AUTOMATIC CALCULATION OF SUSY AMPLITUDES *

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ABSTRACT

We automatically calculate cross sections for various production processes of the SUSY particles in the MSSM. This is accomplished in terms of the program, GRACE for SUSY. The GRACE for SUSY has following new features. 1) Majorana fermions, such as neutralinos and gluino, have been included. 2) Particle mixings in the MSSM have been included. We have actually calculated some simple processes and compared to results obtained by hand. This program will be extremely efficient for calculating final 3-body or 4-body SUSY processes at electron colliders, gamma colliders as well as hadron colliders.

*This work has been done in collaboration with T.Kaneko, H.Tanaka, M.Jimbo and Minami-Tateya Collaboration at KEK.

Firstly, it should be emphasised that there are needs for automatic computation program of Feynman amlitudes in high energy particle phenomenology. Reasons are as follows. First, the present and future colliders could achieve the very high scattering energy, so processes with many body final states will become more important. Second, in almost known models, especially in SUSY models, many kinds of particles are included, so amplitudes with many virtual states will contribute to the physical processes. These two facts force us to calculate a large number of Feynman diagrams. For example, we consider a 2 to 4 body process at e^+e^- colliders ; $e^+e^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$. This process will be important when the selectron is too heavy to be produced on shell at TeV linear colliders. There are 7 handred and 4 diagrams and they are too many to be calculated with ordinary methods : it must be tiresome and easy to mistake. (Note that this example contains all contributions such as the electron-Higgs couplings and Goldstone boson couplings.)

At the present, there are several codes for automatic calculation of Feynman amplitudes

1. CompHep (Moscow) [1]
2. FeynArts/FeynCalc (Würzburg) [2]
3. Madgraph (Madison) [3]
4. GRACE (Minami-Tateya Collab.(KEK)) [4]

It is known that all these codes work well for the Standard Model calculations. It should be mentioned that we have collaboration with LAPP (Annecy) in using GRACE for LEPII and NLC physics and with Moscow group in cross checking between CompHep and GRACE system. In this talk I will report a recent progress, i.e., the GRACE system becomes to be able to calculate the Supersymmetric processes.

Essentially, new features in the GRACE system are in following two points. 1) We can handle "Majorana" fermions such as the gluino and neutralinos [5], and 2) Particle mixings in the MSSM, neutralino and chargino mixings, are included. Here I should clarify "what can GRACE do?" It can give us

Graph generation

Fortran code genetation (and also REDUCE and FORM code generation)

Phase space integration

Event generation

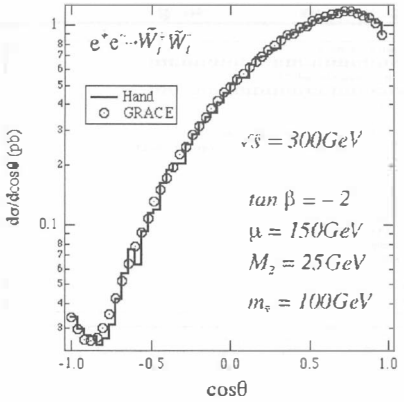

Figure 1: Angular distribution of chargino calculated by GRACE and by hand.

So we can say that *"WE CAN GET CROSS SECTION AND GENERATED EVENTS AUTOMATICALLY!"* It is important that the generated codes describe helicity amplitudes in the general covariant gauge. So we can check the gauge invariance of amplitudes numerically. And also we can choose freely polarization of initial and final state particles.

Next I discuss some physical application of our system. Here are listed some elementary processes for checking the program.

$$e^-e^- \to \tilde{e}^-\tilde{e}^- \quad (1)$$
$$e^-e^+ \to \tilde{e}^-\tilde{e}^+ \quad (2)$$
$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \quad (3)$$
$$e^+e^- \to \tilde{\gamma}\tilde{\gamma} \quad (4)$$
$$\gamma\gamma \to \tilde{e}^+\tilde{e}^- \quad (5)$$
$$\gamma\gamma \to \tilde{\chi}_1^+\tilde{\chi}_1^- \quad (6)$$
$$e^+e^- \to e\tilde{e}\tilde{\gamma} \quad (7)$$
$$e^+e^- \to \tilde{\gamma}\tilde{\gamma}\gamma \quad (8)$$
$$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma \quad (9)$$

As an example, we show in Fig.1 the angular distribution of the lighter chargino in the process (3). Result by GRACE and that by hand are in agreement.

Another example for the MSSM is the 2 to 3 body process (9). If the lightest neutralino is the LSP, it will escape the detector. So the signature of this process is very simple,

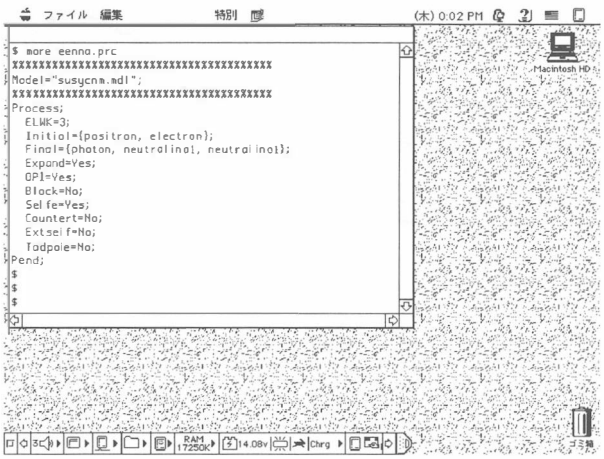

Figure 2: *Process file* for $e^+e^- \to \gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$.

i.e., single photon events. In order to calculate this process, first, you should make the *process file* shown in Fig.2. At this stage, all you must do are to select a model [2], to select an order of coupling, and to define initial and final particles. After running a sub-program called *GRACEFIG*, you can get corresponding Feynman diagrams shown in Fig.3. Subsequently, run sub-programs, *GENFORT* and *INT*. Then you can get the *output file* shown in Fig.4, which consists of three parts. The first part describes input and output SUSY parameters, such as masses and mixing angles of gauginos. You can find the total cross section and some physical distributions in the second part and the third part on the file, respectively. In this example, the total cross section is about 0.11pb and you can find the photon energy distribution of the final photon in Fig.5, where a parameter x is defined by

$$x = \frac{E_\gamma - E_\gamma^{min}}{E_\gamma^{max} - E_\gamma^{min}}. \tag{10}$$

Here we also plotted the background process, $e^+e^- \to \gamma\bar{\nu}\nu$, which is also calculated by GRACE. Note, in our example, the LSP is almost the Bino, which is favorable for dark matter candidate. We can see that the background is much larger than the SUSY process for unpolarized initial beams. But, fortunately, if we take the right-handed initial electron, the background can be suppressed and the signal could be extracted at the soft region of the final photon energies.

In summary, we have developed "a code for automatic calculation of Feynman ampli-

[2] In model files of the GRACE for SUSY, we adopt a notation for SUSY parameters presented in Ref.[6].

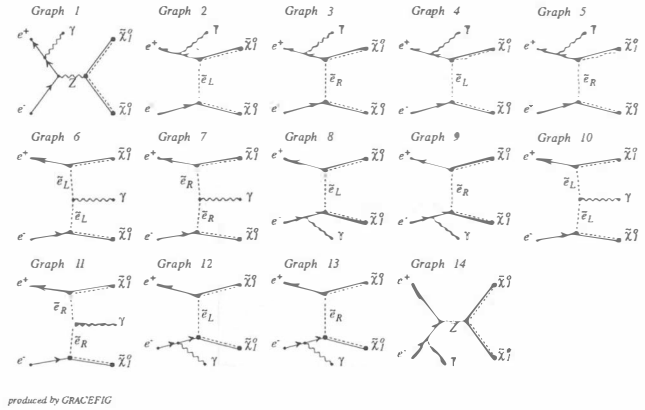

Figure 3: Feynman diagrams for $e^+e^- \to \gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$.

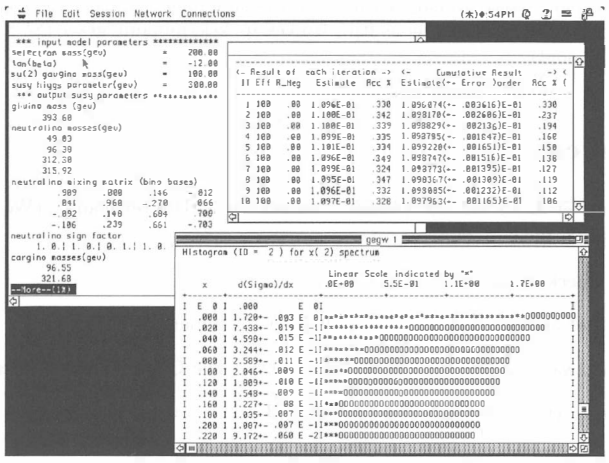

Figure 4: *Output file* for $e^+e^- \to \gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$.

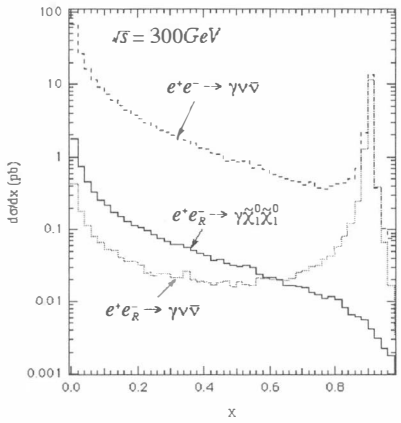

Figure 5: Photon energy distribution. We take $\mu = 300\text{GeV}$, $M_2 = 100\text{GeV}$, $\tan\beta = -12$ and $m_{\tilde{e}} = 200\text{GeV}$.

tudes in SUSY models" This is working well and could be a powerful tool for high energy particle phenomenology. Finally, let me give you an announcement ; you can get GRACE for Standard model via anonymous ftp : ftp.kek.jp/kek/minami/grace (SUSY version will be available soon!).

References

[1] E. Boos et al., *Proc. of AIHEP - 92*, ed. by D. Perret-Gallix, (World Scientific, Singapore, 1992) p. 665

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[3] T. Stelzer and W. F. Long, Comput. Phys. Commun. 81 (1994) 357

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[5] M. Jimbo et al., preprint, hep-ph/9503363

[6] K. Hikasa, *"JLC Supersymmetry Manual"*, (unpublished)