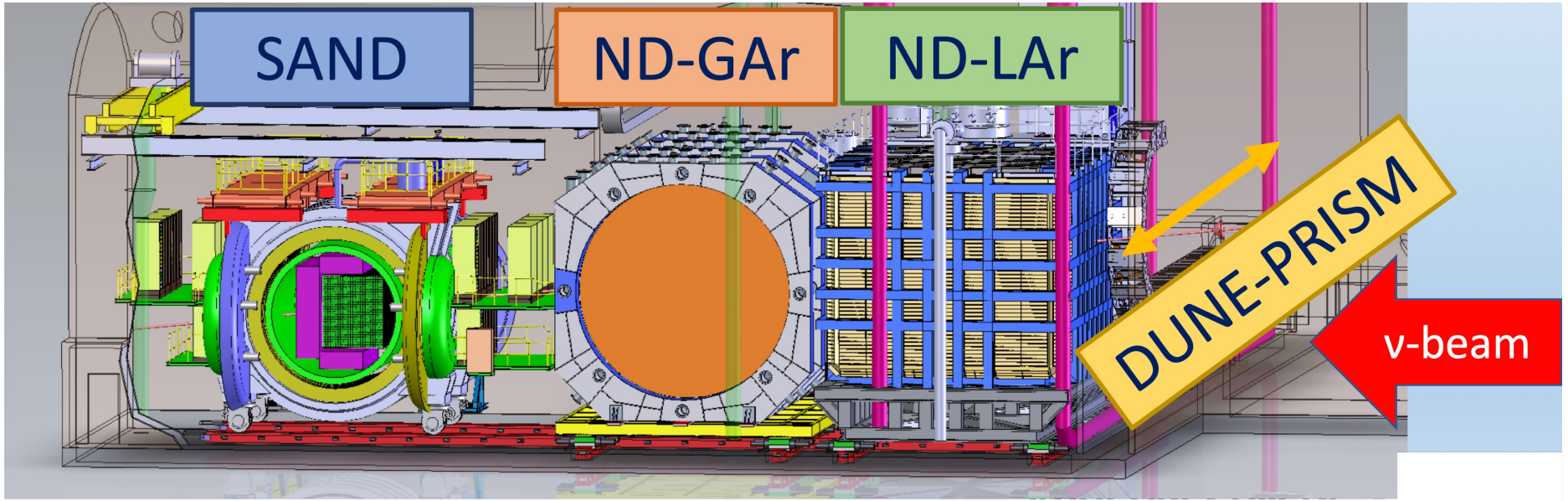
Light Detection System for the DUNE Near Detector

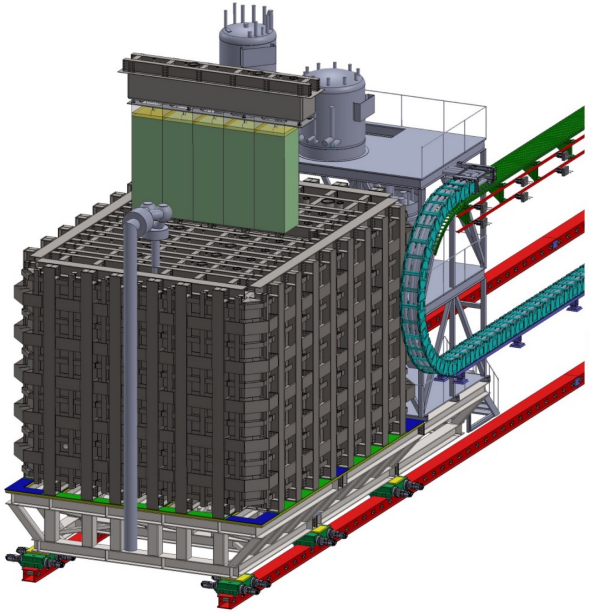
Alexandr Selyunin, Technology & Instrumentation in Particle Physics (TIPP2023)

DUNE Near Detector



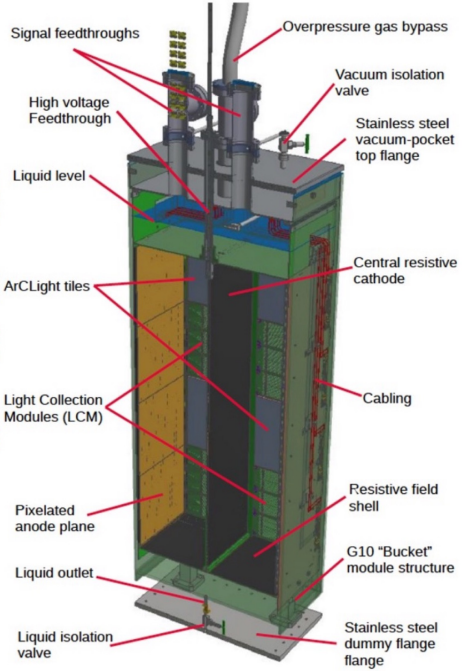
by DUNE collaboration

DUNE ND-LAr TPCs



5 x 7 = 35 TPC modules

by DUNE collaboration



ND module size – 1m x1m x 3m

Light detectors are along the electric field

Key Design Features:

Active size:

5m deep, 7m wide, 3m tall

→ For ν signal containment

Signal rate: ~10 M / yr

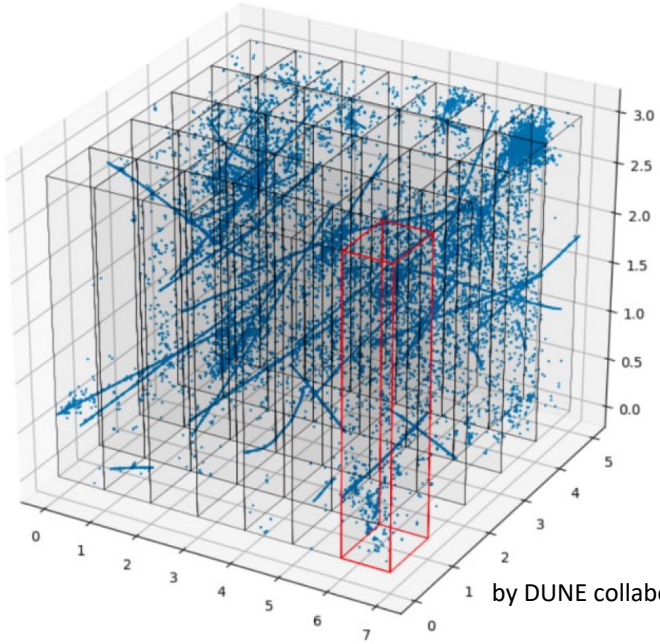
Modular design:

- 5 x 7 hermetic TPC modules
- 3m active height
- Minimal inactive material
- Material density (G10) similar to LAr
- Short drift (50 cm)
- Pixelated charge readout
- Optical segmentation
- High-performance light detection

→ *System reliability and capability to operate in high-rate environment*

Intention of the Light Detection System

- Provide t0-trigger for track correction
- Resolve pile-ups and associate tracks in time
- Assign detached energy events (~ns)



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An event display of the visible energy for a typical spill from the 1.2 MW beam spill coming from the LBNF neutrino beam. The large number of crossing muons and multiple neutrino interactions can be seen along with the segmentation offered by the modular structure of the ND-LAr system

ND LArTPC Module Design

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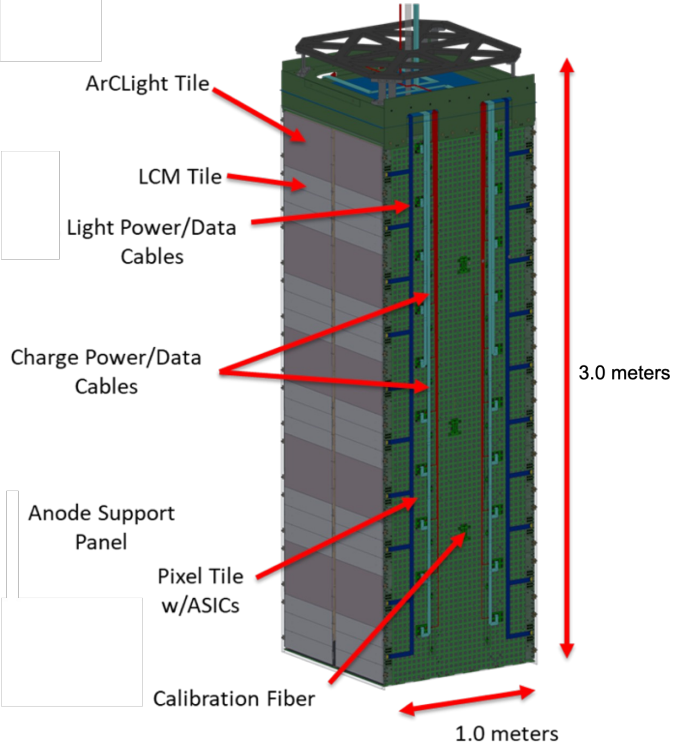
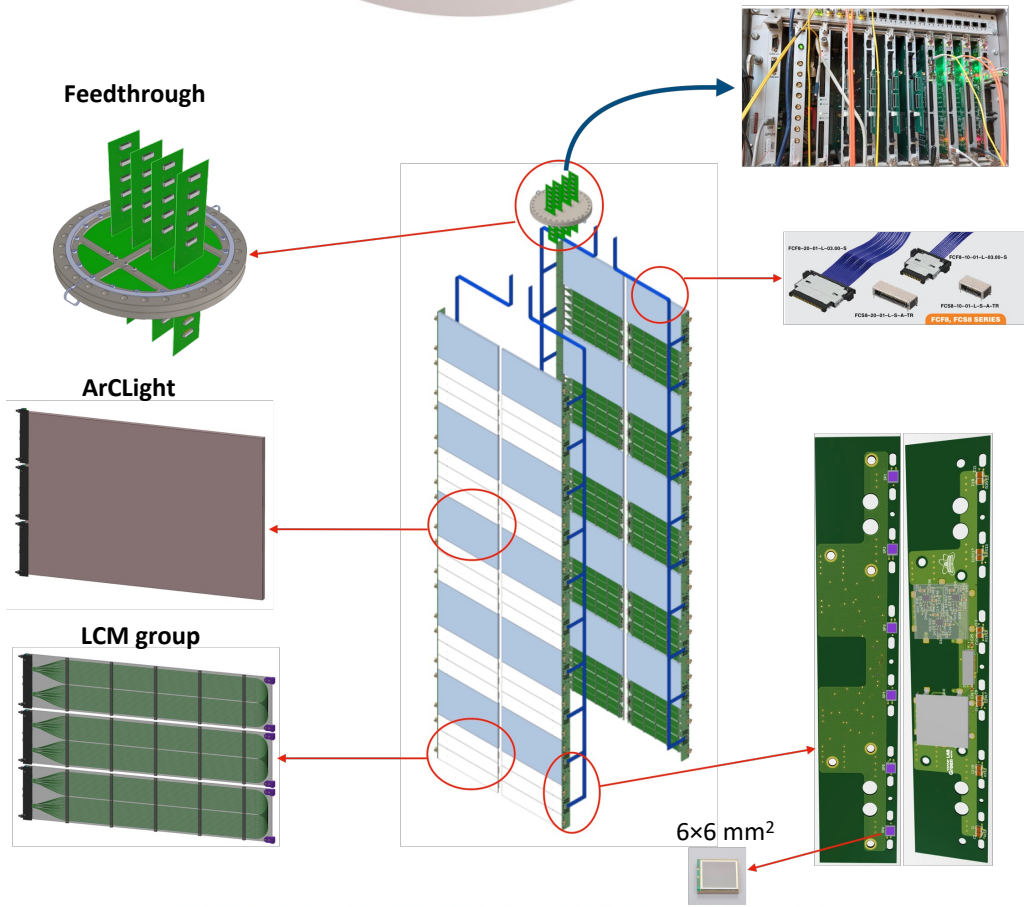
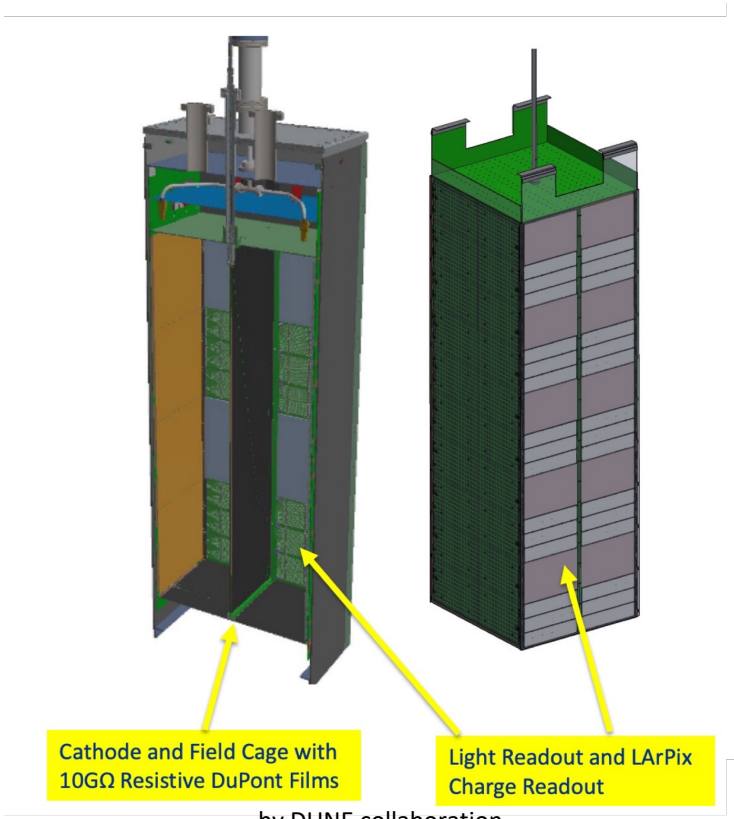




LCM group and ArCLight are fully interchangeable

2x2 Modules: 0.75m × 0.75m × 1.6m



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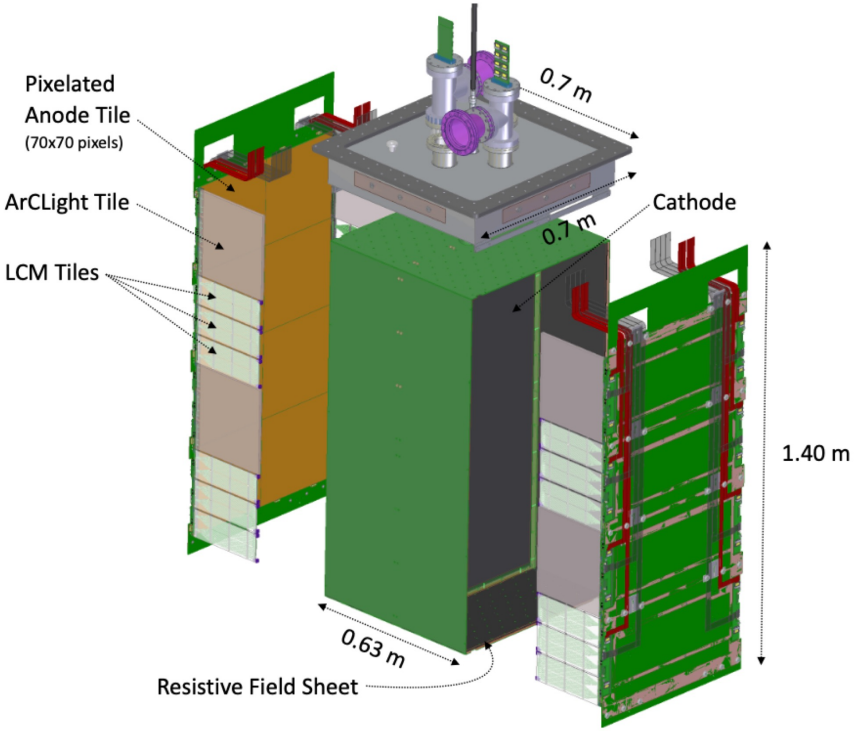


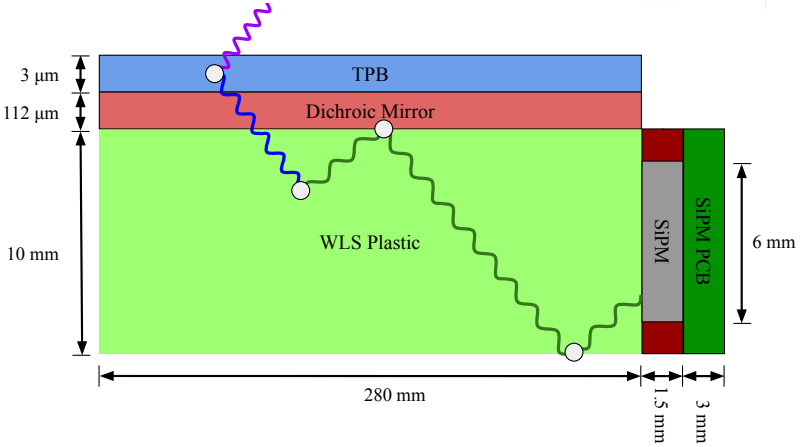
by DUNE collaboration

https://argoncube.org

Light Detectors

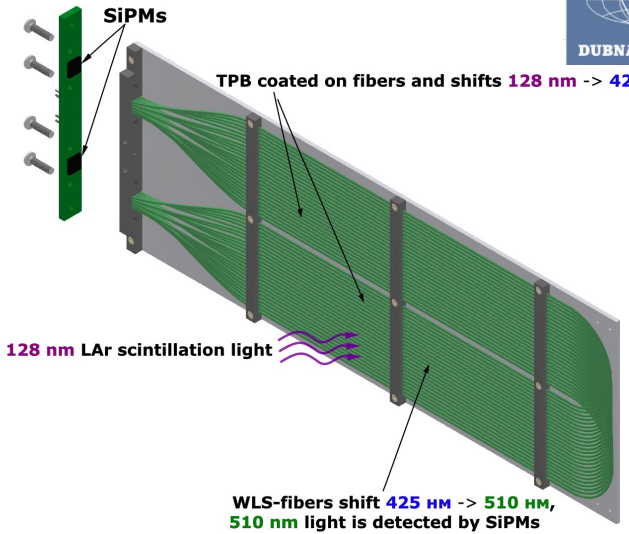
Design drivers:
- Dielectric materials
- Large surface covering
- Relatively high PDE

Both approaches are based on shifting UV light (128 nm) into visible (425 nm) by TPB



+ Provides more rigid construction
+ Spatial resolution in depth

- PDE ~ 0.2% (Currently)
- Heavier



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

- Complex and flexible
- No spatial resolution in depth

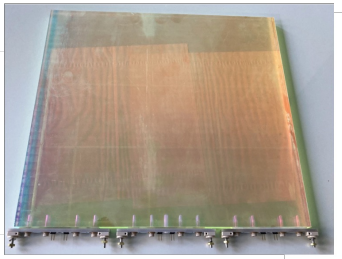
Light Detectors

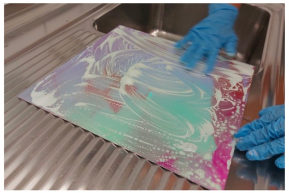
Dzhelepov Laboratory of Nuclear Problems

Joint Institute for Nuclear Research

UNIVERSITÄT BERN

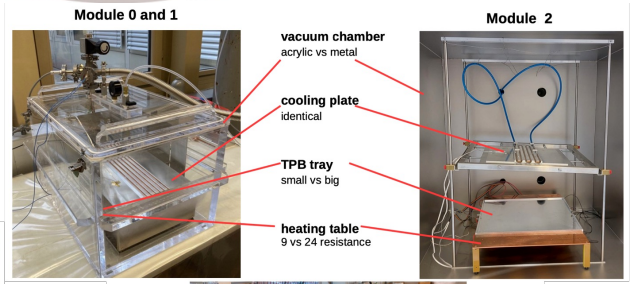
ArCLight





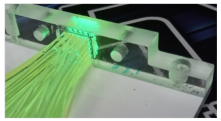
The film is cleaned with soap

The dichroic film is fixed on an aluminum plate

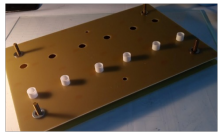


Coated film is removed from aluminum plate

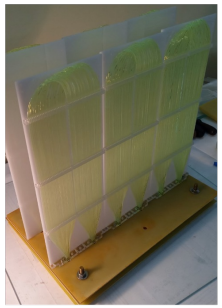
LCM

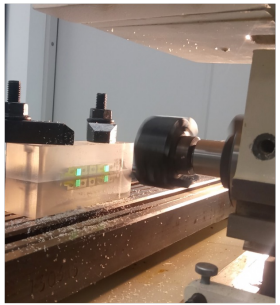


1x1mm groove for glue

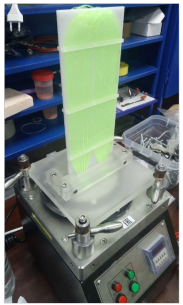


PTFE containers for bundle's fibers (capillary effect)

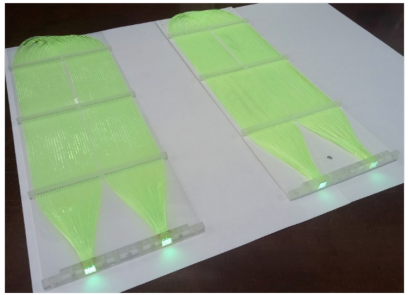




To process with MCD diamond tool

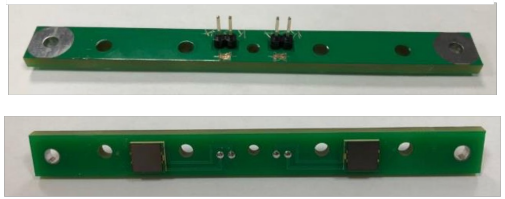


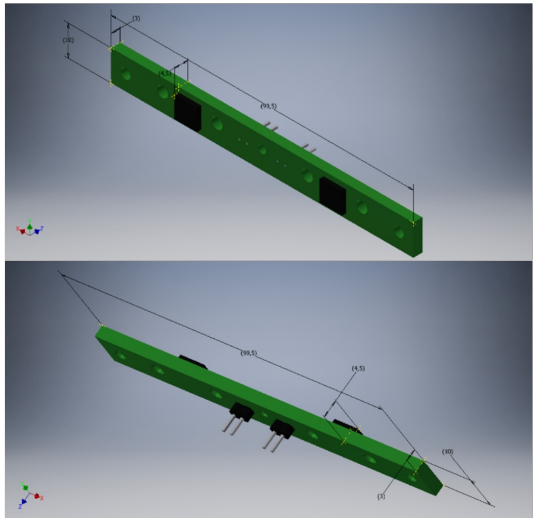
Apply polishing machine for fabric optical connectors



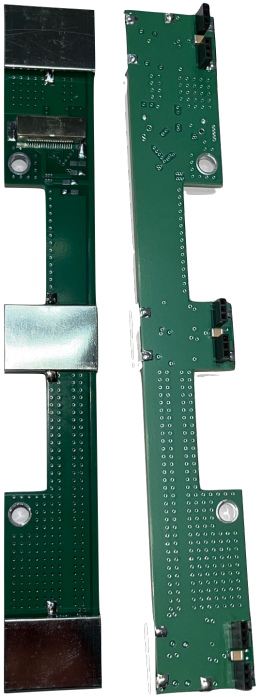
Cold Electronics

- PCB with SiPMs is attached to the LCM
- PCB connected to E-pcb board with embedded pre-amps by means of pins





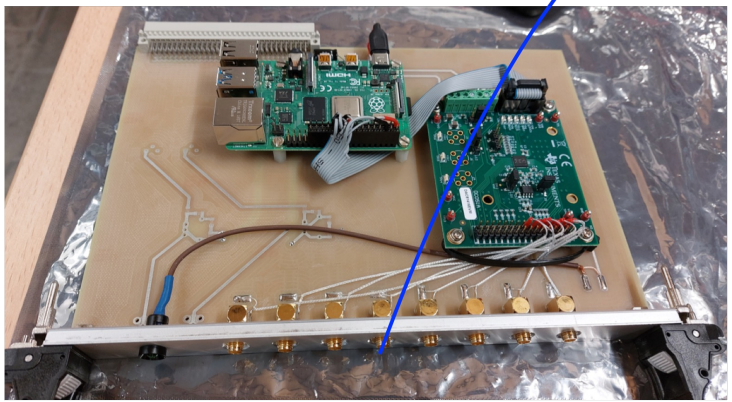
- E-PCB carrying 6 preamps
- Cold preamps (LMH6624) Gain ~ 5
- Power ~ 30-40~mW each @ BW of ~ 30MHZ (~10 ns rise time).
- Interface to 3 SiPM boards (3 LCMs or 1 ArCLight)
- Metal screens use to cancel clock pick up from Charge readout.
- Samtec connectors
- Left and right boards



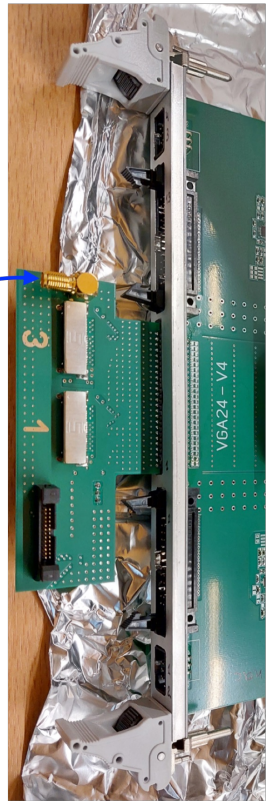
Samtec microcoax cable

Front-End Electronics

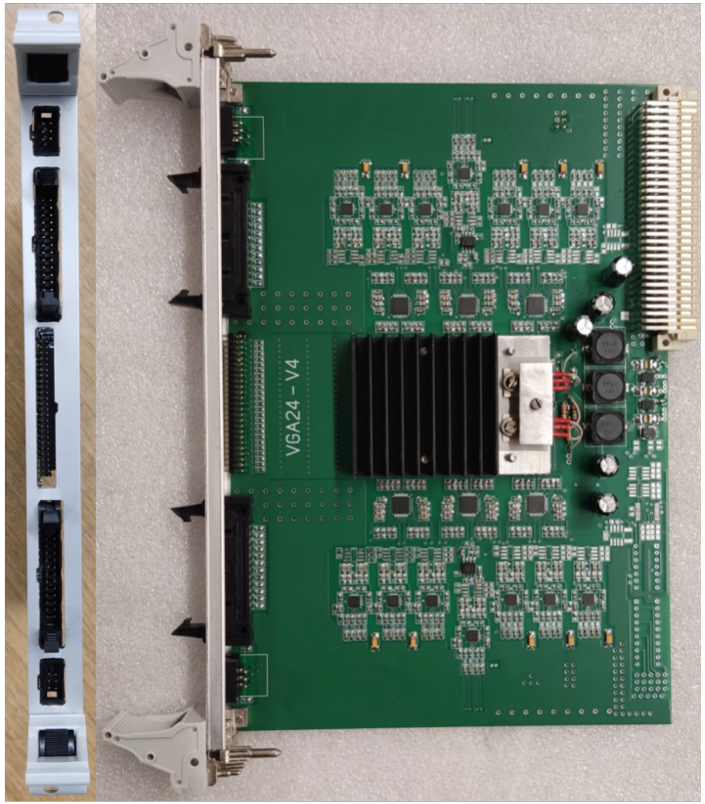
- Variable gain from 0 to 26 dB
- 2x2 Version - 24 channels / module. Drivers to long signal line
- **FSD Version - 60 channels/module. No long lines**
- Adapter board: Interface Microcoax cables to VGA and SiPM PS and Preamps power
- 2x2 Version - Controlled by means of external analogue signal (VGA control unit DAC+RPi)
- **FSD Version - Controlled via CAN-open (DAC onboard)**



VGA Control Unit (2x2)



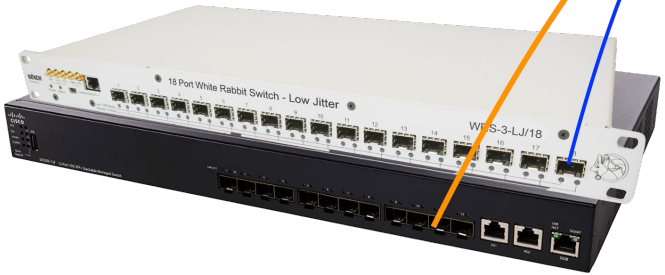
Adapter Board (2x2)



Variable Gain Amplifier Module (2x2 Version)

ADC

- **14-bit @ 62.5 MS/s (16 ns) - Buffer of 2 kSamples = 32 μsec, full range ± 1V**
- Analog inputs on **2x32 channel Diff-pairs connectors**
- Self-triggering mode by a digital threshold
- **64 channels**, 1-unit wide 6U VME64 module, standalone
- **VME64 VXS**
- **Optical link 10 Gbps**
- ADC stream UDP/TCP data packets via M-link MStream ADCs
- **White Rabbit protocol with 8 ns timestamp, <100 ps clock sync**
- Spill = 10 μsec, Light pulse ~ few μsec, ADC window ~ 32 μsec



WR

Data

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

SiPM Power Supply

Main Features:

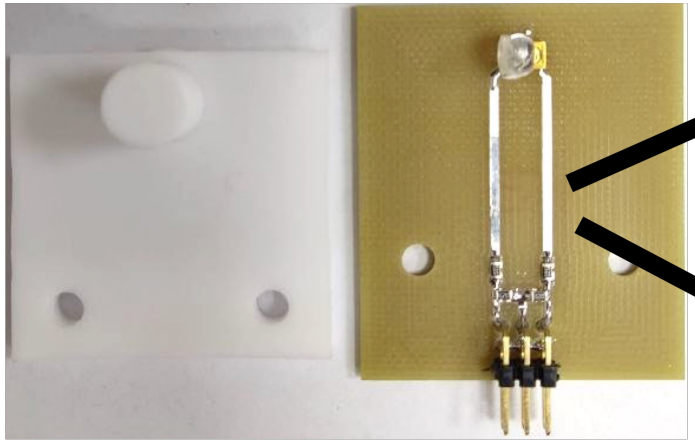
- VME mechanics
- Based on AD5535B chip, 128 ch
- Voltage up to 200 V, 14-bit
- Max current 500 μA/ch
- CAN-open protocol

Design by Marathon Company (MSU)

JINR is the License owner

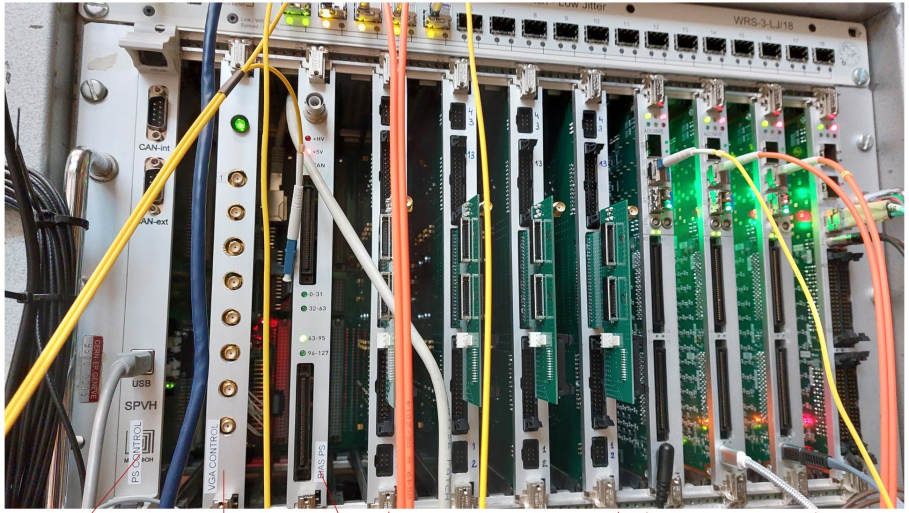
Calibration System

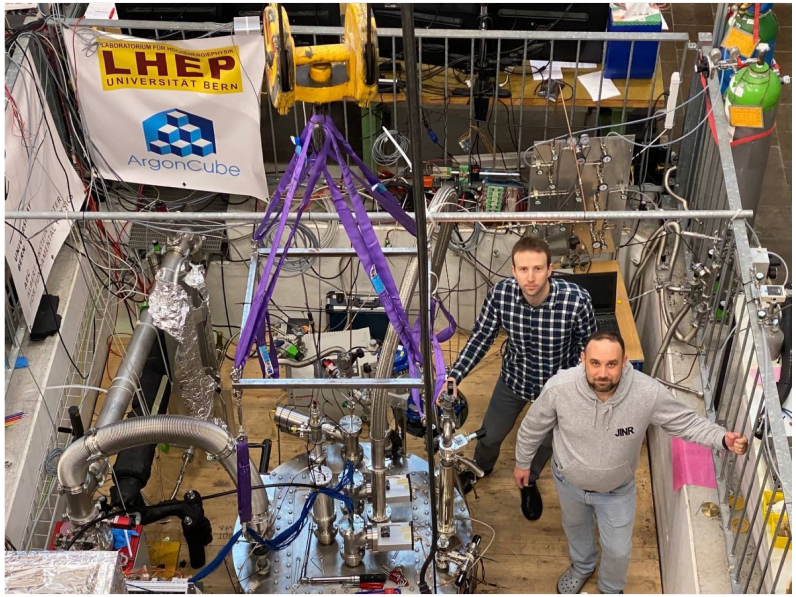
- **LED unit on board: λ = 425 nm**
- **PTFE Diffuser unifies the light field**
- **4 Calibration units per TPC: TOP & BOTTOM // LEFT & RIGHT**
- **50Ω impedance matched**



Supported by RSF Russian Science Foundation under grant #22-22-00389

TPC prototype testing at Bern

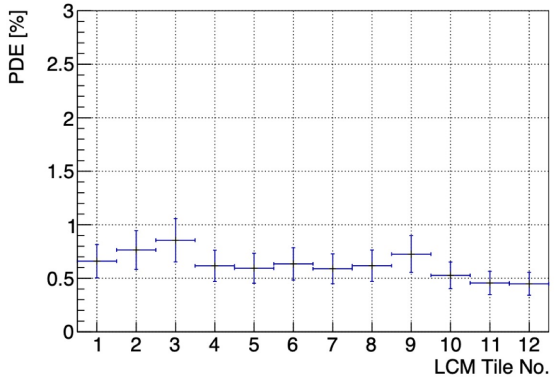




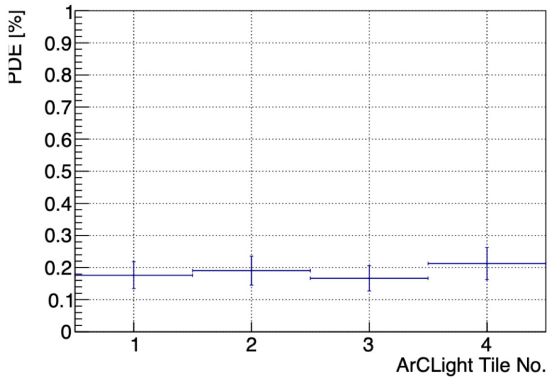
Light System Performance

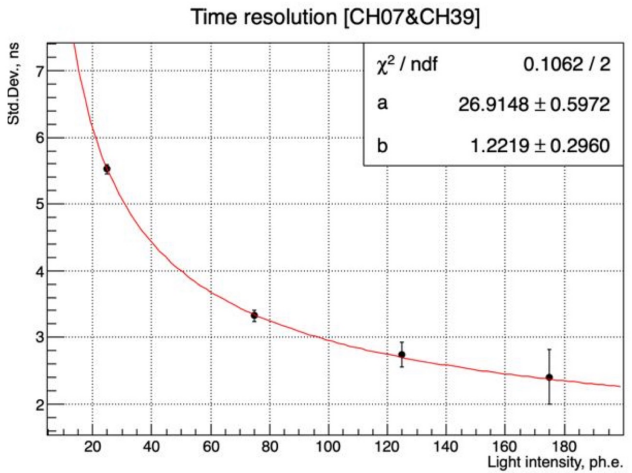
PDE studies by Bern

LCM PDE~0.62%



ACL PDE~0.2%

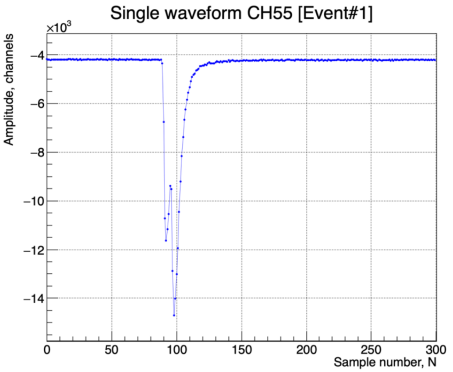




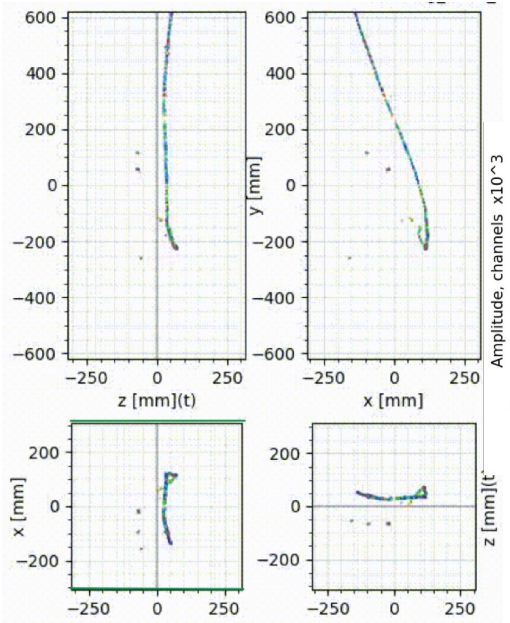
Light System Performance

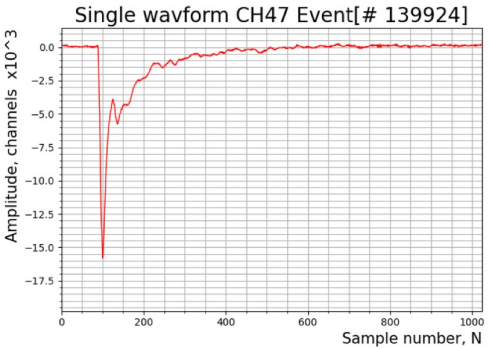
pile-up ~ 3-5 events/10us

100 ns, LED double pulse

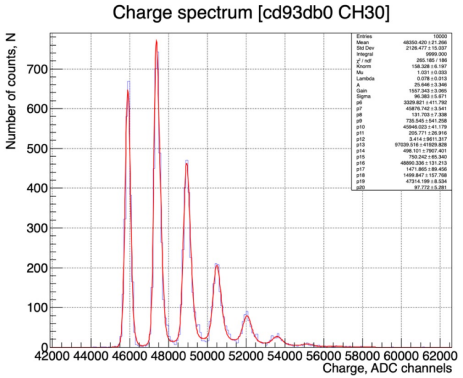


~ 250 ns pile-up, Michel event





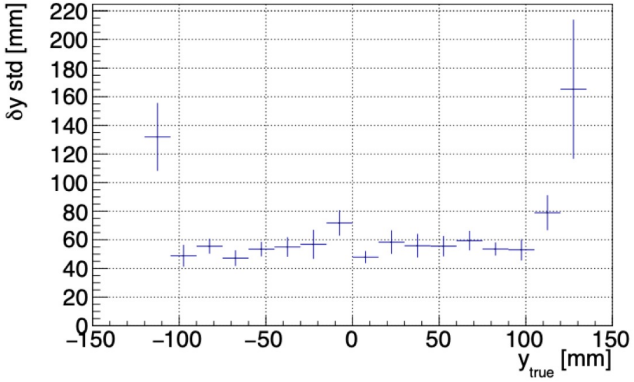
SiPM Calibration spectrum



Light System Performance

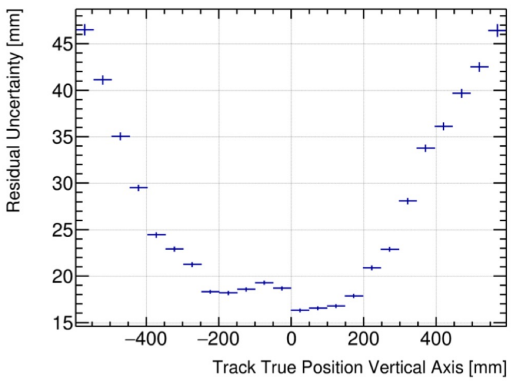
Spatial resolution (preliminary, Bern simulation)

ArCLight spatial resolution ~ 5-6cm



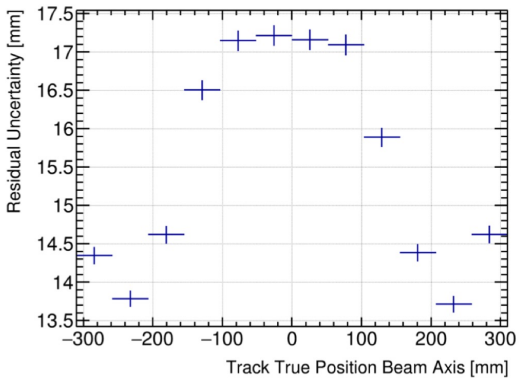
ArCLight spatial resolution reconstructed from SingleCube data (Vertical direction)

Common vertical spatial resolution ~ 2-4 cm



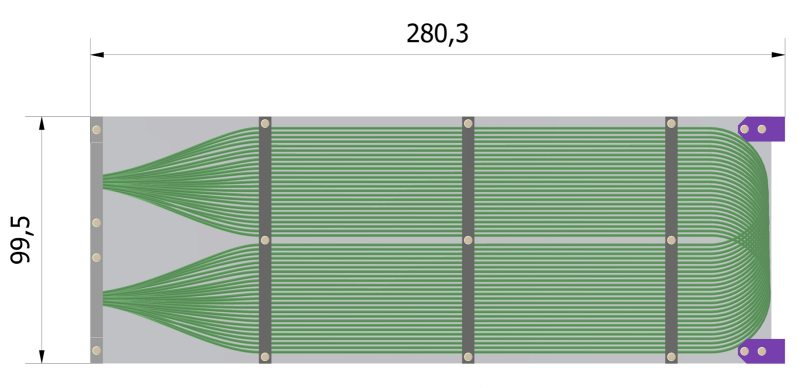
Light Readout spatial resolution simulation for ArgonCube TPC (Vertical direction)

Common spatial resolution along beam ~ 2 cm

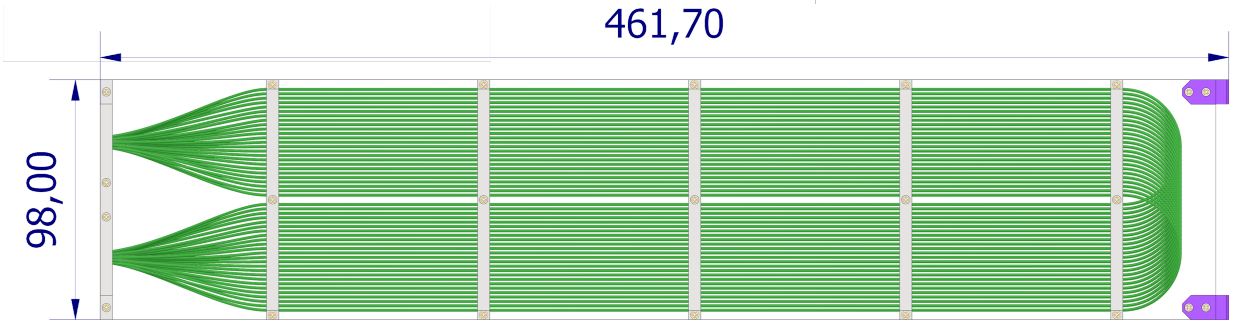


Light Readout spatial resolution simulation for ArgonCube TPC (along beam direction)

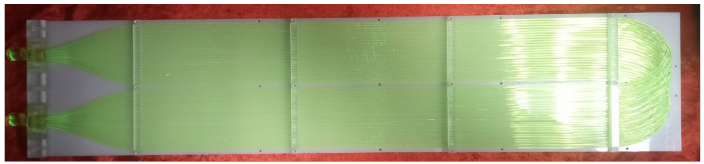
LCM for Full Scale Demonstrator (FSD)



2x2 Version ~20 m of WLS fiber

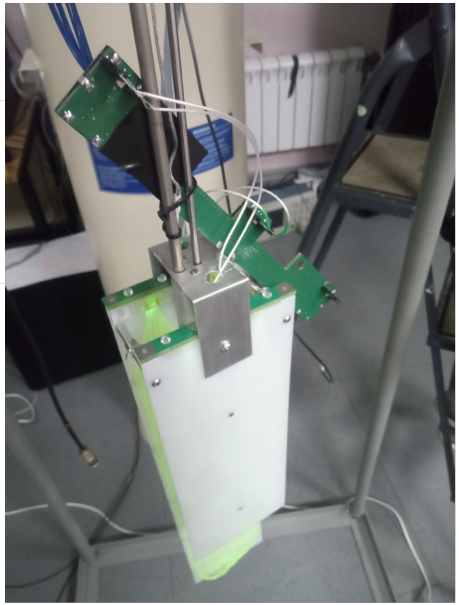


FSD Version ~30 m of WLS fiber

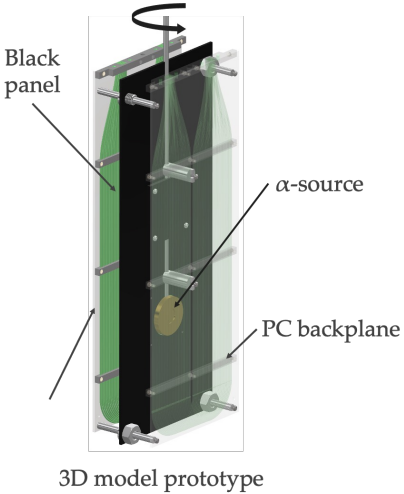


Cryogenic stand at JINR

- Studies with real LAr signal
- Pre-test of the readout chain in LAr



Purity of LAr at level 10^{-5} - 10^{-6}



3D model prototype

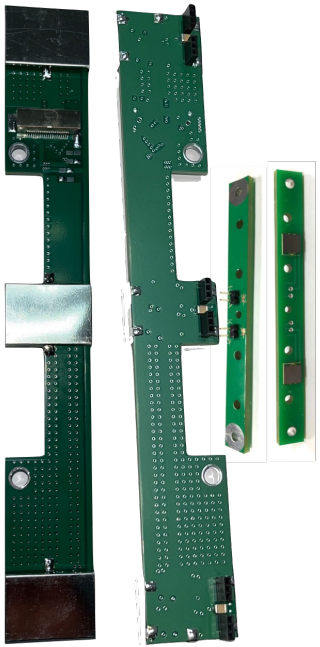
We use
^{241}Am α-source

Supported by
RSF Russian Science Foundation
under grant #22-22-00389

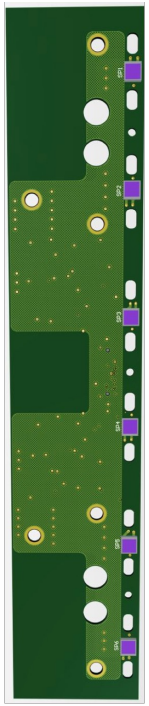
Cold PCB for FSD

2x2 Version

- E-PCB carrying 6 preamps
- Cold preamps (LMH6624) Gain ~ 5
- Power ~ 30-40mW each @ BW of ~ 30MHz (~ 10 ns rise time)
- Interface to 3 SiPM boards (3 LCMs or 1 ArCLight)
- Metal screens use to cancel clock pick up from Charge readout.
- Samtec connectors
- Left and right boards



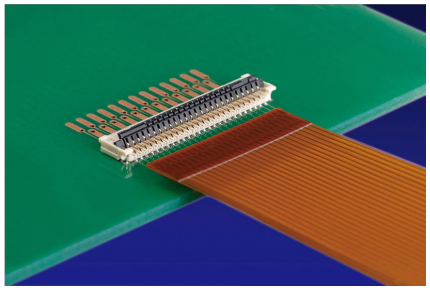
FSD Version



- FSD PCB carrying 6 preamps + 6 SiPM
- 6 SiPM are integrated onto the board
- Cold preamps (LMH6624) Gain ~ 5
- Power ~ 30-40mW each @ BW of ~ 30MHZ (~ 10 ns rise time).
- Metal Screens
- Interface to 3 LCMs or 1 ArCLight
- SiPM number can be doubled
- Samtec or flex cable connector

Samtec microcoaxial cable

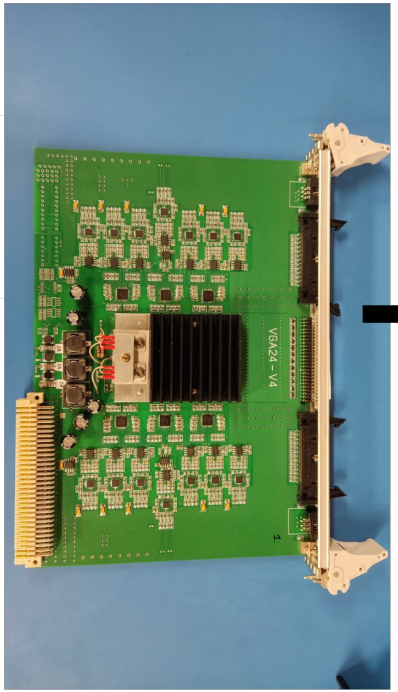
Flexible PCB



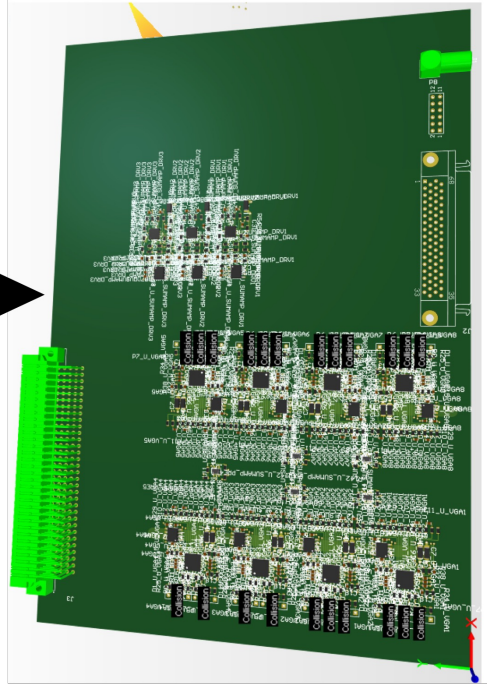
VGA for FSD

2x2 Version

- VME module
- 24 channels
- Needs adapter board for Power and Signal decoupling
- External E-PCB power
- External gain controller



FSD Version



- VME module
- 30 channels
- Onboard Power and Signal decoupling
- Onboard Cold-PCB power
- Onboard gain controller CAN-open

Summary

- Light Detection System demonstrates good performance in prototype testing
- LDS fulfill requirements the DUNE ND LArTPC (rely on prototype testing results)
- 2x2 testing with ν-beam will demonstrate modular approach
- Production for FSD is ongoing