Precise Predictions for SUSY Processes at the ILC

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Recent high precision calculations for production processes of the SUSY particles at the next linear collider are reviewed. Special attention is paid to the input parameter definition. Numerical results for the SPS1a' benchmark point as proposed in the SPA project, are presented.

1. INTRODUCTION

The Minimal Supersymmetric Standard Model (MSSM) provides the most attractive and best studied extension of the Standard Model (SM). The MSSM predicts the existence of not yet observed supersymmetric partners to the SM particles. Among those there are the sfermions $\tilde{f}_i$, the scalar partners of the SM fermions, the neutralinos $\tilde{\chi}_i^0$, the fermionic partners of the photon, Z-boson and the neutral Higgs bosons and last but not least the charginos $\chi_i^\pm$, the fermionic partners of the W-bosons and the charged Higgs bosons.
It is expected that some of these particles will be detected at the LHC or the Tevatron. To determine their precise properties we will have to wait for a linear e^+e^- collider. The future linear collider should allows measurements with high precision. After measuring the masses and the couplings of the supersymmetric particles the main focus will be the extraction of the fundamental parameters of the MSSM. Although straightforward at tree-level, it is no longer simple when higher orders are included which are necessary in view of the precision of the linear collider. The definition of the parameters is not unique beyond the leading order and depends on the renormalization scheme. Therefore, a well-defined theoretical framework has been recently proposed within the so-called SPA (SUSY Parameter Analysis) project [1]. The "SPA convention" provides a clear base for calculating masses, mixing angles, decay widths and production processes. It also provides a clear definition of the fundamental parameters using the $\overline{\mathrm{DR}}$ (dimensional reduction) renormalization scheme which allows one to extract them from future data.
Here we present the one-loop results for the neutralino, chargino and sfermion (of the 3rd generation) production processes which were calculated in the SPA convention mentioned above (for details and other references see [2, 3]). Despite the fact that the parameters in the SPA convention are defined in the $\overline{\mathrm{DR}}$ renormalization scheme, we have used an on-shell renormalization scheme. We show how one can obtain results full in accord with the SPA convention using the on-shell renormalization scheme. For this purpose, the $\overline{\mathrm{DR}}$ parameters are transformed into on-shell parameters which can then be used as input in the calculation. This transformation is presented here in some detail. At the end, we show numerical results for the pair production of stops, sbottoms, staus, charginos and neutralinos in e^+e^- collisions.

2. PARAMETER TRANSFORMATION

The precision achieved by the linear collider implies the need for next-to-leading order predictions to be included. In principle one is free to choose any consistent renormalization scheme for the next-to-leading order corrections.

$$
\begin{tikzcd}
\text{SPA input} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}_{\overline{\mathrm{DR}}} \arrow[r, "\mathrm{diag}"] \arrow[d, "\delta_1"'] & \begin{pmatrix} m_1 & 0 \\ 0 & m_2 \end{pmatrix}_{\overline{\mathrm{DR}}} = \overline{\mathrm{DR}} \text{ masses} \arrow[d, "\delta_2"] \\
\text{On-shell input} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}_{\mathrm{OS}} \arrow[r, "\mathrm{diag}", "\Delta\mathrm{M}"'] & \begin{pmatrix} M_1 & 0 \\ 0 & M_2 \end{pmatrix}_{\mathrm{OS}} = \text{Pole masses}
\end{tikzcd}
$$

$\mathcal{P}$	$\overline{\mathrm{DR}}$	OS
M'	103.22	100.32
M	193.31	197.03
μ	402.87	399.94
$\tan\beta$	10	10.31
$M_{\tilde{Q}_3}$	471.26	507.23
$M_{\tilde{U}_3}$	384.59	410.11
$M_{\tilde{D}_3}$	501.35	538.92
$M_{\tilde{E}_3}$	109.87	111.58
$M_{\tilde{L}_3}$	179.49	181.78

Figure 1: Left: Diagram illustrating the transformation of the sfermion mass matrix parameters from the $\overline{\mathrm{DR}}$ input to the on-shell input and subsequently diagonalizing the matrix to obtain the on-shell masses of the sfermions. Right: Table showing the values of the same parameters in different renormalization schemes for the SPS1a' benchmark point.

We show here that by using any such scheme one can still make a full use of the SPA conventions. One just has to transform the parameters in a consistent way. From now on we focus on transforming the parameters from the $\overline{\mathrm{DR}}$ to the on-shell renormalization scheme.

As an example, we take the sfermion mass matrix (see Fig. 1) which is a non-diagonal matrix at the beginning. There are two equivalent ways how to obtain the sfermion pole masses (as one can see in Fig. 1).

First, in the $\overline{\mathrm{DR}}$ scheme one diagonalizes the SPA input matrix to obtain the $\overline{\mathrm{DR}}$ masses. To get the pole masses one has to subtract the finite parts of the on-shell counterterms δ_2.

If one uses the on-shell renormalization scheme, one first has to transform the SPA input matrix into the on-shell input matrix. This is done by subtracting the finite parts of the on-shell counterterms which correspond to the parameters found in the mass matrix. However, there is a subtlety hidden. As some parameters are common to more than one mass matrix (e.g. $M_{\tilde{Q}_3}$ is found in the stop and in the sbottom mass matrix), there are more possibilities how to define these parameters. This results in more possible counterterms for one parameter which one can use in the transformation. If one chooses one particular definition for the parameter (say we define $M_{\tilde{Q}_3}$ in the sbottom mass matrix) one has to take into account finite shifts ΔM for the same parameter appearing elsewhere (i. e. we use $M_{\tilde{Q}_3} + \Delta M_{\tilde{Q}_3}$ in the stop sector). There are two different approaches how to define these shifts which can be found in [4, 5], where we follow the approach given in [4].

The advantage of using the on-shell input values is that the well-established procedure of on-shell renormalization can be applied.

We use the transformation mentioned above for the SPS1a' benchmark point which we need for the numerical analysis of the production processes. The table with the values of the parameters in different schemes can also be found in Fig. 1.

3. PRODUCTION PROCESSES

The plots in Fig. 2 and 3 depict the total cross-sections of the complete $\mathcal{O}(\alpha)$ and leading higher order results for the neutralino, chargino and 3rd generation sfermion production processes (as presented in detail in [2, 3]). The numerics was done using the SPS1a' benchmark point and the tree-level results were done also in accord with the convention i. e. using $\overline{\mathrm{DR}}$ couplings and on-shell masses. In the case of neutralino and chargino production extra attention is paid to the problem of the separation of the QED and weak corrections. The approach applied here is identical with the one specified in the SPA project (see [1]), where the weak corrections are defined as

$$
\mathrm{d}\sigma^{\mathrm{weak}} = \mathrm{d}\sigma^{\mathrm{virt+soft}} + \frac{\alpha}{\pi}\Big((1 - L_e - \Delta_\gamma)\log\frac{4\Delta E^2}{s} - \frac{3}{2}L_e\Big)\,\mathrm{d}\sigma^{\mathrm{tree}} \tag{1}
$$

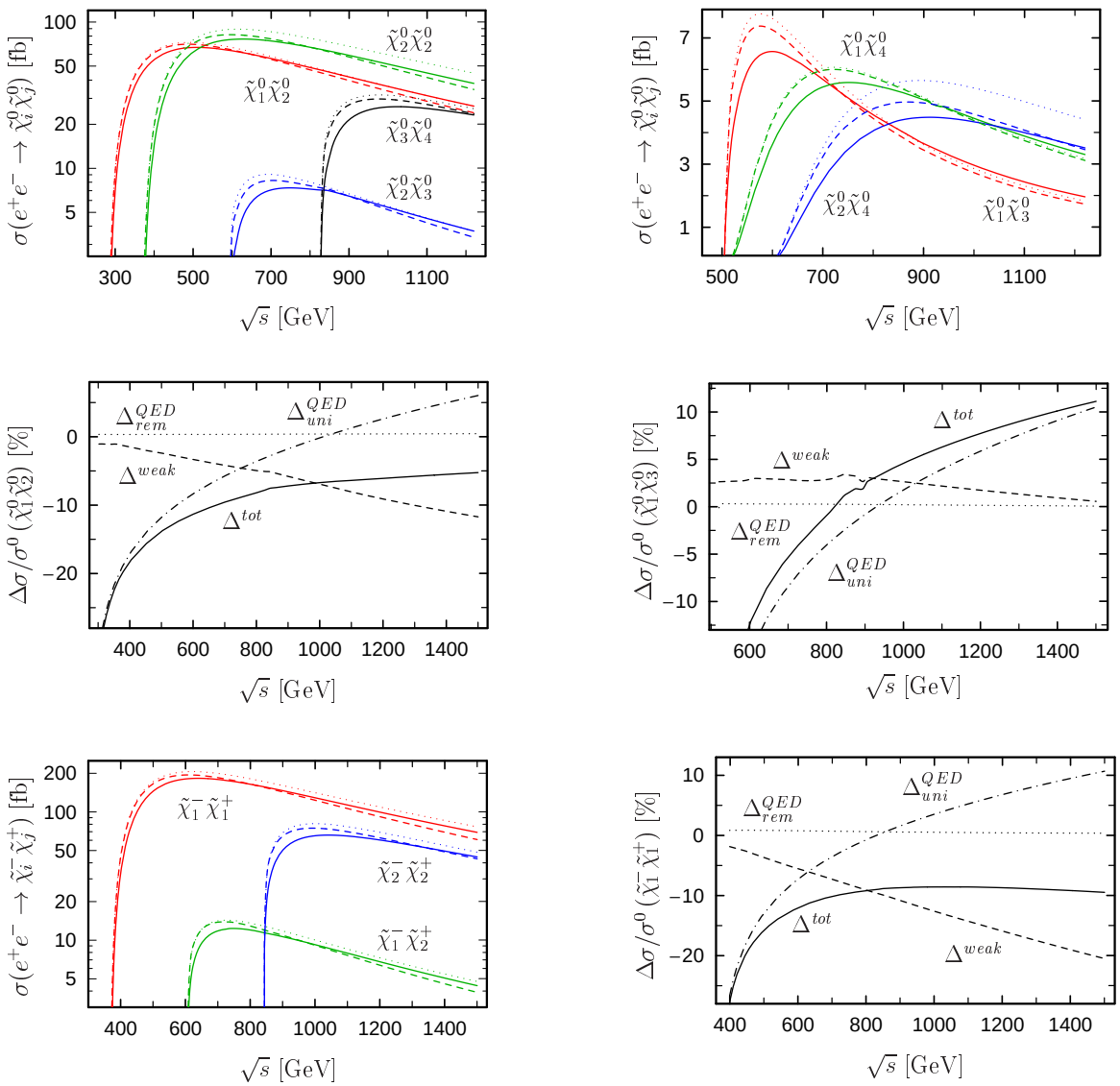

Figure 2: Neutralino and chargino production total cross-sections for all channels and unpolarized beams accompanied by the relative corrections for some channels.

with Δ_γ taking the cut-off dependent terms from final state radiation and inital/final state radiation interference into account (the initial state radiation contribution is contained in the remaining terms). Using this definition one can separate the weak and the QED corrections in a gauge invariant and cut-independent way. The QED corrections are further divided into two parts, the universal one Δ_{uni}^{QED} fully given by a structure function approach and the remainder Δ_{rem}^{QED} (for details see [2]).

The sfermion production cross-sections are presented in Fig. 3 and the emphasis is put on showing the effect of the polarization of the e^+e^- beams. As one can see the polarization has a significant effect on both the tree-level cross-sections and the one-loop corrections.

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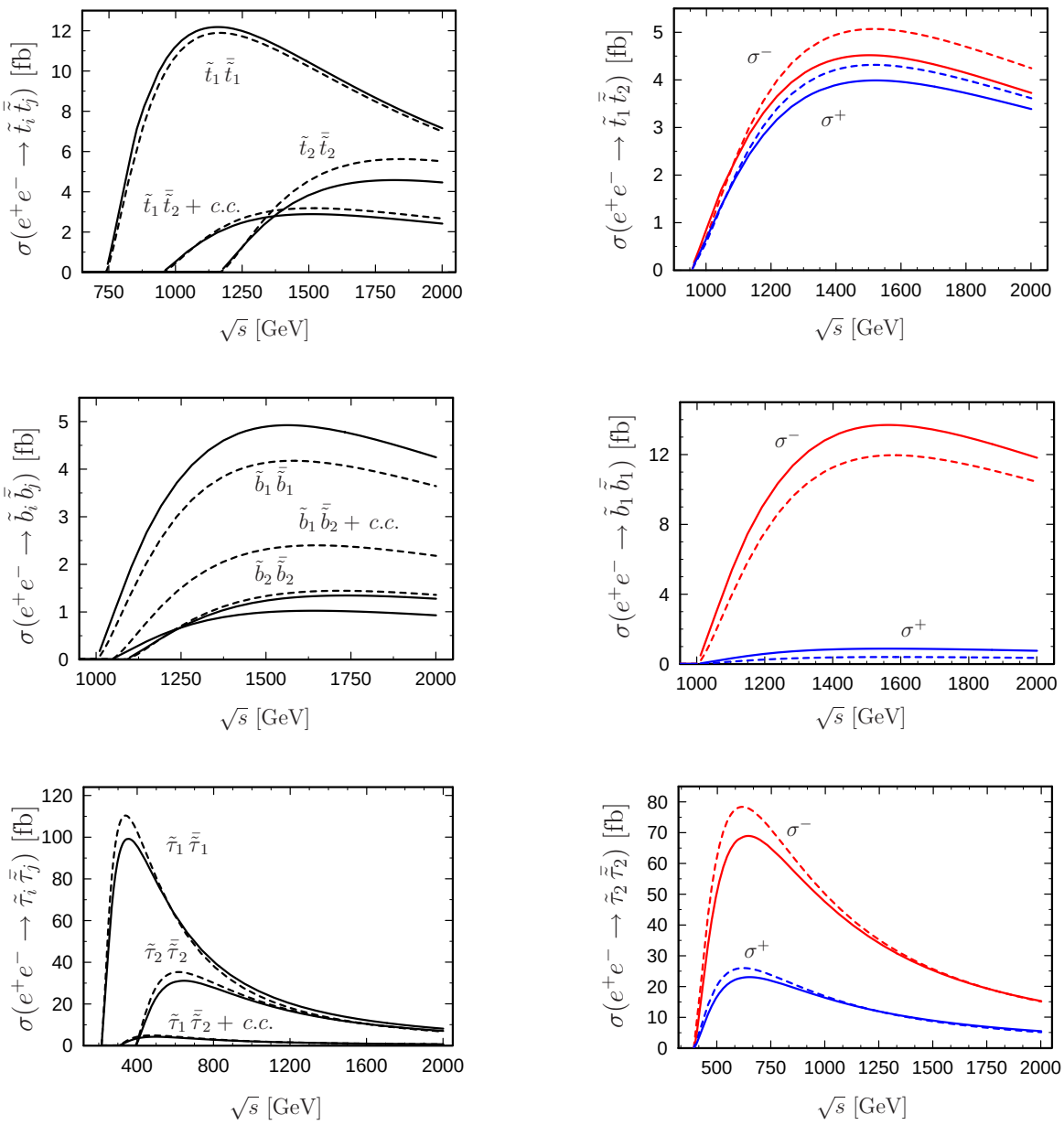

Figure 3: Left: Stop, sbottom and stau production total cross-sections for all channels and unpolarized beams. Right: The total cross-sections for polarized beams where σ^- stands for $P_- = -0.8$, $P_+ = 0.6$ and σ^+ for $P_- = 0.8$, $P_+ = -0.6$ polarizations. The tree-level/complete cross-sections are denoted by dashed/solid lines.

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