

131.ND.02.06 Light Readout: Overview

Nikolay Anfimov, L3 Light Readout Subsystem Lead

ND-LAr Preliminary Design Review

27 June 2022



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U.S. DEPARTMENT OF
ENERGY

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Science

Who am I

Dr. Nikolay Anfimov



- Ph.D. in Physics and Mathematics “Development and application of methods for studying photodetectors”
- Background in EM-calorimetry for COMPASS-II (CERN), APD and scintillator studying for NOvA (FNAL), 20-inches PMT scanning and testing for JUNO (China), SiPM testing for TAO (China), SiPM R&D.
- Head of the Sector of Experimental Methods, Experimental Department of Particle Physics, Dzhelepov Laboratory of Nuclear Problems, Joint Institute for Nuclear Research
- Start working at JINR in 2005

Outline

- Scope
- Requirements
- Interfaces
- Procurement, Manufacturing, QA/QC
- Risks and Prototyping
- Recommendations from Previous Reviews
- Cost and Schedule
- Summary

Intention of the Light Readout System

- Fast t_0 for charge readout $\sim 10\text{-}20$ ns
- Pile-ups resolution $\sim 100\text{-}200$ ns
- Space resolution $\sim 5\text{-}10$ cm to assign pile-ups
- Detached energy assignment <10 ns
- Desirable: TOF < 3 ns

ND LArTPC Design

35 modules in
common cryostat

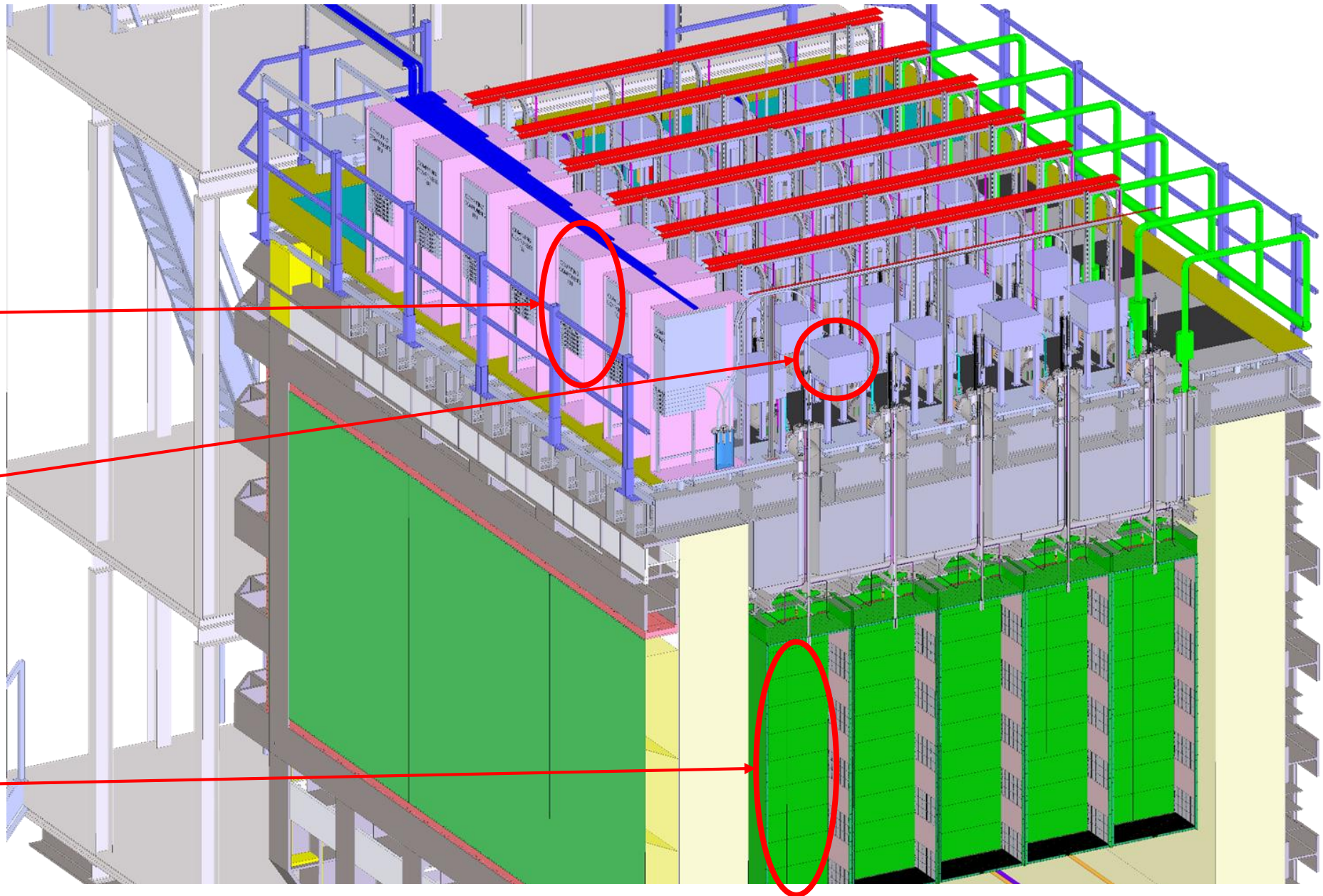
Data/Power Rack:

- WR switch
- 10G Switch
- HV power and splitter

LRO crate:

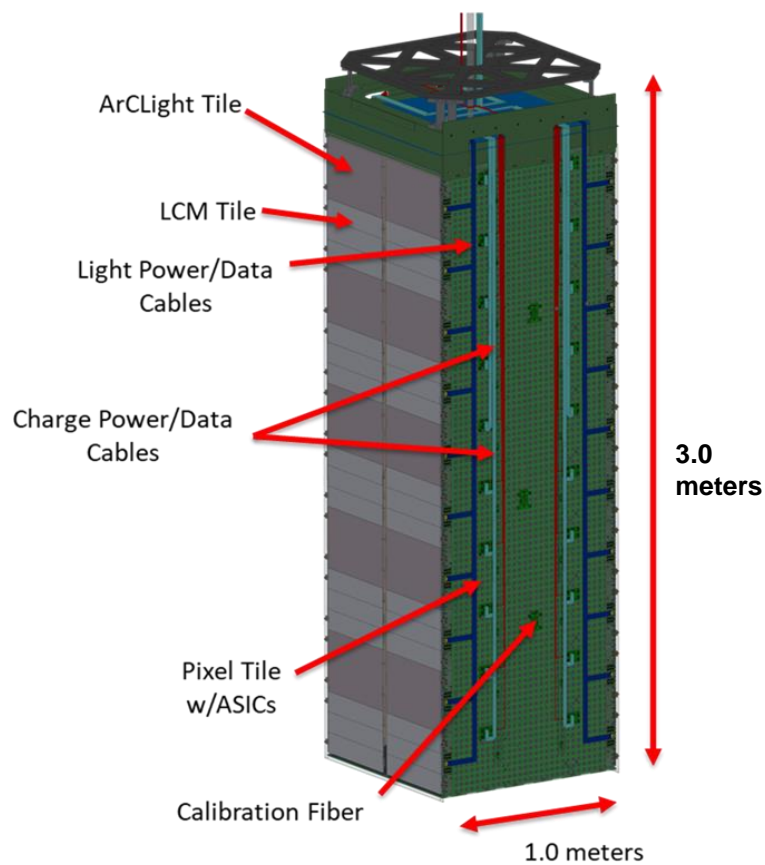
- 5 ADC
- 2 SiPM PS
- 4 VGA
- Controller
- Trigger unit

TPC module



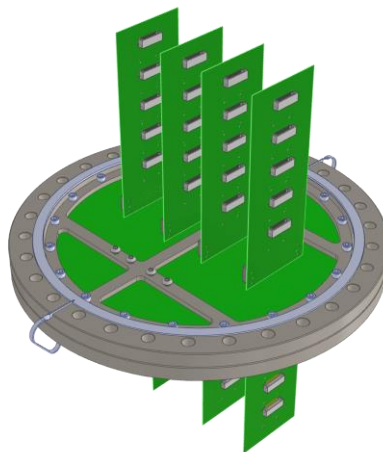
ND LArTPC Module Design

Integrated Module

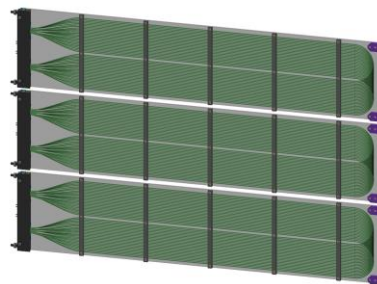


LCM group and ArCLight are fully interchangeable

Feedthrough



ArCLight

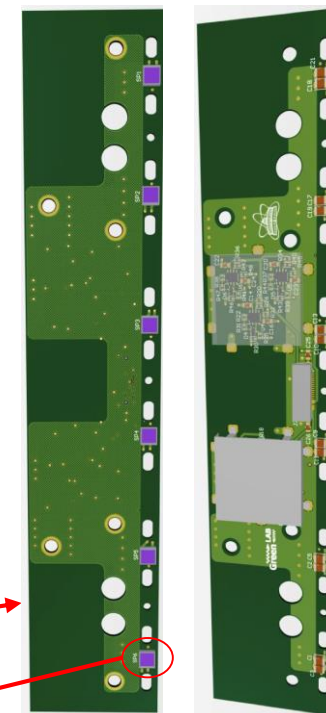


LCM group

To readout



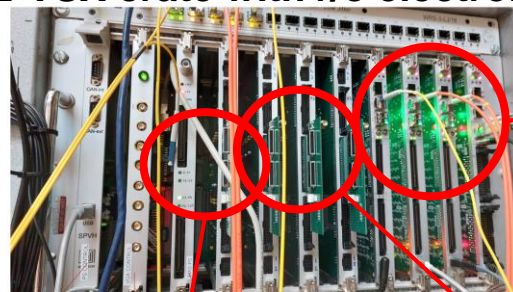
Cold-PCB



6x6 SiPM

Light R/O electronics

VME-VSX crate with r/o electronics



(Combined for FSD)
PS control VGA control PS bias (2 for FSD) 4 VGA (60 ch for FSD) 3 ADC (4 + 1 for FSD)

4+1 ADCs



Synchronization with other subsystems by means of absolute time given by GPS

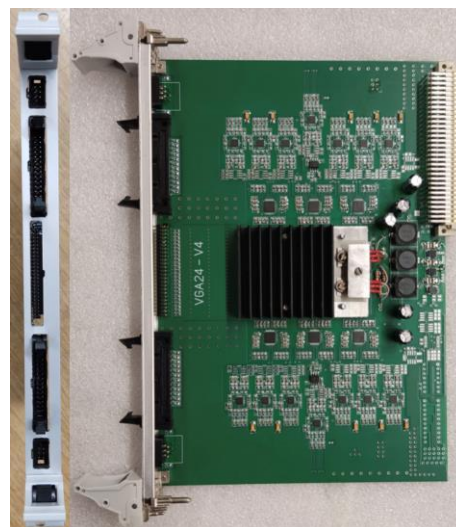
ADC-64 v.3.1



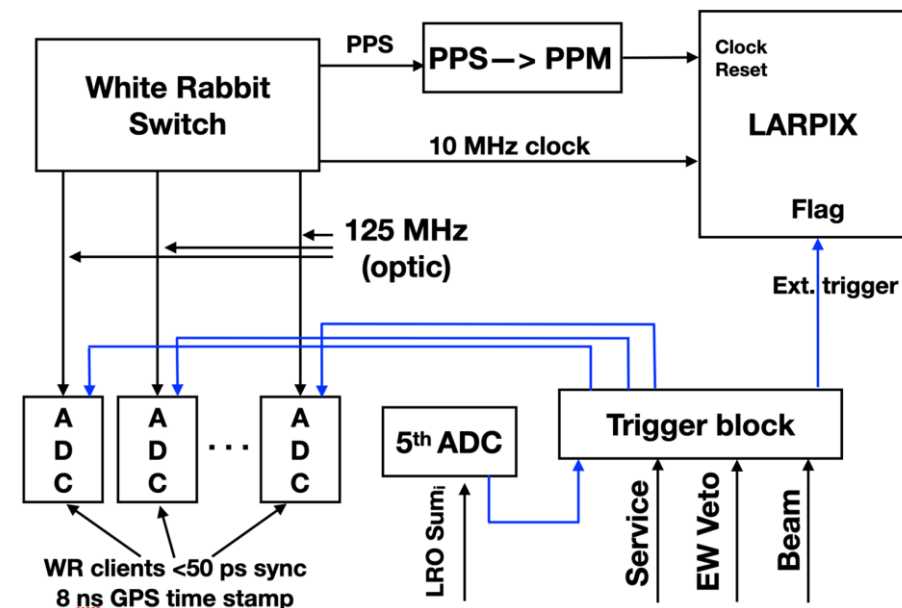
1 Trigger unit
VXS



2 x 128 ch SiPM Power supply and
1 CAN-VME controller (2 SiPM PS + 4 VGA)



4 x 60-ch VGA



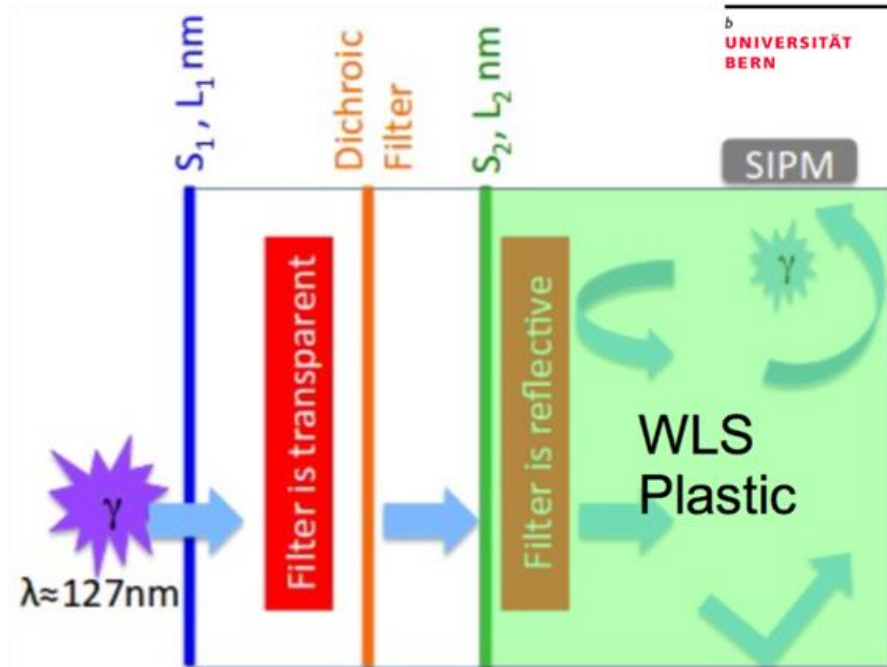
Readout logic

Light traps

ArCLight Concept

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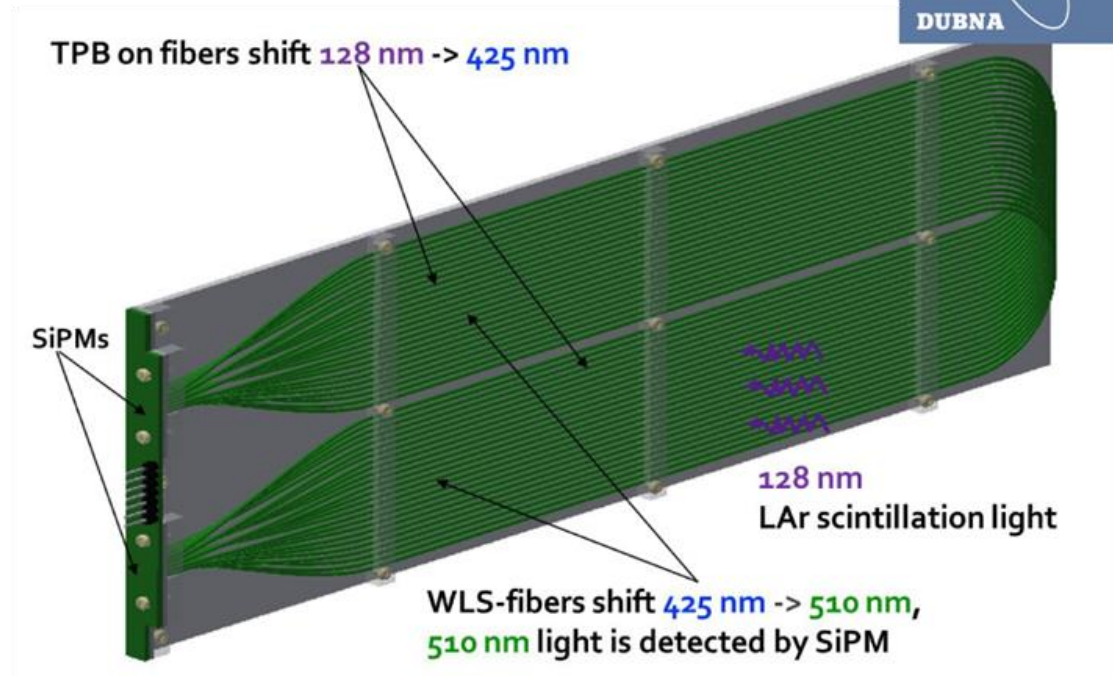
^b UNIVERSITÄT
BERN



- + Provides more rigid construction
- + Spatial resolution in depth.

- PDE ~ 0.2% (Currently)
- Heavier

LCM Concept



- + Easy to scale -> Fibers have long attenuation
- + Doesn't lose efficiency (PDE) with scaling up. PDE ~ 0.6%
- + Can be used as 1 DAQ channel

- Complex and flexible
- No spatial resolution in depth

131.ND.02.06 Light Readout: Scope

Detailed subsystem scope per WBS dictionary

Delineates deliverables, quantities, responsible institutions, and funding source during design, prototyping, production and installation phases

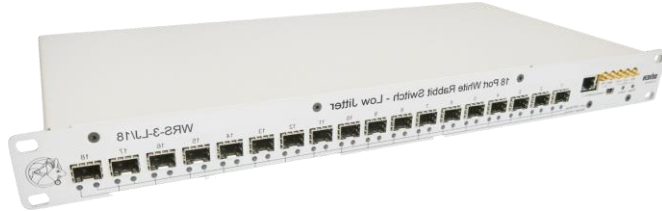
Informed by 2x2 module prototypes and ND-LAr CAD model

Aligned with BOEs and resource-loaded schedule

131.ND.02.06: Light Readout							
WBS Dictionary (Obsolete):							
Design and production of the light readout system for the ND LArTPC modules Includes: - LCM light traps - ArCLight light traps - SIPMs - SIPM circuit boards - Cabling and feedthroughs - SIPM biasing, readout, and control electronics and enclosures - Control and configuration software/firmware - Electronics power supplies - Clock distribution/synchronization system for the light readout - Component testing/QC/QA, and associated tooling - Prototypes for 2x2, Full-scale Demonstrator - Packaging and shipping - Support personnel for prototyping, A&T, and I&I, and their travel							
2x2 version							
Reference CAD image(s):							
Cold-PCB	Samtec cable	Feedthrough (2x2 prototype)	SIPM Biasing module/control	VGA unit	LCM Model (2x2 ver ~ 30 cm)	ADC	SIPM board (2x2 ver)
							
							
Task/Item	Qty	Spares	Institutions	Funding Source	Funding Status	Detailed description	
LCMs	2100	420	JINR	JINR budget	waiting for approval	Design, production, and assembly	If LCM/ArCLight = 50/50
ArCLights	700	140	Bern	Swiss	waiting for approval	Design, production, and assembly	If LCM/ArCLight = 50/50
SIPMs	8400	1680	JINR	JINR budget	waiting for approval	Specification and procurement	
Cold-PCBs	2800	560	JINR/Marathon	JINR budget	waiting for approval	Design, production, and assembly	
Light Readout Feedthroughs	70	14	JINR/Marathon	JINR budget	waiting for approval	Design, production, and assembly	2 per module
Microcoax Cables (diff lengths)	1400	280	JINR	JINR budget	waiting for approval	Design, production, and assembly	
SIPM PS (Biasing) modules	70	14	JINR/Marathon	JINR budget	waiting for approval	Design, production, and assembly	
SIPM PS & VGA control units	35	7	JINR/Marathon	JINR budget	waiting for approval	Design, production, and assembly	4 ADC per module + 1 Sum ADC
VGA unit	280	56	JINR/Marathon	JINR budget	waiting for approval	Design, production, and assembly	
ADCs (readout)	175	35	JINR/AFI	JINR budget	waiting for approval	Specification and procurement	
ADC sync and trigger units	35	7	JINR/AFI	JINR budget	waiting for approval	Specification and procurement	
WR switch	2	1	JINR	JINR budget	waiting for approval	Specification and procurement	
VXS crates	35	7	JINR	JINR budget	waiting for approval	Specification and procurement	
HV power units	35	7	JINR	JINR budget	waiting for approval	Specification and procurement	
Optical cables	245	49	JINR	JINR budget	waiting for approval	Specification and procurement	
LV power units	35	7	JINR	JINR budget	waiting for approval	Specification and procurement	
Power&Signal Adapter boards	280	56	JINR	JINR budget	waiting for approval	Design, production, and assembly	
LRO Slow control software	-	-	JINR	JINR budget	waiting for approval	Developing within DAQ consortium	
LRO DAQ software	-	-	JINR	JINR budget	waiting for approval	Developing within DAQ consortium	
GPS grandmaster (DOWR or similar)	1 port	1 port	Fermilab/?	DUNE-US Project	?	Support at Fermilab testing facilities	
LRO DAQ Networking 10Gbps			Fermilab/?	DUNE-US Project	?	Specification, procurement and installation	
DAQ computers, disks and tapes			Fermilab/?	DUNE-US Project	?	Specification, procurement and installation	
Support during ND A&T	-	-	JINR/Bern/Fermilab/NDLAr	JINR budget/ DUNE-US Project/ Swiss	waiting for approval	Technical/scientific support during TPC Module assembly and test program at the MATF, including travel.	
Support during ND I&I	-	-	JINR/Bern/Fermilab/NDLAr	JINR budget/ DUNE-US Project/ Swiss	waiting for approval	Technical/scientific support during TPC Module installation and integration at the DUNE Near Detector Site, including travel.	
QA/QC and characterization							
LCM Light Yield test			JINR/Marathon	JINR budget	waiting for approval	bench qualification test	
LCM coating			JINR/Marathon	JINR budget	waiting for approval	bench qualification test	
ArCLight LY test			Bern	Swiss	?	bench qualification test	
ArCLight coating			Bern	Swiss	?	bench qualification test	
LCM assembly: QA/QC			JINR/Marathon	JINR budget	waiting for approval	Mechanical+cryo tests after assembly. Sample test of coating	
ArCLight assembly: QA/QC			Bern	Swiss	?	Mechanical+cryo tests after assembly. Sample test of coating	
Microaxial cable assembly: QA/QC			JINR/Marathon	JINR budget	waiting for approval	bench-testing for contact/signal propagation	

131.ND.02.06 Light Readout: Scope

WR Switch



Adapter boards (integrated)



VME VXS



Example of HV source



2460 model



Trigger unit



Production phase deliverables

Task/Item	Qty	Spares	Institutions
LCMs	2100	420	JINR
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ADCs (readout)	175	35	JINR/AFI
ADC sync and trigger units	35	7	JINR/AFI
WR switch	2	1	JINR
VXS crates	35	7	JINR
HV power units	35	7	JINR
Optical cables	245	49	JINR
LV power units	35	7	JINR
Power&Signal Adapter boards	280	56	JINR

131.ND.02.06: Light Readout

WBS Dictionary (Obsolete):

Design and production of the light readout system for the ND LArTPC modules

Includes:

- LCM light traps
- ArCLight light traps
- SiPMs
- SiPM circuit boards
- Cabling and feedthroughs
- SiPM biasing, readout, and control electronics and enclosures
- Control and configuration software/firmware
- Electronics power supplies
- Clock distribution/synchronization system for the light readout
- Component testing/QC/QA, and associated tooling
- Prototypes for 2x2, Full-scale Demonstrator
- Packaging and shipping
- Support personnel for prototyping, A&T, and I&I, and their travel

Reference CAD image(s):

Cold-PCB



Samtec cable



Feedthrough (2x2 prototype)



SiPM Biasing module/control



VGA unit



LCM Model (2x2 ver ~ 30 cm)



ADC



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ArCLight LY test	-	-	Bern	Swiss	?	bench qualification test
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ArCLight assembly: QA/QC	-	-	Bern	Swiss	?	Mechanical+crysto tests after assembly. Sample test of coating
Microcoaxial cable assembly: QA/QC	-	-	JINR/Marathon	JINR budget	waiting for approval	bench-testing for contact/signal propagation

131.ND.02.06 Light Readout: Key Requirements

<https://edms.cern.ch/document/2589287>

Key	Type	Component	Name	Description	Value	Rationale
131.02.03.02.05: Light Readout						
LRO-001	Design Choice	ADCs	ADC Sampling rate	ADC sampling rate shall be > 50	62.5 MegaSamples/s (16 ns time stamp)	Since we have long LAr pulses reasonable sampling frequency is 50-200 MS/s
LRO-002	Specification	ADCs	ADC Synchronization	Synchronization of ADC modules shall be << 1 ns	< 1 ns	It is important to match signals from different ADC modules to provide fine time resolution and for Charge-Light data merging
LRO-003	Specification	ArCLight	ArCLight Light threshold	ArcLight Module shall be triggered when there is greater than ~ 7500 LAr photons	~ 7500 LAr photons	See LRO-038. If energy dissipation in the center then ~7500 photons incident 15 dm^2
LRO-006	Specification	LCM	LCM Light threshold	3LCM Modules shall be triggered when there is greater than ~ 7500 LAr photons	~ 7500 LAr photons	See LRO-038. If energy dissipation in the center then ~7500 photons incident 15 dm^2
LRO-007	Specification	LRO	Time Stamp	Time stamp resolution shall be < 10 ns		Provides absolute time stamp when running ADC
LRO-008	Specification	LRO	Pileups time resolution	LRO shall be able to resolve 2 signals separated by > 200ns		This specification, in combination with LRO-12, should provide the required efficiency and accuracy in charge-light signal matching.
LRO-009	Specification	LRO	time resolution of the LRO	The time resolution of the photon detection system to resolve neutrino interaction time shall be < 10ns	< 10 ns	This specification, in combination with LRO-12, should provide the required efficiency and accuracy in charge-light signal matching.
LRO-010	Specification	LRO	Photon detection efficiency	The photon detection efficiency shall satisfy to LRO-006, LRO-004, LRO-007.	>0.6% (0.4 - 0.5)% is enough with achieved noise level	This specification, in combination with LRO-12, should provide the required efficiency and accuracy in charge-light signal matching. Higher PDE ~2% allows to detect signals ~1 MeV.
LRO-012	Specification	LRO	Spatial Resolution/ fast timing within a module	Horiz/Vert spatial resolution shall be ~10 cm	~10 cm	This specification, in combination with LRO-12, should provide the required efficiency and accuracy in charge-light signal matching.

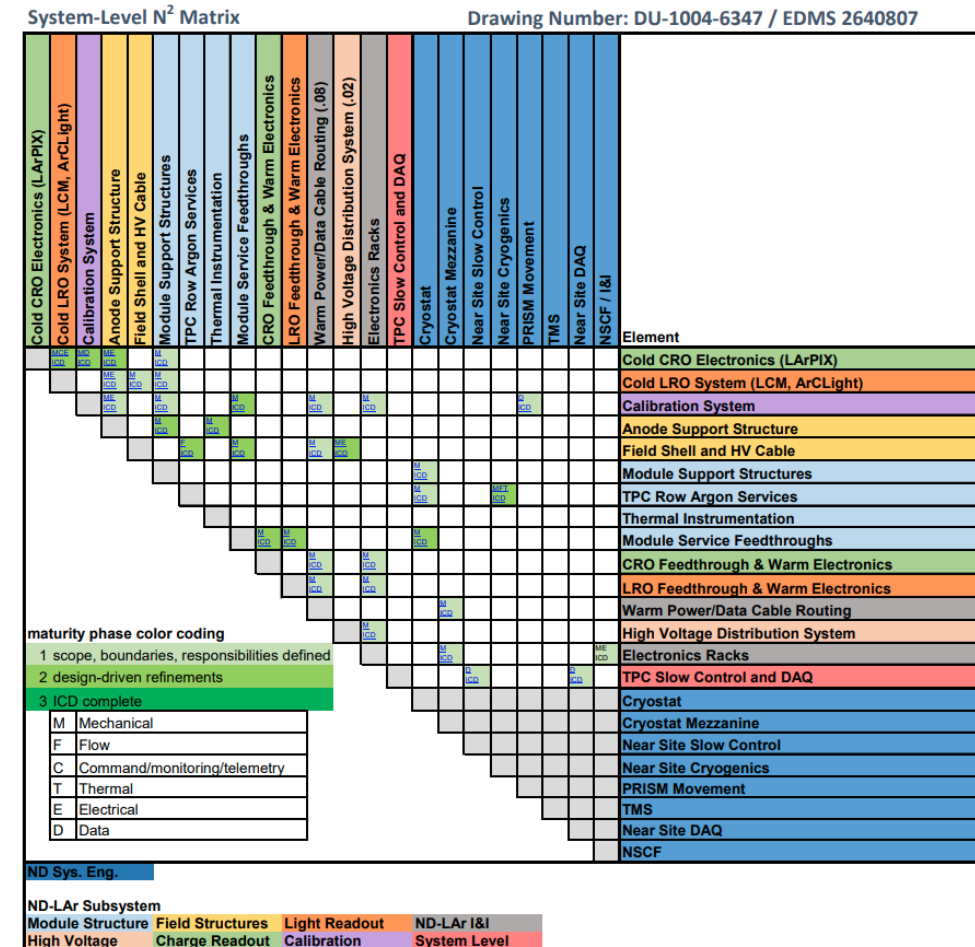
Vast majority of requirements is validated by 2x2 programm

Interfaces

- Engineering CAD model captures interfaces, <https://edms.cern.ch/project/CERN-0000226247>
- Interfaces realized and validated in 2x2 program

Subsystem	Interface	Maturity
Cold-PCB support structure	Mechanical	Defined
Cold-PCB support structure	Cabling	Defined
Calibration system	Mechanical	Partially defined
Dewar structure	Cabling, Feedthrough	Defined
Charge Readout	Trigger	Defined
DAQ	Data IO & control	Partially Defined
Timing	Fiber & WR	Defined
Facilities	Rack AC	Defined
Cryostat structure	Cables & VME Crates	Defined

Defined = meets preliminary design maturity



131.ND.02.06 Light Readout: QAQC, Procurement, Manufacturing

Procurement:

Fiber - Kuraray, WLS Ej-280 Scionix, DH-mirror - ORL Coatings, TPB - Sigma Aldrich;

Electronic components, WR, VME, HV&LV power - commercial.

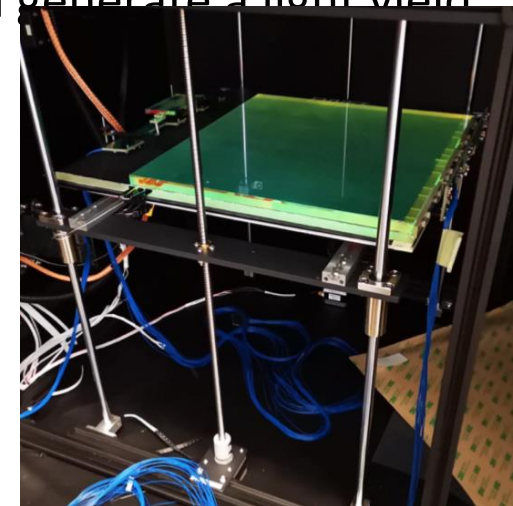
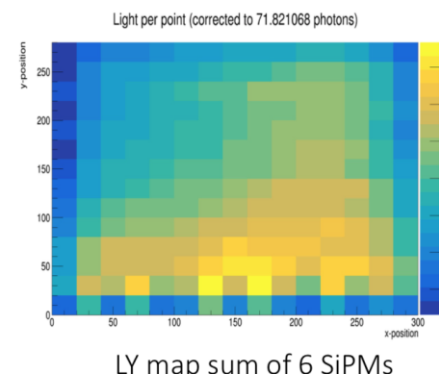
Manufacturing:

All the electronics and LCM assembly will be done by Marathon LTD, ADC-64 - AFI company. ArCLights - UniBe (outsource).

QC is developed by JINR and will be done by the companies.

QA at JINR and UniBe.

After production, all light traps are tested with a UV LED (270 nm), installed at the injection head of a 3D printer setup, to scan the surface and generate a light yield response map.



Link to material in EDMS

<https://edms.cern.ch/document/2587876/1>

<https://edms.cern.ch/document/2605604/1>

<https://edms.cern.ch/document/2605605/1>



Control of TPB layer crystalline structure with optical microscope

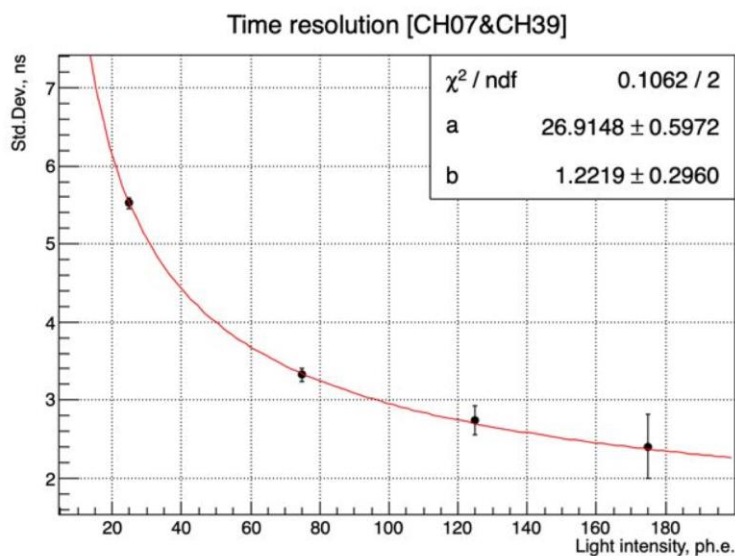


AFI Electronics

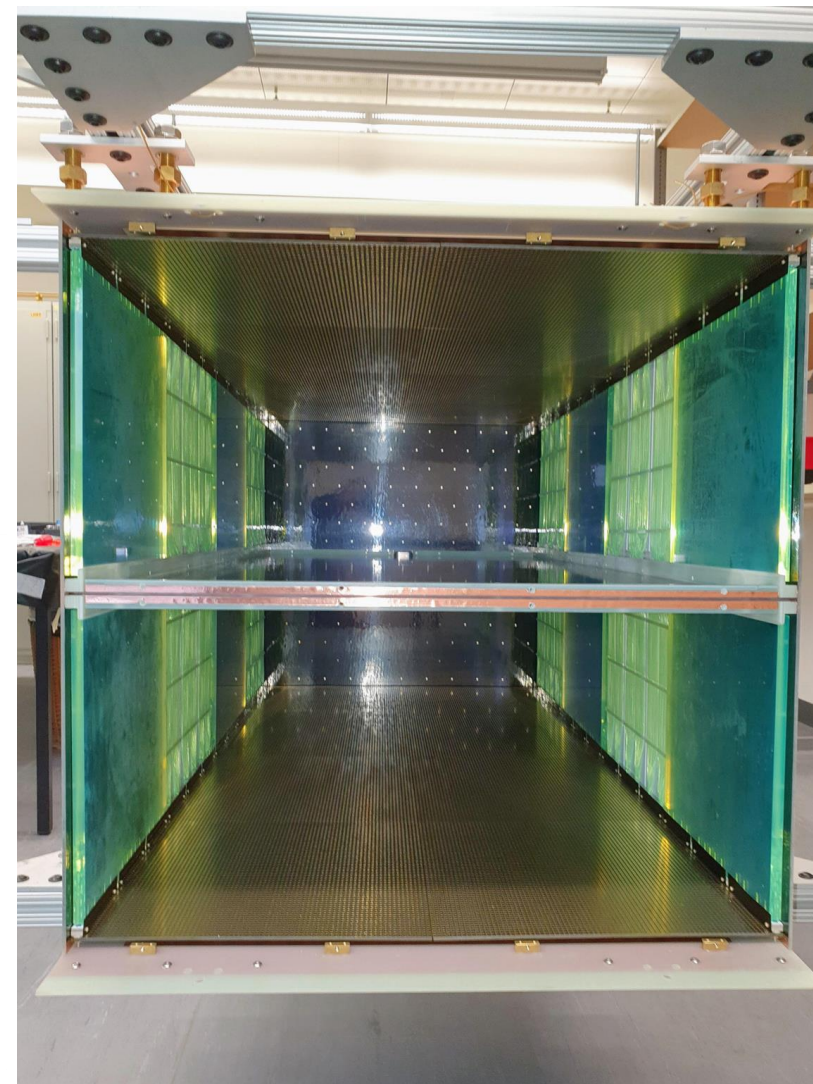
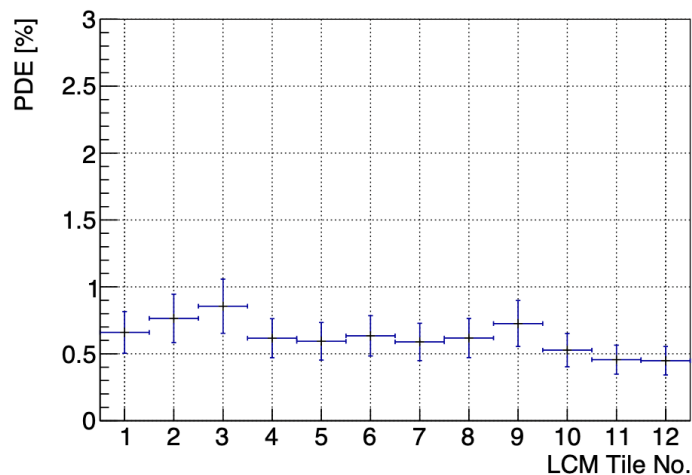
131.ND.02.06 Light Readout: Prototyping

2x2 program substantially advanced technical maturity of light readout system

- Light readout design is mostly mature, no gaps in scope
- Design efficacy evaluated with prototype data
- ~50 LCMs and ~25 ACL tested



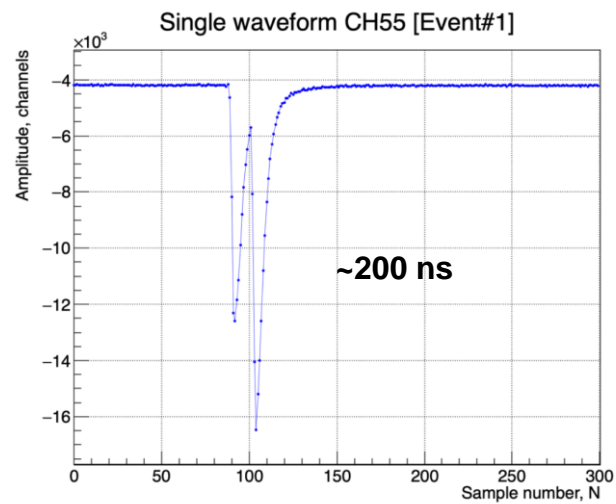
LCM PDE~0.62%



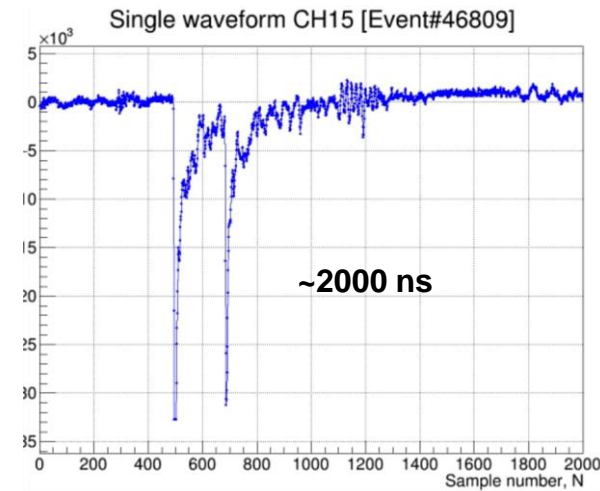
TPC assembly

131.ND.02.06 Light Readout: Prototyping

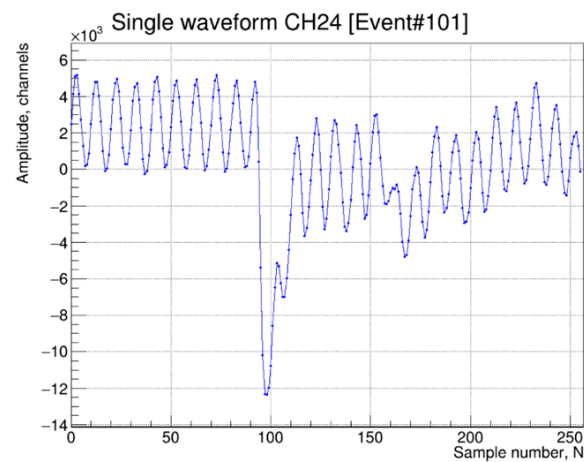
LED double pulses



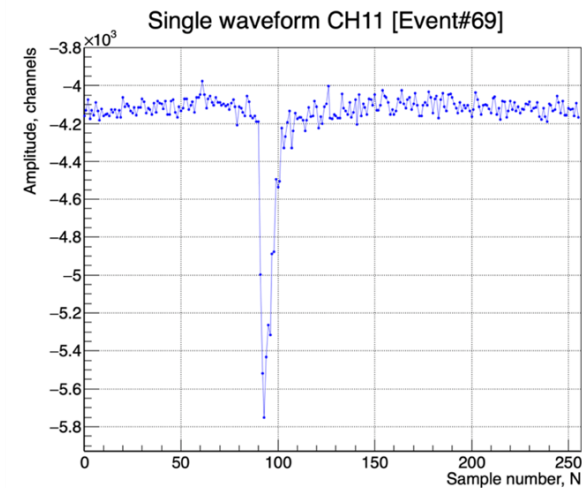
Michel electron



Noise pick-up Mod0

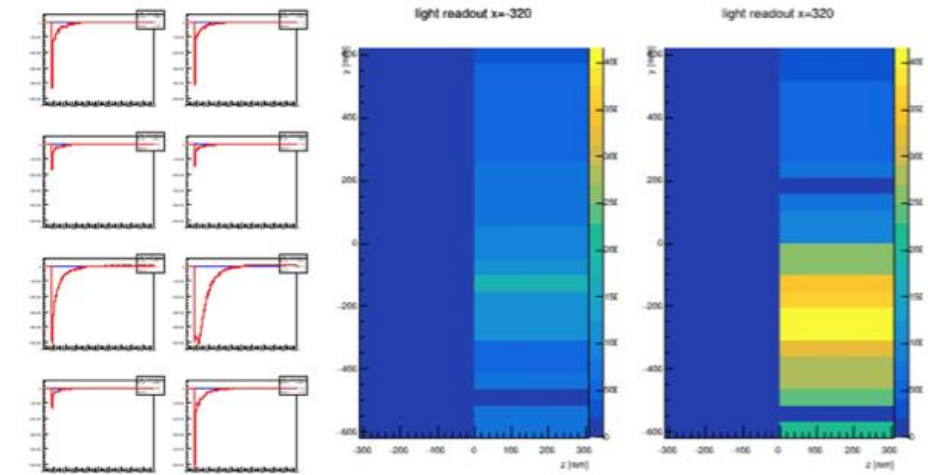
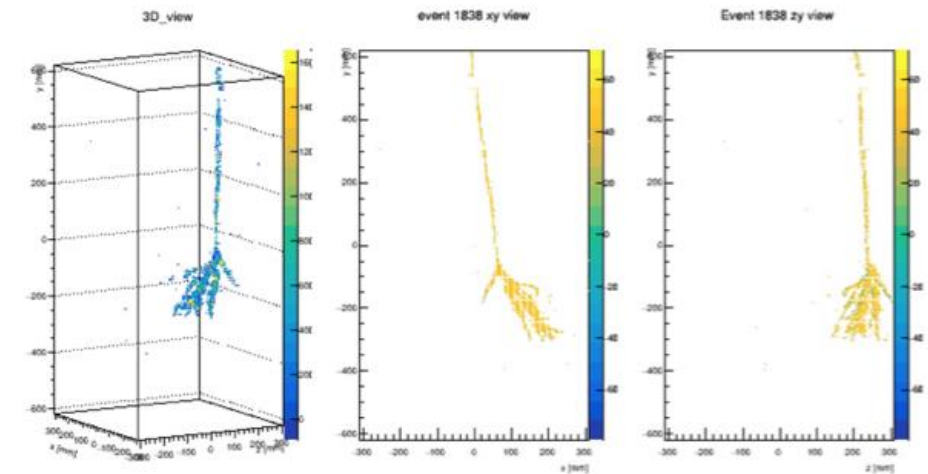


Screening in Mod1



• Feb 2022

How LRO sees events



131.ND.02.06 Light Readout: Risks

Risks actively tracked through Consortium risk registry. Most impactful risks highlighted here. Some are outdated and been mitigated

Title	Summary	Mitigation	Probability	Schedule Impact [Months]	Cost Impact [\$k]
Silicon crisis.	Chip market is unpredicted. This may cause higher prices and long delivery dates	Accommodate funds and place orders in advance.	80%	6-12-18	500-1000
Restrictions of JINR fellows presence onsite	There are FNAL site access issues which restrict arrival of Russian citizens to DOE national laboratories	New Quota request to DOE for 6 JINR fellows from Fermilab officials.	50%	3-4-8	200-300-600
Photon detection efficiency - Arclight	IF ARCLIGHT photon detection efficiency (PDE) does not meet specification that is TBR, THEN we need to use LCM only	ArcLight significantly improved technology. SiPM replacement to higher PDE. Use together with LCM already meet requirement.	20%	0-3-6	700
Spatial Resolution - LCM	IF LCM spatial resolution does not meet specification which is TBD, THEN we may need to use ARCLight modules (both)	Accounting mutual performance with ArClight average spatial resolution may satisfy requirements	20%	0-3-6	700
Light readout components incompatible with LAr or may pollute it	IF some materials proves incompatible with liquid argon, THEN a new replacement will need to be selected, which could increase material cost	Early prototyping and validation of the technology in 2x2 module and FNAL cryogenic test stand	10%	3-12-18	200-750

131.ND.02.06 Light Readout: Recommendation from previous reviews

Recommendation	Status	Response
Access for international collaborators at FNAL/SLAC need to be resolved.	In progress	Invitations to FNAL are ready. Alexander has the visa. Nikolay is in progress for visa. The current situation is uncertain
Need to justify decision to pursue 2 module designs : Need clear explanation of benefits of spatial resolution of ArcLight. Will this benefit continue to exist if only half the modules are ArcLight modules? Need to explain why the lower PDE reported for ArcLight will not damage ND-LAr performance	In progress	ArcLight has a degree of freedom in development to reach the required PDE. Accounting mutual performance with LCM average PDE satisfies requirements Accounting mutual performance with ArcLight average spatial resolution may satisfy requirements (need more analysis)
A QA/QC plan for each of the items in the BOM	Mostly Closed	Addressed in this review. There are some minor uncertainties
A Bill of Materials (BOM) listing all the parts of each of the designs, with links to 3d models and	Mostly Closed	Addressed in this review. There are minor changes in VGA.
A broad schedule for the project, including start and end dates for fabrication, with reasonable milestones set ahead of key decision points/reviews	In progress	There are some uncertainties in procurement and shipment
Labor estimates for fabrication and installation, and a summary of personnel required.	In progress	Labor estimates for installation are not fully accounted.
Suggest you prepare a guide document for directing reviewers to required documents in EDMS.	Closed	This review
An installation plan, including test plans during installation	In progress	Coordination with FNAL is on-going
A document summarizing the two designs, particularly discussing the strengths and weaknesses of each design	In progress	Need more analysis on justification of spatial resolution

131.ND.02.06 Light Readout: Cost

From Mar. 2022 cost review

	Design & Prototyping				Production					
	On-Project		Off-Project		On-Project		Off-Project		On-Project	
	M&S [CY-k\$]	Labor [k-hrs]	M&S [CY-k\$]	Labor [k-hrs]	M&S [CY-k\$]	Labor [k-hrs]	M&S [CY-k\$]	Labor [k-hrs]	Total Cost [FBAY-k\$]	Avg. Uncert.
131.ND.02: ND-LAr										
01 ND LArTPC Management	\$401.5	18.3	-	43.9	\$412.5	13.8	-	72.5	\$10,114.9	10%
02 Module Structure	-	-	-	14.3	-	-	\$2,448.0	22.0	-	-
03 HV	-	-	-	10.5	-	-	\$816.0	14.0	-	-
04 Field Structure	\$159.1	9.4	-	0.6	\$3,560.1	4.9	-	6.5	\$7,642.6	60%
05 Charge Readout	\$1,331.3	17.7	-	16.6	\$3,366.0	5.5	-	20.8	\$10,741.6	35%
06 Light Readout	-	-	-	71.1	-	-	\$5,508.0	15.1	-	-
07 Calibration	\$193.7	1.3	-	33.1	-	-	-	20.3	\$414.0	50%
08 TPC Module Assembly and Testing	\$368.1	7.1	-	8.6	\$103.0	5.7	-	32.0	\$1,865.1	41%
09 TPC Integration and Installation	\$584.2	11.4	-	12.4	\$426.0	9.6	-	15.0	\$5,384.2	50%
10 Module Assembly & Test Facility	-	5.7	-	-	\$1,483.0	10.8	-	27.3	\$4,114.0	60%
11 Full-scale Demonstrator Test Facility	\$1,497.5	9.1	-	6.3					\$3,726.2	60%
12 ArgonCube Test Facility	-	-	\$1,250.0	20.9					-	-
13 2x2 NUMI Test Beam Facility	-	-	\$2,300.0	15.0					-	-
Total:	\$4,535.3	79.9	\$3,550.0	253.2	\$9,350.6	50.5	\$8,772.0	245.5	\$44,002.5	43%

Notes:

1. Extracted EAC from working resource-loaded schedule for internal cost review (P6/Cobra ND-LAr Sandbox, 22 Mar. 2022)
2. Includes all on-project and majority of off-project resource estimates for ND-LAr Consortium.
3. Off-project resources include both international and domestic investments
4. CY-k\$: Costs in current-year direct kilo-dollars. FBAY-k\$: Costs in fully-burdened at-year (escalated) kilo-dollars.

Detailed information is in procurement plan

<https://edms.cern.ch/document/2605605/1>



Design path to FDR

- Light traps longevity (fibers confirmed by Gerda)
- Replacement of Microcoax cables by long flex-PCB
- Expensivity of VXS standard (VME?)
- Cosmic trigger/data suppression
- PDE spread of LCMs
- PDE of long LCMs

Elaboration on technical details in next talk by Alexander Selyunin

Summary

- The ND-LAr light readout system plays important role in delivering DUNE ν oscillation physics
- Validation and maturity of light readout design exercised through 2x2 program
 - Scope is well-defined. Minor changes to FSD: LCM dimensions, VGA, common crate
 - Intra-system and inter-system interfaces are well-understood
 - System requirements evaluated with prototype data and simulation
 - Exercised parts production, QA, and QC with already constructed/operated Module-0, Module-1
- 2x2 program has critically informed labor profiles and schedule projection
- **Demonstrated design maturity at the preliminary design level, 80% ready for FSD & final design phase**