Istituto Nazionale di Fisica Nucleare
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Characterization of a scintillator tile equipped with SiPMs for future cosmic-ray space experiments

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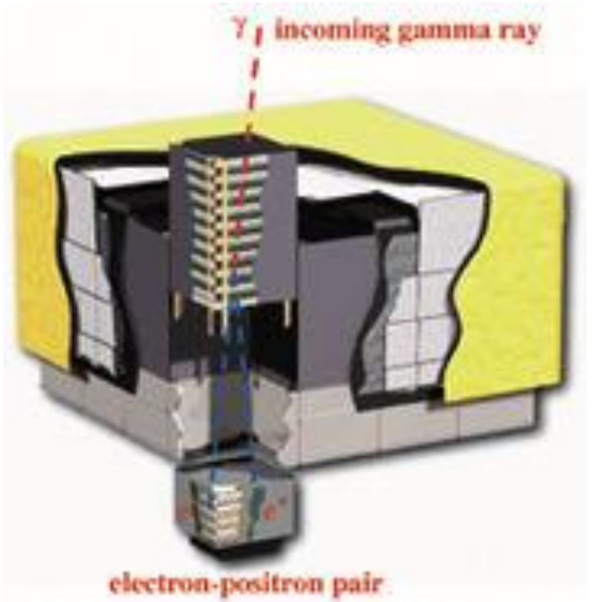
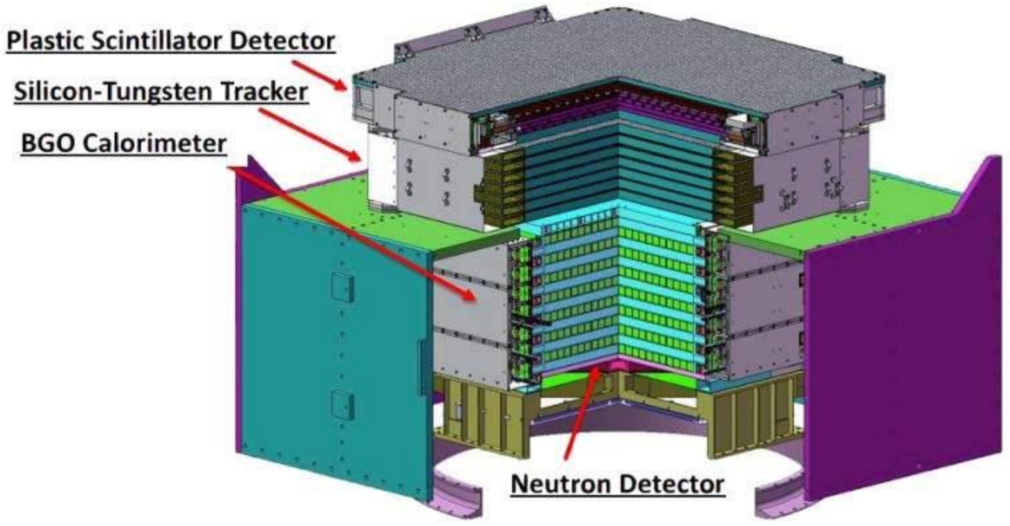
Motivations

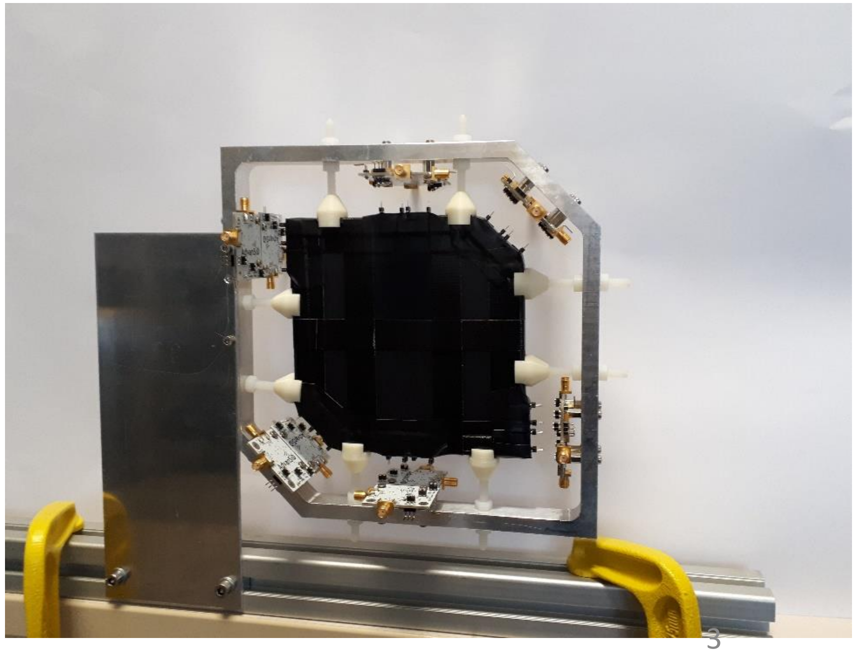
- Plastic scintillators are used for anti-coincidence systems in gamma-ray detectors on satellite experiments (Fermi-LAT, DAMPE,…)
- The detector is often segmented in small tiles to enhance gamma-ray selection efficiency against back-splash
- In most cases scintillators are read-out with PMTs
  - High voltage is required: unpractical on satellites
- SiPMs are suitable to replace PMTs
  - Lower voltages required
  - Better sensitivity to low light yields
- Plastic scintillators coupled to SiPMs are being tested in recent years for future missions, such as HERD, AMEGO, e-Astrogam





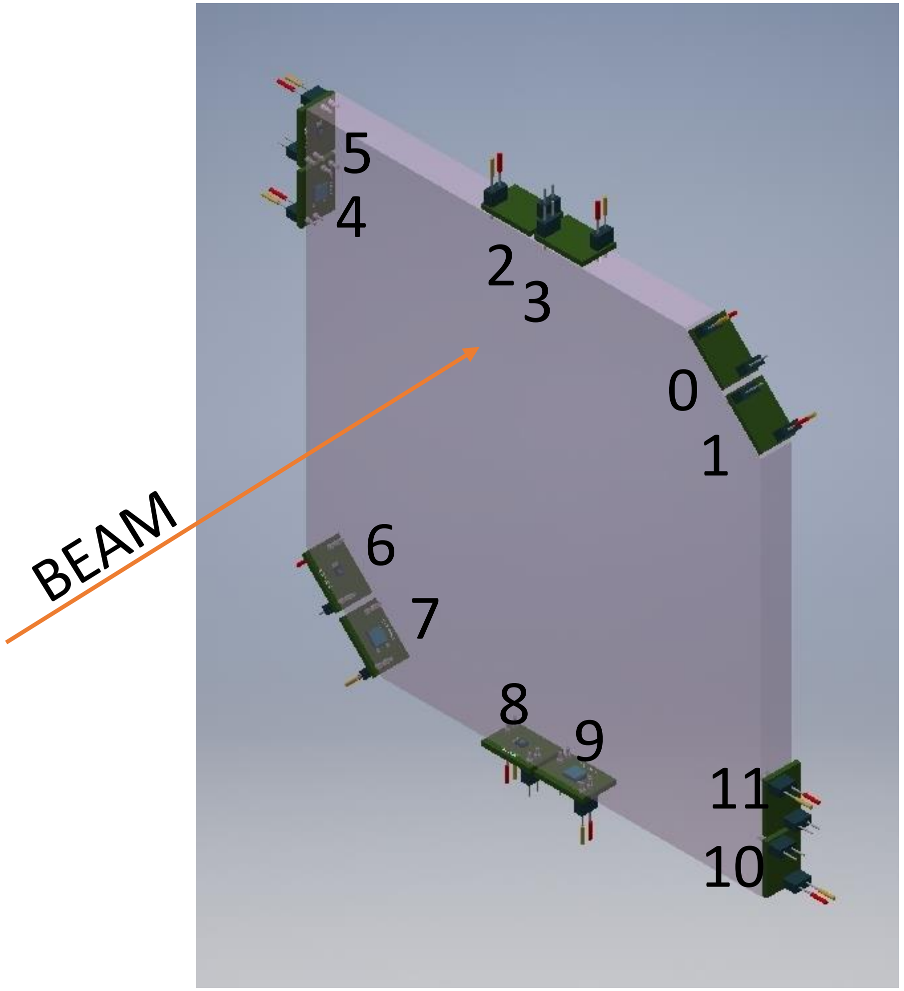
Tile assembly

- Plastic scintillator BC-404:
  - Tile of 15 cm side and 1 cm thickness with two cut edges
  - CAVEAT: the light yield of the scintillator might be deteriorated due to the scintillator age
- Readout:
  - 12 NUV SiPMs produced by FBK
    - 6 small area SiPMs: 1×1mm^2
    - 6 large area SiPMs: 4×4mm^2
  - 40μm cell pitch
  - Peak PDE @400nm: 43%
- Preamplifier:
  - Trans-impedance amplifier
  - Tail cancellation with a RC filter
- Signals integrated with a Caen V792 QDC



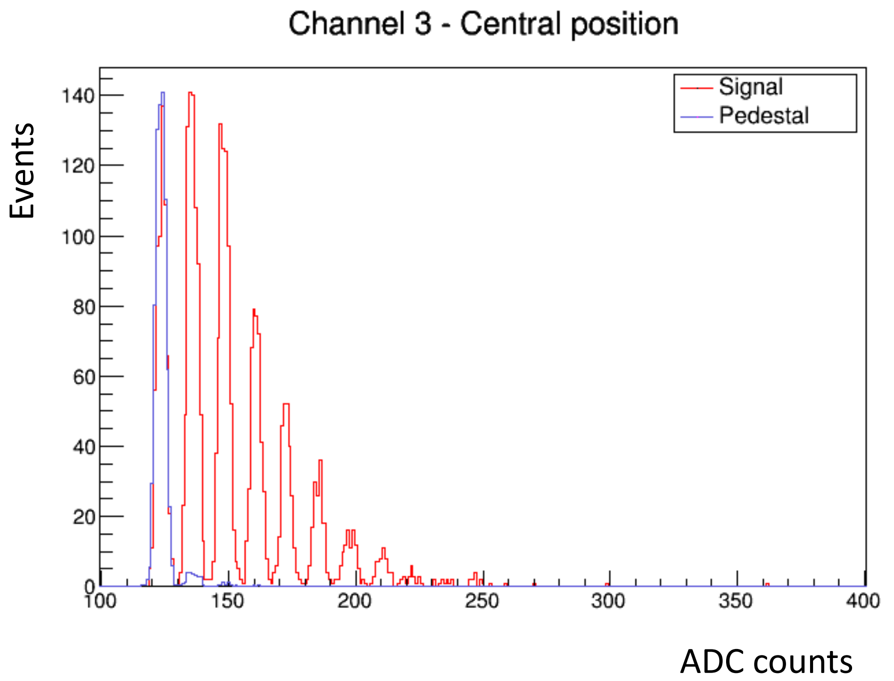
Beam test at CERN PS and SPS

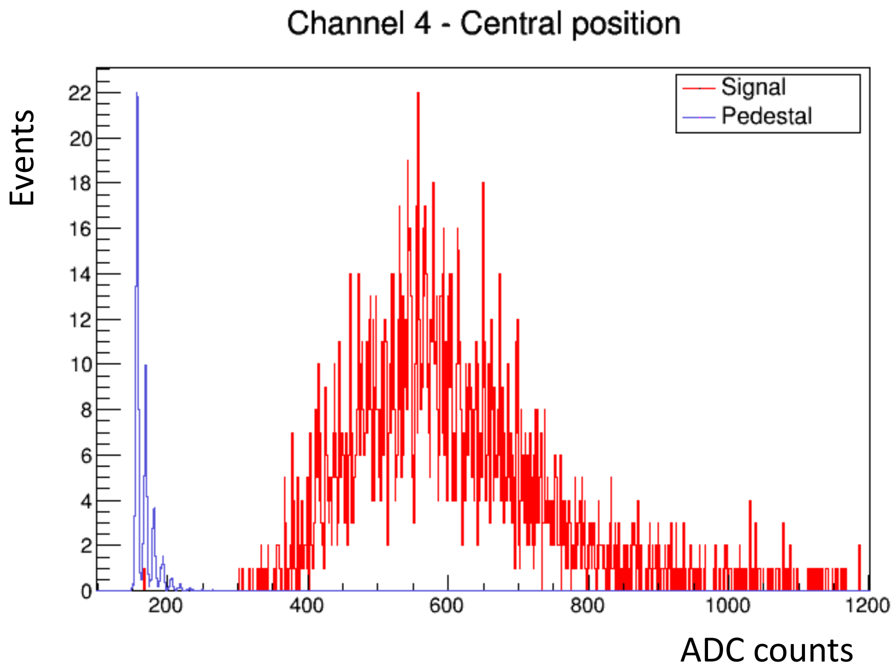
- PS - T10: 2-5 GeV/c particles (e/π)
  - Scintillator irradiated in different positions
  - beam spot diameter = 3cm
- SPS – H8: 20 GeV/c particles (e/π)
  - Scintillator irradiated only in the central position



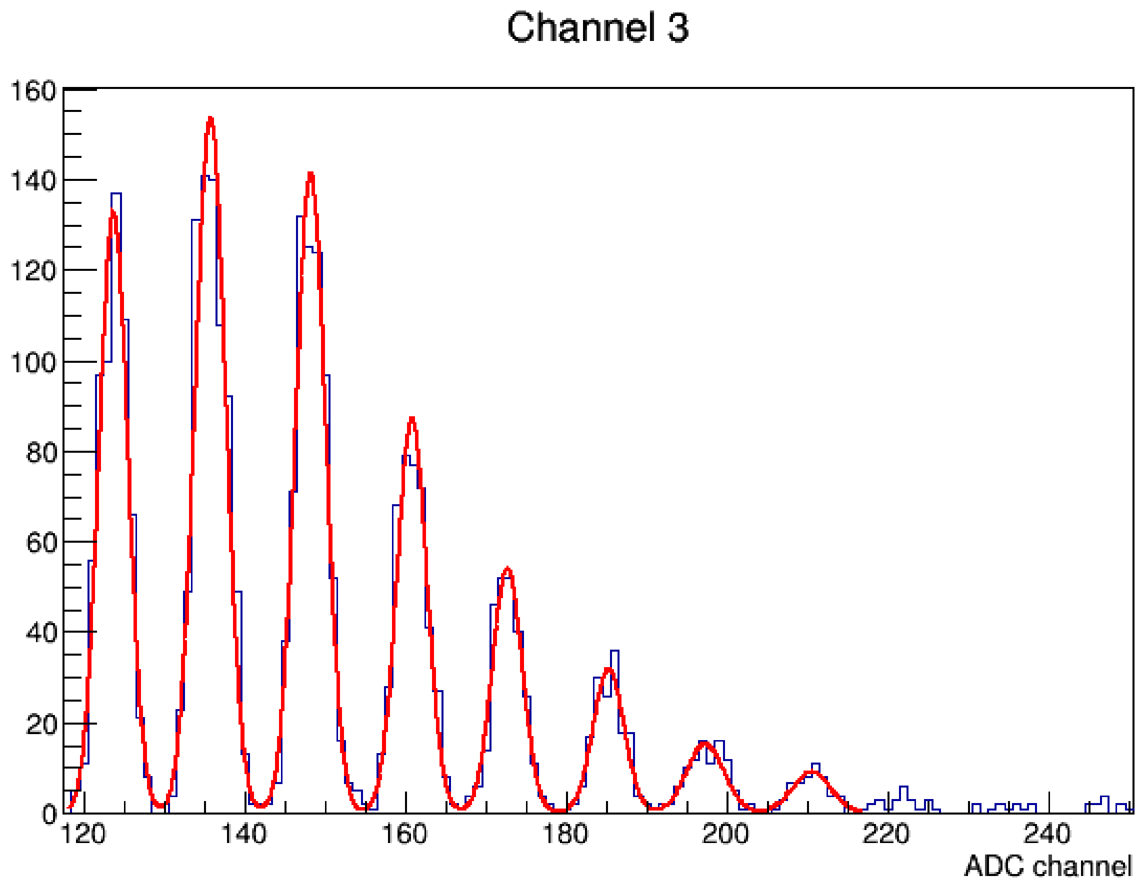
Analysis method

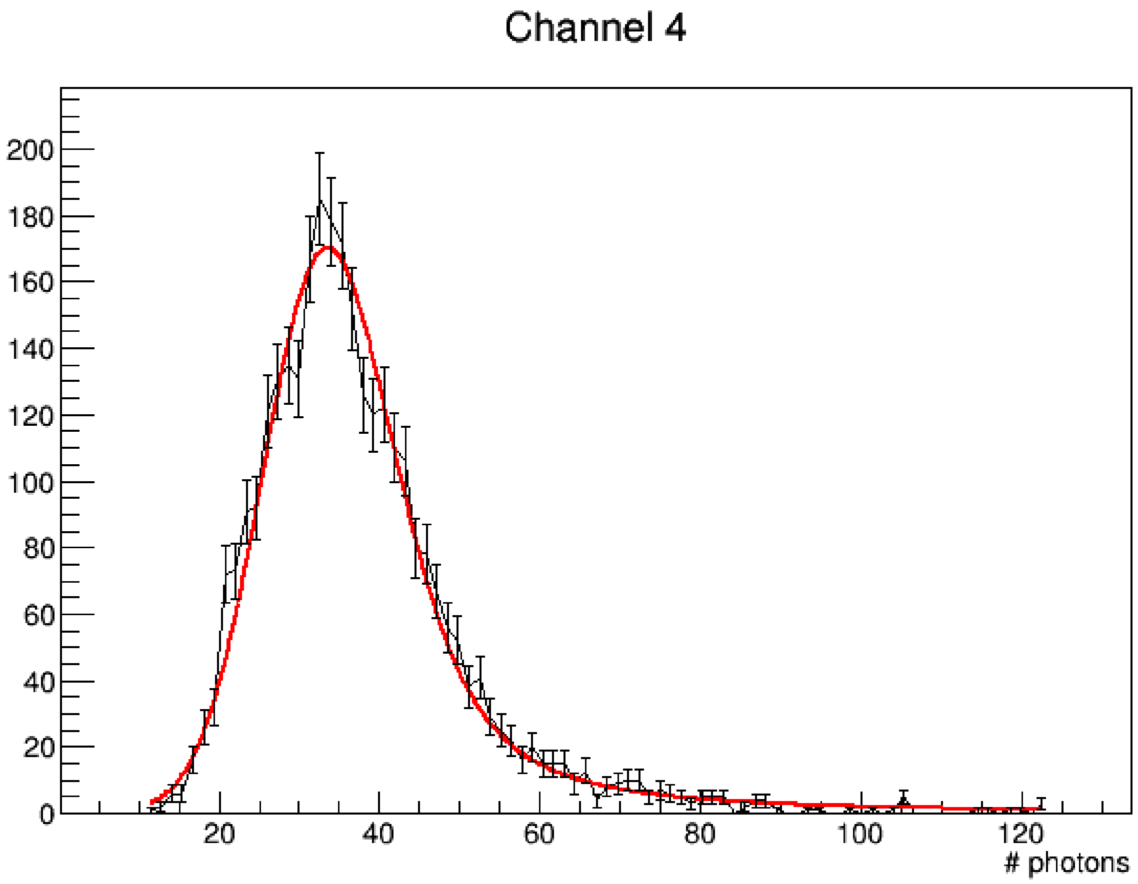
- Small SiPMs (1×1mm^2 area):
  - Charge distributions fitted with multi-gaussian functions
  - Areas of individual peaks fitted with Poisson distributions
- Large SiPMs (4×4mm^2 area):
  - Individual peaks still visible in charge distributions, but difficult to fit due to low statistics
  - Re-binning of histograms and fit with a Landau distribution folded with a gaussian





Examples of the fit procedure

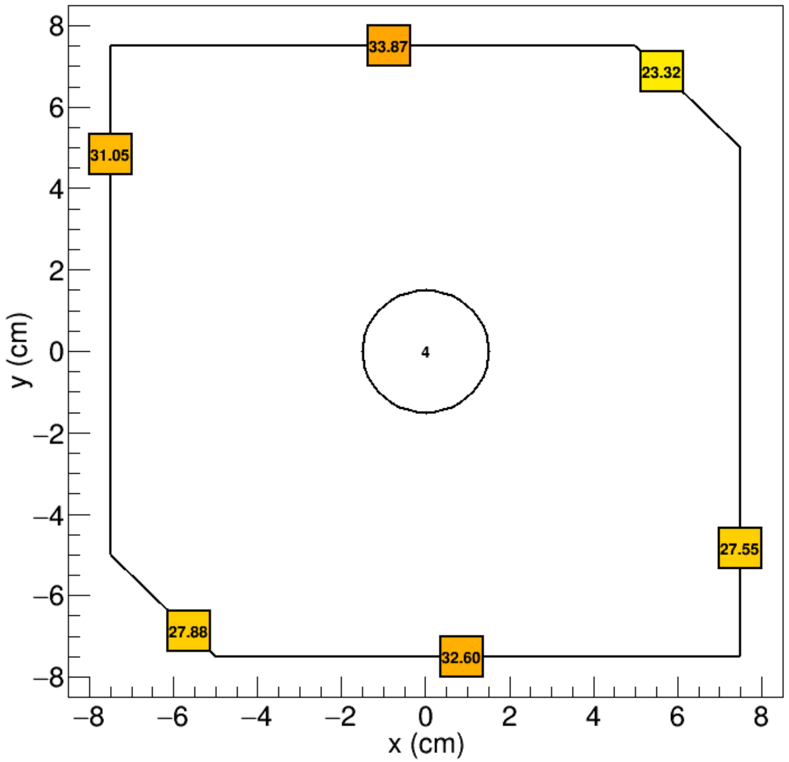




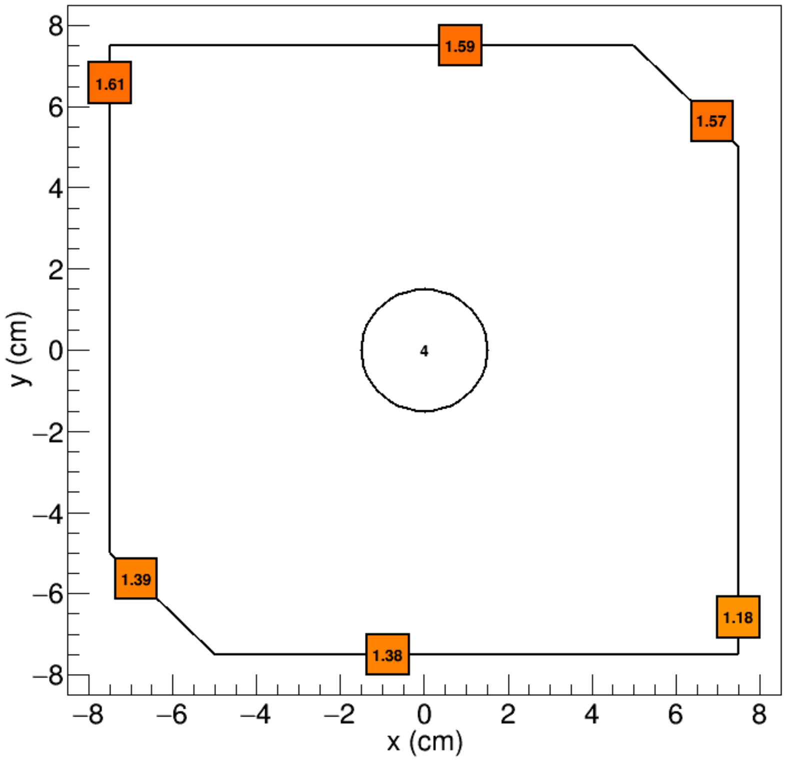
Yield at fixed positions

- Values represent the number of detected photons by each SiPM
- The beam position is indicated by the black circle

Large SiPMs



Small SiPMs



Yield at fixed positions

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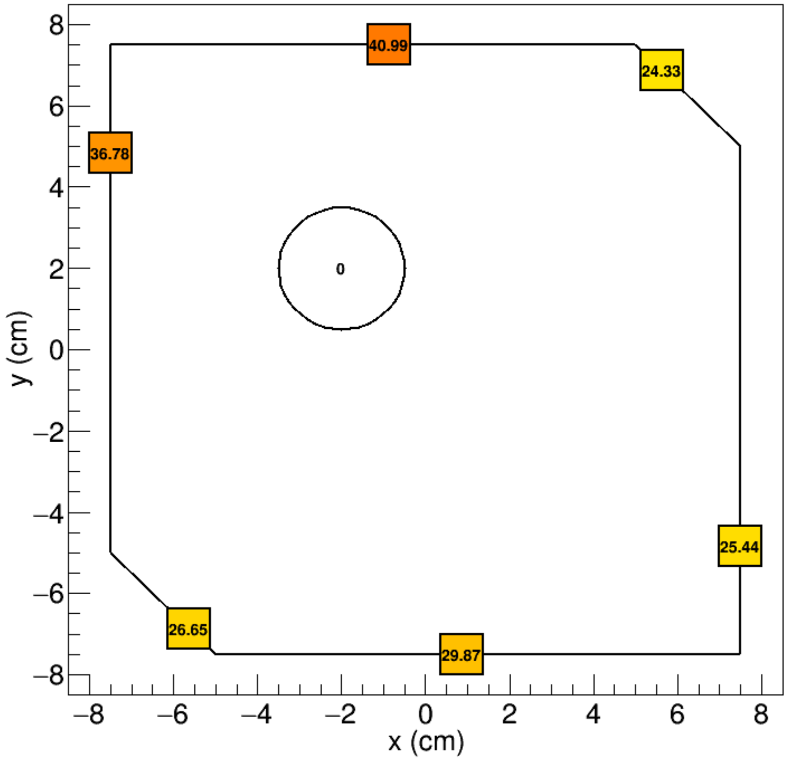
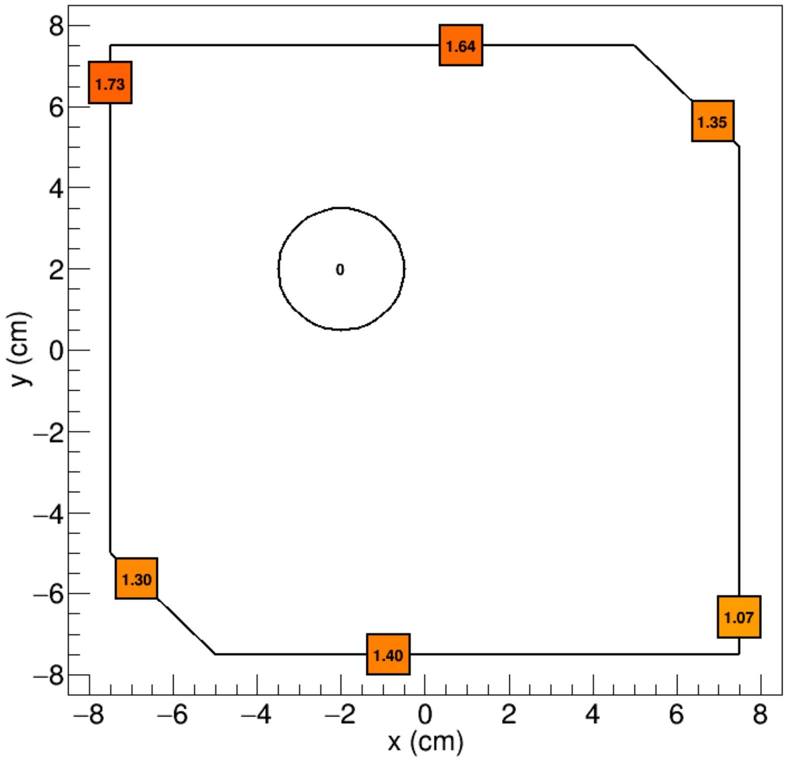
Large SiPMs



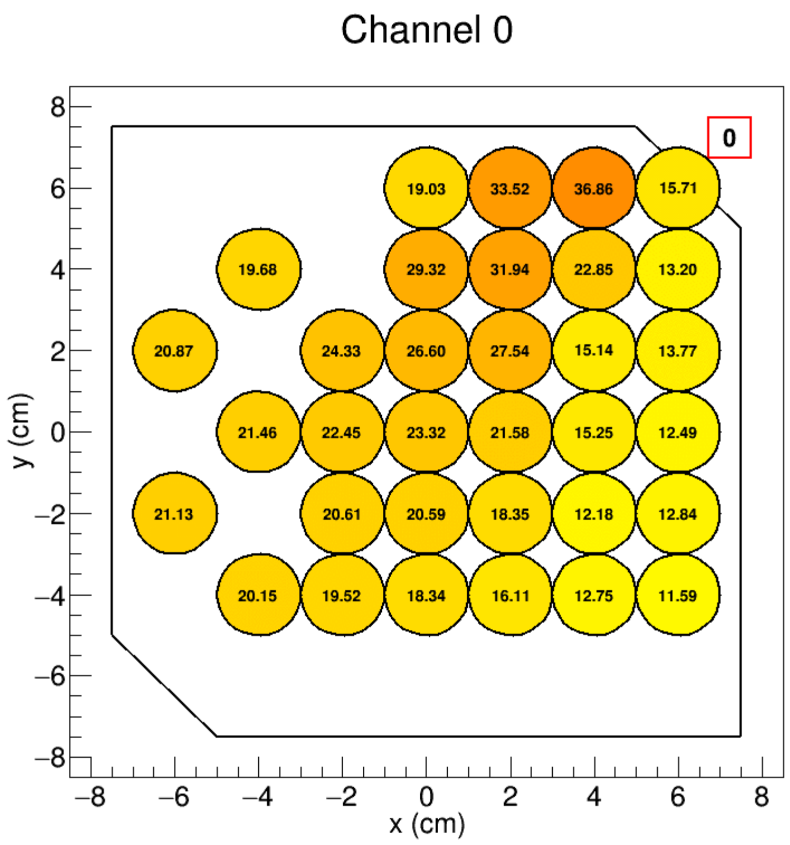
Small SiPMs



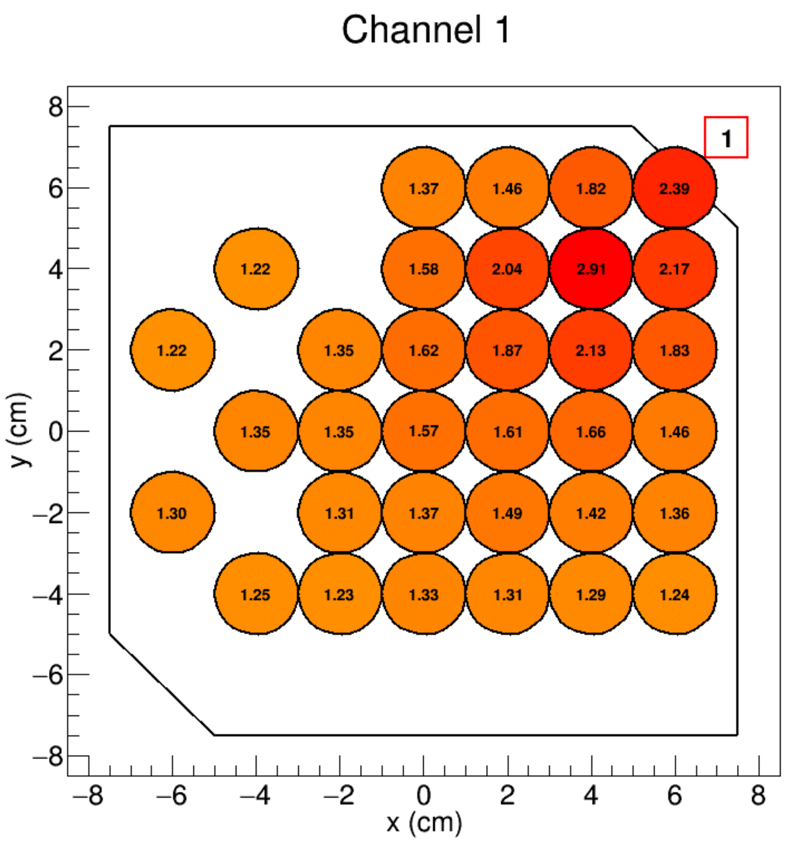
Yield for each SiPM

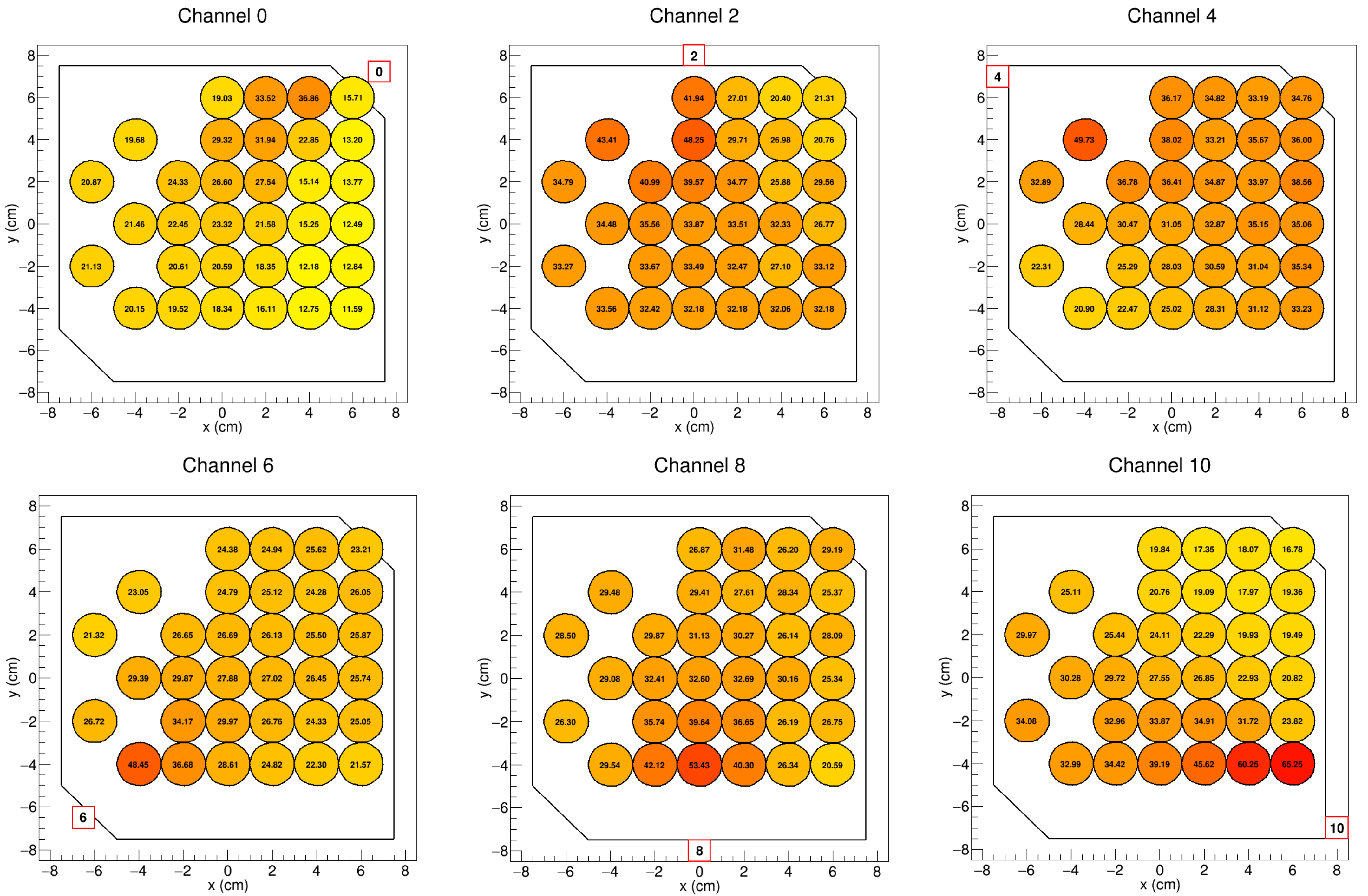
- Values represent the detected photons by the selected SiPM in all positions tested

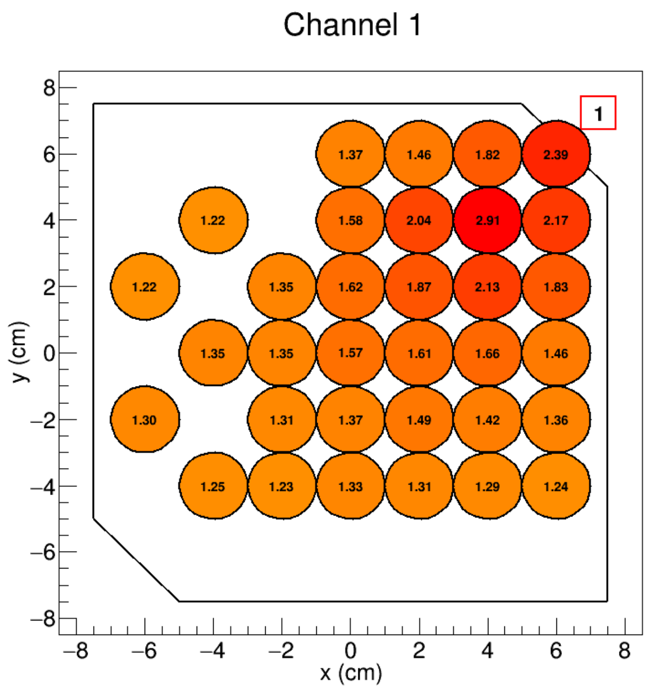
Large SiPMs



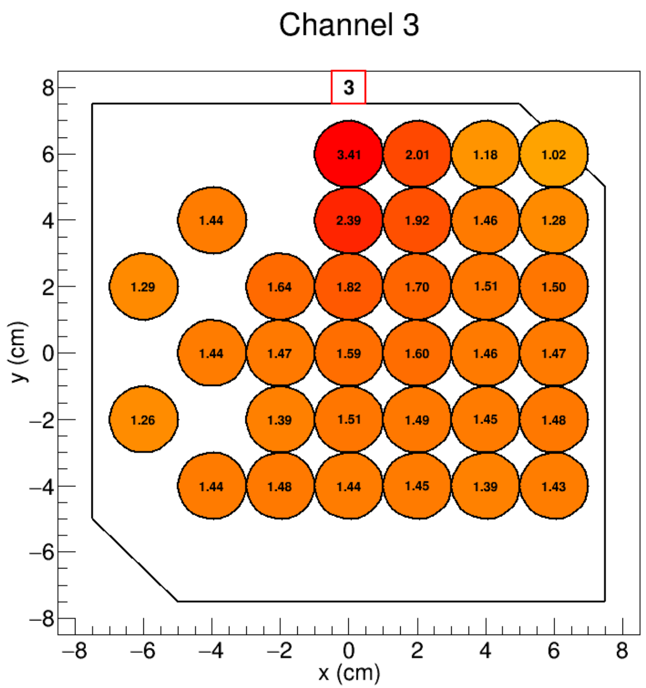
Small SiPMs



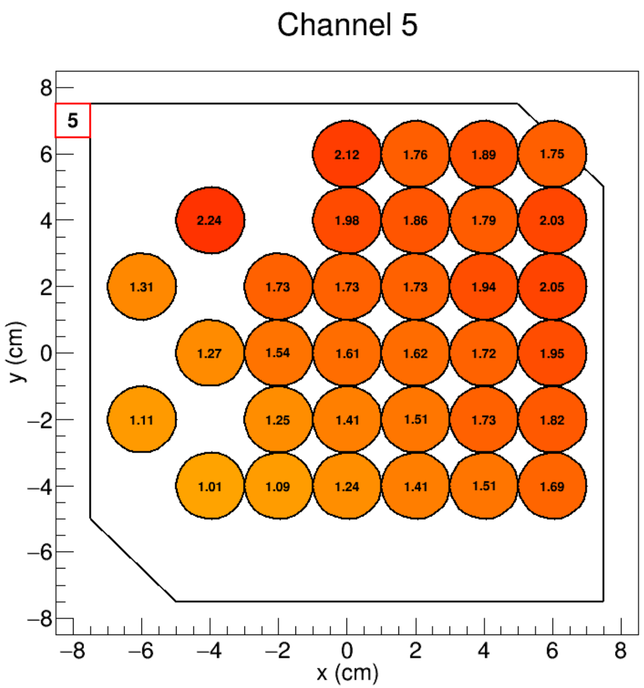

Channel 0
0
19.03 33.52 36.86 15.71
19.68 29.32 31.94 22.85 13.20
20.87 24.33 26.60 27.54 15.14 13.77
21.46 22.45 23.32 21.58 15.25 12.49
21.13 20.61 20.59 18.35 12.18 12.84
20.15 19.52 18.34 16.11 12.75 11.59
Channel 2
2
41.94 27.01 20.40 21.31
43.41 48.25 29.71 26.98 20.76
34.79 40.99 39.57 34.77 25.88 29.56
34.48 35.56 33.87 33.51 32.33 26.77
33.27 33.67 33.49 32.47 27.10 33.12
33.56 32.42 32.18 32.18 32.06 32.18
Channel 4
4
36.17 34.82 33.19 34.76
49.73 38.02 33.21 35.67 36.00
32.89 36.78 36.41 34.87 33.97 38.56
28.44 30.47 31.05 32.87 35.15 35.06
22.31 25.29 28.03 30.59 31.04 35.34
20.90 22.47 25.02 28.31 31.12 33.23
Channel 6
6
24.38 24.94 25.62 23.21
23.05 24.79 25.12 24.28 26.05
21.32 26.65 26.69 26.13 25.50 25.87
29.39 29.87 27.88 27.02 26.45 25.74
26.72 34.17 29.97 26.76 24.33 25.05
48.45 36.68 28.61 24.82 22.30 21.57
Channel 8
8
26.87 31.48 26.20 29.19
29.48 29.41 27.61 28.34 25.37
28.50 29.87 31.13 30.27 26.14 28.09
29.08 32.41 32.60 32.69 30.16 25.34
26.30 35.74 39.64 36.65 26.19 26.75
29.54 42.12 53.43 40.30 26.34 20.59
Channel 10
10
19.84 17.35 18.07 16.78
25.11 20.76 19.09 17.97 19.36
29.97 25.44 24.11 22.29 19.93 19.49
30.28 29.72 27.55 26.85 22.93 20.82
34.08 32.96 33.87 34.91 31.72 23.82
32.99 34.42 39.19 45.62 60.25 65.25
x (cm)
y (cm)



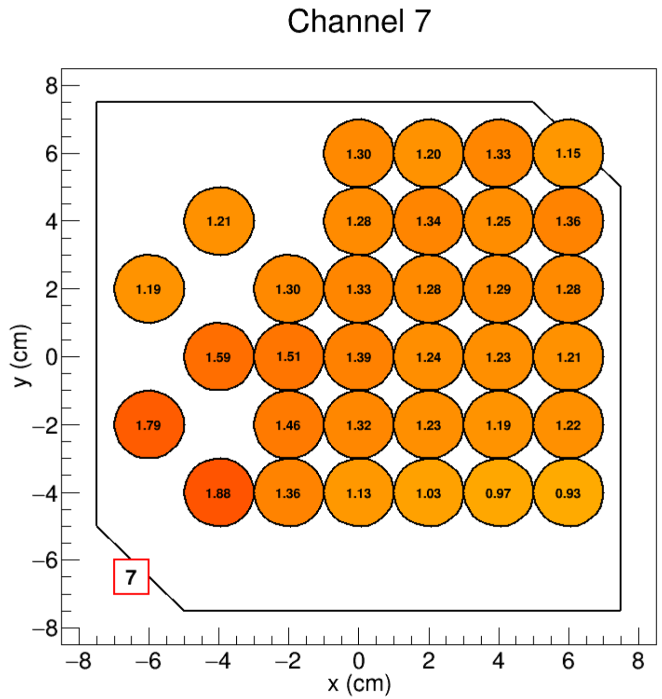
Channel 1
1
1.37 1.46 1.82 2.39
1.22 1.58 2.04 2.91 2.17
1.22 1.35 1.62 1.87 2.13 1.83
1.35 1.35 1.57 1.61 1.66 1.46
1.30 1.31 1.37 1.49 1.42 1.36
1.25 1.23 1.33 1.31 1.29 1.24
y (cm)
x (cm)



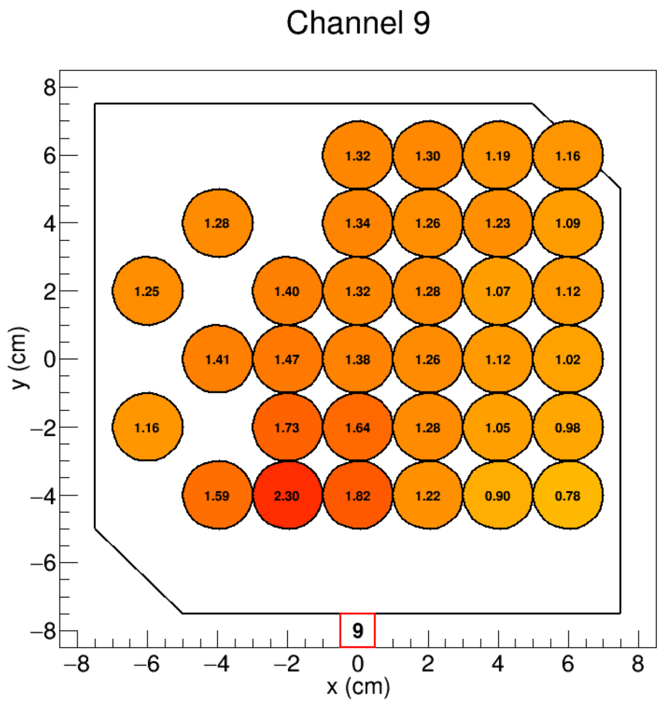
Channel 3
3
3.41 2.01 1.18 1.02
1.44 2.39 1.92 1.46 1.28
1.29 1.64 1.82 1.70 1.51 1.50
1.44 1.47 1.59 1.60 1.46 1.47
1.26 1.39 1.51 1.49 1.45 1.48
1.44 1.48 1.44 1.45 1.39 1.43
y (cm)
x (cm)



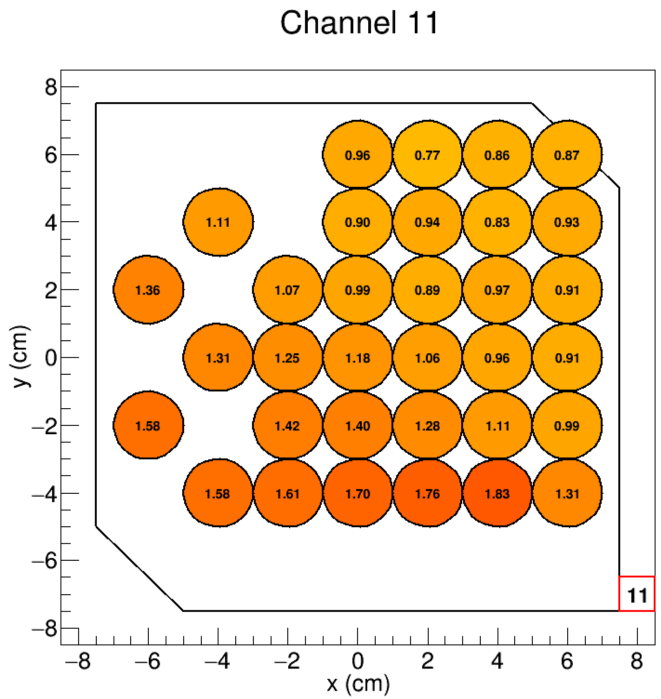
Channel 5
5
2.12 1.76 1.89 1.75
2.24 1.98 1.86 1.79 2.03
1.31 1.73 1.73 1.73 1.94 2.05
1.27 1.54 1.61 1.62 1.72 1.95
1.11 1.25 1.41 1.51 1.73 1.82
1.01 1.09 1.24 1.41 1.51 1.69
y (cm)
x (cm)



Channel 7
1.30 1.20 1.33 1.15
1.21 1.28 1.34 1.25 1.36
1.19 1.30 1.33 1.28 1.29 1.28
1.59 1.51 1.39 1.24 1.23 1.21
1.79 1.46 1.32 1.23 1.19 1.22
1.88 1.36 1.13 1.03 0.97 0.93
7
y (cm)
x (cm)



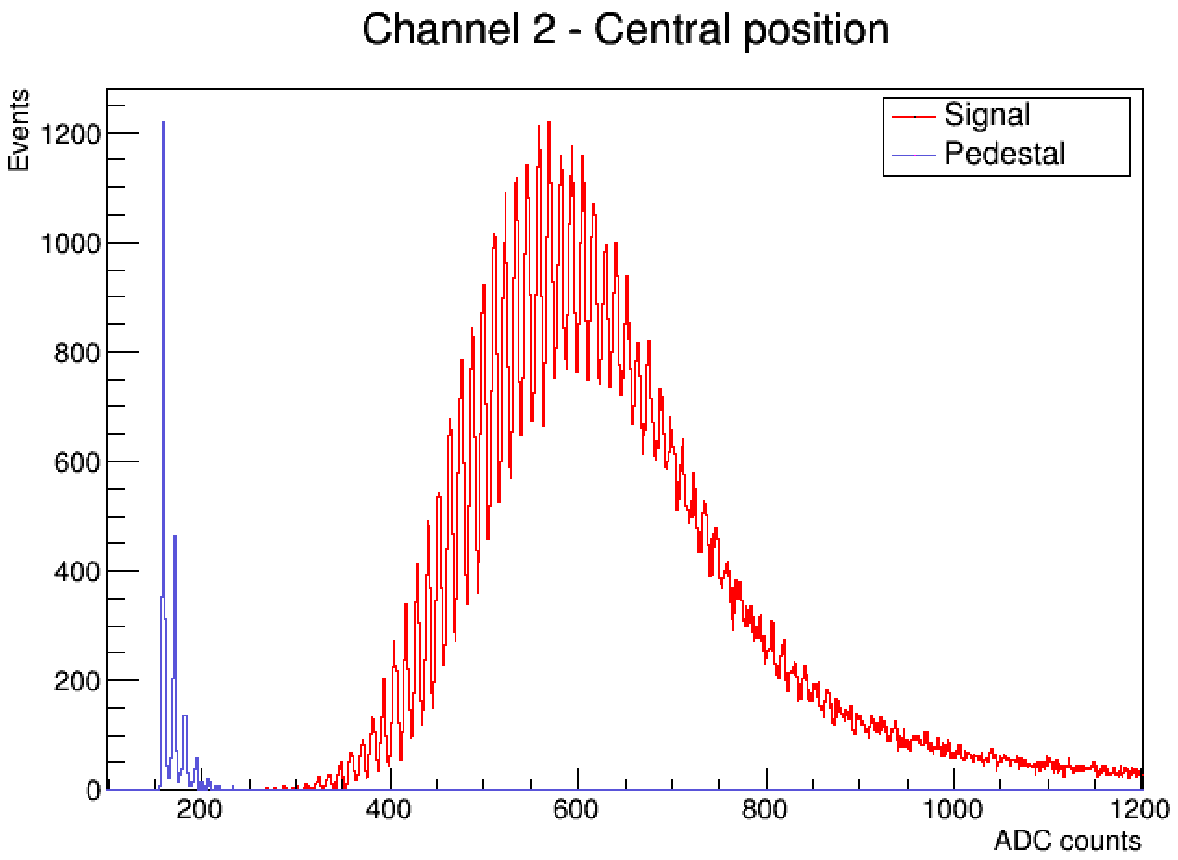
Channel 9
1.32 1.30 1.19 1.16
1.28 1.34 1.26 1.23 1.09
1.25 1.40 1.32 1.28 1.07 1.12
1.41 1.47 1.38 1.26 1.12 1.02
1.16 1.73 1.64 1.28 1.05 0.98
1.59 2.30 1.82 1.22 0.90 0.78
9
y (cm)
x (cm)



Channel 11
0.96 0.77 0.86 0.87
1.11 0.90 0.94 0.83 0.93
1.36 1.07 0.99 0.89 0.97 0.91
1.31 1.25 1.18 1.06 0.96 0.91
1.58 1.42 1.40 1.28 1.11 0.99
1.58 1.61 1.70 1.76 1.83 1.31
11
y (cm)
x (cm)

SPS data

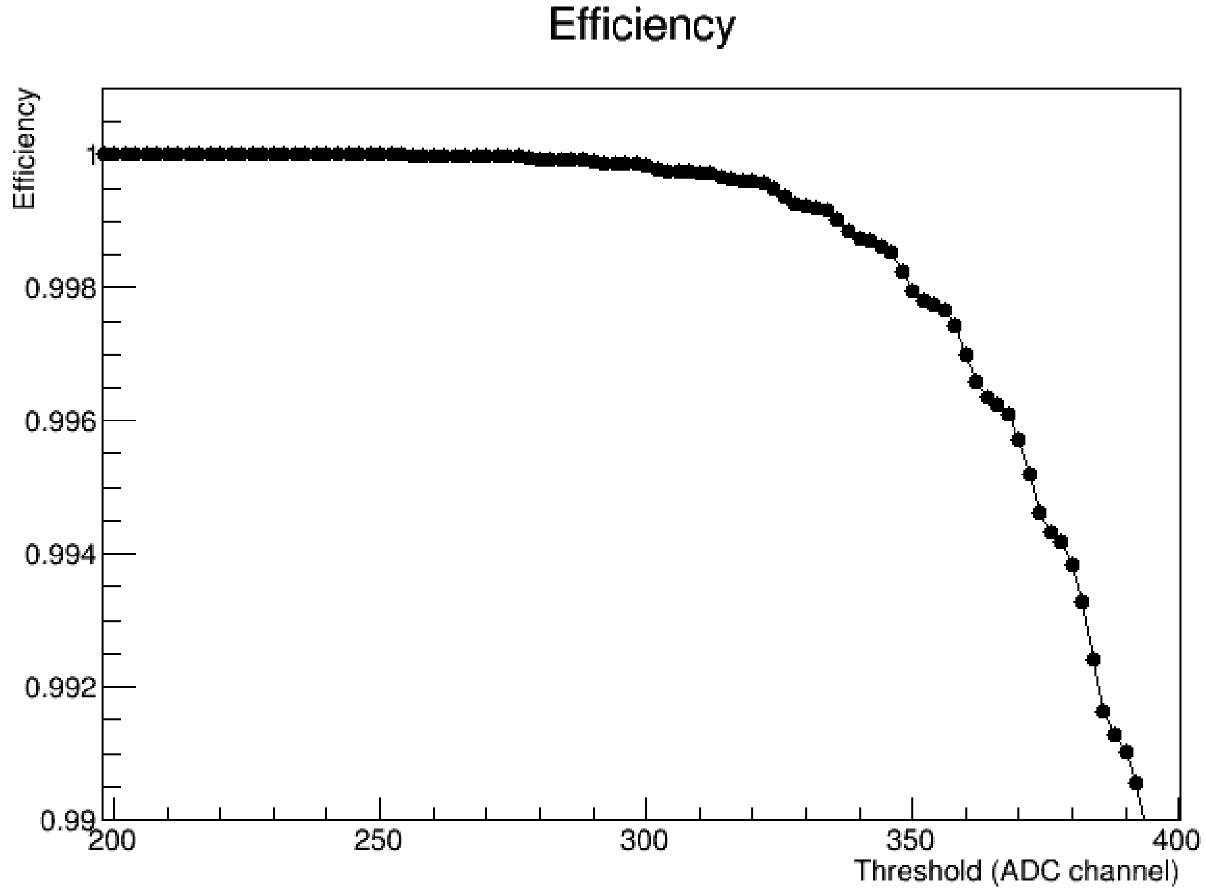
- Scintillator irradiated in the central position with 20 GeV particles



- Good separation of signal and pedestal
- Individual peaks visible up to 40-50 photons

Efficiency (for a large SiPM)

- Efficiency is evaluated as the area of the histogram as a function of the threshold
- The visible steps are due to the individual peaks in the distribution



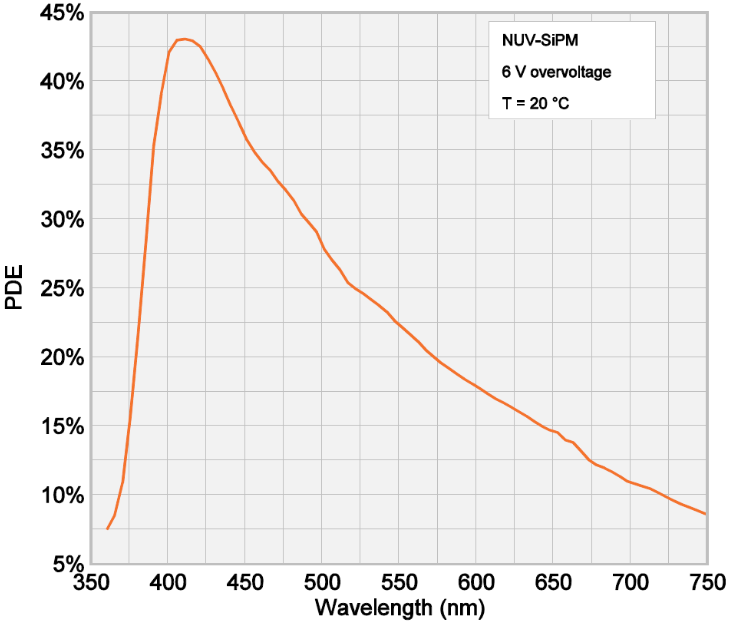
Conclusions

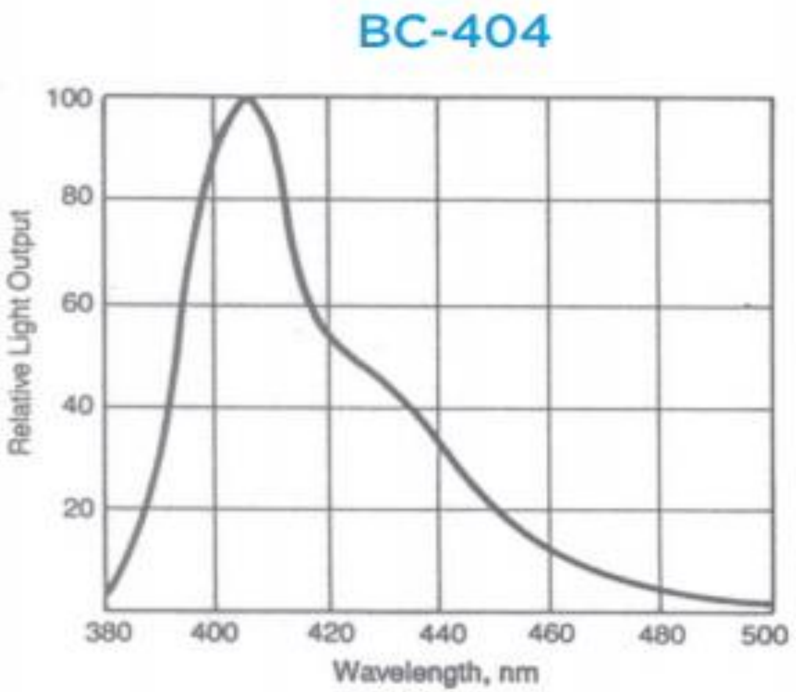
- Small SiPMs detect too few photons
  - Useful to extend the dynamic range to detect/reject ions
- Response is almost uniform in the tile, with peaks in the points closer to the SiPMs
- Efficiency reached with this configuration is close to the requirements of ACD detectors for satellites
  - Improvements can be obtained by summing the signals from individual SiPMs or by implementing coincidences among multiple SiPMs
- Future plans:
  - Repeat tests with a new scintillator and SiPMs
  - Test with cosmic rays or a radioactive source in lab
  - New beam tests

Backup

Scintillator

FBK NUV SiPM
Photon detection efficiency





	BC-400	BC-404	BC-408	BC-412	BC-416
Radiation Detected					
<100keV X-rays			X		
100keV to 5MeV gamma rays				X	
>5MeV gamma rays	X				
Fast neutrons				X	X
Alphas, betas	X	X	X		
Charged particles,cosmic rays, muons, protons, etc.			X	X	X
Principal Uses/Applications	general purpose	fast counting	TOF large area	large area	large area economy
Scintillation Properties					
Light Output, %Anthracene	65	68	64	60	38
Rise Time, ns	0.9	0.7	0.9	1.0	-
Decay Time (ns)	2.4	1.8	2.1	3.3	4.0
Pulse Width, FWHM, ns	2.7	2.2	~2.5	4.2	5.3
Wavelength of Max. Emission, nm	423	408	425	434	434
Light Attenuation Length, cm*	160	140	210	210	210
Bulk Light Attenuation Length, cm	250	160	380	400	400
Atomic Composition					
No. H Atoms per cc ($x10^{22}$)	5.23	5.21	5.23	5.23	5.25
No. C Atoms per cc ($x10^{22}$)	4.74	4.74	4.74	4.74	4.73
Ratio H:C Atoms	1.103	1.100	1.104	1.104	1.110
No. of Electrons per cc ($x10^{23}$)	3.37	3.37	3.37	3.37	3.37

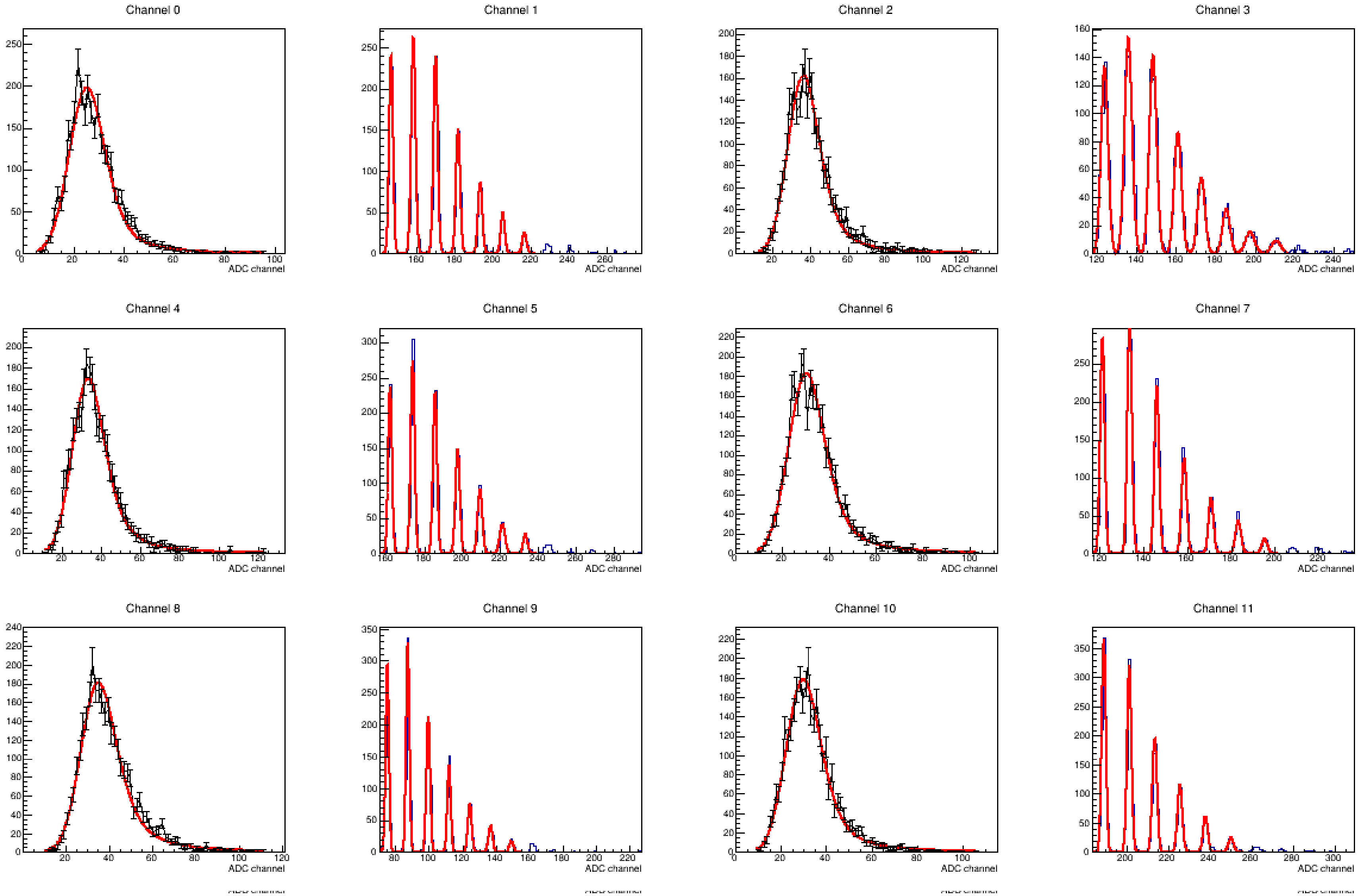
*The typical 1/e attenuation length of a 1x20x200cm cast sheet with edges polished as measured with a bialkali photomultiplier tube coupled to one end.

General Technical Data -

Base	Polyvinyltoluene
Density [g/cc]	1.032
Expansion Coefficient (per°C,<67°C)	$7.8X10^{-5}$
Refractive index	1.58
Softening Point	70°C
Vapor Pressure	May be used in vacuum
Solubility	Soluble in aromatic solvents, chlorinated solvents, acetone, etc. Unaffected by water, dilute acids, lower alcohols, alkalis and pure silicone fluids or grease.
Light Output	At +60°C = 95% of that at+20°C. Independent of temperature from -60°C to +20°C

FBK NUV SiPM photon detection efficiency perfectly match the yield spectrum of the plastic scintillator

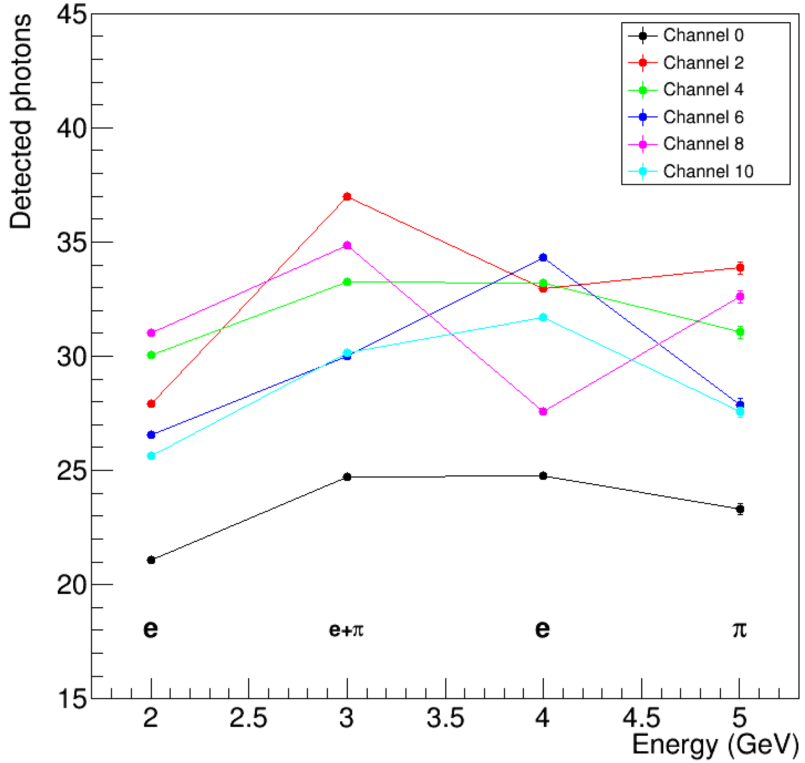
Example channels



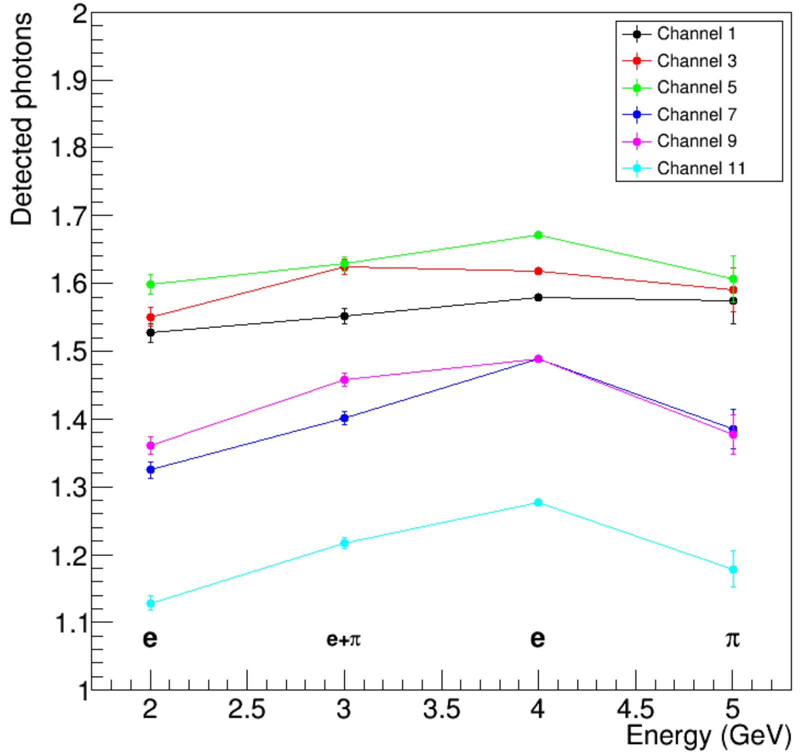
Energy dependence

- Photons detected vs energy of the beam
- Central position
- Runs taken with different trigger configurations : different particles

Large SiPMs



Small SiPMs



- No energy dependence is observed