Instrumentation in Particle Physics

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Executive Summary

High Energy Physics (HEP), which explores the fundamental nature of energy, matter, space and time, is embarking on a new age of discovery at the cosmic, intensity, and energy frontiers. However, HEP projects are technically complex and have significant costs associated with them that are outstripping the internationally available public funding for the field. Instrumentation research and development (R&D) has the potential to transform this situation, by developing novel new acceleration techniques such as plasma wake-field, and novel new detectors that provide enhanced capabilities with significantly reduced cost. The subject of this report is detector instrumentation R&D.

For HEP to have a bright future, priority within the field must be given to investment in the development of both evolutionary and transformative detector instrumentation that is coordinated across the national laboratories and with the university community, international partners and other disciplines. While the fundamental science questions addressed by HEP remain compelling there is acute awareness of the challenging economic situation and the prospects for flat or declining funding for almost all branches of fundamental science, at least near term. Both the HEP laboratories and the universities are affected. In the laboratories, which are the engines for large facilities and the management of large projects, funds available for generic instrumentation R&D and the associated infrastructure are very limited. In the universities, which have also made extremely important contributions to instrumentation and have been key partners in the development and construction of HEP detectors, there has been a significant and sustained decline in support of technical infrastructure. Economic reality suggests that, with few exceptions, the decline in university technical infrastructure and the sustained fiscal pressure on laboratory instrumentation capabilities will not be substantially reversed. In this challenging environment it is essential that the community optimize the use of the available resources to develop new innovative, cost-effective instrumentation, as this is our best hope to successfully accomplish the mission of HEP. Rebalancing the DOE OHEP portfolio to increase the fractional support for instrumentation R&D should be considered

The primary recommendation of this report is that a standing Detector R&D Coordinating Panel (DRDCP) be formed, under the auspices of the DPF Executive Committee, which consists of representatives from the national HEP laboratories and the university community. The DRDCP would be a representative panel of outstanding capability in detector instrumentation R&D. Its primary role would be to promote, coordinate and assist in generic detector R&D nationally on behalf of the community.

The national laboratories support facilities and core engineering to pursue both directed R&D for upgrades and new projects, and generic detector R&D. Both directed and generic R&D are pursued with significant university collaboration. All HEP laboratories already have a designated point of contact (POC) with the funding agency for generic R&D, who coordinates manpower and facilities. It is recommended that each POC represent the natural point of entry for coordinating university-laboratory collaboration for generic R&D. Each POC (or other laboratory designee) would be a member of the DRDCP. This would make the nature of the laboratory facilities and capabilities better known and would enhance access and future university-laboratory *collaboration. Strong university representation on the DRDCP is vital to its success and at least one-half of the members would be leaders in instrumentation R&D from universities.*

The bi-directional process of transfer of ideas and instrumentation from High Energy Physics to other disciplines and vice versa has had many successes. Although the initiation of the process is complicated, and different for the two directions, stronger ties with other communities with an exchange of information on recent developments would benefit all parties involved. It is recommended that HEP initiate the process of systematically reaching out to other communities. This could begin with a series of topical workshops with the basic energy science and nuclear physics communities and later with industrial organizations and NASA, intended to bring these communities closer together and foster interaction and collaboration with mutual benefit.

Due to the very long timescales of HEP experiments, opportunities to participate in the design, prototyping and building of detectors are infrequent. In consequence the level of instrumentation experience and expertise among young experimentalists in HEP has declined. This situation needs to be changed. It is recommended that the organization of, and participation in, the ICFA initiated and sponsored instrumentation school be supported. The development of a common set of lectures and laboratory courses would be very beneficial. It is desirable to organize a school dedicated entirely to detectors, with academic credits recognized by all U.S. universities. The program could occasionally be extended with advanced topical schools.

A major challenge facing the community is limited participation of young US scientists in leading-edge instrumentation R&D. A concern is that this will cause the US to fall behind in its impact on, and contribution to, developments in both detection and accelerator instrumentation, to the detriment of both the national and international HEP communities. The creation of a prestigious postdoctoral or graduate student fellowship, or both, is recommended. Support would be awarded through a rigorously reviewed national competition.

Excellence in instrumentation development is not universally recognized and rewarded, for example by advancement in university or laboratory positions. We recommend that an APS award in the general area of particle physics instrumentation R&D be established to encourage and reward physicists who have made a significant, recent contribution to developing detector instrumentation, with a preference for physicists who are early in their career

The DRDCP can provide oversight and coordination for many of the recommendations in this report and should be established by the DPF Executive Committee expeditiously.

Introduction and Charge

Instrumentation is the great enabler of science both pure and applied. Instrumentation is critical to the mission and culture of High Energy Physics, which is to explore the fundamental nature of energy, matter, space and time. Our field is embarking on a new golden age of discovery with the recent turn-on of the LHC, and with new experiments being planned at existing and proposed new accelerators, deep underground, at the South Pole, and in space that together will reveal the origin of mass, explain the matter anti-matter asymmetry of the universe, search for extra spatial dimensions, determine the nature of dark matter and dark energy, and may probe the Planck scale. For the very first time we may come to know how our universe was born, how it will evolve, and its ultimate fate.

However, we embark on this adventure of discovery with instrumentation that, while representing a towering achievement, often is a scaled-up version of techniques used in the past. We have, for example, gargantuan accelerators equipped with enormous experiments that have tremendous costs associated with them that are outstripping the internationally available public funding for particle physics. The result is often projects with exceptionally long time scales for construction and completion, and major de-scoping of detectors and their capabilities to the detriment of physics reach to match costs. In addition the time scales for our experiments and our large collaborations may have insulated us from instrumentation advances and innovations in industry.

Instrumentation R&D has the potential to transform this situation, from novel new acceleration techniques such as plasma wake-field, to novel new detectors that provide enhanced capabilities with significantly reduced cost. However, there has been a decline in DOE and NSF funding for instrumentation research and development during the last two decades at universities and national laboratories. If this funding trend is not reversed declining capabilities will surely lead to a dramatic change in how our field functions, and we will confront a different kind of future for HEP– the golden age of discovery will be stalled and its goals unfulfilled. Energy, matter, space, and time will remain enigmas.

Almost all science, but particularly the field of HEP, would clearly benefit from the development of both evolutionary and transformative detector instrumentation that is coordinated across the national laboratories and with the university community and international partners and with other disciplines. Instrumentation R&D is inherently necessary to our scientific future. A workshop on detector R&D in high energy physics was held at Fermilab from October 7-9, 2010, to survey the detector research and development currently being carried out at national laboratories and universities, to identify the areas of detector R&D that hold greatest promise, and to identify current challenges and future needs of all stakeholders and discuss the future of detector R&D in the U.S. One of the conclusions of the workshop was that there seems to be an acute awareness that for a sustained viability of the field a renewed investment in instrumentation development with the appropriate organization is needed. In response to this, the DPF executive committee appointed a Task Force to address the organization of HEP instrumentation. Their charge considered three broad areas in instrumentation.

The first area was large-scale instrumentation research. The premise is that DOE and NSF would benefit from coordinated and independent expert community involvement in sorting the many diverse instrumentation R&D proposals. The merit of a standing body for a national R&D program, its relation to existing projects, and the university-laboratory collaboration was raised. The charge was formulated as four specific questions:

> *Q1. Please comment on the need, merit, and process for evaluating and promoting the national R&D program through a standing body. Please indicate possible reporting strategies and suggest the auspices under which such a body might be organized.*
>
> *Q2. Please comment on the appropriate role for a standing panel on instrumentation in the instrumentation R&D programs for upgrades to existing projects and future projects.*
>
> *Q3. Please comment on possible models for university-laboratory large-scale collaborative projects within a national instrumentation program.*
>
> *Q4. Please comment on the relative importance of developing strategic links to, for example, materials science, condensed matter physics, and electrical and computer engineering both in the academy and in industry to the future of HEP instrumentation as the complexity of our experiments increases. How might these links be developed and sustained?*

The second area was the model for entrepreneurial instrumentation science. Infrastructure to conduct instrumentation R&D at our universities is dwindling and non-existent in many cases. This is in stark contrast to the past and one of the bases of concern for the future of instrumentation as a focal point of the Particle Physics enterprise in the United States and for the future of the field as a whole. While the available personnel and technical infrastructure have shrunk, the intellectual and entrepreneurial spirit among individual university faculty and laboratory scientists fortunately continues. The Task Force was charged to evaluate methods to continue to encourage and support individual efforts. The charge was formulated as follows:

> *Q5. Might targeted resources be established at each of the five national laboratories in order to specifically support particular needs of individual researchers at the universities and the laboratories? This could be in the form of specific needs (e.g., engineering design time) or specific resources for small-scale collaboration among and between university and laboratory scientists. How might such a program be administered?*

The last area the Task Force was asked to address was graduate student and post-doctoral training. Graduate student training is evolving. In the past graduate students received training in both instrumentation and data analysis. Today the majority of students participate in large experiments where the hardware projects are few and spaced apart by many years. For university groups without local instrumentation R&D programs, students often do not have the opportunity to develop the instrumentation skills that will be necessary to perpetuate the practice of continuous innovation in instrumentation required for the future success of HEP. The questions to be addressed were:

> *Q6. Should instrumentation R&D continue to be a preferred experience in the life of U.S. graduate students, or should only a few students have this experience? What are the implications?*
>
> *Q7. There are currently a number of few-week, academic, intensive instrumentation experiences for graduate students offered around the world. Should there be an on-going U.S.-based program of instrumentation schools hosted at the national labs and/or well-equipped universities? What might a program look like? Would it instead be preferable to have U.S. events as part of a global instrumentation education program?*
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> *Q8. Please comment on the suggestion that a national instrumentation fellowship program be created by the NSF and DOE for Ph.D. students and postdoctoral scholars to encourage and support research in instrumentation.*

Organization of Task Force

In response to the charge from the DPF executive committee, recognizing its breadth and scope, the chairs created six different subgroups each to address a specific issue. During the course of the discussions two subgroups were combined given their interconnectedness. The resulting five subgroups are:

- Detector R&D Coordinating Panel and Targeted Resources at the National Laboratories
- Instrumentation Schools
- Interdisciplinary Links
- National Fellowships
- National Prize

A chair was appointed for each of the five subgroups and Task Force members volunteered to join the deliberations. Each group wrote a position paper on their findings and recommendations, which are presented in the following sections.

As the membership of the Task Force was necessarily small, the chairs also invited numerous instrumentation experts from the U.S. and international communities to serve as advisors to the Task Force. When the Task Force was beginning its work the advisors contributed written responses to various charge elements that provided valuable input to the subgroups. Later, the advisors provided feedback on early versions of the position papers. Some advisors volunteered to join a Task Force subgroup and became authors of the position papers.

The Task Force report, individual position papers, the documents referenced in the Task Force report, the Task Force membership and the names of the national and international advisors to the Task Force may be found at

http://www.physics.purdue.edu/dpf_instrumentation_taskforce/

The Task Force met three times face-to-face, at the APS meeting in May in Anaheim, at the Technology and Instrumentation in Particle Physics (TIPP11) conference in June in Chicago, and at the DPF meeting in Providence. In addition both the Task Force and the subgroups met numerous times by phone. The Task Force also conducted two Town Hall meetings to obtain community input. The first of these was at TIPP11; the second was at the DPF meeting. The agenda for each meeting is linked from the Task Force page and links are also in an appendix to this report. The draft report was given to the DPF Executive Committee in October and presented to HEPAP on October 28 at the HEPAP Fall meeting in Washington D.C. The report was made available to the DPF membership for a final two- week comment period on October 28. Comments from the HEPAP and DPF memberships will be incorporated and the final report submitted to the DPF Executive committee in November.

Detector R&D Coordinating Panel and Targeted Resources for the HEP Community

Overview

The Task Force evaluated the need for a standing body to promote and assist in the coordination of the detector R&D supported by the Department of Energy and the National Science Foundation – the national detector R&D program. The Task Force makes the follow recommendation:

Recommendation:

> *A standing body – Detector R&D Coordinating Panel - should be formed to promote and stimulate the national instrumentation and detector R&D program.*

Possible roles for the Detector R&D Coordinating Panel (DRDCP) are described and discussed later in this report. We also include summaries of comparable activities in Europe and Asia.

The Task Force also evaluated different means for establishing and operating the DRDCP. We conclude that the primary role of the DRDCP to promote and assist the national detector R&D program is consistent with a standing body that is largely self-organized (i.e. would not be managed by any national laboratory, the DPF or the funding agencies) but fully representative of the high energy physics national laboratories and universities supported by the DOE and NSF. The Executive Committee of the Division of Particles and Fields of the American Physical Society should have an important role in the organization and continued oversight of the DRDCP, in collaboration with the five high-energy physics national laboratories.

Recommendation:

> *The Detector R&D Coordinating Panel should be largely self-organized and consist of representatives from the national high energy physics laboratories and the university community to form a representative Panel of outstanding capability in detector and instrumentation R&D.*

The Task Force also considered the appropriate role of a standing panel such as the DRDCP in upgrades to existing or future large projects.

Recommendation:

> *The primary role of a standing body such as a Detector R&D Coordinating Panel should be to promote and assist in generic detector R&D*

However, we note in making this recommendation that there are and will be many areas of overlap between generic R&D and future detector upgrades or projects. In this context, the DRDCP efforts may support instrumentation R&D programs organized in the established context of upgrades to existing projects or future large projects.

Roles of a Standing Body

The principal role of a Detector R&D Coordinating Panel would be to promote national detector R&D and stimulate new ideas in instrumentation development. Improved coordination among the national HEP laboratories and university groups engaged in detector R&D is also a key goal. In this regard, the DRDCP could also help facilitate utilization of targeted resources at the national laboratories for the HEP community (see below for more discussion). The DRDCP could also act as a resource for the funding agencies, in a limited role, as described below.

The specific roles of the Detector R&D Coordinating Panel could be to:

- Make available up-to-date information on elements of the national detector R&D program and what kind of detector development is going on in the community, to improve efficiency, reduce duplication, and optimize the use of limited resources for maximum effect;
- Expand coordination among the national laboratories, leading to improved resource utilization;
- Provide a forum (and information) for enhanced access to selected resources at the national laboratories for university groups;
- Stimulate detector R&D through workshops and studies in a coordinated way;
- Stimulate new ideas, especially of the scale requiring substantial collaboration, particularly among laboratories and universities;
- Instigate a concerted effort to involve industry in workshops and studies with the intent of later involvement in R&D;
- Provide a coordinating function for joint educational activities related to instrumentation (schools and other events);
- Act as a resource for the funding agencies, e.g., in establishing SBIR categories, improving the response to program solicitations, and other opportunities.

Roles of a standing body that we do not consider to be appropriate include:

- Acting as a Program Advisory Committee for any of the national laboratories;
- Acting as a standing review body for proposals to the funding agencies or for peer review of proposals;
- Providing a "roadmap" for the national detector R&D program.

The DRDCP will be expected to be cognizant of the overall national HEP scientific roadmap as determined by the agencies, HEPAP and its subpanels. The activities of the DRDCP to support generic detector R&D would be aligned with the scientific directions of the field.

Coordination of instrumentation resources at national laboratories for the HEP community

The five national laboratories each pursue generic instrumentation R&D, as well as directed upgrade R&D for existing programs and proposal-based project-specific development efforts for future experiments. The generic R&D activities are supported by efforts ranging in size from specialized fabrication facilities and engineering capabilities, to broader sensor and detector fabrication facilities, electronics design and test capabilities, DAQ design and engineering, and test beam facilities. The upgrade and project-development R&D is usually short term and based on specific program goals. Generic R&D is targeted towards long-term and often transformational development of new capabilities. Both forms of R&D effort are usually pursued in collaboration with University groups and easily saturate the current capabilities of existing core engineering and instrumentation manpower.

In recent years, the national laboratories have moved to designate a manager as a point of contact (POC) for their generic R&D programs. This person establishes priorities for manpower and facilities within the generic R&D program, and usually coordinates these efforts with other project-specific laboratory R&D efforts. The R&D POC represents a natural point of entry for coordinating University-laboratory collaboration on future R&D efforts and for optimal use of instrumentation facilities. Our expectation is that the R&D POC will be designated as the laboratory representative on the DRDCP, bringing a greater degree of coordination between the laboratories in the use of facilities and instrumentation capabilities, and making the nature of these facilities and capabilities more widely known and accessible. We believe these measures will enhance access and future University-laboratory collaboration in generic instrumentation R&D.

Formation and Operation of the DRDCP

The Task Force recommends that the DRDCP be initiated under the auspices of the DPF Executive Committee and become largely self-organized. The DRDCP would not be directly managed by any national laboratory, the DPF, or the funding agencies. However, the DRDCP would inform the laboratories, the DPF Executive Committee (or designated individuals), the funding agencies and the community at large of its work on a regular basis. A possible model for membership of the DRDCP is the following:

- One representative from each of the five HEP national laboratories (ANL, BNL, FNAL, LBNL and SLAC);
- At least an equal number of representatives from the university community.

The DRDCP should consider if observers from outside the U.S. would be appropriate.

It would be the responsibility of the management at each of the national laboratories to appoint the appropriate representative. In this regard, we note that the laboratories typically have an individual that is responsible for HEP generic R&D (KA-15 supported work) as a POC. It may be that these individuals are the most appropriate as the laboratory representatives but in any case the person appointed should be able to represent the laboratory and be active in detector R&D.

Membership from the university community is critical to the success of the DRDCP. The DPF Executive Committee could act to select university representatives for the DRDCP (as was done for this Task Force). It is essential that the university representatives be active in detector R&D. It is also essential that there be a balanced representation, taking into account support from both the NSF and DOE.

Although the DRDCP would be largely self-organized, the laboratories and university community (through the DPF Executive Committee) may wish to provide an initial direction to the Panel through, for example, a mission statement or equivalent.

The term of service on the DRDCP should be at least two years. A mechanism to rotate the university membership should be developed but could continue to involve the DPF Executive Committee.

Role of the DRDCP in Upgrades to Existing Projects and in Future Projects

The Task Force considers that detector upgrade activities under the direct management (funding) of specific projects to not be a significant aspect of the work of the DRDCP. The DRDCP may take note of the technical achievements or promise of such activities but it is not the role of the DRDCP to promote or coordinate established and funded upgrade programs or programs in the future that are directly managed as projects. However, we recognize there may be substantial technical overlap between such projects and more generic detector R&D. The DRDCP, once formed, will need to consider their appropriate involvement in specific R&D related to projects on a case-by-case basis.

We note that the DOE has recently established, but not yet funded, a generic collider detector research and development program.[1] Since this is a generic program and one that involves many U.S. scientists, we consider it to be of substantial interest and relevant to the future role of the DRDCP.

Status in Europe

In this and the following section the organization of detector research and development in Europe and Asia, respectively, are described. Where appropriate its historical context is given.

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[1] http://science.energy.gov/hep/funding-opportunities/collider-detection-research-and-development/

For the LHC project a dedicated review committee for the detector R&D, DRDC, was established by CERN, well before the proposals for the experiments. It dealt with R&D proposals in a wide area needed to design detectors capable of taking data in the very high data rate and high radiation environment of the LHC. Funding of the approved R&D proposals was done in the same way as for regular CERN experiments, where all the participating institutions requested support from their national funding agencies. A similar evolution is expected for the detector upgrades for the SLHC, where the LHCC at CERN will review and monitor the R&D activities.

For detector R&D needed for other large facilities under consideration, such as high energy electron-positron linear colliders and high intensity neutrino beams, there are no host laboratories that could naturally establish such a committee. For the case of the International Linear Collider (ILC), the DESY Program Review Committee agreed to receive reports regularly from the groups working on the various detector R&D activities including those without any involvement from a DESY group, responding to the wishes from the ILC experimental community. There was a general feeling, however, that a European review body for those detector R&D activities would be needed.

The European Committee for Future Accelerators (ECFA), established in 1963, is a particle physics community organization composed of delegates from every CERN member country. In November 2010, it decided to set up an ECFA panel to review detector R&D proposals. It will receive proposals from groups working for detector R&D projects on a voluntary basis, review them, and make recommendations. The proponents can then use the recommendations for their funding negotiation with their national funding agencies. If proposals were funded, the panel would follow the progress by receiving reports regularly. Since the ECFA panel has no funds, it will function as an advisory body to the national funding agencies, and keep track of various R&D activities in Europe. It does not intend to steer the direction of R&D. ECFA is currently in the process of appointing the panel chair and its members so that it could become operational in the fall of 2011.

Fellowship program

At CERN, two types of fellowship programs are dedicated to areas of technical work in instrumentation, accelerator work and computing: the "doctoral student" and "applied fellow" program. They are not for experimental work or for theoretical particle physics. For the doctoral student program, CERN physicists and academic members of the university awarding the doctoral degree provide supervision jointly.

Instrumentation school

Europe has been actively contributing to the ICFA Instrumentation School. Since 2009, the working group on instrumentation of the EIRO forum, consisting of 8 European laboratories (CERN, EFDA-JET, EMBL, ESA, ESO, ESRF, the European XFEL, and ILL), has organized a one weeklong biennial EIROforum School on Instrumentation.

The Advanced European Infrastructures for Detectors at Accelerators (AIDA) initiative is a program by the European Commission Seventh Framework to address the development of advanced detector technologies for future particle accelerators, as well as transnational access to test beams and irradiation facilities. The project concentrates on four areas of detector development, the sLHC, Linear Colliders, neutrino facilities and Super-B factories, with an emphasis on activities and infrastructure common to all four areas. The project started in February 2011 for a period of four years with more than 80 institutes collaborating.

Status in Asia

In Asia, a prominent example of a laboratory-coordinated detector R&D program is the KEK detector technology project. It started in 2005 with four topics and now covers nine separate topics. These include the development of multi-pixel gas detectors, pixilated photon detectors, superconducting detectors, liquid Xe and Ar time projection chambers, Silicon-On-Insulator pixel detectors, the design of application specific integrated circuits, fast pixel signal processing, and the design of CO_2 cooling systems. In each of these activities, there are one or more scientists from KEK who act as coordinators of a core of researchers from universities and other laboratories from a variety of fields such as X-ray astronomy, medicine, and nuclear and high energy experiments. The total number of subscribed researchers is over 300. Approximately one third of them are from abroad. They share the resources of KEK as well as of universities such as test beams and test equipment. They may also submit prototype ASIC chips to foundries. In some cases, KEK and universities have signed separate agreements of collaboration in research so that researchers at universities can utilize both capital and human resources at KEK efficiently, with in addition some financial support from KEK. These activities sometimes overlap with those of the KEK detector technology project. Often, KEK staff or research fellows from other universities mentor university students acquiring expertise in state-of-the-art techniques, which sometimes leads to a Ph.D. thesis. The KEK detector project hosts seminars and workshops. It also offers training courses and awards prizes for excellent theses in the field of detector R&D. So far, it has worked quite well in promoting detector R&D activities.

Instrumentation Schools and Education

Introduction

Scientific studies in high-energy physics involve several interdependent research areas ranging from the theoretical foundations to the fundamental principles of the accelerators and detectors; from the design and construction of the accelerators and their detectors to their commissioning; from their operation to sophisticated statistical analysis of the collected data. The latter step is the culmination of a long chain of activities of a large experimental collaboration; it provides the broadest exposure to the scientists involved and tends to attract most young scientists.

Due to the very long timescales of HEP experiments, opportunities to participate in the design, prototyping and building of detectors are infrequent. In consequence the level of instrumentation experience and expertise among young experimentalists in HEP has declined. This has been substantiated by a broad poll of the community conducted by the ICFA Instrumentation Panel in February 2010 [1,2]. The poll found that:

- A significant fraction of experimentalists are lacking good understanding of their own detectors.
- The principal mode of education in the instrumentation area is 'on the job training' and instruction from peers. A particularly disturbing trend is the diminishing role of university-based instrumentation training among the youngest scientists.

An additional informal poll of various US universities [3] indicates that the area of detectors and instrumentation is poorly covered by the curricula offered in the physics departments at the majority of the schools participating, although there are examples of interdisciplinary courses offered at several schools that partially compensate.

Brief Analysis of Root Causes

The relative lack of experience and expertise in the area of detectors and instrumentation among younger physicists is only a symptom and a consequence of several fundamental changes within the field of high-energy physics. These changes arise from the evolution of the field itself; they include:

- A major change in the scope and nature of experiments. The typical life cycle of an experiment extends over a decade or more thus not giving students a chance to participate in and understand the various phases of an experiment, from conception to R&D, from design and construction to commissioning, from data taking to analysis. The scale and technical sophistication of the experiments has increased considerably and as a result the role of the students has changed and their contribution to the experiments has been reduced.

- Technical education is best acquired in the course of participating in solving real life technical problems. It is widely reported that the technical infrastructure and the support staff, engineers and technicians, at universities have been reduced considerably over the past two decades. This erosion of the technical base is a major obstacle to providing education in instrumentation.

It has often been noted that a major contributor to the lack of education in instrumentation is the fact that scientific excellence in detectors and instrumentation is given little recognition by the academic community. The perceived scientific value of skills in data analysis is greatly favored over even major scientific advances in detectors and instrumentation. These factors greatly discourage, or even prevent, young scientists from pursing a technical career in experimental high-energy physics, while simultaneously sending a negative signal to the students.

This cultural bias is reflected in an imbalance in most textbooks. While technology monographs and laboratory manuals are available, standard undergraduate and graduate particle physics texts do not integrate experimental with theoretical information, typically devoting at most a chapter to the topic of experimental techniques. The lack of properly balanced textbooks is a major impediment to providing a well-rounded education and it unintentionally creates a perception that instrumentation is less important than other parts of the field.

Existing Instrumentation Schools

The need for better education in experimental techniques has been widely recognized and many instrumentation schools are organized around the world to address this [4]. These schools, initiated by the ICFA Instrumentation Panel, offer introductory detector and instrumentation courses and they often include practical laboratory components. In addition to the ICFA-sponsored international schools there are several editions of such schools organized at the national level with recent examples the schools in Italy, Turkey, Argentina, and China.

The laboratory component of these schools is an essential educational ingredient, as universally agreed by instructors and students, but the technical complexity of possible laboratory courses is frequently limited by logistics and other practical constraints imposed by the location of the school. To elevate the level of laboratory courses a new series of schools, Excellence in Detectors and Instrumentation Technology (EDIT), has been initiated. These schools are organized at high-energy physics laboratories and they take advantage of the advanced equipment and setup available there. The first edition of the EDIT school was organized in January 2011 at CERN. The next edition is planned in February 2012 at Fermilab. The survey of the participants of the CERN edition of EDIT indicates that the importance of the laboratory courses was a key factor in the overall success of the school. Another venue for education in instrumentation is provided at IEEE Nuclear Science Symposia, where several technical courses are offered, usually before the Symposium itself. Typically these are one-day courses and about 150 students attend each course.

While all of these educational initiatives play an important role, and are highly appreciated by the students, they reach a relatively small fraction of young physicists and they are naturally limited in scope. Moreover, these schools and courses often involve a broad representation of students with varying backgrounds, thus limiting the depth of the courses offered.

Probably the most important limitation of this type of education is related to the brief duration of such courses. Gaining an understanding and developing expertise in instrumentation requires both time and prolonged contact with the experimental equipment and should be developed at universities as part of the graduate education of a particle physicist.

Need for Systematic and In-depth Education in Detector Technologies

While one-or-two-week-long detector schools help fill the gaps in student preparation, they cannot provide the thorough education necessary to design, construct or operate modern experiments. This can be achieved, in part, with more traditional semester-long courses focusing on particle detectors. The additional time would allow the lecturer to cover the material in a systematic way, and would give the students the time to better assimilate the concepts and apply them in laboratory conditions.

Unfortunately, today individual universities often cannot afford to offer such courses, due to the large investment of faculty time and lab equipment involved compared to the relatively small number of students who could benefit from it. A more global model is needed in which such courses are developed and offered by a consortium of universities in areas where many HEP groups are concentrated, or in collaboration with national laboratories or CERN, where students are stationed for longer periods of time.

In order to make these classes eligible for academic credit even at the most demanding graduate schools, the curriculum must be developed to cover instrumentation in some depth and have both a theoretical introduction to the topic and a laboratory component. Scientists with significant experience should rigorously teach such courses, and students should be periodically tested on their theoretical understanding of the material as well as their ability to apply such concepts in the lab.

Possible Role of National Laboratories

Universities are the primary source of the education of young scientists; they reach the broadest audiences and they have the biggest impact on the level of competence of young researchers. Many of them have, or have access to, state of the art technical resources and expertise. Unfortunately, this is not the norm in the majority of schools. National laboratories have a high concentration of technical expertise and modern equipment in a broad range of disciplines and could have a significant role in developing and implementing a program that would improve the hardware knowledge of both young and more senior researchers.

A series of focused schools centered on the host laboratories' expertise is one way that a diversified national program of instrumentation schools could be implemented that integrates topical lectures from experts in the field and hands-on laboratories with modern equipment. At some laboratories the possibility exists to integrate the instrumentation school with data collection at a test beam. Focused instrumentation schools of short duration offered across the network of laboratories would minimize the burden on the host laboratory. The program of schools should be scheduled to avoid conflict with the anticipated teaching obligations of students and faculty. Most national laboratories have dormitory facilities to reduce the cost to the participants. Additionally, some schools could be hosted by major research universities, such as Cornell or Purdue, which have significant in-house R&D and fabrication facilities.

Continuing Education

Arguably, high-energy physics used to be at the forefront of technological advances in sensors, electronics and areas of computing. This is no longer true. The rapid progress in electronics, computing and in material sciences is driven by a very broad combination of science, technology and consumer needs which advances the limits of technology with ever increasing rate.

This process of technological acceleration challenges our technical expertise severely: the tools evolve rapidly changing their functionality while concurrently new tools and technologies are being developed at a great pace. It is very important that some mechanism is developed to allow the 'detectors and technical experts' to keep up with, and take advantage of, the evolving technologies.

Recommendations

We recognize that a process of improving the level of technical skills of young scientists is quite complicated. It will take time and there are several areas where major changes are necessary. Moreover, the improvements must be conveyed to and addressed by several groups of physicist in parallel. Whereas the primary source of education must be at the universities, some additional forms of education are necessary for current graduate students and post-docs, and even for the senior physicists. In the following we present a collection of initiatives in the form of recommendations, which have been identified in our interactions with a wide circle of our colleagues. Nationally, the DRDCP would provide oversight and coordination of the schools and other initiatives recommended here.

Recommendation:

> *Organization of and participation in the ICFA-initiated and sponsored school (EDIT, ICFA Instrumentation School) should be strongly supported Collaboration with various national schools should be developed. A development of a common set of lectures and laboratory courses would be very beneficial.*

Recommendation:

> *The US Particle Accelerator School (USPAS) provides educational programs in the field of beams and their associated accelerator technologies not otherwise available to the science and technology community.. It is a well-recognized*

consortium providing graduate-level education with a very successful organization and considerable experience in the organization of academic-level courses. Broadening the range of courses to include detectors and instrumentation would be a very positive development. In the longer term it is desirable to organize a new session dedicated entirely to detectors only, perhaps held at various national laboratories on a rotating basis.

Recommendation:

Some of the national laboratories offer various summer programs for students from universities and high schools. These programs offer a unique opportunity for young interested students to participate in research activities. Dedicated detector and instrumentation courses offered for these summer students could provide a deeper understanding of the activities they are participating in and, at the same time, could enhance general knowledge of instrumentation and attract more young people to this area of research.

Recommendation:

Advanced topical schools focused on specific detection techniques or detector systems could be instituted. They could be held at national laboratories or at universities where the relevant infrastructure and expertise is located. Such schools would be aimed at a relatively advanced audience and they could be of potential interest to industry; serving as a platform for the dissemination of knowledge of the latest industrial technological advances, and simultaneously providing education for the technical staff from industry engaged in R&D efforts.

Recommendation:

Develop detector technology teaching facilities based on parts of retired experiments such as D0, CDF, BaBar, CLEO, etc. Establish a dedicated test beam facility for demonstration and examination of various detection techniques. [5]

Recommendation:

Schools are too short to provide the education needed to design, construct or operate a modern experiment. However, this can be achieved, in part, by semester long courses on particle detectors. Unfortunately these courses have become a rarity at U.S. universities due to limited resources and relatively low enrollment. These courses could be developed by consortia of universities and/or in collaboration with national laboratories or CERN.

Interdisciplinary Aspects of Instrumentation

Introduction

This subgroup of the Task Force looked at the interdisciplinary aspects of instrumentation, taking into account that the initial view is focused on HEP. Two somewhat separate aspects emerged related to this task, which are:

- Development of instrumentation in the high-energy physics community and transfer of that technology and/or knowledge to other fields of science ("HEP to other sciences"). Here science is used in a somewhat generic way and can range from nuclear physics to photon sciences to national security to industry.
- Development of instrumentation for needs specific to HEP, but using new technologies or breakthroughs from other fields of science or engineering ("Other sciences to HEP"). An example of this aspect is the use of new materials and techniques developed in materials science for the development of new sensors or detectors for high-energy physics. Again high-energy physics can range from accelerator based physics to particle astrophysics.

Both of these activities exist in different forms at different institutions. Why they exist and how they exist often depends very much on the environment. For example, the instrumentation group at Brookhaven National Laboratory (BNL) is a good example of work being driven by the multi-disciplinary aspects of BNL, whereas instrumentation development at Fermilab is much more focused on HEP. Another important observation is that HEP follows a very different approach to instrumentation than nearly all other disciplines in science. HEP defines a particular measurement and then develops, engineers, and builds detector systems to do that measurement. Nearly all other sciences simply use instruments that are available, mostly from industry. There is a fundamentally different approach in HEP towards instrumentation than in all other sciences.

The perennial issue of resources has been discussed in another section of this report, but it is clear that universities do not have access to the same resources as laboratories. There is a strong desire in universities to not only be a purely analysis and software operation, but to maintain R&D in instrumentation, outside the mainstream umbrella of big experiments. In the next two sections we will list some areas that may deserve further study separated into the categories of "HEP to other sciences" and "Other sciences to HEP".

Findings and Observations for "HEP to Other Sciences"

We note that the process of transfer of ideas and instrumentation to other disciplines is not a process that can be initiated by the field of high-energy physics. It may be stimulated by particle physics, but the need clearly has to arise or be recognized by the other science(s). For example, the value of the development of certain instrumentation for photon sciences may be clear to particle physicists, but particle physicists cannot tell photon science practitioners what they need; they need to tell us. There is a clear role for high-energy physics to reach out to other sciences and explore what their needs are. How to best accomplish this is unclear. It could be organized through DPF or APS. Workshops may also clearly foster cross-fertilization of fields. Conferences such as the Technology and Instrumentation in Particle Physics (TIPP) and the IEEE NSS/MIC conferences are excellent venues to accomplish this.

Findings and Observations for "Other sciences to HEP"

The process of transfer of ideas and instrumentation from other disciplines to high-energy physics is a process that can be initiated by the field of high-energy physics. It deserves further study to find examples of where this has happened in the past or is happening now. This process needs to be a two-way street, that is, both sides need to benefit from their mutual interaction. High-energy physics should, for example, receive a new or cheaper sensor while at the same time other sciences stand to benefit from the collaboration. The question naturally arises: can this be organized nationally; can it be encouraged nationally; or does it only happen locally because of existing connections between people? A related question is the issue of how funding is provided for these nascent activities and if SBIRs can play a role.

Recommendations

Before we list our recommendations, which can all be taken up by the *Detector R&D Coordinating Panel*, it might be useful to illustrate, through a few examples, where high-energy physics has impacted other fields and vice-versa. The process that was followed was that each member of the subcommittee contributed examples (see Appendix D). It was observed that high-energy physics is very enterprising in reaching out to other communities to solve a problem. This is often done in two ways: trying to find a technology somewhere that exists and can be applied, be it from industry or from another science discipline, or develop something from scratch using developments from other sciences. It is also evident that a lot of instrumentation developed for high-energy physics has found its way into other areas, either because the field of high-energy physics has moved into that area (particle-astrophysics, for example) or because others have picked up HEP technologies. It should also be noted that not all particle physics technologies, ASICs for example, find application everywhere.

Recommendation:

> *The field of high-energy physics should reach out to other communities. This should start somewhat locally by establishing a closer relationship with the Office of Nuclear Physics (NP) and the Office of Basic Energy Sciences (BES) of the Office of Science. A workshop, or a series of workshops, intended to bring those communities closer and foster interaction and collaboration with mutual benefit should be held. This should also include the corresponding NSF funded communities.*

Recommendation:

> *Closer connections should be established with the medical community, NASA, and national security community. These should take into account existing relationships.*

Recommendation:

> *The Detector R&D Coordinating Panel should have input on which topics in instrumentation should be encouraged in the yearly SBIR/STTR proposal calls.*

Recommendation:

> *The Detector R&D Coordinating Panel should establish a repository of examples of migration of technologies and instrumentation for other sciences into high-energy physics or, even better, a repository of possible new developments in other fields that might benefit the development of new sensors or instrumentation in general.*

National Fellowships

The issue facing the community is the limited participation of young and upcoming US scientists in leading-edge instrumentation R&D, and the concern that this will cause the US to fall behind in our impact on, and contribution to developments in both detection and accelerator instrumentation, to the detriment of both the national and international particle physics communities.

We support the notion of prestigious named postdoctoral fellowships as a way to encourage greater participation in instrumentation R&D. The former ILC model from last decade, for which the principal investigators were given 50% funding to allow postdoctoral fellows to work half-time on instrumentation research while also working half-time on other research, was generally felt to be an unsuccessful model. It is expected that instrumentation fellowships proposed in this report would support work predominantly on instrumentation-oriented research, which would then allow the recipients to compete for instrumentation-oriented continuing career positions upon completion of their fellowships. While the outlook for the availability of such positions has not been formally assessed, the subcommittee feels confident that the focused training that such support will allow will produce young scientists whose skills are well matched to a broad spectrum of technical careers in both pure and applied research and development.

We support exploring the notion of providing funding at the graduate student level. This might permit some degree of relief from teaching for graduate students early in their studies, to allow them to be introduced to and to engage in instrumentation work at a critical point in their intellectual development, and/or to provide formal recognition for students later in their studies that have demonstrated significant acuity in instrumentation R&D. It was acknowledged that, per dollar invested, postdocs are generally more productive than graduate students, who tend to require only a little less support than postdocs, but who are generally much less experienced and effective. However, we must keep in mind that a primary objective of the fellowship program is to engage and train those who will, in the future, lead progress in instrumentation. In addition, it may be possible to mix modest support with base-grant or department funding to enable a handful of promising graduate students to engage in instrumentation work in their first year or two of studies.

A final issue that we would like to raise is the consideration of instrumentation work as appropriate subject matter for the Ph.D. thesis. In Europe a HEP Ph.D. is often awarded for instrumentation research. This is the exception in the U.S. At most U.S. universities, authority to approve or reject work towards the thesis lies in the hands of the thesis committee, typically a group of faculty within the field of particle physics, or a closely allied field. The Task Force suggests that it is appropriate for leading-edge instrumentation work to satisfy the requirement for the Ph.D. To the extent that such thesis work becomes more commonplace in the U.S. physics community, supporting the most promising thesis candidates with a competitive and prestigious National Fellowship program might be a good way to further the nation's interest in competitive instrumentation research.

Funding of the National Fellowships could come from a variety of sources. The possibility of industry-sponsored fellowships should be explored. Companies that might be interested include those with a large number of employees with a HEP background, companies in proximity to the national HEP laboratories, and companies that have found attendance at HEP instrumentation schools valuable to them and their employees. There are several agency programs that could support fellowships. While the NSF Division of Fellowships would not provide programmatic support, it does award individual fellowships. Successful proposals in the fellowship competition could be submitted by the proponents to the Division of Fellowships. HEP has had few fellowships from this Division in the recent past. Accordingly, if this route is successful it will represent a modest amount of new funding for the field. In 2010 the DOE Office of Science launched a new Graduate Fellowship program

http://see.orau.org/ProgramDescription.aspx?Program=10272

This program could be a source of support for National Instrumentation Fellowships for graduate students. The DRDCP could provide oversight for all aspects of the fellowship program including funding and the national competition.

Recommendation:

We recommend the creation of prestigious postdoctoral or graduate student fellowships, or both. Support would be awarded through a rigorously reviewed national competition. Several models (e.g. NSF fellowships) exist that could help to frame how the application and review process might be carried out. The DRDCP could establish the competition and advocate for funding of the fellowships with federal agencies and with industry.

National Prize

Advances in our field are driven to a large part by experiment, and the experimental advances are driven to a great extent by developing new experimental techniques and by applying known techniques to new uses. We all recognize this at a practical level. Nonetheless, it is sometimes difficult to get support for innovative developments that might not have a short-term payout in terms of applications to specific experiments. Excellence in instrumentation development is also not universally recognized and rewarded, for example in advancement in university or laboratory positions. We recommend that an award in the general area of particle physics instrumentation research and development be established. We recognize that developing new instrumentation often takes many years to bear fruit in terms of a significant particle physics result. A goal of this award would be to recognize innovative work in the field more contemporaneous with the work.

In considering the benefit of establishing a new prize or award, it is useful to see how such work has been recognized. The Panofsky prize for experimental particle physics has been awarded seven times for instrumentation development, broadly defined: Willis for liquid argon calorimetery, transition radiation, and hyperon beam development; Nygren for the TPC; Cassiday and Sokolsky for atmospheric fluorescence detection; Menzione and Ristori for silicon strip detectors; Oddone for the asymmetric e^+e^- collider; Grannis for the D0 detector; and Breidenbach for the SLD detector. The Nobel prize in physics has been awarded to Glazer for the bubble chamber, Charpak for wire chambers, Alvarez for the application of bubble chambers for discovering particle resonances, Lawrence for the cyclotron, van der Meer and Rubbia for the SPPS and the UA1 detector, and Blackett for developing the Wilson cloud chamber (Wilson got the prize with Compton for observing Compton scattering). We observe that inventing or developing detector (and accelerator) techniques, adapting known techniques to execute important experiments, and applying a variety of techniques to develop a complicated and very successful major detector system has been recognized and rewarded. Further, the examples given show that existing prizes have usually been given for instrumentation that has been used in important particle physics experiments and usually to relatively senior people in the field.

We recommend that we establish a *substantial award* rather than a prize. First, we have the Panofsky prize, which has been awarded regularly for detector development, but typically to relatively senior people. There does not seem to be a need to duplicate the recognition that the Panofsky prize (or the Wilson prize) affords. Second, it will probably be easier to fund an award, which does not require a $250,000 endowment. Third, it would not set the bar so high (equivalent to the accomplishment recognized by Panofsky, Wilson or Sakurai prizes) that it would be difficult to make an award each year.

We have also considered the possibility of establishing an award for best thesis in detector development. This would have the same goal as an instrumentation award. Before determining whether such an award should be established it would be appropriate to determine how many instrumentation theses are currently being produced in the U.S. each year.

Recommendation:

We recommend establishing a new award as a tool to encourage and reward physicists who have made a significant, recent contribution to developing detector instrumentation, with a preference for physicists who are early in their career. The work for which the award is given would not necessarily have yet contributed to an important particle physics result. The award would be given to recognize development of a new detector technique or an innovative application of known techniques to an important experiment. The work for which this award is given should have been done within the previous five years. The award will be given for a single development and it may be shared equally among up to three individuals. The award will consist of a monetary component and a contribution towards travel expenses for the recipient(s) to attend the APS meeting at which the award is given. The DRDCP could oversee fund raising for the award and the selection of the awardees.

References

(All references may be found at the Instrumentation Task Force homepage http://www.physics.purdue.edu/dpf_instrumentation_taskforce/ .)

1. Adam Para, Reflections on Understanding of Detectors and Instrumentation, talk at the Detectors R&D Workshop, Fermilab, October 2010.
2. Ariella Cattai and Adam Para, Preliminary results from the survey on the necessity of a Detectors and Instrumentation School, April 2010
3. Informal Survey of US Universities on the education in Detectors and Instrumentation [Ron Lipton]
4. Ariella Cattai, Survey of the Instrumentation Schools.
5. Adam Para, John Hauptman and Hanna Arnold, The CDF and D0 detectors as laboratories for students

Appendix A: Task Force Members

Universities:	Marina Artuso, Syracuse University Ed Blucher, University of Chicago Bill Molzon, University of California at Irvine Gabriella Sciolla, Brandeis University Ian Shipsey*, Purdue University Andy White, University of Texas at Arlington
National Laboratories:	Marcel Demarteau*, Argonne Ron Lipton, FNAL David Lissauer, Brookhaven David MacFarlane, SLAC Murdock Gilchriese, LBNL Harry Weerts, Argonne
Ex-officio:	Chip Brock, DPF and Michigan State University Patricia McBride, DPF and FNAL Howard Nicholson, DOE Emeritus and Mount Holyoke

Appendix B: National and International Advisors

National Advisors:

David Asner, PNNL
Chris Bebek, LBNL
Daniela Bortoletto, Purdue University
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Joel Butler, FNAL
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Mike Crisler, FNAL
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Bonnie Fleming, Yale University
Carl Haber, LBNL
Steve Holland, LBNL
Chris Kenney, SLAC
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Geoff Taylor, University of Melbourne
Yifang Wang, IHEP Beijing
Hitoshi Yamamoto, Tohoku University

International Advisors Europe and Canada:

Ariella Cattai, CERN
Joachim Mnich, DESY
Tatsuya Nakada, EPFL
William Trischuk, Toronto
Peter Weilhammer, CERN

Appendix C: Subgroups and Members

Coordinating Panel

Chairs: Murdock Gilchriese (LBNL, co-chair), David MacFarlane (SLAC, co-chair)

Members: Marina Artuso (Syracuse), David Asner (PNNL), Ed Blucher (University of Chicago), Chip Brock (Michigan State University), Priscilla Cushman (University of Minnesota), Jim Fast (PNNL), Ron Lipton (FNAL), David Lissauer (BNL), William Molzon (UC Irvine), Wesley Smith (University of Wisconsin, Madison), Harry Weerts (ANL), Andy White (UTA)

Instrumentation Schools

Chairs: Ariella Cattai (CERN), Adam Para (FNAL)

Members: David Asner (PNNL), Chip Bock (Michigan State University), David MacFarlane (SLAC), Gabriella Sciolla (Brandeis University), Sally Seidel (University of New Mexico)

Interdisciplinary

Chair: Harry Weerts (ANL)

Members: Marina Artuso (Syracuse), Priscilla Cushman (University of Minnesota), Murdock Gilchriese (LBNL), Jim Fast (PNNL), Ron Lipton (FNAL), Andy White (University of Texas at Arlington)

National Instrumentation Fellows Panel

Chairs: Bruce Schumm (UCSC)

Members: Ron Lipton (FNAL), David MacFarlane (SLAC), Gabriella Sciolla (Brandeis University)

National Prize

Chairs: William Molzon (University of California at Irvine)

Members: David Lissauer (BNL)

Appendix D: Interdisciplinary Activities

A necessarily incomplete sample of interdisciplinary activities is listed for "HEP to other Sciences" and "Other Sciences to HEP".

"HEP to Other Sciences"

- Application of active pixel devices to electron microscopy (LBL, UK)
- Development of Silicon-On-Insulator based X-ray imaging sensors (with KEK)
- Collaboration with Upstate Medical (NY) on data acquisition infrastructure, using X-rays to check cable connectivity.
- Collaboration with small high tech companies (such as Composite Mirror Applications in Tucson, AZ) on mirror development for RICH detectors, and now the development of novel thin RF foils for LHCb.
- HEP and NP incubate talent in detector R&D for national security and medical R&D, which is not properly recognized.
- There has been a 30-40 year synergy between radio-analytical chemistry and physics and between basic HEP research and applied environmental radioisotope measurement research. HEP has contributed better instrumentation resulting in less need for chemistry and faster processing. Chemistry has helped remove unwanted materials from detectors for DM searches
- ASICs from HEP. Although ASICs were not invented by HEP, ASICs developed by and for HEP could find application in other fields. There is great synergy in Europe between medicine and HEP - much more so than in the U.S. Because of high cost and limited access to resources, other fields such as NP, shy away from the leading edge HEP technologies, often because of cost and complexity arguments. The capabilities of the HEP community should be made more available to interdisciplinary communities.
- Conventional HEP has well-established connections and has contributed to developments in astrophysics and even astronomy. Examples are AMS, GLAST, DES.

"Other Sciences to HEP"

- Development of doped water based scintillator.
- Development of TES detectors for B-mode polarization of CMB. Required identifying and characterizing a superconducting material and make a sensor out of it with the correct noise characteristics.
- Development of large area, flat panel, picosecond photo-detectors based on being able to make cheap micro-channel plates from glass and functionalize them, i.e. turn them into electron amplification devices (gain 10^5), with Atomic Layer Deposition (ALD).
- Development of new photo-cathode materials for accelerators and photo-detectors

- Willingness to re-invent photo-detectors and redevelop forgotten technologies and/or replace them with new ones.
- Initial development of CCD's
- Development of new photo-sensitive materials for photocathodes for accelerator sources of photo-detectors.
- Developments in the silicon area include:
    - wafer thinning and backside laser annealing (with Cornell Materials Science department and university Nanofab).
    - 3D electronics and sensor integration (with MIT-LL, BNL and commercial firms)
    - Silicon-On-Insulator integrated electronics and detectors (in-progress through an SBIR).
    - Development of 3D silicon technology and active edge silicon sensors (with University Nanofabs)
- Development of cold electronics in collaboration with Georgia Tech University EE department
- D0 silicon flex cables were produced at a Kansas City Plant, a dedicated NNSA facility. Many of the Coordinate Measuring Machines at FNAL came out of NNSA facilities and were reutilized by HEP. While some linkages exist between those realms it would help HEP to strengthen them.
- We believe that the original radiation hard electronics for HEP was developed on the coattails of enormous investments made in the weapons program (NNSA) and for satellites (NASA).

Appendix E: Meetings of the Task Force

May 2, 2011:	Kickoff meeting at the APS Meeting, Anaheim, CA https://indico.fnal.gov/conferenceDisplay.py?confId=4415
June 2, 2011:	Task Force Phone Meeting https://indico.fnal.gov/conferenceDisplay.py?confId=4492
June 8, 2011:	Task Force Phone Meeting https://indico.fnal.gov/conferenceDisplay.py?confId=4514
June 9, 2011:	Town Hall Meeting at the TIPP Conference https://indico.fnal.gov/conferenceDisplay.py?confId=4516
August 1, 2011:	Task Force Phone Meeting https://indico.fnal.gov/conferenceDisplay.py?confId=4663
August 11, 2011:	Town Hall Meeting at the DPF Conference https://indico.fnal.gov/conferenceDisplay.py?confId=4691

Material presented and discussed can be found at the url given for each meeting.