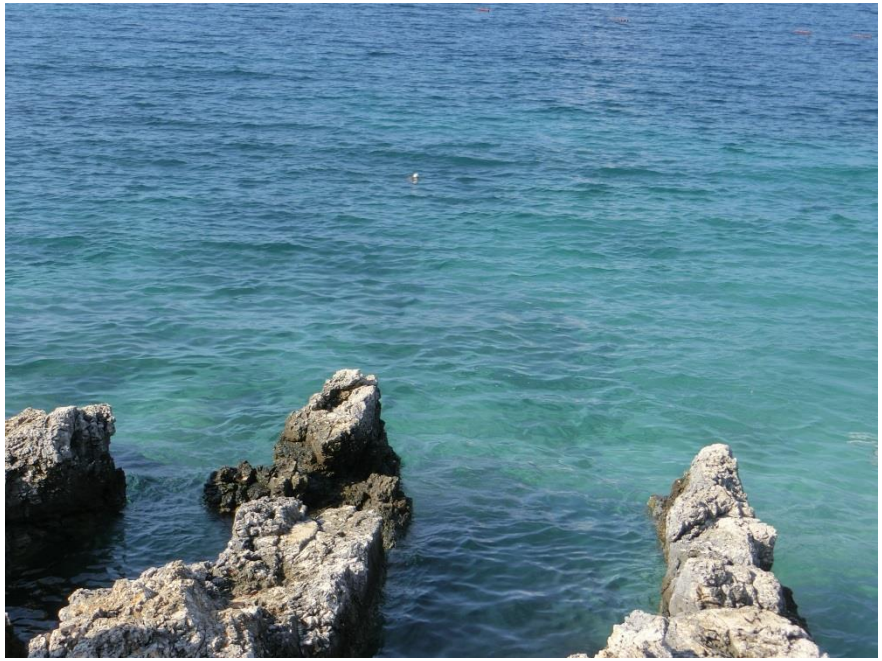
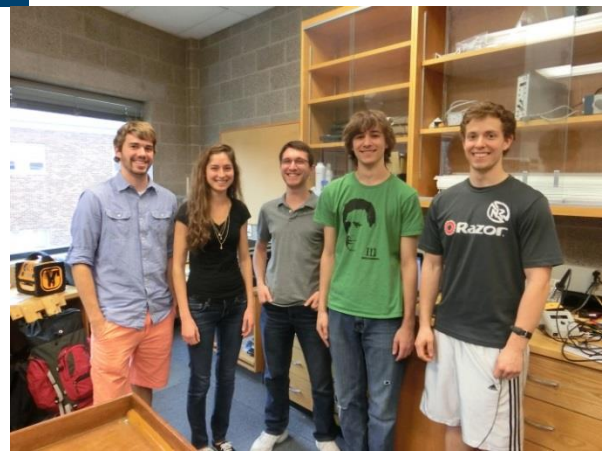
Development of Compact Particle Detectors

Abaz Kryemadhi, Lindsey Barner, Andrew Groves, Jacob Mohler,

Caleb Sisson, and Alex Roth





LHC Workshop, Tirane, Albania: Sep. 26-27, 2016

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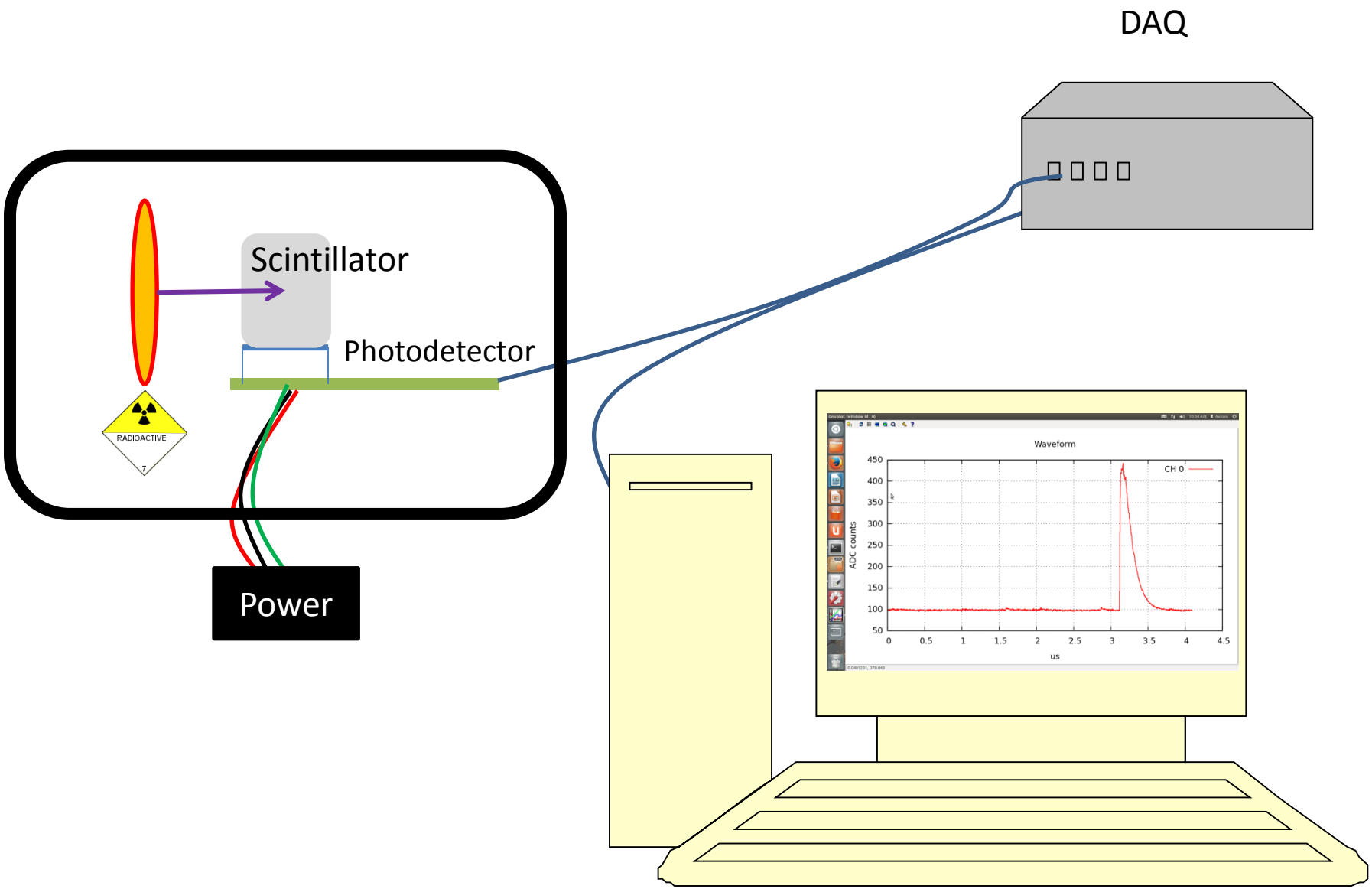
Physics Motivation

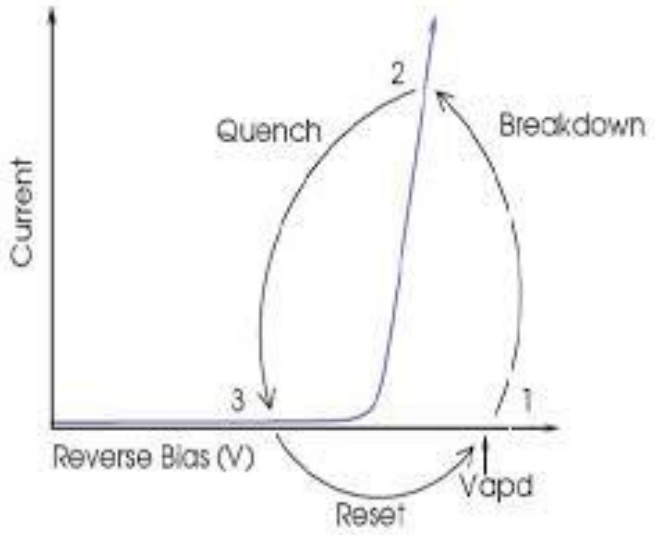
New physics searches from cosmic rays to gamma rays and particle dark matter in space can greatly benefit from

- compact detectors with good energy and angular resolution
  - Multi-segmented EM Calorimeter with minimal dead space
- Low voltage and power consumption
- Ability to withstand take off conditions
- Linearity and uniformity response in energy range in consideration

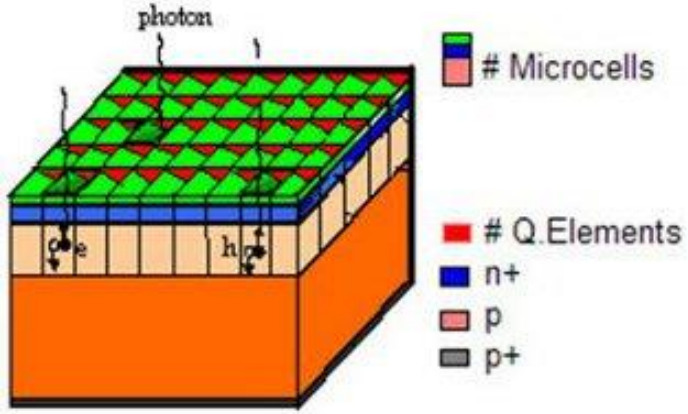
Principle of Detection

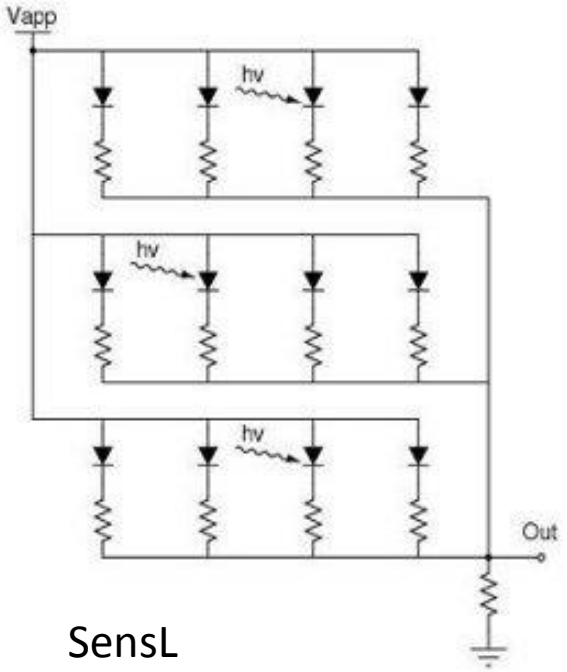


Introduction to Silicon Photomultipliers (SiPMs)



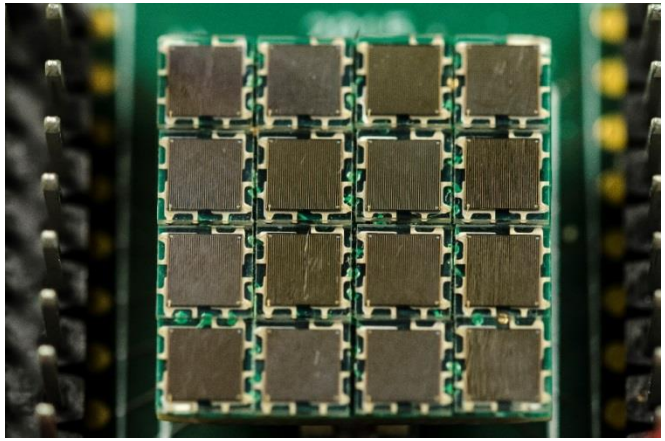
Reverse biased avalanche photodiode
Operated at few volt above the breakdown voltage
Each microcell is a binary device



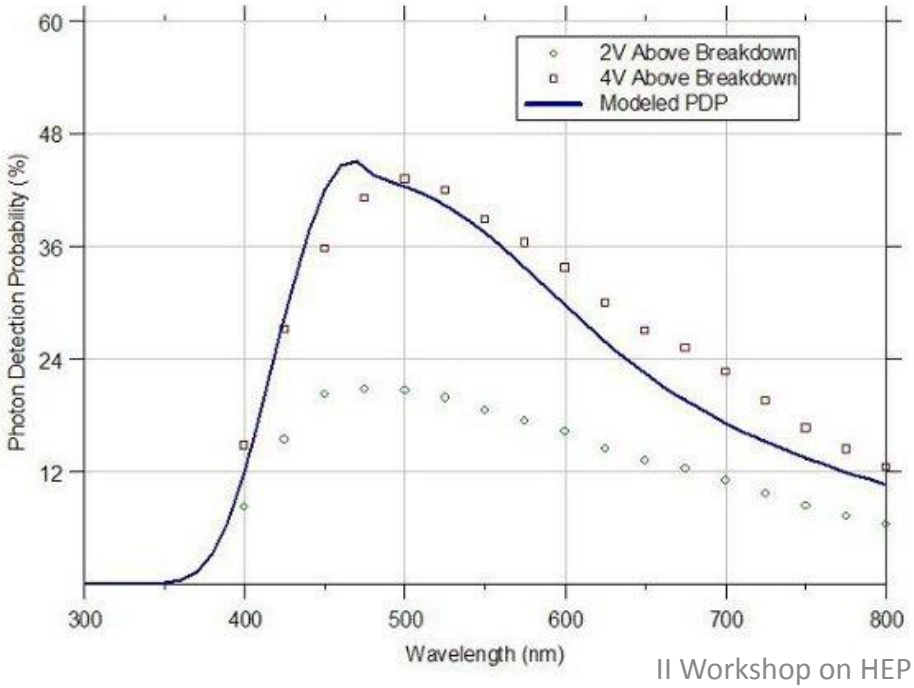


SensL

Introduction to Silicon Photomultipliers (SiPMs)



Sensl: ArrayC30035-16P-PCB



Immune to magnetic fields

Can be combined to form a large reading array

This array number of microcells ~80,000

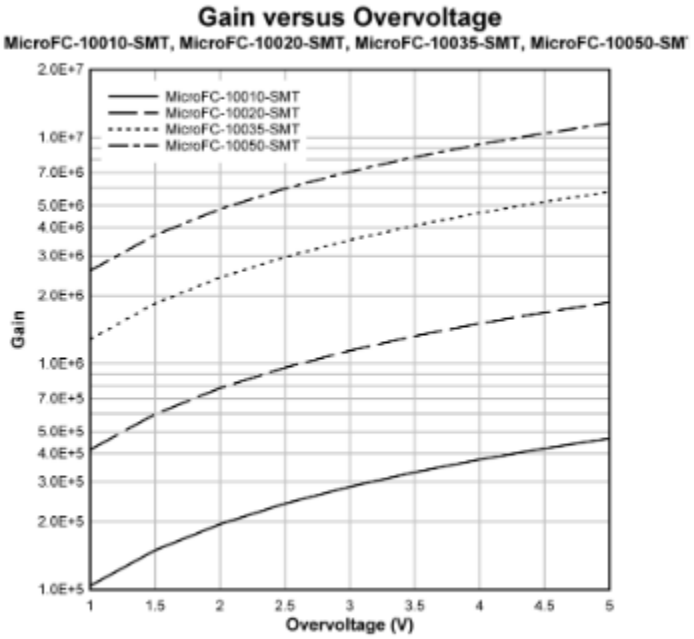
High PDE >40% at peak

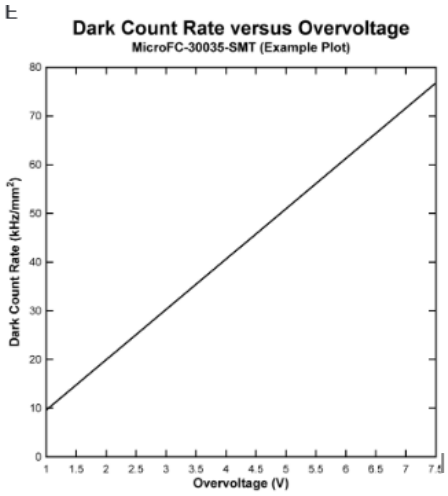
Dark rate <30 kHz/mm^2

Operating voltage <30 V

Temperature Drift ~20 mV/^{0}C

Introduction to Silicon Photomultipliers (SiPMs)





Gain of order of 10^6 comparable to PMT

No Need for sophisticated amplification circuitry

Dark Rate increases with overvoltage and temperature

- For high energy physics not a big concern

Saturation of microcells however could limit the dynamic range

$$N_{fired}(M,V,\lambda) = M\left(1-\exp\left(-\frac{PDE(V,\lambda)\cdot N_{ph}}{M}\right)\right)$$

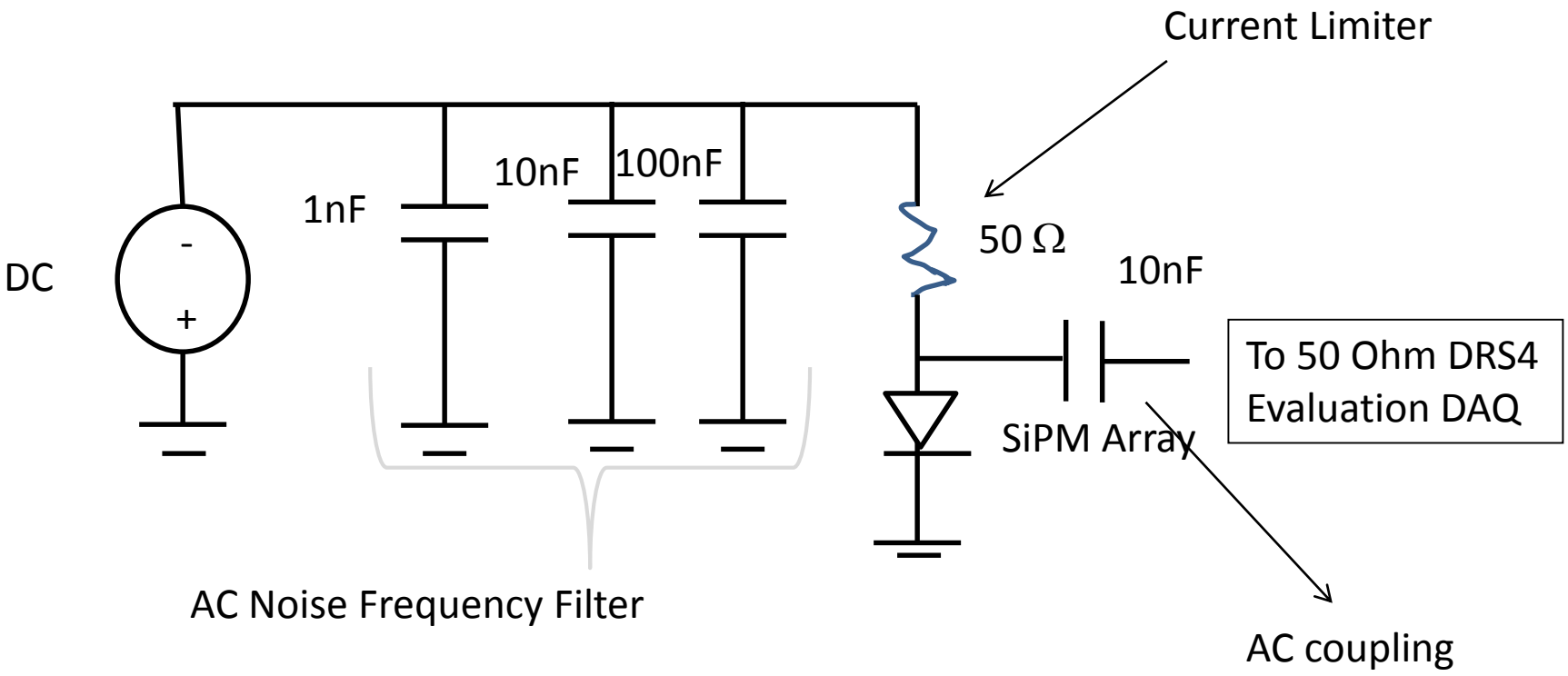
Crystals

Shower Containment

Crystal	LYSO	CeBr3
Density (g/cm^3)	7.4	5.10
Radiation Length(cm)	1.14	1.96
Moliere Radius (cm)	2.07	2.97
Interaction Length (cm)	20.9	31.5
Peak Wavelength (nm)	402	370
Decay Time (ns)	40	17
Light Yield %NaI(Ti)	85	122

Time and Energy Resolution, Also reduction of pile-up

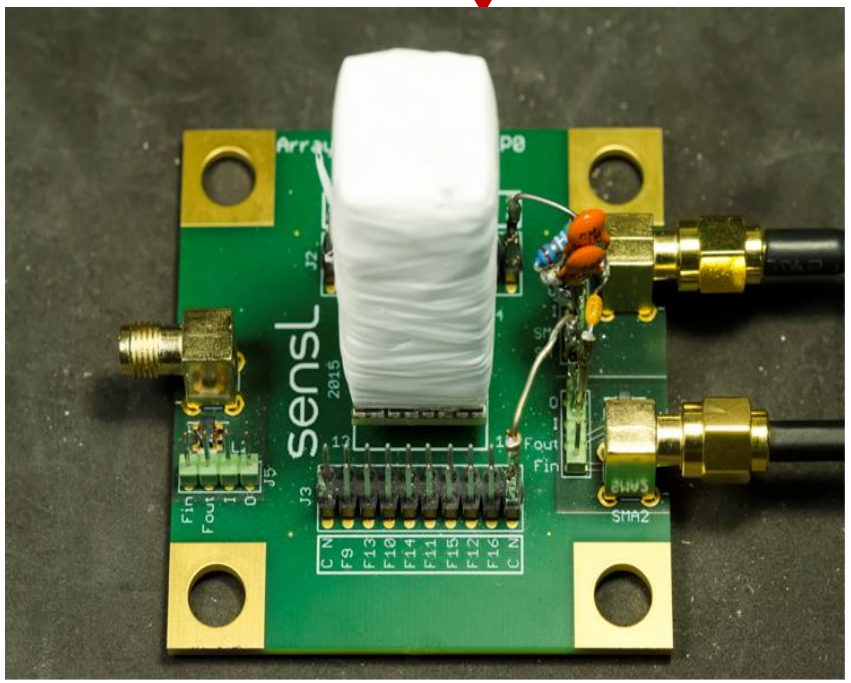
Sensl 4x4 Array Readout



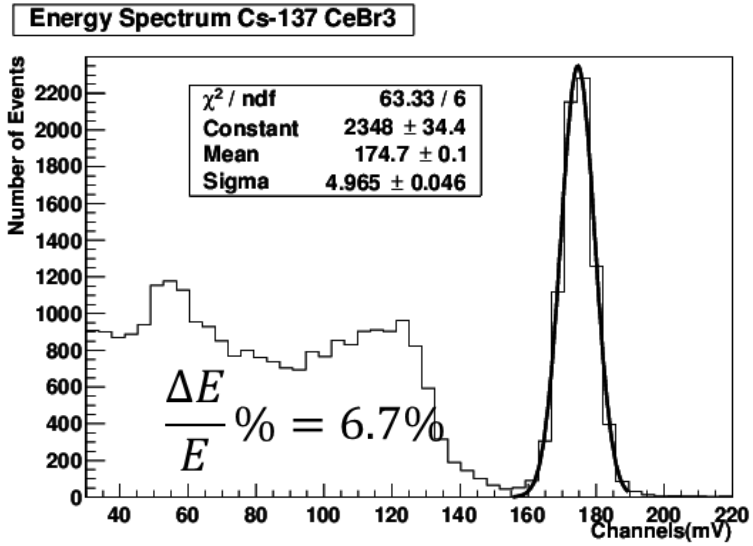
LYSO Crystal developed from EPIC Crystal (16 mm x 16 mm x 40 mm)

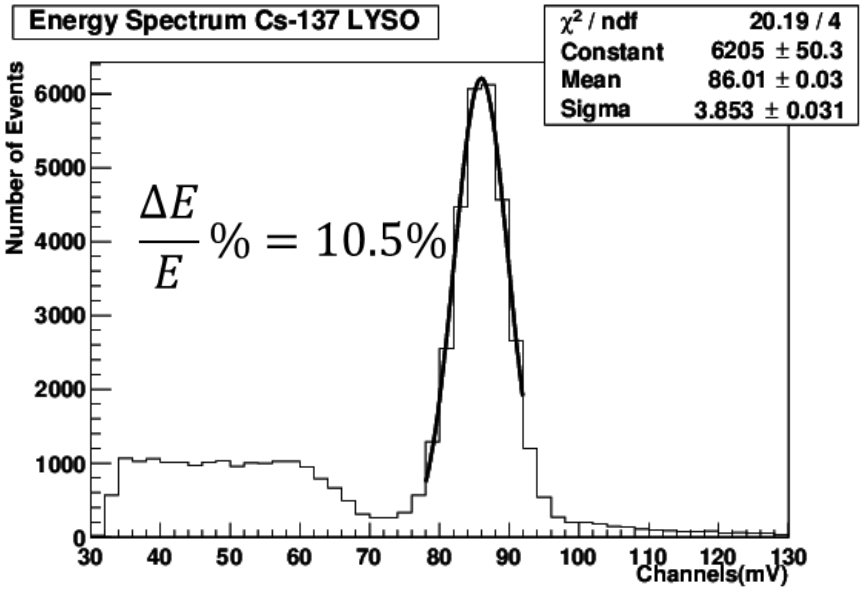
CeBr3 Crystal purchased from Berkeley Nucleonics and made from Sionix Holland (13 mm x 13 mm x 13 mm)

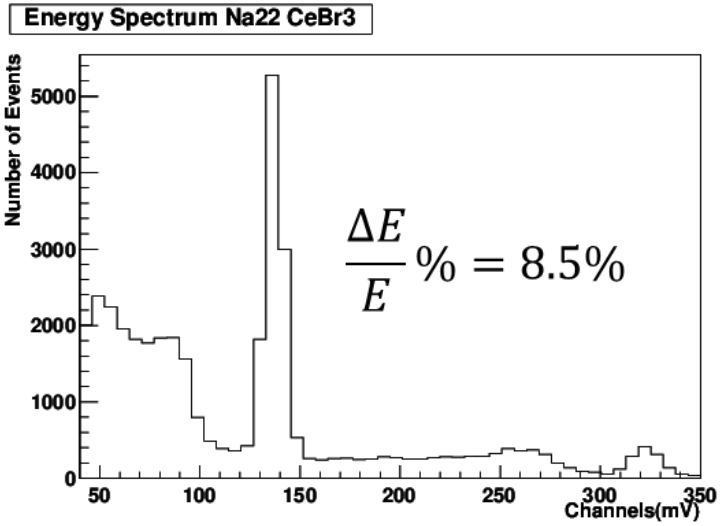
Sensl ArrayC and the Readout Board

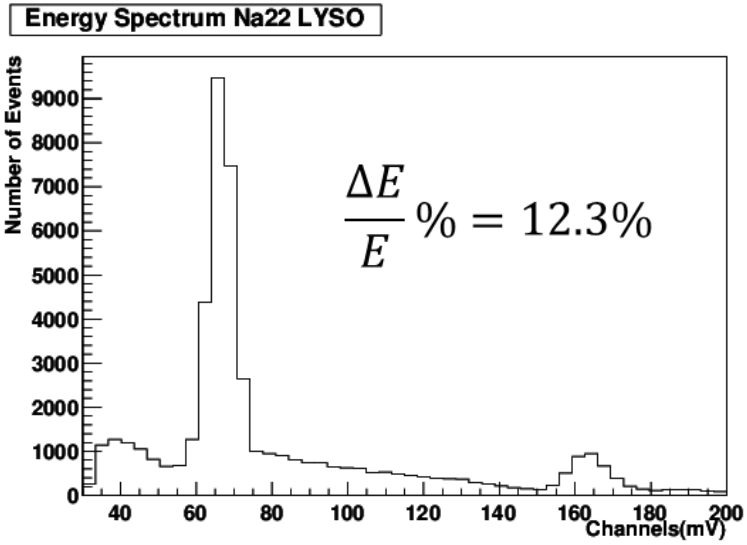


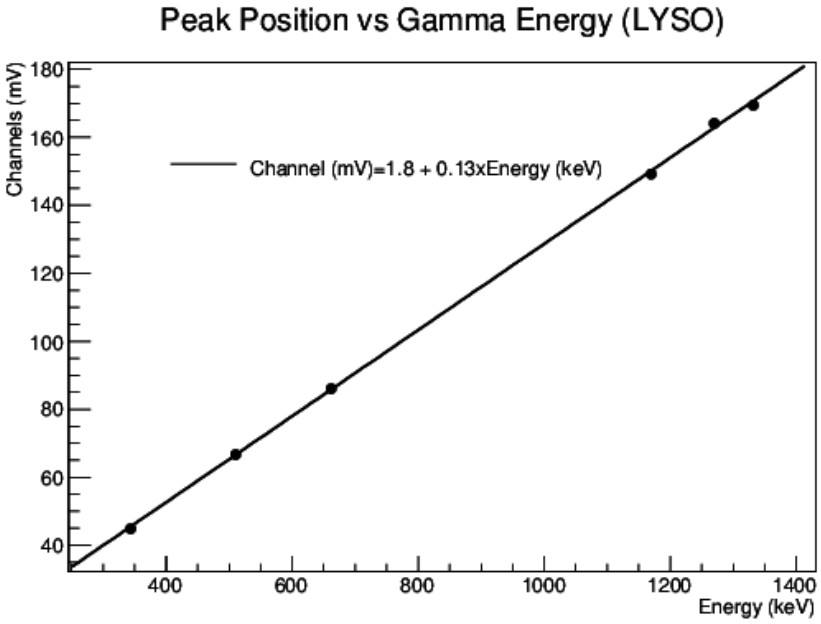
DAQ, Digitizier: DRS4 Evaluation Board developed by Stefan Ritt, Paul Scherrer Institute


Energy Spectrum Cs-137 CeBr3
χ² / ndf 63.33 / 6
Constant 2348 ± 34.4
Mean 174.7 ± 0.1
Sigma 4.965 ± 0.046
$\frac{\Delta E}{E}\% = 6.7\%$
Number of Events
Channels(mV)


Energy Spectrum Cs-137 LYSO
χ² / ndf 20.19 / 4
Constant 6205 ± 50.3
Mean 86.01 ± 0.03
Sigma 3.853 ± 0.031
$\frac{\Delta E}{E}\% = 10.5\%$
Number of Events
Channels(mV)


Energy Spectrum Na22 CeBr3
$\frac{\Delta E}{E}\% = 8.5\%$
Number of Events
Channels(mV)


Energy Spectrum Na22 LYSO
$\frac{\Delta E}{E}\% = 12.3\%$
Number of Events
Channels(mV)

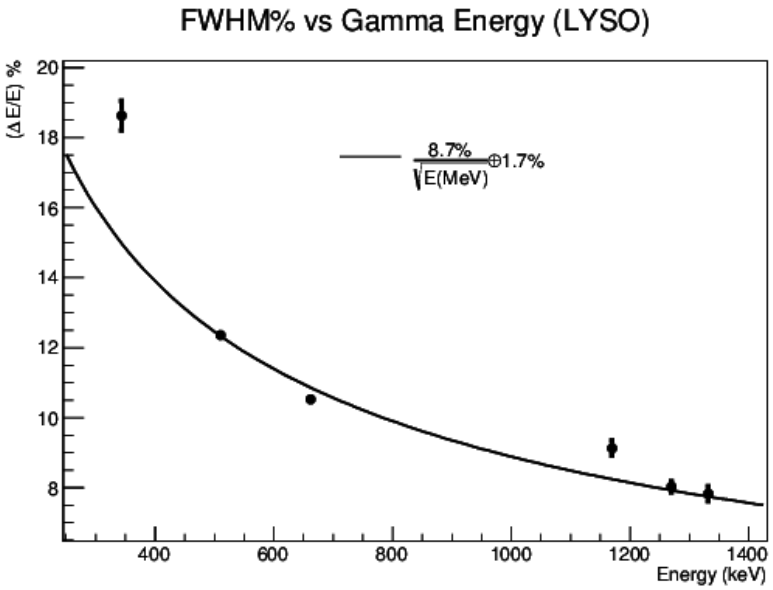


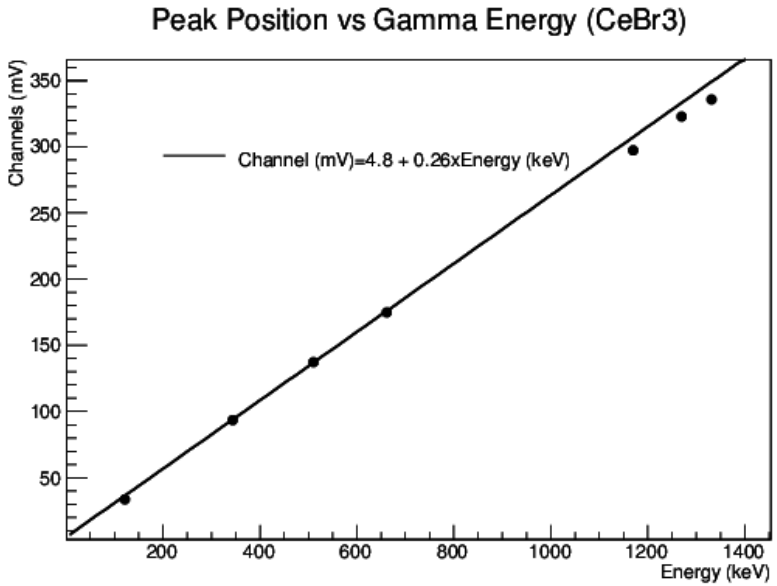
Linear in Gamma Ray Energy Range

Expected to deviate for wider dynamic range

Neutral density filters needed for higher energy

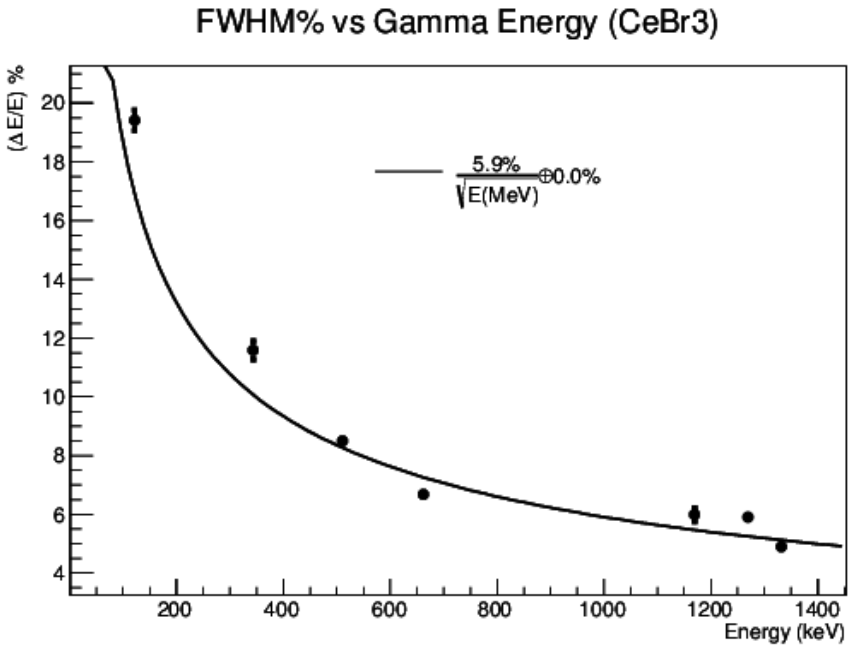
$$\frac{\Delta E}{E}(\%) = \frac{8.7\%}{\sqrt{E_\gamma(MeV)}} \oplus 1.7\%$$



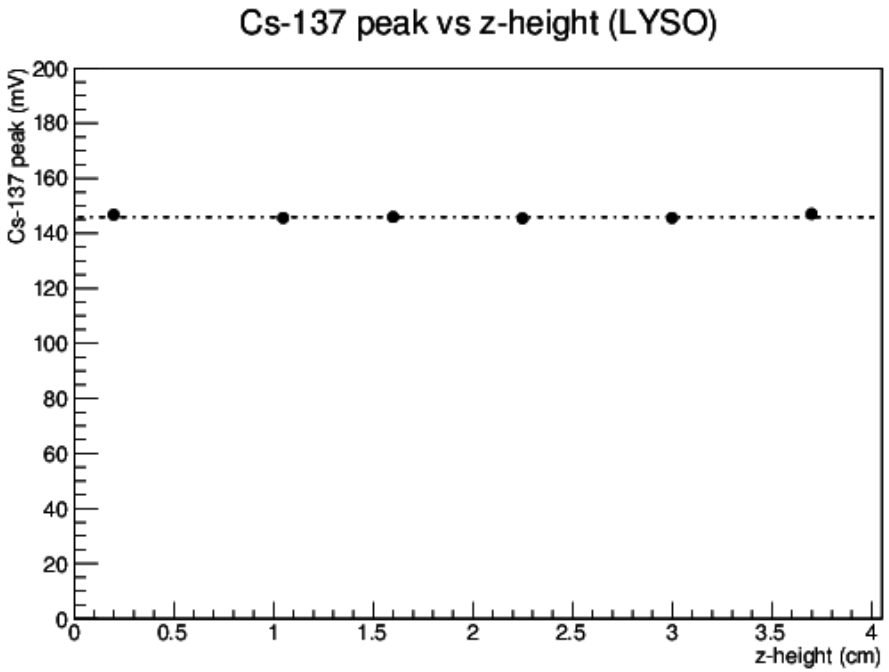


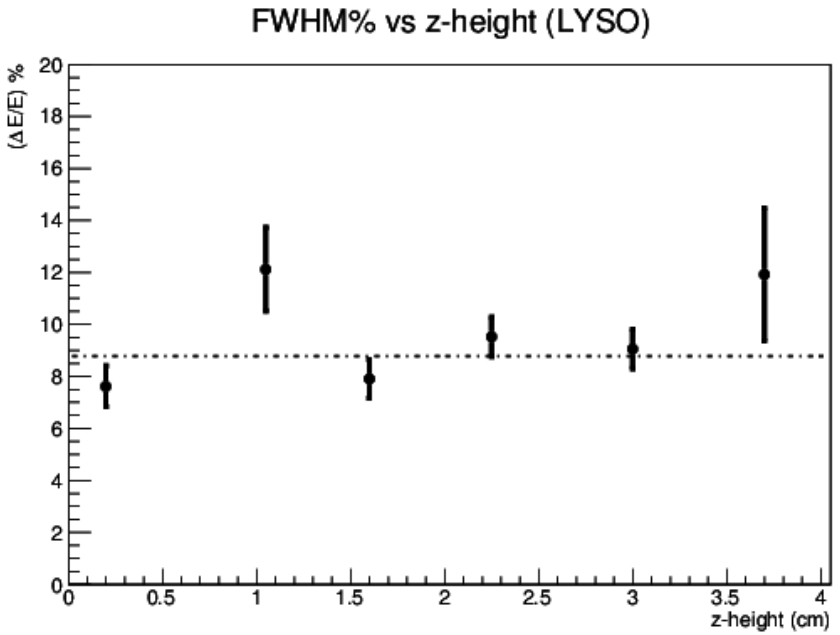
Expected to deviate for wider dynamic range, Saturation function needs to be applied

$$\frac{\Delta E}{E}(\%) = \frac{5.9\%}{\sqrt{E_\gamma(MeV)}} \oplus 0.0\%$$



Uniformity



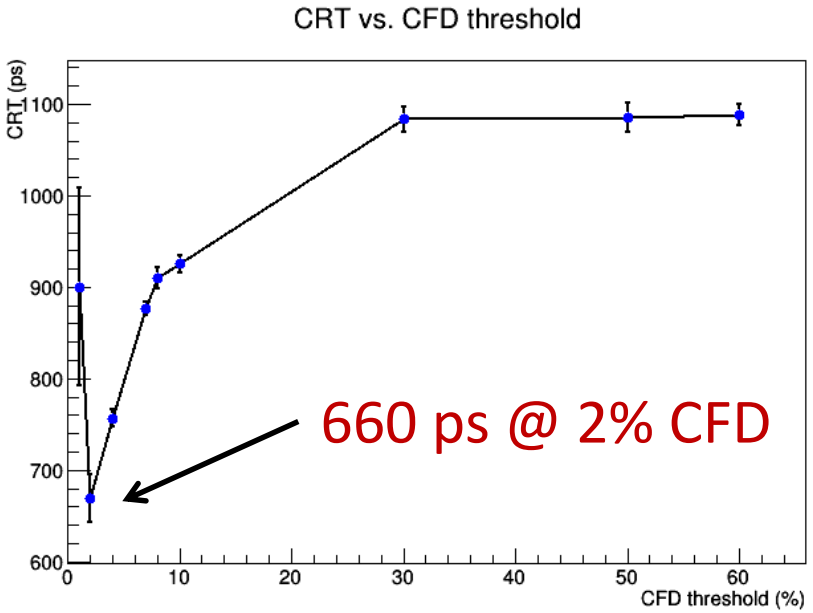


25 mm Tungsten Collimator, Small Aperture, scan across length of crystal

No trends observed in energy resolution

Light yield not affected for these size crystals, self-absorption not an issue

Time Resolution



Sub-nanosecond coincidence resolving time, best timing is picked from the arrival of the early photons.

Good timing important for triggering, event processing and angular resolution

Summary

- A simple readout for the Sensl SiPM 4x4 array was presented
- Both LYSO and CeBr3 mostly linear in gamma ray energies and good energy resolution
- The prospect for use in space is very good, as a multi-segmented EM Calorimeter
- Cost is however an issue, anticipate reduction due to large production for medical applications
- Next→ A mini-calorimeter to be tested at Fermi National Laboratory TestBeam, Chicago, IL