Searches for new physics at HERA

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on behalf of the ZEUS and H1 collaborations

Searches for new physics at HERA

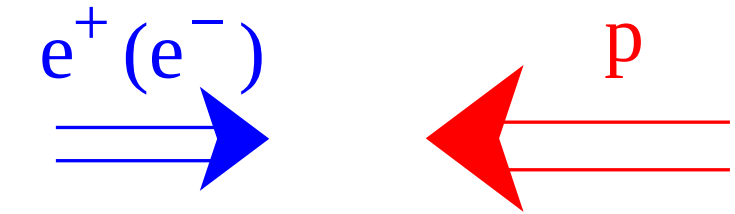
Contact interactions and resonances

- Contact interactions
- Large Extra Dimensions
- Quark radius
- Leptoquarks
- Lepton-flavor violation
- R_p conserving SUSY in MSSM
- R_p violating SUSY
- Excited fermions

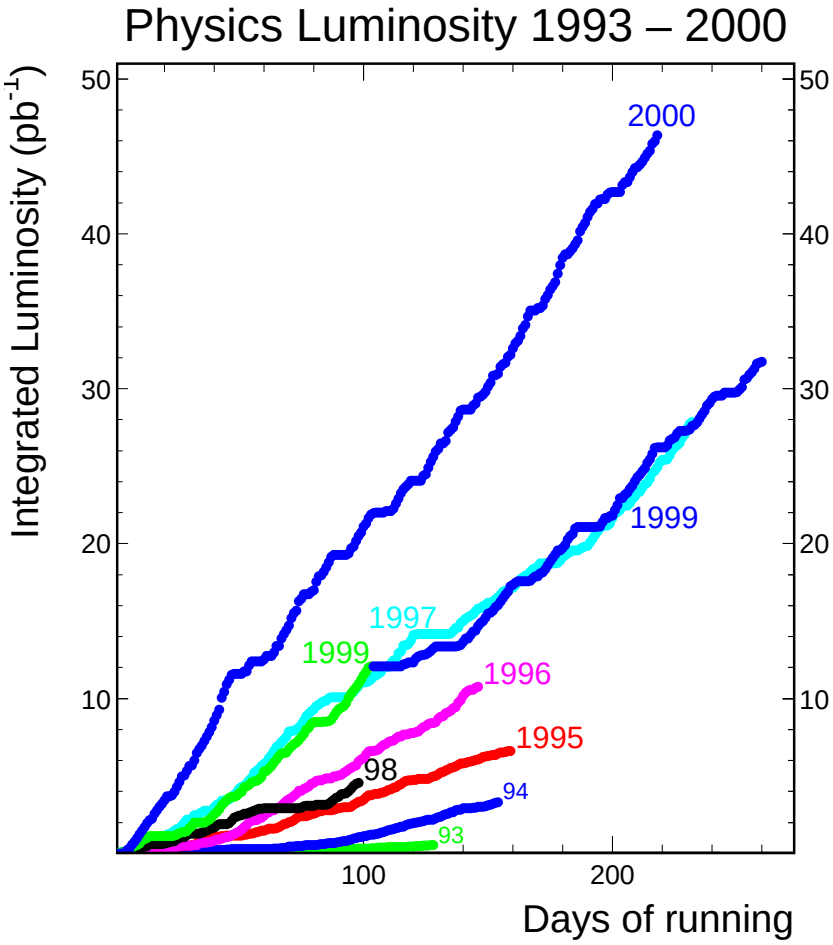
Exclusive final states:

- Isolated leptons with missing transverse momentum
- Top quark production via FCNC
- Multilepton and multimuon events
- $H^{++/--}$
- Magnetic monopoles

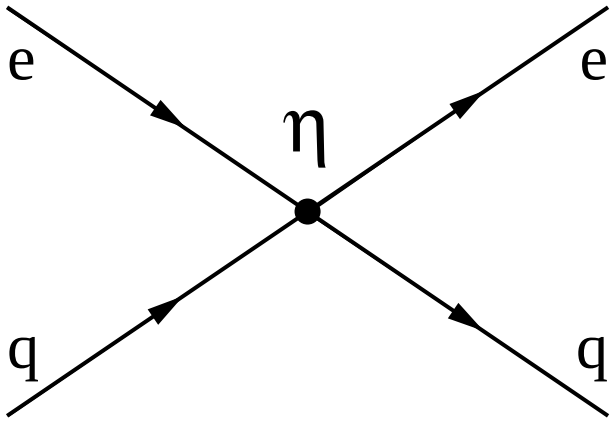
HERA I



Years	Beam	$\sqrt{s}$	Integrated luminosity ZEUS – H1
94-97	e^+	300 GeV	47.7 pb^{-1} – 35.6 pb^{-1}
98-99	e^-	318 GeV	16.7 pb^{-1} – 16.4 pb^{-1}
99-00	e^+	318 GeV	65.1 pb^{-1} – 65.2 pb^{-1}



Contact interactions



HERA can search signs of new physics at energy scales up to ~ 1 TeV and at distances down to $\sim 10^{-16}$cm

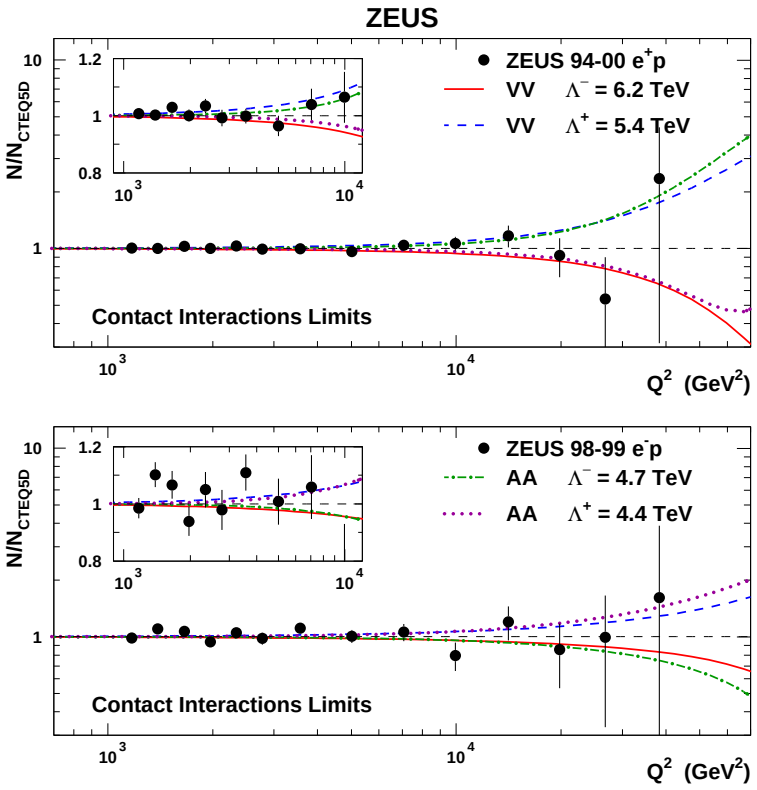
Lagrangian (vector component):

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

- Compositeness → $\eta_{ij} = \epsilon_{ij} \frac{4\pi}{\Lambda^2}$
- Leptoquarks → $\eta_{ij}^{q} = \epsilon_{ij}^{q} \frac{\lambda^2}{M_{LQ}^2}$
- R_p violating SUSY → $\tilde{d}_R$ and $\tilde{u}_L$ correspond to S_0^L and $\tilde{S}_{1/2}^L$ LQs
- Large extra dimensions → $\eta_G = \frac{\lambda}{M_S^4}$
- Quark radius (assuming $R_e = 0$) → $\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \left(1 - \frac{R_q^2}{6}\right)^2$

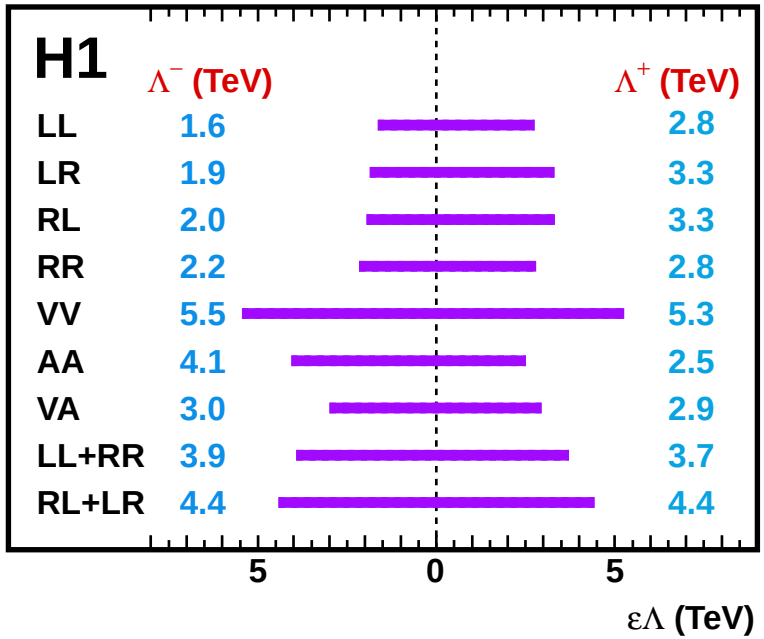
Contact interactions II

Limits on compositeness scale (Λ):



ZEUS: $1.7 - 6.2$ TeV

H1: $1.6 - 5.5$ TeV



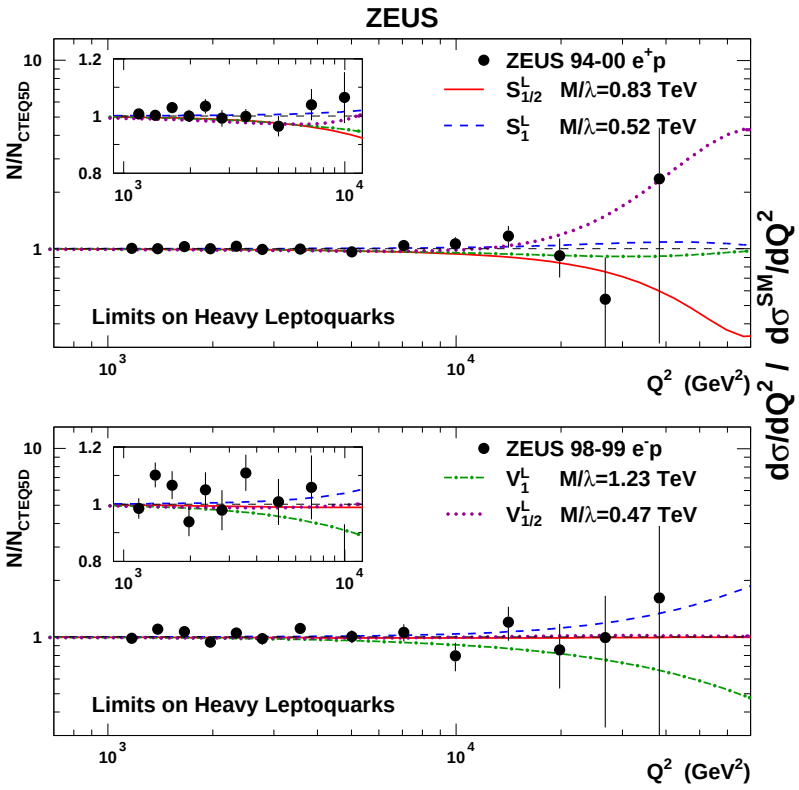
Quark radius:

ZEUS: $0.85 \cdot 10^{-16}$ cm

H1: $1 \cdot 10^{-16}$ cm

Contact interactions III

Limits on Leptoquarks (M_{LQ}/λ):



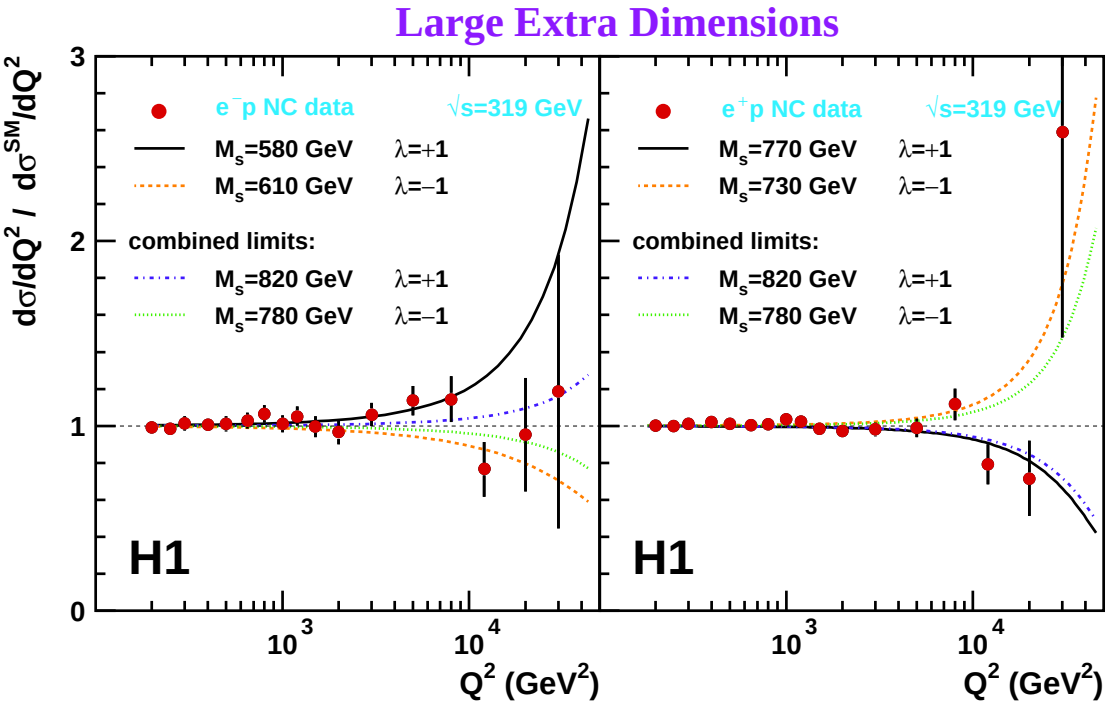
ZEUS: $0.27 - 1.23$ TeV

H1: $0.3 - 1.4$ TeV

Large Extra Dimensions (M_S):

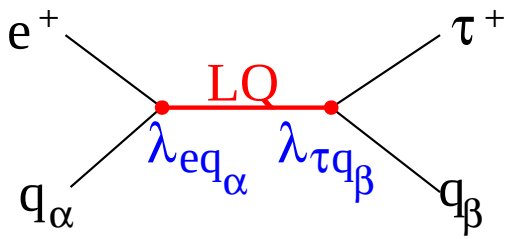
ZEUS: $0.78, 0.79$ TeV

H1: $0.78, 0.82$ TeV

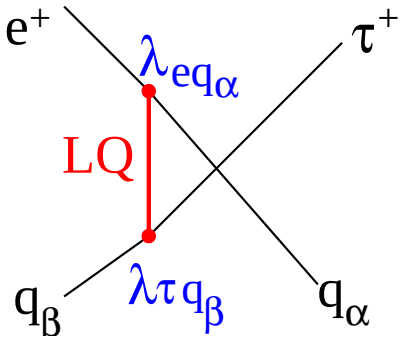


Lepton-flavor violation

a)



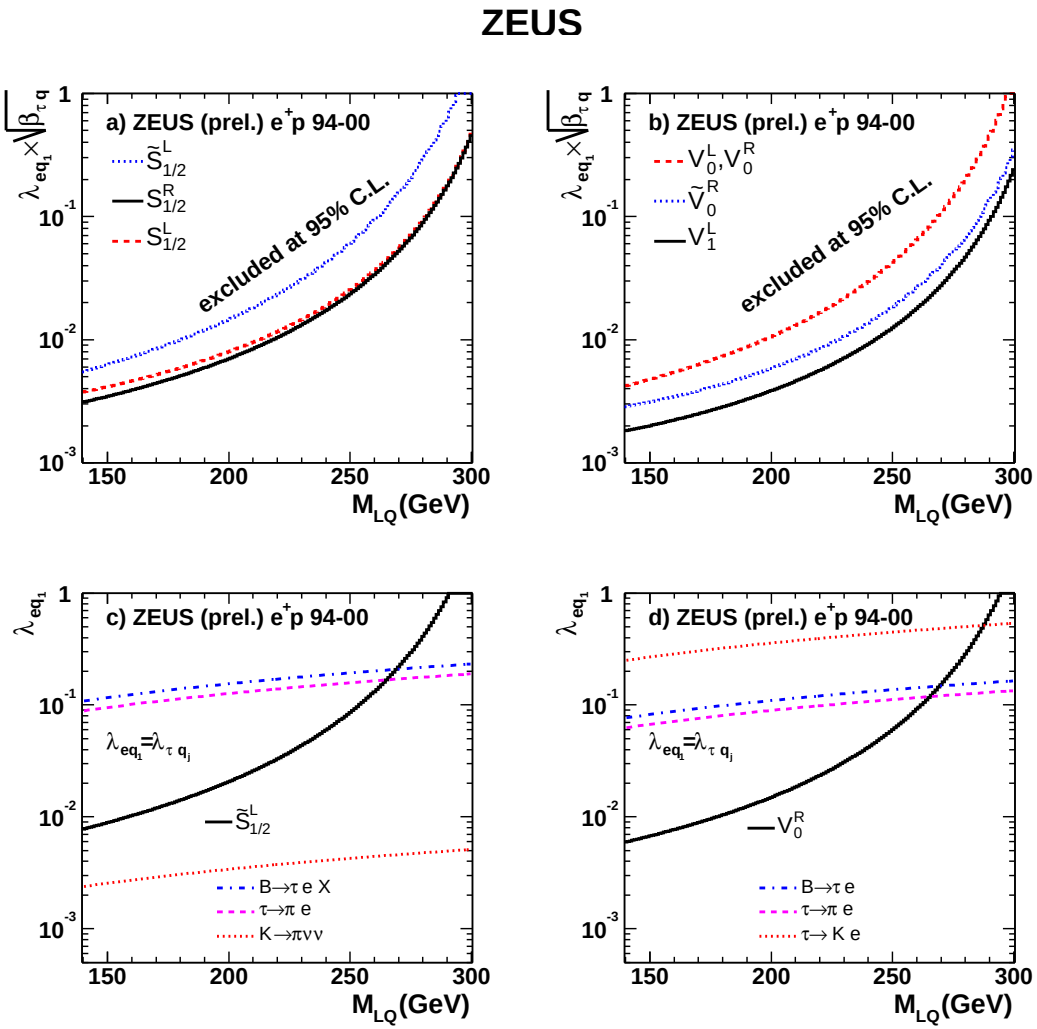
b)



- The recent discovery of neutrino oscillations has shown that the lepton flavor is not conserved at least in the neutral sector.
- Many extensions of SM (GUT and SUSY) predict lepton-flavor violation.
- Signature at HERA: a muon or a tau instead of the electron in the final state.
- High efficiency and low background from SM.

- Buchmüller-Rückl-Wyler leptoquark model has been considered.
  14 LQ types: 7 scalar and 7 vector.
- Both resonant production ($M_{LQ} < \sqrt{s}$) and contact-interaction ($M_{LQ} \gg \sqrt{s}$) have been considered.

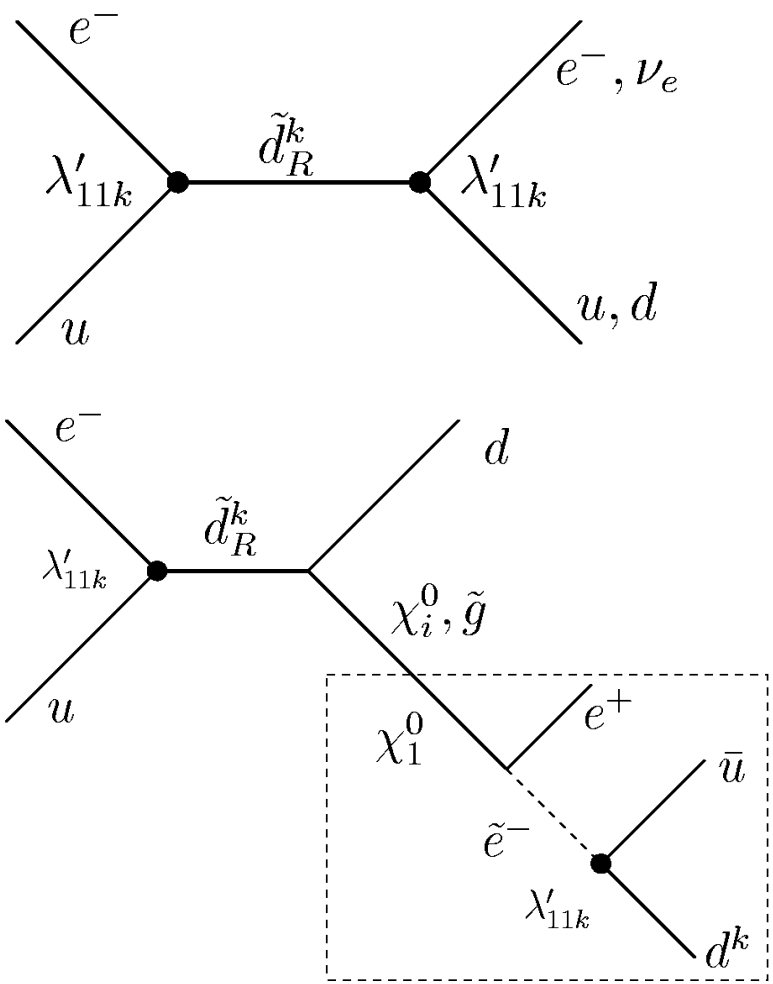
Lepton-flavor violation II



- Limits on $\lambda_{eq_1}\sqrt{B_{lq_j}}$ independent from final-state quark generation for $M_{LQ} < \sqrt{s}$. Several limits also apply to R_P violating squarks.
- Limits on $\frac{\lambda_{eq_i}\lambda_{lq_j}}{M^2_{LQ}}$ for $M_{LQ} \gg \sqrt{s}$ down to 0.4 TeV^{-2}

For $\lambda_{eq_1} = 0.3$ and $B_{lq_j} = 0.5$ LQ masses up to 300 GeV excluded. In general HERA limits better than low energy experiments when higher generation quarks involved

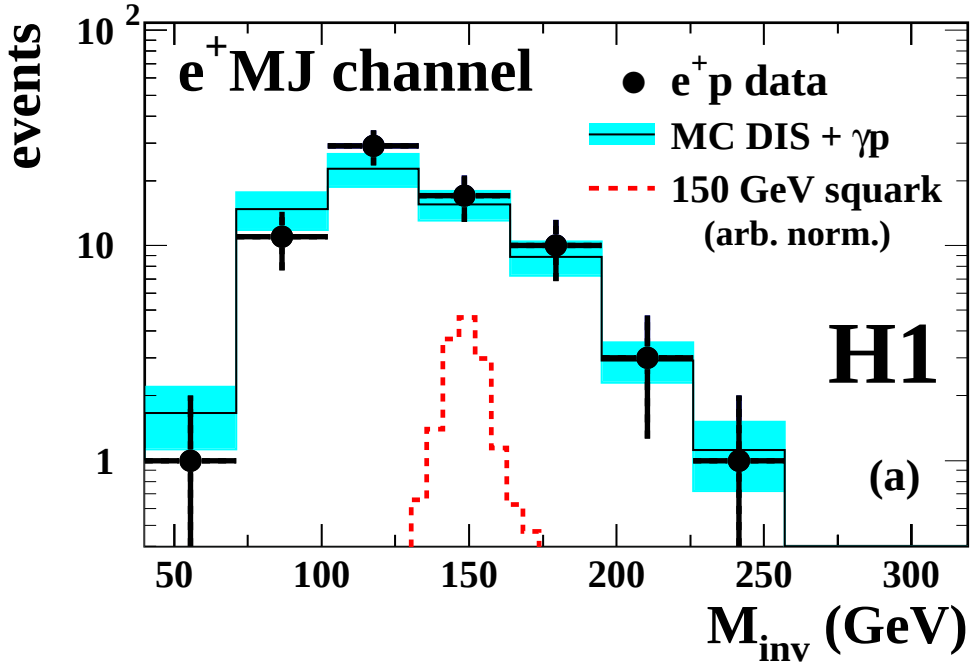
R_p violating SUSY



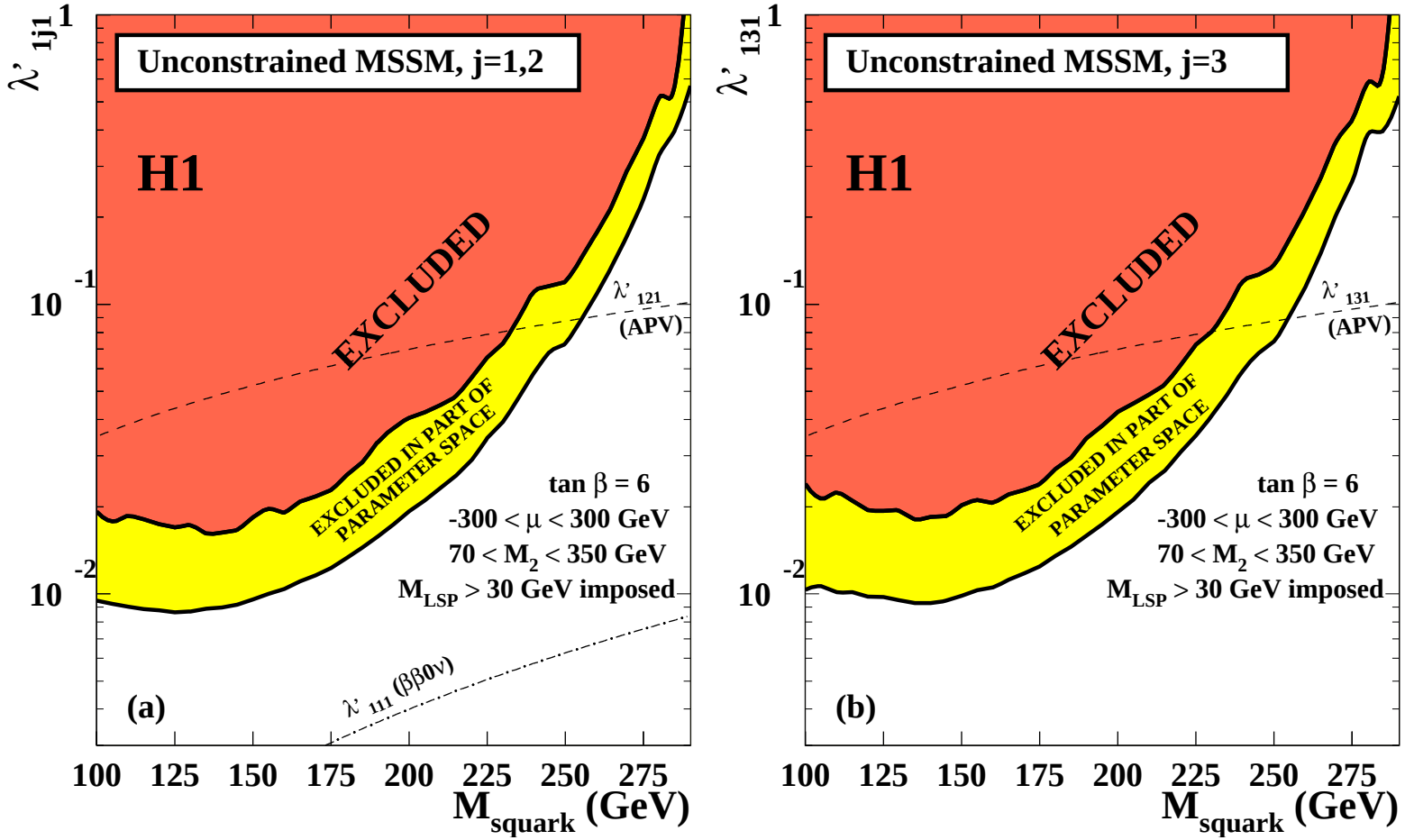
$\tilde{u}_L$ and $\tilde{d}_R$ squark production

Several event typologies in the final state:

- eq
- νq
- $e^{\pm}$ jets
- ν jets
- $e^{\pm} l$ jets
- νl jets



R_p violating SUSY II

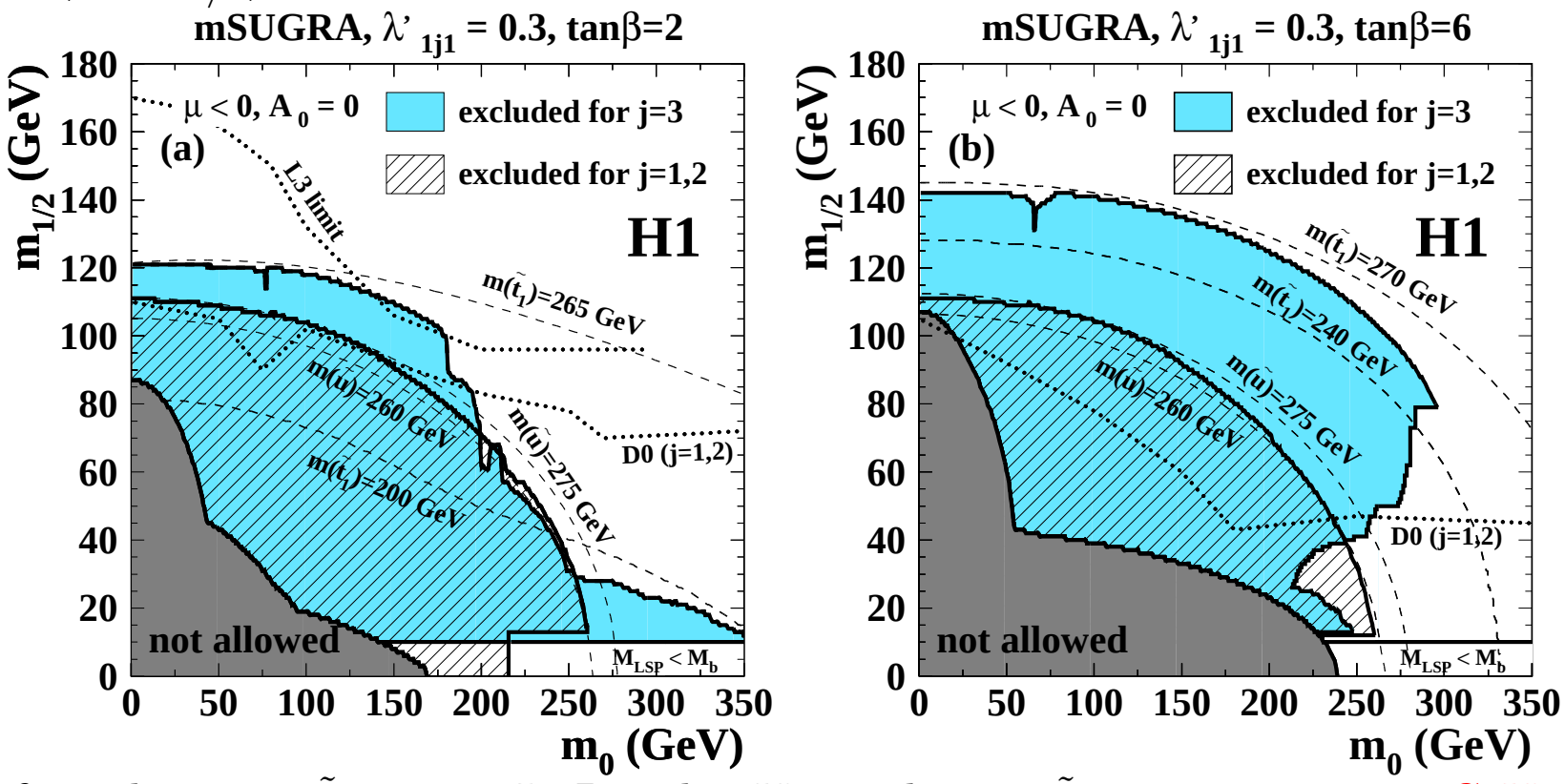


Assuming $\lambda'_{1j1} = 0.3$ ($\lambda'_{11k} = 0.3$) squark mass up to 275 (280) GeV can be excluded

R_p violating SUSY III

mSUGRA (minimal supergravity):

Limits on $(m_0, m_{1/2})$:

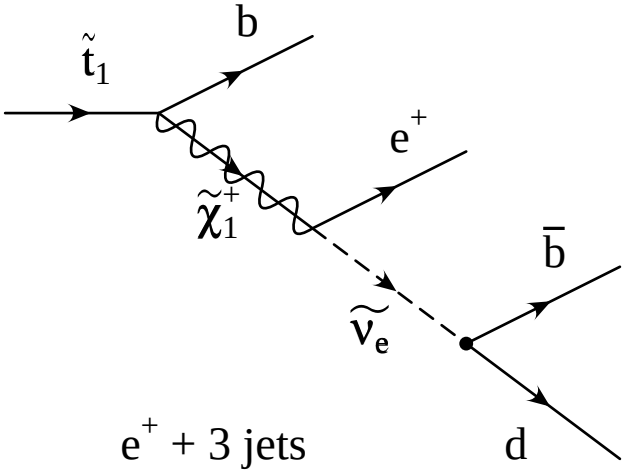


For $\tan\beta = 6$ limits on $\tilde{t}$ improve LEP and TeVatron limits. $\tilde{t_1}$ masses up to 270 GeV excluded for $\lambda'_{131} = 0.3$.

R_p violating SUSY IV

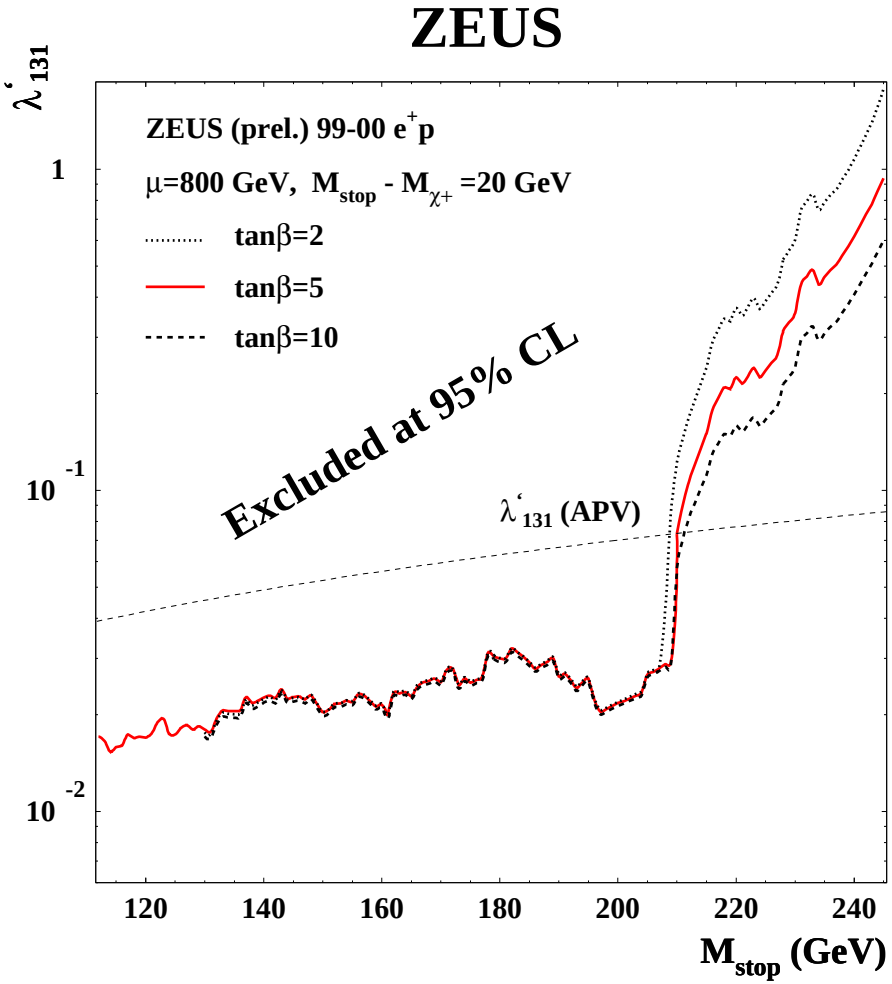
S-top production:

ZEUS searched for s-top production focusing on the $\tilde{t} \to b\chi^+$ decay channel.



Main assumptions:

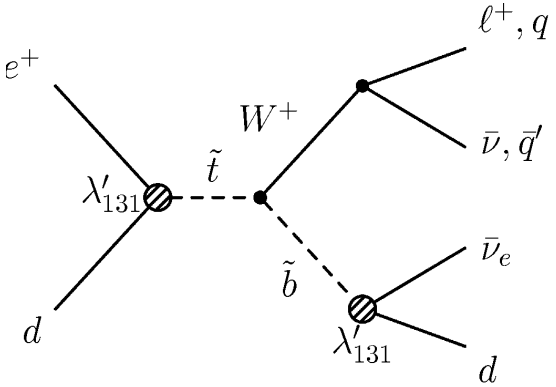
- Only $\lambda'_{131} \neq 0$
- χ^0 is the LSP (and above LEP limits)
- $M_3 = 1$ TeV to suppress $\tilde{t} \to t\tilde{g}$



R_p violating SUSY V

Bosonic s-top decays:

If $M_{\tilde{t}} > M_{\tilde{b}}$ s-top can decay in $\tilde{b}W$:

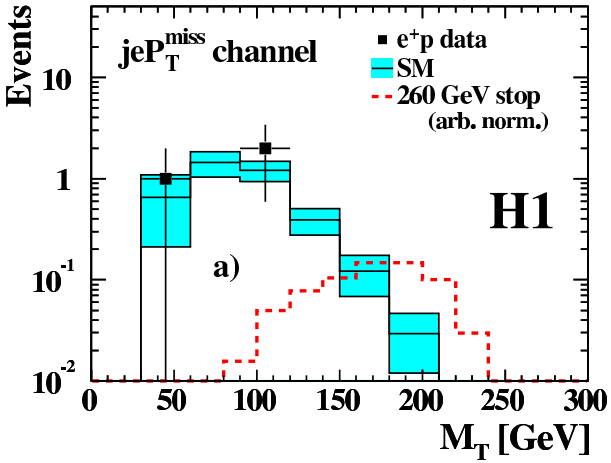


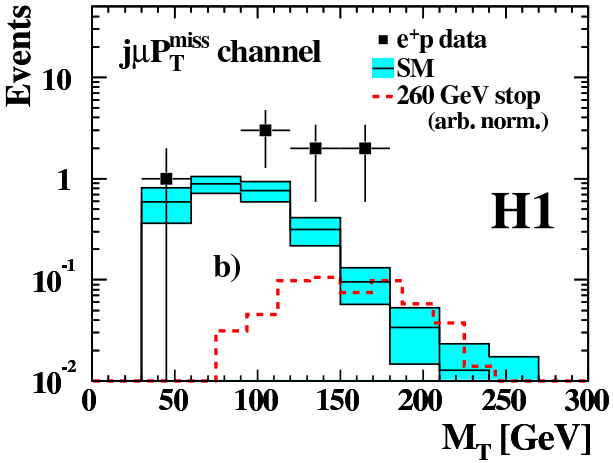
a)

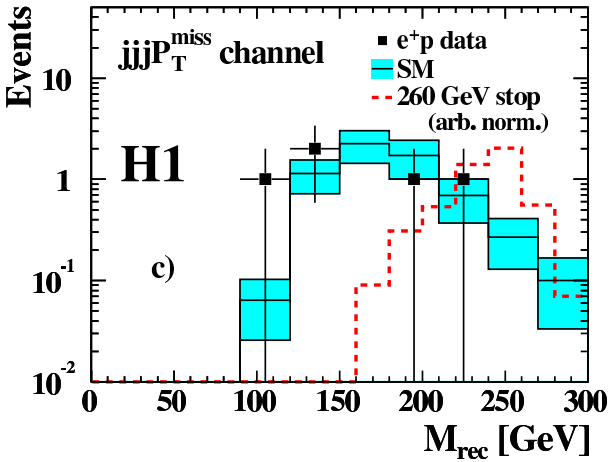
Final state topologies:

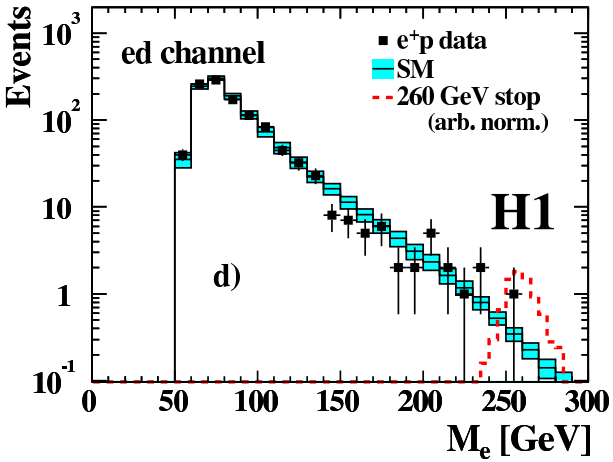
- $l + jet + \not{P}_t$
- $3jet + \not{P}_t$
- $e + jet$

Slight excess in the μ+jet+$\not{P}_t$ channel



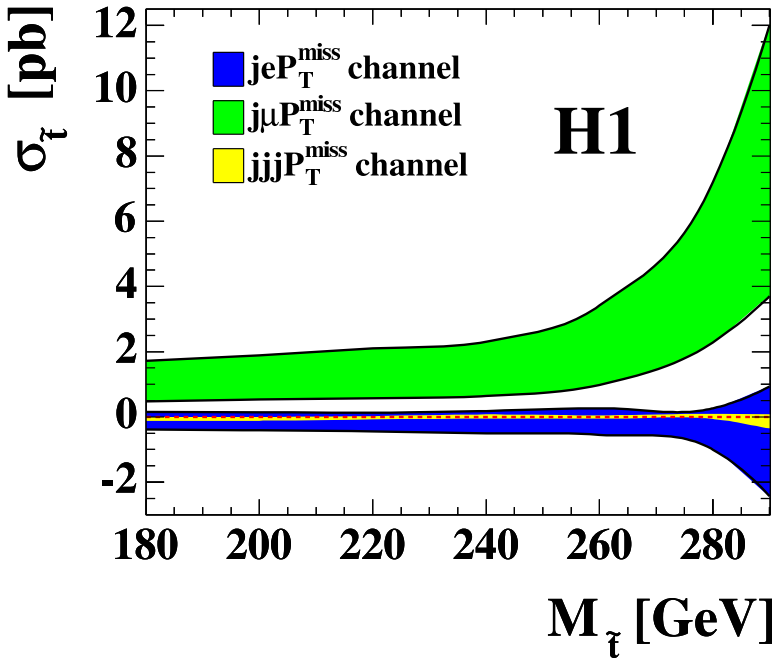




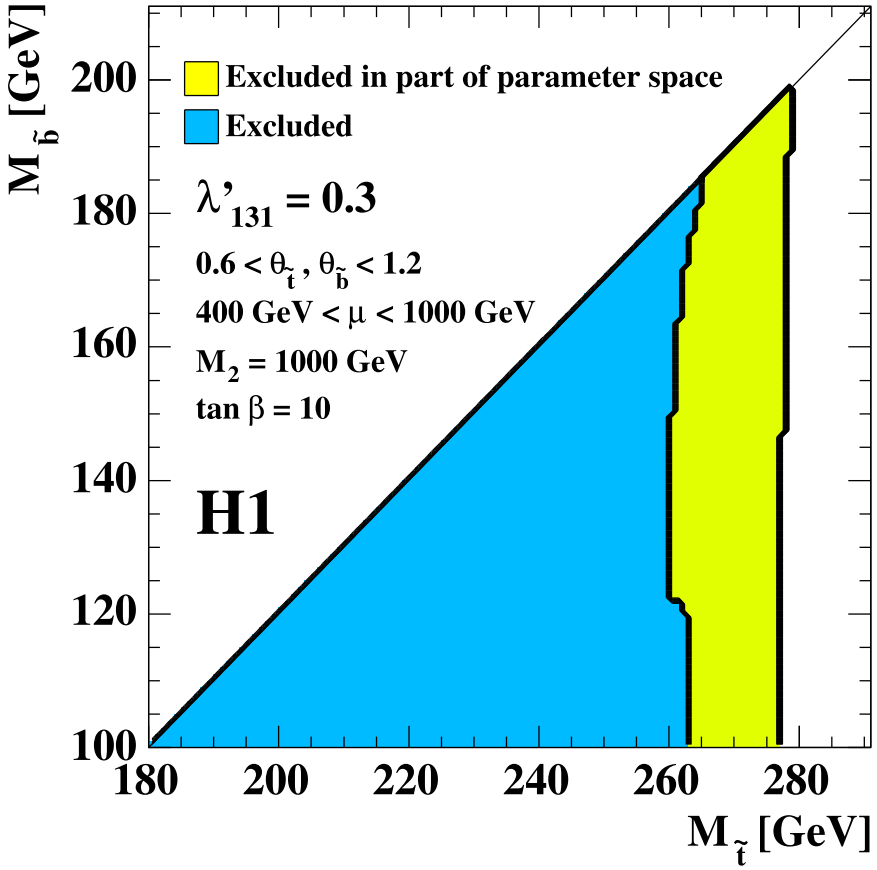


R_p violating SUSY VI

$M_{\tilde{t}} < 275$ GeV can be excluded at 95% C.L.



Excess in the $\mu + jet + \not{R}_t$ channel not supported by other decay modes

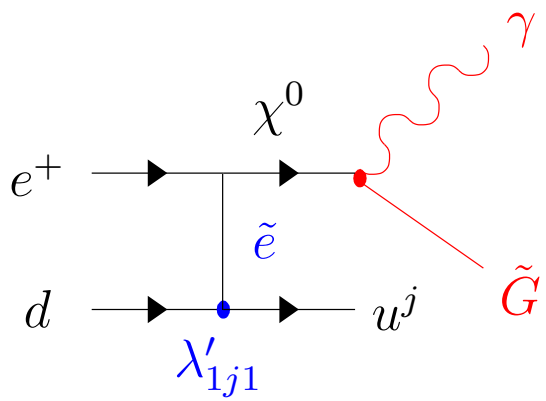


R_p violating SUSY VII

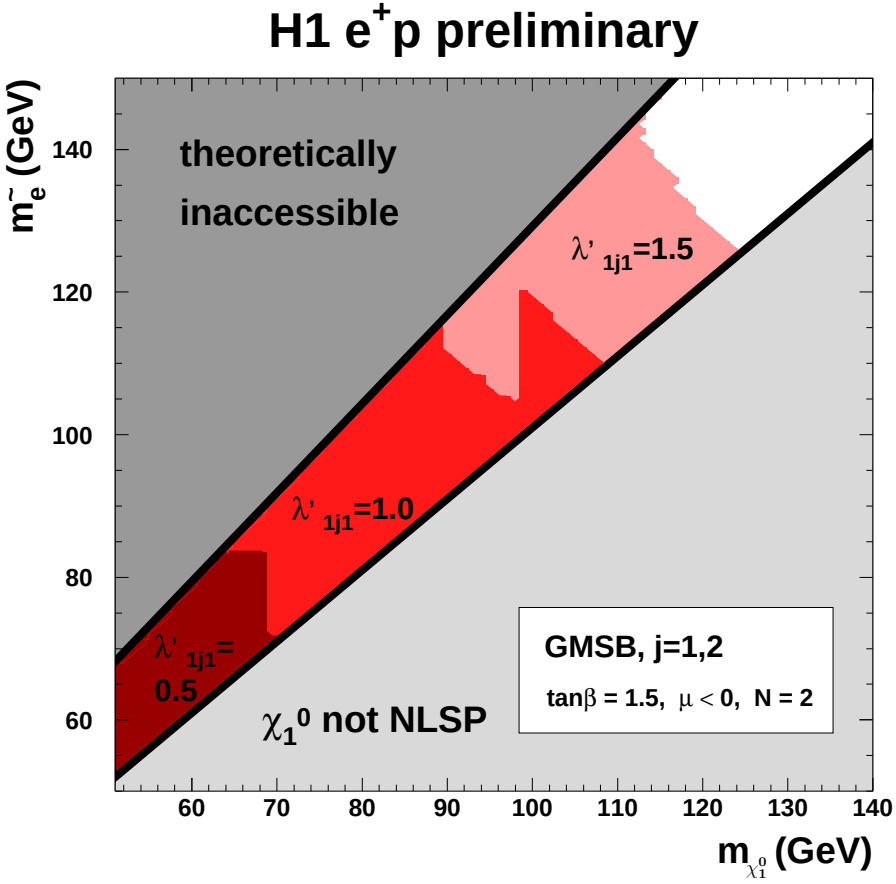
Superlight gravitino:

Gauge mediated supersymmetry breaking model. The gravitino is assumed the LSP and $BR(\chi_1^0 \to \gamma G) = 100\%$

In this model $M_{slepton} \ll M_{squark}$



1 event (2.55 ± 1.30 SM)



$M_{\chi_1^0} < 108$ GeV are excluded for $\lambda'_{1j1} = 1$ (OPAL 91 GeV)

Isolated leptons and missing transverse momentum

	P_T^X	Electrons		Muons		Taus	
		Data	SM	Data	SM	Data	SM
H1	$P_T^X > 25$GeV	4	1.49	6	1.44	0	0.53
H1	$P_T^X > 40$GeV	3	0.54	3	0.55	0	0.22
ZEUS	$P_T^X > 25$GeV	2	2.9	5	2.75	2	0.20
ZEUS	$P_T^X > 40$GeV	0	0.94	0	0.95	1	0.07

H1 finds an excess of events in the e and μ channel (but not in the τ channel) in e^+p data

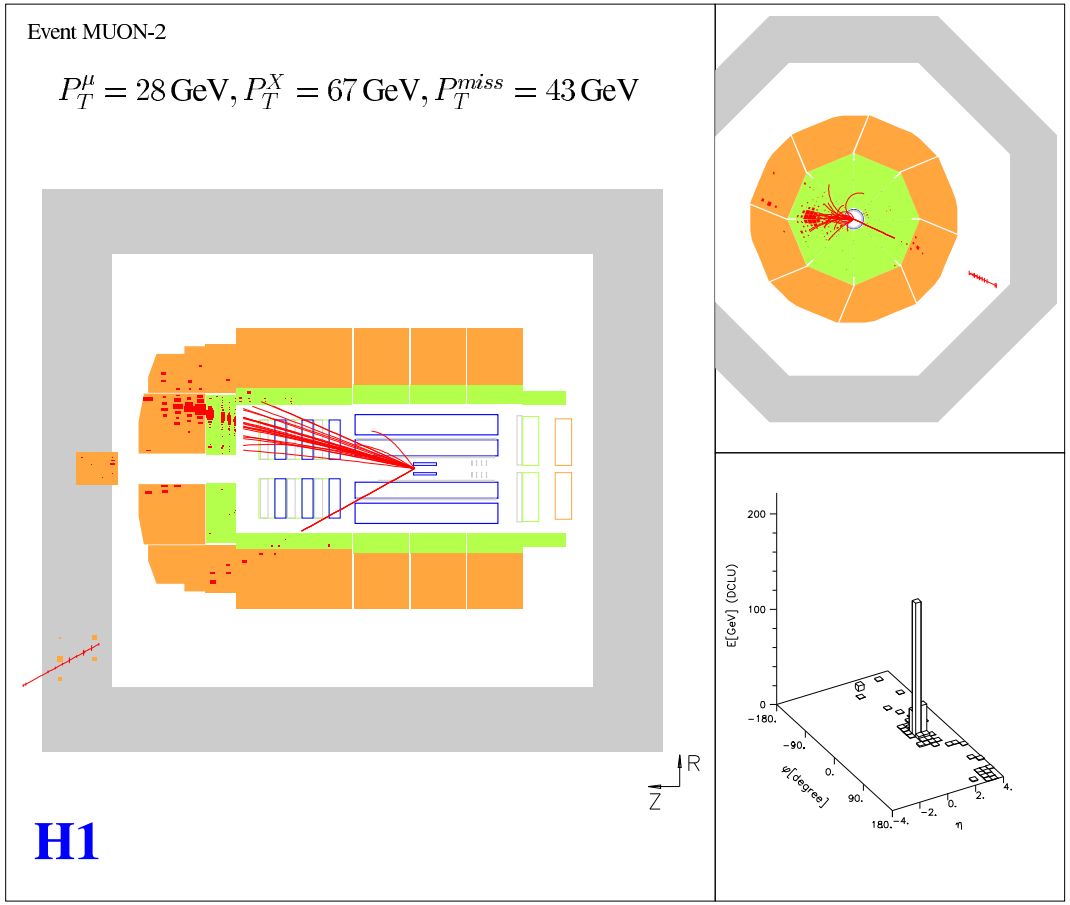
ZEUS finds an excess in the τ channel only

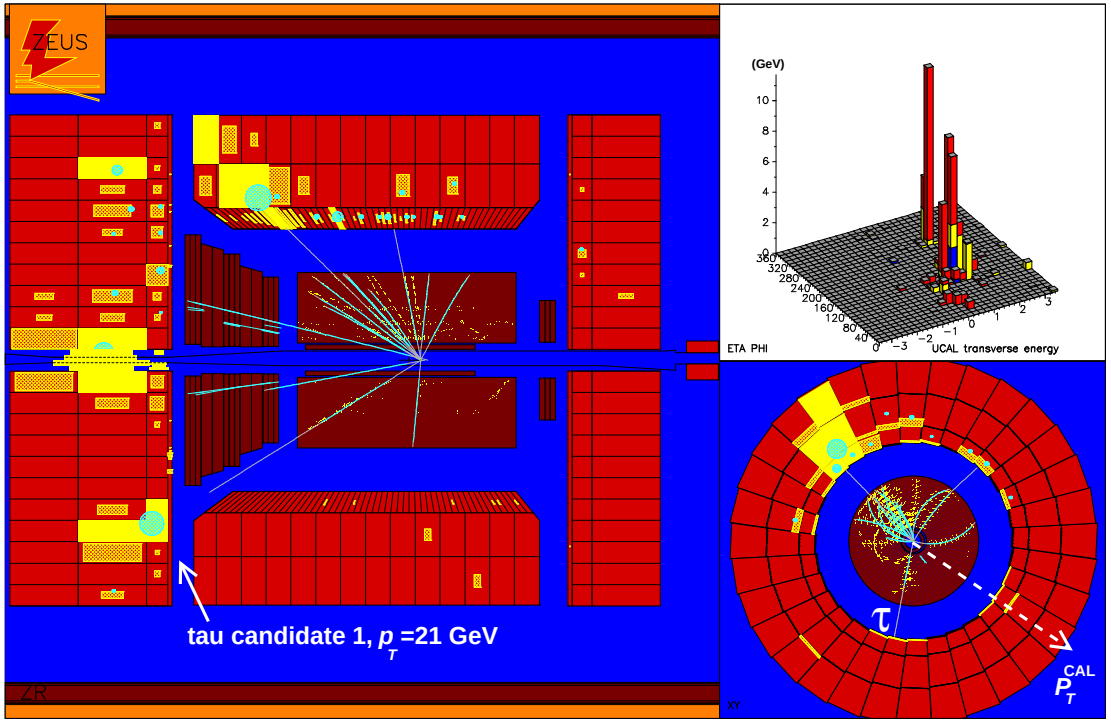
- Possible explanation: top quark production via **FCNC** with anomalous magnetic $k_{tu\gamma}$ or vector v_{tuZ} couplings.
- The ZEUS excess for tau is not compatible with the results in the other channels.

Events with isolated high p_t leptons

H1 event with isolated muon

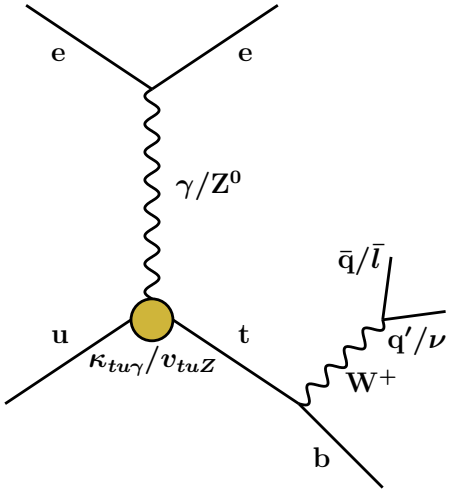
$e^+p \to \mu^+X$

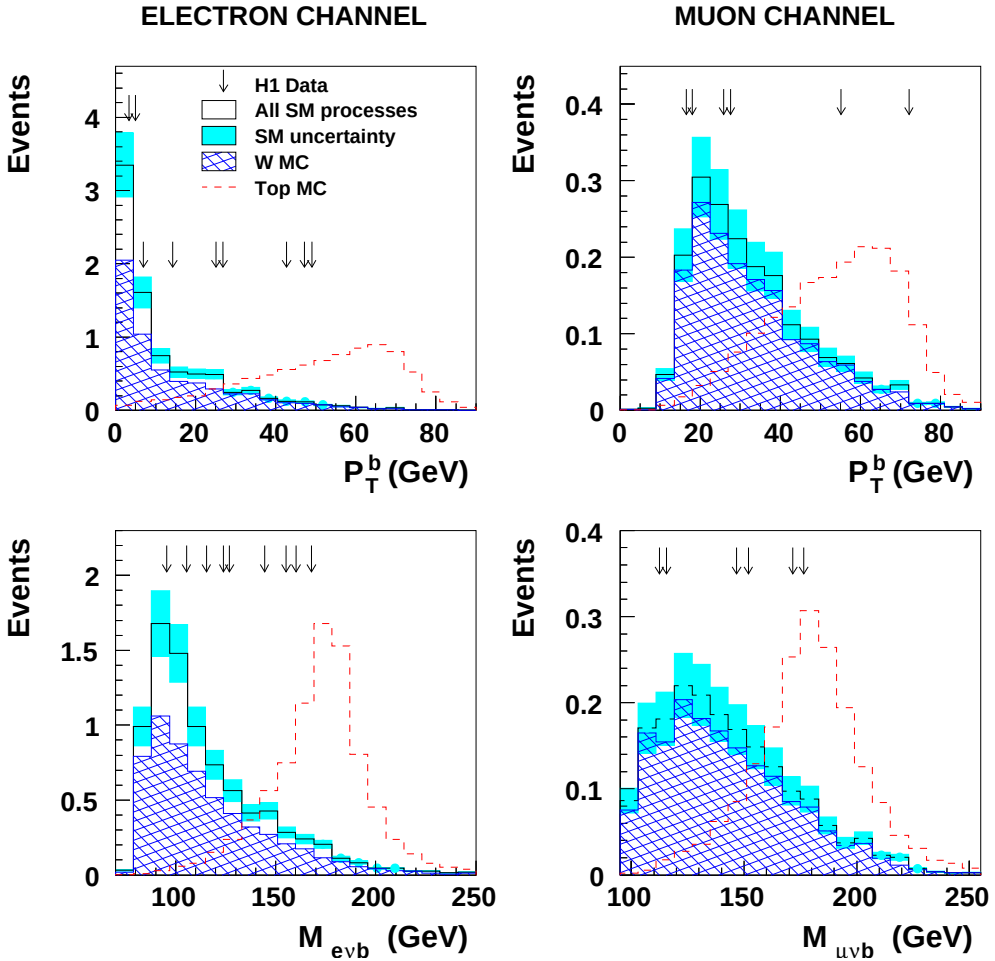




ZEUS event with isolated tau

Single top production





Lepton channel (e, μ):

$P_t^{jet} > 30$ GeV , $P_t^X > 40$ GeV e

$M_{l\nu b} > 140$ GeV

H1: 5 events ($3e$ and 2μ), 1.31 ± 0.22 from SM

ZEUS: no event

Both the experiments found an agreement with the SM in the hadronic channel.

Single top II

H1:

If the excess is due to single top production:

$\sigma = 0.29 + 0.15/-0.14$ pb
$(\sqrt{s} = 318$ GeV)

If statistical fluctuation:

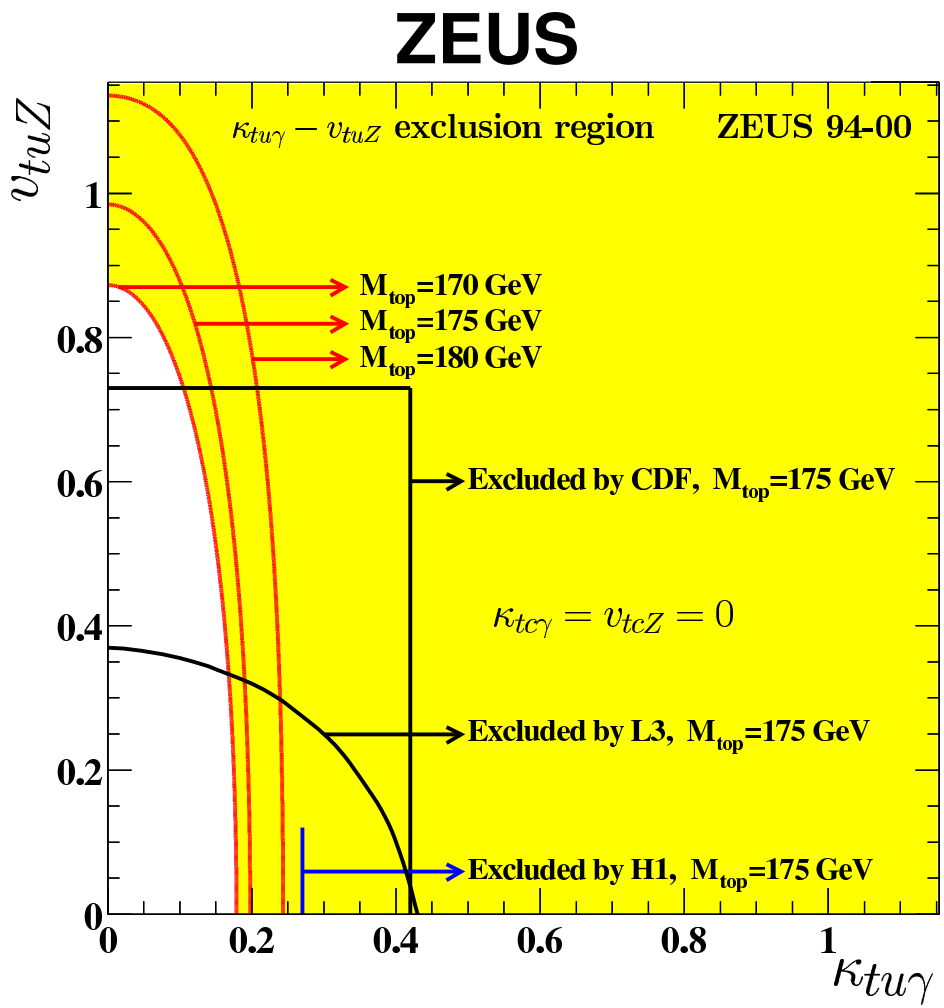
$\sigma < 0.55$ pb at 95% C.L.

ZEUS:

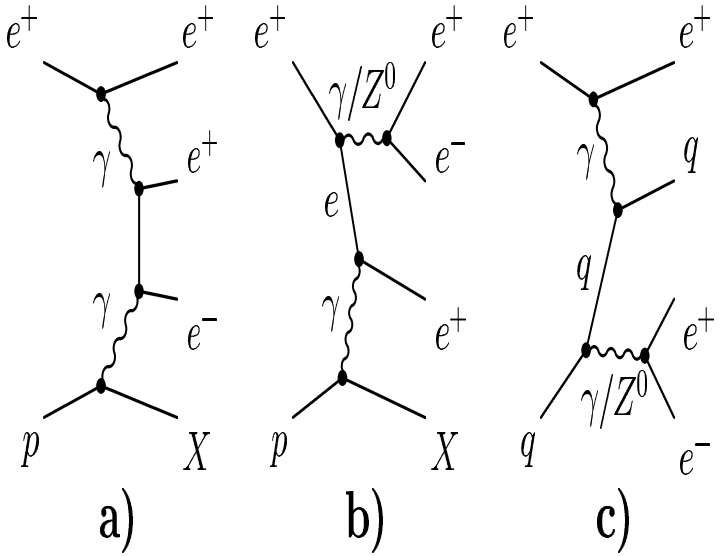
Agreement with SM:

$\sigma < 0.225$ pb at 95% C.L.

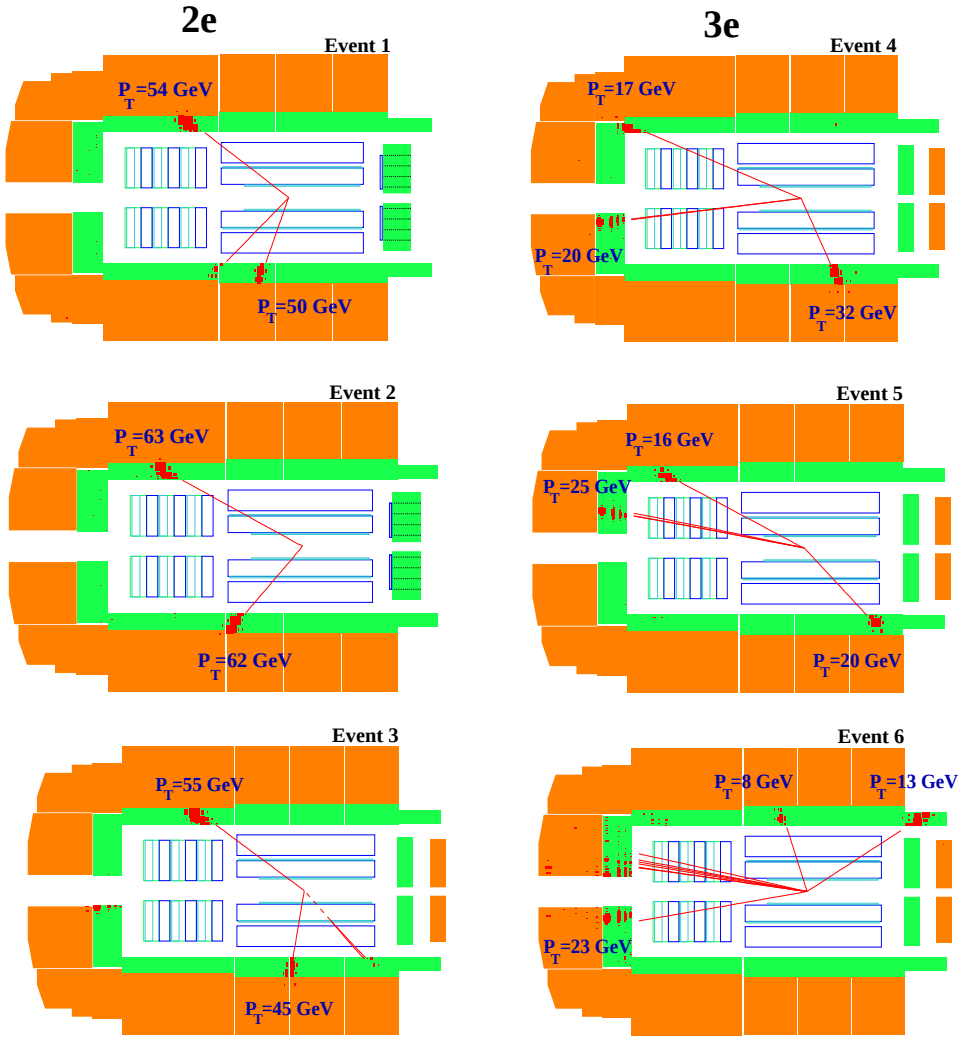
ZEUS limits consider also the efficiency for the Z_0 channel



Multi-leptons events

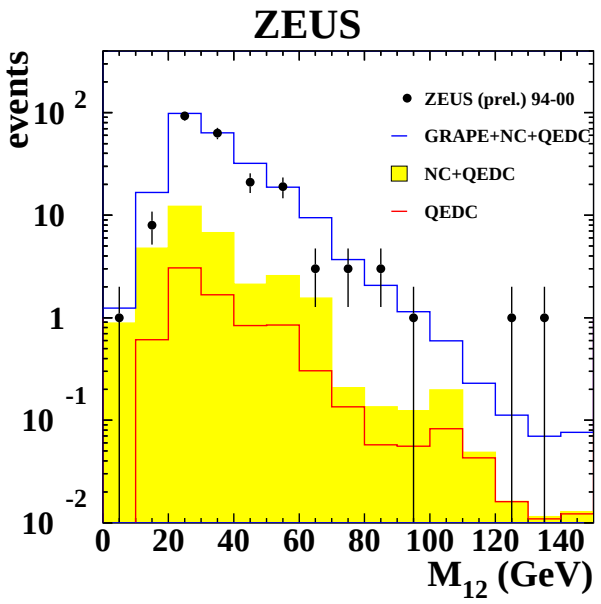


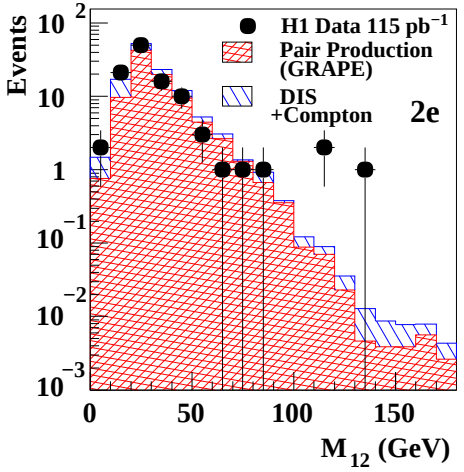
H1 found an excess of events with 2 or 3 electrons and high invariant mass ($M > 100$ GeV)

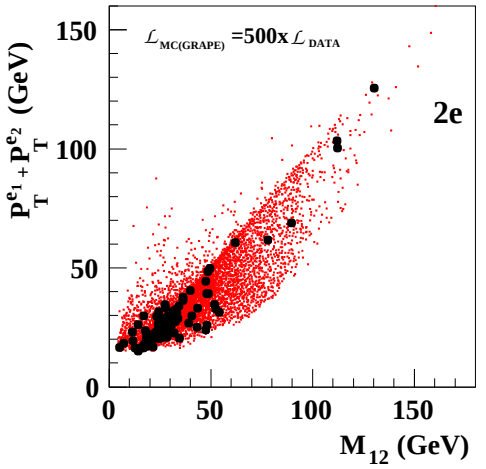


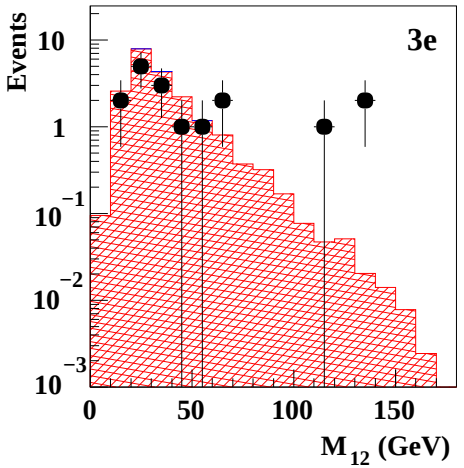
Multi-electron events

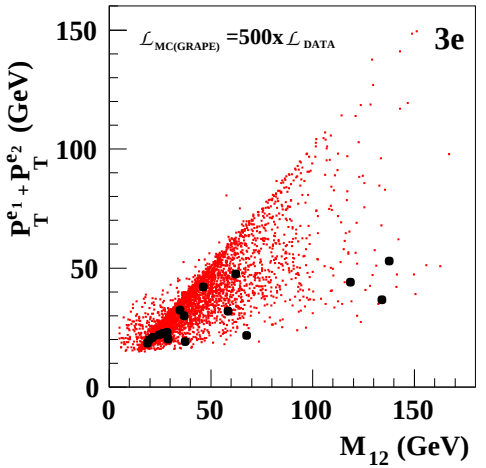
		Data	SM
H1	$2e$	3	0.30 ± 0.04
	$3e$	3	0.23 ± 0.04
ZEUS	$2e$	2	0.77 ± 0.08
	$3e$	0	0.37 ± 0.04





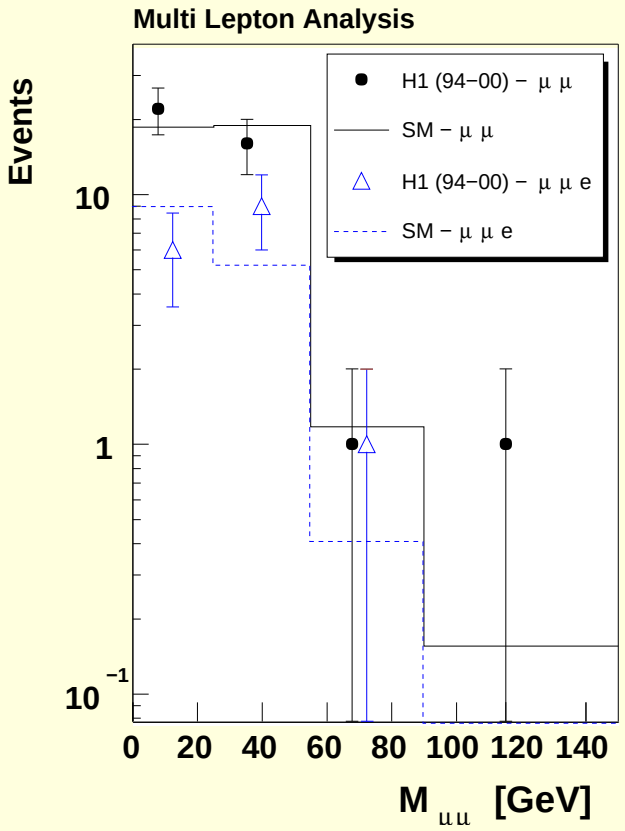






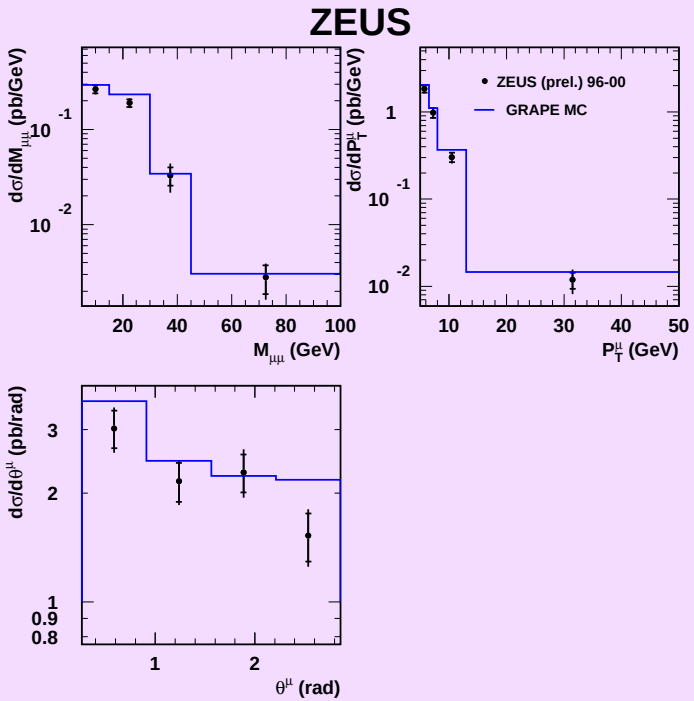
Multi-muon events

H1:



One event with $M_{\mu\mu} > 100$ GeV

ZEUS:

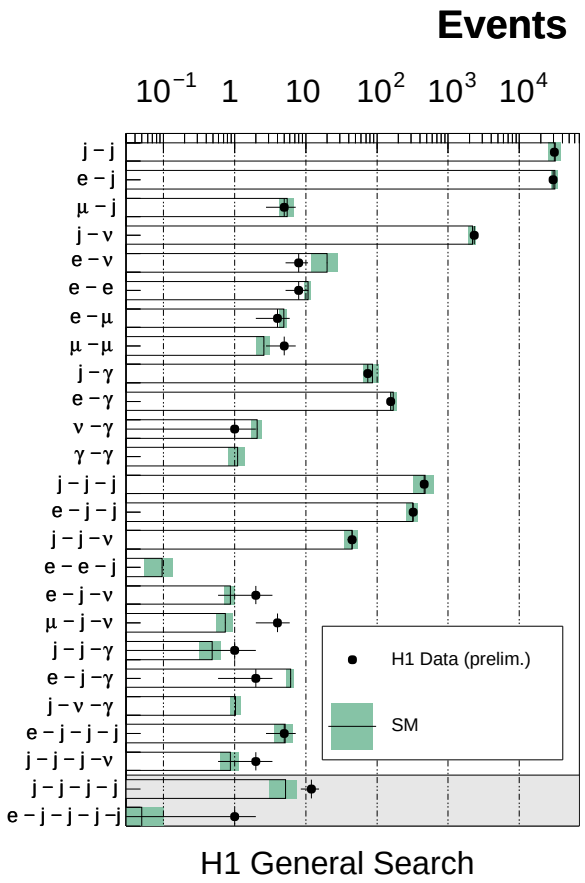


2 events con $M_{\mu\mu} > 100$ GeV
(2.16 from SM)

Good agreement with SM. No events with 3 or more muons.

Generic search of physics beyond SM

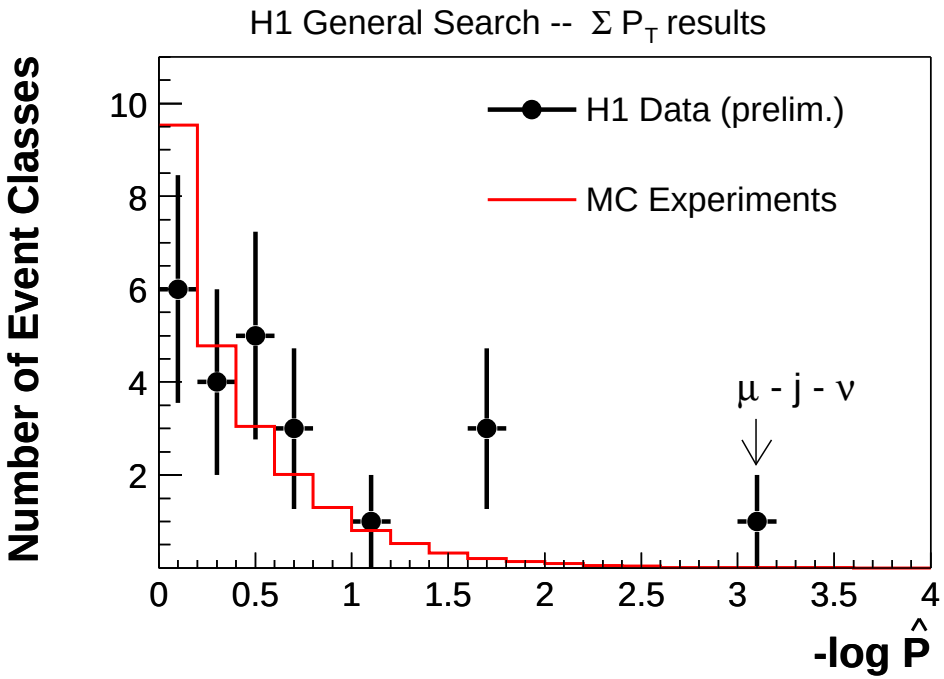
Two or more isolated "objects" with high p_t (electrons, muons, photons, jets, neutrinos)



H1 General Search

Discrepancy between data and MC quantified by the estimator p. For each event class the region with higher p_{min} is considered for M_{all} and $\sum p_t$

$-\log \hat{P}$ = **probability of measure p = p_{min}**

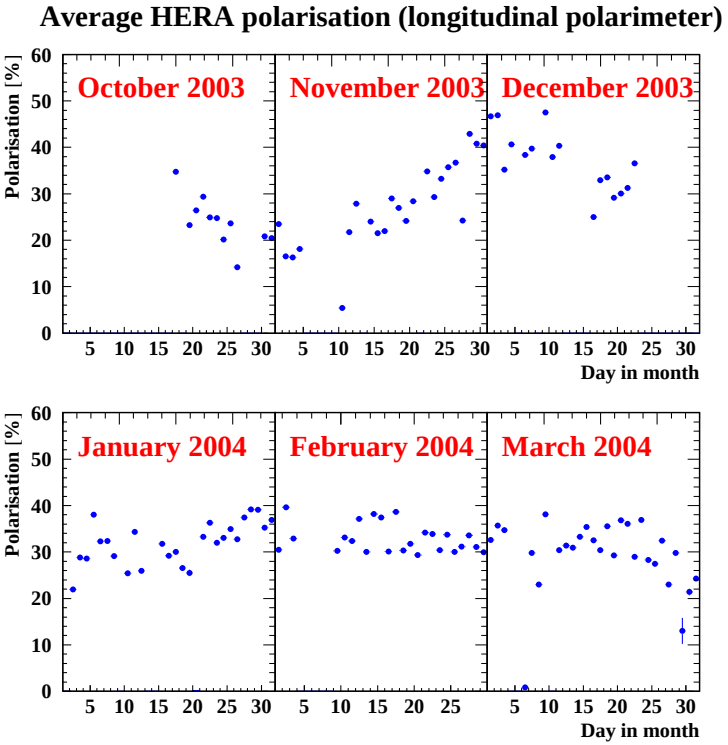


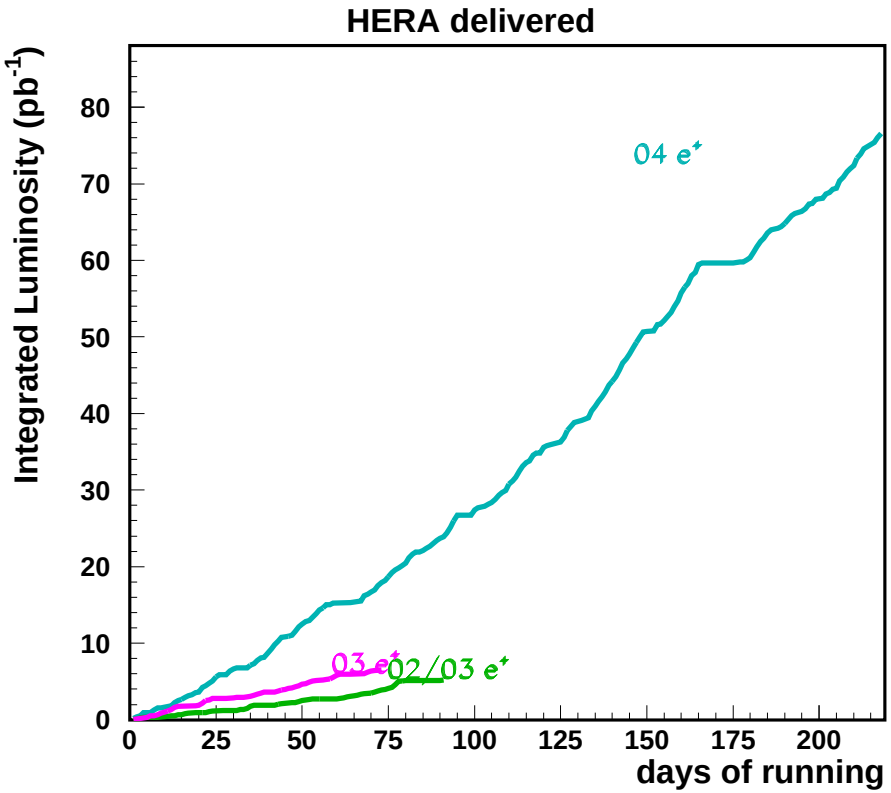
HERA II

New spin rotators installed in 2000

↓

longitudinal polarization of electrons and positrons (up to ∼50%)

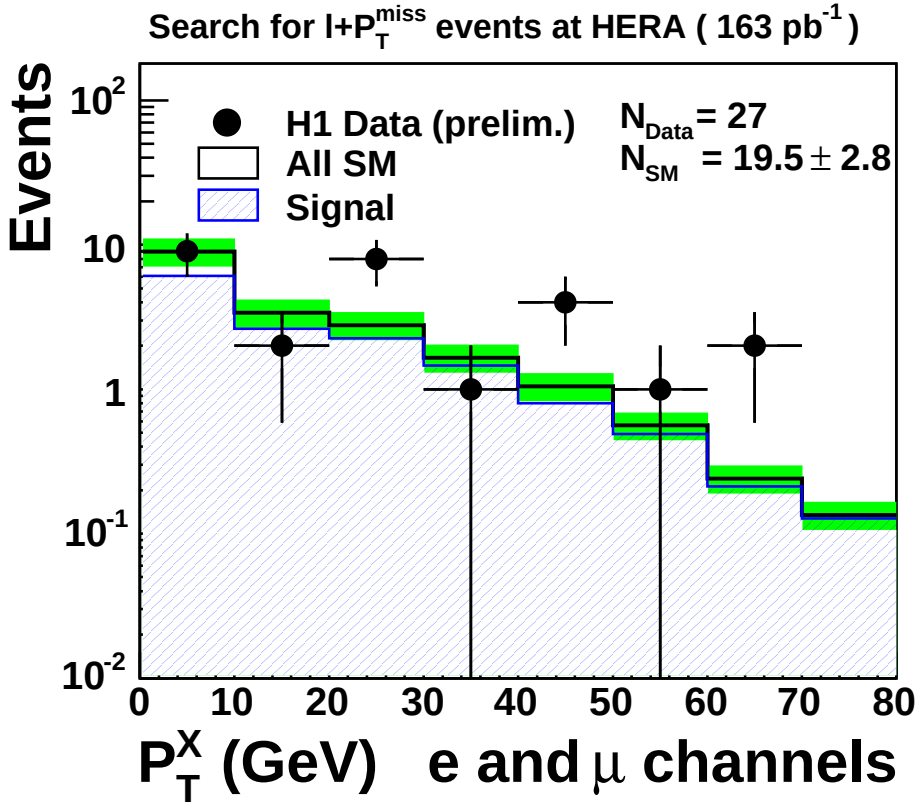




HERA II- first BSM searches

H1 updated the analyses, where an excess of events was found, adding new data (45 pb^{-1}).

Events with isolated e and μ and $\not{P}_t$ (163 pb^{-1}):

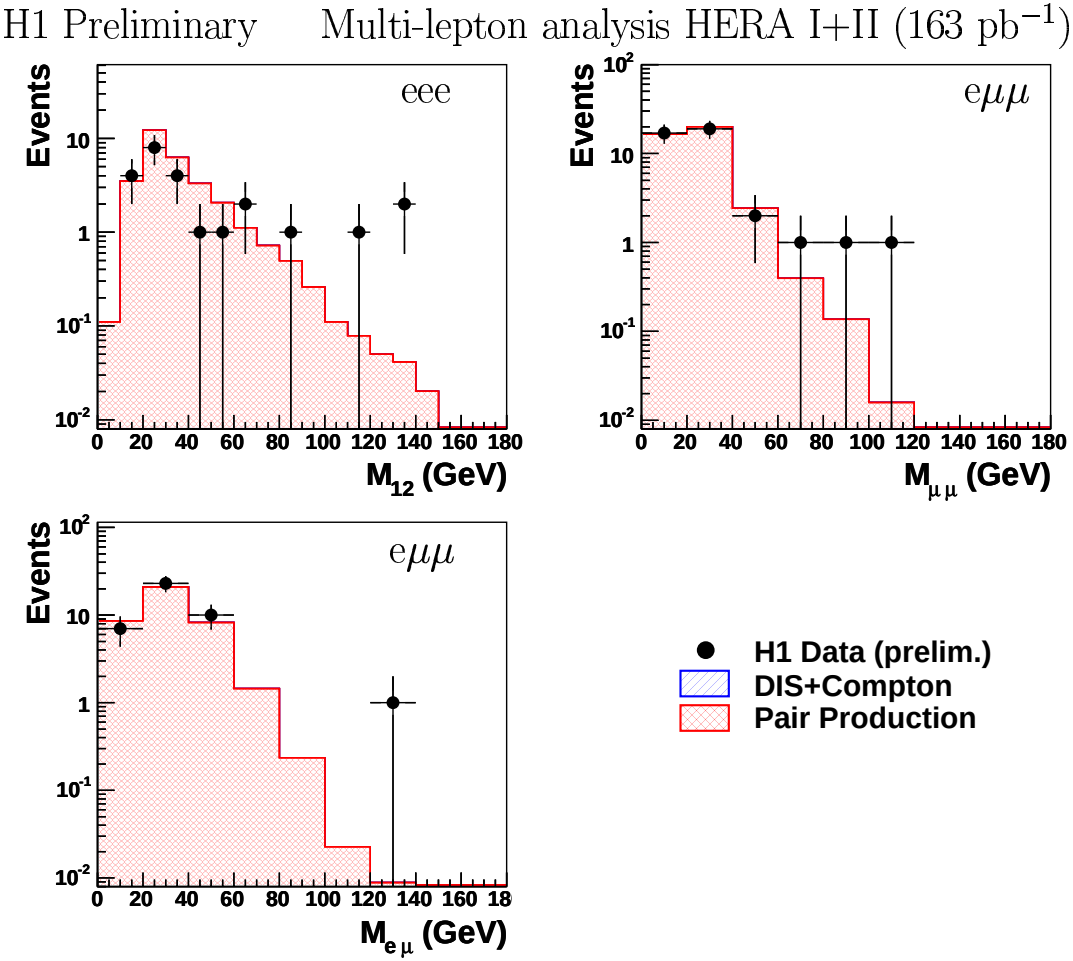


	Electrons		Muons	
	Data	SM	Data	SM
Total	18	15.4	9	4.1
$P_T^X > 25$ GeV	8	2.6	6	2.5

High P_t electrons again...

HERA II- first BSM searches II

Multi-lepton events (163 pb^{-1}):



	Data/SM
ee $M_{12} > 100$ GeV	$3/0.44 \pm 0.10$
$\mu\mu$ $M_{\mu\mu} > 100$ GeV	$0/0.04 \pm 0.02$
eμ $M_{e\mu} > 100$ GeV	$0/0.31 \pm 0.03$
eee $M_{12} > 100$ GeV	$3/0.31 \pm 0.08$
e$\mu\mu$ $M_{e\mu} > 100$ GeV	$1/0.04 \pm 0.01$
e$\mu\mu$ $M_{\mu\mu} > 100$ GeV	$1/0.02 \pm 0.01$

Conclusions

HERA I:

- Various searches of physics beyond Standard Model have been performed using HERA I data.
- Still open questions: events with high p_t leptons and high missing momentum, events with 2 or 3 electrons and high invariant mass.

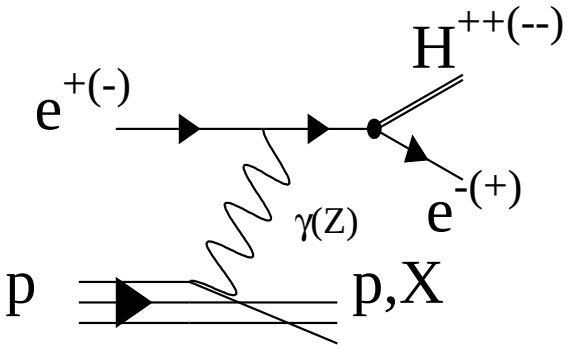
HERA II:

- 700 pb^{-1} of integrated luminosity in the middle of 2007 will help to resolve HERA I puzzles.
- Polarization of electrons and positrons can enhance selectively some BSM signals.
- First results with HERA II data show agreement with SM expectations.

Doubly-charged Higgs production

$H^{++/--}$ is predicted by Left-Right symmetric models where the extended symmetry is broken by a triplet of scalar fields.

Is the excess of events with 2 or 3 electrons seen by H1 due to the $H^{++/--}$ production?



only one event with $M > 100$ GeV is compatible with $H^{++/--}$ production.