Electromagnetic calorimeter with longitudinal segmentation

- 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 electron, muon and pion.
- The prototype of such calorimeter was tested at IHEP U-70 (Serpukhov< Russia). The experimental results presented to particles identification in 5 GeV beam with 80% pion, 15% positron and 5% muon.
- 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.

Principal calorimeter design. The sampling structure of the calorimeter consists of 20 alternating layers of a 5mm thick scintillator and 5mm thickness of lead. A scintillator was produced by injection molding method from PSM-115 polystyrene with dopants : 1.5% PTP and 0.05% POPOR . 4 fibers BCF-92 (1 mm in diameter and 80 cm in length) transmits light from 5 scintillator plates to the silicone 1mm diode of 30 μm pitch (SiPm of 900 pixels).

The fiber pools in scintillation plate (73x73 mm^2) along the groove of 3 mm in depth and 67 mm in diameter.

4 WLS fibers used for light collection on 4 ASiPm (AMPD)

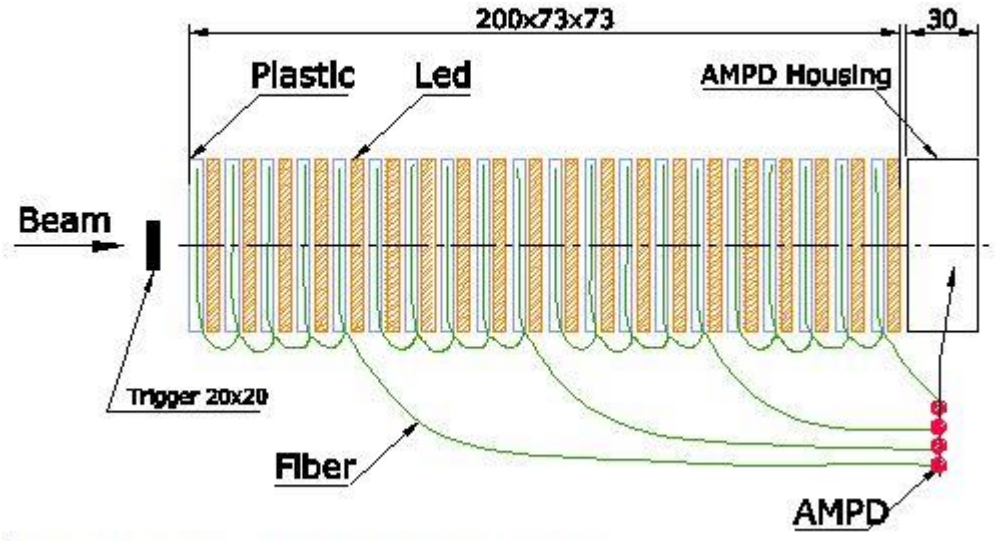


Fig.2. The scheme of the calorimeter module.

One fiber passes in a spiral through 5 layers of the scintillator, thus combining them into one group. In each of the 5 scintillators there are several turns of wolf. The number of turns is increasing in proportion to the removal of the scintillator from the photodetector. For example, in the first scintillator - 3 turns. In the second -2 turns, in 3,4,5 - on one turn. The center of the circumference of the groove is shifted to the corner of the square by 3 mm in order to ensure the exit of the fiber through the side face of the scintillator. When creating such a spiral, each scintillator plate is rotated by 90^0 to avoid an overlapping of all turns along the particle beam.

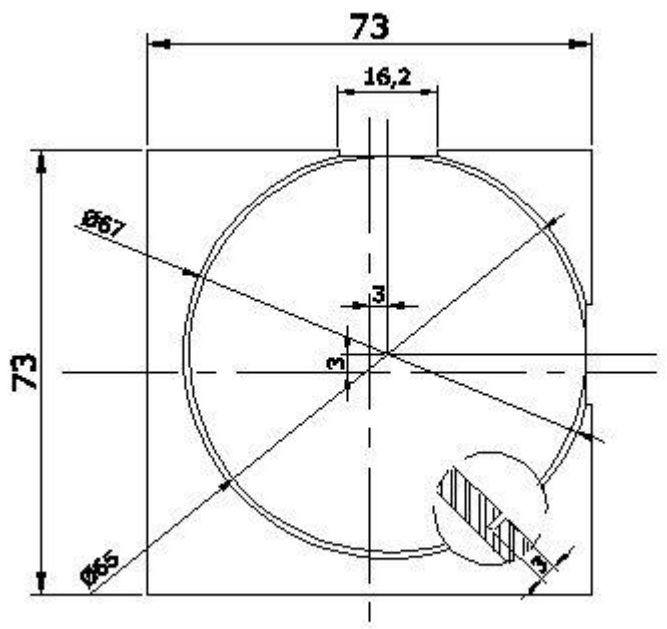
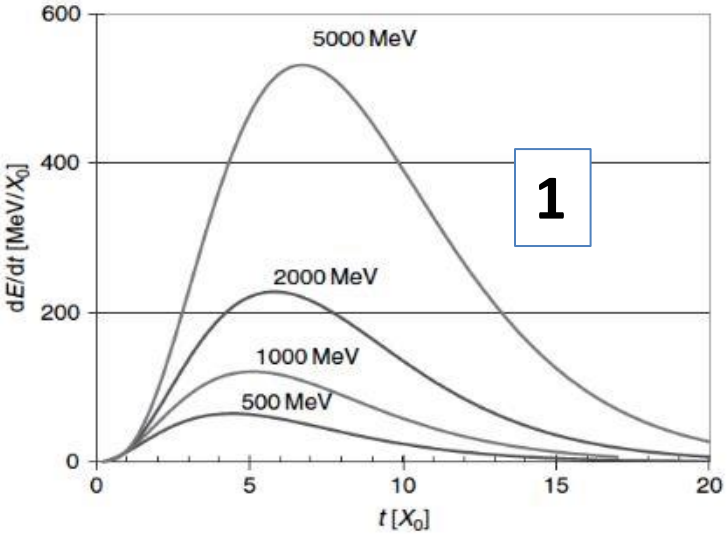
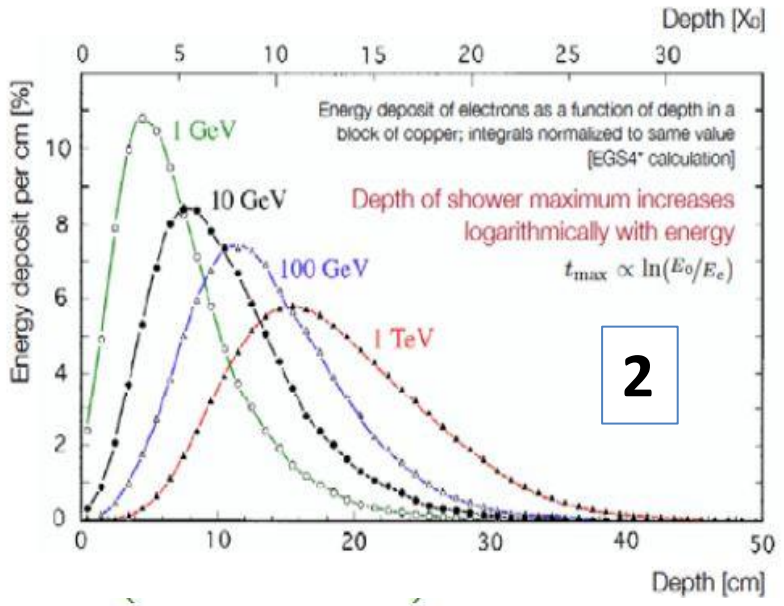
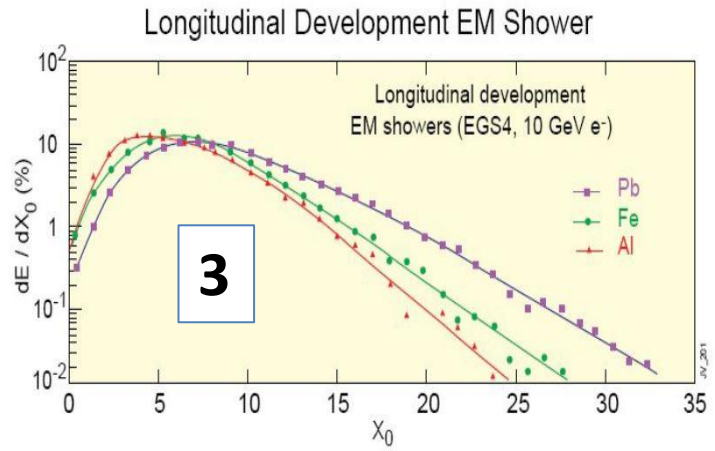


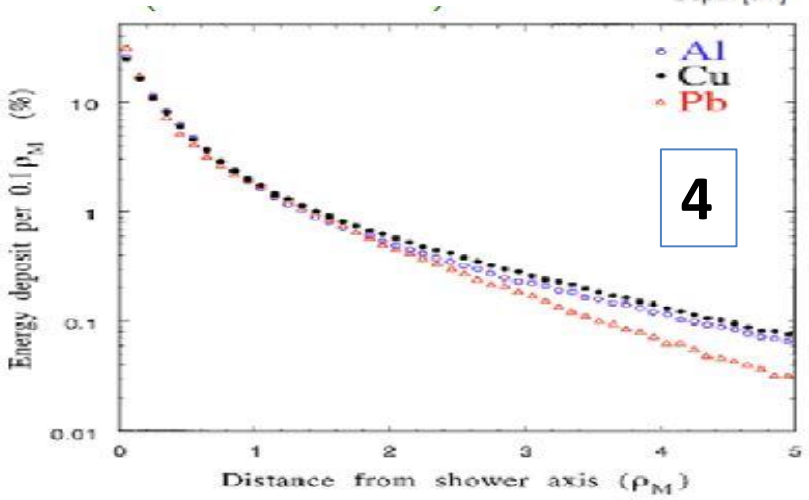
Fig.1. Scintillation plate 5mm thick with a groove for fiber.

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









Measurement of the present electromagnetic calorimeter was fulfilled in positive beam of charged particles with an energy of 5.0 ± 0.2GeV. The beam size was set by a scintillation counter 4x4 cm2, installed in front of the calorimeter. The energy spectra in individual groups are shown in Fig. left. The equalization of signals was done take in account signals from **μ.**

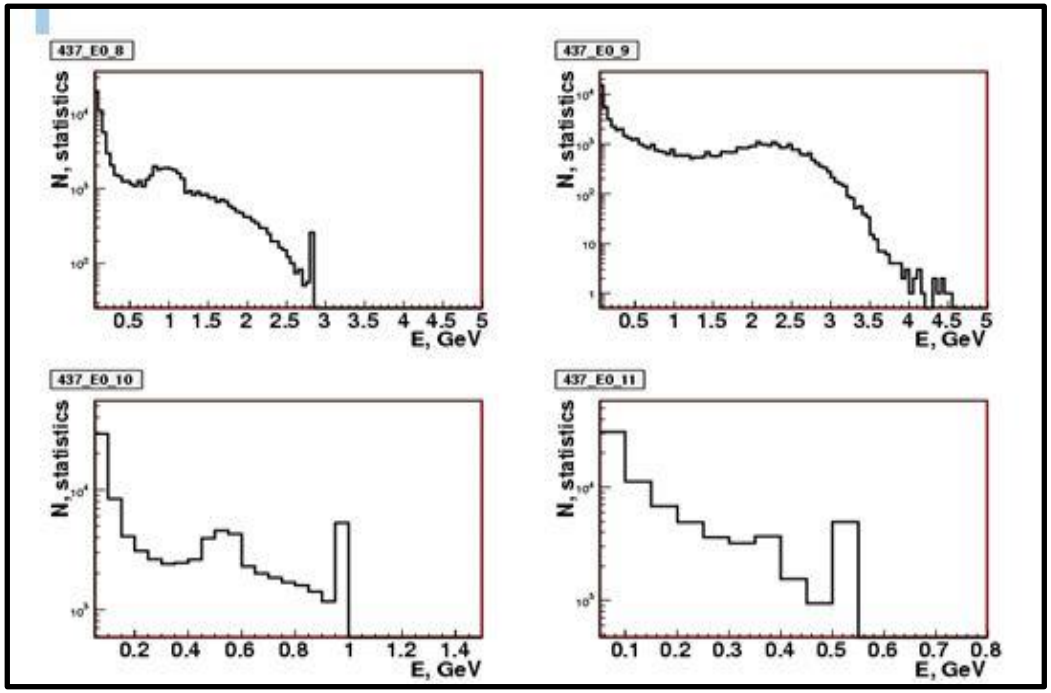
Beam composition:

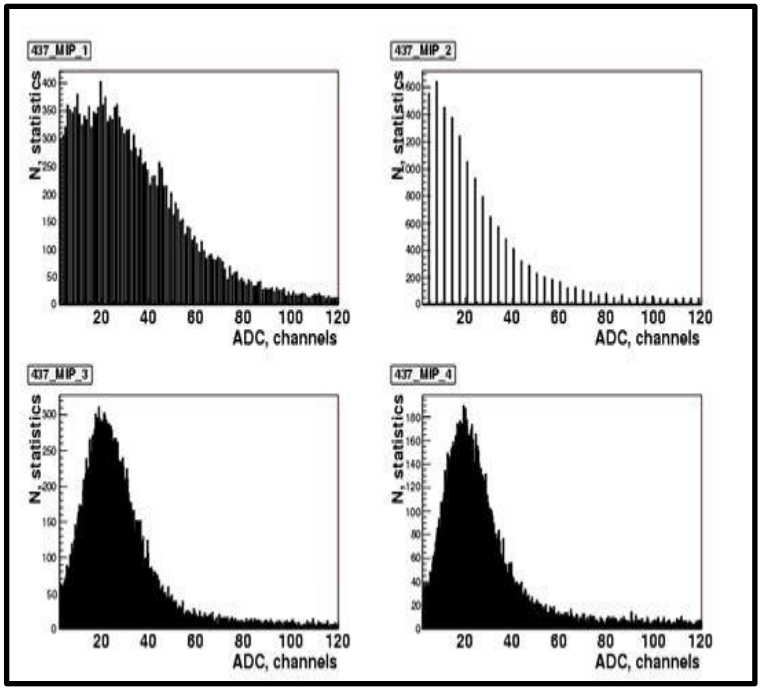
hadron (pi+) - 80%,

positrons (e +) - 15-17%,

μ -mesons (**μ**) - 3-5%.

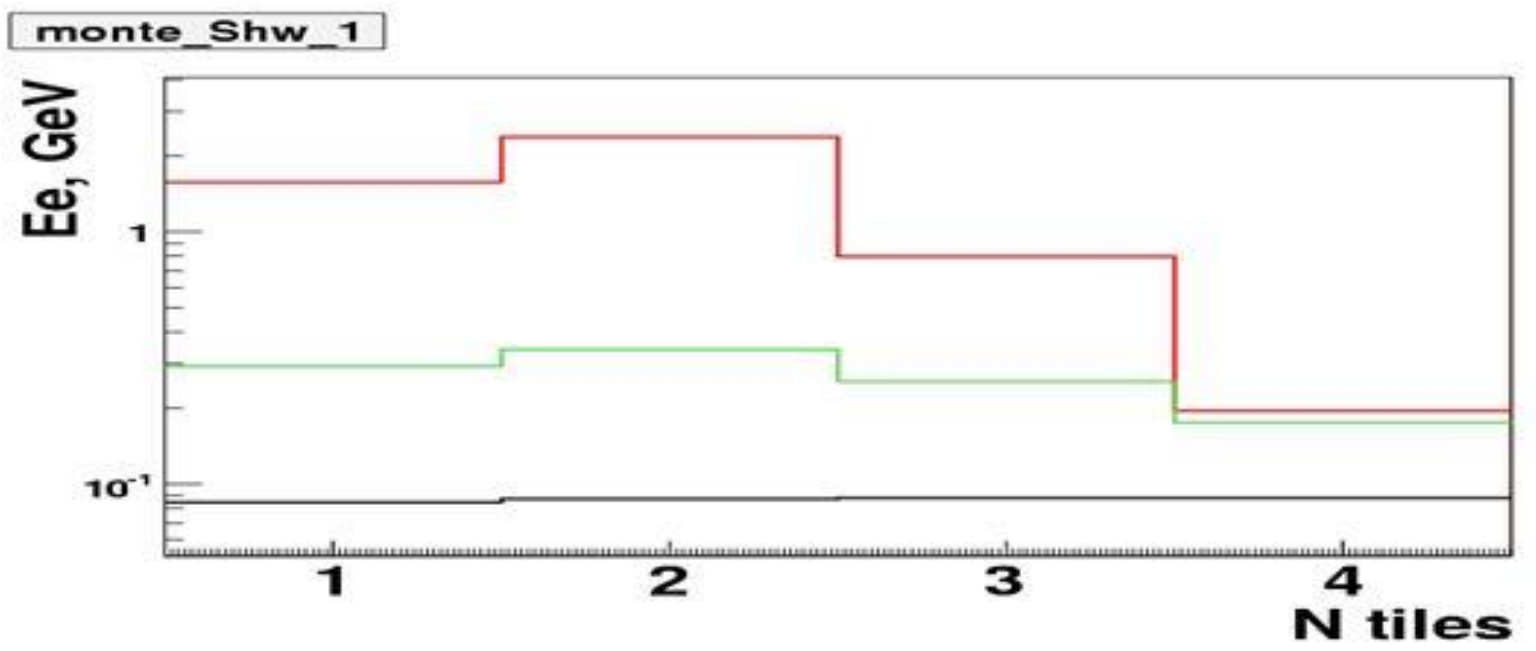
Particles with minimal ionization **μ**) , non-interacting hadrons - were used to equalize the signals um of individual groups of the calorimeter (right).





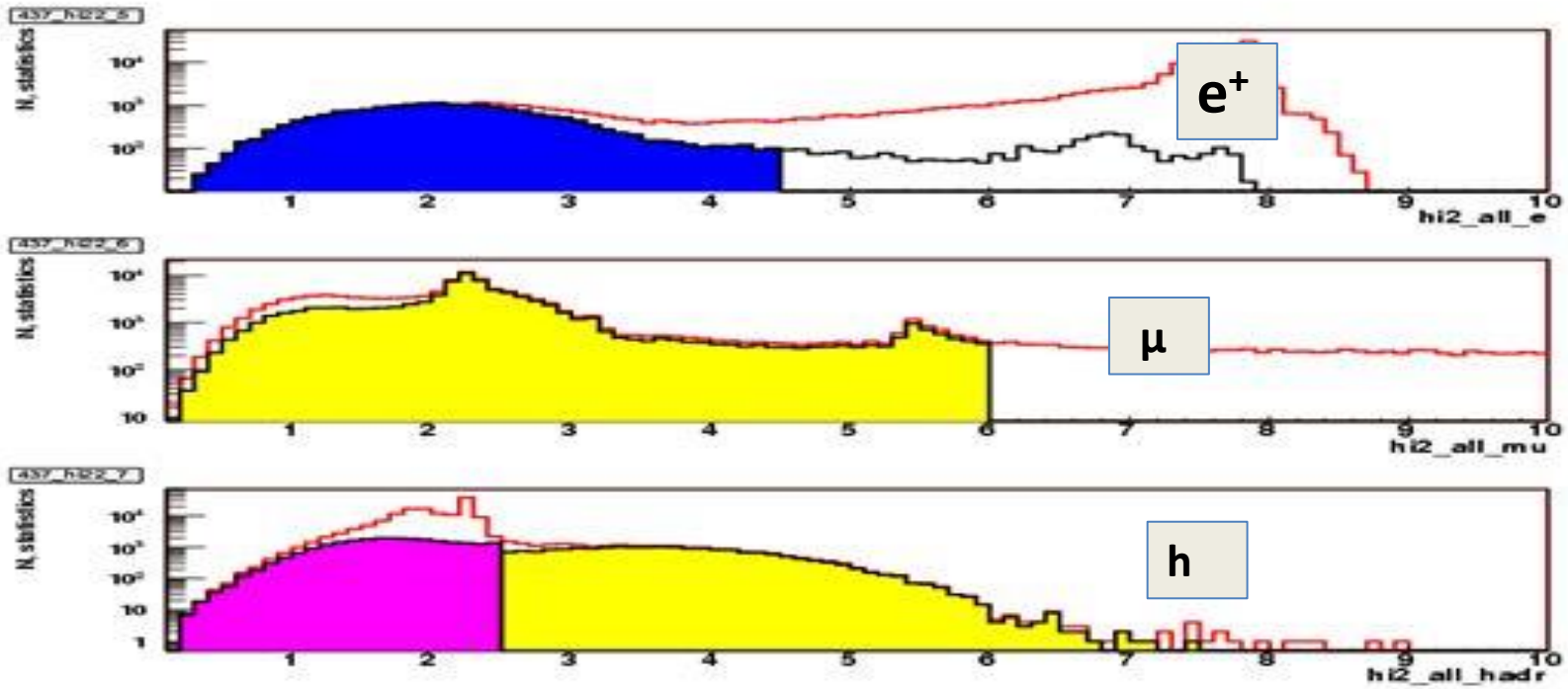
The estimated by MC energy distribution in tiles for hadrons (black), muons (green) , e^+ - positrons (red).

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

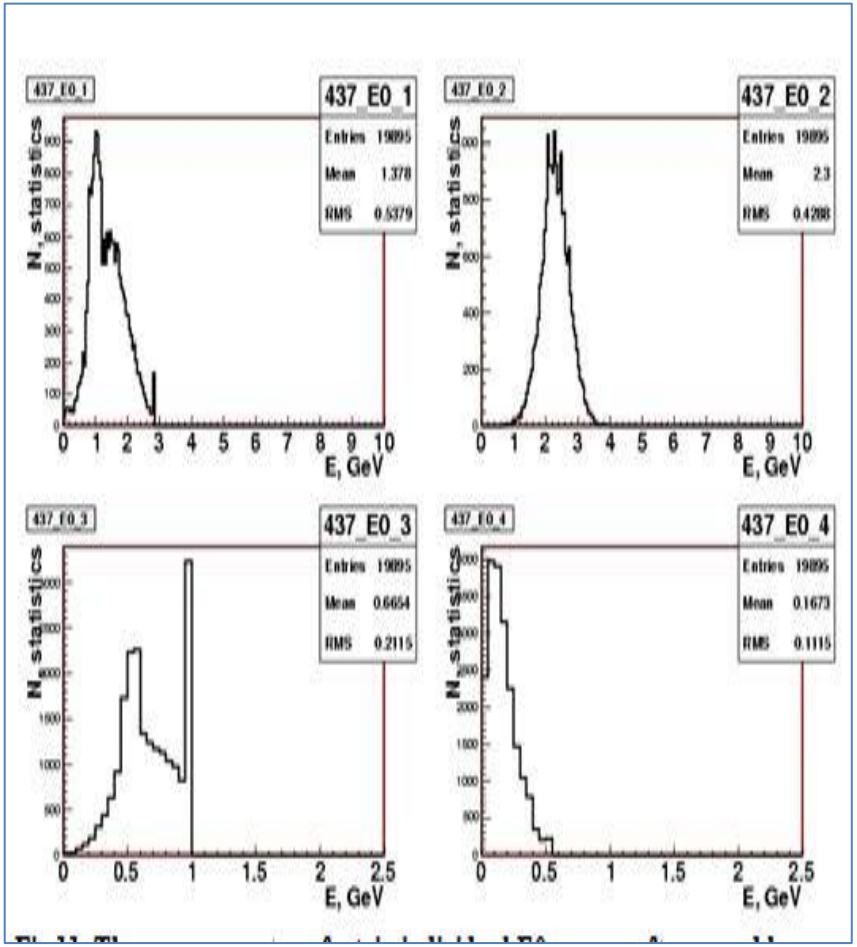


We can define the χ^2 distributions as the square deviation of the Monte Carlo values and experimental results normalized to the corresponding RMS - red lines.

The χ^2 cuts corresponded to χ^2 <6 (for muon - yellow), χ^2 <2.5 (for hadron - magenta) and χ^2 <4.5 (for e^+ - blue) are shown in shaded zones.



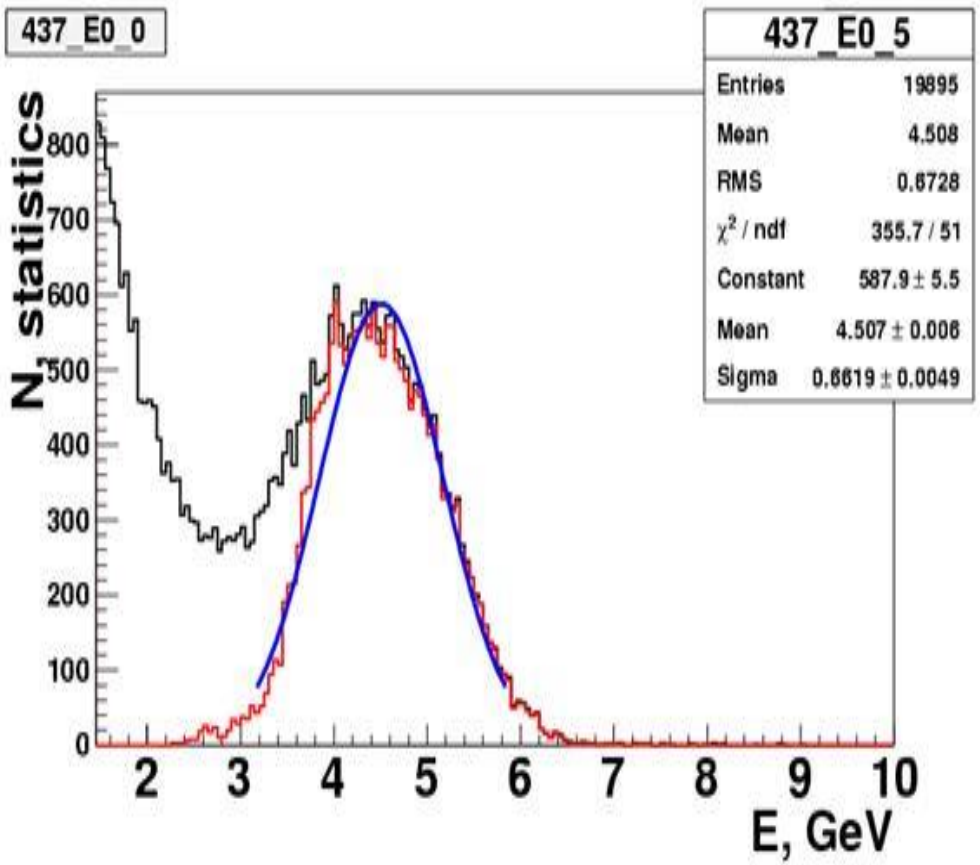
The energy spectra of 5 GeV positions separated from combined beam (~85% hadrons, ~5% muons and ~10% positrons)



The e^+ energy spectra in 4 calorimeters tiles are shown after χ^2 rejection.

The background from scattered positrons on the beam pipe is particularly visible on the spectra in individual groups.

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



The total energy in calorimeter.

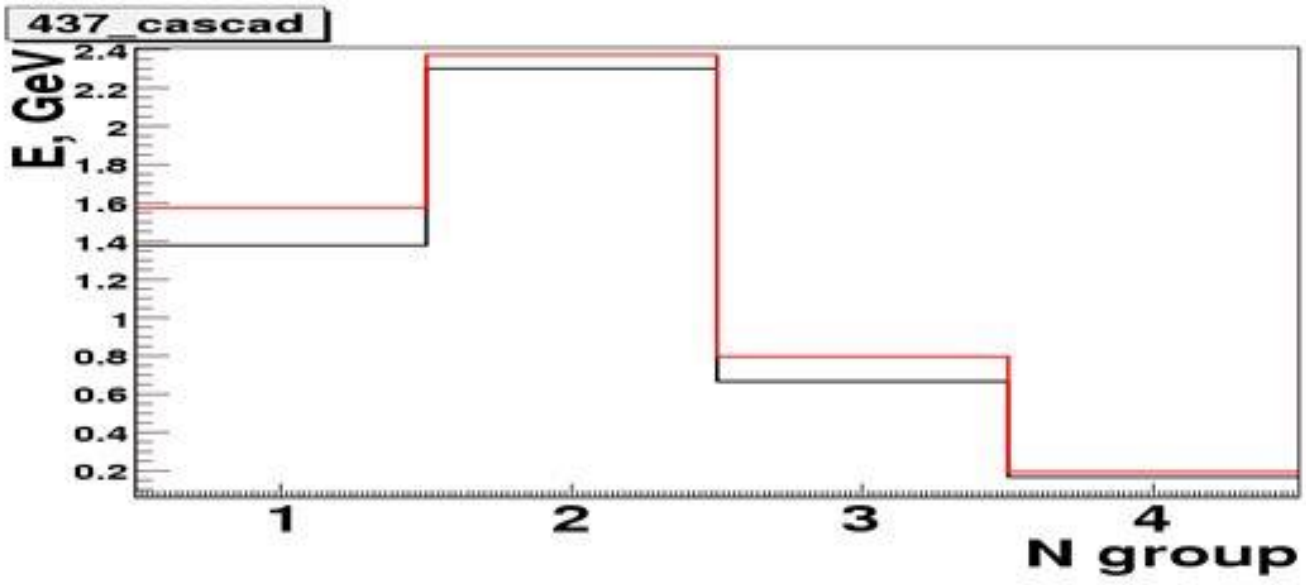
Black and red histograms - the spectra before and after the χ^2 rejection. The blue line – the Gaussian fit for e^+.

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

The average energy response in calorimeters tiles corresponded to cascade curve – Shower shape.

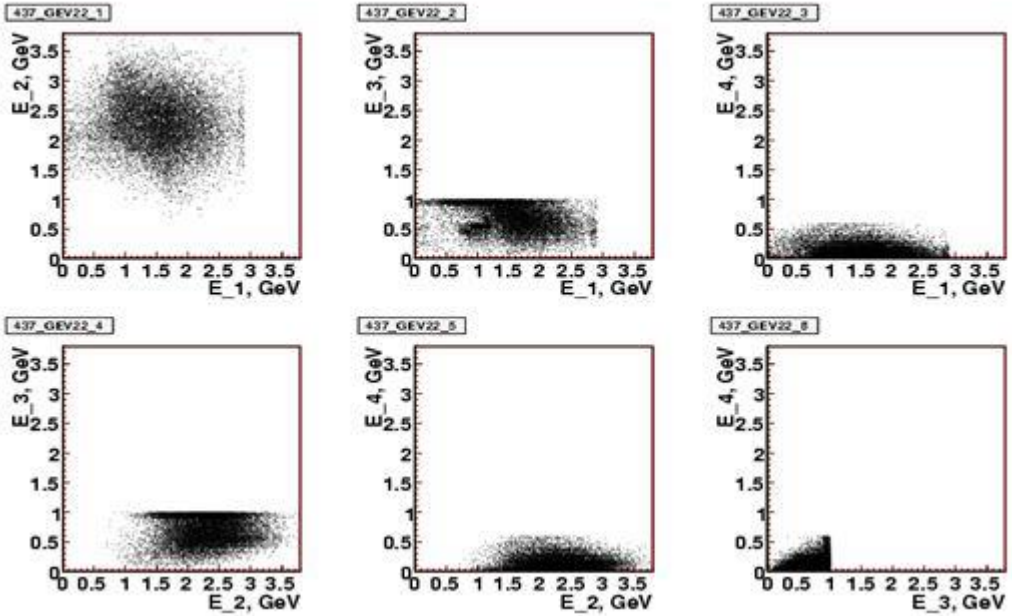
Red line - Monte Carlo calculation for e^+ of 5 GeV.
Black line - e+ energy take in account χ^2 cut.

It is good agreement for experimental and MC results.



Correlation of 5 GeV energy for positron in 4 calorimeters groups.

Correlation matrix for positrons



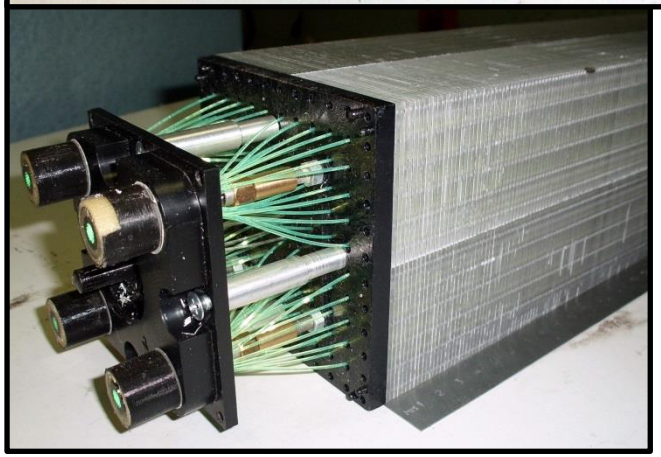
Correlation matrix for positrons:

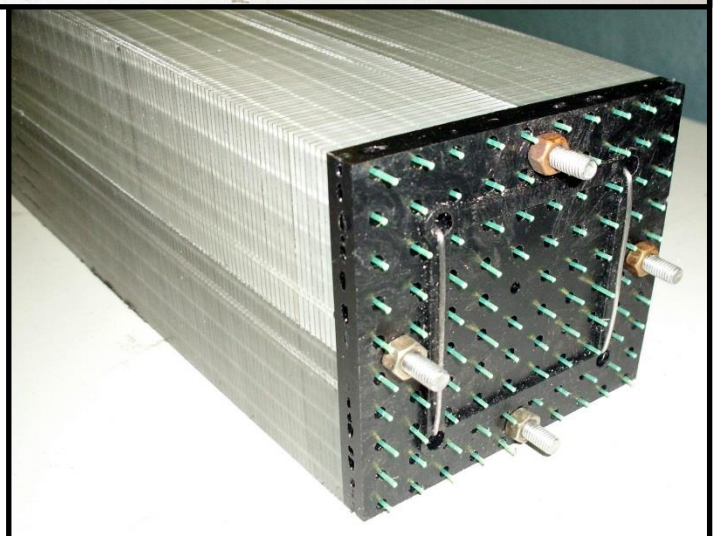
1.0000	**-0.1362**	**-0.2756**	**-0.0248**
000000	**1.0000**	**0.1860**	**0.0461**
000000	00000	**1.0000**	**0.4634**
000000	00000	000000	**1.0000**

EC segmented by deep

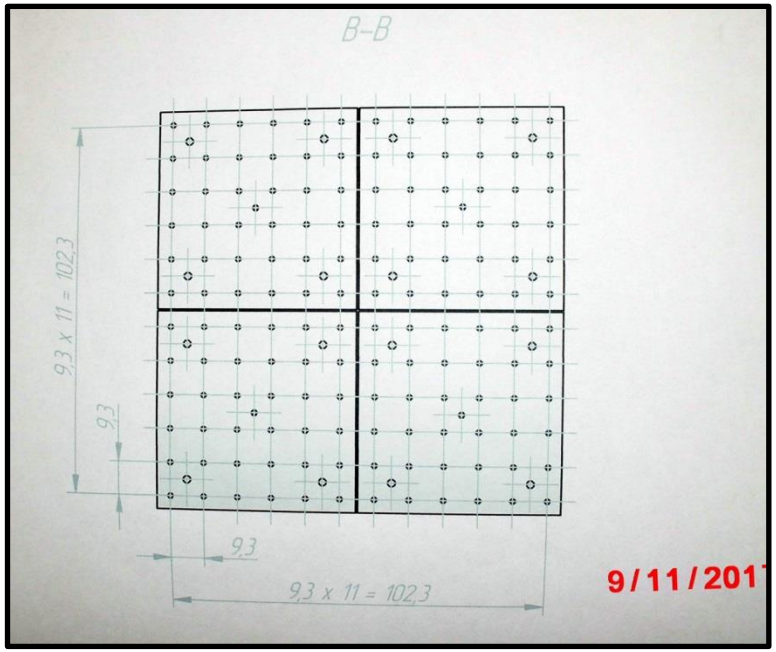
- How to do it ?
- There are 2 ways:
  - Shashlik calorimeter type
  - Tiles with WLS combined in 4 groups
- The possible Photo sensor – (SiPm) AMPD 6 mm
  - S13360-6025PE (25 μm) 5760 pixels
  - https://www.hamamatsu.com/resources/pdf/ssd/s13360_series_kapd1052e.pdf
- WLS – Y11 diameter 1 mm http://kuraraypsf.jp/pdf/all.pdf

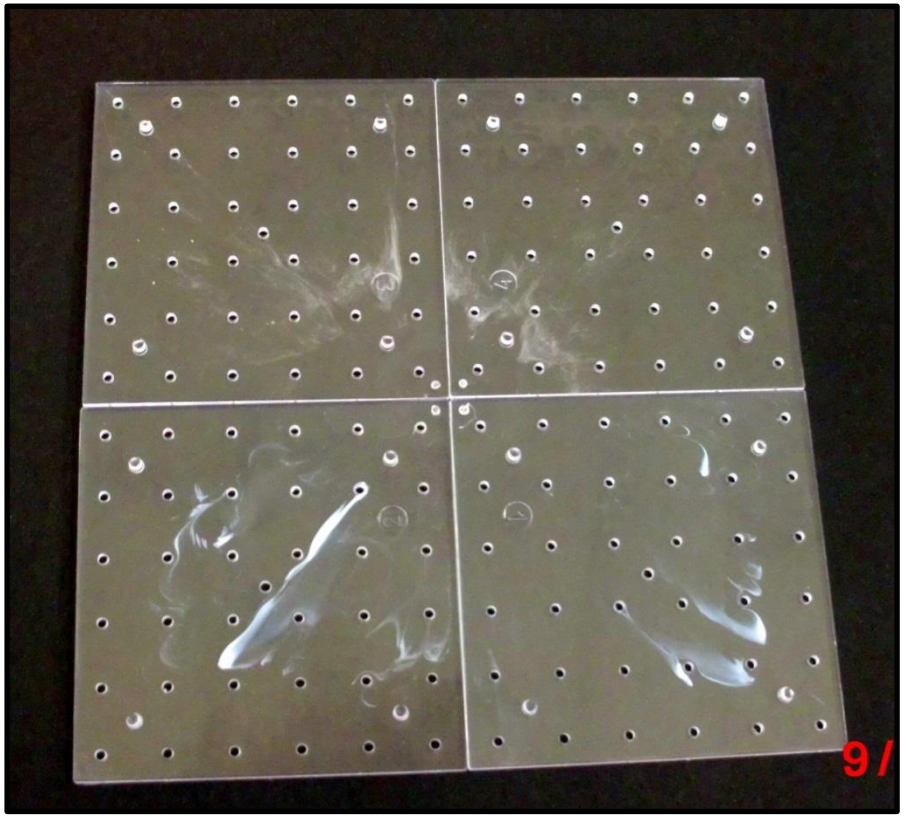
4-towers module with 36 WLS fibers (single side option)



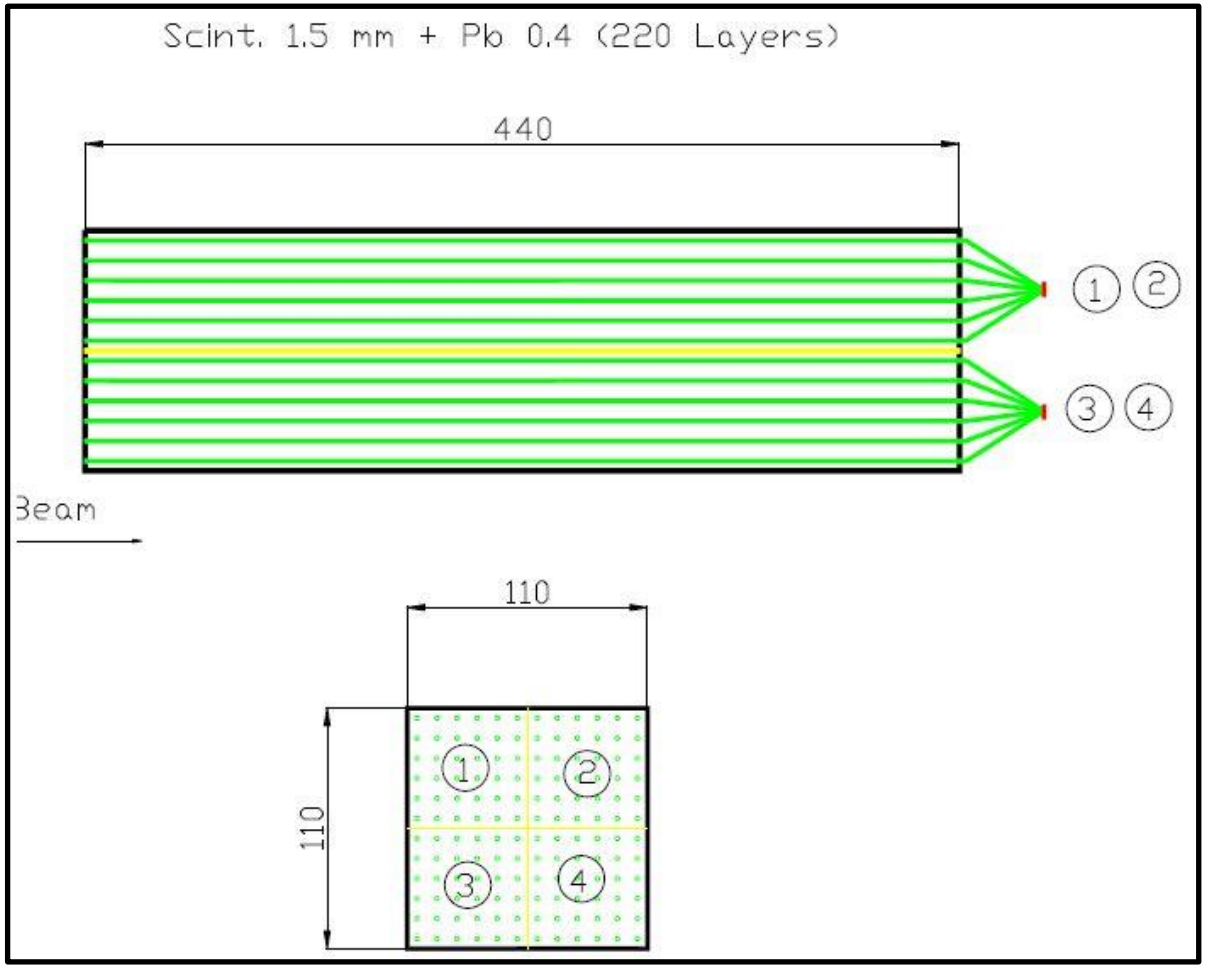


Scintillation tiles: Drawing (left) and photo (right)



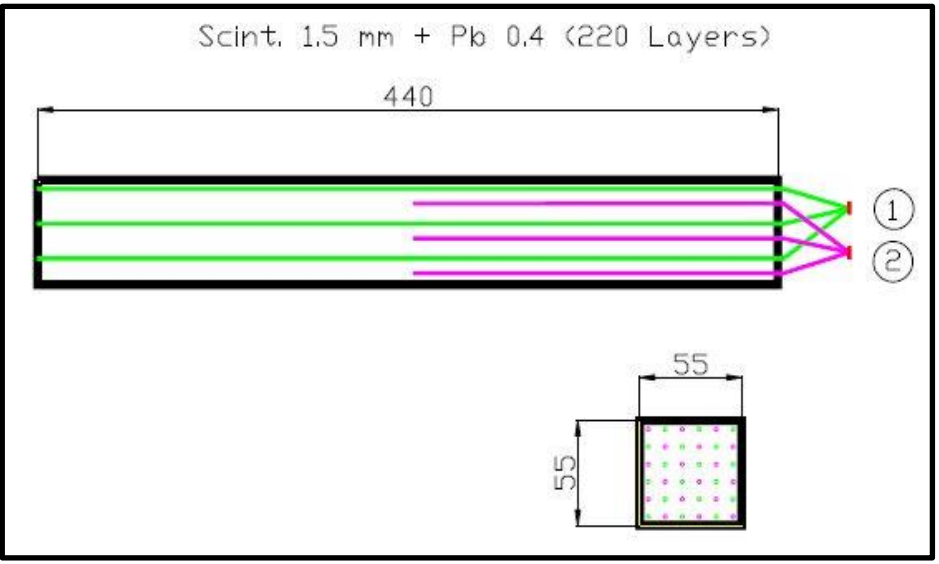


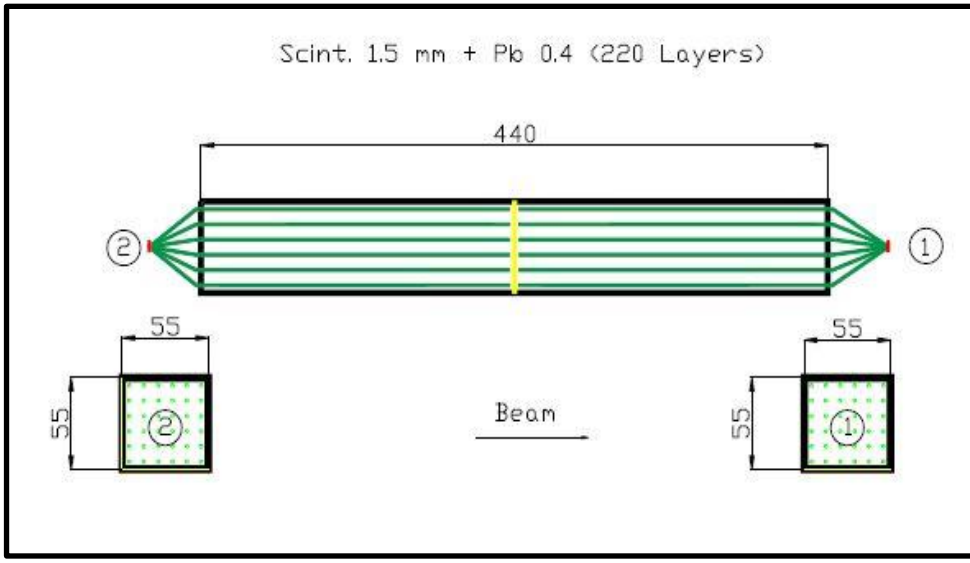
Schematic view 4 Towers EC module



4 Towers 55x55 mm^2
4 – SiPm **6x6 mm**
With 25 µm pitch
36 WLS Y-11 , 1 mm Diam.
Collect ligt to 1 SiPm

Possible solution for Double readout





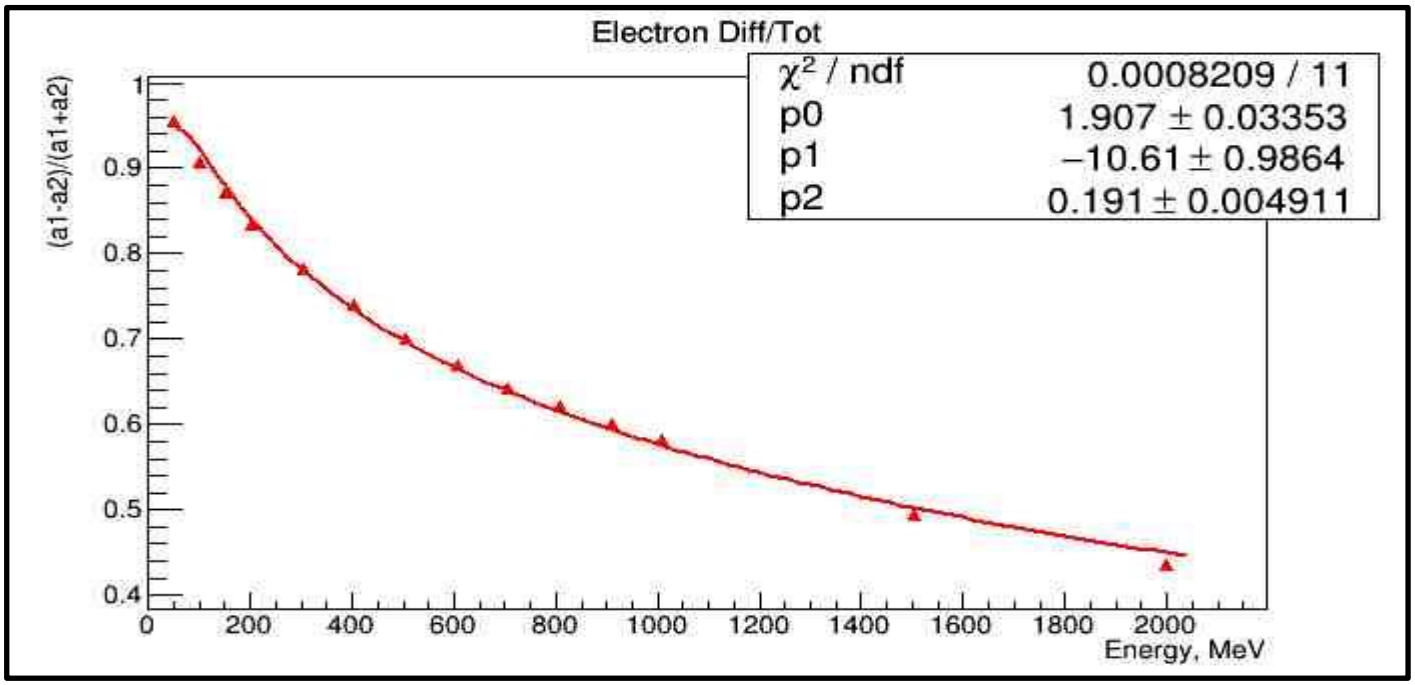
Double Readout: Integral Option with 18 short and 18 long WLS fibers collected light on 2 SiPm in rear EC side.

Double Readout: Differential Option with 36 short WLS fibers from both sides of EC. The light collected on 2 SiPm in front end rear EC sides.

Monte Carlo simulation

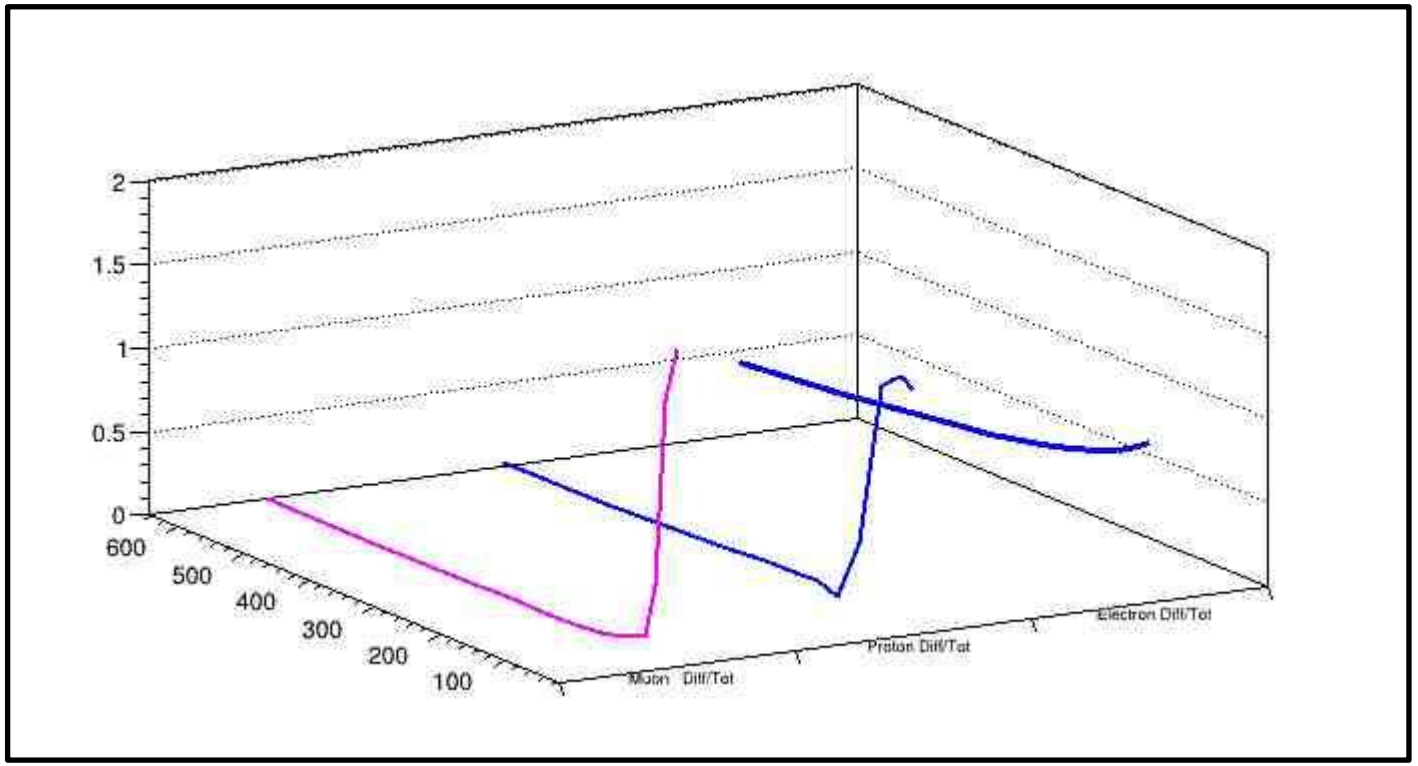
- Preliminary results for e, pi, p, mu particles
- Differential option of EC is discussed
- Energy range: 50 -2000 MeV
- Shower shape taken in account to particles identification using an Asymmetry (A) in the amplitudes distributions in first (a1) and second (a2) EC parts: A=(a1-a2)/(a1+a2)
- The Asymmetry presented as Function of particles Energy

Amplitudes Asymmetry as function an Energy for electrons

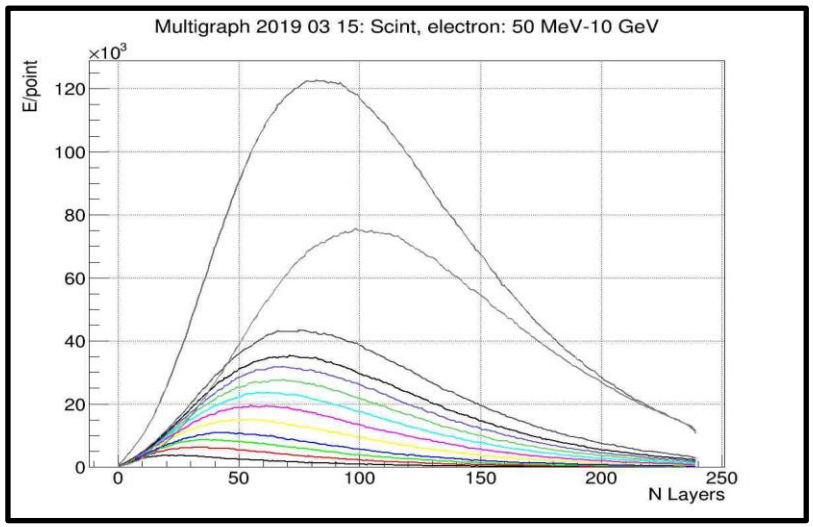


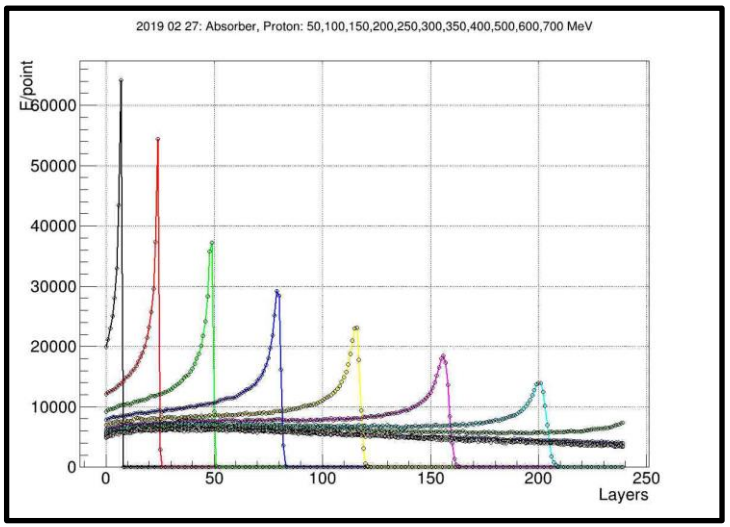
$$A_{electron}s = P_0 + P_1 * E + P_2 * \log(E);$$

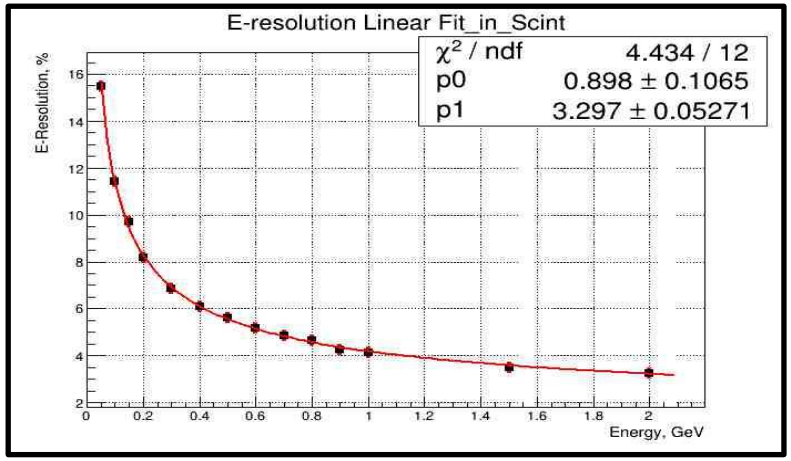
Amplitudes Asymmetry as function an Energy are presented for electrons, protons and muons. The Shape of this curves is quite different.

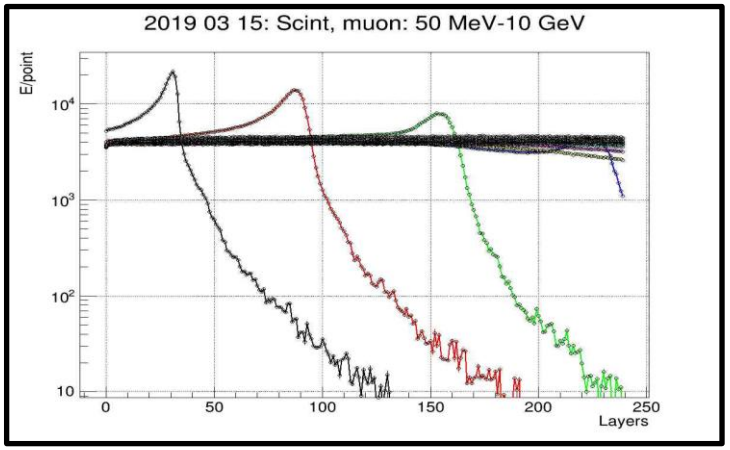


Longitudinal profiles for different particles in EC. E-resolution for electrons.







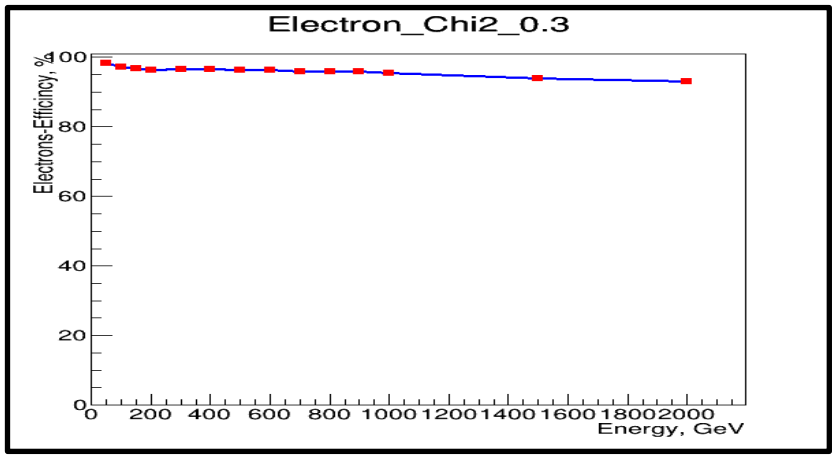


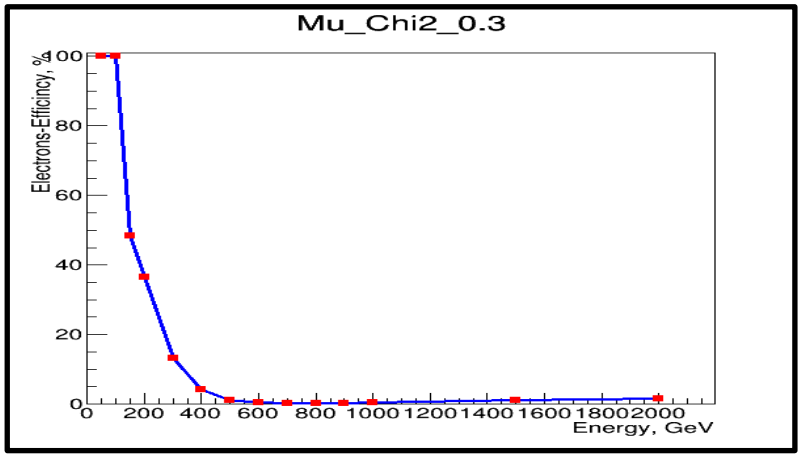
Electron separation

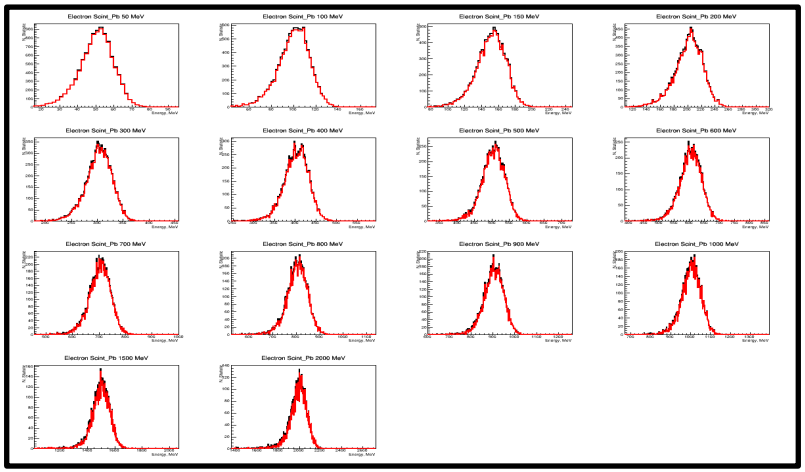
- A_{theor} - Asymmetry theoretical (parametrization vs energy) for electron
- A_{ex} – Asymmetry experimental for Any particles – not evident

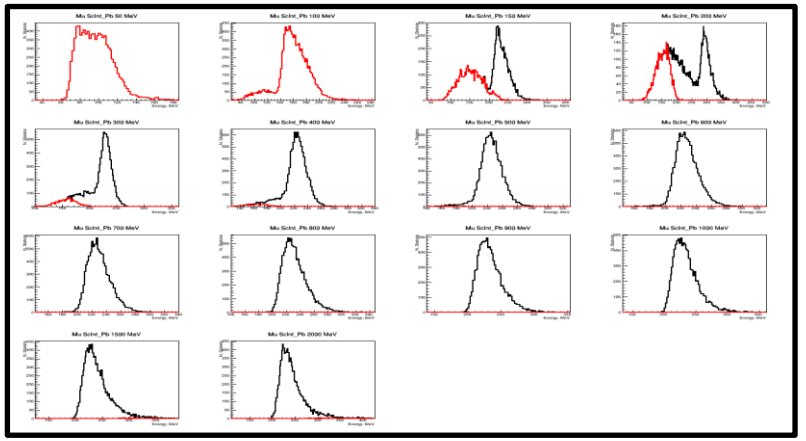
- $X = (A_{theor} – A_{ex})^2$ - Insigne value - Square of derivation use as criteria for particles separation:
- $X < X_0$ – the range for particles separation

Electrons and muon Efficiency vs Energy.
Electrons and muons spectra after selection

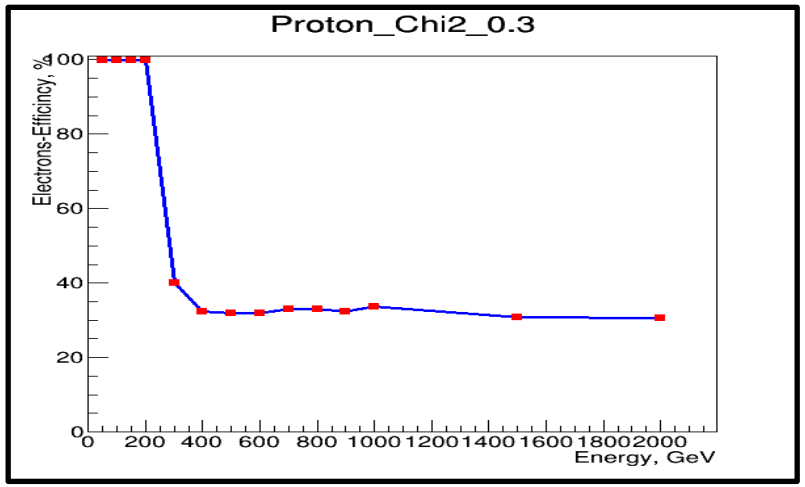


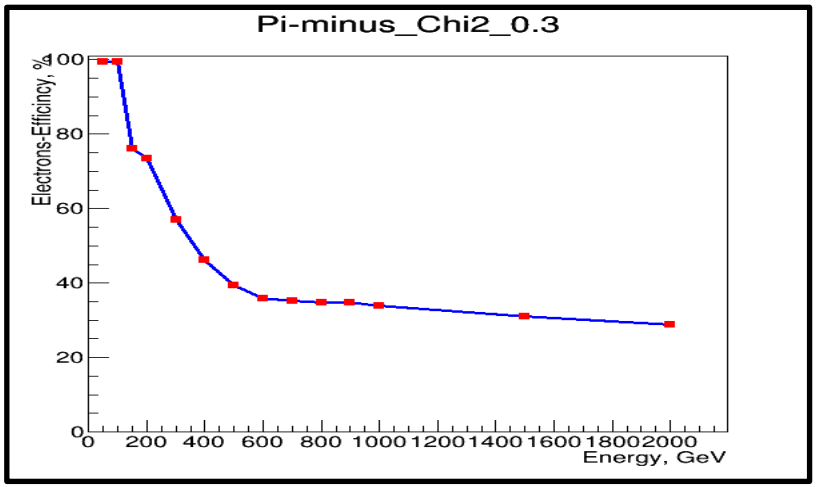


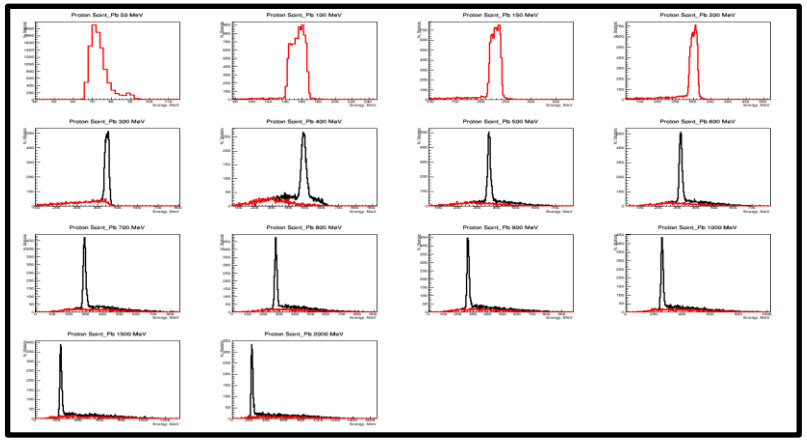


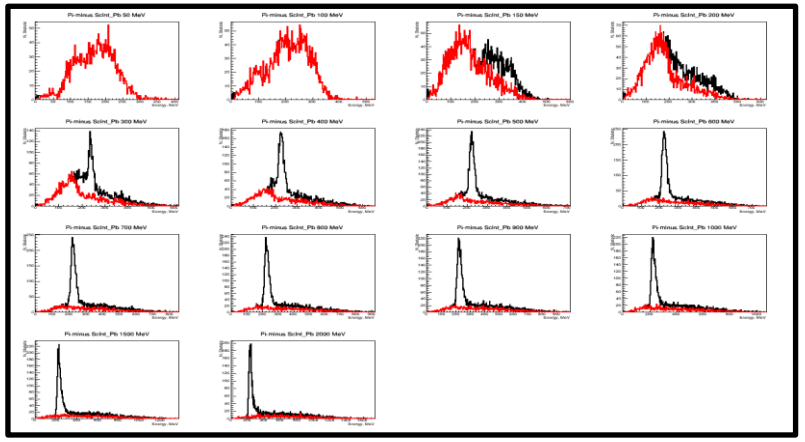


Proton and Pi-minus Efficiency vs Energy. Electron and muon spectra after selection









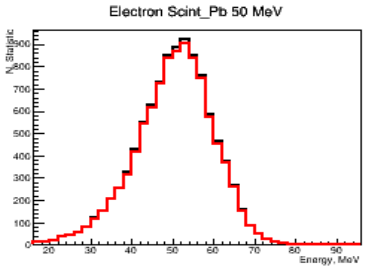
Conclusions

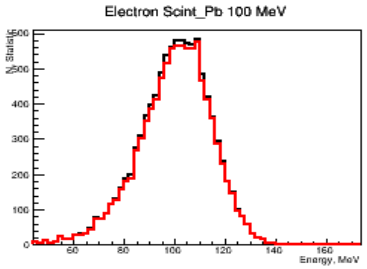
- In energy range 50-200 MeV not possible separate election-muon-proton-pion using only one criteria – longitudinal profile of energy distribution in EC.
- Probably we need use additional criteria for this – Lateral Shower shape.
- Hadron efficiency is equal about 20-30%, E>300 MeV
- Muon efficiency is equal about 1%, E>300 MeV

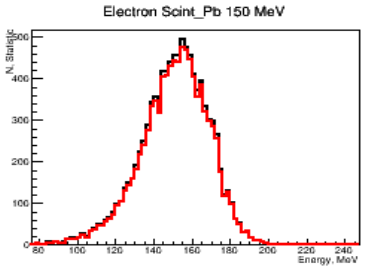
End of Report

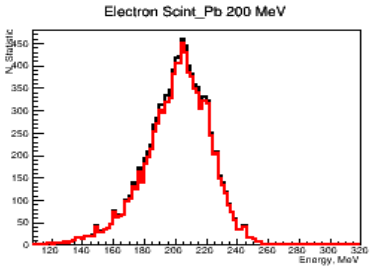
Thanks everybody

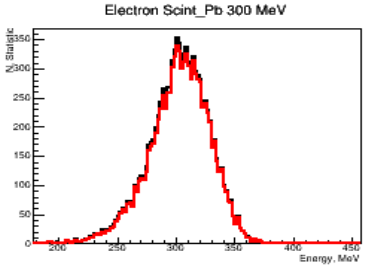
Electron

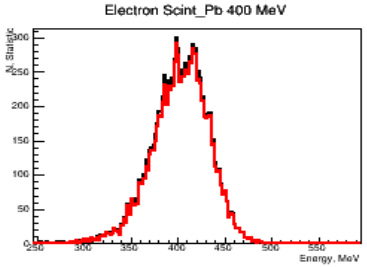

Electron Scint_Pb 50 MeV
N, Statistic
Energy, MeV

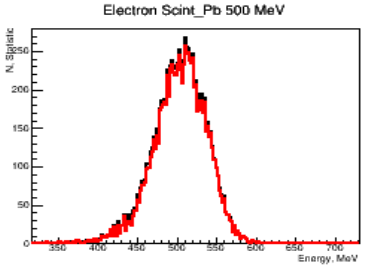

Electron Scint_Pb 100 MeV
N, Statistic
Energy, MeV

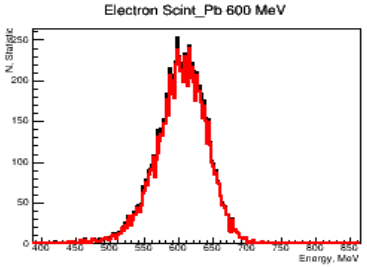

Electron Scint_Pb 150 MeV
N, Statistic
Energy, MeV

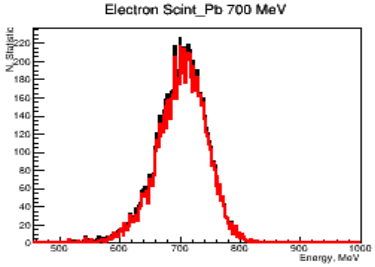

Electron Scint_Pb 200 MeV
N, Statistic
Energy, MeV

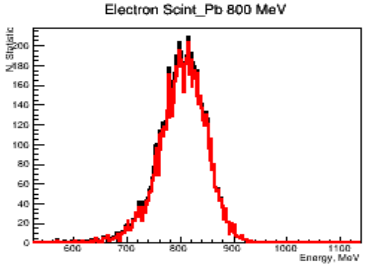

Electron Scint_Pb 300 MeV
N, Statistic
Energy, MeV

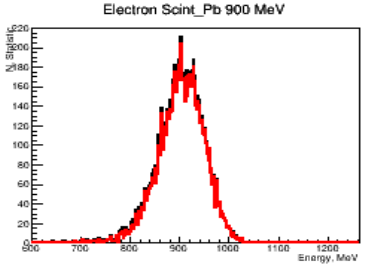

Electron Scint_Pb 400 MeV
N, Statistic
Energy, MeV

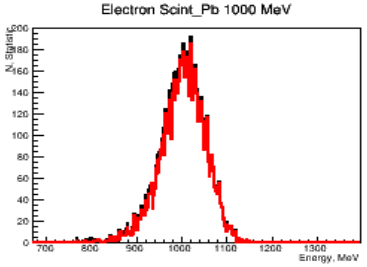

Electron Scint_Pb 500 MeV
N, Statistic
Energy, MeV

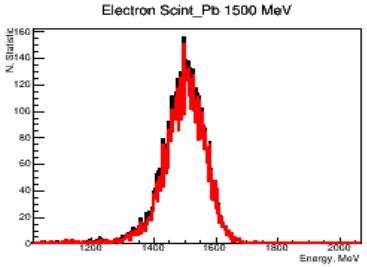

Electron Scint_Pb 600 MeV
N, Statistic
Energy, MeV


Electron Scint_Pb 700 MeV
N, Statistic
Energy, MeV


Electron Scint_Pb 800 MeV
N, Statistic
Energy, MeV


Electron Scint_Pb 900 MeV
N, Statistic
Energy, MeV


Electron Scint_Pb 1000 MeV
N, Statistic
Energy, MeV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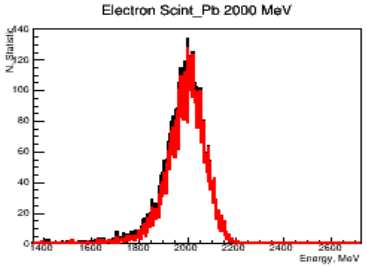
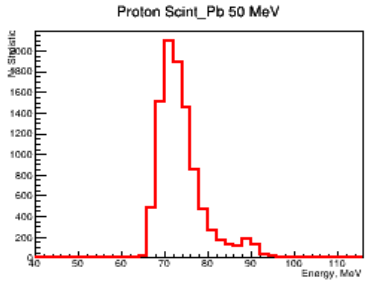
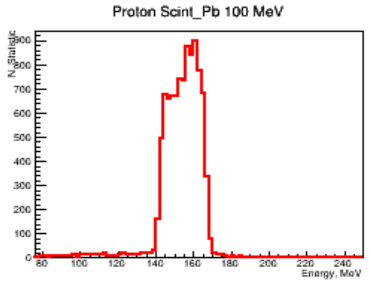
N, Statistic
Energy, MeV


Electron Scint_Pb 2000 MeV
N, Statistic
Energy, MeV

Proton


Proton Scint_Pb 50 MeV
N, Statistic
Energy, MeV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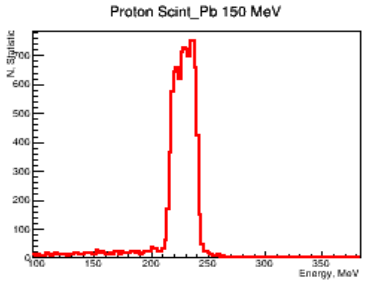
N, Statistic
Energy, MeV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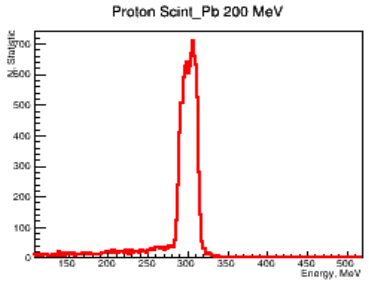
N, Statistic
Energy, MeV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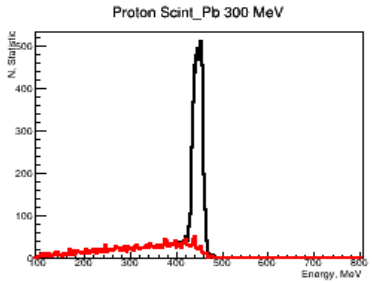
N, Statistic
Energy, MeV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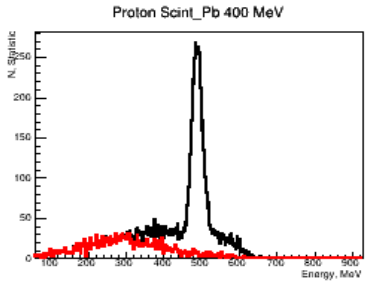
N, Statistic
Energy, MeV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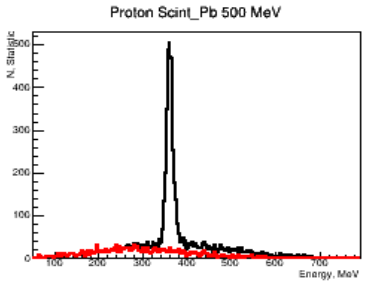
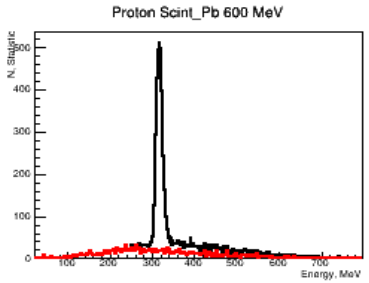
N, Statistic
Energy, MeV


Proton Scint_Pb 500 MeV
N, Statistic
Energy, MeV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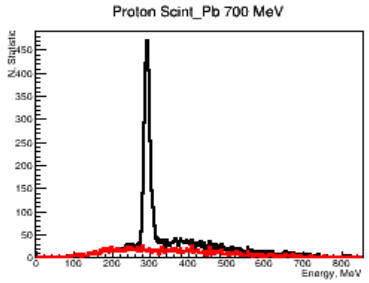
N, Statistic
Energy, MeV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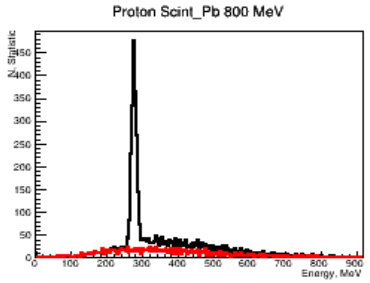
N, Statistic
Energy, MeV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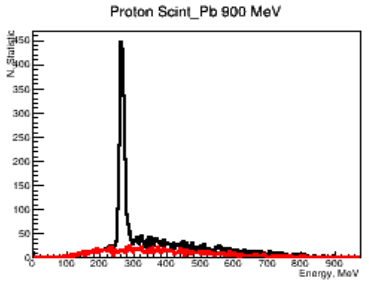
N, Statistic
Energy, MeV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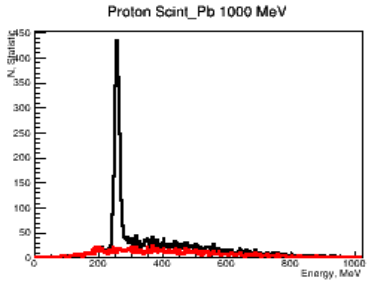
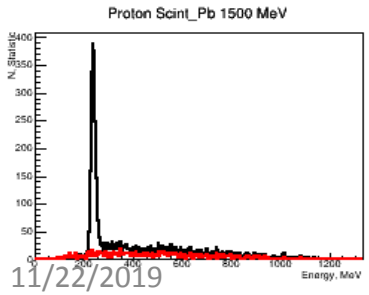
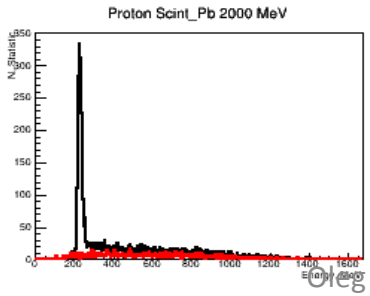
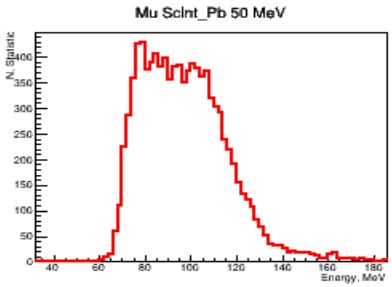
Energy, MeV

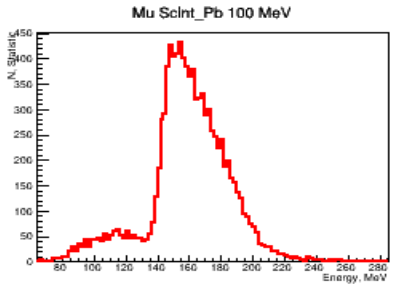

Proton Scint_Pb 1000 MeV
N, Statistic
Energy, MeV

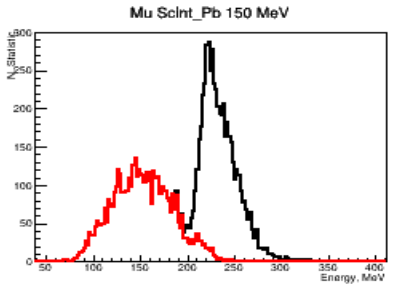

Proton Scint_Pb 1500 MeV
N, Statistic
Energy, MeV

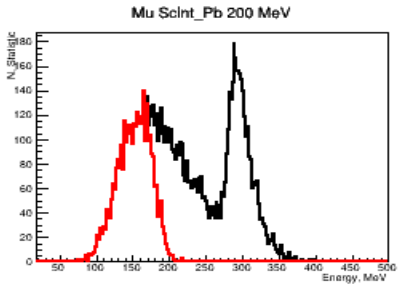

Proton Scint_Pb 2000 MeV
N, Statistic
Energy, MeV

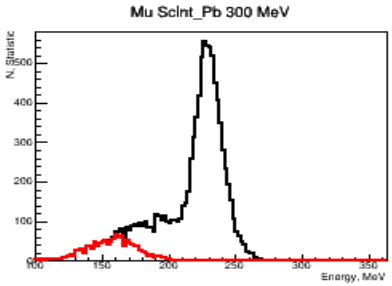
Muon

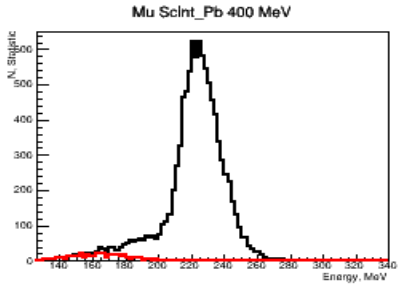

Mu Scint_Pb 50 MeV
N, Statistic
Energy, MeV

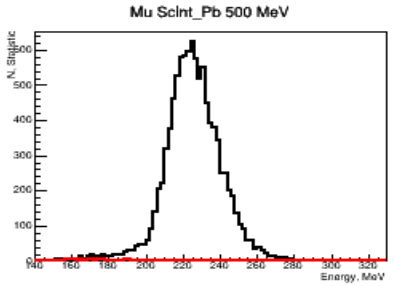

Mu Scint_Pb 100 MeV
N, Statistic
Energy, MeV

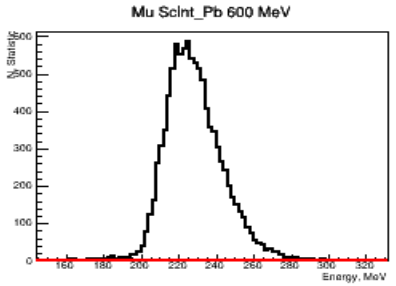

Mu Scint_Pb 150 MeV
N, Statistic
Energy, MeV

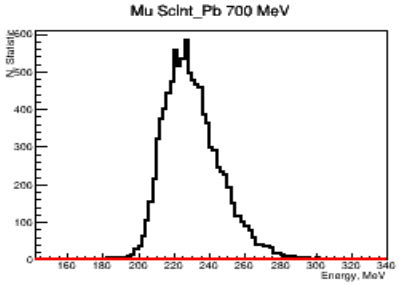

Mu Scint_Pb 200 MeV
N, Statistic
Energy, MeV

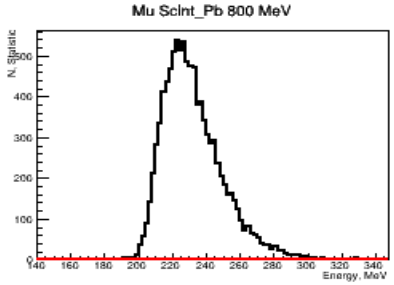

Mu Scint_Pb 300 MeV
N, Statistic
Energy, MeV


Mu Scint_Pb 400 MeV
N, Statistic
Energy, MeV


Mu Scint_Pb 500 MeV
N, Statistic
Energy, MeV


Mu Scint_Pb 600 MeV
N, Statistic
Energy, MeV


Mu Scint_Pb 700 MeV
N, Statistic
Energy, MeV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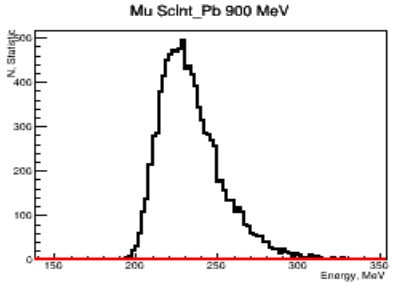
N, Statistic
Energy, MeV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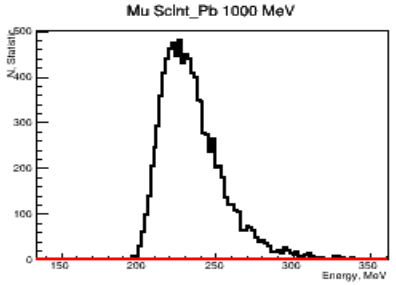
N, Statistic
Energy, MeV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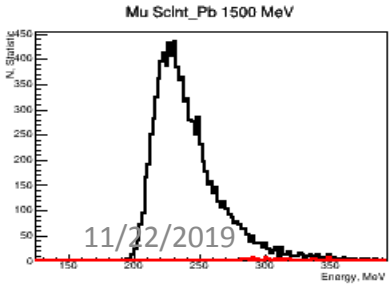
Energy, MeV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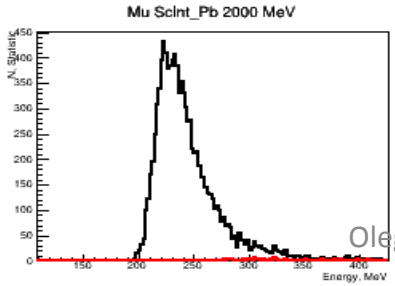
N, Statistic
Energy, MeV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N, Statistic
Energy, MeV