Neutron Scattering Cross Sections: (n,n') (n,γ) (n,n'γ)

Jeff Vanhoy

US Naval Academy, Annapolis, Maryland

Current Team Members

University of Kentucky
Yongchi Xiao, postdoc
Erin Peters, instructor
Steven Yates, prof

Univ Dallas
Elizabeth Chouinard, undergrad
Sarah Evans, undergrad
Sally Hicks, prof

Mississippi State
Kofi Assumin-Gyimah, gradstudent
Stephan Vajdic, gradstudent
Daniel Araya, grad student
Ben Crider, prof

US Naval Academy
Avi Perkoff, undergrad
Madison Roskos, undergrad
Jeff Vanhoy, prof

- UnivKY Lab Overview
- Highlights since last year
  - 13C
  - 7Li
  - 19F
  - n emission spectra
  - 114Cd(n,γ)

With a lil' help from our friends:
Anthony Ramirez @ LLNL
Jarrod Marsh @ ARL-Adelphi

Supported by U.S. DoE FY20/21/22 awards SC0021424, SC0021243, SC0021175, SC000056

University of Kentucky Accelerator Laboratory (UKAL)

- 7-MV single-ended Van de Graaff accelerator
- p, d, ^{3}He and α beams
- pulsed and bunched beam:
  - f = 1.875 MHz and Δt ~1 ns
- primarily conducts neutron-induced reactions and scattering experiments

Basic Nuclear Science

- Nuclear structure via (n,n'γ)

  - Level Schemes and Transitions
  - Spectroscopic Information
  - DSAM Lifetimes

Applied Nuclear Science

- Cross section measurements

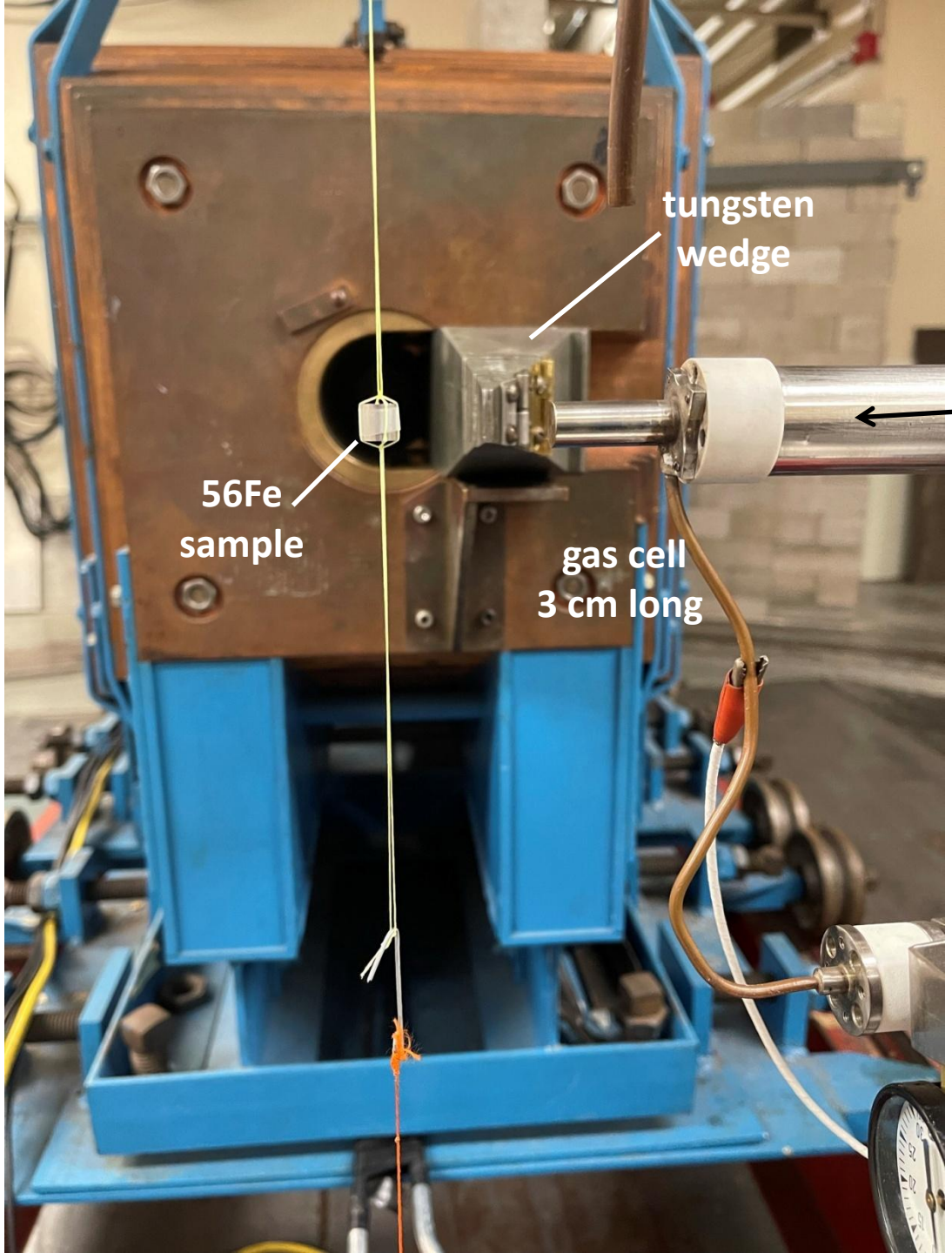
  - (n,n') - Elastic and inelastic cross sections

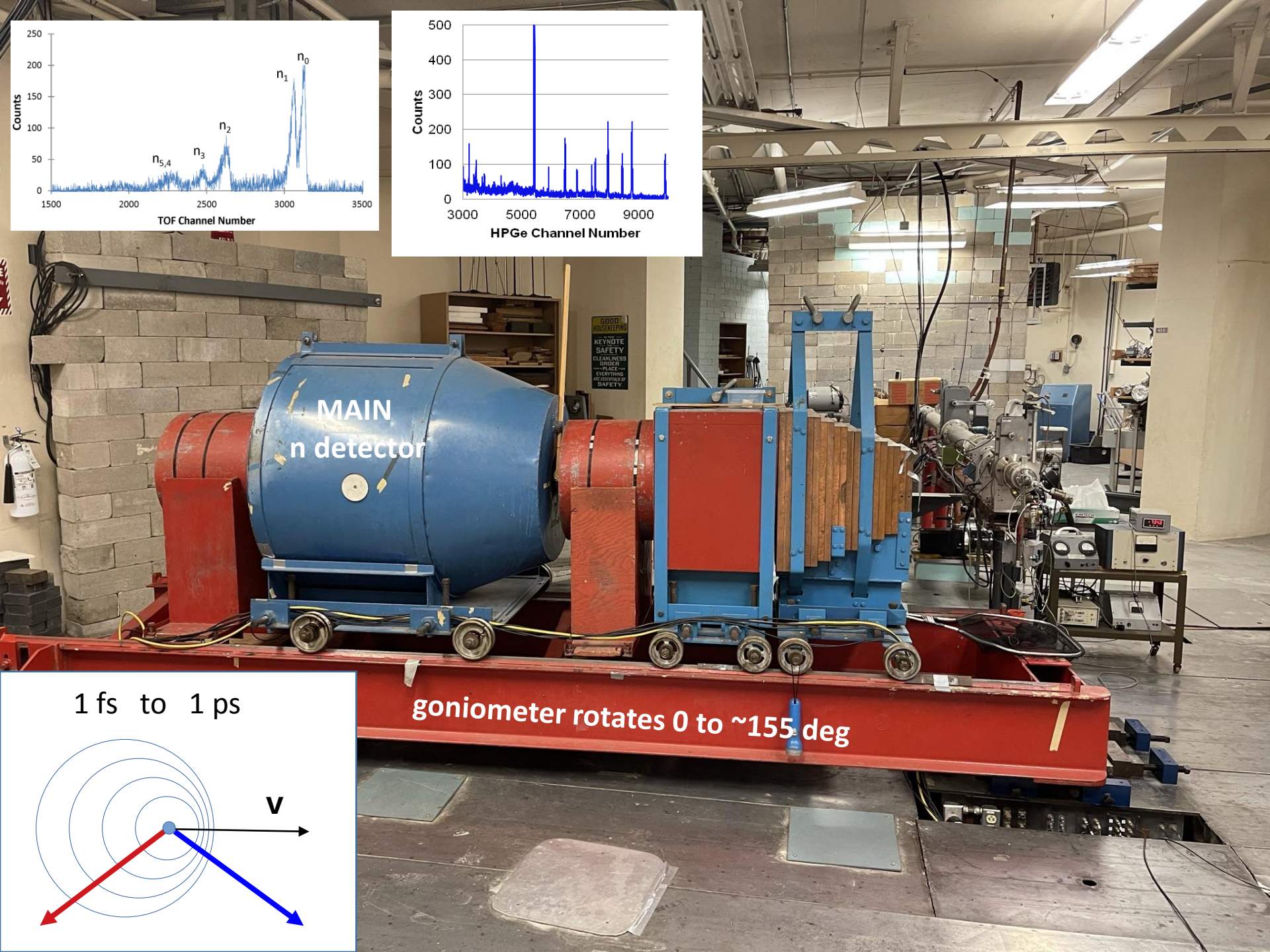
    ^{23}Na, ^{56}Fe, ^{54}Fe, ^{12}C, ^{nat}Si, ^{nat}Li

  - (n,n'γ) - γ-ray production cross sections

    Level cross sections

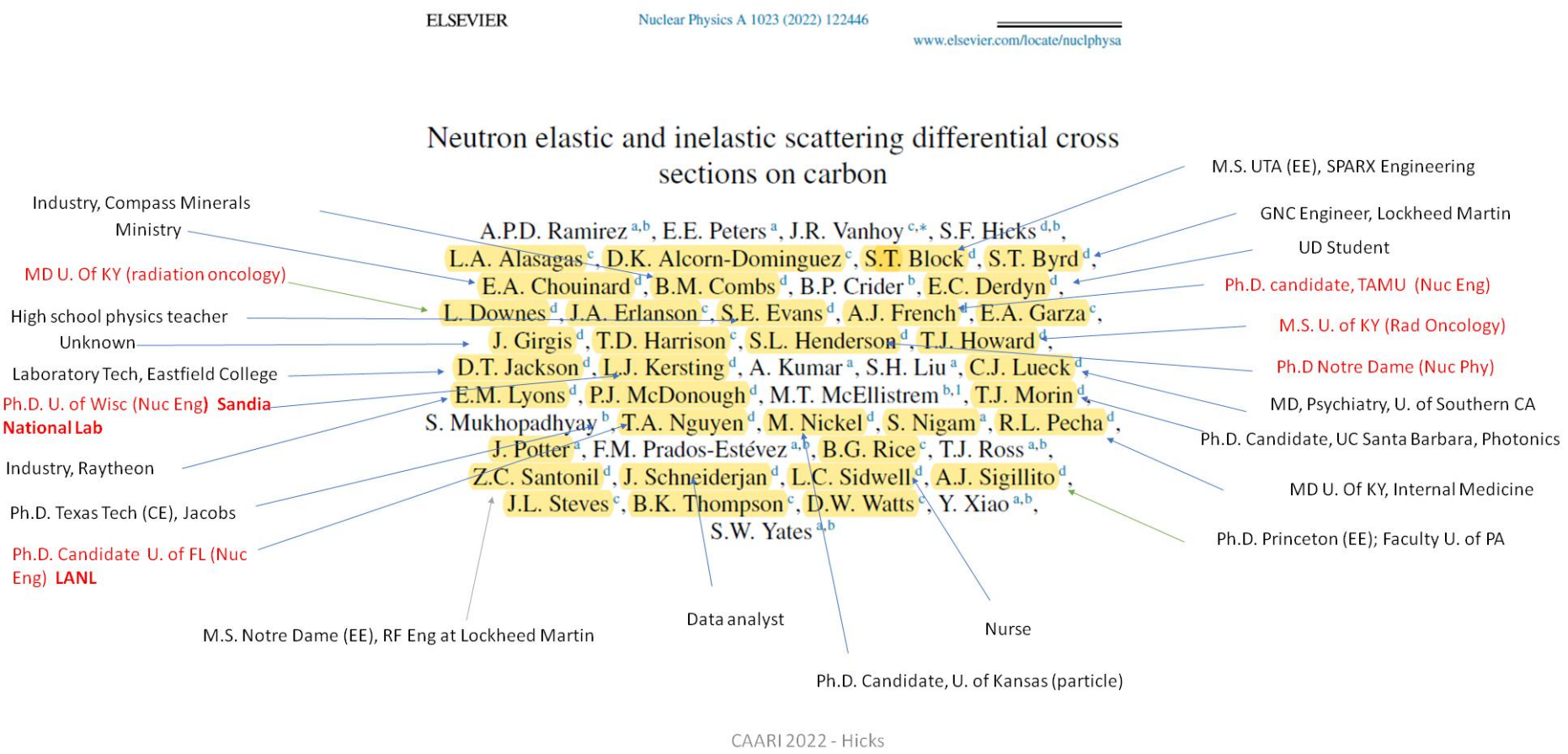
- Detector development


tungsten
wedge
pulsed
p, d, 3He
56Fe
sample
gas cell
3 cm long


MAIN
n detector
goniometer rotates 0 to ~155 deg
1 fs to 1 ps
v
Counts
TOF Channel Number
n0
n1
n2
n3
n5,4
HPGe Channel Number

from Sally Hicks

Undergraduate students on the Carbon paper



64 angular distributions @ 45 energies btw 0.5 to 8.0 MeV

AllanC & MattD late 21, early 22

PHYSICAL REVIEW C VOLUME 23, NUMBER 5 MAY 1981

States in ^{14}C from σ_T and $\sigma_{el}(\theta)$ for ^{13}C+n: Measurement, R-matrix analysis, and model calculations

R. O. Lane, H. D. Knox, and P. Hoffmann-Pinther
John E. Edwards Accelerator Laboratory, Ohio University, Athens, Ohio 45701

R. M. White
University of California, Lawrence Livermore National Laboratory, Livermore, California 94550

G. F. Auchampaugh
University of California, Los Alamos National Scientific Laboratory, Los Alamos, New Mexico 87545

(Received 16 October 1980)

Previous work on 13C

Experimental σ_{tot} total Cross section measured at the old LANL Tandem.

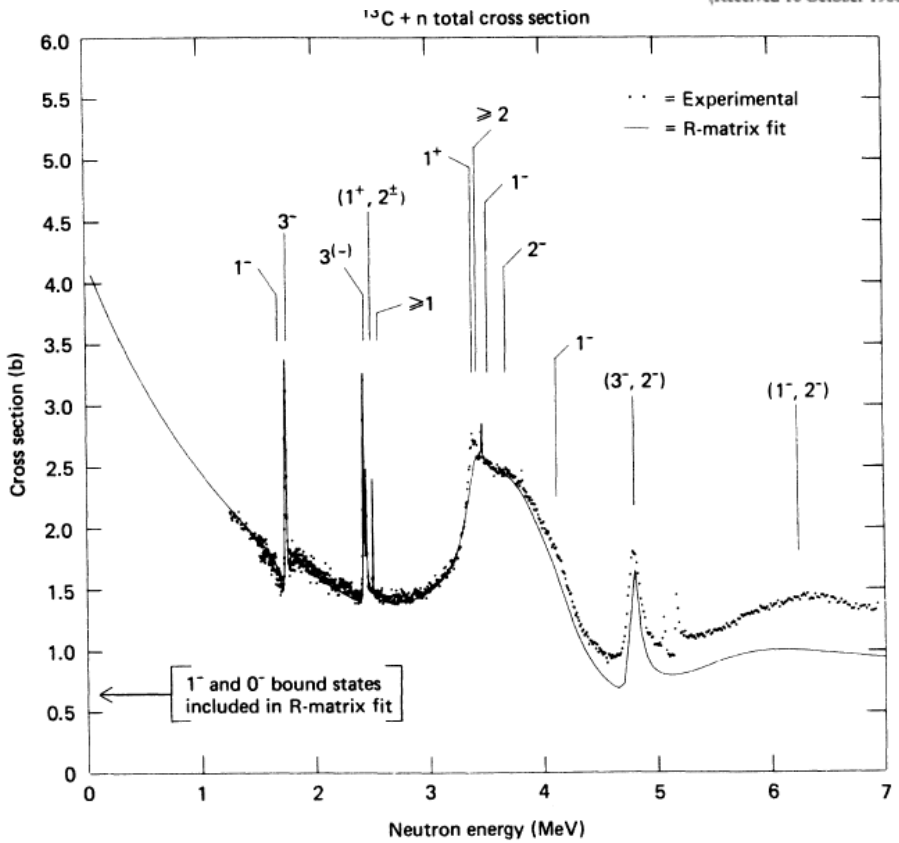


FIG. 3. Total cross section σ_T (points) from Ref. 7 and integrated elastic scattering cross section σ_{el} (curve) from R-matrix analysis for ^{13}C+n. The J^π assignments and approximate locations for states in ^{14}C resulting from the R-matrix analysis are indicated in the figure. Only a representative number from the full set of data points for σ_T are shown to portray adequately the features of the total cross section. The scatter in the points is taken as the measure of errors on σ_T. For the 1⁻ resonance near 1.75 MeV the location of the resonance dip is indicated rather than the calculated resonance energy (see Fig. 4).

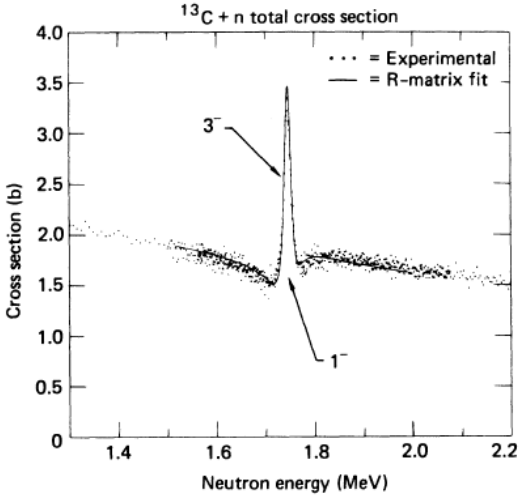
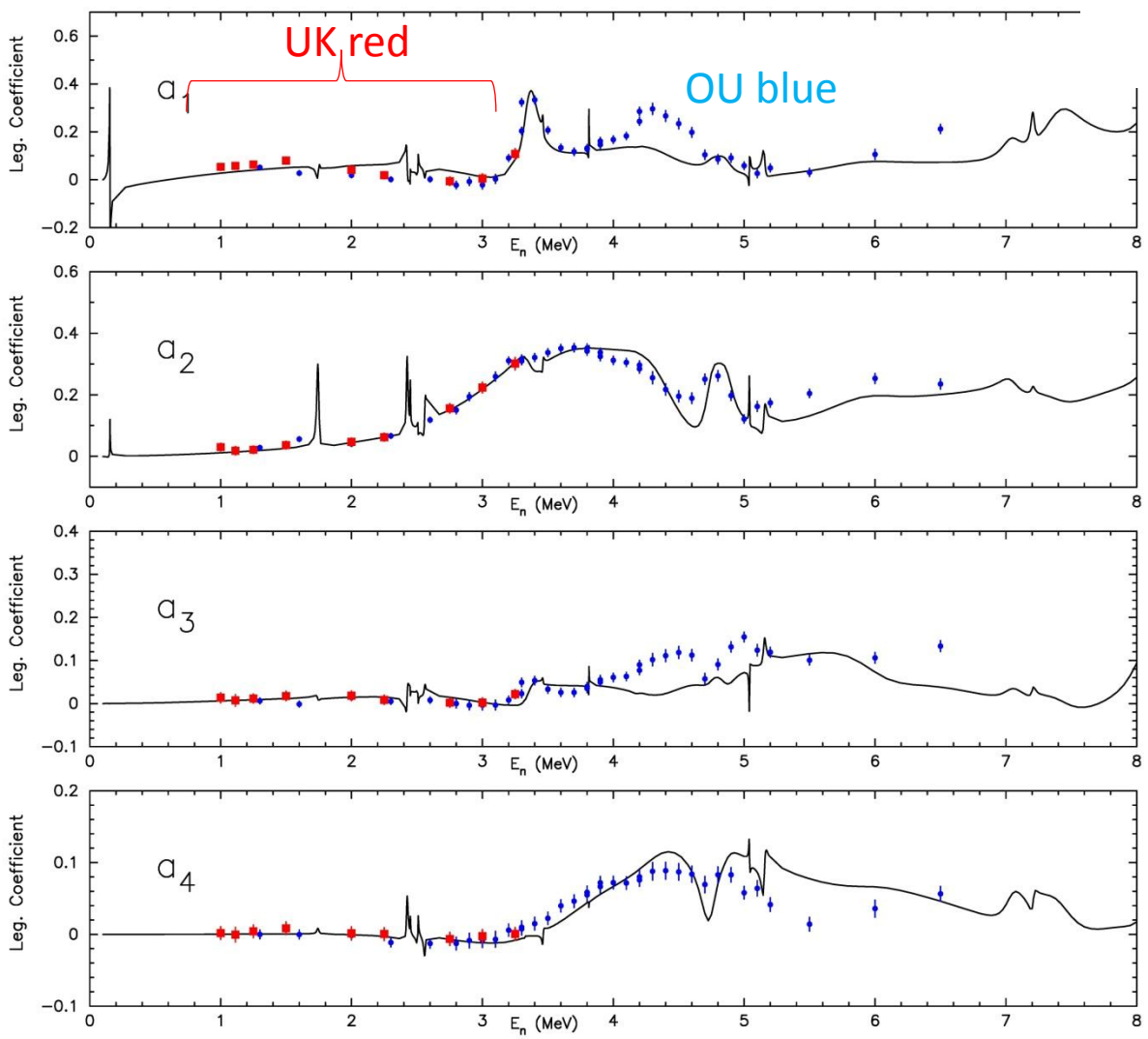


FIG. 4. Expanded plot of the total cross section (points) from Ref. 7 and integrated elastic scattering cross section (curve) from R-matrix analysis for ^{13}C+n for the resonances near 1.75 MeV. The curve has been averaged over the experimental resolution of FWHM = 3.5 keV. Note that in Table I the energy of the 3⁻ resonance (peak) is actually slightly lower than that of the 1⁻ resonance (dip). The apparent reversal of this order occurs in this case because of the slight asymmetry of the 1⁻ dip and the nearly equal energies of the resonances. The full data set for σ_T is shown from $E_n \simeq 1.6$ to 2.0 MeV while only a partial set is displayed outside this region to aid in relating to other figures. The scatter in the points is taken as a measure of the errors.

Angular Distribution Expansion Coefficients

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



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

So far,
we are
right on the money !

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

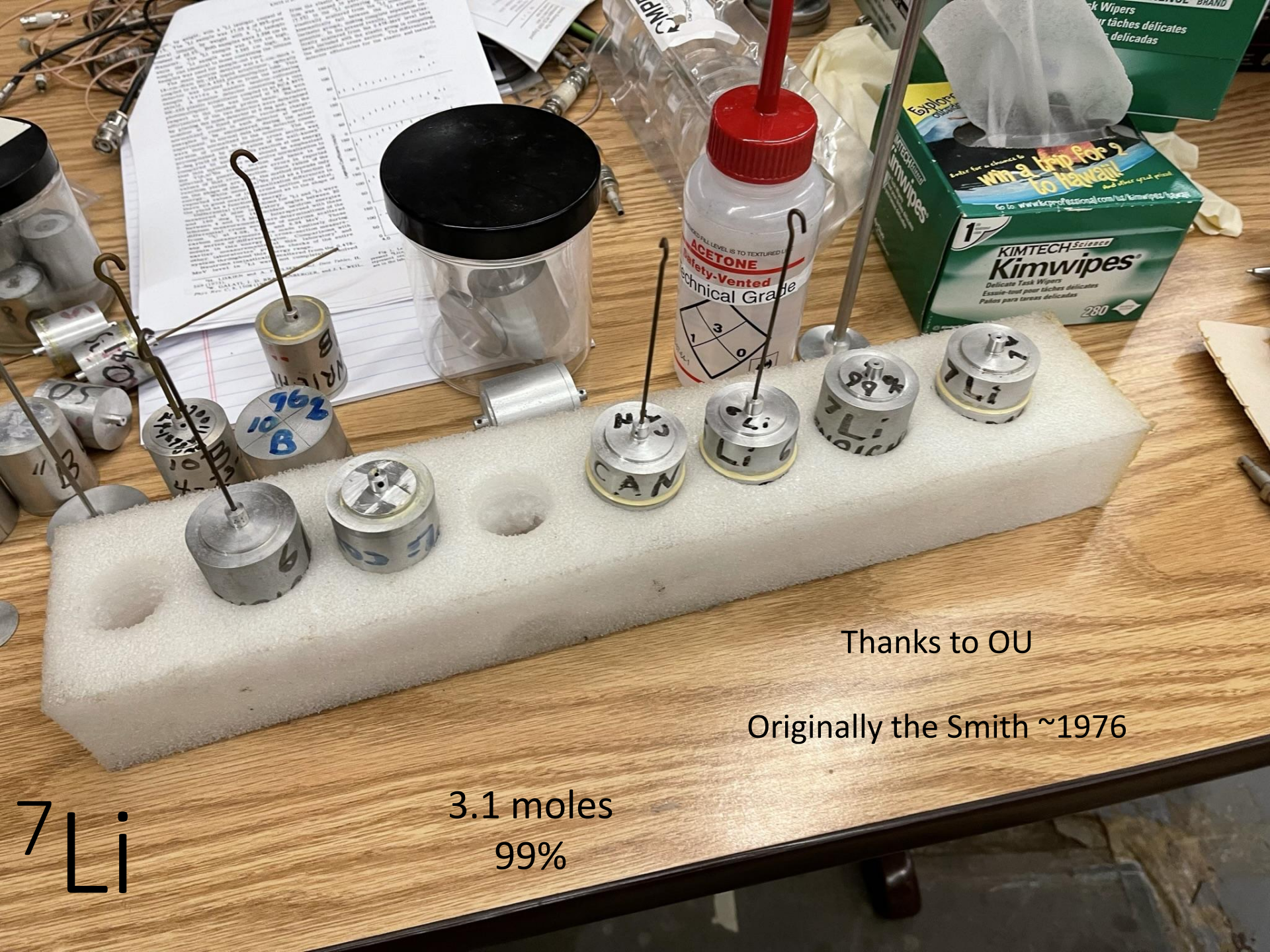
Checked 1-3 MeV in summer

<1.0 MeV in Jan 2023

14 ang dists

Computer currently IT'd

Need to load ENDF/B-VIII.0 into MCNP
& run jobs to simulate energy dependence of 1,2,3 scatters
-- impacts how one strips the yield out of TOF spectrum



Thanks to OU

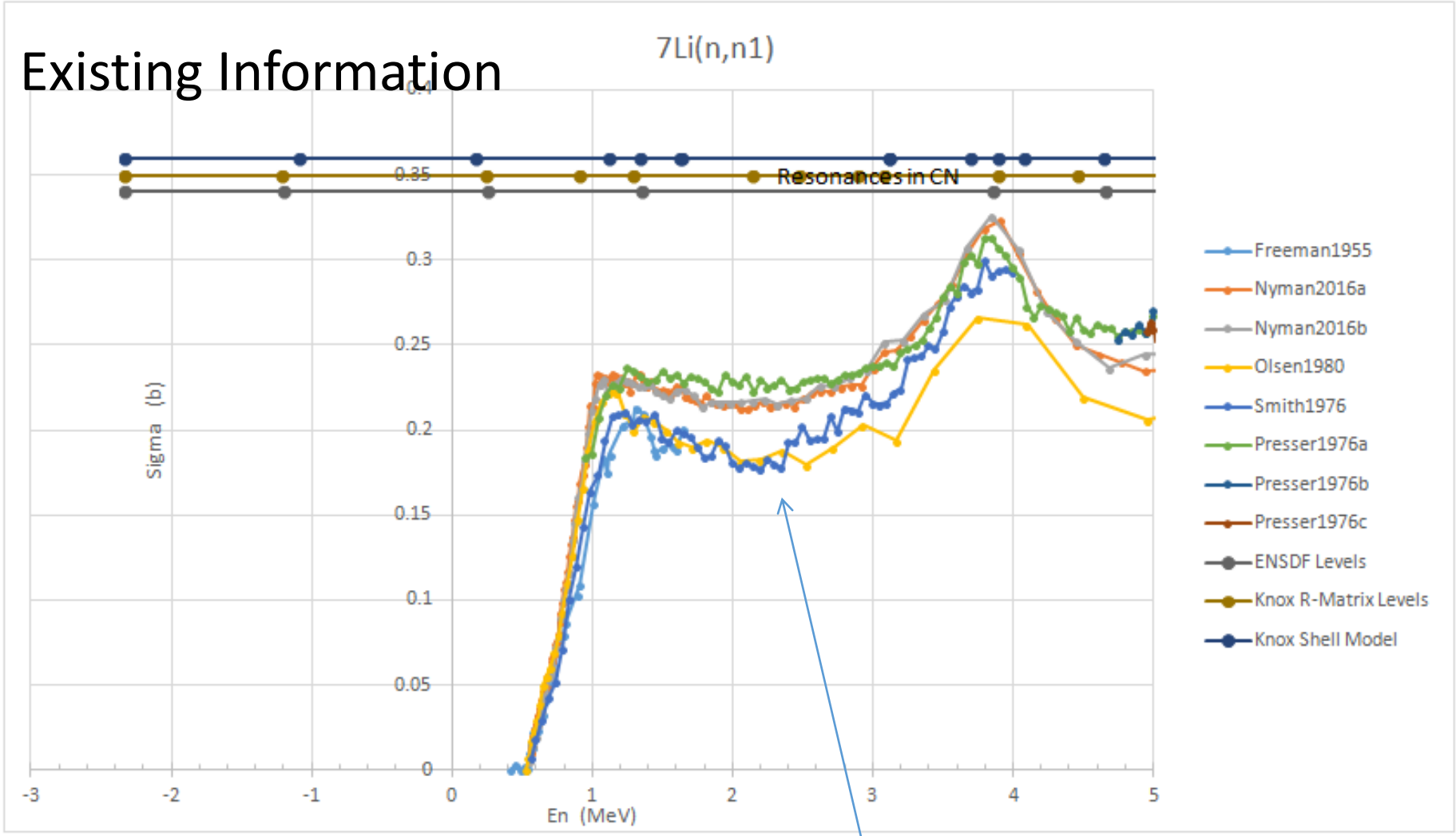
Originally the Smith ~1976

^{7}Li

3.1 moles

99%

Existing Information

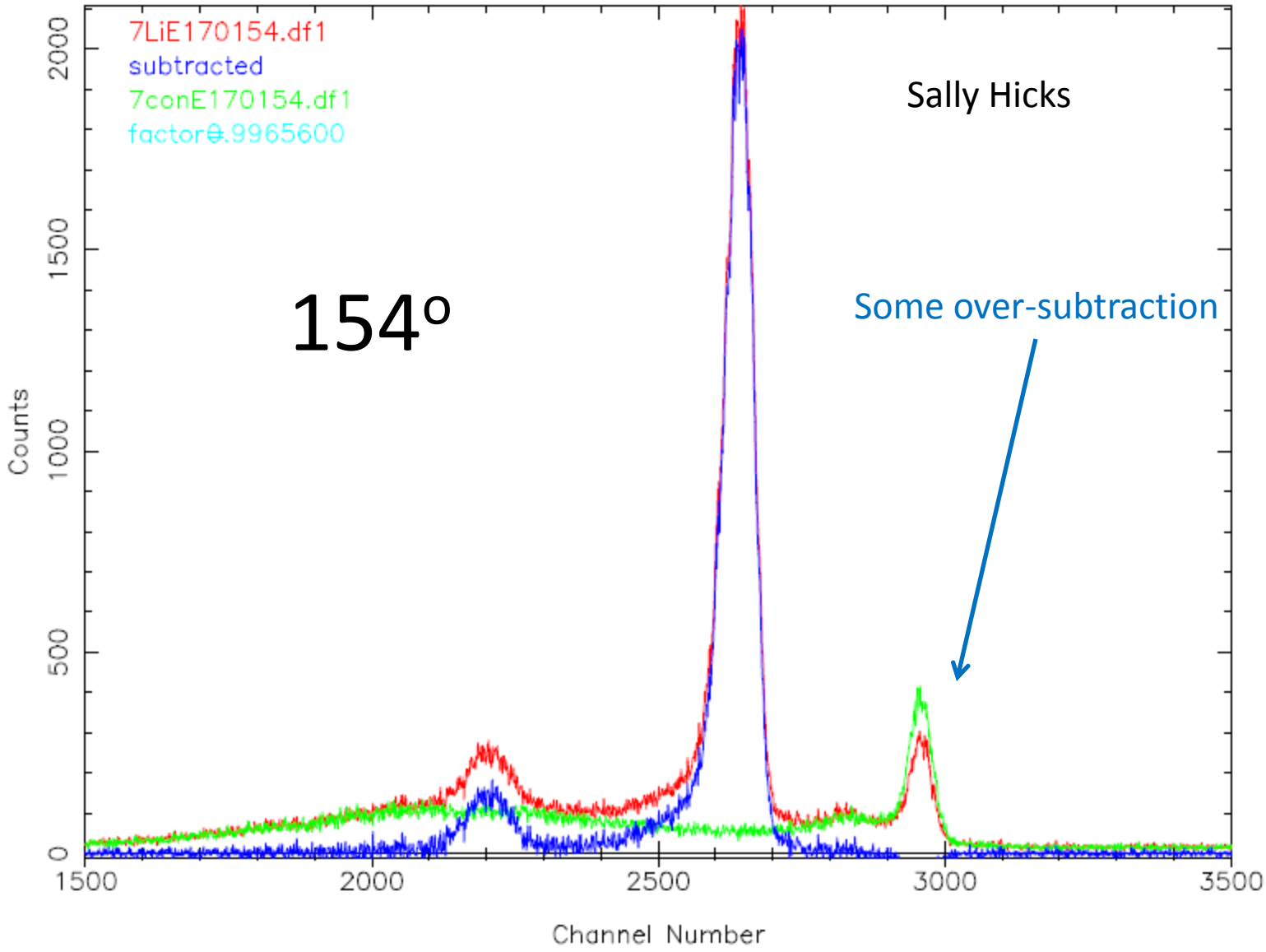


a difference of opinions

Natural Li 2 (n,n'g) excitation functions
6 (n,n') ang dist

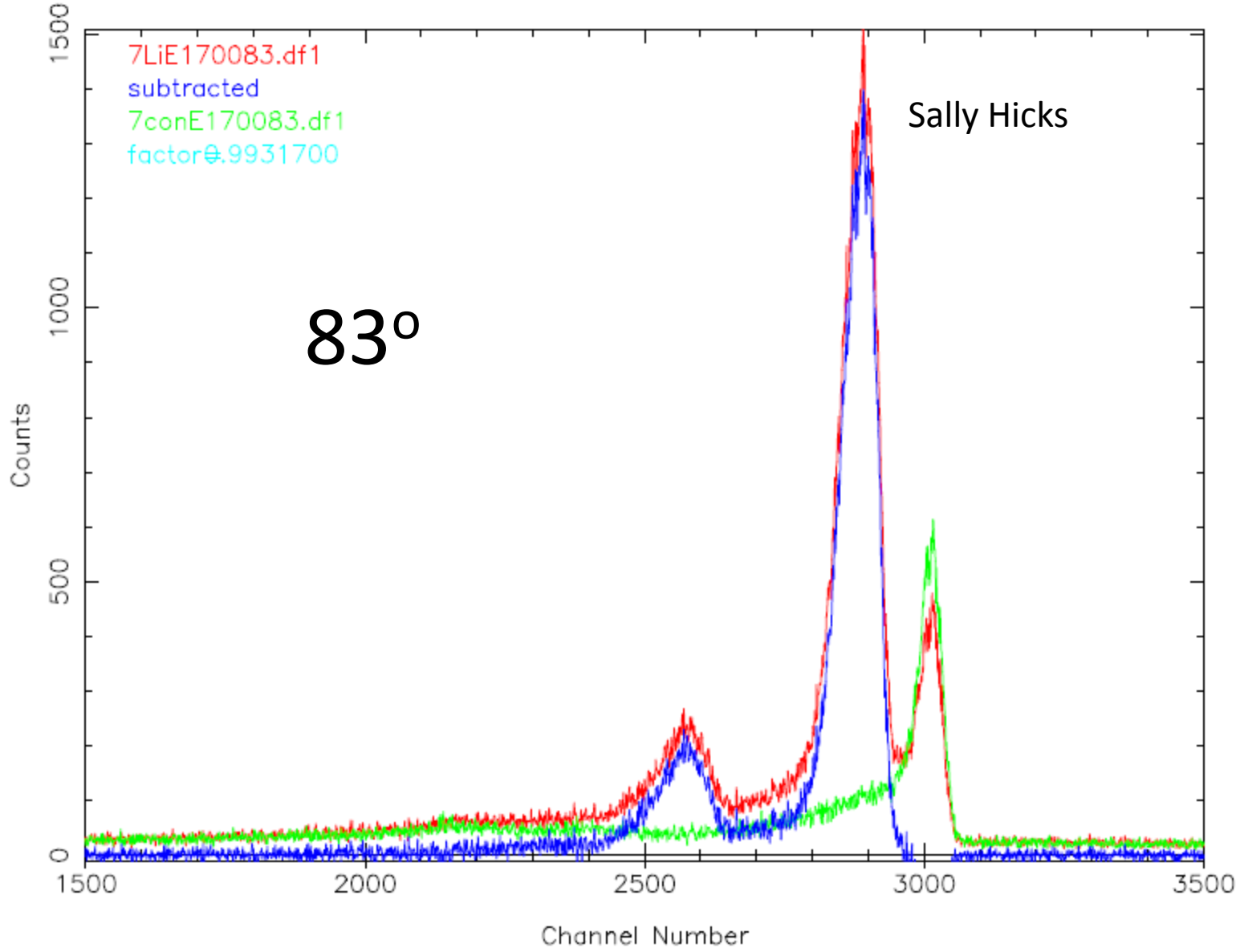
Enriched 7Li 4 ang dist

Unfortunately the empty container wasn't a perfect match for the 7Li sample



Things look tolerable at forward angles >80deg.

Unfortunately the empty container wasn't a perfect match for the 7Li sample



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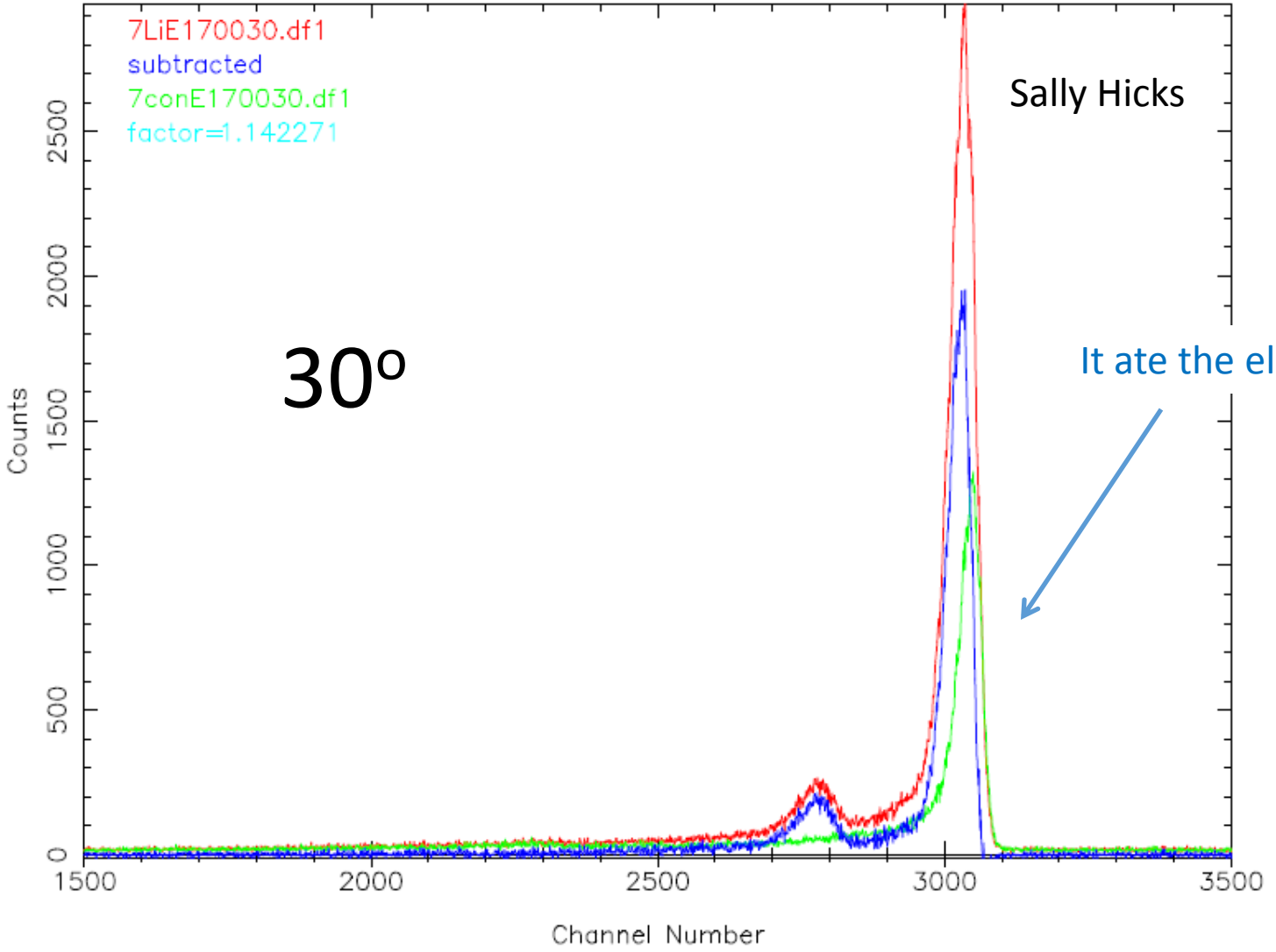
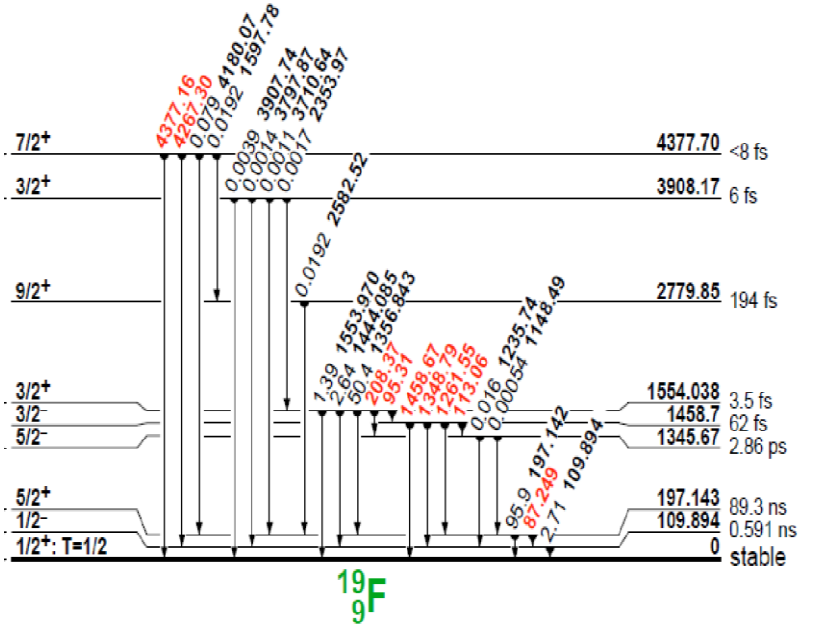


We have to fit the main peak well in order to deal with the elastic tail under the inelastic.

→ Best solution: re-can the sample during spring break 2023

^{19}F

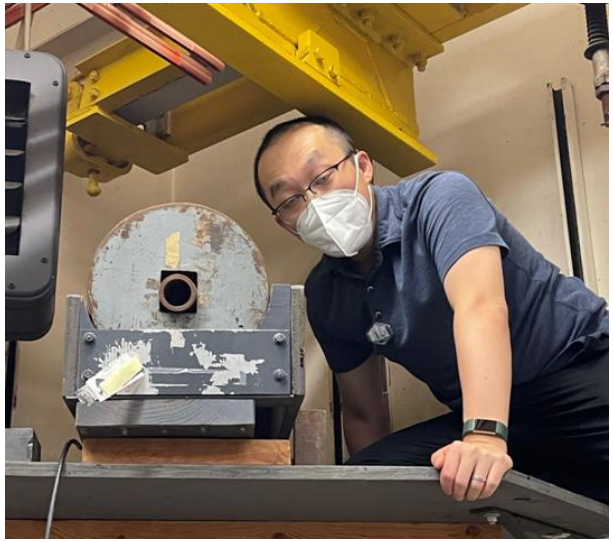


- Effectively no data since 1950s-1960s
  - ENDF & JENDL were noticeably different
  - Modern measurements
    - Similar to ENSDF, but not really
    - Similar to JENDL, but not really
- ^{19}F is an evil nucleus
- 90 ns isomer
- Hard to normalize γ-ray xs at low energies.
- Had to develop new DAQ

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

i) doublets
ii) distorted lineshapes
iii) feeding

Yongchi Xiao



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

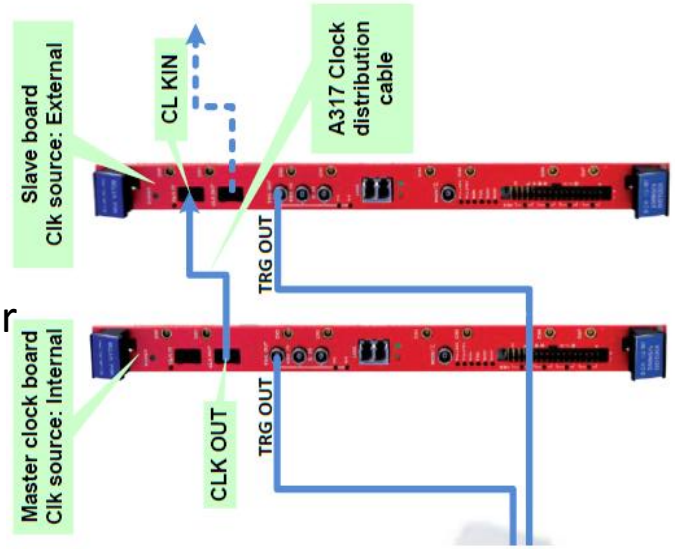
V1782 100 MS/s
HPGe
Long Counter

+ 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

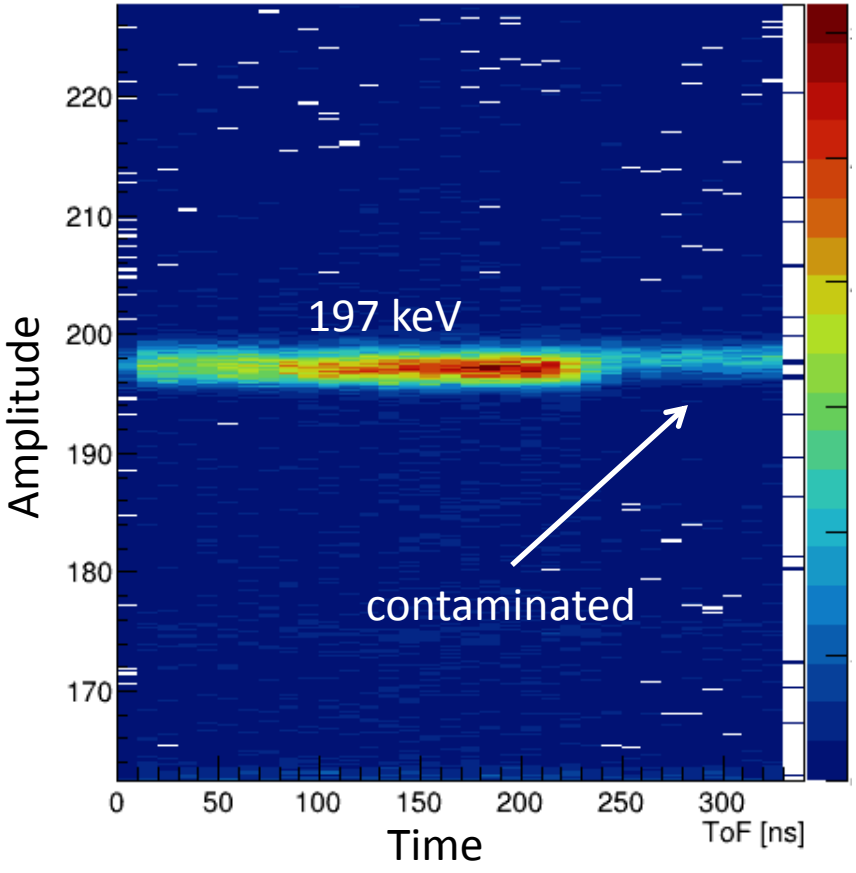
CAEN did not think about some things

- γ peak shapes fill hard disks & buffers fast
- new ways to do things wrong

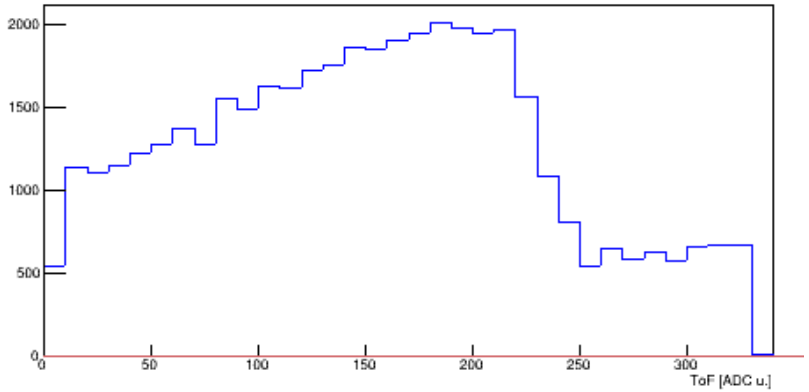


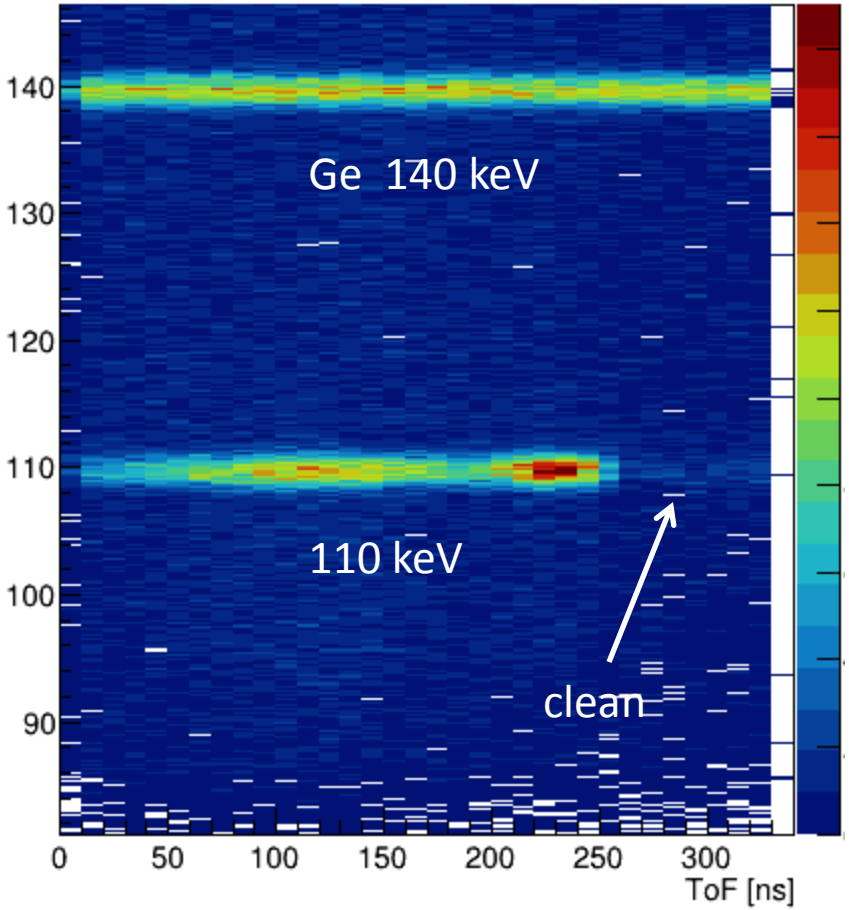
Time-dependent γ-ray Info

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



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

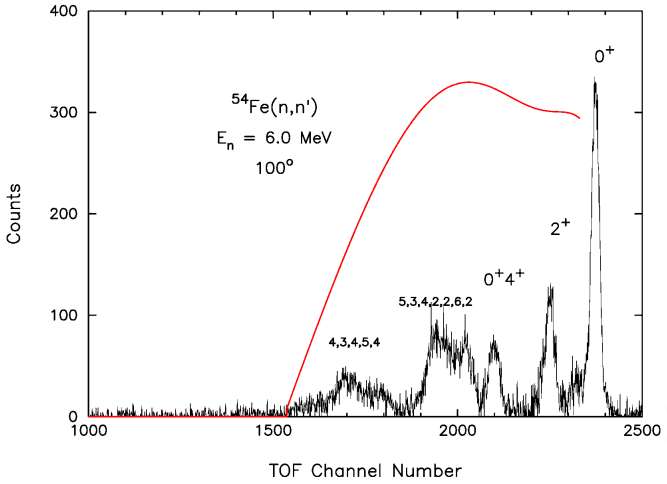


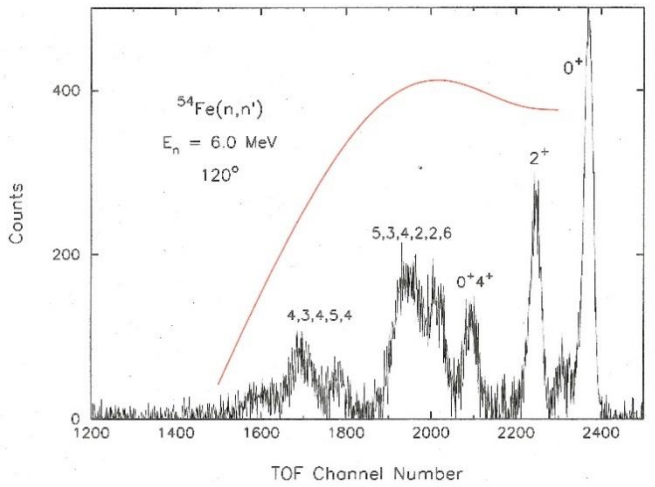


Neutron-Emission Spectra

Avi Perkoff

Transforming tof histograms → energy domain

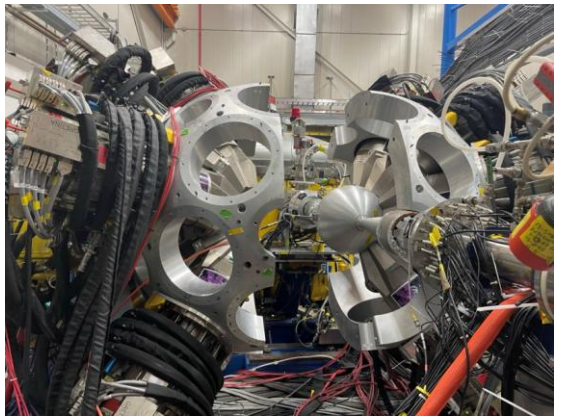




knew C++, Learning python, should have done it in C++

Converting previous UnivKY ^{56}Fe, ^{54}Fe, ^{23}Na
nTOF spectra(θ) into energy spectra(θ)
(efficiency corrected and normalized)

shifts at a recent
^{130}Te CoulEx measurement at ANL/ATLAS
w CHICO / GRETINA arrays

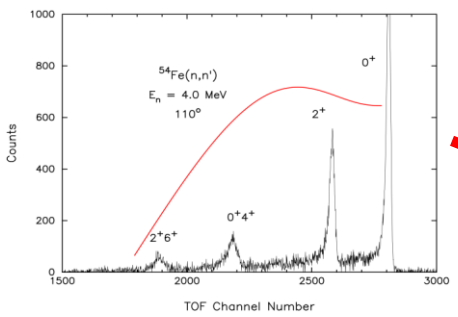


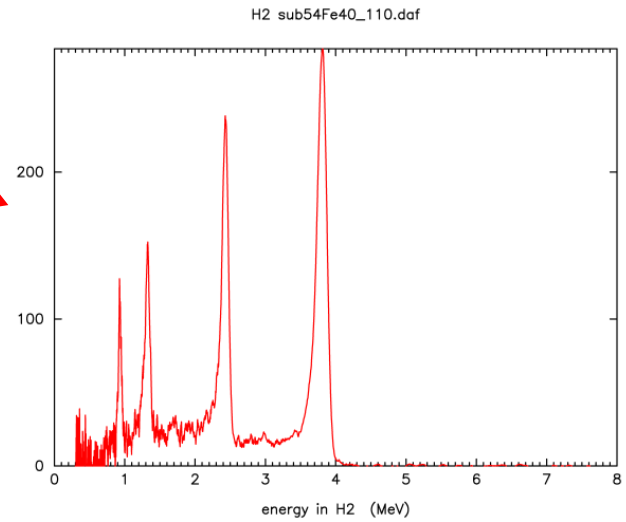
Graduated May 2022 → USMC Pilot

USMC assigned him to continue with the project until Aug 2022.

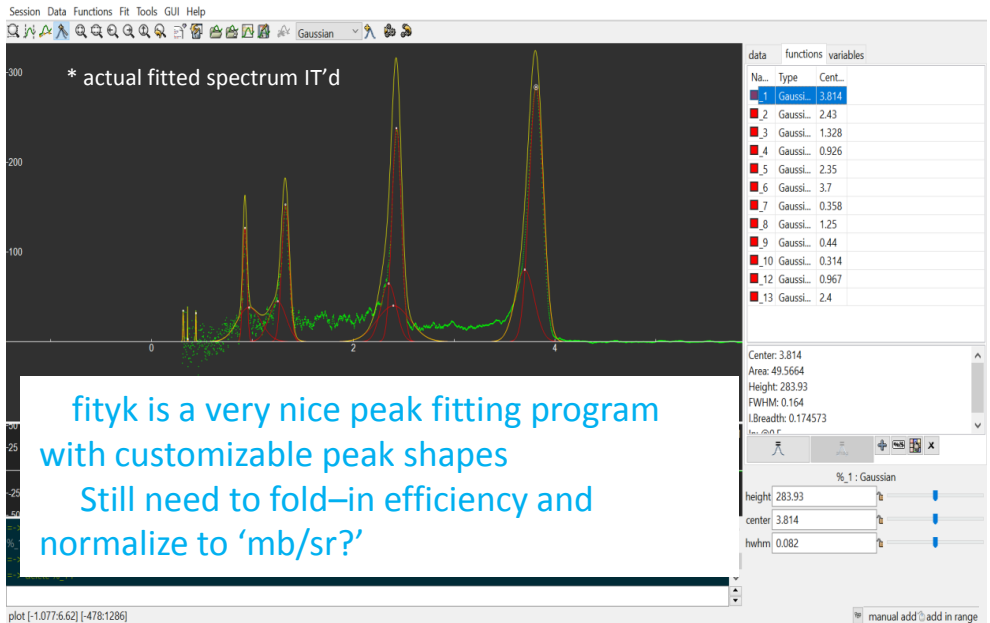
Madison Roskos

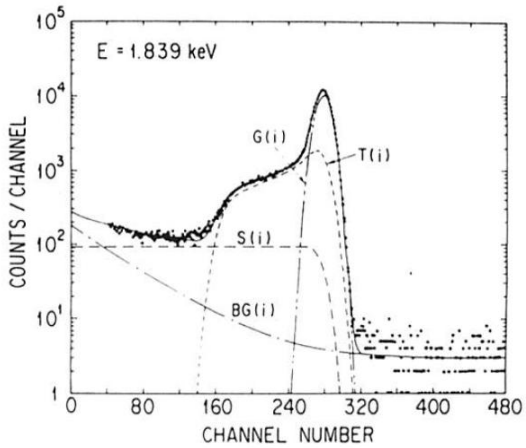
54Fe neutron emission-energies from nTOF spectra





What generates the peak-Shirley effect in neutron detectors, and why is it masked in nTOF spectra?





Johansson and Campbell, "PIXE: A Novel Technique for Elemental Analysis", JWiley&Sons

n-capture @ LANL

Capture @ LANSCE: DANCE

completed

^{112,114}Cd(n,γ) – onsite 2019,2020

^{110,111} Cd(n,γ) – online 2020

attempted

$^{130,132}XeF_2$

Much effort in design and construction of the XeF_2 target @ UnivKY

Scheduled 14 day Xe expt in Sept 2021

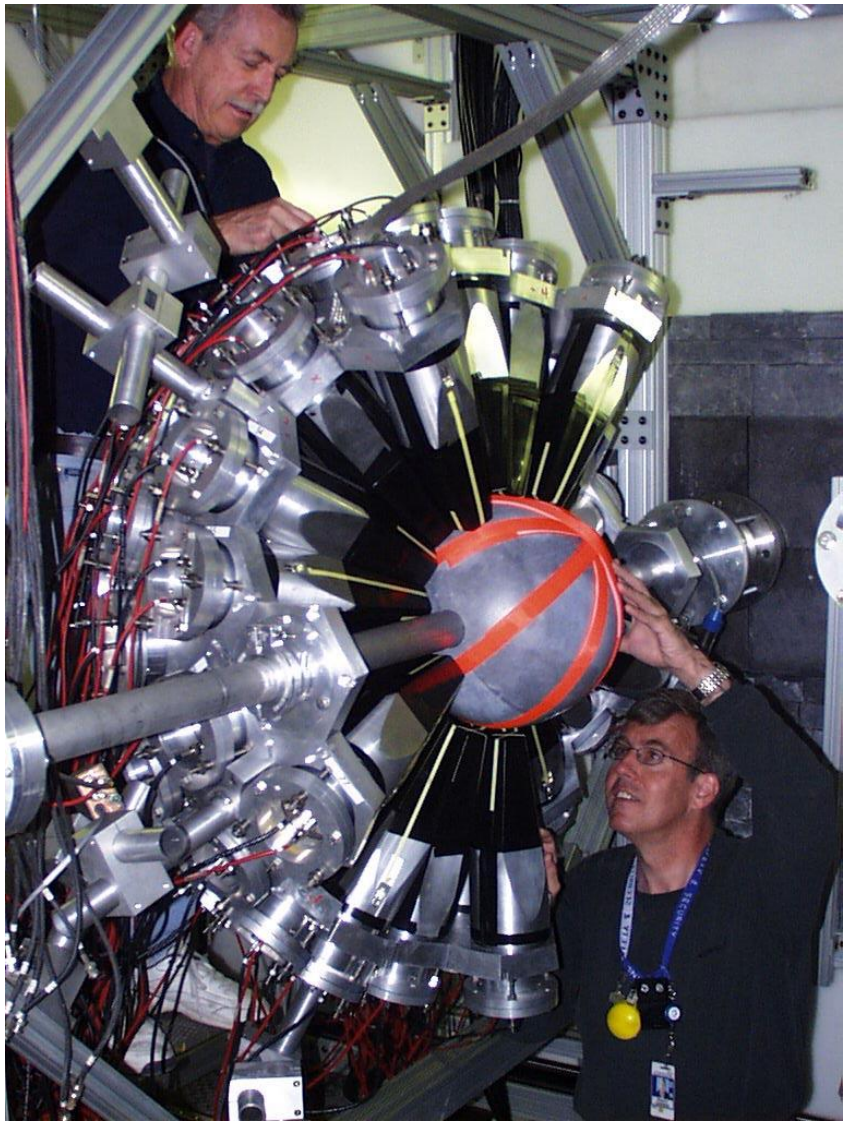
- LAMPF transformer fire
- target stuck in beampipe
- LiH absorber structural failure

→ shifted to distant future

Mississippi State: Dipangkar Dutta
Jeff Winger

National Lab partners: Aaron Couture
Catherine Fry
Matt Mumpower
Chris Prokop

https://lansce.lanl.gov/facilities/lujan/instruments/fp-14/about.php



4π BaF_2 array

Inside of the DANCE ball. The large gray sphere in the center is a ^{6}LiH neutron absorber.

Kofi "TuTu" Assumin-Gyimah

Participated in all expts
DANCE onsite Aug-Dec 2021

114Cd

Ph.D. expected Summer 2023

Finalized DANCE array calibration.
Corrections of & caused by target
Isolated 114Cd(n,g) yields
GEANT sim of thresholds & multiplicities
(w Milan Krticka & Standa Valenta)

Stephan Vajdic

112,113Cd

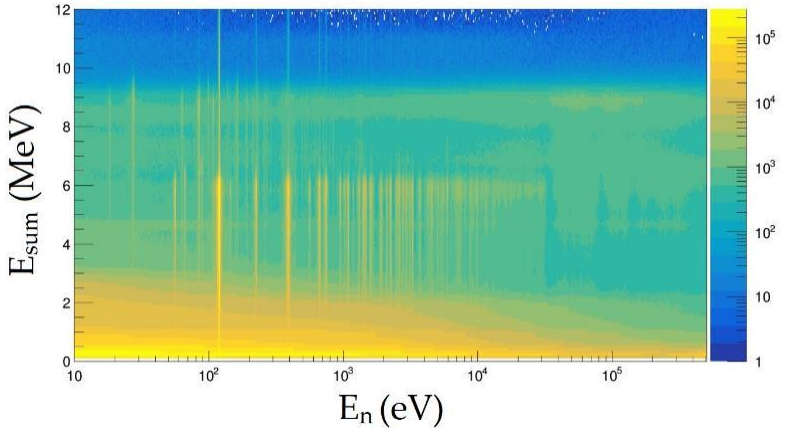
Started – several months in.

Daniel Araya

110,111Cd

Getting Started.

Example Raw Data: γ-energy deposited vs En

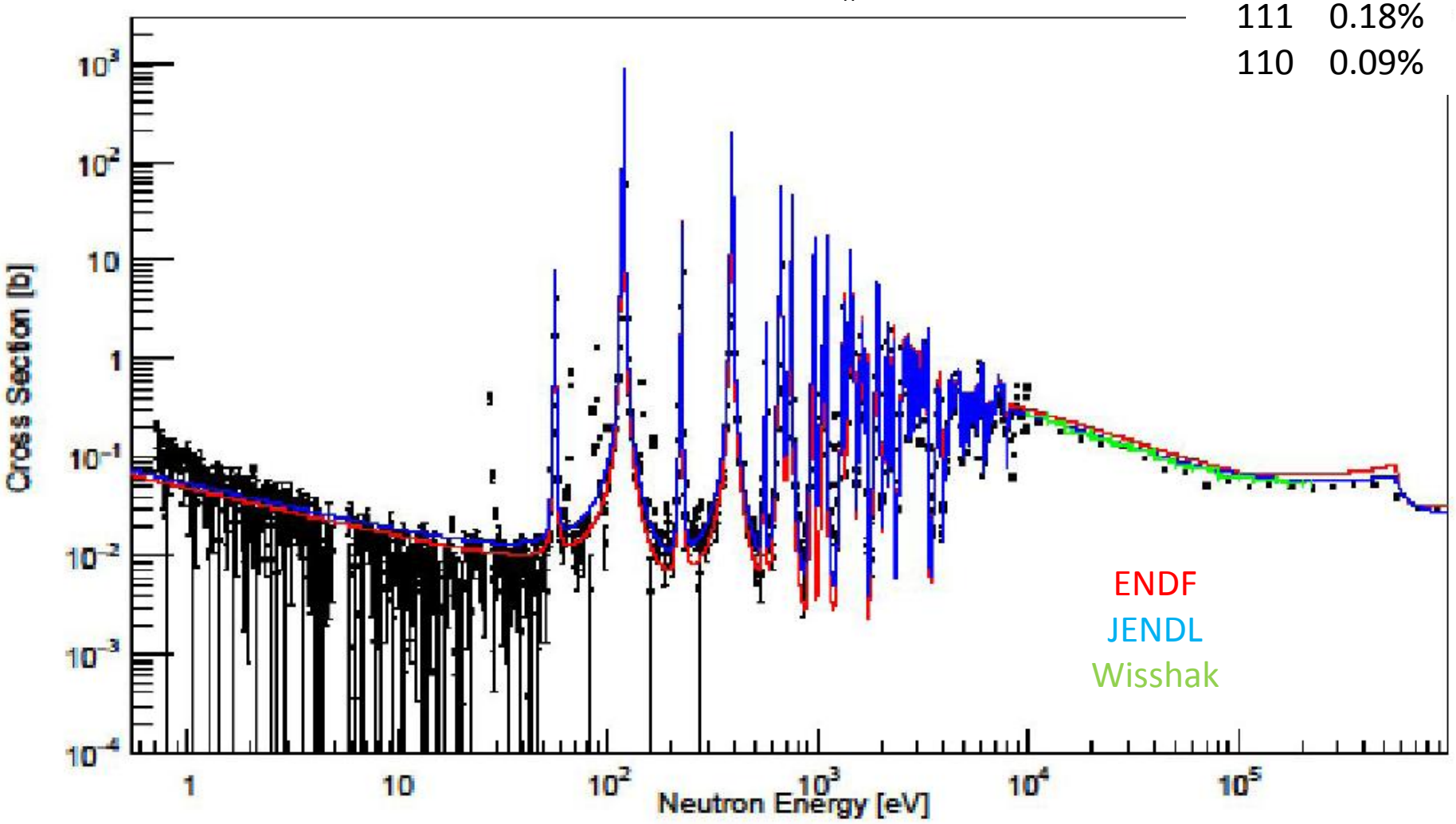


114 sample Cd(n,γ)

with some ^{110,111}Cd resonance contaminations
^{113}Cd interference at low E_n

Assay:

114	98.69%
113	0.40%
112	0.37 %
111	0.18%
110	0.09%



Supported by U.S. DoE FY20/21/22 awards SC0021424, SC0021243, SC0021175, SSC000056

SUMMARY:

- The team is working on many projects.
- Weekly collaboration meetings.
- Many UnivKY runs during summer 2021 & 2022
  to catch up from covid shutdown.
- Finished with ^{13}C data.
- Re-can ^{7}Li and measure again.
- Attack ^{19}F in summer 2023.
- Purchasing new HPGe so we can do γ–γ coinc once again.
- 3 pubs + 10 presentations since last WANDA

NSF 1913028 / 2209178

Dirty Hands

Accelerator Laboratory Skills
Operation, Maintenance, Repair, Design

Jeff Vanhoy

U.S. Naval Academy

Erin E. Peters, Yongchi Xiao, S.W. Yates

U Kentucky

Sally Hicks

U Dallas & U Kentucky

Ben P. Crider

Mississippi State

Supported by U.S. DoE FY20/21/22 awards SC0021424, SC0021243, SC0021175, SC000056

NSF 1913028 / 2209178