University of Kentucky Cross Section Measurements: C, Si, Li, and F

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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

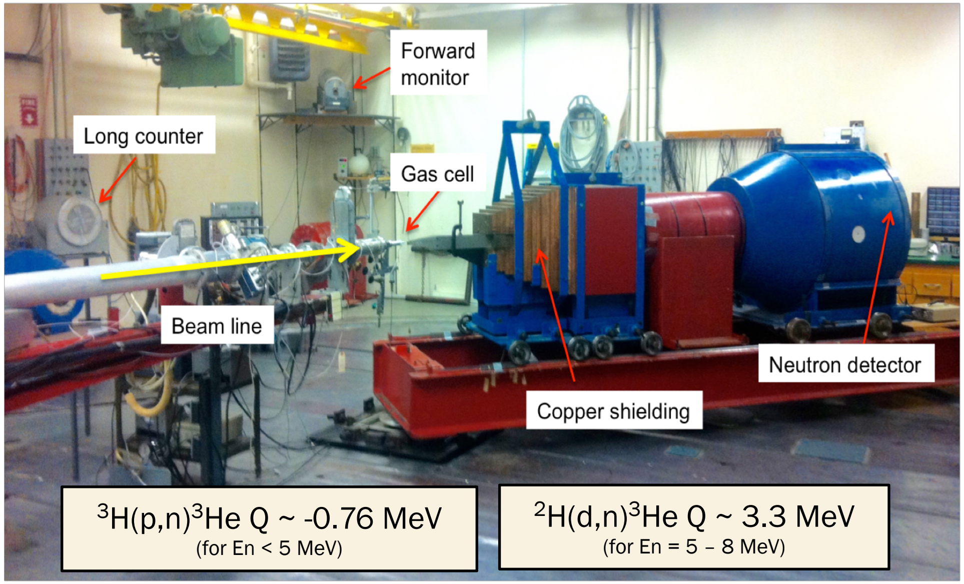
  - (n,n') - Elastic and inelastic cross sections

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

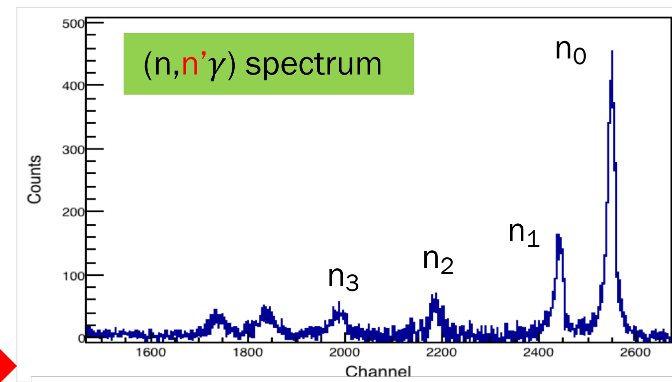
  - (n,n'γ) - γ-ray production cross sections

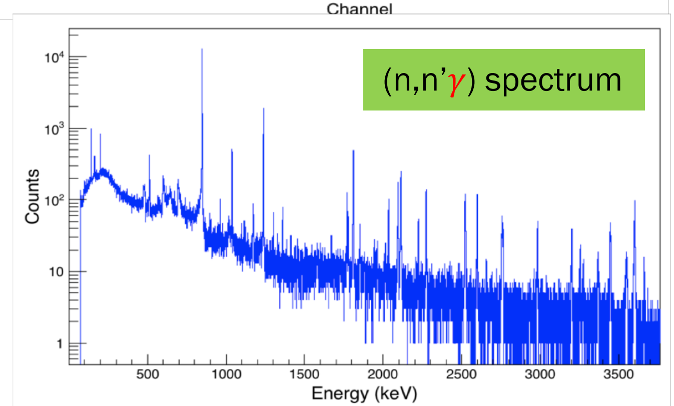
    Level cross sections
- Detector development

UKAL Experimental Hall

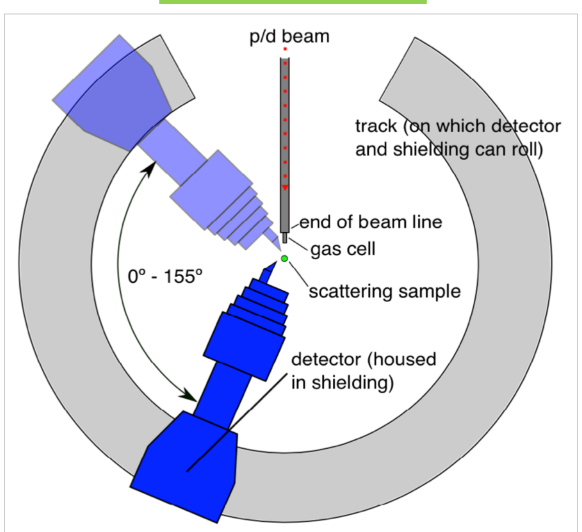


- **Neutron and γ-ray detection**
  - time-of-flight (TOF) method to extract neutron energy spectrum
  - TOF gating also employed to reduce background neutrons and γ-rays
- **Angular distribution and excitation function measurements**

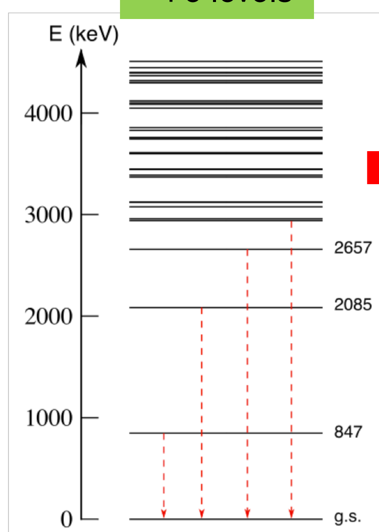




Schematic view

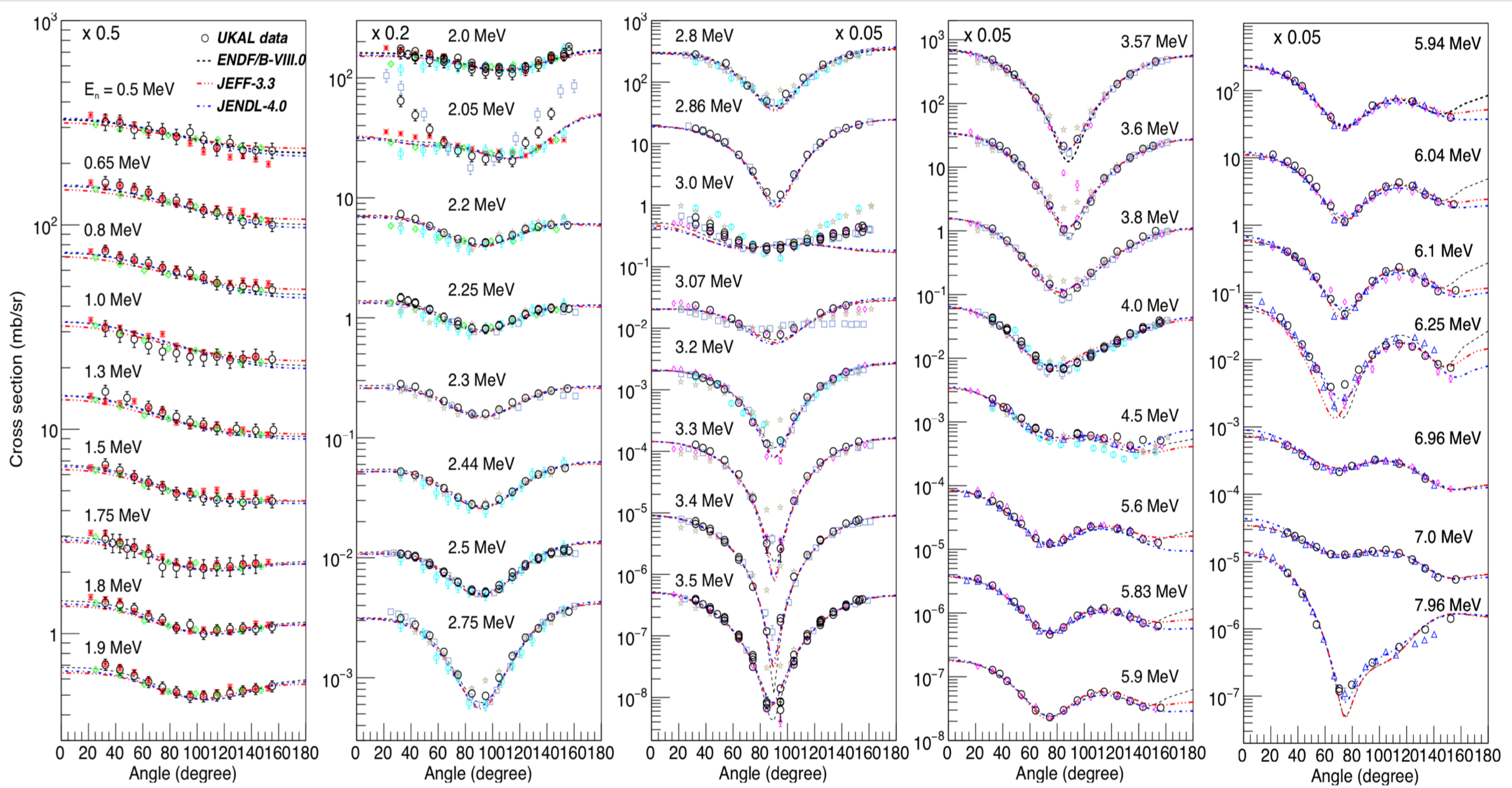


^{56}Fe levels



Differential elastic cross sections for n +^{12}C

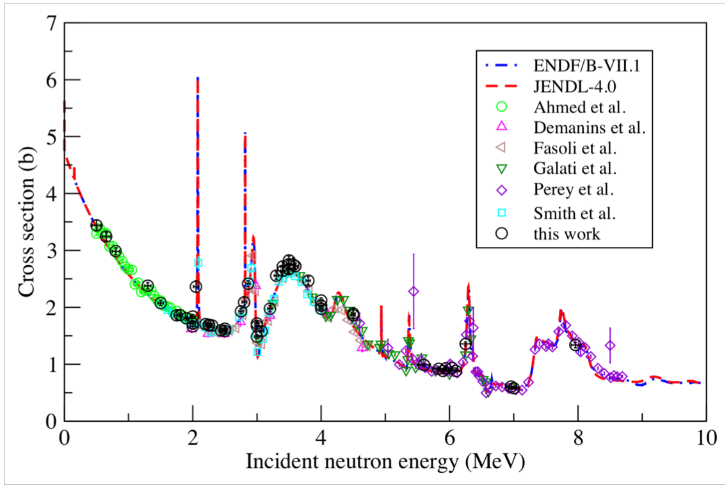
- Data accumulated from previous measurements (~50 elastic angular distributions)



- Comparison with previous measurements (Ahmed, Demanins, Fasoli, Galati, Lane, Perey, Smith) and evaluated cross sections (ENDF-VIII.0, JEFF-3.3, and JENDL-4.0)

Differential elastic cross sections for n+^{12}C

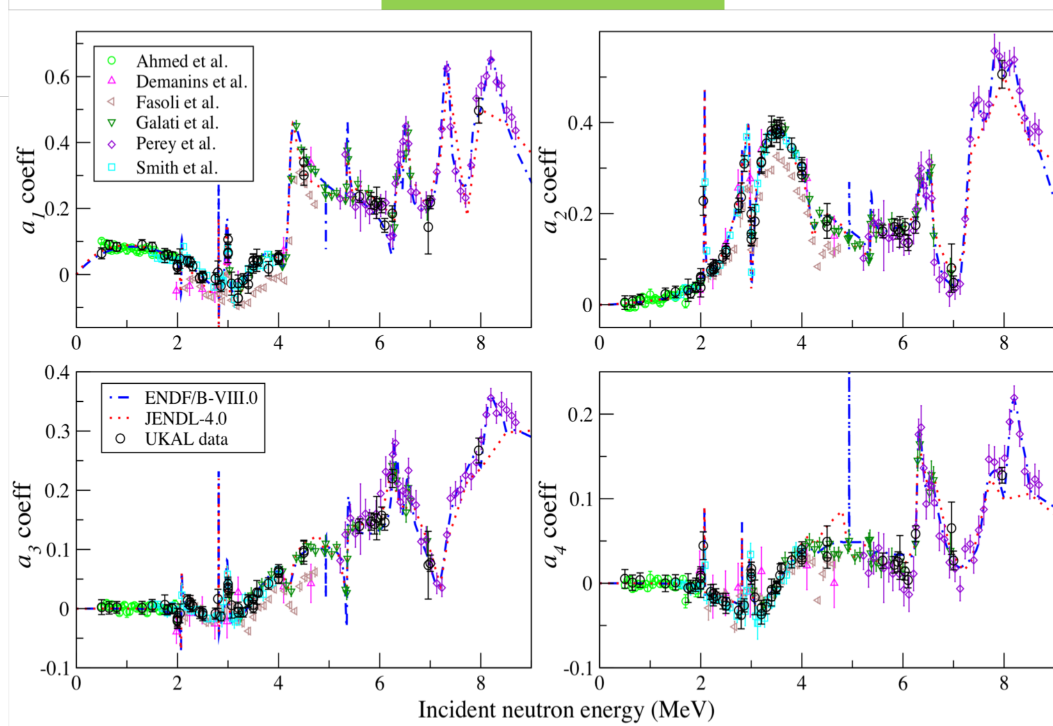
Angle-integrated elastic XS



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

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

Legendre coefficients

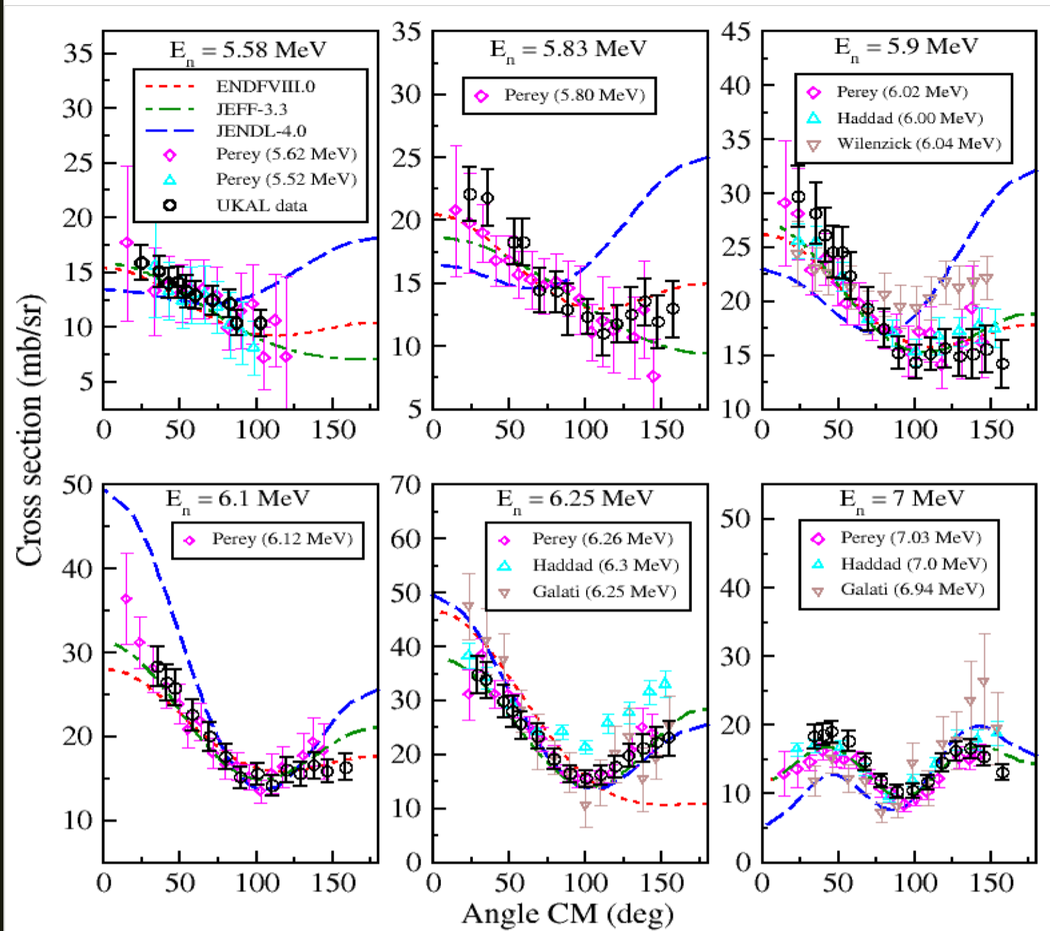


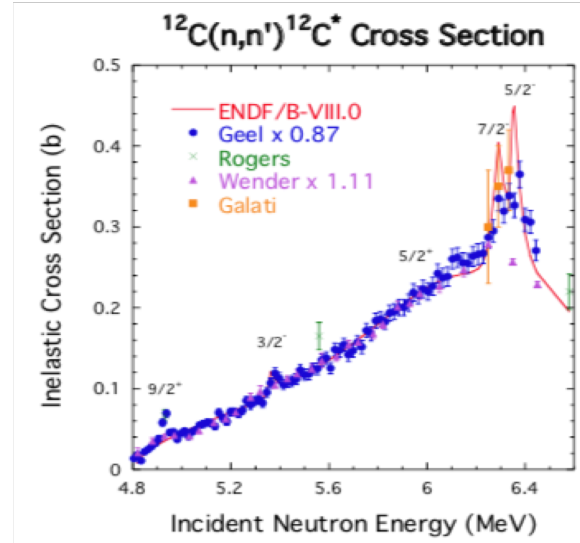
- Legendre coefficients compared with existing data and values from evaluation databases

- Very good agreement with evaluation databases

$^{12}C(n,n_1)^{12}C$ neutron cross sections

- Disagreement between calculations and measurements of neutron inelastic cross sections (E_{lev}=4.439 MeV)





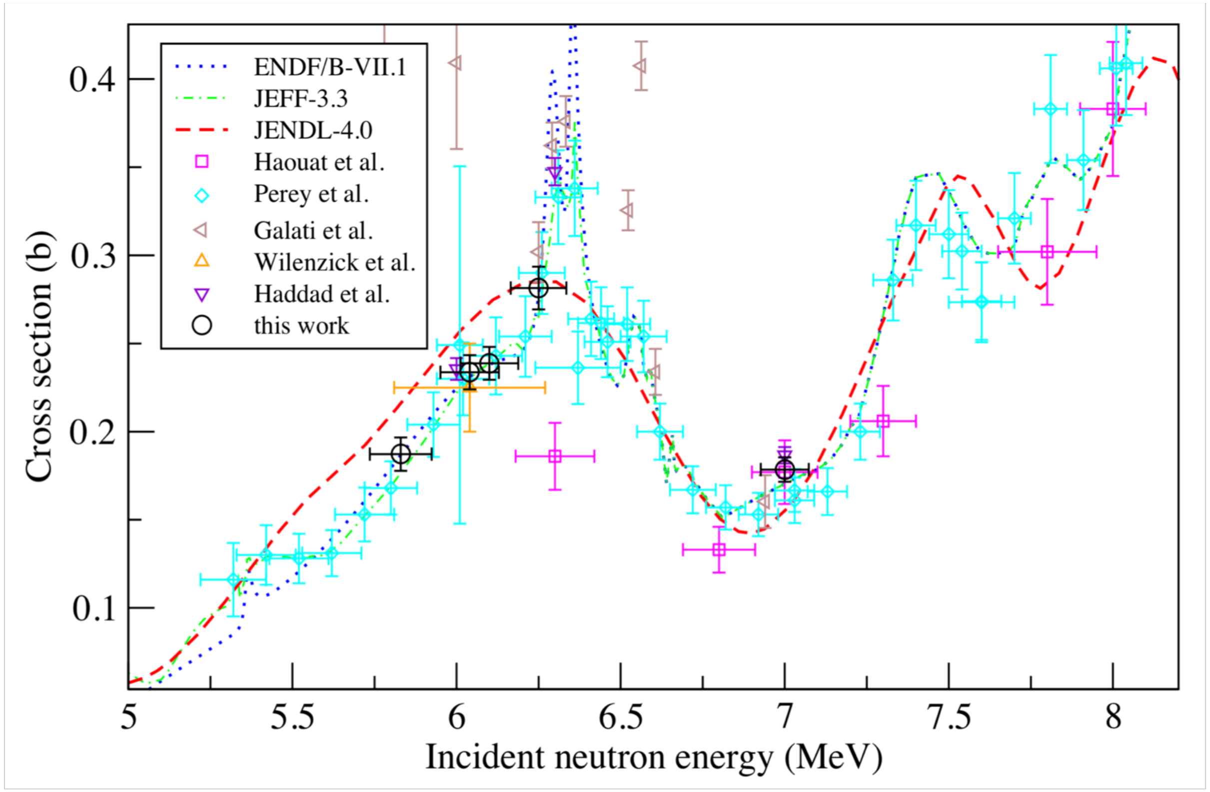
NDS 148 (2018), 1-142

- Discrepancy among evaluation libraries

- Assume that Perey (1978) data are in CM frame

Angle-integrated $^{12}C(n,n_1)\,^{12}C$ cross sections

- Available angle-integrated first inelastic neutron cross section data from EXFOR database and our data

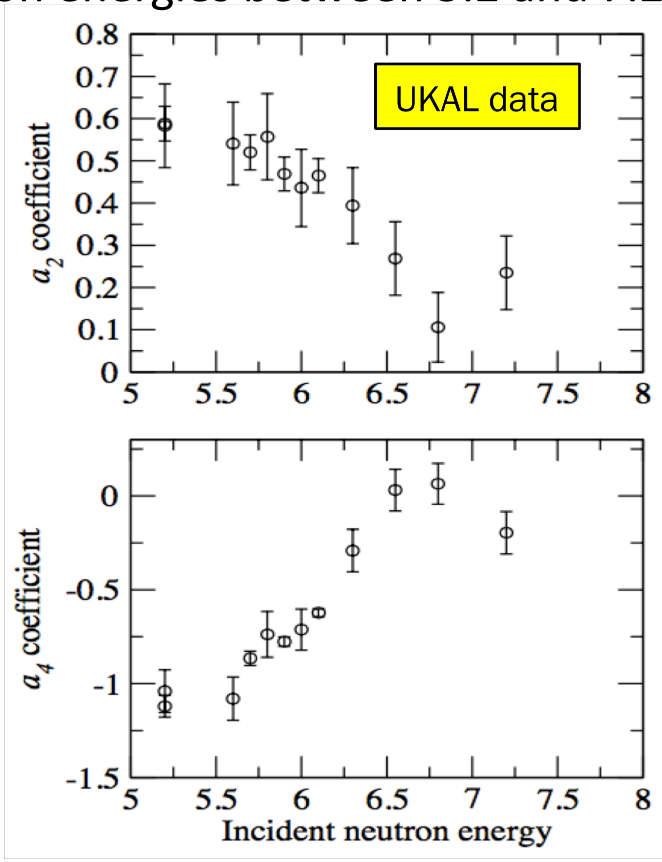


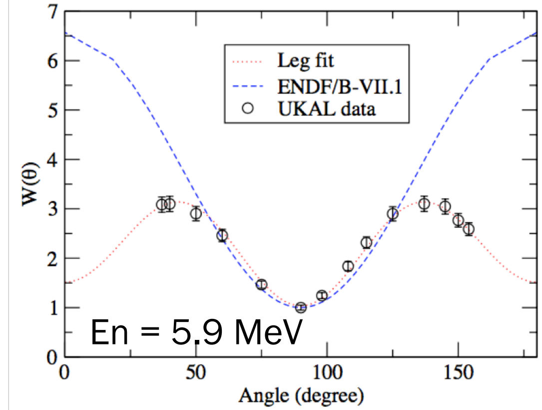
- Our data and existing measurements tend to agree with ENDF and JEFF databases

Photon angular distributions for E_{lev}=4.439 MeV (n+^{12}C)

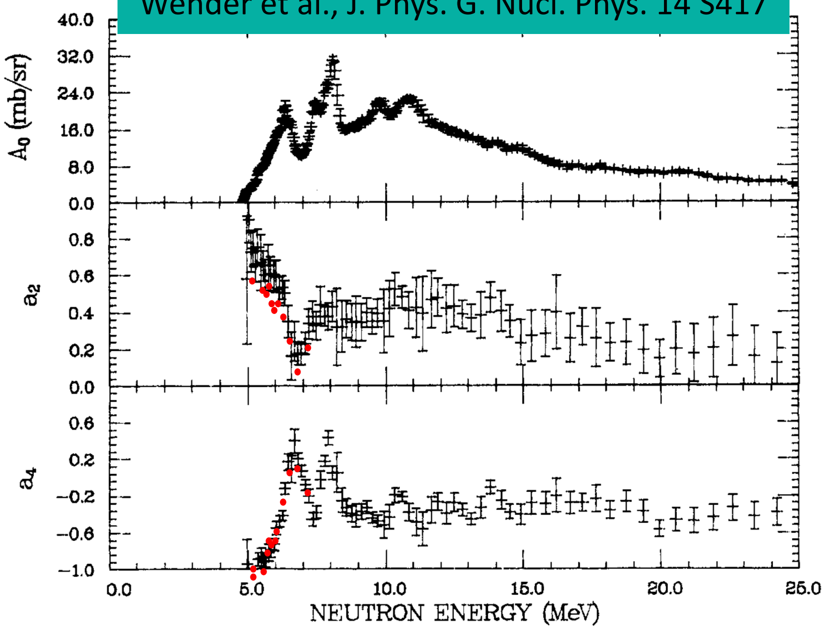
- Angular distributions were measured for neutron energies between 5.2 and 7.2 MeV

W(θ)= $A_0[1 + a_2P_2(\theta) + a_4P_4(\theta)]$



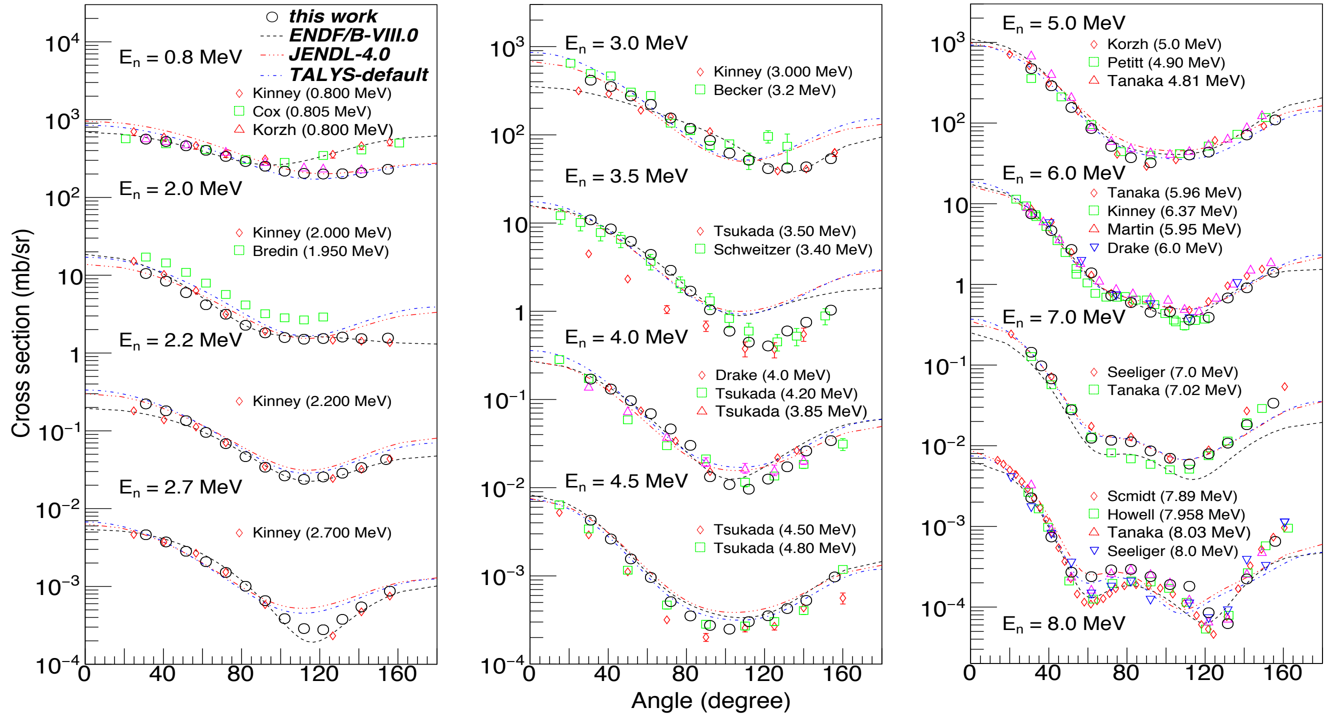


Wender et al., J. Phys. G. Nucl. Phys. 14 S417



- a_2 values are consistently lower than values obtained by Wender et al.

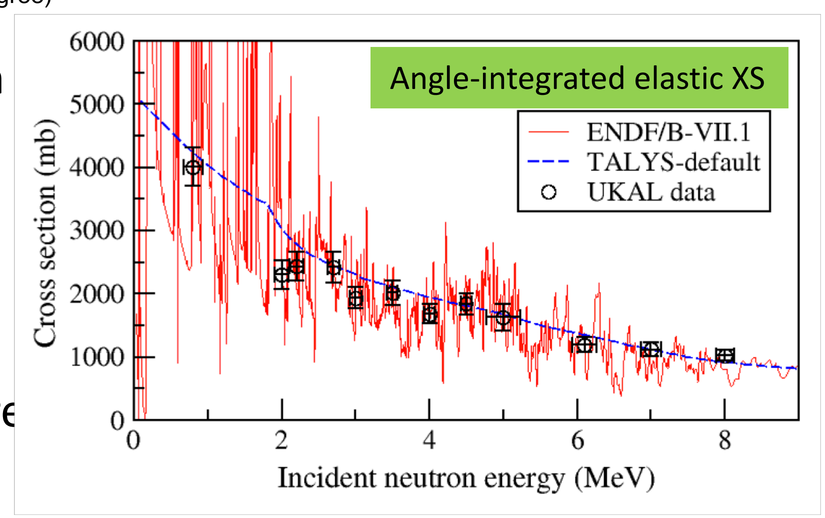
Differential elastic cross sections for n+^{nat}Si



- Differential cross sections measured between = 0.8 – 8 MeV

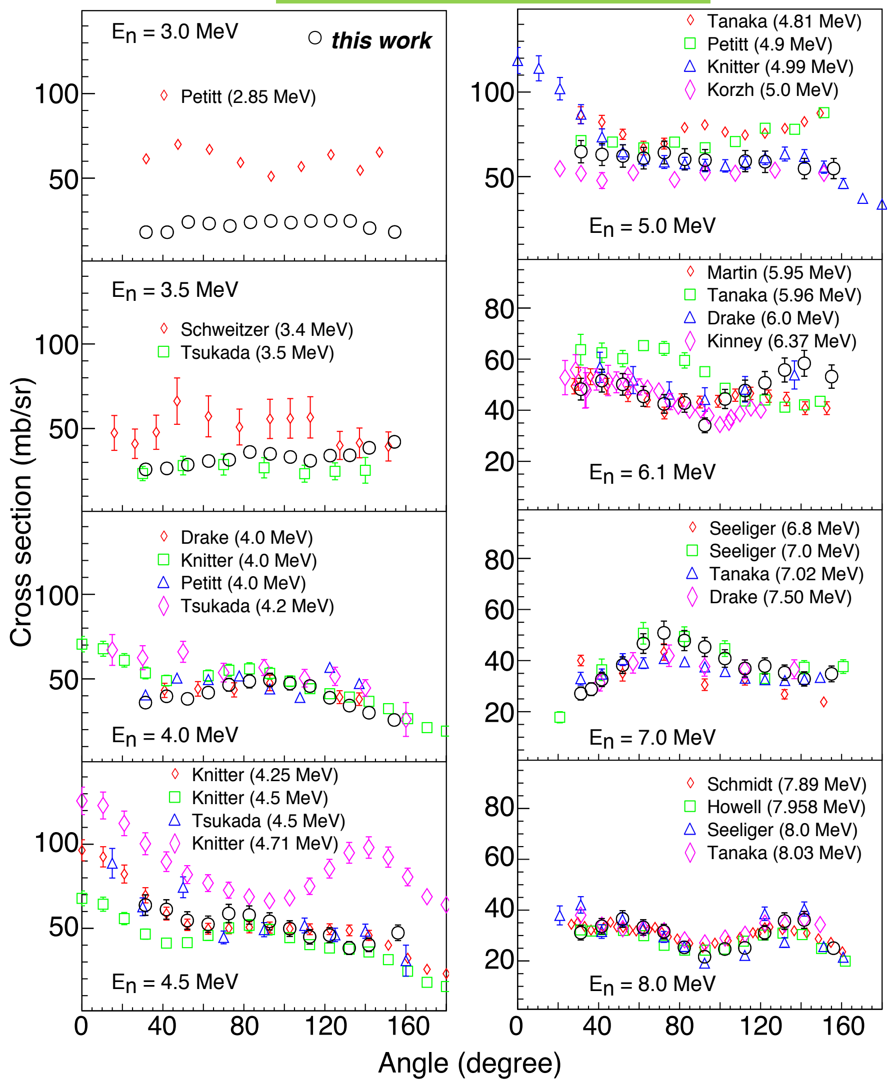
$$W(\theta) = A_0 \sum_L a_L P_L(\cos\theta)$$

- Angle-integrated data obtained from Legendre fit (A_0 coefficient)



Differential cross sections for $^{28}Si(n,n_1)^{28}Si$

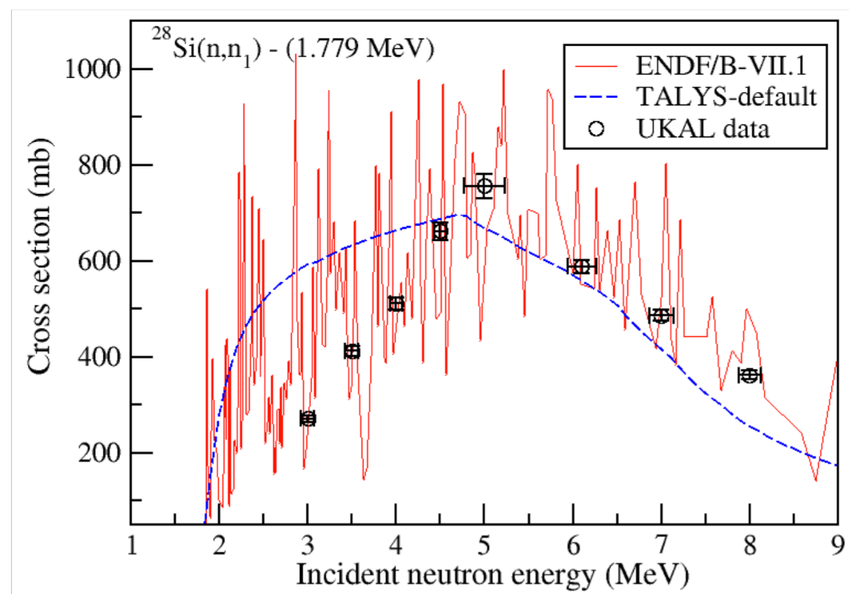
$^{28}Si(n,n_1)$ XS (E_L = 1779 keV)



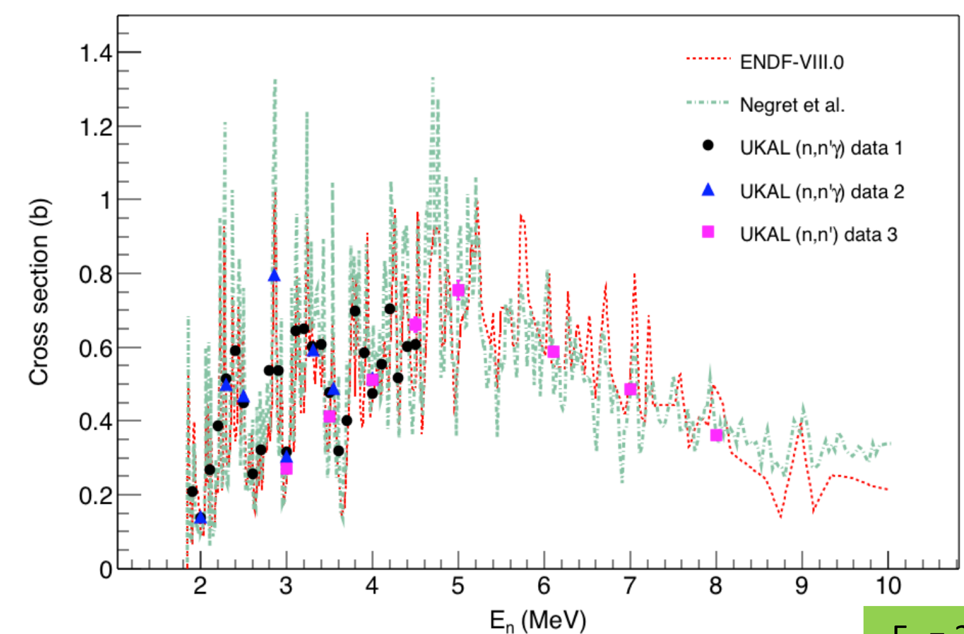
- Differential inelastic cross sections measured between 3.0 – 8 MeV

- No differential inelastic XS from evaluation databases

Angle-integrated $^{28}Si(n,n_1)$ XS

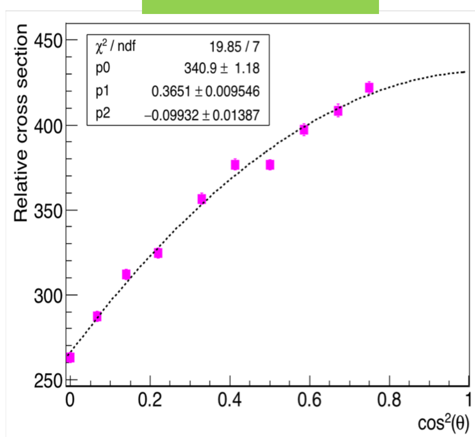


Inelastic neutron cross section data from $^{28}Si(n,n_1\gamma)^{28}Si$ measurement

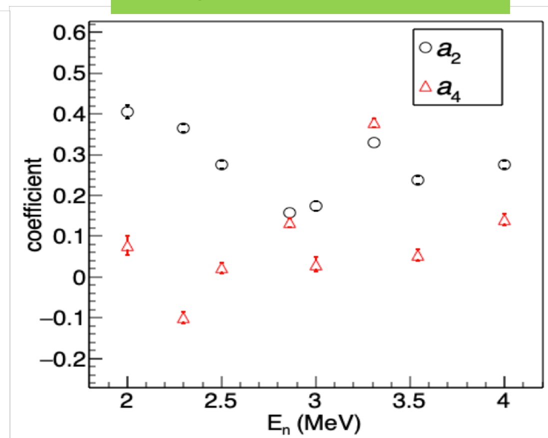


- γ-ray production XS for E_γ = 1779 keV measured at θ = 125° with E_n = 1.9–4.5 MeV (UKAL data 1 and 2)
- γ-ray production XS normalized using ^{48}Ti and ^{56}Fe cross sections
- Uncertainty shown here for the γ-ray production XS is statistical only

E_n = 2.3 MeV



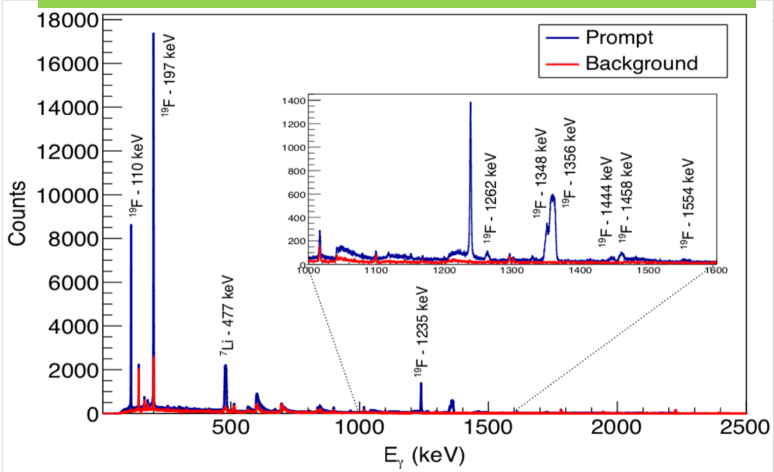
Legendre coefficients



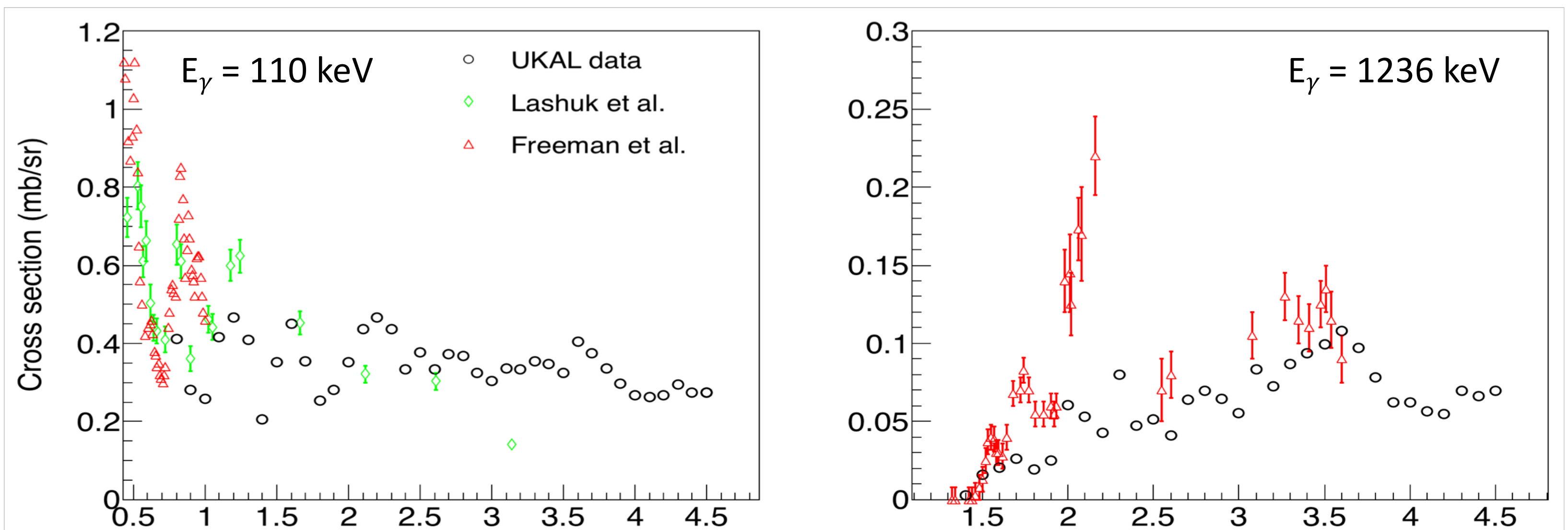
- UKAL data 2 measured with angular distribution
- Cross sections may require a correction factor of about 1.05 due to a_4 ~ |0.1|

Preliminary data for n+^{19}F

Sample spectrum from n+LiF with E_n = 3.5 MeV



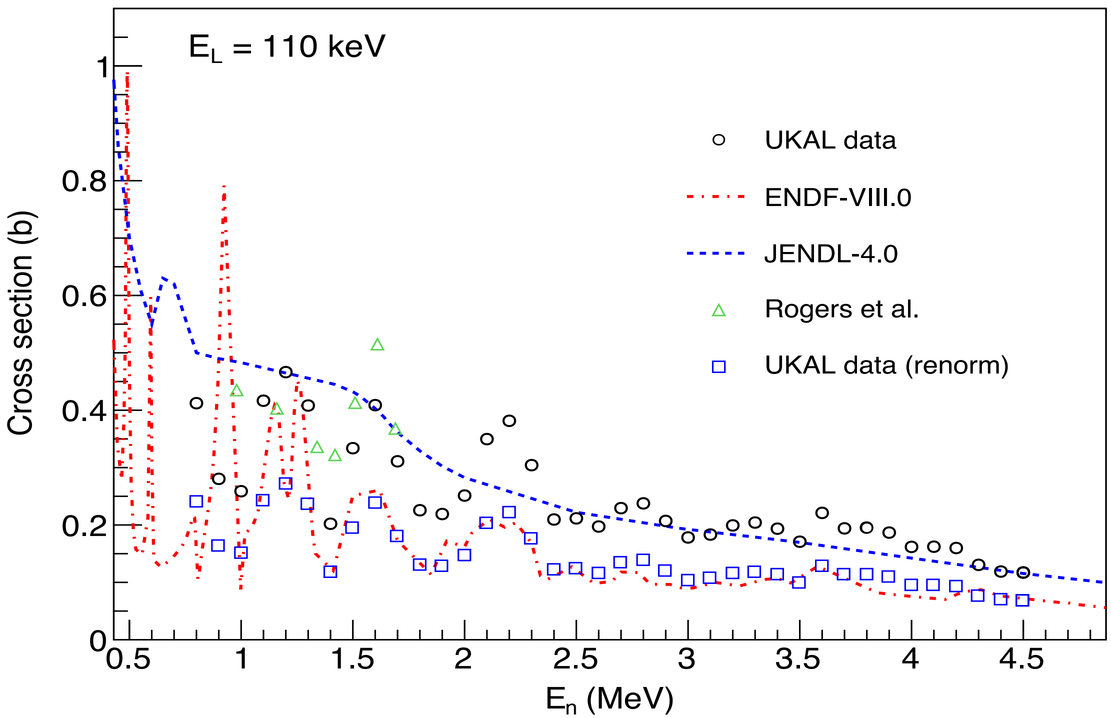
- Sparse data for n+^{19}F reaction
- Inelastic scattering for n+^{19}F measured with E_n = 0.8 – 4.5 MeV
- E_L = 197 keV has a $T_{1/2}$ = 89.3 ns
- Background γ-rays overlap with peaks of interest

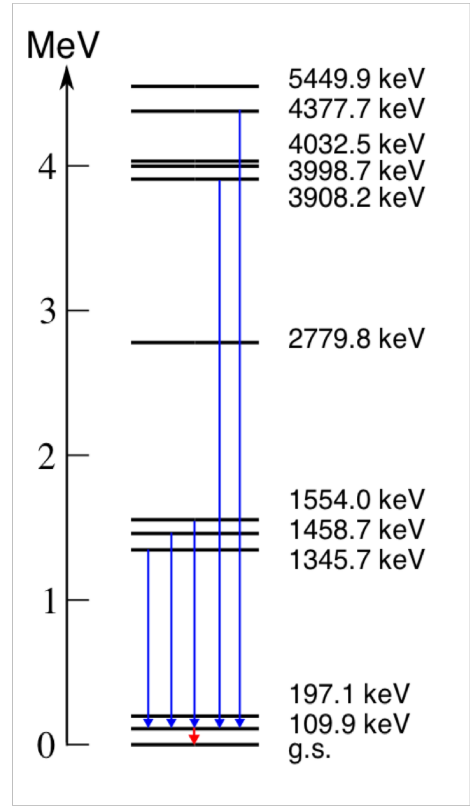


Selected γ-ray production XS

Preliminary $^{19}F(n,n_1)^{19}F$ cross section

$$\sigma_{n,n'} = \sum \sigma_{deexc} - \sum \sigma_{feeding}$$



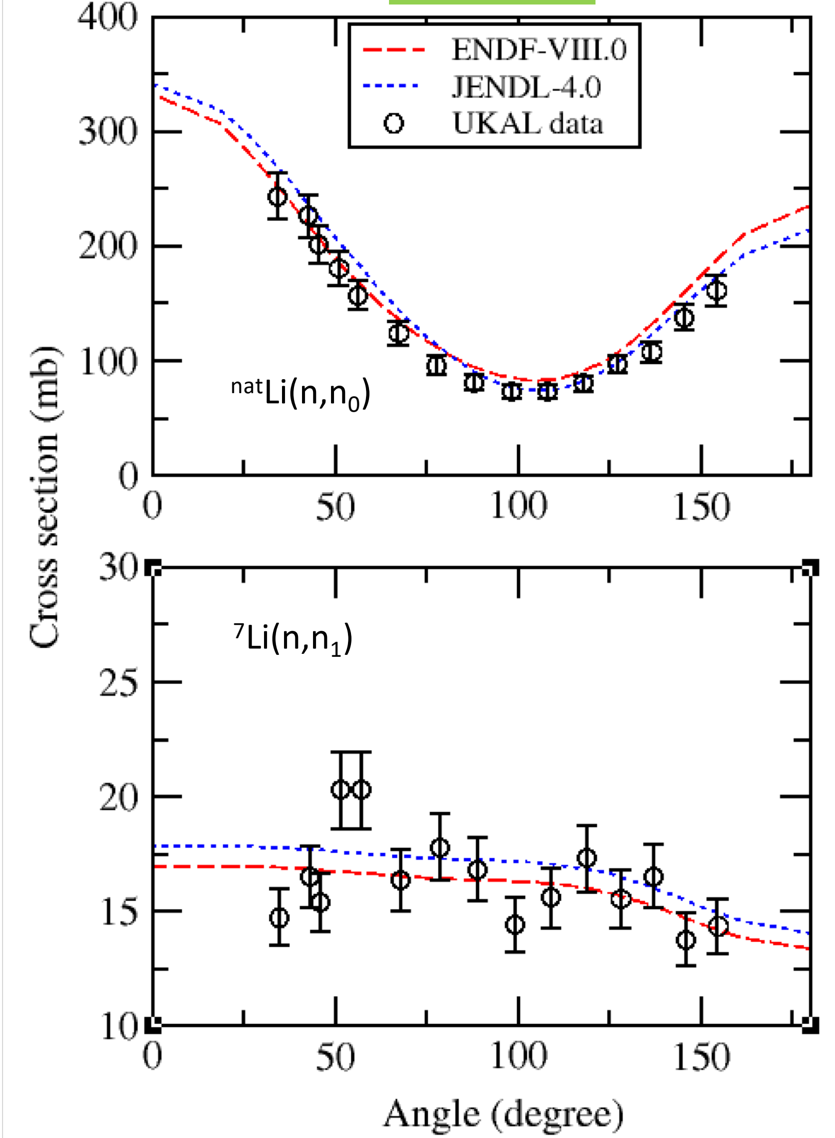


- ENDF-VIII.0 and JENDL-4.0 differ in shape and magnitude

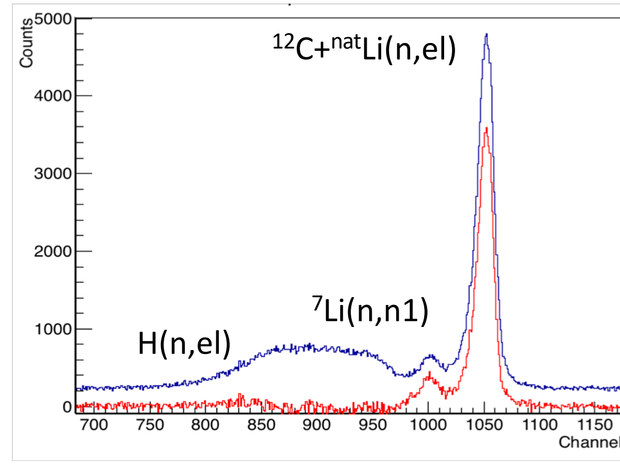
- Our data are closer to JENDL in terms of magnitude but follow the structure presented by ENDF-VIII.0

Preliminary cross sections for n+^{nat}Li

E_n = 3 MeV



Sample spectrum with En = 3 MeV at θ = 40°



- Background (target-out) subtraction at forward angles due to H(n,el)

- Elastic and inelastic cross section measured with E_n = 2 and 3 MeV

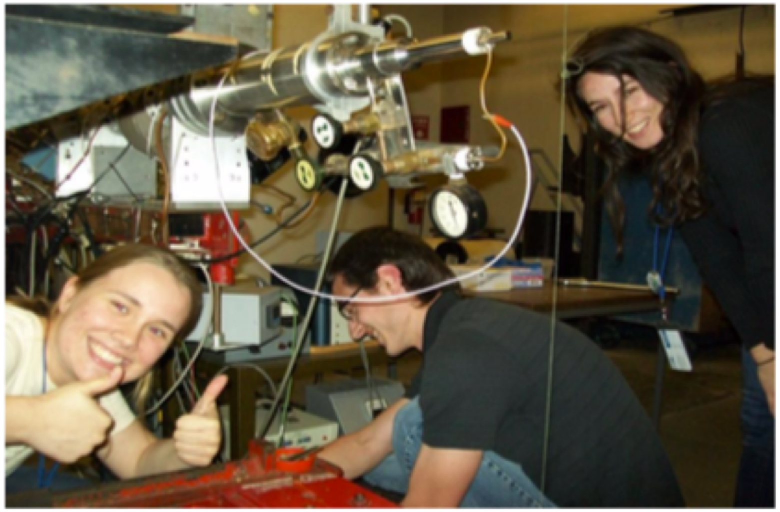
- Additional measurements in the future

Neutron Cross Section Measurements & Nuclear Science Training at UKAL

National Nuclear Security Administration

DE-NA0002931

Elastic & Inelastic Neutron Scattering Cross Sections on Fe, Si, and C



During current 3 year grant

WORKFORCE DEVELOPMENT

11 undergrads + 1 postdoc +

EXPERIMENTAL RUNS

Targets: ^{12}C, ^{nat}Si, ^{56}Fe, ^{nat}Li, ^{19}F

154 days beam-on-target

51 (n,n') angular distributions

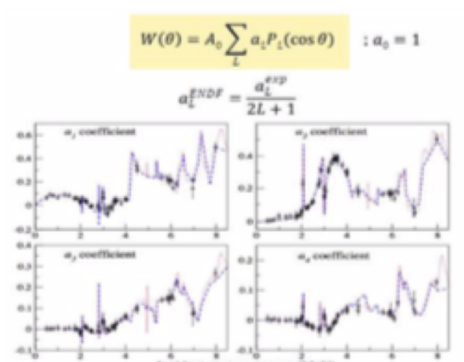
8 (n,n'γ) angular distributions

60 γ-ray production energies

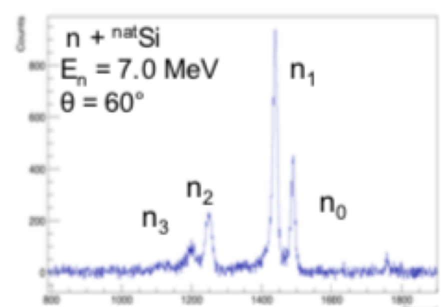
REPORTING

19 presentations & posters

7 publications



Legendre Coefficients for n+^{12}C elastic scattering with R-matrix calculation.



Neutron TOF spectrum for ^{nat}Si

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%

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