^{6}LiF:ZnS(Ag) Neutron Detector and Data Acquisition/Processing System Development

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Abstract:

The Chromatic Analysis Neutron Diffractometer or Reflectometer (CANDOR) is a new instrument under development at the NIST Center for Neutron Research (NCNR) that will use scattering by a broad energy spectrum of neutrons to investigate the structures of materials. The triggering, discrimination, and acquisition of neutrons from a broad energy spectrum over a range of scattering and reflecting angles brings unprecedented design challenges. As well-established ^{3}He neutron detectors would not meet the form factor requirements of CANDOR, it was necessary to develop an ultrathin neutron detector using ^{6}LiF:ZnS(Ag) plastic scintillator coupled to wavelength shifting fibers leading to a Silicon Photomultiplier (SiPM) for readout. The signal from the SiPMs must then be processed using fast electronics to discriminate neutron capture events from other event types. At this stage, we have a highly efficient, extremely thin, neutron detector whose performance is on par with traditional ^{3}He gas-filled tubes at a fraction of the price.

The CANDOR data acquisition (DAQ) system includes waveform digitizers, which use digital signal processing (DSP) techniques to accurately identify neutron events. For this project the neutron detection and data acquisition/processing systems were characterized and evaluated for use in the CANDOR instrument as well as for other applications.

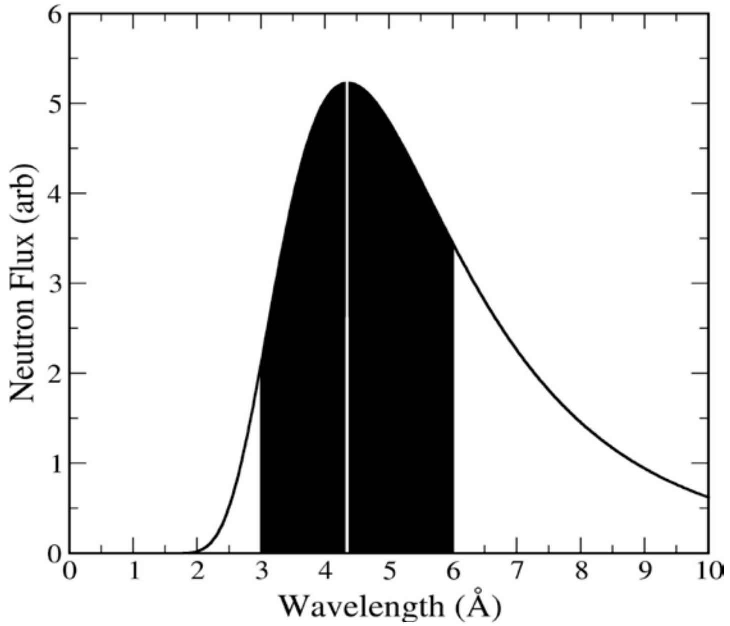
NIST Center for Neutron Research

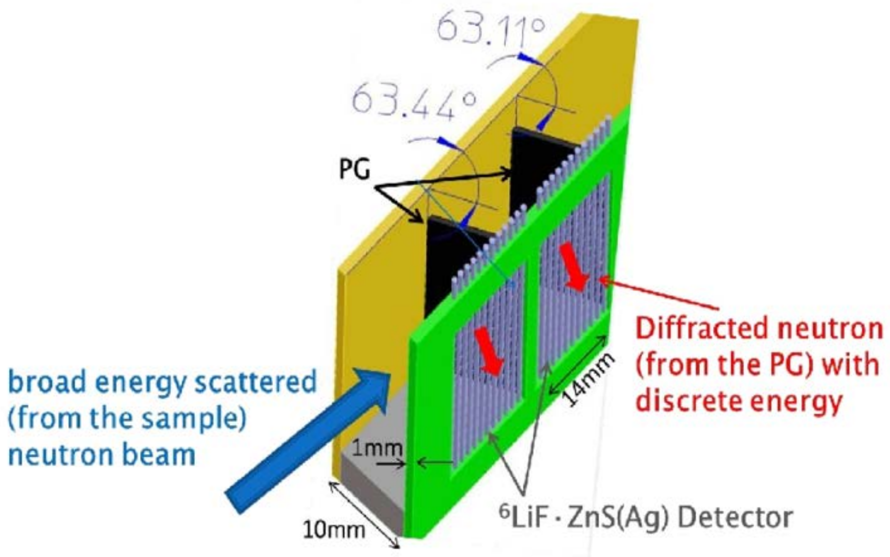
CHRNS Center for High Resolution Neutron Scattering NIST

NIST National Institute of Standards and Technology U.S. Department of Commerce

University of Hawai'i Mālamalama 1907 Ua Mau Ke Ea O Ka 'Āina I Ka Pono

CANDOR – Chromatic Analysis Neutron Diffractometer Or Reflectometer





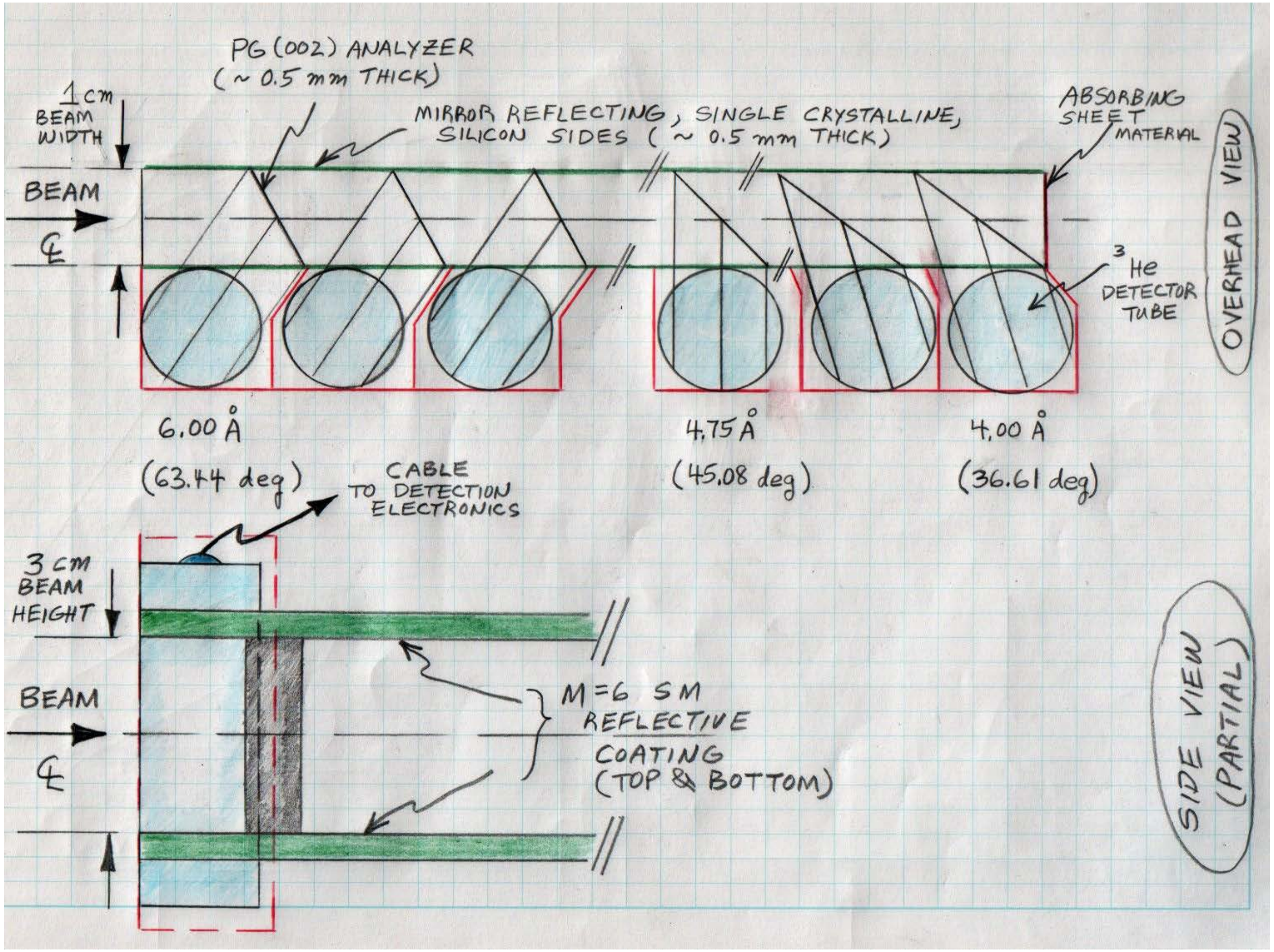
- Neutron Diffractometry and Reflectometry is useful for analyzing the structures and dynamics of materials.
- CANDOR will use a broad range of wavelengths to allow for faster measurements.
- CANDOR required the development of a novel ultrathin detector.

Why not He-3?

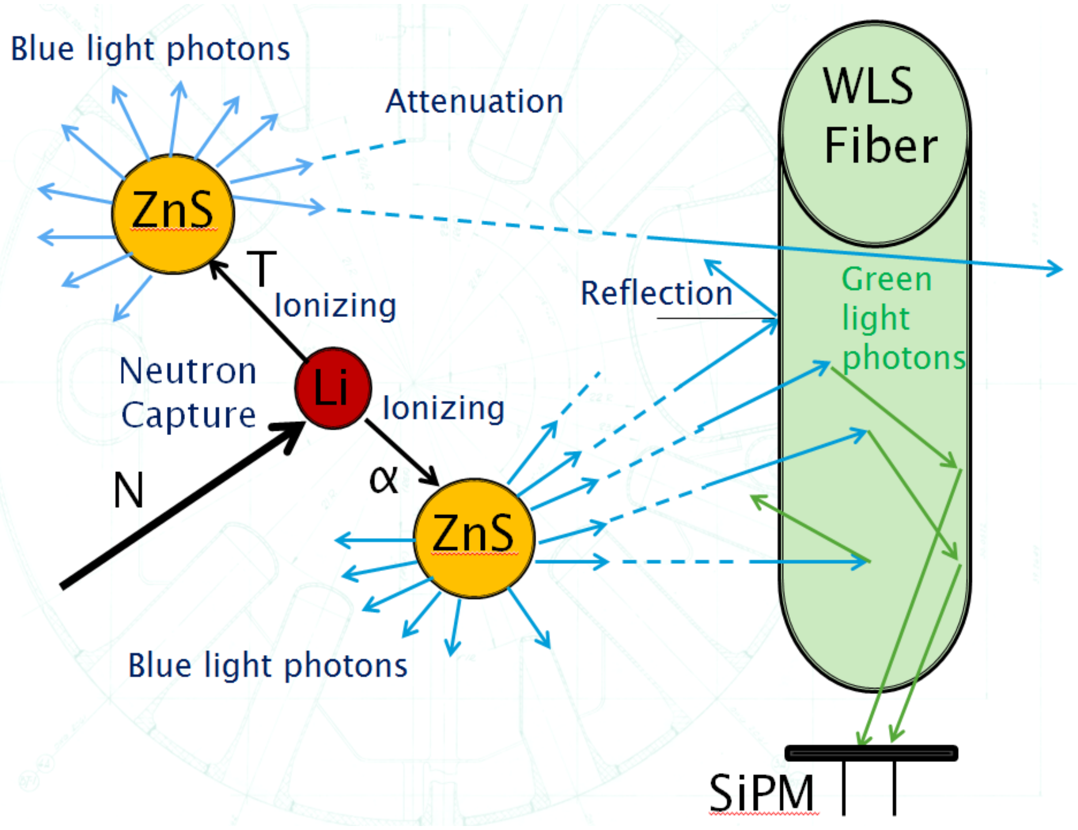
- He-3 tubes are the most widely used detector for their simplicity and gamma rejection ratio.
- He-3 is a gaseous and is optimally used under pressure

- Cylindrical form factor
- Volume requirements increases proportional to the effective area squared
- Very costly due to supply issues

- As a solid, LiF has a higher molar density than He3



Neutron Detection Schematic

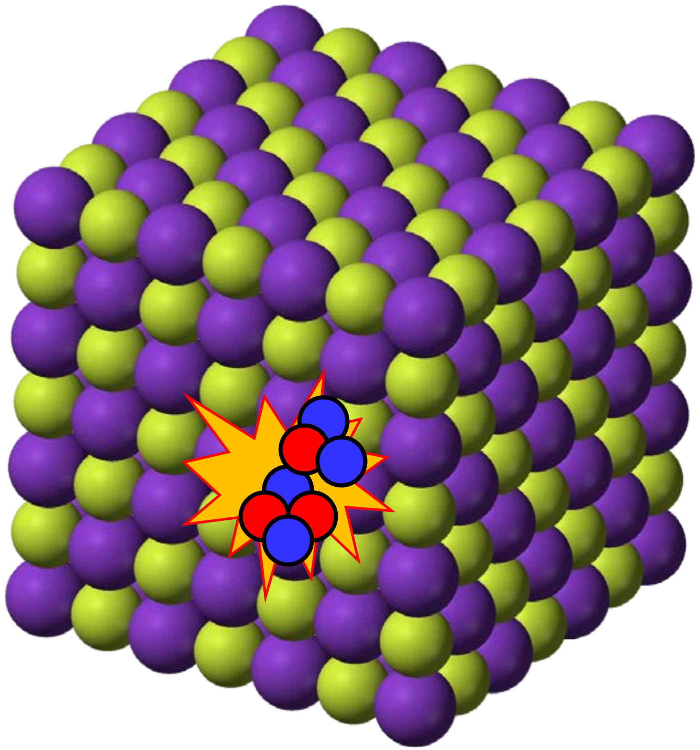


- Neutrons are generally detected indirectly through the products of a neutron capture.

- Left: Detection schematic for CANDOR's LiF:ZnS(Ag) detector.

Absorbing the Neutron

- To the right is a Lithium-Fluoride salt
- Li-6 has a large neutron absorption cross section.
- An alpha and a triton are ejected after the absorption



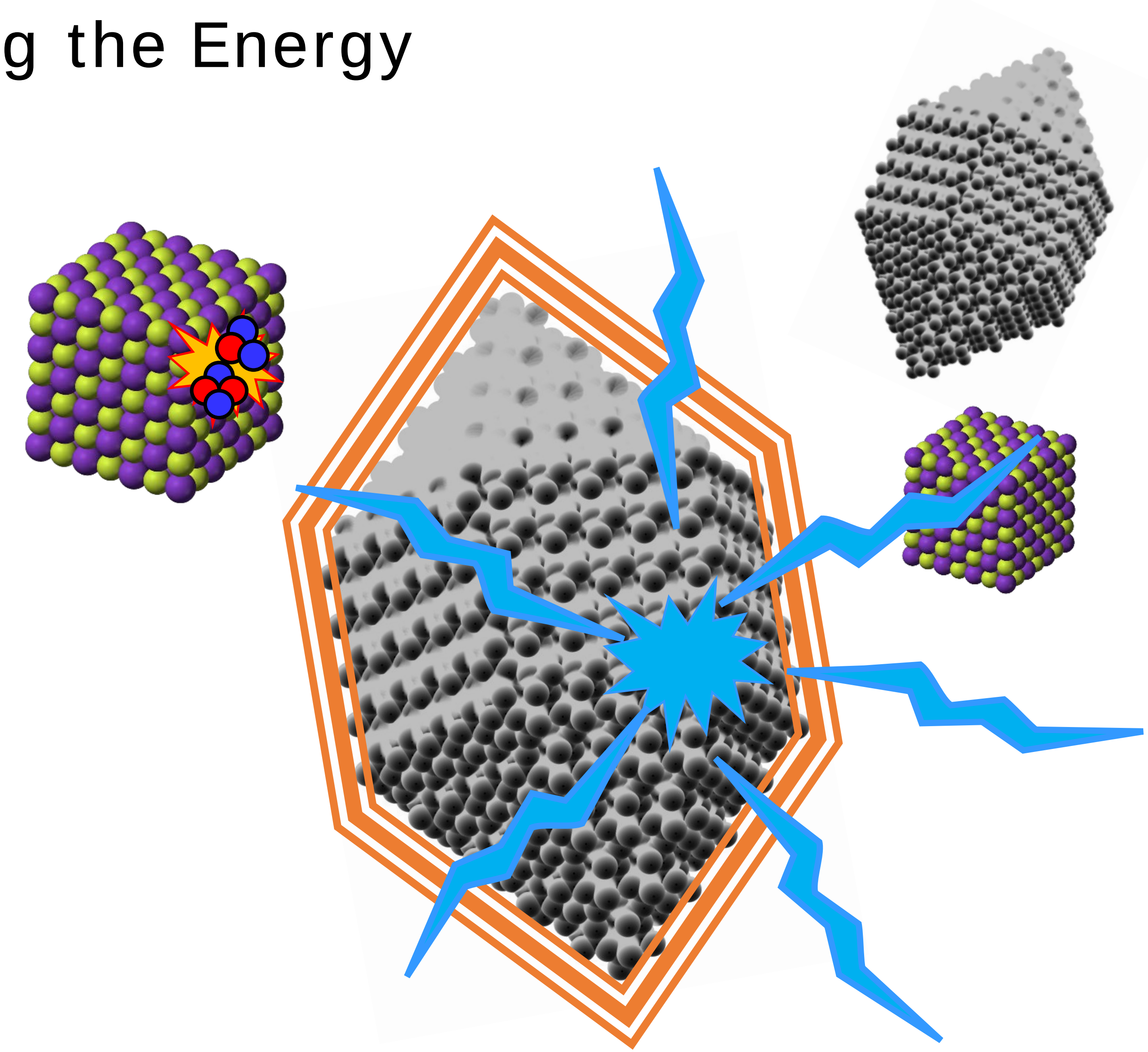
$$^{6}\mathrm{Li} \;+\; \mathrm{n} \longrightarrow \; ^{4}\mathrm{He}\ (\alpha) \;+\; ^{3}\mathrm{H}\ (\mathrm{T}) \;+\; 4.78\ \mathrm{MeV}$$

Harvesting the Energy

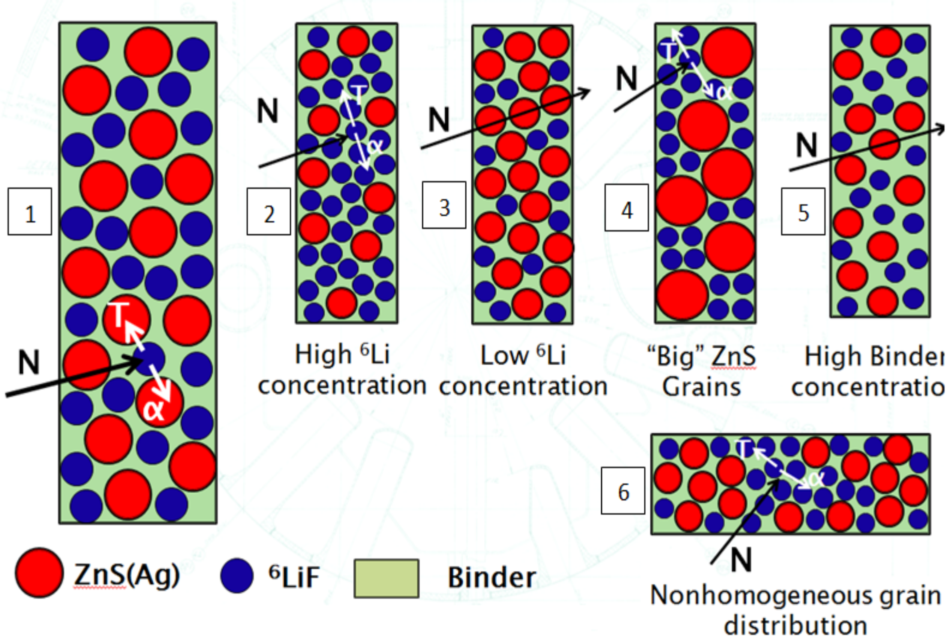
- This is the tough part!

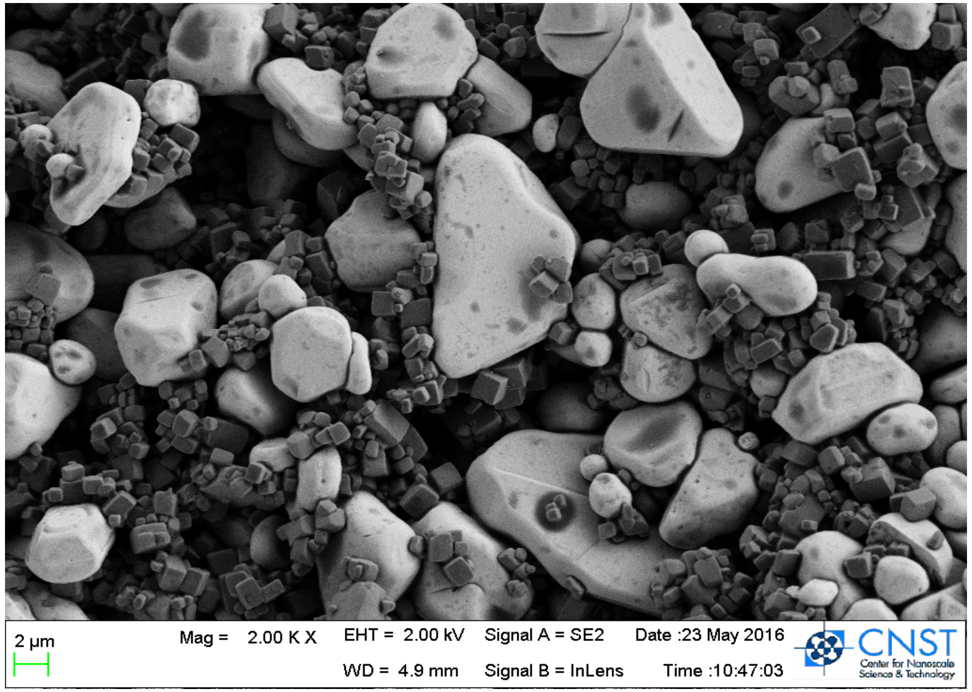
- Harvesting the energy from the high energy Alpha and Triton is a complicated process.

- We use a second material to create visible light from Alpha and Triton: Silver Activated Zinc-Sulfide



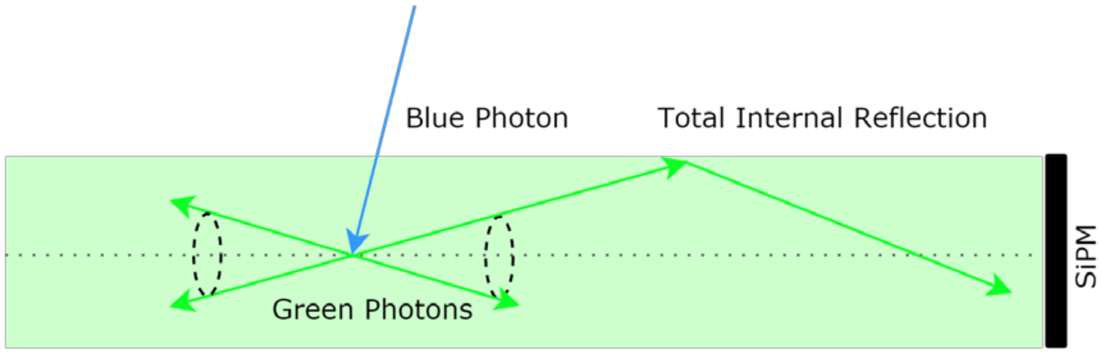
Detector Optimization

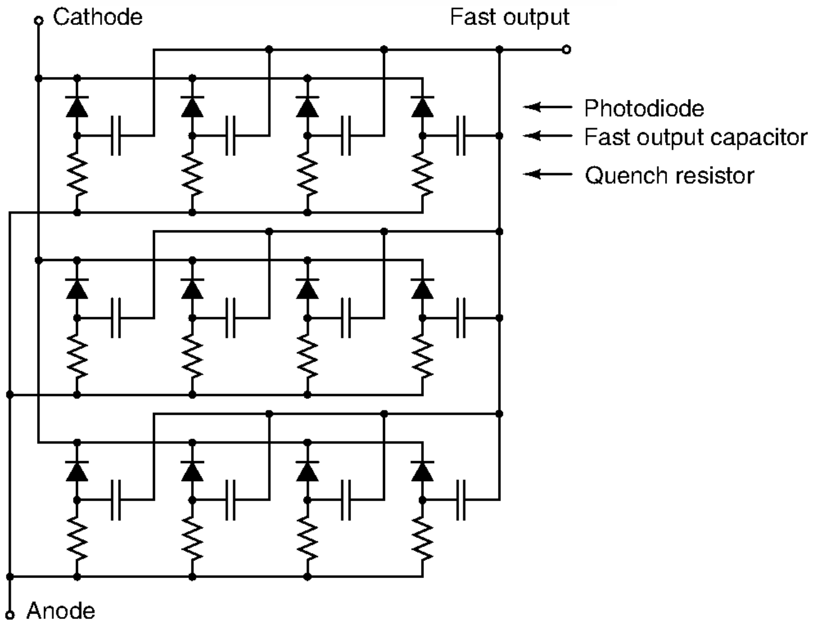




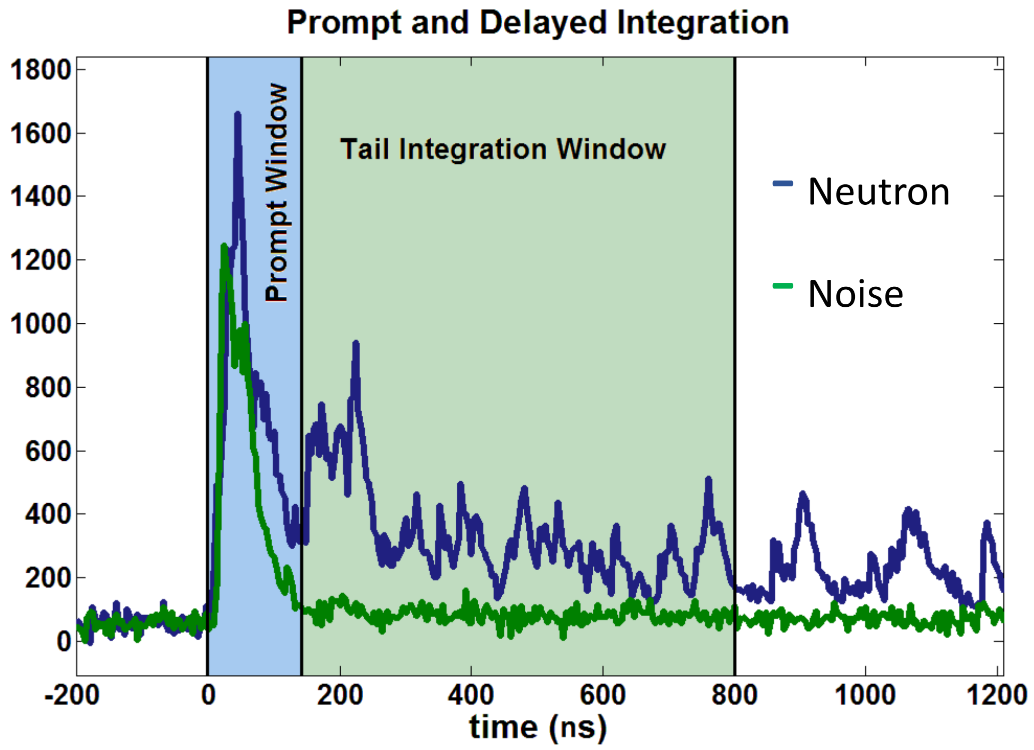
- GEANT4 was used to computationally optimize grain size and proportions for 6LiF:ZnS proportions
- Scintillator thickness was also evaluated using GEANT4
- These were then verified with a high purity neutron beam.
- Left Bottom: Scanning Electron Microscope (SEM) image of the scintillator mixture without binder. Courtesy of CNST

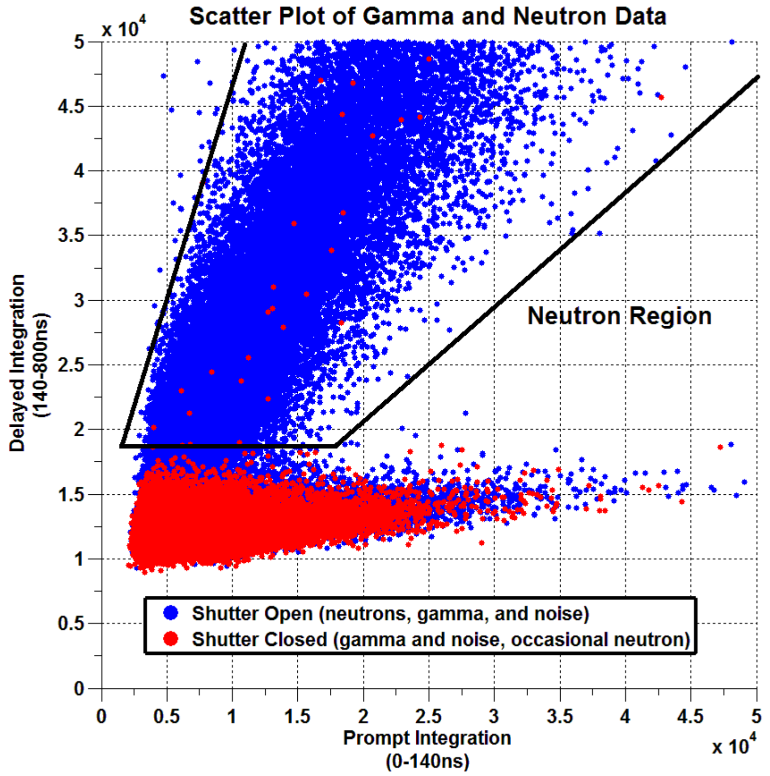
SiPM and Digitizer





Pulse Shape Discrimination



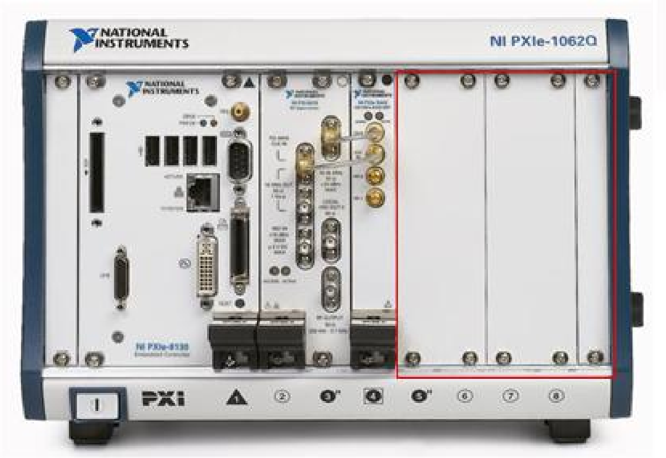


- To distinguish neutron captures from gammas and thermal noise, pulse shape discrimination is used.
- Two window integral discrimination can be done using digital or analog electronics.

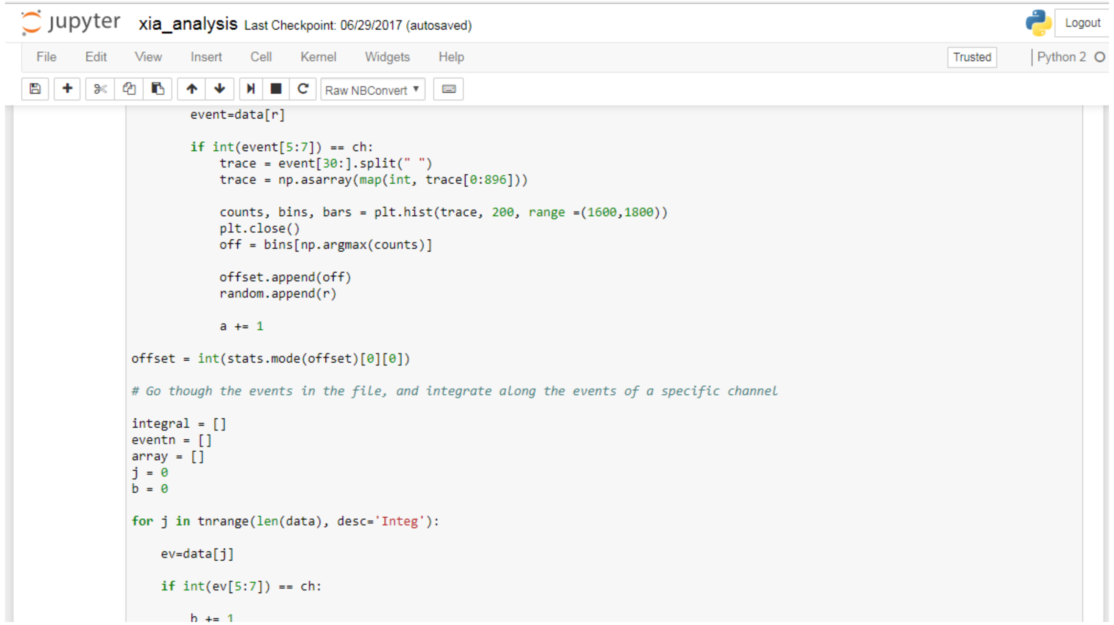
Characterizing the Detector

Old Equipment

New Equipment



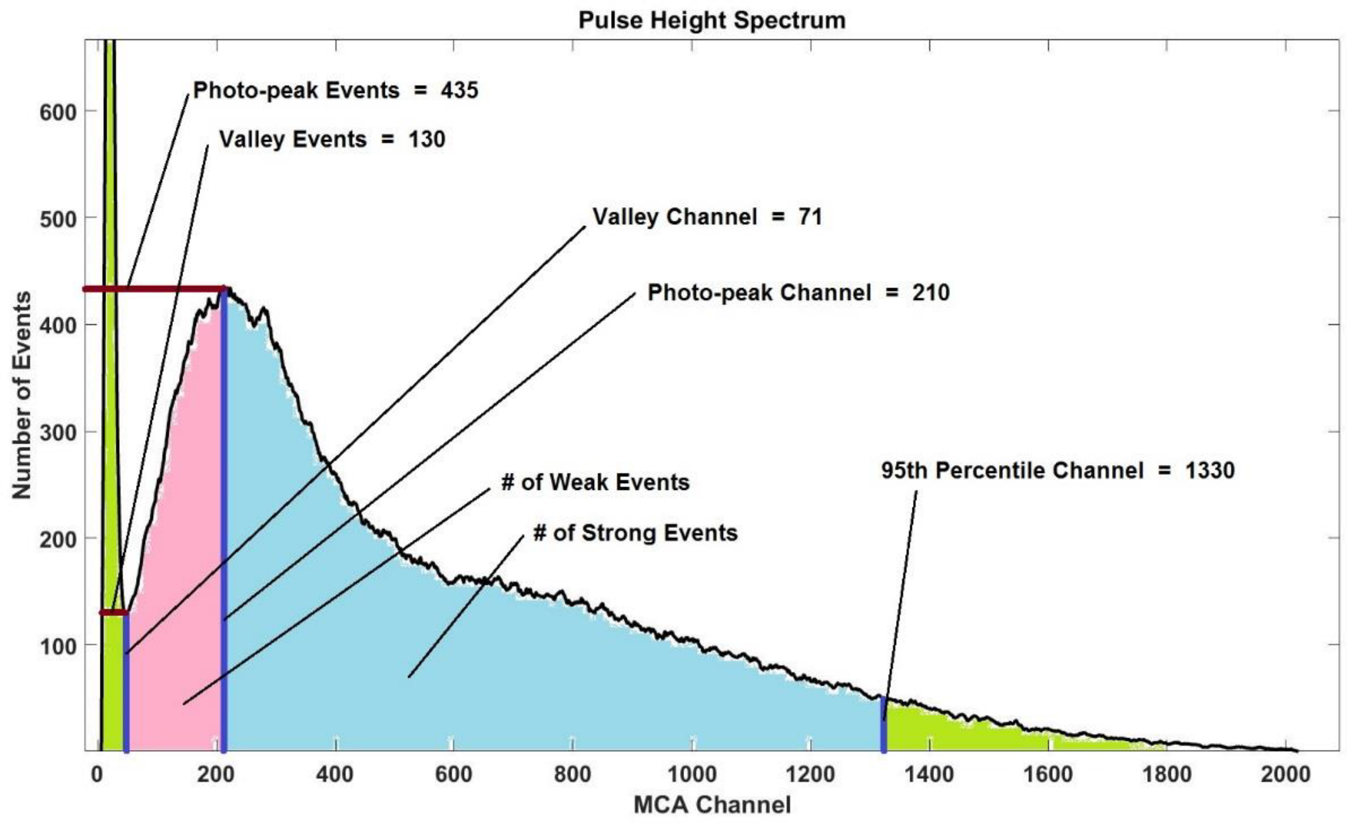
- Python scripts were developed to analyze the digitizer’s output.
- Goal of transitioning from a full test rack of analog and digital electronics to a compact digitizer and computer for detector characterization.

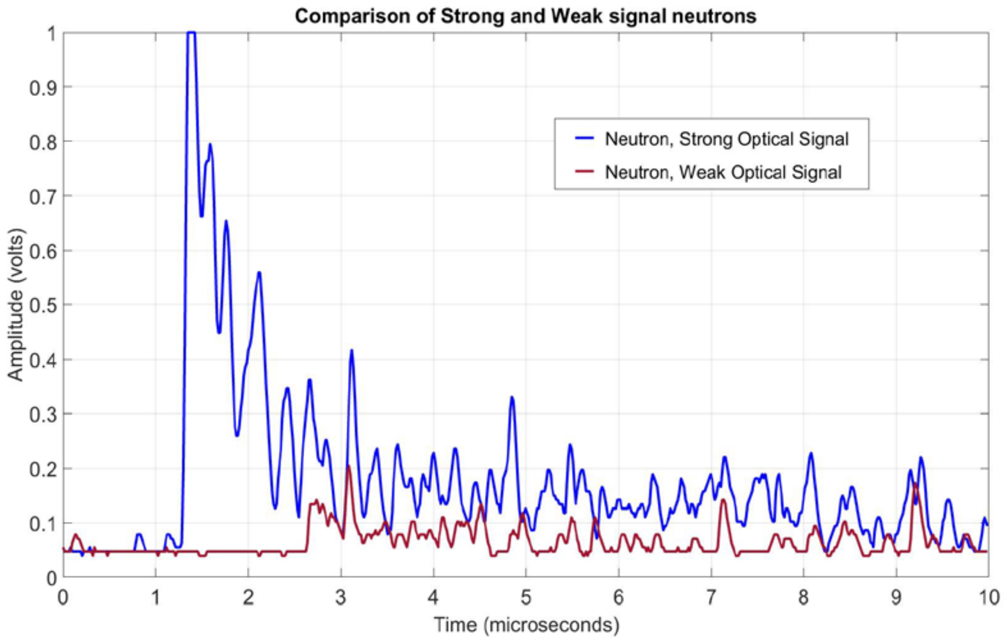


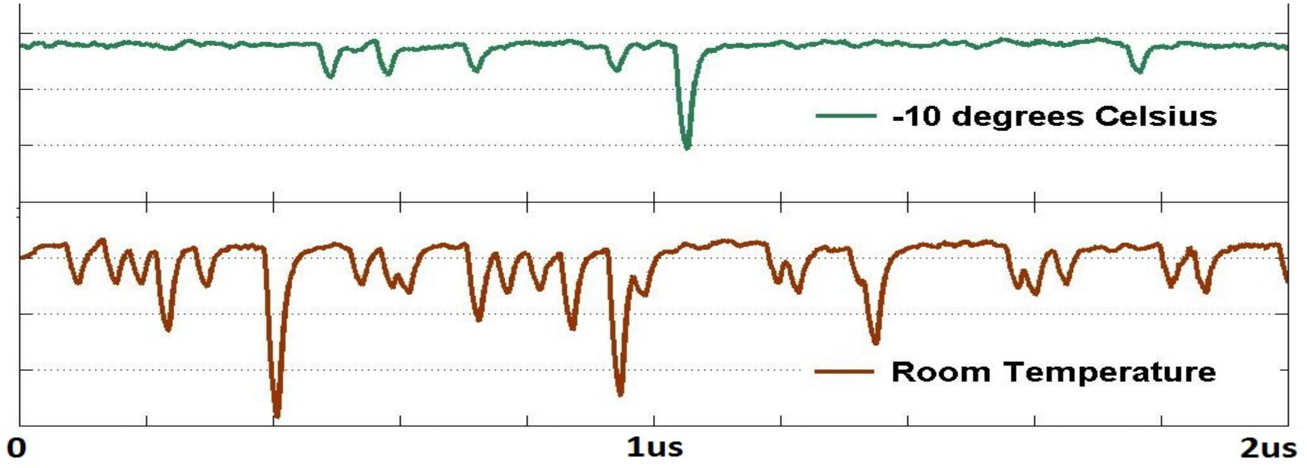
Optical Figure of Merit

- $$\text{FOM} = \left(\frac{Photopeak\ Channel}{Valley\ Channel}\right)\left(\frac{Photopeak\ Counts}{Valley\ Counts}\right)$$

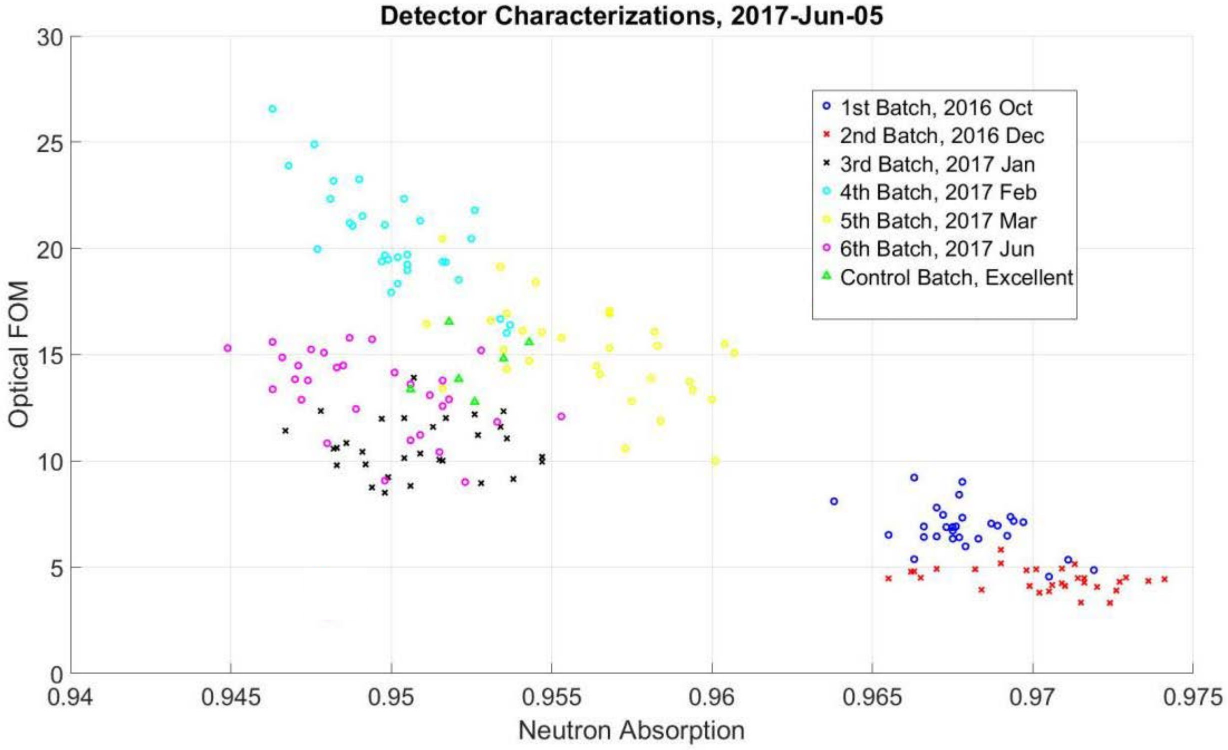
- Designed to be independent of gain.
- Characterizes individual detectors.
- Pulse height spectrum generated using a pure neutron data set.

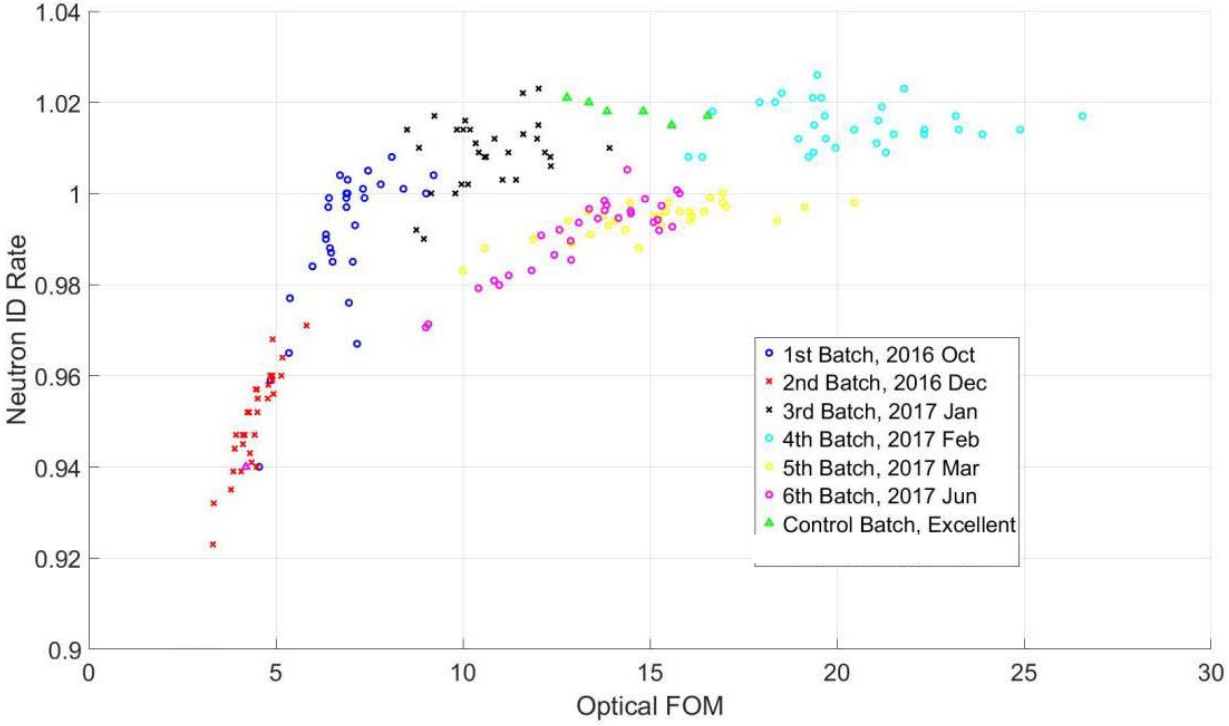




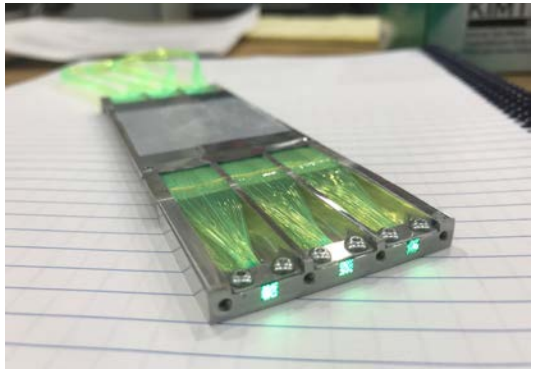


Detector Optimization





- Over 6 batches of detectors we have substantially optimized our detector.
- Optical Figure of Merit (FOM) is a figure derived from the pulse height distribution that helps describe the noise-neutron discrimination.



Detector

- Going from a neutron detection efficiency of 40% to 91%
- The other ~9% of neutrons will either
  - Pass through the detector
  - Scatter off the detector
  - Produce an unrecognizable signal
- Keeping the total cost under $500/3-channel detector
- Detector were developed in partnership with Eljen Technologies.

Thank You

And a Special Thanks to:

CANDOR Team Members

SURF Directors

- **Kevin Pritchard**
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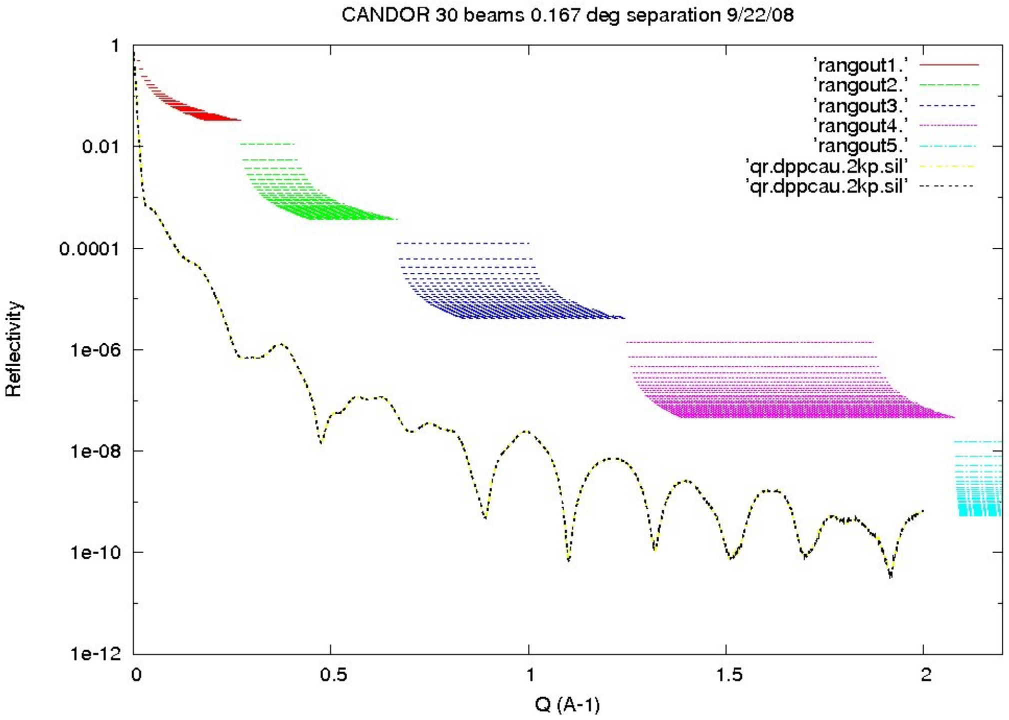
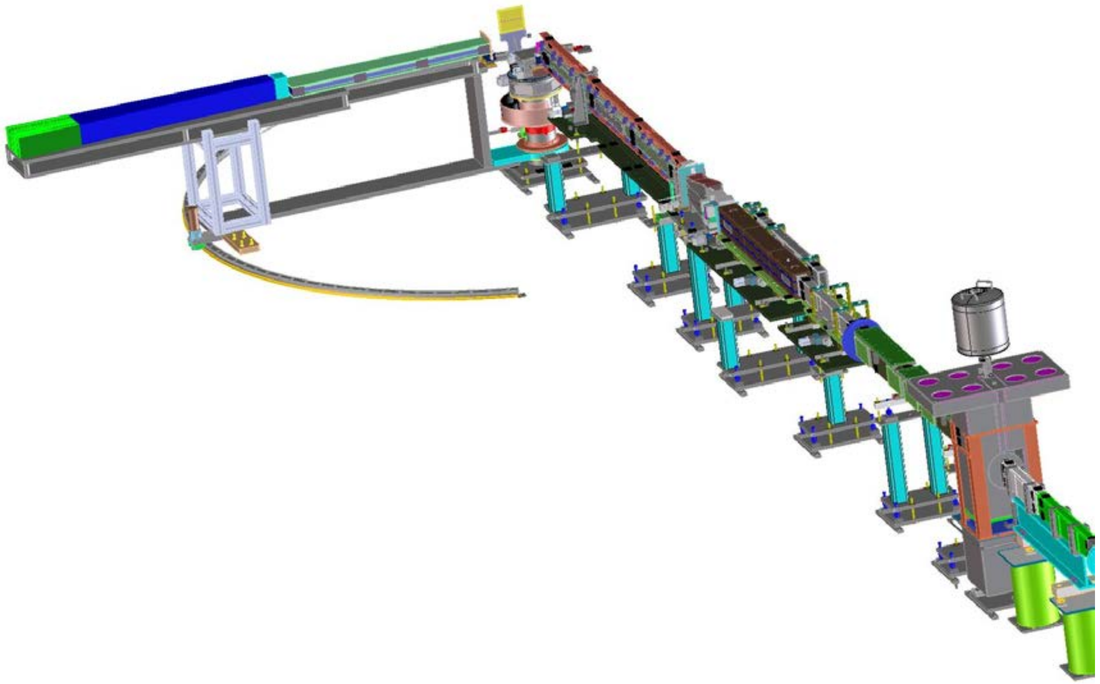
- Chuck Majkrzak
- Christoph Brocker
- Kobi Zada
- **Julie Borchers**
- **Joseph Dura**
- **Brandi Toliver**

Appendix

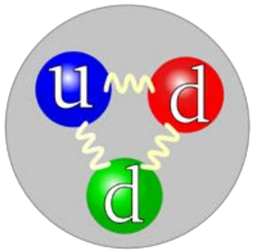
- Why Neutrons?
- Neutron Use Example: Determining Cell Membrane Thickness
- Wavelength Discrimination: Pyrolytic Graphite (PG)
- Optical Figure of Merit (FOM)



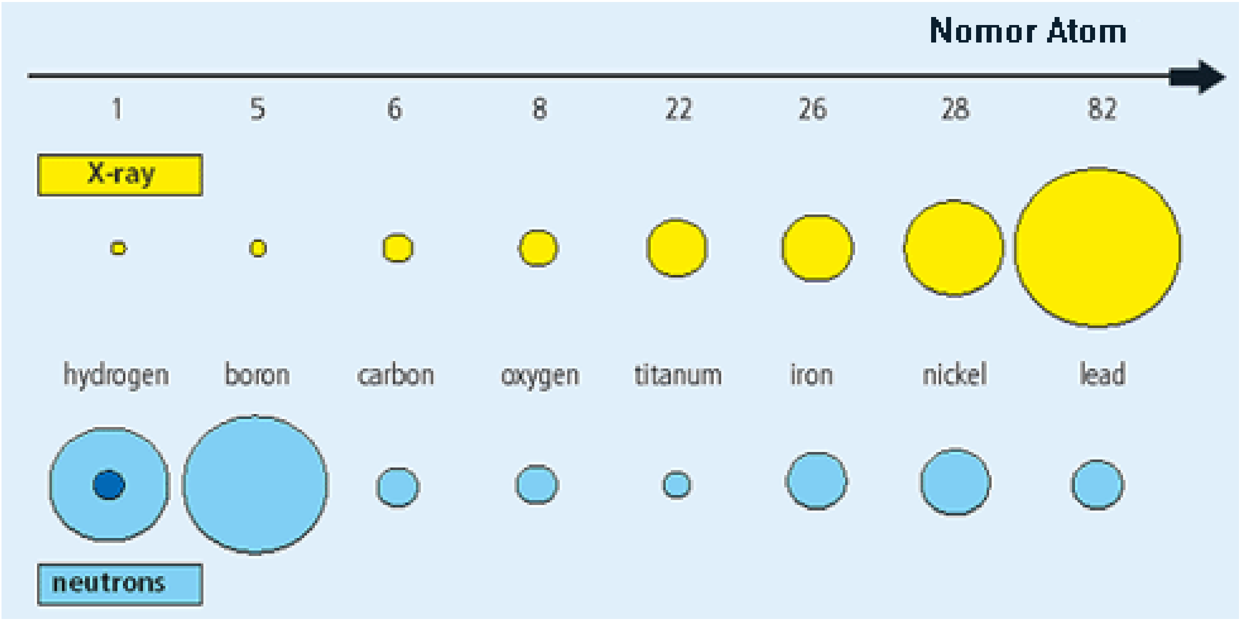


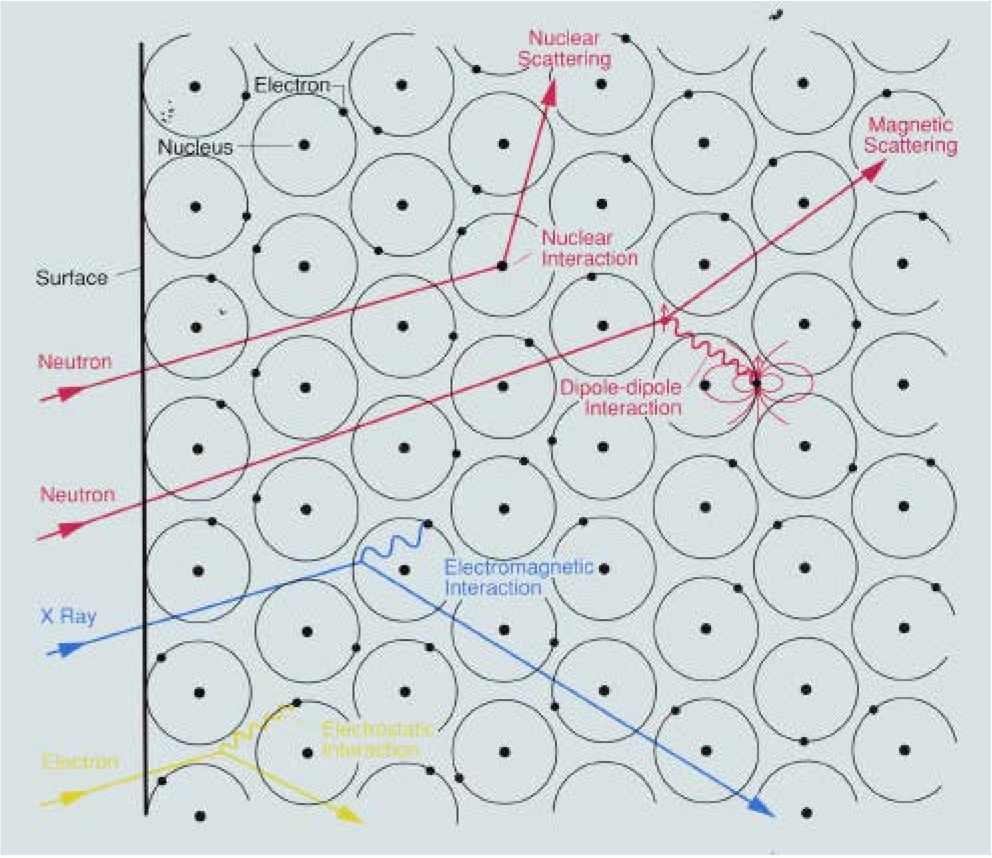
Why Neutrons?

- Useful for determining the positions and motions of atoms in materials.
- Accessible wavelengths comparable to interatomic spacing.
- Magnetic moment allows for probing of magnetic structure.



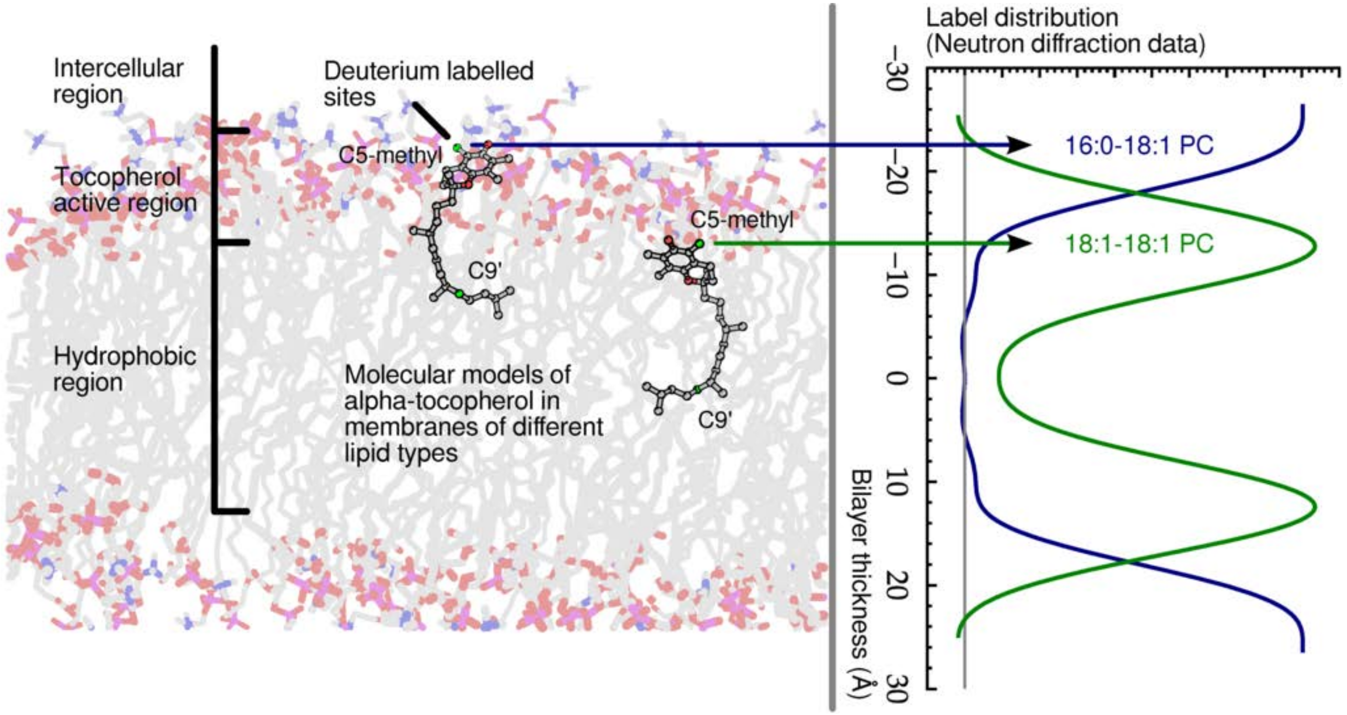
$m_n = 1.675 \times 10^{-27} kg$
Charge = 0, Spin = ½
Magnetic dipole moment:
$\mu_n = -1.913\ \mu_N$

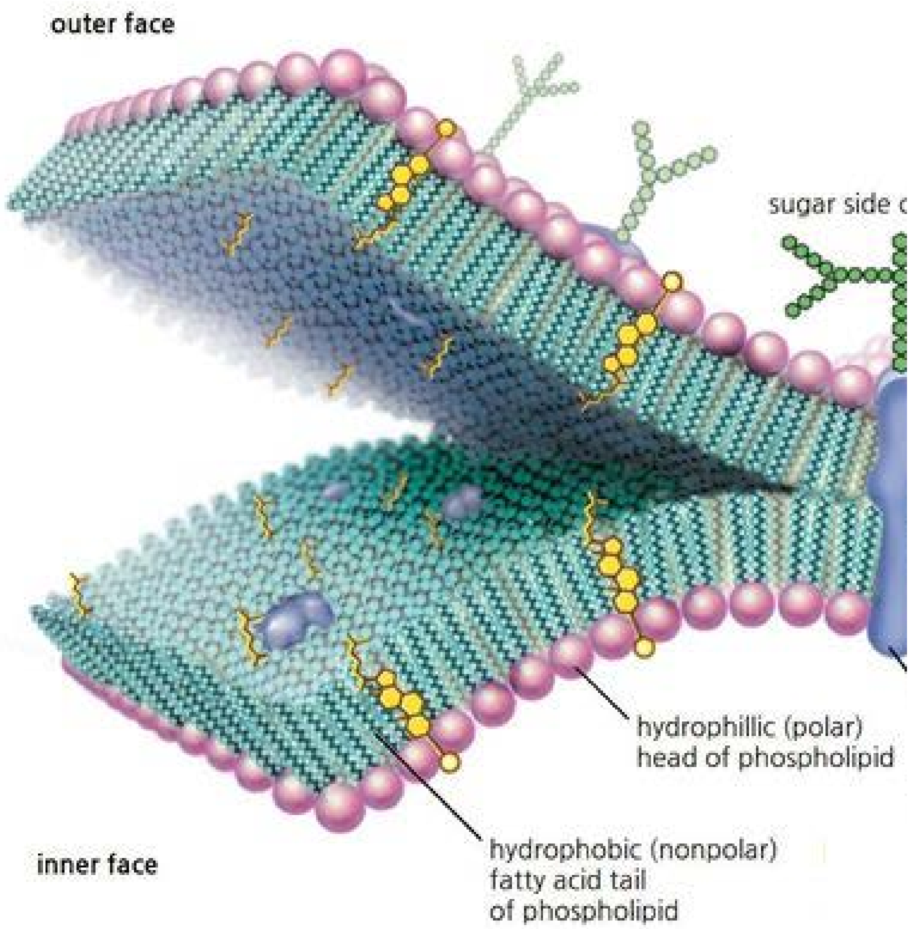




Neutron Use Example: Determining Cell Membrane Thickness

- Cell membrane is comprised of a lipid-bilayer that we now know is ~2 nm thick.
- Neutrons will scatter differently off of the hydrophilic head and the hydrophobic tail.
- Alternative techniques would not have been usable.





Wavelength Discrimination: Pyrolytic Graphite (PG)

- PG has a consistent plane spacing
- Bragg diffraction “selects” the required neutron wavelength.
- Allows access to 4-6 Å neutrons

- $n\lambda = 2d\ sin\theta$