# Response to the DOE Review Panel Questions

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## Question 1:

If the 8" MCP photodetector technology were (for whatever reason) not to materialize, but developments continue on smaller size MCPs using the same technology, what would be the likely impact on future HEP experiments? On other fields?

## Response to Question 1:

It really boils down to cost per unit area. Most experiments in HEP are large, and the cost of MCP's has precluded their use except in specialized low-area applications (e.g. small-angle diffractive production), or in applications where there is sufficient funding to pay a large premium over PMT's (such as Belle, which is paying ~8K$ per square inch to Hamamatsu). The least-expensive MCP-PMT's currently available are the 2" Photonis Planacons, which cost about 11K$ each. While the hollow core/ALD technique will lower the cost of the MCP's themselves, the main costs are still in assembly, testing, QC, and

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the yield of the cathode/seal, and so the price is unlikely to come down by a big factor per unit.

The way to drive down the cost, we believe, is to make the area per MCP-PMT unit as large as one can subject to mechanical and vacuum-system issues, as many of the fixed costs are per unit. The 8”-square LAPPD tubes are equivalent in area to 64 of the Hamamatsu 8K$ tubes, and 16 of the 11K$, and in quantity should cost less on a per unit basis. A smaller unit costing close to the same will have less advantage, and hence fewer adopting applications.

The collider and fixed target systems we have been considering require 10-30 square meters of coverage; an Optical TPC for a near neutrino detector, for example, would require more. Many HEP applications would be prohibitively expensive with small form-factor devices.

Lastly, to get the cost down will require adoption by other fields, possibly including neutron-detection and medical imaging. In both these cases the companies with whom we have had contact, Nova Scientific and PDSi, as well as larger companies, are excited by the disruptive aspects of economical coverage of large area with excellent time and space resolution. If we make smaller devices, not much different from what are already commercially available, it will be much more difficult to generate investment by industry.

## Question 2:

1. Provide a plan for reduced scope and/or extended schedule for the R&D program, in particular alternative funding scenarios. For each case indicate the impact on deliverables/milestones relative to what was presented in the review, and provide a brief rationale for your prioritization.
    a. Funding at 80% of request
    b. Funding at 50% of request.

## Response to Question 2:

We have addressed the two parts to the question, the plan and the impact, in the two sections below.

### Plan and Funding Priorities

Table 1 shows the funding as proposed, and in the 50% and 80% scenarios. The comments give the priority and rationale.

| Task | Proposed | 80% | 50% |
|---|---|---|---|
| Project Management | 242K | 242K | 242K |
| SSL-Berkeley Tile Fabrication and Characterization | 648K | 648K | 648K |
| University Contracts | 495K | 495K | 495K |
| Detector Seal Improvement Program | 51K | 51K | 51K |
| 8"x8" MCP Uniformity, Stability, and Lifetime | 648K | 393K | 134K |
| Single Tile Facility 8" Design | 861K | 717K | 0 |
| Electronics, ASICs, and support | 268K | 134K | 105K |
| Photocathode Improvement Program | 139K | 0 | 0 |
| Total/year | 3,350K | 2680K | 1675K |
| Target | 3,350K | 2680K | 1675K |

Table 1: The tasks within LAPPD for meeting the goals of several detectors after Year 1 and four systems after Year 3, with the proposed average annual amounts. The next column lists what we would allocate in a scenario at 80% funding. The 80% scenario allows meeting the goals for tube and system production for early adopters, but at increased risk and with a loss of developmental R&D aimed at reducing cost and improving performance for specific applications. We have discussed a number of scenarios at the 50% level of funding; our conclusion is that at 50% the LAPPD model of laboratory-university-industry collaborative development is no longer viable, and the goals of delivery of commercializable tiles and systems will not be met. The right-hand column shows one such scenario as a (failed) example.

The rationale for the allocation of priorities by task in Table 1 is listed below:

1. The highest priorities are the first three tasks in the Table: 1) management, 2) tube assembly at SSL, and 3) the test efforts at SSL and the ANL/APS. Without all three of these no tubes will be produced. These tasks are consequently kept at full funding in all three scenarios.
2. The next two tasks, the uniformity, stability, and lifetime tests, and the continuing work on an economical long-lived seal, are essential R&D related to the long-term performance of the tubes. Without these, there is a high risk of meeting a short-term milestone but later finding that fundamental problems appear with the MCP-PMT's from a lack of understanding and characterization.
3. The single-tile facility at ANL is an essential part of the three-prong technology transfer effort to industrial production, as described in the review presentations.
4. The electronics, including a fast-sampling ASIC with a latency appropriate for the upgraded LHC detectors and neutrino applications, is essential. However, the electronics is not now on the critical path compared to tube construction, and so we would postpone some parts of this in the hopes of finding alternative funding in the out-years.
5. Lastly, the program to produce higher QE photocathodes started at ANL and UC is continuing through a BNL/UC/ANL/UCB collaboration, using the BNL light source for X-ray characterization of growth in situ. Losing it will be a loss of a very promising and important area to Argonne, but will not delay the production of tubes (see below for additional comments).

Below we add some detail in terms of the efforts of the working groups, a different cut at the `matrix' of LAPPD effort.

1. **Incom:** Without the Incom MCP substrates there will be no tubes for adopters, so maintaining a flow of orders to Incom to support the continued production of glass blocks is the highest priority. This maintains the infrastructure of production, cleaning, testing, and QC of glass blocks.

2. **ANL ALD Effort**: The next priority is the ALD group of Jeff Elam. As with the substrates, the functionalization of the plates is essential to the production of tubes.

3. **ANL HEPD:** The ANL HEPD group is essential to the management of the project through the Project Manager, and is the interface to the efforts at the other institutions and to industry; the Collaboration could not continue without the ANL HEPD. The Single Tile Facility at Argonne will continue to develop cost-effective and higher-performance photo-detector processes. The requested senior hire would have a substantial impact on ANL's tile production R&D effort. The number of postdocs at ANL has gone from 5 to 1 at the end of three years; replacing 2 of the lost positions is also essential to ANL's ability to develop, make, and test tubes.

4. **SSL/UC/Hawaii:** For the next major step, the production of tubes will take place at SSL, where the production vacuum-transfer facility is being commissioned. The group and its highly-developed set of facilities also is essential to the characterization and quality control of the MCP plates produced by Incom and the ALD group. It is a small group, with well-defined roles for each of the 4 individuals-- we cannot see how to cut this budget and still produce tubes. The Chicago group provides the electronics systems, firmware, mechanical system packaging, and software for the glass tube, as well as management and database/web/computer support. The Hawaii group provides the electronics, firmware, mechanical system packaging, and software for the ceramics package, as well as management. Each of these operations is also small with individuals playing unique roles-- the elimination of any of these groups would require finding other ways to fill these roles, most likely at higher cost and diminished expertise.

5. **ANL Electronics Group:** The transition to supporting early adopters will require hardware, firmware, and software support by LAPPD as the outside groups become familiar with and take ownership of the LAPPD systems. While the outside groups will provide expertise, there needs to be dedicated personnel for development and transfer of knowledge. This support task during the transfer is better suited to a National Lab than to University groups. Cutting this will make a problem for adoption

and promulgation of the systems for initial trials in the field, but is not essential to the production of tubes. However, this is a real need, and there will be a cost associated with it if not inside LAPPD, elsewhere.

6. **ANL Photocathode:** We believe there is a strong role for ANL to play in using the facilities and resources in materials science, in particular the ALD expertise, for photocathode development. Cutting this most likely will not slow the production of tubes with typical QE's, unless we have a problem with QE lifetime or uniformity. However, industry is recently rapidly moving to higher QE's (this may be partly due to LAPPD influence through our series of cathode workshops), and to be attractive to adopters LAPPD should keep pace. There is leverage here given the unique ANL expertise in ALD, and we would like to exploit it (a good example of this is that ANL Chemistry has just developed a way of synthesizing a precursor for depositing antimony, and the LAPPD ALD group is now starting tests to make uniform layers of precisely specified thickness for photocathode production).

## Impact on Deliverables/Milestones

Initially the sole source of tubes is at SSL where the vacuum-transfer facility is being commissioned. These tubes will require electronics, mechanical system assembly, firmware, and software to be useable as detectors.

The 80% scenario still allows meeting the milestones of tube and system delivery, albeit in a non-commercializable process. What is lost is the photocathode development at ANL, in particular the unique ALD expertise, and support for the ANL electronics group. The photocathode effort using ALD would be a unique program that exploits the multi-purpose character of Argonne for detector/sensor development. In addition, it cedes to the competition from industry for high QE photodetectors and from SiPMT's with high QE, possibly impacting the attractiveness to markets and large industry. This would be a substantial loss of leverage from LAPPD, but will not affect the short-term limited milestones.

At the 50% funding level the LAPPD model of laboratory-university-industry collaboration breaks down. There are many ways of implementing a 50% scenario, one of which has been shown in the Table. Others that were considered are funding the Single Tile Production Facility at the expense of SSL and university subcontracts, or simply stretching the schedule. In the 50% funding scenario there is not enough funding to maintain the groups at the institutions that are necessary for meeting the goals of tube production, for testing, QC, systems integration, and the interface and support of the cost-effective STTR with industry. While it may be possible to nominally meet the short-term milestone of delivery of 1-4 prototype tubes in the first year, which the table reflects, the goals of developing a robust cost-effective technology to be transferred to industry and develop useable systems for early adopters would not be met. In addition, it would effectively end the development efforts to increase the yield, lower costs, and

improve performance, all essential for industrial adoption, and would remove the attractiveness of the potential for applications to members of the Collaboration, particularly the talented young physicists.

Moreover, industry cannot afford to go slowly due to fixed costs and competition, including substantial growing interest internationally (Japan and China, among others). The LAPPD model of laboratory-university-industry collaboration, capitalizing on the unique interdisciplinary advantages of the process for transfer to industry, does not lend itself to a slow-down of funding, and would not survive at the 50% level. University groups are governed by the 3-year terms of postdocs and the 3-4-year terms of post-candidacy graduate students. A slow-down will mean the loss of interest by industry and the inability to attract the best postdocs and students to the effort.

### Conclusions

At 80% the milestones for system development and delivery would be met, but with higher risk for the electronics and photocathode efforts. These are both areas of high potential for major breakthroughs affecting price and ease of use, and ones for which we have assembled unique expertise. While they are not essential to meeting the milestones, we believe they should be judged competitively with other ongoing detector developments of similar R&D nature. Both of these have the capability of being transformational in a number of fields and being realized within the time-frame of several years.

The 50% scenario does not support a tech transfer effort with enough testing, characterization, and depth to ensure working detectors. It also does not allow application-specific development, our own motivation. We do not see this as viable.

## Closeout

- Performance over the previous 3 yrs of the R&D period has been excellent.
    - Progress has been impressive
    - Potentially revolutionary technology (ALD+MCP)
    - Most milestone have been met
    - Significant infrastructure and expertise has been developed to prepare for next stage

    *LAPPD: We thank the review panel for the comments – they are much appreciated, and the review process itself was very helpful to us.*

- Collaboration should do more work to develop partnerships with end users for specific early applications
    - Develop science drivers which flow down to specs for performance requirements
    - Prioritize delivery of first articles to these early adopters

    *LAPPD: We have been focusing on making at least one sealed tile before diverting effort into outreach to adopters, while at the same time keeping in close contact with the groups. We are close to having a sealed tile, and developing specs for specific applications will be our next step once we have a tile. In the meantime we are planning a web-based portal for guiding the process of documenting specs for the early adopters.*

- Outreach to industry has been exemplary
    - Keep up the good work
    - Having more partners would be helpful
- Engagement of younger scientists in the project very encouraging
- Committee was impressed with the success of a truly interdisciplinary collaboration – setting a good example for others to emulate

    *LAPPD: Again, we thank the panel. With respect to the outreach to more industrial partners, it is a question of resources. We submitted SBIR/STTR proposals in six areas: photocathodes, MCP substrates and ALD, anodes, ASICs, package assembly (3), and low-cost volume production, for a total of 8 proposals. Three were accepted. This represented a substantial effort; we feel that at present, given the tasks of starting the approved STTR/SBIR efforts, that we cannot handle the additional load of more partners. However, with the approval of our STTR/SBIR proposals we have successfully added industrial capability in the areas of anodes, cathodes, and tube assembly.*

    *With respect to younger scientists, we also are impressed and pleased with how quickly they have become expert at a wide range of technologies. Support for postdocs is crucial, as the leverage of productivity is high. We are requesting funds to keep postdocs on the project.*

    *The success of the interdisciplinary collaboration was driven by having adequate funding to pay for postdocs in these other areas and very small fractions of staff salaries. This proved to be a very good financial deal for HEP, as it spawned efforts in the other areas (X-rays are the best example), got us access to facilities and expertise in other Divisions at ANL, in universities, and in industry, and leveraged far beyond the dollar cost. However, it cannot be done without funding that is flexible enough to allow reaching out to other Divisions at ANL, students at other universities (UIUC, UIC), and industrial partners. The LAPPD funding level and profile turned out to be crucial in building the effort.*

- Prioritization will be critical for the next stage, without losing completely the long-range R&D
    - Previous management approach is too lightweight for next stage

    *LAPPD: We have created an Executive Committee and remade the organization chart to reflect the priorities for the next stage.*

    - ANL should take a larger and more proactive role

    *LAPPD: The proposed senior hire to direct the ANL Single Tile Facility is intended to give ANL a much larger and more proactive role. The hiring of two postdocs to replace two of the four who have moved on will also enable a more proactive role in the testing and application-specific development. We have also clarified the organizational structure to take into account the creation of a Detector Group and the larger ANL plans on detector development. At present, the ANL leadership roles in management, Atomic Layer Deposition, material characterization, testing at the APS, expertise in glass and glass package assembly, and indium top seal are essential roles. The ANL HEP Division role in tube production will grow under the proposed budget, as ANL is the leader in the Single Tile Facility planning and construction, and is the major partner in the new Tech Transfer STTR with Incom.*

    Near-term priority should be production, testing and implementation of first devices

    *LAPPD: This is, and remains, the highest priority of LAPPD. Once this is achieved we can turn more attention to some of the other recommendations, such as more outreach.*

- Assuming success of the first devices, further development of infrastructure to produce devices is recommended

    *LAPPD: This is a continuing effort. Recent steps include the newly-approved Tech-Transfer STTR with Incom, the continuing design of the Single Tile Facility (STF), a new electroding capability at UC, and a new annealing oven for the ALD. Needs include construction and commissioning of the STF, an in-house evaporation facility for deposition of electrodes on the MCPs and windows, a plasma-etch facility, further development of the UHV photocathode deposition R&D facility, and diagnostic/characterization devices. These require equipment funds.*

    - Management should develop a staged strategy that can adapt to funding reality

    *LAPPD: We have started, and will be developing this during the next year.*

    Continue to perform due diligence on legal and patent issues.

    *LAPPD: We will continue to be in close contact with Terry Maynard and the Tech Transfer Office, even more now because of the recent STTR/SBIR approvals.*

# Responses to Review Questions DRAFT

H. Frisch, for the LAPPD Collaboration

18 December 2012

# Parallel Efforts on Specific Applications

**Explicit strategy for staying on task-**
**Multiple parallel cooperative efforts**

**PET**
(UC/BSD, UCB, Lyon)

**Collider**
(UC, ANL,Saclay.

**LAPD Detector Development**
ANL,Arradiance,Chicago,Fermilab, Hawaii,Muons,Inc,SLAC,SSL/UCB, UIUC, Wash. U
**Drawing Not To Scale (!)**

**Muon Cooling**
Muons,Inc
(SBIR)

**K->πνν**
JPARC

**Neutrinos**
(Matt, Mayly, Bob, John, ..; Zelimir)

**Non-proliferation**
LLNL,ANL,UC

**Mass Spec**
Andy Davis, Mike Pellin, Eric Oberla

**All these need work- naturally tend to lag the reality of the detector development**

# MODEL OF ADOPTION

- Model of adoption has been established and is in use:
  - Adopters request LAPPD modules and contacts
  - We ask for simulation effort to establish specs, benefits
  - Presumably at this point adopters write a proposal to funding agencies or labs

# SRI Rubric: Need, Approach, Benefit, Competition

| Application | Market Need | Approach | Benefit | Competition |
|---|---|---|---|---|
| Non-cryogenic Tracking Neutrino Detectors | HEP-Fermilab | Very-large-area, bialkali-cathode | Bkgd rejection, Cost, Readiness | Liquid Argon |
| LE Neutron Detection | Neutron Diffraction | B or Gd Glass no cathode | Time and Position resolution, pulse shape γ/n differentiation, Large area | He3, B tubes |
| LE Neutron Detection | Transportation Security | B or Gd Glass no cathode | Large area pulse shape γ/n differentiation, Large area | He3, B tubes |
| LE Anti-Neutrino Detection | Reactor Monitoring | Large-area, bialkali-cathode | Efficiency, Cost | PMT's, SiPMs |
| HE Collider Vertex Separation | CERN | Psec TOF | Resolution, Radiation-Hard | Silicon Vertex |
| HE Collider Particle ID | CERN, Future Lepton Collider | Psec TOF | Resolution Reach in $P_T$ | None |
| $\pi^0/\eta$ Reconstruction and ID | Rare K Decays (JPARC), Fermilab | Psec TOF | Combinatoric Bkgd Rejection | Conventional TOF |
| Strange Quark ID | RHIC (BNL), ALICE (LHC) Collider | Psec TOF | Resolution Reach in $P_T$ | dE/dx |
| Positron-Emission | Clinical Medical Imaging | TOF, Large Area | Lower Dose Rate, Faster throughput | SiPM |

# Responses To Review Panel

**Question 1: What limited number of applications would you target as priorities in the next stage of development and why?**

**Answer: Three HEP and two directed toward market expansion:**

1. **TOF in the LArIAT Beam**
   a) **Why: Simplest set-up that has a large impact on HEP programs**
   b) **Straight-forward interface to experiment**
   c) **Local, have collaborators in place;**
   d) **Drop in for scintillators and PMTs at higher cost and better performance**
   e) **Spec: 4 stand-alone single tile stations, 10 psec time resolution, 50KHz (needs checking)**

2. **Small (1-4 $m^3$) water neutrino detector prototype**
   a) **Why: Comparison to simulation; test of the optical TPC concept with track reconstruction**
   b) **If successful, no competition**
   c) **From 1 to 6 SuperModules;**
   d) **Spec: Single pe resolution ~ 100psec, low rate**

3. **Pre-converter in KOTO**
   a) **Why: Archetype for 3D localization and precise timing of high energy photons**
   b) **Good access to management and technical expertise in the experiment**
   c) **If successful, no competition**
   d) **1-4 SuperModules**
   e) **Spec: Timing = 1 psec; Rate = 200 kHz; Position = several mm; Trigger latency = 5 µsec**
   f) **HEP benefit: Increased physics reach**

4. **PET**
   a) **Why: Potential to decrease patient dose rate by >10 or increase patient throughput**
   b) **Current state of the art = 300 psec**
   c) **Spec: 50 psec (FWHM) TOF-PET resolution**
   d) **HEP benefit: Potentially large market drives the cost down**

5. **High spatial resolution X-ray diffraction**
   a) **Why: Large area detector with high spatial resolution**
   b) **Large area, high spatial resolution, multi-channel solid state detectors are very expensive and slow**
   c) **Spec: 100 µm spatial**
   d) **HEP benefit: Increase cross-disciplinary ties**

# Responses to yesterday's and dinner's discussion

## HJ Frisch

- Broad Brush- request is to continue at same level as last 3 years, plus bump for Tile Facility at ANL
- ANL is the right place to bring multi-disciplinary expertise and facilities to HEP
- We have assembled a strong group comprised of national labs, universities, and industry- have momentum. Success depends crucially on pace- detector projects historically die if they don't move quickly into experimental use

# Responses to yesterday's and dinner's discussion: risk HJ Frisch

- Technical risk for the next 3 years is less than for the first 3 years
- Risk now is of a different type-
  - Market: Depends on:
    - Interest of users
    - Structural ability of user community to adopt new technologies (funding, career paths)
    - Ease of early adoption
  - Model of adoption has been established and is in use:
    - Adopters request LAPPD modules and contacts
    - We ask for simulation effort to establish specs, benefits
    - Presumably at this point adopters write a proposal to funding agencies or labs