Geometrical considerations on hexagonal SiPMs

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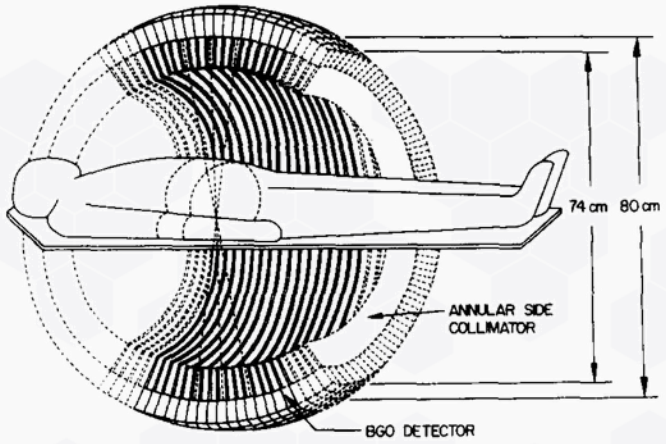
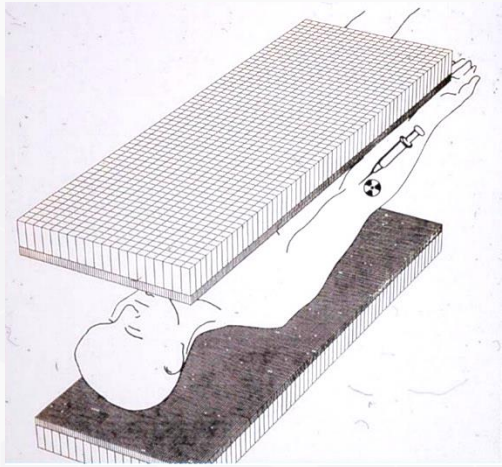
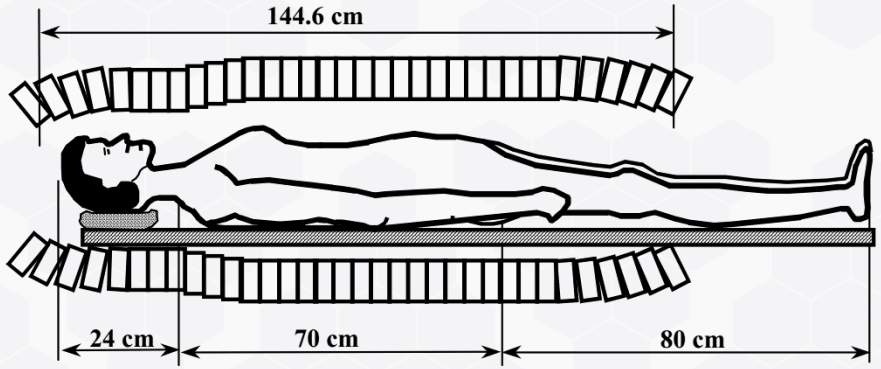
Introduction



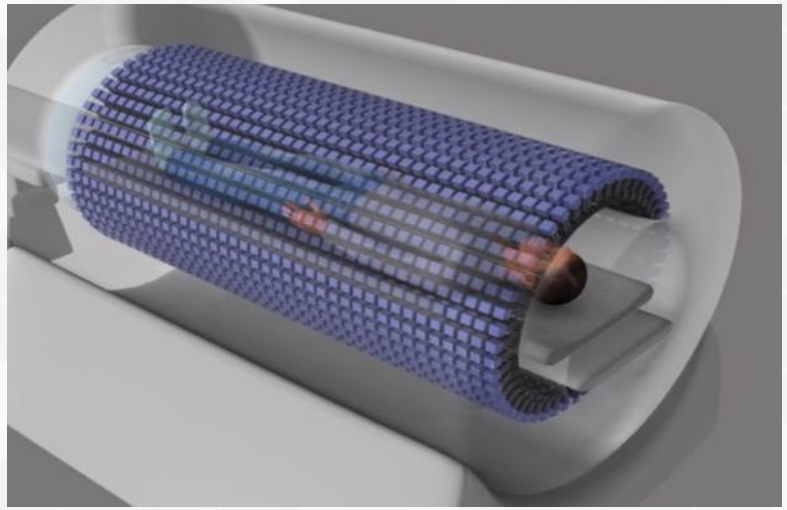
*Z. Cho, **1984***



T. Jones, **1990**

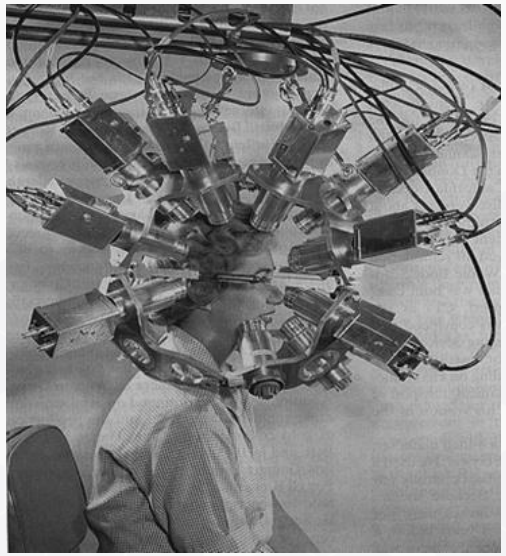


*D. B. Crosetto, **2000***



*S.R. Cherry, **2017***

Organ dedicated PET: BRAIN

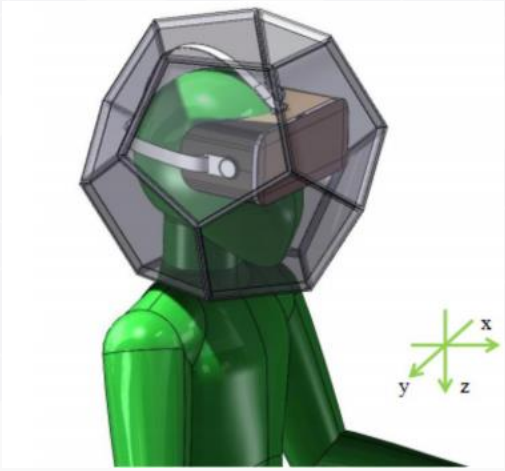


B.N.L., **1966**

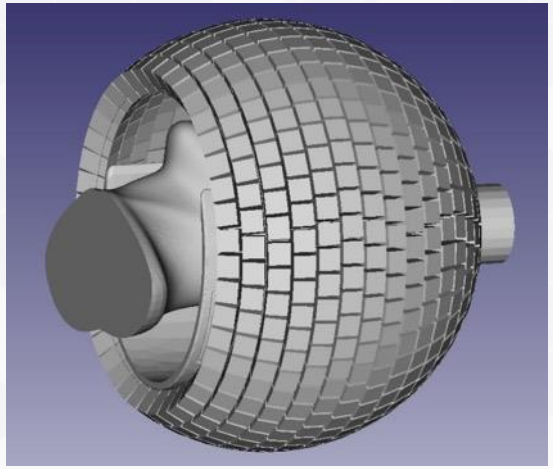
J. Robertson, **1972**

Tashima, **2015**

C. E. Bauer, **2016**

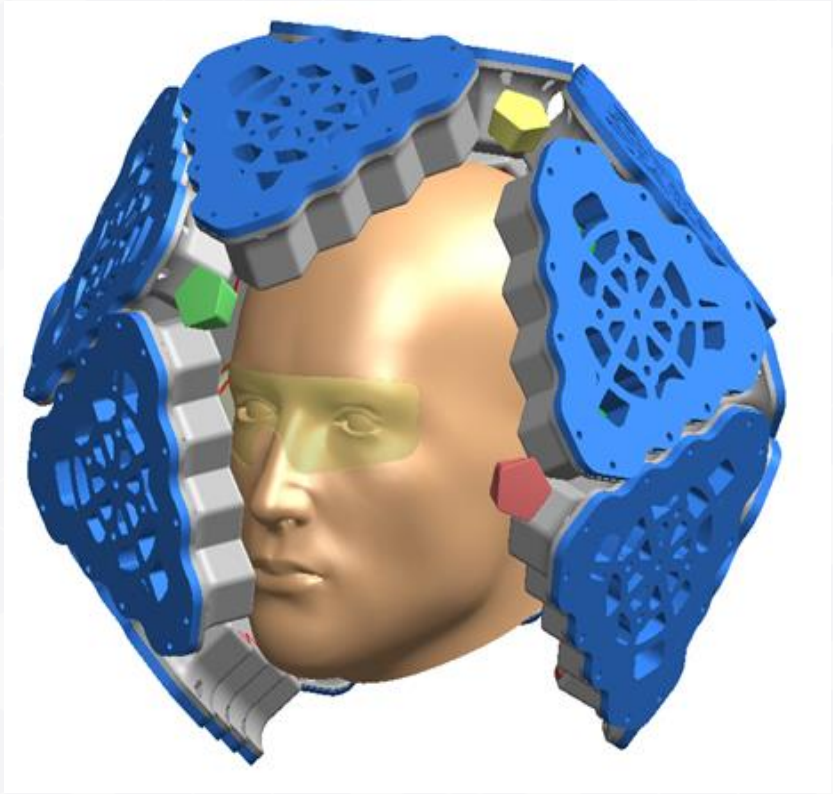


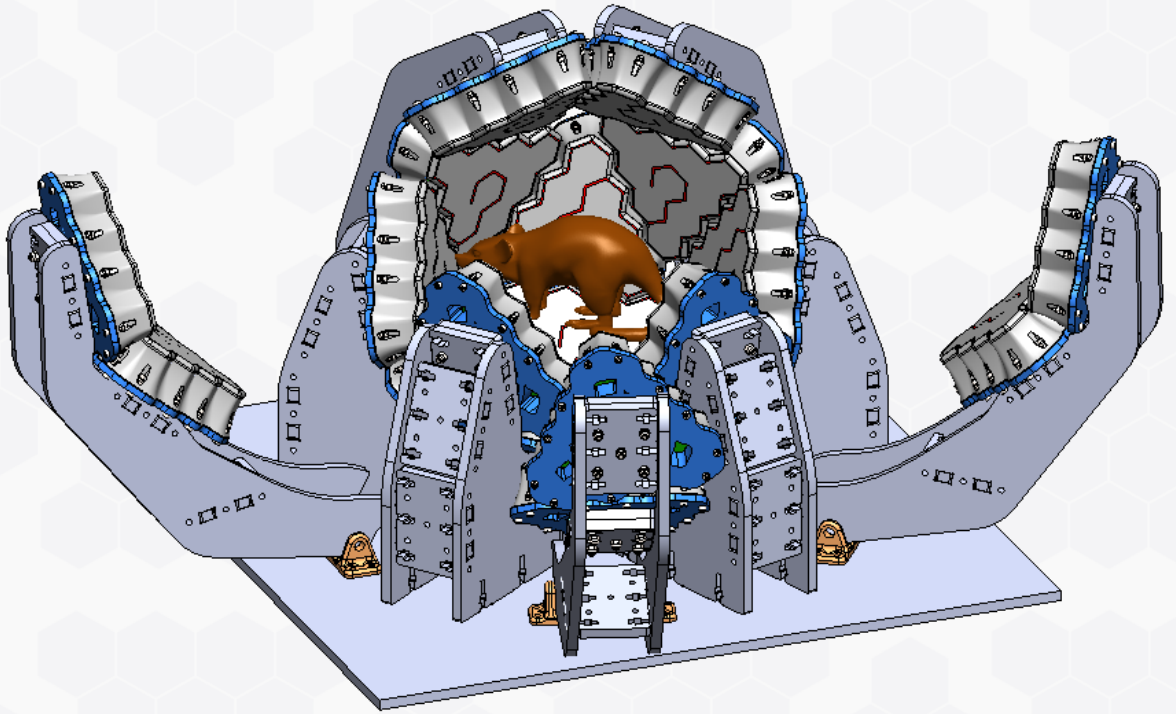
Tao,**2018**



C. Catana, **2019**

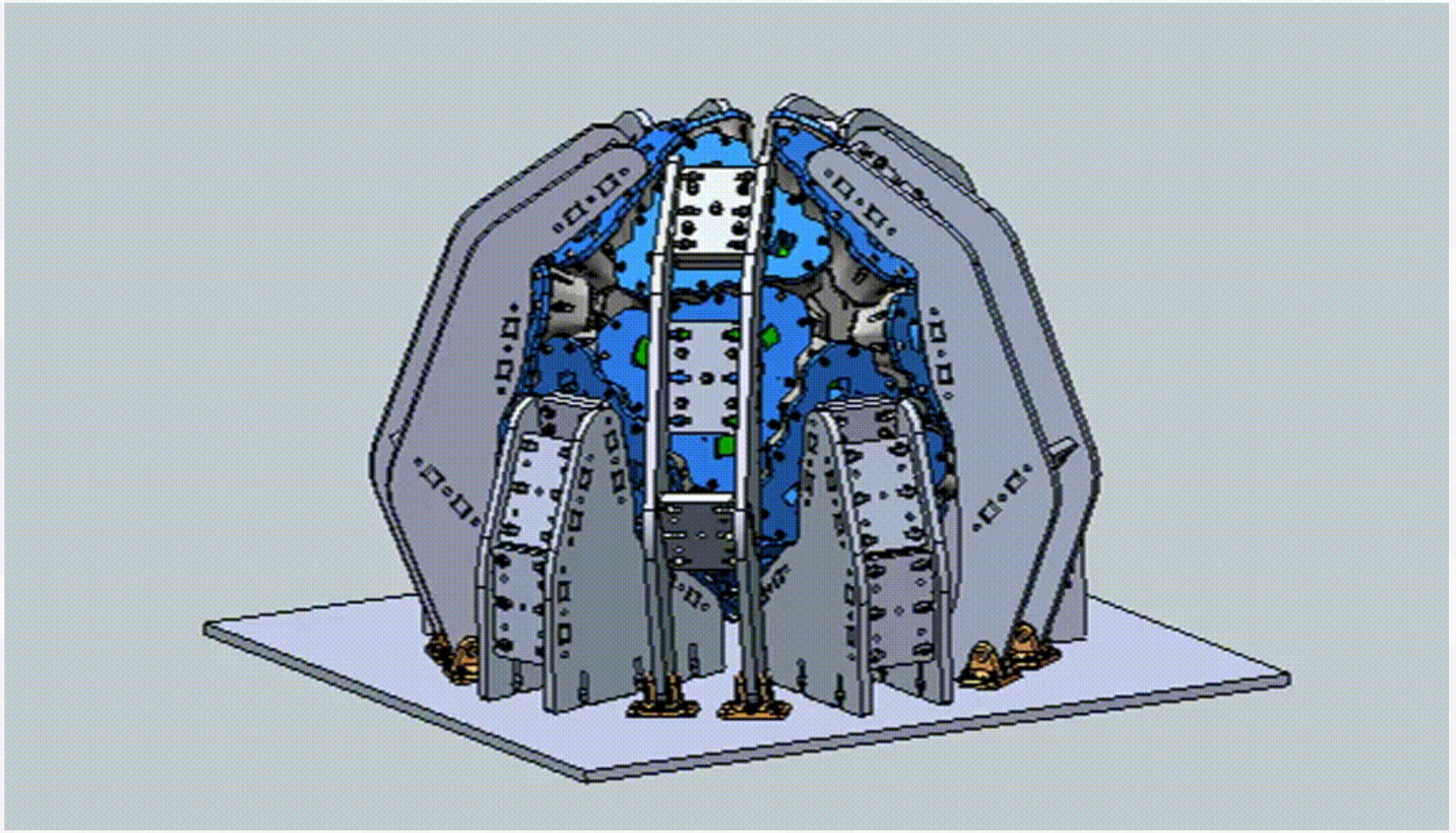
IcoPET





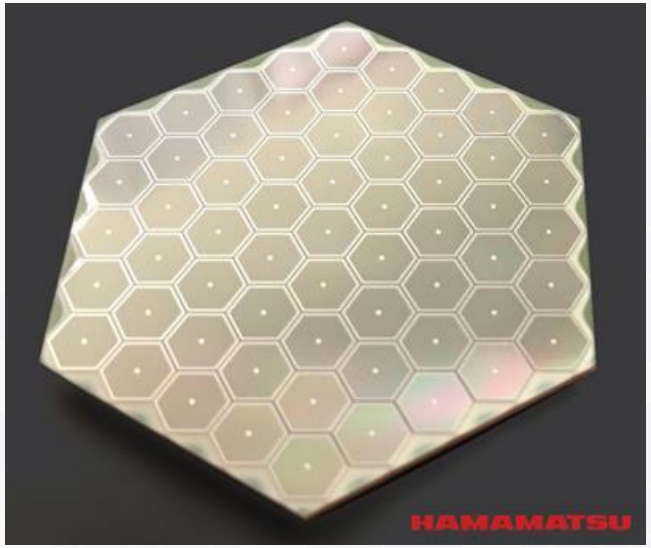
Perez-Benito, D. et al. (2017)

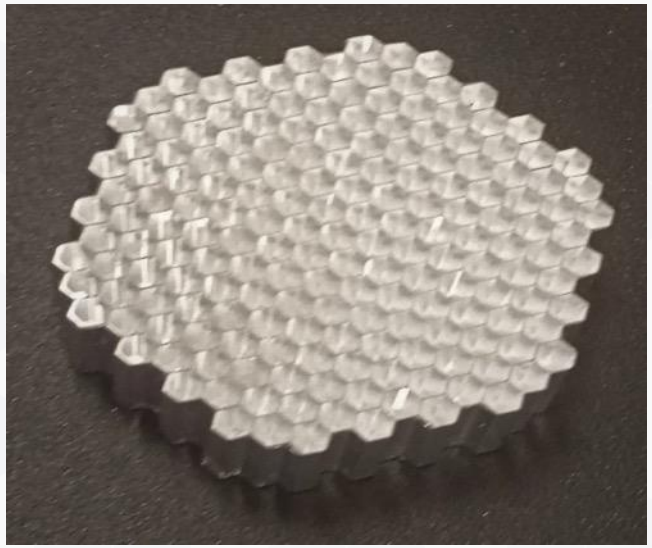
IcoPET

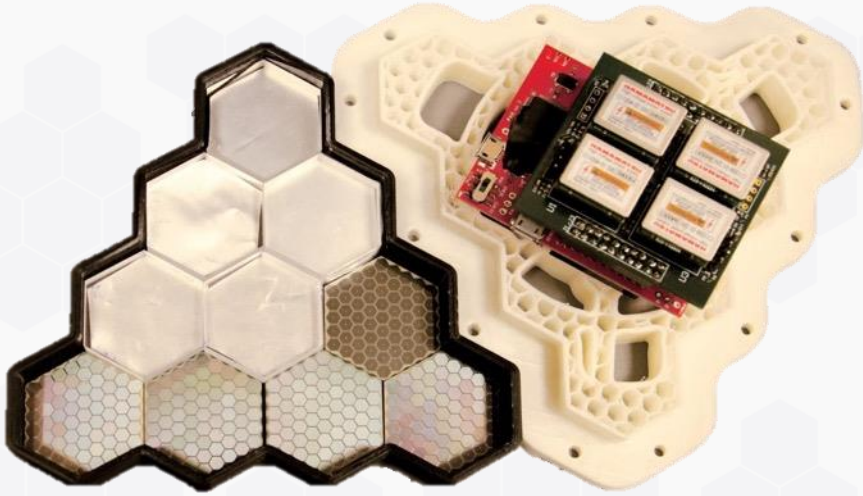


Perez-Benito, D. et al. (2019). SiPM-based PET detector module for a 4π span scanner. Nuclear Instruments and Methods in Physics Research,, 936(18-21), 01689002

Hexagonal detector







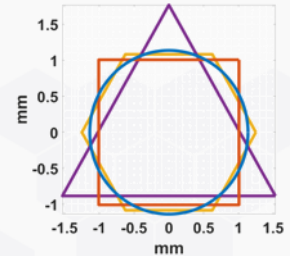
- **Multi-Pixel Photon Counters (MPPC) with 61 channels of 2.25 mm of edge with 2.0 mm of photosensitive surface.**
- **Through silicon via and Optical isolation trench**

- **Hexagonal scintillators of 1.25 mm of edge.**
- **Section ratio 1:3 with respect to photosensitive channel.**
- **181 crystals with ESR reflector and polished finish**

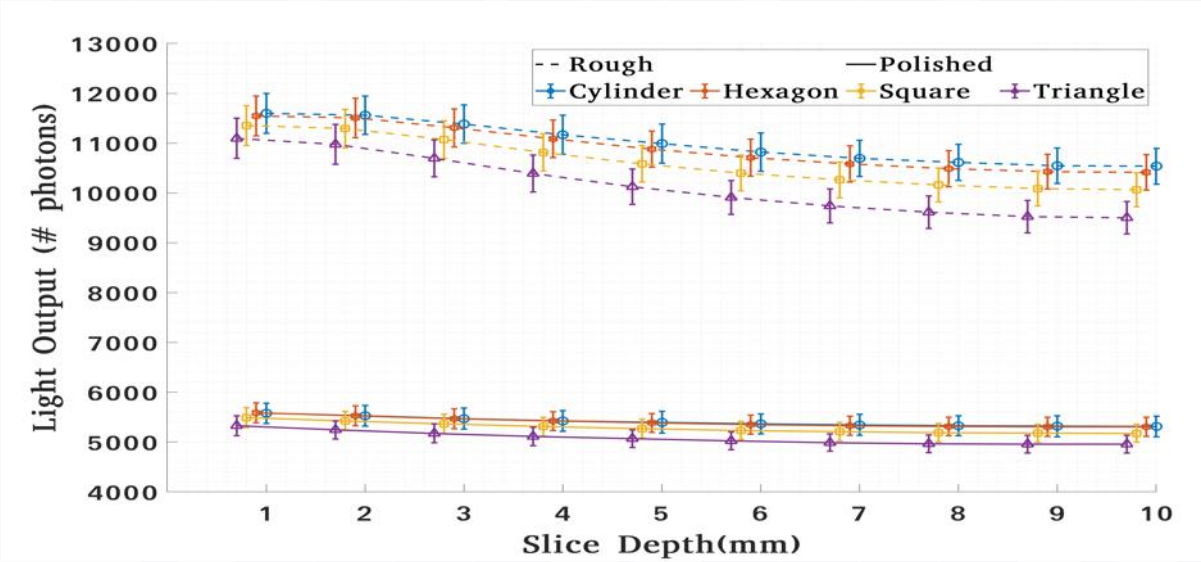
- **Face of 155 mm.**
- **10 scintillators of 10 mm of thickness.**
- **Diameter of the inscribed sphere of 234 mm.**
- **Solid angle coverage of 81% with respect to 4π coverage.**
- **FOV of 152 mm.**

Scintillation geometrical considerations: simulations

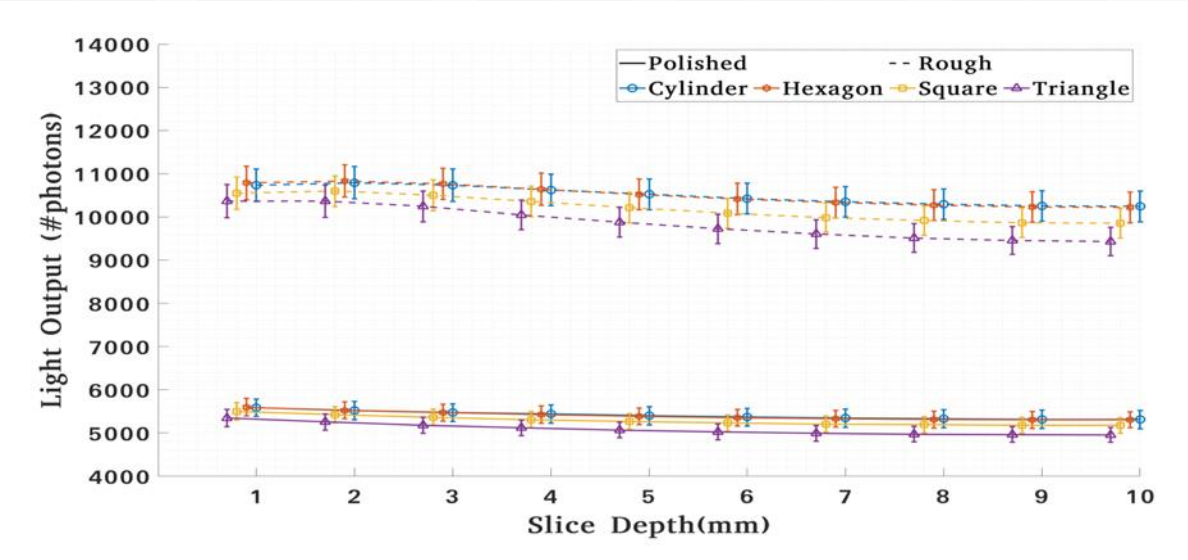
How does affect the hexagonal geometry to the light output?



Lambertian reflector (Teflon)



Specular reflector (ESR)

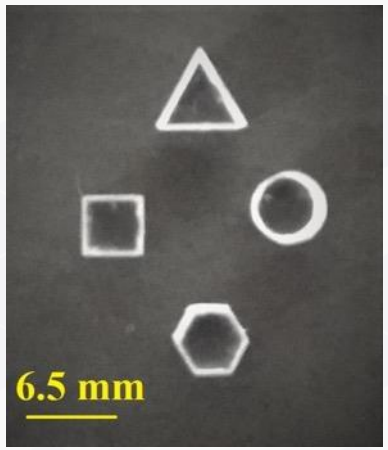


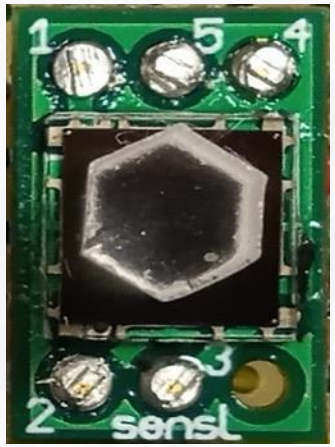
Energy Resolution (%)

	Rough ESR	Polished ESR	Rough Teflon	Polished Teflon
Cylinder	9.72	10.49	11.98	10.48
Hexagon	10.06	9.82	12.30	9.78
Square	10.80	10.03	13.32	10.03
Triangle	12.33	10.56	12.81	10.50

- **Rough finish provides better light output but fewer uniformity**
- **Specular reflector contributes to uniformity**

Experimental validation

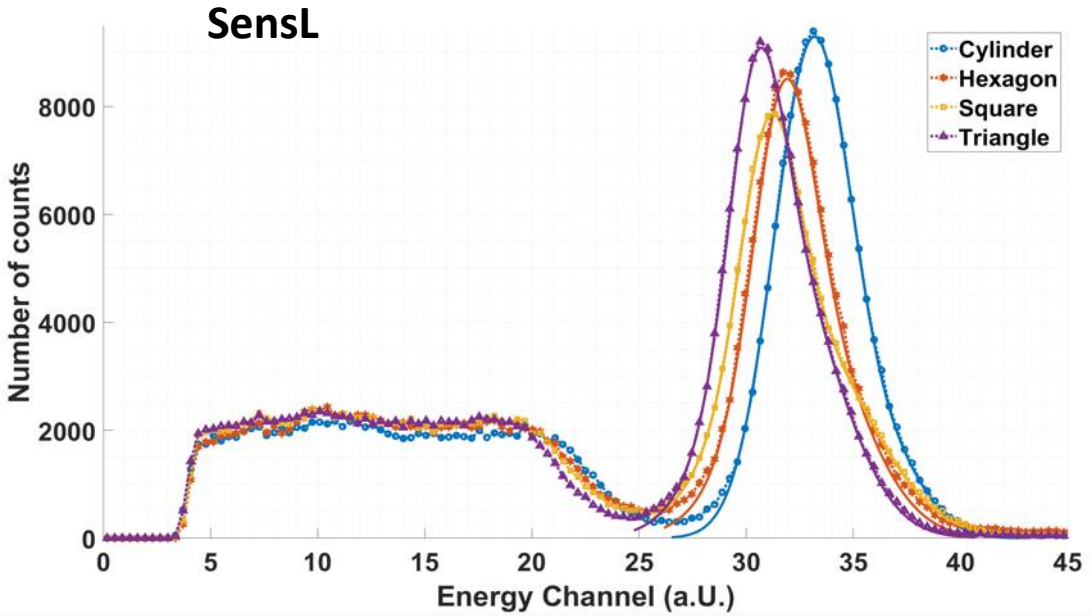


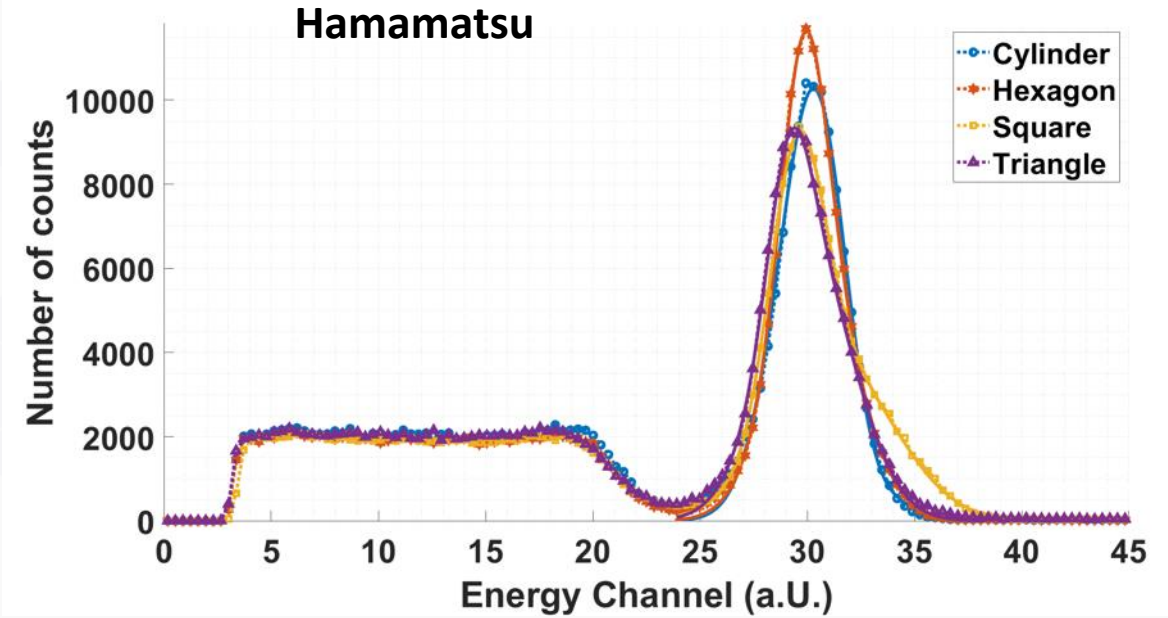


	SensL	*Hamamatsu*
Fill factor	64%	74%
Number of microcells	18,980	14,331
Microcell size	35 μm	50 μm
Peak wavelength	420 nm	450 nm
Voltage breakdown (V_{BR})	24.2 V	38 V
Recommended Operating Voltage	V_{BR}+5 V	V_{BR}+2.7 V
Temperature dependence	21.5 $\frac{mV}{C°}$	34 $\frac{mV}{C°}$
Microcell recharge time	90 ns	xx
Encapsulant refractive Index	1.59	1.57

Energy Resolution (%)

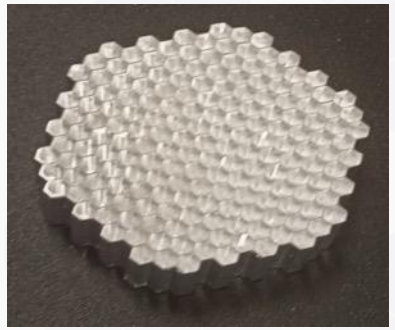
	*S*14160	*MICROFC*
Cylinder	13.4%	11.9%
Hexagon	13.2%	10.9%
Square	14.4%	12.8%
Triangle	13.9%	13.2%

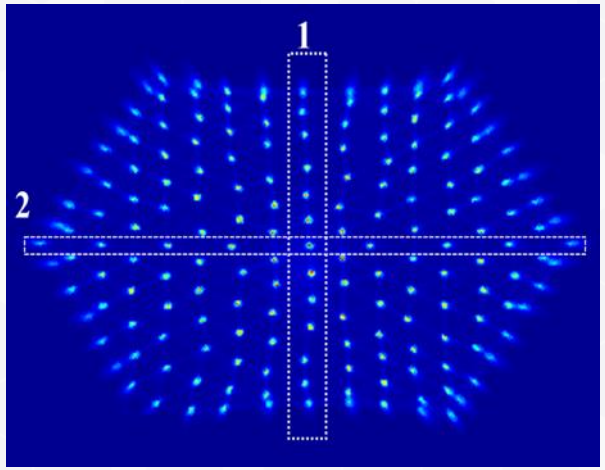




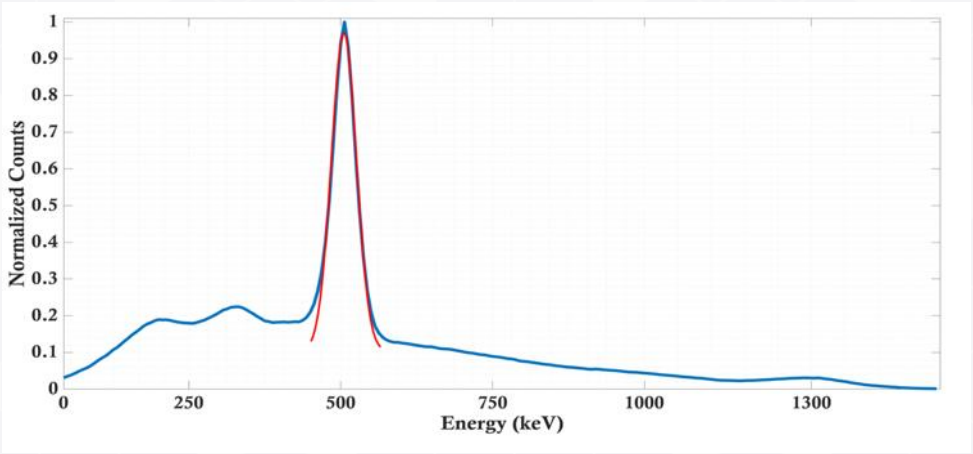
Field Flood of hexagonal detector

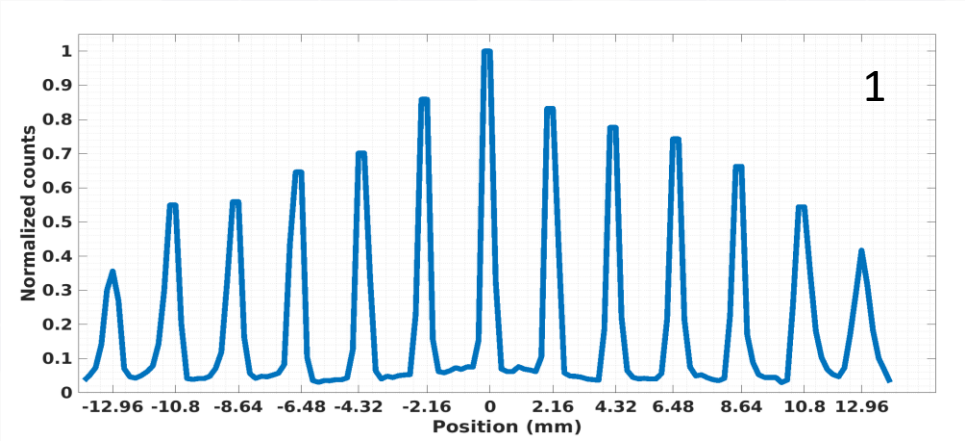
- **Uniform irradiation with ^{22}Na**
- **<u>Multiplexing</u> with 4 channels along XY axis**

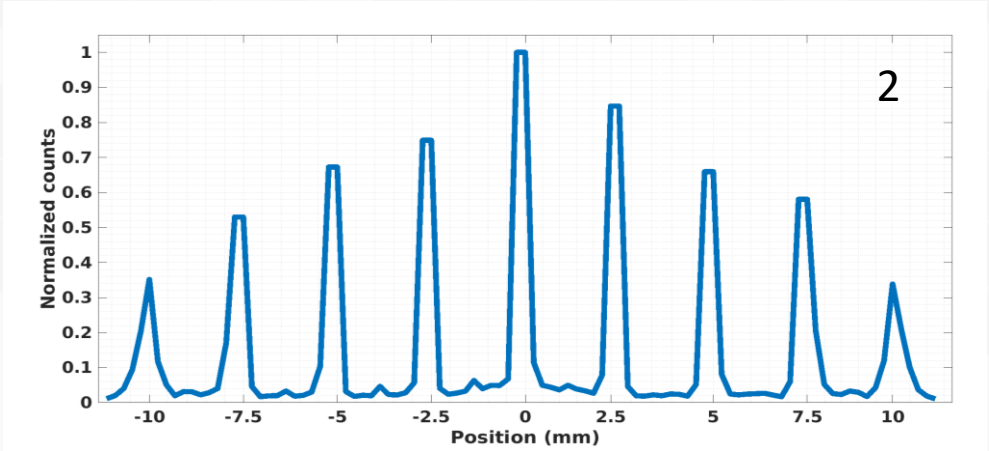




- **Mean Energy Resolution: 5.5 %**
- **Mean peak to valley ratio over 20**

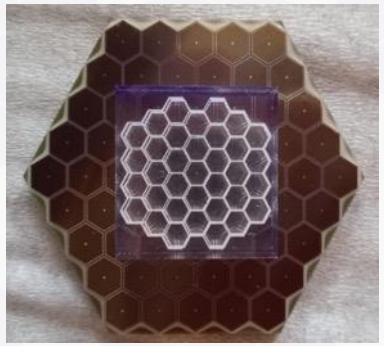


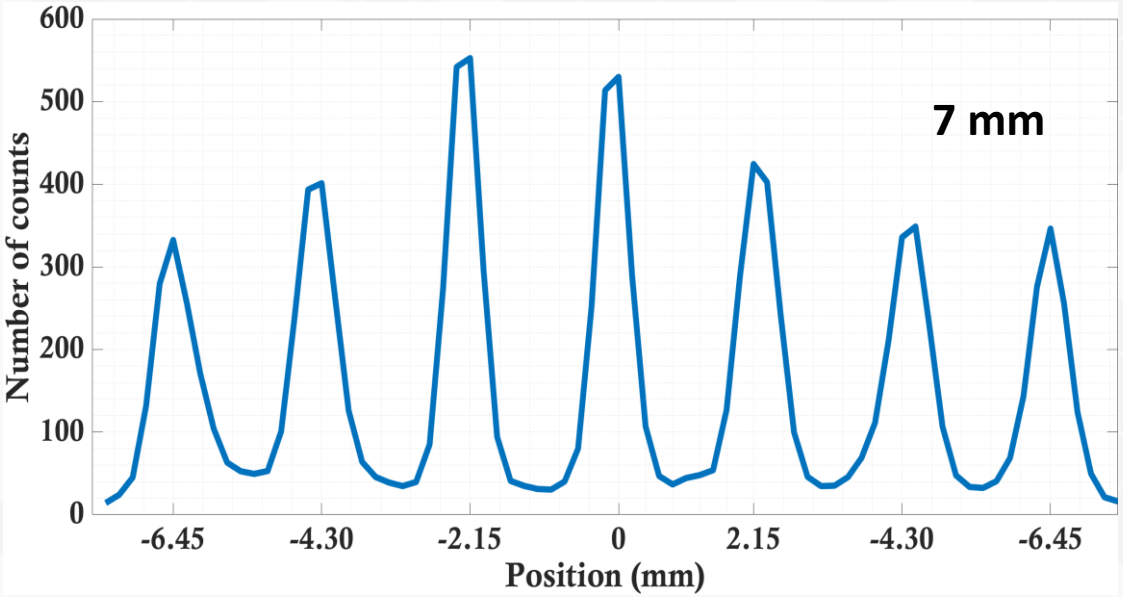


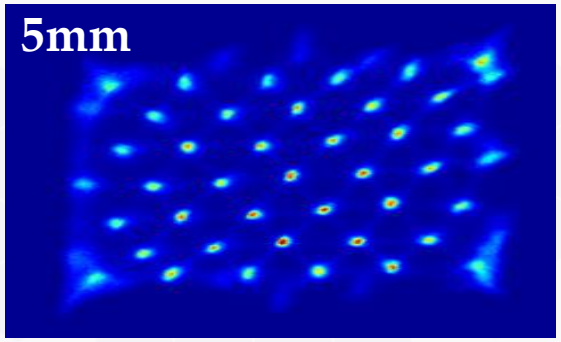


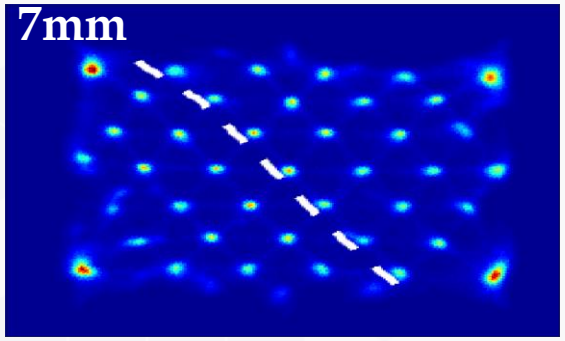
Laser Engraving – Field Flood

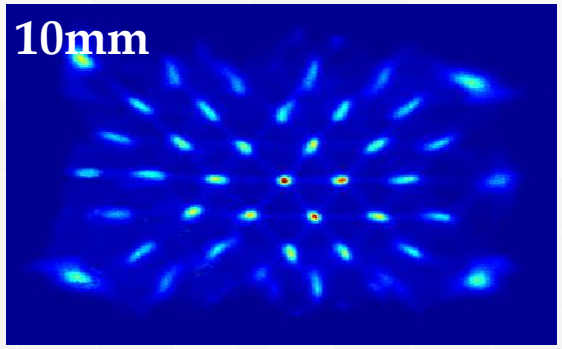
- **Individual** readout hexagonal SiPM
- Uniform irradiation with ^{22}Na
  (no energy window, singles)
- Hexagons of 1.25 mm of edge
- Black painted scintillator

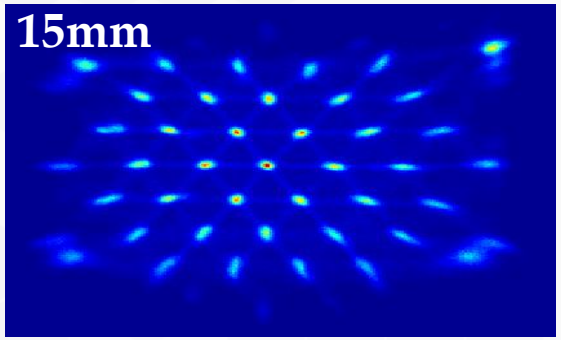








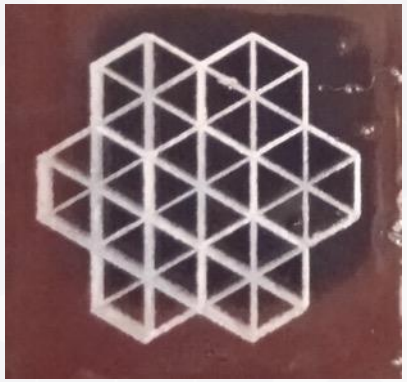


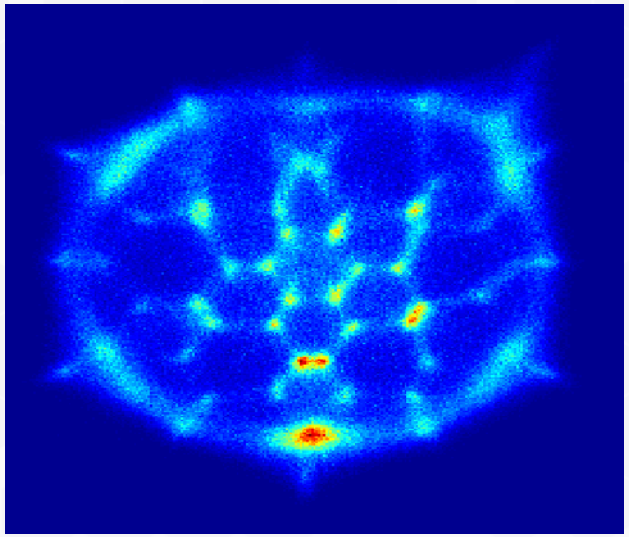


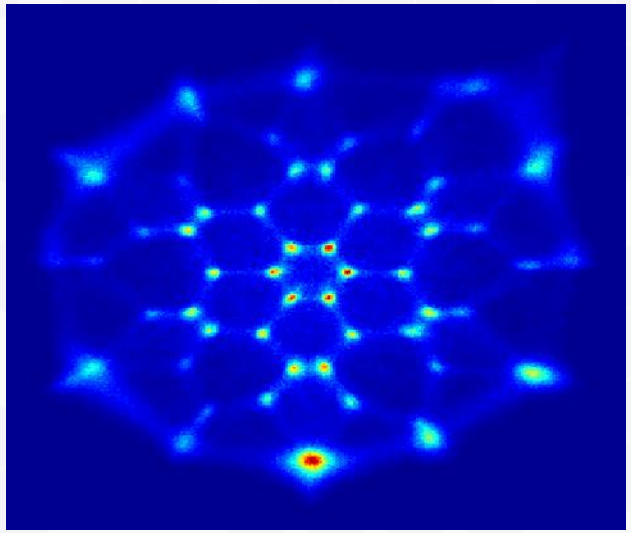
	Peak to Valley		
	Center	Edge	Mean
5mm	18.8	6.7	13.0
7mm	16.1	5.4	9.6
10mm	12.0	5.1	8.2
15mm	10.8	4.7	7.2

Laser Engraving – Triangular crystals

- **Optical permeability can be controlled with the engraving density**
- **42 triangular crystals of 1.25 mm of edge**
- **Individual readout hexagonal SiPM**
- **Uniform irradiation with ^{22}Na**
- **Black painted scintillator**

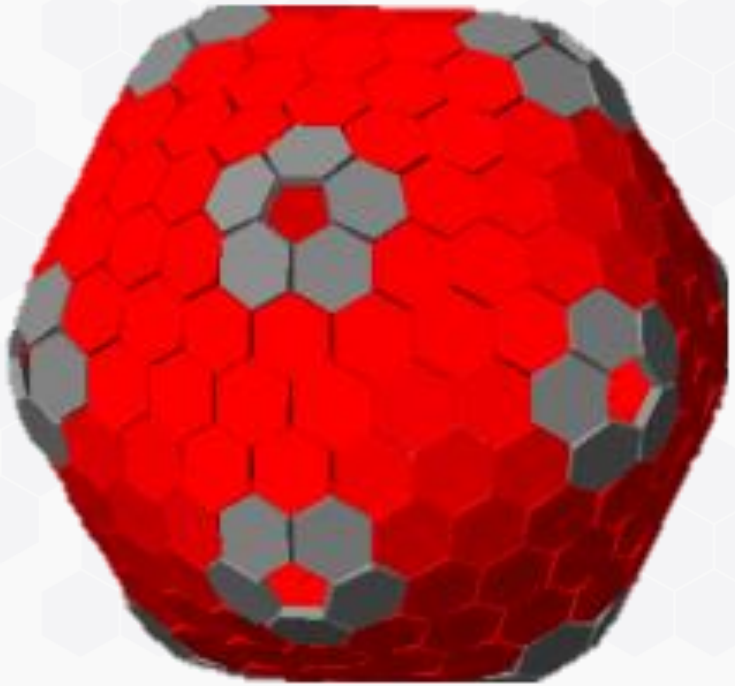


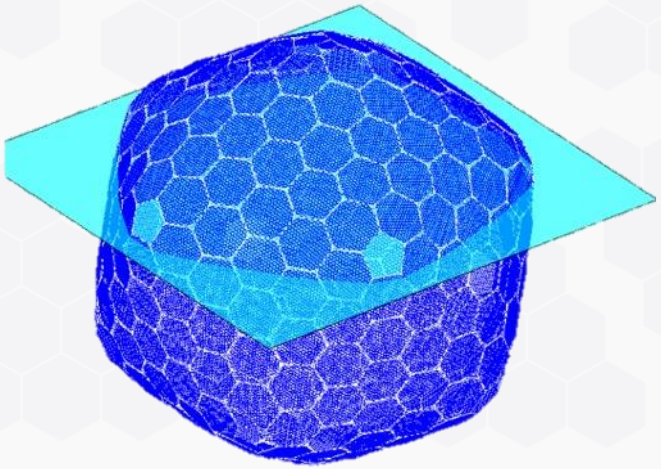


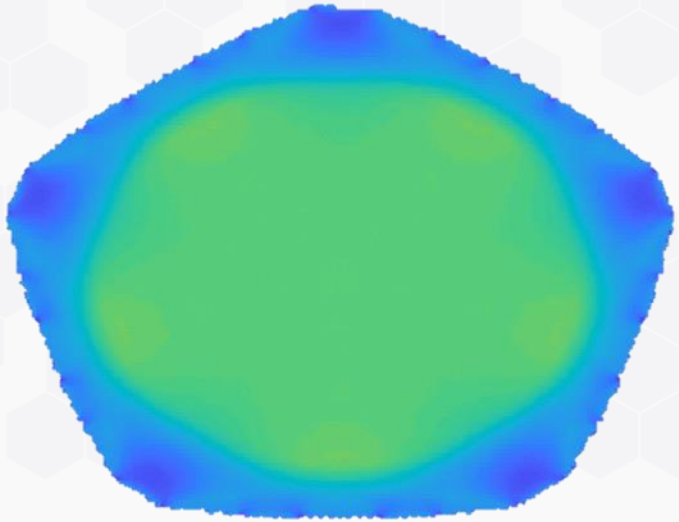


Fullerene

- **Diameter between 26.05 and 28.92 cm**
- **260 hexagonal blocks of 17.61 mm**
- **181 hexagonal crystals for a total of 47,060 crystals**
- **Solid angle coverage of 91.9% over 4π**
- **Analytical sensitivity of 30.7%**
- **498 M LORs**







Conclusions

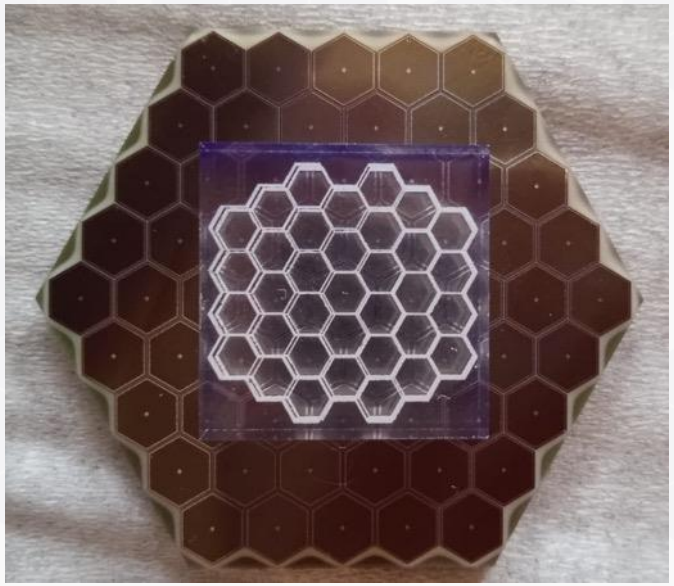
- **We have designed a feasible quasi-spherical PET scanner**
- **Scintillations and photodetectors are hexagonal**
- **The hexagonal crystals are proved to provide better light output and energy resolution than standard square crystals**
- **Using SSLE we have created scintillator crystals with customizable light permeability**

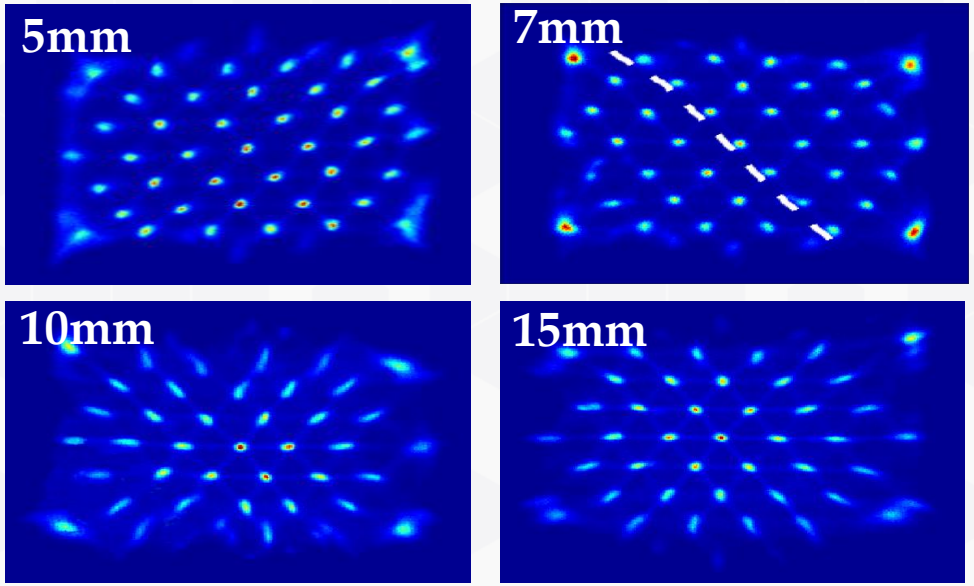
On-going and future work

- **Complete de design of the fullerene**
- **Build the IcoPET prototype of the scanner (Video)**

IcoPET Robotic ”simulation”

Geometrical considerations on hexagonal SiPM

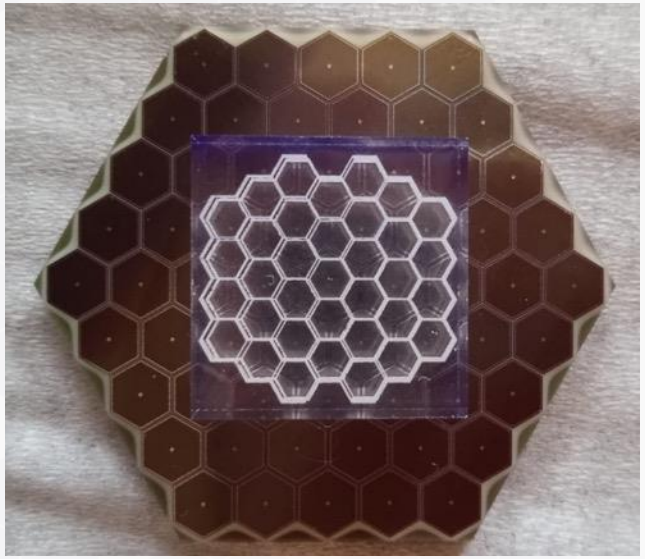




Laser Engraving

Laser

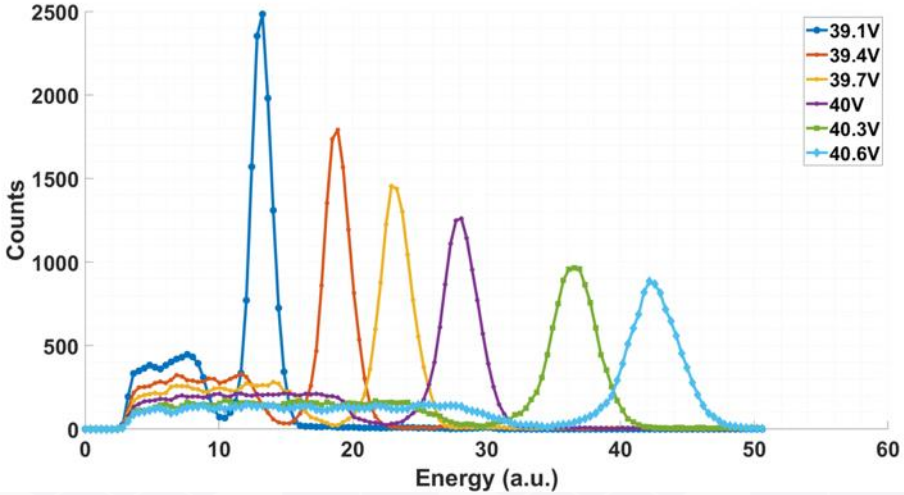
- **Microcracks by dense energy deposition**
- **Nd-YAG with wavelength of 532 nm and pulse width of 6-8 nsec**
- **Average pulse power of 50 mW. Repetition rate of 500 Hz**
- **Power density at focal spot: 8.09×10^9 W/cm^2 @ 500 Hz**
- **Pulse energy: 100µJ @ 500 Hz**

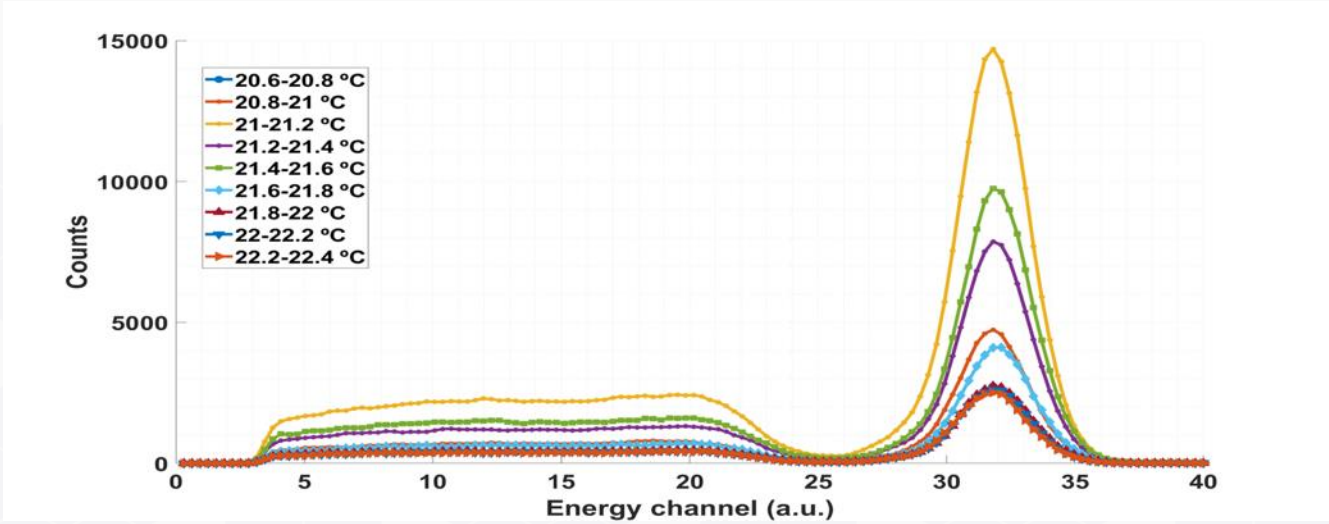


Detector

- **Hexagonal SiPM of 61 channels, each with a side of 2.25 mm**
- **Hexagonal engraved lattice of 35 crystals of 1.25 mm of edge**
- **LYSO square blocks of 15x15 mm and 5 mm, 7mm, 10 mm and 15 mm thickness**

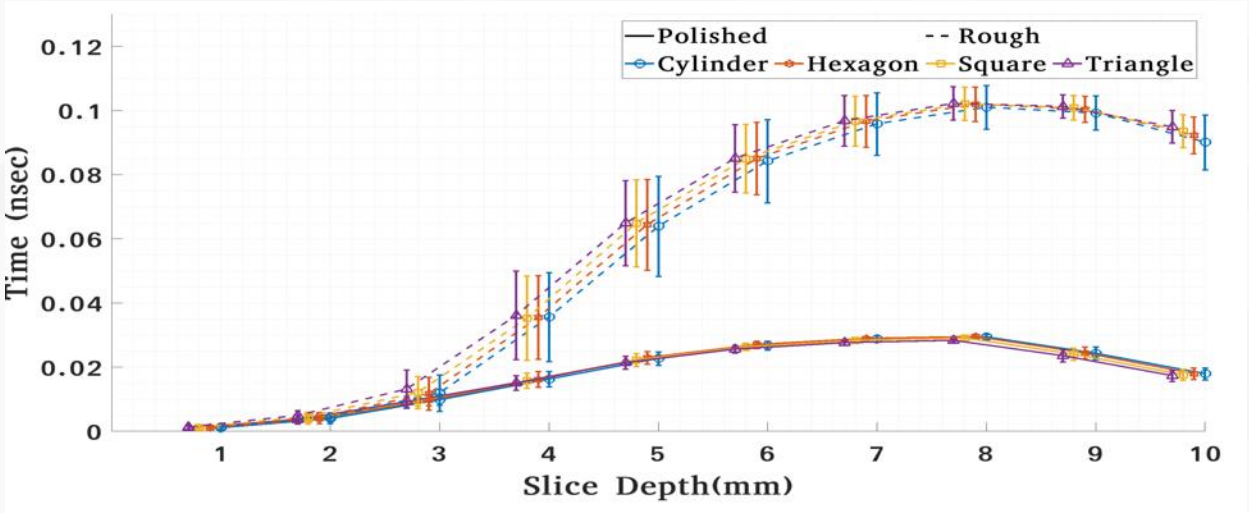
Backup


Counts
Energy (a.u.)
39.1V
39.4V
39.7V
40V
40.3V
40.6V

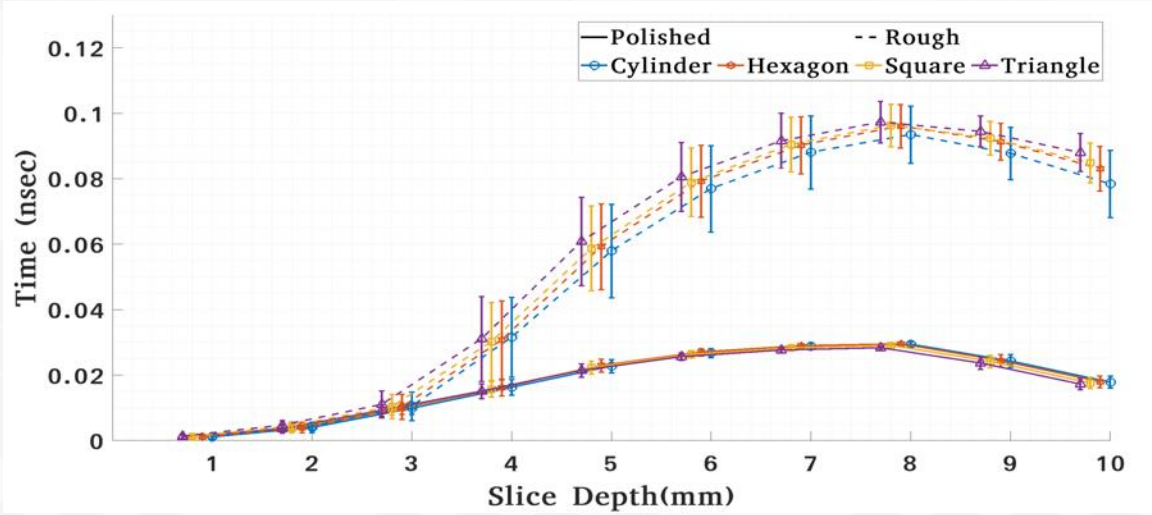

Counts
Energy channel (a.u.)
20.6-20.8 °C
20.8-21 °C
21-21.2 °C
21.2-21.4 °C
21.4-21.6 °C
21.6-21.8 °C
21.8-22 °C
22-22.2 °C
22.2-22.4 °C

Timing

Lambertian reflector (Teflon)



Specular reflector (ESR)



Difference of about 80 ps in depths between 6 and 10 mm