Η παιδεία στην κορυφή
ΥΠΟΥΡΓΕΙΟ ΕΘΝΙΚΗΣ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
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Η ΠΑΙΔΕΙΑ ΣΤΗΝ ΚΟΡΥΦΗ
Επιχειρησιακό Πρόγραμμα
Εκπαίδευσης και Αρχικής
Επαγγελματικής Κατάρτισης

Searches for New Physics at HERA

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Some searches for new Physics at HERA

- New currents modifying Standard Model (SM) Deep Inelastic Scattering (DIS) cross sections (eg. RH currents).
- Search for new particles can be done in single particle production mode. Depends on couplings to SM particles. No absolute mass limits. (eg. Leptoquarks)
- Investigate low SM cross section processes and all possible final states, eg.

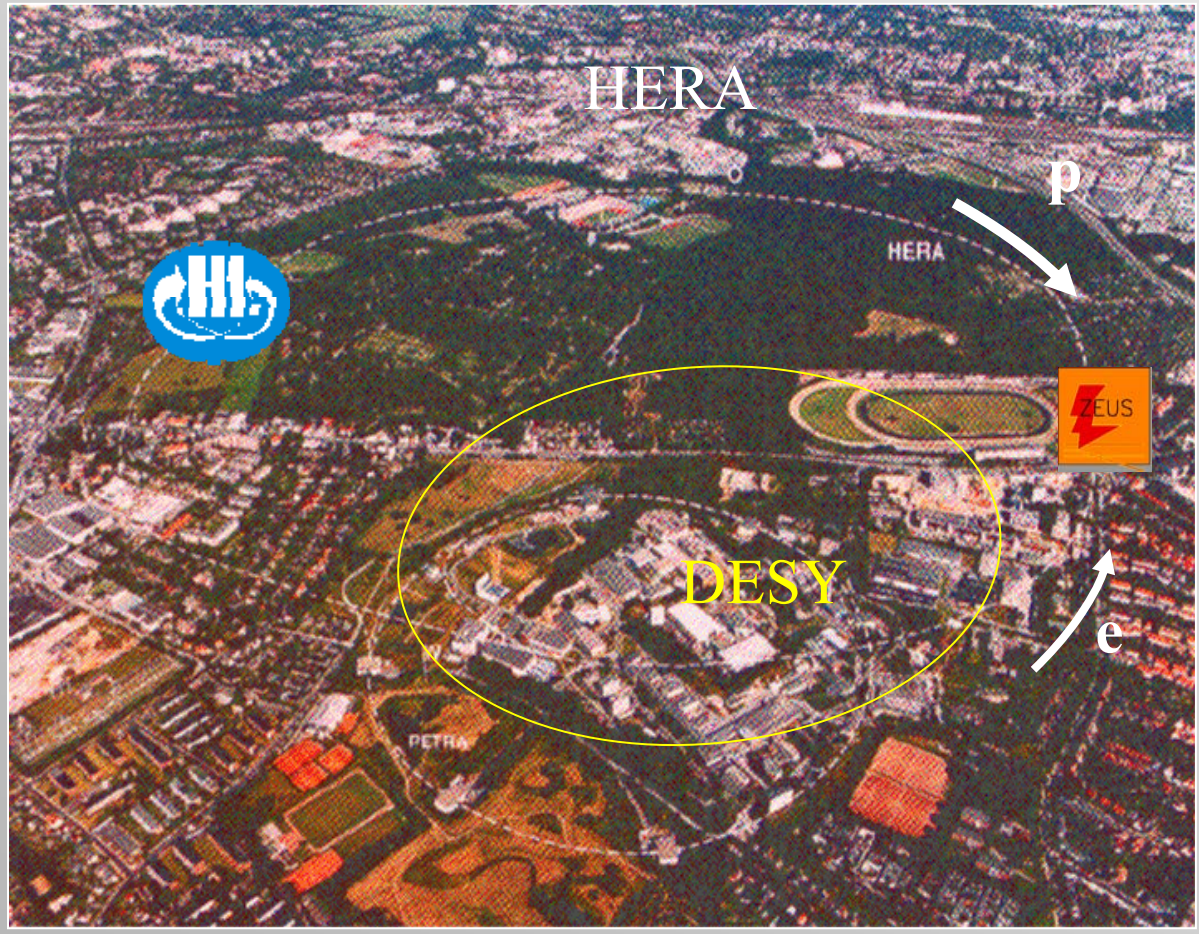
✓ Multileptons

✓ Isolated lepton production

✓ Single top production

✓ Stop production

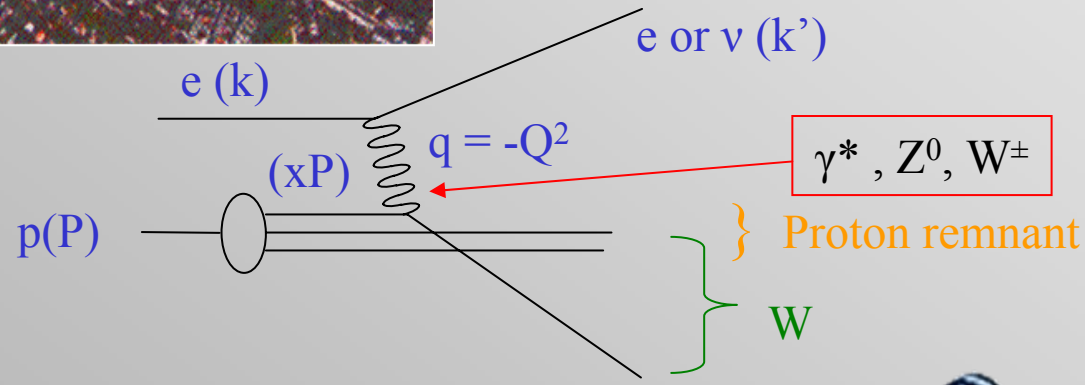
H1 and ZEUS results only



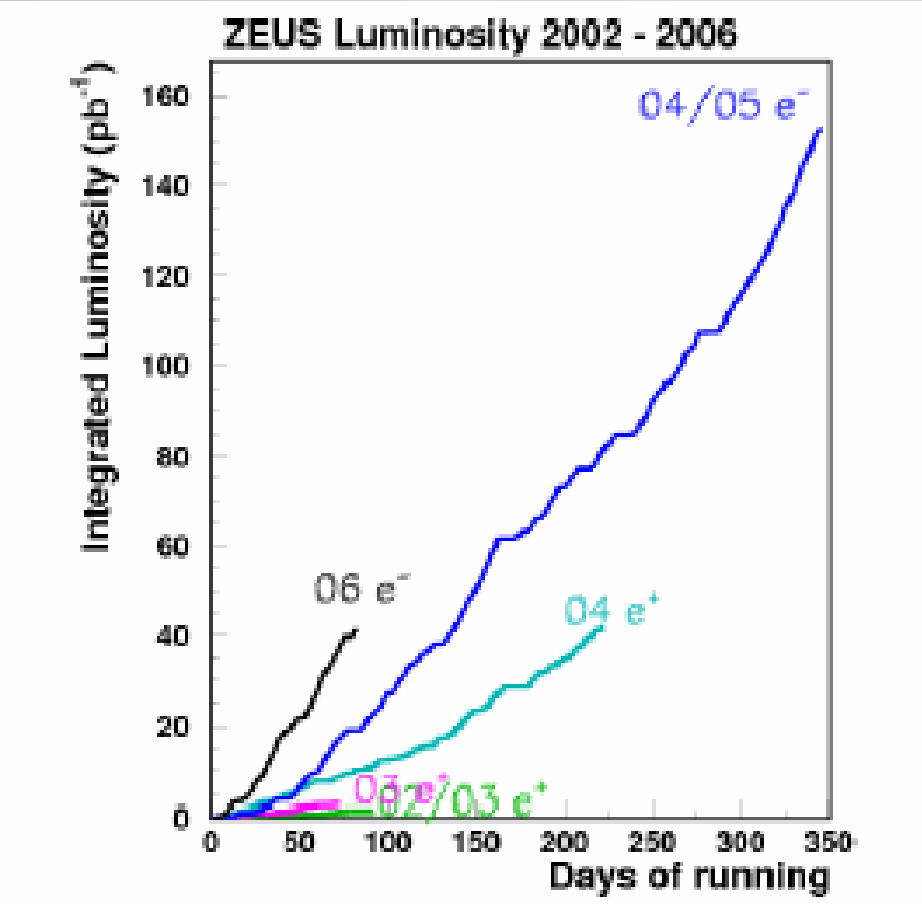
HERA

p : 820/920 GeV

$e^{\pm}$: 27.6 GeV



HERA performance

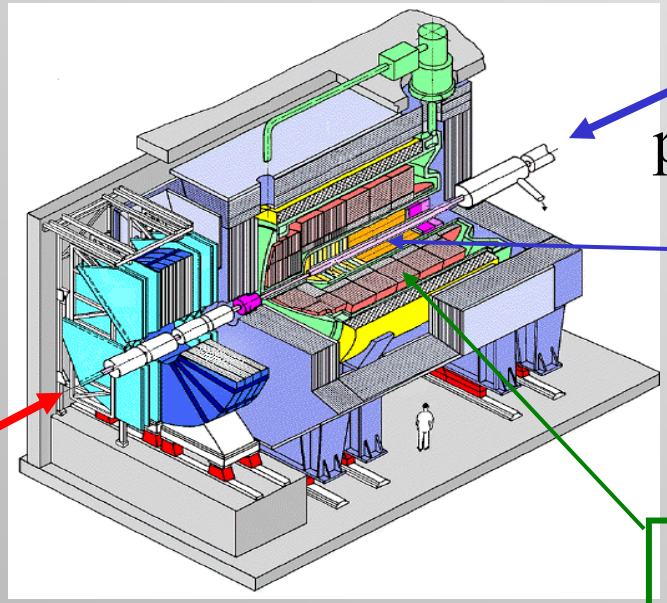


HERA I : intL ~ 130 pb^{-1}

HERA II: intL ~ 230 pb^{-1}

- Detector and Luminosity upgrade
- large backgrounds identified and overcome in 2002 and 2003
- efficient data taking since October 2003
- long run scheduled till summer 2007
- polarized e^-/e^+ beam with spin rotators

The detectors at HERA - H1



p

Interaction point

e^+

Liquid Argon calorimeter

$$\frac{\sigma}{E} = \frac{12\ \%}{\sqrt{E}}$$ Electrons

$$\frac{\sigma}{E} = \frac{50\ \%}{\sqrt{E}}$$ Hadrons

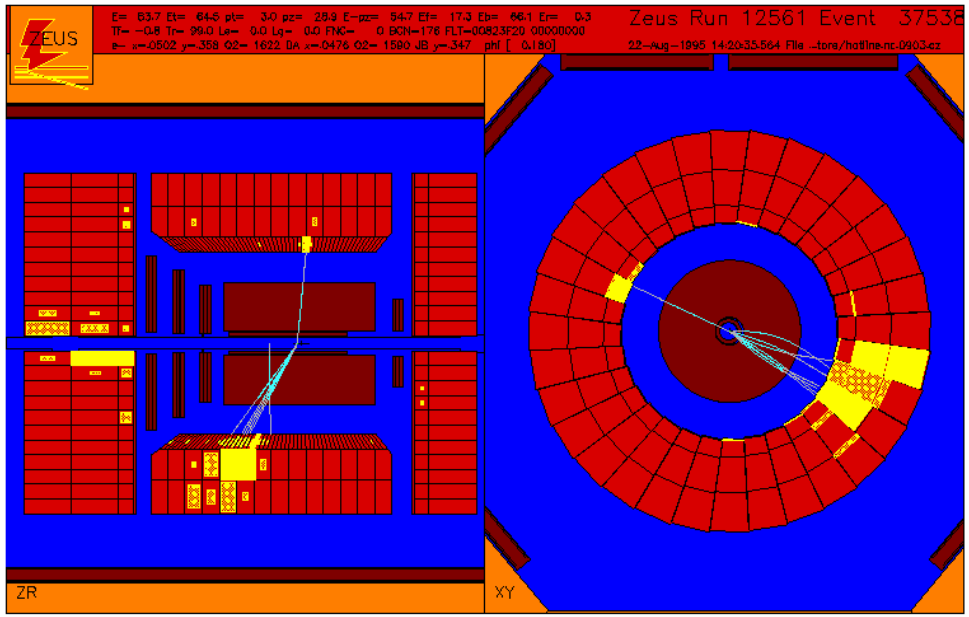
$\sigma_{\theta_e} = 2 - 5$ mrad

44000 cells

Liquid Ar calorimeter

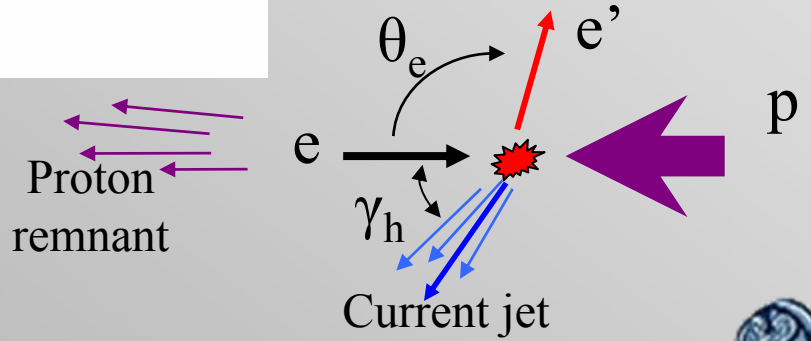
Optimized for electron measurement

The detectors at HERA - ZEUS



Compensated U-Sci calorimeter

Optimized for hadronic system measurements



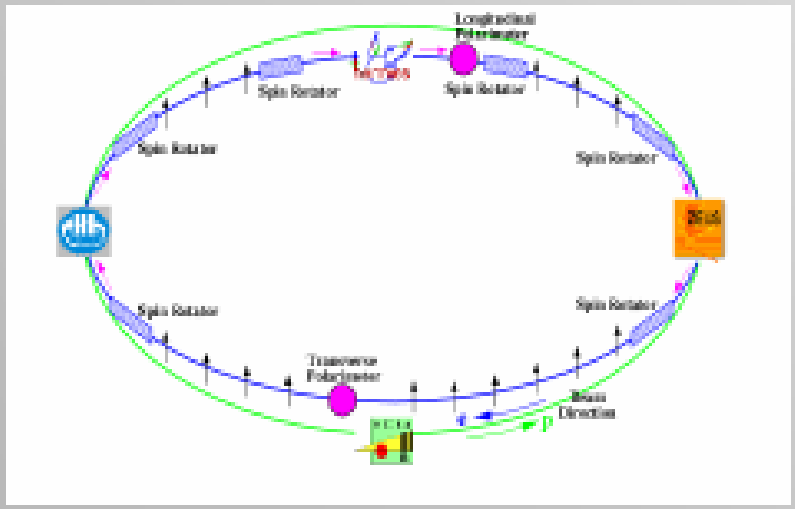
Polarized cross sections at HERA

The transverse polarisation builds up naturally (Sokolov-Ternov effect)

- Spin rotators flip the polarisation by 90º just before the lepton beam enters the interaction regions of experiments
- Typical polarisation ~ 40 %

Polarisation :

$$P = \frac{N_R - N_L}{N_R + N_L}$$



Right Handed currents

Total CC cross section

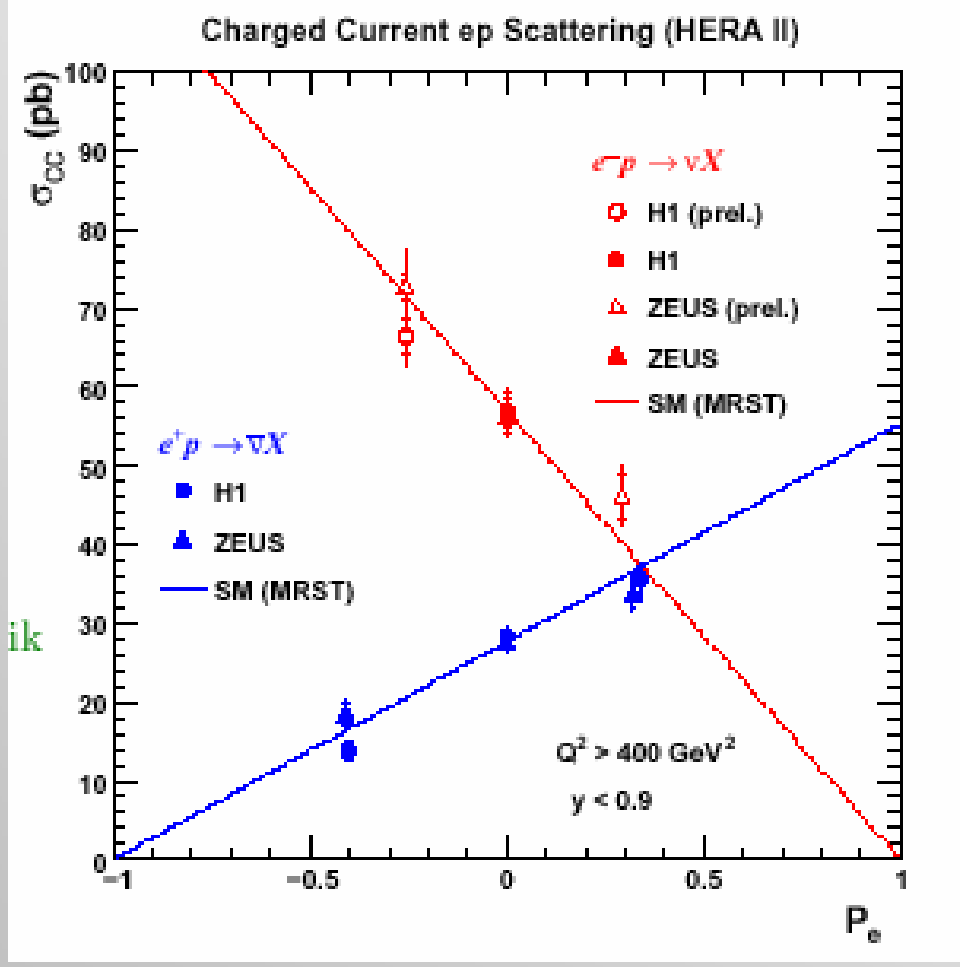
($Q^2 > 400\ GeV^2$)

vs. polarisation $P = \frac{N_R - N_L}{N_R + N_L}$

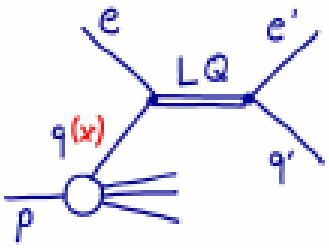
In SM σ (RH) =0 for electrons and σ (LH) =0 for positrons and the total cross-section changes linearly with polarisation.

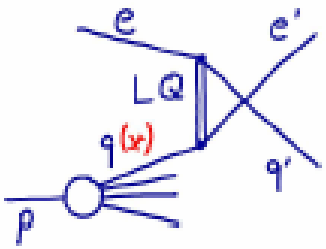
➢ **nonexistence of RH currents within the framework of SM.**

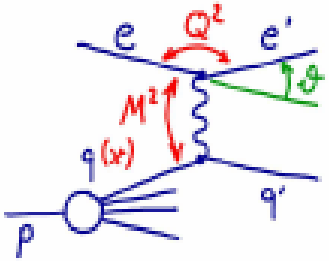
H1 and ZEUS measurements consistent with SM



Leptoquarks (1)





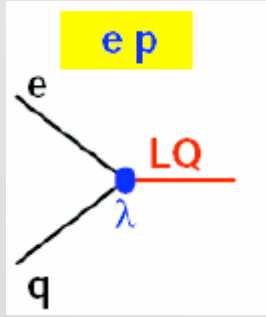


Predicted by several beyond standard model (BSM) theories

Connect lepton and quark sectors

Carry both B and L

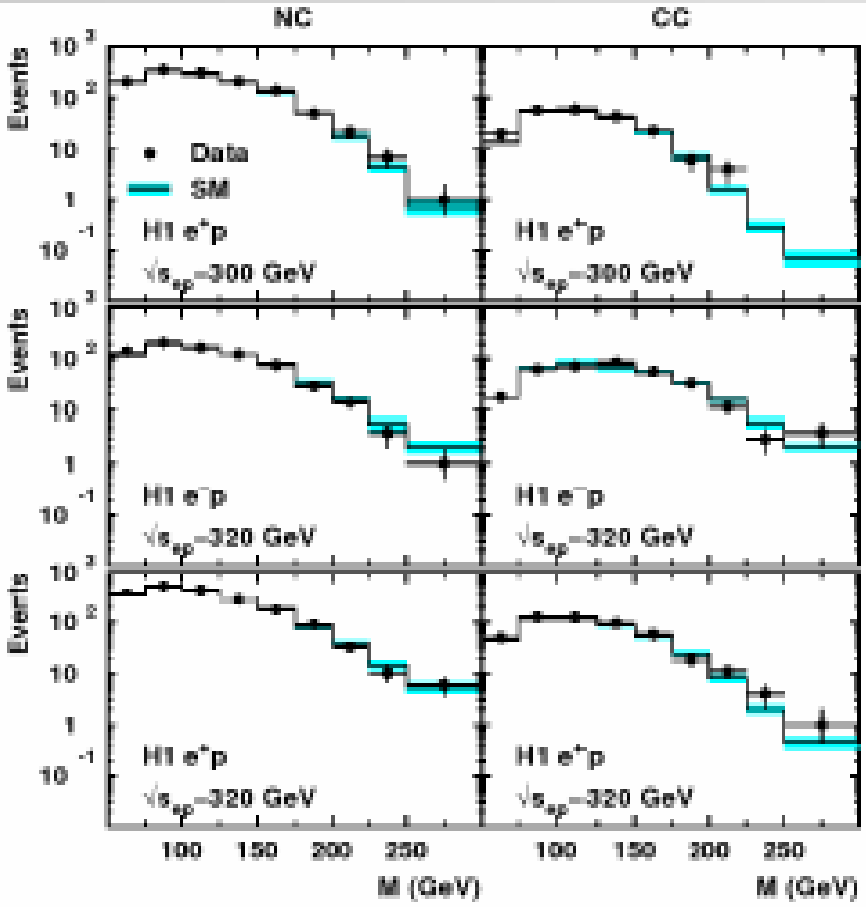
Can be produced in the s-channel in HERA as a resonance



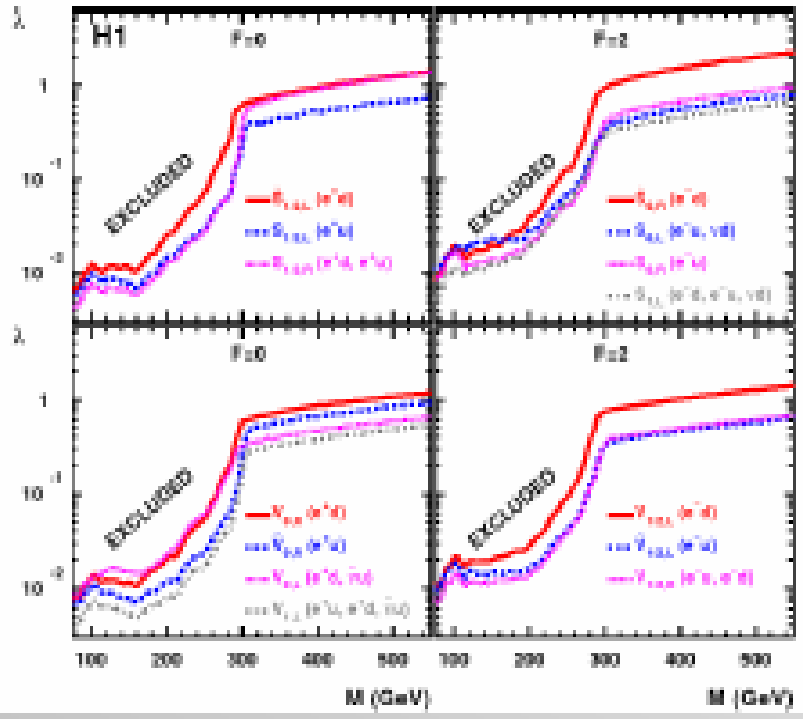
They are scalar or vector color triplet bosons

Experimental signature is lepton and jet in final state

Leptoquarks (2)



$37\ \mathrm{pb}^{-1}\ (e^+p,\ \sqrt{s} \approx 300\ \mathrm{GeV})$
$15\ \mathrm{pb}^{-1}\ (e^-p,\ \sqrt{s} \approx 320\ \mathrm{GeV})$
$65\ \mathrm{pb}^{-1}\ (e^+p,\ \sqrt{s} \approx 320\ \mathrm{GeV})$

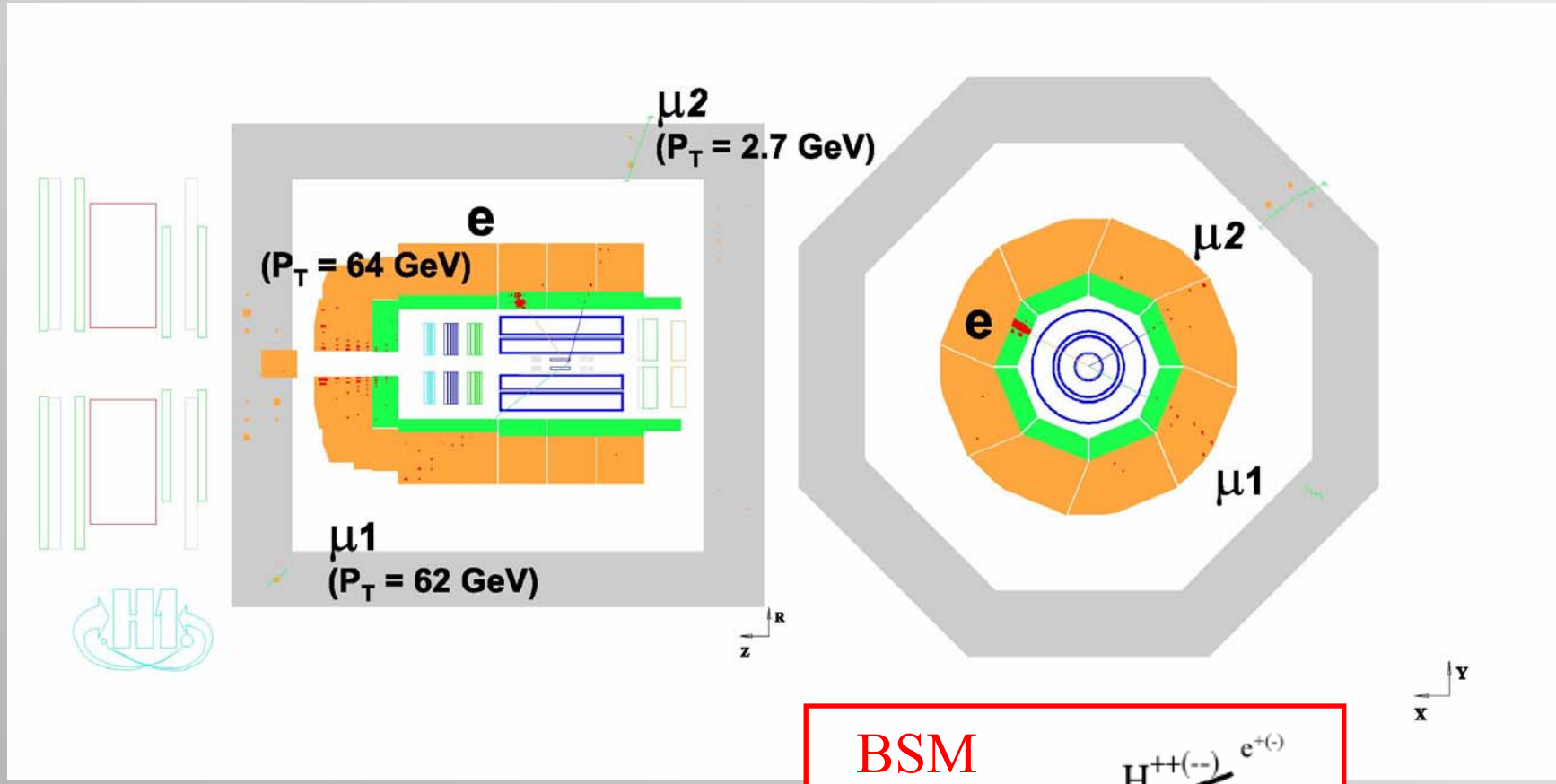


No leptoquarks seen so far.

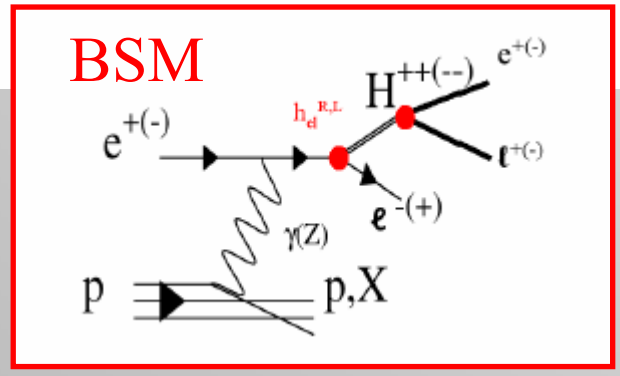
Limits have been set in 14 LQ types

Still good discovery potential for some types in HERA-II

Multi leptons



SM production through $\gamma\gamma$ interactions



Multileptons

Yield of dileptons with hight P_T

H1 Preliminary 275 pb^{-1} (1994–2005)

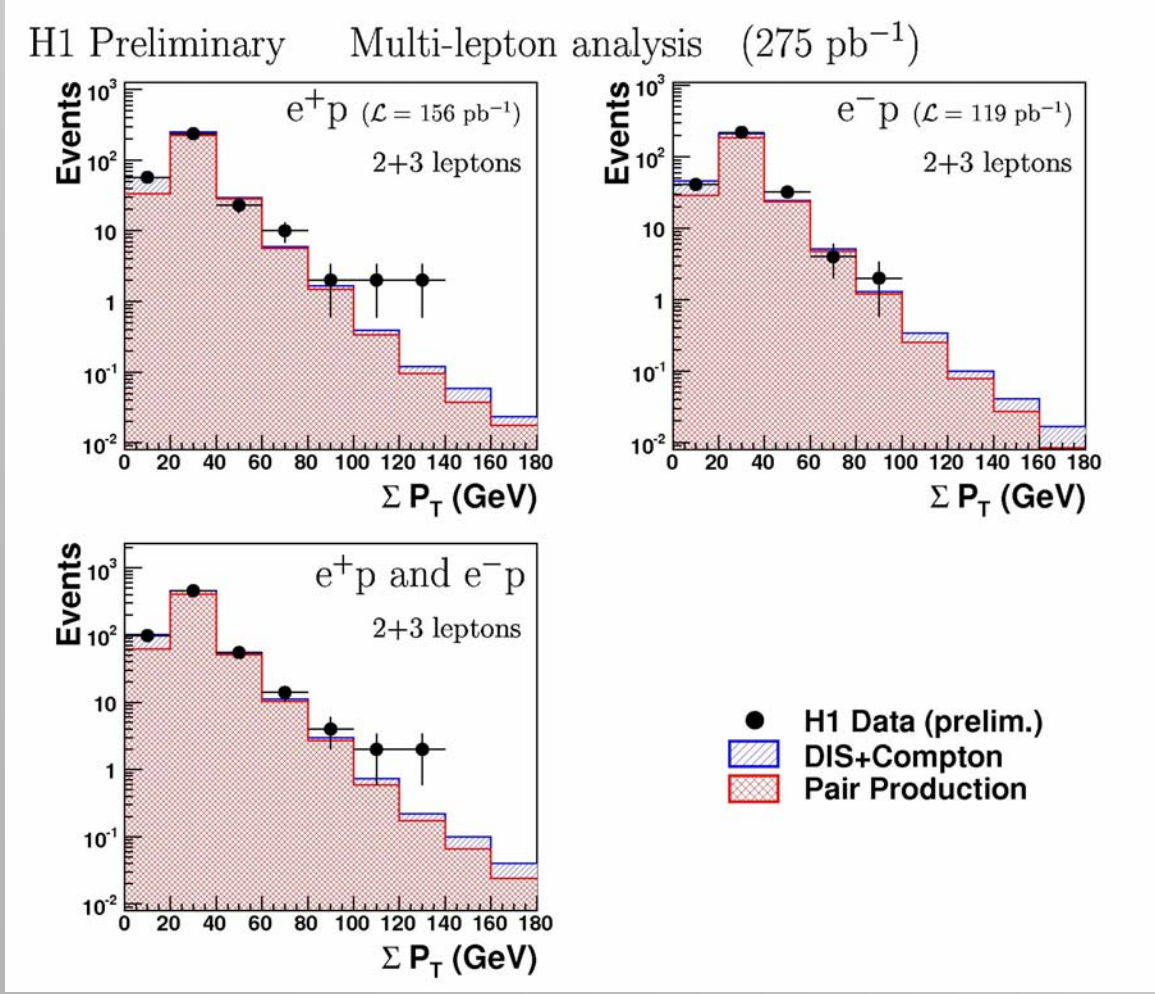
Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (156 pb^{-1})				
ee M_{12} >100 GeV	3	0.44 ± 0.10	0.29 ± 0.09	0.15 ± 0.04
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.03 ± 0.02	0.03 ± 0.02	—
eμ $M_{e\mu}$ >100 GeV	0	0.29 ± 0.03	0.29 ± 0.03	—
eee M_{12} >100 GeV	3	0.29 ± 0.06	0.29 ± 0.06	—
e$\mu\mu$ $M_{e\mu}$ >100 GeV	1	0.04 ± 0.01	0.04 ± 0.01	—
e$\mu\mu$ $M_{\mu\mu}$ >100 GeV	1	0.015 ± 0.007	0.015 ± 0.007	—
e^-p collisions (119 pb^{-1})				
ee M_{12} >100 GeV	0	0.42 ± 0.11	0.23 ± 0.06	0.19 ± 0.06
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.02 ± 0.02	0.02 ± 0.02	—
eμ $M_{e\mu}$ >100 GeV	0	0.24 ± 0.04	0.24 ± 0.04	—
eee M_{12} >100 GeV	0	0.18 ± 0.05	0.18 ± 0.05	—
e$\mu\mu$ $M_{e\mu}$ >100 GeV	0	0.03 ± 0.01	0.03 ± 0.01	—
e$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.004 ± 0.003	0.004 ± 0.003	—

H1 Preliminary 275 pb^{-1} (1994–2005)

Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p $\sum P_T$ >100 GeV	4	0.6 ± 0.1	0.49 ± 0.09	0.11 ± 0.04
e^-p $\sum P_T$ >100 GeV	0	0.5 ± 0.1	0.37 ± 0.10	0.13 ± 0.04
All $\sum P_T$ >100 GeV	4	1.1 ± 0.2	0.86 ± 0.18	0.24 ± 0.06

Combination of di- and tri- leptons with hight P_T

Multi leptons



4 events in e^+p

0.6±0.1 expected

Single leptons. Why?

Many processes indicating new physics would demonstrate themselves with isolated lepton in the final state.

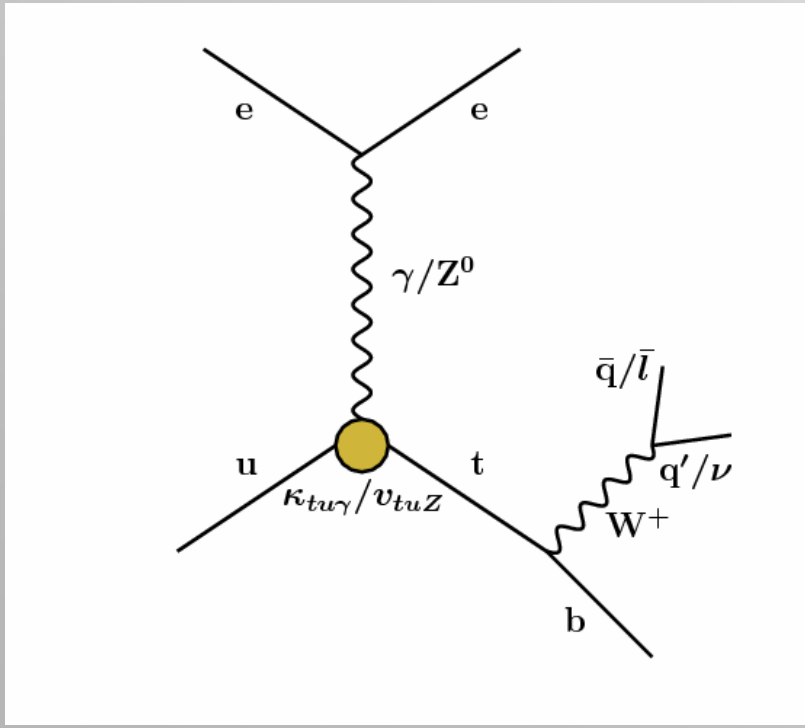
- Supersymmetric processes (eg. $ep \rightarrow \tilde{e}\tilde{q}X$)

- R-parity violating supersymmetric processes (eg. Stop production)

- Top quark production at a rate higher than predicted by SM. Such enhancement could be achieved through flavor changing neutral current process (FCNC) which could be attributed to:

✓Supersymmetry
✓Multi-Higgs-doublet models
✓Exotic quarks (GUT's, string theories, etc)

Single top production



- Flavor Changing Neutral Current events has a small cross section (<1 fb) in the SM
- If events at HERA are attributed to single top production then the process would proceed through anomalous couplings
- Final state electron disappears down the beampipe in 65% of the events

Single top signature

In the leptonic decay channel of the W

- Isolated high energy lepton
- Significant missing transverse momentum
- Jet from the b-quark decay

In the hadronic channel

- Three jets with
- $M_{dijet} \sim M_W$
- $M_{total} \sim M_{top}$

Backgrounds

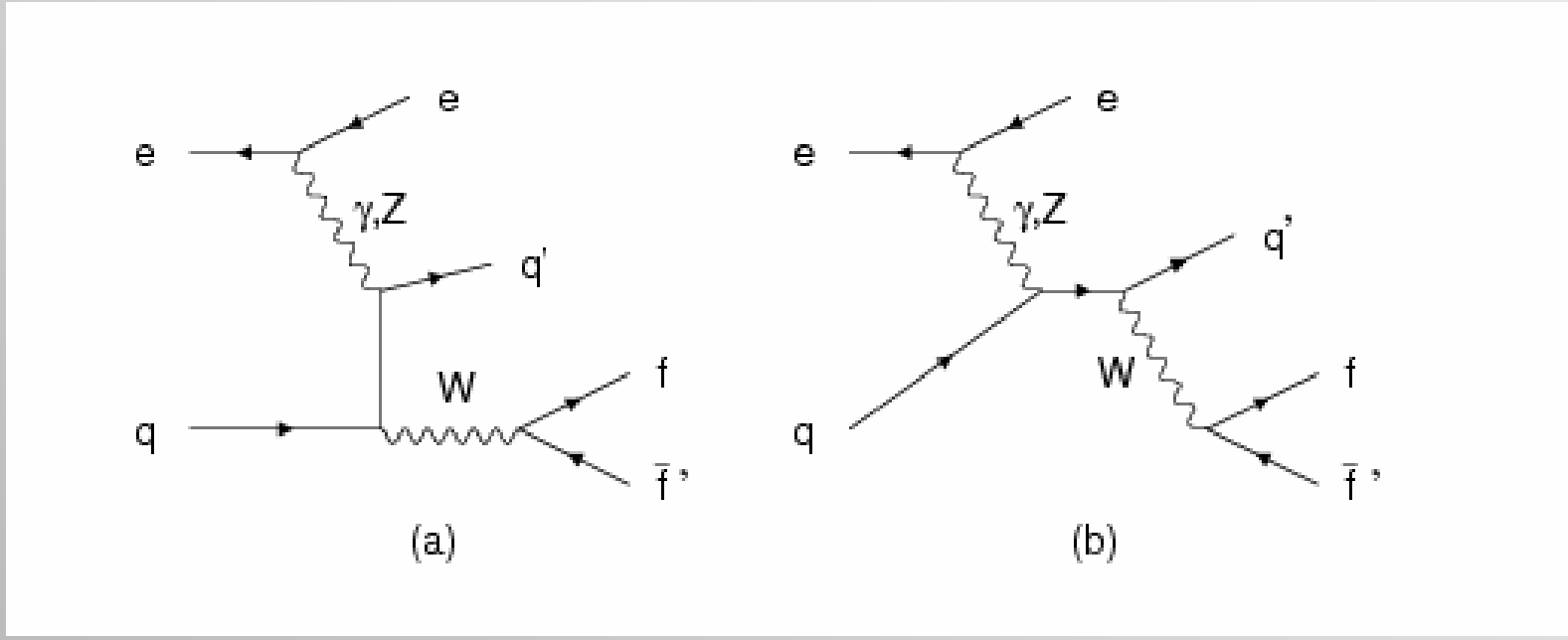
In leptonic channels

- 2γ processes
- NC DIS
- Single W production

Hadronic channel

- QCD

Single Vector Boson Production at HERA



Main source of isolated leptons (SM cross section ~ 1.1 pb @ 318 GeV)

Background

- Badly reconstucted NC and CC DIS events
- Dilepton production

Indicative Event Selection (ZEUS)

Data sets e^+-p and e^--p

1998 – 2005 (HERA-I & HERA-II)

E_{cms} = 318 GeV

p^e_T >10 GeV

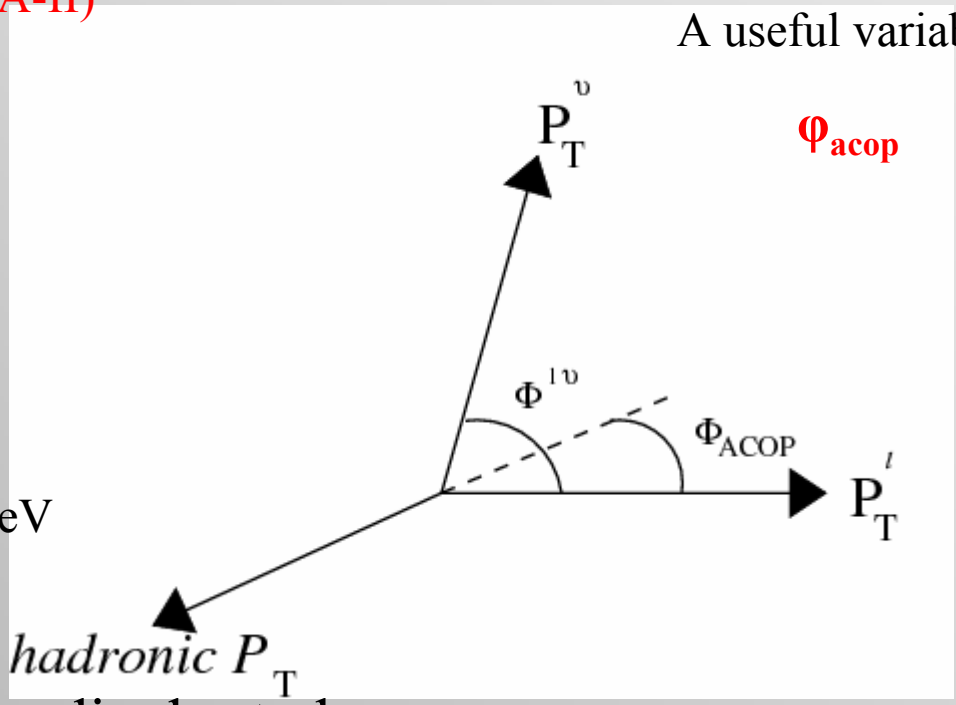
θ_e >1.5

φ_{acop} >0.3 for P^X_T> 4 GeV

Q^2_{elec} >5000 GeV^2 or P_T>25 GeV

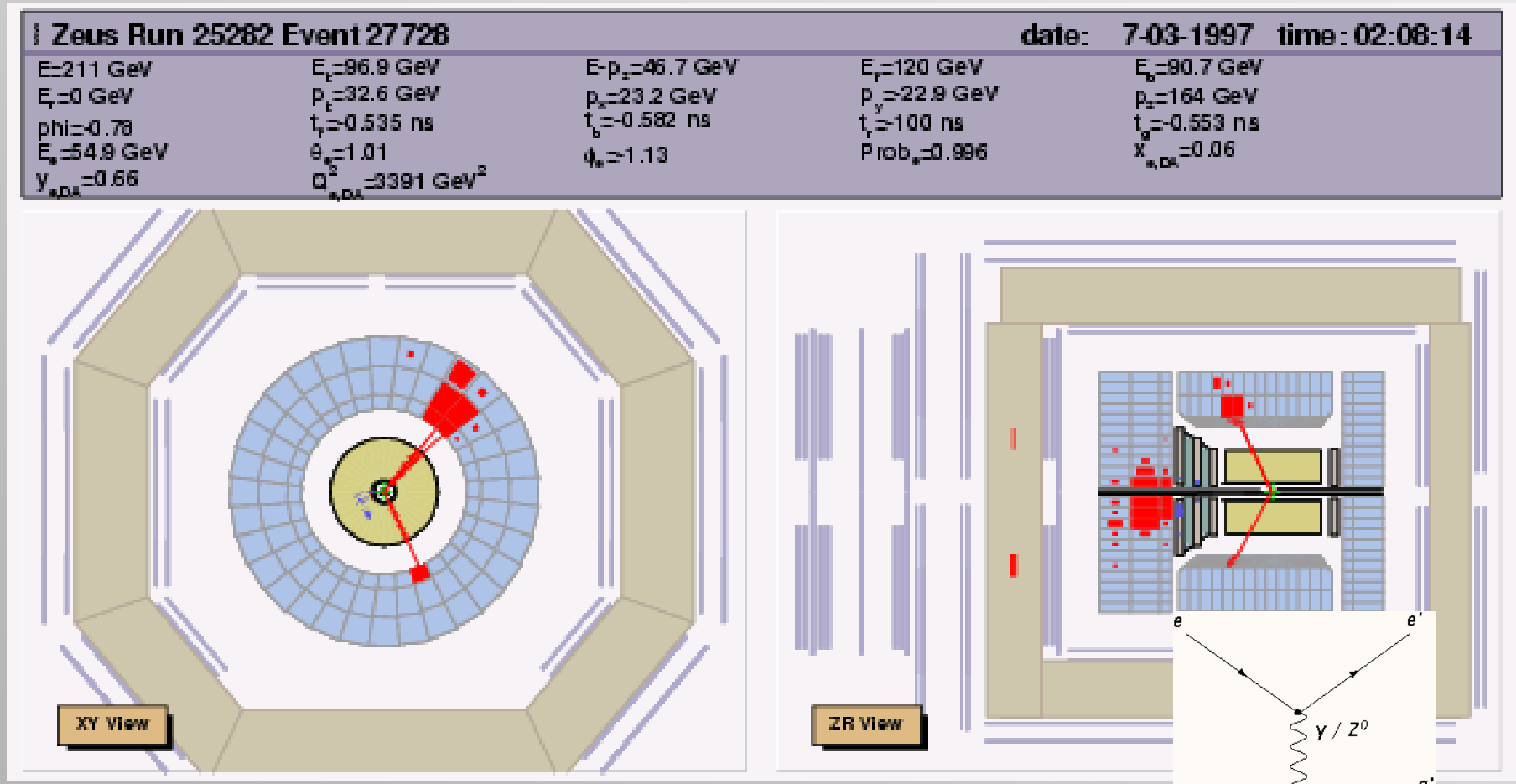
E-P_z < 50 GeV

A useful variable.



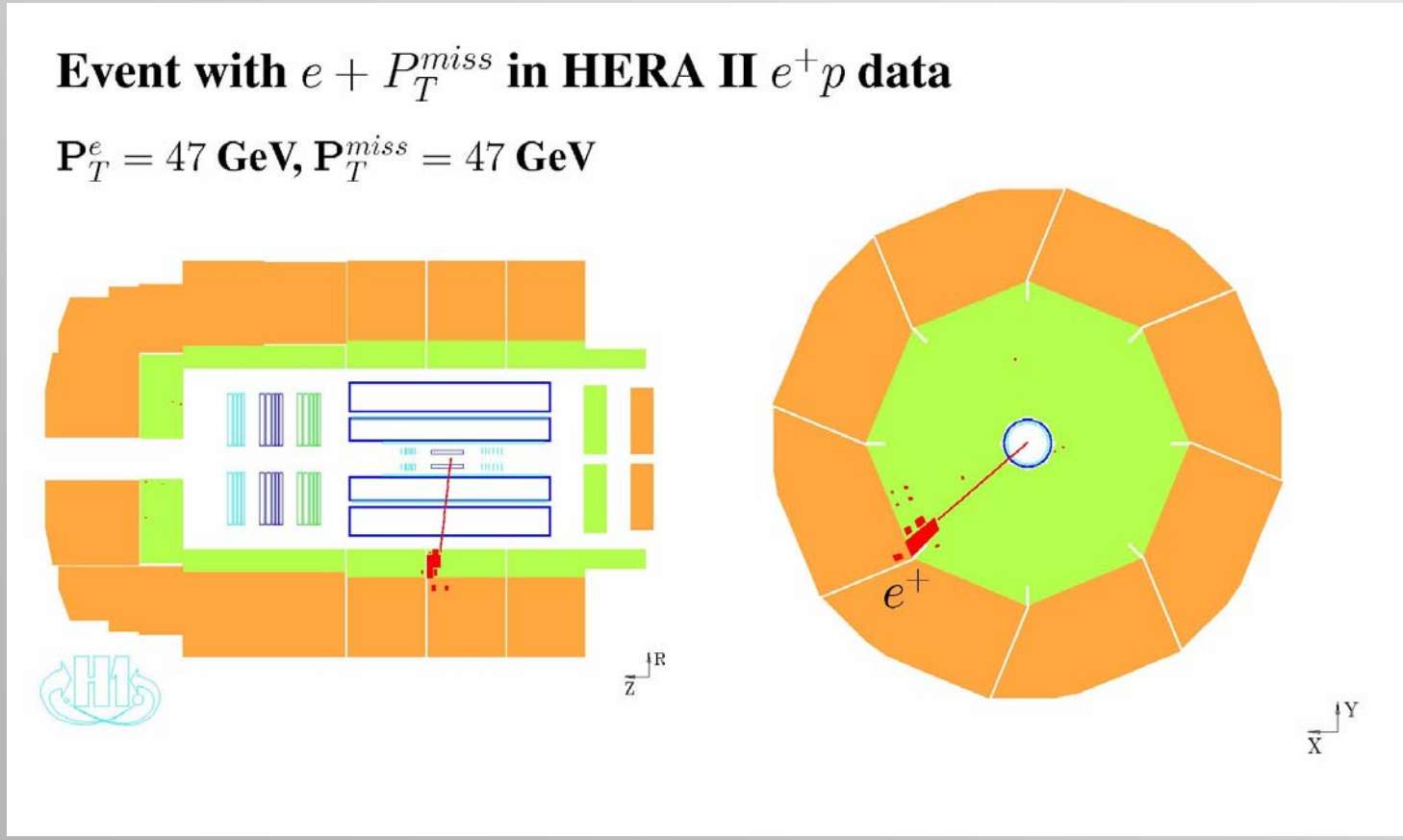
perpendicular to beam

Golden W production event from 1997



DESY note 99-054

H1 event with missing P_T

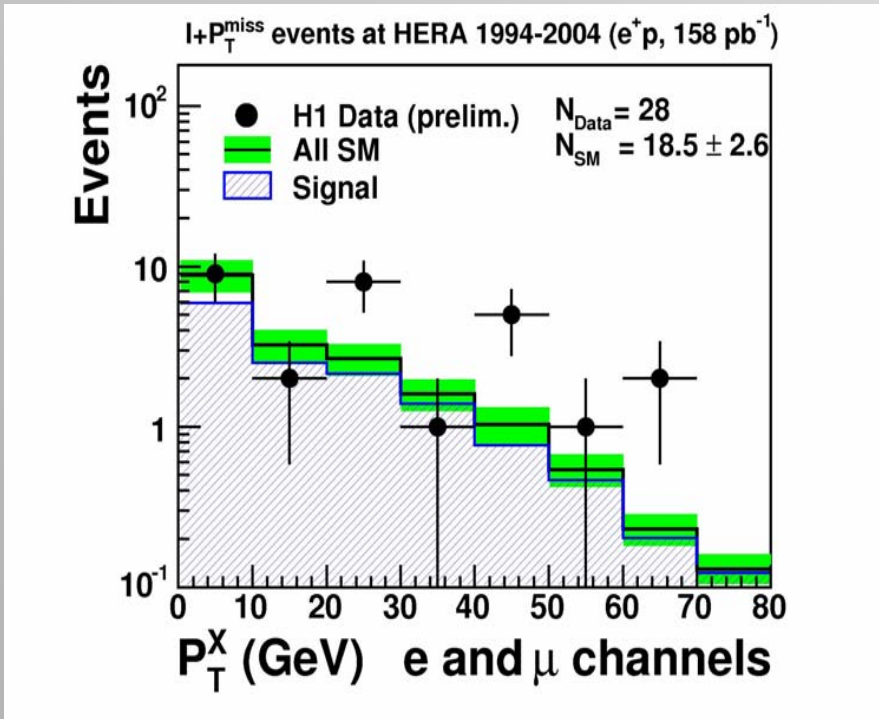


Isolated leptons (H1)

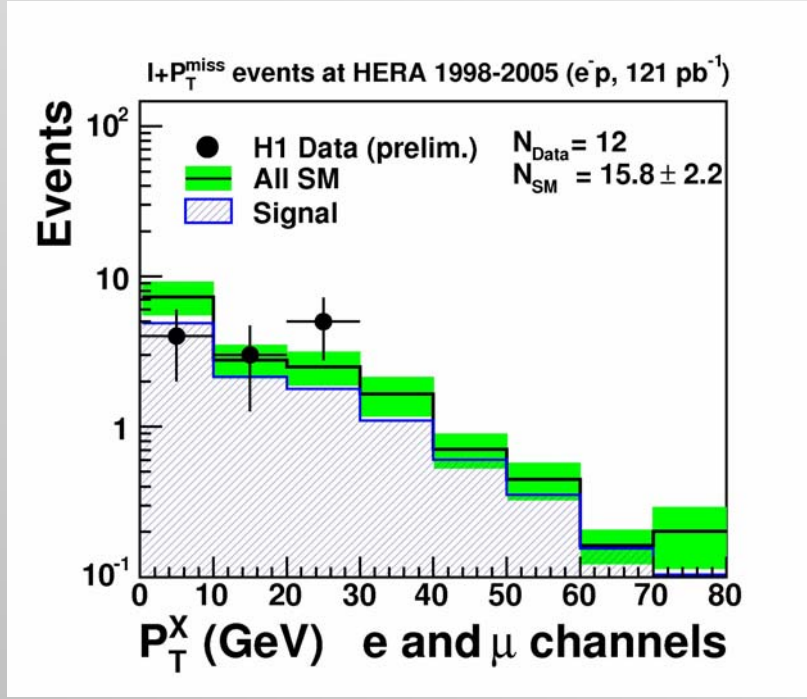
H1 Preliminary		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2004 e^+p	Full Sample	19 / 14.6 ± 2.0 (70%)	9 / 3.9 ± 0.6 (84%)	28 / 18.5 ± 2.6 (73%)
158 pb^{-1}	$P_T^X > 25$ GeV	9 / 2.3 ± 0.4 (80%)	6 / 2.3 ± 0.4 (84%)	15 / 4.6 ± 0.8 (82%)
1998-2005 e^-p	Full Sample	11 / 12.6 ± 1.8 (66%)	1 / 3.3 ± 0.5 (79%)	12 / 15.8 ± 2.2 (68%)
121 pb^{-1}	$P_T^X > 25$ GeV	2 / 2.4 ± 0.5 (62%)	0 / 2.0 ± 0.3 (76%)	2 / 4.4 ± 0.7 (68%)
1994-2005 $e^\pm p$	Full Sample	30 / 27.2 ± 3.8 (68%)	10 / 7.2 ± 1.1 (81%)	40 / 34.3 ± 4.8 (71%)
279 pb^{-1}	$P_T^X > 25$ GeV	11 / 4.7 ± 0.9 (69%)	6 / 4.3 ± 0.7 (78%)	17 / 9.0 ± 1.5 (73%)

Single leptons with missing P_T

positron-proton



electron-proton



Isolated e-candidates (ZEUS)

Isolated e candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) 98-99 $e^- p$ (17 pb^{-1})	$1/0.23 \pm 0.06(67\%)$	$0/0.32 \pm 0.09(65\%)$
ZEUS (prel.) 04-05 $e^- p$ (126 pb^{-1})	$3/1.75^{+0.36}_{-0.32}$ (57%)	$3/2.54^{+0.46}_{-0.45}$ (51%)
ZEUS (prel.) 99-00 $e^+ p$ (66 pb^{-1})	$1/1.04 \pm 0.11(57\%)$	$1/0.92 \pm 0.09(79\%)$
ZEUS (prel.) 03-04 $e^+ p$ (40 pb^{-1})	$0/0.46 \pm 0.10(64\%)$	$0/0.58^{+0.08}_{-0.09}(76\%)$
ZEUS (prel.) 98-05 $e^- p$ (143 pb^{-1})	$4/1.98^{+0.36}_{-0.32}(58\%)$	$3/2.86 \pm 0.46(53\%)$
ZEUS (prel.) 99-04 $e^+ p$ (106 pb^{-1})	$1/1.50 \pm 0.15(59\%)$	$1/1.50^{+0.12}_{-0.13}(78\%)$
ZEUS (prel.) 98-05 $e^\pm p$ (249 pb^{-1})	$5/3.48^{+0.39}_{-0.36}(58\%)$	$4/4.36 \pm 0.47(61\%)$
H1 (prel.) 1994-2005 $e^\pm p$ (279 pb^{-1})	-	$11/4.7 \pm 0.9(69\%)$

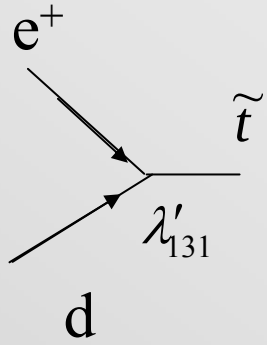
Supersymmetric searches

- HERA is limited in the search for supersymmetric particles due to the restriction of pair-production of SUSY particles.

- However, for mechanisms allowing single supersymmetric particle production it could still further the experimental limits

Terminology (1) – R-parity

- R-parity $R_P=(-1)^{3B+L+2S}$ +1 for particles
  -1 for sparticles



R-parity conservation
Implies pair production of supersymmetric particles
Stable LSP (cold dark matter candidate)

R-parity violation
Resonant supersymmetric particle production
Supersymmetric particles can decay back to SM particles

R-parity violating terms $W_{R_P} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} U_i \overline{D}_j \overline{D}_k$

λ are dimensionless free parameters

For stop production in ep colliders (lightest Sparticle) $\lambda'_{131} \neq 0$

Terminology (2) – some parameters

Stop Branching ratios and

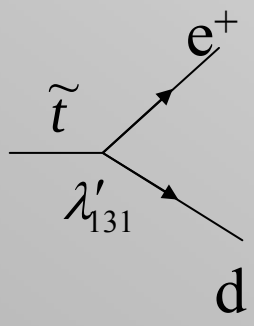
Neutralino, chargino and gluino masses

controlled by:

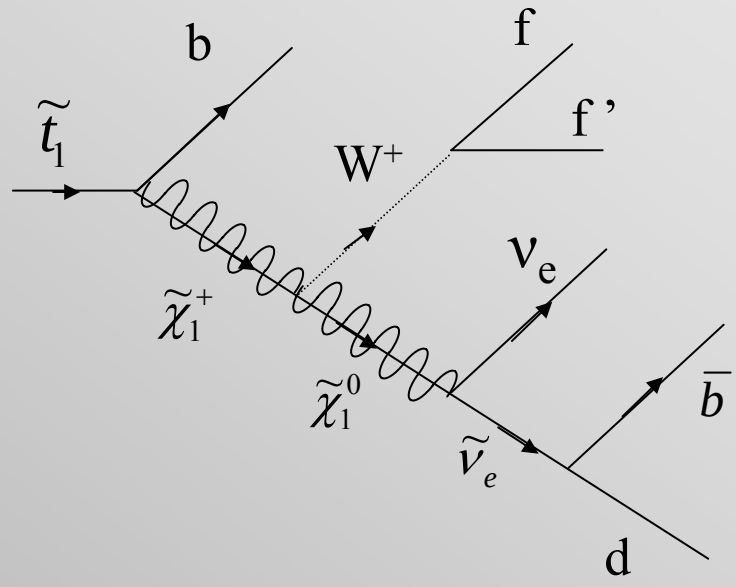
- μ : mixes Higgs superfields
- M_1, M_2, M_3 SUSY breaking parameters
  Related to U(1), SU(2), SU(3) gauginos
- tanβ
- $\lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk}$

Decay modes to look for

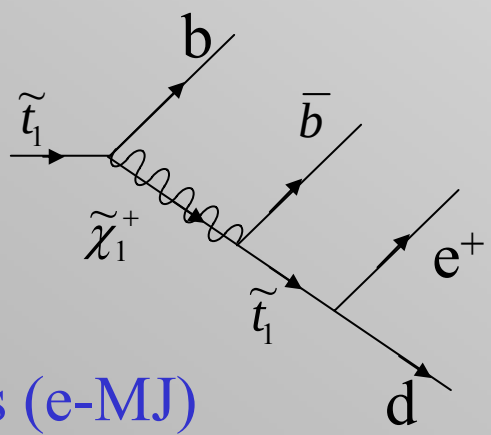
e+ + one jet (e-J)



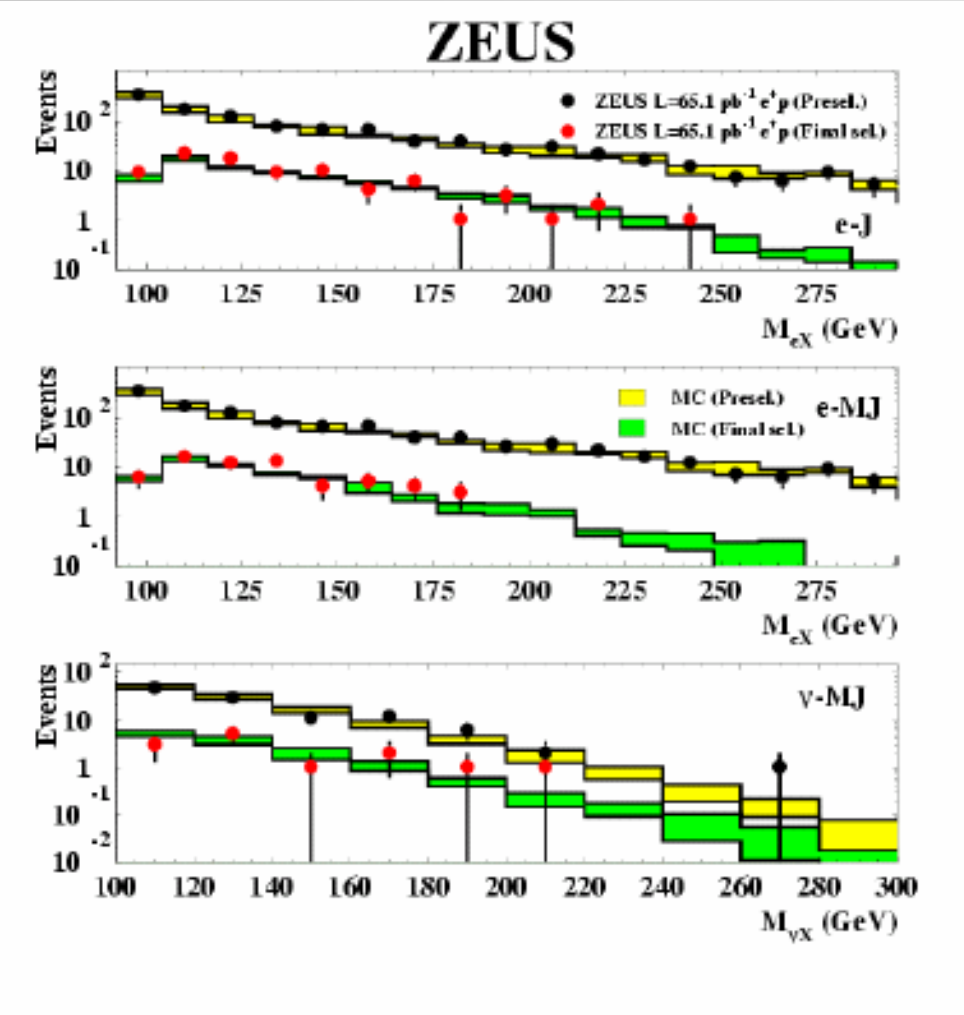
ν + many jets (ν-MJ)



e+ + many jets (e-MJ)



Invariant mass distributions



- Good agreement between data and MC
- No evidence of resonance
- M_{LX}>100 GeV

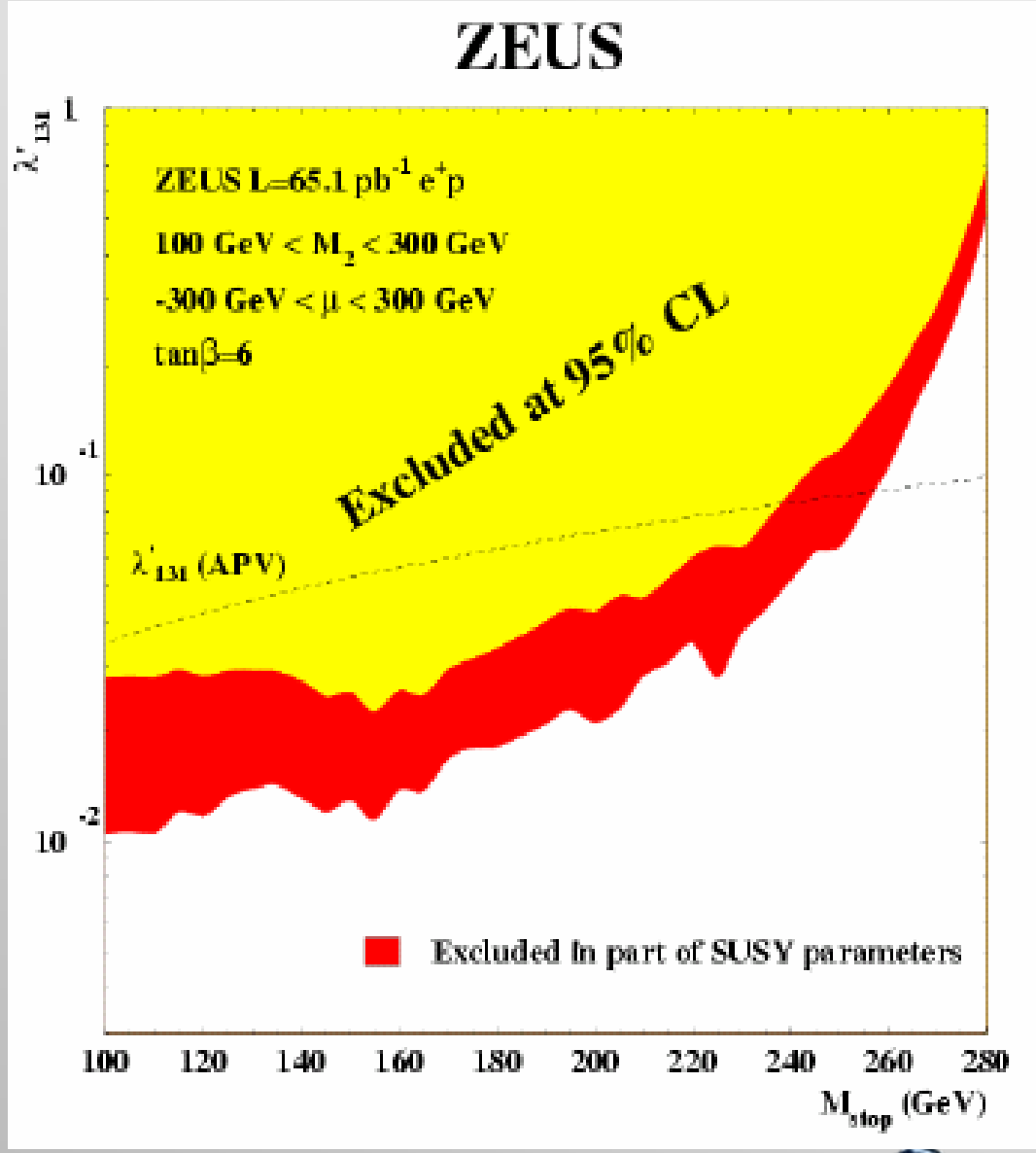
$$M_{LX}^2 = 2E_e^{beam}\sum_i \left(E + P_Z\right)_i$$

Limits on Minimal Supersymmetric Model

Limits are calculated for different values of SUSY parameters
100 GeV< M_2 < 300 GeV (step 30 GeV)
-300 GeV < μ < 300 GeV (step 20 GeV)
Not considered scenario where:
- neutralino not LSP
- $M_{\chi 0}$ < 30 GeV (excl. by LEP)

Yellow region: excluded at 95% C.L
Red region: excluded in part of the SUSY parameters

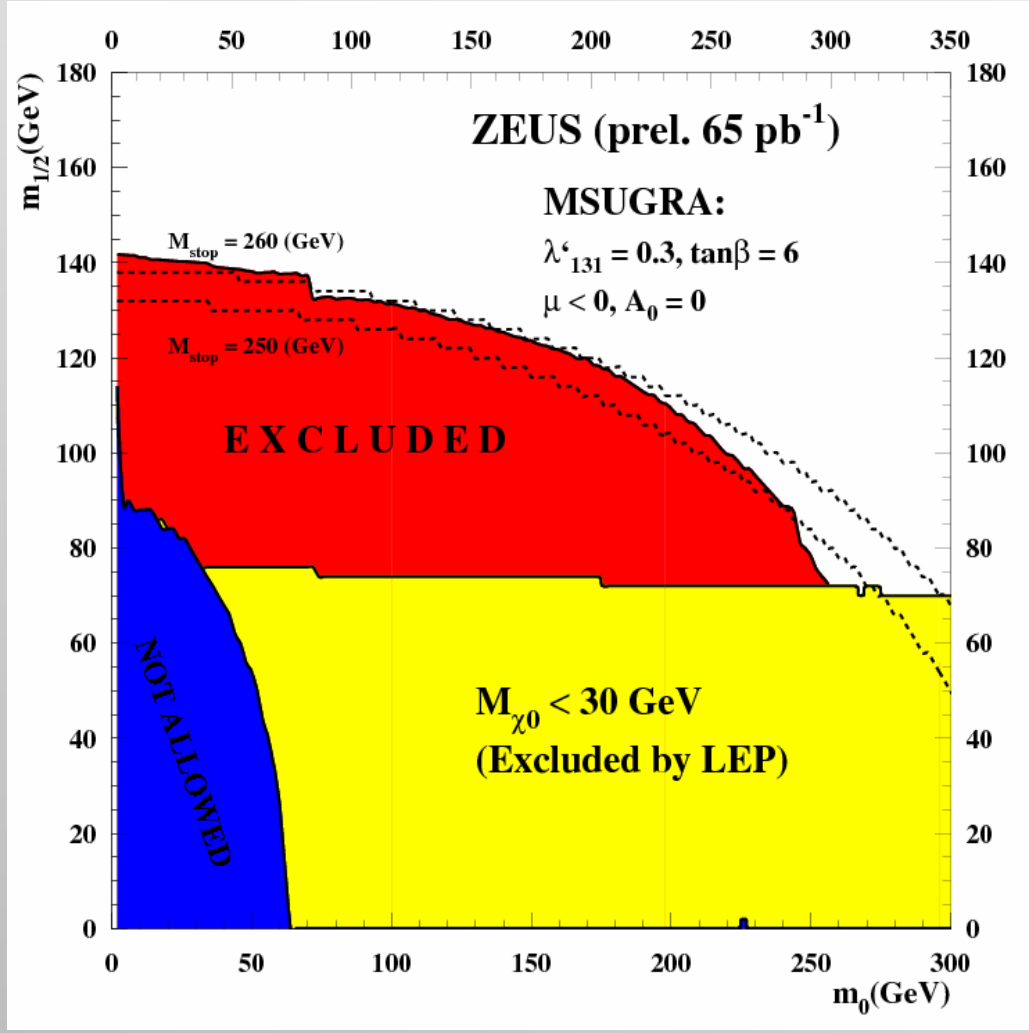
More restrictive limit up to masses ~240 GeV compared to low energy experiments (APV)



STOP - mSUGRA

- Stop, chargino and neutralino masses and BR are determined by the value of m_0, $m_{1/2}$, tanb , sign(μ).
- Limit based on a Bayesian approach.
- Red region: excluded at 95% C.L. The exclusion limit in the plane (m_0, $m_{1/2}$) was defined as the region of the plane for which R < 0.05, where R is the ratio between the signal and the SM likelihoods.
- Blue region: No solutions.
- Yellow region: $M_{\chi 0}$ < 30 GeV (already excluded by LEP)

Limits can rule out a stop with mass up to 270 GeV



Summary

HERA II performs very well and the experiments H1 & ZEUS have been successfully upgraded

New limits on the parameter space of many BSM processes have been established by HERA

Results from HERA experiments are consistent with each other and with SM.

There is however a persistent excess of events over the SM in high P_T lepton searches (observed by H1 in e^+p collisions).

New data is expected at HERA II giving the possibility of pushing the limits of many BSM processes