SAMMY Workshop

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Part 3, Experimental Data

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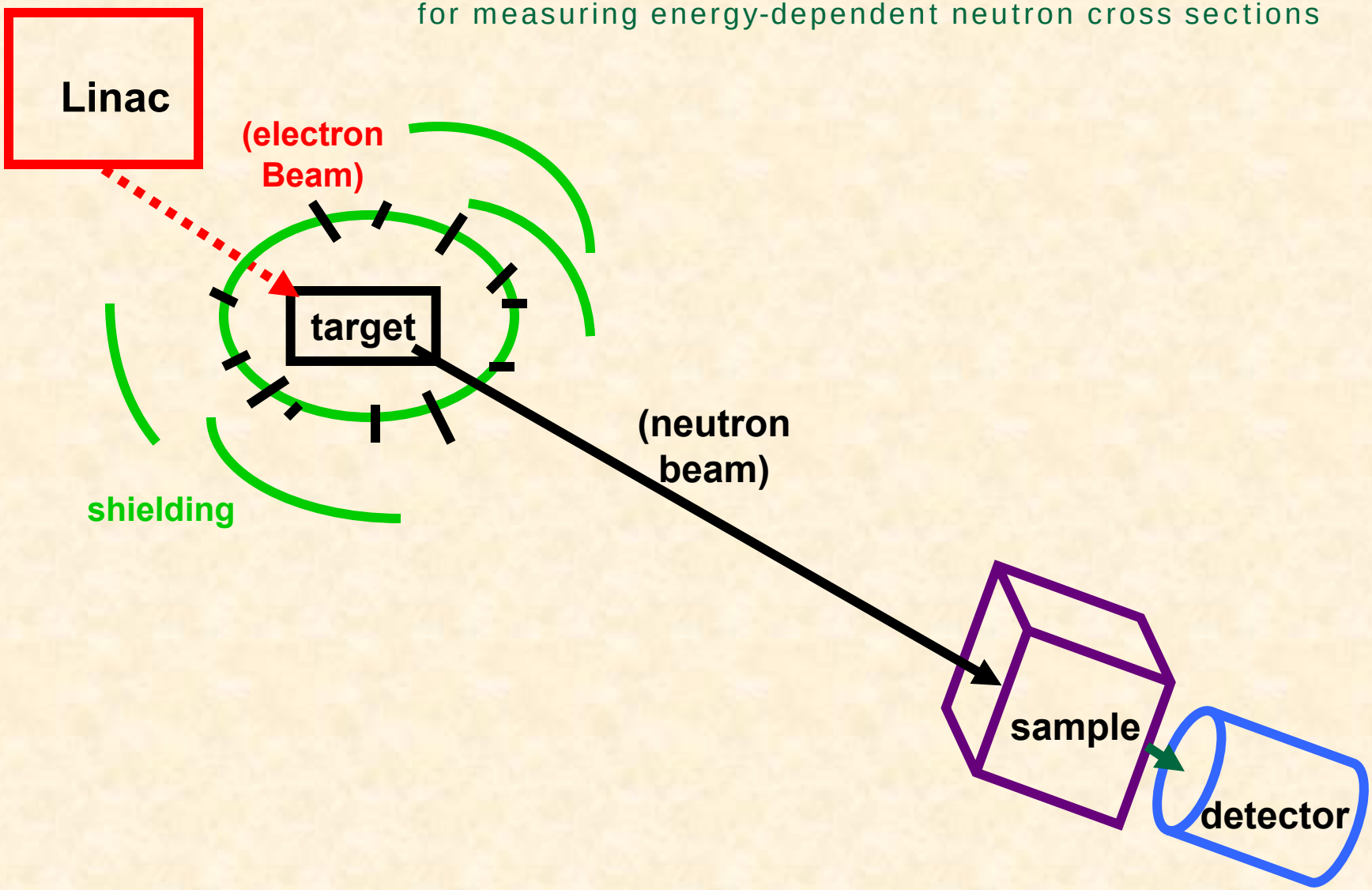
Why do we care about cross sections?

- **Fundamental physics**
  - **Humans are curious about everything**
- **Practical applications**
  - **So we can calculate when a reactor would go critical, or how much shielding is needed**
  - **Medical needs**
  - **Nuclear astrophysics / stellar evolution**

Time of Flight Experiment

for measuring energy-dependent neutron cross sections



What do we learn from time-of-flight?

- **Measure path length *L* precisely**
- **Know time t_0 at which neutron leaves target**
  - **because beam is pulsed**

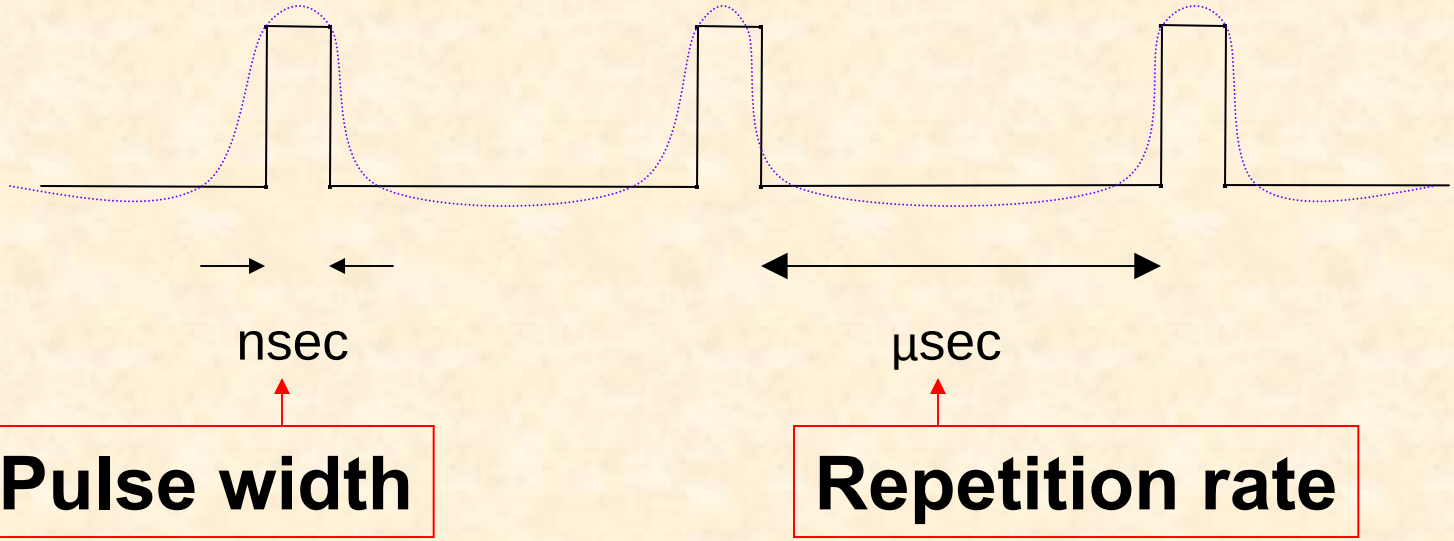
or proton, or fission fragment, or whatever

- **Find time *t* at which neutron reaches detector**
- **Therefore know energy *E:***

$$E = \frac{m}{2}\left(\frac{L}{(t - t_0)}\right)^2$$

***Data* are "number of counts reaching detector" vs "time" (i.e. vs "energy")**

Linac e- beam



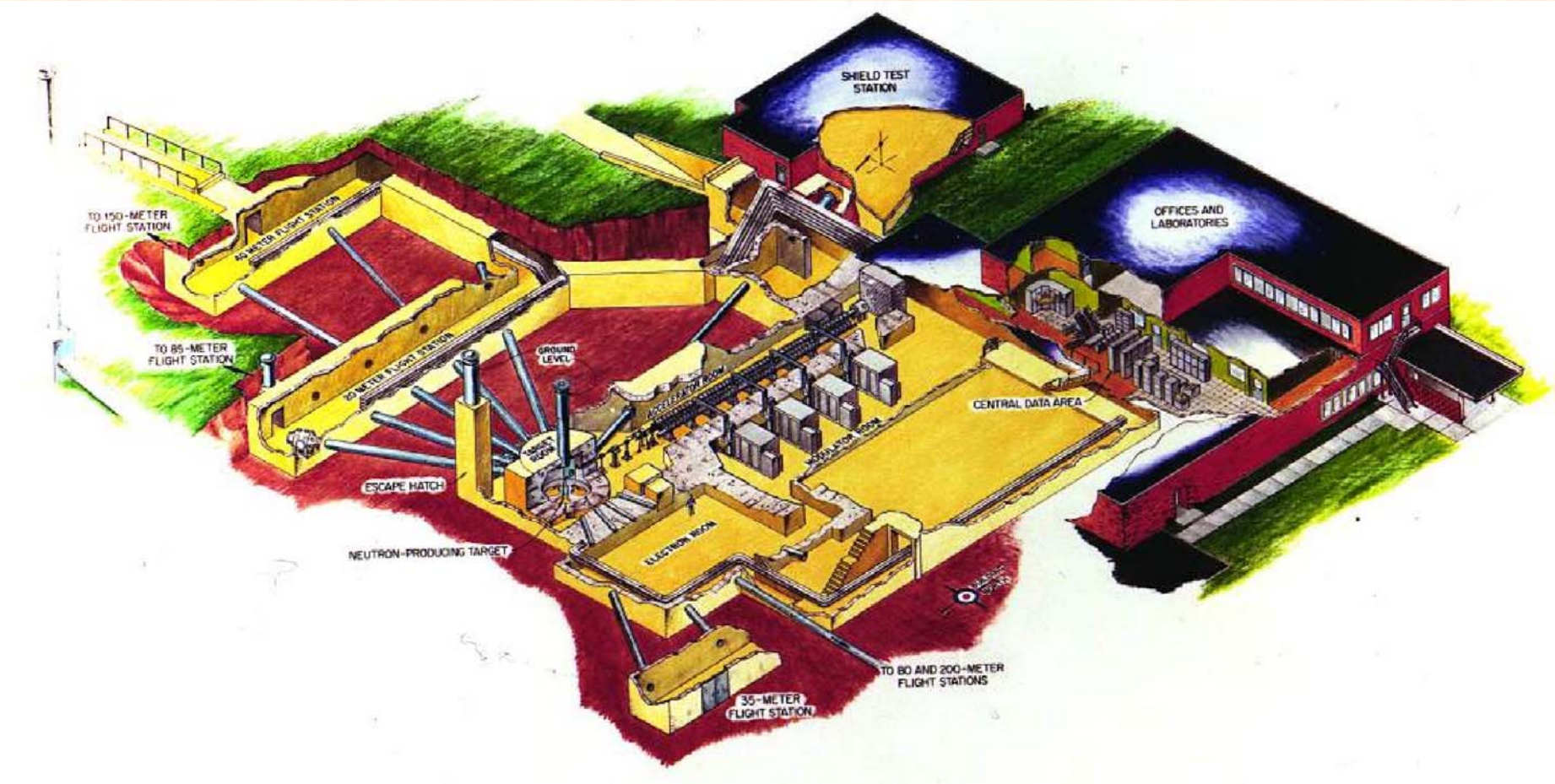
These will change from site to site, and from experiment to experiment. Likewise, pulse shape will change.

Target composition –
Ta + H_2O at ORELA at Oak Ridge, TN, USA
^{235}U at GELINA at Geel, Belgium
Pb at CERN in Geneva, Switzerland

To summarize: time of flight experiments
measure energy-dependent neutron cross sections as follows:

- **An accelerator produces a beam of electrons. (Usually this is a linear accelerator such as the Oak Ridge Electron Linear Accelerator (ORELA), the Geel LINAC (GELINA), or the Gaerttner LINAC at Rensselaer Polytechnic Institute.)**
- **The electrons hit a target (water and tantalum at ORELA, uranium at GELINA).**
- **This produces neutrons, which fly straight outward in all directions. Shielding and collimators are used to collimate the beam.**
- **The neutrons are used as a probe to study nuclei. Samples of the material to be studied are placed in the beam line where neutrons will interact with nuclei in the sample.**
- **Detectors literally count the particles that reach them.**
- **Experimentalists "reduce" the "count" to a quantity which resembles a "cross section." This data-reduction process involves dead-time corrections, background subtraction, normalization, and many other operations.**
- **The next step is to interpret the results in terms of phenomenological scattering theory (R-matrix theory). *The major emphasis of this class will be on this step.***

The ORELA Facility



ORELA Facility Details

- **Electron energy** **180 MeV maximum**
- **Peak Current** **20 amps maximum**
- **Power on target** **60 kW maximum**
- **Electron beam diameter** **1 cm**
- **Neutron targets**
  - **Ta with H_2O moderator**
  - **Be block (En > 1 MeV)**
- **Neutron production (Ta target)**
  - **10^{11} neutrons/pulse**
  - **10^{14} n/sec at 50 kW** **5×10^{18} n/sec (peak)**

ORELA Facility Details, cont.

- **Neutron spectrum (Ta target)**
  - **4×10^{13} n/MeV/sec at 1 MeV**
  - **4×10^{10} n/MeV/sec at 14 MeV**
- **Number of**
  - **flight paths = 10**
  - **flight stations = 18**
- **Flight path lengths = 9 to 200 m**
- **For additional details, see the web site http://www.phy.ornl.gov/orela/orela.html/**

CERN nTOF Facility details

- **Proton energy ~80 GeV**
  - **7 ×10^{12} protons / pulse (dedicated), ~50 % (parasitic)**
- **Neutron targets: natural Pb**
- **Neutron flux (?)**
  - **10^6 neutrons in 0.14 eV to 150 MeV with 1 cm collimator**
- **Number of flight paths = 1**
- **Number of flight stations = 1**
- **Flight path length = 185 m**

CERN nTOF Facility details, cont.

- **Natural lead target is 60 cm × 80 cm × 80 cm with 20-cm square hole in back side (so effectively 40 × 80 × 80)**
- **Target is surrounded by 5 cm of water moderator**
- **"Beam reducers" trim neutron beam to 60 & 40 cm**
- **Two collimators reduce beam to ~9 cm and ~ 1 cm**
  - **1 cm for capture; larger for fission**
- **Proton beam: Gaussian ~ 6 nsec with 2.4 seconds between pulses**
- **Supercycle is 7 cycles: nTOF gets all of some cycles ("dedicated") and portions of some cycles ("parasitic")**

Cross-Section Measurement Facilities

Facility	United States				Europe	
Parameters	ORELA	LANSCE	IPNS	RPI	GELINA	n_TOF
Source	e^- linac	p spallation	p spallation	e^- linac	e^- linac	p spallation
Particle E (MeV)	140	800	450	>60	120	20000
Flight Path (m)	10-200	7-55	~6-20	10-250	8-400	185
Pulse Width (ns)	2-30	125	40	15-5000	1-2000	7
Max Power (kW)	50	64	6.3	>10	11	45
Rep Rate (Hz)	1-1000	20	30	1-500	Up to 900	0.278-0.42
Best Intrinsic Resolution (ns/m)	0.01	3.9	2.0	0.06	0.0025	0.034
Neutrons/s	1×10^{14}	7.5×10^{15}	8.1×10^{14}	4×10^{13}	3.2×10^{13}	8.1×10^{14}

Slide borrowed from Klaus Guber of ORNL

Comparison: ORELA, LANSCE, IPNS

- Each facility has its own characteristics:
  - ORELA has very good neutron energy resolution but the penalty will be a lower neutron flux.
  - LANSCE and IPNS have higher n-flux per burst but inferior resolution.
  - ORELA is an undermoderated n-source whereas LANSCE and IPNS are highly moderated sources. This can have severe consequences for the resolution of resonances.
- For comparison usually a figure of merit (FOM) is used: $\text{n-flux}/(dE/E)^2$

Slide borrowed from Klaus Guber of ORNL

Comparison of Existing Experiments

	ORELA	ORELA	ORELA	GELINA	GELINA	DANCE at LANSCE	IPNS	n_TOF
Flight path length [m]	200	40	10	400	55	20	20	185
Pulse width [ns]	6	8	24	1	1	125	40	7
Power [kW]	13	8	50	11	11	64	6.3	45
Repetition Rate [Hz]	800	525	1000	800	800	20	30	0.42
Neutron Flux @ 1keV [neutron/s/cm2]	6.6E+01	1.0E+03	1.0E+05	2.5E+01	1.3E+03	1.2E+05	1.0E+05	2.9E+03
Intrinsic Resolution [ns/m]	0.0300	0.2000	2.4000	0.0025	0.0182	6.2500	2.0000	0.0378
Realistic Resolution dE [eV] @ 1keV	0.08	0.38	1.94	0.05	0.36	3.48	2.5	0.49
FOM @ 1keV (Flux/(dE/E)^2) [n/s/cm2]	1.16E+10	6.85E+09	2.67E+10	2.60E+10	2.60E+10	9.93E+09	6.1E+09	1.2E+10

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Types of Differential Data

- transmission
- total cross section
- elastic cross section
  - (angle-integrated or differential)
- fission
- inelastic
- capture
- absorption
- reaction
- eta
- self-indication
- combinations of the above

SAMMY can accommodate all of these. Other options can be added with relative ease.

Integral data can also be included in SAMMY analyses –

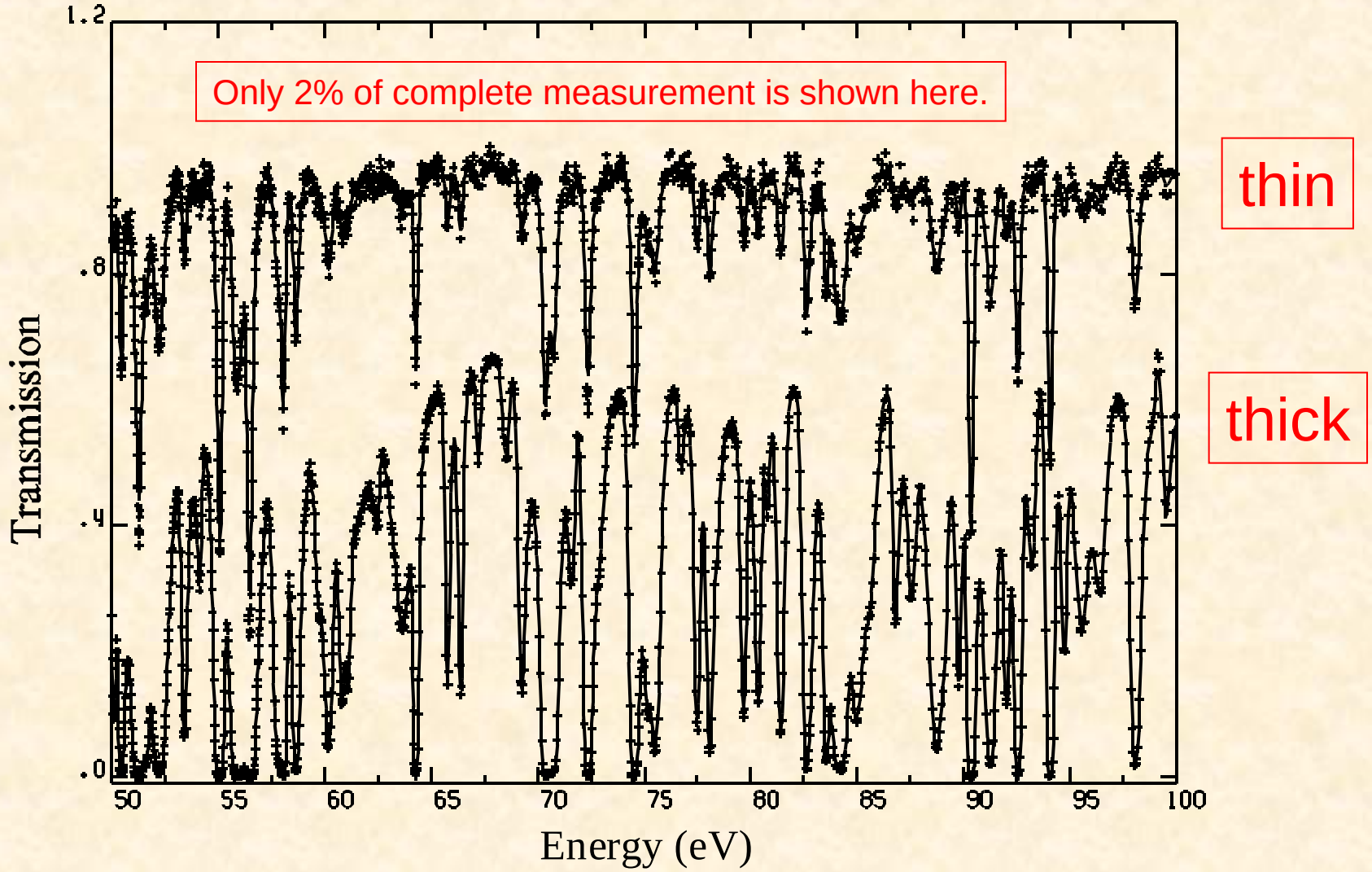
- **Thermal cross section**
- **Average integral**
- **Maxwellian average**
- K_1, K_{eff}
- **Westcott's g-factor**
- **α**
- **Resonance integral**
- **Reaction Rates**
- **NJOY's α**
- **NJOY's η**

Examples of differential data

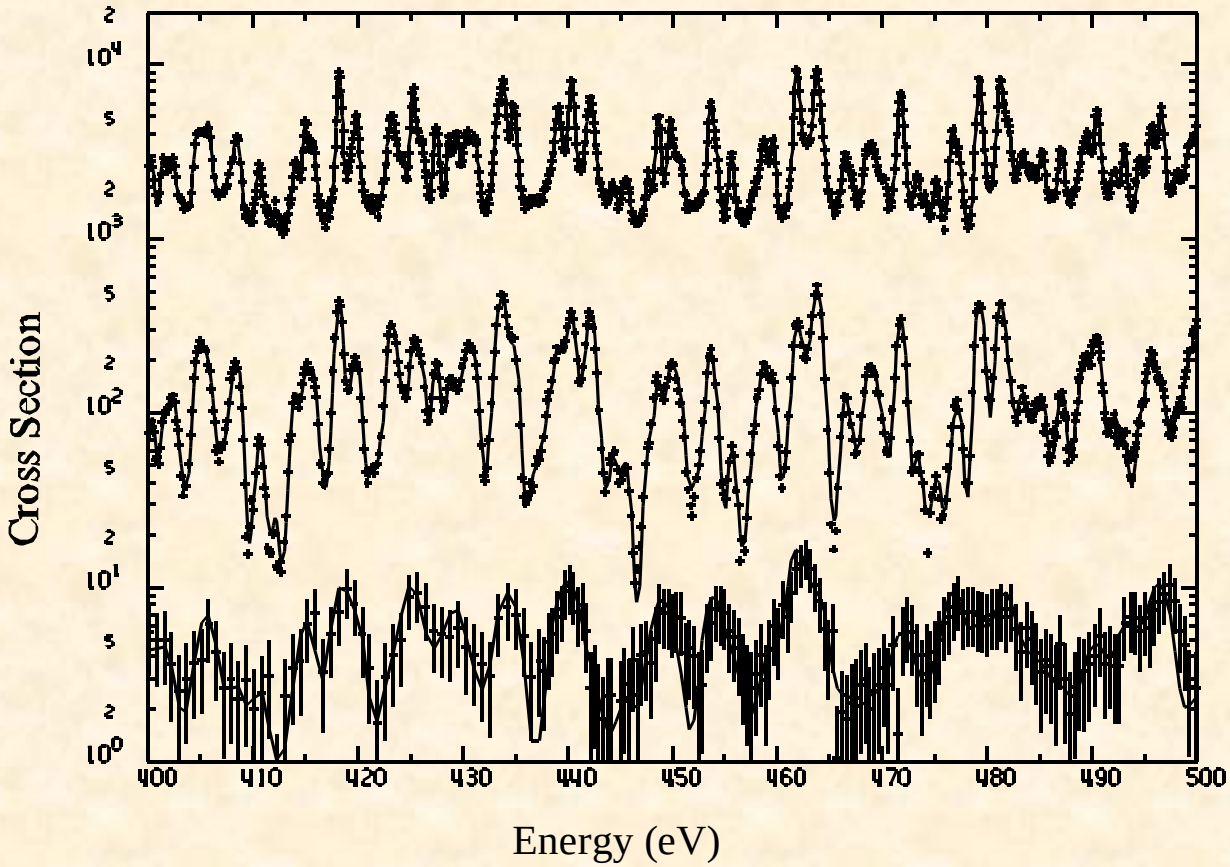
1. Transmission example ^{235}U

- **^{235}U experimental and calculated neutron transmission in the energy range from 50 to 100 eV. Results of two sample thickness transmission experiments of Harvey et al. are displayed.**
  - **From the ORNL evaluation of L. C. Leal, H. Derrien, N.M. Larson, and R.Q. Wright, *R-Matrix Analysis of ^{235}U Neutron Transmission and Cross Sections in the Energy Range 0 to 2.25 keV*, ORNL/TM-13516, Oak Ridge National Laboratory (November 1997). Also *Nucl. Sci. and Eng.* 131, 230 (February 1999).**

Transmission data example: ^{235}U



2. Total, fission, & capture on ^{235}U



total x100

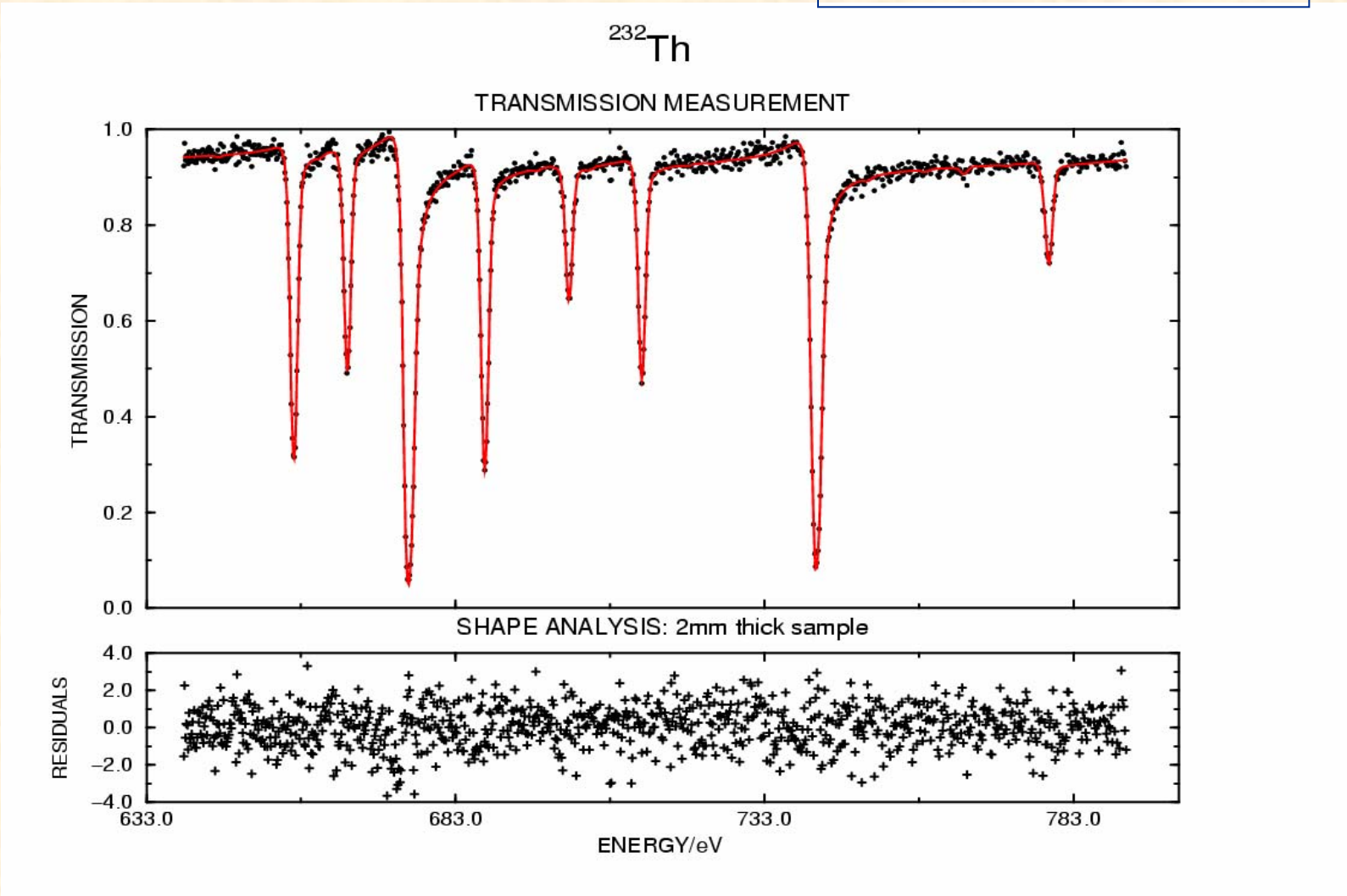
fission x10

capture

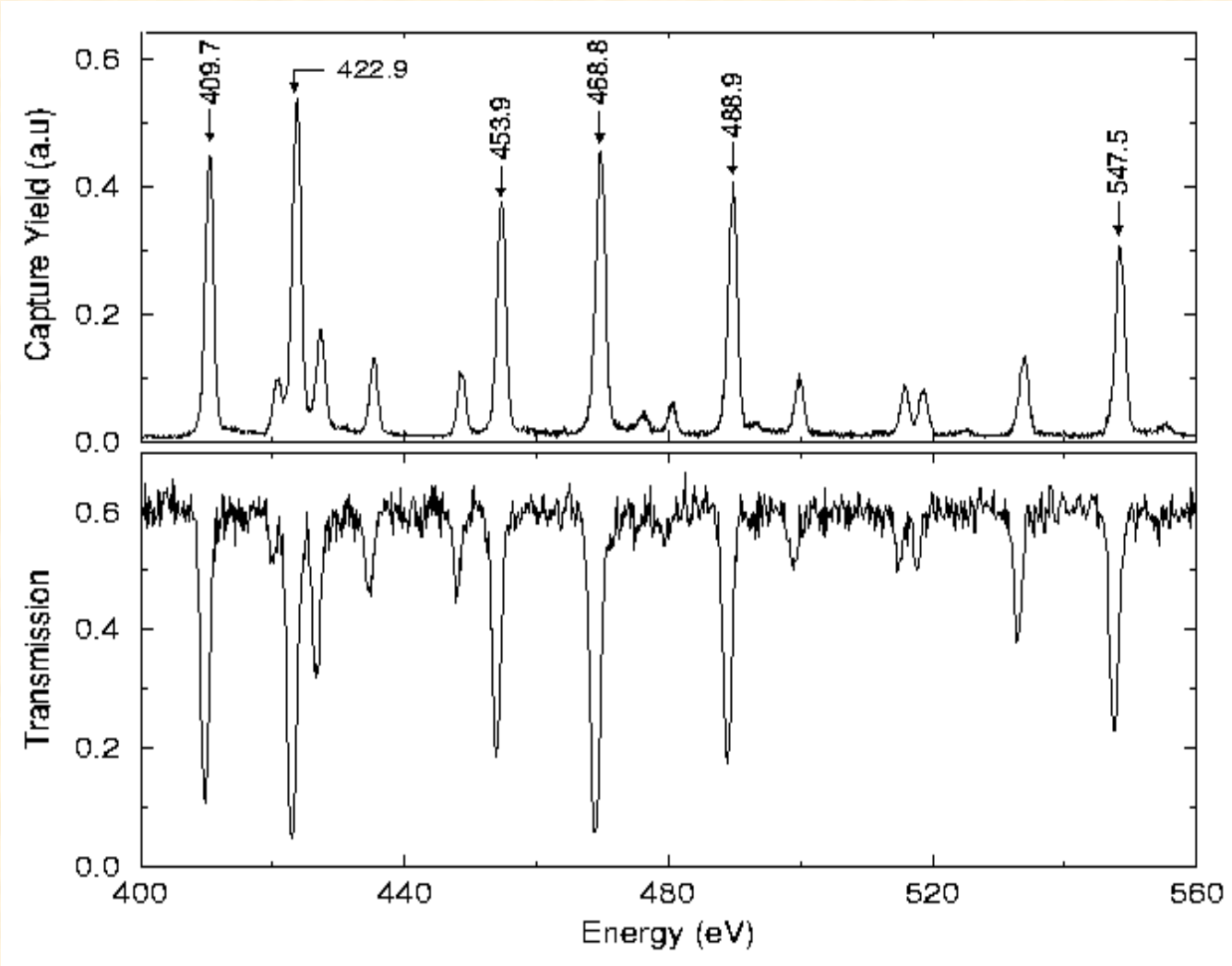
^{235}U experimental and calculated total cross section, fission cross section, and capture cross section in the energy range from 400 to 500 eV. Harvey et al. total cross section (multiplied by 100), Weston fission (multiplied by 10), and deSaussure capture cross sections are displayed.

3. ^{232}Th transmission

Plot courtesy of Peter Schillebeeckx, Geel

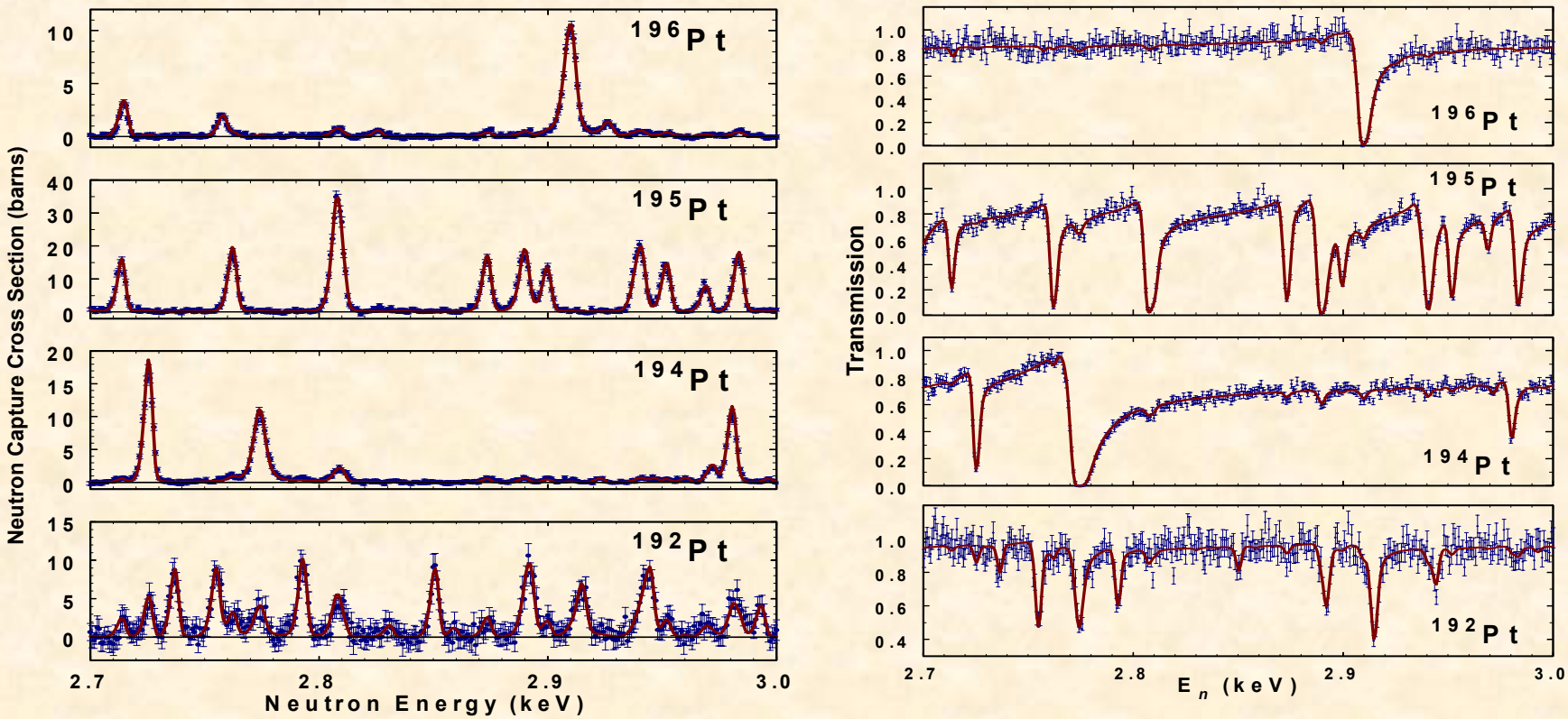


4. Capture and Transmission of ^{129}I



Plot courtesy of Peter Schillebeeckx of IRMM/Geel

5. Neutron Capture and Total Cross Section Experiments at a White Neutron Source: Typical Results

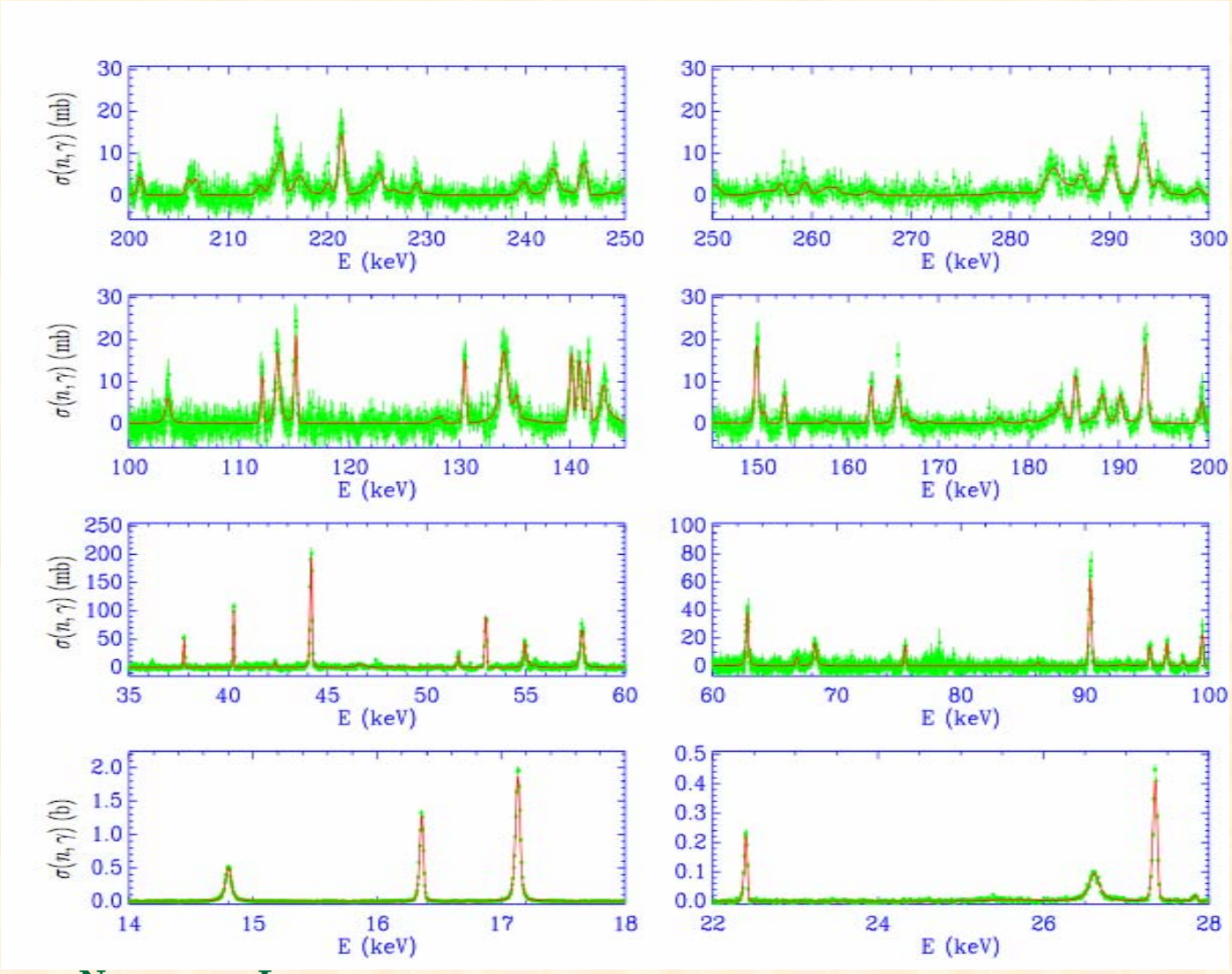


Only small part (0.06%) of energy range of data shown.

Separate sample-out and background measurements needed.

Plot courtesy of Klaus Guber of ORNL

6. Comparison of SAMMY Fits with ORELA ^{nat}Cl capture data



Plot courtesy of Klaus Guber of ORNL