



*The conference of AYSS*



# Mass Characterization of SiPM Tiles for the TAO Experiment at JUNO.

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# JUNO

(The Jiangmen Underground Neutrino Observatory)

## Goals:

- Neutrino mass hierarchy measurements
- Oscillation parameters measurements
- Astrophysics and rare processes

## Location:

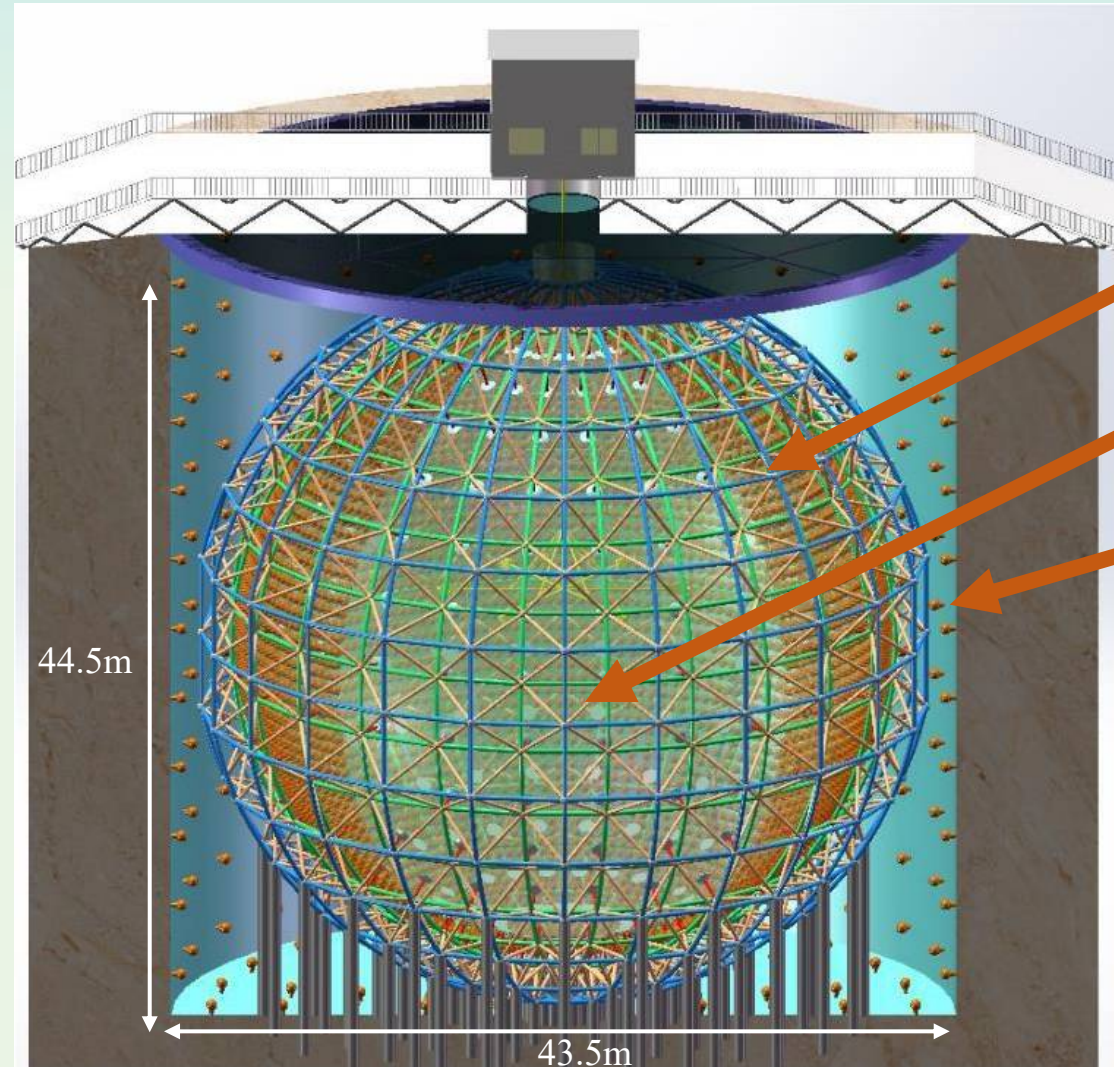


## Powerful source:

Yangjiang and Taishan power plants  
26.6 GWth in 2020, later 35.7 GWth

## Ideal baseline:

52.5 km



- Acrylic Sphere 35.4m diameter

- 20 kton liquid scintillator

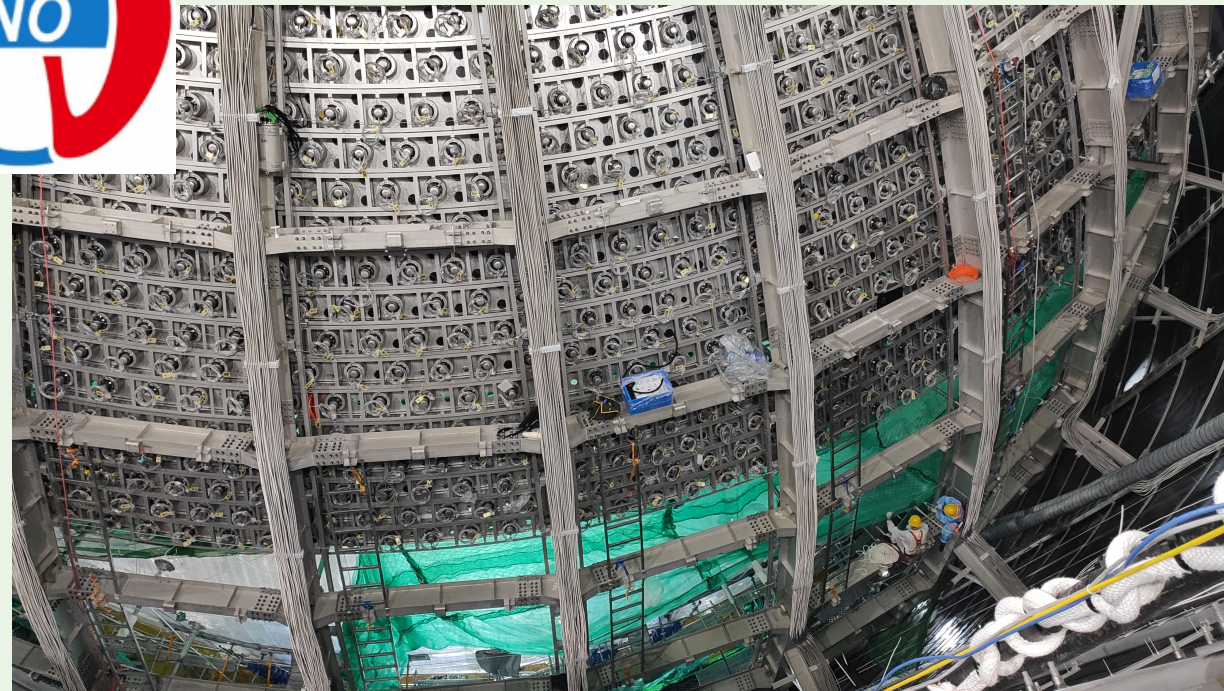
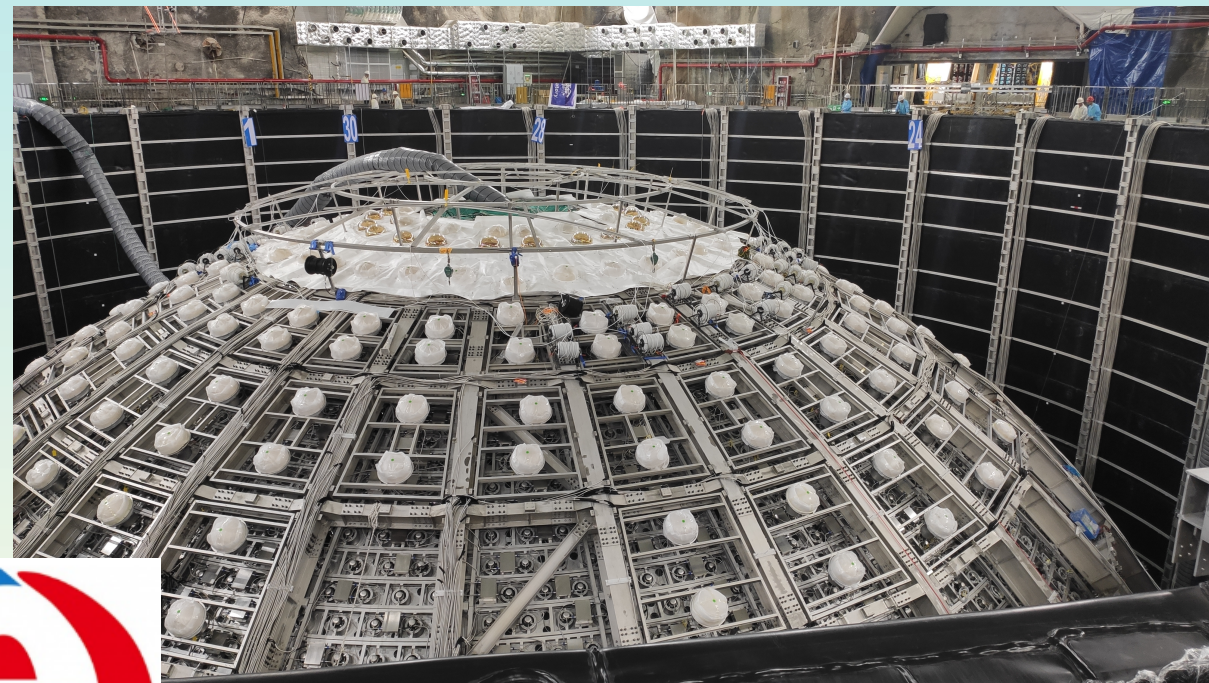
- Water Cherenkov Veto 20kt ultrapure water and 2000 20" PMTs

- About 20,000 large 20" photomultiplier tubes (PMTs)

- 25000 3" small PMTs

- 700 m underground





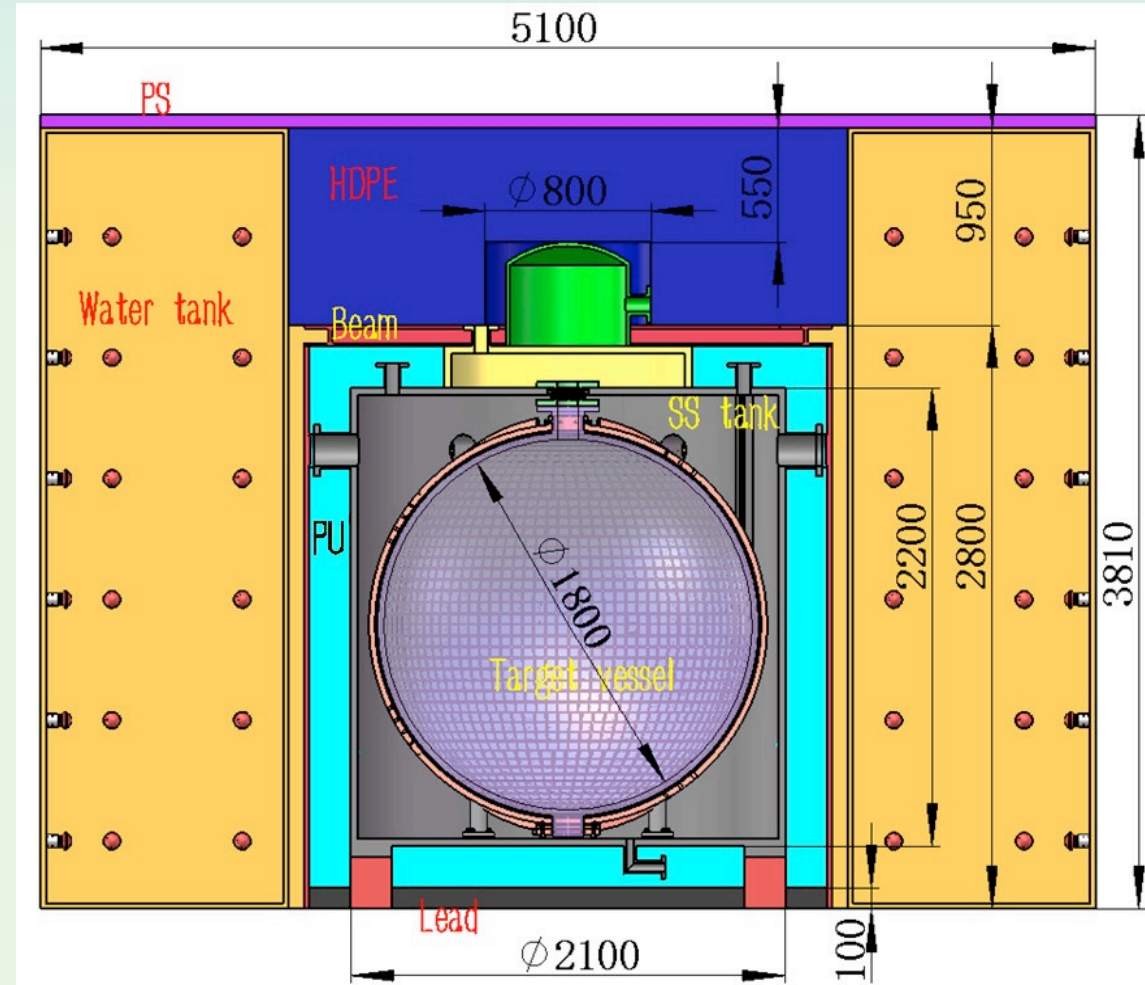


# TAO

## The Taishan Antineutrino Observatory (satellite experiment)

### The main TAO's goals are:

- 1) to measure primary spectrum for JUNO
- 2) A new benchmark for investigation of the nuclear database
- 3) Reactor monitoring: status/fuel
- 4) New physics: sterile neutrino



Schematic view of the TAO detector.

- A spherical acrylic vessel will be contain ~ 2.8 ton liquid scintillator.

- TAO will be placed at 44.15 m from a core of the Taishan Nuclear Power Plant.

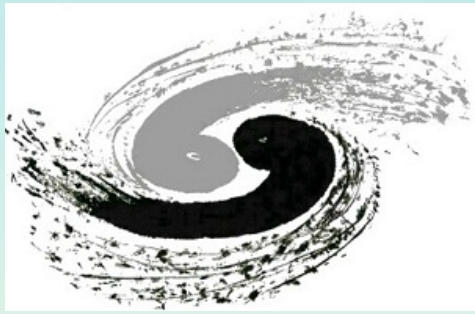
- Sphere will be covered by ~10 m<sup>2</sup> Silicon Photomultipliers (SiPMs)

- TAO will be operates at -50°C

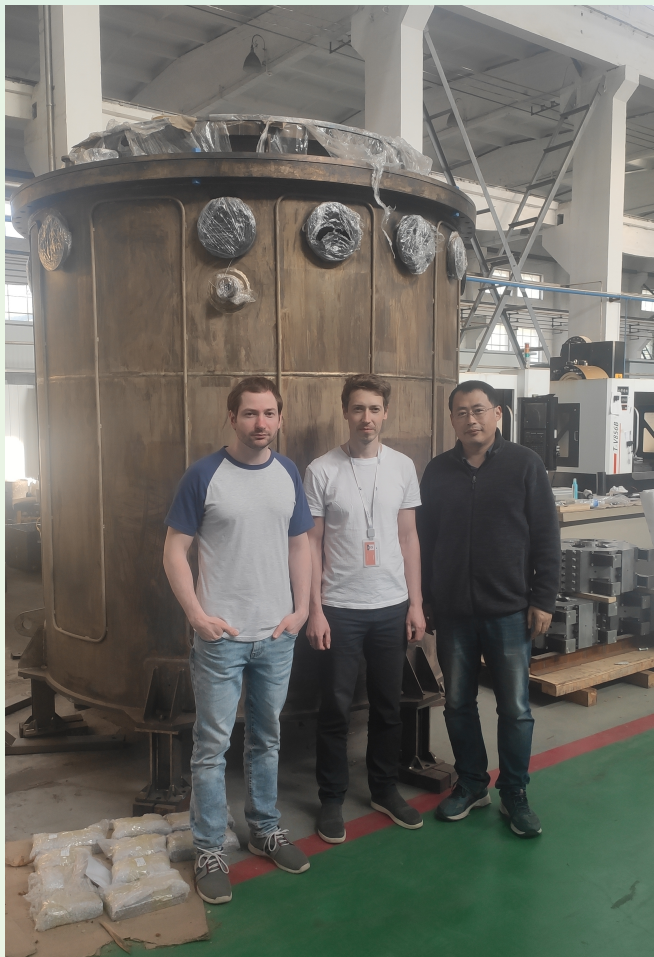
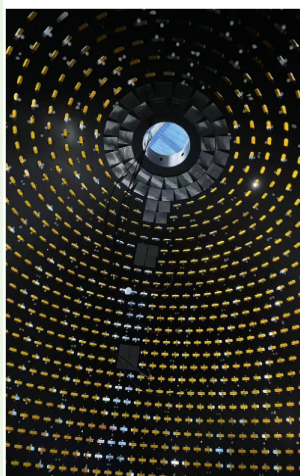
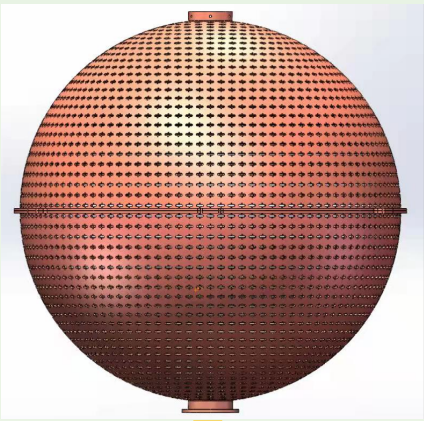
- SiPMs are grouped in tiles ~ 4100 pcs

- all tiles need to be comprehensively characterized





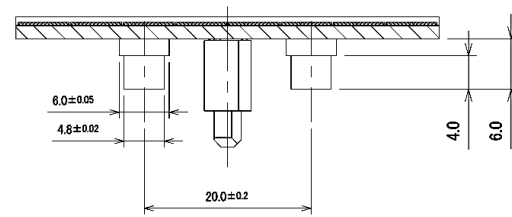
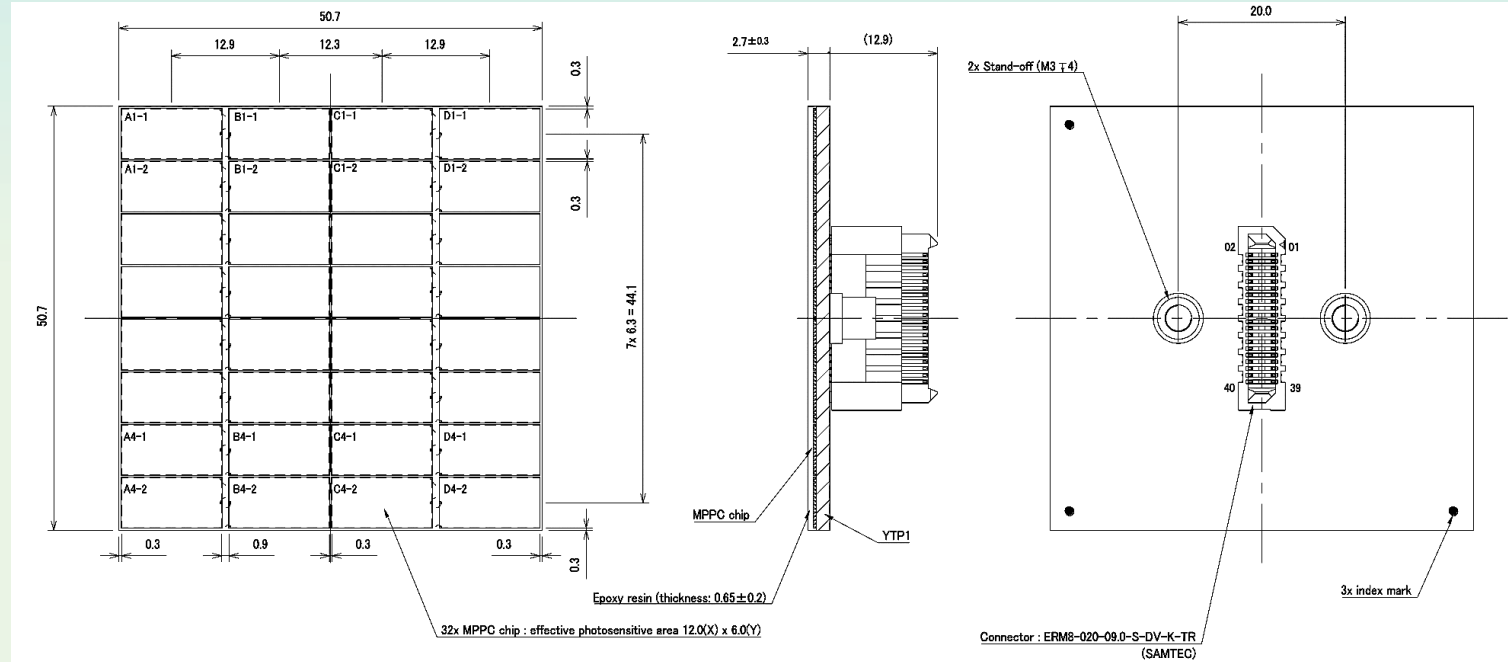
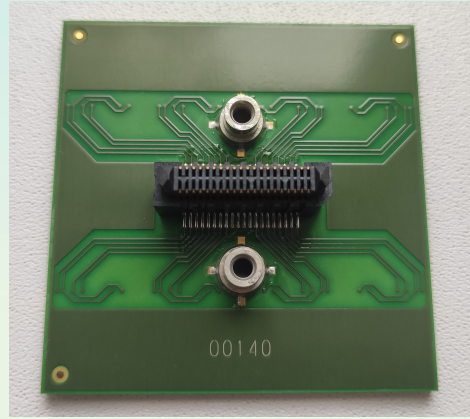
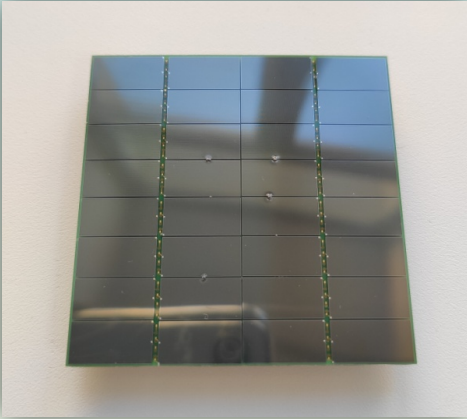
IHEP





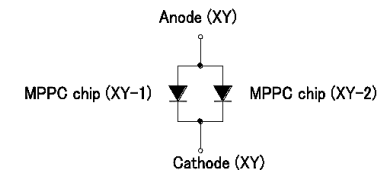
# TAO SiPM Tiles

Hamamatsu S16088



[NOTE]

1. General tolerance:  $\pm 0.1$
2. Connected each of 2 chips in parallel (X: A - D, Y: 1 - 4)

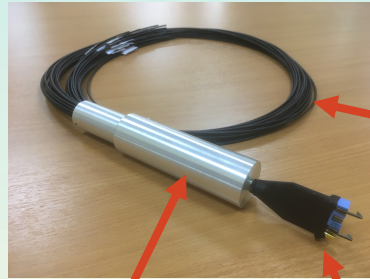


Parameters	Value	Units
Number of channels	16 (Connected 2 chips in parallel)	
Effective photosensitive area	12.0(X) × 12.0(Y)	mm <sup>2</sup> /ch.
Pixel Pitch	75	μm
PDE at 420 nm	Typ. 47	%
Breakdown voltage	53 +/-5	V
Gain	4.0 × 10 <sup>6</sup>	
Dark count rate at -50°C	Typ. 2000 / Max. 6000 (Typ. 13.9 / Max. 41.7)	cps/ch. cps/mm <sup>2</sup>
Crosstalk probability	Typ. 12 / Max. 15	%

# Requirements on SiPMs specifications

Parameters	Specification
<b>Uniformity of breakdown voltage (within Tile)</b>	within 0.19V range
<b>Dark Count Rate in each channel [ @-50°C ]</b>	< 41.7 Hz/mm <sup>2</sup>
<b>Gain in each channel</b>	>1×10 <sup>6</sup>
<b>Photon Detection Efficiency (PDE)</b>	≥ 44%
<b>Crosstalks</b>	<15%

# Scanning station design



Light splitter

Optical fibers

LED

Reference SiPMs

Interface board

Motherboard

Working position

Service position

Fibers

Diffusers

Interface PCB

Mother board

Reff.SiPM

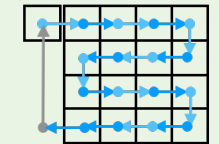
SiPM Tile

can be lifted up

60 mm along X-axis

60 mm along Y-axis

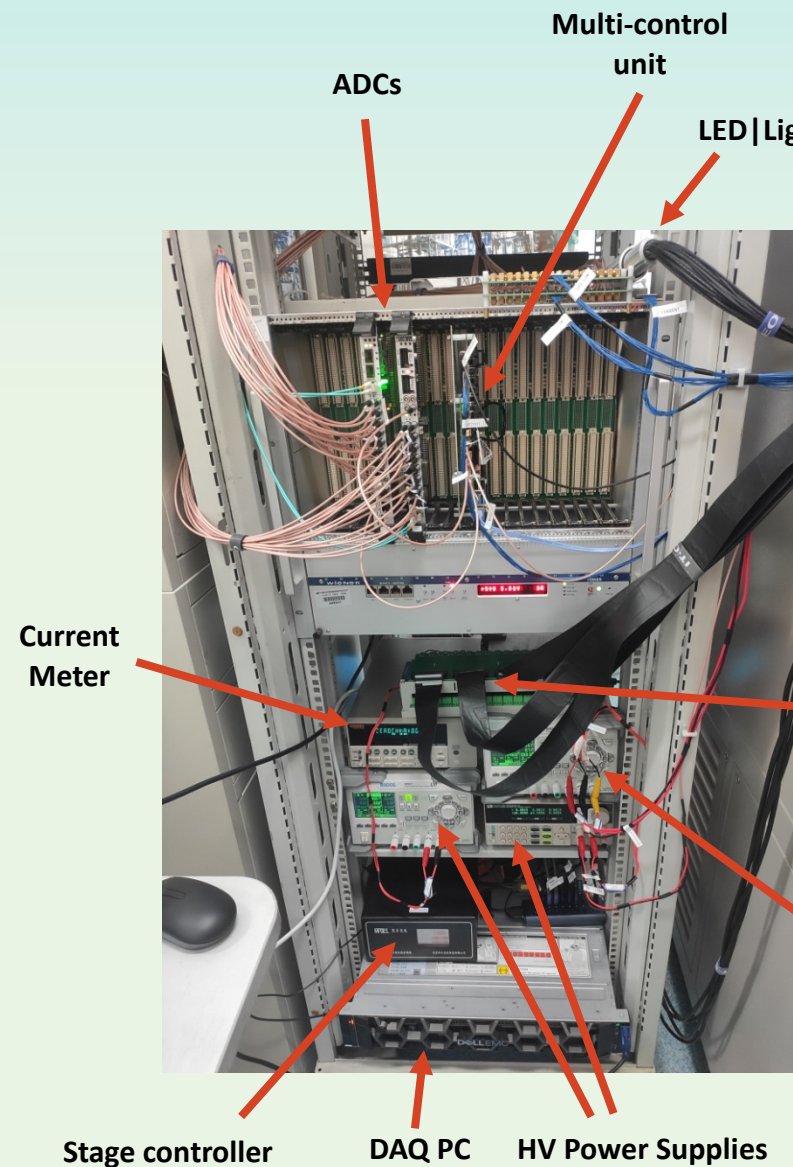
Translation stage



Free movement on two axes



# Mass-testing setup



LED | Light splitter

Optical Fibers

Environmental chamber

Tiles

Diffusers

16CH HV Multiplexer

5V Power Supply

Motherboard

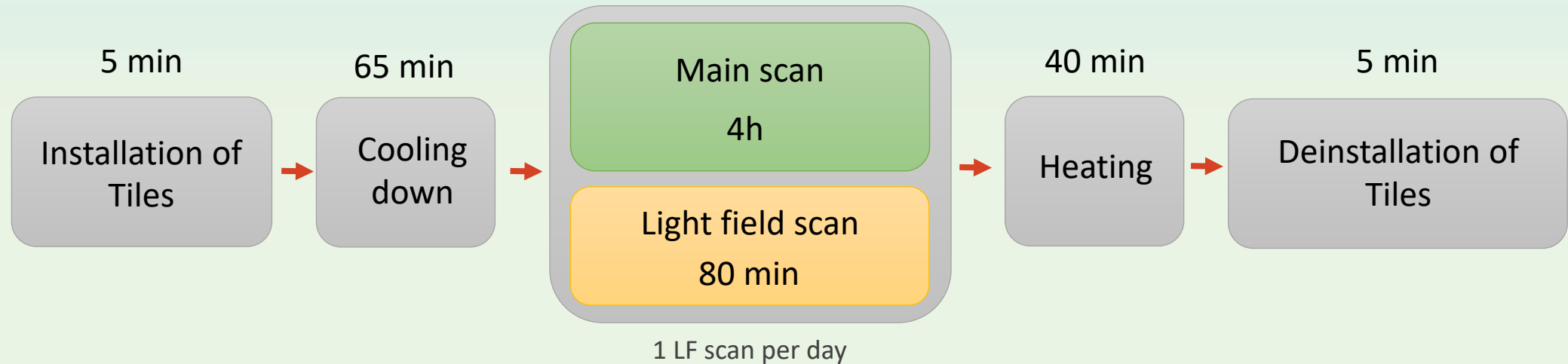
Inside env. chamber [-50°C]

Translation stage



IHEP

# Overview of testing procedures



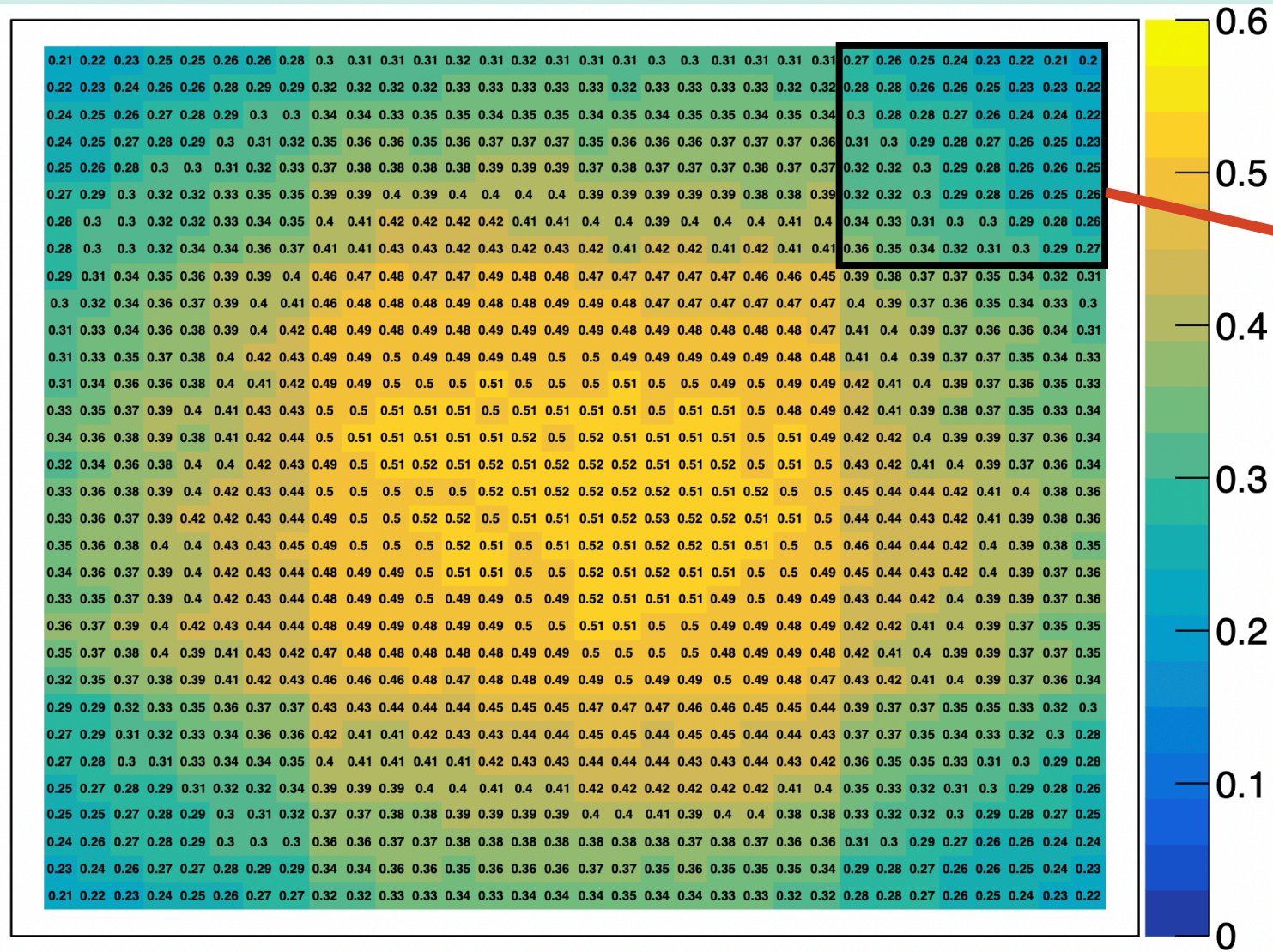
Total procedure time  $\approx$  6h

$\sim$ 3 scans/day (48 tiles)

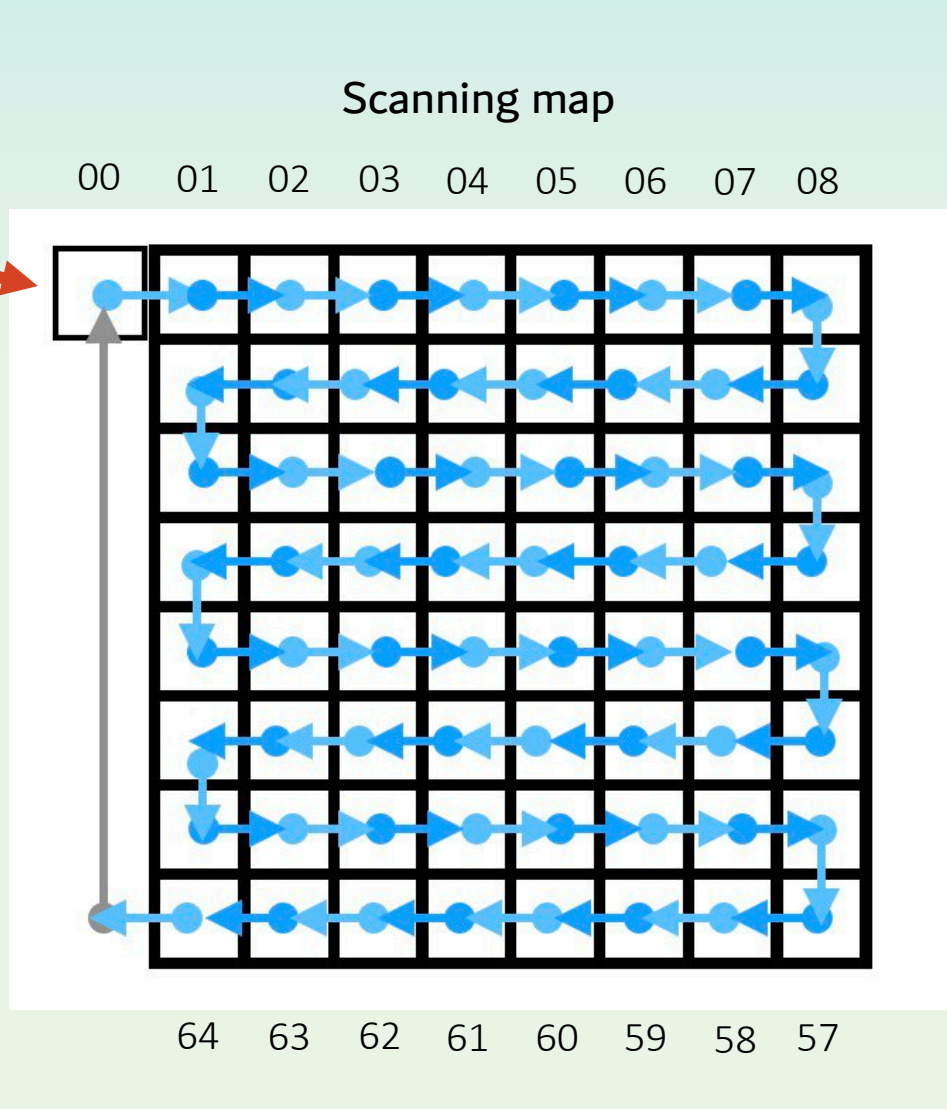
Total estimated mass testing time  $\approx$  90 days



# Calibration of the light field



The light field map





# Monitoring system



Monitor Settings Main-DB Light-DB

MAIN RUN
LIGHT RUN
STOP RUN

OSCILLOSCOPE

Hardware Info: Status: OK

Run configuration Info:

<b>Server status:</b>	Web	Digitizers		MCUnit	SiPM Power		HV Multiplexer		LED		Current Meter		Stage Controller		Stage Decoder	
<b>Device status:</b>	Server	080C-635B	0CD9-6B60		connected	/dev/ttyUSB4		/dev/ttyUSB1		/dev/ttyUSB0		disconnected		/dev/ttyUSB3		
<b>Tile position #:</b>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
<b>TSensor SN:</b>	cc705ff	4063fff	d858fff	d4b74ff	cd7e2ff	40505ff	f3f51ff	c5a72ff	cd8c9ff	d6cb7ff	cdefcff	d8890ff	d7480ff	ce2b6ff	d1a6dff	d83a6ff
<b>Temperature:</b> <a href="#">show</a>	-48.69	-49.44	-48.81	-49.50	-47.50	-47.94	-49.00	-49.19	-47.56	-48.44	-47.25	-48.56	-47.75	-47.69	-48.88	-48.63
<b>Tile SiPMs Voltage:</b>	relay # 1								52.998 V							
<b>Reff. SiPMs Voltage:</b>	ON								52.919 V							
<b>LED state:</b>	OFF								0							
<b>Measurement mode:</b>	Spectrum								Current							
<b>Current multiplexer CH#:</b>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
<b>Current meter:</b>	Tile #4								-5.943261e-9 A							
<b>Stage position:</b>	#home [X:0, Y:0]								Decoder X: 0				Decoder Y: 0			

Setting:	Value:
Applied config ID:	28
LED intensity:	400
Trigger frequency:	600
Trigger type:	0
Run statistics:	30000
Start from voltage:	48
Number of voltage points:	6
First overvoltage point:	1
Voltage step:	1
Reff.SiPM voltage:	52.92

<b>Run status:</b>	Current Multiplexer - Set Channel: 5 - Server status code: 200 MCUnit: ok																						
<b>Run progress:</b>	-4.0V	1.0V	2.0V	3.0V	4.0V	5.0V	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12	CH13	CH14	CH15	CH16	6.0V

Monitoring system of the mass-testing setup

# Analysis

## 1. Gain

$$G_{pix} = \frac{Q_1}{K_{amp} \cdot q_e}$$

$Q_1$  - (peak 1 – pedestal)  
 $K_{amp}$  - coeff. of the amplifier  
 $q_e$  - elementary charge

## 2. PDE

$$PDE_{tile SiPM} = \frac{\mu_{tile SiPM}}{\mu_{ref SiPM}} \times PDE_{ref SiPM}$$

$$\mu = -\ln\left(\frac{N_0}{D_0}\right) \cdot \mu - \text{average number of photoelectrons}$$

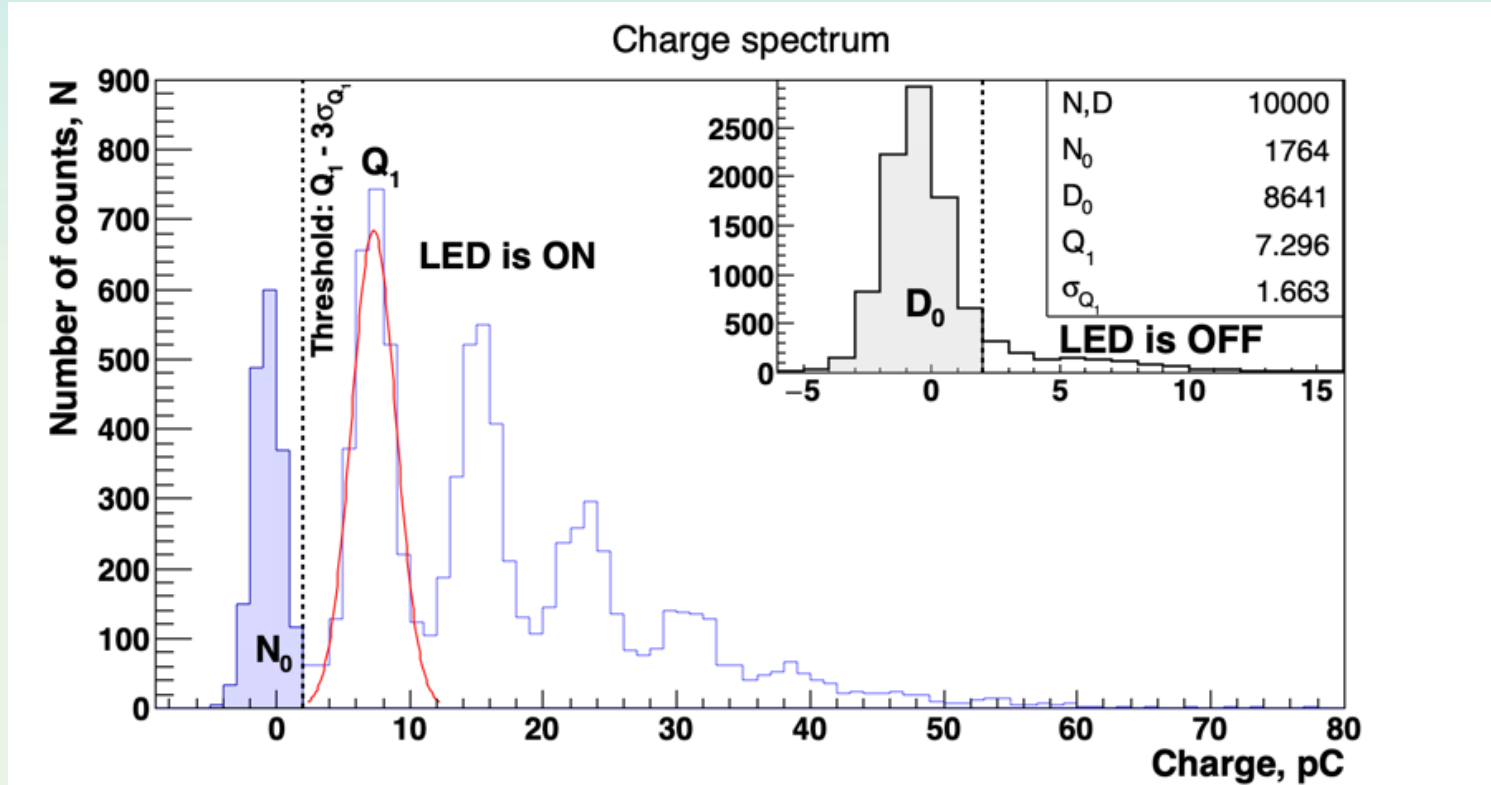
## 3. Crosstalks

$$P_{crosstalk} = 1 - \exp(-\lambda)$$

$$\lambda = 1 - \frac{\mu Q_1}{S}$$

$\lambda$  - number of fired pixels in the first generation

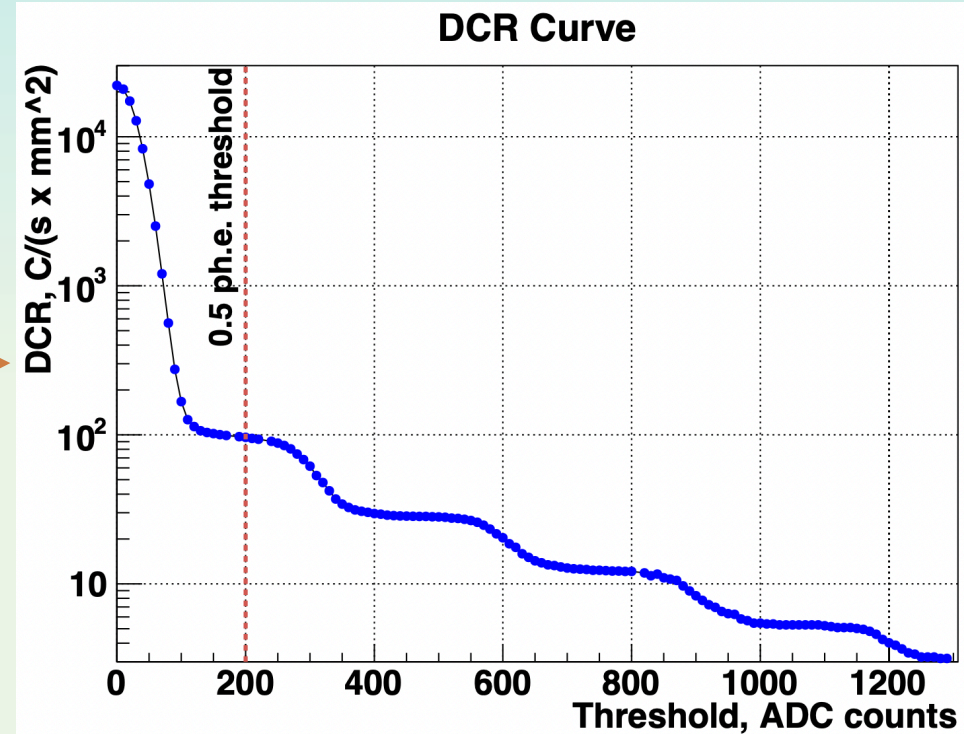
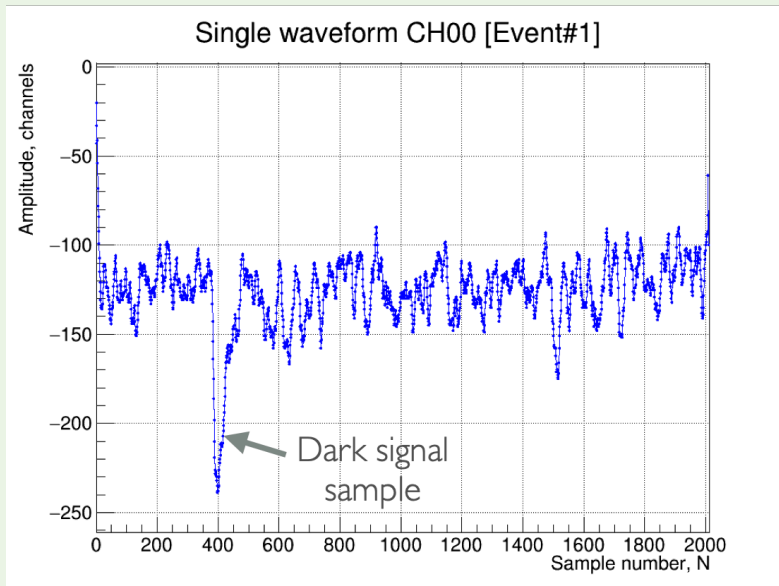
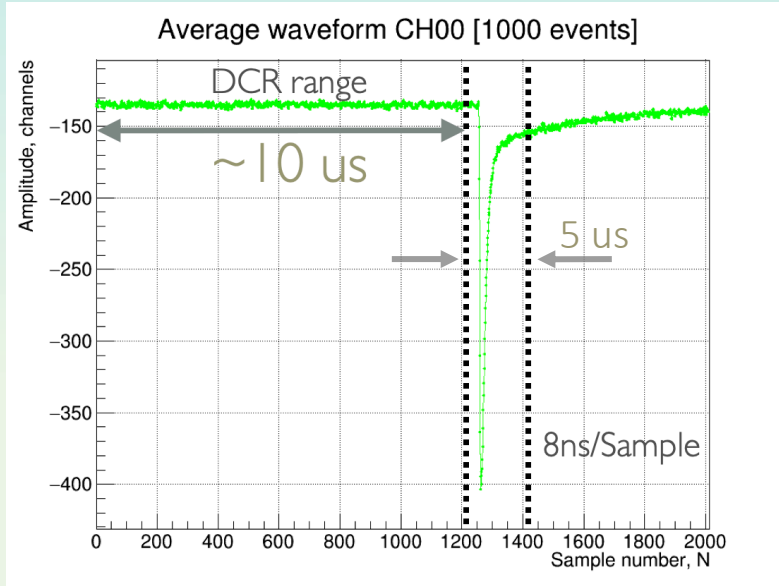
S. Vinogradov, Analytical models of probability distribution and excess noise factor of solid state photomultiplier signals with crosstalk, *Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment* 695 (2011).



Typical charge spectrum of SiPMs. Charge spectrum illustrates the pedestal method for evaluation of an average number of photoelectrons.

Shaded area and  $N_0$  - pedestal events on signal spectrum, shaded area and  $D_0$  - pedestal events on dark spectrum (incorporated picture)

# Dark count rate



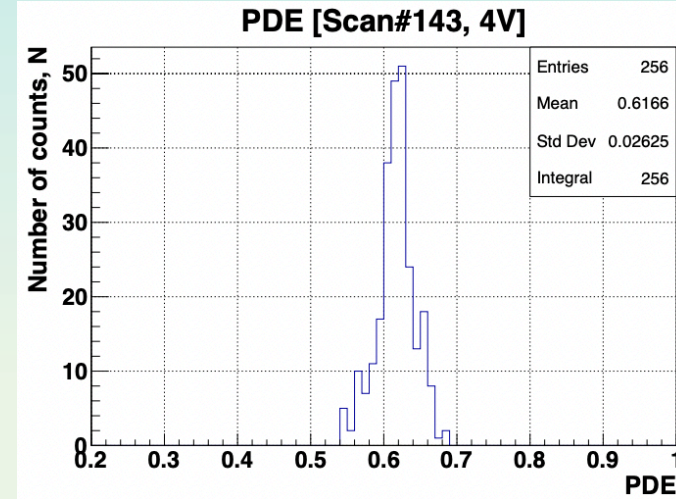
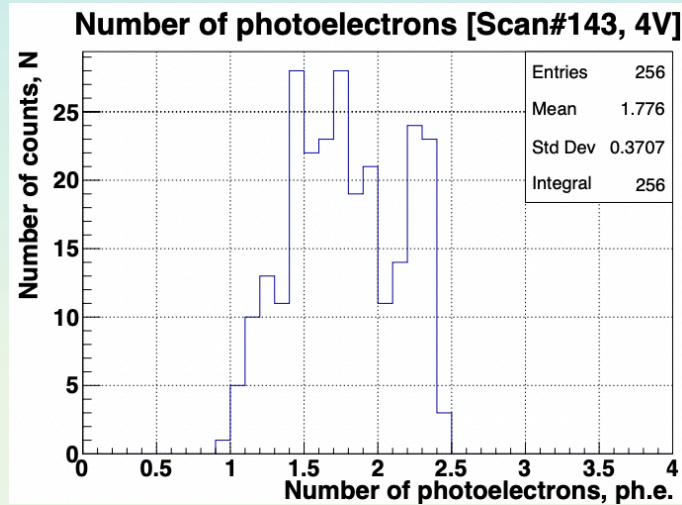
## Run parameters

Parameters	Value	Units
Time window	10	us/oscillogram
Number of oscillograms	30k	-
Total acquisition time	0.3	second
SiPM area	144	mm <sup>2</sup>

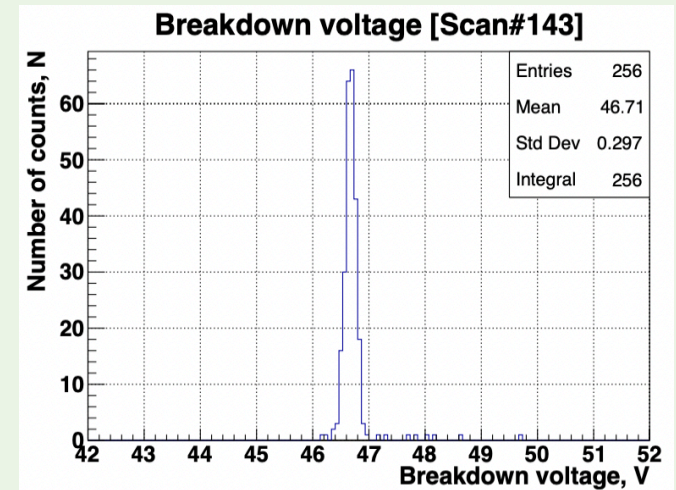
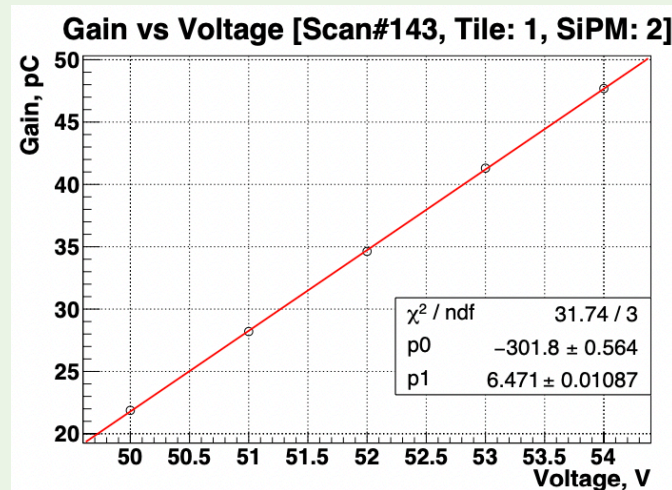
[ max: 41.7 Hz/mm<sup>2</sup> / typical: 13.9 Hz/mm<sup>2</sup> ]



# Results examples



An example of the distribution of values for 4 V overvoltage:  
(a) - number of photoelectrons, (b) - photon detection efficiency



(a) - Gain voltage dependence, (b) - breakdown voltage distribution overall  
SiPMs in a single run

# Summary

- **the setup design has been developed**
- **the testing procedures and methods have been developed**
- **the testing setup has been produced and putted into operation in China (summer 2023)**
- **> 2000 tiles have already been tested**
- **the data analysis is in progress**
- **the TAO detector assembling plans – 2024 year**

**Thank you for attention!**

**Questions?**