ZnS neutron detectors

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Content

- ZnS scintillator
- Detection efficiency
- Signal processing
- ZnS + fibre geometry
- Detector performance

ZnS scintillator

- ZnS:Ag scintillator, mixed with LiF + binder or sintered B_2O_3

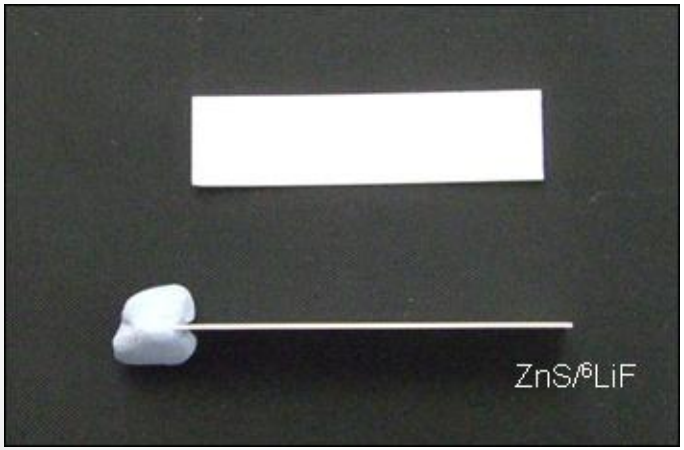
✓ High light output ⇒ flexible light collection
✓ Very low γ-sensitivity
✓ Available in large sizes and flexible geometry
✓ Acceptable neutron detection efficiency
✓ Good (electronic) noise immunity

✗✓ Opaque

✗ Long afterglow ⇒ not high speed

ZnS scintillator

- Most popular ZnS/LiF manufacturers: Applied Scintillation Technology (AST), Eljen and Saint Gobain (Bicron).
- ZnS + LiF mixture in binder (similar for ZnS + B_2O_3).
- Big mismatch refractive index of ZnS (2.4) and LiF (1.4) ⇒ opaque.



Light scatters a lot ⇒ High light loss ⇒ need thin scintillator.

ZnS scintillator

- Needs careful optimisation of ZnS : LiF ratios, particle size and thickness of scintillator.

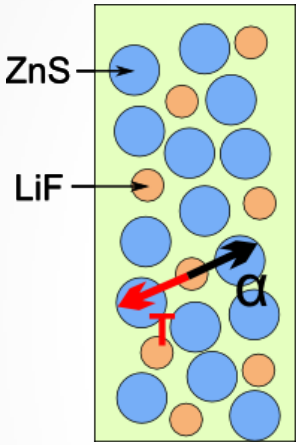
- Ref: Hutchinson, D. P.; Proc. SPIE Vol. 3769, p. 88-91.

- ! Needs to be tailored to application !

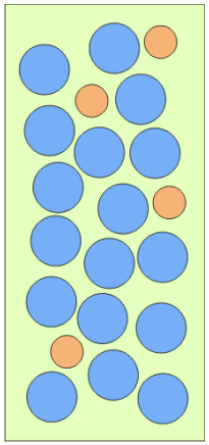
  For example, better light coupling between ZnS scintillator and PMT ⇒ can afford to loose more light ⇒ can use thicker scintillator.

ZnS scintillator

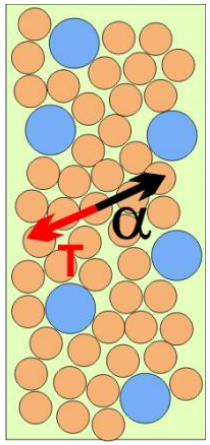
- Mixing ratio (ZnS:LiF)



Assume this is good mixing ratio



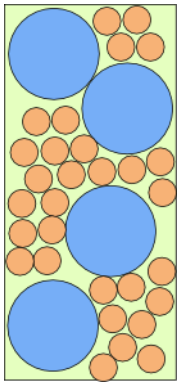
Not enough LiF



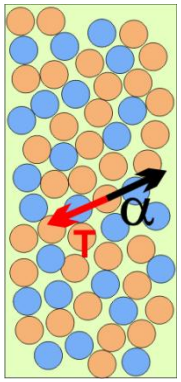
Too much LiF ⇒ not enough energy loss in ZnS

ZnS scintillator

- ZnS particle size



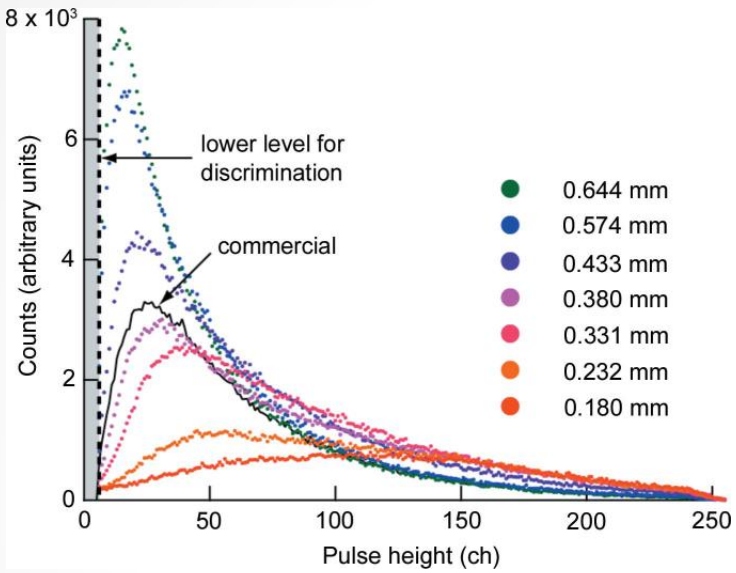
LiF too clustered
(like too much LiF)



Scintillation light is scattering too much ⇒ high light loss

- People usually only optimize mixing ratio and thickness.

ZnS scintillator



- 2:1 ZnS / LiF
- H. Iwase et al., J. Appl. Cryst. (2012). 45, 507-512

- Light output drops dramatically with thickness.
- Terms like 4:1 refers to weight ratio ZnS / LiF.
- Most institutes use 2:1 ZnS:LiF ratio, ~450 μm thick.

ZnS scintillator

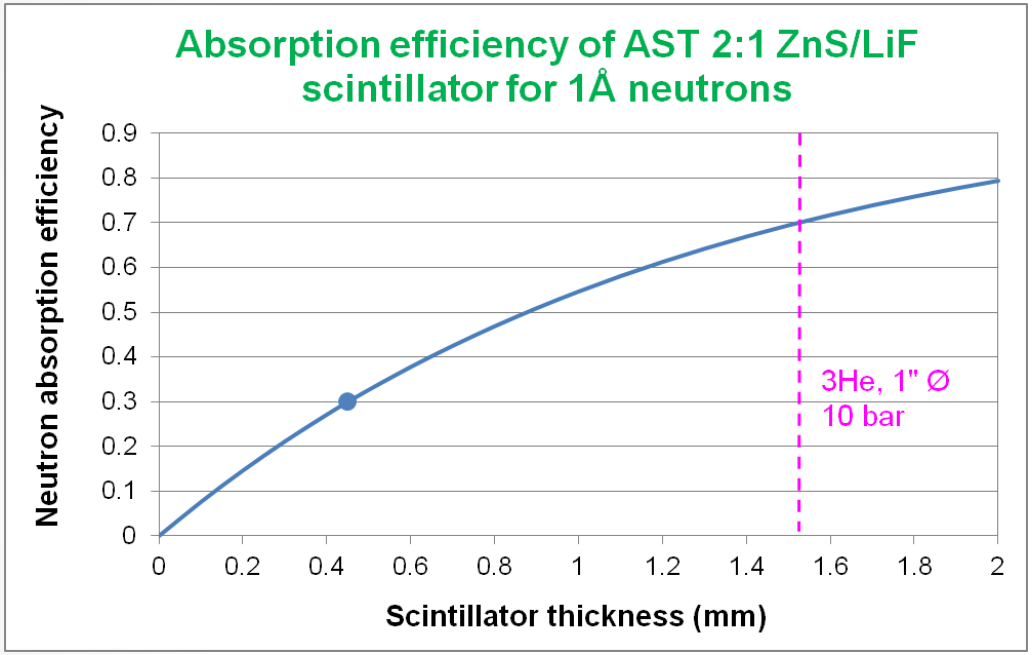
- Japan is developing ZnS + B_2O_3 mixture.
- Ref: T. Kojima et al., Nuclear Instruments and Methods in Physics Research, A529(2004)325.
- ^{10}B vs. ^{6}Li : higher σ_{abs} ⇨ more efficient
  : lower Q ⇨ thinner
- Range of ^{7}Li and α very short ⇒ sintered.
- Faster (~2 times).

ZnS scintillator

- Very interesting scintillator.
- Production technology has been transferred to industry, but not yet commercially available.

- J-PARC just built SENJU detectors (2.8m^2) with this type of scintillator.

Detection efficiency

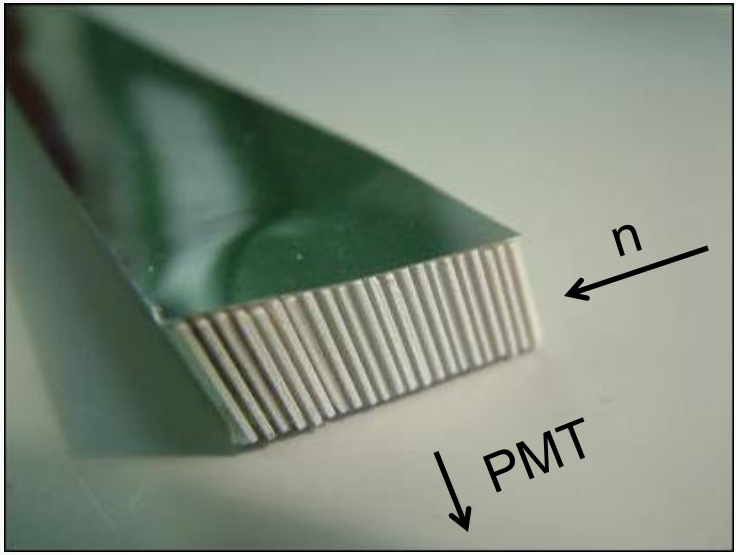


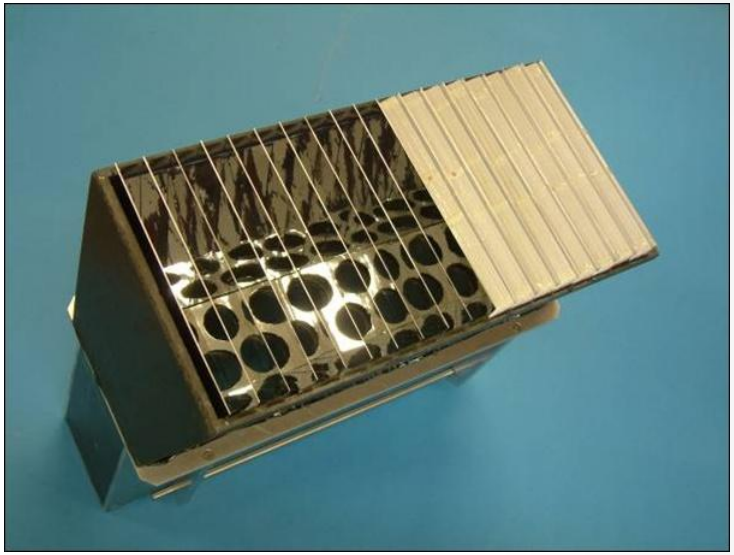
- Neutron absorption efficiency not neutron detection efficiency

- 50% efficiency ⇒ need 0.9mm = 2 sheets of 0.45mm thick

Detection efficiency

- How to make it (very) efficient: NIMROD detector.



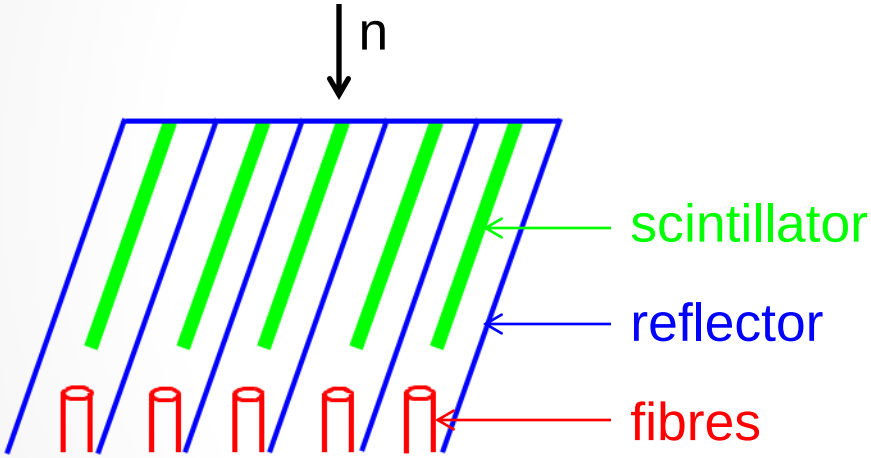


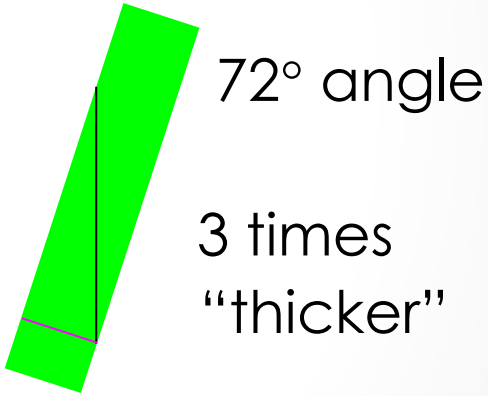
- Sandwich of 22 sheets of ZnS and 0.5mm non-borated glass.
- ~25% efficient at 10eV (0.09 Å).
- Not enough light for (wavelength shifting) fibre read out.

Detection efficiency

- How to make it efficient:

- Angled scintillator ⇒ For same thickness scintillator (light output), effective thickness for neutron absorption higher

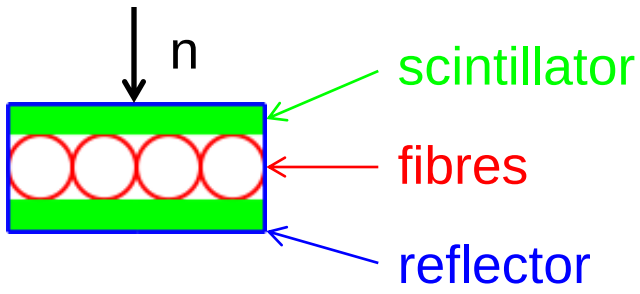




- Can be used for both clear fibre and wavelength shifting fibre (not the best).

Detection efficiency

- Wavelength shifting fibre (WLSF)

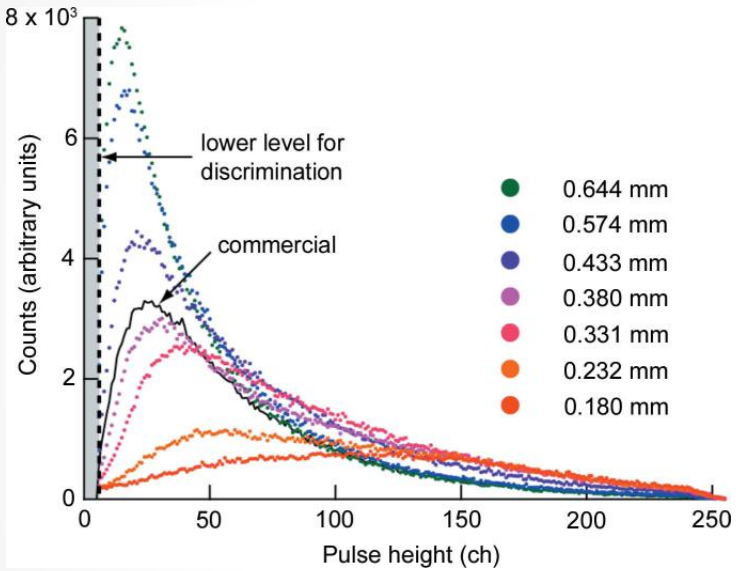


- WLSF, sandwiched between 2 scintillators, wrapped in aluminium (reflector) foil.

- Still 50% efficient at 1Å.
- Could stack more to get higher efficiency.

Signal processing

- Opaque ⇒ no pulse height resolution



- ZnS directly coupled to PMT
- Will get lot worse when fibre coupled

➢ Hard to make stable?

Signal processing

- Factors affecting the stability/temperature sensitivity:
  1) PMT gain
  2) ZnS light output
  3) Stability of electronics

- Is to possible to obtain stability < 0.3% over week?

- YES!, if you do the signal processing right

- Remainder of talk will only discuss WLSF detectors

Signal processing

- Look at single photon level

- Raw PMT signal:
- Neutron:

- Gamma:

- Train of (single photon) pulses.
- Fewer pulses from gamma.

Signal processing

- Determine pulse density

✓ Doesn't depend on pulse height ⇒ independent of gain of PMT (provided that electronics can recognize single photons).

✓ Allow use of simple digital electronics ⇒ cheap + no stability problems with electronics.

✗ More sensitive too afterglow ⇒ slower.

Signal processing

- Many different ways to determine pulse density.
- At ISIS we use low pass filters (integrators) ⇒ give "analogue" signal.
- Recorded some signals.

Signal processing

- Oscilloscope on 4us/div

Signal processing

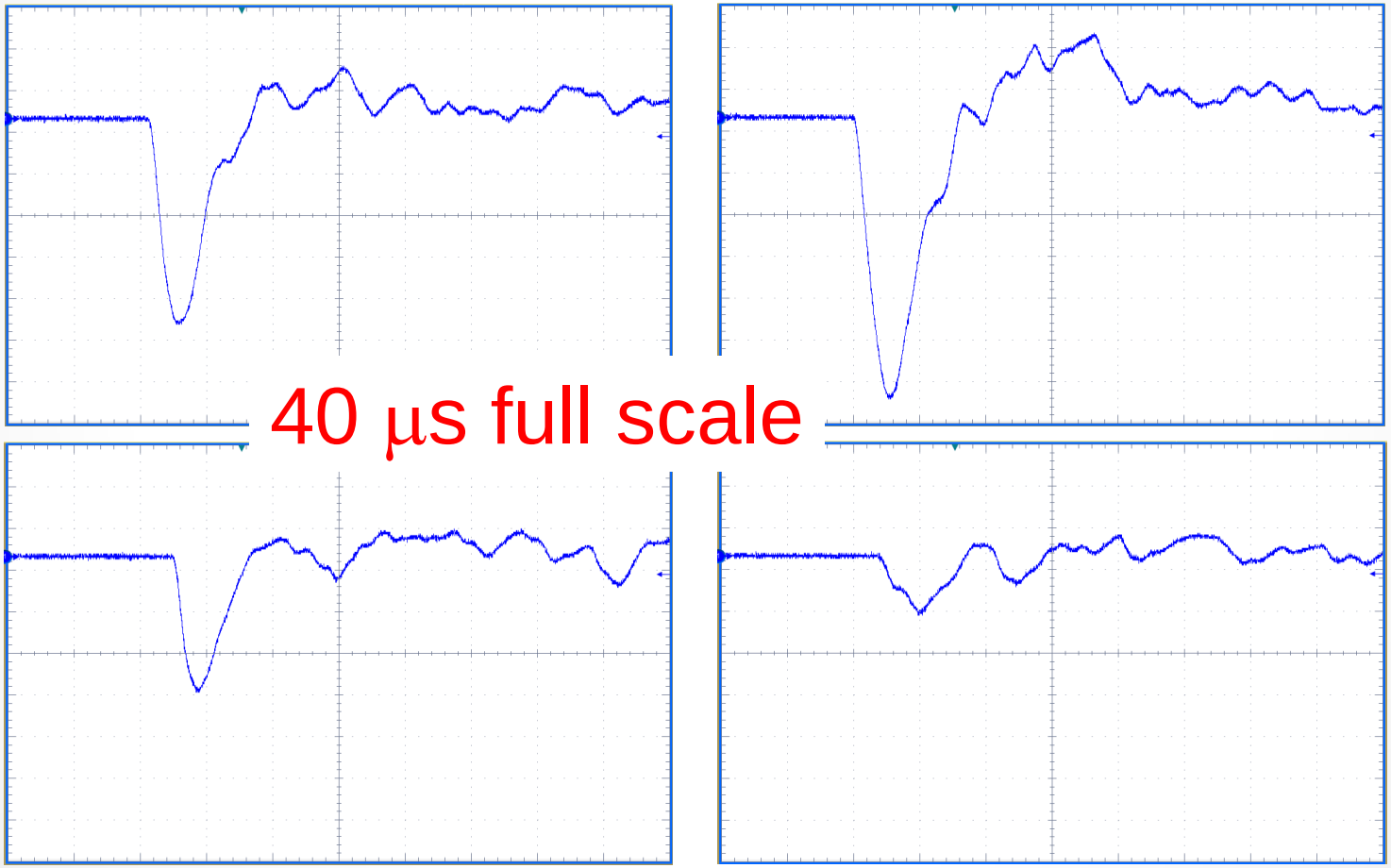
- Oscilloscope on 16us/div

Signal processing

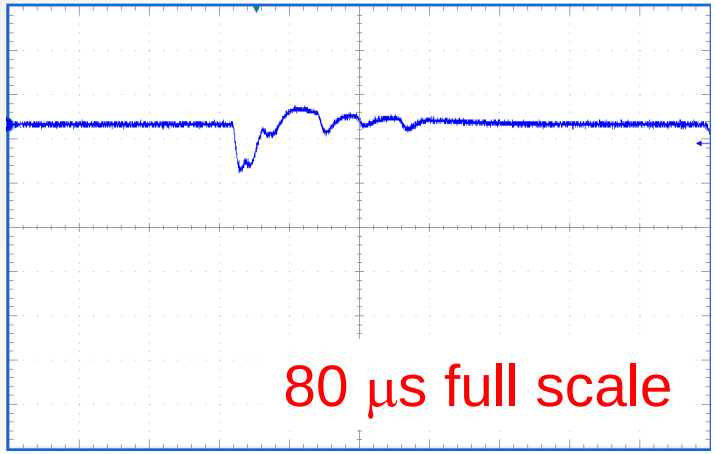
- Oscilloscope on 40us/div

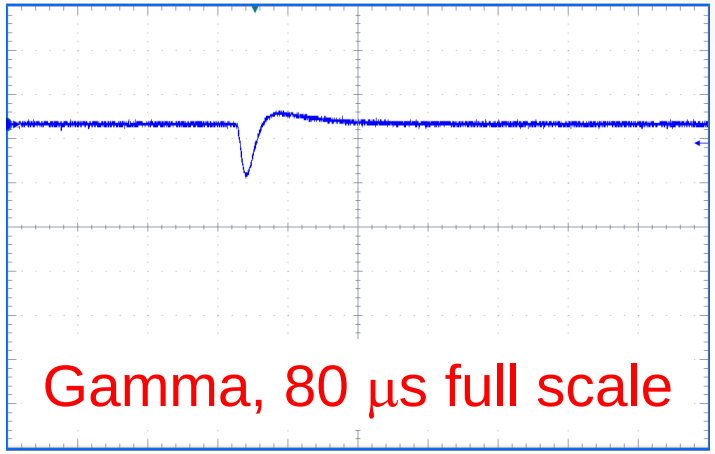
Signal processing

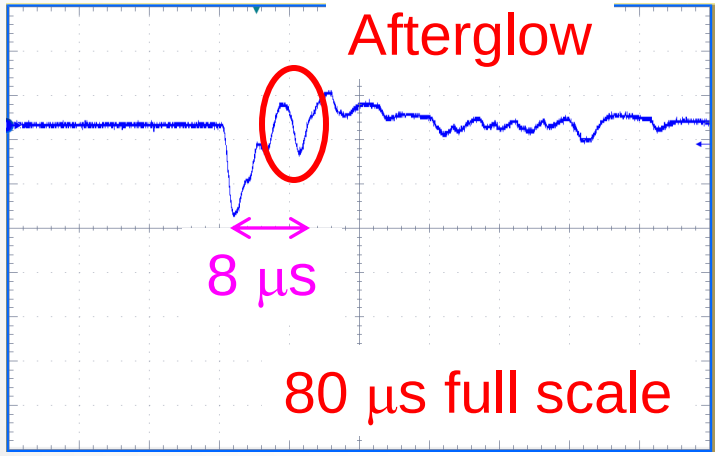
- Pictures of a few (processed) signals

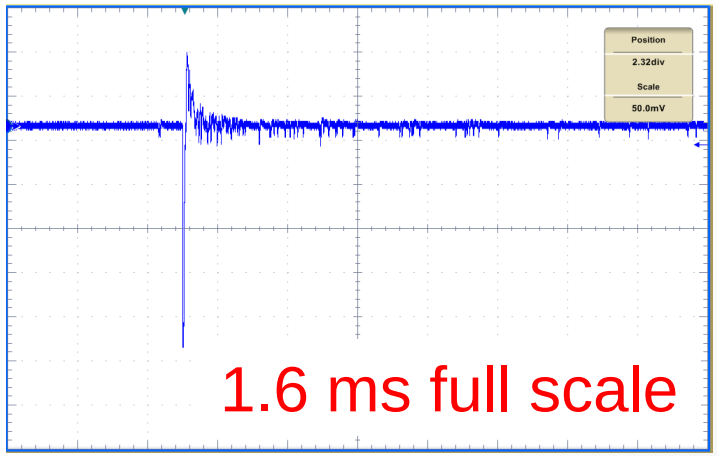


Signal processing









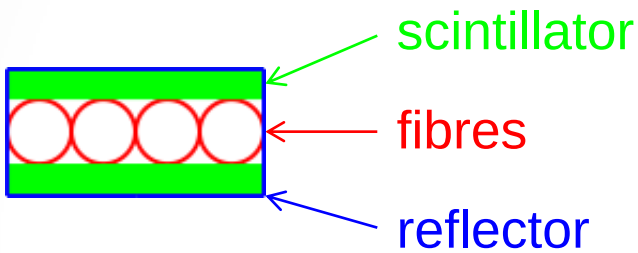
Signal processing

- Afterglow: Bright flash of light >> 1μs after neutron.
- Easy to count neutrons twice (multi-count).
- Multi-count suppression reduces count-rate capability a lot.

➢ Reduction of afterglow in ZnS scintillator can make detector considerably faster.

ZnS + fibre geometry

- 1D position sensitivity (best performance):
- Scintillator + WLSF wrapped in aluminium foil:

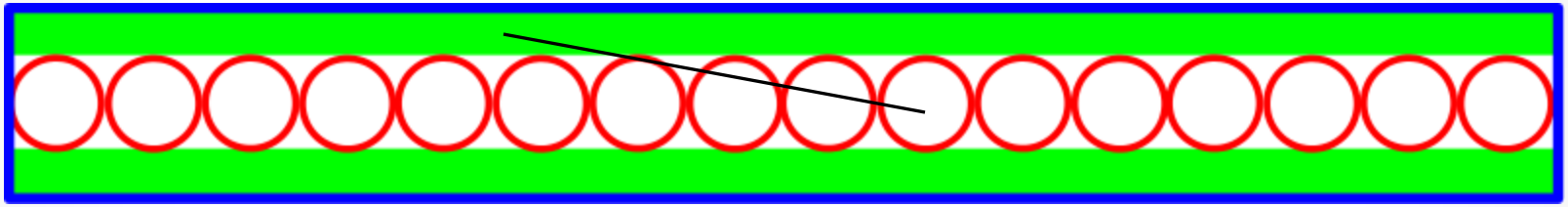


(1 scintillator element)

- WLSF close to scintillator ⇒ best light collection.
- Scintillator element completely wrapped in foil ⇒ no light crosstalk into other scintillator elements.
- Relatively labour intensive to make (many elements).

ZnS + fibre geometry

- Cheaper to make + better position resolution:
- 2 Big scintillators + WLSF wrapped in aluminium foil:

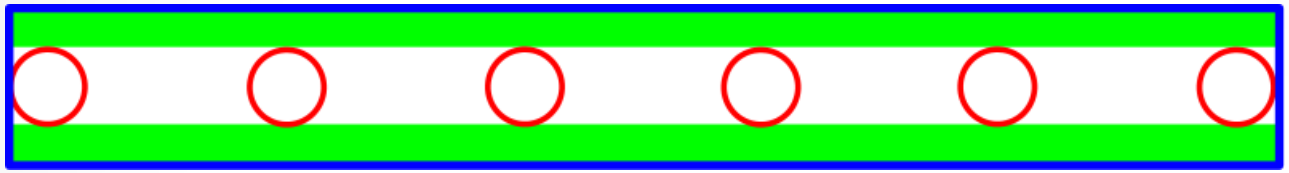


✓ Good light collection.

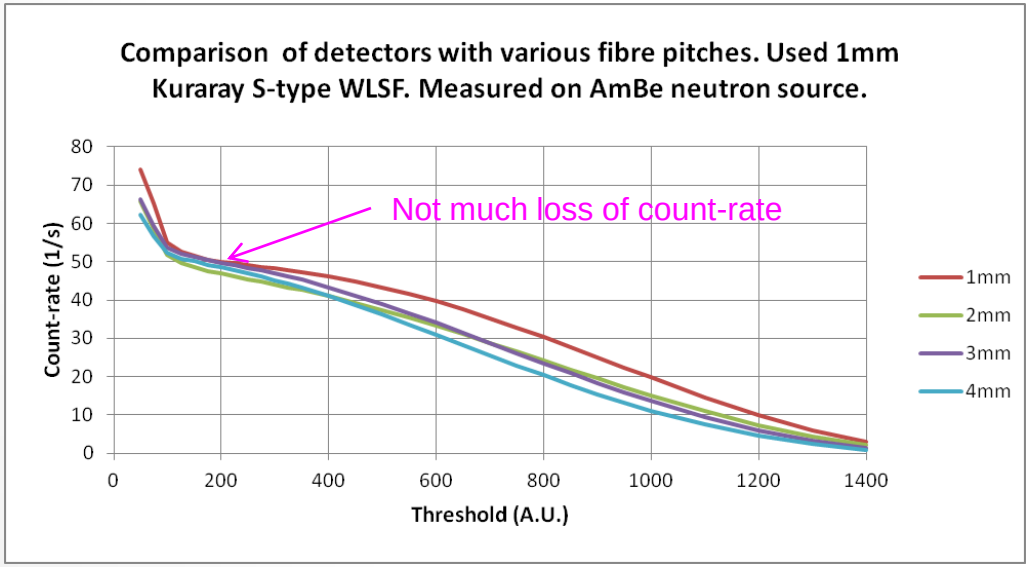
✗ Light can spread over few WLSF ⇒ more cross-talk.

ZnS + fibre geometry

- Even cheaper to make:

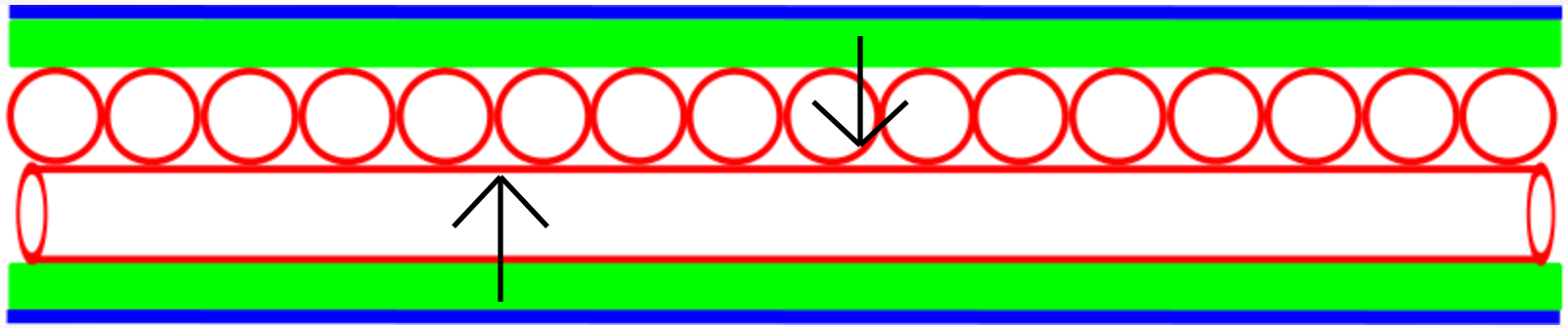


- More light loss, but not unacceptable:



ZnS + fibre geometry

- 2D principle (crossed fibre):

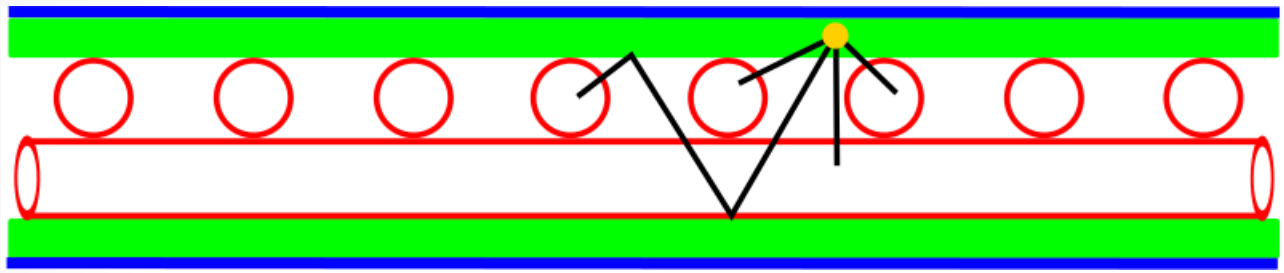


× Doesn't work (well).

- Not enough light absorbed in both layers.

ZnS + fibre geometry

- Leave gaps between fibres:

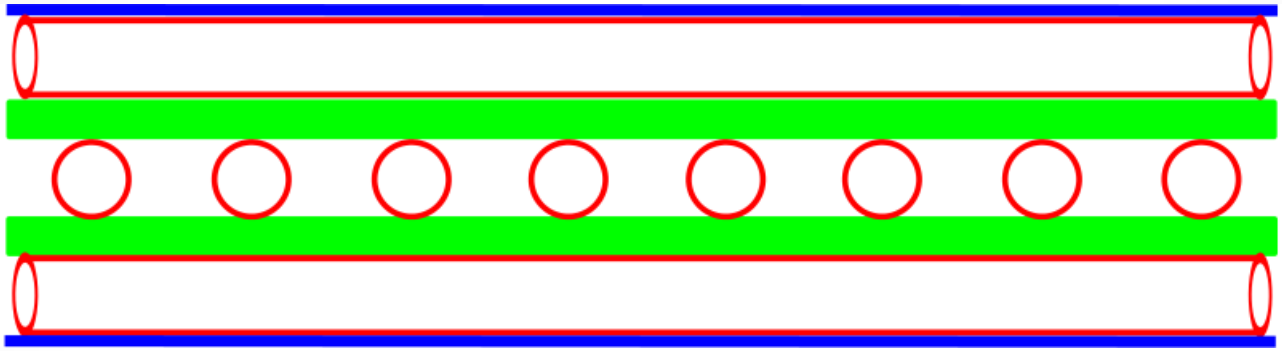


✓ Get better light distribution over fibres in x and y-direction

✗ Light travels further ⇒ more cross-talk (misplacements)

ZnS + fibre geometry

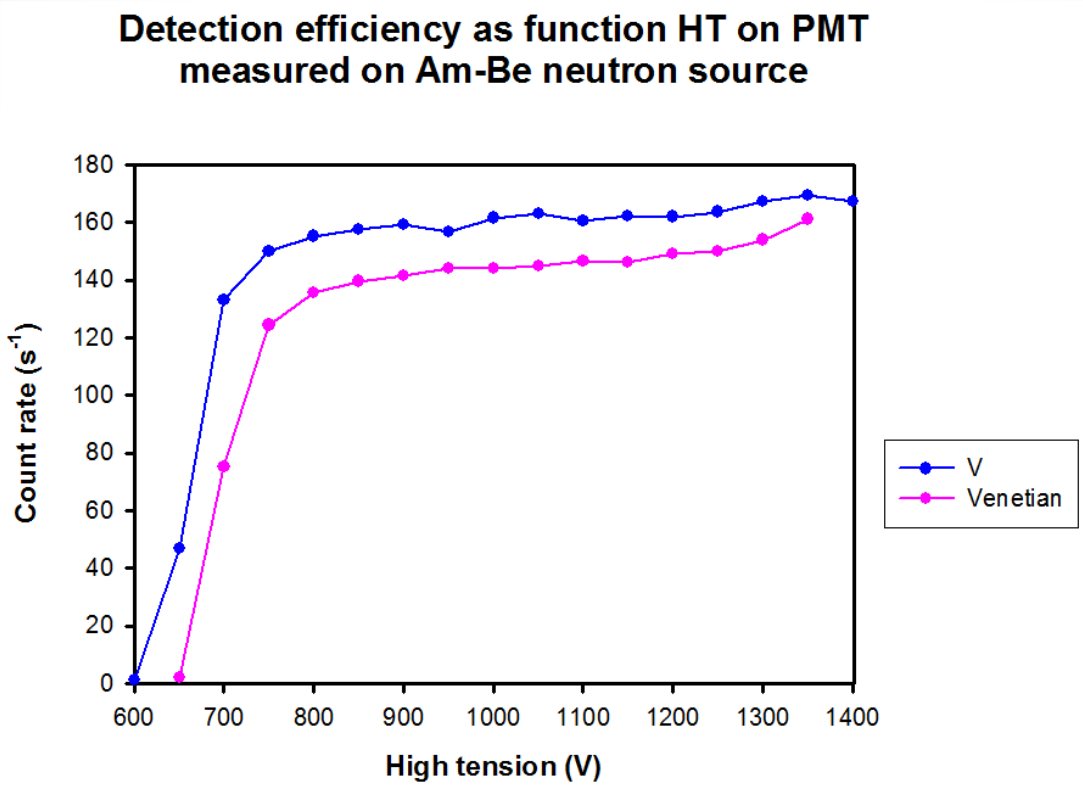
- Crossed fibres on opposite sides of scintillator



✓ Light doesn't spread out far.

✗ Need more fibres and thinner scintillator ⇒ more expensive.

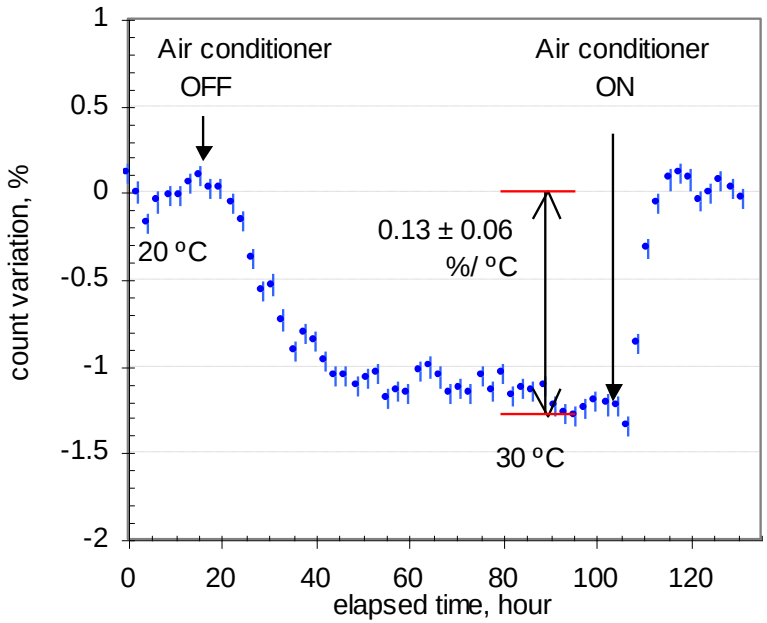
Performance



✓ Count-rate varies very little as function of high voltage.

Performance

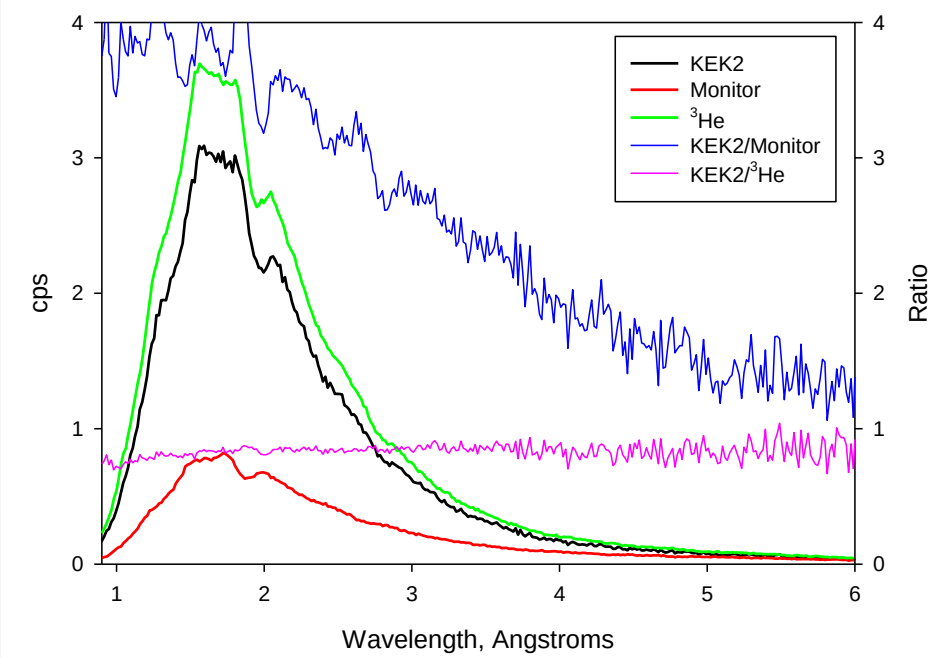
- Temperature stability:



➢ Very temperature insensitive

Performance

- Count-rate (efficiency) comparison of KEK2 (clear fibre ZnS) detector and 3He gas tube.

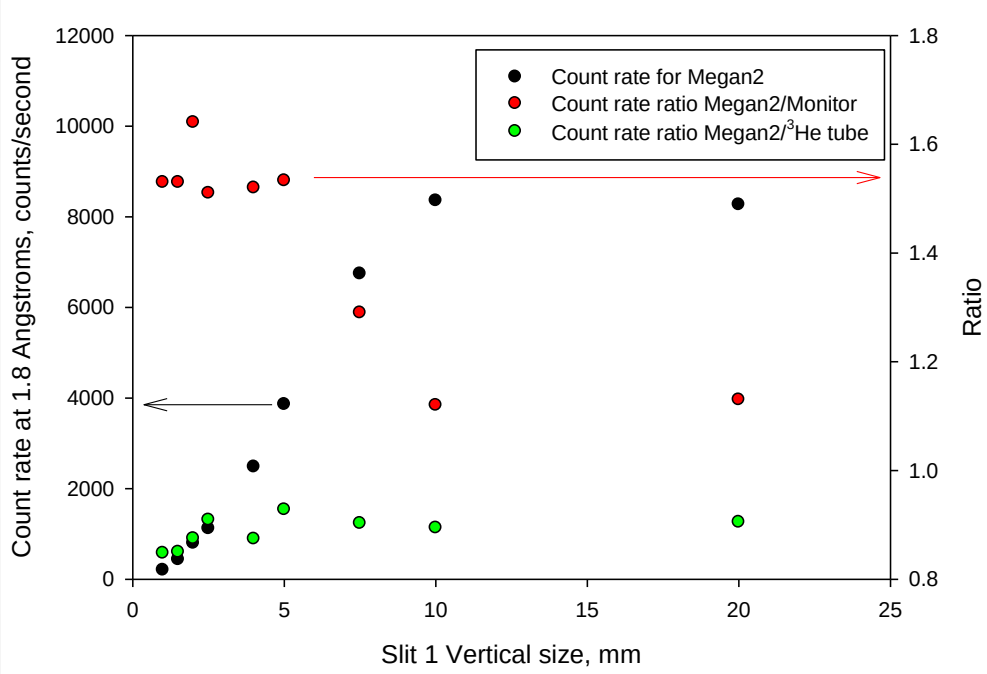


- Efficiency of gas tube: 70% at 1.5Å
- Measured efficiency of KEK2: 55% at 1.5Å
- Theoretical efficiency of KEK2: 65% at 1.5Å
- Efficiency of KEK2 = efficiency of WLSF

➢ Measured efficiency of ZnS detector 80% of theoretical efficiency.

Performance

- Count-rate capability of WLSF detector:

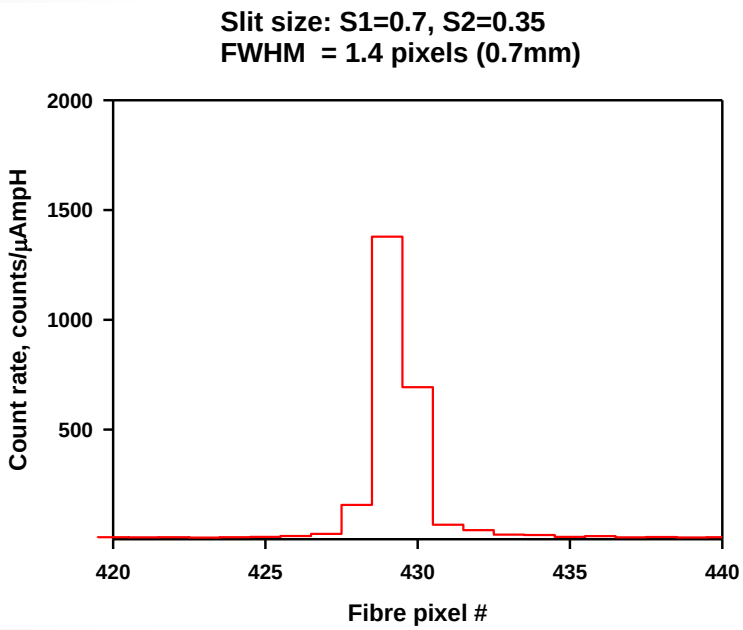


- Count-rate good up to 4 kHz per scintillator.
- 1 PMT looks at 4 scintillators ⇒ rate capability of PMT is 4 times higher

- Rate capability: 16kHz per PMT.

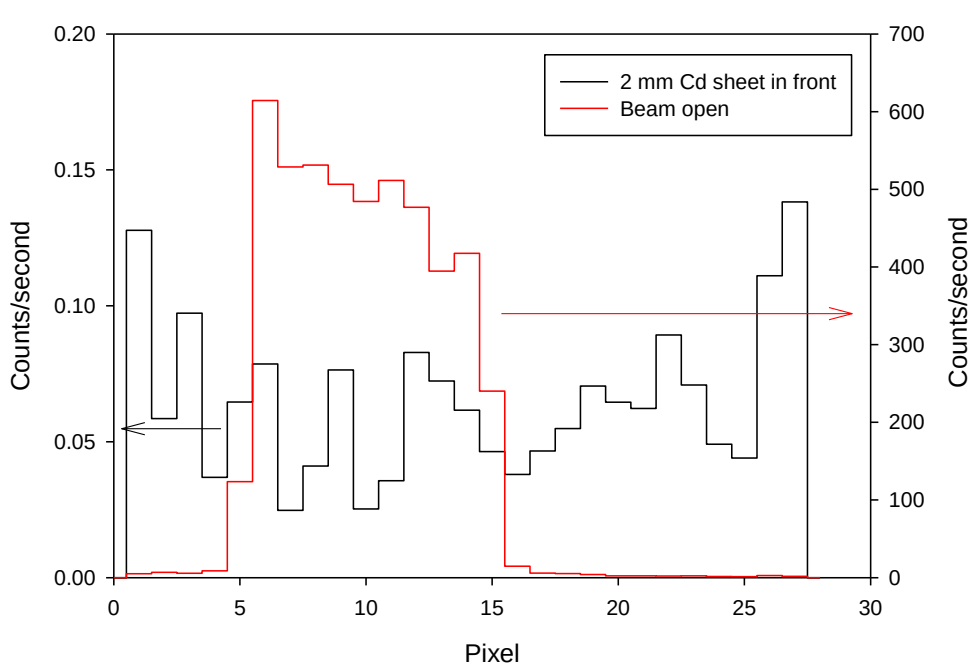
Performance

- Position resolution of 1D detector with 0.5mm WLSF:



Performance

- Sensitivity to Cd gammas:



- ^{60}Co sensitivity: <1e-6.
- ^{137}Cs sensitivity: <1e-8.

The End

ORNL team wins R&D 100 award for wavelength-shifting scintillator detector