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

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on behalf of the

Collaborations

New Physics Searches at HERA

Searches for new Resonances or Contact interactions:

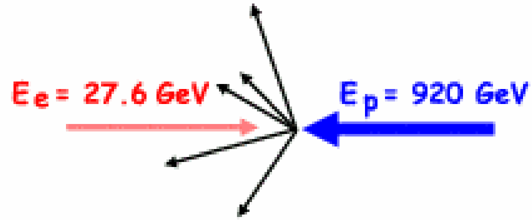
- Lepton Flavor Violation
- Leptoquarks
- Contact Interctions
- Extra Dimensions
- Quark Radius
- Excited Fermions
- SUSY in MSSM
- R-Parity-violating SUSY Searches

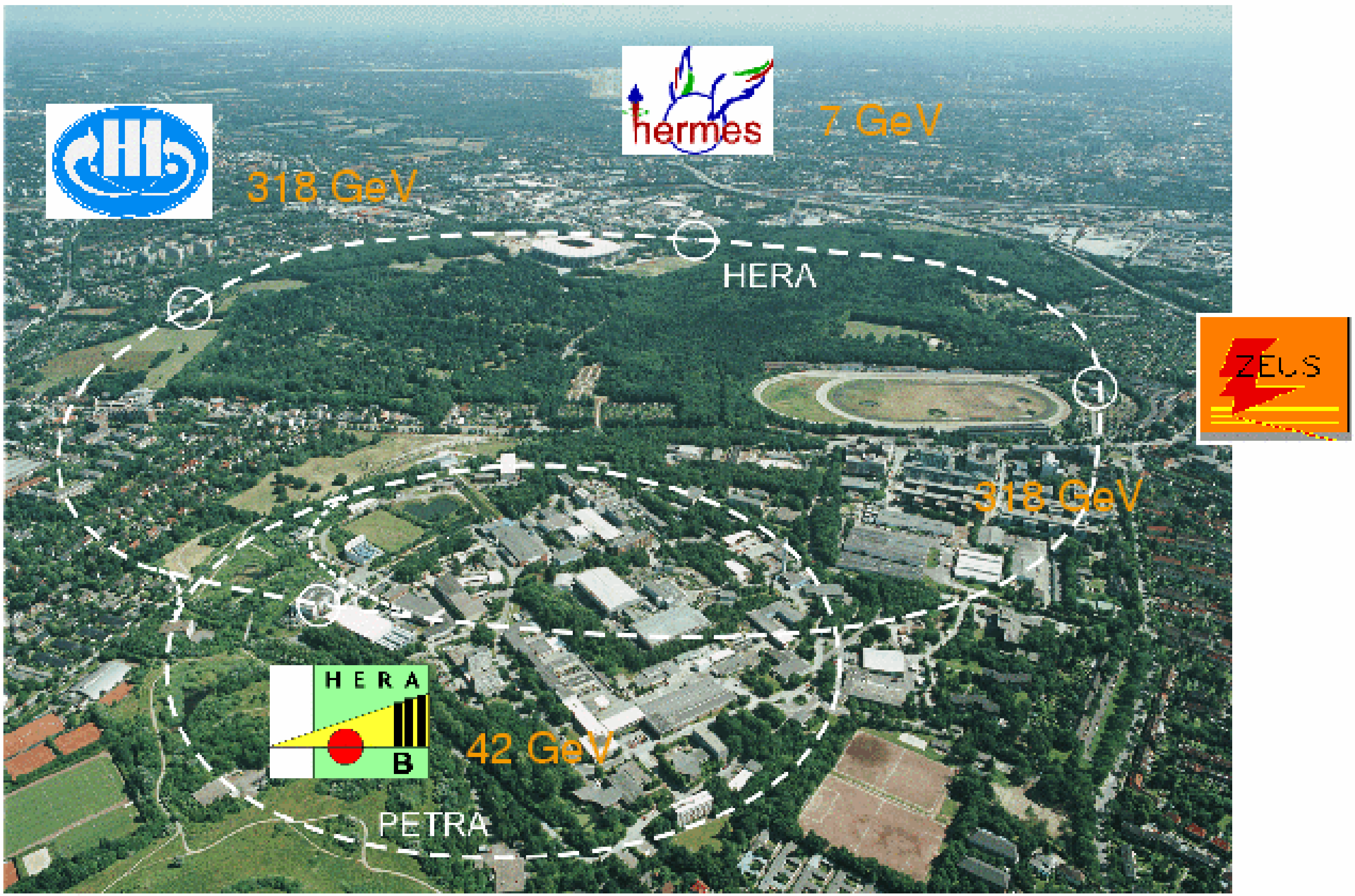
Exclusive Final States:

- 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



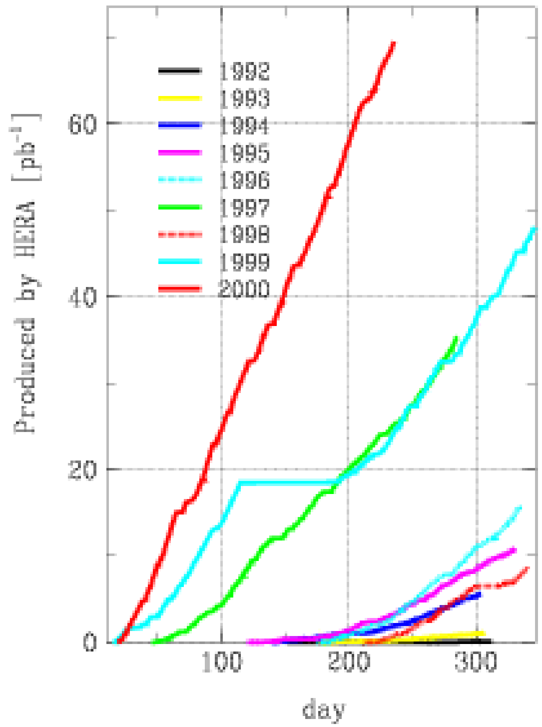


HERA Delivered Luminosities

HERA I

analysed here: H1 118 pb^{-1}

ZEUS 130 pb^{-1}



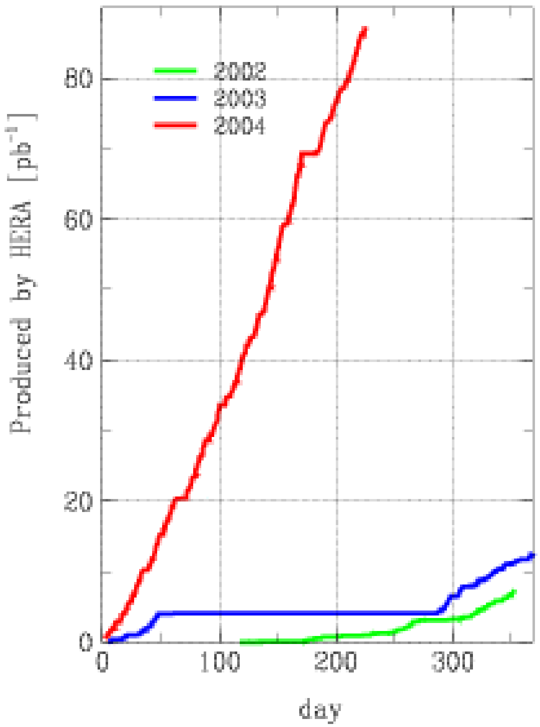
$\sqrt{s} = 320$ GeV:
e^+p (65 pb^{-1})
e^-p (17 pb^{-1})

$\sqrt{s} = 300$ GeV:
e^+p (48 pb^{-1})

steady progress year by year

HERA II

analysed here: H1 53 pb^{-1}



$\sqrt{s} = 320$ GeV:
$e^+_L p$
$e^+_R p$

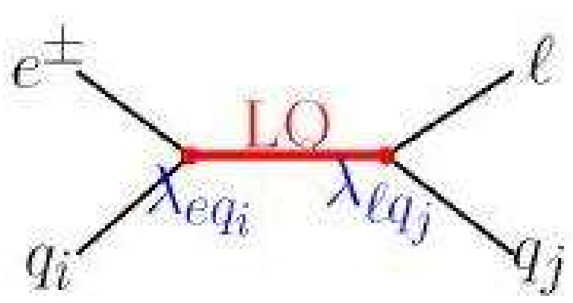
very good year 2004!

longitudinally polarisied positron beam

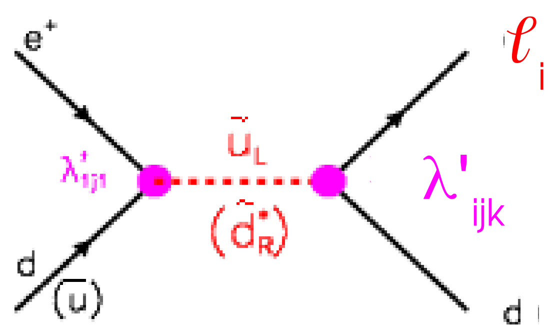
Lepton Flavor Violation

- Neutrino oscillation: lepton flavor **not conserved**
- Many **extensions from SM**:
  GUT, SUSY, compositeness, technicolor predict e→μ, e→τ
- Charged leptons: very stringent limits from **rare decays**, especially for e→μ

- 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



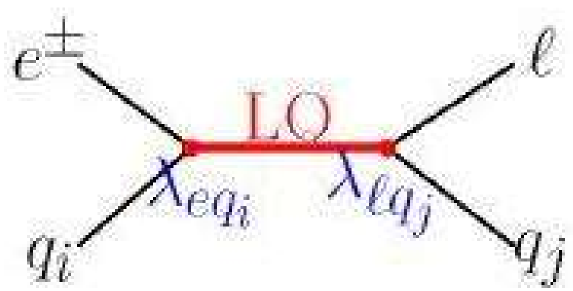
Leptoquarks

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

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
- decays: e.g. $BR(LQ \to lq) = \beta(lq) = 1, 1/2, 0$

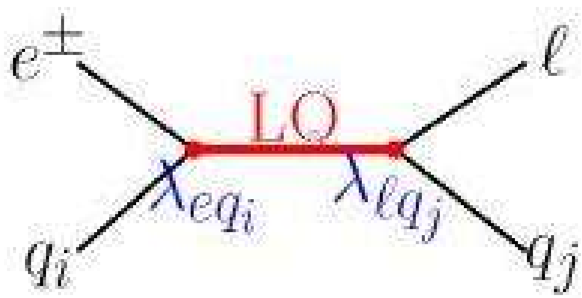
Low mass $M_{LQ} < \sqrt{s}$

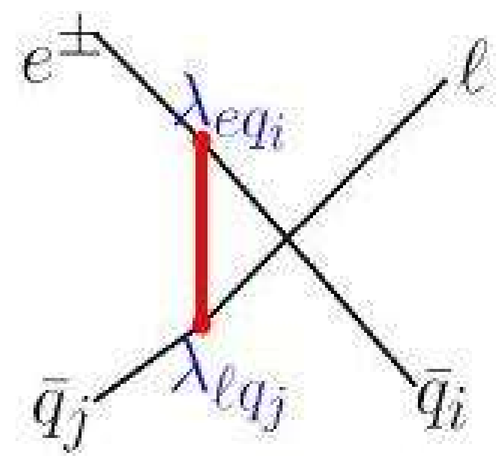


Narrow Width Approximation

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

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

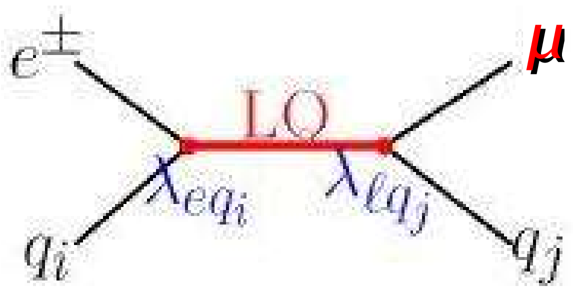




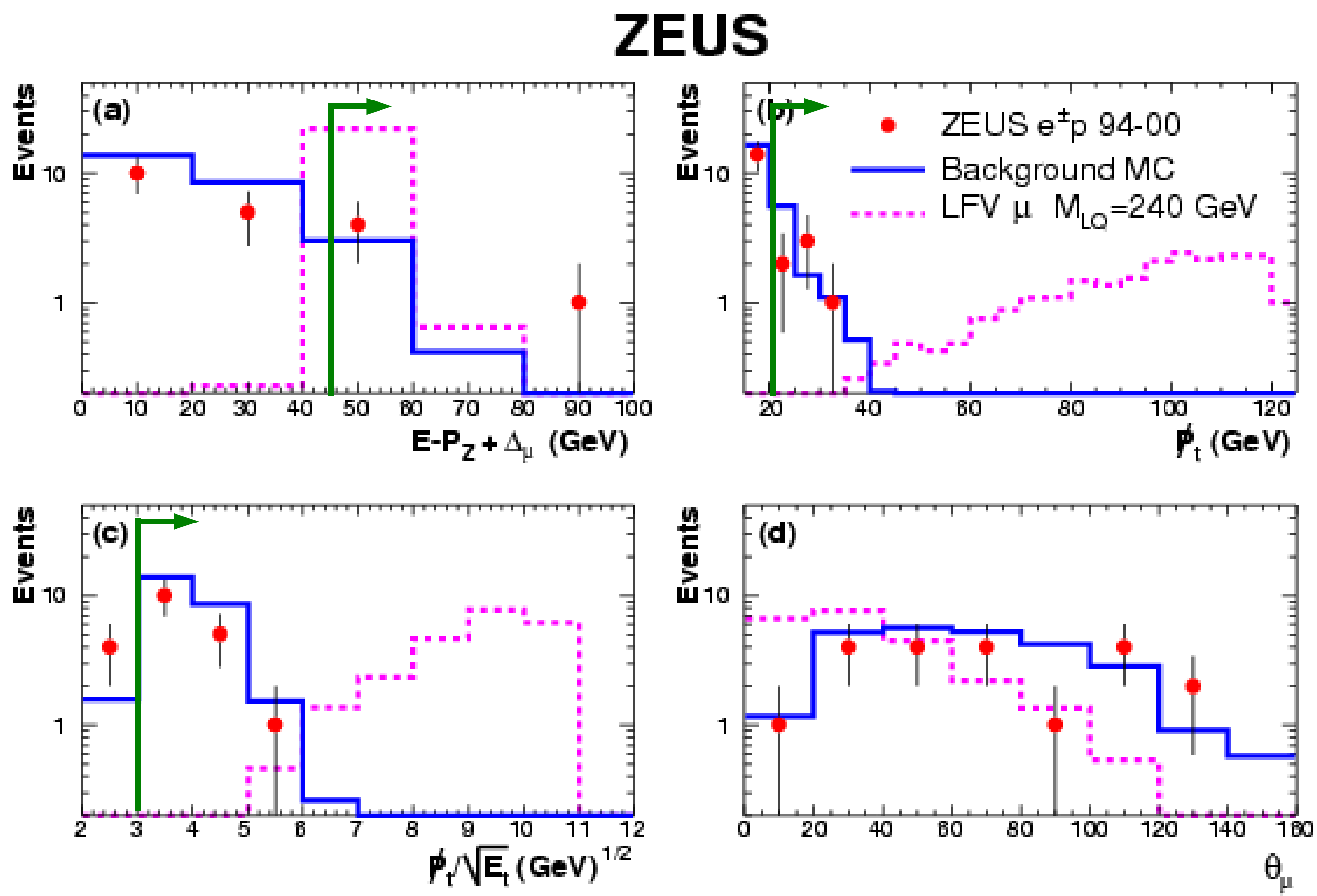
Contact Interaction Approximation

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

$e \rightarrow \mu$ Transition (leptonic τ decays similar)

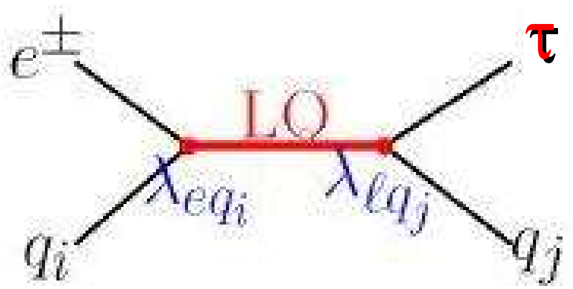


- $P_T^{miss} > 15$ GeV
- Isolated, in direction of P_T^{miss}
- No electron

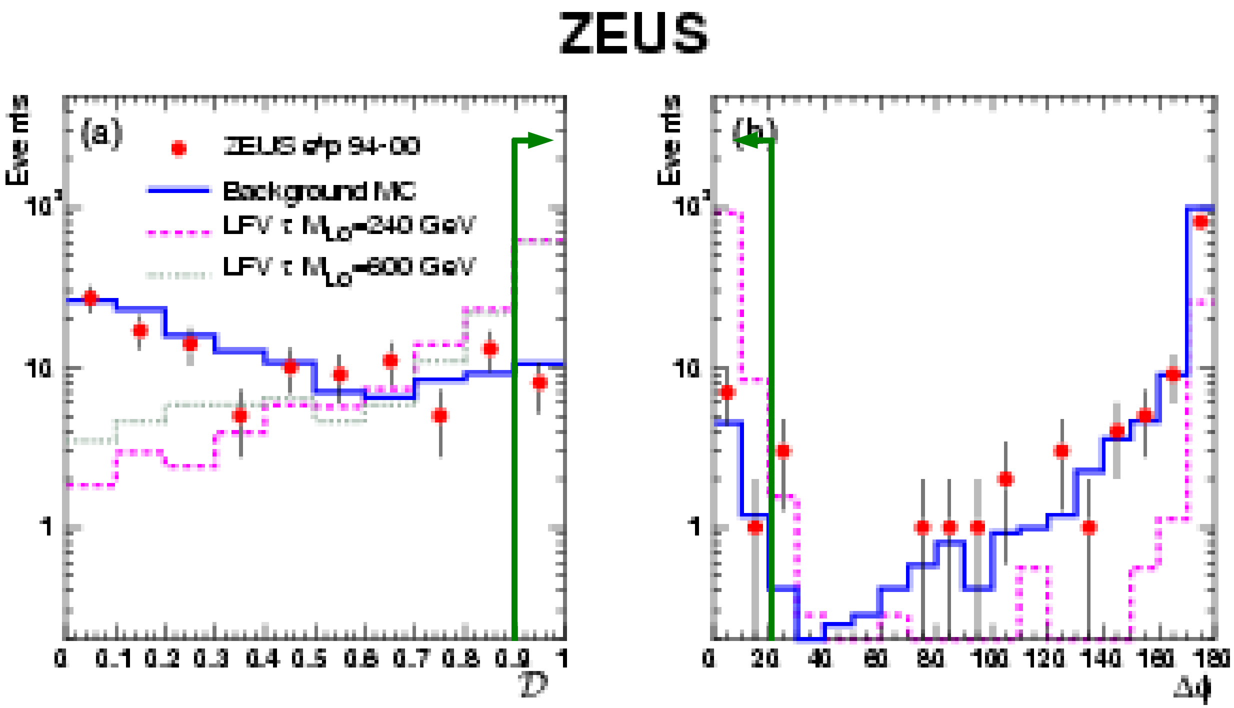


➡ 0 event, 0.87 ± 0.15 expected

$e \rightarrow \tau$ Transition (hadronic decays)

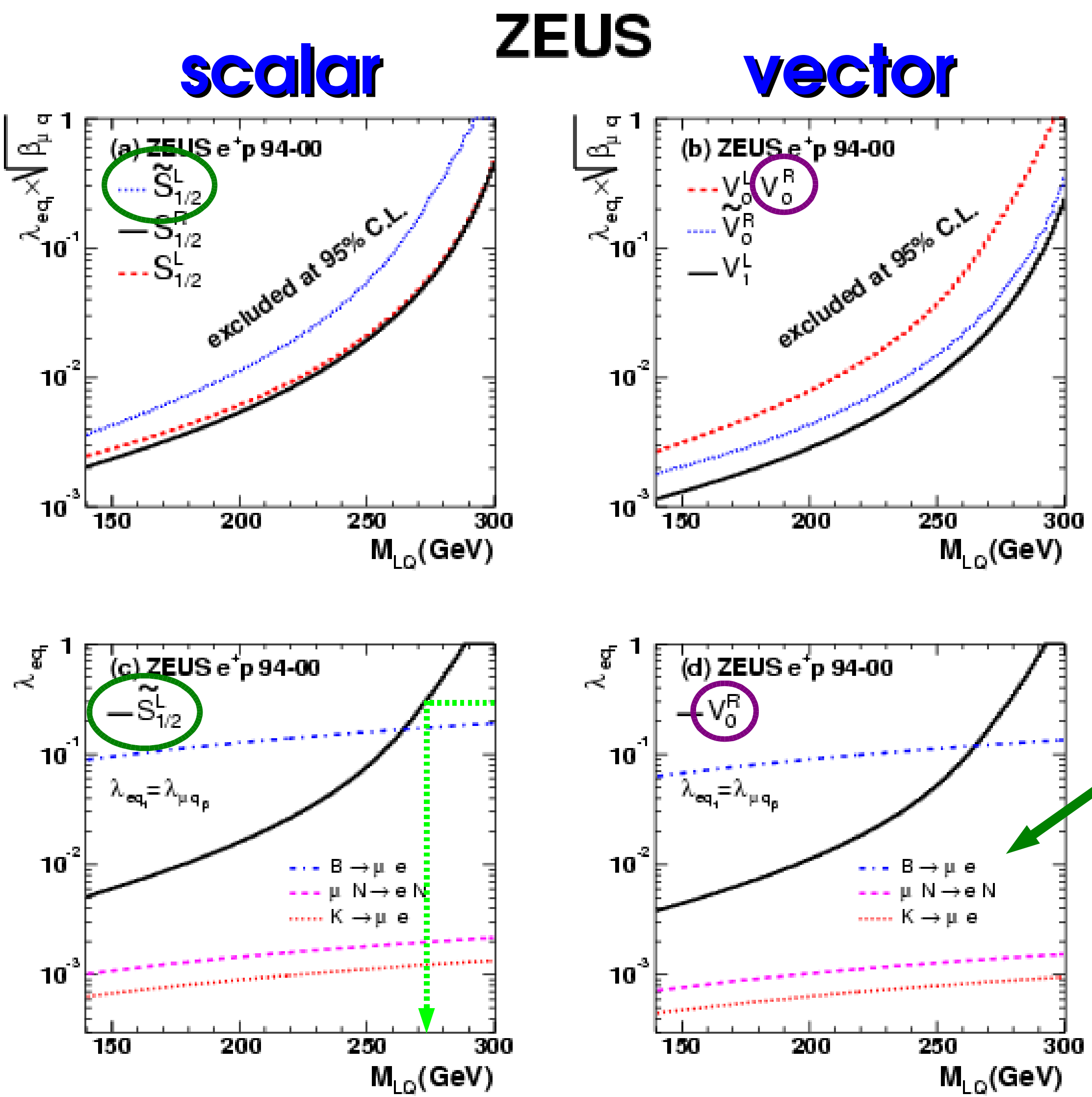


- $E_T > 45$ GeV
- $15 < E - P_z < 60$ GeV
- Energy deposit in RCAL less than 7 GeV
- No electron with energy larger 10 GeV
- Discriminant of 6 jet shape variables:



➡ 0 event, 1.1 ± 0.5 expected

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



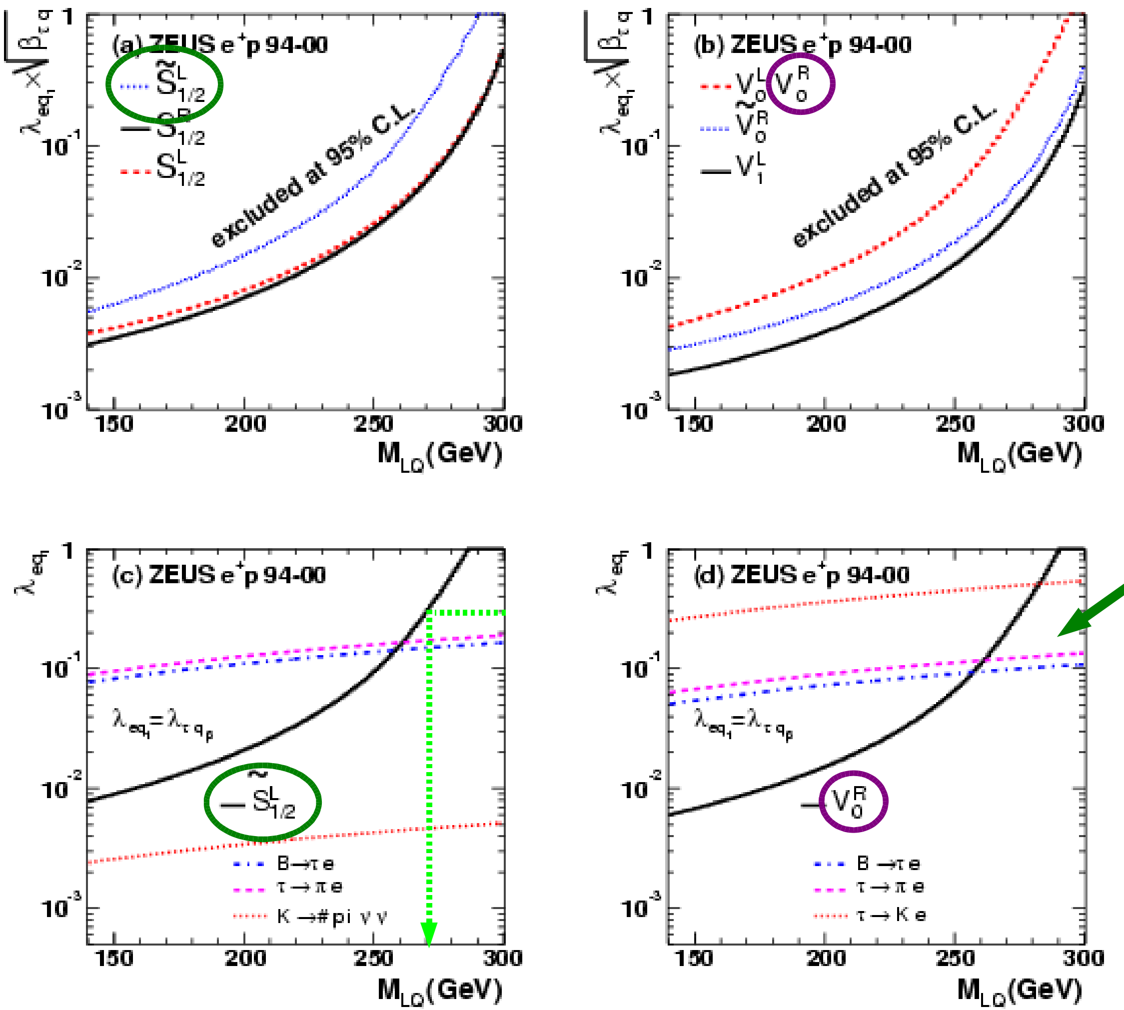
Indirect constraints from low energy experiments

➡ 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 mode ls:

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

B: baryon number

L: lepton number

B: spin

$R_P = 1$ for SM particles

$R_P = -1$ for SUSY particles

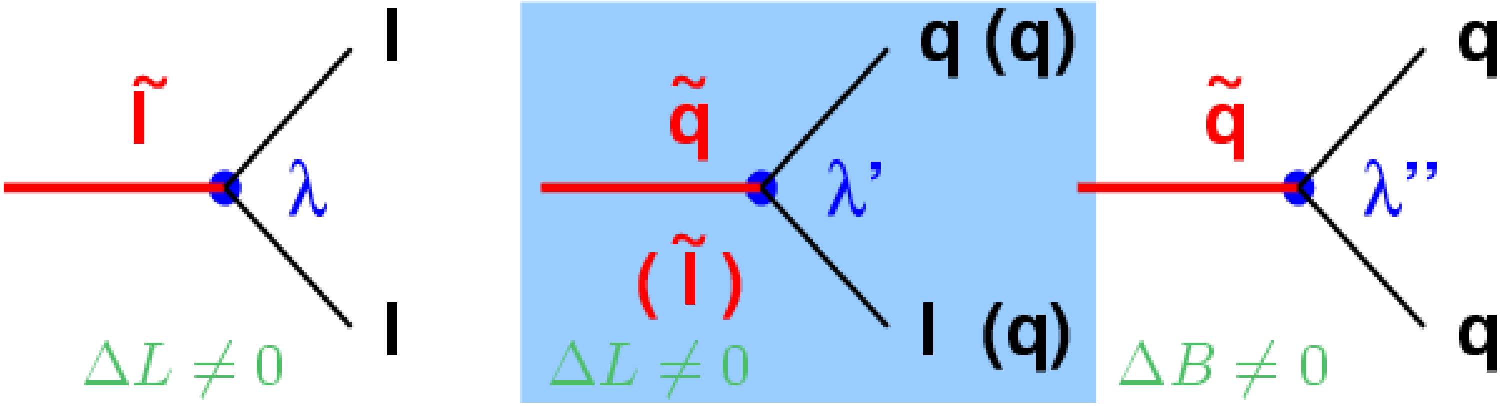
R-Parity conservation:

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

R-Parity Violation at HERA

- R_P can explicitly be broken by trilinear couplings in superpotential

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

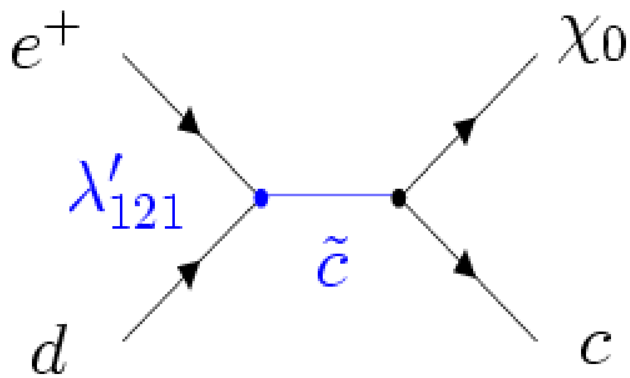


- single sparticle production
- unstable LSP
- final states with large multiplicity

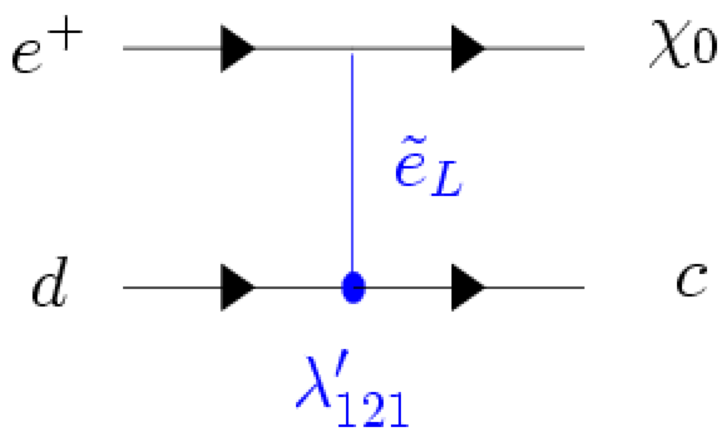
$\Rightarrow$ assume that one $\not R_p$ coupling dominates

R_p-violating Neutralino Production at HERA

so far: s channel squark



new: t channel selectron

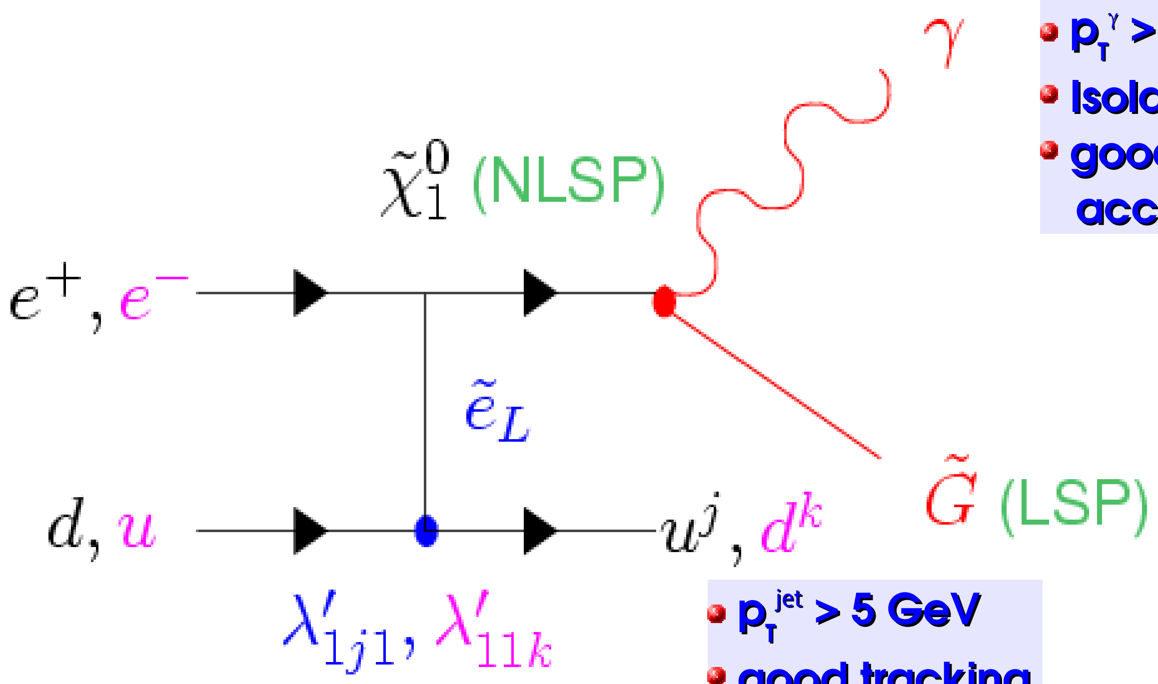


NEW:

$\Rightarrow$ analyse SUSY independent of TeVatron mass bounds on squarks

$\Rightarrow$ 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

- $p_T^{miss} > 25$ GeV

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

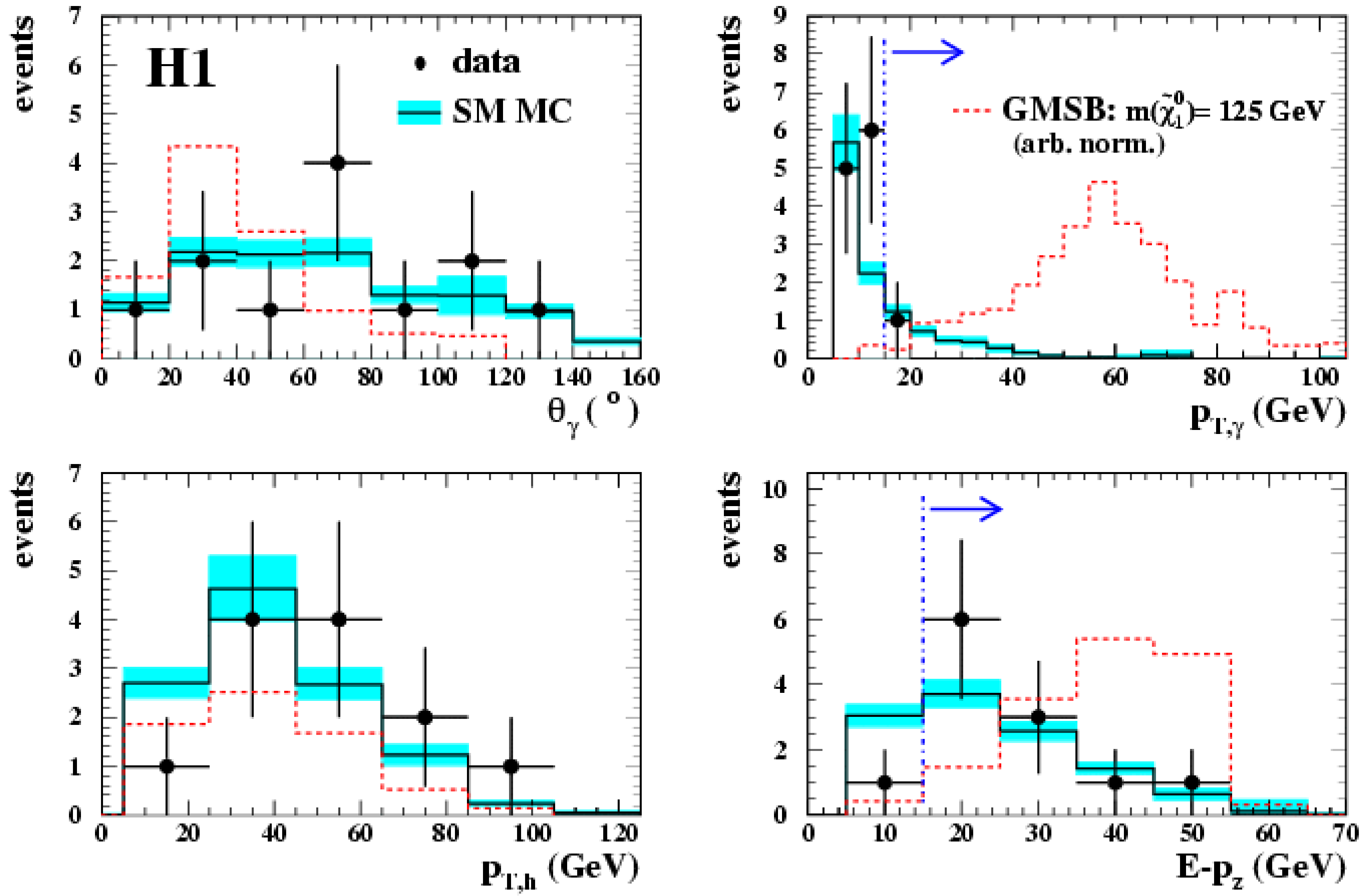
⇒ study of $R\!\!\!/_p$ SUSY independent of squark mass, dependent on $m_{\tilde{e}_L}, m_{\chi^0}$

⇒ Gauge Mediated SUSY Breaking: slepton masses lower than squark masses

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

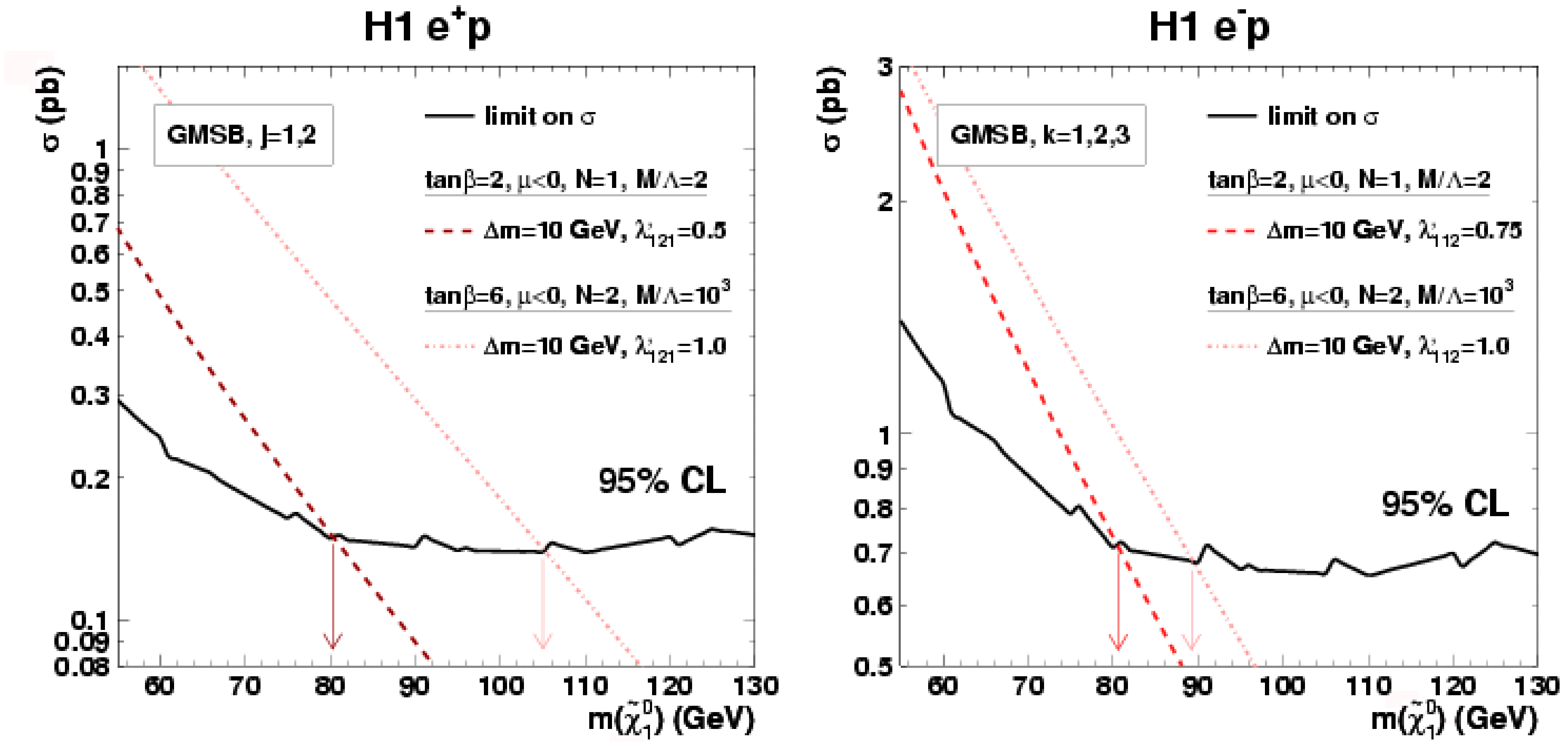
Distributions and Final Selection Cuts

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



➡ 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

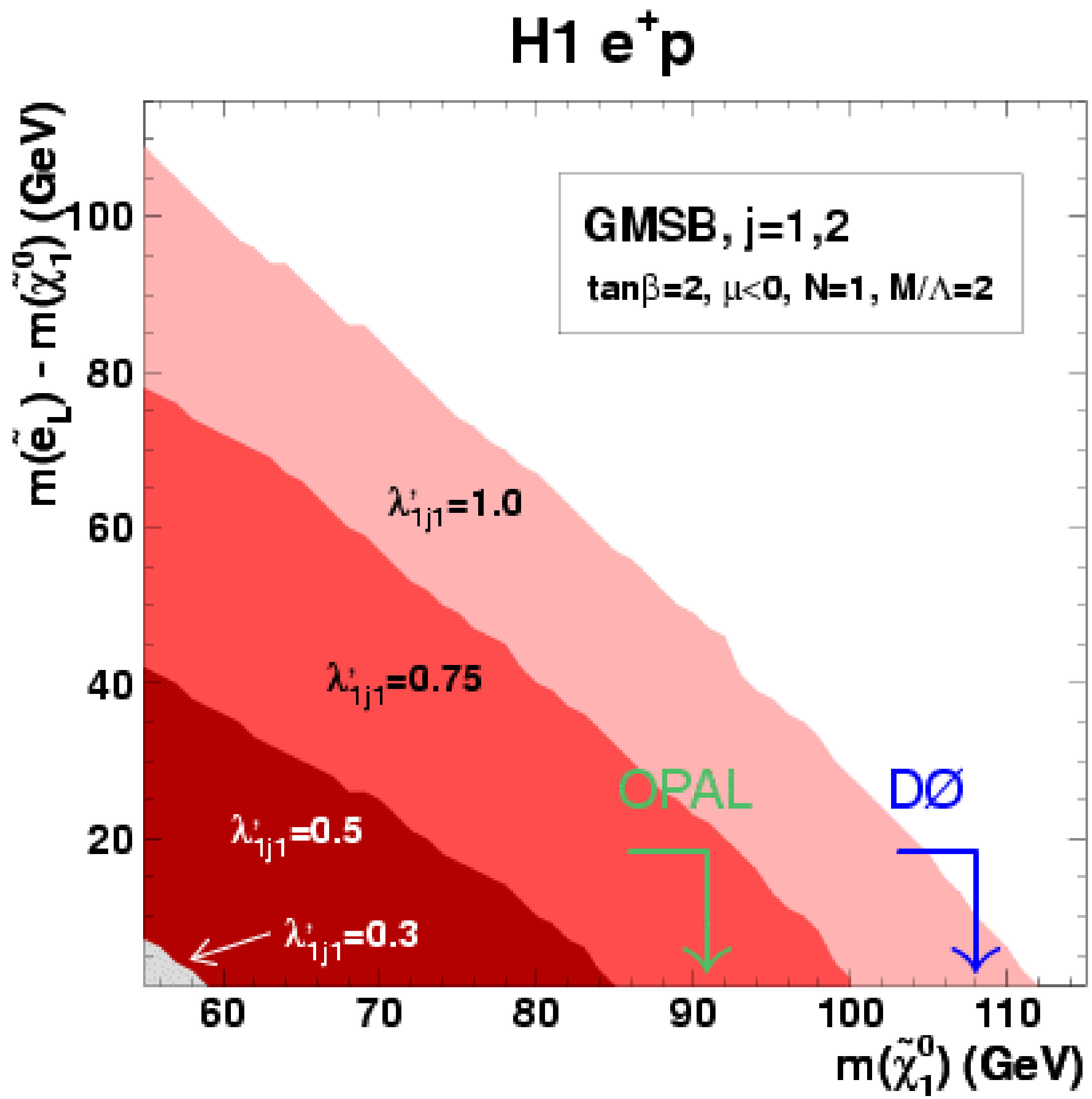
$(\tan\beta = 2, \mu < 0, N = 1, M/\Lambda = 2)$

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

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

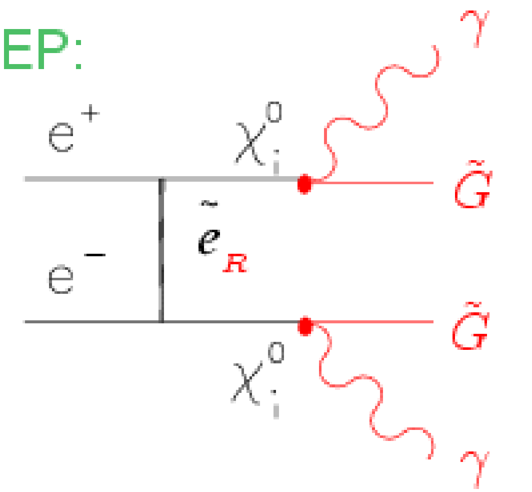
$\Rightarrow$ first limits independent of squark masses

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

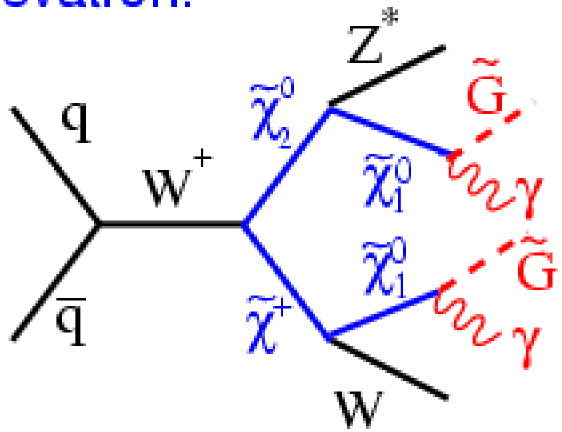


R_P conserving SUSY

LEP:



Tevatron:



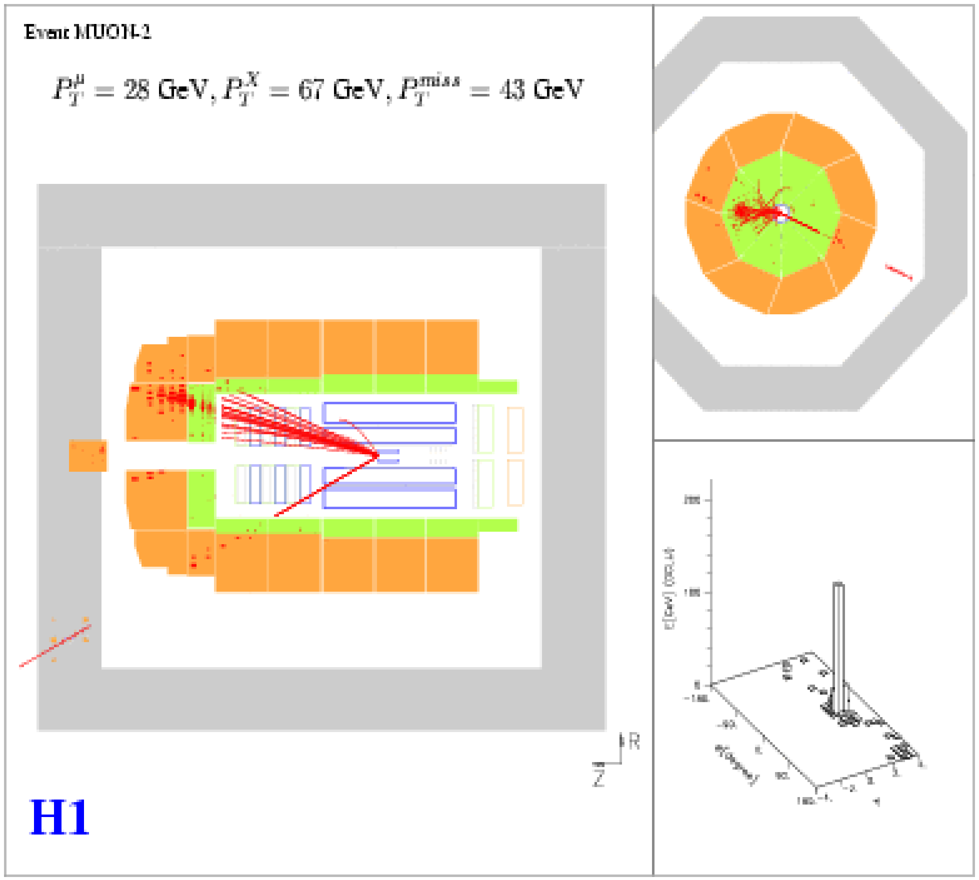
$\Rightarrow m(\tilde{\chi}_1^0) < 112$ GeV for $\lambda'_{1j1} = 1$

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

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

High p_t Lepton Events at HERA

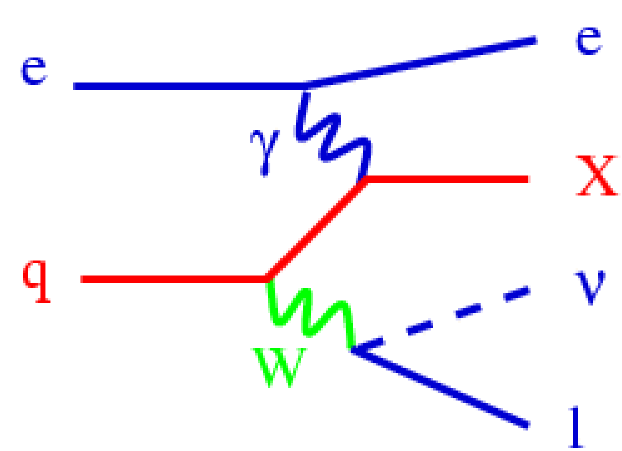
$$e^+p \to \mu^+ X + PTmiss$$



- isolated lepton
- high hadronic p_T
- missing calorimeter p_T

Standard Model:

dominated by W production

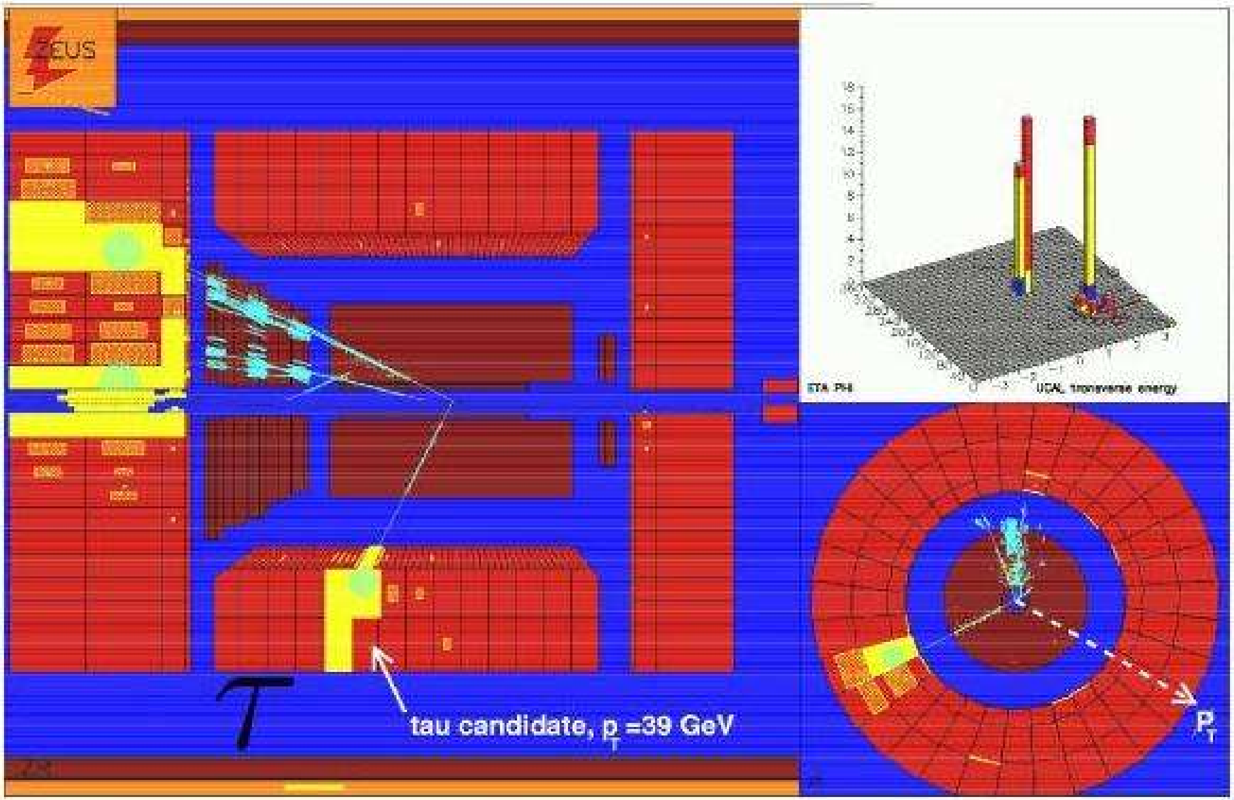


- **Possible other explanations:**

Anomalous top production, RPV SUSY: e.g. ep → $\tilde{t}$ → $\tilde{b}$W **(no deviation)**

High p_t Lepton Events at HERA

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 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 ±1.5	8 / 2.94 ±0.51	5 / 5.81 ±1.36	≈ 75(15)%
$P_T^X > 25$ GeV	5 / 1.76 ±0.29	6 / 1.68 ±0.30	0 / 0.53 ±0.10	≈ 85(50)%
$P_T^X > 40$ GeV	3 / 0.66 ±0.13	3 / 0.64 ±0.14	0 / 0.22 ±0.05	≈ 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 ±3.2	12 / 11.9 ±0.6	3 / 0.4 ±0.12	≈ 17(48)%
$P_T^X > 25$ GeV	2 / 2.9 ±0.46	5 / 2.75 ±0.21	2 / 0.2 ±0.05	≈ 50(50)%
$P_T^X > 40$ GeV	0 / 0.94 ±0.11	0 / 0.95 ±0.12	1 / 0.07 ±0.02	≈ 60(70)%

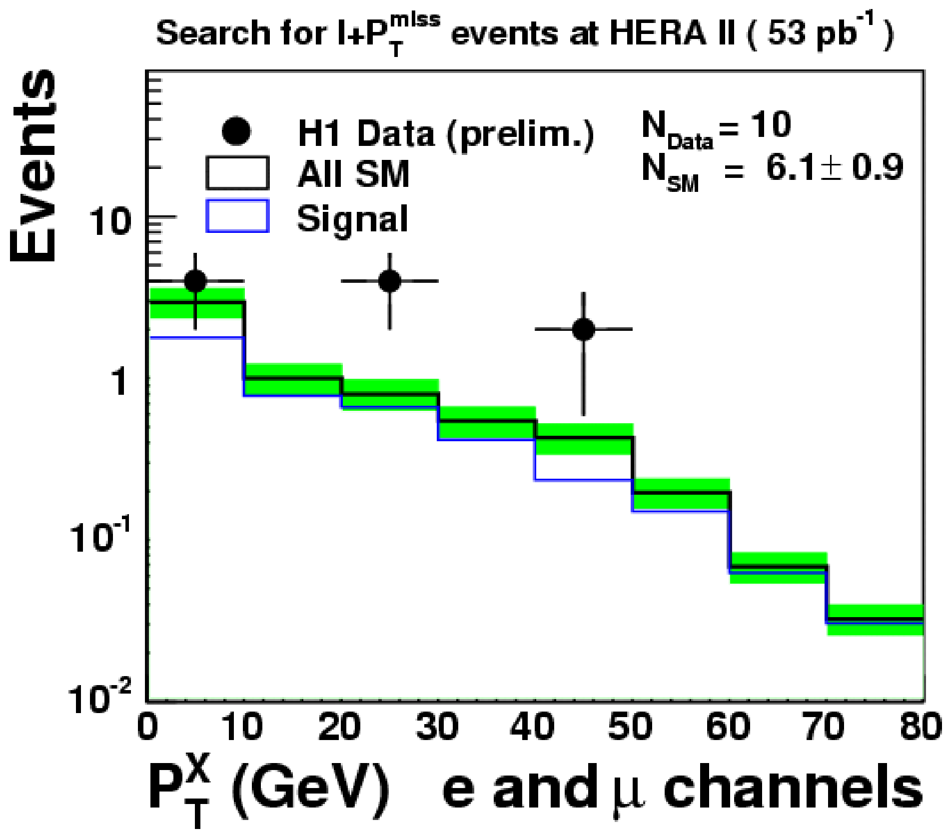
W contribution is NLO: Diener, Schwanenberger, Spira

➡ **observed excesses in H1 + Zeus do not match channels**

Isolated Leptons at HERA II

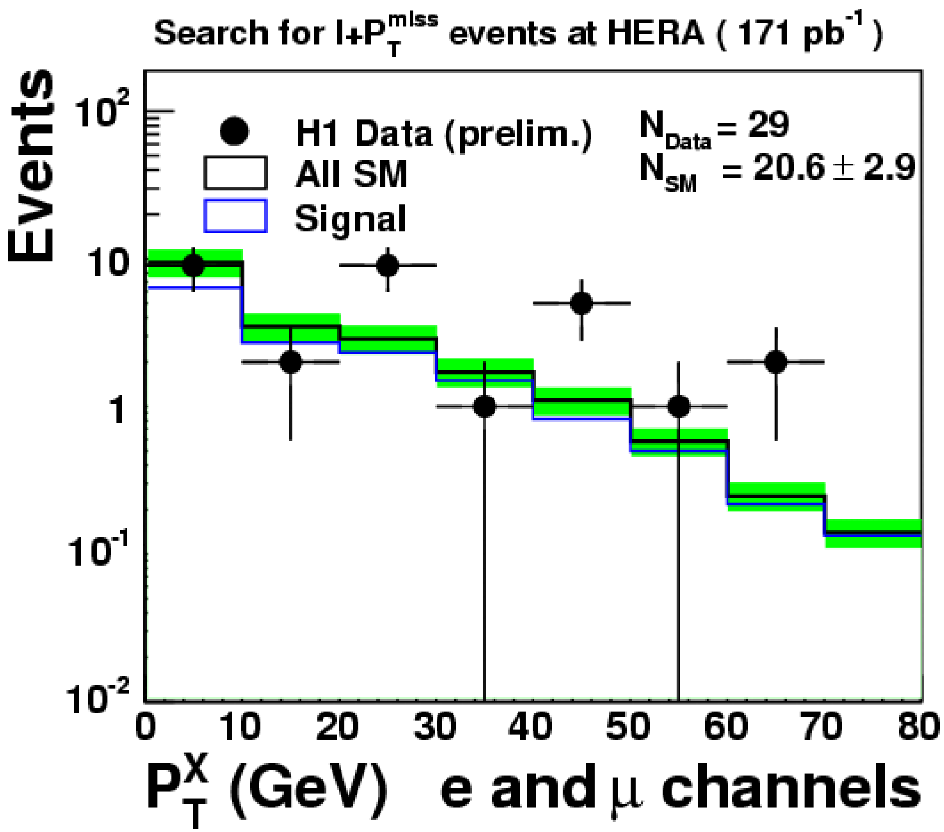
H1 Collaboration (updated since ICHEP)

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 $\mathcal{L}(e^{\pm}p) = 171$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau$^{\mathrm{prel.}}$ obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	$20/16.3 \pm 2.2$	$9/4.3 \pm 0.7$	5 / 5.81 $\pm$1.36	$\approx$ 75(15)%
$P_T^X > 25$ GeV	$10/2.6 \pm 0.5$	$6/2.5 \pm 0.5$	0 / 0.53 $\pm$0.10	$\approx$ 85(50)%

ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130$ 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)%

W contribution is NLO: Diener, Schwanenberger, Spira

➡ **combined electron+muon:**

full sample : 29/20.6 ± 2.9 (74%)

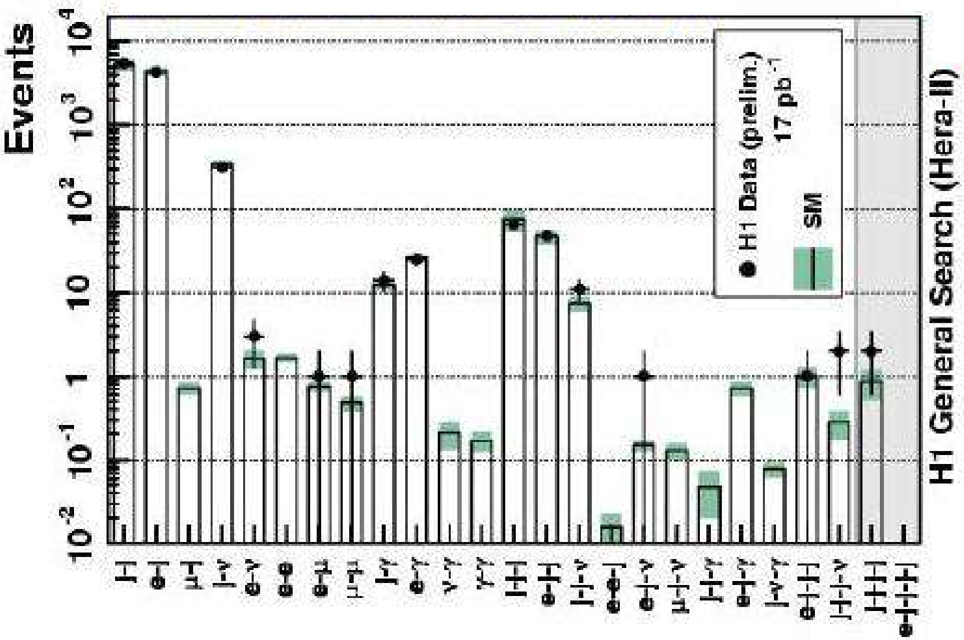
P_T^X>25 GeV : 16/5.1 ± 1.0 (85%)

General Search

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



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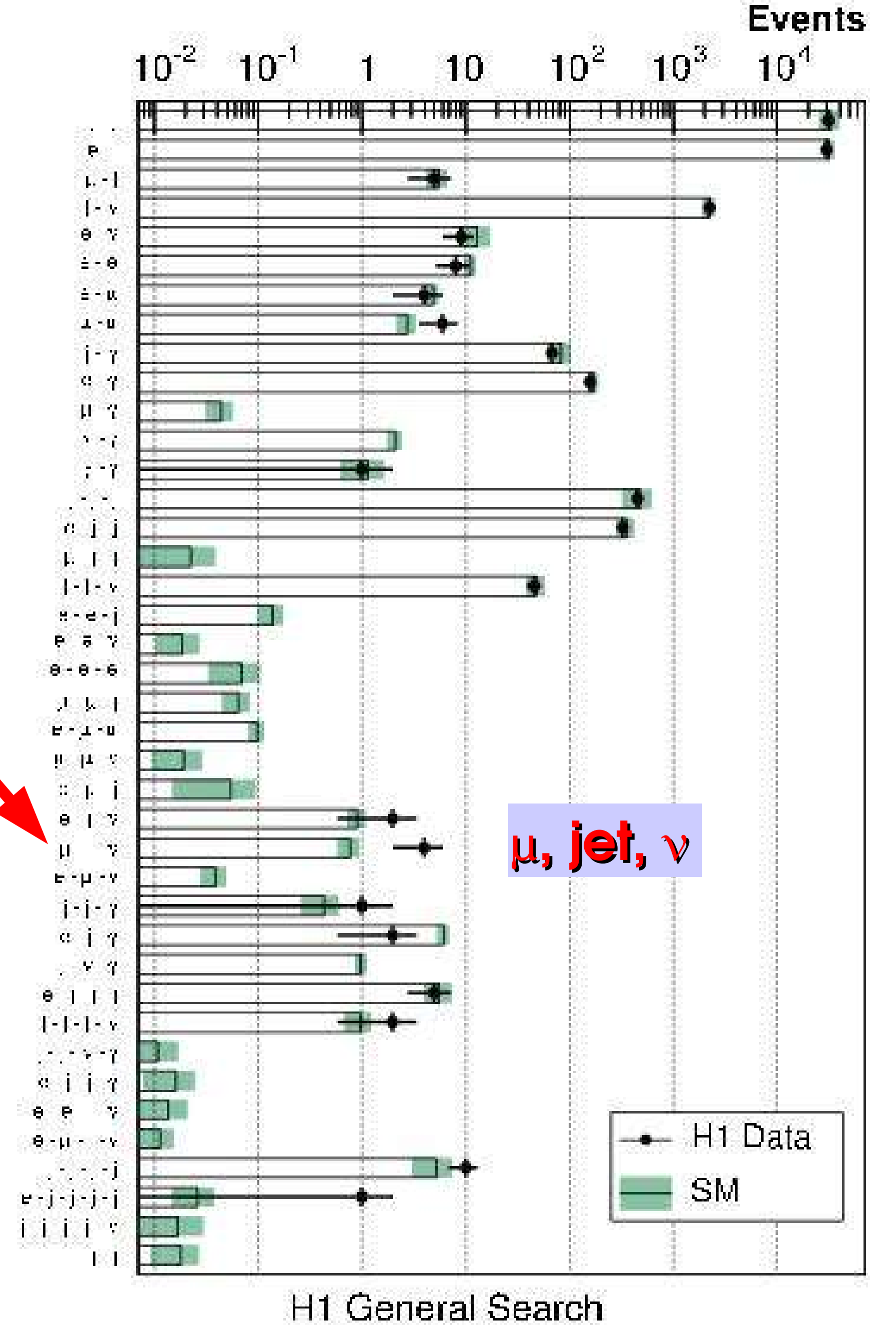


Magnetic Monopoles

- 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):

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

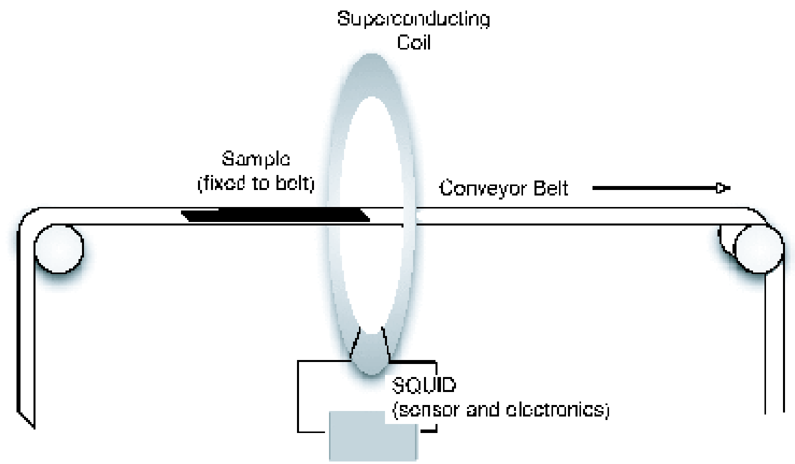
- $n = 1$ ➡ minimum magnetic charge g_D
- down quark: $e = -1/3$ ➡ fundamental magnetic charge $3g_D$
- Dirac: n is even if particle has electric and magnetic charge
  ➡ fundamental magnetic charge $> 3g_D$

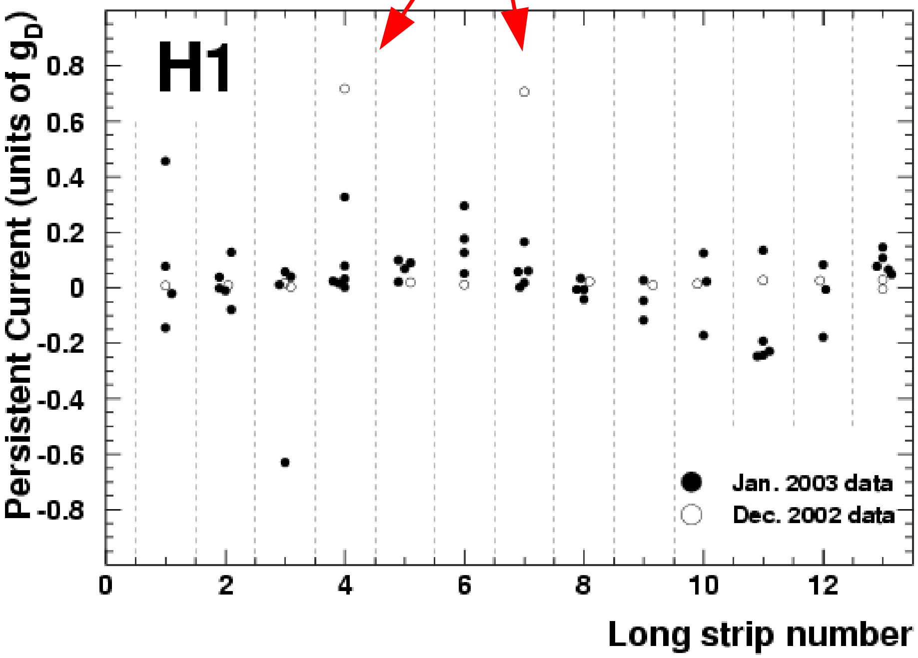
Magnetic Monopoles

- 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"