University of Kentucky Accelerator Activities

Jeff Vanhoy,
US Naval Academy, Annapolis, Maryland

Current Team Members

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

Univ Dallas
Sally Hicks, prof

Mississippi State
Kofi Assumin-Gyimah, gradstudent
Stephan Vajdic, gradstudent
Ben Crider, prof

US Naval Academy
Bijan Nichols, undergrad
Jeff Vanhoy, prof

- Lab Overview
- Activities from last 3 years
- Where we are at today
- Activities for next 3 years

Special thanks to Anthony Ramirez, currently @ LLNL.

Supported by U.S. DoE FY20/21 awards SC000056, SC0021175, SC0021243, SC0021424, and NA-0002931 (2015),

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

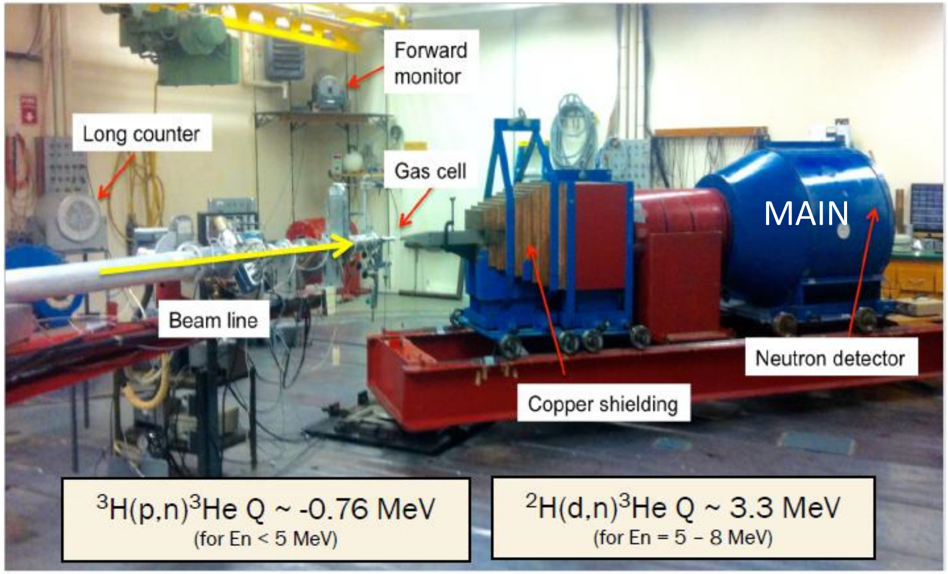
  - (n,n') - Elastic and inelastic cross sections

    ^{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

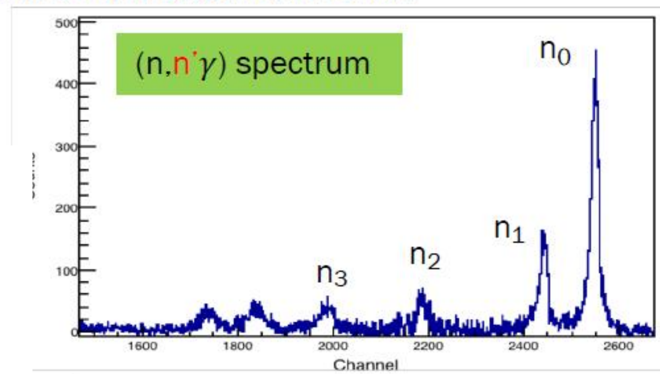
UKAL Experimental Hall



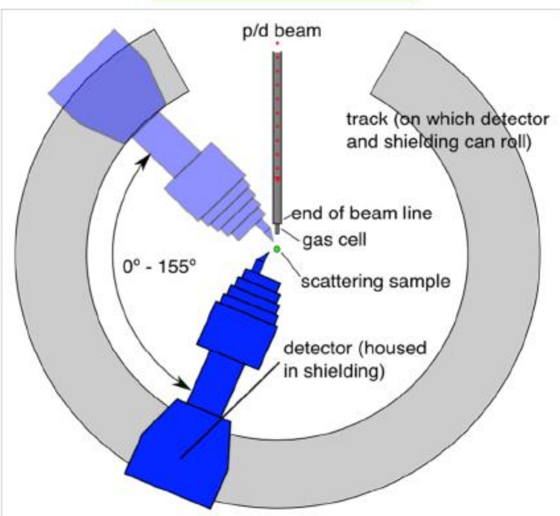
- Neutron and γ-ray detection

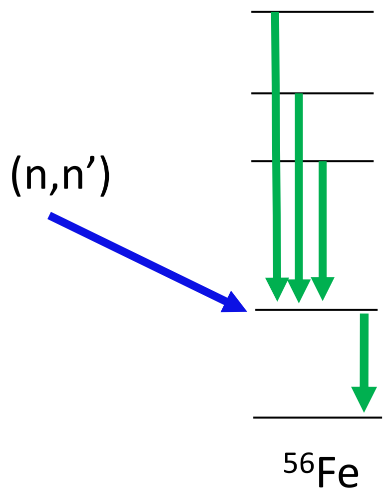
- time-of-flight (TOF) method to extract neutron energy spectrum
- TOF gating also employed to reduce background neutrons and γ-rays

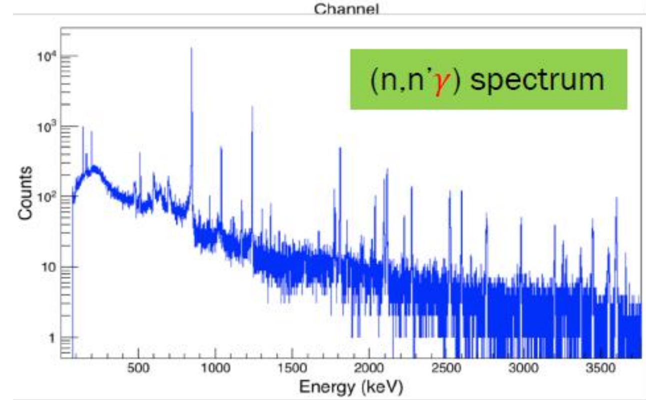
- Angular distribution and excitation function measurements



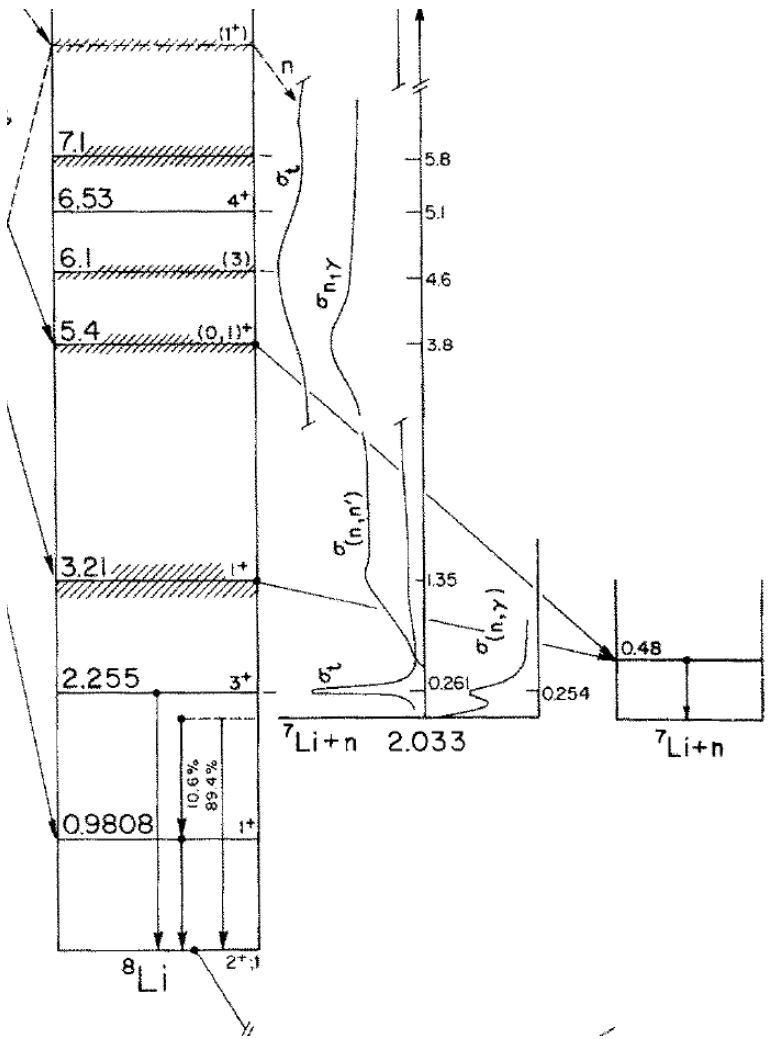
Schematic view

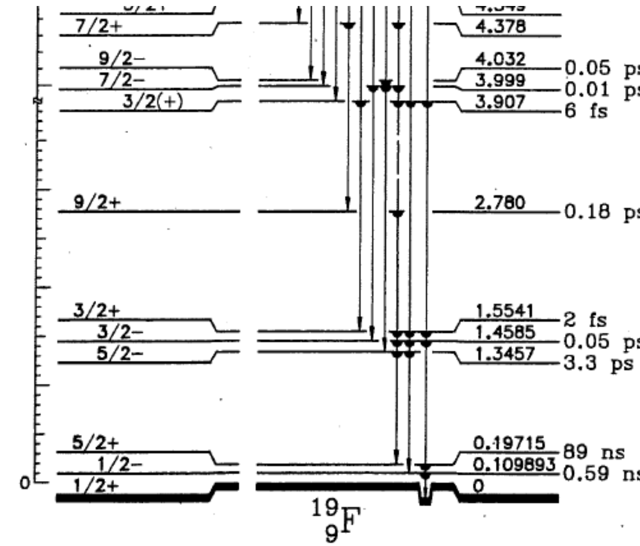


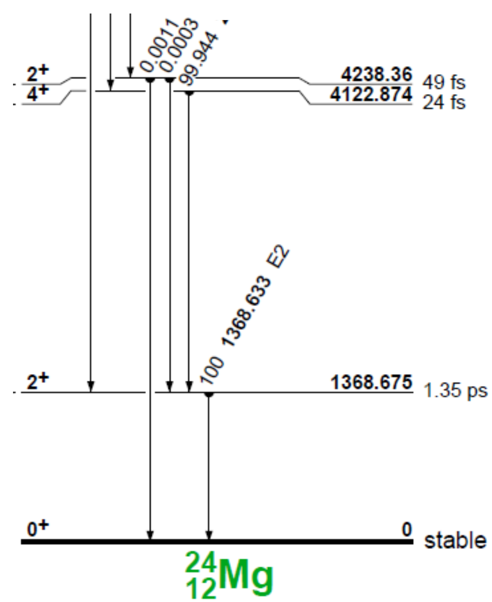




Last 3 year's Activities

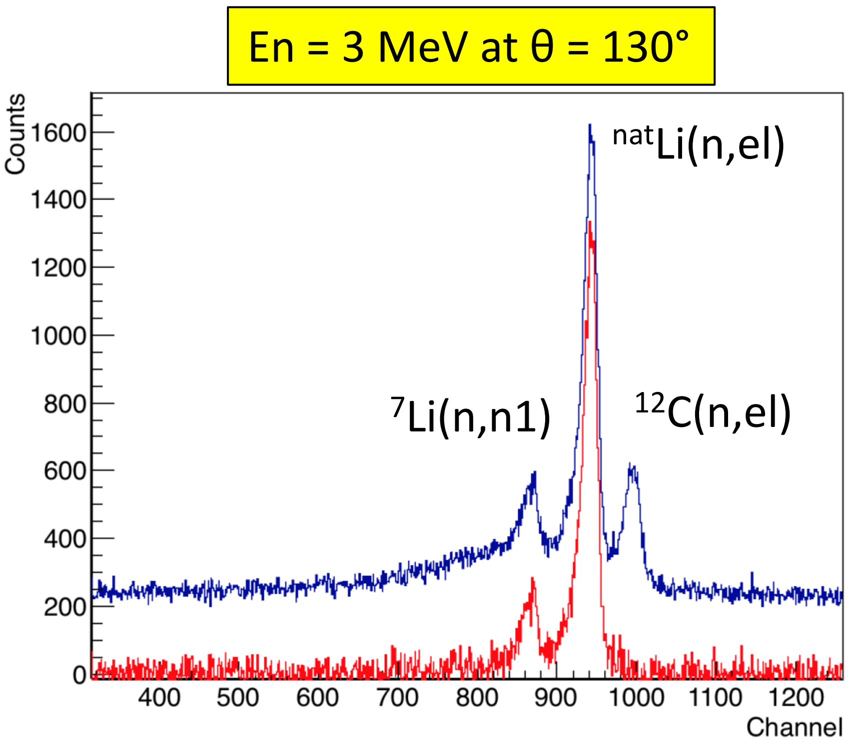


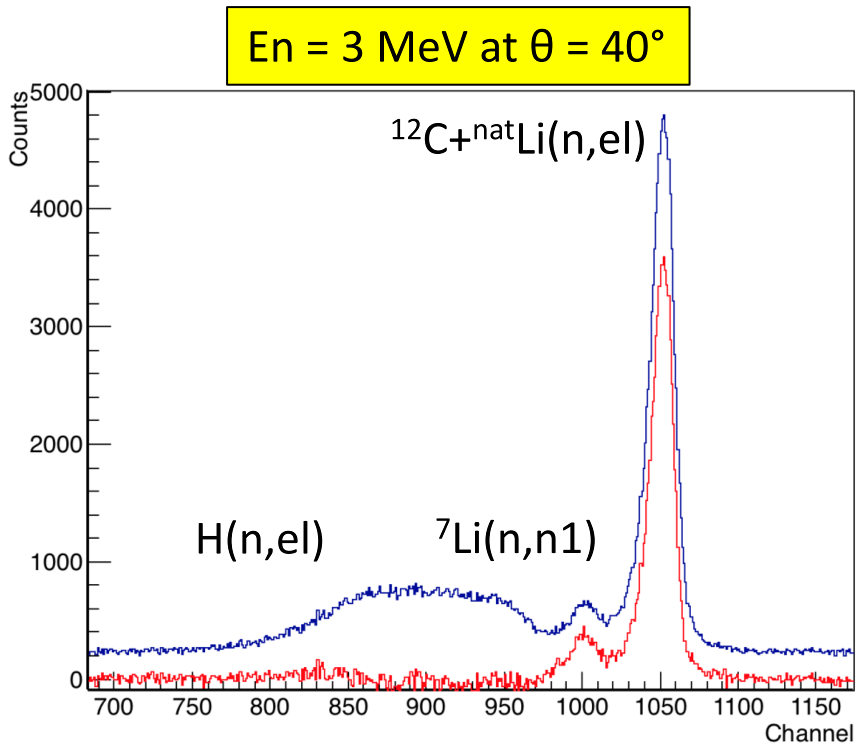




^{nat}Li

Li(n,n)



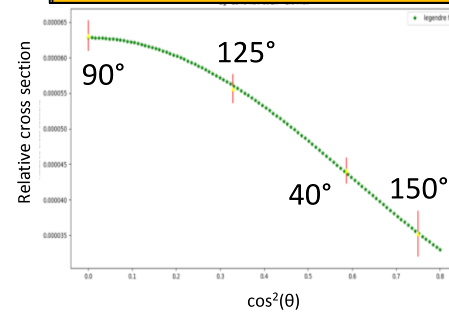


- ^{nat}Li scattering sample was placed inside a polyethylene container. Hence, the additional C and H elastic peaks in the raw spectra (blue).
- Spectra subtracted with contribution by the container (red) display over subtraction due to the H(n,el) bump as shown in the histogram at the right.

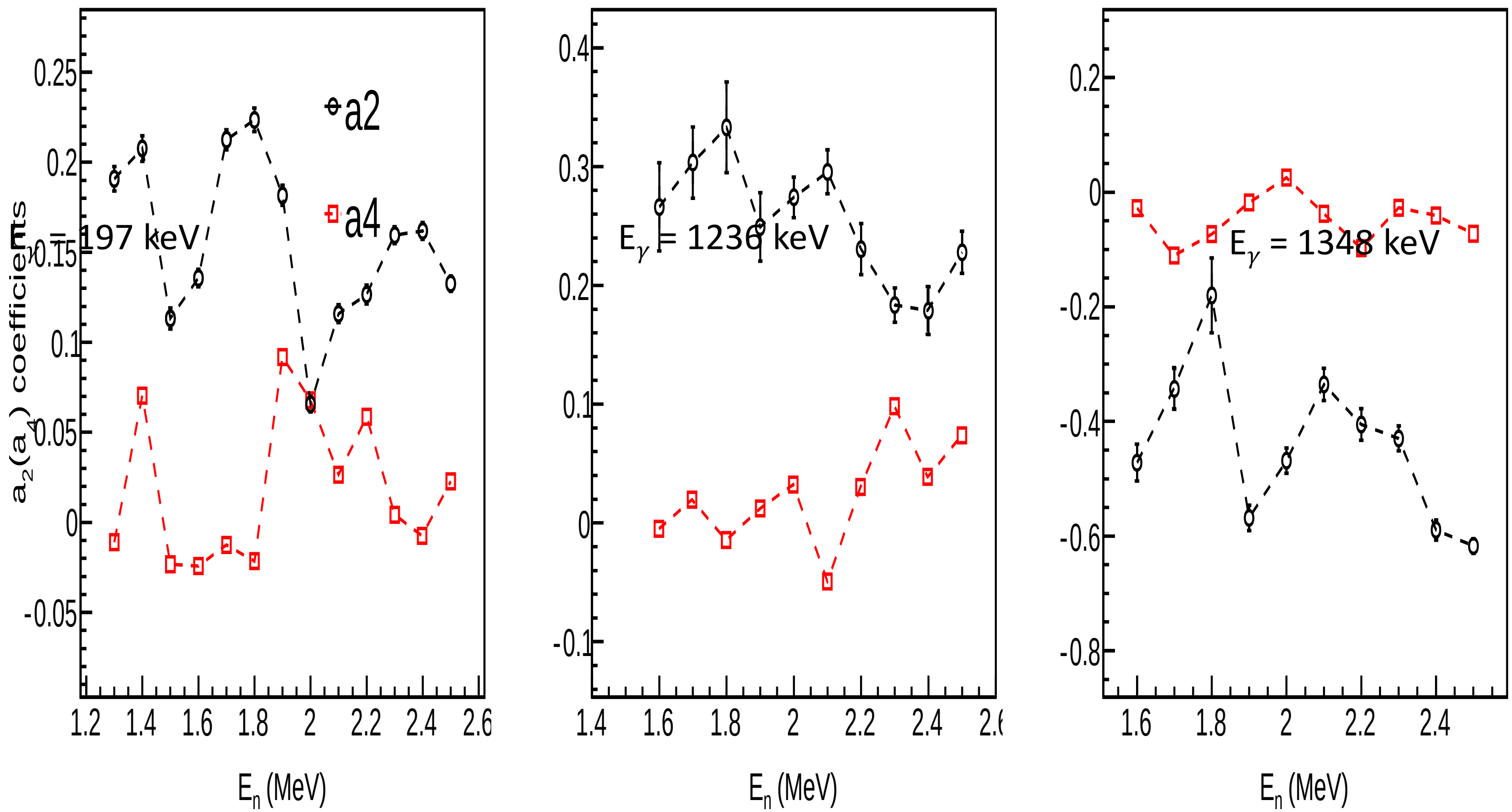
^{19}F

Angular distribution of γ-rays from ^{19}F(n,n'γ)

$$\frac{d\sigma}{d\Omega}(E_\gamma) \approx A_0[1 + a_2P_2(x) + a_4P_4(x)]$$



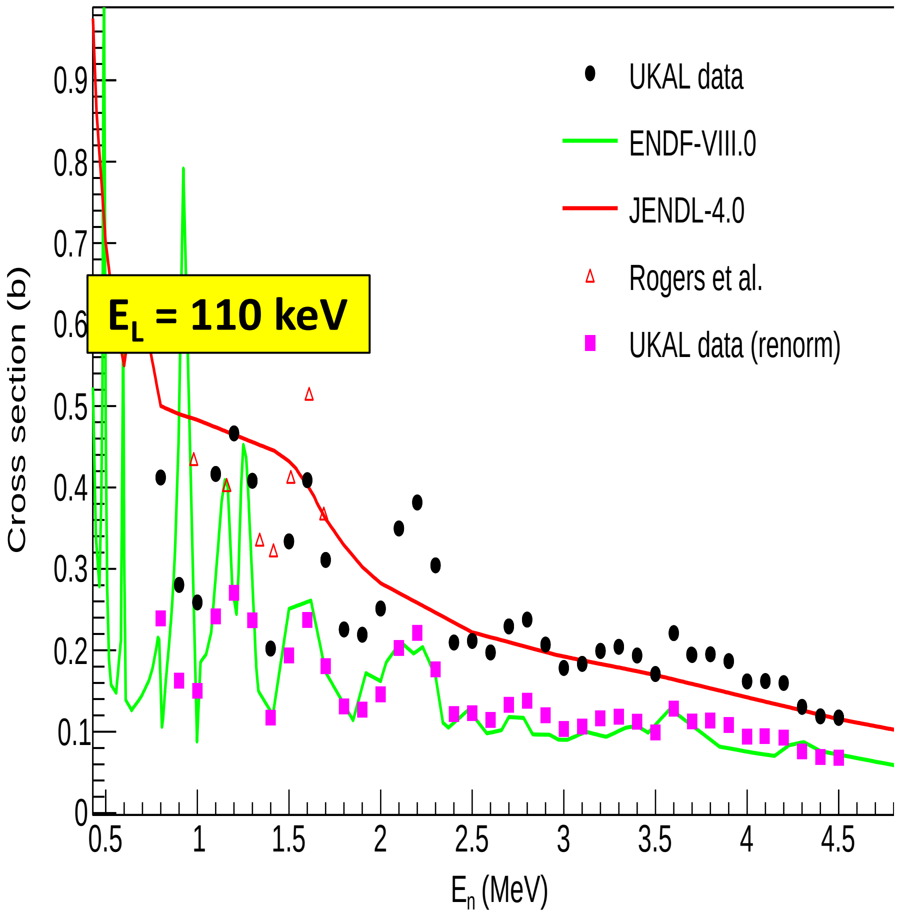
- a_4 values are < |0.1|

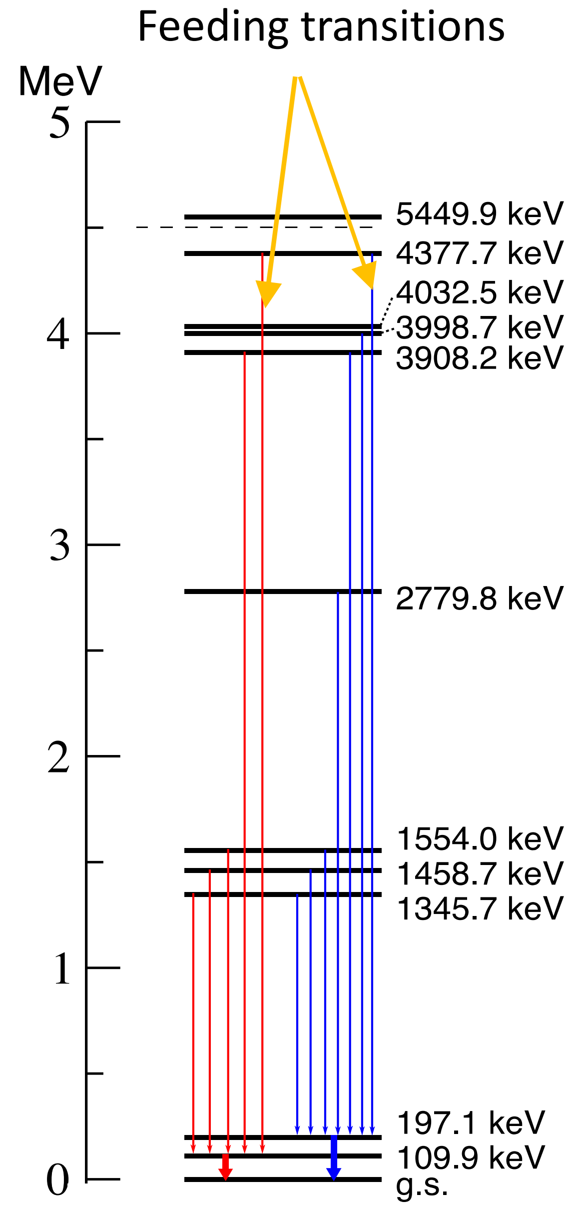


^{19}F

➢ Deducing ^{19}F level cross sections

1^{st} excited → gnd

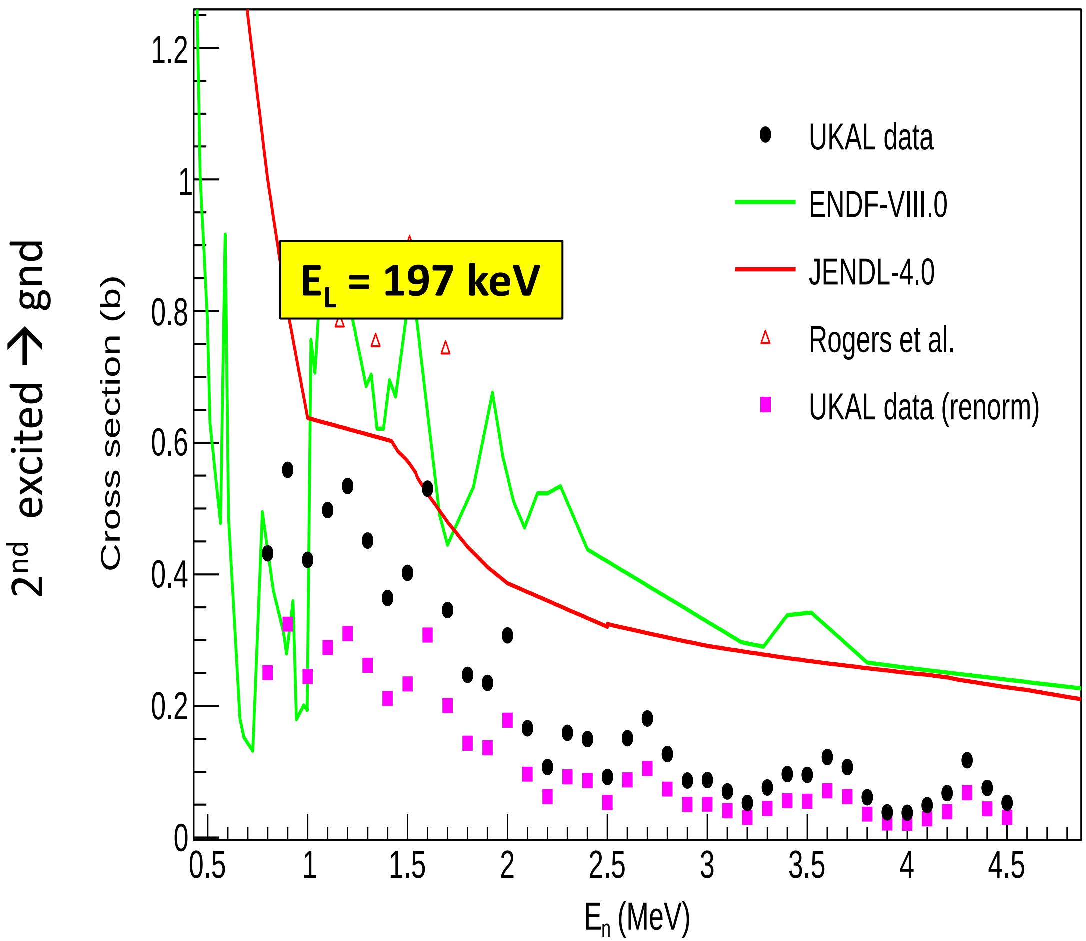


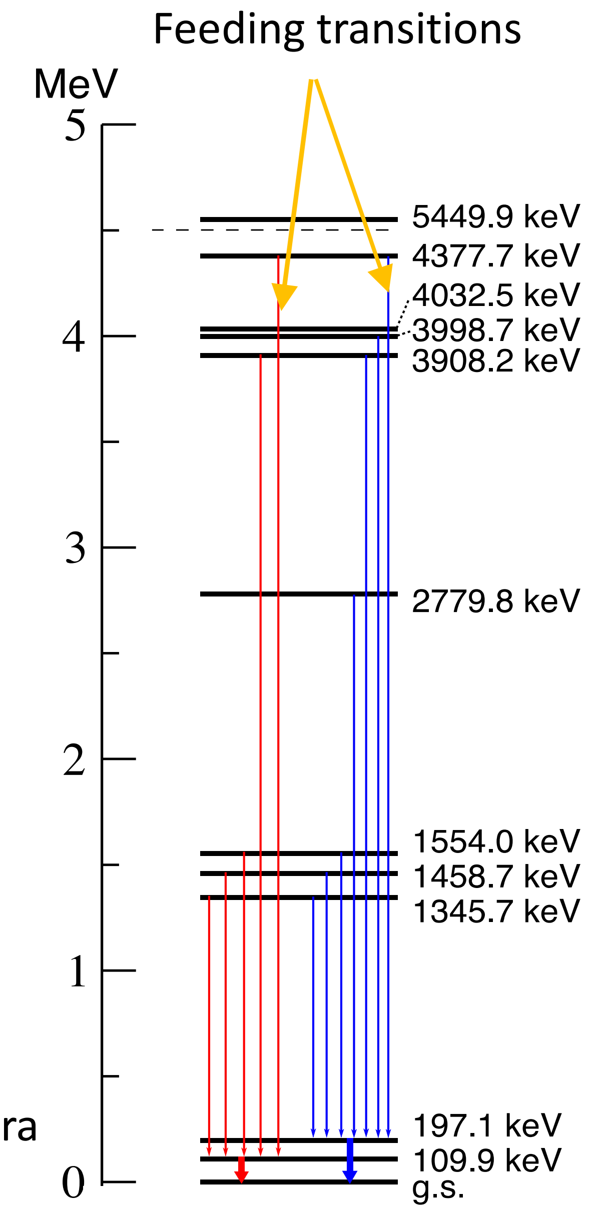


- ENDF-VIII.0 and JENDL-4.0 differ in shape and magnitude
- Our data are closer to JENDL in terms of magnitude but follow the structure presented by ENDF-VIII.0
- UKAL data (renorm) are data multiplied by arbitrary factor so that it agrees with ENDF.

^{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.

Measurement Status

Measurements	Status
$^{nat}Li(n,n)$ & $(n,n'\gamma)$	1. Measured γ-ray excitation function 0.8-4.5 MeV with accompanying angular distributions in 0.1 MeV steps on LiF target. 2. Measured 2.0 & 3.0 MeV (n,n') data angular distributions on Li metal target
$^{19}F(n,n)$ & $(n,n'\gamma)$	1. Measured γ-ray excitation function 0.8-4.5 MeV with accompanying angular distributions in 0.1 MeV steps on LiF target. 2. Measured a trial LiF(n,n) angular distribution 3. May go to a CaF_2 or TaF target. Traditional target is CF. 4. The 89 ns lifetime of the 197 keV level causes huge problems in our n & γ TOF spectra. 5. Current DAQ software not equipped to take time-tagged event mode data. → Ben Crider
$^{24}Mg(n,n'\gamma)$	0. 24Mg is very deformed like 23Na 1. Measured γ-ray excitation function 0.9-4.5 MeV with accompanying angular distributions . 2. a4 coefficients remain complicated
$^{nat}Si(n,n)$ & $(n,n'\gamma)$	1. Isotopically enriched samples not available. 2. Don't appear to be learning anything from the data we took.

Lessons Learned

- n + ^{nat}Li
  - ENSDF & R-matrix CN descriptions seem inconsistent.
  - Must take isotopic data, samples waiting to be ordered.
  - There are 2 'experimental' shapes to the $\sigma_{(n,n1)}$ threshold.
- n + ^{19}F
  - The 89 ns 2nd excited level wreaks havoc on measurements b/c counts dribble out of the TOF spectrum.
  - New digital DAQ required so can measure time dependence of γ-ray events.
- n + ^{24}Mg
  - (n,n'γ) a_4 coefficients can be large, therefore can't trivially extract (n,n_k) cross sections from γ-ray data unless ang distrib measured.
  - γ-ray angular distributions measured with 4-7 points depending on apparent size of the a_4.
- .

Where we are at today

Today’s Status

- DOE-NP Funded for Next 3 years
  - All 4 school waiting for funds to become active
    - UD, USNA, MS State official start 1 Sept
    - UnivKY official start 1 Dec
    - MS State has functioning money.
    - Collaboration holding weekly mtgs
    - New DAQ quotes -- ready to order
    - COVID restrictions prevent major runs

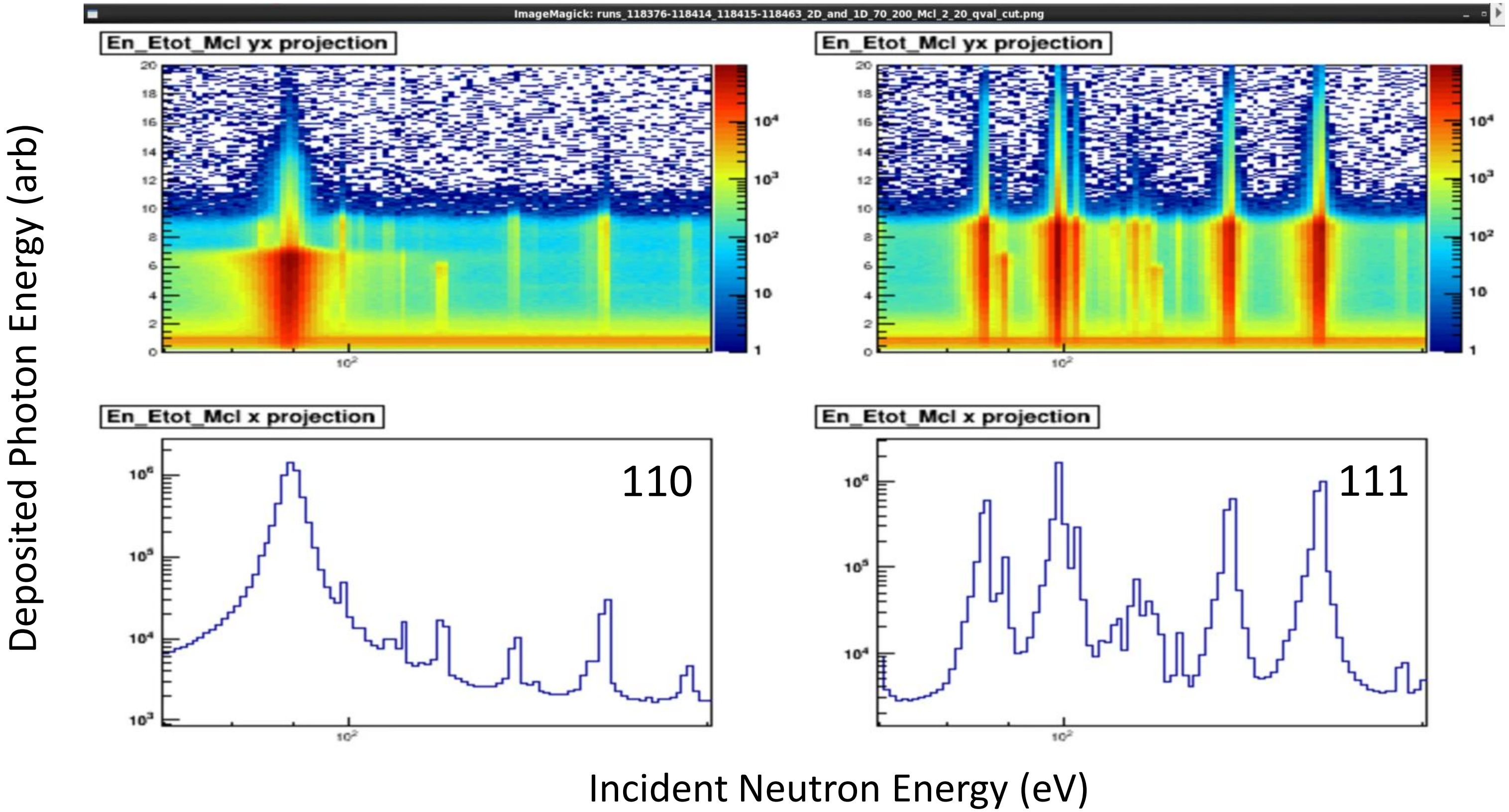
- Hired postdoc Yongchi Xiao
    - Hired from other funds (started 1 Oct)
    - Learning/developing γ-ray data analysis procedures in ROOT

- Recruited Students
  - Undergrad: Bijan Nichols
  - Gradstudents: Kofi Assumin-Gyimah, Stephan Vajdic

- Lee Bernstein, LBL
  - Perhaps sending students to help during summer.

- ^{110,111,112,113,114}Cd(n,γ) measurements at DANCE completed !

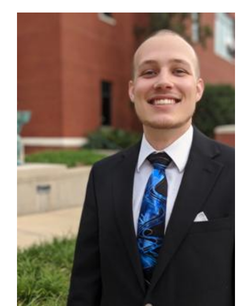
$^{110,111}Cd(n,\gamma)$ @ DANCE 14days in Sept2020



Step 1: Convert to XS

Step 2: Extract γ-ray strength function

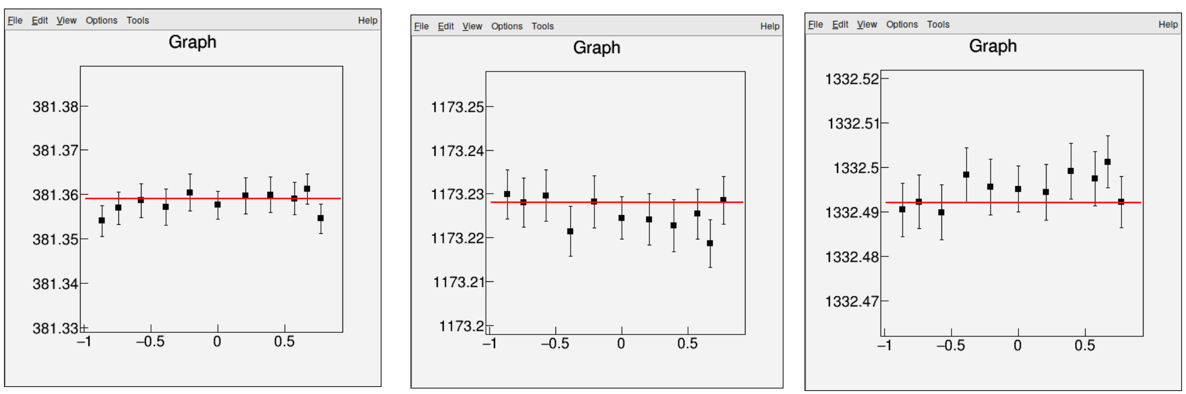

Kofi


Stephan

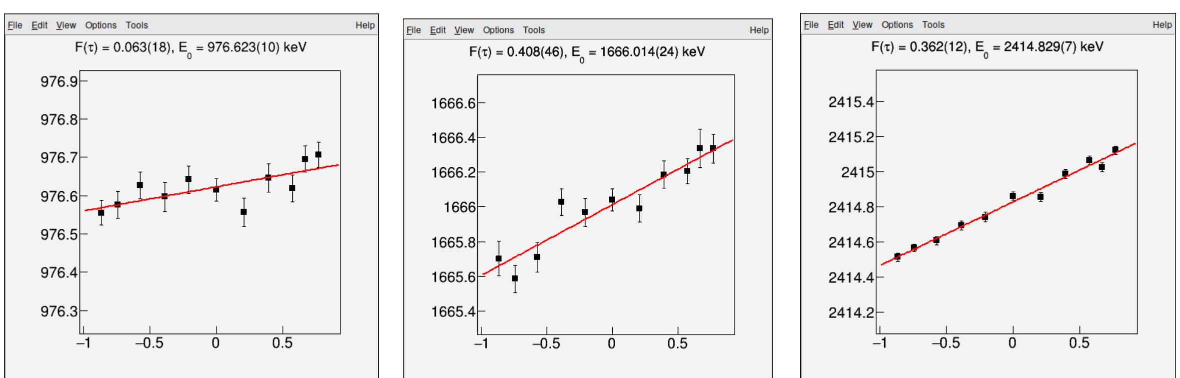
New Postdoc, New Data Acquisition System

Yongchi

Calibration Lines



Xe Lines w Doppler Shifts



Until the DAQ system arrives, YX trying to use ROOT to fit “Kentucky data”

Next 3 years

Primary Projects

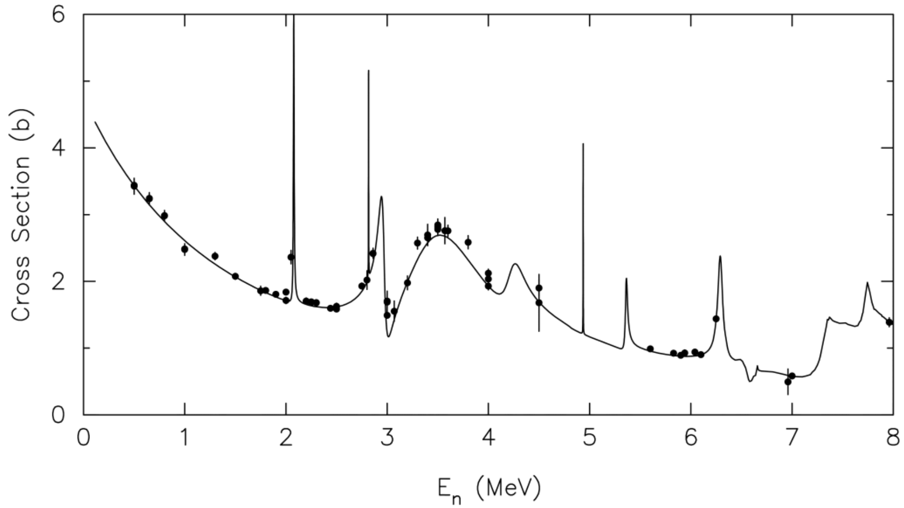


Fig. 1. The ENDF8 [11] angle-integrated $^{12}C(n,n)$ cross sections; data are from previous UKAL measurements.

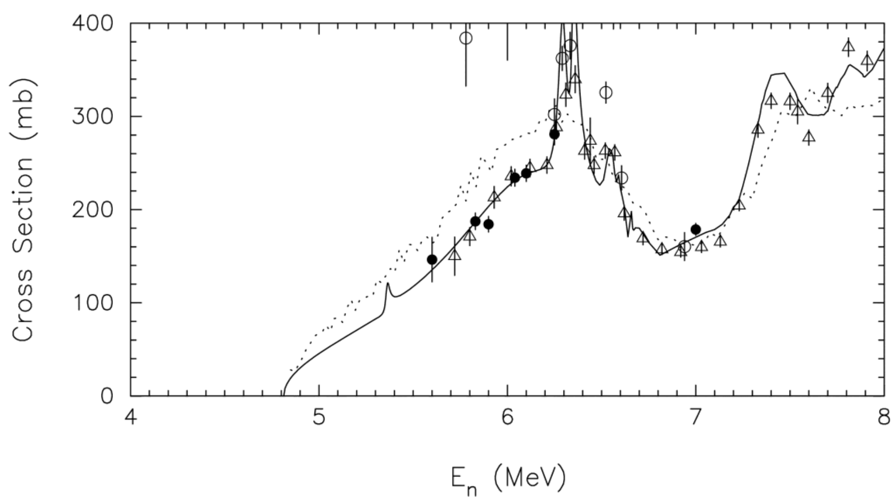


Fig. 2. The ENDF8 angle-integrated $^{12}C(n,n_1)$ cross section annotated with previous experimental measurements found in EXFOR. UKAL data are given by blackened circles.

12C(n,n')

4-6 additional angular distribution measurements in the range 5-8 MeV to assist with resonance parameters.

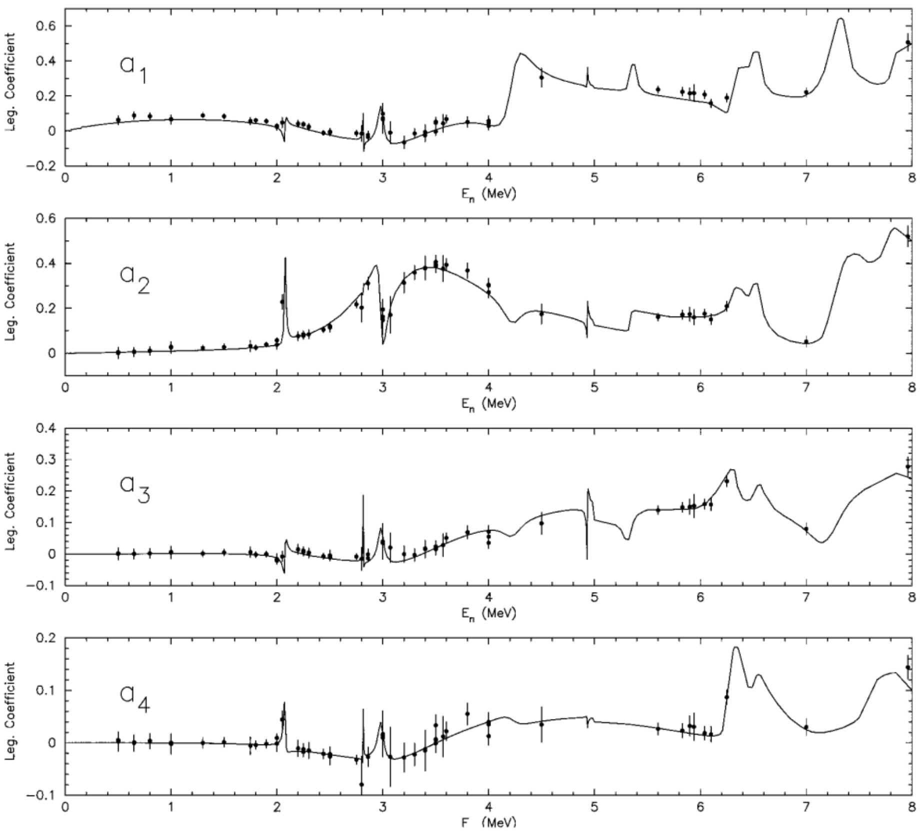
Are there problems down at 100-300 keV we should measure?

Have request for back-angle measurements at and just above 1 MeV.

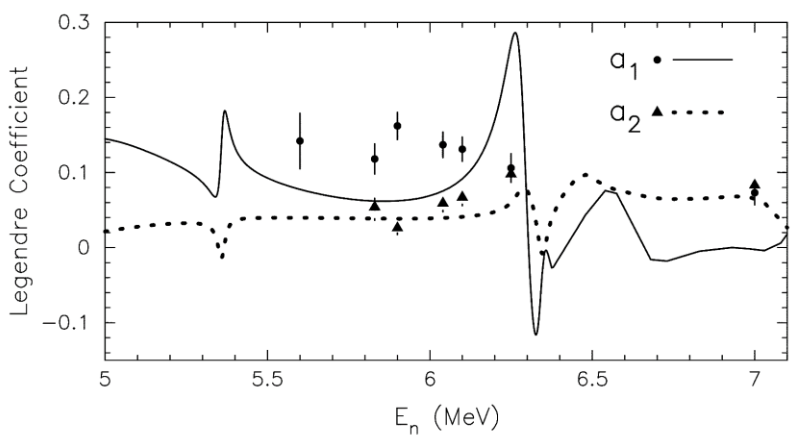
Carbon Elastic Legendre Coefficients: Results vs ENDF

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

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



→ Elastic agreement is very satisfying.



Agreement with ENDF coefficients is not so satisfying.

→ Describing (n,n_1) is difficult

Primary Projects

7Li(n,n$_k$) and (n,n'γ)

We need isotopic samples to generate useful information.

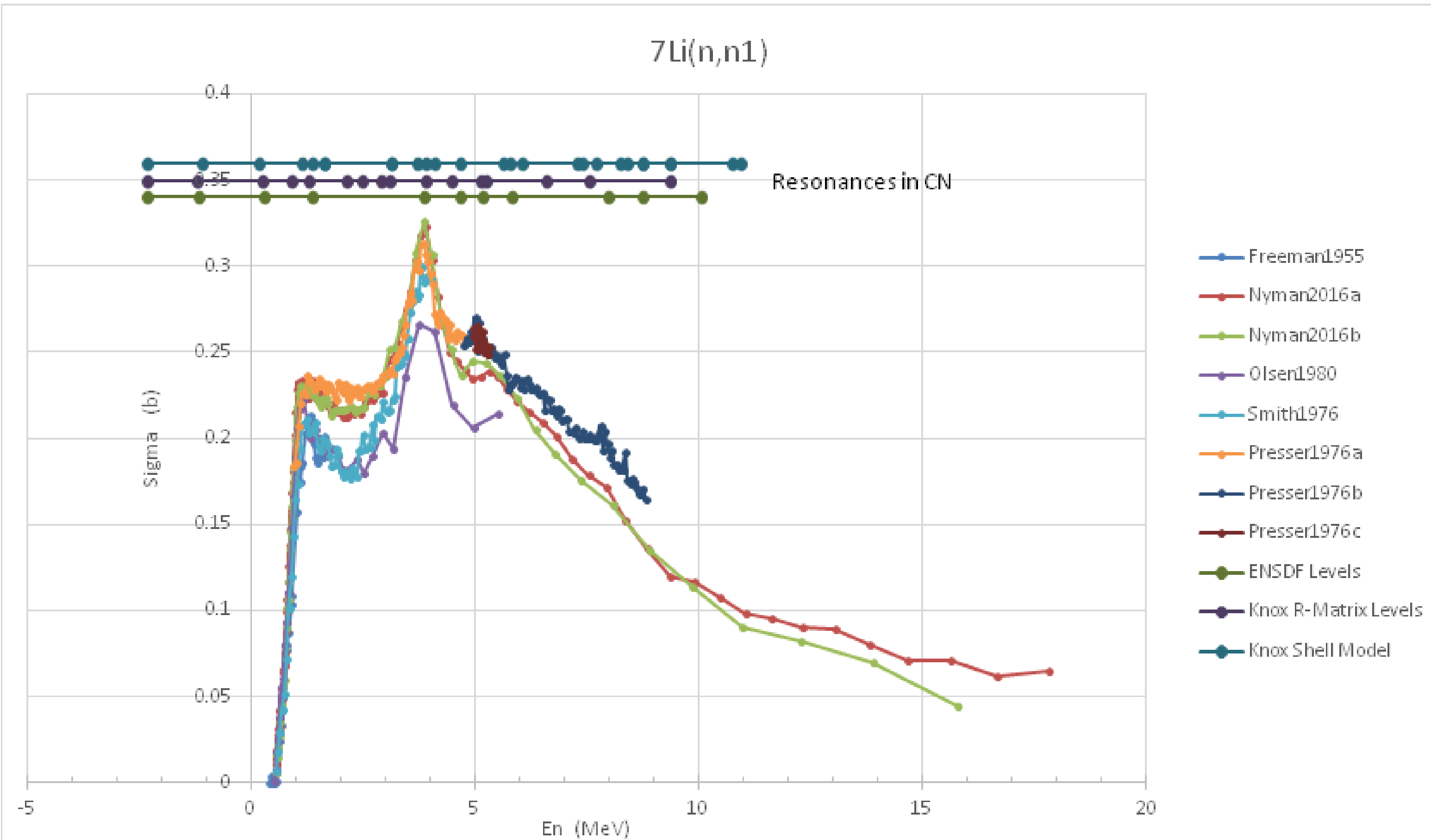


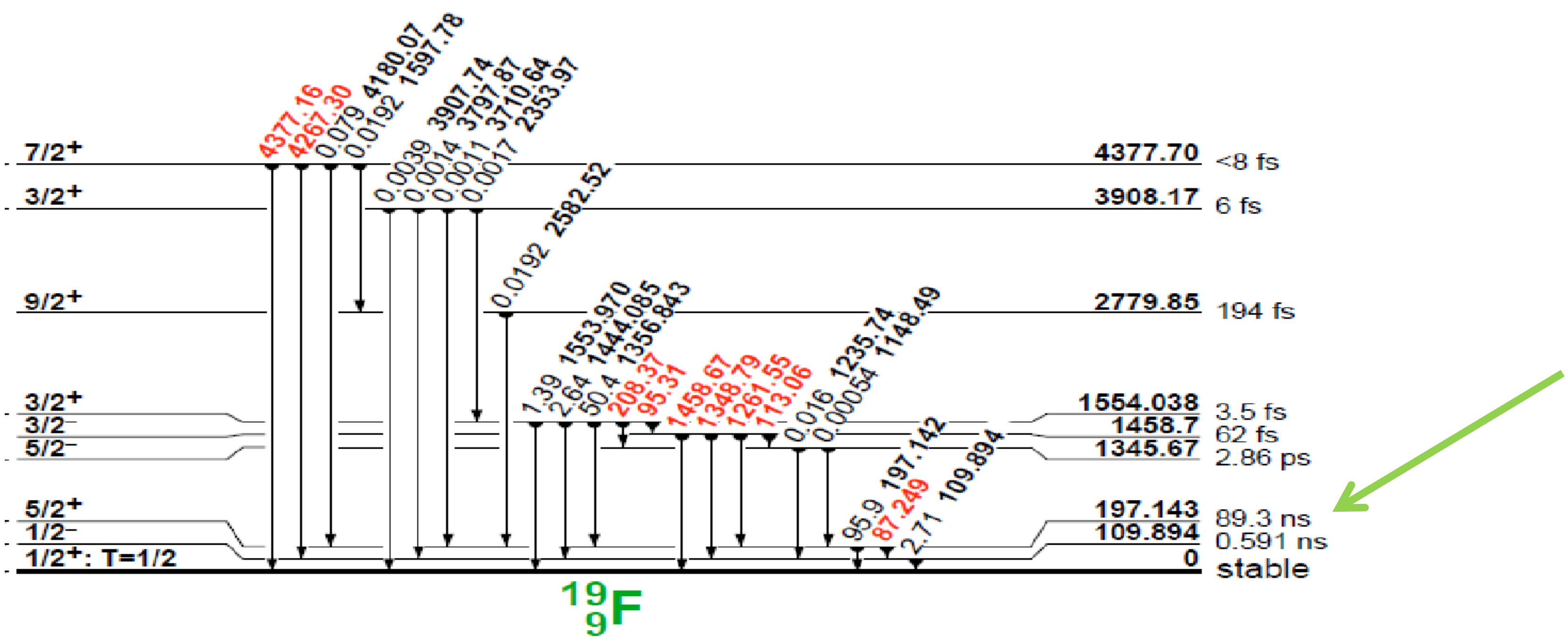
Fig. 3. Measured / inferred ^{7}Li(n,n$_1$) cross sections from EXFOR compared to two R-matrix calculations. The position of the resonances are indicated along with the adopted levels of the ^{8}Li compound nucleus from ENSDF.

Primary Projects

19F(n,n'γ)

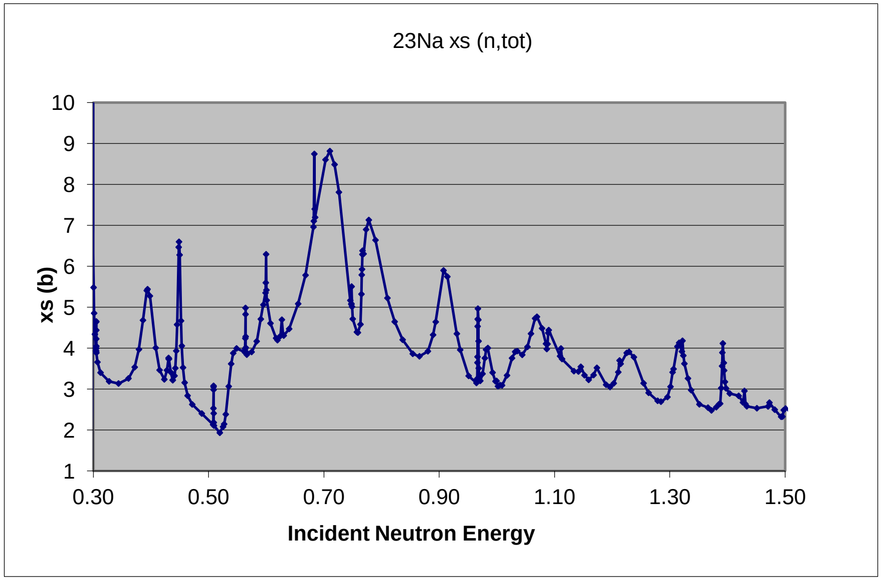
Surprisingly few detailed neutron scattering data exist for 19F. Industrial manufacturers of compact molten salt reactors employ FLiBe as a base material and have called for an increased understanding of its properties.

Cross sections in the lower portion of the fast neutron region exhibit resonances, but countable resonances disappear about 2.5 MeV. Total cross sections have been measured for 19F, but few experimental angular distributions exist. This is a problem for R-matrix reaction model analysis because the 19F ground state is Jπ = ½+, and, therefore, at least two partial widths are involved in the formation and decay of the compound nucleus.



As mentioned previously, the 89 ns isomer causes a lot of trouble.

Secondary Projects (only if we have time)



Sodium-23 is a component in …..

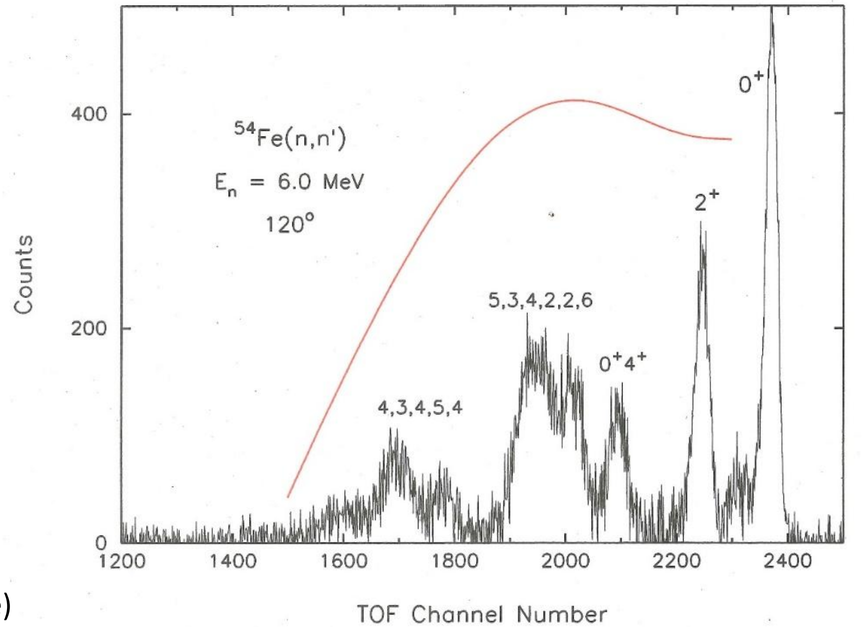
Measurements below 1.3 MeV.

More ang distrib for resonance information

Iron-56, one of the most ubiquitous materials, ….

Possible addn'l measurements upon request.

Conversion of existing HE data to neutron emission spectra.



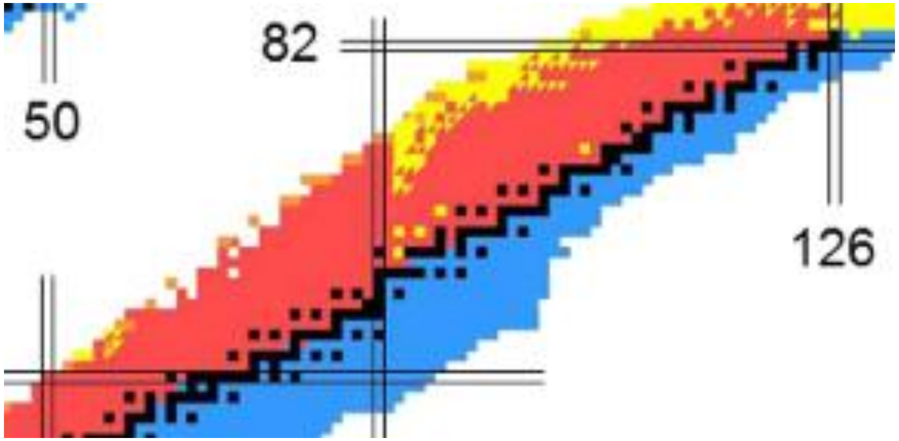
(OK, the figure is 54, but you get the picture)

Secondary Projects (only if we have time)

Conversion of Previously Measured Angular Distribution Data to Differential Cross Sections.

The active interrogation community is aware that much (n,n'γ) data for nuclear structure purposes have been measured at UKAL.

The list includes most major stable isotopes of the elements Na, Fe, Ge, Se, Zr, Mo, Ru, Pd, Cd, Sn, Te, I, Xe, Ba, Ce, Nd, Sm, Gd, Dy, and Er.



Secondary Projects (only if we have time)

n-γ Angular Correlations. The team has assisted associates at the nELBE time-of-flight facility (https://www.hzdr.de/db/Cms?pNid=35) with n-γ angular correlation calculations and have been encouraged to submit beamtime proposals for targets of common interest (^{56}Fe, ^{28}Si, ^{54}Fe). Such measurements have the potential to improve the precision of our γ-ray production cross sections…

Neutron emission spectra.

In the High Priority Request List [1], the fast reactor design community has requested emission spectra for neutron inelastic scattering on ^{23}Na and ^{56}Fe between 0.5 and 20 MeV incident energy and on ^{238}U between 65 keV and 20 MeV. The laboratory GELINA has made precise measurements of the γ-ray emission spectra of these nuclei; however, that laboratory does not have the capability to determine the emitted neutron energy.

Neutron capture.

The team has also been repeatedly asked to participate in (n,γ) measurements at the Institute Laue-Langevin. However, those experiments tend to be basic research instead of satisfying applied interests of the US government programs. The ILL FIPPS array employs high resolution HPGe detectors but with a continuous neutron beam. The DANCE array at LANL employs low resolution BaF_2 detectors with a pulsed neutron beam. Some team members would like the option to participate in some limited capacity, should funds be available.

CdTe(n,γ) ^{100}Ru(n,γ) -- awaiting rescheduling

SUMMARY:

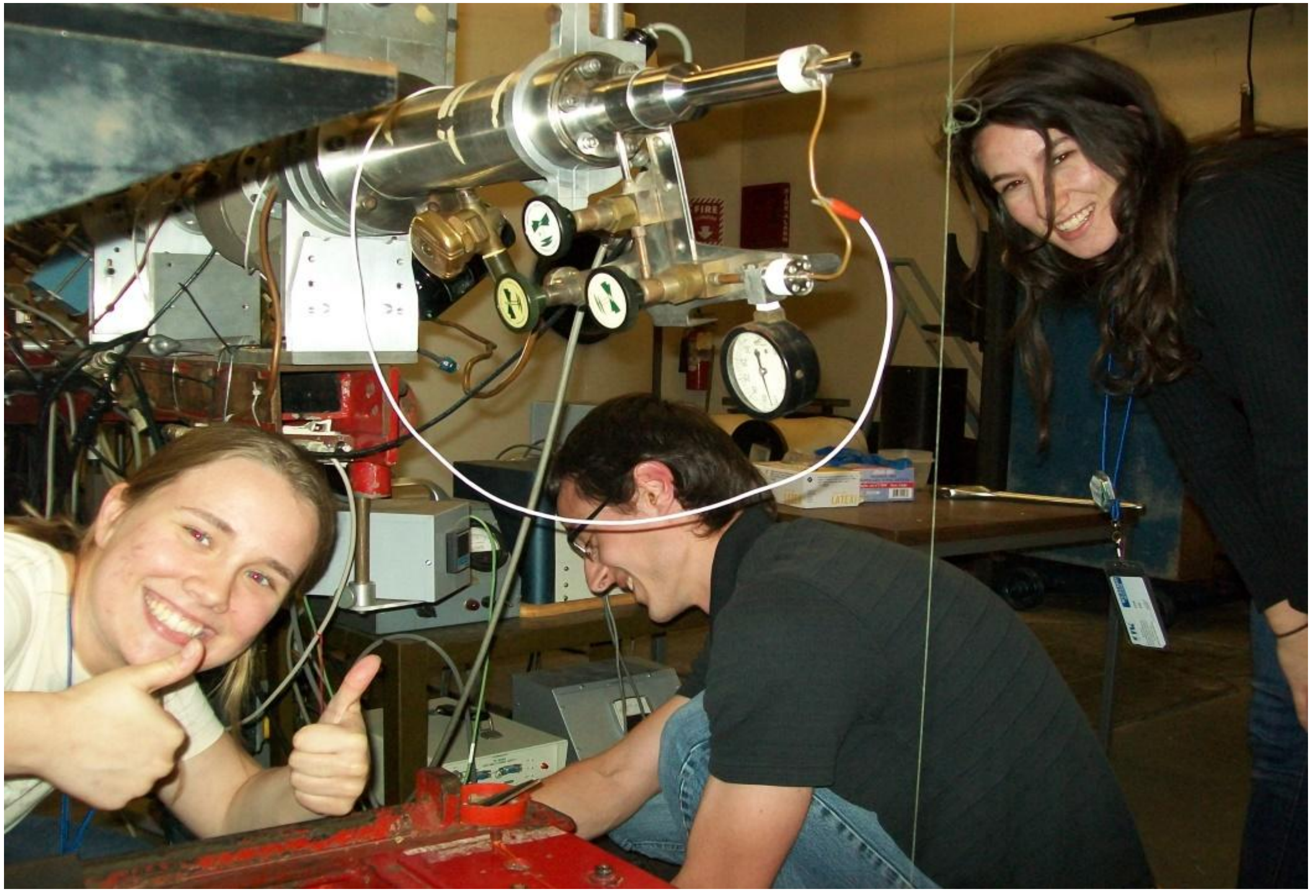
Much to do.

Have identified the students.

Must travel to take data and efficiently collaborate.

END

END



Uncertainties in Angular Distribution Values

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%

making new MCNP tests with improved gas cell description to make this more definite

depends on the target nucleus

- Overall during ^{23}Na runs: elastics ~8-10%
  inelastics ~13-18%

- Overall during $^{54\text{-}56}$Fe runs: elastics ~7-10%
  inelastics ~10-14%

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