# Development of a gamma-blind neutron-efficient detector using silicon detectors and a reactive lithium film

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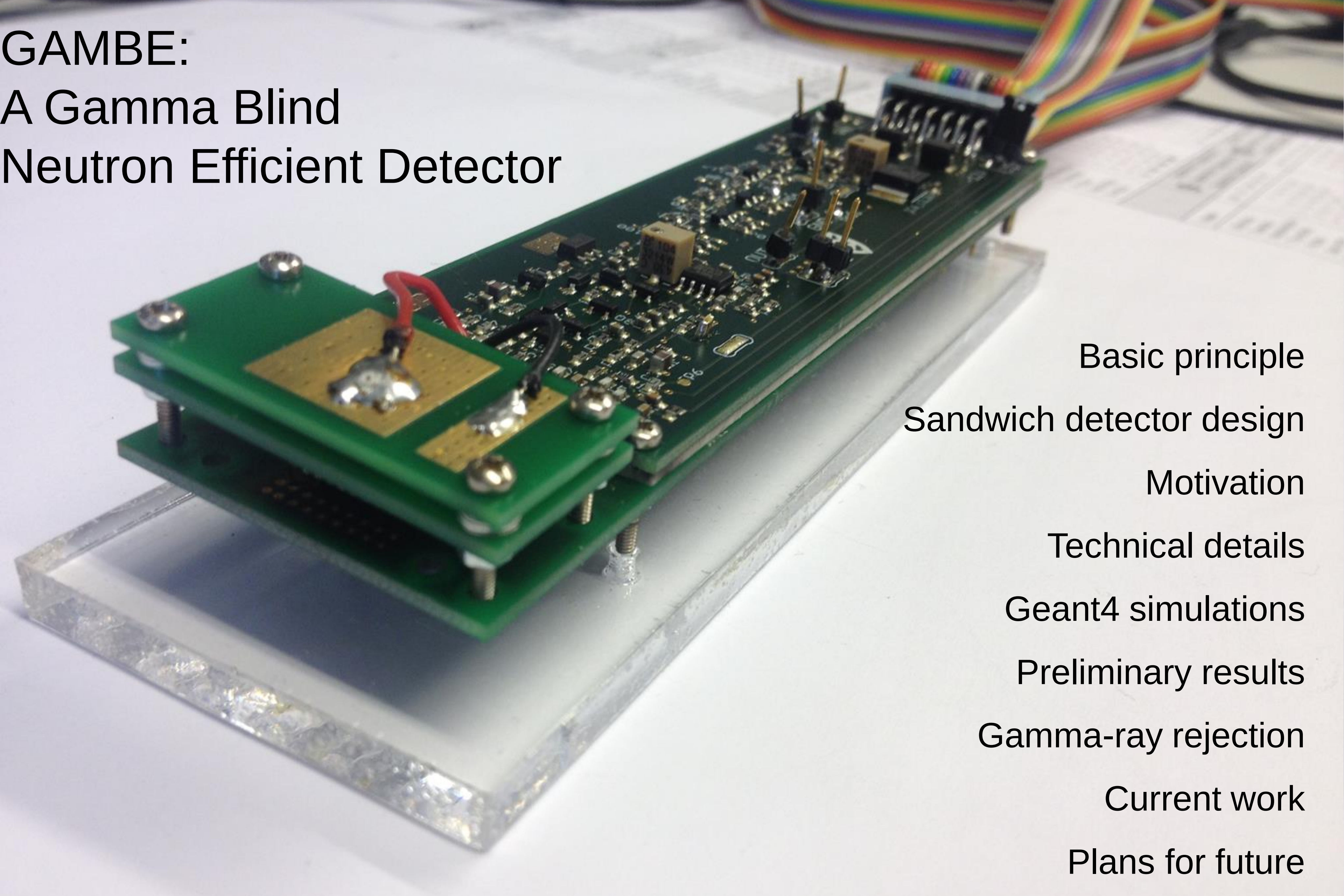
# GAMBE:
# A Gamma Blind
# Neutron Efficient Detector



Basic principle

Sandwich detector design

Motivation

Technical details

Geant4 simulations

Preliminary results

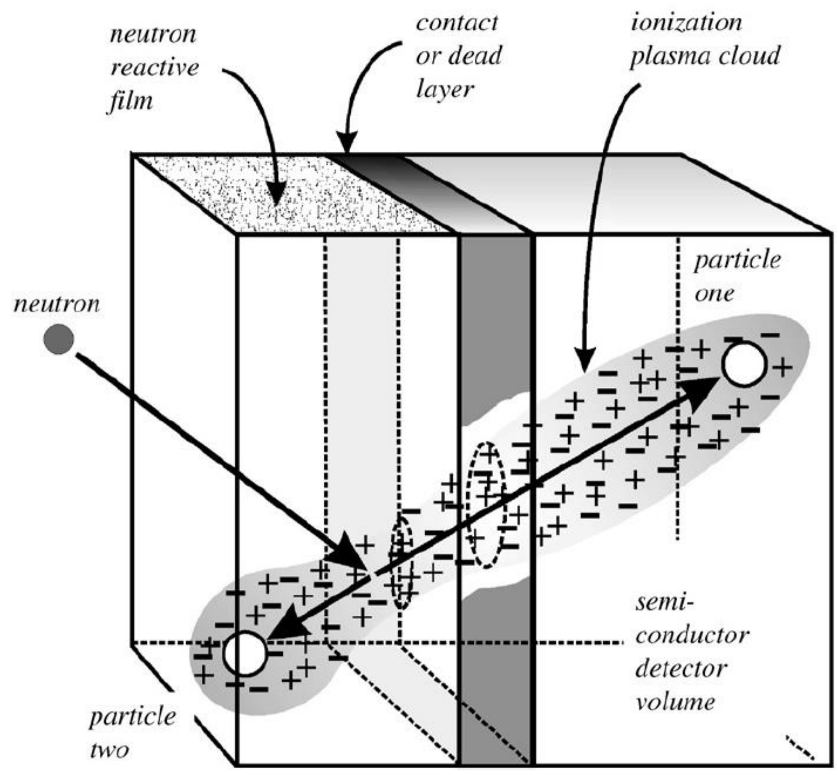
Gamma-ray rejection

Current work

Plans for future

# Reactive film coated semiconductor thermal neutron detectors

- Thin layers of neutron-reactive material are applied to semiconductor detectors.
- In the presence of thermal neutrons, the reaction products may be measured by the semiconductor detectors.
- The reactive layer must be thin enough to allow the reaction products to escape.
- If high detection efficiency is required, the layer must be as thick as possible.
- Lithium-6 and Boron-10 common reactive materials. Cross-sections 940b and 3840b.

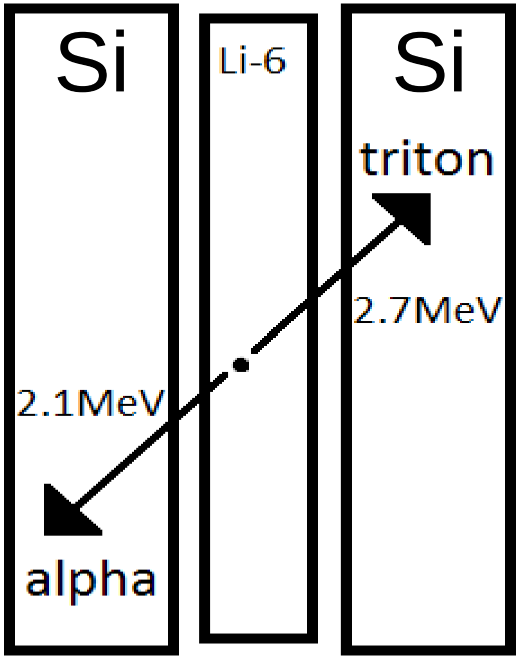



$$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H \ (2.3\ MeV)$$

$$^{10}B + n \rightarrow {}^{7}Li + {}^{4}He \ (2.8\ MeV)$$

D. McGregor, Nuclear Instruments and Methods in Physics Research A 500 (2003) 272–308

# Principle of operation of 'sandwich' detector




$^{6}Li(n\ ,\ \alpha)^{3}H$

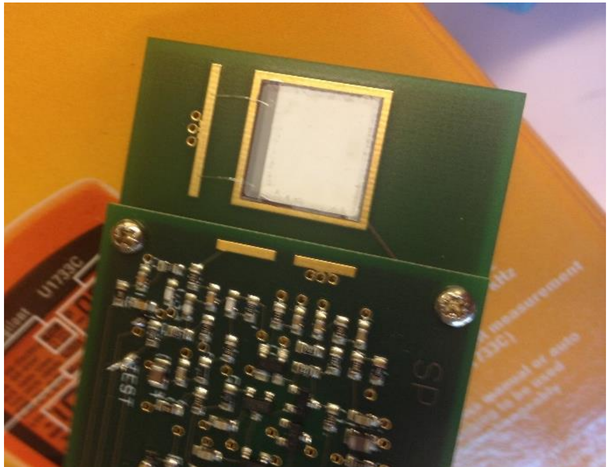
- Using two detectors, both reaction products can be measured.
- Optimal film thickness calculated using Geant4.
- ~7um for lithium fluoride ~40um for lithium metal
- At present, using lithium-6 fluoride as the active layer.
- Natural abundance: 92.5% $^{7}Li$

  7.5% $^{6}Li$

A. Ndoye, F. Cosset, Nuclear Instruments and Methods in Physics Research A 423 (1999) 414–420

# Motivation

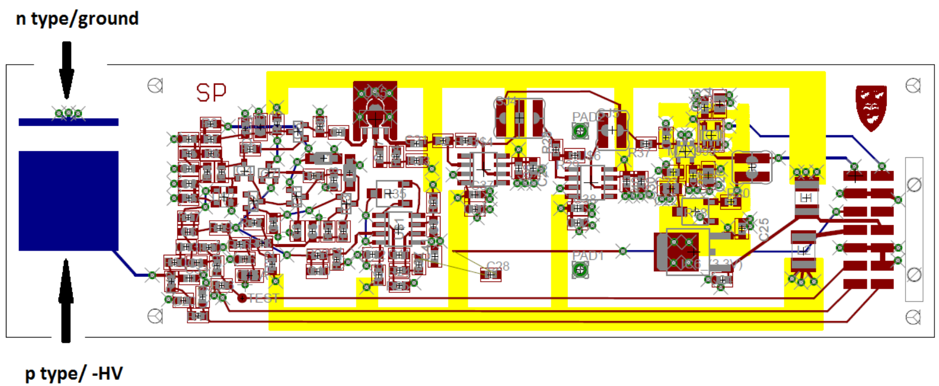
- Relative shortage/expense of Helium-3 has raised interest in alternative neutron detection technologies.
- Gamma-radiation often present where neutrons will be monitored.
- At present, available coated surface detectors measure only one reaction product. Improved gamma-ray discrimination may be achieved if both reaction products are measured.
- Use of reactive films with silicon detectors provides a compact technology for neutron detection.



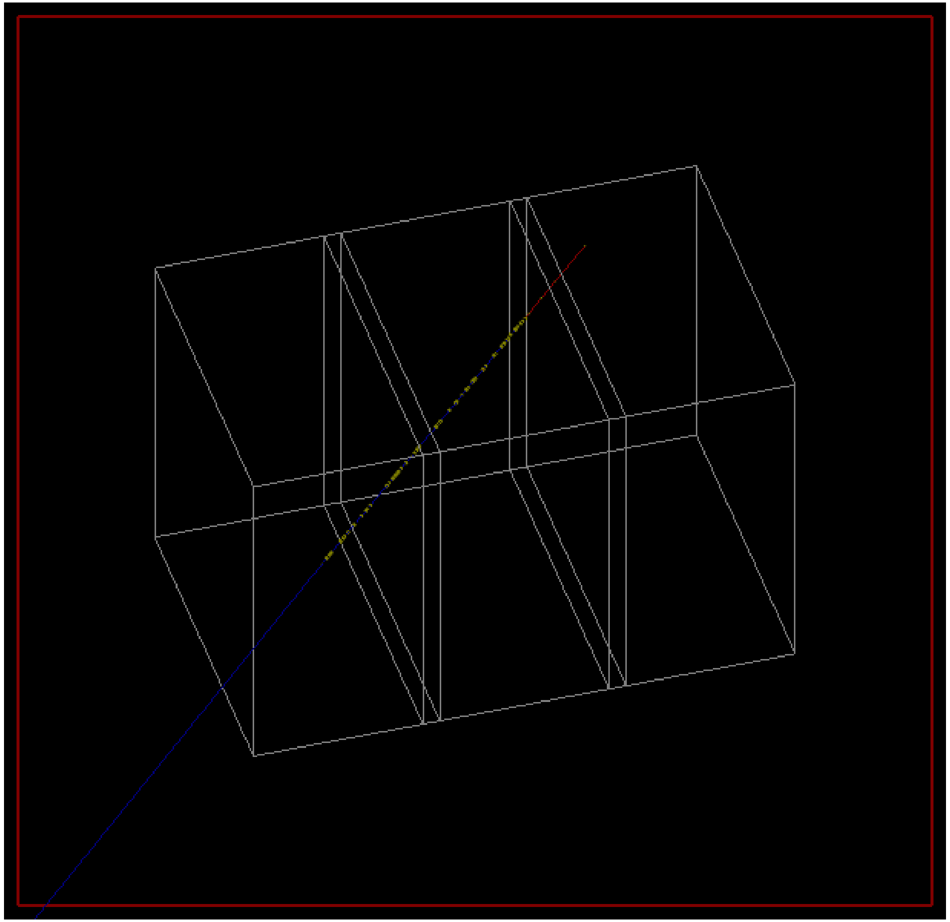
*Lithium fluoride coated diode*

# The neutron detector system

- *Silicon diodes used: 300um thickness, n-implant p-bulk, not passivated, 1um Al, cm$^2$ area.*
- *7um lithium fluoride layer evaporated onto implant face of diode.*
- *Amplifier boards outputs ~500ns pulse and trigger pulse.*
- *ADC and FPGA board output digitized pulse traces and flag coincidence events.*
- *DAQ generates online histograms, displays traces event-by-event. Data logged for offline analysis.*

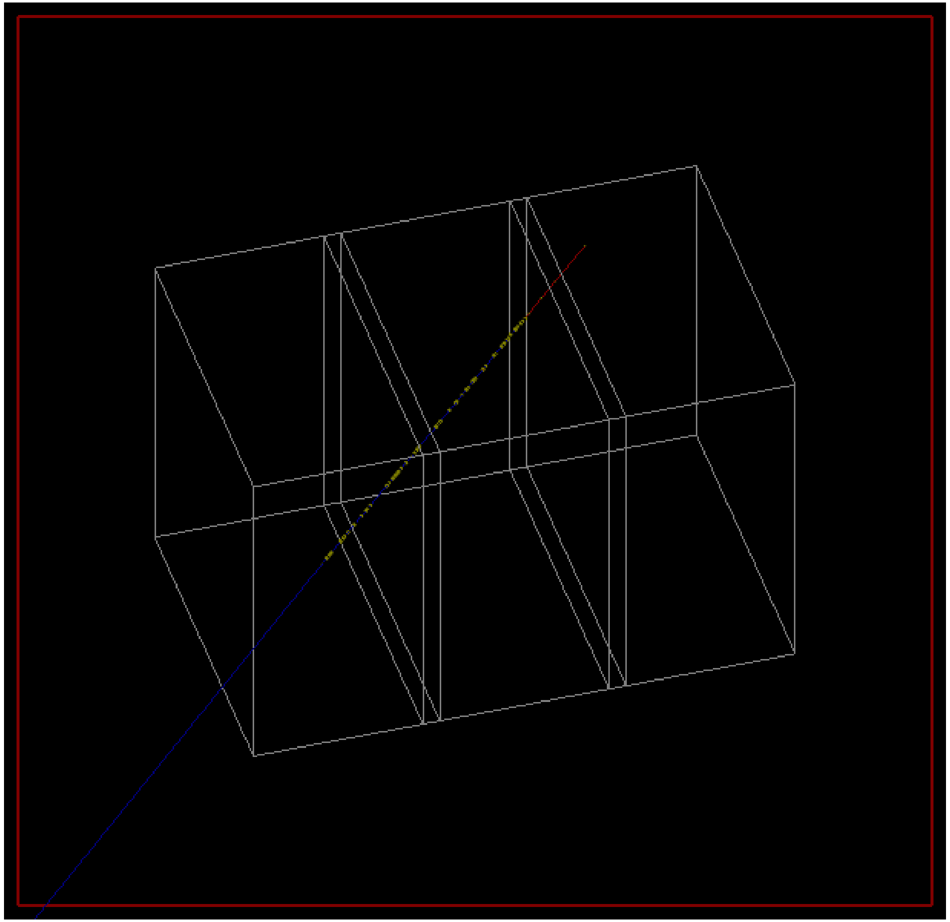


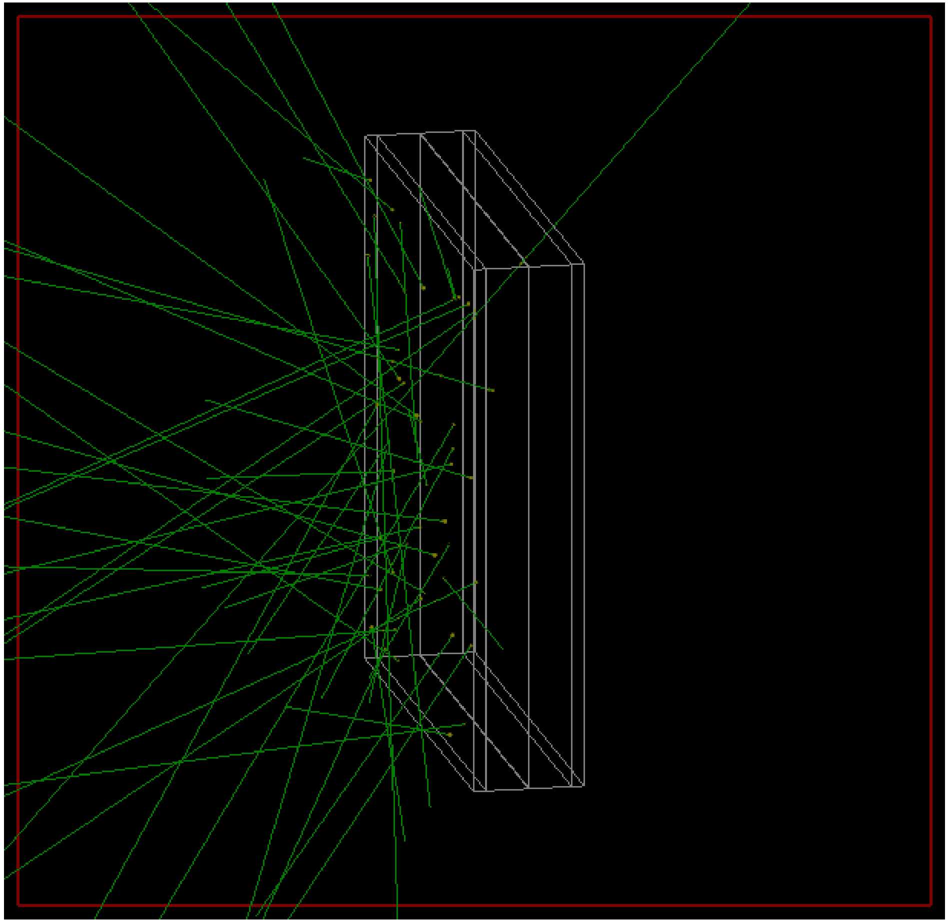

# Geant4 Simulations



- Simulate alpha-triton pairs in random capture sites within film then calculate efficiency using capture probability from neutron capture cross section.
- Thickness and type of reactive film varied.
- Barriers and separations also introduced.
- Also possible to simulate the process from thermal neutron interaction with detector.

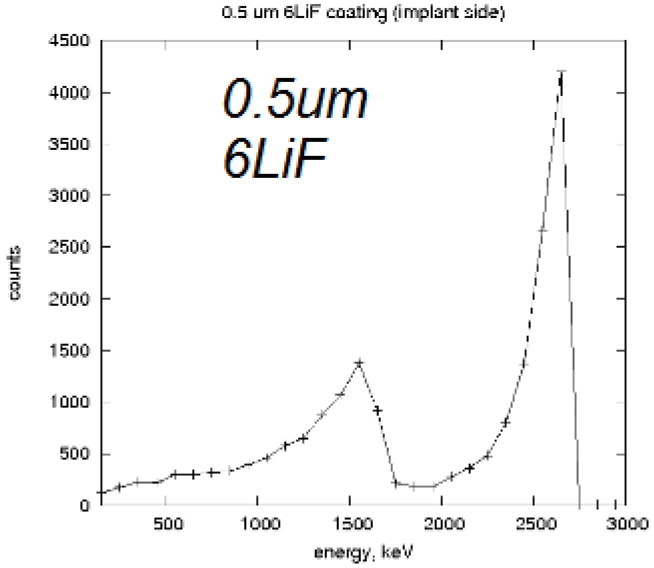
# Geant4 Simulations

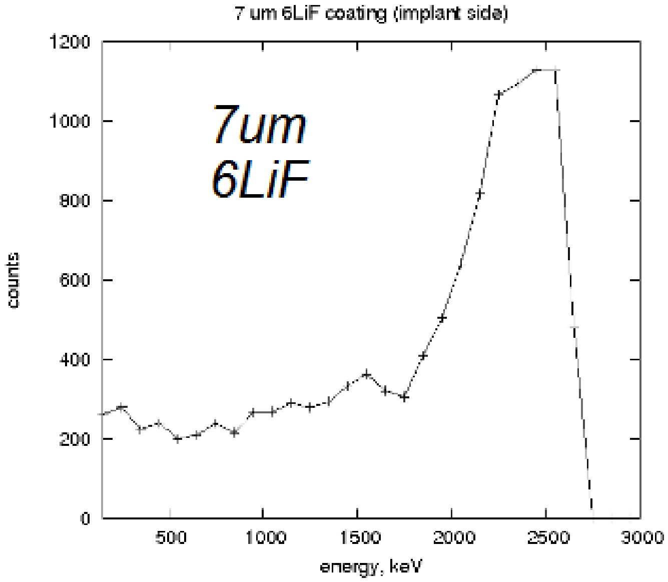


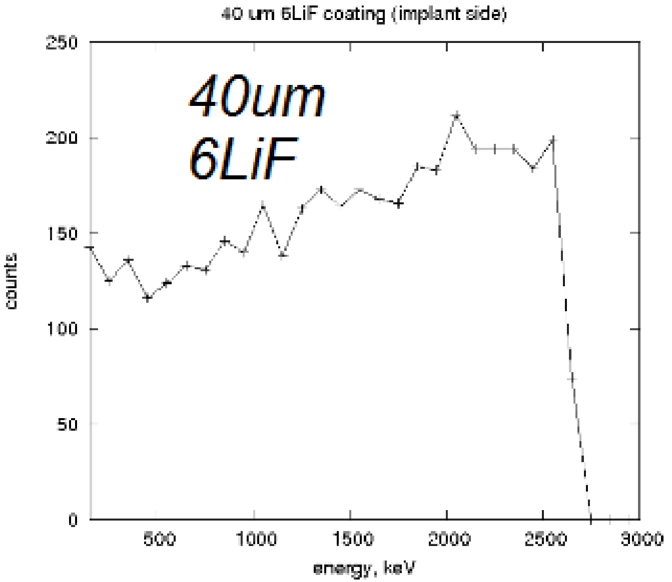


# Geant4 Simulations - neutrons

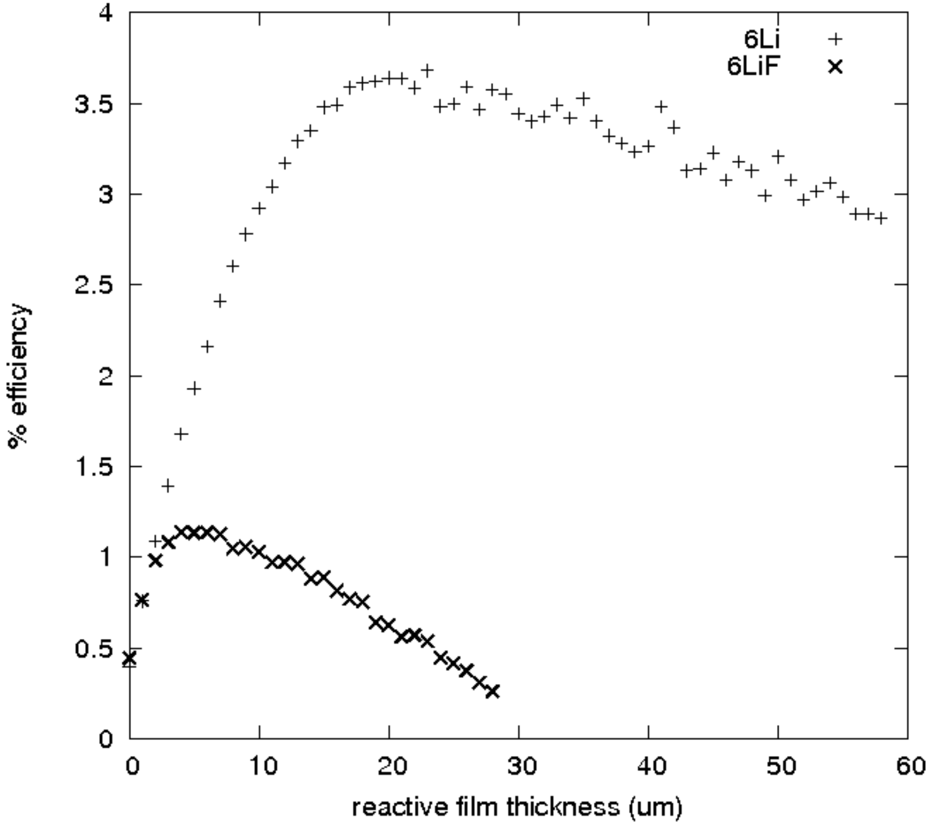
- Alpha-triton energy spectrum dependent on reactive layer thickness.
- Spectral information lost for thicker reactive layer.
- Optimal thickness is balance between thermal neutron capture and transmission of reaction products to detectors.



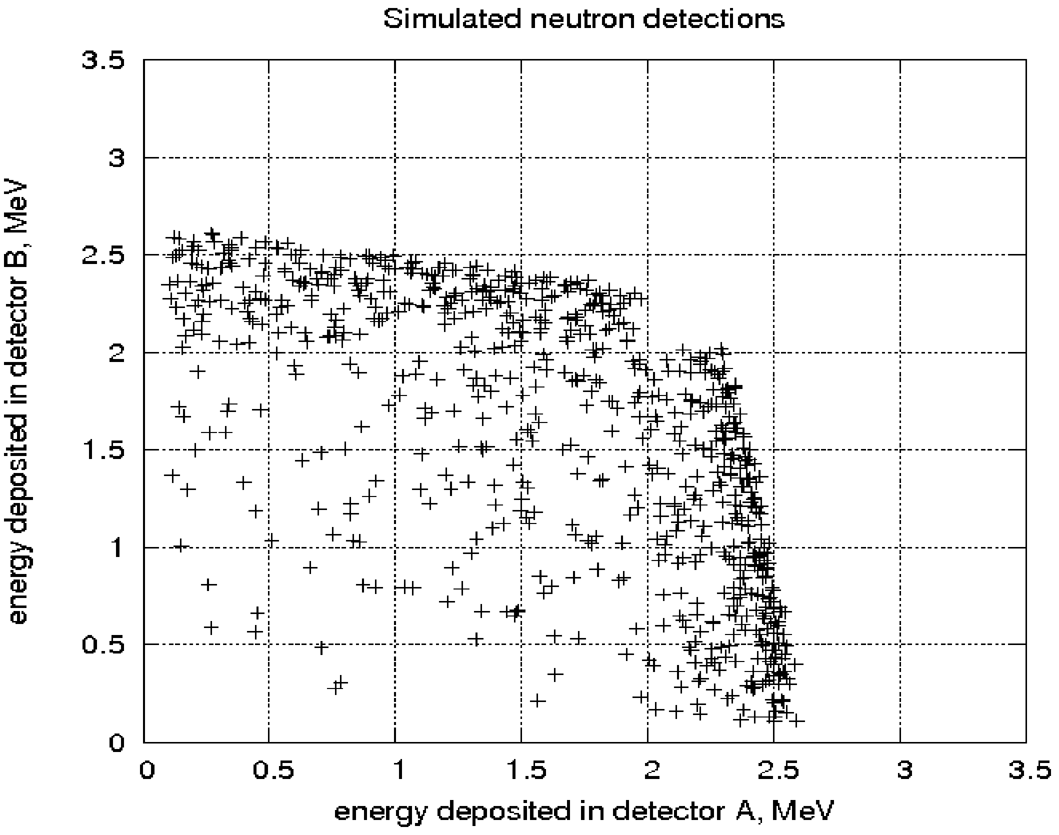



# Lithium Fluoride vs Lithium metal




- Lithium fluoride is chemically stable, easy to handle, store and incorporate into a detector.
- Lithium metal very reactive, must be handled in inert atmosphere and is stored under mineral oil.
- Incorporating lithium metal into silicon detector system problematic.
- Lithium metal much less dense, tritons and alphas can travel further.

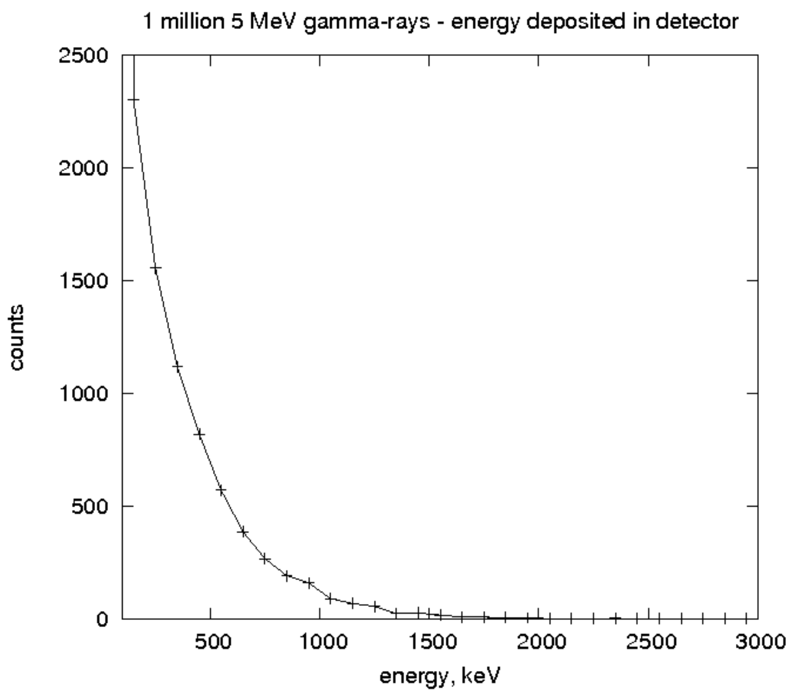
# Geant4 Simulations - neutrons

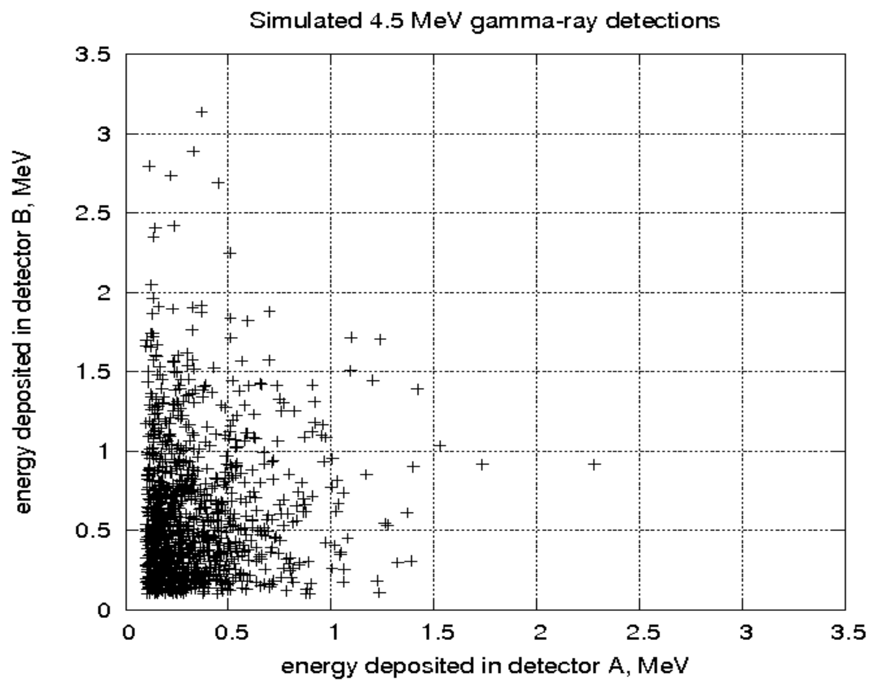



- Neutron-induced alpha-triton coincidence events have a distinct signature, which allows selective pulse-height conditions to be applied for the purpose of gamma-discrimination.

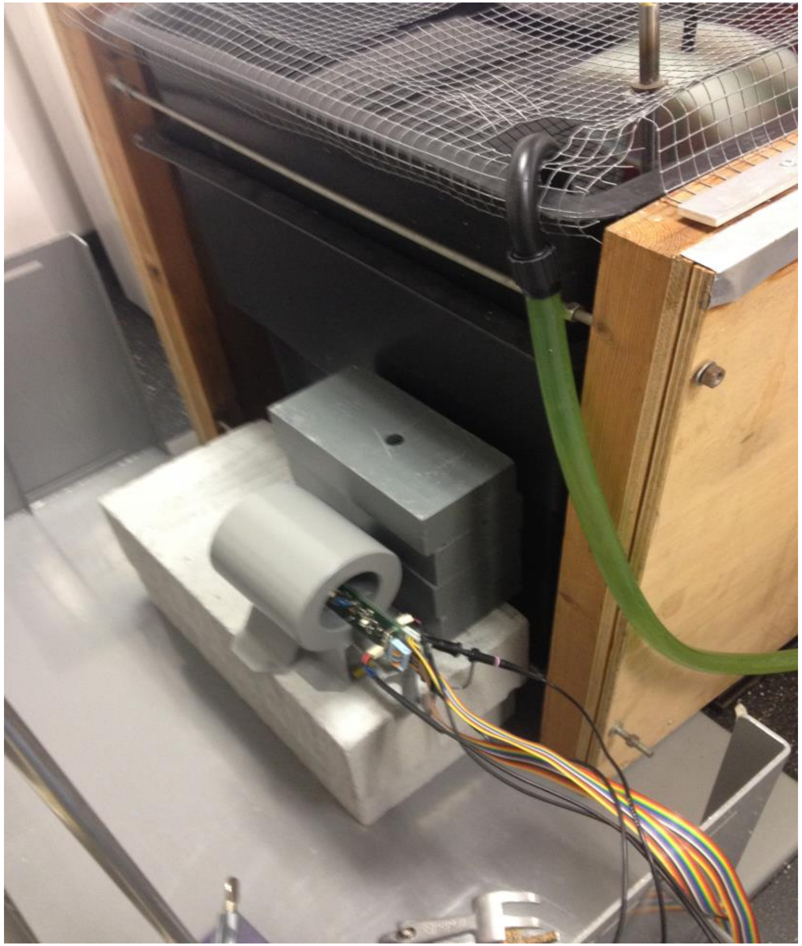
# Geant4 Simulations – gamma rays

Gamma rays (even those of high energy) result in energy spectrum skewed to very low energy. At 5 MeV the probability of causing a neutron-like signal is less than $10^{-6}$.

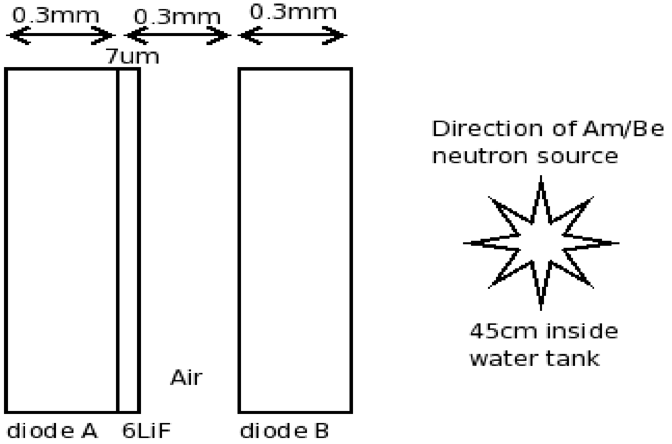


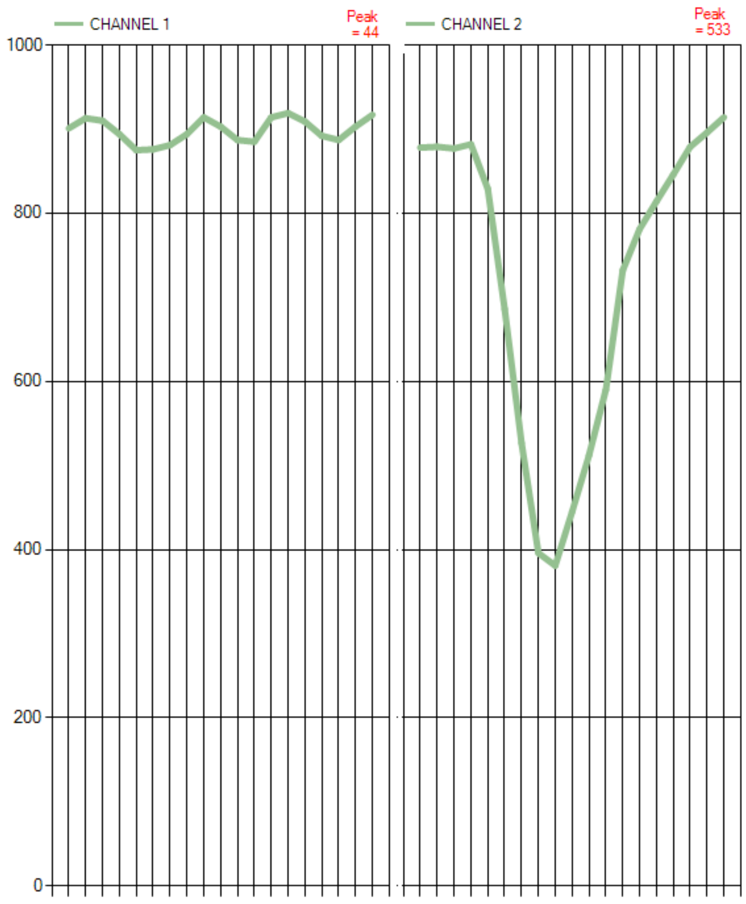
# Measurements in the radiation laboratory.



- *1Ci Am/Be source, water moderated*
- *Neutrons at source up to 11MeV*
- *~2.6 million neutrons emitted/second*
- *4.4MeV gamma-ray emitted for ~50% of neutrons*

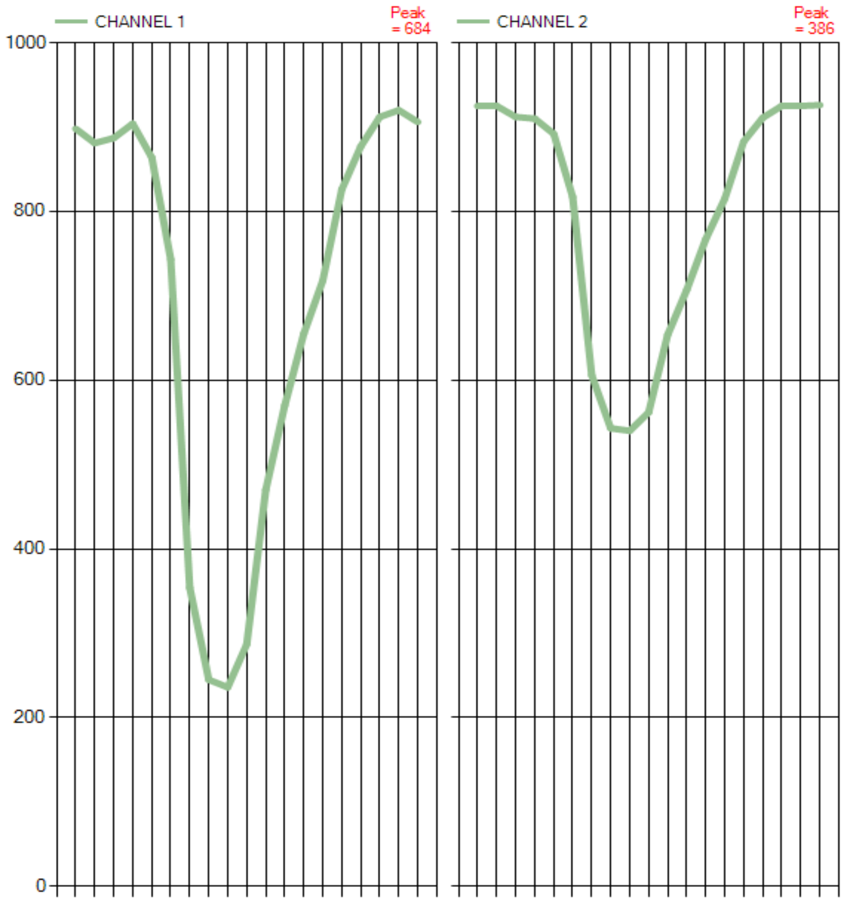


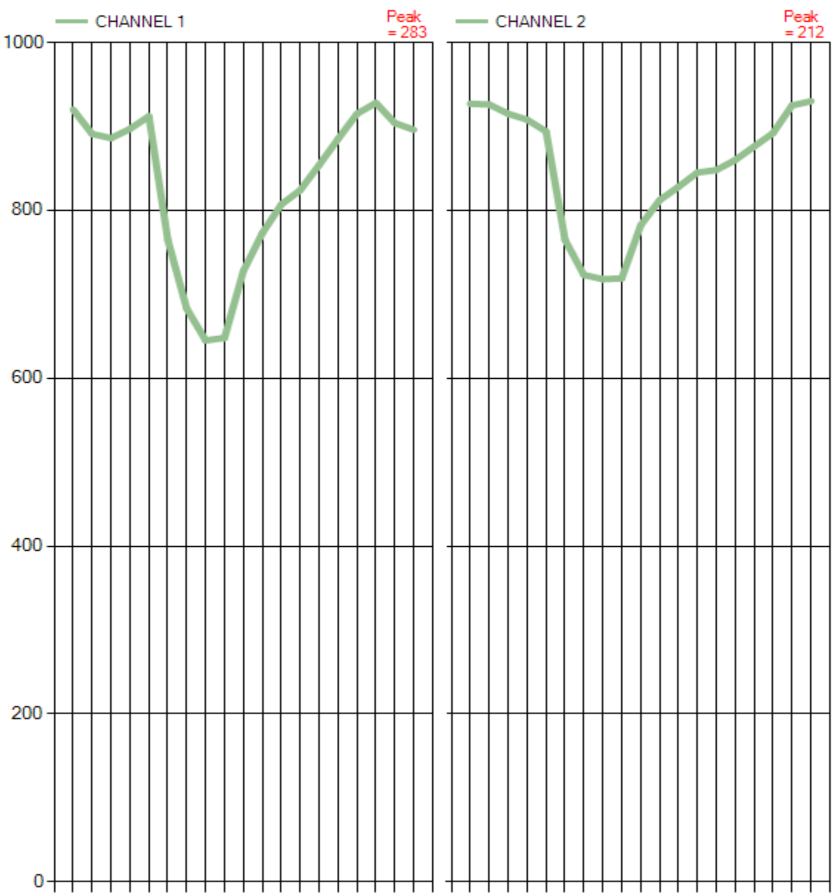
# Example pulse trace



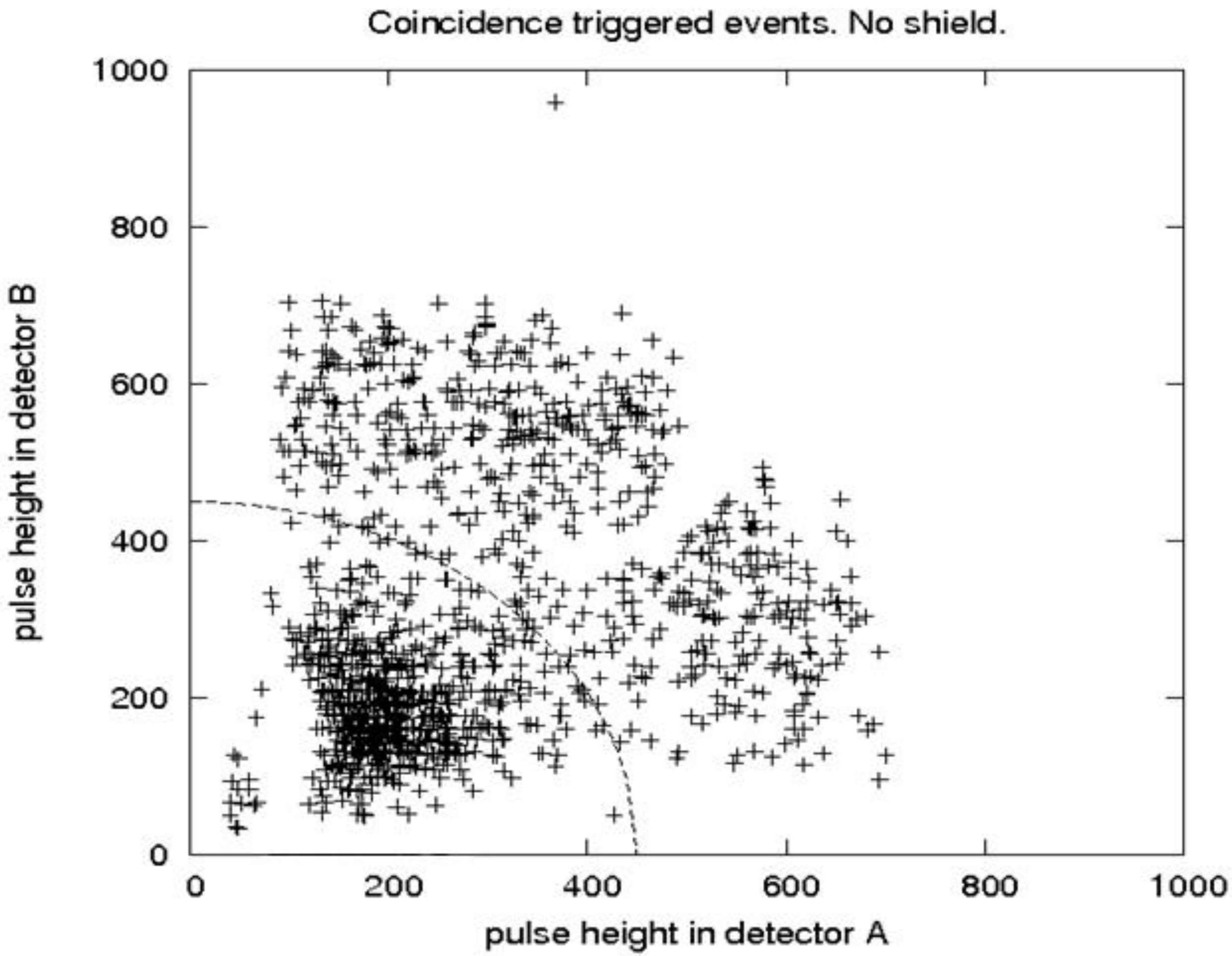

- Y-range: 2V
- X-range: 1000ns

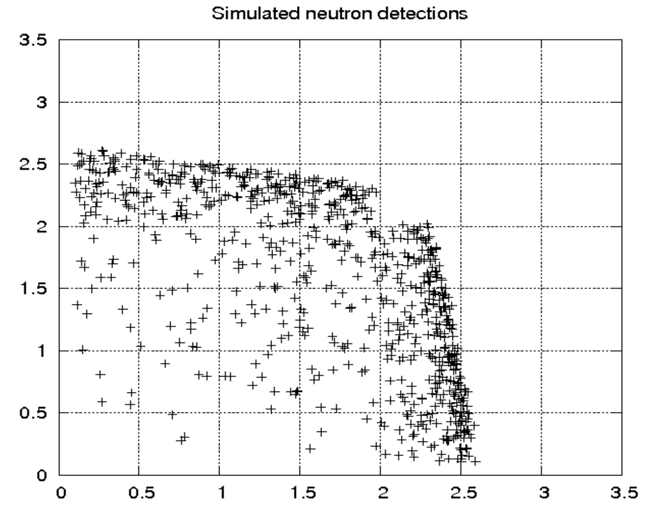
# Example coincidence events

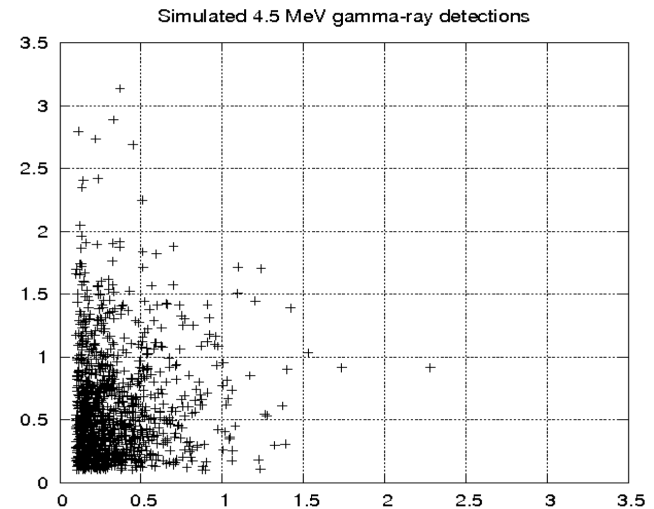


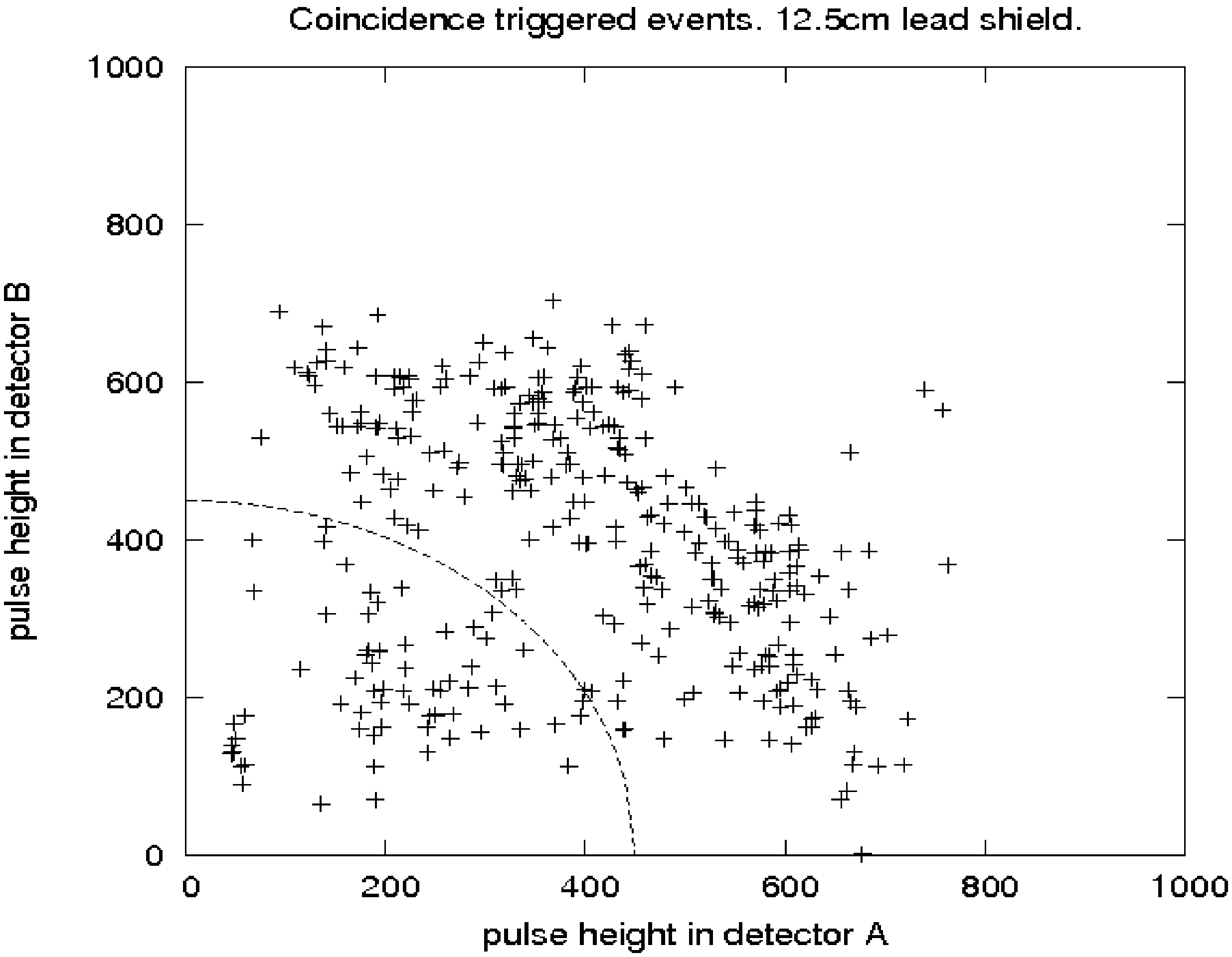
# Measurements – no shielding

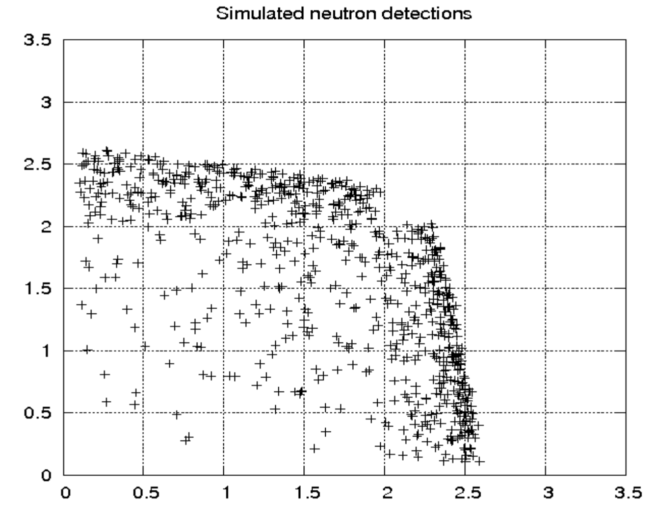


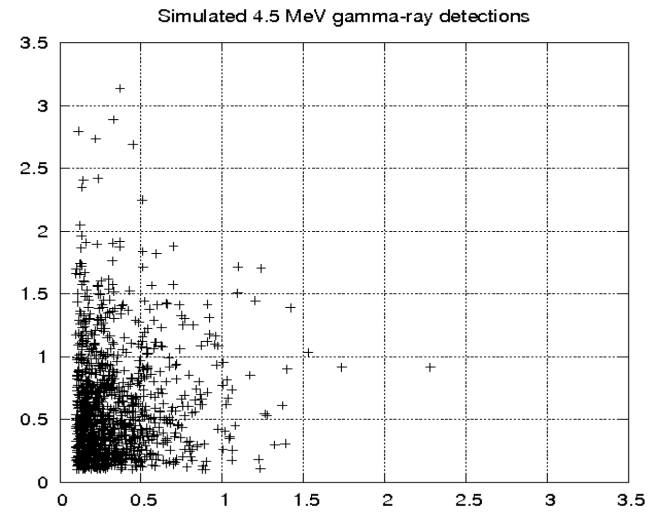



# Measurements – lead shield



# Results – Efficiency

- Comparison with $^{3}He$ detectors of known efficiency
- Neutron flux at detector position 4.41nv (neutrons/cm$^2$/s)
- Detector efficiency measured as 2.4%
- Results in accord with simulations

# Gamma Rejection

- Gamma-ray rejection ratio (*GRR)* defined as fraction of incident gamma-events which give neutron-like signal, for a $^{60}$Co source – 1.17 and 1.33 MeV.
- Techniques to reject gammas are being investigated.

  - Pulse height discrimination using single detector

  - 2-D pulse height discrimination using both detectors

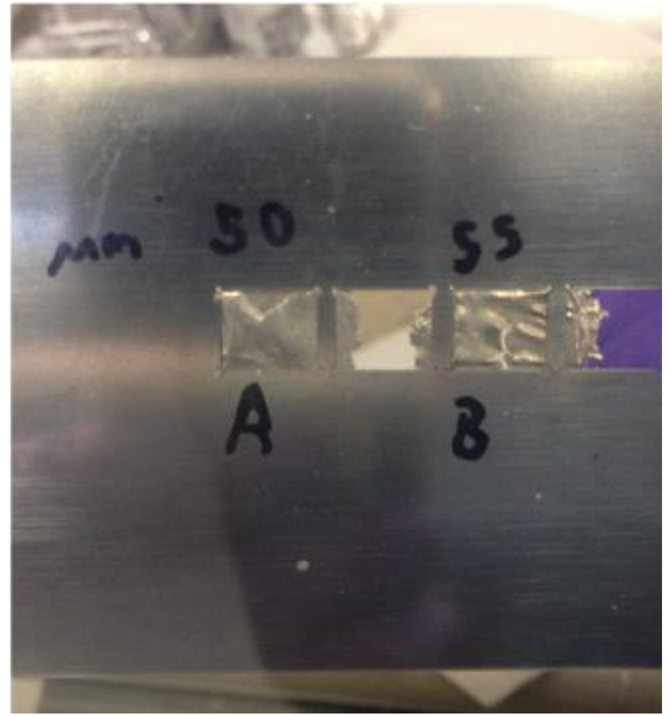
  - Alpha-triton coincidence measurements

- Gamma-ray rejection ratio better than $10^{-7}$ for $^{60}$Co.

# Lithium-6 foil detector

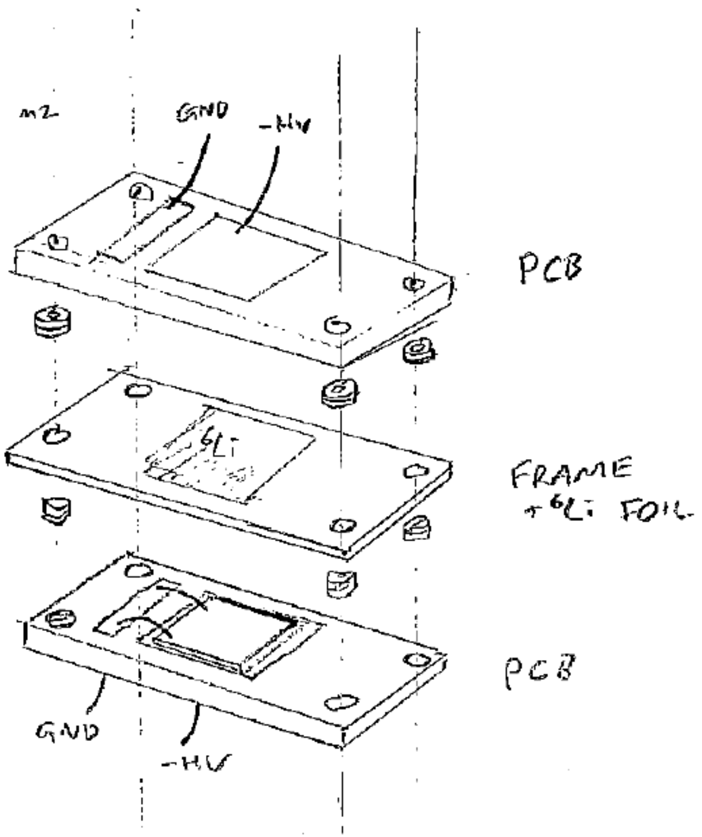
- Lithium very reactive and quickly degrades/corrodes in air.
- Lithium on silicon detectors problematic.
- Enclosure has been (is being) produced to maintain stable lithium foil.
- Argon environment, vacuum.
- Manufacturing methods exist to produce lithium foil.
    - Nuclear Instruments and Methods in Physics Research A 762 (2014) 119–124
- Cold rolling technique can produce small ($cm^2$) pieces of foil, 30um thick.

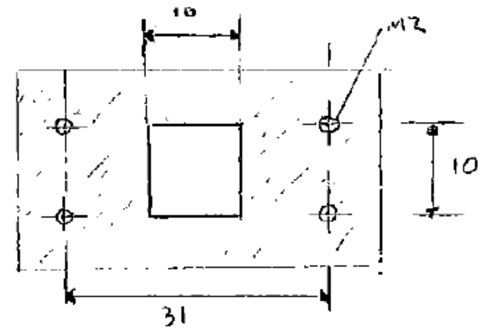
# Lithium-6 foil detector

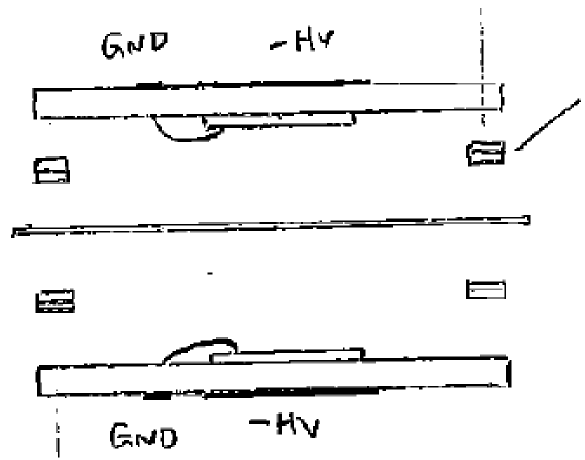



# Lithium-6 foil detector

Mounting the foil and silicon detectors

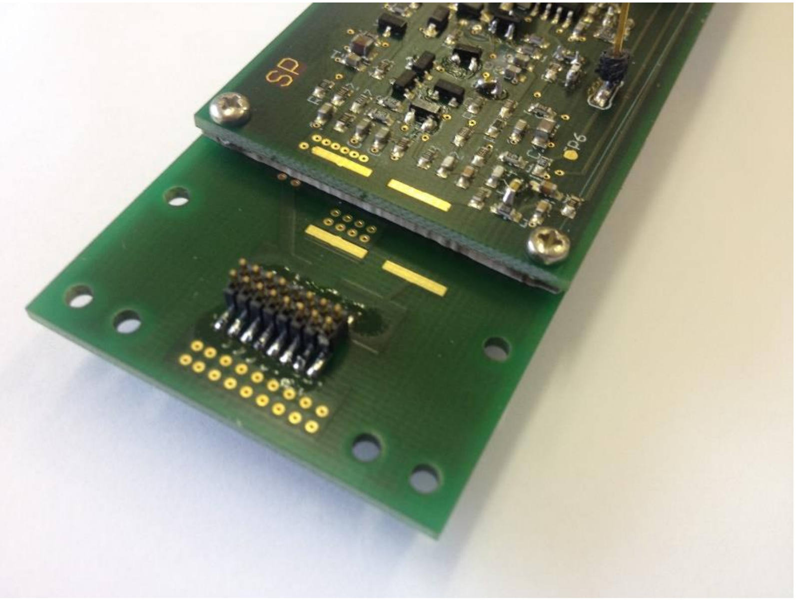


# Improvements made to detector

- **DAQ:** Previously, only pulse heights were recorded. Now all pulse traces written to file to allow better energy resolution and better discrimination against pulses due to electronic noise.
- **Front end:** System now more modular, connectors mean different detector configurations can be used with ease.



# Summary

- Alpha-triton coincidences following $^{6}Li(n,\alpha)^{3}H$ reaction have been recorded, and can be used as a method of thermal neutron detection.
- Measured thermal neutron detection efficiency in agreement with simulations. Alpha-triton energy spectra in agreement with simulations.
- Gamma-ray discrimination using this method under investigation.
- Methods of maintaining stable lithium foil are being developed, and an inert gas/vacuum test-enclosure is near completion.
- Multi layer detector could achieve ~20% detection efficiency.

Acknowledgements

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Science & Technology Facilities Council

FONDAZIONE BRUNO KESSLER

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