Initial Steps for Understanding The STEREO Experiment

Relevant Papers links:

https://arxiv.org/2111.01519

https://arxiv.org/abs/1804.09052

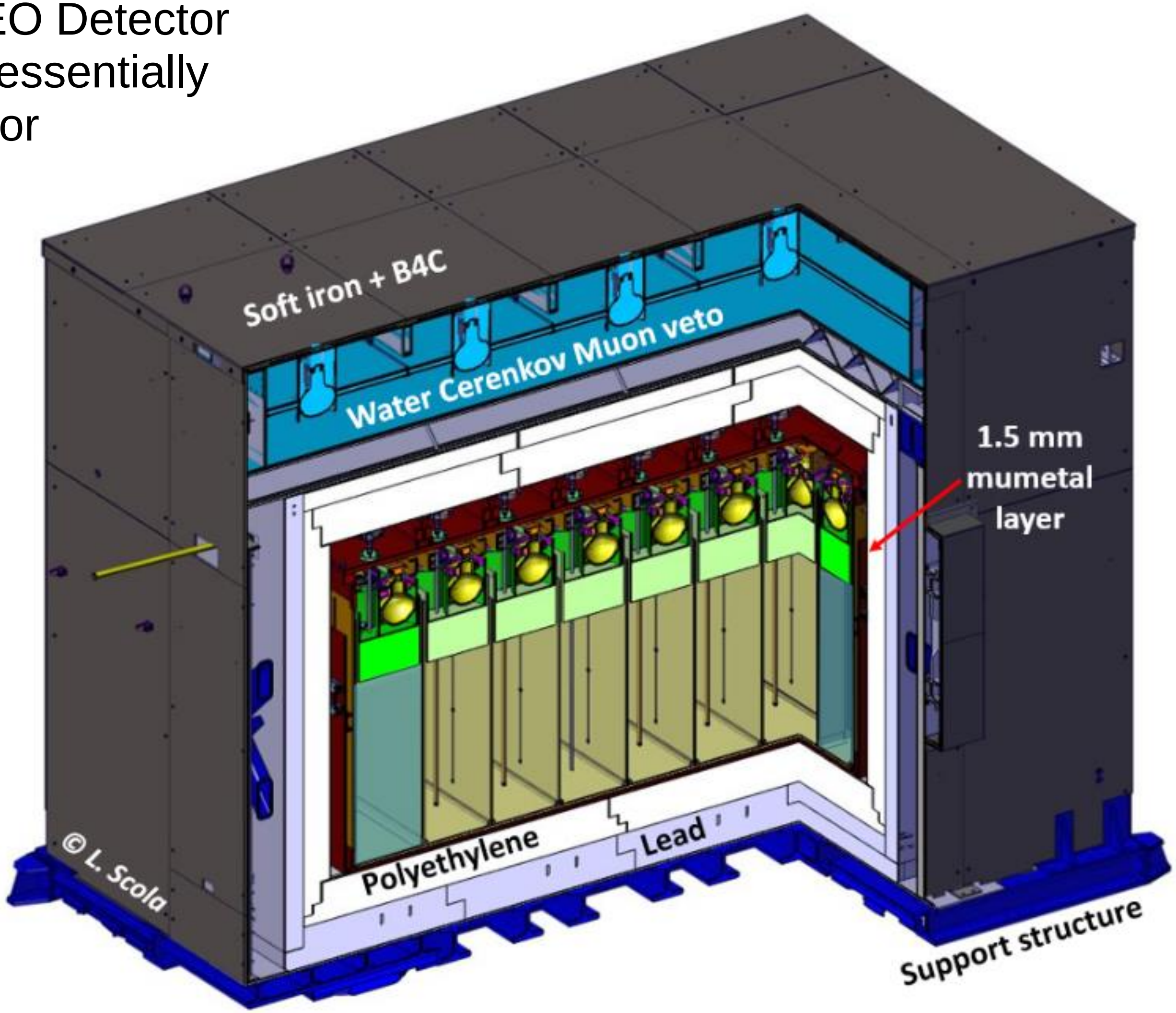
https://publications.anl.gov/anlpubs/2010/08/67595.pdf

Cary Rock / UT

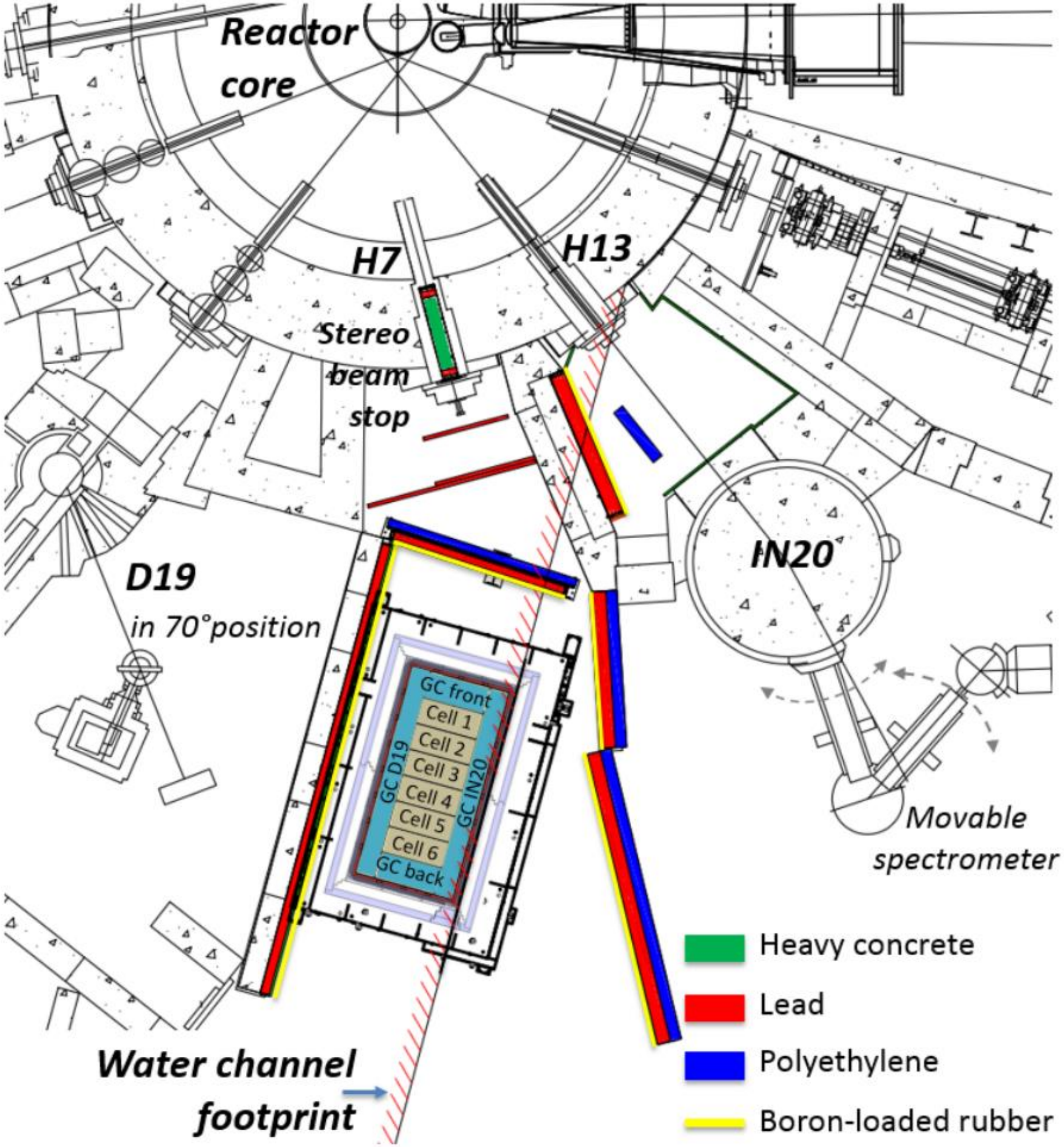
7/12/2022

UTK/ORNL Group Meeting

Neutrino STEREO Detector
at ILL reactor is essentially
a neutron detector



[3] Allemandou et al



[3] Allemandou et al

STEREO search for $n \rightarrow n'$

- Result of UT-ORNL group search [1]:

  $p < 5.5 \times 10^{-8}$, θ ~< 10^{-3} for mixing, for mass splitting be ~60 neV (Δm)

- Results of STEREO [2]:

  $p < 3.1 \times 10^{-11}$, ΔE similar to Δm ($H_{11=n}$) from neV up to 10 keV

- (is it better limits ?)

- Checking to see if they've done their simulations of the reactor correctly

  – They mention that the maximum effect of the uncertainties is ~20% between a more-detailed and a less-detailed simulation

- Next UT/ORNL SNS 2020 data publication I assume should address the comparison with STERO data.

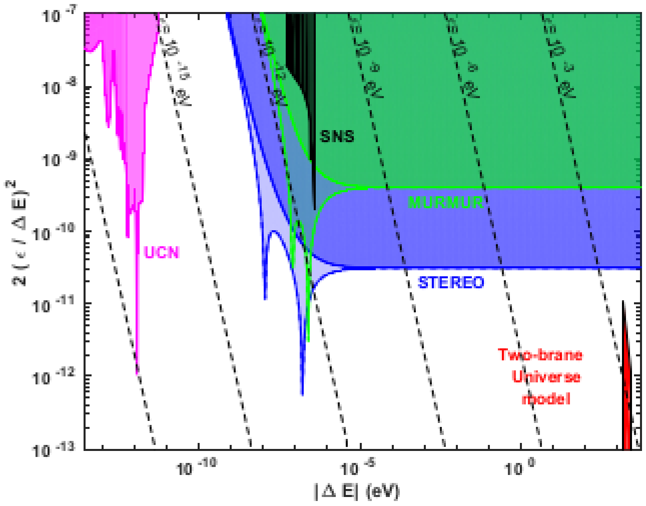
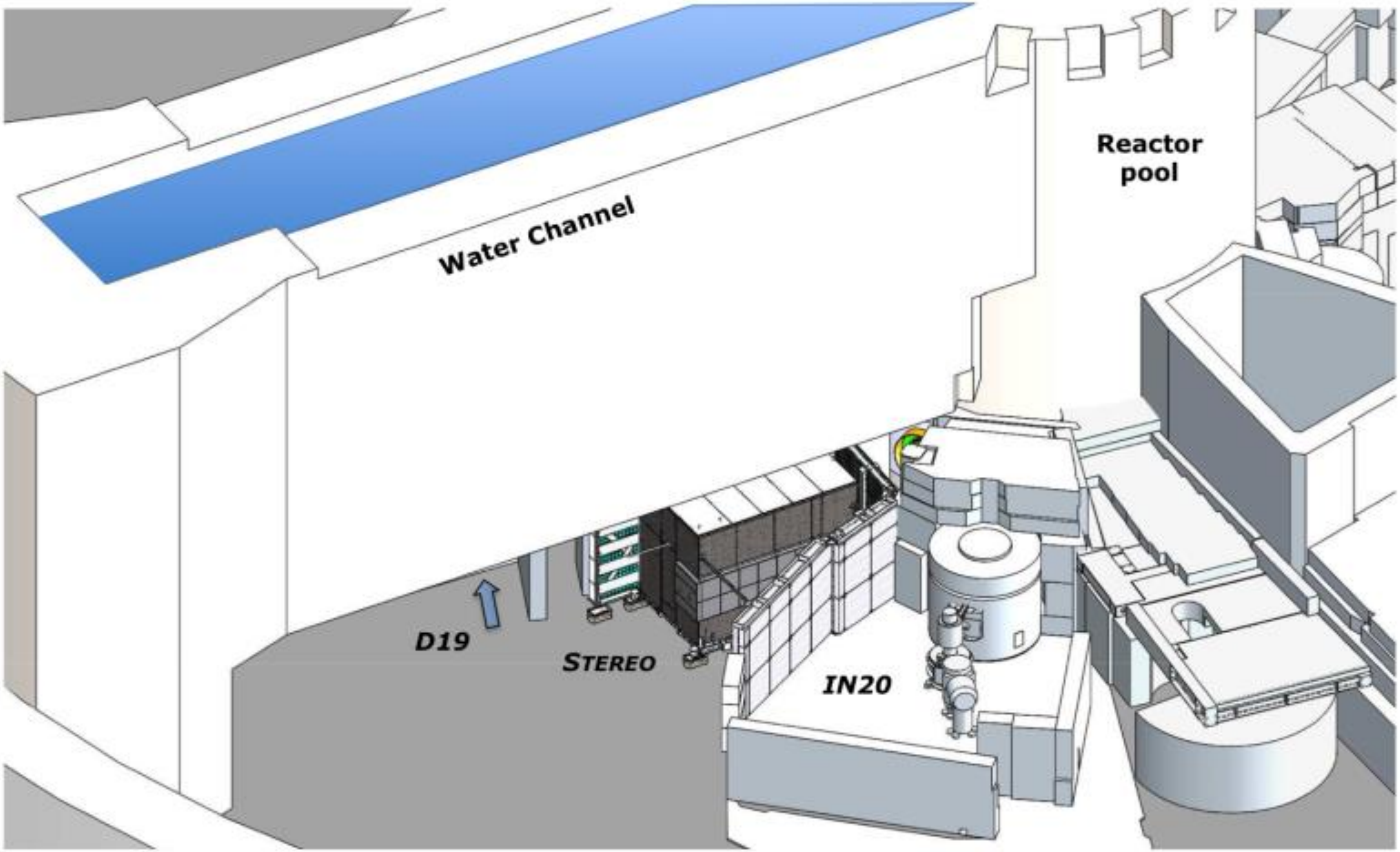


FIG. 3. Exclusion contour from STEREO (blue), MURMUR (green), ultra cold neutrons experiments (magenta) and cold neutron experiment at SNS (black). The dark (light) green and blue contours correspond to the $\Delta E > 0$ ($\Delta E < 0$) case. The two most sensitive points — $\Delta E = 11$ neV and 167 neV — result from the Fermi potentials of the scintillator and D_2O, respectively. The expected region corresponding to the two-brane universe model is also plotted (red). The ratio $2(\epsilon/\Delta E)^2$ corresponds to the Eq 2 limit for high values of ΔE.



[3] Allemandou et al

ILL Reactor core schematic with heavy water vessel

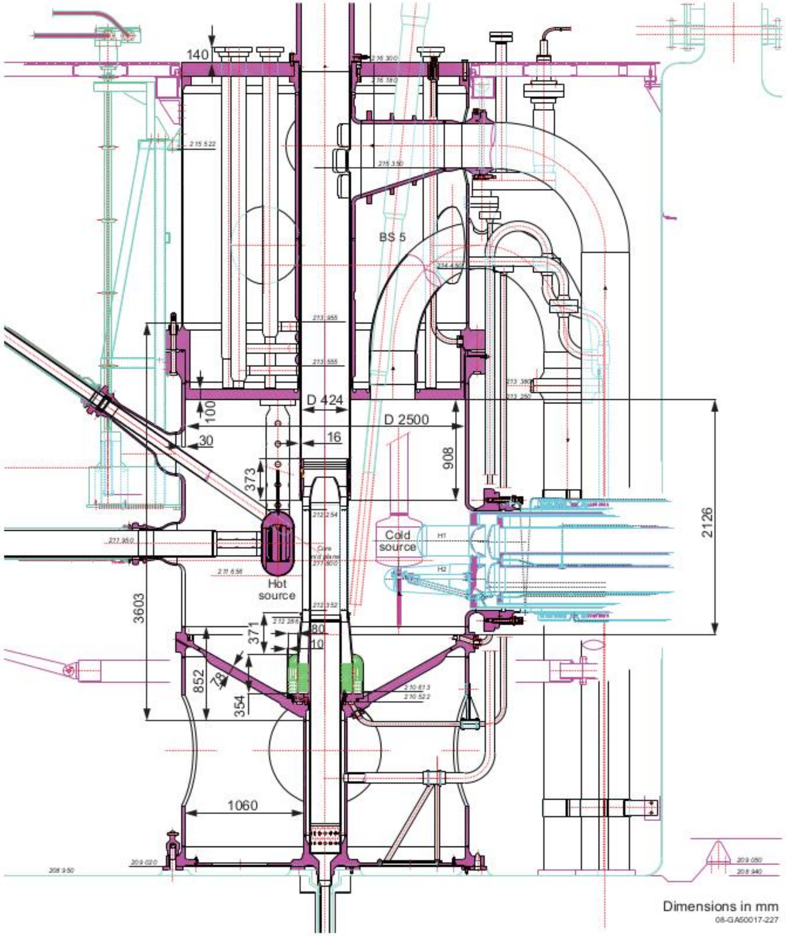
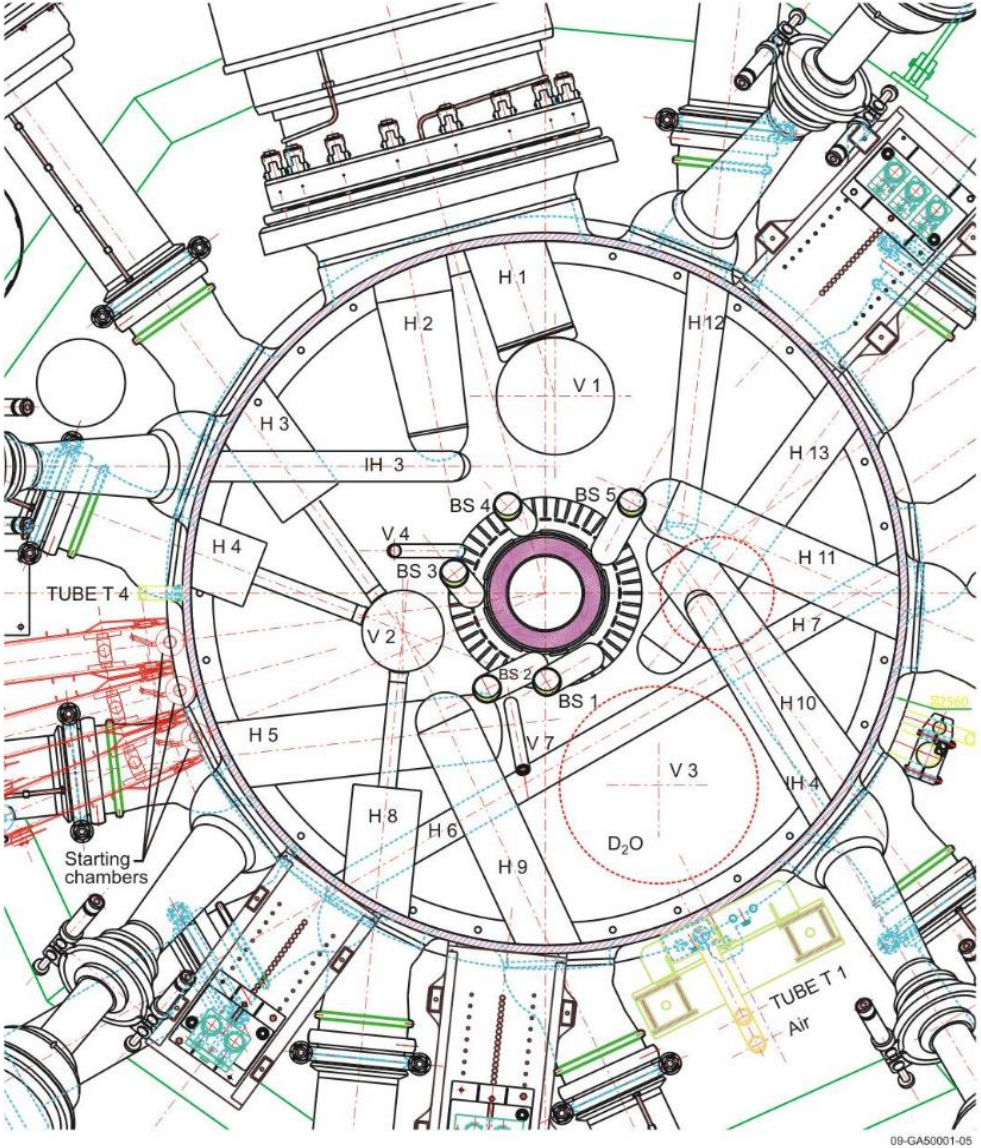


Figure [2.3]: Cross section of the reactor [Ref. 9]

[4] Bergeron et al

Cross-section of ILL reactor with D_2O reflector



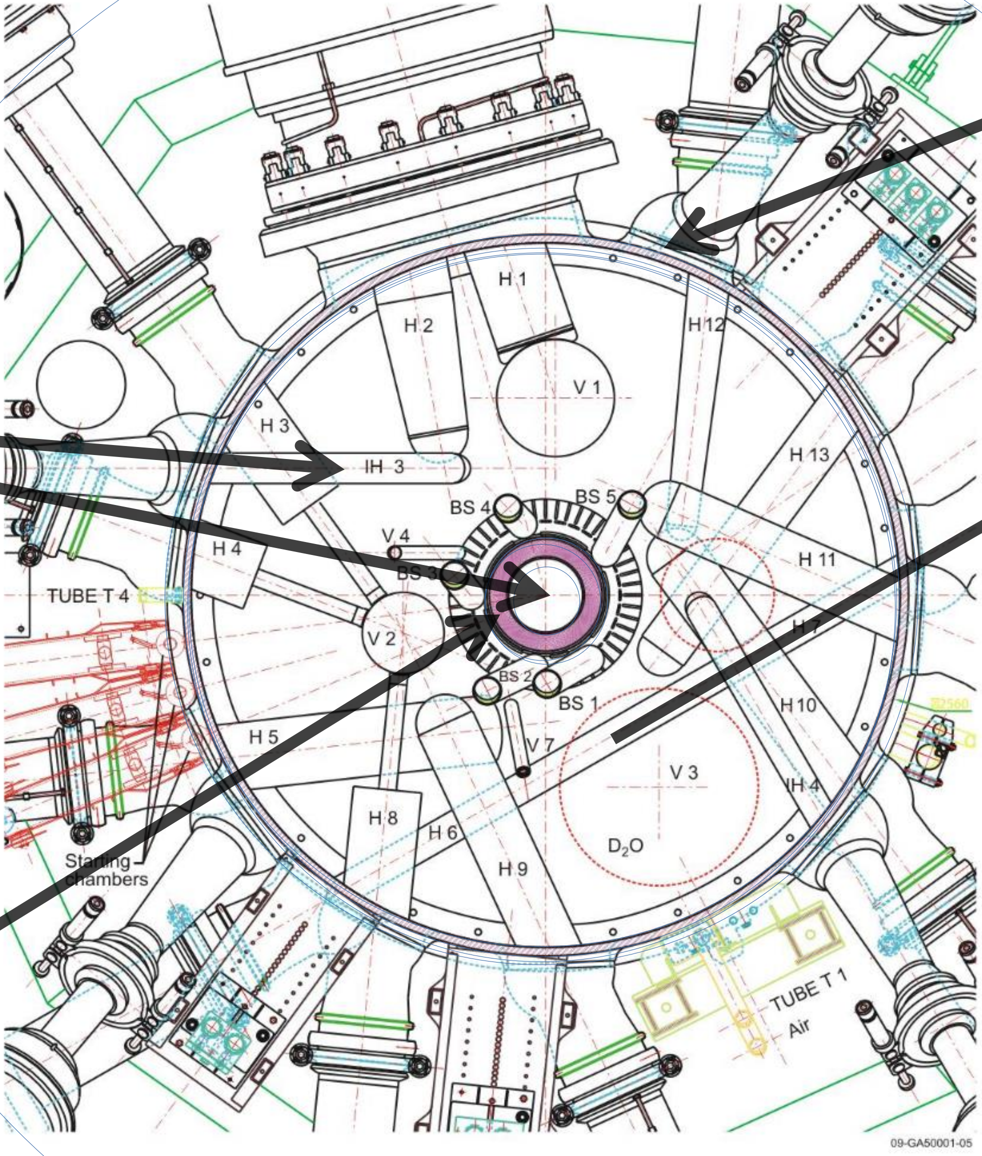
[4] Bergeron et al

Cross-section of ILL reactor with D_2O reflector

Aluminum D_2O Vessel

To STEREO Detector

D_2O Moderator

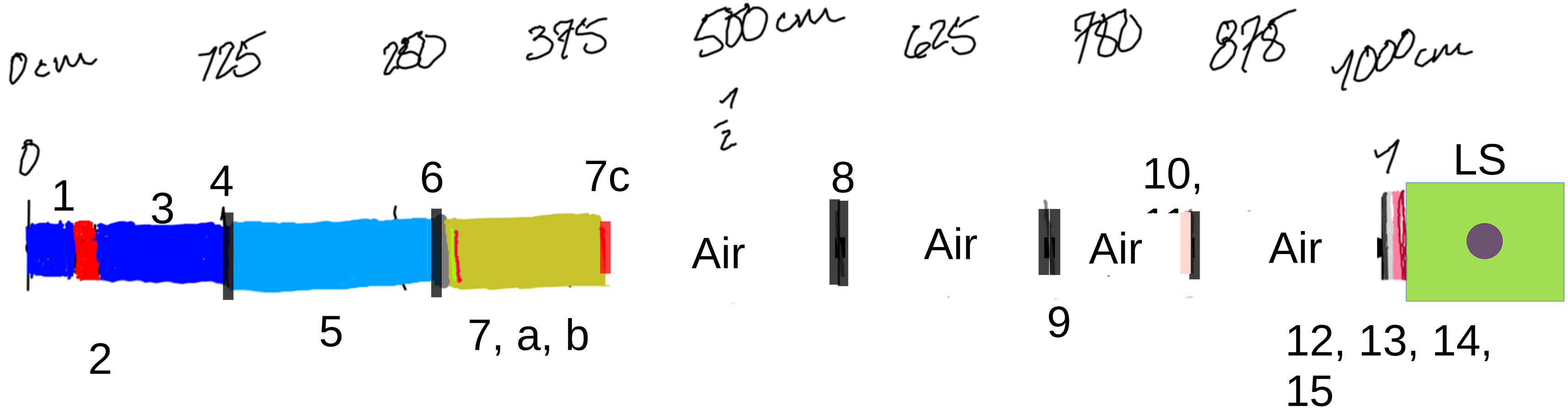


H_2O Surrounding

HEU Fuel

[4] Bergeron et al

Radial Material Distribution In 1D



From left to right:

1. Dark blue: D_2O
2. Red: HEU Core
3. Dark blue: D_2O
4. Gray: Aluminum Vessel Wall
5. Light Blue: H_2O
6. Gray: Stainless Steel Vessel Wall
7. Olive Yellow: Heavy Concrete

7a. Yellow: Boral Aluminum

7b & c. Red: Lead

8. & 9. Gray: Lead Wall

10. Light Pink: PE Cover
11. Gray: Lead Wall
12. Black: Boron Carbide Detector Cover
13. Gray: Soft Iron
14. Pink: Borated PE Cover
15. Red: Lead Frame

Table of Results

#	Material	Thickness (cm)	From→to in radial (cm)	# Density	V (neV)	W_th (neV)	Σ_abs (1/cm)	Σ_el (1/cm)	El. scatt. length (cm)
1	D2O	105	20 – 125	3.329E+022	166.042	0.047	3.788E-05	6.495E-01	1.540
2	Aluminum-27	3	125 – 128	6.026E+022	54.155	0.008	1.392E-02	9.057E-02	11.041
3	H2O	150	128 – 278	3.343E+022	-14.617	0.409	2.224E-02	5.626E+00	0.178
4	AISI 304 Stainless	5	278 – 283	8.702E+022	914.077	0.419	1.280E+00	4.507E+00	0.222
5	Heavy Concrete	125	283 – 408	0.000E+000	-1882.918	68.871	1.330E+02	4.088E+02	0.002
6	H7 Pipe Plug			-1.000E+000	477.186	8.514	2.164E+02	3.342E+02	0.003
7	Air	150	408 – 558	2.079E+019	0.046	0.000	3.081E-05	2.060E-04	4853.946
8	Lead	5	558 – 563	3.296E+022	80.767	0.027	5.636E-03	2.729E+00	0.366
9	Air	150	563 – 713	2.079E+019	0.046	0.000	3.081E-05	2.060E-04	4853.946
10	Lead	10	713 – 723	3.296E+022	80.767	0.027	5.636E-03	2.729E+00	0.366
11	Air	106.2	723 – 829.2	2.079E+019	0.046	0.000	3.081E-05	2.060E-04	4853.946
12	PE	10	829.2 – 839.2	3.894E+017	-0.0002	0.000	5.208E-07	1.321E-04	7569.981
13	Lead	10	839.2 – 849.2	3.296E+022	80.767	0.027	5.636E-03	2.729E+00	0.366
14	Air	150	849.2 – 999.2	2.079E+019	0.046	0.000	3.081E-05	2.060E-04	4853.946
15	Soft iron	1	999.2 – 1000.2	8.491E+022	209.072	0.087	2.174E-01	9.866E-01	1.014
16	B4C covering	0.8	1000.2 – 1001	1.373E+023	199.289	6.154	8.427E+01	7.282E-01	1.373
17	Lead lining	10	1001 – 1011	3.296E+022	80.767	0.027	5.636E-03	3.664E-01	2.729
18	5% borated PE	14.7	1011 – 1025.7	3.879E+017	139.098	5.632	7.726E+01	5.279E-01	1.894
19	Mu-metal	0.15	1025.7 – 1025.85	8.991E+022	34.630	0.020	5.578E-02	2.250E-01	4.445
20	Acrylic (PMMA)	2.4	1024.85 – 1027.25	6.580E+021	-19.901	0.150	8.321E-03	2.064E+00	0.484
	GC Scintillator	36.9	1027.25 – 1064.15						
21	Linear Alkylbenzene			2.478E+021	-1.079	0.061	3.314E-03	8.407E-01	1.190
22	Phenylxylylethane			2.831E+021	-1.232	0.070	3.786E-03	9.602E-01	1.041
23	Diisopropylnapthalene			2.427E+021	-1.056	0.060	3.246E-03	8.234E-01	1.214
24	Acrylic (PMMA)	2.4	1067.15 – 1069.55	6.580E+021	-19.901	0.150	8.321E-03	2.064E+00	0.484
	Gd-doped Scintillator	36.9	1069.55 – 1106.45						
25	Linear Alkylbenzene			2.478E+021	-1.079	0.061	3.314E-03	8.407E-01	1.190
26	Phenylxylylethane			2.831E+021	-1.232	0.070	3.786E-03	9.602E-01	1.041
27	Diisopropylnapthalene			2.427E+021	-1.056	0.060	3.246E-03	8.234E-01	1.214
28	Gd(thd)3			8.517E+020	10.524	3.378	4.234E+01	4.313E+00	0.232

Simulation Considerations

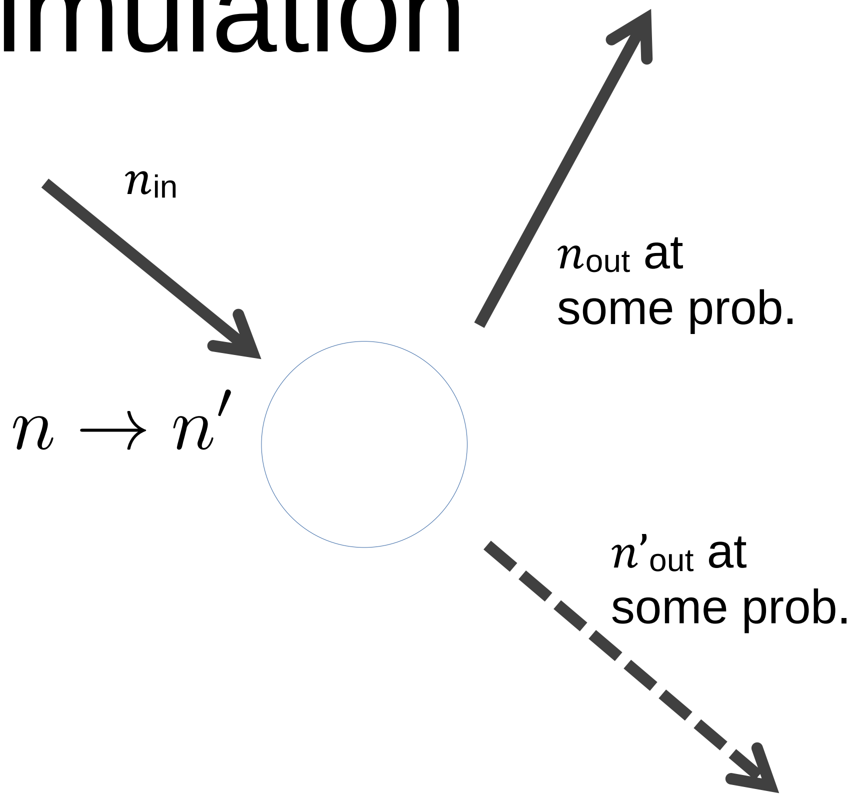
- Low-energy, thermal neutrons $\rightarrow$ Only Elastic and Absorption
  - Neglecting neutron decay
  - In moderators (D_2O & H_2O), $\Sigma_{abs} \ll \Sigma_{sc}$
- In the shielding, absorption becomes important ($\mathrm{Im}(V_{opt})$)
- In the detector, oscillation back to n depends on Δm and mixing angle θ_0,
- Calculation must be repeated for every set of parameters (Δm and mixing angle)

Basic Outline of the Simulation

- Assume neutrons coming from core are already thermalized and propagate via diffusion in spherically symmetric model (rough approximation) without change of average velocity
- At appropriate steps, compute scattering and absorption as relevant (e.g., absorption in moderators, etc.)

– For scattering events, Accept/Reject some probability to scatter; remove particle for absorption

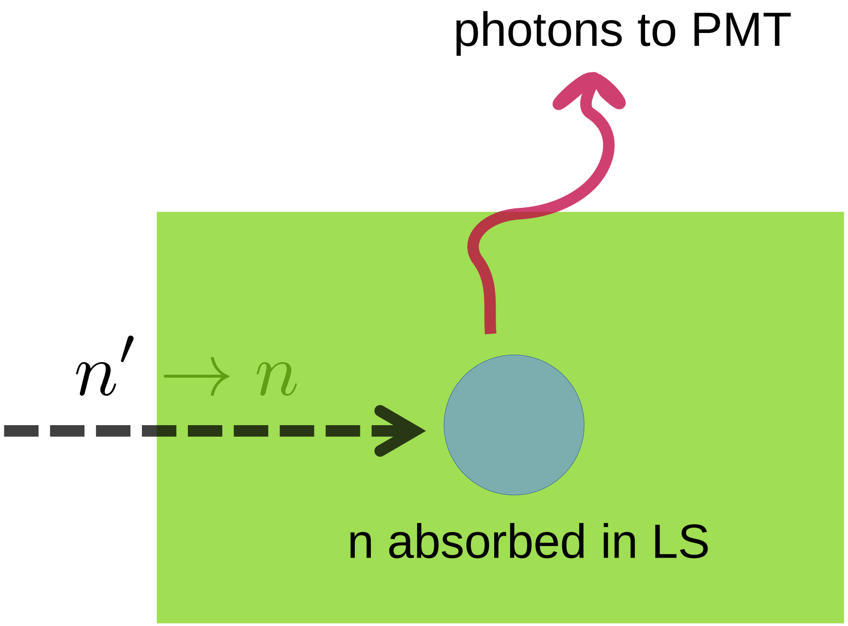
$$\psi_{state} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \text{ or } \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$



Scattering "measures" n_{in} into either n or n' pure states. "Sets" the state accordingly: depending on the scattering result

Basic Outline of Simulation, cont.

- Track particles as they (eventually) reach detector
- "Roll the dice" to see if $n' \to n$ in detector, record result
- Final result will be a function of the solid angle occupied by the detector (in counting)
- Between two scattering events, the evolution is treated by formula from [5] where ρ_{11} & ρ_{22} are calculated together with absorption.
  - $P(Absorption) = 1 - (\rho_{11} + \rho_{22})$



n'_{in} "reappears" as n in the LS and is detected

References

[1] Broussard et al, *Experimental Search for Neutron to Mirror Neutron Oscillations as an Explanation of the Neutron Lifetime Anomaly*, Physical Review Letters **128** vol. 21 (2022) https://arxiv.org/abs/2111.05543

[2] H. Almazan et al, *Searching for Hidden Neutrons with a Reactor Neutrino Experiment: Constraints from the STEREO Experiment*, Physical Review Letters **126** vol. 6 (2022) https://arxiv.org/abs/2111.01519

[3] N. Allemandou et al 2018 *JINST* **13** P07009 https://arxiv.org/abs/1804.09052

[4] A. Bergeron, A. Tentner, J.G. Stevens, *Feasibility Analyses for HEU to LEU Fuel Conversion of the Laue Langevin Institute (ILL) High Flux Reactor (RHF)*, Nuclear Engineering Division, Argonne National Laboratory (2010) https://publications.anl.gov/anlpubs/2010/08/67595.pdf

[5] Y. Kamyshkov, J. Ternullo, L. Varriano, Z. Berezhiani, *Neutron-Mirror Neutron oscillations in* Matter, Symmetry **2** vol. 14 (2022) https://arxiv.org/abs/2111.01791

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