Neutron Detectors for Stawell Underground Physics Lab

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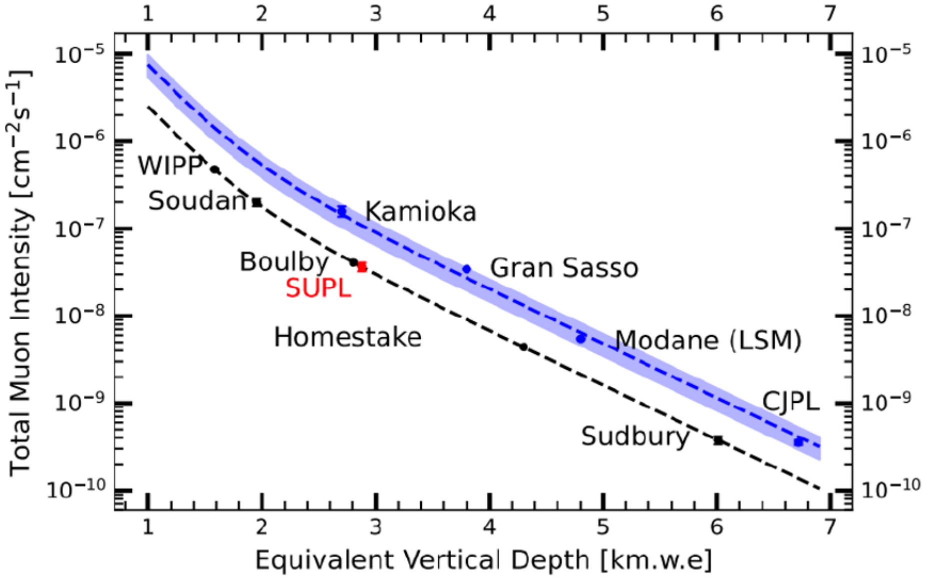
In This Talk:

- Stawell Underground Physics Laboratory
- Background neutrons and their impact on ultra-sensitive physics experiments
- Our Neutron Detector System

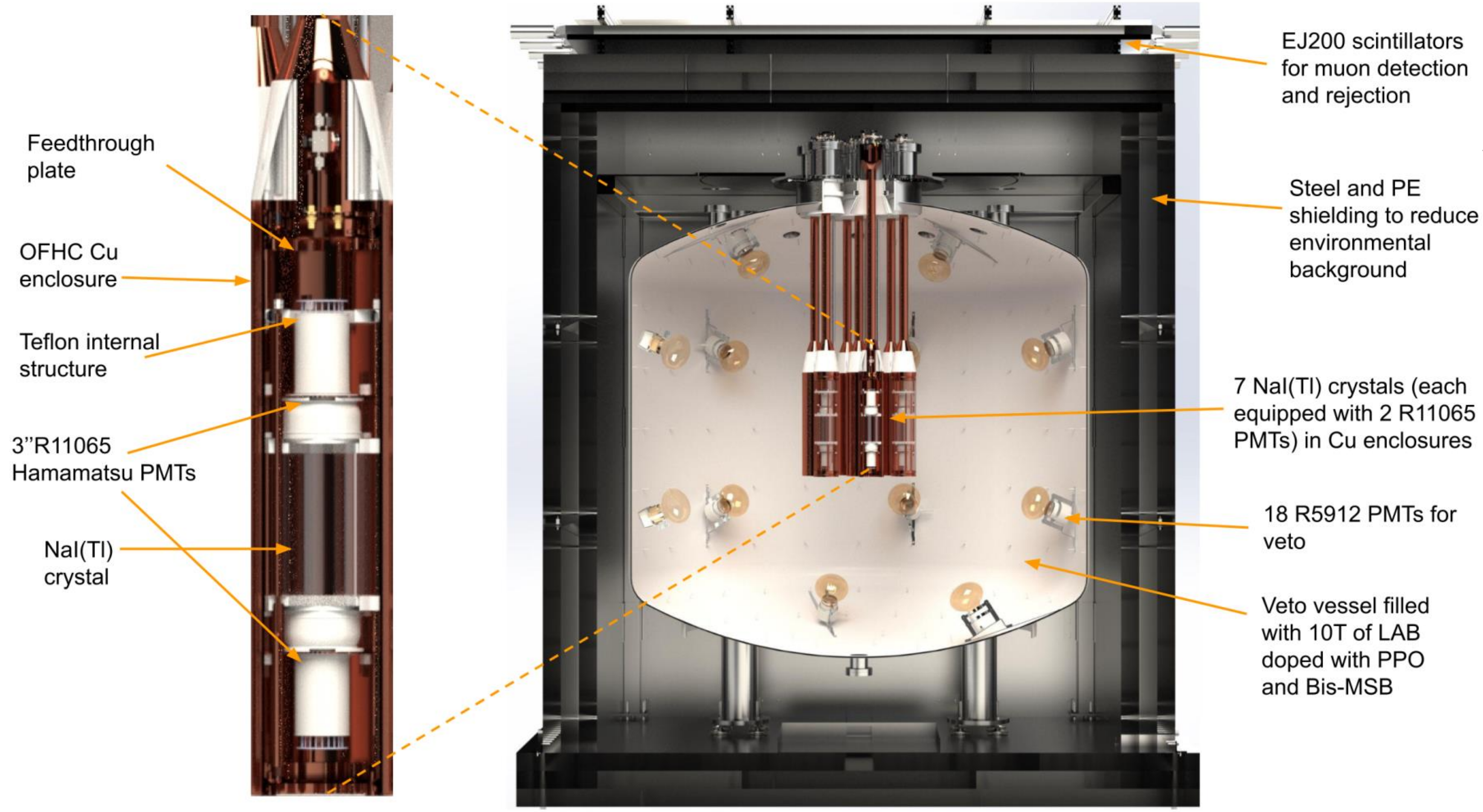
Stawell Underground Physics Laboratory

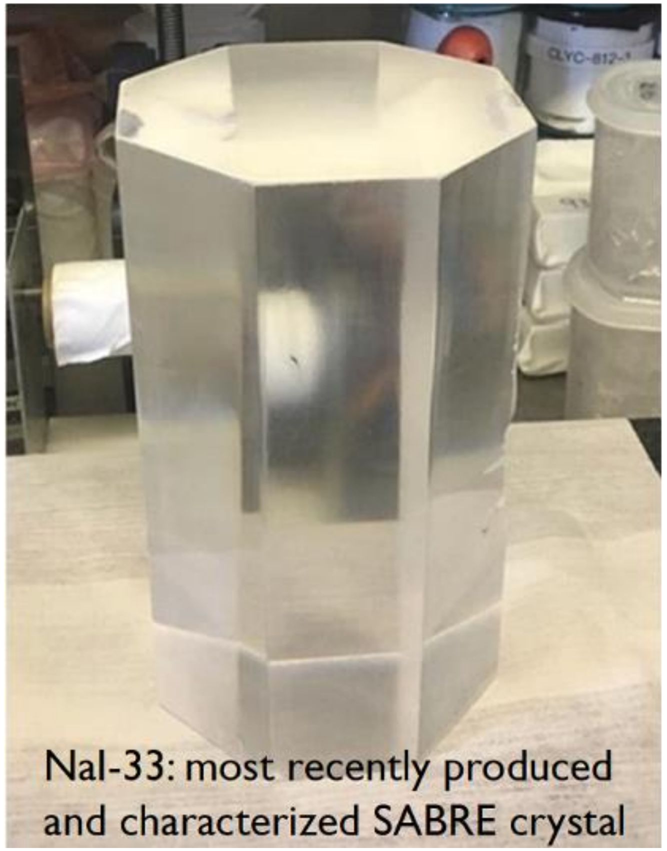
Stawell Underground Physics Lab

- SUPL is the first underground physics laboratory in the Southern Hemisphere.
- The lab is located 1km underground within the Stawell Gold Mine.
- The initial construction of the lab is completed. SABRE South will be the first experiment in the lab, to be assembled in 2024-25.



SABRE South Detector




NaI-33: most recently produced and characterized SABRE crystal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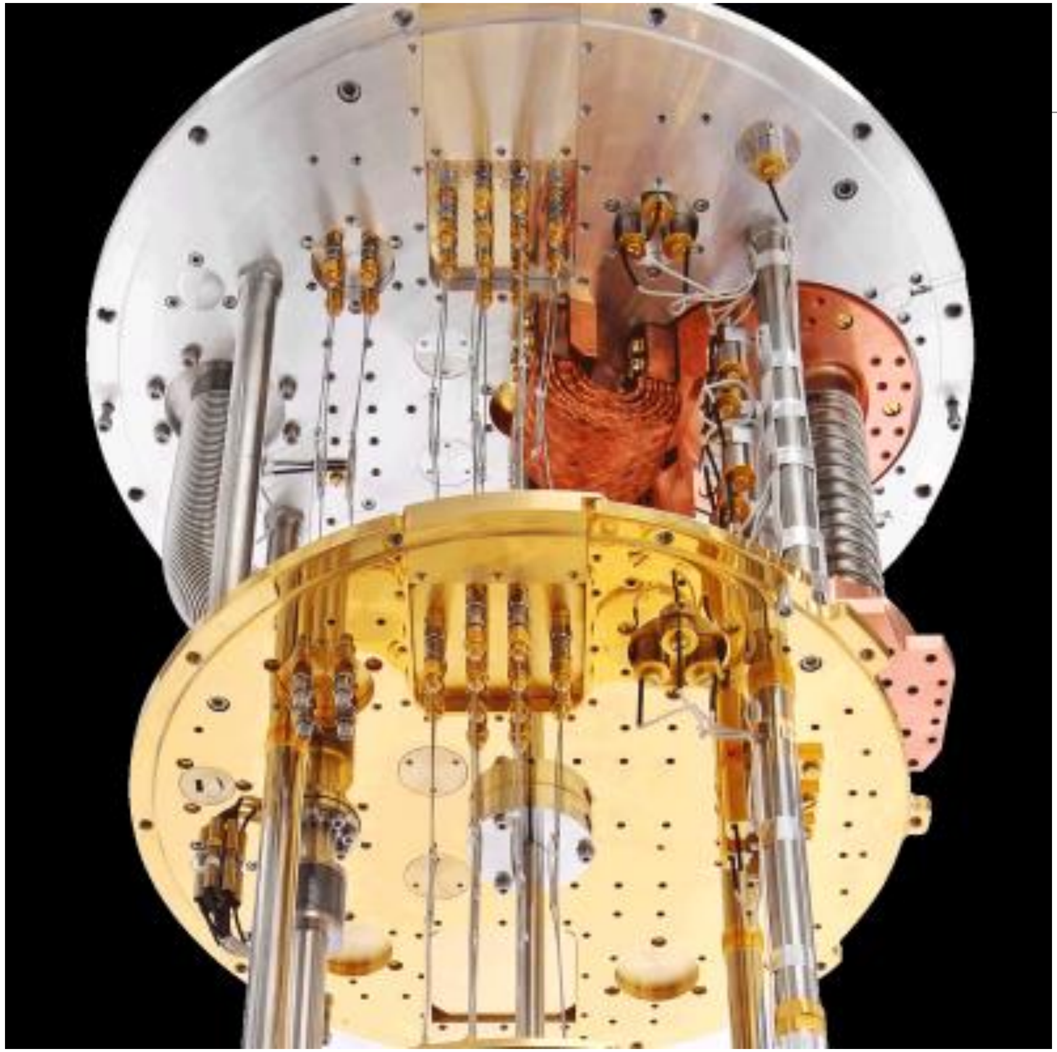
CELLAR - Cryogenic Experimental Laboratory for Low-background Australian Research



- ARC Center of Excellence for Engineered Quantum Systems (EQUS) to purchase and install a dilution refrigerator in SUPL.
- The fridge will allow the unique opportunity to host experiments in both ultra low-background and ultra low-temperature.
- A second fridge at Swinburne allows for comparative measurements and prototyping.

Image: bluefors.com

Background Neutron Sources

- Neutrons cause events in detectors via nuclear recoils or nuclear activation.
- (α,n) reactions from Uranium decay chains.
- Spontaneous fission of heavy elements (U238) in the surrounding rock.
- Cosmogenic activation considered to be negligible in underground labs.

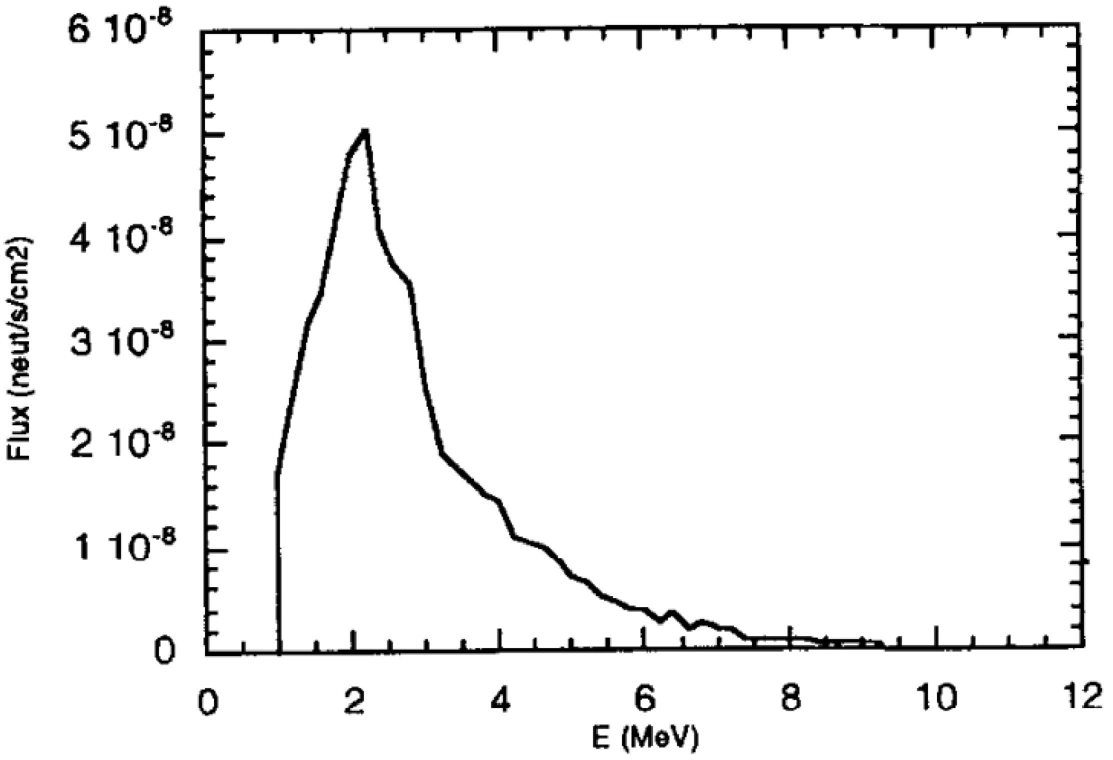


Fig. 13. Simulation of the neutron spectrum in the Modane Underground laboratory above 1 MeV.

V. Chazal et al. Astroparticle Physics 1998
https://doi.org/10.1016/S0927-6505(98)00012-7

Experiment Backgrounds

- Preliminary measurements by SABRE Collaboration estimate the background neutron flux at SUPL $3 \cdot 10^{-5} cm^{-2}\ s^{-1}$ and a fast neutron flux $7 \cdot 10^{-6} cm^{-2}\ s^{-1}$
- This leads to a background contribution for the SABRE experiment of less than 0.1%.
- Other experiments may be more impacted, SABRE has advanced shielding and veto system. (Eg an unshielded SABRE crystal would have 10s of neutron events per day)

	Rate [cpd/kg/keV$_{ee}$]	Veto Efficiency [%]
Crystal radiogenic	$5.2 \cdot 10^{-1}$	13
Crystal cosmogenic	$1.6 \cdot 10^{-1}$	40
Crystal PMTs	$3.8 \cdot 10^{-2}$	60
PTFE wrap	$4.5 \cdot 10^{-3}$	13
Enclosures	$3.2 \cdot 10^{-3}$	85
Conduits	$1.9 \cdot 10^{-5}$	96
Liquid scintillator	$4.9 \cdot 10^{-8}$	> 99
Steel vessel	$1.4 \cdot 10^{-5}$	> 99
Veto PMTs	$1.9 \cdot 10^{-5}$	> 99
Shielding	$3.9 \cdot 10^{-6}$	> 99
External	$O(10^{-4})$	> 99
Total	$7.2 \cdot 10^{-1}$	27

Table 12 Background rate in the dark matter measurement region for the SABRE South components after a 6 month cool-down period, and the corresponding veto efficiency.

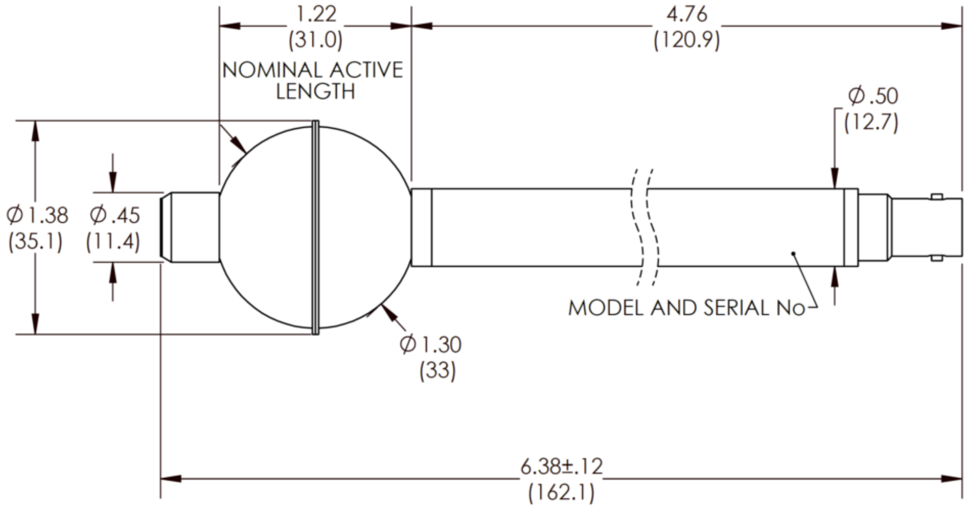
arXiv:2205.13849

He-3 Detectors

$$n + {}^{3}_{2}He \rightarrow p + {}^{3}_{1}H + 764\ \text{keV}$$

Chamber of He-3 gas with HV applied. Charge readout via central anode wire. Connected to module with charge sensitive preamp, discriminator, HV supply, etc.

- He-3 pressure: 2 atm
- Efficiency: 8 cps/nv



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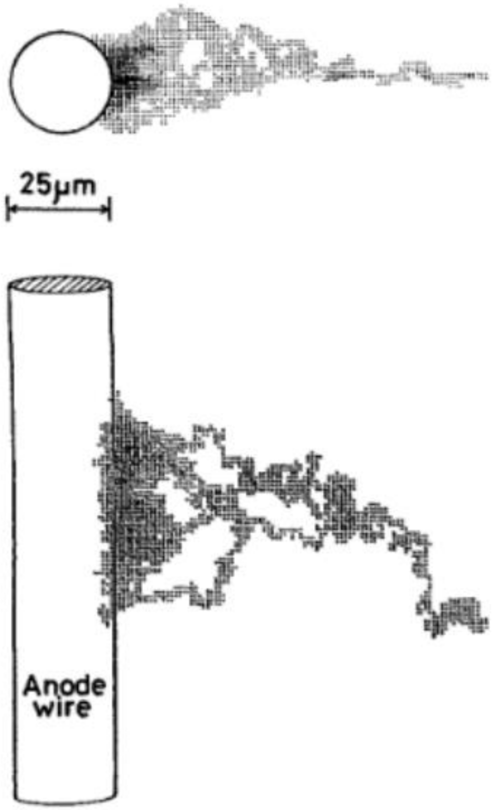


doi: 10.1109/TNS.1985.4336890

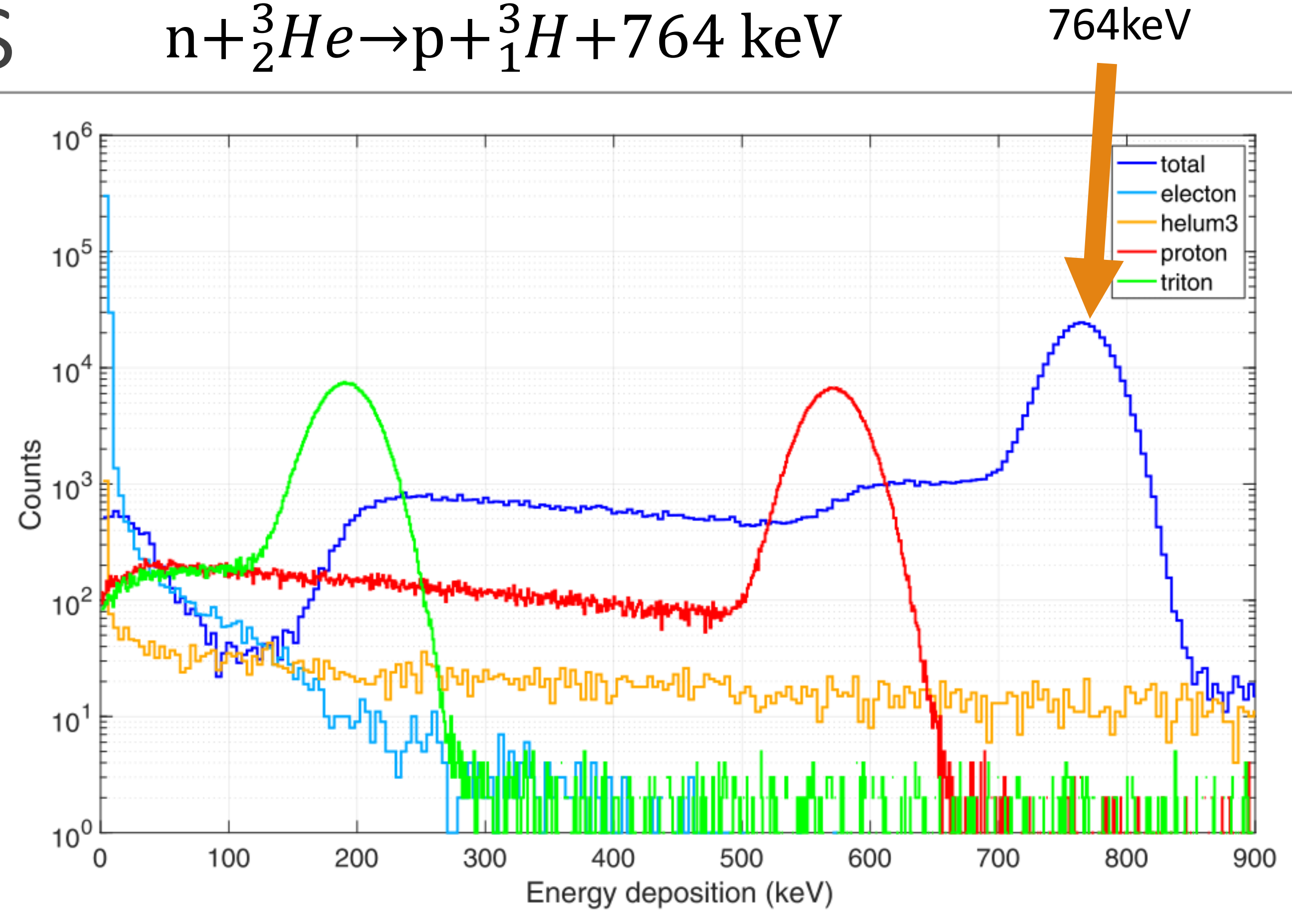
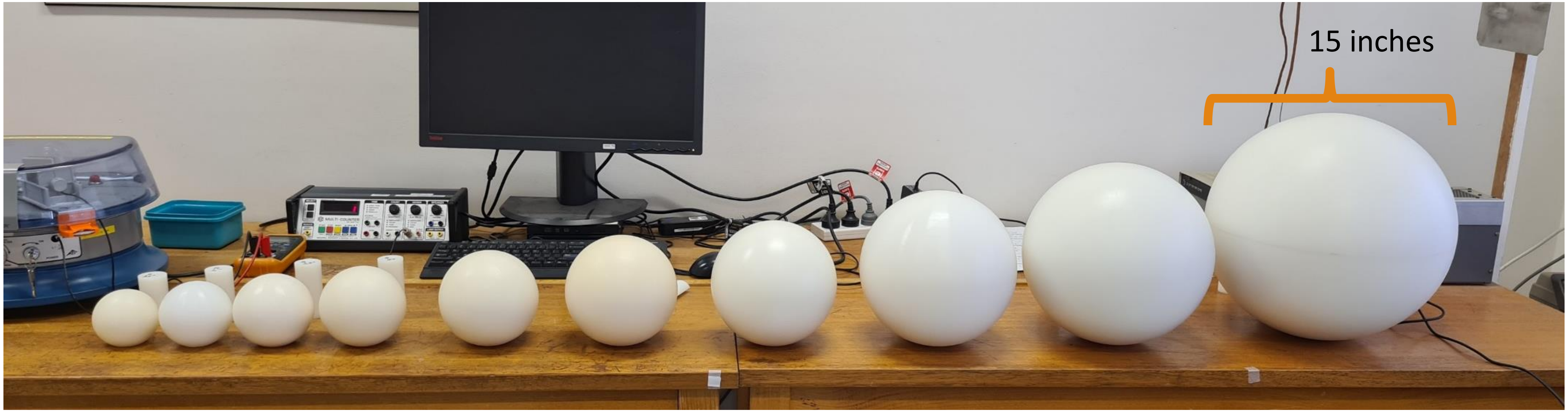


Fig. 5 Simulated energy deposition for the reaction products in configuration (ThermN)

arXiv:1902.09870

Bonner Spheres



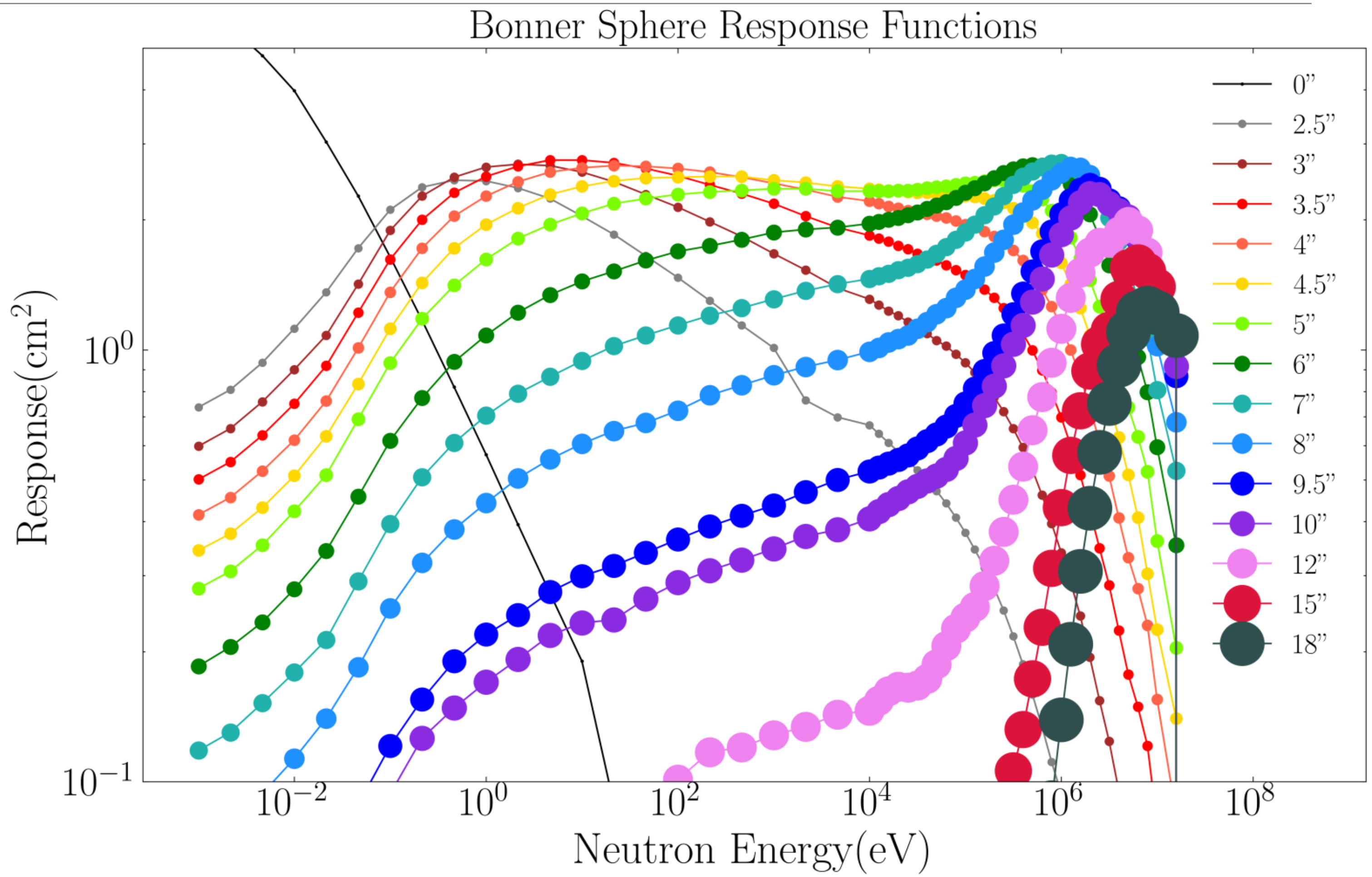
- Twelve polyethylene spheres with diameters ranging from 3 to 18 inches (3.5-15 inch pictured).
- Moderate higher energy neutrons down to thermal (low ~eV) energies for He-3 Detectors.

Response Functions

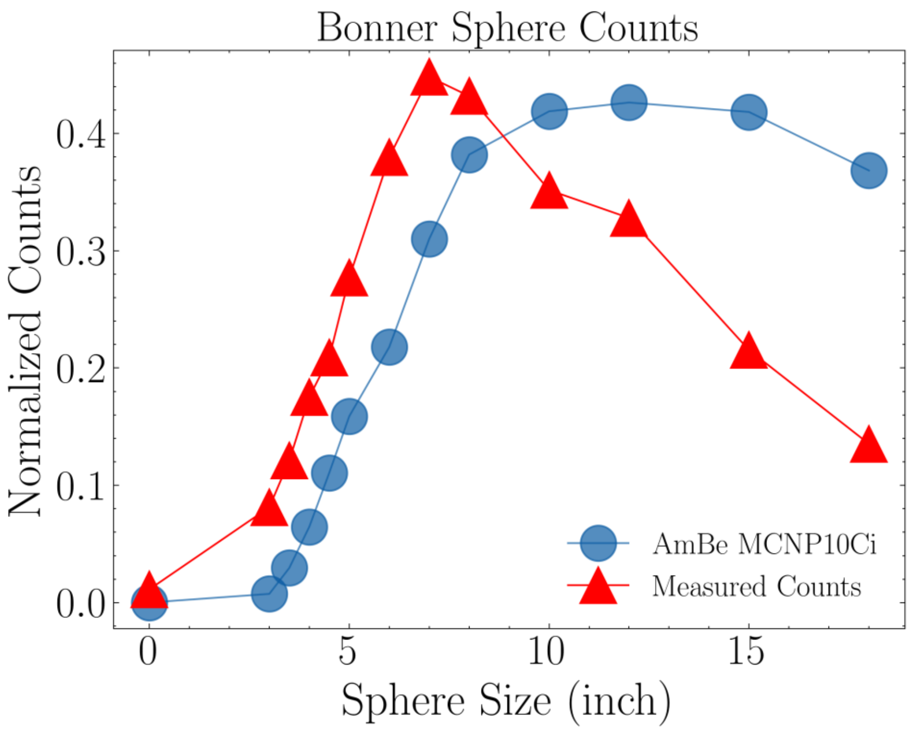
Express response of each sphere as an area.

Relates the count rate (Z) in each sphere to the neutron flux ($\Phi(E)$).

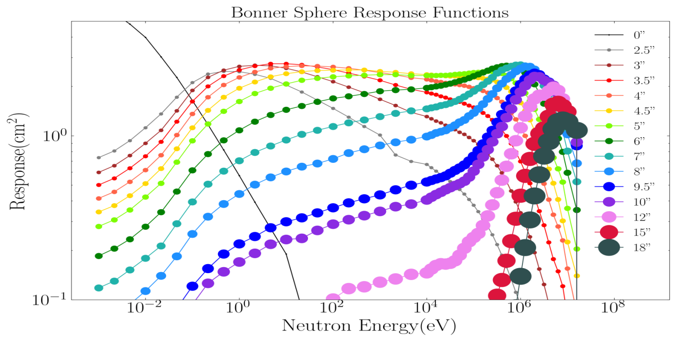
$$Z_i = \int dE\, \Phi(E) R_i(E)$$



Unfolding



Forward Folding



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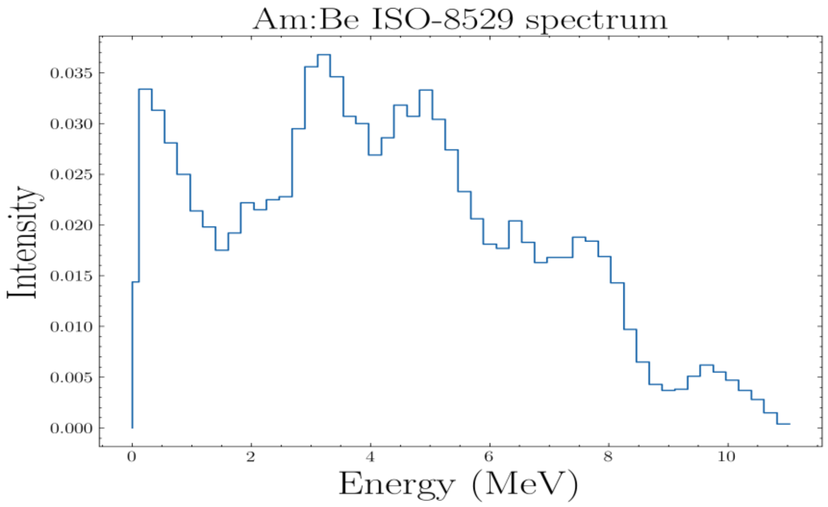
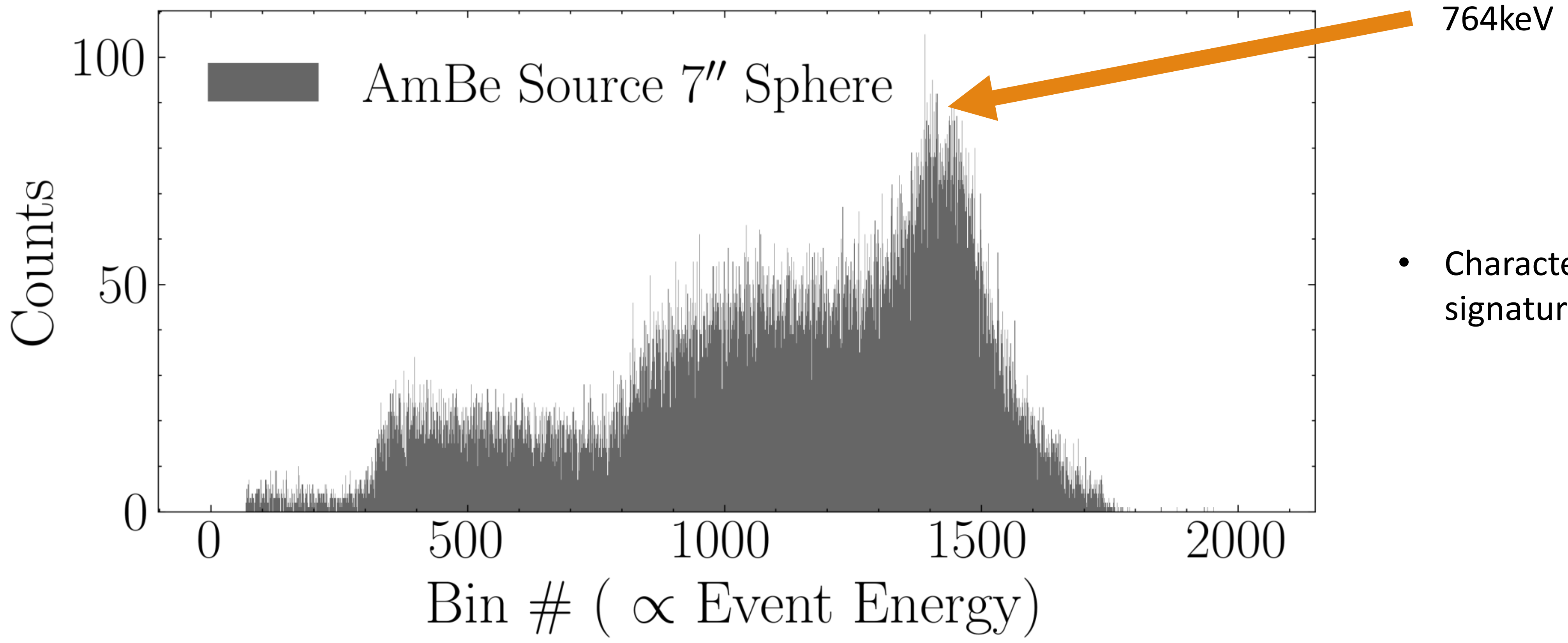


- Use minimizer with estimation of SUPL background as prior and regularization conditions.
- Finds local minimum.

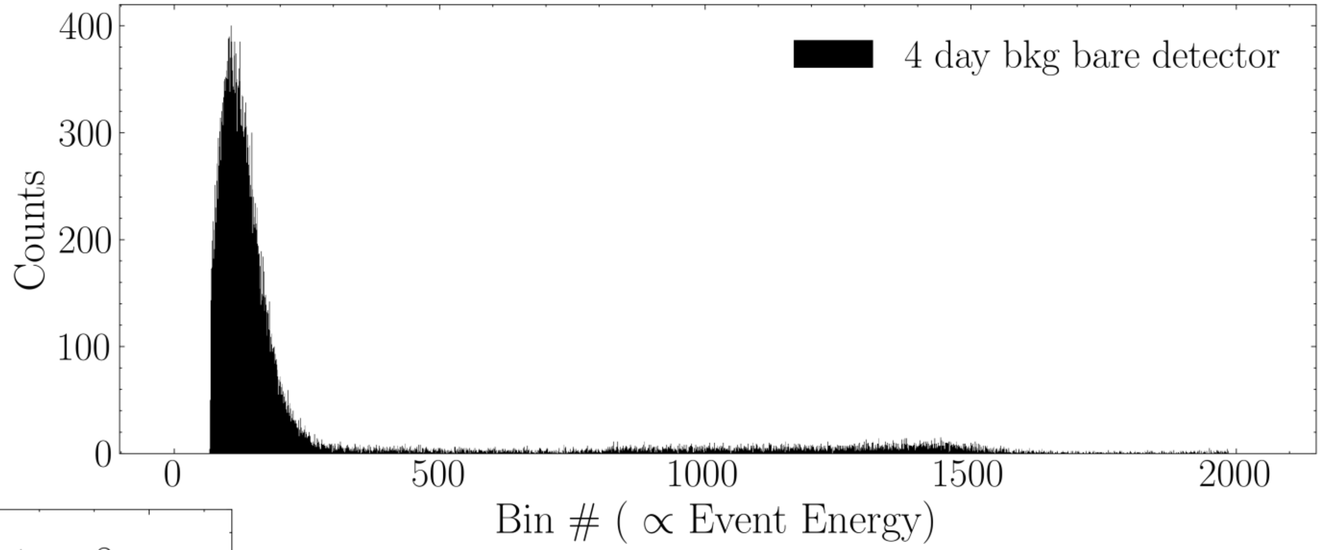
- MCMC for improving fit

Calibration: 241AmBe

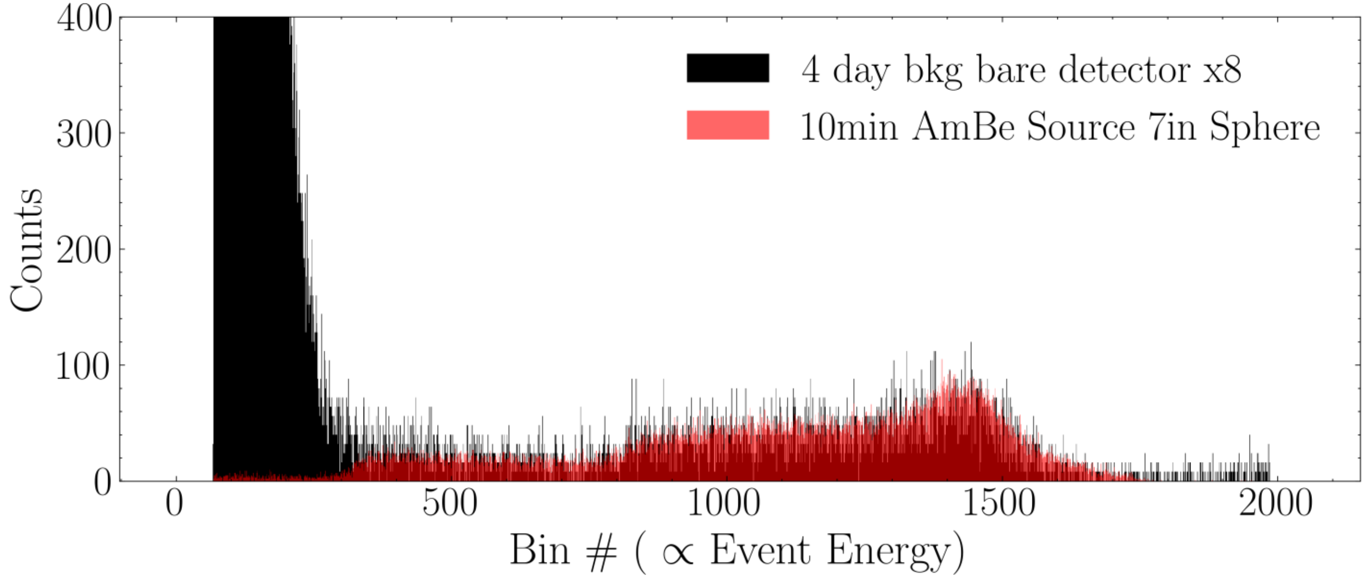


- Characteristic thermal neutron signature clearly visible.

Calibration: Surface Lab (background)



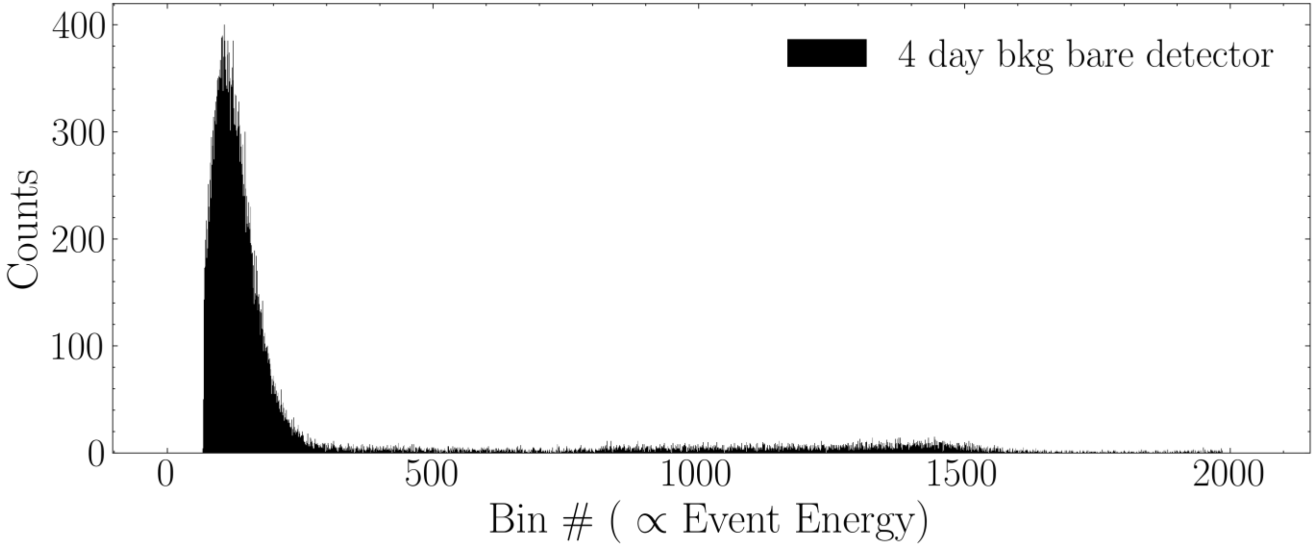
- Gammas are dominant
- ~1000 neutrons per day

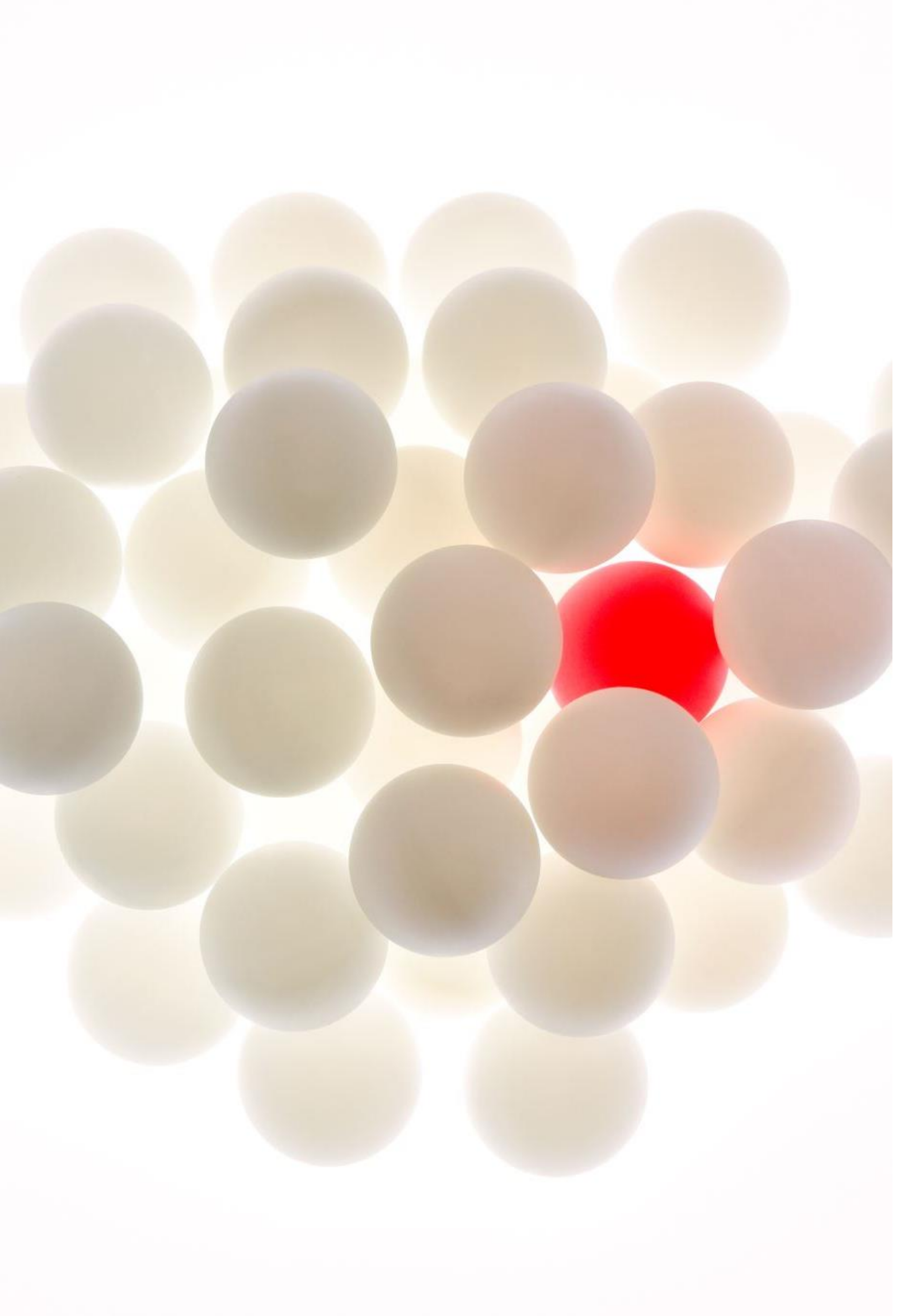


- Overlap between neutrons and gammas visible at low energies.
- High energy background visible.
- Background reduction important because rates in SUPL expected to be 2-10 neutrons per day!

Detector Backgrounds – Low Event Rate

- Expected event rate in SUPL is in the order of 10 counts per day per detector.
- Require 100s of counts in each sphere for statistically significant data -> multiple months data taking.
- At low event rate internal background of detectors can become significant. Alpha emissions from detector walls.





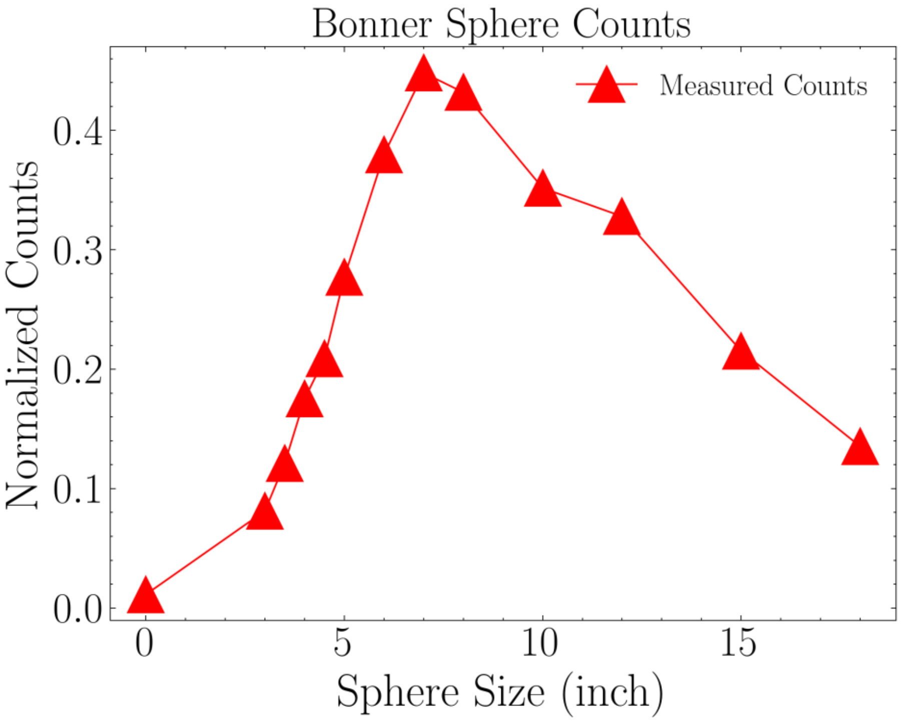
Conclusion

- Bonner sphere neutron detector system to be deployed at SUPL.
- It will provide detailed neutron background data for planned and ongoing high sensitivity experiments.

END

Works in Progress

Unfolding



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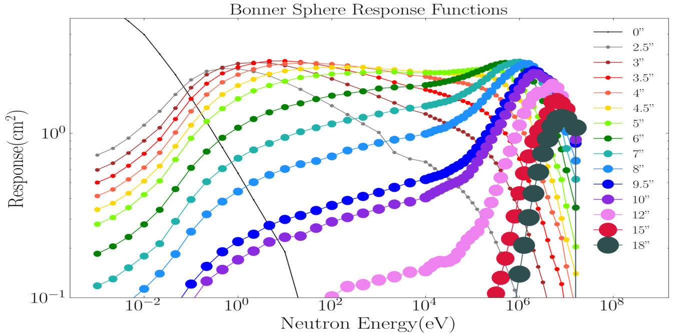
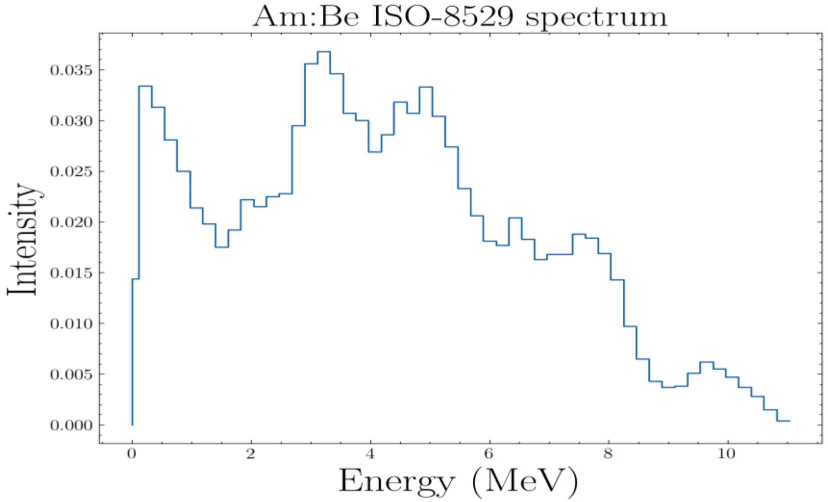


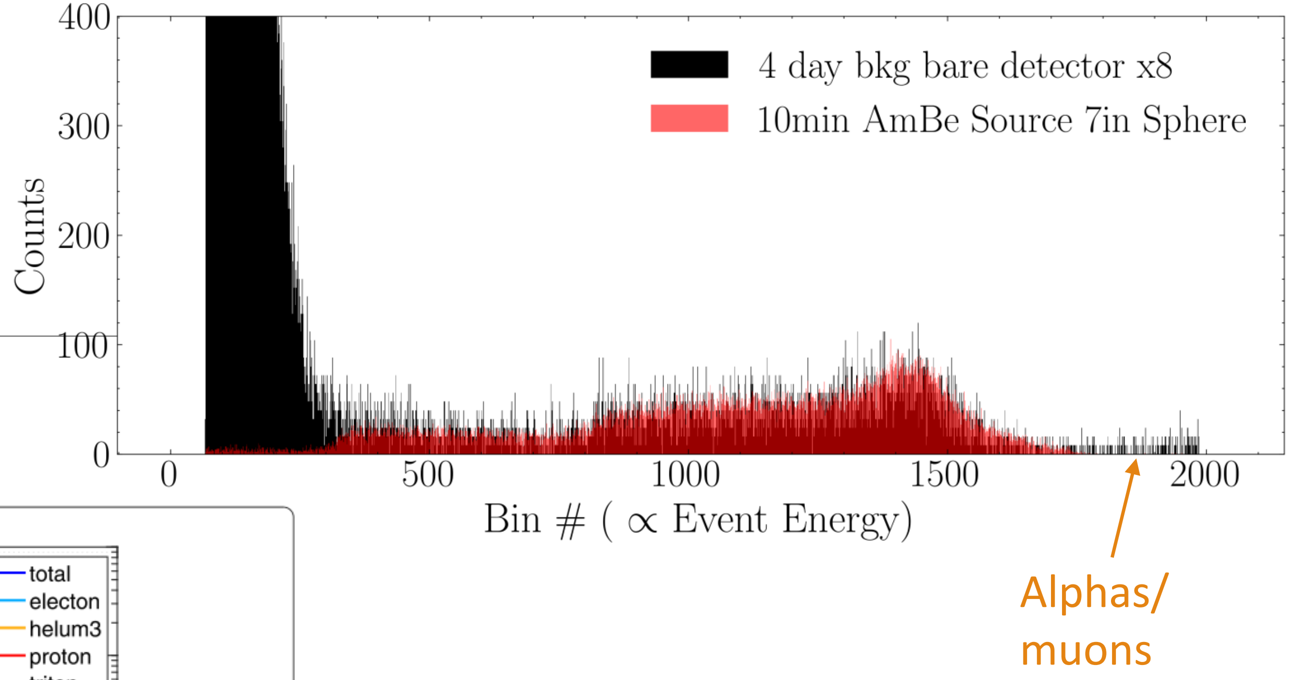
$$Z_i = \int dE\ \Phi(E) R_i(E)$$

Unfolding



- MCMC for improving fit

Data Cleaning – Energy Cuts



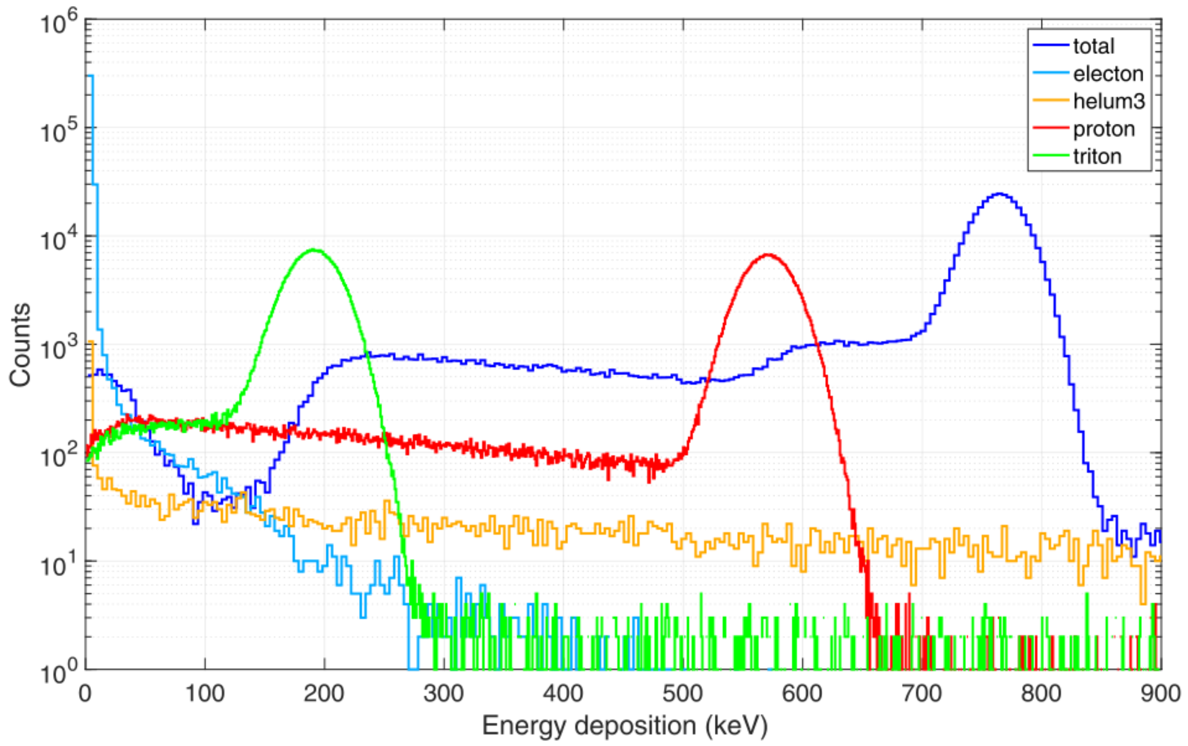


Fig. 5 Simulated energy deposition for the reaction products in configuration (ThermN)

- Single energy cut where gammas become dominant is simplest solution.
- Better would be to fit for the neutron signal to account for neutrons in gamma energy region.

Data Cleaning – Pulse Shape Cuts

- Recording pulse shapes can allow event ID.
- Electrons are captured faster than positive ions -> fast rise times associated with gamma events.
- Motivates use of digitiser over simple pulse height analysis.