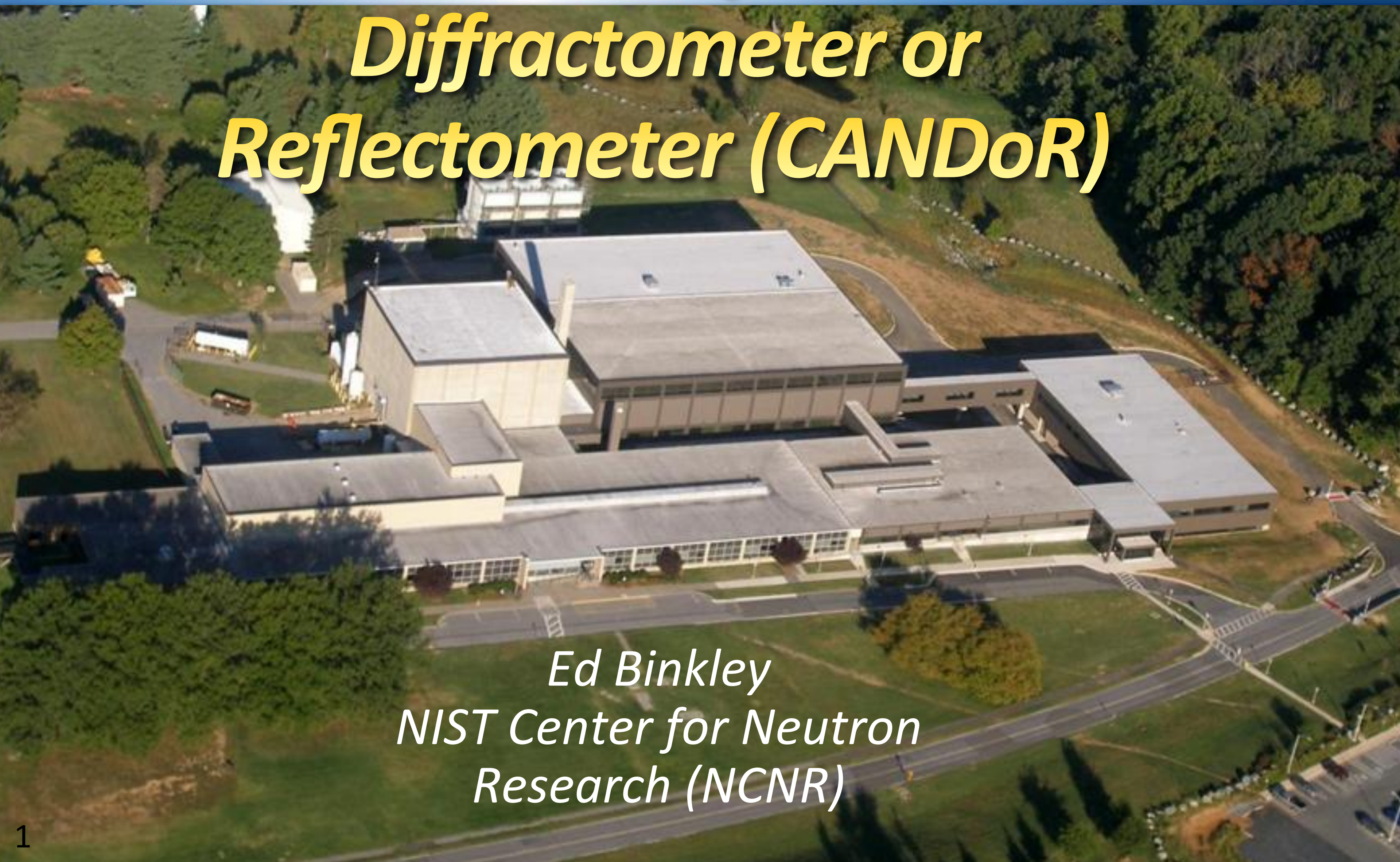
Chromatic Analysis Neutron Diffractometer or Reflectometer (CANDoR)



Ed Binkley
NIST Center for Neutron Research (NCNR)

CANDoR Detector Evolution

Overview

- *Candor Detector Array*
- *Optimization and Challenges*
  - *Frame size*
  - *Scintillation compound choice and evaluation*
  - *Manufacturing issues*
  - *Fiber Loop?*
  - Highly Oriented Pyrolytic Graphite *(HOPG) Accuracy*
  - *Holder Structure*

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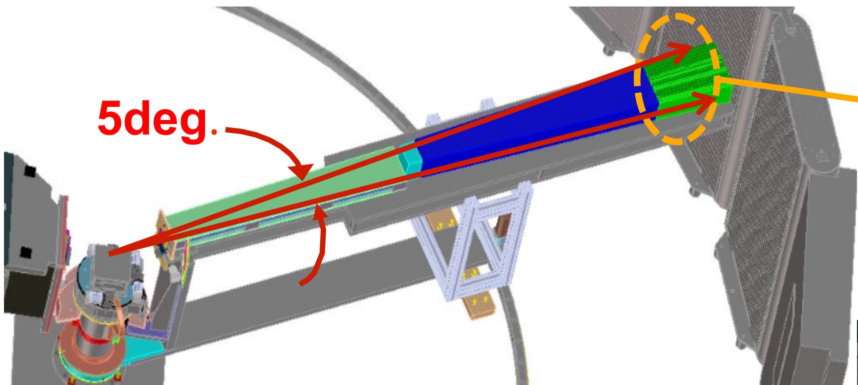
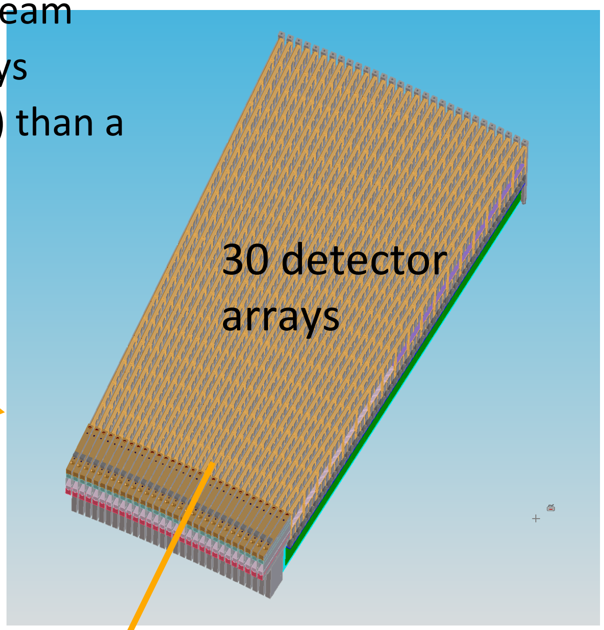
CANDoR Detector Array

- Polychromatic white beam (4 to 6 Angstroms) vs monochromated beam
- Five degree angle analyzed by multiple closely spaced detector arrays
- Equals significantly shorter measurement times (>1000 times faster) than a single detector





54 detectors per array

=1620 detectors total

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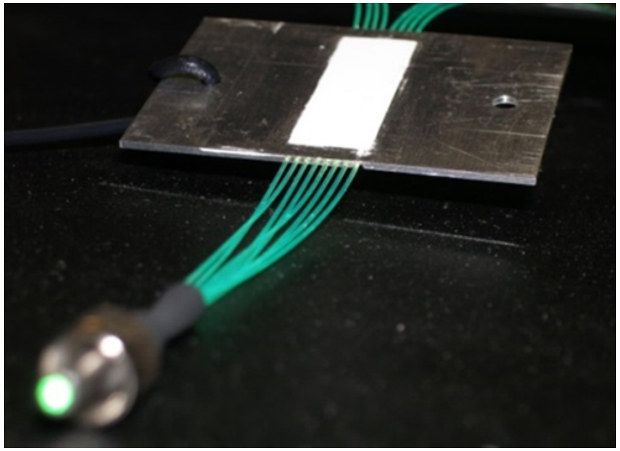
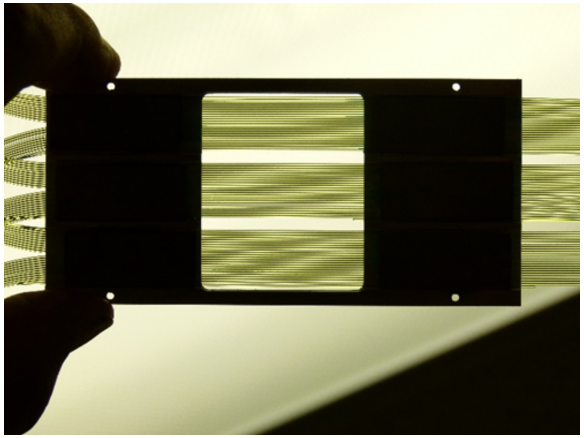
CANDoR Detector Frame Choice

- Started testing with only 8 fibers per frame
- Finished with 24 fibers per frame (12 if looped)

- Started with 1 mm thick frame
- Finished with 1.6 mm thick frame w/reflectors





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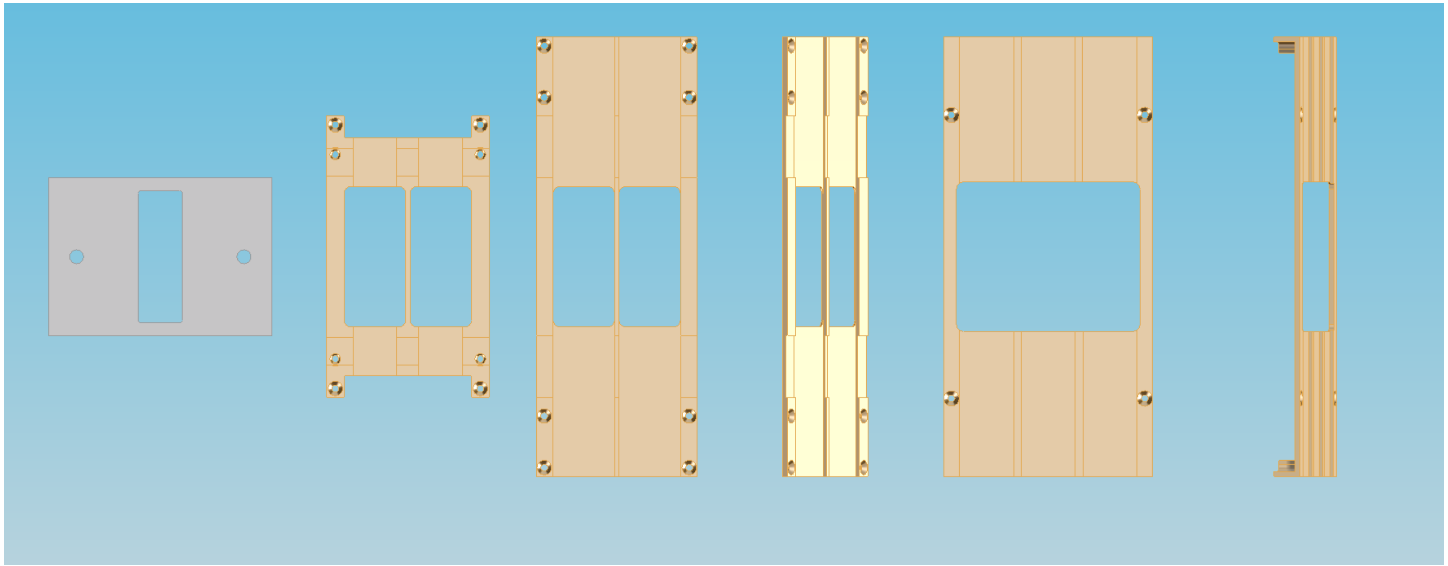
CANDoR Detector Frame Choice

Neutron Detection Frame Evolution – Optimizing the length of the array



Single frame for initial testing. Length = 1080 mm

Double frame to save space. Length = 864 mm

Triple frame for final choice. Length = 792 mm

Saving space and manufacturing costs.

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CANDoR Compound

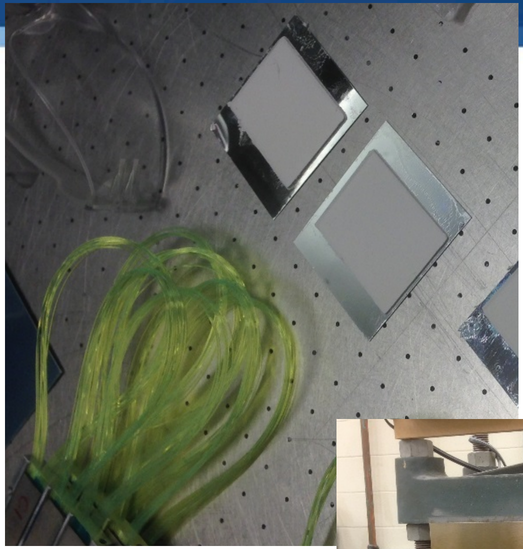
- Two ways to make a Frame
- Painted Compound
  - Easier to change the formula
  - Better adhesion to fibers
  - Frame thickness determines compound thickness

  - More “Craft” Dependent
  - Not good adhesion to reflector
  - Overall not as efficient

Candor Compound Choice

- Pressing compound
  - More consistent thickness
  - Good adhesion to reflector
  - 5% better overall efficiency

  - More complicated multi step assembly
  - May not always adhere to fibers as well



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CANDoR Detector Evaluation

- Frame Properties- Can we stay consistent
  - Measure Stopping power (Li content)
  - Measure neutrons that pass thru the detector vs the neutron count of an open beam gives a percent neutrons stopped.

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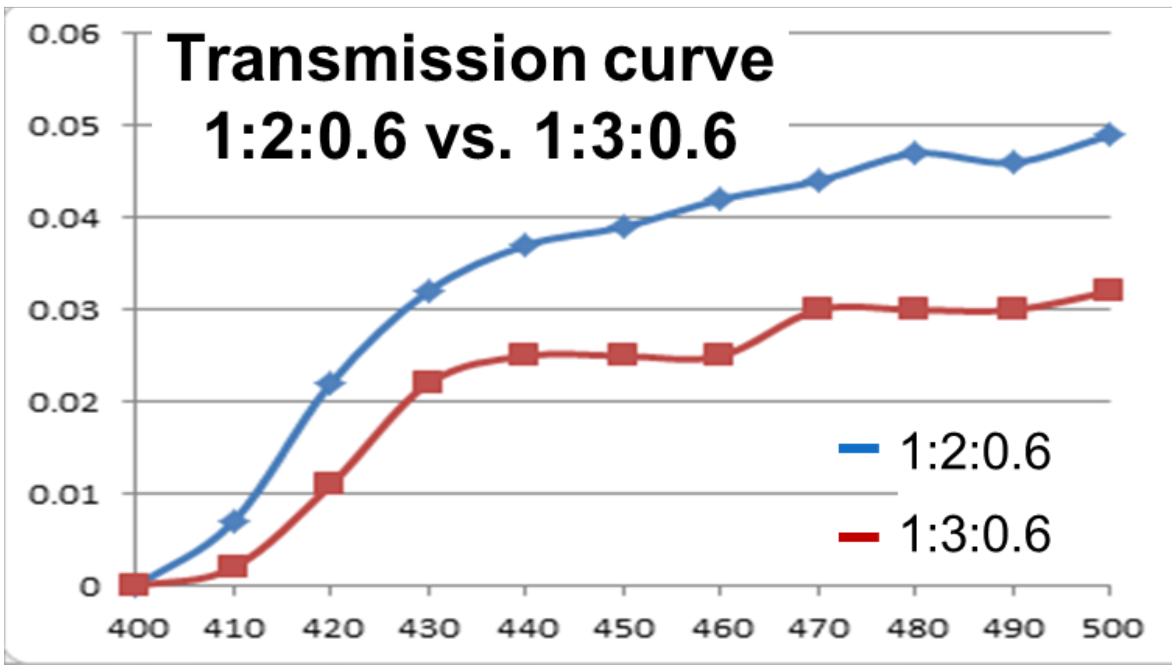
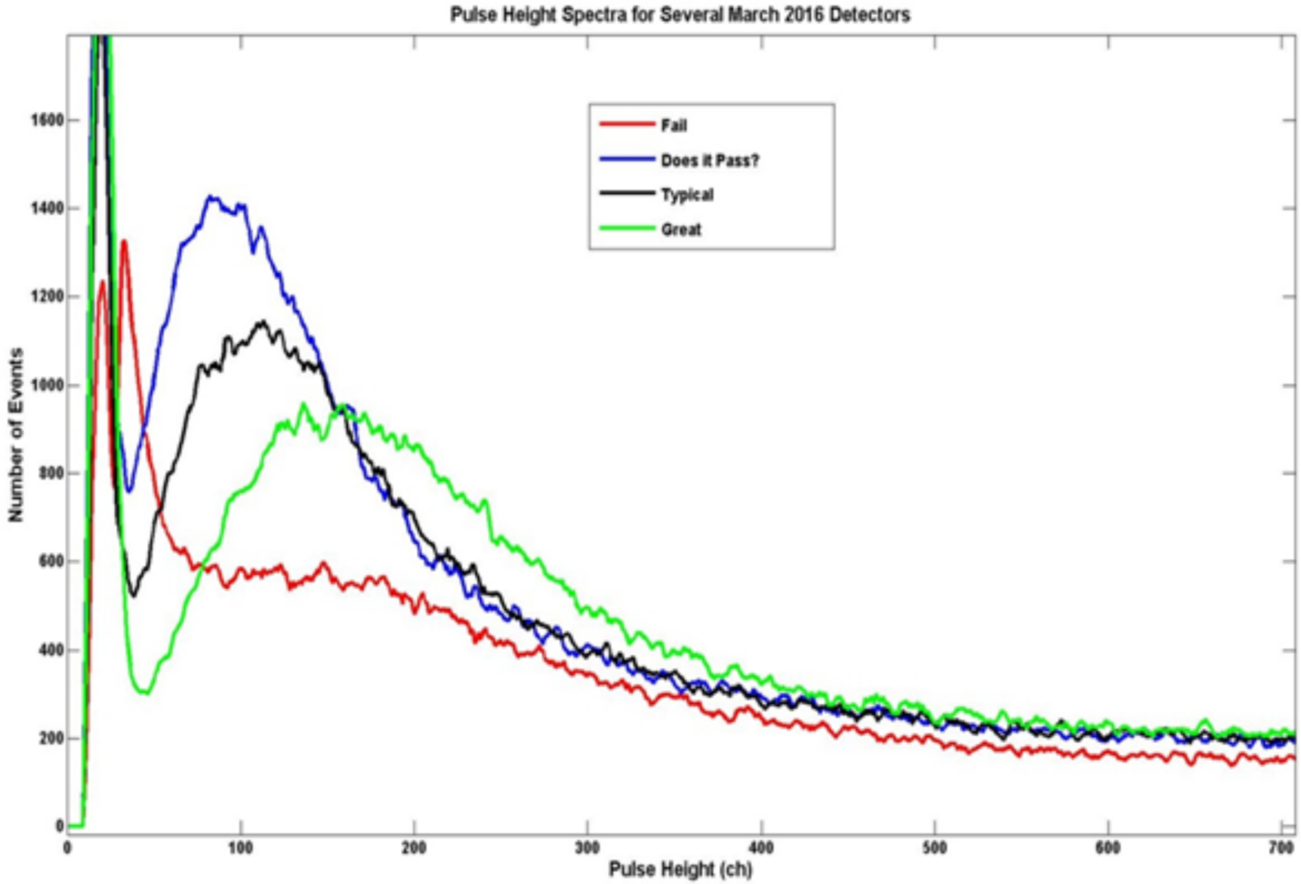
CANDoR Detector Evaluation

- Frame Properties- Testing
  - Transparency- the ease that the photons can get to the fibers.



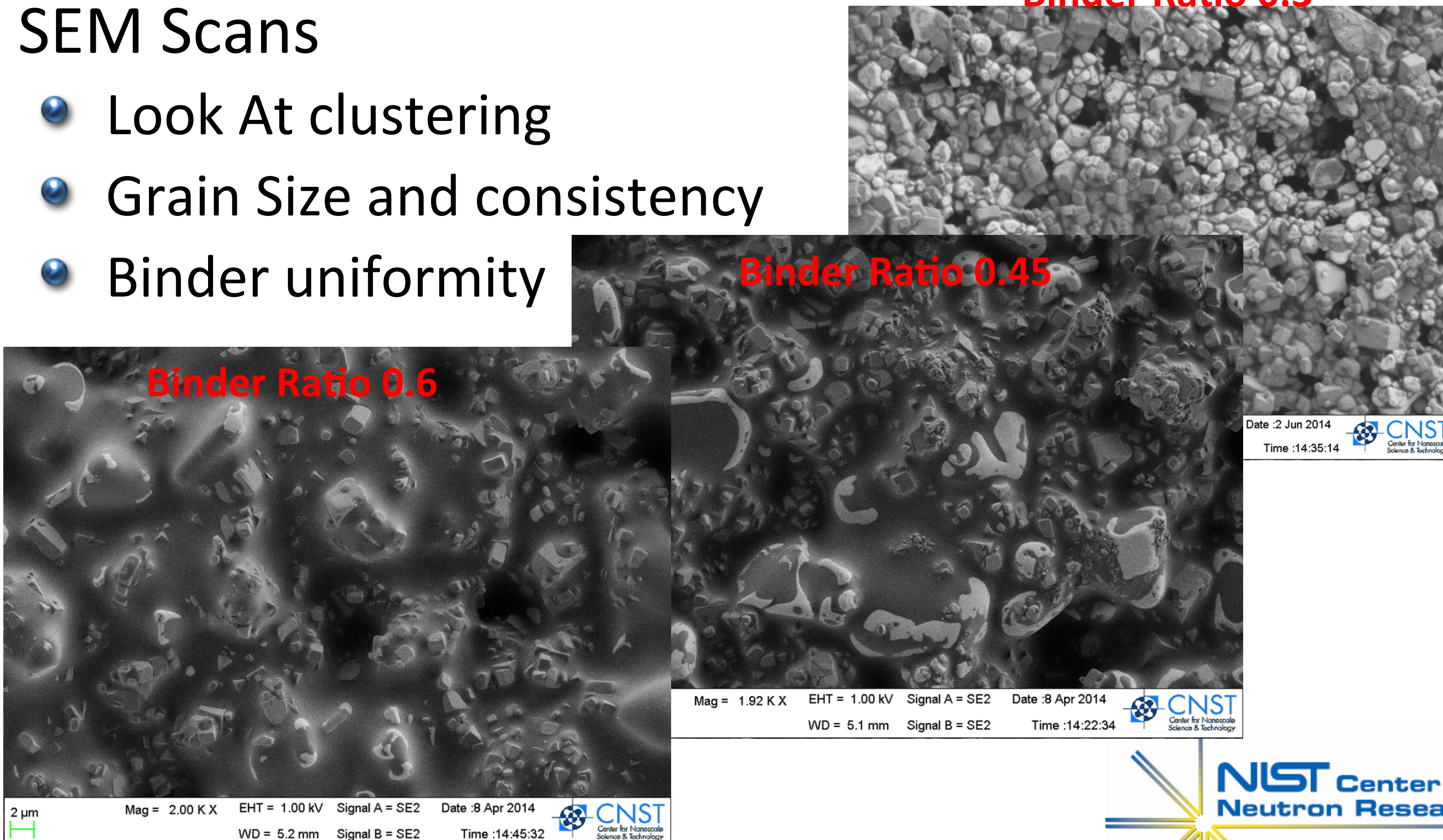
CANDoR Detector Evaluation

- Light output -Photons and their Intensity produced from ZnS



CANDoR Detector Evaluation

- SEM Scans
  - Look At clustering
  - Grain Size and consistency
  - Binder uniformity



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CANDoR Detector Manufacturing

- Same compound different results
  - Noticed compound variations from different batches that should be the same
  - Similar Stopping power with less light output
  - Process is very “Craft Dependent”

- We still don’t know all the answers
  - New ZnS compound is being tested to provide more light output
  - Binder concentrations are still being adjusted

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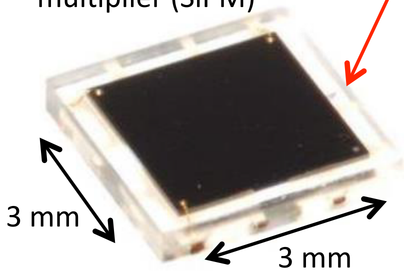
CANDOR Scintillator

Triple Frame Detector

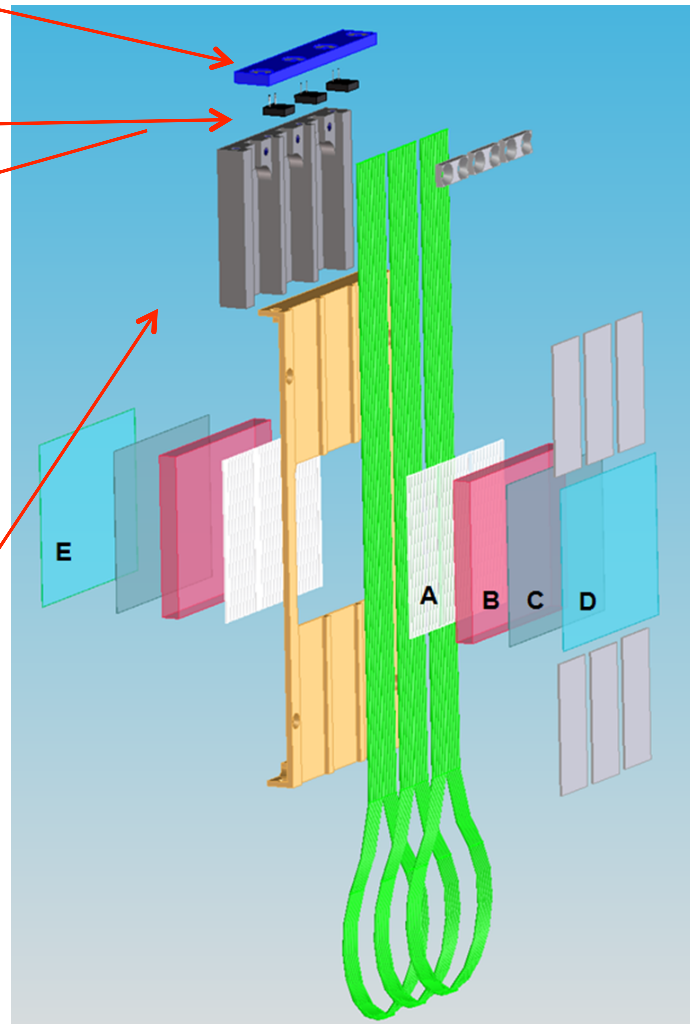
PC Board for SPiM (Diodes)

Diodes

Enlarged Silicon Photo-multiplier (SiPM)



WLS Fiber Bundling Block



A. Primer Layer –ZnS w/Nickel Killer
B. Compound Layer
C. ZnS (no Li)
D. Reflector Alonad
E. Reflector Vikuiti

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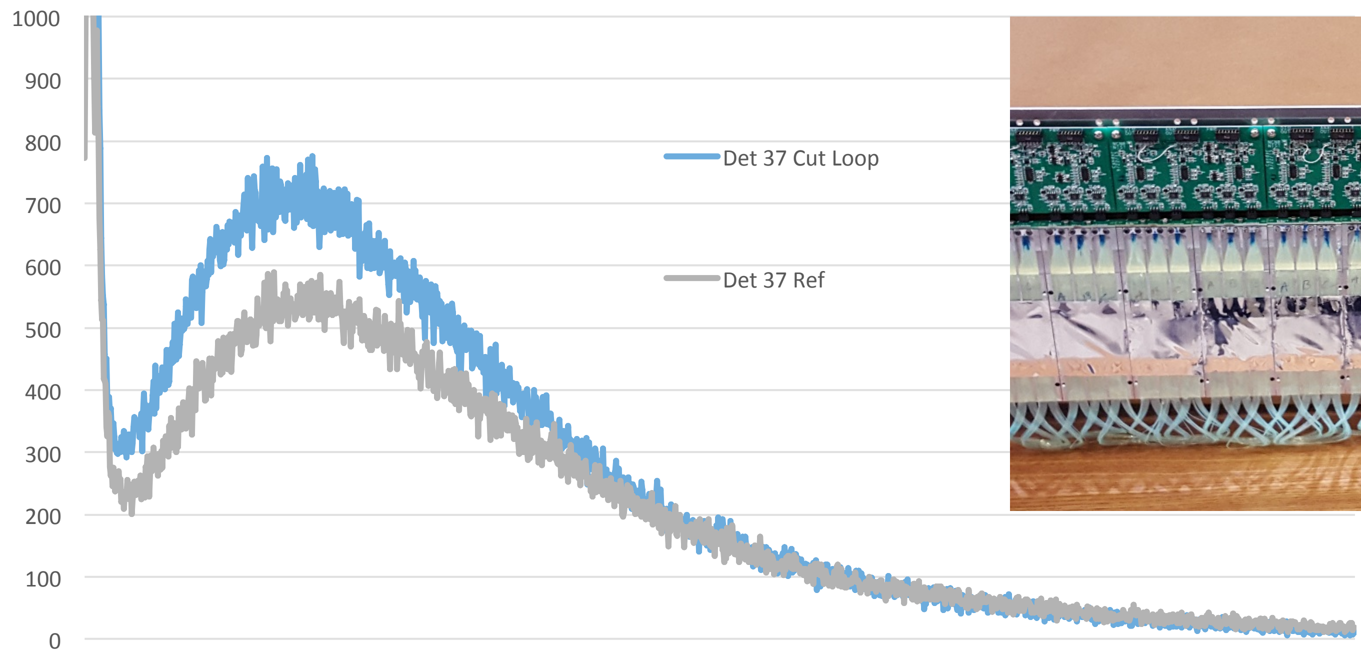
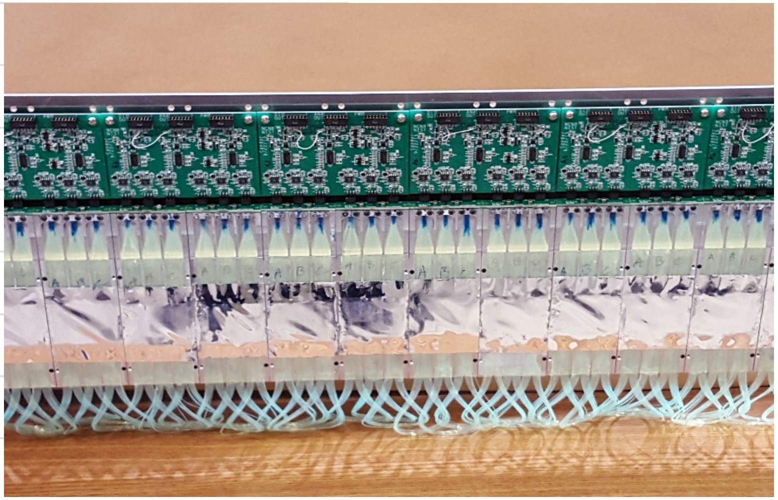
CANDOR Detector

The Final Step

Cutting the Fiber loop





Total 3% overall loss in efficiency

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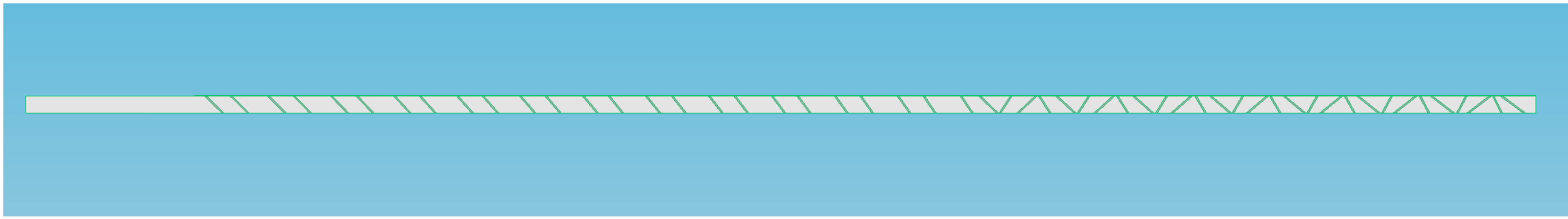
CANDoR Module Evolution



Using 2 sides to optimize length

- HOPG is transparent to all but the energy of the angle.
- Saves Length (But only approx. 20 mm more)

Not used

- Cross talk or scattered neutrons 1-2% from reflector inside the module were causing irregular results and the space saving was not enough to continue testing.
- Makes Mechanical assembly easier

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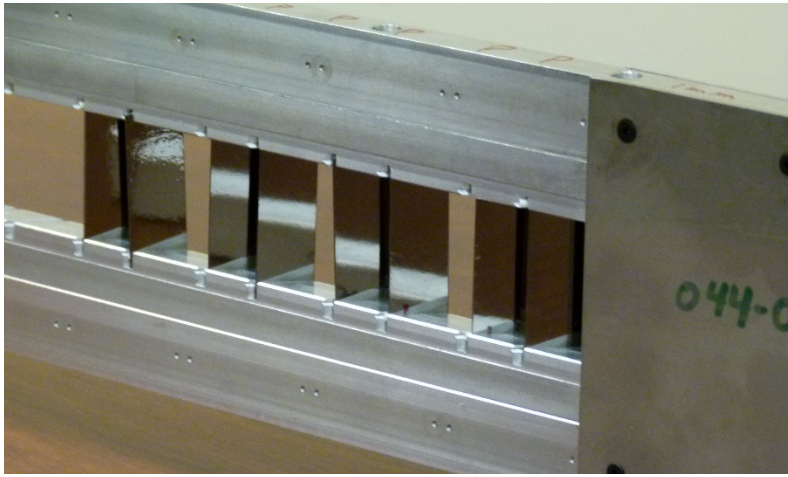
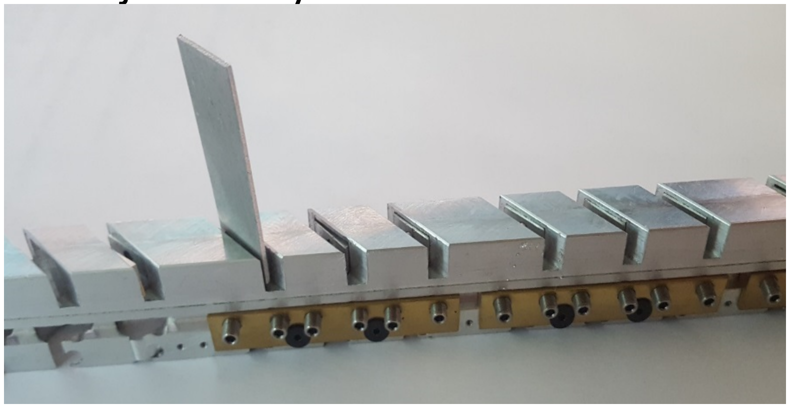
CANDOR Module HOPG Alignment



<u>Alignment of the HOPG Issues</u>

- Machining must produce angles tolerance of +/- .05 Deg
- HOPG Crystal matrix has a matrix tolerance +/- .05 deg
- Using Borated Aluminum makes machining tolerances harder to maintain
- Crystals originally held with an elastic tube (rubberband) on both top and bottom, this caused alignment issue to the precision angle needed.
- Now held bottom only with set screw on a rotating spindle for adjustability.



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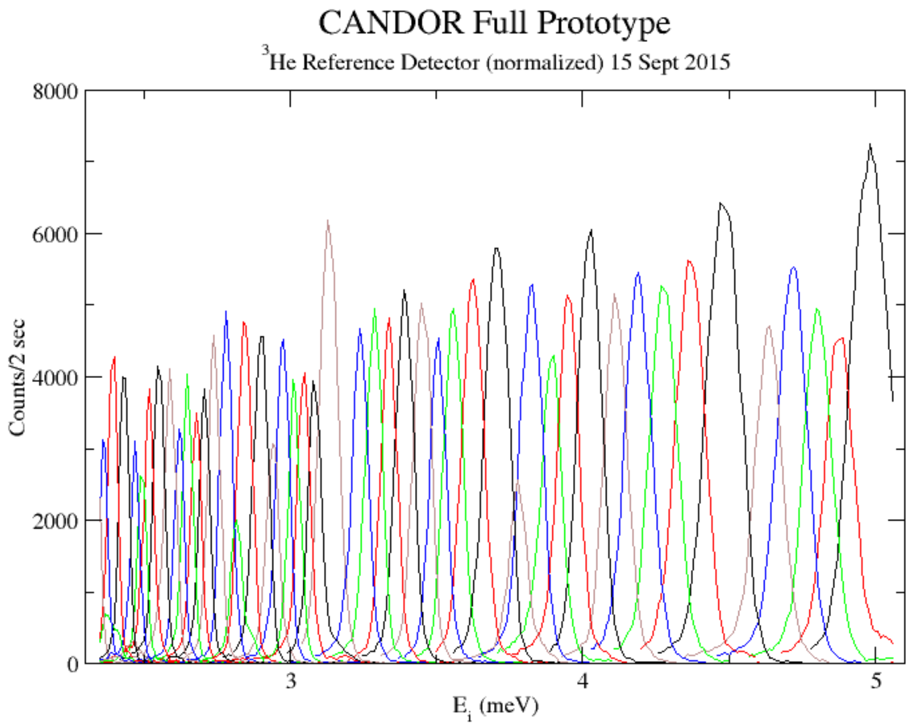
CANDoR Detector Array

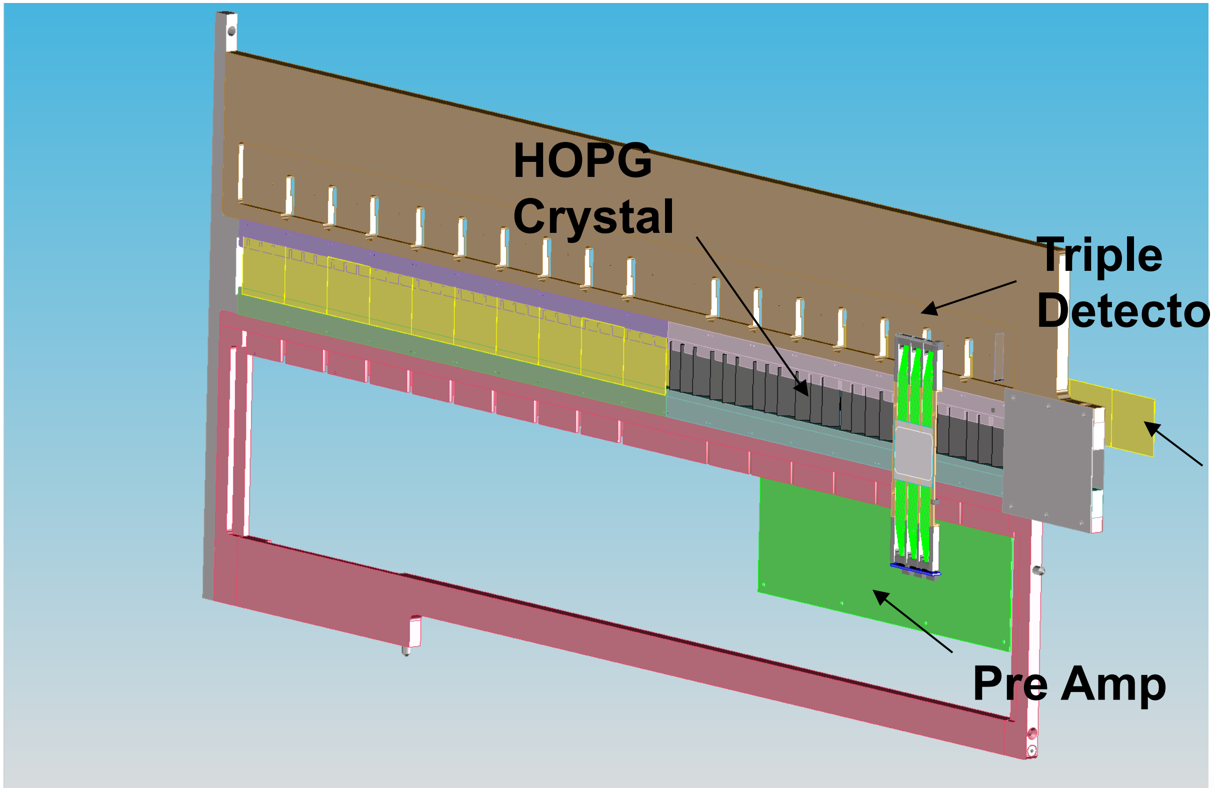
Detector Module (1/30 of the Array)

- 54 Pyrolytic Graphite Crystals will sequentially select neutrons wavelengths between 4.0 – 6.0 Angstrom by orienting each individual crystal to the appropriate angle of crystal reflecting surface we associate it to a specific neutron energy.
- Typical Output shown below.



CANDoR Module

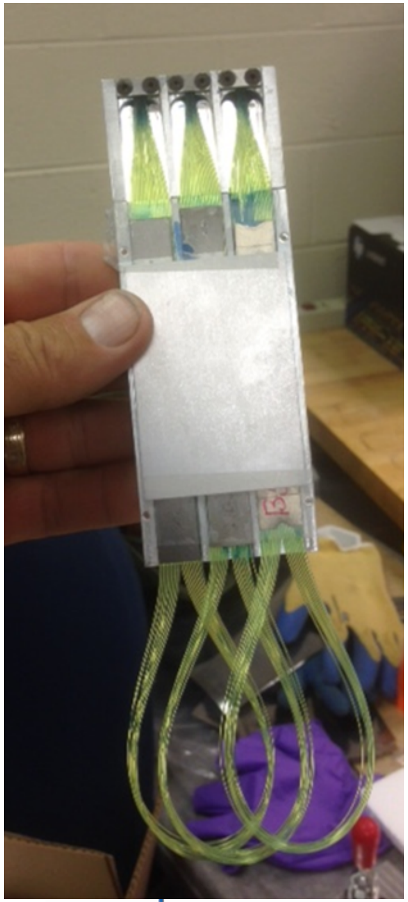
- Detector Array



CANDOR Scintillator

Looking Forward

- Testing of the Array adjustment with neutrons
- Testing of the new ZnS
- Address Manufacturing consistency problems
- Install this instrument on a beam line



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THANK YOU

QUESTIONS?

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Denim 2015

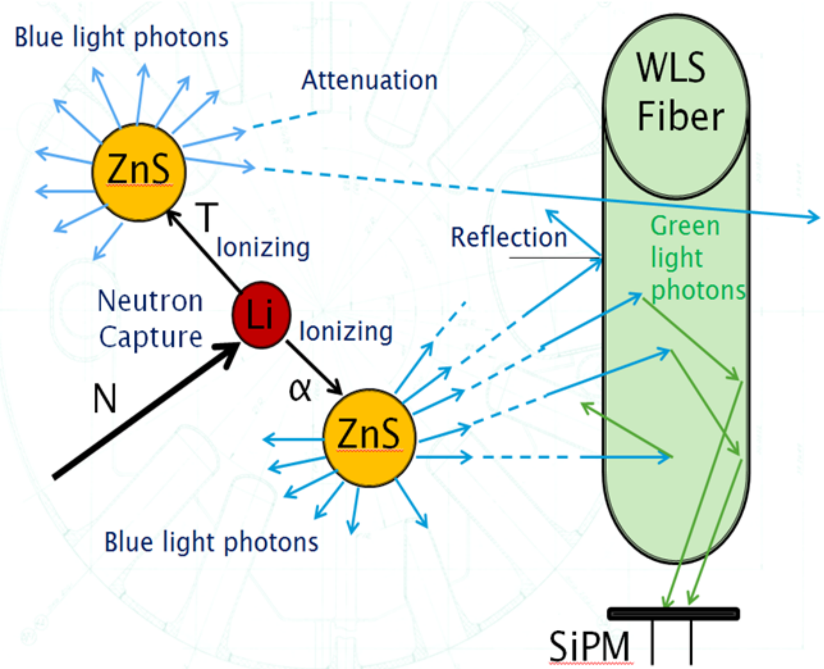
- Presentation from 2015 and overview of the Detector

CANDoR How it works

Neutron Detection

6LiF:ZnS(Ag)

- The neutron is captured by 6Li in the scintillator (6Li (n,α) 3H reaction
- The alpha and tritons ionize the ZnS(Ag) and produce blue light photons.
- Blue light photons are then absorbed by the fluorescent dye in the WLS fibers and re-emitted as green light photons, which are then conducted down the fiber to the SiPM.



CANDoR Detector

Challenges or things to be optimized

- Neutron Capture Sensitivity: The likelihood of interaction between an incident neutron and a target nucleus (6Li).
- Stopping power, the ability to stop all the neutrons that it sees.
- Measurable Signal: The scintillator is opaque to its own scintillation light.
- Gamma Rejection: The scintillators are inherently sensitive to gamma ray photons.
- The silicon photomultipliers are subject to thermally induced noise.
- Scintillation decay time (double counting).

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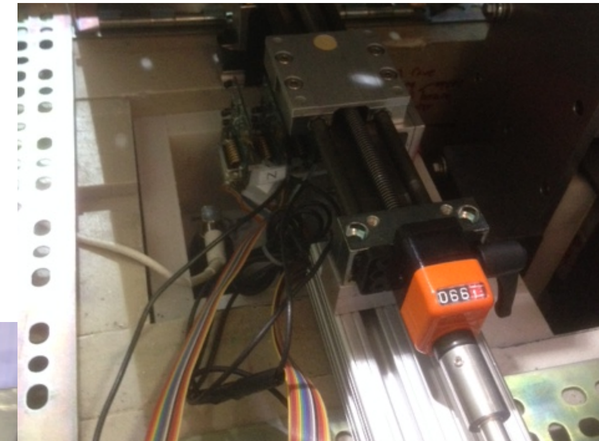
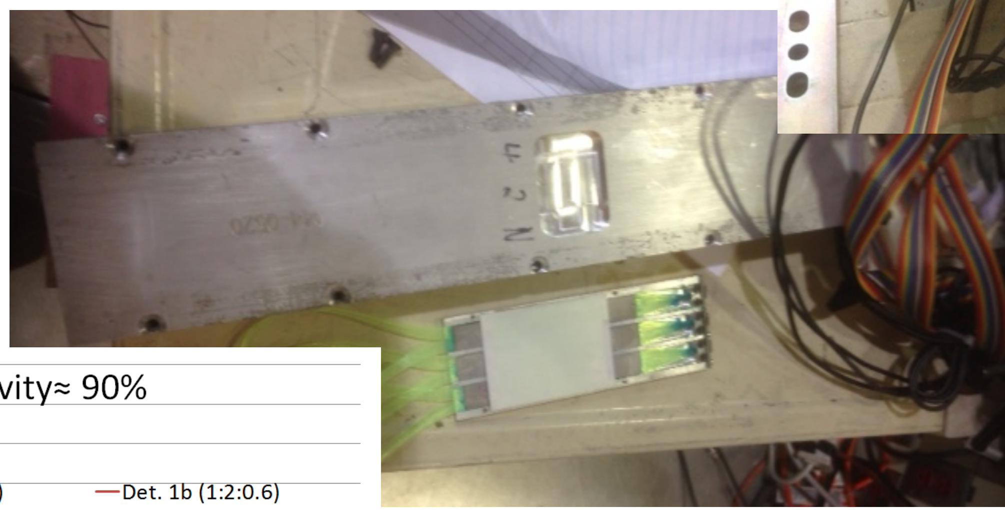
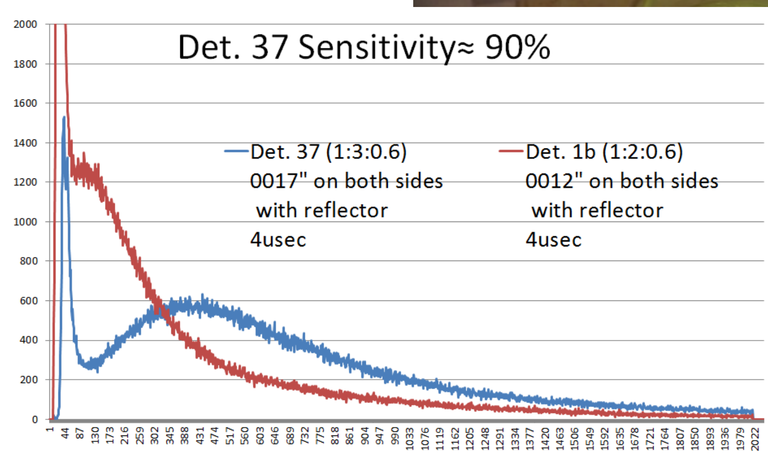
CANDOR Scintillator Testing

<u>All testing relative to HE3</u>

- Stopping power-Neutrons stopped
- Sensitivity- Neutrons counted
- Light spectrum- the brightness of events counted







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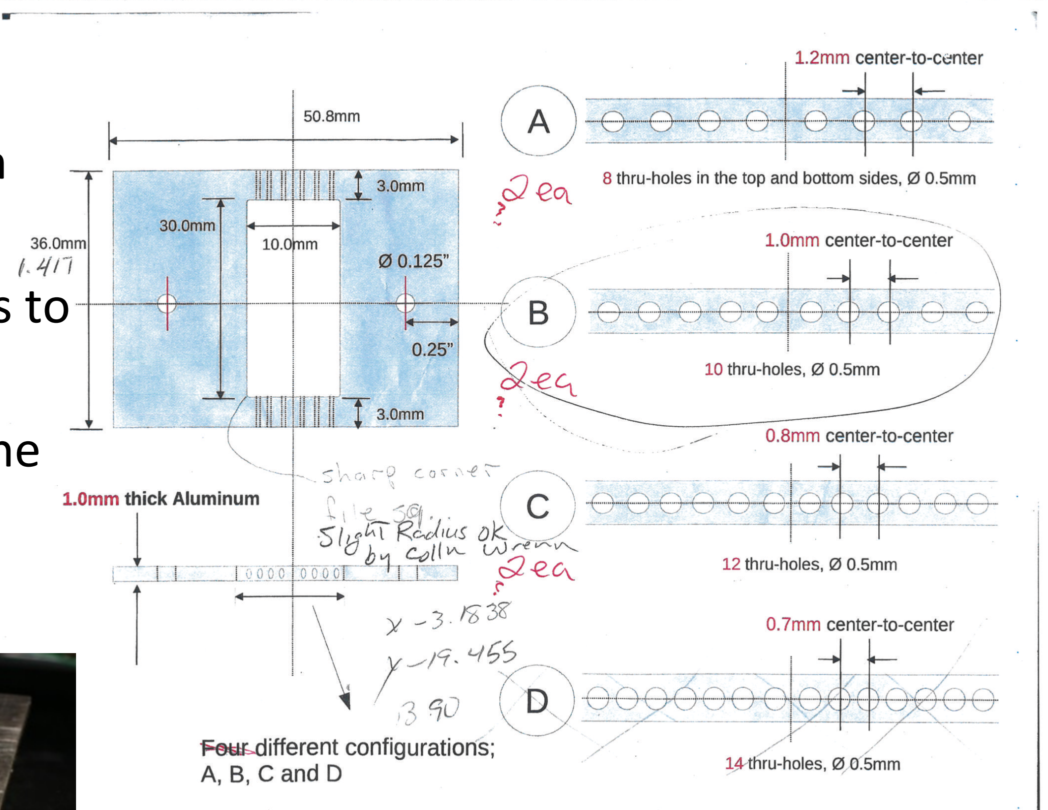
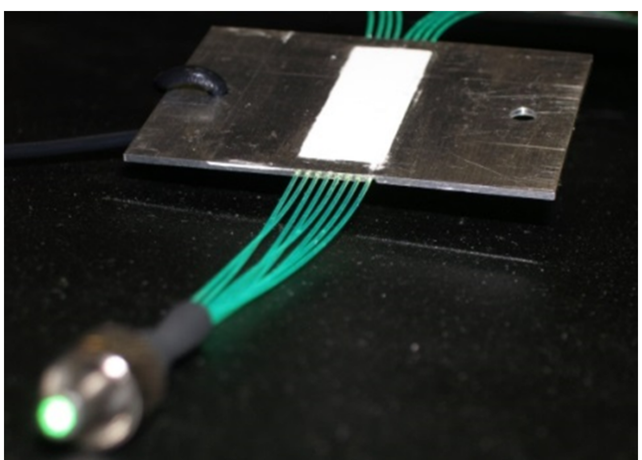
CANDoR Detector Development

Frame Design

- First frames had few fibers with spacing between fibers.
- These were complicated frames to produce.
- And labor intensive to thread the fibers.
- Poor sensitivity





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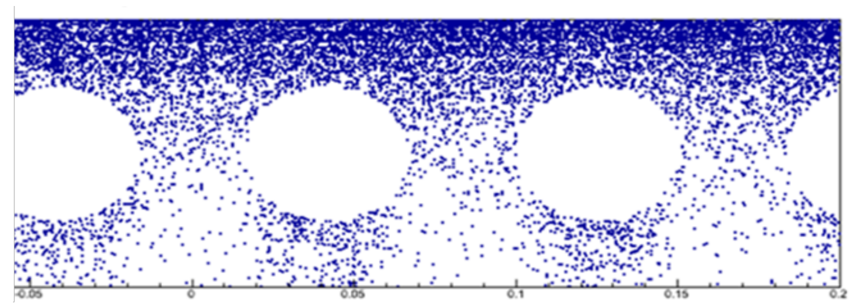
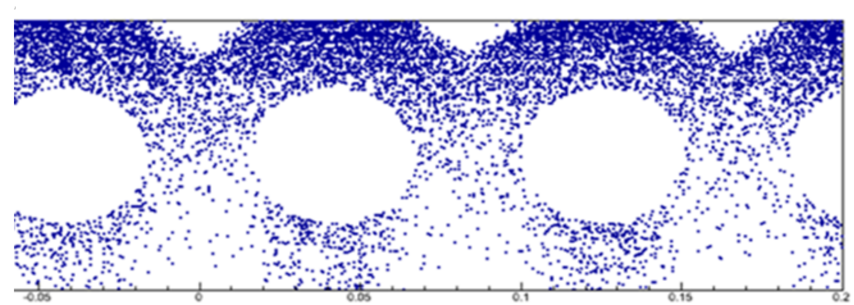
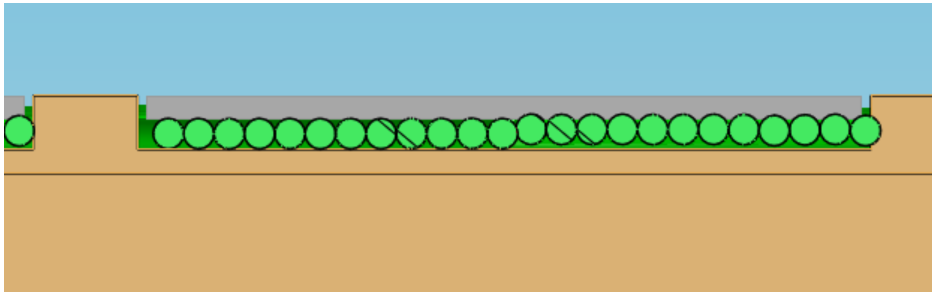
CANDoR Detector Development

Fiber Spacing Changes Light Collection

- Neutron events happen most near the surface of the detector.
- Due to the opaqueness of the compound some of these events are unlikely to be captured.
- We are losing events in area where they happen MOST!





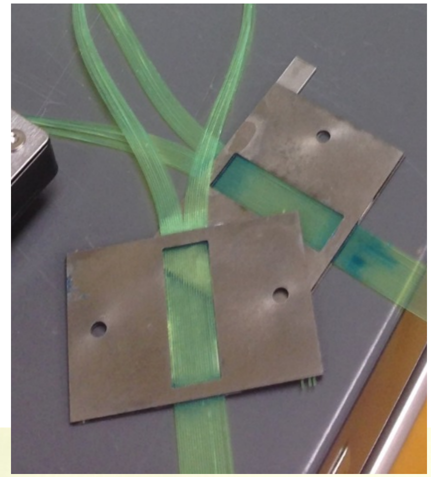


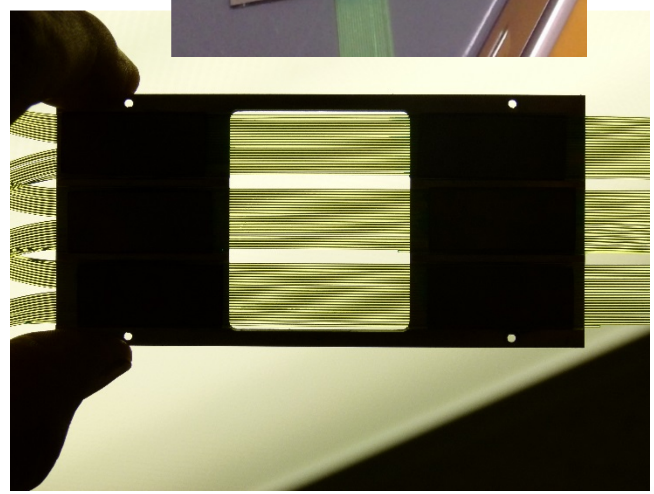
CANDoR Detector Development

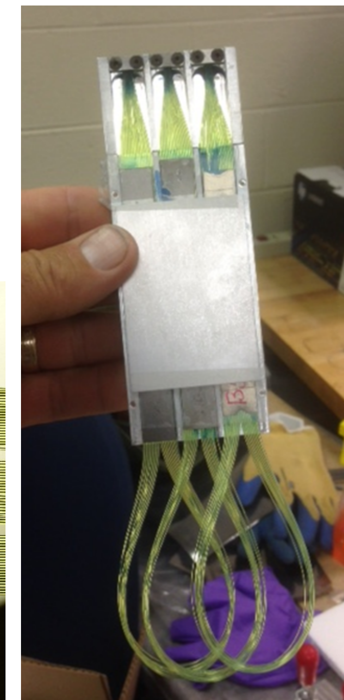
Solution-

More Fibers More Light

- We eliminate the dead spots by filling the frame with fibers
- Win-Win-Frames are easier to produce and no more fiber threading thru small holes
- Labor is easier for the detector
- Fibers are relatively cheap







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CANDOR Scintillator Compound

Scintillation Compound

- Three components- ^{6}LiF, ZnS(Ag), & binder
- High stopping power with ^{6}Li density
- High Light output with ZnS(Ag) density
- Binder is transparent
- Grain Size of the ZnS(Ag)
- Clustering of ZnS(Ag)
- Ratio of components to one another
- 1:2:0.6 vs 1:3:0.6

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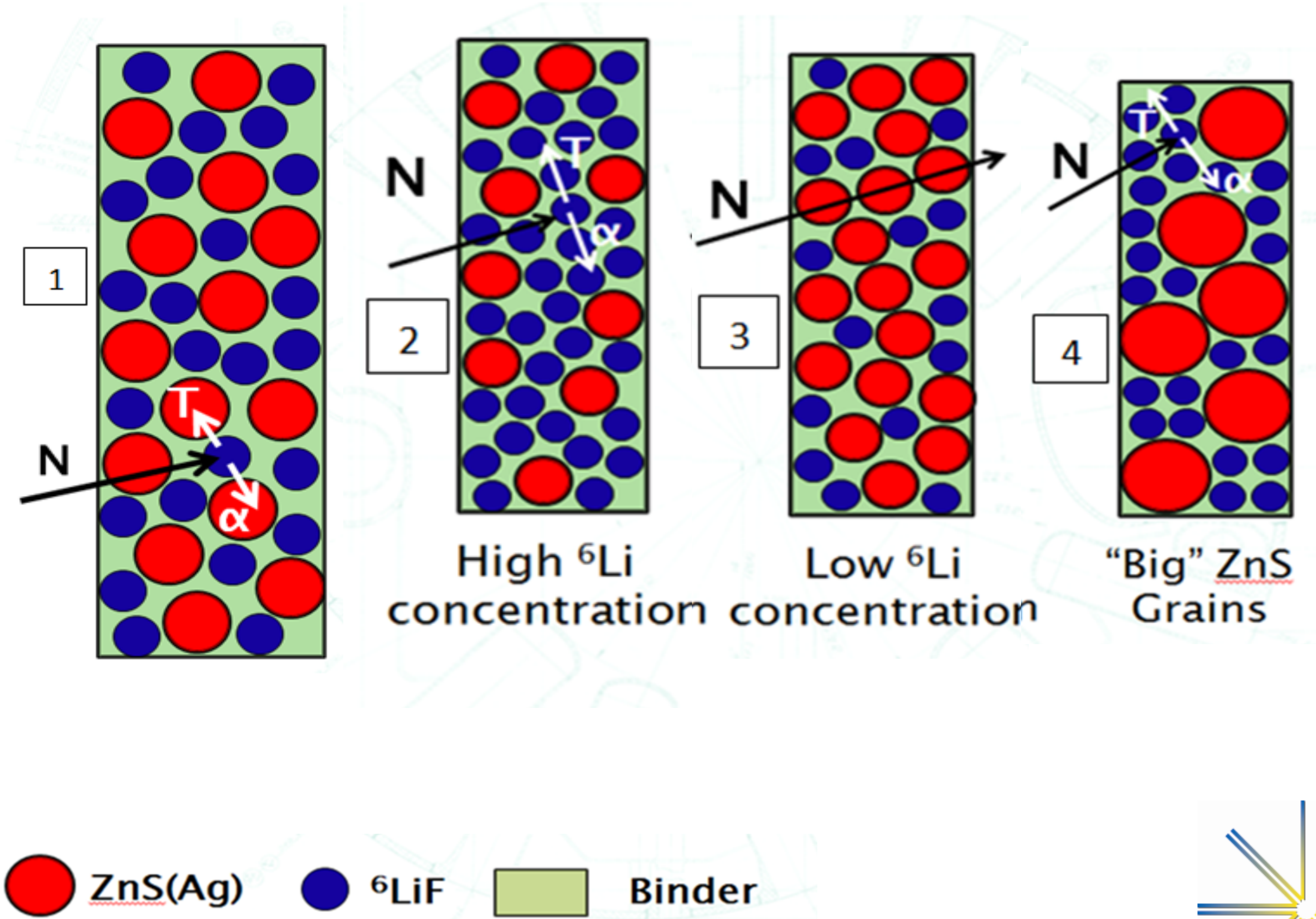
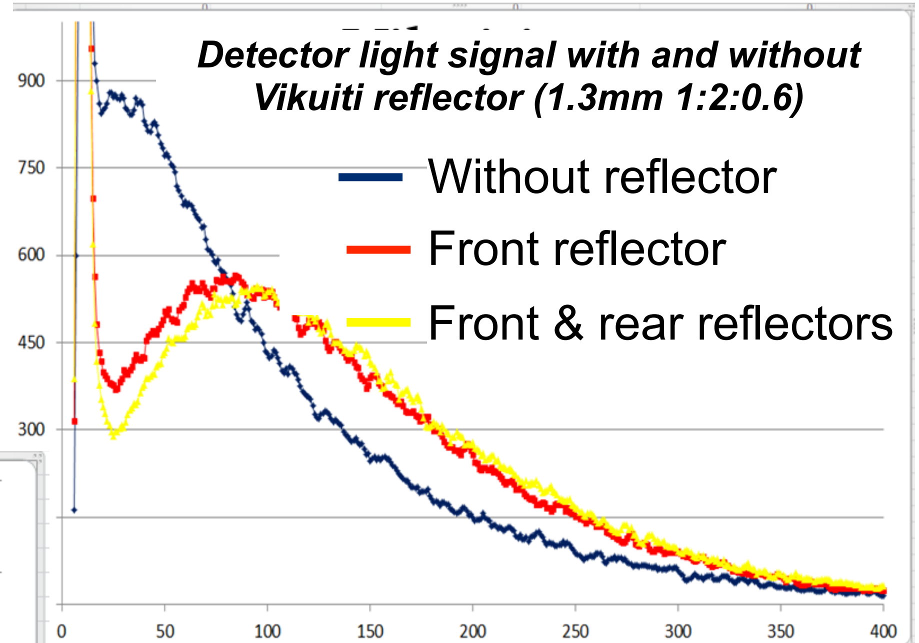
CANDOR Scintillator Compound

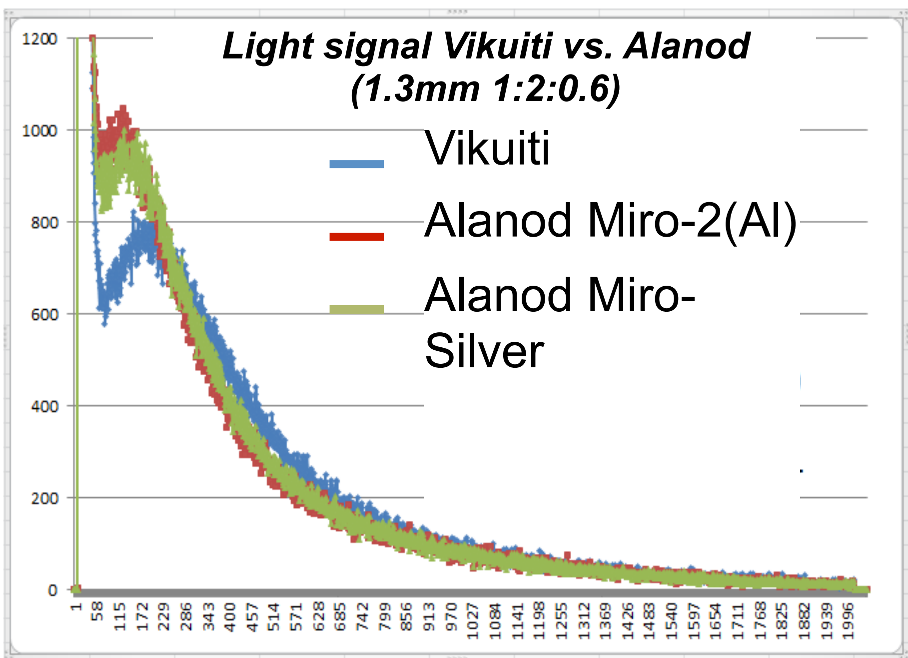


CANDOR Detector Reflectors

Reflectors increase the light energy

But the Type of reflector matters





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CANDOR Scintillator

SiPM Silicone Photo-Multipliers

- Dark noise Rate- High dark count becomes harder to distinguish between the tail and noise
- PDE-Photo Detection Efficiency
- Recovery time
- Rise time
- After Pulsing, Delay Cross Talk, Cross Talk

Luckily Sensl and Hamamatsu as well as other manufactures are improving these properties for us.

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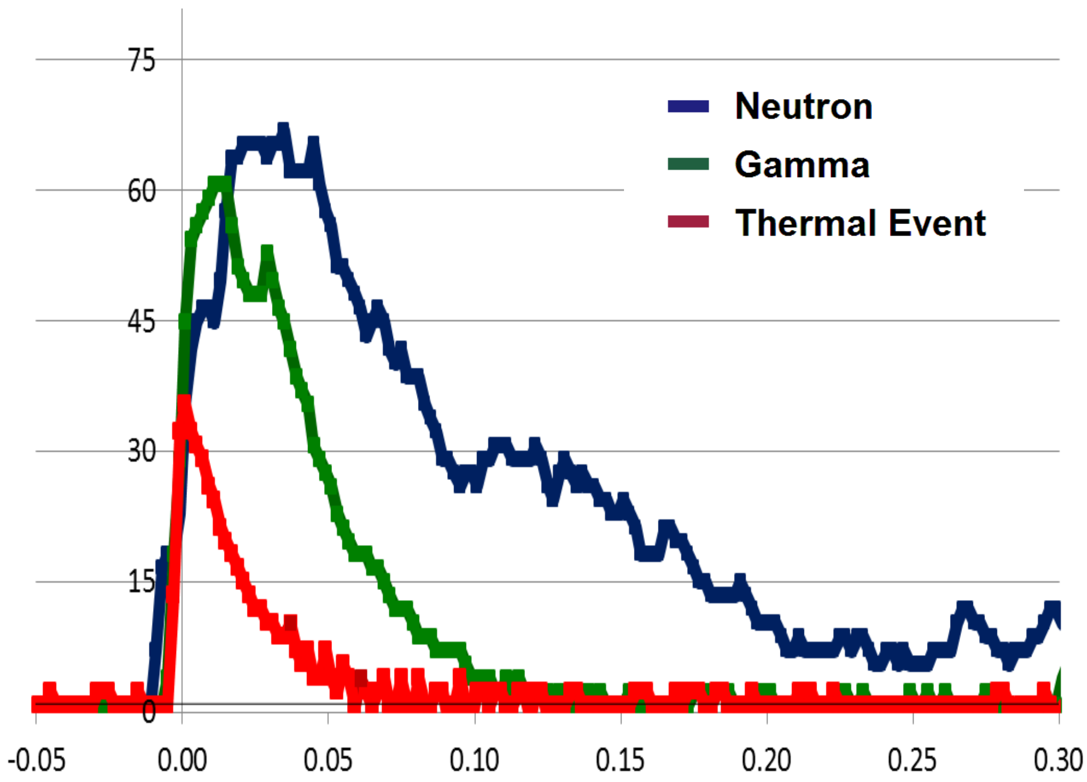
CANDOR Scintillator

Discriminators

Using the Pulse shape vs the pulse peak



Typical waveform events measured with a short recovery time diode

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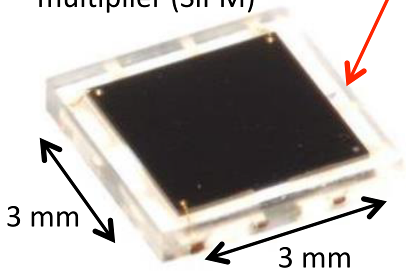
CANDOR Scintillator

Triple Frame Detector

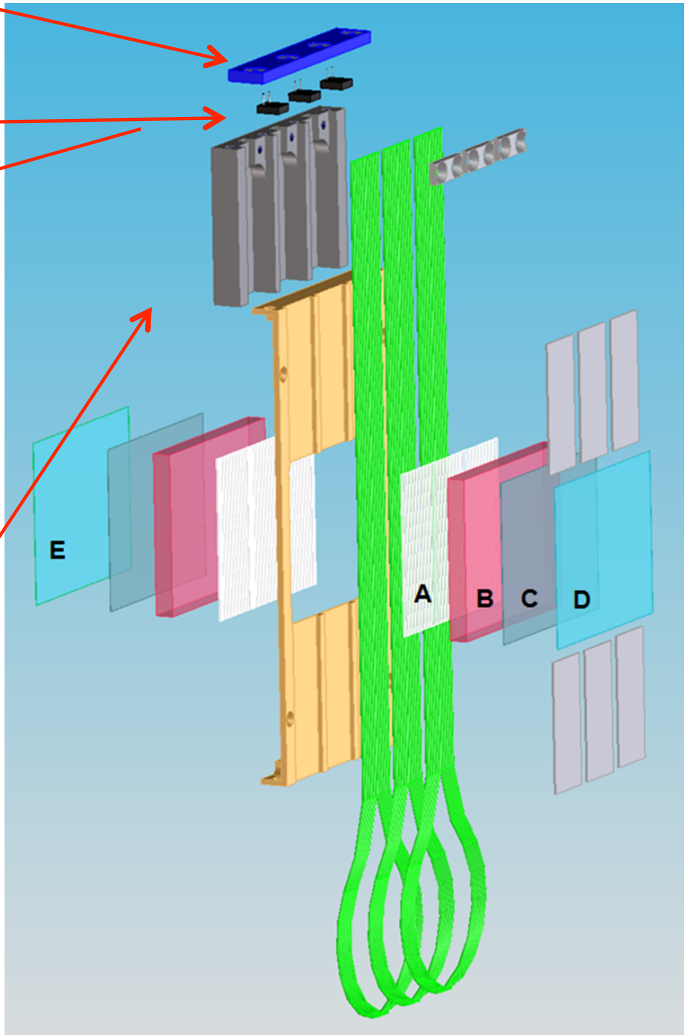
PC Board for SPiM (Diodes)

Diodes

Enlarged Silicon Photo-multiplier (SiPM)



WLS Fiber Bundling Block



A. Primer Layer –ZnS w/Nickel Killer
B. Compound Layer
C. ZnS (no Li)
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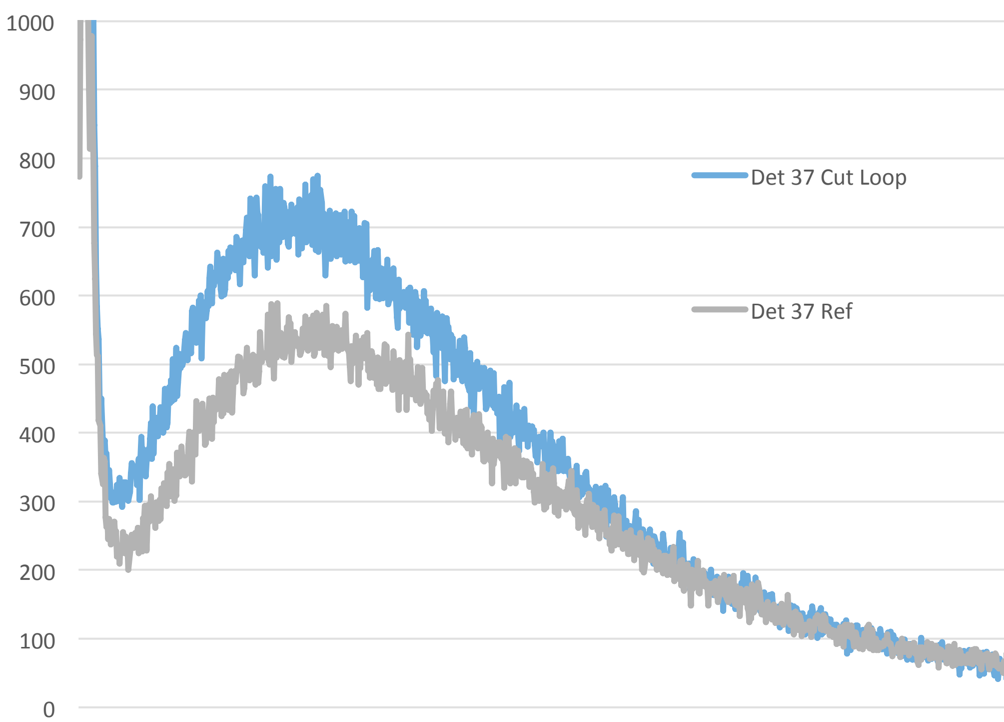
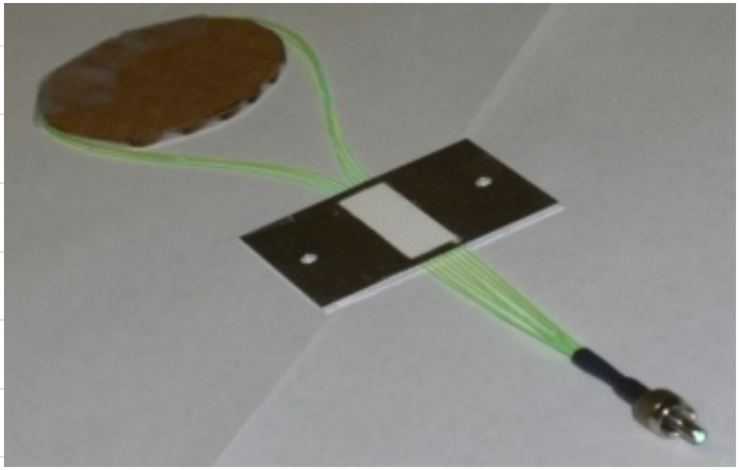
CANDOR Detector

The Final Step

Cutting the Fiber loop





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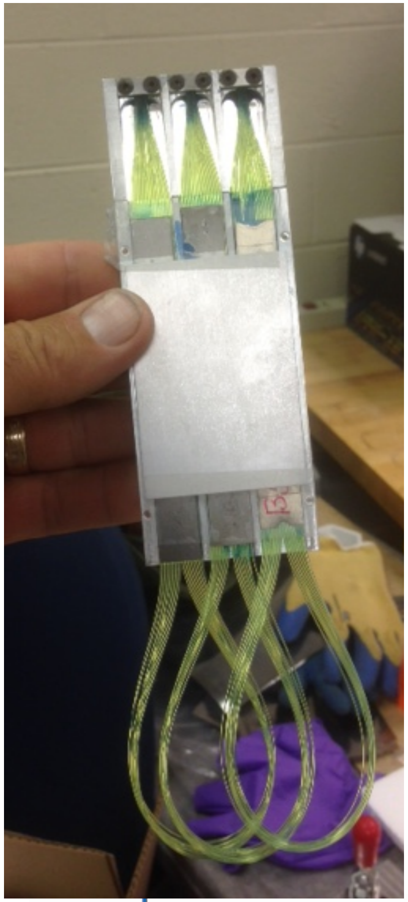
CANDOR Scintillator

Conclusions

- Mechanical design, more fibers more light
- Optimal thickness for the correct compound
- Compound advances
- Discriminator improvement using Pulse shape
- Addition of reflectors to keep light in detector
- Ease of manufacturing
- Now producing >90% vs 45% last year



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THANK YOU

QUESTIONS?

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CANDoR HOPG Adjustment

- Adjustment allows looser machining tolerance
  - Now we are using Borated Aluminum which is harder to machine to tight tolerances.
  - This allows compensation for HOPG tolerances.
  - Initial testing gives better than +/- .05 Deg