STEREO Update

Cary Rock / University of Tennessee, Knoxville

ORNL-UT N→N' Meeting

February 9, 2023

Overview

- Analysis of STEREO reactor simulation not yet completed but we are close.

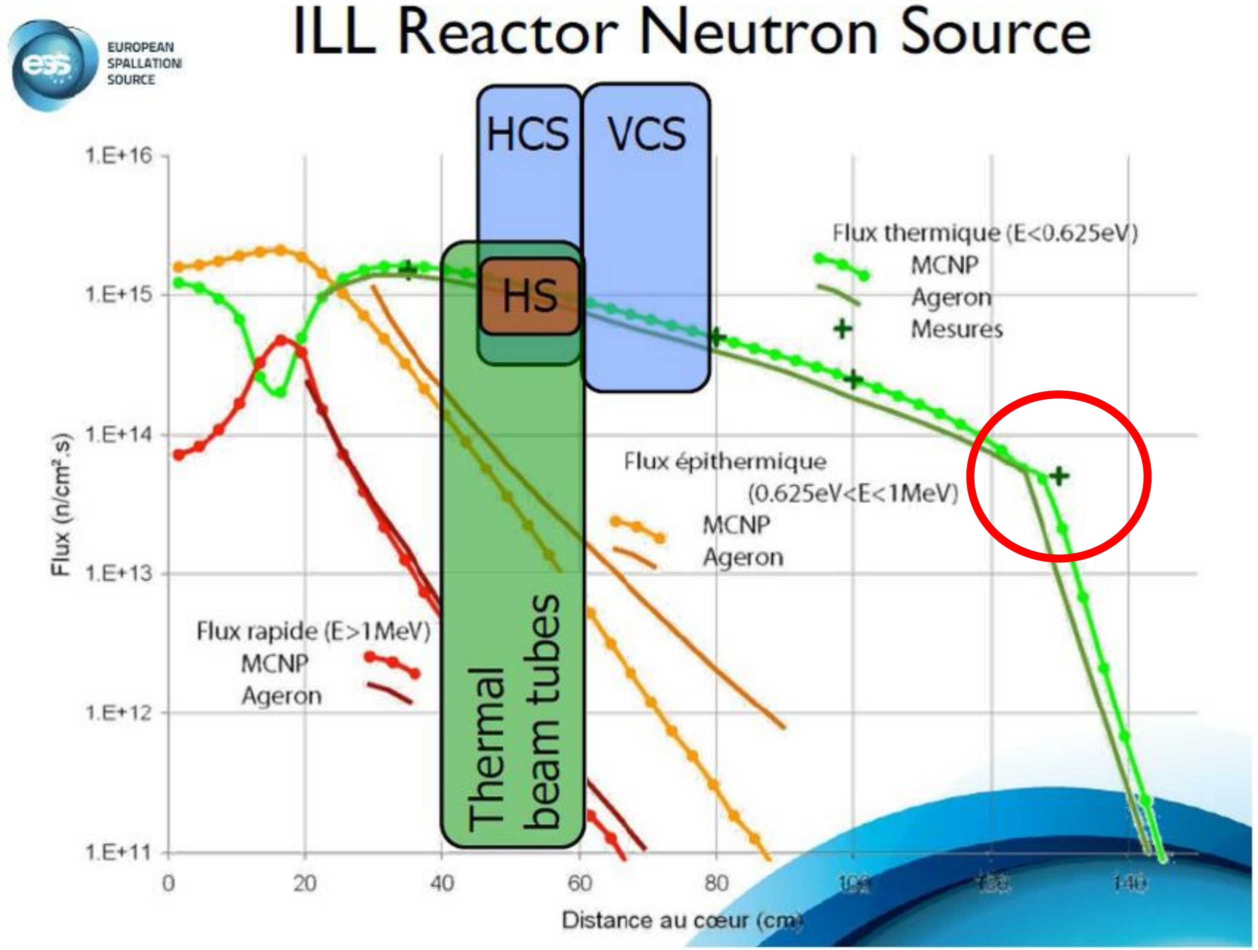
- Progress reported in several issues:

1) Large Mixing Angle Exclusion in D_2O
2) What Can Be Learned from a H_2O Reactor?
3) Attempt for Radial n absorption, n' production plot (for fixed dm and theta)
4) Update of Material Parameter Table
5) Better Understanding the Scintillator
6) 8mm B_4C Surprises

1) Large Mixing Angle Exclusion in D_2O Neutron Flux in the ILL Reactor

- MCNP-calculated and measured neutron flux in D_2O* agree to better than <10 ? %

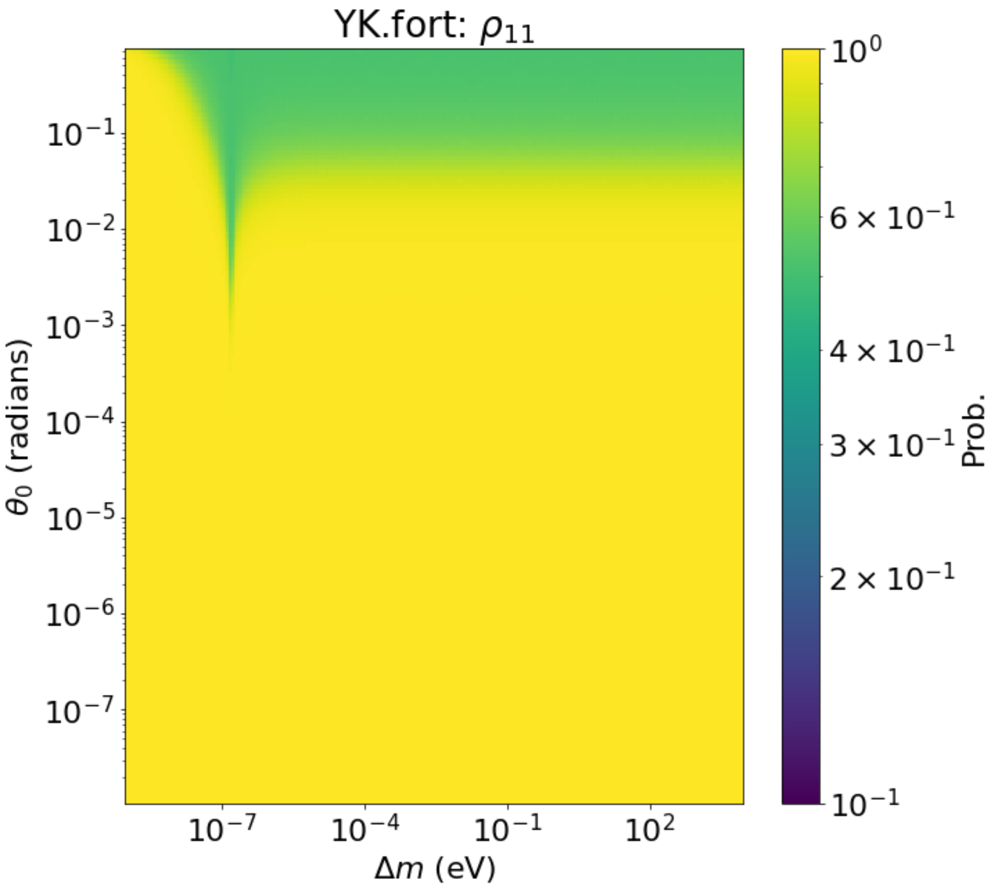
- Will take 10% as an uncertainty of the flux measurements that would be giving max space for $n \rightarrow n'$ disappearance effect

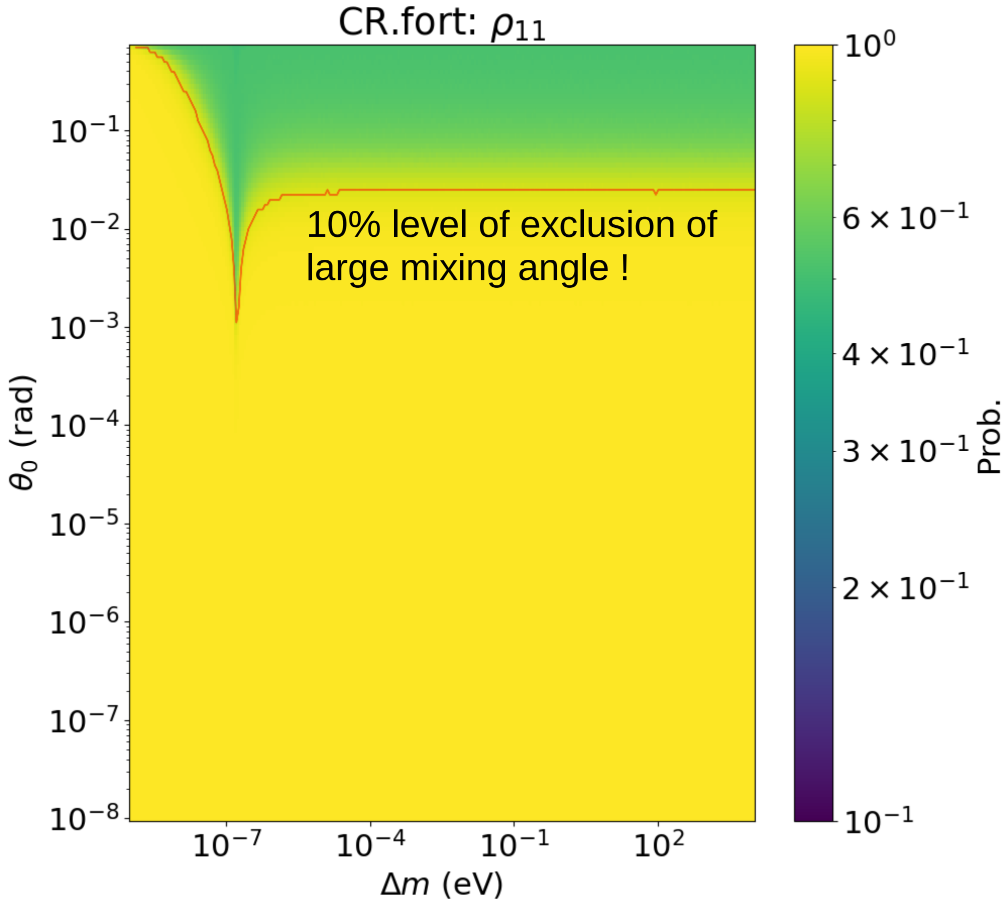


* Figure Source: S.G. Arutunian et al., "Thermal Neutron flux monitors based on a vibrating wire", *Nucl. Inst. Meth.*, **797**, (2015)

1) Large mixing-angle n→n' oscillations can reduce flux by >10%

Cross check of Calculation with D_2O – 105 cm, 117 el. sc. Events (λ_{sc} = 2.2 cm)



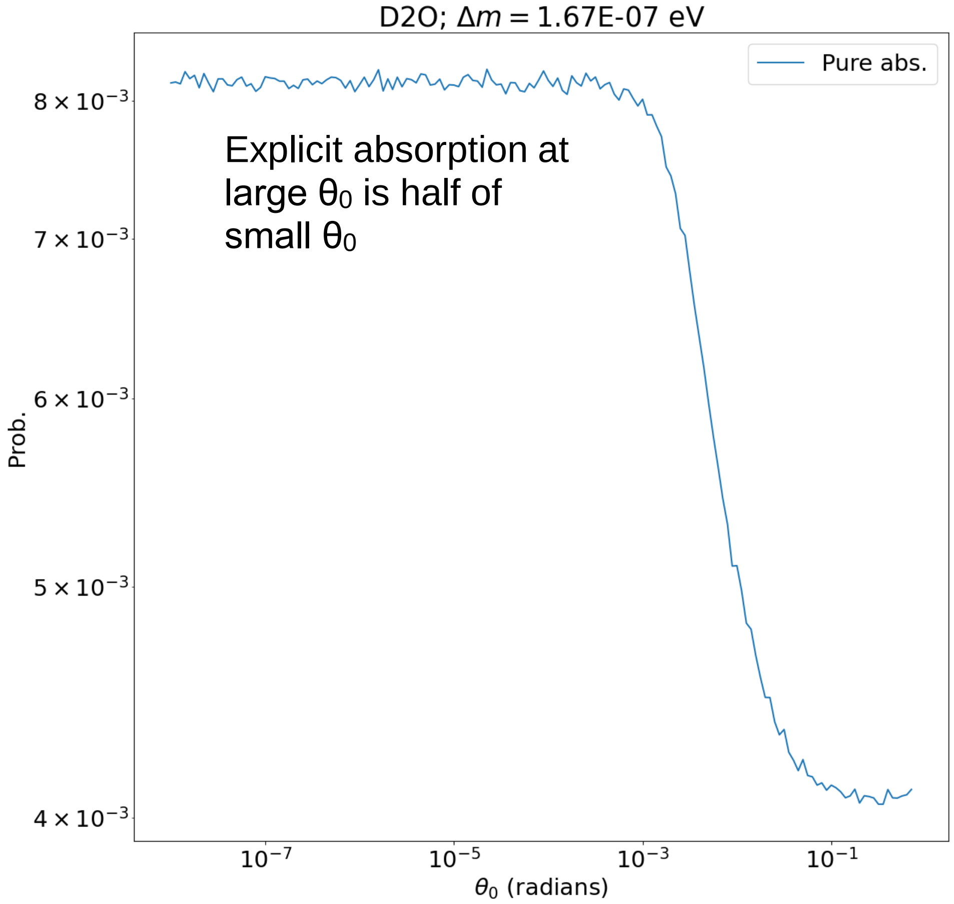


1) Large mixing-angle n→n' oscillations can reduce flux by >10%

D_2O Comparison at Fixed Δm vs. θ_0

- Absorption at small angles is 8×10^{-3} which is close to the direct absorption calculation from λ_{abs} for ordinary neutrons

- At large mixing angles $\theta_0 > 0.01$ radians, absorption is factor of 2 lower due to n spending ~50% of the time in the n' state



2) What Can Be Learned from a H_2O Reactor?

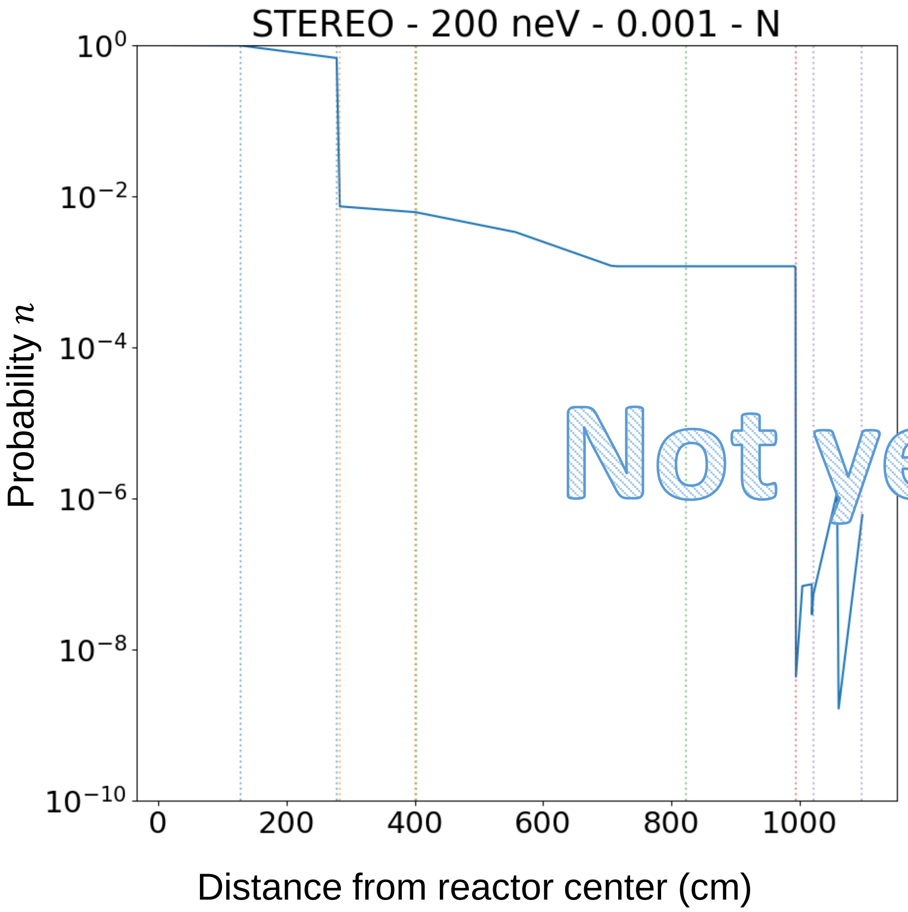
McMaster's LWR – Suggested by Dr. Heilbronn

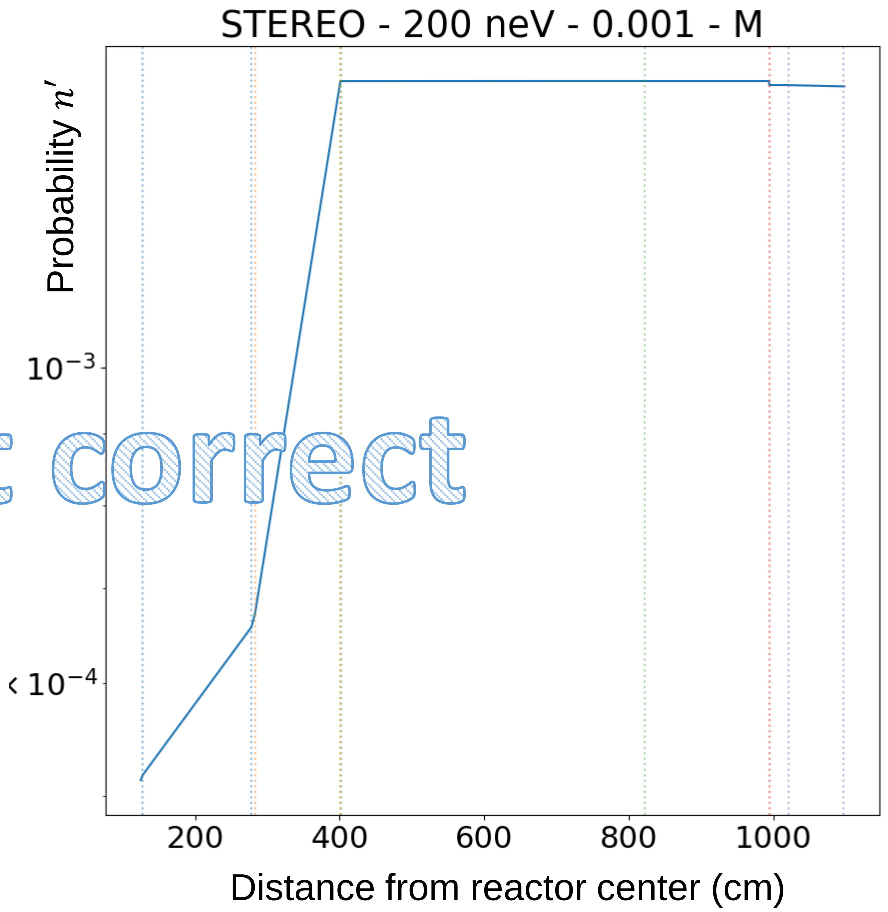
- Original paper was to compare MCNP's calculations to real reactor measurements as related to fuel burnup and flux.
- Demonstrated that MCNP and measurement agree within 5.7%, although not clear at what distance.

In general, the uncertainties associated with measurements of the total, thermal, epithermal, and fast fluxes are on the order of 5.5%, 5.7%, 35%, and 5.8%, respectively. In all cases, counting times and geometries were adjusted so that the measurement uncertainty was less than 1.5%. The uncertainties associated with sample position in the irradiation site and the reactor power level (both of which have magnitudes of approximately 3.5%) dominate the remaining portion of these reported uncertainties. The uncertainty

Source: E.L. MacConnachie, D. R. Novog, "Measurement, simulation and uncertainty quantification of the neutron flux at the McMaster Nuclear Reactor", *Annals of Nuclear Energy*, **151**, (2021), 107879

3) Attempt for Radial n absorption, n' production plot (for fixed Δm and θ_0)





Not yet correct

4) Update of Material Parameter Table

Parameters of Included Material Layers

	Material	Thickness (m)	V (eV)	W_abs (eV)	El. scatt. length (m)	Diffusion Steps
1	D2O	1.05	1.659E-07	2.959E-15	2.200E-02	117
2	Aluminum-27	0.03	5.412E-08	1.008E-12	1.104E-01	1
3	H2O	1.5	-1.461E-08	1.610E-12	2.590E-03	95
4	AISI 304 Stainless	0.05	9.135E-07	9.270E-11	2.219E-03	54
5	H7 Pipe Plug	1.18	4.769E-07	8.058E-09	2.992E-05	130000
6	Air	1.5	1.198E-10	5.756E-15	1.881E+01	1
7	Lead	0.05	8.072E-08	4.081E-13	3.664E-03	32
8	Air	1.5	1.198E-10	5.756E-15	1.881E+01	1
9	Lead	0.1	8.072E-08	4.081E-13	3.664E-03	66
10	Air	1.062	1.198E-10	5.756E-24	1.881E+01	1
11	PE	0.1	-1.694E-13	3.771E-26	7.570E+01	1
12	Lead	0.1	8.072E-08	4.081E-13	3.664E-03	66
13	Air	1.5	1.198E-10	5.756E-24	1.881E+01	1
14	Soft iron	0.01	2.089E-07	1.574E-11	1.014E-02	2
15	B4C covering	0.008	1.992E-07	6.101E-09	1.373E-02	2
16	Lead lining	0.1	8.072E-08	4.081E-13	2.729E-02	66
17	5% borated PE	0.147	1.390E-07	5.594E-09	1.894E-02	17
18	Mu-metal	0.0015	3.461E-08	4.039E-12	4.445E-02	1
19	Acrylic (PMMA)	0.024	-1.989E-08	6.024E-13	4.844E-03	10
20	GC Scintillator	0.369	8.419E-09	1.675E-12	1.688E-03	553
21	Acrylic (PMMA)	0.024	-1.990E-08	2.150E-09	4.844E-03	10
22	Gd-doped Scintillator	0.369	8.503E-09	2.613E-11	1.678E-03	556

?

5) Better Understanding the Scintillator

- Two types of liquid scintillator
- 36 cm LS (gamma catcher)

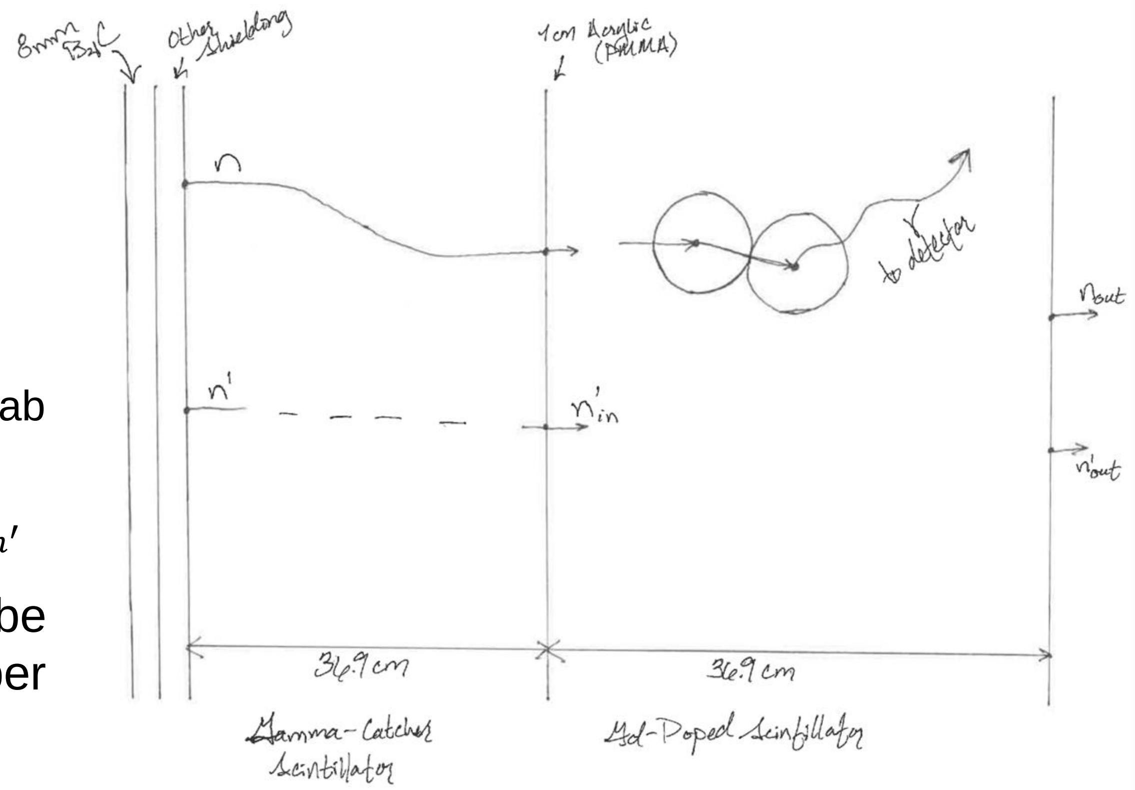
  $+\ 6 \times 36$ cm LS with Gd

– Otherwise almost identical LS composition.

- STEREO result is referred to the first LS(Gd) slab for n detection. Detected ↘

$$P_{after}(n) = P_{before} - \color{red}{abs.signal} + P_{n' \to n} - P_{n \to n'}$$

Absorbed signal is what is detected and will be compared to STEREO's stated 3.1×10^{-11} per initial neutron produced in the reactor



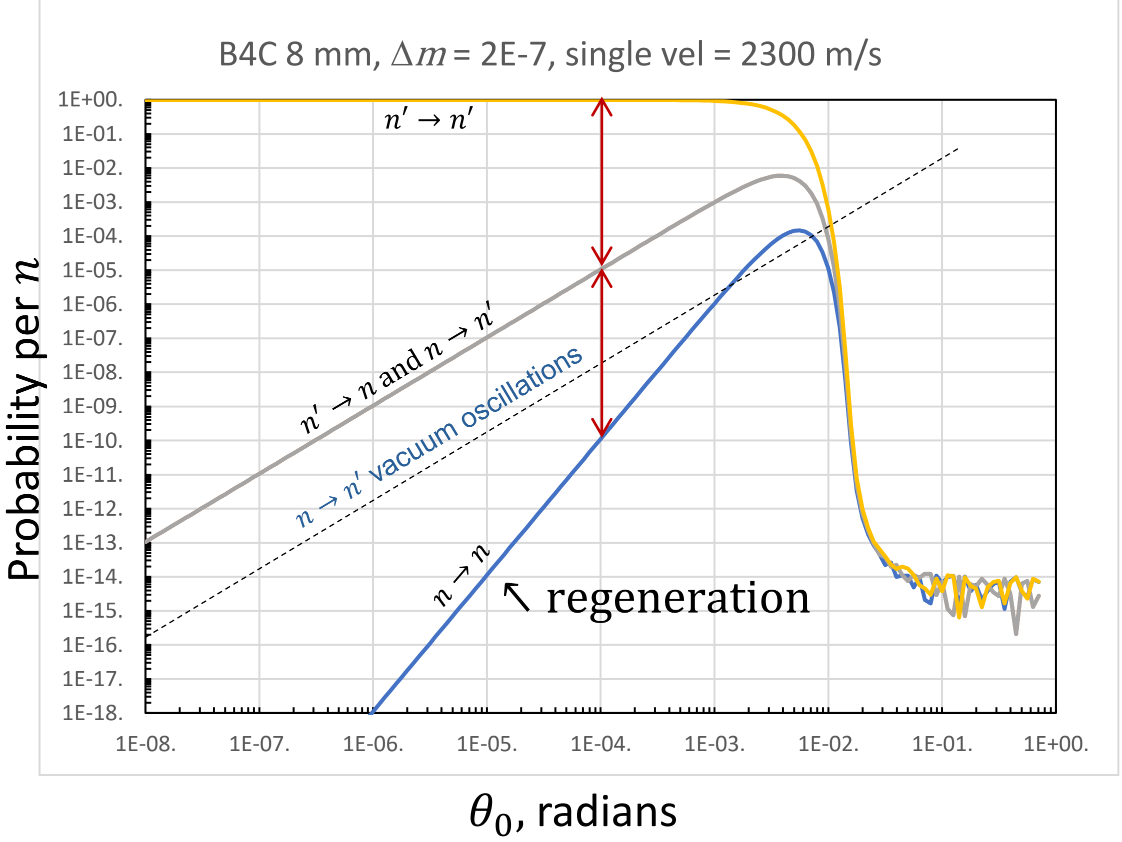
6) 8mm B4C Surprises

- For consistency's sake, a check was made at fixed velocity v = 2300 m/s

- It was assumed no elastic scattering for 8mm B4C ($\lambda_{el} = 1.3$ cm)

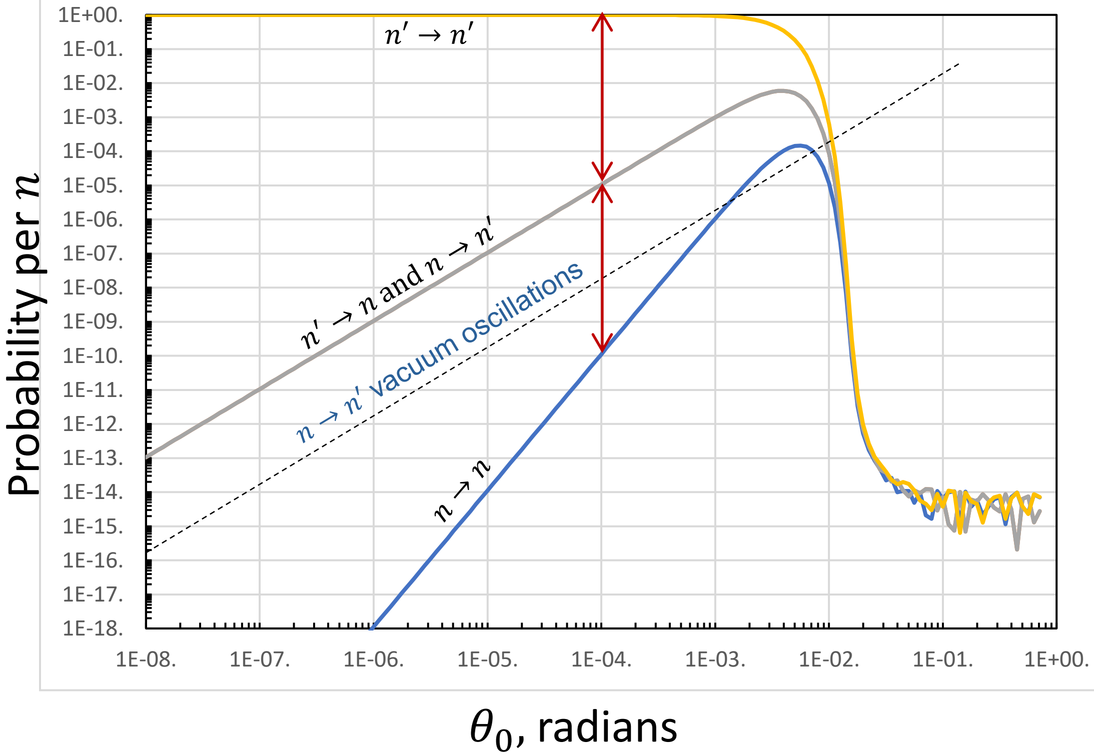
- Δm = 2.0E-7 eV, in resonance

- YK and CR had consistent numbers.

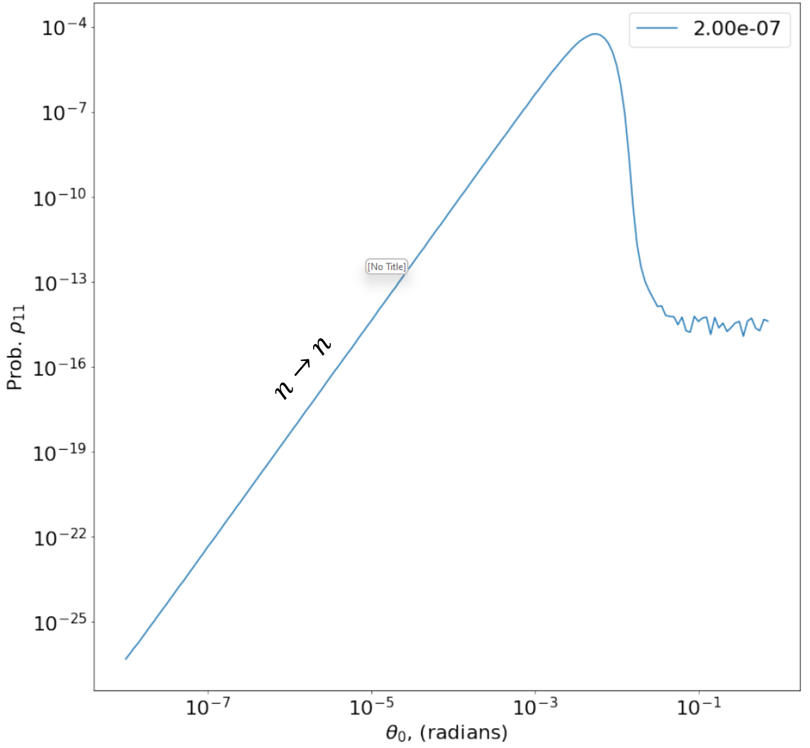


Presence of possible elastic scattering for neutrons with fixed velocity doesn't change significantly the overall character of absorption

B4C 8 mm, Δm = 2E-7, single vel = 2300 m/s, no elastic

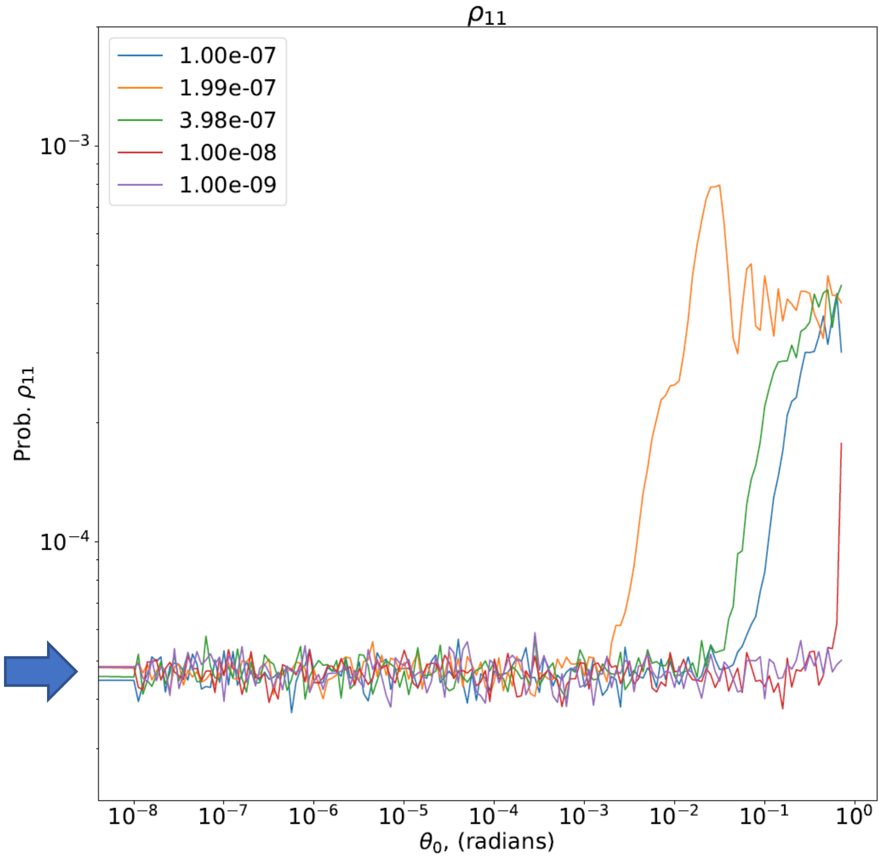


B4C 8 mm, Δm = 2E-7, single vel = 2300 m/s , with elastic



6) 8mm B4C averaged over velocity spectrum

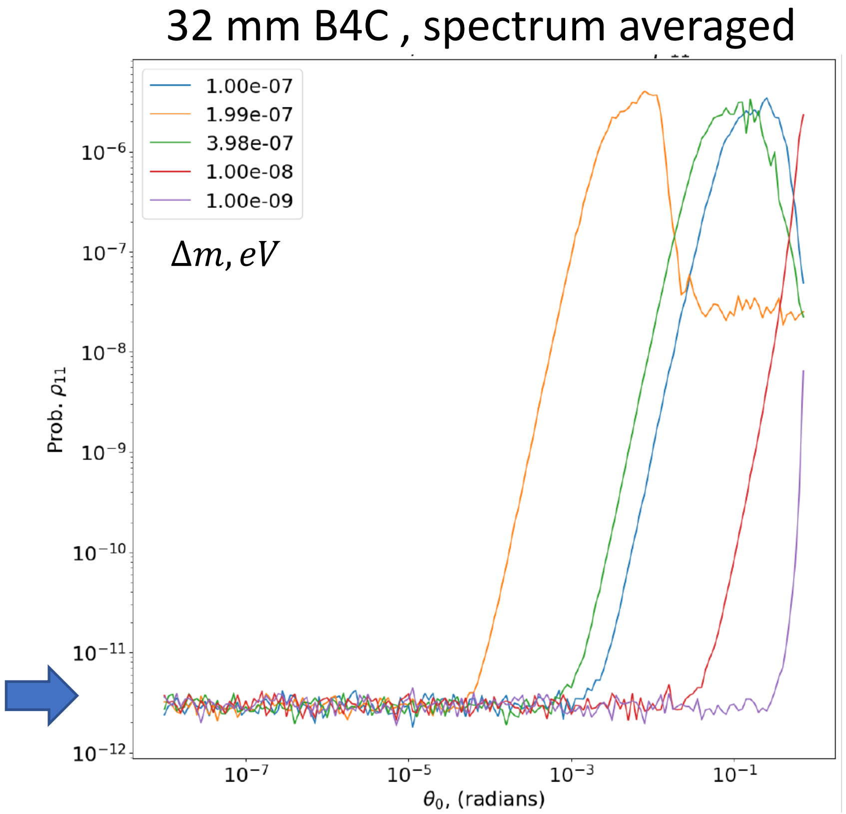
- Elastic scattering length x is distributed as $e^{-x/\lambda_{el}}$ ($\lambda_{el} = 1.3$ cm)
- After spectrum averaging the level of ρ_{11} is constant at small mixing angles θ_0! for all Δm.
- $\rho_{11} \sim 5 \times 10^{-5}$ instead of being $\exp(-8\,mm/\lambda_{abs}) = 2 \times 10^{-53}$ $\lambda_{abs} = 0.066\,mm$
- If "flat absorption" is an effect, could we have seen it in the SNS-2019 experiment with 32 mm B4C?



6) 32 mm B4C averaged over velocity spectrum

- Elastic scattering length x is distributed as $e^{-x/\lambda_{el}}$ $(\lambda_{el} = 1.3$ cm)

- with 32 mm B4C the “flat absorption” could not have been seen.



6) Conclusion

- All these calculations were made with Z. Berezhiani analytic formula. Should be re-checked with density matrix evolution calculations.

- We need to study velocity dependence of this effect

- We will also look at Cd absorber for similar effect.