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LEPTON ACCELERATORS AND RADIATION SOURCES: R&D INVESTMENT at BNL

**A White Paper describing the R&D program
on advanced lepton accelerators and radiation
sources at BNL**

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INTRODUCTION

A key aspect of the mission of Brookhaven National Laboratory (BNL) is to construct, operate and use large facilities for the breadth of scientific disciplines supported by the Department of Energy. An important component of the success of BNL comes from innovative accelerator R&D. The Courant - Snyder strong focusing principle was crucial to the Alternating Gradient Synchrotron, the harbinger of all modern circular accelerators. The Green - Chasman lattice that optimizes photon source parameters was implemented first at the National Synchrotron Light Source and has been adopted by many of the present state-of-the-art synchrotron radiation facilities. The Palmer two-in-one magnet design has been chosen for the LHC, the 7+7 TeV proton collider now under construction at CERN in the existing LEP tunnel.

BNL has shown its determination to remain at the forefront of accelerator based science through its continued investment in long range accelerator R&D. The laboratory has a broad program in accelerator technology development including projects such as high T_c magnets at RHIC, Siberian Snakes at the AGS, brightness upgrades on the NSLS storage ring, and spallation source R&D in several departments. This report focuses on a segment of the overall program: the lepton accelerator and coherent radiation source R&D at the laboratory. These efforts are aimed at (1) development of high brightness electron beams, (2) novel acceleration techniques, (3) seeded Free Electron Laser (FEL) development, and (4) R&D for a muon collider.

To pursue these objectives, BNL has over the past decade introduced new organizational arrangements which provide vision, opportunity, and coordination in this area of accelerator R&D. The BNL Center for Accelerator Physics (CAP) is an interdepartmental unit dedicated to promoting R&D which, because of long development time, cannot be readily conducted within the programs of operating facilities. The Accelerator Test Facility (ATF) is managed by CAP and the NSLS as a user facility dedicated to accelerator and beam physics problems of interest to both the High Energy Physics and Basic Energy Sciences programs of the DOE. Capitalizing on these efforts, the Source Development Laboratory (SDL) was established by the NSLS to facilitate coordinated development of sources and experiments to produce and utilize coherent sub-picosecond synchrotron radiation. This White Paper describes the programs being pursued at CAP, ATF and SDL aimed at advancing basic knowledge of lepton accelerators and picosecond radiation sources.

The Roles of CAP, ATF and SDL

The Center for Accelerator Physics

The Center for Accelerator Physics (CAP) is an interdepartmental organization with the goals of promoting advanced accelerator R&D and providing educational programs to train students and researchers in accelerator physics. The center was formed in 1988 by members of the NSLS, Physics Department and the Instrumentation Division. The resident staff is joined by frequent short term visitors and students. Workshops and seminars on advanced accelerator topics are organized regularly by CAP.

The primary research activities of CAP include:

- 1) studies of a high luminosity muon collider,
- 2) construction of an X-band cluster klystron,
- 3) development of a high gradient photocathode,
- 4) conduction of the experimental research program at the ATF, and
- 5) provision of theoretical support for ATF activities.

The Accelerator Test Facility

The ATF has been in operation for the past few years as a users' facility for accelerator and beam physicists. This unique facility is dedicated to long range R&D in accelerator and beam physics, available to the community through a peer-reviewed process. The facility's users come from national laboratories, universities and industry, and eight graduate students have received degrees based on work performed at the ATF.

The ATF has a unique combination of a high-brightness electron beam, synchronized-high-power lasers, a well-equipped 3 beamline experiment hall, and advanced diagnostics and control systems. The ATF's program in RF guns is recognized internationally. With its synchronized lasers and electron beams of unprecedented brightness, the ATF is an ideal site for R&D on advanced accelerator concepts, FELs, femtosecond X-ray sources and similar topics. These tools have been crucial to recent ATF record achievements: the measurement of Self Amplified Spontaneous Emission (SASE) at 1 μm , and laser acceleration by the Inverse Cerenkov and Inverse FEL mechanisms.

Basic accelerator technology which was developed at the ATF is used at the NSLS and has seeded projects in other parts of BNL, like the Center for Radiation Chemistry Research and the Source Development Laboratory, as well as outside BNL, e.g. the Compact Infra-Red FEL built by Northrop-Grumman Corporation and Princeton University.

The Source Development Laboratory

The science outlined in the NSLS Deep Ultra-Violet Free Electron Laser (DUV-FEL) conceptual design report (BNL 49713) will be pursued at the SDL, now under construction. The full SDL accelerator system consists of a high brightness short pulse linac, a station for coherent synchrotron and transition radiation experiments, a short bunch storage ring, and an ultra-violet free electron laser utilizing the 10 meter long NISUS wiggler, originally built by STI Optronics for Boeing Aerospace. The 210 MeV linac includes a magnetic bunch compressor

after the second linac section at approximately 80 MeV. With this equipment, much of it recovered from earlier projects, the SDL program is comprised of four major elements: a non-linear emittance correction experiment; 100 μm compressed bunch experiments for coherent transition radiation; a compact storage ring with high frequency RF for generation of coherent far-IR radiation; and the Ultraviolet Project Free Electron Laser (UP-FEL).

A Road Map for the Future

There is a fundamental synergism between many aspects of the accelerator and source development at BNL that enriches and strengthens the overall program. The integrated research effort is enhanced by applying the resources of the CAP, ATF and SDL where they are most effective. Conceptually, the work can be visualized in a matrix as depicted in Table 1:

Topic	CAP	ATF	SDL
Muon collider	x		
High Brightness Beam	x	x	x
Laser Acceleration	x	x	
Coherent Radiation Sources		x	x

Table 1. Organizational research subject matrix

The research on lepton accelerators and short wavelength radiation sources can be viewed also in terms of goals and stages, given in approximate time order in Table 2. A more complete picture is provided in the appendix of this paper.

High Brightness e-Beam R&D	Laser Acceleration	Source Development	Muon Collider
Cathode development	Combined IFEL / ICA experiment	Self Amplified Spontaneous Emission (SASE)	Develop collider model
Study of emittance growth	CO ₂ terawatt laser	High Gain Harmonic Generation (HGHG)	Demonstrate proton targeting & π capture
Ultra-high electric field photoinjector	Demonstration of 1 GeV laser acceleration	Femtosecond x-rays by Compton back-scattering	Demonstrate ionization cooling
Non-linear emittance correction		Coherent synchrotron radiation	Build model components

Table 2. Research efforts goals

The basic energy science objective of source development, and in particular Free Electron Laser techniques, is approaching fruition at the ATF and the beginnings of such work have been initiated at the SDL. This work is proceeding in collaboration with other synchrotron radiation facilities and industry.

FELs can provide an important tool reaching beyond the capabilities of high brightness synchrotrons. Science that explores non-linear effects at short wavelength, dilute systems or intensity correlation studies, require high peak power and will only become possible when appropriate sources, such as FELs, are available. The production of high brightness electron beams is essential to the generation of coherent short wavelength radiation.

Ongoing studies for accelerator development relevant to high energy physics are addressing issues important to the design of actual devices on a number of time scales. First, we have projects like the cluster klystron aimed at machines of the NLC generation. The muon collider, which is at an earlier stage of study and development than the NLC, is focused further into the future. Activities in laser acceleration are in the proof-of-principle stage, and are being pursued on an even longer time scale. The ongoing development at the ATF of a compact terawatt class CO₂ laser will open up important new opportunities in laser acceleration.

Common to both high energy physics and basic energy science missions is the essential work on high-brightness electron beams. BNL has achieved a position of international leadership in the development of high-performance electron guns and state-of-the-art diagnostics, as exemplified by the widespread use of the "BNL gun", the ATF measurement of slice emittance in a 10 ps electron bunch and achievement of unprecedentedly high 6-D electron phase-space density. The next step is to pursue non-linear emittance compensation. Laser photocathode RF guns have provided a major improvement in the brightness, which was further enhanced by the introduction of (linear) emittance compensation. The dream of another major improvement by the introduction of non-linear corrections has been brought within reach by the development of the slice-emittance diagnostic and the availability of lasers with longitudinal pulse shaping. Once non-linear emittance correction has been achieved, it should simplify the design of VUV and X-ray FELs. The resulting increase in the brightness will make it possible to build such FELs with much lower energy accelerators, and shorter wigglers, substantially reducing the system's cost.

In the area of laser acceleration, research efforts at the ATF are approaching two important milestones. The first is the proposed combined Inverse FEL (IFEL) / Inverse Cerenkov Accelerator (ICA) experiment and the other is the installation of the high power CO₂ laser to facilitate user experiments in plasma wake-field acceleration. The combined IFEL / ICA experiment is in a position to achieve, for the first time, two important goals in laser acceleration: injection of a bunched beam into the acceptance of a laser accelerator and staging of two laser accelerator units. Experimental demonstration for laser accelerators of these required steps for high energy acceleration must be accomplished before laser accelerators can be seriously considered for any high-energy application. This IFEL / ICA experiment can be carried out in a period of several years, which is also the time scale for bringing the terawatt CO₂ laser into operation at its full power. In this manner, a natural decision point for the laser acceleration program will arise, providing an opportunity for users to embark on an ambitious experiment to accelerate a high-quality beam to an energy of one GeV.

The NSLS has been pursuing the development of Free Electron Lasers, emphasizing single-pass FEL amplifiers, which have advantages over oscillators in the short wavelength regime where cavity mirrors are unavailable. BNL has been a leader in coordinating the national effort on FEL development, hosting the workshops "Prospects of a 1 Å FEL" in 1990 and "Towards Short Wavelength FELs" in 1993, as well as pursuing subsequent efforts to develop a national collaboration in the field. While a consensus has not yet emerged, we have moved forward to establish a consistent program. Whenever possible we have collaborated with other

laboratories, as exemplified by the highly successful "Next Generation Photocathode RF Gun" developed with SLAC and UCLA, and the SASE experiment at ATF being developed with ANL using a wiggler from Cornell.

Key to our plans is the development of sub-harmonically seeded FELs in which harmonic generation converts a laser seed to much shorter wavelength radiation. A proof-of-principle High-Gain Harmonic-Generation (HGHG) FEL experiment is planned to be carried out at the ATF in the infrared using a CO₂ laser seed. Both the SASE and HGHG work will be extended into the VUV at the SDL, using the NISUS wiggler. These experiments at the ATF and the SDL are milestones, not just for the BNL program, but also for other projects like the proposed Linear Coherent Light Source at SLAC and the Tesla Test Facility FEL at DESY, Hamburg. The goal of these efforts is basic experimental research in FEL physics, which has been recommended by numerous panels and review committees as an imperative on the way to developing short wavelength FELs. An initial success in this program has been the ATF measurement of SASE at 1 μ m. At the SDL, it is planned to utilize the output of the FEL to carry out prototype experiments to gain experience in providing FEL beams to users.

The muon collider study, initiated two years ago, will be comprised for the next year mostly of theoretical work. If these studies are encouraging, then an experimental program will be proposed to (1) test high gradient, low frequency RF cavities, (2) demonstrate the required proton targeting and pion capture, (3) demonstrate ionization cooling, and (4) build various model components. It is expected that this phase of R&D will continue for about four years. At that time a decision will have to be made on whether to start serious design of a demonstration collider that could use the AGS as a proton source. Such a machine might have a center of mass energy of 0.5 TeV or lower, depending on the results concerning the top quark and its implications for the light Higgs Boson.

The cluster klystron work at CAP is moving toward beam testing of the magnetron injection gun with studies continuing through the rest of calendar 97. At the end of the year a decision will be made whether to continue with the construction of a test klystron or to bring the study to a close. The decision will need to take into account (1) the observed gun performance, (2) possible funding for an expanded effort and (3) competition for resources with the muon collider R&D.

Perspective

BNL provides major facilities for the national and the international science and technology communities. No laboratory can remain at the forefront of its defined mission without a significant R&D component. BNL has a long tradition in accelerator innovations and instrumentation advances, leading to major scientific discoveries. Now, as always, we must carefully investigate technologies for the future, while optimizing the utilization of existing laboratory resources. As we move into the next century, the efforts of the users, Brookhaven National Laboratory, and the Department of Energy are needed to provide a path toward fulfilling the nation's needs for particle and photon beams in science and technology.

Further Description of Advanced Lepton and Photon Source R&D

Photo-Cathode and Ultra-High Electric Field R&D

The science and technology of laser photo-emission is at the very heart of photocathode RF guns. The laser laboratory in the Instrumentation Division, with its state-of-the-art short pulse lasers and diagnostic tools, has been the test bed for cathode evaluation. Currently, the focus of this research is on

- 1) the measurement of the reliability of copper cathodes,
- 2) improving the quantum efficiency of magnesium cathodes and
- 3) studies of the enhancement of emission due to the Schottky effect.

Studies in copper indicate that the electron yield is relatively insensitive to minor variations in the bulk material, but very sensitive to the surface treatment. Parameters for *in situ* laser cleaning in terms of the laser energy density and the sample exposure time have also been established. Experimental determination of the emission as a function of phase in the ATF RF gun are in progress. It is hoped that the measurement of the enhancement of the emission by the electric field will allow the determination of parameters like the work function, zero field quantum efficiency and field enhancement coefficient.

In the past few years, there has been increased interest in reducing the emittance growth of the photoelectrons due to space charge and RF dynamics in a RF gun. Generation and acceleration of electrons in the presence of constant field gradients, with amplitudes much larger than that presently achievable in RF guns is expected to shed more light on these phenomena, and reduce the emittance growth. To facilitate these studies, a high voltage pulser capable of delivering 1 MV in 0.2-2 ns has been constructed. This pulse was applied to a diode with copper and stainless steel electrodes and an electrode gap of 1 mm. Preliminary results indicate that field gradients > 1 GV/m can be sustained by both these materials with a negligible dark current. This is a field regime that, in the past, could not be achieved over a macroscopic area. This device opens up many research directions. Preparations to irradiate the cathode with ultra-short laser pulses and study the generated relativistic electron bunches are under way. Calculations indicate a beam brightness larger than 10^{16} A/m²rad² might be possible, which is three orders of magnitude higher than achieved so far.

Laser Photocathode RF Guns

At the forefront of our research program is the development of electron beams with a high density in 6-D phase space for use in laser acceleration of electrons and the production of coherent radiation. These high density beams are the cornerstone for future high performance machines, such as X-ray Free Electron Lasers and Linear Colliders.

In collaboration with SLAC and UCLA, the ATF has developed the "Next Generation RF Gun", which has recently demonstrated a normalized rms emittance of 2.5 mm-mrad with a bunch charge of 1 nC, using a Gaussian distributed laser pulse. This result is consistent with

simulations that predict a 1 mm-mrad emittance under these conditions but with a "flat-top" laser distribution.

Building on experiments at the ATF, the SDL laser photocathode RF gun and linac will be used to perform a non-linear emittance correction experiment. The Ti:sapphire laser driving the photocathode will be modulated longitudinally and transversely to control the evolution of the 6-D phase space of the beam bunch, resulting in a substantial improvement in electron beam brightness.

Laser R&D

The ATF is developing a high-pressure CO₂ laser system that will be capable of terawatt power, down to picosecond pulse length. Short-pulse, high-power CO₂ lasers open new prospects for high-gradient laser-driven electron accelerators and Compton back-scattering generation of sub-picosecond x-rays. The advantages of 10 μm wavelength CO₂ laser radiation over the more widely exploited solid state lasers with wavelength of the order of 1 μm for laser acceleration are based on the proportionality of the ponderomotive potential to λ^2 , of the phase slippage distance to λ , and of the laser accelerator structures cross section area to λ^2 . In the generation of x-rays by Compton back-scattering, the advantages of CO₂ lasers are the larger number of photons per pulse energy, the higher pulse energy and the much greater capability in terms of average power. The larger linac energy needed for a given x-ray wavelength is also an advantage, since the x-ray's angular spread is inversely proportional to the electron energy. In both types of applications the increased average energy possible with CO₂ lasers is a great advantage.

Laser Acceleration Experiments

The distinguishing feature of the laser acceleration R&D program at the ATF is the focus on very detailed studies of laser acceleration systems and the emphasis on achieving laser acceleration over relatively long distances. Two experiments have successfully demonstrated acceleration at the ATF, the IFEL experiment and the ICA experiment.

Inverse Cerenkov acceleration is an example of a first order, far field acceleration process where the particle interacts with just one electromagnetic wave. Here, the inclination of the wave vector is responsible for developing a longitudinal accelerating field, while the medium produces retardation of the phase velocity of the wave to match the speed of electrons. The IFEL scheme is an example of a second order, far field laser acceleration process. The field of a wiggler magnet is used to force the electrons into a transverse oscillating motion, coupling the beam to the transverse field of the co-propagating laser.

The ICA experiment has achieved an acceleration of 3.7 MeV over a distance of 20 cm with a laser power of about 1 GW. The IFEL has achieved an acceleration of 1 MeV over a distance of 47 cm with about 0.5 GW laser power. While both experiments have established world records in their class, the limited laser power available has resulted in a low acceleration

gradient in comparison to what has been demonstrated by plasma accelerators. This situation will change with the availability of the ATF's terawatt picosecond CO₂ laser which is now under construction. The new laser will provide enough power to produce an accelerating gradient approaching one GV/m in experiments like the IFEL and the ICA, with a short enough pulse to avoid optical damage. The short pulse length will also provide our users with exciting possibilities for experiments exploring plasma wake-field acceleration.

An important diagnostic is now being tested downstream of the IFEL experiment. This Coherent Optical Transition Radiation detector, aimed at measuring the bunching produced by the IFEL device, is a first step towards establishing a new experiment, called the Combined IFEL / ICA experiment. In this proposed experiment, the IFEL will be used to bunch the injected beam into the acceptance of the ICA. For this purpose the IFEL and ICA devices will be placed in tandem. This arrangement will test for the first time the staging of two laser acceleration units, an important milestone in the field of laser acceleration.

Short Wavelength FEL R&D

Short wavelength Free Electron Lasers have great potential as the next generation of synchrotron light sources. In the past decade, significant advances have been made in the theory and technology of high brightness electron beams and single pass FELs. These developments facilitate the construction of practical UV and X-ray FELs and have prompted proposals to DOE for the construction of such facilities. SASE and HGHG are the two leading candidates for VUV to x-ray FELs.

Several groups in the United States are developing plans for short wavelength FEL facilities. However, reviewers have pointed out that it is essential to first carry out proof-of-principle experiments to increase confidence that the shorter wavelength devices will perform as calculated. The need for such experiments has now been broadly accepted by the FEL community.

Such a proof-of-principle experiment has been carried out recently at the ATF, where SASE has been measured at a wavelength of 1 μm . The plans are to extend this measurement to shorter wavelengths, and study in detail the physics of SASE, including the saturation regime, as part of the national effort to develop short wavelength FELs.

Efforts at BNL in short wavelength FEL are predicated on the production of high quality radiation for user application. This objective is embodied in the development of sub-harmonic seeded FELs for this purpose. In this approach, harmonic generation in the FEL converts a seed laser wavelength from near UV to deep UV (DUV) or soft x-rays. These sub-harmonically seeded FELs are configured to produce an energy modulation in the electron beam in a first wiggler. The energy modulation is then converted to spatial modulation by the dispersive section. The prebunched beam produces and then amplifies radiation in the second, longer wiggler, operating in a high-gain single-pass mode. This leads to our choice of the name "High-Gain, Harmonic-Generation" (HGHG) FEL.

This strategy has the benefit that it eliminates many of the optical limitations of oscillator configurations at short wavelength, and allows for a much broader range of possible pulse formats, while retaining the coherence of the seed laser. The stability requirements of our users have led us to the development of the seeded beam FEL. A key benefit is the fact that the

central wavelength stability of the HGHG FEL is fixed by the seed laser and not the electron beam.

A proof-of-principle HGHG experiment has been approved for the ATF. The availability of the Cornell wiggler makes it possible to execute a SASE experiment in 1997 to be followed shortly by HGHG. The experiment will be installed on the ATF Beam Line 2, which has already operated for several experiments, including a 10 micron Inverse FEL. It is very well instrumented and includes an entry port for the seed CO₂ laser.

The 210 MeV electron beam and the 10 m NISUS wiggler of the SDL will provide an opportunity to extend the HGHG experiments to DUV wavelengths and to explore applications of tunable picosecond VUV radiation for research, where there are no suitable alternative sources. For example, photofragmentation studies using direct, single photon excitation are possible at these wavelengths for a variety of molecules important to atmospheric science such as CH₄, H₂O, CO₂, and chloro-fluorohydrocarbons. The narrow bandwidth of the FEL and its tunability are critical for studying these molecules, having highly structured electronic manifolds below 200 nm wavelengths. The variable pulse length of the FEL to sub-picosecond duration is also a valuable attribute for the study of electron transfer dynamics in pump-probe experiments. The unprecedented combination of high peak power, readily tunable pulse length, wavelength, and bandwidth, combined with the short wavelength operation of the SDL UV-FEL, make it an extremely interesting source for a broad range of science.

Other Radiation Experiments

Using the magnetic bunch compressor at the SDL, electron bunches as short as 100 μ m with 1 nC charge can be generated. Such bunches radiate coherently at wavelengths longer than the bunch length. Pump-probe experiments utilizing coherent transition radiation from such bunches are planned. When equipped with a superconducting S-band RF cavity, the compact storage ring will be a source of millimeter wave coherent synchrotron radiation.

Pursuing another aspect of source development, x-rays will be generated by Compton back-scattering of the ATF's 1 TW CO₂ laser from its 70 MeV electron beam. Preliminary estimates indicate that it should be possible to generate $2 \cdot 10^8$ elliptically polarized 8 keV x-rays in a pulse of duration as short as 3 picoseconds. With a compression of the electron bunch, the pulse length of the x-rays can be shortened to about 100 femtoseconds rms. Femtosecond x-rays have recently been demonstrated at LBNL and have attracted considerable interest in the scientific community.

High Luminosity Muon Collider

The possibility of muon colliders was introduced by A. Skrinsky (Novosibirsk, Russia, 1970s) and D. Neuffer (Fermilab, USA). More recently, R. Palmer (BNL, USA) has shown how high luminosity might be achieved. These ideas have been aggressively developed over the past two and a half years in a series of workshops and collaboration meetings between scientists from Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley

National Laboratory and various universities. These studies have concentrated on a 4 TeV version of a muon collider and on a 0.5 TeV demonstration machine.

The Muon Collider concept is complementary to standard approaches to high energy accelerators, having unique technical and physics advantages and disadvantages when compared with both hadron and electron machines.

Advantages

- Synchrotron radiation from a charged particle varies inversely as the fourth power of the mass. Since muons are heavier than electrons, it is possible to use a conventional circular accelerator for the collider ring, instead of the linear single pass accelerators needed for e^+e^- colliders, greatly reducing the size of the collider facility. High luminosity is obtained by using the same particles for more than 1,000 bunch crossings before the muon lifetime reduces the luminosity significantly.
- Both beams may be partially polarized, albeit at the cost of some reduction in the luminosity. This is an important feature for studying and classifying new particles.
- The machine can fit on existing sites. After the source is developed, one envisages a collider operating at low energy, such as 250×250 GeV. As one understands the problems and gains experience, the energy of the collider would be increased. The beams of muons, neutrinos, and kaons produced in the complex are very intense and offer many opportunities for new physics. In particular, neutrino physics, rare muon decay experiments, and rare K decay experiments would be ideally suited for such a facility. Rare decays such as $\mu \rightarrow e + \gamma$ may be one of the few handles on unraveling physics at a very high mass scale.

Technical Difficulties

The above advantages do not come without an accompanying set of difficulties that are still not completely understood. The feasibility study presented at the Snowmass 96 Workshop made strides toward answering some of these questions but there are technical challenges that still must be addressed.

Since muons only survive for about 2 μ s in their rest coordinate system, it becomes a challenge to produce and cool the required 2×10^{12} muons of each sign before a significant loss through decay has occurred. Once they reach 2 TeV, their lifetime is a little over 40 milliseconds, which is enough to allow over 1,000 turns in a colliding ring. A major problem occurs from electrons that arise from the decay of the muons. These electrons heat the superconducting magnets, both through the direct showers that they produce, as well as by the synchrotron radiation that they emit in the magnetic field. In the interaction region they cause serious backgrounds for the detector. Finally, we note that the muons are created into a diffuse phase space; it becomes a tremendous technological challenge to collect these muons into two bunches, cool and accelerate them, and inject them into a collider ring with a small, well-defined emittance. The feasibility study has addressed many of these problems and suggested preliminary solutions, but much work remains to be done.

Physics Considerations

As for an e^+e^- collider, the full energy of the projectile is available for exploring the production of new particles. This is in contrast to a proton collider where only a small fraction of the proton's momentum is available in the quark subsystems. A 2 x 2 TeV muon collider would thus have a significantly higher effective energy than the LHC (Large Hadron Collider, CERN), the highest energy proton collider now planned.

A feature that has attracted considerable theoretical interest is the fact that s-channel studies of Higgs production is possible. This is due to the strong coupling of muons to the Higgs channel due to the large mass of the muon. If the Higgs sector is more complex than just a simple standard model Higgs, it will be necessary to measure the widths and quantum numbers of any newly discovered particles in order to ascertain the structure of the theory. In addition to the increased coupling strength of the muons, the beamstrahlung, bremsstrahlung and synchrotron radiation are much reduced for muons, which allow in principle for much better definition of the beam energy.

Research and Development Plan

The Center for Accelerator Physics has been playing a major role in muon collider studies. Workshops were organized and the feasibility study book, presented at Snowmass 96, was coordinated and edited by CAP staff. Comprehensive articles describing the evolving ideas and scenarios for a high luminosity machine have been periodically published. A WEB page has been established to insure the fast dissemination of results and to coordinate the technical effort.

Simultaneously, an R&D plan has been developed with BNL in close contact with Fermilab and LBNL, aimed at establishing a collaboration between BNL and these national laboratories, as well as with a number of US universities and CERN. Over the next year or so we expect that additional simulation studies will define the experimental hardware development effort needed to complement these theoretical studies. Certainly, CAP has been and will continue to be a strong leader in this effort.