LoI : Measurements of the top quark mass at the ILC*

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1 Introduction

The measurement of the quark top mass is relevant for the following reasons:

- It is one of the fundamental parameters of the Standard Model (SM).
- Together with the mass of the Higgs and the mass of the W sets a coherence test for the model.
- It is a key parameter to understand the stability of the universe

In the present document we discuss two measurements of the top quark mass that can be performed at the ILC. Both methods provide uncertainties that are significantly smaller than those of current measurements at proton colliders, and at the same time provide the top quark mass in theoretically well defined mass definitions. In the first measurement, a dedicated set or runs around the production threshold (threshold scan) provides sensitivity to the top quark mass, its width and its Yukawa coupling. In the second measurement, at a center-of-mass energy of 500 GeV, the quark top mass is measured in the continuum in events where an initial state photon has been radiated. This later method also provides information on the running of the top quark mass.
The potential of both measurement strategies has already been studied for linear electron-positron colliders, but do provide significant potential for additional studies to further understand systematic limitations, and to optimize the reach of a future experimental program at the ILC.

2 Measurement of top quark mass in the threshold scan

The measurement of the top quark mass and other top quark properties in a threshold scan is performed by comparing the measured energy evolution of observables, such as the total $t\bar{t}$ production cross section, with theoretical predictions based on different input values. Previous studies using the total cross section have shown that a statistical precision of the mass on the level of 10 to 30 MeV, depending on the collider and the assumed running scenario, is achievable, with total systematic uncertainties in the range from 40 - 75 MeV, dominated by theory uncertainties and selected parametric and experimental uncertainties [1, 2, 3, 4]. The simultaneous measurement of the mass, width, Yukawa Coupling and strong coupling constant is also possible, and an optimisation of the distribution of the integrated luminosity over the threshold region holds the potential for a further reduction of statistical and selected systematic uncertainties [3, 4, 5].

2.1 Next steps

To date, all newer studies have only considered the total cross section as observable, and have relied on selection efficiencies and background levels obtained in full detector simulations slightly above the threshold [1]. Future studies extending the already existing broad basis in this area could

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- Add additional observables at the threshold, including asymmetries possibly making use of polarised beams and kinematic observables
- Determine the evolution of signal efficiency and background rejection over the threshold region making use of the recently available features of event generators to simulate the top quark pair threshold at NLO
- Fully integrate measurements of the luminosity spectrum of the colliders into the analysis, including unfolding of the luminosity spectrum effects

among many other possibilities.

3 Measurement of top quark mass in the continuum

In this method the mass of the quark top is extracted from the $t\bar{t}$ production cross section together with one initial radiated photon as function of the center of the mass energy left after the radiation:

$$s' = s\left(1 - \frac{2E_\gamma}{\sqrt{s}}\right). \tag{1}$$

The top quark mass is extracted by fitting the theoretical prediction -parametrized by the top quark mass- to the measured cross section. This theoretical prediction requires a matched calculation that includes the enhancement of the cross section at the production threshold from bound-state effects [6] while remaining valid well above threshold [7, 8]. The matching is done in analogy to Ref. [9].

The predicted uncertainties on the top mass (in the $\overline{\text{MS}}$ mass scheme) for this method, including detector systematics, are estimated in [10, 11, 12] and summarized in Table 1. The statistical uncertainty is the dominant source of systematic uncertainty.

cms energy	ILC, $\sqrt{s} = 500\,\text{GeV}$	
luminosity [fb^{-1}]	500	4000
statistical	350 MeV	110 MeV
theory	55 MeV	
lum. spectrum	20 MeV	
photon response	85 MeV	
total	360 MeV	150 MeV

Table 1: Predicted uncertainties for the measurement of the top quark mass in the continuum under the $\overline{\text{MS}}$ mass scheme.

This method also allows the measurement of a scale-dependent top quark mass for scales below m_t by extracting the mass from different sections of the differential cross section as a function of $\sqrt{s'}$. For this prospect study the MSR mass scheme is used and a 5σ significance is expected for $m_t^{\text{MSR}}(R)$, $R < m_t$ [10].

3.1 Next steps

- An increase in the detector acceptance (currently 8° in Ref. [10]) would significantly increase the statistics and immediately reduce the dominant uncertainty.
- The production process of $t\bar{t}$ with a radiated gluon, instead of a photon, can be explored.

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