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Los Alamos NATIONAL LABORATORY EST. 1943

Li-glass scintillator detectors for neutron-induced fission output studies

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Neutron output studies in neutron-induced fission reactions are important for not only advances in fission physics, also in multiple applications for fast reactors, accelerator-driven systems for transmutation of nuclear waste, defense, and homeland security. Improvement on the quality of data in the average neutron energy distribution and the neutron multiplicity on uranium isotopes and 239Pu is necessary. Especially, most of the previous studies have only measured down to ~1 MeV neutron energies due to the limited neutron-gamma separation, when used with liquid scintillators. In the "Chi-Nu" array currently consisting of liquid scintillators at Los Alamos National Laboratory in collaboration with Lawrence Livermore National Laboratory, we have implemented 6Li-glass detectors to measure neutron energies as low as 50 keV in order to provide more reliable neutron outputs from fission events. We will present the performance of 6Li-glass detector with a 252Cf source and in-beam studies on 235U(n,f), in comparison with MCNPX calculations. A 7Li-glass detector was studied for better understanding of beam-induced backgrounds.

^{6}Li-glass Scintillator Detectors for Neutron-Induced Fission Output Studies

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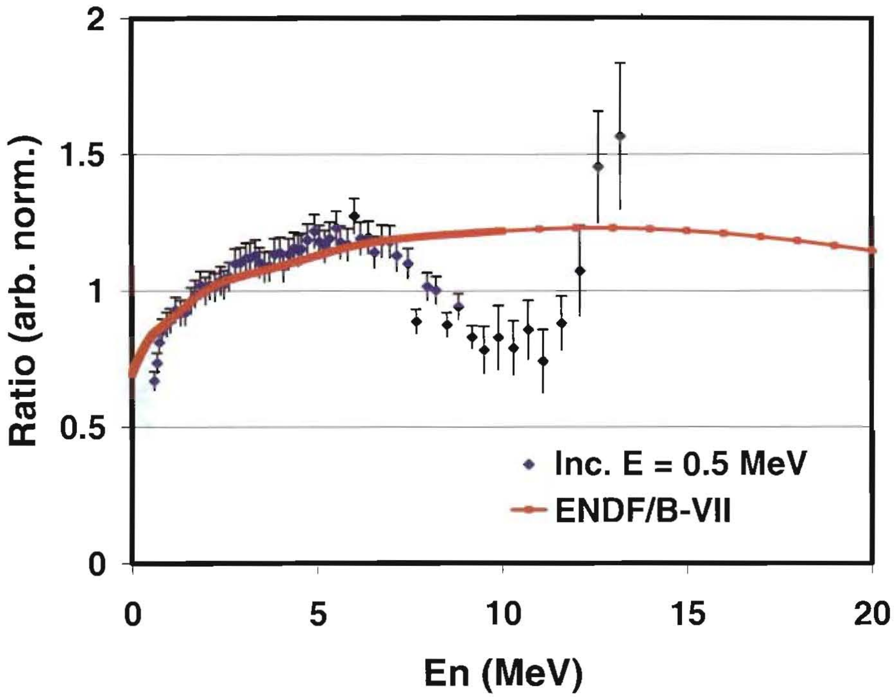
Introduction to prompt fission neutron output study at LANL

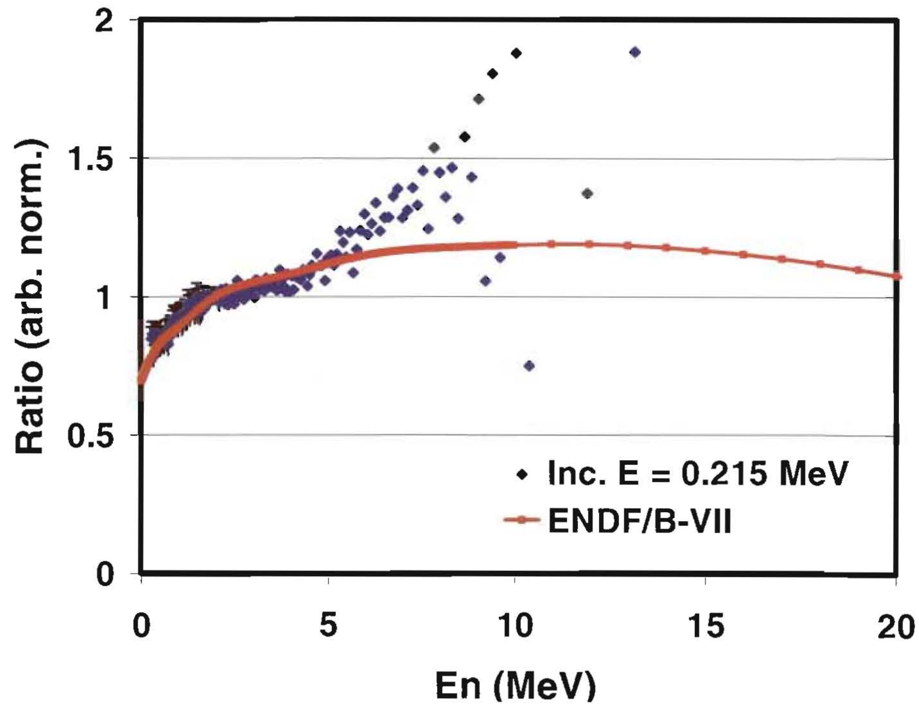
- Prompt fission neutron spectrum is important in applications for fast reactors, defense, homeland security, and advances in fission physics.
- Neutron multiplicity and the characteristics of fission outputs are necessary for the development and design of accelerator-driven systems for transmutation of nuclear wastes.
- Not sufficient experimental work on major Uranium isotopes and ^{239}Pu at the relevant neutron energies; for ^{239}Pu, the present two sets of data show discrepancy.
- The "Chi-Nu" is the on-going project for neutron output study with a close collaboration with LLNL at LANL.

There are <u>only</u> two good data sets for ^{239}Pu(n,f) emission neutron spectra and they disagree

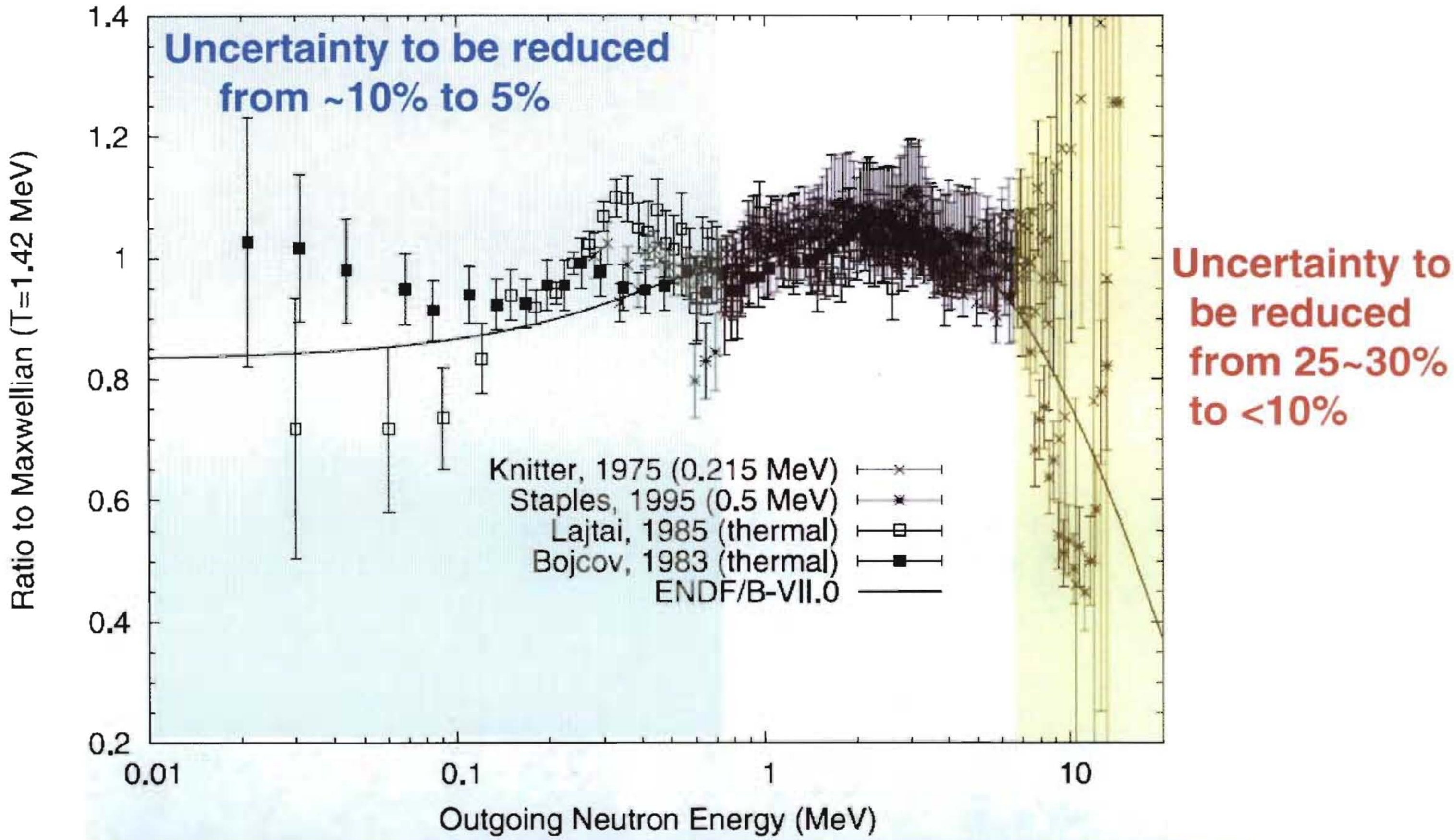
Staples vs. Maxwellian T=1.30 MeV (Nucl. Scien. Eng., 1998)



Knitter vs. Maxwellian T=1.30 MeV (J. Atomkernenergie, 1975)

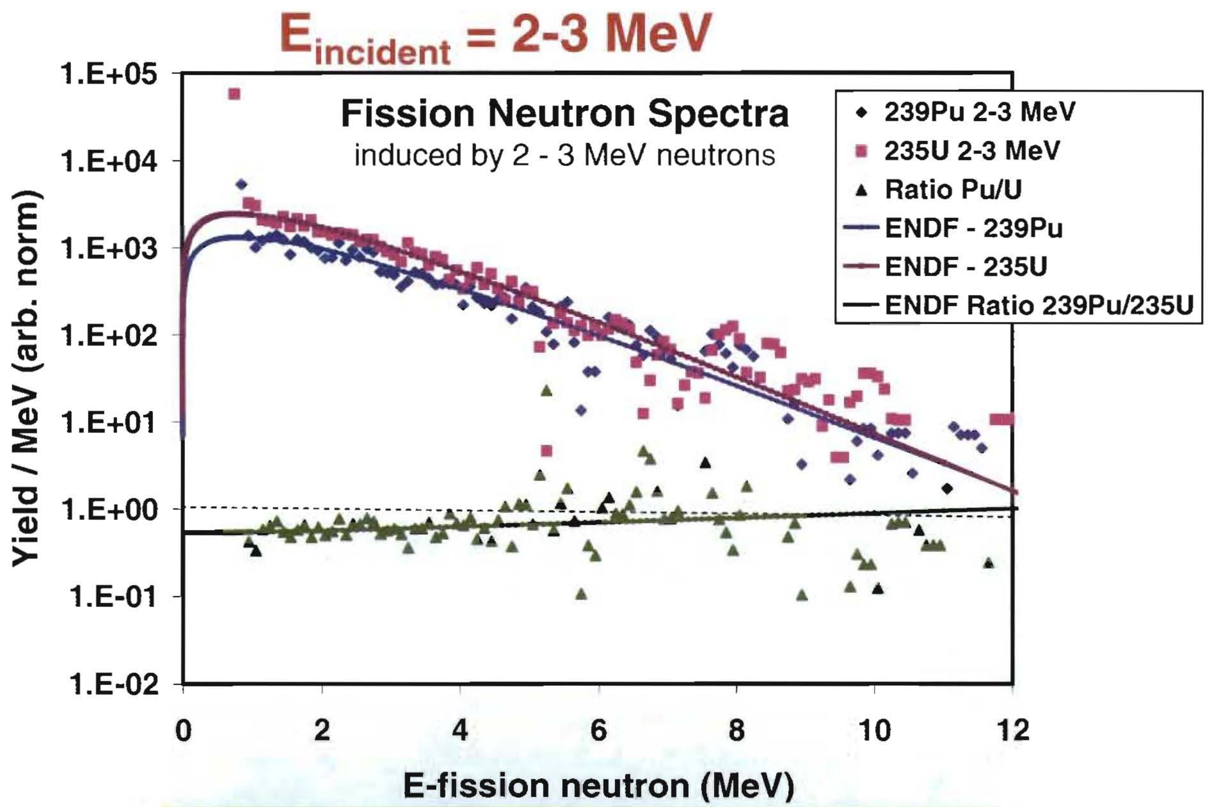


Required uncertainty to impact data evaluation

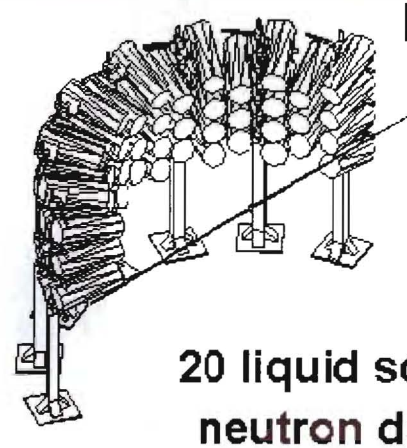


"Uncertainty qualification of prompt fission neutron spectrum", P. Talou et al., Nucl. Sci. & Eng. (2010)

Previous study of prompt fission neutron output measured on ^{235}U and ^{239}Pu at LANL

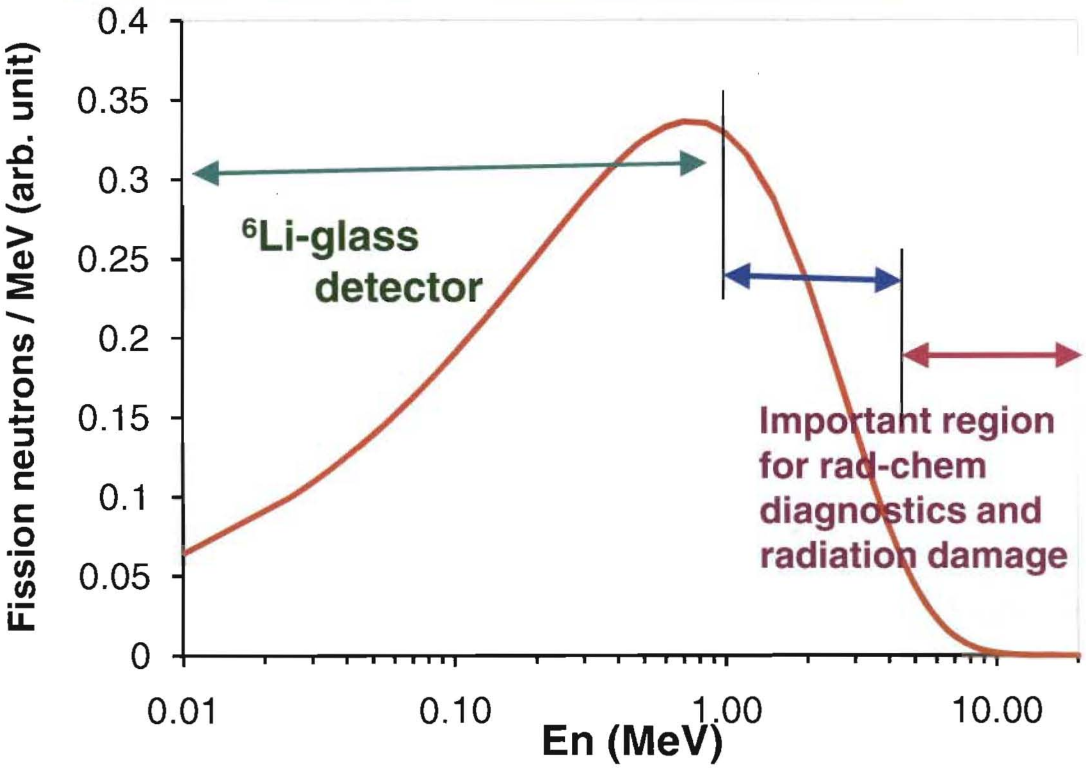


Noda et al. Phys. Rev. (2011, in press)



- Good data for emission energies of 1 to 6 MeV
- Neutrons below 1 MeV are not measured
- Data above 6 MeV need much better statistics

Fission neutron output spectrum : Watt distribution



Green arrow : about 35 % of fission-induced neutrons are produced at less than 1 MeV.

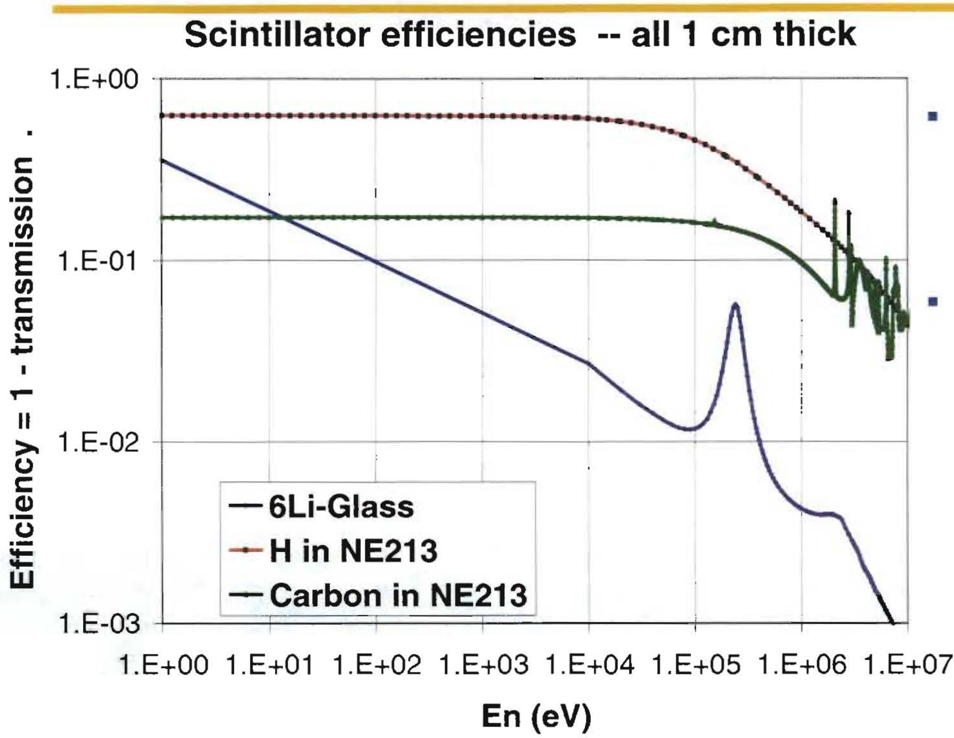
Blue arrow : number of neutrons in this region is determined by nu-bar and the shape of the entire spectrum.

Purple arrow : above 6 MeV, hydrogen and helium generated from (n,p) and (n,α) can do radiation damage on structural materials.

* This plot is the neutron emission of spontaneous fission in ^{252}Cf.

Up to now the unmeasured data below 1 MeV are obtained by extrapolating from the fit to Watt distribution.

^{6}Li-glass detectors for measuring low-energy neutrons (< 1 MeV)



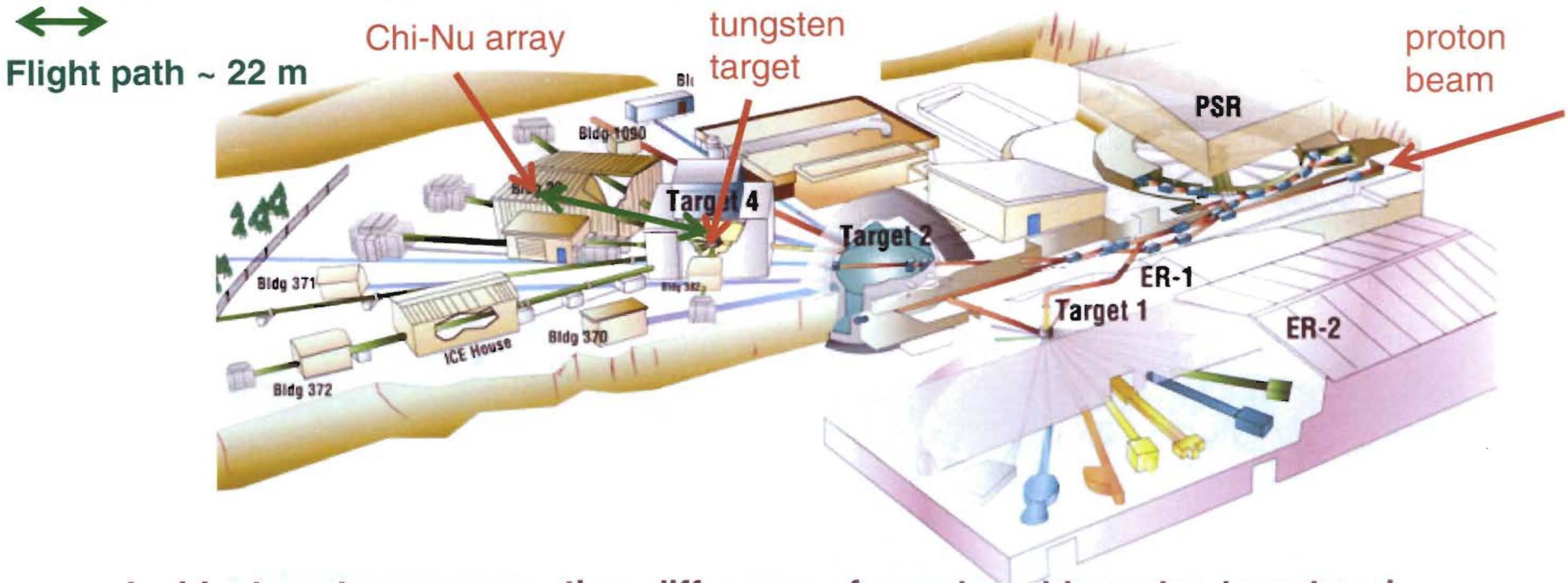
- NE213 shows the similar characteristics as liquid scintillators (EJ301) used in Chi-Nu.
- Although the efficiencies (red and green lines) are still high at En < 1 MeV, it is difficult to separate neutrons from gamma rays using pulse shape discrimination method.

- ^{6}Li-glass detector has an usable efficiency below 1 MeV and can differentiate neutrons from gamma rays in this region.
- The pulse height is generated from the ^{6}Li(n,α)^{3}H reaction, where the α and triton products have a kinetic energy of about 4.8 MeV.

^{252}Cf source measurement

Los Alamos Neutron Science Center (LANSCE) & WNR

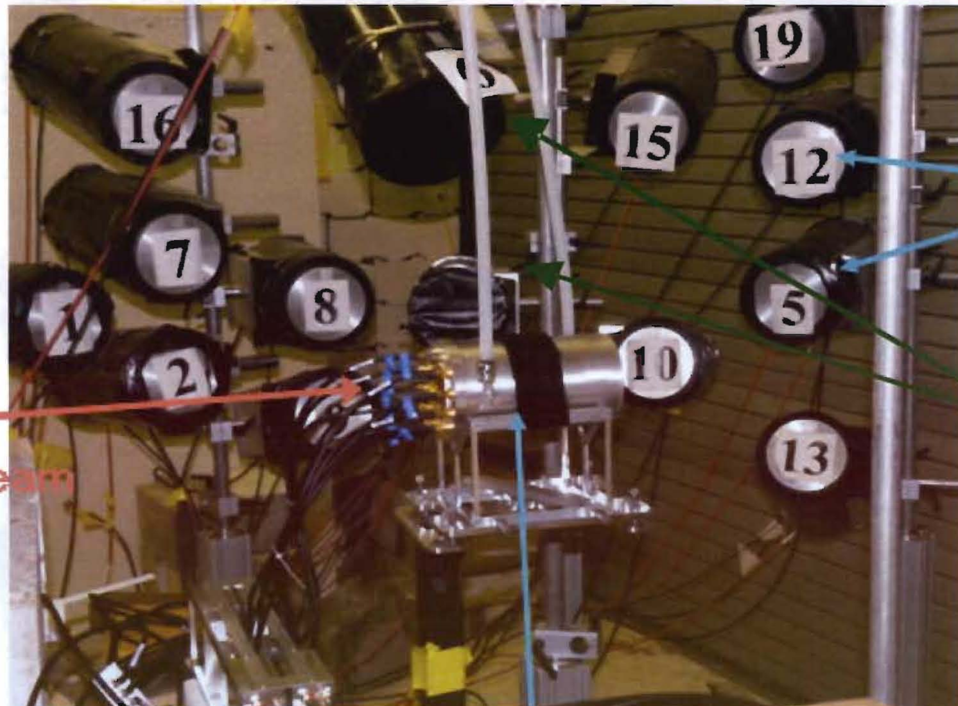
Protons are accelerated up to 800 MeV, then bombarded at a tungsten target to produce a white spectrum of neutrons at 1-600 MeV.



Incident neutron energy : time difference of a proton at tungsten target and a fission event at a target

Outgoing neutron energy : time difference of a fission event at a target and a neutron detected in detectors (double time of flight)

Neutron detector array : liquid scintillators & ^{6}Li-glass detectors



liquid scintillators

^{6,7}Li-glass detectors

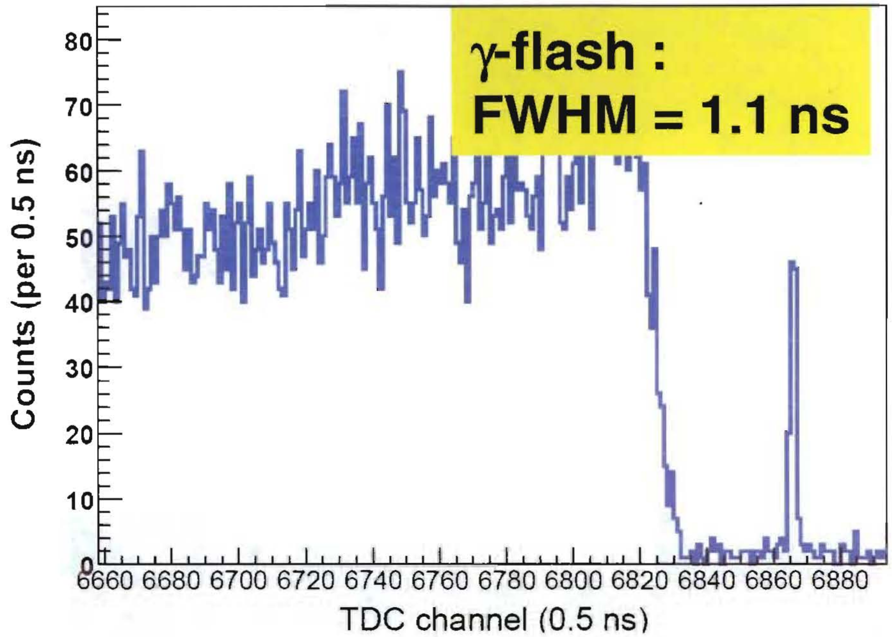
Neutron beam

Parallel Plate Avalanche Counter (PPAC)

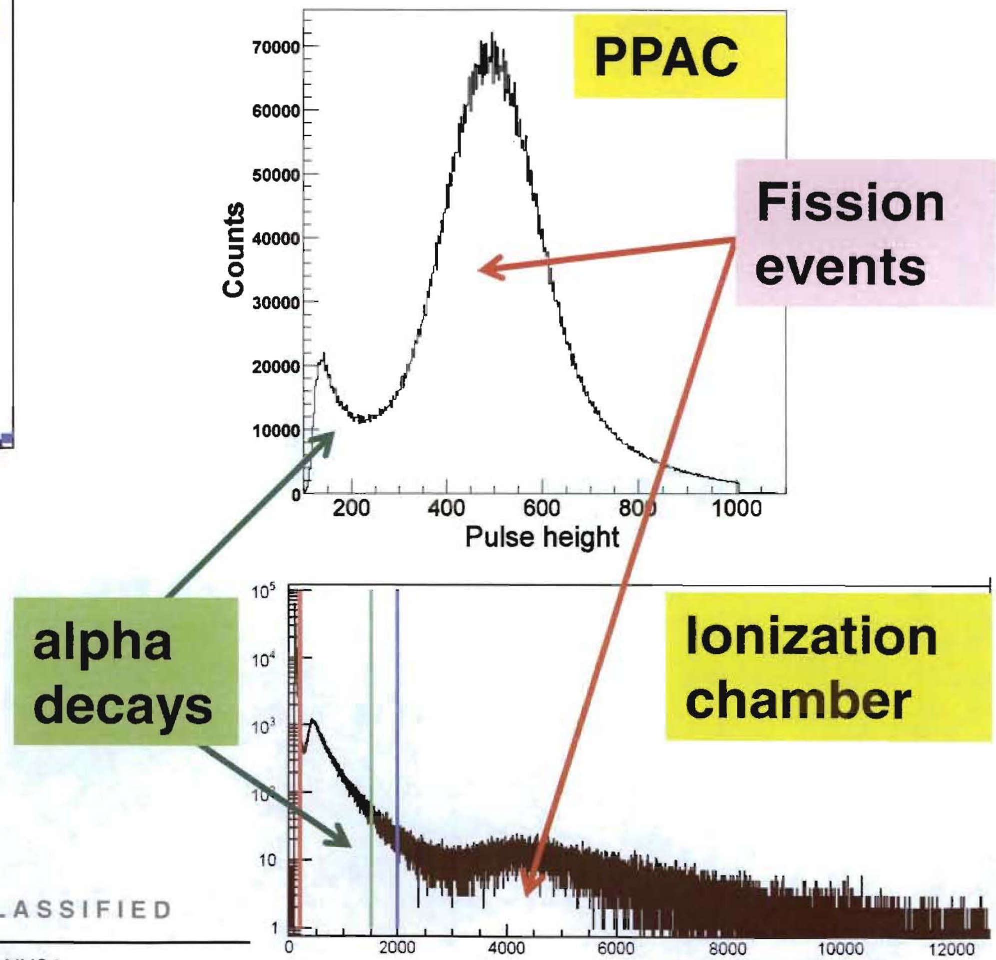
LLNL-developed PPAC has 10 cathode foils to maximize the amounts of actinides to be electroplated, and used as a fission chamber.

17 cm

PPAC: time resolution and ratio of fission-to-alpha decays



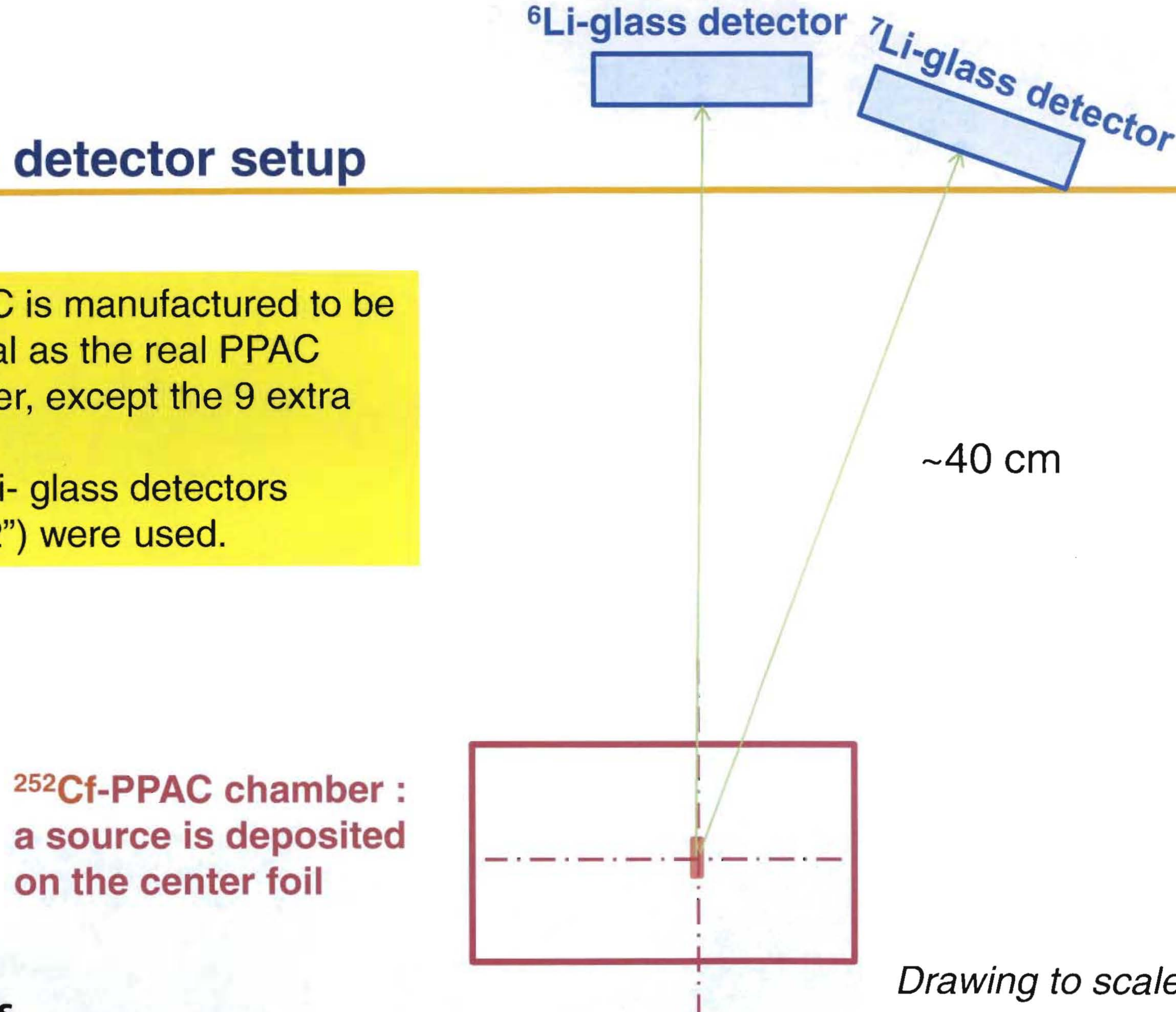
By adjusting the bias voltage in PPAC, it can reduce the pulse height of alphas.



By comparing to the timing resolution of ionization chamber, ~4.5 ns, the PPAC resolution (1.1 ns) shows the improvement by a factor of 4.

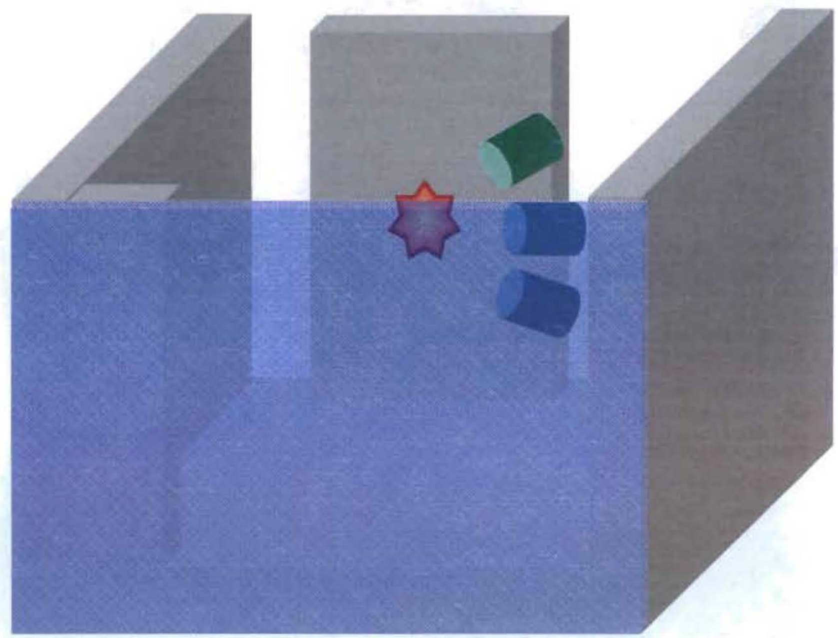
Li-glass detector setup

- ^{252}Cf-PPAC is manufactured to be identical as the real PPAC chamber, except the 9 extra foils.
- ^{6}Li- and ^{7}Li- glass detectors (4"X1/2") were used.



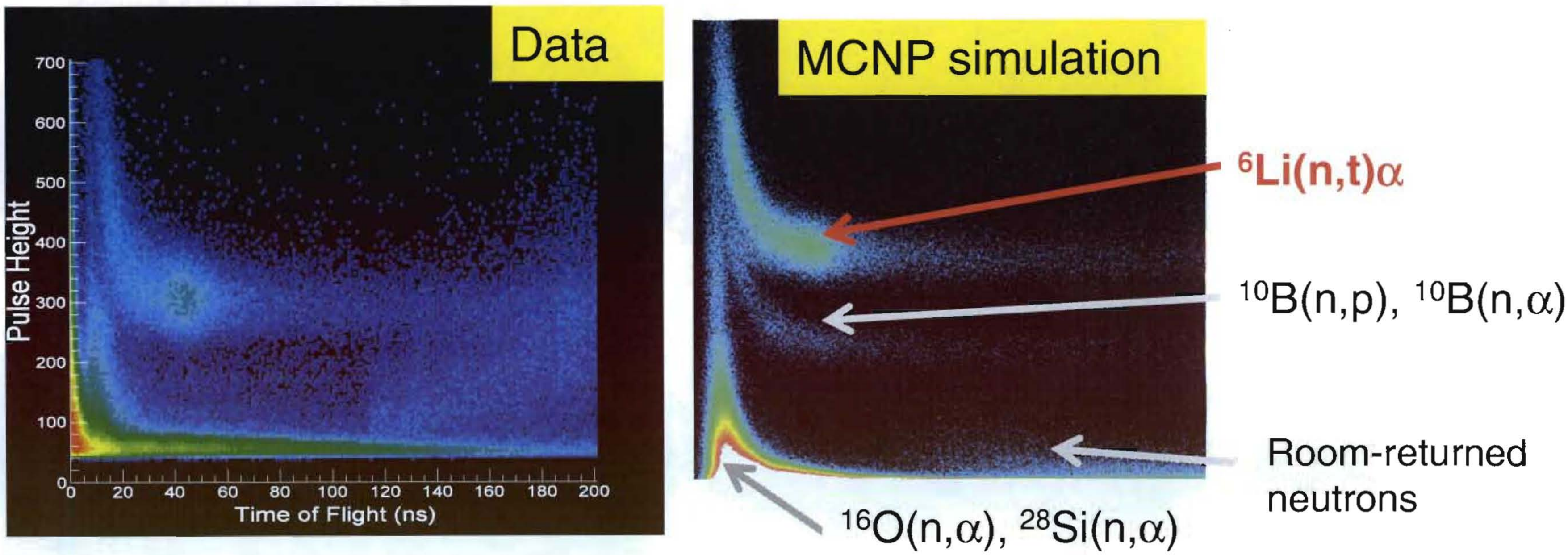
MCNPX setup

- Calculations were performed by T. Tadeucci at LANL.
- MCNP-Polimi was used.
- Room geometry includes shielding blocks, floor, and a roll-up door.
- Detector assembly includes a Li-glass scintillator, a PMT, a PVC tube, and aluminum mounts.
- ^{252}Cf source includes the aluminum PPAC housing and G10 rings for target mounts.



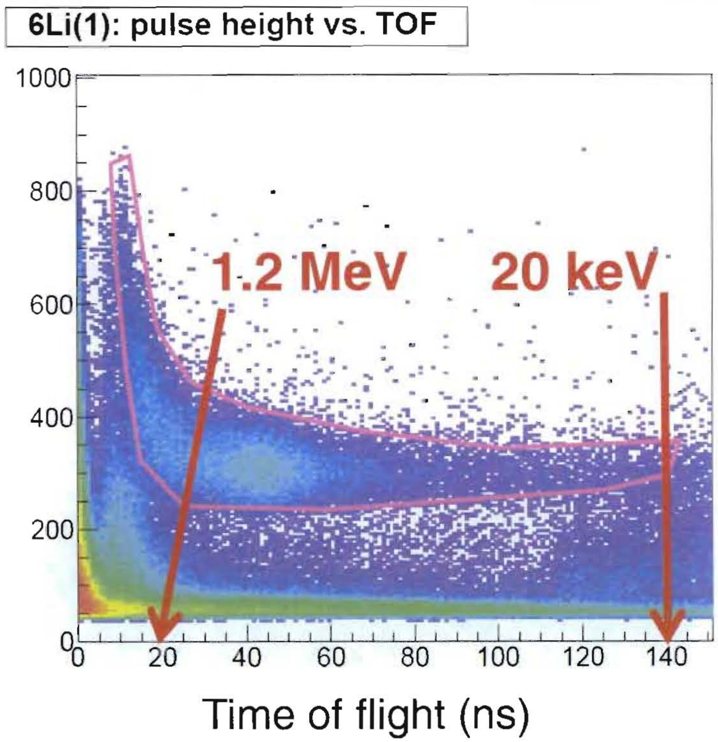
Grey : concrete shielding blocks (1'X6')
Green : detectors
Blue : iron wall (1/8" thick)

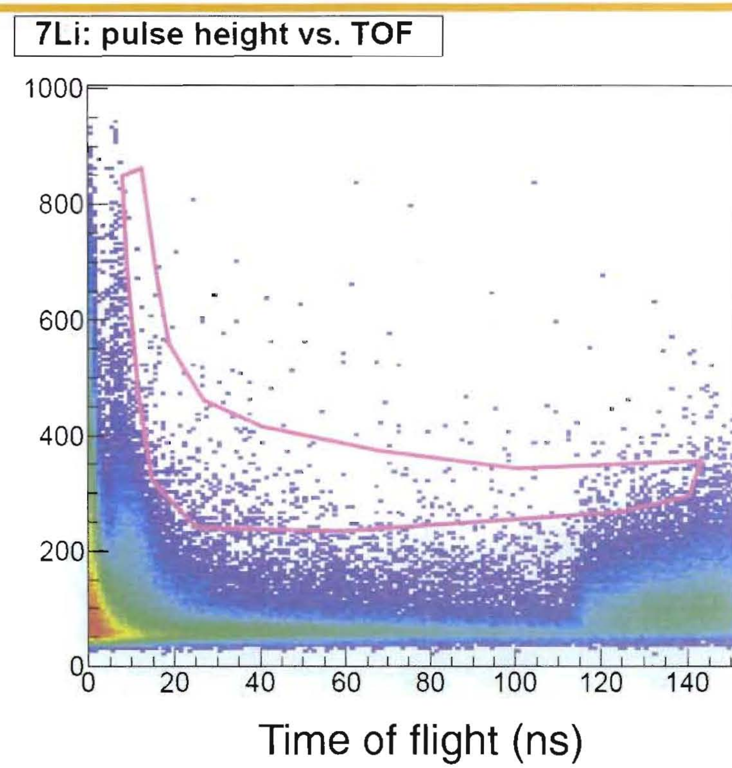
Pulse height vs. Time of Flight in ns



1. Background reactions on glass materials are included.
2. Gamma rays from inelastic scattering on potentially O, Si, Al, Mg, and Li are not included in simulation.

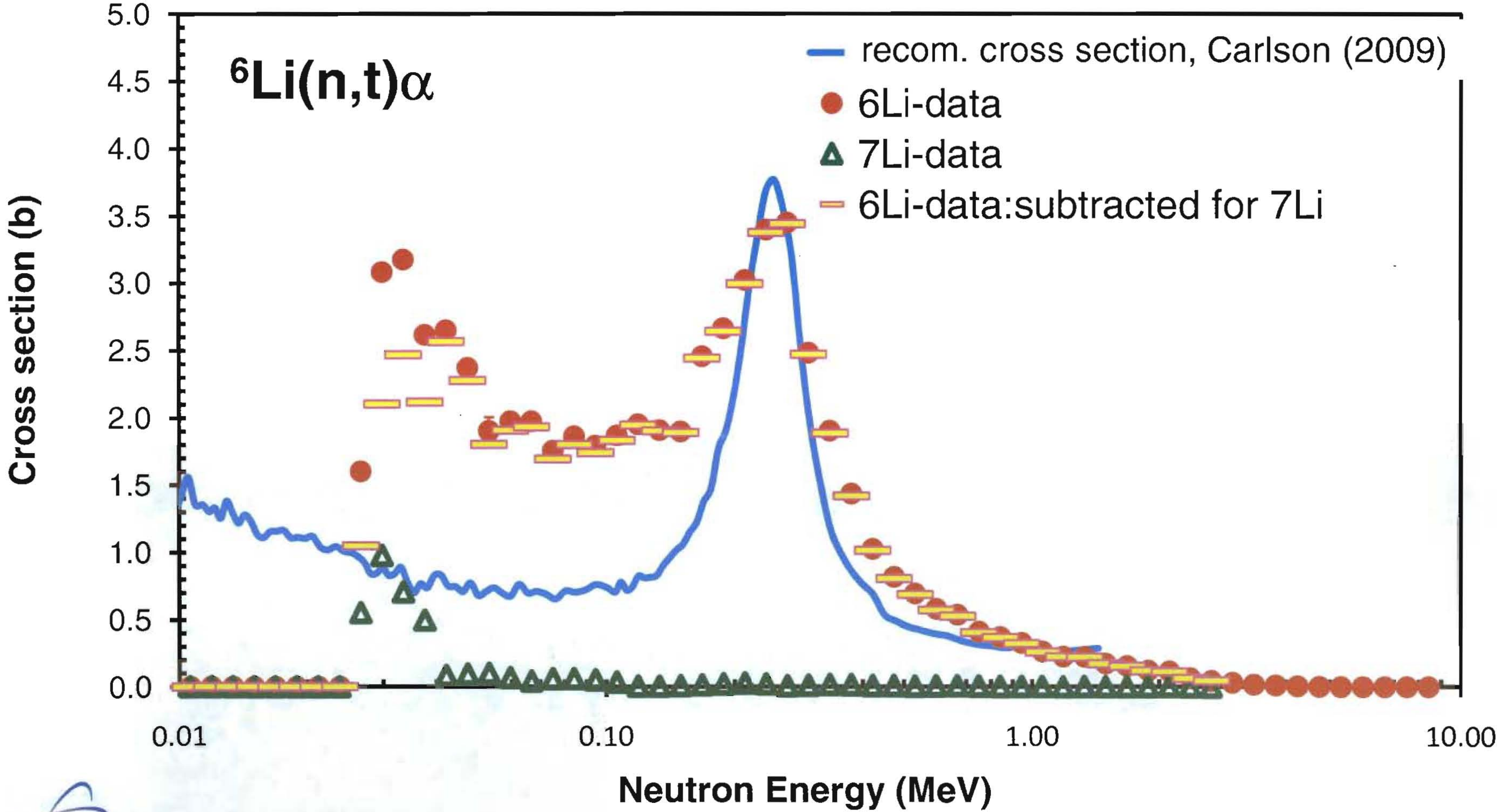
Comparison of ^{6}Li-glass and ^{7}Li-glass detectors



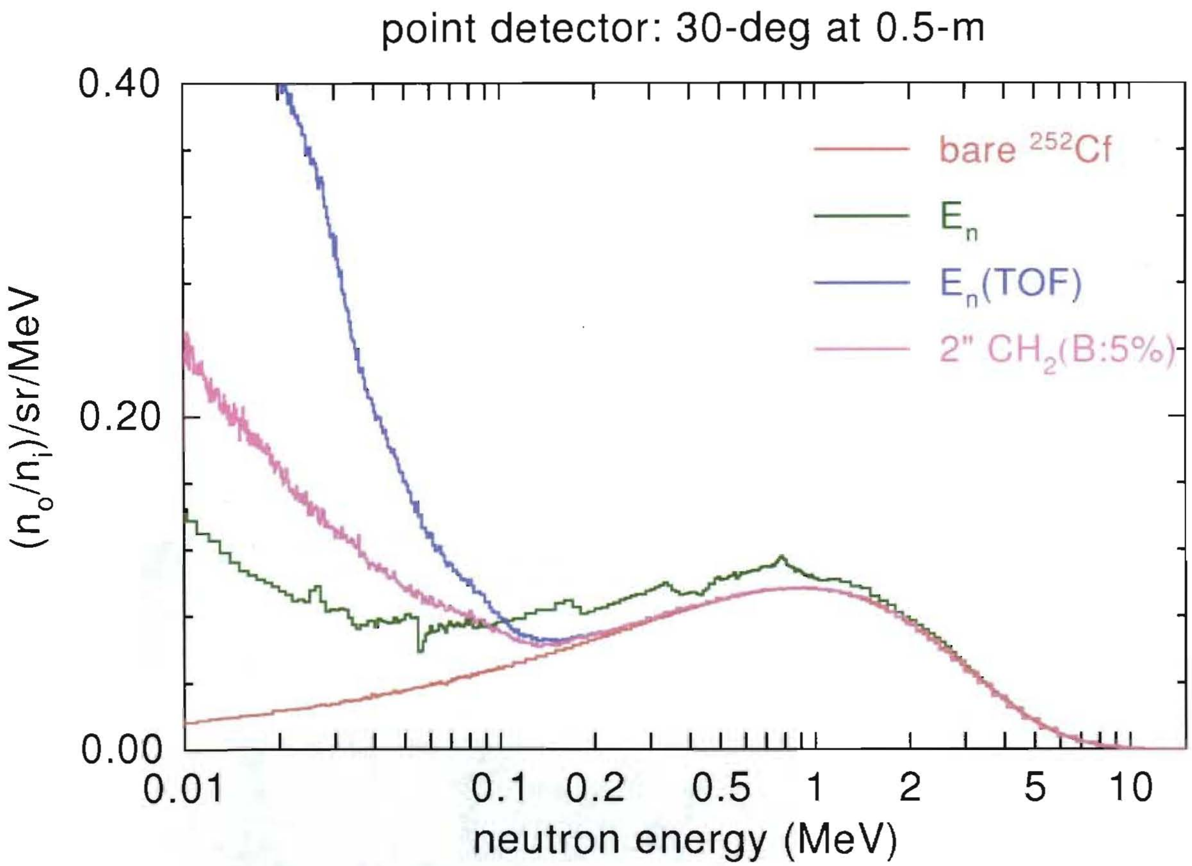


Software cut in pulse height vs. TOF is used to identify low energy neutrons.

Neutron Output Yield from ^{252}Cf

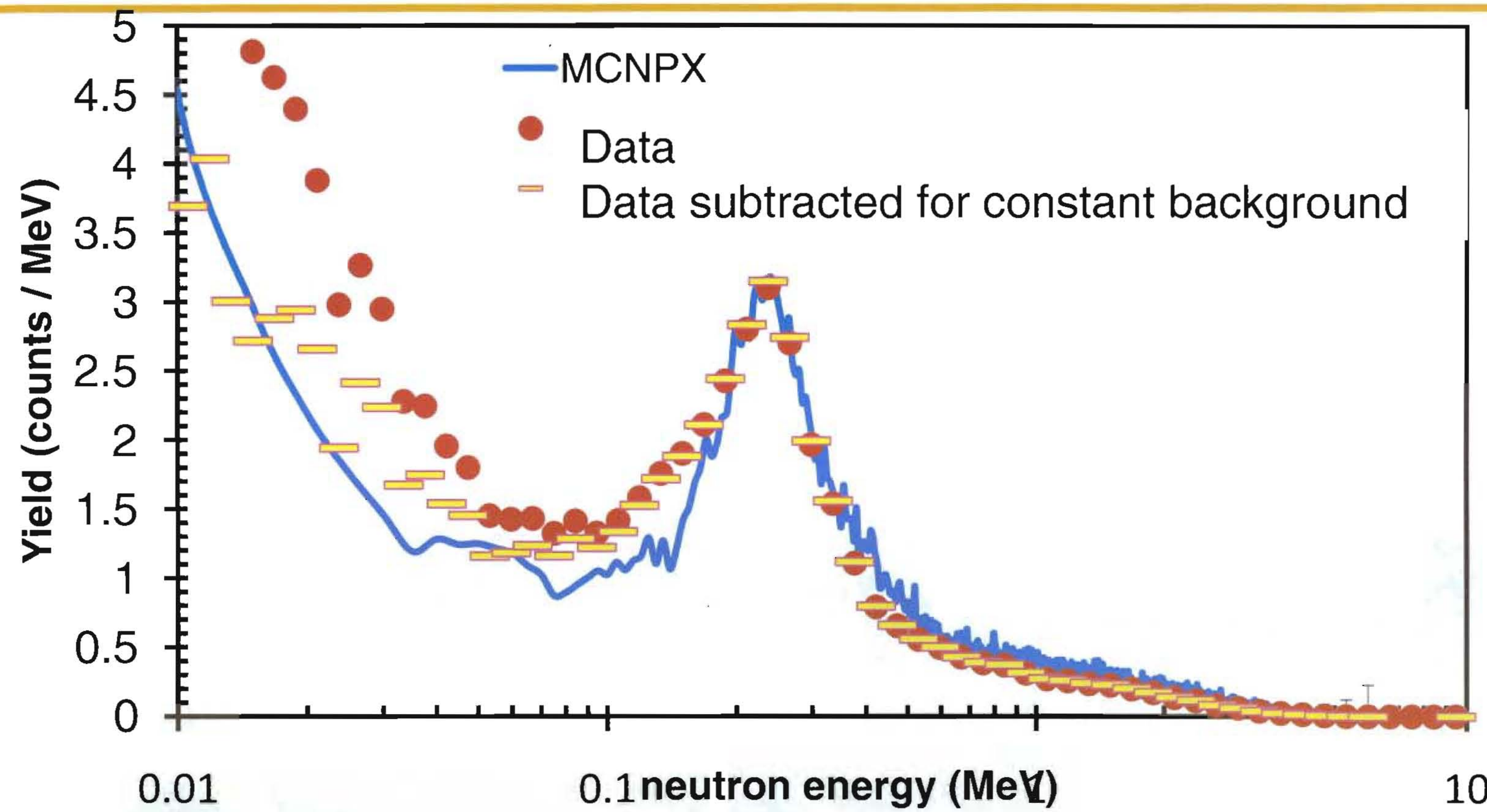


MCNP simulations for estimating the effect of "room-return" neutrons in ^{6}Li-glass detector



- "Room-return" neutrons : originally higher energy neutrons backscattered in the room, then detected with a delayed time of flight.
- The simulation also reveals the concrete floor and shielding blocks play the main contribution.
- New flight path is designed to have concrete materials to be further away from the detector array, including a pit (18'X18'X7') under it.

MCNPX calculation for a realistic setup compared to data

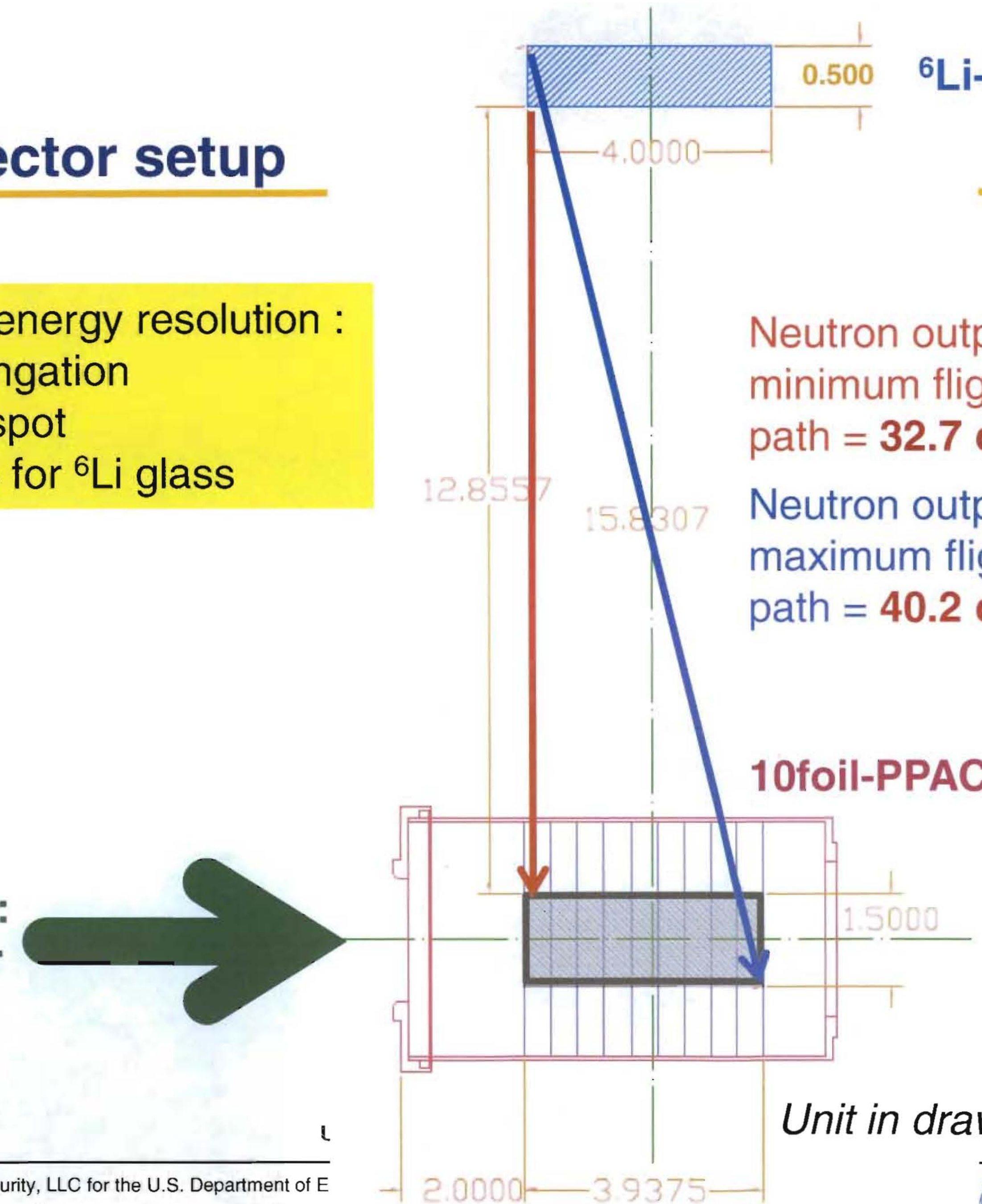


Constant background subtraction improves the agreement between the data and the simulation.

$^{235}U(n,f)$ measurement

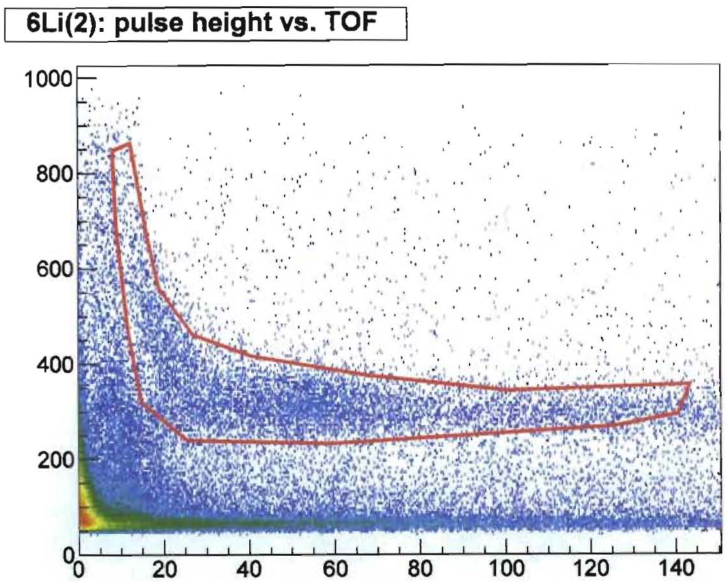
Li-glass detector setup

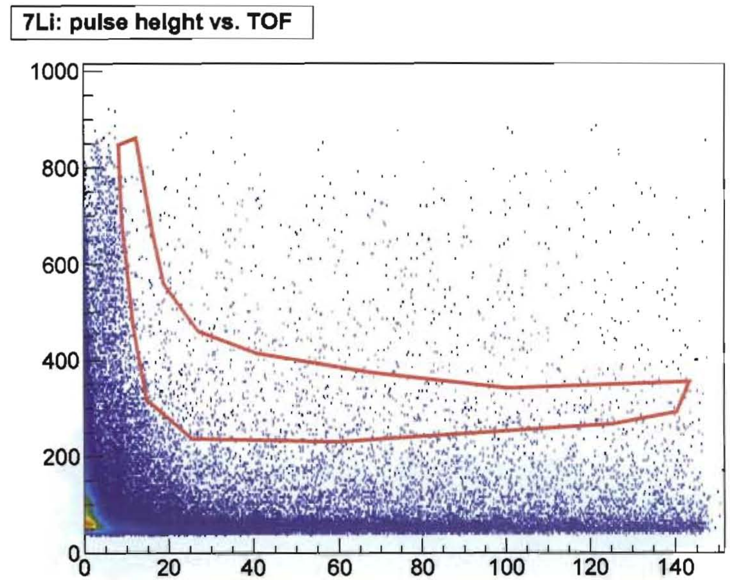
Contributions to the energy resolution :
1. Extended foil elongation
2. Extended beam spot
3. Large solid angle for ^{6}Li glass



Unit in drawing : inch

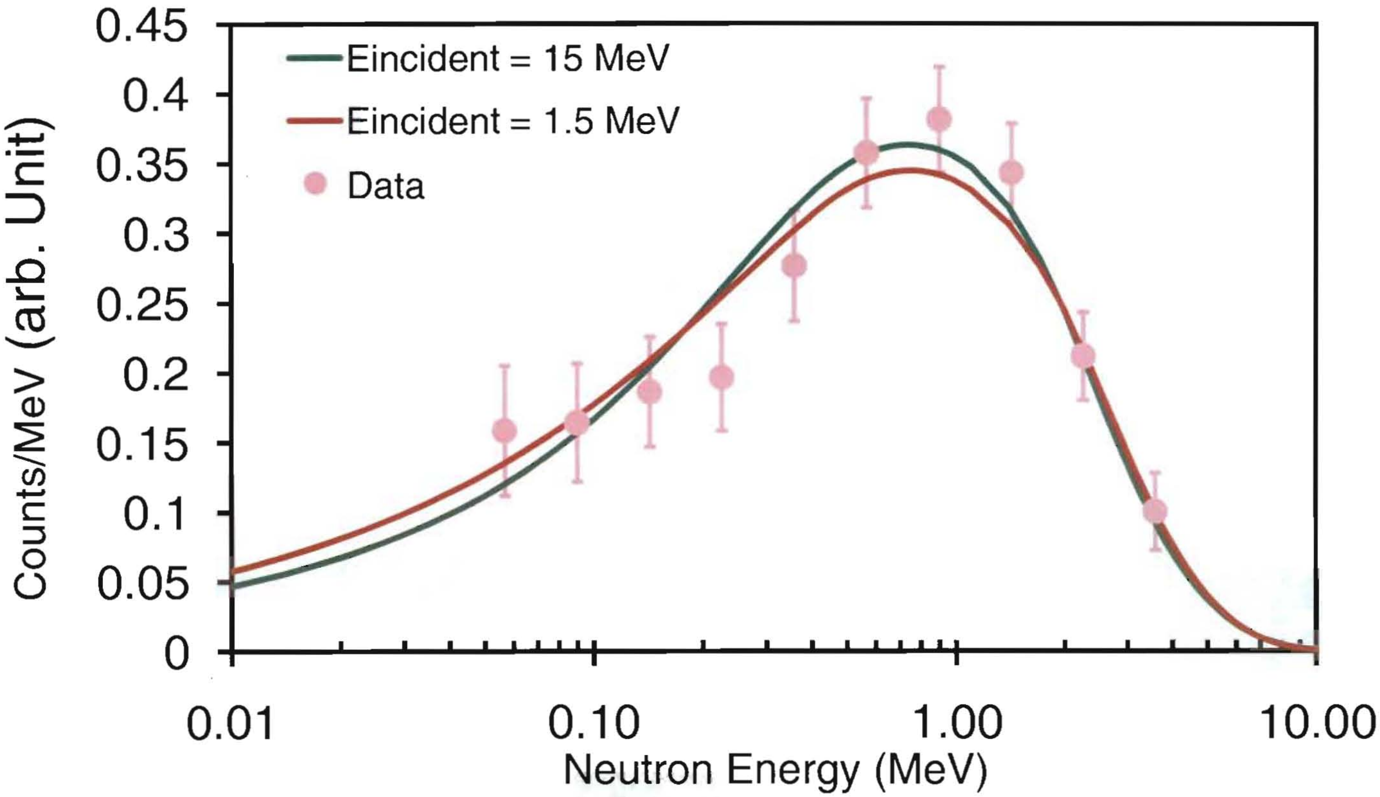
235U(n,f) data taken with ^{6}Li and ^{7}Li glasses





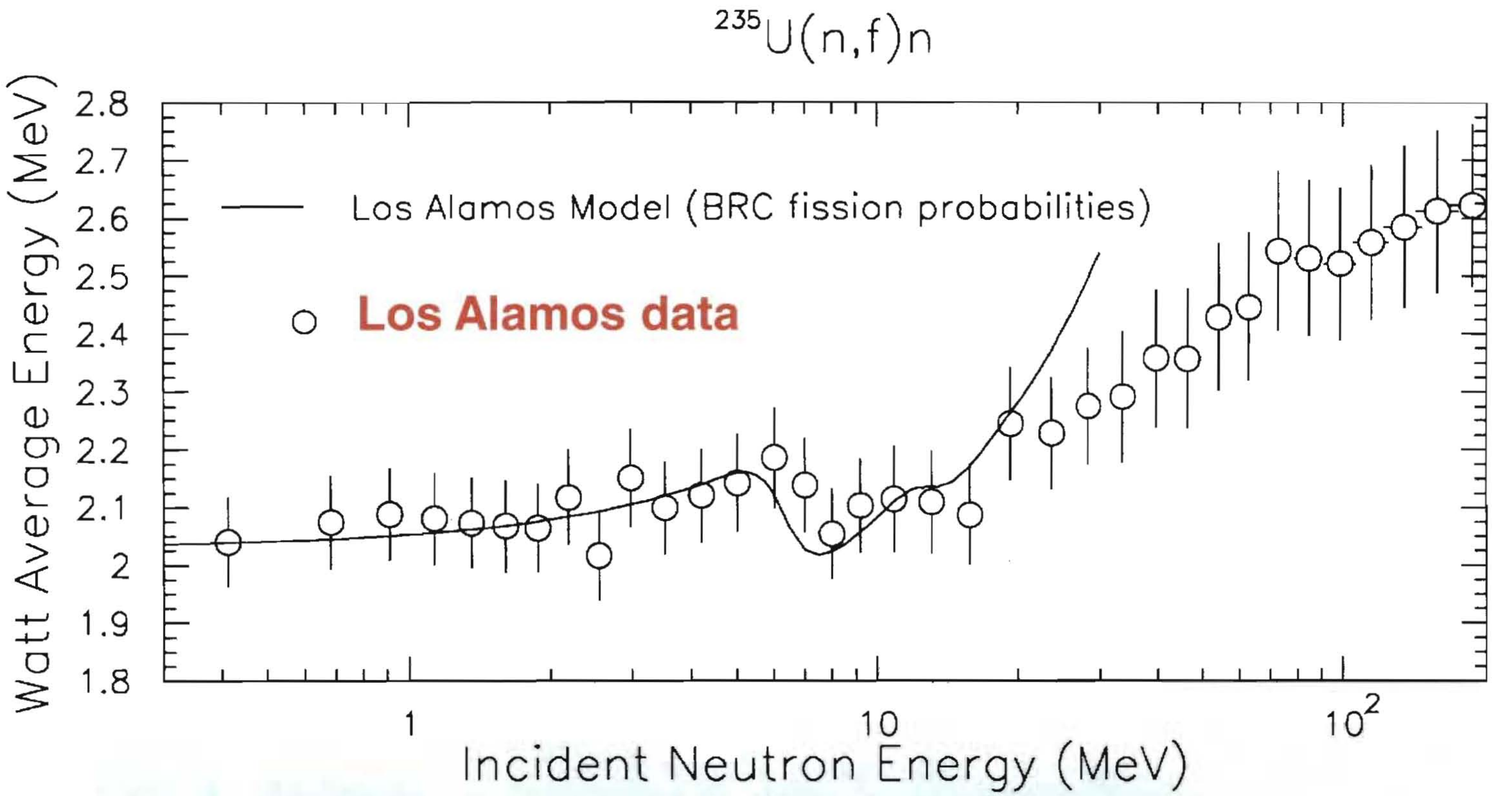
- The software gate obtained from the calibration with a ^{252}Cf source was used to extract the yield.
- The yield of ^{6}Li-glass detector was subtracted by the yield of ^{7}Li-glass detector for the background correction.

Preliminary Neutron output distributions compared with the LA model (Madland and Nix, 1982)



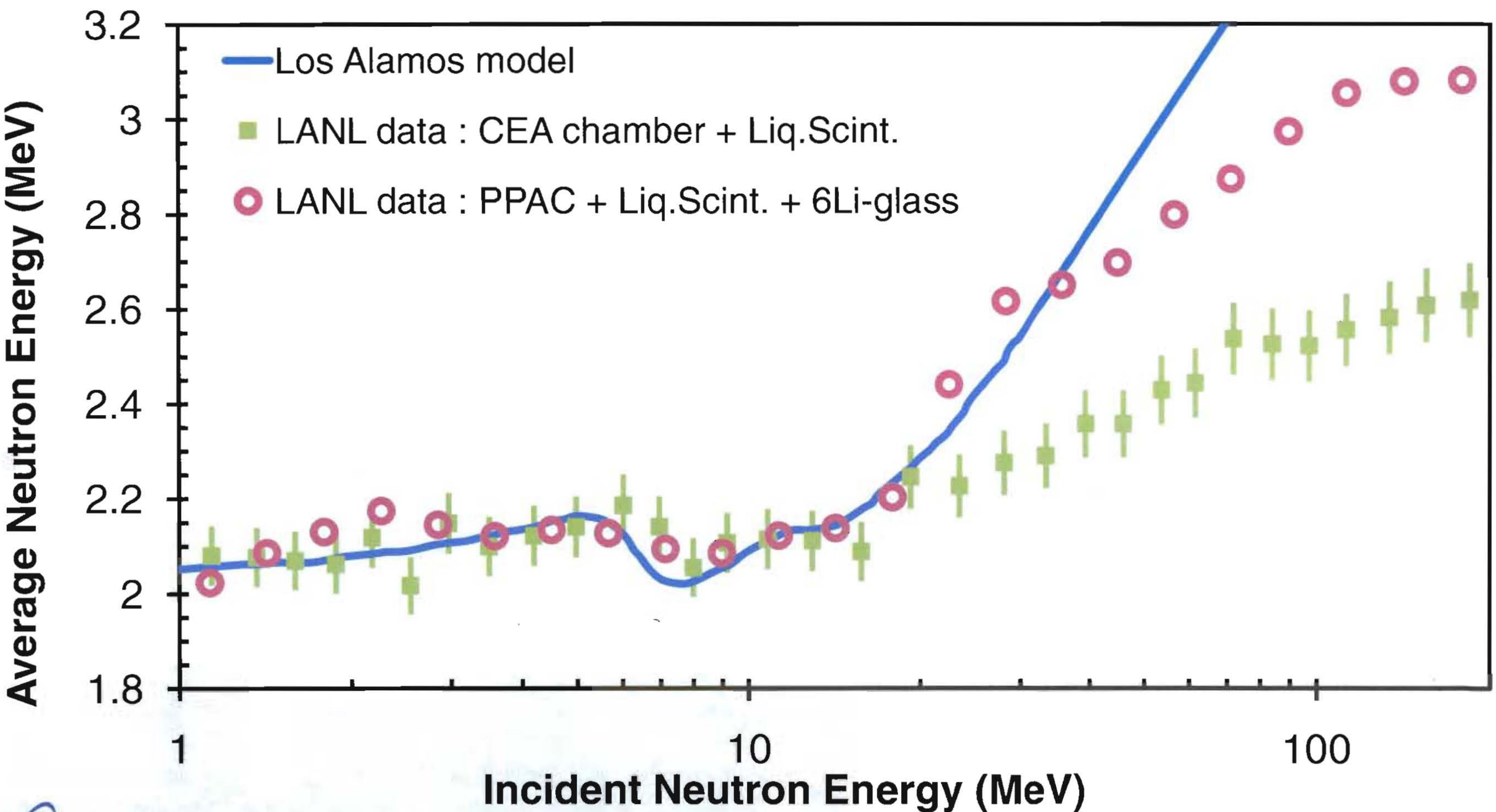
Data are taken for all incident energies, due to a limited statistics.

Previous study on $^{235}U(n,f)$, using only liquid scintillators



Phys. Rev. Lett. **T. Ethvignot, M. Devlin, H. Duarte, T. Granier, R.C. Haight, B. Morillon, R.O. Nelson, J.M. O'Donnell, and D. Rochman (2005)**

Preliminary Average neutron output energy



Summary and Outlook

1. Systematic analysis of $^{235}U(n,f)$ using ^{6}Li-glass detector measurements with different settings is underway to better understand the detector response with MCNP calculations.

2. Expand to have 20 ^{6}Li-glass detectors and 50 liquid scintillators for improved statistics, and develop digital signal processing for waveform analysis for potentially better selection of low energy neutrons from background gammas.

3. Plan to measure multiple actinide targets using the PPAC and the "chi-nu" neutron detector array for improved nuclear data.

Contribution

Los Alamos National Laboratory :

LANSCE-NS : R.C. Haight, T. Taddeucci, M. Devlin, N. Fotiadis, A. Laptev, R. Nelson, J. O'Donnell, F. Tovesson, J. Ullmann, S. Wender

C-NR : T. Bredeweg, M. Jandel, D. Vieira

Lawrence Livermore National Laboratory :

C. Y. Wu, J. Becker, A. Chyzh, E. Kwan