Optical Readout for Imaging Neutron Scintillation Detectors

Donald P. Hutchinson, Roger K. Richards, L. Curt Maxey, R. G. Cooper, and David E. Holcomb
Engineering Science and Technology Division
Oak Ridge National Laboratory
Bethel Valley Road, Oak Ridge, TN 37831

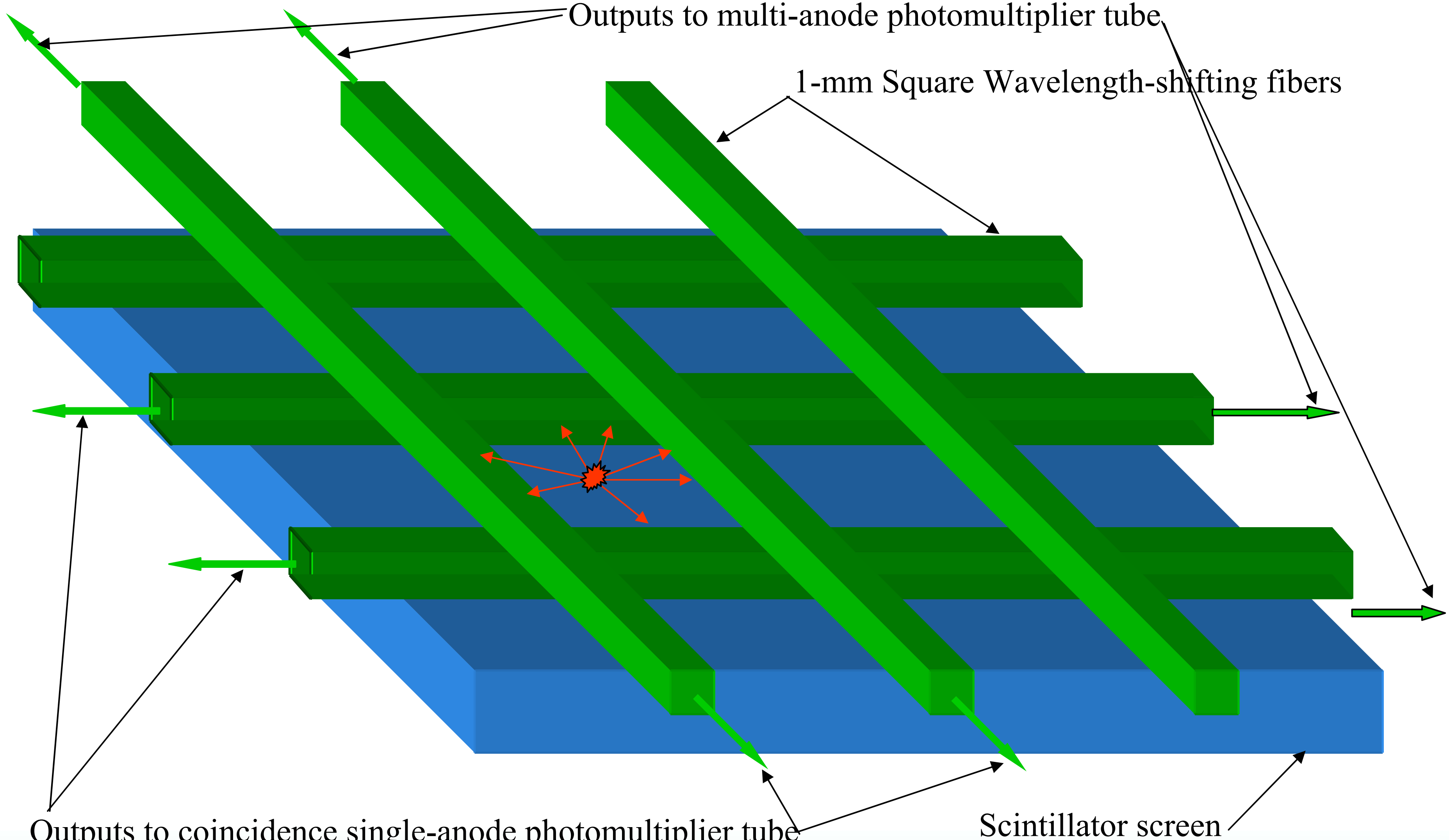
Neutron Detector Screen Design

The scintillator screen for this 2-D detector consists of a mixture of ^{6}LiF and silver-activated ZnS powder in an epoxy binder. Neutrons incident on the screen react with the ^{6}Li according to the equation

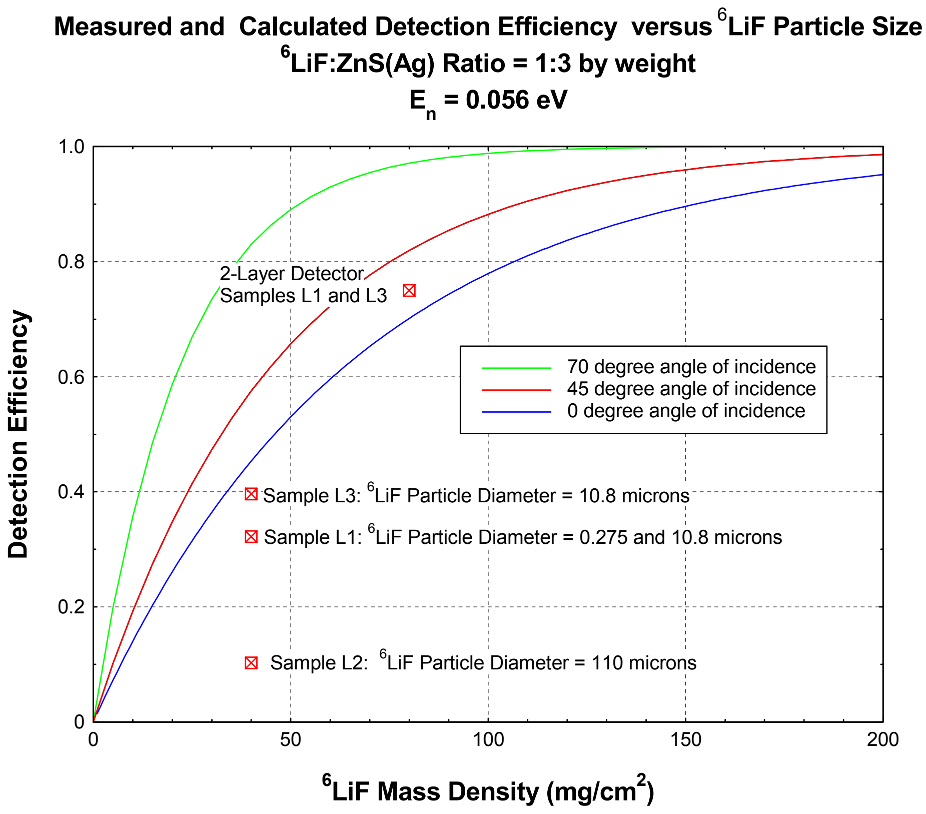
$$ {}_{0}^{1}n + {}_{3}^{6}Li \rightarrow {}_{1}^{3}H + {}_{2}^{4}He + 4.78 MeV $$

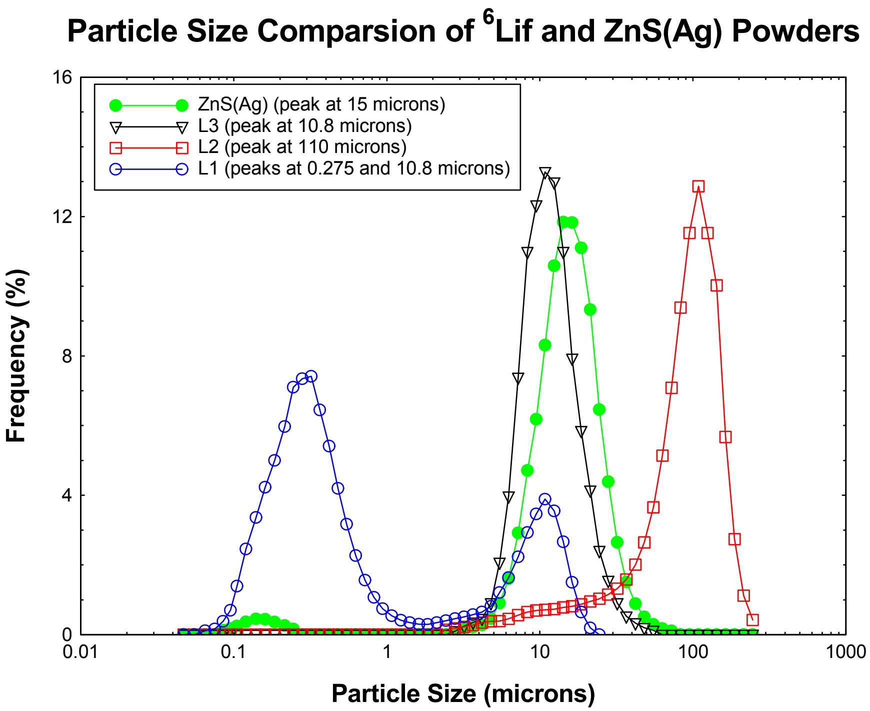
to produce a triton and an alpha particle. Collisions with these charged particles cause the ZnS(Ag) to scintillate at a wavelength of approximately 450 nm. The 450 nm photons are absorbed in the wavelength-shifting fibers where they converted to 520 nm photons emitted in modes that propagate out the ends of the fibers. The optimum mass ratio of ^{6}LiF:ZnS(Ag) was determined to be 1:3. The screen is made by mixing the powders with uncured epoxy and pouring the mix into a mold. The powder then settles to the bottom of the mold before the binder cures. After curing the clear epoxy above the settled powder mix is removed by machining. A mixture containing 40 mg/cm^2 of ^{6}LiF and 120 mg/cm^2 of ZnS(Ag) is used in this screen design. This mixture has a measured neutron conversion efficiency of over 90%.

Principle of Crossed-Fiber Position-Sensitive Scintillation Detector



The particle size of the ^{6}LiF and ZnS(Ag) powders must be Optimized for efficient detection.

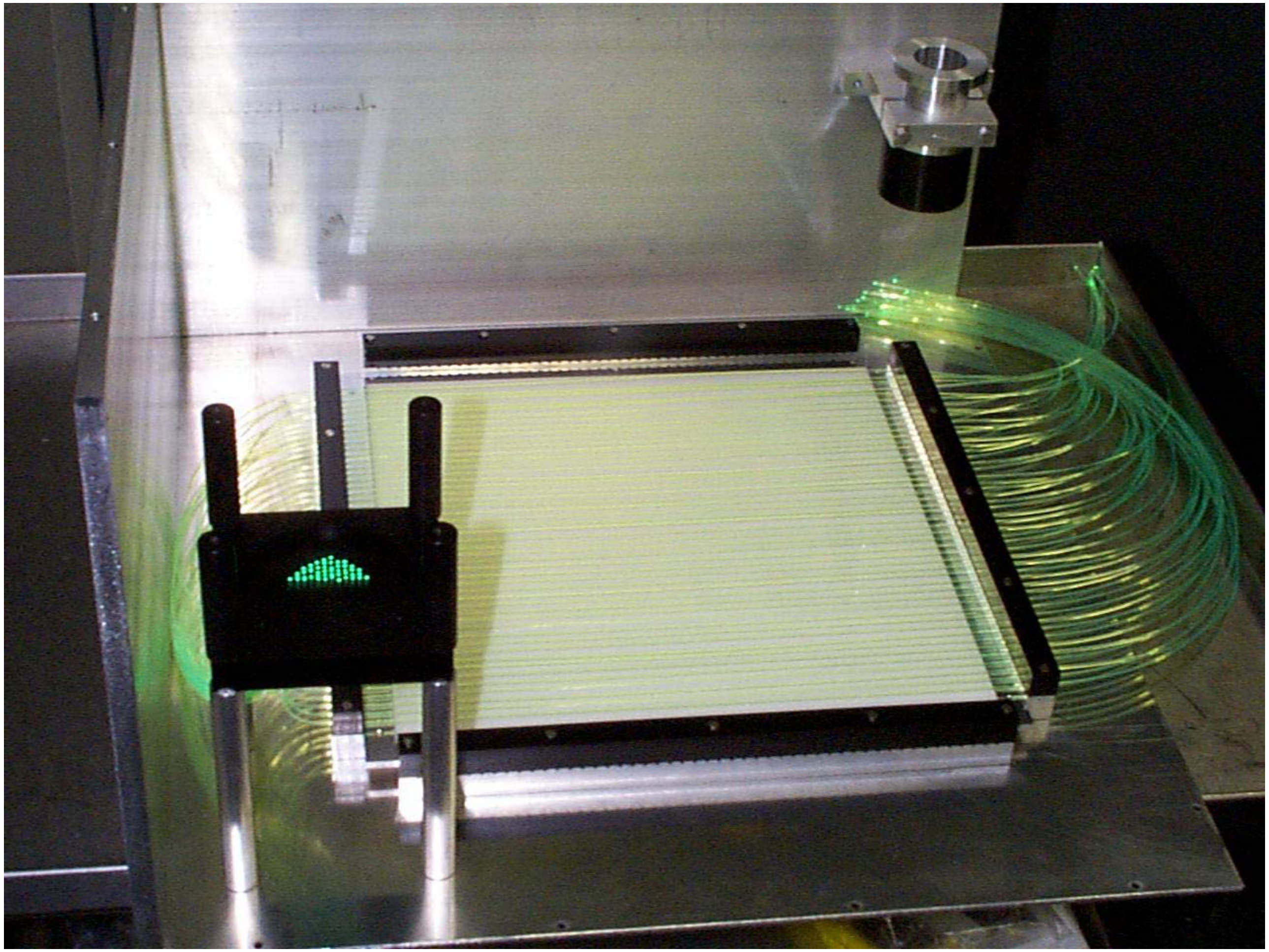




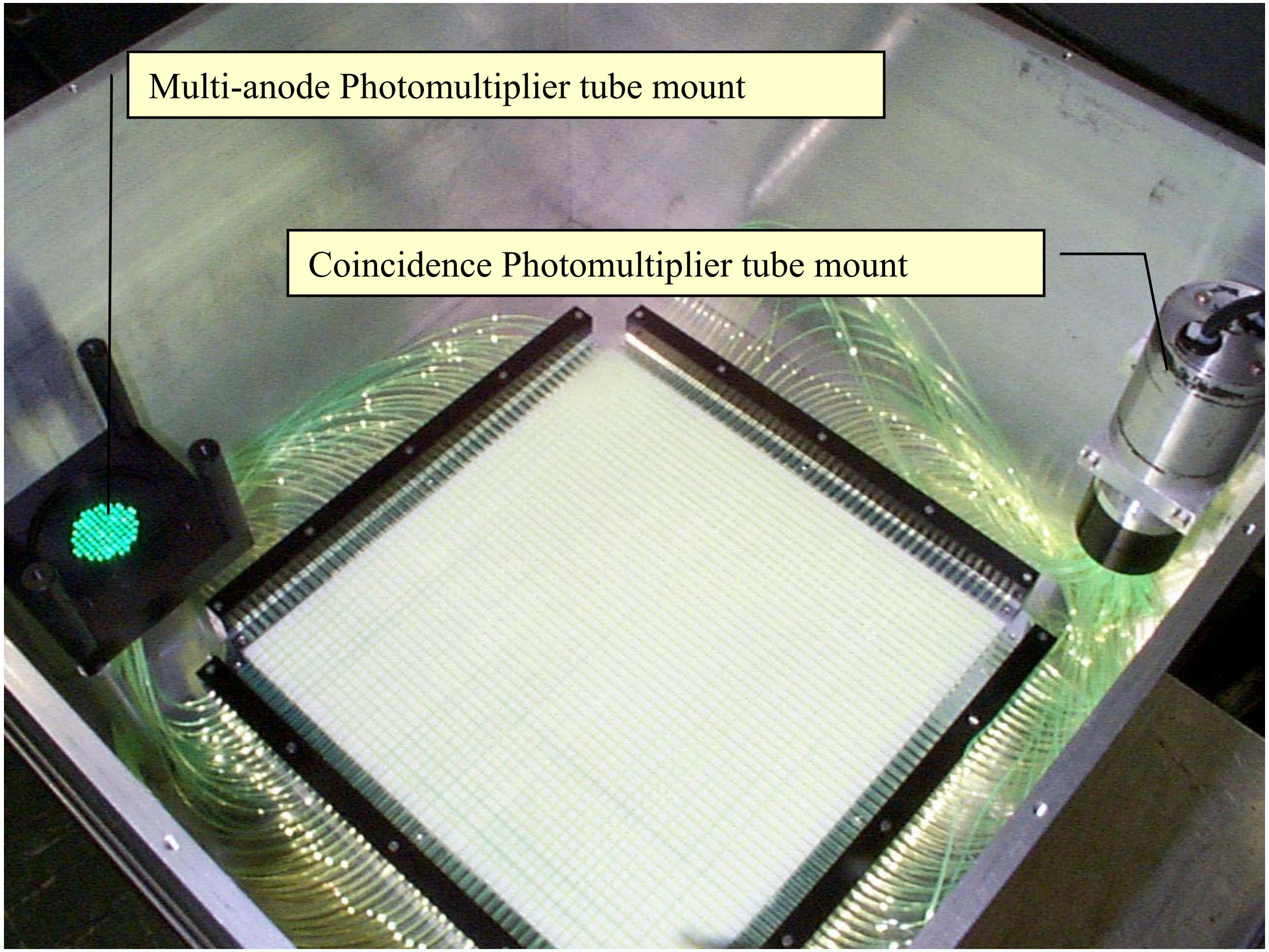
Crossed-Fiber Scintillation Prototype Detector Characteristics

- Size: 25-cm x 25-cm
- Thickness: 2-mm
- Number of fibers: 48 for each axis
- Multi-anode photomultiplier tube: Phillips XP1704
- Coincidence tube: Hamamastu 1924
- Resolution: < 5-mm
- Shaping time: 300 nsec
- Count rate capability: ~ 1 MHz
- Time-of-Flight Resolution: 1 μsec

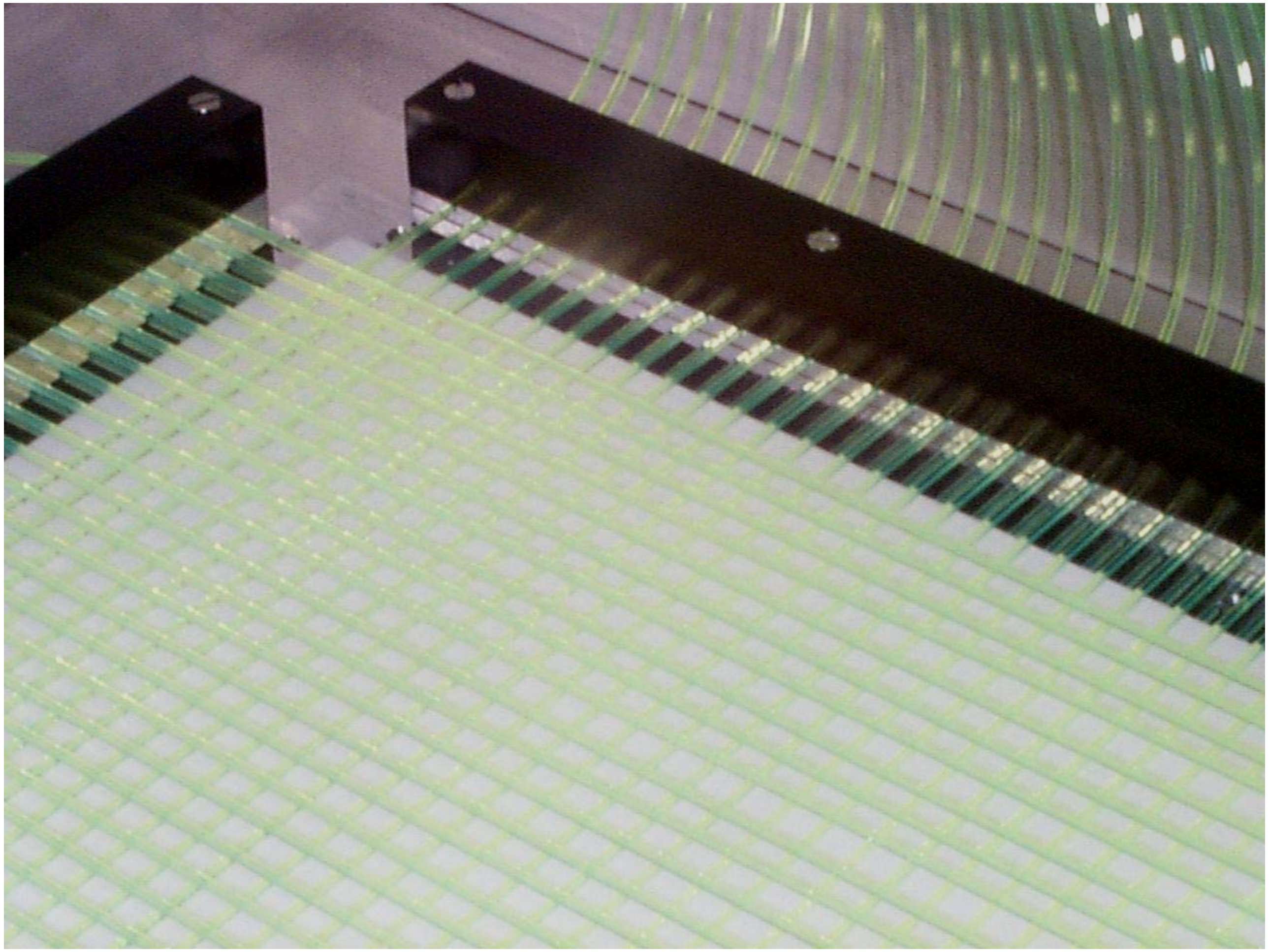
Crossed-fiber detector with Y-Axis fibers installed

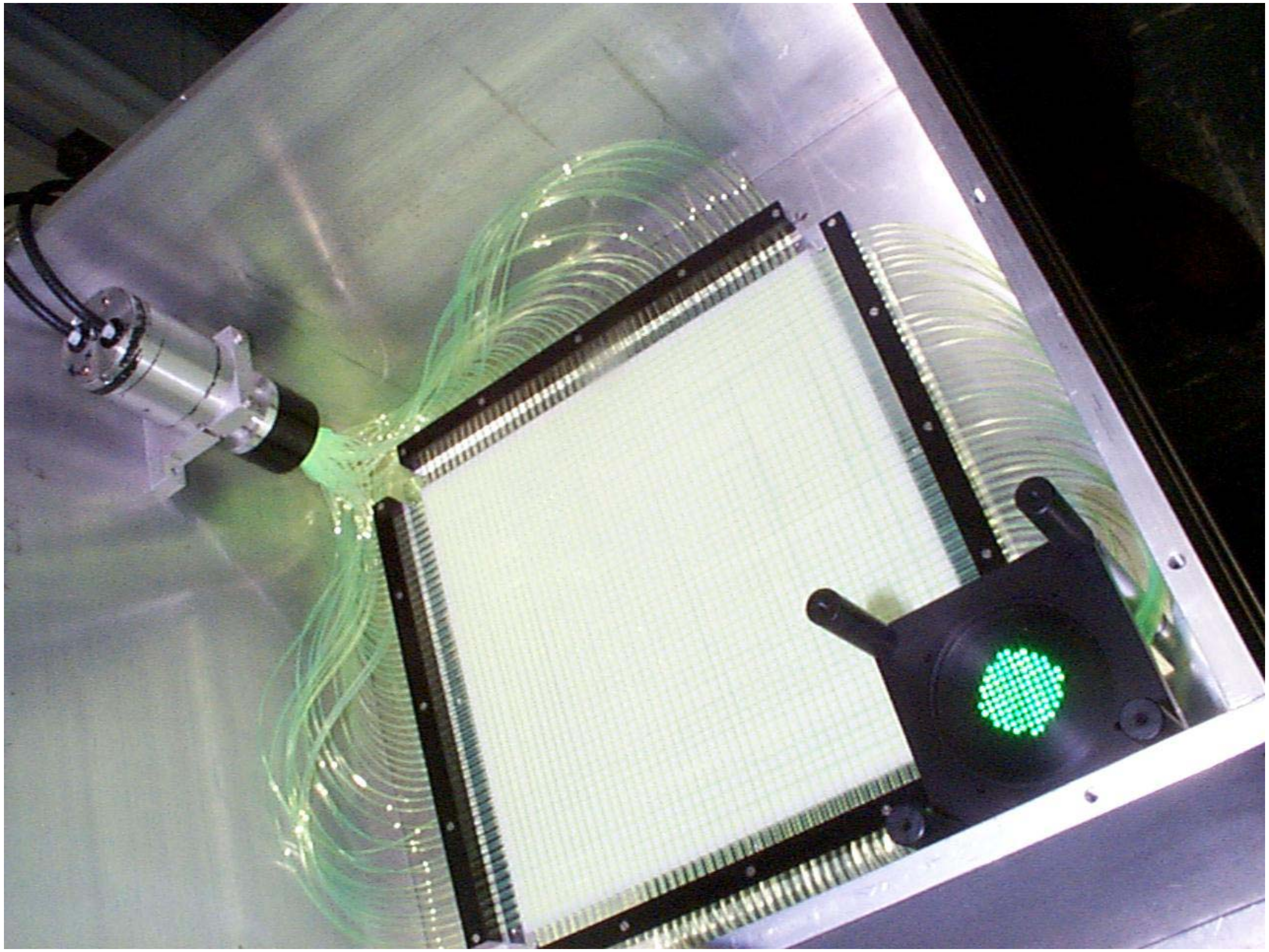


The scintillator screen uses an array of 48 fibers for each axis for position detection.

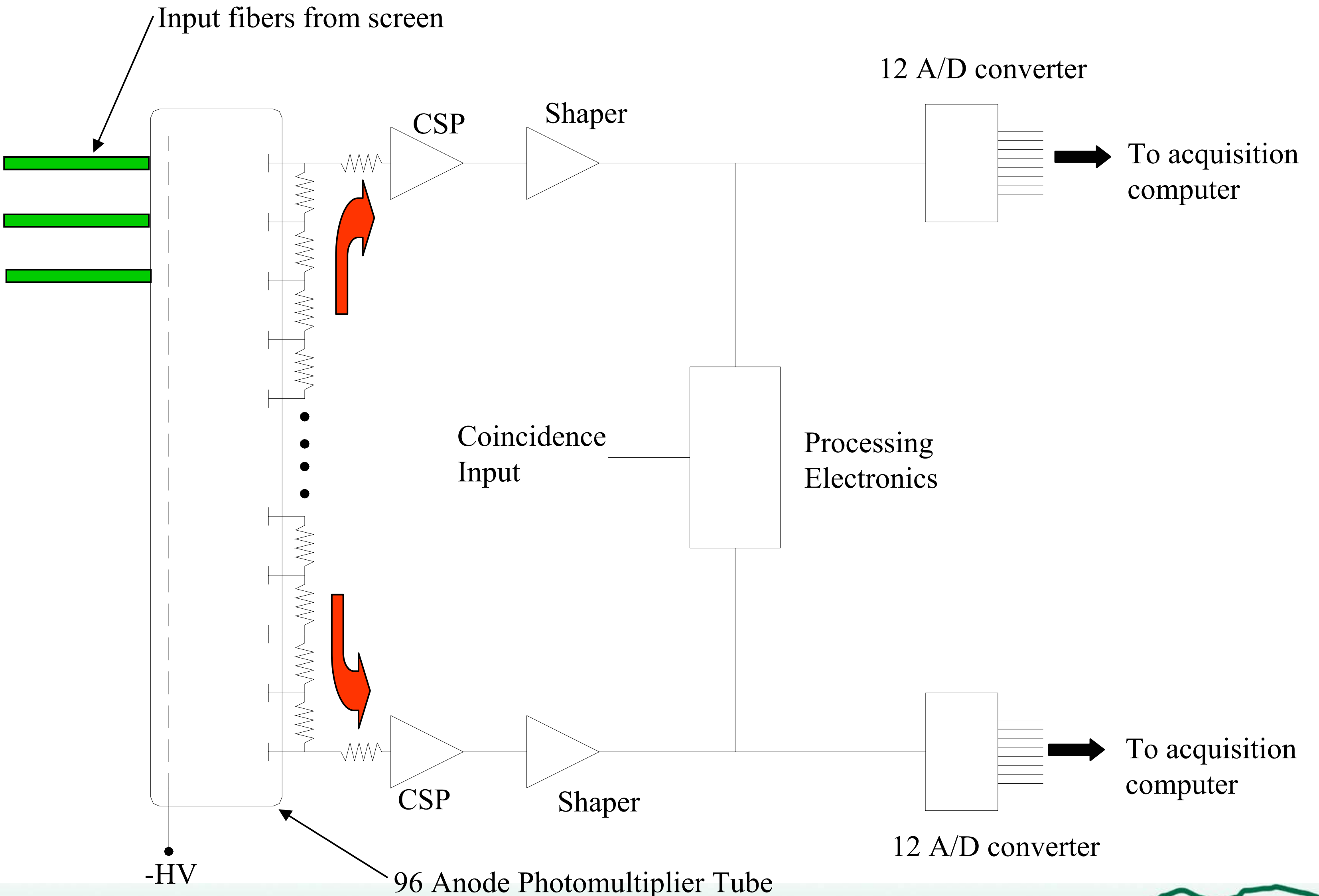


Close-up view of fibers and scintillator



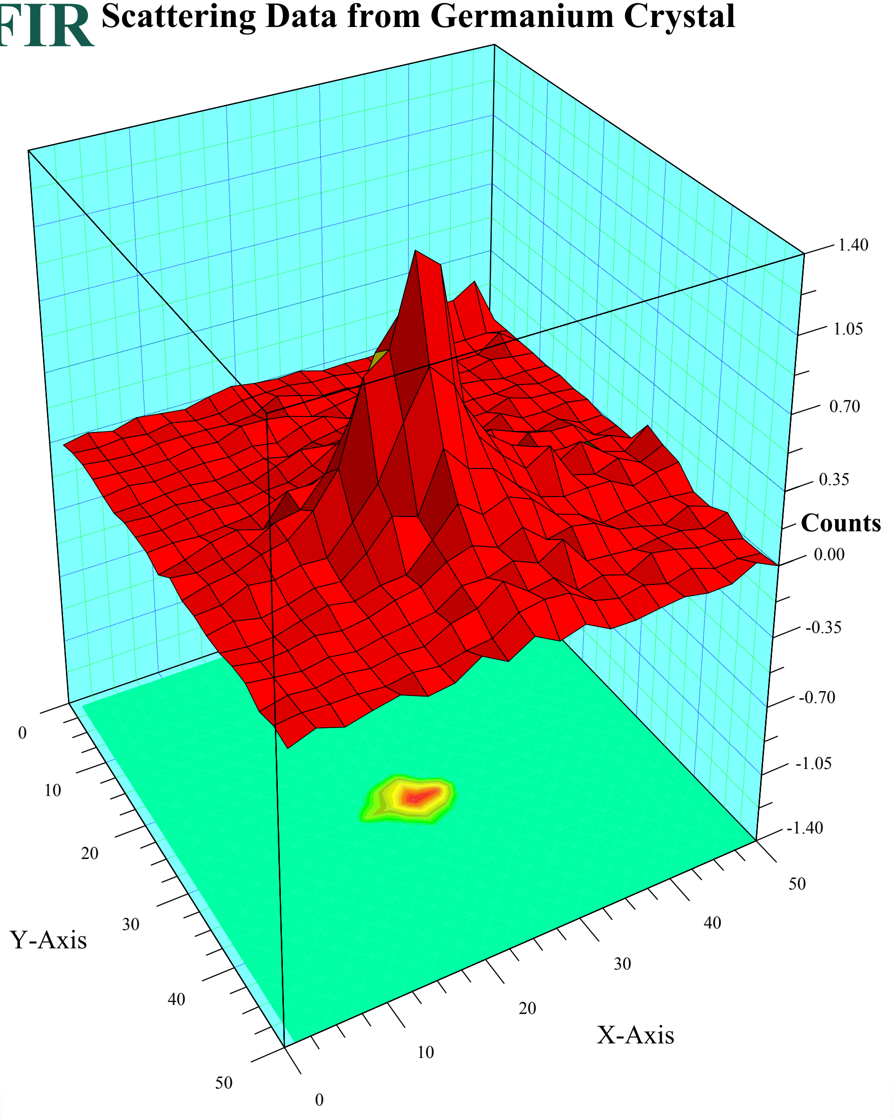


Electronics Scheme for Crossed-Fiber Scintillation Detector

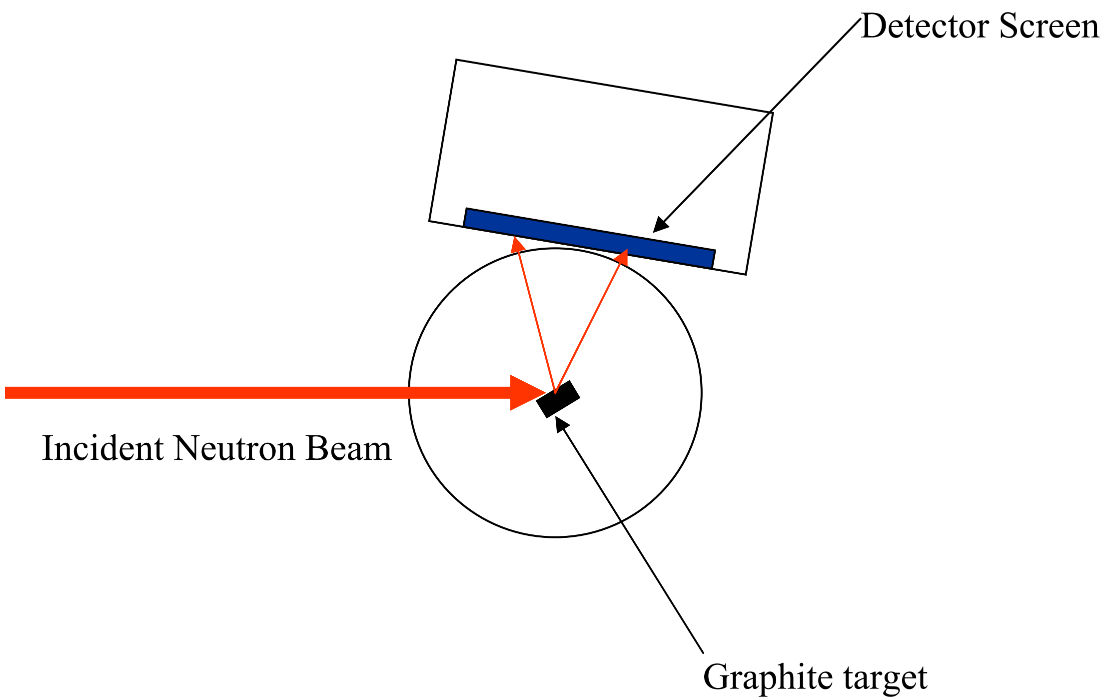


Neutron Scattering from Germanium Crystal Using the Crossed-fiber Detector on HFIR

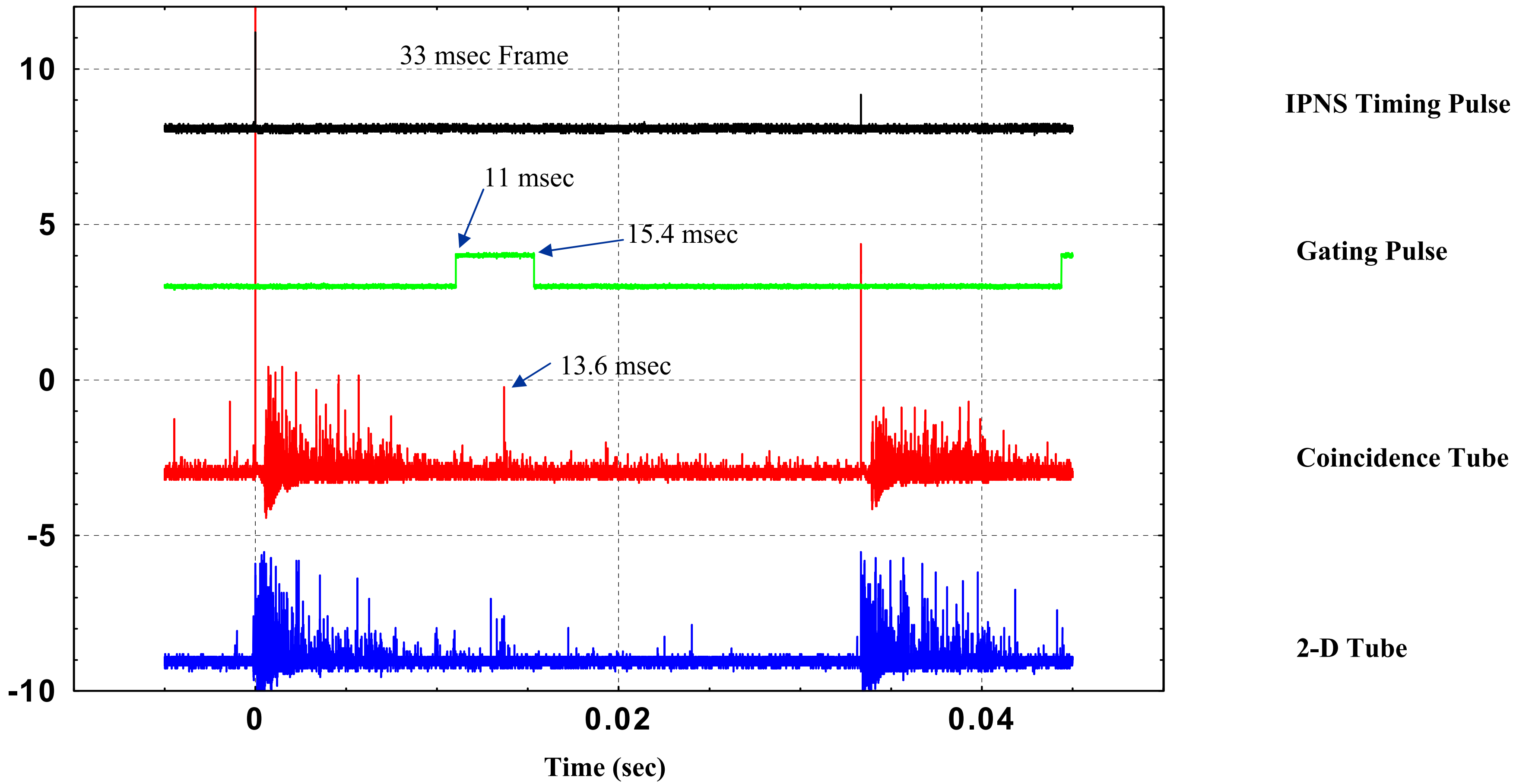
- Normalized scattering from 1-cm high germanium crystal
- $E_n \sim 0.056$ eV
- Detector 50-cm from crystal



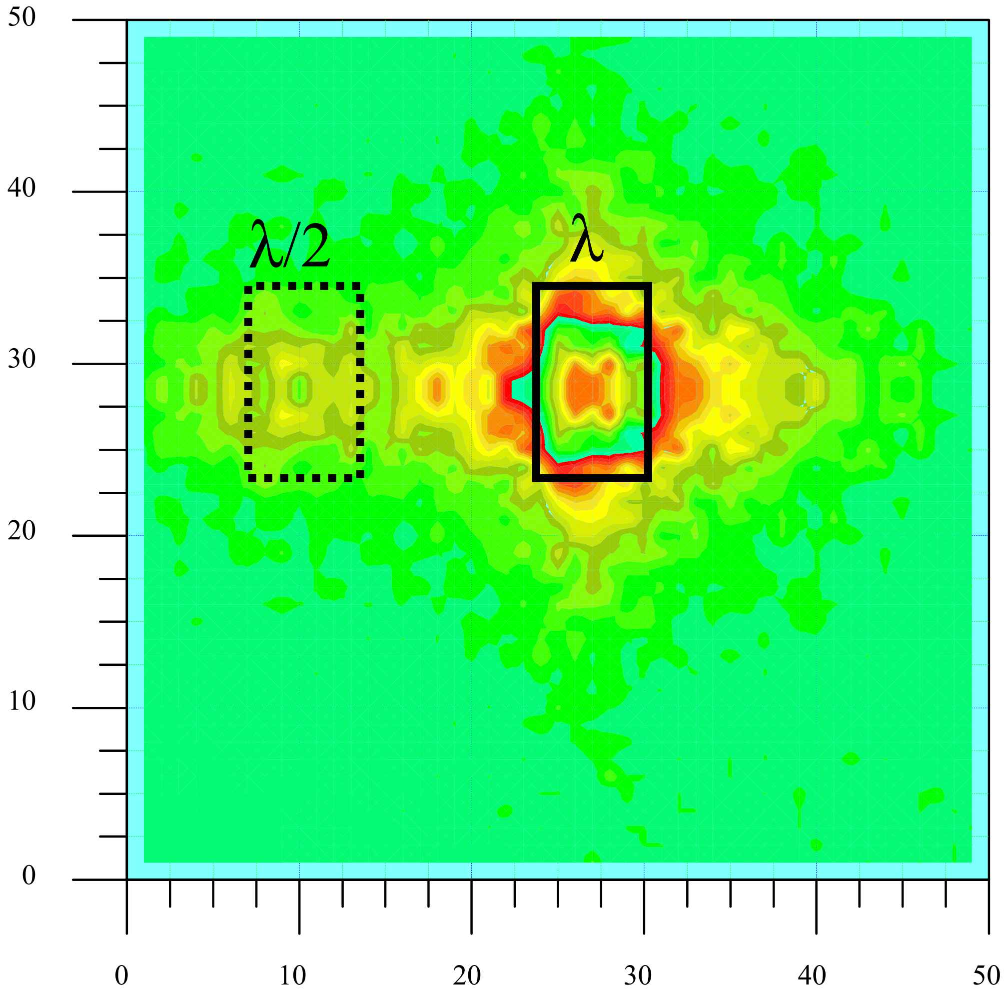
Neutron Scattering Geometry for First Test on IPNS



Experimental Timing With Graphite Target



Measurements on IPNS With Graphite Target



Neutron Image for
δt = 11-15.4 msec
Velocity = 714-1000 m/sec
(λ= 5.54Å to 3.956Å)
With graphite target

Note: Data folded about horizontal axis to improve statistics

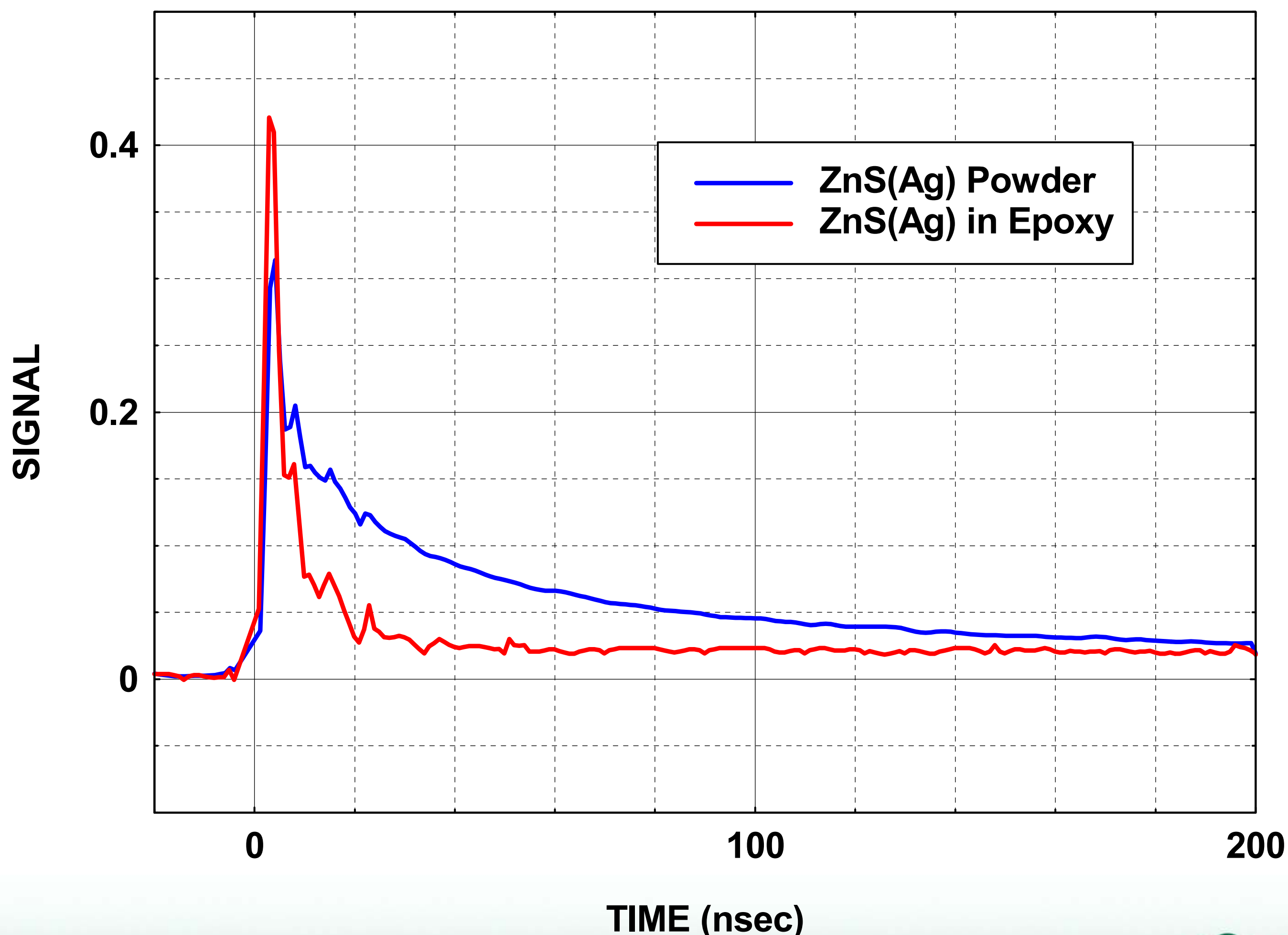
Needed Improvements Identified

- Shielding
  - B_4C enclosure around detector
- Dynamic range
  - Front end amplifiers have a limited voltage range
  - Parallel A/D Converters
    - Simultaneous low and high voltage capture
- Software
  - Increase array size for better statistics
    - Change to "C" code
- Examine need for coincidence tube
  - Current architecture appears to be overly restrictive
  - Data appears to be under-sampled by 3-way coincidence requirement—reduces effective efficiency of detector

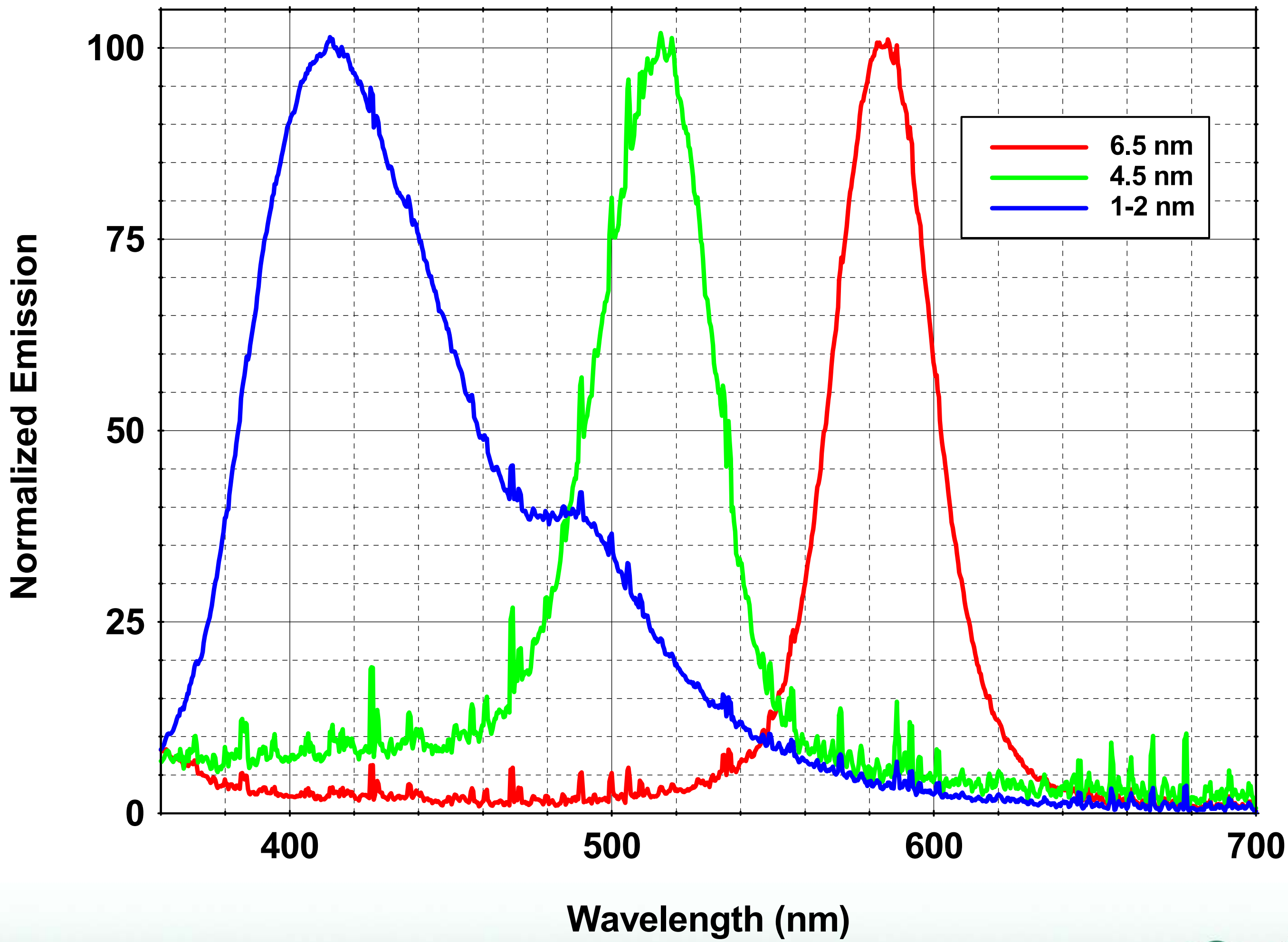
Future Directions

- **Improved scintillator screens**
  - **ZnS(Ag) Nanocrystal scintillators**
    - **Emission wavelength may be “tuned”**
    - **Faster decay time**
    - **Transparent matrix to combine neutron converter with scintillator**

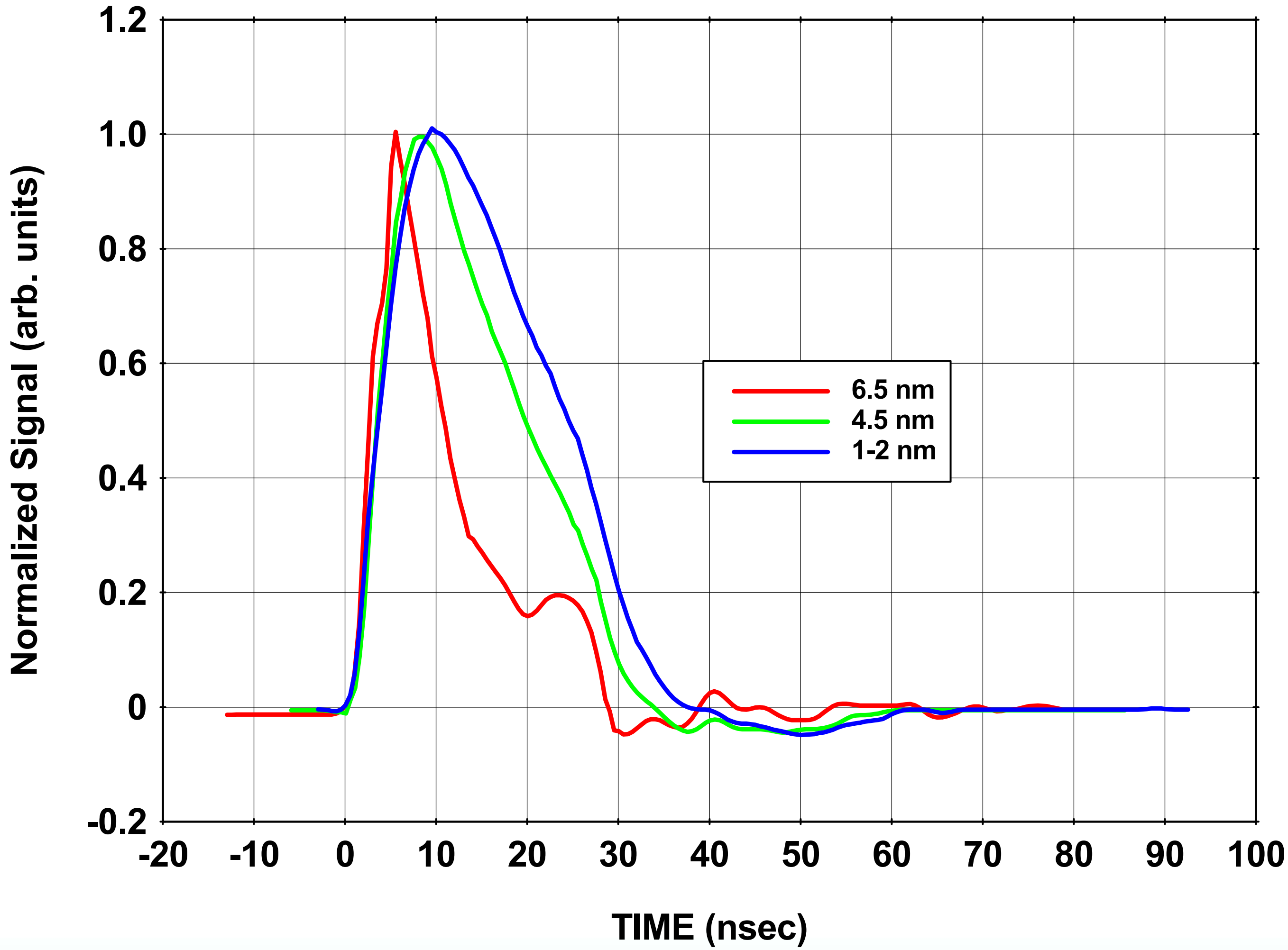
ZnS(Ag) Scintillator Emission from UV Laser Excitation
Visible spectrum (360-1000 nm)



The normalized emission for three ZnS(Ag) nanocrystal particle sizes can be controlled by selecting the appropriate physical particle diameter.

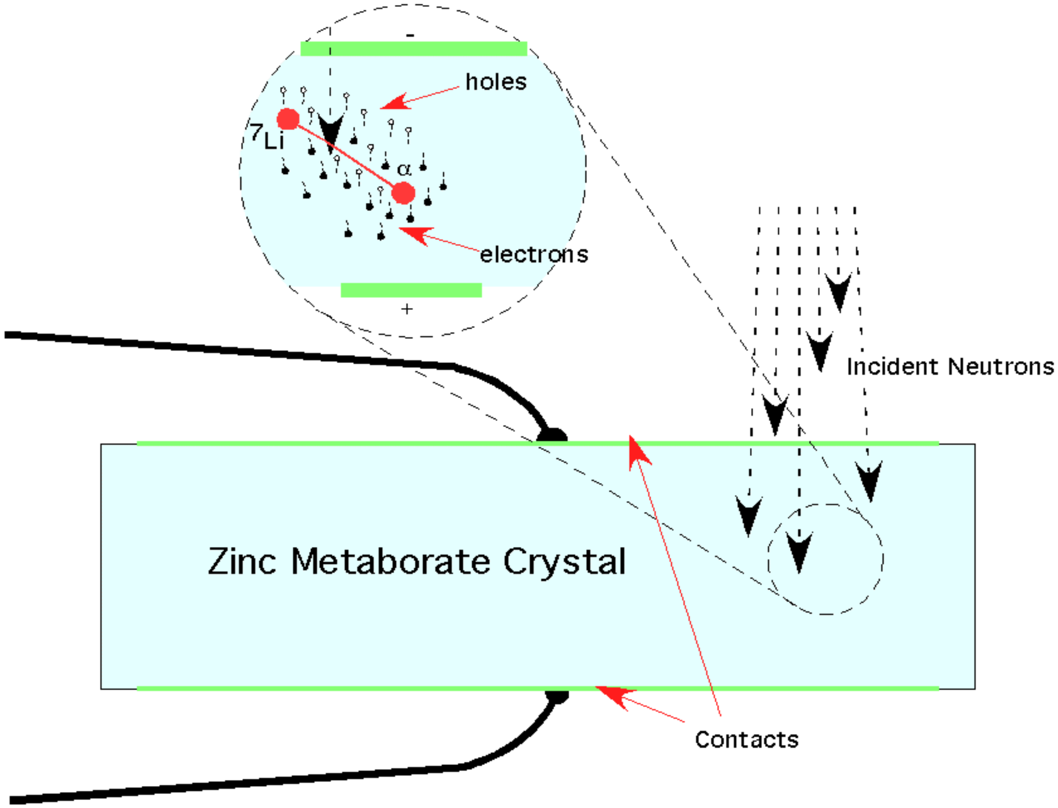


All three nanocrystal samples exhibit a decay time of less than 30 nsec when excited by a 1-nsec pulsed N_2 laser.



Single Crystal Zinc Metaborate Neutron Detectors

Featuring -- Position Sensitivity, Large Area, High Efficiency, High Speed, Gamma Rejection, Mechanical Ruggedness, and Low-Cost



Technical Tasks

- Repeatably grow electronic grade crystals
- Demonstrate crystal doping
- Characterize crystal charge transport properties
  - Electron Beam Induced Current
  - Transmission Ellipsometry for Internal Electric Field Measurement
  - Electrical Property Characterization
  - Optical Band Measurements
- Develop prototype detector
- Characterize detector performance

Milestones

1 year	Repeatable High Quality Crystal Growth
2 years	Detector Grade Semiconducting Crystals
2.5 years	Prototype Detector System

Annual Cost - $275,000/year
Total Cost - $687,500

Team

David E. Holcomb
(865) 576-7889
HolcombDE@ornl.gov
Lynn A. Boatner
(865) 574-5492
BoatnerLA@ornl.gov
Gerald E. Jellison, Jr.
(865) 576-7309
JellisonGEJr@ornl.gov

UT-BATTELLE

ornl