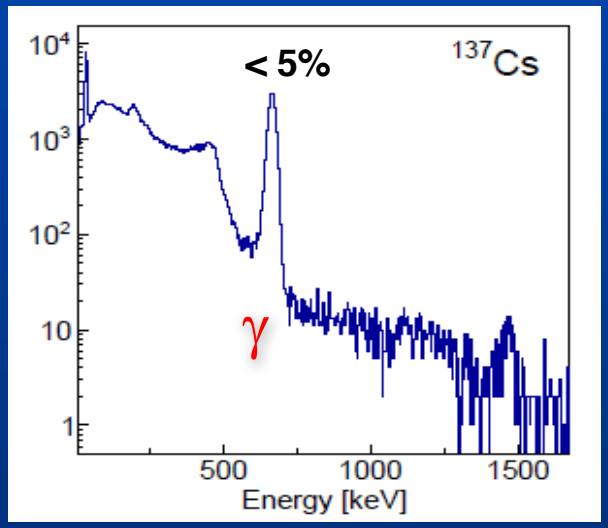
Fast Neutron Spectroscopy with C^7LYC Scintillators

Partha Chowdhury

University of Massachusetts Lowell

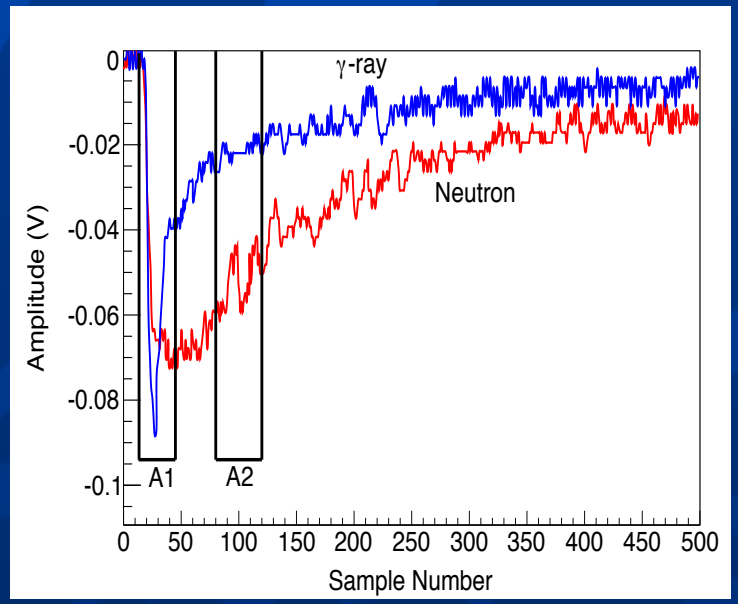
Work supported by U.S. Department of Energy

Cs_2LiYCl_6 (CLYC): novel dual n-γ scintillator



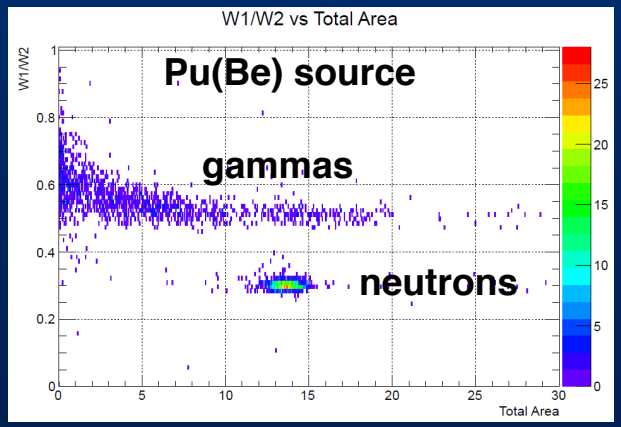
SBIR Grant with RMD Inc.

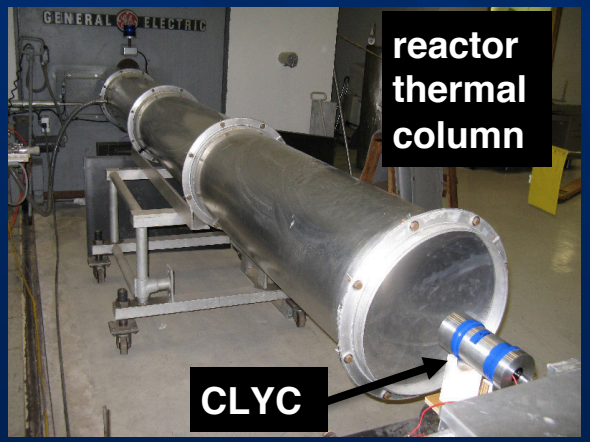
- Gamma resolution better than NaI
- Excellent n-γ pulse-shape discrimination

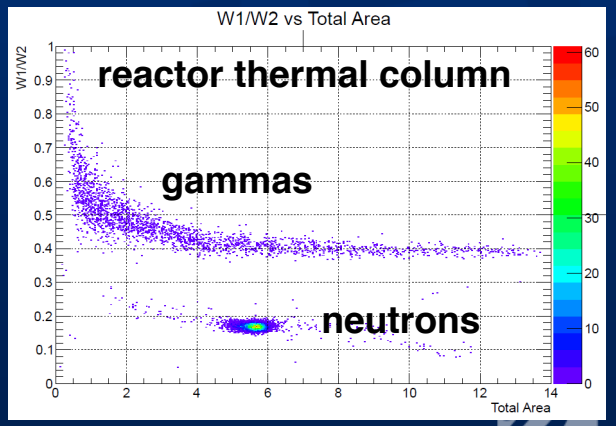


Thermal neutron response

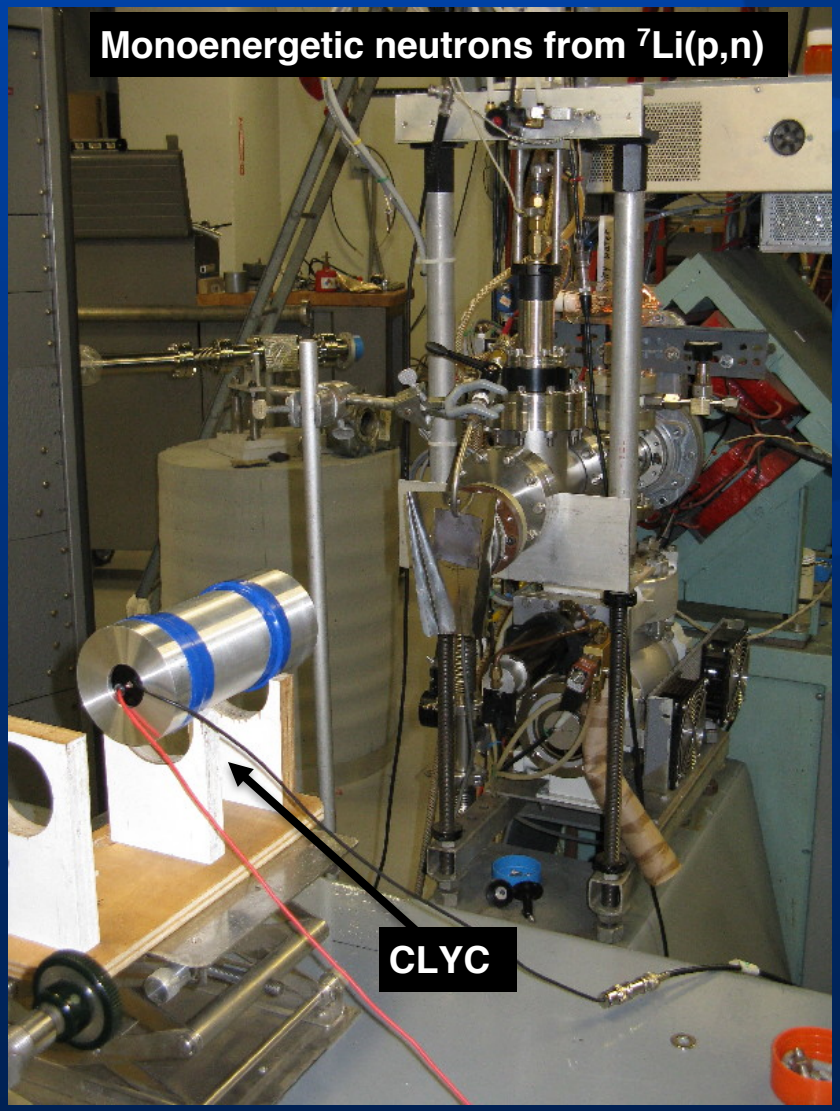
$^6Li(n,\alpha)^3H$, Q = + 4.8 MeV



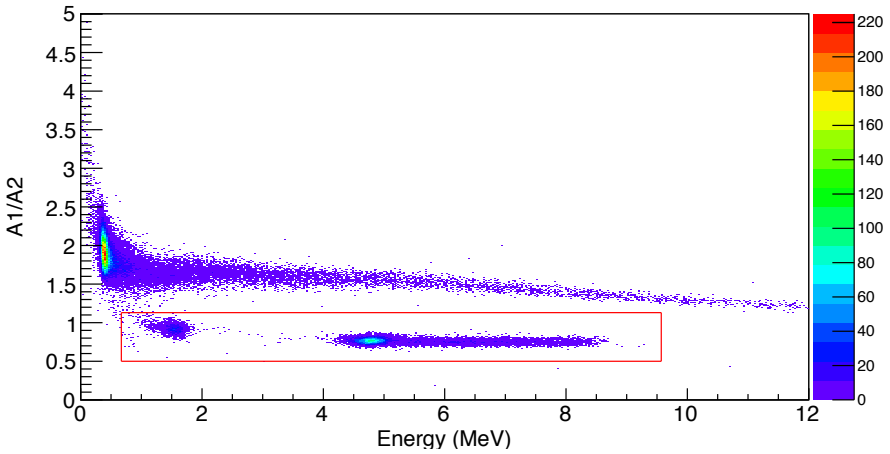


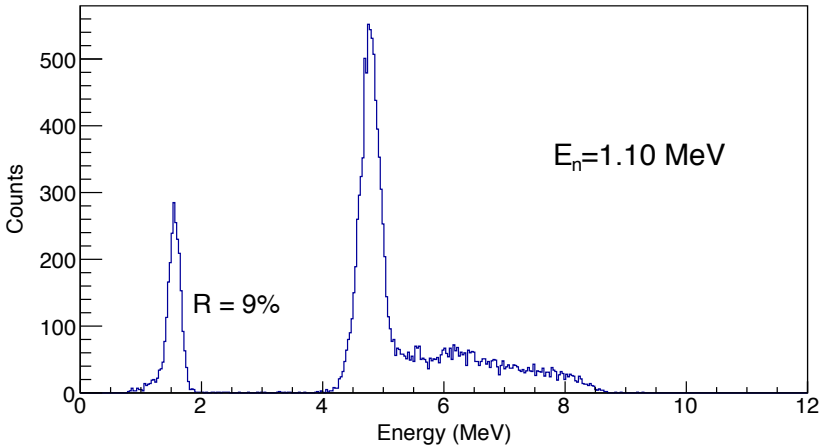


Cs_2LiYCl_6 (CLYC): fast neutron response

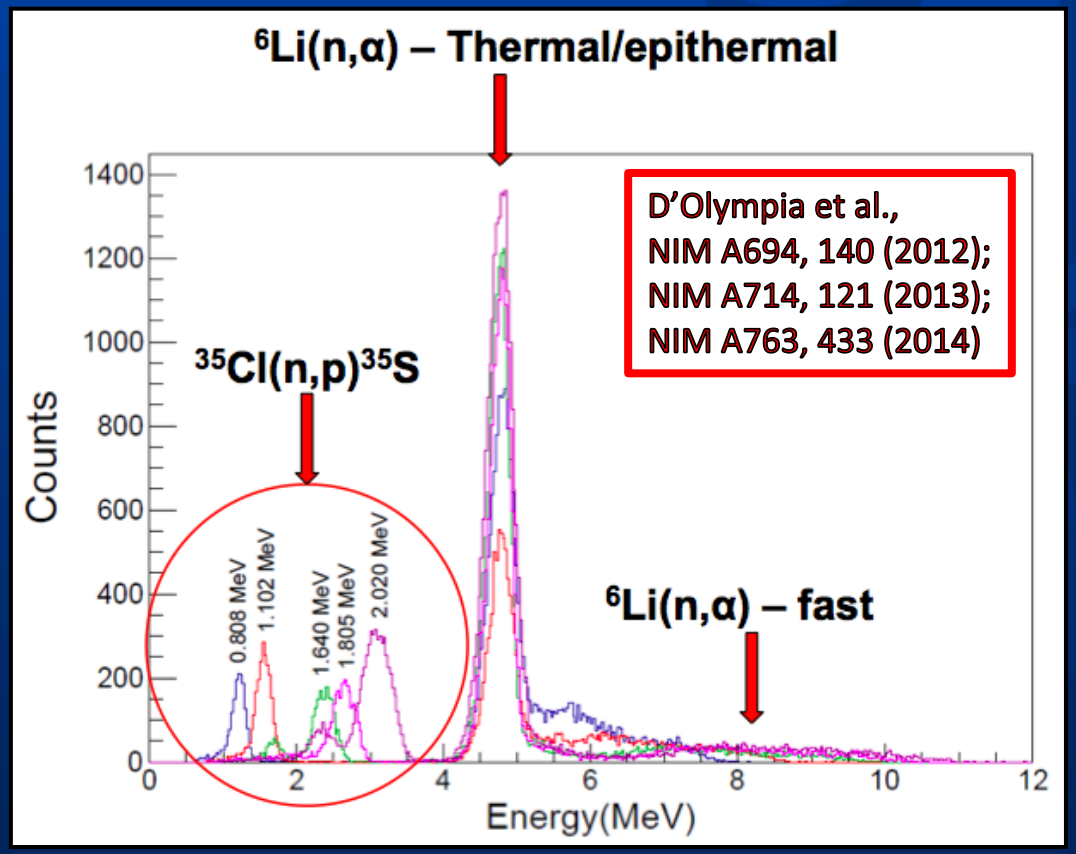


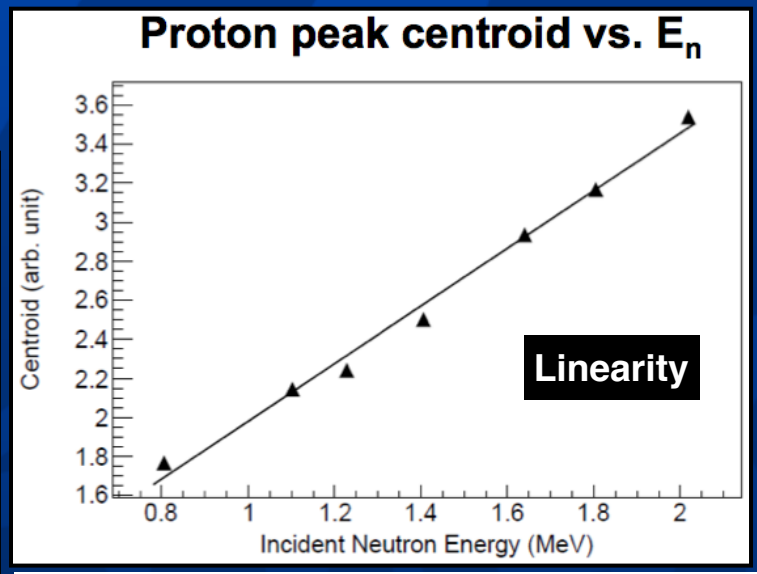
Fast neutron response at Van de Graaff

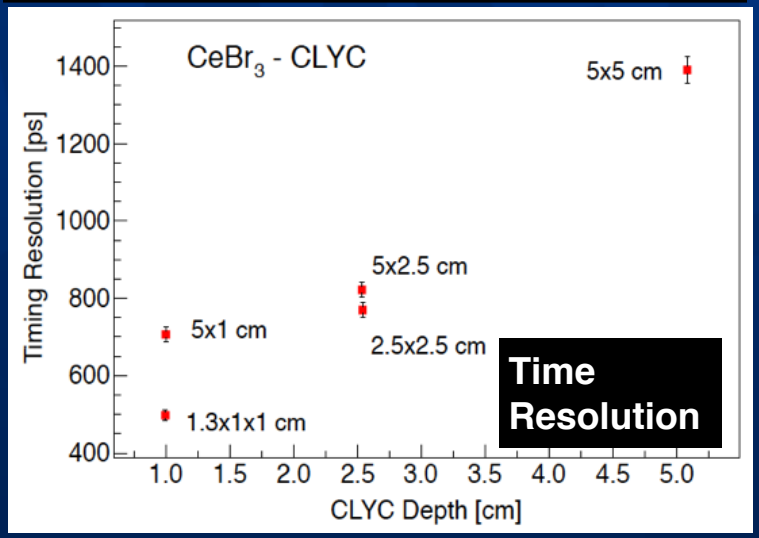




Cs_2LiYCl_6 (CLYC): fast neutron response

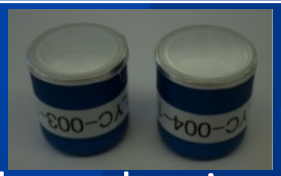


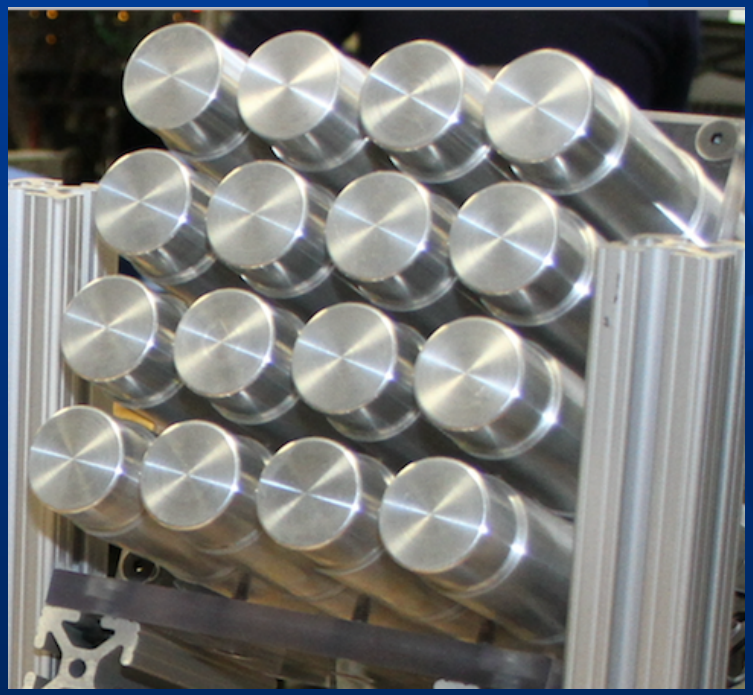




SCANS : Small C^7LYC Array for Neutron Spectrocopy

- Eliminate $^6Li(n,\alpha)$ thermal peak via ^7Li-enriched C^7LYC
- Explore fast neutron spectroscopy potential (NNSA grants)
- A 16-element array of 1” x 1” C^7LYC (largest crystals available at the time)



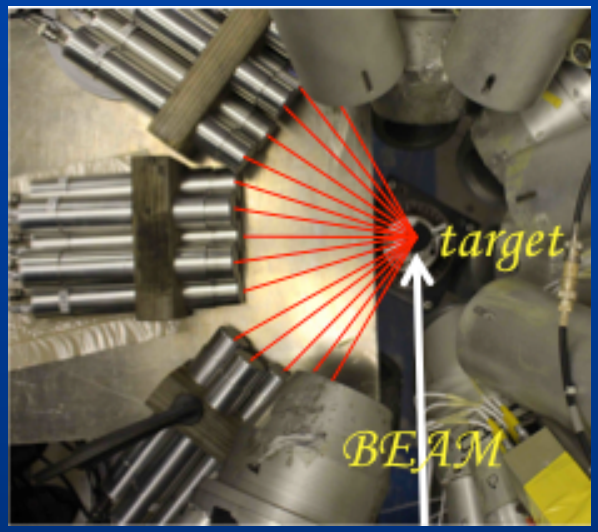


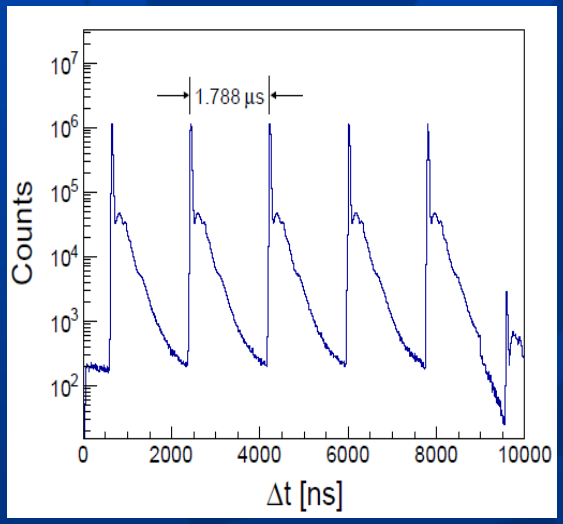
VME Struck Digitizers
- 16 Ch – 250 MS/s
- 14 bit ADC
- n/γ firmware

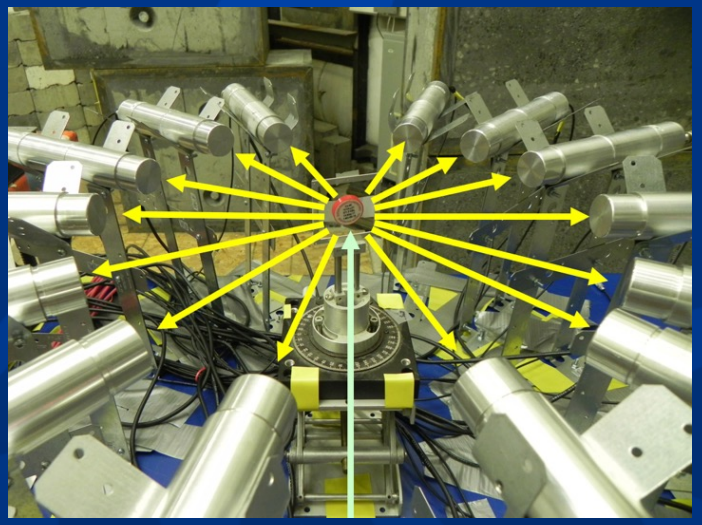
- ~10% neutron pulse height resolution !!
- No long ToF arm needed
- Geometrical efficiency can be enhanced by placing close to target

- Nuclear science with SCANS (C^7LYC)
- Elastic/inelastic neutron scattering at Los Alamos
- Beta-delayed neutron spectroscopy at CARIBU

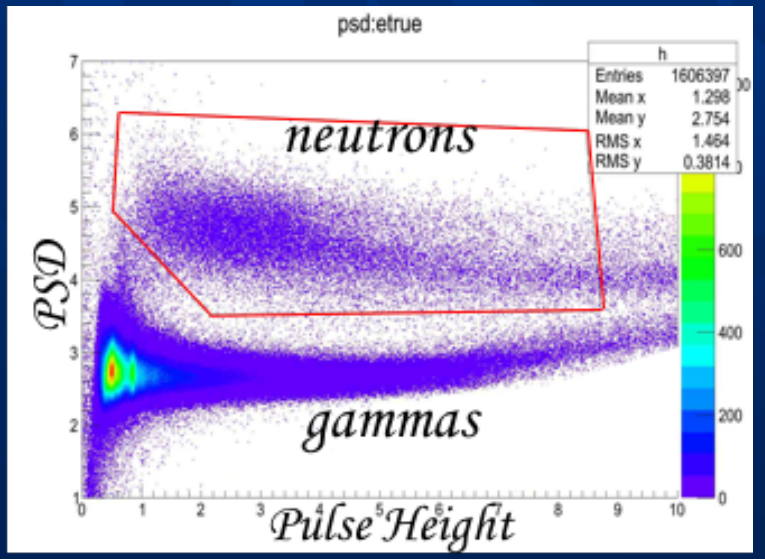
^{56}Fe(n,n') SCANS at LANSCE



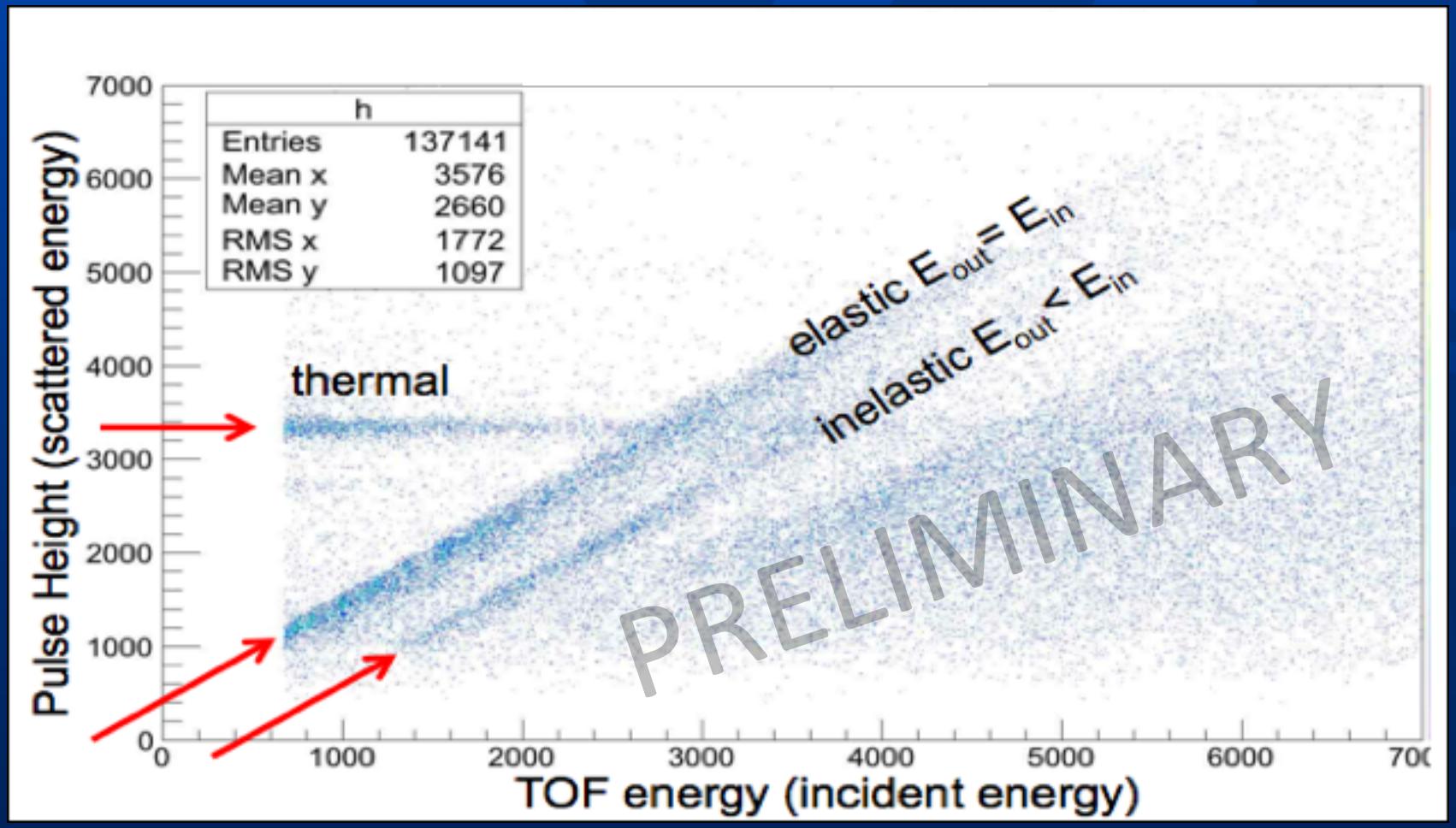




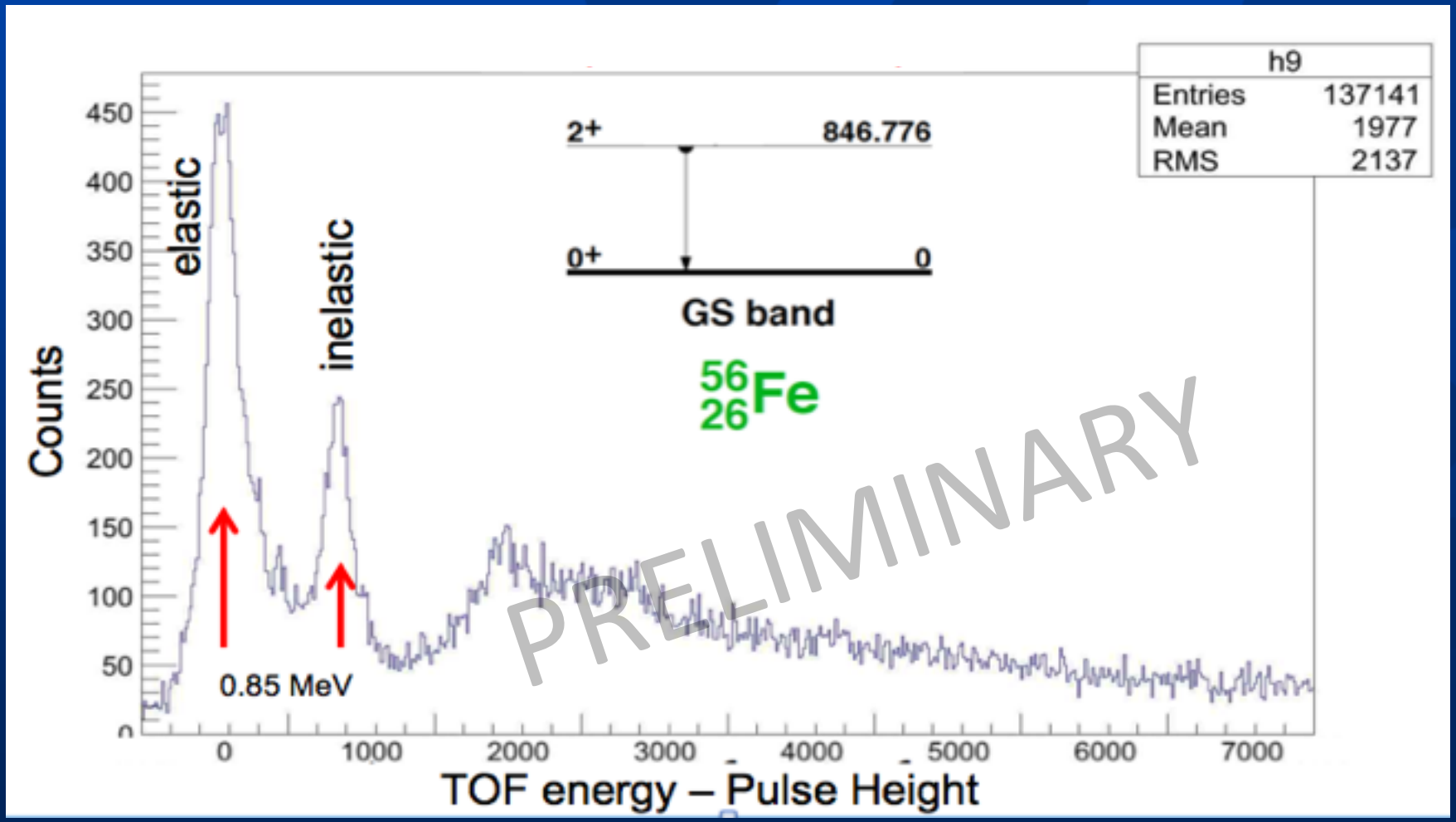
- 100 MeV pulsed protons on W spallation target
- 20 m flight path to scattering target (Fe)
- C^7LYC detectors 17 cm from target
- TOF to detector provides incident energy
- Pulse height in C^7LYC provides scattered energy

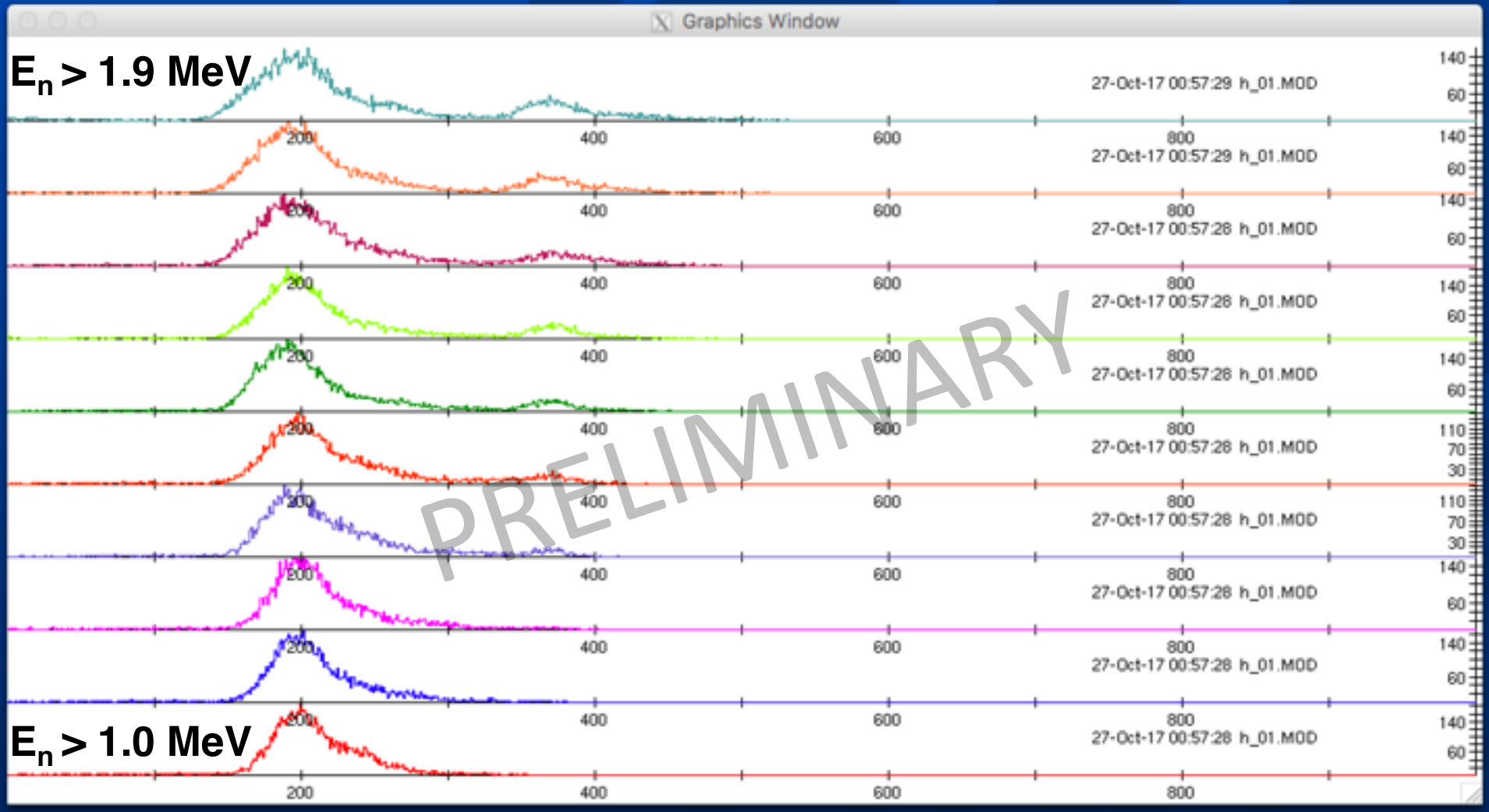


^{56}Fe(n,n') SCANS at LANSCE



^{56}Fe(n,n') SCANS at LANSCE

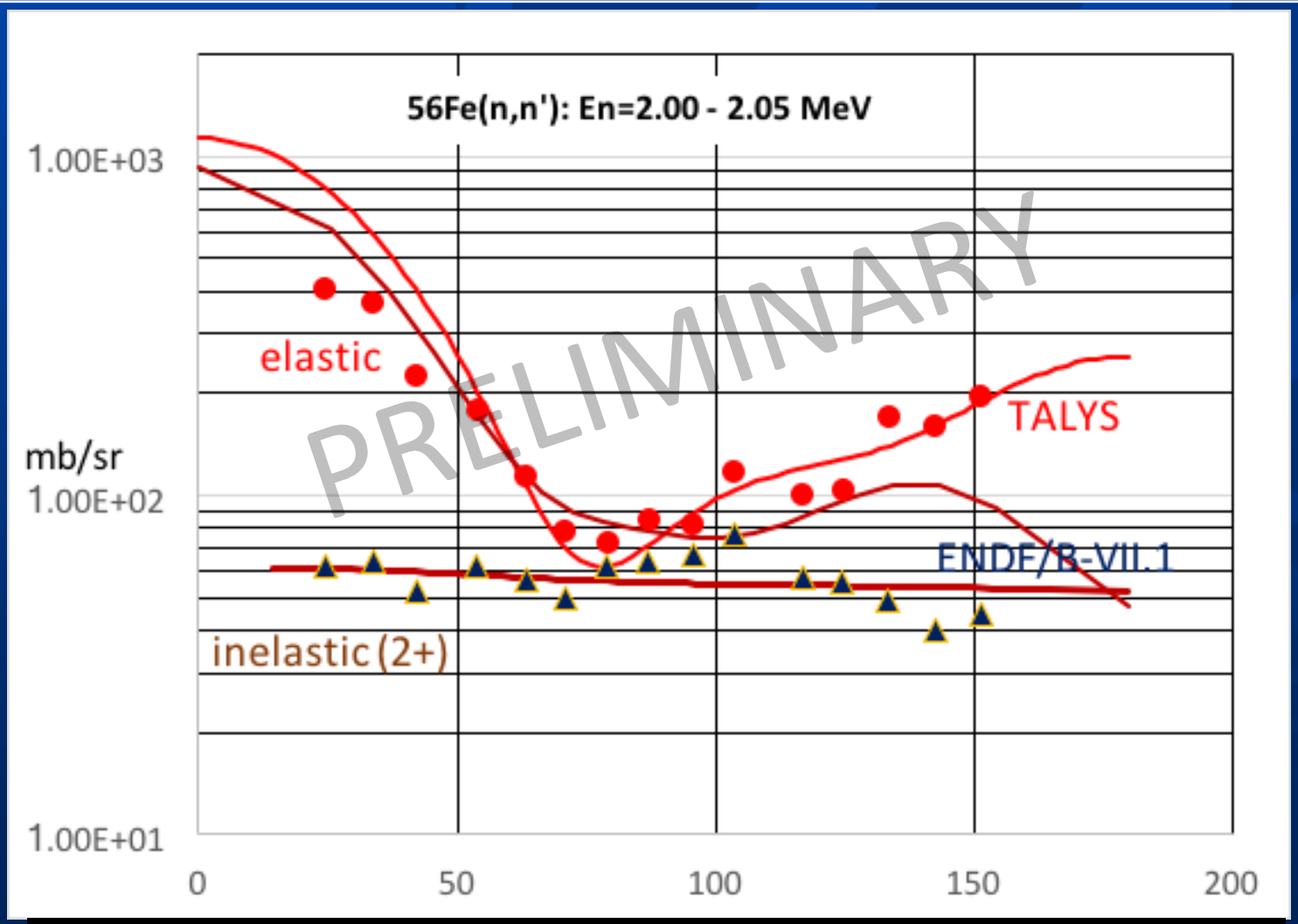




100 keV slices on incident neutron energy

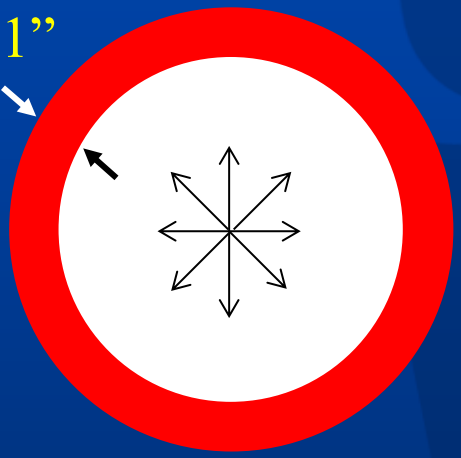
^{56}Fe(n,n') at LANSCE

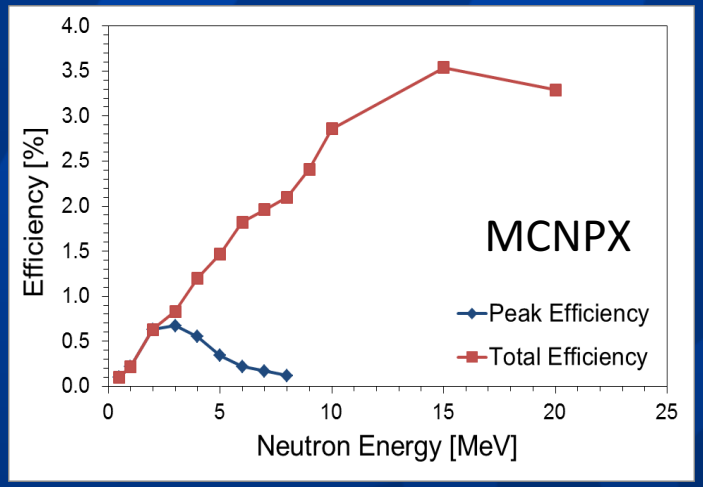
^{56}Fe elastic/inelastic relative cross-sections

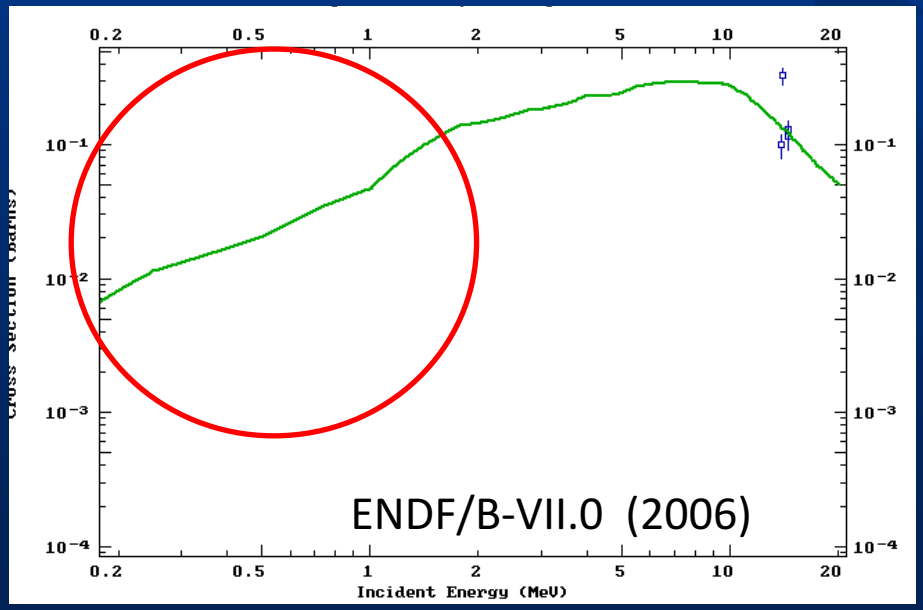


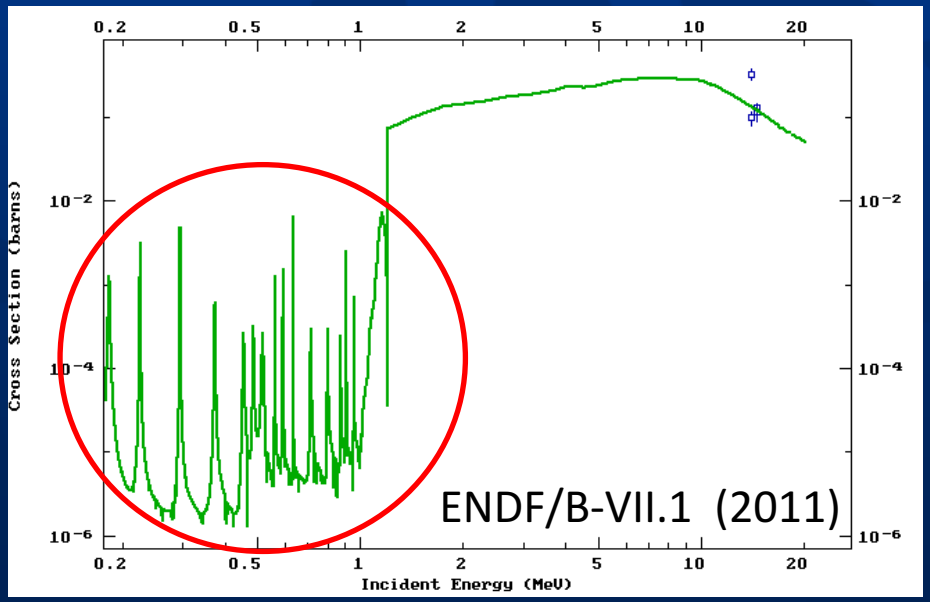
present data (50-keV slice) with arbitrary normalization compared with simulations/database for elastic angular distribution cross-sections

Efficiency estimates & $^{35}Cl(n,p)$ cross-sections



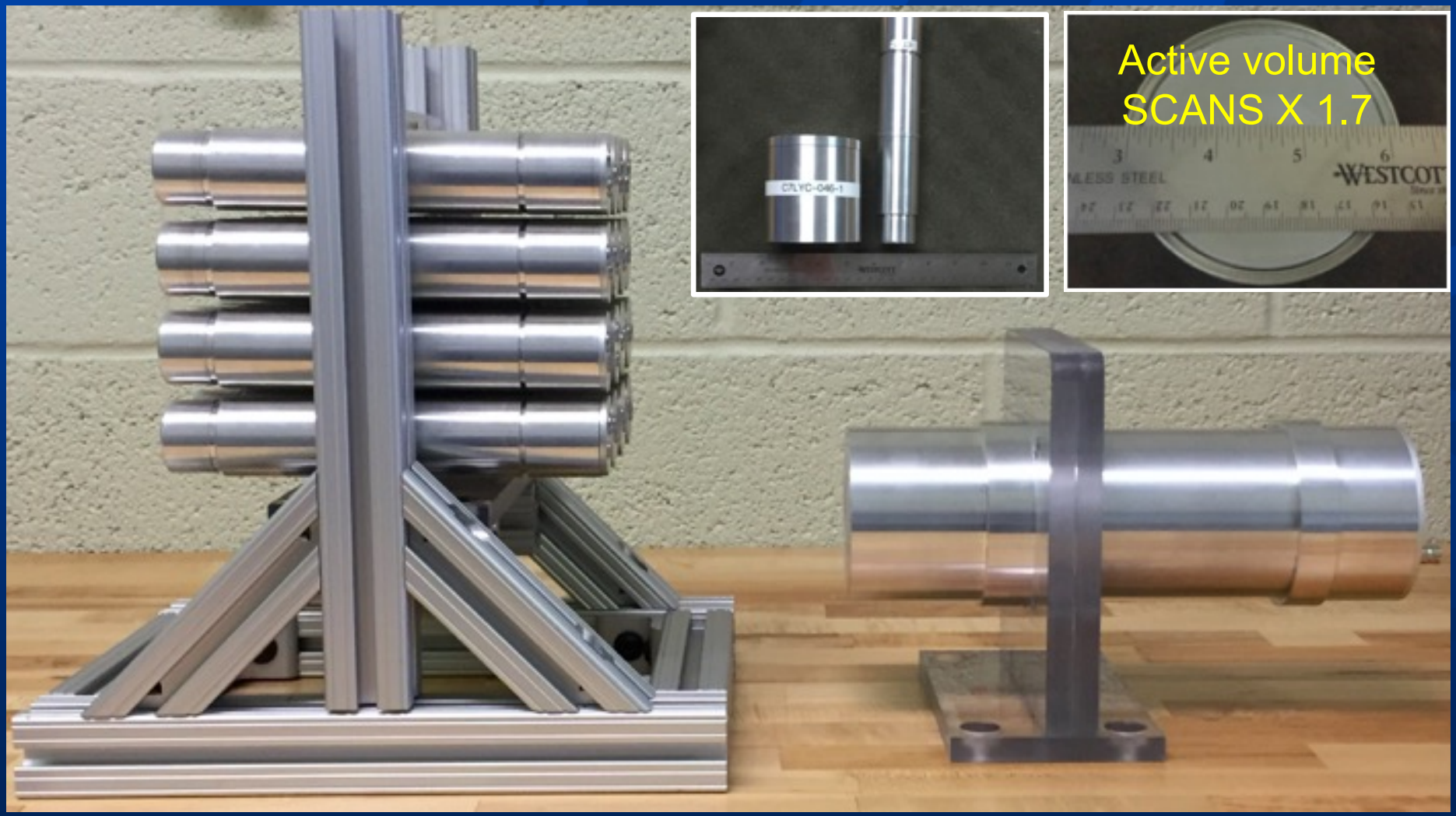




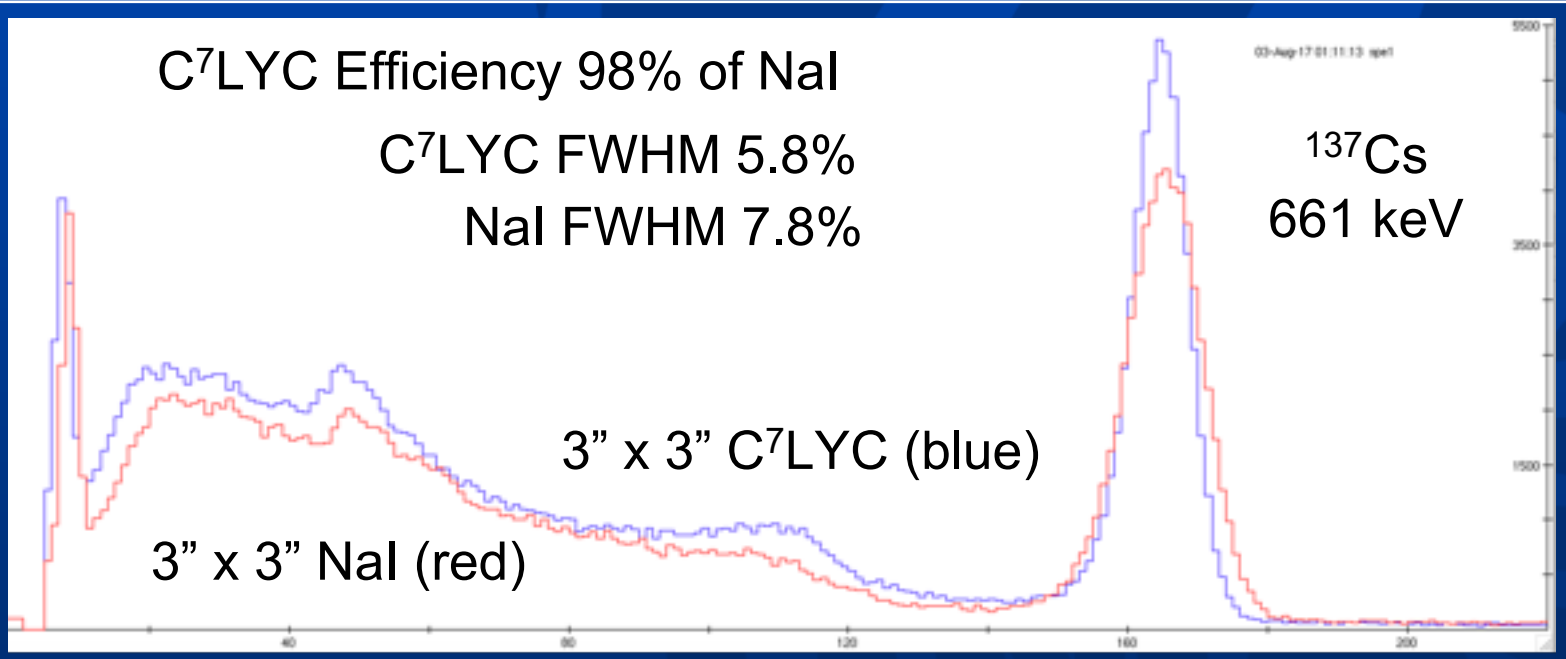


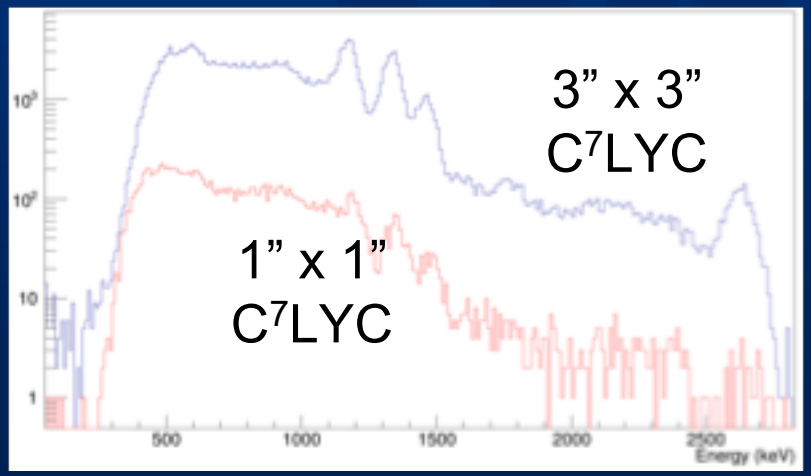
LANL-led experiment (Jan 2018)

the first 3” x 3” C^7LYC

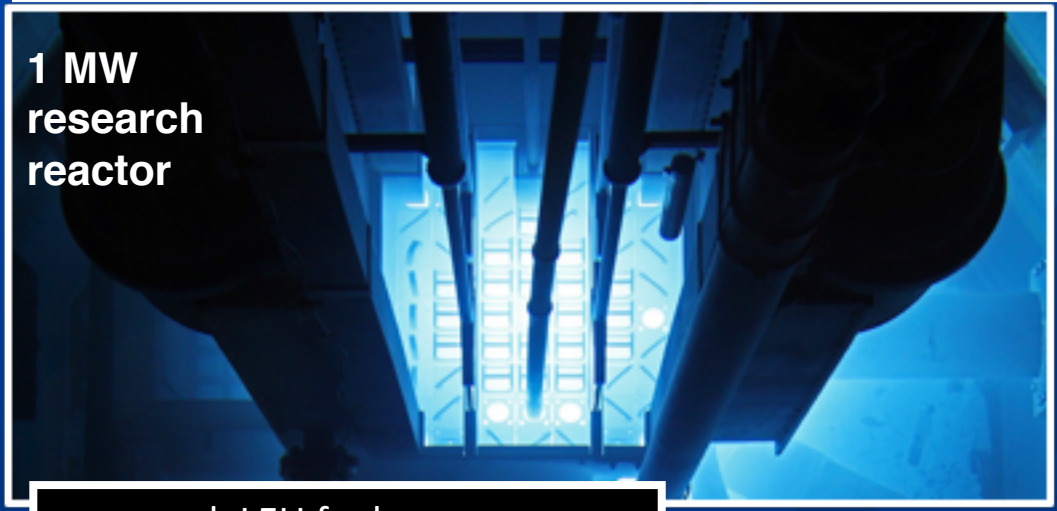


the first 3” x 3” C^7LYC





UMass Lowell Radiation Laboratory: Facilities



1 MW research reactor

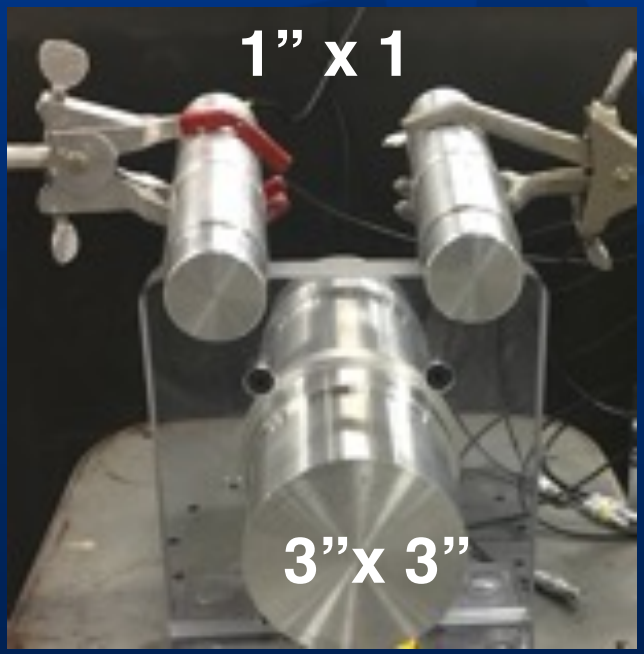
open pool; LEU fuel;
3 horizontal beam ports;
in-core sample (~10^{13} n/cm^2/s);
thermal column (~10^6 n/cm^2/s);
digital neutron radiography
hot cell with remote manipulators

5.5 MV CN single ended Van de Graaff

p, d, α beams;
100 µA DC beam;
Mobley buncher;
sub-ns pulsing;
mono-energetic pulsed neutrons via ^{7}Li(p,n);
neutron beam line;
proton microprobe;
scattering chamber

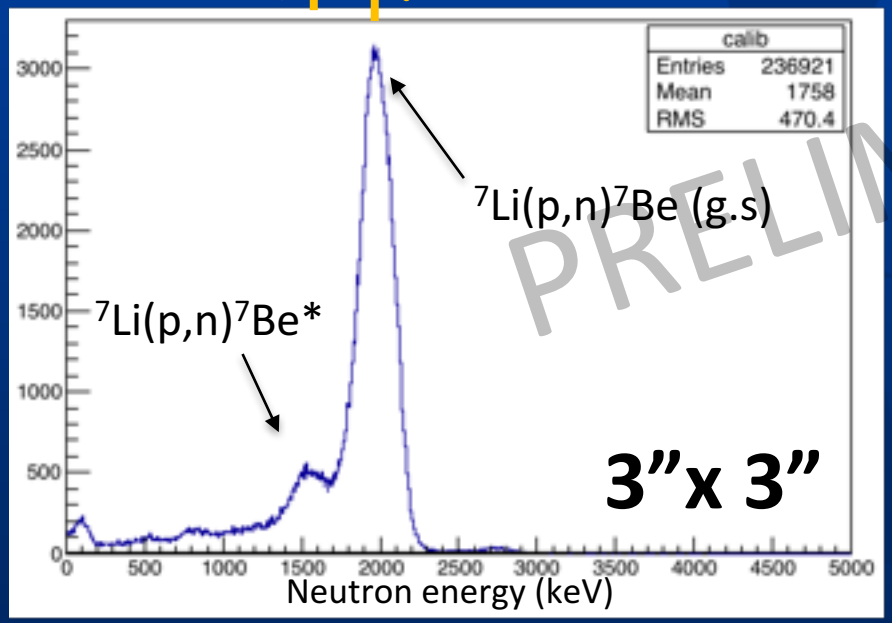
C^7LYC measurements at UMass Lowell

- Directly measure C^7LYC efficiency at accelerator
- Mono-energetic neutrons via $^7Li(p,n)^7Be$
- Neutron production rate via ^7Be assay (52-day half-life)
- One ^7Be per neutron, 10% β-decay branch, 479-keV γ-ray

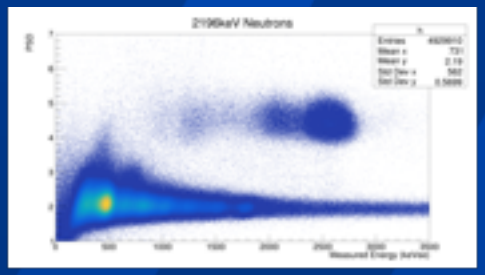


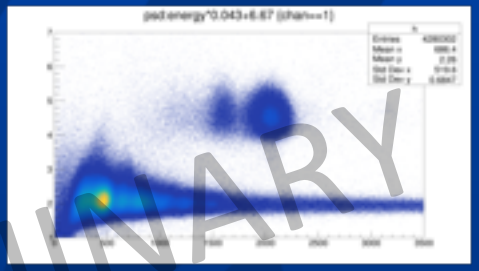
C^7LYC tests at UML

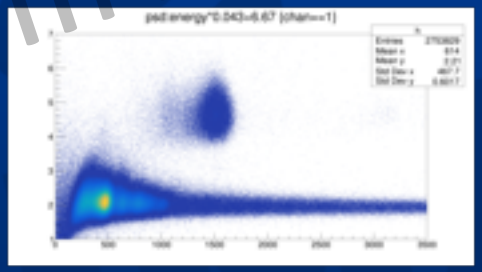
Neutron spectrum from $^7Li(p,n)^7Be$

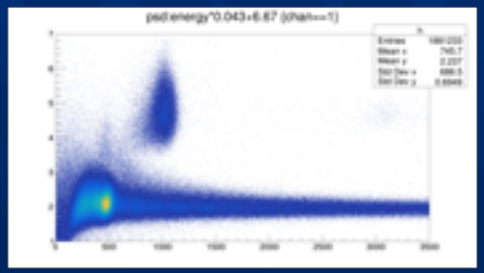


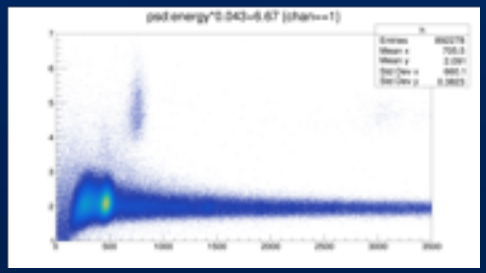
In progress !





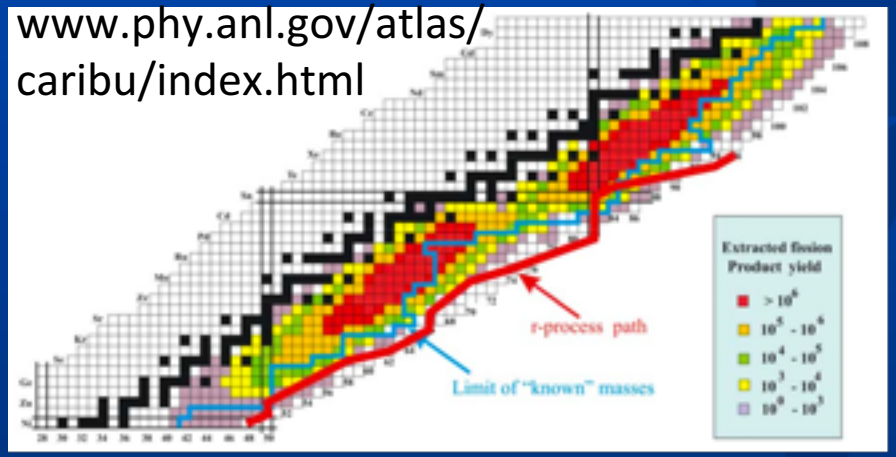






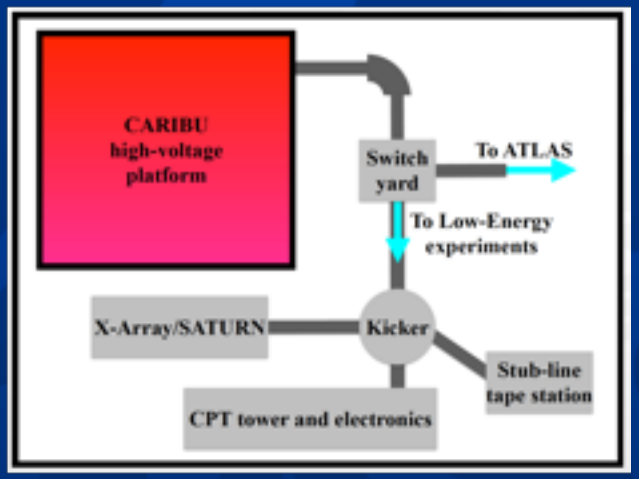
β-delayed neutron emitters at CARIBU

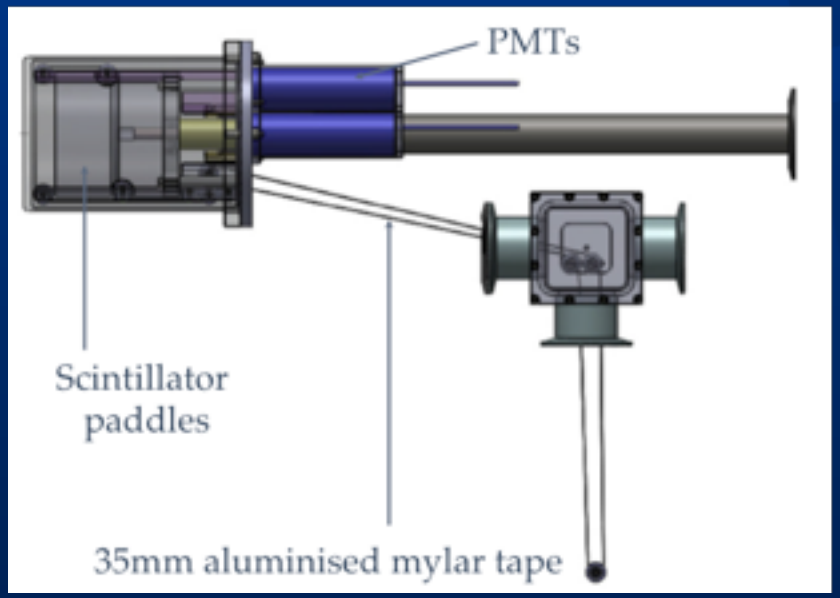
www.phy.anl.gov/atlas/caribu/index.html



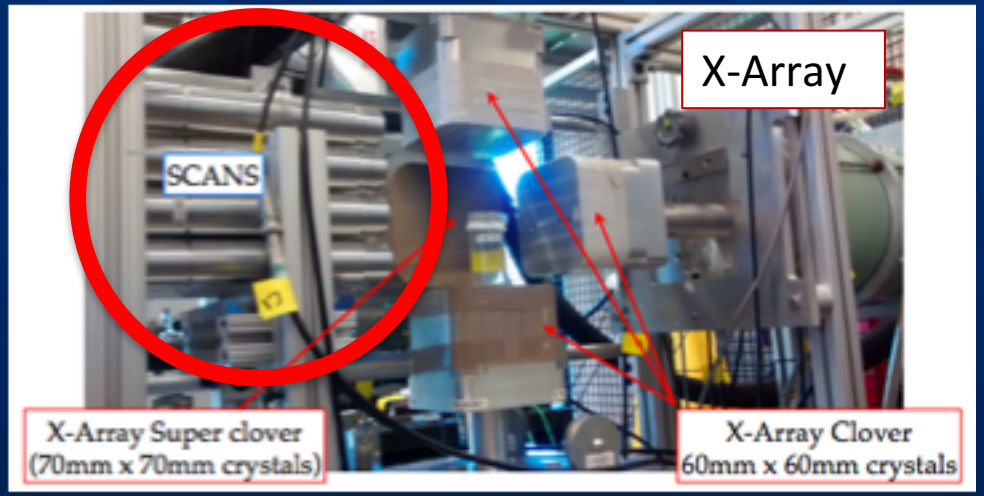
CAlifornium Rare Isotope Breeder Upgrade

1-2 Ci ^{252}Cf source
Gas catcher
1: 20000 isobar separator



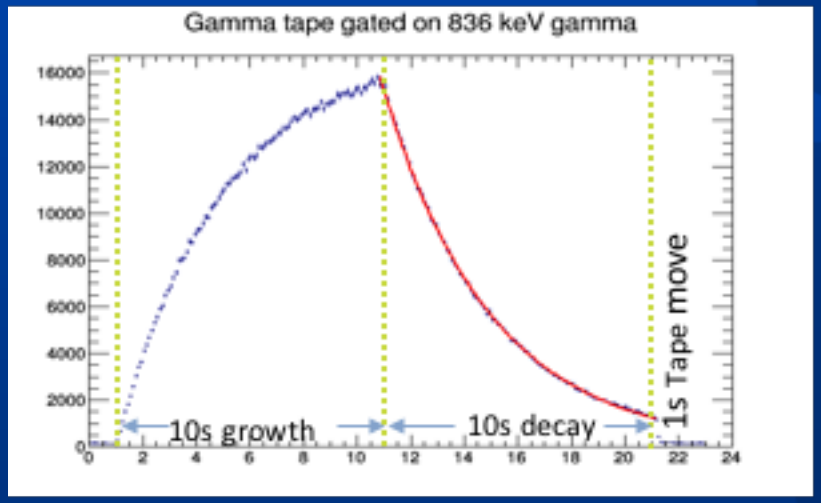


SATURN (Scintillator And Tape Using Radioactive Nuclei)



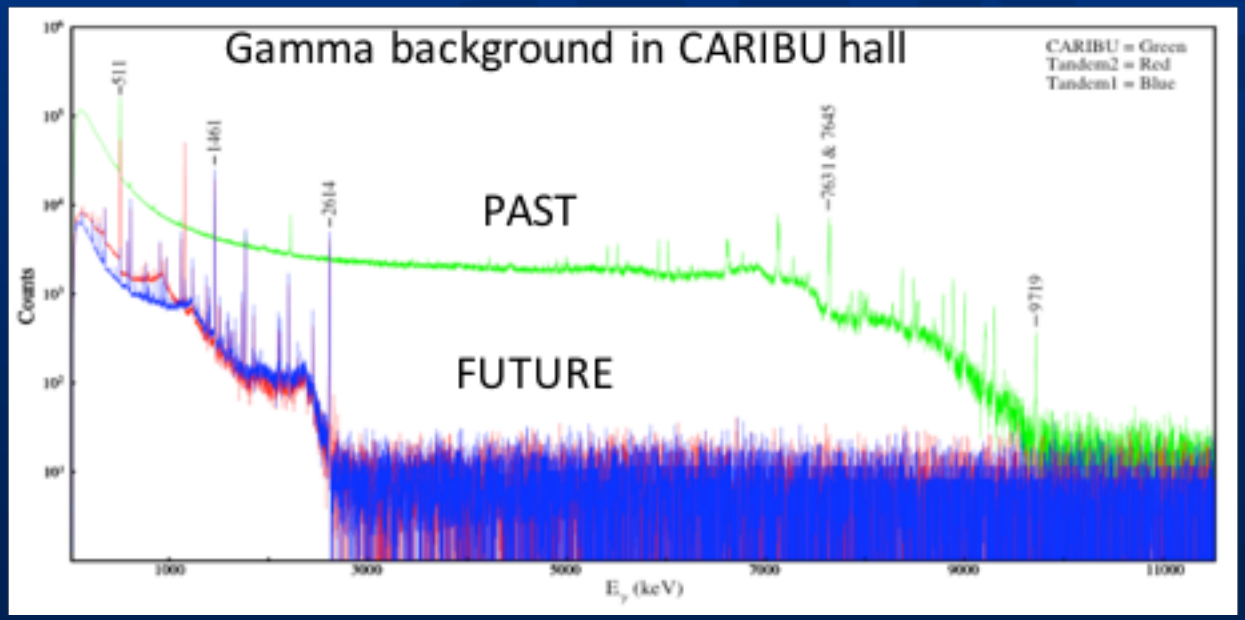
A.J. Mitchell at al., NIM A763, 232 (2014)

$^{94}Rb \rightarrow {}^{94}Sr$



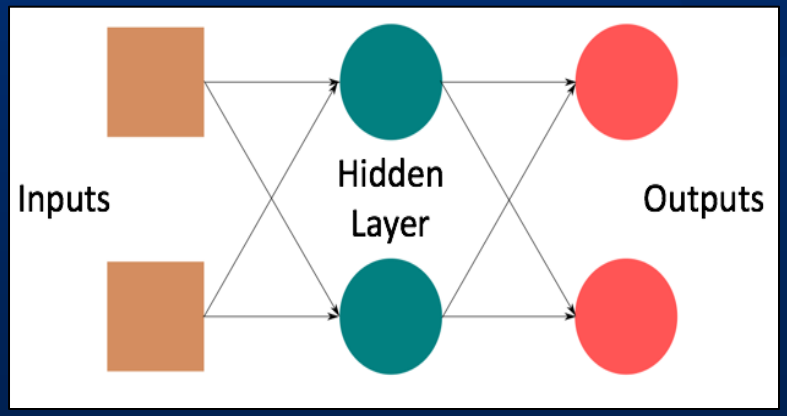
Measured $t_{1/2}$ 2.75(2)s
(compare with 2.76(6)s)

CLYC results inconclusive, to be repeated in new low-background CARIBU hall



machine learning n-γ discrimination

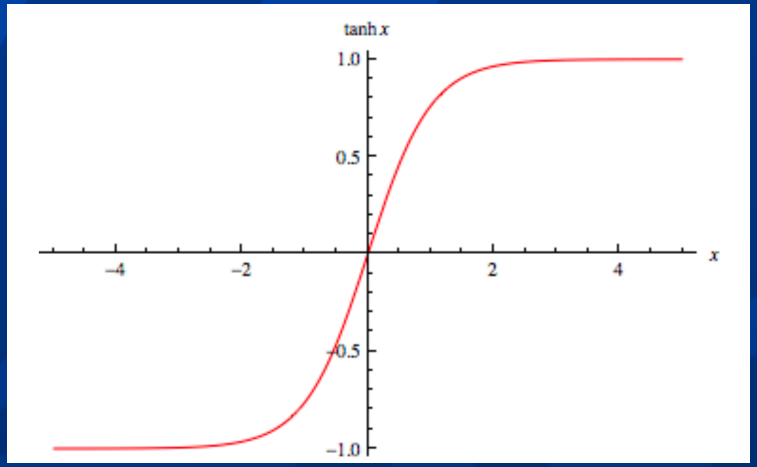
- n/γ PSD a binary classification problem
- Common target of machine learning algorithms
- Artificial neural networks promising for n/γ PSD in liquid scintillators
- "Supervised learning" – requires pre-classified training data
- Feed forward neural network
- Interconnected "hidden" layers of 'artificial neurons'
- Each neuron has many inputs x_i and one output z
- The output is a weighted sum of its inputs
- Passed through an 'activation function' f



$$z = f\left(\sum_{i=1}^{N} w_i x_i\right)$$

machine learning n-γ discrimination

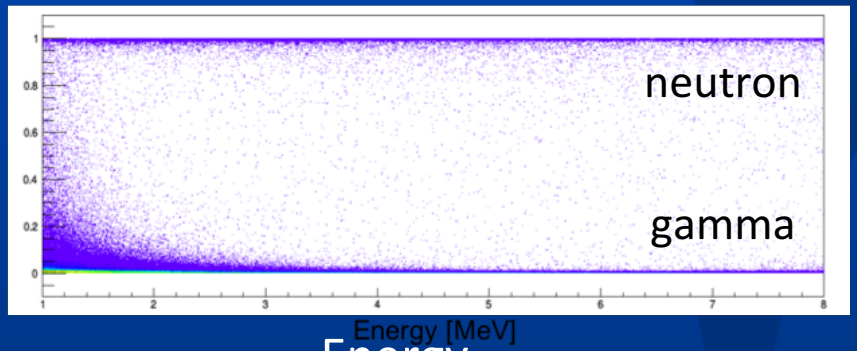
- Trace presented to network as inputs
- Passed through a single hidden layer
- Activation function tanh x
- Vary weights and biases of each neuron
- Maximize accuracy over training data
- Output of ANN 1 or 0 (n or γ)



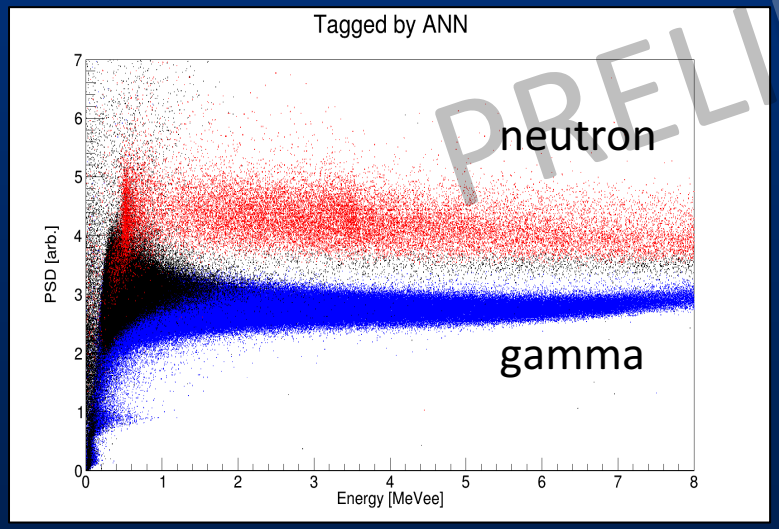
- ~500 lines of Python and C++, classifier is in Python, using Keras
- Keras - wrapper around Tensorflow machine learning library
- Optimization algorithm is 'stochastic gradient descent'
- 544 inputs, 544 neuron hidden layer, 1 neuron output layer

- Training data: 20k γ and 20k neutrons between 1.5 and 5 MeV
- One complete optimization pass over training data --'epoch'
- For the datasets and networks used, each epoch took 3-4s

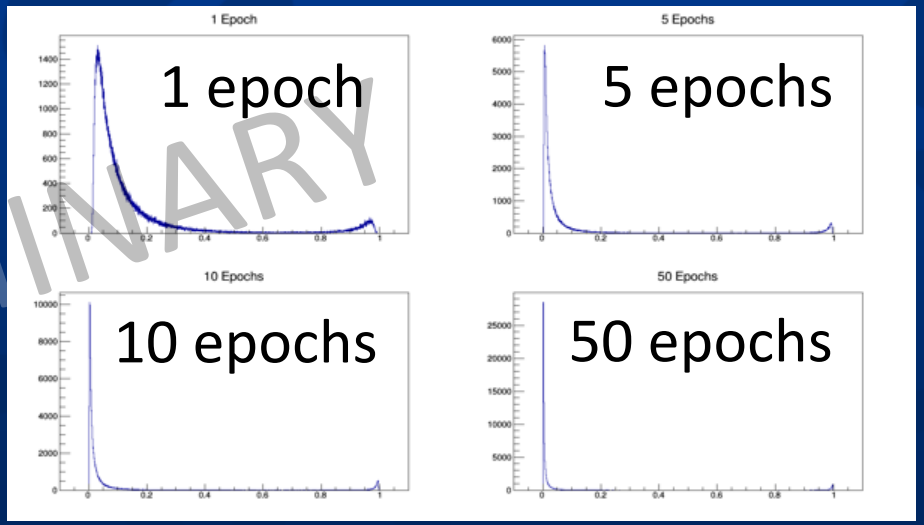
ANN: Supervised Learning



Artificial Neural Network
Supervised learning



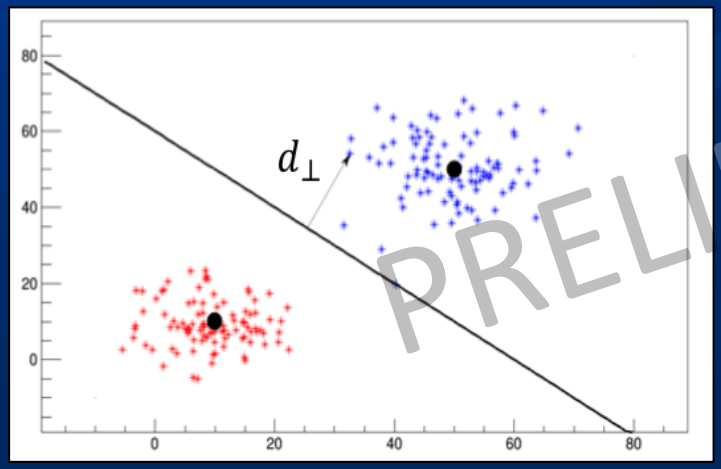
Separation increases with more training

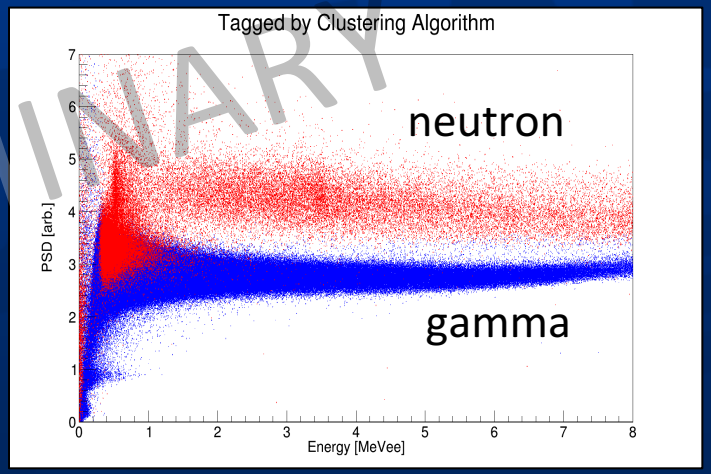


Unsupervised learning: K-means clustering

- Cluster analysis algorithms do not require pre-classified training data
- C^{++} implementation of ***kmeans^{++}*** algorithm
- K=2 for n/γ discrimination
- Perpendicular distance from hyperplane between centroids provides separation
- Training data set had ~28K neutrons and ~1.5M gamma rays

K-means Clustering: Unsupervised learning

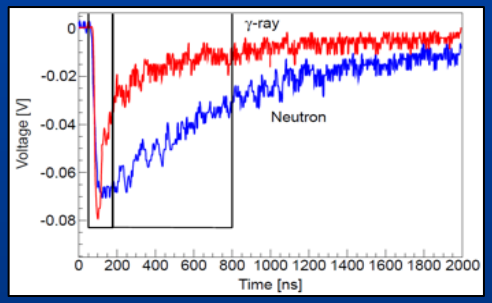


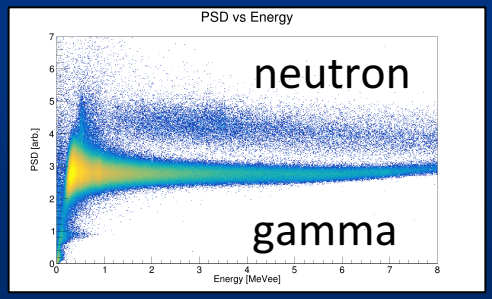


Machine learning algorithms capable of separating neutrons and gamma-rays in CLYC scintillators in the energy range investigated

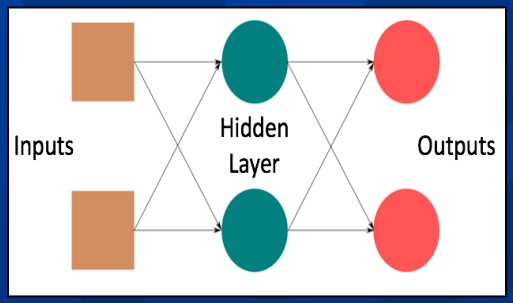
machine learning n-γ discrimination

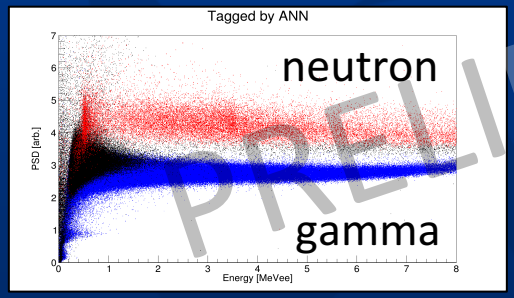
Charge comparison
Generates training data



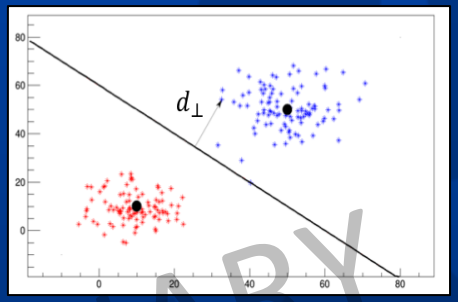


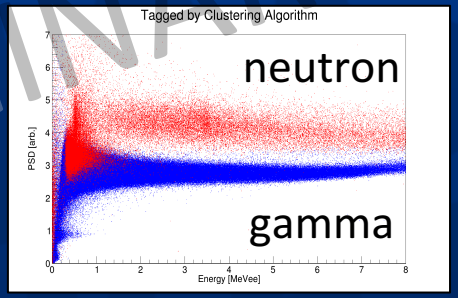
Artificial Neural Network
Supervised learning





K-means Clustering
Unsupervised learning





Machine learning algorithms capable of separating neutrons and gamma-rays in CLYC scintillators in the energy range investigated

WORK IN PROGRESS!!

n/γ discrimination at energies < 1 MeV needs improvement

Summary

- C^7LYC: emerging scintillator for fast neutron spectroscopy
- Right energy window for β-delayed and fission neutrons
- LANL $^{56}Fe(n,n')$ proof-of-principle experiment a success
- Efficiency and low energy response at UML Van de Graaff
- $^{35}Cl(n,p)$ cross-sections awaited for MCNPX simulations
- β-delayed neutron emitters at CARIBU
- Machine learning n-γ discrimination
- Auxiliary detector candidate for FRIB decay station?

Work supported by U.S. Department of Energy
NNSA-SSAP Grant DE-NA0002932 and
Office of Science Grant DE-FG02-94ER40848

UMass Lowell collaborators

Undergrads

Thomas Harrington

Michael D'Eon

Graduate students

Tristan Brown

Emery Doucet

Nathan D'Olympia

Emily Jackson

Patrick Copp

Post-docs

A.J. Mitchell

Gemma Wilson

Chris Morse

Edward Lamere

Faculty

Kim Lister

Andrew Rogers

Peter Bender

Thank you for your attention!