Electromagnetic Calorimeter for SPD

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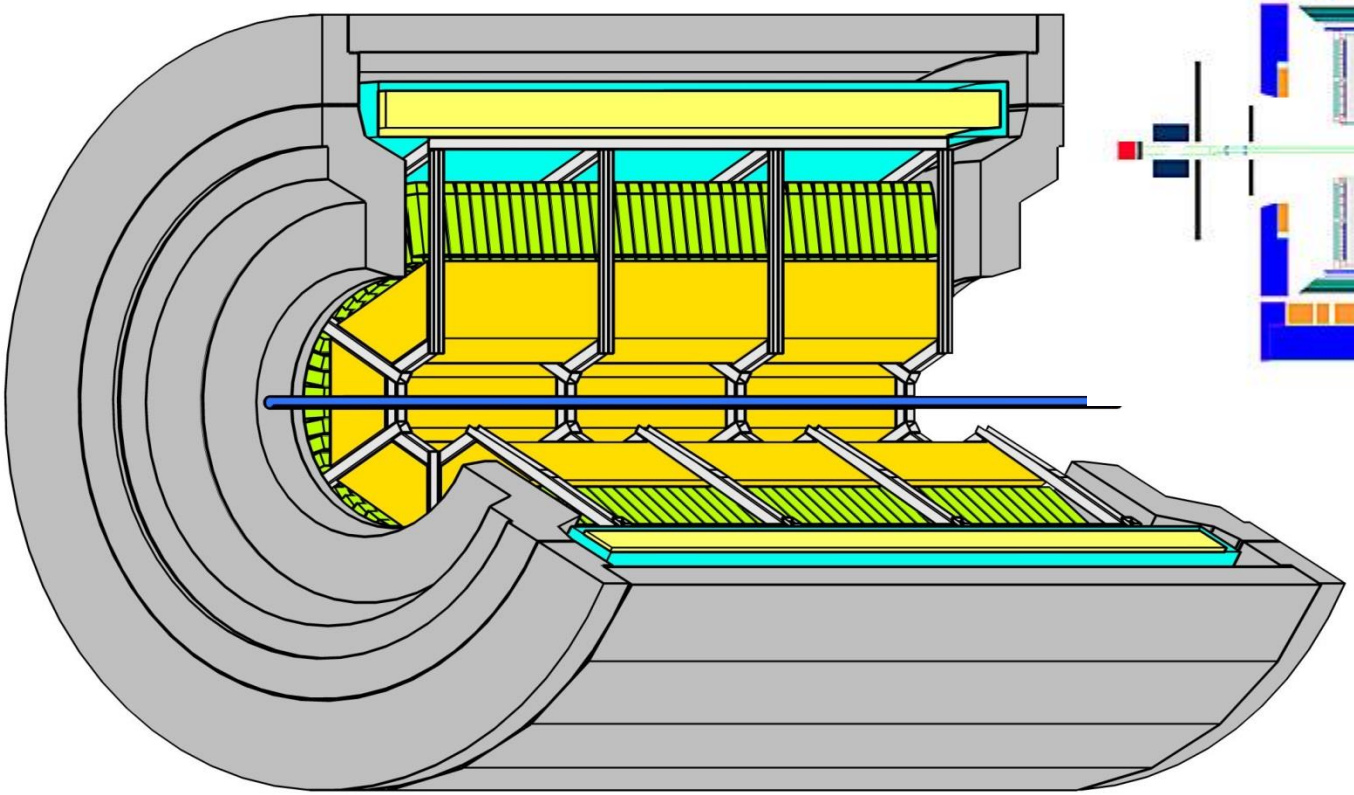
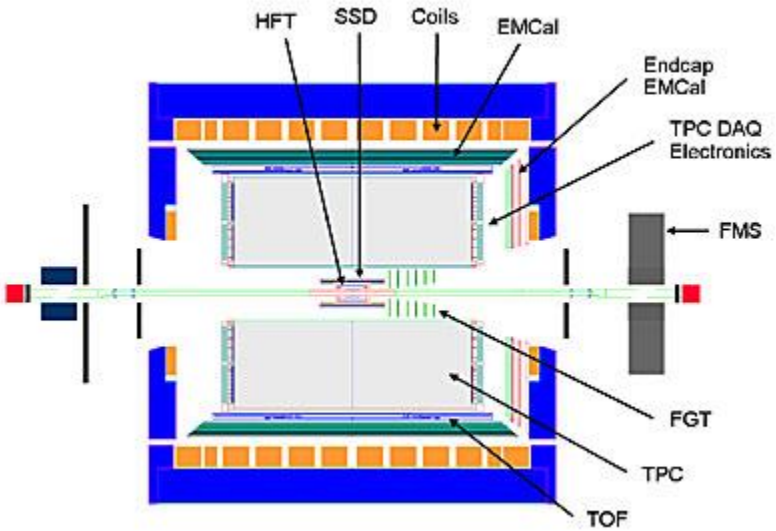
1. **SPD layout**
2. **Electromagnetic Calorimeter options**
    1. **Sampling calorimeters**
    2. **Cristal calorimeters**
    3. **Possible EC Production & cost estimation**

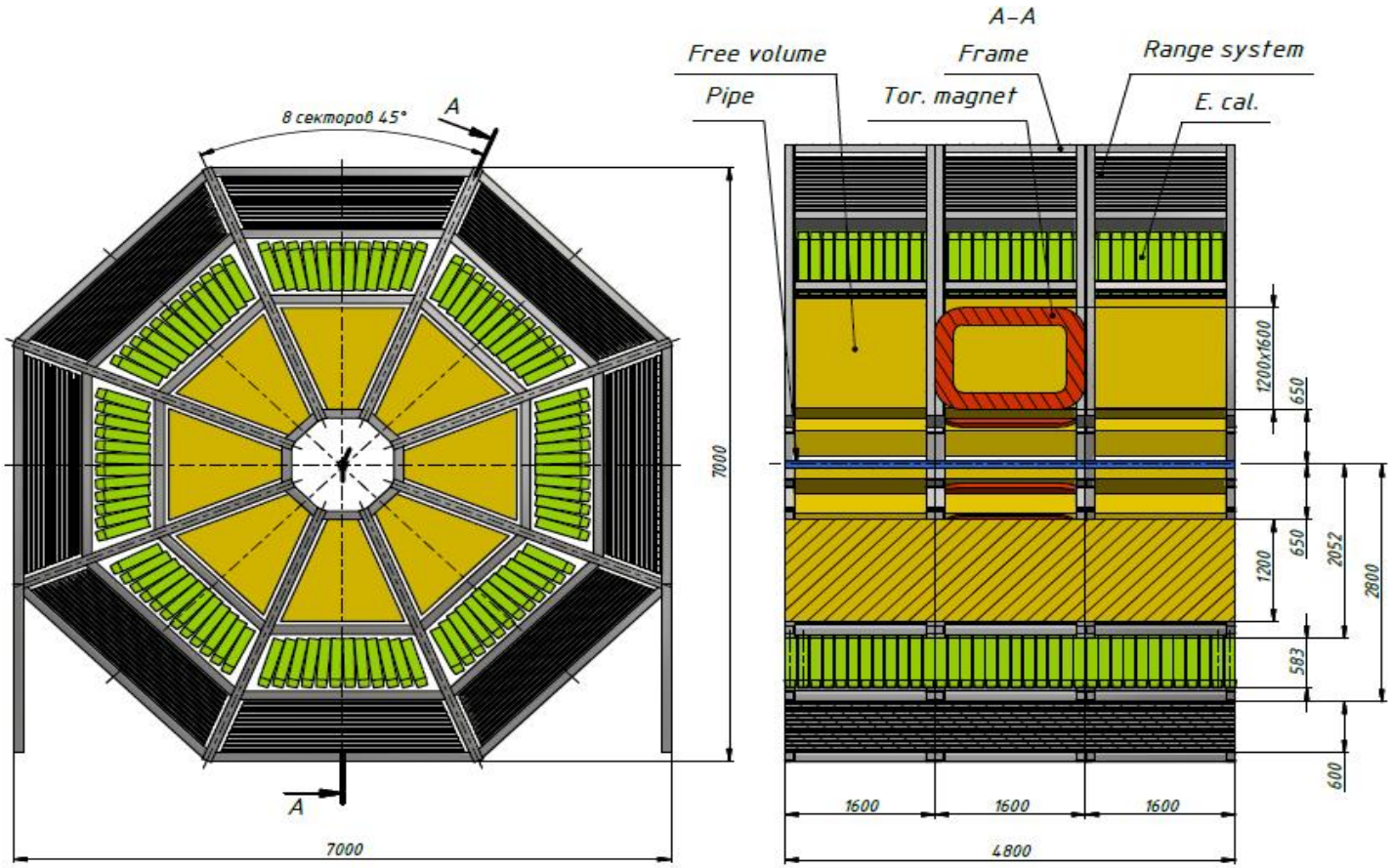
NICA facility up to date in Dubna

SPD with Solenoidal magnet

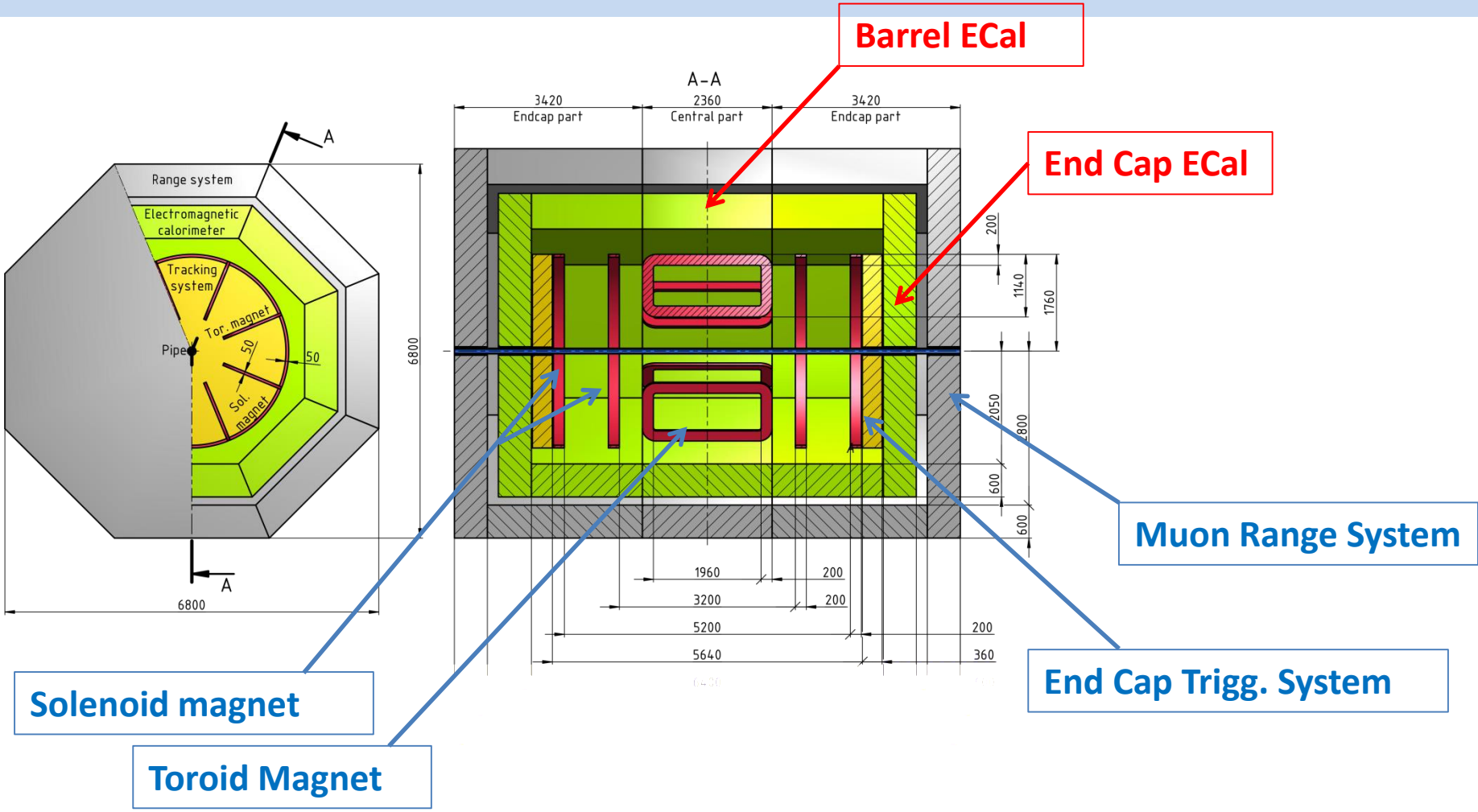




SPD with Toroidal magnet



ECal integrated to Hybrid SPD



ECal – γ - Energy range

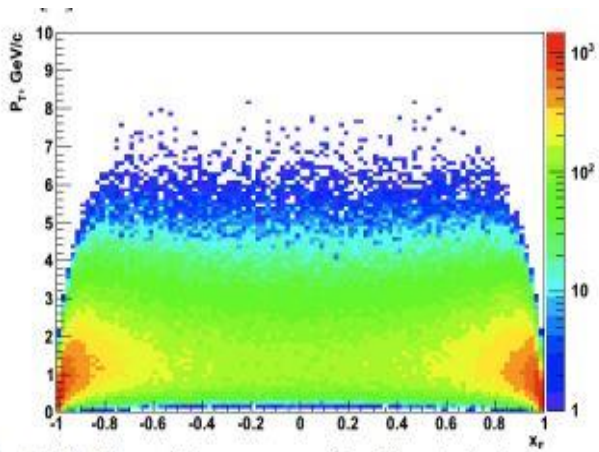


Fig. 5.10: The plot p_T vs. x_F for direct photons.

As follow from SPD LoI (02.06.2014):
The prompt gamma energy range:
Up to 10 GeV in forward (0^0-30^0)
Up to 5 GeV in middle (30^0-60^0)
Up to 3 GeV in transverse (60^0-90^0) angles range.

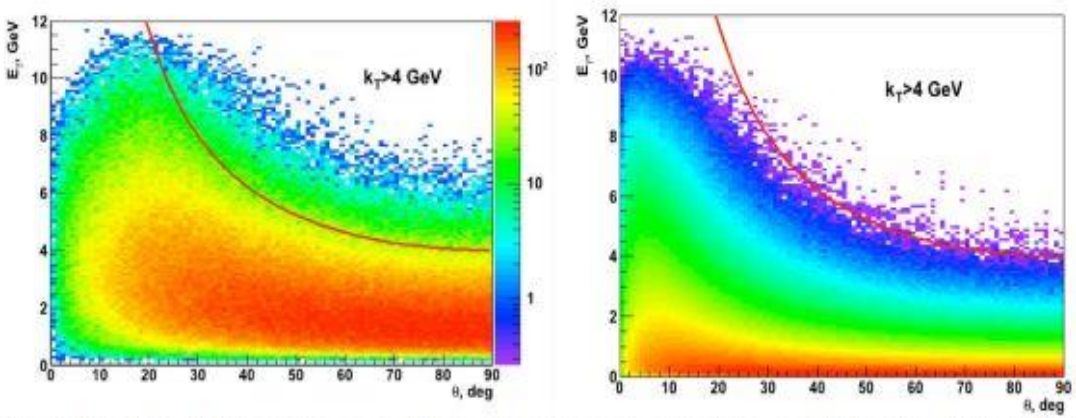
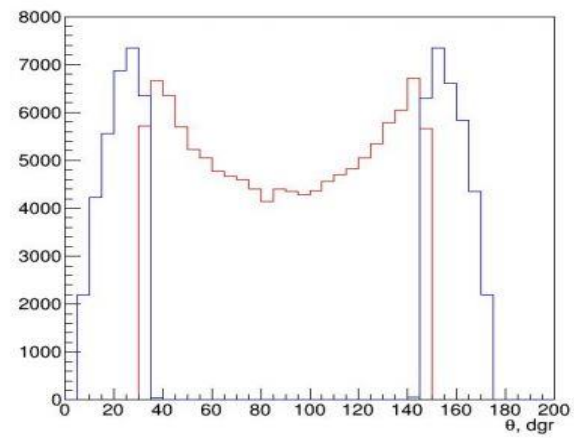
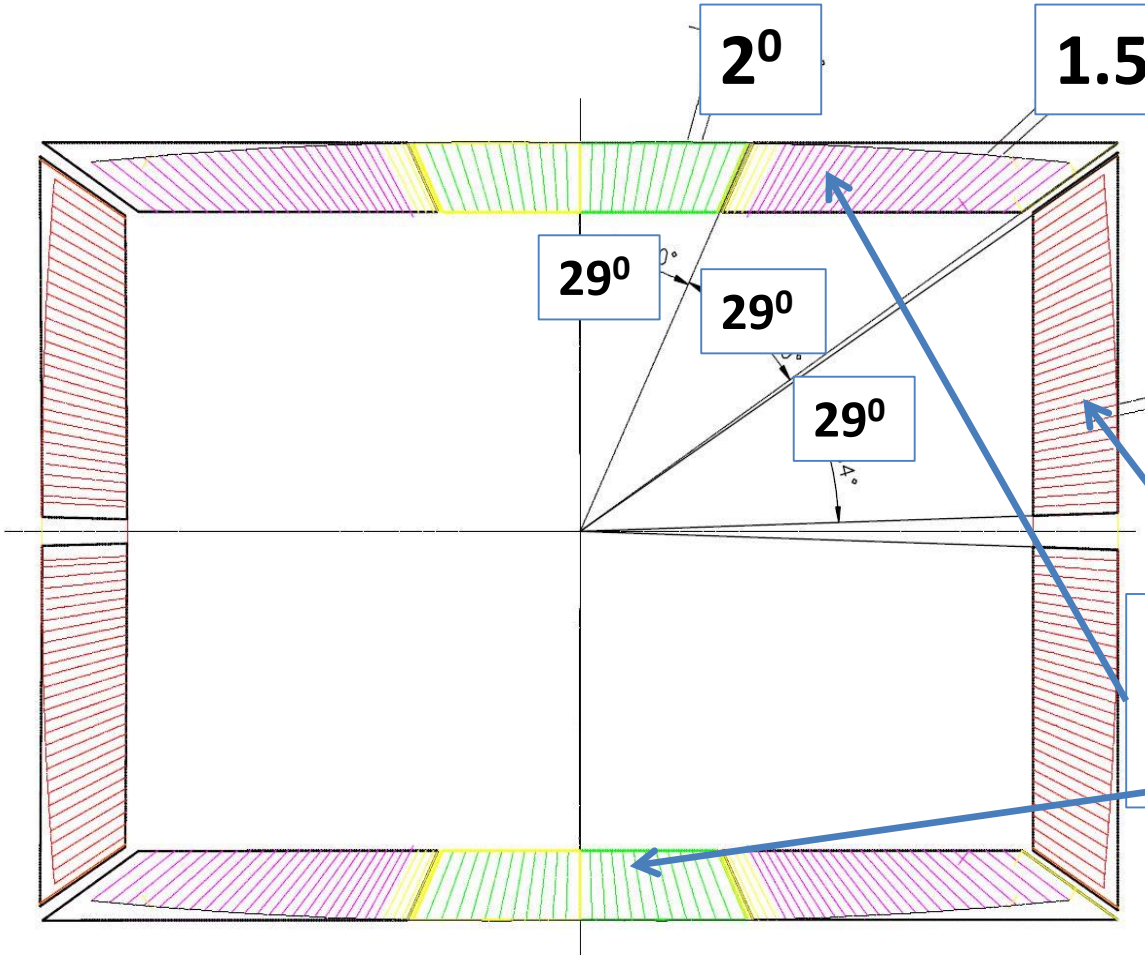


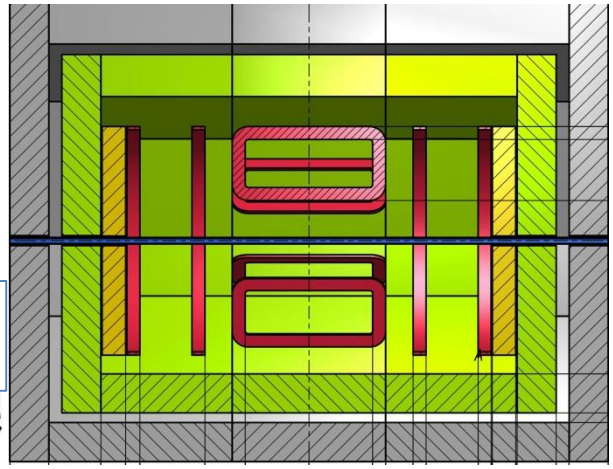
Fig. 5.11: Distribution of energy E_γ as a function of scattering angle θ: left - direct photons, right - minimum bias photons. Red lines correspond to the cut p_T > 4 GeV.



The angular occupancy for proton collision at √s ~ 26 GeV

ECal integrated inside of SPD





Forward - 3.5 cm Cells size
Middle - 5.5 cm Cell size
Transverse - 7.0 cm Cell size

ECal integrated inside of SPD

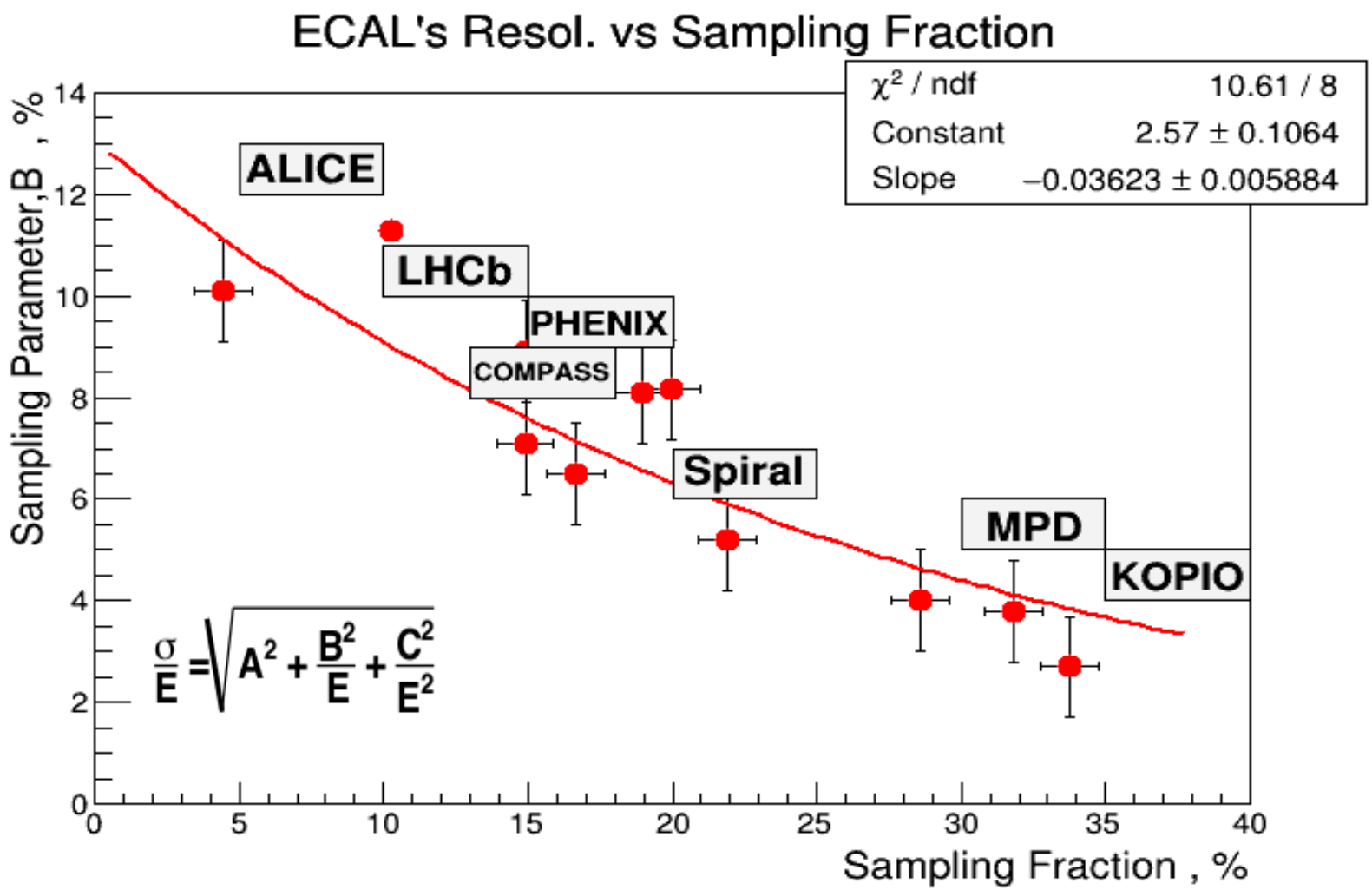
Take in account the energy range of gamma and electrons SPD
Ecal should be able take energy from 10 MeV up to 10 GeV

Ecal should have a good E resolution especially an low energy < 1 GeV

This parameter can be reached by :

- Fine granularity (in case of sampling EC) (sampling fraction >20%)
- Radiation length should be not less 15 X_0
- Cells size should be closed to Moliere Radius – 2,5 – 3,5 cm

ECal's sampling resolution in experiments of last 20 years



The table of shashlik modules types and their energy resolution

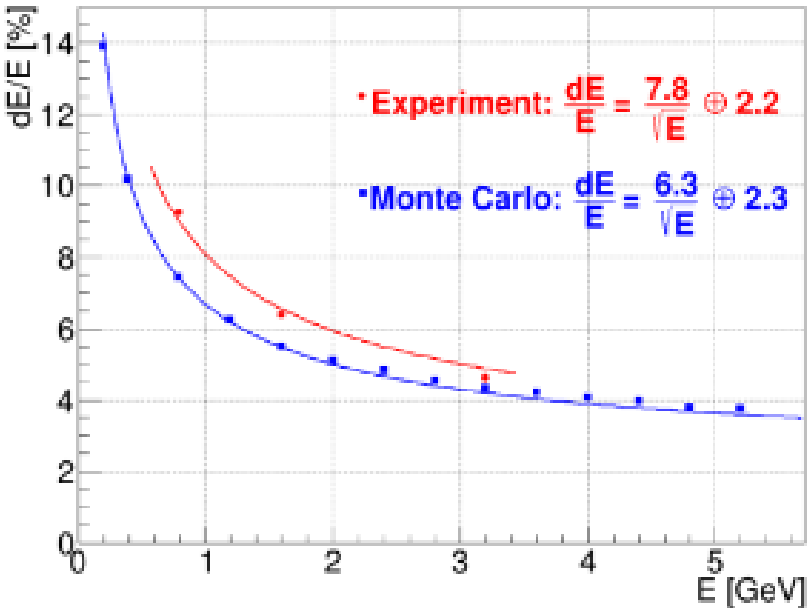
Generation of Shashlyk module	Sampling		N, layers	X_0, cm	WLS fiber		Photo Detector	$N_{p.e.}$, muon	$N_{p.e.}$, 1 GeV photon	Energy resolution, %					
	Sc, mm	Lead, mm			Type	D, mm				Sampling term	Photo statistic term	Constant term 1)	Noise term 2)	Instability of P. D. 3)	Total (1 GeV photon)
1	4.0	1.40	60	2.2	BCF-92, SC	1.2	PMT FEU-85	320*	1200**	5.6	2.9	3.2	0.0	3.2	7.9**
2	1.5	0.35	240	3.1	Y11(200)M, DC	1.0	PMT EMI-9903B	1080*	3600**	2.7	1.7	2.1	0.0	1.1	4.0**
3	2.0	0.35	240	3.8	Y11(200)M, DC, S-type	1.0	PMT EMI-9903B	1860*	6200	2.5	1.3	2.1	0.0	1.1	3.7
3	2.0	0.35	240	3.8	Y11(200)M, DC, S-type	1.2	PMT EMI-9106B	2300	7600	2.5	1.1	2.1	0.0	0.3	3.5
4	1.5	0.25	320	3.8	Y11(200)M, DC, S-type	1.2	PMT EMI-9106B	1900	6300	2.1	1.2	2.1	0.0	0.3	3.3
3	2.0	0.35	240	3.8	Y11(200)M, DC, S-type	1.0	PIN diode 18x18 mm²	17,700*	59,000	2.5	0.4	2.1	4.0	0.0	5.2
3	2.0	0.35	240	3.8	Y11(200)M, DC, S-type	1.0	Drift PIN diode C_{p0} = 0 pF	16,000	52,000	2.5	0.4	2.1	1.7 0.7	0.0	3.7
3	2.0	0.35	240	3.8	Y11(200)M, DC, S-type	1.0	APD 10x10 mm² M = 50	16,000	40,000	2.5	0.5	2.1	0.1	0.0	3.3
5	1.5	0.25	320	3.8	Y11(200)M, DC, S-type	1.0	APD 10x10 mm² M = 50	10,000	32,000	2.1	0.6	2.1	0.1	0.0	3.0

Sampling, Photo-Stat., Const. term, Noise term ---- there are the main factors has influence on Energy resolution for sampling calorimeters

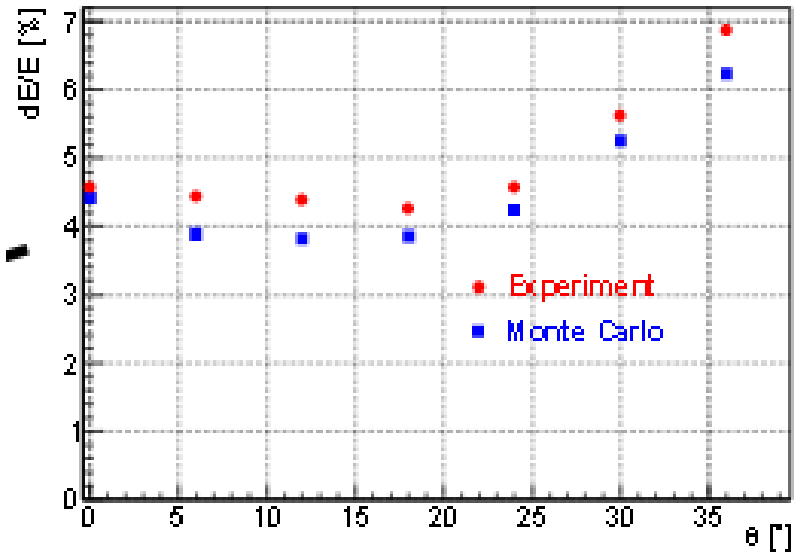
COPMASS ECal : Lead + Plastic Scintillator

COMPASS ECal modules production: Kharkov 2011

COPMASS ECal : Lead + Plastic Scintillator 194 modules x9 cells(1746 ch)

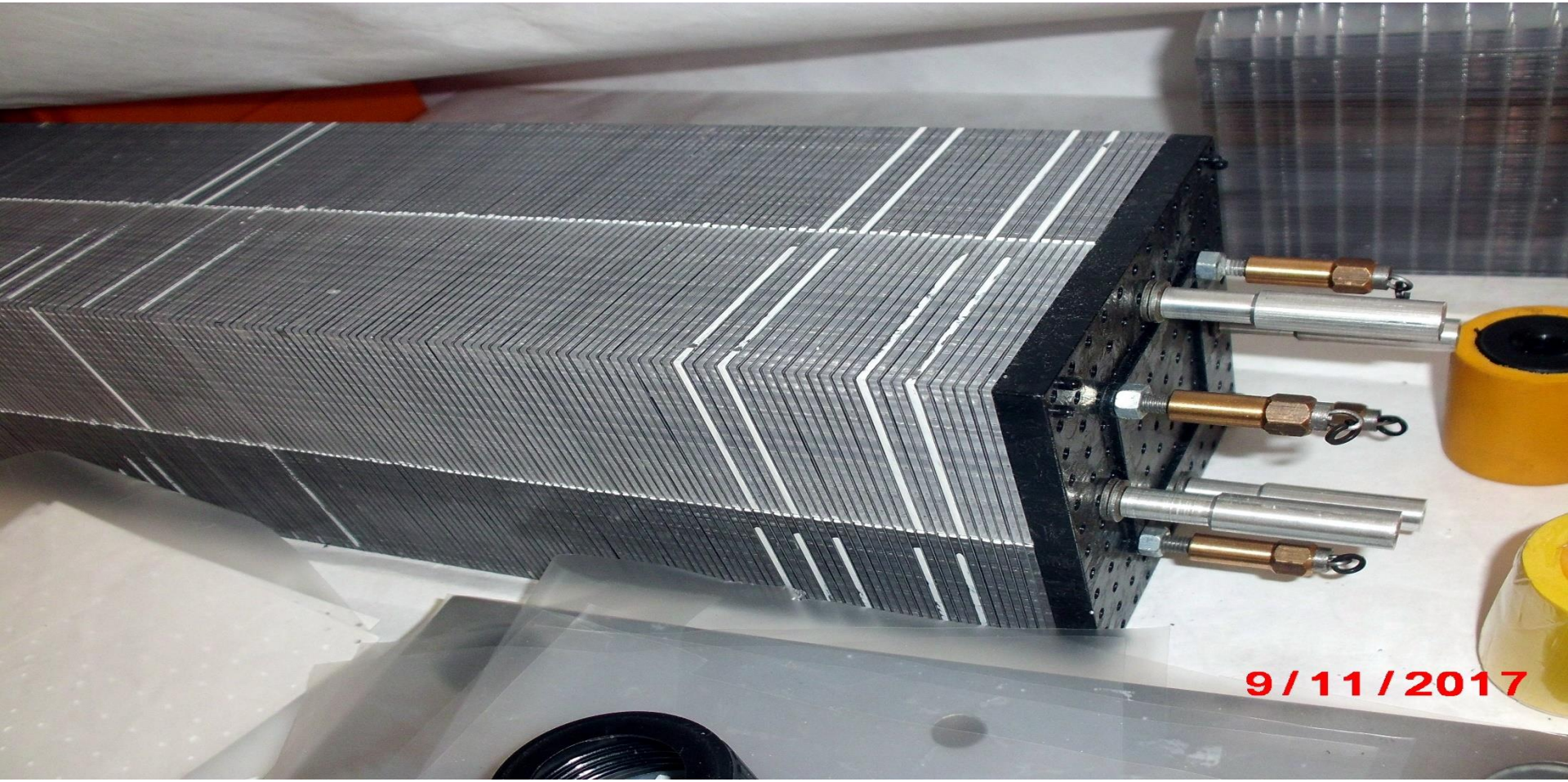


Ecal0 E-resosutio vs Beam Energy



Ecal0 E- resolution vs Beam impact angle

KOPIO ECal : Lead + Plastic Scintillator



KOPIO ECal : Lead + Plastic Scintillator

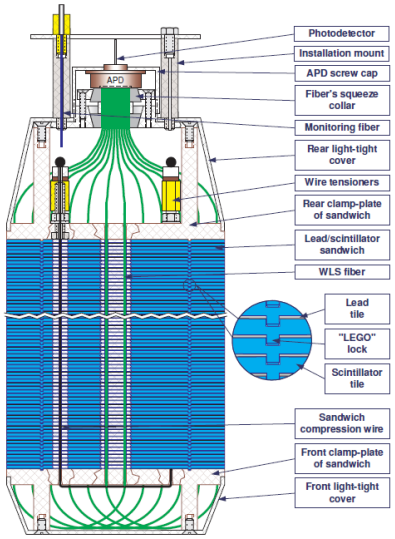
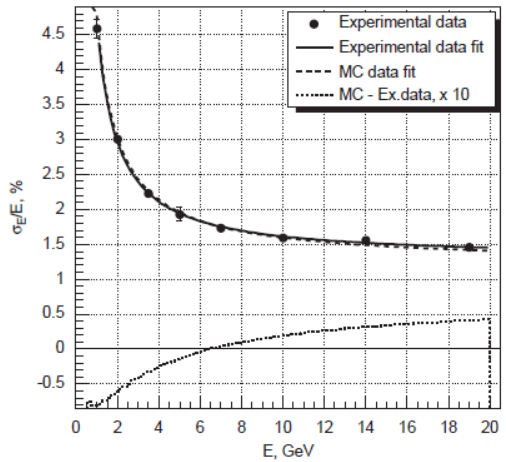


Fig. 1. The Shashlyk module design.



$$\Delta x = \sqrt{a^2 + \frac{b^2}{E}}$$

- Energy resolution $(3 \div 3.5)\%/\sqrt{E(\mathrm{GeV})}$
- Time resolution about 80 ps$/\sqrt{E(\mathrm{GeV})}$
- Calorimeter granularity $\sim 10 \times 10$ cm^2

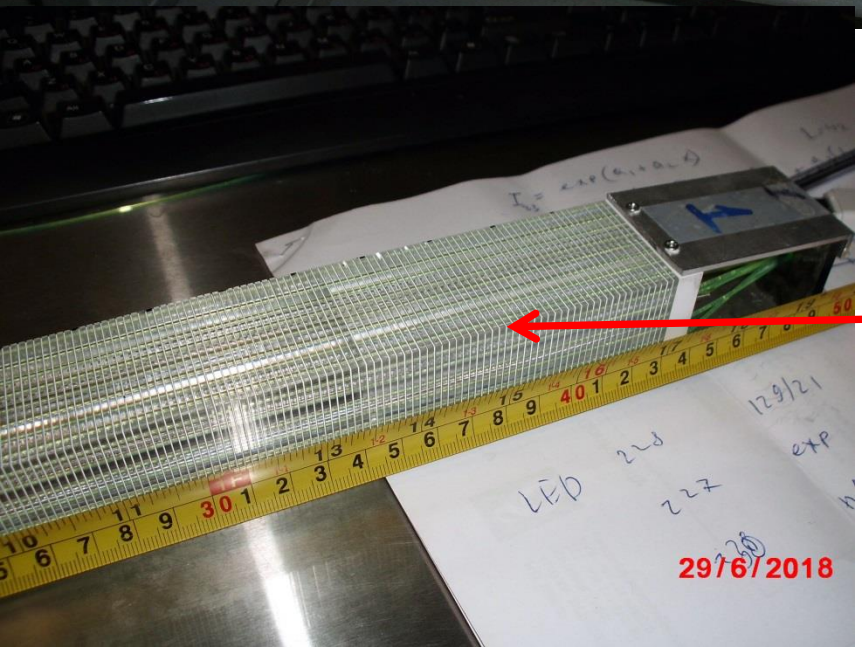
Parameters of the prototype Shashlyk module for KOPIO.

Transverse size	110×110 mm^2
Number of the layers	240
Polystyrene scintillator thickness	1.5 mm
Lead absorber thickness	0.35 mm
Reflective paper (TYVEK) thickness	2×0.06 mm
Number of holes per layer	12×12
Holes spacing	9.5 mm
Holes diameter in Scintillator/Lead	1.4/1.5 mm
WLS fibers per module	72×1.3 m ≈ 92 m
Diameter of WLS fiber	1.0 mm, (1.2 mm)
Diameter of fiber bundle	14 mm, (17 mm)
Effective radiation length X_0	31.5 mm
Effective Molière radius R_M	54.9 mm
Effective density	2.75 g/cm^3
Active length	473 mm ($15.9X_0$)
Total length (without photodetector)	610 mm
Total weight	18.0 kg

MPD (NIKA) ECal : Lead + Plastic Scintillator

One sector from MPD Ecal assembling via of 16-modules in Projective geometry presented here.

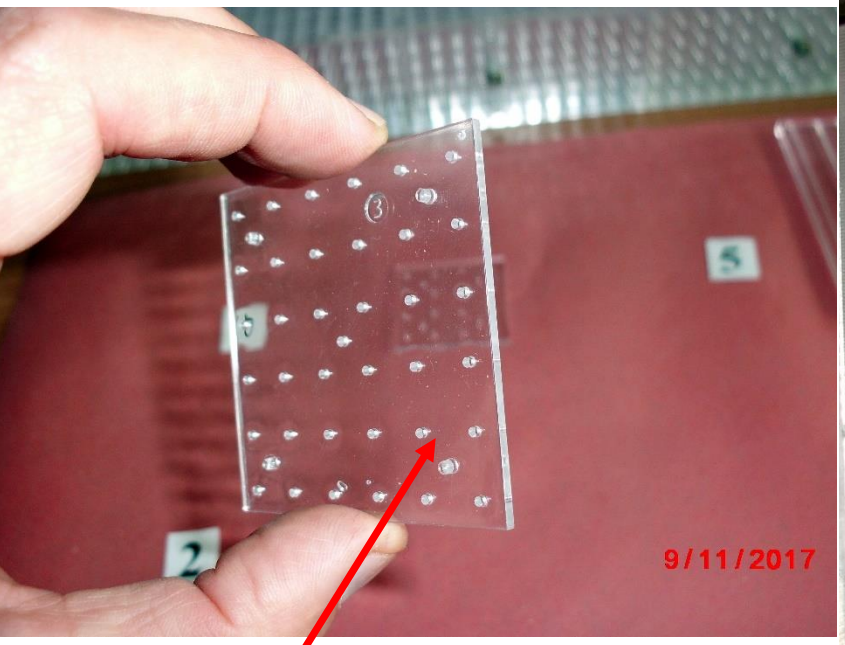
It is first prototype before of mass production started soon.

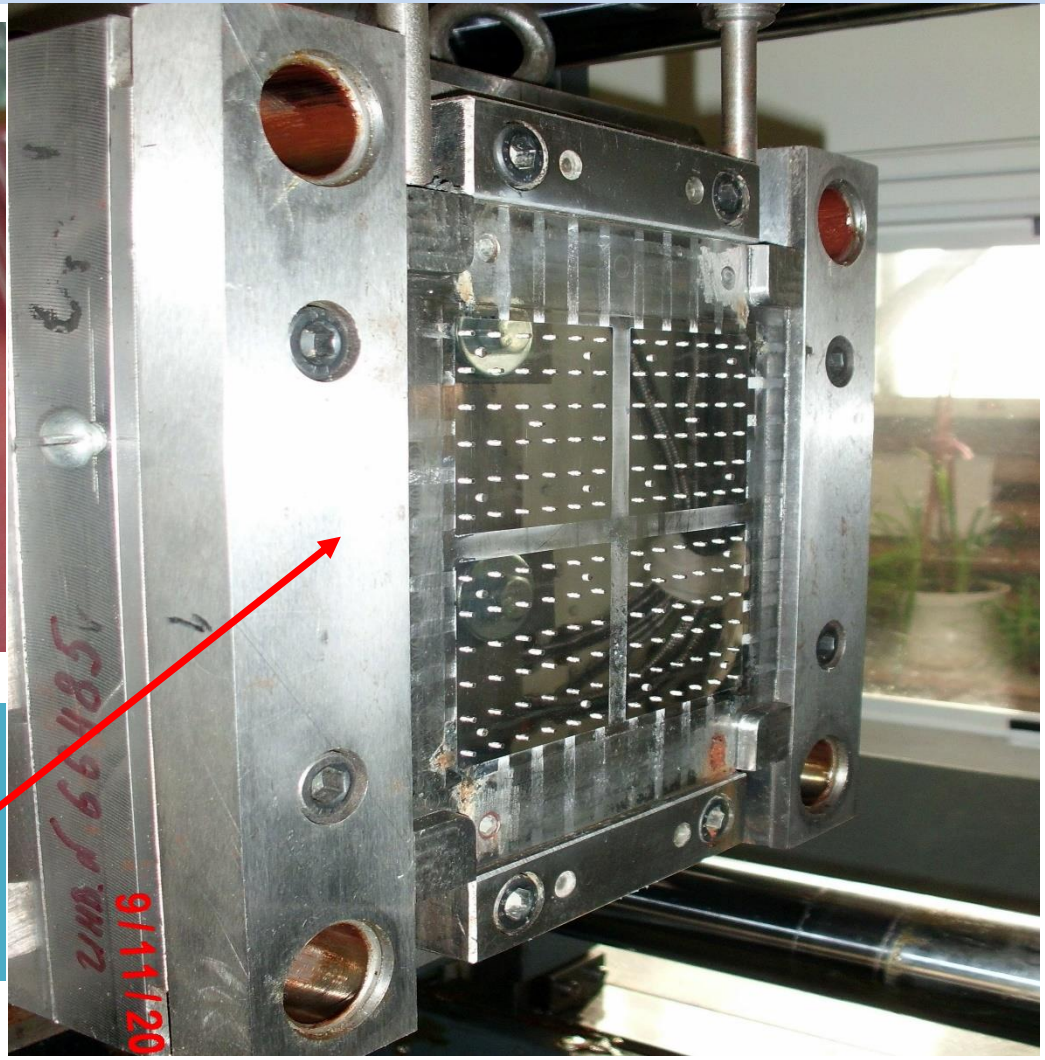


Single Ecal module of MPD (40x40 mm^2)
Fine granularity sampling structure (SF=31%), Rad. Length=12.6 X_0

- 220 Layers of Scintillator-Lead plates 1.5 and 0.3 mm respectively .
- Expected E –resolution ~3%/Sqrt(E);

Sampling Ecal
Scintillator tile production molding by pressure technology

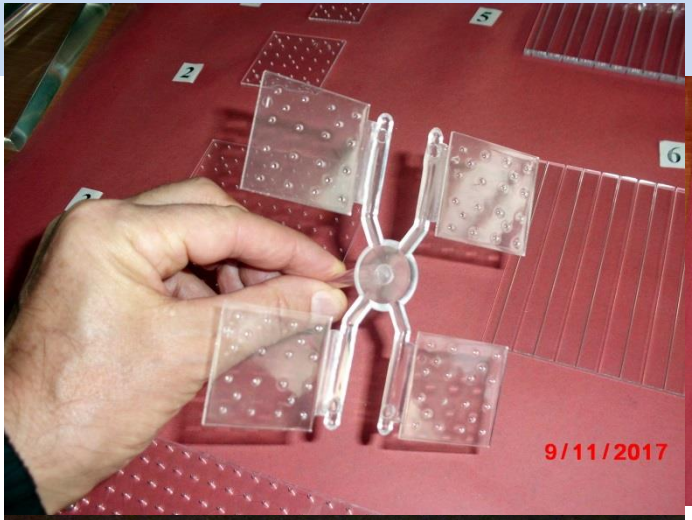


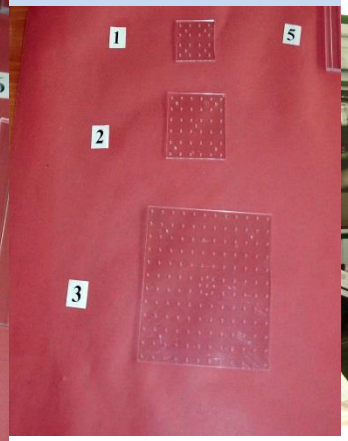


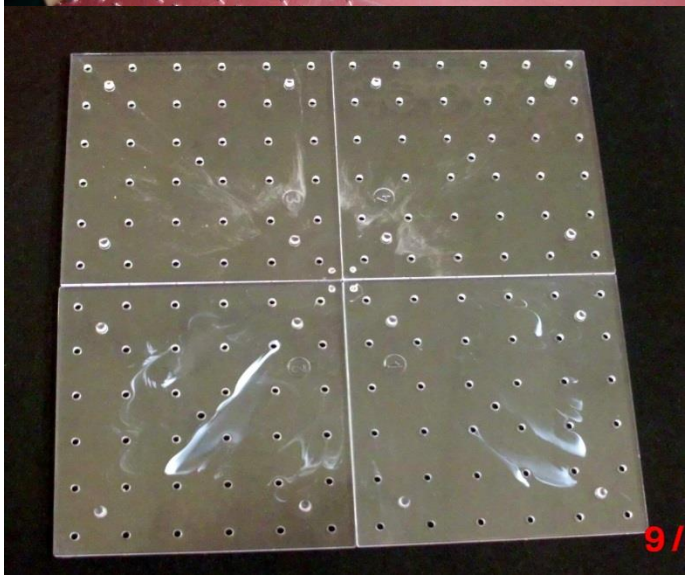
Single tile 1.5 x 55x55 mm^3 with LEGO signs for Lead fixation

4 Sets Matrix Form for this tiles

Sampling Ecal
Scintillator tile production molding by pressure technology



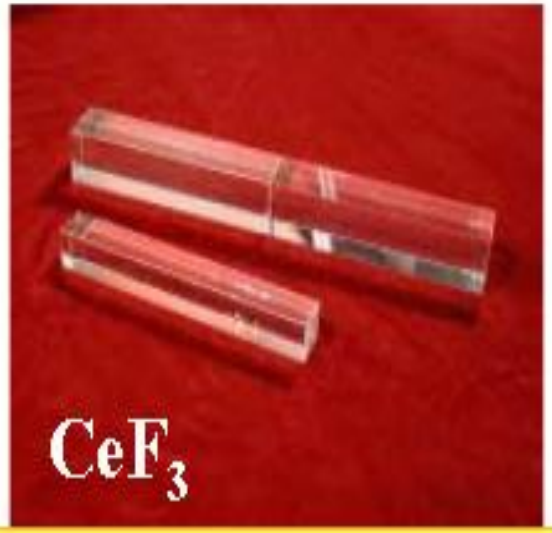


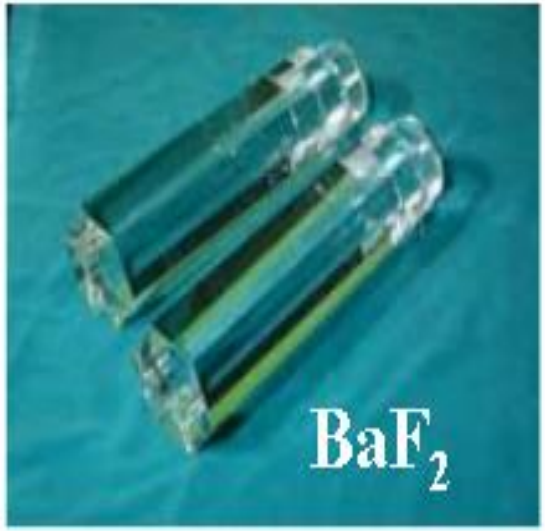


Molding machine used for scintillator production from granulated Polystyrene wit dopants: 1.5% Pt-Terphenyle and 0.05% POPOP (420 nm and 2,5 ns decay time).
Radiation hardness closed to 10^7 Rad (10^5Gy)
The scintillator tiles with different sizes could be made.
The production procedure is automatically and allow one Sycle per minute.

Crystal Scintillator Calorimeter
Crystals building blocks

These crystals make light!





Crystals are basic components of electromagnetic calorimeters aiming at precision as well as of many medical imaging devices

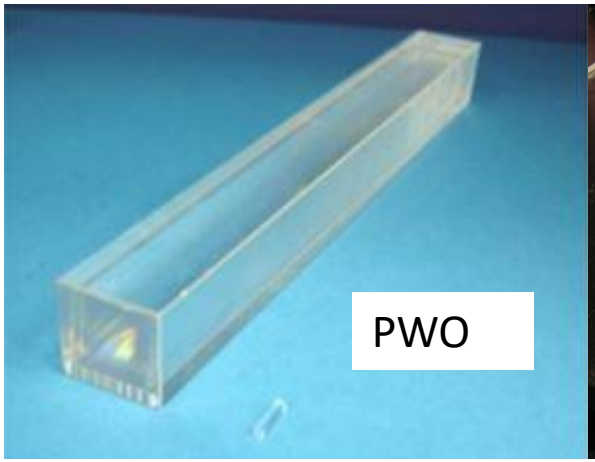
Crystal Scintillator Calorimeter qualities

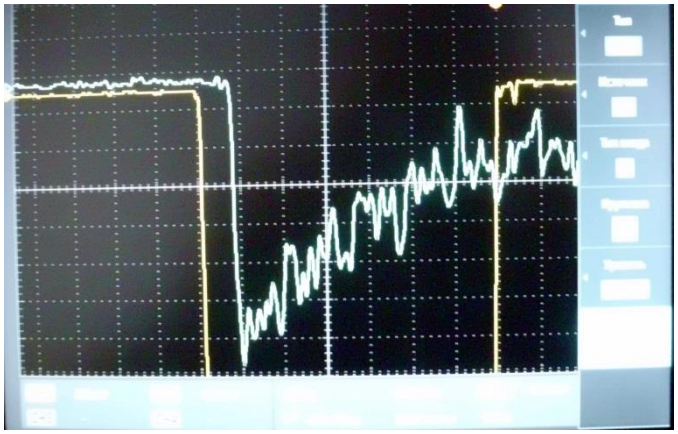
Ideal Calorimeter qualities:

- Total absorption calorimeter
- Short radiation length and Moliere radius, X0=0.89 cm
- High light output (~10.000 Phe/MeV)
- Very fast (10-30 ns decay time)
- Radiation resistant up to 10^5 Gy

Non-ideal qualities:

- Expensive ~ 10 USD/ cm^3
- Small light output (~100 Phe/MeV)
- Temperature dependent (~2.2%/^{0}C)
- Very slow (500 ns decay time)

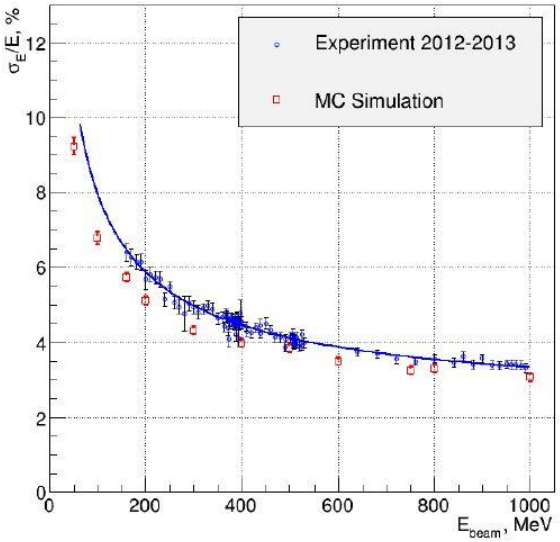


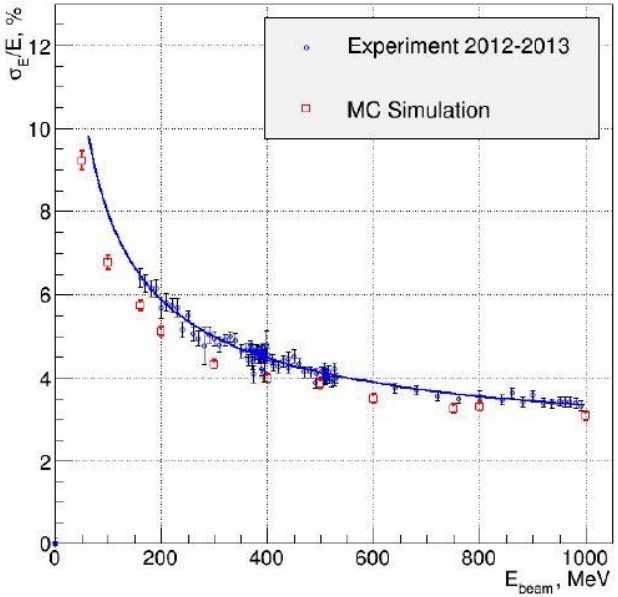


Cristal's property

		Sodium Iode	Thallium activated CsI	Cesium Iode	Barium Fluoride	Germanium Fluoride	$Bi_3Ge_4O_4$	$PbWO_4$
		NaI(Tl)	**CsI(Tl)**	**CsI**	**BaF2**	**CeF3**	**BGO**	**PbWo4**
Radiation Len.	**cm**	**2,59**	**1,85**	**1,85**	**2,06**	**1,68**	**1,12**	**0,89**
Moliere Radius	**cm**	**4,80**	**3,50**	**3,50**	**3,39**	**2,63**	**2,23**	**2,19**
Humidity		**High**	**Low**	**Low**	**Not Sens.**	**Not Sens.**	**Not Sens.**	**Not Sens.**
Light Wave Length	**nm**	**410**	**550**	**563 315**	**310 220**	**340 300**	**480**	**420**
Decay Time		**230**	**1000**	**35**	**620**	**30**	**300**	**6**
Light Output	**%**	**100**	**45**	**20**	**20**	**8**	**18**	**2**
Price	**USD/cm³**	**1,5**	**2,0**	**3,0**	**2,5**	**3,0**	**7,0**	**2,6**
PHE/MeV				**16800**	**9950**	**4500**	**8200**	**200**
Temperature	**%/grad**	**-0,30**	**0,01**				**-1,50**	**-2,00**

BGO Calorimeter test beam results
CMD-2 detector, Novosibirsk





$$\frac{\sigma_E}{E}[\%] = \frac{2.71}{\sqrt{E[\text{ГэВ}]}} \oplus 1.26$$

$$\frac{\sigma_E}{E}[\%] = \frac{2.43}{\sqrt{E[\text{ГэВ}]}} \oplus 2.28$$

$$\sigma_x[\text{мм}] = \frac{0,97}{\sqrt[4]{E[\text{ГэВ}]}} + 1,45$$

R.R. Akhmetshin, D.N. Grigorev, V.F. Kazanin, A.A. Ruban, V.P. Smakhtin, Yu.V. Yudin

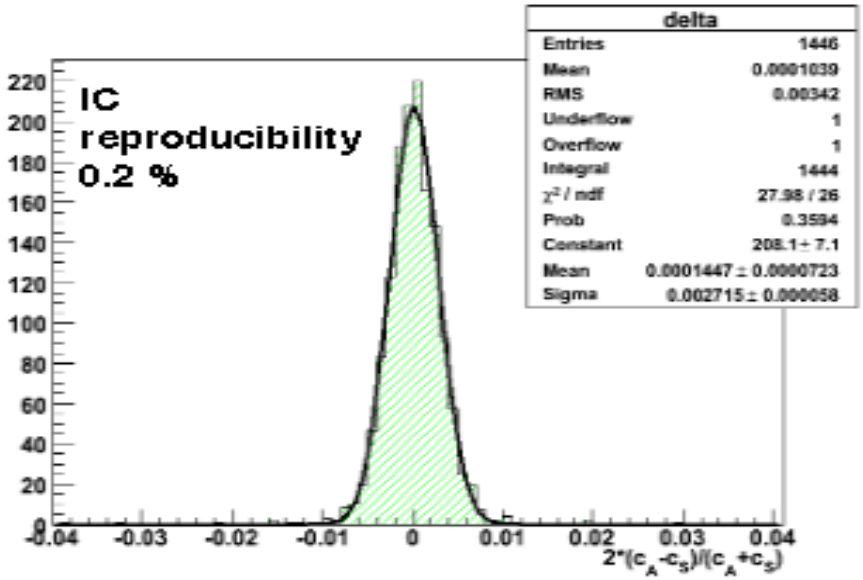
The BGO endcap calorimeter with photodiode readout for the CMD-2 detector.

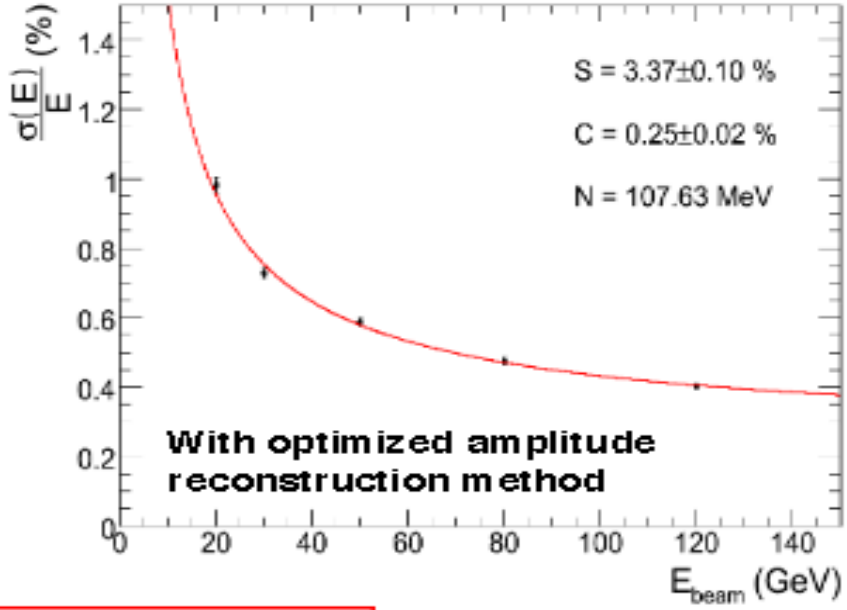
Nucl.Instrum.Meth.A453,249-254,2000

CMS ECal Test beam results
PWO crystal calorimeter

Inter-calibration (IC) with electron beam

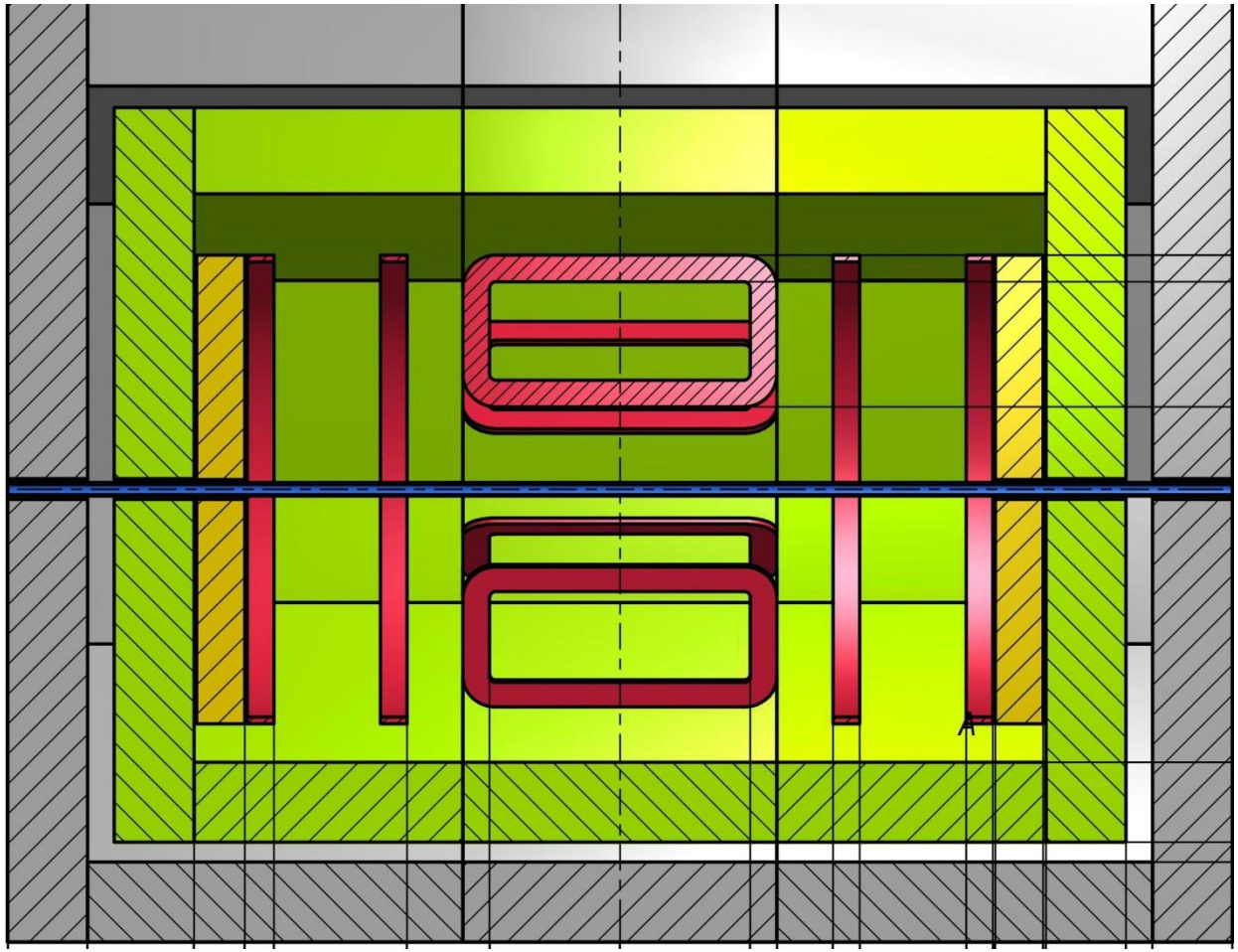
- 9 SMs intercalibrated with electrons @ 120 GeV H4
- 1 SMs partially calibrated with electrons @ 50 GeV H2



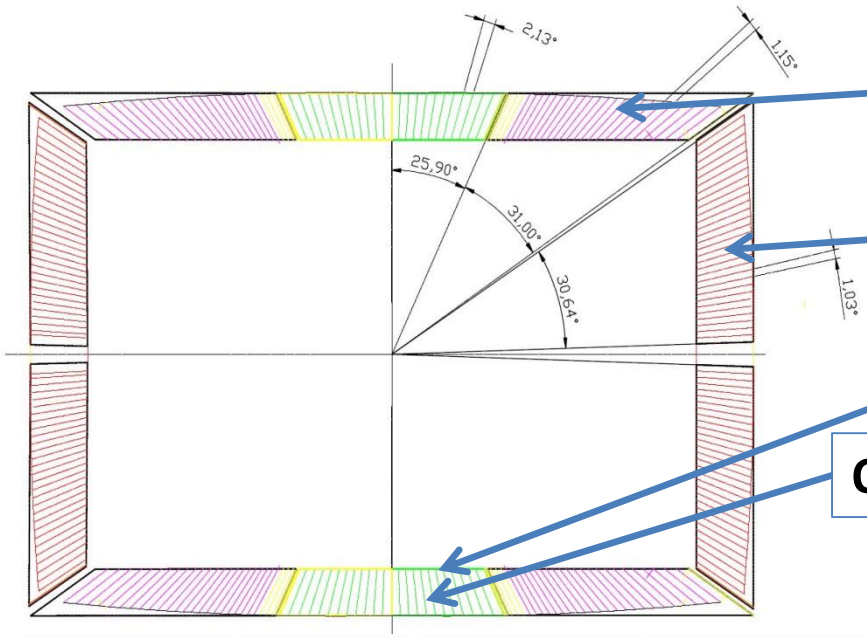


$$\frac{\sigma}{E} = \frac{3.37\%}{\sqrt{E}} \oplus \frac{108}{E} \oplus 0.25\%$$

SPD Ecal for Hybrid magnet



SPD ECal , Price estimation



Barrel – Sc+Pb , 55 mm cells

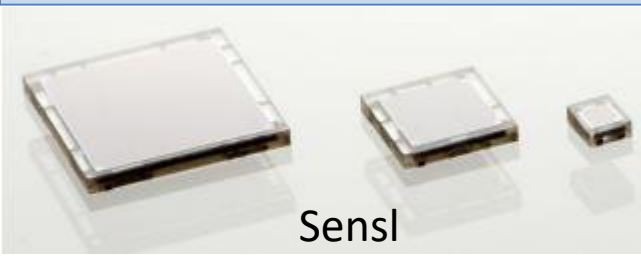
Cap – Sc+Pb , 40 mm cells

Barrel – Sc+Pb , 55 mm cells

Optional: Barrel – BGO, 30 mm cells

Ecal Type	N Barrel	N Cup	USD Price Barel	USD Price Cap	Barel Tonn	Cap Tonn	FE Board Number	FE board Price USD
BGO	21 820	28 696	32 991 101	21 694 260	33			
PWO	21 820	28 696	9 426 029	6 198 360	39			
Sc+Pb	66 568	16 142	6 994 504	3 392 087	65	16		
Sc+Pb	35 210	8 538	4 414 780	1 794 162	65			
Total	73 171		40 797 968		114		1 143	2 858 226

Photo sensor type
Power control SPD Ecal

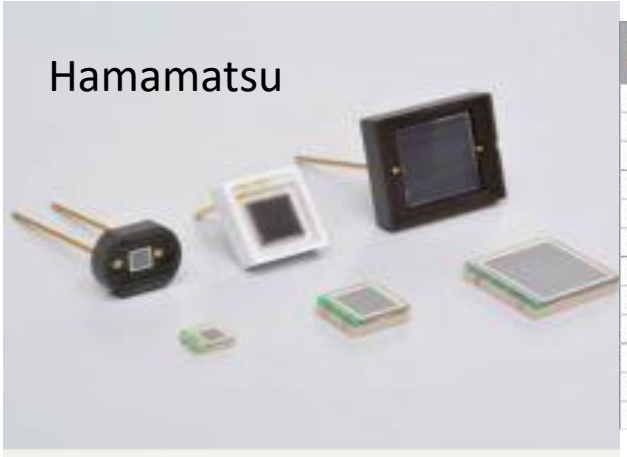


Type no.	Pixel pitch (μm)	Effective photosensitive area (mm)	Number of pixels	Package	Fill factor (%)
S13360-1325CS	25	1.3 × 1.3	2668	Ceramic	47
S13360-1325PE				Surface mount type	
S13360-3025CS		3.0 × 3.0	14400	Ceramic	
S13360-3025PE				Surface mount type	
S13360-6025CS		6.0 × 6.0	57600	Ceramic	
S13360-6025PE				Surface mount type	

Possible Silicon Multy-pixel Photomultiplier (Multy-Pixel Photon Counter) for ECal

http://sensl.com/downloads/ds/DS-MicroCseries.pdf
MicroFC-60035-SMT

https://www.hamamatsu.com/resources/pdf/ssd/s13360_series_kapd1052e.pdf - S13360-6025PE



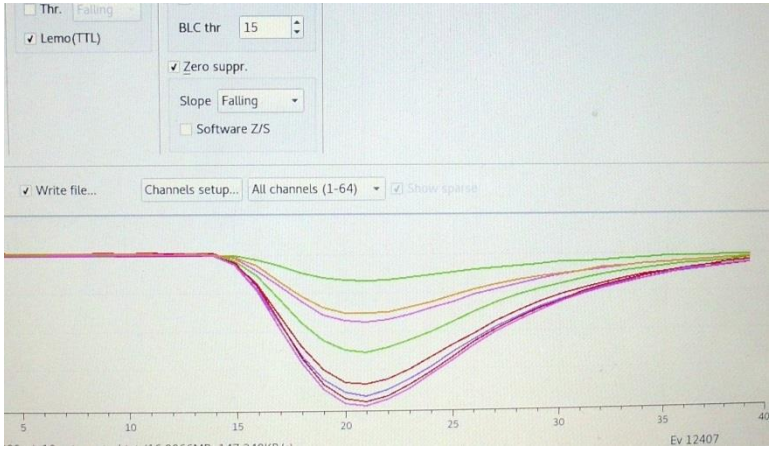
Sensor Size	Microcell Size	Parameter[1]	Overvoltage	Min.	Typ.	Max.	Units
1mm	10μ, 20μ, 35μ, 50μ	Breakdown Voltage (Vbr)[3]		24.2		24.7	V
3mm	20μ, 35μ, 50μ						
6mm	35μ						
1mm	10μ, 20μ, 35μ, 50μ	Recommended overvoltage Range (Voltage above Vbr)[2]		1.0		5.0	V
3mm	20μ, 35μ, 50μ						
6mm	35μ						
1mm	10μ, 20μ, 35μ, 50μ	Spectral Range[4]		300		950	nm
3mm	20μ, 35μ, 50μ						
6mm	35μ						
1mm	10μ, 20μ, 35μ, 50μ	Peak Wavelength (λp)			420		nm
3mm	20μ, 35μ, 50μ						
6mm	35μ						

Frontend for SPD Ecal

ADC64 board used for signals digitizing

https://afi-project.jinr.ru/projects/adc64-sw/files

As a FE electronics unit we have designed and constructed ADC 64 channel. ADC board is a waveform digitizer. It quantize analogue input signal and samples it at fixed time intervals. Zero suppression logic is based on baseline estimation and threshold value. Signal shaping is performed in digital form with FIR filters. It allows to reduce the number of waveform points required for digital signal representation with minimum loss of accuracy. The ring type memory allows the read back of last 30 µs of waveforms.



ADC-64 waveform with 30 samples
Data taking in nuclear (Argon) Beam
BM&N – JINR – March 2018

SPD Electromagnetic calorimeter

CONCLUSIONS:

1. SPD ECal design has depended from Experimental setup option:
   - Solenoid - Tor – Hybrid magnet Types
2. Lead Plastic EC production possible now:
   1. Cells size: 5.5x5.5cm^2 or 4x4cm^2
   2. Geometry: strain or projective ?
   3. Price: 3 392 087 + 4 414 780 = 7 806 867 USD
3. The Crystals calorimeter :
   1. BGO crystal possible , but expensive : 32 991 101 USD
4. FE (ADC-64) Price: 2 858 226 USD
5. Photo sensors + Power Control: 1 577 741 USD

Electromagnetic Calorimeter for SPD

O. Gavrishchuk, JINR, Dubna

Thanks everybody for attention !