Photon Detector System

David Warner
LBNF/DUNE-US Directors Review
20-22 May 2020
Who am I

- Research Scientist: Colorado State University.

- Worked on:
  - DUNE
    - L2 manager for SP-PD since September 2019.
  - LBNE
    - Project Engineer for Far Detector Photon Detector since far detector technology down-select.
  - T2K (Japan)
    - Project Engineer for Pi Zero Detector (P0D).
  - Pierre Auger Observatory (Argentina)
    - Managed surface detector talk liner and PMT enclosure sub-project.
  - HAWC (High-Altitude Water Cerenkov) detector (Mexico)
    - Leader of water containment task force.
Outline

• Brief PD System Description
• Scope
• Organization
• Requirements and Specifications
• Major Activities
• Interfaces
• Cost Summary
• Schedule Summary
• Risks
• ProtoDUNE Plans
• Summary
Photon Detector System Scope (DUNE-US Scope)

• LAr scintillation light collector based on the X-ARAPUCA concept

• PD bars, also called modules, ten per APA, each 209cm long by 12cm wide.

• Photon detectors are mounted inside the APA frame structure on stainless steel rails.

• LED diffusers mounted to cathode planes inside the TPC provide system monitoring.
Photon Detector System Scope (ii)
(DUNE-US Scope)

- Signals read out with SiPM photosensors
  - Hamamatsu (Japan), FBK (Italy)
- Warm Readout Electronics (DAPHNE)
- Cold active ganging electronics
- Monitoring (LED flashers, fibers, diffusers)
Scope: Design, Fabricate, Assemble and Test PD Modules and Associated Components for one 10kt Module

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Quantity (per 10 kT)</th>
<th>Primary Responsibility</th>
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</thead>
<tbody>
<tr>
<td>Detector support</td>
<td>Support rails, electrical connectors, cables</td>
<td>10 per APA. 1,500 total</td>
<td>DUNE-US</td>
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<tr>
<td>Light collector modules</td>
<td>X-ARAPUCA modules (frames, filters, assembly)</td>
<td>10 per APA. 1,500 total</td>
<td>Brazil</td>
</tr>
<tr>
<td>Photosensors</td>
<td>6X6mm$^2$ SiPMs</td>
<td>192 per module. 288,000 total</td>
<td>Italy, Spain, Czech Rep.</td>
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<tr>
<td>Cold electronics</td>
<td>Photosensor ganging (6X SiPM passive, 8X active)</td>
<td>1 per module 1,500 total</td>
<td>Italy, Spain</td>
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<tr>
<td>Warm electronics</td>
<td>DAPHNE system. Based on Mu2e ultrasound ADC</td>
<td>1 unit per APA 150 total</td>
<td>Colombia, Peru, DUNE-US</td>
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<tr>
<td>Calibration and monitoring</td>
<td>Pulsed UV flasher with CPA mounted diffusers</td>
<td>204 diffusers,</td>
<td>DUNE-US</td>
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<tr>
<td>Installation and integration</td>
<td>Module insertion, installation in cryostat</td>
<td></td>
<td>DUNE-US, Brazil, Italy</td>
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</tbody>
</table>
DUNE-US Organization

CSU – Colorado State University
SDSMT – South Dakota School of Mines
ANL- Argonne National Lab
FNAL- Fermilab
PD Consortium Organization

Project Management Board
- David Warner
- Robert Wilson
- Flavio Cavanna
- Kate Scholberg
- Alex Himell
- Ana Machado
- Ettore Segreto
- Deywis Moreno
- Jaroslav Zalesak
- Laura Patrizii
- Francesco Terranova
- Carmem Palomares

Physics/Simulations WG Conveners
- Alex Himmel
- Andrzej Szelc
- Laura Paulucci

Photosensor WG Conveners
- Vishnu Zutshi
- Robert Wilson
- Laura Patrizii

Integration WG Conveners
- Ernesto Kemp
- Yasar Onel

Light Collector WG Conveners
- Ana Machado
- Flavio Cavanna
- Denver Whittington

Electronics/Cabling WG Conveners
- Matt Toups
- Claudio Gotti
- Deywis Moreno

protoDUNE WG Conveners
- Leon Mualem
- Paola Sala
- Zelimir Djurcic
- Jaroslav Zalesak

Ettore Segreto
Lead

David Warner
Technical Coordinator
Requirements and Specifications

- Three requirement categories: EB held, TB held, and consortium held

- High-level Requirements
  - Light Yield
    - Requirement: > 20 PE/MeV avg., > 0.5 per MeV minimum throughout drift volume
  - Calorimetric energy reconstruction independent of TPC
  - Correct association of scintillation light with TPC events
  - Time resolution
    - <1microsecond
    - Provides ~1mm position resolution in drift volume

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2235</td>
<td>SP Light yield</td>
<td>The average light yield (LY) shall be high enough to reach similar calorimetric energy resolution with the PDS for low energy supernova neutrinos as with the TPC. The average LY shall also be sufficient to enable triggering on neutrinos from supernova bursts. The minimum LY in the active volume shall be sufficient to correctly associate scintillation light with events with energy &gt;200 MeV with efficiency &gt;99%.</td>
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<tr>
<td>2237</td>
<td>Time resolution</td>
<td>The time resolution of the photon detection system shall be less than 1 microsecond in order to assign a unique event time.</td>
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<td>2254</td>
<td>SP LAr nitrogen contamination</td>
<td>The nitrogen contamination in the LAr shall remain below 25 ppm in order not to significantly affect the number of photons that reach the detectors (for both fast and late light components).</td>
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</table>

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<tr>
<th>ID</th>
<th>Name</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>2291</td>
<td>Clean SP POS assembly area</td>
<td>To minimize LAr contamination due to PD modules, all PD assembly and integration shall occur within a class 100,000 clean assembly area.</td>
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<td>2292</td>
<td>SP PDS spatial localization in y-z plane</td>
<td>Events inside the active volume shall be localized in the y-z plane to within &lt; 2.5m using light signals.</td>
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<tr>
<td>2293</td>
<td>SP PDS environmental light exposure</td>
<td>Blue/UV light exposure to the PD modules should be minimized. No exposure to sunlight at any time. UV filtered light (&gt;400 nm) during all exposure.</td>
</tr>
<tr>
<td>2298</td>
<td>SP PDS modules inserted through APA side tubes</td>
<td>PD modules must fit and be secured to the APA through slots in one side of the APA, as designed in concert with APA group between the PD and the APA side tube slot and support frame is required for installation.</td>
</tr>
<tr>
<td>2299</td>
<td>No mechanical interference with APA, SP-CE and SP-HV detector elements (clearance) and SP PDS</td>
<td>SP-PD system, including cables and mechanical supports, must fit within APA and not interfere with SP-CE.</td>
</tr>
<tr>
<td>2301</td>
<td>SP PD cabling cannot limit upper-lower APA junction gap</td>
<td>The PD cabling system must not limit the separation of the APAs when assembled into a two-APA stack.</td>
</tr>
<tr>
<td>2302</td>
<td>Maintain SP PD-APA clearance at LAr temperature</td>
<td>Allowance must be made for PD modules and cables to allow cooldown to LAr temperature.</td>
</tr>
<tr>
<td>2303</td>
<td>Data transfer rate from SP-PD to DAQ</td>
<td>&lt;6 Gbps per APA per DAQ design.</td>
</tr>
<tr>
<td>2304</td>
<td>Signal-to-noise in SP-PD</td>
<td>The signal-to-noise ratio (single PE pulse height / baseline noise RMS) shall be greater than 4.</td>
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<tr>
<td>2305</td>
<td>Dark noise rate in SP-PD</td>
<td>The dark rate per electronics channel (e.g., summed across all ganged photosensors) shall be no more than 1 kHz.</td>
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<tr>
<td>2306</td>
<td>Dynamic Range in SP-PD</td>
<td>The dynamic range shall be large enough that no more than 20% of expected beam events have channels which saturate.</td>
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</table>
DUNE-US Activities
1500 Detector Support Assemblies -- CSU

Rails
- Support Structure for modules
- Mounted to APA frame prior to wiring
- Includes module/cable electrical connector

Cables
- Routed inside APA frame prior to stringing
- Allows for connecting upper to lower APA
DUNE-US Activities
Monitoring System-- SDSMT/ANL

• Fiber-Diffuser System (SDSMT)
  - CPA-mounted diffusers (204)
  - Teflon-jacketed fiber
  - Cryostat optical fiber penetrations

• LED driver/controller (ANL)
  - Modified ProtoDUNE 1 readout module (SSP)
  - 18 control modules per DUNE FD module
  - Reads out via slow control fiber
DUNE-US Activities
150 Warm Electronics Modules-- FNAL

- FNAL participation in module design/layout
  - Based on Mu2e electronics (FNAL)
  - FNAL assisting with system engineering, grounding
- BACKUP for purchase of DAPHNE M&S
DUNE-US Activities
Installation and Integration-- CSU, SDSMT

• Photon Detector Installation Team:
  – 1 Post-doc, one technician, two grad students per team
  – Two teams per day (two shifts)
  – One international team, one DUNE-US

• Responsibilities:
  – Module insertion
  – Warm electronics installation
  – Monitoring installation supervision
  – Post-installation testing
PD Validation Plan

• Validation Test Stations:
  - ProtoDUNE 1: Initial photosensors, cabling, ARAPUCA concept, monitoring system
  - UNICAMP: X-ARAPUCA detection efficiency, operational tests
  - Italy/Spain/Czech Republic/NIU: Photosensor testing, cold photosensor active ganging electronics validation
  - Ash River/PSL: PD/APA interface testing, cold mechanical interface validation, cable/connector cold validation
  - ICEBERG: TPC Electronics/PD interface validation. PD warm electronics/DAQ interface
  - ProtoDUNE 2: Module 0 validation tests of all detector elements.

• Major Review Schedule:
  - Preliminary (60%) Design Review (PDR): June 2020
  - Final Design Review (FDR): Q4 2020
  - Production readiness review (PRR) Q1 2022
Interfaces

PD system interfaces are controlled in a series of interface control documents held by DUNE project management and available in EDMS

- **PD/APA**
  - PDs installed inside APAs
  - PD cables run through APA frames

- **PD/DAQ**
  - PD/DAQ readout speed and timing coordination

- **PD/TPC**
  - PD/TPC share cable trays and cryostat penetrations

- **PD/HV**
  - Monitoring system diffusers and fibers mount to cathode plane assemblies
## Cost Summary

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<th>WBS#</th>
<th>WBS title</th>
<th>Actuals thru Mar-20</th>
<th>BAC</th>
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<td>131.02.02.05.01</td>
<td>Photon Detector Project Management</td>
<td>$.1 M</td>
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<td>131.02.02.05.03</td>
<td>Photon Detector Final Design</td>
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<td>131.02.02.05.04</td>
<td>Photon Detector Design/Management</td>
<td>$.8 M</td>
<td>$.4 M</td>
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<td>131.02.02.05.06</td>
<td>Project Management</td>
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<td>131.02.02.05.10</td>
<td>Validation/Development Phase</td>
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<td>131.02.02.05.11</td>
<td>Production Setup</td>
<td>$.4 M</td>
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<td>131.02.02.05.12</td>
<td>Production phase, First Detector Module</td>
<td>$2.4 M</td>
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<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$.8 M</strong></td>
<td><strong>$6.8 M</strong></td>
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</table>

### Budget to go by WBS

131.02.02.05.1  
- 2 Production phase, First Detector Module, $2.4 M, 41%

131.02.02.05.0  
- 6 Project Management, $1.8 M, 31%

131.02.02.05.1  
- 1 Production Setup, $.4 M, 7%

131.02.02.05.0  
- 0 Validation/Development Phase, $1.2 M, 21%

### Budget to go Labor vs M&S

- Fermilab Labor $.5 M, 9%
- US-DUNE Non-FNAL Labor $2.9 M, 50%
- M Material $2.4 M, 41%
NOTE: Most preliminary estimates backed up with vendor quotes, and ProtoDUNE 1 Time and Motion Studies. Awaiting Preliminary Design Review to improve estimate quality.

- **Preliminary, $4 M, 58%**
- **LOE/Oversight, $2 M, 27%**
- **Actuals, $1 M, 13%**
- **Conceptual, $M, 2%**
## Schedule Summary (Milestones)

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<th>Category</th>
<th>CY 2020</th>
<th>CY 2021</th>
<th>CY 2022</th>
<th>CY 2023</th>
<th>CY 2024</th>
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<th>CY 2027</th>
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<td>PRR PD mechanical/optical Complete</td>
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<td>Begin PD module assembly</td>
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<td>PD Module Assembly and testing #1</td>
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<td>Integrate/Install Components</td>
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<td>Installation of PD Modules</td>
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<td>ProtoDUNE II Close TCO, Cool &amp; Fill</td>
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<td>ProtoDUNE II Commission &amp; Operate</td>
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Legend:
- DOE & NonDOE Task
- Milestone
- NonDOE Task

Charge Question 9
Risks

• Installation/integration labor:
  - RISK: Insufficient non-project student and postdoc labor resources identified to meet current projections

• DAQ communications:
  - RISK: DAPHNE cost-optimal configuration transfers data at 4.8 gbs. FELIX currently requires 9.6 gbs. May require more expensive DAPHNE configuration.

• DAPHNE international partners found:
  - OPPORTUNITY: Latin American partners in Colombia, Peru and Paraguay are currently leaders in the engineering and assembly/testing of DAPHNE. Additional resources are being sought from these existing collaborators, and/or additional international collaborators may be identified, to cover expenses currently back-stopped in the US project.

<table>
<thead>
<tr>
<th>Type</th>
<th>ID</th>
<th>Title</th>
<th>Prob.</th>
<th>Cost Impact</th>
<th>Schedule Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threat</td>
<td>RT-131-FD-251</td>
<td>PDS Warm Electronics requires additional engineering/re-spin</td>
<td>30%</td>
<td>$30-60K</td>
<td>3-6 months</td>
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<tr>
<td>Threat</td>
<td>RT-131-FD-253</td>
<td>PD warm electronics require more costly components (e.g. FPGA)</td>
<td>30%</td>
<td>$150-300K</td>
<td>2 months</td>
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<td>Opportunity</td>
<td>RT-131-FD-254</td>
<td>International partners found to cover warm electronics costs</td>
<td>30%</td>
<td>$0-450K</td>
<td>None</td>
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</table>
ProtoDUNE-2 plans

- 40 “Module 0” PD modules
  - Single- and double-sided modules
  - Two candidate SiPMs (down-select following ProtoDUNE 2)

- “Module 0” readout chain
  - Cables/connectors/flanges
  - Cold amplifiers
  - DAPHNE warm readout electronics
  - DAQ interface firmware

- “Module 0” Monitoring system
  - Single LED control unit (modified SSP)
  - 8 diffusers
  - Final candidate flanges, fibers
Summary

• DUNE-US Scope, schedule, costs, interfaces and risks well understood

• International PD consortium solidly established

• PD design validation underway

• Prototyping proceeding successfully

• ProtoDUNE 2 experience will provide validation for PRR in January 2022
BACKUP SLIDES
Impact of COVID-19

• Lab work stopped at nearly all national laboratories / universities worldwide at the end of March 2020

• Activities stopped / delayed
  – PD/APA cold integration testing at PSL halted
  – Light collector module (X-ARAPUCA) tests at ICEBERG, Milano test beds halted
  – Warm electronics (DAPHNE) prototypes fabrication delayed
  – Module mechanical prototyping/production preparation at UNICAMP Brazil delayed.
  – Impact of these delays on the ProtoDUNE 2 schedule not yet critical, but failure to restart by late June 2020 may begin to impact our schedule

• Some progress continuing however
  – Module/rail installation tests at Ash River satisfactorily completed
  – Cable bundle installation in APA frames at PSL satisfactorily completed
  – Sample photosensor fabrication/delivery continuing
    • Hamamatsu photosensors delivered to Milano late April 2020
    • FBK photosensors expected to be delivered mid-May 2020
Plans for Restart

• Some European labs/universities beginning to reopen on a limited basis
  - Photosensor testing may begin (Italy, Spain)
  - X-ARAPUCA module (small prototypes) (Italy)
  - Photosensor active ganging (cold testing) (Italy)

• APA/PD cold interface testing at PSL progressing, albeit at a reduced rate

• Many US and Latin American institutions beginning to evaluate schedules for re-opening, but the prognosis is unclear.

• Priority Validation Items (Critical Path for FDR, ProtoDUNE):
  - Photosensors: Progressing, but at slowed pace
  - Warm electronics: Prototype module design fabrication continuing, should proceed through delivery of fabricated modules in Summer 2020. At that point availability of US, Latin American testing sites becomes critical
  - PD/DAQ interface: PD/DAQ interface tests scheduled for Q3 2020 are critical to ProtoDUNE 2 electronics development. Requires re-opening of DAQ testing sites
  - Light collector module prototype components can be ordered from commercial sites in the US, Brazil, Spain. This allows progress to continue through early summer 2020. Test sites (Brazil, Italy, Spain, US) will be needed to allow validation testing

• Summary: Situation not yet critical, but will rapidly deteriorate if reopening of US, Latin American sites delayed past June 2020
ES&H

• The PD safety plan is based largely on the ProtoDUNE experience.

• Particular concerns include: UV exposure, chemical safety (particularly during application of optical coatings and cleaning of components), Cryogenic operations (during photosensor and module testing), and working at heights (I&I activities).

• As an international consortium, a major focus of our current ES&H planning centers on generating a consortium-wide plan to be followed at all fabrication, assembly, testing and I&I sites.
  – Plan will satisfy safety requirements for both LBNF/DUNE and institutions where work is occurring.
  – Final safety plan approval by DUNE/LBNF ES&H manager and PD consortium leadership will be part of pre-production site review.
• As in the case of safety planning, the international nature of our consortium poses special challenges.
• Our QA and QC plans will largely be informed by the experience of ProtoDUNE.
• All designs will be validated to meet Consortium and Project specifications.
• A QA/QC database will be generated and maintained online. All collaborators will be required to upload all QC documentation regularly.
• A QC plan will be approved as part of the design review process, travellers will be maintained (paper or electronic).
• All paper travellers will be maintained online as part of the database.
• A Consortium QC/QA manager position is planned, and will be appointed in May 2020.