(1)

R-parity violating SUSY and the New Events

- Very Briefly: What is R-parity and WHY go beyond
- R-parity violation → New signals in colliders including single squark production at HERA
- Valence versus sea quark productions and limits on $R\not{p}$ couplings → $\tilde{c}_L$, $\tilde{t}_L$ } production at HERA
- Decay patterns: main distinction between
  - $R\not{p}$-SUSY → MSSM decay modes
  - scalar leptoquarks → Bounds from Tevatron. Tight for $B_{eq} \simeq 1$.
- Conclusion: If events are indeed due to new physics, R-parity violation seems a promising possibility.

S. Lola, DIS'97, WG (V)

Based on hep-ph/9703276
G. Altarelli, J. Ellis, G. Giudice, S.L, M. Mangano (+)
References on page 3b

(2)

SUSY ⊕ $SU(3) \otimes SU(2) \otimes U(1)$

$\mathcal{L} = \mathcal{L}_{KINETIC} + \mathcal{L}_{INTERACT.}$

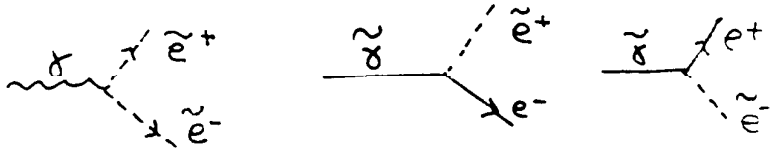
- $\mathcal{L}_{KINETIC}$: contains interactions of gauge bosons and gauginos

So as: For each SM coupling, also those where:

2 particles in a vertex substituted by S-particles

ie FOR

ALSO



THESE GIVE RISE TO:

* Pair s-particle productions

* MSSM decay modes ! distinguish $\tilde{q}$ from leptoquarks (discussed later)

- $\mathcal{L}_{INTERACT.}$ ⇝ generates Yukawa Couplings

(superfield notation) $H_1 L_i \bar{E}_j$ $H_1 Q_i \bar{D}_j$ $H_2 Q_i \bar{U}_j$ → genera fermio masse

$L_i L_j \bar{E}_k$ $L_i Q_j \bar{D}_k$ $\bar{U}_i \bar{D}_j \bar{D}_k$

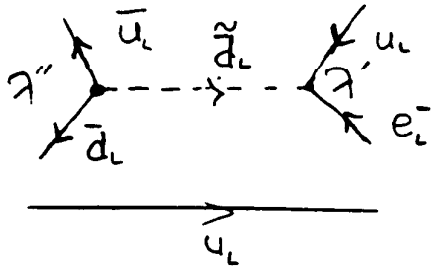
$\Delta L \neq 0$ $\Delta B \neq 0$

R-parity : SM particles $+1$ Fayet 1977

SUSY $\gg$ -1 Farrar, Fayet 1978

If violated, the above trilinear $\Delta L \neq 0, \Delta B \neq 0$ terms present

Imposed to avoid fast proton decay, via

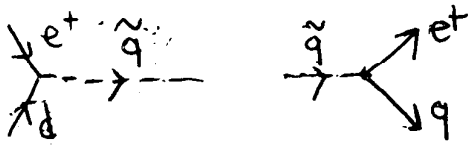


also motivated by several GUTS + string ↑ constructio

- Can avoid this, even if R-parity is violated, but dangerous operators are NOT simultaneous present

$\not{R_p}$ ⟶ new signals as compared to MS

- ✱ Single s-particle productions ($\tilde{q}$ production at HERA)
- ✱ LSP decays/leptoquark-like s-fermion decay
- ✱ $\not{p}$ ⇝ lepton/jet events in excess (like hera events) to SM processes, or in ne exotic modes. (ie cascade decay



- **45** R-parity violating couplings

- { To explain HERA data } need the $L_1 Q_j \bar{D}_k$ operators

R-parity collider Searches

Subject of studies, already from the '80's.

Hall, Suzuki, Dawson, Dimopoulos, Barbieri, Zwirner, Masiero, Barger, Giudice, Han, Ross, Valle, Ellis, Phillips, Aulah, Dreiner, Sakai, Yanagita, Bhattacharyya, SL, McCurry, Choudhurry, Hirsch, Klapdor, Kovalenko and many more

R-parity searches at HERA

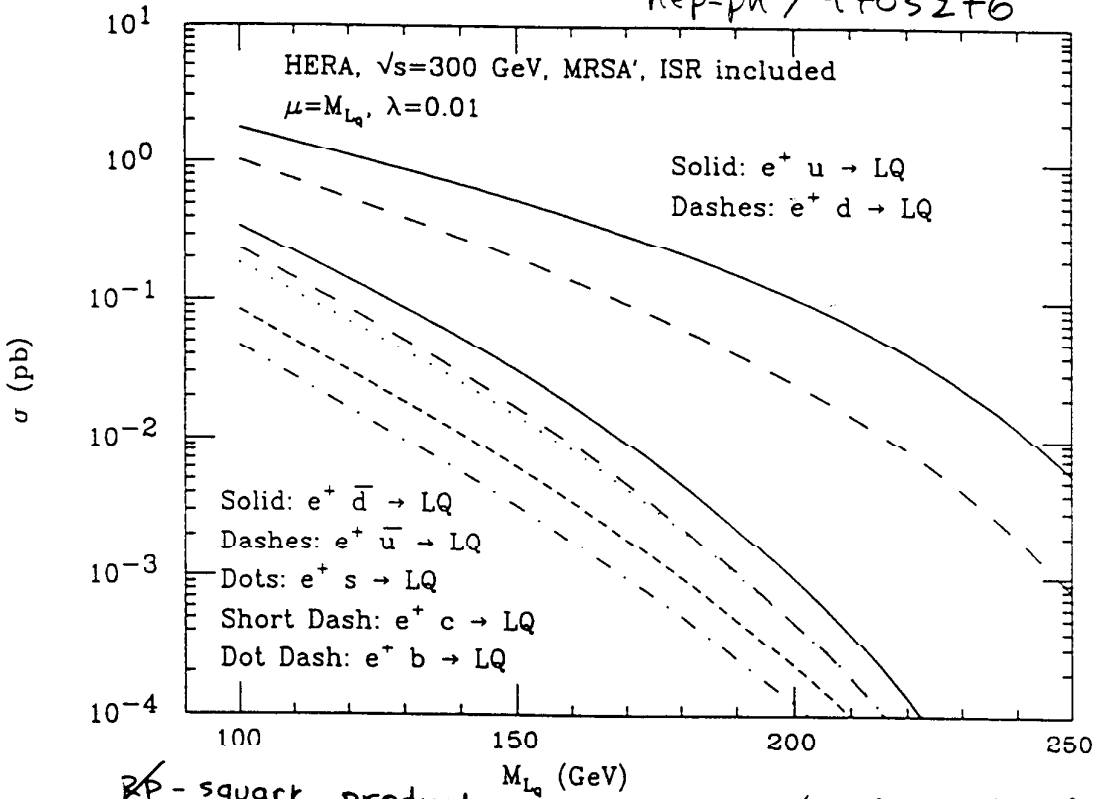
Hewett (proceedings Snowmass 1990)
Dreiner, Butterworth, Morawitz,
Kon, Kobayashi, Nakamura, Kitamura, Adashi
(focusing on $\tilde{t}$ production)
Perez, Sirois.

HERA large Q^2-data and R-parity

D. Choudhury, S. Raychaudhuri hep-ph/9702392
G. Altarelli, J. Ellis, G. Giudice, SL, M. Mangano, hep-ph/9703
H. Dreiner, P. Morawitz, hep-ph/9703279
J. Kalinowski, R. Ruckl, H. Spiesberger, P. Zerwas, hep-ph/9703
T. Kon, T. Kobayashi, hep-ph/9704221
R. Barbieri, A. Strumia, Z. Berezhiani/9704275

•
•
•

G. Altarelli, J. Ellis, G. Giudice, S.L, M. Mangano
hep-ph / 9703276



~~RP~~ - squark product. c's at HERA (ks for scal. LQ)

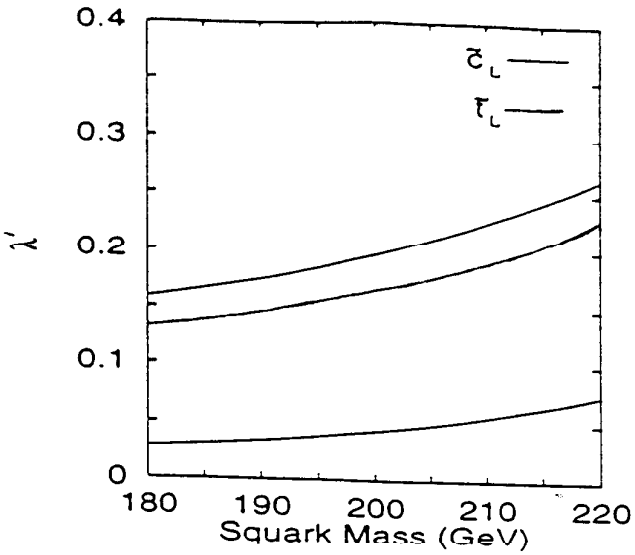
(a) $e^+ + \text{valence } q \rightarrow \tilde{u}_L, \tilde{c}_L, \tilde{t}_L$ (not possible, as we will see, from $0\nu\beta\beta$ decays) productions via $\lambda' L_1 Q_{1,2,3} \bar{D}_1$: $\lambda' \simeq 0.04/\sqrt{\tau}$

(b) $e^+ + \text{sea quarks} \rightarrow$ need $\lambda' \simeq \frac{0.3}{\sqrt{B}} \sim e$ (a $B_{eq} \simeq 0.5$ natural)

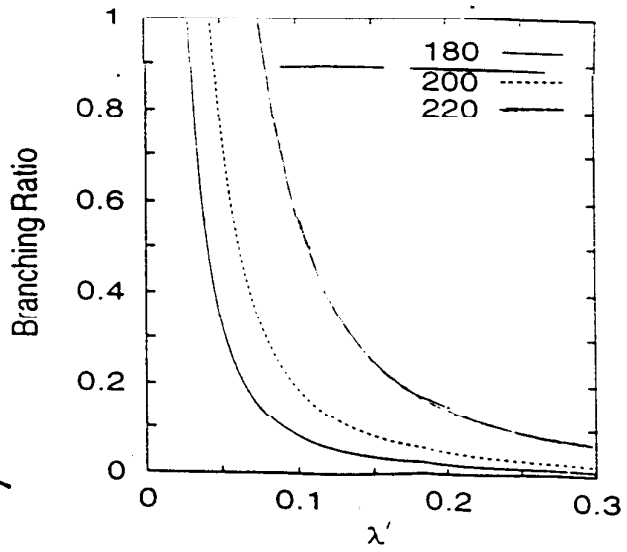
(c) BUT also: Resonance may **NOT** be produced by scattering to $\bar{u}$ or $\bar{d}$ quarks, since
$\sigma(e^-\bar{d}) \sim 25\, \sigma(e^+\bar{u})$
$\sigma(e^-\bar{u}) \sim 200\, \sigma(e^+\bar{u})$
and no signal in $1\,pb^{-1}$ of e^-p ...

D. Choudhury, S. Raychaudhuri (4

hep-ph/ 9703279



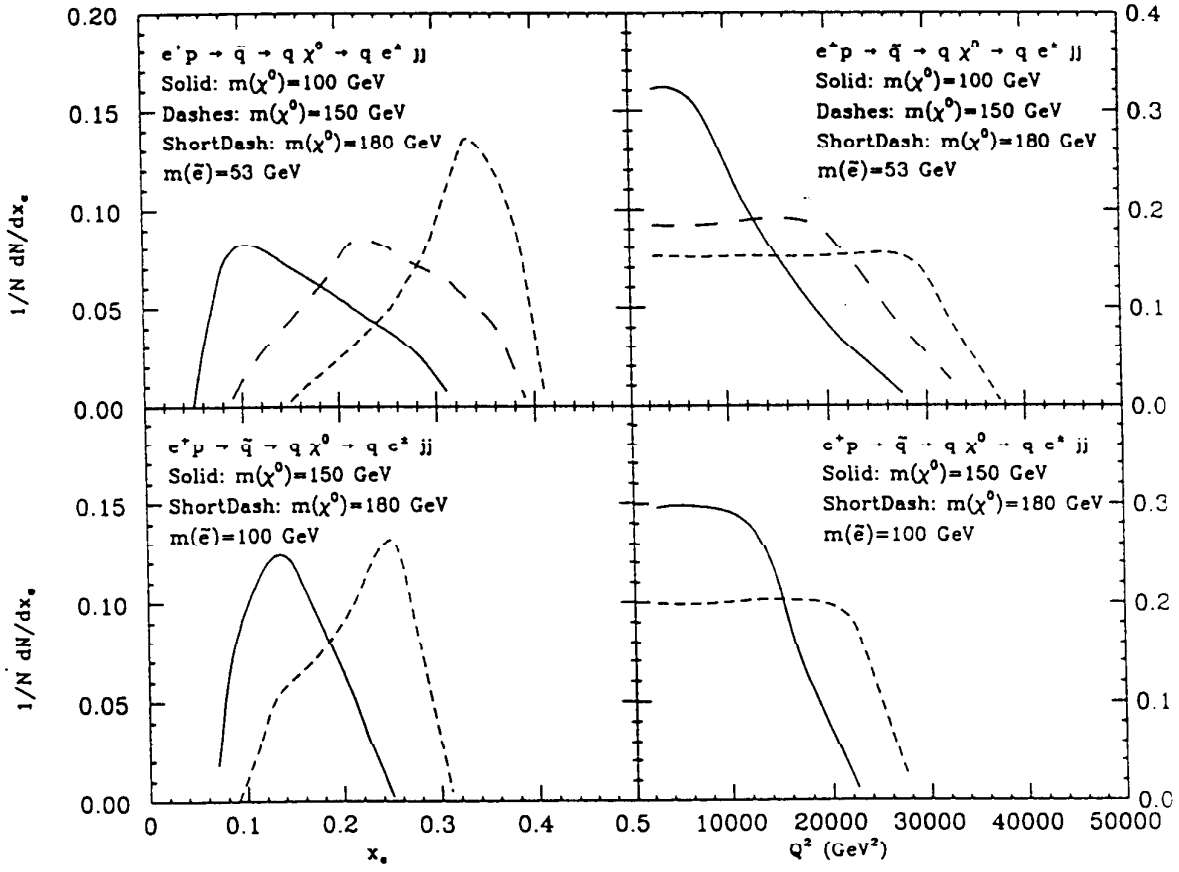
Range in λ' that may account for HERA data. Small B ($\tilde{q}_i \to e^+ d$) requires larger couplings.



Similar results by other groups, listed on page (3b)

G. Altarelli, J. Ellis, G. Giudice, S L, M. Mangano
hep-ph/ 9703276

(4c)



Cascade decays:
Broader distributions, 'wrong' sign leptons in 50% of cases

BOUNDS

half-life limit of ^{76}Ge,

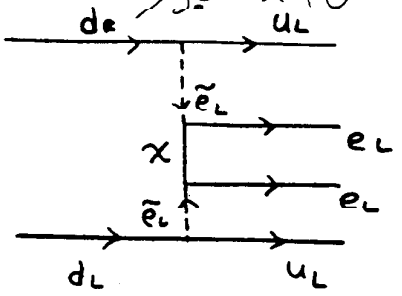
(*) here we always refer to strongest constraint

(a) Neutrinoless double beta-decay

56×10^{24} yr (90% CL).

ie:

(one indicative diagram)



more present!

most constr.

Flavour: λ'_{111}

Constraint:

$\lambda'_{111} < 4 \cdot 10^{-4} \frac{m_{\tilde{f}}}{100\ GeV}$

! kills possibility for $\tilde{\nu}_L$ productic at HERA

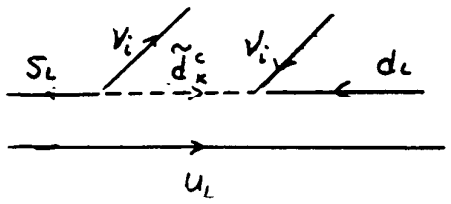
(b) Charged current Universality

modifications to nuclear β decay

Flavour: λ'_{112}, λ'_{113}

Constraint: $\lambda' \lesssim 0.03 \frac{m_{\tilde{f}}}{100\ GeV}$

(c) $K^+ \longrightarrow \pi^+ \nu \bar{\nu}$



$BR[K^+ \to \pi^+ \nu \bar{\nu}] \leq 5.2 \times 10^{-9}$

Flavour: $j=1$ / $j=2$: Dominant constraint for π^0 {12k, 21k, 22k, 31k, 32k.

Constraint: $\lambda' < 0.012\ m_{\tilde{f}}/100\ GeV$.

(d) Atomic parity violation : in e-nucleon scattering.

Arises in SM due to the electroweak interference term

$$\pm \; 2 \, M_{em} M_{weak}$$

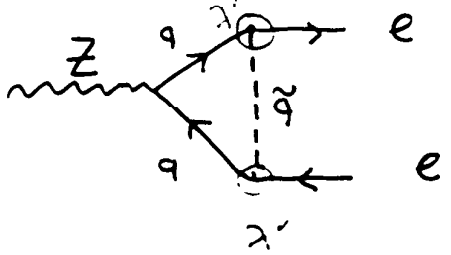
due to the opposite behaviour of M_{em}, M_{weak} under reflections.

Flavour : dominant effect for λ'_{131} (not bou by othe process.

Constraint: $\lambda' < 0.26 \; m_{\tilde{f}} / 100 \text{ GeV}$

(e) One-loop corrections to the Z width:

ie:



Flavour: dominant effect for λ'_{i3k}

Constraints:

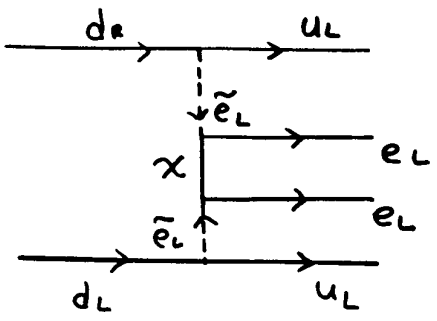
$$\left.\begin{aligned} \lambda'_{132} &< 0.51 \\ \lambda'_{232} &< 0.44 \\ \lambda'_{233} &< 0.44 \\ \lambda'_{33k} &< 0.26 \end{aligned}\right\} \; m_{\tilde{f}} / 100 \text{ GeV}$$

BOUNDS

(*) here we always refer to strongest constraint

(a) Neutrinoless double beta-decay

ie: (one indicative diagram)



more preseut!

most constr. Flavour: λ'_{111}

Constraint:

$$\lambda'_{111} < 4.10^{-4} \frac{m_{\tilde{f}}}{100\ GeV}$$

! kills possibility for $\tilde{\upsilon}_L$ production at HERA

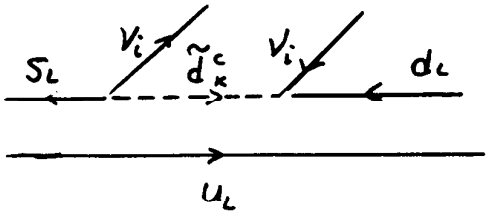
(b) Charged current Universality

modifications to nuclear β decay

Flavour: λ'_{112}, λ'_{113}

Constraint: $\lambda' \lesssim 0.03 \frac{m_{\tilde{f}}}{100\ GeV}$

(c) $K^+ \longrightarrow \pi^+ \nu \bar{\nu}$



Flavour: $j=1 / j=2$: Dominant constraint for: {12k, 21k, 22k, 31k, 32k.

Constraint: $\lambda' < 0.012\ m_{\tilde{f}}/100\ GeV.$

From cross section AND constraints,

3 main possibilities; for $\tilde{t}$ spart. production

- $\tilde{c}_L$ production via λ_{12k} } through valence quark (e+d col
- $\tilde{t}_L$ production via λ_{13k} }
- $\tilde{t}_L$ production via λ_{23k} } through sea quark (e+s co

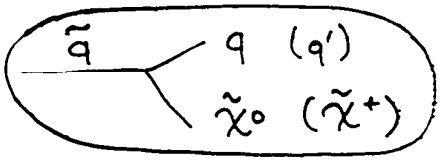
and also proposed:

- $\tilde{t}_1$ and $\tilde{t}_2$ (both stop quarks). Broader mass distribution from overlapping double resonanc peaks Kon, Kobayashi, hep-ph/9704221

NOTE:

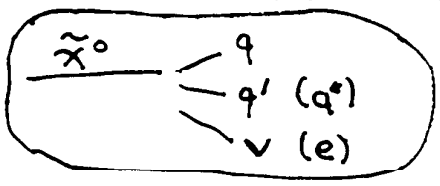
(a) $\lambda_{ijk} Q_j \bar{D}_k \rightarrow e_i^L \tilde{u}_j^L \bar{d}_k$

$\rightarrow \nu_i^L \tilde{d}_j^L \bar{d}_k$



For $\tilde{c}_L$, $\tilde{t}_L$ production, a coupling*, CC events, only.

in cascade decays, with broader distribution



+ other possible modes

(b) STRONG BOUNDS on colour-triplet scalars fro Tevatron; for $B(eq) \simeq 1.0$

But in ~~R/~~, $B(eq) \neq 1.0$ unlike leptoquark schem due to MSSM decays.

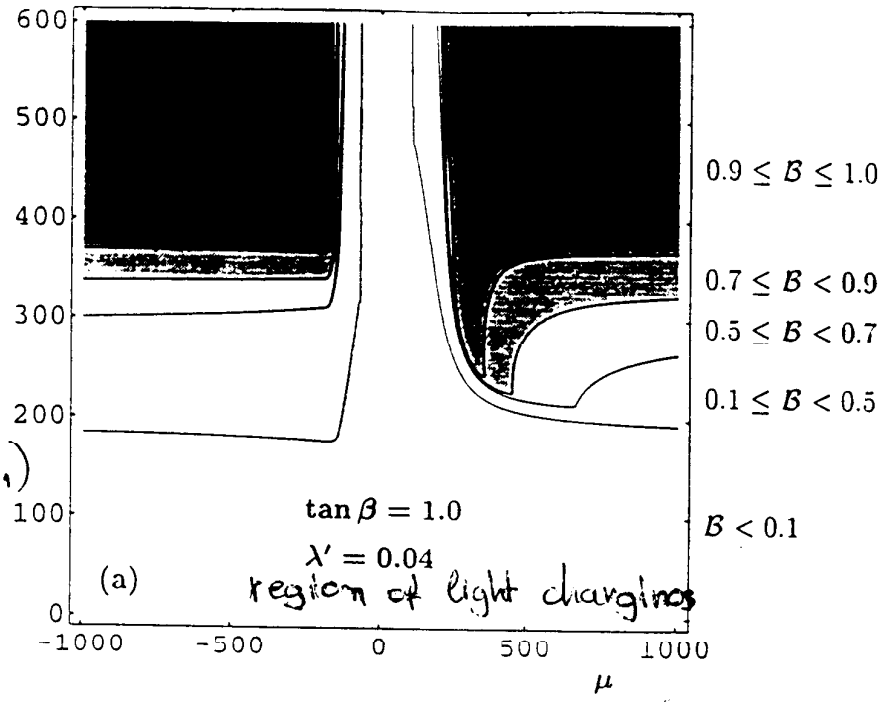
$B(eq)$ depends on: → mass spectrum of gauginos

→ mixing of gauginos

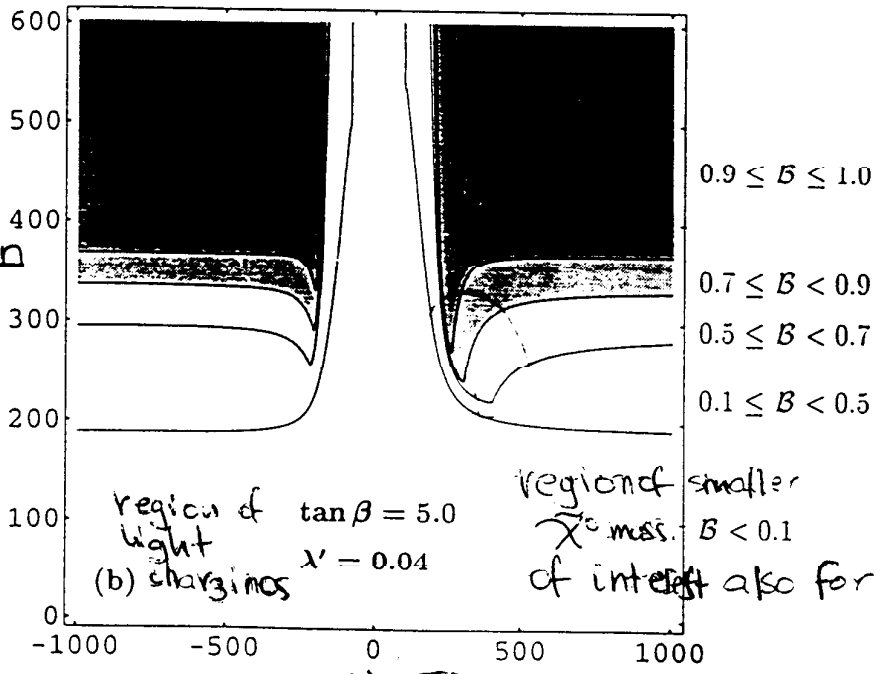
+ CC events may appears if decay proceeds via a coupling different from the one in the squark-production. & simultan coupl. to e

G. Altarelli
J. Ellis
G Giudice, S L
H L Hangano

$\tilde{c}_L$ decays B (R/ mode)



Neutr. coupl. to
$\tilde{c}_L, \tilde{t}_L \simeq$
$\frac{g}{2}\left(N_{i2} + \frac{1}{3}\tan\theta_W N_{i1}\right)$



Existence of Regions with balance between R/p and 2p conserving modes

also for ALEPH ever

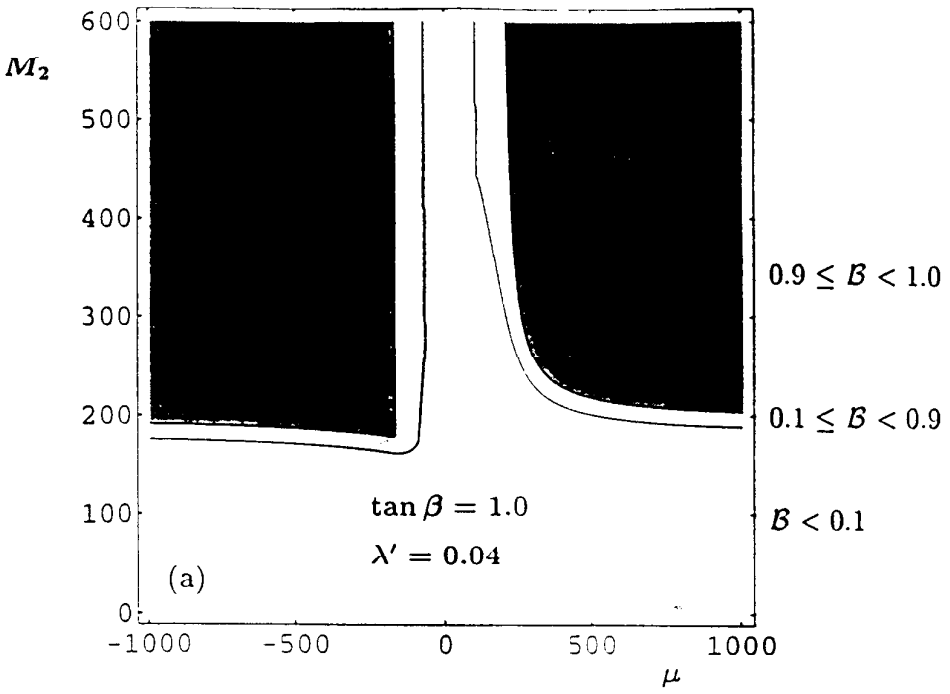
(1) R/p mode large for: (a) $m_{\tilde{\chi}^+}$ large, such as $\tilde{q} \to q'\tilde{\chi}^+$ suppressed by phase space

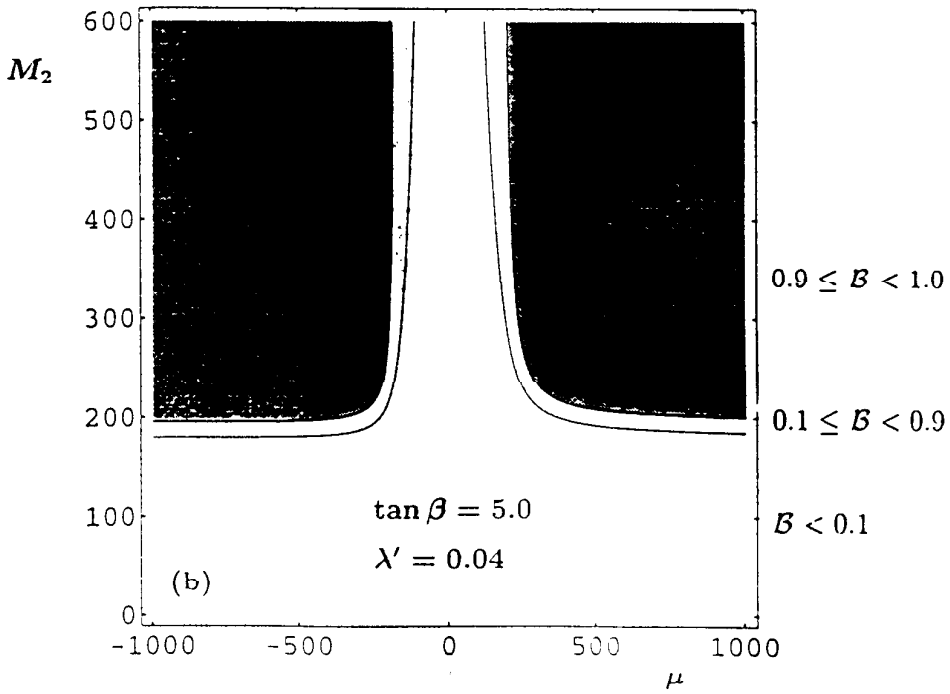
(b) A region of cancellations, leading to small coupling for $\tilde{q} \to q\tilde{\chi}^0$, even for relatively small $m_{\tilde{\chi}^+}$

(2) $m_{\tilde{\chi}^+} < 85$ GeV region, excluded by LEP 2

G. Altarelli
J. Ellis
G. Giudice, SL,
M. Mangano

$\tilde{t}_L$ decays: B(R/ mode)



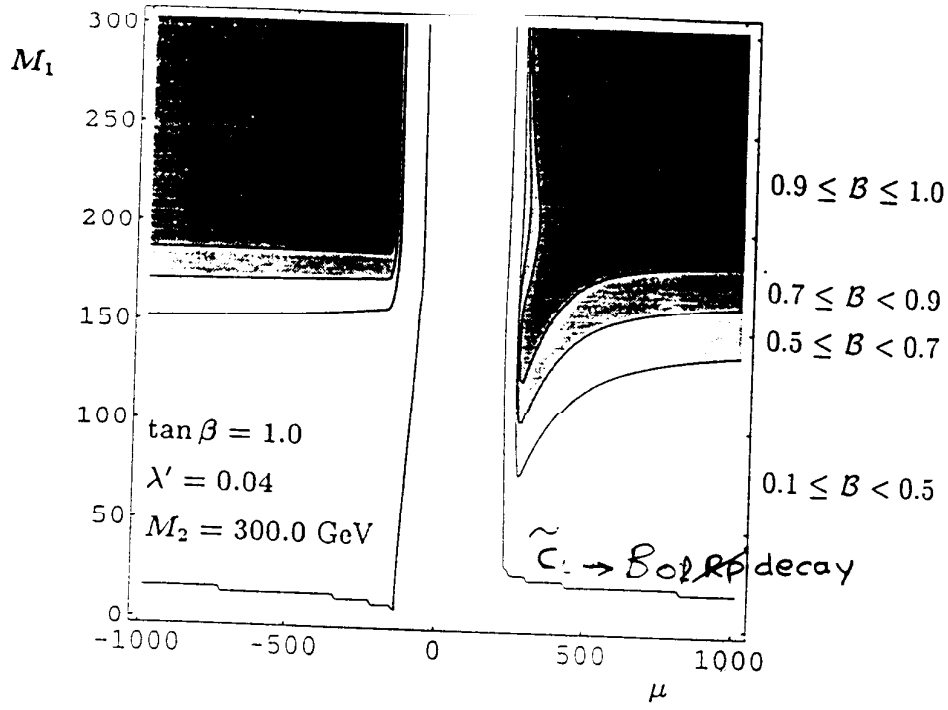


Here, the mode $\tilde{t}_L \to t\tilde{\chi}^0$ is naturally "closed". The ~~R/p~~ mode, either dominates (for heavy charginos) or is suppressed (for light charginos) except for a small region $\tilde{t}_L \to c\tilde{\chi}^0$ ← can be smaller, for new mode

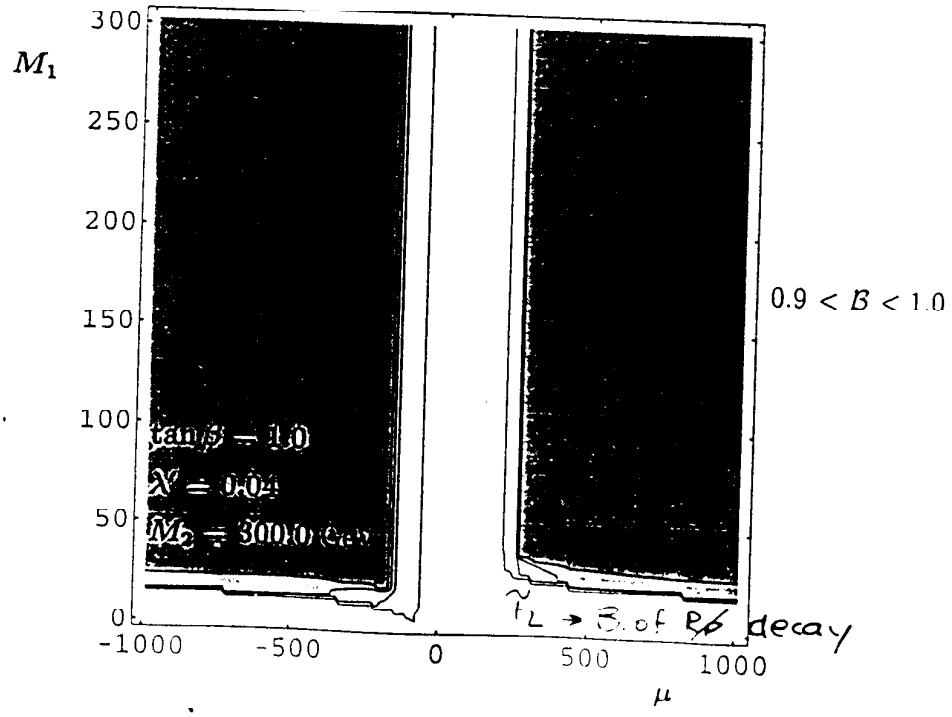
But B_{eq}

G. Altarelli, J. Ellis,
G. Giudice, S.L., M. Mangano

(10)



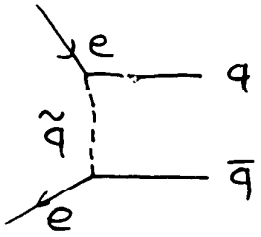
Chargino masses > 85 GeV, Neutralino masses > 15 GeV
(Breaking gaugino Unification condition)



TESTS and CONCLUSIONS

tests: a lot of this in the last weeks in the papers we listed.

- Virtual squark exchanges at LEP 2] summarised in DIS '97 by J. Kalinow



+ Interference with SM proc.

small effect for $\lambda_1 Q_{2,3} \bar{D}_1$ operator, but:

For $e^+ s \to \tilde{t}$ expect deviations in $e^+e^- \to s\bar{s}$ at LEP

- e^- beam runs at hera (expect NO signal in ep chann
- $\tilde{\chi}^0$ ($\tilde{\chi}^+$) cascade decays
- K → $\pi \bar{\nu} \nu$ (should be within access if a $\tilde{c}_L$ is produc
- Squark pair Production at Teratron
  + Cascade Decays

conclusion

⟹ If signals are there, R/p seems a good possibility → Should be able to test proposed solutions in near future

→ Interesting implications for flavour