Electroweak physics and searches for new physics at HERA

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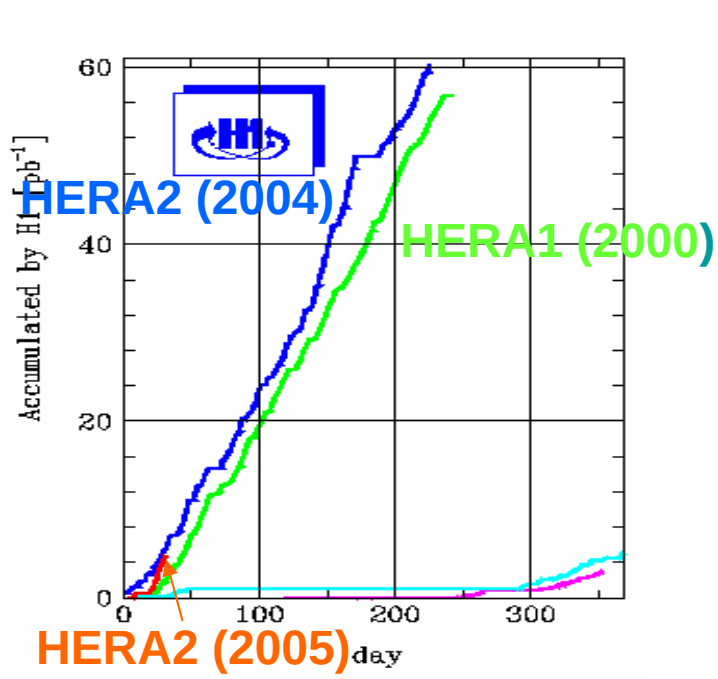
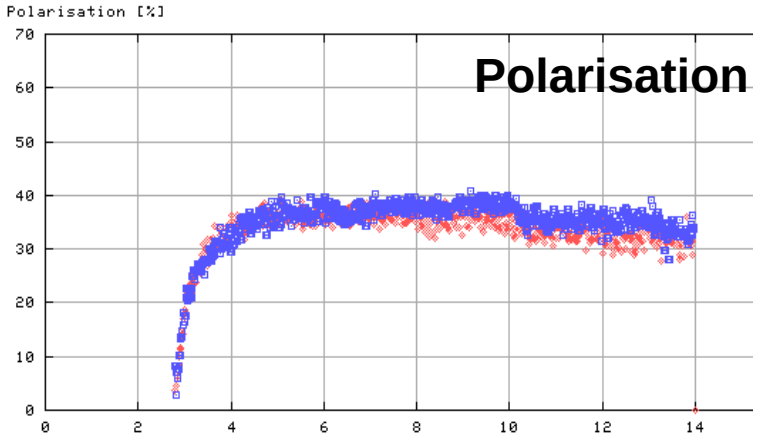
The HERA electron-proton collider

E_e 27.6 GeV, E_p 920 (820) GeV

$\sqrt{s}$ = 320 GeV (300 GeV)





Hera 1: 100 pb^{-1} e^+ p

15 pb^{-1} e^- p

Hera 2: high luminosity running with polarized leptons:

60 pb^{-1} e+ p

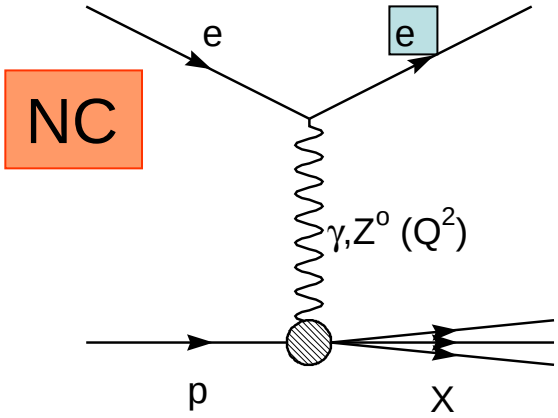
since 1/2005 e- p:

20 pb^{-1} e-p

<P> ~ 40% (h+/-1)

Deep inelastic ep scattering

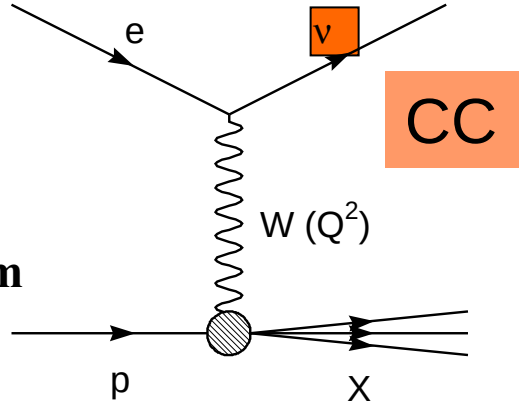
Test eq interactions at highest energies

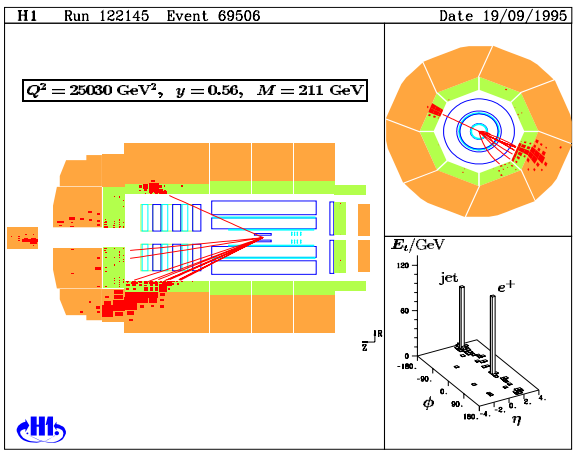


Q^2 – momentum transfer squared ("resolution")

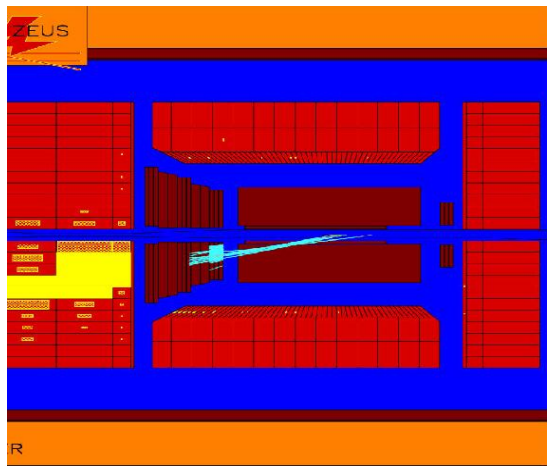
x – fraction of proton momentum carried by struck quark

y – inelasticity (fractional electron loss)





$$Q^2 = s\,x\,y$$

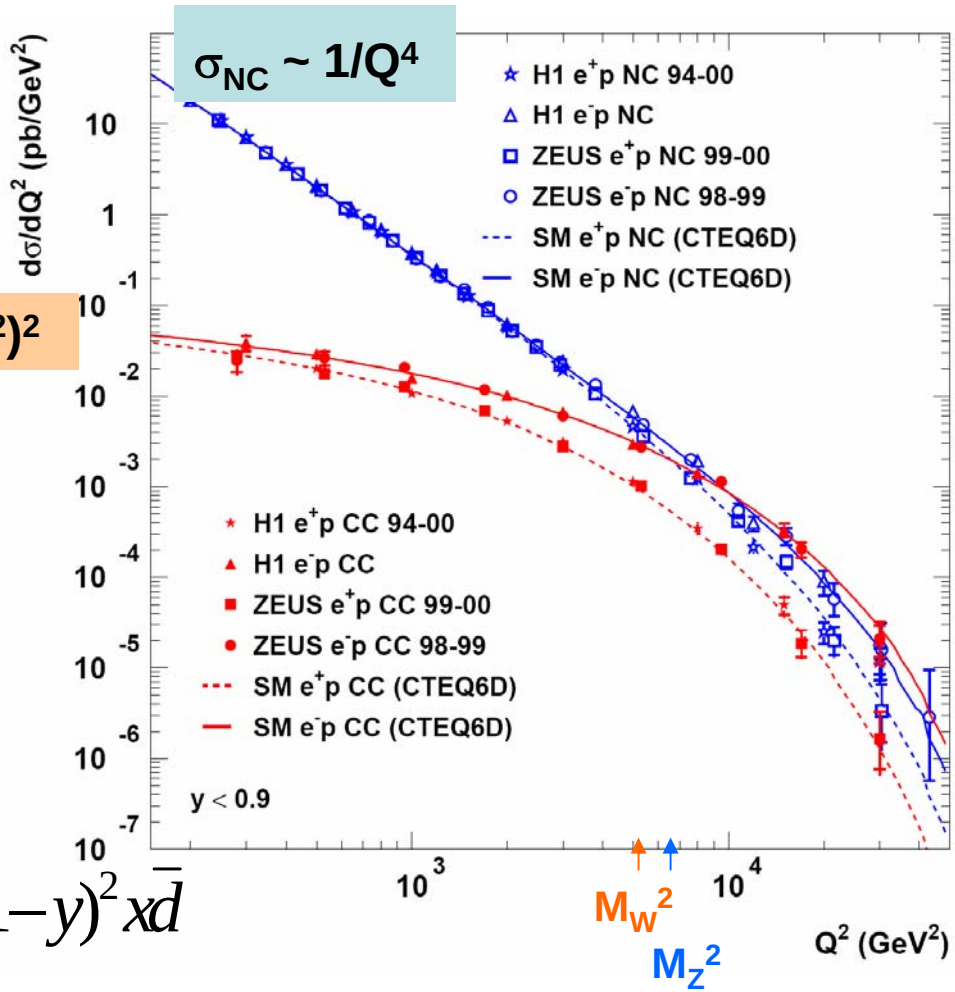


Charged and neutral current cross section measurements

Unification of em and weak interaction at $Q^2 > M_{W2}$

$\sigma_{NC} \sim 1/Q^4$

$\sigma_{CC} \sim 1/(Q^2 + M_W^2)^2$



$\sigma_{NC}(e^+p) < \sigma_{NC}(e^-p)$ at high Q^2:

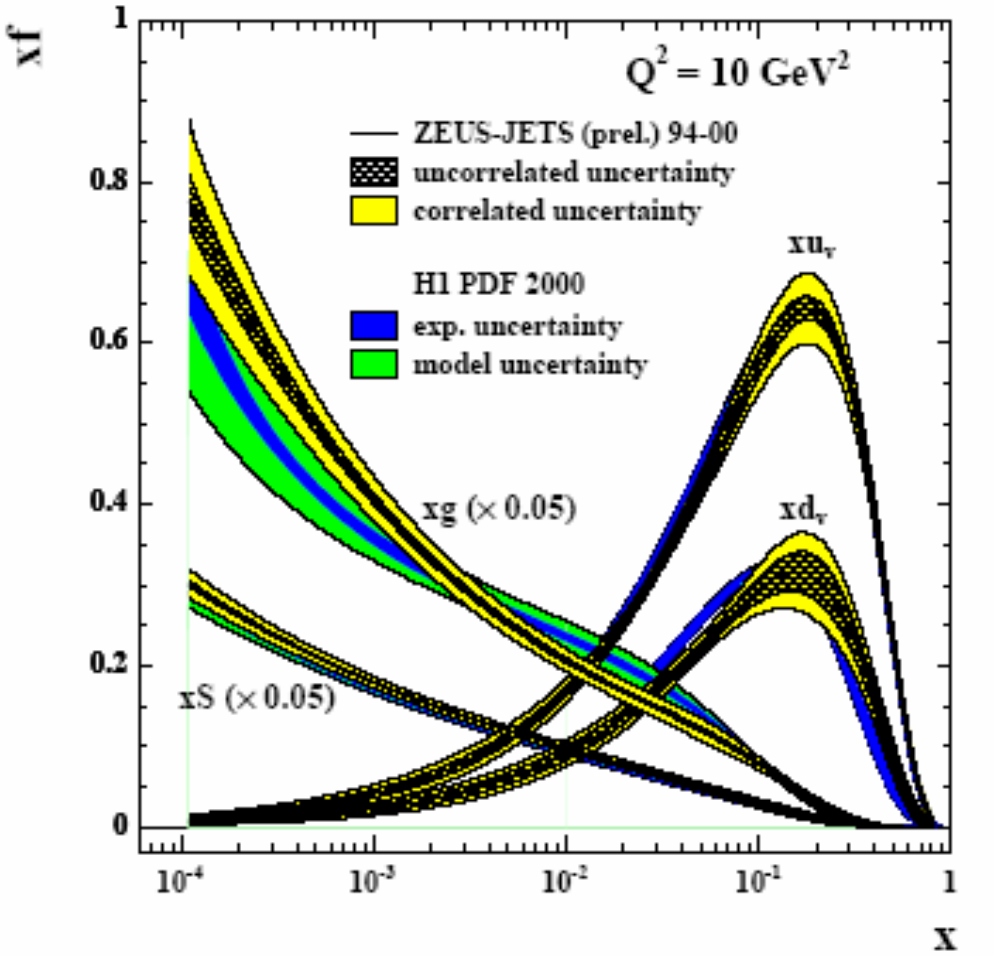
$\Delta\sigma_{NC}$ dominated by coupling of the γZ interference to valence quarks:

$$xG_3 = \sum e_q a_q (q - \bar{q})$$

$\sigma_{CC}(e^+p) < \sigma_{CC}(e^-p)$

$$\tilde{\sigma}^{+}_{CC} \sim x\bar{u} + (1-y)^2 xd \quad < \quad \tilde{\sigma}^{-}_{CC} \sim xu + (1-y)^2 x\bar{d}$$

Parton density functions (PDFs)



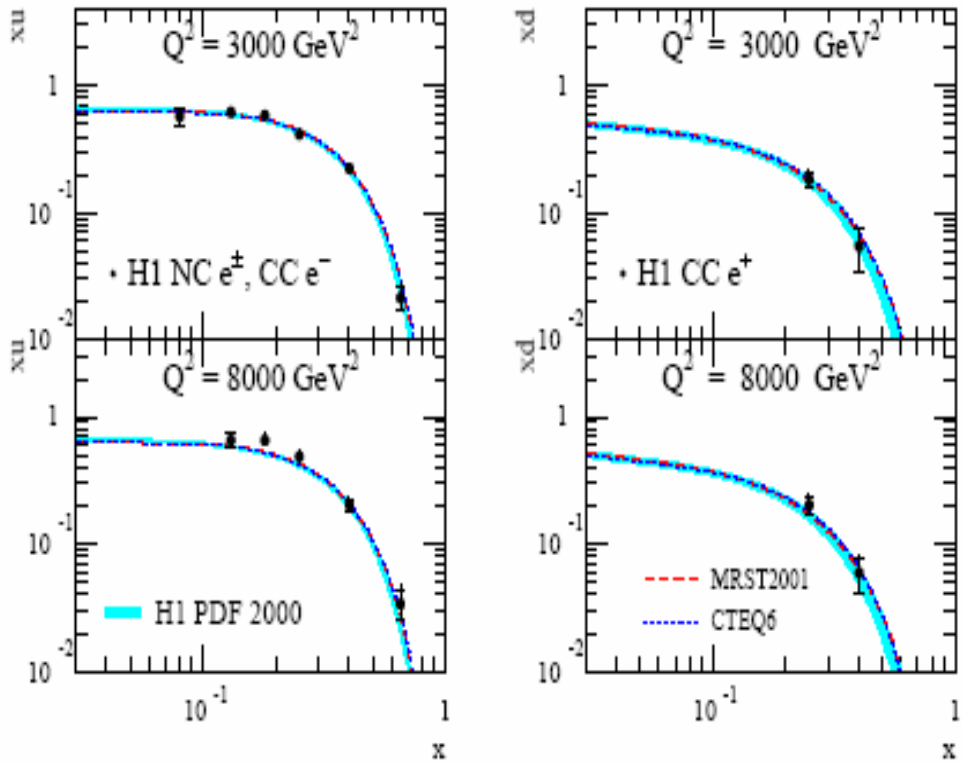
Combined fits allow the extraction of parton density functions (PDFs)

H1 and ZEUS pdfs are in agreement and agree with global fits

Extract flavor sensitive parton distributions at high x

Complementary measurement to QCD fit

Extract u and d quark distributions in x,Q^2 bins where they contribute at least 70% to the cross section

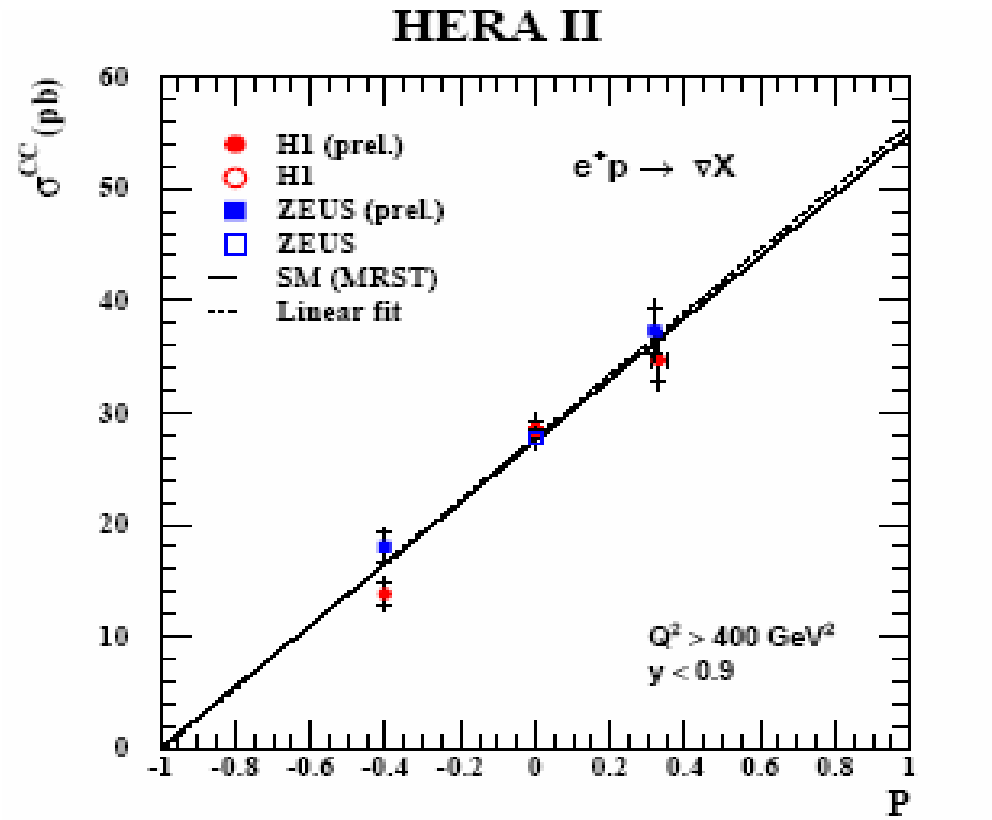


Good agreement with PDF from QCD analysis

Charged current measurement with polarized leptons

SM charged currents are left-handed.
σ_{CC} with polarized leptons:

$$\sigma_{CC}^{\pm} = (1 \pm P)\ \sigma_{CC}^{(P=0)}$$

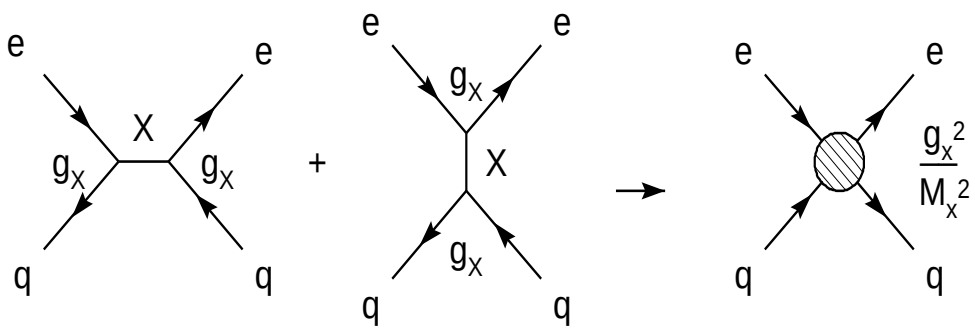


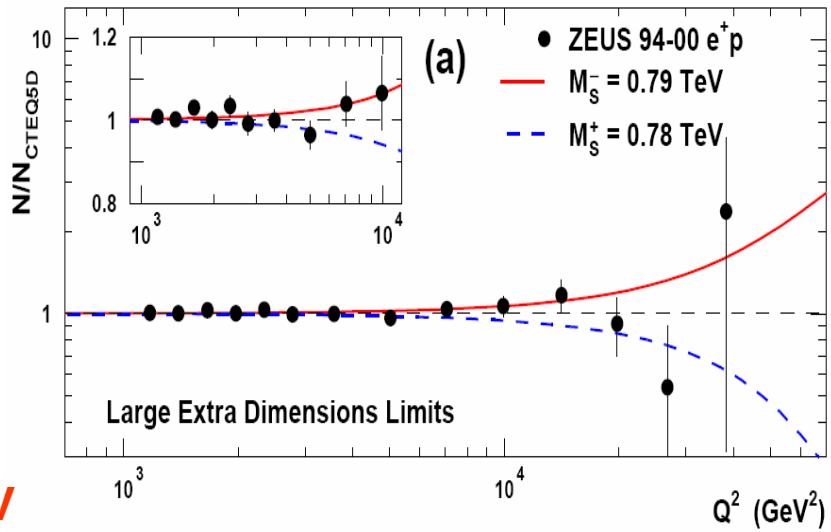
No hint for right handed charged currents

Contact interactions

Deduce limits from the NC cross section

Parameterize interference of any new particle field associated to large scale ($M_X >> \sqrt{s}$) with γ or Z field of the "regular" NC DIS





Leptoquarks
R parity violating SUSY } **M/λ<0.3-1.4 TeV**

Quantum gravity effects with large extra dimensions M_s**>0.8 TeV**

Radius of valence quark $< 0.85\ 10^{-18}$**m**

Compositness scale $\Lambda < 1.6\text{-}5.5$ **TeV**

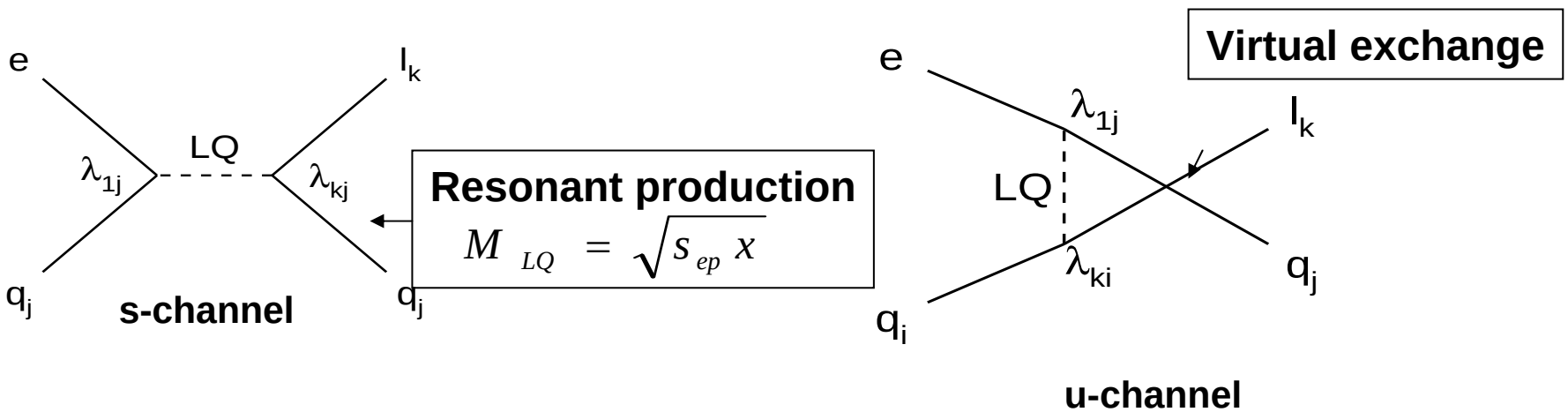
Similar results From H1

Leptoquarks

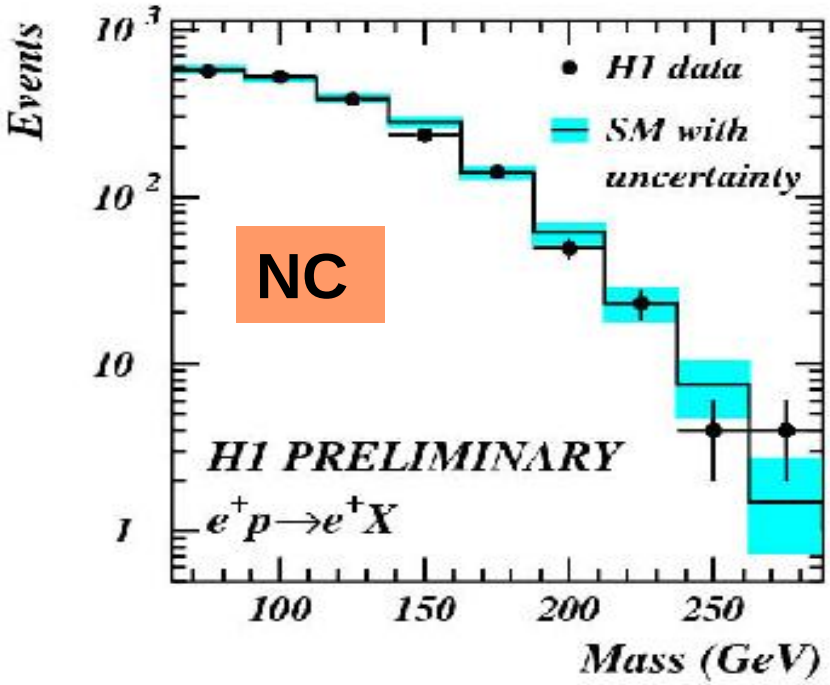
LQ are color triplet scalar or vector bosons with
B and L: fermionic number $F = 3B_q + L_l$, $|F| = 0, 2$
Sum of electric charges within one LQ generation is 0

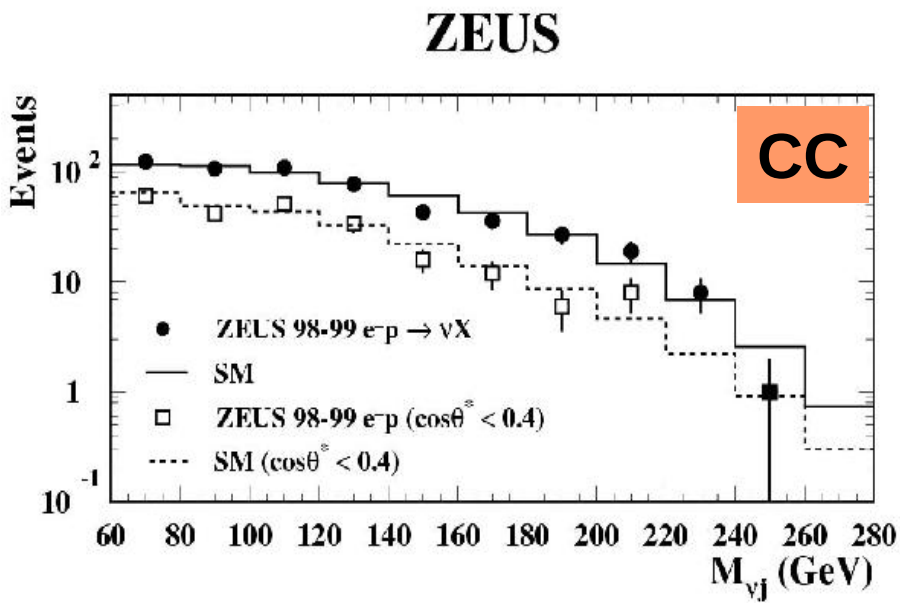
LQ are part of many theories beyond the SM
(GUT-like theories, Superstring-'inspired' E6-models, Technicolor,Compositness…)

HERA unique facility for resonant production of LQs:



Leptoquark resonance searches



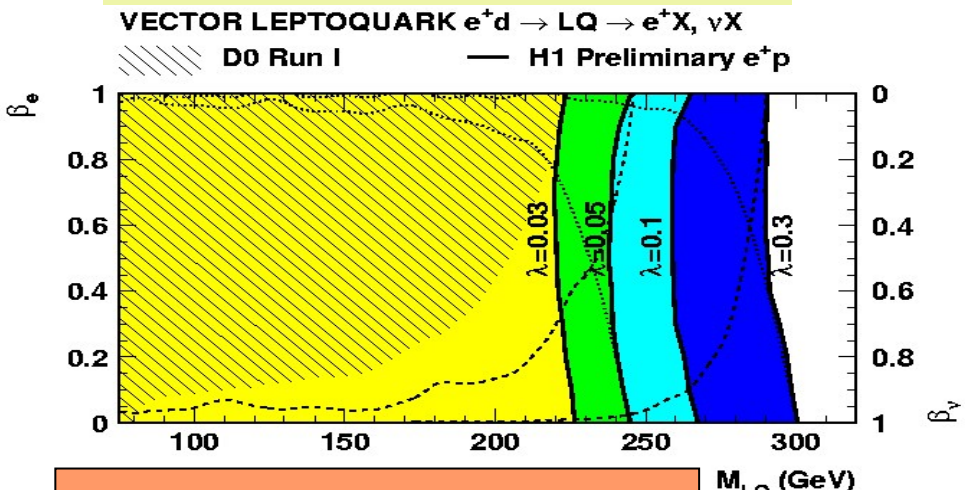


Similar agreement of $e^-p \to e^-X$ and $e^+p \to \nu X$ spectra (F=0,+/- 2)

Good agreement with the Standard Model
Hence derive mass and coupling exclusion limits

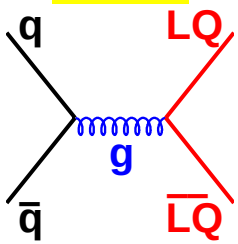
Leptoquarks
Mass and coupling limits

BRW:β =0,0.5, generic models β free



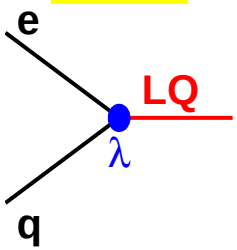
HERA limits independent of β

p p

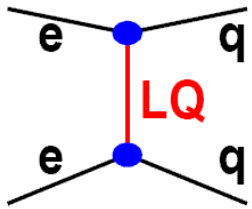


independent of λ

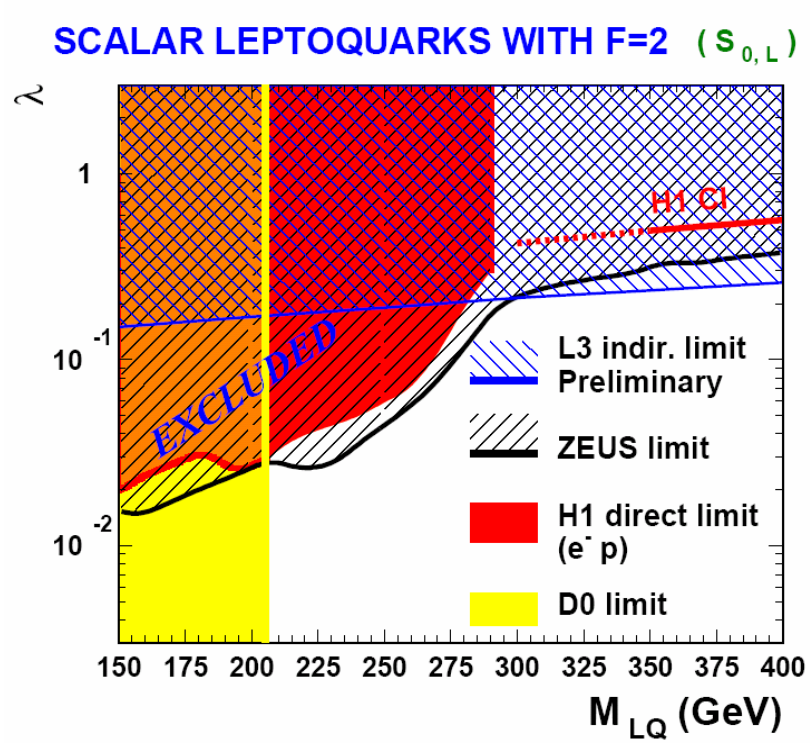
e p



e e



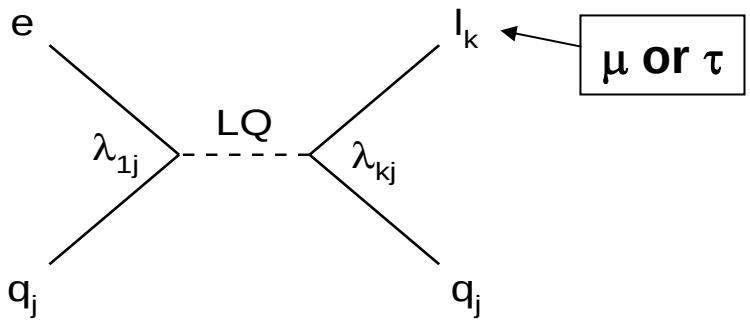
strong dependent of λ

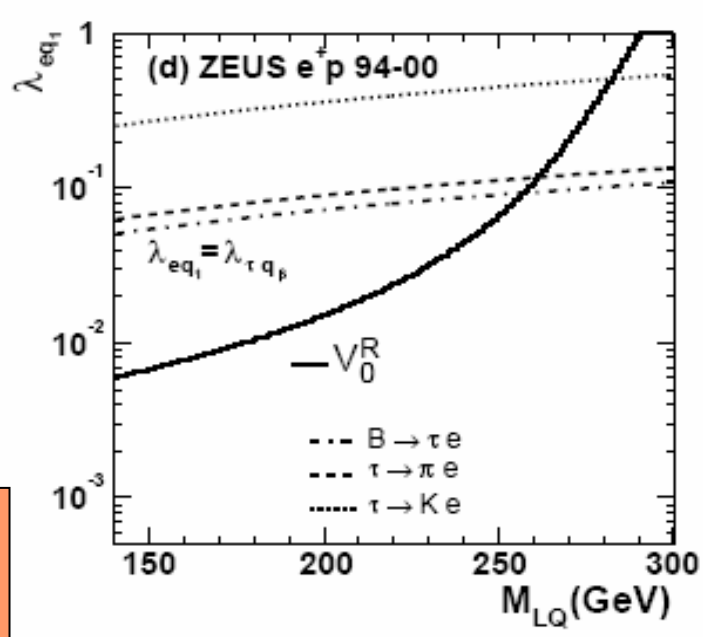


For $\lambda=\sqrt{4\pi\alpha_{em}}$ LQs with M<290 GeV are ruled out

Lepton Flavor Violation

Search for ep->μX and ep->τX
Possibly mediated by LQ or squarks





No evidence found
limits on M_{LQ} and $\lambda_{\mu q}$, $\lambda_{\tau q}$ derived

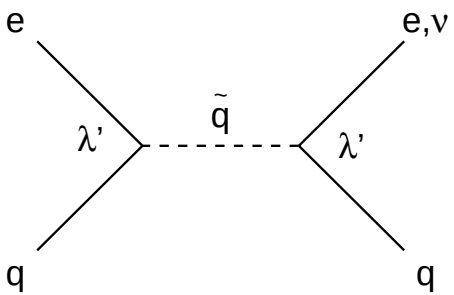
Similar results from H1

Supersymmetry

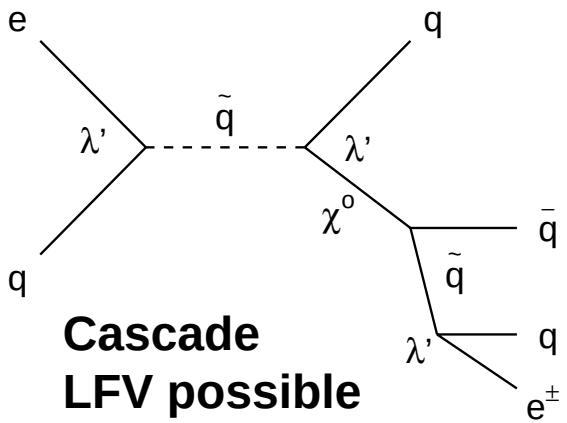
Each fermion (boson) gets a supersymmetric bosonic (fermionic) partner.

- **Particles carry the number $R_p = (-1)^{L+3B+2S}$ which is 1 for particles and -1 for sparticles.**
- **Many different models depending on SUSY breaking mechanism (gravity mediated, gauge interaction) and on R_P conservation/violation.**
- **If R_P might be violated SUSY particles can be singly produced and the LSP is not stable**

At HERA best discovery reach is the R_pV resonant production of a squark

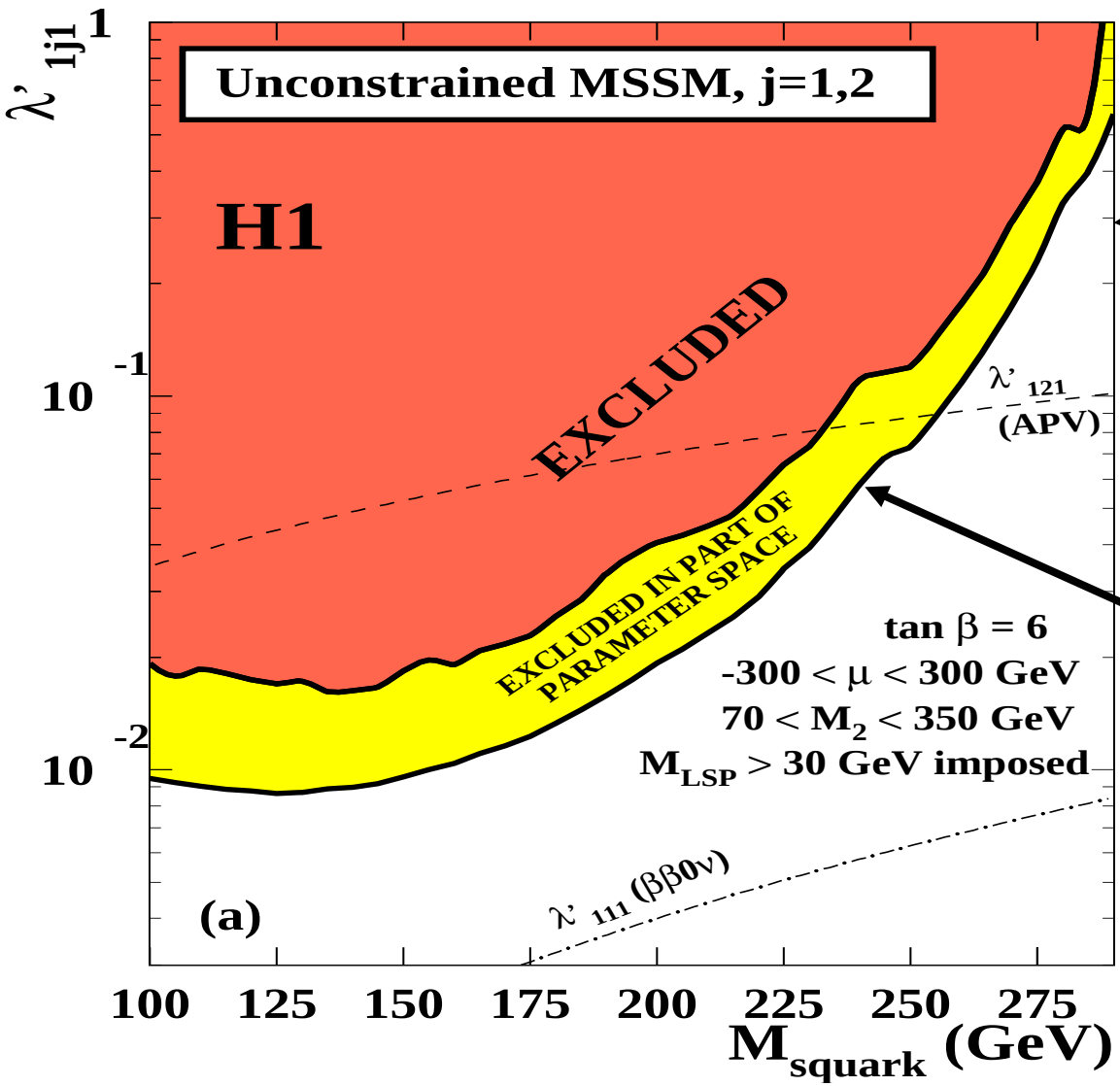


Leptoquark-like



Cascade
LFV possible

R-parity violating SUSY limits - 1



For

$\lambda'_{1j1} = \sqrt{4\pi\alpha_{em}}$

squarks below ~275 GeV are ruled out

Limits on λ'_{1j1} widely independent on μ and M_2

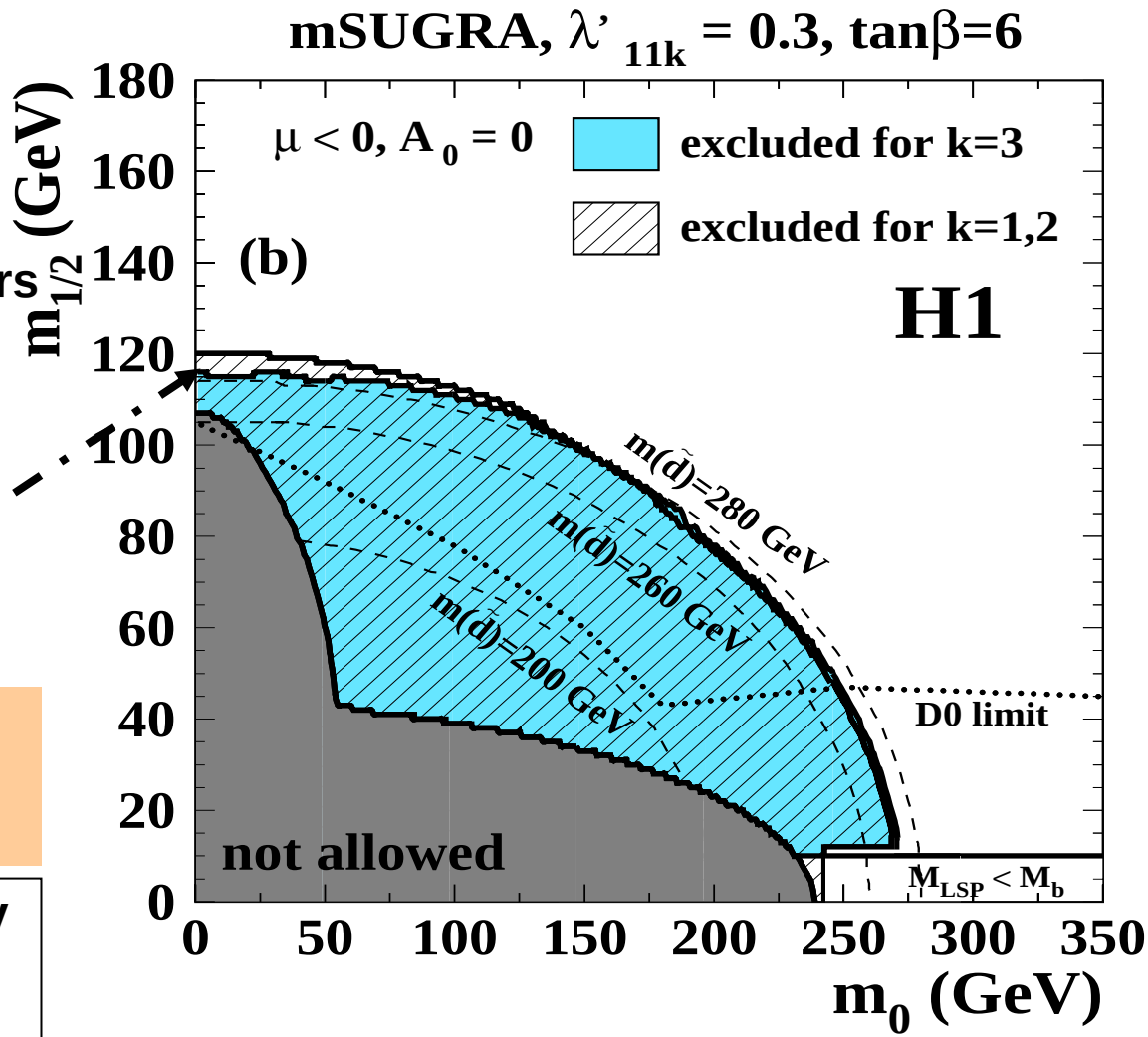
R-parity violating SUSY limits - 2

mSUGRA constrained by

- λ, tan β, sign of μ, A_0

and universal mass parameters at the GUT scale:

- m_0 scalar fields
- $m_{1/2}$ gauginos



M_{squark}< 285 GeV ruled out

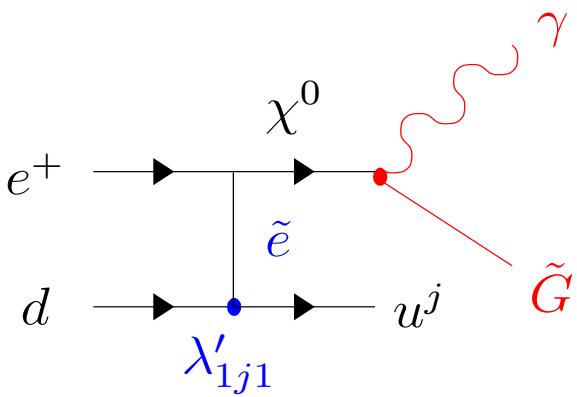
For Squark= $\tilde{d}_R, \tilde{s}_R, \tilde{b}_R$

For λ'_{1j1}=0.3 M_{squark} < 275 GeV (Squark = $\tilde{u}$, $\tilde{c}$, $\tilde{t}$ **) nearly fully excluded**

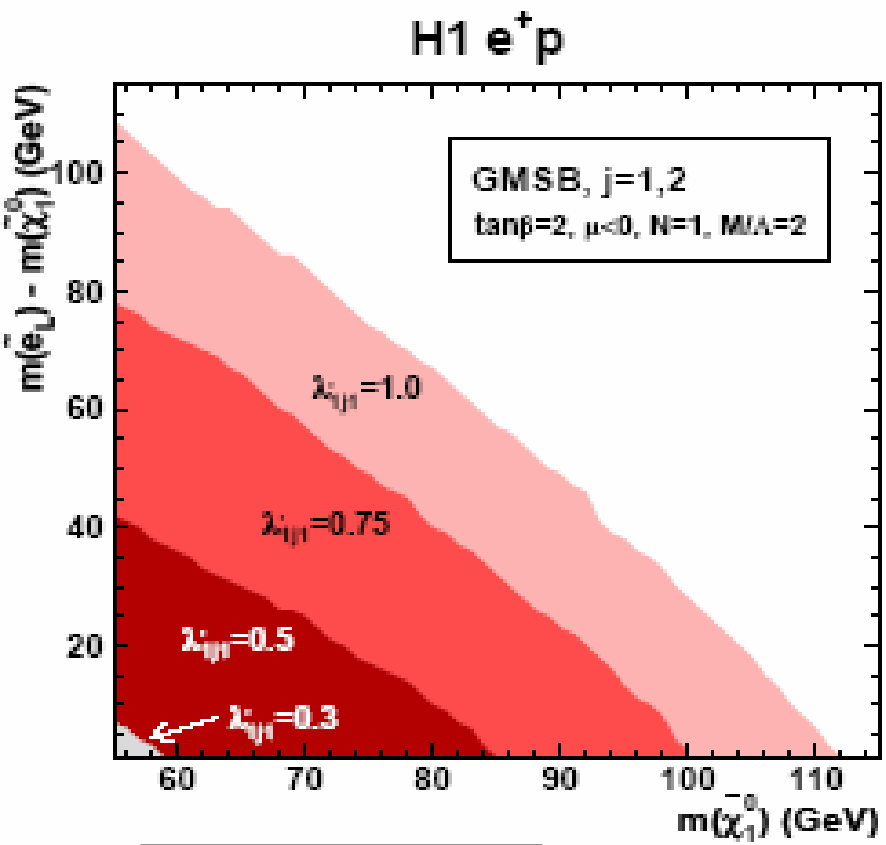
Search for gravitinos

GMSB (Gauge mediated SUSY breaking)

- **an extension of R_P-violating SUSY**
- **gravitino as the LSP (< 1 GeV)**
- **NLSP is the neutralino, with short lifetime and decay into a stable gravitino**



***t*-channel selectron exchange**



Signature: An isolated γ, a jet and $P_{T,miss}$

1 candidate event after all selection cuts

Limits for λ'=1.0 :

$m_\chi > 108$ GeV

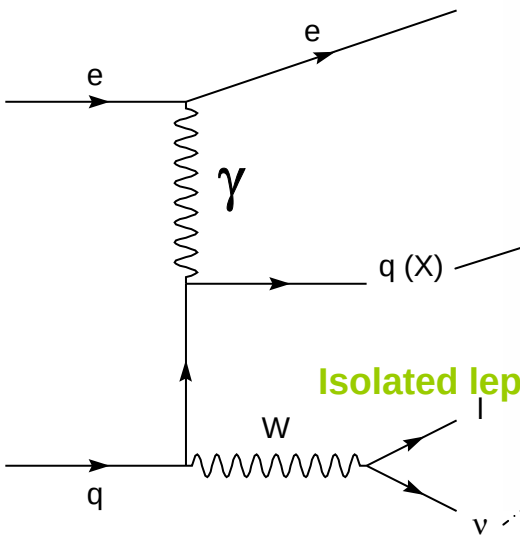
& $m_e > 138$ GeV

First constraints at HERA indep. of squark mass

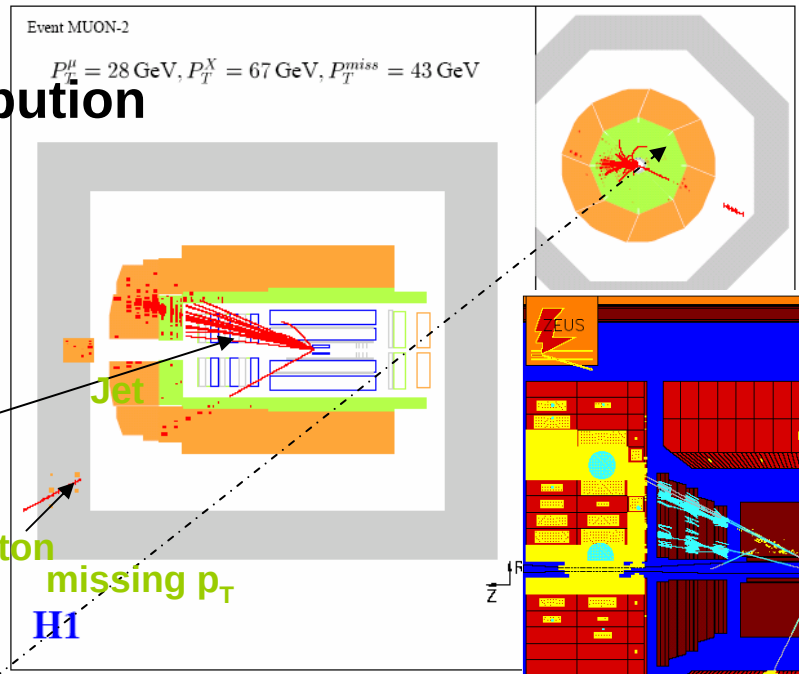
Isolated leptons

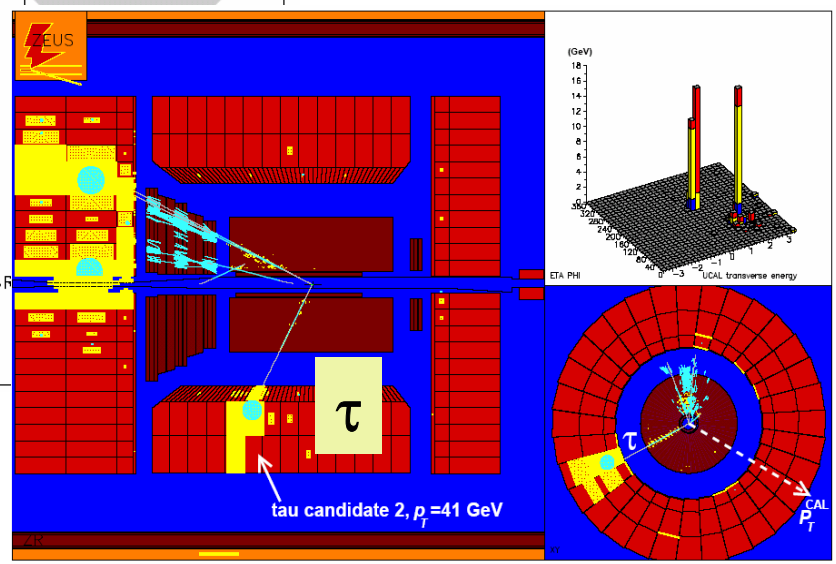
Zeus and H1 are looking for events with isolated leptons with high p_T , jet with high p_T and $p_{T,miss}$

W production dominant SM contribution



$e^+p \rightarrow \mu^+X$





Isolated lepton results in numbers

HERA 1 1994-2000

H1 118 pb^{-1}	Electron ob/ex	Muon ob/ex	Tau (prel.).
12< PtX < 25 GeV	1/ 1.96 ± 0.27	2 / 1.11 ± 0.19	5 / 5.81 ± 1.36
$25 < P_T(X) < 40$ GeV	1 / 0.95 ± 0.14	3 / 0.89 ± 0.14	0 / 0.53 ± 0.10
$P_T(X) > 40$ GeV	3 / 0.54 ± 0.11	3 / 0.55 ± 0.12	0 / 0.22 ± 0.05
ZEUS 130 pb^{-1}	**Electron ob/ex**	**Muon ob/ex**	**Tau ob/ex**
All data	24 / 20.6 ± 3.2	12 / 11.9 ± 0.6	3 / 0.4 ± 0.12
$P_T(X) > 25$ GeV	2 / 2.9 ± 0.46	5 / 2.75 ± 0.21	2 / 0.2 ± 0.05
$P_T(X) > 40$ GeV	0 / 0.94 ± 0.11	0 / 0.95 ± 0.12	1 / 0.07 ± 0.02

H1 HERA 1 + HERA2 1994-2004

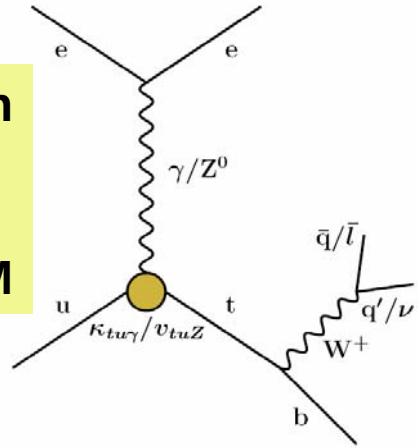
H1 Lumi = 163 pb^{-1}	Electron ob/ex	Muon ob/ex		Comb. ob/ex
All data	20 / 16.1 ± 2.2	9 / 4.2 ± 0.7		29 / 20.3 ± 2.9
$P_T(X) > 25$ GeV	10 / 2.7 ± 0.5	6 / 2.6 ± 0.5		16 / 5.3 ± 1.0

Interesting events seen by both experiments – Effect to be followed up with incoming data

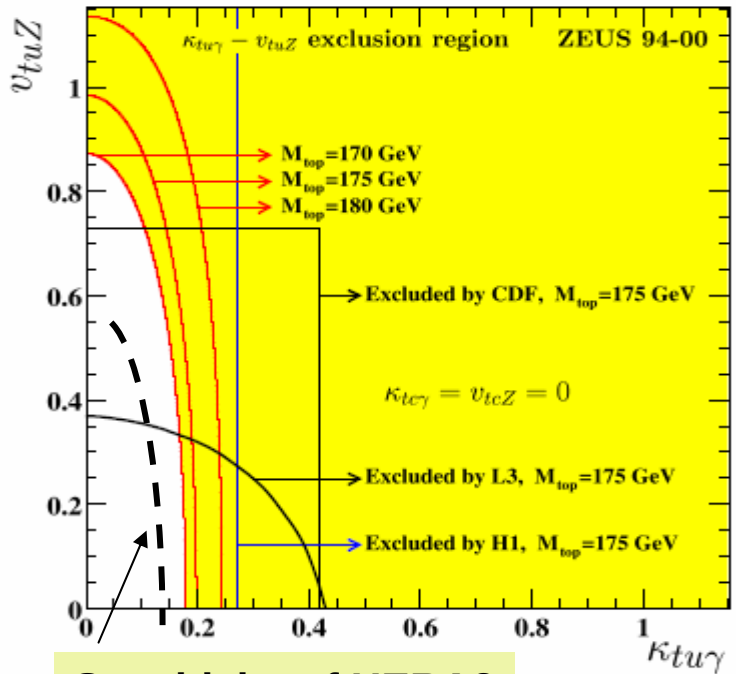
Anomalous (FCNC) single top production

Isolated lepton, p_{Tmiss} and a hard jet also the signature for *t→bW→blν*

SM cross section ep->νtbX < 1fb, but present in extensions to SM



Cross-section Limits:
(√s=318 GeV ; CL 95%)
H1 : σ (*ep→etX*) < 0.55 pb (5 candidate events)
ZEUS: σ (*ep→etX*) < 0.225 pb (0 events)



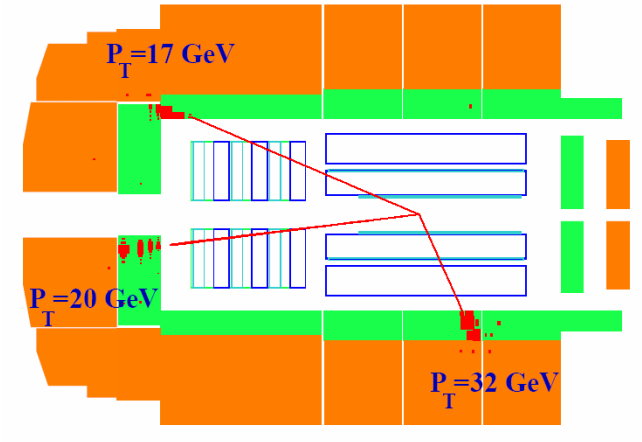
Sensitivity of HERA2

Comparable to limits from LEP (*e⁺e⁻→γ,Z→tu*)

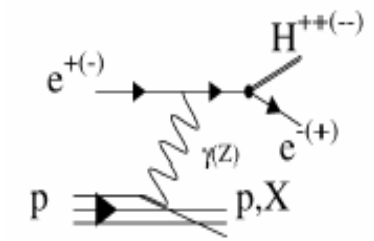
and TeVatron (rare top decays : *t→γq, Zq*)

HERA is very sensitive to $\kappa_{tu\gamma}$ and only slightly sensitive to v_{tuZ}

Search for Multi-Lepton Events

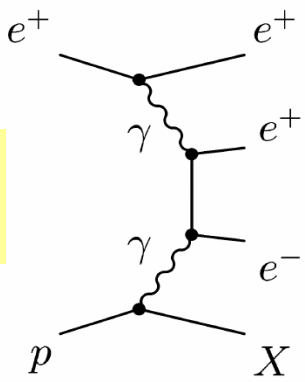


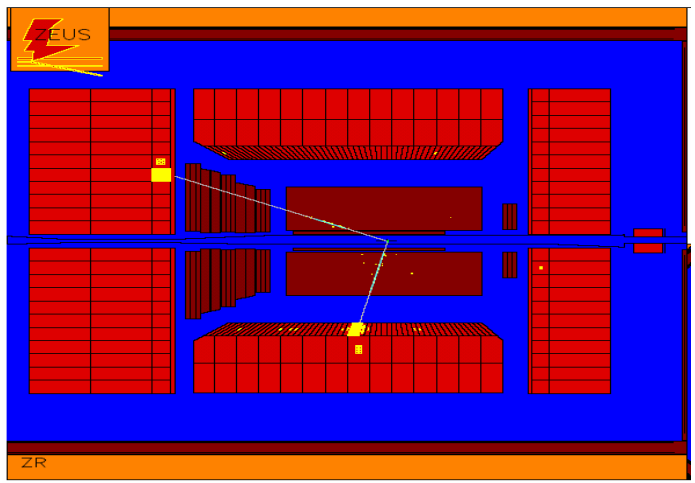
BSM: H^{++} at high mass



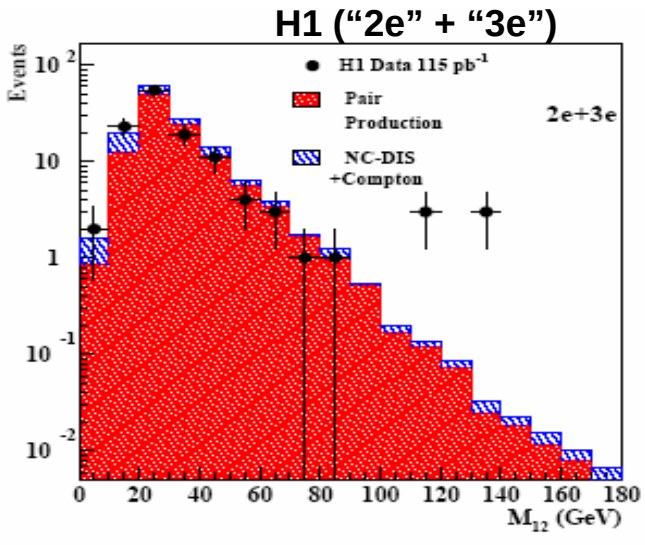
H++->2e (2μ,2τ)

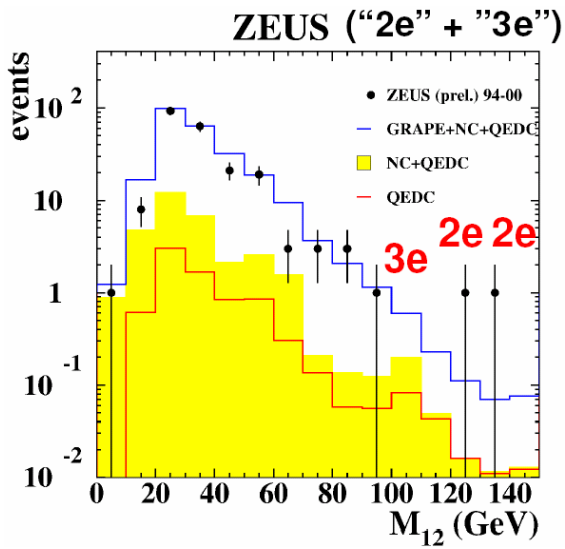
(Main) SM contribution:





Multi-electron events at high invariant mass





good agreement with SM found in μ and τ channels

M_{12} = mass of two highest p_T electrons

selection	H1 (115 pb^{-1})	ZEUS (130 pb^{-1}) [prelim.]
2e, M > 100 GeV	3 / 0.30 ± 0.04	2 / 0.77 ± 0.08
3e, M > 100 GeV	3 / 0.23 ± 0.04	0 / 0.37 ± 0.04

1 candidate for H++ ⇒ limits: $M_{H^{++}} > 130$ GeV ($h_{ee} = 0.3$)

Conclusion

HERA - the worlds only electron proton collider - provides unique possibilities to test the SM and search for new physics in ep scattering at highest energies

Exploring the full HERA 1 data set no signal of BSM physics observed, but some interesting deviations found to be followed up in the future.

First results from HERA 2 have been presented confirming the HERA 1 observations. HERA2 start-up is promising - with the new incoming data (700 pb-1 until 2007) sensitivity to new physics will increase.