Research Updates:
High Rate Pixelated Neutron Detector

Su-Ann Chong

Monthly Group Meeting

June 5^{th}, 2020

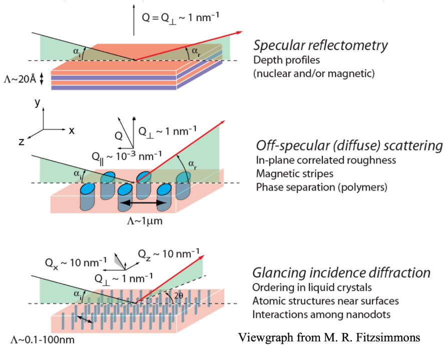
Outline

Neutron Reflectometry (NREF)

Neutron reflectometry is a neutron scattering technique that makes use of the reflection of neutrons to probe and analyze interfacial structure and composition.

Capability:

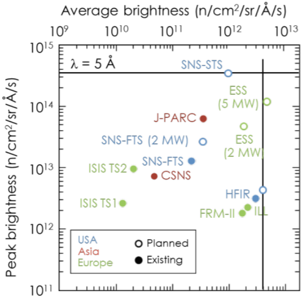
- Specular reflectivity: Depth profiles
- Off-specular reflectivity: Surface roughness
- Glancing incidence diffraction: Atomic structure near the surface

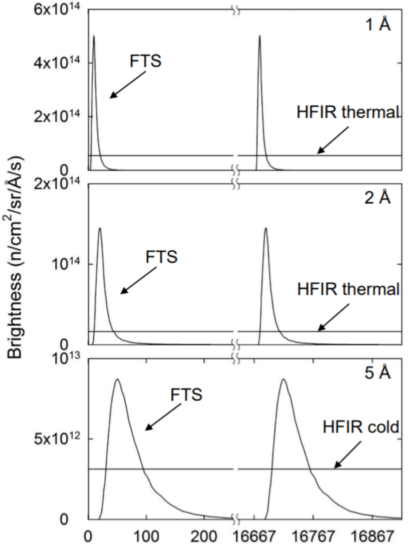


Viewgraph from M. R. Fitzsimmons

Motivation

- Increasing neutron flux in upcoming instruments
- Current detector technology lacks in counting rate capability





Project Goals

The detector requirements for neutron reflectometers at ORNL are summarized here.

The project goal is to aim to satisfy all aspects of the requirements, except the active area of the detector.

Detector Requirement

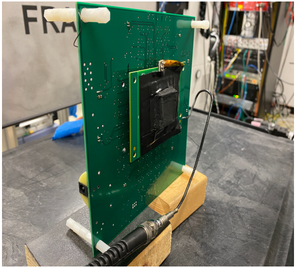
Parameter	Desired
Counting rate	1 MHz/cm^2
Detector efficiency	60% (2Å)
Gamma sensitivity	1×10^{-6}
Spatial resolution	1 - 2 mm
Active area	20×20 cm^2

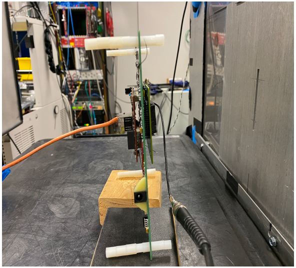
It is expected that the final detector prototype has an active area of 6.4×6.4 cm^2 for this project. Once the final detector prototype has been fully tested and validated, it can be expanded to larger systems of 20×20 cm^2.

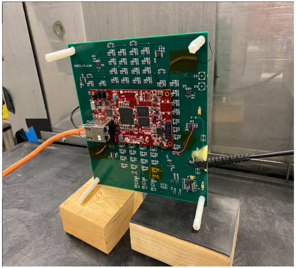
Outline

Current Detector Prototype

Scintillator	8×8 array of GS20 ($2 \times 2 \times 2$ mm^2)
Photosensor	8×8 array of SiPM (1 mm^2 active area)
Readout	Independent channel readout for fast signal processing
Signal Processing	Pulse height discrimination & Time-Over-Threshold
Acquisition	Custom firmware and software







Detector Performance

Current detector prototype showed satisfactory performance for detection efficiency and spatial resolution.

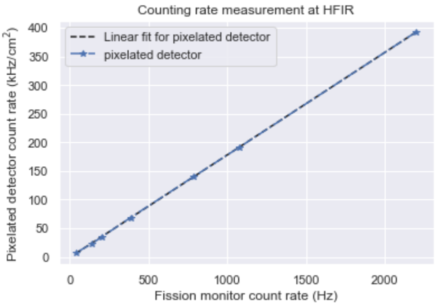
Evaluation

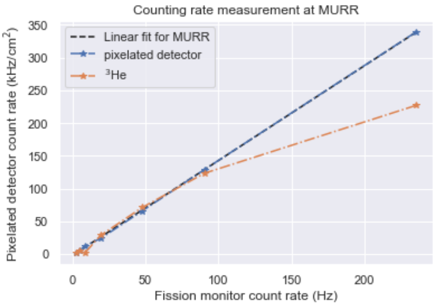
Parameter	Achieved	Goal
Counting rate	400 kHz/cm^2	1 MHz/cm^2
Detector efficiency†	74% (1.8Å) 92% (4.2Å)	60% (2Å)
Gamma sensitivity‡	1×10^{-4}	1×10^{-6}
Spatial resolution	2 mm	1 - 2 mm
Active area	1.6×1.6 cm^2	6.4×6.4 cm^2

† Detection efficiency relative to a 10-atm ^{3}He gas detector.
‡ Gamma sensitivity is obtained using ^{60}Co source.

Key Results: Counting rate

The counting rate of the detector is verified linearly up to the maximum available flux at the beamline.

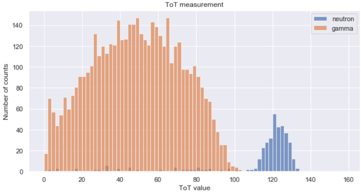




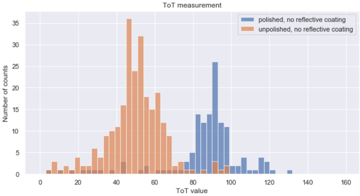
There has not been much progress made in terms of validating the maximum counting rate capability of the detector prototype since March update due to COVID-19. I've been assigned to be in Phase 2 of returning to ORNL, so hopefully we can carry out more counting rate test at HFIR in the coming months.

Key Results: Gamma Sensitivity

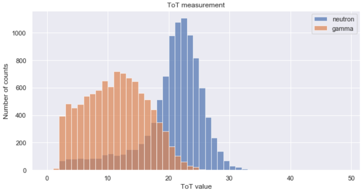
The Time-Over-Threshold (ToT) measurements provide an insight to the gamma sensitivity of the detector.



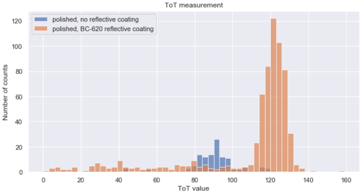
6×6 mm^2 SiPM pixel area



surface roughness



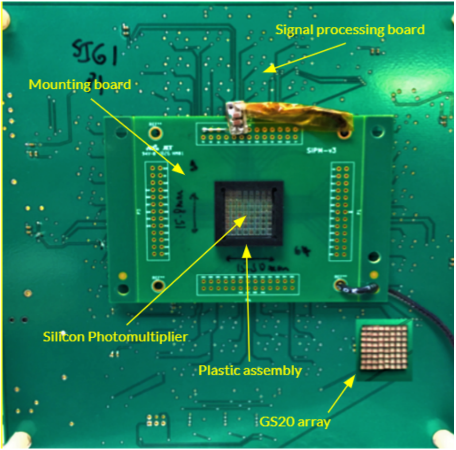
1×1 mm^2 SiPM pixel area



type of reflector

Key Results: Active Area

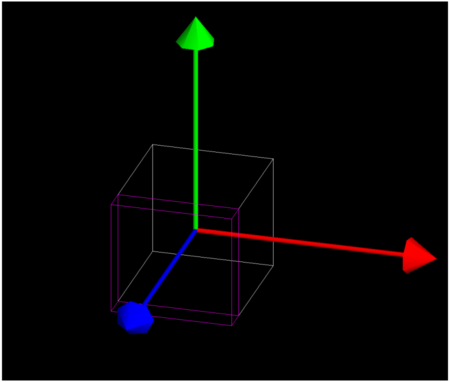
Current detector active area is 1.6 $\times$ 1.6 cm^2. In order to achieve an active area is 6.4 $\times$ 6.4 cm^2 without introducing dead space within the area, the SiPMs need to be arranged adjacent to one another forming a configurantion of 4 $\times$ 4 SiPM arrays.

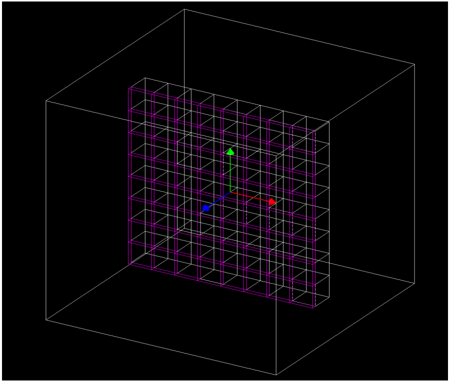


Outline

Geant4 Simulation

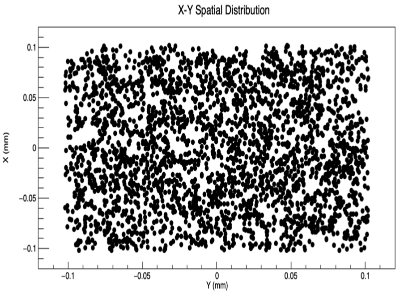
In order to better understand the ToT spectrum with different surface finishes (roughness/reflector) as well as the mismatch between scintillator area and photosensor area, a Geant4 simulation is developed.

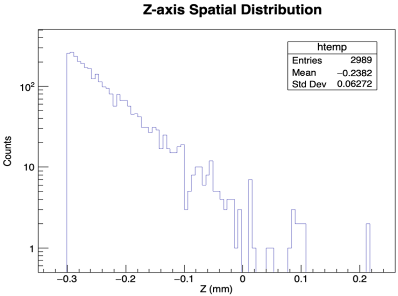




Geant4 Simulation: Initial Validation

It is important to make sure that particle source is properly defined. Shown here is a uniform monoenergetic neutron source of 25 meV using the Geant4 General Particle Source (GPS).

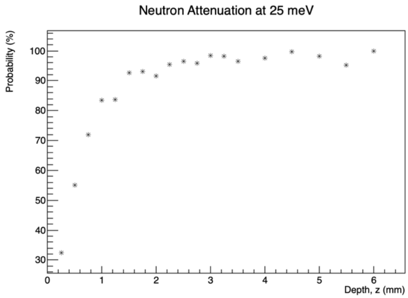


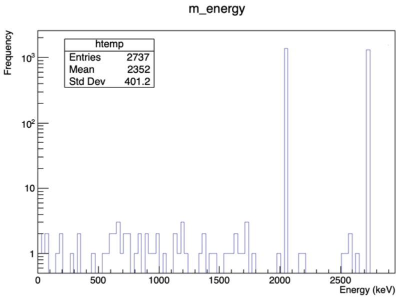


Geant4 Simulation: Initial Validation

From the datasheet, it is said that 1 mm thick of GS20 can achieve a detection efficiency of 75% and 2 mm thick of GS20 can achieve 95%. The simulation also shows the energy deposition from the neutron capture on ^{6}Li.

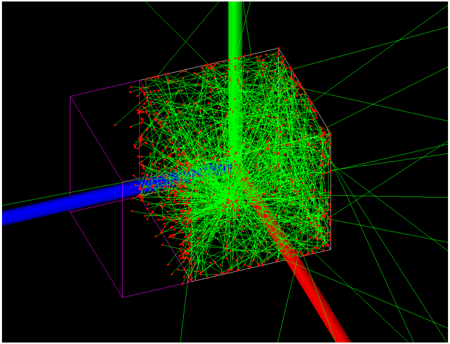
$$n +^6 Li \rightarrow \alpha \ (2.73 \ MeV) +^3 H \ (2.05 \ MeV)$$

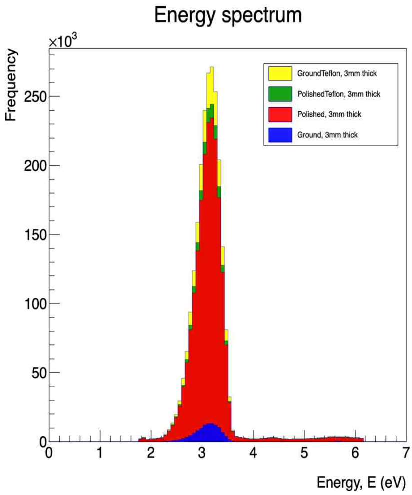




Geant4 Simulation: Work in Progress

The optical properties of the scintillator has been included. In order to simulate the optical surface of the scintillator, LUT data from G4REALSURFACEDATA are used.





SiPM Readout System

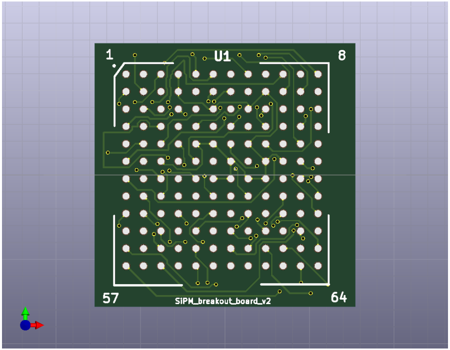
Possible readout systems as an alternative solution:

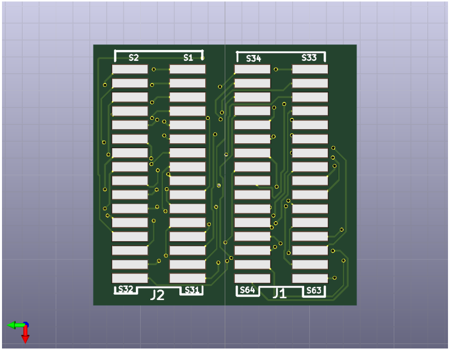
Comparison

Company	CAEN	Petsys
Module Name	A5202 + DT5215	TOF ASIC evaluation kit
ASIC chip	CITIROC-1A (x2)	TOFPET ASIC
Channel/ASIC chip	32	64
Dynamic range	400 pC	1500 pC
Maximum channel hit rate	20 MHz	600 kHz
Max output data rate	6.25 Gb/s	3.2 Gb/s
Acquisition modes	PHA, TOT	PHA, TOT, TOF
Availability	Coming soon	In stock

Board Layout

Printed circuit board (PCB) layout for SiPM break-out board (BOB). Some SiPM comes with a connector, some comes with ball grid array (BGA). Having a BOB allows the SiPM to be readily mounted to other boards that come with the readout module.





SiPM BGA Connections

Another reason to layout a BOB is to allow easy routing of many unordered traces. It's good for book keeping.

BGA Connections for the ArrayC-10035-64P-BGA

Note that the silkscreen has a typo. The solder balls marked A8 and M8 should read A12 and M12 respectively.

	1	2	3	4	5	6	7	8	9	10	11	12
A	S8	F7	S7	F6	S6	F5	S5	S4	CM	S3	F2	F1
B	F8	S16	S14	CM	F13	S13	S12	F4	CM	F3	S2	S1
C	F16	F15	F14	S15	CM	F12	CM	F11	S11	F10	S10	F9
D	F23	S23	F22	S22	F21	S21	F20	S20	F19	S19	F18	S9
E	F24	S24	F30	S30	CM	S29	CM	CM	S27	S18	S26	F17
F	F31	S31	CM	CM	F29	CM	F28	S28	F27	CM	F26	S17
G	F32	S32	F39	CM	CM	CM	CM	S36	F34	S34	F25	S25
H	S40	F40	S39	F38	S38	F37	S37	F36	F35	S35	S41	F33
J	S48	F48	S47	F47	S46	F46	S45	F45	S44	F44	S42	S33
K	F56	S55	F54	S54	F53	S53	F52	S52	F43	S43	F42	F41
L	S56	F55	S63	S62	S61	S60	F51	S51	F50	S50	F49	S49
M	F64	S64	F63	F62	F61	F60	F59	S59	F58	S58	F57	S57

CM	Common I/O
Sn	Standard I/O of pixel n
Fn	Fast output of pixel n

Outline

This Summer

Goals:

- Wrap up Geant4 simulation on GS20, and compare results with experimental results
- Once the SiPM readout system is finalized, lay out the connector board that interfaces the SiPMs with the readout system.
- Work on a peer-reviewed journal on the latest work and upgrades on the detector prototype.

Possible work:

- Explore other scintillators or photosensors as alternatives
- Explore other signal processing techniques to improve the neutron-gamma discrimination of the detector
- Improve our DAQ software

Thank you for your time!