A Personal Perspective on the US High Energy Physics Detector R&D Program

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October 7, 2010

Overview

Overview of the talk:

I.Motivation for Detector R&D in HEP. (3)

II. General organization of the DOE Detector R&D program as of 7/31/10. (7)

III.Recommendations for the future program. (7)

IV.Specific projects. (9)

V.Summary (2)

Motivation (1)

Future research in High Energy Physics requires an enabling Detector R&D program to pursue that research at the energy, intensity, and cosmic frontiers.

This program should:

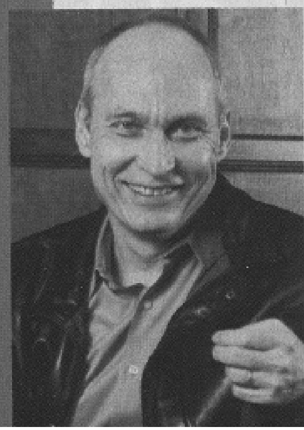
1) Develop **novel new** detector technologies and methods.

2) **Improve the characteristics of existing detectors** commonly used in High Energy Physics. (Increase speed, improve radiation hardness, improve energy resolution, improve precision, improve mechanical robustness, reduce intrinsic radioactivity backgrounds, etc.)

3) Develop **cheaper technologies** for large detector systems.

Motivation (2)

reference frame



(Physics Today September 2009)

A century of physics: 1950 to 2050

Michael S. Turner

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Opportunities: 2000–2050

The game-changing advances of the past 50 years provide clues about the questions that are ripe to be answered and the most promising physics to pursue. The past will be a hard act to follow, but I think the next 50 years may produce an even more impressive record of accomplishments and discoveries. Here's what I foresee:

Instrumentation for the 21st century. No one does it better than physicists when it comes to innovation in instrumentation, and thus the future of all scientific fields surely rests in our hands.

Motivation (3)

Nobel prizes for instrumentation:

1992: Charpak *"for his invention and development of particle detectors, in particular the multiwire proportional chamber"*.

1960: Glaser *"for the invention of the bubble chamber"*.

1954: Bothe (1/2) *"for the coincidence method and his discoveries made therewith"*.

1950: Powell *"for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method"*.

General Organization of Detector R&D at DOE – as of July 31, 2010 (1)

- The Detector R&D Program at DOE is intended to fund the research and development of **GENERIC**
  - sensors
  - detector systems
  - data acquisition systems

  which are likely to be important for research in High Energy Physics.

- It also provides support for
  - test beams

  for detector testing and evaluation.

- In addition the program provides,
  - core funding, including up to 50% of the total wage and benefit support for a few KEY technical people and physicists who have a history of playing an important and continuing role in detector development.*

* This insures that all HEP personnel have at least half their wage and benefit support coming from a proton accelerator, electron accelerator, or non-accelerator research area.

General Organization of Detector R&D at DOE – as of July 31, 2010 (2)

GENERIC is defined here as

- Detector R&D which may be motivated by a specific experiment but which is likely to be of general use to other existing or future HEP experiments. (For experiments large enough to require the CD approval process, GENERIC means pre-CD0.)

- Upgrades to existing detectors which are far enough in the future so that there is no consensus on a single, well defined, technological upgrade path.

General Organization of Detector R&D at DOE – as of July 31, 2010 (3)

University Program ($3.66M/year)

ADR Program ($0.75M)

Short term support for new ideas.

Base funding ($1.55M)

Support for longer term Detector R&D

One shot funding ($0.31M)

Opportunistic funding based on availability

Special Projects

ILC Detector R&D (Some Lab – $0.9M)

Compensated calorimetry ($0.15M)

LHC Detector Development[2] ($2.0M)

Lab Program ($21.7M/year)

LDRD programs (except Fermilab)

Short term support for new ideas.

Base funding ($18.6M)

Support for infrastructure and Detector R&D

One shot funding ($0.15M)

Opportunistic funding based on availability

Special Projects

Large Area Photodetectors[1] ($2.24M)

Water Base Liquid Scintillator ($0.20M)

Wireless Detector Readout[3] ($0.23M)

Test Beam – SLAC ($1.5M)

[1]Includes $1M of FY09 ARRA funding.

[2] Planned for 2011

[3]FY09 funding released in FY10.

General Organization of Detector R&D at DOE – as of July 31, 2010 (4)

The Advanced Detector R&D program (ADR) is designed to give University researchers **relatively short term detector development funding**. (This funding is NOT intended to support a continuing or extensive program in Detector R&D at a University.) The ADR program is restricted to Universities since it can be thought of as an analog of National Laboratory LDRD funding.

In 2010, $750,000 of new funding was set aside for this program. In addition, the total second and third year mortgage has generally been limited to between $150,000 and $200,000 leaving only $550,000 to $600,000 to fund new proposals.

Funding for researchers who 1) have a good track record of detector development in the ADR program and 2) are interested in maintaining a productive long term Detector R&D program at their home institution are best funded by Detector R&D core support rather than repeatedly applying for ADR support.

General Organization of Detector R&D at DOE – as of July 31, 2010 (5)

Recently funded ADR proposals:

Evaluation of 0.25 mm silicon-on-sapphire technology for ASICs for front-end electronics

Advanced fiber optic systems for high energy physics experiments

Development of single crystal chemical vapor deposition (CVD) diamond

Development of large cryogenic germanium detectors

Testing commercial silicon photomultipliers for radiation hardness

Development of large area photodetectors

Design and prototyping of a high granularity scintillating calorimeter

Liquid crystal optical readouts for gas detectors

Interconnect technologies for particle detectors

Fast feature extracted high precision timing

Development of quartz structures for ultralow background high pressure phototubes

Color coding: Sensors Detector Systems Core technologies

General Organization of Detector R&D at DOE – as of July 31, 2010 (6)

The FY2010 ADR program:

28 proposals were received, of which 27 were considered generic and reviewed by four reviewers. Of these, there were two collaborative proposals, one consisting of two proposals and one consisting of three proposals. **A total of 76 reviewers reviewed one or two proposals.**

K$	FY10	FY11	FY12	Totals
Requests	2747	2070	655	5472
Avail. Funding	600	100-150	0-50	750

It is clear from the funding requests that many of the proposal funding profiles were not well matched to the funding profile of the program.

General Organization of Detector R&D at DOE – as of July 31, 2010 (7)

When I was at DOE, I had favored single proposals with prioritized multiple research components from CMS, ATLAS, ILC, and perhaps the muon collider to be panel reviewed by the funding agencies.[1] I discussed the LHC part of this plan in some detail with Daniela Bortoletto from CMS and Abe Seiden from ATLAS.

However, there was concern at DOE that this might not be the best way to manage this program fairly, so the details of the LHC and ILC Detector R&D program were not decided at the end of July.

[1] All detector research components for a given detector community would be required to be included in that detector's R&D proposal, but the community could prioritize these individual research components in the proposal.

Recommendations for a future National Detector R&D program (1)

In July 2009 DOE conducted a review of the Detector R&D programs at Argonne, Brookhaven, Fermilab, Lawrence Berkeley, and SLAC national laboratories. At that time, reviewers were asked for suggestions for a future national detector R&D program. (This workshop is a result of one of those suggestions.) This and some of the other ideas which were presented are given and briefly discussed in the following slides.

Recommendations for a future National Detector R&D program (2)

- Establish an annual conference/workshop in generic detector R&D which would be useful ***to increase communication and encourage collaboration between laboratories and universities***, both in the U.S. and abroad. It should also serve to identify future physics detector needs which are not currently being addressed and help to coordinate the lab R&D efforts.

When I was at DOE, I was unable to identify any place in the program other than the DOE HEP Office where physicists were looking at the HEP Detector R&D program ***as a whole*** and trying to identify ways of reducing the costs of commonly used technologies or developing new facilities to reduce costs in emerging research areas. For example, we buy phototubes from Hamamatsu, we buy enriched isotopes from France and Russia, and we continue to use cables and fibers to read out detector systems. Finding better, cheaper ways to do some of these things would substantially leverage existing funding.

Recommendations for a future National Detector R&D program (3)

- Develop a mechanism to provide overall coordination of the R&D activities in the laboratories to increase efficiency and optimize the use of the ~$20M spent on laboratory generic R&D.

There is an enormous amount of expertise and infrastructure at the national laboratories which are involved in the U.S. High Energy Physics program. Making sure that we reduce duplication of efforts is important to financially optimize the program.

Recommendations for a future National Detector R&D program (4)

- Create a National Instrumentation Advisory Board which meets on a yearly basis and advises DOE and Labs on their instrumentation program from a national and international perspective.

This is a specific suggestion for a mechanism to make the community active in looking at the HEP program as a whole and trying to identify ways of reducing costs commonly used technologies or developing new facilities to reduce costs in emerging research areas.

Recommendations for a future National Detector R&D program (5)

- Allocate funding for "Grand Challenges" to encourage the formation of multi-lab and multi-disciplinary approaches to new and important problems (such as the large-area photo-detector project).

It will be important that DOE be able to opportunistically fund relatively large, ambitious high risk detector R&D projects in the future which have the potential to significantly reduce the cost of future HEP research. The photodetector development effort and to a lesser extent the development of water based liquid scintillator are example of what I think of as "Grand Challenges".

Recommendations for a future National Detector R&D program (6)

- Create a National Instrumentation Fellowship directed at Ph.D. students and postdocs to encourage them to pursue research in instrumentation.

There is concern about the number of PhD HEP physicists who have an expertise in Detector development, particularly since it is difficult for graduate students and postdocs to have significant detector development roles in the very large detectors which currently characterize the field. This suggestion is an attempt to raise the visibility of this activity and emphasize its importance to the future of HEP physics.

Recommendations for a future National Detector R&D program (7)

It has been my hope that this workshop marks the beginning of efforts on the part of the High Energy Physics community to:

1) implement some or all of the previous suggestions and/or to identify other ways for the community to optimize available funding for Detector R&D and

2) to use the results of this R&D to more effectively leverage available program resources in a strong, successful future program.

Specific Projects (1)

DOE has recently funded some specific Detector R&D projects. These include

- **A large area, picosecond resolution photomultiplier.**

- **Water based liquid scintillator**

- **A small effort on wireless detector readout**.

I would also like to suggest here that the construction of the DUSEL underground laboratory provides an opportunity to construct a facility of mile long vertical pipes which might be used to use gravity to carry out gaseous isotopic separation.

Specific Projects (2)

Large Area Photodetector:

For years, the high energy physics community has purchased photomultipliers as a primary, albeit relatively expensive photon detector particularly for covering large areas. While the quantum efficiency of a conventional photomultiplier tube has been increasing, particularly in recent years, a basic photomultiplier tube has a timing resolution limited by fluctuations in electron transit times and has a typical pixel size corresponding to the size of the phototube.

There is a market for large, fast, photomultipliers. In particular, photomultipliers are a major cost for a water Cerenkov LBNE detector. Mechanical robustness is also a major concern. Large area medical scanners would benefit from flat, high speed, less expensive photo technology. National security applications include large area scanners for radioactive materials and for monitoring nuclear reactors.

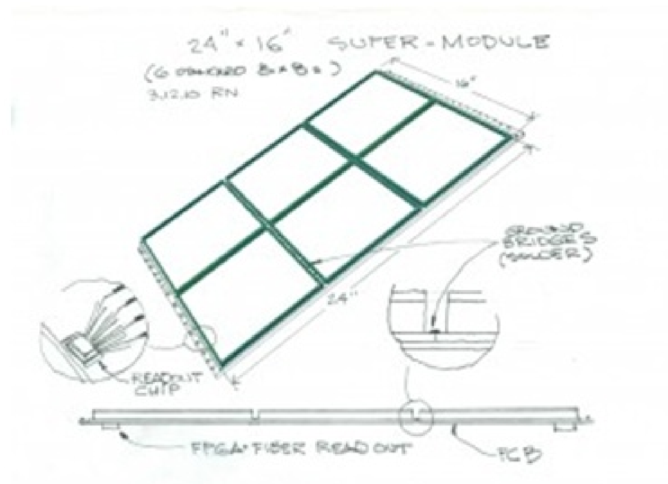
Specific Projects (3)

DOE has recently funded a major effort to develop, large area, flat screen, picosecond resolution photomultiplier tubes using microchannel plates fabricated with atomic layer deposition and transmission line readout with millimeter size effective pixels with a target of a lower cost than a comparable sized commercial photomultiplier tube.

One of the most distinguishing features of this effort is its "high risk – high payoff" nature which is increasingly unusual in times of very large, expensive HEP detectors. Detector R&D is one of the few areas of HEP where high risk projects can and should be carried out.

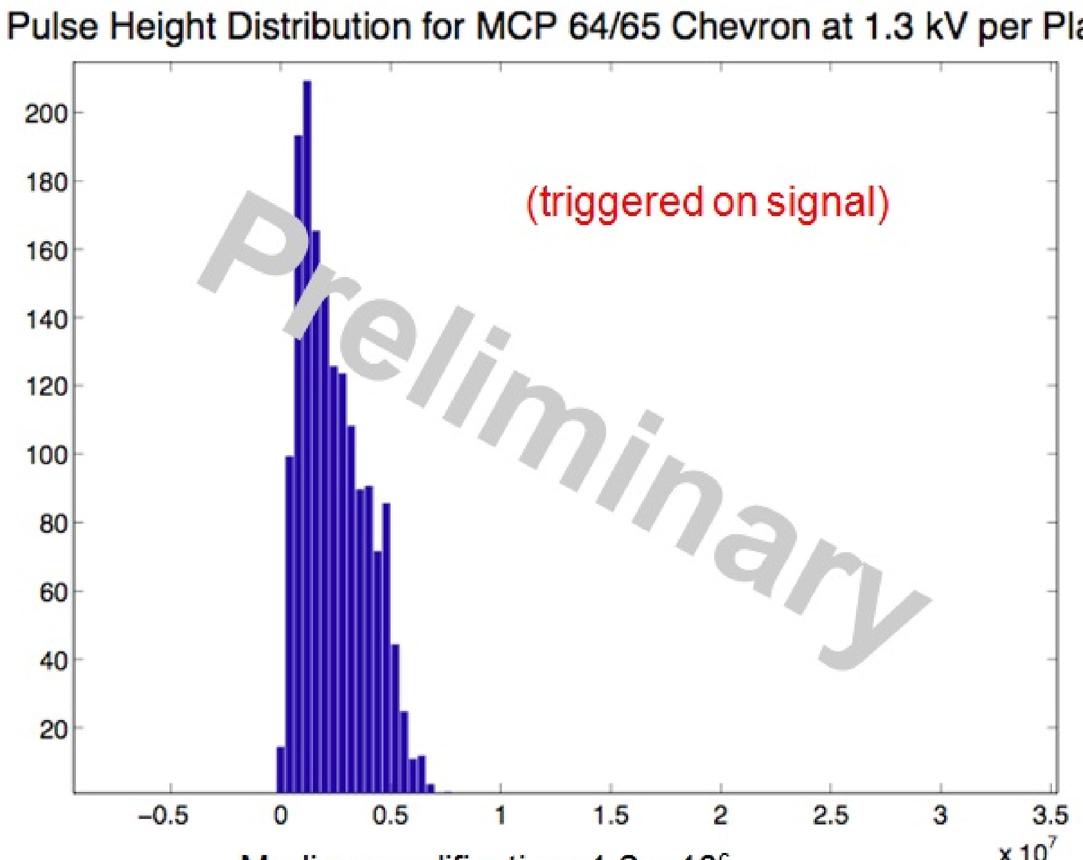
Specific Projects (4)

Complete assembly for 8” x 8” photodetector module .
(From the Large Area Photodetector web page blog.)



Design for 16” x 24” supermodule made from 8” x 8” detectors. The 16” x 24” backplane has the readout strips which couple to each detector.

Specific Projects (5)



Median amplification: 1.2×10^6
Mean amplification: 2.44×10^6

Specific Projects (6)

Water based liquid scintillator:

There is currently an effort underway at Brookhaven National Laboratory in the Nuclear Chemistry Division (Minfang Yeh) to develop water based liquid scintillator.

The primary motivation is to produce a liquid scintillator which is intrinsically cheaper than pseudocumene (PC)/mineral oil based scintillator for very large detectors. For example, the cost of PC/mineral oil for NOvA, which uses oil based scintillator, was ~$20M.

A water based scintillator which would produce Cerenkov light as well as scintillation light could also be useful in compensated calorimetry and for particle ID in large detectors.

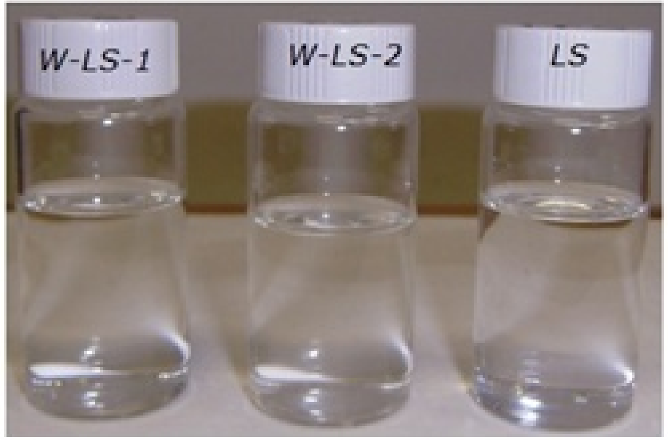
Aside from HEP, there should be a national security market for water based scintillator.

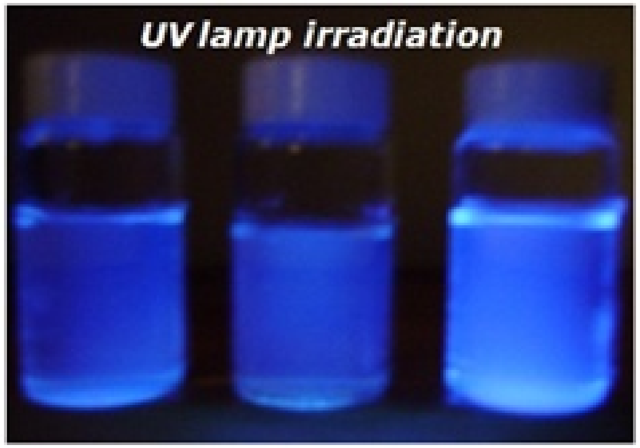
Specific Projects (7)

A very promising candidate for water based scintillator is Linear Alkyl Benzene (LAB) sulfurnated to make Linear Alkyl Benzene Sulfonate (LAS), a chemical manufactured in large quantities for biodegradable detergents. The material is inexpensive (currently about $2k/ton) and relatively environmentally benign.

A 10% mixture of LAS in water is comparable in scintillation yield to a typical oil based liquid scintillator and appears to be stable with time.

A variety of further studies are underway on this candidate.





Specific Projects (8)

Wireless readout:

Wireless readout systems are used in experiments flown in space, but the only large scale wireless readout experiment that I ran across at DOE was AUGER where the size of the detector array made any kind of cabling impractical. This readout system had to be developed specifically for this experiment using cell phone technology.

There is currently some R&D at Argonne on a detector readout system which is wireless and fiberless.

Although the readout bandwidth of a wireless system may be too small for LHC scale detectors, there are likely to be a number of future large scale experiments at the intensity frontier which ought to benefit greatly by a wireless, fiberless readout system.

Specific Projects (9)

Isotopic separation:

DUSEL offers the opportunity to build approximately a 1500 meter long vertical pipe or set of vertical pipes with access along their entire length which could be cooled or heated. These might be used to separate isotopes of noble gasses such as Argon or Xenon using gravity, possibly in combination with thermal gradients. It is interesting to note that for a given atom of mass m, the height for which its gravitational potential energy equals its rms thermal kinetic energy is

$$h = (3kT)/(2mg)$$

and h is the order of 1000 meters for atoms in the range of 40 – 180 amu and temperatures of the order of 100 ^{o}K.

Summary (1)

I believe that DOE is interested in maintaining its relatively new Detector R&D program in the coming years because:

- Detector R&D will enhance the ability of the US HEP community to play major roles in detector development and construction in future international physics experiments
- Detector R&D will enable the US HEP community to develop novel experiments with world leading sensitivities for discovering new physics or improving the precision of existing experimental results
- Detector R&D will help optimize the use of limited funding in expensive, large scale experiments

Summary (2)

I also believe that DOE will need the wisdom of the HEP community to properly manage the Detector R&D program in the coming years. It will therefore be important for the community to find appropriate ways to:

- Obtain an overview of the national HEP Detector R&D program
- Identify major Detector R&D projects or initiatives which could have a major impact on the international HEP program.
- Develop a mechanism for advising DOE on HEP Detector R&D priorities
- Encourage new HEP physicists to become involved in Detector R&D

Backup Slides

Isotopic Separation

Isotopic Separation:

One possible future use for isotopic separation is the separation of the double beta decay (Xe136, possibly Xe134) and non double beta decay isotopes of xenon. One possible scheme might be to hold a 1450 meter pipe filled with gaseous xenon just above the condensation temperature of the liquid (~165 ^{o}K) and cool the bottom one meter and top one meter of the pipe to the point where the gas condenses to a liquid at a slow enough rate to keep the gas in approximate thermal equilibrium in the pipe. Using an equation derived from the ideal gas law

$$n = n_0 \, e^{-(mgh/kT)}$$

the heavier Xe136 isotope is slightly enriched at the bottom of the pipe by the order of a percent and the lighter isotopes of xenon are enriched at the top of the pipe. An array of 100 or so pipes could be used to get enrichment factors of order 2. Iterations could give enrichment factors of one or two orders of magnitude.