PERSPECTIVES IN PRECISION STUDIES

Precision studies have established the SM at the one-loop level and have proven to be complementary to direct searches. For example, they constrained the mass of the top quark, m_t, before it was discovered at the Tevatron. The extraction of m_t from precision data is still competitive and in agreement with the kinematic mass measurement. Similarly, the mass of the Higgs boson, M_H, can be constrained from above. However, limits on M_H are rather weak, reflecting the fact that decoupling effects are generally small. This should be kept in mind if one attempts to constrain new (super) particle masses by indirect means. Moreover, even when significant deviations are seen in some observables it is usually difficult to attribute them to a specific kind of new physics.

Therefore, the next essential step is to exploit the direct production capabilities of facilities like the LHC or the NLC. After new discoveries are made, precision studies will once again play their complementary role. Any new physics will come with many a priori independent parameters, and existing and upcoming precision measurements will help to constrain them.

Two different aspects of this intertwining arise: what will be the implications of measurements at future colliders for precision tests, and what feedback can a continued program in precision physics provide for direct studies?

The first aspect is much more straightforward to predict. At present, SM fits are limited by the uncertainties in the "input" parameters m_t, M_H, α_s and $\alpha_{QED}(M_Z)$. The quotes remind us, that in practice, these are determined from a global fit to all data, as well (with any direct information implemented as external constraints), and the quality of a distinct input quantity becomes diluted. The uncertainties in these parameters propagate into the predictions for SM observables, as well as new physics parameters, such as the oblique S, T and U parameters. Even a modest determination of M_H would significantly improve the constraints on S and T (S tends to negative values for large M_H). Since the NLC would provide a high precision measurement of M_H, one could completely eliminate one of the uncertain inputs. M_H determinations are harder in the case of a heavy Higgs, but in that regime precision observables are also much less sensitive to it.

Similarly, an NLC run at the Toponium resonance would determine m_t within 200 MeV. Incidentally, this is also the uncertainty entering the relation between the top pole mass, m_t^p, and the $\overline{MS}$ running mass, thus representing a limitation on m_t in any global fit which employs m_t^p as an external constraint. At the very least in this sense would "the NLC provide the definite top mass measurement".

The m_t measurement would be correlated with α_s. For m_t fixed, $\alpha_s(M_Z)$ would be extracted from the Toponium resonance with an error of ± 0.008 or better. In a global fit, one would include two independent constraints together with a covariance matrix, which means a proper presentation of results is called for. There is another correlation between α_s and the weak angle, $\sin^2\theta_W$, from $R_{\rm had}$ on top of the Z resonance, and a fit might result in a smaller error in α_s (strongly depending on the presence of new physics parameters). An independent precision measurement of α_s could come from jet event shape analyses at the NLC, provided that perturbative QCD calculations can be improved to $\mathcal{O}(\alpha_s^3)$. A very interesting possibility is to use the NLC as a Z factory by running it on the Z pole. Since α_s measurements at $R_{\rm had}$ are primarily limited by statistics, this would give a significant improvement over the LEP result.

By running the NLC at PETRA and TRISTAN energies, the scale dependence of α_s may be measured in a perturbative regime and in a single experimental environment. These topics will be discussed in the QCD working group at Snowmass. In any case, it will be important to add at least a second precision determination of the strong coupling parameter from a high energy machine to the one from LEP 1. There are also prospects that lattice simulations of Charmonium and Υ spectra will yield high precision values of $\alpha_s(M_Z)$. The present error from an unquenched Υ calculation is already quoted to be ± 0.002. It will be important to have a similar study of Charmonium to check consistency.

So it seems that all relevant SM input parameters would be improved significantly with a clean machine as provided by the NLC, with the exception of $\alpha_{QED}(M_Z)$. With the lack of new ($e^+e^- \to$ hadrons) data at intermediate energies, it will be hard to find independent information on the hadronic contribution to vacuum polarization. The hadronic uncertainty entering the anomalous magnetic moment of the muon, a_μ, the experimental error in which will be reduced by at least a factor of 20 in the new experiment at BLN scheduled for this year, is virtually uncorrelated with the one in $\alpha_{QED}(M_Z)$. a_μ will be sensitive to the electroweak sector only after new e^+e^- data at the rho resonance became available.

We note, however, that a similar and strongly correlated (with $\alpha_{QED}(M_Z)$) contribution affects the relation between the weak mixing angle, $s^2_{\rm eff}$, as measured at the Z-pole and a low energy definition, s^2_0, extracted from various experiments at low momentum transfer Q^2. Again, in a global fit, this effect of the "running" of $\sin^2\theta_W$ may help to some extent to constrain the hadronic uncertainty, if a high precision determination of s^2_0 can be achieved. Curiously, such a determination may be provided by a high energy collider: high energy polarized Møller scattering off a fixed liquid hydrogen target has been proposed, using a collider with a polarizable electron beam, such as the SLC or the NLC. Indeed, the left-right polarization asymmetry, which is extremely sensitive to s^2_0, is proportional to Q^2, and thus grows approximately linearly with the beam energy. Q^2 would be about (160 MeV)^2 when the 50 GeV beam at the SLC is used, and about (500 MeV)^2 at a 500 GeV NLC. A precision of ± 0.0007 in s^2_0 might be achieved at the SLC in only a 3 month run. Here we have assumed that the uncertainty from the polarization measurement and other normalization errors are small compared to the statistical one. The question arises whether polarization measurements in Møller scattering can be performed with similar precision as in the e^+e^- mode. Since normalization uncertainties are proportional to the asymmetry, which we expect to be larger at the NLC, an error estimate there is not completely straightforward and could be a suitable topic for the Snowmass Workshop.

Atomic parity violation (APV) experiments are also sensitive to s^2_0. So far, precision studies have been completed only in Cs and Tl, where experimental and theoretical (atomic structure) uncertainties are simultaneously at a satisfying level. Interestingly, while the experimental error dominates in Cs, the opposite is true in Tl. This shows that it will be useful to study APV in as many nuclei as possible, decreasing susceptibly to underestimated systematic errors. It is also possible to study ratios of various isotopes in which many systematic and atomic structure uncertainties cancel. New limitations may arise at some level, however, due to nuclear structure uncertainties. At any rate, it should be emphasized that APV is rather important for constraints on physics beyond the SM, such as leptoquarks, the S parameter, new gauge structures, extra heavy fermions and effective 4-Fermi operators.

Further information on s^2_0 could come from improvements in deep inelastic (DIS) neutrino scattering. An upgraded CCFR experiment could result in a ± 0.0015 error. Similarly, a new (anti-)neutrino-electron scattering experiment, for example at LAMPF, might provide a 1% measurement. These experiments are also sensitive to the T parameter. For example, DIS could yield a constraint of ± 0.3.

Given the prospects of having extremely precise SM parameters at one's disposal, it will be possible to determine new physics parameters more precisely and/or more of them simultaneously. Further support will be provided by new or more precise measurements at high energy colliders. The error in the W mass, which is already known to 0.2%, will decrease by a factor of about 4 through the upgrades at LEP and the Tevatron. Constraints on U, which at present is the poorest known oblique parameter, will thus considerably improve. The same facilities will measure the W width at the 1% level or better. An ep collider, such as HERA, is particularly sensitive to new gauge structures and anomalous gauge couplings. But HERA will also contribute $\mathcal{O}(1)$ constraints for the T and U parameters. It must also be mentioned that the results from LEP 1 will still improve, as not all of the data is included, yet. Moreover, a large fraction of reported results are still preliminary and uncertainties will be smaller in finalized results.

The NLC will add a variety of constraints to this list. The total top width would be especially interesting if it could be measured at the 5% level or better. A 7% statistical precision for the branching ratio $B(H \to b\bar{b})$ would also be possible, a useful measurement especially in the context of supersymmetry. Of particular interest for the precision program would be a 10% measurement of the Higgs-photon-photon vertex which can be obtained in the $\gamma\gamma$ mode of the NLC. The return to the Z-pole, as already mentioned in the context of α_s, would clearly be a bright option for the precision program. For example, with the available high statistics and the better b-tagging capabilities at the NLC, it should be possible to repeat the R_b measurement with greater precision. Many, if not all, of the other LEP 1 observables could be redone, as well, and Snowmass should make a concentrated effort in finding out how valuable this would be.

The Tevatron and the LHC will be able to improve the m_t precision to ± 2 GeV. This is inferior to the NLC, but results will be available sooner. Hadron colliders are also capable of measuring $s^2_{\rm eff}$ through forward-backward asymmetries into lepton final states. For example, CDF is projected to achieve a ± 0.002 determination. Future hadron colliders might do even better than that. They will also contribute information about the top width, and cross section measurements will be interesting, e.g., for α_s. Clearly, it will be essential to work out and summarize detailed projections at Snowmass.

Given the complexity of the precision program, this list is necessarily incomplete. For example, the whole domain of rare processes has not even been touched upon. But we hope, that it will provide some stimulation for discussions at Snowmass. There we should identify more precision observables and evaluate precision projections more carefully. Here we have discussed exemplarily SM gauge couplings and masses, as well as the S, T and U parameters representative for new physics. Clearly, other types of new physics parametrizable as 4-Fermi operators should be addressed, as well as new gauge structures, extra heavy fermions, supersymmetry, and so on. Note that LEP 1 and SLD are only sensitive to Z properties. We should also try to determine what feedback the precision sector can have for the design of future colliders.