The Detector R&D Program

G. Crawford
for
Dr. Howard Nicholson, Program Manager
Office of High Energy Physics
Office of Science

June 3, 2010

Organization of Talk

- **Overview of the program**
  - Purpose and Motivation
  - Funding, Manpower, and General Information
- **Special programs and Initiatives**
  - Advanced Detector R&D - ADR (Universities)
  - Large Area Photodetector
  - Water Based Liquid Scintillator
- **Detector System Development**
  - ILC
  - LHC Upgrades
  - Muon Collider
- **Summary**

Overview - Purpose of the Program

- 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 for a few KEY technical people and physicists who have a history of playing an important and continuing role in detector development

Overview - Definition of Generic

GENERIC is defined here as

- Fundamental R&D on properties of particle detectors
- 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 (e.g., Project X experiments, ILC)
- 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.
  - e.g., LHC detector upgrades (more on this later)

Overview - Motivation

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

This program should:

- Develop novel detector technologies.
- 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)
- Develop less expensive technologies for large detector systems.

Overview - Physics Today September 2009

reference frame

A century of physics: 1950 to 2050

Michael S. Turner

Michael Turner is the Bruce V. and Diana M. Rauner Distinguished Service Professor at the University of Chicago and a founding member of its Kavli Institute for Cosmological Physics.

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.

Overview - Funding Statistics

Generic Detector R&D Funding – History, Current, Projected

$ in Millions	FY09 (Actual)	FY10 (Expected)	FY11 (Projected)
Universities[1]	3.5	3.6	3.7
Laboratories[1]	21.2	20.1	19.4
R&D Initiatives		1.2	2.3
Supplements [2]		0.6	0.8
Program Funding	**24.7**	**25.5**	**26.2**
ARRA Funding	5.9[3]	0.0	0.0
Total Funding	**30.6**	**25.5**	**26.2**

[1] The split between Universities and Laboratories in FY10 and FY11 is approximate and subject to change as is total FY11 funding.
[2] Supplemental funding is approximate and subject to change; provided to both labs and universities.
[3] Includes 0.9M (out of $10.8M) of university infrastructure grants directly identified for detector R&D, along with support for large area photodetector R&D

Overview – Core Personnel & General Information

FY09 actual:

- **Core funding** supports research groups at 8 universities and 5 labs
  - This is explicitly KA1503 budget code; there may be additional individuals performing detector R&D work who are supported under other budgets
- Approximately 82 FTEs : 8 FTEs at Universities and 74 FTEs at labs
  - Currently there is no core funding for Detector R&D at LLNL and LANL. All detector R&D funding to these laboratories is one-shot.

FY09 data

MANPOWER	Universities	ANL	BNL	FNAL	LBNL	SLAC	Total
FTEs	7.6	7.4	3.0	40.4	13.0	11.0	82.4
Heads	16	36	6	147	22	24	251

Current Detector R&D Research Topics

Examples of current detector R&D at the laboratories:

3D vertex pixel detectors
ASIC development
CCD development
Radiation hard silicon development
Measurements of basic properties of liquid argon
Water based liquid scintillator
Large area photodetectors
Intelligent silicon devices
Nanowire carpet hybrid pixel detectors

Liquid argon detector development including cold electronics and purity testing

----

Color coding: Sensors Detector Systems Data Acquisition Systems
Core Technologies

Current Detector R&D Research (Cont.)

Crystal compensated calorimetry

High pressure xenon TPC development

Lepton collider detector development including resistive plate chamber digital hadron calorimetry

Chromatic Cerenkov compensation for improved timing resolution

Detector simulation toolkits

Particle flow algorithm development

High rate DAQ and trigger development

Wireless fiberless DAQ systems

DC to DC converters

Color coding: Sensors Detector Systems Data Acquisition Systems

Core Technologies

Special Programs - ADR

The Advanced Detector R&D program (ADR) is designed to give University researchers relatively short term (1-2 years) detector development funding.

- Peer-reviewed proposals under an annual special solicitation
- Targeted mostly for fundamental R&D on properties of detectors or detector systems
- The ADR program is restricted to Universities since it can be thought of as an analogue of National Laboratory LDRD funding.
- This funding is NOT intended to support a continuing or extensive program in Detector R&D at a University (that is the purpose of the core program)
- Currently $750k of new funding for this program is set aside each year. Typically ~$500-$600k is available to fund new proposals each year (remainder is “mortgage” from previous years’ awards).

Special Programs – ADR (Cont.)

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

Color coding: Sensors Detector Systems Core technologies

Special Programs – ADR (Cont.)

The FY2010 ADR program:

- 28 proposals were received, of which 27 were considered generic; each was reviewed by four reviewers. A total of 76 reviewers reviewed one or two proposals.
- Of these, there were two collaborative proposals
- Plan on funding ~5 highest-rated proposals:

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

Many of the proposal funding profiles were not well matched to the funding constraints of the program.

Detector R&D Initiatives

- **In addition to the core and ADR funding, it is desirable to have detector R&D funds set aside for larger initiatives which can address broad programmatic priorities, e.g.:**
  - Next-generation Intensity Frontier experiments
  - Future Energy Frontier detectors
  - New scientific opportunities

- **These initiatives should have clear timelines and deliverables, but are generally understood to be both "high-risk" and "high-payoff:"**
  - The result may well be that there are technical show-stoppers
  - But if it works, it can be paradigm-changing

- **Some examples follow**
  - Community workshops are planned to identify other compelling new opportunities

Large Area Photodetector

- There is currently a large effort underway at the University of Chicago and Argonne National Laboratory, partially supported by ARRA funds, to develop a large area, "flat panel" photodetector
  - using atomic layer deposition and relatively inexpensive channel blanks to generate a microchannel plate gain stage.
  - The readout consists of transmission line traces on circuit board with custom ASIC processing capability.

- The goal of this R&D is to produce 8" square modules with only ground and high voltage connections suitable for industrialization by 2012 which can be tiled to a readout tray to make 16" x 24" flat panel photodetectors.

The design goals of such a device are:

- Very good timing resolution (~10 psec)
- Good spatial resolution (~mm)
- High gain (~1 x 10^6)
- Less expensive than conventional photomultipliers of similar area
- Thin and mechanically robust with relatively few electrical connections
- Internal signal processing capability

Large Area Photodetector (Cont.)

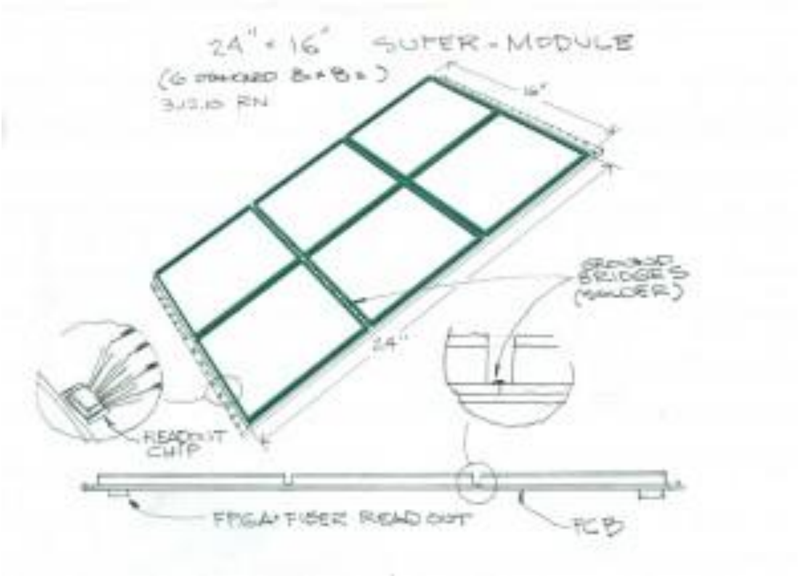
The market for such a device is potentially large. A few examples:

- 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 might include large area scanners for radioactive materials and for monitoring nuclear proliferation.

Some of the progress to date is shown on the following slides.

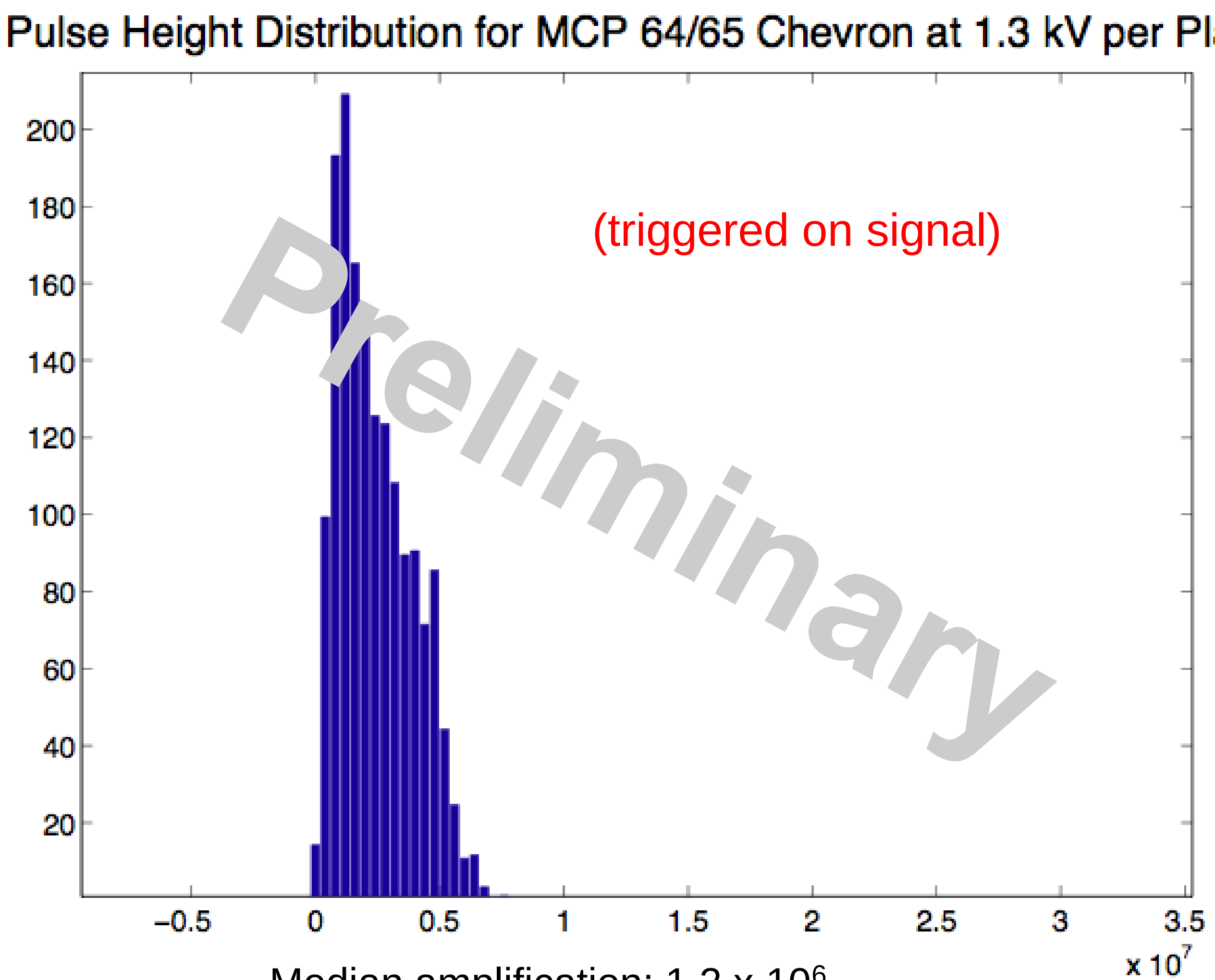
Large Area Photodetector (Cont.)

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.

Large Area Photodetector (Cont.)



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

Water Based Liquid Scintillator

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

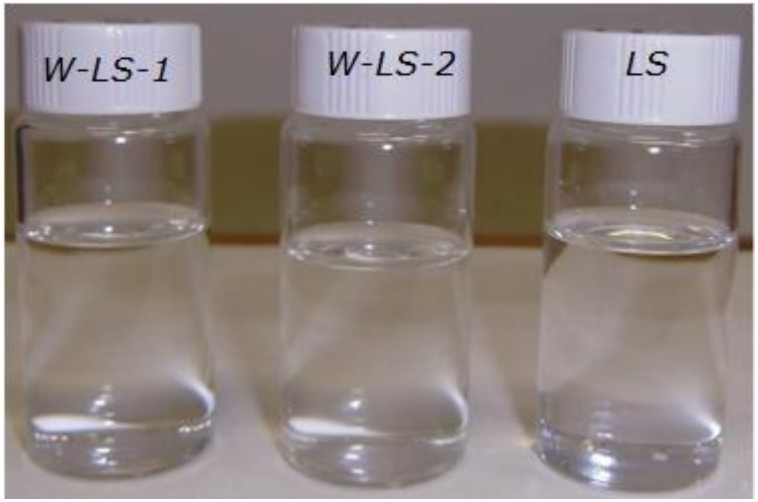
- The primary motivation is to produce a liquid scintillator which is intrinsically cheaper than pseudocumene (PC)/mineral oil based scintillator with comparable performance for very large detectors.
  - For example, the cost of PC/mineral oil for NOvA is ~$20M.

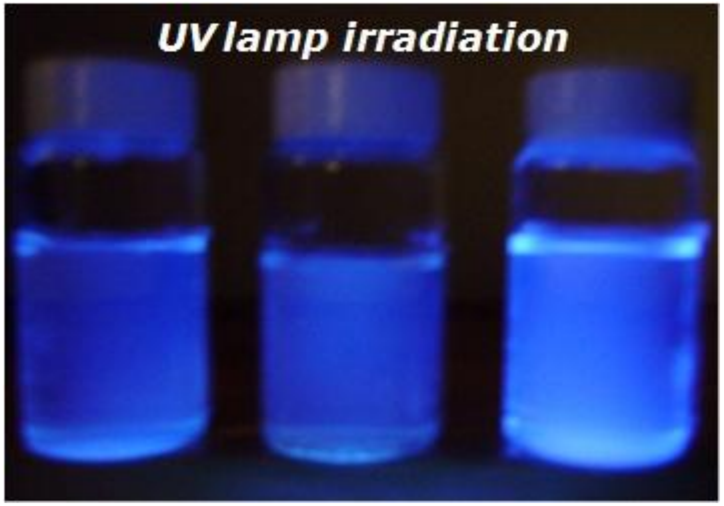
- A water based scintillator which would produce Cerenkov light as well as scintillation light could also be useful in compensated calorimetry and for particle ID in large detectors.

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

Water Based Liquid Scintillator (Cont.)

- A very promising candidate for water based scintillator is Linear Alkyl Benzene (LAB) sulfunated 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.





Detector Systems Development

- **In the past, it has been useful to have directed R&D funds set aside for development of specific detector concepts, e.g.:**
  - LHC detectors and their upgrades
  - ILC detectors
- **This model worked well enough in the old (institutional) HEP management model where one could think of these as "virtual facilities"**
- **However, this R&D structure does not fit well with current DOE project/budget management concepts**
  - e.g., pre-CD0 but driven by specific detector concepts
  - Not tied to an existing US accelerator facility
- **For these reasons, among others, these directed R&D activities are in transition**

Detector System Development – ILC

- Dedicated DOE funding for ILC Detector R&D began in FY2004 and has waxed and waned with the fortunes of the ILC itself.
- It has been largely driven by development of specific detector concepts in parallel with the development of the ILC Reference and Technical Designs, overseen by the ILC Global Design Effort
- It has been funded under different mechanisms over that time:
  - DOE and DOE+NSF
  - Individual grants, “umbrella” grants, and lab financial plans
  - Community driven but always peer reviewed
  - A total of about $5M has been provided to universities and a similar amount to labs (DOE only)
- We are committed to completing the current R&D as planned through FY2011 to inform the ILC Technical Design Phase process
- However, for reasons noted on the previous slide
  - We will transition this effort to a generic collider detector R&D program

Detector System Development – LHC Upgrades

- Because of the anticipated slow luminosity ramp up of the LHC, OHEP plans to transition some of the directed LHC detector upgrade R&D funding into the generic Detector R&D budget starting in FY11.

- Details of how this transition will take place are still being developed

- Beginning in FY12 it is anticipated that proposals for generic detector R&D inspired/motivated by CMS, ATLAS, ILC and possibly muon collider detectors will compete for funding for future energy frontier collider detectors.

- Exact scope/timing of eventual LHC detector upgrades and US participation therein to be determined by CERN schedule and further international discussions.
  - See Mike's talk tomorrow for more details

Detector System Development – Muon Collider

- HEP has asked FNAL to coordinate a national proposal for muon-based accelerator R&D
  - We have also informally asked the national labs to coordinate a parallel effort on detectors for future lepton colliders
  - First milestone is a white paper later this summer
  - Eventual goal is a directed national program on lepton collider detector R&D that is coordinated with related accelerator R&D efforts

- It is anticipated that eventually muon collider-inspired detector R&D will also compete for generic detector R&D funding with other collider detector R&D.

- Once reasonable muon accelerator beam parameters can be determined, simulations using some of the tools developed for the ILC Detector studies to study benchmark capabilities would be appropriate.

Summary

- The Detector R&D program has been recently established at DOE to establish a structure for detector R&D at the Universities and Laboratories and to oversee the use of funding to
  - prioritize the use of limited resources to optimize their impact on the HEP program
  - reduce duplication of funding in detector R&D efforts and
  - identify new areas in which detector R&D funding can impact the HEP program

- R&D directed at specific future detector concepts, which was previously supported with dedicated funding (ILC, LHC) will be largely transitioning to generic detector R&D support

- The Detector R&D community needs to find mechanisms for identifying new opportunities for detector R&D initiatives and for communicating current work throughout the University and Laboratory communities.
  - A workshop is being planned for October by Fermilab and Argonne to begin this process and others are on the horizon.
- The DOE Detector R&D program needs a new program manager since my term at DOE will be over July 31, 2010.

Backup

Detector System Development – ILC (Cont.)

DOE ILC Detector Development Funding at Laboratories:

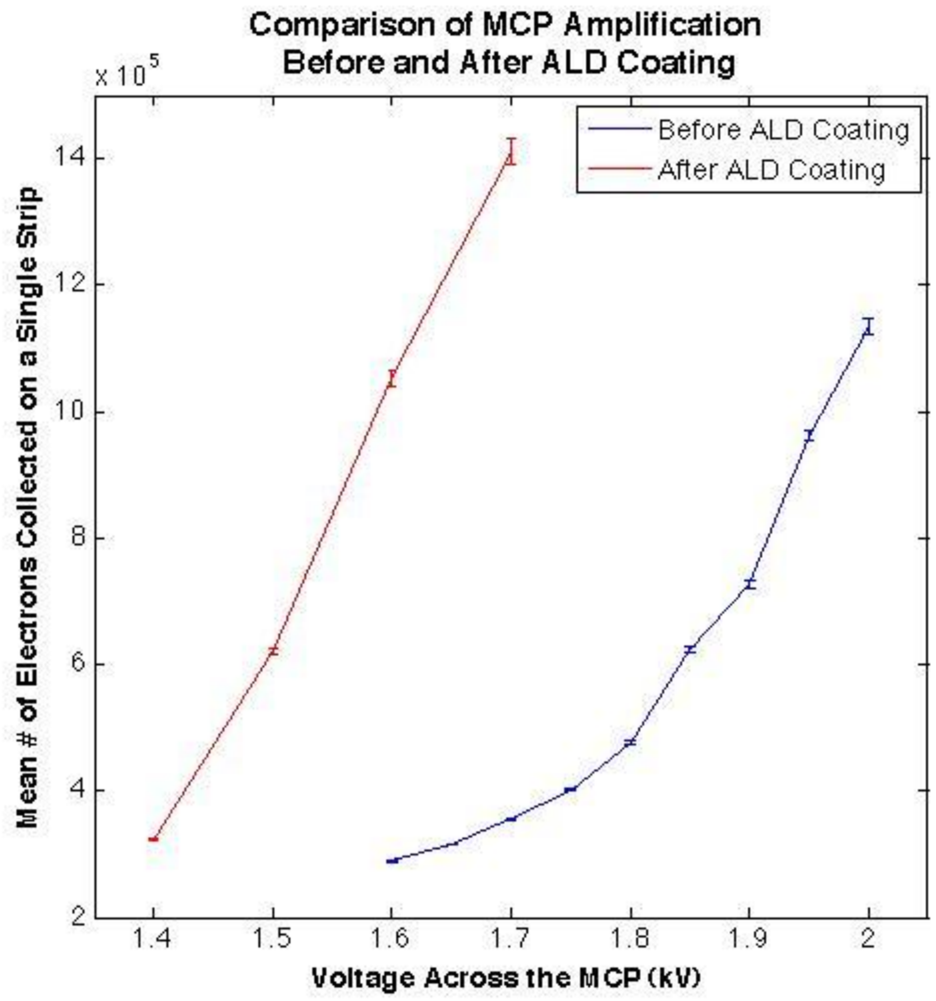
Until FY09, Detector Development Funding at Laboratories was not tracked in detail and a considerable amount of the detector development work which was motivated by ILC detector development was also generic. The laboratory funding for detector R&D since FY09 primarily motivated by the ILC is given below.

K$	FY09 Actual	FY10 Estimated	FY11 Estimated
Argonne[1]	1000	1000	1000
SLAC[2]	750	750	750
Run Tot	1750	3500	5250

[1] Argonne plans to spend ~$1M/year on the resistive plate chamber digital hadron calorimeter through FY11
[2] SLAC spent ~$0.75M in FY09 on SiD development

Large Area Photodetector (Cont.)

The effect of Atomic Layer Deposition on the performance of a commercial microchannel plate.

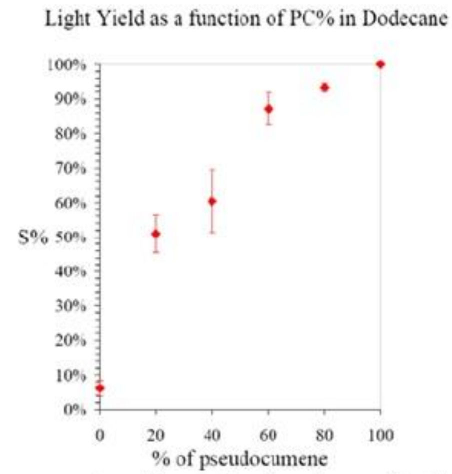


Water Based Liquid Scintillator (Cont.)

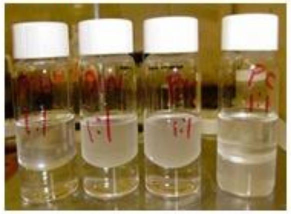
Water-based Liquid Scintillator: M. Yeh

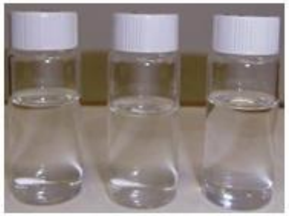
- develop a W-LS to be used as energy spectrometers in large-scale physics experiments
- to replace the hundreds to many tons of unloaded or metal-loaded organic liquid scintillators to
  - simplify the sensitive detection medium
  - less compatibility issue
  - cost savings
- non-linear photon production plus superior water attenuation length makes it possible to detect Physics below Cherenkov threshold

$p \rightarrow k^{+} + \bar{\nu}$ mode at > 3×10^{33} yrs (SK)

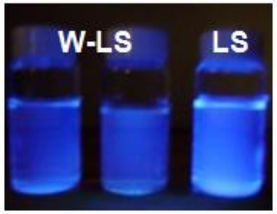


Conventional W-LS cocktails

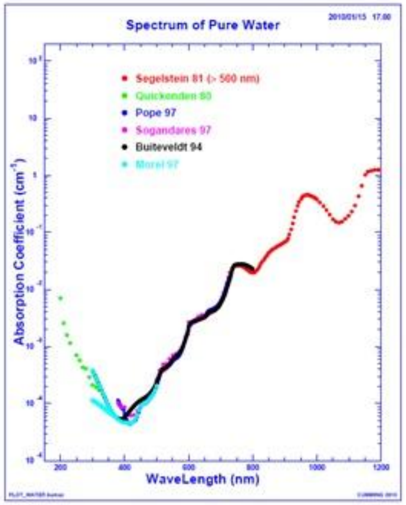




Plenty of light for few LS% loading in H_2O



New-generation BNL W-LS



Continuing focus on the online-purification (>25m) and scintillation time (<12ns) for W-LS

M. Yeh

Detector System Development – ILC (Cont.)

Current projects being funded in ILC Detector R&D program for the SiD detector concept

Chronopixel development – development of a vertex sensor with time stamping.

3D sensor simulation – model charge collection as a function of pixel spacing, doping profiles, and pinning layers.

Alignment procedures – development of a frequency scanned laser interferometry alignment process.

Silicon development – develoment of a silicon microstrip tracker.

DC to DC conversion – project to increase the efficiency of power delivery without adding to the material budget.

Sensors and connects – low mass sensor, electronics, readout development.

Silicon tungsten EM calorimetry – development of high granularity electromagnetic calorimeter suitable for particle flow analysis.

GEM based digital hadron calorimetry – alternative to an RPC digital hadron based calorimeter being developed at ANL.

Detector System Development – ILC (Cont.)

RPC aging studies – studies of Bakelite developed by the BES-III Muon group.

RPC based digital hadron calorimetry – RPC calorimeter being developed at ANL with collaborators from Boston University and the University of Iowa.

Particle flow algorithm development – work to improve the performance of the current SiD/Iowa particle flow algorithm.