Electromagnetic Calorimeter (EC) options for SPD:

1. SPD layout
2. Electromagnetic Calorimeter options
    1. Cristal calorimeters
    2. Sampling calorimeters
3. Possible EC Production

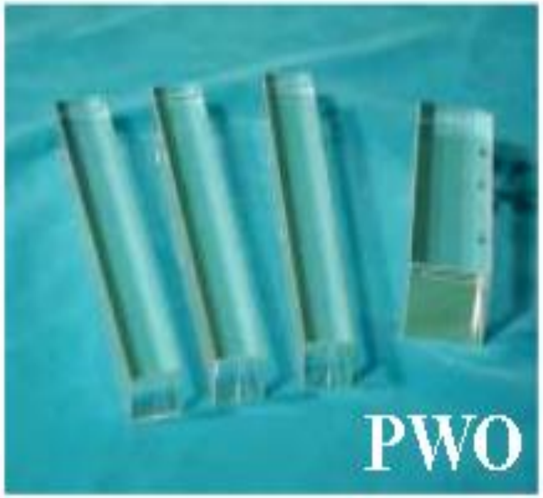
Heavy crystals properties:

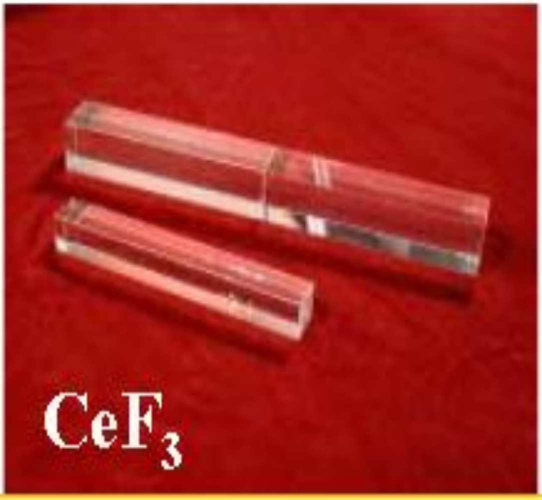
Таблица 1. Свойства тяжелых сцинтилляторов

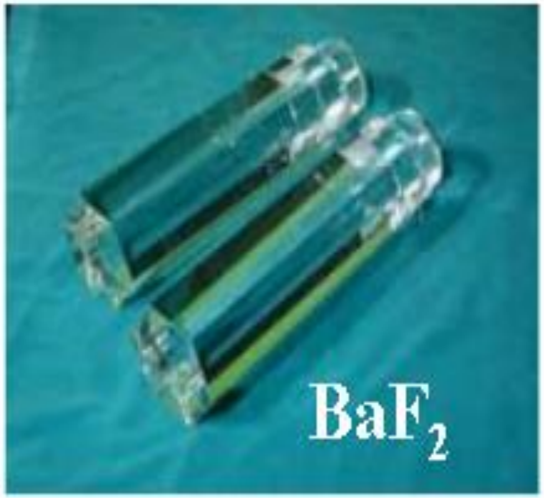
Свойства	NaI(Tl)	CsI(Tl)	CsI	BaF_2	CeF_3	BGO	$PbWO_4$
Плотность, г/см^2	3,67	4,51	4,51	4,89	6,16	7,13	8,28
Температура плавления, °C	651	621	621	1280	1460	1050	1123
Радиационная длина, см	2,59	1,85	1,85	2,06	1,68	1,12	0,89
Мольеровский радиус, см	4,8	3,5	3,5	3,39	2,63	2,33	2,19
Длина взаимодействия, см	41,4	37,0	37,0	29,9	26,2	21,8	22,4
Показатели преломления	1,85	1,79	1,95	1,50	1,62	2,15	2,30
Гигроскопичность	Высокая	Незначительная	Незначительная	Отсутствует	Отсутствует	Отсутствует	Отсутствует
Длина волны излучения (в максимуме), нм	410	550	563 315	310 220	340 300	480	440 530
Длительность излучения, нс	230	1000	35 6	630 0,9	30 9	300	5 (39 %) 15 (60 %) 100 (1 %)
Относительный световыход	100	45	20	20	8	18	1,3
Стоимость, доллар/см^3	1–2	2	3	2,5	3	7	2,6

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

PWO4 crystals technology

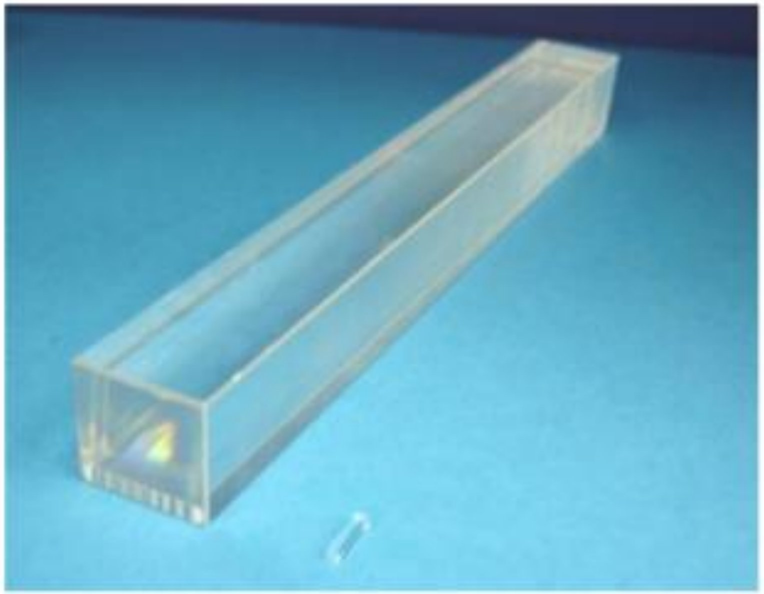
Scintillating Crystal Calorimeter: Lead-Tungstate ($PbWO_4$)

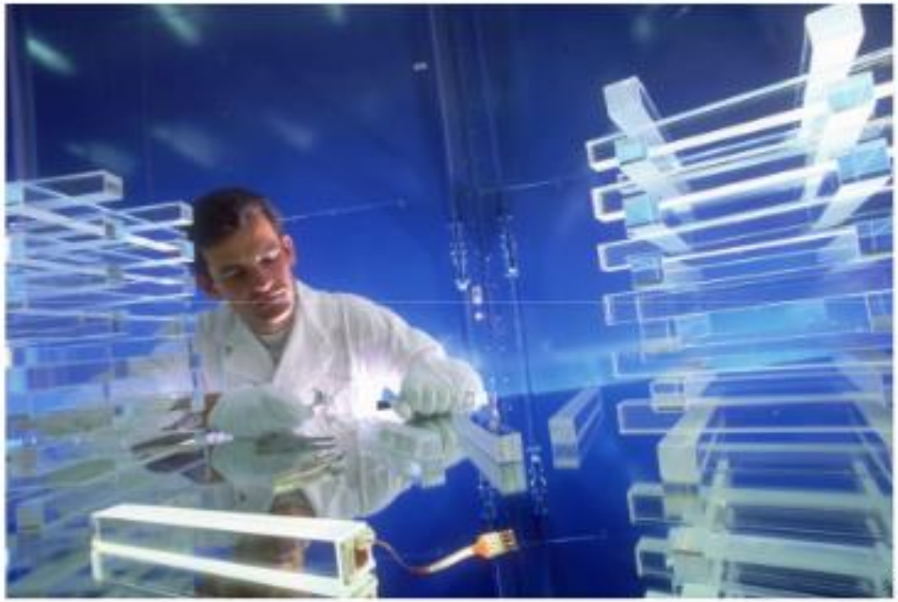
Ideal calorimeter qualities:

- Total absorption calorimeter
- Short radiation length and Moliere radius, X_0=0.89cm and R_M=2.1cm
- Very dense
- Very fast
- Radiation resistant

Non-ideal qualities:

- Expensive
- Small light output
- Temperature dependent (~2.2%/°C)





8

PWO4 properties

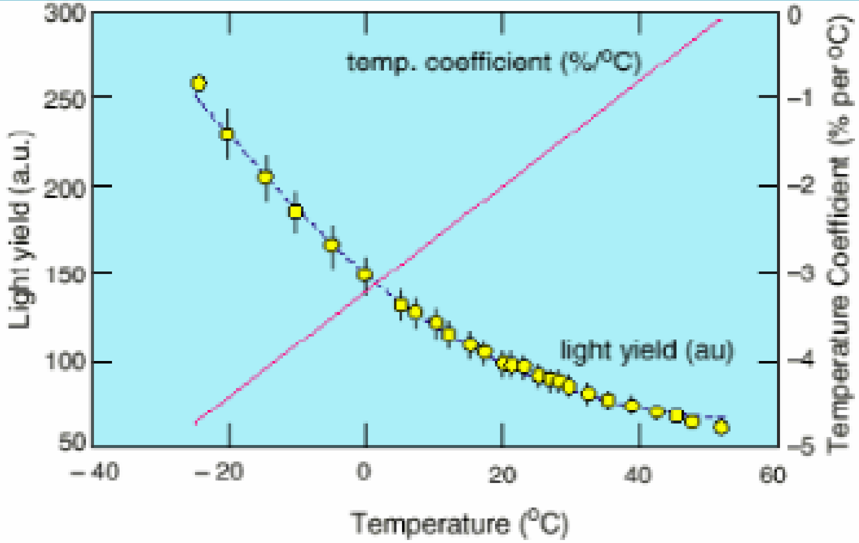
Fast light emission : ~80% in 25 ns

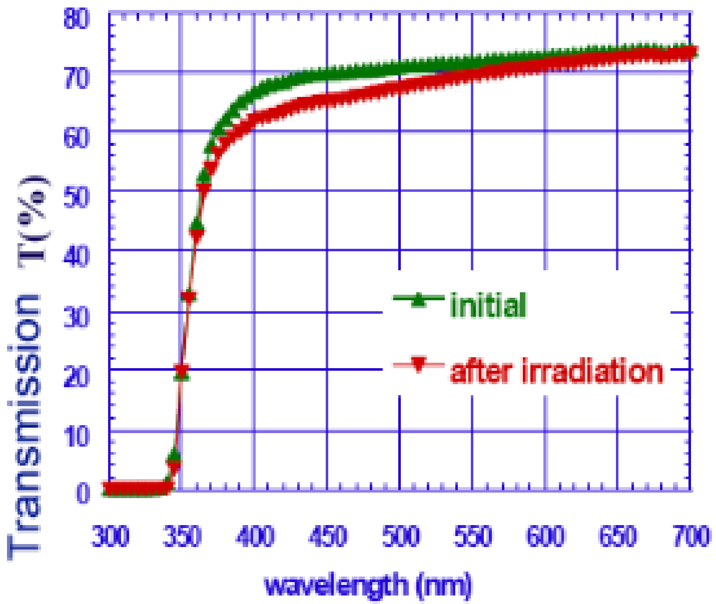
Peak emission : ~425 nm (visible region)

Short radiation length : X_0 = 0.89 cm

Small Molière radius : R_M = 2.10 cm

Radiation resistant to very high doses.





But:

Temperature dependence ~2.2%/°C

→ Stabilise Crystal Temp. to ≤ 0.1°C

Formation and decay of colour centres in dynamic equilibrium under irradiation

→ Precise light monitoring system

Low light yield (~1% NaI)

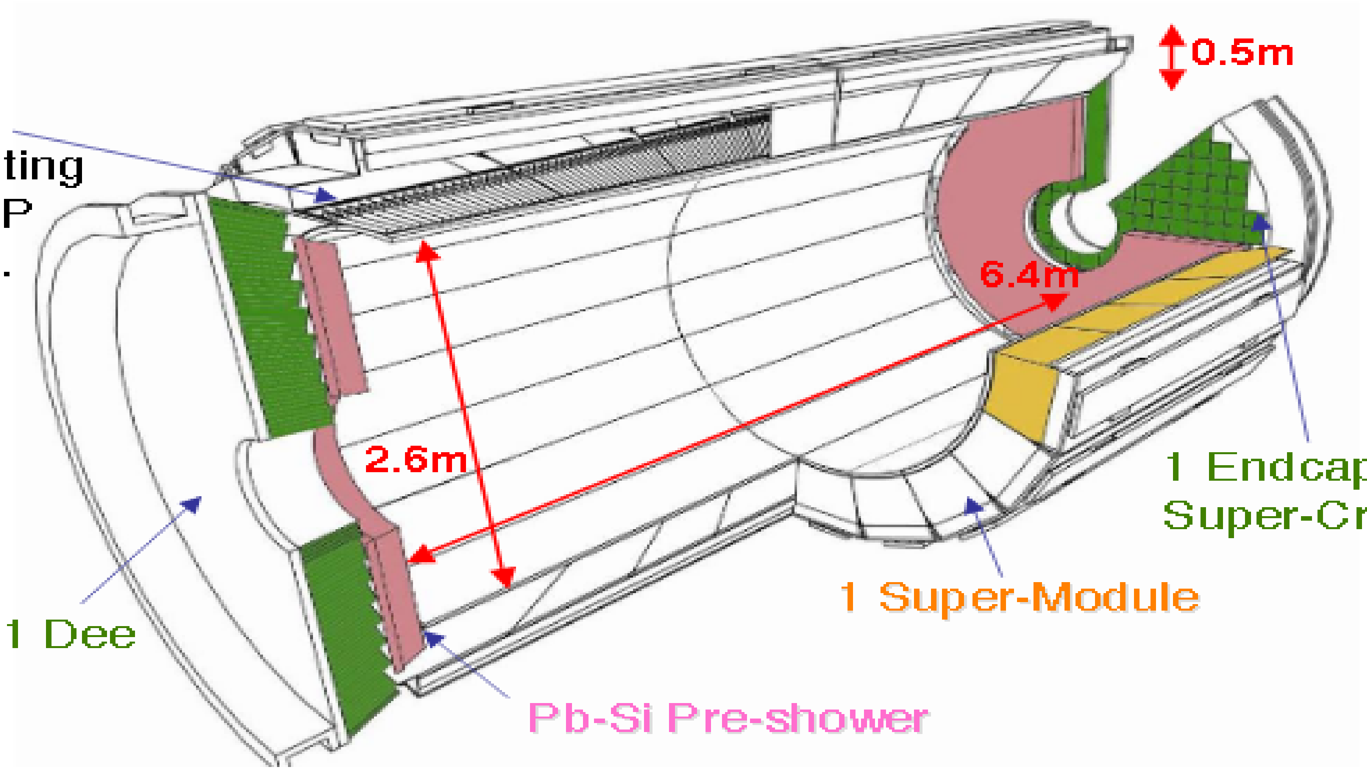
→ Photodetectors with gain in mag field

CMS PWO4 EC Design

Barrel (EB):
- 61200 crystals total
- 36 Supermodules (SM), each 1.7k crystals

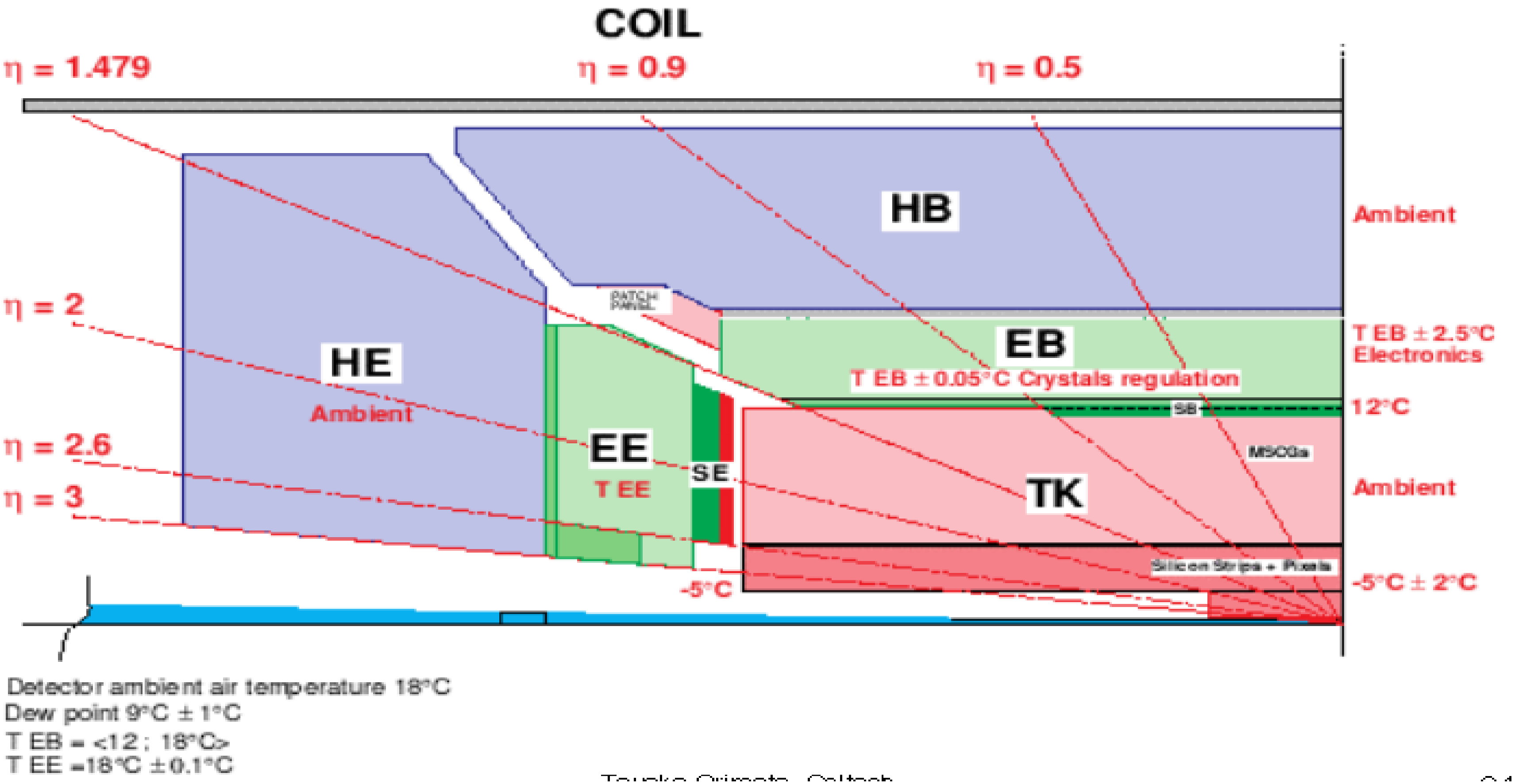
Endcap (EE):
- 14648 crystals total
- 4 Dees, each 3662 crystals
- Crystals combined into SuperCrystals of 5x5 crystal

Crystals are projective and positioned pointing slightly off the IP to avoid cracks.



1

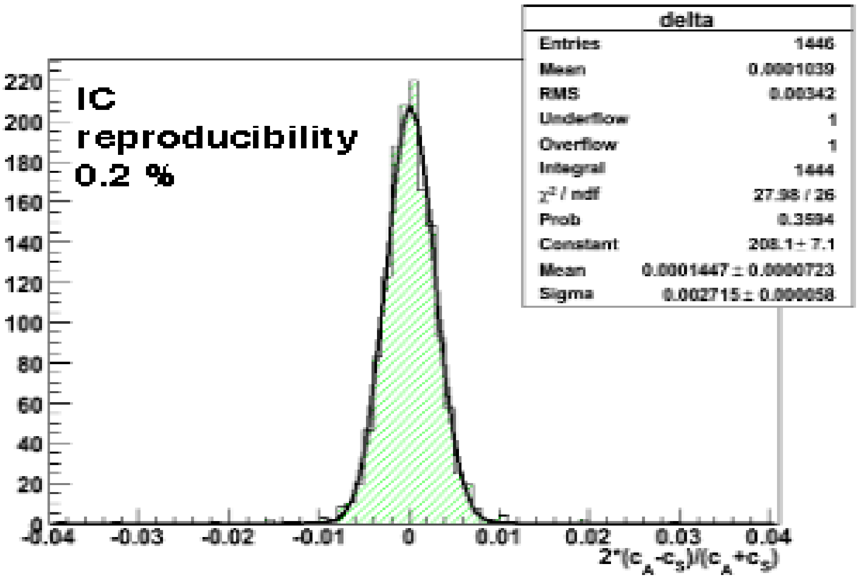
CMS Rapidity Coverage

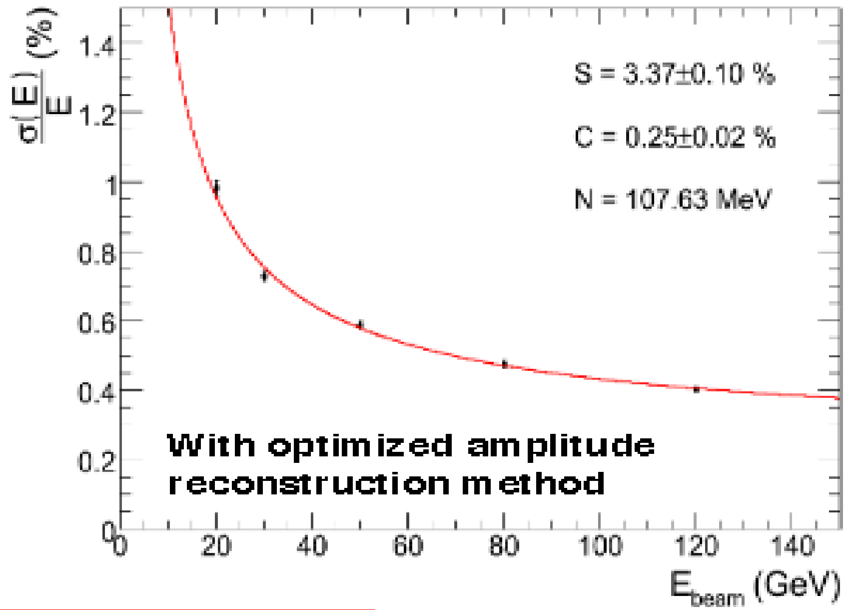


CMS EC Test beam results

Inter-calibration (IC) with electron beam

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





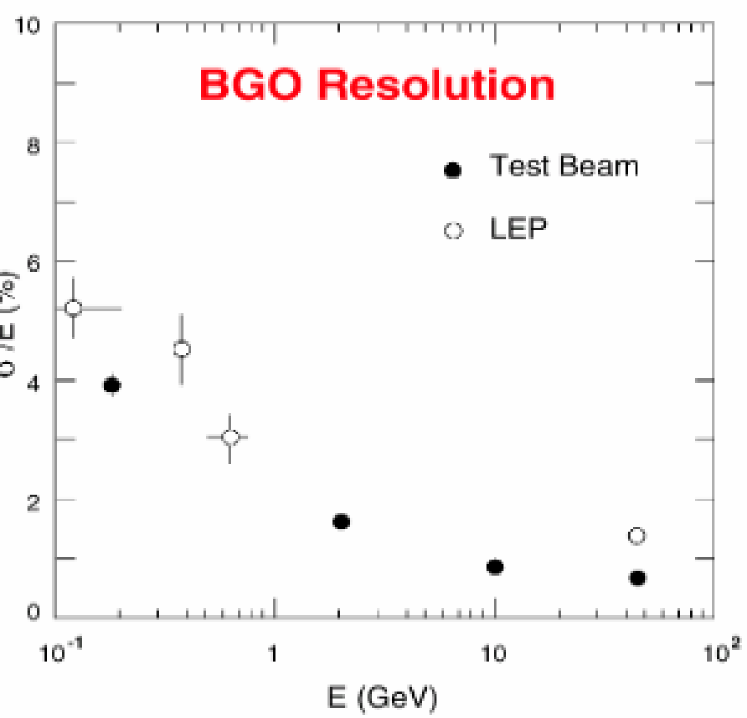
$$\frac{\sigma}{E} = \frac{3.37\%}{\sqrt{E}} \oplus \frac{108}{E} \oplus 0.25\%$$

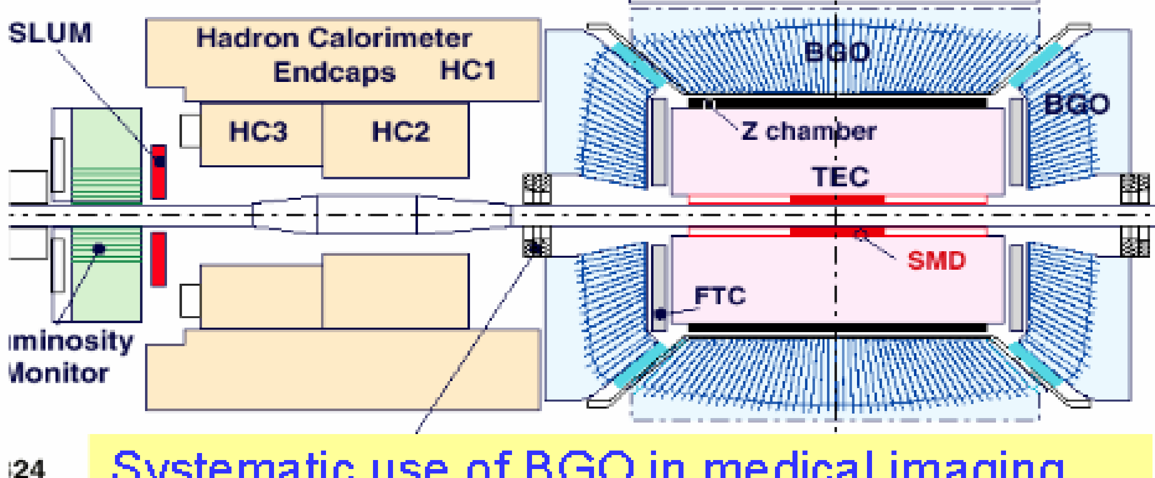
L3 BGO EC Design (LEP, CERN)

- 7680 EB + 3640 EC BGO crystals
- PIN diode read-out (no gain)
- Eγ range 0.5 → 100 GeV

A change of scale is possible!

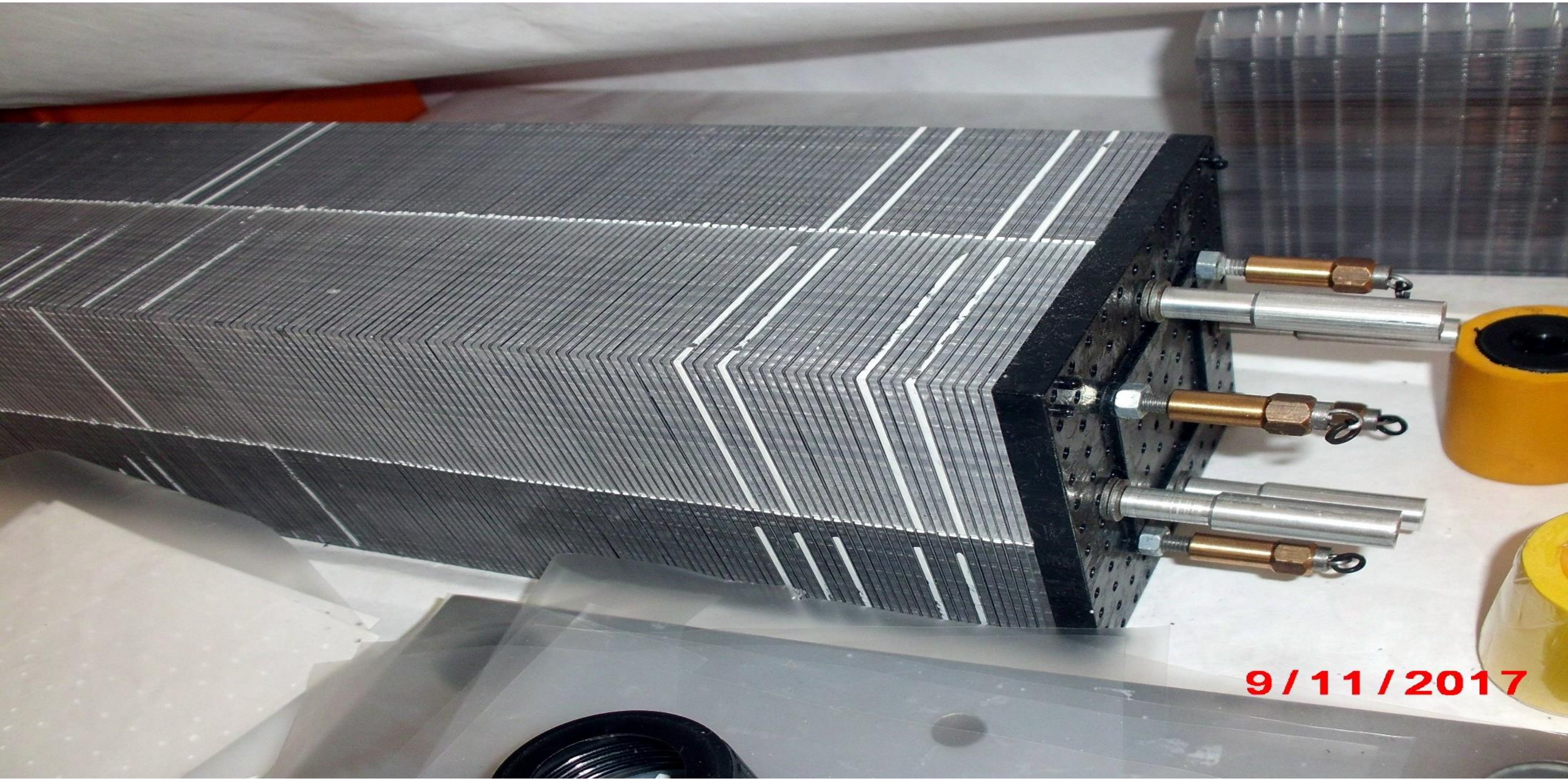
BGO: $Bi_3Ge_4O_{12}$
about 1 m^3, 7 ton





Systematic use of BGO in medical imaging could only be made possible through the large effort of the L3 collaboration to develop low cost mass production technology for BGO, with the help of the Shanghai Institute of Ceramics in China.

Sampling EC : Lead + Plastic Scintillator



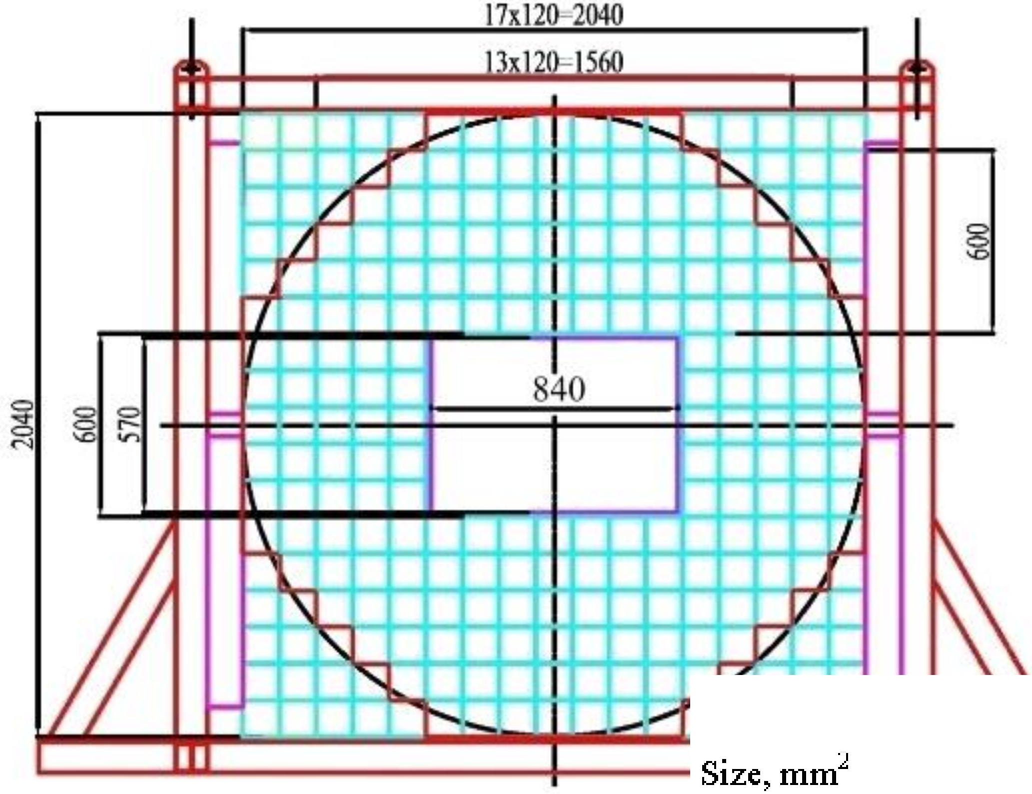
Sampling EC : Lead + Plastic Scintillator

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 $C_{PD} = 0$ pF	16,000	52,000	2.5	0.4	2.1	1.7	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

COMPASS EC modules production: Kharkov 2011

COPMASS Ecal0 – Lead Plastic sampling calorimeter
194 modules x9 cells(1746 ch.)
2011-2017

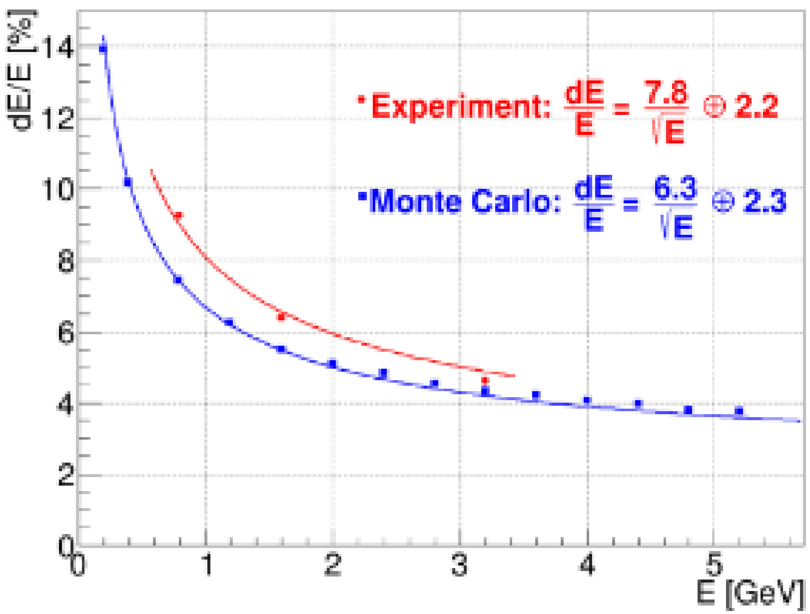
COPMASS EC : Lead + Plastic Scintillator 194 modules x9 cells(1746 ch)

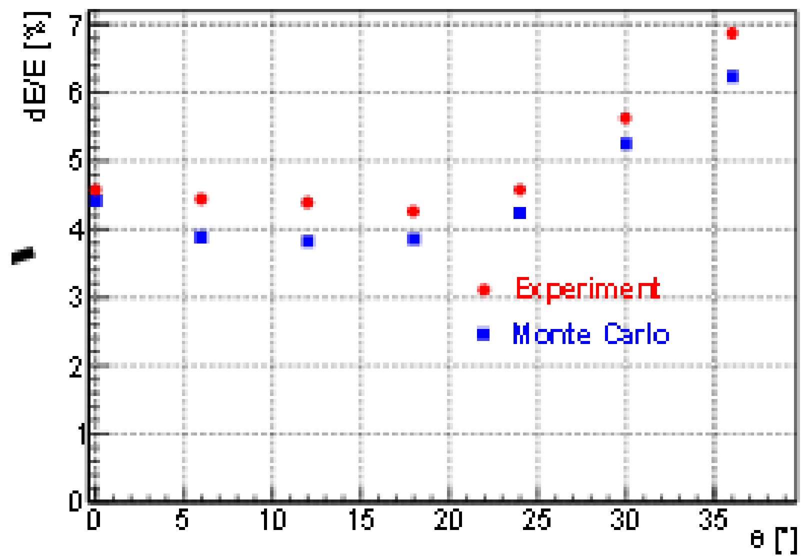


Technology	Shashlyk
Scintillator	Polystyrene Kharkov
Absorber	Lead
Number of layers	109
Sc / Pb plates thickness, mm	1.5/0.8
Pb/Sc plates dimension, cm	12.0x12.0/4.0x4.0
Moliere radius, cm	3.5
Radiation length, cm	1,64
Number of tower	9
Fiber	KYRARAY Y11(150 or175)*
Number of fibers per tower	16
Diam. of bundle, mm	6.5
Light guide	Winston cone glued to photodetector
Photodetector	MAPD -Zecotek(type will be defined)
Total thickness, cm	25.2(~ 15 X0)
ADC	MSADC
Thermostabilization	Peltier cooler

	Zecotek MAPD-3N	Hamamatsu S12572-10P
Size, mm^2	3 x 3	3 x 3
Pitch, μm	8 (size: 5)	10
Number of pixels	135 000	90 000
Bias voltage, V	90	70
Gain $\cdot 10^5$	3-5	14
PDE, % (λ=520 nm)	30	10

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





Ecal0 E-resosutio vs Beam Energy

Ecal0 E- resolution vs Beam impact angle

Sampling EC : KOPIO

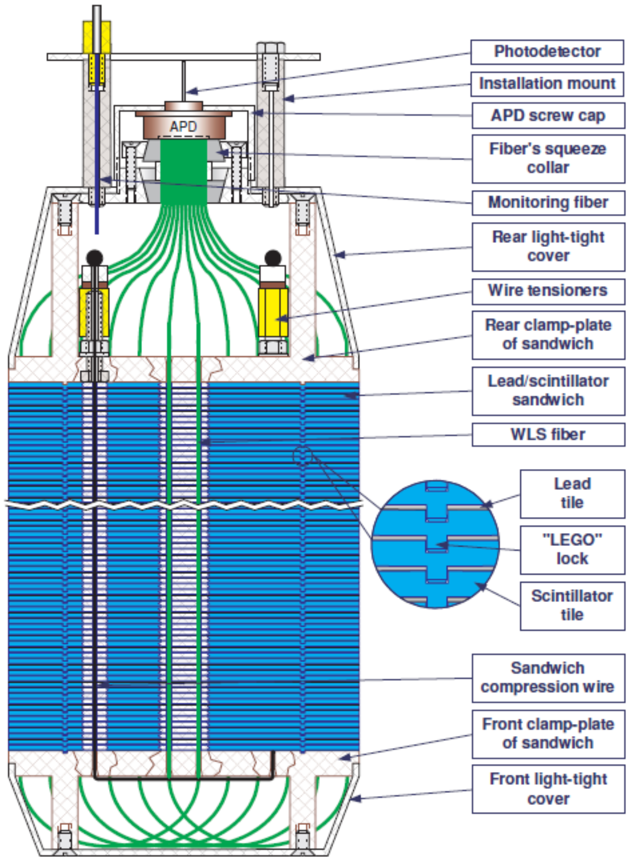
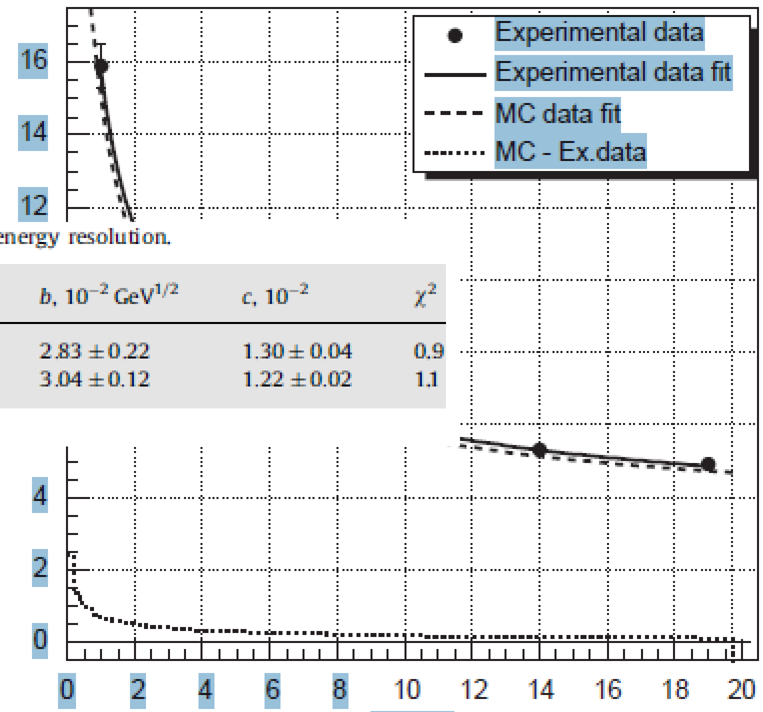


Fig. 1. The Shashlyk module design.

$$\frac{\Delta E}{E} = \sqrt{\left(\frac{a}{E}\right)^2 + \frac{b^2}{E} + c^2}$$



tting function parameters for the energy resolution.

	a, 10^{-2} GeV	b, 10^{-2} GeV$^{1/2}$	c, 10^{-2}	χ^2
xperimental fit	3.51 ± 0.28	2.83 ± 0.22	1.30 ± 0.04	0.9
onte Carlo fit	3.45 ± 0.28	3.04 ± 0.12	1.22 ± 0.02	1.1

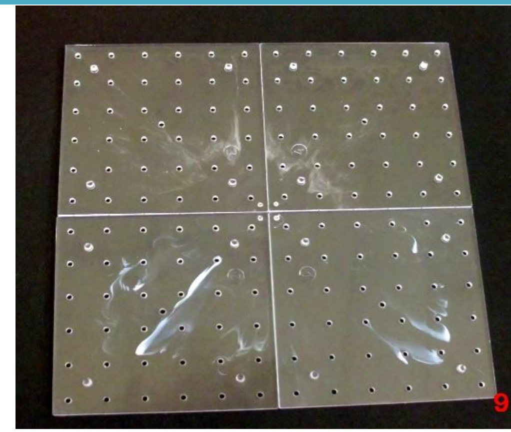
es

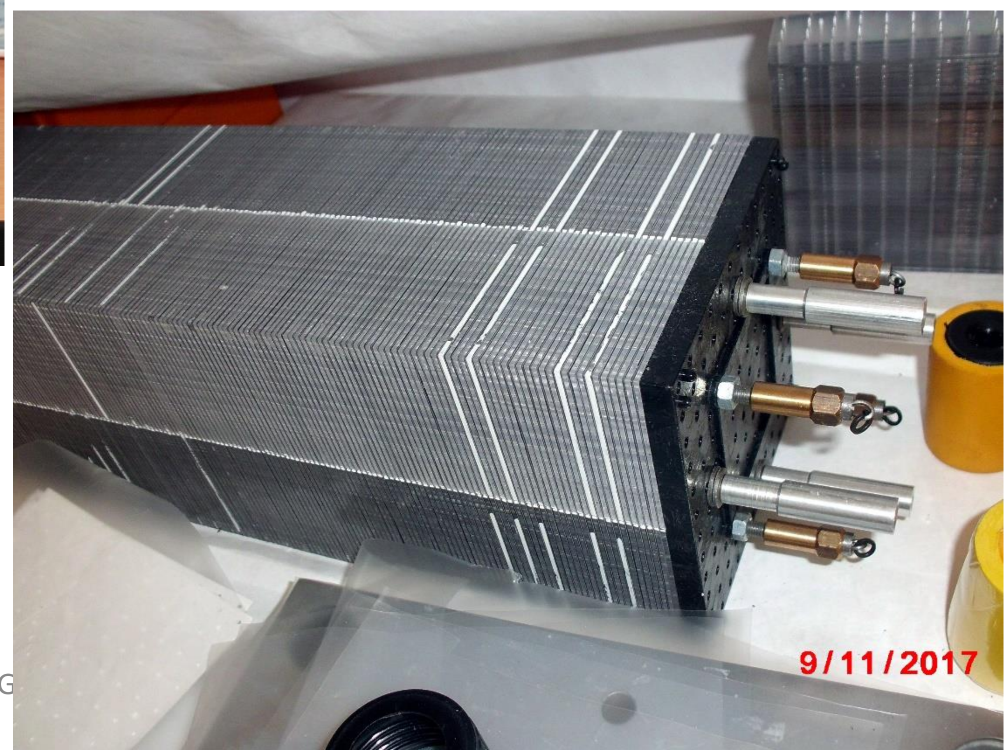
ne modules assembled controlled x, y-moving cross the beam with a precision of 0.4 mm. The beam line 2B of the U70 accelerator, described in detail in Ref. [12], was used to study the performance of the prototype. The secondary beam of negatively charged particles with momenta of 1–19 GeV/c contained more than 70% electrons mixed with muons and hadrons (mainly π^- and K^-). Particle identification was not available at this beam line. The

Table 1
Physical properties of the module.

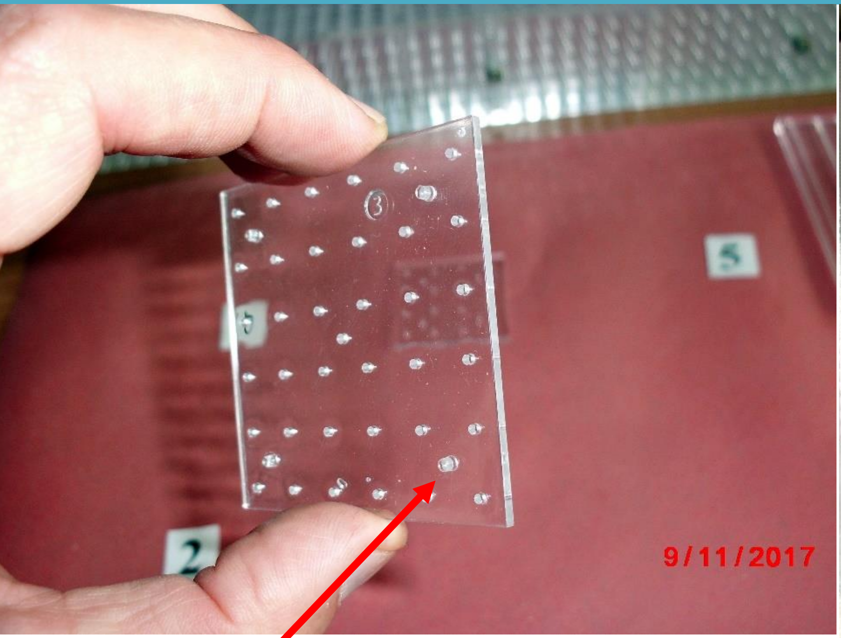
Lead plate thickness	0.275 mm
Scintillator plate thickness	1.5 mm
Number of layers	380
Effective radiation length, X_0	34 mm
Total radiation length	$20X_0$
Effective Molière radius, R_M	59 mm
Module size	$110 \times 110 \times 675\,\text{mm}^3$
Module weight	18 kg

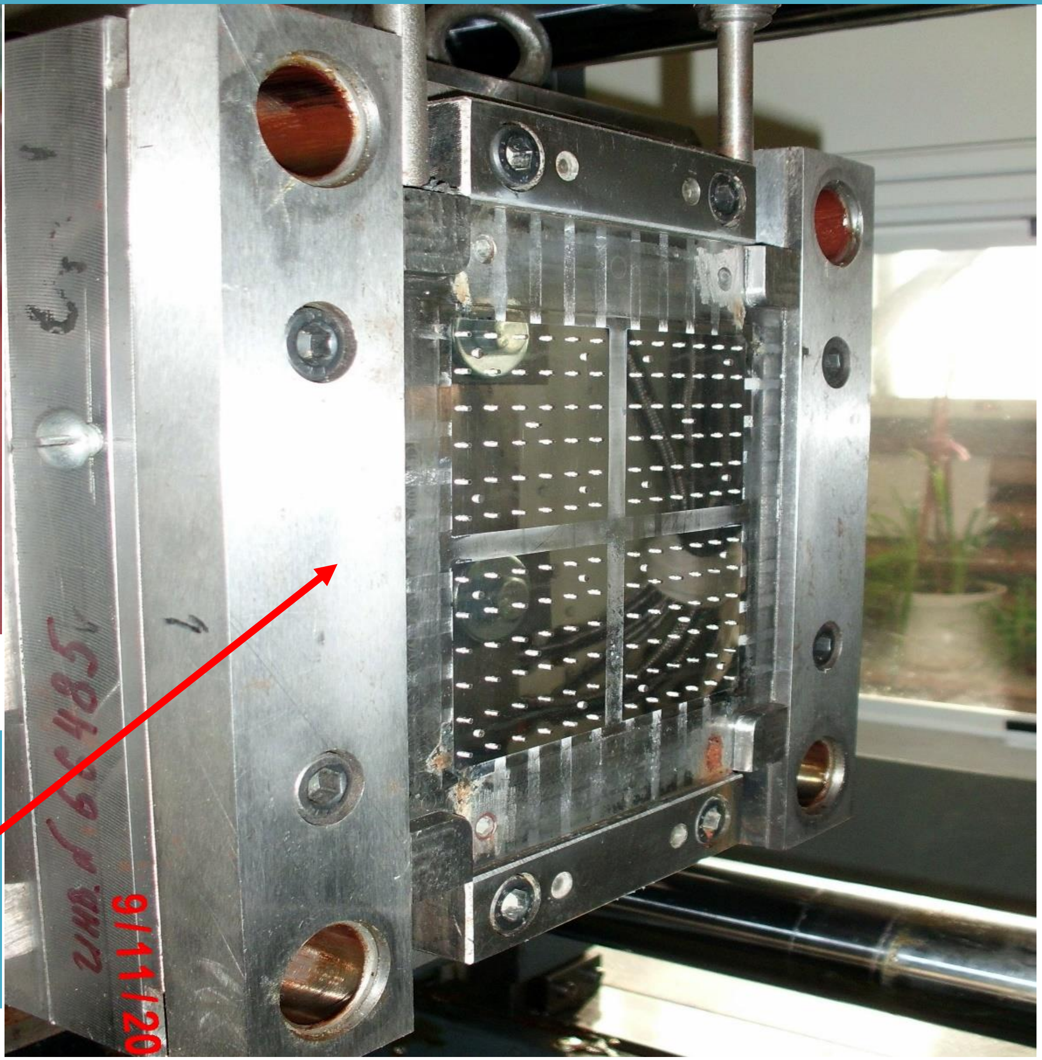
Sampling EC : KOPIO





Sampling EC : KOPIO tile production available now





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

Press Form for KOPIO tiles – 4 Sets

Sampling EC : KOPIO
Molding mashie in IHEP facility

Possible production:
1000 tiles ~ 15 cells per 8h

Sampling EC
In IHEP facility

Experience:

KOPIO 1.5x5.5x5.5
PHENIX 4x5.5x5.5
PANDA 1.5x5.5x5.
COMPASS 1.5x4x
spiral shashlick

Sampling EC : Molding IHEP facility

Sampling EC : IHEP facility for housin production for PWO4 Cristalls

IHEP muon (1-20 GeV) test beam area

Experimental test in muon beam at U-70, IHEP Protvino

The module test was performed at IHEP U-70 accelerator in muon beam. The test aria is shown on fig.14. The calorimeter module was assembled directly on place to avoid the lifting this heavy (~200 kg) device.

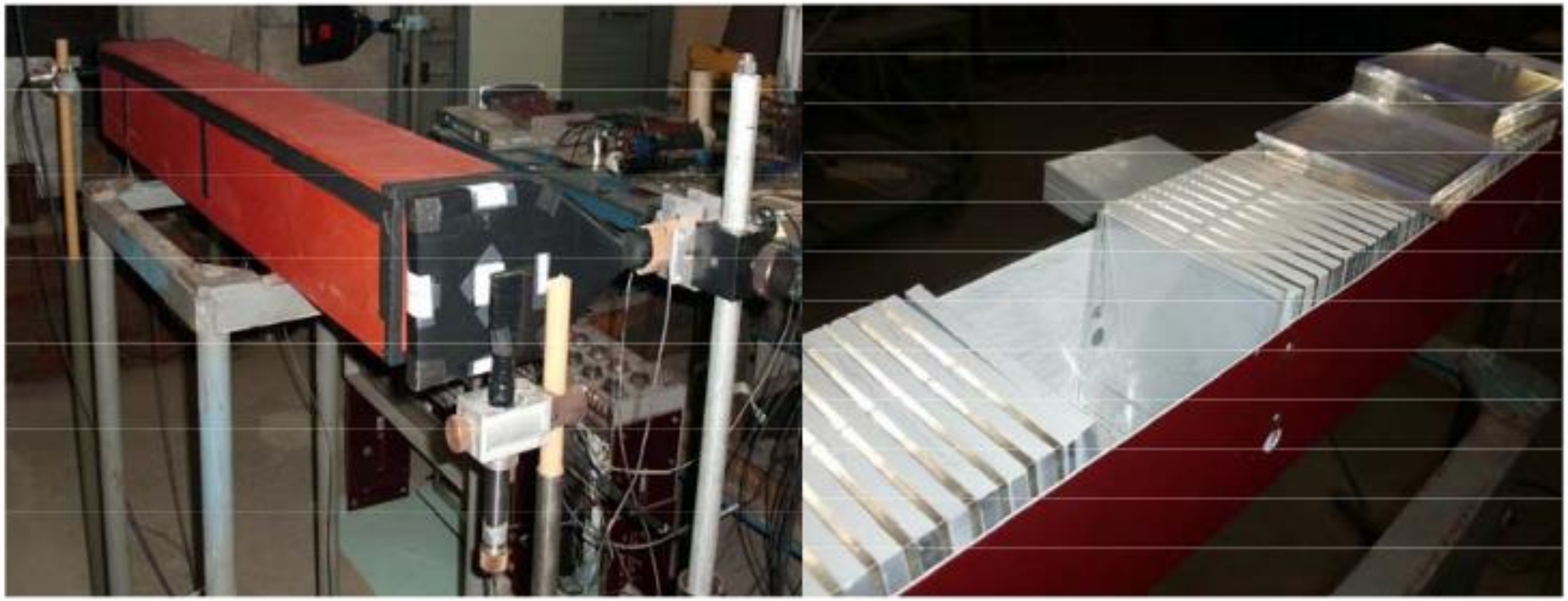
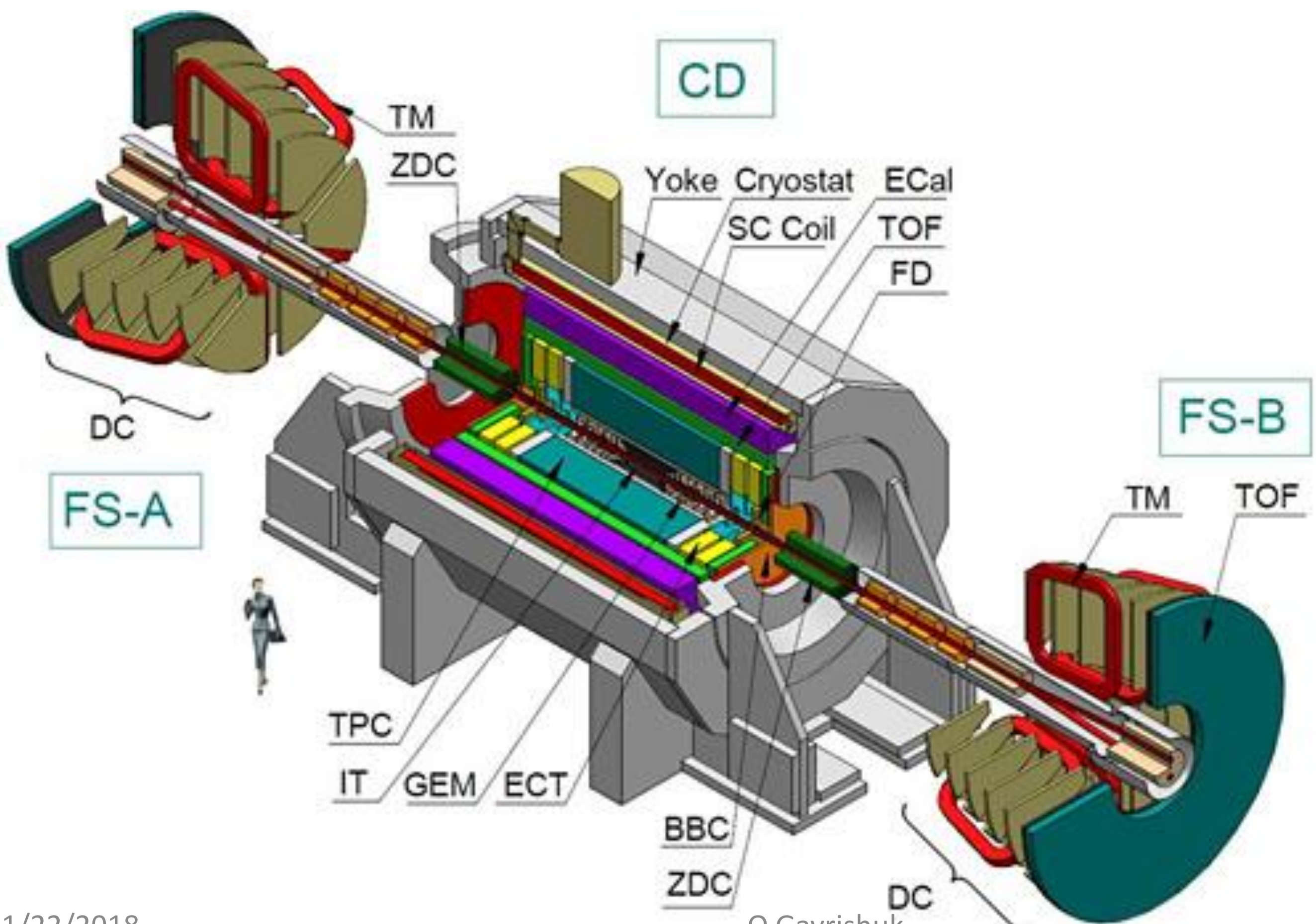


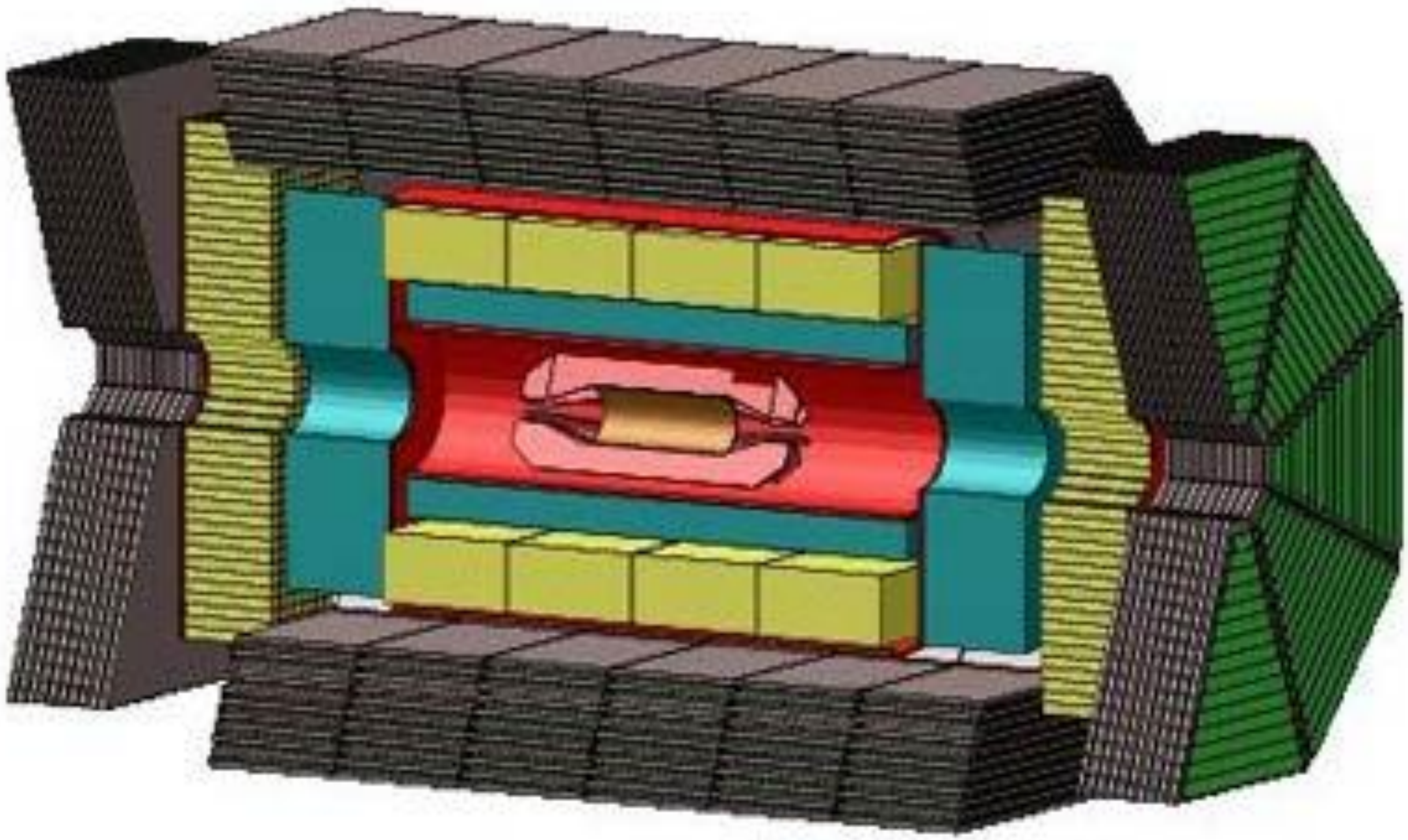
Fig. 14. Photos: left – test beam setup, right – module inside view during assembling: 64 layers of 10 mm thick led and 4 mm thick scintillator plates are stacked in box.

SPD

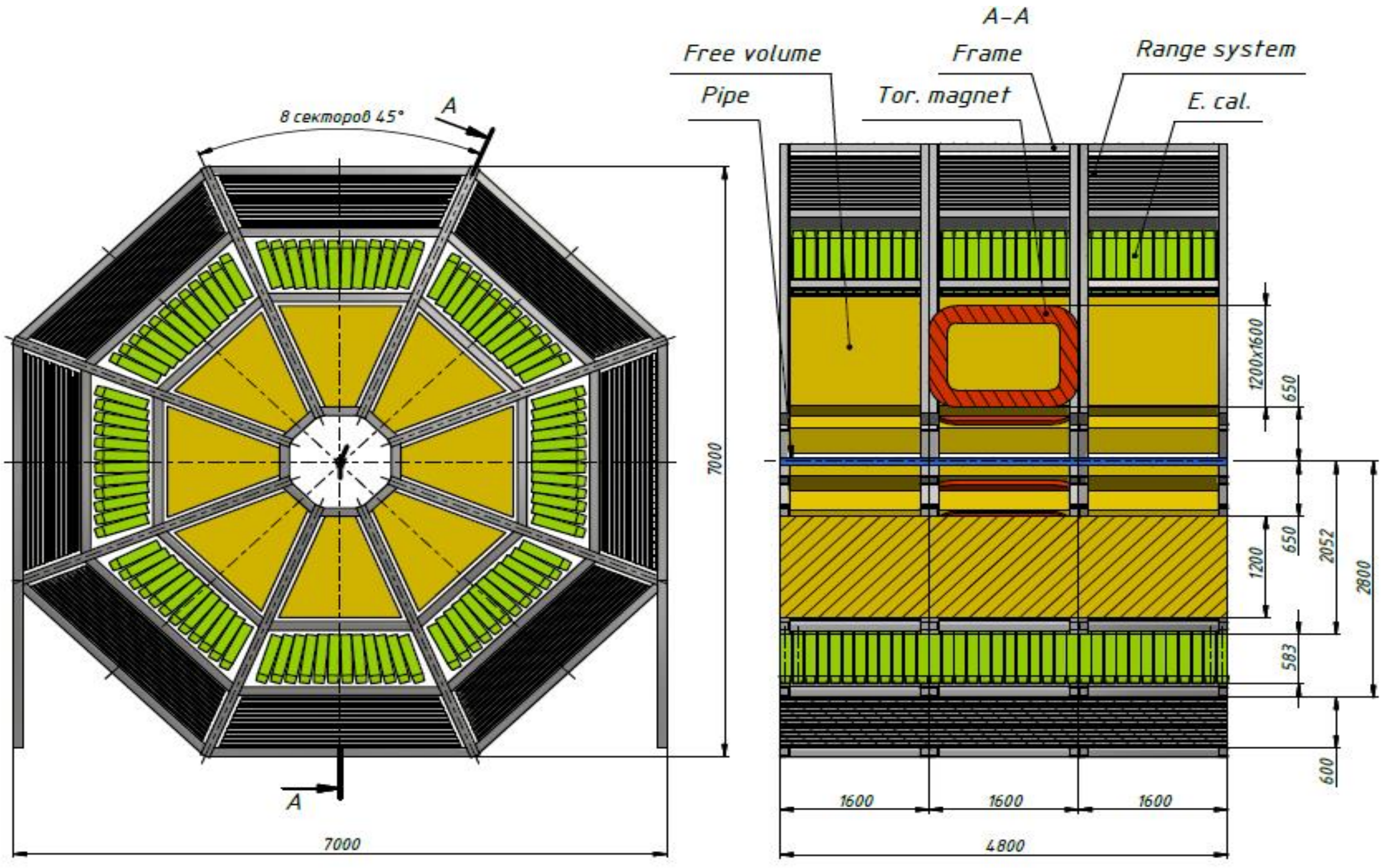
MPD model


CD
TM
ZDC
Yoke
Cryostat
ECal
SC Coil
TOF
FD
DC
FS-A
FS-B
TM
TOF
TPC
IT
GEM
ECT
BBC
ZDC
DC

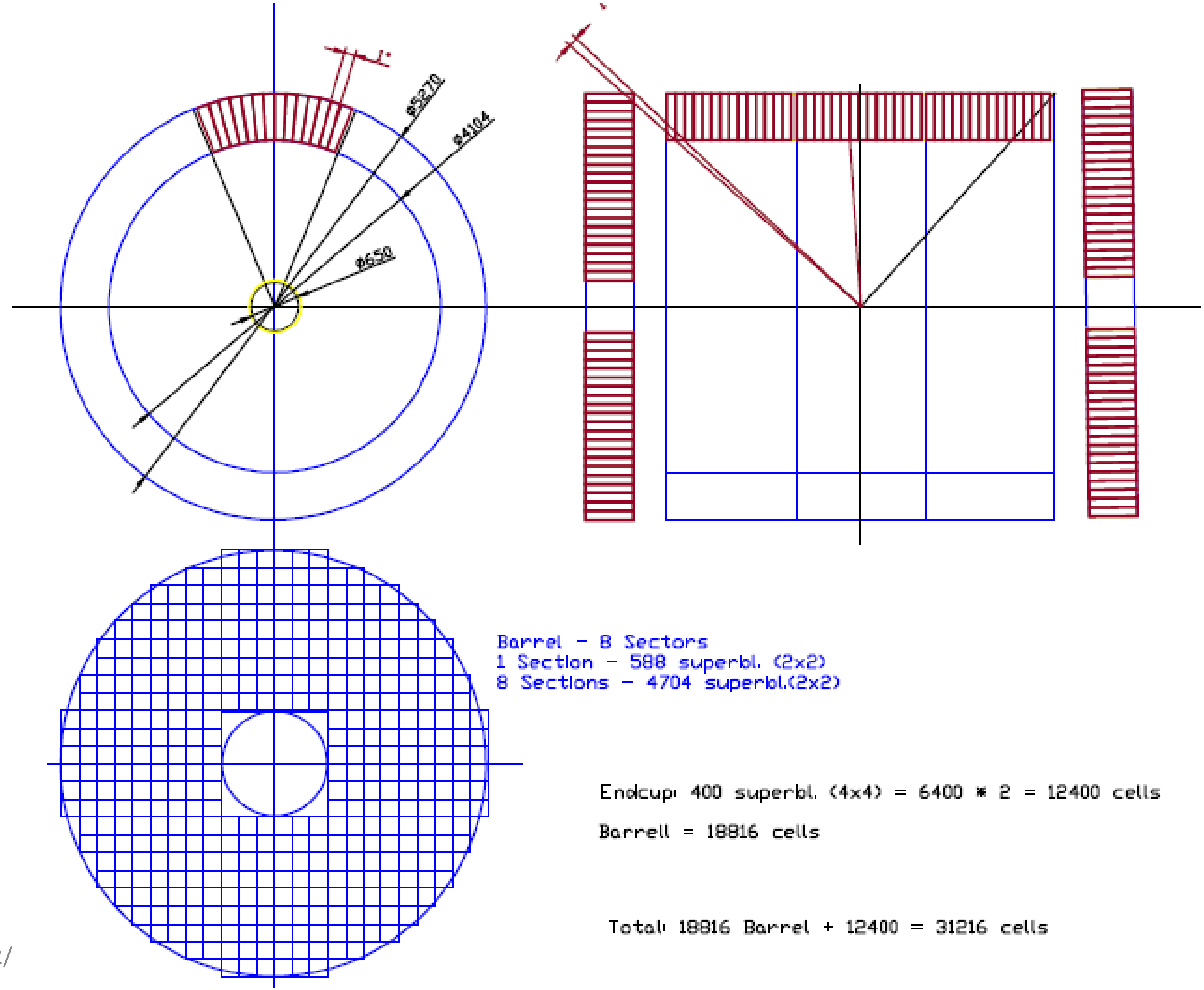
SPD model



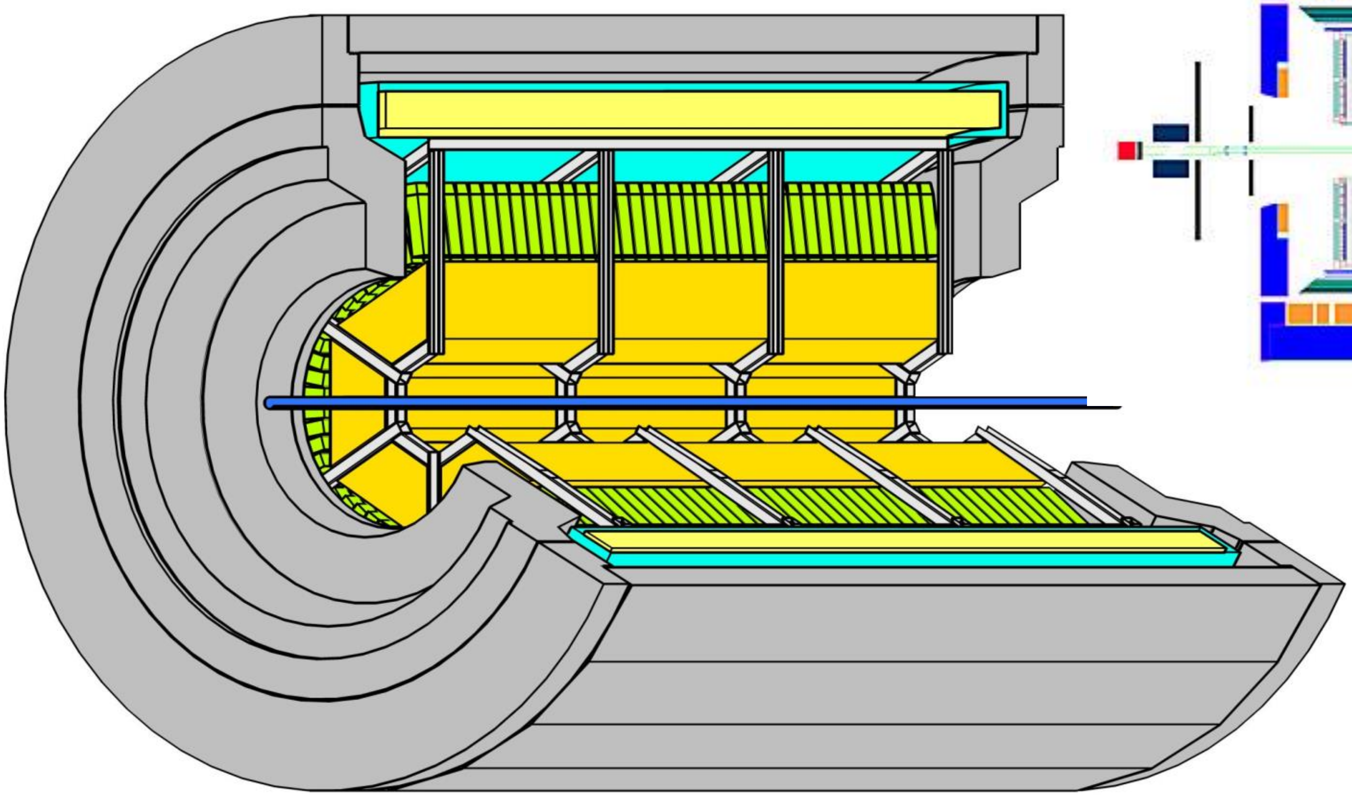
SPD Electromagnetic Calorimeter with tor magnet option

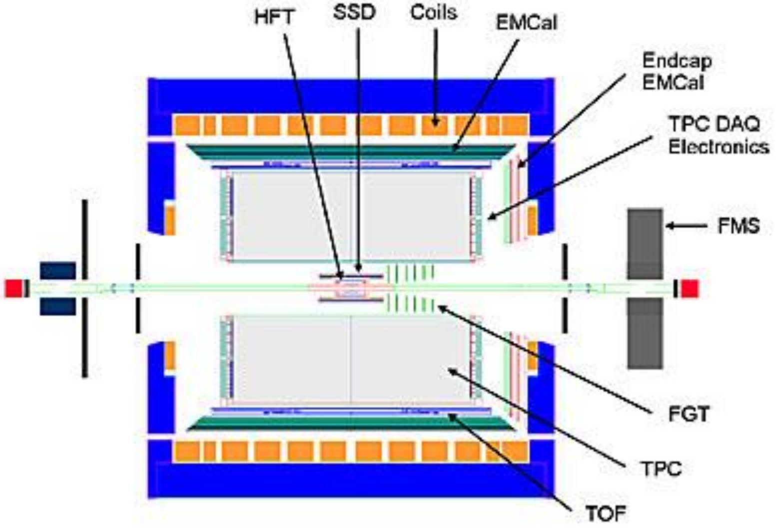


SPD EC : tor magnet option

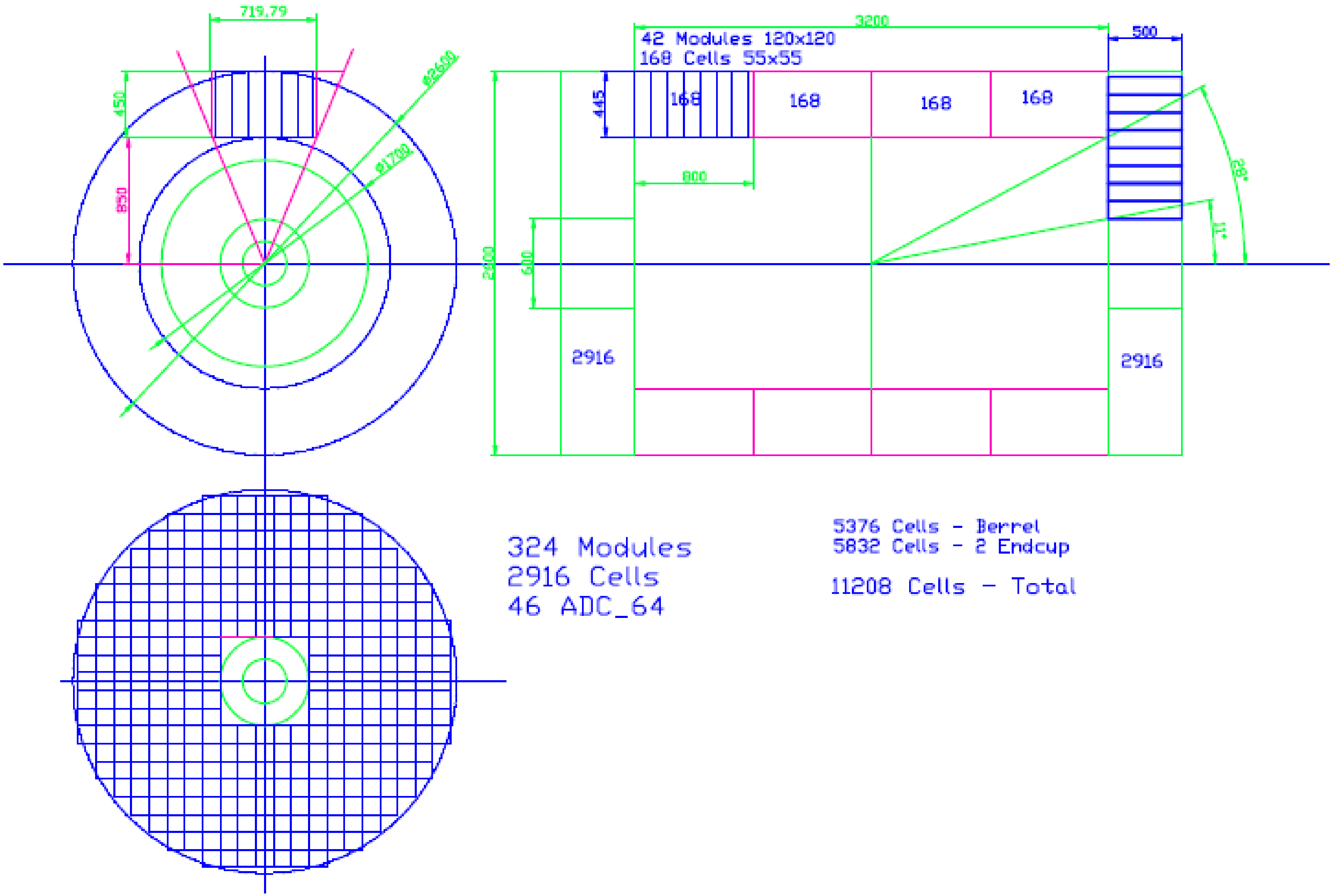


SPD solenoid option





SPD EC : solenoid option



324 Modules
2916 Cells
46 ADC_64

5376 Cells - Berrel
5832 Cells - 2 Endcup

11208 Cells - Total

SPD

CONCLUSIONS:

1. SPD EC design not possible without final Experimental setup drawing:

   Solenoid or Tor magnet ?

1. The Cristal Electromagnetic Calorimeter not discussed yet but:
2. The Crystals housing production is developed in IHEP from carbon plastic material
   1. BGO crystal production possible in Novosibirsk : the price 480.000 Rub/kg
   2. BGO crystal can be produced in China too
   3. PWO4 crystals production possible in Bogorodick (Belarus)
3. Lead Plastic EC production possible now as possible soon in IHEP:
   1. Choice of cell size: 5.5x5.5 or 4x4
   2. Geometry: strain or projective
4. Beam test possible: e+ up to 10 GeV – IHEP – Giperon (18 Channel)
5. Beam test possible : muon 1-20 GeV – IHEP test beam facility

SPD

**Thanks everybody
for attention !**