The Physics Prospects for CLIC

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Abstract. - Following a brief outline of the CLIC project, this talk summarizes some of the principal motivations for an $e^+e^-$ collider with $E_{CM} = 3$ TeV. It is shown by several examples that CLIC would represent a significant step beyond the LHC and ILC in its capabilities for precision measurements at high energies. It would make possible a complete study of a light Higgs boson, including rare decay modes, and would provide a unique tool to study a heavy Higgs boson. CLIC could also complete the studies of supersymmetric spectra, if sparticles are relatively light, and discover any heavier sparticles. It would also enable deeper probes of extra dimensions, new gauge bosons and excited quarks or leptons. CLIC has unique value to add to experimental particle physics, whatever the LHC discovers.

1 - The CLIC Project

The conceptual layout of CLIC is shown in the left panel of Fig. 1 [1]. The basic idea is to use a relatively high-intensity, low-energy beam to drive a relatively low-intensity, high-energy beam. The fundamental principle resembles that of a conventional AC transformer. The low-energy drive beam serves as an RF source that accelerates the high-energy main beam with a (hopefully) high accelerating gradient. The left panel of Fig. 1 displays the base-line configuration for a 3-TeV $e^+e^-$ collider, the primary objective of the CLIC R&D programme.

Table 1 shows the nominal parameters for CLIC operating at its nominal design energy of 3 TeV [3]. It also shows an alternative set of parameters for operation at 500 GeV. Note a few key parameters: the nominal luminosity at each energy is well above $10^{34}$ cm$^{-2}$s$^{-1}$, the main linac frequency (cf, the 50/60 Hz of a conventional AC circuit) is now 12 GHz (more similar to the frequency proposed previously for the
NLC and the JLC), the accelerating gradients assumed are 80 (100) MV/m for the 500-GeV (3-TeV) options, and the total site lengths are 13.0 (48.3) km [1].

The CLIC technology is less mature than that of the ILC, and requires more R&D. In particular, the target accelerating gradient is considerably higher than the ILC, and requires very aggressive performance from the accelerating structures. The right panel of Fig. 1 shows that the nominal CLIC accelerating gradient has been exceeded in an unloaded structure with a very low breakdown probability, below $3 \times 10^{-7}$ per metre, after RF conditioning for 1200 hours. The T18 structure that achieved this performance was designed at CERN, built at KEK, and RF tested at SLAC. Thus it was the fruit of a truly international effort.

The beam gymnastics needed to provide the 12 GHz drive-beam power source, the RF power generation and two beam acceleration in CLIC standard modules are being demonstrated in CLIC Test Facility 3, which is being built by a large international team [4]. CLIC R&D is being carried out by a world-wide collaboration consisting of 24 members representing 27 institutes involving 17 funding agencies from 15 countries including Turkey. It is organized in a similar manner to an experimental collaboration, with each of the institutes represented in a Collaboration Board.

The mandate to the CLIC team is to demonstrate the feasibility of the CLIC concept by the end of 2010 in a Conceptual Design Report. If this effort is successful, and if the new physics revealed by the LHC warrants, the next phase of R&D on engineering and cost issues could be completed by the end of 2015. This would serve as the basis for a Technical Design Report and a request for project approval.

The prospects for approval of the CLIC project would clearly depend not only on its technical feasibility and cost, but primarily on its physics capabilities and complementarity to other accelerators such as the ILC. These have the subjects of various studies since 1987, from which the following sections of this talk have been drawn. The main source is a comprehensive study of CLIC physics published in...
2004 [5], with significant Turkish participation, from which a few selected topics are now discussed.

2 - Light Higgs Physics

We do not yet know whether the Higgs boson exists, still less whether it resembles the particle predicted in the framework of the Standard Model - and one should never sell the bearskin before catching the bear! That said, the combined Higgs probability distribution obtained by combining the direct searches at LEP [6] and the Tevatron [7] with the indirect information provided by high-precision electroweak measurements [8] seems to favour a relatively light Higgs boson, as shown in Fig. 2. The electroweak data would, by themselves, yield an almost parabolic $\chi^2$ function, but this is already being eroded at intermediate values of $m_h \sim 170$ GeV by the negative results of direct searches at the Tevatron - and the CDF and D0 searches are continuing. Currently, the favoured range of Higgs masses is $m_h < 140$ GeV, but masses larger than 200 GeV are still not excluded. Specifically, the Gfitter group finds

$$m_h = 116.4^{+18.3}_{-1.3} \; \text{GeV},$$

and quotes the ranges (114, 145) GeV at the 68% confidence level and (113, 168) and (180, 225) GeV at the 95% confidence level [9].

With just a fraction of 1/fb of integrated luminosity, as seen in the left panel of Fig. 3 [10], the ATLAS and CMS experiments would be able to a Standard Model-like

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Table 1: Latest sets of CLIC parameters for $\sqrt{s} = 0.5$ TeV and the nominal 3 TeV [3].

| Center-of-mass energy | CLIC 500 G | CLIC 3 TeV |
|-----------------------|------------|------------|
| Beam parameters       | Conservative | Nominal | Conservative | Nominal |
| Accelerating structure | 502        | G        | 502         | G        |
| Total (Peak T) luminosity | $2.3(1.4) 	imes 10^{36}$ | $2.7(1.3) 	imes 10^{36}$ | $5.9(2.0) 	imes 10^{36}$ |
| Repetition rate (Hz)  | 50         | 50        | 50          | 50        |
| Luminosity            | 50         | 50        | 50          | 50        |
| Bunch charge (nC)     | 12         | 12        | 12          | 12        |
| Bunch separation (ms) | 0.5        | 0.5       | 0.5         | 0.5       |
| Beam pulse duration (ns) | 840       | 840       | 840         | 840       |
| Beam power (MWatts)   | 4.9        | 4.9       | 14          | 14        |
| Horizontal norm. emitt ($10^{-5}$) | 3/40     | 2.4/25    | 2.420       | 0.66/20   |
| Vertical FF focusing (mm) | 10.4     | 8/0.1     | 4/0.1       | 4/0.1     |
| Horizontal IP beam size (mm) | 248/5.7   | 202/2.3   | 83/1.1      | 40/1      |
| Hadronic events/interaction at IP | 0.07      | 0.19      | 0.75        | 2.7       |
| Coherent pairs at IP  | 10         | 100       | 5.19        | 3.810^6   |
| BDS length (km)       | 1.87       | 2.75      | 48.3        |           |
| Total site length km  | 13.0       | 48.3      | 190         | 3810^6    |
| Wall plug to beam transfer eff | 7.5%      | 6.8%      | 6.8%        |           |
| Total power consumption MW | 129.4     | 415       | 129.4       | 415       |
Figure 2: The $\chi^2$ likelihood function for the Standard Model as a function of the Higgs mass, as obtained \cite{9} by combining the indirect information from the precision electroweak data - which would yield a smooth, near-parabolic function, and the negative results from the direct searches at LEP - which cut off low masses, and the Tevatron - which erode the likelihood between 140 and 200 GeV.

Higgs boson weighing between 140 and 600 GeV. Therefore, either the Tevatron or the LHC may soon be able to exclude an intermediate-mass Higgs and tell us that it must either be very light, close to the LEP lower limit, or else very heavy. What could CLIC contribute in either of these scenarios?

If there is a light Higgs boson, the ILC will be able to study many of its properties in some detail. The cross section for producing it at CLIC will be even much larger than at the ILC, as seen in the left panel of Fig. 4. The increase compared with lower centre-of-mass energies is more pronounced for higher $m_h$, but is substantial already for $m_h \sim 120$ GeV. This increase will open up the possibility of measuring rare Higgs decays which are unobservable at the LHC and difficult to measure at a lower-energy $e^+e^-$ collider, and two examples are displayed in Fig. 5. In the left panel we see that CLIC could measure the $h\mu^+\mu^-$ coupling with an accuracy of 4% if $m_h = 120$ GeV, and in the right panel we see that CLIC could measure the $h\bar{b}b$ coupling with an accuracy of 2% if $m_h = 180$ GeV \cite{5}.

The double-Higgs production cross section at CLIC would also be much larger than at lower energies, as seen in the right panel of Fig. 4 \cite{5}. As a result, if the Higgs mass is in the low-mass region, the triple-Higgs coupling could be measured quite accurately at CLIC: to 11% if $m_h = 180$ GeV, or to 9% if $m_h = 120$ GeV, as seen in the left panel of Fig. 6. Because of the higher cross sections at higher centre-of-mass energies, the measurement at CLIC could be significantly more accurate than at a
Figure 3: The amounts of integrated LHC luminosity at $E_{CM} = 14$ TeV required (left) either to exclude a Standard Model Higgs boson at the 95% confidence level (blue line) or discover it at the 5-$\sigma$ level (red line), and (right) either to exclude a gluino (blue dashed line) or discover it (blue solid line). The corresponding thresholds for $\chi$ pair production in $e^+e^-$ are shown in red [10].

3 - Accompanying New Physics?

If $m_h$ is as light as 120 GeV, the present electroweak vacuum is rendered unstable by radiative corrections induced by the top quark, unless new physics intervenes. One possibility for this is some form of contact interaction, and the high CLIC centre-of-mass energy gives it an edge over a lower-energy collider in searching for such a symptom of new physics. Studies show that CLIC would be sensitive to new contact interactions in $e^+e^- \rightarrow \mu^+\mu^-$ with scales up to 300 TeV [5].

One of the most compelling examples of possible new physics is supersymmetry, which would help stabilize the electroweak vacuum [11]. Supersymmetry is discussed later in its own right. Here I note that one of its predictions is the existence of heavier neutral Higgs bosons, a pseudoscalar $A$ and a scalar $H$, which would be quite difficult to detect at the LHC, depending on their masses. In general, an $e^+e^-$ collider could extend the search up to close to the kinematic limit. This sensitivity is exemplified for CLIC in the right panel of Fig. 6, where we see that a pseudoscalar $A$ boson would be detectable at CLIC if its mass were up to 1100 GeV or more, depending on the value of $\tan \beta$, the ratio of Higgs VEVs in the minimal supersymmetric extension of the Standard Model (MSSM) [5].
Figure 4: Inclusive single Higgs production cross section (left) and double Higgs production (right) as functions of the Higgs mass, each for three values of the $e^+e^-$ centre-of-mass energy \[5\].

4 - Theorists getting Cold Feet?

With the imminent discovery (or demise) of the Higgs boson, many theorists seem to be getting cold feet: can it really be true? Now may be the last chance to stake a claim to an alternative theory, and many theorists are seizing it.

Maybe the Higgs boson does exist, and is even light, as in little Higgs models \[12\]? In these models, the Higgs is a pseudo-Nambu-Goldstone boson that is a bound state of new strong-interaction dynamics that appears at $\sim 10$ TeV. One-loop quadratic divergences in the Higgs mass-squared are cancelled by an extra ‘top-like quark, gauge bosons and extra scalars related to the Higgs boson, all with masses $\sim 1$ TeV. These would be prime fodder for discovery at CLIC.

Alternatively, perhaps our interpretation of the high-precision electroweak data is incorrect \[13\]? As is well-known, there are some apparent discrepancies between different subsets of the electroweak data. For example, measurements of hadronic final states in Z decays tend to prefer a higher value of $m_h$ than do measurements of leptonic final states. Also, the low-energy measurement of $\sin^2 \theta_W$ by the NuTeV collaboration seems to differ from other measurements \[13\]. Most observers would consider these discrepancies to be symptomatic of underestimated systematic errors, or some other experimental problems. But perhaps they are due to some unknown new physics? In that case, the Standard Model would be an incomplete paradigm for analyzing the high-precision electroweak data, the apparent preference for a low-mass Higgs boson might be wrong. In that case, a there might be a heavier Higgs boson, ripe for observation at CLIC.
Another corridor towards a heavier Higgs boson might be opened up by the inclusion in the electroweak fit of higher-dimensional operators composed of Standard Model fields. As shown in Fig. 7, if one such operator is present with a coefficient scaled by a high scale $\Lambda \sim 3-10$ TeV (possibly generated by the exchange of some massive state), a Higgs weighing up to 1 TeV might be compatible with the high-precision electroweak data [14].

One example of a theory with massive states that invalidate the electroweak ‘bound’ is provided by a model with a fourth generation [15]. In this model, the Standard Model electroweak fit could accommodate (even prefer) a heavier Higgs weighing $\sim 300$ GeV [16], for which the cross section at CLIC would be encouragingly large, as seen in Fig. 4.

Finally, let us mention Higgsless models [17]. These are beset by strong $WW$ scattering, which tends to feed back into an unacceptable fit to the high-precision electroweak data. This problem can be somewhat mitigated in variants with extra dimensions, but is still a serious issue for such models.

5 - What if the Higgs is Heavy - or Non-Existent?

If the Higgs boson does indeed weigh 1 TeV or so, its observation will be difficult at the LHC, though not impossible, thanks to the $WW$ fusion mechanism for Higgs production. However, such a heavy Higgs boson would not be visible directly at the ILC. There would be no problem producing and measuring it at CLIC, as seen in Fig. 8, which shows the recoil mass distribution for a heavy Higgs boson produced in the reaction $e^+e^- \rightarrow e^+e^- H$, in a simulation for a nominal $M_H = 900$ GeV [5].
If there is no Higgs boson at all, the LHC might find a hint of strong $WW$ scattering, but this new physics would not be visible directly at a lower-energy $e^+e^-$ collider. On the other hand, either the LHC or the ILC might be able to discover associated physics related, e.g., to extra dimensions. However, CLIC would be uniquely well placed to study strong $WW$ scattering directly, with high statistics and precision. CLIC would also be best placed to see/understand other aspects of scenarios with associated high-scale physics, such extra dimensions or composite models of Higgs, quarks and leptons.

6 - Supersymmetry

There are many reasons to like supersymmetry, including its intrinsic beauty, its utility in controlling radiative corrections to the Higgs mass and thereby solving the naturalness aspect of the hierarchy problem [18], the help it offers for the unification of the gauge couplings GUTs, the fact that it predicts a light Higgs boson weighing $< 150$ GeV [19], as apparently favoured by the precision electroweak data [8, 9], and the fact that it predicts naturally the existence and a suitable density for the astrophysical cold dark matter [21]. Moreover, supersymmetry is an (almost) essential ingredient in string theory.

These are all good arguments but, to paraphrase Feynman, if we had one really convincing argument, we would not need to give several!
Figure 7: Fits to the electroweak data that include one or another higher-dimensional operator scaled by a high scale $\Lambda \sim 3 - 10$ TeV may allow a heavier Higgs boson [14].

The left panel of Fig. 9 compiles the constraints on the simplest version of the minimal supersymmetric extension of the Standard Model, in which the scalar and spin-1/2 sparticle masses are each constrained to be all equal to $m_0$ and $m_{1/2}$, respectively, at the grand unification scale (the CMSSM), assuming that the lightest supersymmetric particle (LSP) is the lightest neutralino (a mixture of partners of the photon $Z$ and Higgs boson) [22]. The bottom-right part of the $(m_{1/2}, m_0)$ plane is excluded in this case, because there the LSP is the charged stau. Regions at low $m_{1/2}$ are excluded by LEP searches for charginos and the Higgs boson, and by $b \rightarrow s\gamma$ decay. There is also a diagonal (pink) band that is favoured if one uses the published low-energy $e^+e^-$ data to calculate $g_\mu - 2$ [23, 24]. However, this is a controversial constraint, so we will treat it as optional. Finally, note the thin diagonal (turquoise) strip within which the relic LSP density matches that inferred from astrophysics and cosmology by WMAP and other experiments. Combining all these constraints, we see that there is a limited region of the WMAP strip that is compatible with all the constraints, but that this extends to relatively large values of $m_{1/2}$ and hence sparticle masses, if the potential $g_\mu - 2$ constraint is discounted.

The gluino mass increases proportional to $m_{1/2}$ along this WMAP strip, and the lightest neutralino is also simply proportional. Therefore, a given reach in the gluino mass translates directly into an LSP mass, and hence a threshold for sparticle production in $e^+e^-$ collisions, as seen in the right panel of Fig. 3 [10]. With just 100/pb of data at 14 TeV, the LHC should be able to discover the gluino if it weighs less than 1.1 TeV, or exclude a gluino weighing less than 1.5 TeV if it sees nothing. In the former case, the threshold for sparticle pair production in $e^+e^-$ collisions would be below 0.5 TeV, and hence accessible to the ILC. However, in the latter case, the
Figure 8: The invariant mass recoiling against an $e^+e^-$ pair at CLIC operating at a nominal $\sqrt{s} = 3$ TeV in the case of a heavy Higgs boson [5].

The extension of the WMAP strip to high mass scales in the left panel of Fig. 9 shows that sparticles might be quite heavy. As seen in the right panel of Fig. 9, the LHC would be able to discover supersymmetry in most (but not all) of the parameter space of the CMSSM. An $e^+e^-$ centre-of-mass energy of 1 TeV would cover only a part of the WMAP-compatible parameter space, whereas 3 TeV should be enough to cover (almost) all of it, at least in the CMSSM [25].

7 - How Soon might Supersymmetry be Detected?

So far we have been treating all the constraints on supersymmetric models as if they were $\delta$-functions. What happens if one makes a frequentist likelihood analysis, taking the $g_{\mu} - 2$ indication at its face value?

Fig. 10 displays the 68% and 95% confidence level regions in the $(m_0, m_{1/2})$ plane for the CMSSM (similar results are found if one relaxes scalar-mass universality for the Higgs multiplets) [26]. We see that much of the 68% region would be covered already with 50/pb of integrated luminosity with the LHC at 10 TeV, and all of it with 100/pb at 14 TeV. We also see that supersymmetry would be discovered by the LHC with 1/fb over almost all the 95% region, and this amount of integrated luminosity would also suffice to exclude supersymmetry throughout the 95% region.

The best-fit point in the CMSSM has $\tan\beta \sim 10$ and quite low $m_{1/2}$, similar to benchmark point B [29] or SPS1a [30]. As such, it has a relatively light spectrum,
that offers good opportunities to the ILC. The best-fit spectrum is shown in the left panel of Fig. 11, where we see that an $e^+ e^-$ collider with 0.5 TeV could produce all the sleptons, the lighter chargino and the second-lightest neutralino. One would need $\sim 1$ TeV to produce the heavier neutral and charged Higgs bosons, and to pair-produce the heavier charginos and neutralinos. A centre-of-mass energy above 1 TeV would be needed to produce squarks. Thus, even in this encouraging example, there would be work for both the ILC and CLIC. This is just one illustration that, even in low-mass supersymmetric scenarios where the ILC can produce some sparticles, studies of strongly-interacting sparticles would require the higher centre-of-mass energy of CLIC.

An important word of warning: the result of this likelihood analysis depends sensitively on the treatment of $g_\mu - 2$. If one rescales the error in the comparison between theory and experiment, as seen in the right panel of Fig. 11, the preferred region of the $(m_0, m_{1/2})$ plane expands and contracts considerably [26]. (The same is true for rescaling the error in $b \to s\gamma$.) Moreover, if one uses $\tau$ decay data to calculate $g_\mu - 2$ in the Standard Model, the discrepancy with experiment essentially disappears, and very large sparticle masses beyond the reach of the ILC are allowed, even favoured.

Examples of possible CLIC sparticle measurements are shown in Fig. 12. In the left panel, we see that CLIC would be able to measure well the dilepton spectrum in
Figure 10: The $(m_0, m_{1/2})$ plane in the CMSSM: the best-fit point is indicated by a filled circle, and the 68 (95)% confidence-level contours from our fit are shown as dark grey/blue (light grey/red) overlays, scanned over all $\tan \beta$ and $A_0$ values [26]. Also shown are some 5-$\sigma$ discovery contours at ATLAS [27] and CMS [28] with 1 fb$^{-1}$ at 14 TeV, and the contour for the 5-$\sigma$ discovery of the Higgs boson in sparticle decays with 2 fb$^{-1}$ at 14 TeV in CMS. These were estimated assuming $\tan \beta = 10$ (similar to our best-fit value) and $A_0 = 0$.

The above examples assumed a neutralino LSP, but an alternative is a gravitino LSP. In this case, if the scale at which supersymmetry breaking originates is large, the next-to-lightest sparticle (NLSP) would be metastable, since it would decay via gravitational-strength interactions. The NLSP need not be neutral in such a scenario, and a metastable charged NLSP would have many interesting signatures.

The left panel of Fig. 13 displays the $(m_{1/2}, m_0)$ plane for one example of a scenario with a gravitino LSP, with a mass $m_{3/2} = 0.2 m_0$ [31]. The NLSP decays could...
in principle mess up the agreement between Big-Bang Nucleosynthesis (BBN) calculations of the light-element abundances and astrophysical observations. Respecting these constraints, and incorporating the important effects of stau bound states [32], one is forced into the light (yellow) shaded region of the left panel of Fig. 13. In fact, the BBN calculations do not agree perfectly with the measured $^6\text{Li}/^7\text{Li}$ ratio, and the darker (pink) shaded region in Fig. 13 is that where stau NLSP decays actually improve the BBN calculations [31].

In order to study the CLIC capabilities for sparticle measurements in gravitino LSP scenarios with a stau NLSP, we have considered four benchmark scenarios, three with relatively light staus detectable at the LHC [33], and one ($\theta$) chosen inside this Lithium ‘sweet spot’ [34]. The total cross sections for $e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1$ production in these four benchmark scenarios are shown in the right panel of Fig. 13.

Also shown there are the cross sections for producing slow-moving staus with $\beta\gamma < 0.4$, which decrease rapidly as $E_{CM}$ increases [34]. The interest in these events is that such slow staus would stop in a typical experimental calorimeter. They would then decay later into a gravitino and a tau, and the decay lifetime and tau energy would provide valuable information about the mass of the gravitino and the mechanism of supersymmetry breaking.

In fact, since all heavier sparticles decay into gravitinos via staus in such a scenario, the total cross section for stau production is much larger than the simple pair-production cross section shown in the right panel of Fig. 13, as also is the cross section for stoppable stau production. This is shown in Fig. 14, where we see that, e.g., the total cross section for stoppable stau production at $E_{CM} = 3$ TeV is about 30 times larger than that from $e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1$ alone.
We conclude that CLIC would be good for detecting and measuring supersymmetry also in gravitino LSP scenarios, which might even require relatively heavy spectra.

8 - Other possible CLIC Physics

The second-favourite option for new physics beyond the Standard Model may be extra dimensions. They could rewrite (at least) the hierarchy problem, might provide a dark matter candidate, and could help in the unification of the fundamental interactions. Moreover, extra dimensions are also essential in string theory.

They might show up via Kaluza-Klein excitations of Standard Model particles, which would appear as direct-channel resonances in $e^+e^-$ annihilation. The high energy offered by CLIC might even provide the opportunity to observe more than one excitation, as seen in Fig. 15. It has been shown that CLIC could measure the mass of a $Z'$ boson with an accuracy of 0.01%, and its width with an accuracy of 0.4% [5].

In some extra-dimensional scenarios, gravity leaks out from four dimensions, and may become strong at some energy $\sim 1$ TeV accessible to the LHC. In this case, CLIC might be able to produce microscopic black holes. These would decay very quickly into energetic quarks, leptons, photons and neutrinos. Such black-hole events would be easy to distinguish from Standard Model backgrounds [5].

9 - Conclusions

CLIC will provide unique, high-precision physics at the energy frontier. In the TeV energy range, it provide beamstrahlung and backgrounds similar to those provided by
the ILC. Furthermore, detailed experimental simulations have shown that the beamstrahlung and other backgrounds at CLIC would not present insurmountable obstacles to exploiting fully the higher centre-of-mass energies made available by CLIC. Several specific examples given above show that CLIC will be able to make accurate measurements at high energies. The high energy offered by CLIC will added value to studies of the physics of a light Higgs boson, and provide unique access to a heavy Higgs boson. CLIC would also have advantages in studies of supersymmetry or extra dimensions, should they appear at the LHC. If the new physics beyond the Standard Model has a relatively low threshold, CLIC will provide unique insight into the heavier states that may help distinguish between models. On the other hand, if the new physics is heavy, CLIC may be the only place to study it with precision.

The future course of high-energy physics will be determined by the LHC, and we do not know what it will find. However, all the scenarios that have been studied would best be explored by a high-energy $e^+e^-$ collider. Since we do not know the LHC threshold, the world community should have available the widest possible technology choice when LHC results appear. The ILC technology is more mature that than of CLIC, but the latter offers more flexibility in energy. Until the time comes to choose, the CLIC and ILC teams are working together, for example in studies of positron sources, damping rings, beam dynamics, beam delivery, interaction regions, detectors and costing. The aim of the CLIC team is to determine the feasibility of the CLIC technology by the end of 2010, around the time when the first LHC physics results will...
Figure 14: Compilation of the principal $e^+e^-$ annihilation cross sections in scenario $\theta$. Comparison with Fig. 13 shows that the total cross section for stoppable staus with $\beta\gamma < 0.4$ is considerably larger than that from $e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1$ alone [34].

become available, and the time comes for the particle physics community to decide its next step in collider physics.

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