

## Closing remarks

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**Abstract.** This talk will consist of a set of personal remarks giving my impressions of the International Workshop on Linear Colliders (LCWS06) and a theorist's perspective.

**Keywords.** Linear collider; photon collider.

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### 1. Introduction

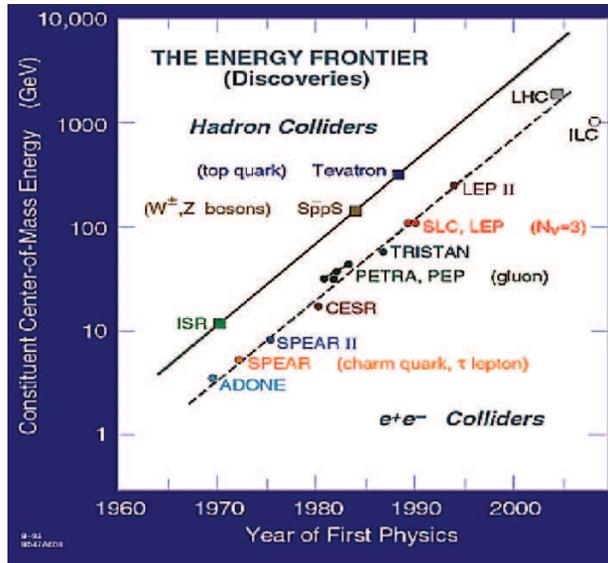
The physics summary talks of this morning have given us a flavour of the deliberations that have gone on here in the past one week. In my concluding remarks I will not be repeating these discussions. Instead, I wish to make a set of personal remarks about the workshop. This Linear Collider Workshop is really very special, for me, in that this is the first time that the meeting is being held in India! More seriously, this is the first time the meeting of the Global Design Effort (GDE) [1] was held concurrent with the LCWS. There were sessions, both plenary and parallel, joint between the GDE and the LCWS. Further, an Education and Outreach Workshop [2] for physics teachers, was conducted by the QuarkNet [3] team from Fermi National Accelerator Laboratory, along with the Indian Academy of Sciences, Bangalore. The first I hope, will present an opportunity to the vibrant Indian Accelerator Physics Community to identify parts of the ILC project which match with their own ongoing and future programs, and the second with a view to involve the young students of Bangalore in a unique experiment where they would work with students around the world, in logging some cosmic ray data. Our hope is that in the process they will get excited about new frontiers in high energy physics. We were also able to organise some interaction sessions of the members of the Indian industry who had been involved in making magnet positioning systems and magnets for the LHC, as well as some who had participated in building detectors, with industry experts as well as ILC physicists from outside India. We hope all this would work towards increasing the awareness of the ILC project in India.

## 2. Synergy of ILC physics, accelerators and detectors

Like many in the audience, my own personal love affair with the linear collider started about two decades ago, when the linear collider was called ‘JLC’ or ‘NLC’ (or) later TESLA depending on which region you belonged to! The discussions were dominated by talks which presented feasibility of a linear collider in TeV range, projecting the wonderful physics these colliders will help us do. Many in the audience will remember discussions right at the beginning at the LCWS in Hawaii, about the need of a combined international effort and the idea of an ‘international linear collider’ enunciated by Bjorn Wiik there. For a few years after that, however, the three regions went their separate ways. In fact, a large number of physicists in all the three regions worked very hard to bring out reports which discussed in great details the accelerator and detector designs as well as the physics potential of these machines [4]. Since these reports have come out, the process of globalisation, enunciated back in 1993, has now become a reality in the form of the Global Design Effort (GDE), which in fact had its meeting here along with LCWS06. As a matter of fact, LCWS itself had gone global a little while before this with the formation of the world wide study (WWS) for physics and detector studies at a future linear collider. Quite a few of the Linear Collider Workshops (LCWS’s) have now been held under the aegis of the WWS. In the LCWS held in Paris (2004) and SLAC (2005), joint sessions between the scientists working on physics and detectors on the one hand and accelerator physicists on the other, were held. As a matter of fact, the whole process of this dialog was accelerated further by the two ILC (International Linear Collider) Workshops held at KEK (2004) and Snowmass (2005). At this LCWS the GDE meet was concurrent with the LCWS. The discussions in the MDI (machine detector interface) session in this very auditorium, actually indicated that there is a need of yet more such discussions. My closing remarks are going to be in the context of this very intense and close interaction between the accelerator, detector and physics community which is now the hallmark of the future progress of the ILC. At a very personal level, I became aware of this interaction, when the possible danger to the clean LC environment from the hadronic backgrounds [5] due to beamstrahlung effects, was pointed out by us. In fact we were directed to it not so much by an interest in LC’s at that time, but more by our interest in interaction of high energy photons and effects of photon structure on them. After that I had to learn what is meant by ‘pinch effects’ in beam dynamics whereas till then all I knew were ‘pinch singularities’ in integrals.

In fact, one may argue that the above mild surprise at this interplay of particle physics and accelerator physics is perhaps unwarranted in view of the long history of synergy between the two communities, from the very birth of the two subjects. Rutherford’s words, “It has long been my ambition to have available for studies a copious supply of atoms and electrons which have energies transcending those of the alpha particles from the radioactive bodies”, in fact, do not sound very different from our words today when we physicists try to substantiate the necessity of energy upgrade of a future LC. Historically, cosmic ray experiments were done using the highest energy natural accelerator. But the fast pace of progress in accelerator physics *accelerated* the progress in our understanding of particle physics. On the one hand the accelerators did not accelerate only the particles but also the development

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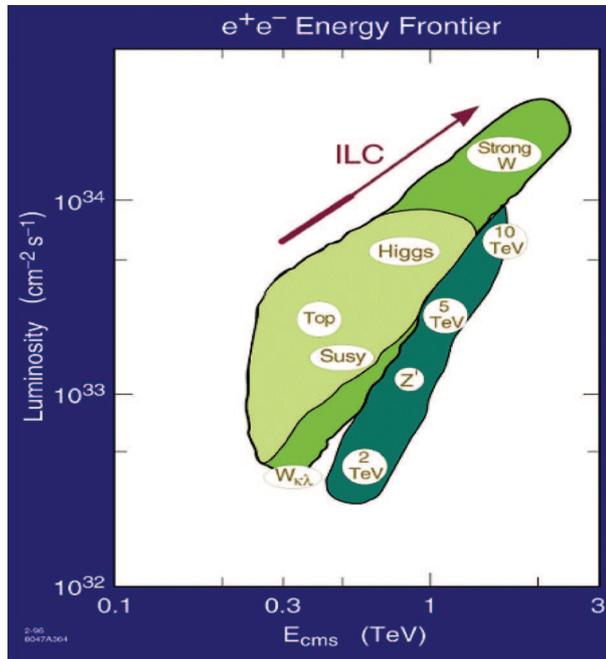


**Figure 1.** A summary of different  $p\bar{p}$  and  $e^+e^-$  colliders and the physics they helped study.

of the subject and on the other, the theoretical developments kept on raising the bar on the required energies and luminosities of the particle beams. The circular accelerators grew in size from the tiny vacuum chamber of Lawrence and Livingston, to the giant rings of Fermilab, Tristram, CERN and HERA. SLAC pioneered the way towards high energy linear collider through SLC. Now the GDE is looking at the designs and costs of the TeV energy international linear collider, whose base design is almost getting finalised. Theorists are busy evaluating the best possible energy *and time* for the ILC to have, so as to reap full advantages from the LHC *and* the ILC [6]. Figure 1 pictorially depicts the side-by-side development of different kinds of colliders and the physics they helped us discover. This does not include the variety of fixed target experiments which brought us information about quark-parton structure of matter. The worldwide community of particle physicists and accelerator experts are now convinced of the need of the ILC [4] and the process of exploring these energy frontiers has been set in motion. Figure 2 shows energies and luminosities of an ILC required to explore a particular physics issue. These plots are very slightly adapted versions of plots available from the SLAC website.

### 3. Options

I believe, where perhaps we physicists still need to work is in making stronger the physics case for the *options* of (1) a  $\gamma\gamma$  collider [7] and (2)  $e^-e^-$  colliders. For the  $\gamma\gamma$  collider case, in fact, the community needs to bring forth discussions about the feasibility of the needed technology. We heard at this workshop many discussions about the reference design report (RDR), baseline design report (BDR), the concept



**Figure 2.** Energy frontiers for  $e^+e^-$  colliders and the physics they will unravel.

design report (CDR) and their scheduling. Joint GDE/LCWS sessions of the MDI (machine design interface) have taken place. The issue of the number of interaction regions has come up now and then, in the parallel and the plenary sessions. It seems that even though the RDR contains two interaction regions, due to cost considerations we will most likely settle only for one interaction region. However, that would also mean the end of the  $\gamma\gamma$  option, as it requires a different crossing angle for the beams, from that for the  $e^+e^-$  option.

What is clear is that the  $\gamma\gamma$  community would not want the GDE to forget the possibility of implementing the  $\gamma\gamma$  option in the future, while discussing the designs and costs. In the discussions at the LCWS06 (and at other places since then) one has not seen much of that! On the other hand, since Jeju, a transition has been going on. The  $\gamma\gamma$  group has been having more and more common sessions with the Higgs group, with the new physics group and not just with the QCD group. At this meeting alone there were three such common sessions. The  $\gamma\gamma$  colliders [8] and a higher energy collider with  $t\bar{t}H$  final state [9], are indeed the only two options which can determine the all important CP property of the Higgs boson *unambiguously*. Only the  $\gamma\gamma$  colliders can offer a very clean determination of the CP mixing in the Higgs sector [10] and last but not the least, has the cleanest measurement of the width of the Higgs boson into the  $\gamma\gamma$  channel, viz.  $\Gamma(H \rightarrow \gamma\gamma)$ . The last is a very good probe of the heavy, non-decoupling physics. The message from all these is that the physics case for a  $\gamma\gamma$  option is getting stronger and stronger. The discussions on  $\gamma\gamma$  technology [11] are becoming realistic starting from the pioneering ideas [12].

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In fact there will be a workshop on ‘Physics and Technologies of Laser-Electron Interaction toward the ILC’ in Hiroshima, Japan on 12–14 December 2007. The plea from the  $\gamma\gamma$  community to the GDE and all the rest is to keep this option in mind and not take steps that will close the doors completely to this option at the ILC, when it comes into being. It is clear that the GDE and WWS have been working very hard. Since the time of LCWS06, where this talk was given, many other ILC related meetings have been having common sessions with GDE. A very aggressive time table has been set and many of the deadlines mentioned in the opening talk [1] of the LCWS06, are being met. Let us just remember that while we are making decisions keeping in mind the cost of physics, we may also want to keep in mind the cost of these decisions to the physics. Given the enormous amount of effort and thinking going on in the subject and the progress already achieved, I fully expect that the accelerator and the physics community will address this (and similar issues in future) effectively and we will achieve the goal of seeing the broken symmetry, depicted in the logo of LCWS06, at the ILC.

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