Searches for new Physics in ep Collisions at HERA

XXXXth Rencontres de Moriond
Electroweak Interactions and Unified Theories
La Thuile, Aosta Valley, Italy, March 5-15, 2005

Christian Schwanenberger
DESY/Universität Bonn

on behalf of the

Collaborations

New Physics Searches at HERA

Searches for new Resonances or Contact interactions:

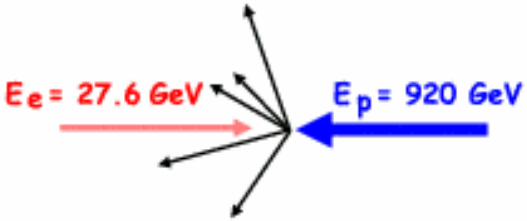
- Lepton Flavor Violation
- Leptoquarks
- Contact Interctions
- Extra Dimensions
- Quark Radius
- Excited Fermions
- SUSY in MSSM
- R-Parity-violating SUSY Searches

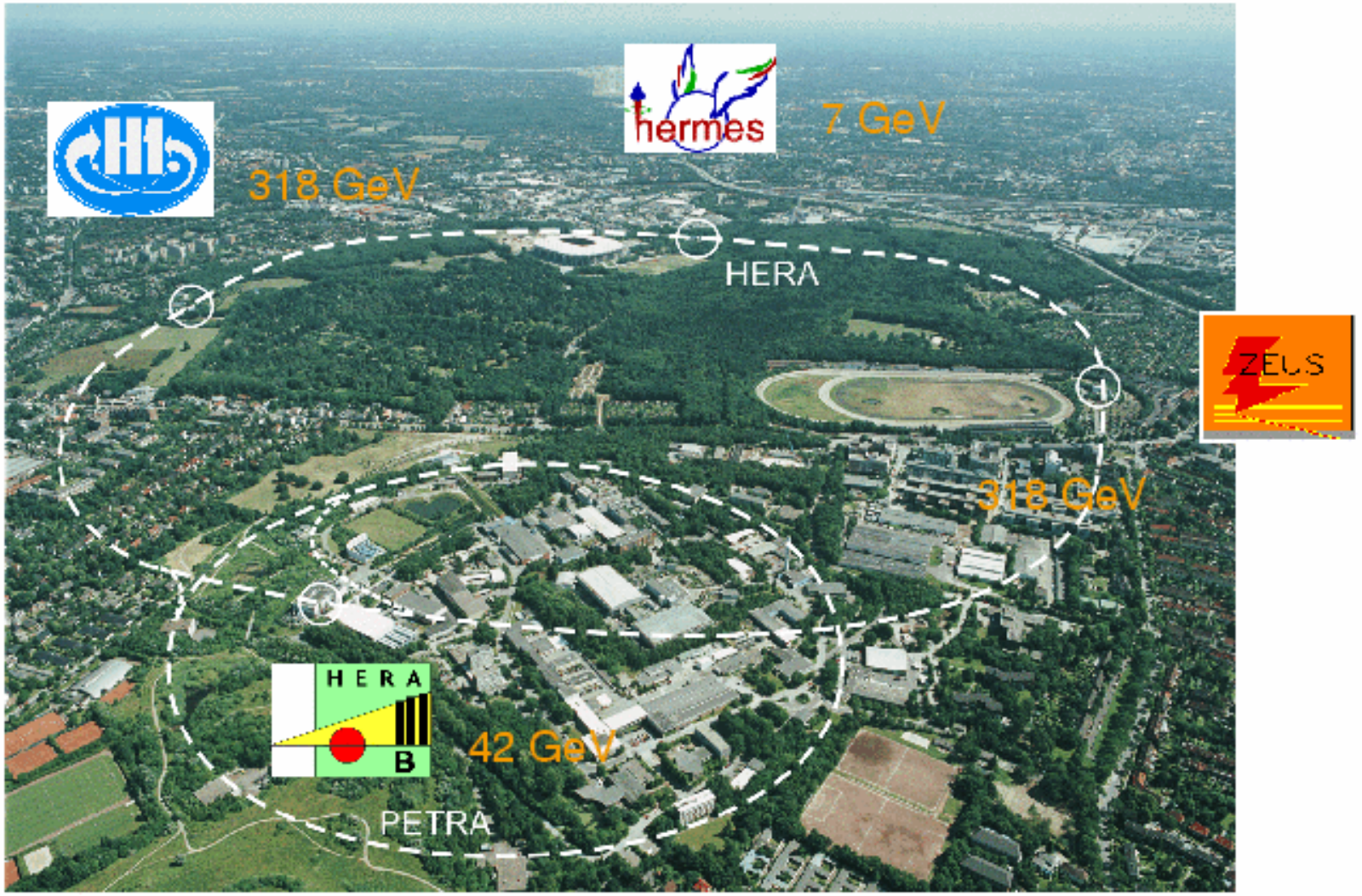
Exclusive Final States:

- Isolated Leptons and missing pT (HERA II)
- Single Top Production
- Multi-Lepton Events (HERA II)
- Double-charged Higgs
- Superlight Gravitinos
- Magnetic Monopoles
- General Search (HERA II)
- Pentaquarks

➡ What is new compared to summer (ICHEP)

HERA: ep Collider and Experiments



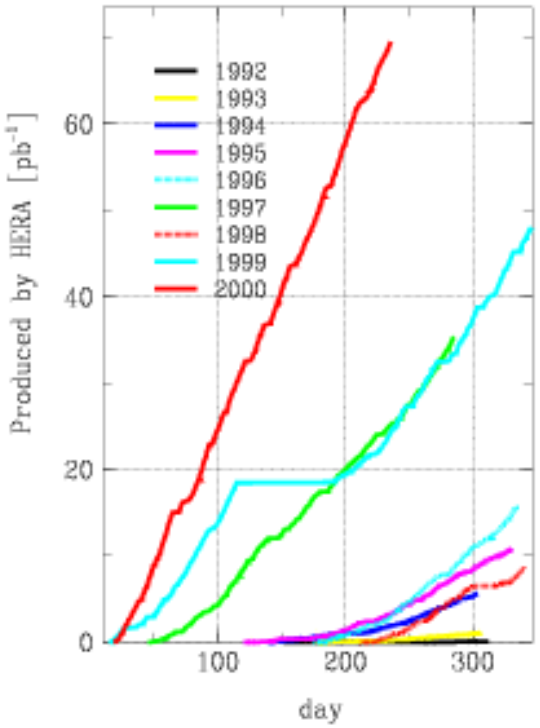


HERA Delivered Luminosities

HERA I

analysed here: H1 118 pb^{-1}

ZEUS 130 pb^{-1}



$\sqrt{s} = 320$ GeV:

e^+p (65 pb^{-1})

e^-p (17 pb^{-1})

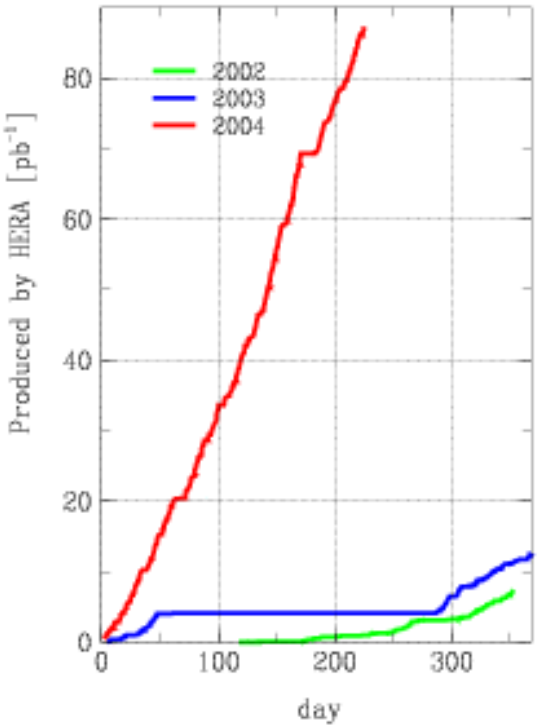
$\sqrt{s} = 300$ GeV:

e^+p (48 pb^{-1})

➡ steady progress year by year

HERA II

analysed here: H1 53 pb^{-1}



$\sqrt{s} = 320$ GeV:

$e^+_L p$

$e^+_R p$

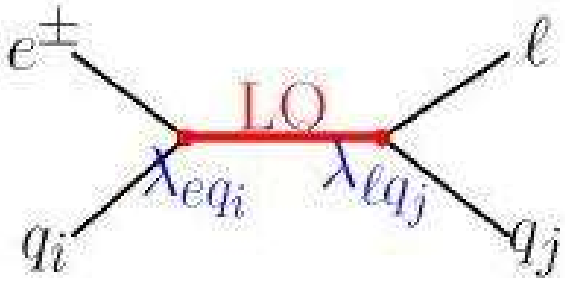
longitudinally polarised positron beam

➡ very good year 2004

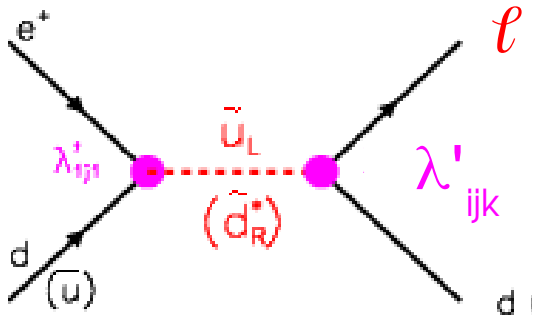
Lepton Flavor Violation

- Neutrino oscillation: lepton flavor **not conserved**
- Many **extensions from SM**:
  GUT, SUSY, compositeness, technicolor predict $e \to \mu$, $e \to \tau$
- Charged leptons: very stringent limits from **rare decays**, especially for $e \to \mu$

- At **HERA**: LFV can be mediated by **LQ**s which couple to different generations



- At **HERA**: LFV can be mediated by **R-parity-violating** SUSY



Leptoquarks

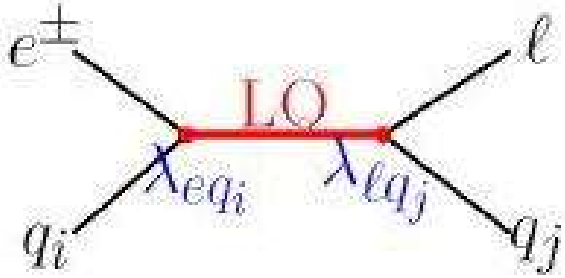
- **Extensions from SM:**
  couple to leptons and quarks, carry B, L ≠ 0

Phys. Lett. B 191 (1987) 442

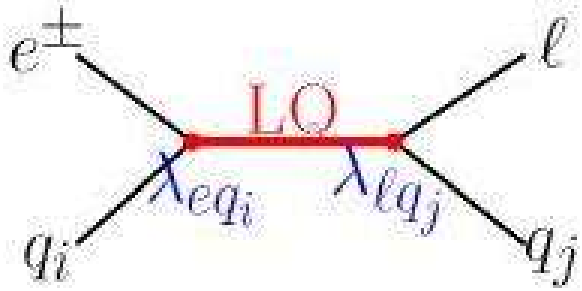
Buchmüller-Rückel-Wyler (BRW) Minimal Model:

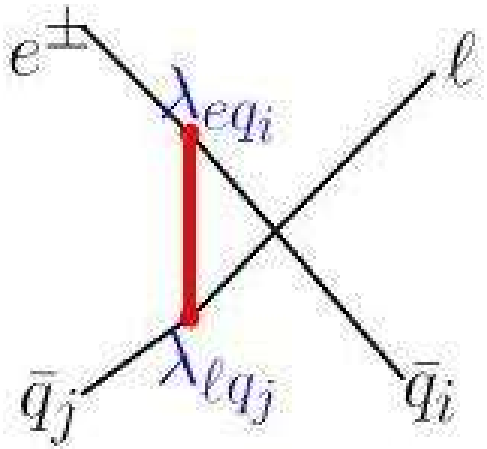
- Chiral coupling invariant under SM gauge transformation
- 7 scalar and 7 vector leptoquarks with fermion number:
- F = -(3B + L) = 0 or 2

Low mass $M_{LQ} < \sqrt{s}$



High mass $M_{LQ} >> \sqrt{s}$





Narrow Width Approximation

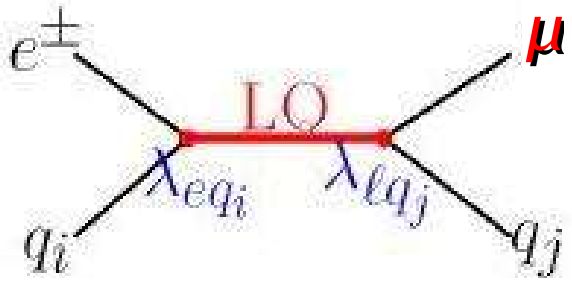
$$\sigma^{NWA} \propto \lambda^2_{eq_i} \beta_{lq_j}$$

BR(LQ→lq)

Contact Interaction Approximation

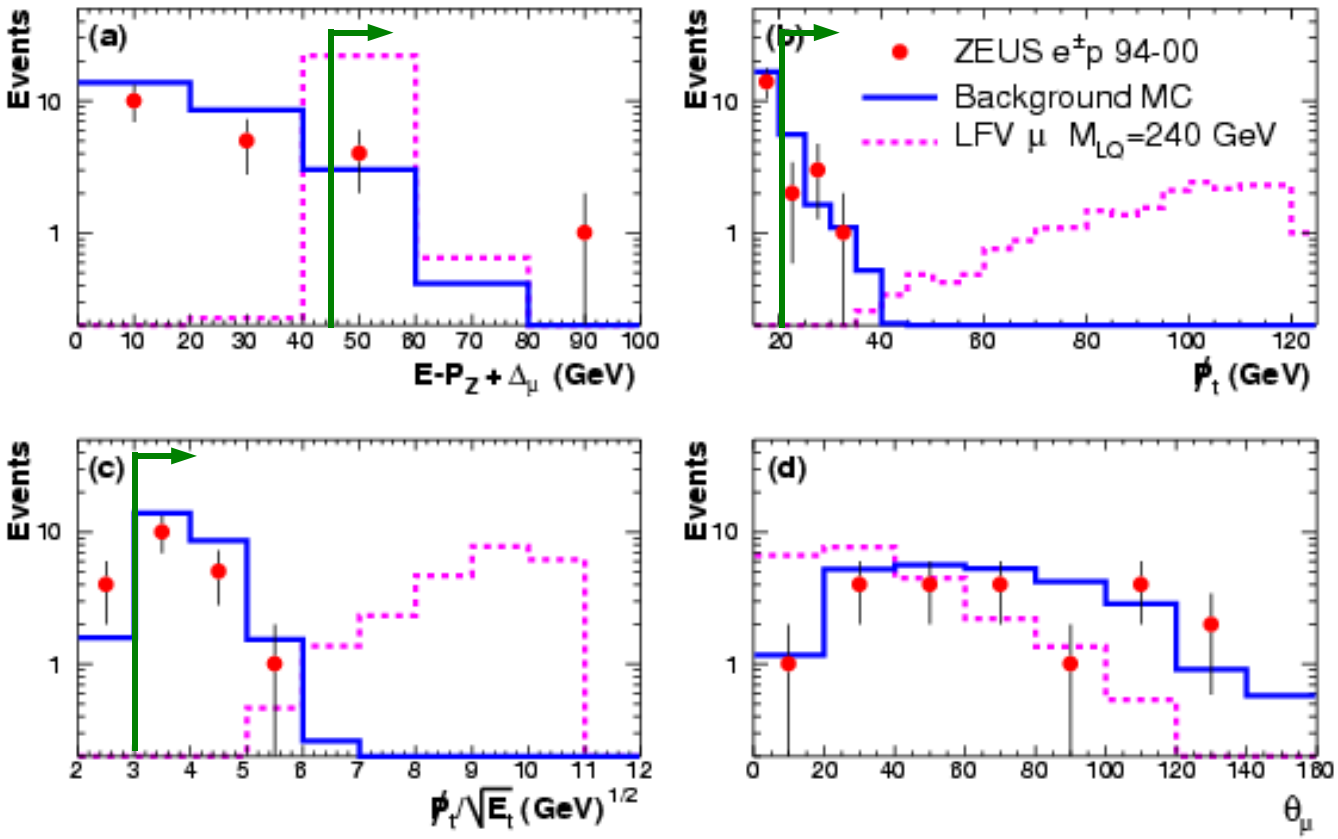
$$\sigma^{HMA} \propto \left(\frac{\lambda_{eq_i} \lambda_{eq_j}}{M^2_{LQ}} \right)^2$$

e → μ Transition (leptonic τ decays similar)



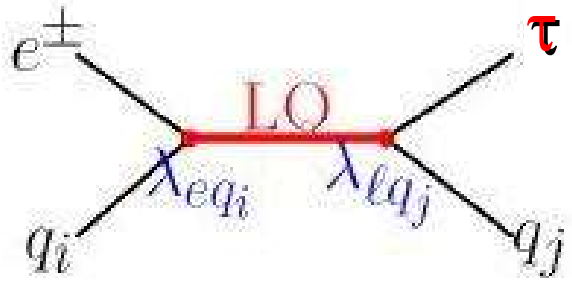
- P_T^{miss} > 15 GeV
- isolated μ, in direction of P_T^{miss}
- no electron

ZEUS hep-ex/0501070

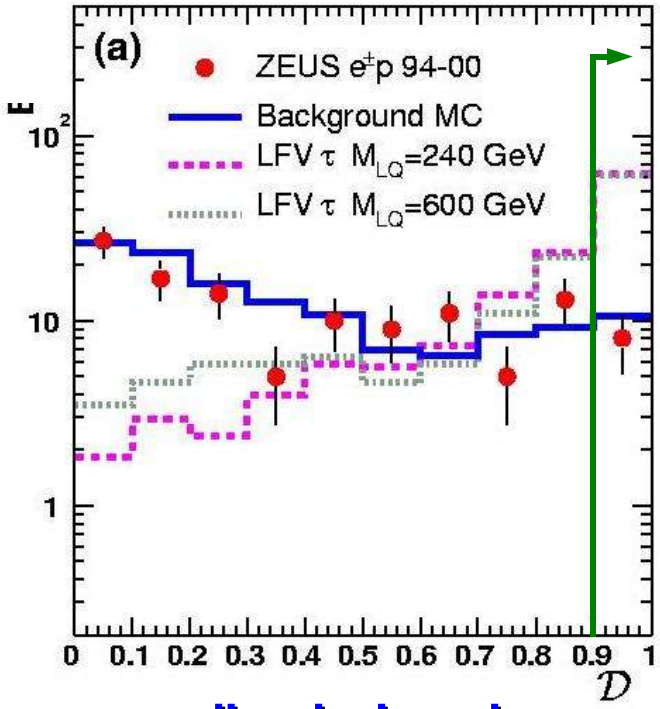


➡ 0 event, 0.87 ± 0.15 expected

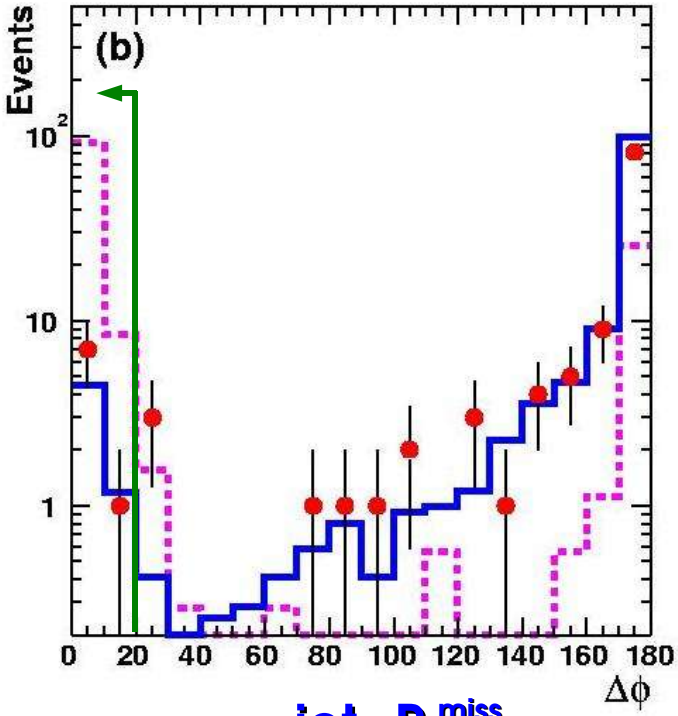
e → τ Transition (hadronic decays)



- E_T > 45 GeV
- 15 < E – P_z < 60 GeV
- Energy deposit in RCAL less than 7 GeV
- No electron with energy larger 10 GeV
- Discriminant of 6 jet shape variables:



discriminant



τ jet -P_T^{miss}

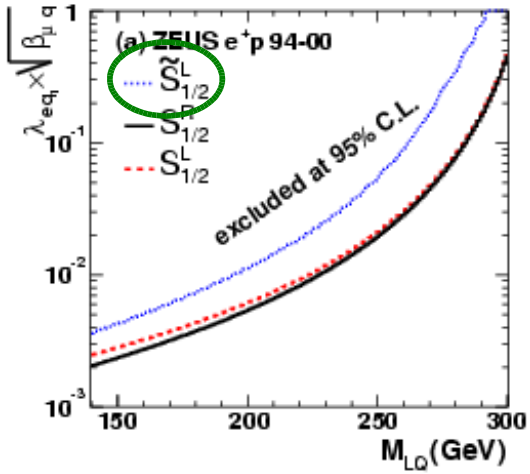
➡ 0 event, 1.1 ± 0.5 expected

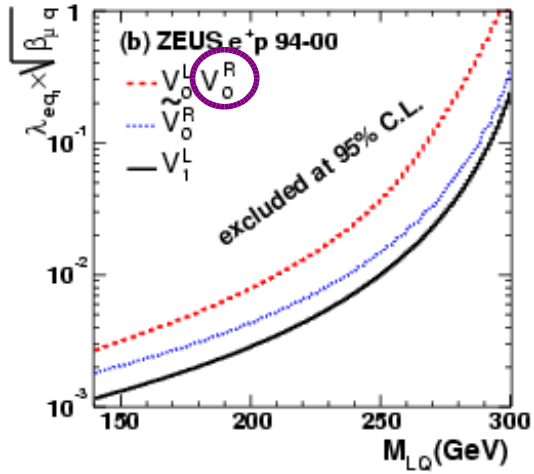
Limits for F=0 Low Mass LQs for μ Channel (130 pb^{-1})

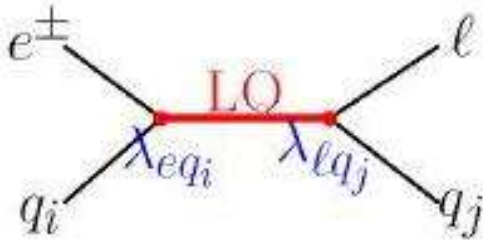
ZEUS

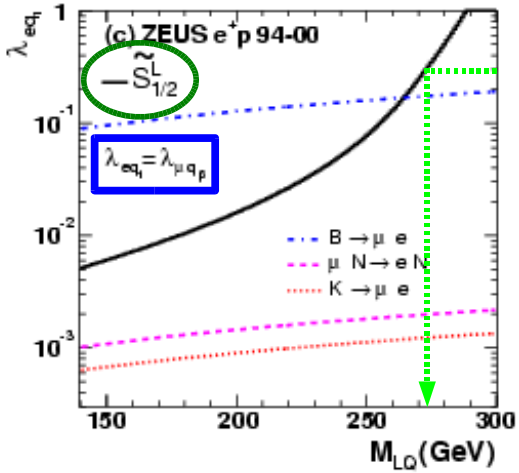
scalar

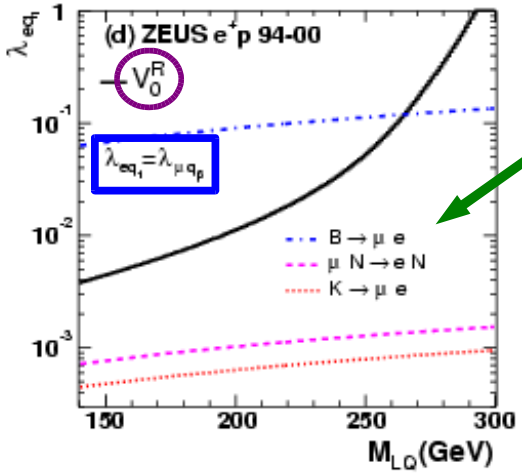
vector











Indirect constraints from low energy experiments

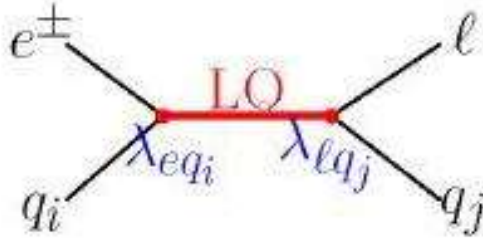
➡ for couplings of em strength: LQs of mass 257-299 GeV excluded

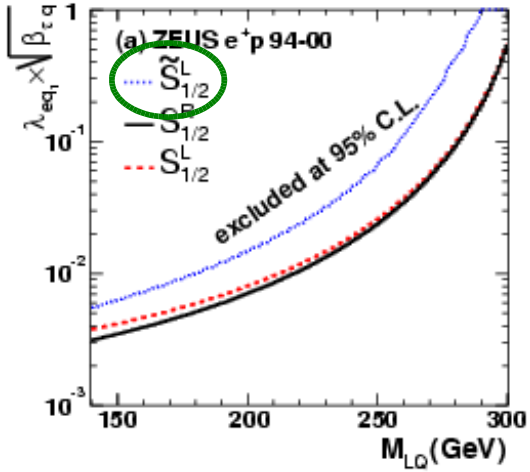
Limits for F=0 Low Mass LQs for τ Channel (130 pb^{-1})

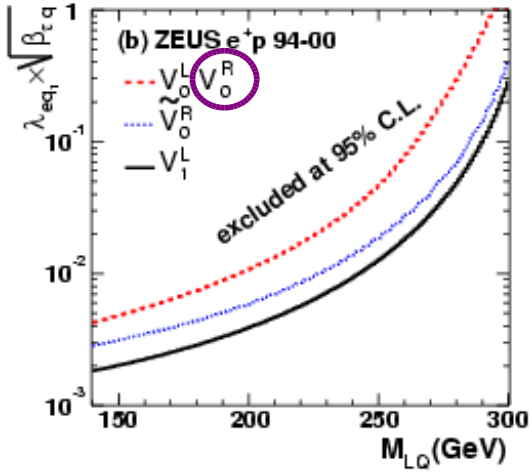
ZEUS

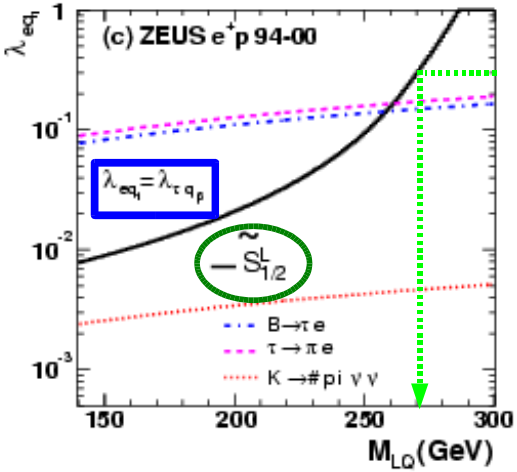
scalar

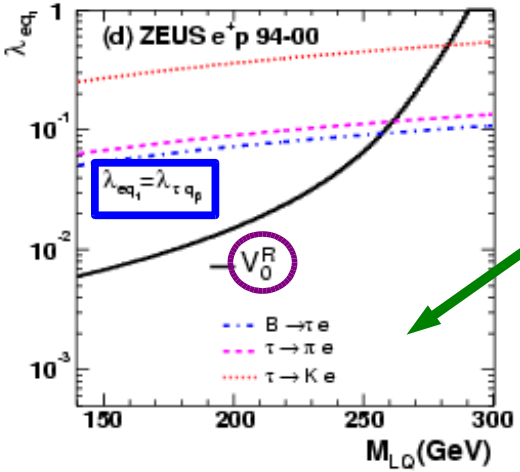
vector











Indirect constraints from low energy experiments

➡ more stringent than from rare B, K, τ decays for M_{LQ} = 250-280 GeV

R-Parity

discrete multiplicative symmetry in SUSY models:

$$R_P = (-1)^{3\mathrm{B}+L+2S}$$

B: baryon number

L: lepton number

S: spin

$R_P = 1$ for SM particles

$R_P = -1$ for SUSY particles

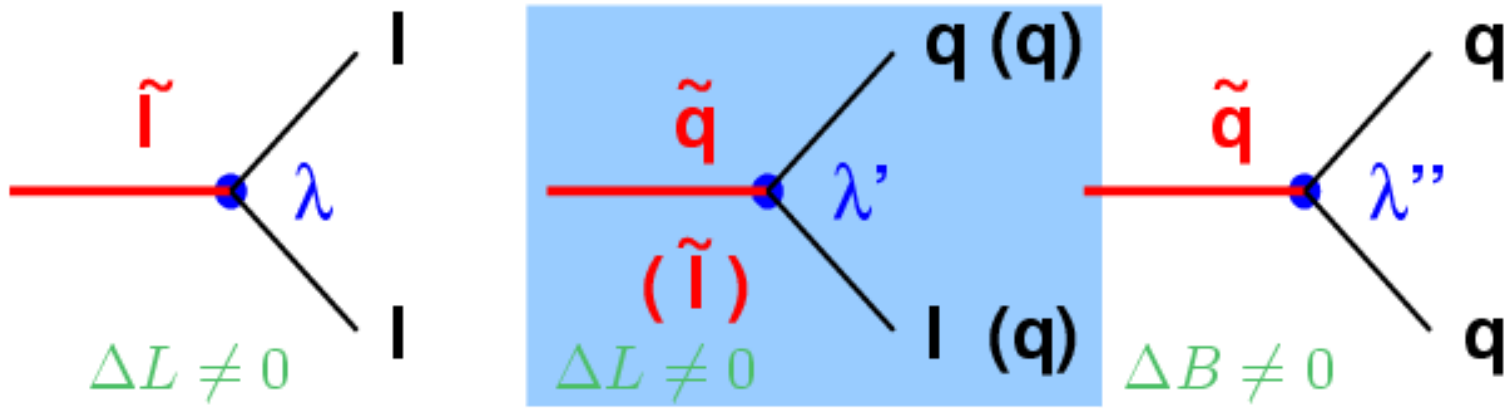
R-Parity conservation:

- SUSY particles produced in pairs
- LSP is stable
- experimental signature of SUSY: E_T^{miss}

R-Parity Violation at HERA

- R_P can explicitly be broken by trilinear couplings in superpotential

$$W_{\not R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

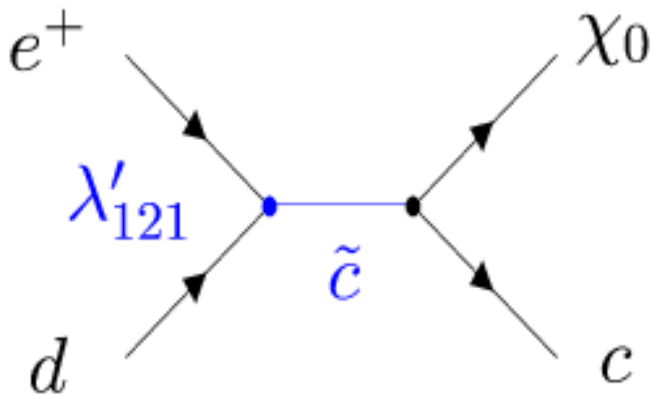


- single sparticle production
- unstable LSP
- final states with large multiplicity

$\Rightarrow$ assume that one $\not R_p$ coupling dominates

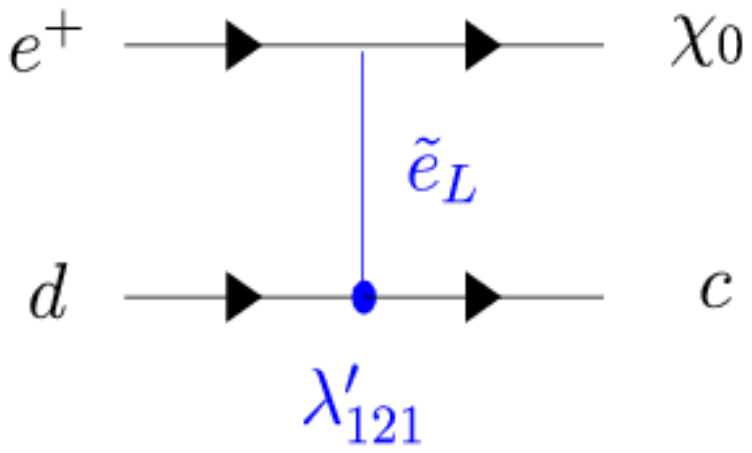
R_p-violating Neutralino Production at HERA

so far: s channel squark



example diagram

new: t channel selectron

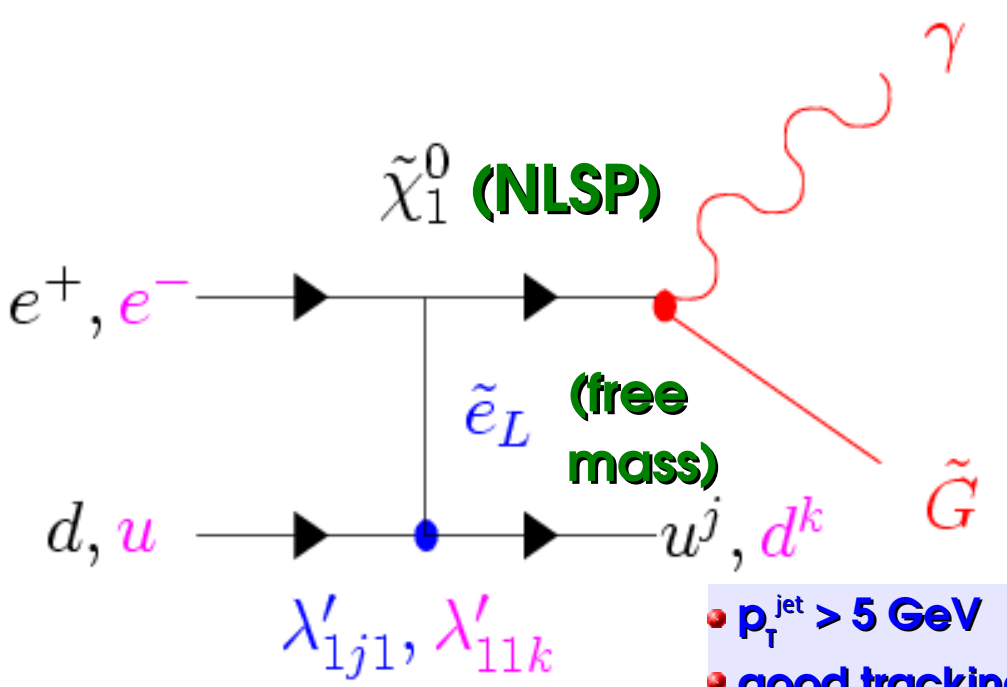


NEW:

$\Rightarrow$ independent of squark sector $\rightarrow$ not affected by Tevatron limits

$\Rightarrow$ set first limits on λ'_{121} for low selectron mass & large squark mass

Gravitino Production via t Channel Selectron Exchange



- $p_T^\gamma > 5$ GeV
- Isolated
- good tracking acceptance

- $p_T^{jet} > 5$ GeV
- good tracking acceptance

- $p_T^{miss} > 25$ GeV

$\Rightarrow$ study of $\not{R}_p$ SUSY independent of squark mass, dependent on $m_{\tilde{e}_L}, m_{\chi 0}$

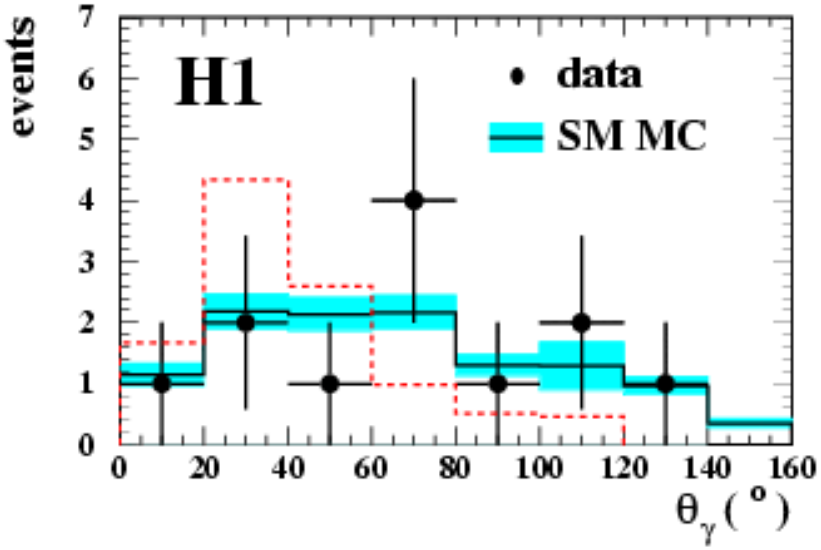
$\Rightarrow$ Gauge Mediated SUSY Breaking: slepton masses lower than squark masses

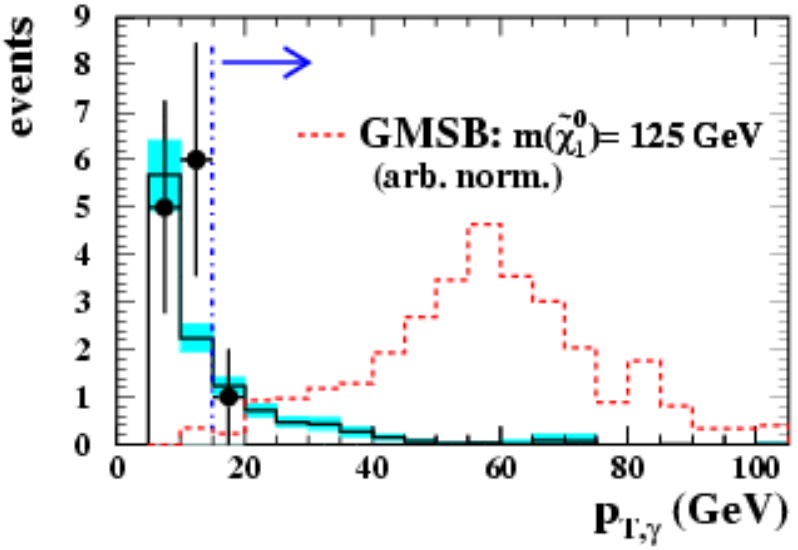
$\Rightarrow$ analyse gravitino ($= p_t^{\text{miss}}$) + photon decay of neutralino for the first time

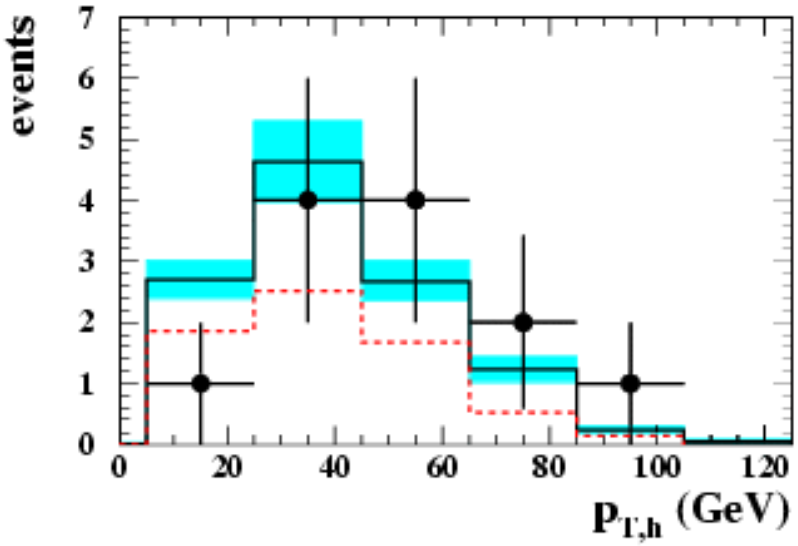
Distributions and Final Selection Cuts

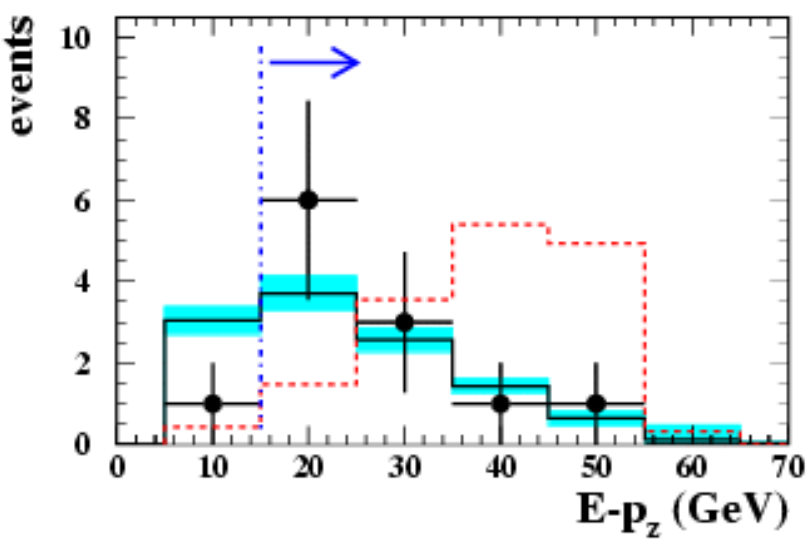
64.3 pb^{-1} of e^+p data, 13.5 pb^{-1} of e^-p data

hep-ex/0501030
accepted by PLB

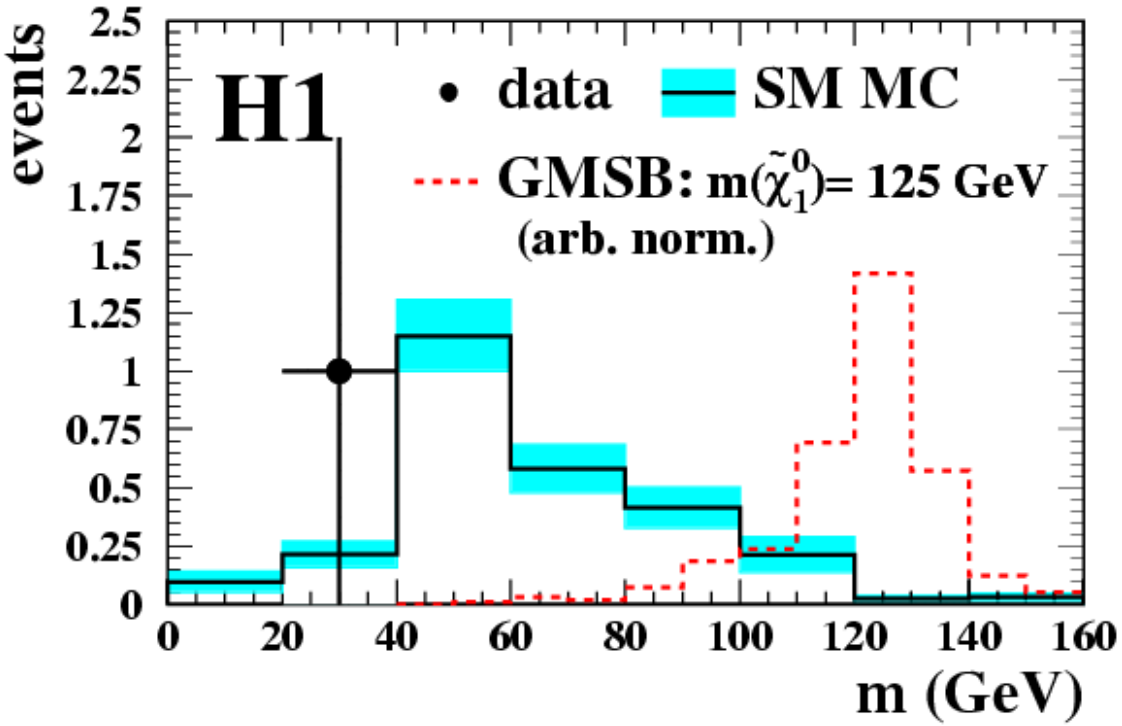


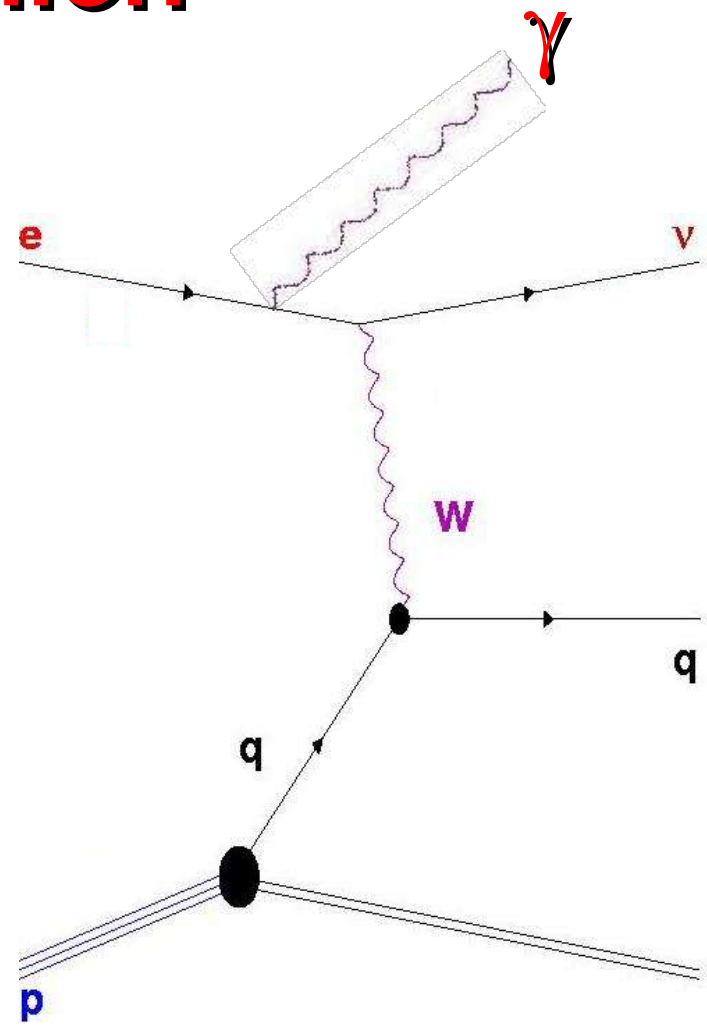






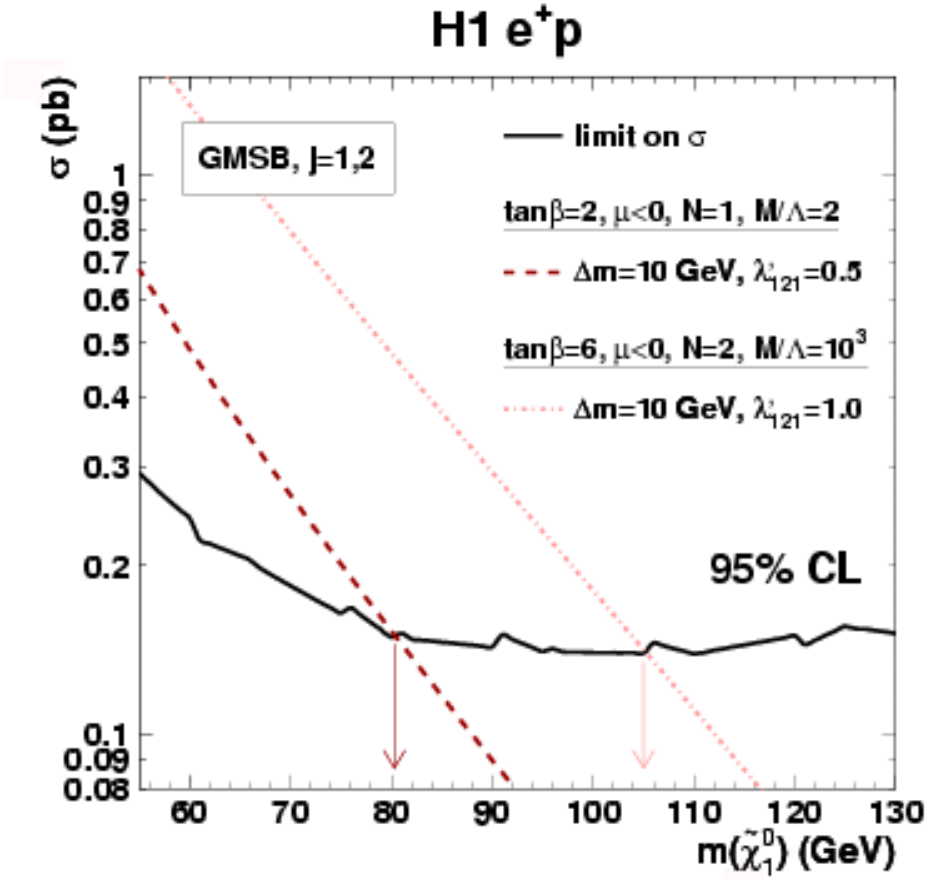
Final Selection

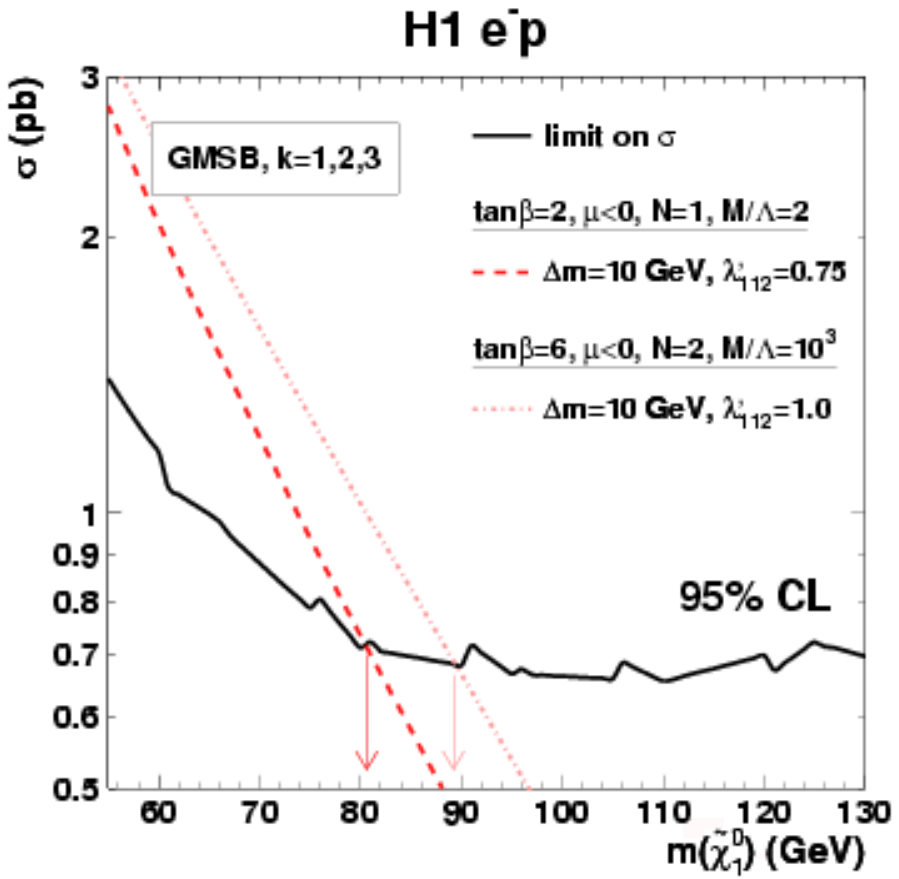




➡ 1 event, 2.9 ± 0.3 expected (radiative CC)

Limits on Cross Section





$\Rightarrow \lambda'_{121} < 0.5$ for $m(\tilde{\chi}_1^0) \approx 80$ GeV

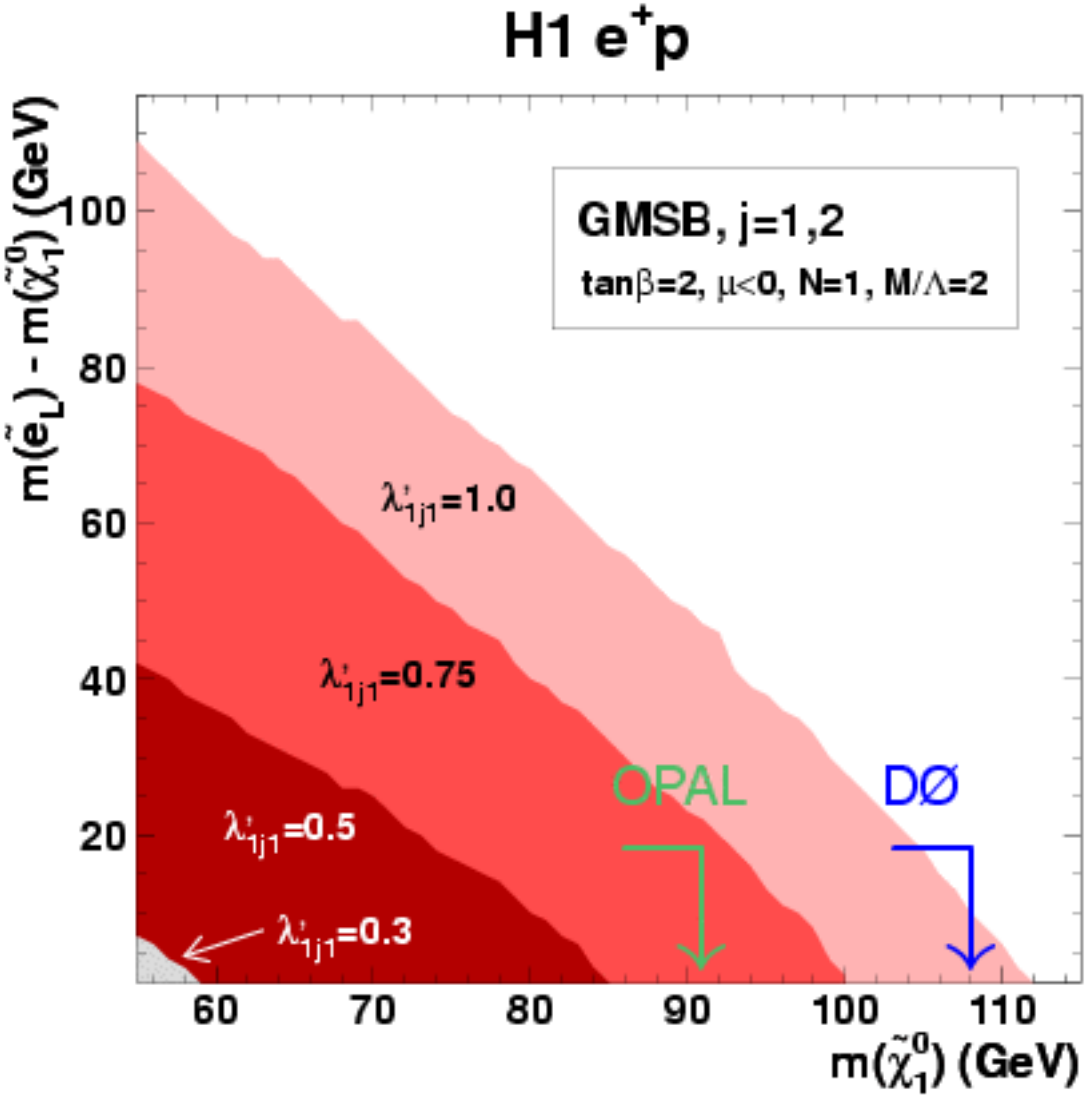
$(\tan\beta = 2, \mu < 0, N = 1, M/\Lambda = 2)$

$\Rightarrow \lambda'_{11k} < 0.75$ for $m(\tilde{\chi}_1^0) \approx 81$ GeV

$(\tan\beta = 2, \mu < 0, N = 1, M/\Lambda = 2)$

$\Rightarrow$ first limits independent of squark masses

Limits in R_p-violating GMSB (e^+p)

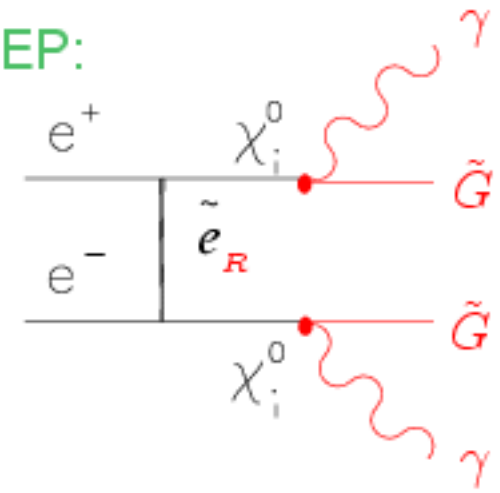


$\Rightarrow m(\tilde{\chi}_1^0) > 112$ GeV for $\lambda'_{1j1} = 1$

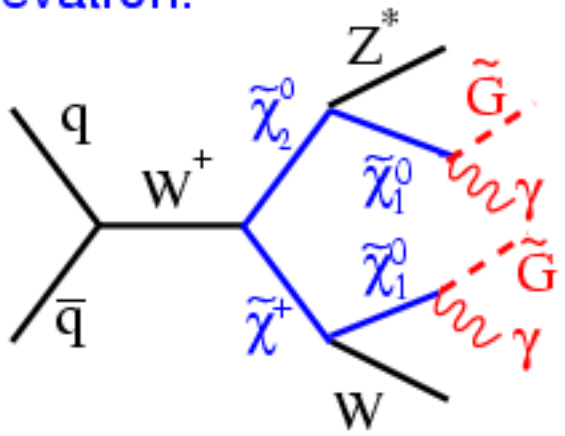
$\Rightarrow m(\tilde{e}) > 164$ GeV for $\lambda'_{1j1} = 1$

R_P conserving SUSY

LEP:



Tevatron:

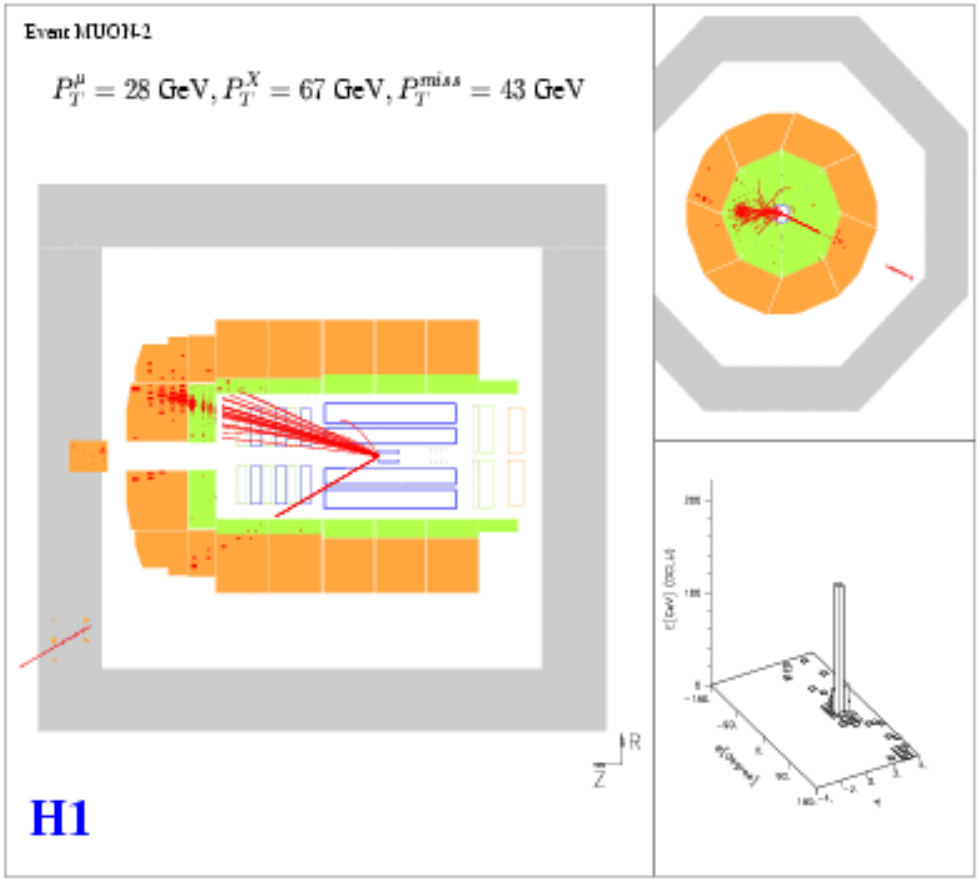


$\Rightarrow$ HERA is complementary and competitive for $\lambda' \approx 1$

High p_t Lepton Events at HERA

Phys. Lett. B 561 (2003) 241

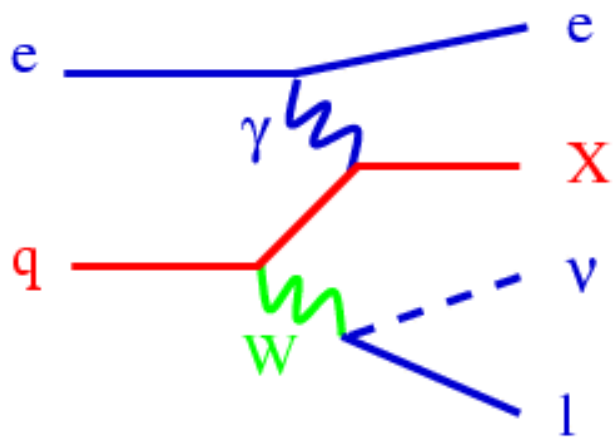
$$e^+p \rightarrow \mu^+X + PTmiss$$



- isolated lepton (e or μ)
- high hadronic p_T
- missing calorimeter p_T

Standard Model:

dominated by W production



in NLO-QCD: Diener, C.S., Spira

Eur. Phys. J C 25 (2002) 405

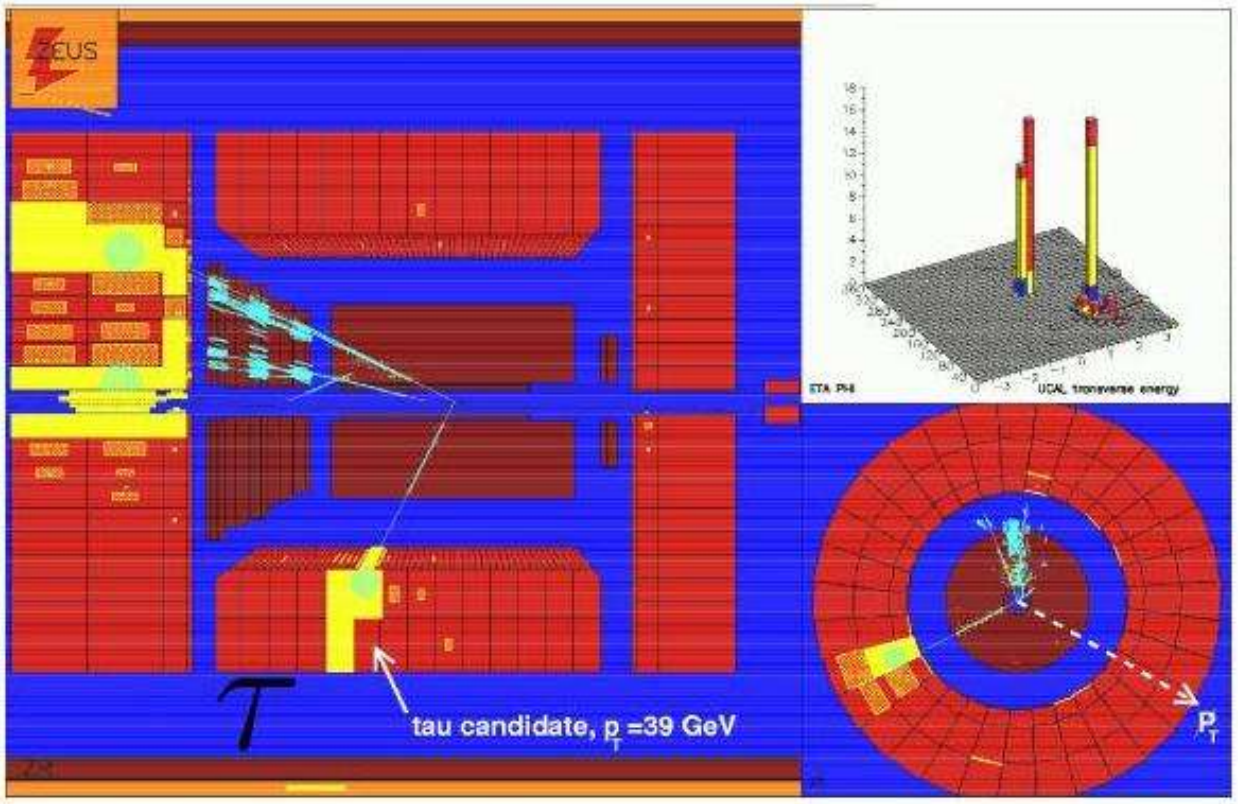
- Possible other explanations:

Anomalous top production, RPV SUSY: e.g. ep → $\tilde{t}$ → $\tilde{b}$W

High p_t Lepton Events at HERA

Phys. Lett. B 583 (2004) 41

Example of Tau Candidate



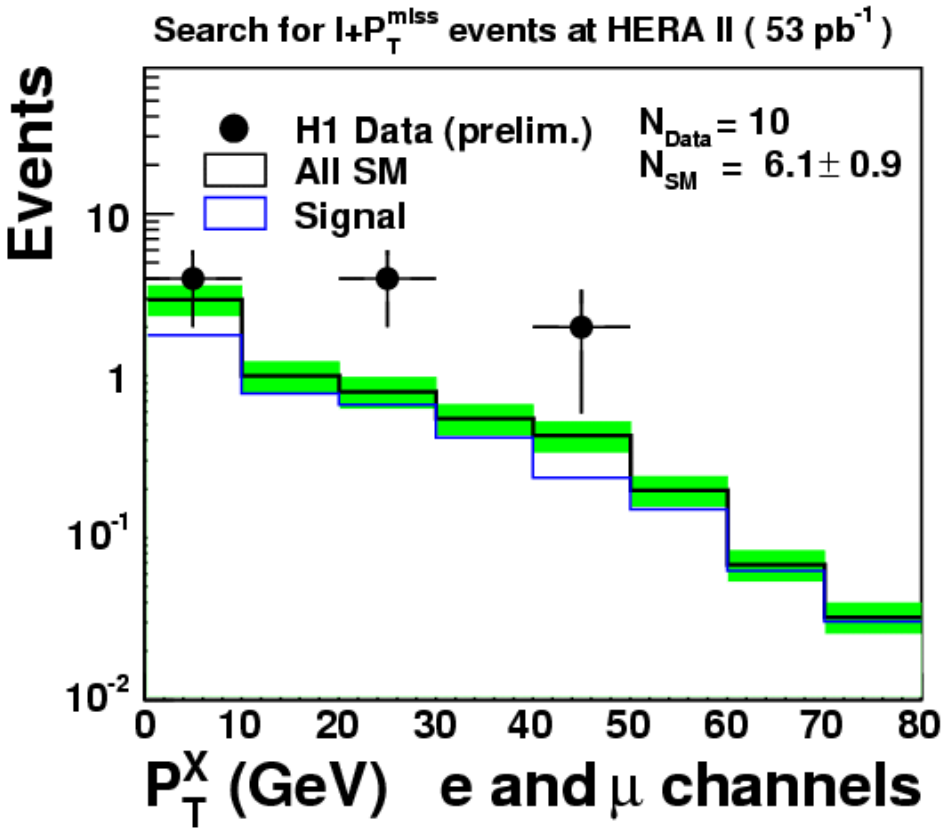
$P_T^{CAL} = 39\,GeV \quad P_T^{X} = 37\ GeV \quad M_T = 68\,GeV$

τ jet: collimated "pencil like"

Isolated Leptons at HERA II

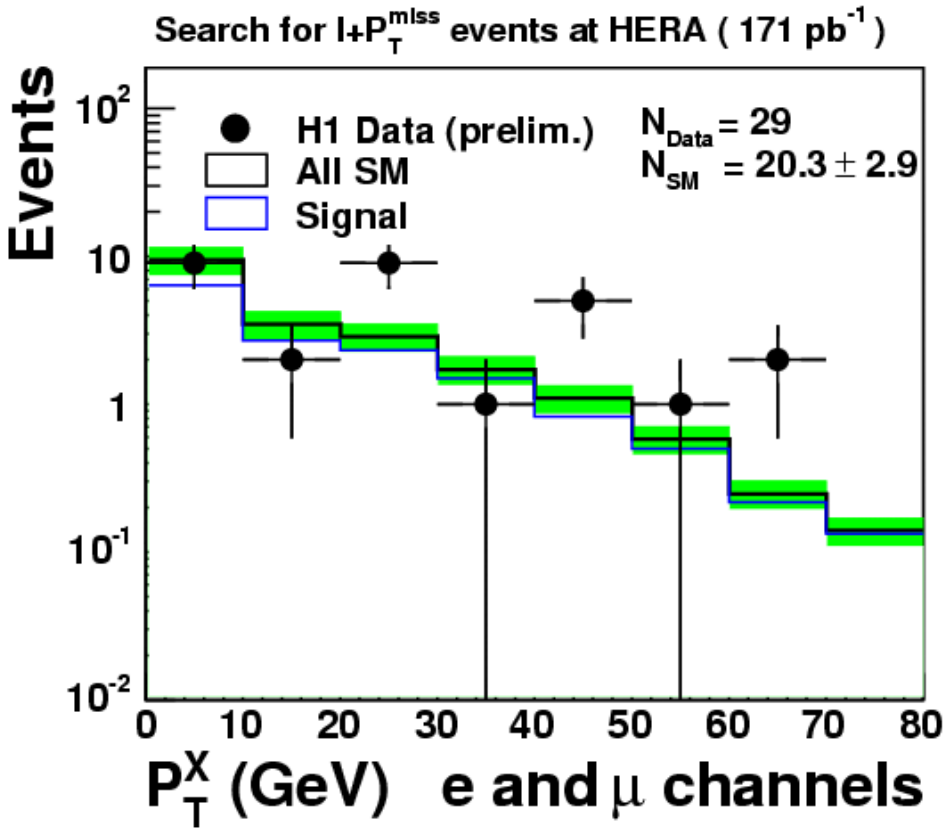
H1 Collaboration (updated since ICHEP)

HERA II: complete data sample



➡ slight excess at high p_T^X

HERA I+II combined



➡ clear excess at high p_T^X

Updated Isolated Lepton Results at HERA II

H1 1994-2004 $\mathcal{L}(e^{\pm}p) = 171\ \text{pb}^{-1}$	Electron obs./exp.	Muon obs./exp.	Tau$^{\text{prel.}}$ obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	20/16.1 $\pm$2.2	9/4.2 $\pm$0.7	5 / 5.81 $\pm$1.36	$\approx$ 75(15)%
$P_T^X > 25$ GeV	10/2.7 $\pm$0.5	6/2.6 $\pm$0.5	0 / 0.53 $\pm$0.10	$\approx$ 85(50)%

ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130\ \text{pb}^{-1}$	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	24 / 20.6 $\pm$3.2	12 / 11.9 $\pm$0.6	3 / 0.4 $\pm$0.12	$\approx$ 17(48)%
$P_T^X > 25$ GeV	2 / 2.9 $\pm$0.46	5 / 2.75 $\pm$0.21	2 / 0.2 $\pm$0.05	$\approx$ 50(50)%

➡ **combined electron+muon:**

full sample : 29/20.3 ± 2.9 (74%)

P_T^X>25 GeV : 16/5.3 ± 1.0 (85%)

= HERA II

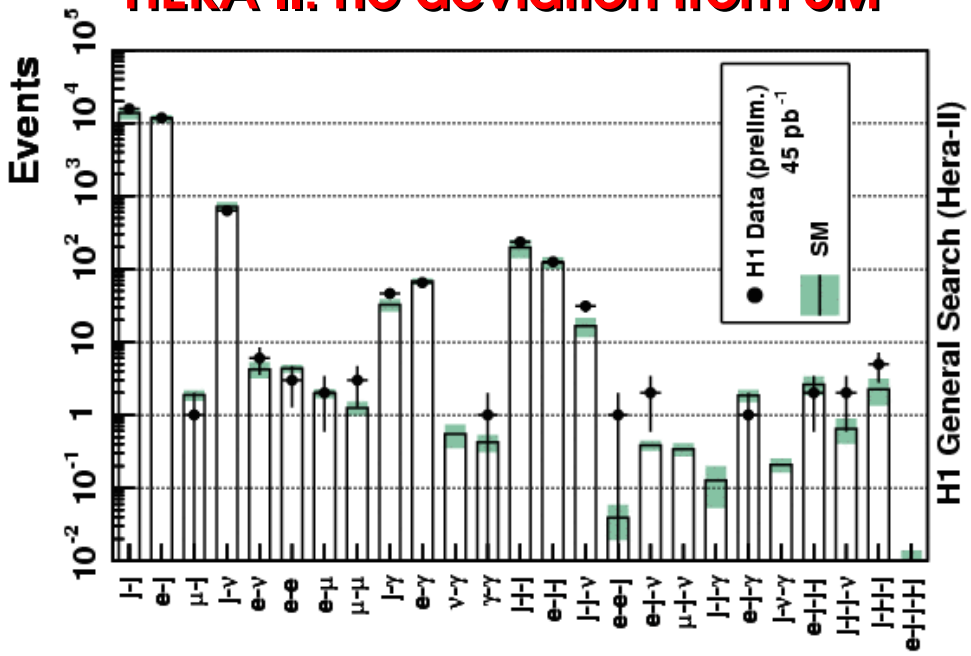
General Search

Phys. Lett. B 602 (2004) 14

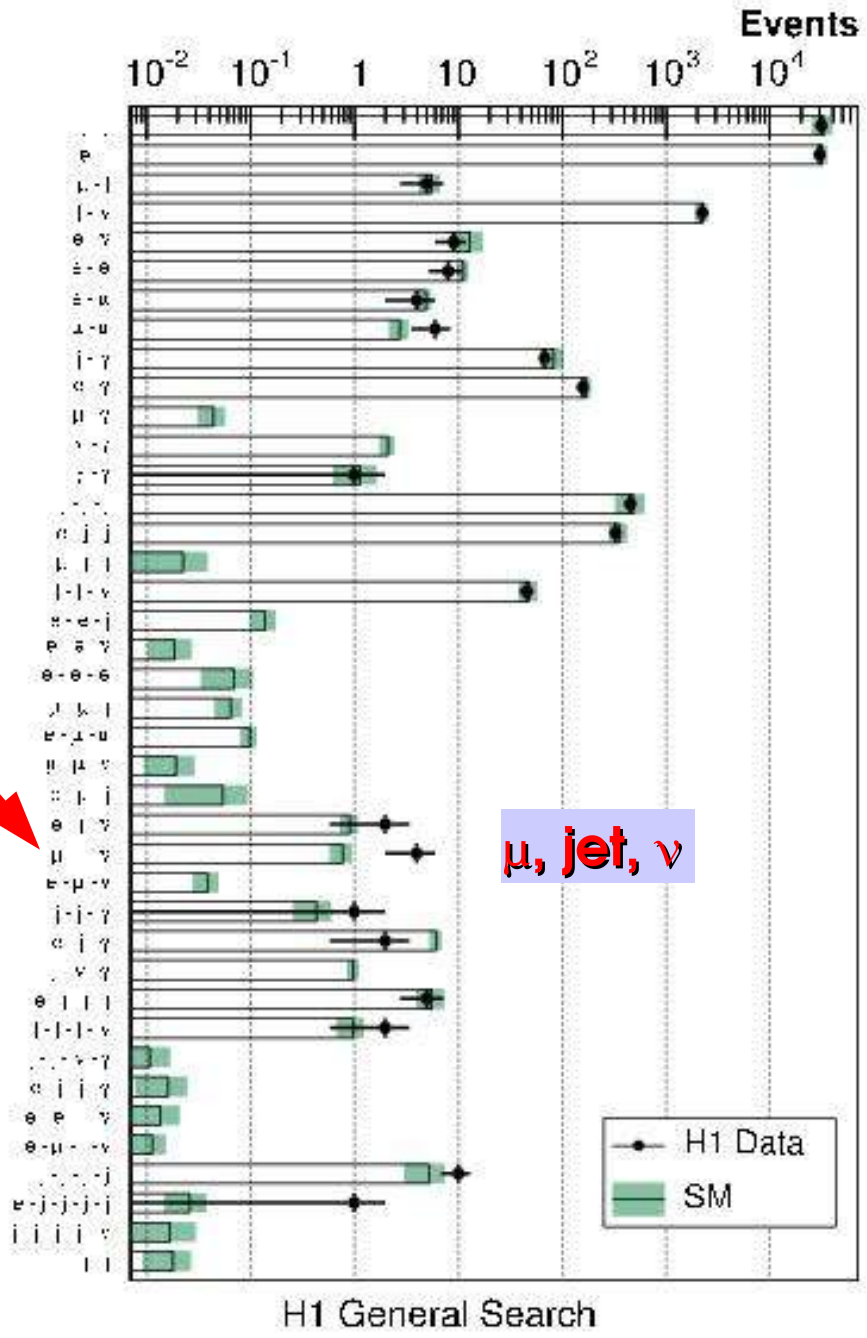
Objects: e, μ, γ, ν, jet

- **Common phase space:**
  - P_T (object) > 20 GeV
  - 10° < Θ(object) < 140°
  - Isolation: $R_{\eta\phi}$ (object) > 1.0
- **Consider topologies with 2 or more objects**
- **Search for deviation from SM**

HERA II: no deviation from SM



?



Magnetic Monopoles

hep-ex/0501039

- Dirac: Existence of Magnetic Monopoles
  leads naturally to an explanation of charge quantisation
- Also predicted from theories which unify the fundamental forces
- Formation of a monopole condensate provides a possible mechanism for quark confinement

Quantisation of angular momentum of a system with electric charge e and a monopole with magnetic charge g leads to charge quantisation condition (Dirac):

$$e\,g = n\,\hbar\,c\,/\,2$$

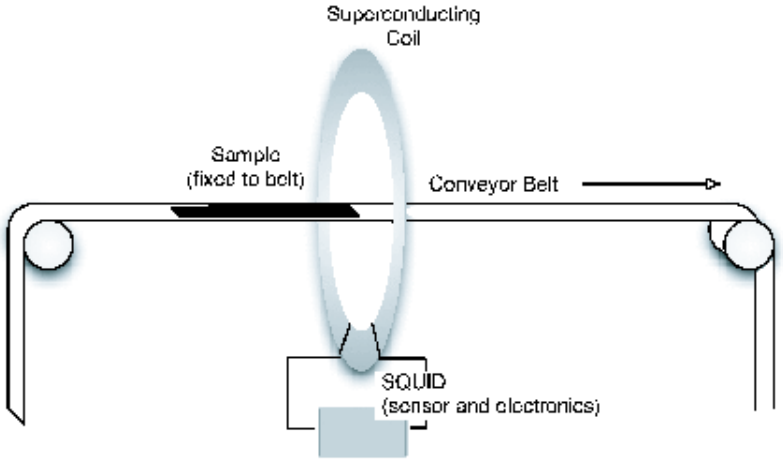
- n = 1 ➞ minimum magnetic charge g_D
- down quark: e = -1/3 ➞ fundamental magnetic charge $3g_D$
- Dirac: n is even if particle has electric and magnetic charge
  ➞ fundamental magnetic charge > $3g_D$

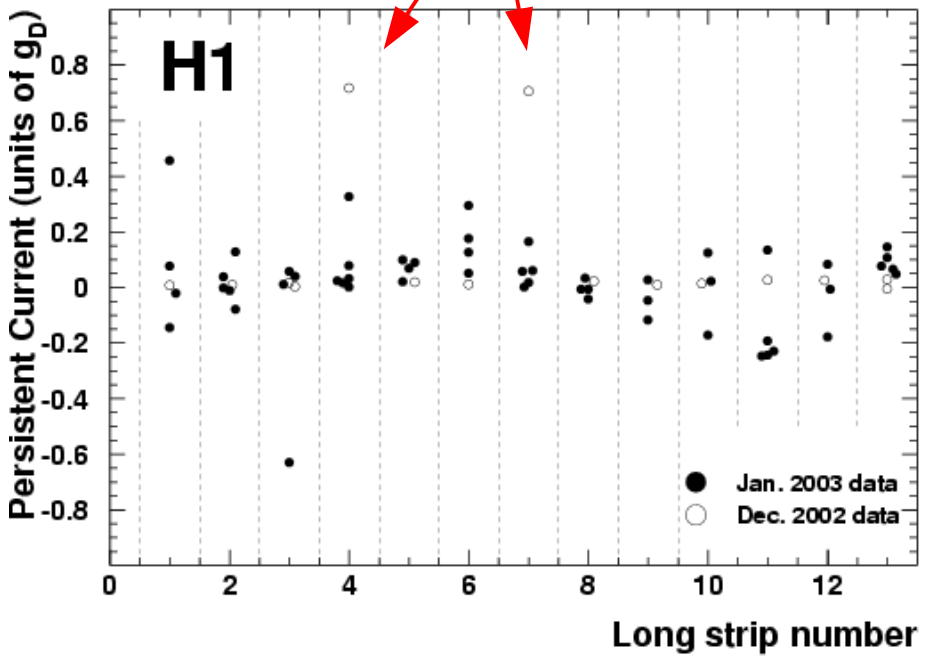
Magnetic Monopoles

- Heavily ionising magnetic monopoles produced in e^+p collisons may stop in Al beam pipe around interaction point
- Binding energy in Al is expected to be large
  ➡ permanently trapped if stable
- Data from 1995-1997: 62 pb^{-1}, $\sqrt{s}$ = 300 GeV

Fluctuations not reproducible

- beam pipe cut in long thin strips and analysed in **Superconducting Quantum Mechanical Interference Device (SQUID)**





➡ sensitive down to 0.1g_D

➡ no monopoles were found

Summary

- HERA performs a wide range of searches for physics beyond the SM
- No evidence for new physics found yet
- Limits on Lepton Flavor Violation and Leptoquarks
- Limits on Superlight Gravitino Production
- Limits on Magnetic Monopoles
- Still very interesting excesses in $ej\nu$ + $\mu j\nu$ by H1, in $\tau j\nu$ by ZEUS
  and also in recent data $ej\nu$ by H1

➡ more luminosity needed to solve "Isolated Lepton Puzzle"

Outlook

- HERA provides now e^-p collisions (only $\cong$20 pb^{-1} from 1998/99)

➡ interesting potential for more "New Physics from HERA"

Backup

Isolated Lepton Results at HERA I

H1 1994-2000 $\mathcal{L}(e^{\pm}p) = 118\,\text{pb}^{-1}$	Electron obs./exp.	Muon obs./exp.	Tau$^{\text{prel.}}$ obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	11 / 11.5 $\pm$1.5	8 / 2.94 $\pm$0.50	5 / 5.81 $\pm$1.36	$\approx$75(15)%
$P_T^X > 25$ GeV	5 / 1.76 $\pm$0.30	6 / 1.68 $\pm$0.30	0 / 0.53 $\pm$0.10	$\approx$85(50)%
$P_T^X > 40$ GeV	3 / 0.66 $\pm$0.13	3 / 0.64 $\pm$0.14	0 / 0.22 $\pm$0.05	$\approx$90(55)%
ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130\,\text{pb}^{-1}$	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	24 / 20.6 $\pm$3.2	12 / 11.9 $\pm$0.6	3 / 0.4 $\pm$0.12	$\approx$17(48)%
$P_T^X > 25$ GeV	2 / 2.9 $\pm$0.46	5 / 2.75 $\pm$0.21	2 / 0.2 $\pm$0.05	$\approx$50(50)%
$P_T^X > 40$ GeV	0 / 0.94 $\pm$0.11	0 / 0.95 $\pm$0.12	1 / 0.07 $\pm$0.02	$\approx$60(70)%

W contribution is NLO: Diener, Schwanenberger, Spira
Eur. Phys. J C 25 (2002) 405

➡ observed excesses in H1 + Zeus do not match channels