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Above-ground scintillator studies

Scott Kiff

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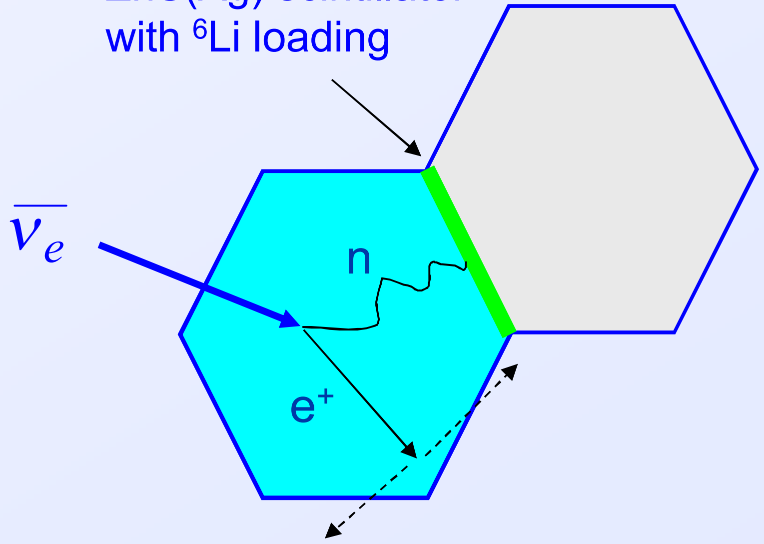
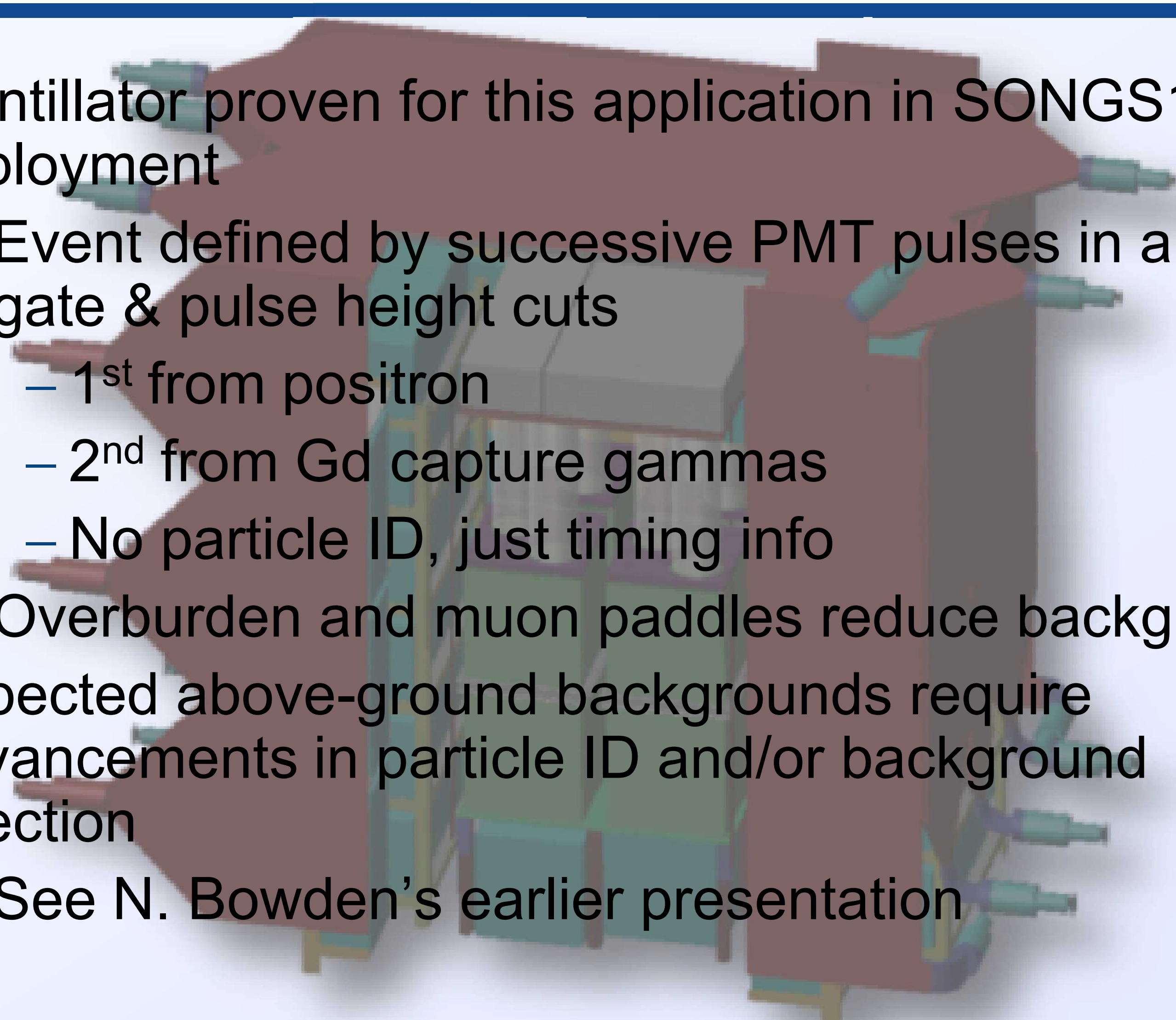


Scintillator motivation



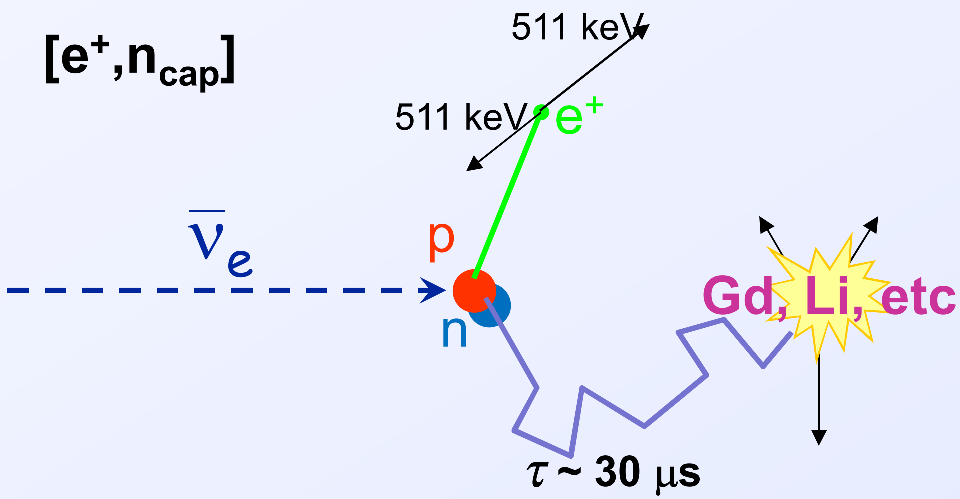
- Scintillator proven for this application in SONGS1 deployment
  - Event defined by successive PMT pulses in a fixed gate & pulse height cuts
    - 1st from positron
    - 2nd from Gd capture gammas
    - No particle ID, just timing info
  - Overburden and muon paddles reduce background
- Expected above-ground backgrounds require advancements in particle ID and/or background rejection
  - See N. Bowden's earlier presentation

Review: The Inverse Beta Signal

- The scintillation detector will utilize inverse beta decay to generate events:

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

  - inverse beta-decay produces a pair of correlated events in the detector
- Gd or other neutron capture agent loaded into liquid scintillator captures the resulting neutron after a relatively short time

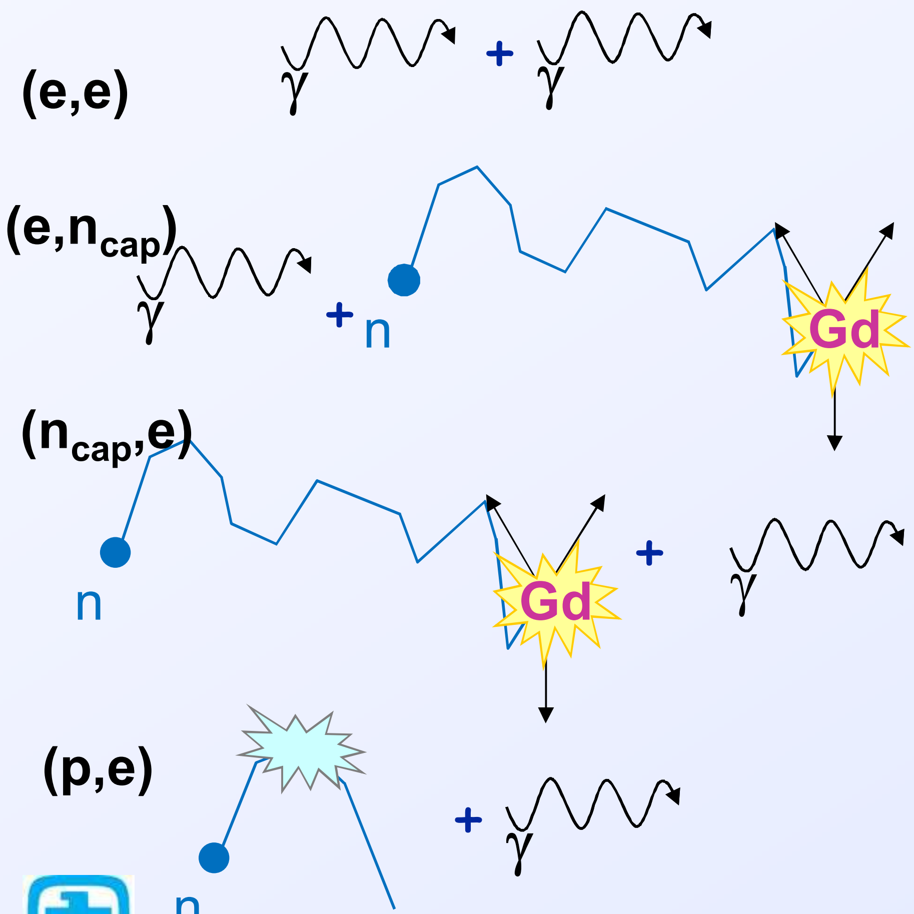


Prompt, n capture signals

- Positron
  - Immediate
  - 1- 8 MeV (incl. 511 keV γs)
- Neutron
  - Delayed (τ = 28 μs for Gd)
  - ~ 8 MeV gamma shower

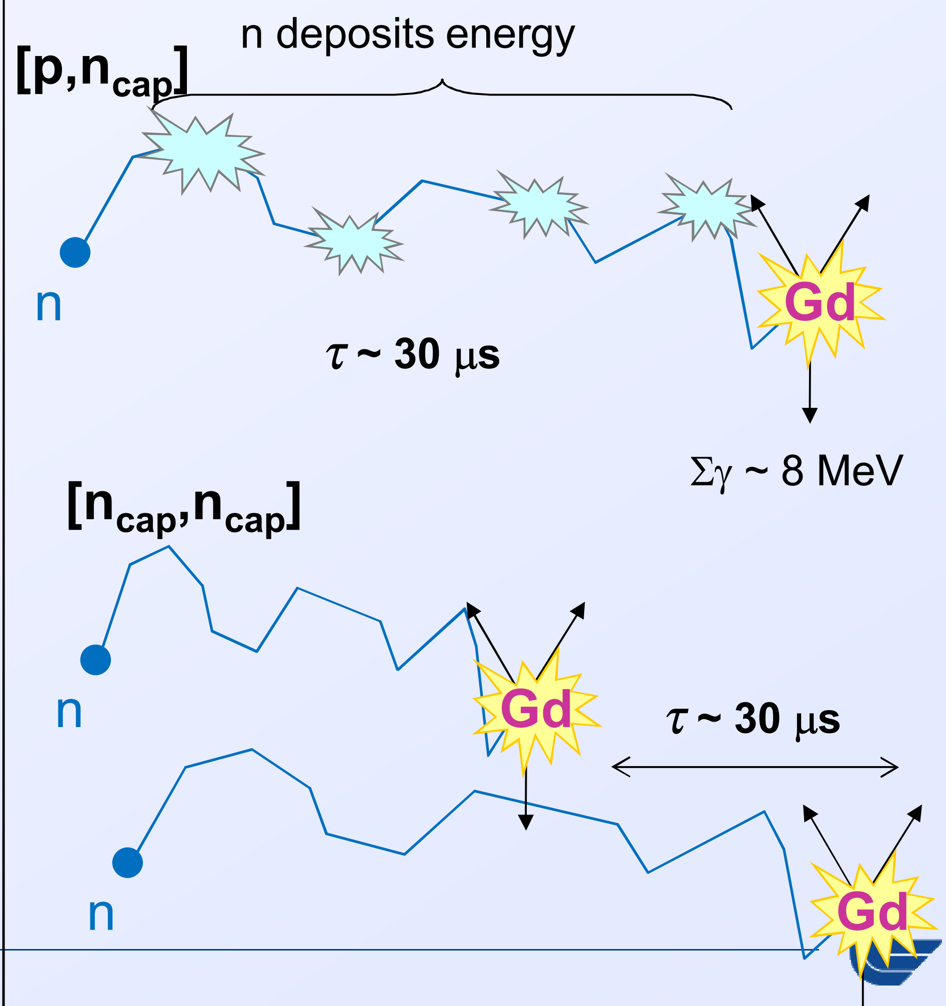
Inverse Beta Backgrounds

- **Uncorrelated Backgrounds**
  - **Random coincidences, Poisson time distribution**



Etc,etc

- **Correlated Backgrounds**
  - **Have the same time structure as antineutrino interactions**



What Particle ID or Insensitivity Can Do

	Particle ID Capability Interaction	Fast Neutron Scatter	Neutron Capture	Positron (b.t.b 511 keV)
	Identify Antineutrino Signal $[e,n_{cap}]$ or $[e^+,n_{cap}]$		✓	✓
Reject Corr. Bkg	$[p,n_{cap}]$	X		X
Reject Corr. Bkg	$[n_{cap},n_{cap}]$		X	X
Reject Uncorr. Bkg	(e,e), (n_{cap},e) , (n_{cap},n_{cap})		X	X
Reject Uncorr. Bkg	(p,x), (p,p), (x,p)	X		
Reject Uncorr. Bkg	(e,n_{cap})			X

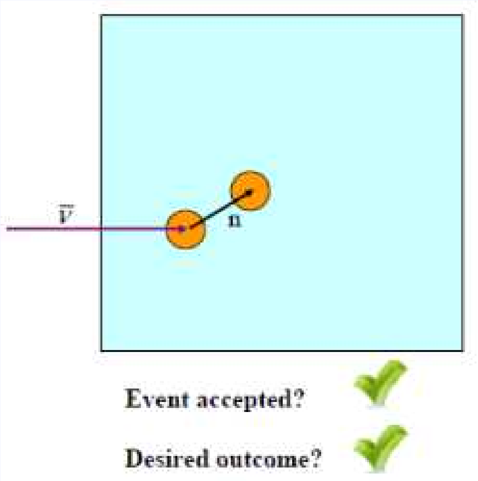
How can Particle ID be Implemented?

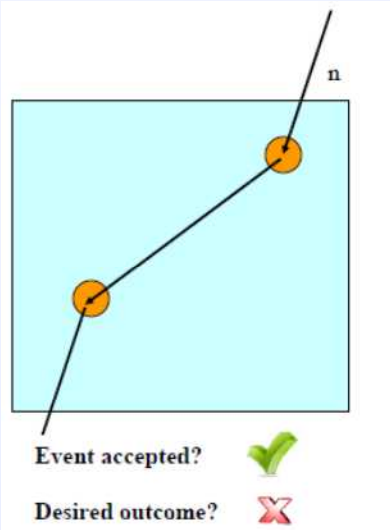
- Fast Neutron Scatter (proton recoil)
  - Pulse Shape Discrimination in Liquid Scintillator
  - Resolve multiple neutron scatters via segmentation (?)

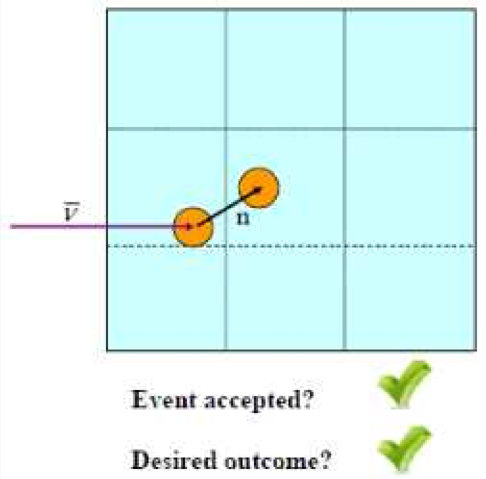
- Neutron Capture
  - Pulse Shape Discrimination in ^{6}Li or ^{10}B doped Liquid Scintillator
  - Separate neutron capture detector (e.g. ^{3}He tubes)
  - Multiplicity of Gd gamma ray shower via segmentation (?)
  - (LiZnS, LGB later in talk)

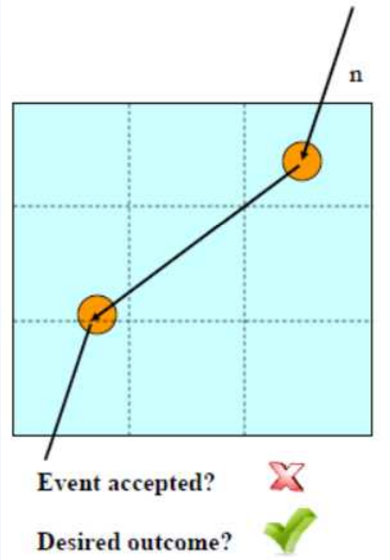
- Positron
  - Identify back-to-back 511 keV annihilation gammas via segmentation

Segmentation concept









Signal generation within a single unit cell

- There are four possible configurations of a detector segment:
  - Homogeneous scintillator without particle ID
    - Impossible in above-ground backgrounds with no segmentation
  - Homogeneous scintillator with particle ID (example: PSD in a liquid scintillator to exclude proton recoils)
  - Separate detection media for positron and neutron capture, single readout
  - Separate detection media for positron and neutron capture, independent readout

LGB: Separate detection media, single readout

- $LiGd(BO_3)_3$:Ce is being investigated at LLNL
- LGB is an inorganic crystal scintillator composed of neutron capture agents (!)
- ^6Li and ^{10}B neutron captures are bright compared to Li or B doped organic scintillators
  - Lower quenching of high dE/dx interactions than organics
  - Light yield from $^6Li + n \rightarrow {}^3H + {}^4He$ is ~40,000 photons
- Time constant of inorganic scint. is very long (~200ns) compared to organics (~ few ns)
- To some extent, isotopics can be selected, e.g.

$$^{6}Li^{nat}Gd(^{11}BO_3)_3:Ce$$

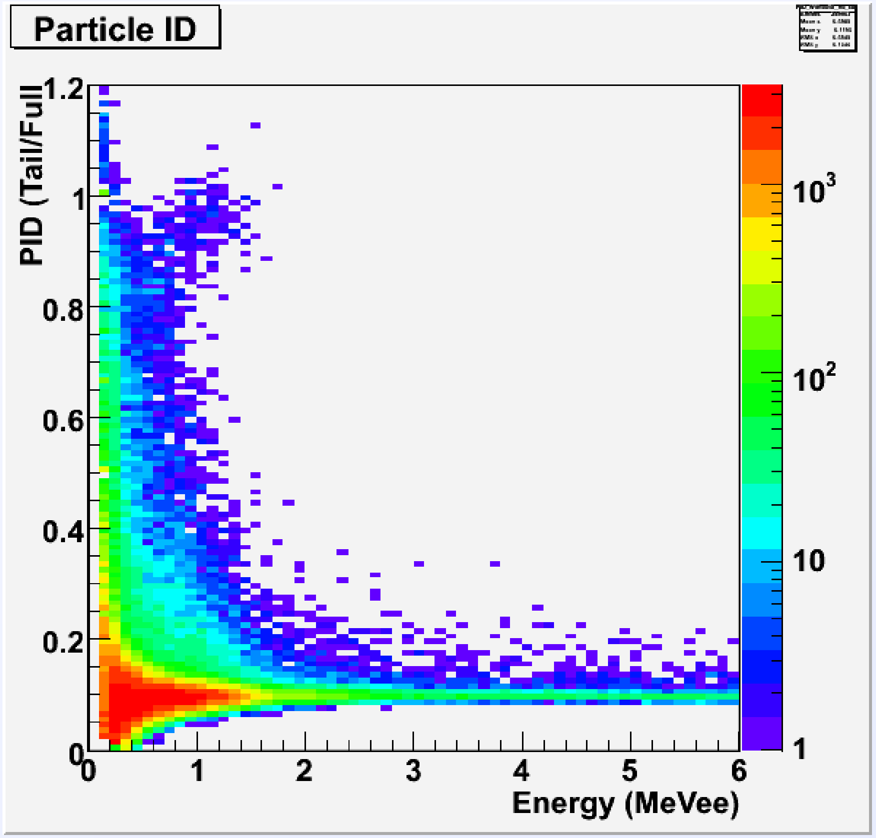
LGB as an antineutrino detection medium

- **Small grains of crystal (~1mm) mixed with plastic scintillator:**
  - **H for antineutrino target**
  - **e^+ in plastic scintillator**
  - **LGB for neutron capture (via PSD)**
  - ***BUT:* little to no fast n rejection**

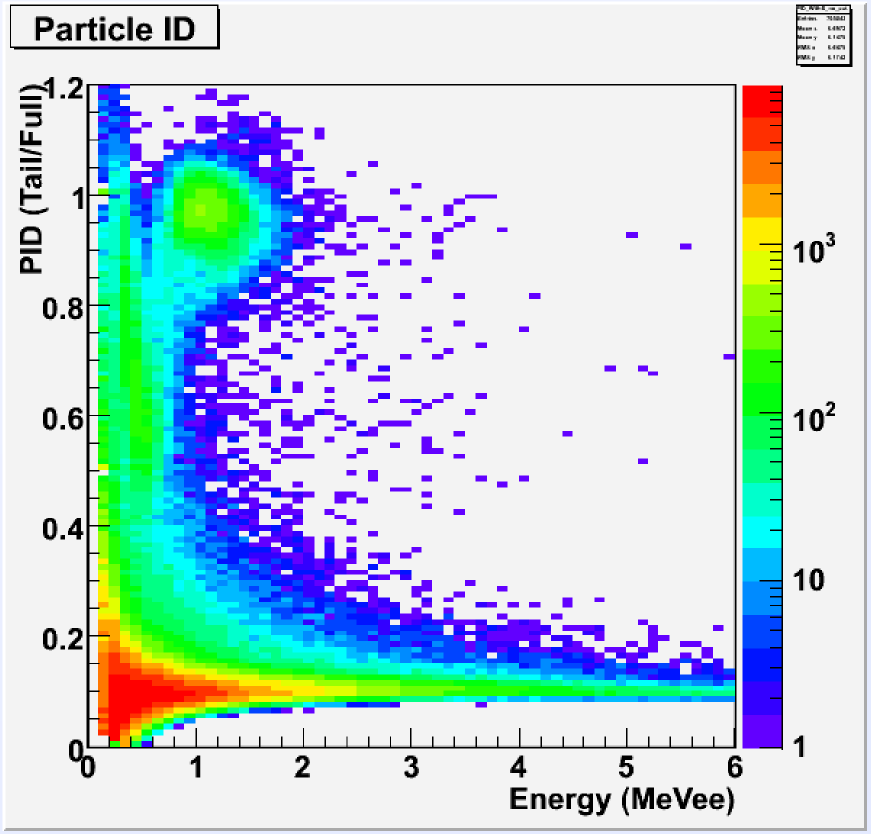
- **LGB index (n = 1.65) is well matched to plastic (~~n~~ n = 1.58)**
- **5 inch right cylinder sample is 1% by weight LGB**
  - **0.1% by weight ^{6}Li**
  - **0.4% by weight ^{nat}Gd**
- **Good for uncorrelated background reduction; poor correlated proton recoil/capture background discrimination**

Neutron Capture Selection via PSD

Background



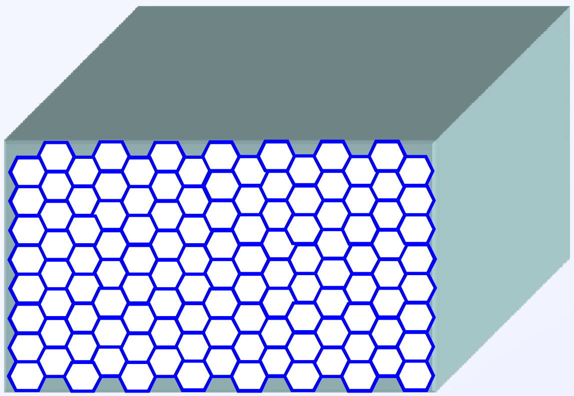
^{252}Cf + background

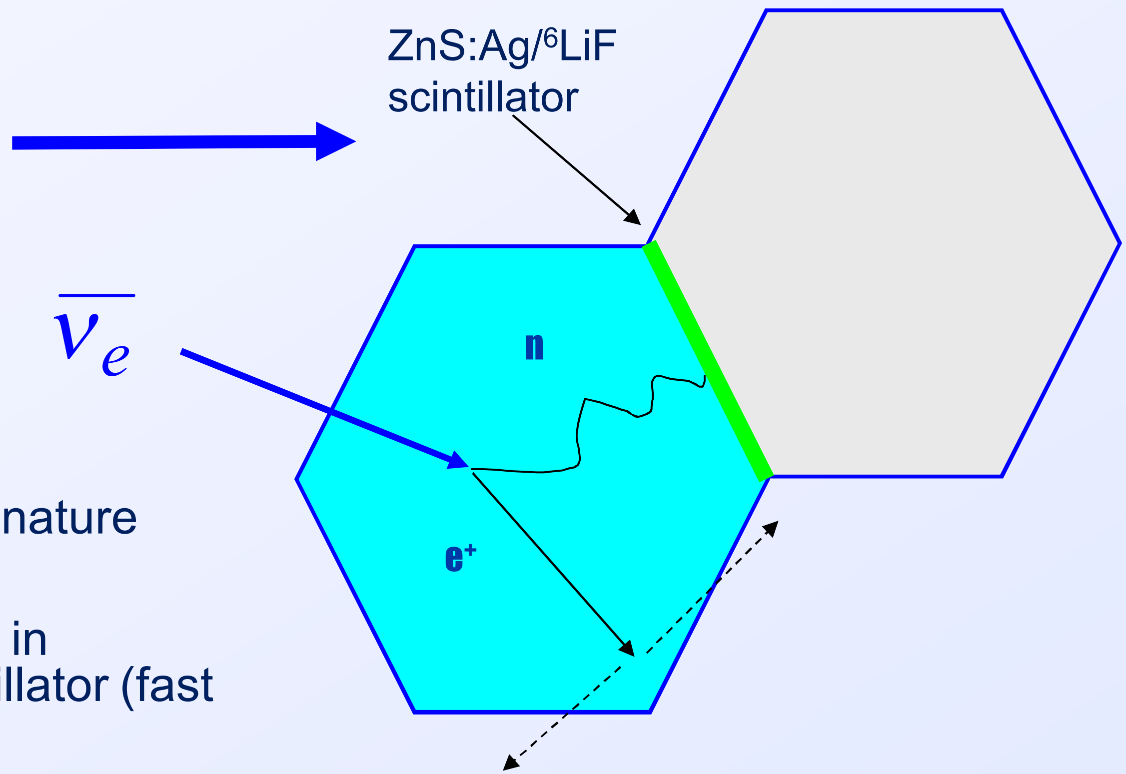


ZnS:Ag/^{6}LiF: Separate detection media, single readout

- ZnS:Ag/^{6}LiF is an inorganic crystal scintillator
  - Reduced quenching of heavy ion depositions
  - Time constant is very long (~200ns) compared to organics (~ few ns)
  - ^{6}Li is a strong thermal neutron absorber

ZnS:Ag/^{6}LiF: Proposed Design

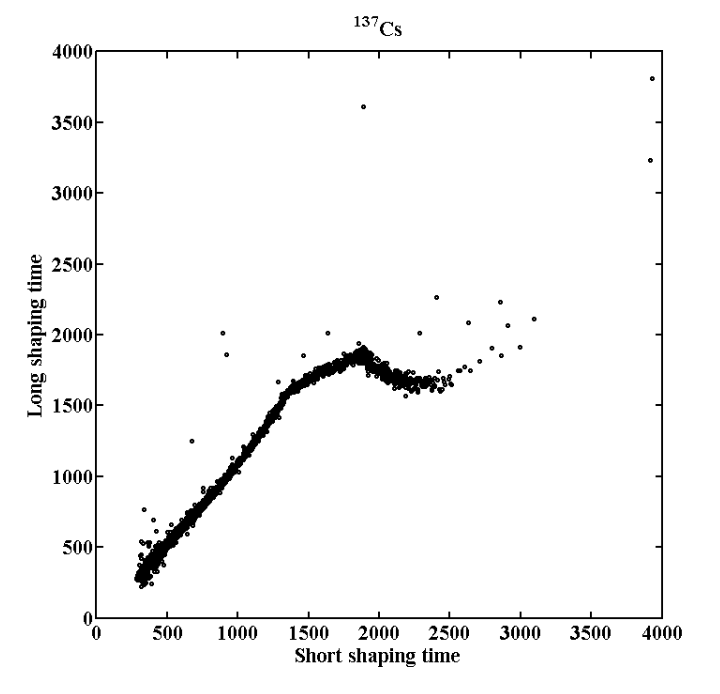


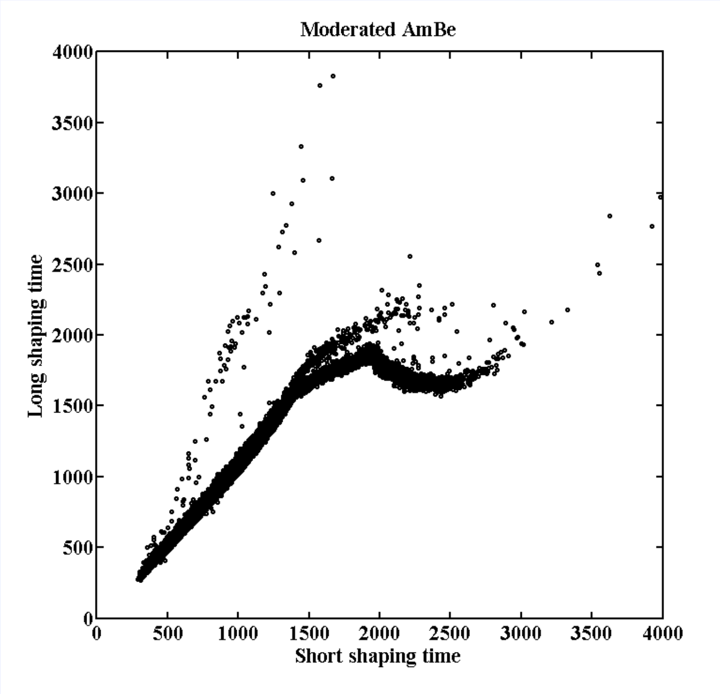


- Antineutrino interaction signature
  - Positron
    - Electron-like event in hydrogenous scintillator (fast pulse decay)
  - Neutron
    - Bright ZnS pulse in two adjacent cells about ~10 μs after positron

ZnS:Ag/^{6}LiF experiments: painted inserts

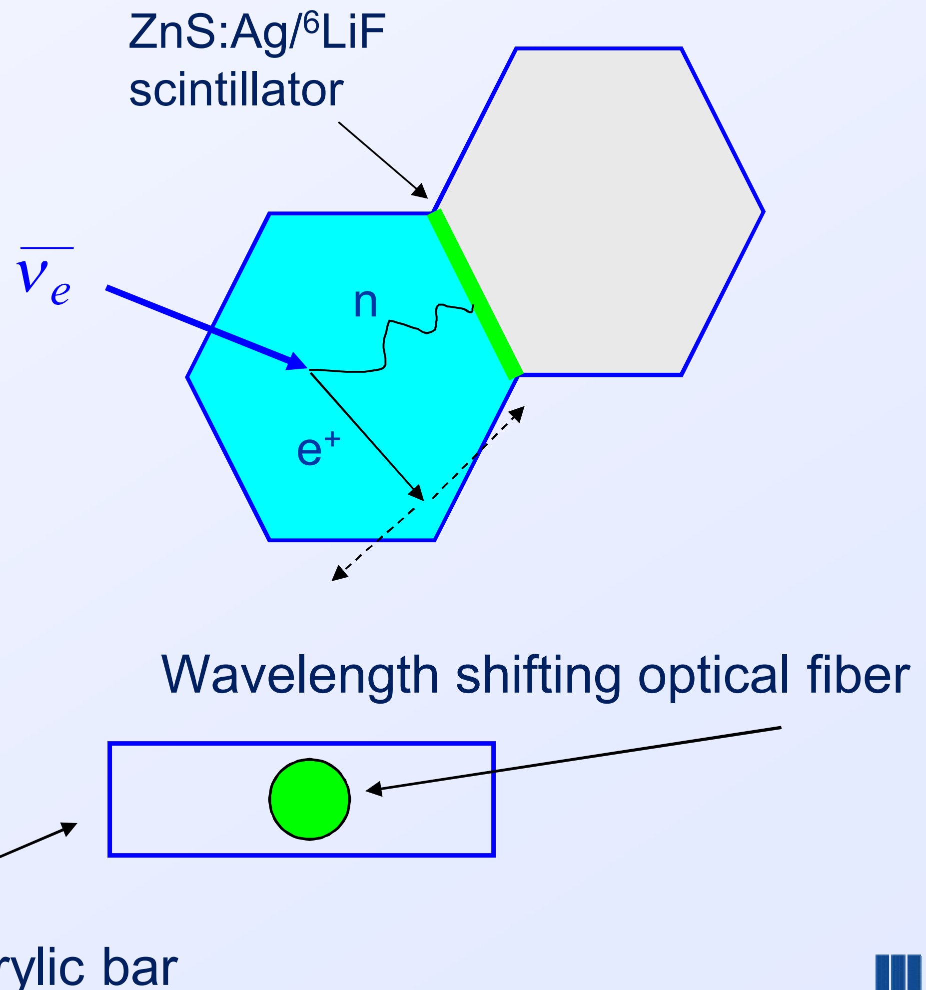
- Coated inserts in a liquid scintillator cell
- Liquid scintillator produced gamma and fast neutron differentiation; paint generates thermal neutron capture signal





ZnS:Ag/^{6}LiF: Separate detection media, independent readout

- If time multiplexing does not work, may have to read out ZnS layers separately



WLS fiber readout is a proven concept

- Success reported in the literature (LANL, U. of Tokyo)
- Flexible geometries allow placement of fiber-readout PMTs outside of detection volume

Reprinted from Belian et al, NIM A 505 (2003) 54-57.

Summary

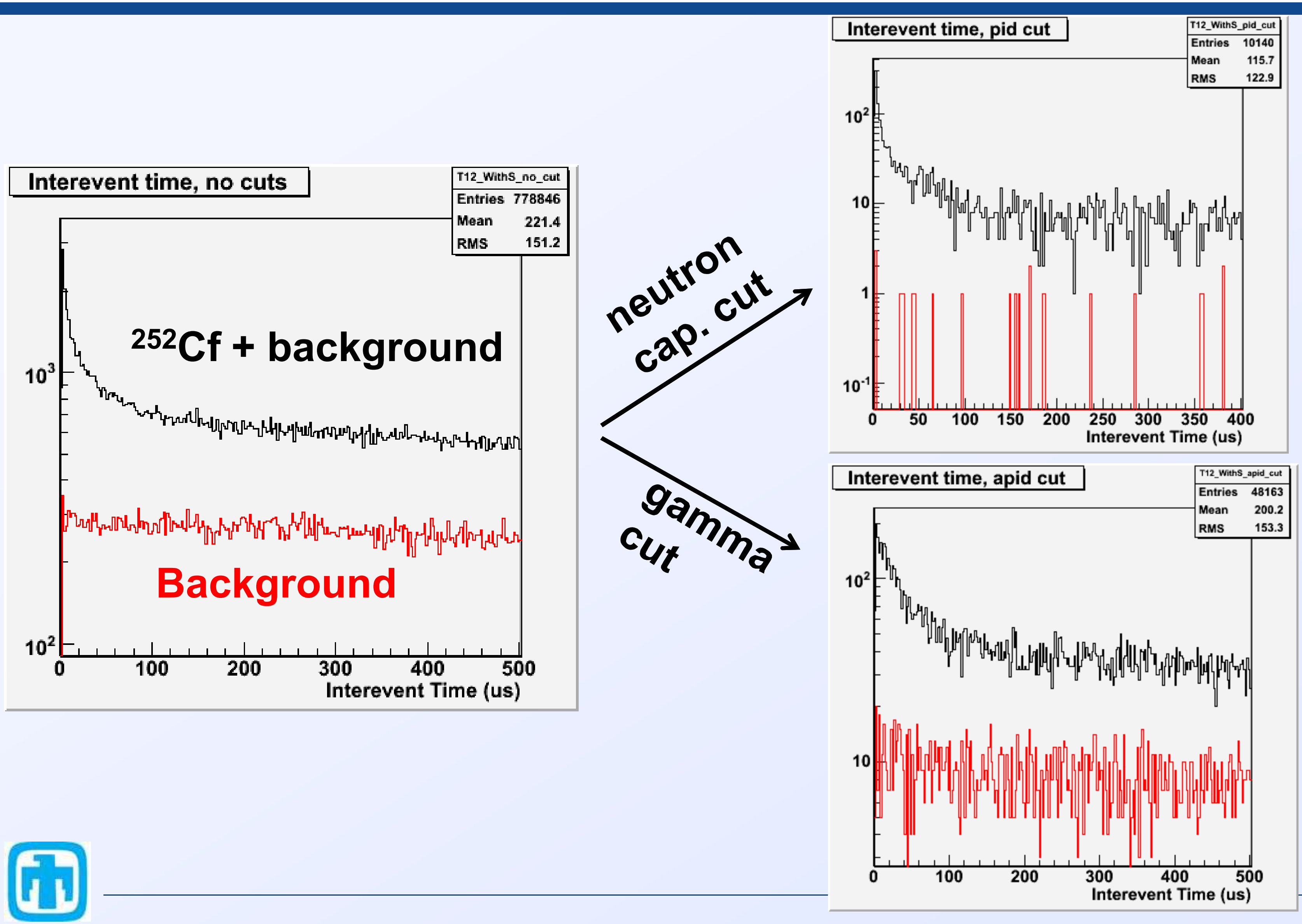
- The above-ground backgrounds necessitate advancement of the current SONGS scintillator technology
  - Particle ID
  - Segmentation
- LGB and ZnS:Ag/^{6}LiF produce distinct thermal neutron signatures
  - Cost, availability, overall efficiency in system
- ZnS:Ag/^{6}LiF plastic bars with WLS fibers are another option
  - Proven technology
  - Geometry flexibility

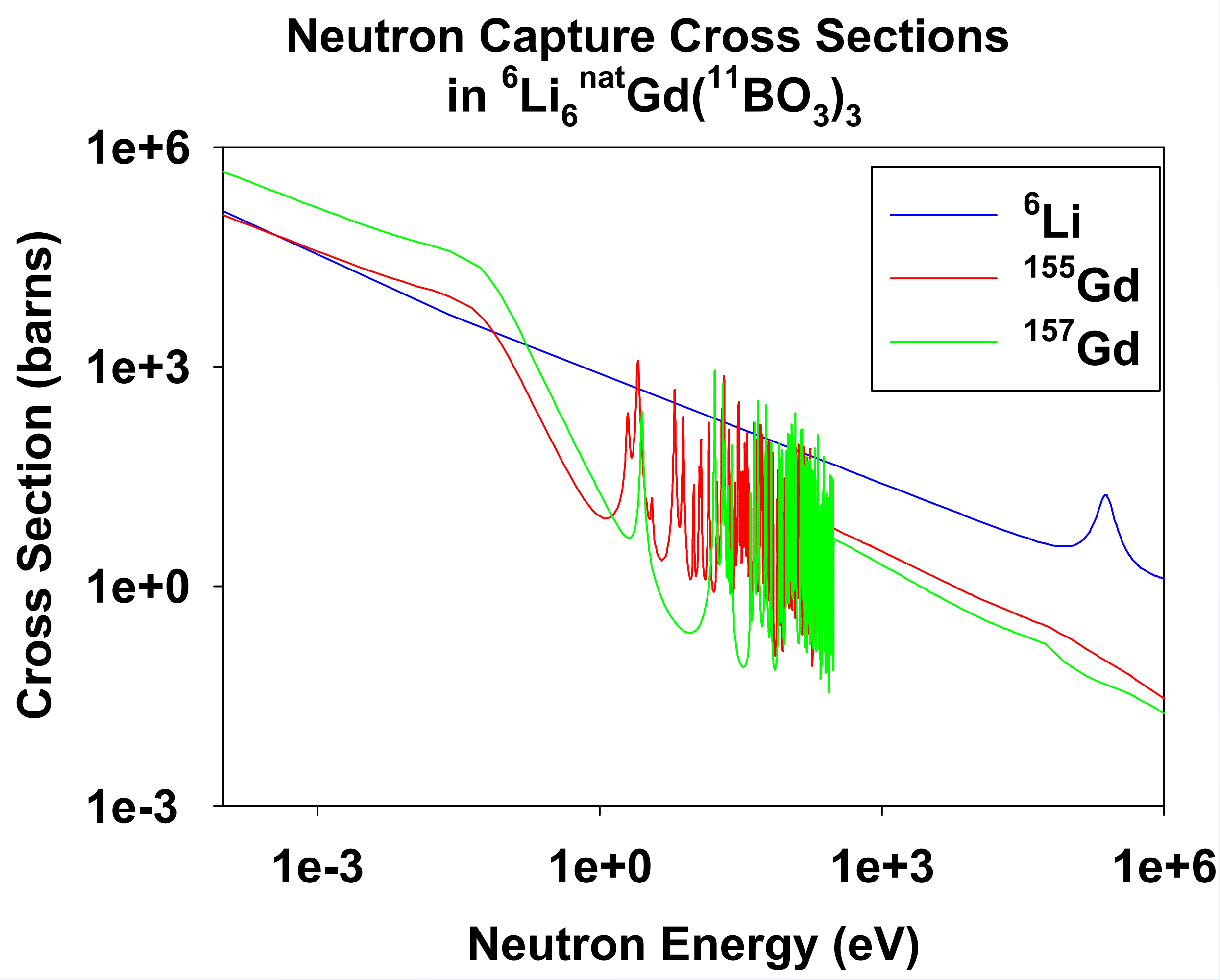
Cell size optimization studies

- (Use Lorraine's simulations to show optimal cell sizing for neutron capture efficiency vs. hydrogen displacement)

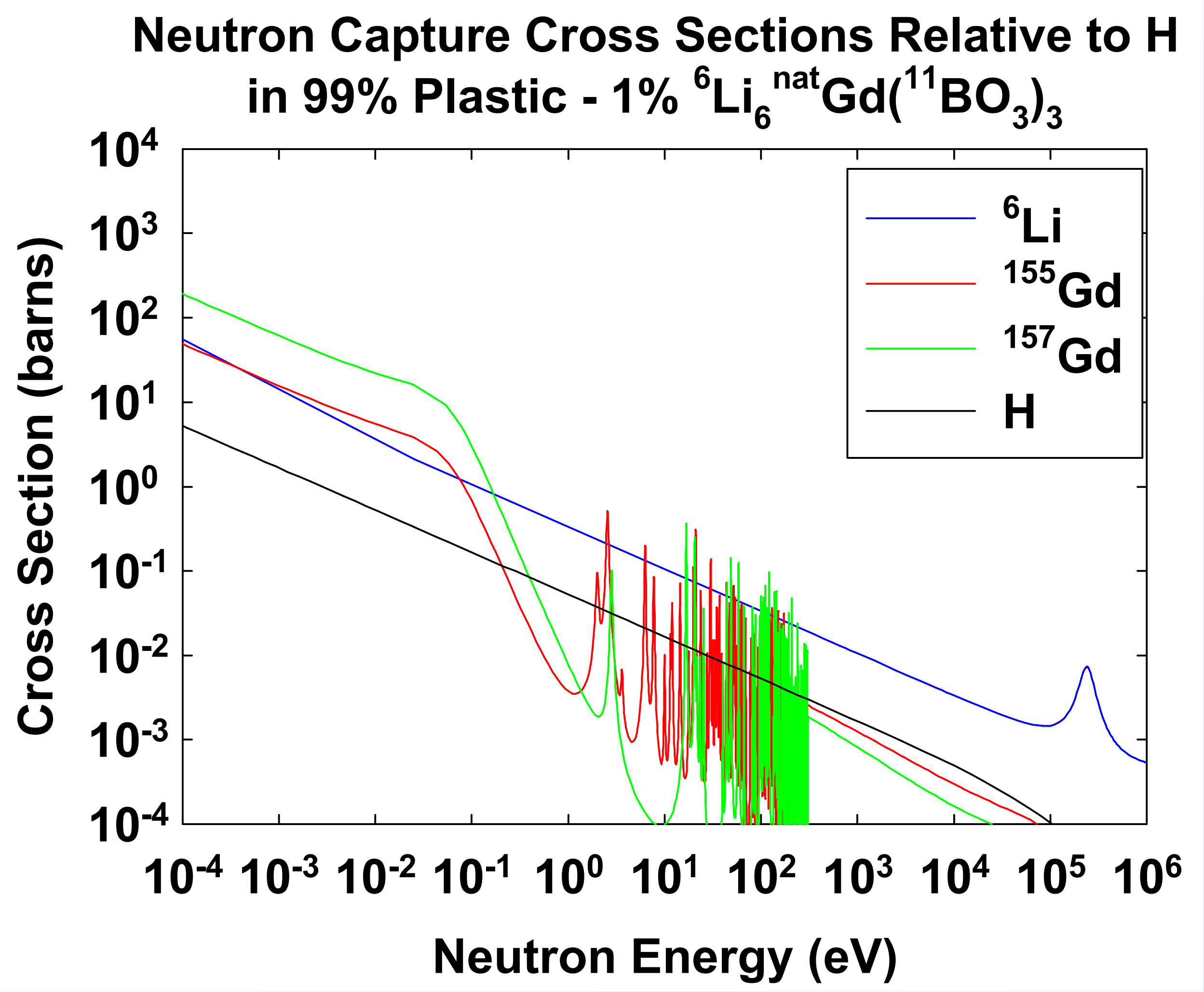
- Slow experimental progress is due to focus on materials development and lack of definite material choice.

Capture Time distributions





Neutron Capture Cross Sections
in $^{6}Li_{6}{}^{nat}Gd(^{11}BO_{3})_{3}$
1e+6
1e+3
1e+0
1e-3
Cross Section (barns)
1e-3
1e+0
1e+3
1e+6
Neutron Energy (eV)
^{6}Li
^{155}Gd
^{157}Gd



Neutron Capture Cross Sections Relative to H
in 99% Plastic - 1% $^{6}Li_{6}{}^{nat}Gd(^{11}BO_{3})_{3}$
Cross Section (barns)
Neutron Energy (eV)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}
^{6}Li
^{155}Gd
^{157}Gd
H