What's Happ'nin at Kentucky

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US Naval Academy, Annapolis, Maryland

NSF 1913028 / 2209178

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Today's Members

University of Kentucky, Chemistry
Erin Peters, lecturer
Jackson Dowie, postdoc
Steven Yates, lab director

University of Dallas
University Kentucky, Chemistry
University Kentucky, Physics
Sally Hicks, emeritus / adj

Mississippi State University
Stephan Vajdic, grad student
Daniel Araya, grad student
Ben Crider, prof

US Naval Academy
Jeff Vanhoy, prof

FiberTek, Inc
Jarrod Marsh

Recent Players

University of Kentucky, Chemistry
Yongchi Xiao, postdoc

University of Dallas
Elizabeth Chouinard, undergrad
Sarah Evans, undergrad

US Naval Academy
Avi Perkoff, undergrad
Madison Roskos, undergrad

LLNL
Anthony Ramirez

Since WINS 2018 Predeal
- finished $^{12}C(n,n)$
- $^{nat}Li(n,n)$
- new digital DAQ
- $^{13}C(n,n)$
- $^{54}Fe(n,p)^{54}Mn \rightarrow {}^{54}Fe$
- $^{24}Mg(n,n\gamma)$

New Initiatives
- $^{19}F(n,n\gamma)$
- $^{7}Li(n,n)$ w dDAQ, ROOT
- ^{51}V level scheme
- restoring $\gamma-\gamma$ coinc
- dynamic biasing

Future
- in the hopper
- challenges at UKAL

Dirty Hands

Laboratory Skills

Operation, Maintenance, Repair, Design

Dirty Hands brought to you by

University of Kentucky
60 years
UK
1964-2024
Accelerator Laboratory

Dirty Hands

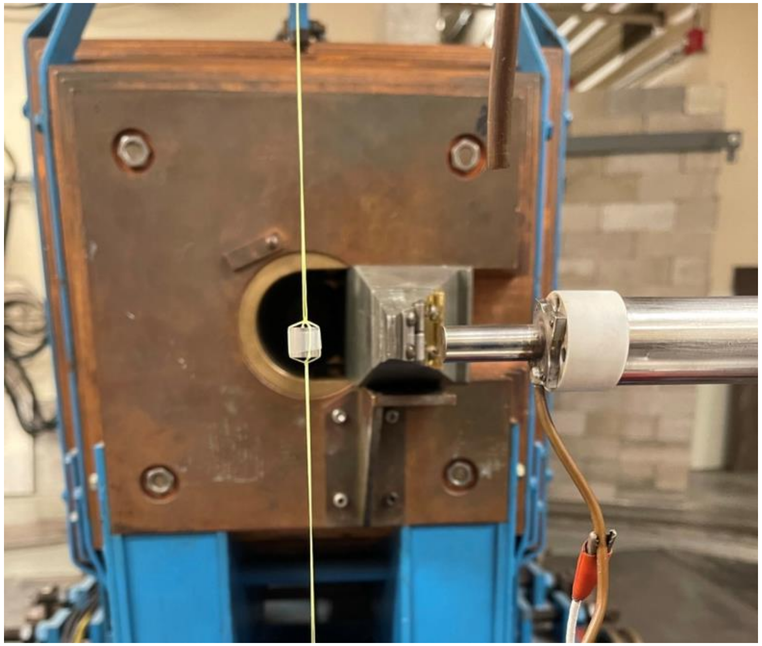
Laboratory Skills

Operation, Maintenance, Repair, Design

Dirty Hands brought to you by University of Kentucky Accelerator Laboratory 60 years UK 1964-2024

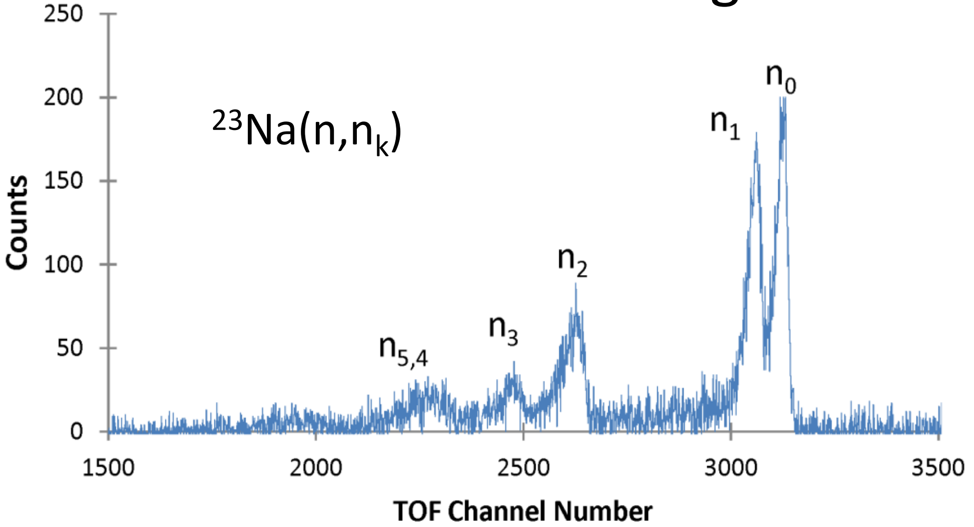
Quick reminders about the University of Kentucky Accelerator Lab programs

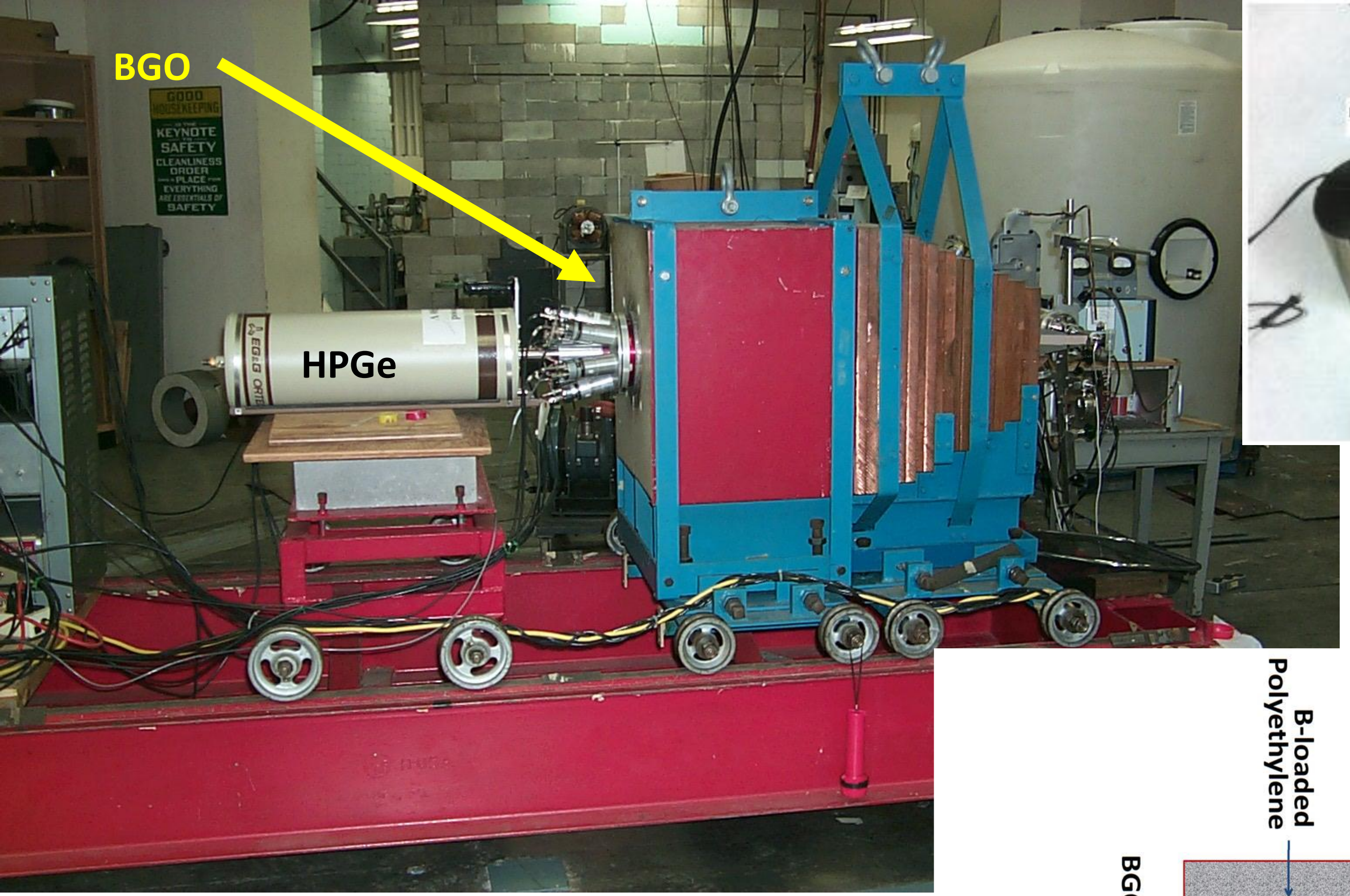
- **Accelerator**
  - HVEC Model CN: 7 MV
  - rf source
  - p, d, ^{3}He, α, … ions
  - Authorized for ^{3}H gas targets
  - measure exit neutron energy
  - 1 ns pulse widths every 533 ns
- **Basic Nuclear Science**
  - Nuclear Structure via (n,n'γ)
    - Level Schemes & Transitions
    - Spectroscopic Information
    - DSAM Lifetimes
  - (^{3}He,nγ)
- **Applied Nuclear Science**
  - Differential (n,n') Cross Sections
    - ^{12,13}C, ^{7}Li, ^{19}F , ^{54,56}Fe , ^{23}Na , ^{28}Si
  - Detector Development
    - Univ Guelph / TRIUMF
  - measurements for friends

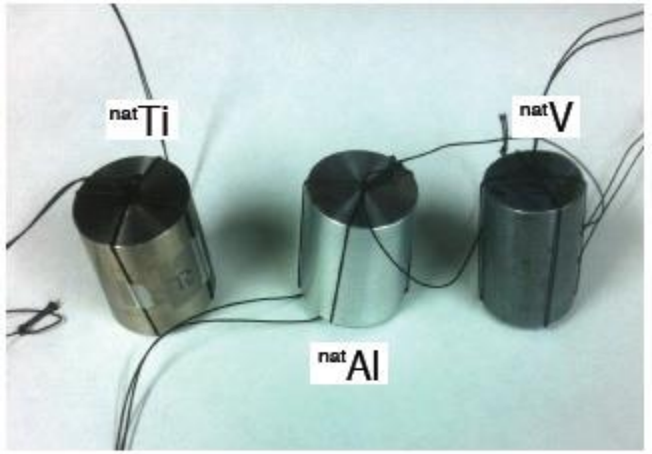


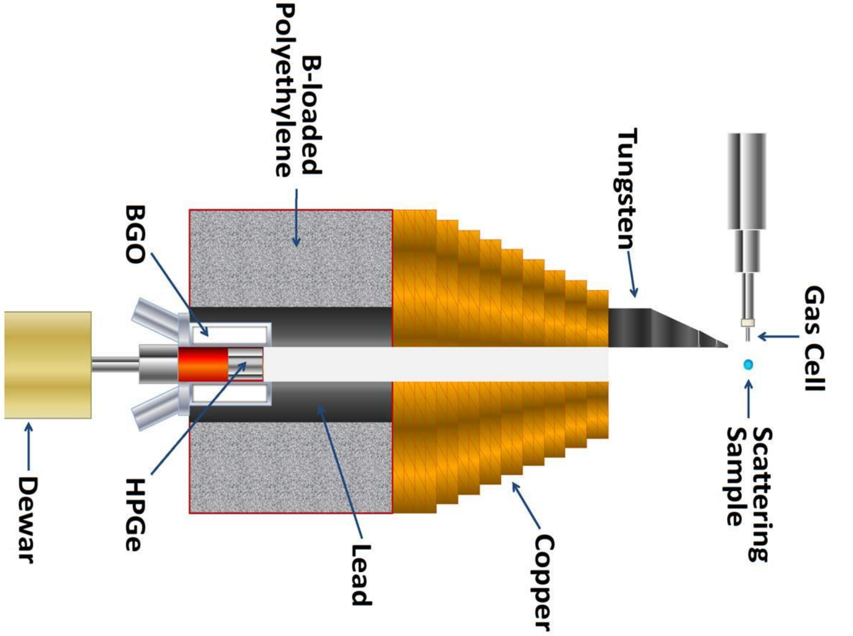
Neutron Time-of-Flight

Pulsed beam. PSD.
Exit channel neutrons sort by flight time.





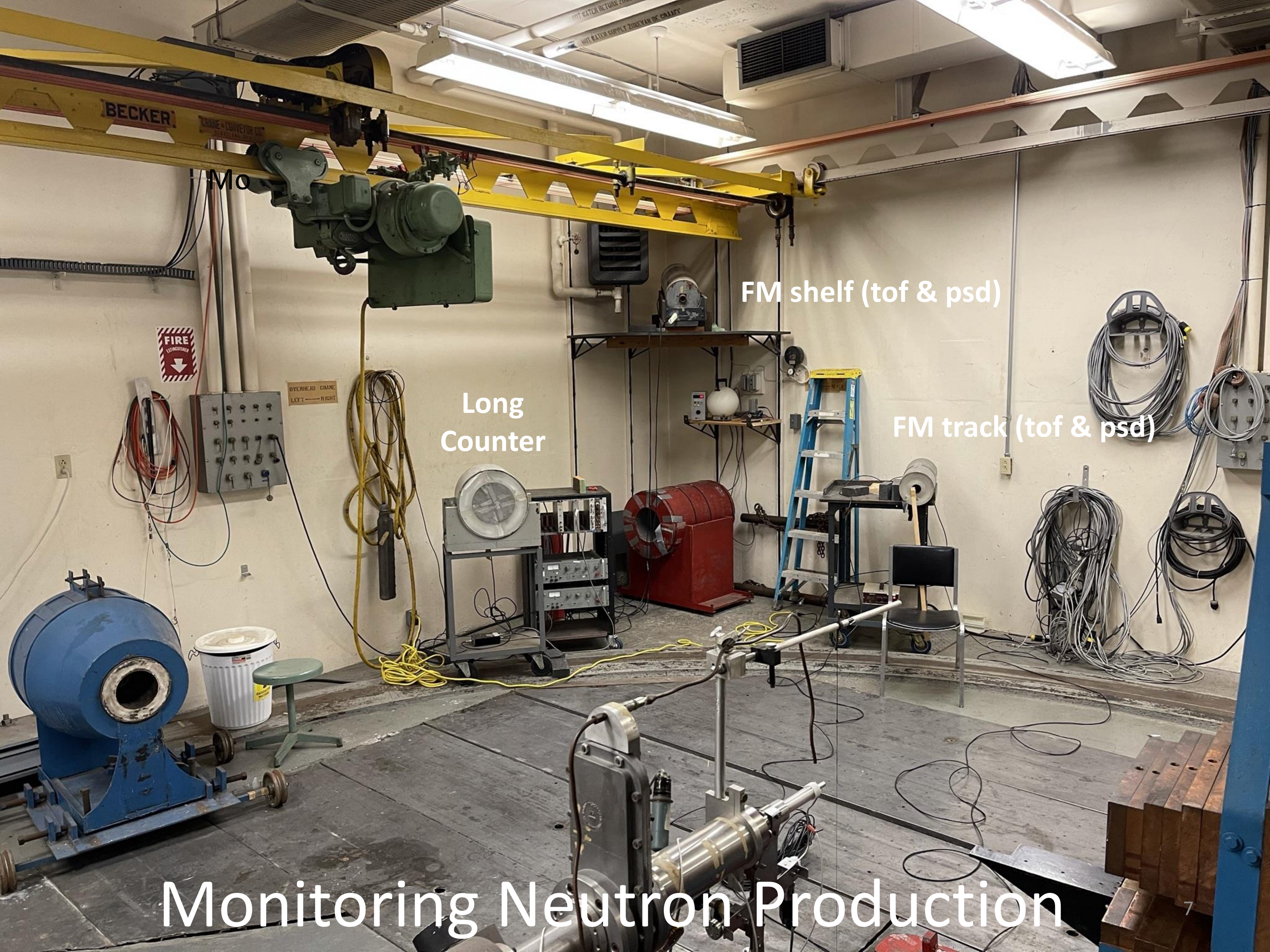




γ-Ray Detection

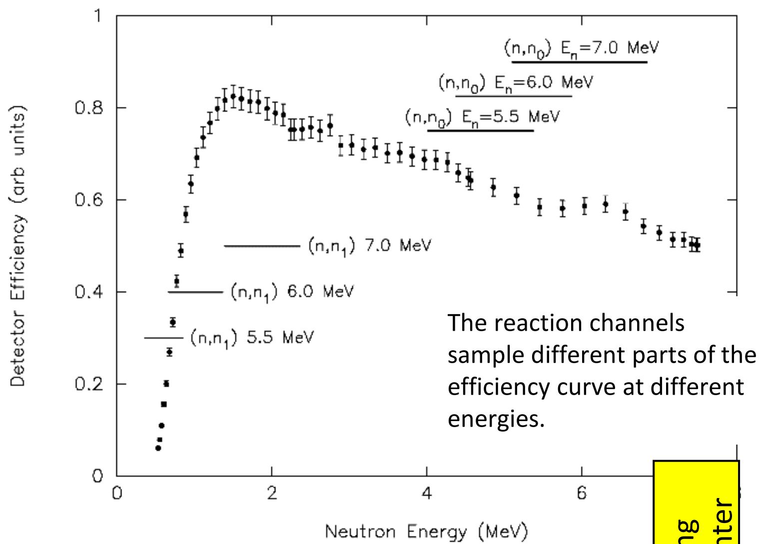
(singles setup)

Monitoring Neutron Production



Measuring MAIN Detector Efficiency

example from former 12C

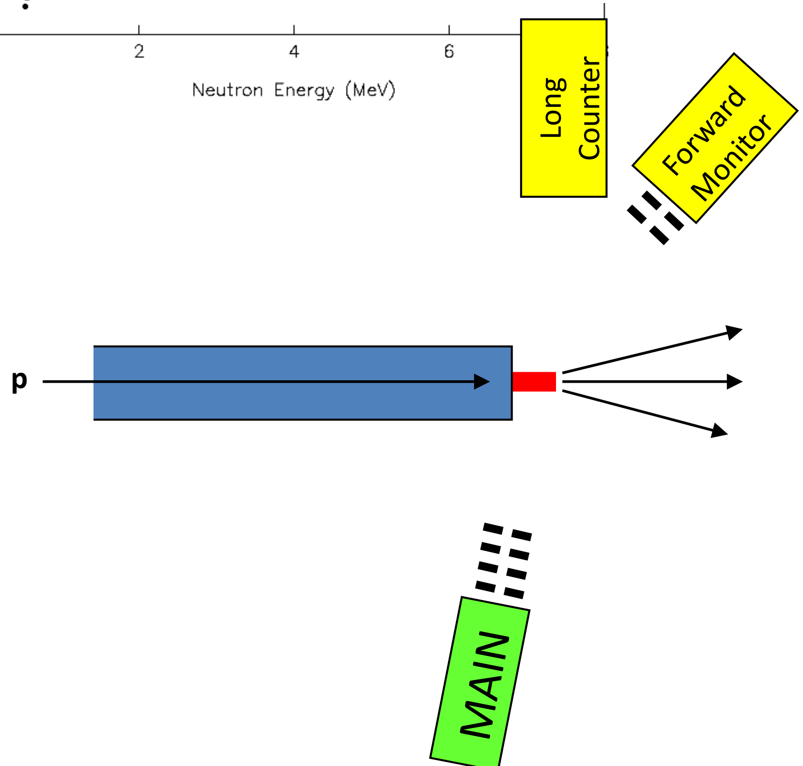


The reaction channels sample different parts of the efficiency curve at different energies.

$$eff(E_n) = \frac{Yield}{FM \bullet \frac{d\sigma}{d\Omega}_{Tpn}}$$

MAIN detector efficiencies must be measured because of

- **descriminator threshold effects**
- **individ scintillator assembly behaviors**
- **sub-LLD pileup**



Measure
angular / energy dependence of the T(p,n) or D(d,n) source reactions.

Generic UKAL Uncertainties

Issue	
Counting Statistics n_0, n_1	<1%
Ability to Extract Yield from Peaks in Spectra (elas)	~2% usually
Ability to Extract Yield from Peaks in Spectra (inel)	...hum
Monitoring Neutron Production	<1%
Sample Mass	<<1%
H(n,n) reference XS	<0.5%
Detector Efficiency	
3H(p,n) $d\sigma/d\Omega$	~3%

Issue	
Atten & Mult Scat	
$n\sigma$	0.3 %
sample radius	0.3 %
sample-Tcell dist	0.2 %
method	<5%

Back-burner project to make this more definite

depends on the level scheme of the target nucleus – overlapping peaks?

- Overall during ^{23}Na runs: elastics ~8-10%
  inelastics ~13-18%
- Overall during $^{54-56}$Fe runs: elastics ~7-10%
  inelastics ~10-14%

Overall during C runs: elastics ~6%
inelastics ~10%

We cannot make sub% determinations of cross section values, however our angular distributions guide selections of model parameters.

^{nat}C

Undergraduate students on the [nat] Carbon paper

data taken 2011-2016 & 2016-2020

64 (n,n') ang distrib at 45 incident energies btw 0.5 - 8 MeV
+ 12 (n,n'γ) btw 5.6-7.8 MeV

} a monster project

ELSEVIER Nuclear Physics A 1023 (2022) 122446
www.elsevier.com/locate/nuclphysa

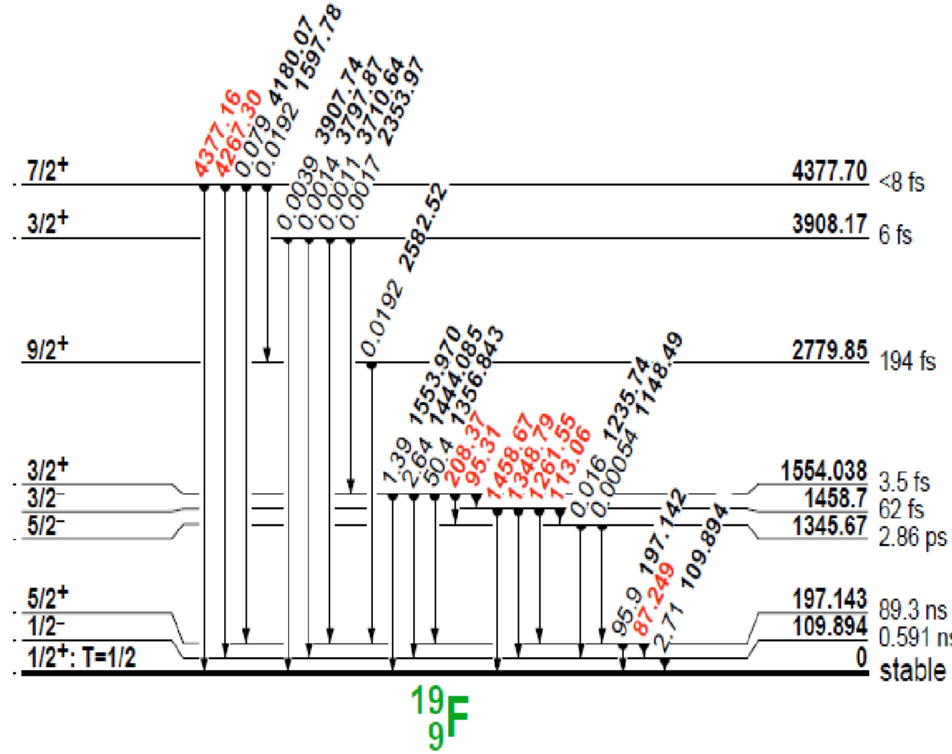
Neutron elastic and inelastic scattering differential cross sections on carbon

A.P.D. Ramirez[a,b], E.E. Peters[a], J.R. Vanhoy[c,*], S.F. Hicks[d,b], L.A. Alasagas[c], D.K. Alcorn-Dominguez[c], S.T. Block[d], S.T. Byrd[d], E.A. Chouinard[d], B.M. Combs[d], B.P. Crider[b], E.C. Derdyn[d], L. Downes[d], J.A. Erlanson[c], S.E. Evans[d], A.J. French[d], E.A. Garza[c], J. Girgis[d], T.D. Harrison[c], S.L. Henderson[d], T.J. Howard[d], D.T. Jackson[d], L.J. Kersting[d], A. Kumar[a], S.H. Liu[a], C.J. Lueck[d], E.M. Lyons[d], P.J. McDonough[d], M.T. McEllistrem[b,1], T.J. Morin[d], S. Mukhopadhyay[b], T.A. Nguyen[d], M. Nickel[d], S. Nigam[a], R.L. Pecha[d], J. Potter[a], F.M. Prados-Estévez[a,b], B.G. Rice[c], T.J. Ross[a,b], Z.C. Santonil[d], J. Schneiderjan[d], L.C. Sidwell[d], A.J. Sigillito[d], J.L. Steves[c], B.K. Thompson[c], D.W. Watts[c], Y. Xiao[a,b], S.W. Yates[a,b]

Industry, Compass Minerals
Ministry
MD U. Of KY (radiation oncology)
High school physics teacher
Unknown
Laboratory Tech, Eastfield College
Ph.D. U. of Wisc (Nuc Eng) **Sandia National Lab**
Industry, Raytheon
Ph.D. Texas Tech (CE), Jacobs
Ph.D. Candidate U. of FL (Nuc Eng) **LANL**
M.S. Notre Dame (EE), RF Eng at Lockheed Martin
Data analyst
Nurse
Ph.D. Candidate, U. of Kansas (particle)
M.S. UTA (EE), SPARX Engineering
GNC Engineer, Lockheed Martin
UD Student
Ph.D. candidate, TAMU (Nuc Eng)
M.S. U. of KY (Rad Oncology)
Ph.D Notre Dame (Nuc Phy)
MD, Psychiatry, U. of Southern CA
Ph.D. Candidate, UC Santa Barbara, Photonics
MD U. Of KY, Internal Medicine
Ph.D. Princeton (EE); Faculty U. of PA

Ramirez, Phys Rev C 1023, 122446 (2022)

^{19}F



- Effectively no data since 1950s-1960s
- ^{19}F is evil
- 90 ns isomer
- Hard to normalize xs at low energies.
- Had to develop new DAQ

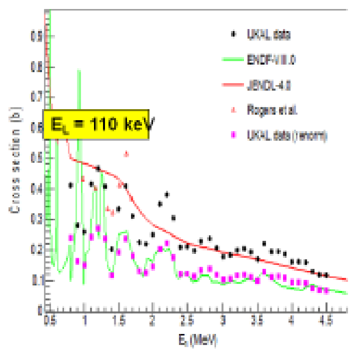
https://depositphotos.com/13830278/stock-illustration-cartoon-red-devil.html

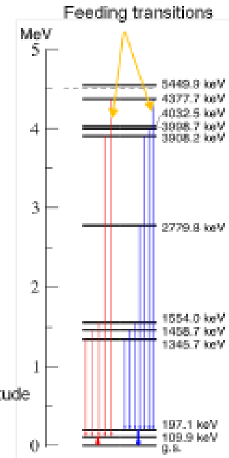
^{19}F

May 2018 Measurements at UKAL

110 keV ½+
isotropic

^{19}F ➢ Deducing ^{19}F level cross sections





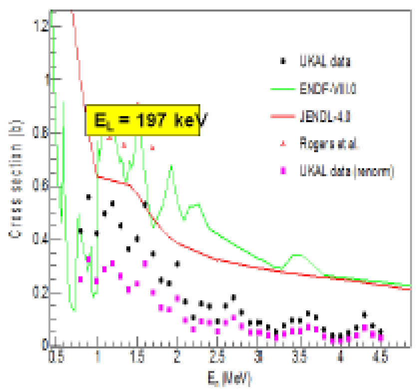
- ENDF-VIII.0 and JENDL-4.0 differ in shape and magnitude
- Our data are closer to JENDL in terms of magnitude but follow the structure presented by ENDF-VIII.0
- UKAL data (renorm) is data multiplied by arb factor so that it agrees with ENDF.

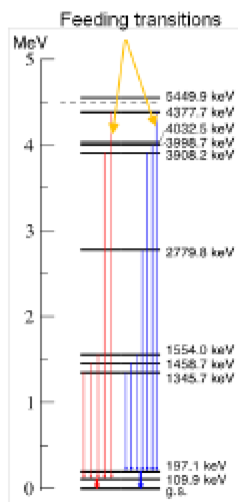
Anthony's results for the 110-keV 1st excited level are similar in magnitude to JENDL, but follow the fluctuations in ENDF better. Our results track ENDF very well over the whole range if we scale them by an arbitrary factor. The Rogers 1961 EXFOR points are scattered all over the place.

197 keV 5/2+
$a_4 \leq 0.1$

→ ~4% problem

^{19}F ➢ Deducing ^{19}F level cross sections





- E_L = 197 keV has a long lifetime with $T_{1/2}$ = 89.3 ns. Our spectra were obtained by gating the TAC on the prompt γ-ray region resulting to a large discrepancy in magnitude when compared to the values in evaluation libraries.

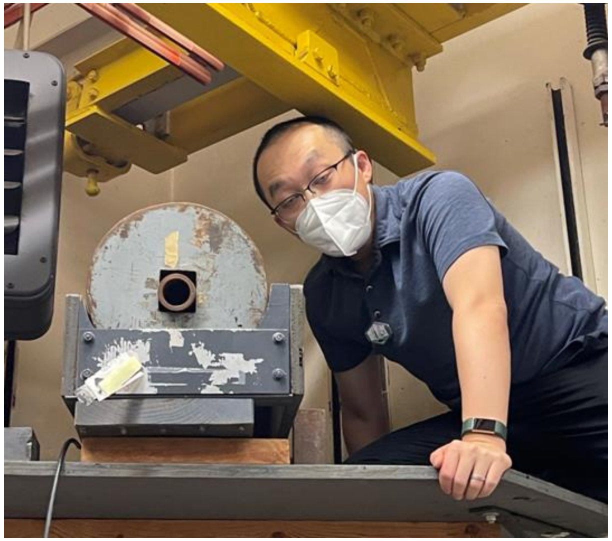
Anthony's results for the 197-keV 2nd excited level are significantly below the JENDL and ENDF. If we rescale them by the factor used previously, they get even worse.

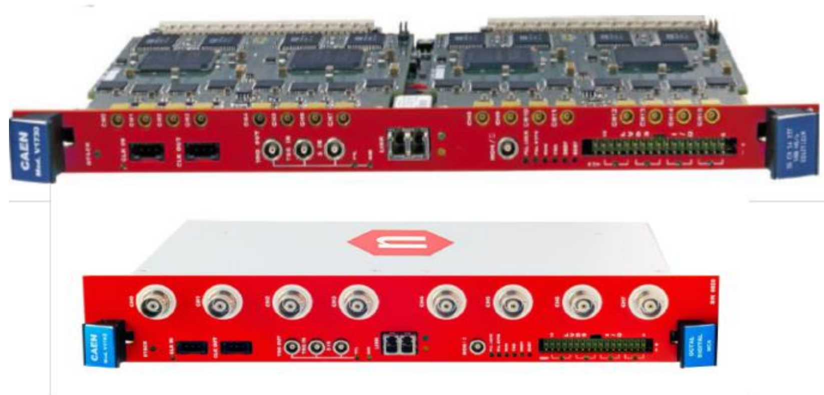
This problem occurs because we miss recording yield from the 90-ns isomer while using the analog DAQ system.

Marcus Nyman had similar problems w 2018 data @ GELINA

Yongchi Xiao

New Data Acquisition System



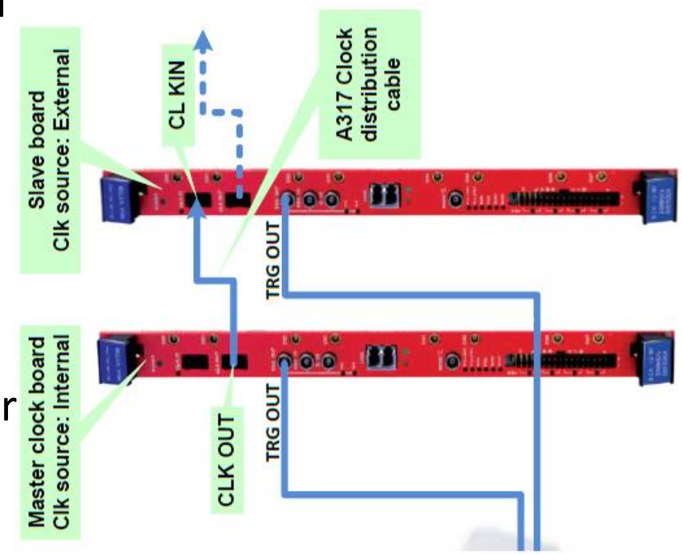


V1730 500 MS/s
scintillators nTOF
MAIN & FM
beam pulse

V1782 100 MS/s
HPGe
Long Counter

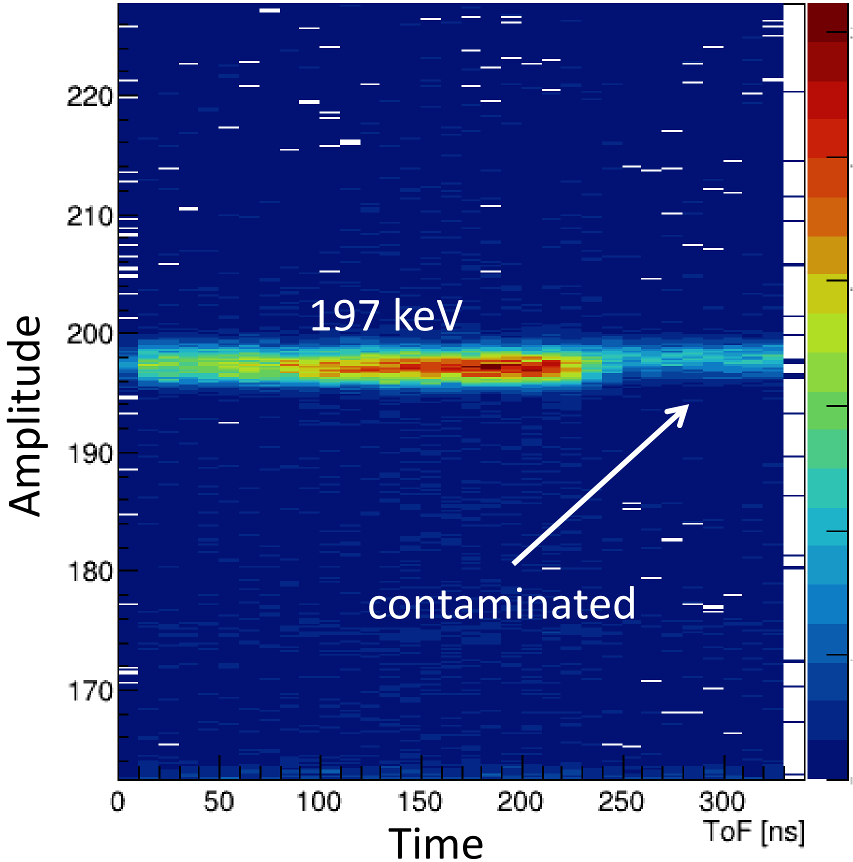
+ can record time-dependent γ-ray spectra
+ observe time dependence of background
+ trapezoidal filter can be fine tuned for each detector, kinda
+ can replay data & change your mind about settings
+ n detector efficiencies less of a hassle
+ can actually digitize the 1.875 MHz beam pulse

- ~~can't do detailed live-monitoring of data coming in~~
- ~~time consuming development, testing, refining~~
- modules may not perform as expected or play well together
- γ peak shapes fill hard disks & buffers fast
- new ways to do things wrong
- team members not satisfied with γ resolution

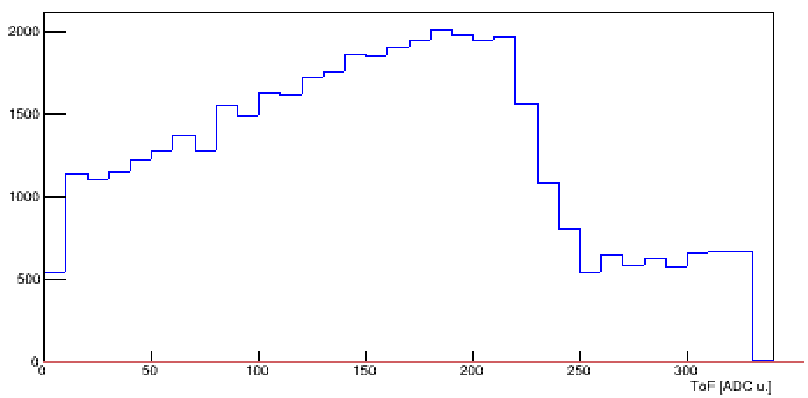


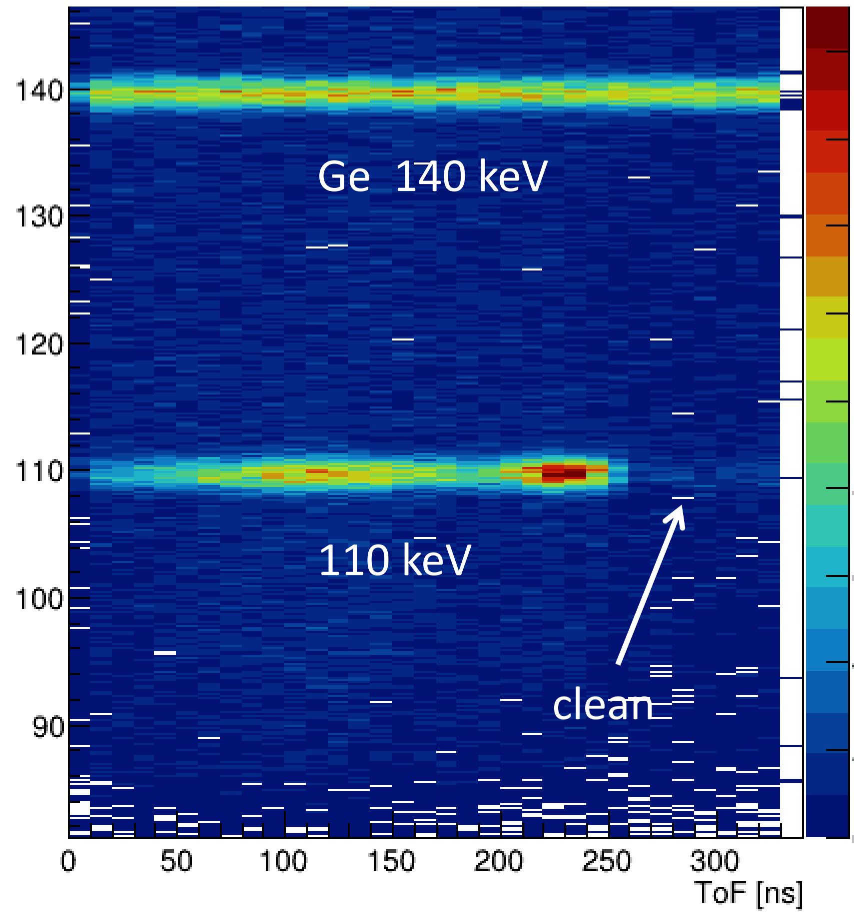
19F Practice Data

Information about 197keV transition using time recording features of new dDAQ



TOF distrib of 197, contaminated by 70Ge(n,γ)

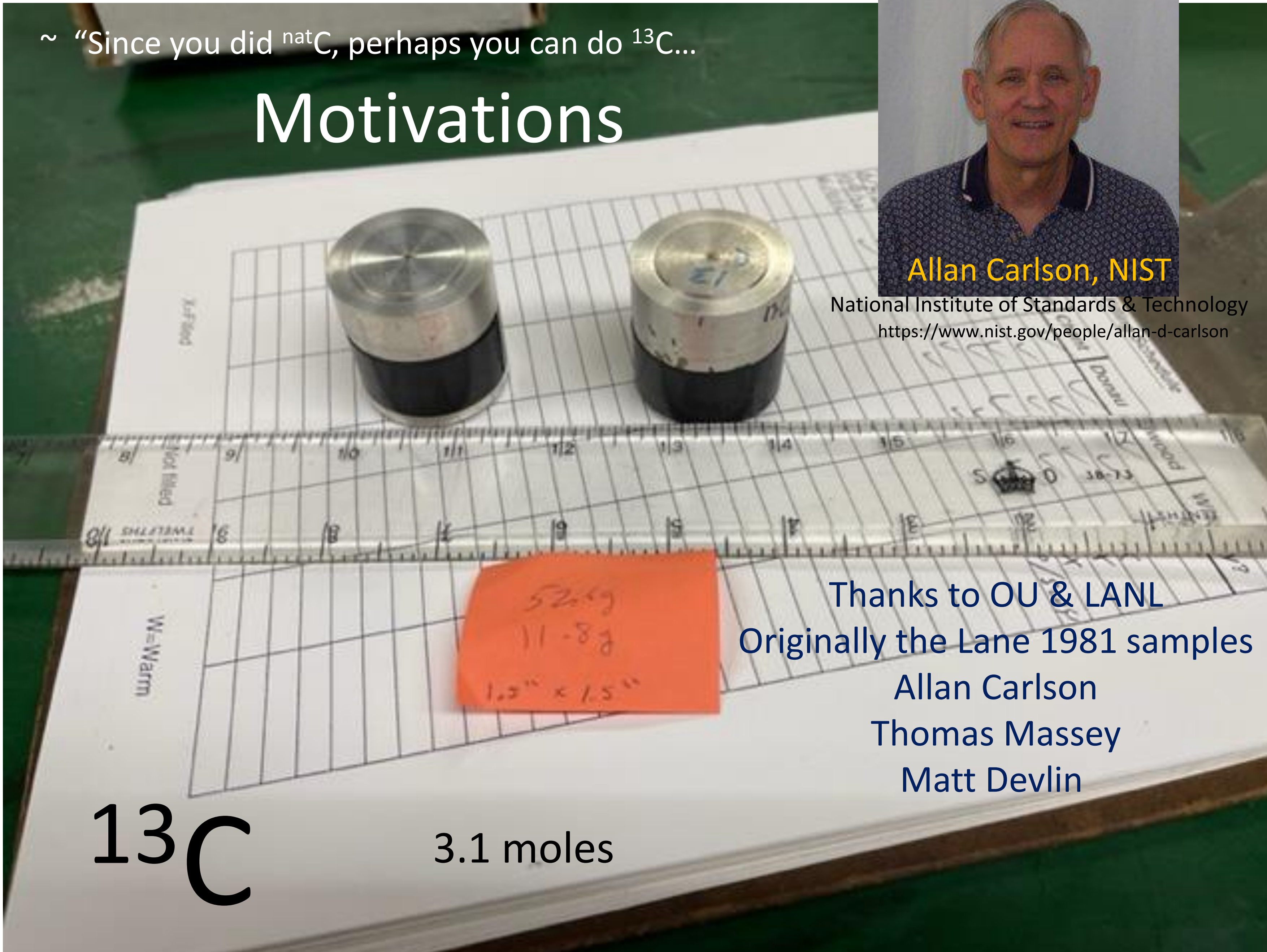




can remove time-dependent bckgnd effects

~ “Since you did ^{nat}C, perhaps you can do ^{13}C…

Motivations



Allan Carlson, NIST

National Institute of Standards & Technology

https://www.nist.gov/people/allan-d-carlson

Thanks to OU & LANL

Originally the Lane 1981 samples

Allan Carlson

Thomas Massey

Matt Devlin

^{13}C

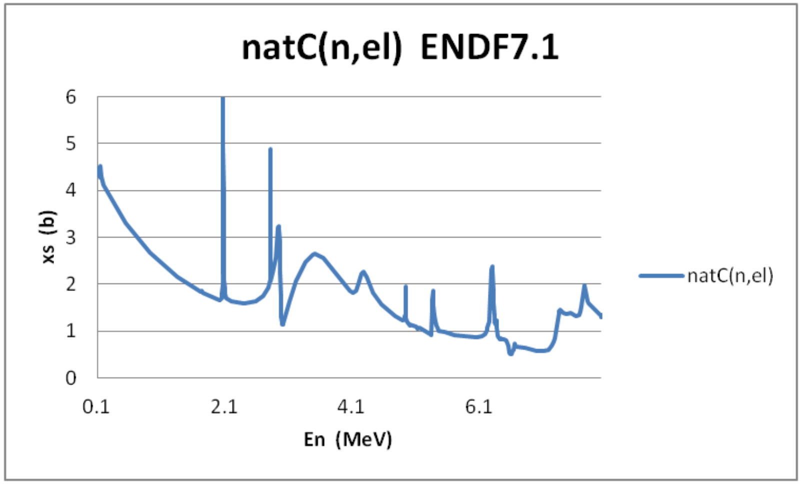
3.1 moles

Motivations

ENDF 7.1 → ENDF 8.0 → ENDF 8.1

2011 | 2018 | soon

some were happy
some were surprised
some were upset
some were mad



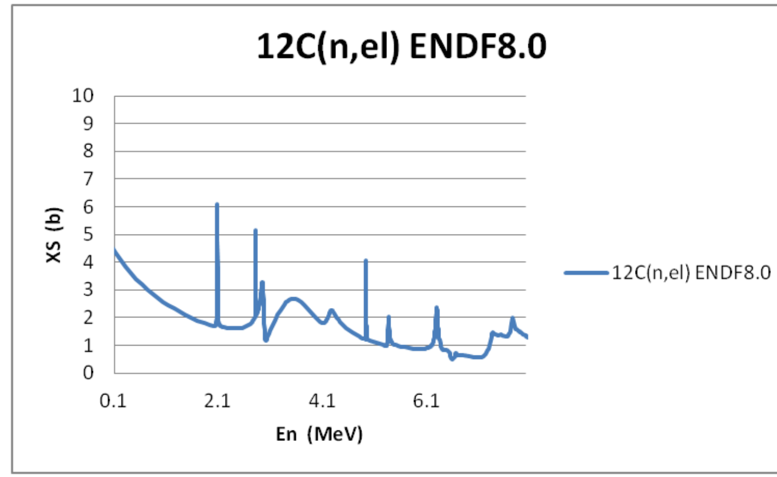
very small
abundance fluctuations

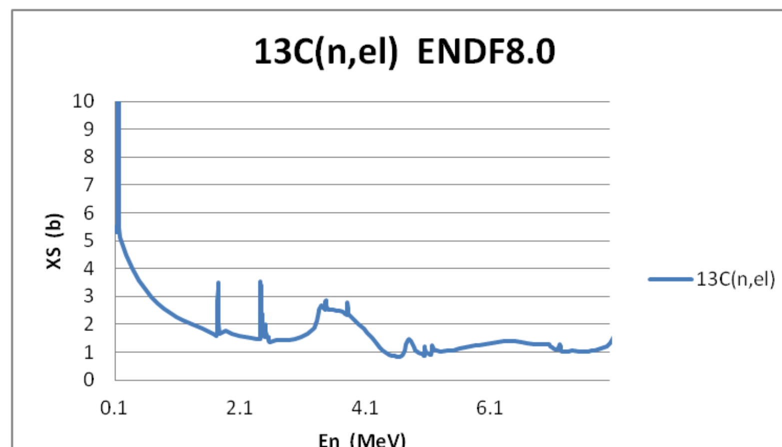
±5

0.9890

0.0110

±5





^{nat}C is a xs ***standard***

btw 1 keV and 1.8 MeV

uncert 0.68 - 0.71%

Carlson NDS 110, 3215 (2009)
Carlson NDS 148, 143 (2018)

"Evaluation of Nuclear Data Stds"

Motivations

Carlson NDS 148, 143 (2018) “Evaluation of Nuclear Data Stds”

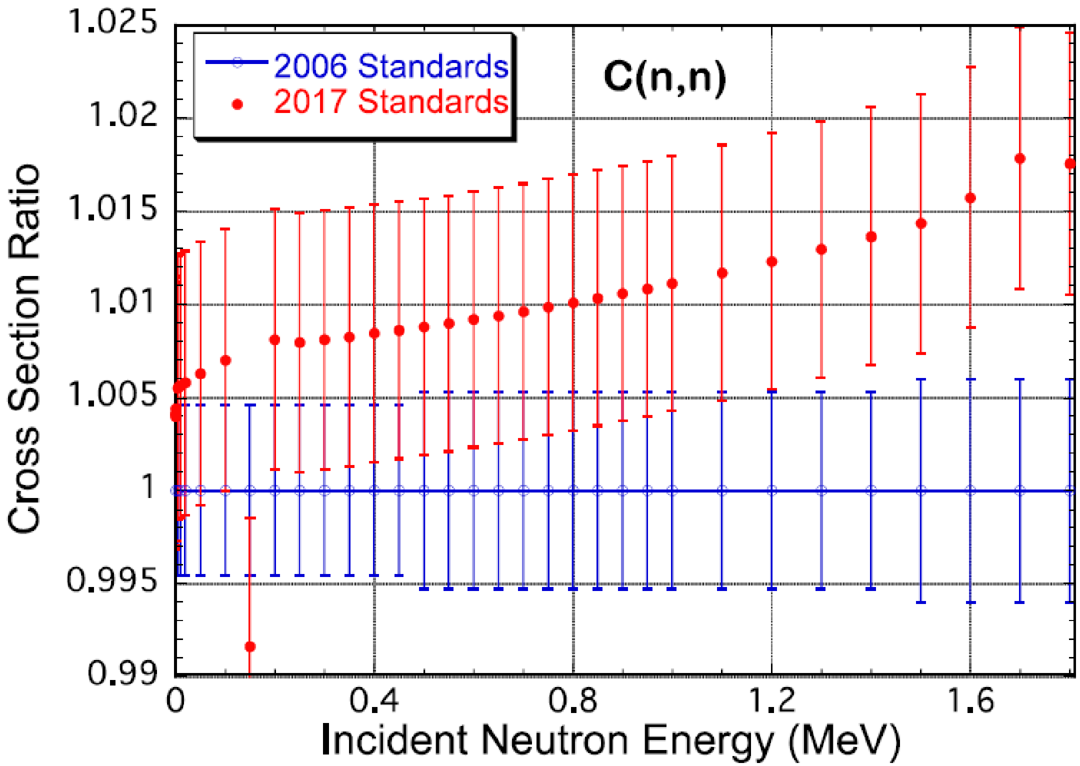


FIG. 18. (Color online) Comparison of the carbon total elastic cross section for the 2017 evaluation with the 2006 standards evaluation. The unrecognized systematic uncertainty of 0.65 % has been included in the 2017 data. The baseline at 1.00 is the 2006 standards evaluation. The structures at about 0.15 MeV and 1.76 MeV are a result of changes in the evaluated ^{13}C total cross section.

Worries

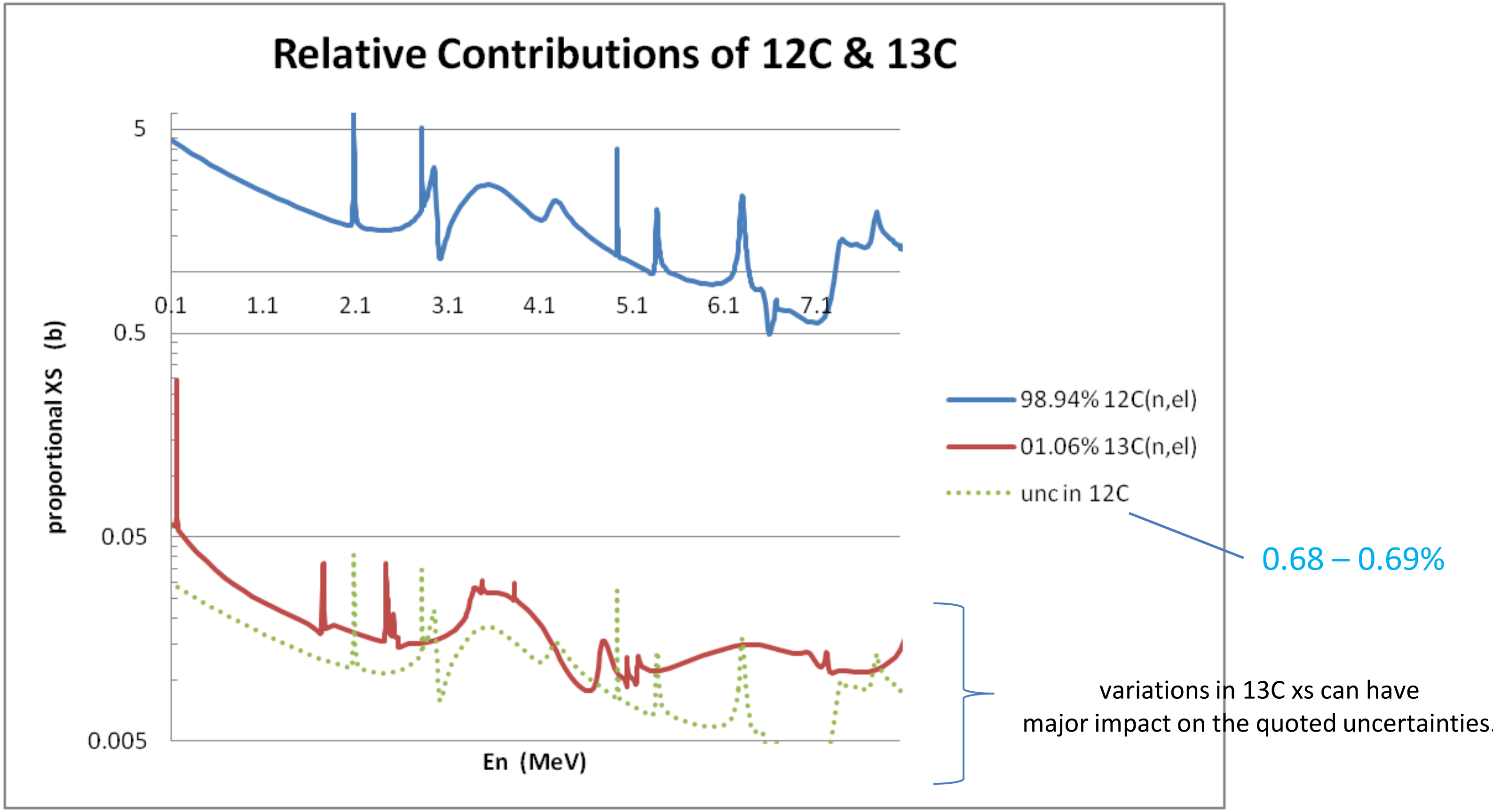
that the 2017 & 2006 values differ by more than the uncertainty

Alan Carlson “Recent Standards Work”
CSEWG 2022 @ BNL Nov 2022

Differences are due to addition of 13C information

Recent RPI data indicate less discrepancy in 0.15 - 0.40 MeV region.

Motivations



Modeling cross sections (even in the 'plain' regions) requires a huge amount of information.

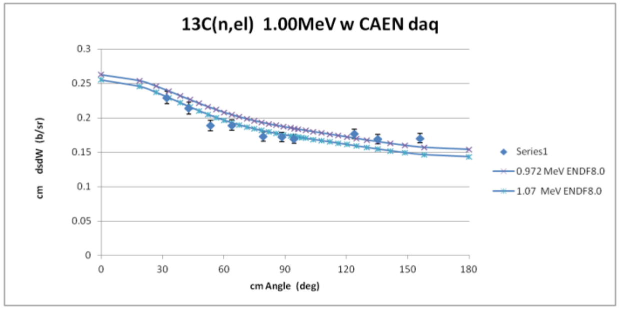
Potential scattering (think: OM + corrections)

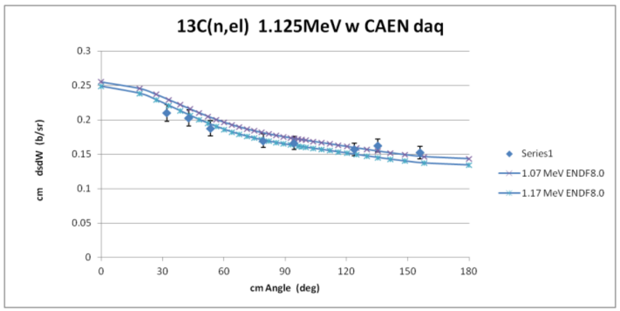
Resonances (+ CN state properties, mixing, interference, subthreshold tails)

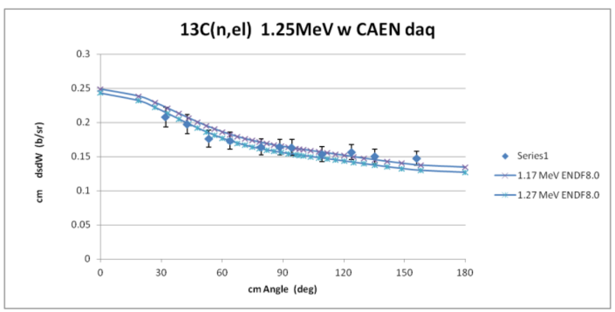
ALSO: The ENDF recommended values are deduced by examination of the CN and not an individual reaction channel.

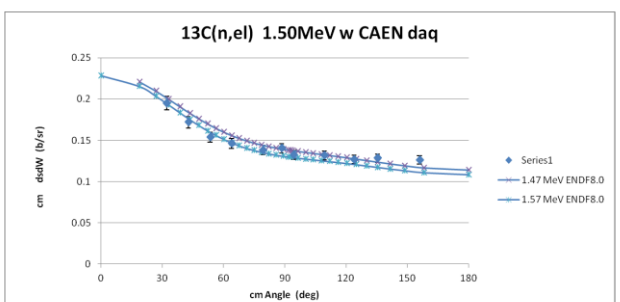
Gerry Hale
Mark Paris

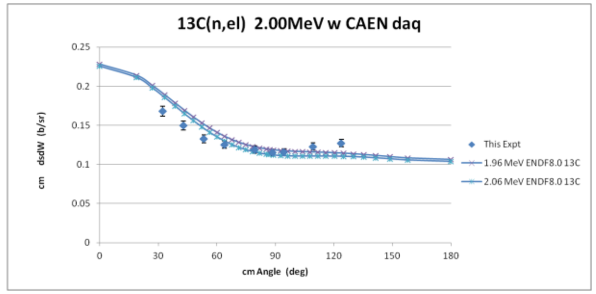
E_n > 1.0 MeV n+13C elastic scattering angular distributions (preliminary)

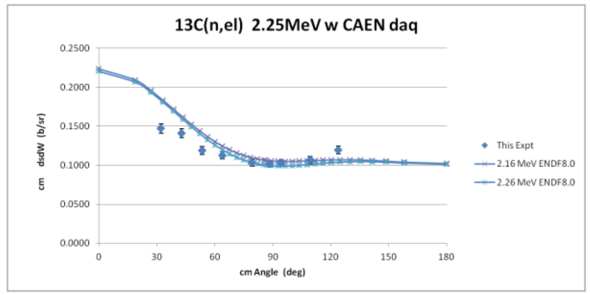


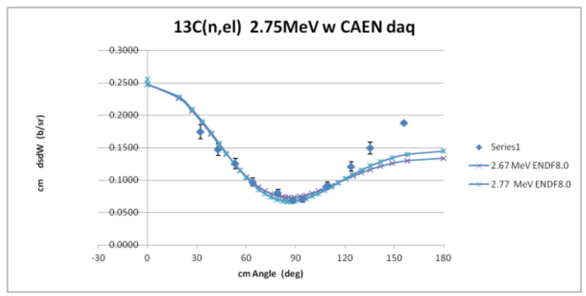


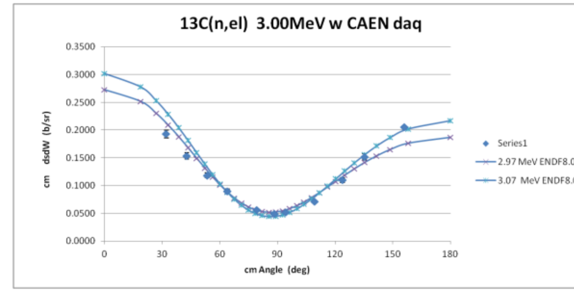


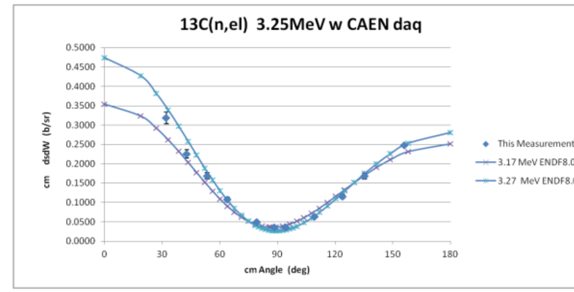












Angular distributions seem bland.

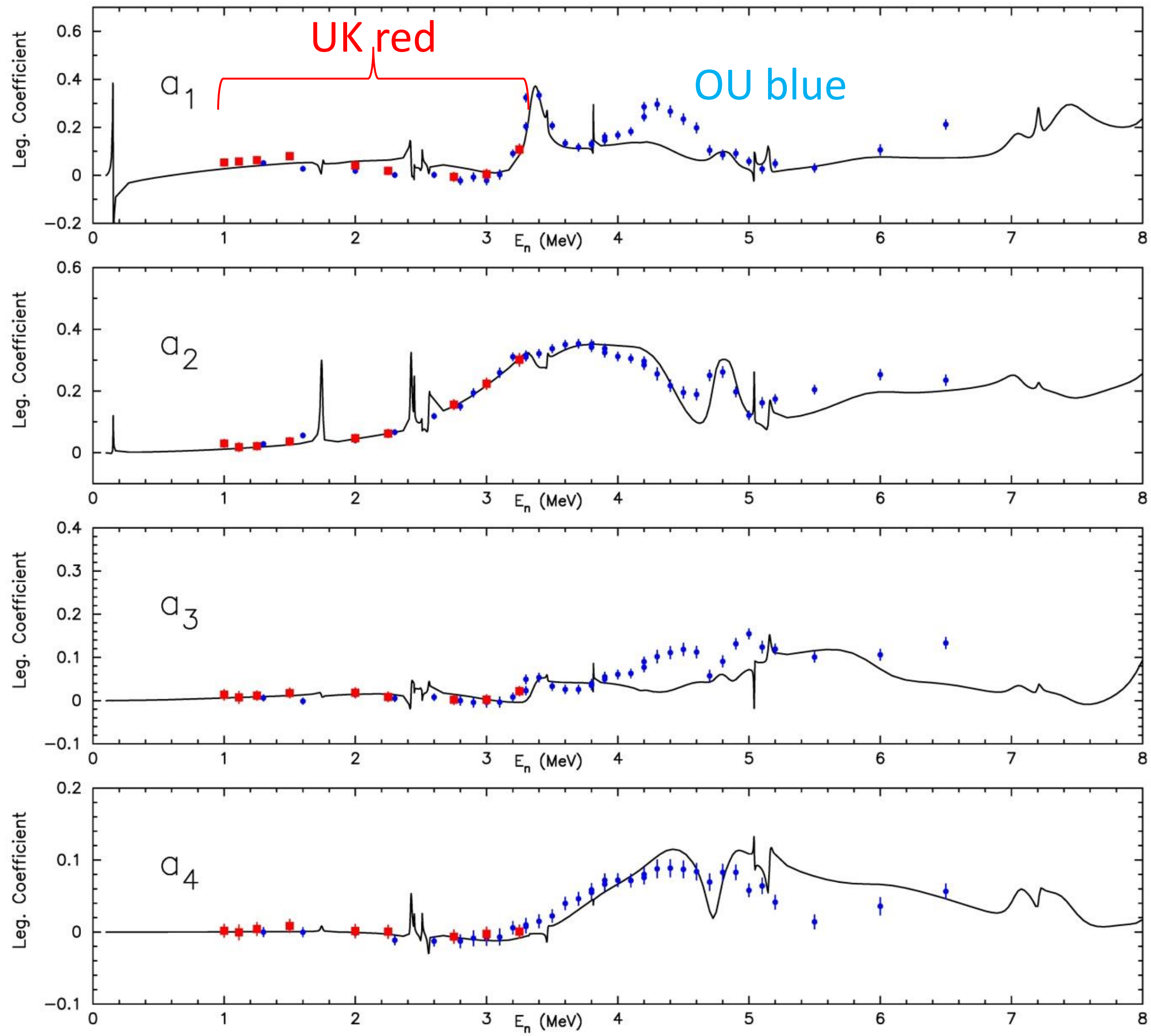
Detail is apparent if one examines Legendre expansion coefficients.

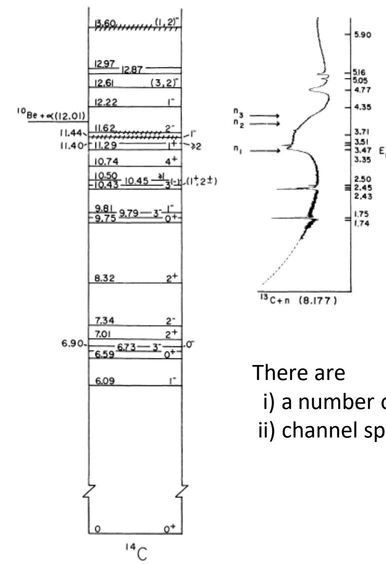
$$W(\theta) = A_0 \sum_L a_L P_L(\cos\theta) \quad ; a_0 = 1$$

$$a_L^{ENDF} = \frac{a_L^{exp}}{2L+1}$$

Comparison of the ENDF8.0 Legendre Coefficients compared to the coefficients from the LANE1981 experimental measurements (preliminary).

Detail is apparent if one examines Legendre expansion coefficients.
Legendre coeffs contain info on reaction mechanism amplitudes.





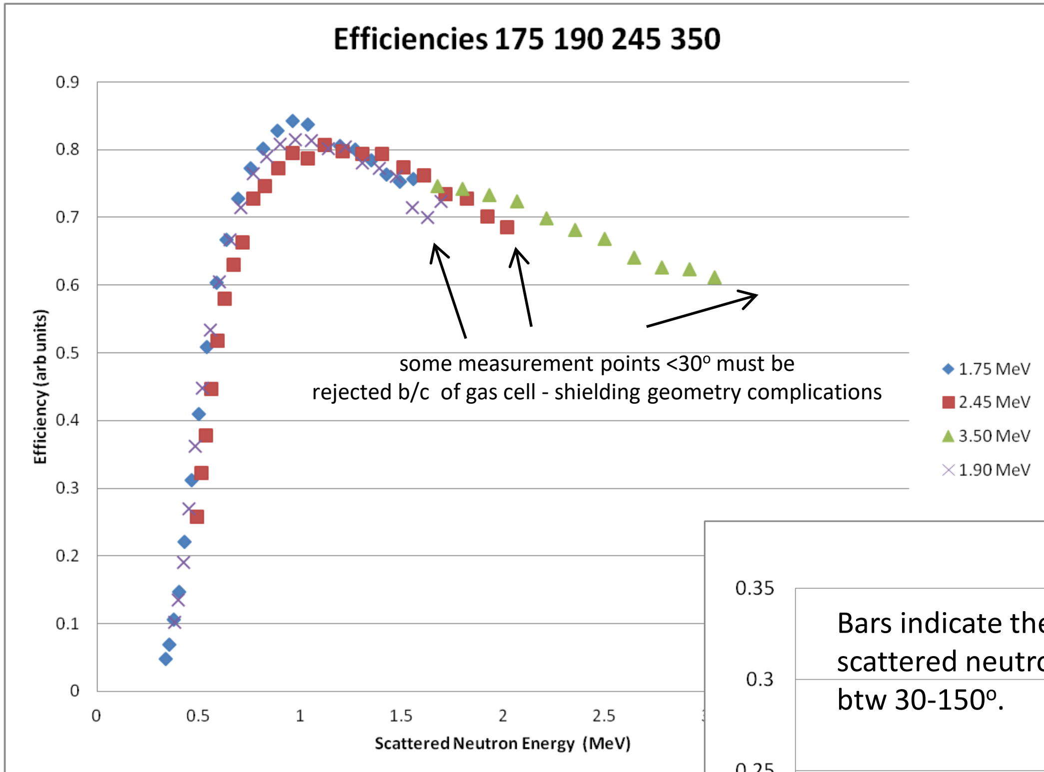
There are
i) a number of CN levels
ii) channel spin mixing.

Discrepancies btw current ENDF & 1981 experimental measurements.

So far, we are extremely consistent with OhioU values !

We need to go lower in energy & check out the 4-5 MeV region

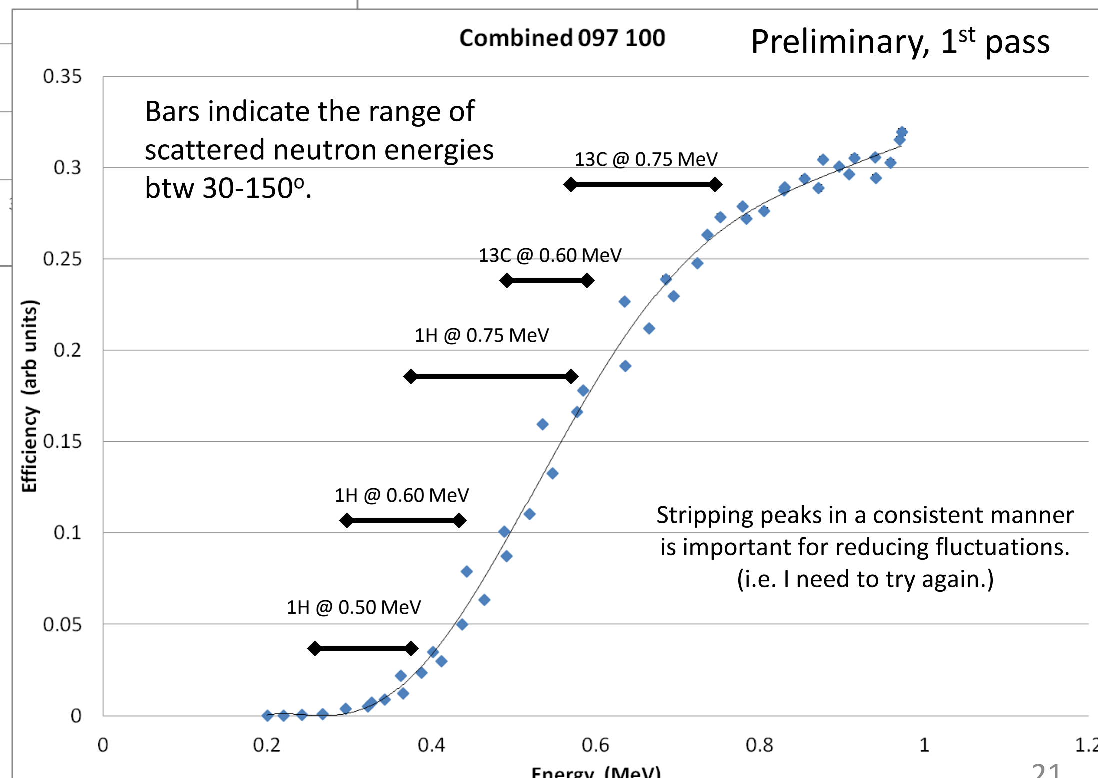
Above E_n = 1 MeV measurements go well

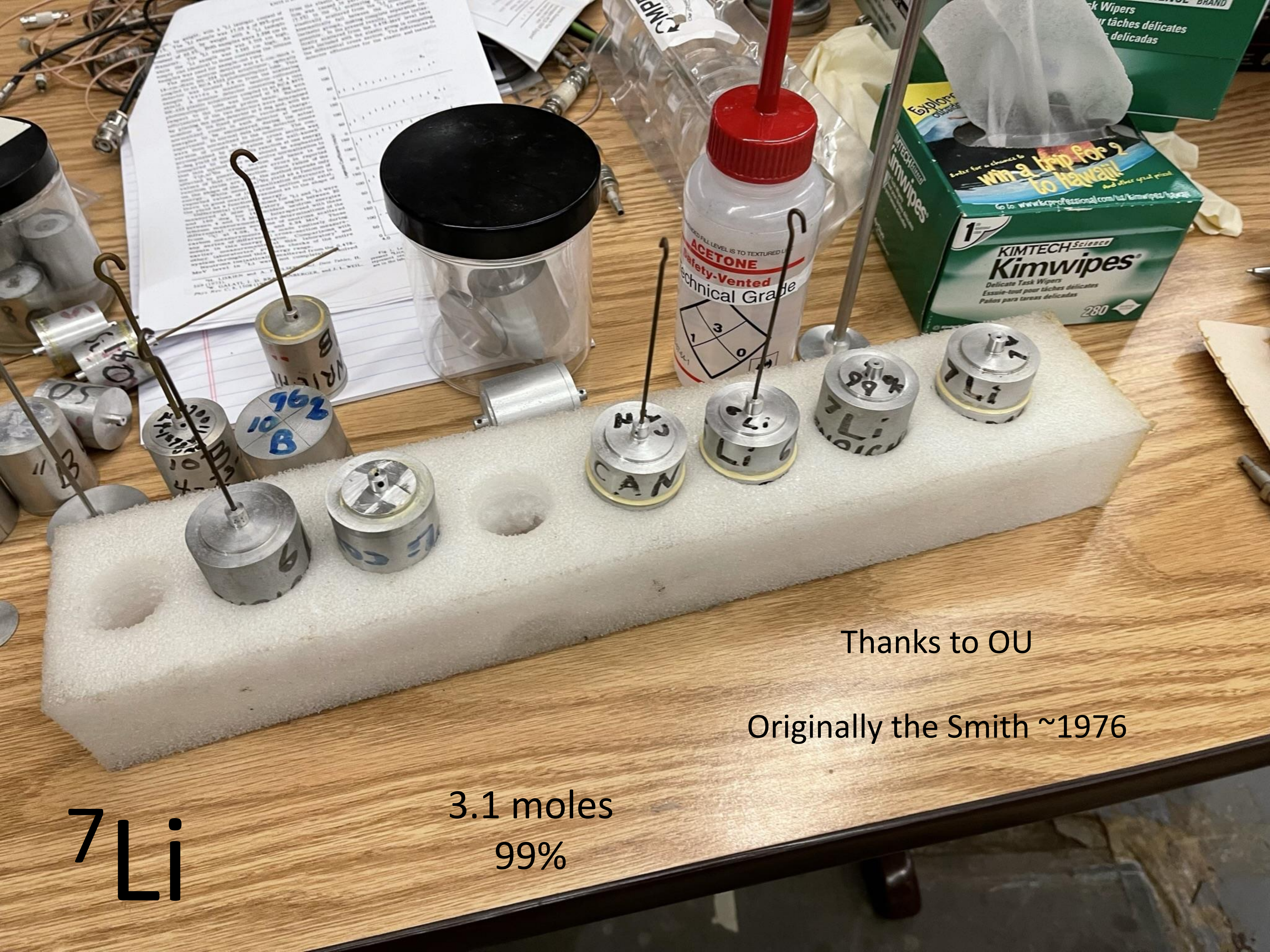


digital DAQ provides more dynamic range for scintillators

Below 1 MeV, challenges develop which require more work.

Our usual H(n,n) xs normalization reaction, not usable E_n<0.6 MeV b/c scattered neutron energies become too low for our EJ301 detectors.





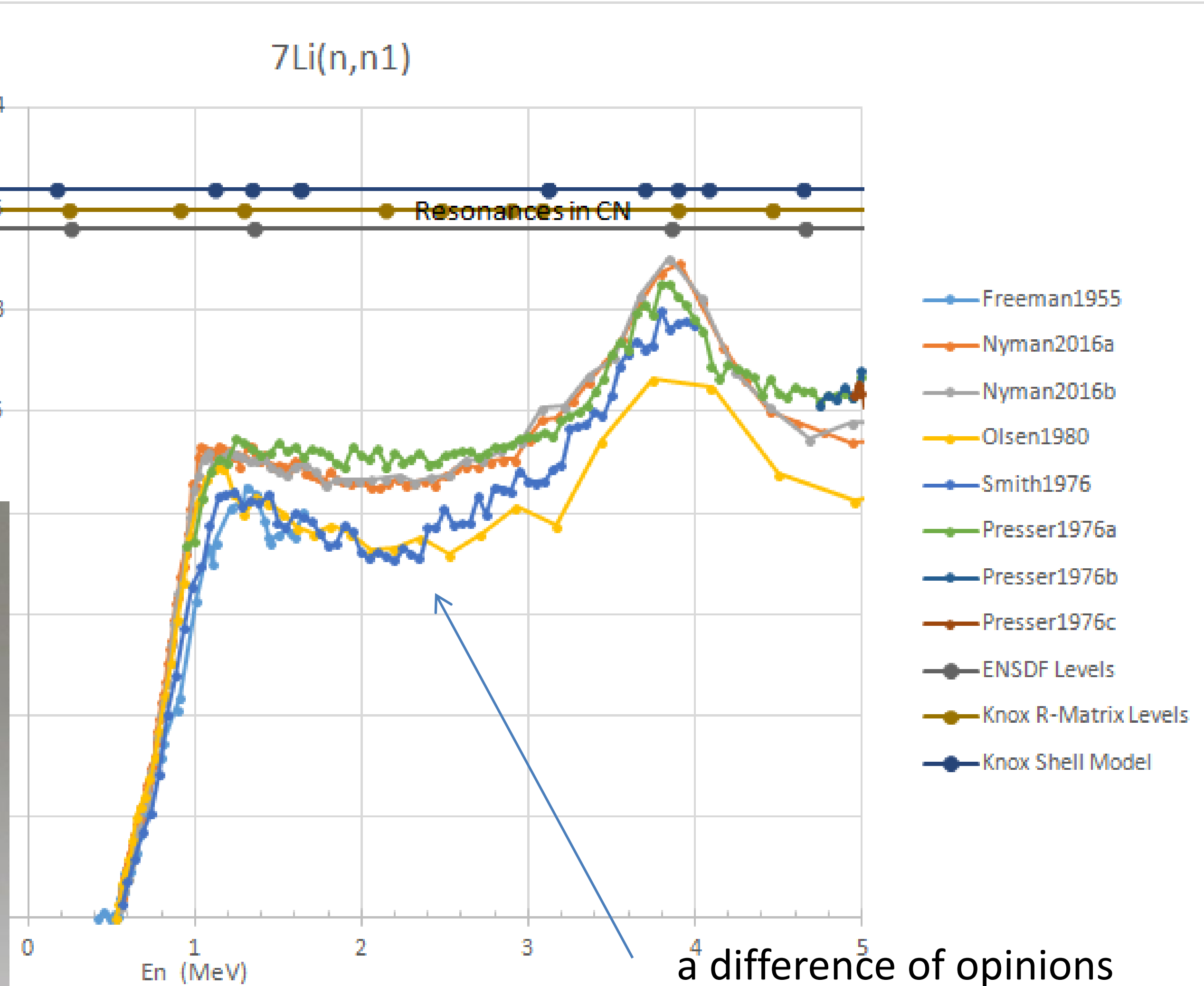
Thanks to OU

Originally the Smith ~1976

^{7}Li

3.1 moles
99%

^{7}Li



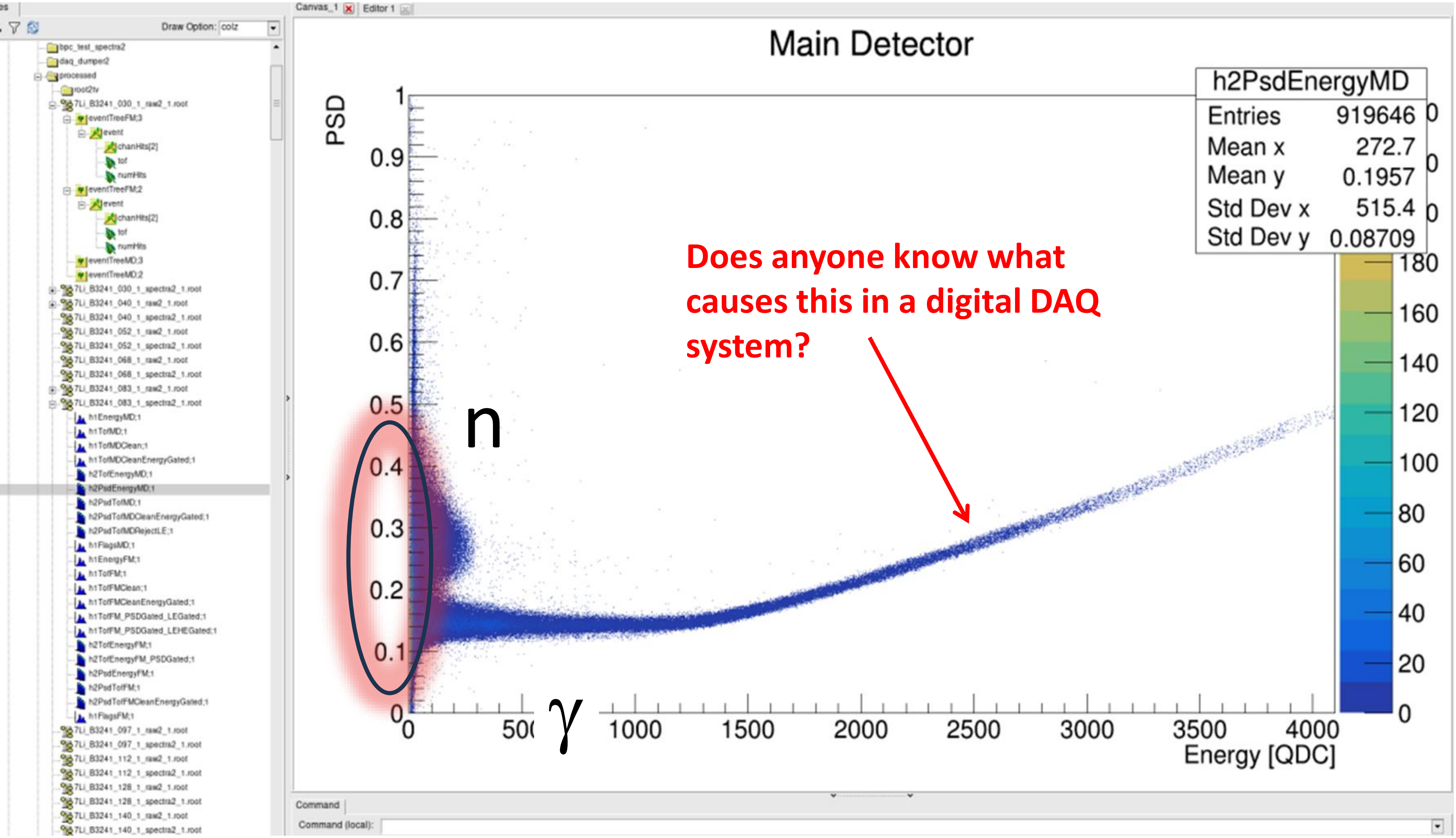
Daniel Araya
Mississippi State Univ

natLi measurements 2018, 2019
Price of enriched Li goes up 3x
OhioU loaned us enriched targets 2022
- - - targets didn't have matching empty container.
Re-canned in March 2023
Re-measured in July 2023 with dDAQ, **analysis w ROOT**.

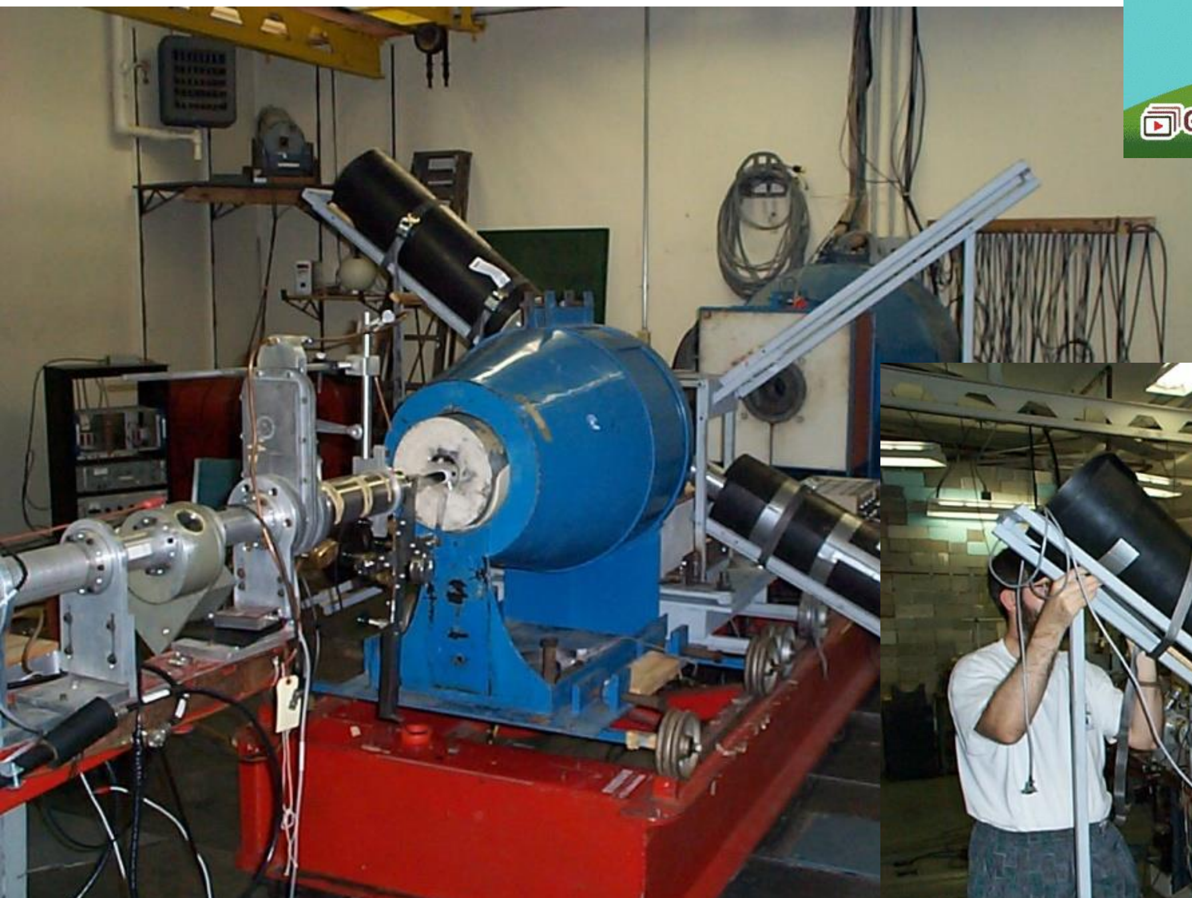
^{7}Li

from Daniel

EJ301 or C6D6 liquid scintillator



Return of (n,n'$\gamma\gamma$) Coincidence Measurements



Can the technique of **Dynamic Biasing** help in the modern world?

1960 Boring γ-ray atten in samples

1971-x dynamic biasing becomes popular

1970-1 Englebrecht methods for
neutron atten and MS corrections.

1975 Velkey describes Monte Carlo methods
for correcting ang dist

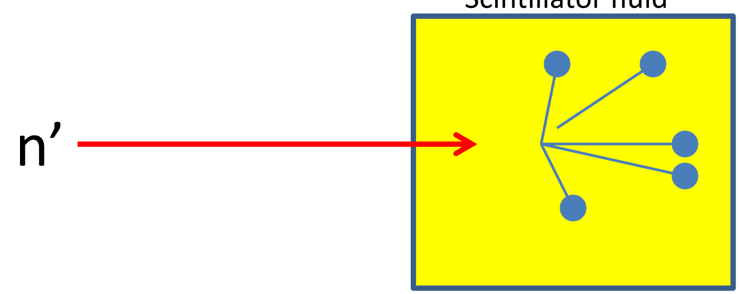
1980-y McEllistrem writes MULCAT

1980 MULCAT-BRC Lilley & MTM

1984 GAMBIT has been written by now.

the idea:

Each channel in a nTOF spectrum is intended to represent a specific energy of scattered neutrons.



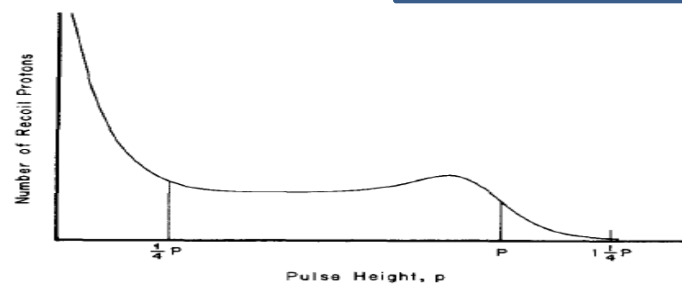
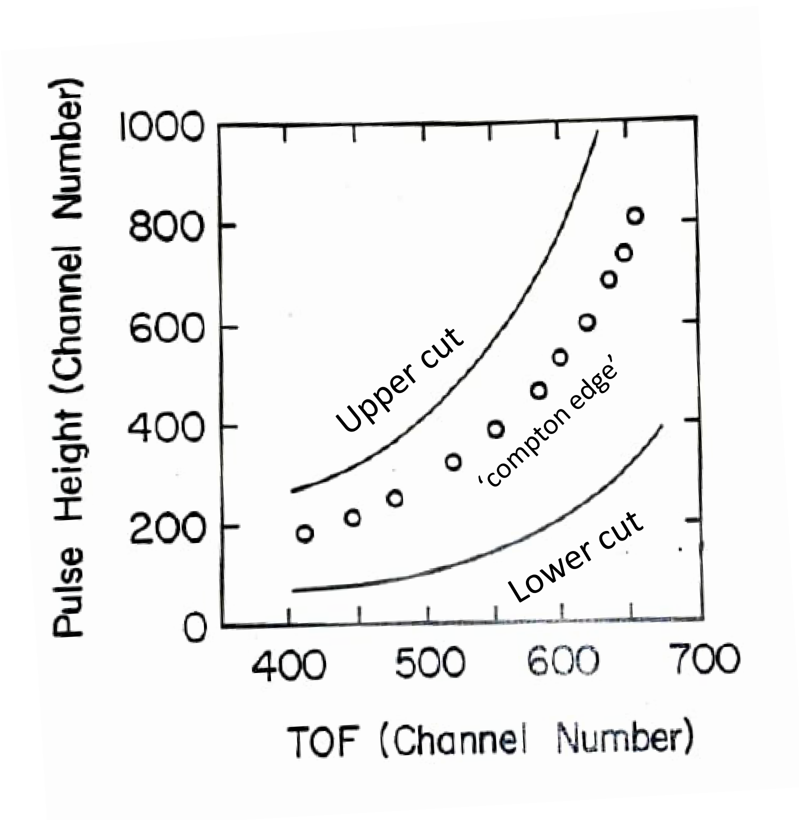


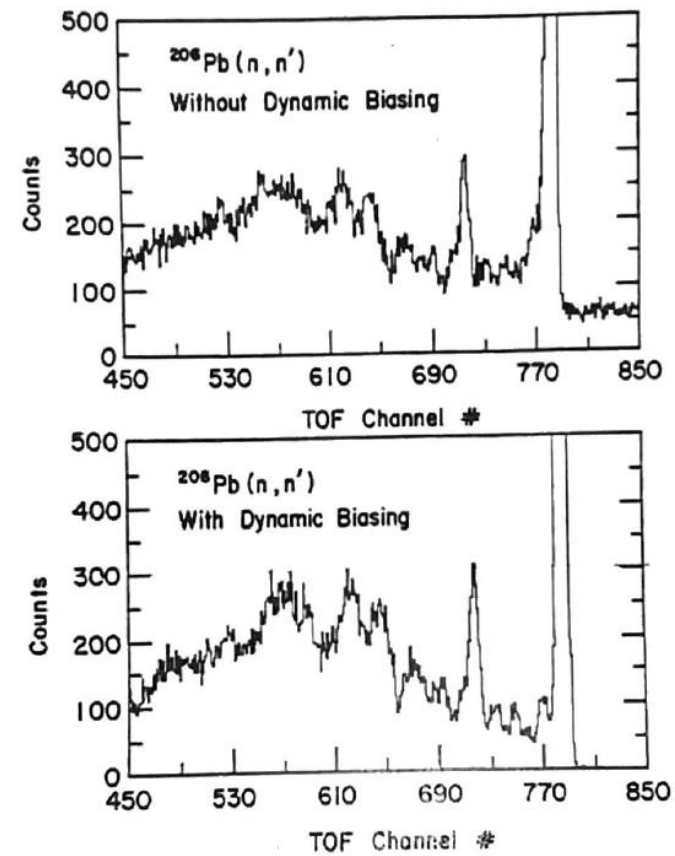
Fig. 2. A typical proton recoil spectrum for monoenergetic neutrons incident on a neutron scintillation detector.

Using signals from forward recoiling protons reduces bckgnd & sharpens TOF peaks, especially for low energy n.

Brandenberger & Grandy, NIM 93, 495 (1971)

Can the technique of Dynamic Biasing help in the modern world?





improves weak & overlapping peaks

Figure 10.
A neutron TOF sprectrum from ^{204}Pb at 7 MeV incident energy is shown in the top panel. Most of the background in this spectrum is due to neutrons since PSD methods have been used to eliminate γ-rays. The TOF spectrum in the lower panel is also from ^{204}Pb at 7 MeV, but uses the method of dynamic biasing to eliminate the neutron background. The weakly excited inelastic levels near channel 770 are much more clearly resolved in the lower spectrum.

Can the technique of Dynamic Biasing help in the modern world?

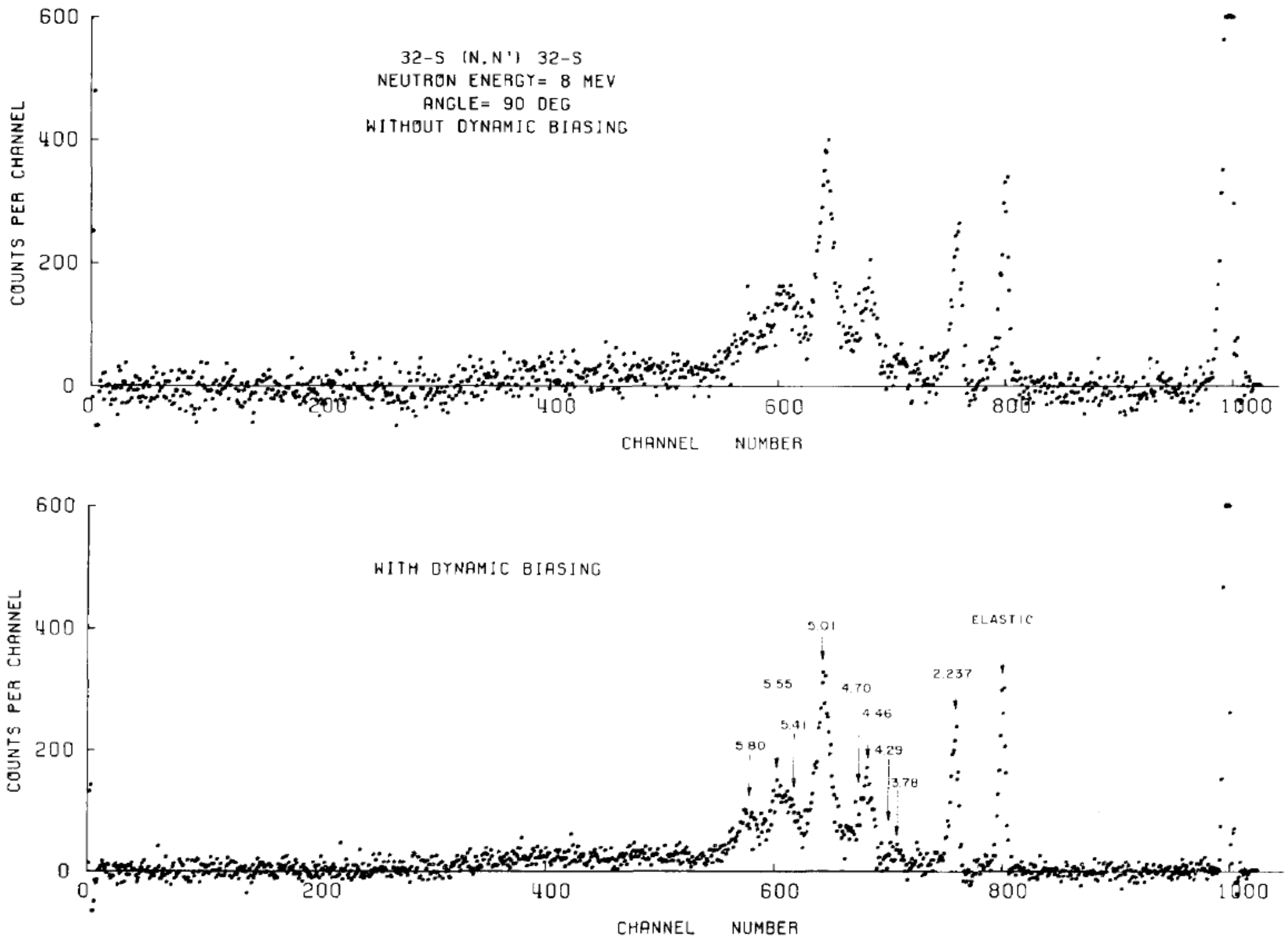


Fig. 11. Time-of-flight spectrum of 8.0 MeV neutrons scattered from ^{32}S after background subtraction. The spectrum is shown with and without dynamic biasing.

Brandenberger & Grandy, NIM 93, 495 (1971)

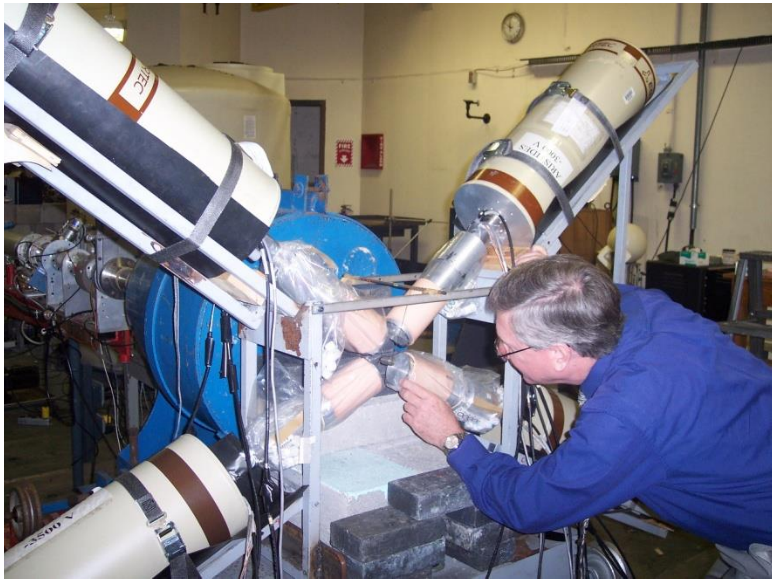
Projects in the Hopper

<u>Cross Section Related</u>

- $^{19}F(n,n'\gamma)$ w dDAQ
- ^{13}C btw 4-5 MeV
- $^{51}V(n,n'\gamma)$ level scheme
- $^{50,53}Cr(n,\gamma)$ at DANCE
- Conversion of existing data to n Emission Spectra

<u>Nuclear Structure Related</u>

- $^{51}V(n,n'\gamma)$ level scheme
- $^{130,132,134,136}Xe(n,\gamma)$ at DANCE
- Return of $(n,n'\gamma\text{–}\gamma)$ coincidence



Dirty Hands
Laboratory Skills
Operation, Maintenance, Repair, Design

Dirty Hands

Laboratory Skills

Operation, Maintenance, Repair, Design

It may be possible to subtract off the contribution from the 70Ge(n,γ) with sample-in & sample-out information.