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Abstract:

For the SUSY Standard Model we give a detailed discussion how HERA can be used for disentangling the mixing structure in the neutralino sector. We present 3-dimensional plots for the total cross section and for the polarization asymmetry for selectron-squark production, varying both the sfermion masses and a mixing parameter. The main results are: (i) production rates at HERA are reasonably large for a wide range of mixing parameters; (ii) the polarization asymmetry depends only weakly upon the sfermion masses and thus is a very useful tool in determining mixing parameters or mass splittings between left and right handed selectron masses.

I. Introduction

The search for supersymmetry (SUSY) will be one of the major tasks of the next generation of particle accelerators. In particular the SUSY standard model /1/, which in most scenarios of superstring inspired phenomenology arises as the low energy effective theory, requires the existence of new superpartners for all known quarks, leptons, Higgses and gauge bosons. Their mutual interaction, to a large extent, is determined by gauge and supersymmetry. For the ep-machine HERA various production mechanisms of supersymmetric particles have been considered, but with the present bounds /2/ on the masses of SUSY particles only one process continues to be of interest: the production of a scalar electron and a scalar quark via the exchange of neutralinos (Fig. 1). It has been estimated /3, 4/ that the cross section for this process is sufficiently large, provided the sum of the masses of scalar electron and quark does not exceed 180 GeV. The main experimental signature for this production process is missing momentum at both the lepton and the hadron branch, and detailed suggestions for the data analysis have been made in Refs. 3 and 4.

Apart from the existence of SUSY particles there exists another reason why this process will be of particular interest. Although much of the structure of the SUSY standard model follows from symmetry principles alone (supersymmetry and gauge symmetry), there are still quite a few free parameters in the model: apart from the masses of all scalar quarks and leptons there are also those parameters which result from the (soft) breakdown of supersymmetry and which give masses to the gauginos, especially to the photino, Zino, and the Wino. The translation from these parameters into physical masses requires the diagonalization of mass matrices, since the mass eigenstates are linear combinations of photino, Zino, and Higgsino (neutralino sector) or Wino and Higgsino (chargino sector). An experimental investigation of the gaugino sectors, therefore, will be an import part of the search for supersymmetry. The production process of Fig. 1 is particularly well-suited for examining the neutralino sector, since it allows for the exchange of all neutral fermions.

With our present understanding it seems reasonable to ask the following question: how do cross sections vary as functions of the SUSY-breaking parameters? What range of values can be explored by the HERA machine? In case SUSY particles are found it would, of course, be of extreme importance to find out, whether they fit into the SUSY standard model. This would, amongst others, make it necessary to measure those

parameters which determine the mixing structure. As a starting point, one might assume that the mass of one gaugino has been measured already, say the mass of the lighter of the two charginos. Then, even if one imposes one (theoretically very plausible) constraint, one is still left with a few free parameters which cannot be fixed by measuring only production cross sections, and one is lead to look for additional pieces of experimental information. A natural candidate is the use of polarized electron beams, and it is therefore of interest to calculate polarization asymmetries as a function of the mixing parameters.

In this paper we try to answer some of these questions. We first have calculated the integrated cross section as function of two (continuously varying) parameters: the sum of selectron and squark mass and one of the SUSY breaking parameters (at fixed mass for the lightest chargino). Results are shown in three-dimensional plots, and they nicely illustrate how the cross section varies as a function of the parameters: the strongest variation comes as a function of the "external" masses of selectron and squark, whereas all the SUSY breaking parameters (including the mass of the lighter chargino) only moderately affect the value of the cross section. This implies that HERA will be sensitive to a large range of the mixing parameters. Another consequence, on the other hand, is that the cross section is not well-suited to discriminate between different values of the mixing parameters. It, therefore, will be very useful to measure polarization asymmetries at HERA. We have calculated the polarization asymmetry as a function of the same parameters as we did for the production cross section, and the results are again shown in 3-dimensional plots. The most striking feature is that the polarization asymmetry practically stays constant when we vary the sum of masses of selectron and squark, whereas we find some variation in the direction of the mixing parameters. This suggests that the combination of production cross section and polarization asymmetry will be an excellent tool for fixing the values of the mixing parameters in the neutralino sector. We also have calculated both the production cross section and the asymmetry as a function of the mass difference between left-handed and right-handed selectron: here the polarization asymmetry shows a rather strong dependence and thus will be even more useful.

Similar calcuations have been performed and presented in two recent papers by Bartl et al. /5/ and by Komatsu and Rückl /6/. The first paper investigates, for three different sets of mixing parameters, the integrated cross section, the differential cross section for the decay electron and the polarization asymmetry. The second paper contains calculations of cross sections and charge asymmetries, both for the neutral current process $ep \to \tilde{e}\,\tilde{q}\,X$ and for the charge current process $ep \longrightarrow \tilde{\nu}\,\tilde{q}\,X$; all this is done for four different sets of mixing parameters. Since our emphasis is on the dependence upon the mixing parameters, we consider a continuous variation of one of them and thus cover a rather wide range. Moreover, three-dimensional plots turn out to be helpful in visualizing the variation in the high-dimensional parameter space. As to the polarization asymmetry, our analysis shows that it will be a useful tool. It should, however, be noted that the charge asymmetry which has been considered by Komatsu and Rückl /6/, from an experimental point of view, will be obtained more easily. As a function of "external" selectron and squark mass and of the "internal" SUSY mixing parameters it shows a rather similar dependence. In Ref. 7 a comparison between both asymmetries will be presented.

Our paper is organized in two parts. We first review those parts of the SUSY Standard Model which are essential for our discussion. In the second part (section 3) we first give a theoretical discussion of the interrelation between Wino and neutralino masses and the mixing parameters entering the Lagrangian. We then present and discuss our numerical results.

II. The Model

Our calculations are done for the minimal SUSY-extension of the standard model, which includes soft-breaking terms. We briefly summarize our notation and present the formulae for the cross sections. The mass matrix for the charginos follows from the interaction of the Higgs super-multiplets with the gauginos and from soft SUSY-breaking terms:

$$\mathcal{L}_{int}^{chargino} = -\frac{i g_2}{\sqrt{2}}\left[\psi_{H_1}^1 \tilde{W}^+ v_1 + \psi_{H_2}^2 \tilde{W}^- v_2\right] + M_2 \tilde{W}^+ \tilde{W}^- - \mu\, \psi_{H_1}^1 \psi_{H_2}^2 + h.c. \tag{2.1}$$

Here ψ_{H_1}, ψ_{H_2} are the two SU(2)-doublet Weyl spinors of the Higgsinos; $\tilde{W}^{\pm} = (\tilde{W}^1 \mp i\tilde{W}^2)/\sqrt{2}$ are the charginos; v_1 and v_2 the vacuum expectation values of the two scalar Higgs h_1 and h_2 with hyperchange $+\,^1/2$, $-\,^1/2$, resp.:

$$\langle h_1 \rangle = \frac{v_1}{\sqrt{2}}\begin{pmatrix} 0 \\ 1 \end{pmatrix}, \qquad \langle h_2 \rangle = \frac{v_2}{\sqrt{2}}\begin{pmatrix} 1 \\ 0 \end{pmatrix}. \tag{2.2}$$

The gauge couplings are defined within the covariant derivative:

$$\mathcal{D}_\mu = \partial_\mu - i g_2 \vec{I}\,\vec{W}_\mu + i g_1 Y B_\mu . \tag{2.3}$$

The constants M_2 and μ are the coefficients of soft-breaking terms which appear as the result of the breakdown of local SUSY at some higher energy scale. The 2x2 mass matrix to be diagonalized is

$$M_C = \begin{pmatrix} M_2 & \sqrt{2}\, m_W \sin\theta_V \\ \sqrt{2}\, m_W \sin\theta_V & \mu \end{pmatrix} \tag{2.4}$$

where $\tan\theta_V = v_1/v_2$. Let M_C be diagonalized by the two unitary matrices U, V: $U M_C V^{-1} = M_{cdiag}$, where the mass eigenvalues are (with $s_V = \sin\theta_V$, $c_V = \cos\theta_V$)

$$\tilde{M}_{C1,2} = \frac{1}{2}\left(M_2 + \mu \pm \sqrt{(M_2-\mu)^2 + 8 m_W^2 s_V c_V}\right) \tag{2.5}$$

Define

$$\psi^+ = \begin{pmatrix} i\tilde{W}^+ \\ \psi_{H_2}^2 \end{pmatrix}, \quad \psi^- = \begin{pmatrix} i\tilde{W}^- \\ \psi_{H_1}^1 \end{pmatrix}, \quad \chi_i^+ = V_{ij}\psi_j^+, \quad \chi_i^- = U_{ij}\psi_j^- .$$

These Weyl spinors can be combined to form two charged Dirac spinors:

$$\tilde{\chi}_1 = \begin{pmatrix} \chi_1^+ \\ \bar{\chi}_1^- \end{pmatrix} , \qquad \tilde{\chi}_2 = \begin{pmatrix} \chi_2^+ \\ \bar{\chi}_1^- \end{pmatrix} . \tag{2.6}$$

In terms of these spinors (2.1) takes the convenient form:

$$\mathcal{L}_{int}^{chargino} = - \tilde{M}_{C1} \bar{\tilde{\chi}}_1 \tilde{\chi}_1 - \tilde{M}_{C2} \bar{\tilde{\chi}}_2 \tilde{\chi}_2 . \tag{2.7}$$

For later discussion it will also be useful to solve (2.5) for μ. In terms of the mass of the lighter chargino, $\tilde{M}_{c1}$ (which can also be negative):

$$\mu = \frac{2 m_W^2 s_v c_v + M_2 \tilde{M}_{C1} - \tilde{M}_{C1}^2}{M_2 - \tilde{M}_{C1}} . \tag{2.8}$$

The mass matrix of the neutralinos follows from another part of the interaction of the Higgs super-multiplets with the gauginos:

$$\mathcal{L}_{int}^{neutral} = \frac{i g_2}{2} \left(\tilde{W}^3 \psi_{H_1}^2 v_1 - \tilde{W}^3 \psi_{H_2}^1 v_2 \right) + \frac{i g_1}{2} \left(\tilde{B} \psi_{H_1}^2 v_1 - \tilde{B} \psi_{H_2}^1 v_2 \right)$$
$$+ \frac{1}{2} M_2 \tilde{W}^3 \tilde{W}^3 + \frac{1}{2} M_1 \tilde{B} \tilde{B} + \mu \psi_{H_1}^2 \psi_{H_2}^1 + h.c. \tag{2.9}$$

Here M_1 is a further free parameter of a soft SUSY-breaking term. One conveniently defines:

$$\psi = \begin{pmatrix} i \tilde{\gamma} \\ i \tilde{Z} \\ \psi_- \\ \psi_+ \end{pmatrix} \tag{2.10}$$

with ($s_W = \sin \theta_W$, $c_W = \cos \theta_W$)

$$\begin{aligned} \tilde{\gamma} &= s_W \tilde{W}_3 - c_W \tilde{B} \\ \tilde{Z} &= c_W \tilde{W}_3 + s_W \tilde{B} \\ \psi_+ &= c_v \psi_{H_1}^2 + s_v \psi_{H_2}^1 \\ \psi_- &= s_v \psi_{H_1}^2 - c_v \psi_{H_2}^1 \end{aligned} \tag{2.11}$$

Then (2.9) becomes:

$$\mathcal{L}_{int}^{neutral} = - \frac{1}{2} \psi^T M_n \psi \tag{2.12}$$

with

$$M_n = \begin{pmatrix} M_1 c_W^2 + M_2 s_W^2 & (M_2 - M_1) s_W c_W & 0 & 0 \\ (M_2 - M_1) s_W c_W & M_1^2 s_W^2 + M_2^2 c_W^2 & -m_Z & 0 \\ 0 & -m_Z & \mu \sin 2\theta_v & \mu \cos 2\theta_v \\ 0 & 0 & \mu \cos 2\theta_v & -\mu \sin 2\theta_v \end{pmatrix} \tag{2.13}$$

This symmetric matrix can be diagonalized by the orthogonal matrix N of eigenvectors. Defining the spinors

$$\chi_i = (N^T)_{ij} \psi_j \tag{2.14}$$

with $N = (\vec{x}_1, \vec{x}_2, \vec{x}_3, \vec{x}_4)$ we can form four Majorana spinors

$$\check{\chi}_i = \begin{pmatrix} \chi_i \\ \bar{\chi}_i \end{pmatrix} . \tag{2.15}$$

The Lagrangian (2.9) then becomes:

$$\mathcal{L}_{int}^{neutral} = - \frac{1}{2} \sum_{i=1}^{4} m_i \bar{\check{\chi}}_i \check{\chi}_i \tag{2.16}$$

where m_i are the eigenvalues of (2.13). For special cases it is straight forward to diagonalize (2.13) and to find analytic expressions for the neutralino masses. For example, supergravity models /8/ suggest that M_1 and M_2 are related through

$$M_1 = \frac{5}{3} \frac{s_W^2}{c_W^2} M_2 \tag{2.17}$$

If M_1 (and M_2) are small (compared to m_z and μ) we always have a pure light photino state. For $v_1 = v_2$ $\cos\theta_v = 0$, and ψ_+ decouples from the rest of the matrix. The remaining 2x2 matrix can easily be diagonalized. For more general cases one uses the computer.

Next we present the formulae for the cross sections. The Feynman rules which follow from our conventions are consistent with those in Ref. 1. We first consider the parton subprocess $e+q \to \tilde{e}+\tilde{q}$ with definite initial helicities (Fig. 1). In the tree approximation we only keep the diagrams with B and W_3 in the exchange channel. Through (2.11) and (2.14) they are expressed in terms of eigenstates of the mass matrix (2.13). For the squares of matrixelements we obtain:

$$|M^f_{LL}|^2 = 4xs \sum_{i,j=1}^{4} \frac{E_L^i E_L^j F_L^i F_L^j \; m_i m_j}{(Q^2+m_i^2)(Q^2+m_j^2)}$$

$$|M^f_{RR}|^2 = 4xs \sum_{i,j=1}^{4} \frac{E_R^i E_R^j F_R^i F_R^j \; m_i m_j}{(Q^2+m_i^2)(Q^2+m_j^2)}$$

$$|M^f_{LR}|^2 = 4\left[xs\,Q^2 - (Q^2+m^2_{\tilde{e}_L})(Q^2+m^2_{\tilde{q}_R})\right] \cdot \sum_{i,j=1}^{4} \frac{E_L^i E_L^j F_R^i F_R^j}{(Q^2+m_i^2)(Q^2+m_j^2)} \tag{2.18}$$

$$|M_{RL}|^2 = 4\left[xs\,Q^2 - (Q^2+m^2_{\tilde{e}_R})(Q^2+m^2_{\tilde{q}_L})\right] \cdot \sum_{i,j=1}^{4} \frac{E_R^i E_R^j F_L^i F_R^j}{(Q^2+m_i^2)(Q^2+m_j^2)}$$

In $M^f_{\lambda\sigma}$ (λ,σ = L,R) the subcripts refer to chiralities of electron and quark, resp. (note that for energies large against the rest masses chirality = helicity). The masses m_i are the eigenvalues of the mass matrix (2.13): they can also be negative. By the transformation $\psi \to i\gamma_5\psi$ such a negative eigenvalue can always be turned into a physical (i.e. positive) mass, but then (2.18) has to be charged accordingly: $m_i m_j \to \eta_i \eta_j |m_i||m_j|$ where $\eta_i = +1\ (-1)$ if m_i was positive (negative).

The coupling constants $E^i_{L,R}$, $F^i_{L,R}$ are:

$$\begin{aligned} E_L^i &= Q_e \cdot x_i(1) + g_L^e \cdot x_i(2) \\ E_R^i &= Q_e \cdot x_i(1) + g_R^e \cdot x_i(2) \\ F_L^i &= Q_f \cdot x_i(1) + g_L^f \cdot x_i(2) \\ F_R^i &= Q_f \cdot x_i(1) + g_R^f \cdot x_i(2) \end{aligned} \tag{2.19}$$

where $x_i(1)$, $x_i(2)$ ... are the first, second, ... components of the eigenvector $\vec{x}_i$ of (2.13), belonging to the eigenvalue m_i, and the couplings $g^{1,f}_{L,R}$ are listed in Table 1.

The differential cross section for selectron-squark production in deep inelastic ep-scattering then is:

$$\frac{d^2\sigma(\lambda)}{d\nu\, dQ^2} = \frac{\pi\alpha^2}{s^2\nu} \cdot \frac{1}{2} \sum_f \frac{q_f(x_f, Q^2)}{x_f} \left\{ |M^f_{\lambda L}|^2 + |M^f_{\lambda R}|^2 \right\} \tag{2.20}$$

The q_f's are the distribution functions /9/ of the quark with flavor f. We have averaged over the helicity of the quark, and for simplicity we have assumed that for each flavor left and right-handed squarks have the same mass. Then the connection between x_f and Q^2 and ν is:

$$x_f = \frac{Q^2 + m^2_{\tilde{q}_f}}{2\nu} \tag{2.21}$$

For each flavor the differential cross section in x_f is:

$$\frac{d^2\sigma(\lambda)}{dx_f\, dQ^2} = \frac{\pi\alpha^2}{s^2} \cdot \frac{1}{2x_f^2}\; q_f(x_f, Q^2)\left\{|M_{\lambda L}|^2 + |M_{\lambda R}|^2\right\}. \tag{2.22}$$

Finally, integrated cross sections are:

$$\sigma(\lambda) = \int_{x_1}^{1} dx \int_{Q_1^2}^{Q_2^2} dQ^2 \; \frac{d^2\sigma(\lambda)}{dx\, dQ^2} \tag{2.23}$$

with $d^2\sigma/dx\,dQ^2$ from (2.20). For simplicity we further assume that $m_{\tilde{q}}$ is independent of flavor, and in (2.22) we sum over f. The limits of integration are:

$$x_1 = \frac{(m_{\tilde{e}_\lambda} + m_{\tilde{q}})^2}{s}$$

$$Q^2_{2,1} = \frac{1}{2}\left\{ xs - m^2_{\tilde{e}_\lambda} - m^2_{\tilde{q}} \pm \sqrt{(xs - m^2_{\tilde{e}_\lambda} - m^2_{\tilde{q}})^2 - 4 m^2_{\tilde{e}_\lambda} m^2_{\tilde{q}}} \right\} \tag{2.24}$$

In the following section we shall present results for the unpolarized cross section

$$\sigma_u = \frac{1}{2}\left[\sigma(-) + \sigma(+)\right] \tag{2.25}$$

and the polarization asymmetry (left-right asymmetry):

$$A_{LR} = \frac{\sigma(-) - \sigma(+)}{\sigma(-) + \sigma(+)} \tag{2.26}$$

III. Results

Before we start presenting and discussing the results of our calculations, we have to say a few words about the mixing problem mentioned in the previous section. Our theory has to be considered as a function of several parameters of the supersymmetric sector: the masses of scalar quarks and leptons (each of them can be different for left and right-handed species), the ratio v_1/v_2, and the symmetry breaking parameters M_1, M_2 and μ (which determine the masses of charginos and neutralinos). Taking the attitude that, with our present status of understanding, all these parameters are unknown, we are interested in three questions: first, how do observable quantities (cross sections, asymmetries) vary as a function of these parameters; secondly, which range is of interest for HERA; finally, in which way can we fix these parameters from experiment, once signals for supersymmetry have been found. In order to make our analysis somewhat simpler we have choosen to link M_1 and M_2 together ((2.17)). Furthermore, it turns out that, to a very good approximation the integrated cross section (2.23) only depends upon the sum $m_{\tilde{e}}+m_{\tilde{q}}$, rather than the individual masses (this can, in part, be seen directly from (2.24): the strongest dependence is through the lower limit x_1). Next we assume that the mass of one of the gauginos may be known, say the lighter chargino: As a result, we are left with only three parameters, $m_{\tilde{e}}+m_{\tilde{q}}$, M_2 and v_1/v_2. For a fixed value of $\tilde{M}_{c1}$ and v_1/v_2 we have functions of the two variables $m_{\tilde{e}}+m_{\tilde{q}}$ and M_2.

Since the parameter M_2 is not a physical mass one might want to express it in terms of, say, the mass m_1 of the lightest neutralino. It follows, however, from the formulae given in the previous section that m_1 does not uniquely determine M_2. First of all, there is the sign ambiguity: $\tilde{M}_{c1,2}$ in (2.5) and the eigenvalues m_i of (2.13) can be either positive or negative, and these two cases, from an experimental point of view, are indistinguishable. An experimental determination of $\tilde{M}_{c1}$, therefore, allows already for two different relations between M_2 and μ (cf. eq. (2.8)), depending upon whether $\tilde{M}_{c1}$ is positive or negative. Secondly, even once a choice has been made, the mass m_1 of the lightest neutralino may still allow for different values of M_2. We illustrate this situation in Figs. 2a-d: for different values $\tilde{M}_{c1}$ (+ 50 GeV, - 50 GeV, - 80 GeV, - 150 GeV) we plot, as a function of M_2, the chargino (lower figure) and neutralino masses (upper figure) (always absolute values). As an example, the smallest neutralino mass m_1 in Fig. 2a stays almost constant over a large range in M_2. Hence m_1 does not fix M_2. It is because of these ambiguities that we will present our results as a function of the (unphysical) parameter M_2 rather than the (more physical) lightest neutralino mass m_1.

There is another peculiarity in the translation from the SUSY breaking parameters M_2 and μ to physical masses. It follows from (2.5) and (2.8) that, if the lightest chargino is heavier than $\sqrt{2 s_V c_V} \cdot m_W$, the parameter M_2 has to be bigger than $\sqrt{\tilde{M}_{c1}^2 - 2 s_V c_V m_W^2}$. This explains why our plots in Figs. 2d,e do not start at $M = 0$ but further to the right.

It may also be useful to say a few words about the mixing content of the mass eigenstates. In Figs. 2a-d we have chosen $v_1 = v_2$; hence one of the Higgsino states always decouples (cf. discussion after (2.17)). The corresponding neutralino mass is drawn as a dashed line. The coupling of this state to electron or quark is tiny and can therefore be neglected. As to the remaining states, for $M_2 = 0$ there is always a massless pure photino state. With increasing M_2, this state gets admixtures of Zino and Higgsino. The two other eigenstates are always mixtures and do not show any simple pattern.

After this general discussion we turn to our results. In Figs. 3a-e we plot the integrated cross section for $\tilde{e}\,\tilde{q}$-production as a function of the sum of selectron and squark mass (80 GeV $\leq m_{\tilde{e}} + m_{\tilde{q}} \leq$ 200 GeV) and M_2 ($0 \leq M_2 \leq 200$ GeV). $\tilde{M}_{c1}$ has the values 50 GeV, - 50 GeV, - 80 GeV, - 150 GeV, resp. In Fig. 3e we take again $\tilde{M}_{c1}$ = - 50 GeV, but now $v_1/v_2 = 0.1$ (in all other cases $v_1 = v_2$). Clearly, the strongest variation is in the direction of the "external" masses $m_{\tilde{e}} + m_{\tilde{q}}$. We indicate where the cross section passes the value 0.1 pb: one concludes that HERA should be able to detect SUSY events provided $m_{\tilde{e}} + m_{\tilde{q}} \leq$ 180 GeV. This cofirms similar findings of Refs. 3 and 6. In the direction of M_2 there is much less variation: some changes are seen mainly for small $M_2 \lesssim$ 50 GeV. Comparing Figs. 3a-e one feels that the variation of the cross sections as a function of $\tilde{M}_{c1}$, or v_1/v_2 is of the same order of magnitude as the variation in M_2: all these parameters only affect masses and mixing in the t-channel, and integrated cross sections are less sensitive to it, than they are to the "external" masses. An important consequence of this is that HERA will cover a wide range of values of these mixing parameters and neutralino masses. As a further test , we have extended, for Figs. 3b, the M_2-direction up to 600 GeV: for $m_{\tilde{e}} + m_{\tilde{q}}$ = 80 GeV, the cross section drops by a factor of 4 between M_2 = 200 GeV and M_2 = 600 GeV, for $m_{\tilde{e}} + m_{\tilde{q}}$ = 150 GeV by a factor of 3. For Fig. 3a, the cross section drops somewhat less.

It will, on the other hand, be difficult to extract these mixing parameters from $\tilde{M}_{c1}$ and the SUSY cross sections alone. We therefore have to look for other quantities and their dependence upon the mixing structure. Apart from the charge asymmetry (which has been discussed in Ref. 6) the most promising candidate is the use of polarization. As a start, we have calculated the polarization asymmetry for the same range of parameters as we have used for the cross section. This provides a substantial generalization of calculations contained in Ref. 5. Our results are shown in Figs. 4a-e. The most striking difference between cross section and asymmetry is the dependence upon selectron and squark masses: here it is much weaker than in Figs. 3a-e. As a function of the other parameters - $\tilde{M}_{c1}$, v_1/v_2, M_2 - the variation is the same order of magnitude in both cases. Strongest variation is again in the region of small M_2.

A combination of cross section and polarization asymmetry could, therefore, be used for disentangling the mixing structure in the neutralino sector. In a first step one isolates the events in which SUSY particles are produced. This is discussed in some detail in Ref. 3, Assuming that the masses of SUSY particles $m_{\tilde{e}}$, $m_{\tilde{q}}$, $\tilde{M}_{c1}$ are measured independently - either at LEP or, by other methods /11/, at HERA - the values of the integrated cross section and the polarization asymmetry provide two constraints on the mixing parameters in the neutralino sector.

It should, however, be noted that the same procedure could be applied also to the charge asymmetry which, from an experimental point of view, can be obtained more easily. The results of Komatsu and Rückl /6/ indicate that this quantity also behaves very nicely: there is little variation in the direction of selectron and squark mass, whereas as a function of mixing parameters the asymmetry seems to vary somewhat stronger than the polarization asymmetry. A direct comparison of charge and polarization asymmetry is made in Ref. 7 and confirms this impression. It therefore seems as if the measurement of the integrated cross section and of both asymmetries may be sufficient to completely fix the mixing structure in the neutralino sector.

In all calculations discussed so far we have assumed that left and right handed scalar electron have the same mass. In many models /10/, however, soft SUSY breaking gives different masses to the SUSY partners of left and right handed isodoublet particles which leads to a mass splitting between, e.g., $\tilde{e}_L$ and $\tilde{e}_R$ up to the order of 10 GeV. Here polarization of incoming electrons seems to be an excellent method to measure such a mass difference. We therefore have calculated the polarization asymmetry as a function of the averaged selectron mass $m_{\tilde{e}} = \frac{1}{2}(m_{\tilde{e}_R}+m_{\tilde{e}_L})$ (more precisely: $m_{\tilde{q}}+m_{\tilde{e}}$) and the mass splitting $\Delta m_{\tilde{e}} = m_{\tilde{e}L} - m_{\tilde{e}R}$. In Figs. 5a and b we plot our results for the unpolarized cross section and the polarization asymmetry, resp. Whereas the cross section does not depend at all upon the mass splitting, the asymmetry is seen to be rather sensitive to it. In the direction of the average mass, on the other hand, we have the opposite behavior: σ drops rapidly whereas the asymmetry stays approximately constant. This suggests that, again, the combination of cross section and asymmetry could be used to narrow down the number of unknown parameters. In fact, this may be the place where the polarization asymmetry is most valuable.

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Table 1

	e	u	d
Q	-1	$\frac{2}{3}$	$-\frac{1}{3}$
g_L	$\frac{-1+2s_W^2}{2s_W c_W}$	$\frac{-4/3\, s_W^2+1}{2s_W c_W}$	$\frac{-1+2/3\, s_W^2}{2s_W c_W}$
g_R	$\frac{s_W}{c_W}$	$-\frac{2}{3}\frac{s_W}{c_W}$	$\frac{s_W}{3c_W}$

Figure Captions:

Fig. 1: The process $ep \to \tilde{e}\,\tilde{q}\,X \to e\,\gamma\,X$

Fig. 2: Eigenvalues (absolute values) of the neutralino mass matrix (upper figure) and of the chargino mass matrix (lower figure) as a function of M_2; the mass M_{c1} of the lightest chargino is held fixed.

(a) $\tilde{M}_{c1}$ = 50 GeV, v_1/v_2 = 1; (b) $\tilde{M}_{c1}$ = - 50 GeV, v_1/v_2 = 1;

(c) $\tilde{M}_{c1}$ = - 80 GeV, v_1/v_1 = 1; (d) $\tilde{M}_{c1}$ = - 150 GeV, v_1/v_2 = 1;

(e) $\tilde{M}_{c1}$ = - 50 GeV, v_1/v_2 = 0.1

The dashed curves in Figs. (a)-(d) belong to the Higgsino state which decouples from the other states.

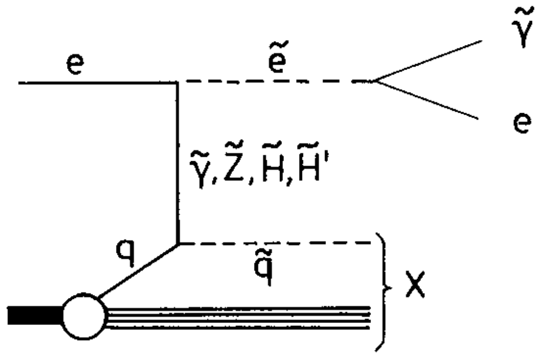
Fig. 3: Integrated cross sections as functions of $m_{\tilde{e}}+m_{\tilde{q}}$ and M_2. The black lines indicate where the cross section passes the value 0.1 pb. The parameters $\tilde{M}_{c1}$ and v_1/v_2 are the same as in Fig. 2.

Fig. 4: Polarization asymmetries as functions of $m_{\tilde{e}}+m_{\tilde{q}}$ and M_2. The parameters $\tilde{M}_{c1}$ and v_1/v_2 are the same as in Figs. 2 and 3.

Fig. 5: Integrated cross section (a) and polarization asymmetry (b) as functions of $m_{\tilde{e}}+m_{\tilde{q}}$ and $\Delta m_{\tilde{e}}$ (see text). Values of the parameters are M_2 = 0, $\tilde{M}_{c1}$ = - 50 GeV, v_1/v_2 = 1.

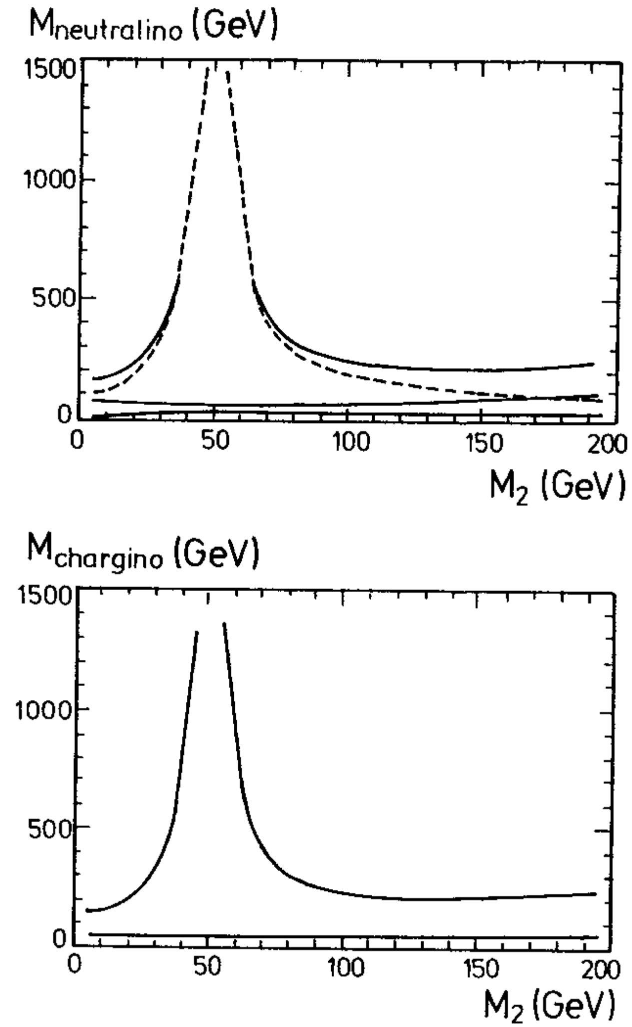
Table caption:

Table 1: Coupling constants in eq. (2.19)



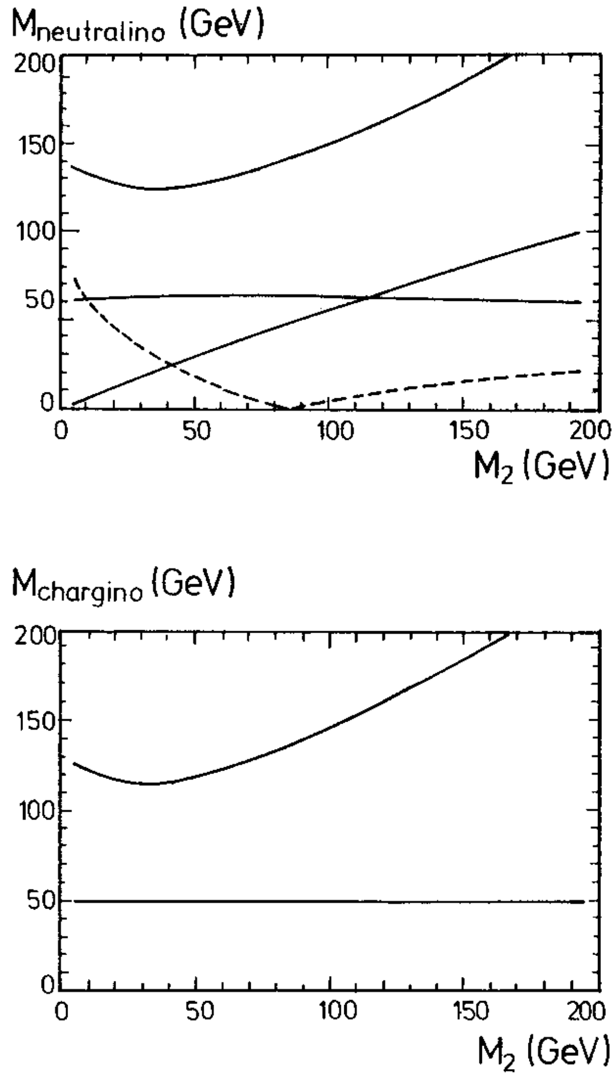
e
ẽ
γ̃
e
γ̃, Z̃, H̃, H̃'
q
q̃
X

Fig.1



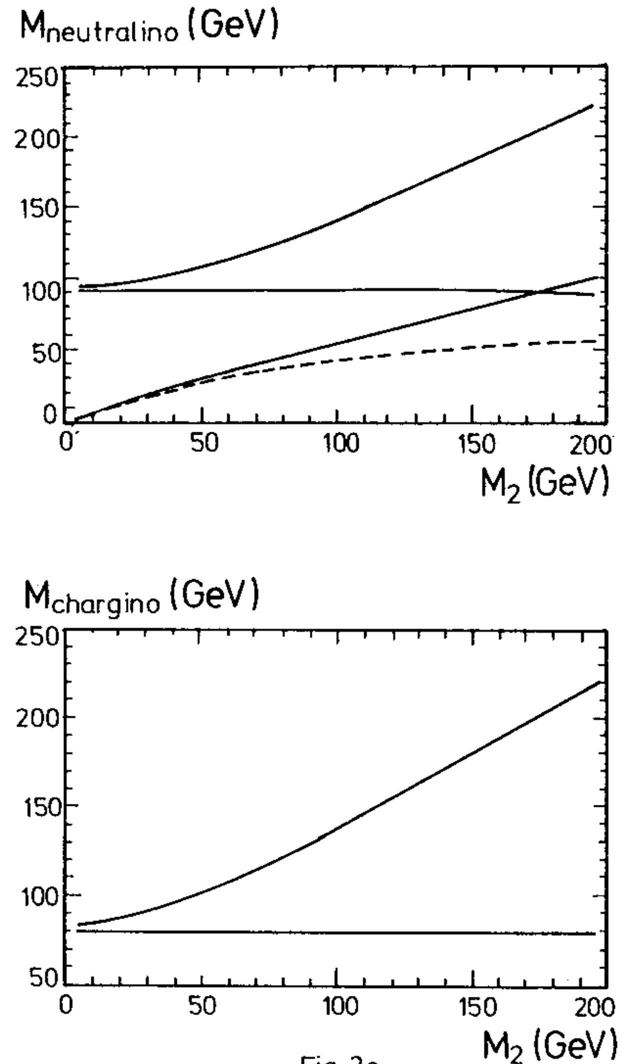
Mneutralino (GeV)
1500
1000
500
0
0
50
100
150
200
M2 (GeV)
Mchargino (GeV)
1500
1000
500
0
0
50
100
150
200
M2 (GeV)

Fig. 2a



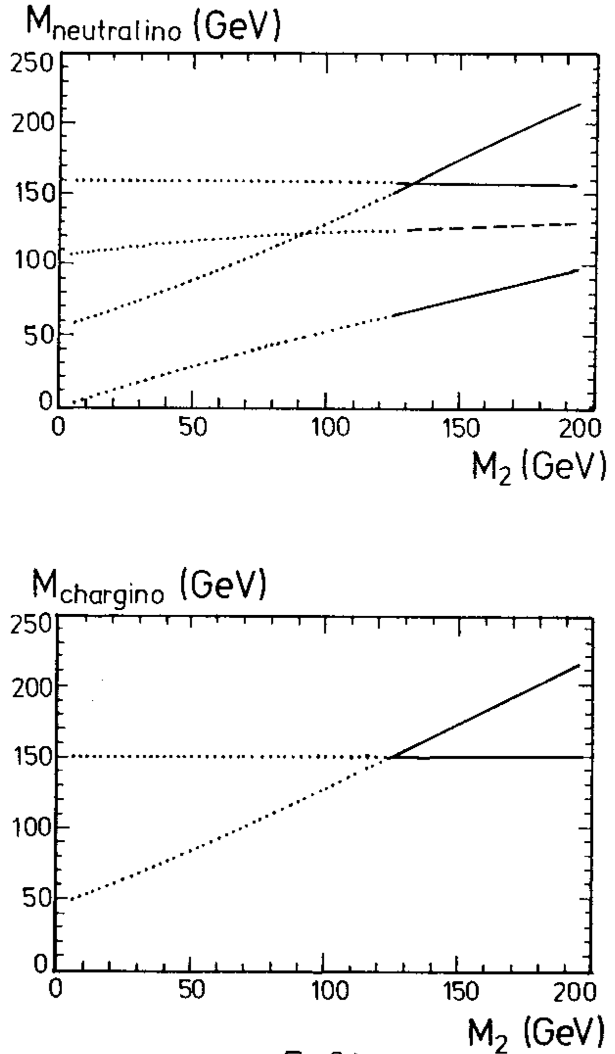
M_neutralino (GeV)
M_2 (GeV)
M_chargino (GeV)
M_2 (GeV)

Fig. 2b



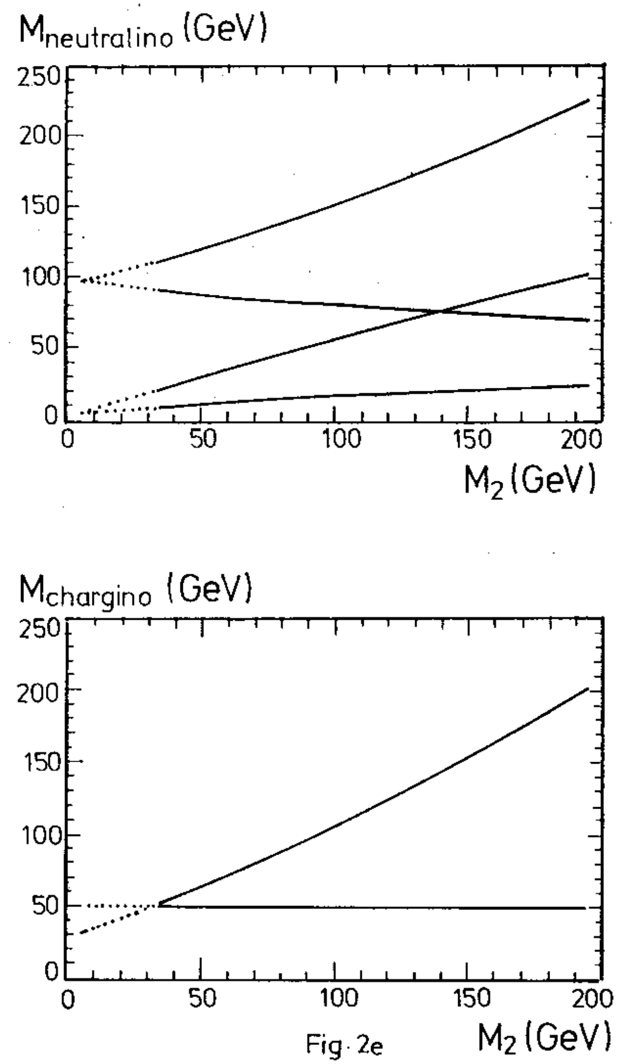
M_neutralino (GeV)
M_2 (GeV)
M_chargino (GeV)
M_2 (GeV)

Fig. 2c



$M_{neutralino}$ (GeV)
250
200
150
100
50
0
0
50
100
150
200
M_2 (GeV)
$M_{chargino}$ (GeV)
250
200
150
100
50
0
0
50
100
150
200
M_2 (GeV)

Fig. 2d



$M_{neutralino}$ (GeV)
250
200
150
100
50
0
0
50
100
150
200
M_2 (GeV)
$M_{chargino}$ (GeV)
250
200
150
100
50
0
0
50
100
150
200
M_2 (GeV)

Fig. 2e

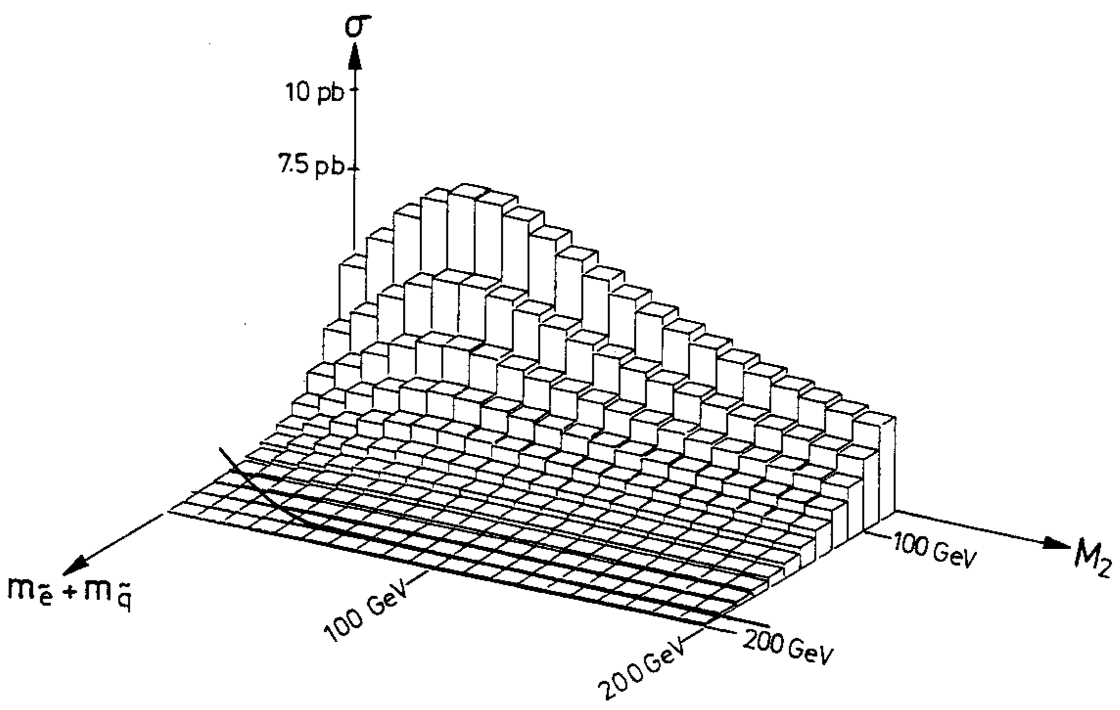

σ
10 pb
7.5 pb
100 GeV
M2
m_ẽ + m_q̃
100 GeV
200 GeV
200 GeV

Fig. 3a

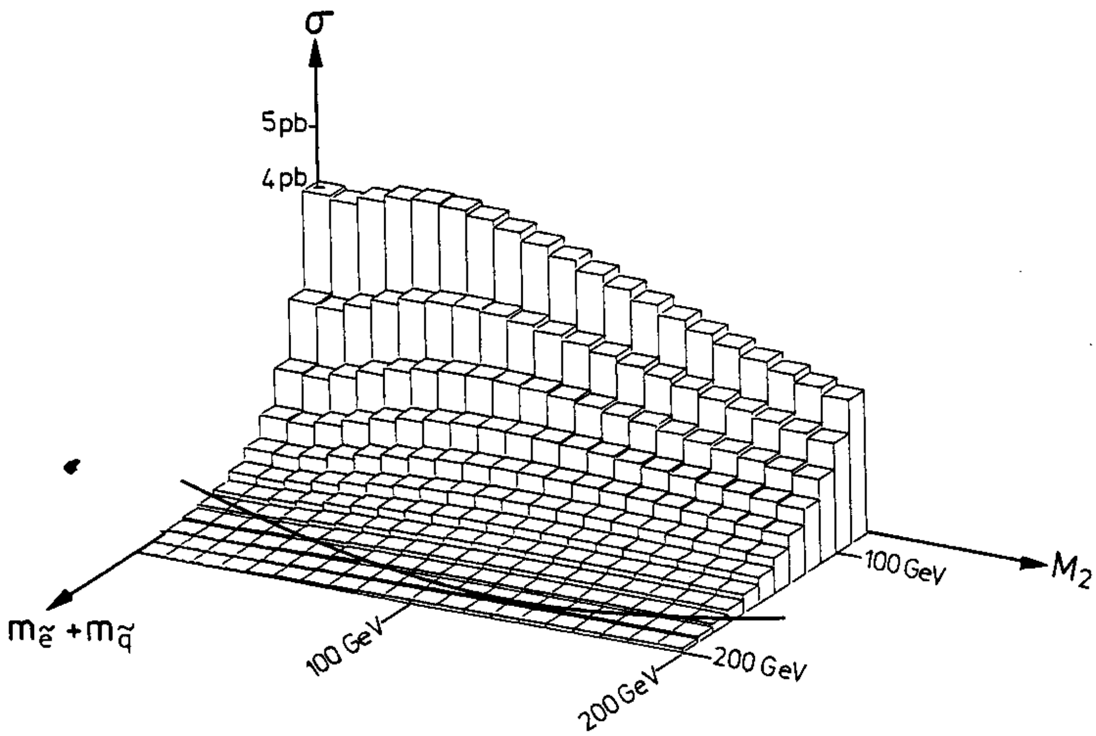
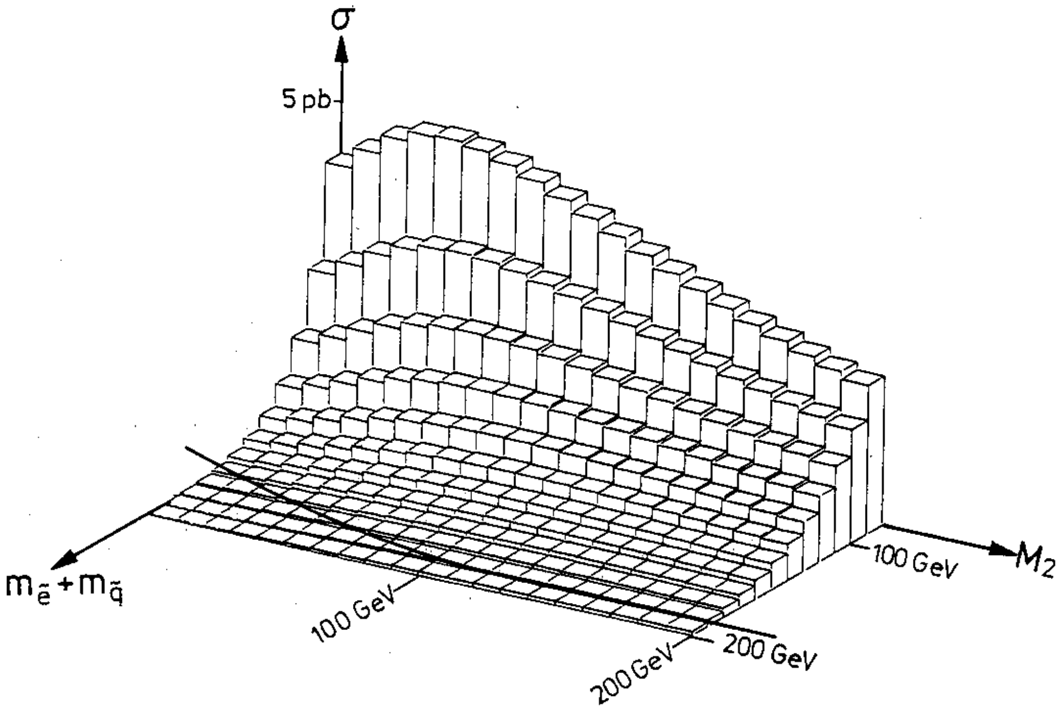
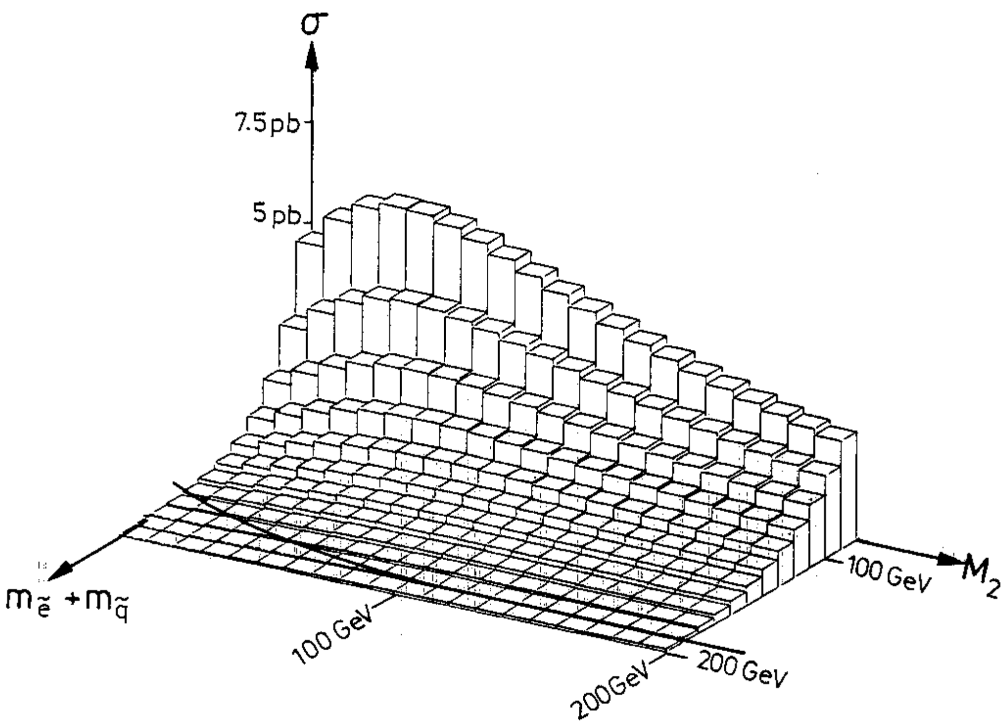

σ
5 pb
4 pb
100 GeV
M2
m_ẽ + m_q̃
100 GeV
200 GeV
200 GeV

Fig. 3b



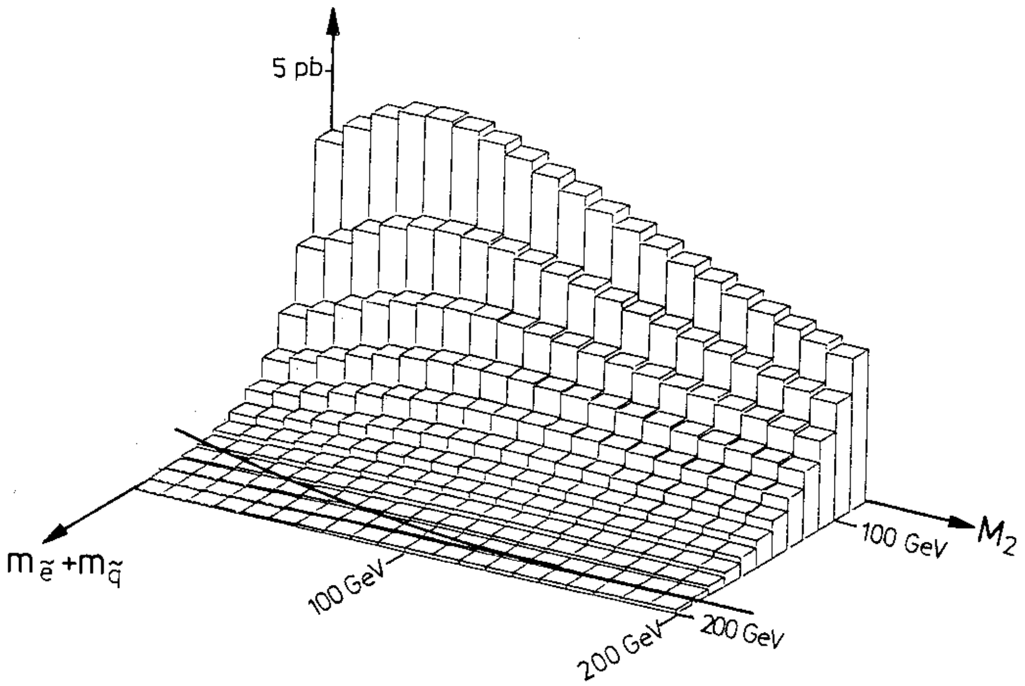
σ
5 pb
$m_{\tilde{e}} + m_{\tilde{q}}$
100 GeV
200 GeV
200 GeV
100 GeV
M_2

Fig.3c



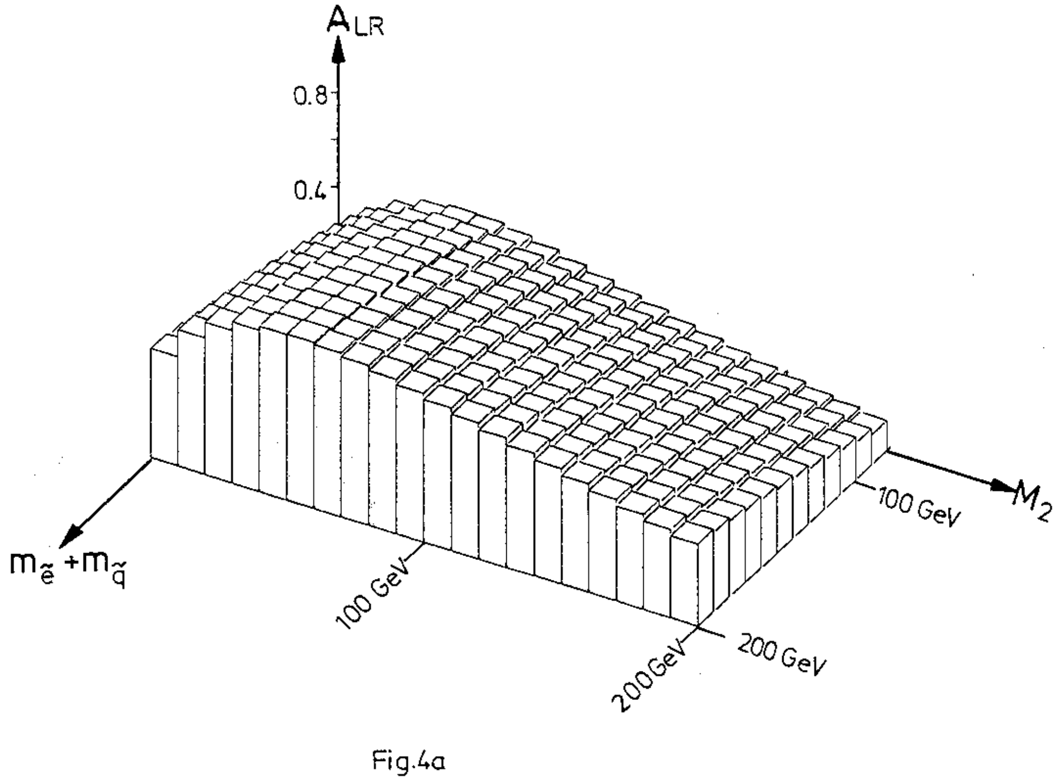
σ
7.5 pb
5 pb
$m_{\tilde{e}} + m_{\tilde{q}}$
100 GeV
200 GeV
200 GeV
100 GeV
M_2

Fig.3d



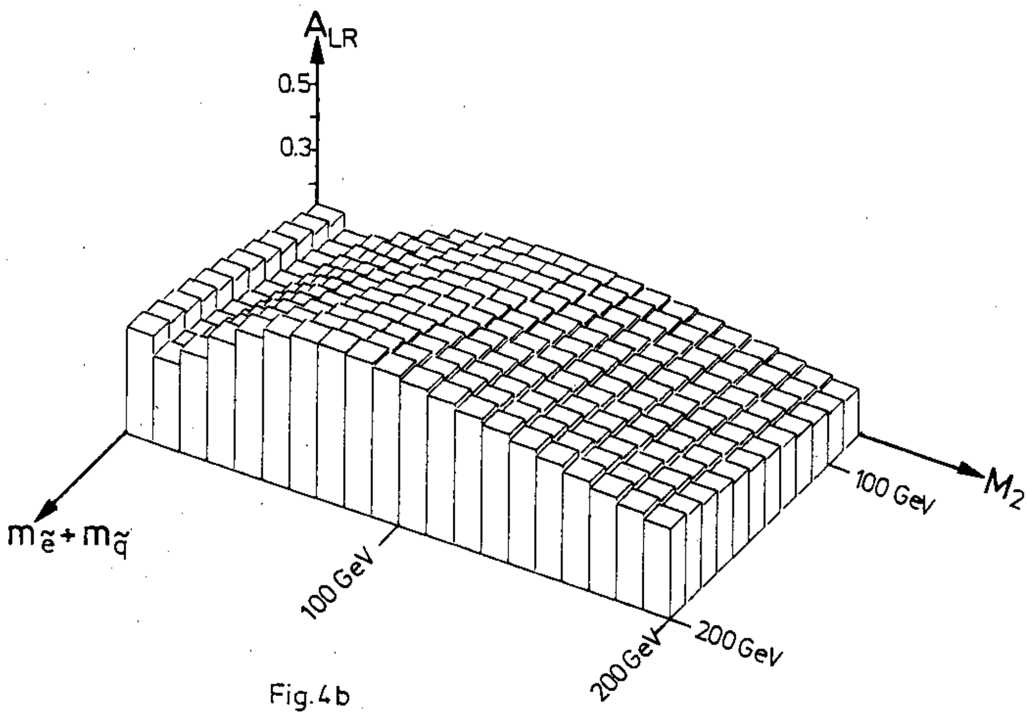
5 pb
$m_{\tilde{e}} + m_{\tilde{q}}$
100 GeV
200 GeV
100 GeV
200 GeV
M_2

Fig. 3e



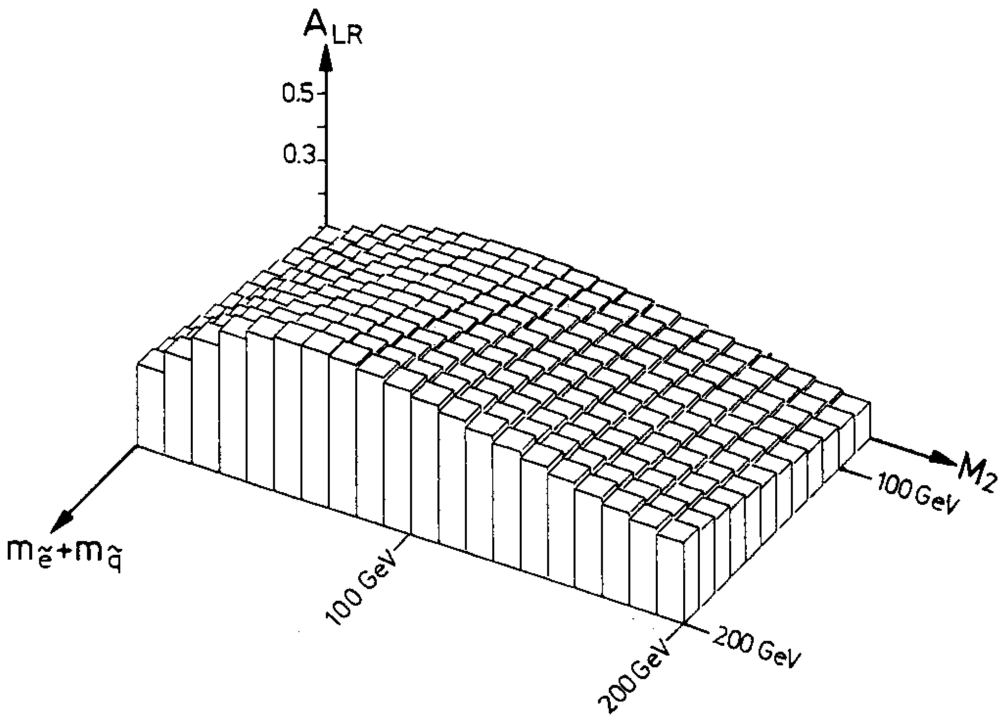
A_{LR}
0.8
0.4
$m_{\tilde{e}} + m_{\tilde{q}}$
100 GeV
200 GeV
100 GeV
200 GeV
M_2

Fig.4a



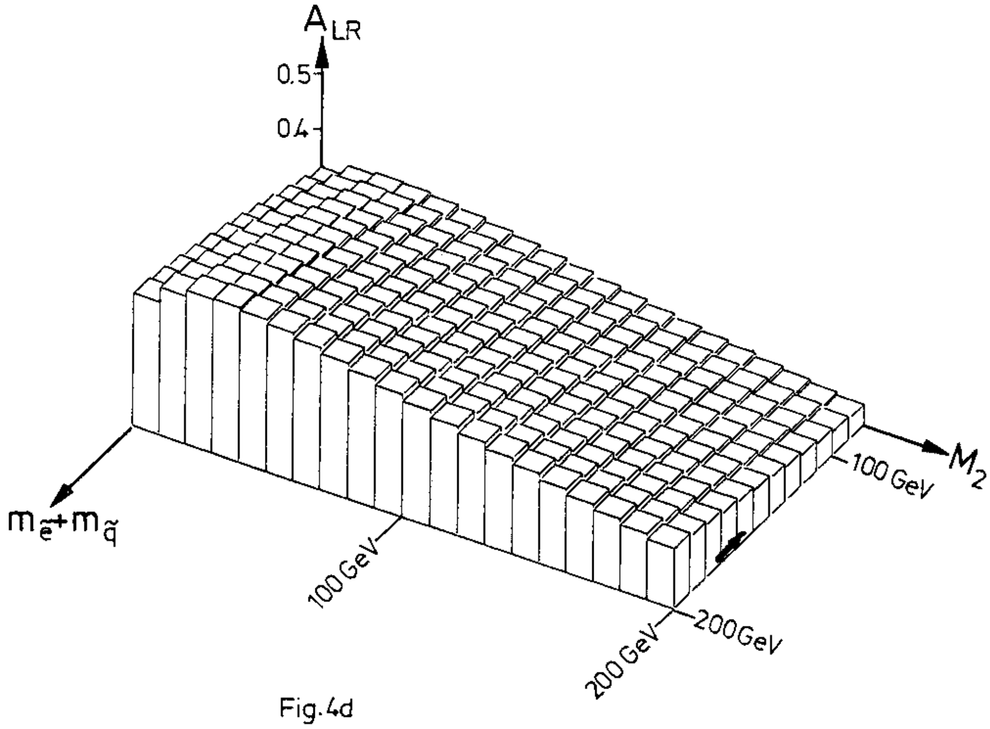
A_LR
0.5
0.3
M_2
100 GeV
200 GeV
m_ẽ + m_q̃
100 GeV
200 GeV

Fig. 4b



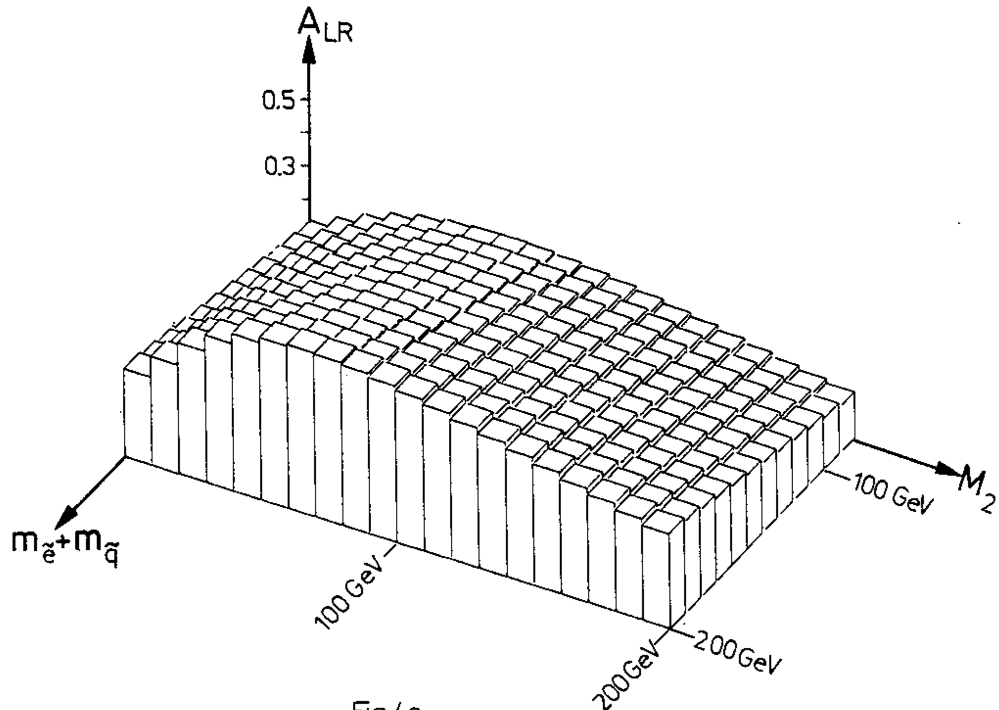
A_LR
0.5
0.3
M_2
100 GeV
200 GeV
m_ẽ + m_q̃
100 GeV
200 GeV

Fig. 4c



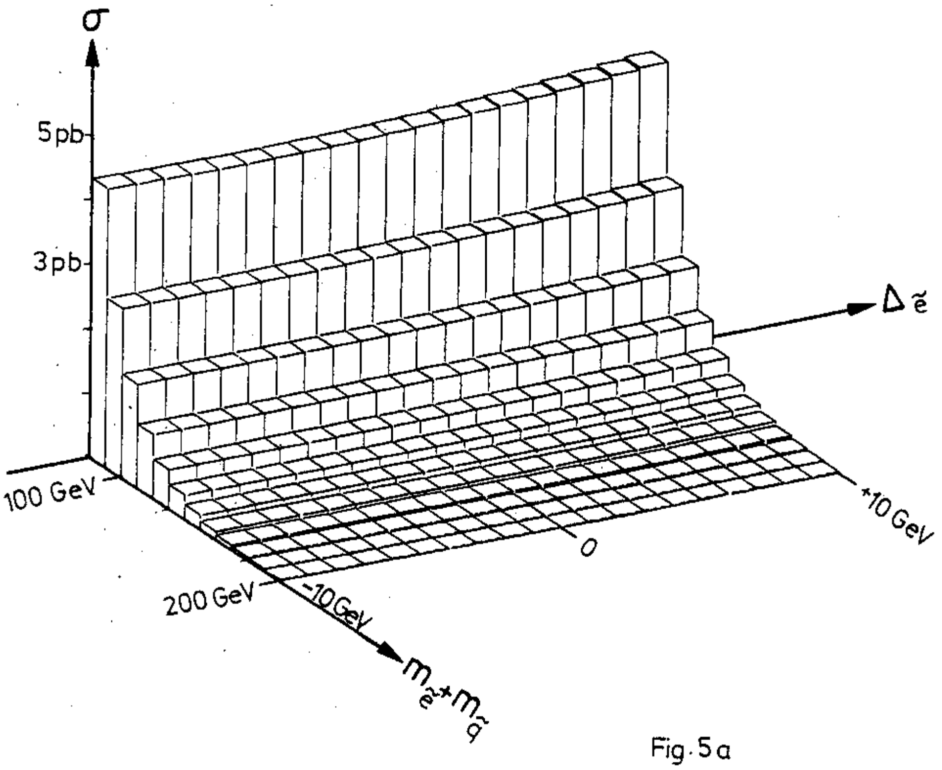
A_LR
0.5
0.4
M_2
100 GeV
m_ẽ+m_q̃
100 GeV
200 GeV
200 GeV

Fig.4d



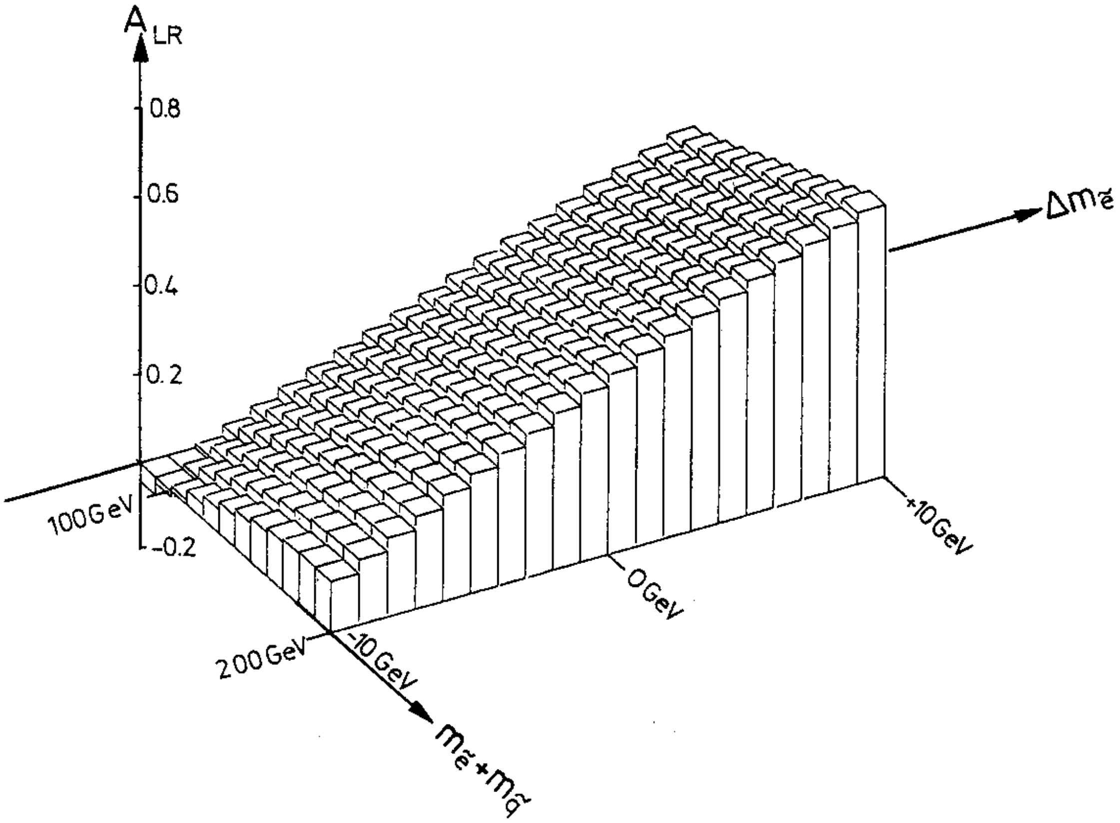
A_LR
0.5
0.3
M_2
100 GeV
m_ẽ+m_q̃
100 GeV
200 GeV
200 GeV

Fig.4e



σ
5pb
3pb
Δẽ
100 GeV
200 GeV
-10GeV
0
+10GeV
$m_{\tilde{e}}+m_{\tilde{q}}$

Fig. 5a



A_{LR}
0.8
0.6
0.4
0.2
-0.2
$\Delta m_{\tilde{e}}$
100GeV
200GeV
-10GeV
0GeV
+10GeV
$m_{\tilde{e}}+m_{\tilde{q}}$

Fig. 5b