SPA PROJECT: SUPERSYMMETRY PARAMETER ANALYSIS AT LHC/ILC

SPA COLLABORATION

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High-precision analyses of supersymmetric parameters aim at reconstructing the fundamental supersymmetric theory and its breaking mechanism. A scheme, SPA Convention, has been proposed in Ref.[1] which defines the proper theoretical frame for these analyses. This procedure will be reviewed for SUSY processes at the LHC and ILC, and it will be exemplified specifically for minimal supergravity and a left-right symmetric scenario.

1. The SPA Convention

A stable bridge between the electroweak scale and the Planck scale is built by supersymmetry, characterized by a typical scale of order TeV. If this picture is realized in nature, methods must be developed to reconstruct the fundamental supersymmetric theory and its breaking mechanism near the Planck scale.

Technically this target requires precision measurements of masses, mixings and couplings of supersymmetric particles from which the basic gaugino and scalar mass parameters in the Lagrangian can be extracted. By means of renormalization group methods they can be extrapolated to reconstruct the physics scenario near the Planck scale where all interactions including gravity are expected to unify.

The SPA Convention[1] defines the regularization and renormalization scheme for precision calculations, as well as the set of input parameters. Two points are of particular importance. *(i)* The masses of the heavy SUSY particles are introduced as pole masses; *(ii)* The $\overline{\mathrm{DR}}$ scheme is chosen as regularization and renormalization scheme, proven recently to be mathematically consistent, to preserve supersymmetry, at least up to the two-loop level in non-trivial examples, and complying with the factorization theorem in hadron collisions.

The SPA program has been carried out so far for a specific mSUGRA point SPS1a′, compatible with all constraints from low-energy precision measurements and from the relic density of cold dark matter. The SPS1a′ spectrum is fairly light, providing the opportunity to study the entire ensemble comprehensively and with high resolution.

(a) LHC: Squarks and gluinos are produced at LHC directly in diagonal and mixed pairs in large numbers, about one million particles in the SPS1a′ range. After including the next-to-leading order super-QCD corrections, the predictions are under good theoretical control with small residual renormalization and factorization scale dependence in contrast to the leading order prediction. However, refinements in the prediction of quark/gluon parton densities are called for.

Non-colored supersymmetric particles, charginos/neutralinos and sleptons are primarily generated in cascades like

$$\tilde{q}_L \to q + \tilde{\chi}^0_2 \to q + \ell^\pm + \tilde{\ell}^\mp \to q + \ell^\pm + \ell^\mp + \tilde{\chi}^0_1$$

with $q\ell^+\ell^- \not{E}_T$ observed in the final state. From exploring edges/thresholds and distributions of 2- and 3-parton invariant masses, the masses of colored particles and non-colored particles can be measured at accuracies of 8 GeV and 5 GeV, respectively. Strong correlations between the heavier particle masses and the mass of the LSP, the lightest neutralino which escapes detection, prevent a better resolution. Moreover, part of the non-colored particles cannot be isolated due to small signal rates with large backgrounds underneath.

(b) ILC: These problems can be solved in the clean environment of $e^\pm e^-$ collision experiments. In decays like $\tilde{\mu}^-_R \to \mu^- \tilde{\chi}^0_1$ the accuracy in the determination of the LSP mass $m_{\tilde{\chi}^0_1}$ can be improved by nearly two orders of magnitude to a level of 50 MeV. The steep increase of S-wave $\tilde{e}^-_R \tilde{e}^-_R$

production leads to the same improvement for slepton masses. Production and decay of sleptons as well as charginos/neutralinos are theoretically under control up to one-loop corrections. The accuracy achieved this way is sufficient for LHC experiments but the two-loop effects must be studied in the future to match LC experimental results.

Based on the relations between masses and Lagrangian gaugino and scalar mass parameters at the SUSY scale $\tilde{M}$, set to 1 TeV in the SPA Convention, and known to two-loop order, the basic Lagrangian parameters can be extracted at a precision of per-cent to per-mille level.

2. Reconstruction of the Planck-Scale Scenario

High-precision measurements of low-energy Lagrangian parameters are the necessary ingredient for extrapolation to high scales, so as to reconstruct the physics scenario potentially near the Planck scale where particle physics and gravity unify. Performing such extrapolations, universal structures and symmetries can be discovered, and equally important, the impact of high-scale physics degrees of freedom can be explored. The transport from the Tera- to the Planck-scale is carried out by means of the renormalization group, solved so far to three-loop order and encoded in transport programs such as Spheno.

(a) Minimal Supergravity is the simplest realization of a supersymmetric theory linked to gravity by incorporating gravity induced universal gaugino and scalar mass parameters at the GUT scale.

Starting from present measurements of the electroweak and strong gauge couplings, the couplings match at the unification scale with an accuracy of 2%, cf. Fig. 1. Improving the accuracy of the gauge couplings at the electroweak scale by running GigaZ, a window of more than $8\,\sigma$ opens for the impact of parameters associated with the high-scale physics scenario.

A similarly stringent test of universality at the GUT scale can be performed in the gaugino sector with results in parallel to the gauge couplings. The scalar mass parameters evolve from rather different values at the Terascale to universal values at the GUT scale, Fig. 2. A global fit performed for the universal gaugino and scalar mass parameters within the mSUGRA frame,

$$M_{1/2} = 250.0 \pm 0.2 \text{ GeV} \quad \text{and} \quad M_0 = 70.0 \pm 0.2 \text{ GeV} \tag{1}$$

returns a very precise parametric picture of the grand unified scenario.

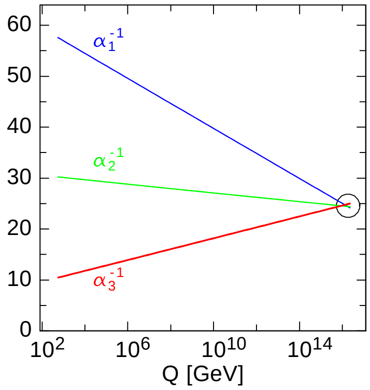

Figure 1. *Evolution of the electroweak and strong gauge couplings to the unification point; Ref.* [1].

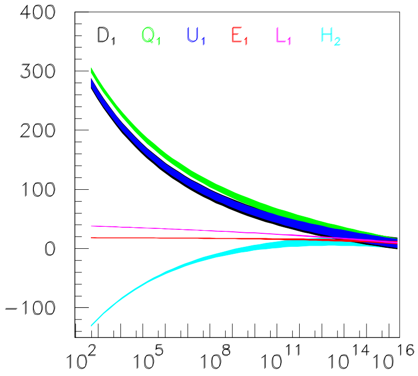

Figure 2. *Evolution of the scalar mass parameters of the first generation in the mSUGRA point SPS1a′ to the universality point at the GUT scale in coherent LHC+LC analyses; Ref.* [1].

(b) Left-right Symmetric Extension: Neutrino oscillations imply the extension of MSSM by right-handed neutrino and R-sneutrino fields. A natural explanation for small neutrino masses is offered by the seesaw mechanism which introduces right-handed neutrino fields with masses close to 10^{10} to 10^{14} GeV. These fields affect the running of the scalar mass parameters. Since the R fields are SM neutral, they couple only by Yukawa interactions. In the third generation they generate a kink in the evolution of the scalar L-mass and the Higgs-H_2 mass parameters. By relating the universal scalar parameters with their values at the Tera-scale, the position of the kink can be determined: $M_{\nu_{R3}} = (5.3 \pm 1.6) \times 10^{14}$ GeV in the LR extended SPS1a′ scenario.

Thus, coherent high-precision high-energy LHC+LC analyses, as formulated in the SPS1a′ program, can provide us with a telescope to the fundamental physics scenario near the Planck scale.

References

1. J. A. Aguilar-Saavedra *et al.*, “Supersymmetry parameter analysis: SPA convention and project”, Eur. Phys. J. C **46** (2006) 43 [arXiv:hep-ph/0511344]; and references quoted therein.