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SUSY virtual effects at the LEP2 boundary

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Abstract. We examine the possibility that SUSY particles are light, i.e. have a mass just beyond the final kinematical reach of LEP2. In this case, even if light particles are not directly detected, their virtual effects are enhanced by a "close-to-threshold" resonance in the s-channel. We find that this resonant effect is absent in the case of light sfermions, while it is enhanced in the case of light gauginos, since neutralinos and charginos add coherently in some regions of the allowed parameter space. We discuss this "virtual alliance" in detail and try to examine the possibilities of its experimental verification.

One of the most interesting sectors of the experimental program at LEP2 [1] is the search for supersymmetric particles. In the specific case of the lightest Higgs boson, these efforts are particularly supported by the existence, within a large class of supersymmetric models [2], of an upper bound of approximately 130–150 GeV, which is not much beyond the final kinematical reach (∼100–110 GeV) of the accelerator. This has motivated a rigorous and detailed study of the production mechanism and of its visible manifestations. This has been fully illustrated in several dedicated references [3]. Since the nature of the light Higgs couplings with the SM gauge bosons and light fermions makes the detection of virtual effects at one loop rather remote, not much effort has been concentrated on this alternative possibility.

For the remaining supersymmetric particles the situation appears to be slightly different to us. In fact, no definite rigorous upper bound exists on their masses; one can only expect from reasonable arguments based on "naturalness" requests [4] that a limit of a few hundred GeV should not be violated. On the other hand, the possibility of small but visible virtual effects is not a priori unconceivable. In particular, the existence of SUSY particles with a mass just beyond the LEP2 reach could be observed as a consequence of a resonant enhancement of self-energies, vertices or boxes due to the production threshold of couples of these particles in the s-channel. Note that this remark is far from obvious because, in principle, the separate enhancements coming from the different diagrams could well interfere destructively and lead to an unobservable effect.

The aim of this paper is precisely to show that a specially favorable situation is provided by the hypothetical existence of a light chargino with a mass "close" to 100 GeV (in our analysis we will assume that the kinematical reach of LEP2 is 200 GeV; this assumption can be easily modified if this turns out to be a pessimistic – or optimistic – input). In such a case, the overall virtual contributions of self-energies, vertices and box origin from chargino pairs to several observables will not be negligible. On top of this, for a large sector of the parameter space of the model considered, an important extra help will come from the simultaneous resonance of virtual neutralinos, whose effect will add coherently to that of the charginos. This kind of "virtual alliance" would lead to small but observable effects, which we will discuss here in some detail. As we will show in the second part of the paper, the effects would be completely different in the case of virtual contributions due to light sfermions since, owing to the zero spin of the particles involved, the resonant mechanism is practically absent. Therefore, the light chargino–neutralino contribution appears to be a reasonably well identifiable one in this special and favorable case. We will devote the first part of this short paper to a detailed numerical analysis of this effect.

At the beginning of our investigation we will choose the relevant observables that might be used as indicators of (small) virtual SUSY effects. By definition, these observables must be those that will be measured at LEP2 with the best experimental accuracy, and for which an extremely accurate theoretical prediction within the SM is obviously available. In practice, these requests select three optimal candidates, i.e., the muon production cross section σ_μ, the related forward–backward asymmetry $A_{\mathrm{FB},\mu}$ and the cross section for hadronic (u, d, s, c, b) production σ_5. For these quantities we will assume the expected experimental precision quoted in a recent dedicated Workshop [1], which roughly amounts to less than a relative 1%; we keep in mind that this value might (hopefully) be improved.

In order to proceed in a rigorous and self-contained way, we decided to evaluate both the SM prediction and the SUSY virtual effect by using the same computational program. With this purpose, we have first carried out the SM analysis using the semianalytic program PALM, that was illustrated in a previous paper and to which we refer for all the technical details [5]. In a second step, we added to the theoretical PALM SM prediction, computed at the one loop level, the extra virtual SUSY effects. This has been done in a consistent way by adding the corresponding SUSY contributions to the special, gauge invariant combinations of self-energies, vertices and boxes that were grouped in the SM calculation. Technically speaking, this corresponds to systematically adding *finite* SUSY quantities, since all contributions in our approach are *subtracted* at the Z peak, $q^2 = (\text{c.m. energy})^2 = M_Z^2$. Here we do not insist on these details, since they can already found be in [5] as far as the SM calculation is concerned; the discussion of the SUSY virtual effects at one loop, at general q^2 values (here we only consider the LEP2 boundary situation $\sqrt{q^2} = 200\,\text{GeV}$) will be given in a more exhaustive forthcoming paper [6].

The theoretical model that we have considered is the MSSM [7], which we will not discuss in detail here. Our starting assumption has been the existence of a light *chargino* with a mass "just" beyond the LEP2 reach. Obviously, this input can (and will) be easily modified, but we will use it in a first qualitative investigation. We have assumed the GUT relation between the SU(2)⊗U(1) gauginos' soft mass parameters $M_1 = (5/3)\tan^2\theta_\text{w} M_2$ to be satisfied [7]. In our simplified approach we neglect left–right mixing in the sfermion mass matrices and we take all physical slepton masses to be degenerate at a common value $m_{\tilde{l}}$ and all squarks masses to be degenerate at $m_{\tilde{q}}$. We willl return to this point in the final comments. We also assume that the initial and final state fermions are massless; this is justified at the c.m. energies that we consider, since we cannot have the top as final state. When the mass of the lightest chargino is fixed, M_2 varies accordingly as a function of the supersymmetric Higgs mass parameter μ. Gluinos are assumed to be so heavy that they are decoupled. This is justified by recent bounds from hadronic colliders [8]; moreover, here we are interested in new physics coming from the weak SU(2) sector of MSSM. Contributions coming from gluinos will be considered in a subsequent paper [6].

Our approach is based on a theoretical description of the invariant scattering amplitude at one loop of the process $\text{e}^+\text{e}^- \to f\bar{f}$ that uses, as experimental input parameters, quantities which are measured (apart from the electric charge $\alpha(0)$) on top of the Z resonance, as discussed in previous papers [9]. In terms of the differential cross section for the corresponding process, this leads to the following expression:

$$\frac{\text{d}\sigma_{\text{e}f}}{\text{d}\cos\theta}(q^2,\theta) = \frac{3}{8}(1+\cos^2\theta)\sigma_1^{\text{e}f} + \cos\theta\,\sigma_2^{\text{e}f}, \tag{1}$$

with

$$\begin{aligned}
\sigma_1^{\text{e}f} &= N_f(q^2)\left(\frac{4\pi q^2}{3}\right)\Bigg\{\frac{\alpha^2(0)Q_f^2}{q^4}\left[1+2\tilde{\Delta}_{\alpha,\text{e}f}(q^2,\theta)\right] \\
&\quad +2\alpha(0)|Q_f|\left[\frac{q^2-M_Z^2}{q^2((q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2)}\right]\left[\frac{3\Gamma_\text{e}}{M_Z}\right]^{1/2} \\
&\quad \times\left[\frac{3\Gamma_f}{N_f(M_Z^2)M_Z}\right]^{1/2}\frac{\tilde{v}_\text{e}\tilde{v}_f}{(1+\tilde{v}_\text{e}^2)^{1/2}(1+\tilde{v}_f^2)^{1/2}} \\
&\quad \times\Bigg[1+\tilde{\Delta}_{\alpha,\text{e}f}(q^2,\theta)-R_{\text{e}f}(q^2,\theta)-4s_\text{e}c_\text{e} \\
&\quad \times\left\{\frac{1}{\tilde{v}_\text{e}}V_{\text{e}f}^{\gamma Z}(q^2,\theta)+\frac{|Q_f|}{\tilde{v}_f}V_{\text{e}f}^{Z\gamma}(q^2,\theta)\right\}\Bigg] \\
&\quad +\frac{\left[\frac{3\Gamma_\text{e}}{M_Z}\right]\left[\frac{3\Gamma_f}{N_f(M_Z^2)M_Z}\right]}{(q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2}\Bigg[1-2R_{\text{e}f}(q^2,\theta)-8s_\text{e}c_\text{e} \\
&\quad \times\left\{\frac{\tilde{v}_\text{e}}{1+\tilde{v}_\text{e}^2}V_{\text{e}f}^{\gamma Z}(q^2,\theta)+\frac{\tilde{v}_f|Q_f|}{(1+\tilde{v}_f^2)}V_{\text{e}f}^{Z\gamma}(q^2,\theta)\right\}\Bigg]\Bigg\},
\end{aligned} \tag{2}$$

$$\begin{aligned}
\sigma_2^{\text{e}f} &= \frac{3N_f(q^2)}{4}\left(\frac{4\pi q^2}{3}\right)\Bigg\{2\alpha(0)|Q_f| \\
&\quad \left[\frac{(q^2-M_Z^2)}{q^2((q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2)}\right]\left[\frac{3\Gamma_\text{e}}{M_Z}\right]^{1/2} \\
&\quad \times\left[\frac{3\Gamma_f}{N_f(M_Z^2)M_Z}\right]^{1/2}\frac{1}{(1+\tilde{v}_\text{e}^2)^{1/2}(1+\tilde{v}_f^2)^{1/2}} \\
&\quad \times\left[1+\tilde{\Delta}_{\alpha,\text{e}f}(q^2,\theta)-R_{\text{e}f}(q^2,\theta)\right] \\
&\quad +\frac{\left[\frac{3\Gamma_\text{e}}{M_Z}\right]\left[\frac{3\Gamma_f}{N_f(M_Z^2)M_Z}\right]}{(q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2}\left[\frac{4\tilde{v}_\text{e}\tilde{v}_f}{(1+\tilde{v}_\text{e}^2)(1+\tilde{v}_f^2)}\right] \\
&\quad \times\Bigg[1-2R_{\text{e}f}(q^2,\theta)-4s_\text{e}c_\text{e} \\
&\quad \times\left\{\frac{1}{\tilde{v}_\text{e}}V_{\text{e}f}^{\gamma Z}(q^2,\theta)+\frac{|Q_f|}{\tilde{v}_f}V_{\text{e}f}^{Z\gamma}(q^2,\theta)\right\}\Bigg]\Bigg\},
\end{aligned} \tag{3}$$

where $N_f(q^2)$ is the conventional color factor which contains standard QCD corrections at variable q^2, and where the theoretical input in (2) and (3) contains the partial *leptonic and (light) hadronic* Z widths Γ_l, Γ_f and the *related* weak effective angles s_l^2, s_f^2 ($v_{l,f} \equiv 1-4s_{l,f}^2$) measured on top of the Z resonance [9]. The functions that appear in brackets are defined as follows:

$$\widetilde{\Delta}_{\alpha,\text{e}f}(q^2,\theta) = \widetilde{F}_{\gamma\gamma,\text{e}f}(0,\theta) - \widetilde{F}_{\gamma\gamma,\text{e}f}(q^2,\theta), \tag{4}$$

$$R_{\text{e}f}(q^2,\theta) = I_{Z,\text{e}f}(q^2,\theta) - I_{Z,\text{e}f}(M_Z^2,\theta), \tag{5}$$

$$V_{\text{e}f}^{\gamma Z}(q^2,\theta) = \frac{\widetilde{A}_{\gamma Z,\text{e}f}(q^2,\theta)}{q^2} - \frac{\widetilde{A}_{\gamma Z,\text{e}f}(M_Z^2,\theta)}{M_Z^2}, \tag{6}$$

$$V_{\text{e}f}^{Z\gamma}(q^2,\theta) = \frac{\widetilde{A}_{Z\gamma,\text{e}f}(q^2,\theta)}{q^2} - \frac{\widetilde{A}_{Z\gamma,\text{e}f}(M_Z^2,\theta)}{M_Z^2}, \tag{7}$$

where

$$I_{\mathrm{Z,e}f}(q^2,\theta) = \frac{q^2}{q^2 - M_{\mathrm{Z}}^2}\left[\widetilde{F}_{\mathrm{ZZ,e}f}(q^2,\theta) - \widetilde{F}_{\mathrm{ZZ,e}f}(M_{\mathrm{Z}}^2,\theta)\right], \qquad (8)$$

$$\widetilde{A}_{\mathrm{ZZ,e}f}(q^2,\theta) = \widetilde{A}_{\mathrm{ZZ,e}f}(0,\theta) + q^2\widetilde{F}_{\mathrm{ZZ,e}f}(q^2,\theta), \qquad (9)$$

$$\begin{aligned}\widetilde{A}_{\mathrm{ZZ,e}f}(q^2,\theta) &= A_{\mathrm{ZZ}}(q^2) - (q^2 - M_{\mathrm{Z}}^2)\left[\left(\Gamma^{(\mathrm{Z})}_{\mu,\mathrm{e}}, v^{(\mathrm{Z})}_{\mu,\mathrm{e}}\right)\right.\\ &\quad \left. + \left(\Gamma^{(\mathrm{Z})}_{\mu,f}, v^{(\mathrm{Z})}_{\mu,f}\right) + (q^2 - M_{\mathrm{Z}}^2)A^{(\mathrm{Box})}_{\mathrm{ZZ,e}f}(q^2,\theta)\right], \qquad (10)\end{aligned}$$

$$\begin{aligned}\tilde{F}_{\gamma\gamma,\mathrm{e}f}(q^2,\theta) &= F_{\gamma\gamma,\mathrm{e}f}(q^2) - \left(\Gamma^{(\gamma)}_{\mu,\mathrm{e}}, v^{(\gamma)}_{\mu,\mathrm{e}}\right) - \left(\Gamma^{(\gamma)}_{\mu,f}, v^{(\gamma)}_{\mu,f}\right)\\ &\quad -q^2 A^{(\mathrm{Box})}_{\gamma\gamma,\mathrm{e}f}(q^2,\theta), \qquad (11)\end{aligned}$$

$$\begin{aligned}\frac{\widetilde{A}_{\gamma\mathrm{Z,e}f}(q^2,\theta)}{q^2} &= \frac{A_{\gamma\mathrm{Z}}(q^2)}{q^2} - \left(\frac{q^2 - M_{\mathrm{Z}}^2}{q^2}\right)\left(\Gamma^{(\gamma)}_{\mu,f}, v^{(\mathrm{Z})}_{\mu,f}\right)\\ &\quad - \left(\Gamma^{(\mathrm{Z})}_{\mu,\mathrm{e}}, v^{(\gamma)}_{\mu,\mathrm{e}}\right) - (q^2 - M_{\mathrm{Z}}^2)A^{(\mathrm{Box})}_{\gamma\mathrm{Z,e}f}(q^2,\theta), \qquad (12)\end{aligned}$$

$$\begin{aligned}\frac{\widetilde{A}_{\mathrm{Z}\gamma,\mathrm{e}f}(q^2,\theta)}{q^2} &= \frac{A_{\gamma\mathrm{Z}}(q^2)}{q^2} - \frac{q^2 - M_{\mathrm{Z}}^2}{q^2}\left(\Gamma^{(\gamma)}_{\mu,\mathrm{e}}, v^{(\mathrm{Z})}_{\mu,\mathrm{e}}\right)\\ &\quad - \left(\Gamma^{(\mathrm{Z})}_{\mu,f}, v^{(\gamma)}_{\mu,f}\right) - (q^2 - M_{\mathrm{Z}}^2)A^{(\mathrm{Box})}_{Z\gamma,\mathrm{e}f}(q^2,\theta). \qquad (13)\end{aligned}$$

The quantities $A_{ij}(q^2) = A_{ij}(0) + q^2F_{ij}(q^2)$ $(i,j = \gamma,\mathrm{Z})$ are the conventional transverse γ,Z self-energies. $A^{(\mathrm{Box})}_{\gamma\gamma,\gamma\mathrm{Z},\mathrm{Z}\gamma,\mathrm{ZZ,e}f}(q^2,\theta)$ are the projections on the photon and Z Lorentz structures of the box contributions to the scattering amplitude $\mathcal{A}_{\mathrm{e}f}$, and the various brackets (Γ_μ, v_μ) are the projections of the vertices on the different Lorentz structures to which $\widetilde{A}_{\gamma\gamma}$, $\widetilde{A}_{\mathrm{ZZ}}$, $\widetilde{A}_{\gamma\mathrm{Z}}$, $\widetilde{A}_{\mathrm{Z}\gamma}$ belong. In our notations $A^{(\mathrm{Box})}_{\gamma\gamma}$ is the component of the scattering amplitude at one loop that appears in the form $v^{(\gamma)}_{\mu,\mathrm{e}}A^{(\mathrm{Box})}_{\gamma\gamma}v^{(\gamma),\mu}_{f}$, where $v^{(\gamma),\mu}_{\mathrm{e},f} \equiv -|e_0|Q_{\mathrm{e},f}\gamma^\mu$ is what we call the photon Lorentz structure; analogous definitions are obtained for $A^{(\mathrm{Box})}_{\mathrm{ZZ}}$, $A^{(\mathrm{Box})}_{\gamma\mathrm{Z}}$, $A^{(\mathrm{Box})}_{\mathrm{Z}\gamma}$ with the Z Lorentz structure defined as

$$v^{(\mathrm{Z}),\mu}_{\mathrm{e},f} \equiv -\frac{|e_0|}{2s_0c_0}\gamma^\mu(g^0_{V,\mathrm{e},f} - g^0_{A,\mathrm{e},f}\gamma^5).$$

More details can be found, e.g., in [5]. Here we only stress the fact that all previous quantities $\tilde{\Delta}_\alpha$, R, $V_{\gamma\mathrm{Z}}$, $V_{\mathrm{Z}\gamma}$ are separately gauge invariant and therefore their evaluation in the SM can be performed without intrinsic ambiguities, which leads to the numerical results that are fully discussed in [5].

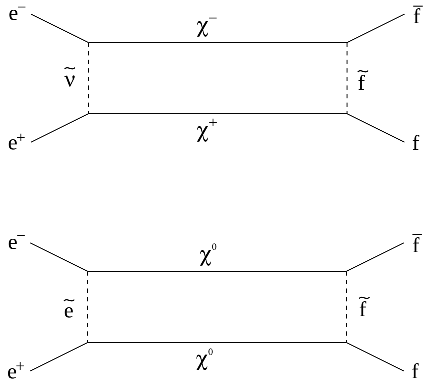

Fig. 1. Boxes

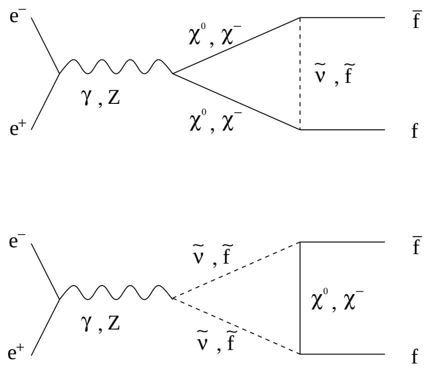

Fig. 2. Vertices

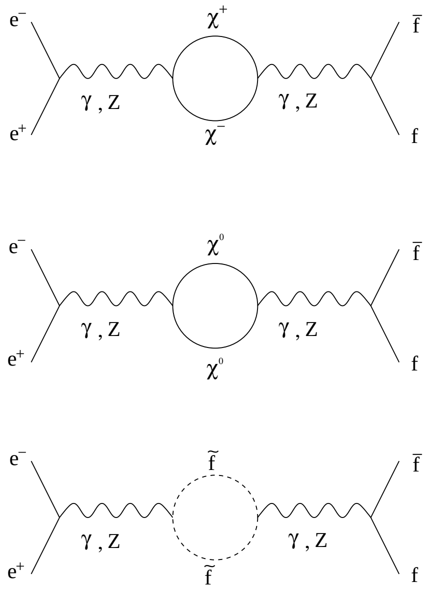

Fig. 3. Self-energies

For computing the SUSY effect on the three chosen observables, we have calculated the quantities $(\tilde{\Delta}_\alpha$, R, $V_{\gamma\mathrm{Z}}$, $V_{\mathrm{Z}\gamma})^{\mathrm{SUSY}}$. These are *finite* contributions which are generated by Feynman diagrams of the self-energy, vertex and box type. In Figs. 1, 2 and 3 we diagrammatically represent some of the relevant graphs, omitting for simplicity other ones, e.g., external self-energy insertions. As a technical comment, we would like to note that one could

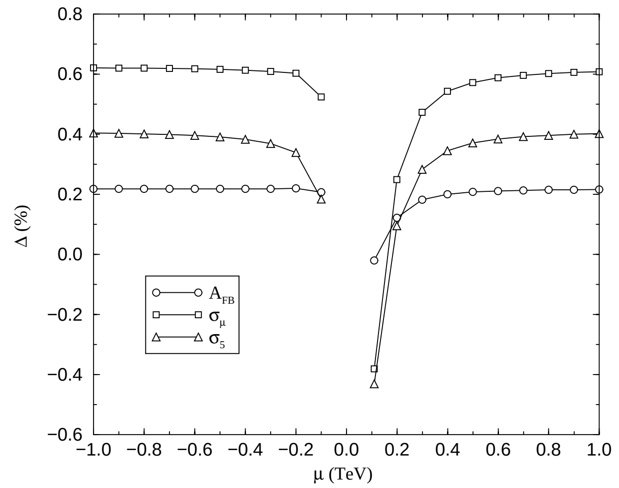

Fig. 4. SUSY effects on the three observables considered with the mass of the lightest chargino fixed at 105 GeV and with $\tan\beta = 1.6$. $m_{\tilde{q}}$ is fixed at 200 GeV and $m_{\tilde{l}}$ at 120 GeV

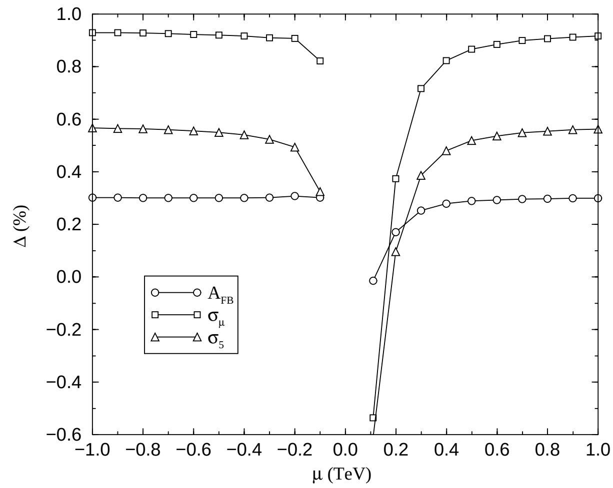

Fig. 5. SUSY effects on the three observables considered with the mass of the lightest chargino fixed at 100 GeV and with $\tan\beta = 1.6$. $m_{\tilde{q}}$ is fixed at 200 GeV and $m_{\tilde{l}}$ at 120 GeV

expect various Lorentz-invariant Dirac structures to contribute to the amplitudes under consideration, especially in the case of SUSY boxes that have an unconventional structure with respect to the SM ones. However, due to a "generalized Fierz identity", which will be discussed in detail elsewhere [6], it is possible to demonstrate that only four independent Dirac structures (i.e., $\gamma^\mu P_{\mathrm{L,R}} \otimes \gamma_\mu P_{\mathrm{L,R}}$, where $P_{\mathrm{L,R}}$ are the chiral projectors) contribute in the massless external fermions case that we consider here.

When we insert the expressions of the SUSY contribution to (4)–(7) into the general equations (1)–(3) and when we perform the angular integration by means of the PALM program, we have computed the overall (SM) and (SM + MSSM) values. Although the program is able to estimate initial state radiation (ISR) effects [5], we have not inserted a discussion of this kind of effects for our present investigation at $\sqrt{q^2} = 200\,\mathrm{GeV}$; we believe that for the purposes of this preliminary investigation this attitude can be safely tolerated.

We first have considered a case in which the light chargino mass is fixed at 105 GeV, the physical masses of the sleptons are equal to 120 GeV, and the physical masses of the squarks are assumed to be 200 GeV. We set $\tan\beta = 1.6$ and verified that, when we vary it from 1.6 to 40, no appreciable change takes place. With this choice, we computed the *relative* SUSY shifts on the three chosen observables $\mathcal{O}_i$,

$$\Delta^{\mathrm{SUSY}}\mathcal{O} \equiv \frac{\mathcal{O}^{\mathrm{SUSY}} - \mathcal{O}^{\mathrm{SM}}}{\mathcal{O}^{\mathrm{SM}}}$$

and $(\mathcal{O}_{1,2,3} = \sigma_\mu, \sigma_5, A_{\mathrm{FB},\mu})$.

Figure 4 shows the variations of the relative effects on the observables when $\sqrt{q^2} = 200\,\mathrm{GeV}$ and μ varies in its allowed range. One sees that the size of the SUSY contribution to the muon asymmetry remains systematically negligible, well below the 6–7 per mill limit that represents an optimistic experimental reach in this case [1]. The weakness of this effect is due to two facts: the dominance of the photon contribution in $\sigma_1^{\mathrm{e}\mu}$ and of the photon–Z interference in $\sigma_2^{\mathrm{e}\mu}$, and a subsequent accidental cancellation between $\tilde{\Delta}_{\alpha,\mathrm{e}\mu}$ and $R_{\mathrm{e}\mu}$ in the resulting $\tilde{\Delta}_{\alpha,\mathrm{e}\mu} + R_{\mathrm{e}\mu}$ contribution to $A_{\mathrm{FB},\mu}$. On the contrary, in the case of the muon and hadronic cross sections, the size of the effect approaches, for large $|\mu|$ values, a limit of 6 per mill in σ_μ and 4 per mill in σ_5, which represent a conceivable experimental reach at the end of the overall LEP2 running period.

In fact, this explains our choice of the value $M_{\chi^+_{\mathrm{light}}} = 105\,\mathrm{GeV}$ with the LEP2 limit at 200 GeV; other couples of the light chargino mass and of the LEP2 limit separated by a larger gap would produce a smaller effect, i.e. an unobservable one. On the other hand, smaller gaps (e.g. a lighter but still unproduced chargino *or* a larger LEP2 limit) would increase the effect, as one can see in Fig. 5, towards the 1% values that appear to be experimentally realistic.

Let us now discuss the qualitative features of the results that we obtain. As one sees from Fig. 6, the one-loop SUSY effects have different signatures. Those of an "oblique" (universal) type, corresponding to self-energies, have a negative effect on all three observables; those of a non-universal type (vertices and boxes) lead to a positive effect in all three cases. Now, when $|\mu| >> M_2$ we have a light "gaugino-like" chargino of a (fixed) mass $105\,\mathrm{GeV} \approx M_2$, and a heavy "higgsino-like" chargino with a mass of the order of $|\mu|$ itself. At the same time, in the neutralino sector the situation is very similar, with two heavy "higgsino-like" neutralinos and two light "gaugino-like" neutralinos of masses M_1 and M_2. Then, one chargino and one neutralino are "gaugino-like" and have roughly the same mass, of order $M_2 \approx 105\,\mathrm{GeV}$; they "resonate" coherently in the vertex, box and self-energies contributions. This situation, which we call "virtual alliance", is made evident in Fig. 7, where neutralinos are seen to contribute for about 25% to the total signal. Note that an

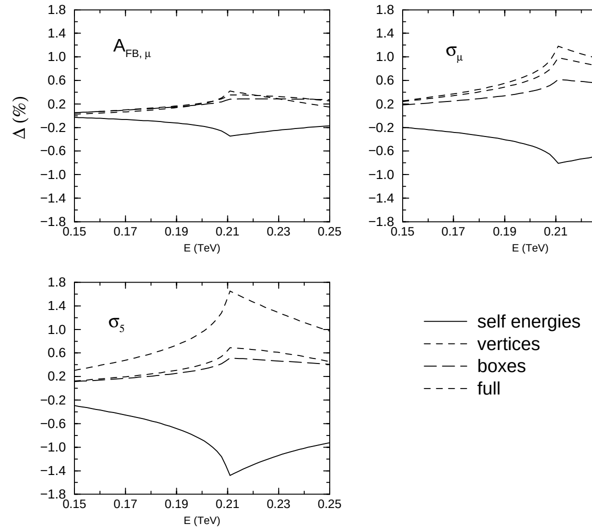

Fig. 6. Heavy sfermions–light chargino scenario. Self-energy, box and vertex SUSY effects on the three observables considered as a function of the c.m. energy with a high $|\mu|$ value. The mass of the lightest chargino is fixed at 105 GeV. The other parameters are: $m_{\tilde{q}}$=200 GeV, $m_{\tilde{l}}$=120 GeV, $\tan\beta = 1.6$

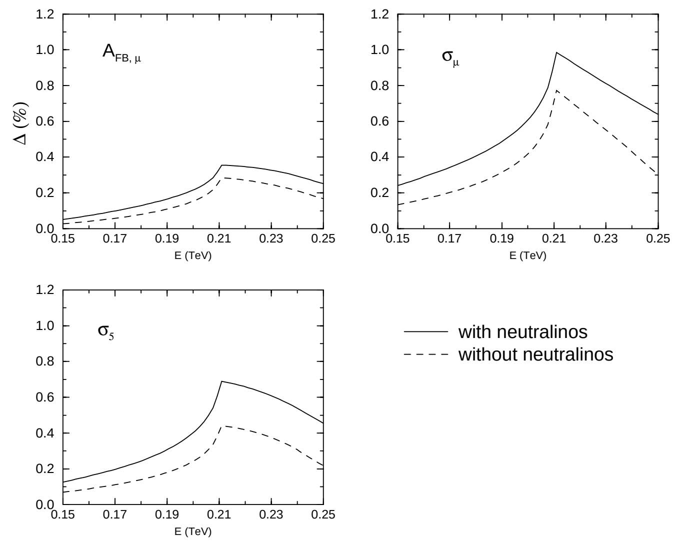

Fig. 7. Total SUSY effects on the three observables considered with and without a contribution of neutralinos. The parameters are the same as in the previous figure

important contribution to the overall effect in the chosen configuration is that coming from the SUSY *boxes* [10].

The opposite happens when $M_2 >> |\mu|$. In this situation we have light "higgsino type" charginos and neutralinos, with masses of the order of $|\mu| \approx 105$ GeV, and heavy "gaugino type" charginos and neutralinos. Since higgsinos are decoupled from massless fermions, their contribution to boxes and vertices disappears and the overall signal is consequently weakened (see Fig. 5).

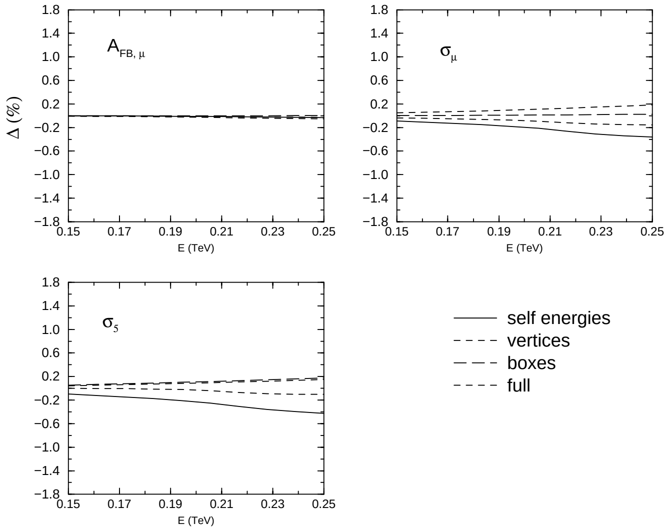

Fig. 8. Light sfermions–heavy chargino scenario. Self-energy, box and vertex SUSY effects on the three observables considered as a function of the c.m. energy with a high $|\mu|$ value. The mass of the lightest chargino is fixed at 300 GeV. The values of physical sfermion masses are: $m_{\tilde{l}}$=105 GeV, $m_{\tilde{q}}$=200 GeV

Let us now consider a different situation, where the lightest chargino is "heavy" and decoupled; we set its mass equal to 300 GeV and we assume that all sleptons are now "light" (i.e. $m_{\tilde{l}} = 105$ GeV). The analogue of Fig. 6 is then represented in Fig. 8. As one sees from the figure, the signal has now almost completely disappeared. This fact can be qualitatively interpreted as a disappearance of the "quasi-resonance" chargino–neutralino contributions which are not compensated by analogous slepton terms. The reason is the fact that *spinless* particles, and not spin 1/2 particles, have to be produced, because of angular momentum conservation, in a $l = 1$ angular momentum state. This causes a relative "threshold" p-wave depression factor $\approx q^2 - 4m_{\tilde{l}}^2$ in the spinless case, which cancels the threshold enhancement. Note also that, since we are not considering final electron–positron states, we do not have any box contributions with sfermion pairs in the s-channel (see Fig. 1).

Another important comment is related to our choice of using a "Z-peak subtracted" representation. This has the consequence that all the *energy independent* new physics contributions that can be reabsorbed in the Z-peak input quantities ($\Gamma_f, \sin^2\theta_{\mathrm{eff}}, \cdots$) do not affect our final result. Such is the case for all those values of sfermion splittings and/or mixings that contribute to the $\Delta\rho$ parameter. These contributions are automatically reabsorbed when we replace G_μ by Γ_l as theoretical input. They are, though, taken into account by the experimental error on our theoretical input, in this case Γ_l. In [5] it is exhaustively discussed that this would generate a strip of theoretical error in our prediction of the 1 per mill size, which is well below the considered LEP2 experimental accuracy.

Note that, as a consequence of this "LEP1 based" approach, all our residual subtracted theoretical one-loop combinations of self-energies, vertices and boxes are finite and thus separately computable. In a forthcoming paper [6] we will discuss a dedicated numerical code (SPALM), which is already available upon request, in more detail.

At this point we should mention that in a recent paper [11] a calculation of virtual SUSY effects has been performed, which covers an energy range from 200 GeV to the TeV range. The approach followed by the authors of [11] is different from ours, particularly since the theoretical input parameters are different and do not contain our LEP1 input. This makes a detailed comparison more subtle, in particular concerning "relative" shifts when the input parameters are different. Since the "virtual alliance" case that we considered here has not been treated in [11], we postpone a complete and clean comparison of the two approaches to a forthcoming paper [6].

In conclusion, we have seen that in the large $|\mu|$ configuration, a delicate interplay exists between virtual SUSY contributions from self-energies, vertices and boxes that might lead, for a conveniently light chargino, to a small but visible effect. Our prediction is that the signature of the effect is a positive shift of the muonic and hadronic cross sections. Given the relative smallness of the signal, an important help comes from the light neutralino, in particular from its box contribution that adds coherently to that of the chargino and gives a 25% enhancement of the signal. This can be interpreted as a kind of "virtual alliance", as we anticipated in the abstract. The observation of the predicted simultaneous small excess in the two cross sections, typically at the 1% level at most, could well be within the reach of a series of dedicated LEP2 experiments.

References

1. Proceedings of the Workshop on Physics at LEP2, Geneva, Switzerland, 1996, CERN 96-01 (1996), edited by G. Altarelli, T. Sjostrand, F. Zwirner
2. M. Quiros, J.R. Espinosa, CERN-TH-98-292 (1998), presented at the 6th International Symposium on Particles, Strings and Cosmology (PASCOS 98), Boston, MA, USA, 22–27 March 1998, hep-ph/9809269 and references therein.
3. Proceedings of the Workshop on Physics at LEP2, Search for New Physics, Geneva, Switzerland, 1996, CERN 96-01, edited by G. Altarelli, T. Sjostrand and F. Zwirner, p. 46
4. R. Barbieri, G.F. Giudice, Nucl. Phys. B **306**, 63 (1988); G.W. Anderson, D.J. Castano, Phys. Lett. B **347**, 300 (1995); P. Ciafaloni, A. Strumia, Nucl. Phys. B **494**, 41 (1997); L. Giusti, A. Romanino, A. Strumia, IFUP-TH-49-98, 1998, hep-ph/9811386
5. M. Beccaria, G. Montagna, F. Piccinini, F.M. Renard, C. Verzegnassi, Phys. Rev. D **58**, 093014 (1998)
6. M. Beccaria, P. Ciafaloni, D. Comelli, F. Renard, C. Verzegnassi, A Z-peak subtracted analysis of virtual SUSY effects at future e^+e^- colliders, in preparation.
7. H.P. Nilles, Phys. Rep. **110**, 1 (1984); H.E. Haber and G.L. Kane, Phys. Rep. **117**, 75 (1985); R. Barbieri, Riv. Nuov. Cim. **11**, 1 (1988); R. Arnowitt, A. Chamseddine, P. Nath, Applied $N = 1$ Supergravity (World Scientific, 1984); for a recent review see, e.g., S.P. Martin, hep-ph/9709356.
8. Particle Data Group 1998, Eur. Phys. J. C **3**, 1 (1998)
9. F.M. Renard, C. Verzegnassi, Phys. Rev. D **52**, 1369 (1995); Phys. Rev. D **53**, 1290 (1996)
10. J. Layssac, F.M. Renard, C. Verzegnassi, Phys. Lett. B **418**, 134 (1998)
11. W. Hollik, C. Schappacher, hep-ph/9807427.