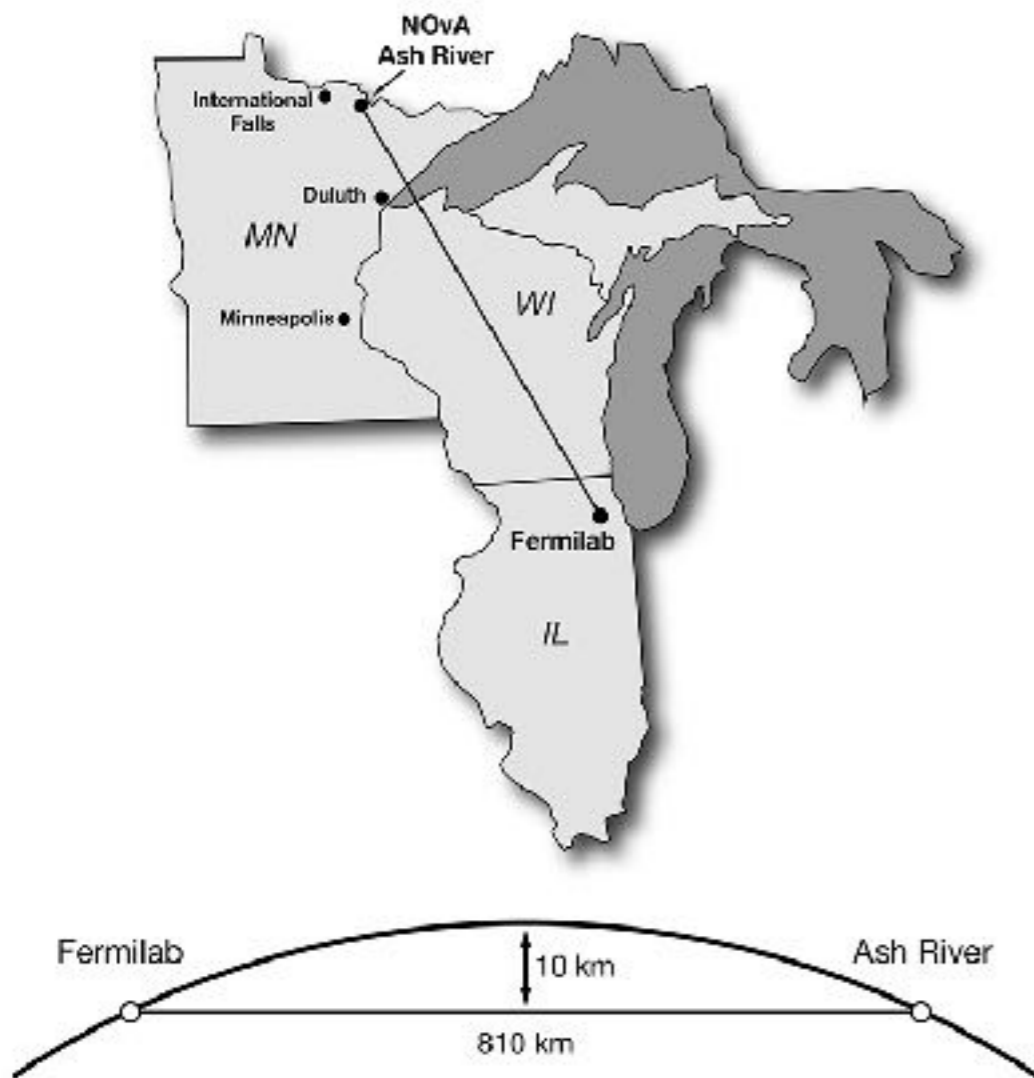


# Light Readout System of the ArgonCube Liquid Argon Modular TPC for the Near Detector of the DUNE experiment.

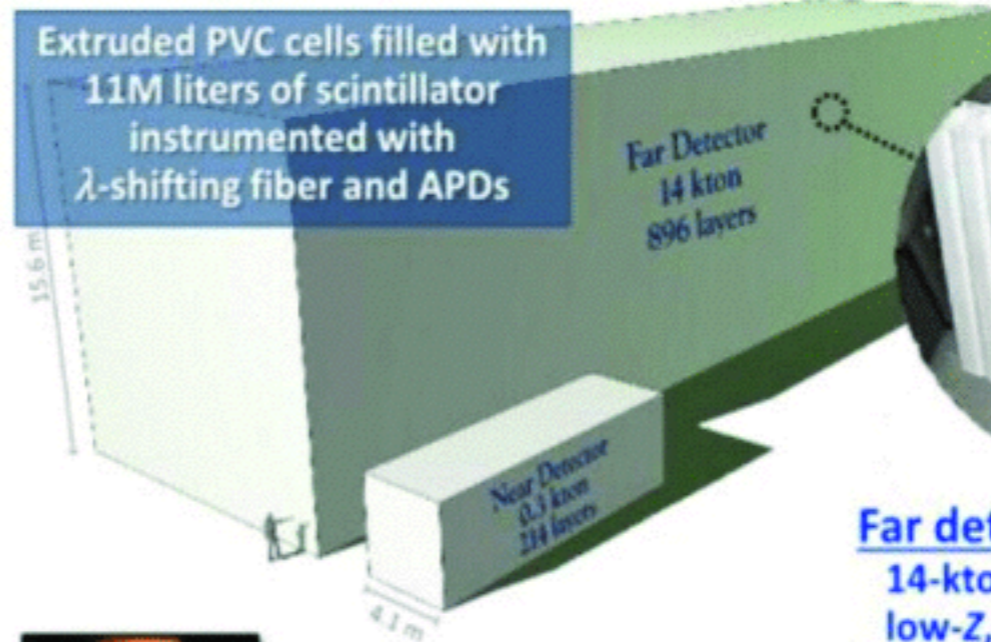
Nikolay Anfimov,  
DLNP Seminar  
9<sup>th</sup> April 2020

# The NOvA experiment



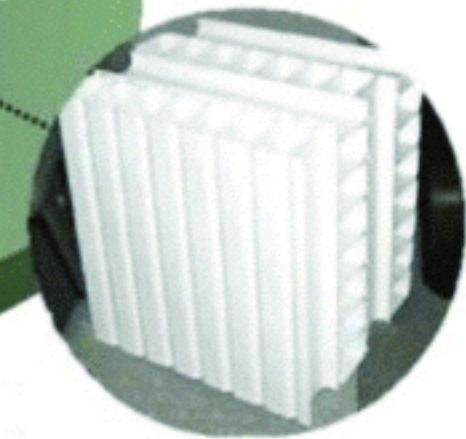
## NOvA detectors

Extruded PVC cells filled with 11M liters of scintillator instrumented with  $\lambda$ -shifting fiber and APDs



## A NOvA cell

To APD



1560 cm

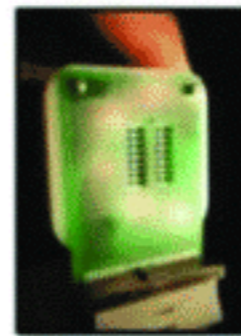
4 cm x 6 cm

### Far detector:

14-kton, fine-grained, low-Z, highly-active tracking calorimeter  
→ 344,000 channels

### Near detector:

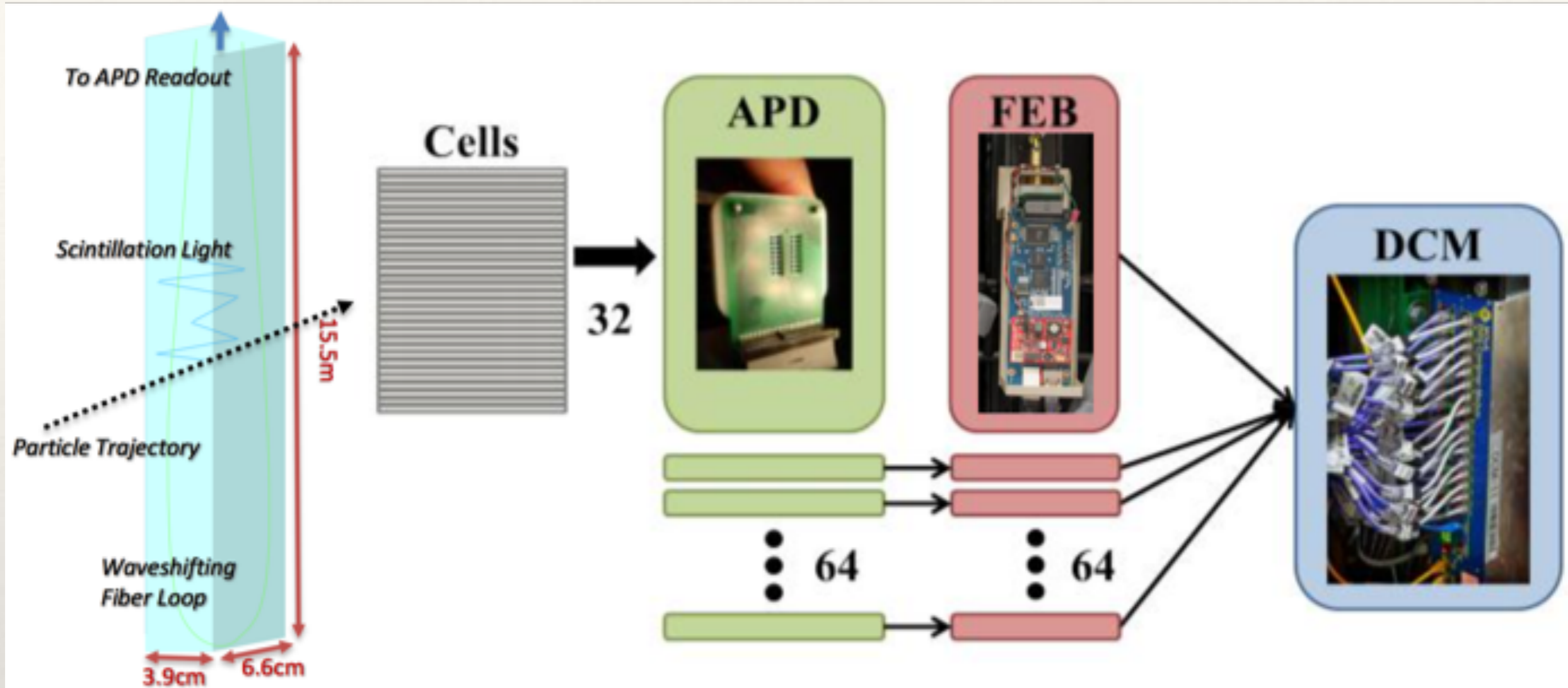
0.3-kton version of the same  
→ 20,000 channels



32-pixel APD

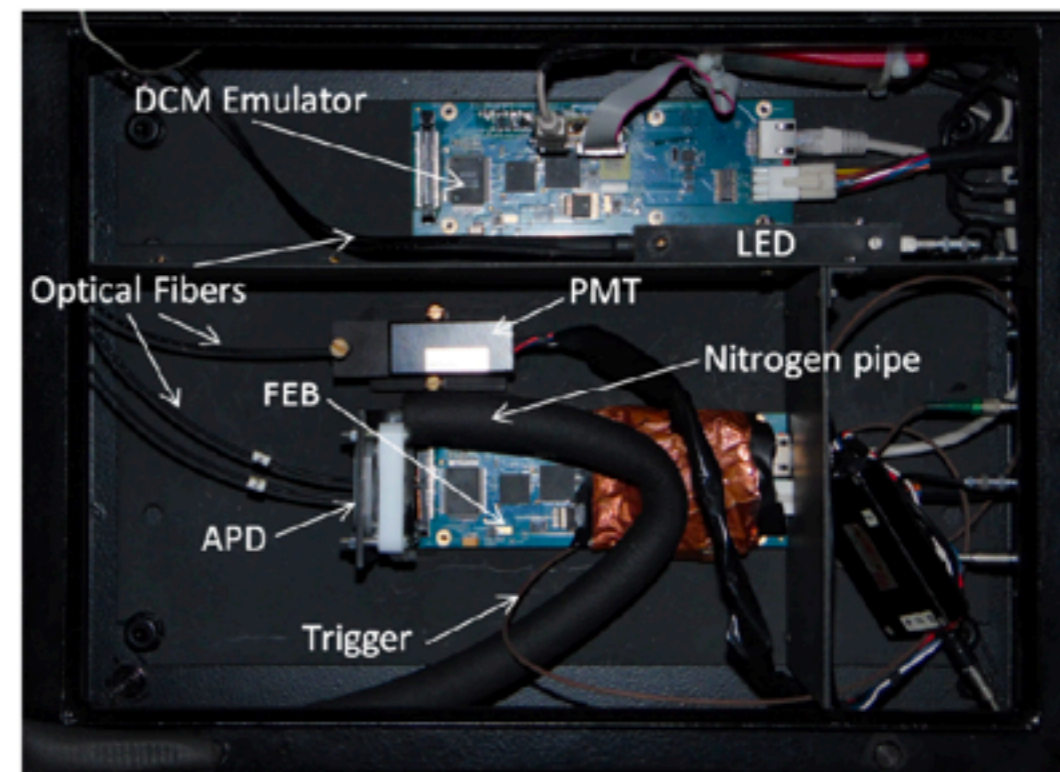
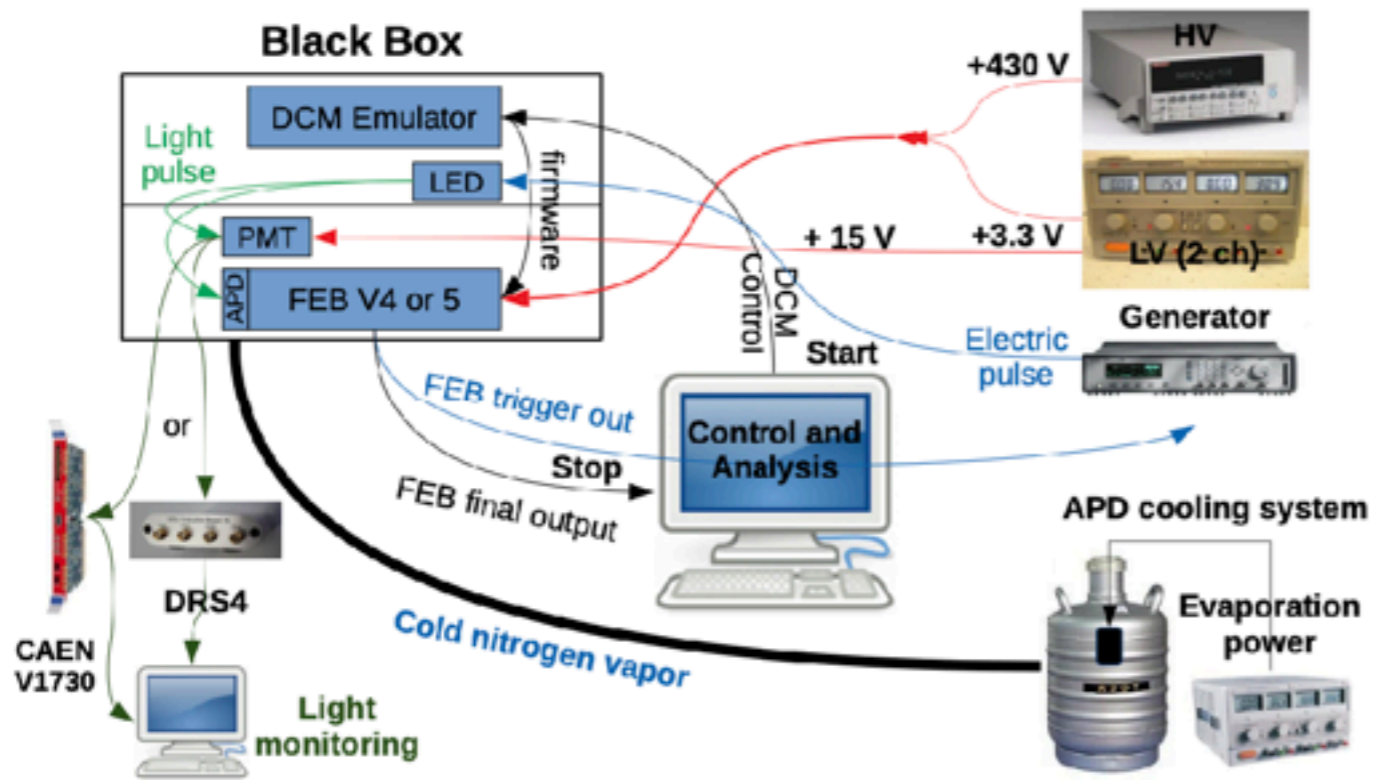
Fiber pairs from 32 cells





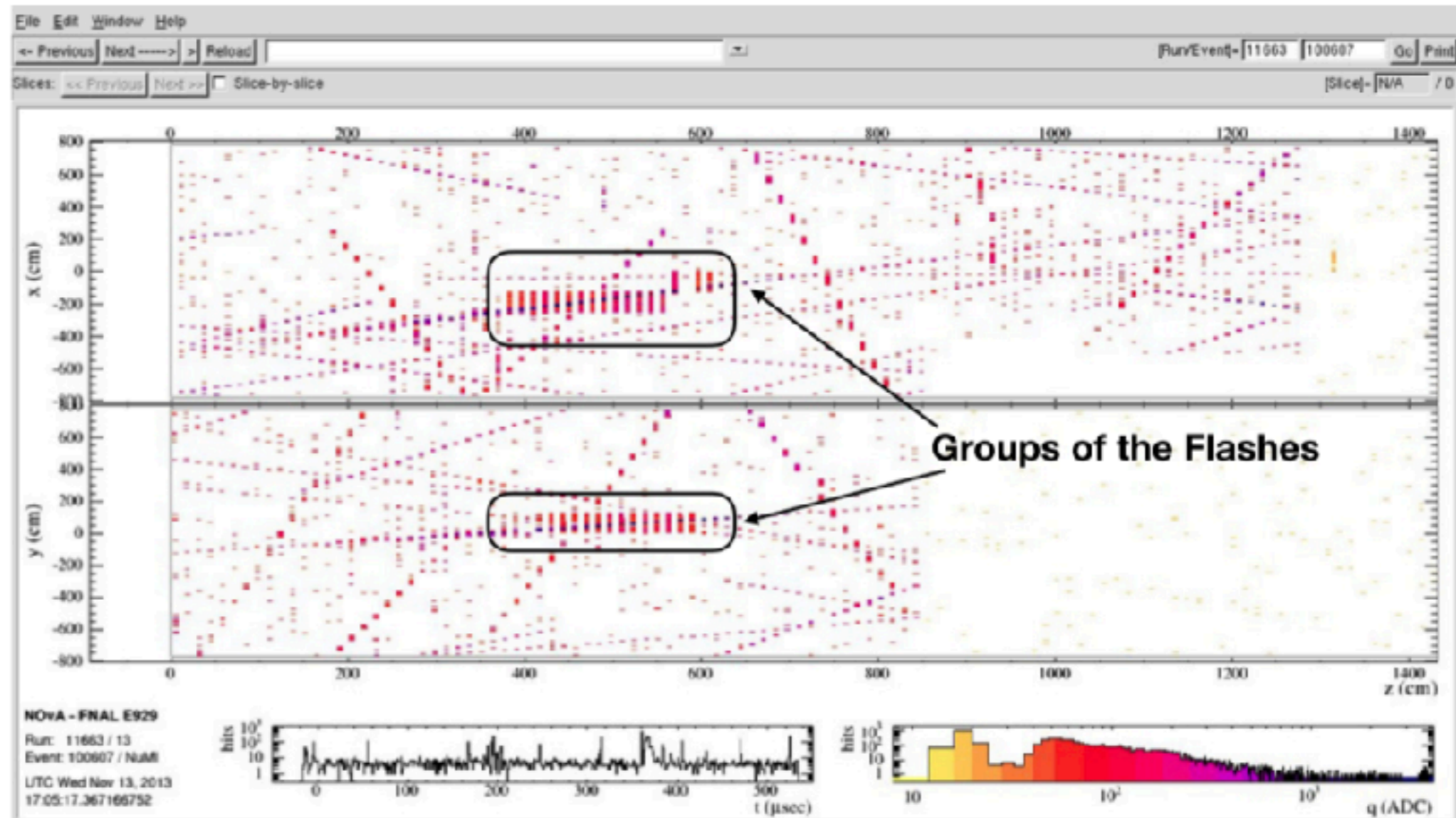
# NOvA readout

Scintillator (bar) -> Fiber(loop)  
 -> APD(32) -> FEB(64) ->  
 DCM(12) -> DiBlock(14).



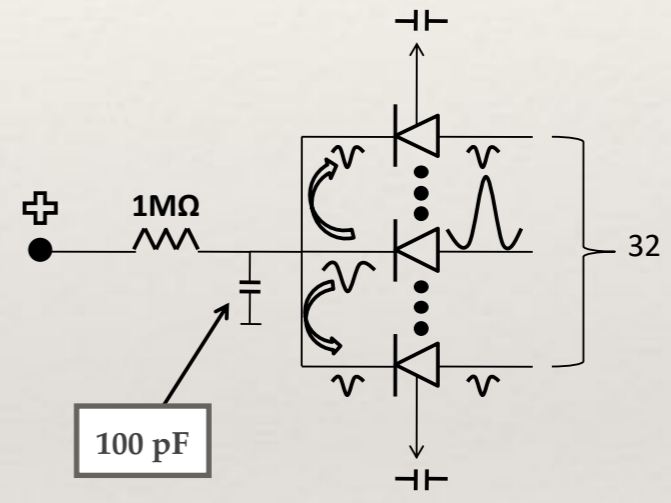
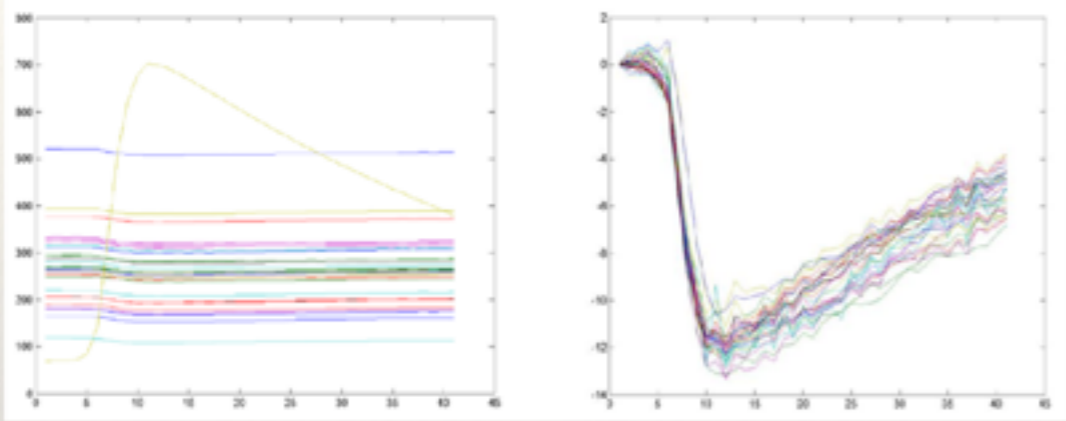
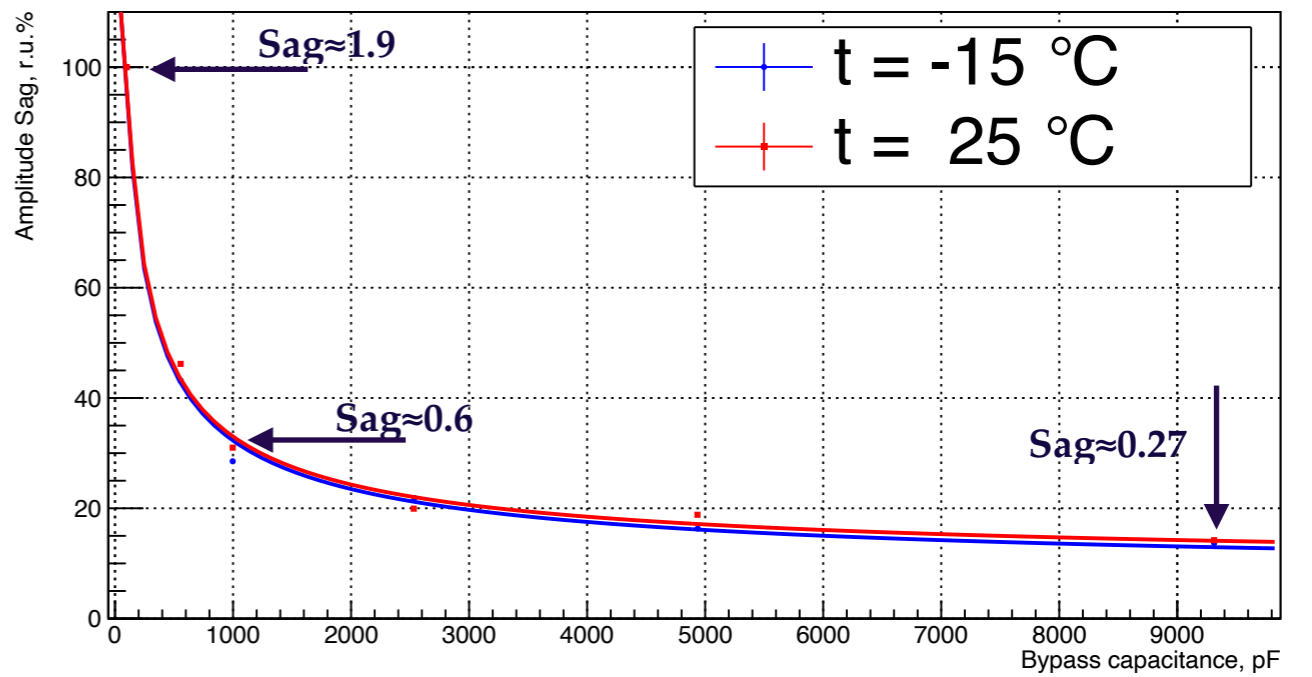
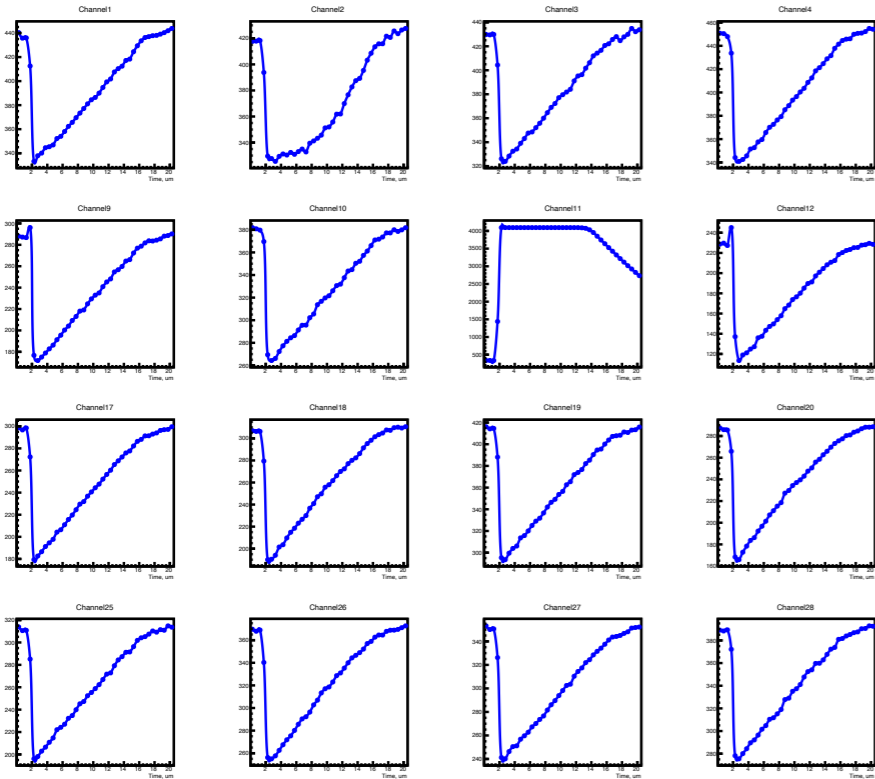
# JINR electronic bench

1. Sag study
2. Pulse shape parameters



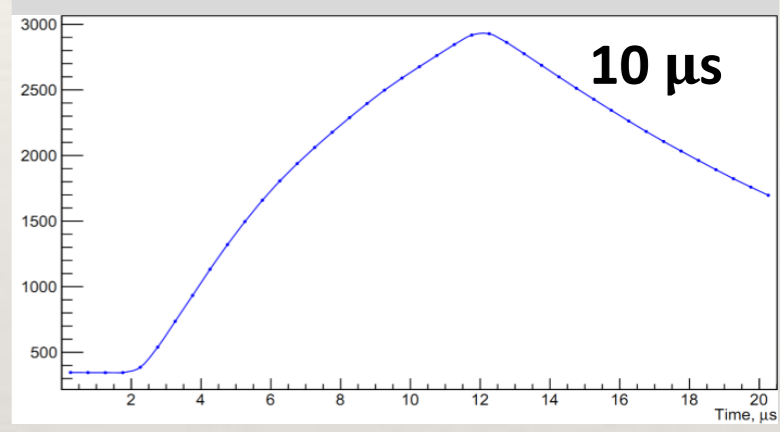
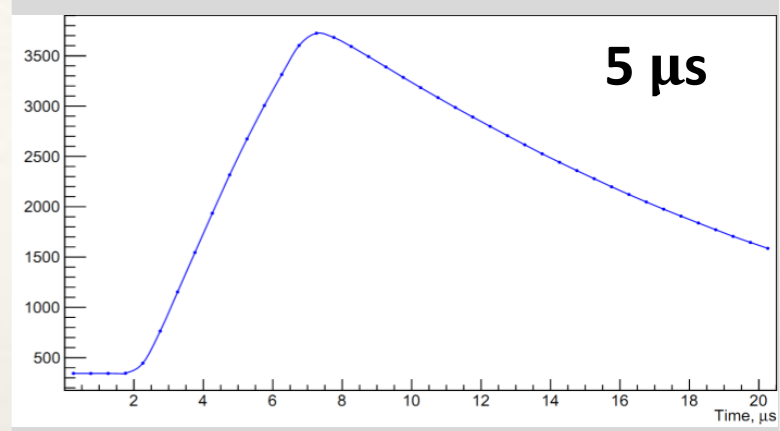
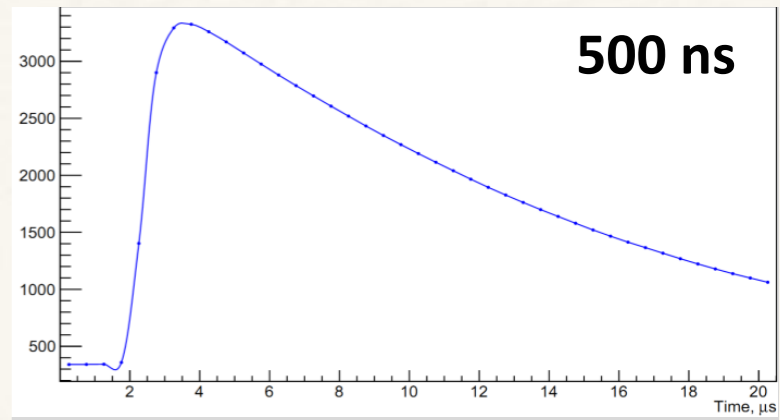
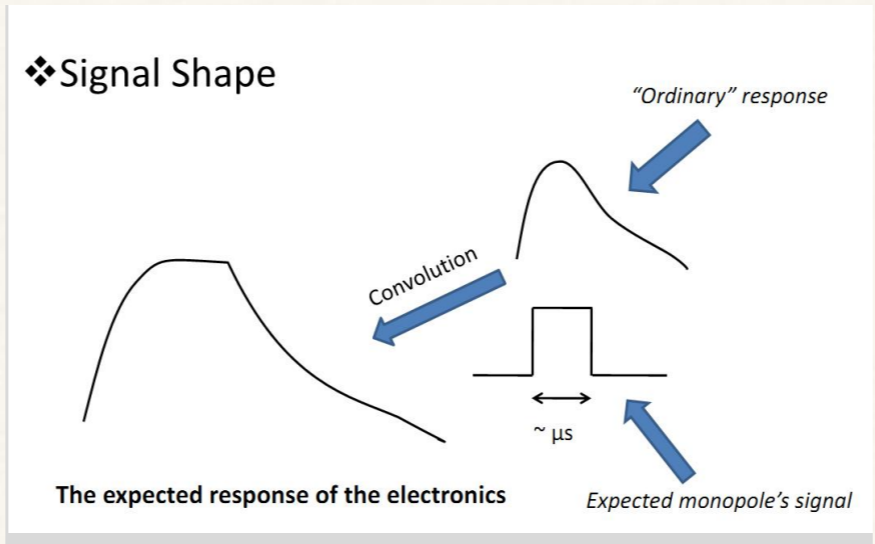
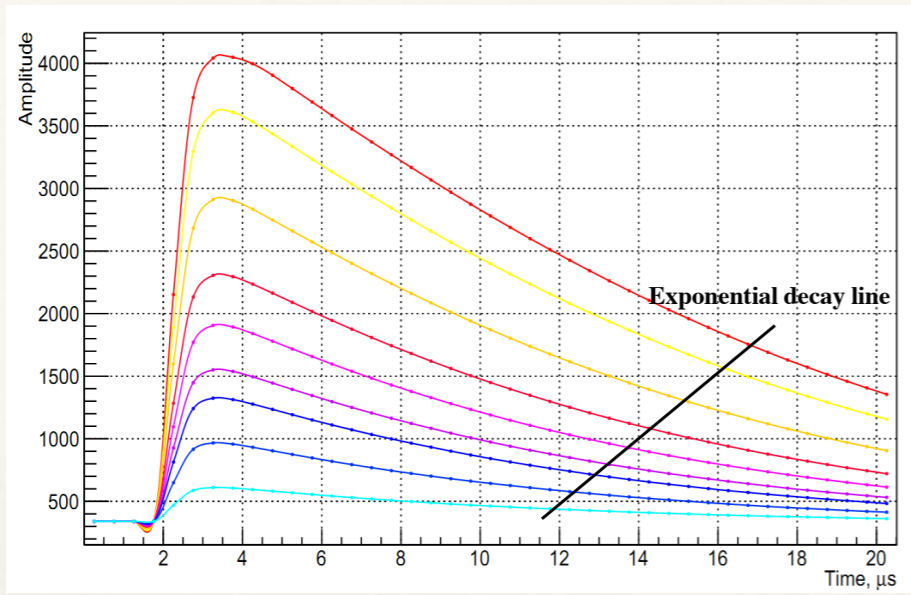
JINR electronic bench. Sag (Flash)

An example of the Flashes

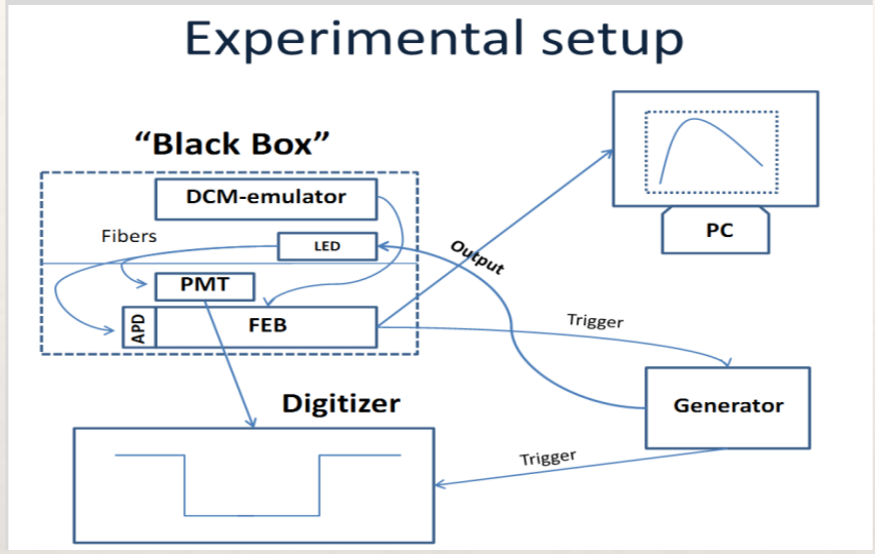


# JINR electronic bench. Sag (Flash)

1. High amplitudes triggers all other channels in a FEB
2. Channels are not decoupled
3. Small bypass Capacitor
4. We can use the sag effect to measure high-amplitude signals



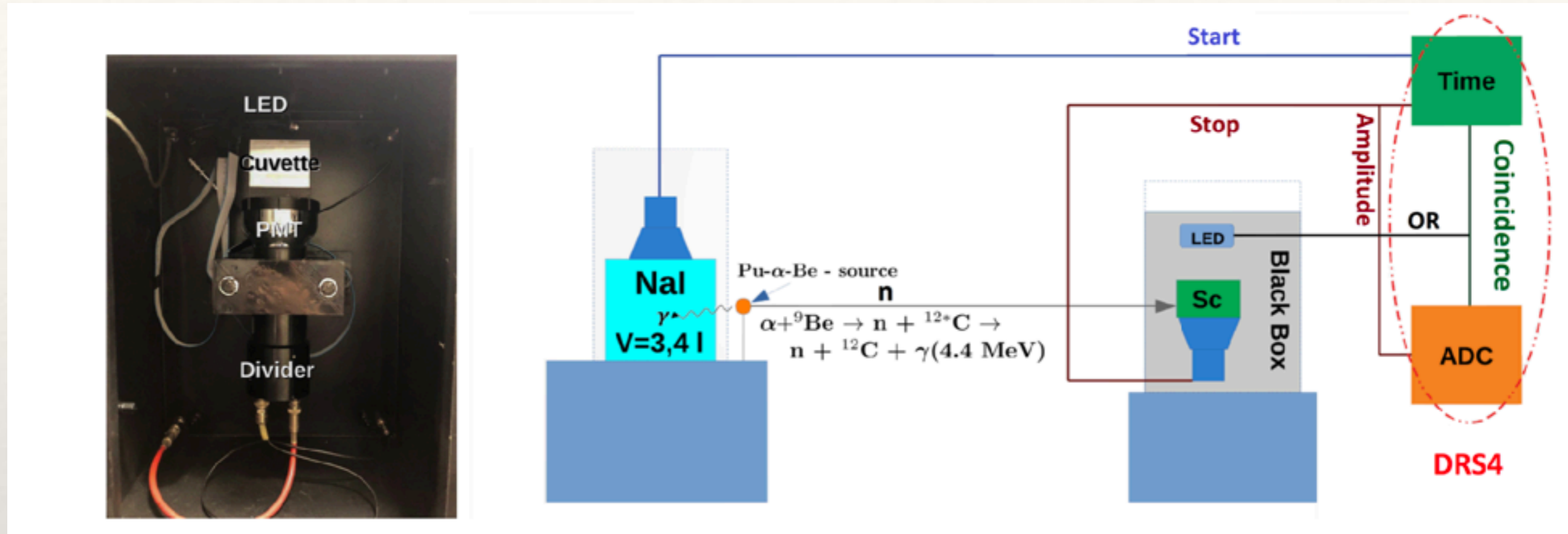
$$\frac{PE \times 4095}{MaxADCPE} \frac{1}{fPeak} e^{-\frac{t}{F}} \left(1 - e^{-\frac{t}{R}}\right)$$



# JINR electronic bench. Shaping

1. Higher amplitude -> longer falling edge
2. Longer pulse -> longer rising edge

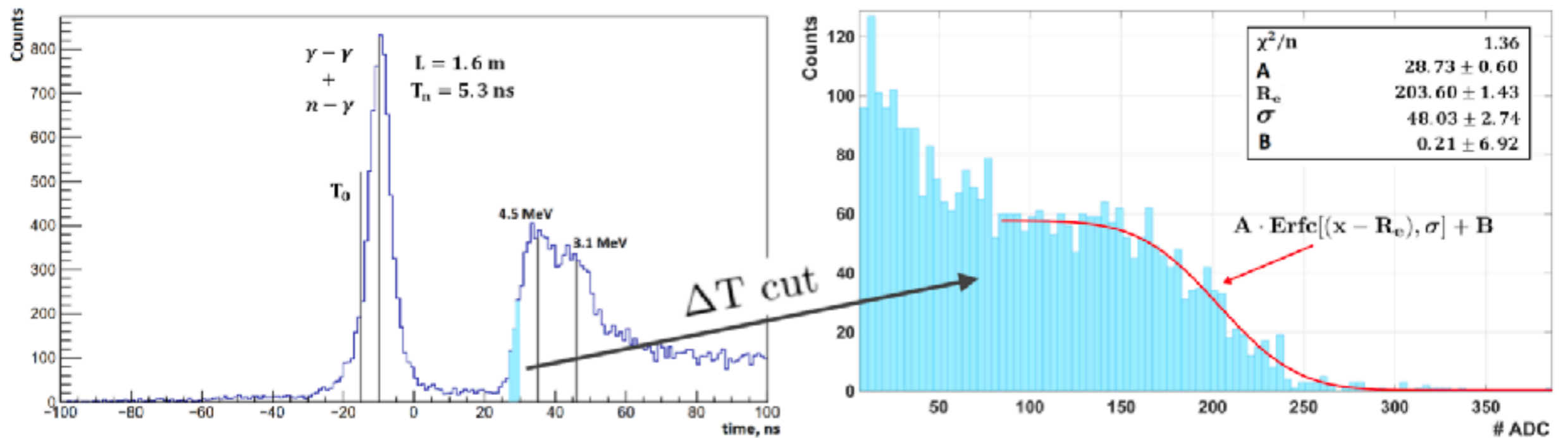
Many thanks to our colleagues from RCLAB for great help in preparation of this work!



# JINR scintillator bench

1. Linearity with  $\gamma$ -sources
2. Recoil protons response
3. Cherenkov (plan)

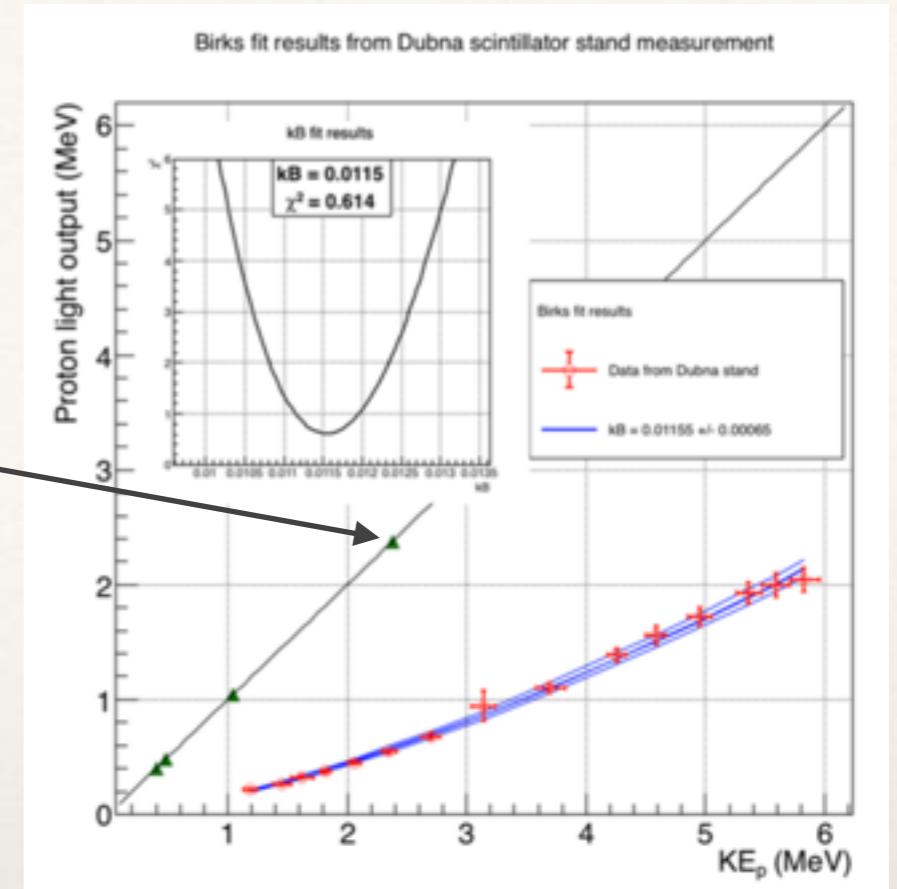
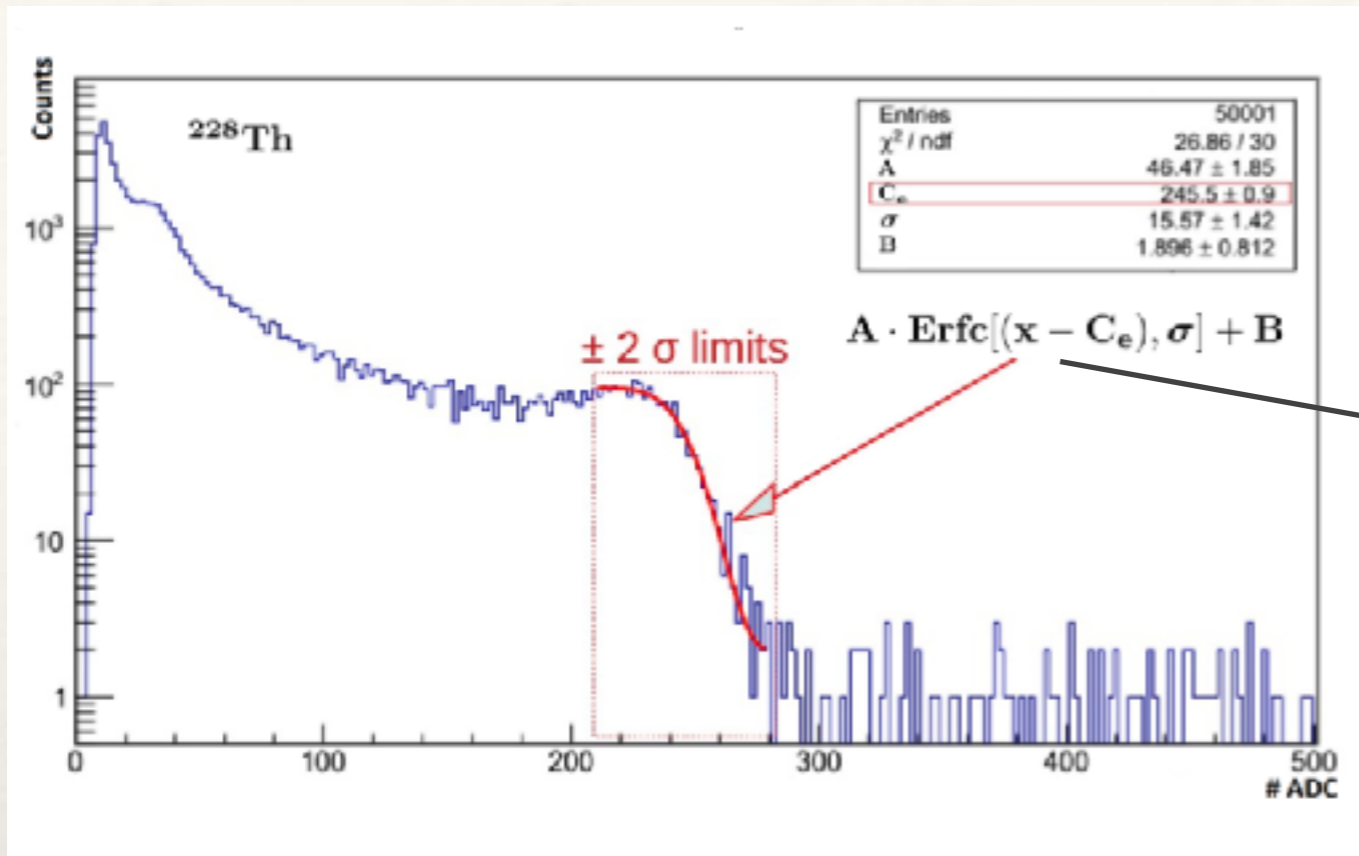




# JINR scintillator bench. TOF-Neutrons & Protons

Recoil protons response

1. Using TOF -> real neutron energy
2. Associate with max recoil energy.

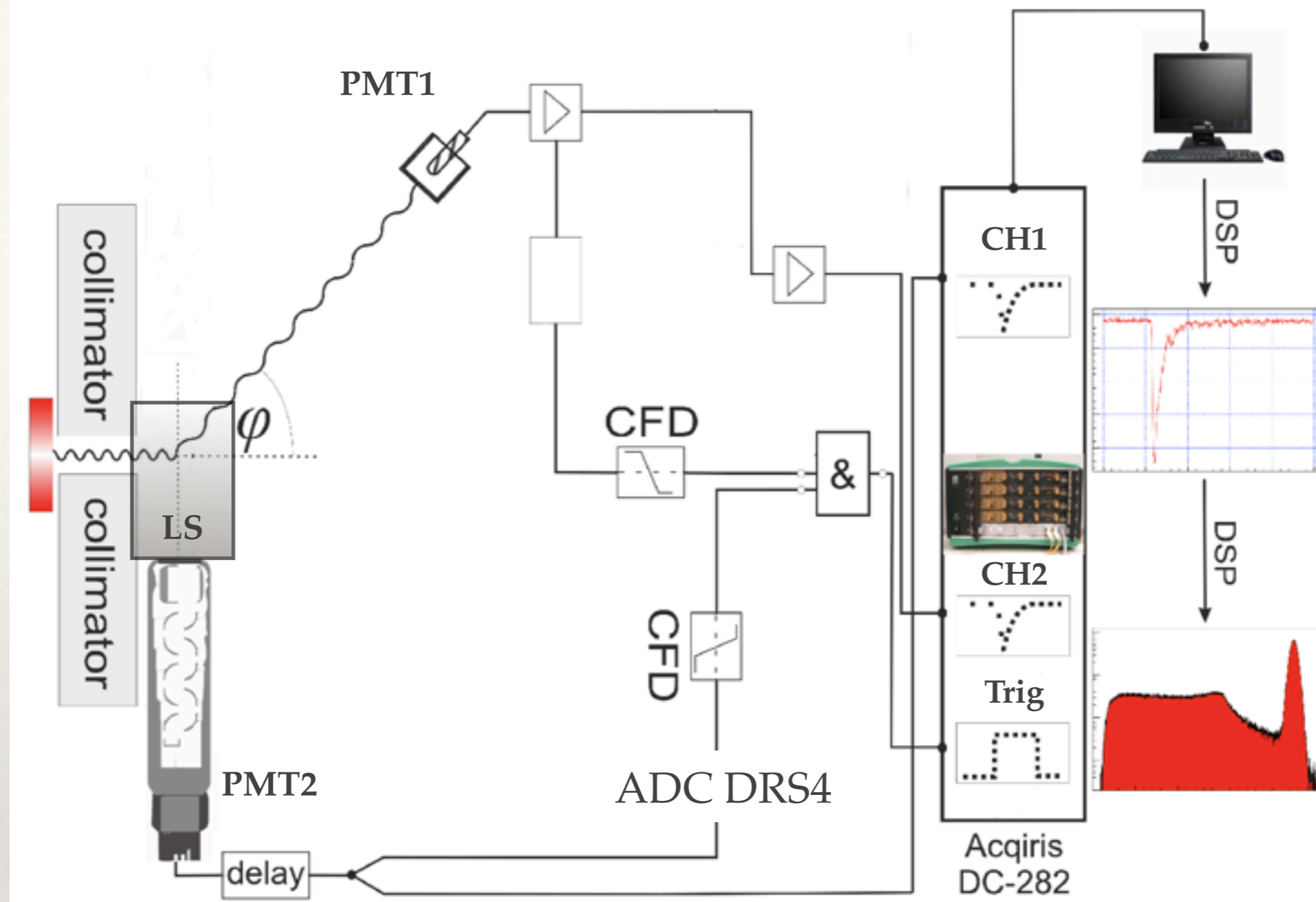


$$\frac{dS}{dx} = \frac{S \frac{dE}{dx}}{1 + k_B \frac{dE}{dx}} \quad \text{MC} \rightarrow \quad k_B = (1.155 \pm 0.065) \cdot 10^{-2} \left[ \frac{\text{g}}{\text{MeV} \cdot \text{cm}^2} \right]$$

$$k_B = (1.13 \pm 0.07) \cdot 10^{-2} \left[ \frac{\text{g}}{\text{MeV} \cdot \text{cm}^2} \right] \quad \leftarrow \text{Numerical NIST}$$

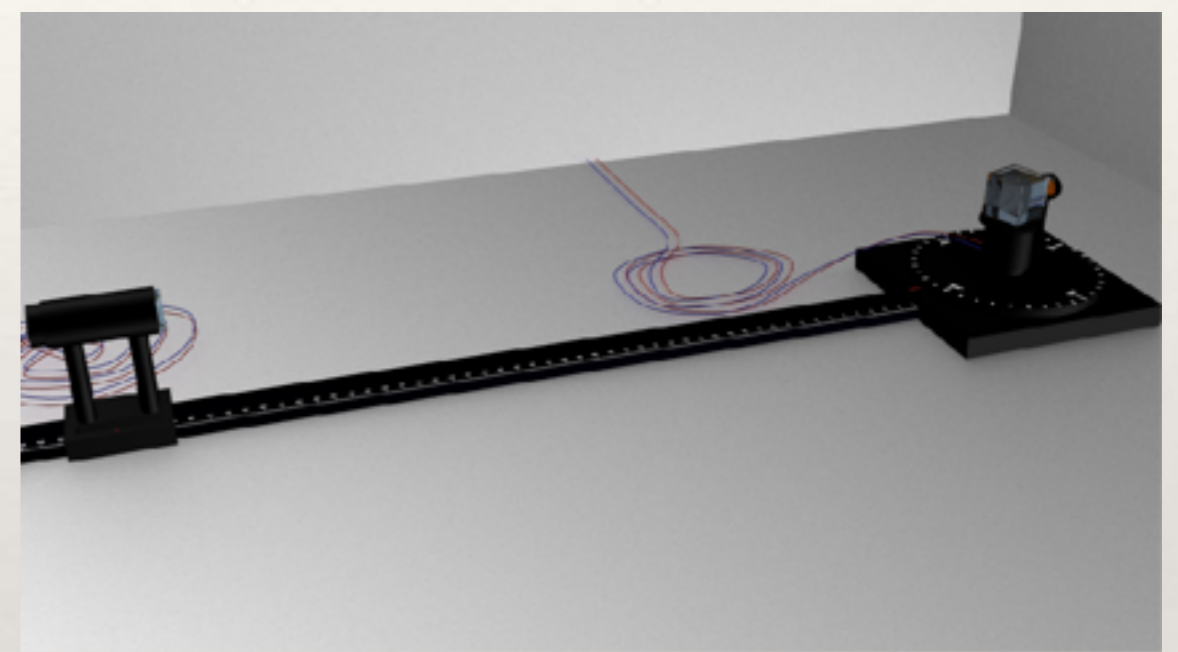
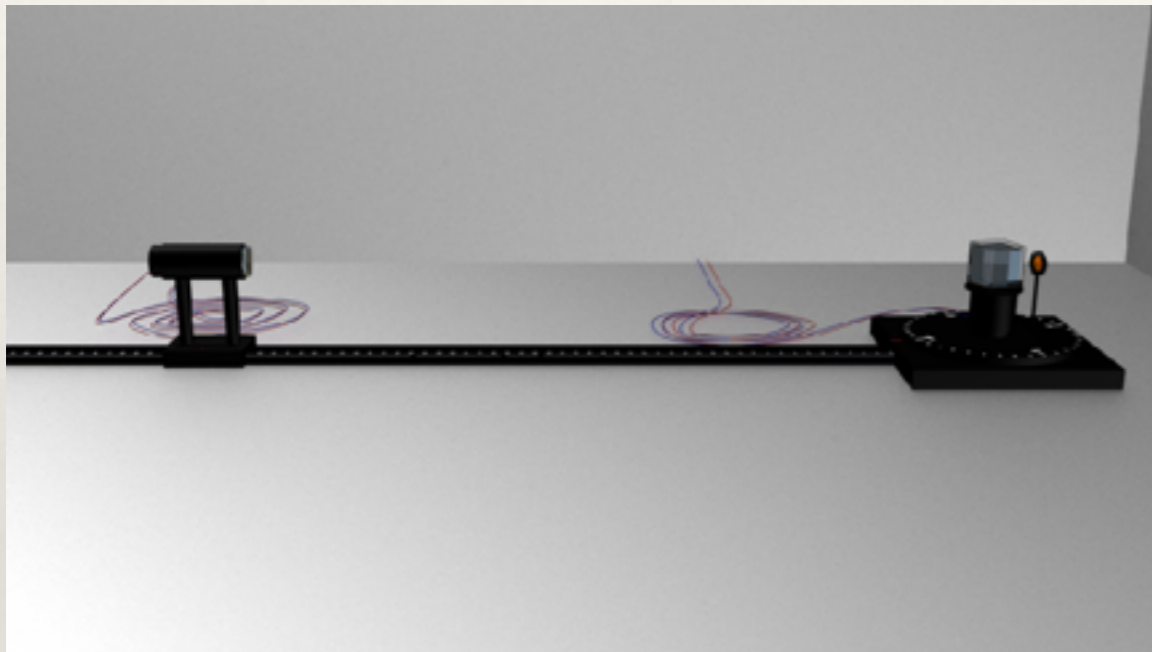
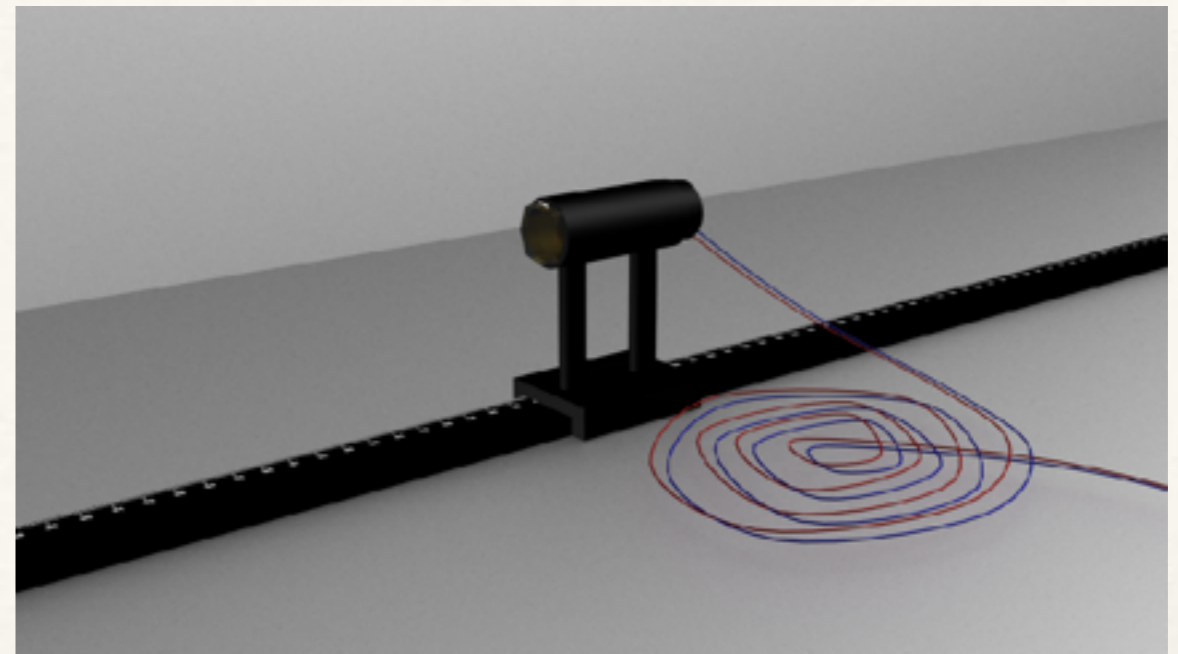
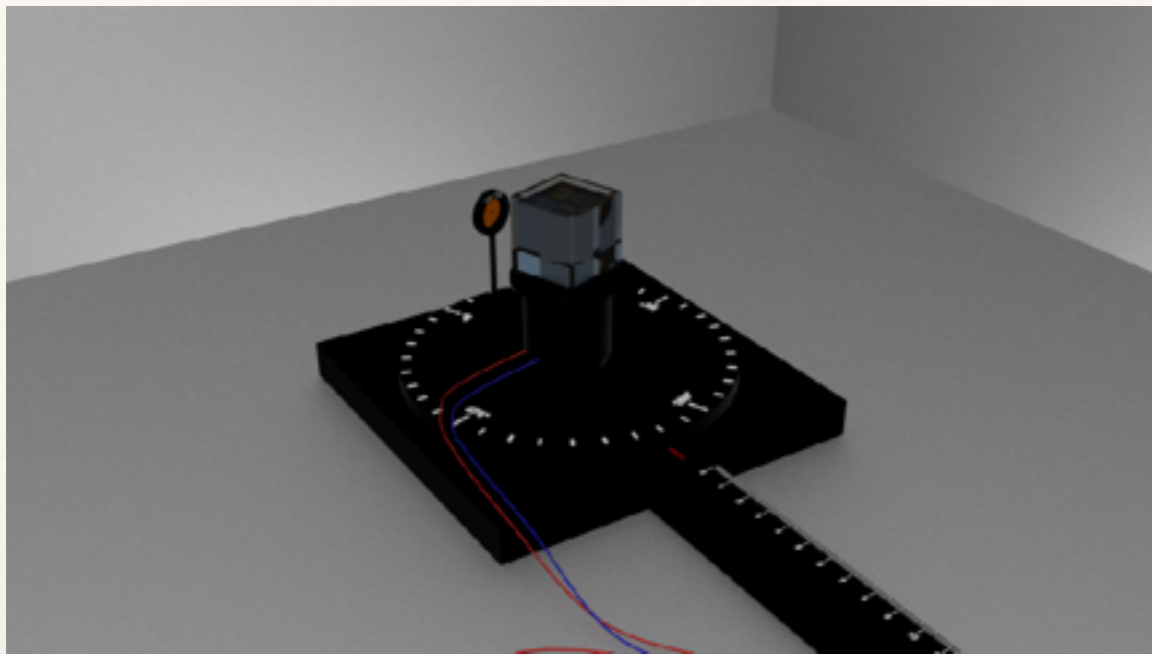
# JINR scintillator bench. Calibration and Birks

1. Linearity tested with  $\gamma$ -sources
2. Energy scale calibrated wrt Compton's edge energy
3. Birks constant was obtained from MC and Num Calculus



# JINR scintillator bench. Cherenkov

1. Radiation Premise is about to be ready
2. Already ordered additional PMT and NaI-crystal
3. Radioactive sources are purchased



# JINR scintillator bench. Cherenkov

1. Idea is to rotate source with cuvette wrt  $\gamma$ -detector
2. Standard optical tools
3. Model is ready for production

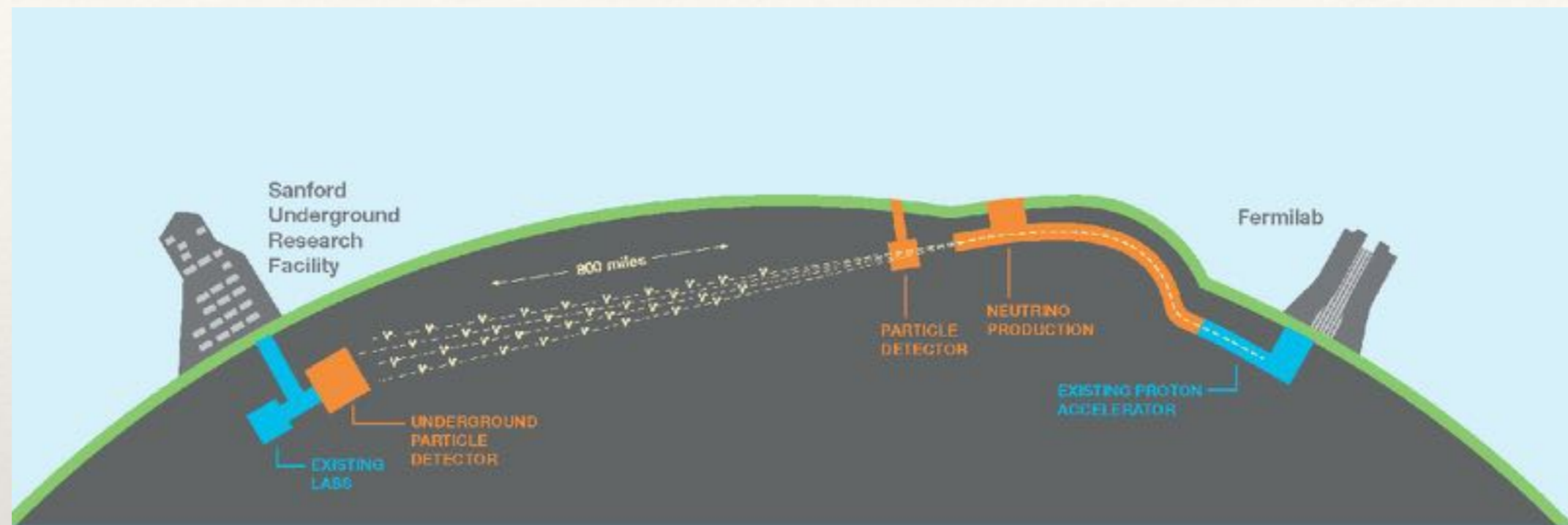
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# Methodical group

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- ❖ Anfimov Nikolay - Group Leader
- ❖ Alexander Olshevskiy - research consultant (JINR-NOvA Leader)
- ❖ Samoylov Oleg - Analysis / research consultant (DetSim convener / JINR-NOvA Deputy)
- ❖ **Alexander Antoshkin - hardware/measurements/analysis**
- ❖ Albert Sotnikov - hardware / measurements / analysis
- ❖ Rybnikov Arseniy - software / analysis
- ❖ Dmitriy Fedoseev - mechanics / electronics
- ❖ Sergey Sokolov - mechanics

# The DUNE experiment

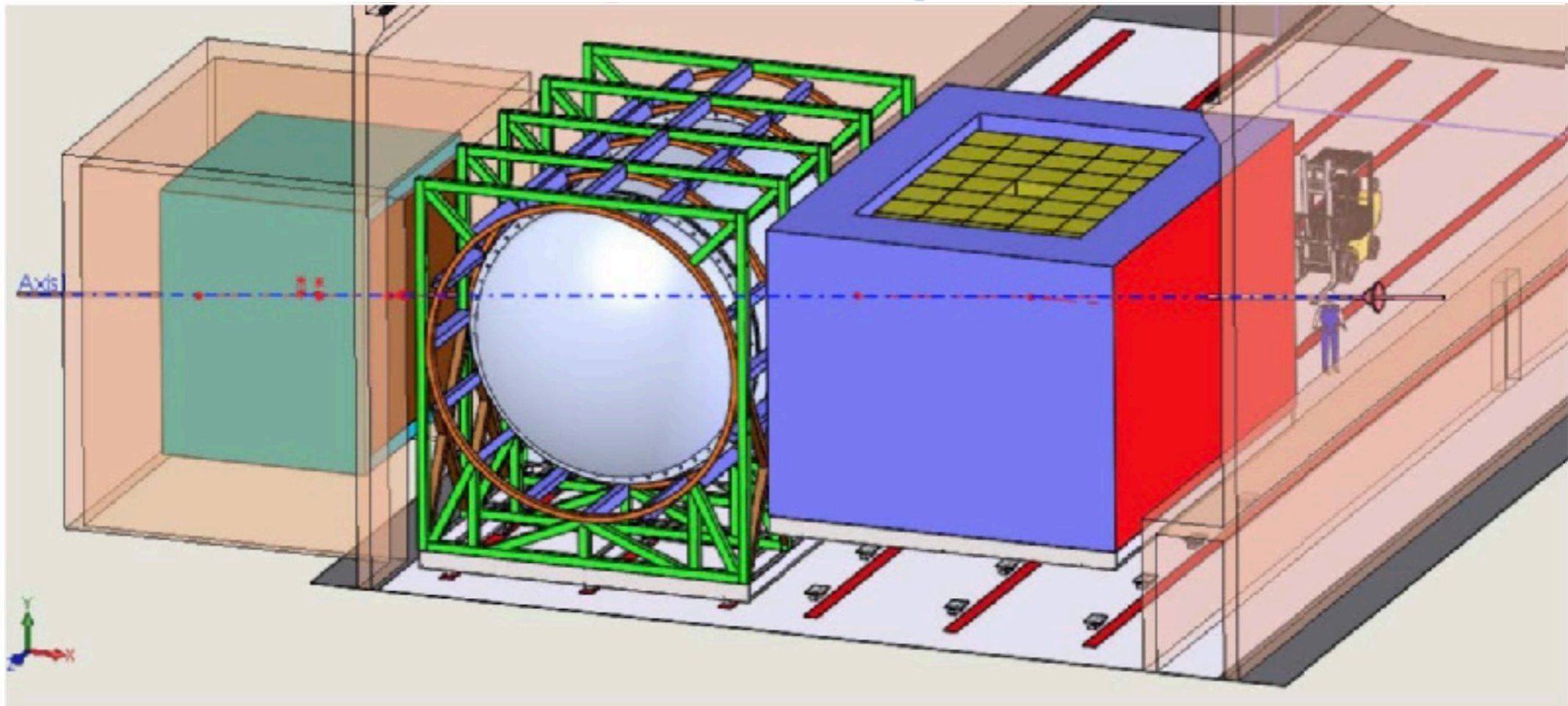


## Deep Underground Neutrino Experiment



# Near Detector

## The DUNE Near Detector Complex



ArgonCube: Pixel-based LArTPC, unmagnetized (150 Tons)

MPD: "Multi-Purpose Detector": High-Pressure Gas TPC, solenoid, ECAL, muon stack

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# ArgonCube Collaboration

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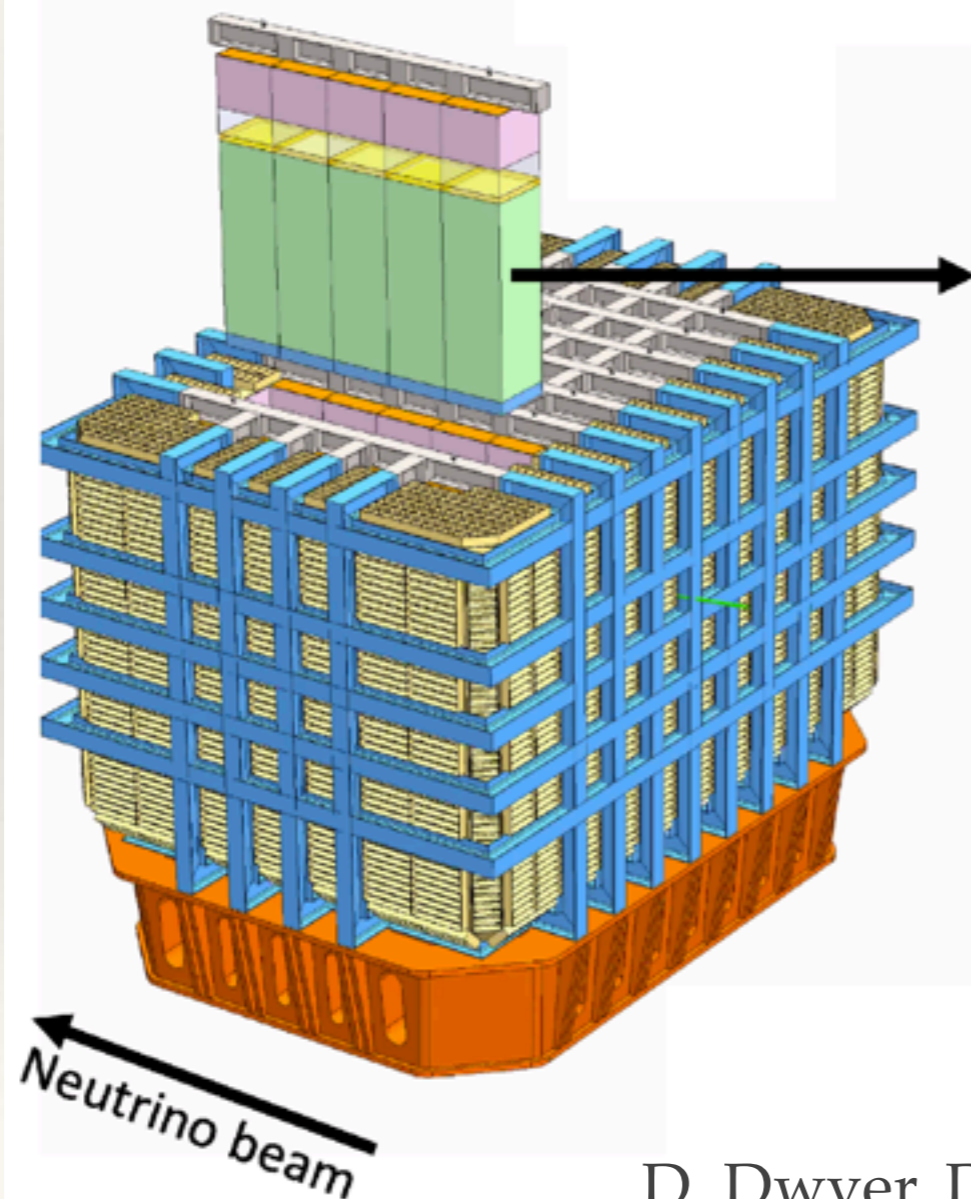




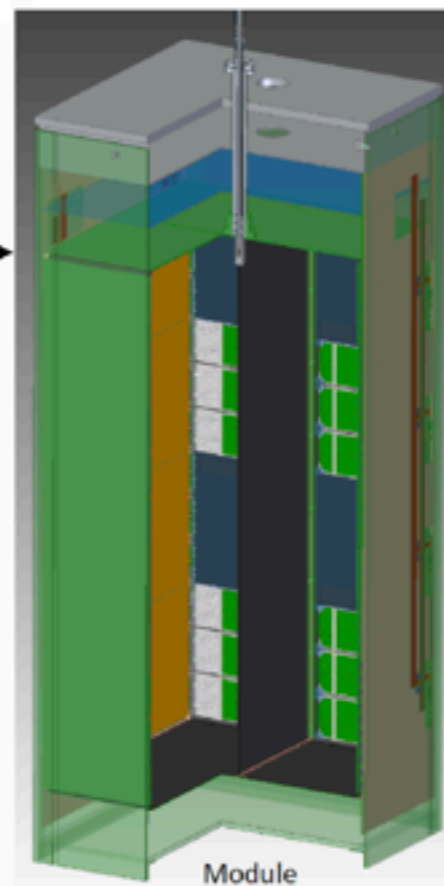
# ArgonCube TPC

## Near Detector LArTPC Design

ND LArTPC



TPC Module



### Key Design Features:

#### Active size:

5m deep, 7m wide, 3m tall  
→ For  $\nu$  signal containment

Signal rate:  $\sim 10$  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*

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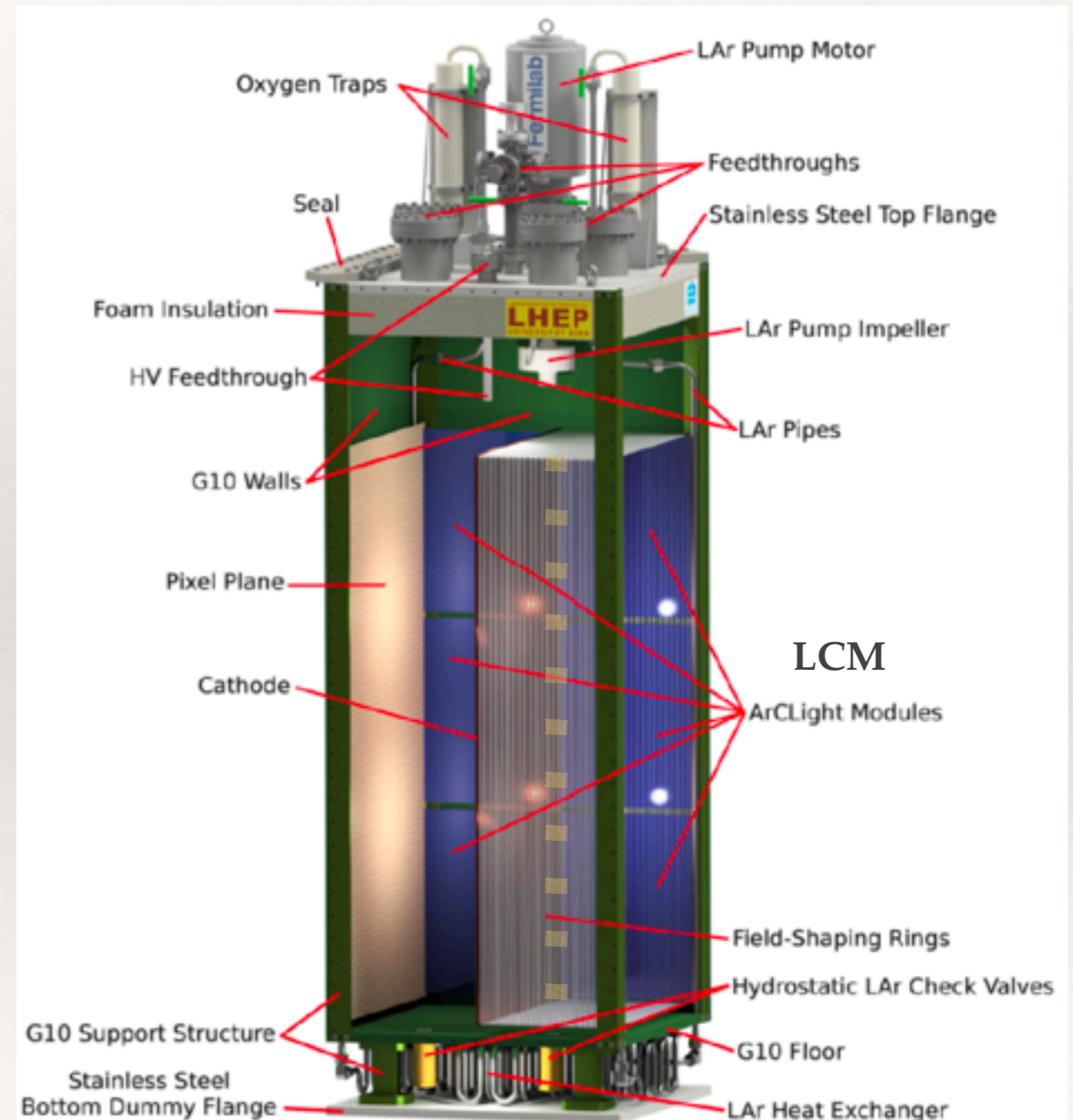
# ArgonCube time schedule

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- ❖ LAr purification test - **March-April 2020** (UniBe).  
Preliminary test of Light R/O: electronics readout chain + DAQ, efficiencies of different modules, data merging, etc...
- ❖ Single TPC module tests - **June-July 2020 (?)**. Performance of full Light R/O system chain + DAQ, joint analysis with Charge R/O system.
- ❖ 2x2 TPC demonstrator - **2021-22(?)**. NuMi beam @ Fermilab.
- ❖ Full-scale ArgonCube TPC > **2025**.

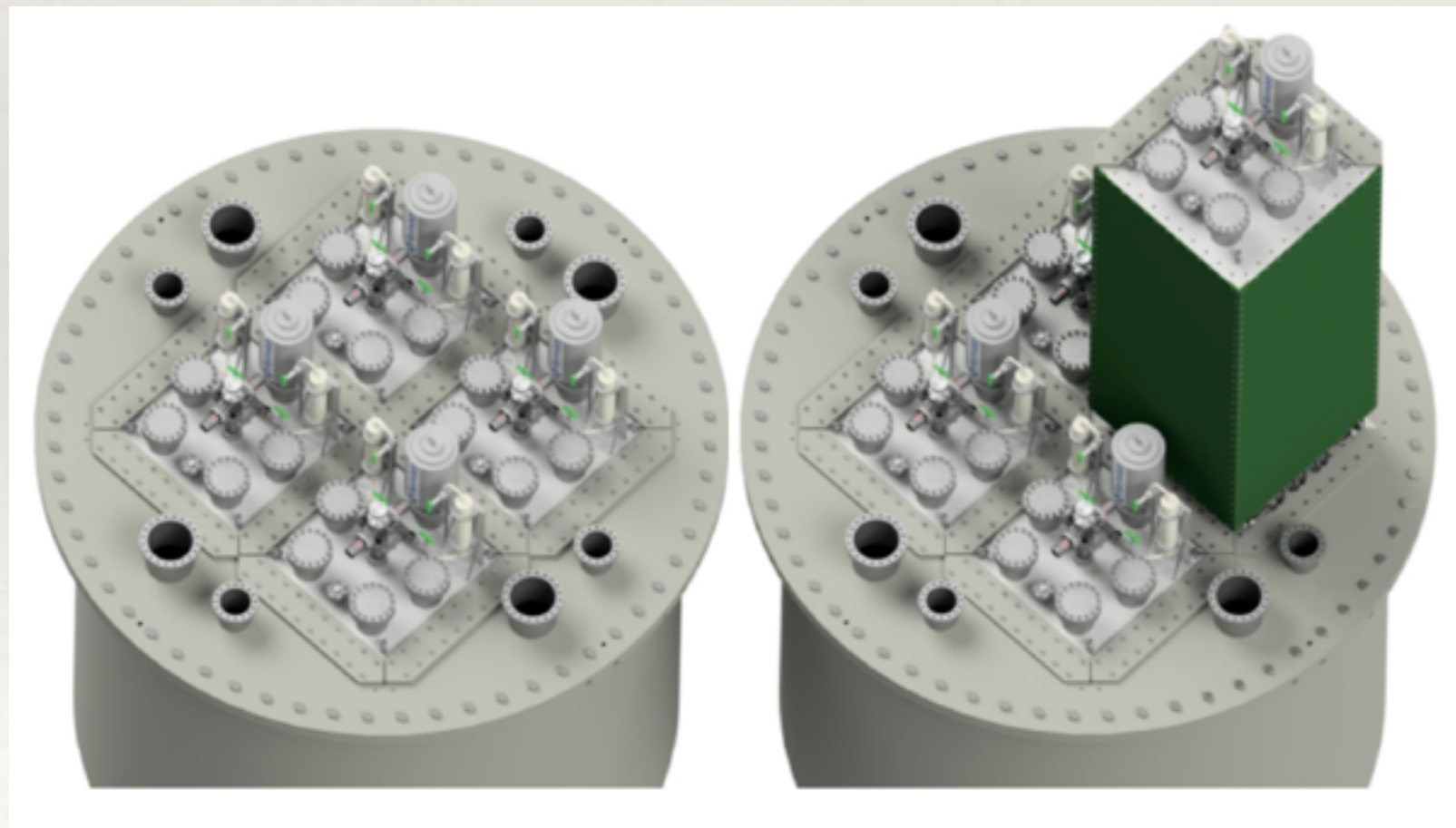
# ArgonCube Module Prototype

- ❖ Size - 670x670x1200 (1810) mm
- ❖ Cathode plane in the center
- ❖ LCM/ ArcLight ~  
30 cm x 120 cm - 4 planes
- ❖ Current solution  
LCM/ ArcLight = 50 / 50%.
- ❖ 48 SiPM for LCM and 48  
ArcLight

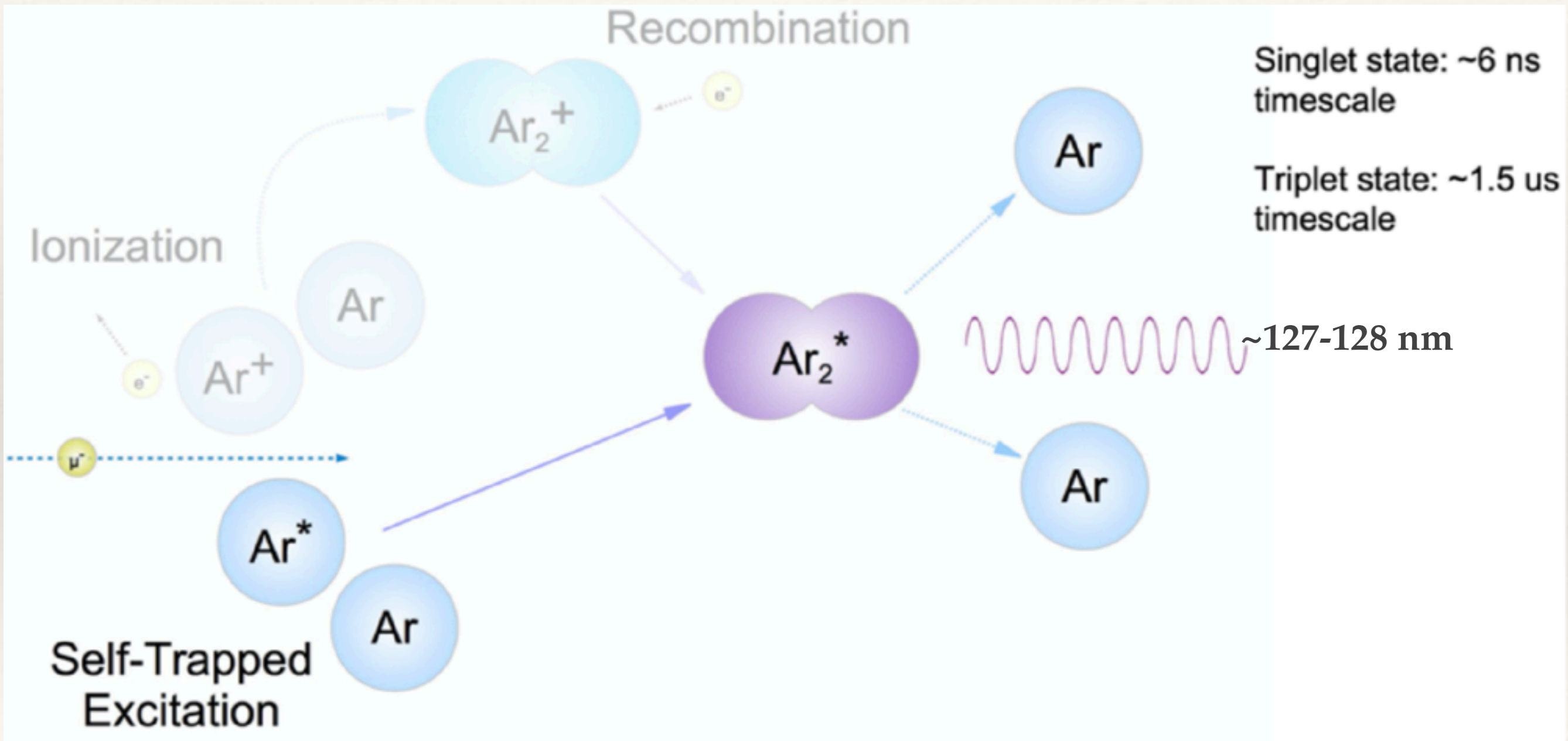


# 2x2 demonstrator

- Cryostat vessel for 2x2 TPC @ UniBe
- Pre-tests of 2x2 @ UniBe before shipment to Fermilab
- **Not reasonable for 1 TPC test because of huge volume**



# LAr scintillation mechanism

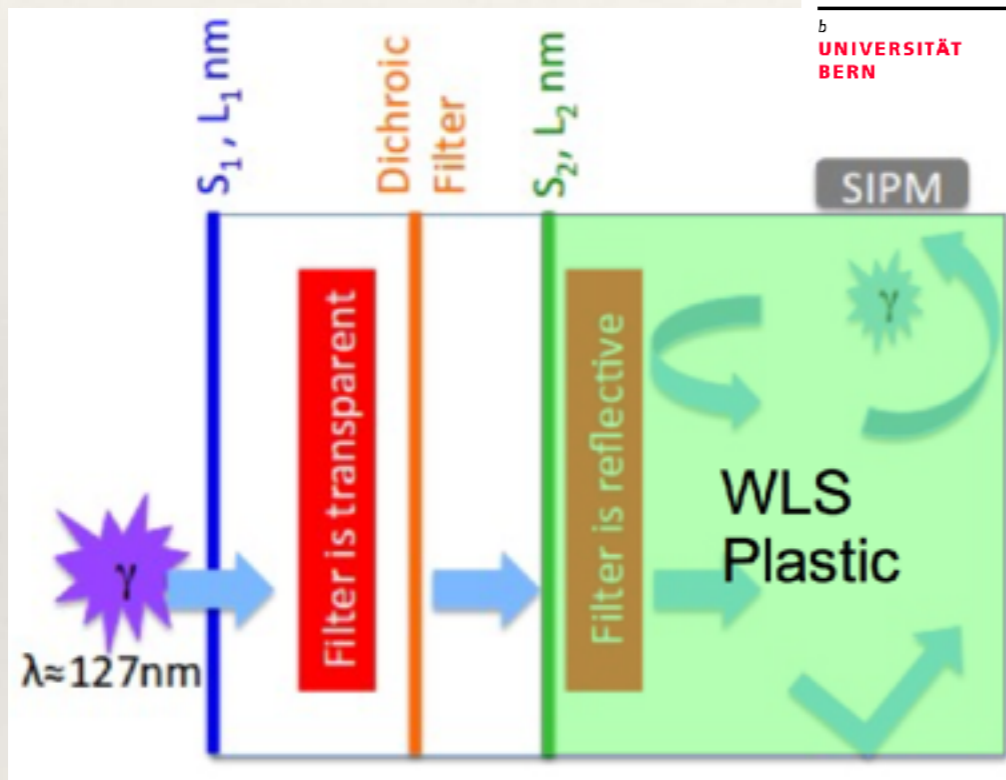
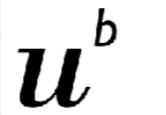


Light output  $\sim 30 - 40$  thousand photons / MeV!

# Light readout. LCM & ArCLight

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

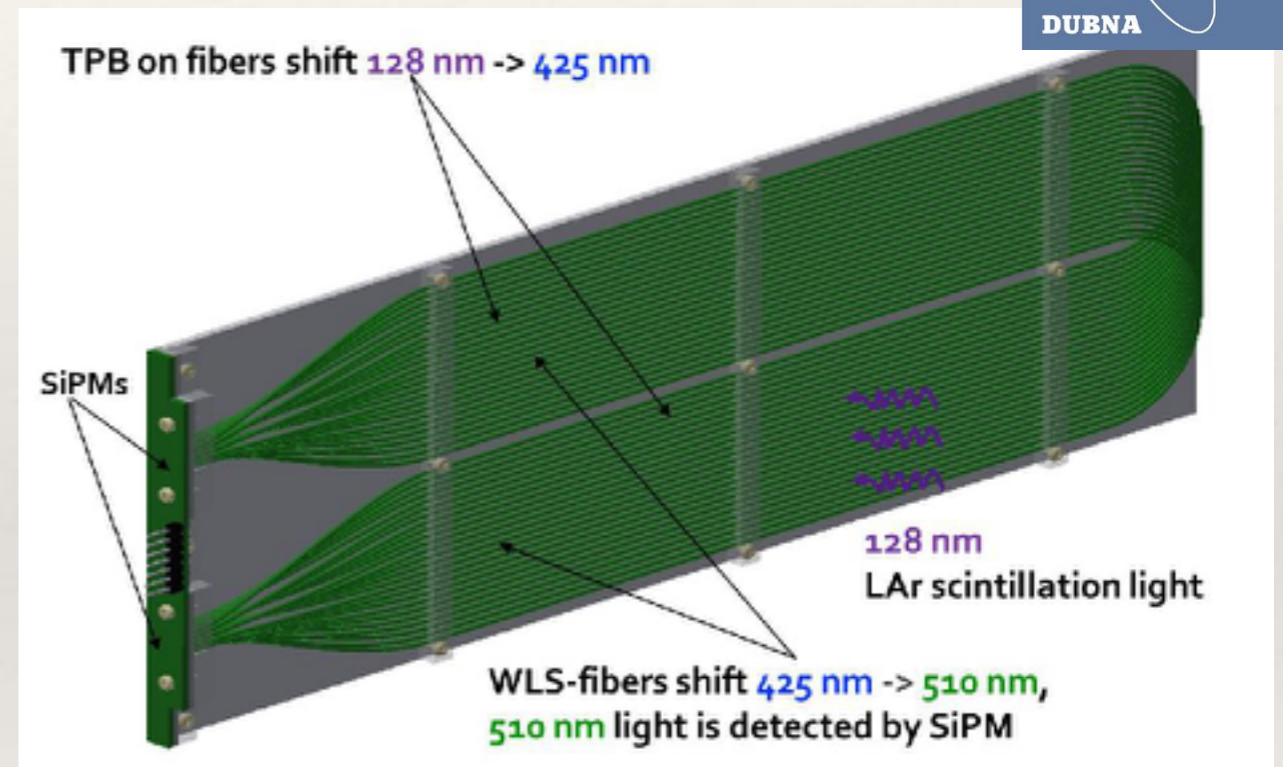
ArCLight Concept



UNIVERSITÄT BERN

SiPM

LCM Concept



- + Provides more rigid construction
- + Better spatial resolution
- + Thickness from 4 mm. Currently - 10 mm.
- Can lose PDE for scaling up.

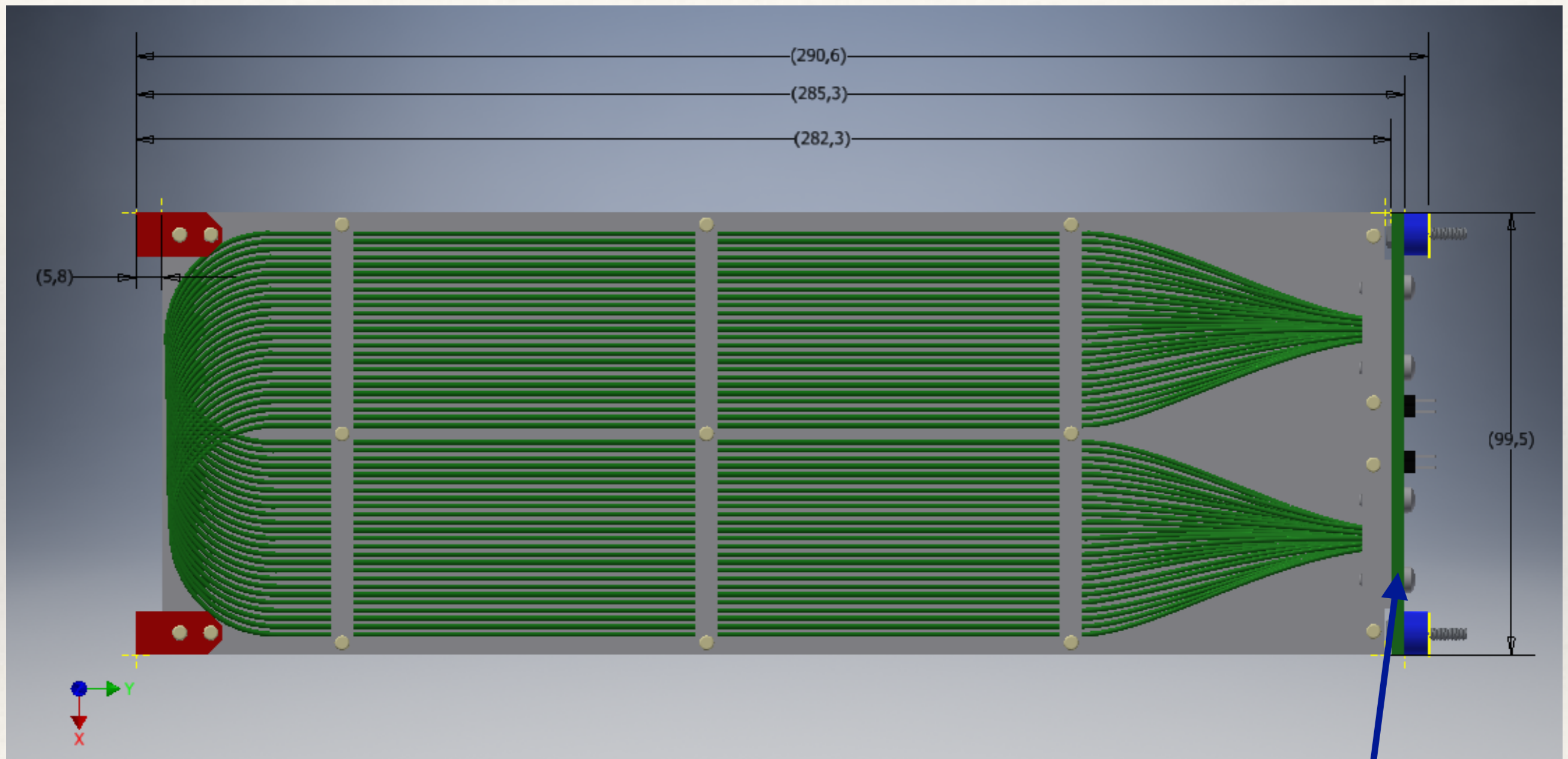
- + Easy to scale -> Fibers have long attenuation
- + Doesn't lose efficiency (PDE) with scaling up. PDE ~ 1 - 2 %
- Thickness ~ 10 mm

# ArCLight production

- ❖ 10 mm WLS-plastic, dichroic/mirror films, and TPB are available at UniBe for ArCLights production
- ❖ 50 SiPMs(6x6 mm<sup>2</sup>) of SMD-type were received from Dubna (for 8 ArCLights)
- ❖ **Price ~ 400 USD each**



# LCM design



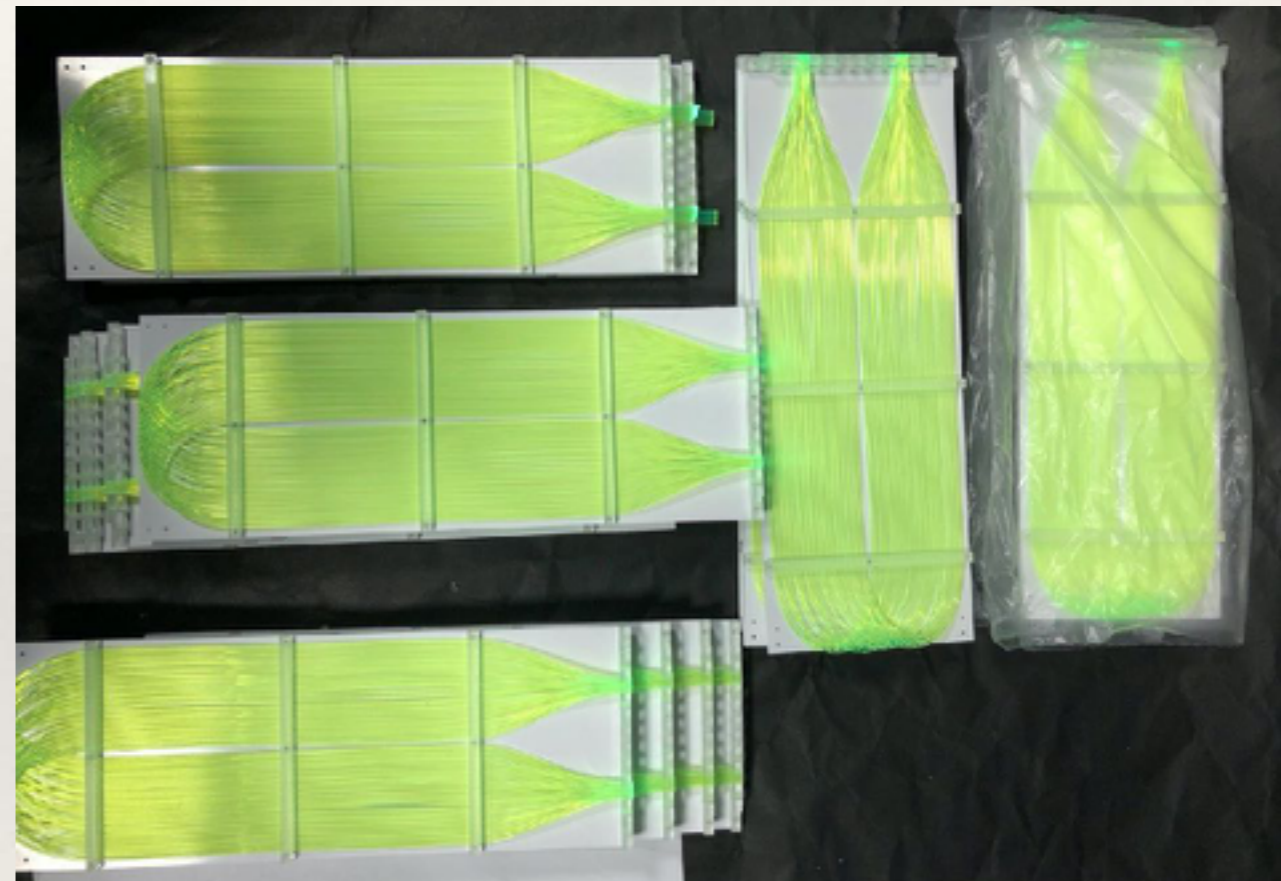
Red tips are used to fix LCM at cathode bracket

PCB with SiPMs



# LCM production

- ❖ JINR has produced 28 LCM already
- ❖ We have received 2km of the Kuraray WLS fibers. Now ~3 km available@JINR
- ❖ TPB and Bis-MSB are in Dubna.
- ❖ JINR have 120 SiPMs(6x6 mm<sup>2</sup>) SMD type and 120 Ceramic case type
- ❖ Prototyping - 2 pcs / day
- ❖ ~ **300 USD/LCM**

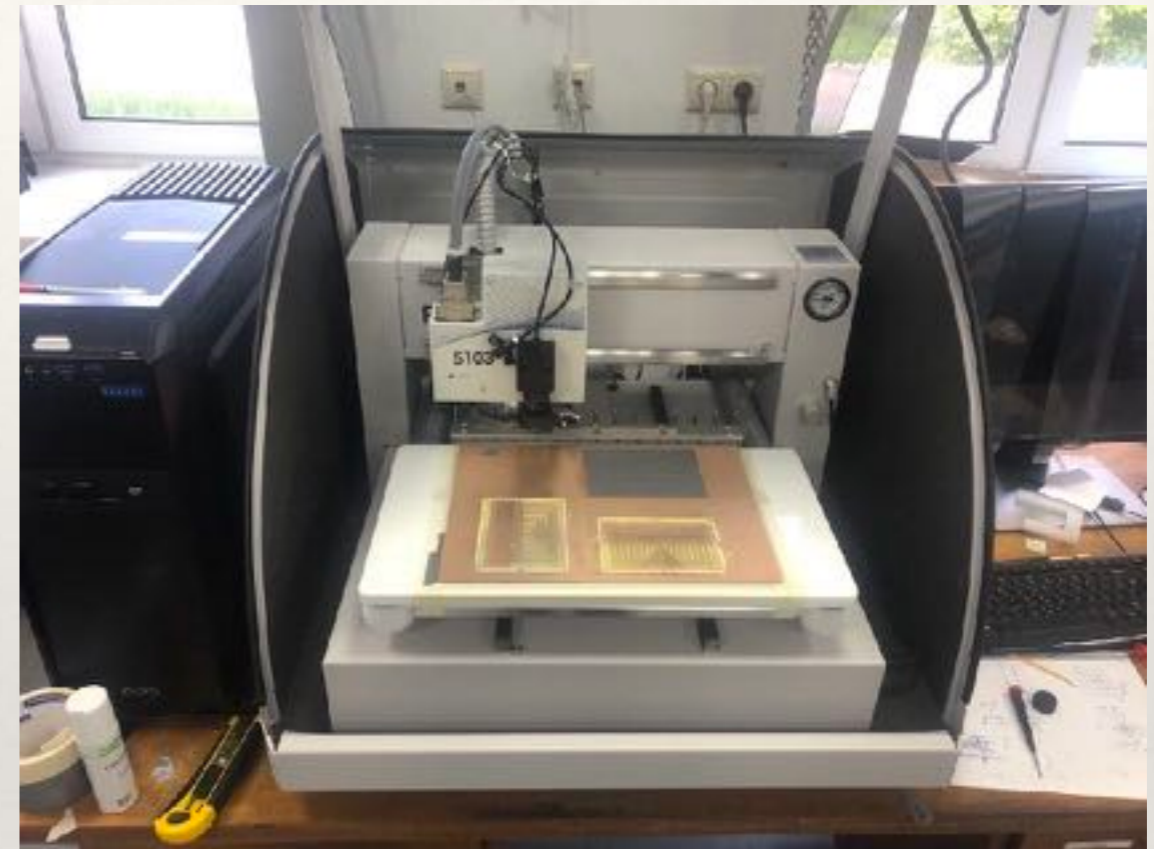


# CNC Machinery @ JINR



CNC - Milling machine  
to produce components for LCM

We are going to produce all  
mechanical components in our lab

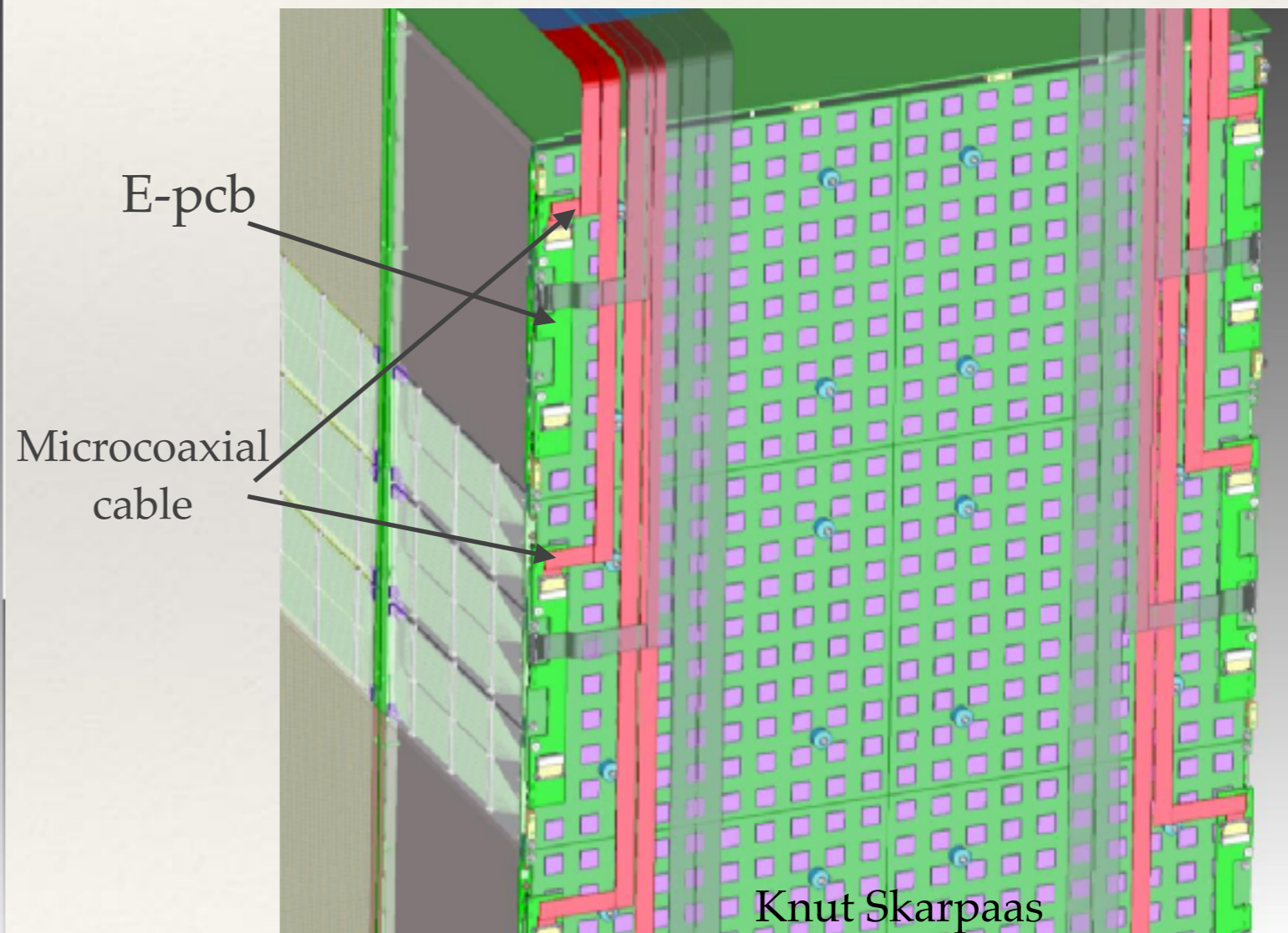
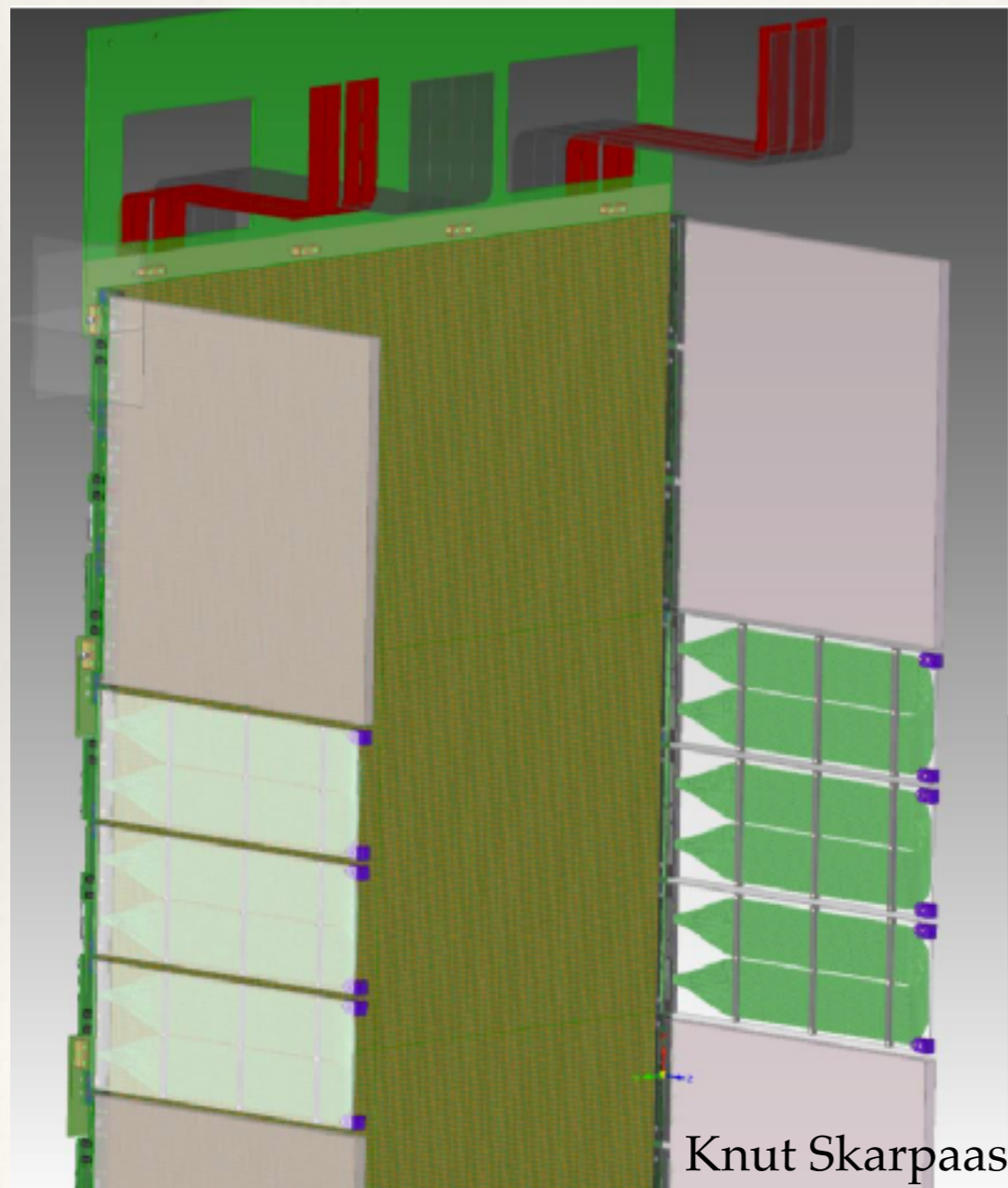


Fully automatic CNC-Milling  
For PCB prototyping and precise components

PCB will be printed, SiPM SMD-mounted  
at JINR electronics facility or  
on Outside company

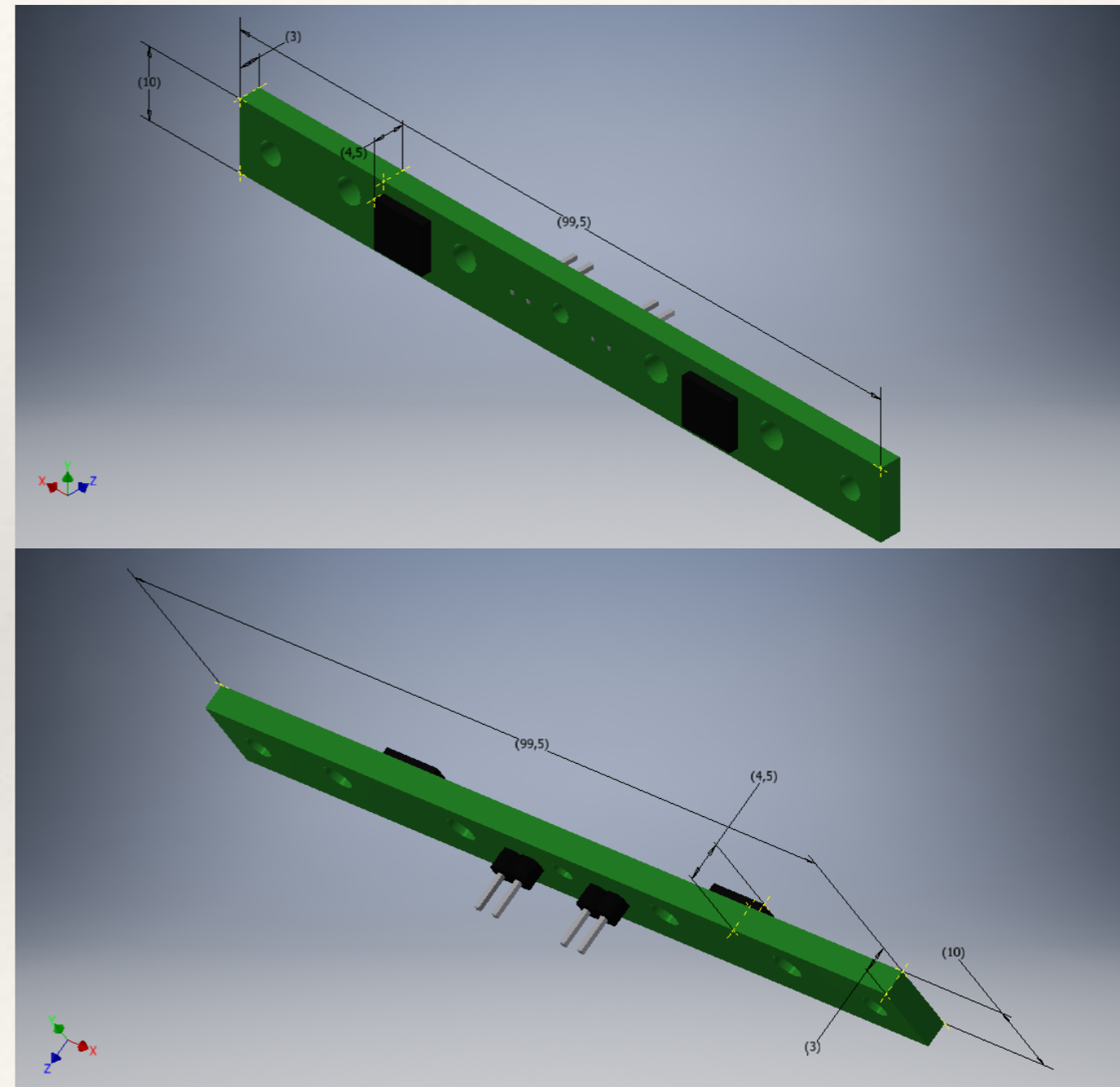
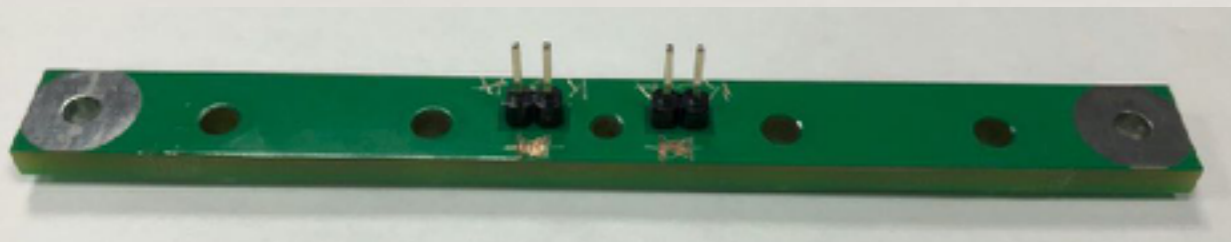
# LCM/ArcLight layout

- 3 LCM/1 ArcLight are alternated at the TPC. 24 LCMs and 8 ArcLights per TPC
- Floating ends are limited by brackets at the cathode plane

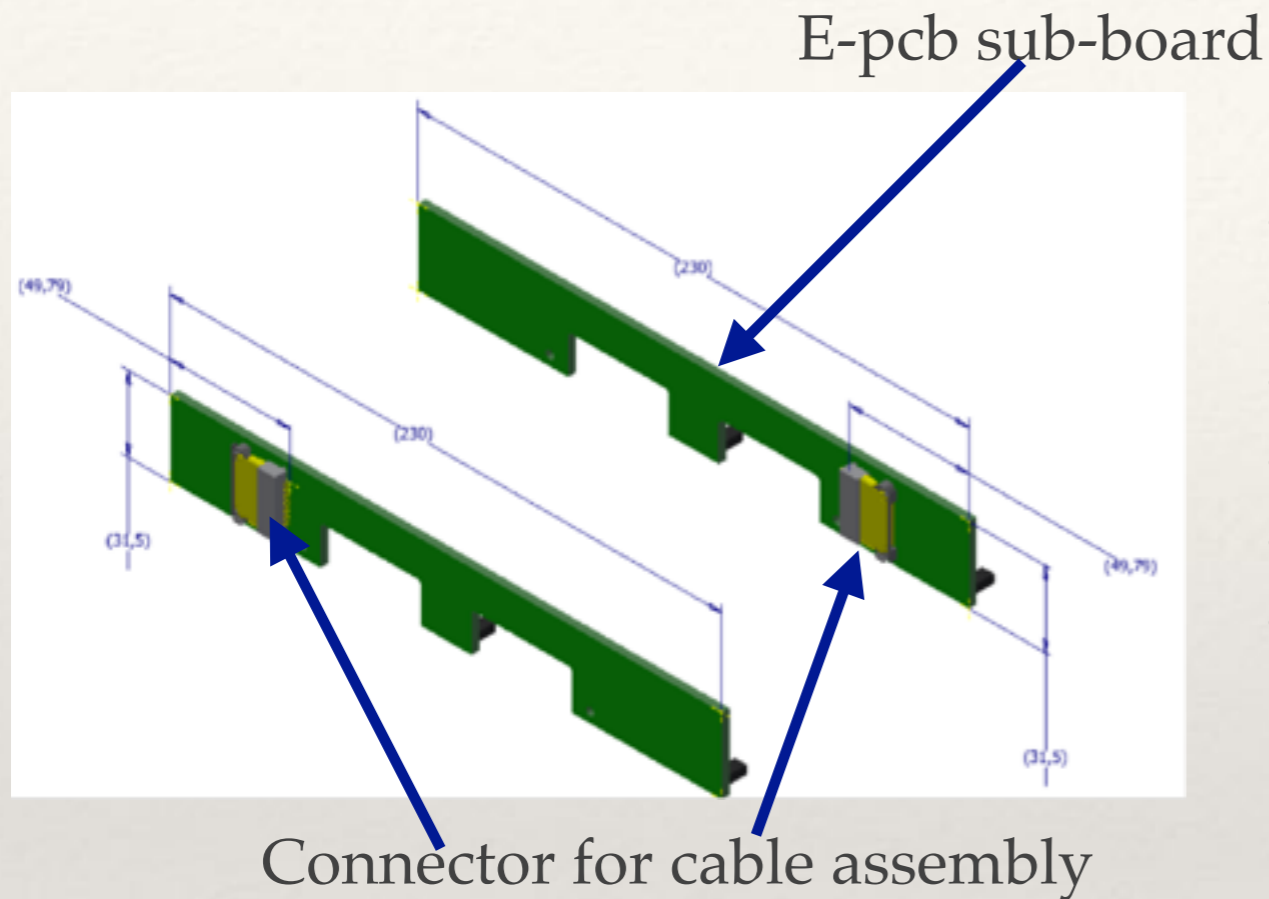


# PCB with SiPMs for LCM

- PCB with SiPMs is attached to the LCM
- PCB connected to E-pcb board with embedded pre-amps by means of pins
- Two types of PCB: 1 / 2 for SMD SiPM type, 1 / 2 for Ceramic case type (higher PDE)
- ArcLight PCB has 6 SiPM



# LCM/Arclight readout

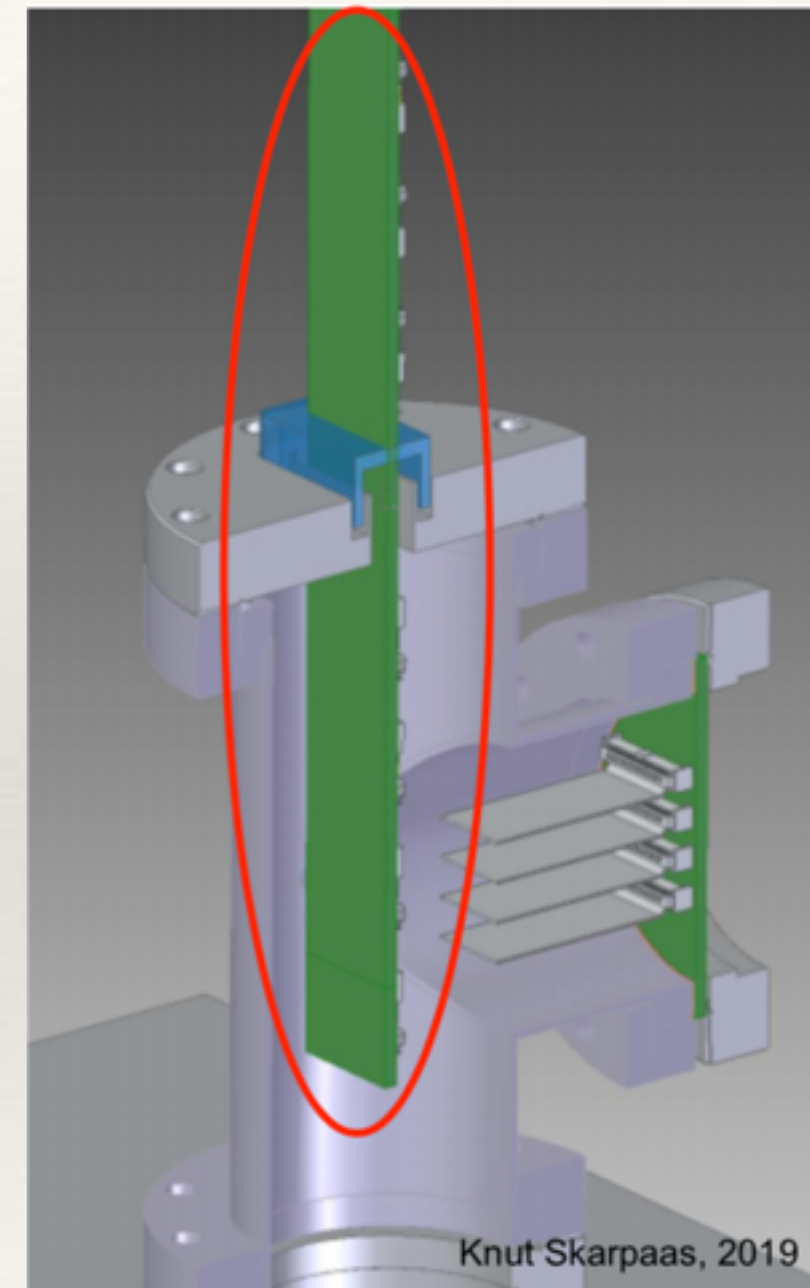


- «left» and «right» E-pcb
- 3 LCM or 1 ArCLight per E-pcb board (6 SiPMs)
- 16 E-boards / TPC
- 6 Cold pre-amps are located on the E-pcb
- 1 micro coaxial cable assembly
- Cables passes through the feedthrough

## Preamps

- Cold preamps (LMH6624) Gain ~ 5
- Power ~ 30-40~mW each @ BW of ~ 30MHZ (~10 ns rise time).
- Variable Gain Amplifier - VGA for range adjustment (MIP and single p.e)
- Summ of VGAs for self-triggering
- VGAs are adjustable for ArCLight and LCM separate
- JINR has produced pre-amps and gain variable amplifiers for all 96 ch ~ 10 USD / ch

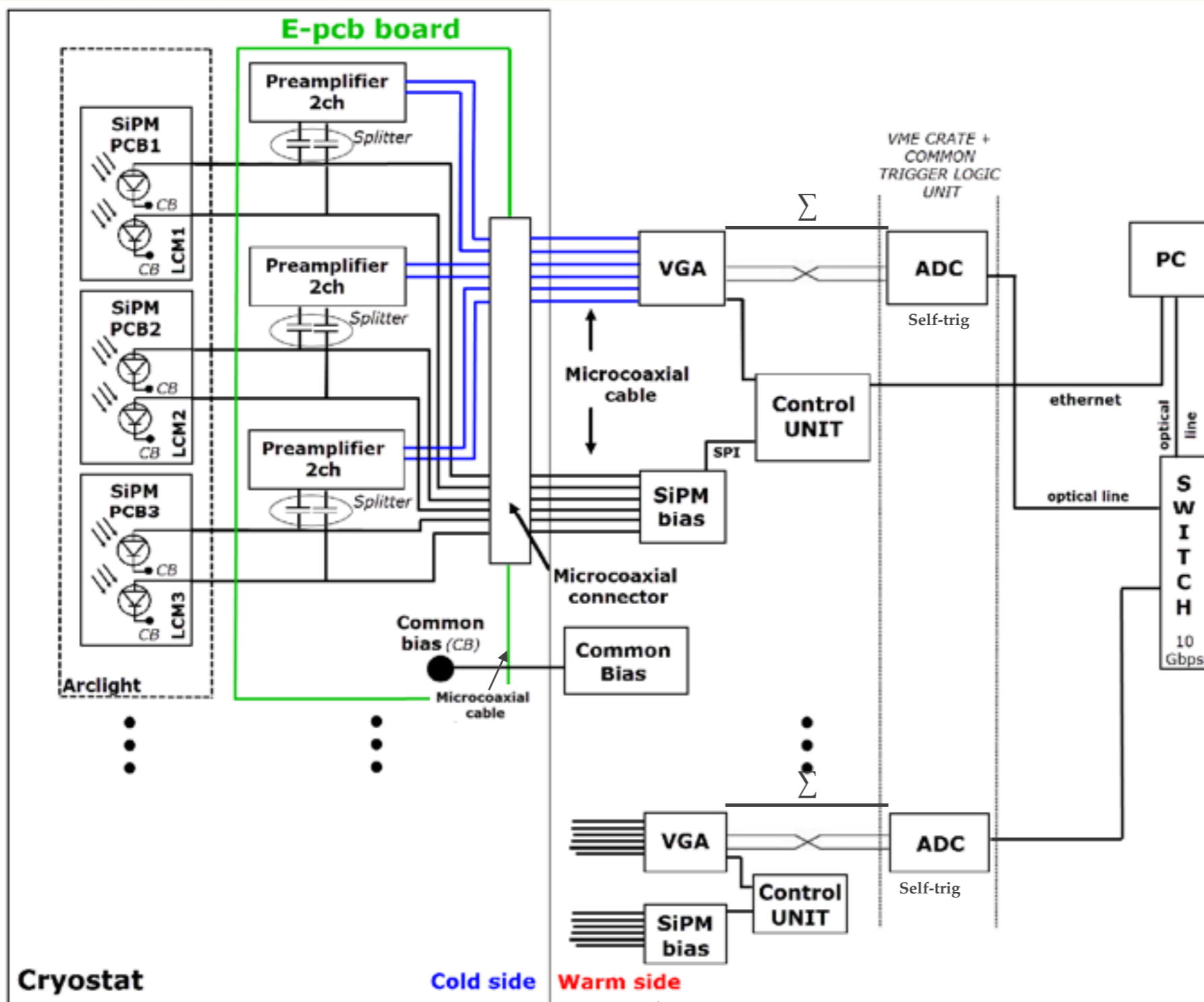
# Micro coaxial cables/feedthrough



- Samtec FCF8-20-01-L-XX.XX-S, XX.XX - cable length
- Each cable assembly is 20 micro-coaxial cables
- We have purchased 25 cables
- We have purchased 80 connectors
- ~240 USD per E-pcb (80 USD per LCM)

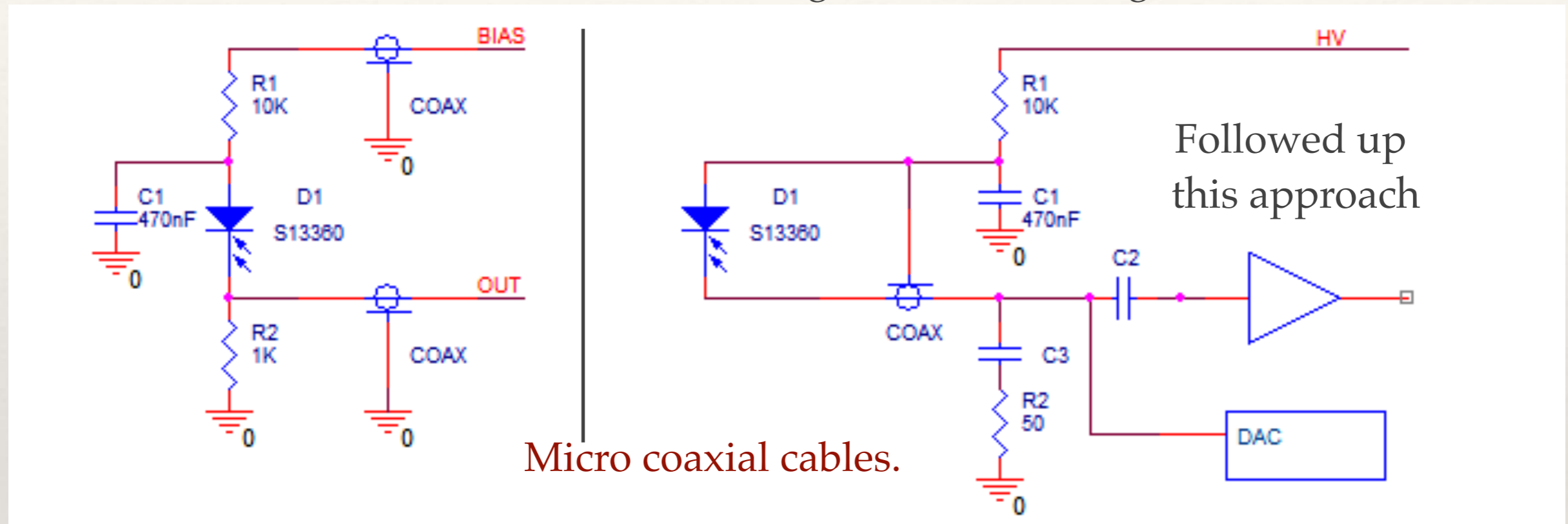
- 1 TPC = 8 ArCLight + 24 LCM = 16 E-pcb boards = 96 SiPM
- 32 FCS8-20-01-L-S-A-TR connectors: 16 - warm, 16 - cold

# SiPM readout and Trigger



# SiPM Biasing and Readout

We are considering both side biasing



One side biasing ( multi-ch PS)

Both side biasing (1 ch PS + DAC)

- + Less components - higher MTTF
- + DC coupling / direct grounding
- Expensive

- + Easy to manage adjustment
- Complex schematics - less MTTF
- AC coupling / decoupled ground (**load rate/ background rate?**)



# SiPM Power supply (JINR)



Vol #1	Vol #2	Vol #3	Vol #4
Vol	Vol	Vol	Vol
1 50	26 50	49 50	71 50
2 50	26 50	50 50	71 50
3 50	27 50	50 50	72 50
4 50	28 50	50 50	73 50
5 50	29 50	50 50	74 50
6 50	30 50	50 50	75 50
7 50	31 50	50 50	76 50
8 50	32 50	50 50	77 50
9 50	33 50	50 50	78 50
10 50	34 50	50 50	79 50
11 50	35 50	50 50	80 50
12 50	36 50	50 50	81 50
13 50	37 50	50 50	82 50
14 50	38 50	50 50	83 50
15 50	39 50	50 50	84 50
16 50	40 50	50 50	85 50
17 50	41 50	50 50	86 50
18 50	42 50	50 50	87 50
19 50	43 50	50 50	88 50
20 50	44 50	50 50	89 50
21 50	45 50	50 50	90 50
22 50	46 50	50 50	91 50
23 50	47 50	50 50	92 50
24 50	48 50	50 50	93 50



- DAC81416EVM by TI + Tektronix PWS4721
- Operating voltage up to +/-20, +40 V
- Operating: HV < 60 V, I < 20 mA.
- 16 Bit
- 10 ppm/°C
- **Price ~ 10 USD/ch (EVM)**
- Custom-made slow control
- **Reliability is being tested**



# Front-End electronics

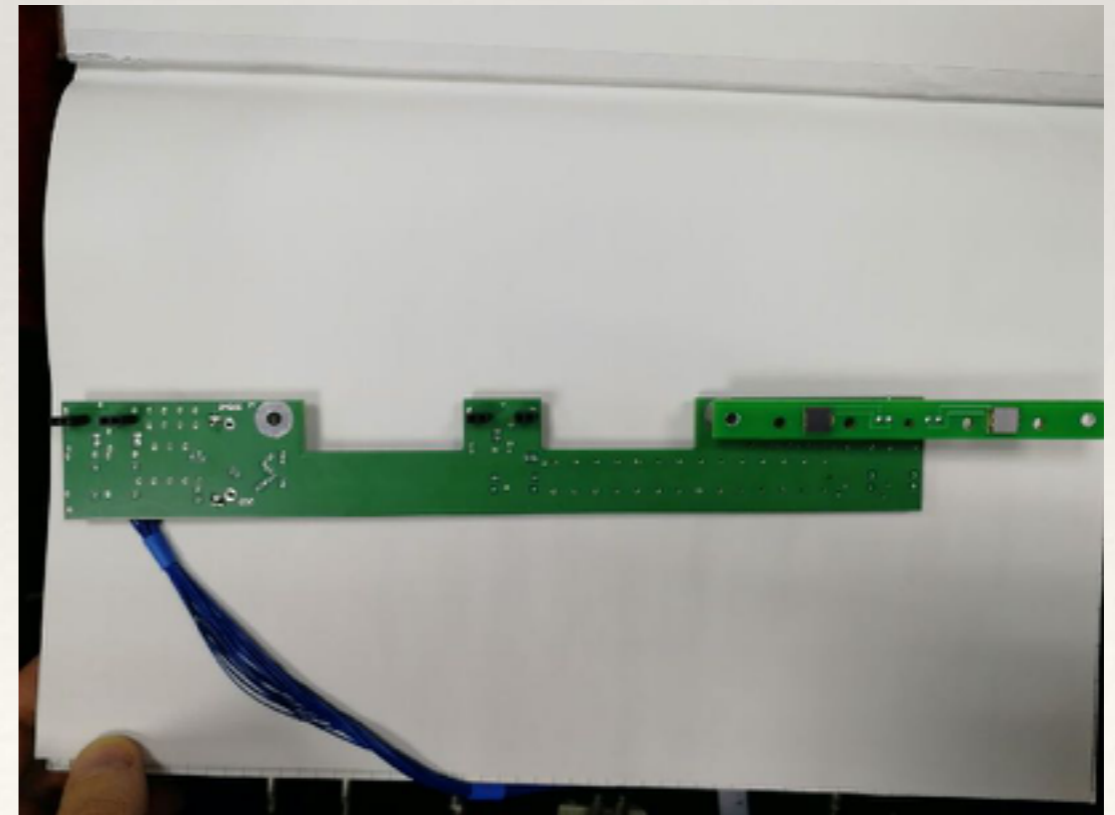
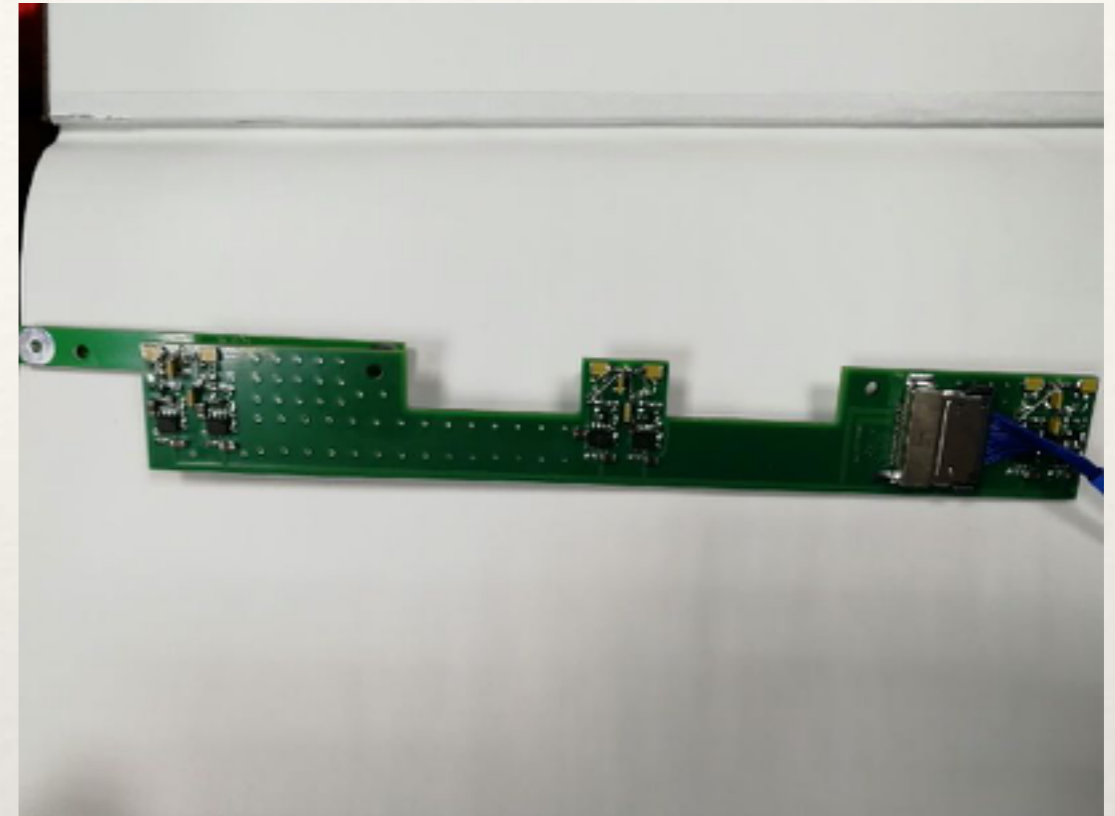
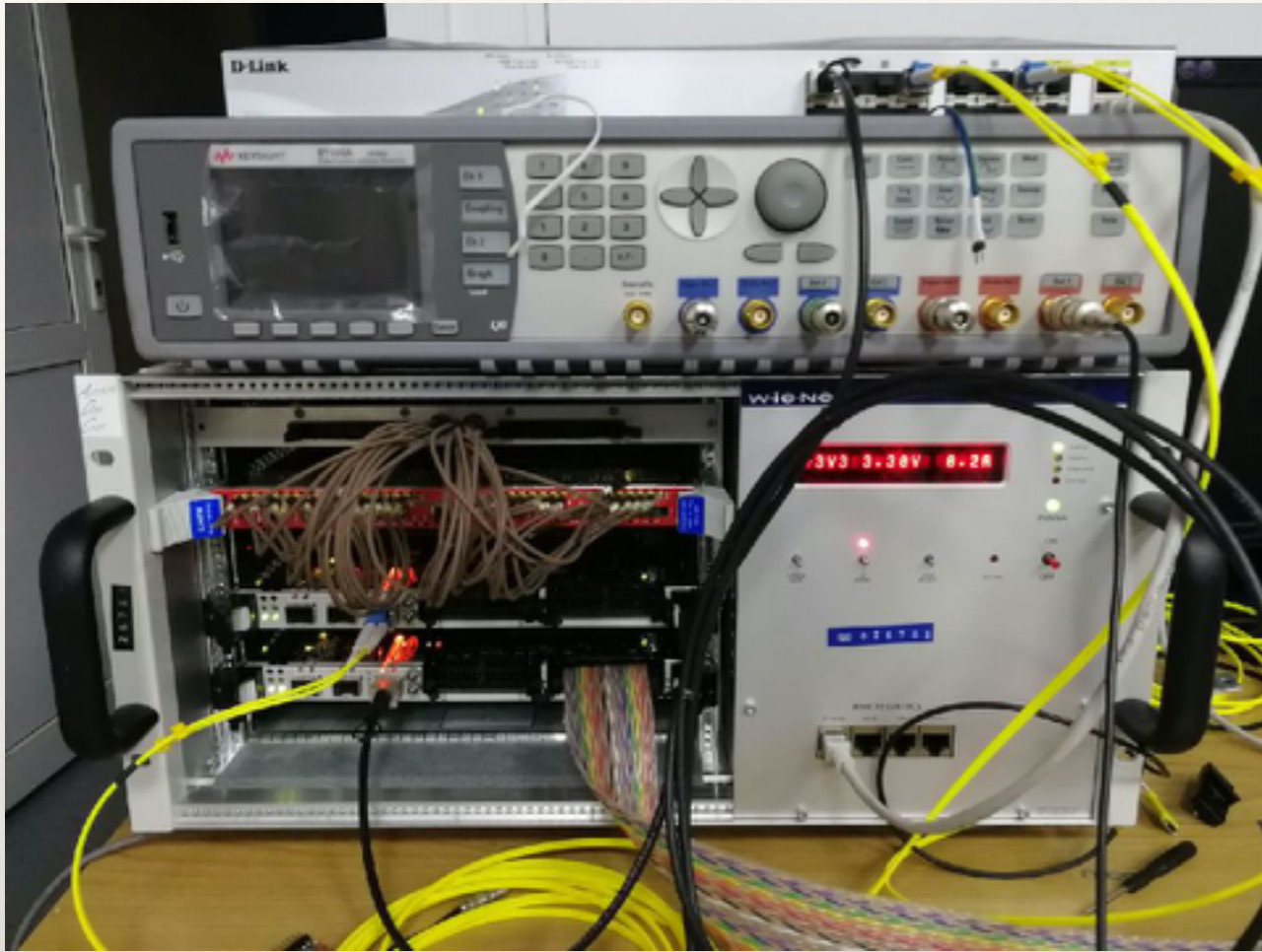
Two of JINR ADC(64 ch)

Price ~ 60 USD / ch

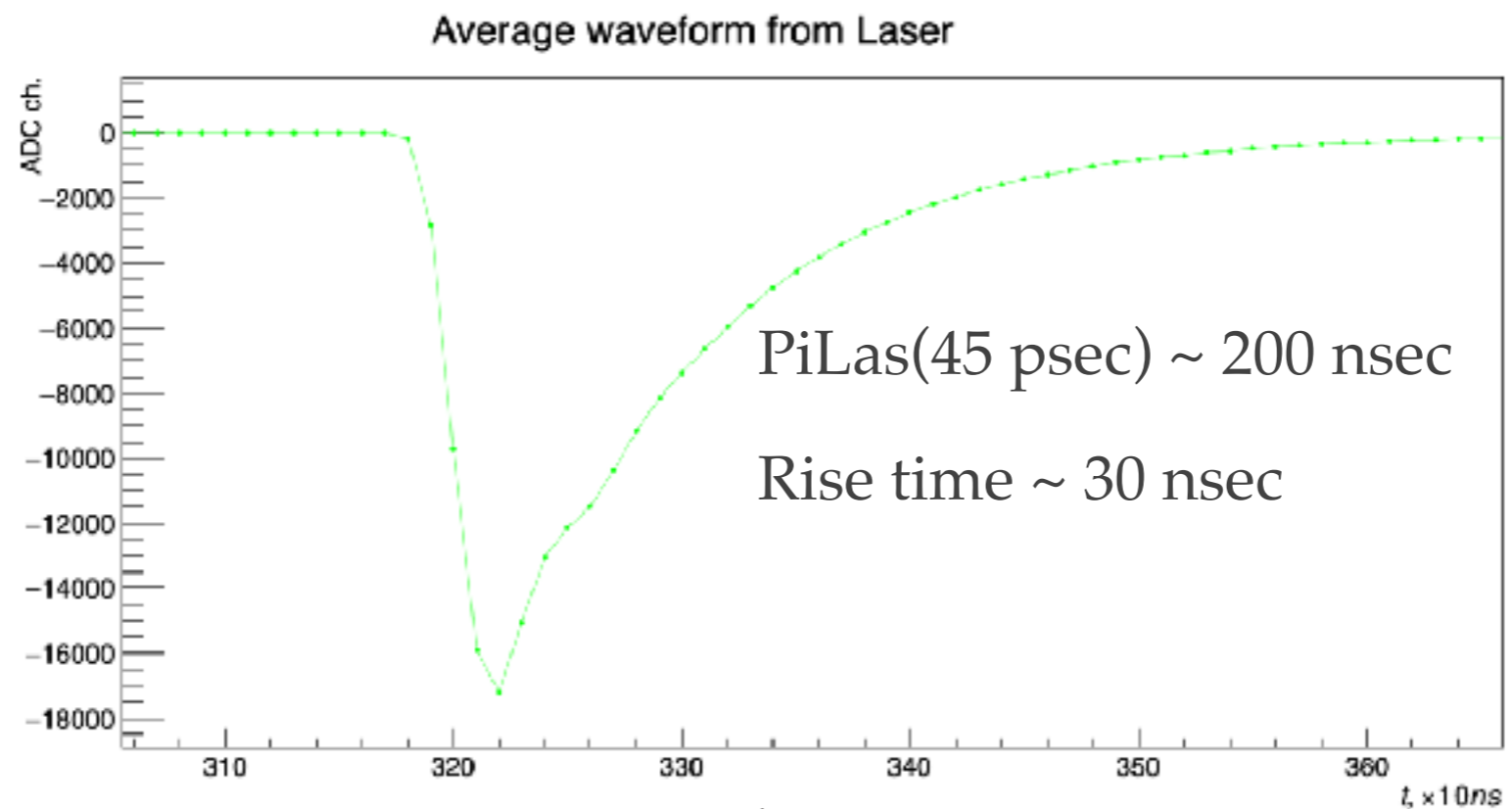
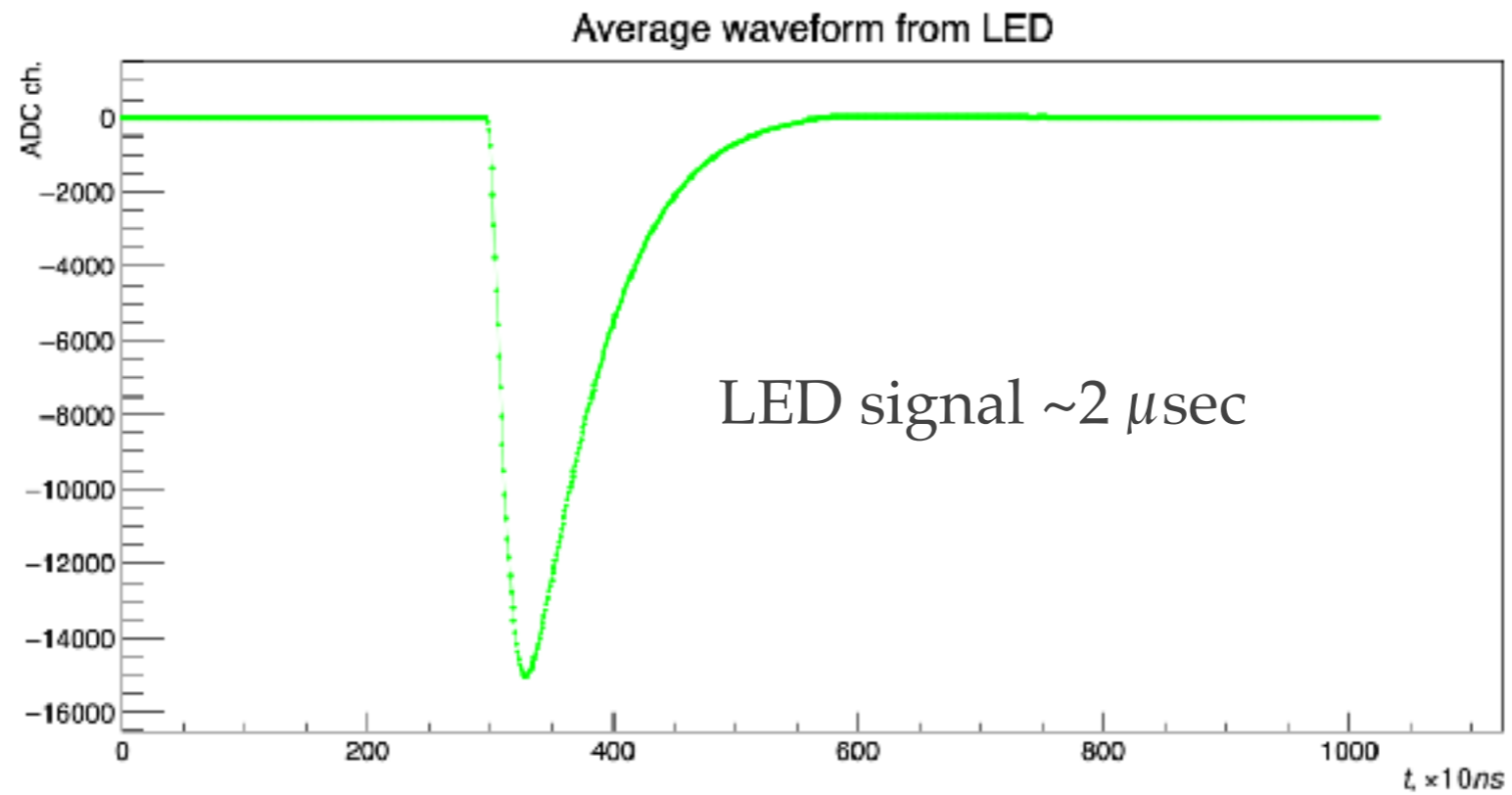
- 10-bit @ 100 MS/s (10 ns) - Buffer of 2 kSamples = 20  $\mu$ sec, full range  $\pm 0.8V$
- Analog inputs on **Diff-pairs** connectors
- **64 channels**, 1-unit wide 6U VME64 module, standalone
- VME64 and Ethernet 10 Gbps
- ADC stream UDP / TCP data packets via M-link MStream ADCs
- **White Rabbit protocol with 1 ns timestamp**
- Spill = 10  $\mu$ sec, Light pulse ~ few  $\mu$ sec, ADC window ~ 16  $\mu$ sec



# Readout chain test

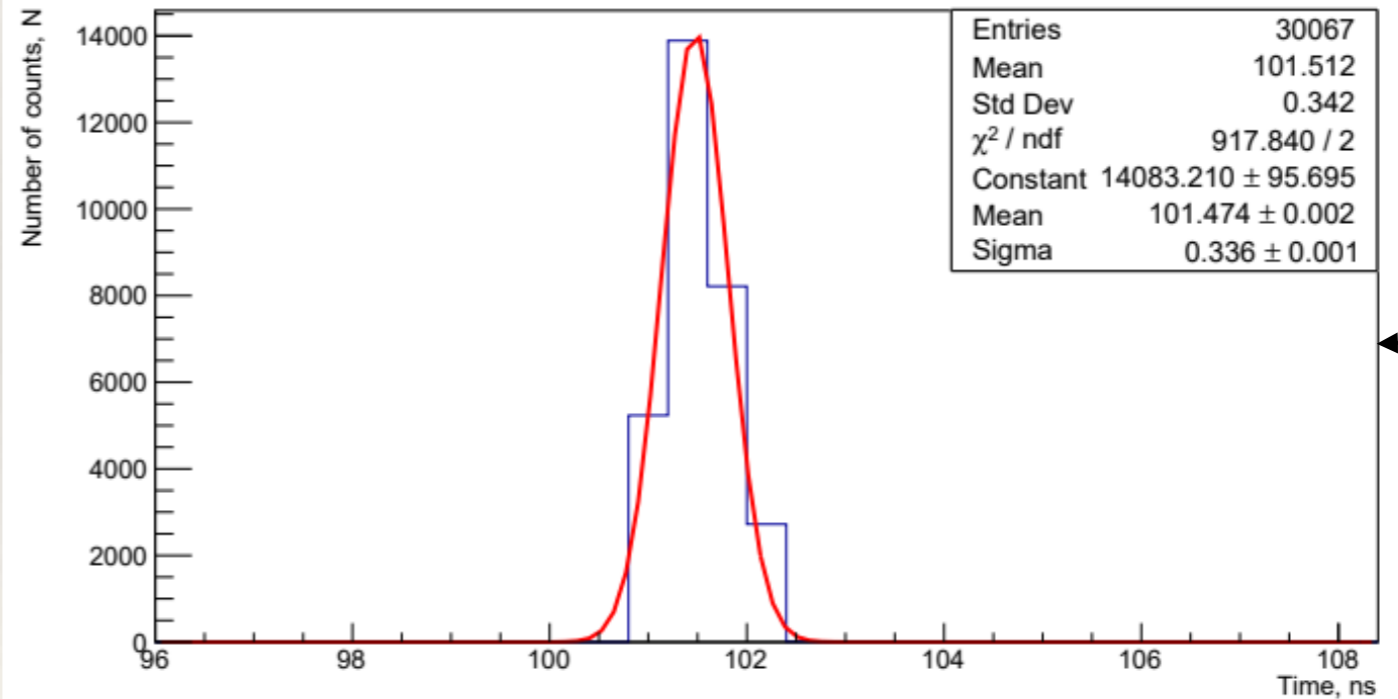
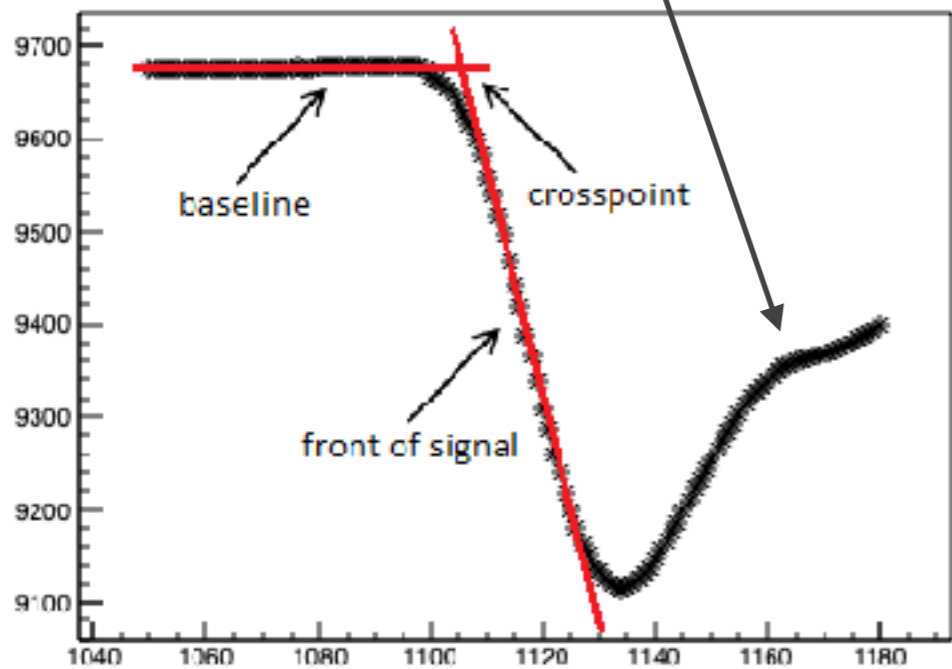
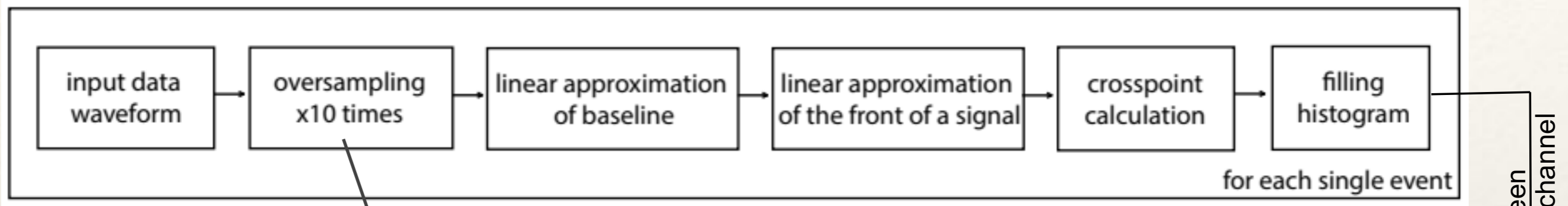


# Readout chain test



# Time measurement

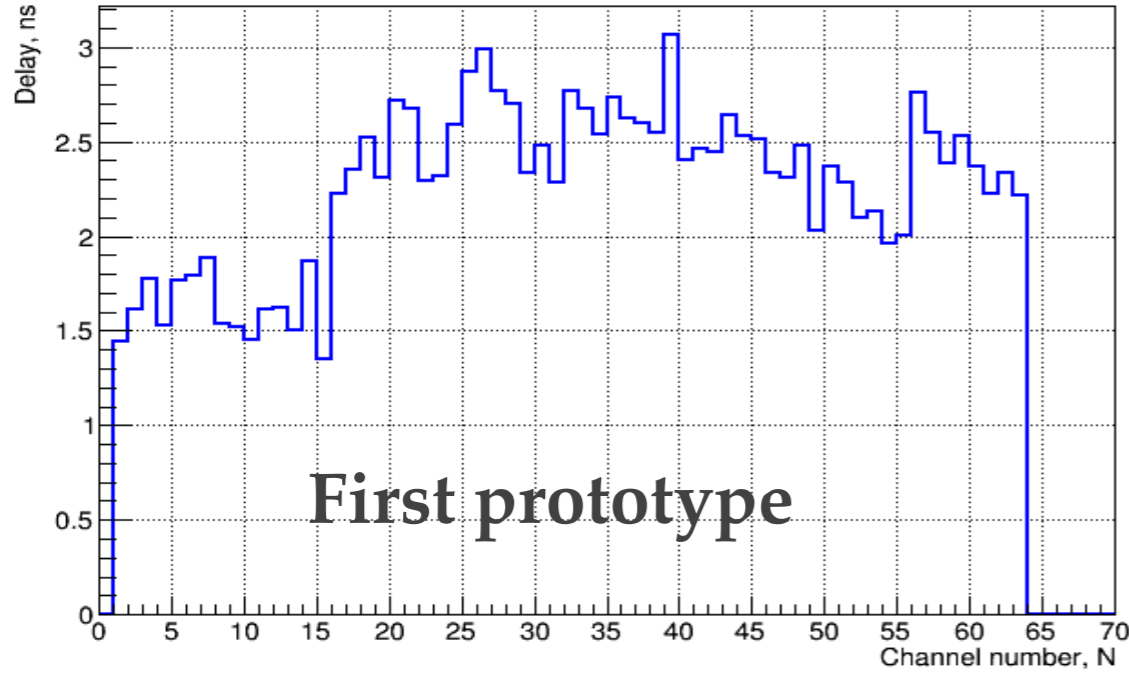
1-st approach - linear fitting procedure of baseline and front of the signal



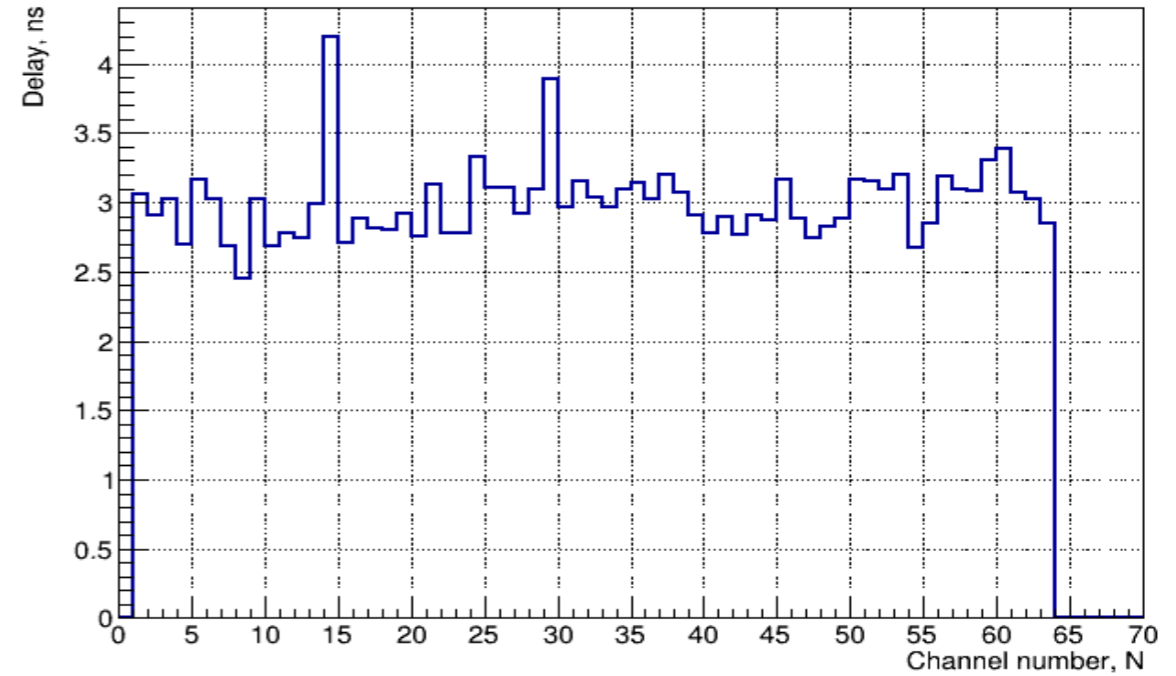
Fit error  $\sim 200\text{ps}$ , Bin width = FWHM  $\sim 500\text{ps}$ ,

# ADC's channels delays

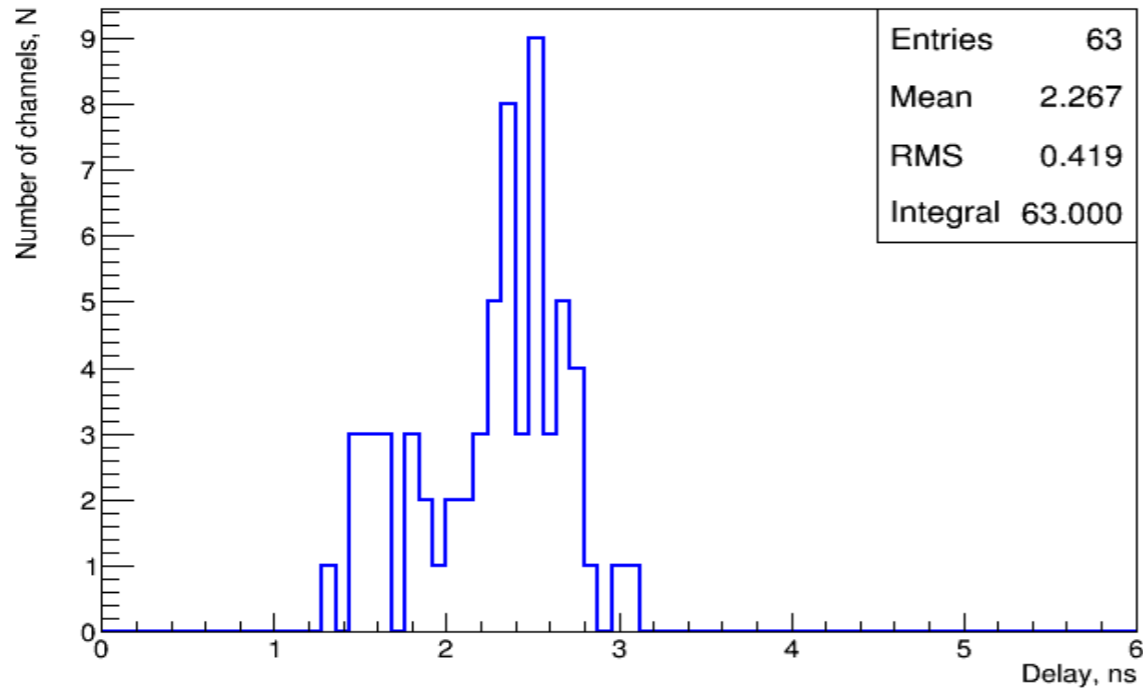
Profile of channel delays [ADC1 SN:a7af865]



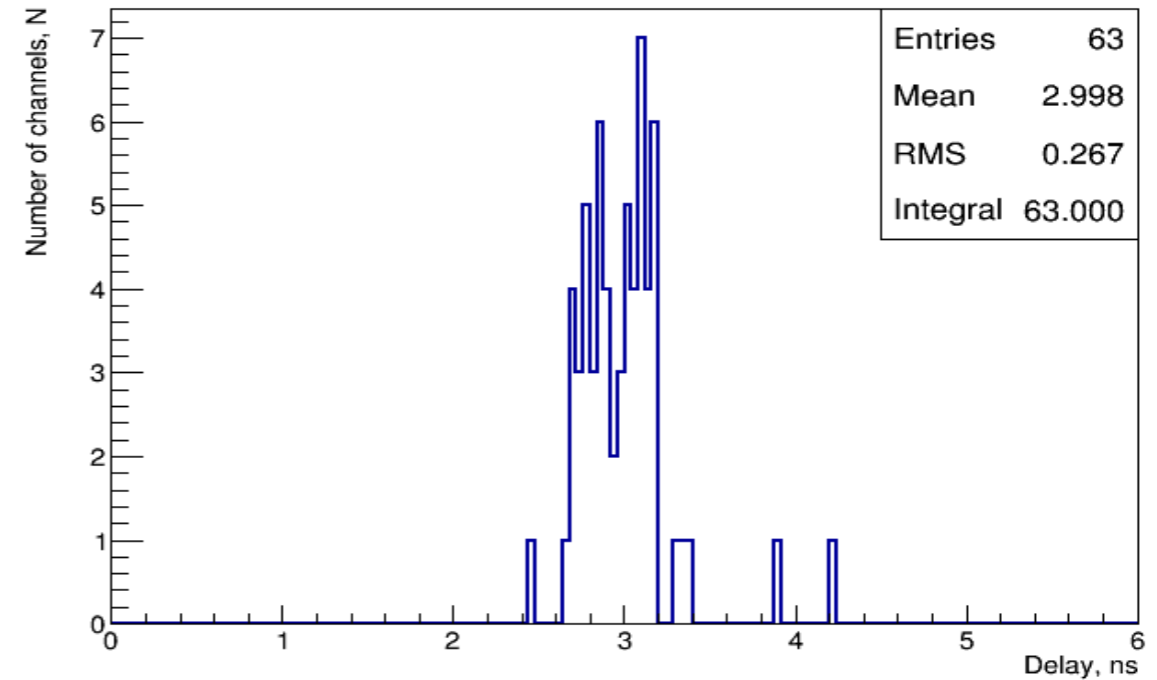
Profile of channel delays [ADC2 SN:0xA7B54BD]



Distribution of channel delays [ADC1 SN:a7af865]



Distribution of channel delays [ADC2 SN:0xA7B54BD]



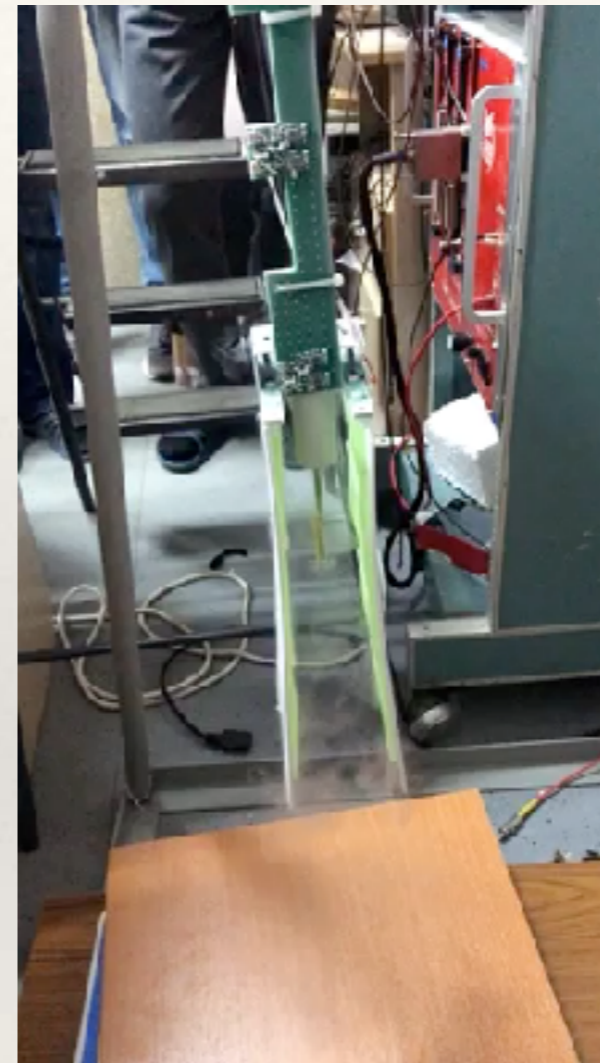
Time calibration is needed: ADC, cables, amplifiers delays

# Cryogenic stand at JINR

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



Purchase LAr from Kurchatov's Institute  
Purity of LAr at level  $10^{-5}$  -  $10^{-6}$

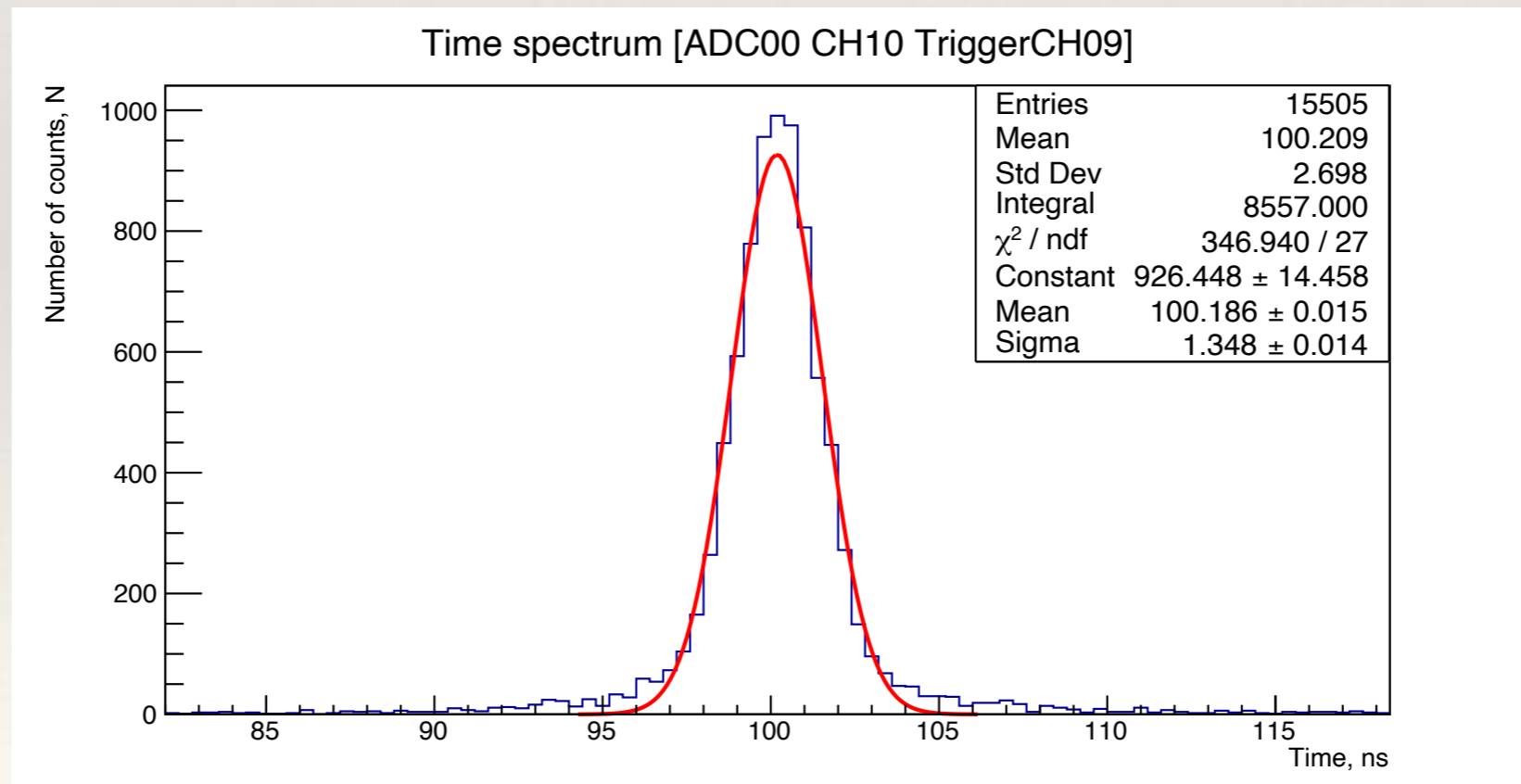
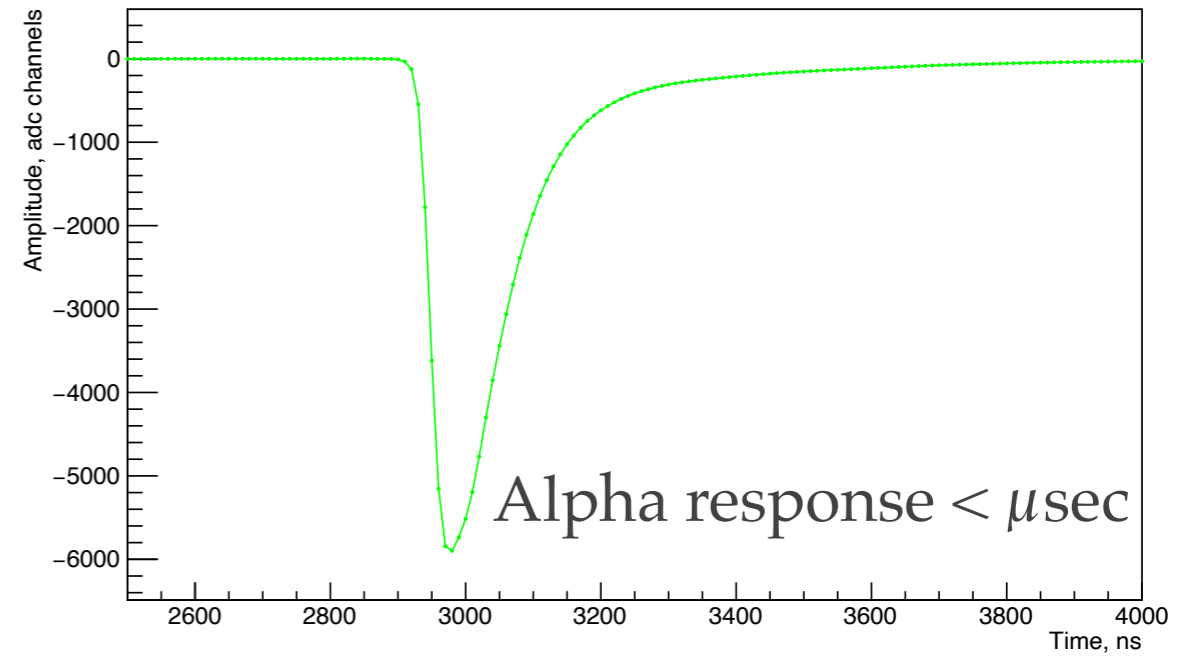
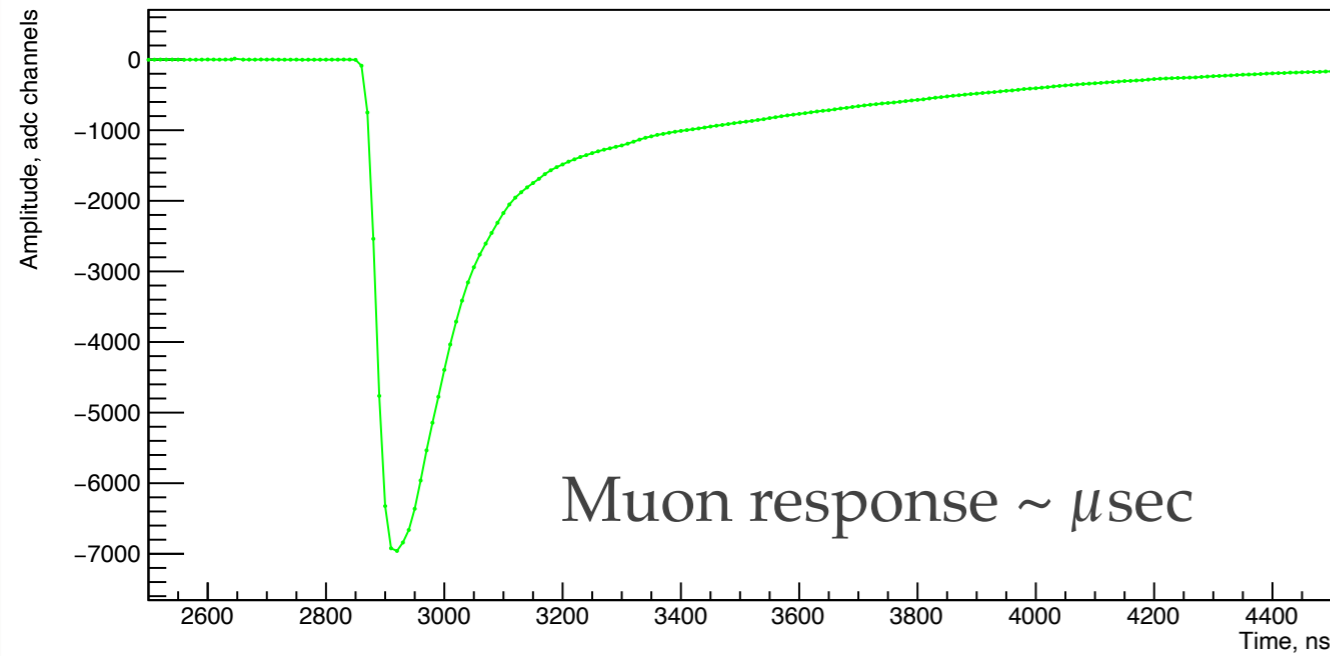


We use open  
 $^{241}\text{Am}$   $\alpha$ -source

## Preliminary

Polishing increase light yield  $\sim 5\%$  -> Use machinery cutting  
bis-MSB / TPB  $\sim 60\%$

# Readout chain test in LAr





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# Methodical group

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- ❖ Anfimov Nikolay - Group Leader
- ❖ **Selyunin Alexander - Group deputy, hardware/measurements/analysis - leader.**
- ❖ Alexander Olshevskiy - research consultant (JINR-NOvA / DUNE Leader)
- ❖ Samoylov Oleg - DetSim / research consultant (JINR-NOvA / DUNE Deputy)
- ❖ Artem Chukanov - Detector Simulations (light readout)
- ❖ Rybnikov Arseniy - software for online analysis leader / measurements
- ❖ - Albert Sotnikov - hardware / measurements / analysis
- ❖ - Butorov Ilya - software for online analysis leader asst.
- ❖ - Sharov Vladislav - analysis
- ❖ - Ksenia Kuznetsova - analysis / paper work
- ❖ Dmitriy Fedoseev - mechanics asst. / electronics leader
- ❖ - Chetverikov Alexey - mechanics asst. / electronics asst.
- ❖ Sergey Sokolov - mechanics leader
- ❖ - Chalyshev Vyacheslav - mechanics asst.
- ❖ Basil Gromov - software for slow control
- ❖ Denis Korablev - DAQ leader

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## Single TPC test (resp. N. Anfimov, A.Selyunin)

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### Shipment (K. Kuznetsova, A. Selyunin)

- ❖ 26 LCM (8 bis-MSB, 18 - TPB), 1 ADC module, Tektronix PWS4721, DAC Power supply (96 ch + 16 spare).

### ✓DAQ pre-installation (N. Anfimov, D. Korablev)

- ❖ 1 ADC + 2 LCM + Optical Card + Full readout chain for 12 channels are at Bern for Light Readout test.

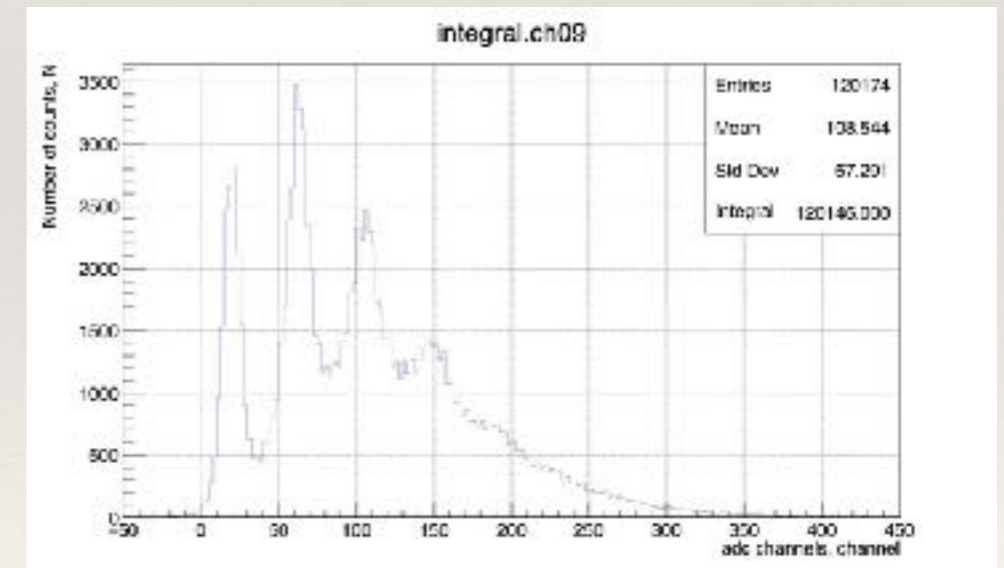
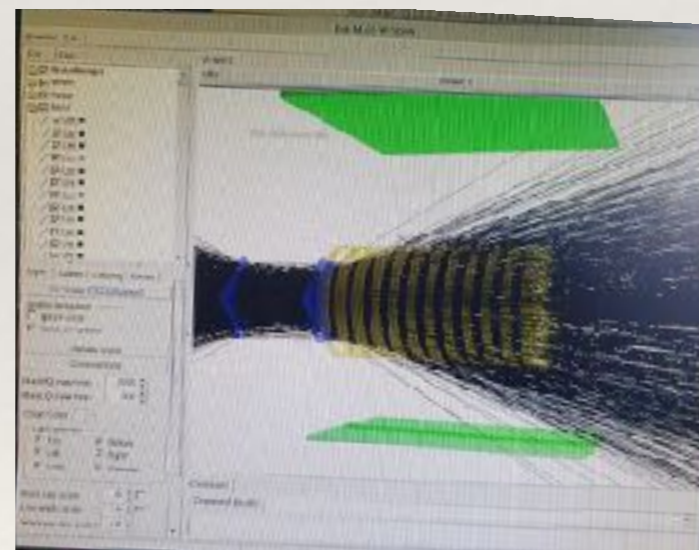
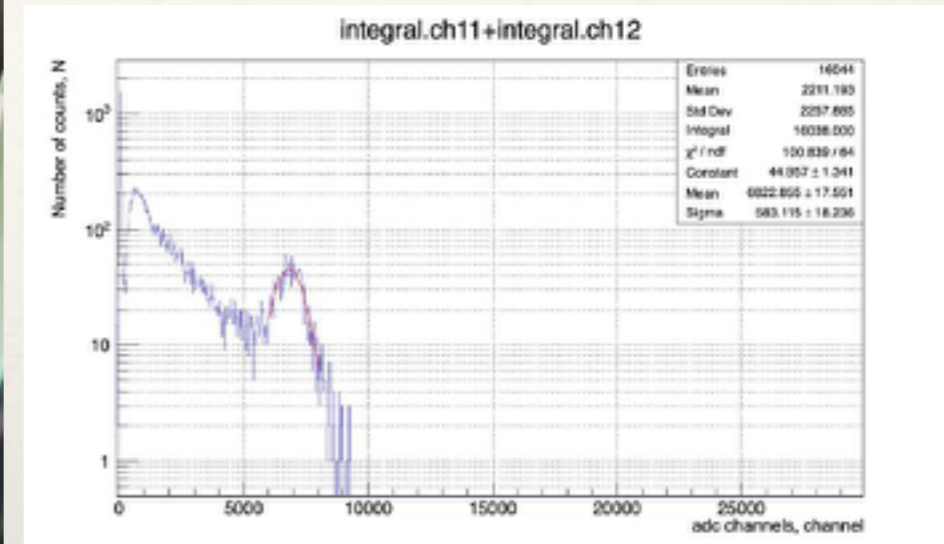
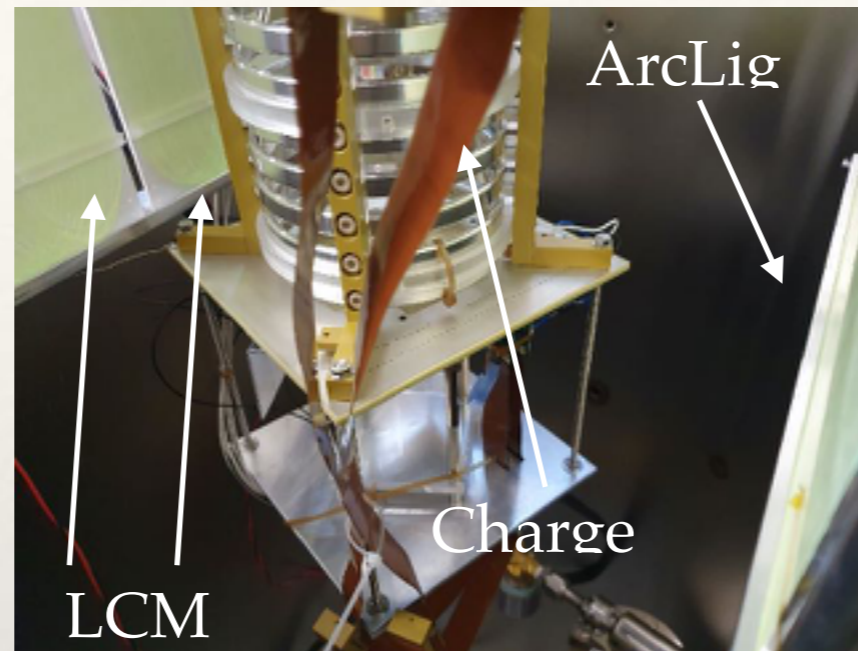
### Readout (D. Fedossev, A. Chetverikov)

- ❖ 96 VGAs+ 16 E-PCBs + SiPM Boards will be ready in May(?).

### Software (A. Rybnikov, I. Butorov, B. Gromov)

- ❖ Online analysis software is ready
- ❖ SiPM Power Slow-control is ready to use

# Tests at UniBe



- Main goal is to test LAr purification
- All Light readout chain has been tested successfully.
- **Efficiencies comparison is still not clear.** 43

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# 2x2 Tests

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1. 384 R/O channels (192 for LCM and 192 - ArcLight)
2. 96 (192) LCM and / or 32 (64) ArcLight
3. We will use 7 ADC VME modules + 1 VME trigger unit + White Rabbit switch
4. 384 Programmable Gain Amplifiers (PGA)
5. 4 modules (7 EVMs) of custom made power supply based on DACs

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# Summary.

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- ❖ Pre-test of Light R/O with LAr purity test.
- ❖ Development of the time calibration system for Light R/O.
- ❖ Single TPC test schedule for L.R/O is in good shape, **but COVID-2019**. We aim to test L.R/O system performance and compatibility with pure LAr.
- ❖ Cryogenic stand upgrade and operations @ JINR ~ 15 kUSD/year
- ❖ 2x2 Test schedule will be arranged after the single TPC test
- ❖ Total budget for 1 + 2x2 tests ~ 200 kUSD
- ❖ Further R&D for 50 cm long LCM/ArcLights ~ 50 kUSD