Proposal for a US strategy towards physics & detectors at future lepton colliders

Argonne National Laboratory
Brookhaven National Laboratory
Fermi National Accelerator Laboratory
Lawrence Berkeley National Laboratory
SLAC National Accelerator Laboratory

1. Introduction

For several years, there has been a strong international consensus that an e^+e^- collider will be needed to study the underlying physics of the new phenomena in the mass range from 0.2 – 1.0 TeV, which are expected to be discovered at the LHC. It has also been suggested that this physics might be addressed by a muon collider, making it crucial to understand these different approaches to a lepton collider. Current accelerator technology, either available, being developed or being considered, folded with cost constraints, limits the reach of a possible energy frontier lepton-lepton collider to about $\sqrt{s}$ = 4 TeV. The possible machines being considered are at different stages of feasibility: the International Linear Collider (ILC), the Compact Linear Collider (CLIC) and various warm variants, and the muon collider (MuC). ILC and CLIC are both linear electron colliders, with ILC starting at $\sqrt{s}$ = 0.5 TeV, ultimately reaching 1 TeV and CLIC being able to reach $\sqrt{s}$ = 3 TeV. The muon collider is currently proposed for running up to a center of mass energy of $\sqrt{s}$ = 4 TeV. All of these machines have varying luminosity performance within their energy range. All of them aim to fully understand the underlying physics at the TeV scale, but they address different physics depending on their energy range, beam energy spread, luminosity characteristics, polarization, backgrounds, and lepton type. There are R&D programs around the globe at different stages of maturity to develop the necessary accelerator and detector technologies. This document outlines the creation of a single detector research program in the US with the goals to:

- Establish the physics capability of lepton colliders.
- Establish the requirements of detector systems so the physics can be extracted, taking into account the very different operating conditions at each machine.
- Provide feedback to the machine design to further optimize the physics potential.
- Propose necessary detector and other R&D to verify detector technologies.
- Compare the physics potential of these machines and carry out a cost-benefit analysis.
- Coordinate the detector and physics program.

Such a coordinated program of support for the university and national laboratory community would by its nature have a very close relationship to the corresponding machine development programs.

The physics and detector programs for the three major collider options are at different stages of development. The ILC program is far more mature than the others, but has struggled for recognition and funding in the last few years in the US. The CLIC effort is centered mostly at CERN and the muon collider detector effort needs to get restarted to go beyond the initial studies made a decade ago. Since the broad physics goals of any lepton collider are similar, a unified lepton collider physics & detector program would ensure an objective comparison of the options and allow each effort to benefit from progress and accomplishments in the others. The program must actively coordinate the different efforts and ensure that the work is done in a coherent, efficient and cost effective way. Below we give a description of the status of the physics and detector R&D program for each collider, a more detailed description of the proposed framework, and finally a comparison of the planned parameters for each machine.

2. Description of current lepton collider physics & detector efforts

2.1 Worldwide efforts

The worldwide consensus on the need for a TeV scale linear collider (>several hundred GeV) has led to the formation of various international structures to guide the efforts. The International Linear Collider Steering Committee (ILCSC) was created by ICFA in the early 2000s. The mission of the ILCSC is to promote the construction of an e^+e^- linear collider through world-wide collaboration. The ILCSC appointed the International Technology Review Panel (ITRP) in 2004 to choose between superconducting and normal conducting technology [1]. After the ITRP decision, the ILCSC launched the Global Design Effort (GDE) for the ILC and appointed a GDE director in 2005 [2]. ILCSC also appointed an ILC Research Director (RD) [3] in 2007. The Global Design Effort and the ILC Research Director report to the ILCSC, and the Project Advisory Committee (PAC) reviews their work for the ILCSC. CLIC has an independent reporting and oversight structure and does not report to the ILCSC, but there are ILC-CLIC working groups to work on common solutions [4]. The muon collider is not currently connected to the ILCSC.

The World Wide Study of the Physics and Detectors for Future Linear e^+e^- Colliders, commonly referred to as the WWS, was established and recognized by ICFA in 1998 to study the physics and detectors at a linear collider [5]. It now provides a regular report to the ILCSC and advises the ILCSC on physics and detector issues. The WWS is a global organization with three chairs, each representing a different region of the world. The WWS organizes linear collider workshops and its "American branch" is the American Linear Collider Physics Group (ALCPG) [6]. While the emphasis of the WWS studies shifted to the ILC after the formation of the GDE, the WWS has maintained in its charter the broader scope of all future linear colliders. It could have a role in defining the physics and detector capabilities at any lepton collider, although there is currently very little interest in the muon collider in Asia or Europe.

2.2 ILC

ILC Global aspects

The ILC Global Design Effort (GDE) manages all aspects of the international accelerator R&D program for the ILC. The GDE produced the Reference Design Report (RDR) in 2007, which outlined the machine and its parameters, presented the status of the accelerator R&D, outlined the physics achievable by a machine reaching 0.5 and 1 TeV, and described the three ILC detector concepts that were being studied at that time. The physics and detector part of this exercise was organized by the WWS.

Since 2007, the ILC Research Director (RD) has managed the physics and detector R&D part of the program that had previously been guided by the WWS. One of the first tasks of the RD was to call for Letters of Intent (LOI) from the detector concepts. This call was issued in October 2007 for LOIs due in March 2009. Three groups (ILD, SiD, and 4^{th}) responded with LOIs. The LOIs clearly demonstrated in simulation that the anticipated physics could be extracted from the ILC. The RD set up the International Detector Advisory Group (IDAG) to review the LOIs and recommend which concepts should be validated [7]. In the fall of 2009, following the recommendation of the IDAG, the RD validated the ILD and SiD concepts as ILC detectors. These two concepts will be developed further as part of a 'TDR' for the ILC, planned to be submitted by the end of 2012. This is the next milestone for the ILC.

US detector activities for the ILC

The focus here will be on the US aspects of the ILC physics and detector activities and not on the well-defined and funded accelerator R&D program. The Linear Collider Steering Group of the Americas (LCSGA) consists of representatives from the HEP national laboratories and from the community and acts as an advocate for US linear collider activities, with a current emphasis on the ILC. Since its formation in 2002, the ALCPG has promoted and facilitated physics and detector activities through workshops and working group efforts (including full detector concepts), and the ALCPG co-chairs lead the LCSGA subcommittee on physics and detectors. US groups currently participate in both the ILD and SiD detector concepts.

Dedicated DOE funding for ILC detector R&D began in 2004. It has been largely driven by development of specific detector concepts in parallel with the development of the ILC Reference and Technical Designs, overseen by the ILC Global Design Effort. DOE and NSF have supported ILC detector R&D carried out by university groups for several years, most recently (starting in FY09) through umbrella grants to each of the three detector groups (ILD, SiD, and 4^{th}). The current three-year cycle of funding for detector R&D for universities is the last round of funding targeted towards the ILC technical design phase. It will transition to a more generic collider detector R&D program in 2012. ILC detector R&D efforts at the national laboratories are currently funded through the Detector R&D program, which is primarily focused on generic detector research.

Future support for detector R&D to complete the detailed baseline design for the ILC detectors is uncertain and probably not matched to the GDE schedule, which calls for a 'TDR' in 2012. The LOIs were completed with strong contributions from the US and relied heavily on the software framework that was developed at SLAC to support the SiD simulation, algorithm development, and reconstruction. There is a very real possibility that the US ILC effort for the development of detectors will fall below a critical mass and become too fragmented, adversely affecting not only the ILC, but all linear collider efforts.

2.2 CLIC

CLIC Global aspects

CLIC is a mostly European effort centered at CERN with the aim of developing and designing a $\sqrt{s}$= 0.5 to 3 TeV electron-positron collider. It has its own organization with steering board and advisory committees. The physics and detector studies are integrated with the machine study. CLIC is not a globally organized effort like the ILC, but it has an agreement of collaboration with the ILC GDE. The ILC physics and detector community has setup an ILC-CLIC joint working group and CLIC very much encourages participation from all regions of the world.

Current plans are to produce a Conceptual Design report (CDR) around spring 2011, which will cover both the machine and the physics and detector program. If the CDR is well received, it will be followed by roughly a five-year development and design phase, resulting in a Technical Design Report (TDR) around 2016.

The physics & detector efforts for the CDR are very focused with the main goal of demonstrating that precision physics can indeed be done in the CLIC machine environment. The two validated ILC detector concepts, ILD and SiD, are being used as a starting point. A set of physics benchmarks is being developed and they will be tested using CLIC adapted versions of ILD and SiD. The choice to use “existing” ILC concepts was a conscious one, trying to take advantage of the work already done and to use existing expertise and existing simulation and reconstruction frameworks.

CLIC has welcomed teams from ILD and SiD, but CERN has also established a real effort in this direction that is doing the work needed for the CDR. Several editors for the CDR and leaders of working groups are from the ILC community worldwide, although the effort is largely European dominated [9].

US detector activities for CLIC

The CERN decision to use the existing ILC detector concepts has led to some US participation in the CLIC CDR physics and detector efforts. As an example, the software framework for simulation and reconstruction that is being used was developed in the US, and the algorithms need to be adapted for the CLIC environment. CERN strongly encourages participation from all regions and has a program that financially supports visitors to work on the CDR.

Because CLIC uses the ILD and SiD concepts, there is a natural synergy between these detector collaborations and related CLIC efforts. Members of both communities attend the same workshops, even if organized by one side. However, currently there is no recognized, funded, or otherwise identified CLIC detector/physics activity in the US.

2.4 Muon Collider

Muon Collider Global aspects

The main proponent for a future $\sqrt{s}$ = 1.5 TeV - 4 TeV Muon Collider is the U.S., where the Muon Collider is part of a long-term strategy for the future of Fermilab, with Project X, a Neutrino Factory and a Muon

Collider being possible elements of that program [8]. The R&D for the accelerator has a long history and elements of it are actually carried out by an international collaboration, such as the Muon Ionization Cooling Experiment at RAL (MICE), the target experiment at CERN (MERIT), and the Muon Cooling test facility at Fermilab (MuCOOL). However, it is fair to say that at the moment Fermilab is the driving force behind a Muon Collider, and that, although there have been interactions between the ILC and Muon Collider communities, there is no global physics and detector effort for the Muon Collider aspects of the program.

A Muon Accelerator Program (MAP) to address the technical challenges and feasibility issues relevant to the capabilities needed for future Neutrino Factory and multi-TeV Muon Collider facilities has been submitted to DOE. An interim organization to oversee and guide this R&D for the next five years has been established. This proposal is now under review. If approved it would greatly advance a US based accelerator R&D program for a Muon Collider and the US contributions to the international R&D effort for a Neutrino Factory.

US detector activities for the Muon Collider

The physics and detector program for the Muon Collider has not been established yet and was not part of the accelerator proposal. An assessment of the physics capability of a Muon Collider, along with detector and background studies, was first conducted over a decade ago. Much has changed over the last 10 years, including the design of the Muon Collider lattice, and the state-of-art in detector technologies. Work on establishing backgrounds and interfaces to existing detector simulations is ongoing at Fermilab.

One question that arises is to what degree a Muon Collider can benefit from work either already done or underway for the ILC or CLIC. For example, the ILC and CLIC software frameworks and algorithms could be employed for all lepton collider options and could provide a framework for a quantitative comparison of the physics reach of the different machines. On the other hand, operating conditions for the three machines are rather different. For example, a Muon Collider has a much smaller center of mass energy spread than either electron-positron machine, but suffers from the additional source of background from the decays of the muons. Also, the center of mass energy variability is significantly different for the three options. A common quantitative comparison of future lepton collider facilities is desirable.

3. A US strategy for lepton collider physics & detector research

Future lepton colliders, especially the accelerators, are actively being developed worldwide. The work is funded in different parts of the world with regional emphasis on different options. This is driven by the anticipation that there will be new particles and fields at the TeV scale that need to be explored with lepton colliders. The assumption is that the lepton accelerators will enable precision measurements of the new particles to elucidate the underlying physics. The superconducting RF technology for the ILC is the most mature option and the GDE aims to have a buildable technical design available as early as 2012. However, physics discoveries at the LHC may point to higher energies than can be achieved with the ILC and questions of affordability have been raised in the U.S. In addition, the delayed startup of the

LHC means that physics discoveries may come somewhat later than envisioned a few years ago. It is therefore prudent for the international community to pursue a broader range of lepton collider machine options and funding agencies are developing and supporting related machine R&D programs for this reason.

The ultimate justification for a new energy-frontier project, however, will come from its physics reach, and the capability for extracting precision measurements from lepton colliders at TeV energies needs to be understood properly. The machine options have very different backgrounds and operating conditions. A comprehensive comparison of the physics reach at each machine will require a dedicated physics and detector effort over the next few years. The goals of such a US effort could include:

- Participate in the development of the physics and detector program of lepton colliders
- Coordinate the US efforts within the global physics and detector efforts
- Define the physics case and the required detector and machine performance
- Define required detector concepts (if they do not exist)
- Determine whether existing detector concepts can be used
- Compare the physics potential of all options on an equal footing
- Make use of existing software frameworks to do the work, avoiding duplication
- Define the R&D needs of the detector concepts
- Guide and monitor the R&D
- Define a program that can be executed within a specified and limited budget

Currently some of this work, like the ILC, is conducted in the US as part of a larger global effort. However, such R&D is far enough in advance of any defined future project that the importance and need for this effort struggles to be formally recognized by the agencies. With this white paper we hope to engage the US community, both the universities and laboratories in a discussion and establishment of a coherent “Lepton Collider Physics & Detector” program with the goal of providing answers to questions of physics performance capabilities in anticipation of a strategy decision in the future when the physics landscape is better understood. This program would have responsibility for performing lepton collider studies and would have a structure to guide and monitor these activities. It would coordinate and prioritize these activities and work with existing groups to maximize the US contribution to any effort.

Following an airing and discussion of the ideas outlined in this document, the next step would be to write a proposal along the suggested lines for the funding agencies to evaluate and implement. In overview, it will propose a coherent and coordinated approach to preparing the case for lepton collider physics. The alternative is to keep working on and funding future lepton collider accelerator R&D with very small detector R&D efforts, resulting in a lack of clear answers and consistent comparisons on the physics potential of such colliders. This is the path we are on now; it is not a good path forward, as it will not be efficient and effective, and it will not provide a well understood basis for future strategic decisions.

Appendix 1: Tables of machine parameters

		ILC	ILC	CLIC	CLIC	MC	MC
E_{cms}	TeV	0.5	1	0.5	3	1.5	4
f_{rep}	Hz	5	4	50	50	12	6
f_{RF}	GHz	1.3	1.3	12	12	n/a	n/a
G_{RF}	MV/m	31.5	31.5	80	100	n/a	n/a
n_b		2625	2625	354	312	1	1
Δt	ns	369	269	0.5	0.5	10000	27000
N	10^9	20	20	6.8	3.7	2000	2000
σ_x	nm	655	554	202	40	5900	2000
σ_y	nm	5.7	3.2	2.26	1	5900	2000
ε_x	μm	10	10	2.4	0.66	25	25
ε_y	μm	0.040	0.036	0.025	0.020	25	25
L_{total}	10^{34} cm^{-2}s^{-1}	2.0	2.8	2.3	5.9	1.0	4.0
$L_{0.01}$	10^{34} cm^{-2}s^{-1}	1.6	2.0	1.4	2.0	1.0	4.0

Table 1: Summary of some examples of machine design parameters for various lepton collider options.

References

[1] http://www.ligo.caltech.edu/~BCBAct/ITRP_home.htm
[2] http://www.linearcollider.org/GDE
[3] http://www.linearcollider.org/physics-detectors
[4] http://clic-study.web.cern.ch/CLIC-Study/
[5] http://www.linearcollider.org/physics-detectors/WWS
[6] http://physics.uoregon.edu/~lc/alcpg/
[7] http://www.linearcollider.org/physics-detectors/Detectors/IDAG
[8] http://www.fnal.gov/pub/muon_collider/
[9] http://clic-study.web.cern.ch/CLIC-Study/Mtgs_Wkg_Grp.htm