

Searches for new physics at HERA

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on behalf of the **ZEUS** and **H1** collaborations



Searches for new physics at HERA

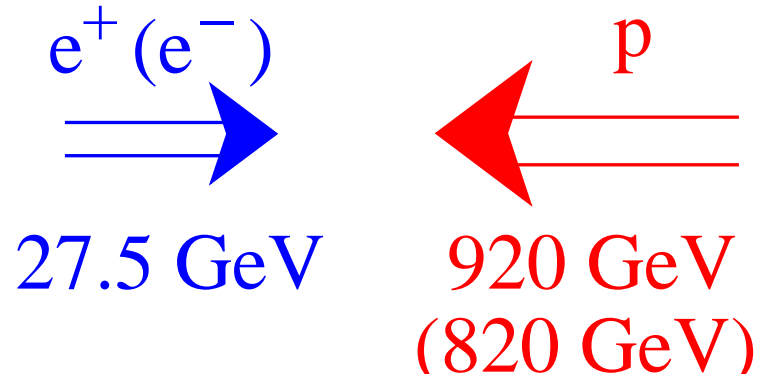
Contact interactions and resonances

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

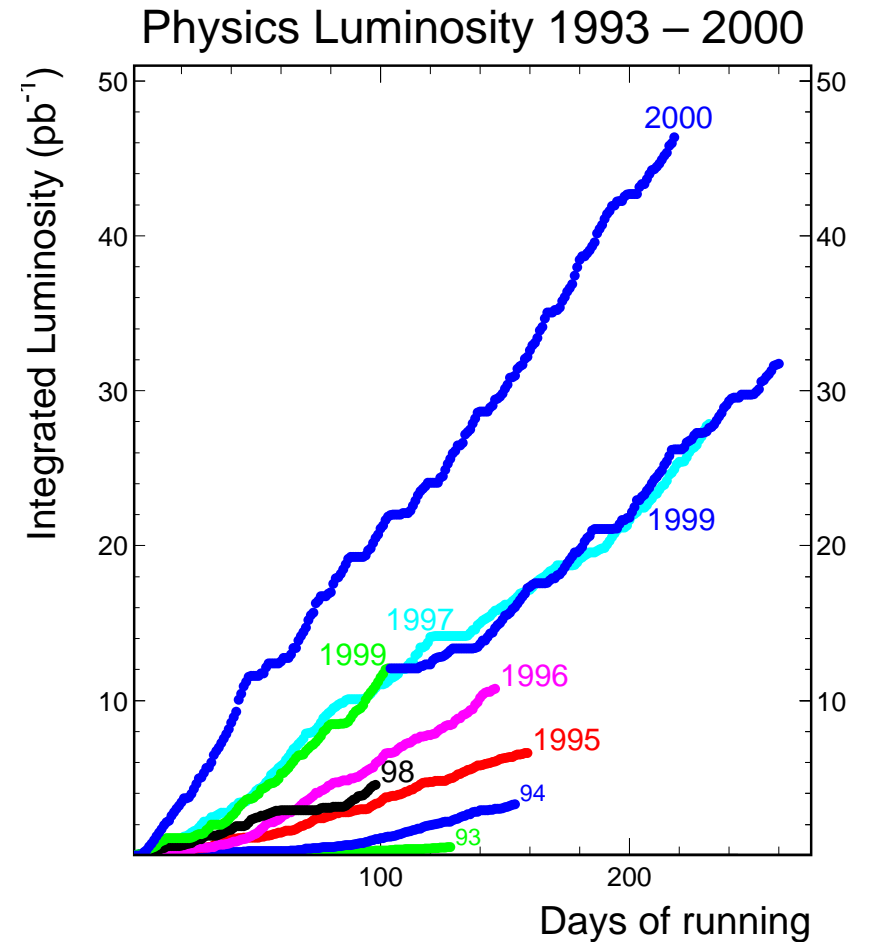
Exclusive final states:

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

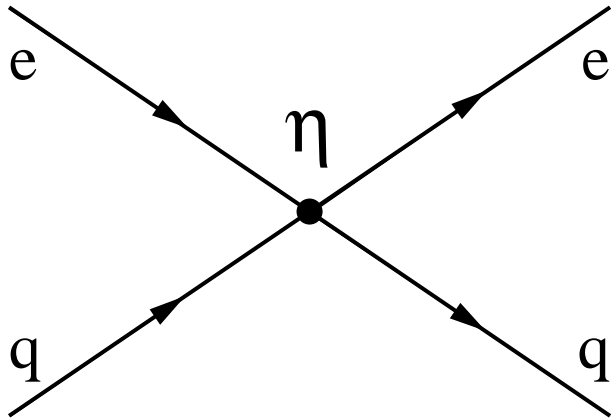
HERA I



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

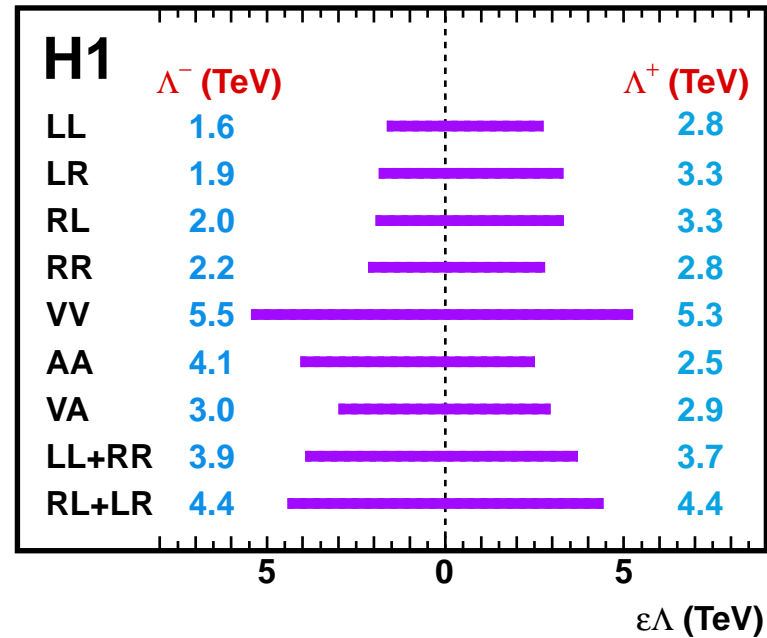
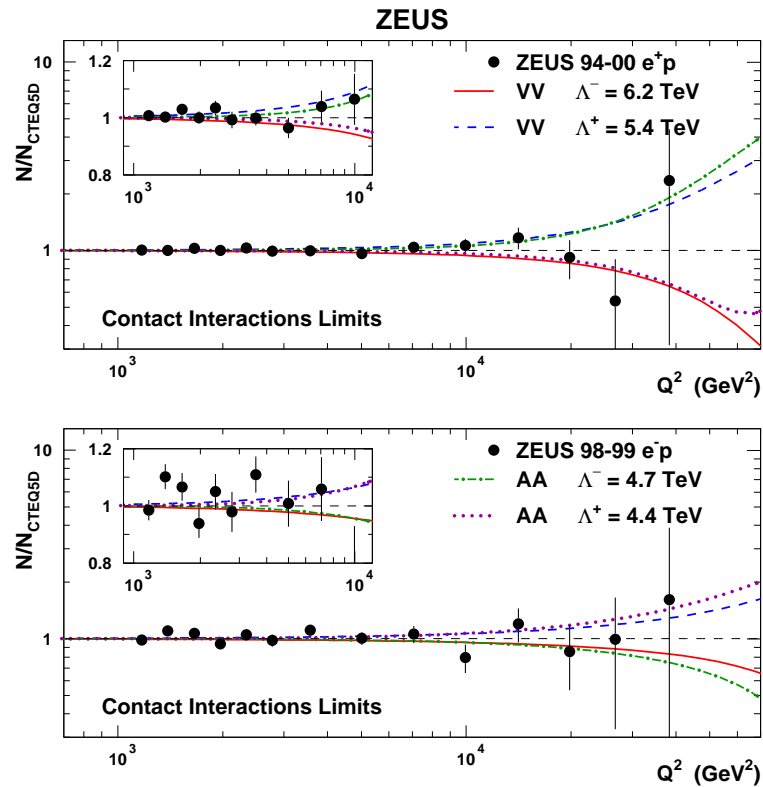
Lagrangian (vector component):

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

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

Contact interactions II

Limits on compositeness scale (Λ):



Quark radius:

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

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

ZEUS: 1.7 – 6.2 TeV

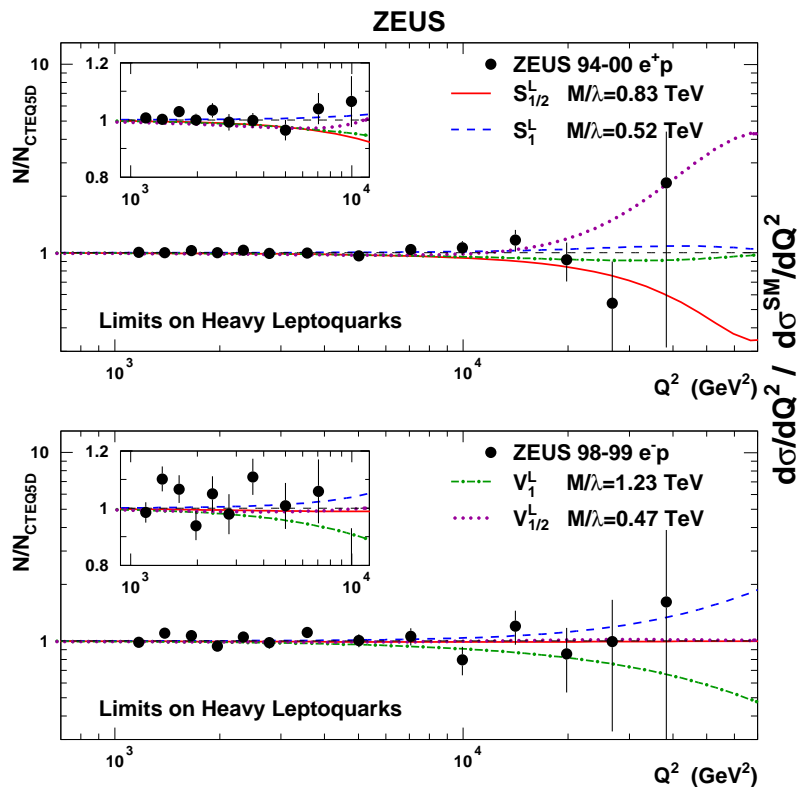
H1: 1.6 – 5.5 TeV

Contact interactions III

Limits on Leptoquarks (M_{LQ}/λ): Large Extra Dimensions (M_S):

ZEUS: 0.78, 0.79 TeV

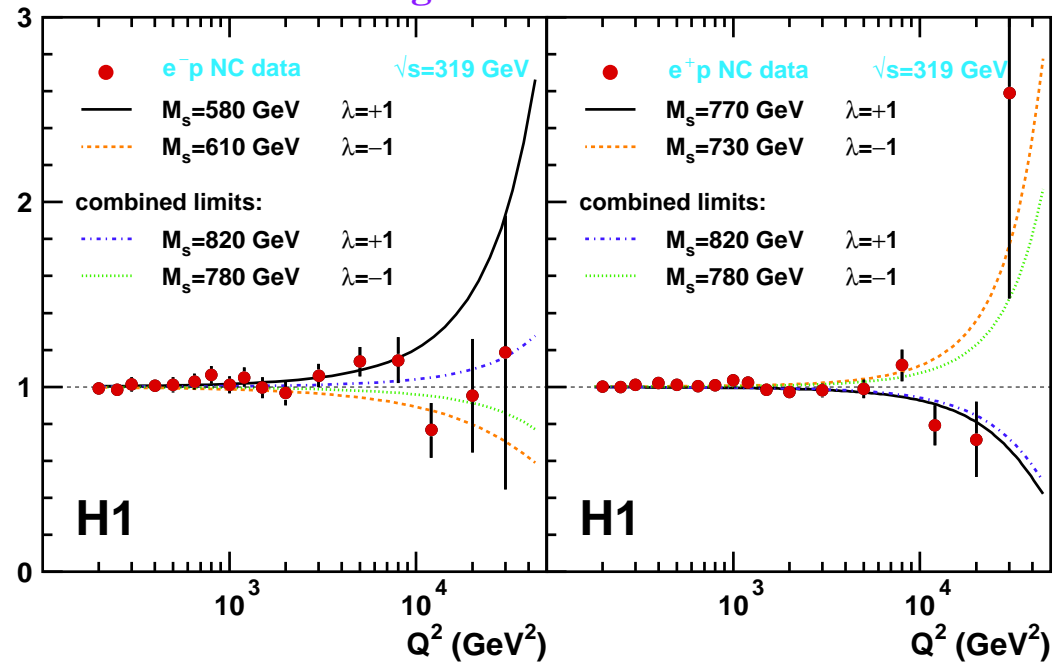
H1: 0.78, 0.82 TeV



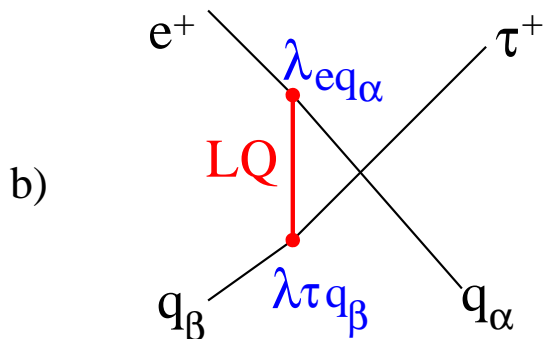
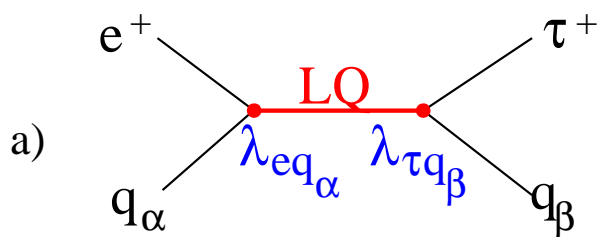
ZEUS: 0.27 – 1.23 TeV

H1: 0.3 – 1.4 TeV

Large Extra Dimensions



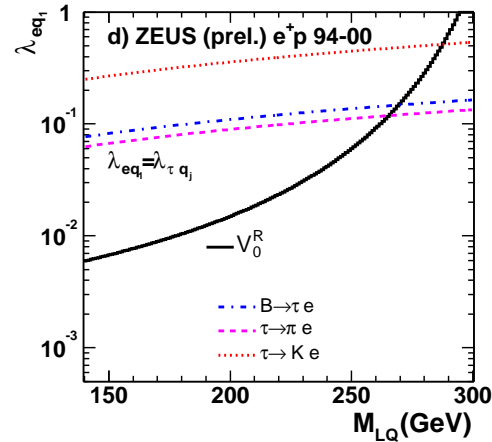
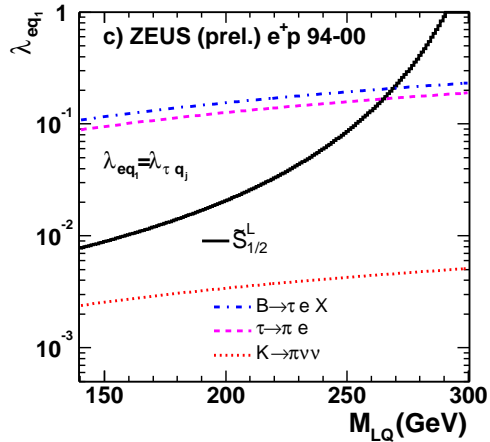
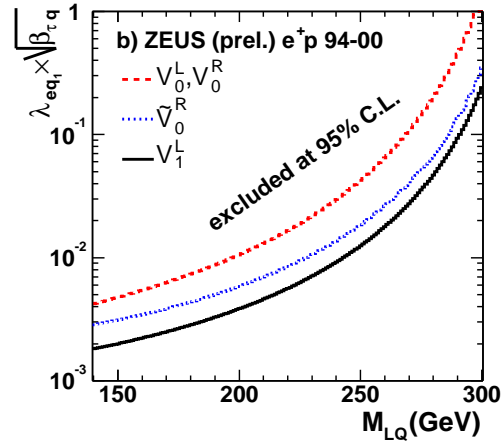
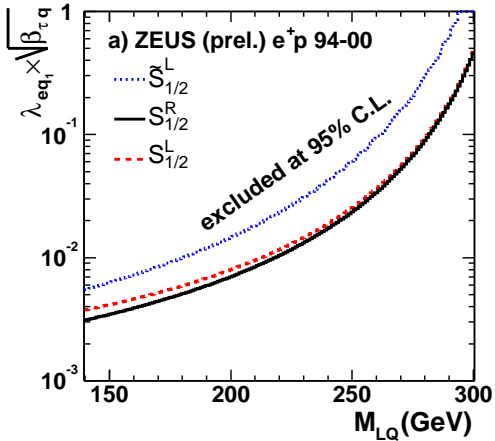
Lepton-flavor violation



- 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

ZEUS



- 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 $\frac{\lambda_{eq_i} \lambda_{lq_j}}{M_{LQ}^2}$ for $M_{LQ} \gg \sqrt{s}$ down to 0.4 TeV^{-2}

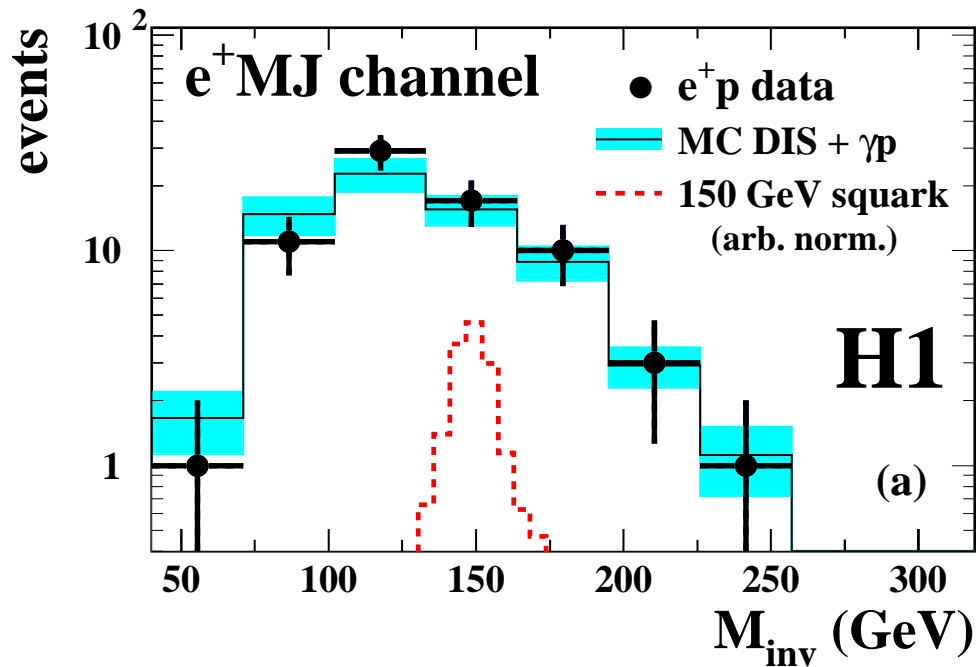
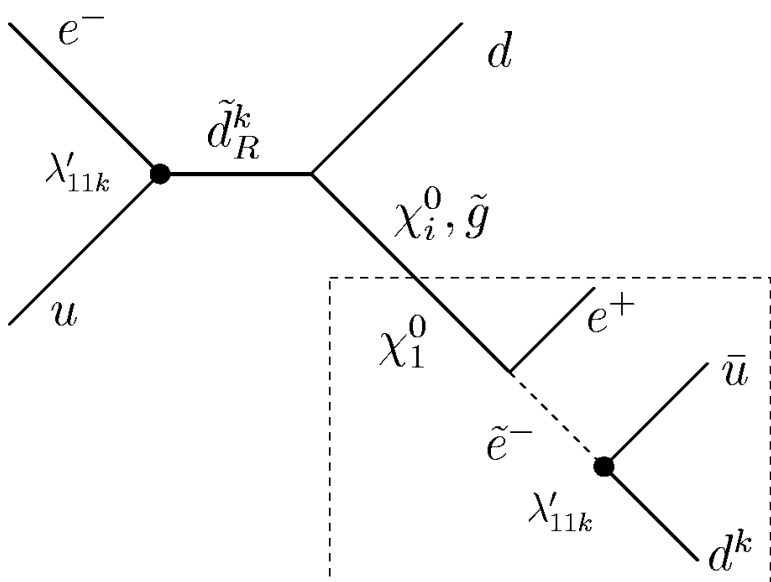
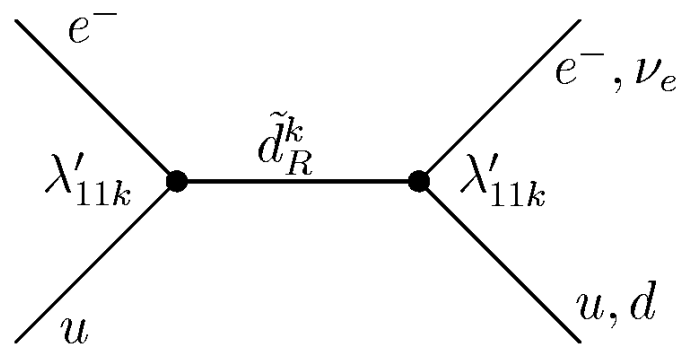
For $\lambda_{eq_1} = 0.3$ and $B_{lq_j} = 0.5$ LQ masses up to **300 GeV** excluded. In general HERA limits better than low energy experiments when higher generation quarks involved

R_p violating SUSY

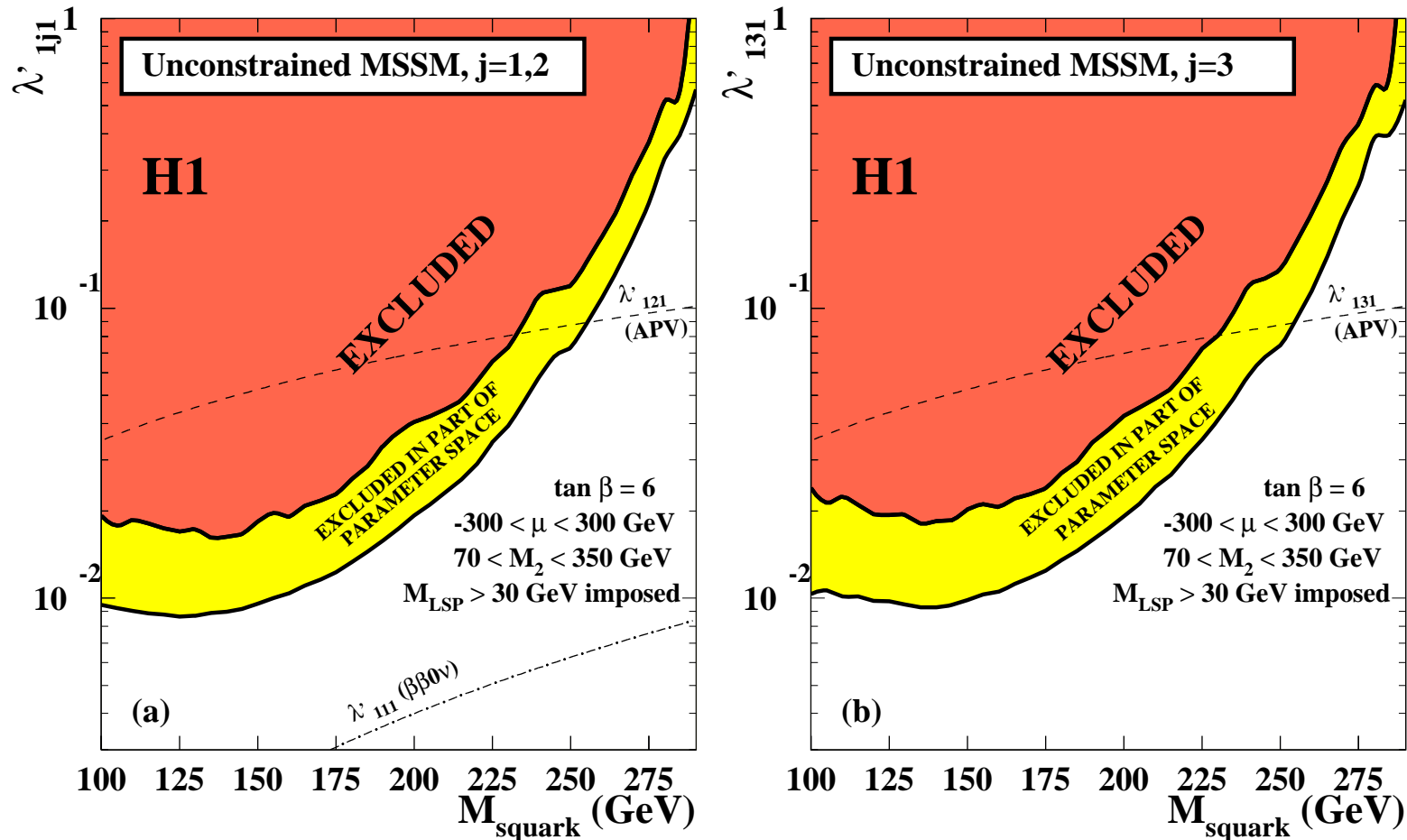
\tilde{u}_L and \tilde{d}_R squark production

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

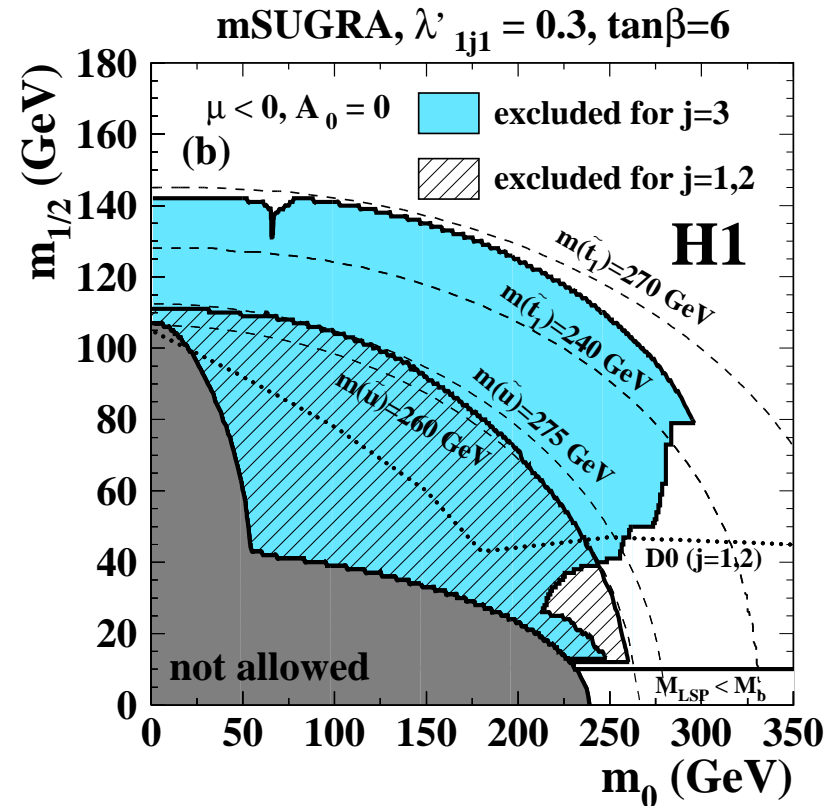
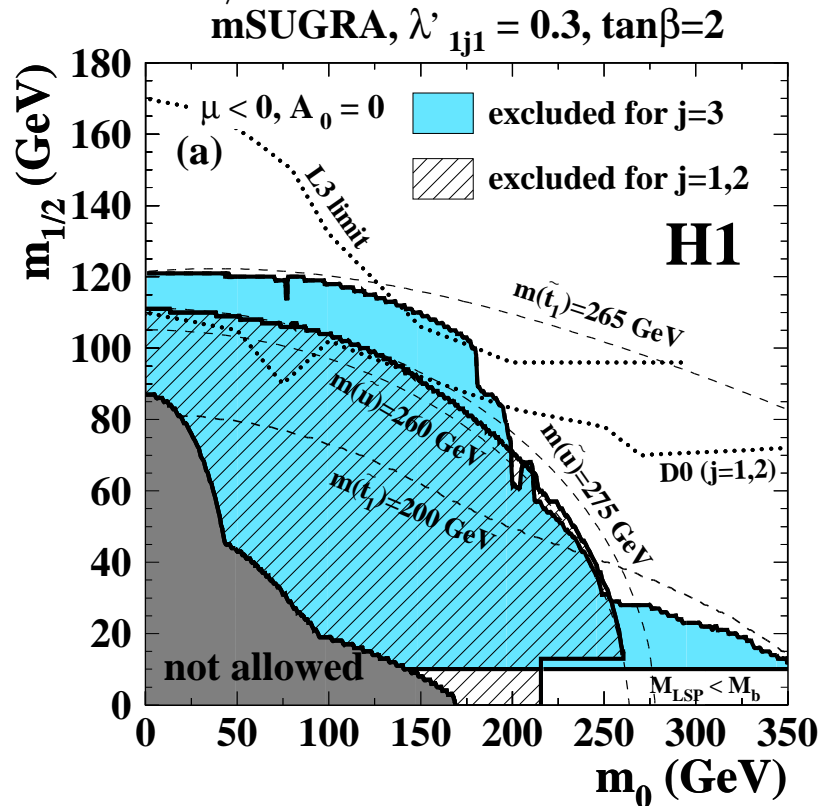


Assuming $\lambda'_{1j1} = 0.3$ ($\lambda'_{11k} = 0.3$) squark mass up to 275 (280) GeV can be excluded

R_p violating SUSY III

mSUGRA (minimal supergravity):

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

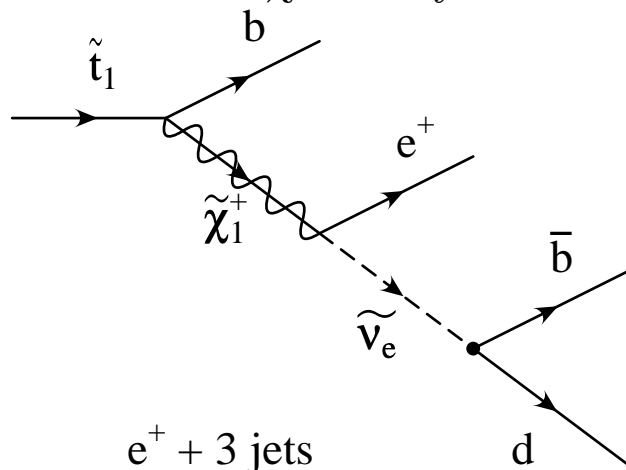


For $\tan\beta = 6$ limits on \tilde{t} improve LEP and TeVatron limits. \tilde{t}_1 masses up to **270 GeV** excluded for $\lambda'_{131} = 0.3$.

R_p violating SUSY IV

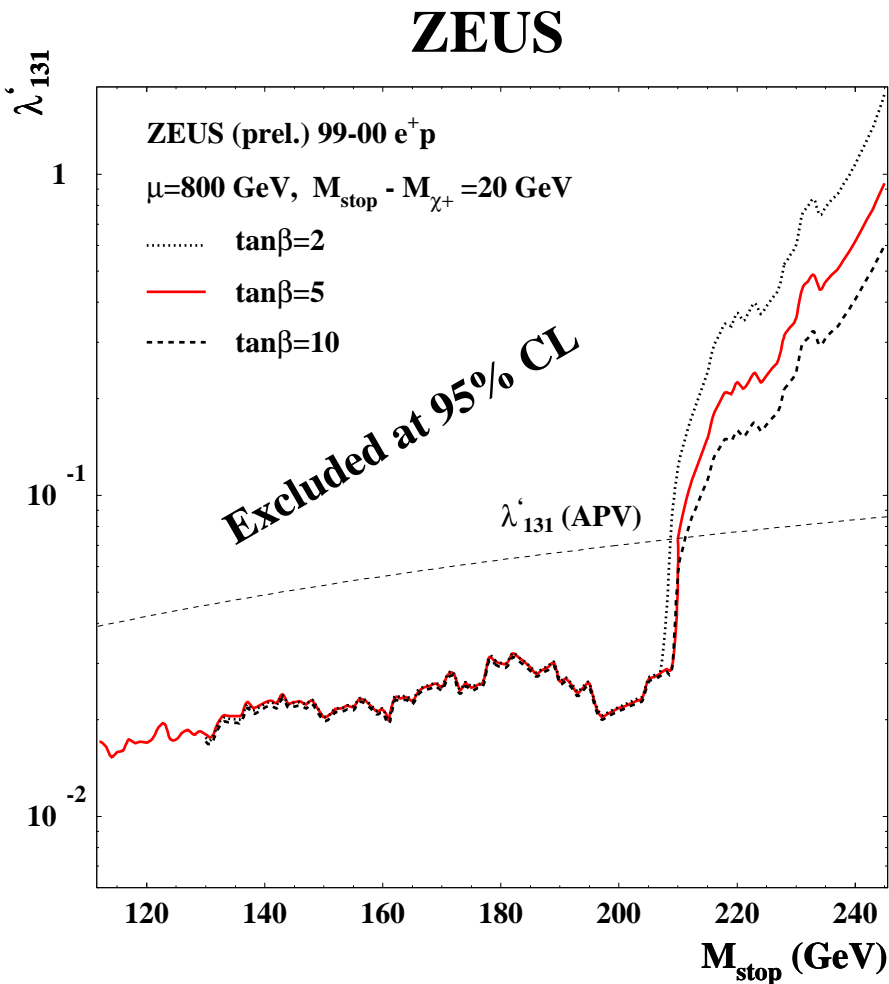
S-top production:

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



Main assumptions:

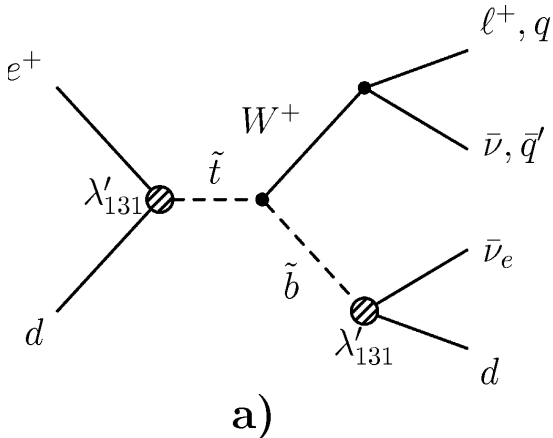
- Only $\lambda'_{131} \neq 0$
- χ^0 is the LSP (and above LEP limits)
- $M_3 = 1 \text{ TeV}$ to suppress $\tilde{t} \rightarrow t\tilde{g}$



R_p violating SUSY V

Bosonic s-top decays:

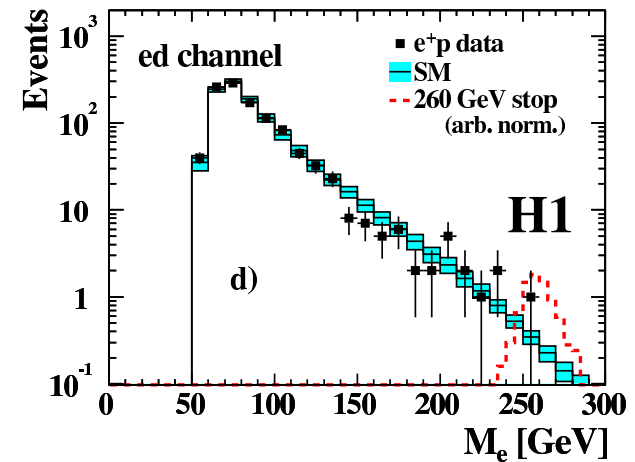
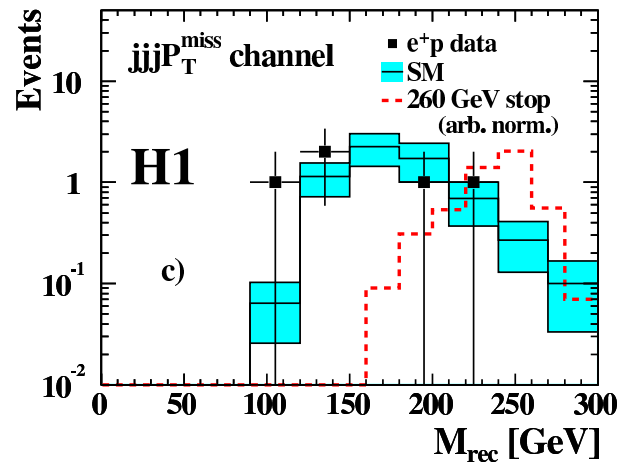
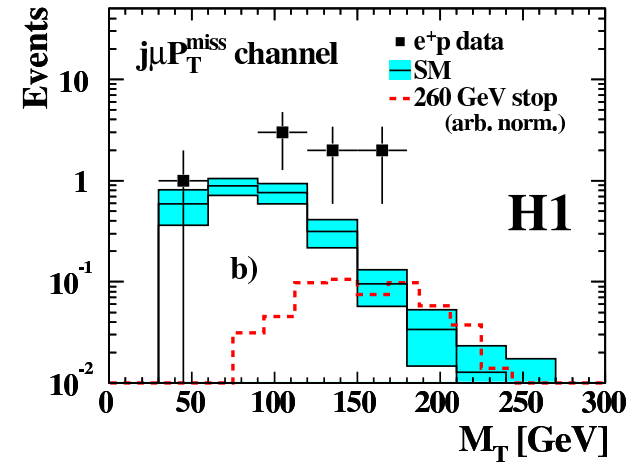
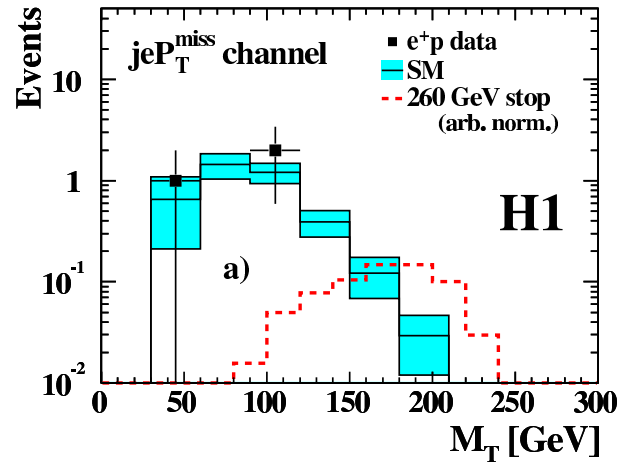
If $M_{\tilde{t}} > M_{\tilde{b}}$ s-top can decay in $\tilde{b}W$:



Final state topologies:

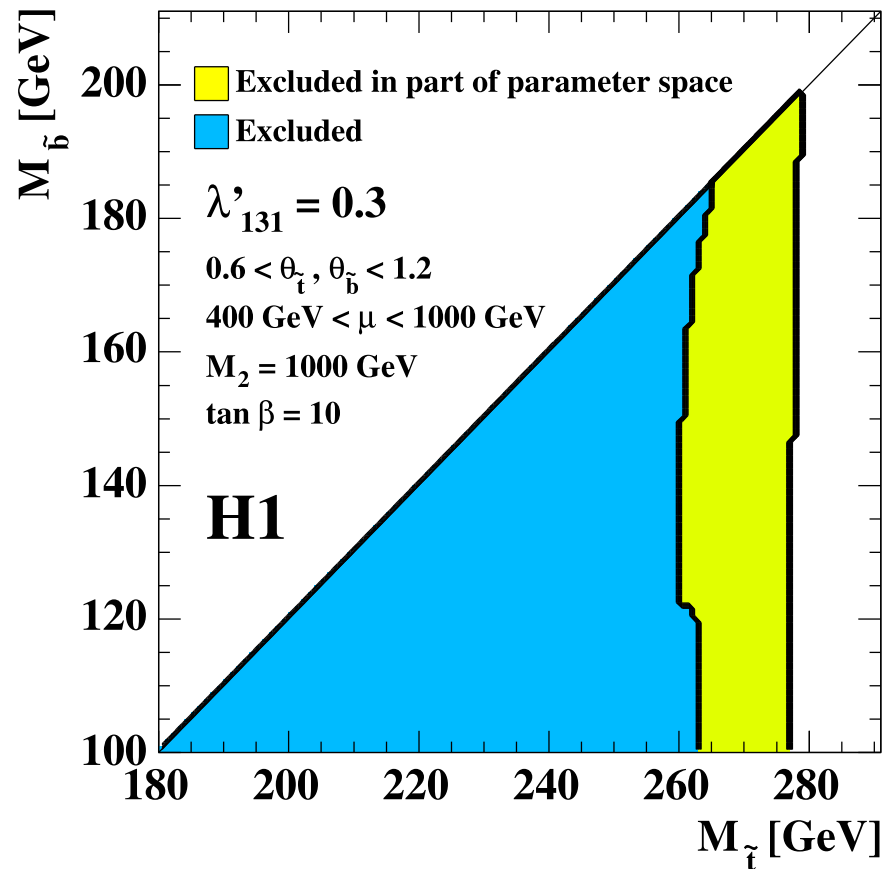
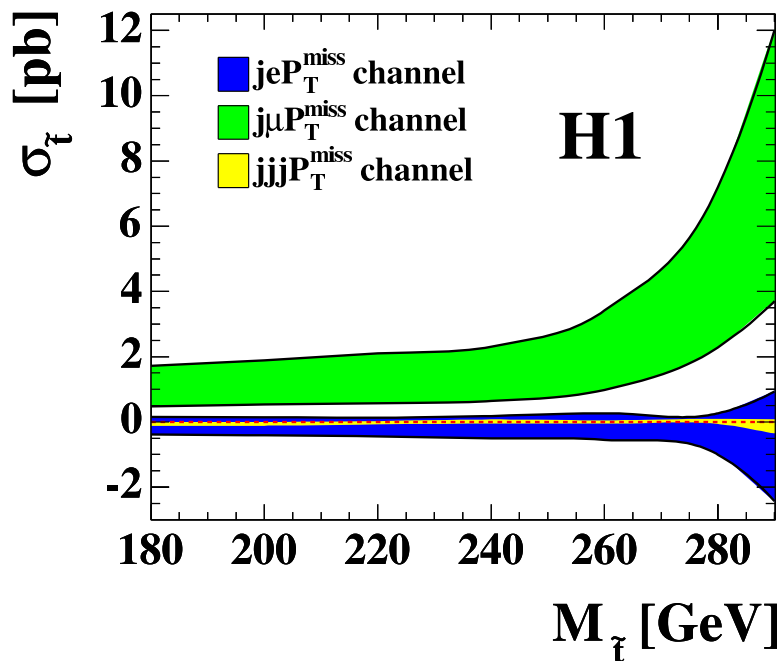
- $l + jet + R_t$
- $3jet + R_t$
- $e + jet$

Slight excess in the $\mu + jet + R_t$ channel



R_p violating SUSY VI

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



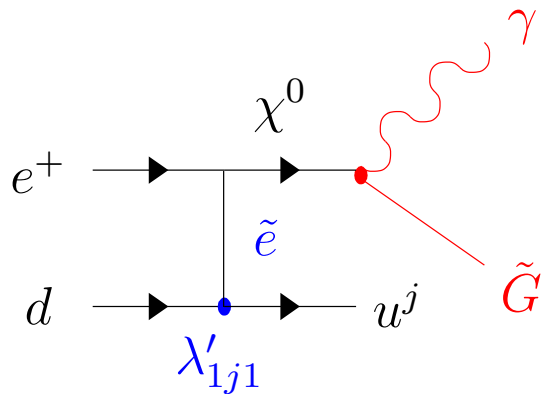
Excess in the $\mu + jet + R_t$ channel not supported by other decay modes

R_p violating SUSY VII

Superlight gravitino:

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

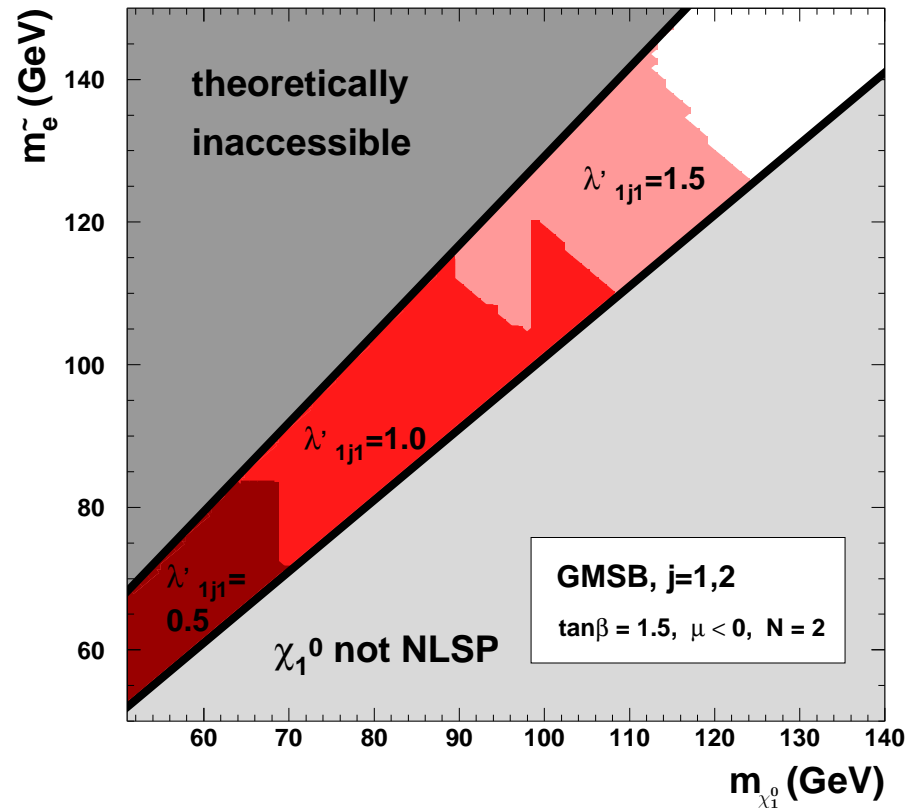
In this model $M_{slepton} \ll M_{squark}$



1 event (2.55 ± 1.30 SM)

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

H1 e⁺p preliminary



Isolated leptons and missing transverse momentum

		Electrons		Muons		Taus	
		Data	SM	Data	SM	Data	SM
H1	P_T^X						
	$P_T^X > 25\text{GeV}$	4	1.49	6	1.44	0	0.53
	$P_T^X > 40\text{GeV}$	3	0.54	3	0.55	0	0.22
ZEUS	$P_T^X > 25\text{GeV}$	2	2.9	5	2.75	2	0.20
	$P_T^X > 40\text{GeV}$	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.

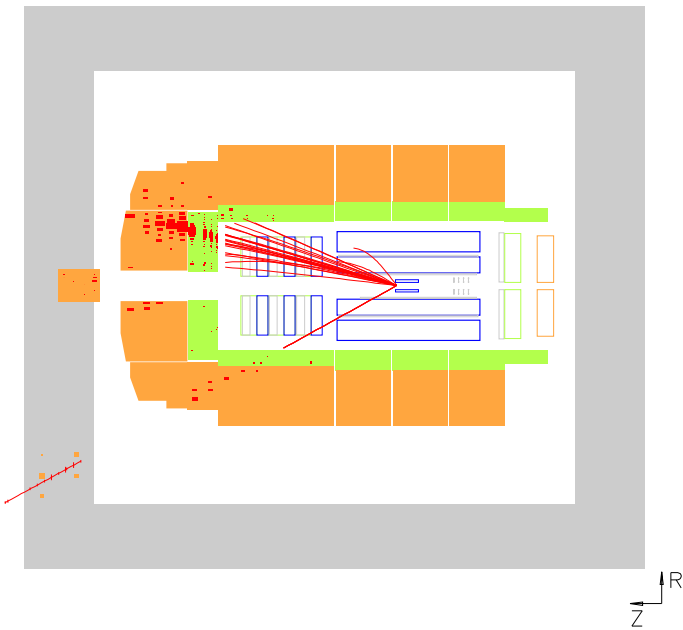
Events with isolated high p_t leptons

H1 event with isolated muon

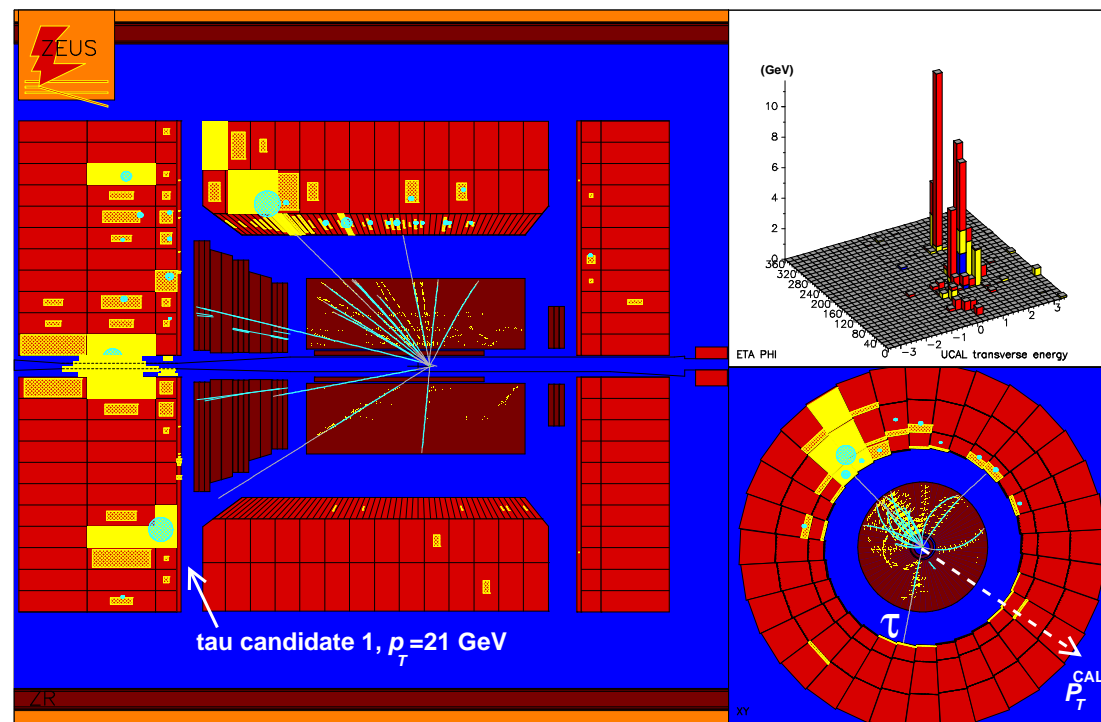
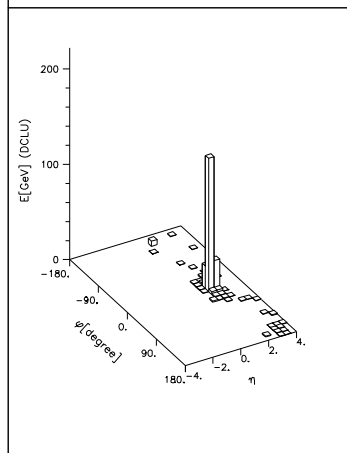
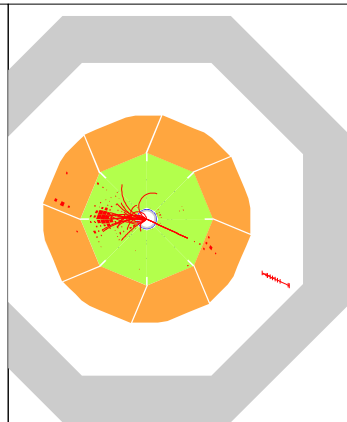
$$e^+p \rightarrow \mu^+ X$$

Event MUON-2

$$P_T^\mu = 28 \text{ GeV}, P_T^X = 67 \text{ GeV}, P_T^{\text{miss}} = 43 \text{ GeV}$$

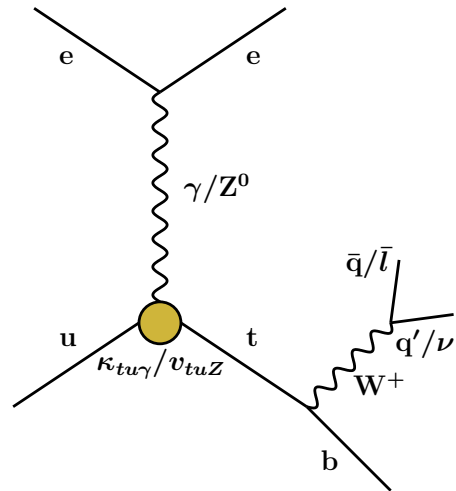


H1



ZEUS event with isolated tau

Single top production



Lepton channel (e, μ):

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

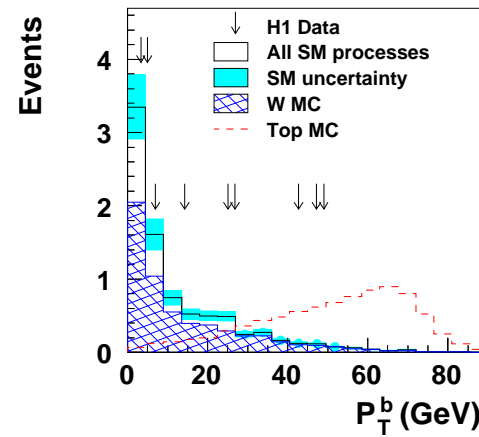
$$M_{l\nu b} > 140 \text{ GeV}$$

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

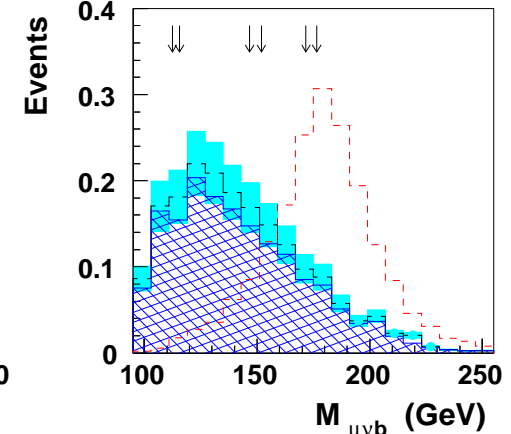
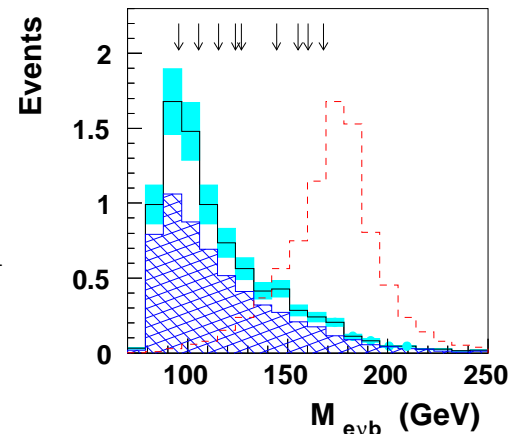
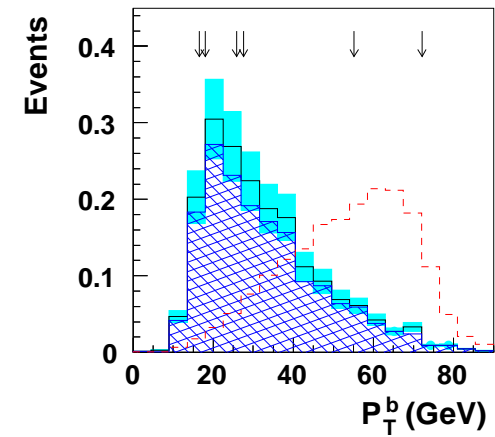
ZEUS: no event

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

ELECTRON CHANNEL



MUON CHANNEL



Single top II

H1:

If the excess is due to single top production:

$$\sigma = 0.29 + 0.15 / - 0.14 \text{ pb}$$

($\sqrt{s} = 318 \text{ GeV}$)

If statistical fluctuation:

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

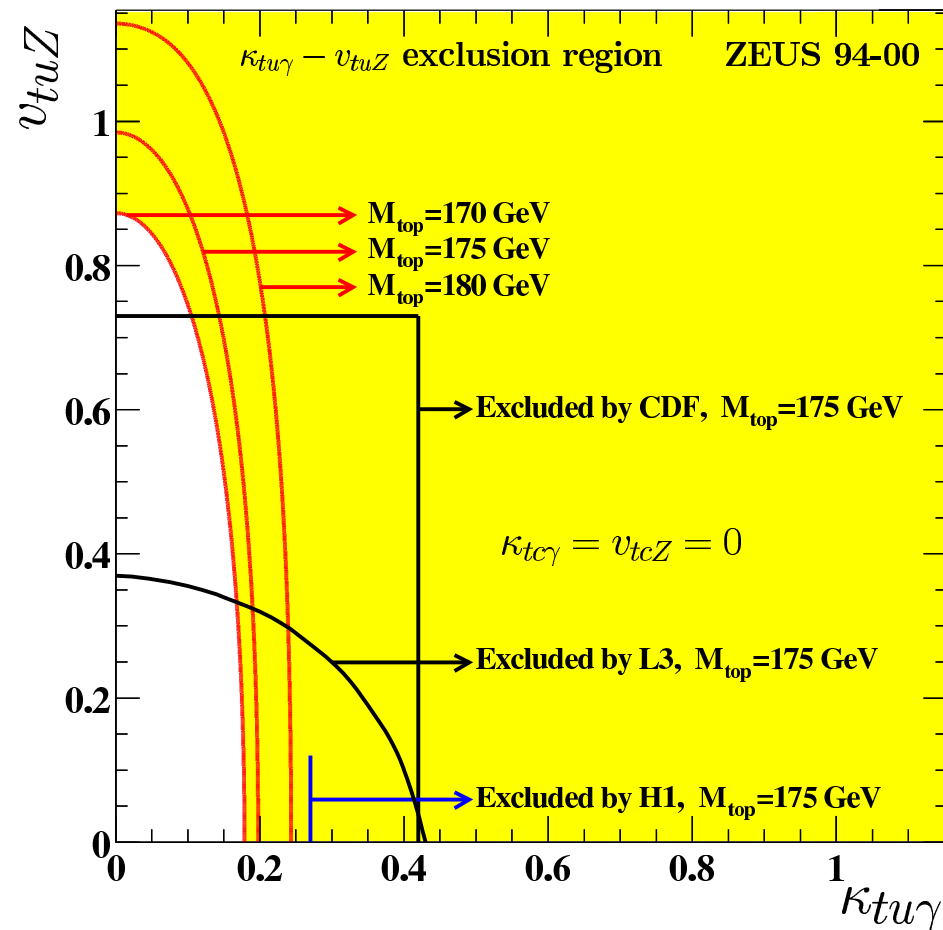
ZEUS:

Agreement with SM:

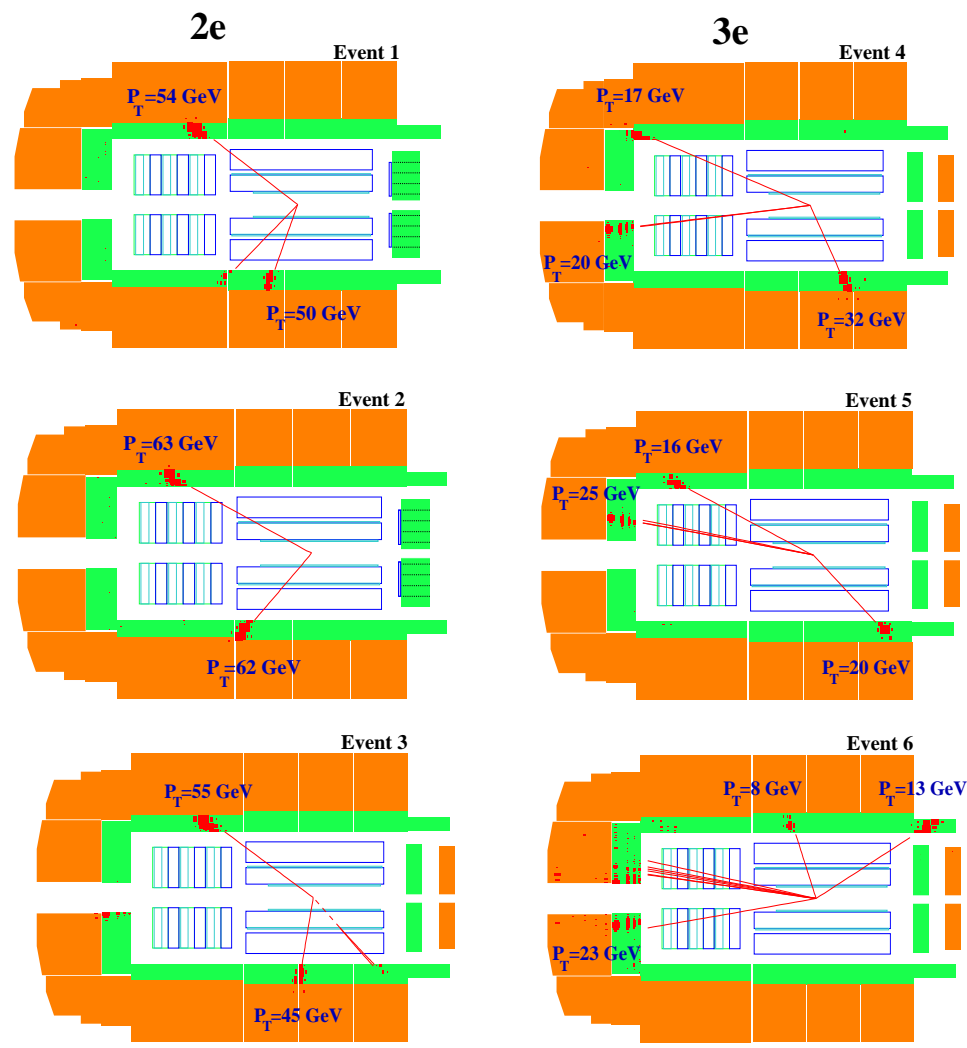
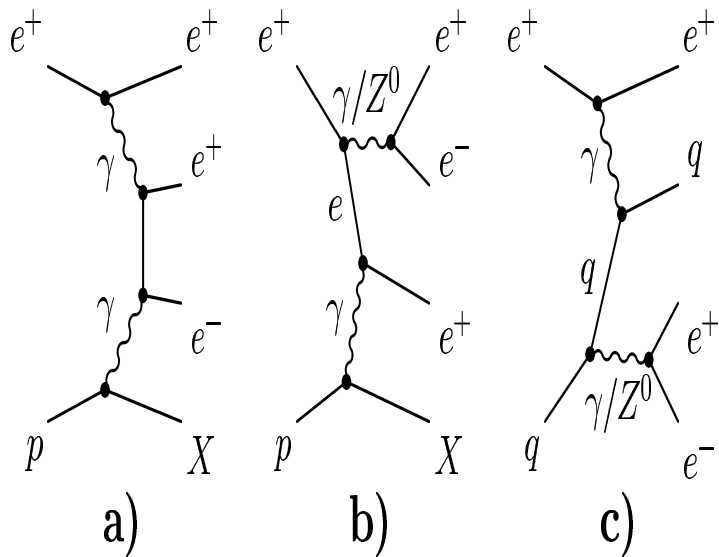
$$\sigma < 0.225 \text{ pb at 95\% C.L.}$$

ZEUS limits consider also the efficiency for the Z_0 channel

ZEUS



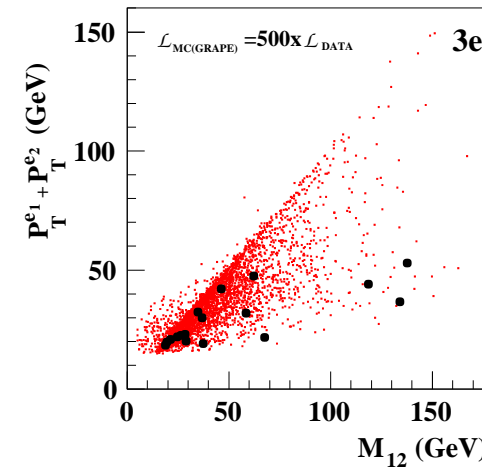
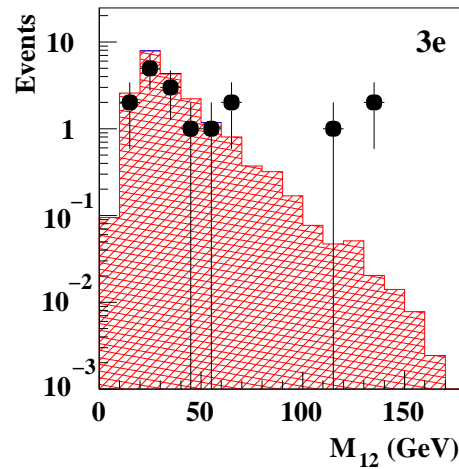
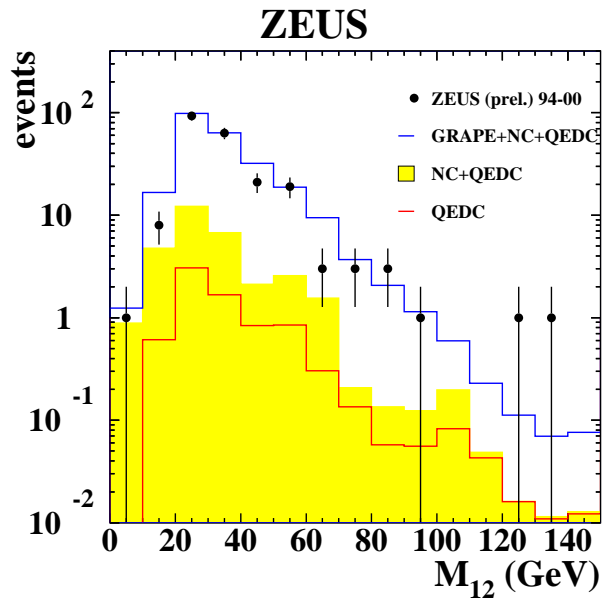
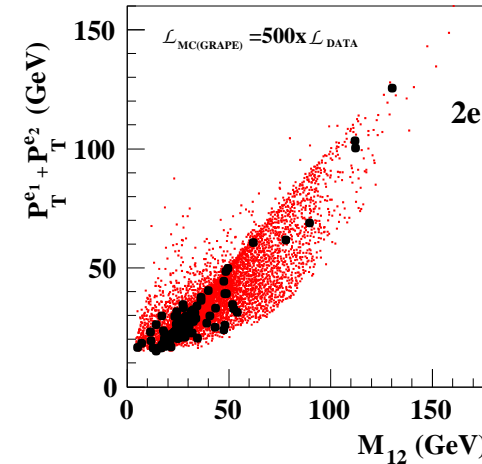
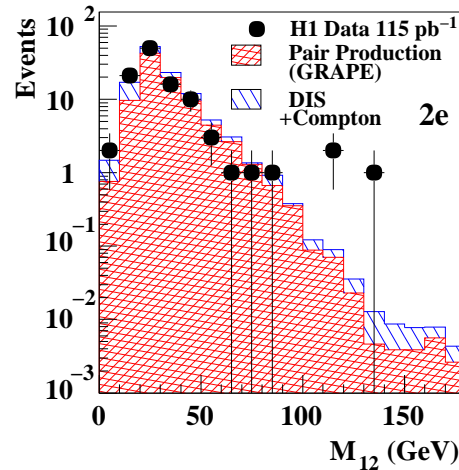
Multi-leptons events



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

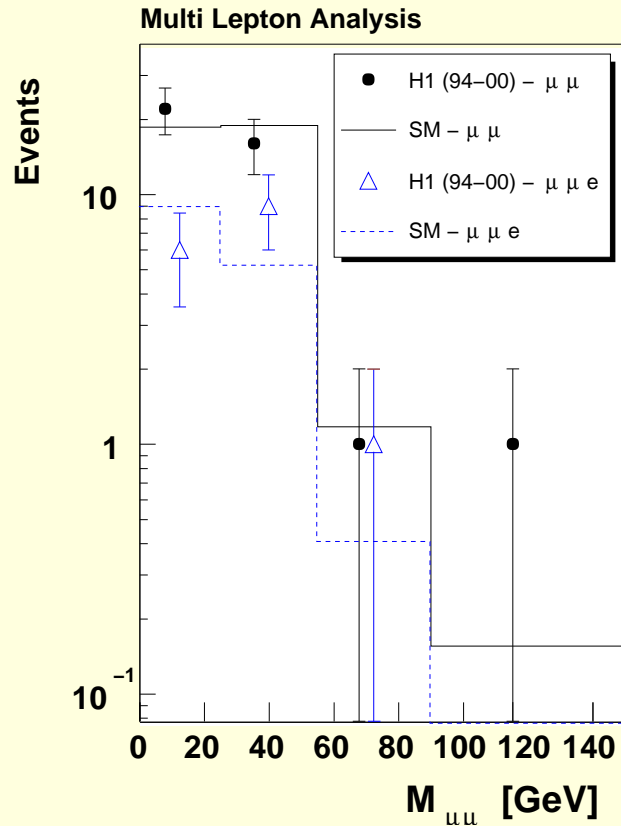
Multi-electron events

		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



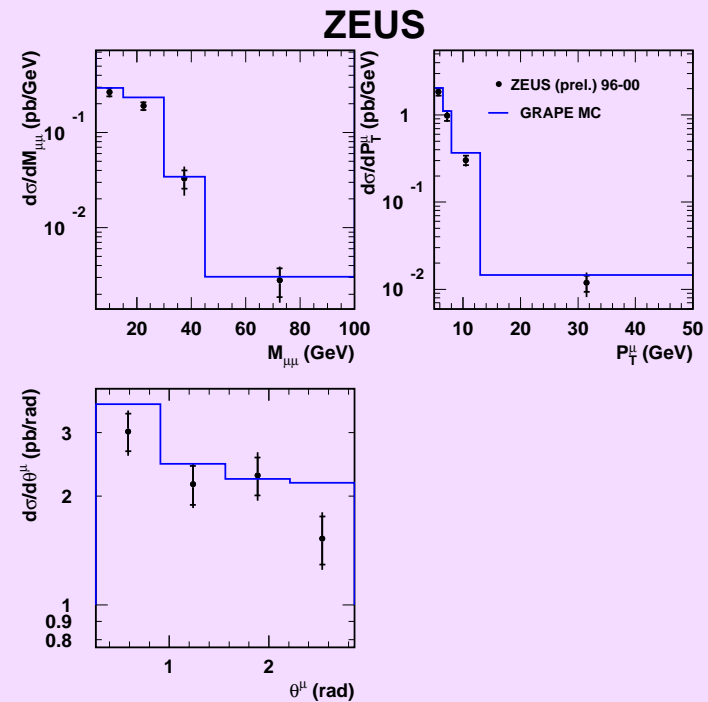
Multi-muon events

H1:



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

ZEUS:



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

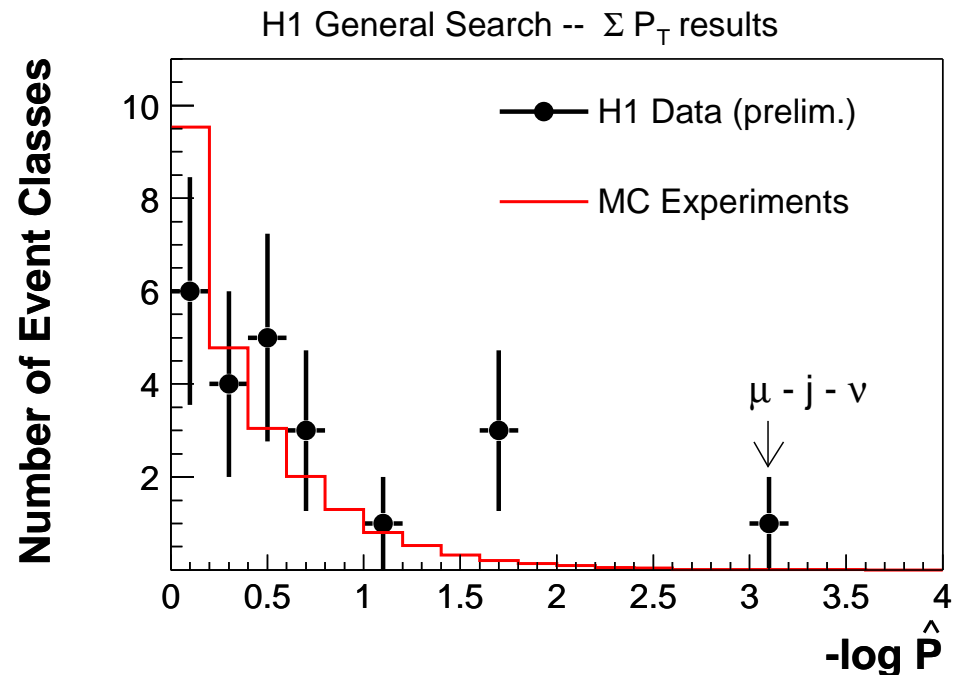
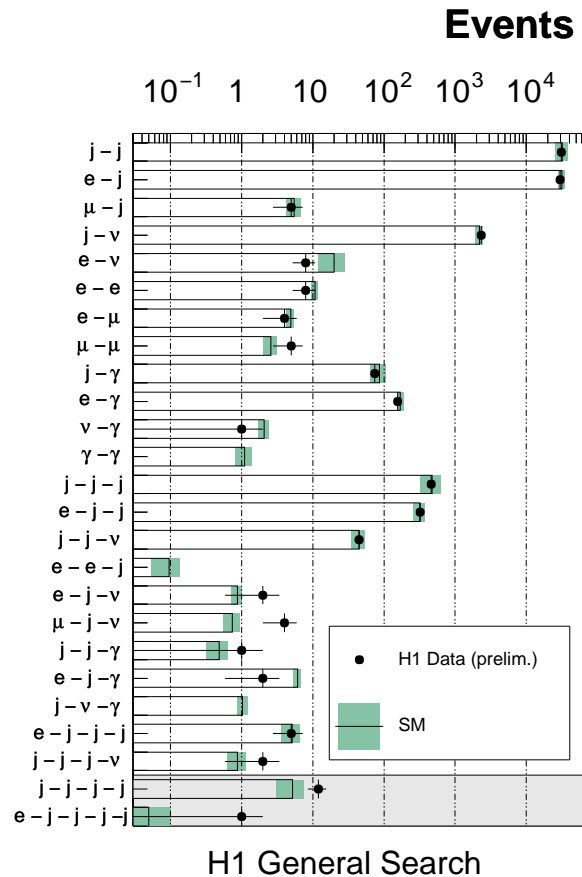
Good agreement with SM. No events with 3 or more muons.

Generic search of physics beyond SM

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

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 $\sum p_t$

$-\log \hat{P} = \text{probability of measure } \mathbf{p} = \mathbf{p}_{min}$



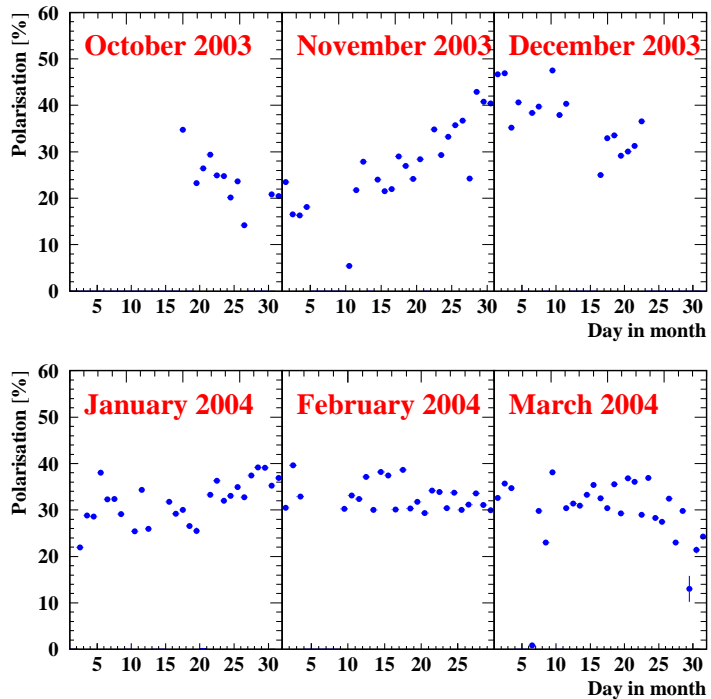
HERA II

New spin rotators installed in 2000

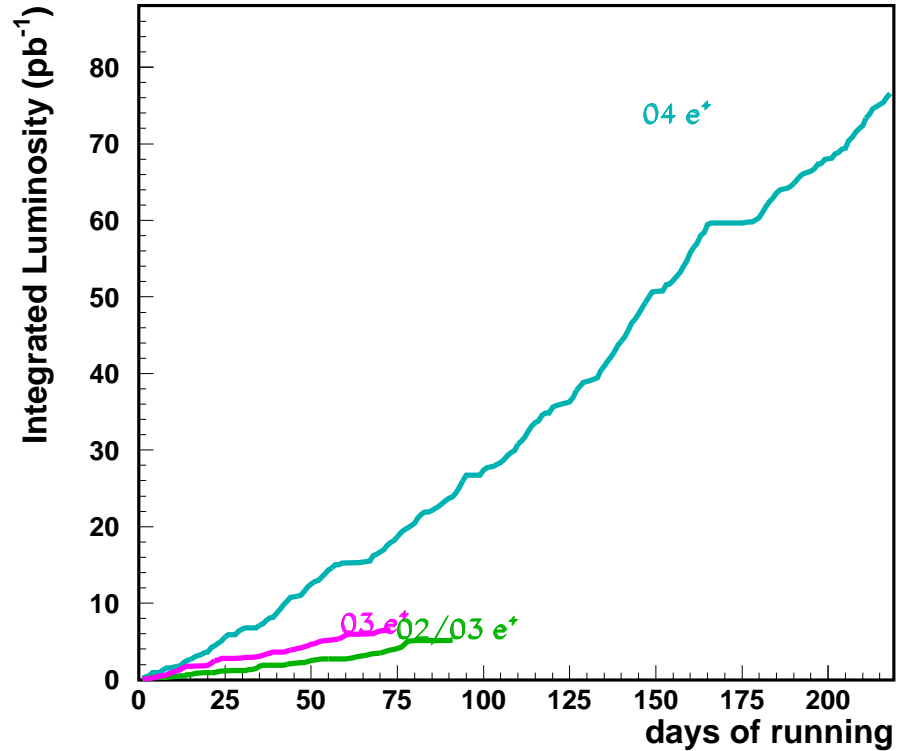


longitudinal polarization of electrons and positrons (up to $\sim 50\%$)

Average HERA polarisation (longitudinal polarimeter)



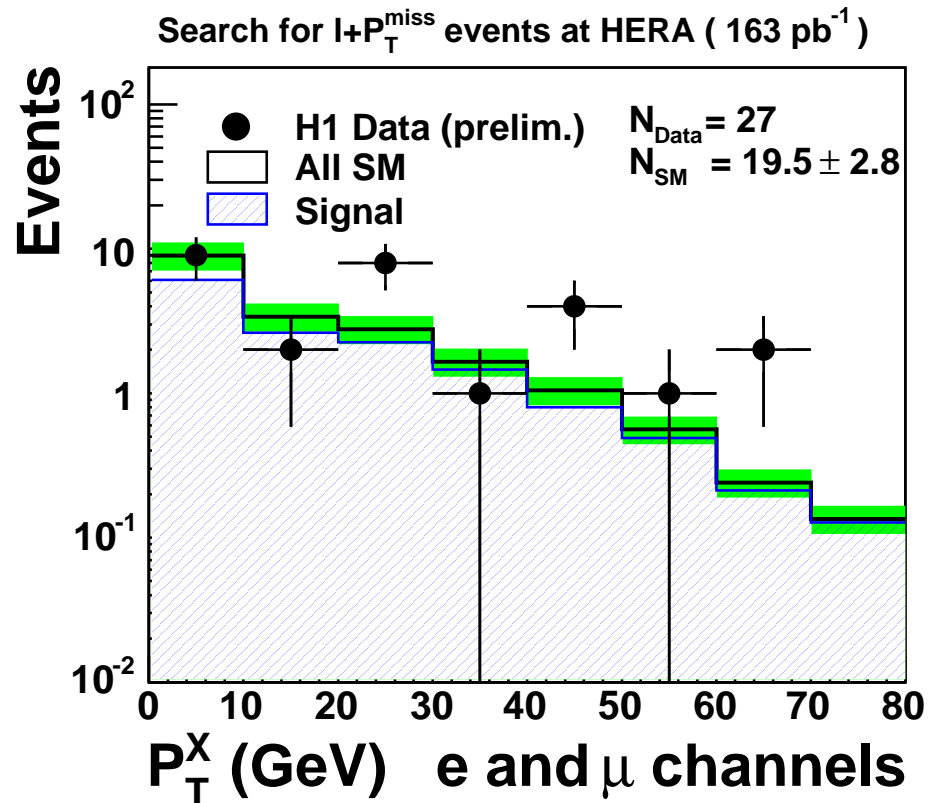
HERA delivered



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 R_t (163 pb^{-1}):



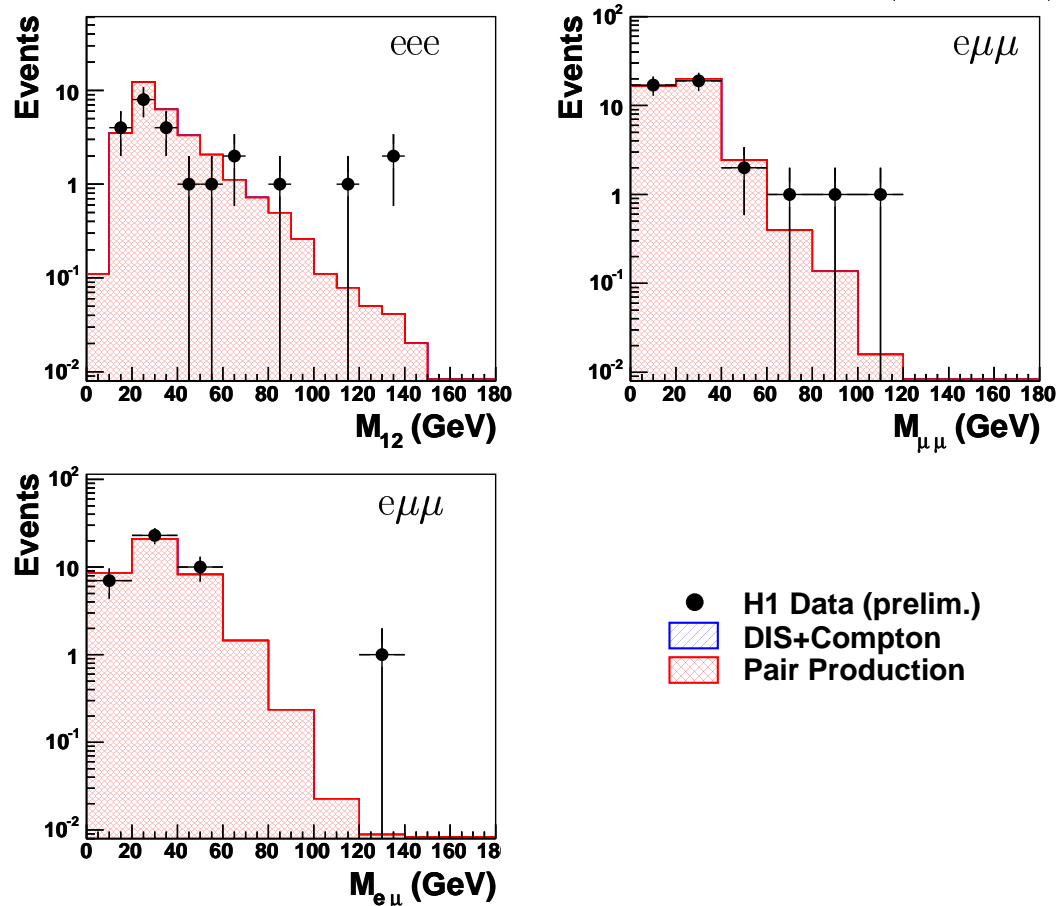
	Electrons		Muons	
	Data	SM	Data	SM
Total	18	15.4	9	4.1
$P_T^X > 25 \text{ GeV}$	8	2.6	6	2.5

High P_t electrons again...

HERA II- first BSM searches II

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

H1 Preliminary Multi-lepton analysis HERA I+II (163 pb^{-1})



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

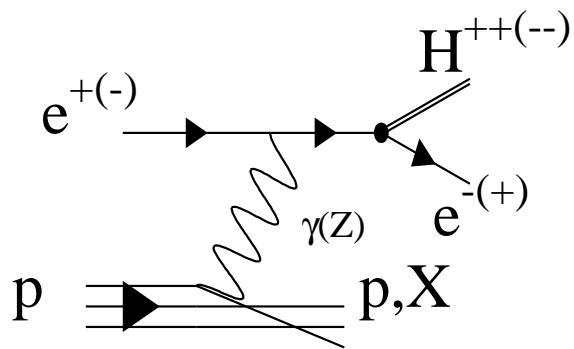
HERA II:

- 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.

H1 Higgs search: $H^{\pm\pm}$ limits

