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Search for Supersymmetric Particles at PETRA

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ABSTRACT

Recent results on searches for scalar leptons, photinos, neutralinos, and charginos in e^+e^- collisions at c.m. energies up to 46.78 GeV are reviewed.

Suche nach supersymmetrischen Teilchen bei PETRA

ZUSAMMENFASSUNG

Neue Ergebnisse zur Suche nach skalaren Leptonen, Photinos, Neutralinos und Charginos in e^+e^- Kollisionen bei Schwerpunktsenergien bis zu 46.78 GeV werden vorgestellt.

Invited talk at the International Europhysics Conference on High Energy Physics, Bari, Italy, 18/24 July 1985

1. INTRODUCTION

Supersymmetric models /1/ predict a partner for each known particle with a spin differing by $|\Delta j| = 1/2$. An essential feature of supersymmetry (SUSY) is that these new particles must have the same couplings as their ordinary partners, but there exist essentially no prediction on their masses, because of the unknown nature of SUSY breaking. Therefore, in SUSY processes the only unknown parameters are the masses of the SUSY particles involved. Searches for supersymmetric reactions should be as independent as possible from specific assumptions on the SUSY mass spectrum.

SUSY particles carry a (in most models) conserved quantum number R-parity. For this reason, they can be produced only in associated production. Of particular phenomenological importance is the lightest SUSY particle (LSP) since all SUSY particles eventually will decay into it. It is favoured to be uncolored and neutral. Moreover, it is stable (R-parity conservation) and almost non-interacting, i.e. ν-like. Therefore a general signature for supersymmetric processes is missing energy and momentum carried away by the LSP. Although limited in the available c.m. energy, as compared to hadron colliders, e^+e^- collisions offer a very clean laboratory where potential SUSY processes would stick out clearly over a well understood conventional background.

2. UNSTABLE PHOTINOS

In models with global supersymmetry breaking there appears a light spin 1/2 goldstino $\tilde{G}$ /2/. A massive photino is expected to decay into a photon and a goldstino with a life time $\tau = 8\pi d^2/m_{\tilde{\gamma}}^5$ (see Ref. /3/) were d characterizes the scale of supersymmetry breaking. In locally supersymmetric models, however, the goldstino is absorbed into a massive gravitino and the photino is expected to be stable as the lightest supersymmetric particle.

Photinos can be pair produced in e^+e^- interactions by t-channel exchange of a scalar electron (see Fig. 1 d.). The subsequent decay into photon and goldstino produces, in case of a heavy photino, an acoplanar pair of photons with missing energy and momentum carried away by the unobserved goldstinos, whereas for a light photino its decay photons are boosted into the original photino direction giving rise to a pair of collinear photons with missing energy. All four PETRA experiments /4,5,6,7/ looked for these signatures and did not observe any candidates. Figure 2 shows the status of the relevant searches. Fig. 2a also indicates a cosmological bound on the mass of unstable photinos /3/, while cosmological bounds on stable $\tilde\gamma$ masses are discussed in Ref. /8/. We can conclude, independent of any specific model for a photino decay, that if $m_{\tilde e} \lesssim 80\text{-}100$ GeV the photino is either stable or sufficiently long lived not to decay inside a detector or decays into an invisible final state (e.g. $\tilde\nu\nu$). For this reason the searches discussed below assume a stable resp. invisible photino.

3. COMBINED SEARCHES for $\tilde e$ and $\tilde\gamma$, stable $\tilde\gamma$

Searches for scalar electrons and photinos have been carried out by looking for the processes shown in Fig. 1 a-c.

Pair production of $\tilde e$'s followed by the decay $\tilde e \rightarrow e\tilde\gamma$ results in an acoplanar pair of electrons and missing energy and momentum in the unobserved photinos. Obviously, this process is limited to $m_{\tilde e} < E_{beam}$.

$\tilde e$ masses up to $\sqrt{s} - m_{\tilde\gamma}$ can be reached in the production of a single $\tilde e$ and a $\tilde\gamma$ in the collision of a beam electron with a radiated quasi real photon (Fig. 1b). The signature for this reaction is a single hard electron from the $\tilde e$ decay and nothing else in the detector (the second electron escapes unobserved along the beam pipe).

A third possibility is to tag $\tilde\gamma$ pair production via $\tilde e$ exchange with a photon radiated in the initial state (Fig. 1c), the signature being a single (soft) photon in the detector, very similar to $e^+e^- \rightarrow \gamma\nu\nu$. Since here no real $\tilde e$'s are produced, this process is sensitive even to $m_{\tilde e} > \sqrt{s}$.

The reaction shown in Fig. 1a has been studied by all PETRA experiments /4,9,6,10/, while 1b and 1c were investigated by CELLO and JADE /4,9/. JADE obtains $m_{\tilde e} > 26$ GeV provided the SUSY partners of the left- and right-handed electron are degenerate in mass. The combined CELLO limits on $\tilde\gamma$ and $\tilde e$ mass are indicated in Fig. 3.

4. ZINOS

In e^+e^- interactions zinos ($\tilde z$) can be produced together with a $\tilde\gamma$ via $\tilde e$ exchange. The experimental signature for this reaction of course depends on the decay modes of the zino. Depending on the SUSY mass spectrum, various scenarios are possible:

heavy gluino ($m_{\tilde g} > m_{\tilde z}$), heavy sneutrino ($m_{\tilde\nu} > m_{\tilde z}$): The zino decays via scalar exchange into an fermion anti-fermion pair and a photino (see diagram in Fig. 4a). In case of equal scalar quark and lepton masses one expects a leptonic branching fraction of 13 % per lepton generation. The signature is an acoplanar lepton resp. jet pair or, for smaller zino masses, a single jet with an empty opposite hemisphere.

light gluino ($m_{\tilde{g}} < m_{\tilde{z}}$): In this case the dominant zino decay would be hadronically into $q\bar{q}\tilde{g}$ followed by $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$ (see diagrams in Fig. 4b), due to the stronger hadronic $\tilde{q}q\tilde{g}$ coupling. Also here one expects acoplanar jets resp. single jets.

light sneutrino ($m_{\tilde{\nu}} < m_{\tilde{z}}$): Perhaps the scalar neutrino is the lightest SUSY particle /11/. Then the zino would decay exclusively into an invisible $\tilde{\nu}\nu$ final state and the only possibility to put limits on its mass would be initial state radiation tagging similar to $e^+e^- \rightarrow \gamma\tilde{\gamma}\tilde{\gamma}$ and $e^+e^- \rightarrow \gamma\nu\nu$ discussed above.

MARK-J has searched for leptonic zino decays /12/, while CELLO/13/ and JADE/14/ considered both hadronic and leptonic final states. Figs. 4a and b show excluded zino masses for different decay scenarios.

5. WINOS

Winos ($\tilde{w}$) can be pair produced via one photon annihilation and via t-channel sneutrino exchange. Similar to the zino case various decay scenarios are possible:

$m_{\tilde{g}} > m_{\tilde{w}}, m_{\tilde{\nu}} > m_{\tilde{w}}$: The wino decays into $l\nu\tilde{\gamma}$ or $q\bar{q}'\tilde{\gamma}$ via W or via scalar exchange with a leptonic branching fraction of O(10%) per lepton generation. One expects acoplanar lepton and jet pairs.

$m_{\tilde{g}} < m_{\tilde{w}}$: The wino decays dominantly hadronically into $q\bar{q}'\tilde{g}$, followed by $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$. Winos are pair produced, so that one has 8 quarks in the final state resulting in spherical events with relatively small missing $p_\perp$.

$m_{\tilde{\nu}} < m_{\tilde{w}}$: If the scalar neutrino is light the winos decays exclusively into $l\tilde{\nu}$ final states with the sneutrino escaping unseen, resulting in a final state of two acoplanar leptons.

CELLO/13/ and MARK-J/12/ have looked for acoplanar leptons, while JADE/15/ also searched for acoplanar jets and an excess of spherical events (see Fig. 5). We can conclude that winos below 22 GeV are excluded for ALL potential wino decay modes.

6. GAUGINO HIGGSINO MIXING

In general, photino, zino, and the neutral higgsinos are expected to mix forming so called neutralino mass eigenstates, while winos and charged higgsinos may mix forming charginos /16,17/.

In $e^+e^- \rightarrow \tilde{\gamma}\tilde{z}$ a higgsino admixture in the zino would cause a lowered production cross section due to the small $\tilde{h}\tilde{e}e$ coupling while the zino decay properties would be essentially unaltered /16/.

If the wino in $e^+e^- \rightarrow \tilde{w}^+\tilde{w}^-$ is replaced by a charged higgsino only the one photon annihilation amplitude contributes to production. The decay of a charged higgsino is expected to proceed via W exchange /17/ giving a signature identical to wino pair production. In case the scalar neutrino is light, however, the dominant decay will be $\tilde{w} \rightarrow \tau\tilde{\nu}$, giving rise to an acoplanar τ pair. JADE also studied this signature (see Fig. 5b) so that the limit m > 22 GeV also holds for a charged higgsino.

7. CONCLUSIONS

In conclusion, at PETRA searches have been carried out for the SUSY signatures

- acoplanar lepton, jet, and photon pairs,
- single electrons, single photons, and single jets,
- and for an excess of spherical events

None of these signatures has been observed. Their absence has been used to put limits on the masses of supersymmetric particles:

- $m_{\tilde{e}} > 26$ GeV if $\tilde{\gamma}$ stable
- $m_{\tilde{e}} \gtrsim 100$ GeV if $\tilde{\gamma}$ unstable
- $m_{\tilde{z}} \gtrsim 30 - 40$ GeV if $m_{\tilde{e}} \lesssim 70$ GeV and $m_{\tilde{\nu}} > m_{\tilde{z}}$
- $m_{\tilde{\chi}} > 22$ GeV, $\tilde{\chi} = \tilde{w}^{\pm}$ or $\tilde{h}^{\pm}$

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FIGURE CAPTIONS

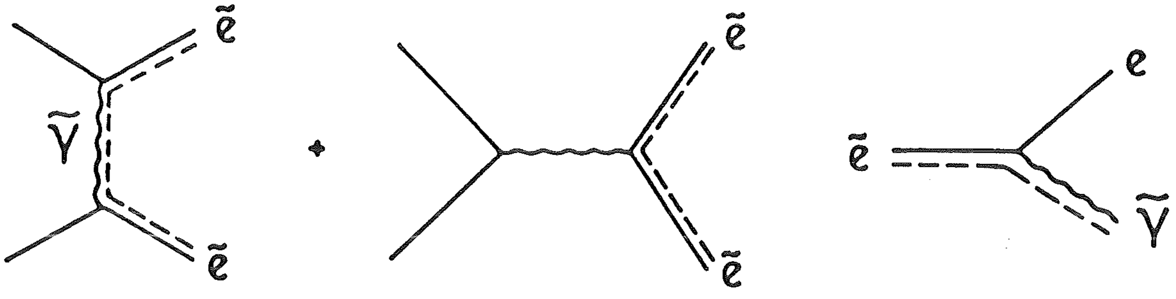
FIG. 1: $\tilde{e}$ and $\tilde{\gamma}$ production processes in e^+e^- interactions.
1a: pair production
1b: single $\tilde{e}$ production
1c: radiative $\tilde{\gamma}$ pair production
1d: pair production followed by $\tilde{\gamma}$ decay.

FIG. 2: Excluded $\tilde{\gamma}$ masses as function of the SUSY breaking energy scale d (2a, assuming $m_e = 40$ GeV) and $\tilde{e}$ mass (2b, assuming $d = (100 \text{ GeV})^2$).

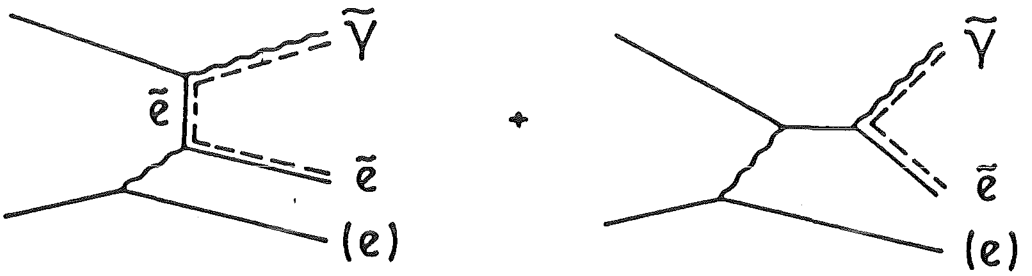
FIG. 3: Excluded $\tilde{e}$ and $\tilde{\gamma}$ masses for stable $\tilde{\gamma}$ (contours A, B, C) and stable $\tilde{e}$ (contour D).

FIG. 4: Limits on $\tilde{z}$ production assuming $m_{\tilde{\nu}} > m_{\tilde{z}}$.
4a: $m_{\tilde{g}} > m_{\tilde{z}}$, combined limit including searches for acoplanar leptons, acoplanar jets, and single jets.
4b: $m_{\tilde{g}} < m_{\tilde{z}}$, assuming the zino to decay 100 % into $q\bar{q}\tilde{g}$.

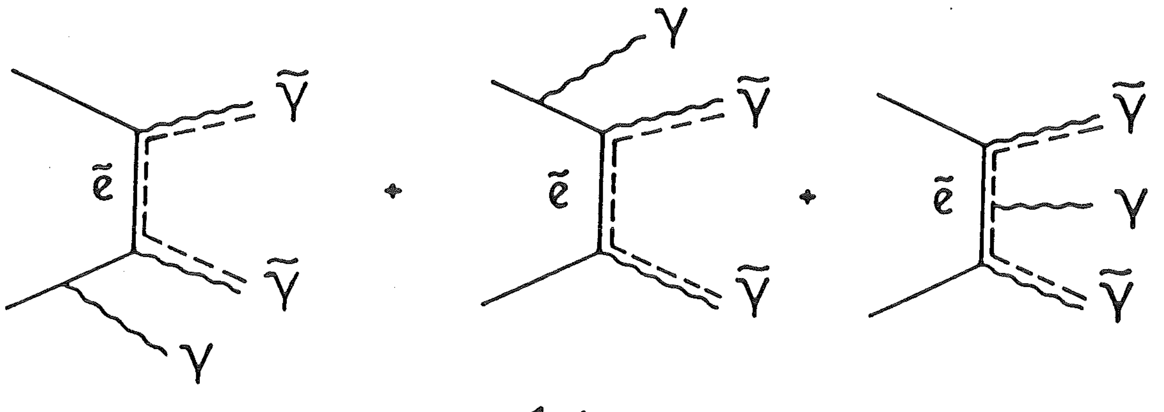
FIG. 5: Limits on chargino ($\tilde{\chi}^{\pm}$) pair production
5a: $m_{\tilde{\nu}} > m_{\tilde{\chi}}$
5b: $m_{\tilde{\nu}} < m_{\tilde{\chi}}$, the full line is for equal decay widths into $e\tilde{\nu}$, $\mu\tilde{\nu}$, and $\tau\tilde{\nu}$, the dashed line is for $BR(\tau\tilde{\nu}) >> BR(e\tilde{\nu}, \mu\tilde{\nu})$.



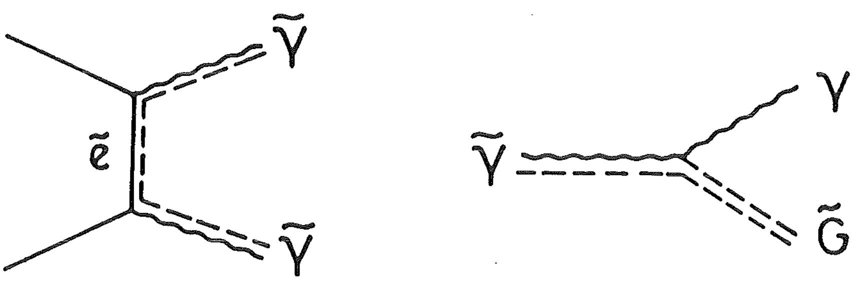
1a)



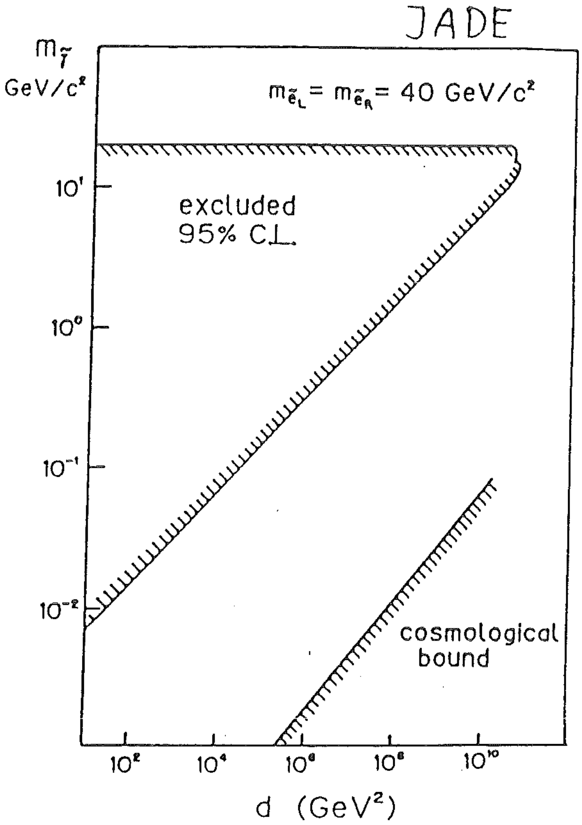
1b)



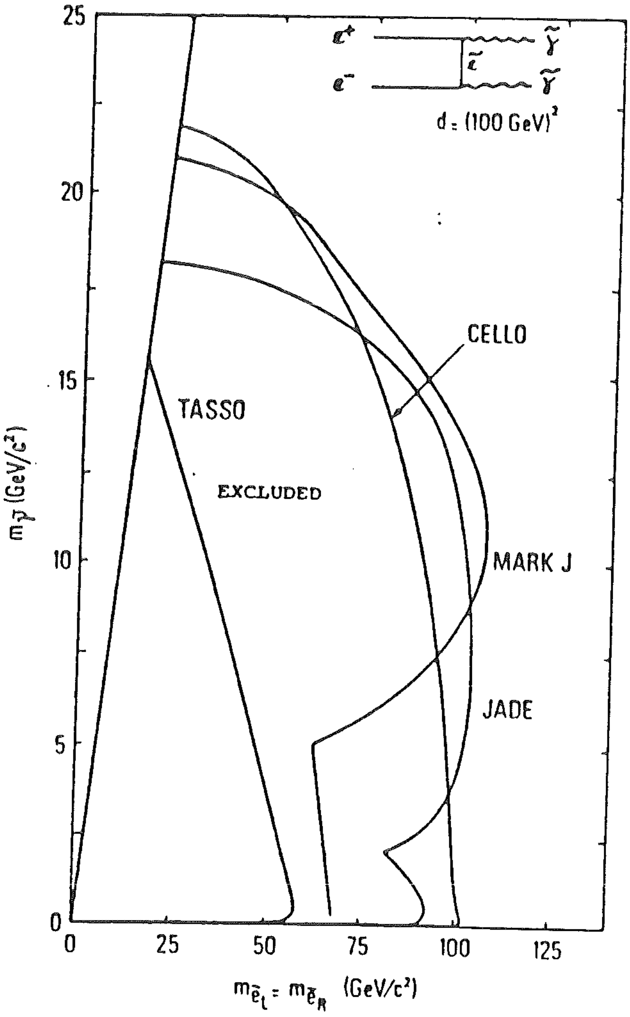
1c)



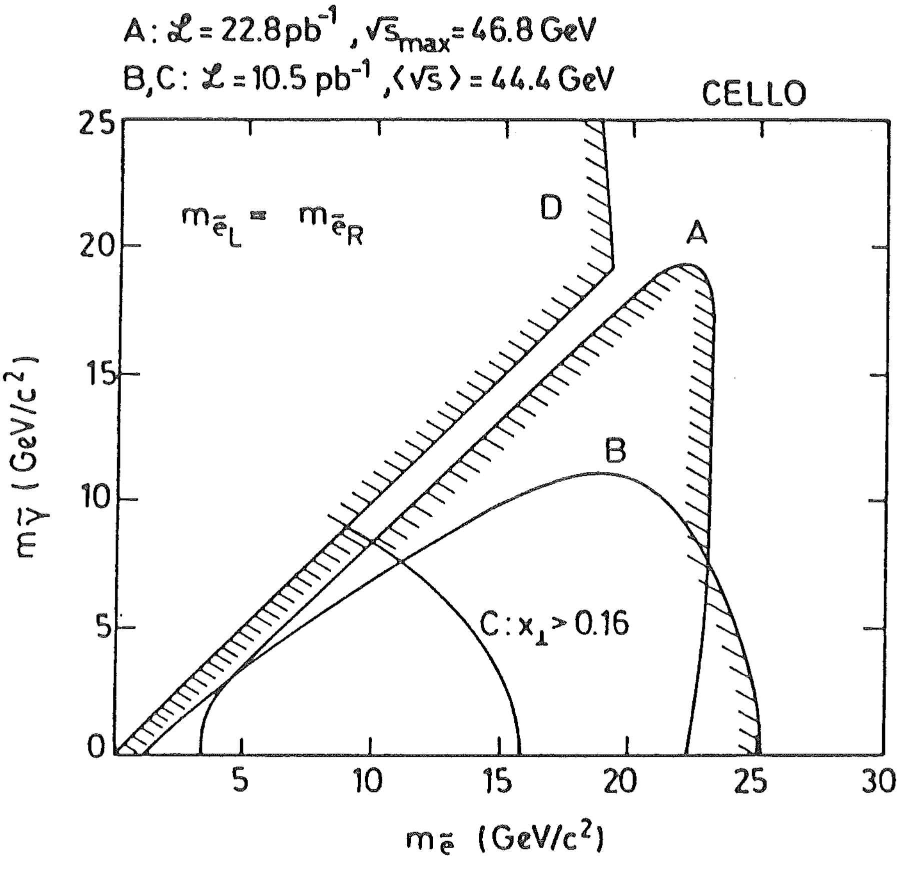
1d)


JADE
$m_{\tilde{\gamma}}$ GeV/c²
$m_{\tilde{e}_L} = m_{\tilde{e}_R} = 40$ GeV/c²
excluded
95% C.L.
cosmological bound
10^1
10^0
10^{-1}
10^{-2}
10^2
10^4
10^6
10^8
10^{10}
d (GeV²)

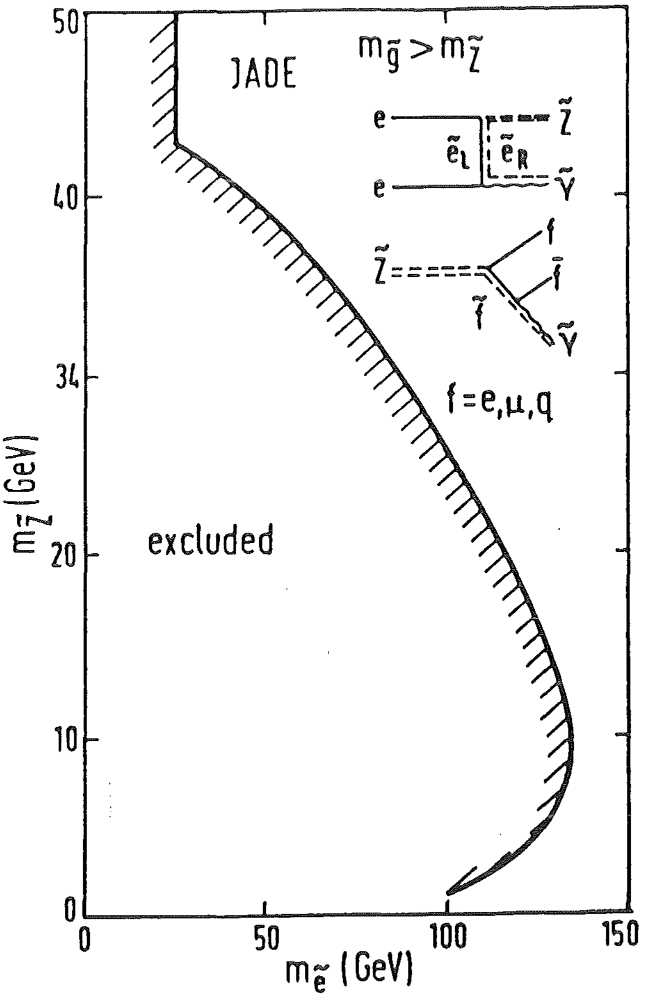
2 a)


e^+
e^-
$\tilde{e}$
$\tilde{\gamma}$
$\tilde{\gamma}$
d = (100 GeV)²
CELLO
TASSO
EXCLUDED
MARK J
JADE
$m_{\tilde{\gamma}}$ (GeV/c²)
0
5
10
15
20
25
0
25
50
75
100
125
$m_{\tilde{e}_L} = m_{\tilde{e}_R}$ (GeV/c²)

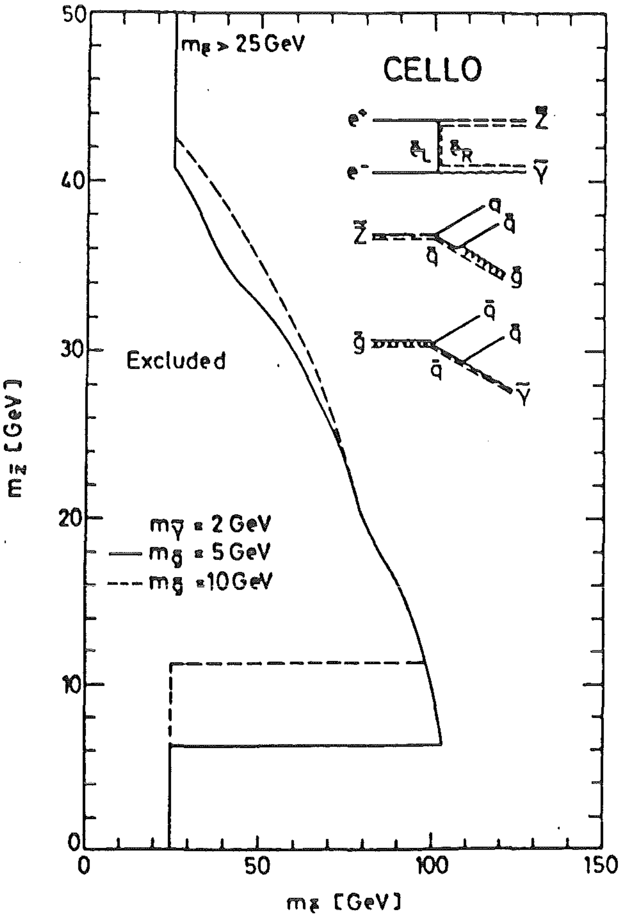
2 b)


A: $\mathcal{L} = 22.8\,pb^{-1}$, $\sqrt{s}_{max} = 46.8$ GeV
B,C: $\mathcal{L} = 10.5\,pb^{-1}$, $\langle\sqrt{s}\rangle = 44.4$ GeV
CELLO
$m_{\tilde{e}_L} = m_{\tilde{e}_R}$
D
A
B
C: $x_\perp > 0.16$
$m_{\tilde{\gamma}}$ (GeV/c²)
0
5
10
15
20
25
5
10
15
20
25
30
$m_{\tilde{e}}$ (GeV/c²)

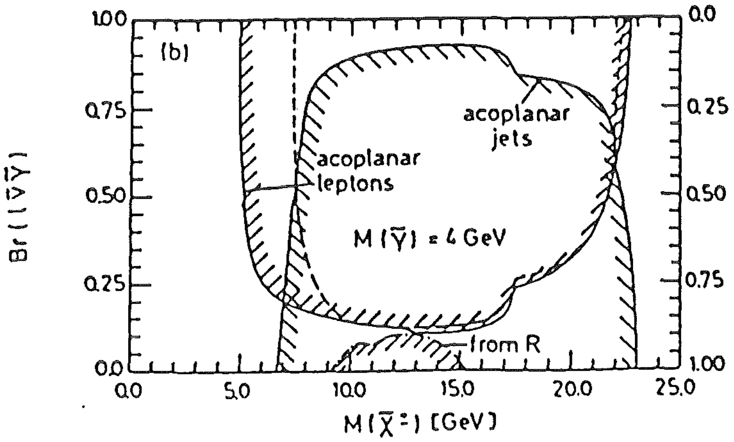
3


JADE
$m_{\tilde{g}} > m_{\tilde{Z}}$
e
e
$\tilde{e}_L$
$\tilde{e}_R$
$\tilde{Z}$
$\tilde{\gamma}$
$\tilde{Z}$
$\tilde{f}$
f
$\bar{f}$
$\tilde{\gamma}$
f=e,μ,q
excluded
$m_{\tilde{Z}}$ (GeV)
$m_{\tilde{e}}$ (GeV)
0
10
20
30
40
50
0
50
100
150

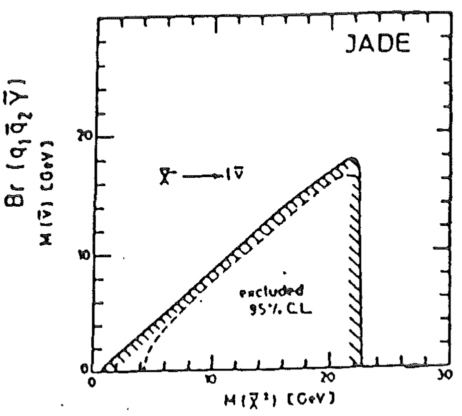
4a)


$m_{\tilde{e}} > 25$ GeV
CELLO
e^+
e^-
$\tilde{e}_L$
$\tilde{e}_R$
$\tilde{Z}$
$\tilde{\gamma}$
$\tilde{Z}$
q
$\bar{q}$
$\tilde{q}$
$\tilde{g}$
$\tilde{g}$
q
$\bar{q}$
$\tilde{q}$
$\tilde{\gamma}$
Excluded
$m_{\tilde{\gamma}}$ = 2 GeV
$m_{\tilde{g}}$ = 5 GeV
$m_{\tilde{g}}$ = 10 GeV
$m_{\tilde{Z}}$ [GeV]
$m_{\tilde{e}}$ [GeV]
0
10
20
30
40
50
0
50
100
150

4 b)


(b)
acoplanar jets
acoplanar leptons
M ($\tilde{\gamma}$) = 4 GeV
from R
Br (l $\tilde{\nu}$ $\tilde{\gamma}$)
M ($\tilde{\chi}^{\pm}$) [GeV]
0.0
0.25
0.50
0.75
1.00
0.0
0.25
0.50
0.75
1.00
0.0
5.0
10.0
15.0
20.0
25.0

5 a)


JADE
$\tilde{\chi}^{-} \longrightarrow l\tilde{\nu}$
excluded 95% C.L.
Br ($q_1 \bar{q}_2 \tilde{\gamma}$)
M ($\tilde{\nu}$) [GeV]
M ($\tilde{\chi}^{\pm}$) [GeV]
0
10
20
0
10
20
30

5 b)