INSTITUTE OF NUCLEAR PHYSICS

SPD NICA

VII SPD Collaboration Meeting

SPD ECAL status 2024

1. ECAL position inside of Cryostat
2. Test results with new SiPm EQR15 11-6060D-S
3. Matrix form for new scintillator production (40x40x1.5 mm^3)
4. Scintillator production in Vladimir

SPD ECAL Requirement

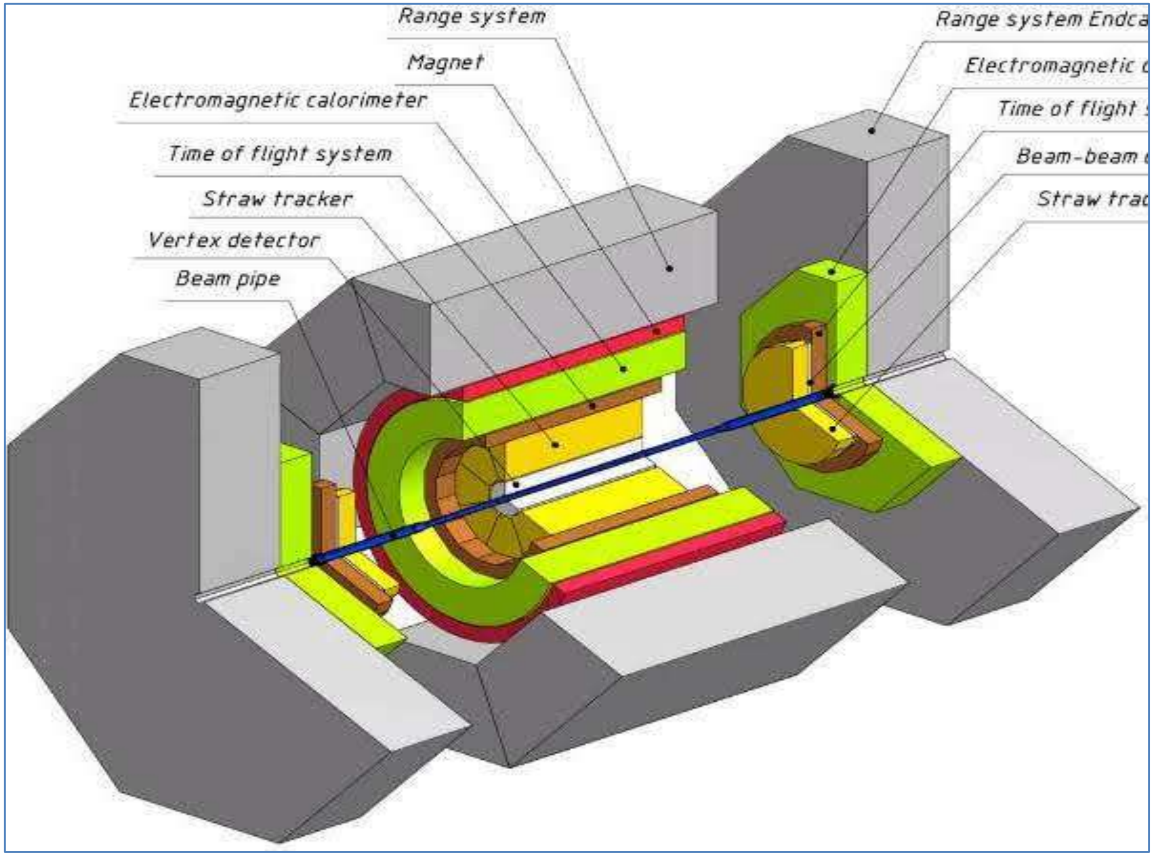
The high multiplicity of secondary particles leads to the requirements of high segmentation and high density of the absorber's medium with a small Moliere radius.

It is required in order to have a sufficient spatial resolution and a capability to resolve overlapping showers. The transverse size of the calorimeter cell should be of the order of the Moliere radius. A reliable reconstruction of photons and neutral pions is possible only for small a overlap of showers.

Occupancy should not exceed 5%, to make possible an efficient photons reconstruction with high precision. The SPD experiment imposes the following requirements on the calorimeter characteristics:

1. – reconstruction of photons and electrons in the energy range from 50 MeV to 10 GeV;
2. – energy resolution for the above-mentioned particles: $\sim 5\%/\sqrt{E[GeV]}$;
3. – good separation of two-particle showers;
4. – operation in the magnetic field;
5. – long-term stability: 2÷3% in a six-month period of data taking.

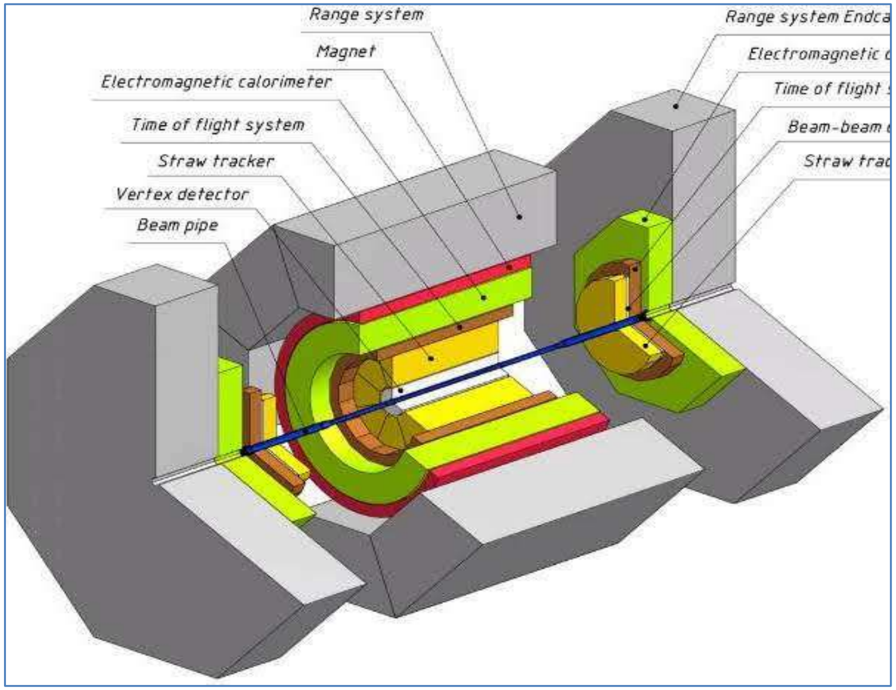
Overview of the SPD ECAL



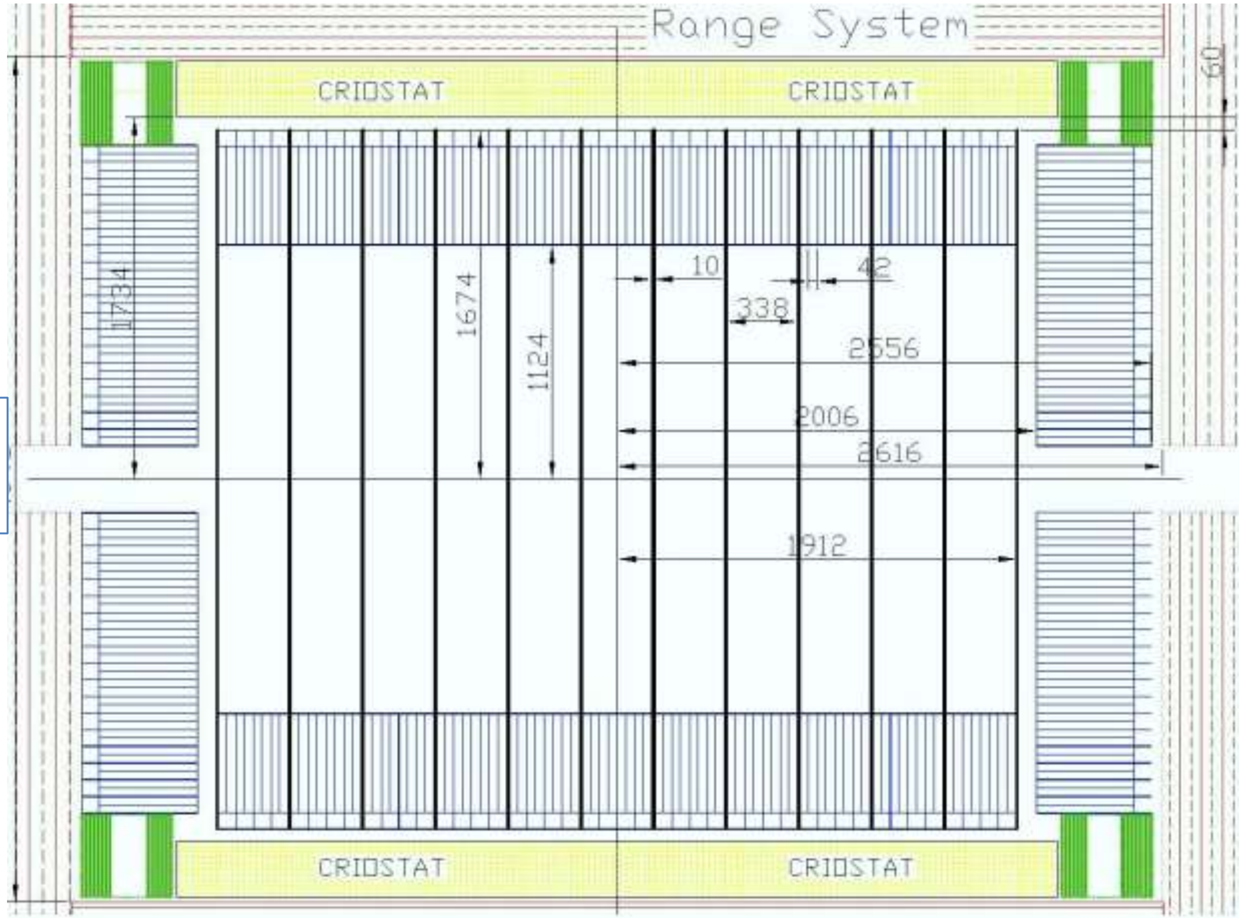
1. The SPD electromagnetic calorimeter is placed between the cryostat with magnet coils and the PID.
2. The calorimeter consists of a barrel and two end-caps, covering a 4π solid angle.
3. The thickness of the calorimeter is dictated by the required thickness of the active part and the size of the readout block consisting of a photodiode and the amplifier boards, as well as by the size of the flexible part of the fibers.

Overview of the SPD ECAL

1. For an efficient absorption of electrons and photons with energies up to 10 GeV, the calorimeter thickness, which is defined by the number of sampling layers, should be at least 17÷20 X0 in terms of radiation lengths X0.
2. For the sampling structure of 190 layers of 1.5-mm polystyrene scintillator and 0.5-mm lead, the length of the active part is 380 mm, which corresponds to 17.6 X0.
3. The transverse size of the calorimeter cell should be on the order of the effective Moliere radius of the calorimeter medium. The selected structure has a Moliere **radius of 58 mm**.
4. The separation efficiency of two photons with energies from 200 MeV to 500 MeV depends on the cell size ***and reaches a plateau*** at a cell size **of 40 mm,** as it was determined in the **MC** simulation.
5. The cells in the barrel part of the calorimeter have a trapezoidal shape in the azimuthal direction to minimize the gaps between the modules. The vertex angle of the trapezoid equals 1.87◦.



SPD ECAL Barrel – side view

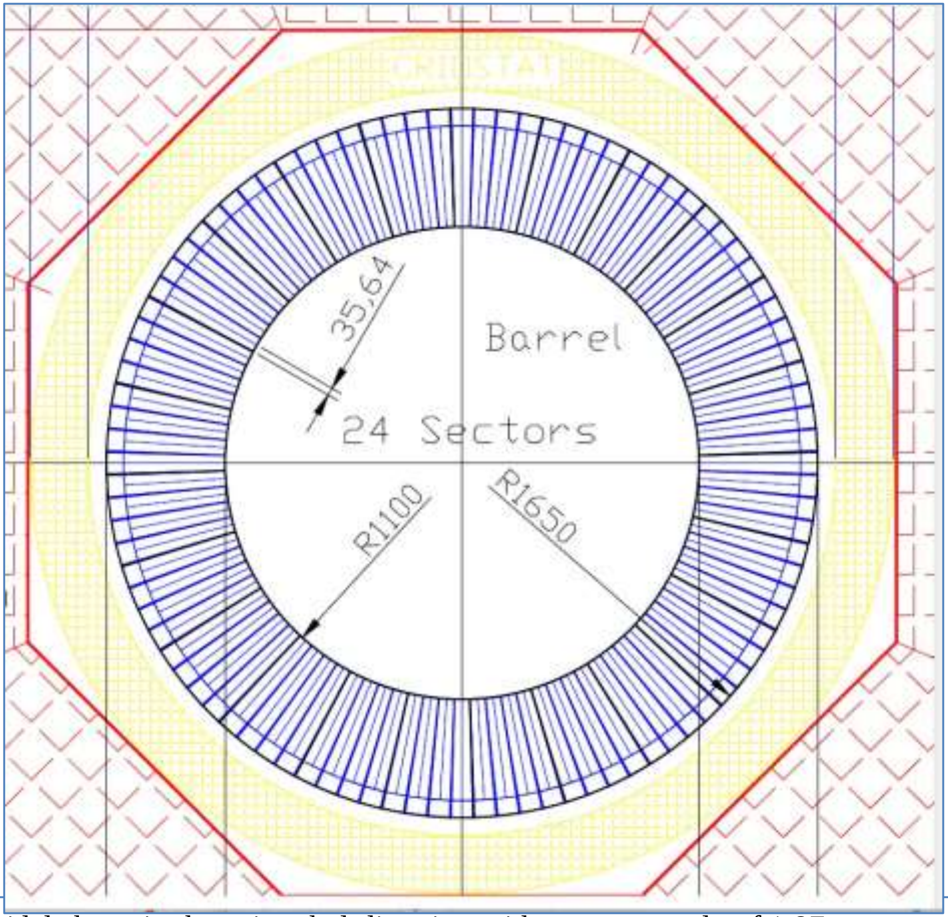


1. 16896 cells
2. 52.9 tons

1. In the direction along the beam axis the cell size is equal **to ~42 mm**
2. The barrel consists of 11 annular rings, located one after another along the beam axis.
3. One Ring containing 384 modules weighing **~4.8 ton.**
4. The ring is made to facilitate moving and ECAL installation using Rails inside of Cryostat.
5. The calorimeter ring is divided into 24 sectors by the angle φ , thus forming a cluster of 64 cells which are read by one ADC
6. In total, there are **16896** cells with a weight **of 52.9 tons**.

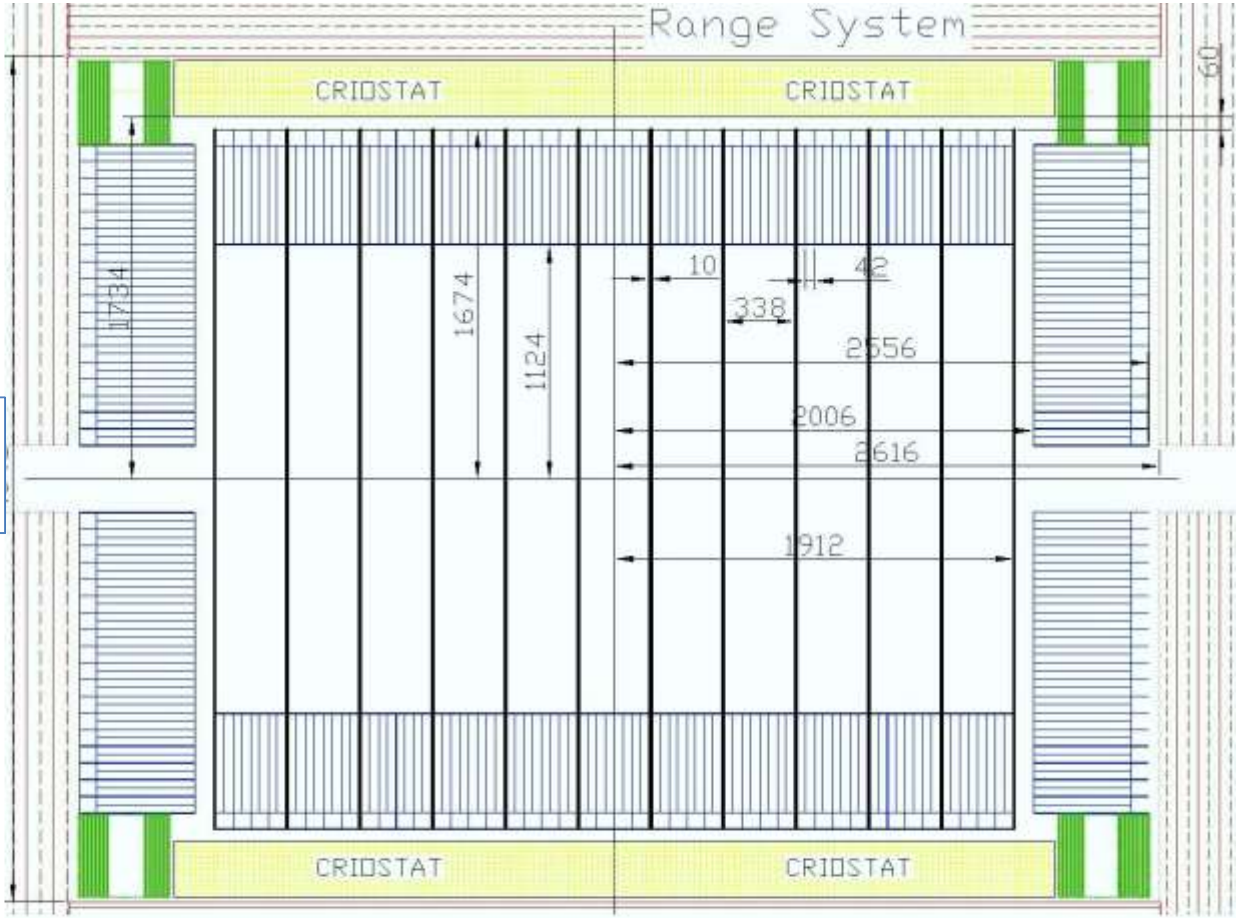
SPD ECAL Barrel – front view

1. cell φ =1.87◦.
2. There are 16896 cells
3. Weight is 52.9 tons



1. The barrel part is composed of the cells of trapezoidal shape in the azimuthal direction with a vertex angle of 1.87◦.
2. The front sizes of one cell is equal **to ~35 mm** (in φ), and **~42** – in the direction along the beam axis .
3. Each layer of the calorimeter's barrel is composed along the φ angle of **96** modules (**4 cells per module**).
4. Calorimeter ring is divided into **24** sectors by the angle φ , thus forming a cluster of **64** cells which are read by one ADC.
5. The calorimeter barrel is composed of 11 rings, as shown in previous slide
6. There are **16896** cells with a weight **of 52.9 tons.**

SPD ECAL Barrel – side view



1. **16896 cells**
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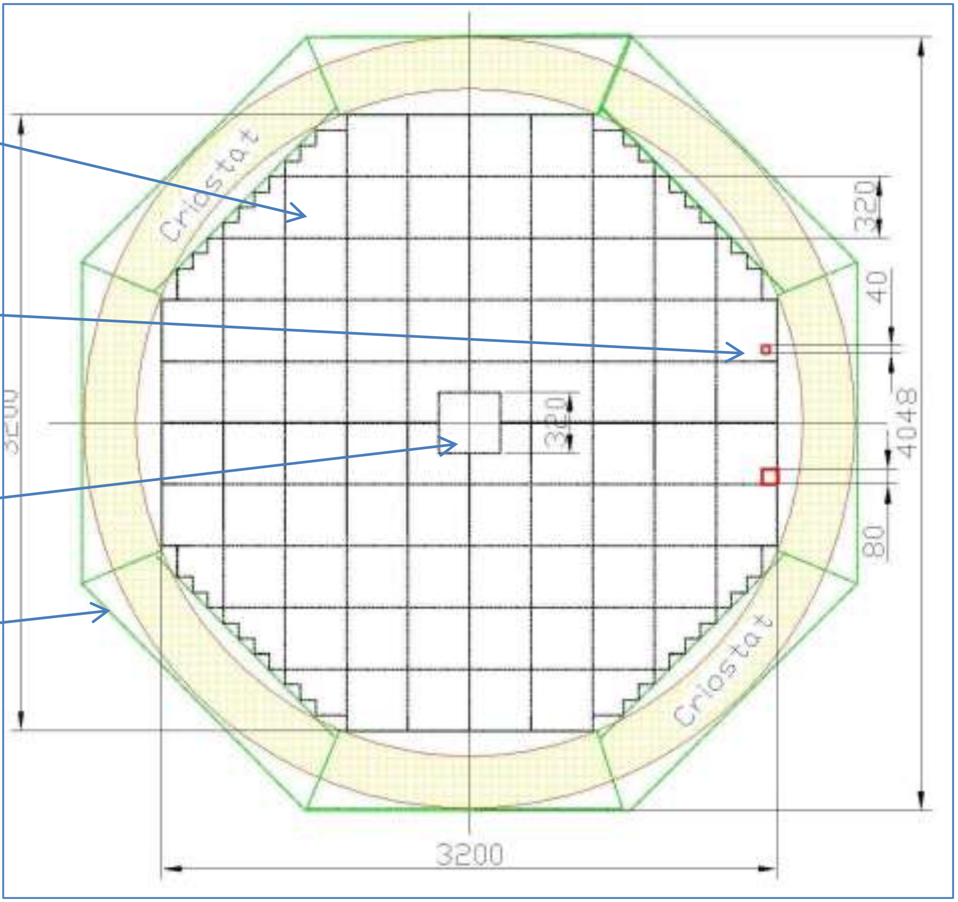
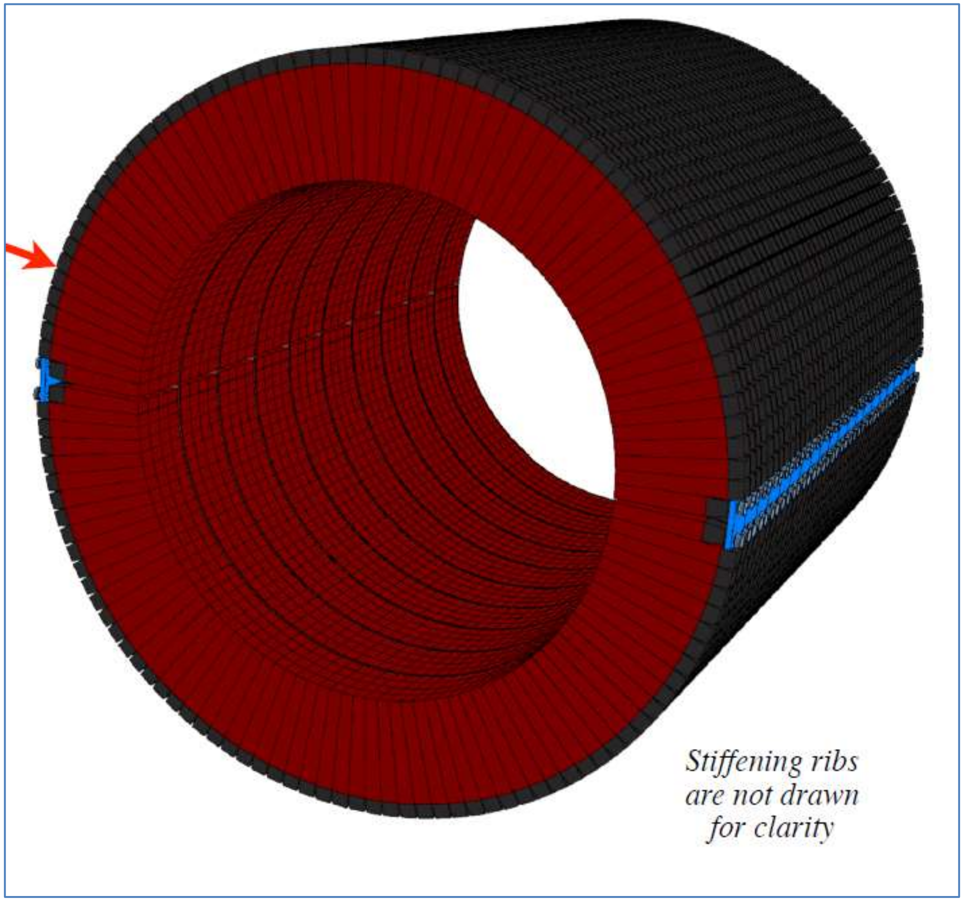
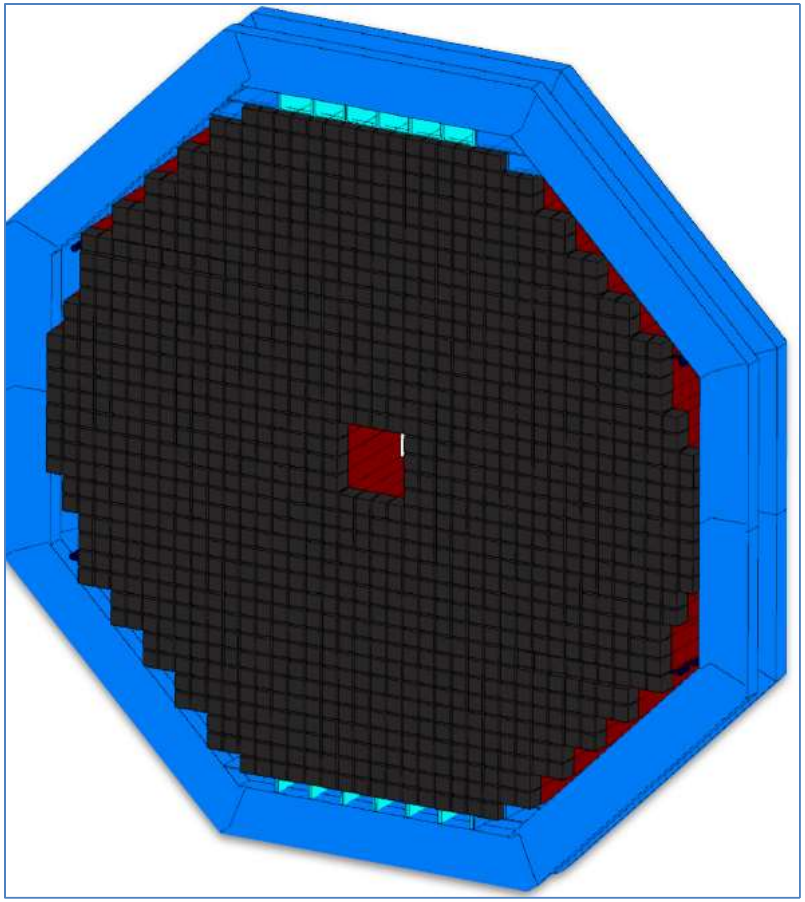
SPD ECAL End Cup via 80 clusters

1. Each end-cap consists of **5.136** cells, grouped by **64** cells, forming **80 clusters** – big squire:
2. All 64 cells of each cluster are connected to 4 pcs. of 16-channel FE-boards for MPPC's bias voltage control and their readout is provided by one ADC. A complete list of ECal's main components – ADC, FE, HV, MPPC, etc.
3. The **cell** cross-section is 40×40 mm2 and the length is 500 mm along the beam.
4. The end-cap has the absorber length equal to 17.6 X0
5. The weight of one end-cap **is 14.4** tons and for two parts **28.8 tons**, respectively.
6. In total, there **are10.272** cells in both end-caps.
7. There is a hole for the beam pipe in the center of each end-cap. The hole has a size **of 320×320 mm2**, which is equivalent to 64 cells.
8. The end-cap is mounted in the Frame that supports it and shapes its geometry. **The Frame**
   is installed on the barrel RS.
1. There is a gap about 6 cm between the end-cap of the RS and the calorimeter's end-cap for the ADC's placement and cable routes. This gap is also necessary for air circulation of the ADC cooling (visible in side view)



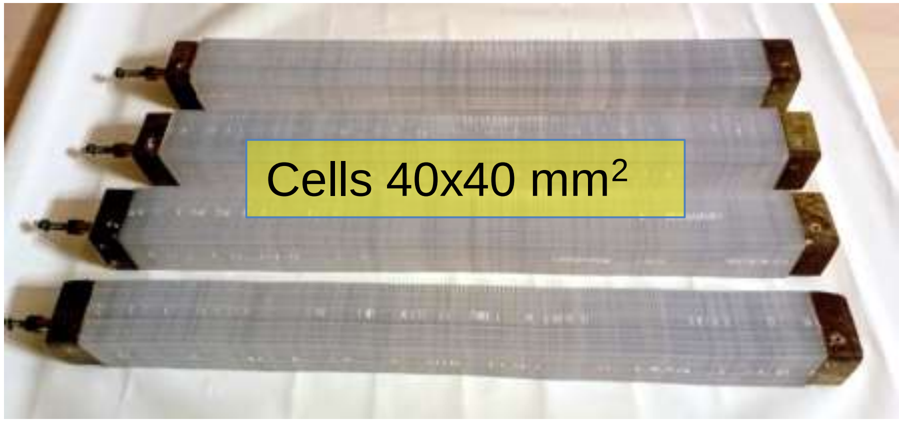
ECAL 3D View Barrel and Cup parts



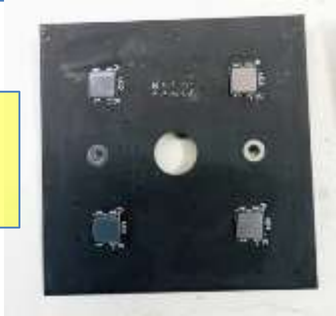


SPD ECAL cells design

1. The module consisted of 190 alternating layers of scintillator and lead with a thickness of 1.5 mm and 0.5 mm, respectively.
2. Absorption length is equal to 17.6X0 and a Moliere radius is anout 5.8 cm.
3. The energy resolution for 1 GeV photons is assumed to to be ~5% .
4. The scintillator plates are made of polystyrene with an 1.5% p-Terphenyl and 0.05% POPOP.
5. Scintillation time of about 2.5 ns and a light output of 60% of anthracene.
6. The scintillator emission light (~420 nm) is absorbed by the WLS of Y-11 (1 mm diameter) and reemitted at 480 nm.
7. SipM type EQR-11-6060 detect the emitted from WLS light with PDE ~40%.



Printed Board wit 4 SiPms



Test results with cosmic particles

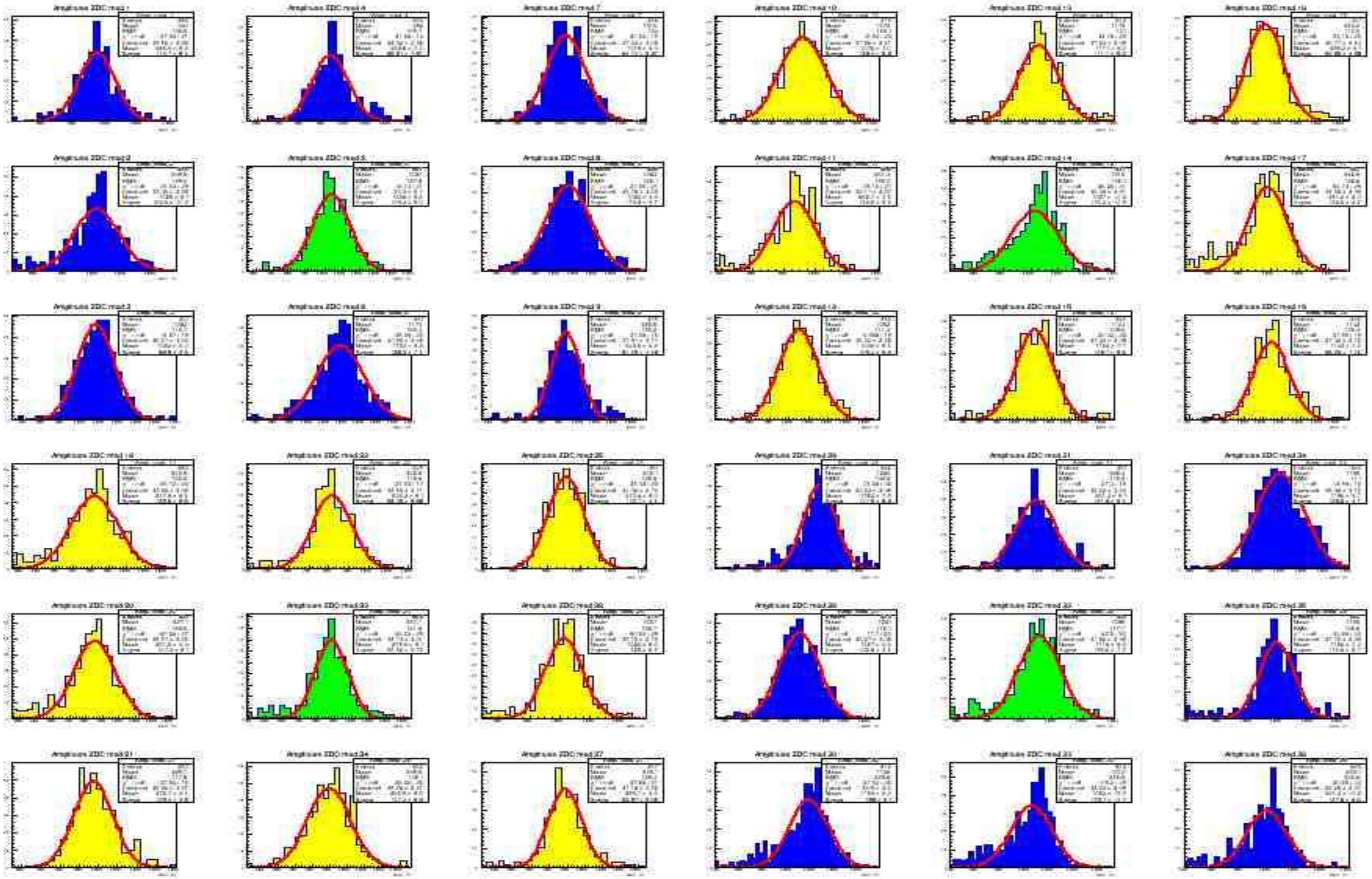
Cosmic Rays

Setup of 4 modules. Each module consist from 9 cells of 4x4 cm^2. Totally tested 36 cells.

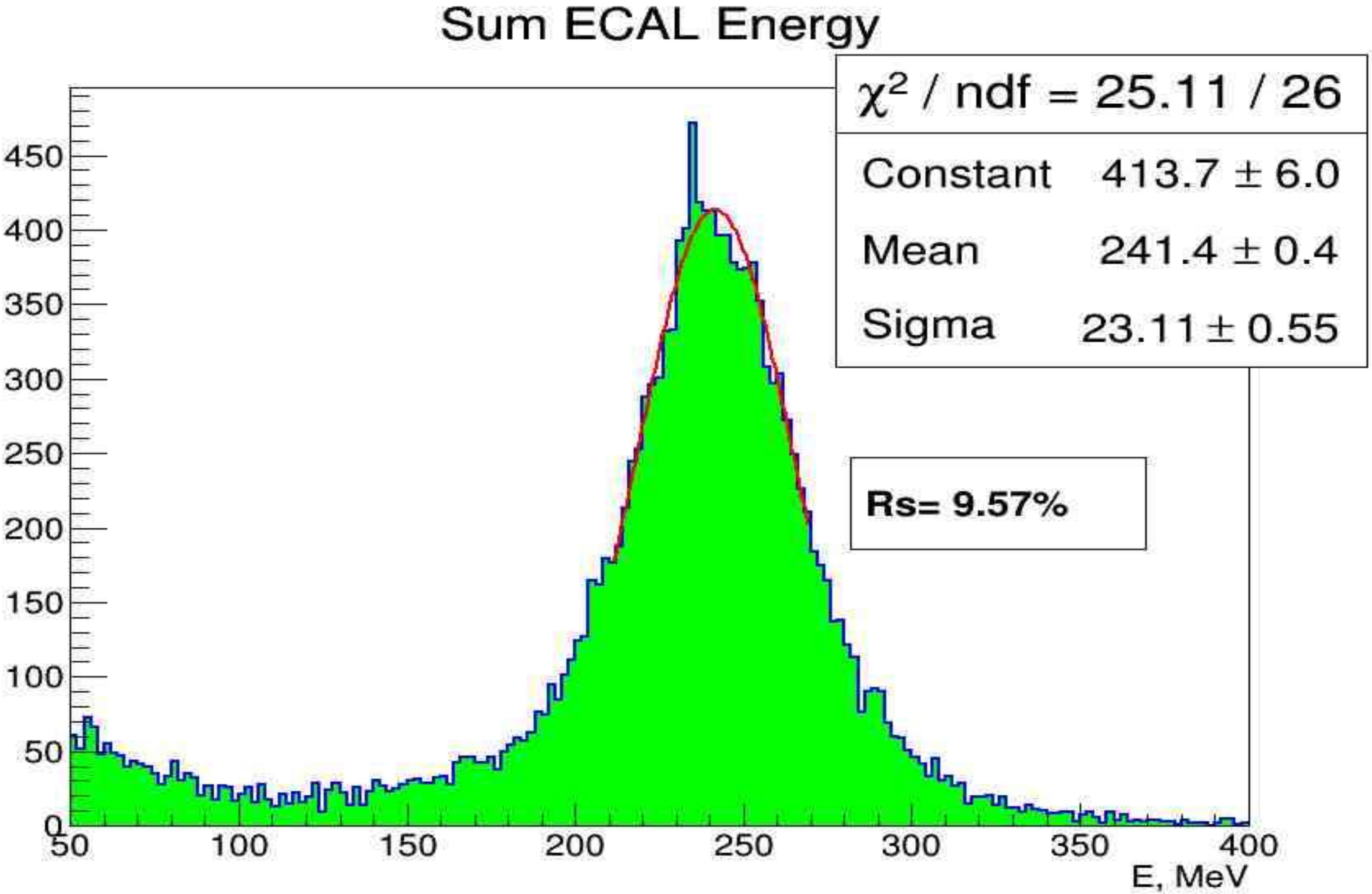
Sampling:
- 1.5 mm Scintillator
- 0.3 mm Lead
- 200 layers

Scintillator composition:
- Polysterene
- 1.5% Paterphenyle
- 0.04% POPOP

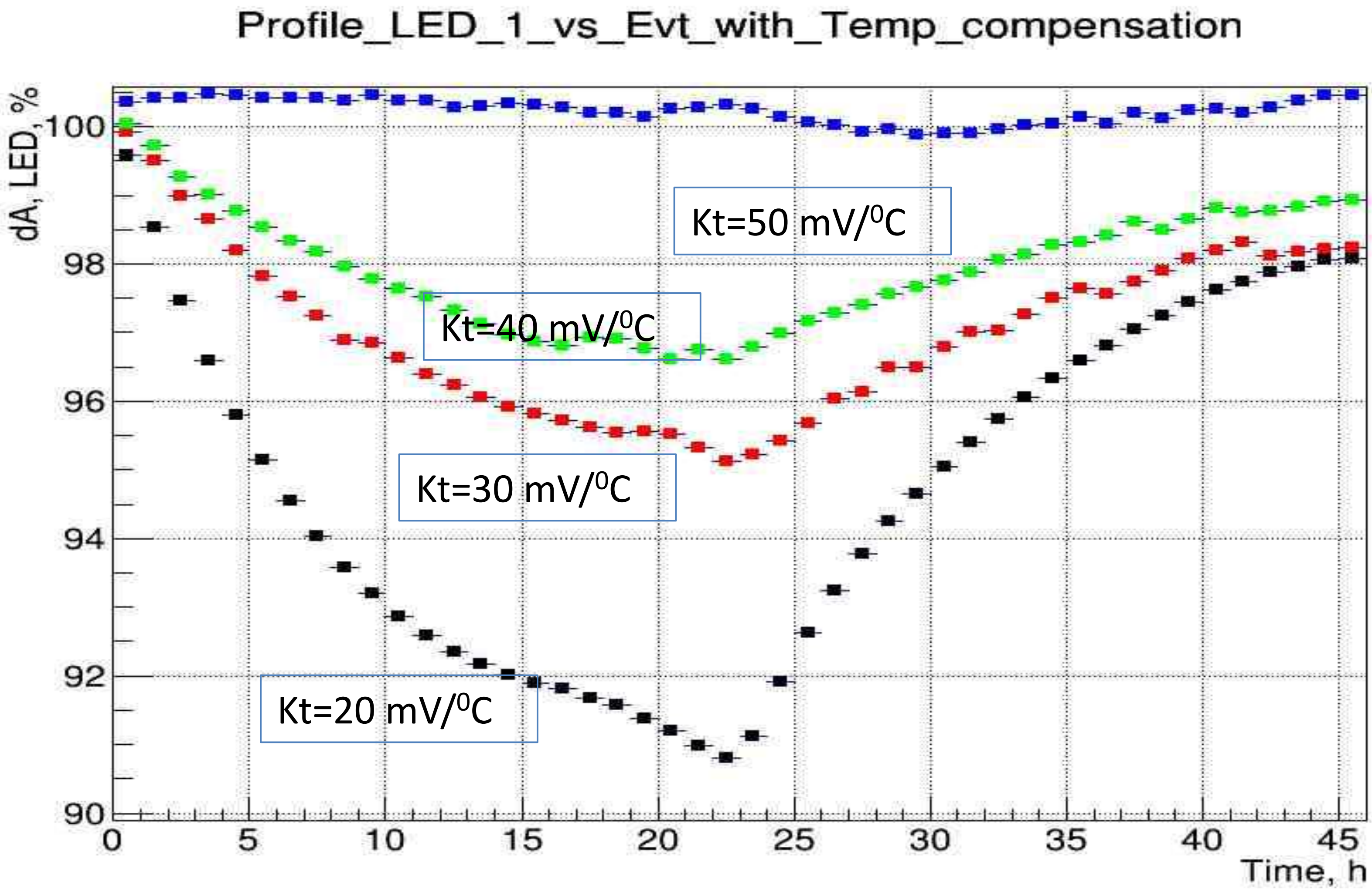
Single Ecal module shown in assembling stage.
It is visible 9 cells as 3x3 matrix with WLS fibers (16 per cell). Y11(200) diameter 1.0 mm was used.



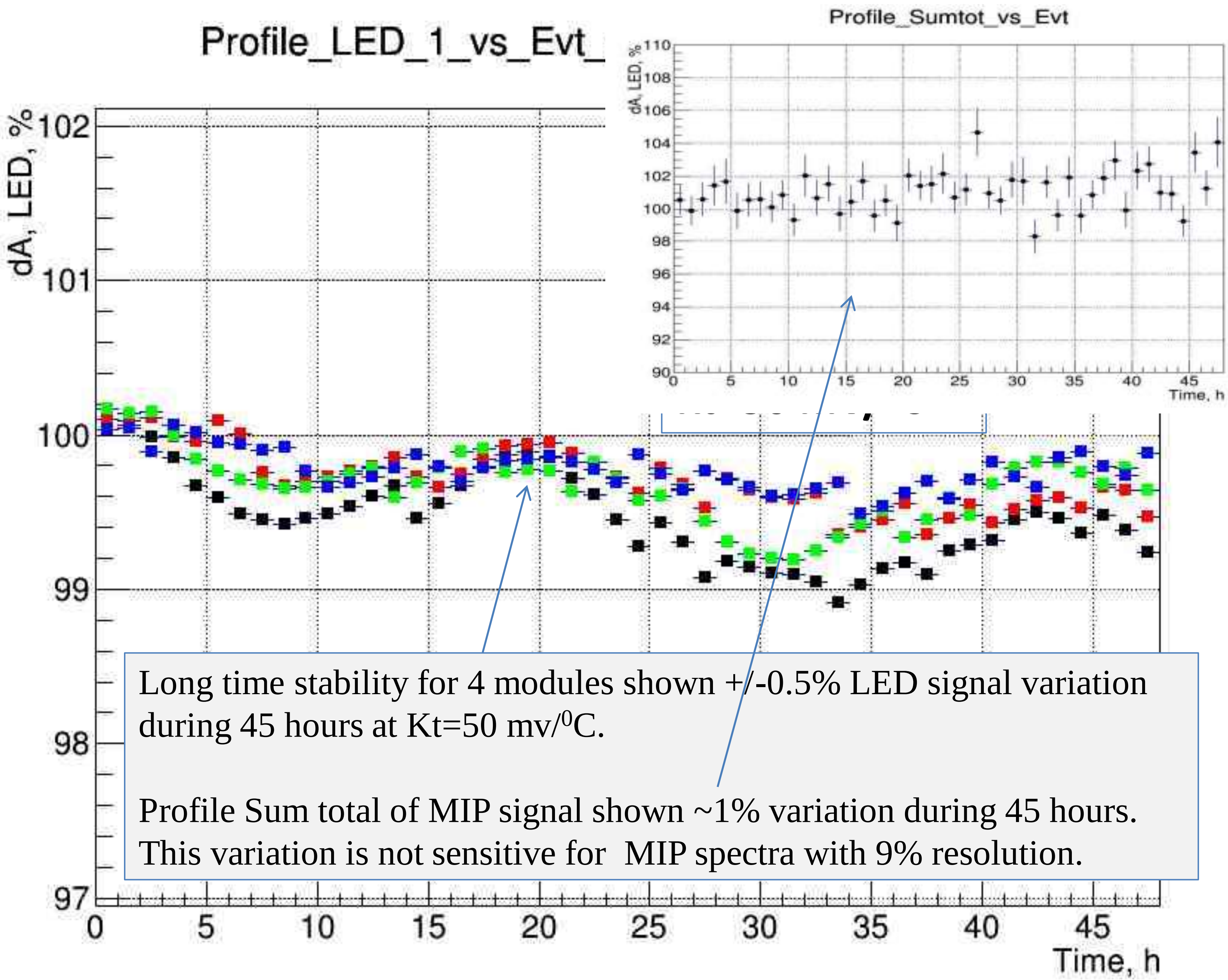
MIP spectra from 36 Cells. Top view shown on picture Above. One hit/event – applied selection criteria during analysis.
Calibration coefficients were found and normalized to 240 MeV.



MIP spectra from 36 Cells as Total Sum take in account the Calibration coefficients normalized to 240 MeV. These Energy resolution corresponded to MC



Test of long time Stability was done with different Kt for individual module.
The temperature variation from 20 to 30 ^{0}C per day was applied.



Long time stability for 4 modules shown +/-0.5% LED signal variation during 45 hours at Kt=50 mv/^{0}C.

Profile Sum total of MIP signal shown ~1% variation during 45 hours. This variation is not sensitive for MIP spectra with 9% resolution.

NDL SiPm Series EQR15 11-6060D-S

www.ndl-sipm.net/PDF/Datasheet-EQR15.pdf

NDL (Novel Device Laboratory, Beijing) http://www.ndl-sipm.net/indexeng.html

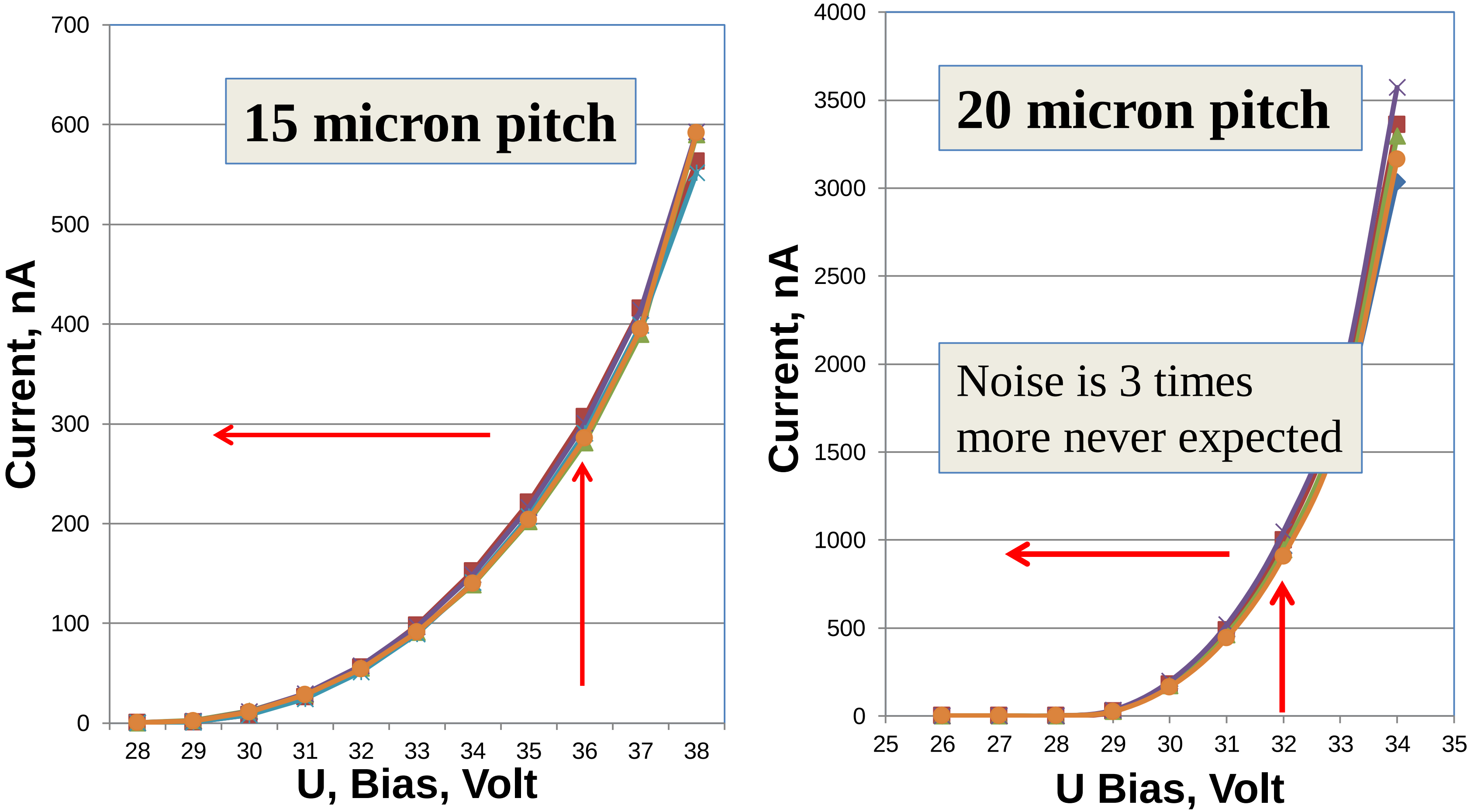
For a conventional SiPM, the quenching resistors are usually fabricated on the surface, and used to connect all APD cells to trace metal lines. In contrast, NDL SiPM employs intrinsic epitaxial layer as the quenching resistors (EQR), and uses a continuous silicon cap layer as an anode to connect all the APD cells**. As a result, the device has more compact structure and simpler fabrication technology, allows larger micro cell density (larger dynamic range) while retaining high photon detection efficiency (PDE).**

EQR15 Series SiPMs

Specifications subject to change without notice

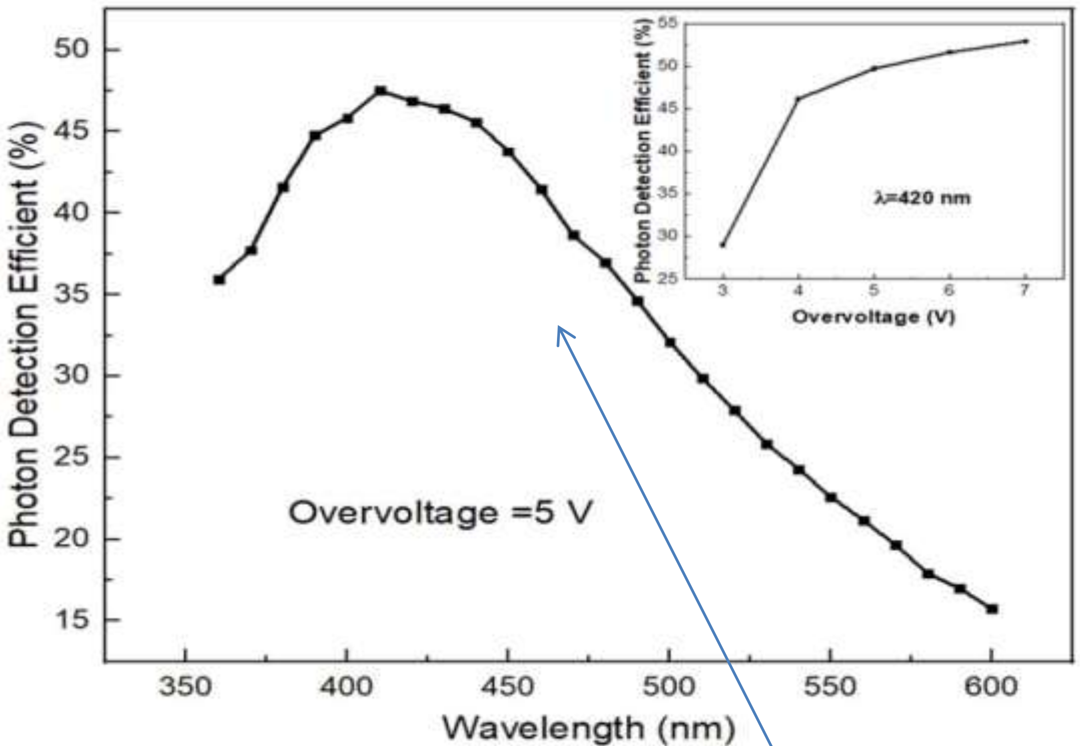
Type	**EQR15-11-6060D-S**	**EQR20-11-6060D-S**	Remarks
Effective Pitch	15 µm	20 µm	
Active Area	6.0x6.0 mm^2	6.24x6.24 mm^2	
Micro-cell Number	160 000	~90 000	
Typical Breakdown Voltage , Va	30 V	27.5 V	
Temperature coefficient	28 $mV/^0C$		Not given
Recommended Oper. Voltage	Va+8V	Va+5V	
Peak PDE at 420 nm	45%	45%	
Gain	$4.0x10^5$	$8.0x10^5$	
Dark Current Rate	250 kHz/mm^2	120 kHz/mm^2	~1000 kHz/mm^2
Terminal Capacitance	5.6 pF/mm^2		Not given

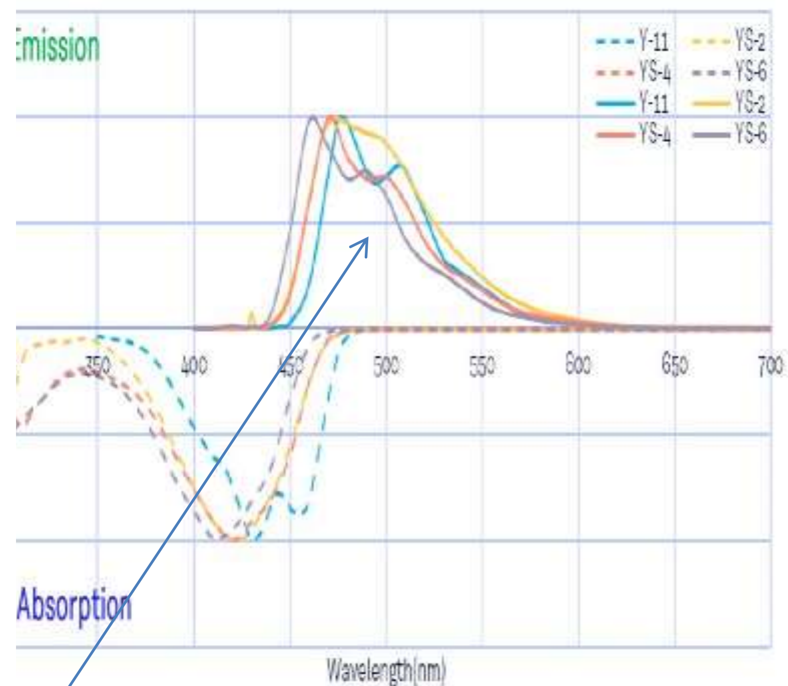
Dark Current for EQR SiPm of 6x6mm^2 with 15 and 20 micron pitch sizes



EQR15 Series SiPMs

Specifications subject to change without notice



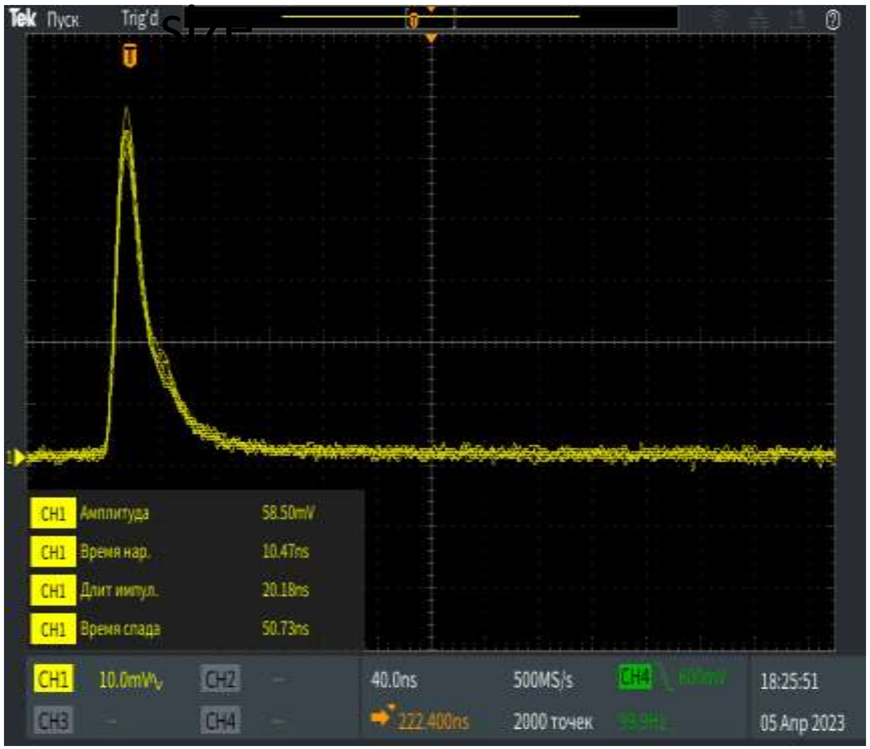


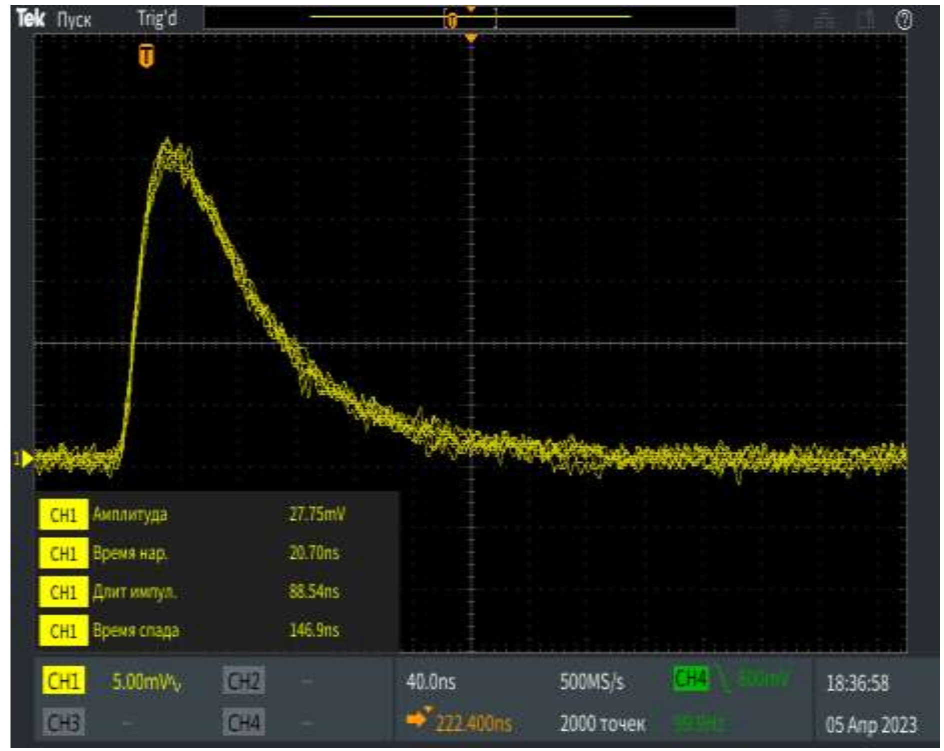
Photon Detection Efficient (PDE) correspond to WLS Emission spectra of Y11.
PDE close to flat maximum about 45% at 6-7 Overvoltage.

EQR15 Series SiPMs

Specifications subject to change without notice

Pulse shape of SiPm with 15 µm pitch and 6x6 mm^2 size



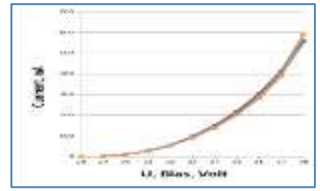


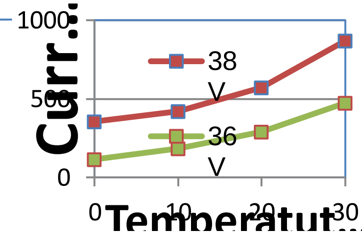
EQR-15-60
Front – 10 ns
Length – 20 ns

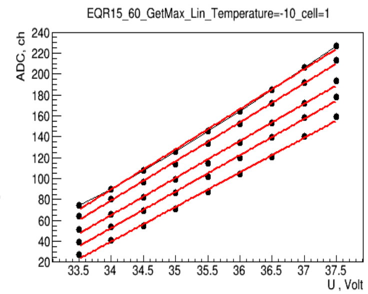
HAMAMATSU S14160-6015
Front – 21 ns
Length – 89 ns

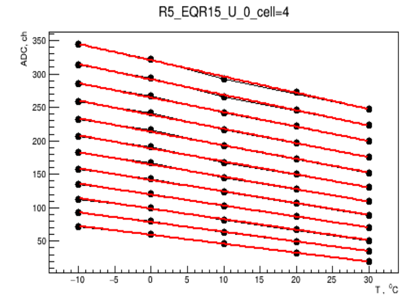
SiPm test Results

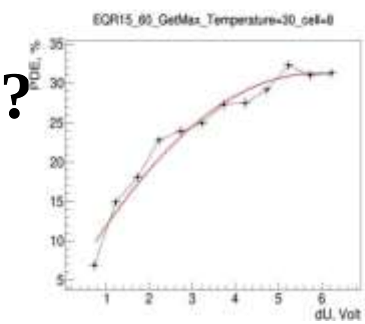
- **Dark Current measurements**
- **Gain vs Overvoltage: dA/dU**
- **Gain vs Temperature: dA/dt**
- **PDE vs Overvoltage**
- **Operation Volt. how to select it ?**
- **Temperature stability studies**

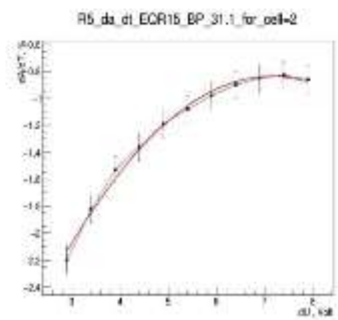






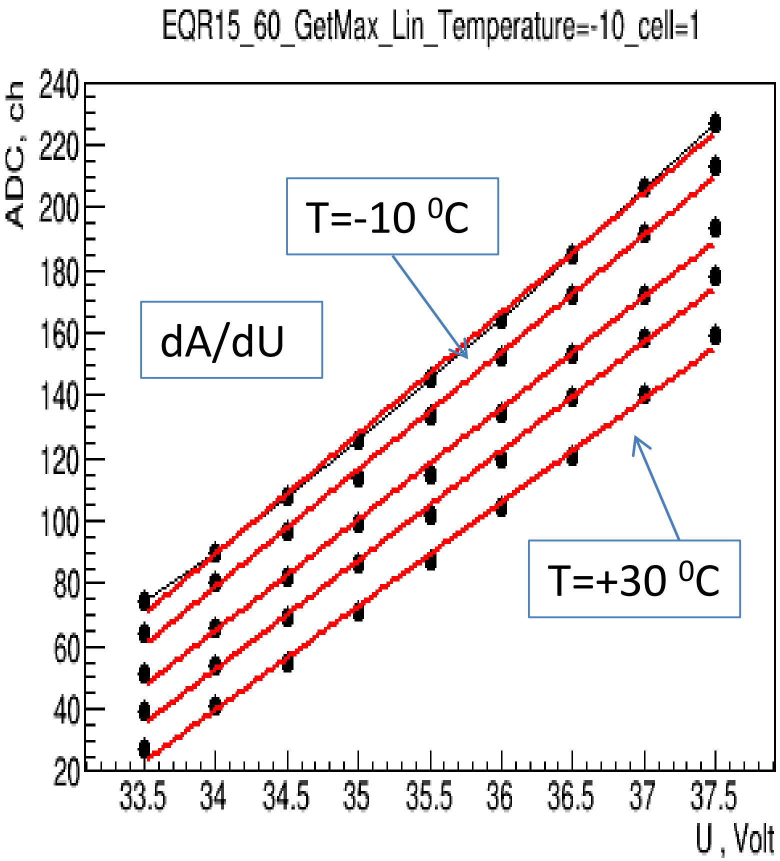


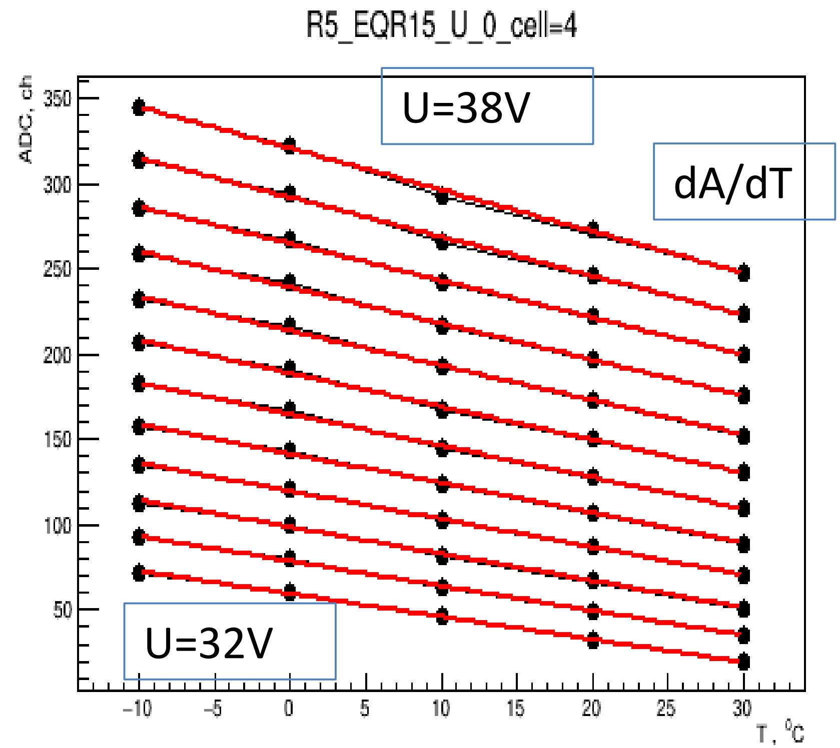




Gain vs Overvoltage allow obtain:
slope=dA/dU vs U

Gain vs Temperature allow obtain:
slope=dA/dT vs T



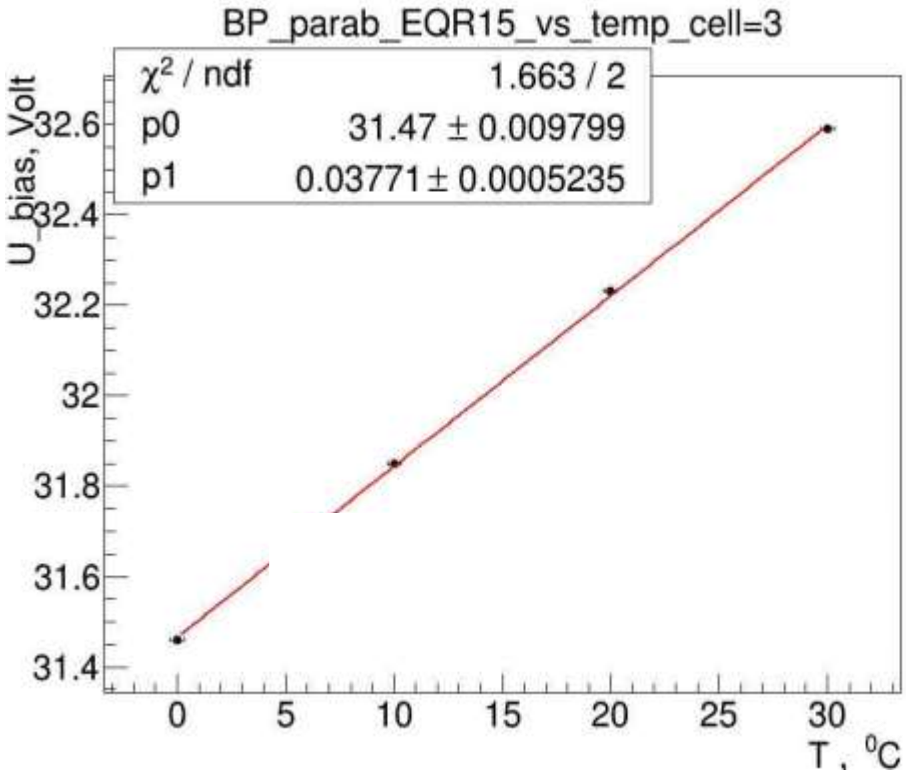


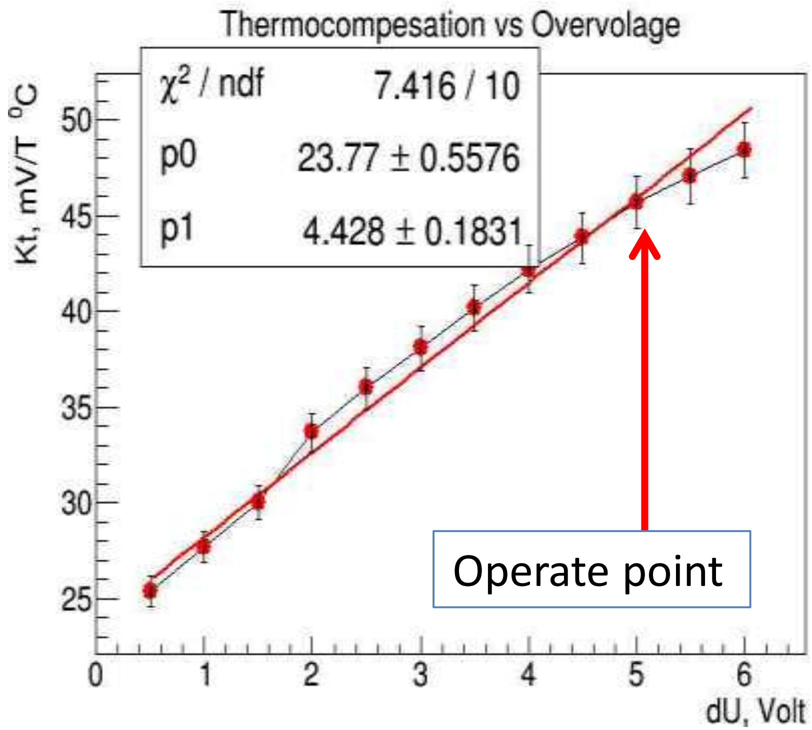
$K_t = dU/dT = dA/dT/dA/dU$

The thermal stabilization coefficient (K_t) was defined as the ratio of the slope dA/dT to the slope dA/dU depending on the applied bias.

Break Point (Bp) was defined as extrapolation point of dA/dU to zero. Take assumption his linear behavior from Temperature we find that Bp=32 V at 20 ^{0}C.

Kt=dU/dT=dA/dt/dA/dU fom previous slides we find that dependence from Overvoltage has linear behavior and equal to ~50 mv/^{0}C at Operation point 5.5 V.

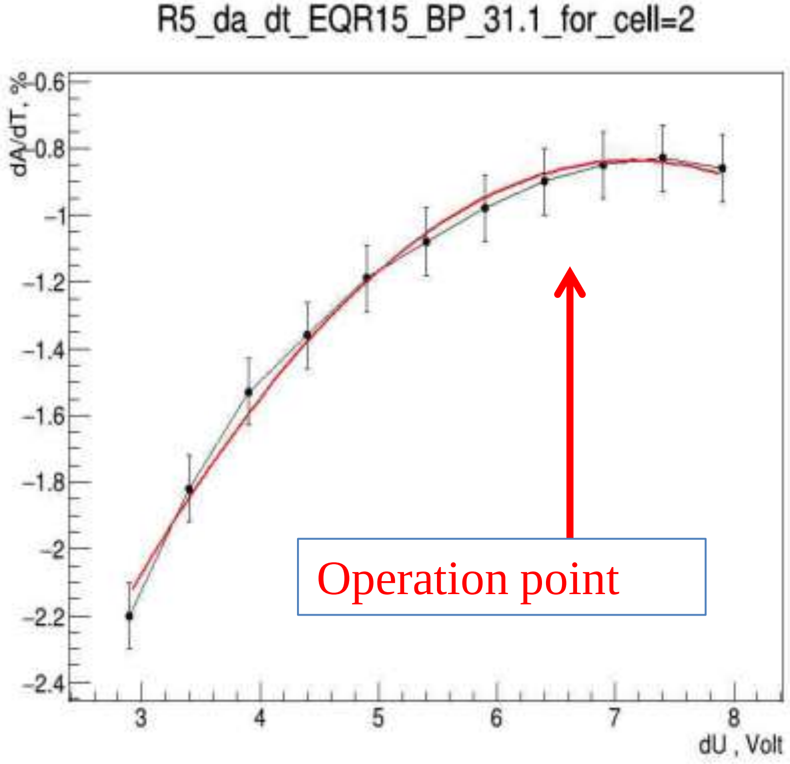




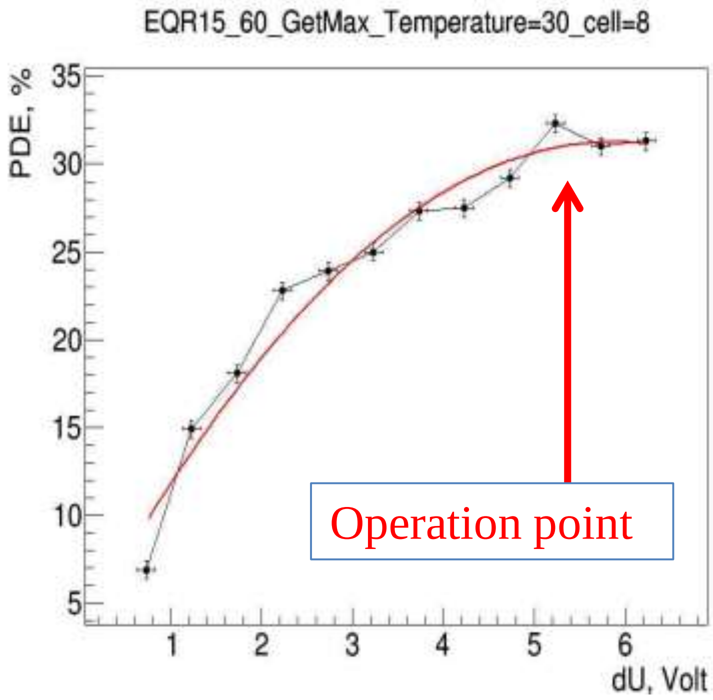
Temperature sensitivity vs dU

Photon Detection Efficient vs dU

dA/dT vs dU



PDE vs dU

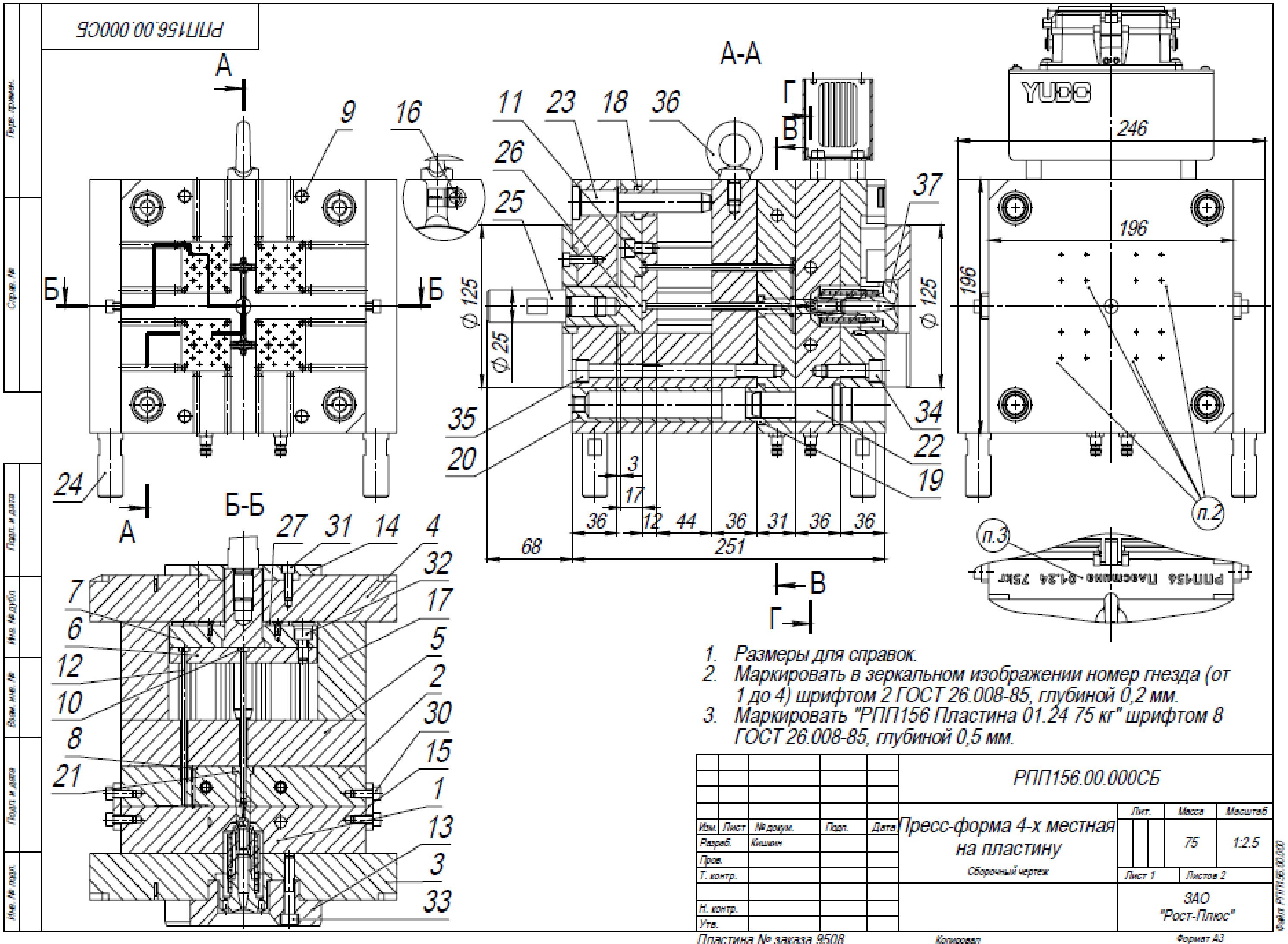


Operation point was found at **dU=6.5 V** take in account that:

1. dA/dT and PDE – has Plato in dU.
2. dA/dT has minimal value ~ 1%/^{0}C , PDE close to maximal value ~ 32%.

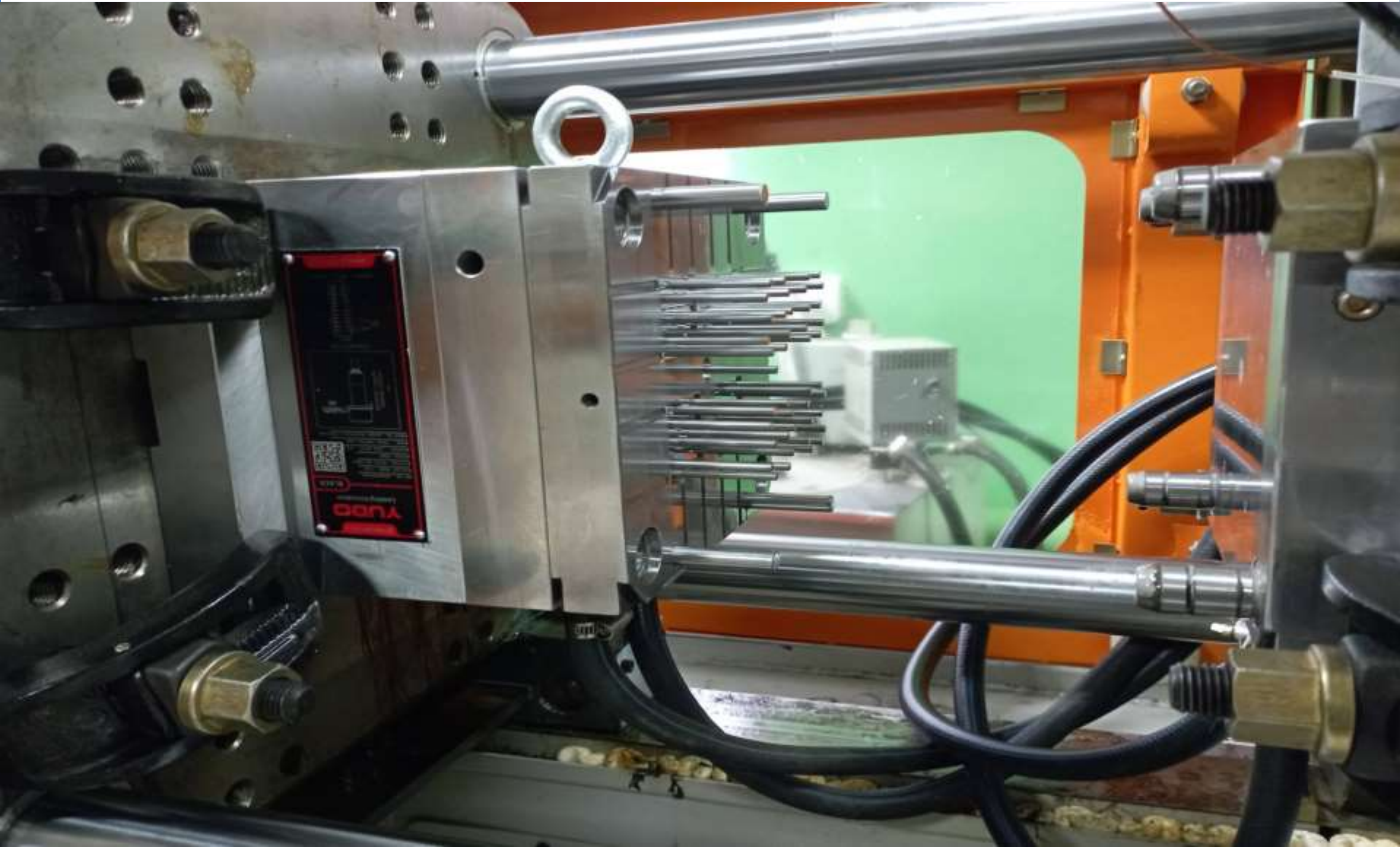
Matrix Form drawing 2023 for scintillator production (40x40x1.5 mm^3)

Shown t drawing of 4 sets Form to produce 4 scintillator plates per one cycle.
Matrix Form it is a special setup for molding by pressure technology.

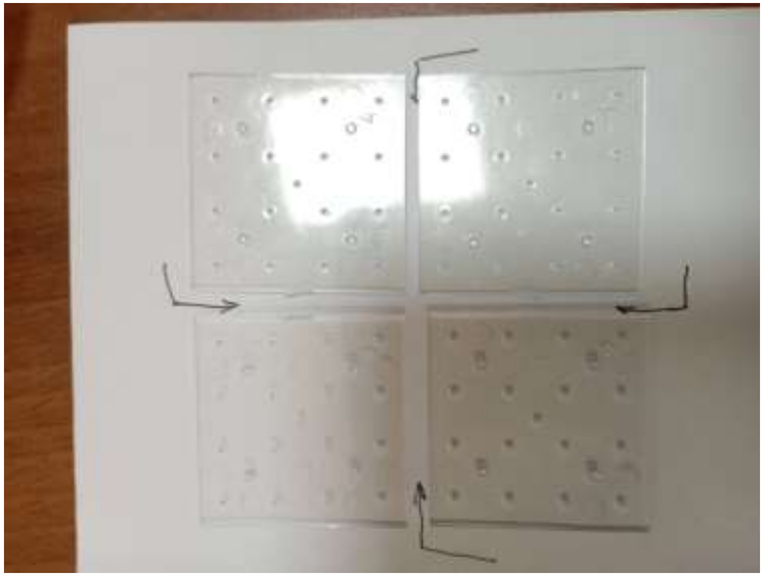


New Matrix Form for scintillators of 40x40x1.5 mm^3 is ready.

This Form was tested in Vladimir in March of 2024.

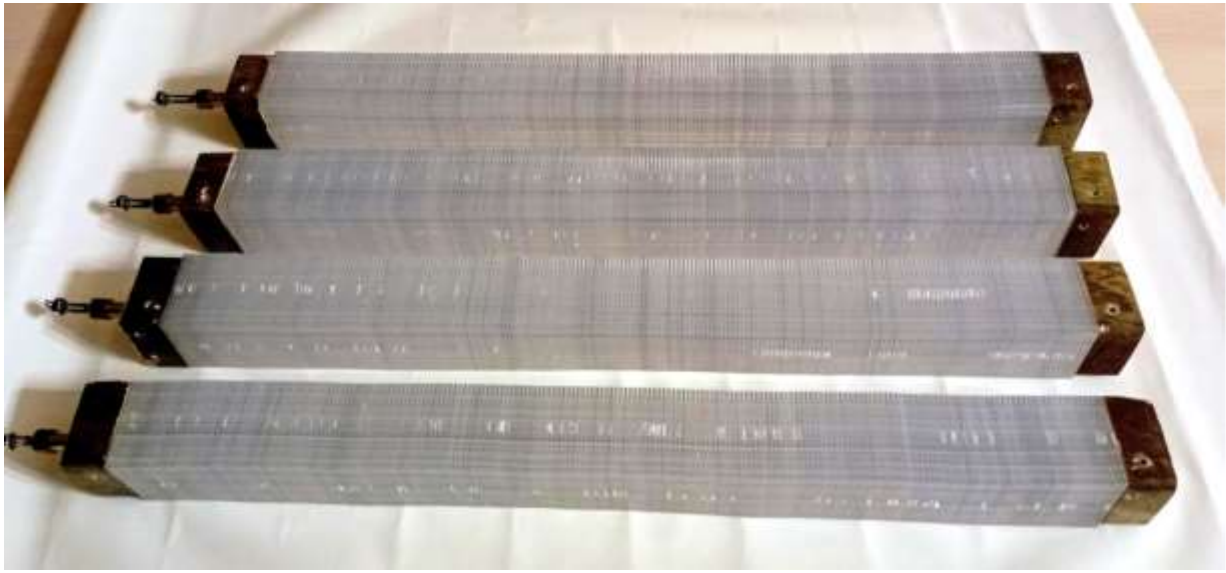


New scintillator tiles produced in Vladimir in April of 2024

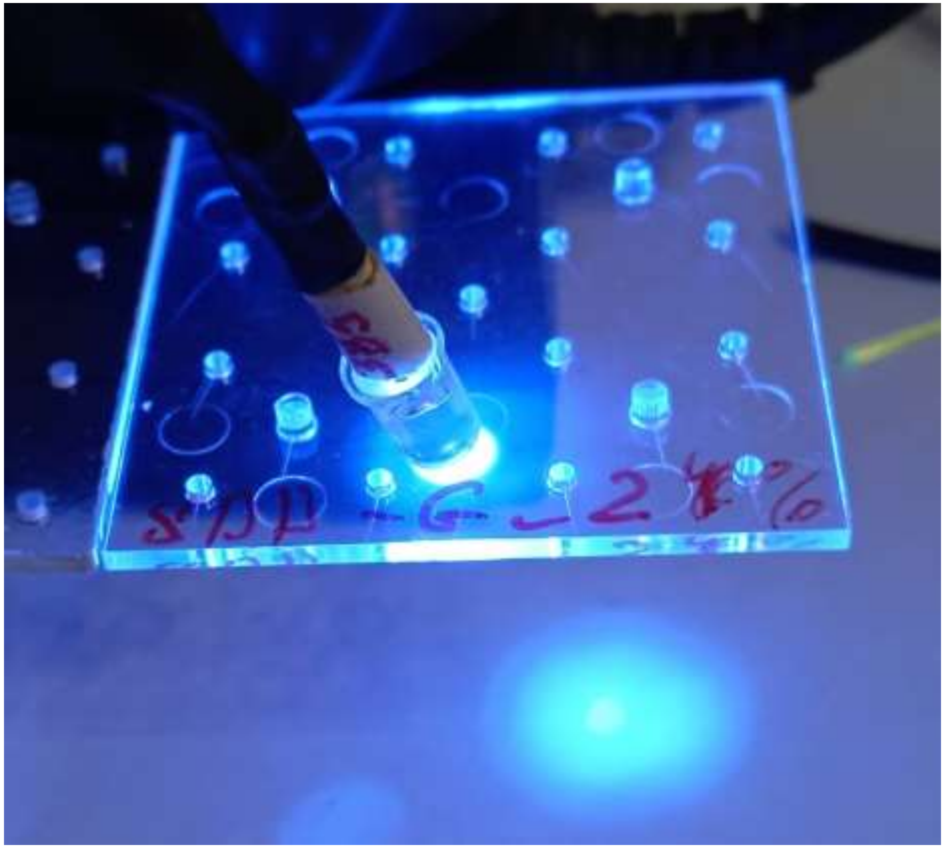


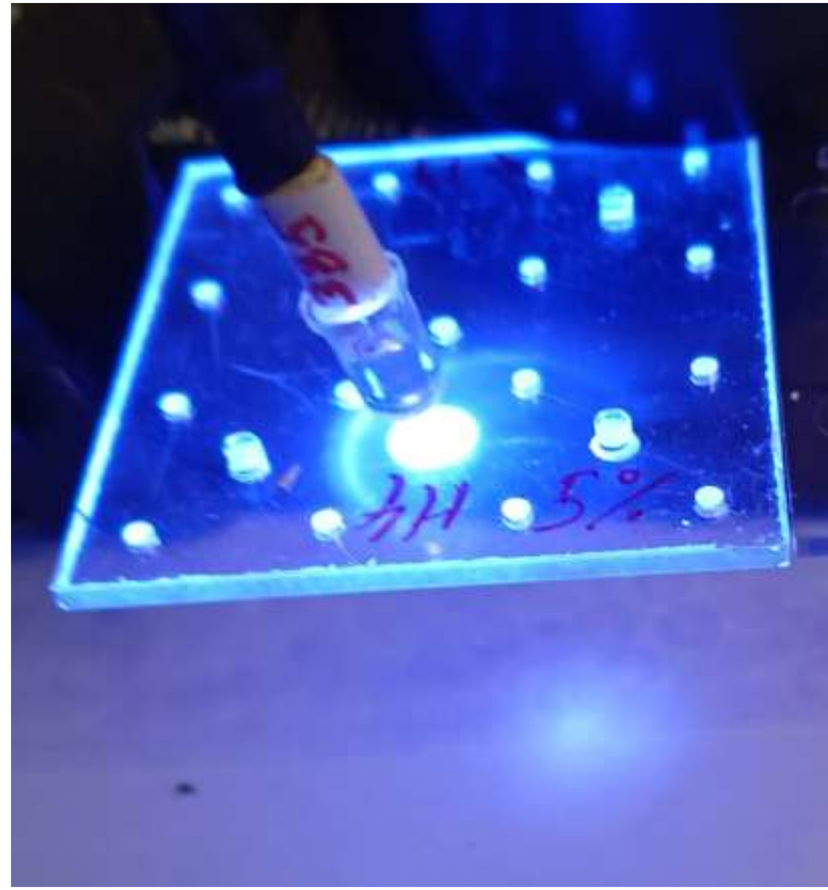
4 tiles from one production cicle

4 cells , assembled in stack to check sizes and tolerance limits.



Test with LED 380 nm shown absorption efficiency at POPOP 0.04% and 0.05%



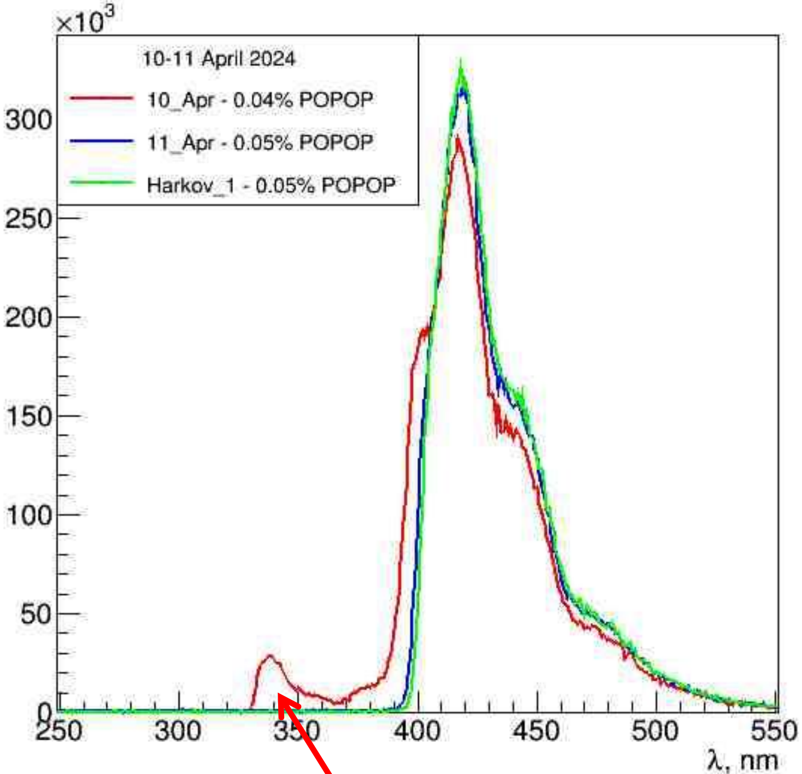


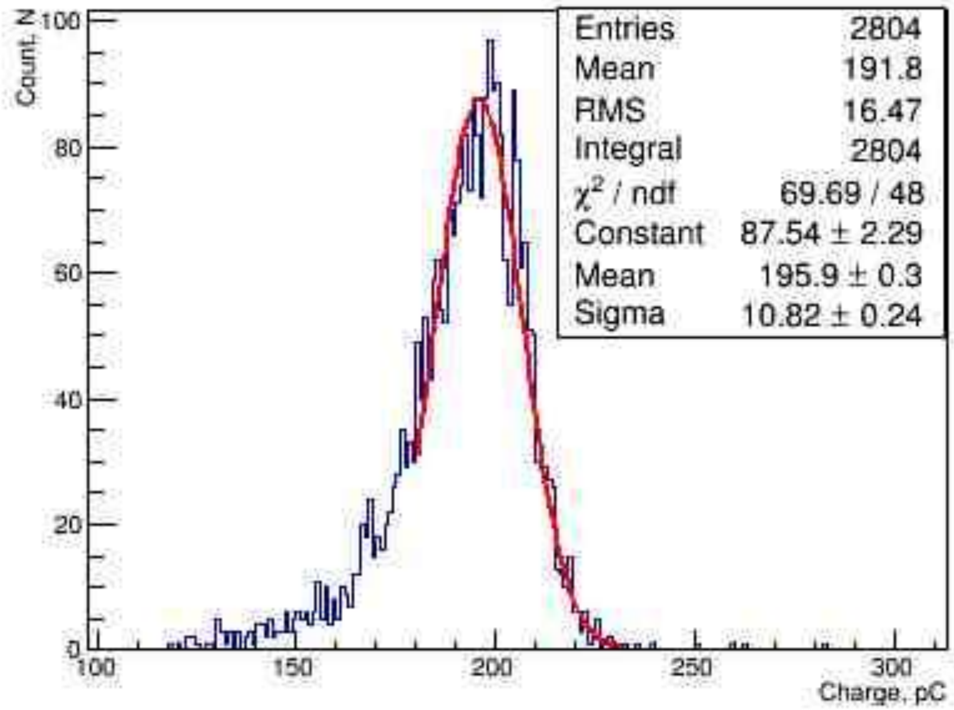
Transparent – not enough light absorption – is bad option

Good enough – 0.05% POPOP

Scintillator Emission spectra depending on the POPOP concentration

Scintillator Charge spectrum from α-source ^{241}Am

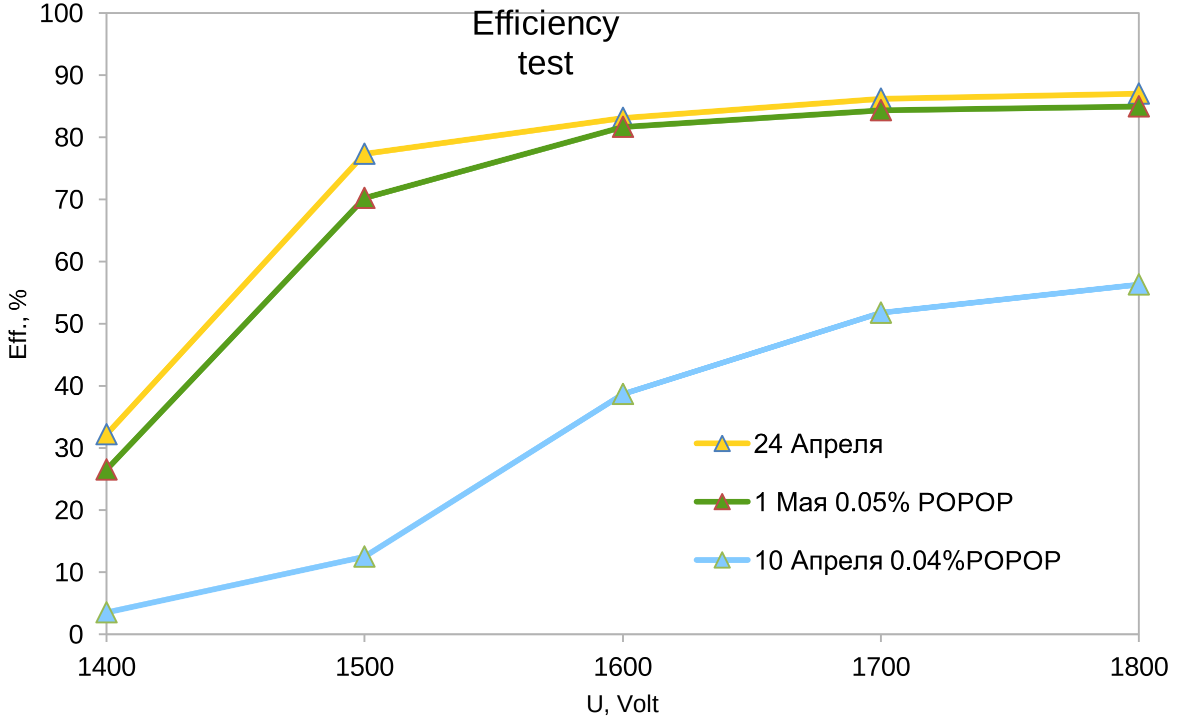




Emission spectra – read illustrate low POPOP concentration

Signal from α-source – illustrate light output from scintillator

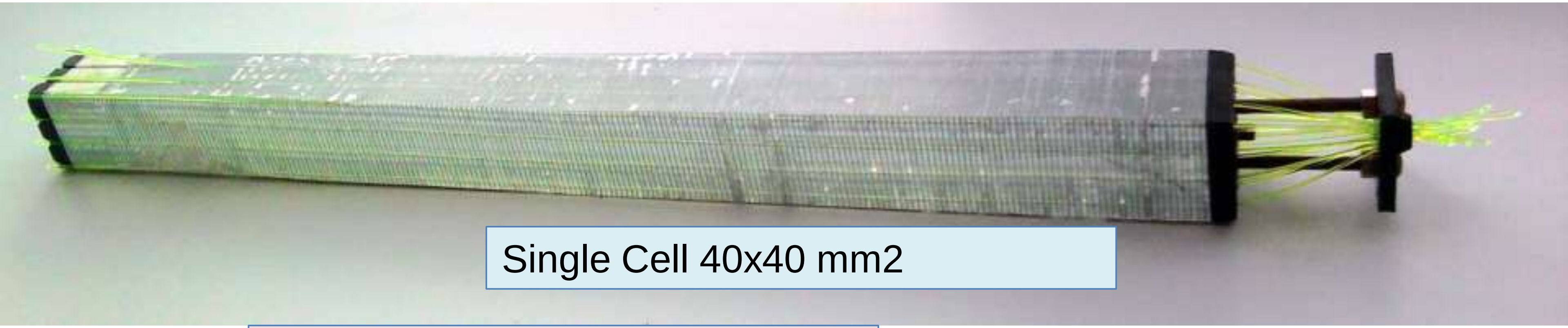
Taking into account the difference in the light output of the plates, it is possible to arrange them in a module in the opposite phase of the attenuation of light into the spectrum of the bias fiber. This will reduce signal scatter and therefore improve measurement accuracy.



Normalization is made to a scintillator produced in Kharkov in 2013. Compound: 2.0% PTP 0.05% POPOP

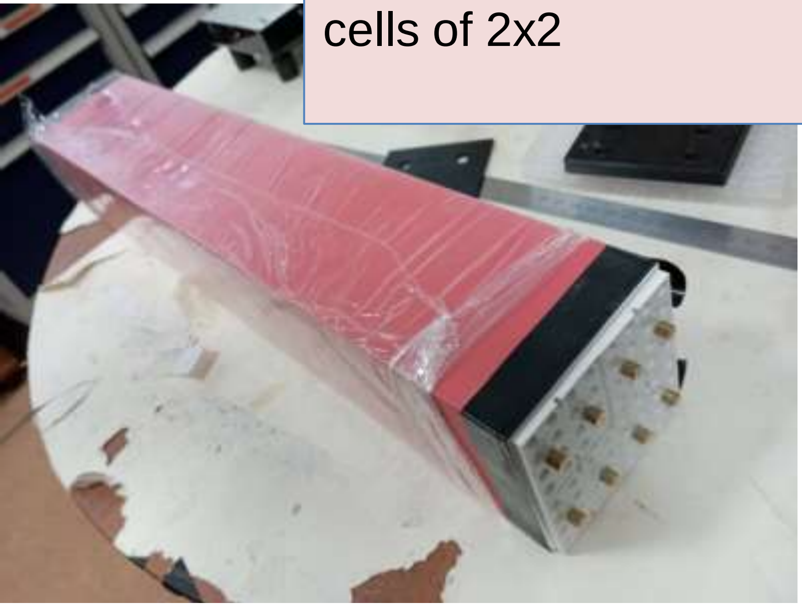
100 % 2.0% PtP + 0.05% POPOP
85% 1.5% PtP + 0.05% POPOP
56% 1.5% PtP + 0.04% POPOP

End Cup for SPD with new scintillator to be produced in 2024 via 256 cells of 40x40 mm^2

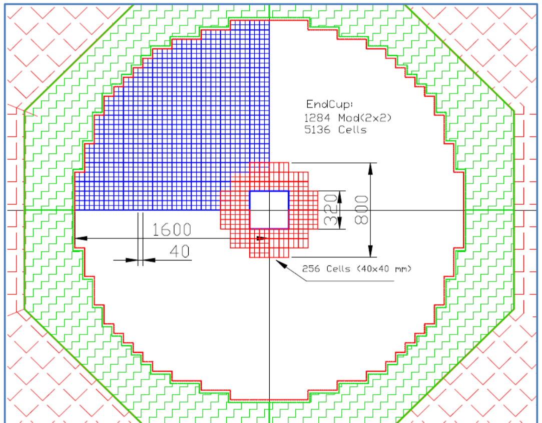


Single Cell 40x40 mm2

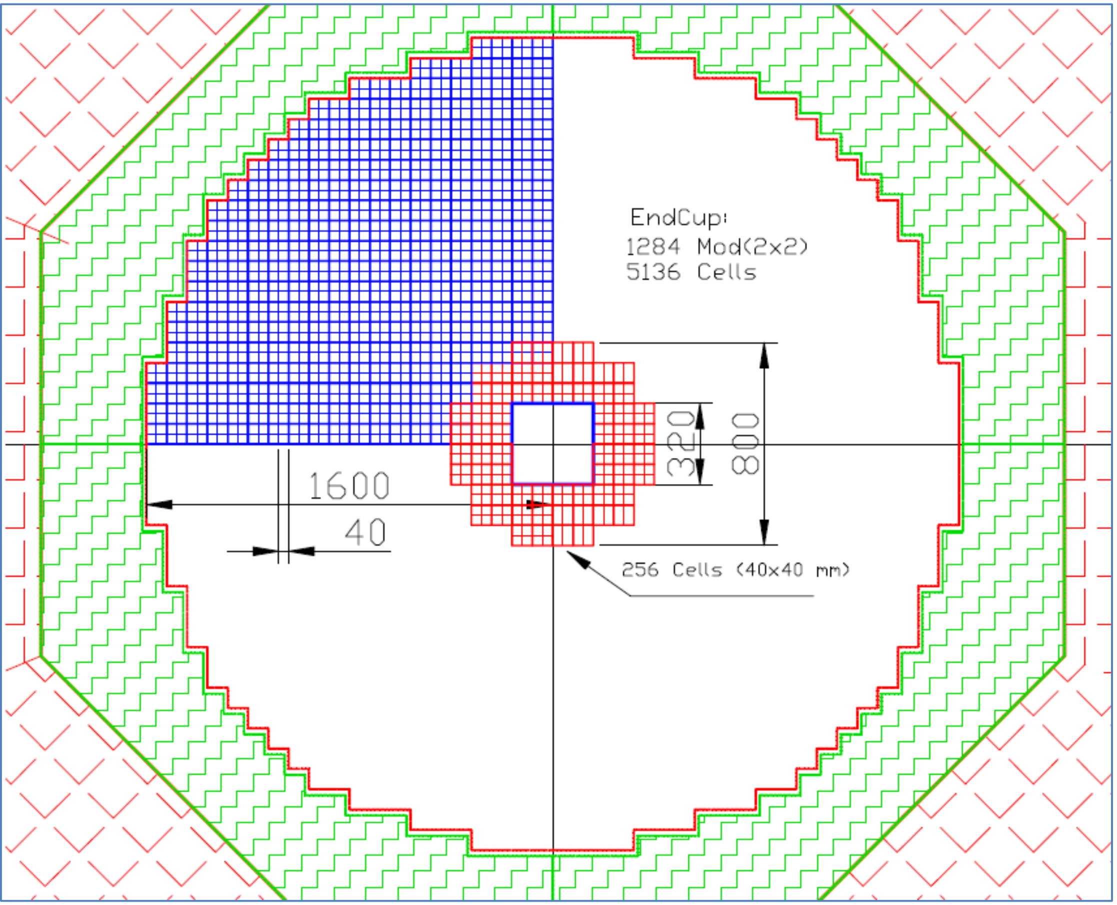
One Module setup consist from 4 cells of 2x2



In red is shown 64 Modules, consisting from 4 cells each of 2x2.



End Cup part (read) for with new scintillator to be produced in 2024 via 256 cells of 40x40 mm^2



This Figure shows in red 64 modules, consisting of 4 cells each. The weight of this assembly is 597 kg. This will require 130 kg of polystyrene, 465 kg of lead, as well as additives: 1.95 kg of P-terphenyl and 65 g. POPOP, and 2000 meters WLS fiber type Y-11.

It is 1/20 part of End Cup and taken time of 36 Days to prepared 51200 Stint. plates.

To read this setup, we need four ADC64 - 64-channel amplitude encoders, as well as 16 boards of 16-channel amplifiers and bias voltage regulators.

Conclusions

1. New ECAL geometry was designed in 2023-2024
2. SiPm EQR15-60 – pitch 15 μm was studied
3. SiPm EQR20-60 – pitch 20 μm will be studied soon
4. New ECAL setup (16 cells) with cell size 4x4 cm^2 was assembled
5. ECAL test in cosmic rays was done
6. Matrix form for new scintillators of 40x40x1.5 mm^3 is ready
7. New scintillator production started in April of 2024
8. Planned produced 160.000 plates – it is 6.4% from one End Cup

End of Report

Thanks for attention to All

VII SPD collaboration meeting

20-24 May 2024