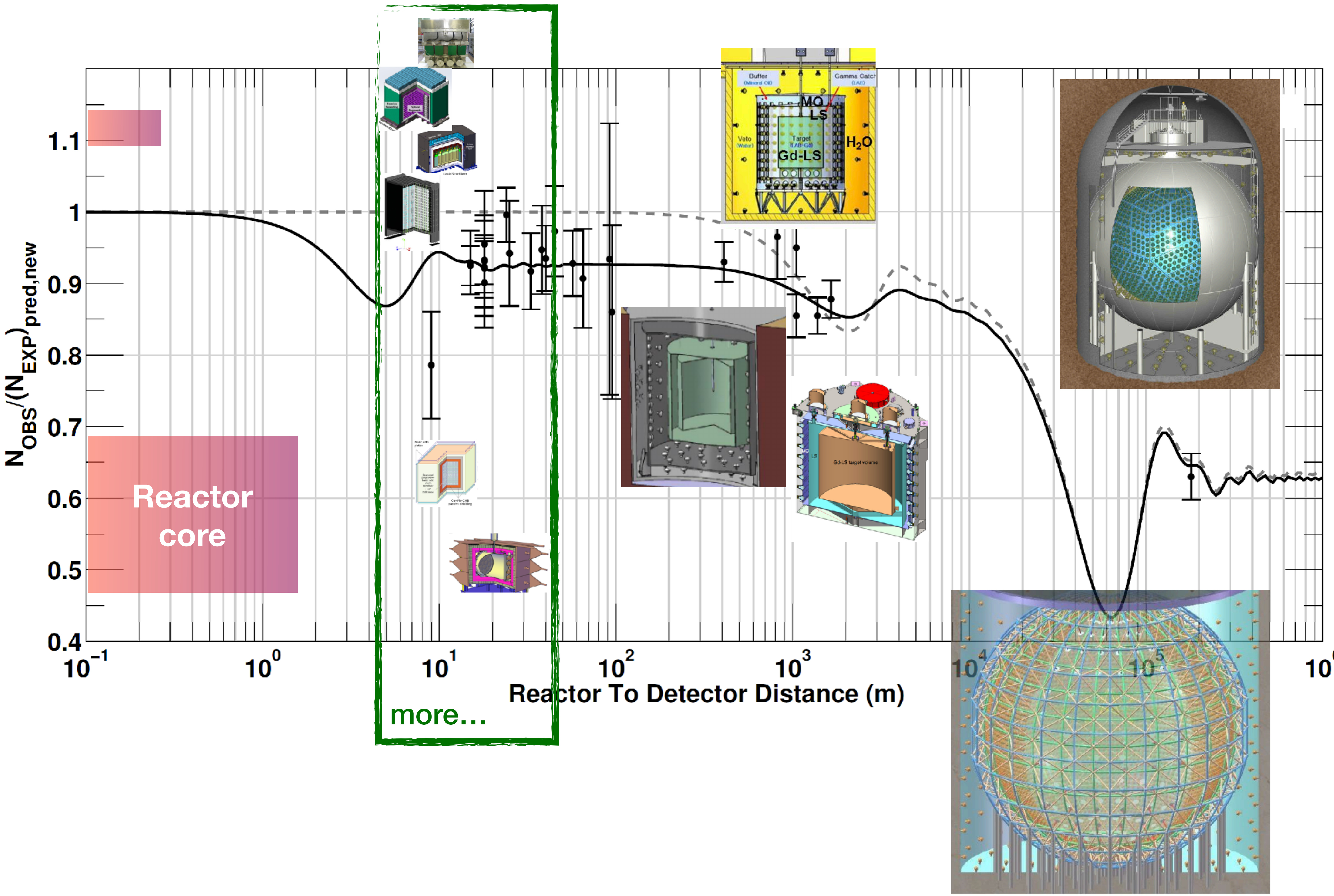
Reactor Short Baseline

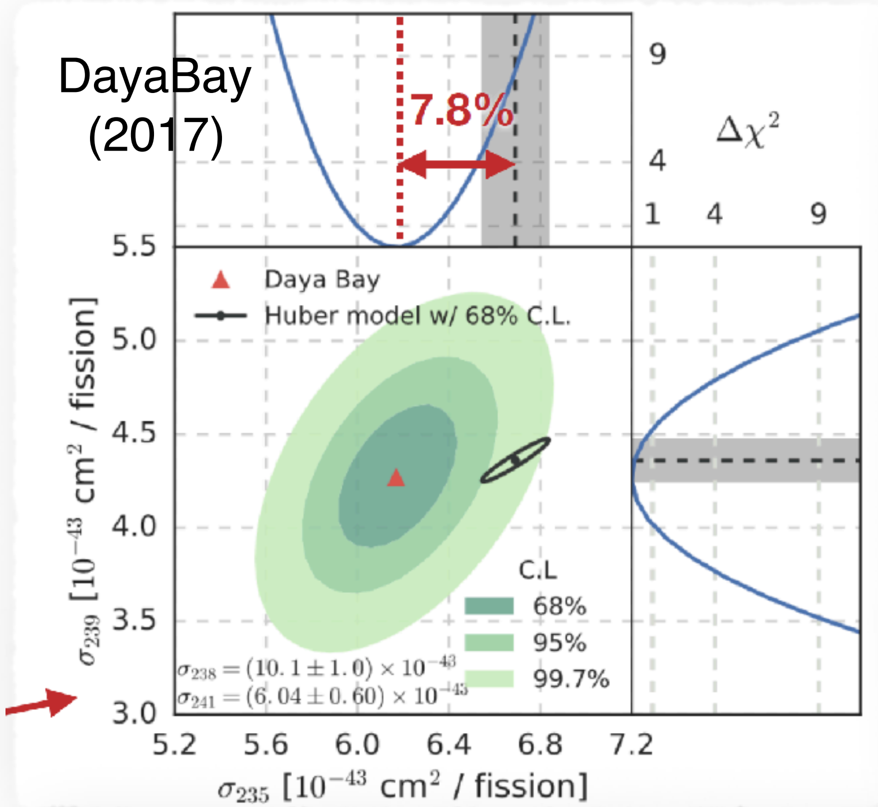
30 AUG 2019
NUFACT2019 @ Daegu, Korea

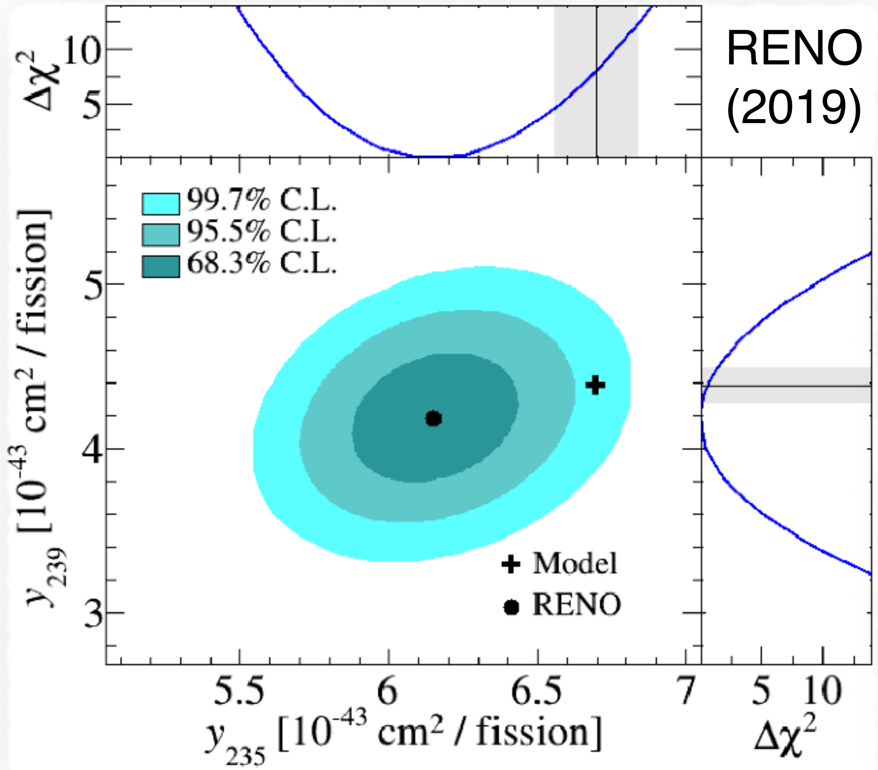
Yoomin Oh
NEOS Collaboration

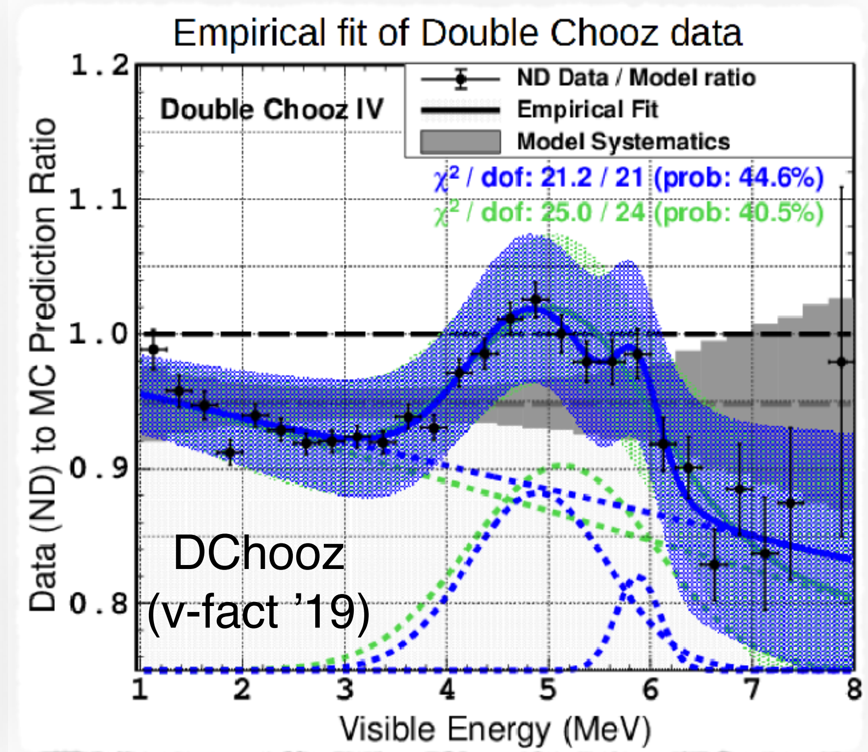


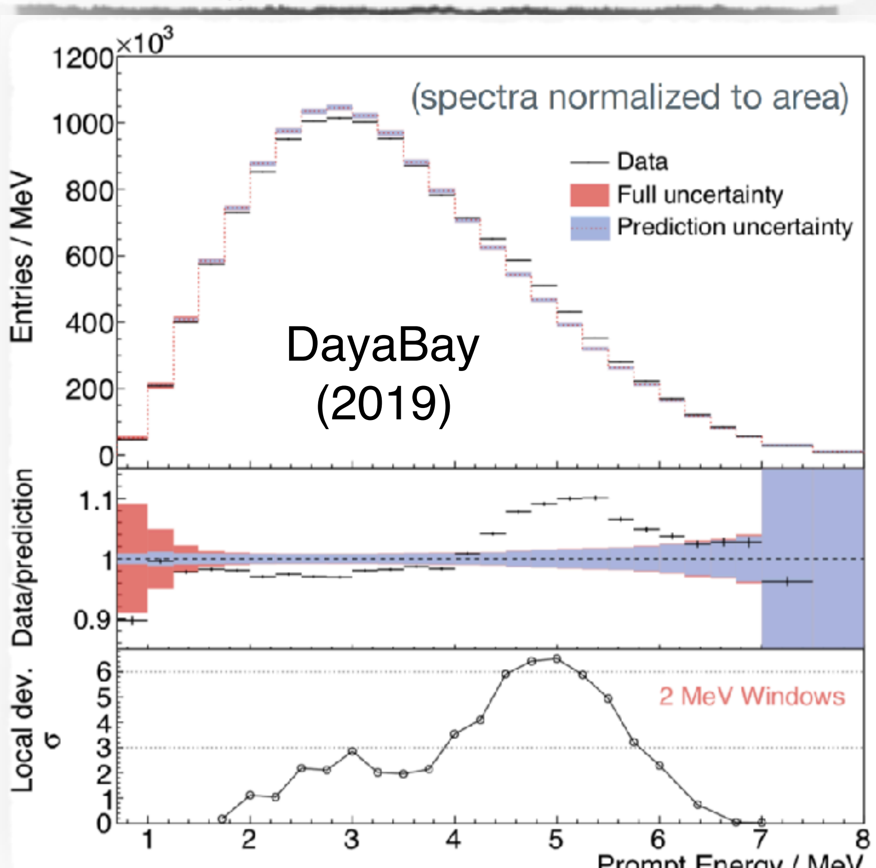
Reactor core
more...
Reactor To Detector Distance (m)
$N_{OBS}/(N_{EXP})_{pred,new}$
MO
LS
Gd-LS
H_2O

Origin of the anomaly?



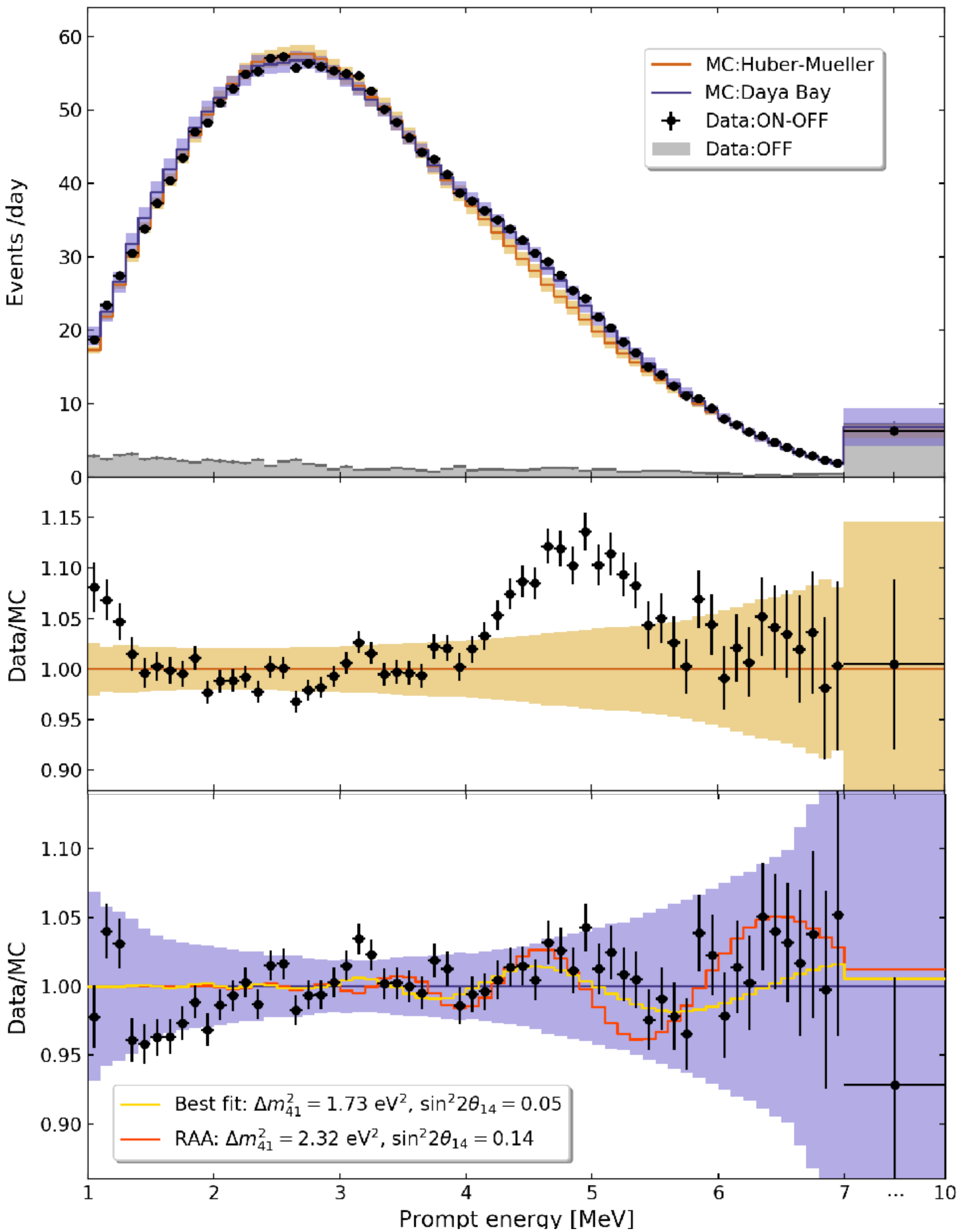


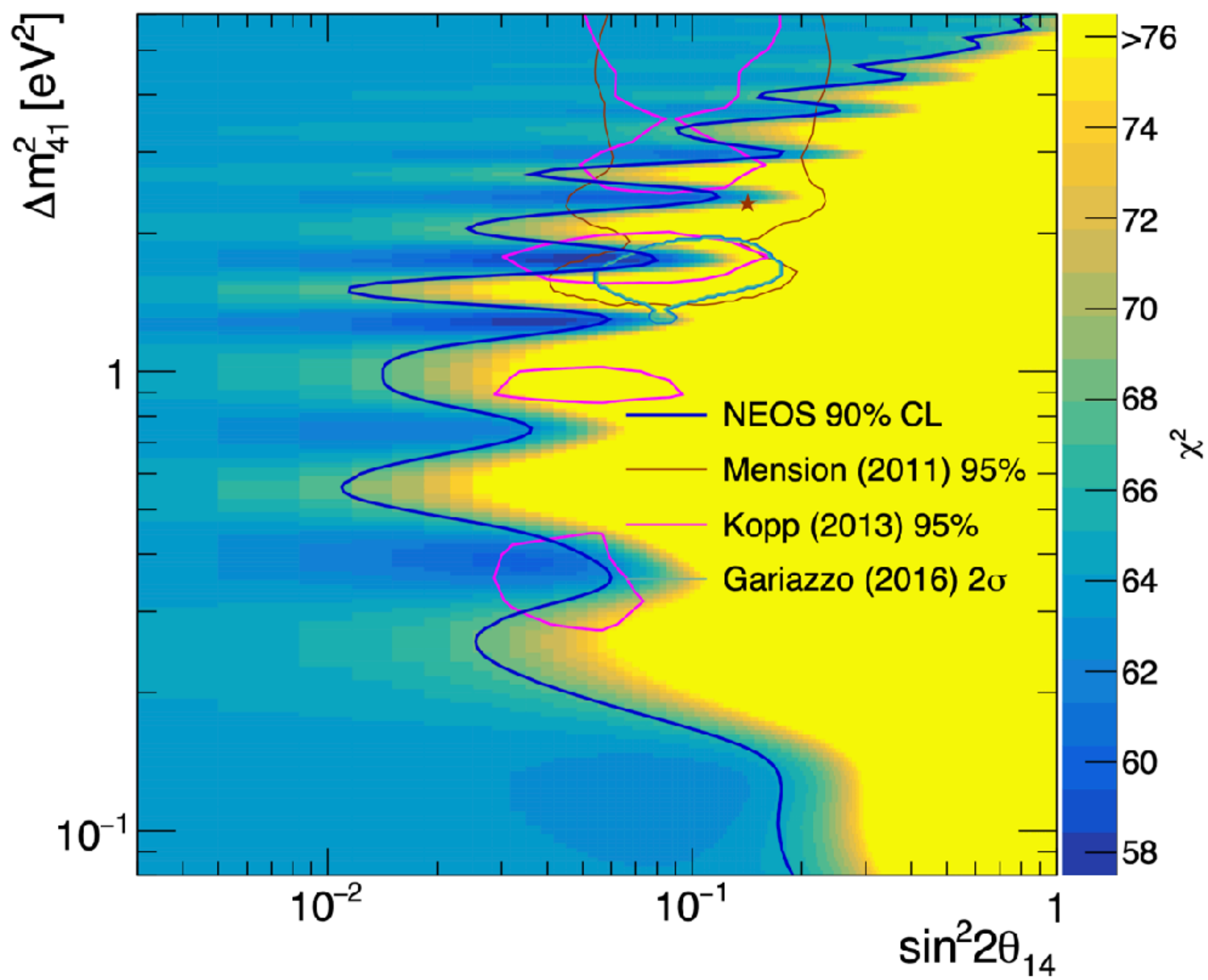




- Disagreement in rate and shape, at hundreds of meters distances from LEU reactors.
- Not likely an energy scale problem.
- Should have been checked with SBL data.

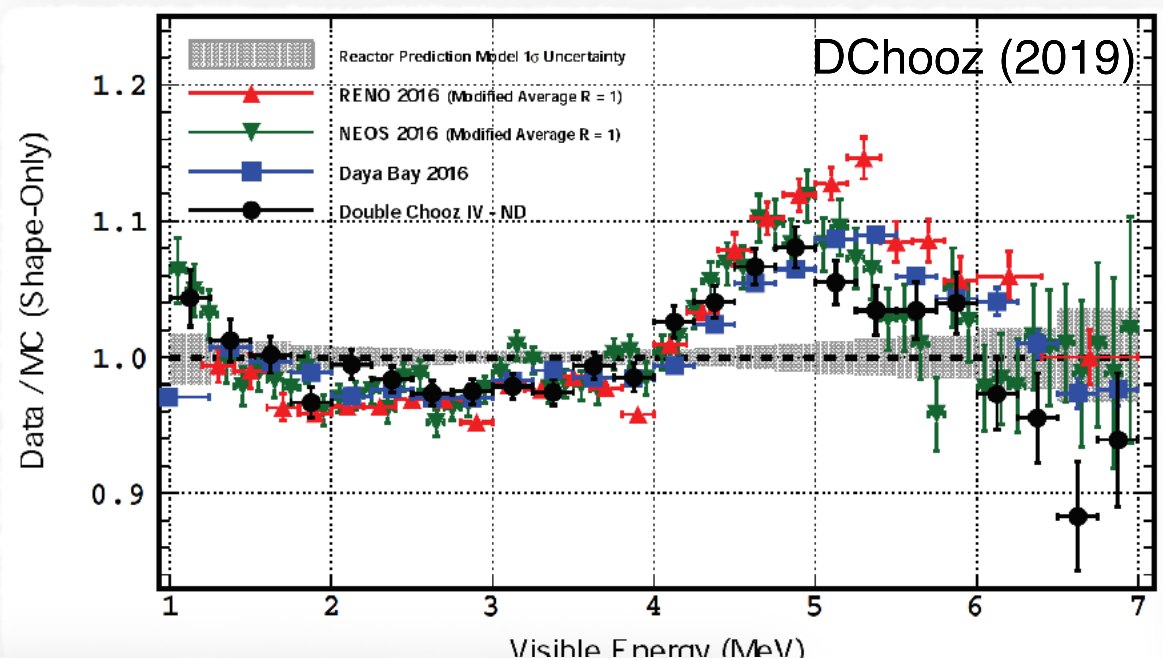
NEOS in 2017

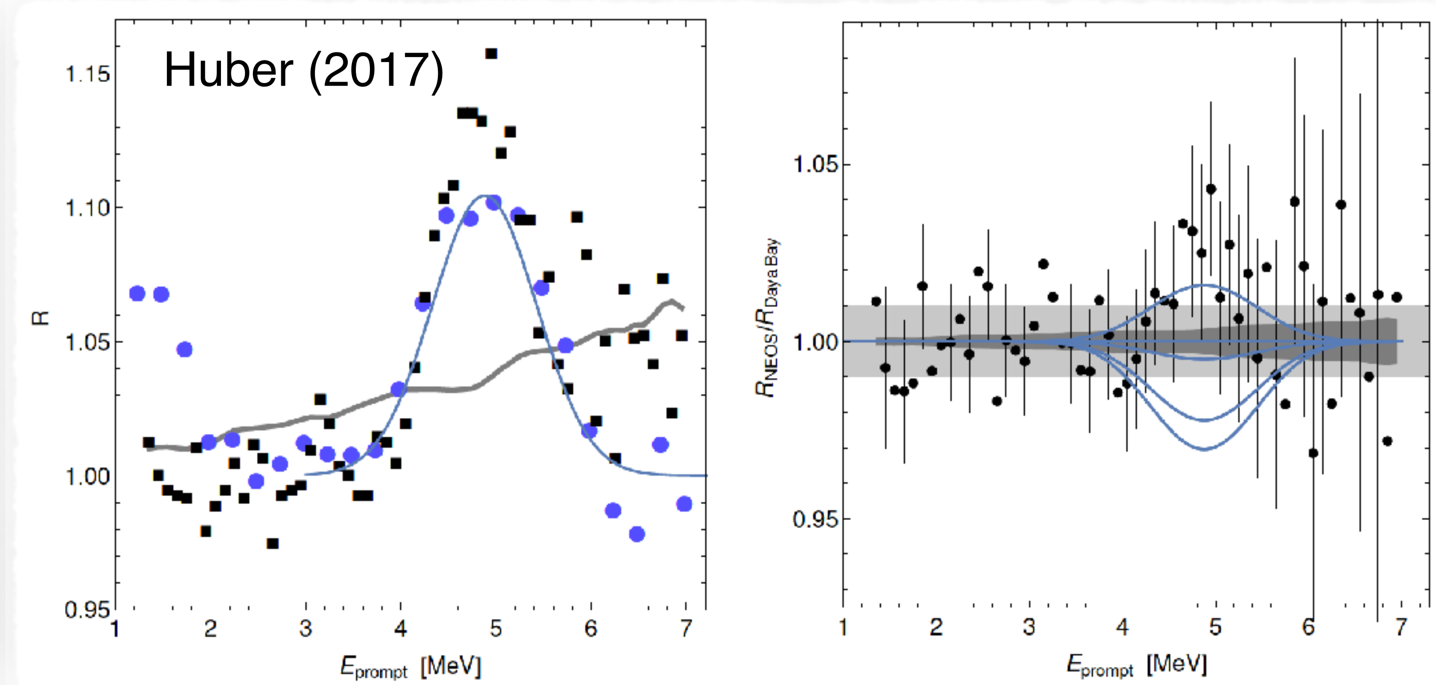


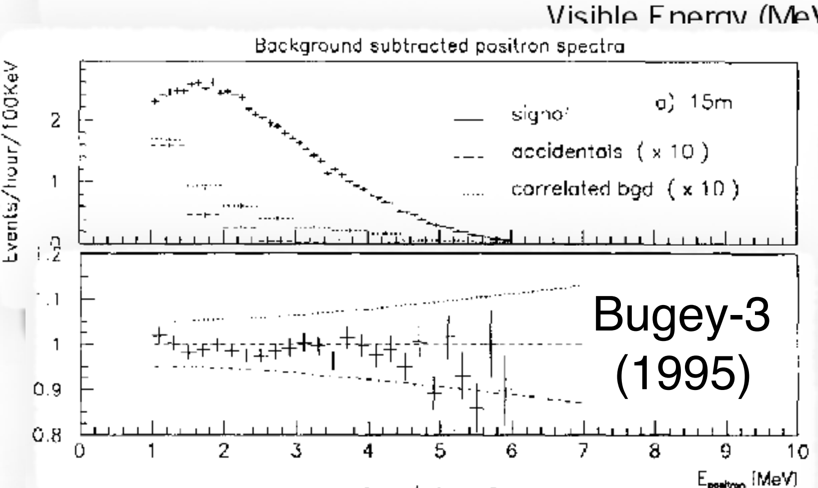


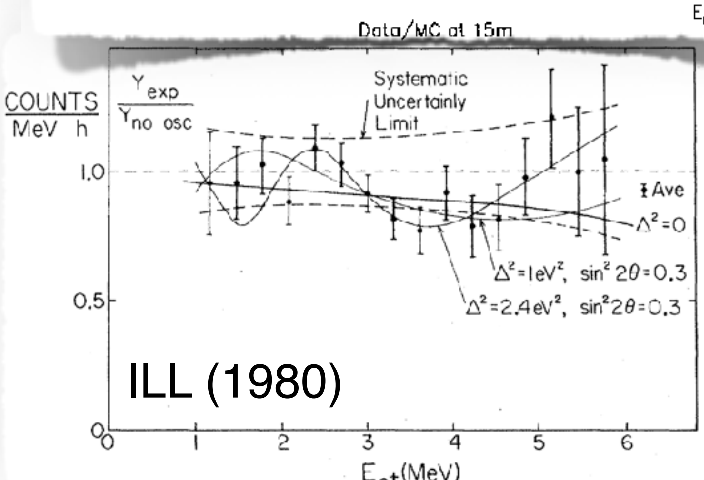
- LEU reactor, 24 m distance.
- Bump is there.
- Found no strong evidence of active-to-sterile oscillation, compared to Daya Bay spectrum.

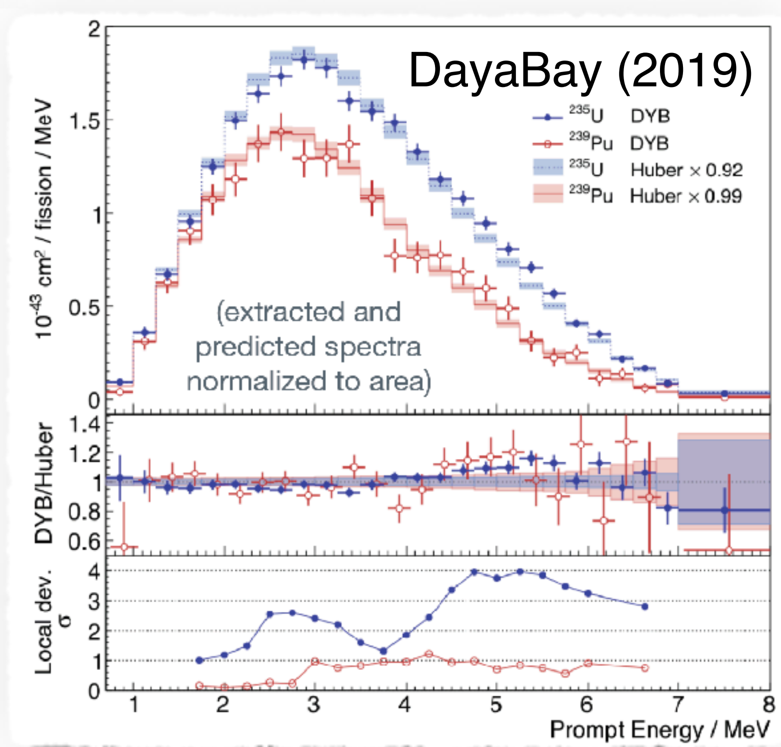
"Bumpology" -P. Huber

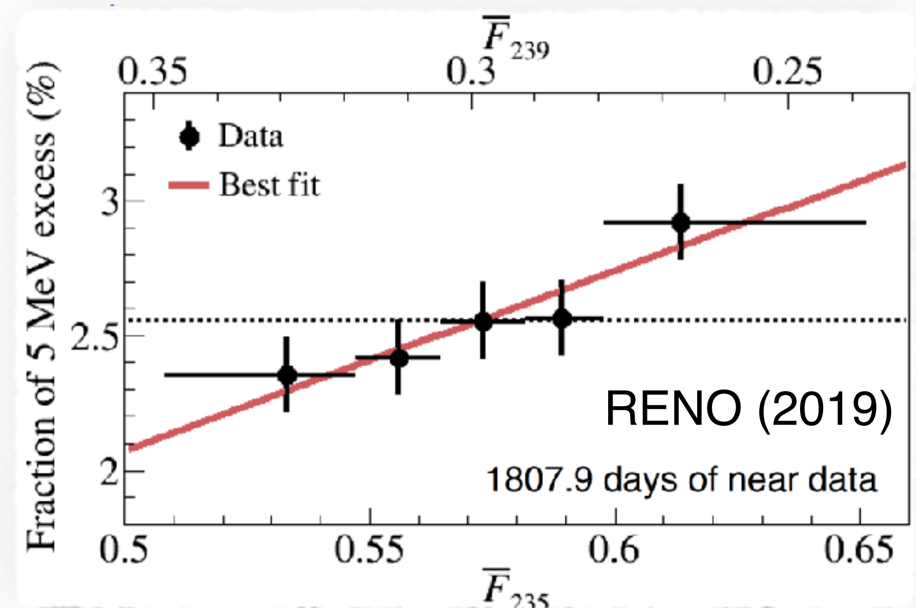




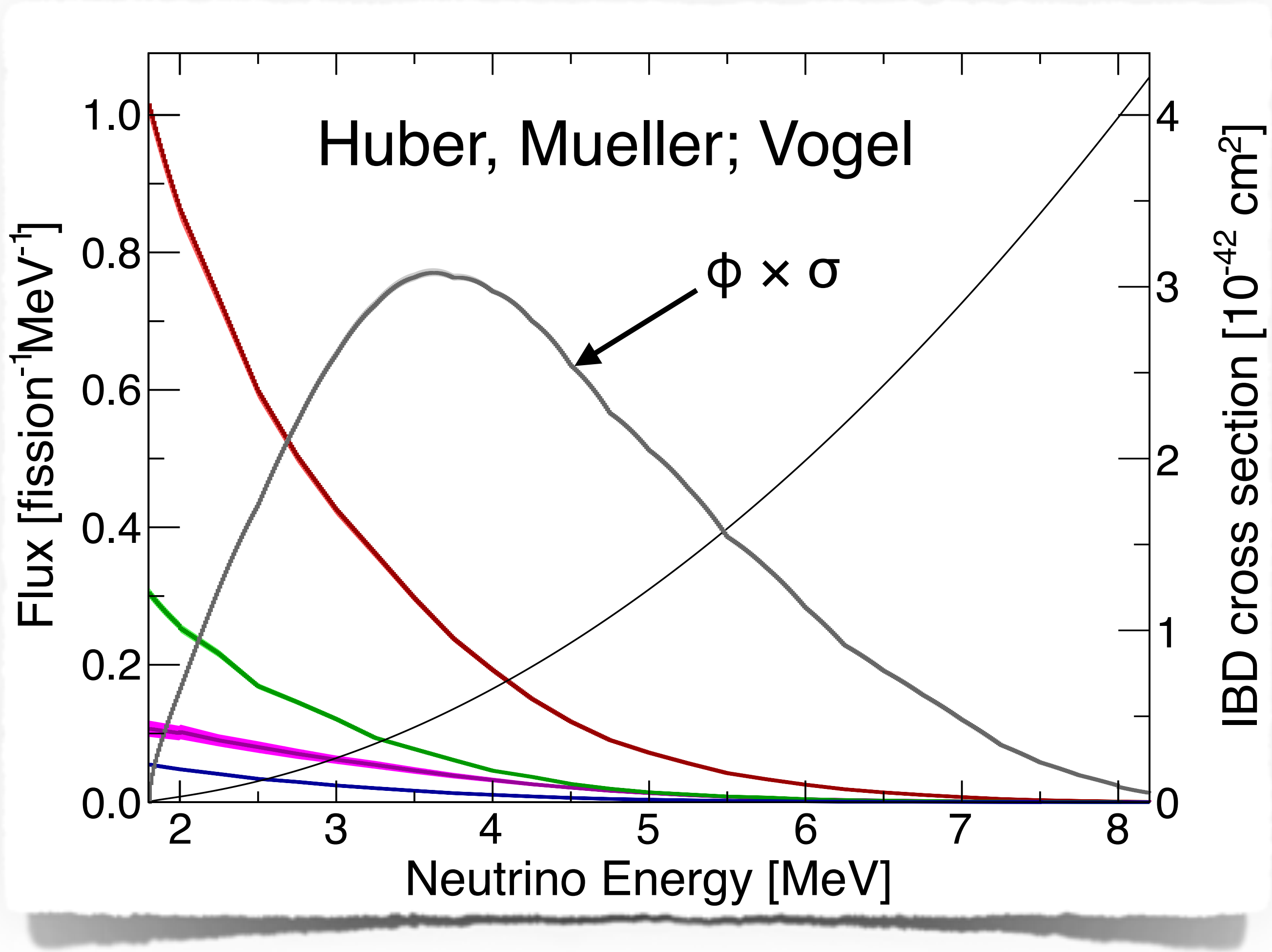


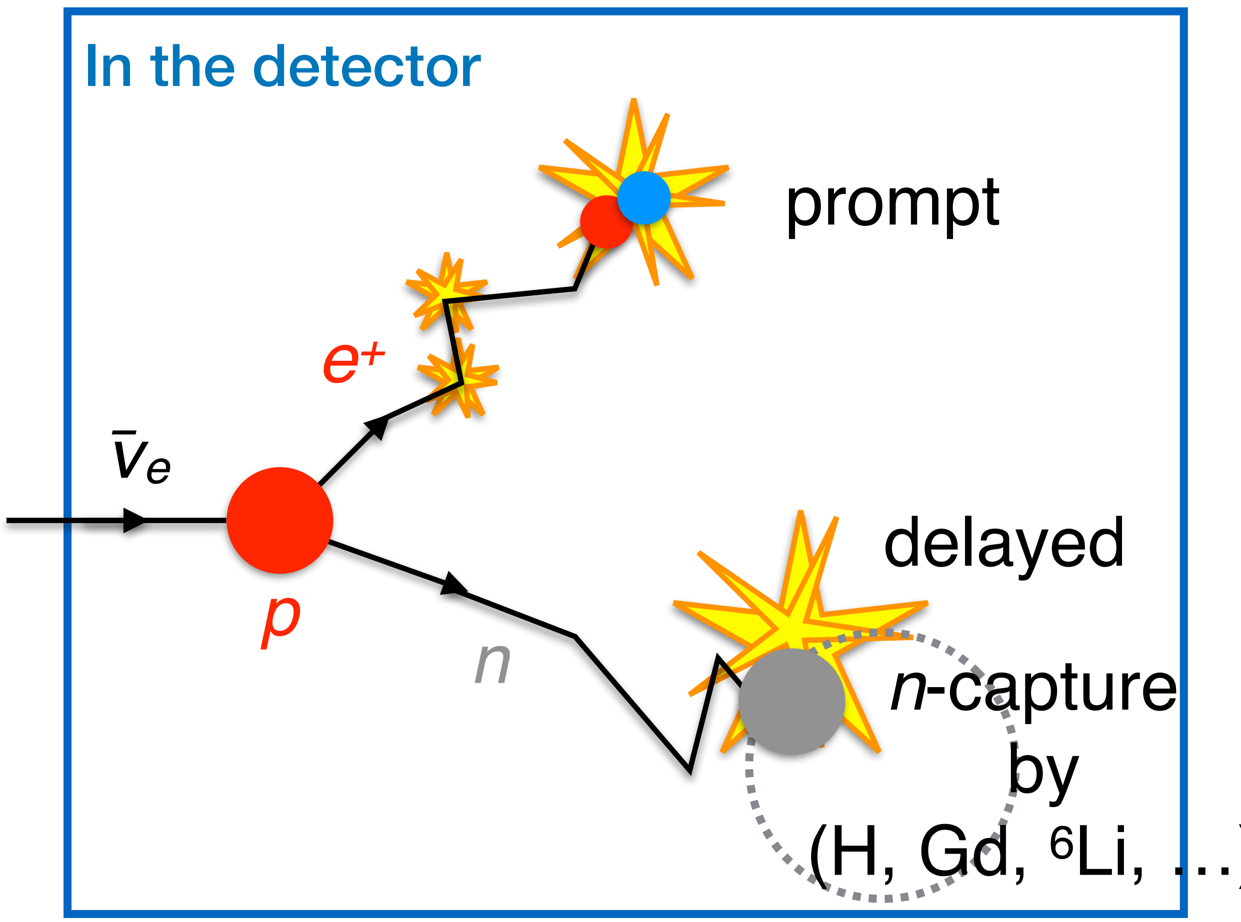






Nuclear reactor as anti-nu factory





- Average of 6, 7 β-decays and anti-ν's from a fission of an element.
- 2 x 10^{20} ν / 4π / GWt
  - O(10k) inverse beta decay events occurs in 1000 kg of organic scintillator with 10% mass of hydrogen atom at 10 m distance from a GWs thermal power reactor.

Characteristics of reactor ν-SBL

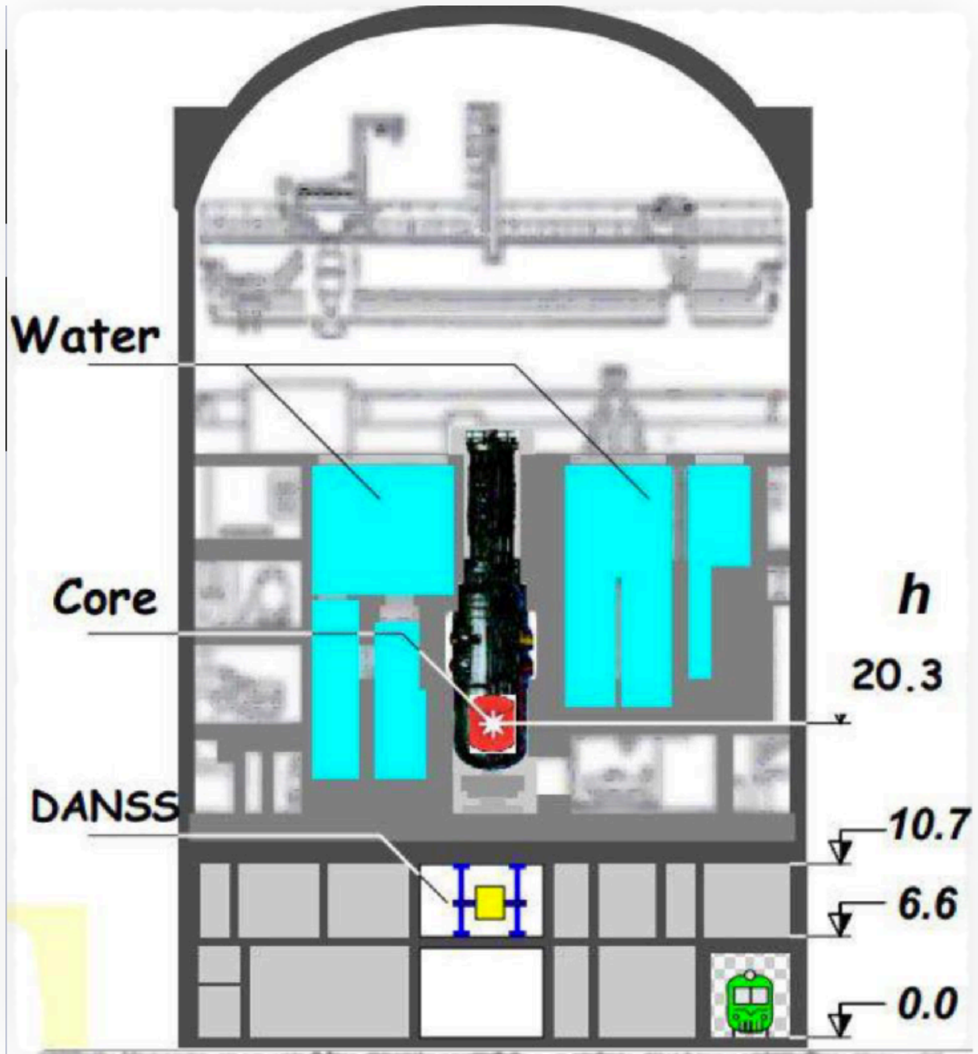
- Single reactor core - ON-OFF, relatively easier to handle fuel data.

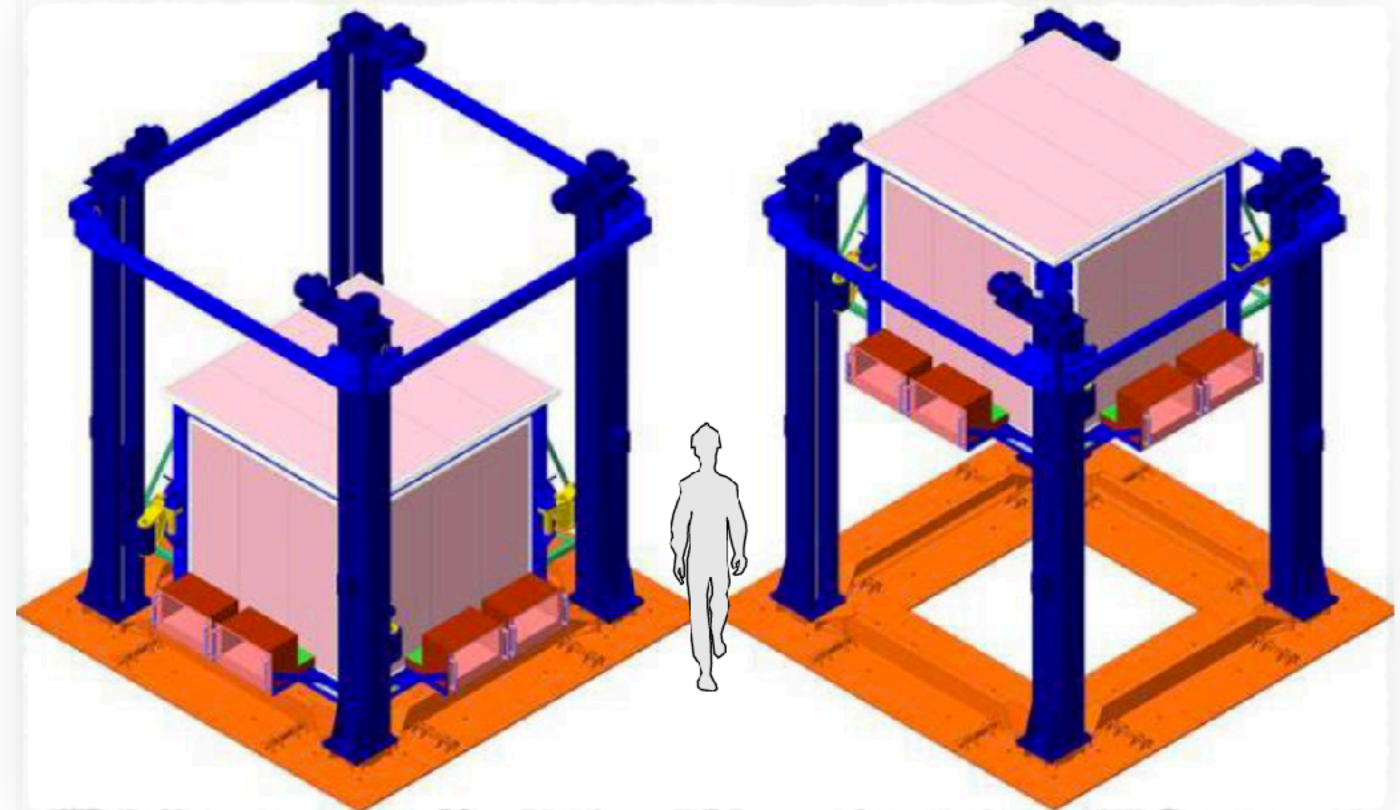
- Limited space - small detector - energy leaks,
- Bare overburden, not enough shielding - high background level (cosmic + reactor).
- Difficult (or impossible) to monitor on-line.

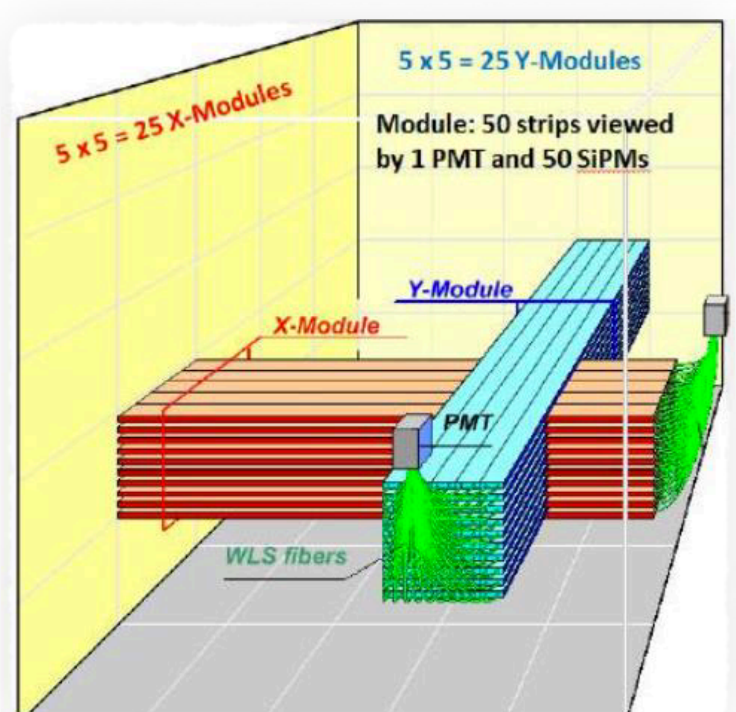
- Segmentation
  - distance (L) resolution
  - selective fiducial volume
- Pulse shape discrimination
  - distinguish electron, gamma events from fast neutron scattering events (prompt) or n-capture (delayed).

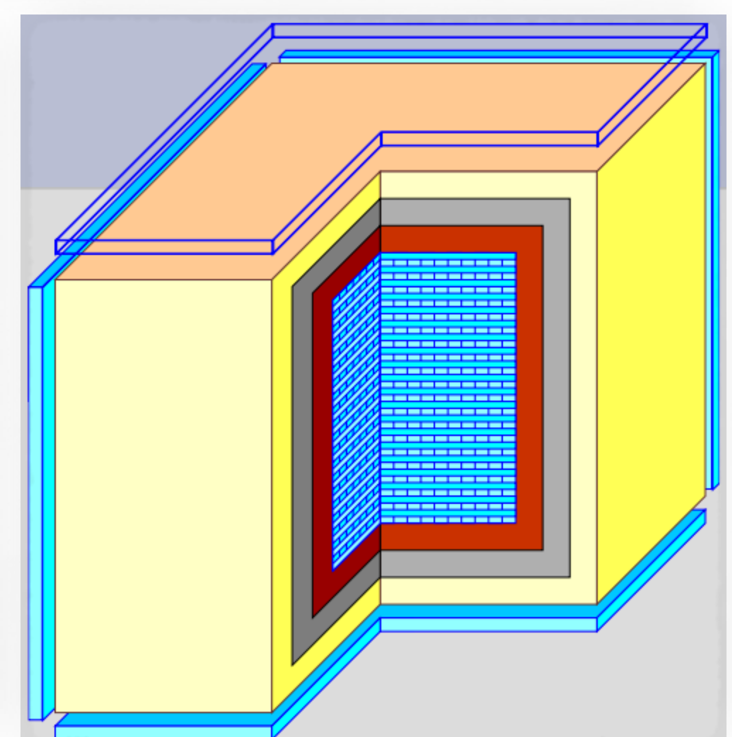
Experiment	Reactor	Baseline	Detector
DANSS	Commercial (KNPP), LEU, 3.1 GWt, Φ3.1 x H3.6 m	10.7~12.7 m	$1 m^3$ highly segmented plastic scintillator + Gd sheet movable detector
NEOS	Commercial (Hanbit-5), LEU, 2.8 GWt, Φ3.1 x H3.8 m	23.7 m	1000 L homogeneous Gd-LS, PSD
Neutrino-4	Research (SM-3), HEU, 100 MWt, 42 x 42 x 35 cm	6-12 m	$1.42 m^3$ segmented Gd-LS, Movable detector
PROSPECT	Research (HFIR), HEU, 85 MWt, Φ0.4 x H0.5 m	7 m	3000 L semented 6Li-LS, PSD
STEREO	Research (ILL) HEU, 58.3 MWt Φ40 x H80 cm	10.3 m	1800 L segmented Gd-LS, PSD
Solid	Research (BR-2), HEU, 50-80 MWt, Φ50 x H90 cm	6-9 m	tons of plastic scintilllator cubes + LiF:ZnS sheet. PSD

DANSS LP2019



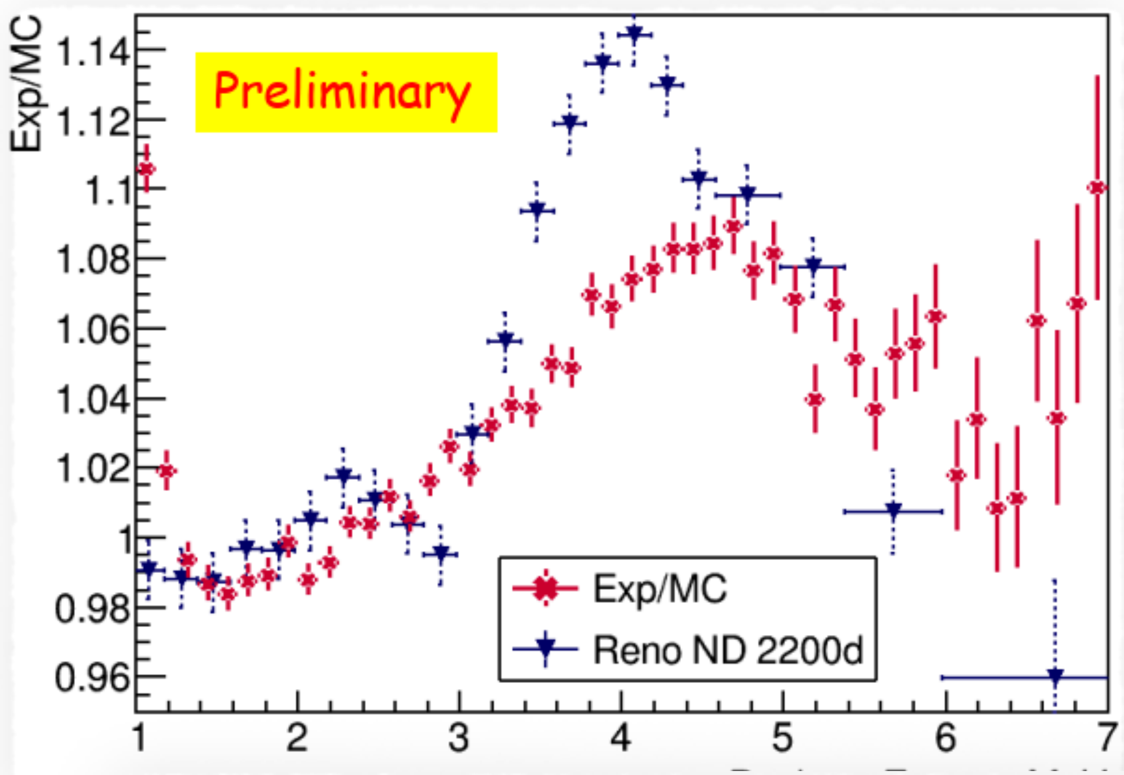




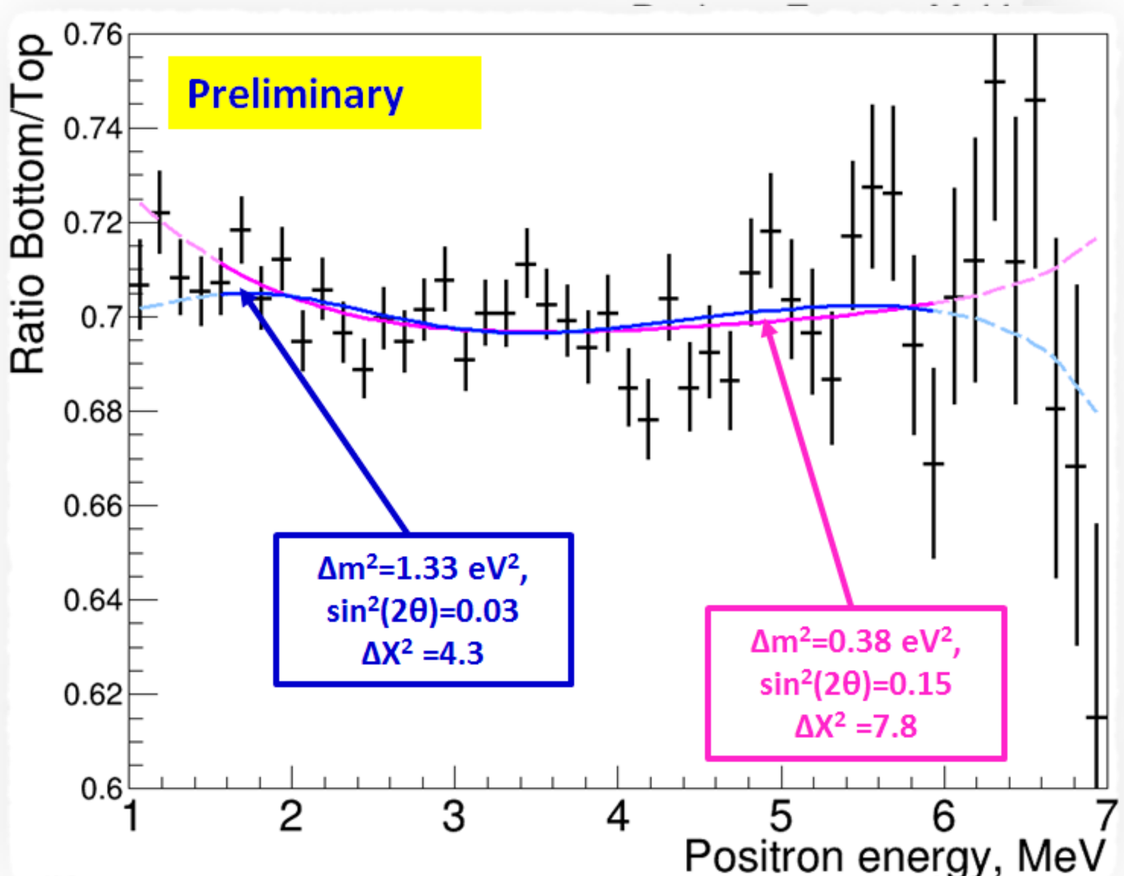


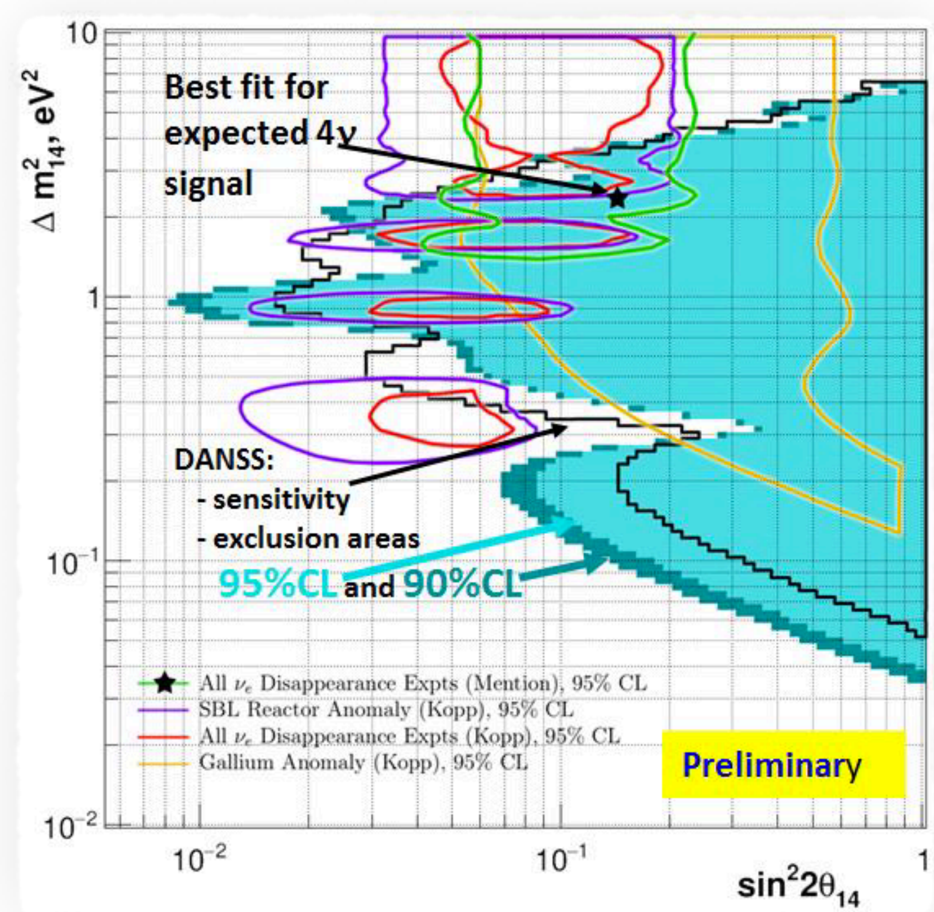
- Commercial 3.1 GWt reactor
- Detector moves between 10.7~12.7 m
- Extruded plastic scintillator strips covered with Gd sheets.

DANSS LP2019

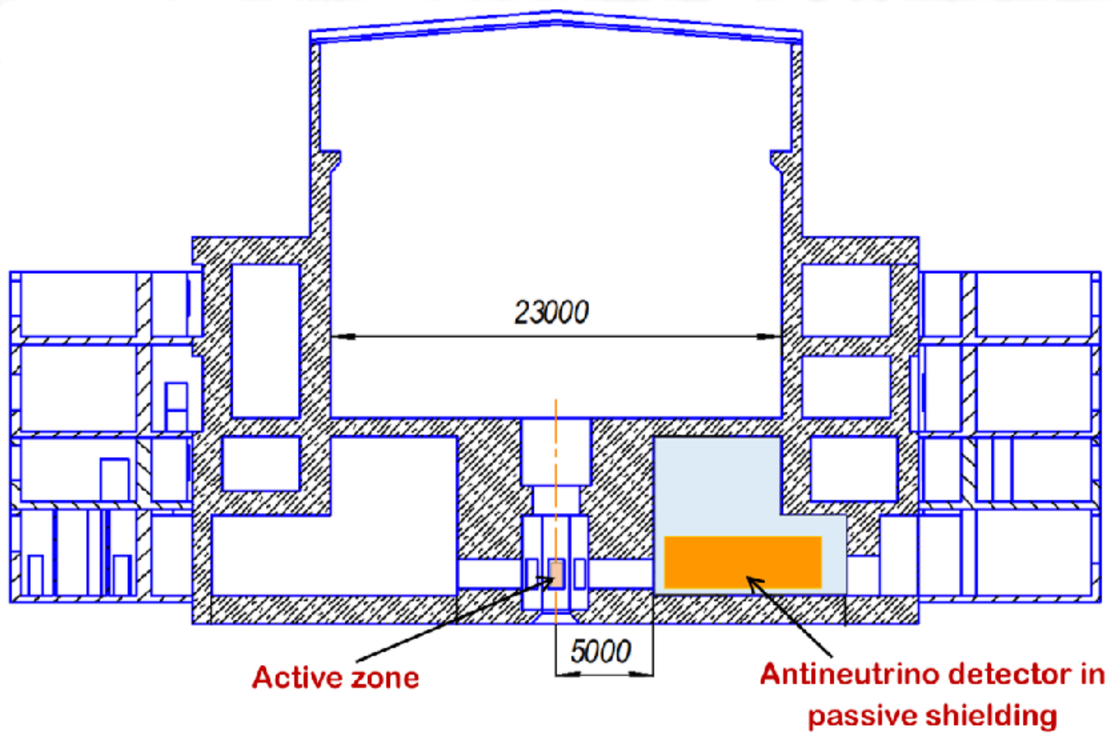


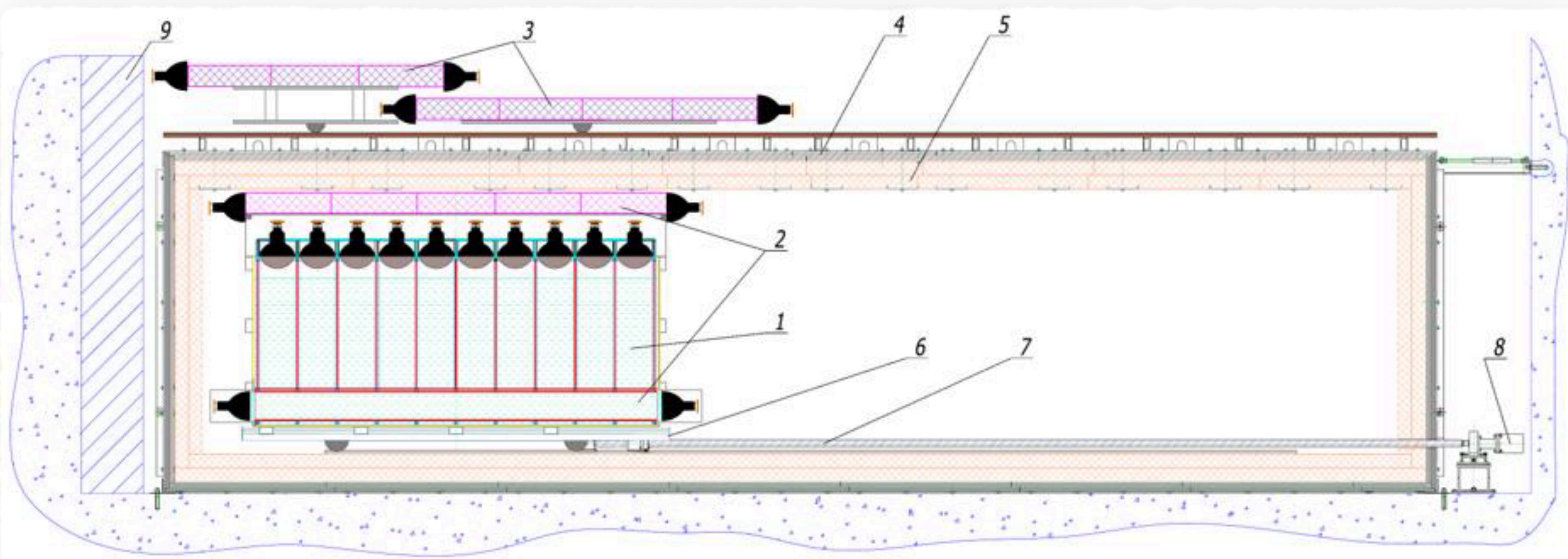
- Large statistics (~4k IBD/day).
- Not a good energy resolution.
- Updated (preliminary) result shows a sign of bump, and no sign for SBL oscillation.



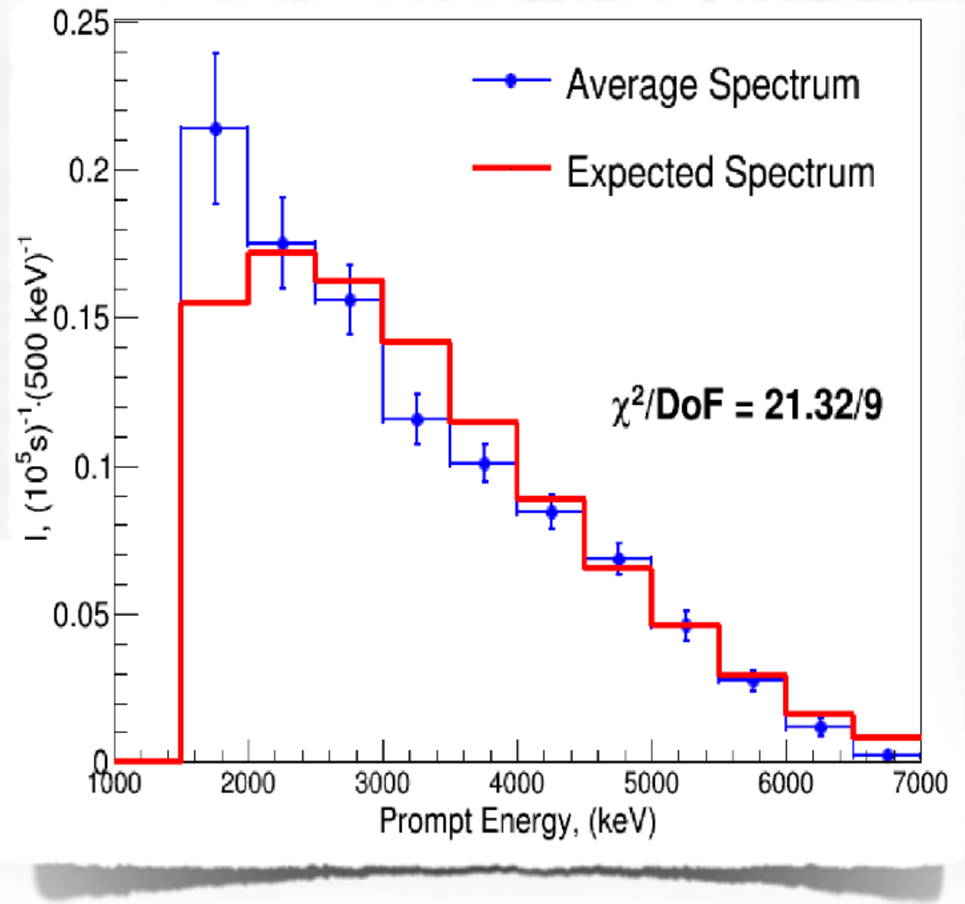


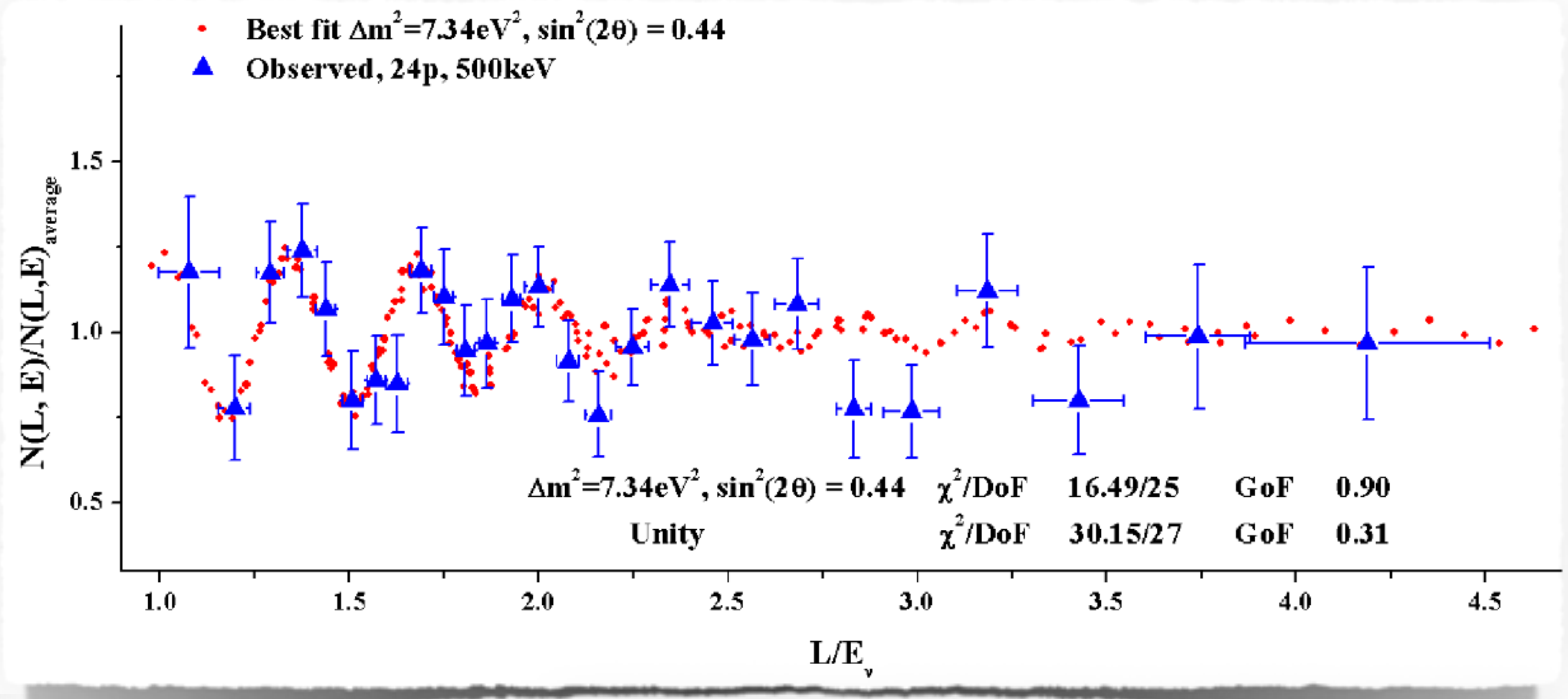
Neutrino-4 AAP2018

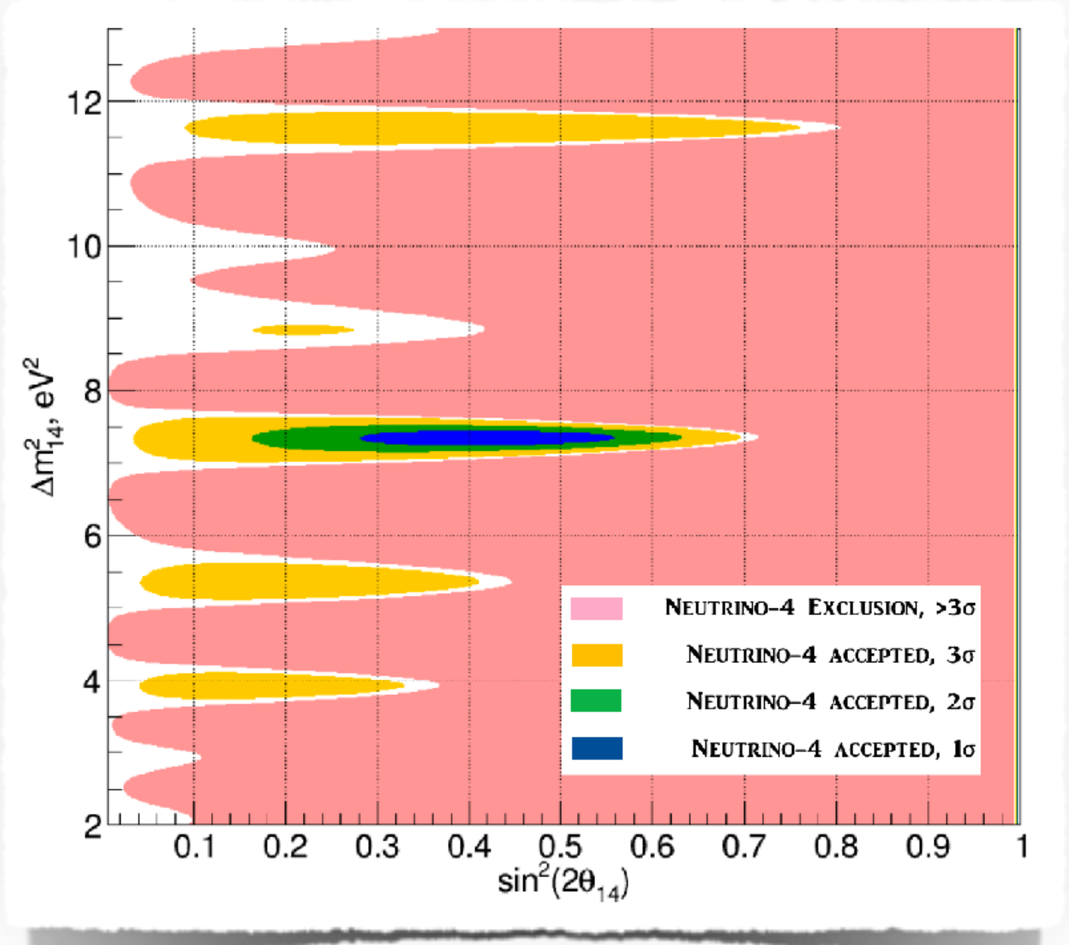




Neutrino-4 AAP2018



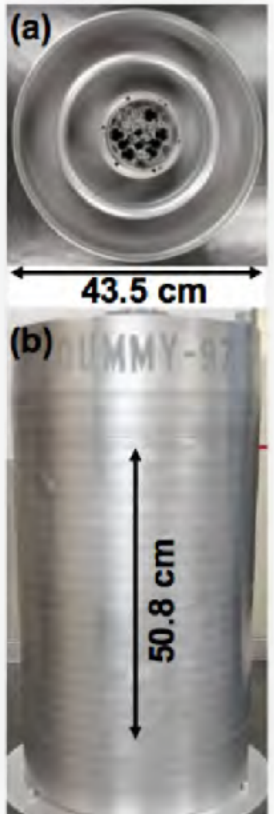


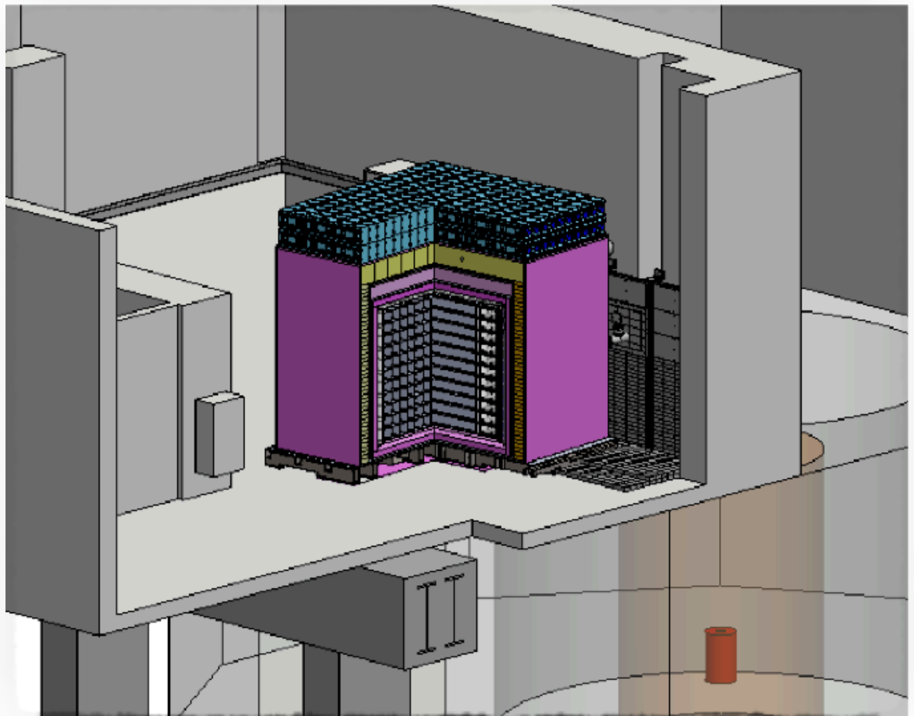


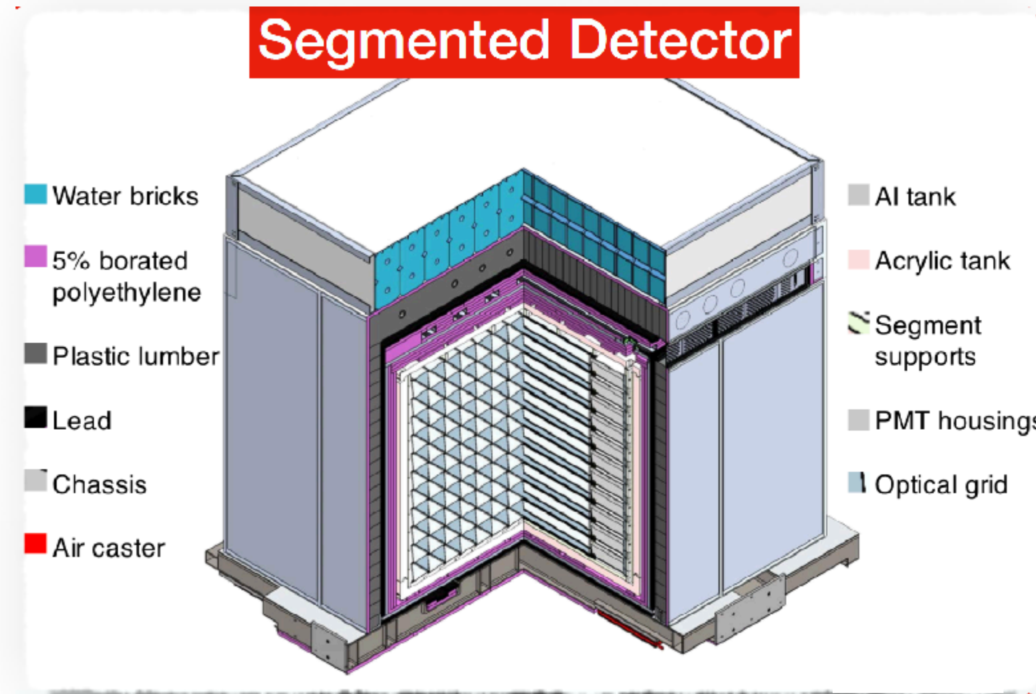
- Surprising result in L/E spectrum.
- Distortions in the averaged spectrum
- χ^2/NDF for no-osc not that bad.
- Needs more systematic/statistical improvement.

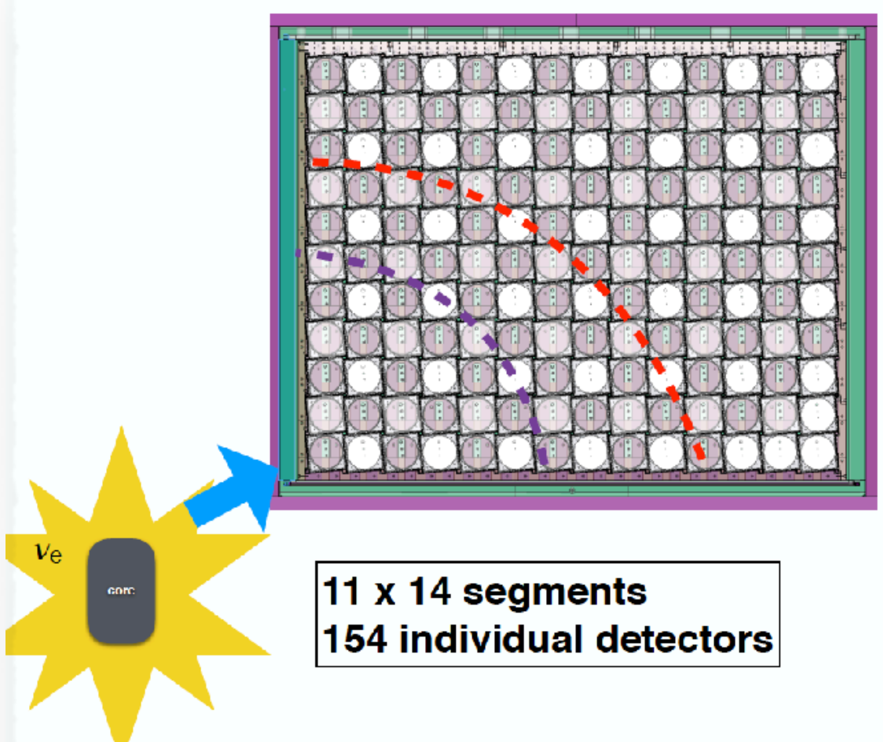
PROSPECT
Precision Oscillation and Spectrum Experiment

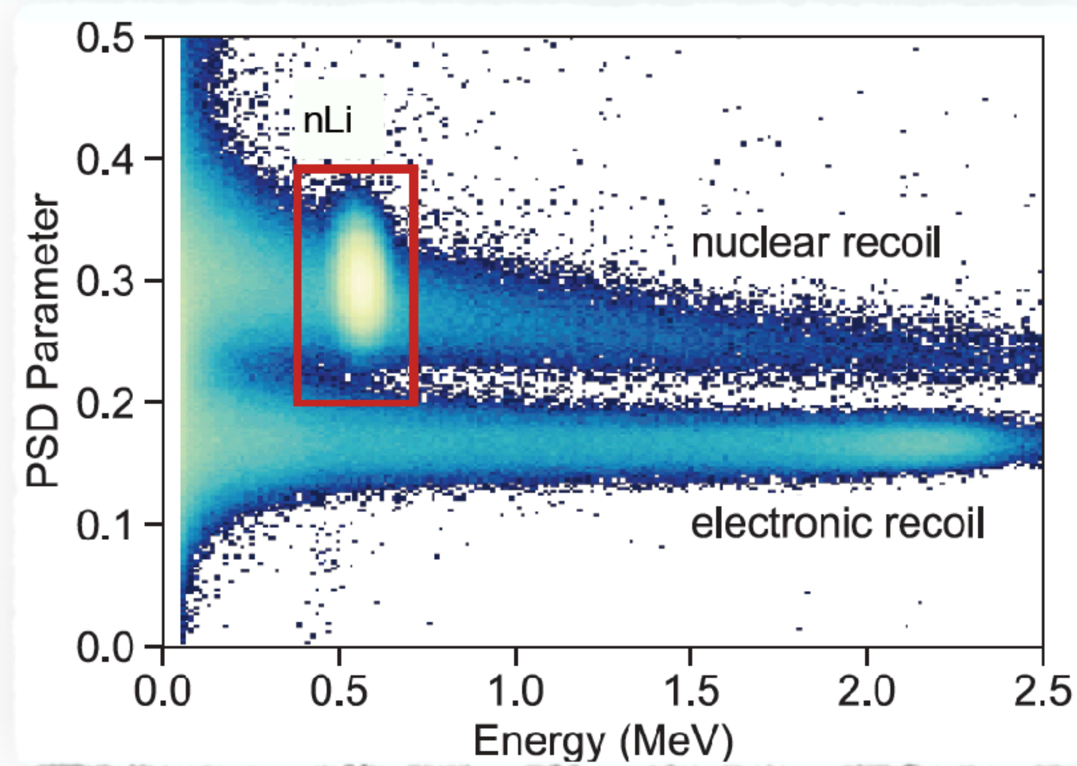
LP2019





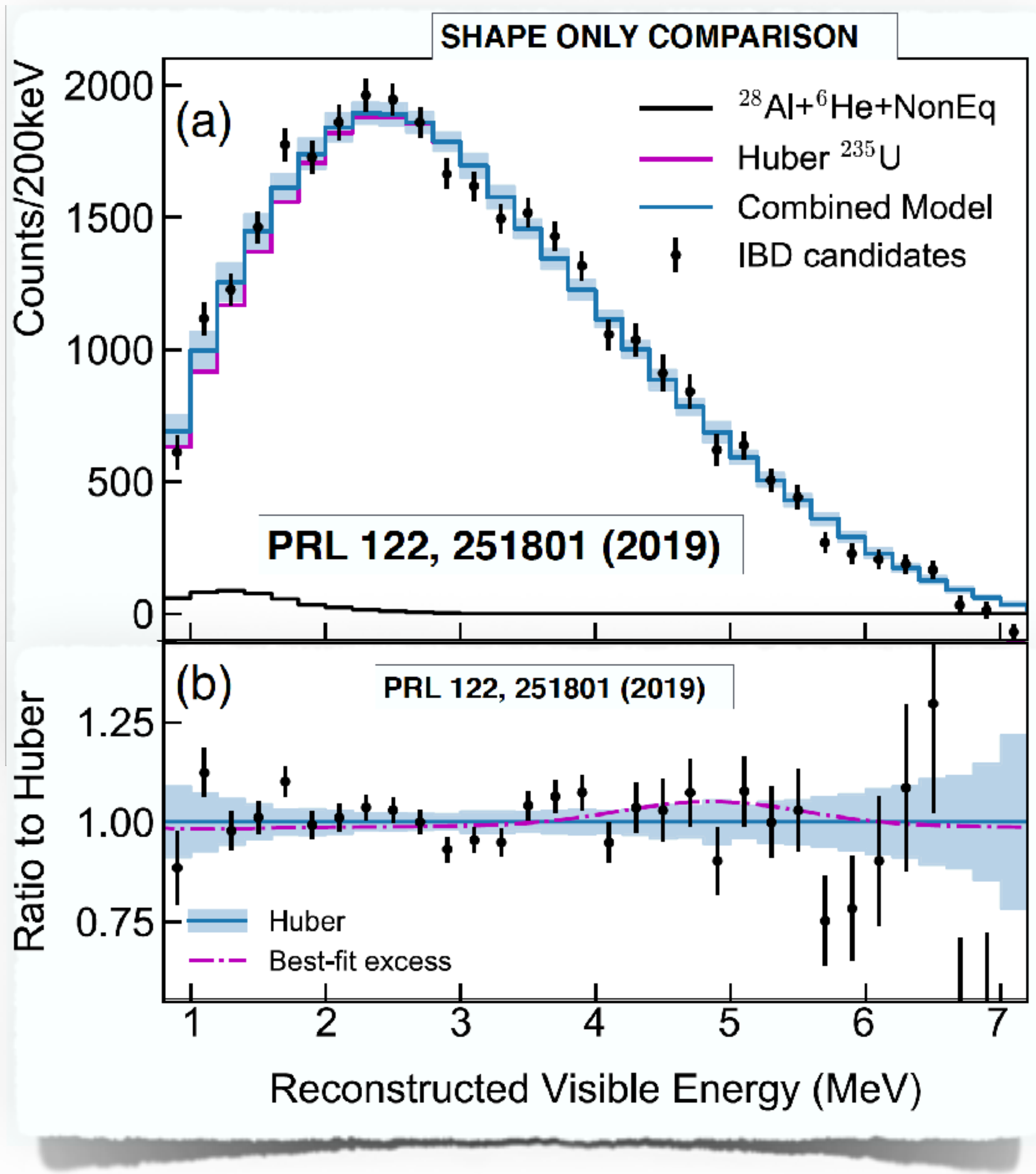


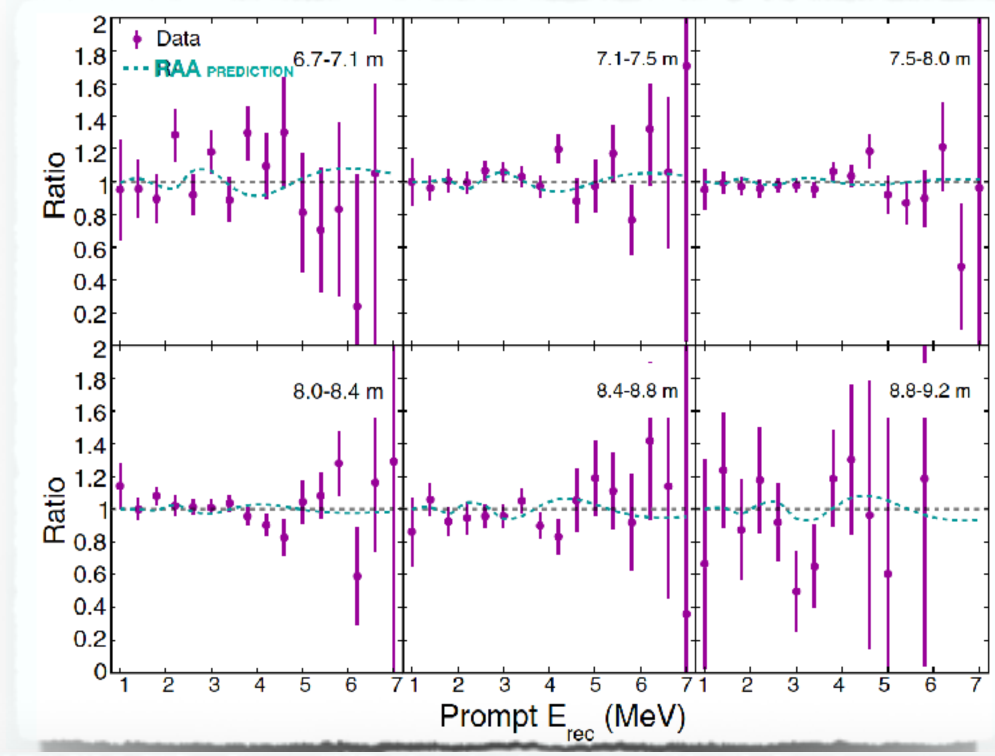


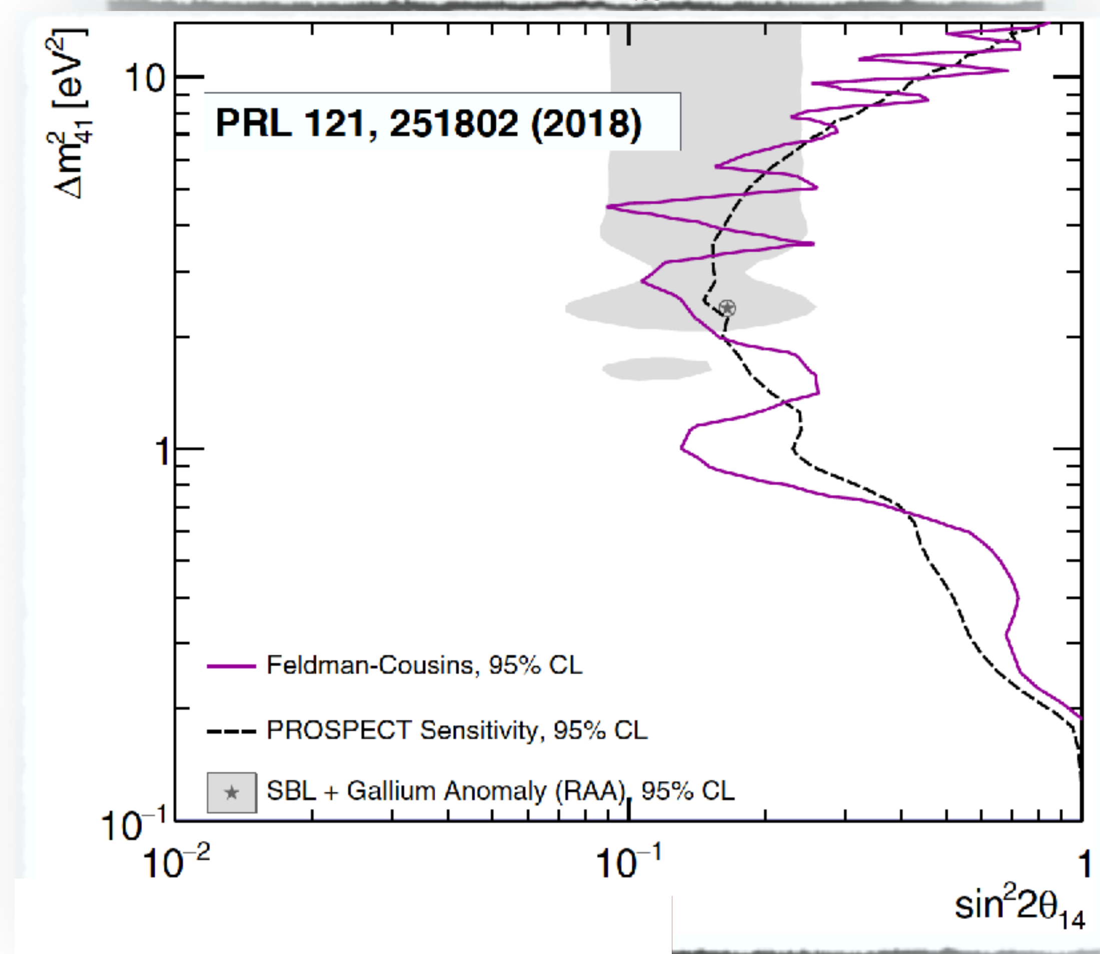


PROSPECT
Precision Oscillation and Spectrum Experiment

LP2019

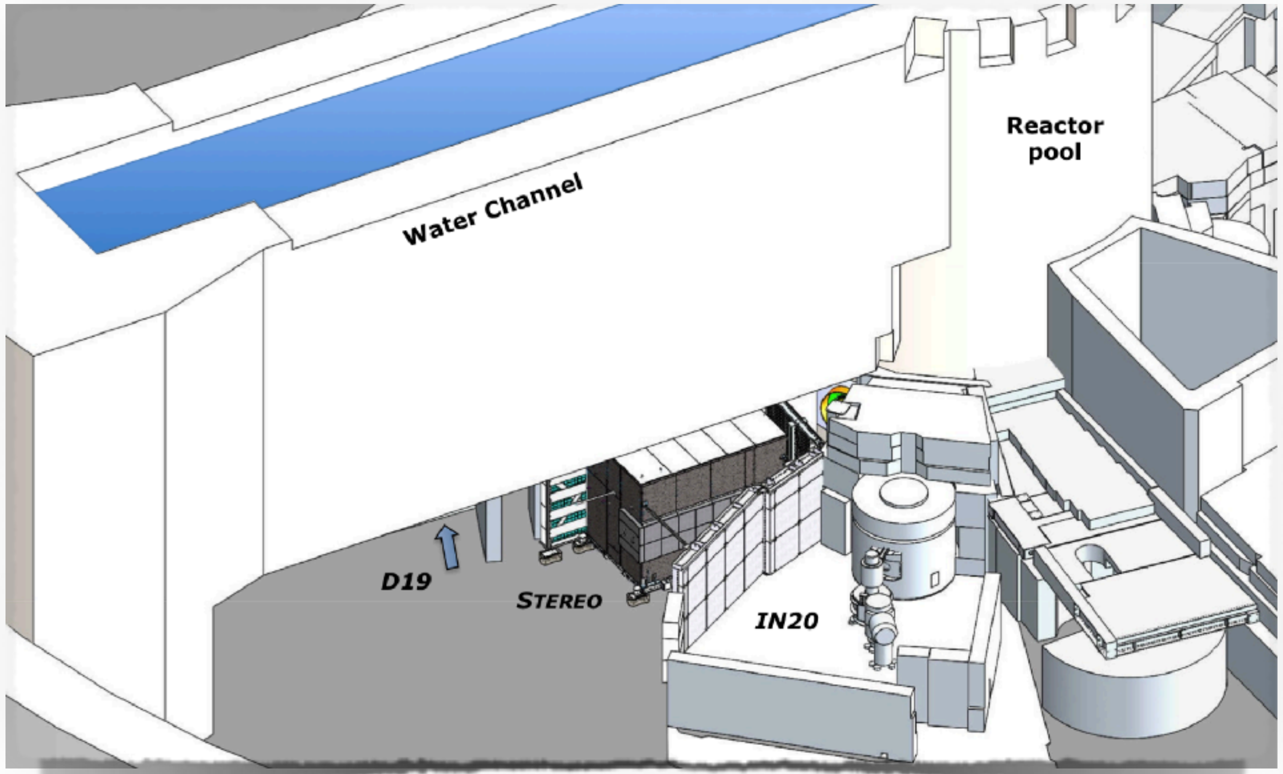


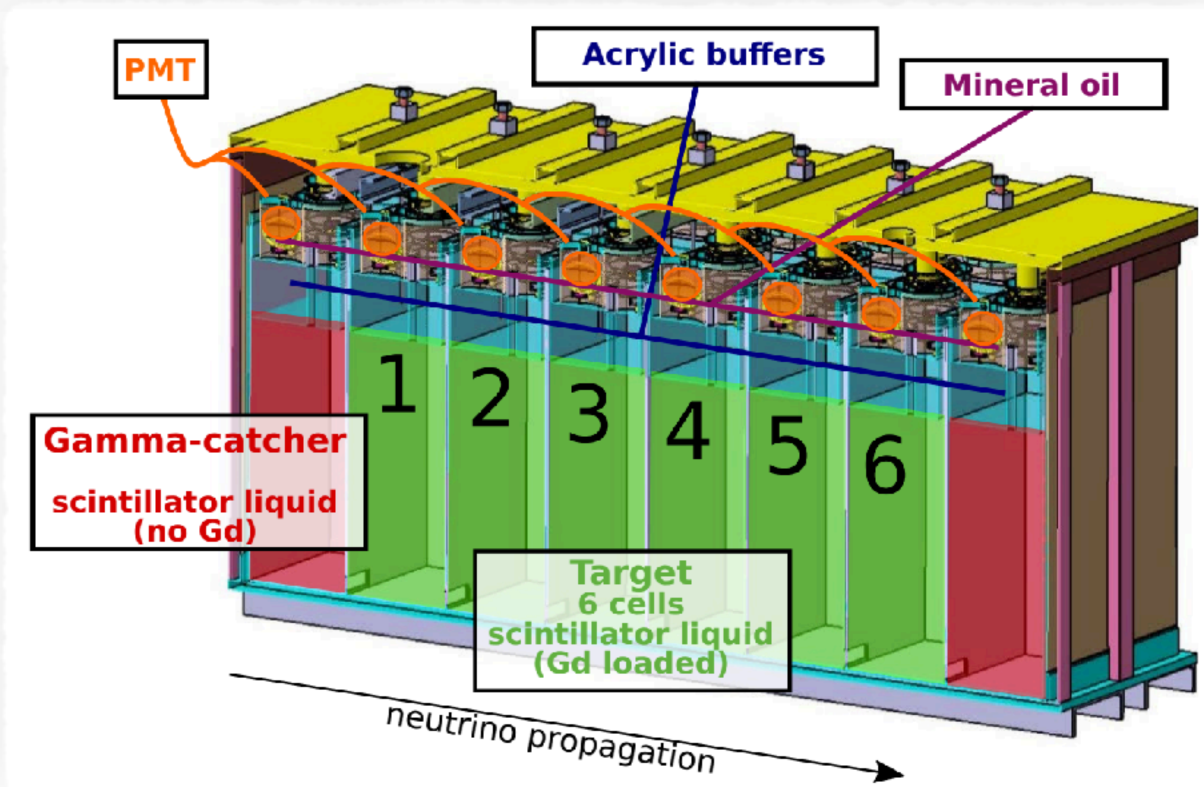


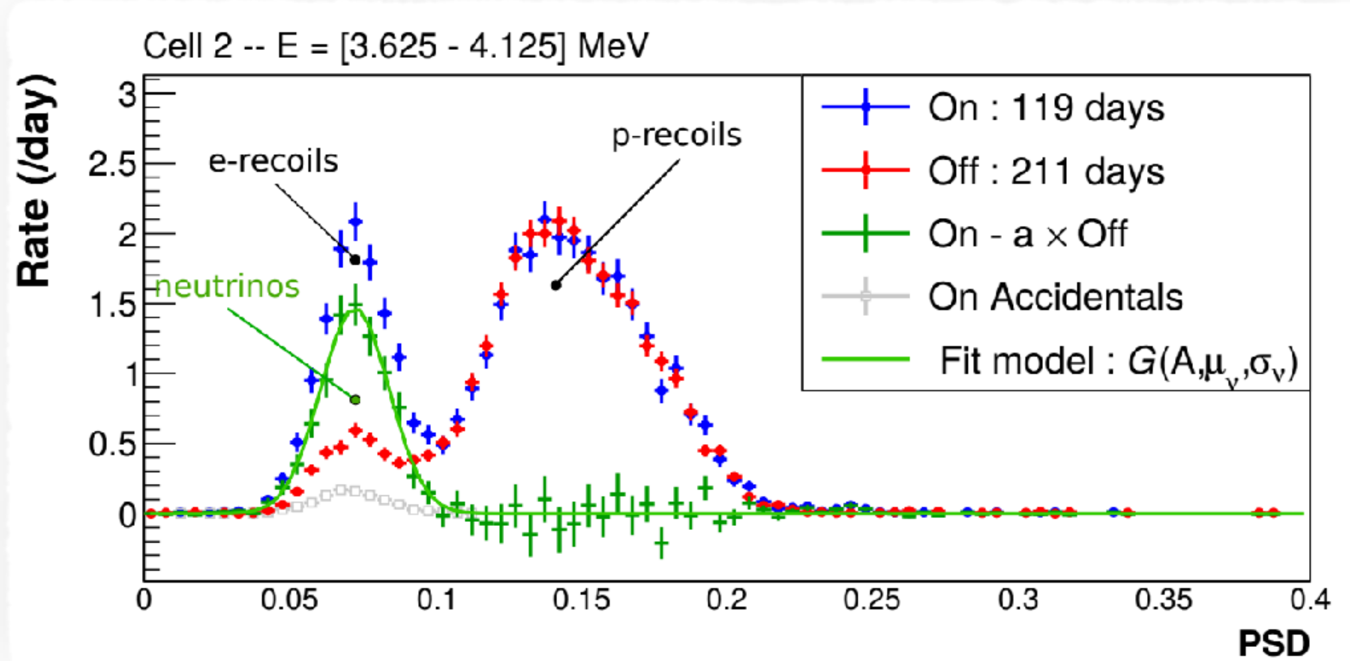


- comparison between groups of segments for oscillation analysis.

STEREO Moriond 2019

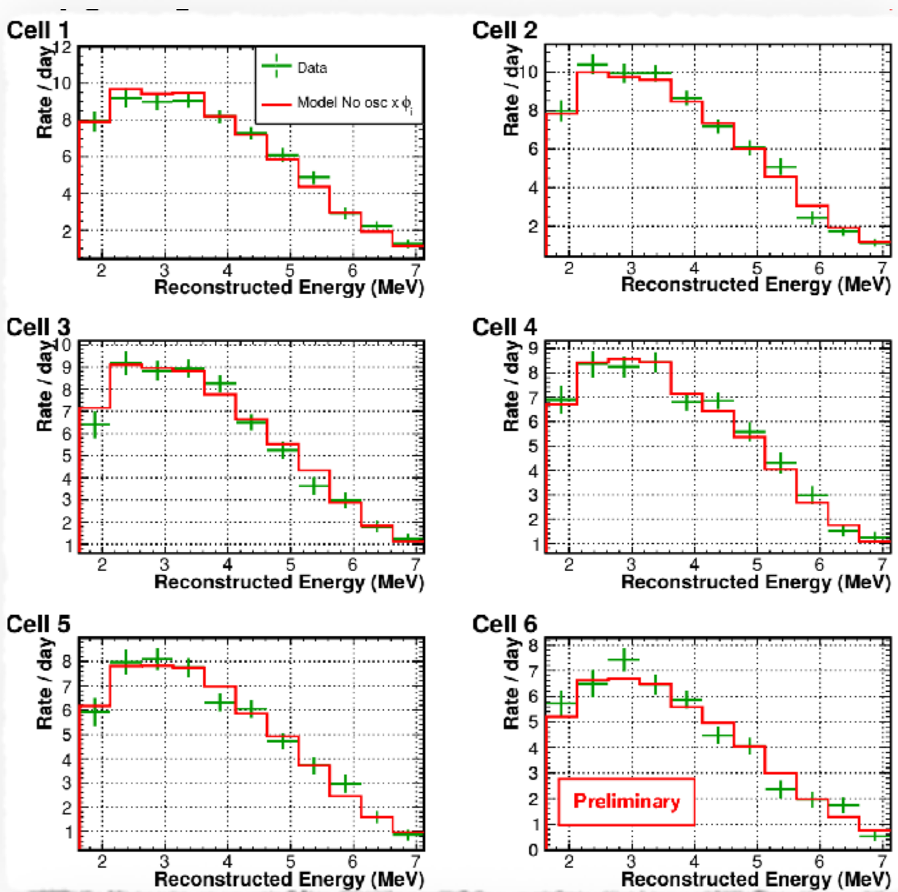


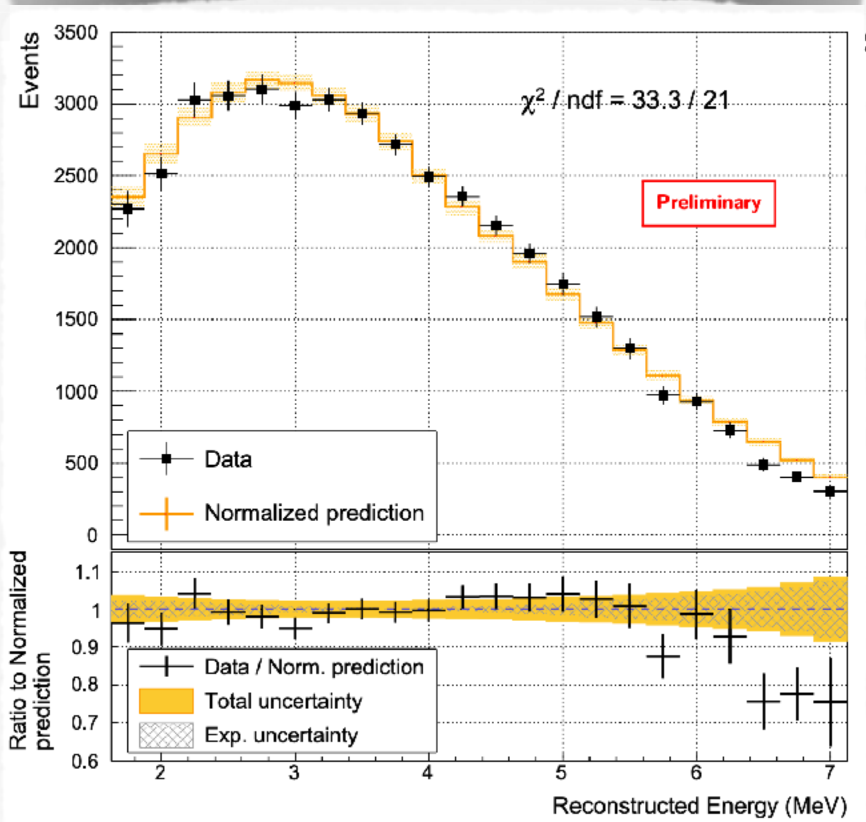


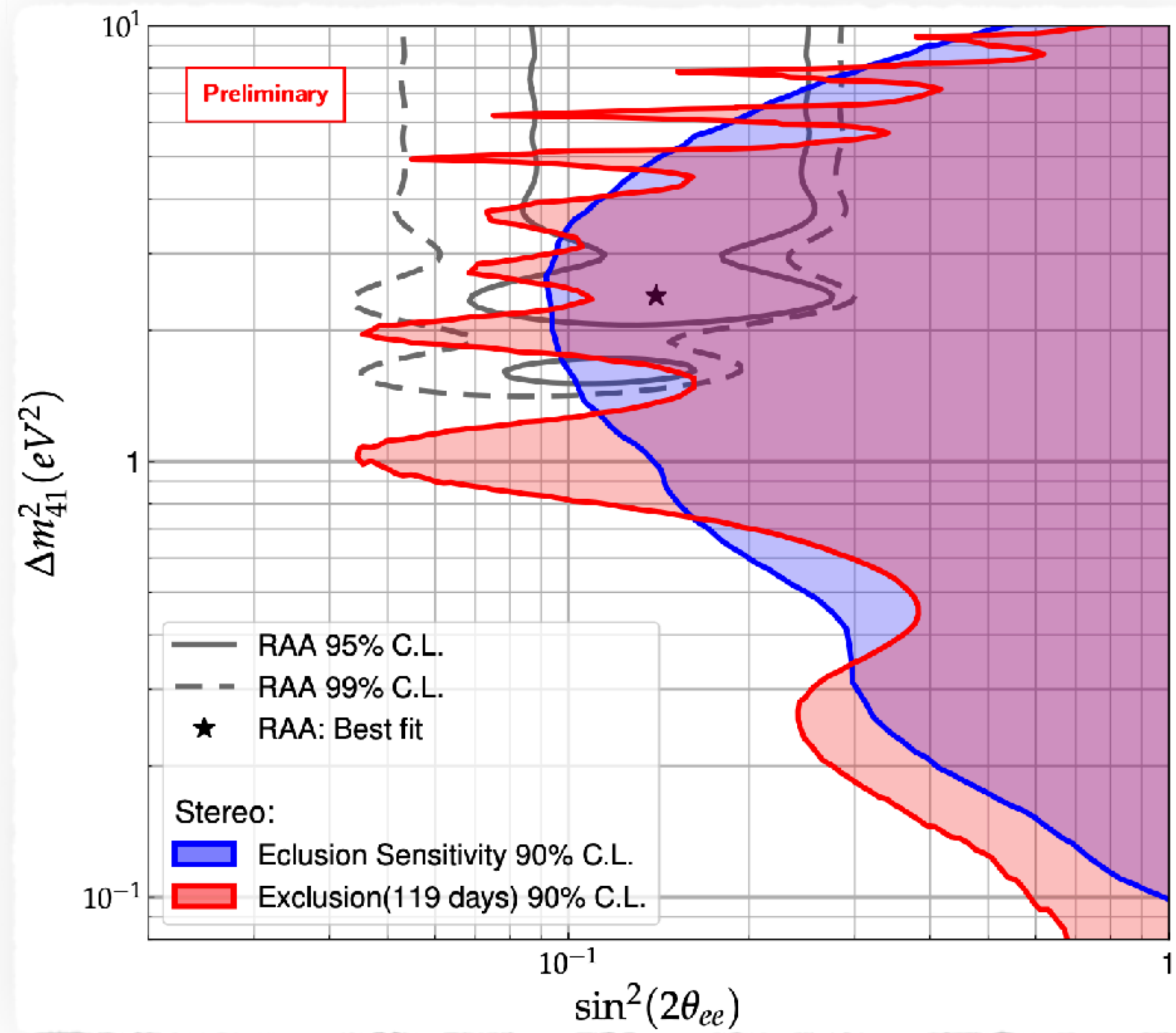


- 58.3 MWt research reactor
- Segmented cells have distance resolution
- Gd-LS with PSD capability

STEREO Moriond 2019

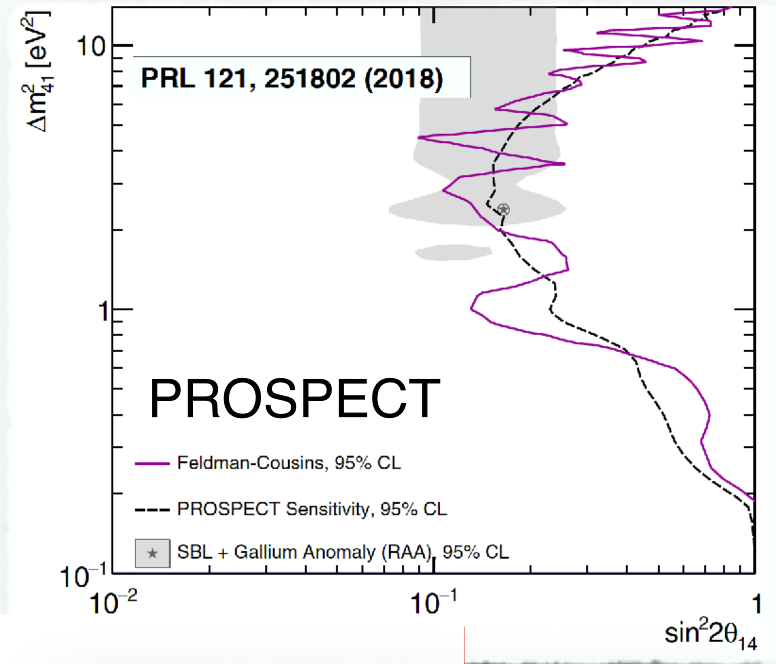


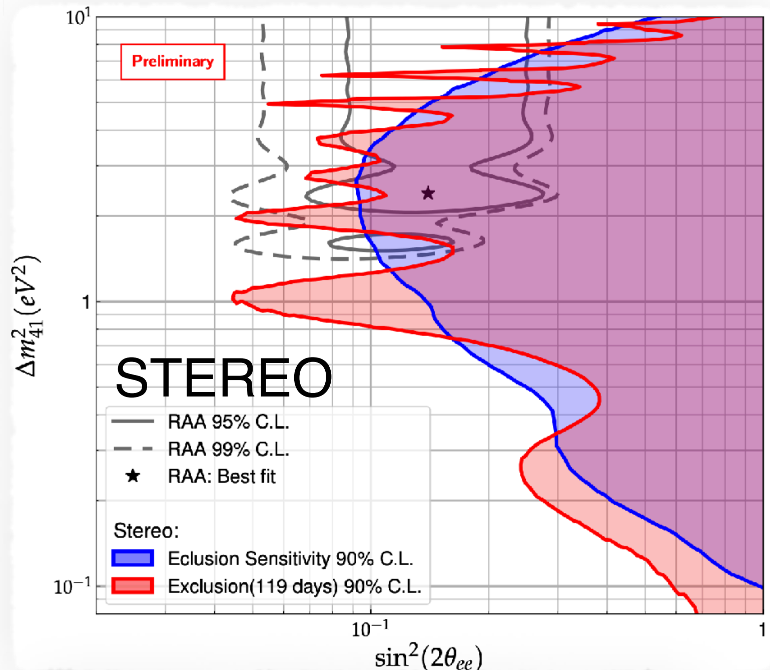


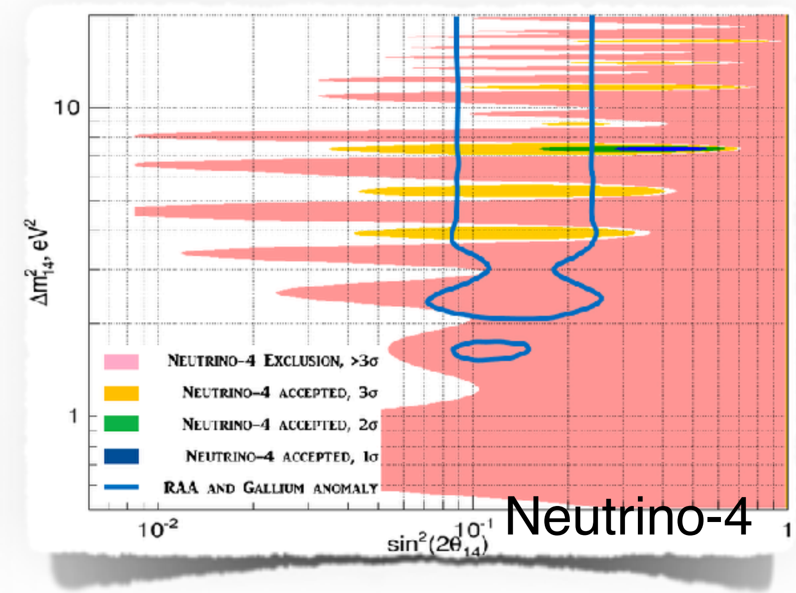


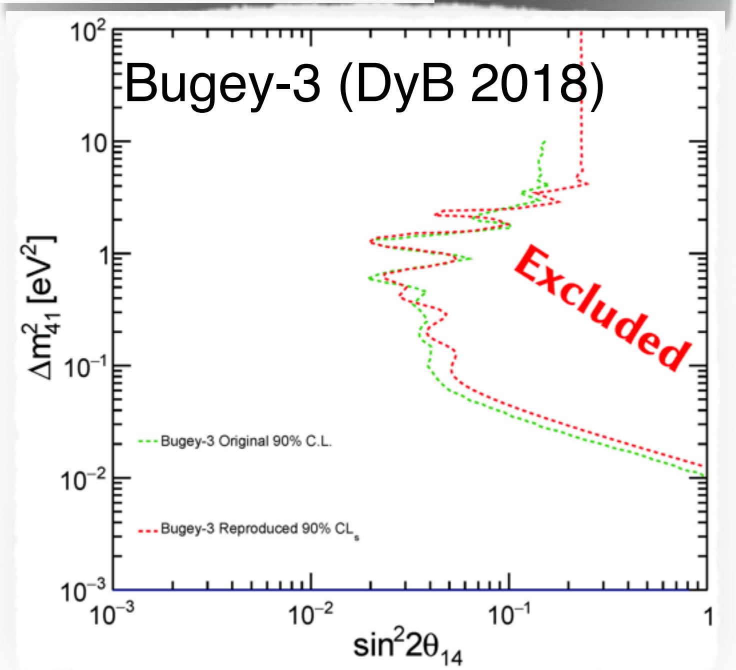
- Comparison between cells for oscillation study, disfavors RAA.
- Expecting more statistical precision.

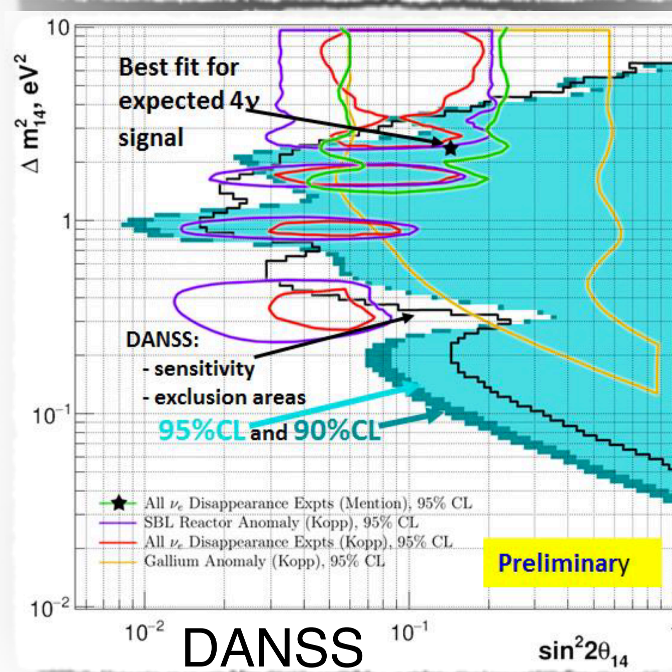
Combined

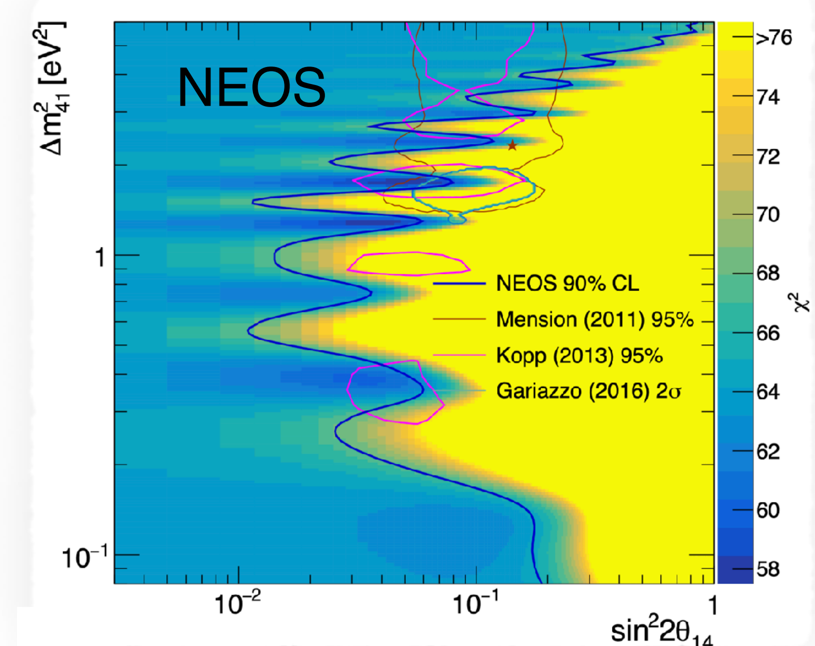












- The original RAA best fit values (0.14, 2.3 eV^2) are disfavored.
- Except for neutrino-4, we share similar bays and capes around 1 eV^2.
  - Different detectors at different reactors, model dependent or independent.

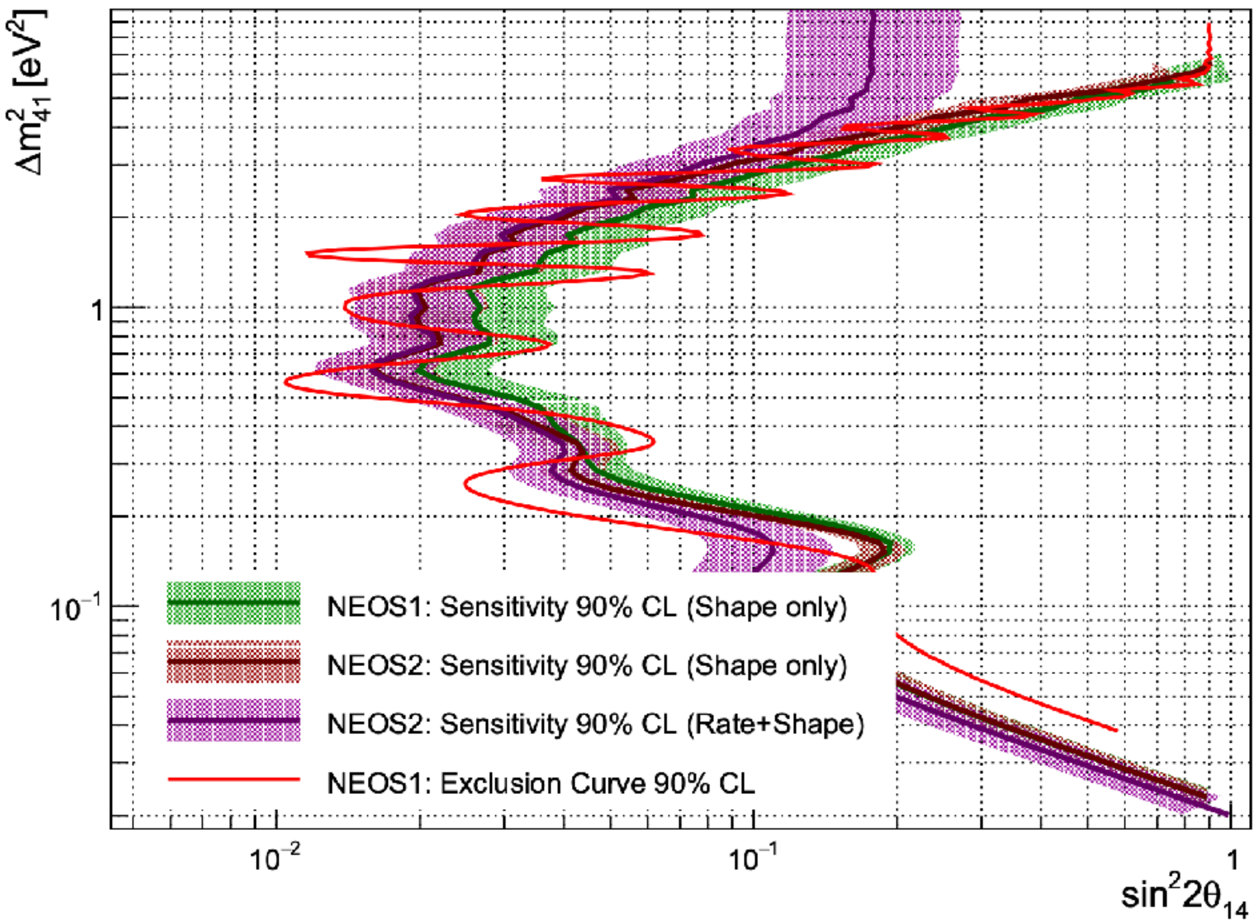
NEOS phase-II

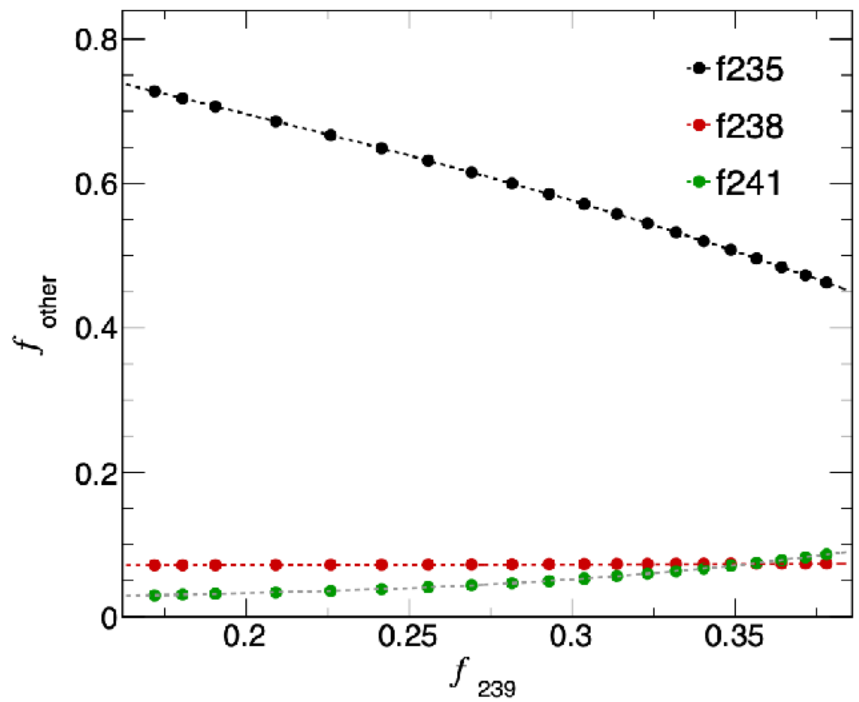
- Shape + rate analysis for sterile neutrino search, or,
- Precision measurement of the spectrum itself.
- Spectrum evolution with the fission fraction change.

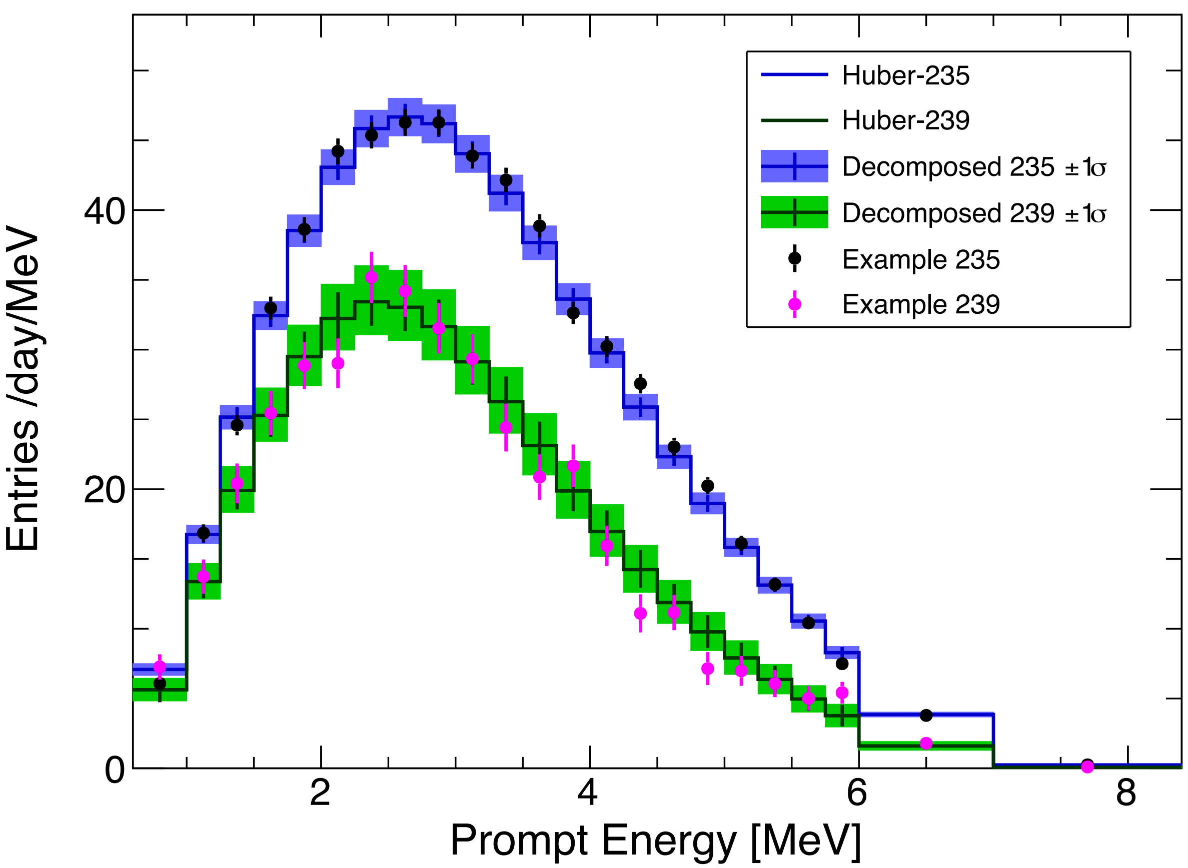
- Measuring a full operation cycle (~500 calendar days) + two background periods before/after the cycle (~100 days).
  - Phase-I: 46 days OFF + 180 days ON as DAQ livetime.
- Same detector, same reactor and same baseline as in phase-I.
  - Newly produced Gd-LS,
  - Minor modifications: leak-proof maintenance, muon counter plastic scintillator.

- Data taking started in September 2018.

NEOS phase-II

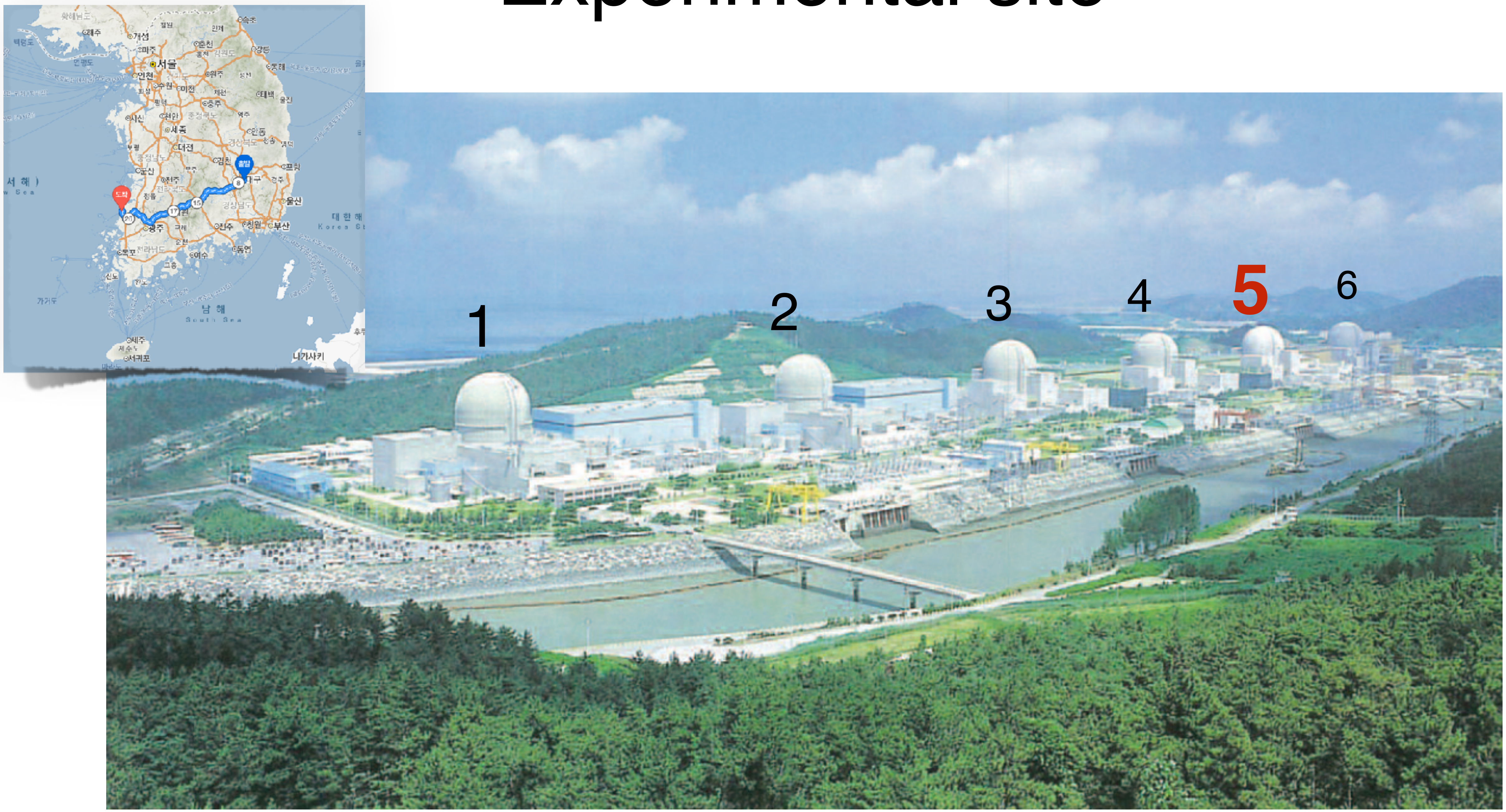






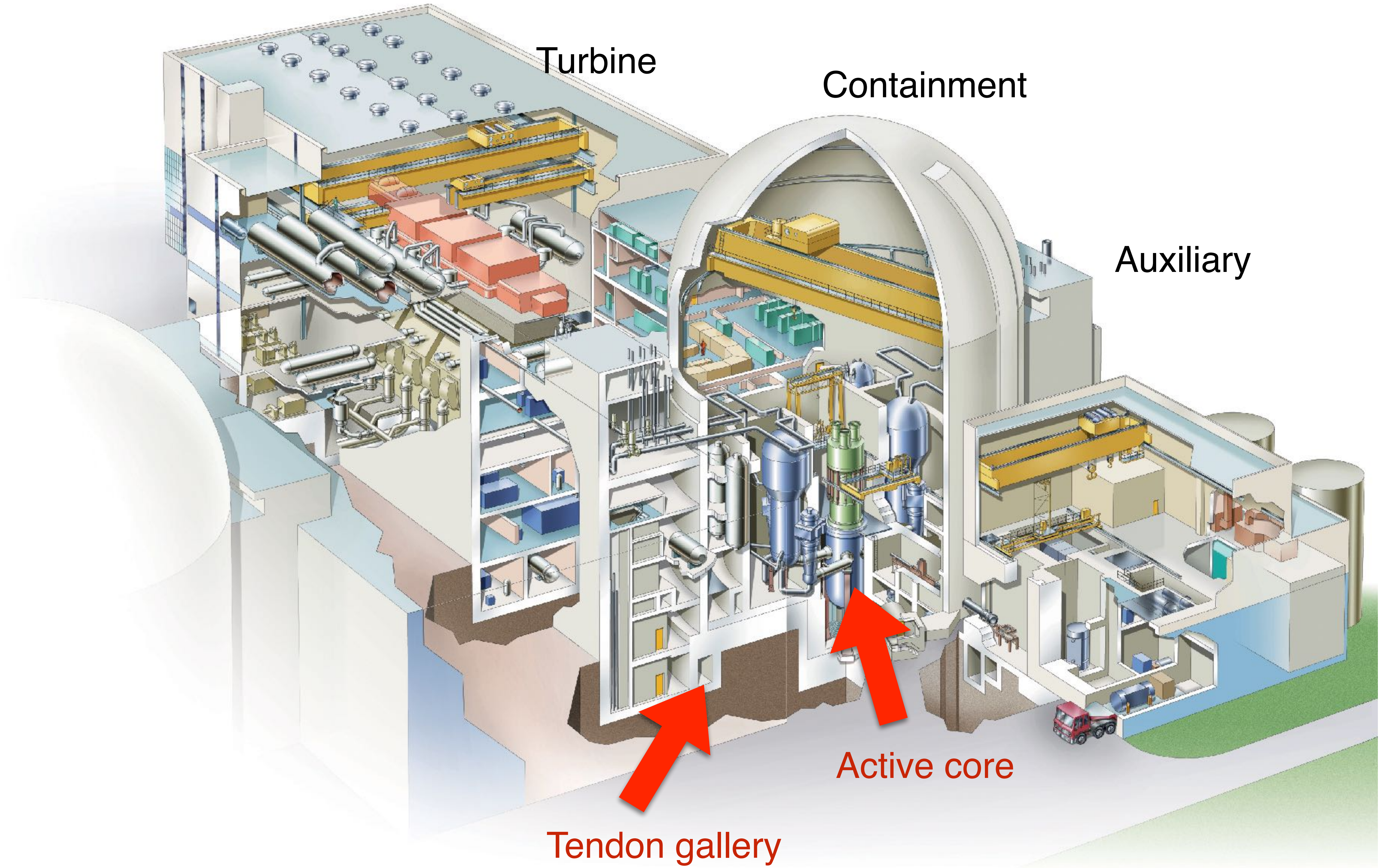
- Not a dramatic improvement of eV sterile neutrino search sensitivity,
- Decomposition of U/Pu spectra, benefitted by large fission fraction changes in a single LEU reactor.

Experimental site



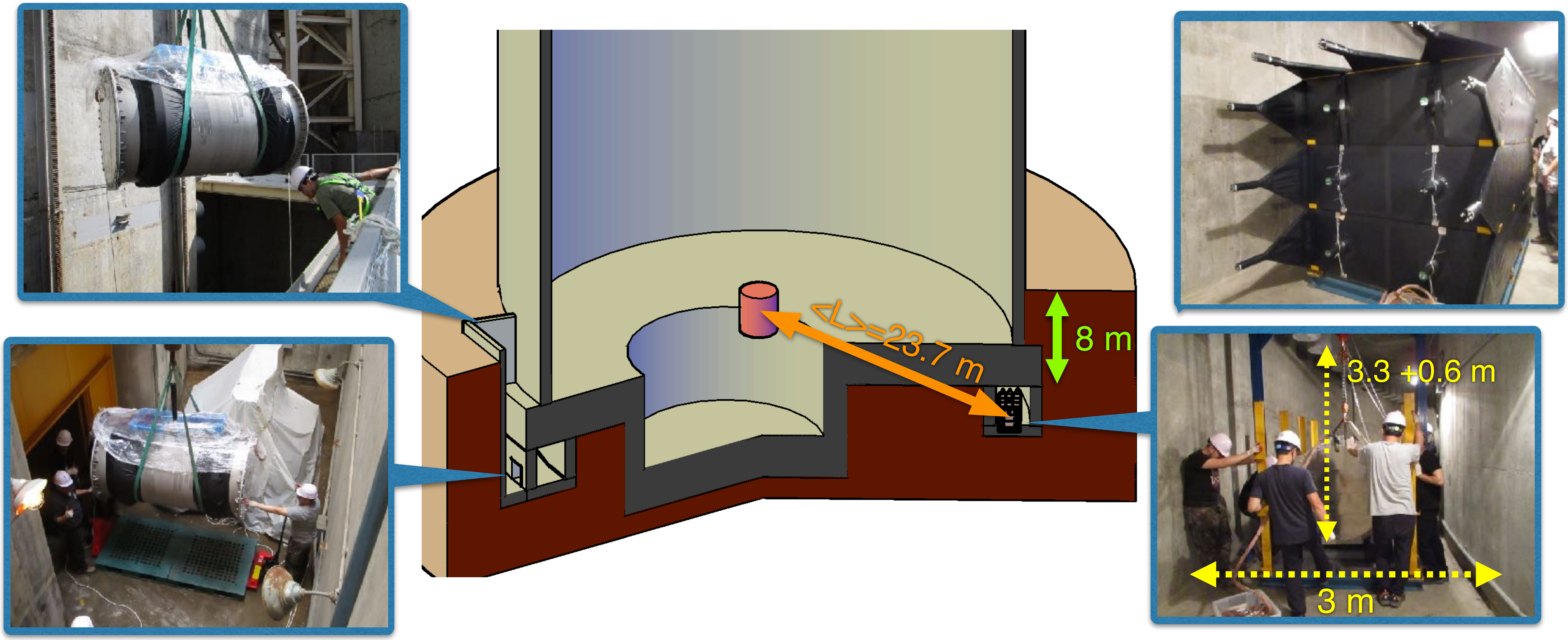
- Hanbit-5 reactor, Yeonggwang (靈光, ghost light), Korea,
- Distance between neighboring cores: 256 m (less than 1% contributions from each of them),
- Same reactor complex used for RENO experiment

Experimental site



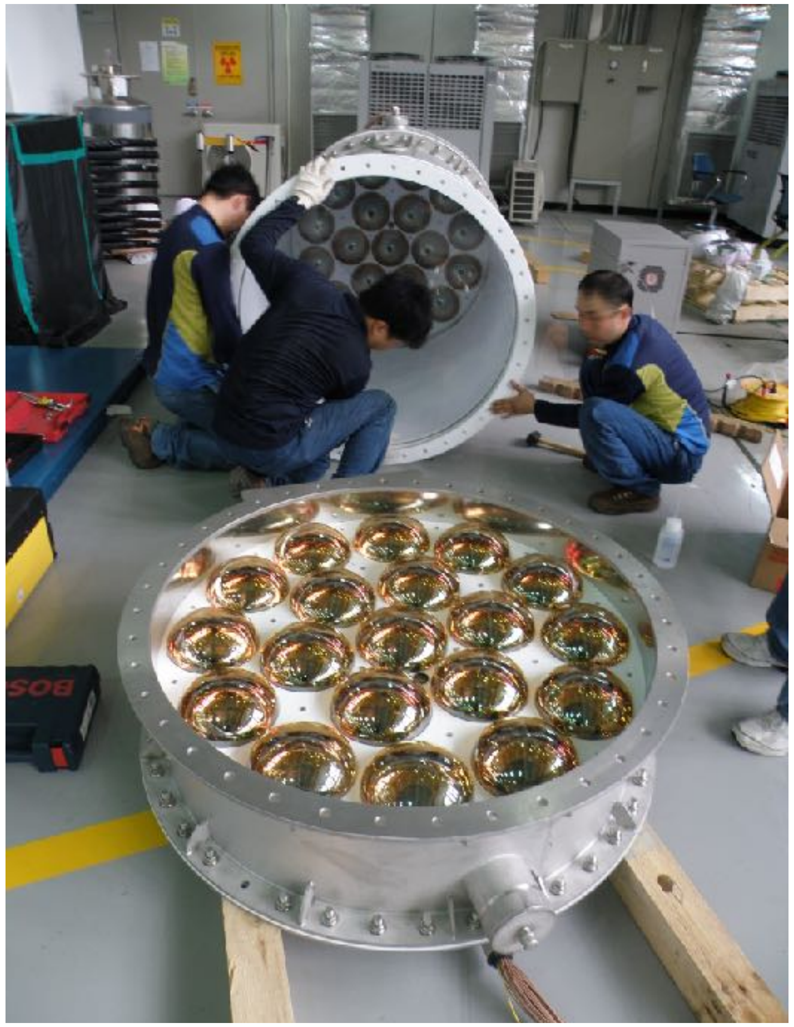
cutaway view of OPR-1000

Tendon gallery



- Not a radioactivity controlled area: no background related to reactor operation,
- Muon rate: about 1/5 of surface (~0.17 μ/cm^2/min),
- Maintenance work every 5 years.

NEOS detector



Homogeneous 1000 L
(Φ103 x L121 cm) volume,
0.5% Gd-doped LS,
90% LAB+ 10% UG-F,
seen by 2 x 19 8-inch PMTs,
PTFE reflector on inner walls.

10 cm thick B-PE,
10 cm thick Pb
for passive shieldings.

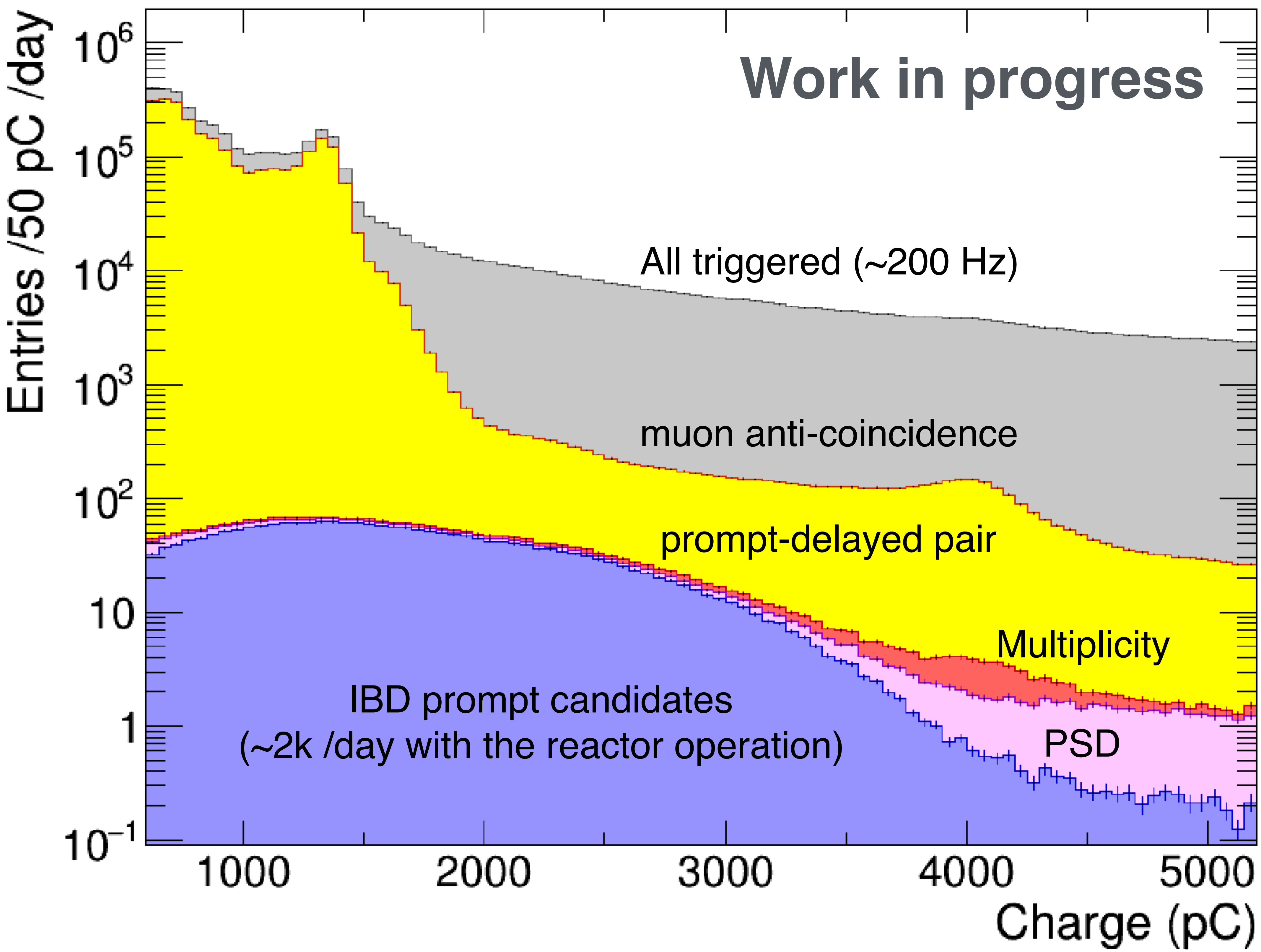
Muon counter:
3(5)-cm thick plastic scintillator
panels surround the most outside
except for bottom.

Data acquisition with

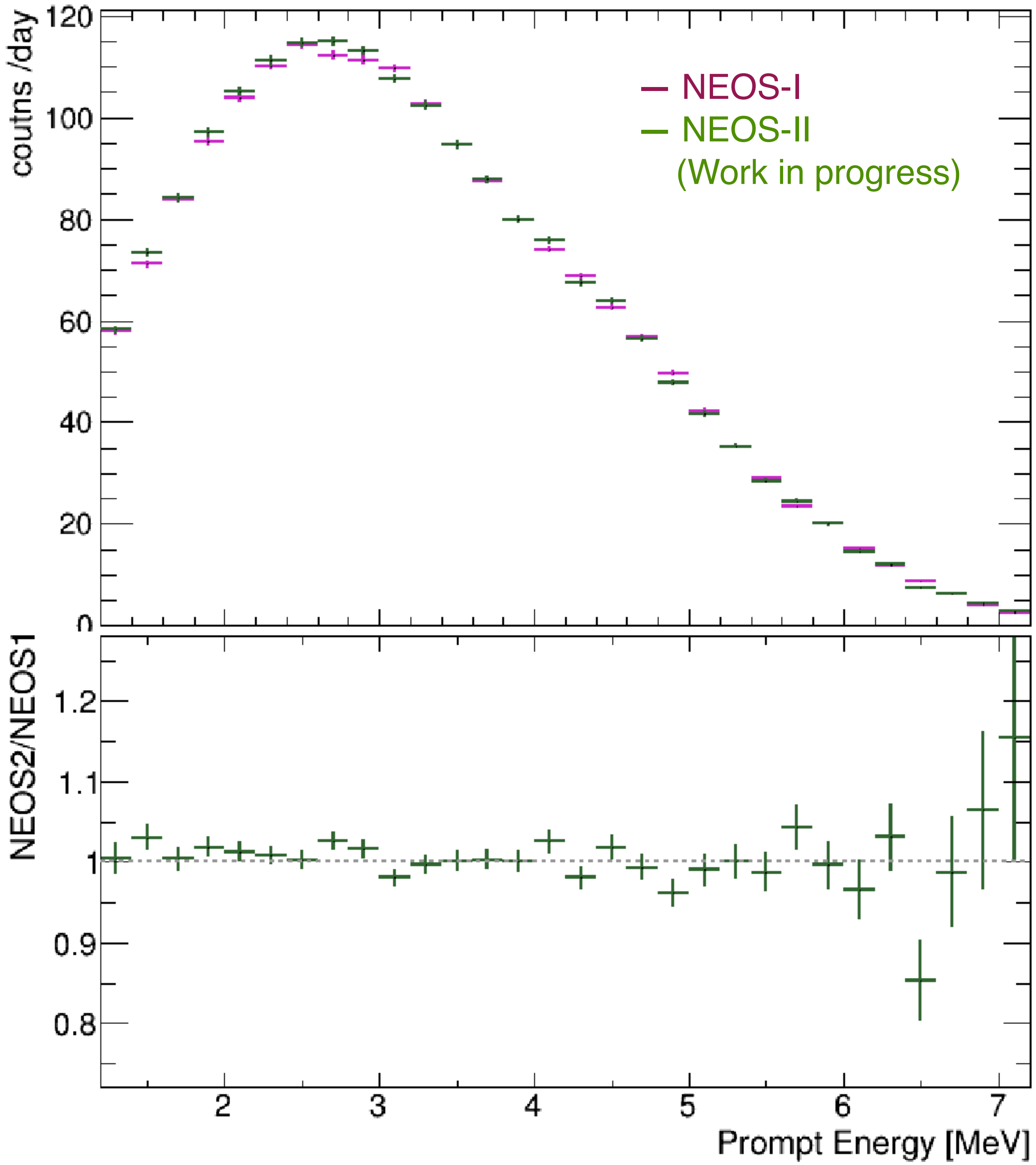
- 500 mega-sampling/sec FADC for target PMTs
- 62.5 mega-sampling ADC for muon counter PMTs.

Slow monitoring: temperatures, radon level, PMT HVs.

IBD candidates



Phase-I and Phase-II



Summary and closing

- Numbers of experimental efforts to find active-to-sterile neutrino oscillation with $\Delta m^2 \sim 1\ \mathrm{eV}^2$ are in progress.
- No strong positive signals, but interesting similarity.
- Sensitivity for $\sin^2 2\theta \lesssim 10^{-2}$ at reactor?
- Precision measurements of reactor spectra with different fuel elements composition are also valuable.
- Unfolding to share the various results.
- Flux modeling - nuclear database being reviewed and updated along with the experimental effort such as total absorption spectroscopy.