Optimising top-quark pair-production threshold scan at the future e⁺e⁻ colliders

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1. THRESHOLD SCAN

One of the main goals of the future e^+e^- colliders ILC, CLIC and FCC-ee is to measure the top-quark mass and width with extreme precision in a scan of the pair production threshold. Detailed simulation studies[1,2] showed that statistical accuracy on the top-quark mass of the order of 20 MeV can be obtained already with $100\,\mathrm{fb}^{-1}$ of data collected at 10 equidistant energy points. However, only the two-parameter fits to the threshold scan data were considered, while the threshold cross section depends also on other model parameters as the top Yukawa coupling and the strong coupling constant. We study the expected precision of the top-quark mass determination from the threshold scan at CLIC, ILC and FCC-ee using the most general fit approach[3] with all relevant model parameters included and expected constraints from earlier measurements taken into account. Even in the most general approach the top-quark mass can be extracted with statistical precision of the order of 20 to 30 MeV provided the strong coupling constant and top-quark Yukawa coupling are known from independent measurements with sufficient precision, see Fig. 1 (left). Influence of collider luminosity spectra is illustrated in Fig. 1 (right).[4] For normalization uncertainty of 1% and strong coupling uncertainty of 0.001, statistical uncertainty on the top-quark mass of 25 MeV can be obtained at FCC-ee already with $100\,\mathrm{fb}^{-1}$ while about $250\,\mathrm{fb}^{-1}$ and $400\,\mathrm{fb}^{-1}$ are required for the same precision at ILC and CLIC, respectively (assuming unpolarised beams).

2. SCAN OPTIMISATION

Additional improvement of the measurement is possible, if the scan scenario is optimized. We propose the optimisation procedure based on the genetic algorithm.[3,4] The scan optimised for mass and width measurement is focused in three energy regions, just below the threshold, in the middle of the threshold, where the cross section slope is highest and at the plateau just above the threshold, see Fig. 2 (left). Statistical uncertainty on the top-quark mass expected at different colliders from the optimised scan scenario is shown in Fig. 2 (right). The uncertainty can be reduced by up to 30%, corresponding to factor of 2 increase in the integrated luminosity.

3. PLANS FOR SNOWMASS'2021

While the analysis[3] has been completed, we plan to improve and extend our study by taking additional effects into account. Beam polarisation should be included not only in the cross section calculations and event simulation, but also as an additional parameter in the scan optimisation procedure. Dedicated study based on full simulation results is also planned for more detailed analysis of backgrounds and systematic uncertainties at the threshold. Finally, we also consider using additional observables,[5] as the top forward-backward asymmetry or top-quark momentum distribution, in the global fit of the threshold measurements, see Fig. 3. We expect additional measurements to reduce both statistical and systematic uncertainties of the extracted top mass. We would also like to verify how additional observables improve precision of the top-quark Yukawa coupling determination from the threshold scan.

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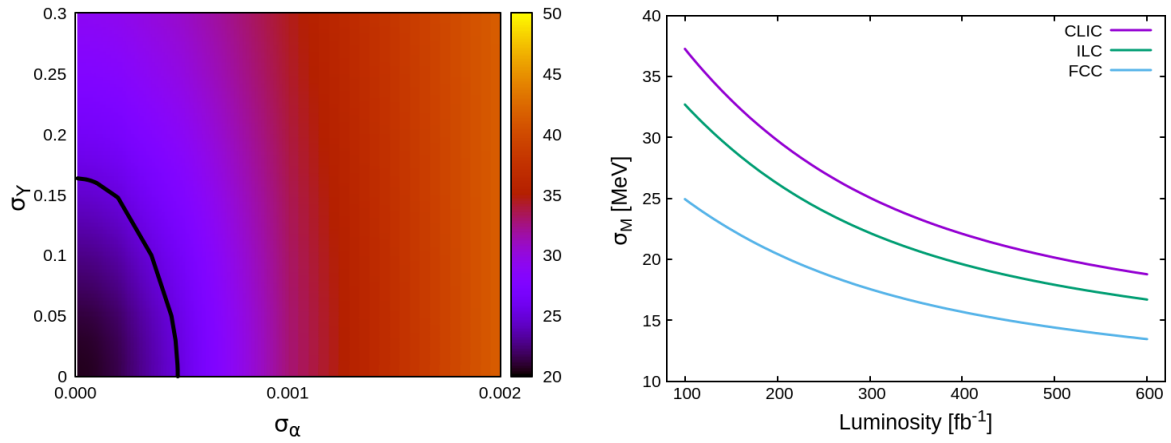

Figure 1. Expected statistical uncertainty on the top-quark mass from the baseline scan scenario: as a function of the strong coupling constant and Yukawa coupling uncertainties at CLIC, for normalisation uncertainty of 0.1% (left) and as a function of the total scan luminosity, for different collider project, normalization uncertainty of 1% and strong coupling uncertainty of 0.001 (right).

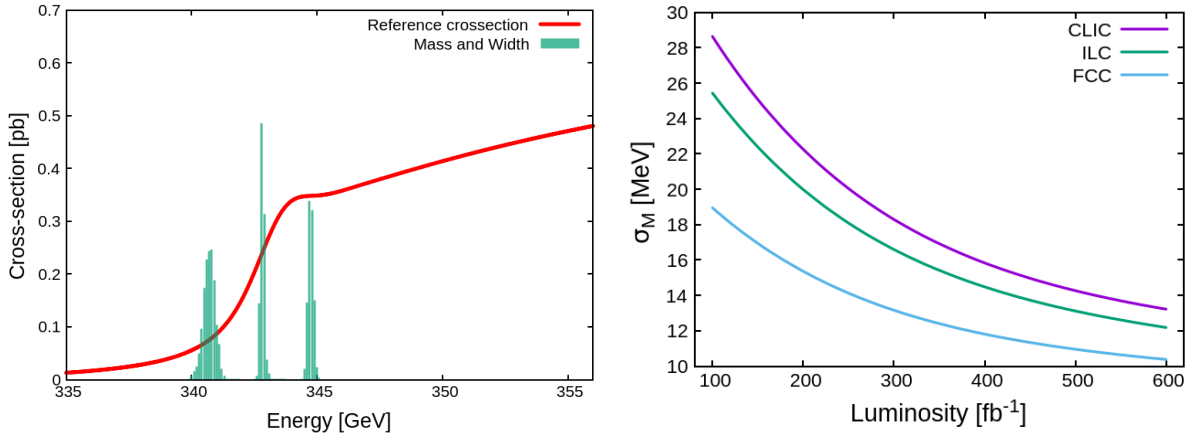

Figure 2. Distribution of the energy points selected by the genetic algorithm for the best measurement of the top-quark mass and width (left). Expected statistical uncertainty on the top-quark mass from the optimised scan scenario, as a function of the total scan luminosity, for different collider project (right).

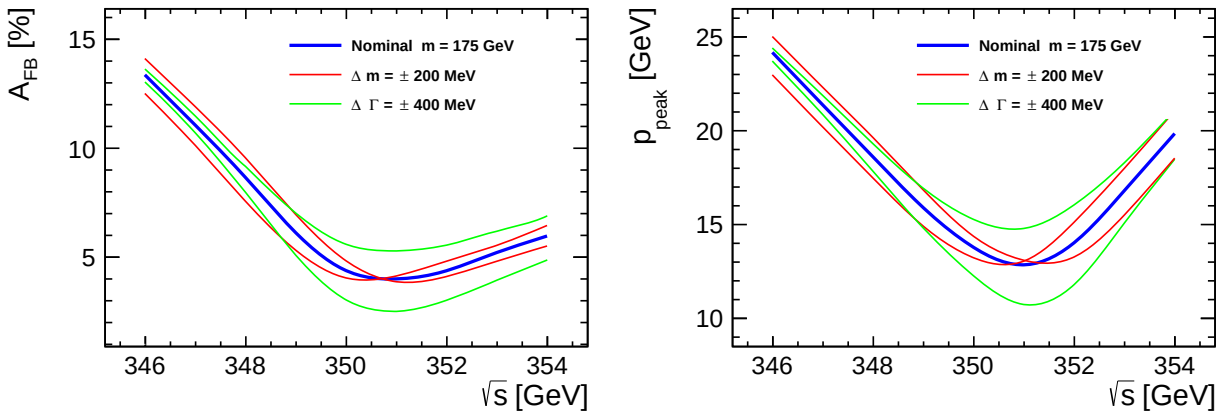

Figure 3. Expected sensitivity of the measured forward-backward asymmetry (left) and top-quark momentum distribution (right) on the top-quark mass and width, as a function of the collision energy. Results adapted from.[5]