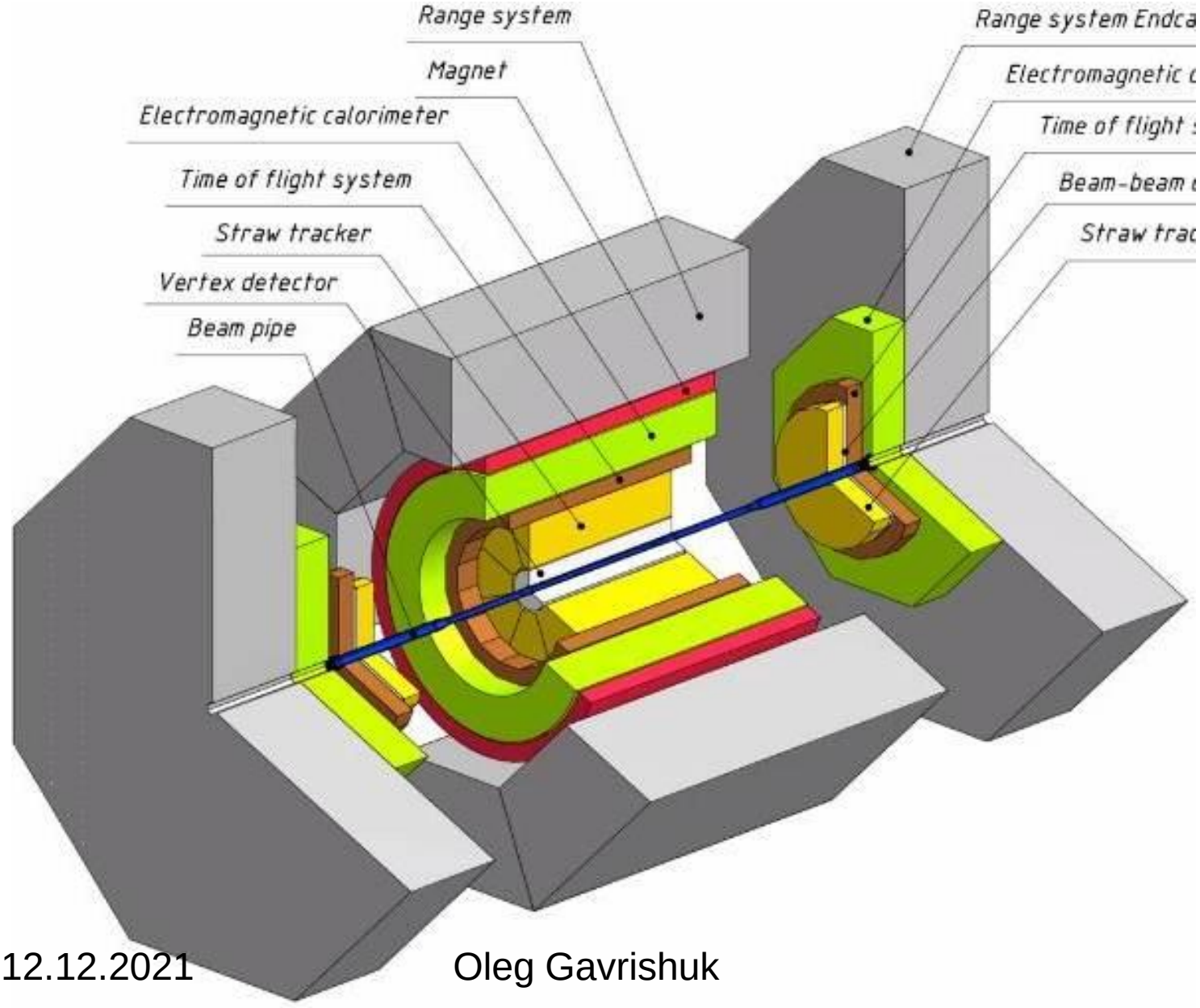
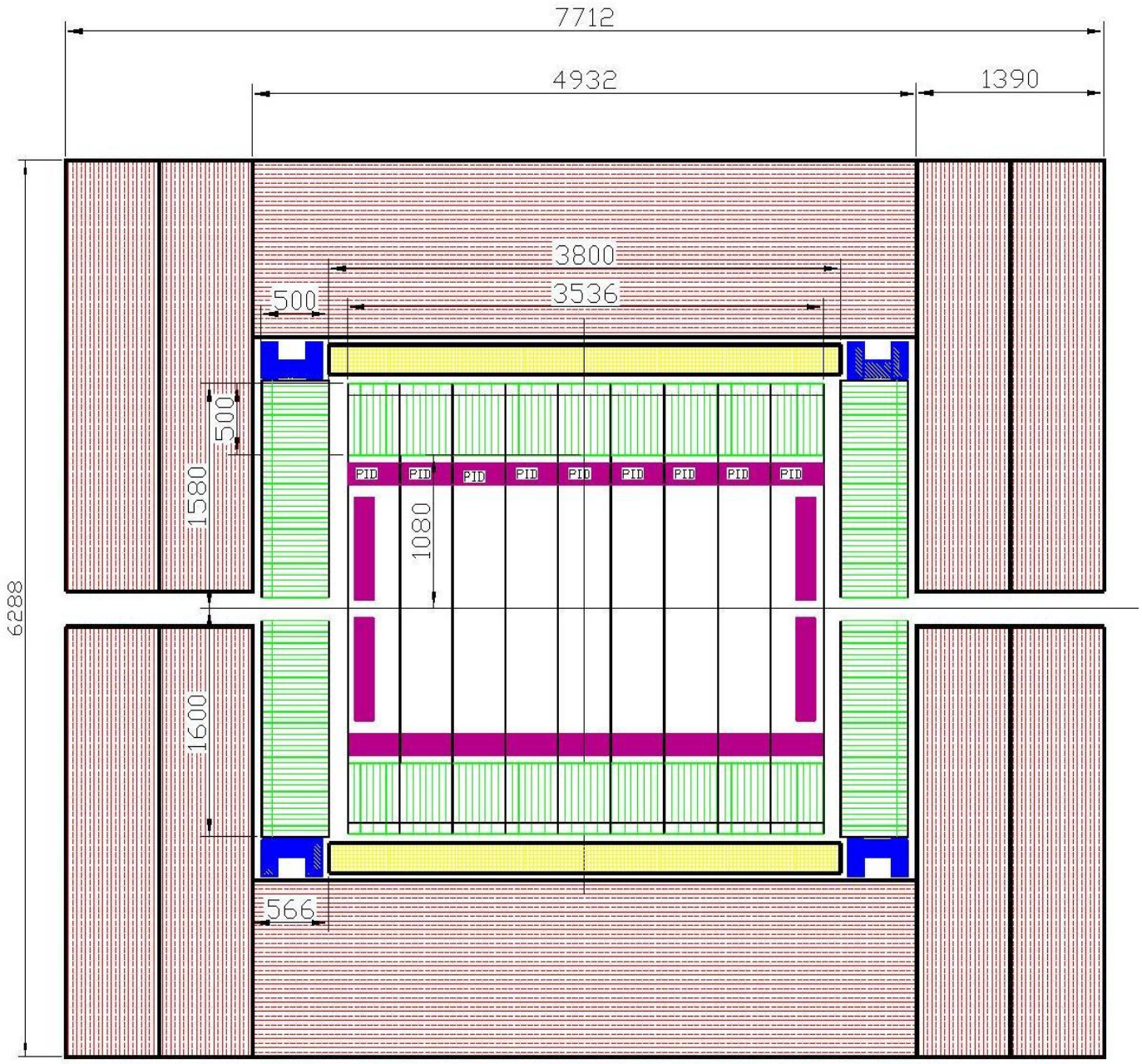
SPD ECAL status
JINR, VBLHEP , December 2021

1. New ECAL position inside of cryostat
2. ECAL cell sizes fitted to 40 mm
3. Module12/12/2021 length fitted to 500 mm
4. Monte Carlo results
5. Test results:
   - MIP resolution versus Threshold;
   - Long time stability;
   - Front-End electronic.
6. Production
7. Cost estimation
8. Possible integration in SPD

SPD 2021 Layout



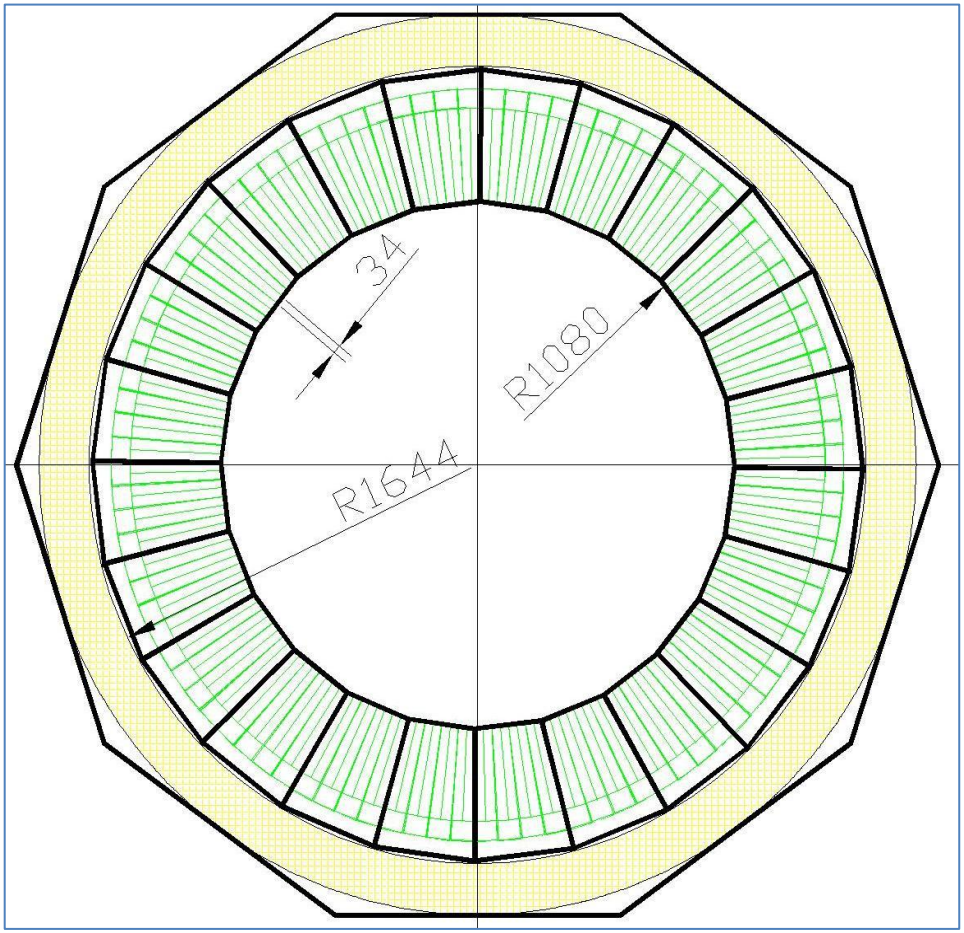


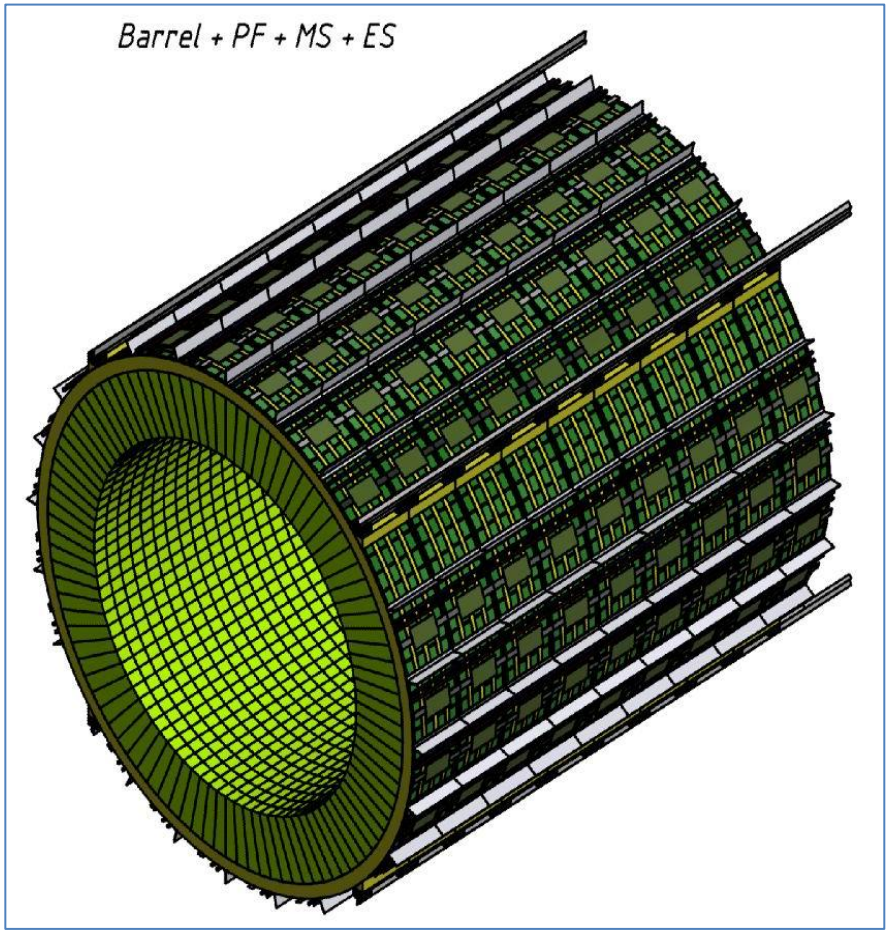
ECAL position (**green**) in the Cryostat (**yellow**), PID (**magenta**) and RS (red) EC-support (blue)

ECAL **Barrel** is located inside of **Cryostat** and Range System **(RS)**, as shown by green hatched boxes.

ECAL **End Cups** are located inside of RS

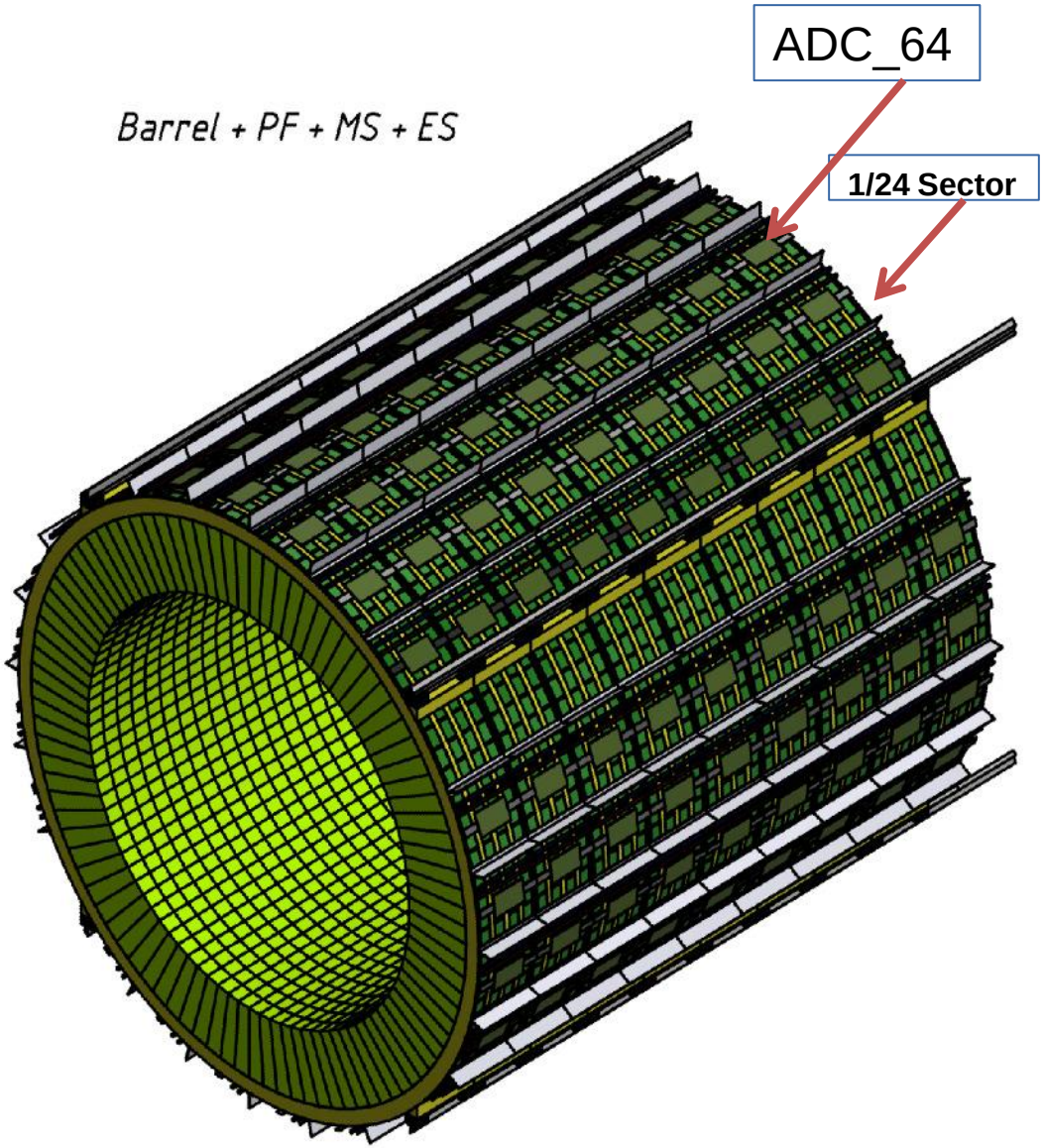
The calorimeter sizes determine by :
- **thickness itself;**
- **Cryostat diameter;**
- **outer size of PID.**





Schematic drawing (left) of the calorimeters cross-section for the Barrel part.
It is sectioned into 192 cells azimuthally with vertex a angle of 1.87^0.
All dimensions are in millimeters. The isometric view shown right.
The Barrel consist from 11 rings with weight 4 ton of each.
One ring contains - 1536 cells of trapezoidal shape.
The barrel have 16896 cells with total weigh equal to 45 tons.
264 ADC64 provide the readout of all Barrel cells.

Barrel Isometrics view



Concept:

1. Barrel consist from 11 Rings
2. One Ring divided on 24 sectors
3. Sector connected to One ADC_64
4. Air cooling assumed
5. Cables can fixed along the sector
6. Ring consist from:
   - 1536 cells, weight=4.0 t
7. Barrel consist from 11 Rings:
   - 16896 cells, weight=44 t

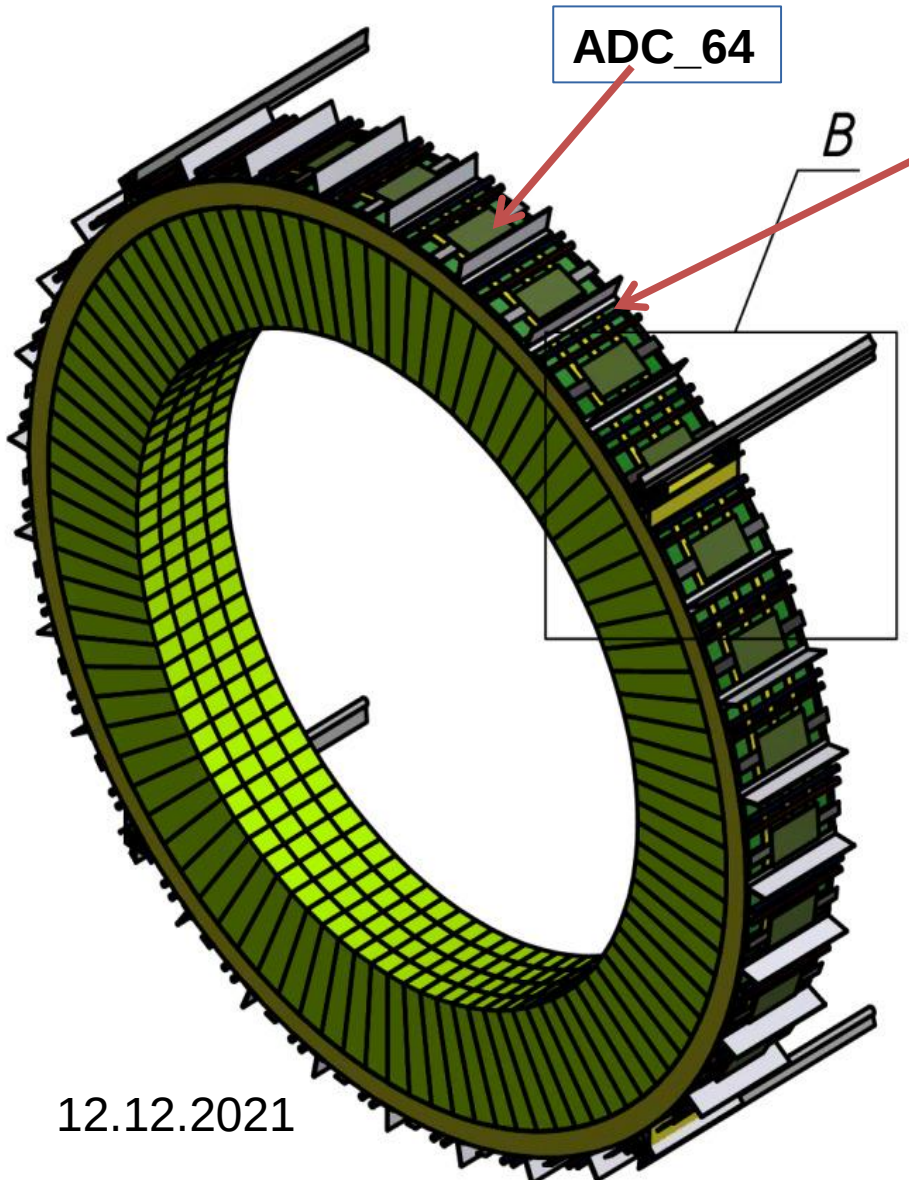
FrontEnd:

1.	Channels:	16896
2.	ADCs :	264
3.	Frontend cards :	1056
4.	HV:	24

Power (kW):

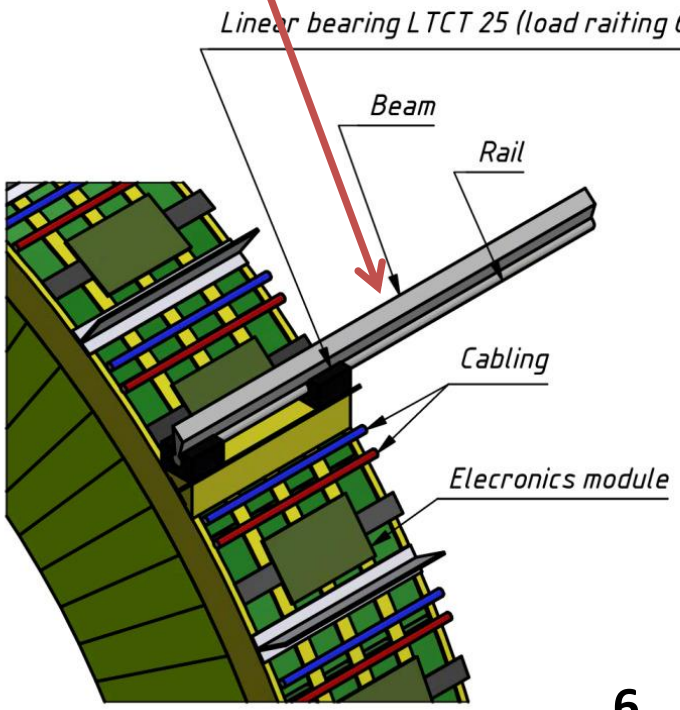
1.	ADC :	4.8
2.	Frontend cards :	1.0
3.	HV:	2.4
4.	Total:	8.2

Barrel Ring installation and support

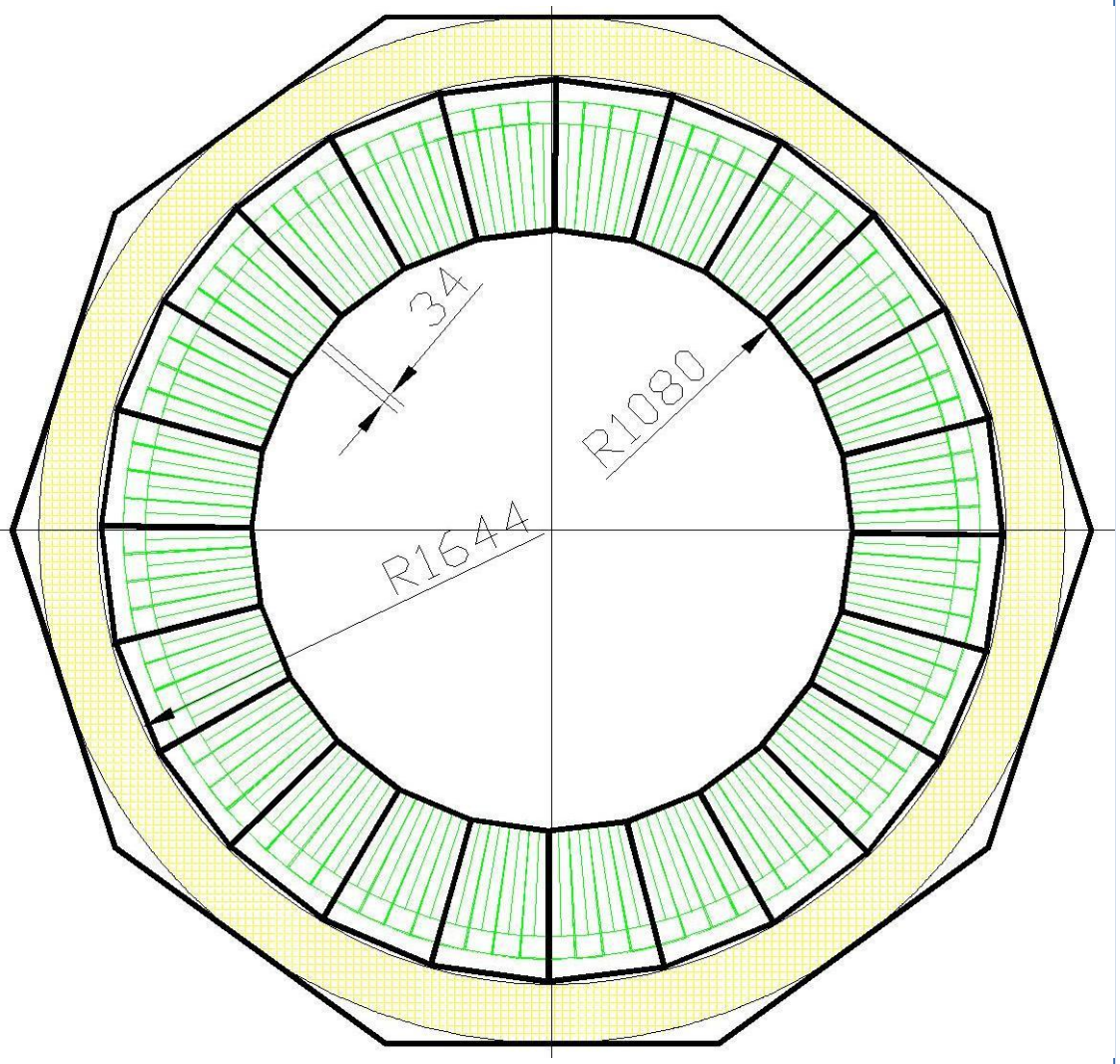


Barrel Ring
Weight ~4.0 t

The Rails



ECAL Barrel composition



Concept:

1. Barrel consist from 11 Rings
2. One Ring divided on 24 sectors
3. Sector connected to One ADC_64
4. Air cooling assumed
5. Cables can fixed along the sector
6. Ring : 1536 cells, ~4.0 t
7. 11 Rings: 16896 cells, ~44 t

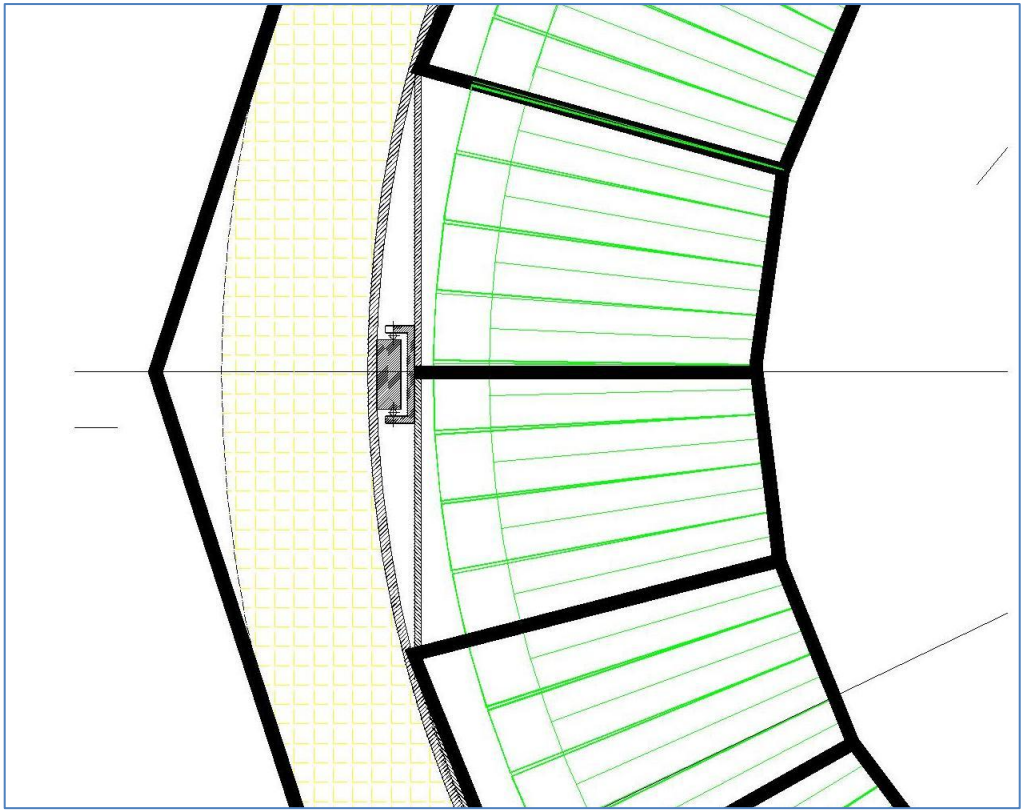
Front End Numbers:

1. Channels:	16896
2. ADCs :	264
3. Frontend cards :	1056
4. HV:	11

Power (kW):

1. ADC :	4.8
2. Frontend cards :	1.0
3. HV:	1.1
4. Total:	6.9

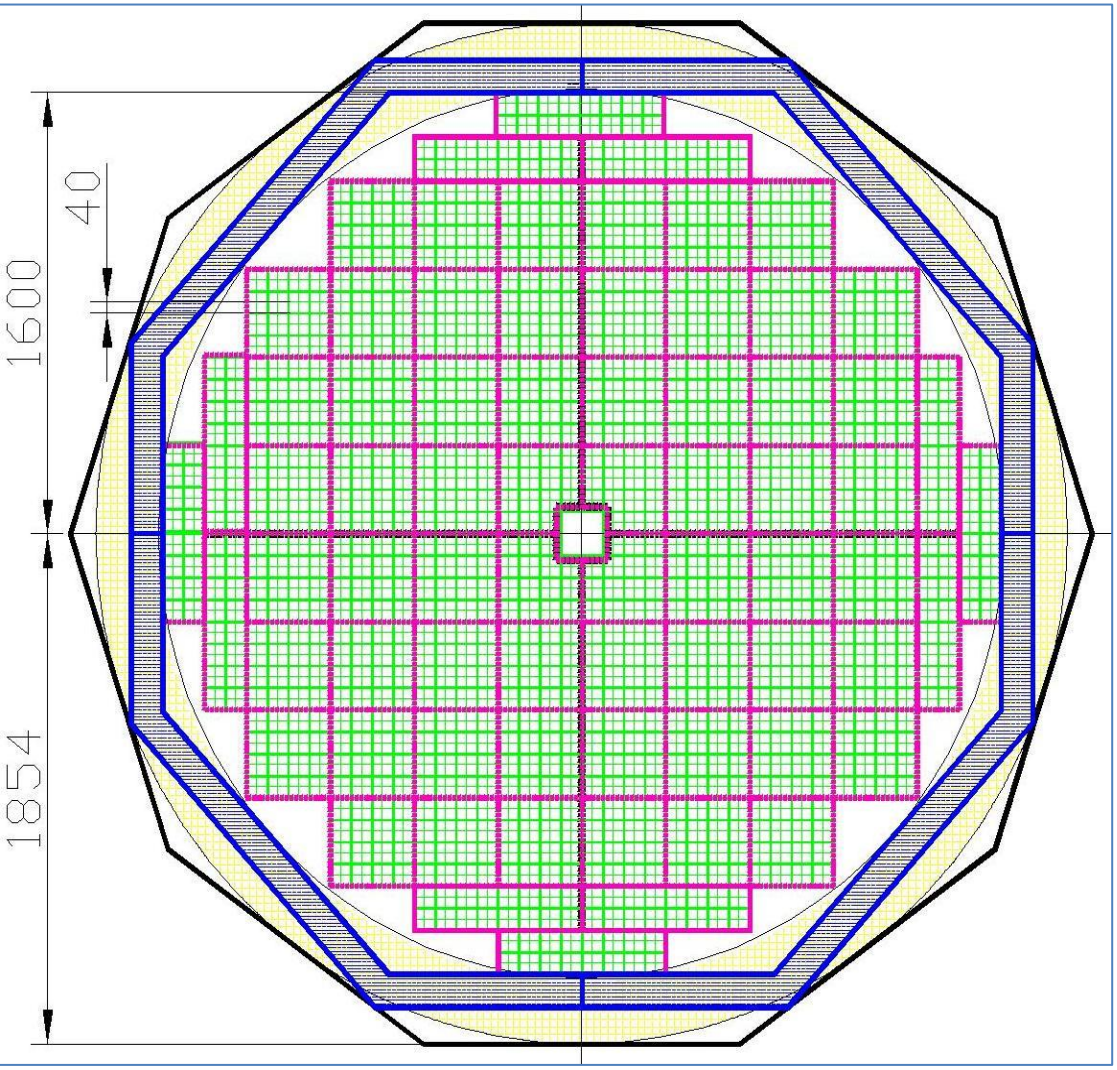
ECAL mounting inside of the cryostat



Concept:

1. Rails welded to Cryostat inner side
2. Roller fixed on the ECALs ring
3. ECAL ring is rolled into the cryostat

ECAL End Cup composition



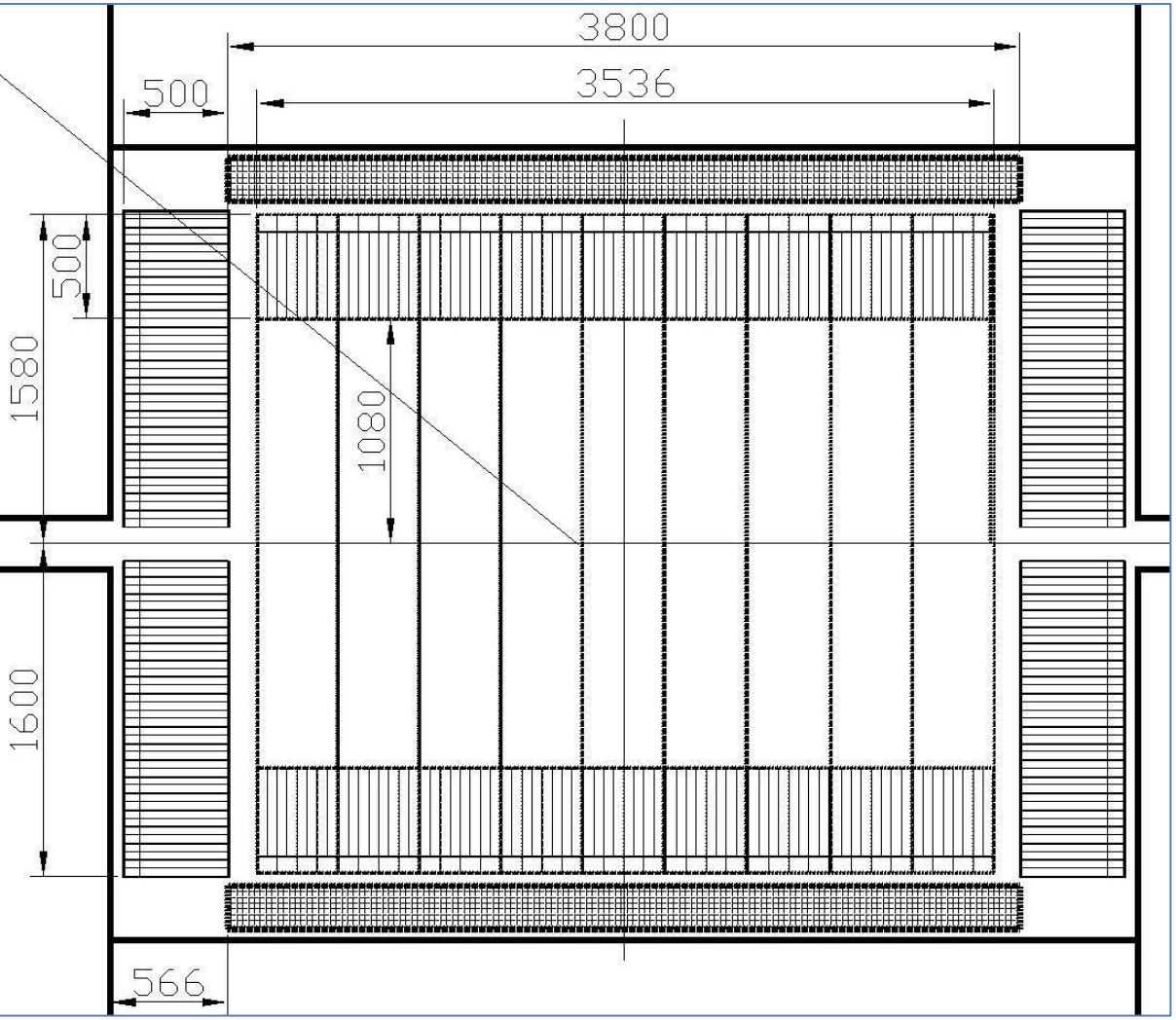
One End-Cap consists from 4 sectors.
One sector – **1152** , of 40x40 mm^2;
One End Cup – **4608** cells ;
The weight – **12** tonn (include Frame)

Frontend Numbers and Power :

ADC64	**72**	1296 W
Amp_16 ch	**288**	288 W
Power unit	**8**	800 W
Total Power (One)		**2.4 kW**

End-Cap – installed in a frame that supports it. The frame is mounted directly to the RS as shown in this figure.
All dimensions are in millimeters. The holes of size 160 ×160 mm^2.

ECAL Barrel and End Cup parts inside of Cryostat



Composition:

Total Cells Number – 26096

Weight (t):

Barel – 45

End Cup_1 – 12

End Cup _2 – 12

Total Weight – 69

Front End Numbers:

ADC_64 – 408

Amp_16 – 1631

HV – 21

Power (kW):

ADC_64 – 7.4

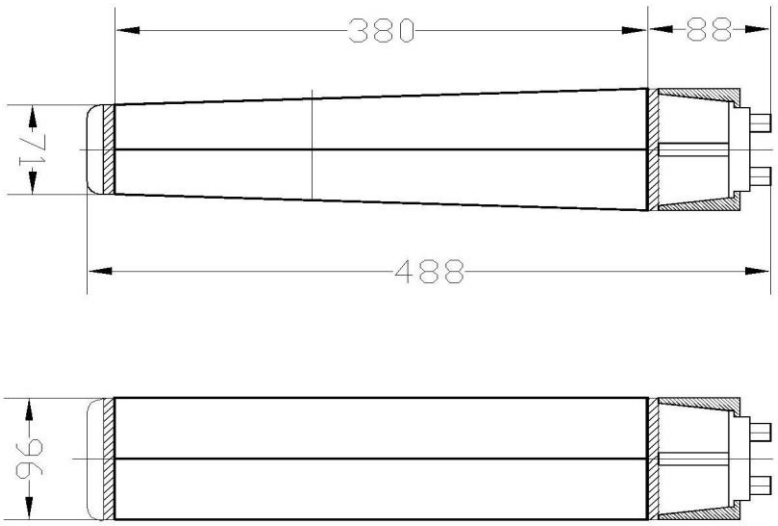
Amp_16 – 1.6

HV – 2.1

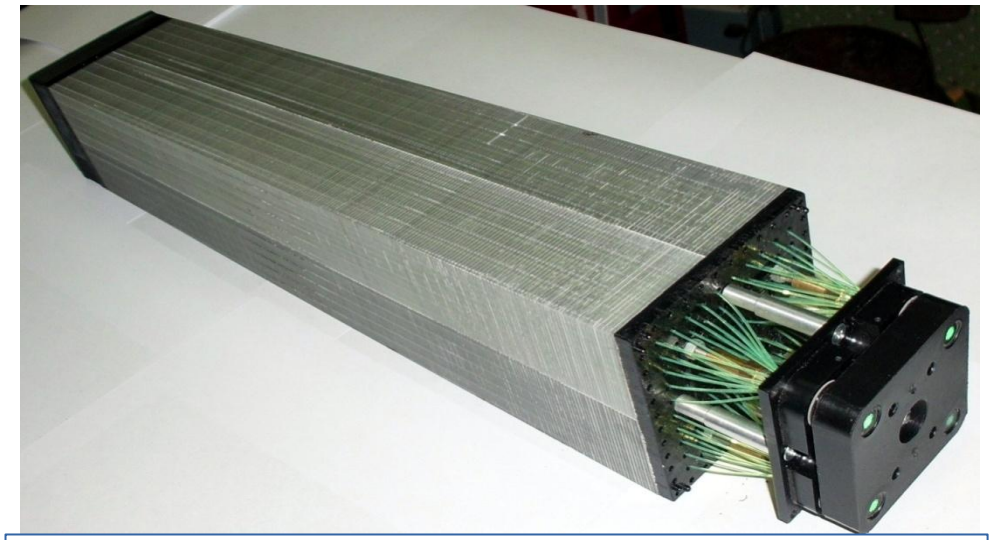
Total Power – 11.1 kW

ECAL module design

Sampling : 190 layers 1.5 Sc+0.5 mm Lead
Active length: 380+10mm
Total length: 500 mm
Moliere radius: R_M=58 mm,
Absorber length: 17.62 X_0

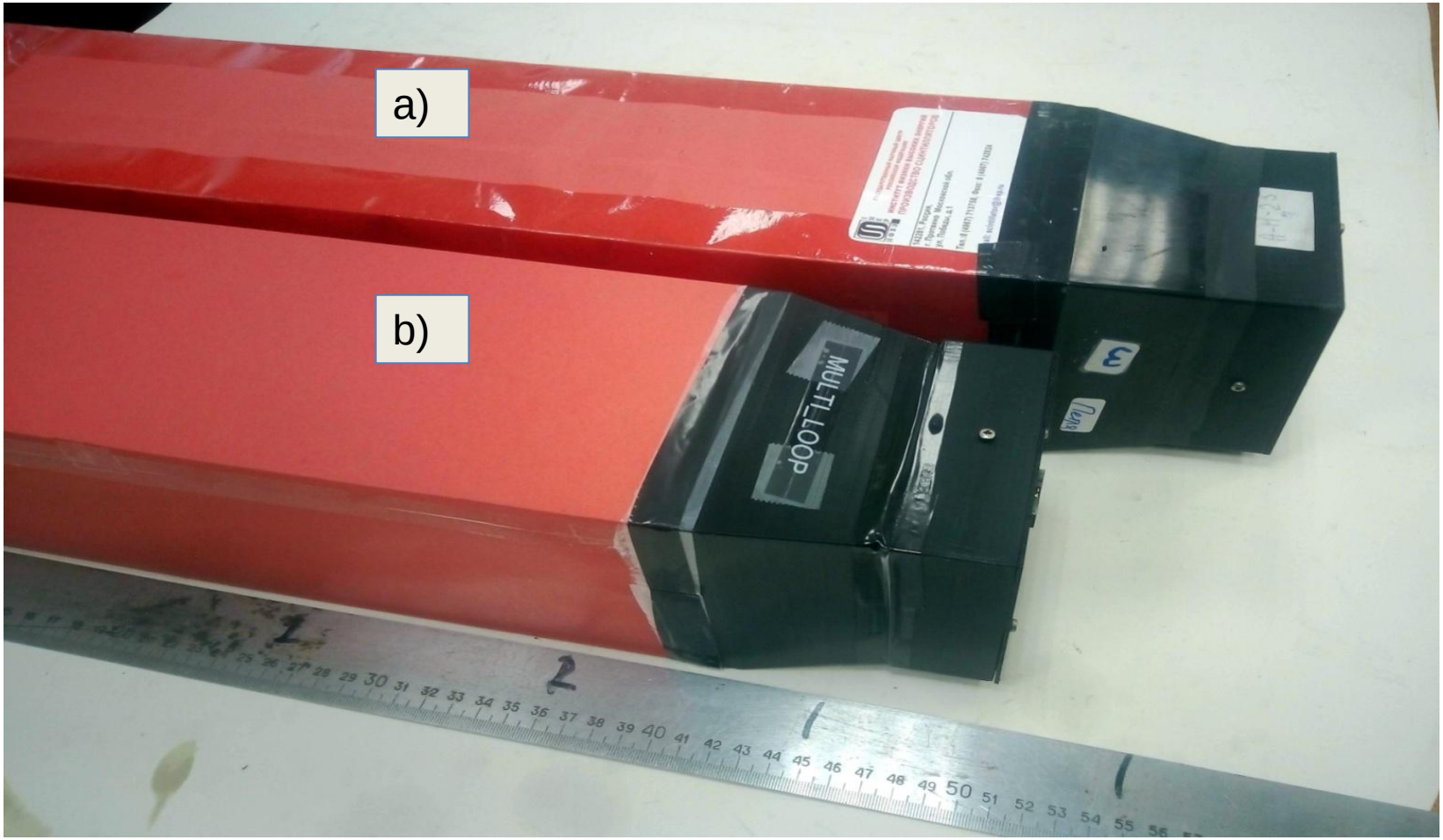


ECAL module drawing:
3.75 degree pfi angle



ECAL module photo consisting from 4 cells after milling.

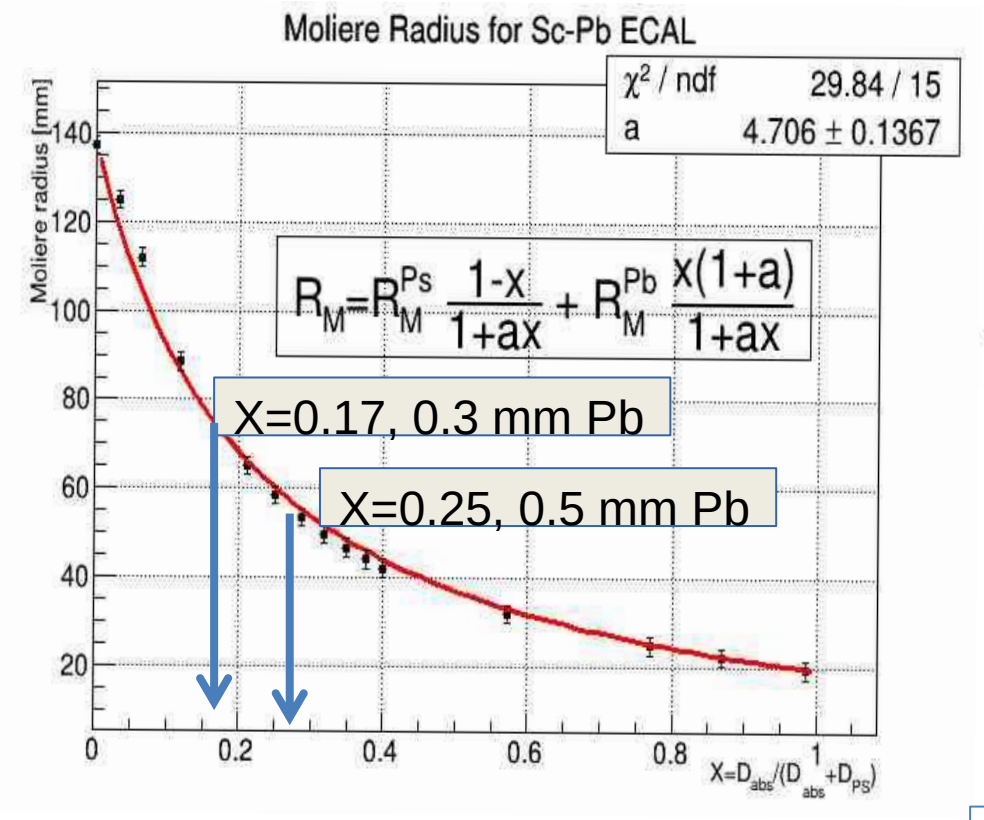
Photo of two ECAL modules with different length:
a) - 220 layers 1.5 Sc+0.3 mm Pb – L=580 mm – R_M=74 mm, 12.56 X_0
b) - 190 layers 1.5 Sc+0.5 mm Pb – L=500 mm – R_M=58 mm, 17.62 X_0



Resent publications

1. **Effect of energy leakage on the energy resolution of E.M. sampling calorimeters**
   Gavrishchuk, O.P. (Joint Institute for Nuclear Research (JINR), Dubna (Russian Federation));
   Kovtun, V.E. , Malykhina, T.V. (V.N. Karazin Kharkiv National University, Kharkiv (Ukraine));
   Voprosy Atomnoj Nauki i Tekhniki; ISSN 1562-6016; ; (no.3-133); p. 76-80
2. **Moliere Radius Simulation for EM Calorimeter**
   O. P. Gavrishchuk, V.E. Kovtun, T.V. Malykhina, Simulation Studies of the Moliere Radius for EM Calorimeter Materials XXVII INTERNATIONAL CONFERENCE ON CHARGED PARTICL ACCELERATORS, ABSTRACT, September 21–24, 2021, Kharkiv, Ukraine
3. **ELECTROMAGNETIC CALORIMETER FOR THE SPD EXPERIMENT**
   Физика элементарных частиц и атомного ядра: 2021. Т. 52. ,Вып. 4. С. 975
   V. N. Azorskyi, N. O. Graphov, O. P. Gavrischuk ∗ , A. I. Maltsev ∗∗, V. V. Tereshenko
   Joint Institute for Nuclear Research, Dubna.
4. **Simulation Study of Energy Resolution of the Electromagnetic Shashlyk Calorimeter for Different of Layers and Absorber Combinations**
   No. 3 (2020): East European Journal of Physics
   Gavrishchuk, O.P. (Joint Institute for Nuclear Research (JINR), Dubna (Russian Federation));
   Kovtun, V.E. , Malykhina, T.V. (V.N. Karazin Kharkiv National University, Kharkiv (Ukraine));
5. **http://spd.jinr.ru/wp-content/uploads/2019/03/meet-180702_prototype_for_spd_ecal.pdf**
6. **Conceptual design of the Spin Physics Detector https://arxiv.org/abs/2102.00442**

Moliere Radius (R_M) for Lead absorbers, simulation results and extrapolation expressions



R_M=74 mm – for 0.3 mm Pb + 1.5 mm Sc
R_M=58 mm – for 0.5 mm Pb + 1.5 mm Sc

R_M for heterogeneous materials MC:
E_C – critical energy, **j** is the index of the number of media (lead, scintillator) and partial contributions **- gives an underestimated result :**

$$\frac{1}{R_M} \approx \frac{1}{E_S} \cdot \sum_j \frac{w_j E_{Cj}}{X_{0j}} \qquad E_S = \sqrt{\frac{4 \cdot \pi}{\alpha}} m_e c^2 = 21.2\,MeV$$

MC estimation can be presented with single parameter: **a** – which depended from absorbed material only:

$$R_M(x) = R_M^{PS} \cdot \frac{1-x}{1+a \cdot x} + R_M^{abs} \cdot \frac{x + a \cdot x}{1+a \cdot x}$$

R_M^{PS}=137.5 cm
R_M^{abs}=19.4 cm

X=0.5/(0.5+1.5)=**0.25** -> Pb=0.5 mm
X=0.3/(0.3+1.5)=**0.17** -> Pb=0.3 mm

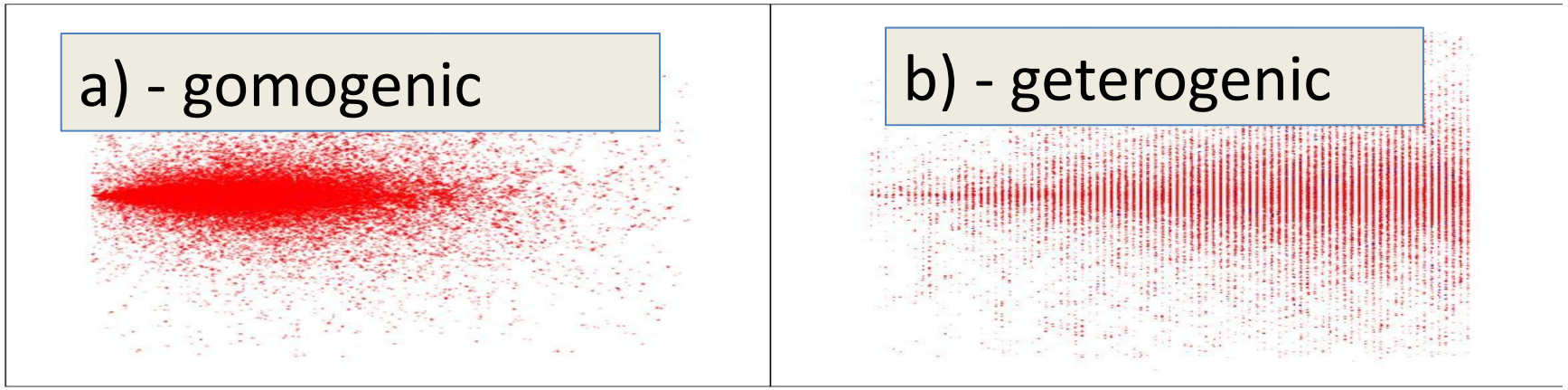
R_M – estimation by MC

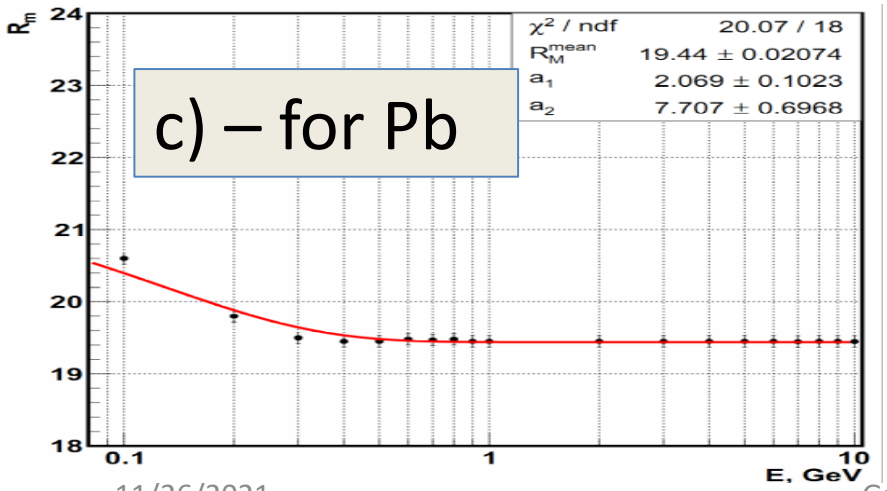
Moliere radii for some homogeneous material	Pb	W	U	PS
R_M ,mm	19.4	11.9	11.14	137.5
R_M dependencies from D_{abs} For calorimeters with Pb absorbers + 1.5 mm Sc	Pb	Pb	Pb	
D_{abs}, mm - Lead	0.3	0.4	0.5	
R_M [mm] - Lead	74.0	65.0	58.5	

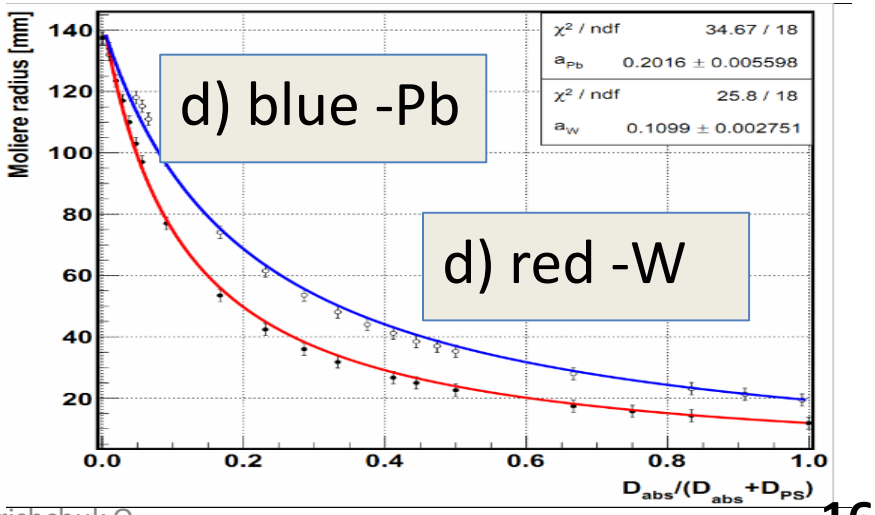
Radius Moliere has dependence from:

a,b,d) Material and structure of absorber;

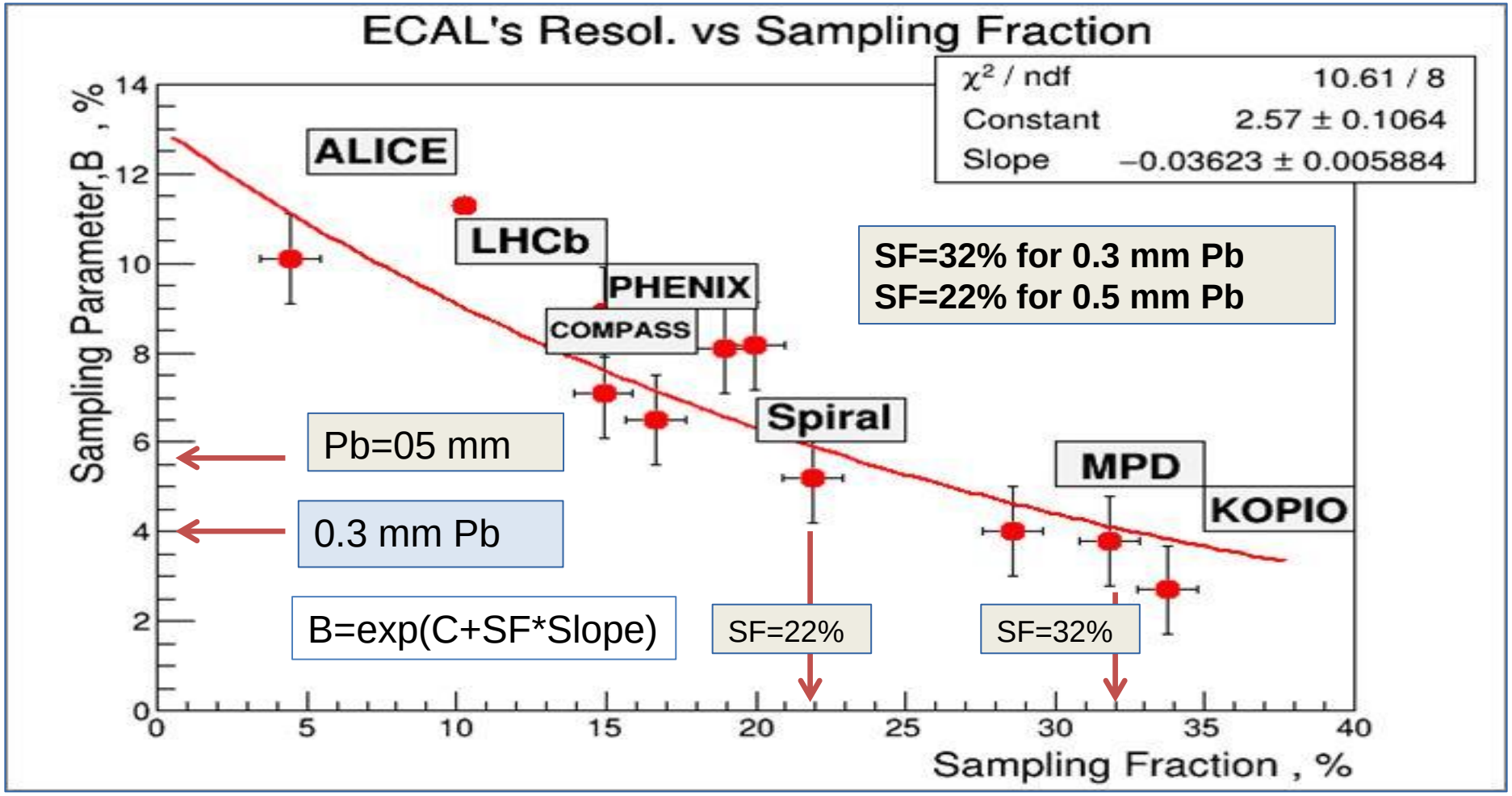
c) Not depended from electrons in energies range > 0.3 GeV.



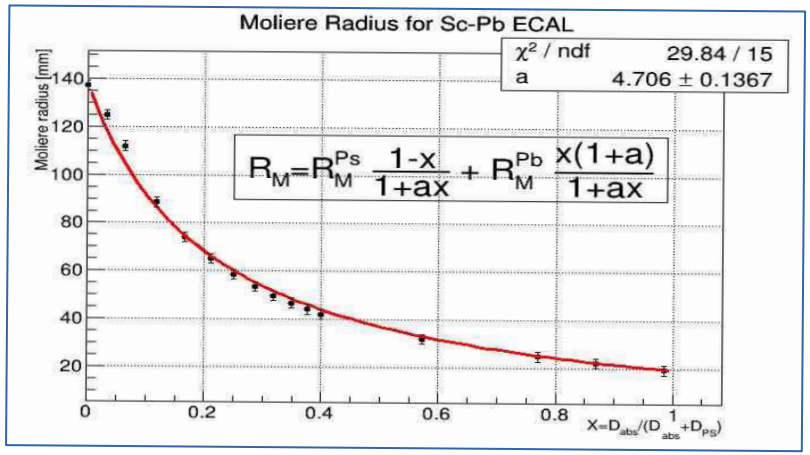


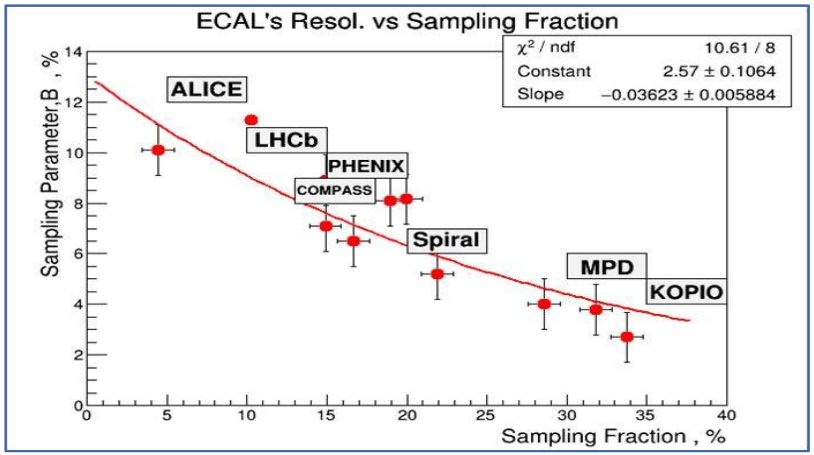


The ECAL energy resolution dependence for shashlick calorimeters from active materials sampling fraction.



The table for Calorimeters type: MPD, SPD, ALICE





$$R_M(x) = R_M^{PS} \cdot \frac{1-x}{1+a\cdot x} + R_M^{abs} \cdot \frac{x+a\cdot x}{1+a\cdot x}$$

B=exp(C+SF*Slope)

$X=D_{abs}/(D_{scin}+D_{abs})$

gr/cm2	X-rad	43,79	6,37	X	mm	%	%	N	cm
N Layers	Setup	Scint, mm	Lead, mm	Param	RMoliere	Sampl_fr	Resol	Rad_X	Cell Sises
220	MPD	1,50	0,30	0,17	74,28	31,83	4,15	12,56	4x4x42
190	SPD	1,50	0,50	0,25	59,85	21,89	5,94	17,62	4x4x39
77	ALICE	1,76	1,44	0,45	40,07	10,25	9,04	20,08	6x6x25

Cosmic test setup

ECAL setup for cosmic tests:
Performed the matrix of 4x4 cells wit sizes 55x55 mm^2 .

Sampling :
- **190 layers;**
- **1.5 mm Sc + 0.5 mm Pb.**

ECAL properties:
- **X_0=17,6 rad. length;**
- **R_M = 58 mm;**
- **L =500 mm – module length**

Mini SPD Setup

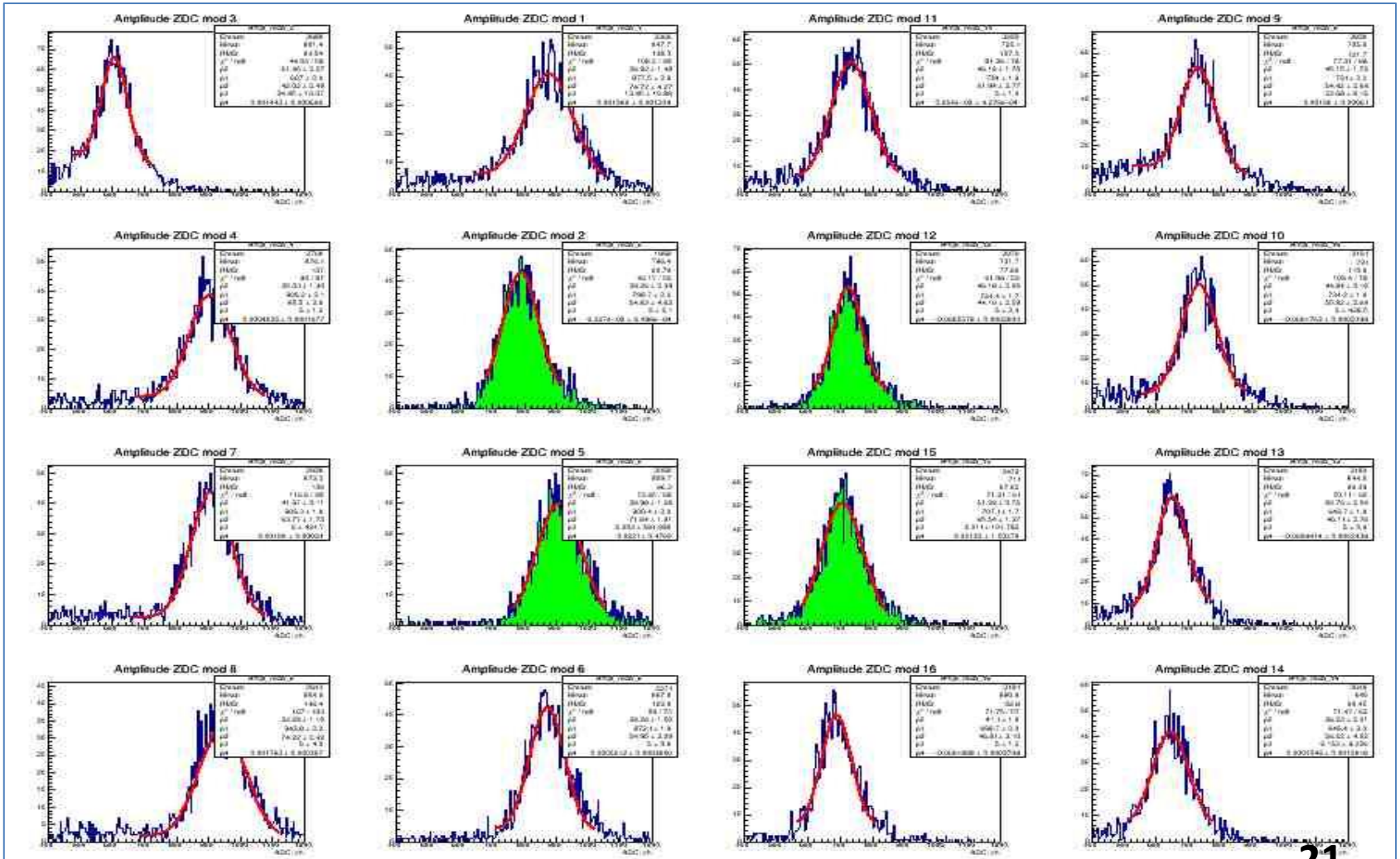
ECAL setup for mini SPD consist from 4 modules of 110x110 mm^2 .

These setup consist from 16 cells of 55x55mm^2.

Sampling structure is:
- **220 layers;**
- **1.5 mm Sc + 0.3 mm Pb.**

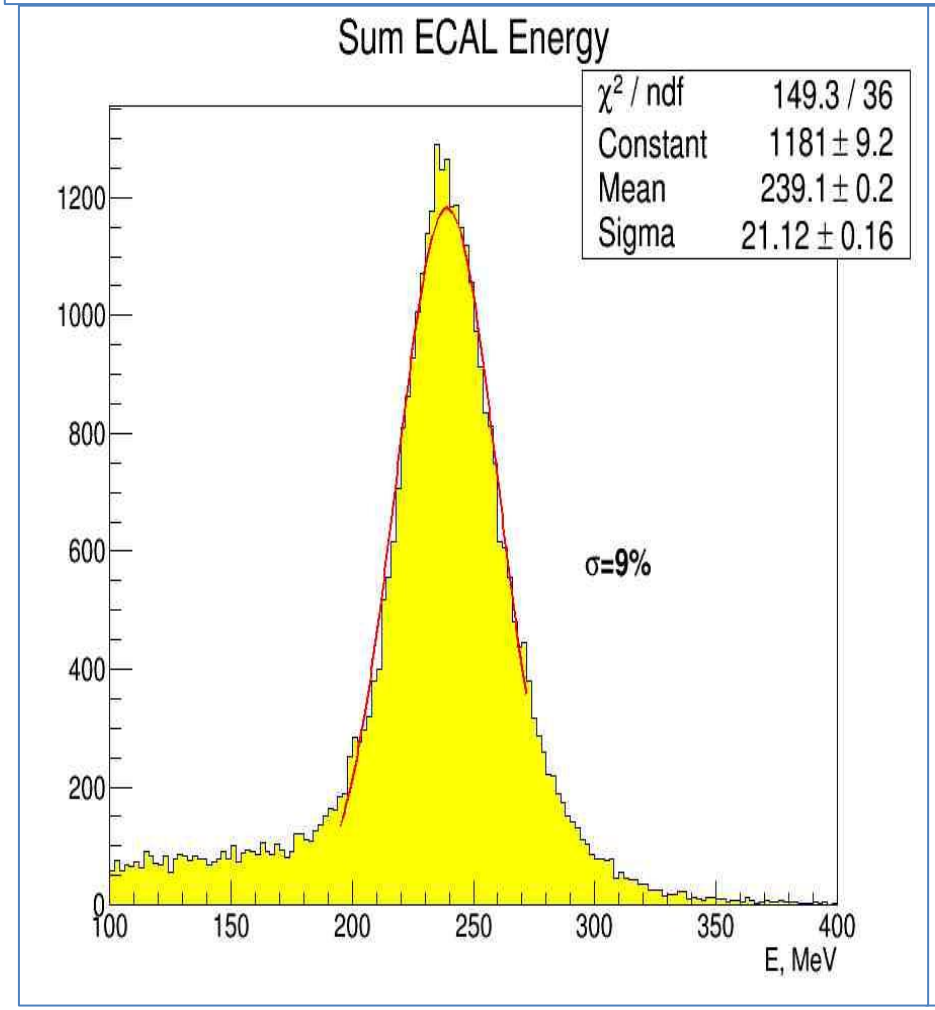
ECAL properties:
- **X_0=12,7 rad. length;**
- **R_M = 74 mm;**
- **L =600 mm – module length**

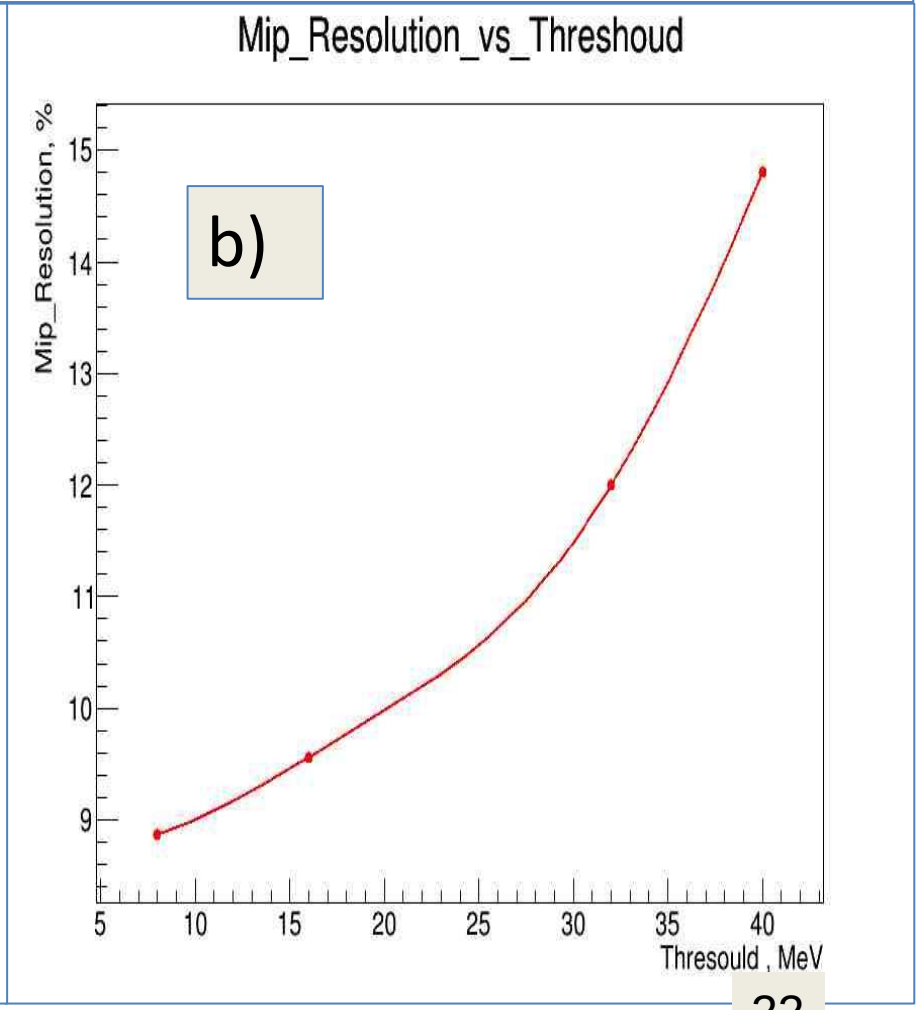
Cosmic MIP peak for ECAL's 16 cells.
Green color corresponded to central cells.



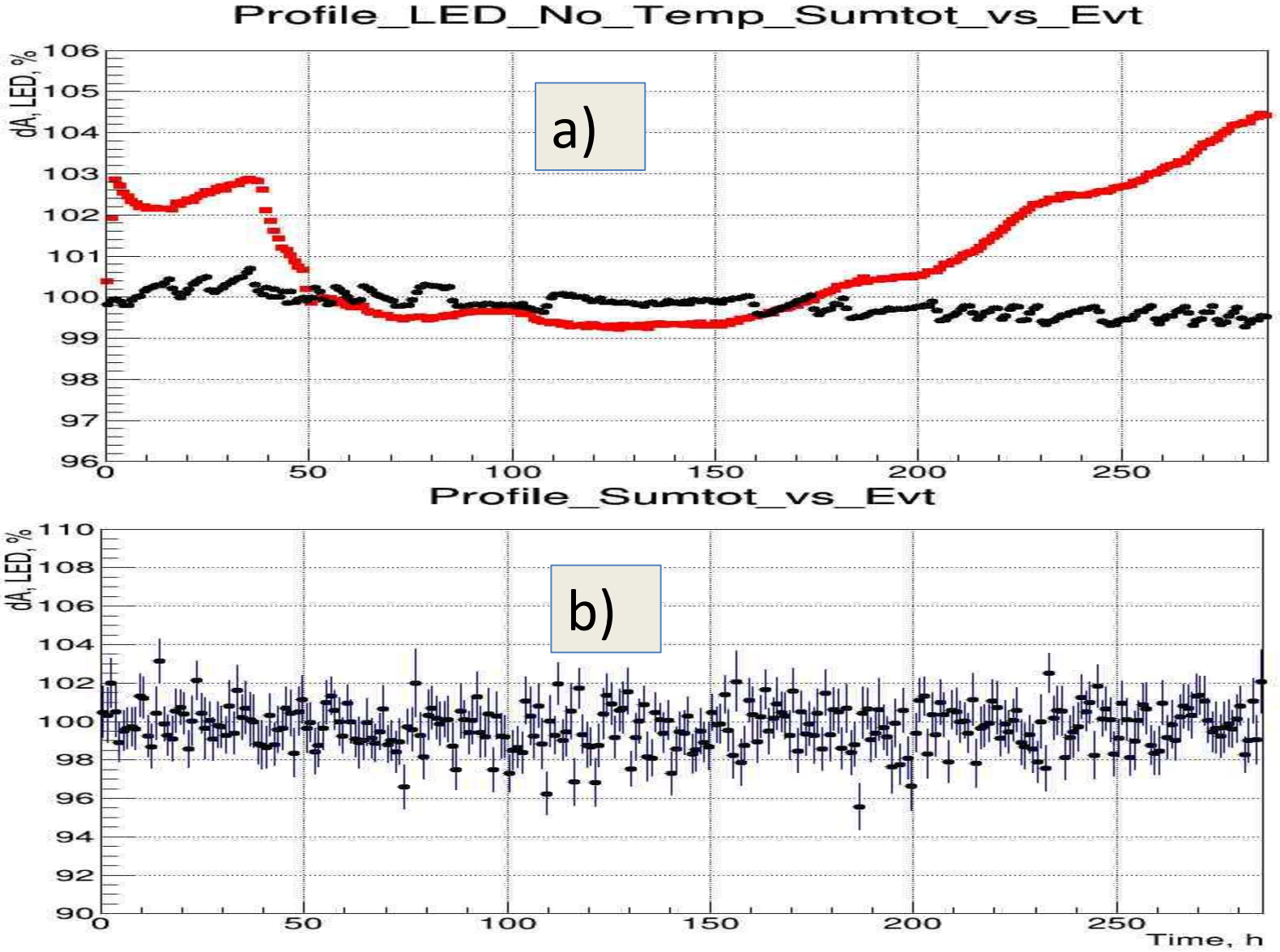
a) **Cosmic MIP peak for sum of 16 cells gives the E resolution equal to 9% at threshold about ~10 MeV .**

b) **The MIP peak E resolution dependence from threshold .**

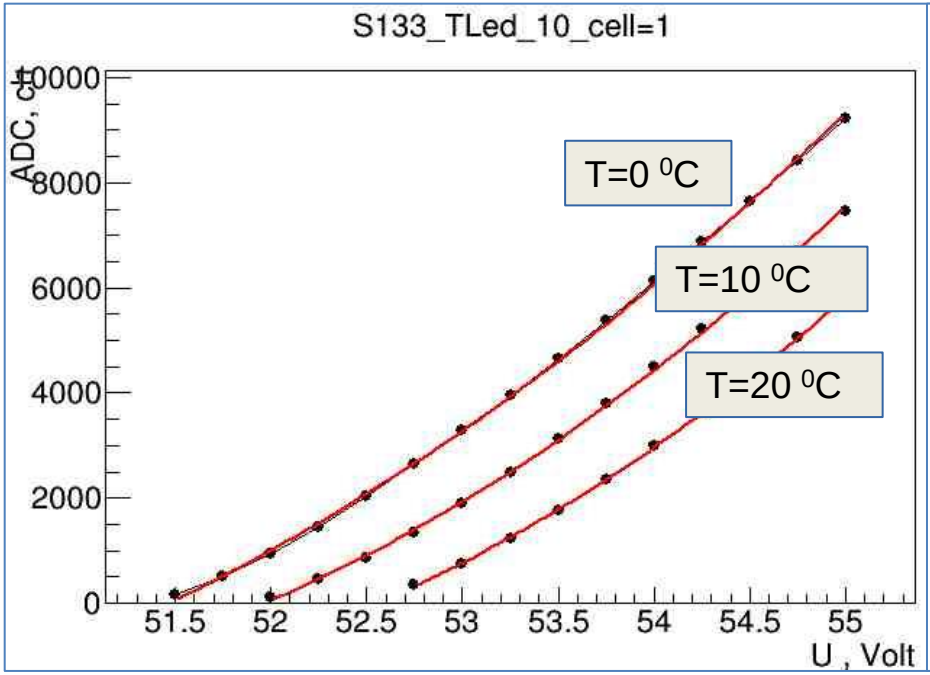


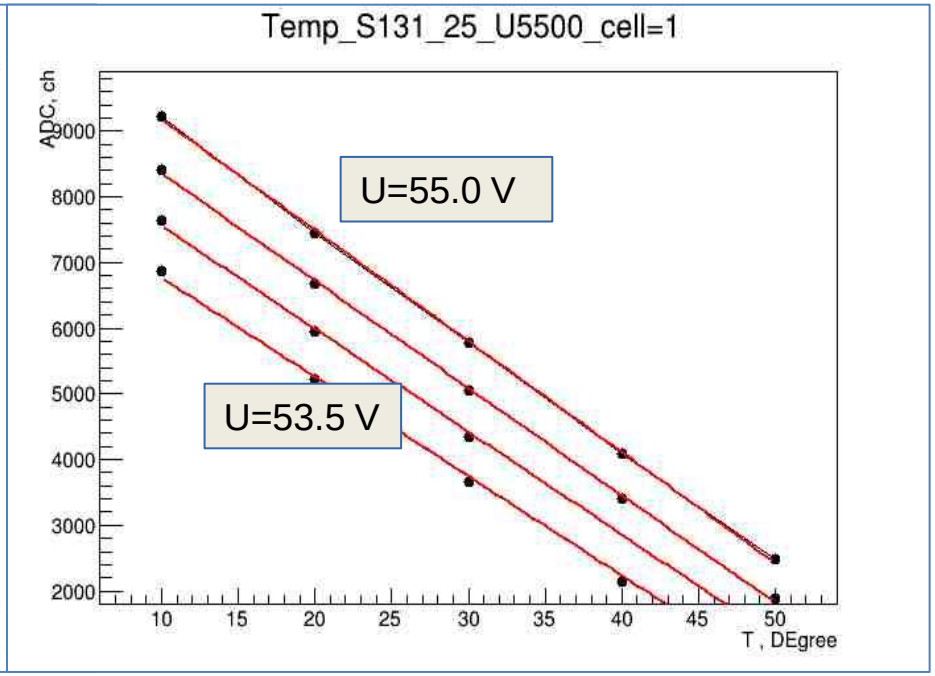


Long time signal behavior: a) - for LED , b) - for MIP



MPPC amplitudes dependences for S13360 series

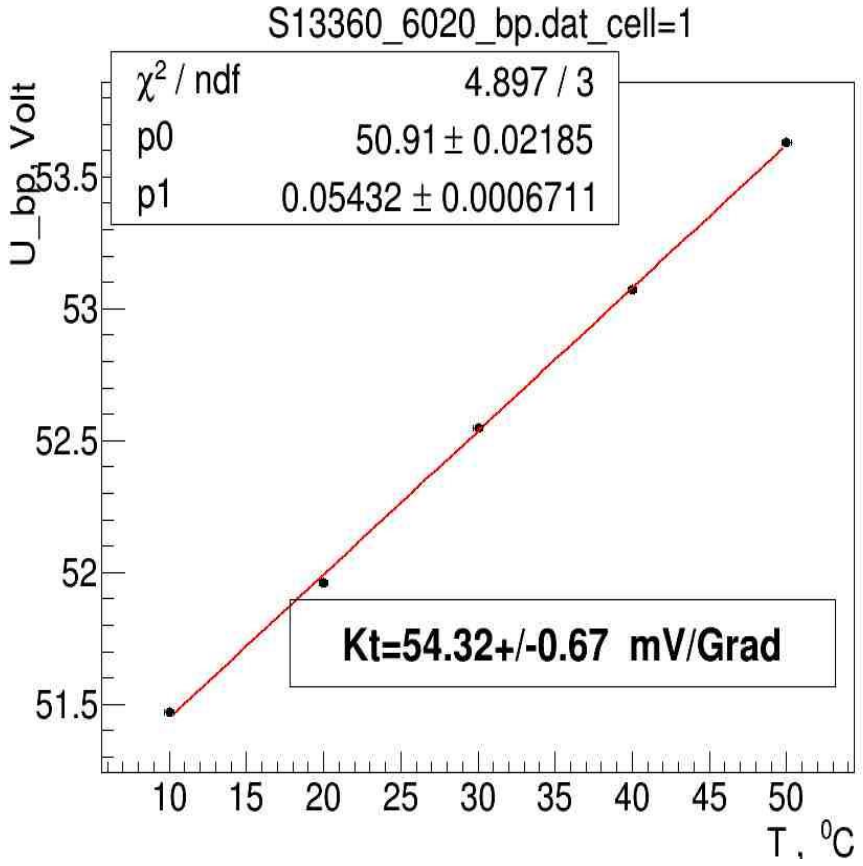


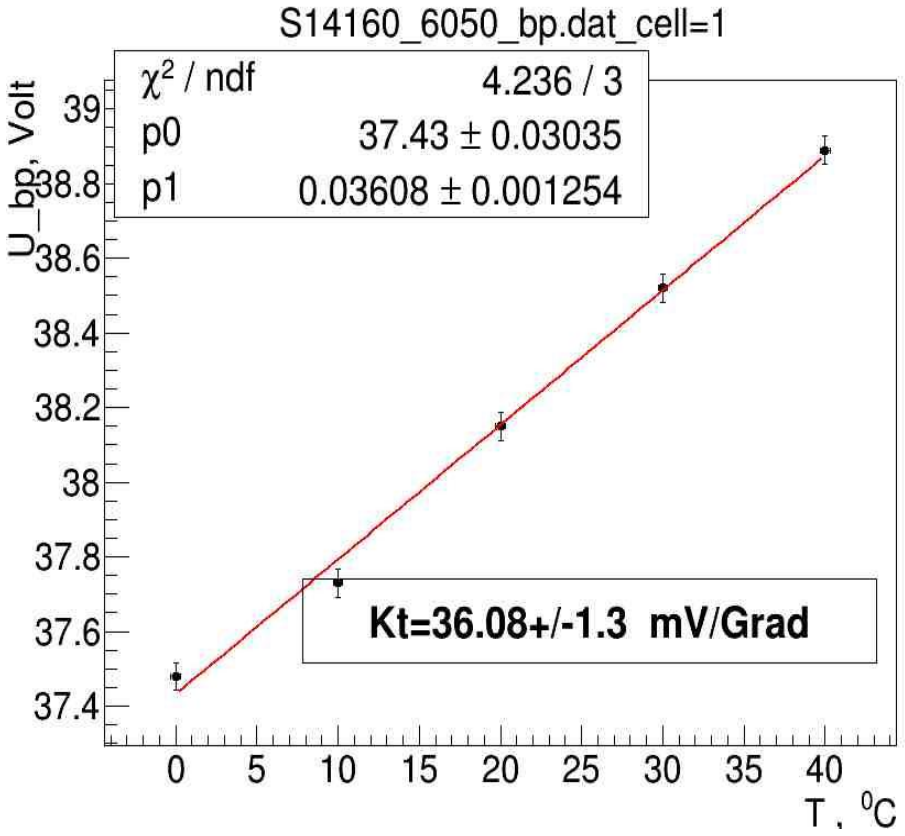


From Bias Voltage at different Temperatures

From Temperature at different Bias Voltages

MPPC break point temperature dependences

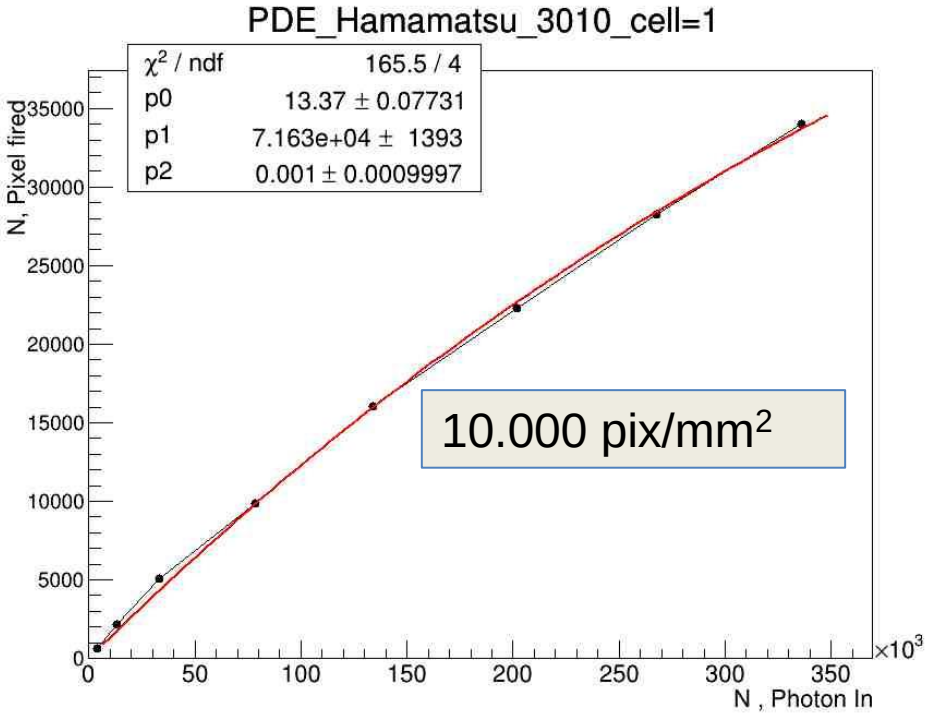


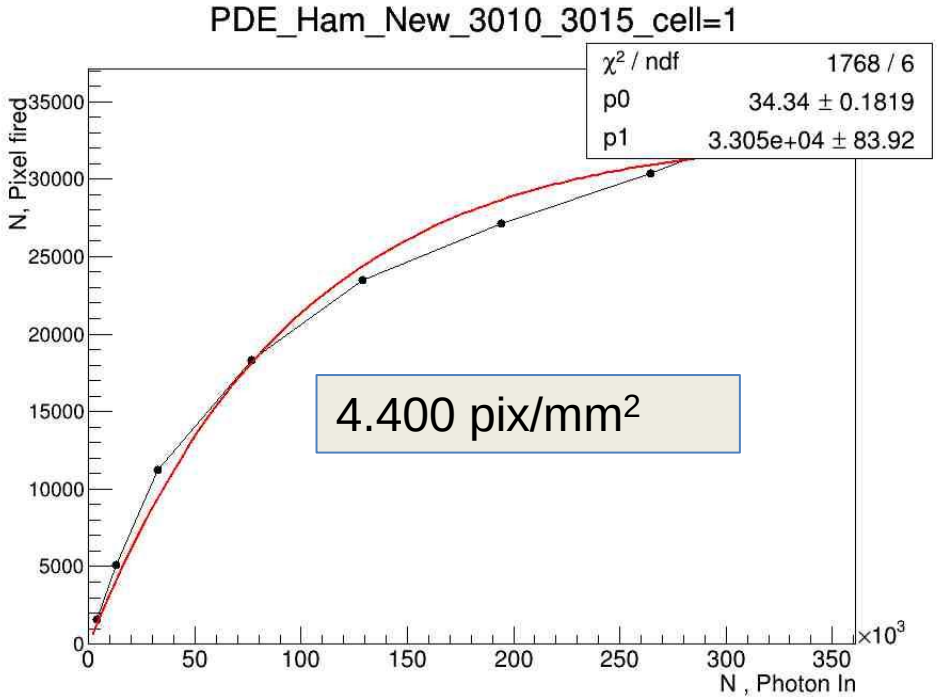


for S13360 -series

for S14160 -series

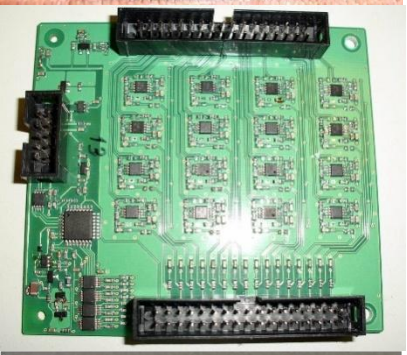
MPPC amplitudes saturation from impact photons

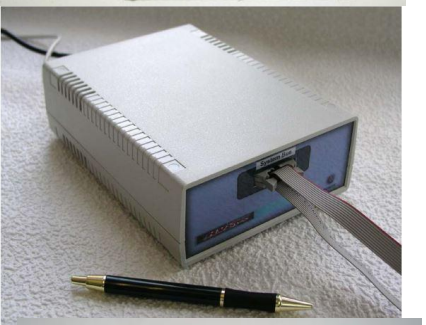


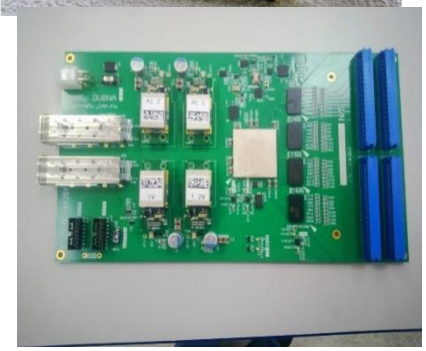


for S14160-3010
90.000 pixels

for S14160-3015
40.000 pixels







ECAL Front END

ECAL channels Numbers for:

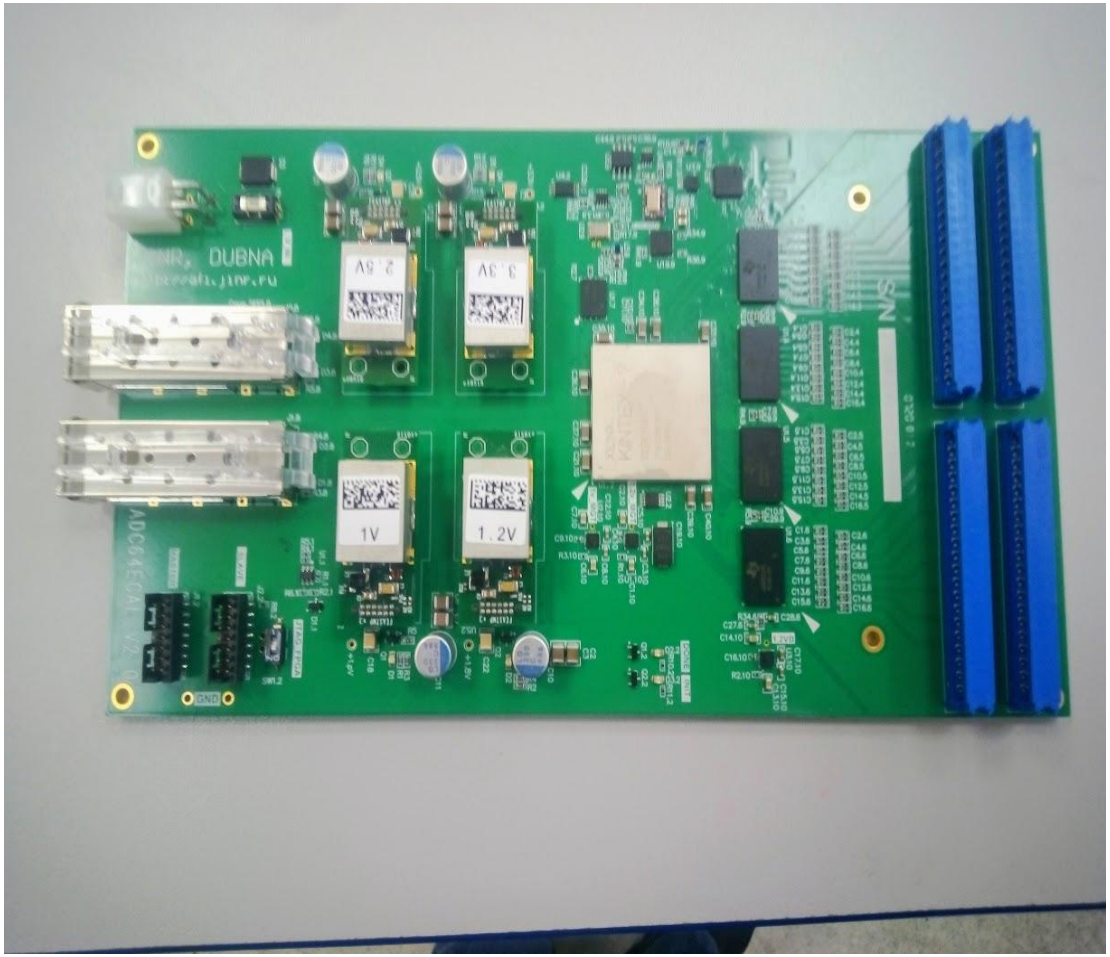
- Barrel = 16,896 ch
- 2 EndCup = 5,760 ch
- **Totally = 22,656 ch**

For this channels Numbers should be supplied of:

1. 16 ch MPPC board – 1416 pc.
2. 16 ch Amplifier Card – 1416 pc.
3. Power unit for Amp. Cards – 32 pc.
4. ADCE-64 – Digitizer – 264+90 – 354 pc.
   for Barrel +2 EndCups

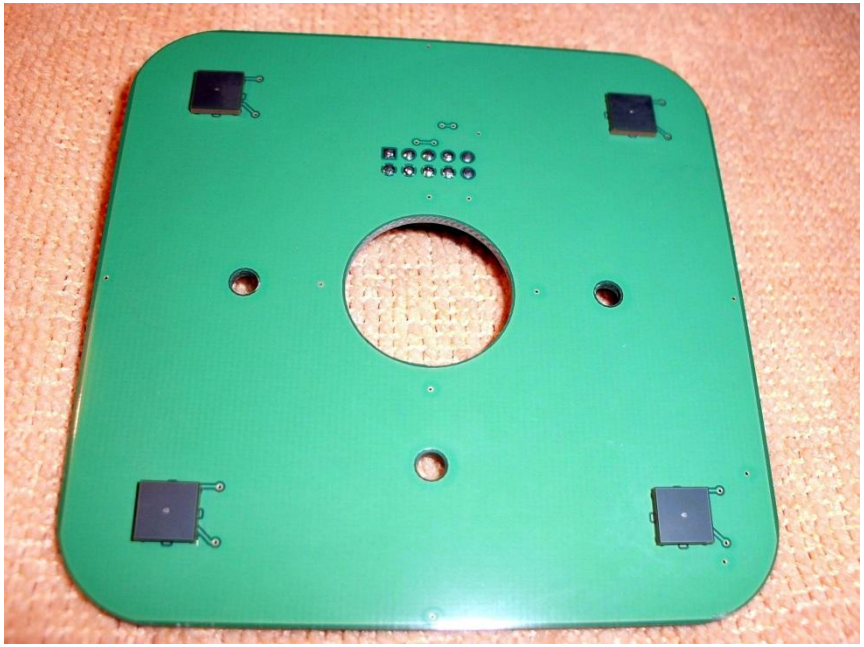
The 64 channel Wave form digitizer designed for ECAL in JINR

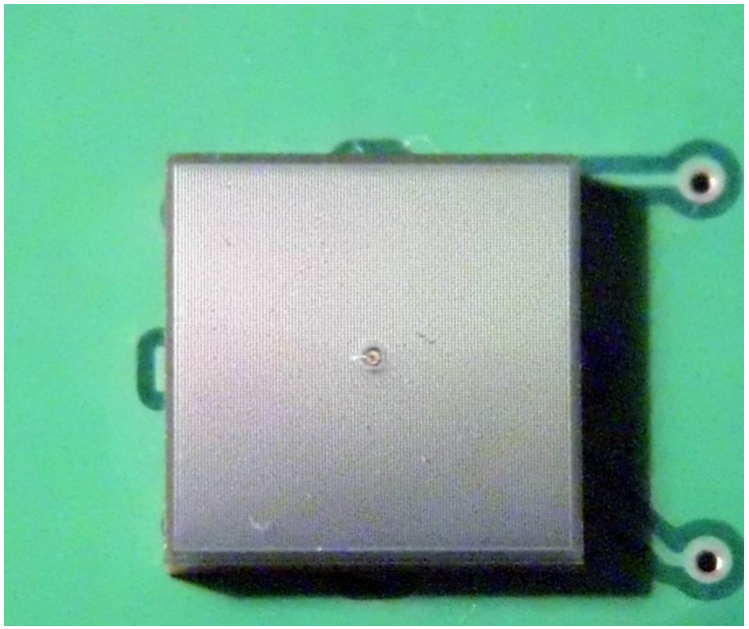
ADC_64Ecal – https://afi-project.jinr.ru/projects/adc64ecal/wiki



1. 64 MHz – samples frequency;
2. 14 – bit/per sample;
3. White Rabbit provides sub-nanosecond synchronization accuracy;
4. Digital Signal processing (DSP) allow zero line adjustment ;
5. Zero suppression mode is possible with certain threshold;
6. Can operate in Streamer mode;
7. Air cooling is possible;
8. **Can operate** in Magnetic field;
9. **Power :** 12.8 (~200 mW/ch)

The PCB board with 4 MPPC 6x6 mm2 (left) and Single MPPC type S14160-6050 or S14160-6015





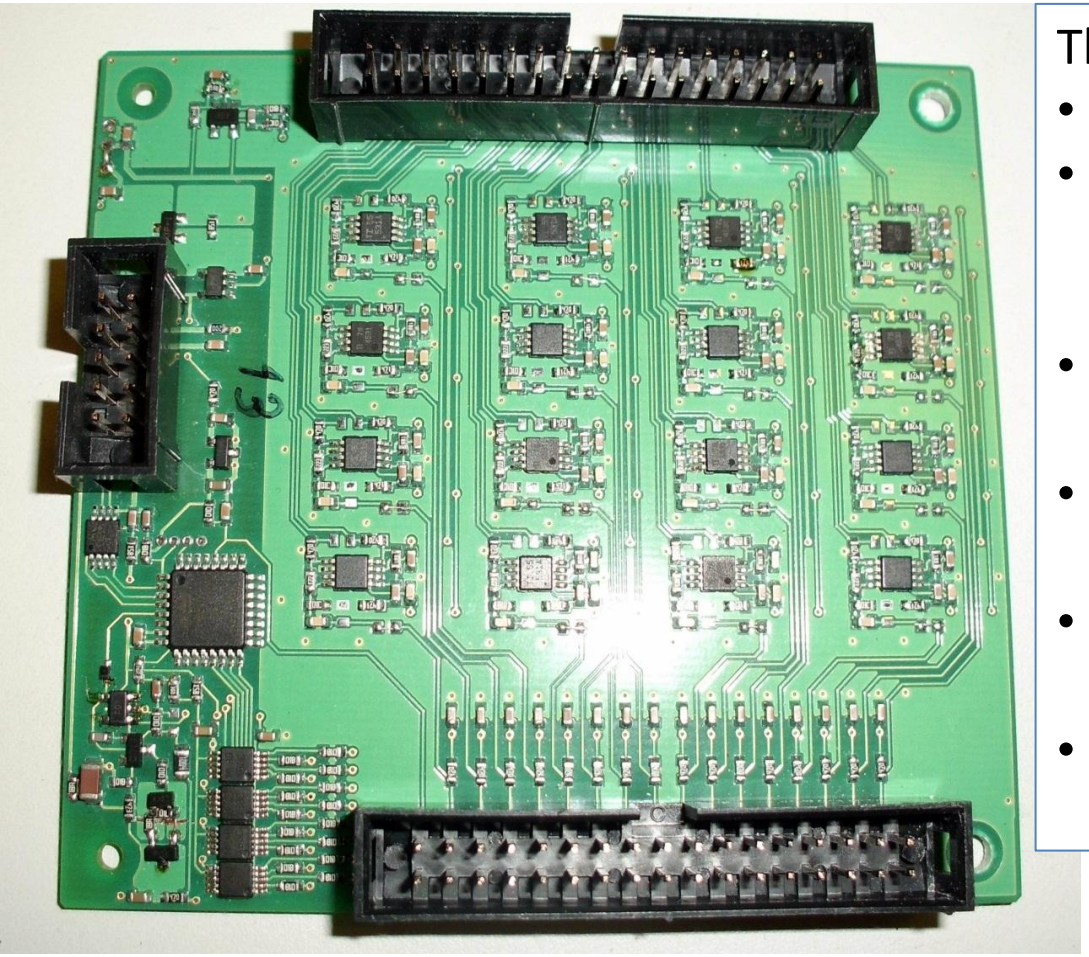
MPPC S14160-6050 :

- Pixel Number: 14.400
- Operation Power: ~40 V
- Temperature depend. : 34 mV/^{0}C
- PDE : ~50% for 480 nm

New MPPC S14160-6015 for 2021:

- Pixel Number =160.000
- Operation Power: ~40 V
- Temperature depend. : 34 mV/^{0}C
- PDE : ~30% for 480 nm

The frontend card for 16 channels produced in http://hvsys.ru/en

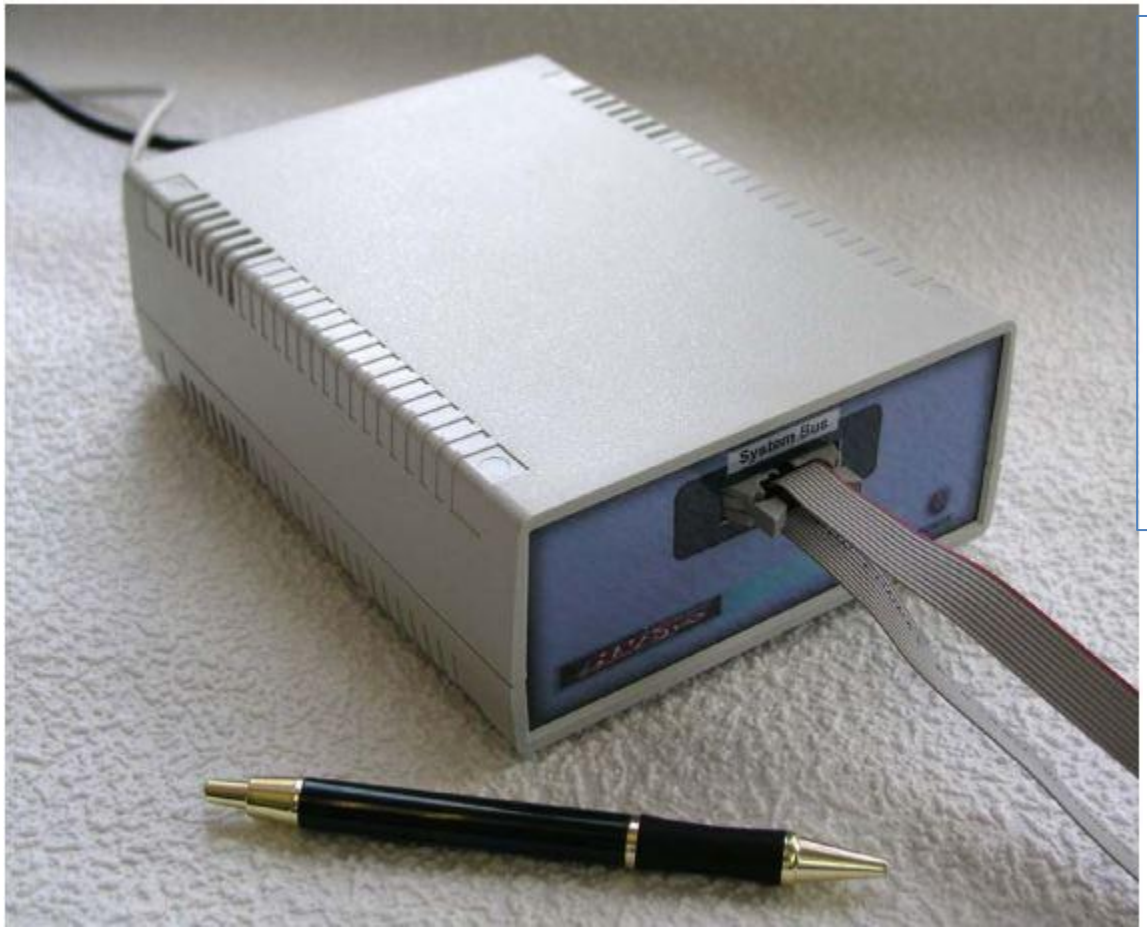


This board controlled of 16 MPPC:

- Bias Voltage: 36 -60 V;
- Connections to:
  - MPPS – with 34 twist pair;
  - ADC - with 34 twist pair ;
- Provide the temperature measurement;
- Remote control via the 5-pair flat cable up to 100 m (RS485);
- H/V Temperature compensation done with software ;
- Power: ~2 W/16 ch.

H/V Power unit for Front END card

http://hvsys.ru/en

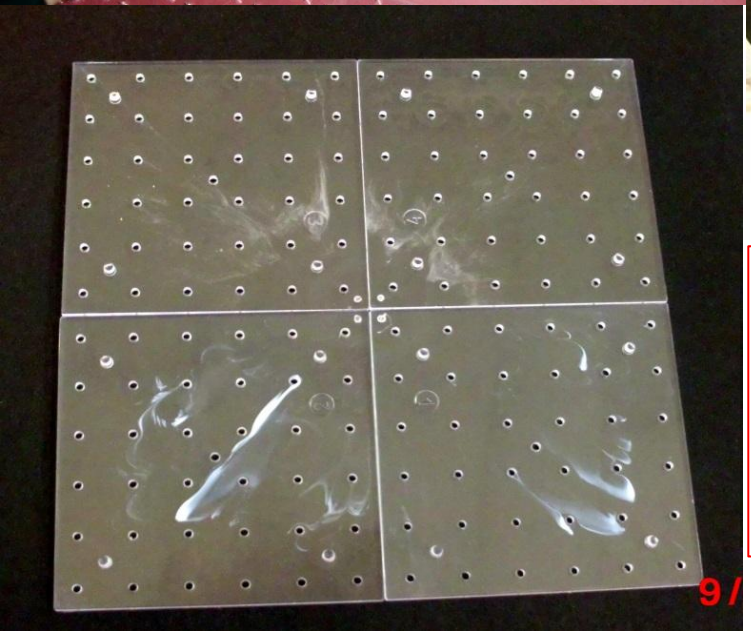


H/V power unit:

- Can operate with 128 Front End Card;
- Remote control via Ethernet;
- RS 485 interface for MPPS;
- Base Power ~60-80 W for front end card ;
- AC ~220 V .

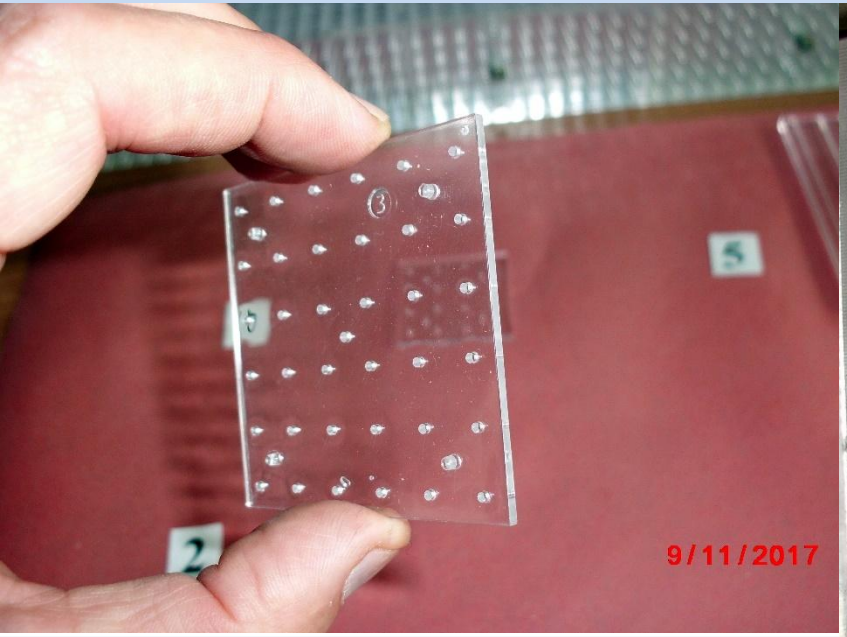
Possible scintillators and modules production

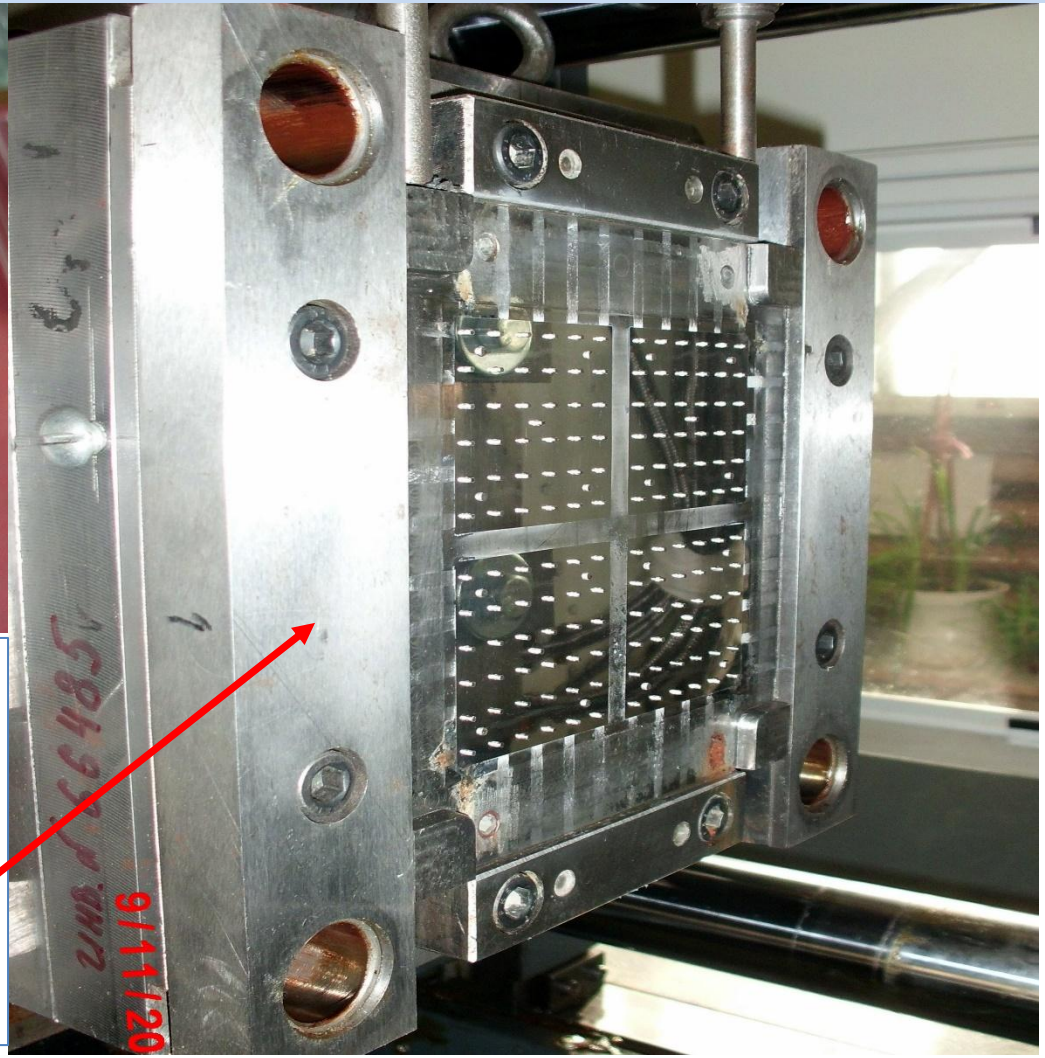
SPD ECAL - scintillator production – molding by pressure technology IHEP, Protvino



Molding machine used for scintillator production from granulated Polystyrene wit dopants: 1.5% Pt-Terphenyle and 0.05%.
The production procedure is automatically and allow one Sycle per ~3 minute (4 tiles).

SPD ECAL Scintillator production: molding by pressure technology IHEP, Protvino





Single tile 1.5 x 55x55 mm^3 with LEGO signs for Lead fixation

4 Sets Matrix Form for this tiles

SPD ECAL module assembled
IHEP , Protvino , 2017

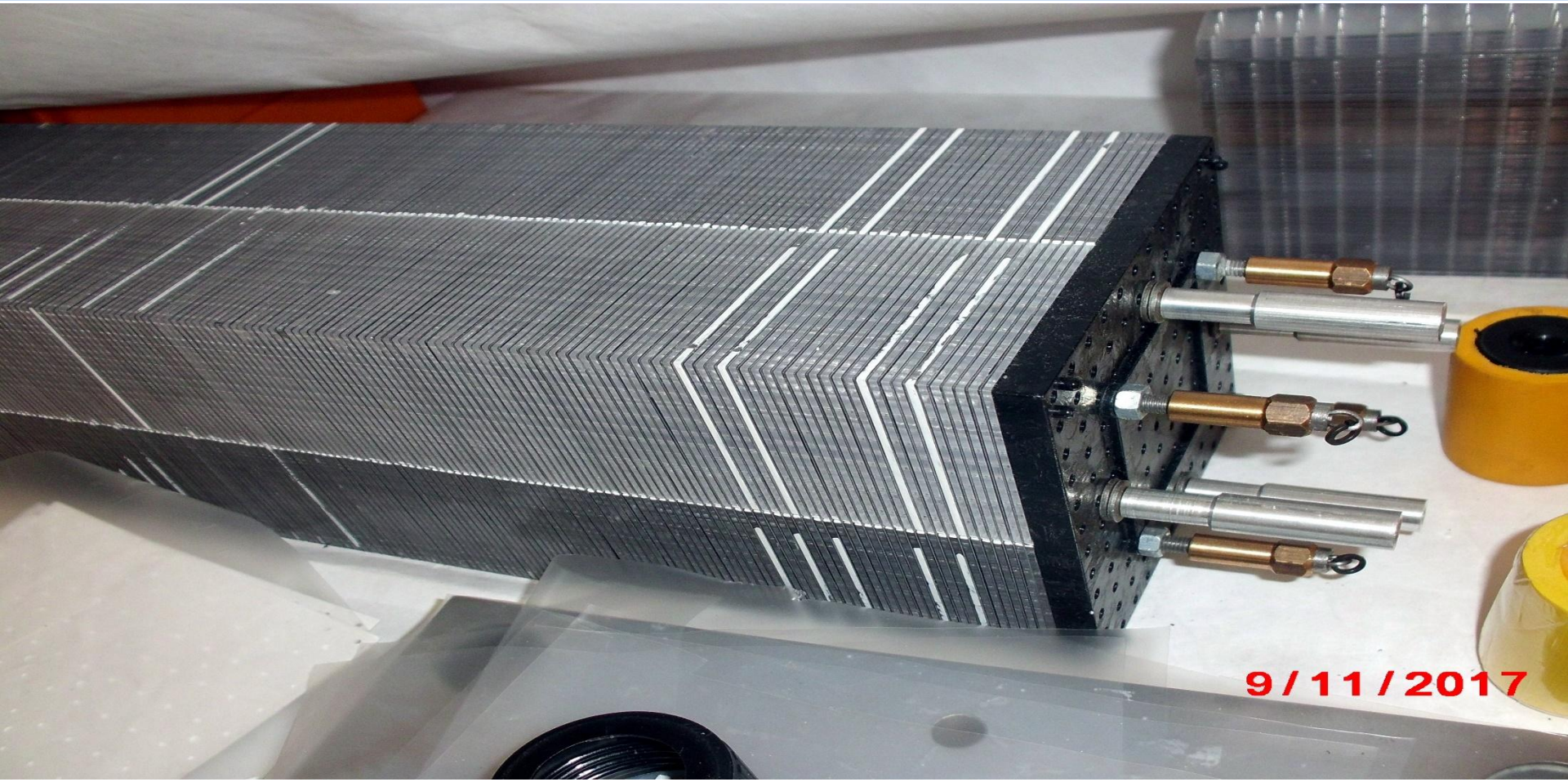


Table 1: Time estimation for ECAL components production:
2 – cells number;
3,4 – scintillator and lead plates in days;
(scintillator and lead production should be done in parallel)
5 – modules (4 cells) assembling, taking into account of 10 modules per day.
6 – time production in years.

1	2	3	4	5	6
Items	**Num.**	**Scint.**	**Lead**	**Assemb.**	**Year**
Barrel	16896	**279**	279	**422**	**1,8**
End Cup-2	4608	**152**	152	**115**	**0,5**
End Cup-2	4608	**152**	152	**115**	**0,5**
Total	26112	**583**	**583**	**653**	**2,8**

Table 2: The Numbers of the ECAL components:

2 – cells of 4x4 cm^2;
3 – 64-channels ADCs;
4 – 16-channels Frontend boards;
5 – Power control units for HV;
6 – MPPC;
7 – WLS fiber length in meters.

1	2	3	4	5	6	7
Item	**N_cells**	**ADC64E**	**FE**	**HV**	**MPPC**	**Fiber, m**
Barel	16896	264	1 056	11	16 896	135168
End Cup-2	4608	72	288	8	4 608	36864
End Cup-2	4608	72	288	8	4 608	36864
Total	26112	408	1 632	**27**	26 112	208896

Table 3: Power consumption of the ECAL components in kW:

2 – ADC ~200 mW/ch;
3 – FE ~2 mW/ch;
4 – HV units ~100 W/box;
5 – total in kW.

1	2	3	4	5
Item	**ADC**	**FE**	**HV**	Total
mW/ch	200	63	1,2	264
Barrel	3,4	1,1	1,2	5,6
End Cup-2	0,9	0,3	0,4	1,6
End Cup-2	0,9	0,3	0,4	1,6
Total	**5,2**	**1,6**	**2,0**	**8,9**

Table 4: The cost estimation for Barrel and End Cups (EC_1 and EC_2):
3,4,5 – electronics devices;
6,7 – modules assembling and for supported frame production;
8,9 – MPPS and WLS fibers ordering;
10,11 – scintillator and lead plates production;
12 – Total cost.
In lower row is shown the prices per channels for different calorimeters components in USD.

1	2	3	4	5	6	7	8	9	10	11	12
Item	**N_cells**	**ADC**	**FE**	**HV**	**Assembl.**	**Frame**	**MPPC**	**Fiber**	**Lead**	**Scint**	**Total**
Barrel	16896	880	451	10	1 690	85	845	845	887	229	**5 921**
EC_1	4608	240	123	2	461	85	230	230	242	62	**1 676**
EC_2	4608	240	123	2	461	85	230	230	242	62	**1 676**
Total	26112	**1 360**	**696**	**14**	**2 611**	**256**	**1 306**	**1 306**	**1 370**	**353**	**9 272**

USD/ch	355	52	27	1	100	10	50	50	52	14	355

Table 5:The weight distribution for ECAL parts:
2,3 – relate to absorber (lead) and scintillator in cells in kg;
4 – cell weight in kg;
5-6 – Lead and Scintillator contribution in ton. ;
7 – Total*) – total weigh take in account supported frame in ton.

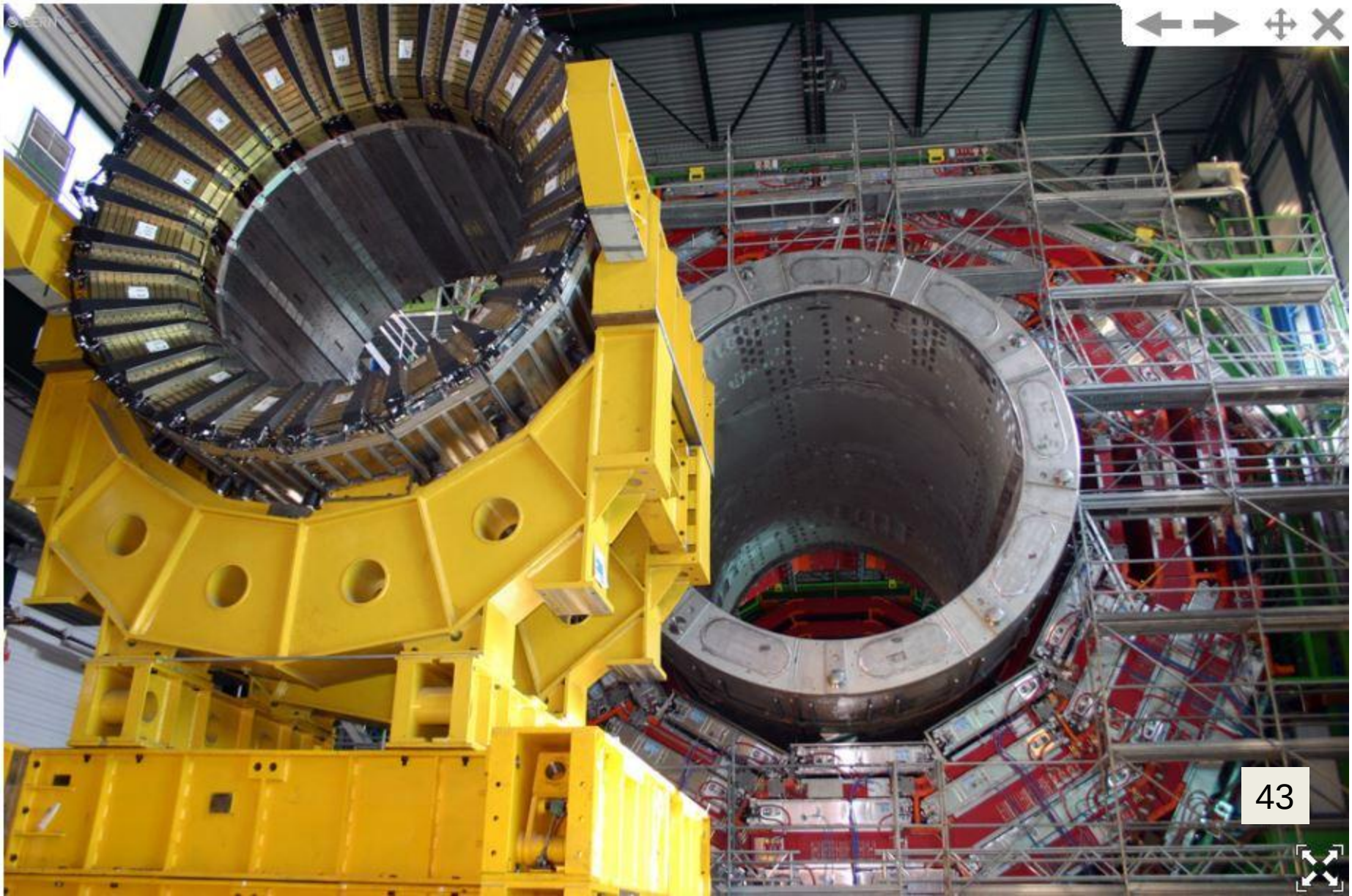
1	2	3	4	5	6	7
Material	**Lead**	**Scint**	**Cell**	**Lead**	**Scint**	**Total*)**
Units	kg	kg	kg	ton	ton	**ton**
Barel	2,07	0,56	2,63	34,98	9,52	**46**
End Cup-2	1,73	0,68	2,40	7,95	3,12	**12**
End Cup-2	1,73	0,68	2,40	7,95	3,12	**12**
Total	5,52	1,92	7,44	50,88	15,76	**70**

Table 6: The ECAL time scale starting from 2022 to 2031 to be commissioned and ready for installation in SPD hall for data taking with beam.

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Task Name										
Infrastructure										
Design Frame										
Frame production										
Cooling System										
Scow Control										
FE R&D										
FE, ADC Producti.										
WLS purchase										
MPPC purchase										
Modules R&D										
Scintillator.Prod.										
Mod. Assembling										
Modules Testig										
ECAL installation										
Comissioning										

How was mounted the Hadrons and Electromagnetic calorimeters in Cryostat for SMS setup at 2008

SMC Hadrons calorimeter mounting into Cryostat - 2008



SMC ECAL assembling procedure inside of HCAL 2008

SMC ECAL assembling 2008 - half part is ready !

Thanks you for attention