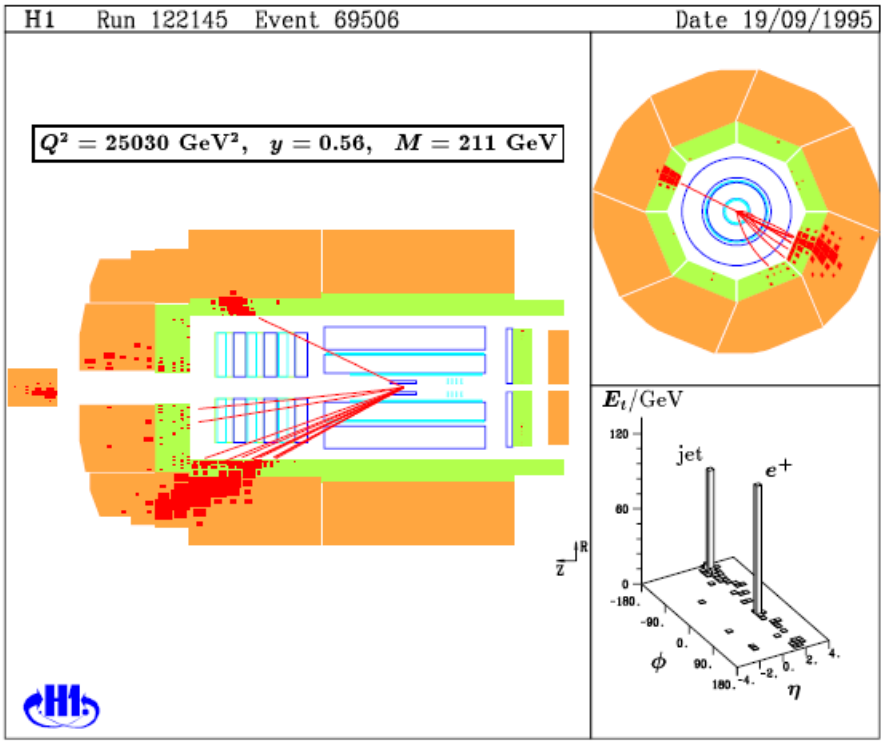
~ 10^8 ep collisions triggered by H1 & ZEUS

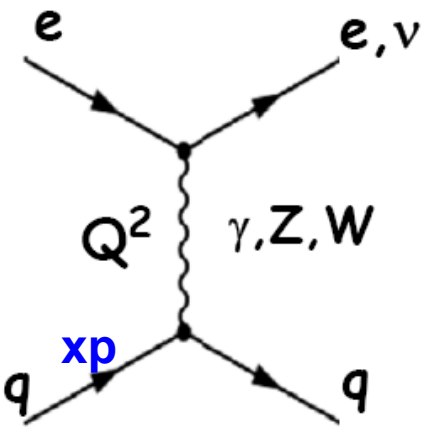
- 96 ns BC → 100 Hz trigger rate
- Thresholds: $P_T > 5$ … 10 GeV for electrons and jets
- Luminosity: ~ 1.6 …3.5 % precision
- Polarisation: ~ 3 ... 5 % precision



HERA data

Neutral current: γ,Z

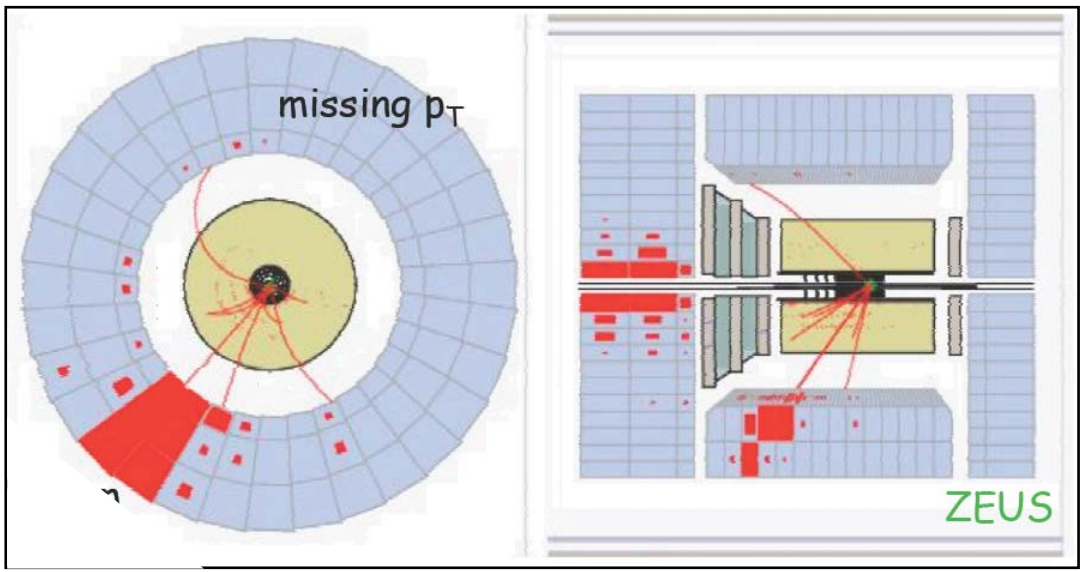




Q^2 up to ~ 40000 GeV^2

→ resolution ~ 0.001 fm

Charged current: W



Calorimeter E-scales:

kinematic constraints

on P_T and long. momentum

θ_e, $\theta_{hadrons}$ → E_e, P_{Te}, $P_{T,Hadronen}$

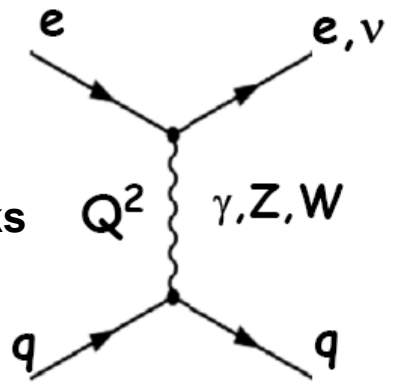
(c.f. γ+jet calibration at LHC)

→ 1% for electrons, 2…3 % for jets

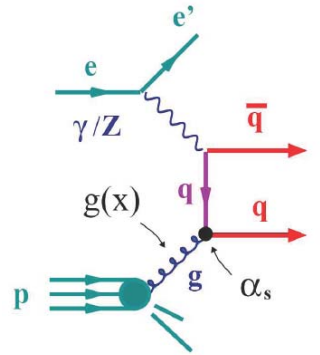
HERA data

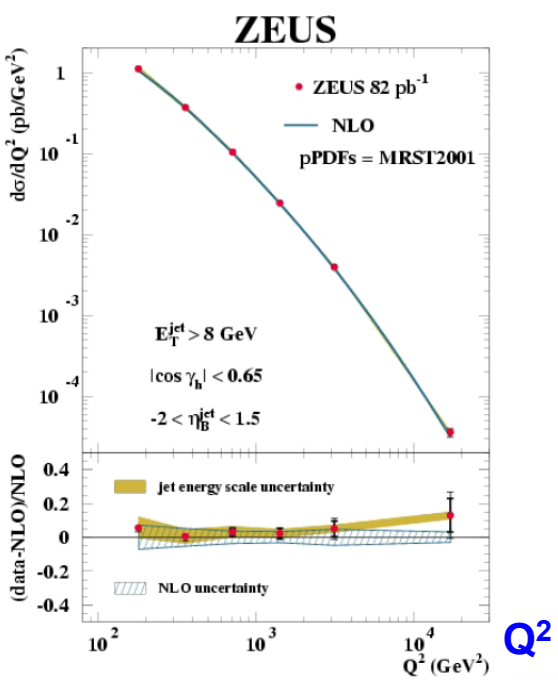
Inclusive measurements

- used for PDF determinations (low Q^2)
- Contact interaction analysis (high Q^2)
- Squarks in RP violating SUSY, leptoquarks
- dominant sources of background for many searches, systematics ~2%

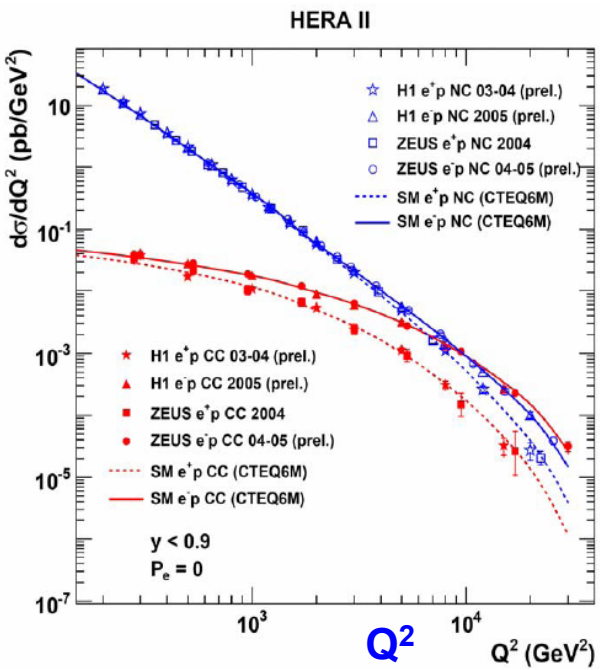


Inclusive Jet Production

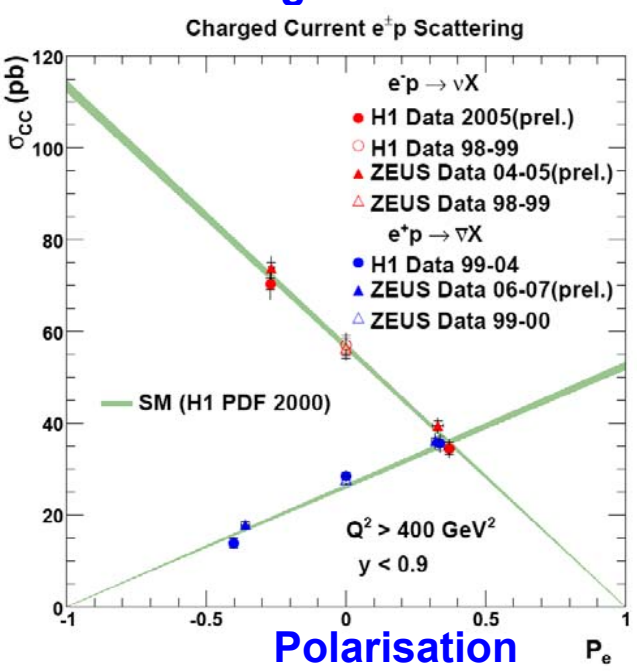




Neutral Current



Charged Current



HERA combined (new analysis):

$\alpha_s(M_Z) = 0.1198 \pm 0.0019\ (\text{exp.}) \pm 0.0026\ (\text{th.})$

Model – independent Search (H1)

HERA: highest energy with lepton in the initial state

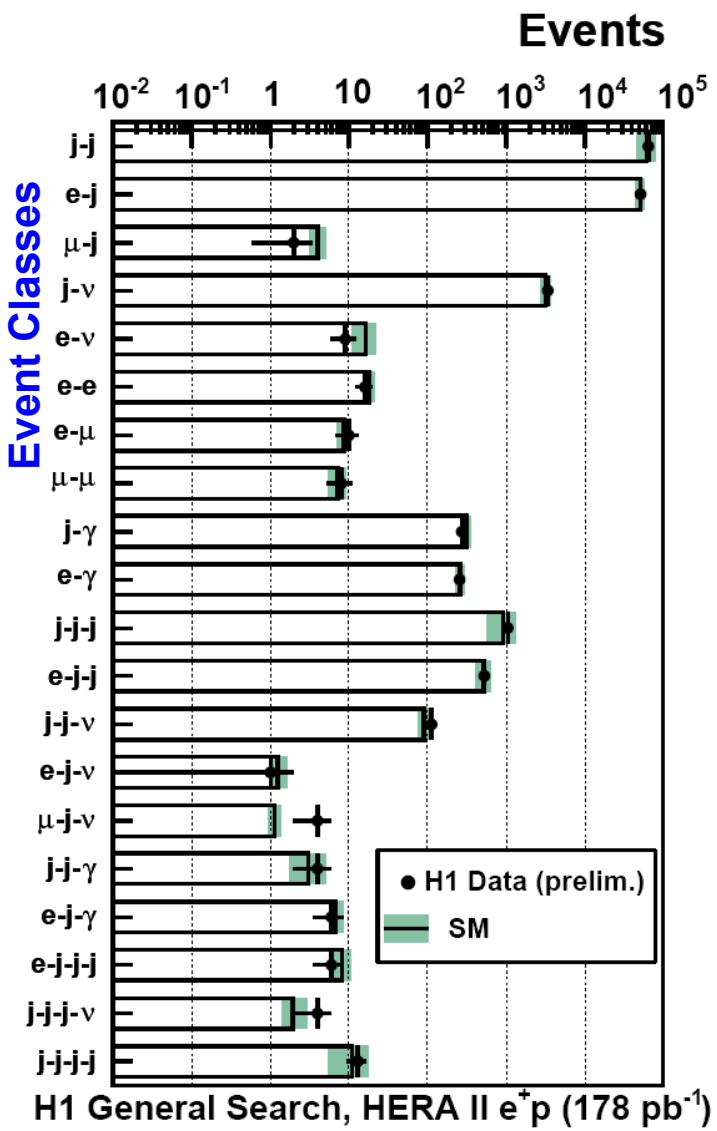
e+q: no pair production, but single production of new particles

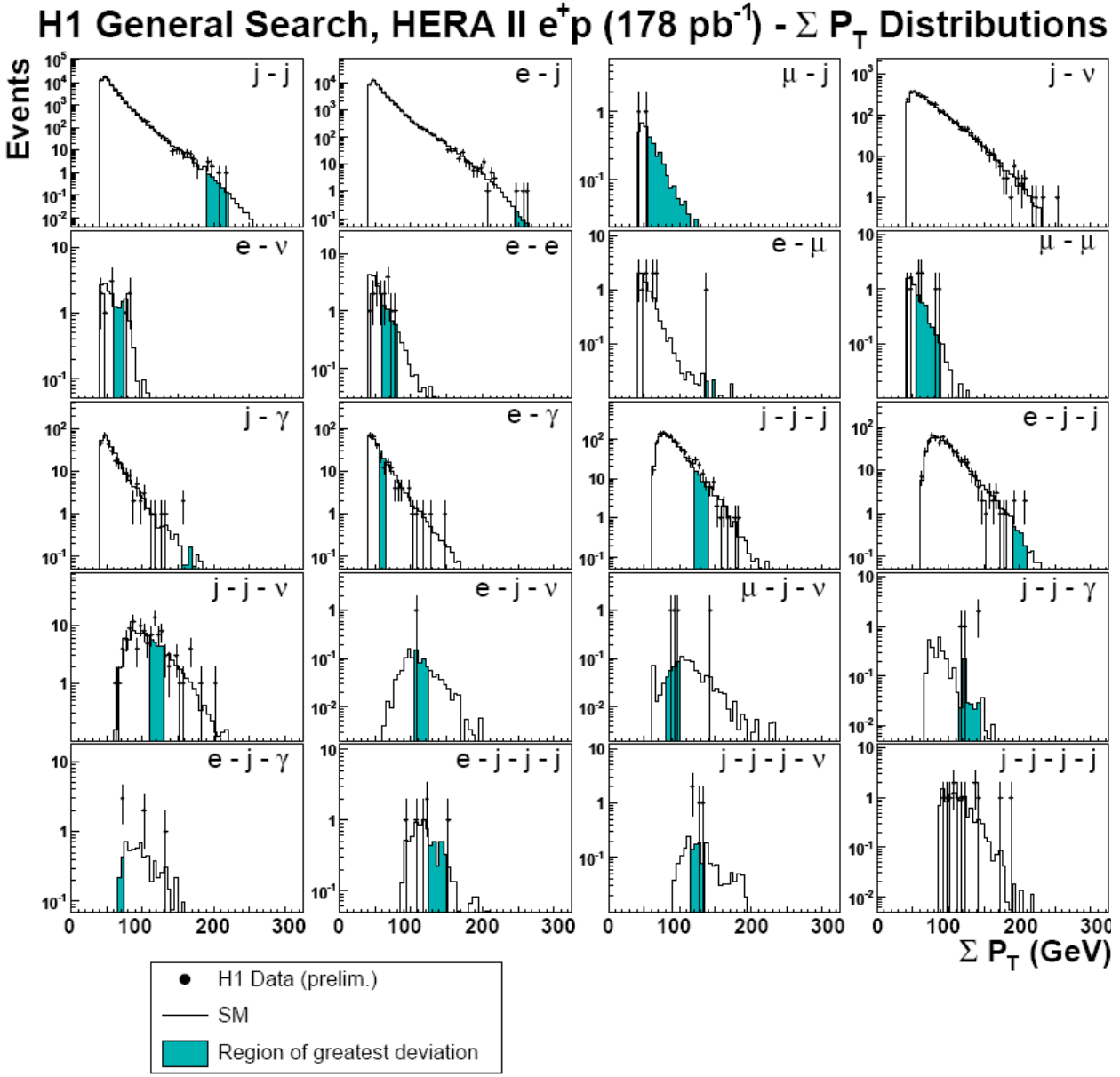
high precision on SM processes

Model independent search

- Inclusive search for particles at high P_T
- Electrons ,Photons, Muons, Hadronic Jets, Neutrinos (PTmiss)
- phase space for all:
  - P_T >20 GeV
  - $10^o < \theta < 140^o$
- All combinations: ee, eγ,eμ,ej,….jj, ejj, ejν → event classes
- Mass and $\sum P_T$ (Jacobi-peak)
- Comparison to SM (LO+PS + K-factors from NLO)
  → look for deviations (max. deviations)
- Statistical interpretation via monte carlo experiments → probability

Model – independent Search





Model – independent Search

Precision :

→Systematics: few %

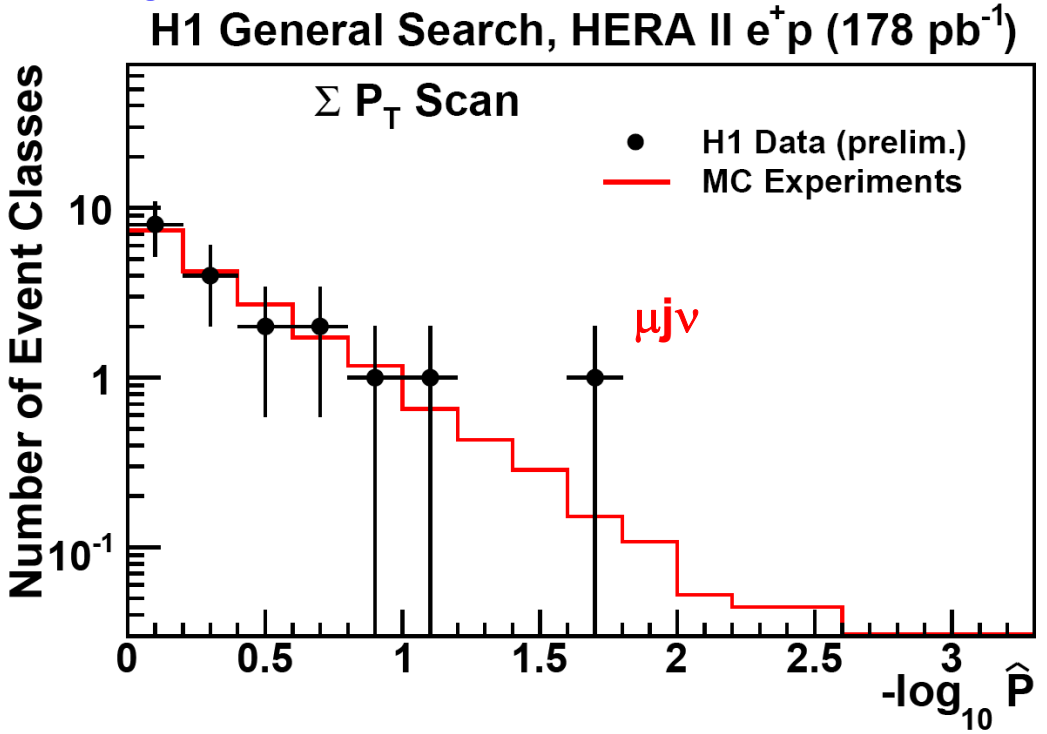
→Statistics: limited at large M, PT and large multiplicity

→Theory: uncertainty large for multi-jet channels

Distribution for data follows expectation

→Excellent understanding of most final states at HERA

Probability of max. deviation for event classes



Exception: Largest deviation for μjν channel

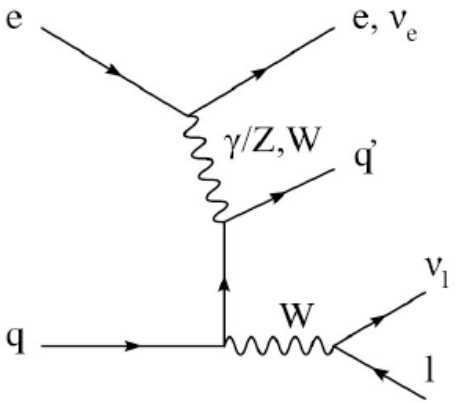
e^+p: H1 observation: 21 / 8.9 ±1.5 events (3.0σ)

ZEUS: no events in excess of SM

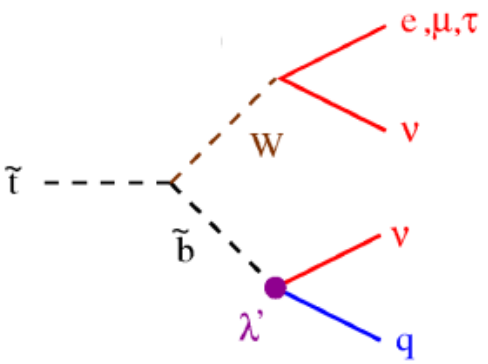
e^-p: H1 and ZEUS: Agreement with SM

Lepton + P_{Tmiss} + X

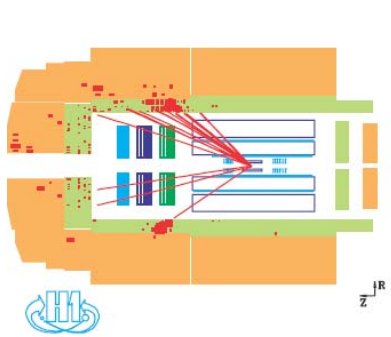
W production in SM: small $P_{T,X}$ of hadrons

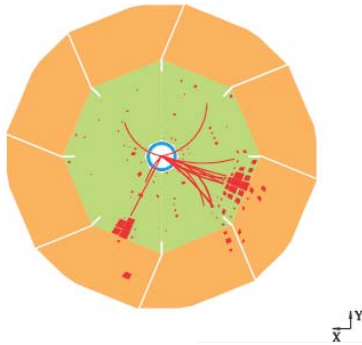


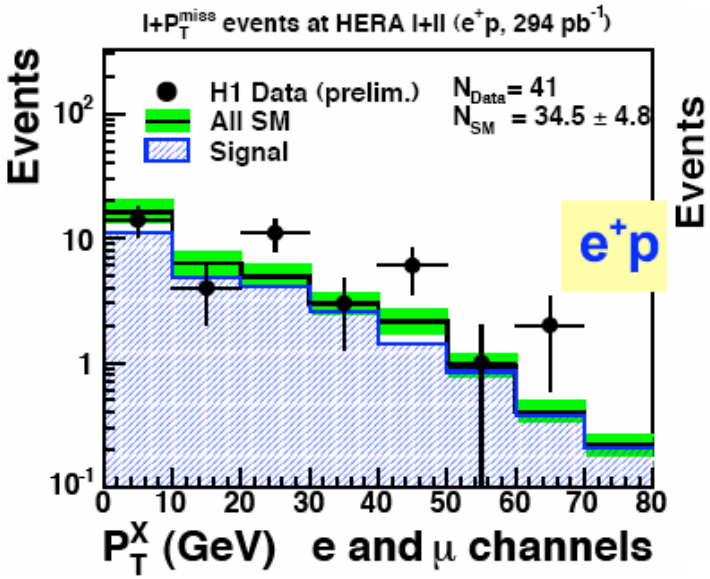
SUSY with R_P violation Single stop production

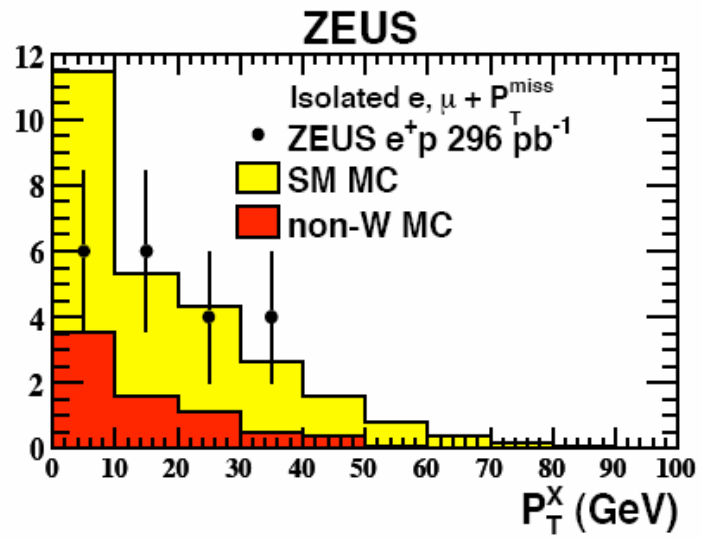


H1: events with unexpected large $P_{T,X}$ > 25 GeV









e,μ + $P_{T,miss}$, e^+p data

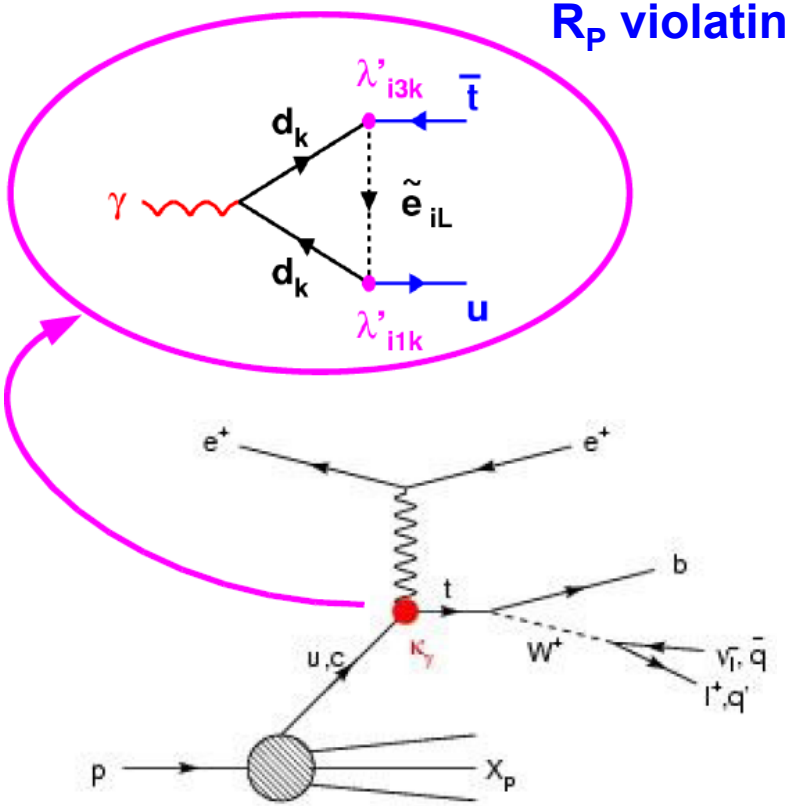
H1: 3 σ

H1+ZEUS: 1.8 σ

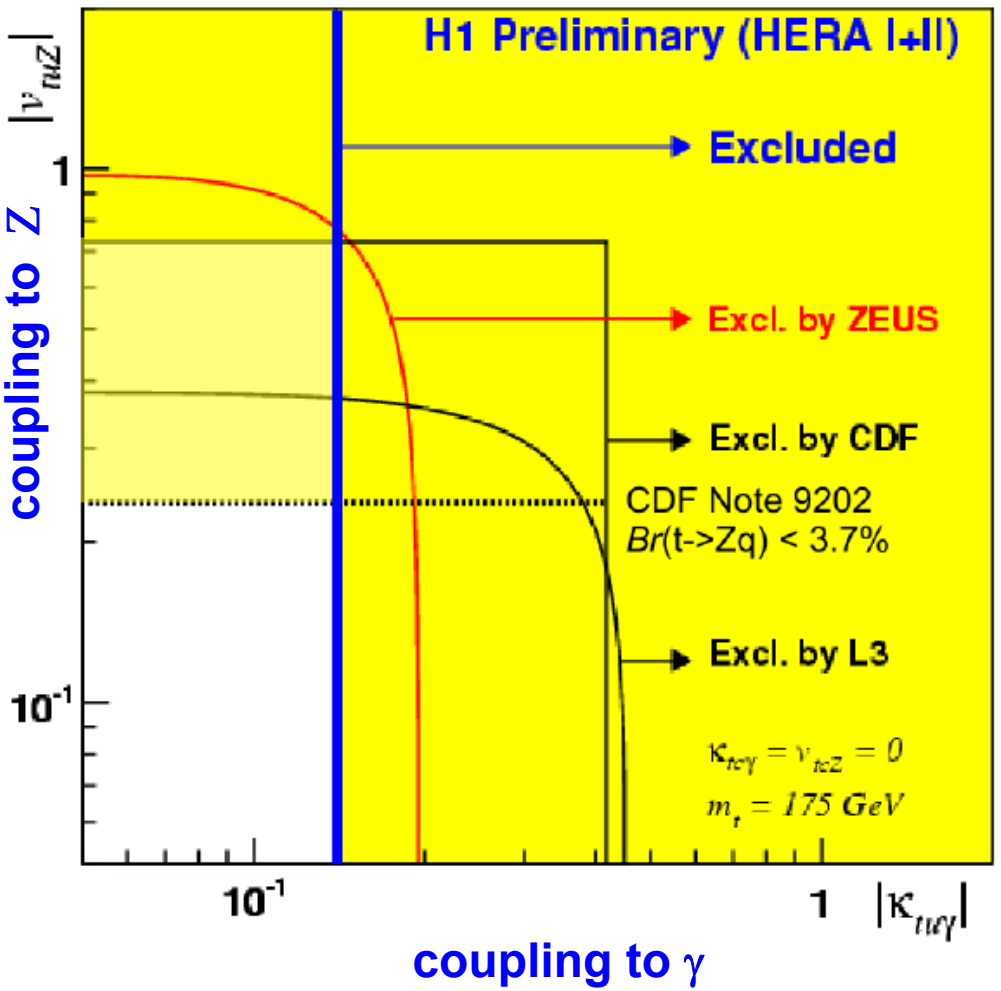
→ not confirmed by ZEUS

Single Top

R_P violating SUSY



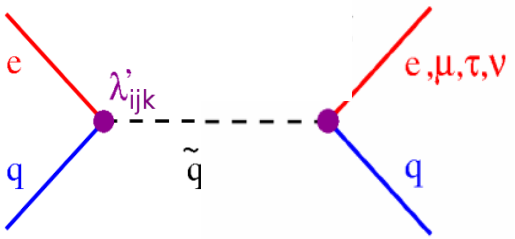
- parameterize tu-vertex by effective couplings $\kappa_{tu\gamma}$ and v_{tuZ}
- explicit reconstruction of top mass



Supersymmetry: R-parity violating

R_P conserved:

- e+q → selectron-squark
- E_{CMS} too small (Tevatron constrains)



R_P violation:

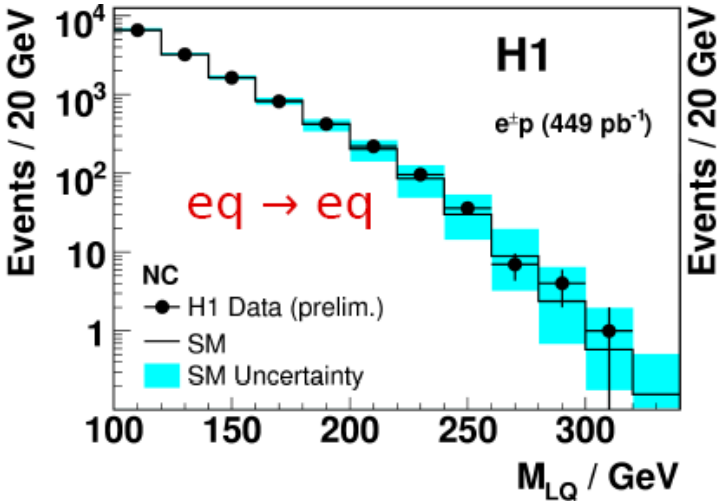
$$W_{RPV} = \lambda'_{ijk} L_i Q_j \bar{D}_k$$

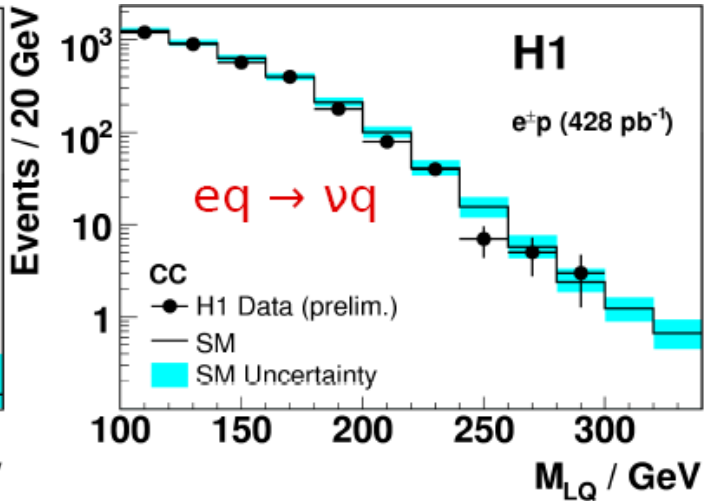
$$e^+ d \xrightarrow{\lambda'_{1j1}} \tilde{u}_{j,L} \rightarrow e^+ d$$

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

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

- e+q → squark (s-channel resonance + u-channel)
- irreducible background / interference with deep inelastic e+q → e+q



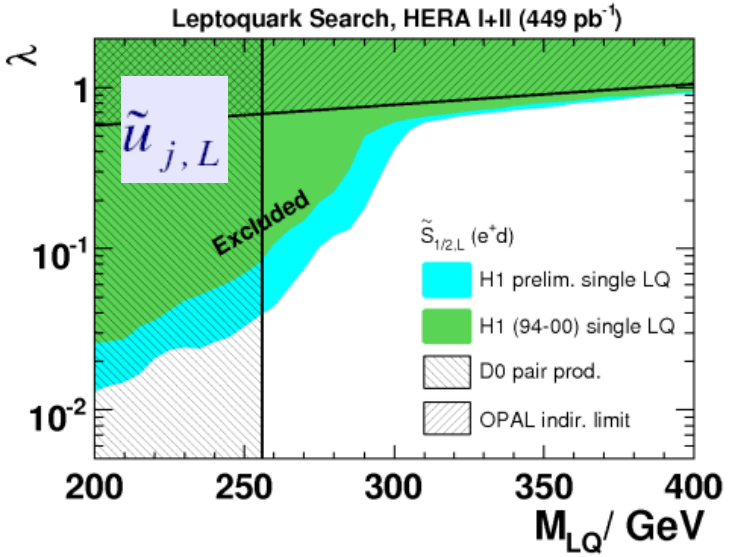


No significant deviation from standard model expectation observed

Squarks in R_P viol. SUSY

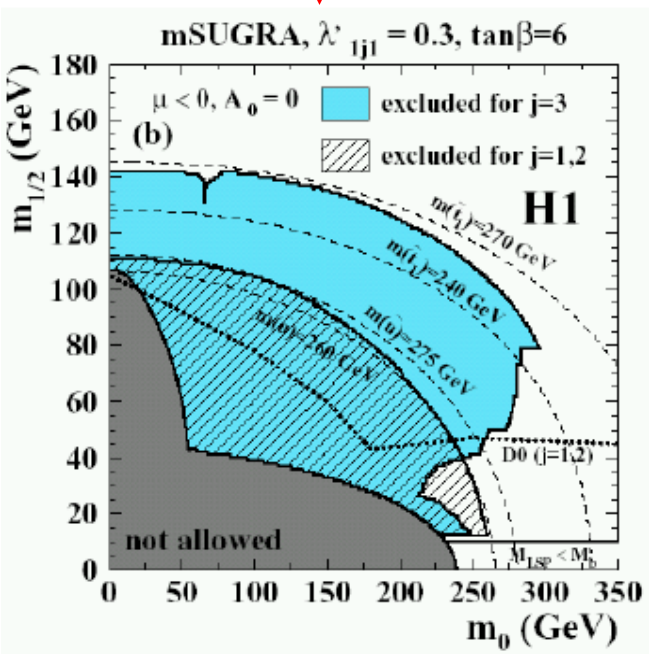
if decays via λ' dominate, BR(R_P-viol.=1)

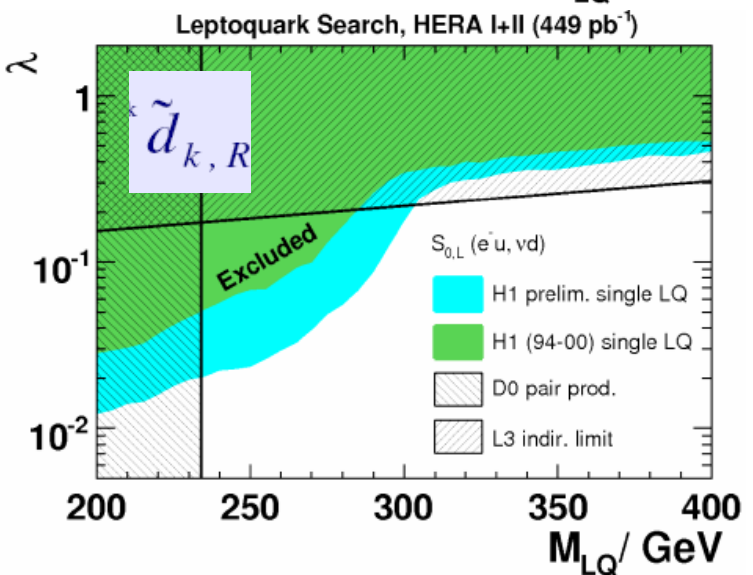
- mass range up to & beyond E_{CMS} due to interference
- signature same as for some leptoquarks



If squark decays into gauginos are possible

- 3-body decays of gauginos into e+jets
- scan of mSUGRA parameter space

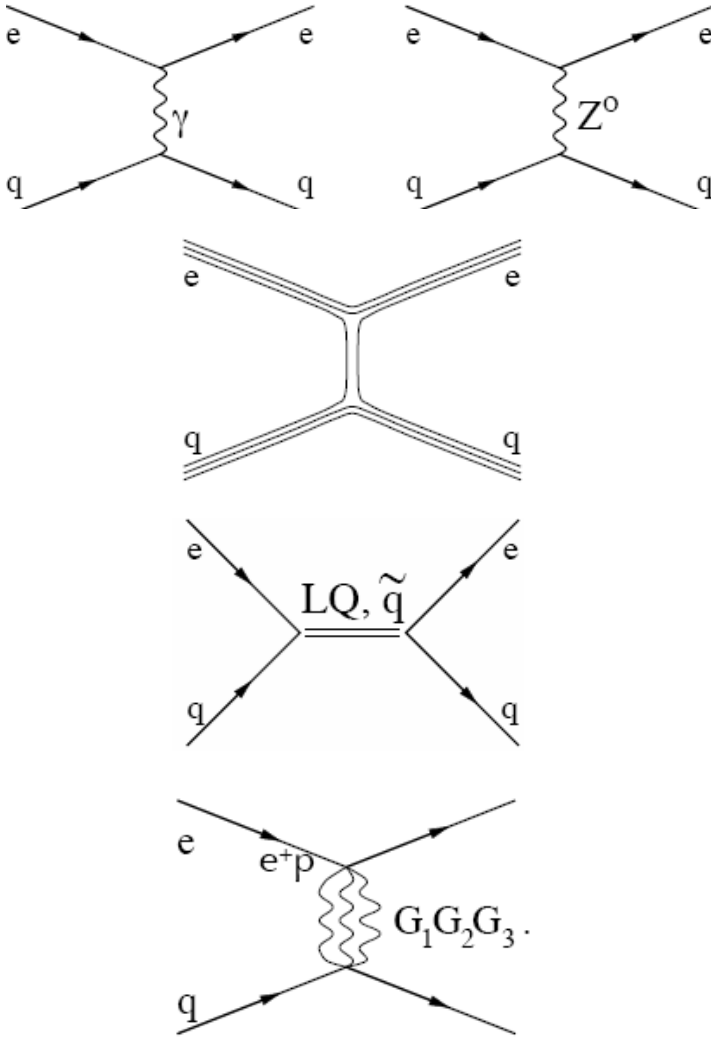




Similar results for couplings with lepton flavour violation

Contact Interactions

Standard Model



+ 4-Fermion interaction

$$\mathcal{L}_{CI} = \sum_{i,j=L,R\,;\,q=u\ldots b} \eta_{ij}^{eq}(\bar{e}_i\gamma^\mu e_i)(\bar{q}_j\gamma_\mu q_j)$$

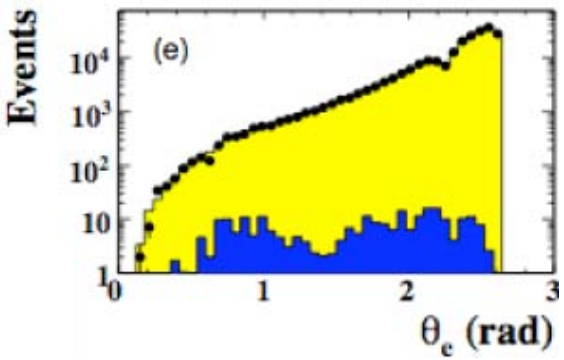
$$\eta_{ij} = \epsilon_{i,j}\frac{4\pi}{\Lambda^2}$$ **Compositeness**

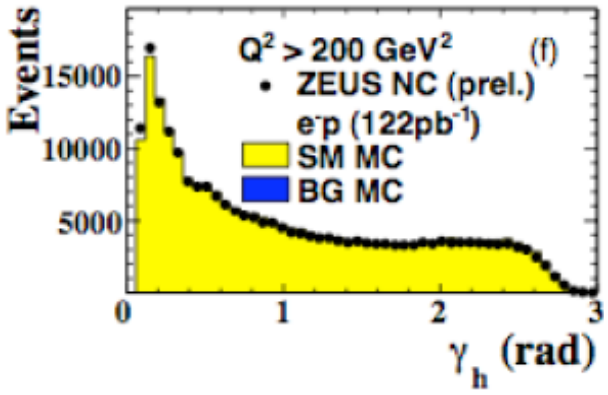
$$(1-\frac{R_q^2}{6}Q^2)$$ **Quark radius**

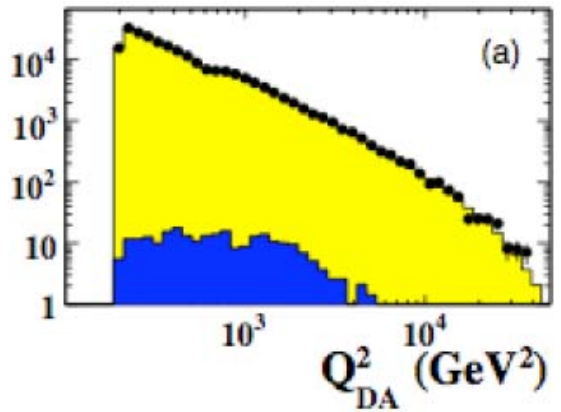
$$\eta \sim (\lambda/M_{LQ})^2$$ **Leptoquark (M> E_{CMS}) Squarks in R_P-viol.**

$$\eta_G \sim 1/M_S^4$$ **Large Extra Dimensions**

Contact Interactions





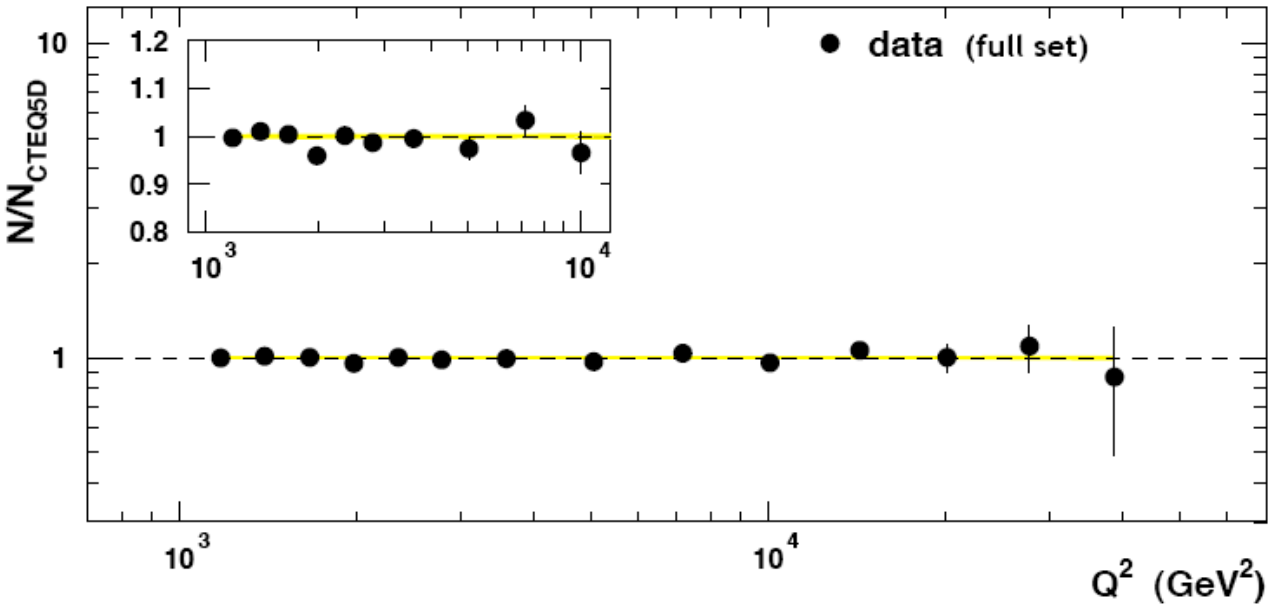


ZEUS ep data

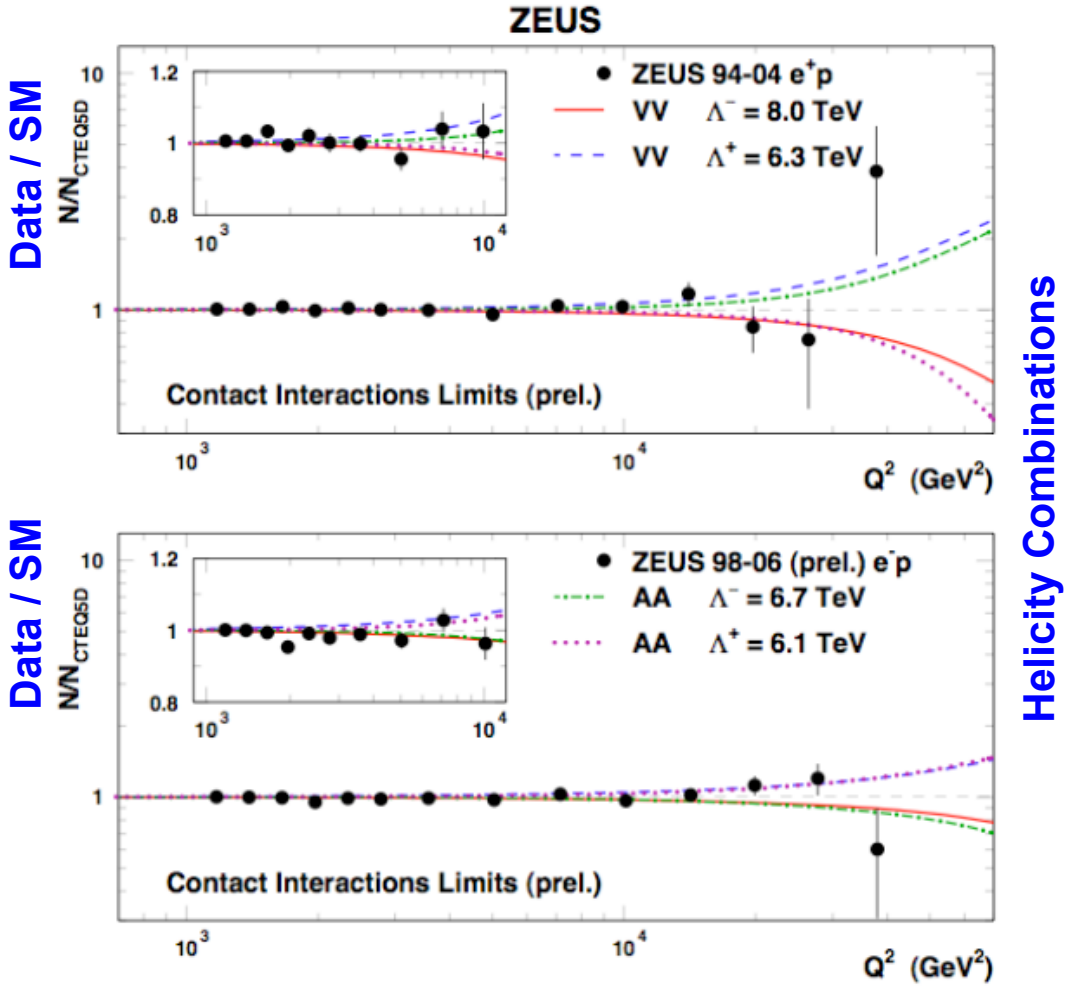
- HERA I $\sqrt{s}$ = 300 GeV 1994-2000 128 pb^{-1}
  - unpolarized e^+ (112 pb^{-1}) and e^- data sets
- HERA II $\sqrt{s}$ = 318 GeV 2003-2005 146 pb^{-1}
  - polarization e^- –0.27, +0.33, e^+ –0.41, +0.32

Measurement via 2-angle method:

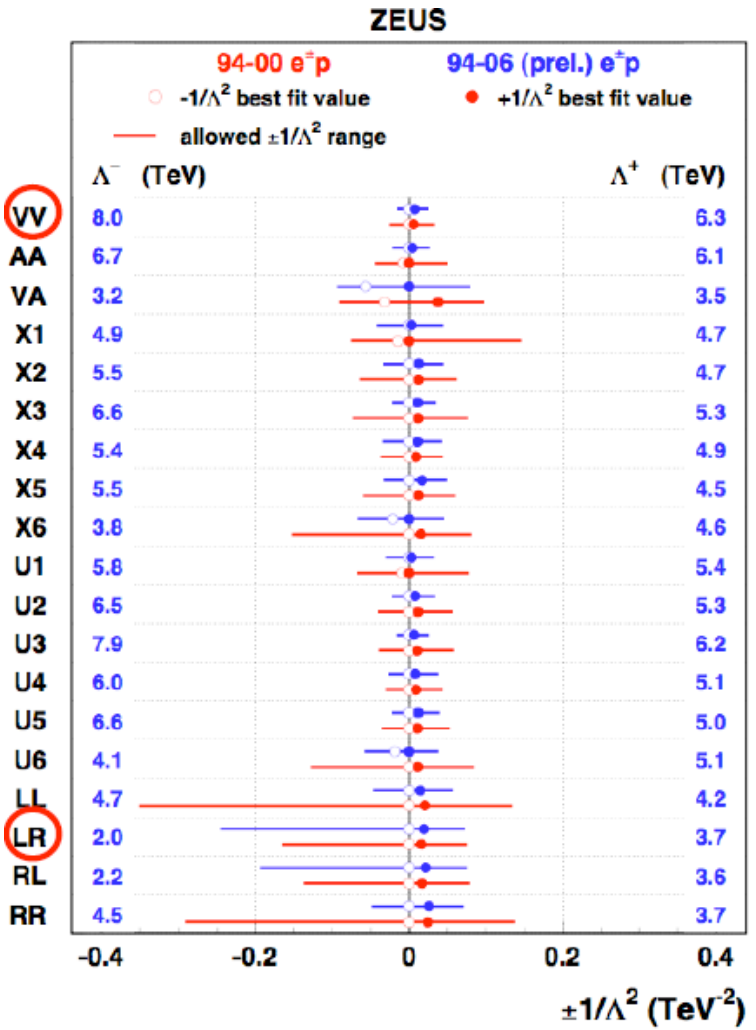
- **Resolution << Binning**
- **Results limited by statistics**



Contact Interactions



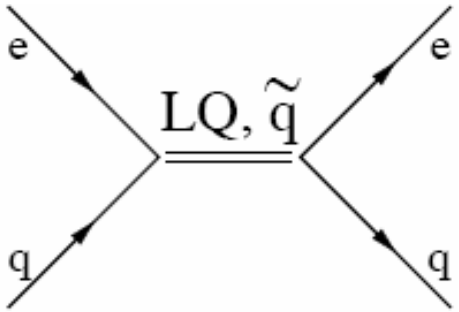
Helicity Combinations



Typical Range of Contact Interaction scales:

2 … 8 TeV

Leptoquarks (indirect)



Leptoquark masses excluded for:

- **Indirect search**

  M / λ‘ > 0.3 … 2 TeV

- **Direct searches for peak in M_{eq}**

  M<300 GeV → λ < 0.01

Squarks in R-parity viol. SUSY:

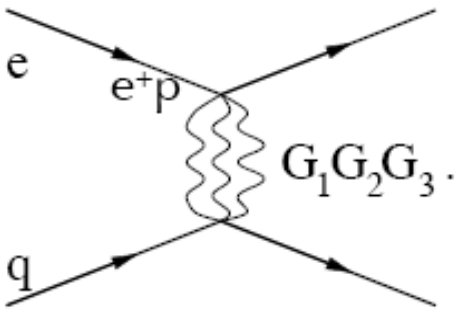
$\lambda'_{ijk}\, L_i\, Q_j\, D_k$ coupling

$\tilde{u}$ has same coupling as $\tilde{S}_{1/2}$

same limit applies

	ZEUS 1994-2005 (prel.) $e^{\pm}p$		
	Model	Coupling Structure	95% C.L. (TeV) M_{LQ}/λ_{LQ}
scalar	$S_{\circ}^{L}$	$a_{LL}^{eu} = +\frac{1}{2}$	0.96
	$S_{\circ}^{R}$	$a_{RR}^{eu} = +\frac{1}{2}$	0.82
	$\tilde{S}_{\circ}^{R}$	$a_{RR}^{ed} = +\frac{1}{2}$	0.32
	$S_{1/2}^{L}$	$a_{LR}^{eu} = -\frac{1}{2}$	0.88
	$S_{1/2}^{R}$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.46
	$\tilde{S}_{1/2}^{L}$	$a_{LR}^{ed} = -\frac{1}{2}$	0.44
	S_{1}^{L}	$a_{LL}^{ed} = +1,\ a_{LL}^{eu} = +\frac{1}{2}$	0.74
vector	$V_{\circ}^{L}$	$a_{LL}^{ed} = -1$	0.80
	$V_{\circ}^{R}$	$a_{RR}^{ed} = -1$	0.62
	$\tilde{V}_{\circ}^{R}$	$a_{RR}^{eu} = -1$	1.33
	$V_{1/2}^{L}$	$a_{LR}^{ed} = +1$	0.46
	$V_{1/2}^{R}$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	1.00
	$\tilde{V}_{1/2}^{L}$	$a_{LR}^{eu} = +1$	1.10
	V_{1}^{L}	$a_{LL}^{ed} = -1,\ a_{LL}^{eu} = -2$	1.91

Large Extra Dimension

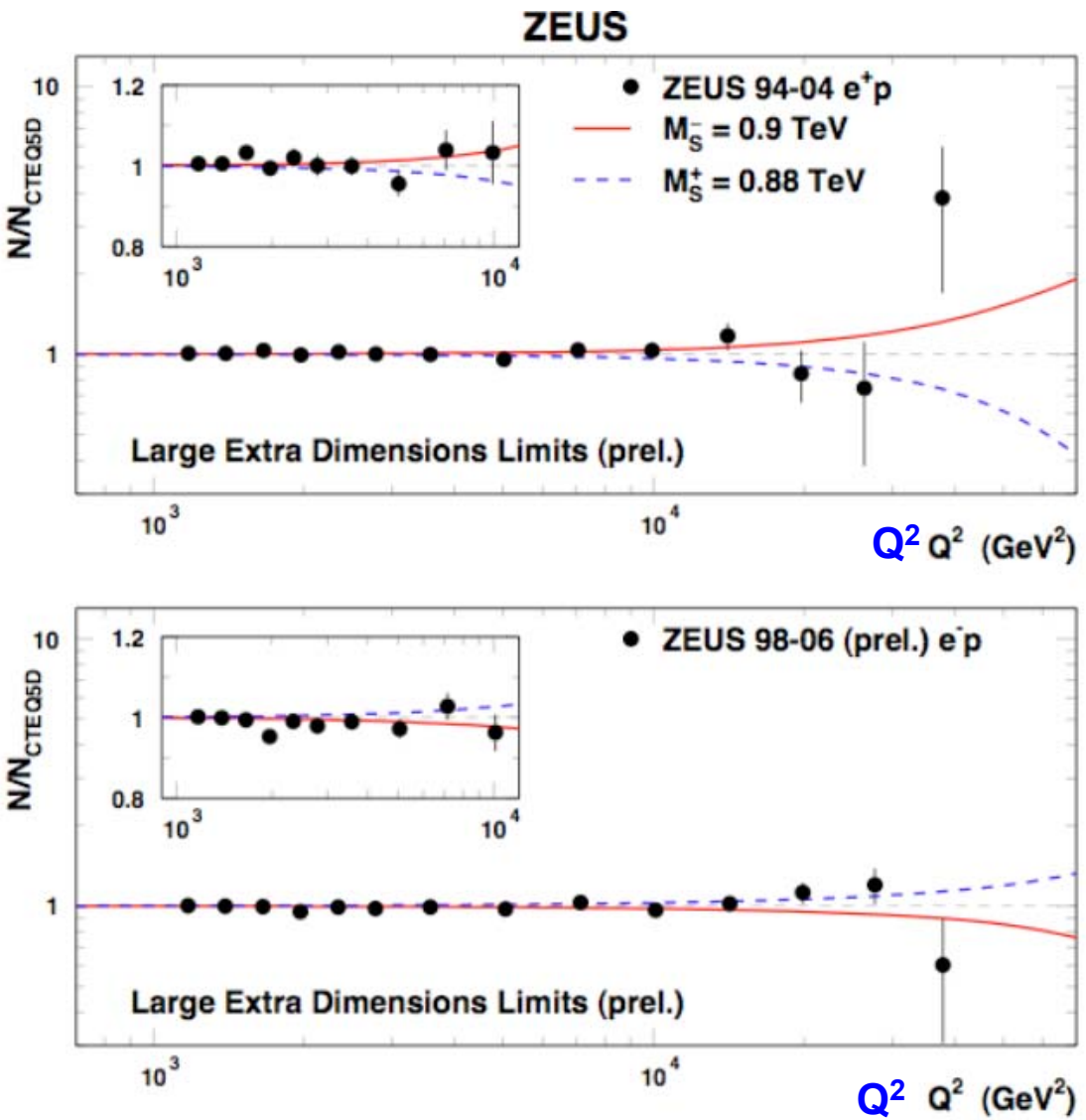


LED's limited to

- $M_{S(-)} > 0.9$ TeV
- $M_{S(+)} > 0.9$ TeV

Quark Radius limited to

- $RQ < 0.62 \times 10^{-18}$ m

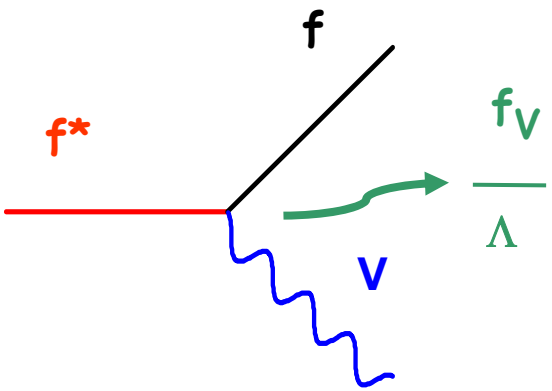


Excited Leptons (H1)

Effective lagrangian to parameterize compositeness:

- **Spin ½, isospin ½, vector currents as SM leptons**

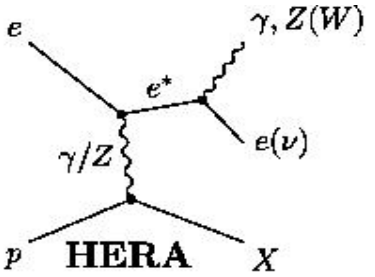
$$L_{F^*F} = \frac{1}{2\Lambda}\bar{F}^*_R\sigma^{\mu\nu}[gf\frac{\vec{\tau}}{2}\partial_\mu\vec{W}_\nu + g'f'\frac{Y}{2}\partial_\mu B_\nu]F_L + h.c.$$

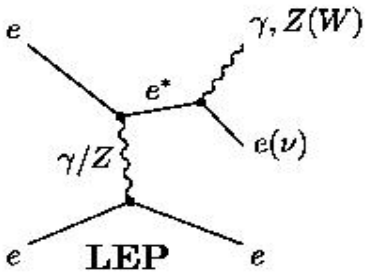


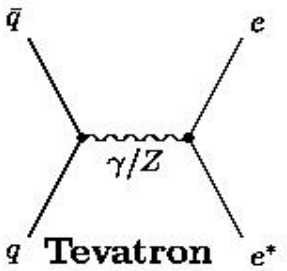
Λ **compositeness scale**

f, f ' relative strength

for W_μ, B_μ → γ,Z

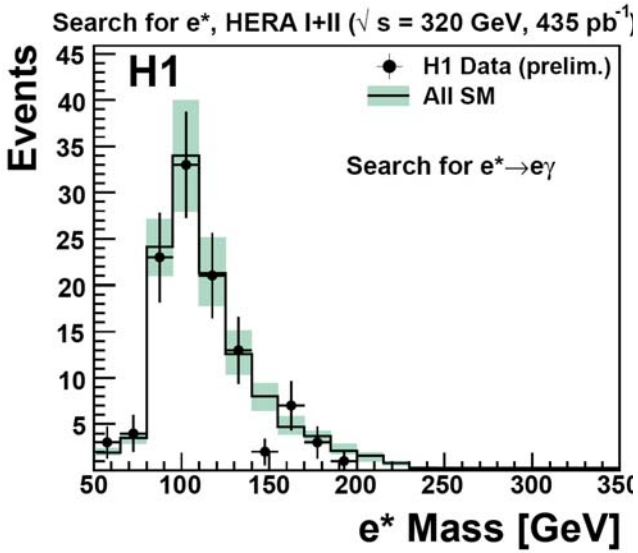


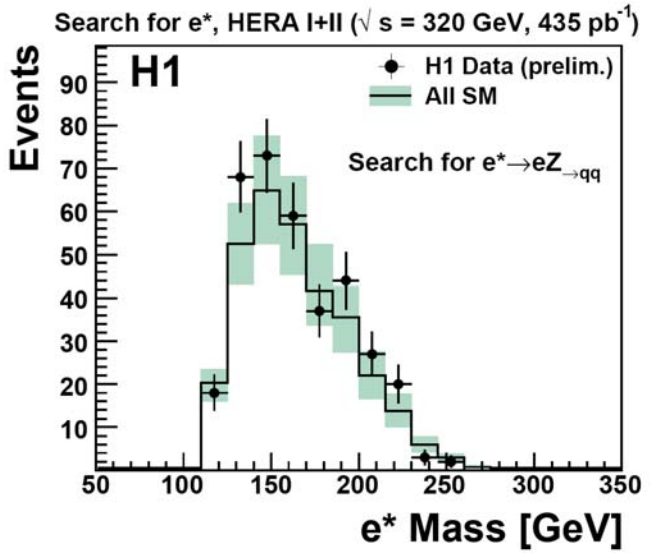


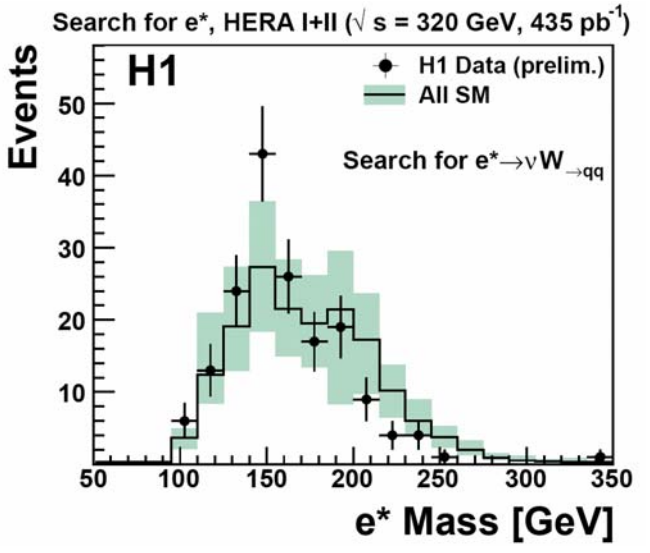


Resonance production for masses < E_{CMS}

Excited electrons





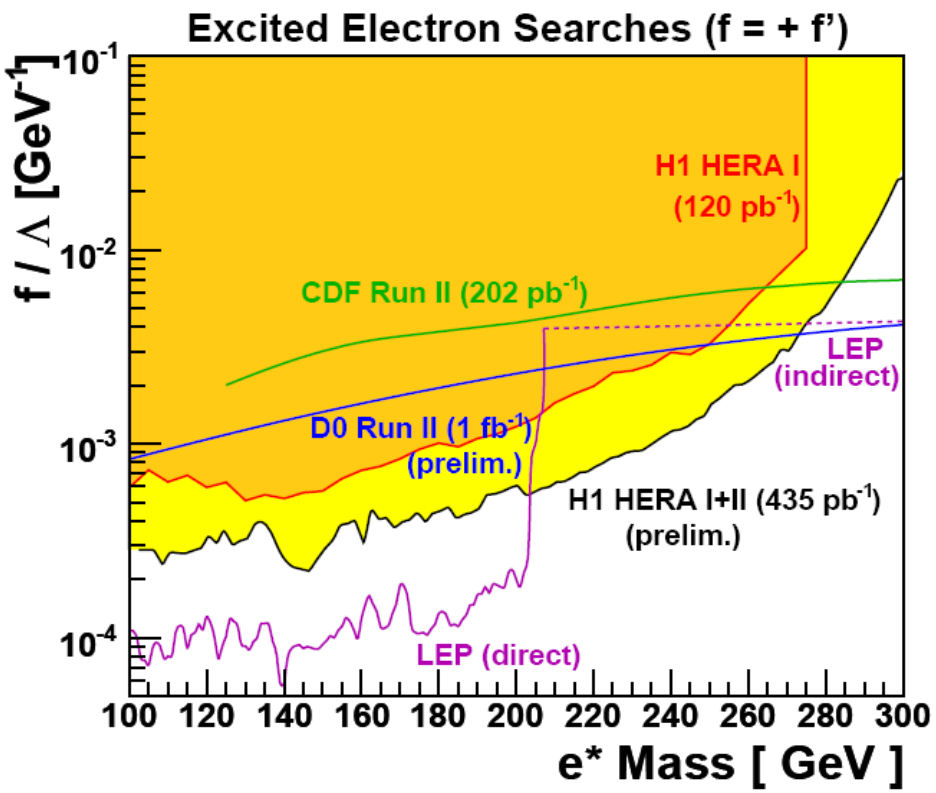


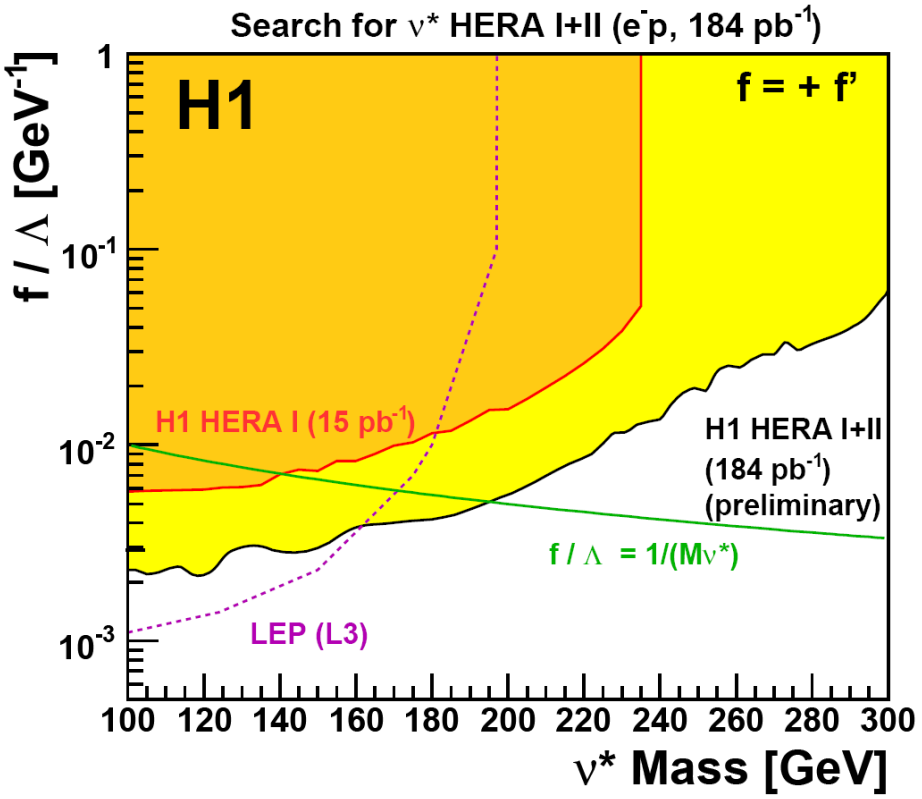
Search for e* HERA I+II ($\sqrt{s} = 320$ GeV, 435 pb^{-1}, preliminary)

Selection	Data	SM	Efficiency × BR
$e^* \to \nu W_{\hookrightarrow qq}$	172	175 ± 39	~ 40 %
$e^* \to e Z_{\hookrightarrow qq}$	351	318 ± 64	~ 45 %
$e^* \to e\gamma$	112	125 ± 19	60–70 %

Full statistics: No excess seen

Excited Electrons and Neutrinos





HERA: Limits typically 220 … 280 GeV for M ~ Λ / f

LEP: M>208 GeV direct search

LEP/Tevatron: indirect limits for M>280 GeV

Conclusion

HERA: final statistics available: 0.5 fb^{-1} per experiment

Precision dictated by

- luminosity for indirect searches: Contact interactions
- beam energies for direct searches
- experimental errors small in most cases

Model – independent search (H1 full statistics):

- few % level of understanding of ~ ALL final states at HERA
- exception: H1: $\mu j \nu$ channel for e+ scattering
  ZEUS: not confirmed

Resonance searches on squarks, leptoquarks

- mass limit for small couplings ~ 300 GeV, and beyond via interference

Contact interactions (ZEUS 285 pb^{-1}):

- limits on scale ~ 10 x E_{CMS} … up to 7.5 TeV
- improvements from luminosity and polarisation still to come

Excited Leptons (H1 full statistics):

- mass limit ~ 220 … 280 GeV