Post Helium-3 Neutron Detection at BYU

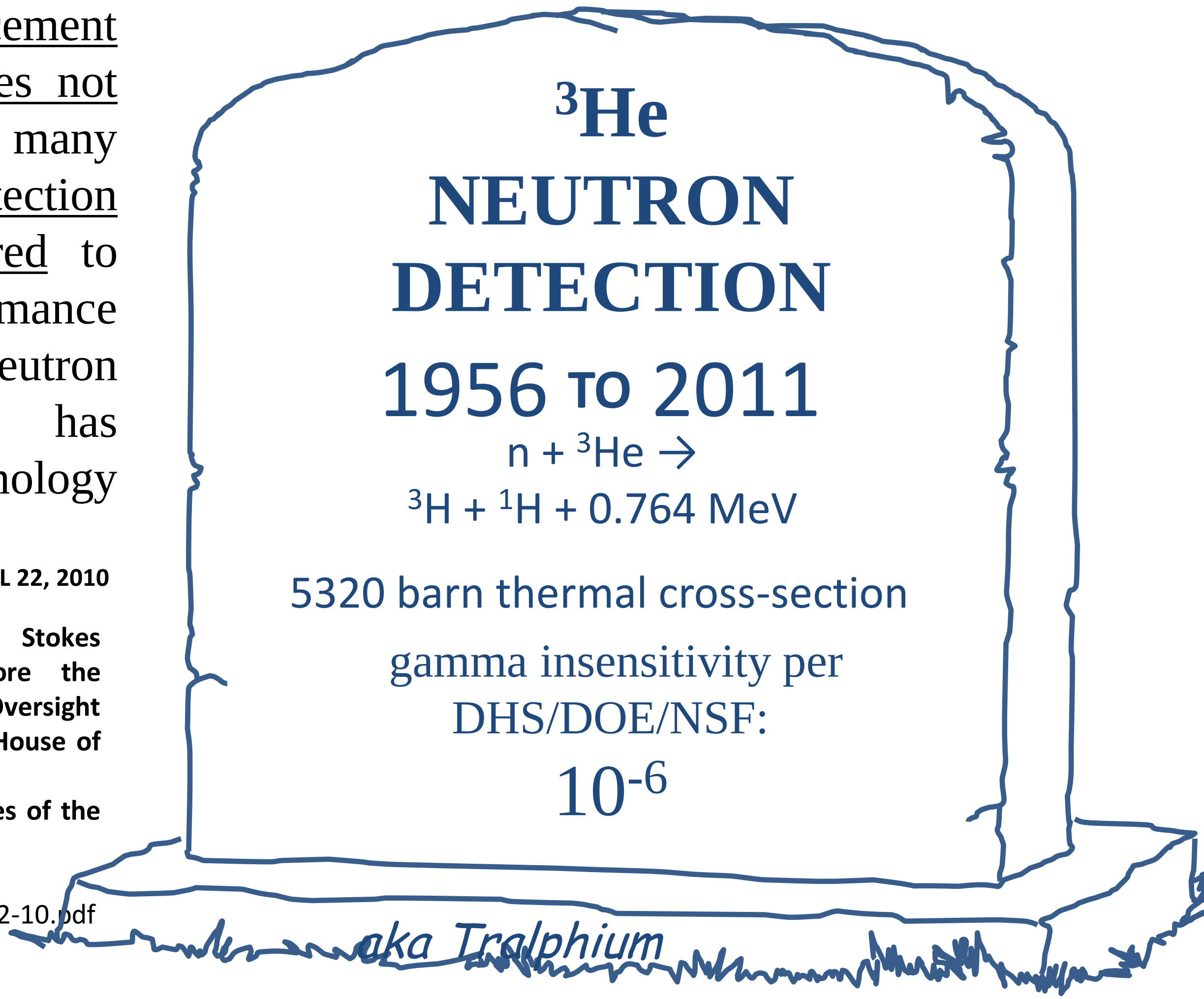
John E. Ellsworth
Inventions of J. Bart Czirr and Lawrence Rees

"… a drop-in replacement technology for Helium-3 does not exist today. Furthermore, as many as six different neutron detection technologies may be required to best address the performance requirements of the neutron detection applications GE has served historically with technology using Helium-3."

THOMAS R. ANDERSON, APRIL 22, 2010

Product Line Leader, GE Energy, Reuter Stokes Radiation Measurement Solutions Before the Subcommittee on Investigations and Oversight Committee on Science and Technology, U.S. House of Representatives Hearing on "Caught by Surprise: Causes and Consequences of the Helium-3 Supply Crisis"

http://www.parttec.com/Helium-3_Congress_Hearing_Anderson_Testimony_4-22-10.pdf



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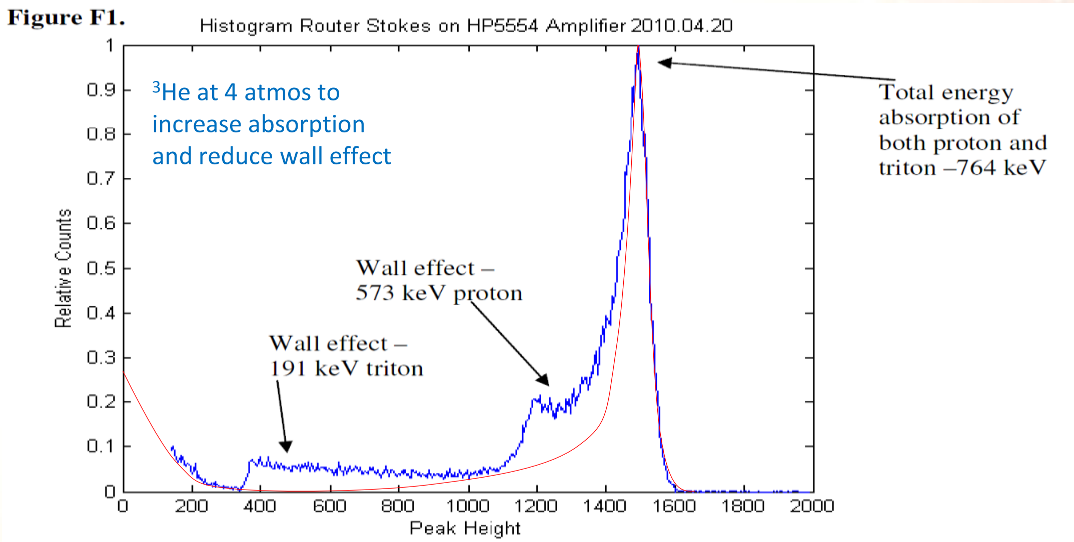
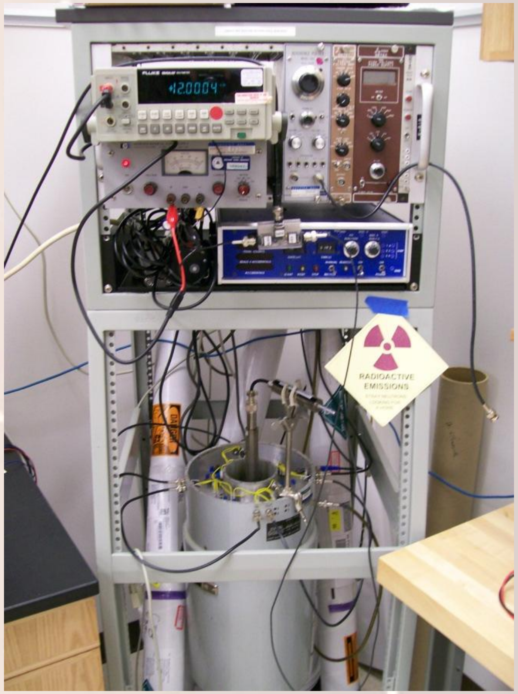
motivation

- **Neutron Energy Spectroscopy to low energies**
  - Measure sparse neutrons in background field
  - ★ Identify nuclear reactions (astrophysics)
- ★ **Explore nuclear fission, both spontaneous and induced**
  - Age old question: to what degree do neutrons erupt from scission or fission fragments
  - Degree of mutual attraction of pairs of emitted neutrons
- **Create a drop-in replacement for 3He detectors**
  - Possibly improve material identification (DHS)
- **ToF detector/source system that will allow modestly funded universities entry to second tier nuclear science**

Helium-3 Neutron Detection

typical ^{3}He proportional counter pulse height spectrum



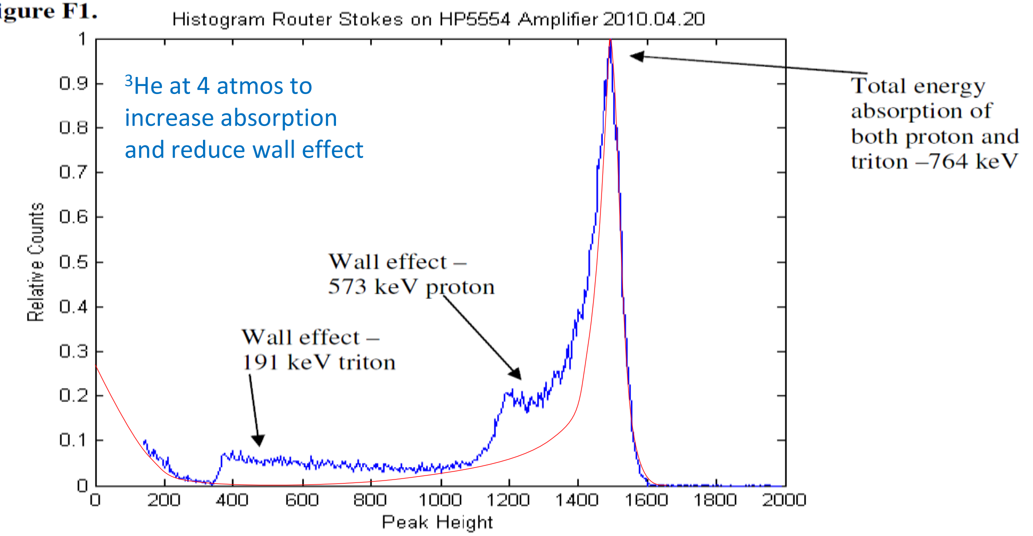


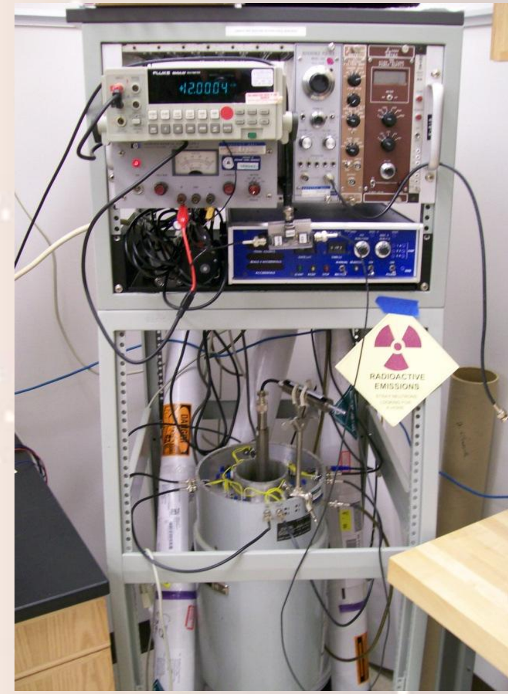
J E Ellsworth, Transducer Signal Noise Analysis for Health Monitoring (SW-7440). Master Task Agreement No. 15022, Task Order No. 10, Amended October 1, 2009

Helium-3 Neutron Detection

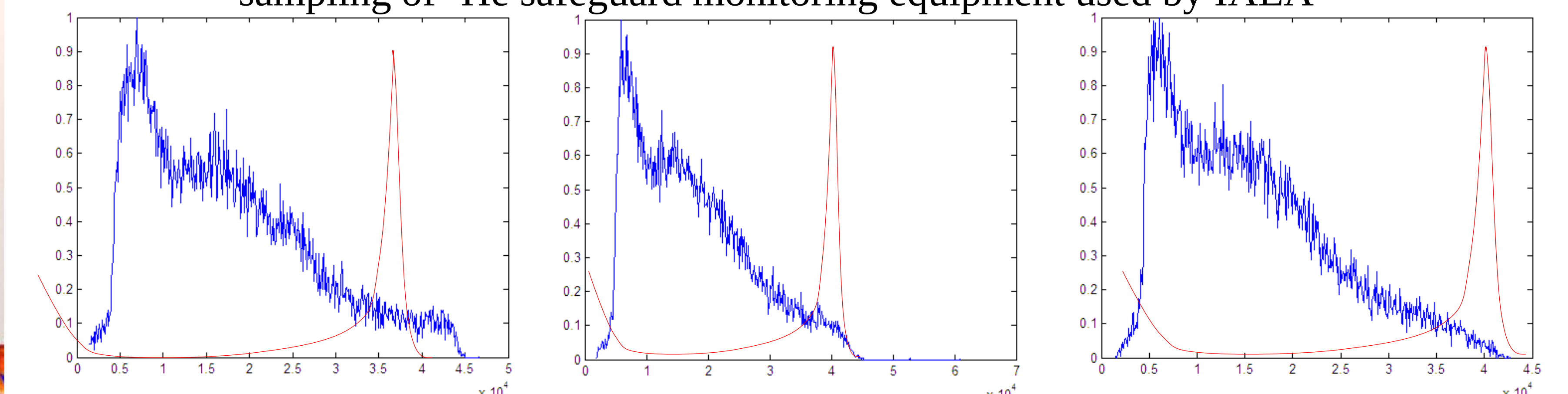
typical ^{3}He proportional counter pulse height spectrum

Figure F1.



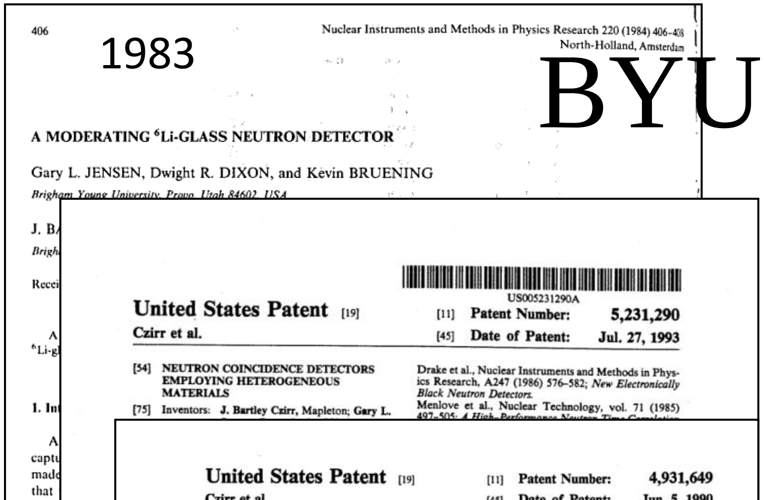


sampling of ^{3}He safeguard monitoring equipment used by IAEA

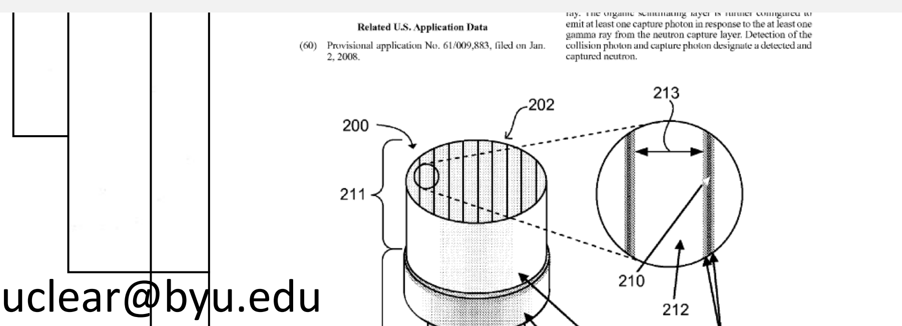


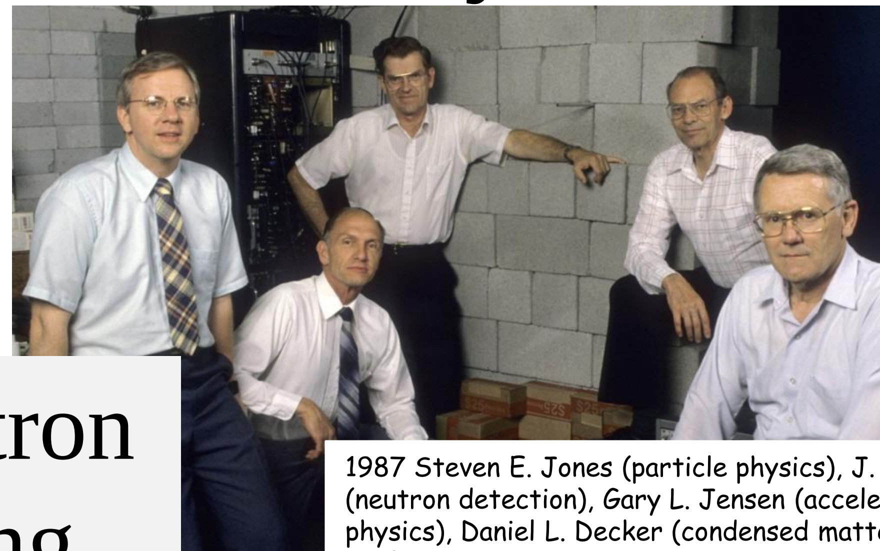
J E Ellsworth, Transducer Signal Noise Analysis for Health Monitoring (SW-7440). Master Task Agreement No. 15022, Task Order No. 10, Amended October 1, 2009

BYU Nuclear Physics Group

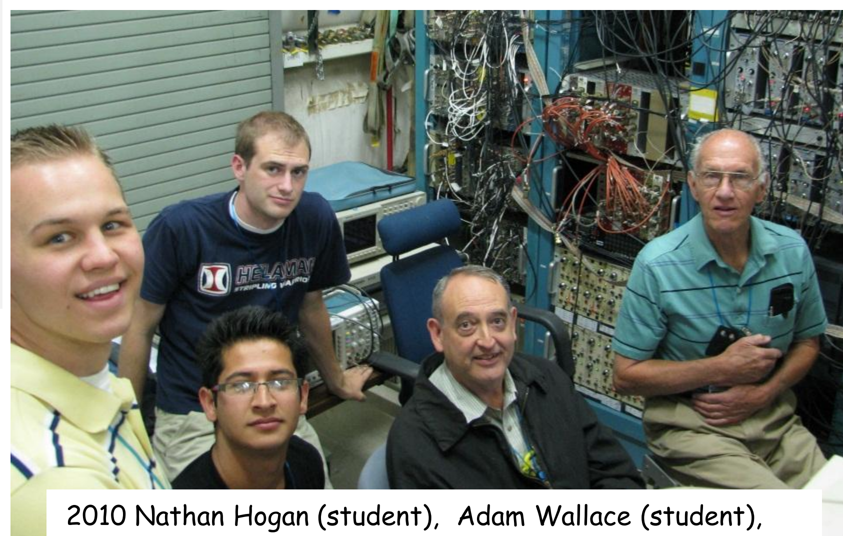


Capture gated neutron spectroscopy using heterogeneous scintillators and multi-pulse discrimination





1987 Steven E. Jones (particle physics), J. Bart Czirr (neutron detection), Gary L. Jensen (accelerator physics), Daniel L. Decker (condensed matter and dep't chairman), and E. Paul Palmer (Geo-physics)



2010 Nathan Hogan (student), Adam Wallace (student), Suraj Bastola (student), Lawrence Rees (nuclear physics), and J. Bart Czirr (neutron detection)

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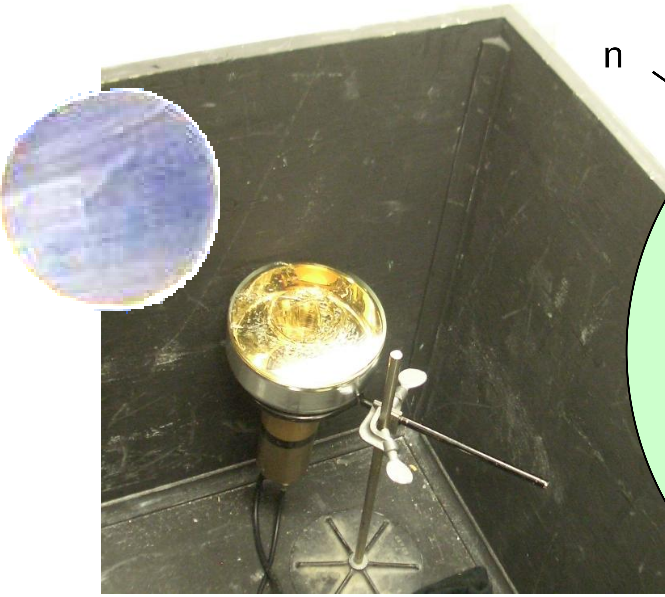
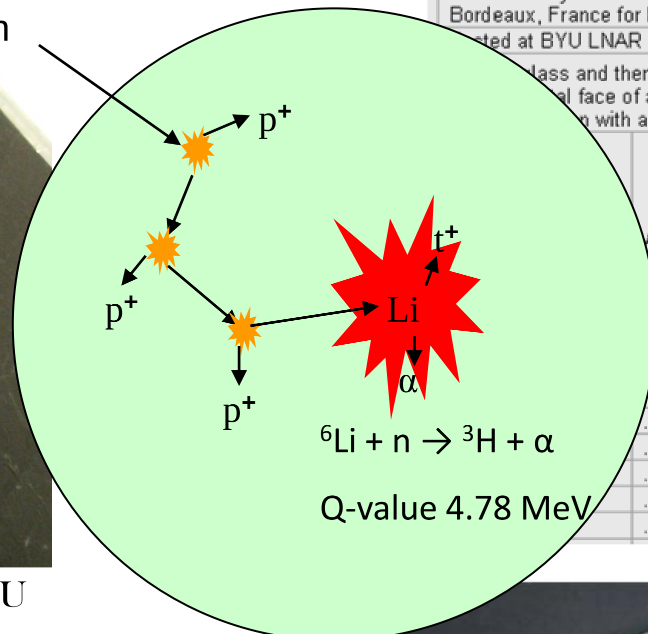
some technologies

capture gated neutron spectroscopy and multi-pulse discrimination

Lithium Gadolinium Borate Cerium (LGB) Crystal in Plastic Scintillator



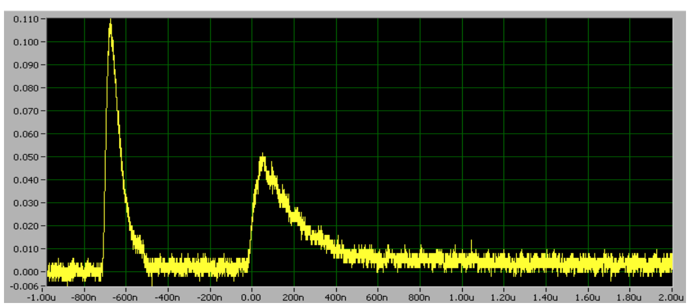
The “black box” in LNAR lab, BYU



LiGdBCe Crystals were grown at Institut de Chimie de la Matière Condensée de Bordeaux, France for Photogenics, Inc.
...ted at BYU LNAR Lab Oct 8, 2007
...lass and then LGB crystals where each in-turn affixed with optical grease to ...al face of a PMT placed in a dark box and exposed to a Cf252 source. ...n with an ORTEC Trump MCA card and spectroscopy software.

6.5 times brighter than Li glass

Amplifier Gain	Li Pulse Height	Li gain	B Pulse Height	B gain	Relative Brightness to Li Glass Cz/GS-20
40X300	259	2.158			
6X30	271	15.056	67	3.72	6.98
6X30	248	13.778	63	3.50	6.38
6X30	252	14.000	64	3.56	6.49
6X30	251	13.944	65	3.61	6.46
.6X30	259	14.389	66	3.67	6.67
.6X30	115	6.389	too low		2.96
.6X30	249	13.833	63	3.5	6.41
.6X30	181	10.056	52	2.888889	4.66
.6X30	170	9.444	too low		4.38



proton recoil and Li capture pulses

- polyvinyl-toluene (PVT) doped with anthracene
- 10% LGB by weight

Built by Photogenics, Inc under patents license from BYU:
1) Heterogeneous Neutron Scintillator
2) Multi-pulse Neutron Scintillator

some technologies

Lithium Gadolinium Borate Cerium (LGB) Crystal

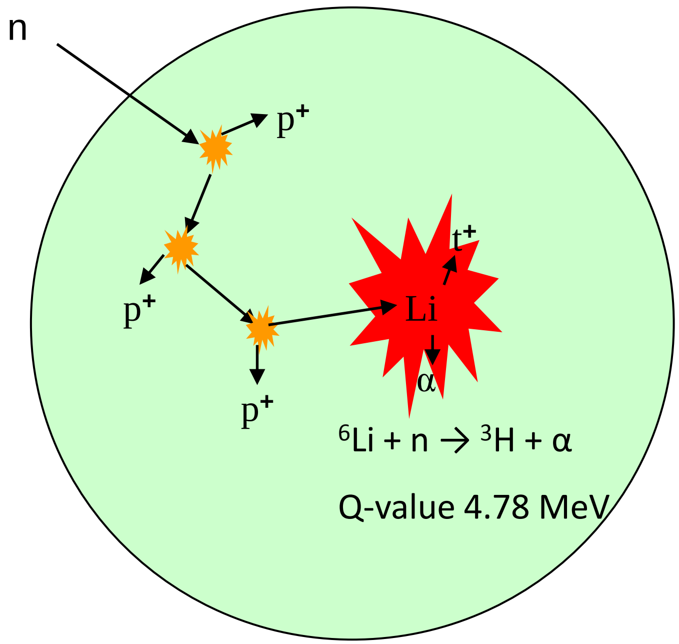
LiGdBCe Crystals were grown at Institut de Chimie de la Matière Condensée de Bordeaux, France for Photogenics, Inc.						
Tested at BYU LNAR Lab Oct 8, 2007						
Lithium glass and then LGB crystals where each in-turn affixed with optical grease to the horizontal face of a PMT placed in a dark box and exposed to a Cf252 source. Data was taken with an ORTEC Trump MCA card and spectroscopy software.						
Sample	Amplifier Gain	Li Pulse Height	Li gain	B Pulse Height	B gain	Relative Brightness to Li Glass Cz/GS-20
GS-20 Li Glass	.40X300	259	2.158			
Cz272	.6X30	271	15.056	67	3.72	6.98
Cz274	.6X30	248	13.778	63	3.50	6.38
Cz275	.6X30	252	14.000	64	3.56	6.49
Cz283	.6X30	251	13.944	65	3.61	6.46
Cz277	.6X30	259	14.389	66	3.67	6.67
Cz278	.6X30	115	6.389	too low		2.96
Cz279	.6X30	249	13.833	63	3.5	6.41
Cz276A	.6X30	181	10.056	52	2.888889	4.66
Cz276B	.6X30	170	9.444	too low		4.38

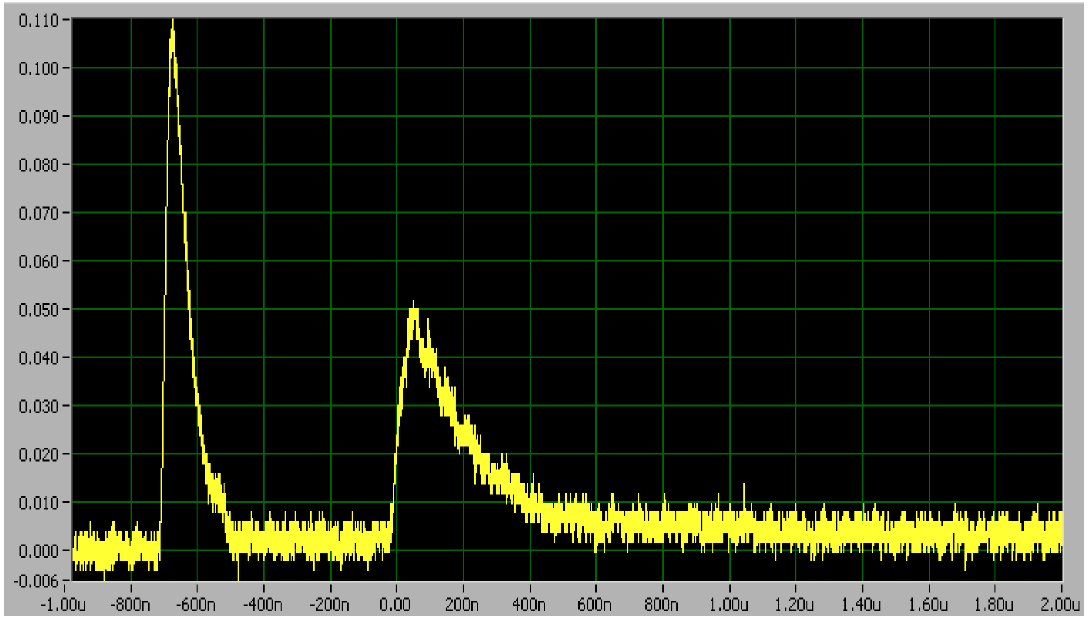
6 to 7 times brighter than Li glass

some technologies

capture gated neutron spectroscopy and multi-pulse discrimination

Lithium Gadolinium Borate Cerium (LGB) Crystal in Plastic Scintillator



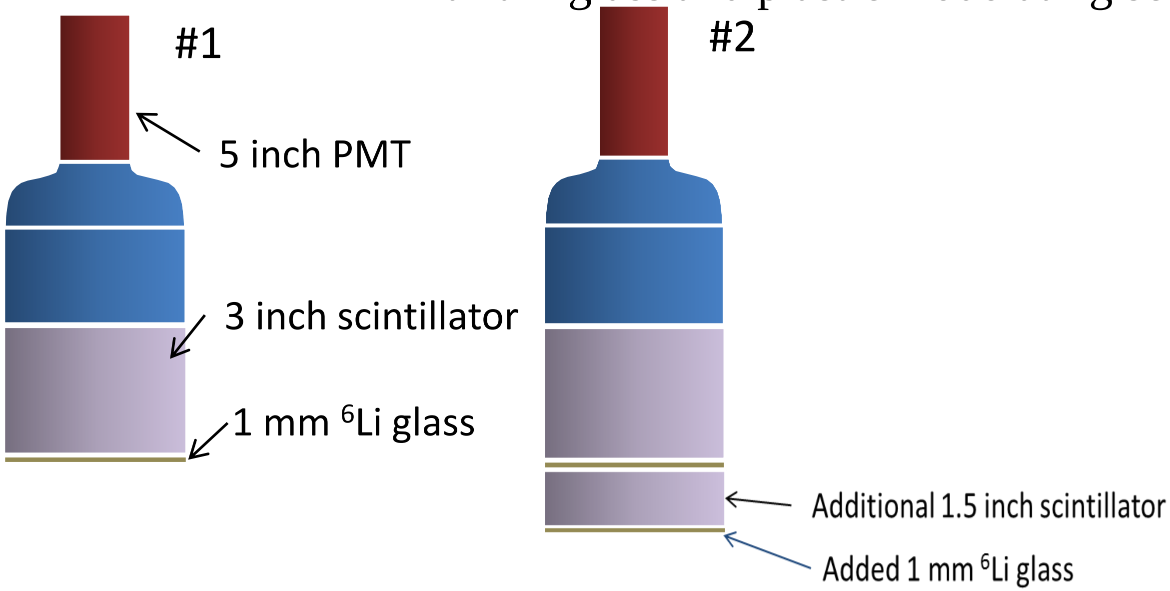


proton recoil and Li capture pulses

Built by Photogenics, Inc under patents license from BYU:
1) Heterogeneous Neutron Scintillator
2) Multi-pulse Neutron Scintillator

some technologies

lithium glass and plastic moderating scintillator



- #1 showed 10^{-4} n- γ discrimination
- MCNP calculations suggested 5% efficiency for bare ^{252}Cf
- Low-Room-Return-Lab measurements gave an efficiency of 5.3%
- #2 Having some plastic in front of the ^{6}Li glass is better for bare ^{252}Cf source

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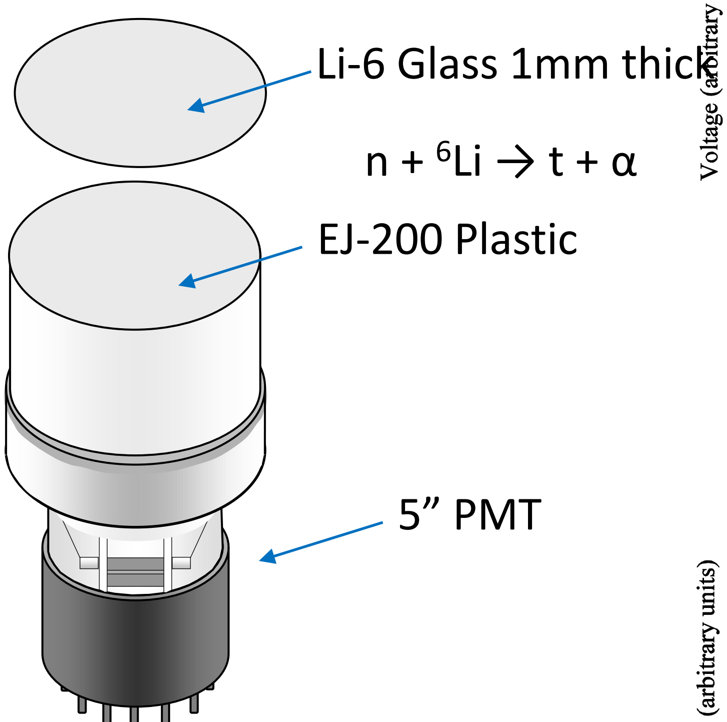
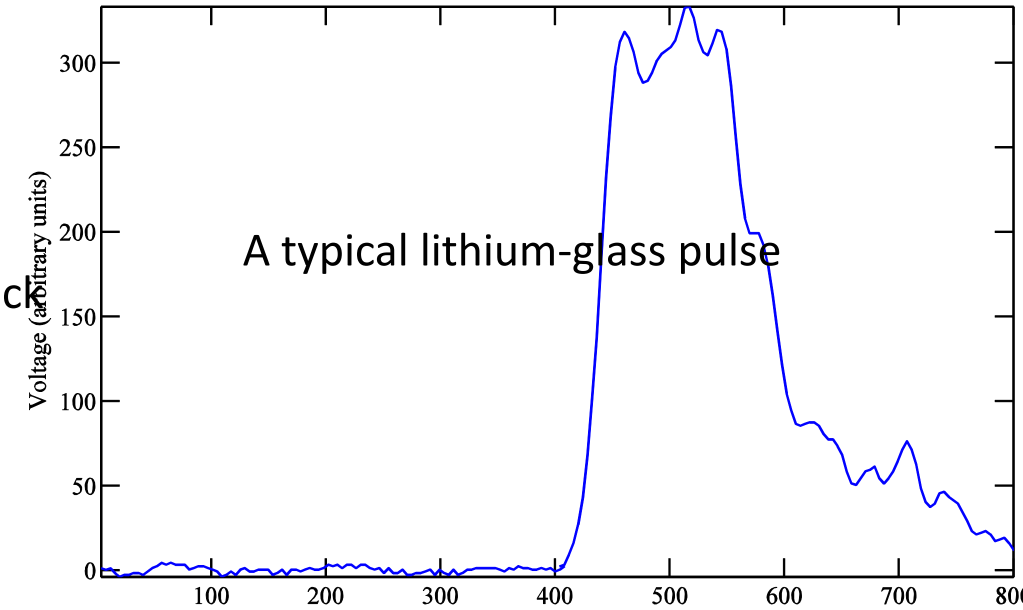
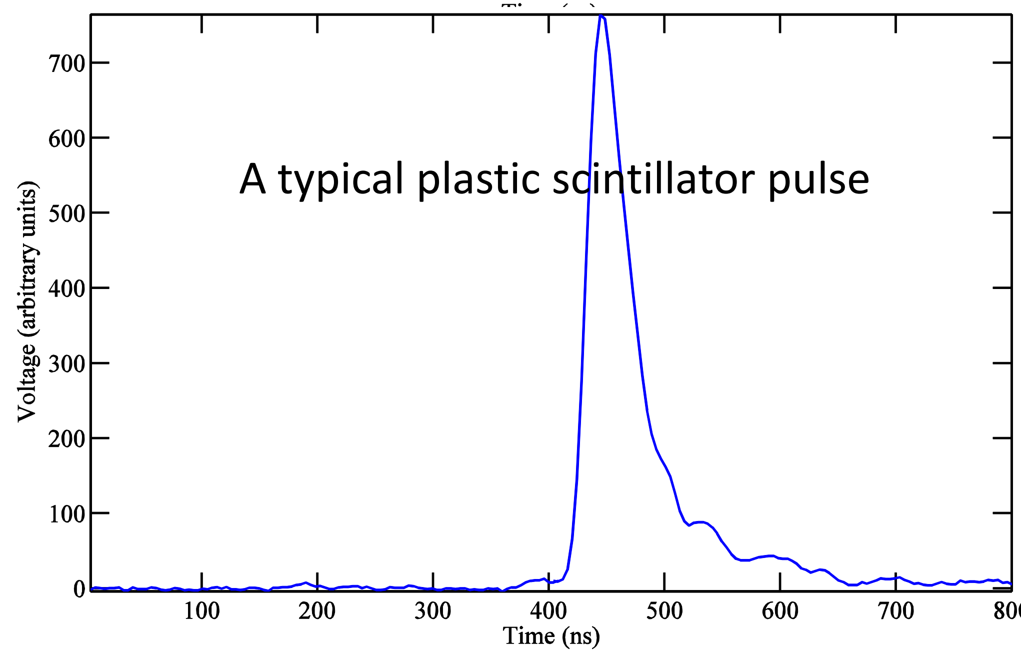
some technologies

capture gated neutron spectroscopy and multi-pulse discrimination







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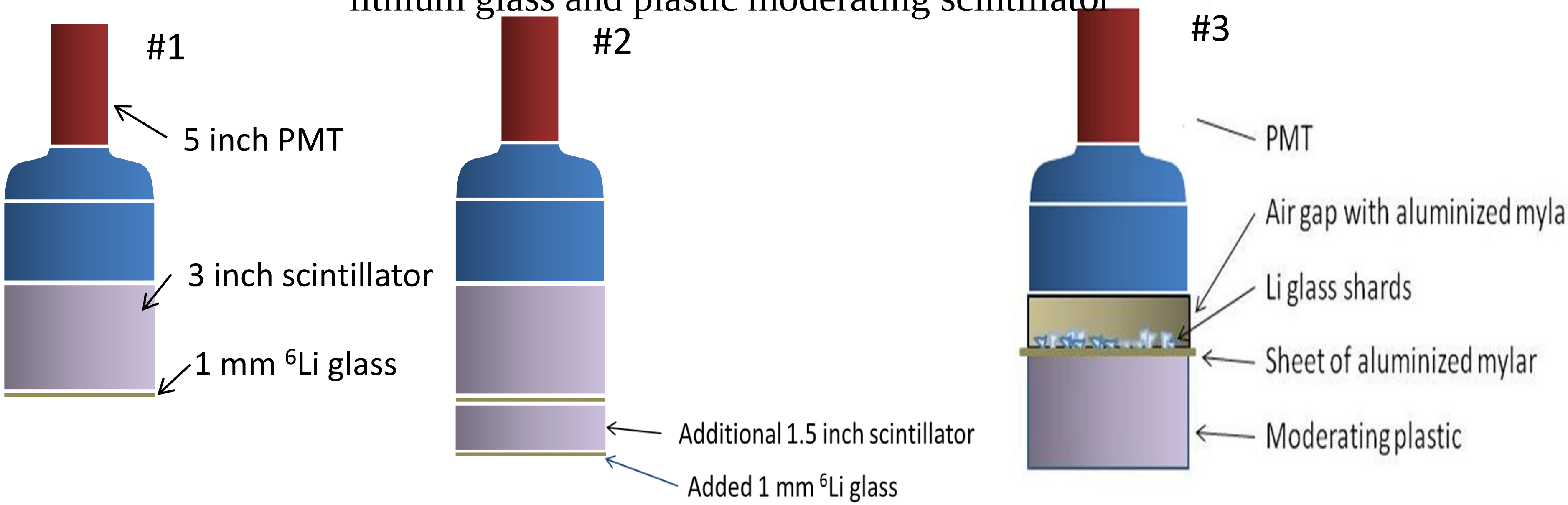
some technologies

lithium glass and plastic moderating scintillator



- #1 showed 10^{-4} n- γ discrimination
- MCNP calculations suggested 5% efficiency for bare ^{252}Cf
- Low-Room-Return-Lab measurements gave an efficiency of 5.3%
- #2 Having some plastic in front of the ^{6}Li glass is better for bare ^{252}Cf source
- #3 BROKEN GLASS DETECTOR: 1mm glass shards placed on top of plastic scintillator / moderator limits electron absorption from gamma rays

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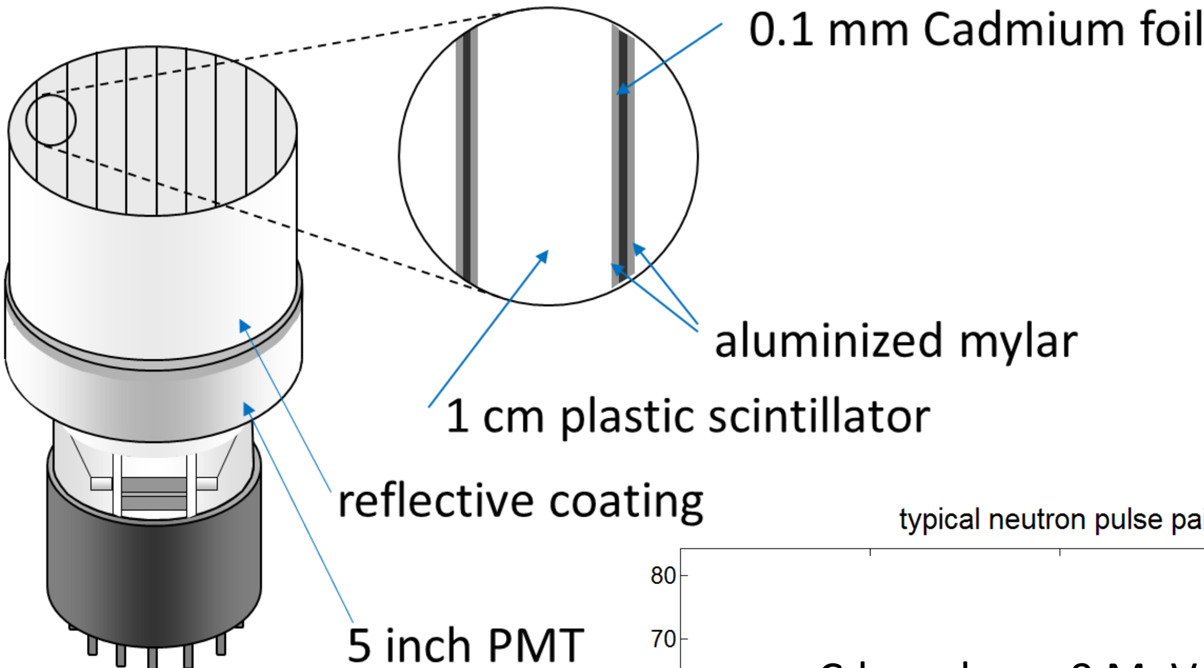
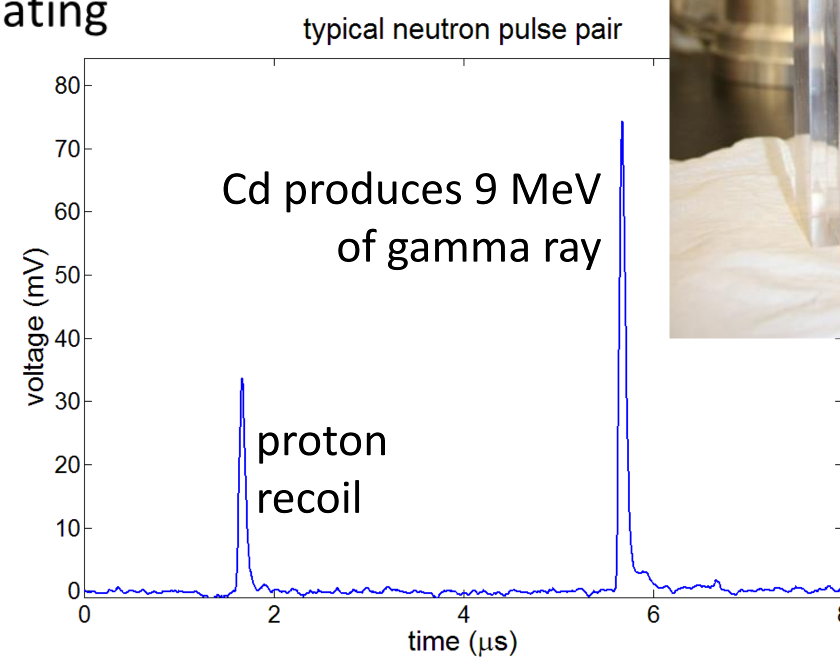
some technologies

capture gated neutron spectroscopy and multi-pulse discrimination

cadmium metal in plastics scintillator





113Cd +n $\rightarrow$ 114Cd + γ (9MeV)

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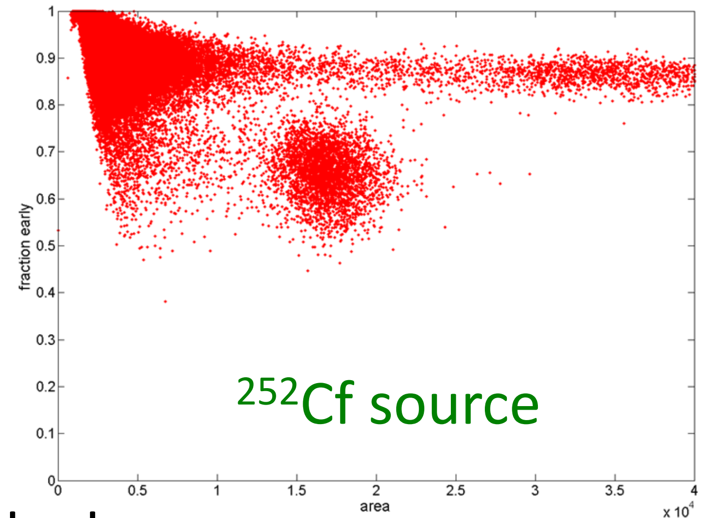
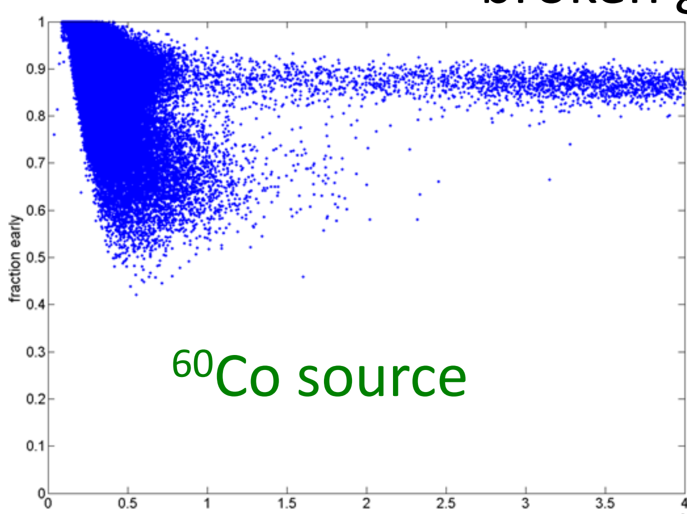
CAEN 4 Channel 12 bit 250 MS/s Digitizer

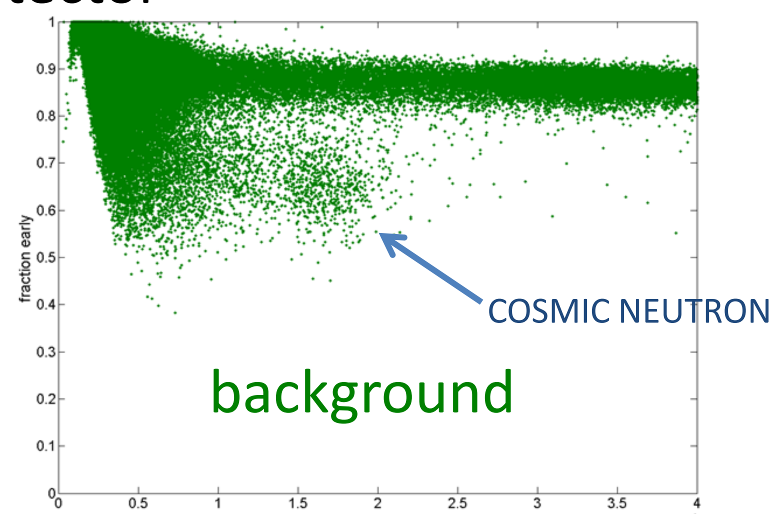
some tools

waveform digitizing and
Pulse Shape Discrimination (PSD)



broken glass detector



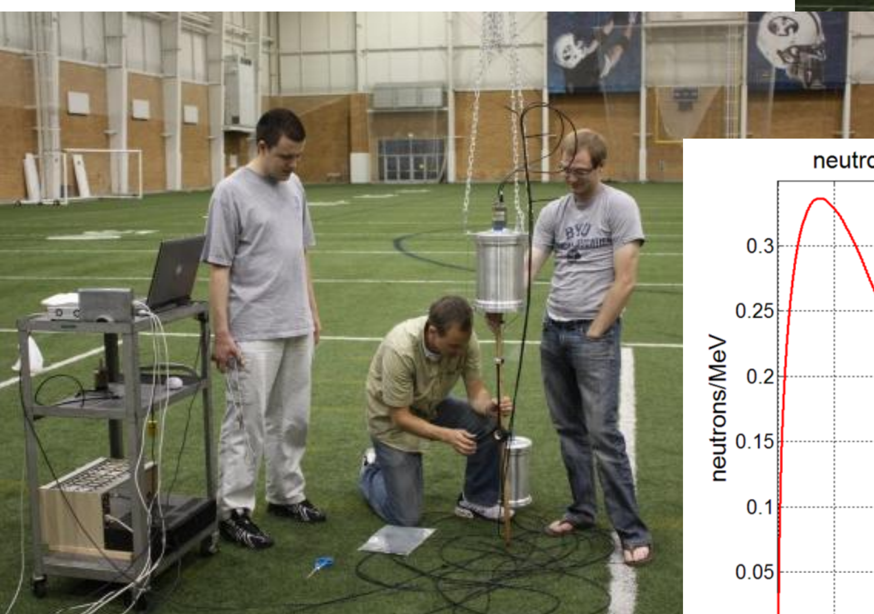


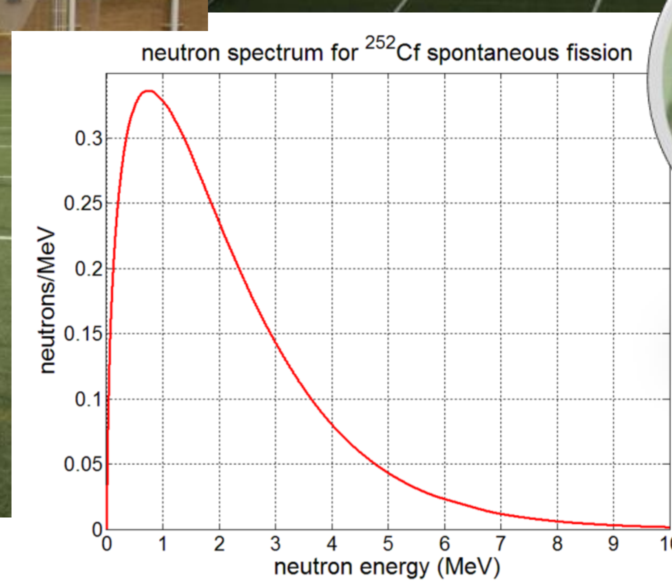
< 10^{-6} incident gammas from ^{60}Co misidentified as neutrons

some tools

low room return testing, BYU Indoor Practice Field (IPF)

- Detector suspended in the air 45 feet from all structural materials (concrete, ground, steel, etc)





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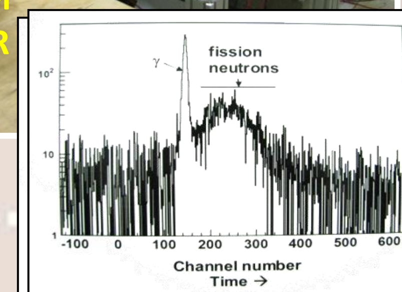
some tools

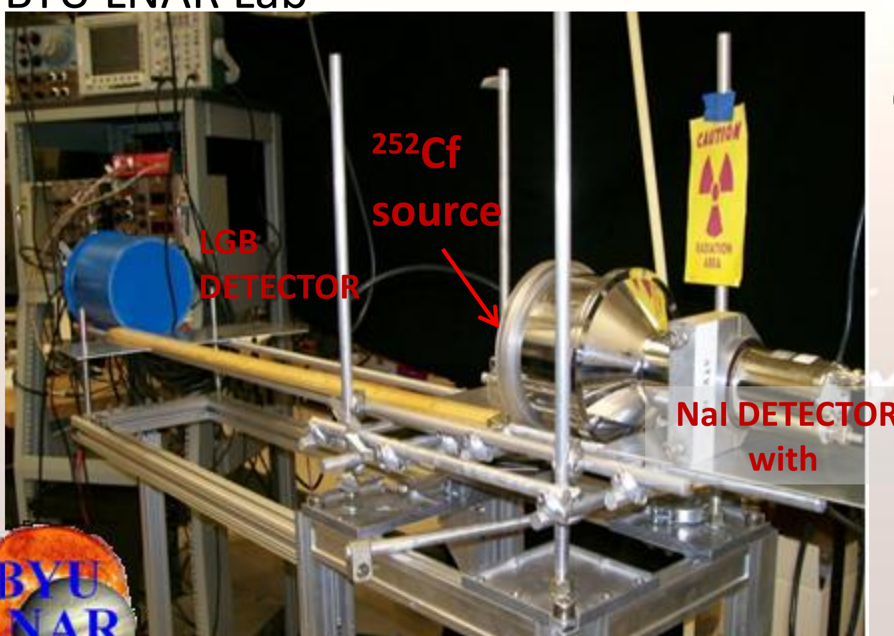
Time of Flight (ToF) testing

URANIUM FISSION TARGET

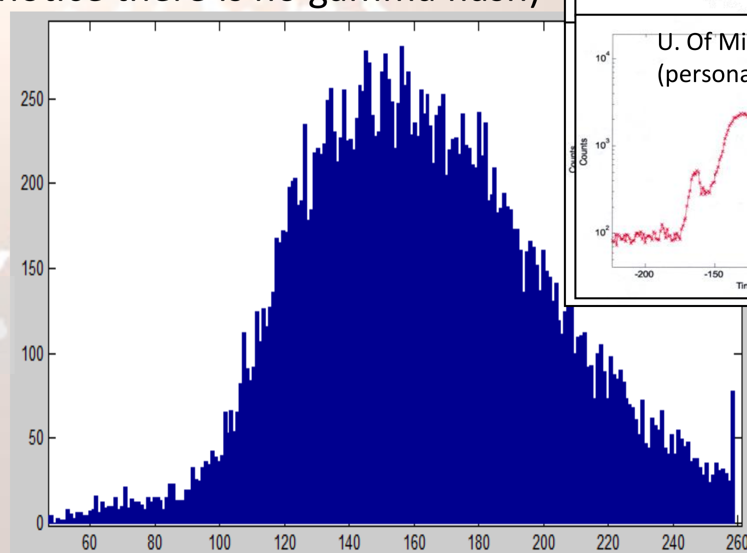
LANL LANSCE 800 MeV neutron facility

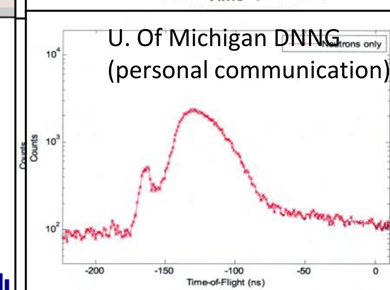


BYU LNAR Lab



5"$_{DIA}$ LGB ToF distribution
(notice there is no gamma flash)

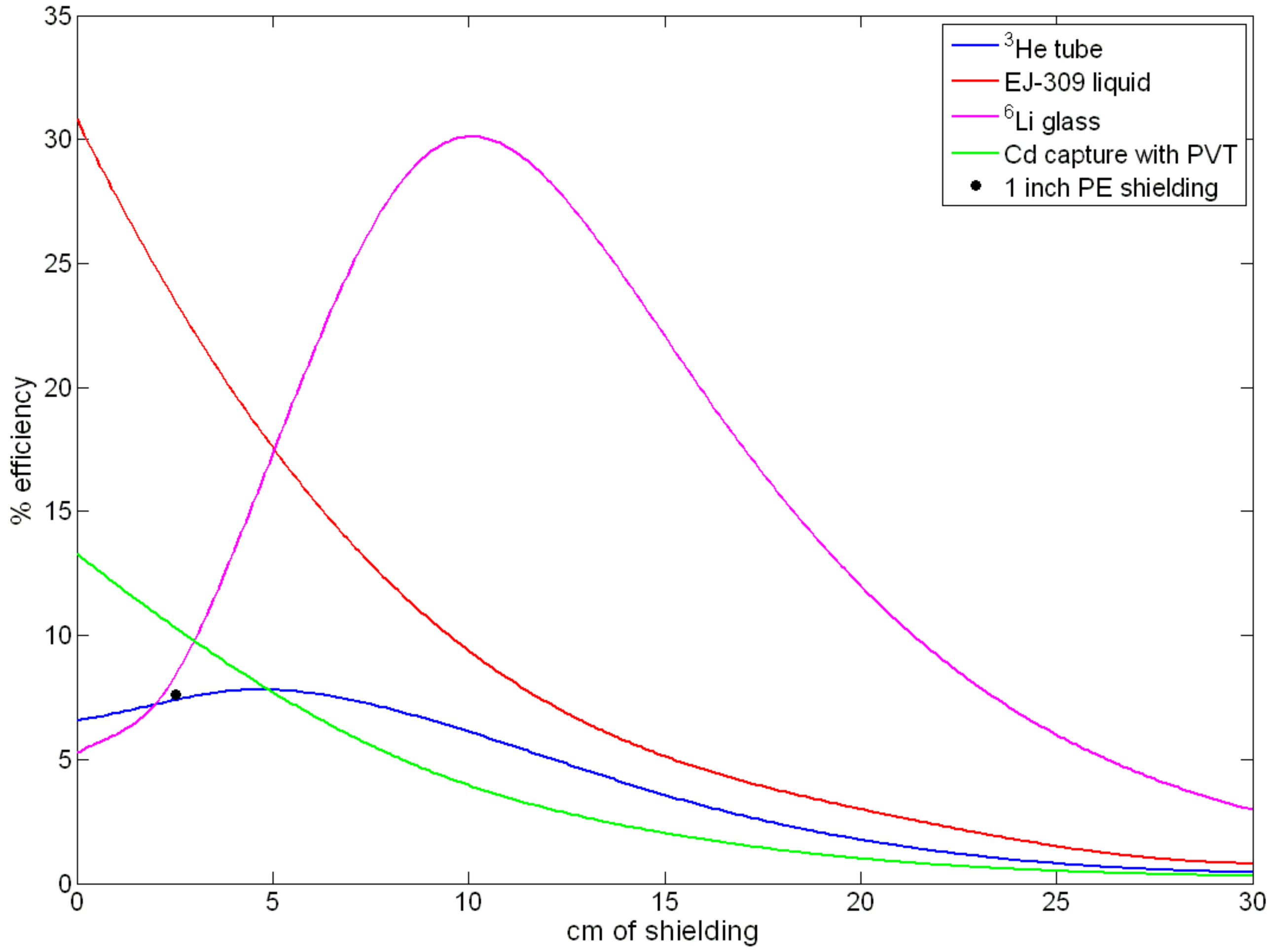




some lessons learned

Lithium glass with moderating scintillator shows better efficiency for a shielded neutron source.

MCNP by Lawrence Rees



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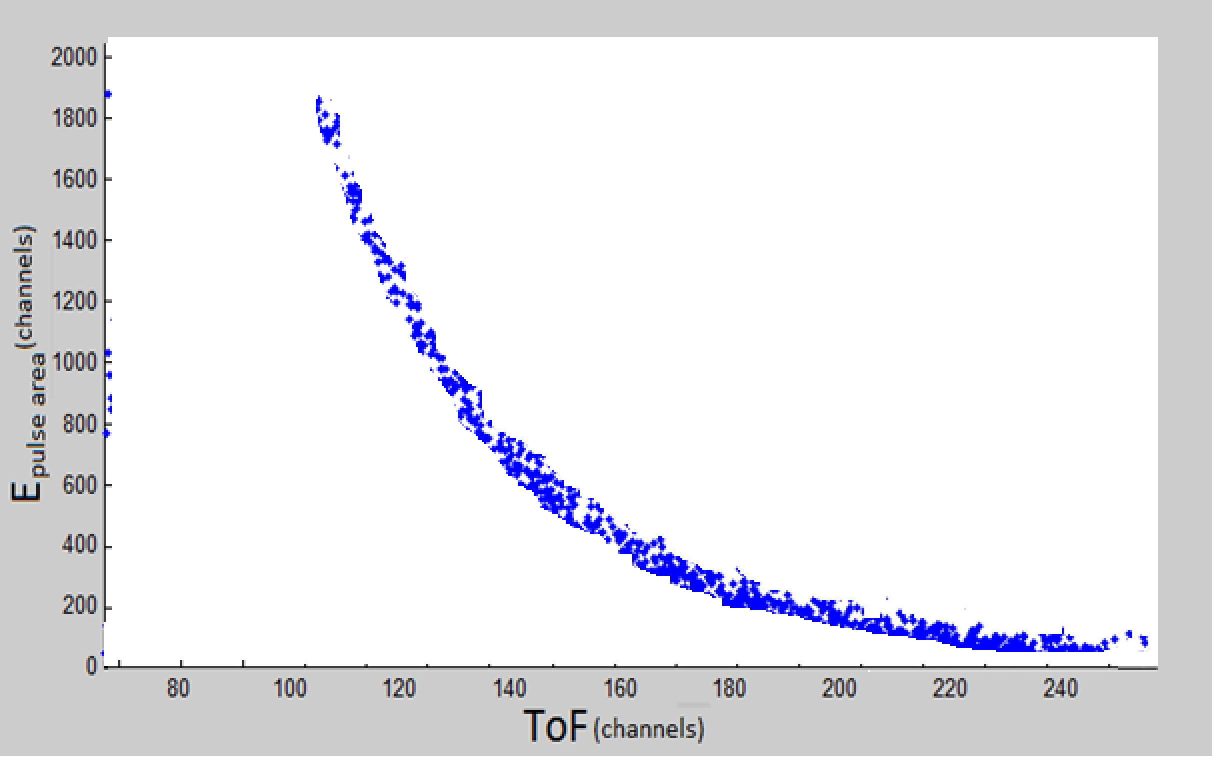
some lessons learned

Expecting a nice tight E to ToF fit?

LNAR Lab LGB detector E vs. ToF



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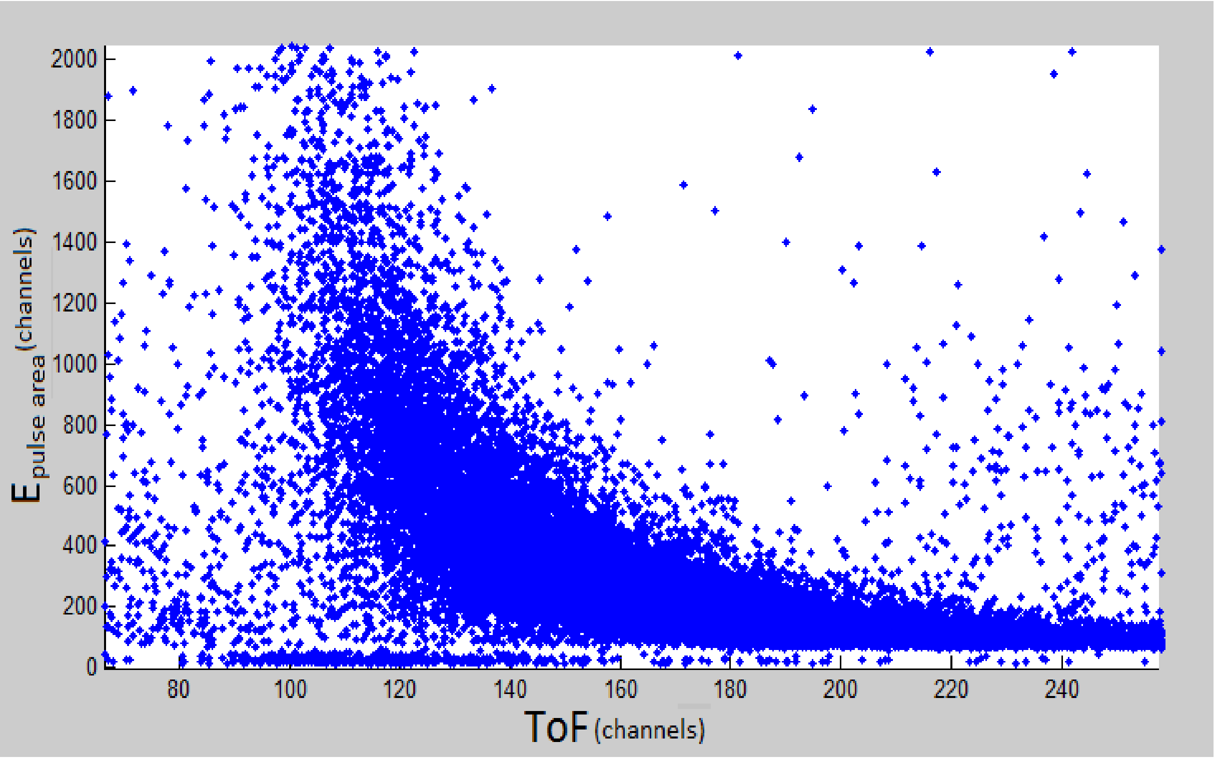
some lessons learned

Light from plastic proton recoil is non-linear.

LNAR Lab LGB detector E vs. ToF



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some lessons learned

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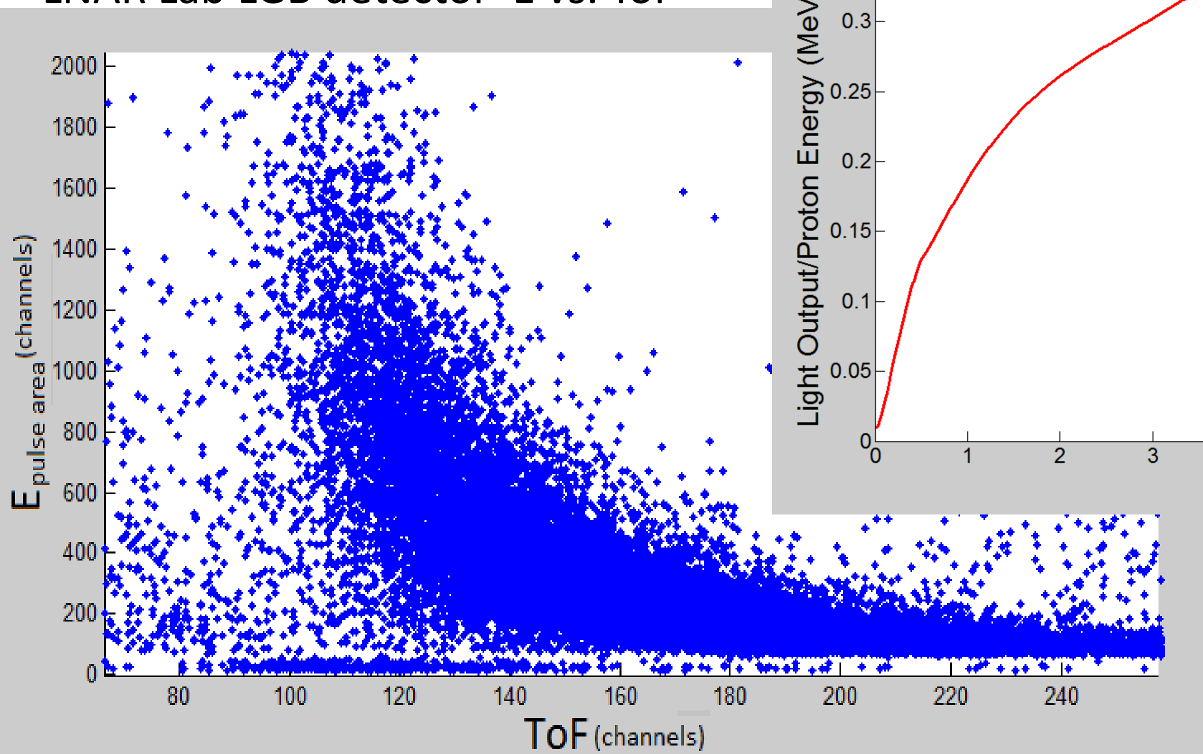

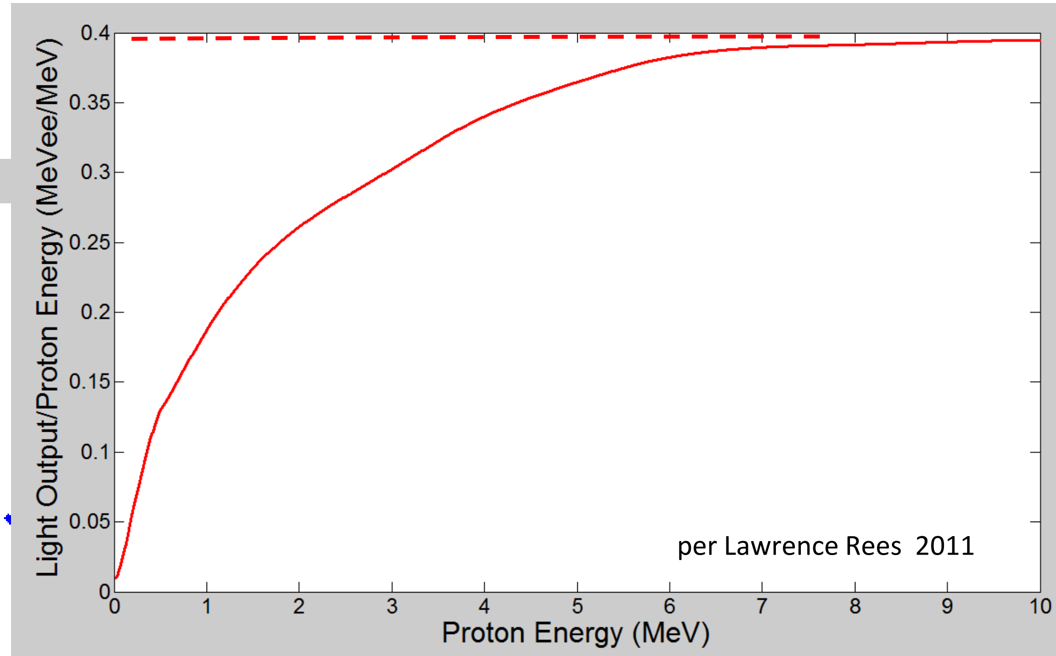

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some lessons learned

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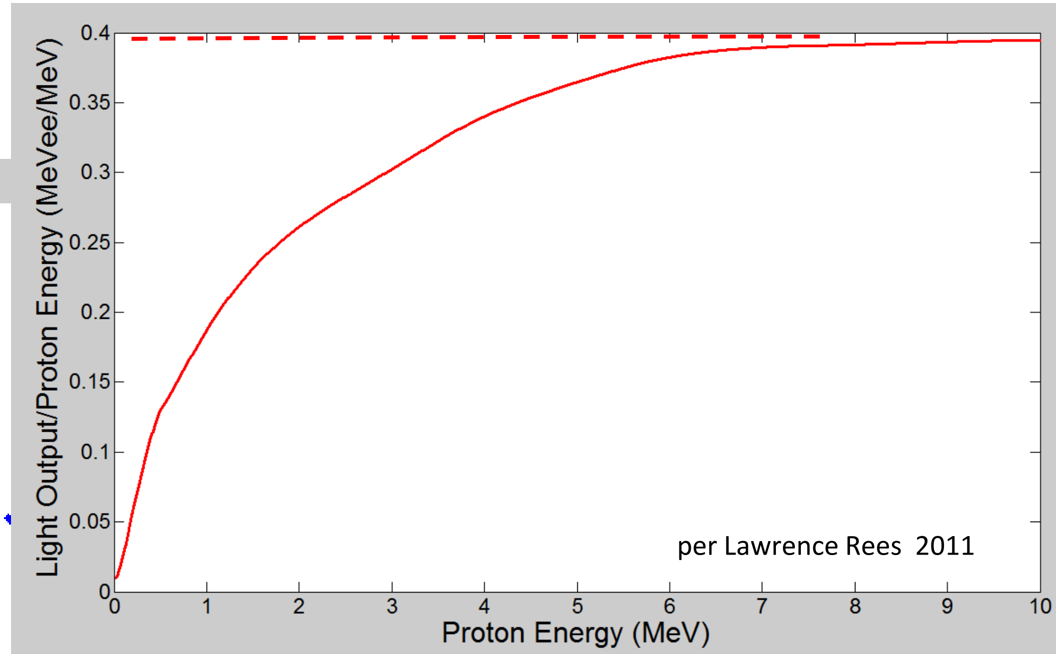

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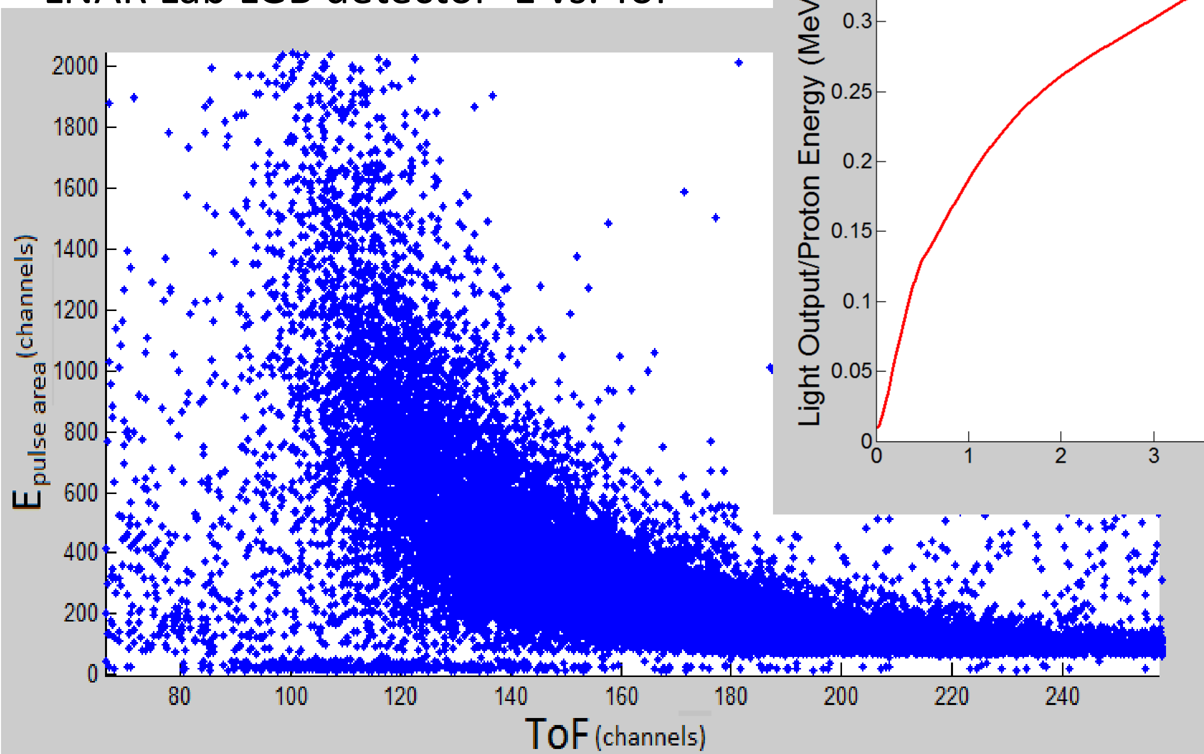

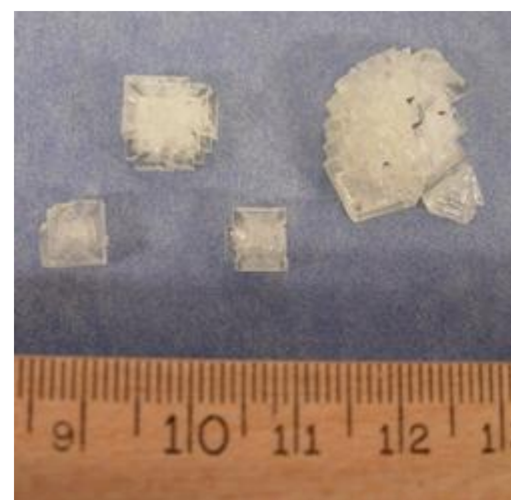

Solution: inorganic hydrogenous crystal that has high hydrogen content:

NH_4X (Br, I, etc)

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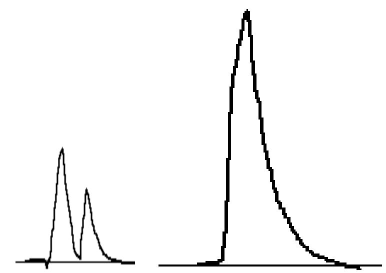
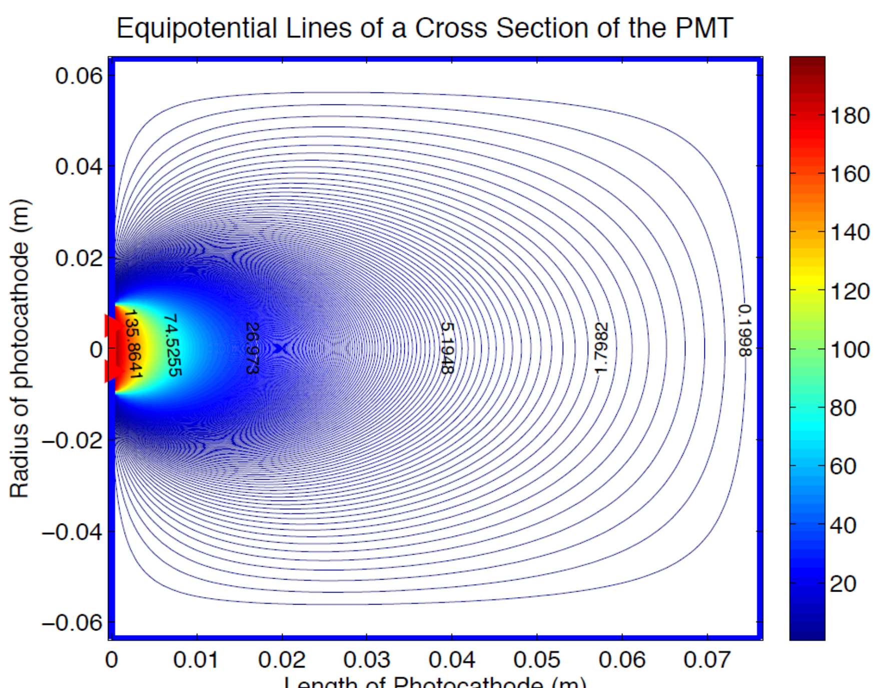
some lessons learned

troubles with PMTs

Inconsistent rise time across face of PMT – Constant Fraction Discriminators (CFD) depend on consistent rise time (15% threshold)



In the Cd detector low energy gammas register multiple pulses separated by about 100 ns

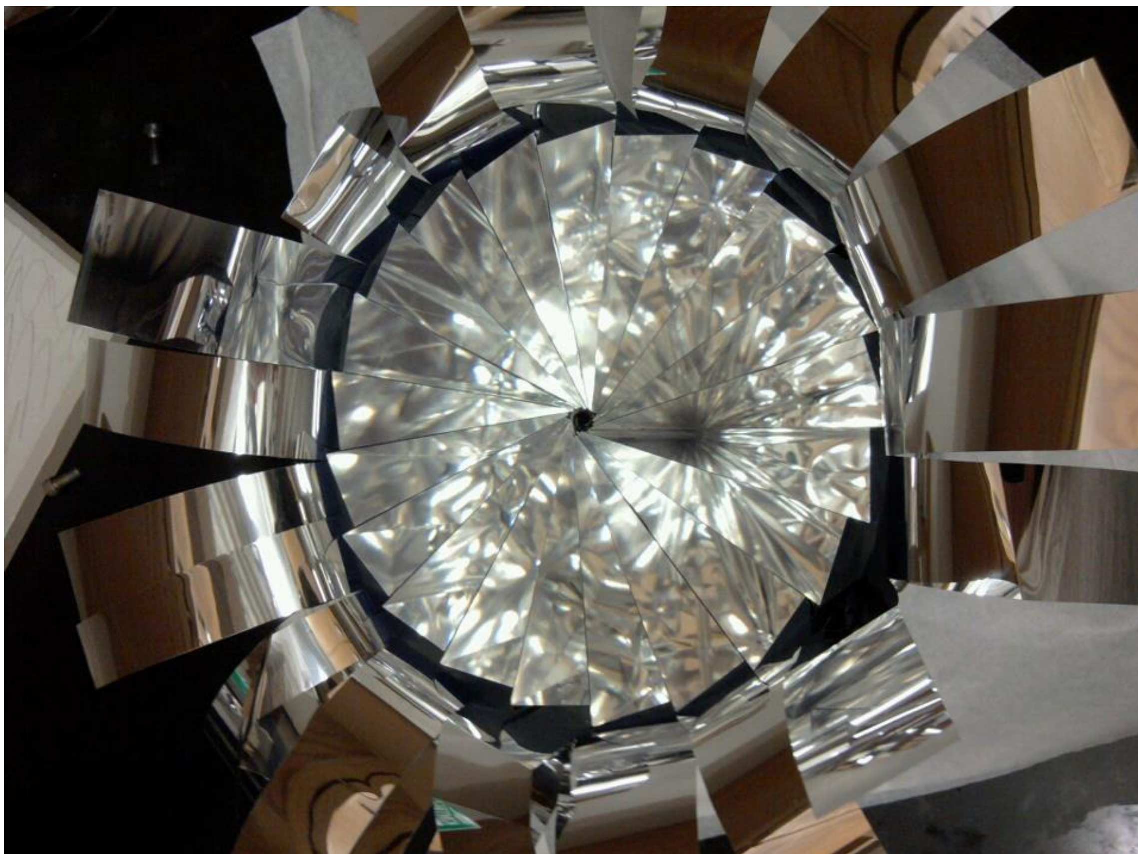


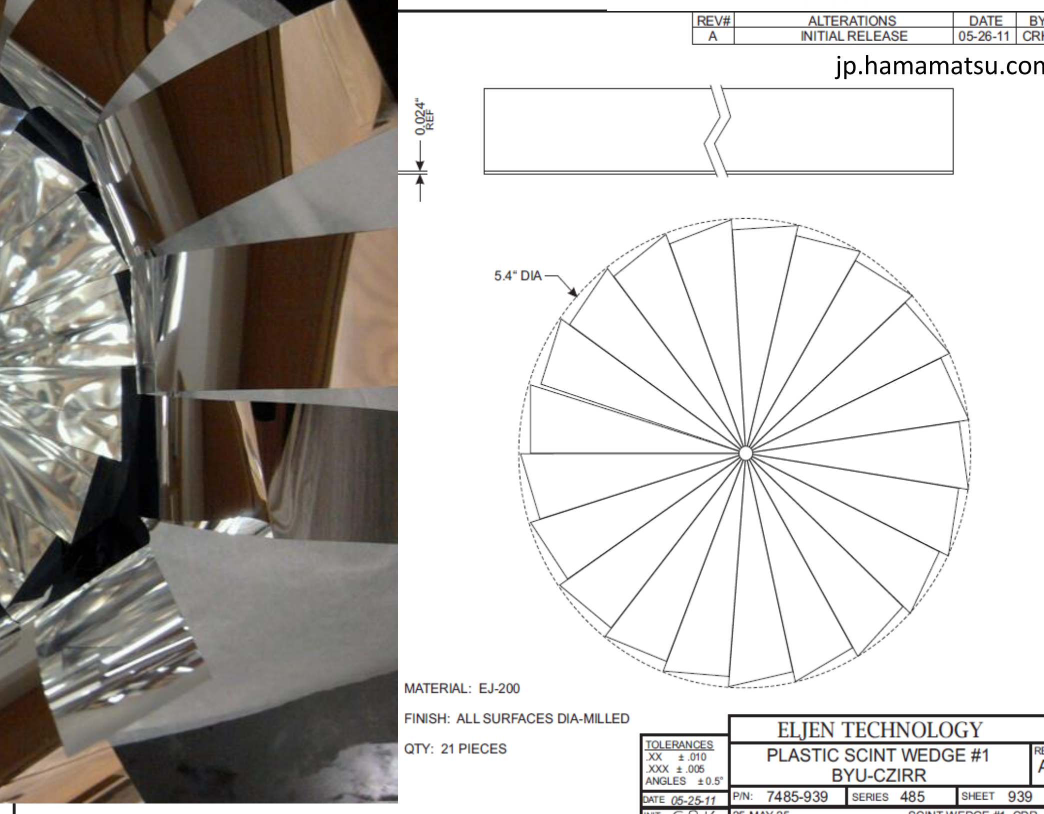
Modeling of a PMT showed electron propagation time from photocathode to 1st dynode varied by ~150 ns from center to edge of the PMT face

some lessons learned

solutions

- Use a 10X faster PMT having 14 dynodes (Pos 2000V)
- Use plastic wedges in place of slabs so light is delivered at the edge in balance with the center





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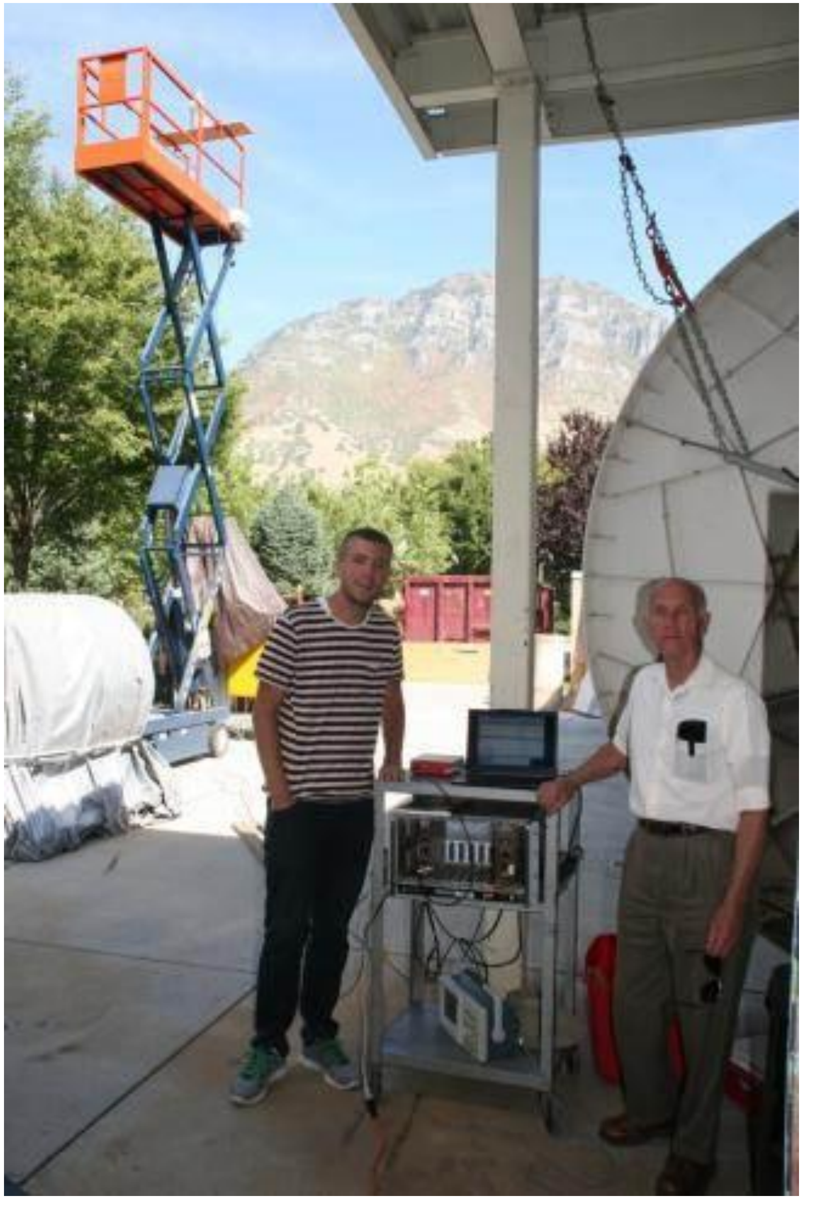
some lessons learned

For suppressing room return:

20’ from concrete is as good as 50’.

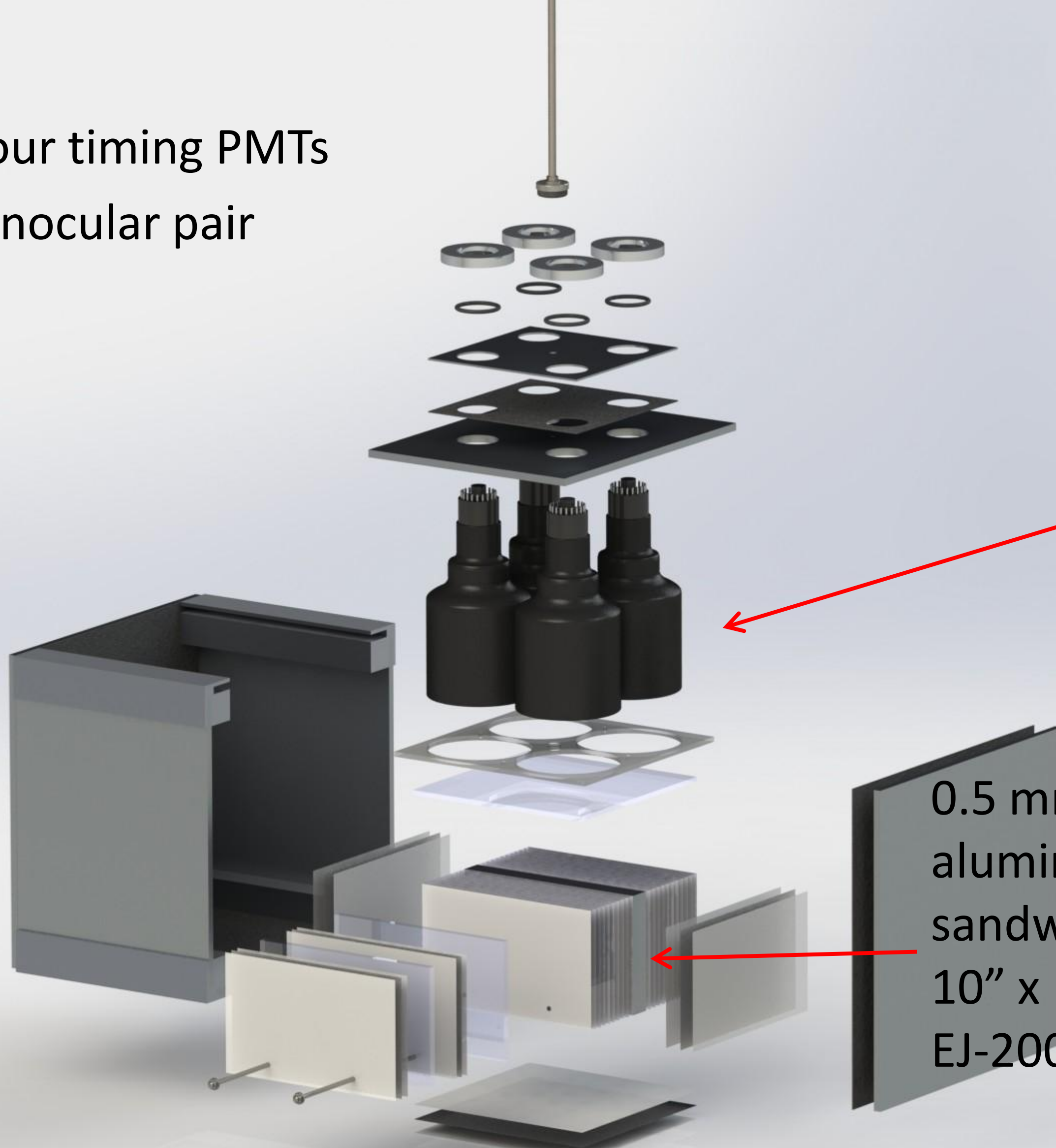
20’ is about 1% different than set at infinity.

Scissors lift enables testing much heavier detector systems.



Useful Product: Cd – Plastic Detector

- Four timing PMTs
- Binocular pair



4 ea. R1250 PMTs

0.5 mm sheet Cd foil and aluminized mylar sandwiched between 6” x 10” x 1cm-thick sheets of EJ-200

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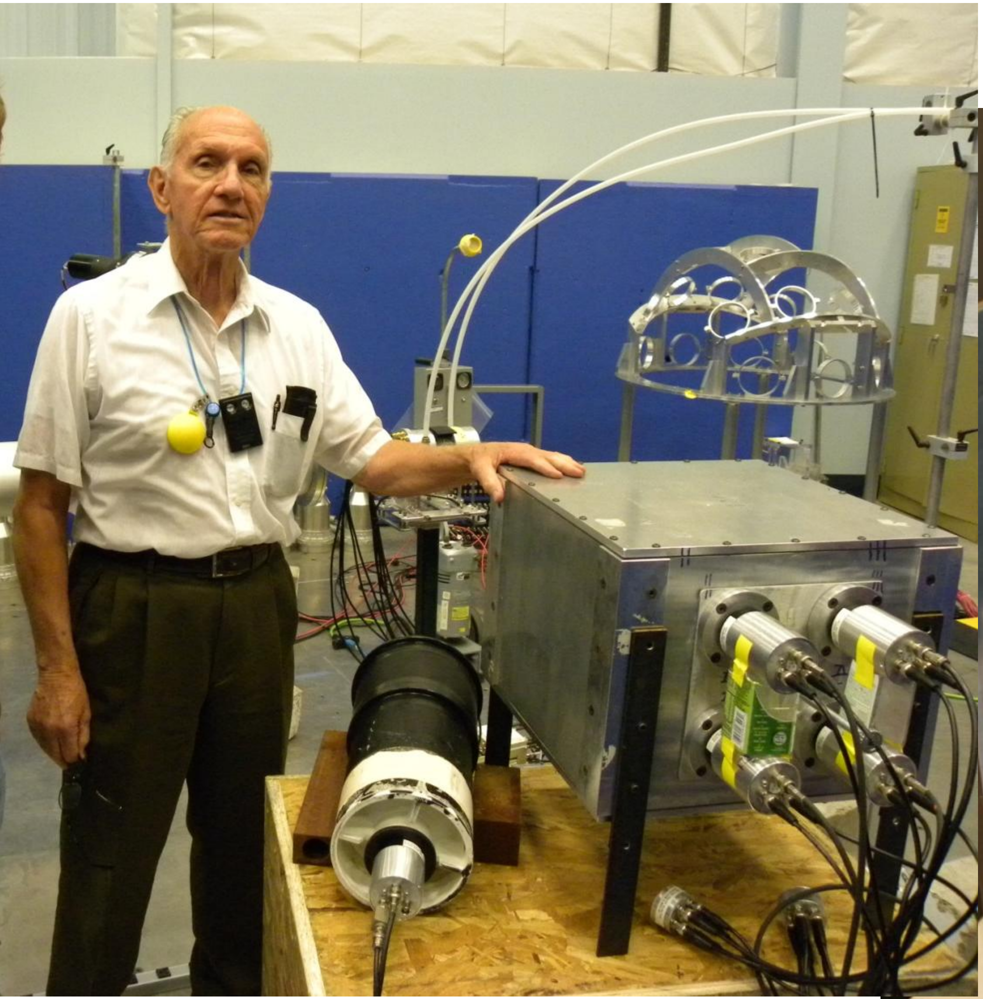
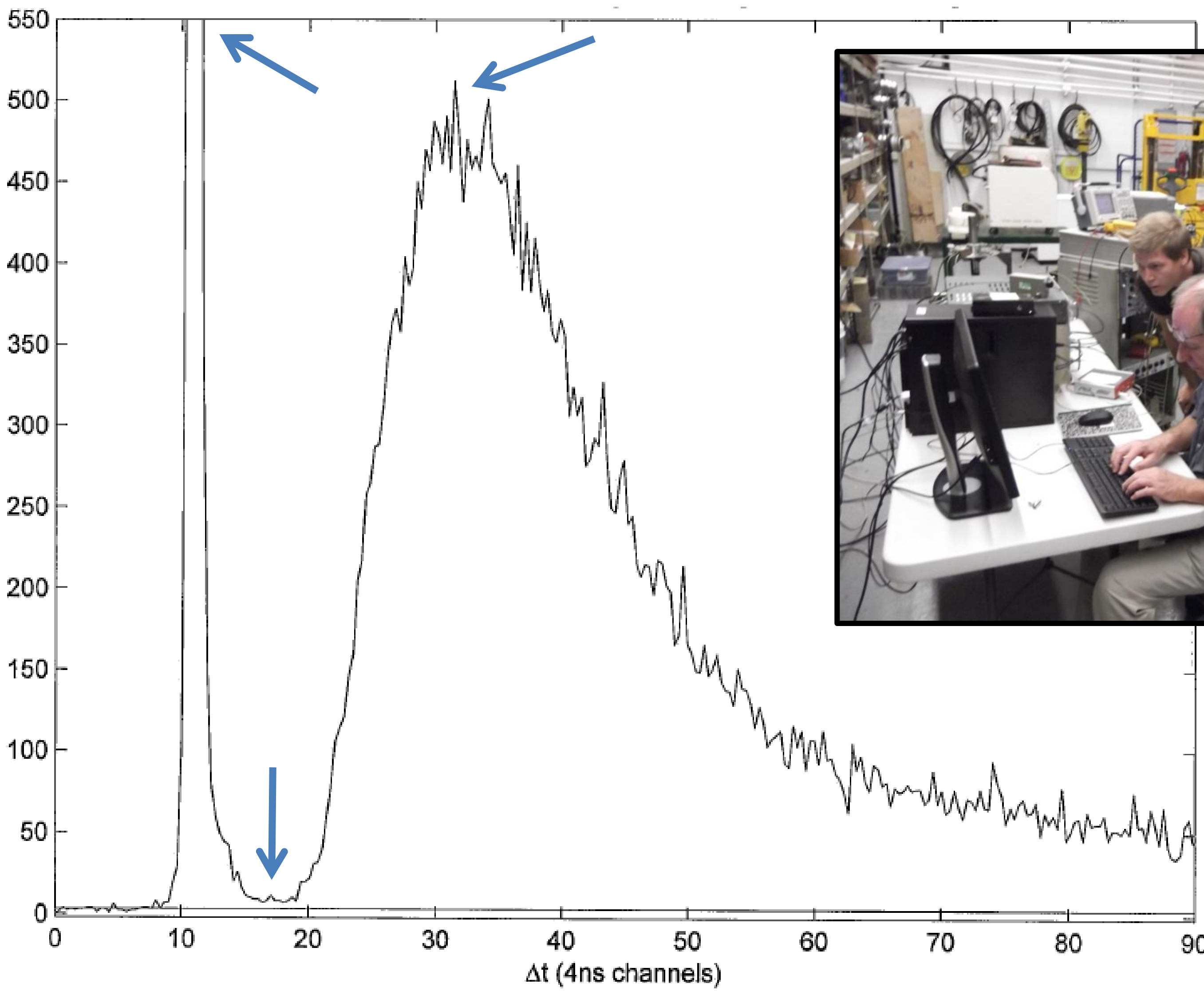
Useful Product: Cd – Plastic Detector



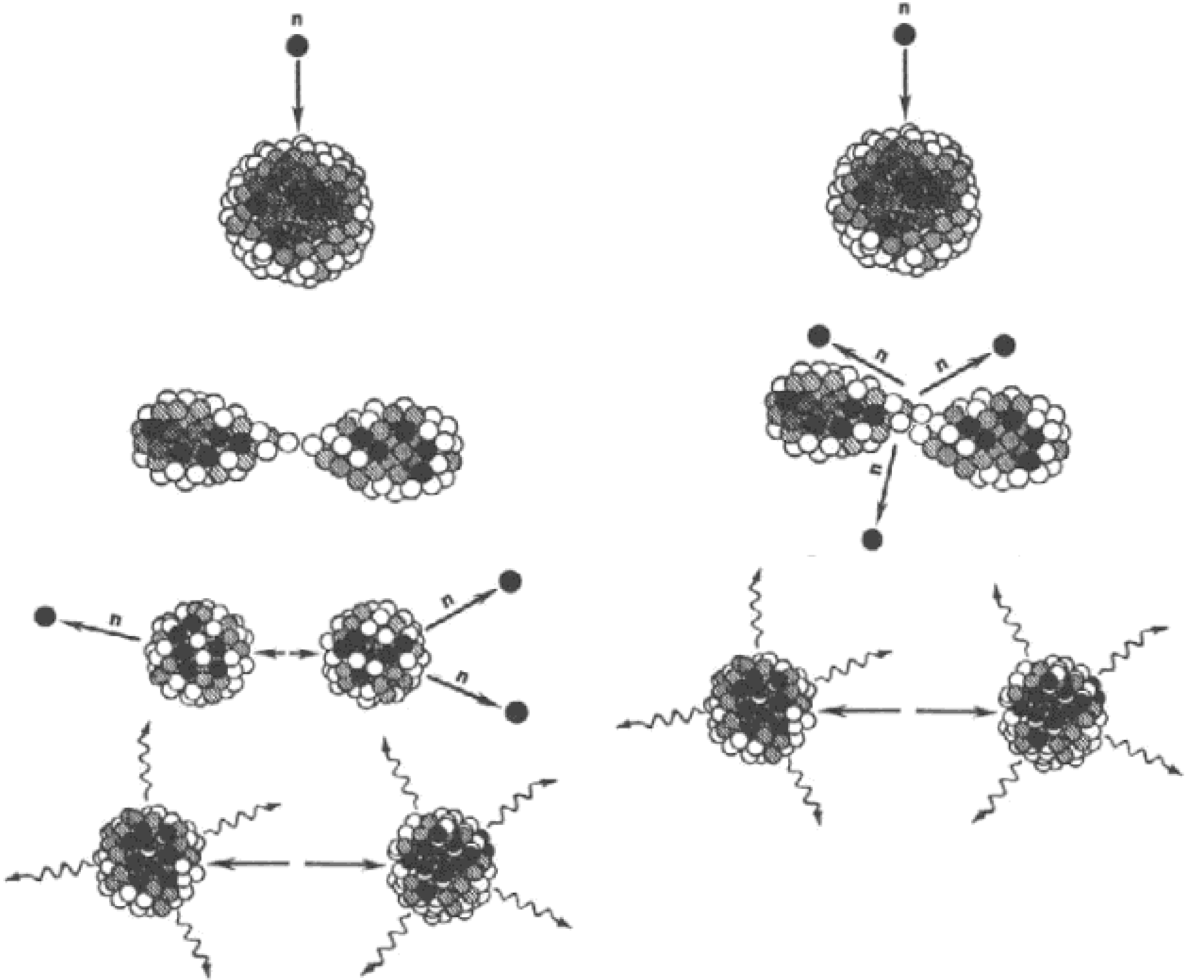
J. Bart Czirr at LANL LANSCE
WNR Lab ToF Facility
Aug 28, 2013

Useful Product: Cd – Plastic Detector

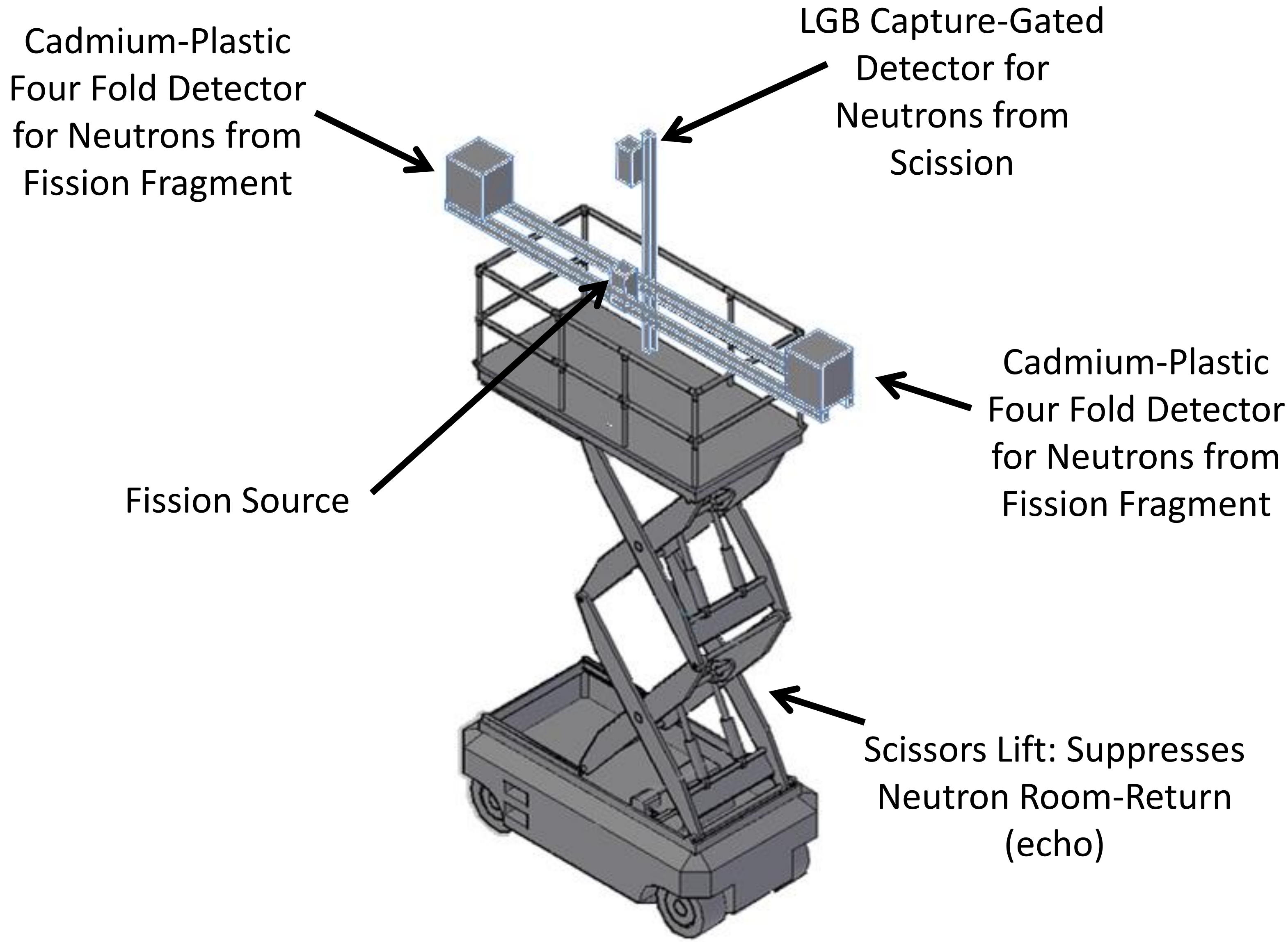
Using Nikolai Kornilov's ^{252}CF Fission Chamber, Edwards Accelerator Lab Ohio University Aug 16, 2013



Down to ~ 50keV and more to go!



Based on Fig 1 form The Great Soviet Encyclopedia (1979)


Cadmium-Plastic Four Fold Detector for Neutrons from Fission Fragment
LGB Capture-Gated Detector for Neutrons from Scission
Fission Source
Cadmium-Plastic Four Fold Detector for Neutrons from Fission Fragment
Scissors Lift: Suppresses Neutron Room-Return (echo)

Thank You

Support provided by: BYU CPMS, DOE, NNSA, DHS, and INL

Post Helium-3 Neutron Detection at BYU

John E. Ellsworth, J. Bart Czirr, and Lawrence Rees
Undergraduate Researchers: Nathan Hogan, Adam Wallace, Stephen Black, Steven Gardiner, Brian James, Suraj Bastola, and Nirdosh Chapagain, Andrew Hoffman, and Neil Turley

Development of spectrometers for studying low flux neutrons mixed in a field of gamma and cosmic rays has continued at BYU since 1982. As ^{3}He, the archetypal neutron detector medium, becomes scarcer, BYU and associates have been pursuing technologies that may serve as acceptable detectors, even for low energy fission neutrons. Presented will be 1) some technologies: typical ^{3}He safeguard monitoring equipment, capture gating techniques, multi-pulse discrimination, and hybrid developments; 2) some tools: low room-return lab, LANL LANSCE time of flight, and fission spectroscopy; 3) and some lessons learned: PMT timing disparity, plastic non-linearity, and pulse fragmentation.

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