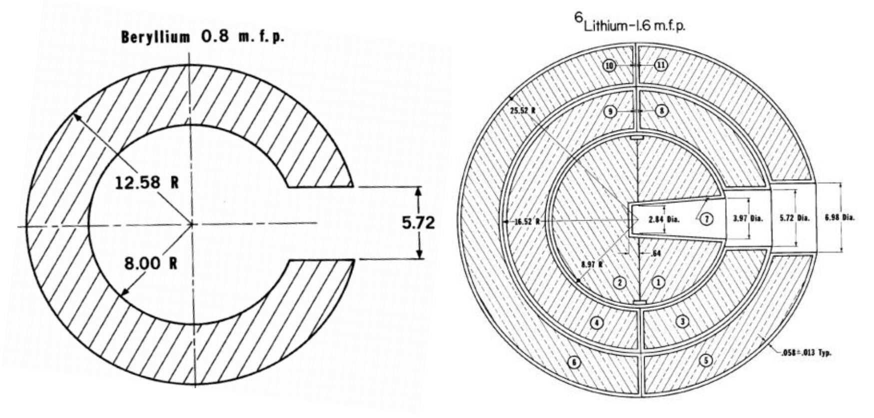
AWE NUCLEAR SECURITY TECHNOLOGIES

Pulsed sphere modelling

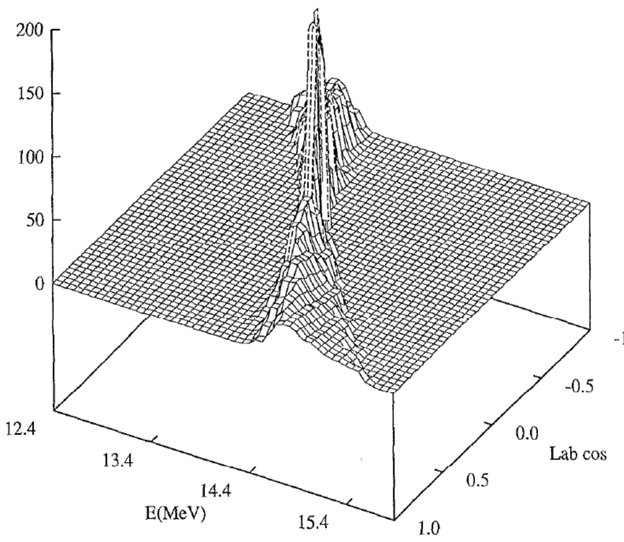
Nuclear Data Week, BNL, November 2025

Jake Land, **Tim Gaines**

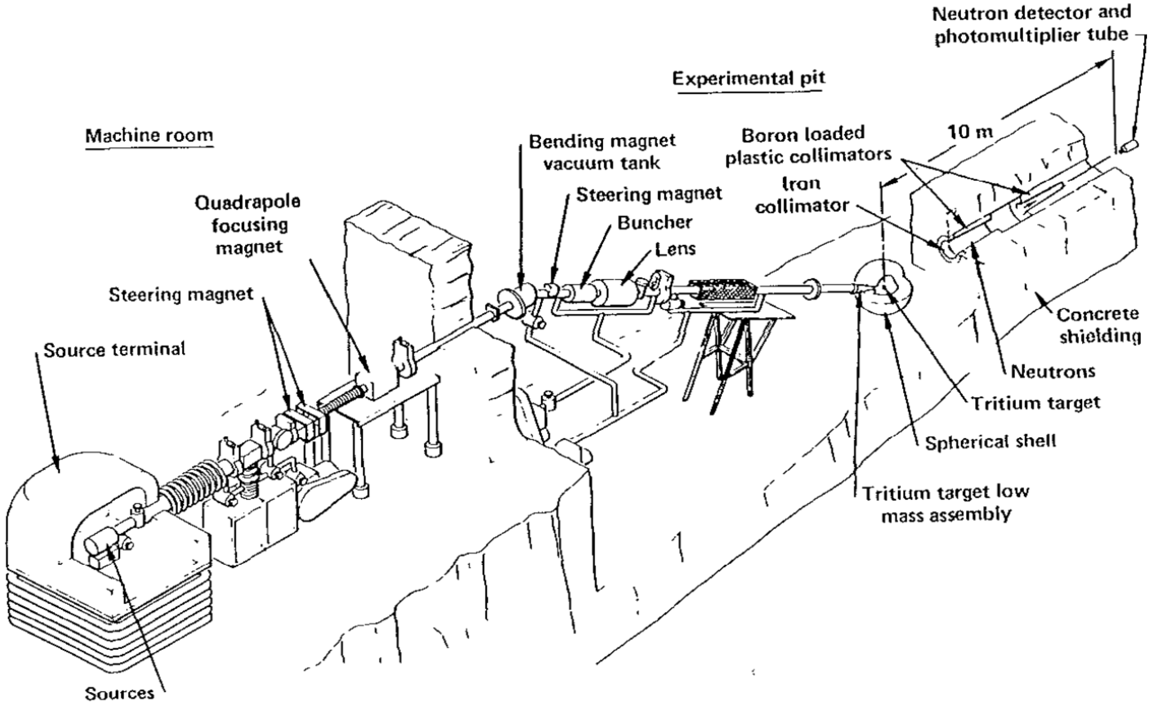
Pulsed spheres



- Pulsed spheres were a series of experiments performed at LLNL where nToF measurements were performed for a range of materials from a 14 MeV source
- 14 MeV neutron source generated from a 400 keV deuteron beam onto a tritium loaded target
- Significant range of MCNP models with an imposed source based on Marchetti's calculations exist



Updated source based on TRIM calculation, Marchetti, UCRL-ID-131461



C. Wong et al, Livermore pulsed sphere program: program summary through July 1971, 1972, UCRL-51144

Pulsed spheres

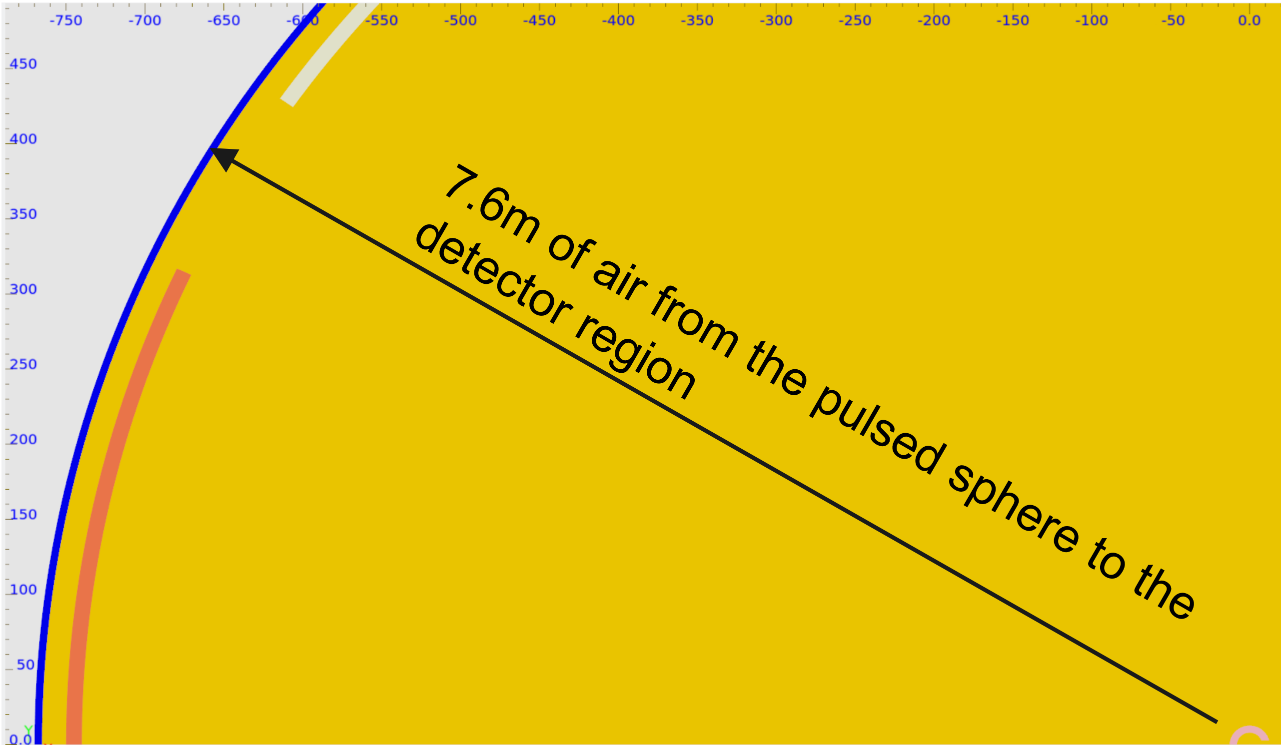
- Detailed MCNP models exist to simulate a range of the LLNL pulsed sphere experiments (along with similar experiments, Wyman Spheres, Oktavian spheres etc).
- The neutron source is based on work by Marchetti simulating the DT interaction in the titanium-tritium target layer and then acts as an imposed source in MCNP. Other codes also exist for simulating charged particles in a target layer (DROSG, SRIM)
- AWE has a Monte Carlo neutron transport code which has been developed to perform charged particle transport (CPT). Uses ACE nuclear data files, processed using NJOY, allowing data to be easily compared against results in MCNP.
- The AWE code and MCNP are both using exactly the same neutron interaction data
- Pulsed spheres represent a good experiment to compare a calculation of a charged particle induced reaction against experimental measurements
- Modelled in 2D and considered to be axially-symmetric, room/background not yet modelled fully, but a 2D approximation can be introduced (or the problem can be modelled in 3D, not yet done)

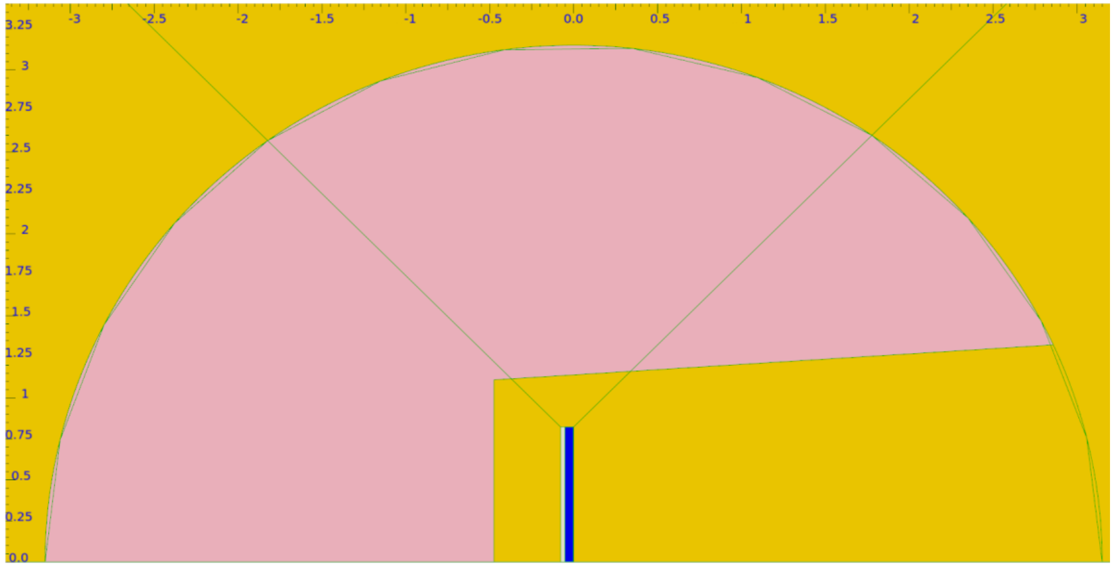
Charge Particle Transport

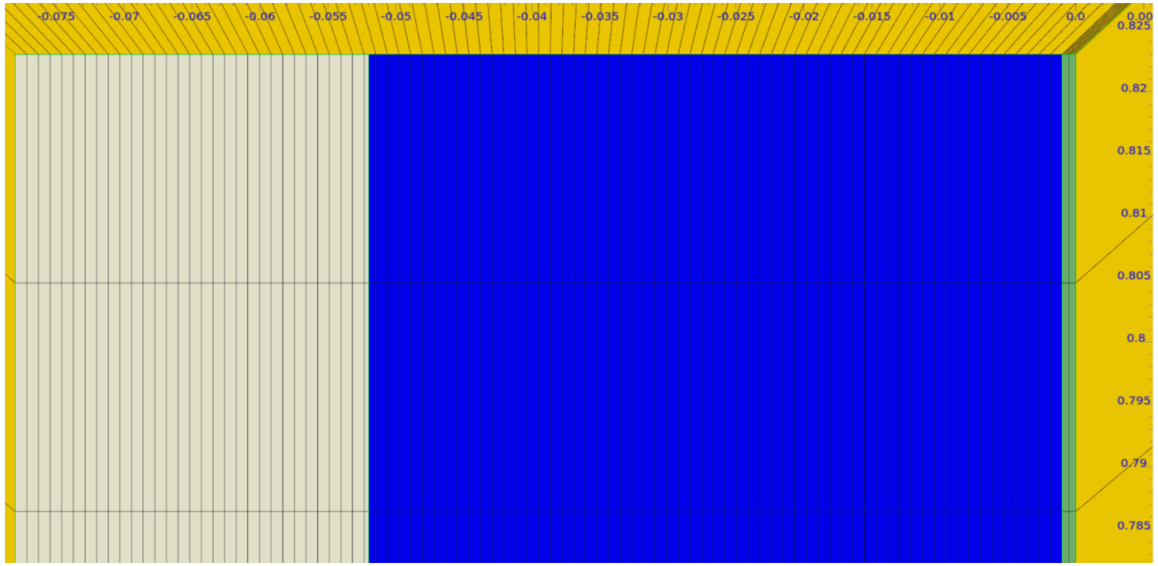
- We can use the incident deuterium on tritium data from ENDF/B-VIII to calculate the neutron source. The neutrons are transported through the full target assembly before interacting with the pulsed sphere assembly.
- The code has options for a range of stopping power/scattering models for charged particles.
- In theory, we can also model Ti(d,X) interactions (data supplied with TENDL) but are considered to be relatively low in comparison so have been ignored
- For later investigations, the code can do a full range of incident light ion interactions

Pulsed spheres

- Full target modelled: Ti-T layer, tungsten, steel
- 400 keV deuteron beam modelled over the width of the target, sourced immediately in front of the target
- First plotting the neutron spectrum around the target and comparing the to spectra defined in MCNP

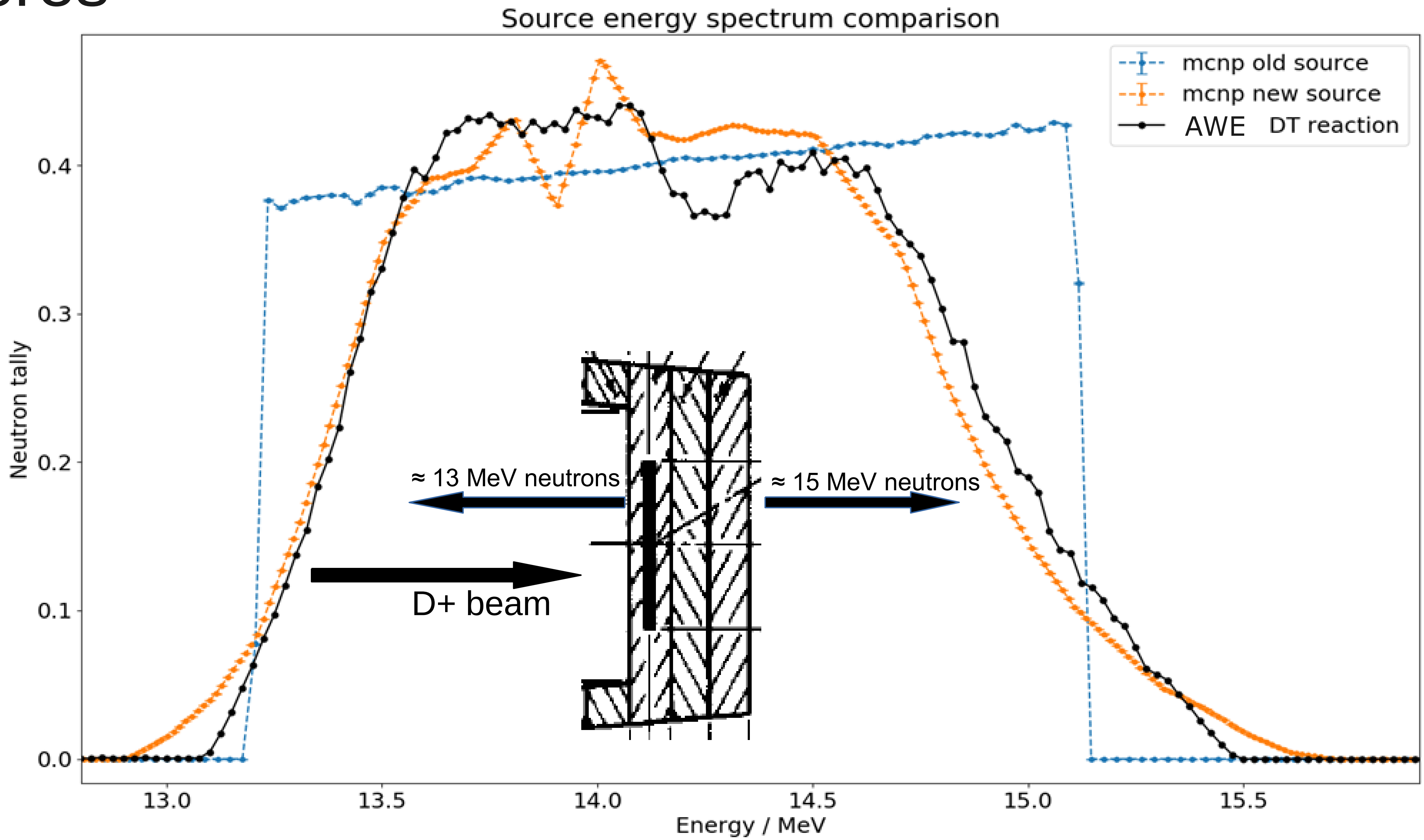






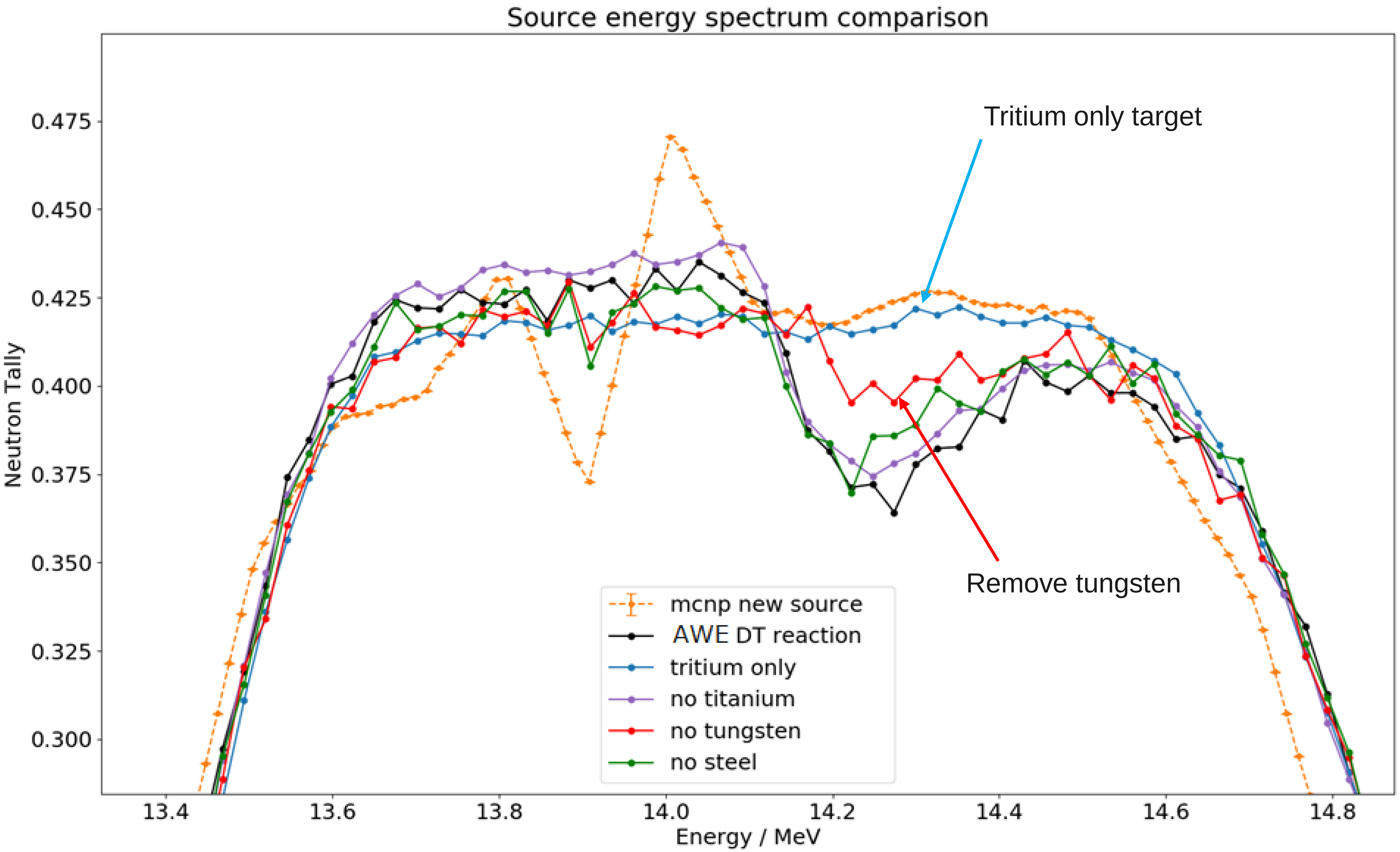
Pulsed spheres

- **Integrated flux surface tally 180° about the target**
- Older MCNP inputs showed a simple spectra (blue), modern inputs provide the revised spectra (orange).
- AWE generated spectra in black
- The resonance doesn't match between MCNP and AWE calculation
- The AWE calculated spectrum shows that neutrons around 14.2 MeV are being absorbed, this is not shown in MCNP
- Relative decrease at high energies makes sense for neutrons absorbed in the tungsten target, lower energy neutrons this is not seen at 90-180°



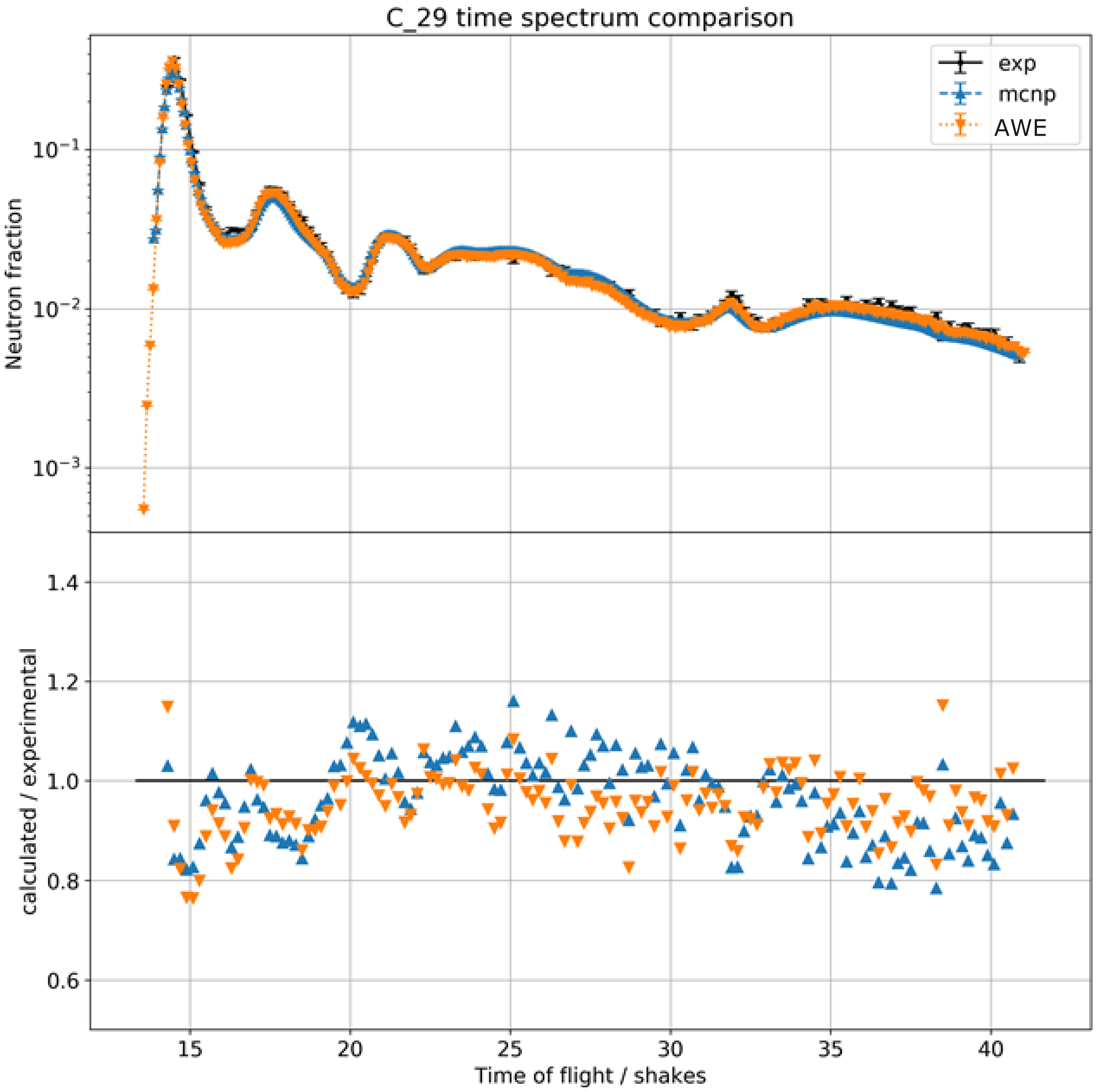
Pulsed spheres

- Removing one of, or all, the metal components of the target confirms the neutron losses and down scatter to the target
- Removing everything except the tritium (blue curve) shows a good match the MCNP source
- Removing the titanium or steel has a limited impact
- Removing the tungsten (red curve) has a larger impact on the drop at high energies and increase in lower energies compared to tritium only target
- No modification can generate the resonance shown in the MCNP spectrum



Pulsed spheres

- With confidence we are generating a good neutron spectrum from the D beam, can compare output from AWE compared to MCNP
- **Number of models where both AWE and MCNP match the experimental data**
- Number where AWE and MCNP agree, but neither match the experimental data
- Number where one code is a better match to experimental data
- Number where both codes disagree and neither match the experimental data



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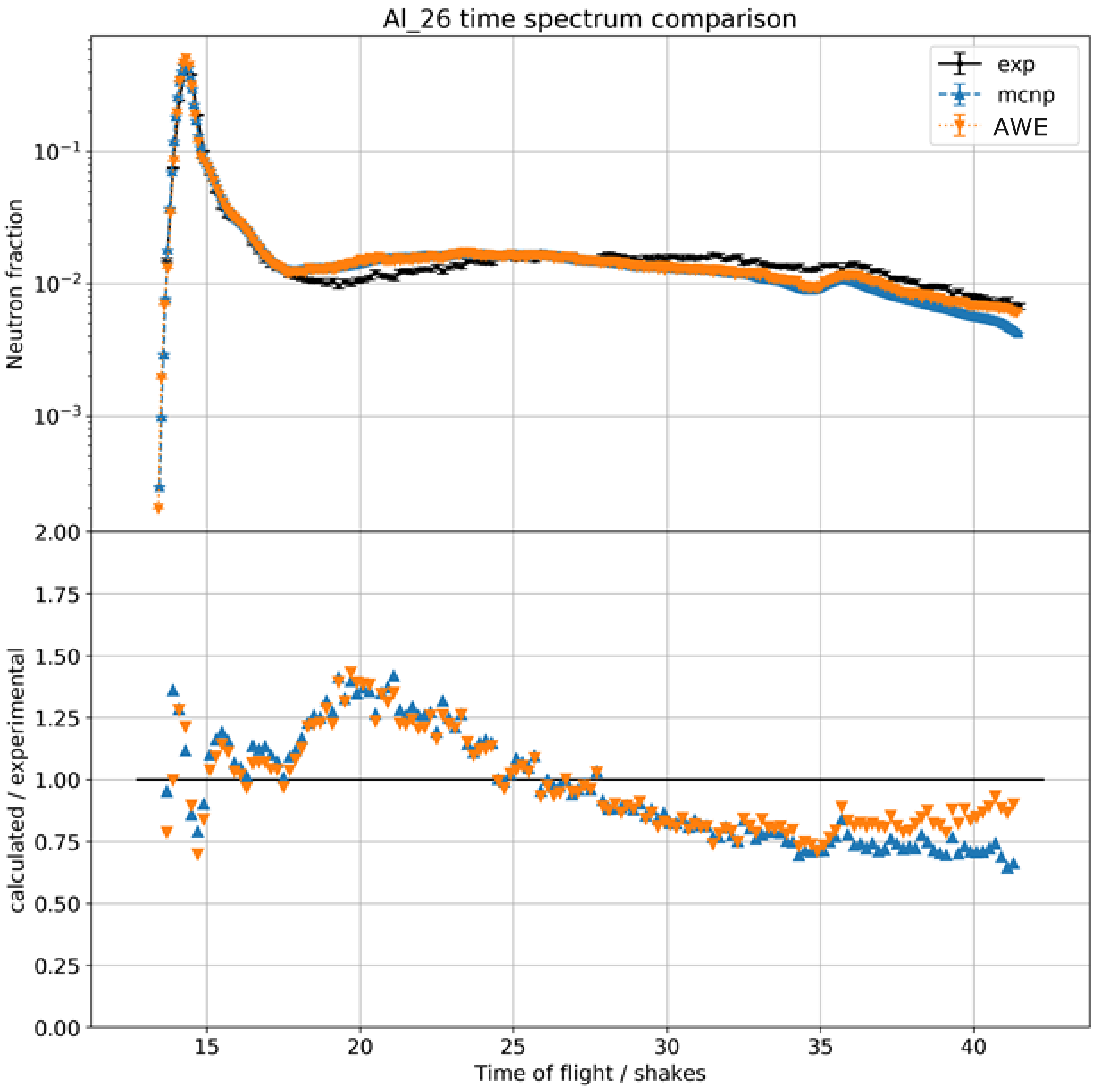

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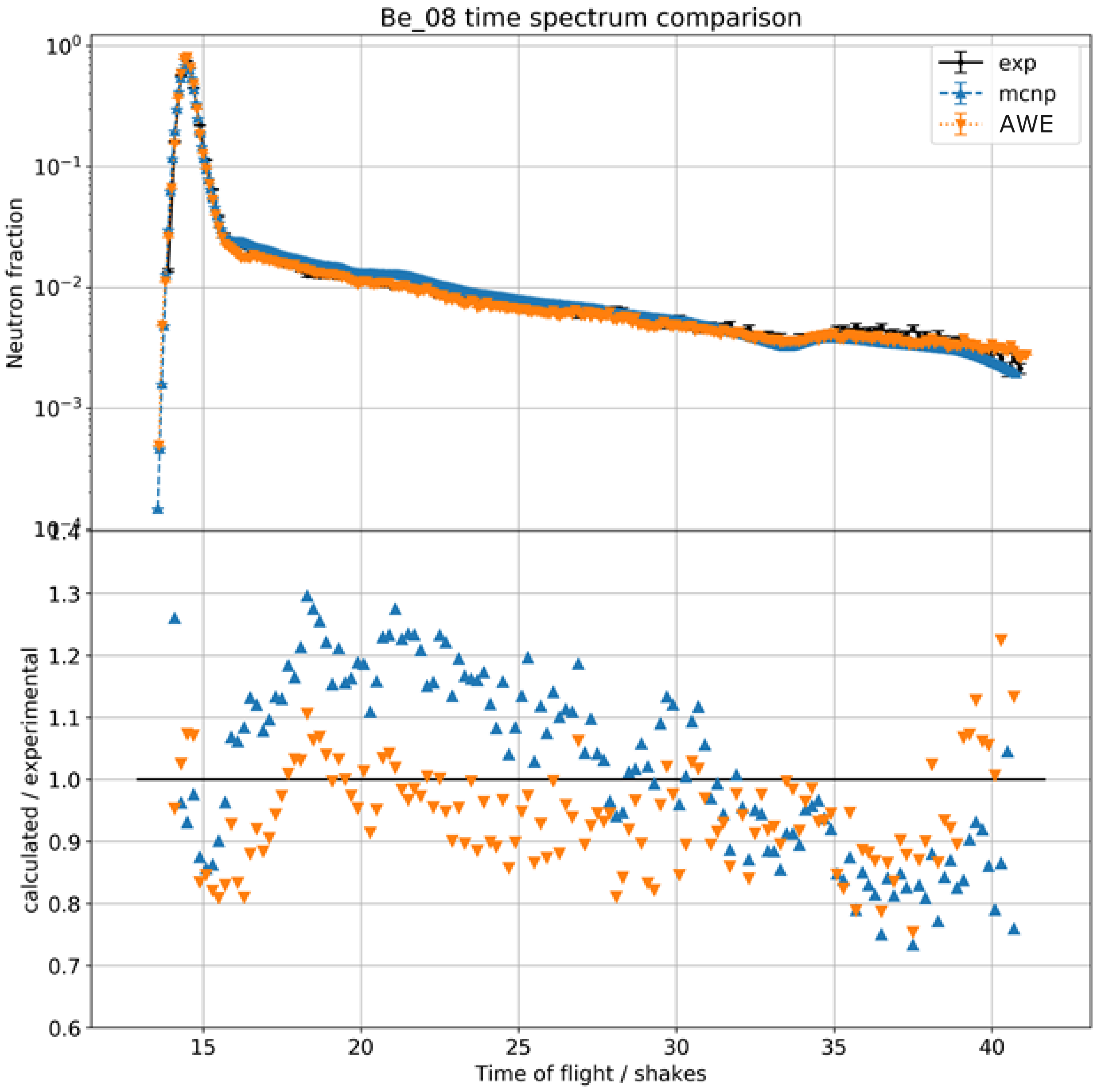

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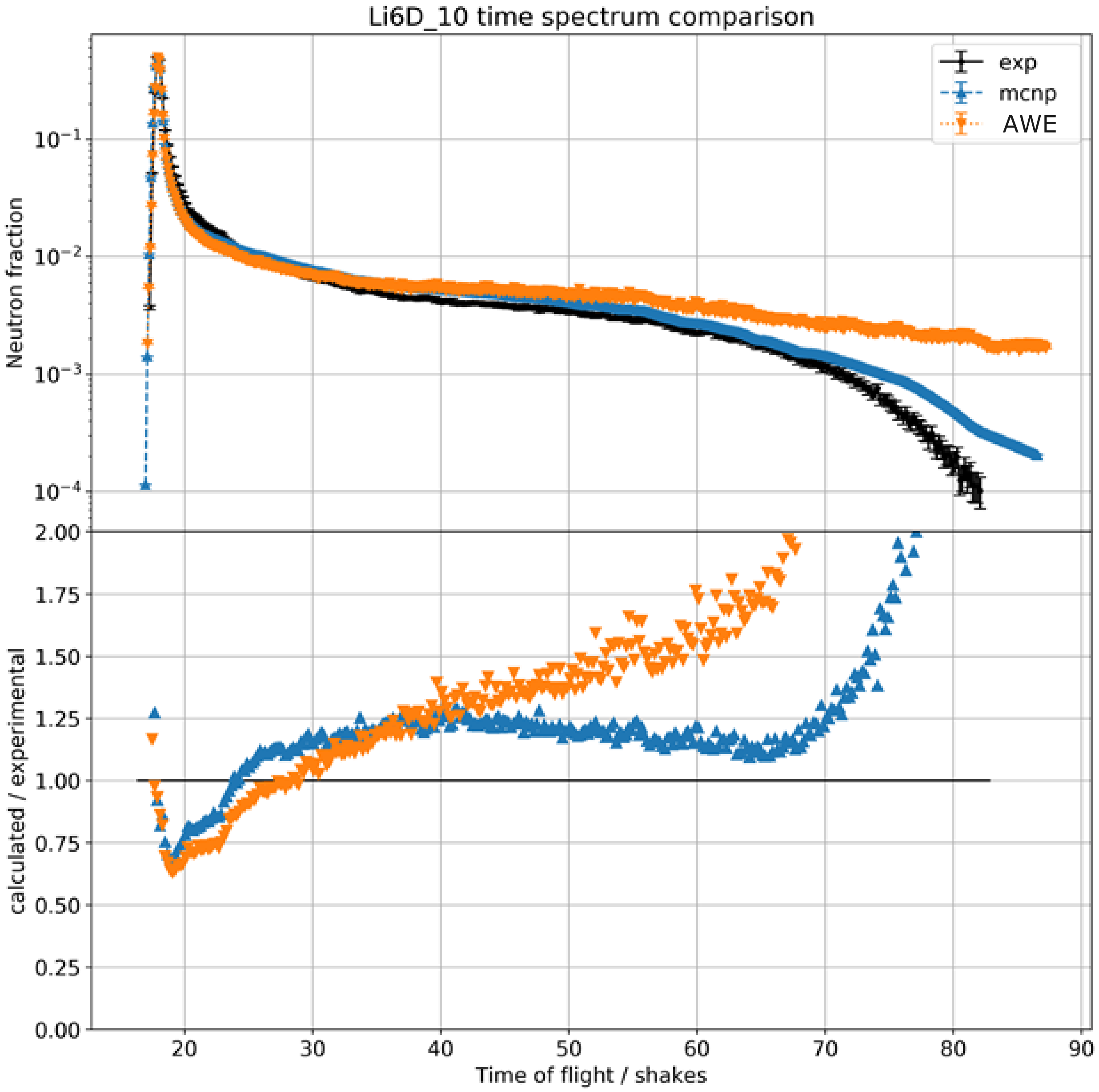
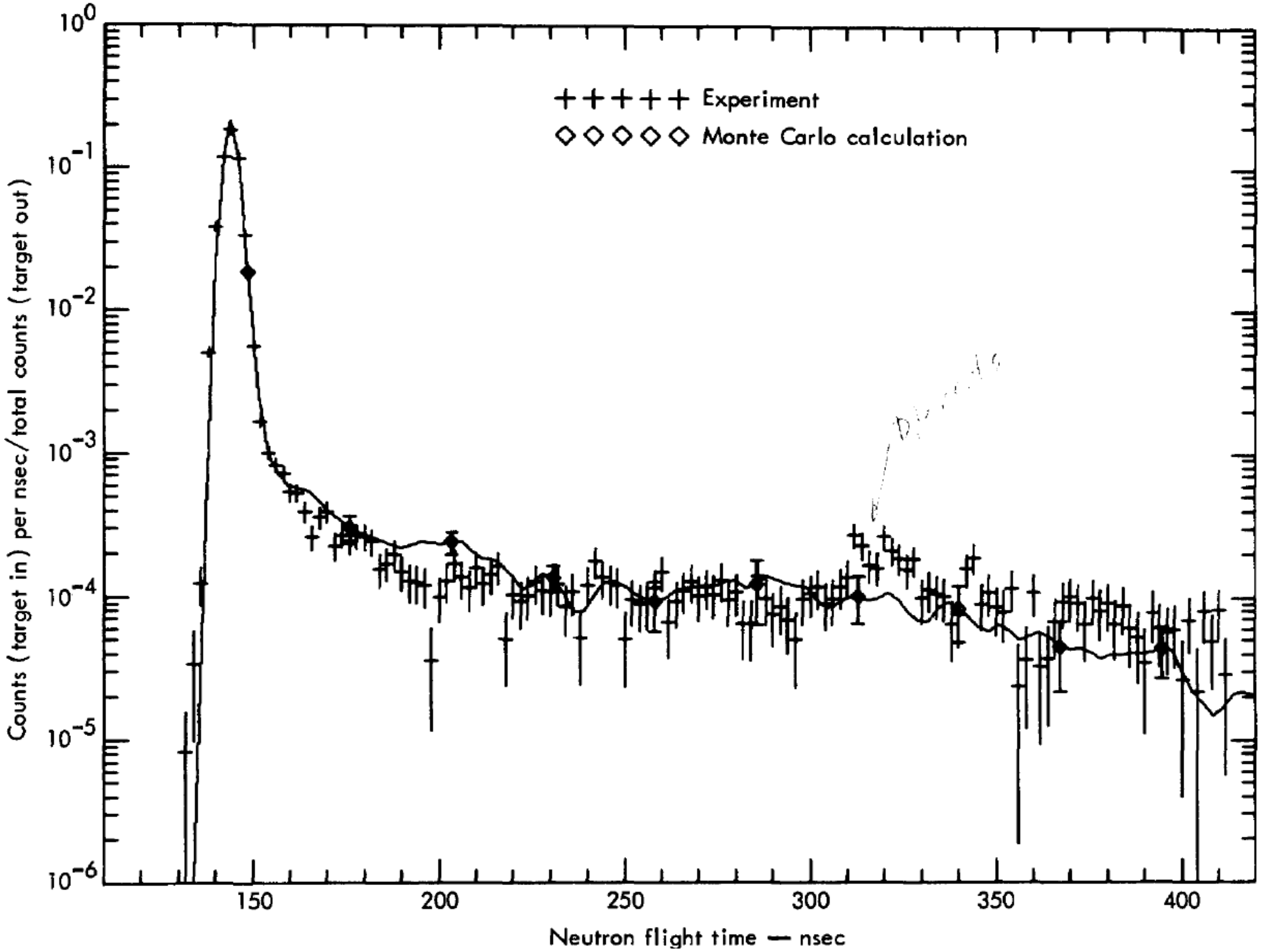


Pulsed spheres

- We do not anticipate the differences in the source definition to be the cause of the most significant differences between the codes.
- The AWE modelled versions are lacking background interference from room return, and use a simple approximation of the collimator (effectively a zero importance region). Some of the MCNP models are much older and also missing backgrounds.
- While both codes are using the same neutron interaction data, differences/bugs will also exist with the implementation of the scattering laws as described by the ENDF/ACE format

D build-up

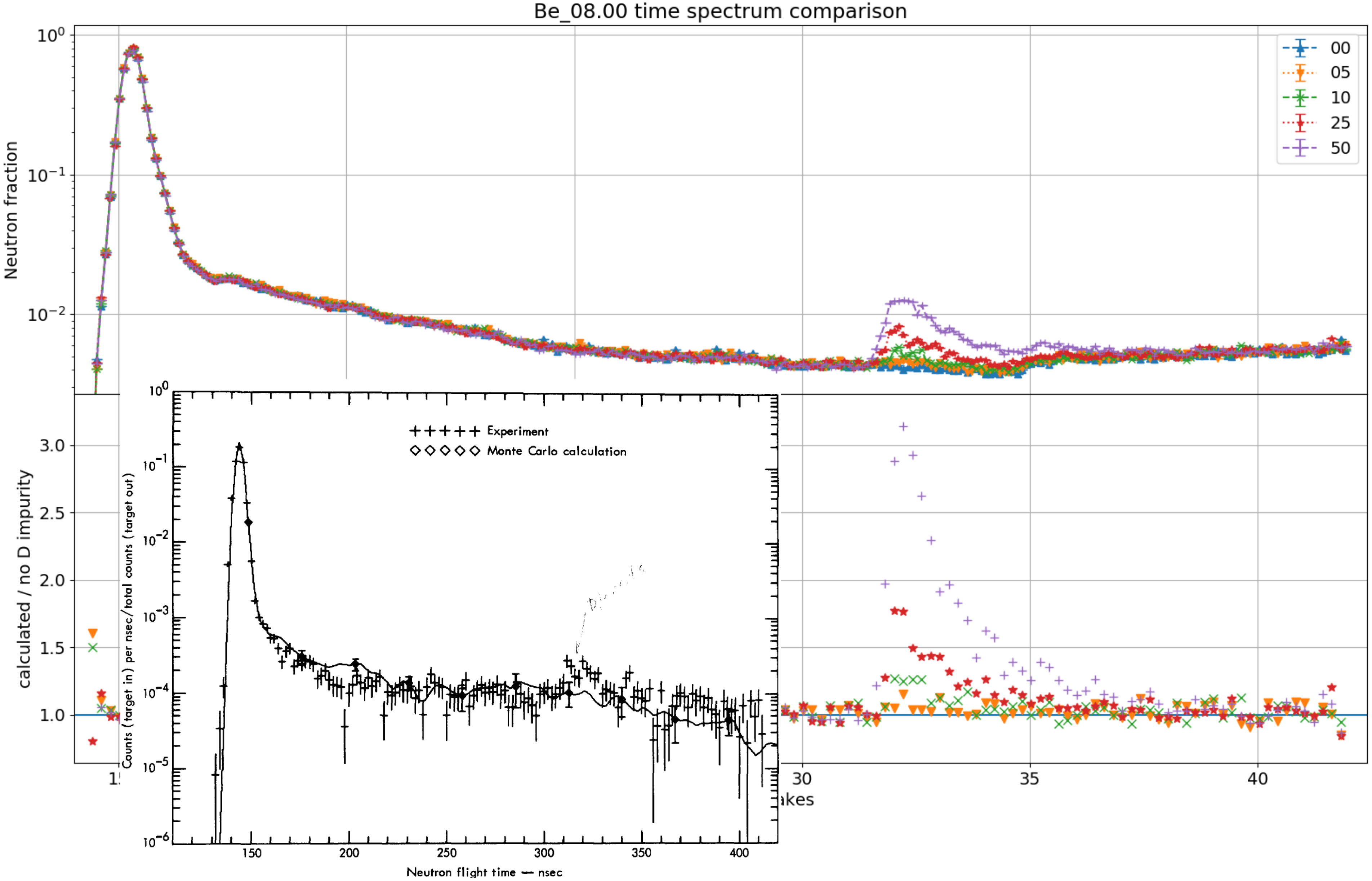
- Many of the experimental data sets feature a peak which correlates to neutrons from DD reactions



C. Wong et al, Livermore pulsed sphere program: program summary through July 1971, 1972, UCRL-51144

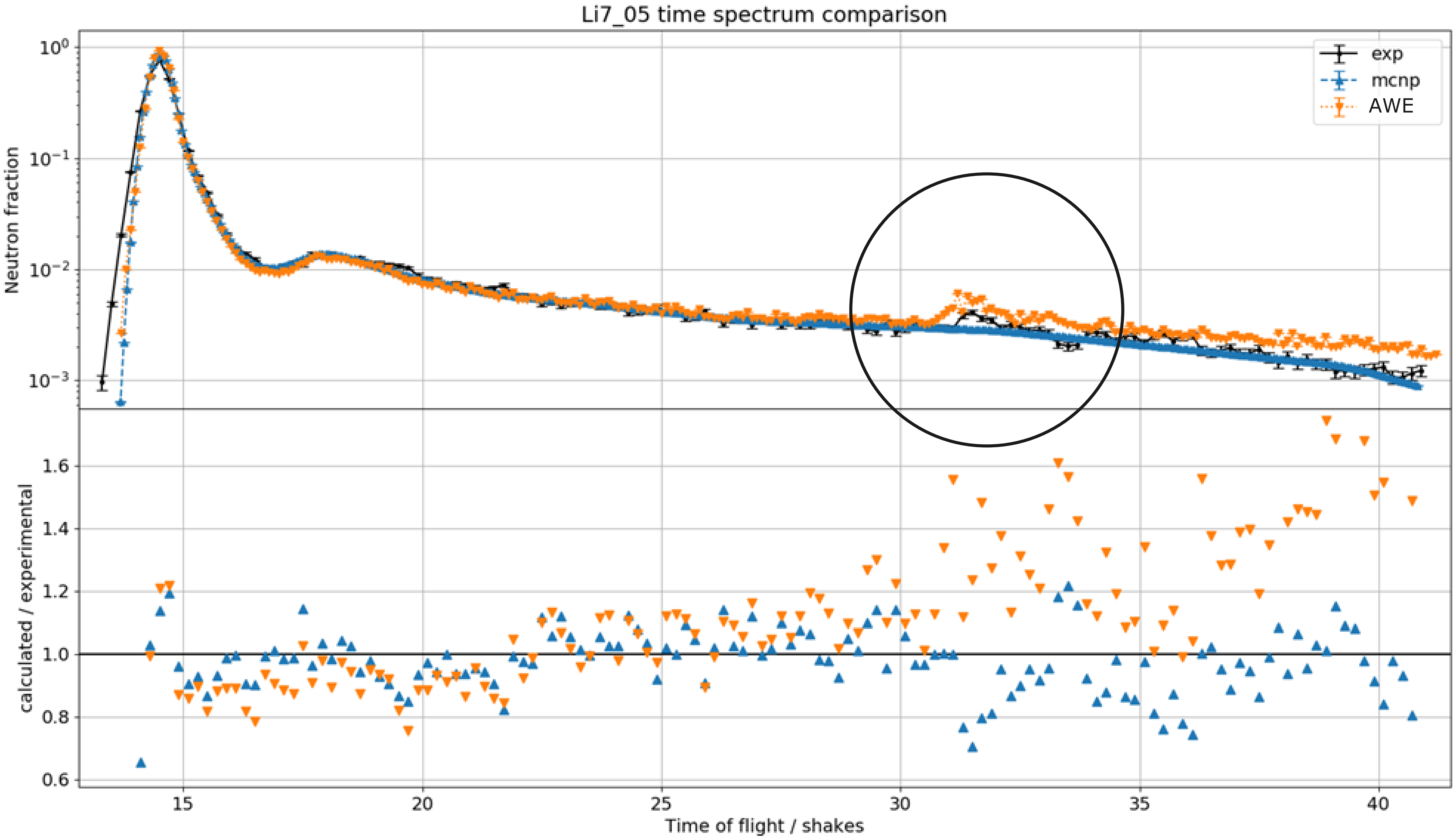
D build-up

- Many of the experimental data sets feature a peak which correlates to neutrons from DD reactions
- Can model the deuteron build up in the target by loading the target with D along with T. Once D concentration reaches approximately 10%, the effect is visible in the time of flight.
- Displacing tritium for deuterium has **no significant impact** to the DT peak (sufficiently saturated in tritium) (NB *I think this was true up to approx. 90% D…)*
- Uncertain on the age of targets used for each experiment. Would be good to know typical D concentrations from a well used target to get an anticipated concentration with age (*Are we expecting D:T ratios of 1:100 or 100:1!*).



D build-up

- Many of the experimental data sets feature a peak which correlates to neutrons from DD reactions
- Can model the deuteron build up in the target by loading the target with D along with T. Once D concentration reaches approximately 10%, the effect is visible.
- Displacing tritium for deuterium has **no significant impact** to the DT peak (sufficiently saturated in tritium) (NB *I think this was true up to approx. 90% D…)*
- Where these upticks appear at DD energies in experimental datasets, possible to load some D to better match these points



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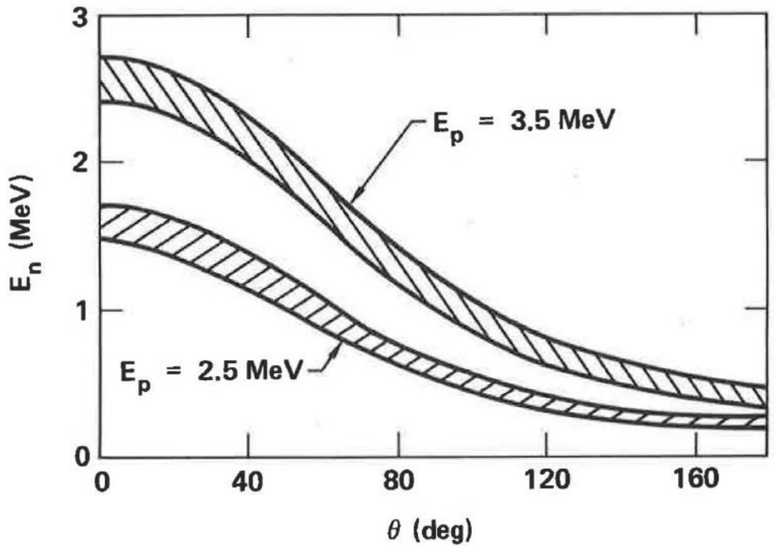
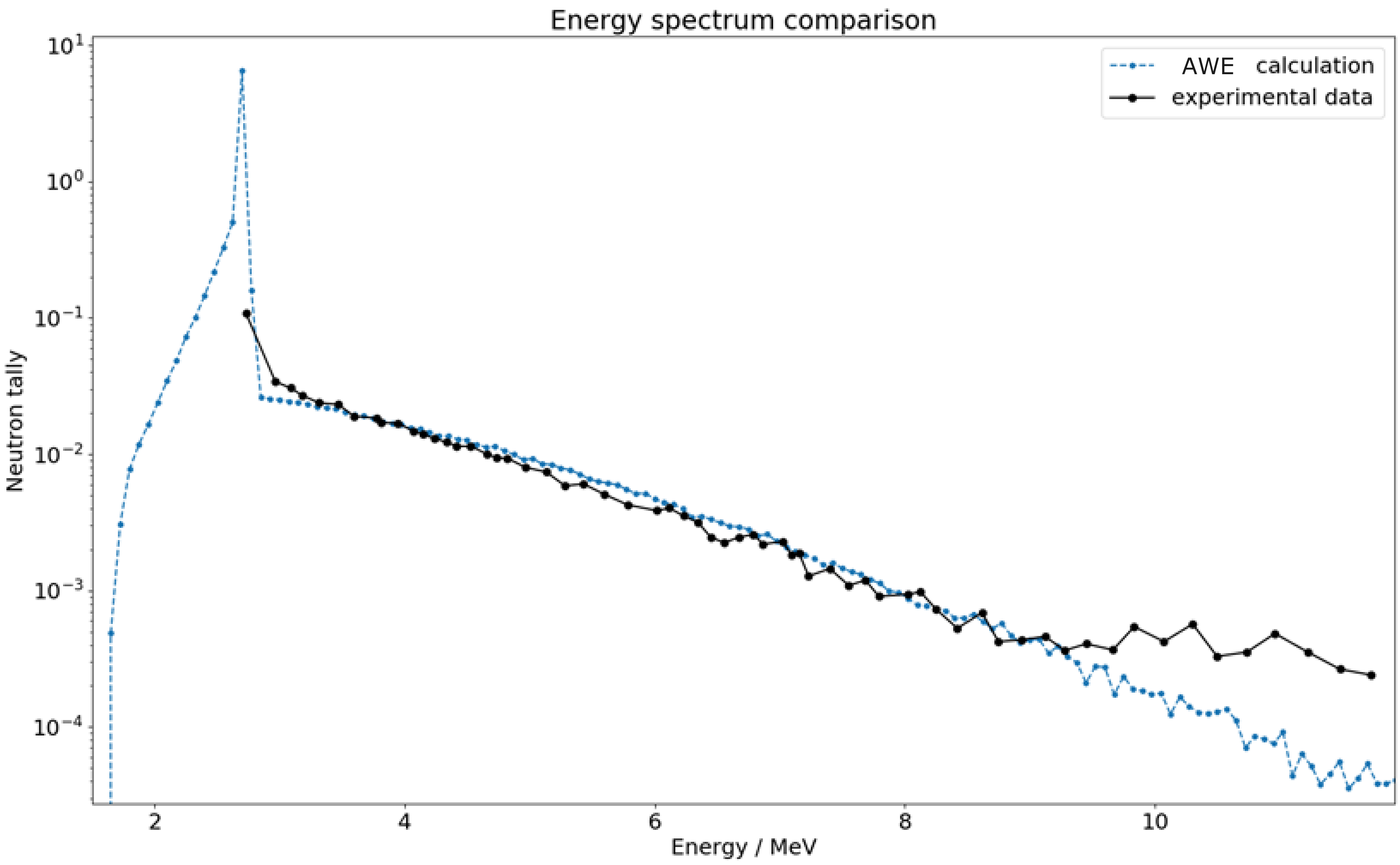
Low energy spheres

- Further similar experiments include proton beams at 2.5 and 3.5 MeV, generating neutrons 0.3-2.7 MeV
- Measuring prompt fission neutron spectra from ^{235}U and ^{239}Pu 0.7 mfp spheres
- ^{235}U inferred experimental energy plotted against calculated energy tally shows a good match
- Limited experimental data available



R.C. Haight et al, The Neutron Emission Spectra from Spheres of U235 and Pu239 pulsed with 0.3-2.7 MeV Neutrons, 1985, UCRL-93591



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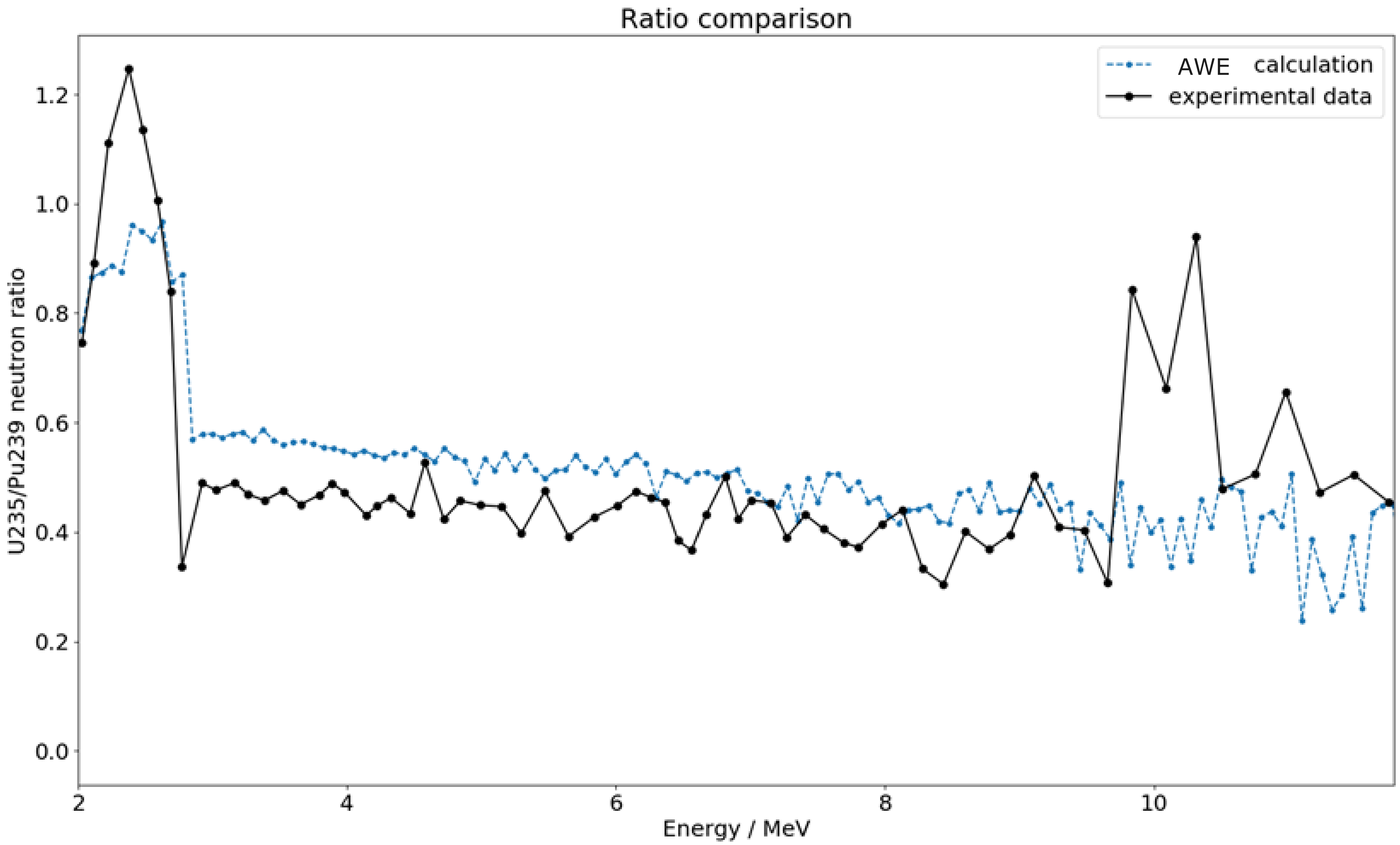
- Measuring prompt fission neutron spectra from ^{235}U and ^{239}Pu 0.7 mfp spheres
- ^{235}U inferred experimental energy plotted against calculated energy tally shows a good match
- Limited experimental data available
- Ratio of U235/Pu239 PFNS was reported
- Calculated U235/Pu239 ratio appears high compared to the reported ratio, but we do not have experimental data for the Pu sphere to compare against

- Good test of other charged particle data



Future work

- This work has been very useful for testing the CPT capabilities in a Monte Carlo transport code (many bugs…). Also a test of the CP induced data in ENDF/B-VIII.0. Unlike critical assemblies, we have limited benchmarks to test this data on.
- 3D environment, would allow us to set up the full emplacement and collimator. Would also allow for modelling of LANL “Wyman spheres” with asymmetrically placed ampules. Would like to set this up to model other accelerator driven experiments and compare against other codes.
- Take the source as generated by CPT and replace the imposed source in MCNP – does the difference in calculated source show any difference?
- Speed up. These models are not fast. The CPT takes a long time, about 90% of the run time! When running with 10M particles, MCNP takes 20 seconds, CPT takes 16 hours!

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