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Accelerator R&D

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Abstract. Accelerator R&D is analyzed into its various categories, important ongoing segments are discussed and the need for a new paradigm in accelerator R&D is put forward in the hope of contributing to a strengthening of accelerator based particle physics around the world.

1 What is accelerator R&D

1.1 Four components

It is useful to decompose accelerator R&D into four components. In descending order of the resources devoted to the practice: a) R&D in support of operation and construction of approved projects, e.g. LHC, TeV Run II, etc. (this category will not be treated herein); b) R&D on relatively well defined but not yet approved accelerator projects, e.g. linear collider, super B-factory; c) R&D in aid of defining potential projects, e.g. neutrino factory or muon collider based on muon storage rings; d) R&D on new principles or processes not directed at a project or particle physics measurement, e.g. laser-plasma related apparatus, new materials, etc..

2 Sampling of ongoing R&D

2.1 R&D on well defined but not yet approved projects — linear collider

2.1.1 Linear collider

TESLA, JLC/NLC and CLIC have active programs that deal with the many important technology developments needed for a successful linear collider. Most visible are the efforts to prove gradient capability claimed in the designs of the three concepts. For TESLA the goal is 35 MV/m, for JLC/NLC it is 65 MV/m and for CLIC, 120 MV/m each trying to maximize the achievable gradient for its technical approach while meeting the HEP physics goals. In the superconducting approach the ultimate gradient is limited by the critical magnetic field for the material used. In the case of niobium the critical magnetic field for pure material under ideal conditions corresponds to 45 to 50 MV/m accelerating gradient. In the warm approaches the ultimate gradient is not known but it is believed that the higher the frequency the higher the achievable gradient. So far the limits have been imposed by physical damage to the cavity surfaces effected by discharges that take place above some threshold gradient. Counter measures include design changes to avoid high peak fields, use of refractory materials at the irises of the cavities and improved cavity preparation methods to minimize contaminants. In the superconducting case, "fully dressed" accelerating units, i.e. with power couplers, helium vessels and tuning fixtures installed, have been operated for many hours at gradients in excess of 35 MV/m without incident. More will be tested. One cryo-module of the Tesla Test Facility contains 8 of these units.

In the NLC/JLC case the current model is able to sustain the needed gradient with an average breakdown rate of about 0.2 per hour. The goal is to make that 0.1 per hour. A model with some improvements and all of the needed HOM damping properties will be tested soon. Other accomplishments include klystron and modulator improvements and successful cold tests of the power pulse compression components. Full power system tests will be carried out soon.

In the CLIC case good progress has been registered through use of tungsten or molybdenum iris inserts. Peak gradients well above the goal have been achieved without significant damage to the iris material. The breakdown frequency yet needs to be reduced. The hall mark rf power generation scheme has demonstrated significant progress in the preliminary phase of the CLIC Test Facility 3 project.

For all the technologies, alignment and stability, particularly at the IP are of great concern. R&D on mountings, motion transducers and feedback system is well advanced although further developments are needed.

2.1.2 Super B-factory

In order to make significant gains in luminosity beyond those already achieved, more current is needed. Plans are to increase the charge per bunch as well as the number of bunches per ring. Besides more capability to dissipate the synchrotron radiation beam power, two of the big issues are dealing with the more intense wakes and using a relatively large crossing angle to control the long range beam-beam interaction. At KEK the wake problem has been addressed by devising a smoother expansion joint that has essentially no discontinuities in the relevant frequency band. The increase of crossing angle is being dealt with by using a crab cavity to make the crossing appear head on in the bunch reference frame. R&D on this cavity is far advanced. At SLAC a new IR has been designed that permits a crossing angle and use of a higher rf frequency to permit closer bunch spacing in under investigation.

2.2 R&D towards defining potential projects

2.2.1 Muon based facilities for neutrino production and Mu–Mu collisions

There are many important technical issues to be addressed here, from the creation of multi-megawatt proton beams for pion production as the source, to targets capable of withstanding that power, to phase rotation, cooling and acceleration, to say nothing of the appropriate design and technology for the final storage ring. In each of these areas there a unique challenges not met or surmounted previously. Solutions for these challenges are being sought through an interesting organizational approach which may well be a paradigm for future HEP projects. Currently of the order of 200 individuals affiliated with of the order 40 institutions — universities, national labs in Asia, Europe and North America — are involved through a network of formal and informal collaborations having both agency and laboratory oversight. There are currently at least six sources of support, all of them quite small. Information about progress and prospects is exchanged at an annual “NuFact” meeting, the most recent of which was held at Columbia University in New York City.

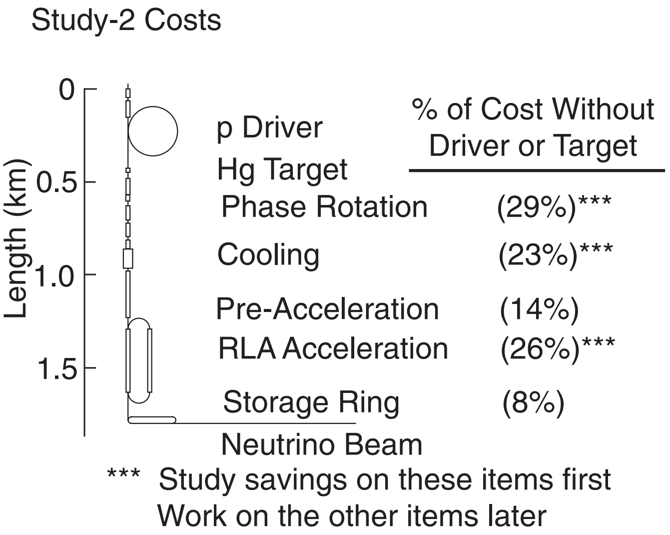

Fig. 1. Results of second cost study, courtesy R. Palmer, BNL

The work is a mixture of system concept design, simulation, calculation, component design and hardware modeling. The system concept work has gone far enough that cost estimates can be made which help focus the R&D efforts. Two such studies have now been made. Figure 1 shows the overall scheme that was evaluated in the second study with the indicators showing which systems need R&D first. Of course the p Driver and targetry have received much attention independently since they are needed for other purposes such as spallation sources and neutrino super beams. The collaboration focuses on phase rotation, cooling and acceleration and considerable progress has been made. Phase rotation is the process of exchanging energy spread for time spread of the muon bunches emerging from the target region. Short bunches with energy spreads in excess of 50% can be manipulated to produce a few percent spread with much longer bunches. It was originally thought that this was best done with an induction linac but recently it has been shown that RF cavity arrangements can do the job much more economically and that will be reflected in the next study to be done. Cooling, which must be done quickly, relies, in most schemes, on energy loss by cyclic ionization in low Z material and reacceleration in RF cavities. This could be done in a linear array of cavities and absorbers or in a ring arrangement reusing the same elements over and over. Recent progress in the ring concept makes it seem possible that this will ultimately be the configuration of choice. Another approach is ”frictional cooling” in which one operates on the low side of the ionization peak of the dE/dx curve. Acceleration schemes have advanced considerably in the last year or two. High gradient superconducting cavities are needed in most schemes So far 11 MV/m has been achieved at 200 MHz and the work continues. The goal is 16 MV/m. For the accelerating system, the recirculating linear accelerator, RLA, shown in Fig. 1, is one option. Fast cycling synchrotrons or FFAG configurations may be more economical. Many important details can be found in accelerator R&D papers given at this conference.

2.3 R&D on technologies for future, undefined projects

2.3.1 High field magnets and SC materials for them

Improvements in Nb3Sn have resulted in critical current densities above 1000 A/mm^2 up to fields of 16 T. The critical current density of this material crosses over that of Bi − 2212 at about 14 T. Model magnets, resembling accelerator dipoles, achieving 14 T and more have been demonstrated[1, 2].

2.3.2 Laser driven plasma wakefield accelerators

Plasma channel guiding to enable extended interaction length between beam and plasma wave has been demonstrated. The experts expect that within a short period of time they will be able to demonstrate 1 GeV acceleration in an apparatus of approximately 15 cm length[3].

2.3.3 Plasma wakefield acceleration

Recently 100 MeV/m acceleration of electrons and positrons has been demonstrated. The accelerating field is generated by a short beam bunch passing through a carefully prepared plasma. Energy is extracted from the head of the bunch and is transferred to particles in the tail[4]. Focusing of 30 GeV electron and positron beams using a plasma lens has also been demonstrated[5], as has the optical matching of such lenses[6, 7].

2.3.4 Photonic band gap accelerators

By using photonic band gap fibers it seems possible to realize an optical wavelength version of the familiar microwave linac[8]. Potential advantages are mass production of the accelerating structure using optical fiber pulling techniques and very high Q for the structures. Rapid pro- gress in the laser community on both high efficiency lasers and photonic band gap fibers will hasten the time at which accelerator applications can be explored.

3 Enhancing the future of particle physics through much strengthened accelerator R&D

It is a truism that HEP progress is limited by the energies and luminosities achievable at accelerators. As we probe deeper in particle physics, the accelerator requirements become more and more difficult to meet in a economical way. The rate at which we have been able to increase elementary CM collision energies has slowed markedly. Looking to the future beyond LHC and the putative linear collider we see few possible alternatives and those that we do see will yet be a very long time in the development before we can tell if they will be viable. Redress of this situation is essential and will have to come from within the HEP community to secure the needed intellectual and monetary resources. Only 10% of those declaring themselves high energy physicists are accelerator professionals. While there have been improvements in training accelerator experts in recent years, the drain into other sciences using accelerators has also increased, presenting a challenge to particle physics to do much more to boost attention to accelerator R&D.

There are several reasons why particle experimenters and theorists should become more involved than at present: 1. manpower (both numbers and expertise) 2. understanding needs; 3. special culture; 4. monetary resources. The only ready source for increased manpower is HEP scientists themselves. We need to take charge of our own fate. We have the general expertise and breadth of vision that can address most of the possibilities and challenges of future needs. Because we understand the needs we are better able to evaluate possible alternatives and make the needed compromises. In terms of culture, particle physicists have a history of international collaboration for more that 50 years, a culture that must be adapted and adopted in the accelerator business. Finally, if particle physicists busy themselves in accelerator R&D that will provide further monetary resources as well as intellectual strength. In the culture of particle physics as opposed to accelerator physics, money follows the interests of the practitioners, a needed culture change in the accelerator component of our field. While even the R&D on well defined but not approved projects is in great want of strengthening, the most dire need is in the areas of defining potential projects such as muon beam based facilities and in exploring new materials, processes and principles needed for generations down the road one or two decades. For this latter category, sometimes referred to as AARD, Advanced Accelerator R&D and exemplified by laser and plasma devices the monetary resources world wide are only on the order of 30 M$ whereas the world investment in particle physics is of order 2 G$. This R&D fraction is not enough. Meeting the challenges of the future means changing the way we do business. We have to do it.

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