# ECal Prototype for SPD

1. Sampling calorimeter essential property:
    1. Fine Scintillator – Lead structure with sampling fraction (SF) 20-30%
    2. Moliere Radius is about 3.3 – 3.4 cm
    3. Number of Radiation length 15-17 – depended from number of layers
    4. Granularity – rectangular cell size 4-5.5 cm – depended from particles occupancy
    5. Scintillator quality : composition, attenuation length
    6. Photo Sensor Photodetector Efficiency (PDE)
    7. Long time stability (essential from temperature)
    8. WLS fibers quality : diameter, attenuation length
    9. Time resolution -

# Характеристики неорганических сцинтилляторов

**Table 28.4:** Properties of several inorganic crystal scintillators. Most of the notation is defined in Sec. 6 of this *Review*.

| Parameter: | $\rho$ | MP | $X_0^*$ | $R_M^*$ | $dE/dx$ | $\lambda_I^*$ | $\tau_{\rm decay}$ | $\lambda_{\rm max}$ | $n^\natural$ | Relative output$^\dagger$ | Hygro-scopic? | $d$(LY)$/dT$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units: | g/cm$^3$ | °C | cm | cm | MeV/cm | cm | ns | nm | | | | %/°C$^\ddagger$ |
| NaI(Tl) | 3.67 | 651 | 2.59 | 4.13 | 4.8 | 42.9 | 230 | 410 | 1.85 | 100 | yes | −0.2 |
| BGO | 7.13 | 1050 | 1.12 | 2.23 | 9.0 | 22.8 | 300 | 480 | 2.15 | 21 | no | −0.9 |
| $BaF_2$ | 4.89 | 1280 | 2.03 | 3.10 | 6.6 | 30.7 | $630^s$ | $300^s$ | 1.50 | $36^s$ | no | $-1.3^s$ |
| | | | | | | | $0.9^f$ | $220^f$ | | $3.4^f$ | | $\sim 0^f$ |
| CsI(Tl) | 4.51 | 621 | 1.86 | 3.57 | 5.6 | 39.3 | 1300 | 560 | 1.79 | 165 | slight | 0.3 |
| CsI(pure) | 4.51 | 621 | 1.86 | 3.57 | 5.6 | 39.3 | $35^s$ | $420^s$ | 1.95 | $3.6^s$ | slight | −1.3 |
| | | | | | | | $6^f$ | $310^f$ | | $1.1^f$ | | |
| $PbWO_4$ | 8.3 | 1123 | 0.89 | 2.00 | 10.2 | 20.7 | $30^s$ | $425^s$ | 2.20 | $0.083^s$ | no | −2.7 |
| | | | | | | | $10^f$ | $420^f$ | | $0.29^f$ | | |
| LSO(Ce) | 7.40 | 2050 | 1.14 | 2.07 | 9.6 | 20.9 | 40 | 420 | 1.82 | 83 | no | −0.2 |
| GSO(Ce) | 6.71 | 1950 | 1.38 | 2.23 | 8.9 | 22.2 | $600^s$ | 430 | 1.85 | $3^s$ | no | −0.1 |
| | | | | | | | $56^f$ | | | $30^f$ | | |

$f$ = fast component, $s$ = slow component

# The possible prototypes options:

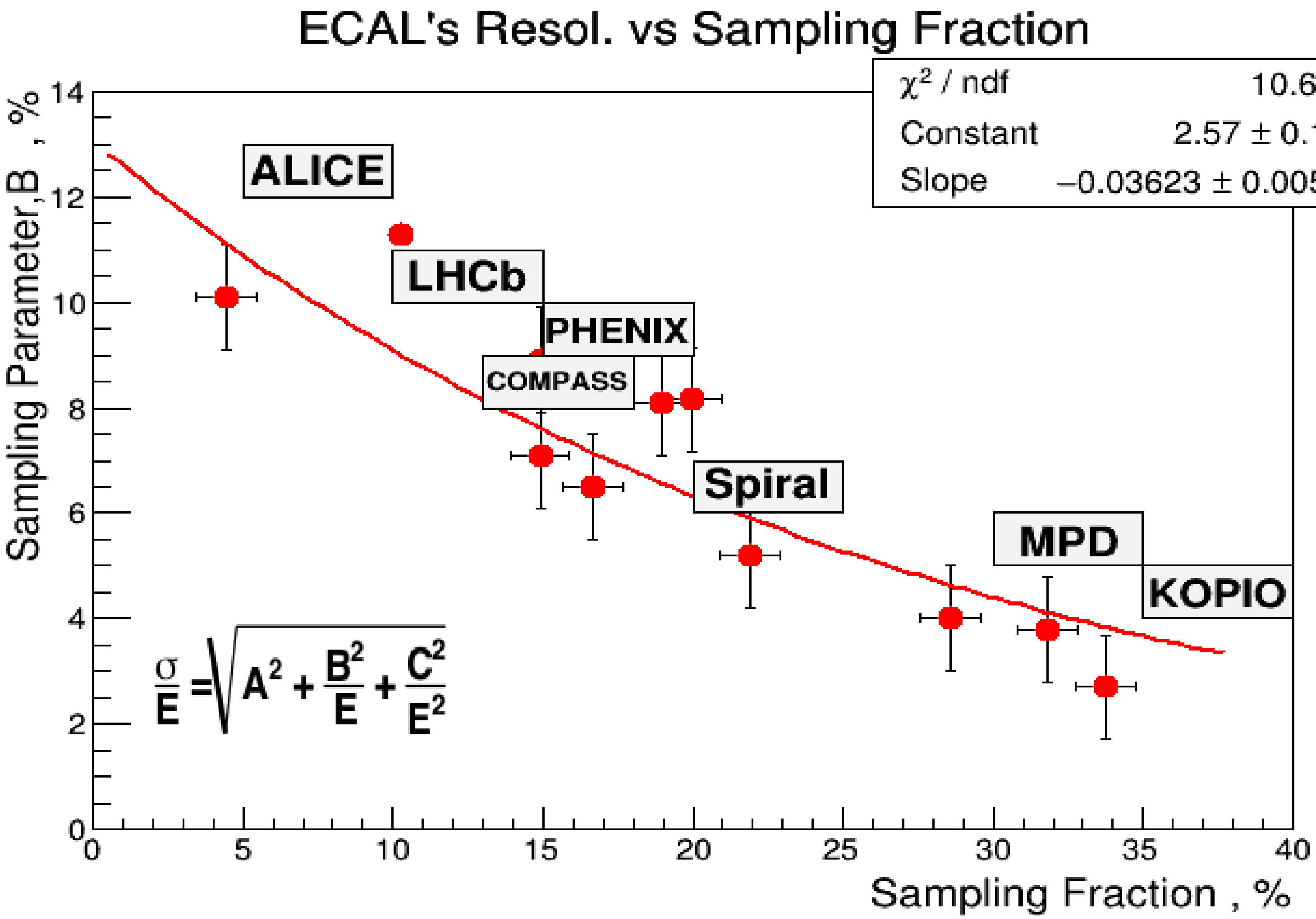
1. KOPIO – the best result was achieved in energy resolution
2. MPD – design under investigation
3. COMPASS – was completed for MPD as BM&N option

# Sampling calorimeters could be used as prototype for SPD ECal

Module design:

1. KOPIO – 4 cells of 5.5x5.5 $cm^2$ rectangular shape
2. MPD – 16 cells of 4x4 $cm^2$ ***trapezoidal*** shape ( ~ 1 degree )
3. COMPASS – 9 cells of 4x4 $cm^2$

# Ecal's sampling resolution in experiments of  last 20 years



# Sampling calorimeters summary table

| | N | Sc | Pb | N | Num | X0 | mm | Pb | Scint | Pb | Sc | Samp. | Sampl. | Const | Nois e | Res % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tiles | mm | mm | layers | Fibers | n | Lengt h | mm | mm | X0 | X0 | Fract. | B% | A% | C% | 1 GeV |
| Compass | 40x40 | 1,50 | 0,80 | 109 | 16 | 15,9 | 256 | 87 | 164 | 15,5 | 0,4 | 14,90 | 8,9 | 1,1 | 1,0 | 9,02 |
| BMN | 40x40 | 1,50 | 0,30 | 220 | 16 | 12,6 | 407 | 66 | 330 | 11,8 | 0,8 | 31,83 | 7,1 | 2,0 | 1,0 | 7,44 |
| MPD | 40x40 | 1,50 | 0,30 | 220 | 16 | 12,6 | 407 | 66 | 330 | 11,8 | 0,8 | 31,83 | 3,8 | 1,0 | 1,0 | 4,05 |
| SPD | 55x55 | 1,50 | 0,30 | 250 | 16 | 14,3 | 463 | 75 | 375 | 13,4 | 0,9 | 31,83 | 3,8 | 1,0 | 1,0 | 4,05 |
| spiral | 38x38 | 1,50 | 0,70 | 170 | 16 | 21,8 | 383 | 119 | 255 | 21,2 | 0,6 | 16,68 | 6,5 | 1,0 | 1,0 | 6,65 |
| phenix | 55x55 | 4,00 | 1,50 | 66 | 36 | 18,3 | 366 | 99 | 264 | 17,6 | 0,6 | 19,94 | 8,2 | 2,1 | 0,0 | 8,42 |
| KOPIO | 110x110 | 1,50 | 0,28 | 300 | 144 | 15,8 | 548 | 83 | 450 | 14,7 | 1,1 | 33,75 | 2,7 | 1,9 | 0,0 | 3,30 |
| VES | 28x38 | 1,50 | 0,60 | 224 | 16 | 24,8 | 482 | 134 | 336 | 23,9 | 0,8 | 18,93 | 8,1 | 2,0 | 0,0 | 8,34 |
| solid | 6.25 hex | 1,50 | 0,50 | 194 | | 18,0 | 398 | 97 | 291 | 17,3 | 0,7 | 21,89 | 5,2 | 2,0 | 0,0 | 5,57 |
| Alice EMCal | 56x6 | 1,76 | 1,44 | 77 | 36 | 20,1 | 256 | 111 | 136 | 19,8 | 0,3 | 10,25 | 11,3 | 1,7 | 4,8 | 12,38 |
| LHCb ECAL | 40x40 | 2,00 | 4,00 | 66 | 16 | 47,4 | 399 | 264 | 132 | 47,0 | 0,3 | 4,46 | 10,1 | 0,9 | 0,0 | 10,14 |
| LHCb ECAL | 40x40 | 1,50 | 0,35 | 230 | 16 | 15,2 | 449 | 81 | 345 | 14,3 | 0,8 | 28,58 | 4,0 | 1,0 | 1,0 | 4,24 |
| COMPASS | 150x150 | 5,00 | 20,00 | 40 | 1 | 143,0 | 1000 | 800 | 200 | 142,6 | 0,5 | 2,28 | 35,0 | 1,0 | 0,0 | 35,01 |
| HCAL_BM&N | 150x150 | 5,00 | 10,00 | 64 | 1 | 114,8 | 966 | 640 | 320 | 114,0 | 0,8 | 4,46 | 30,0 | 1,0 | 0,0 | 30,02 |
| HCAL_ALPOM | 150x150 | 10,00 | 10,00 | 50 | 1 | 90,3 | 1000 | 500 | 500 | 89,1 | 1,2 | 8,54 | 20,0 | 1,0 | 0,0 | 20,02 |

# Ecal of KOPIO

- The best resolution for the "shashlyk" type calorimeter has been achieved by the KOPIO collaboration. A quadratic fit to KOPIO experimental data gives

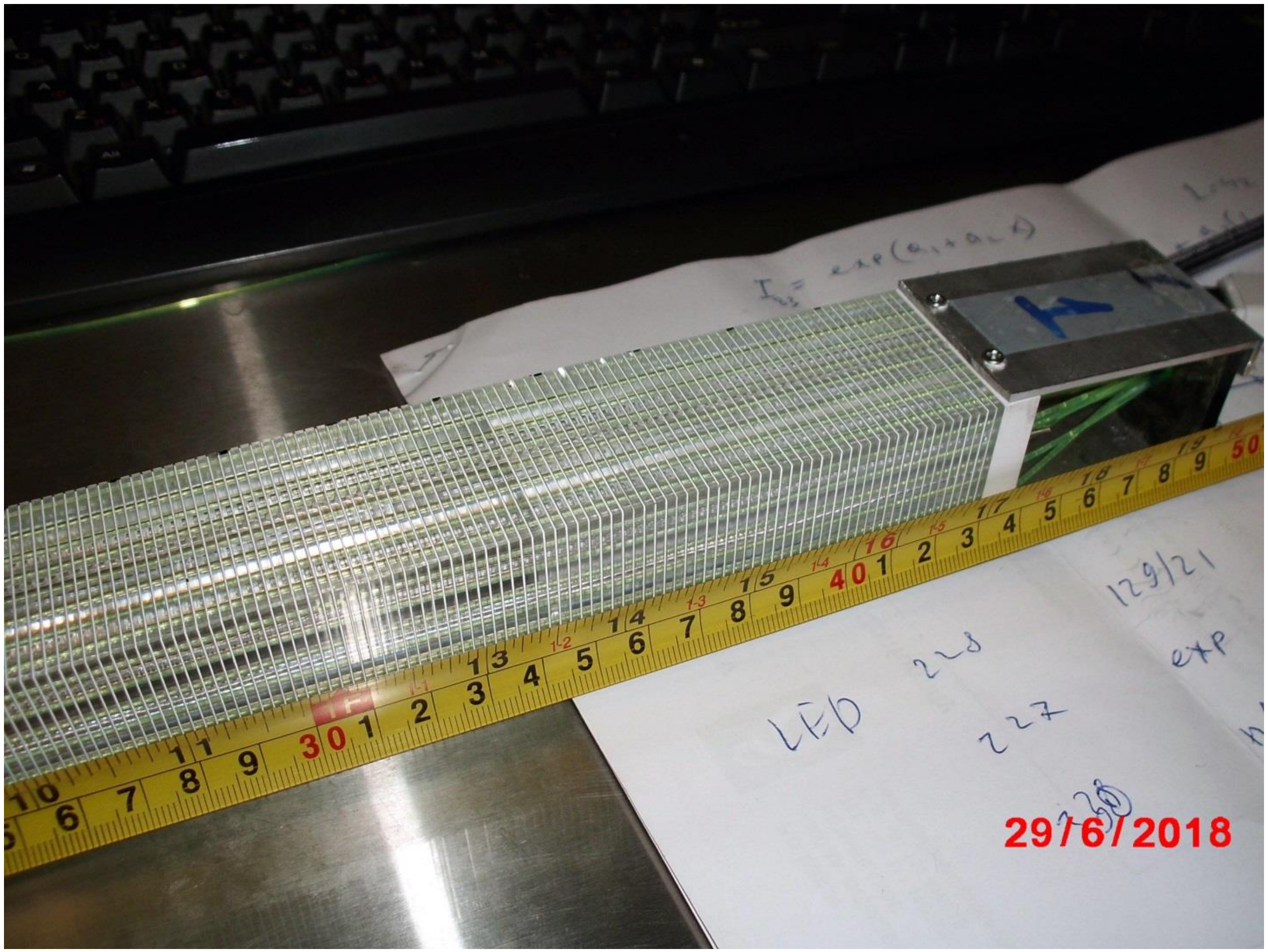
  $$\boldsymbol{\sigma(E)/E = (1.96 \pm 0.1)\% \otimes (2.74 \pm 0.05)\%/p(E)(GeV),}$$

  where $\otimes$ means quadratic summation.
- photo statistics and no uniformity of light collections add to the total energy resolution 2.1%/√E and 1.8%/√E, respectively.
- Attention should be paid to improving the quality of scintillator, optical and mechanical, and to selecting the photo-detector with higher quantum efficiency.

# The table of shashlik modules types and where energy resolution

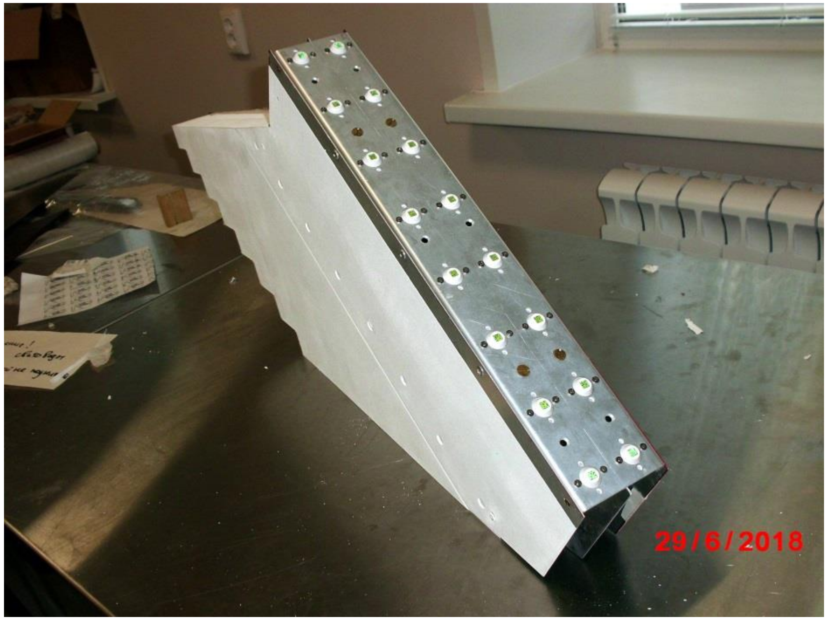
| Generation of Shashlyk module | Sampling | | N, layers | $X_0$, cm | WLS fiber | | Photo Detector | $N_{p.e.}$, muon | $N_{p.e.}$, 1 GeV photon | Energy resolution, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sc, mm | Lead, mm | | | Type | D, mm | | | | Sampling 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 $C_{PD}$ = 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 |

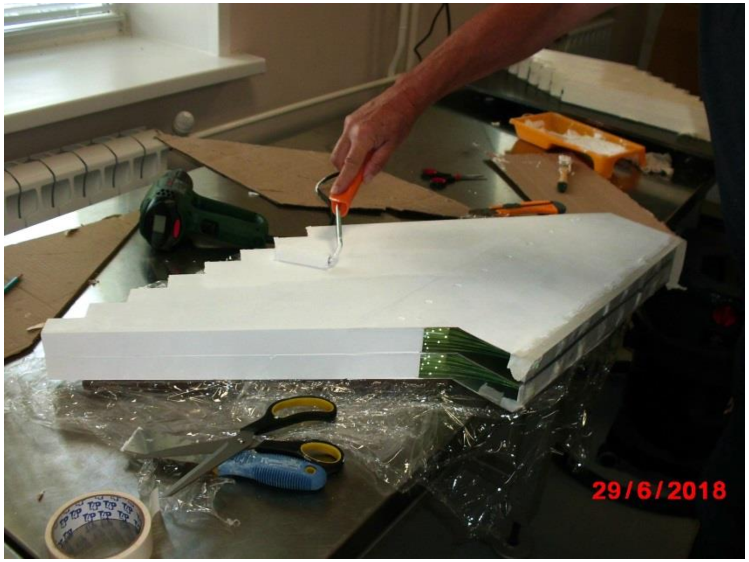
# MPD first module assembling to tesr wrapping and mirror conditions

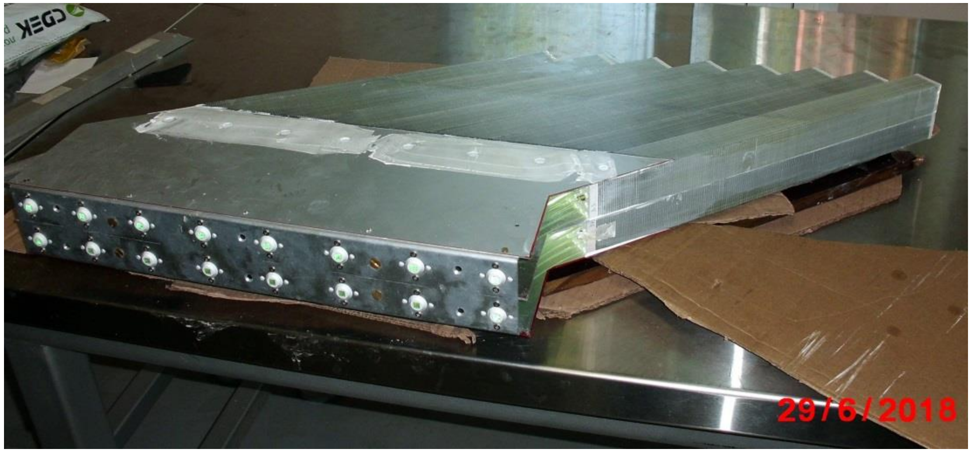


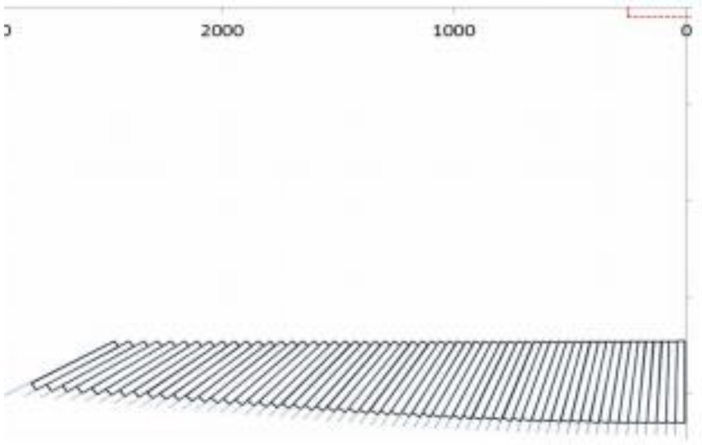
# MPD module first assembling

file:///C:/Users/oleg/Documents/TDR_ECAL_v2.1%20(1).pdf

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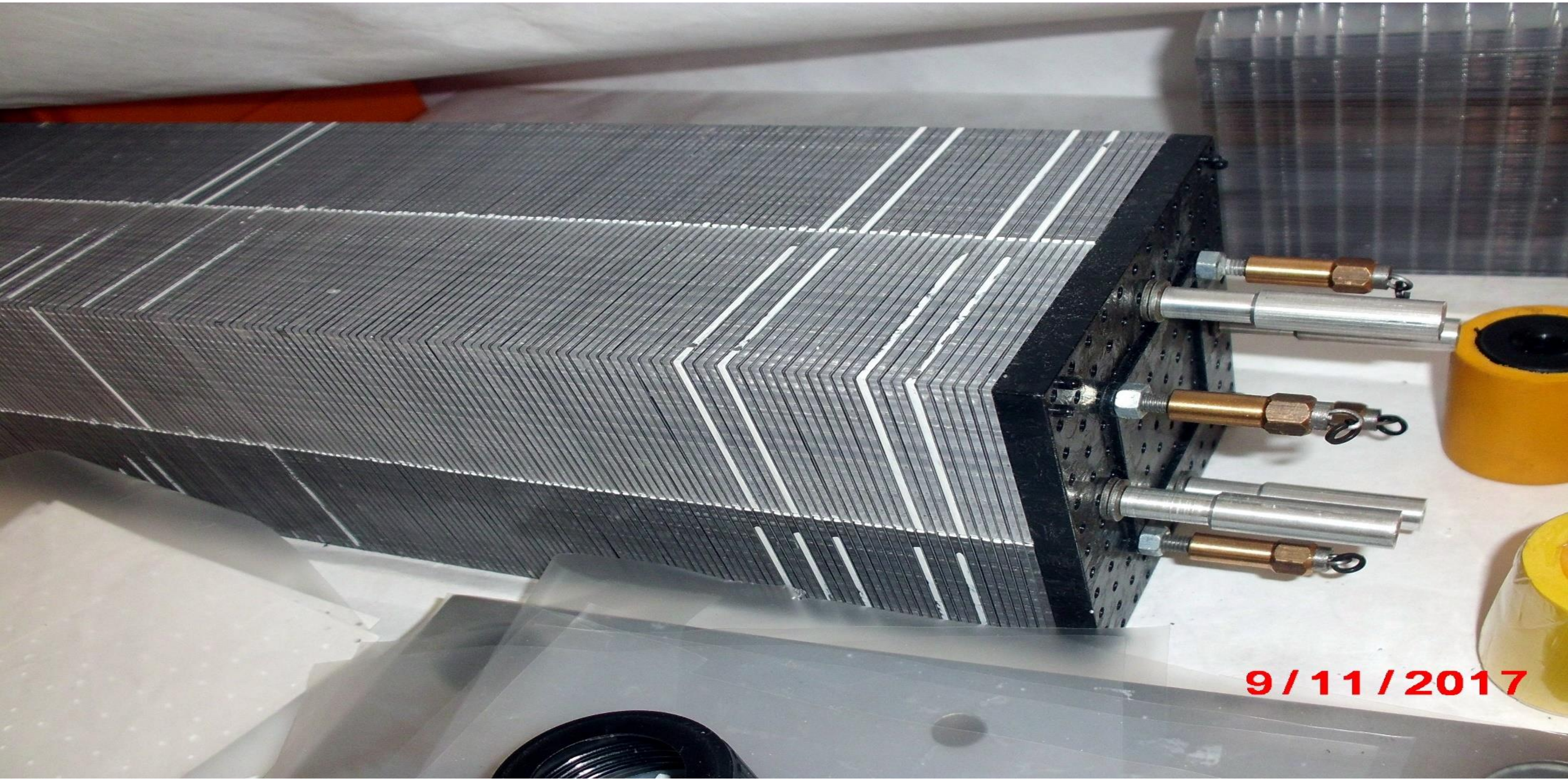
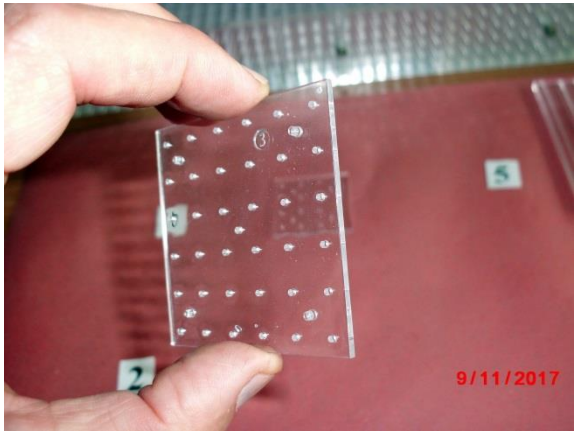
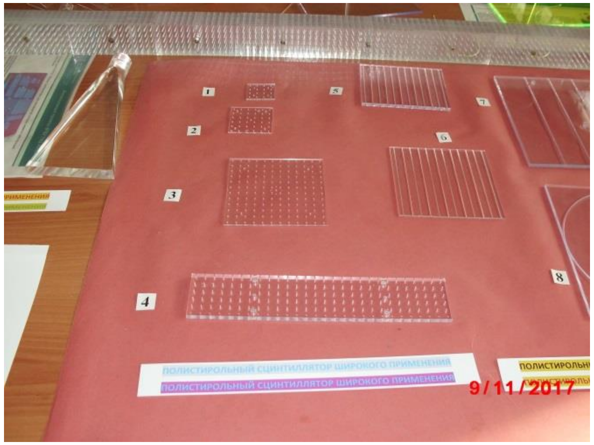
# Sampling EC : Lead + Plastic Scintillator



# Molding machine and scintillator tiles examples

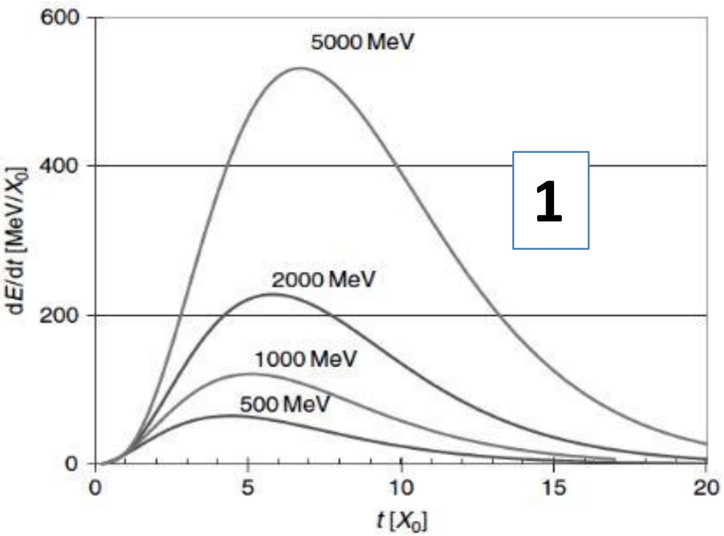



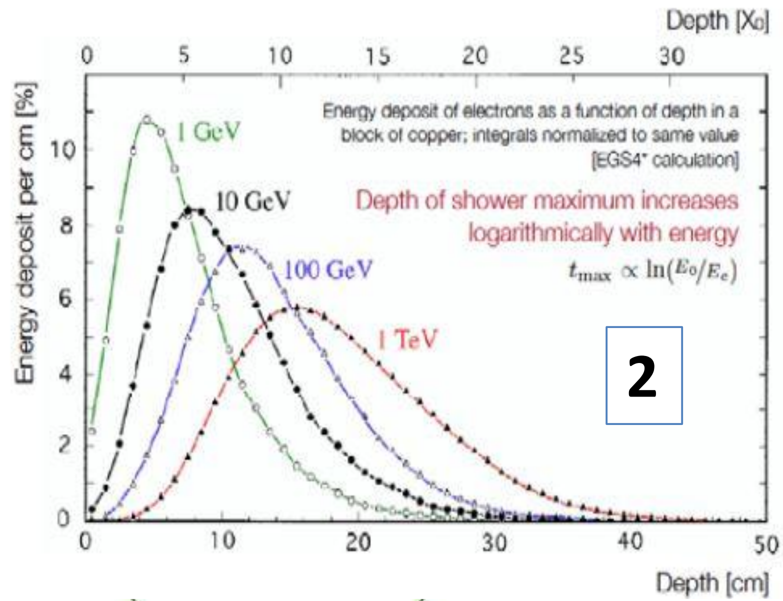



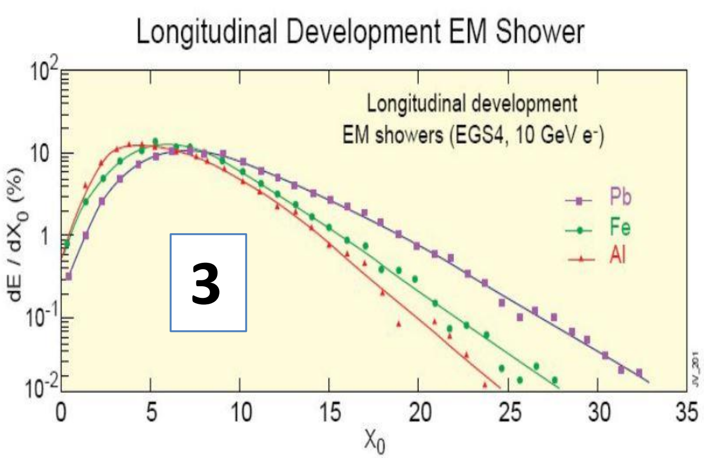
# Depth-divided electromagnetic sampling calorimeter

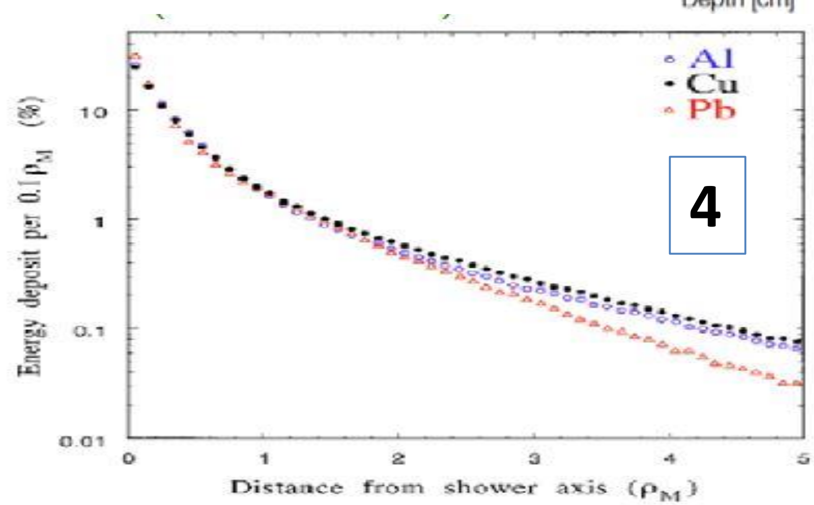
- The electromagnetic calorimeter has divided on 4 tiles along beam line. The idea is to improve particles identification take in account longitudinal shower profile for electrons, muons and hadrons.
- The prototype of such calorimeter was tested at IHEP U-70 and CERN PS in 2007. The experimental results presented to particles identification in 5 GeV beam with 80% pions, 15% positrons and 5% muons.
- The design and results of studies on a beam of particles with an energy of 5 GeV of electromagnetic sampling calorimeters are presented.
- New idea proposed to crate such calorimeter type based on 'shashlik' option with longitudinal segmentation.

1,2 -Theoretical longitudinal Shower shape for electrons with different energies
2 - The longitudinal Shower shape in dependences from material density
4 – Lateral Shower shape in dependences from material density



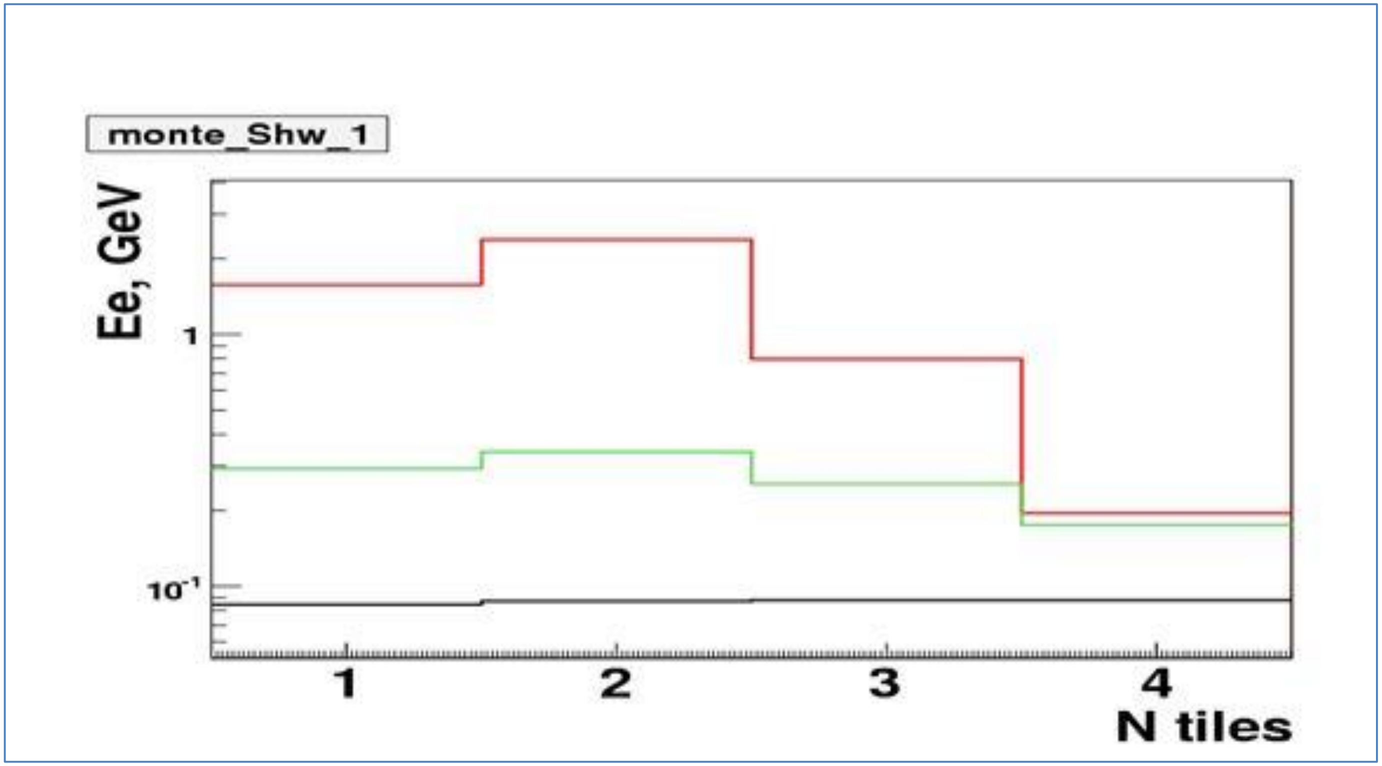



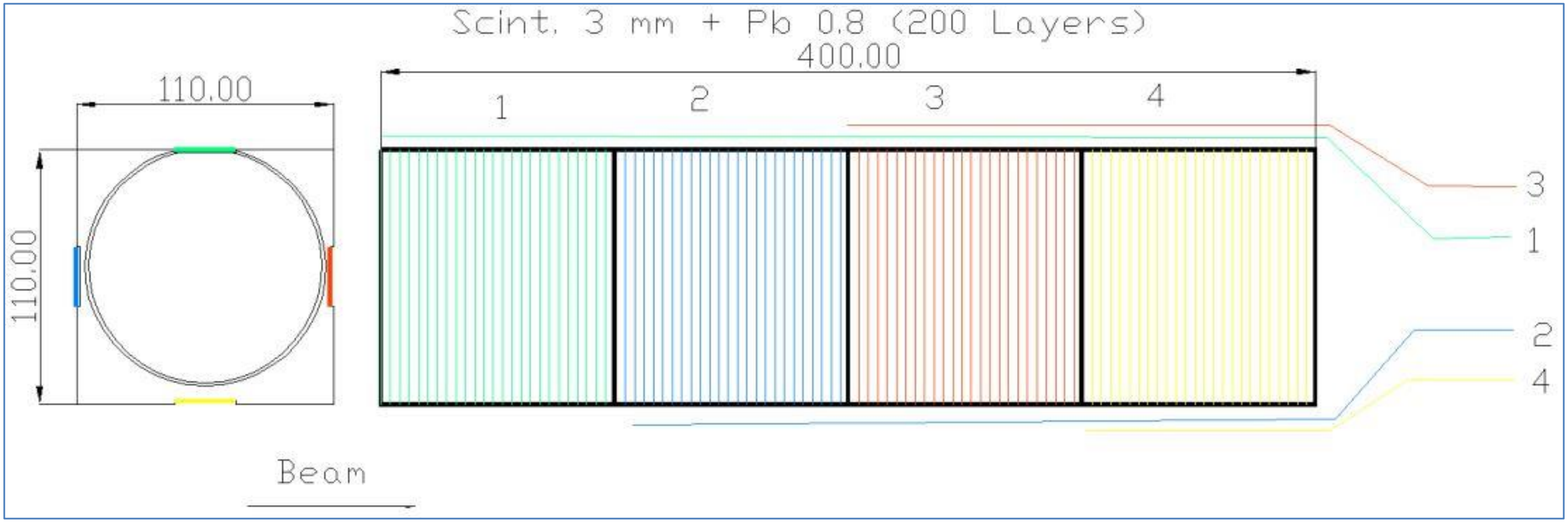



The estimated by MC energy distribution in tiles for hadrons (black), muons (green) , $e^+$ - positrons (red).

A significant difference in the average energy distribution over tiles is for different particle type.

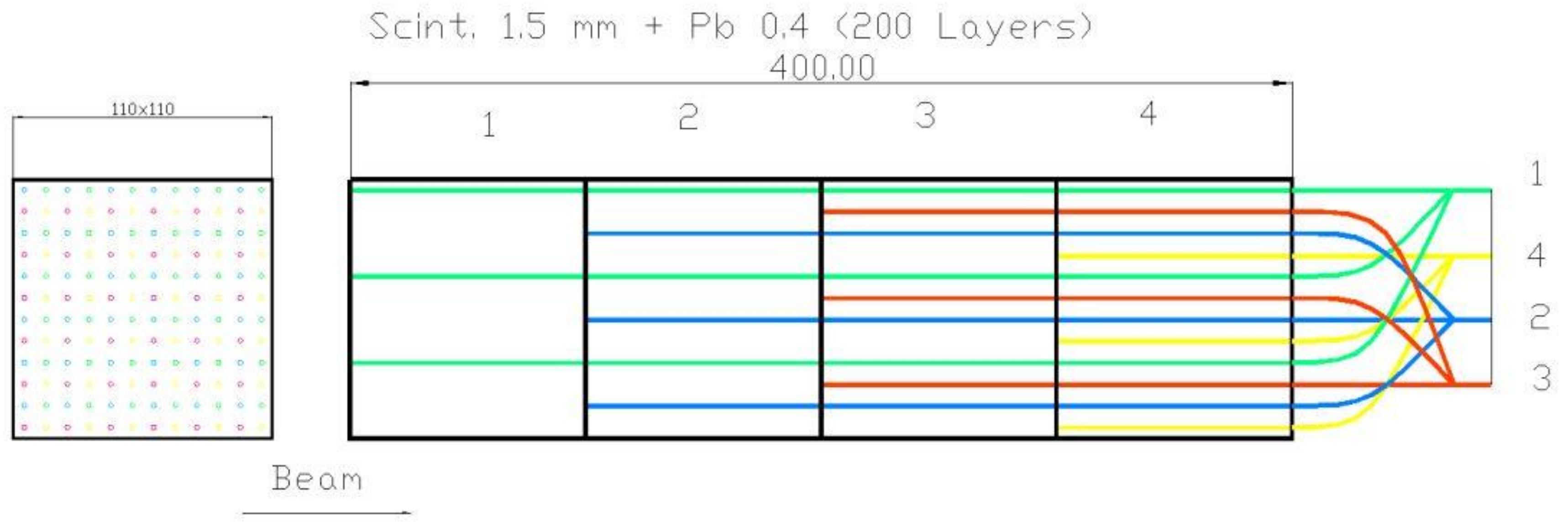


# Differential SPD ECAL option




- Cell size – not limited – could be from 55 to 100 mm
- 25 Scintillators + Lead (3 +0.8 mm) layers per group
- Difficult create projective geometry
- 20 $X_0$ – radiation length

# Integral SPD Ecal option




- Cell size – ~100x100 $mm^2$
- 50 Scintillators + Lead (1.5 +0.4 mm) layers per group – more fine granularity
- Possible projective geometry
- 15 $X_0$ – radiation length

# Monte Carlo simulation ongoing

- Preliminary results for e, pi, mu  particles
- Differential and integral option are compared
- Energy range – around  of 1 GeV
- Shower shape should taken in account to particles identification

# Rough estimation for longitudinal shower shape

# More exact longitudinal shower shape

$$\frac{dE}{dt} = E_0\, t^{\alpha} e^{-\beta t}$$

α,β : free parameters

$t^{\alpha}$ : at small depth number of secondaries increases ...

$e^{-\beta t}$ : at larger depth absorption dominates ...

Numbers for E = 2 GeV (approximate):
$\alpha = 2$, $\beta = 0.5$, $t_{max} = \alpha/\beta$

where t = shower depth in units of $X_0$

$t_{max}$ = depths where the energy deposition is maximal

## The longitudinal shower shape

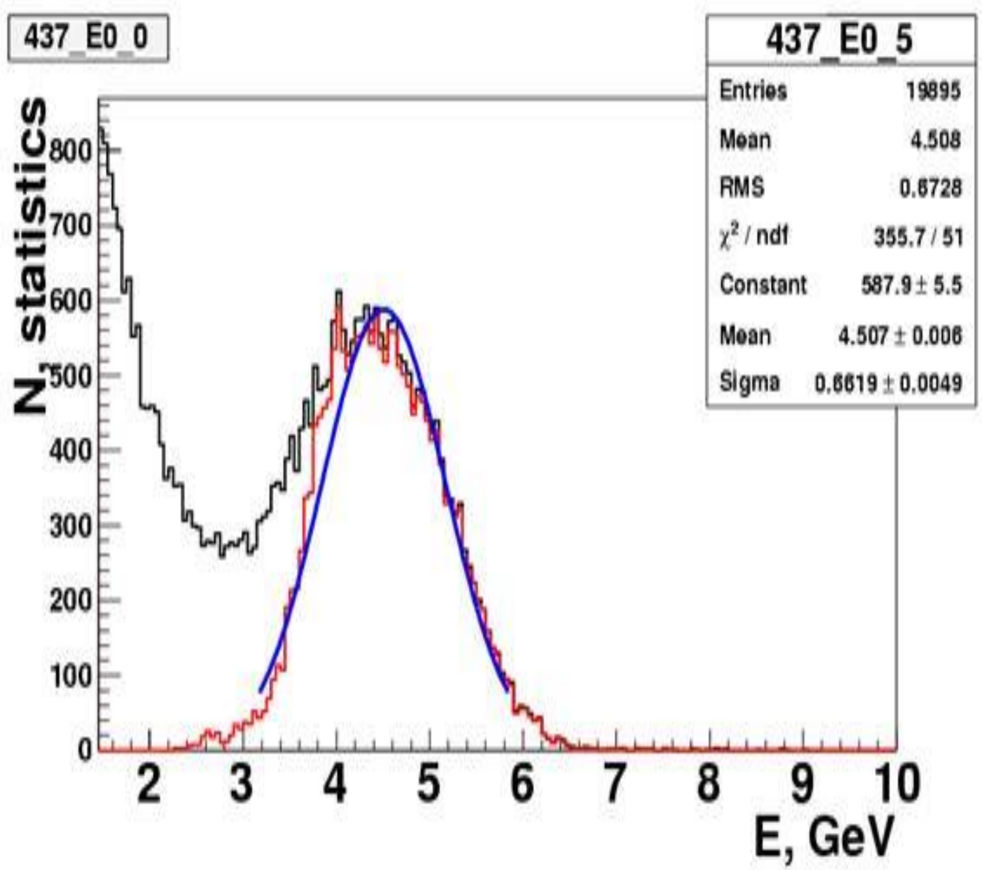
More exact (EGS simulation and measurements)
[Longo 1985]

$$\frac{dE}{dt} = E_0 \cdot \beta \cdot \frac{(\beta t)^{\alpha-1} e^{-\beta t}}{\Gamma(\alpha)}$$

[Γ: Gamma function]

where t = shower depth in units of $X_0$

# The energy spectra of 5 GeV positions separated from combined beam (~85% hadrons, ~5% muons and ~10% positrons)




The total energy in calorimeter.

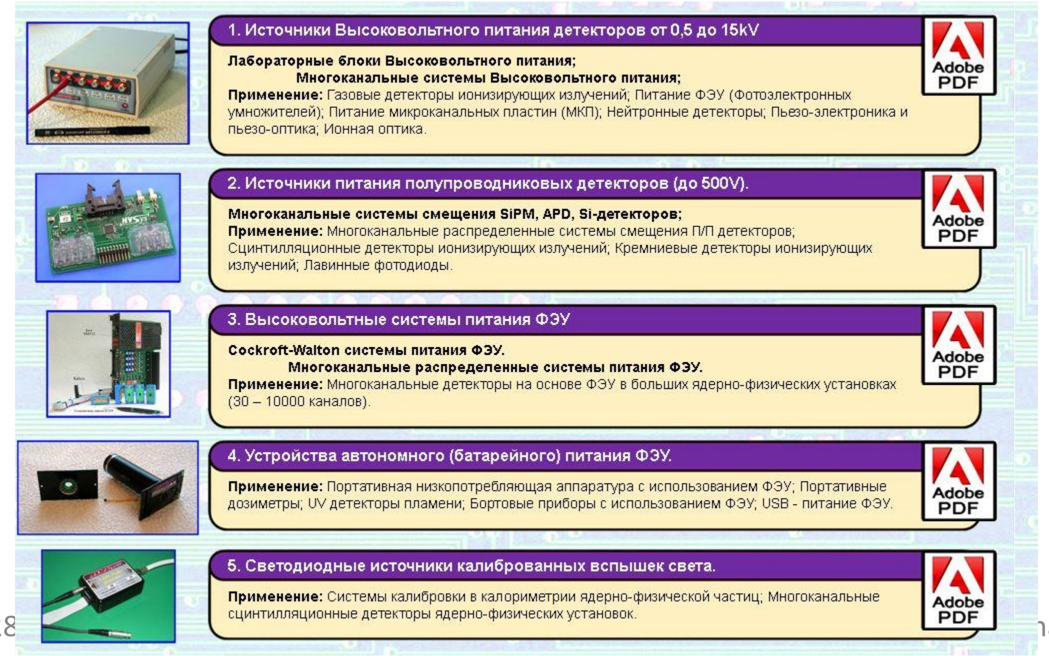
Black and red histograms - the spectra before and after the $\chi^2$ rejection. The blue line – the Gaussian fit for $e^+$.

Background signal is integrated and slightly visible as a small burst at 4 GeV.

# Prototype for SPD Ecal front end electronic

ADC64 board used for signals digitizing
https://afi-project.jinr.ru/projects/adc64-sw/files

Power Supply system & LED control
http://hvsys.ru/



**1. Источники Высоковольтного питания детекторов от 0,5 до 15kV**

**Лабораторные блоки Высоковольтного питания;**
**Многоканальные системы Высоковольтного питания;**
**Применение:** Газовые детекторы ионизирующих излучений; Питание ФЭУ (Фотоэлектронных умножителей); Питание микроканальных пластин (МКП); Нейтронные детекторы; Пьезо-электроника и пьезо-оптика; Ионная оптика.

**2. Источники питания полупроводниковых детекторов (до 500V).**

**Многоканальные системы смещения SiPM, APD, Si-детекторов;**
**Применение:** Многоканальные распределенные системы смещения П/П детекторов; Сцинтилляционные детекторы ионизирующих излучений; Кремниевые детекторы ионизирующих излучений; Лавинные фотодиоды.

**3. Высоковольтные системы питания ФЭУ**

**Cockroft-Walton системы питания ФЭУ.**
**Многоканальные распределенные системы питания ФЭУ.**
**Применение:** Многоканальные детекторы на основе ФЭУ в больших ядерно-физических установках (30 – 10000 каналов).

**4. Устройства автономного (батарейного) питания ФЭУ.**

**Применение:** Портативная низкопотребляющая аппаратура с использованием ФЭУ; Портативные дозиметры; UV детекторы пламени; Бортовые приборы с использованием ФЭУ; USB - питание ФЭУ.

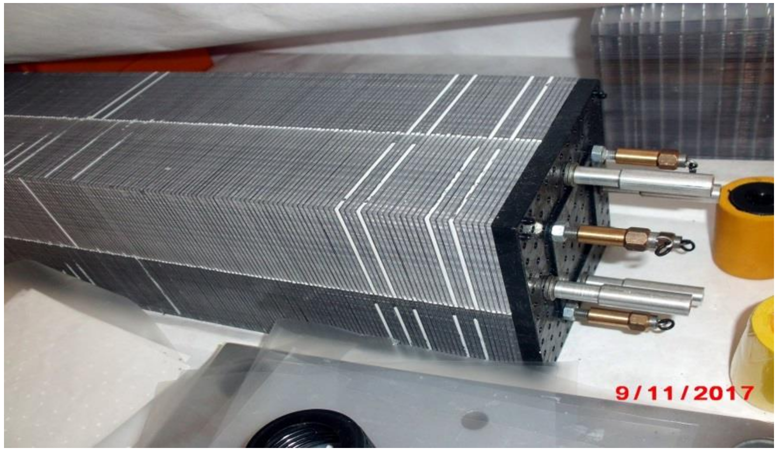
**5. Светодиодные источники калиброванных вспышек света.**

**Применение:** Системы калибровки в калориметрии ядерно-физической частиц; Многоканальные сцинтилляционные детекторы ядерно-физических установок.

# Trigger electronic for prototype testing

1. CAEN NIM crates
2. NIM Trigger logic
   1. Coincidences
   2. Discriminators
   3. Scaler
3. Fast ADC Digitizer 500 MHz
4. 2 Fast digital oscilloscope
5. 2 PC + 1 Lap-top for data taking and data analysis
6. 2 ADC64
7. Power supply units for ADC64
8. Ethernet Switchers for Electronic readout connection

# Prototype for SPD Ecal front end electronic




1. Production of 36 modules: towers 55xx55 mm$^2$ - in IHEP Protvino should be finished in February of 2019
2. Power supply electronic for SiPM (MPPC diodes) – should be ready in February of 2019
3. 100 SiPm (6x6 mm$^2$)– ordered in Sensl
4. 100 MPPCs (6x6 mm$^2$) – ordered in HAMATSY - expected delivery
5. WLS Y11(1mm) 1000 m - ordered in Sensl
6. WLS Y11 (1mm) 2000 m – ordered in HAMATSU – expected delivery
7. 2 ADC64 – ordered in afi-elecronic group http://afi.jinr.ru/
8. 2 PC + 1 Lap-top for data taking and data analysis – are ordered in 2018

- **End of report**
- **Thanks all for attention**