Light Sterile Neutrino Searches at Reactors

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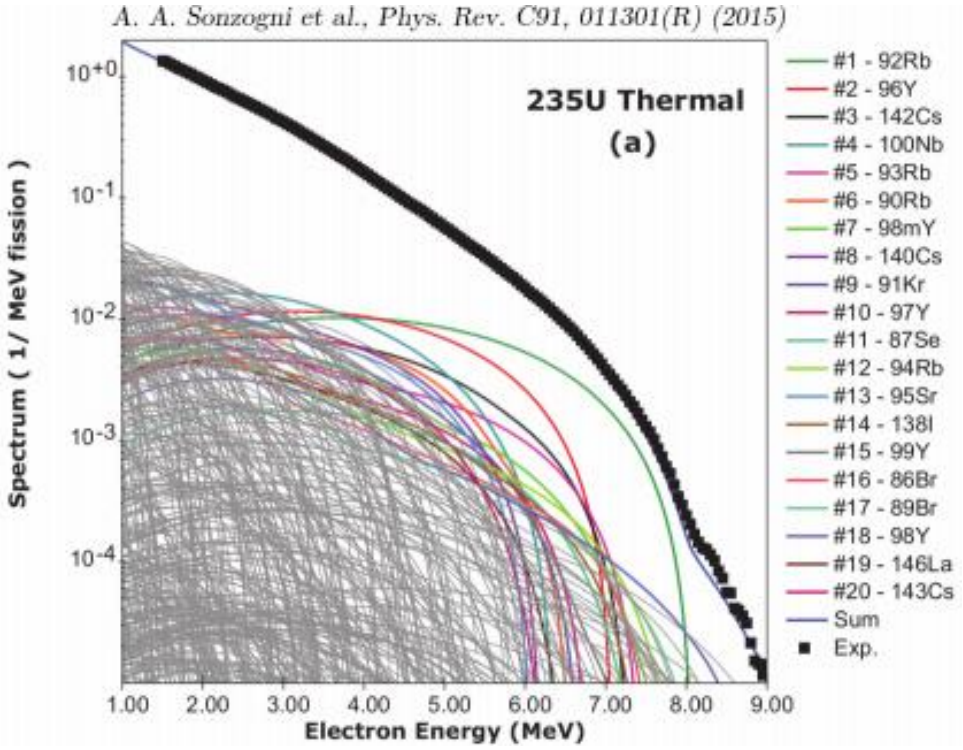
October 24th, 2019

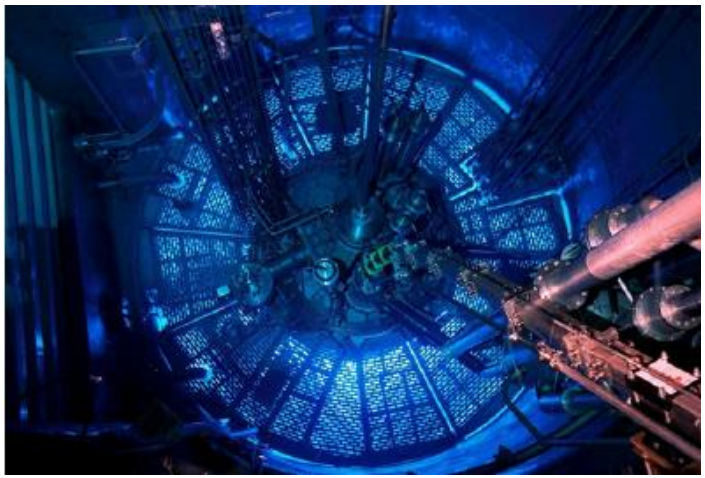
BLV 2019 - Madrid

Reactors as a neutrino source



Pure $\bar{\nu}_e$ source, spectrum up to 8 MeV:
β^- decays of fission products

$> 10^{20}\ \bar{\nu}_e$ /GW / s



Commercial reactors : LEU (Low Enriched Uranium)

- fission isotopes = ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu
- nuclear power = few GW

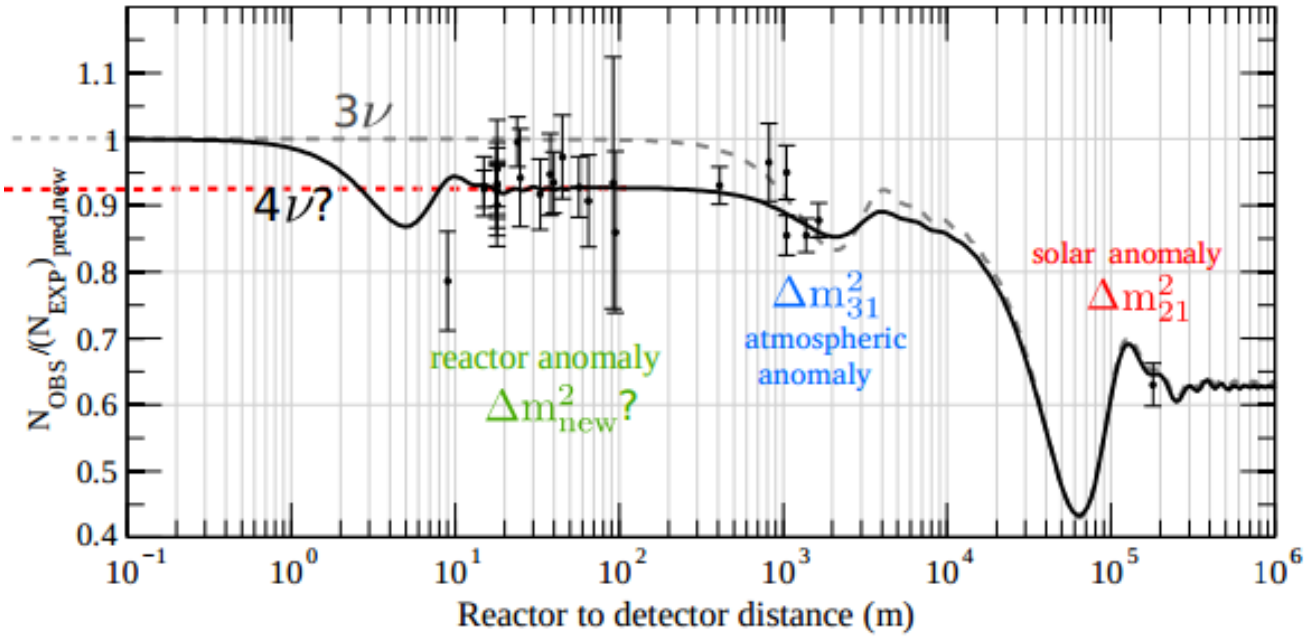
Research reactors : HEU (High Enriched Uranium)

- fission isotopes = only ^{235}U
- nuclear power = 50 – 100 MW
- compact core

The Reactor Antineutrino Anomaly

In 2011, a reevaluation of the emitted flux exhibited a 6.5% deficit at very short baselines from the reactor

Physical Review D 83, 073006 (2011), G. Mention et al.

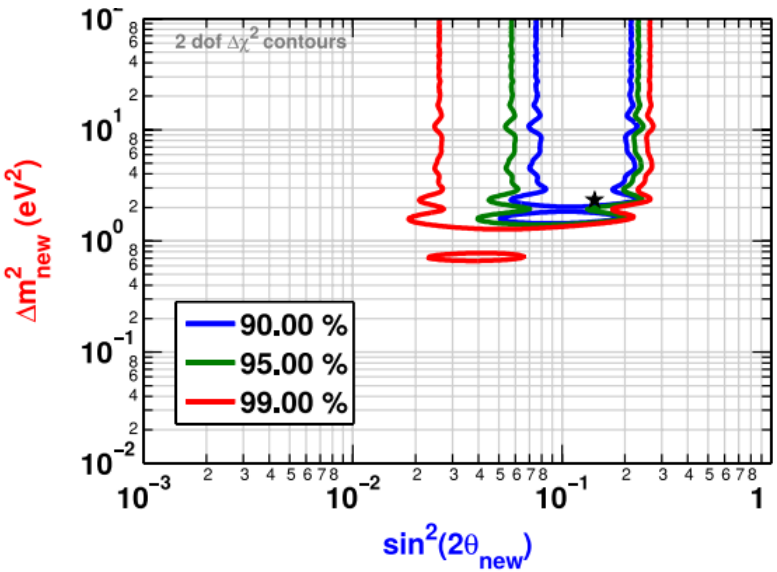


A hint of a new oscillation to a sterile neutrino at eV scale?

2 ν oscillation model

$$P_{survival}(L, E) = 1 - \sin^2(2\theta) \cdot \sin^2(1.27\Delta m^2 \cdot L/E)$$

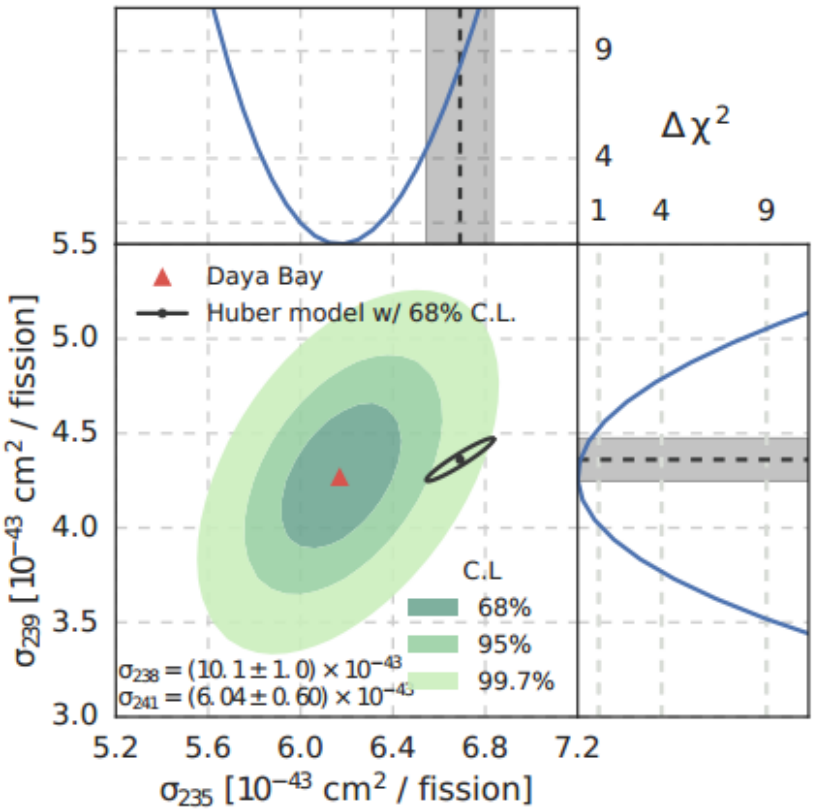
with Δm^2[eV], L[m] and E [MeV]



Or a bias in the model?

Fuel evolution data of Daya Bay

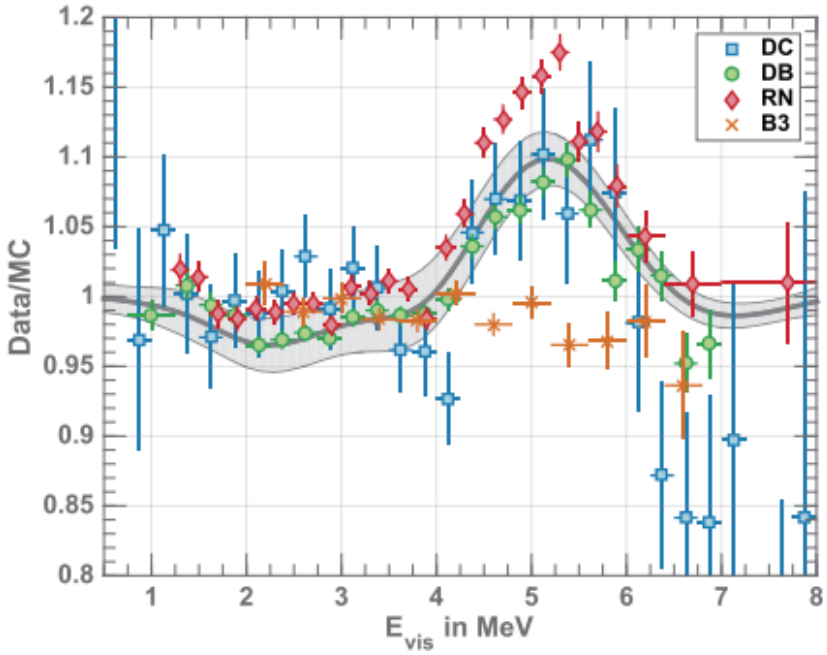
the deficit would be only due to ^{235}U



Phys. Rev. Lett. 118, 251801 (2017)

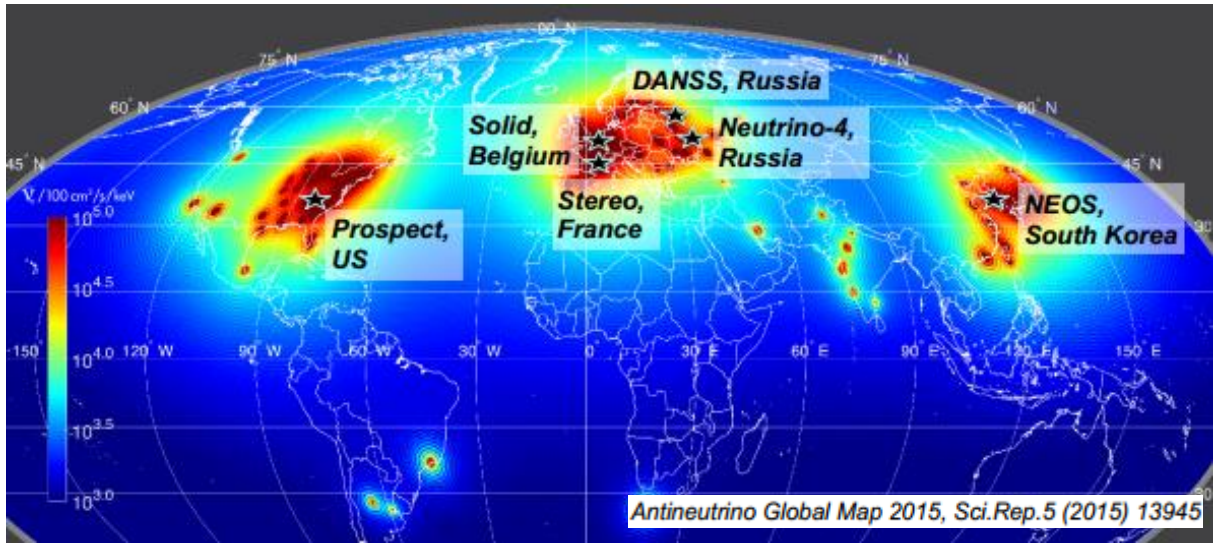
Bump @ 5 MeV?

Cannot be explained by a sterile neutrino.



Physics Letters B 773 (2017)

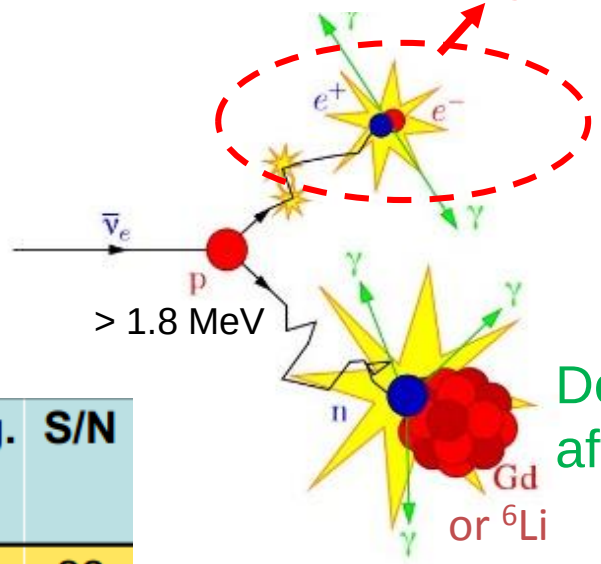
A worldwide experimental program



Invert Beta Decay

$\bar{\nu}_e + p \rightarrow e^+ + n$

Prompt signal gives $\bar{\nu}_e$ energy



Delayed signal after few 10 μs

Experiment	P_{th} (MW)	U enr.	L (m)	Dep. (mwe)	$M_{targ.}$ (t)	Tech.	Seg.	S/N
NEOS	2700	LEU	24	20	1	Gd-LS	N	22
DANSS	3100	LEU	10-12	50	0.9	Gd-PS	Y	≈20
Neutrino4	100	HEU	6-11	5-10	1.5	Gd-LS	Y	<1
STEREO	57	HEU	9-11	15	1.7	Gd-LS	Y	≈1
SoLid	80	HEU	6-9	10	1.6	^{6}Li-PS	Y	0.3
Prospect	85	HEU	7-9	<1	4	^{6}Li-LS	Y	> 1

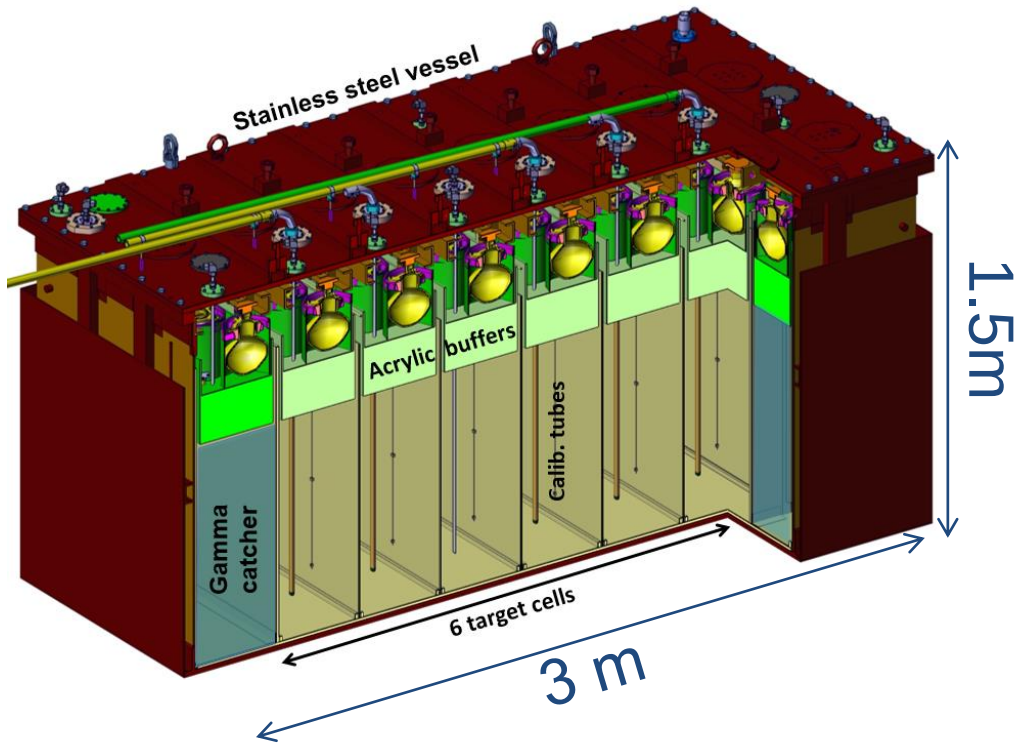
Measurement of the spectrum as a function of the distance

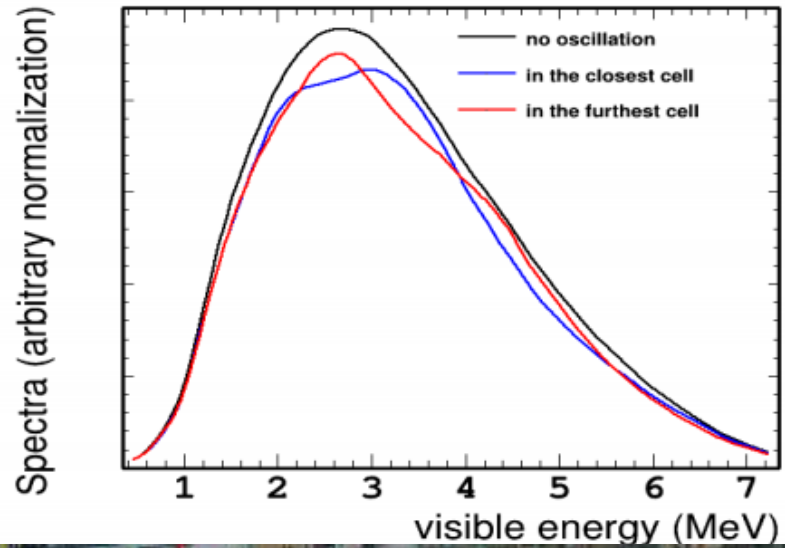
=> Unambiguous sterile neutrino signature

The STEREO Experiment

- 58 MW research reactor – ILL Grenoble (France)
- Highly enriched fuel: ^{235}U (93%)
- compact core Ø40 cm x 80 cm
- **Target** = 6 cells filled with Gd-loaded liquid scintillator, 4 top PMTs per cell
- [9–11] m from core

N. Allemandou et al. JINST 13, 07 P07009(2018).



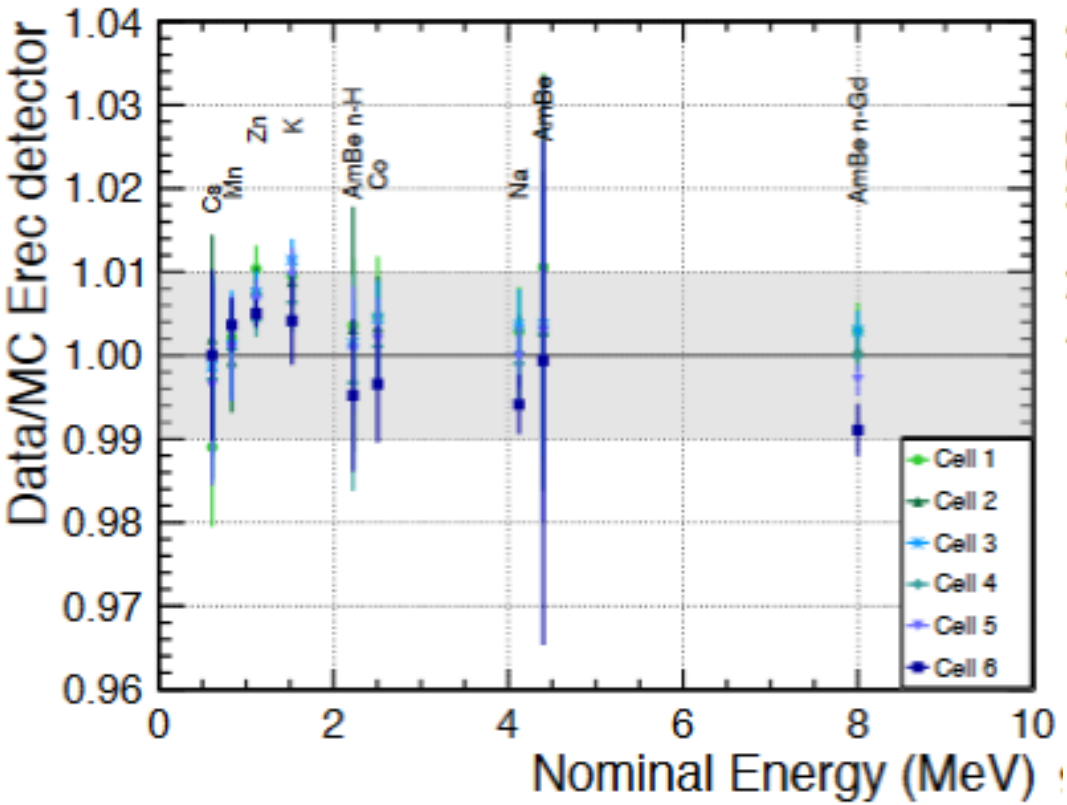


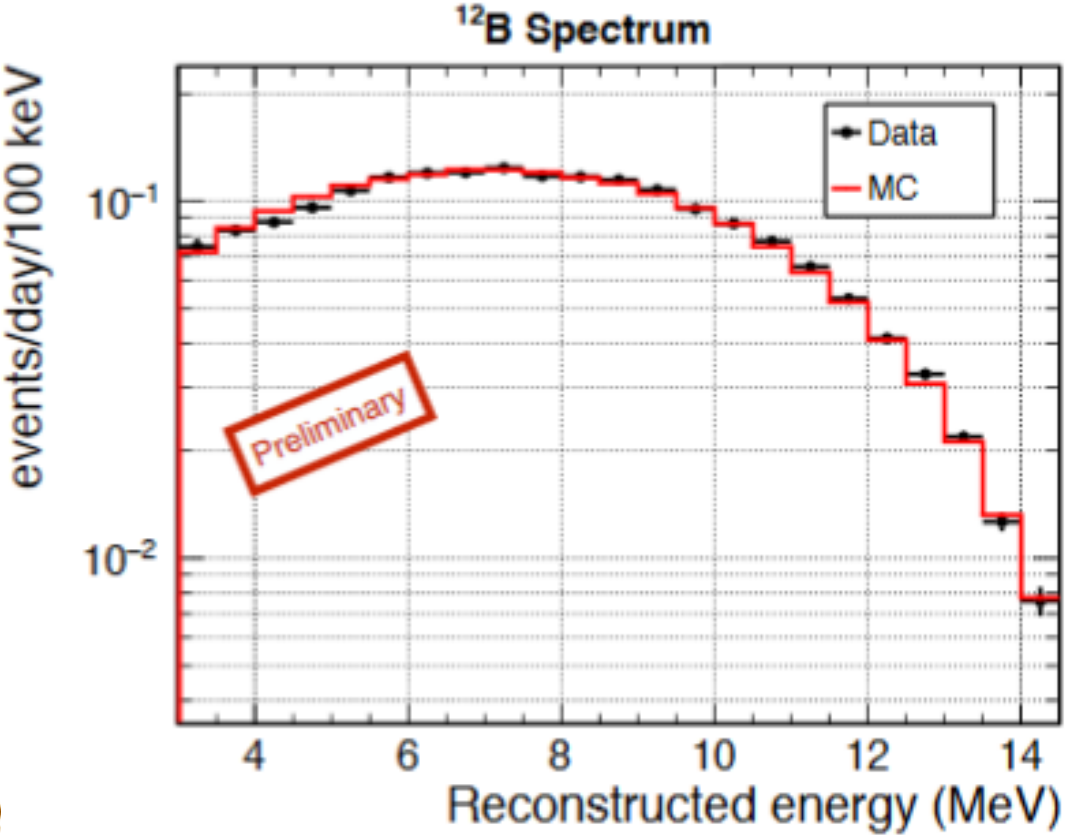
The experimental key points: energy scale

Calibration with sources at different positions inside the detector :
uncertainties at the % level

^{12}B beta spectrum induced by the capture of stopping muon at rest ($\mu^- + {}^{12}C \rightarrow {}^{12}B$)

~ 700 events/day, S/B ratio ~ 0.1 to 1





The experimental key points : background rejection

• IBD signature: time and spatial coincidence between prompt and delayed

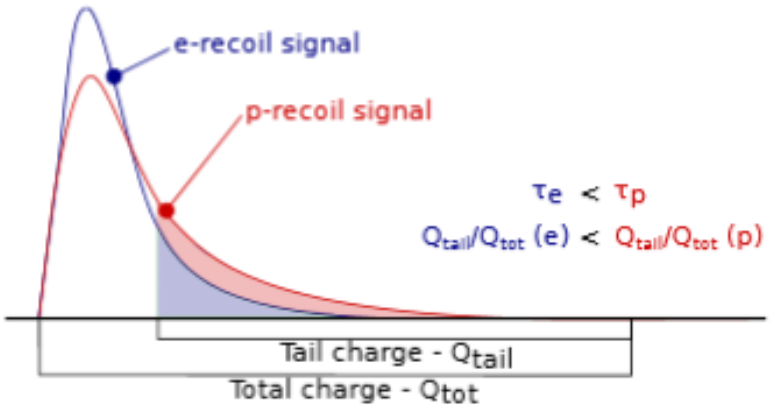
Mean cut efficiency = 61.4±0.9%

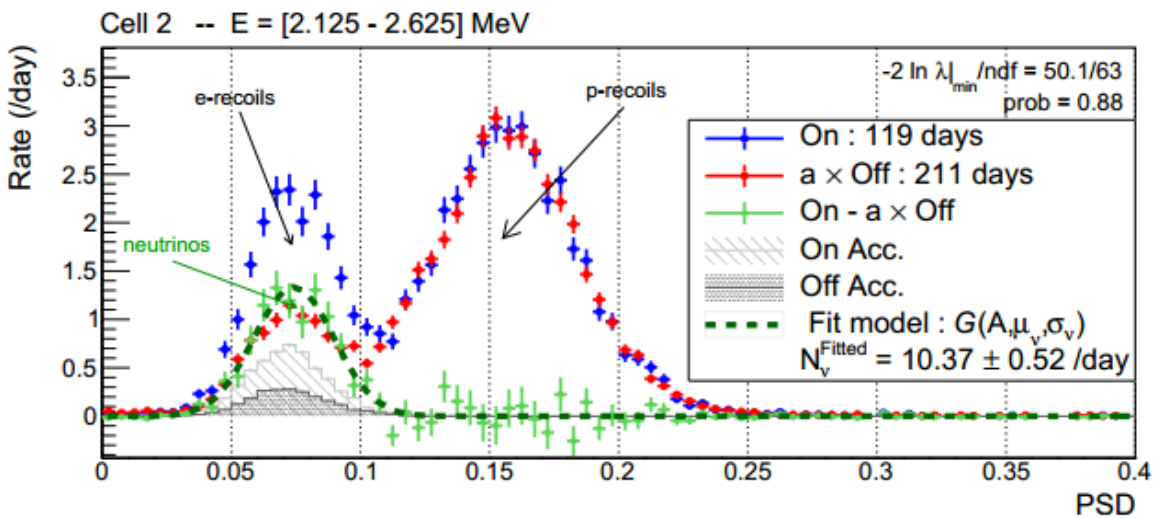
Uncertainty dominated by neutron detection efficiency (delayed signal)

• Anticoincidence selection against cosmics (muon veto, multiple events): 14% dead time

• Pulse Shape Discrimination

to select electron recoils (for prompt events)



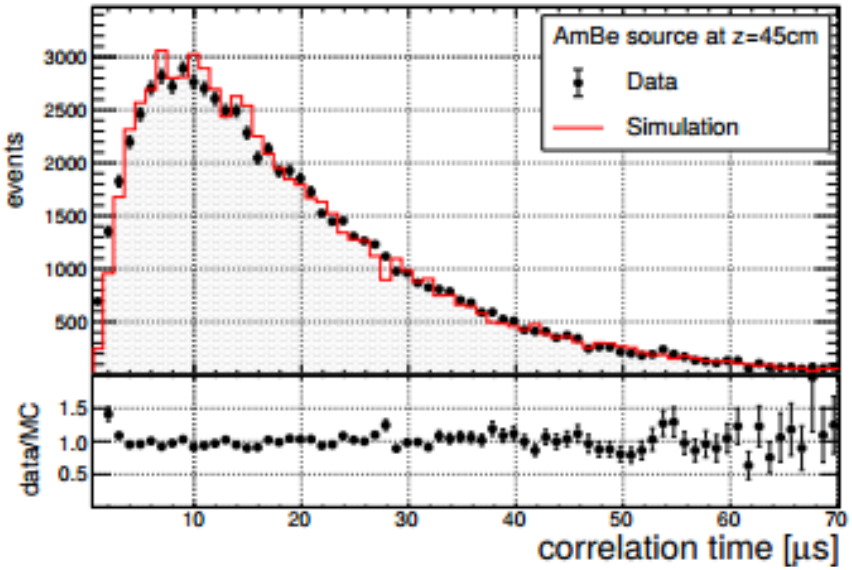


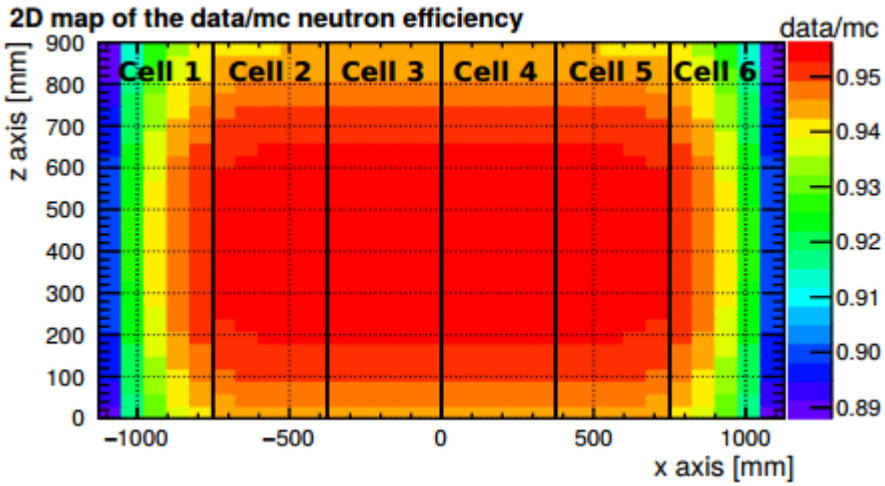
• ON – OFF subtraction with free normalization (to take into account time variations).

S/B ~ 1

The experimental key points : simulation

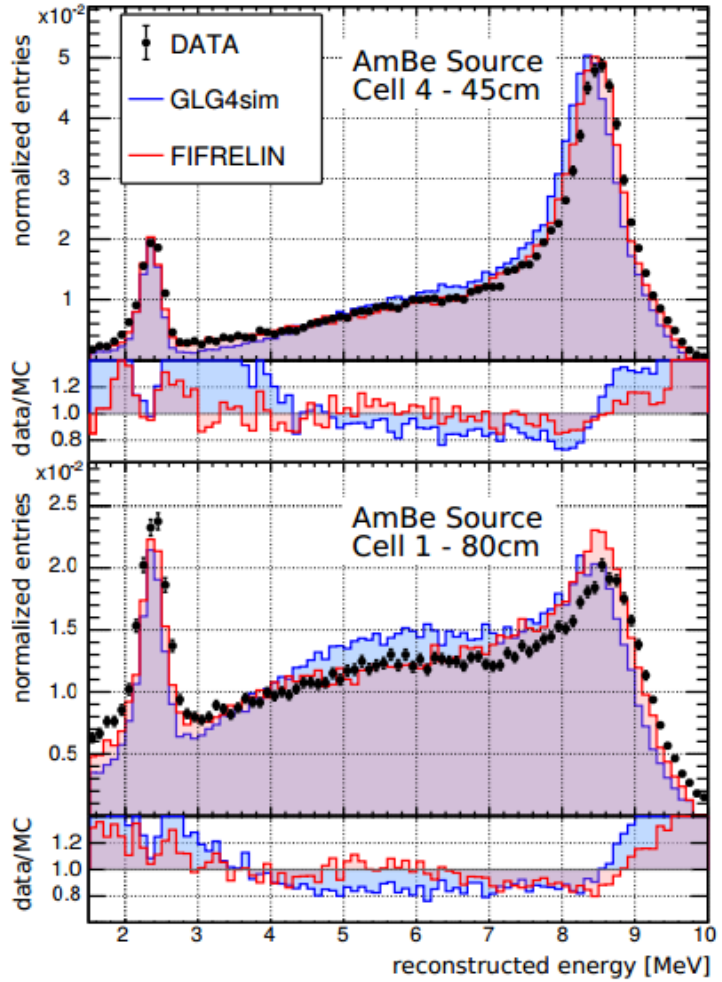
GEANT4 simulation includes the full geometry, validation with calibrations (corrections at the % level)





New Gd gamma cascade

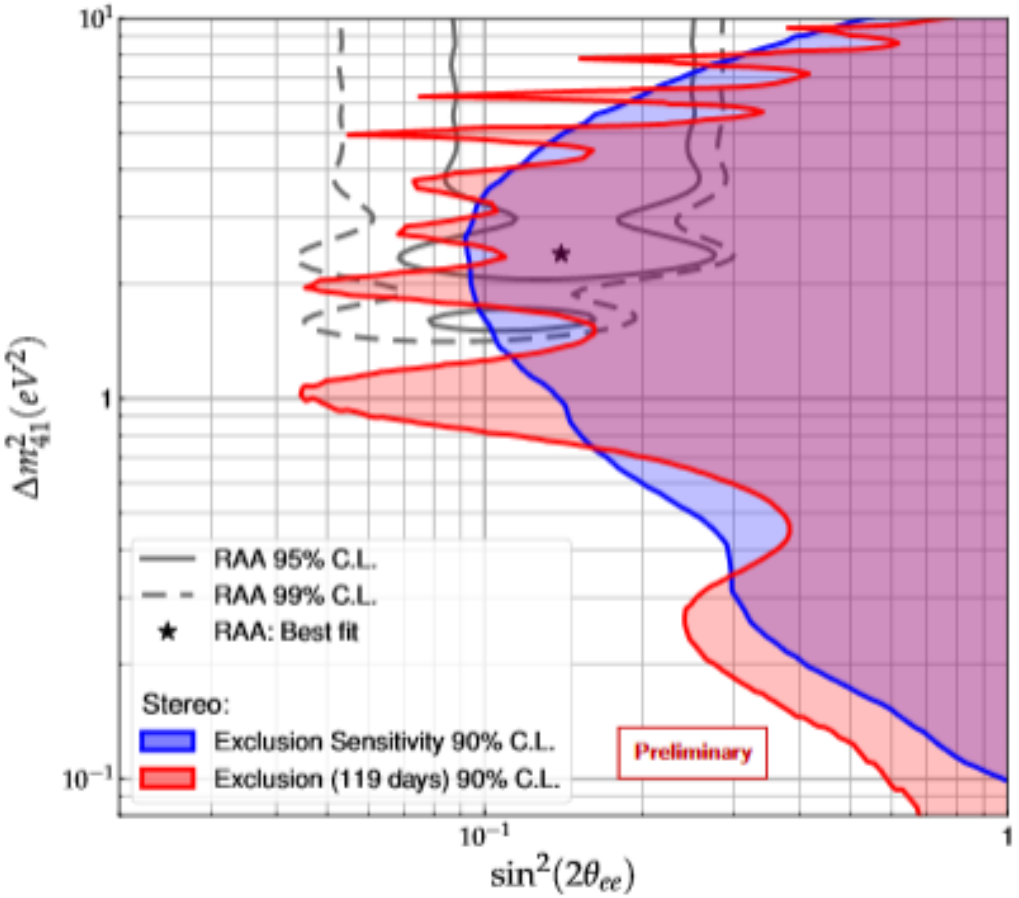
Stereo Collaboration, arXiv:1905.11967.



Current results

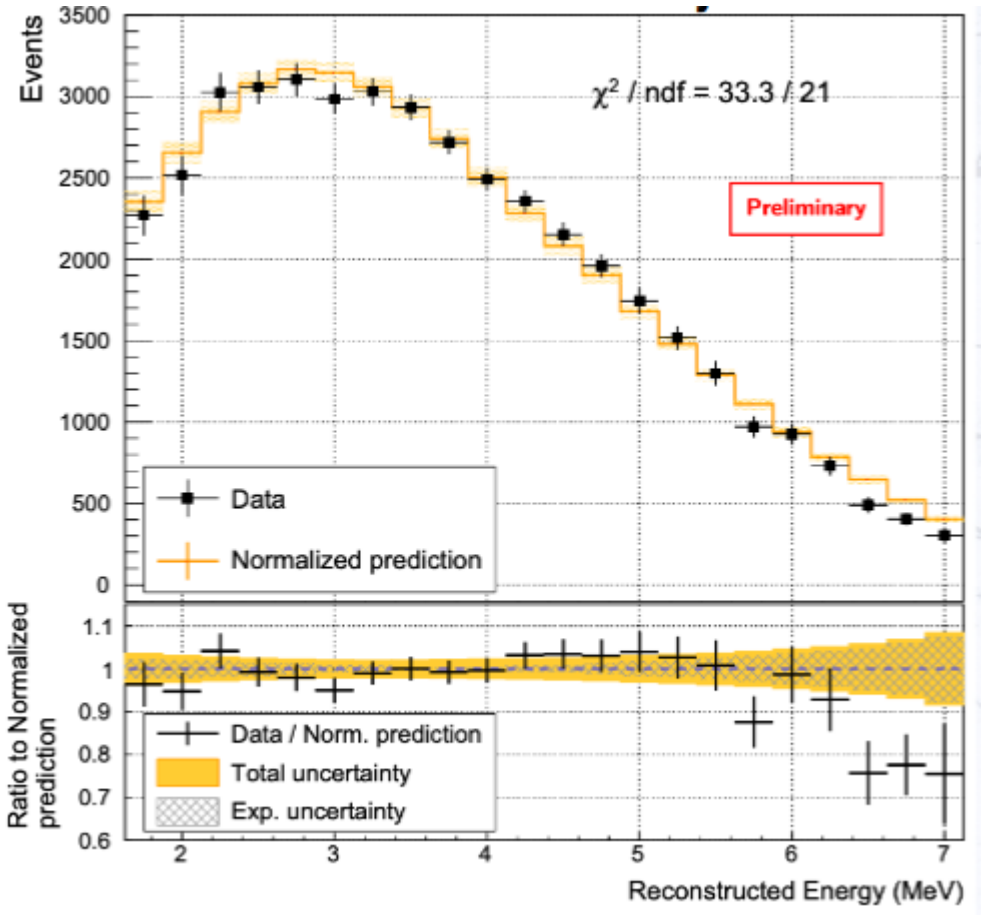
119 days ON, 211 days OFF = 43.4 k $\bar{\nu}_e$

No oscillation, RAA best fit excluded at 99% CL



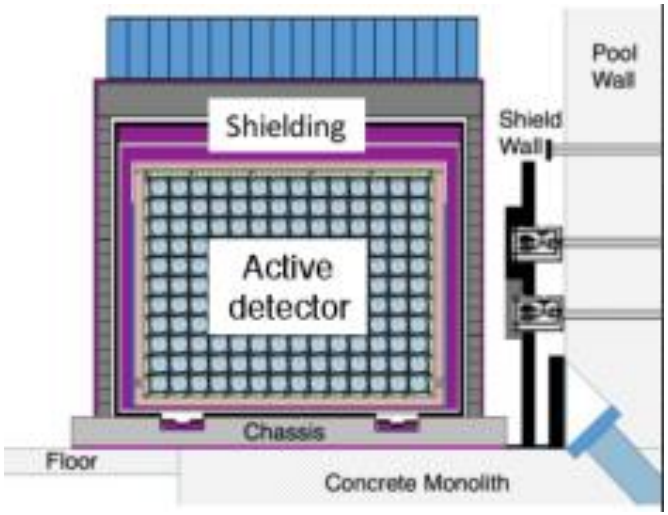
Energy spectrum measurement

Preliminary:
- systematics under study
- more statistics is coming,

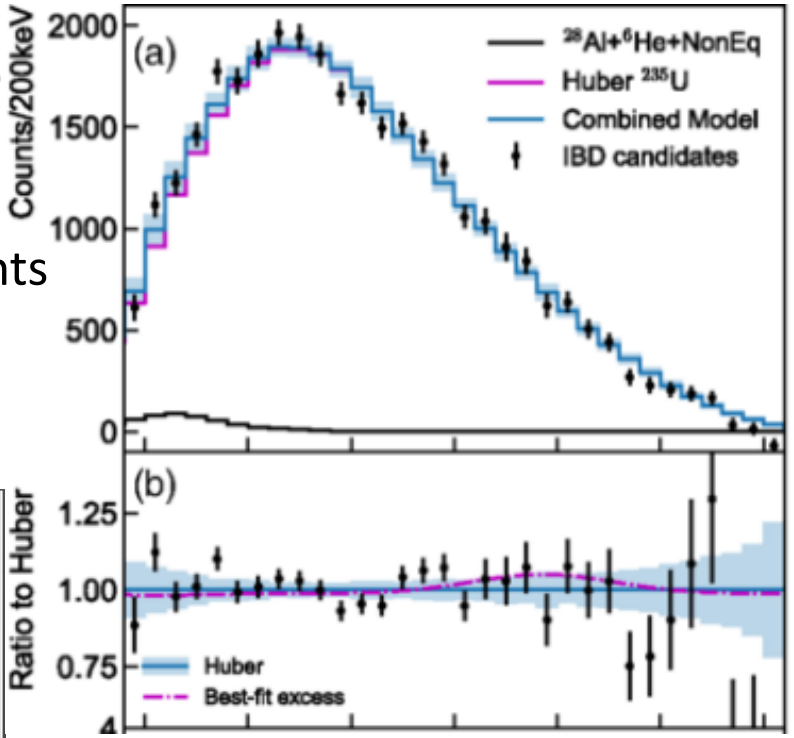


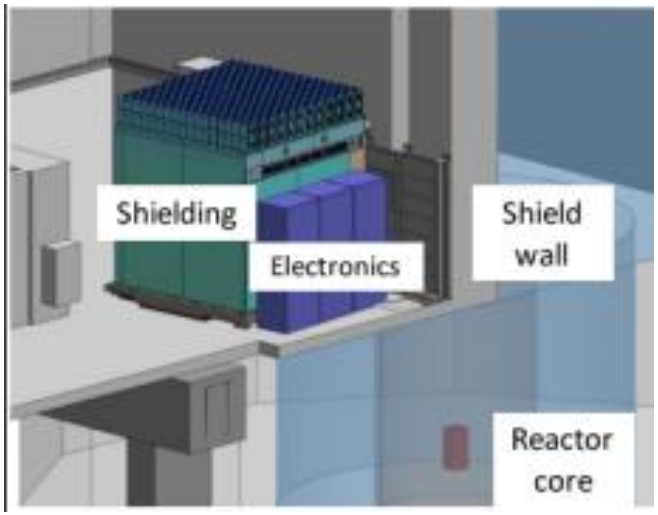
> 300 days ON expected before mid 2020

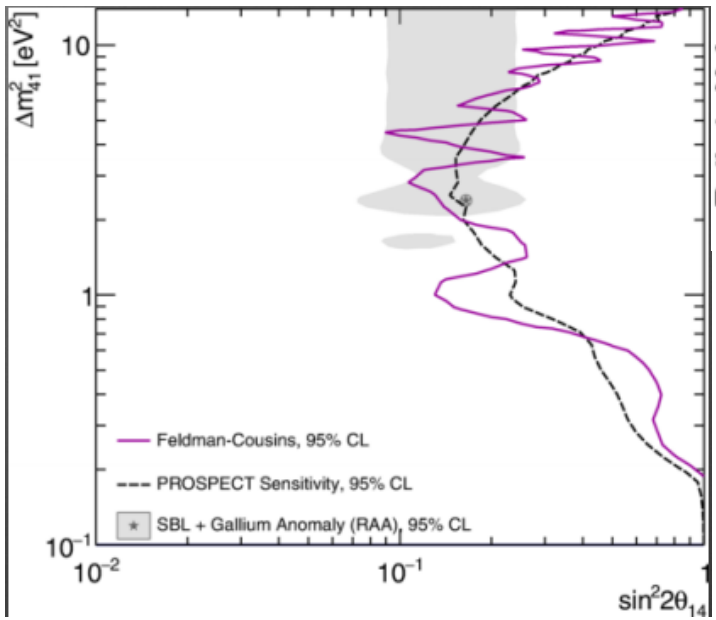
PROSPECT



- 85 MW HEU reactor (HFI, US)
- 4 tons ^{6}Li-doped scintillator
- Baseline: 6.7 m < L < 9.2 m
- 154 optically isolated segments
- Overburden: < 1 m w.e.





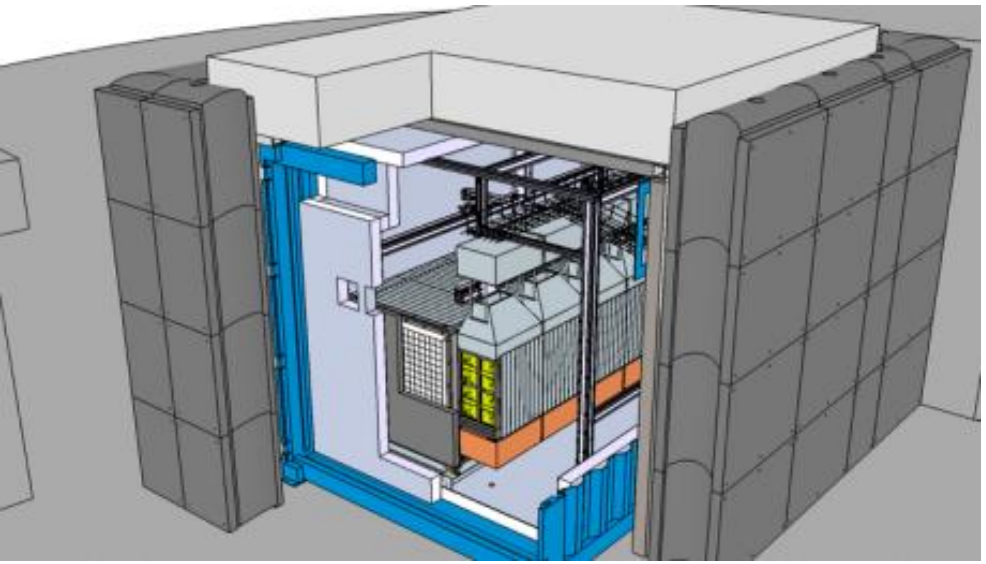


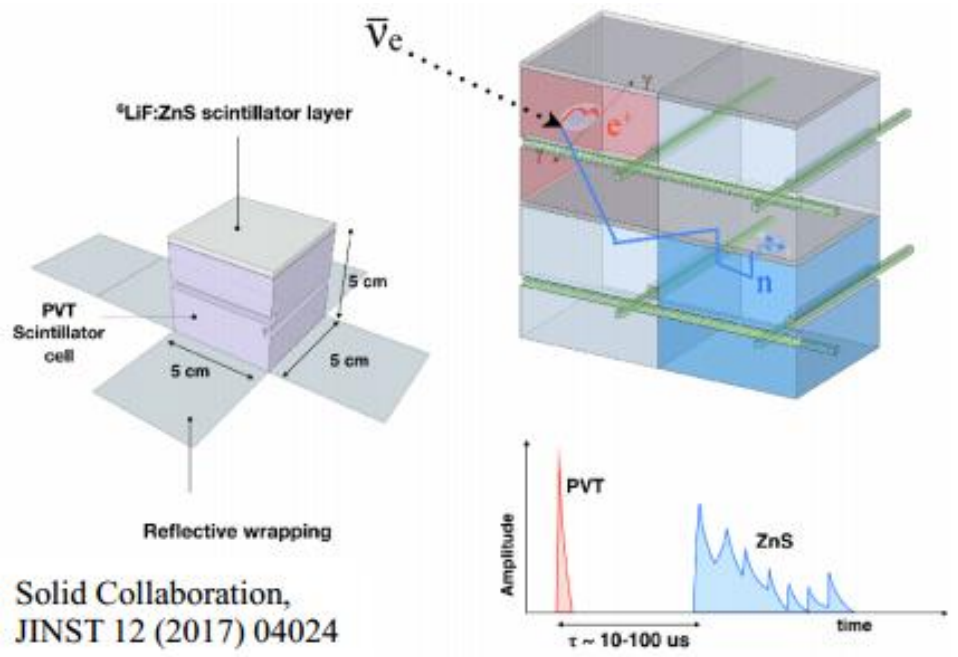
- 33 live days
- 25461 ± 283 IBD events

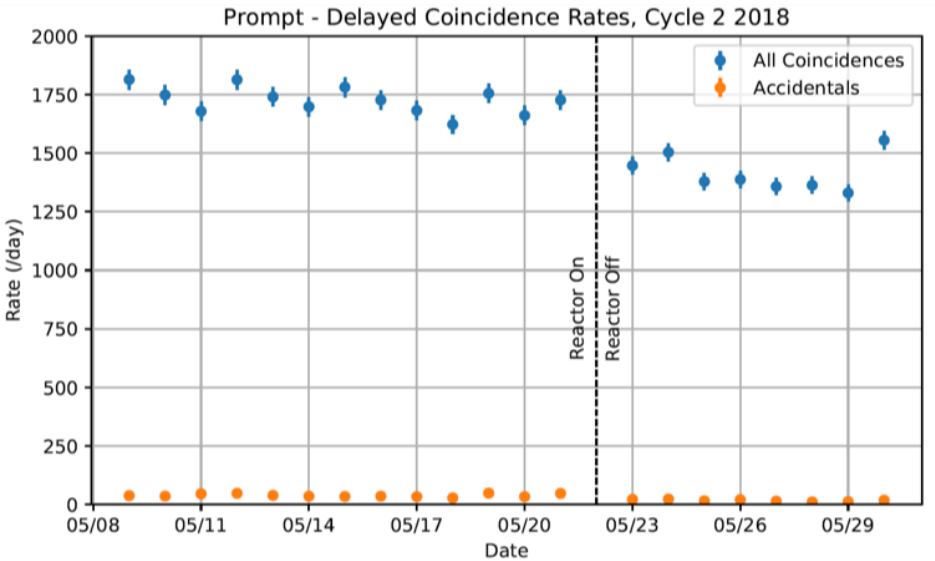
Prospect Collaboration, PRL 122 (2019) 251801

SoLiD

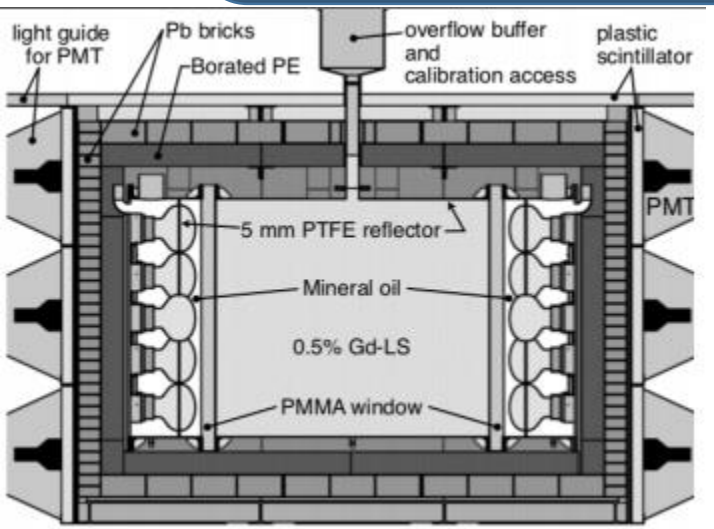
- 80 MW HEU BR2 reactor (Belgium)
- Baseline: 6-9 m
- New technology: Composite scintillator
- High segmentation (12800 cubes)
- Detector mass: 1600 kg



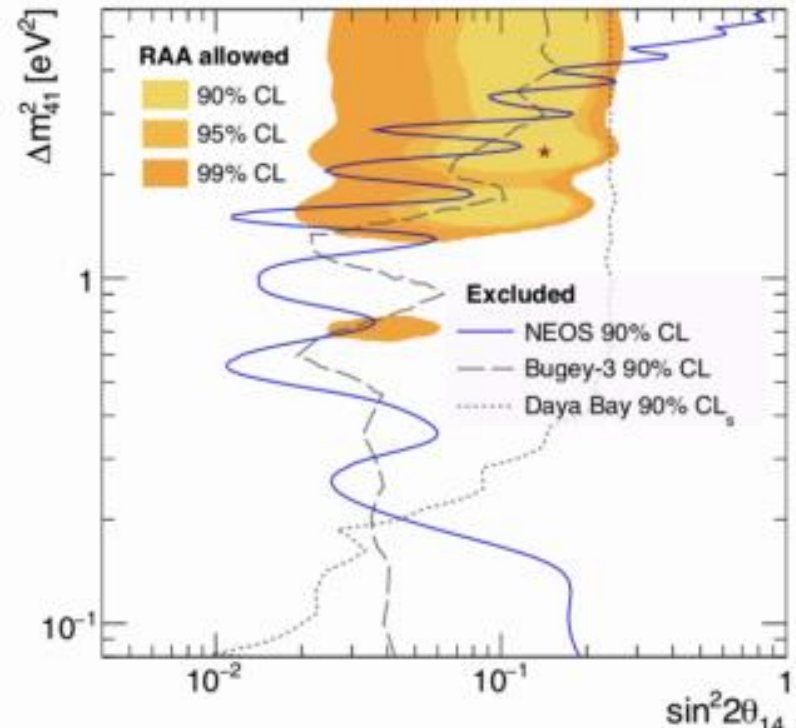




NEOS

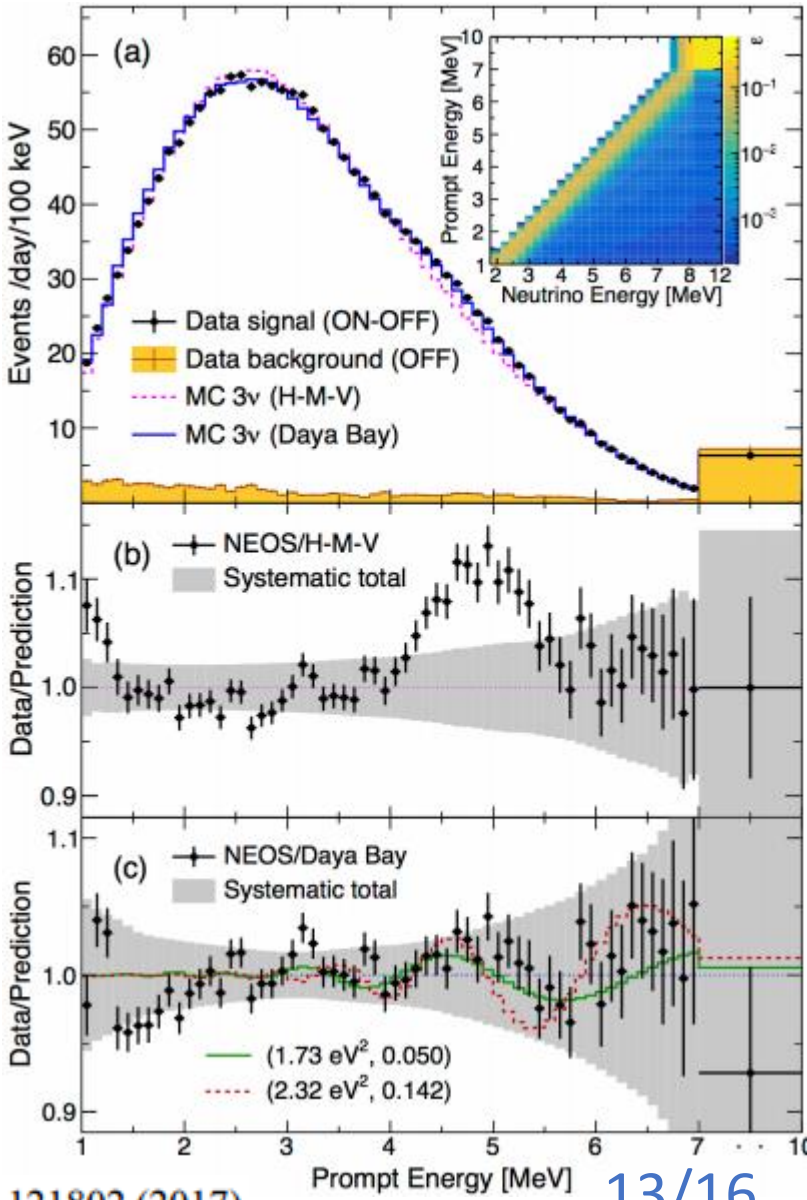


- Hanbit Power Plant (2.8 GW), Yeonggwang, Korea (RENO site)
- Phase I: Sep 2015 - May 2016 (180/46 live days with reactor on/off)
- Phase II: Running since Sep 2018 (goal 500 live days)



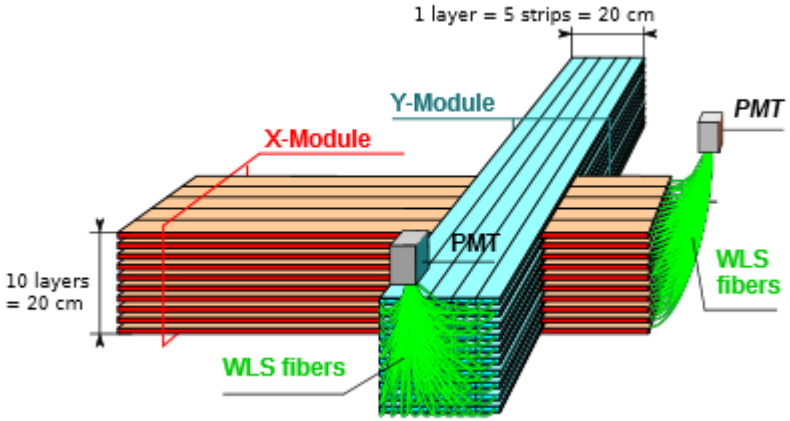
Bump at 5 MeV

Large part of the RAA parameter space excluded

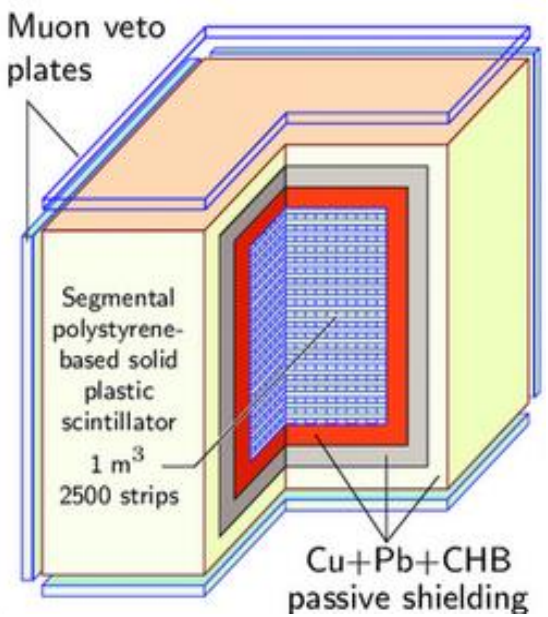


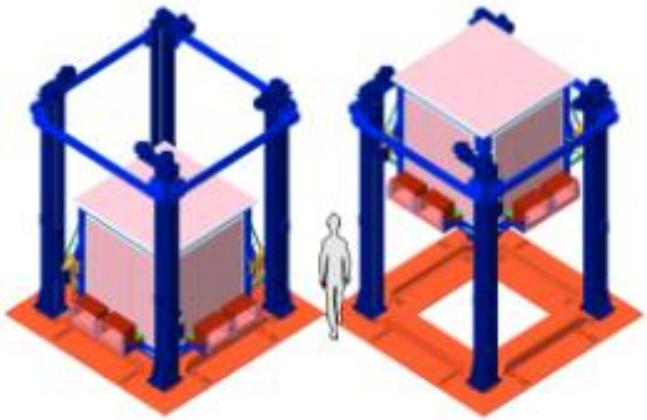
NEOS Collaboration, PRL 118, 121802 (2017)

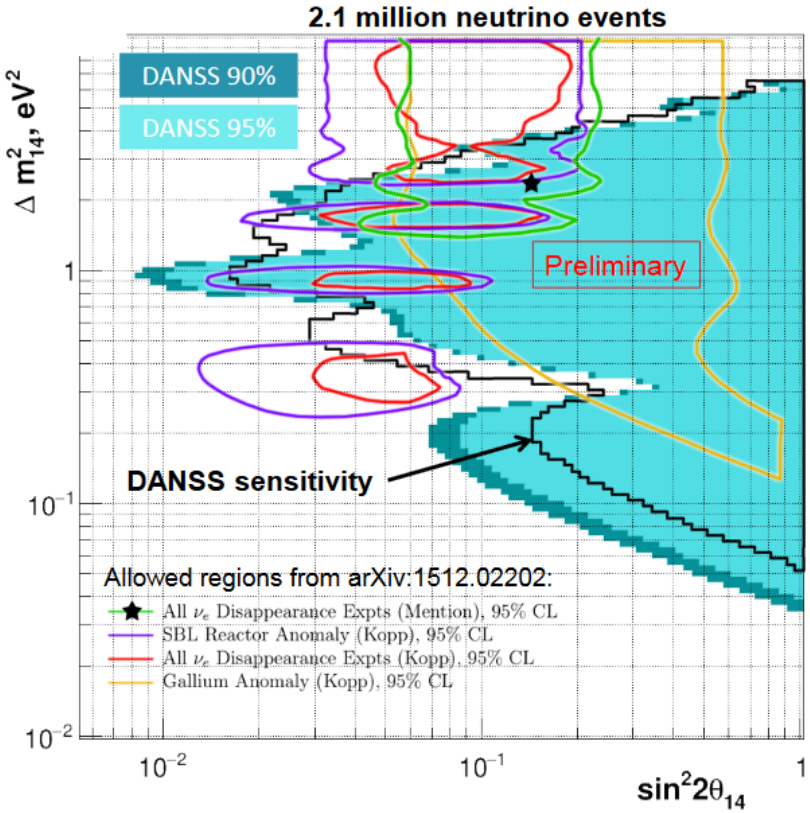
DANSS



- Kalinin Nuclear Power Plant (3.1 GW, LEU),
- 10.7 - 12.7 m baseline (moveable)
- 1 m3 plastic scintillator strips covered by Gd
- Low background site and high statistics (~5000 evts/day)

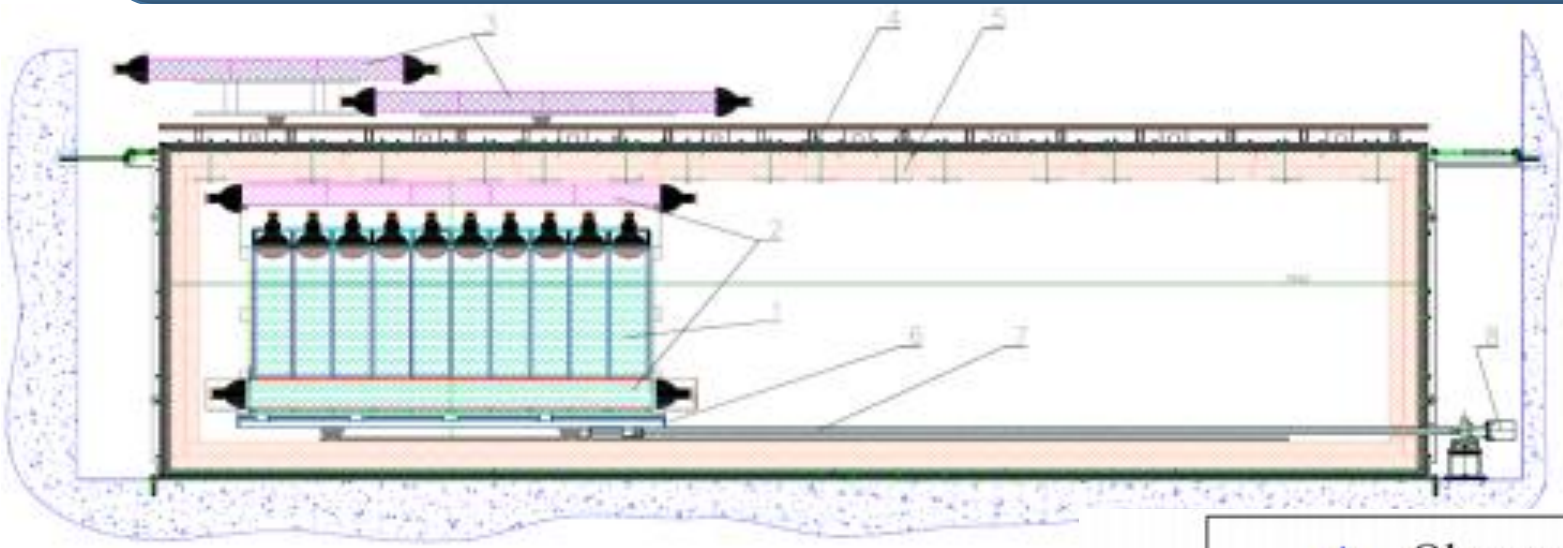




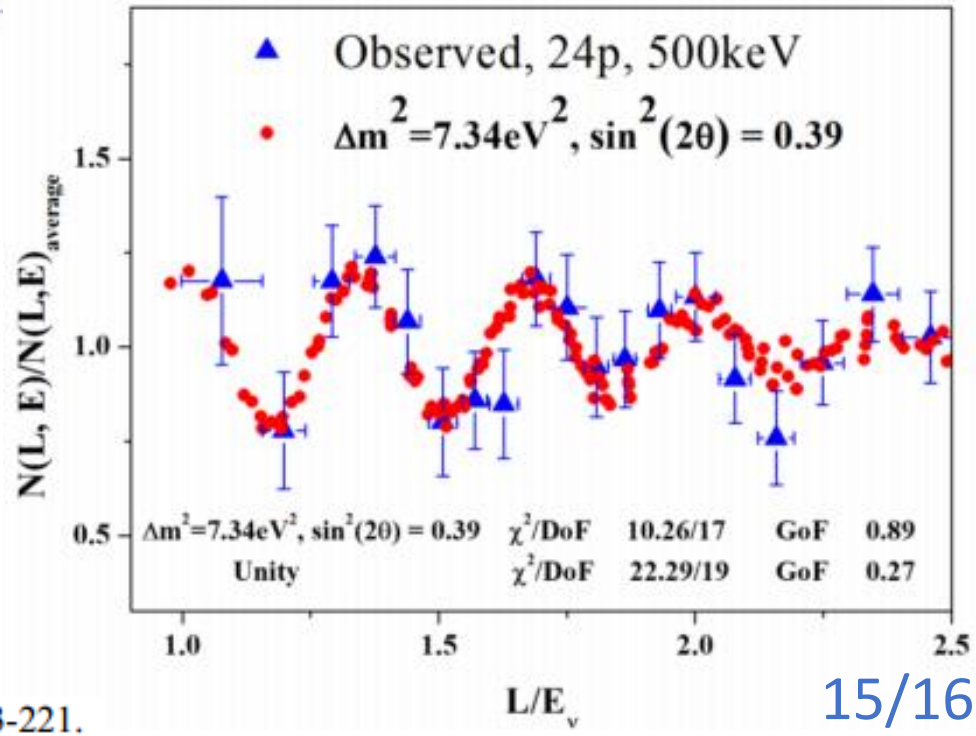


DANSS Collaboration, Phys.Lett. B787 (2018) 56-63

Neutrino4



- 100 MW SM-3 HEU reactor (Dimitrovgrad,Russia)
- Gd-loaded liquid scintillator (1.8 m^3)
- 6-12 m baseline (moveable platform)
- High cosmic background and lack of PSD (S/B ≈0.5)



3σ signal reported in 2018

Neutrino-4 Collaboration, JETP Letters 109 (2019) 213-221.

Conclusions

- First results of short baseline reactor experiments disfavor the sterile neutrino hypothesis: NEOS, DANSS, PROSPECT and STEREO exclude a large part of the RAA contour

- More results expected within 1 year:
  - the RAA parameter space should be fully covered
  - ^{235}U spectrum shape : bump or not bump?
  - spectrum absolute normalization

- Coherent Elastic Neutrino Nucleus Scattering (CENNS) will be the next generation of short baseline reactor experiments looking for new physics (sterile neutrinos, Z', neutrino magnetic moment,…)
  Need sub-keV threshold and good energy resolution