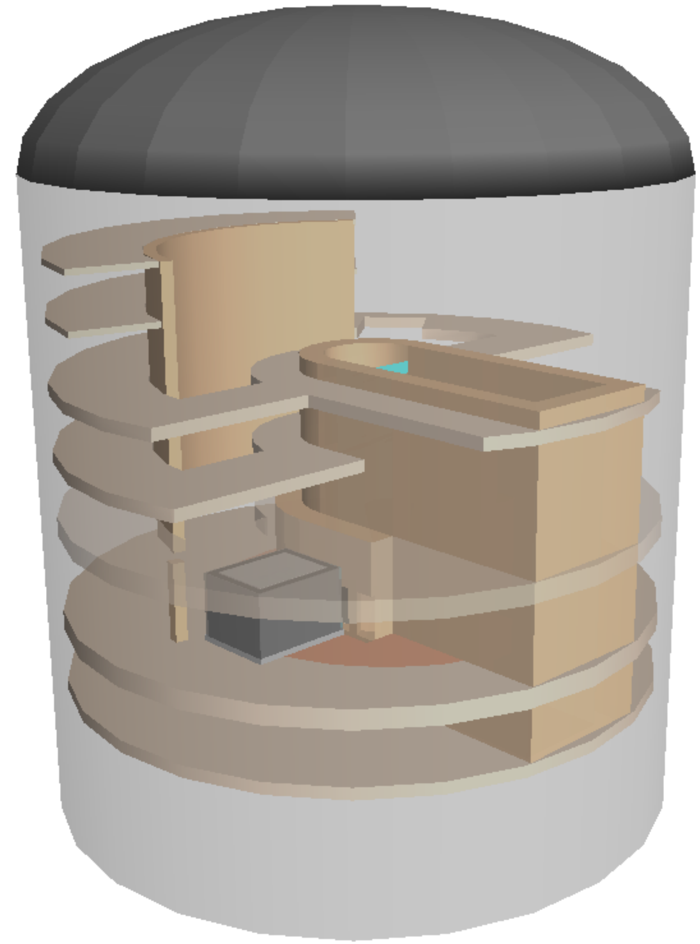
Status and prospects of the SoLi∂ experiment



Nick van Remortel

University of Antwerp, Belgium

On behalf of the SoLid Collab.

IUAP FI.be meeting

Dec 21, 2017

FWO Research Foundation Flanders Opening new horizons

foundation of public utility HERCULES STICHTING

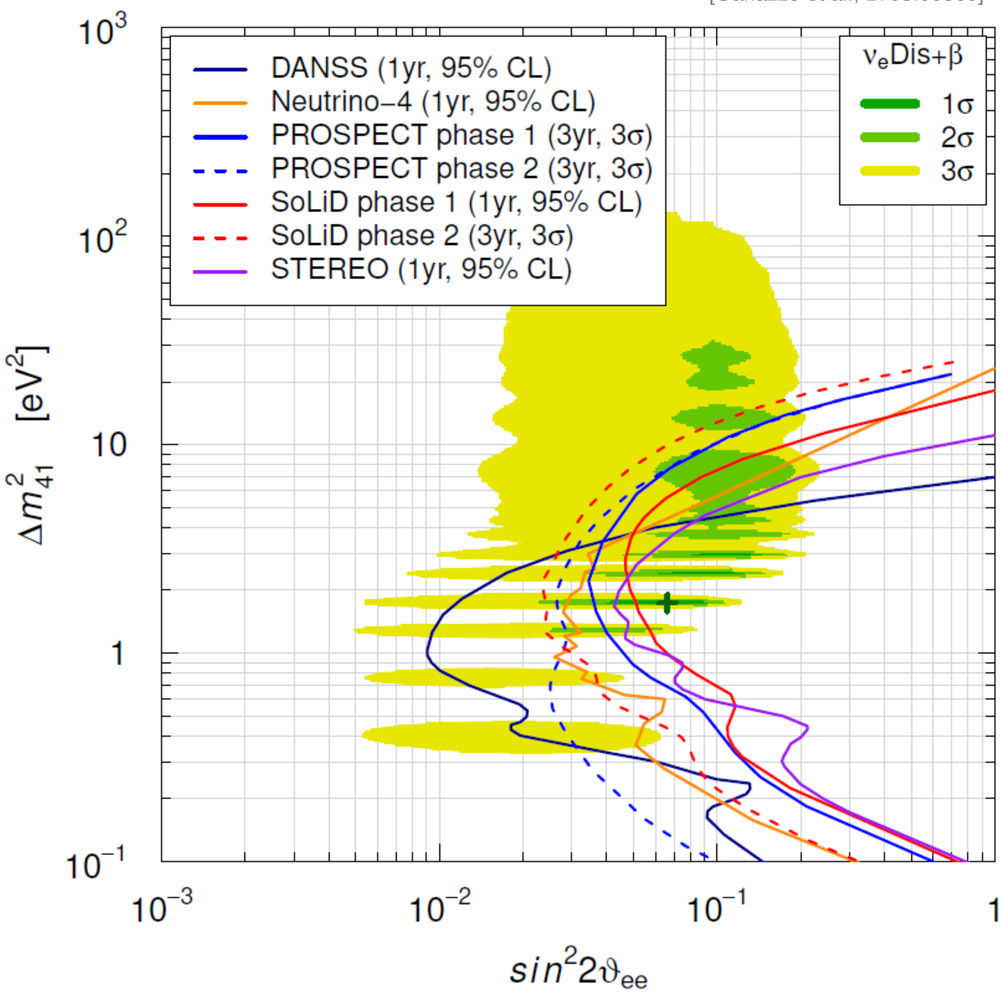
Belgian Science Policy Office belspo

Fundamental .be Interactions

Motivation

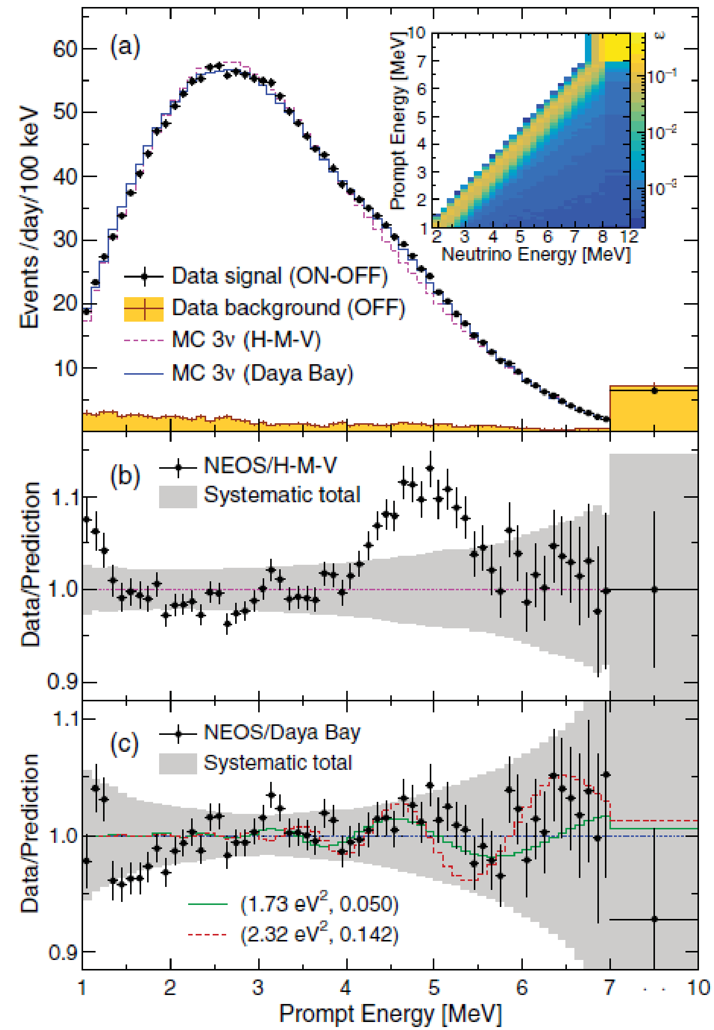
- Resolve several anomalous effects in short baseline neutrino rates

[Gariazzo et al., 1703.00860]



- Resolve discussion on spectral features observed by long baseline reactor expts using common fuels (235U, 238U, 239Pu,241Pu)

[NEOS, PRL 118, 121802 (2017)]



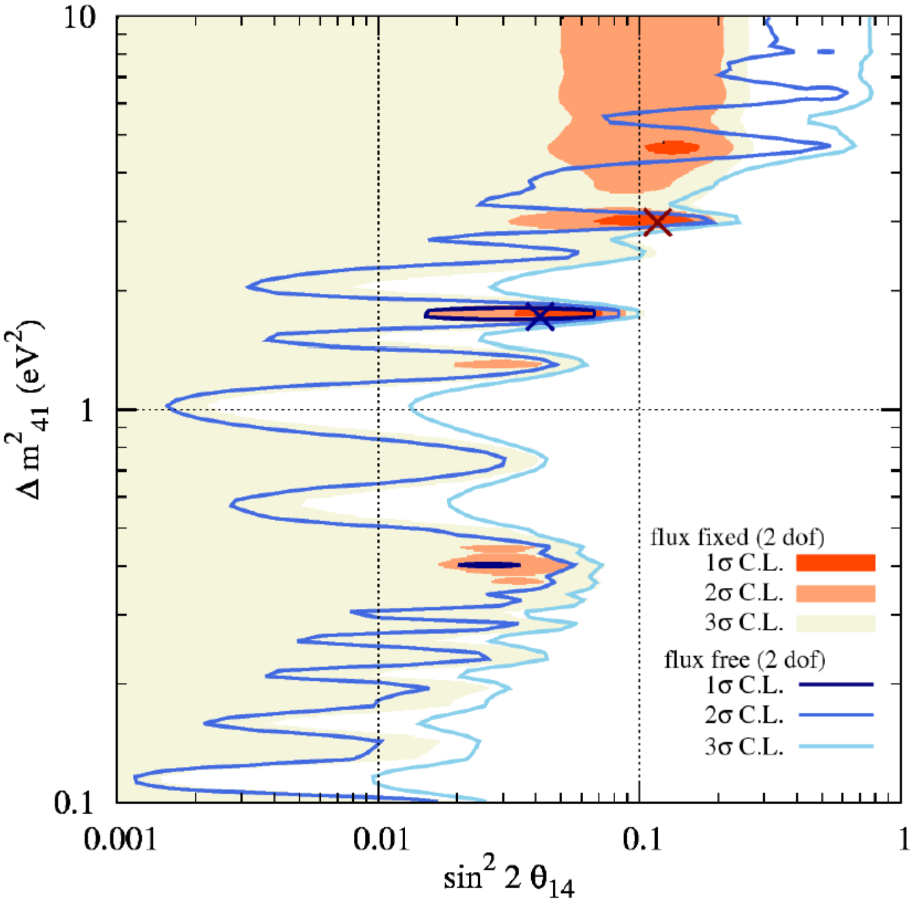
Latest results and global fits: Nuclear effects or sterile neutrino ?

- Flux deficit is different for the 4 parent fission isotopes and 235U seems to be main source of the anomaly [Daya Bay, 1704.01082]
- New results (MINOS, IceCube, Daya Bay, DANSS, NEOS) don't rule-out sterile neutrino hypothesis [Gariazzo et al., 1703.00860 & Dentler et al., 1709.04294]
- Dentler et al., 1709.04294: "We find that the sterile neutrino hypothesis cannot be rejected based on global data and is only mildly disfavored compared to an individual rescaling of neutrino fluxes from different fission isotopes. The main reason for this is the presence of spectral features in recent data from the NEOS and DANSS experiments."

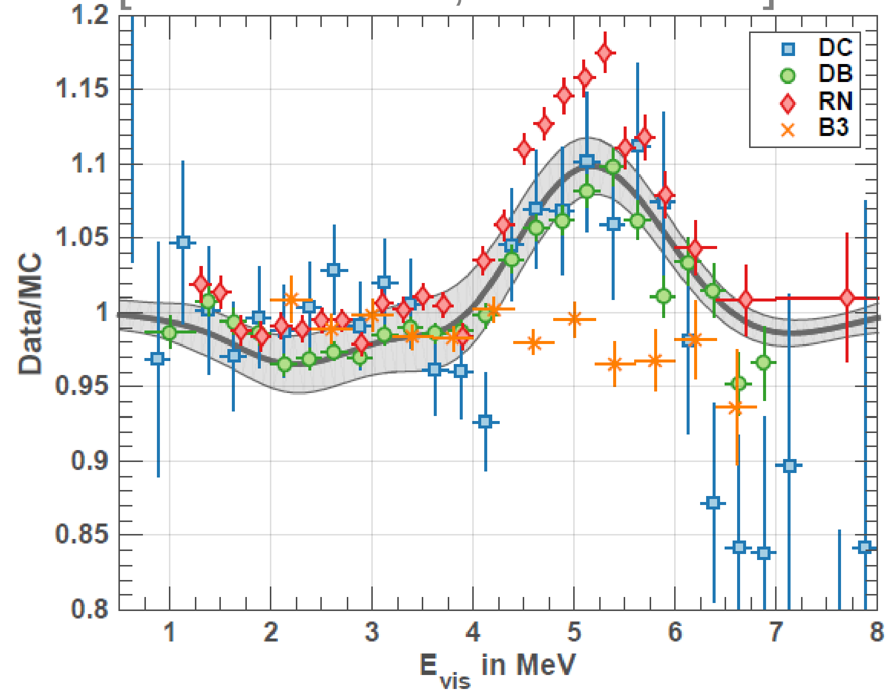
Daya Bay flux	[29]	8	individual fluxes for each isotope (EH1, EH2)	✓
Bugey-3	[45]	35	spectra at 3 dist. with free bin-by-bin norm.	–
NEOS	[21, 26]	60	spectral ratio of NEOS and DayaBay	✓
DANSS	[28]	30	spectral ratio at two distances	✓
Daya Bay spect.	[46]	70	spectral ratios EH3/EH1 and EH2/EH1	✓
KamLAND	[47]	17	spectrum at very long distance	–

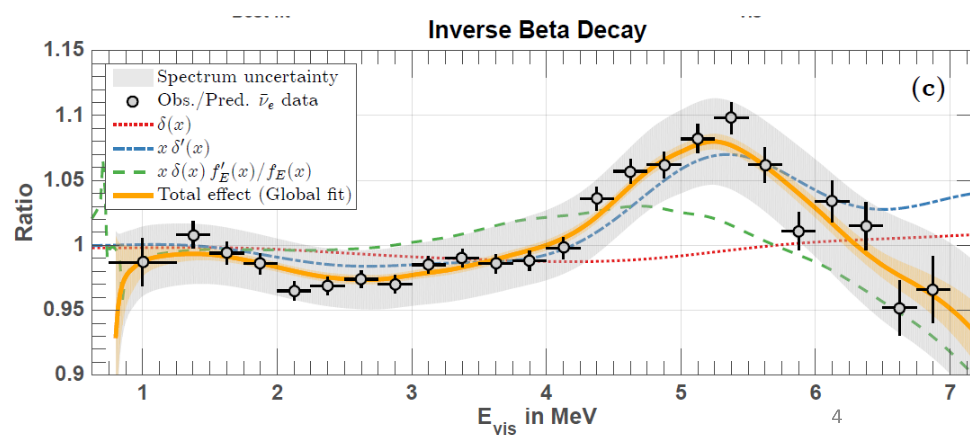
Game for sterile neutrinos around $\Delta m^2 \approx 1 eV^2$ still on

[Dentler et al., 1709. 04294]



[Mention et al., 1705.09434]





Optimal experimental parameters

- Precise oscillation analysis in L and E
- Experimental design relying on:
  - Appropriate energy resolution O(10%) and calibration/linearity (2%)
  - Clean signal samples based on particle ID
  - Analysis of spectral shape&rate over appropriate baseline (0-10 meter)
  - Fine segmentation to allow detailed study of L dependence
- Reactor properties:
  - Sufficient power but compact core
  - Simple fuel mixture (pure 235U), constant over time
  - In wel controlled background environment, and reactor ON/OFF

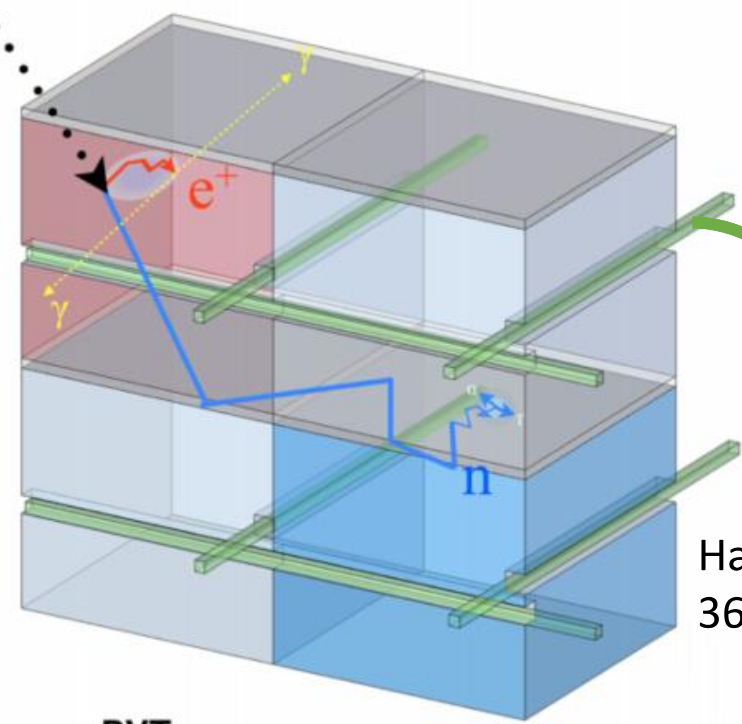
SoLid detector technology

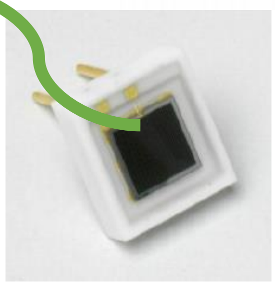
[SoLid, JINST 12 P04024 2017, 1703.01683]

Key detection mechanism: IBD

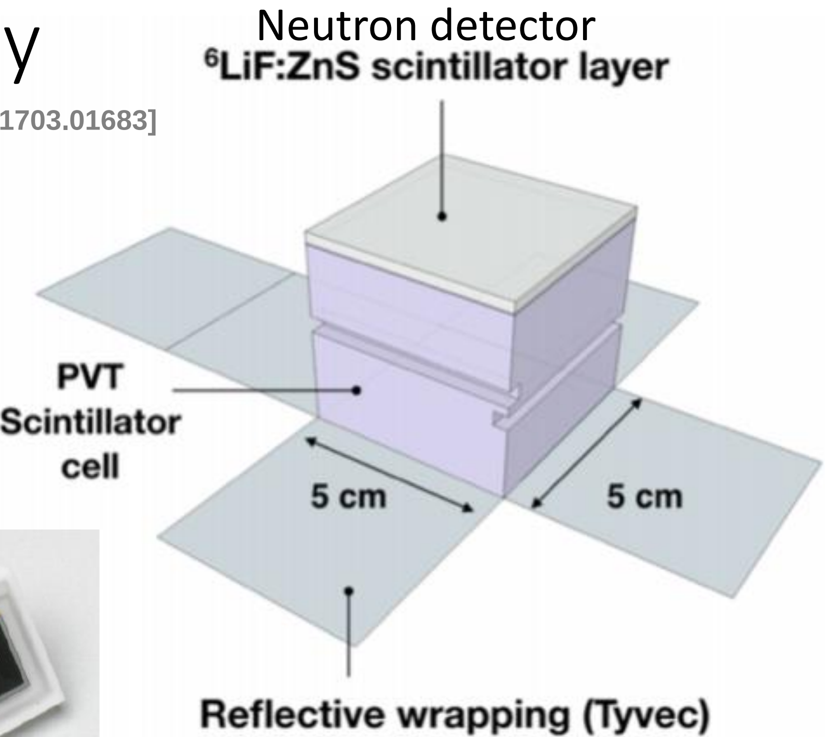
$\bar{\nu}_e$

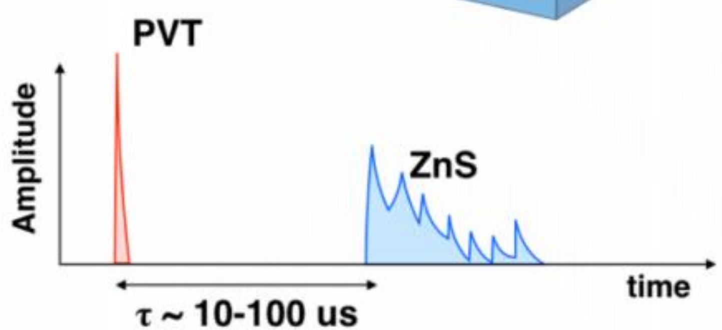
$$\bar{\nu}_e + p \rightarrow e^+ + n$$



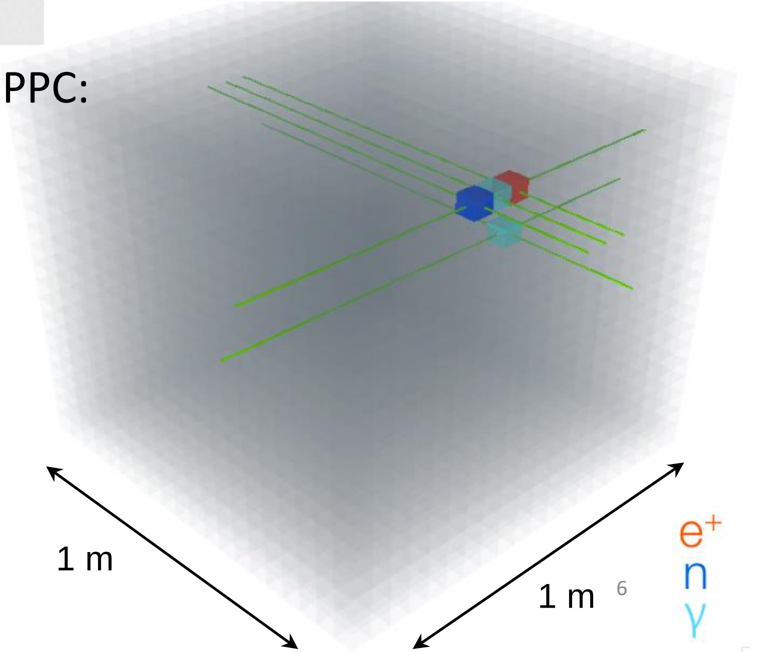


Hamamatsu MPPC:
3600 pixels



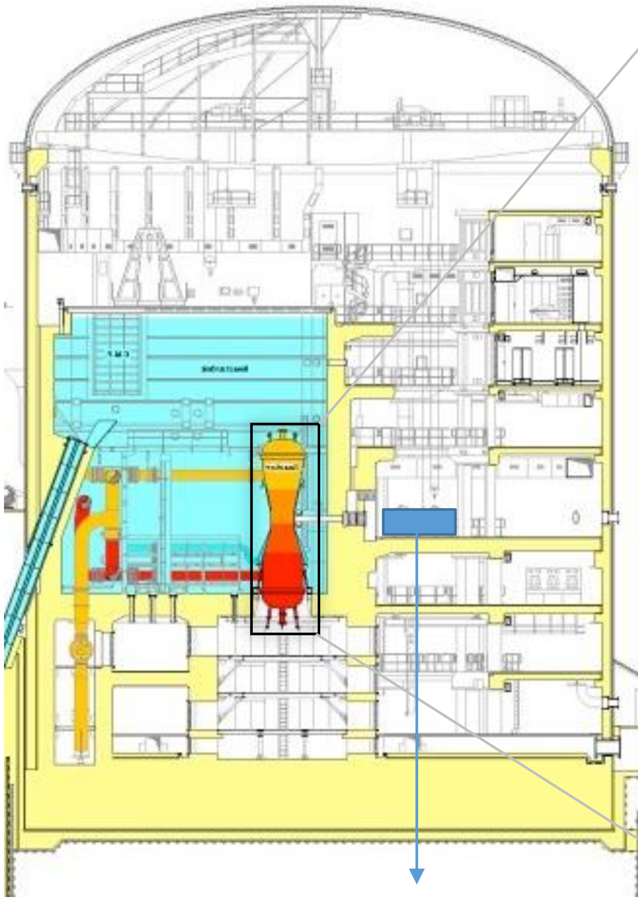


$${}^6_3Li + n \rightarrow {}^4_2He(2.05\ MeV) + {}^3_1T(2.75\ MeV)$$

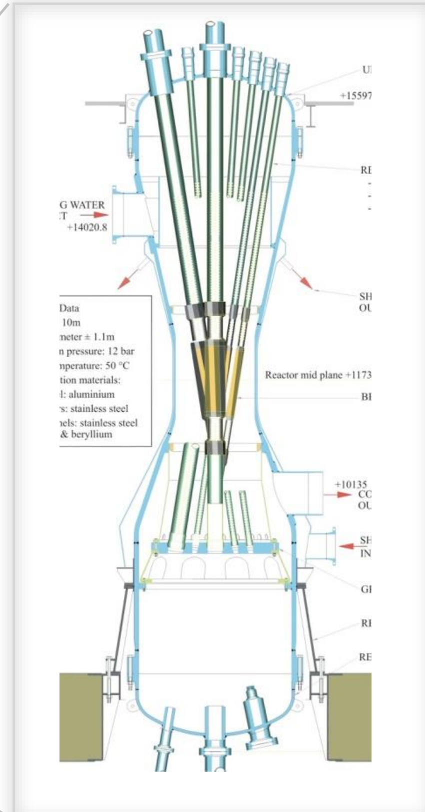


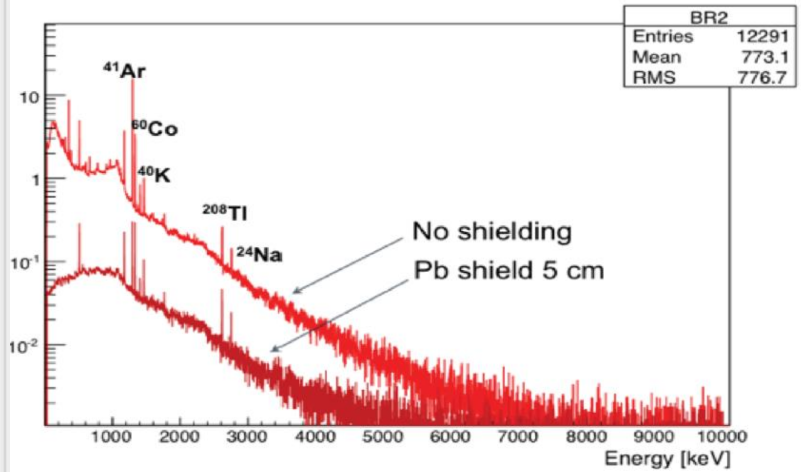
Belgian Reactor 2 (BR2)@ SCK•CEN

BR2 Confinement building



Aluminum pressure Vessel
Twisted core





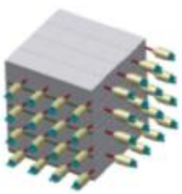
SoLid $\bar{\nu}_e$ detector:

- 1.6 T fiducial
- Baseline: 6 – 8.5m
- On-axis with reactor core

- 93.5% Enriched 235U
- Effective core diameter d=0.5m
- Peak power: 50-80 MW_{th}
- Duty cycle: ~ 150 days/year
- Low accidental background
- Small overburden : 10 mwe

SoLid timeline

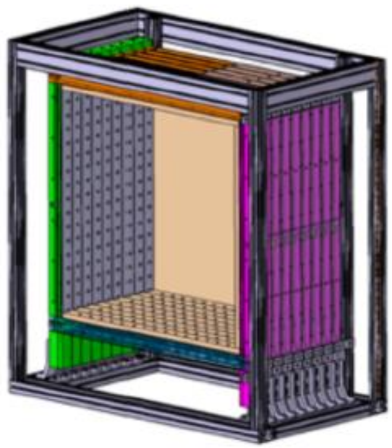
2013



NEMENIX (8 kg)

- 4×4×4 cubes
- proof of concept
- neutron PID

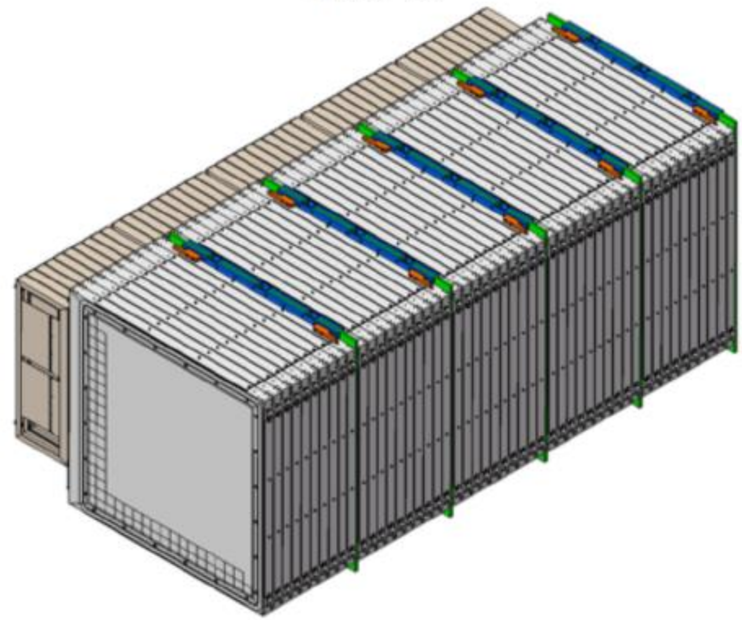
2014-15



SM1 (288 kg)

- 16×16×9 cubes
- 288 channels
- real scale system
- test scalability & production
- proved segmentation power

2016-17



SoLid Phase I (1.6 t)

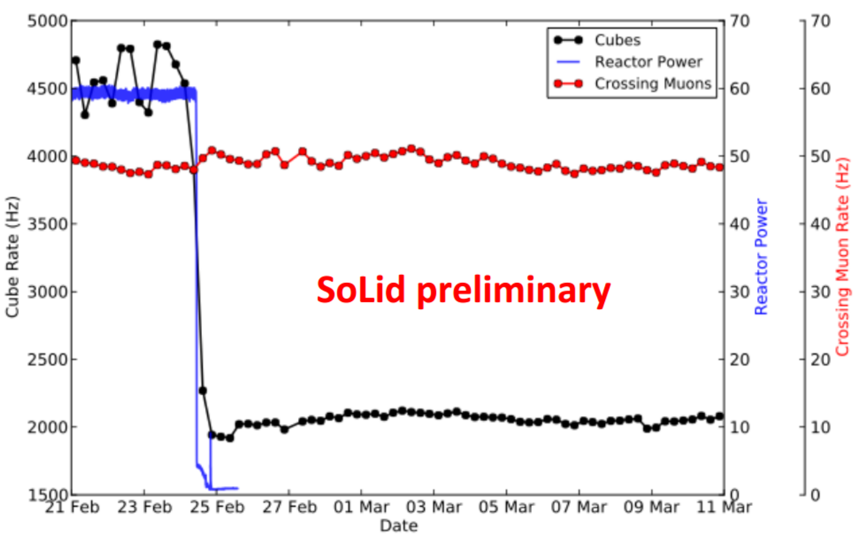
- 16×16×50 cubes
- 3200 channels
- optimized performances
- energy spectrum measurement
- oscillation search

SM1 data taking & operational stability

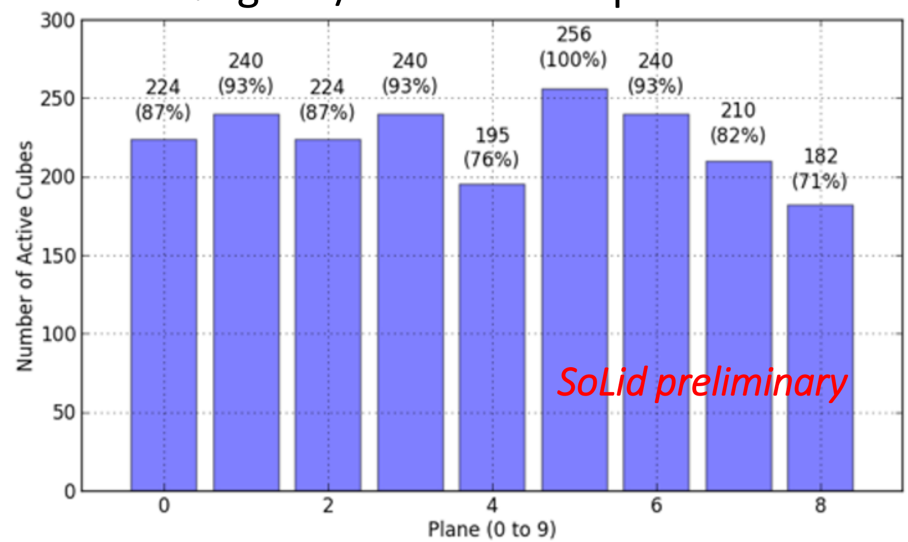
	Period 2015	Exposure Time
Reactor On	00:00 21 Feb → 08:00 24 Feb	50.9 hours
Reactor Off	00:00 01 Mar → 00:00 13 Mar and 00:00 01 Apr → 12:00 11 Apr	428.8 hours

+ Dedicated calibration campaigns with sources: 60Co, AmBe, 252Cf

Stable rates of EM signals

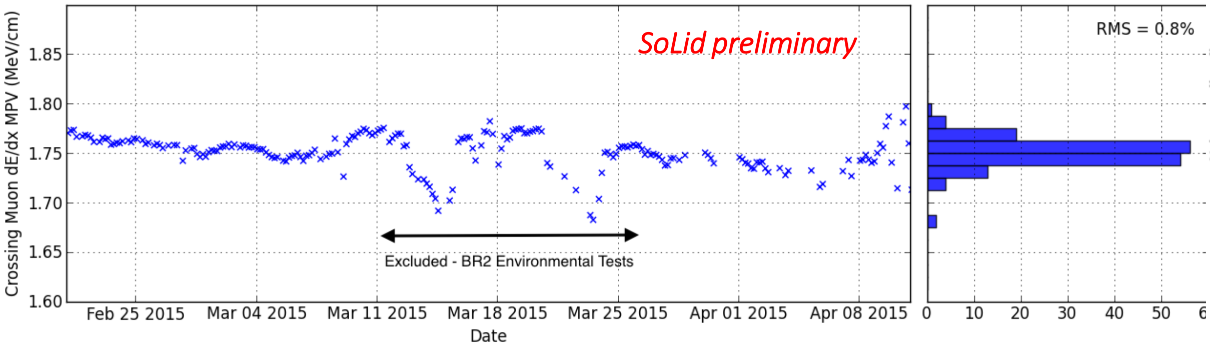


87% good/stable cube operation

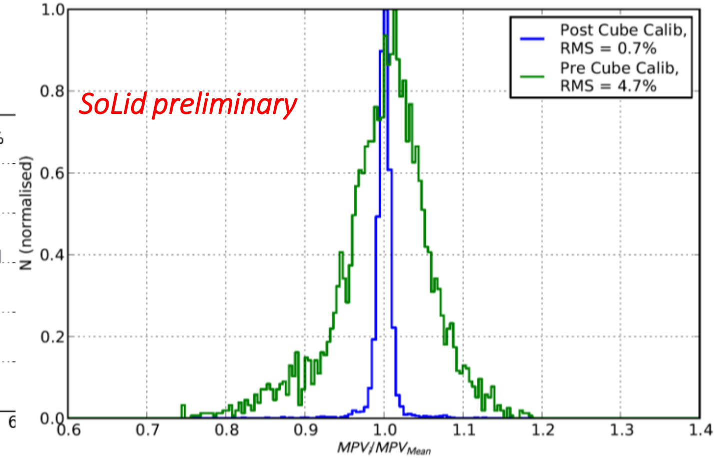


SM1 highlights

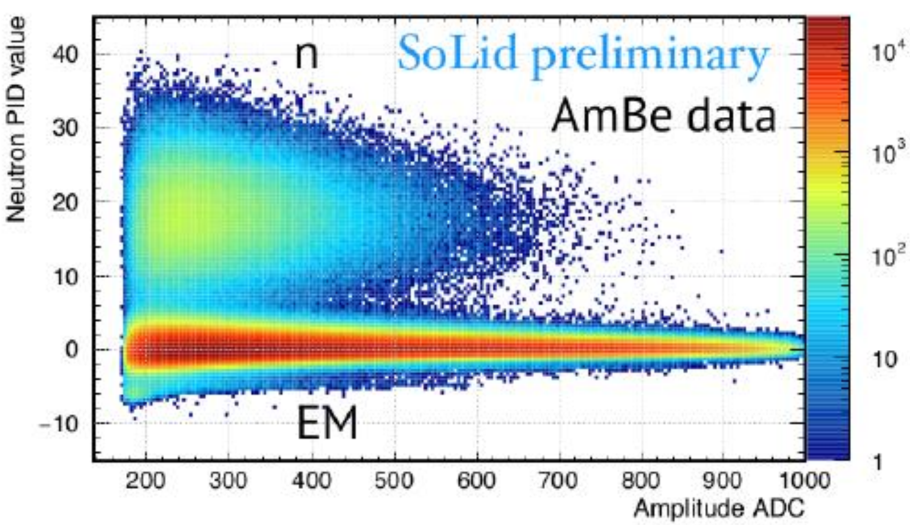
Monitoring with muons

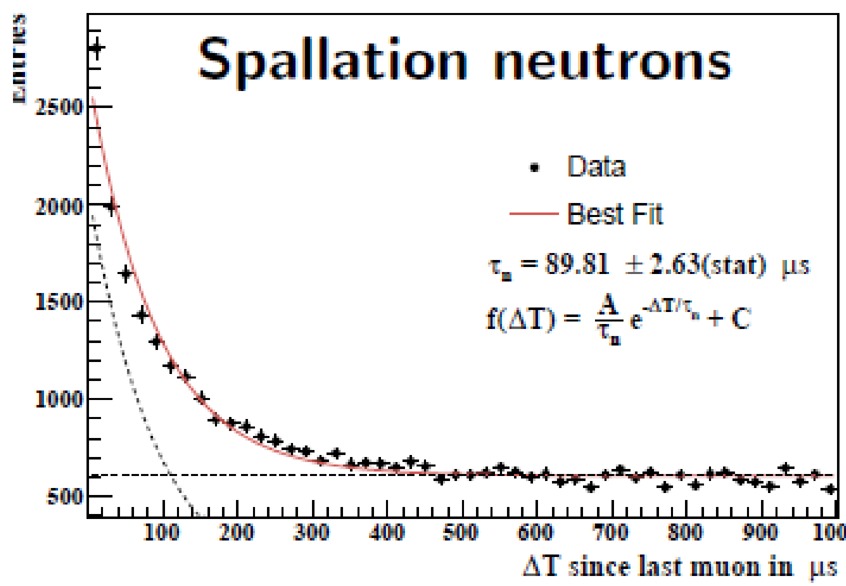


intercalibration with muons



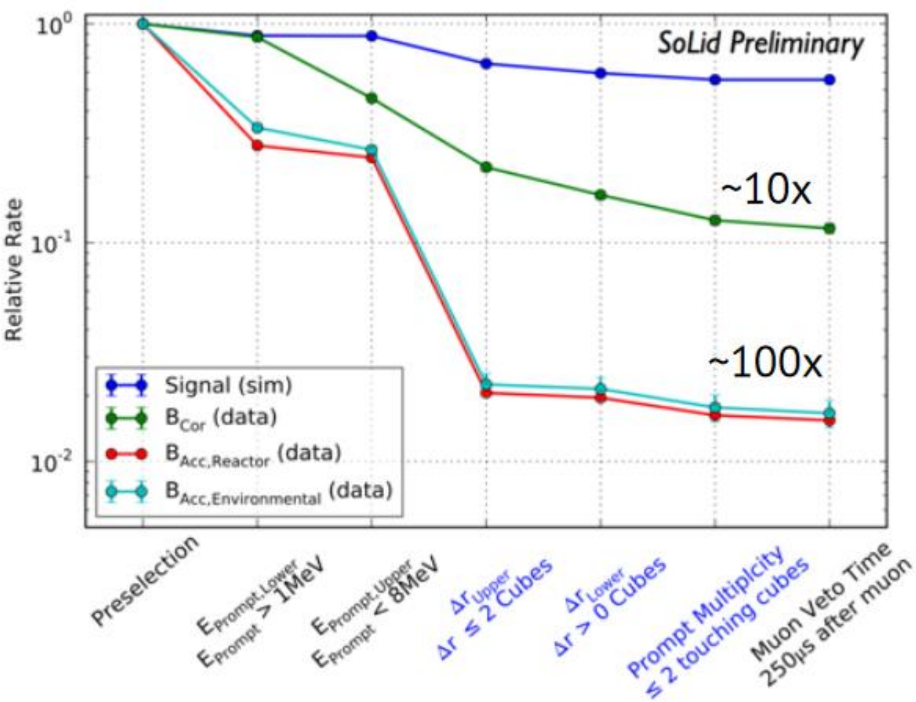
Neutron PID

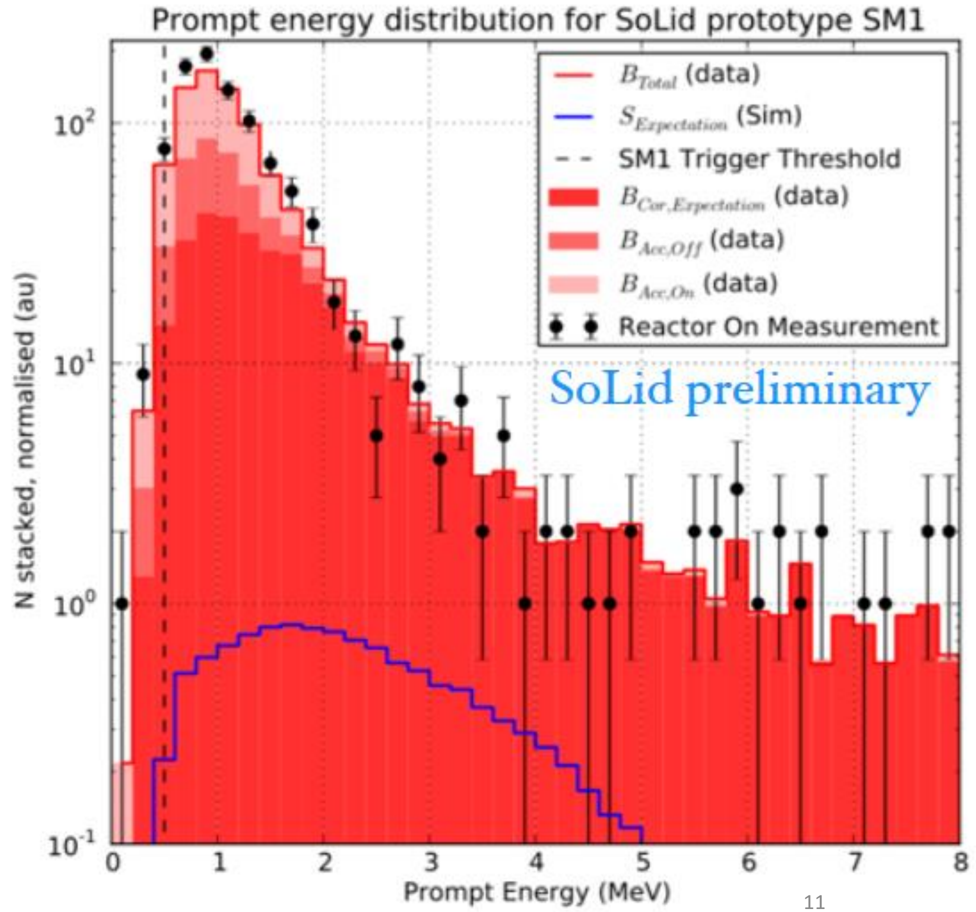




SM1 highlights

- Energy resolution determined to be $\frac{\sigma_E}{\sqrt{E}} = 20\%\ at\ 1\ MeV$
- Neutron detection efficiency was low: 2.5% driven by high thresholds to suppress noisy electronics
- Background rejection power of segmentation demonstrated
- Due to limited exposure and low eff no significant IBD excess observed
- BUT: Lots of lessons learned and many improvements made



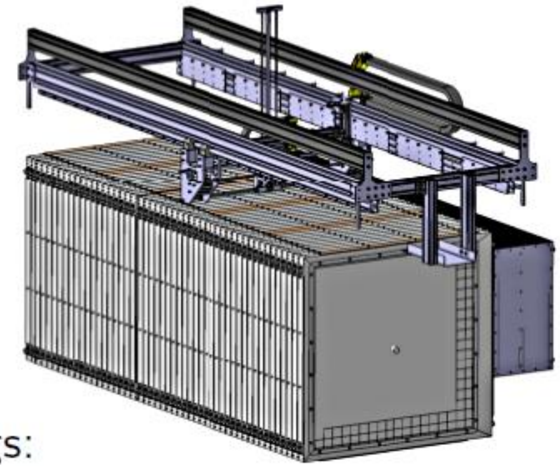


Background spectrum measurement used for re-evaluation of SoLid sensitivity

From 300 kg to 1.6 Ton

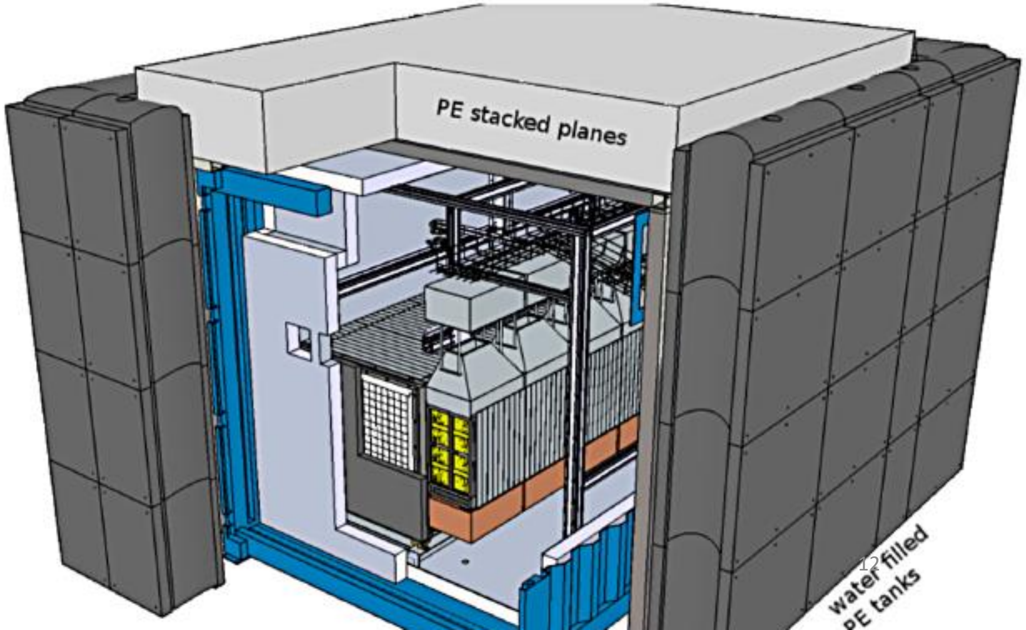
Container 2.4×2.6×3.8 m^3:

- cooling down to 5°C to reduce SiPM dark count rate (~1/10)
- planes of 16x16 cubes
- 5 modules of 10 planes
- automated calibration system between modules

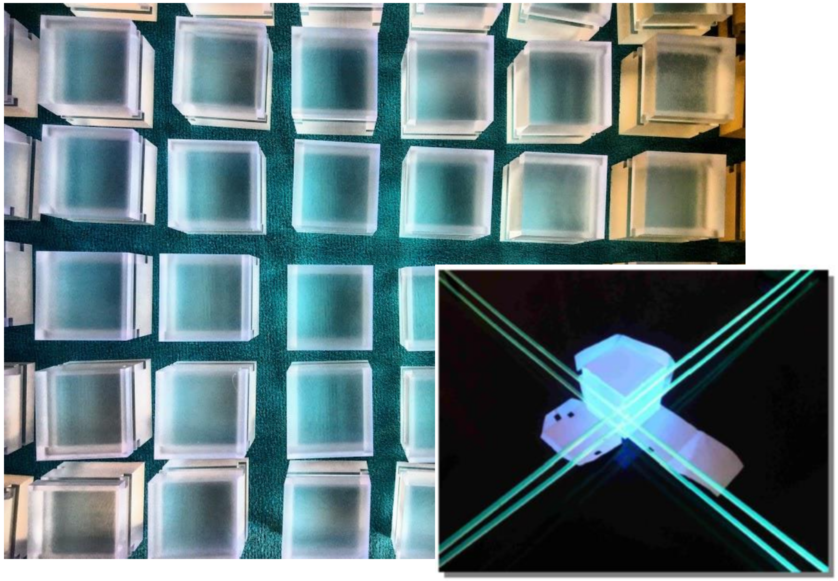


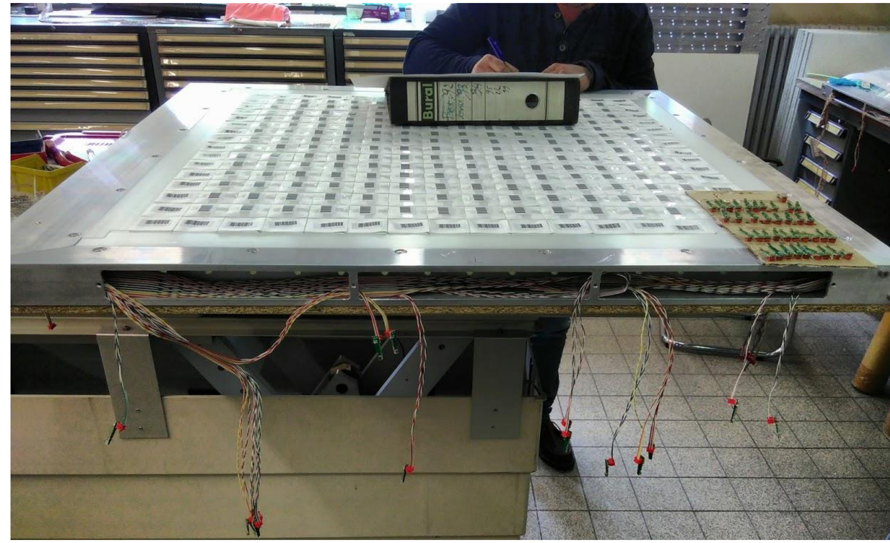
Shieldings:

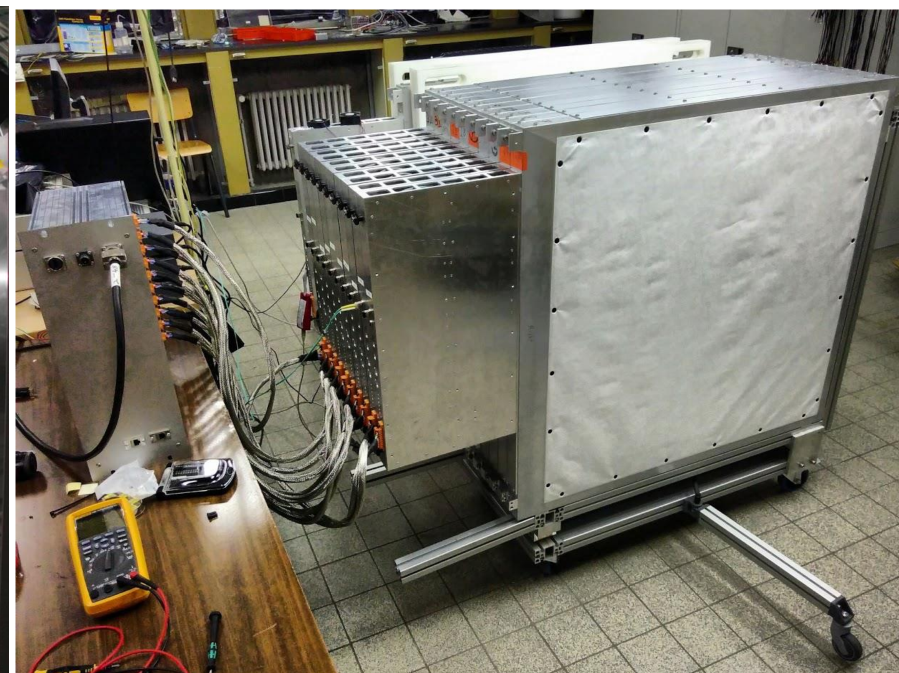
- water walls: 50 cm thick, 3.4 m high, 28 t
- polyethylene ceiling: 50 cm thick, 6 t
- cadmium sheets



Construction & Integration: finished since oct 2017

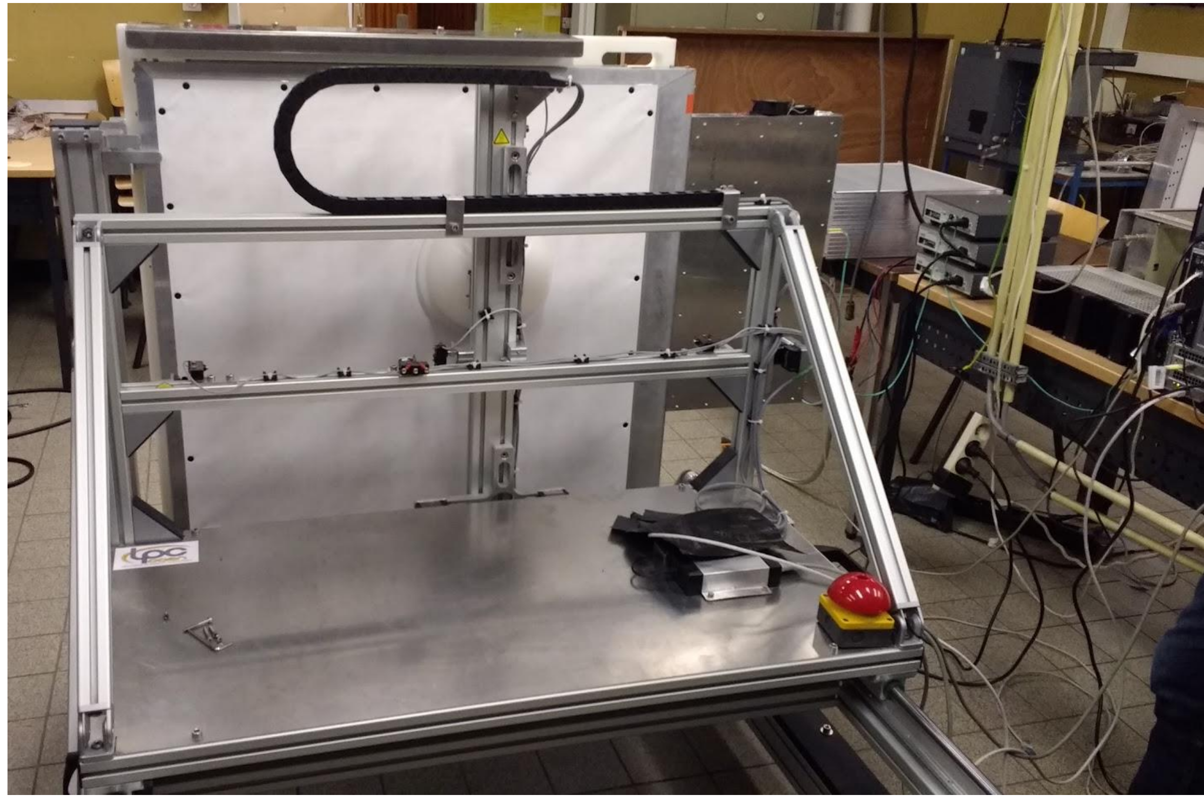


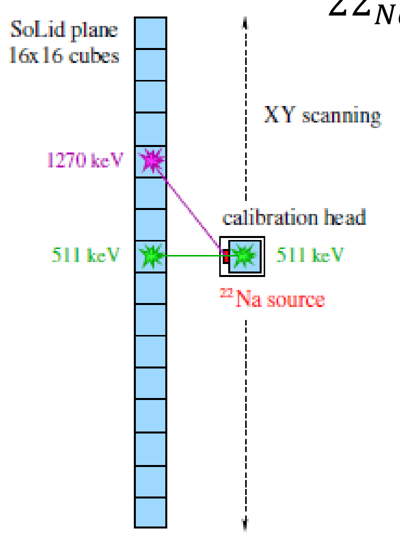




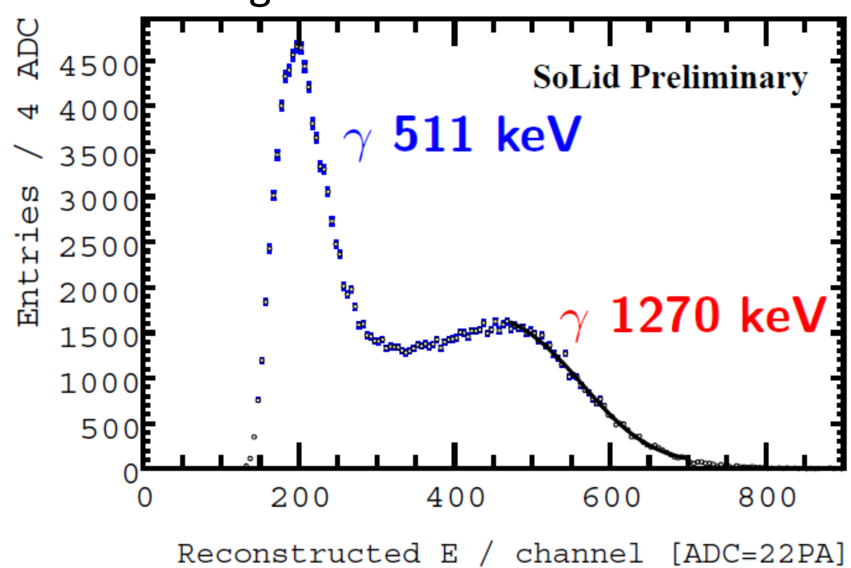
Quality control: CALIPSO

- Automated scanner with active calibration head accommodating various neutron, electron/gamma sources:
- 207Bi, 22Na, 137Cs, 60Co, …
- 235Cf, AmBe
- 16x16 cell plane in 4 hours





22_{Na} Compton edge of 1270 keV gamma used for LY measurement

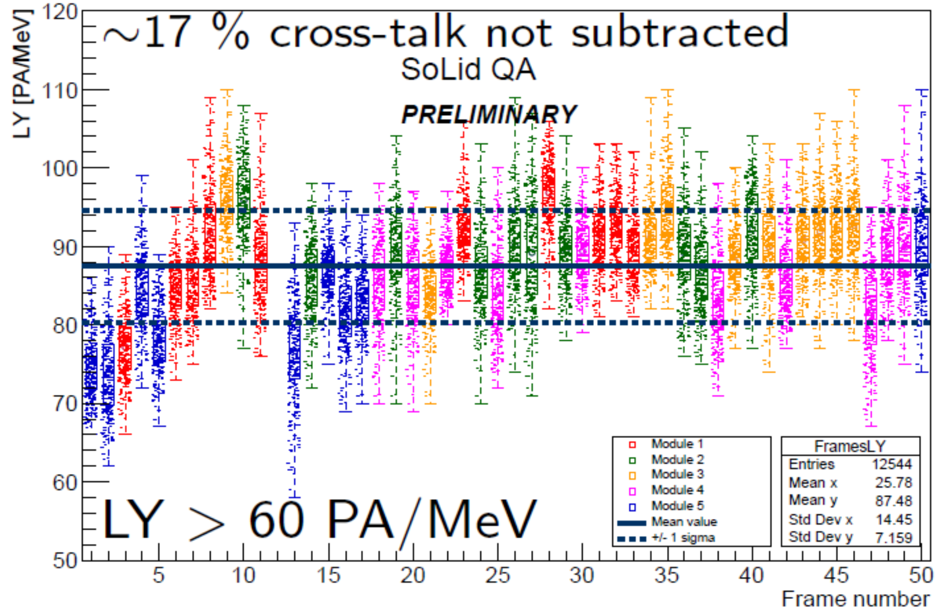


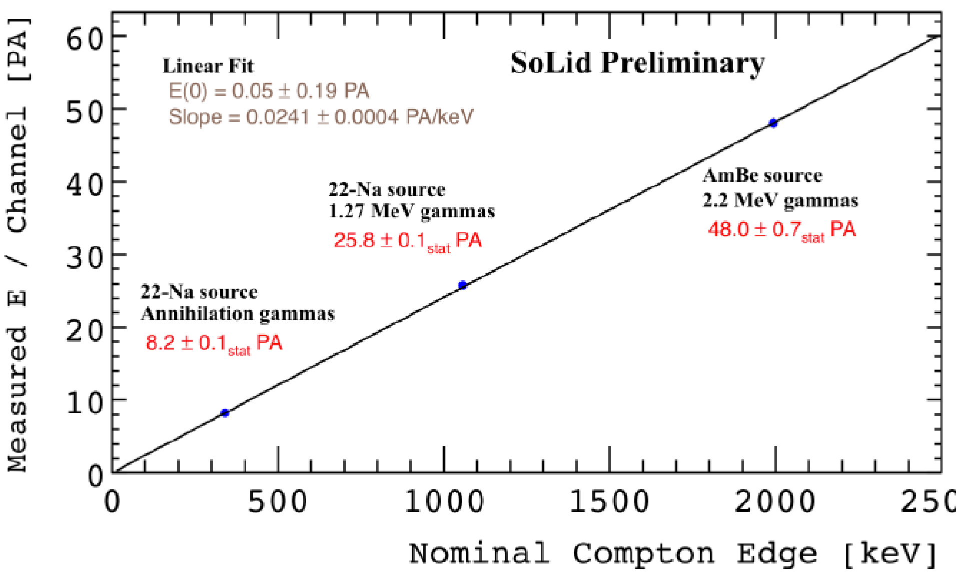
Optical performance

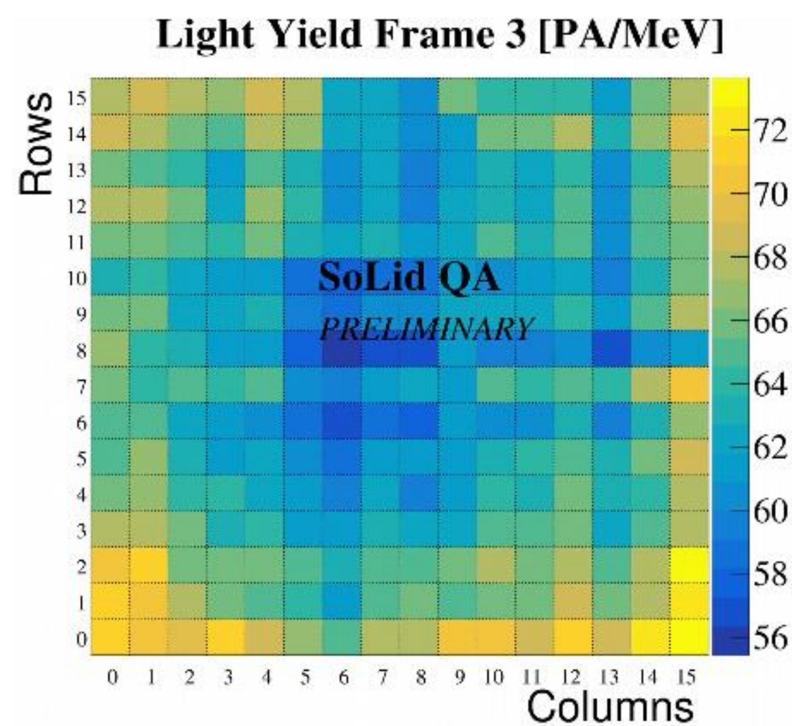
- Improve PVT cube quality and wrapping
- Double readout: from 2 to 4 fibers per cube
- Use double cladded fibers

Impact:

- improved energy resolution from 20% to 12 % at 1 MeV
- Linear response
- Better uniformity of light response in detector: compensate attenuation in fibers





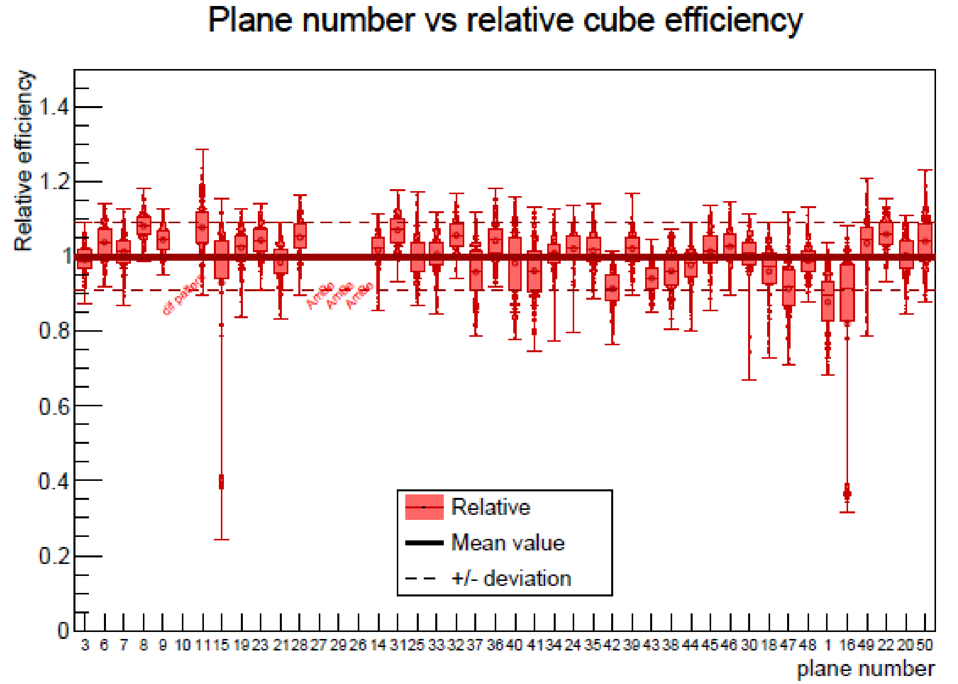


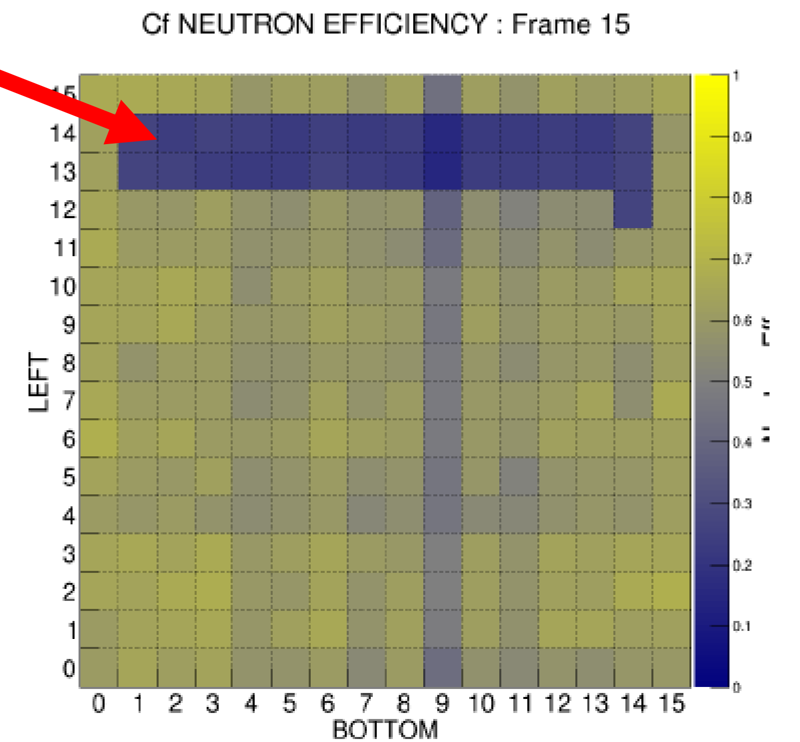
Neutron performance

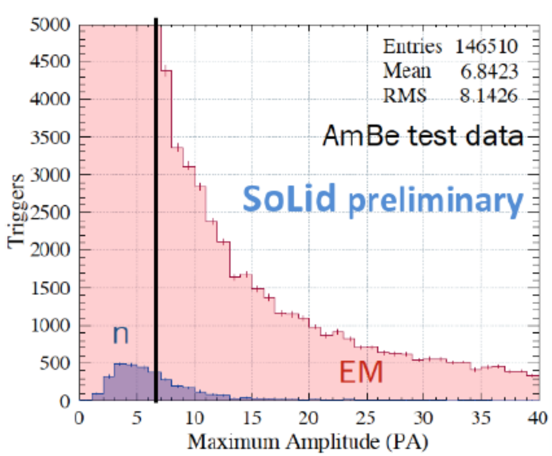
- Doubling LiZnS with different backing
- Better light coupling to PVT cube
- Dedicated neutron trigger based on Peak-over-treshold (PoT)

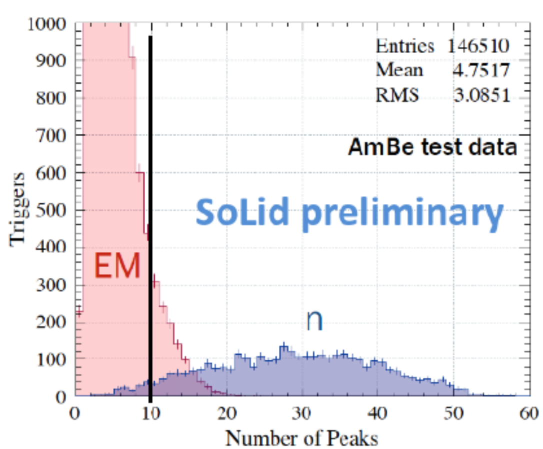
Results:

- Increase neutron capture prob.: 65%→ 80%
- → High detection efficiency (O(60%))
- Shorten the neutron capture time: 90μs→ 65 μs
- →shorter IBD window and less accidentals
- Spot Li screen batches that are off-specifications
- Relative variations in n-response<10%
- Several MC models, based in MCNO and G4 agree within errors







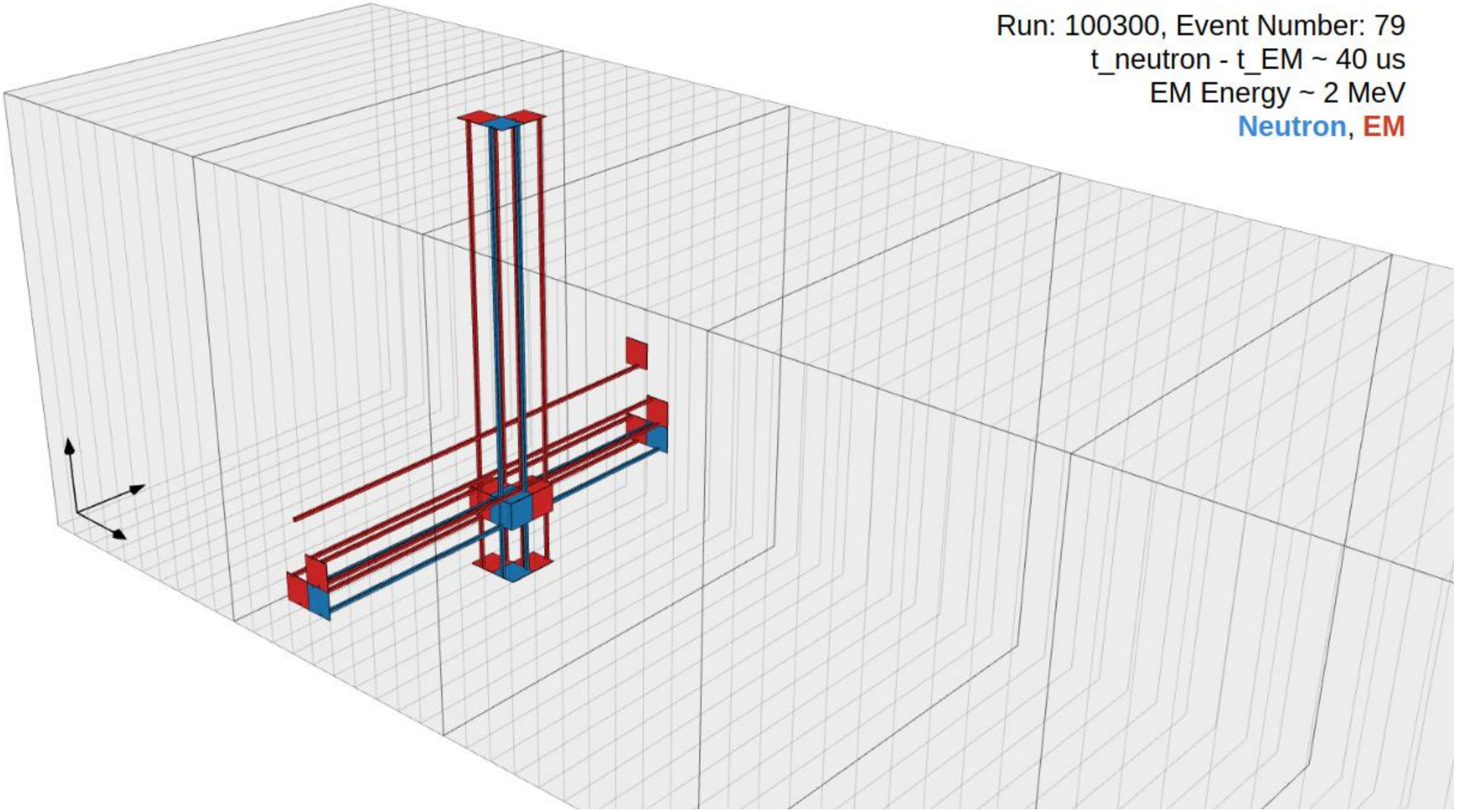


Current Status

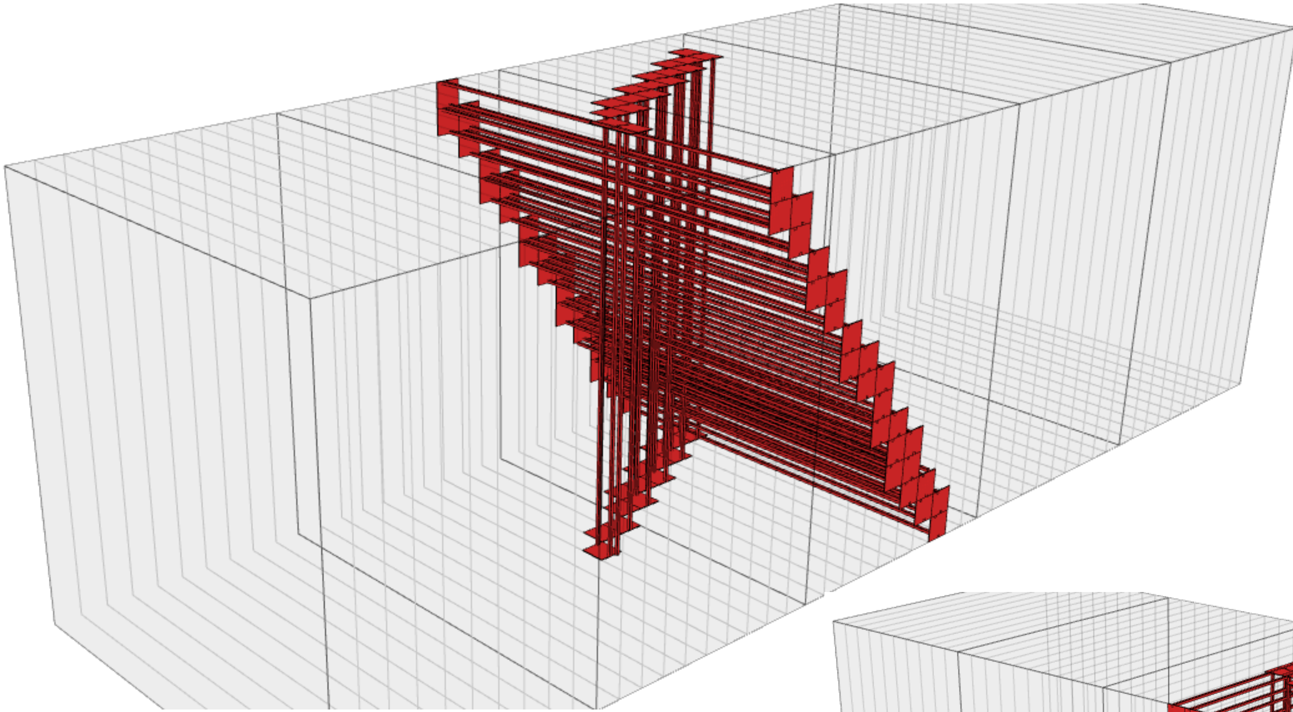
- SoLid was installed at 6.2m from the BR2 core at 60 MW on oct 20
- Taking data since November for dedicated commissioning run:
  - 4/5 modules (1.3 ton) installed: >99% of all installed channels active
  - Light response currently equalized to few %
  - Operating with treshold and neutron triggers in zero suppressed mode
  - Mapping backgrounds as shielding is being erected: large reduction in neutron bg due to 50cm passive water + Cd shielding
  - Gamma bg monitored in parallel with HpGe and NaI detectors
  - Crossing muons well reconstructed
  - Dedicated calibration runs with AmBe performed
  - Since Dec1 at 10˚C ambient temperature taking reactor data in stable conditions
  - Reactor cyle ended on Dec 12: Substantial sample of antineutrino events on tape
  - Taking background reference data over the holidays
  - Ready with 5 modules by Feb 6 for first reactor cycle of 2018

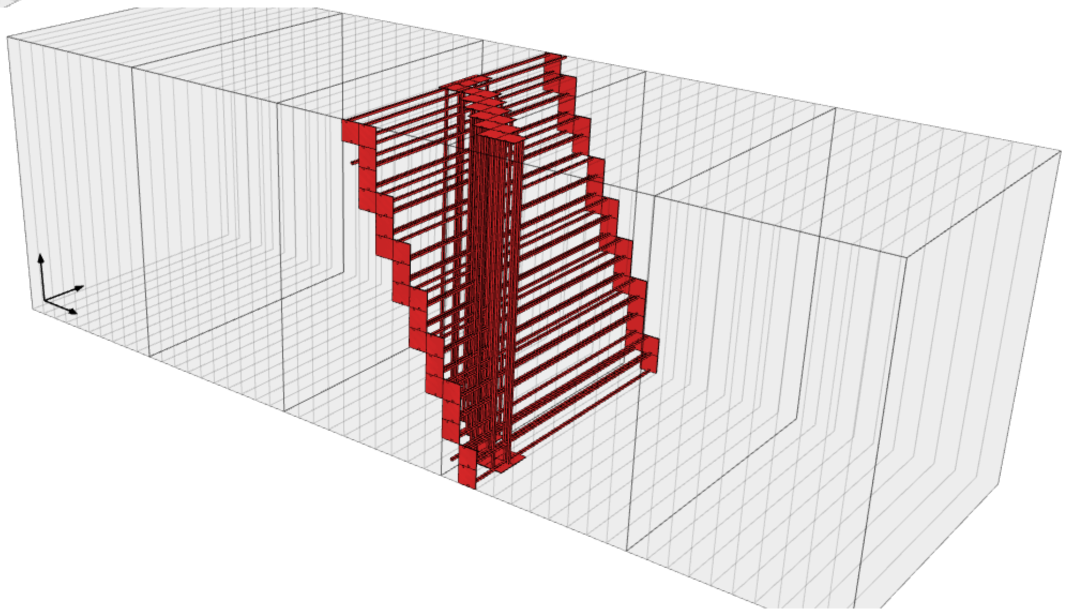

PE 500 R

First IBD event candidate



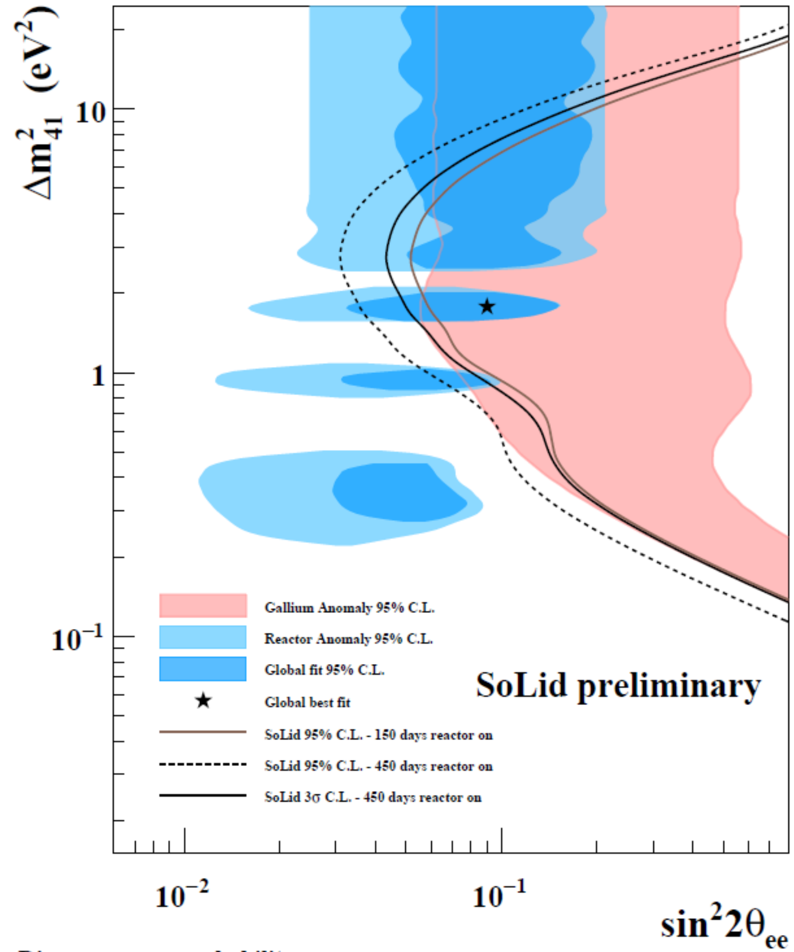
Crossing Muon events

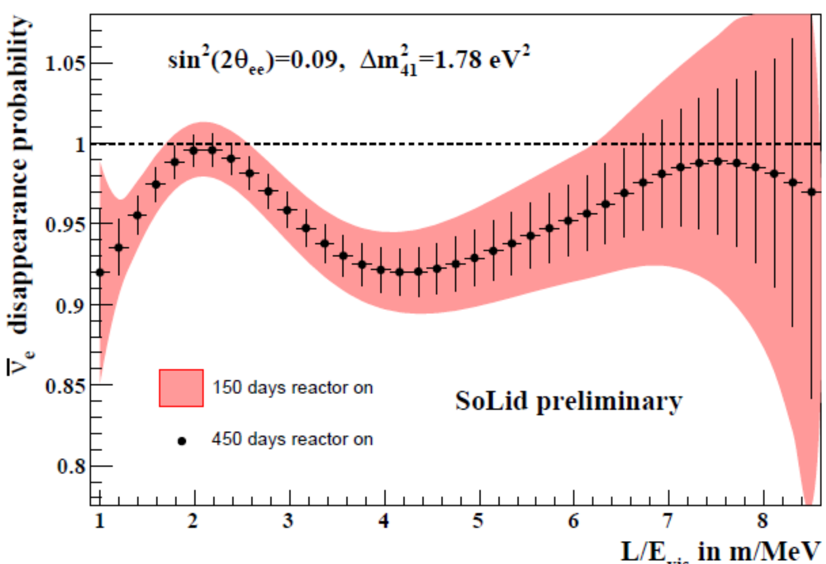


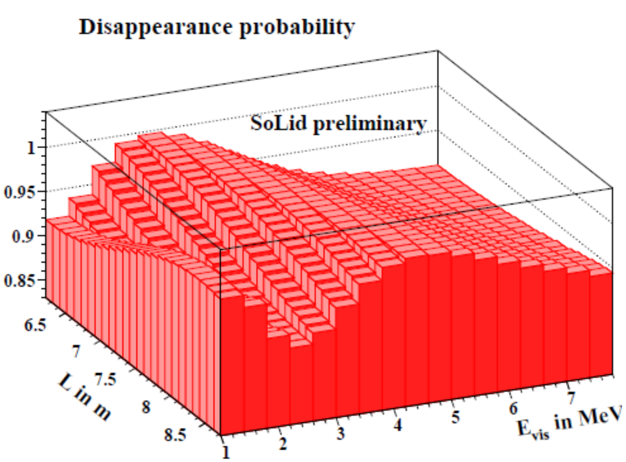


Sensitivity

- SoLid stays with its initial sensitivity estimates, for which input parameters are now confirmed by measurements indicating we can do as good or better:
- Baseline 6.2-8.7 m: O(1500 $\overline{\nu_E}/day$)
- Thermal power 60 MWth
- Detector dimensions 0.8x0.8x2.5 m3
- Detector mass 1.6 t
- Energy resolution $\sigma_E/\sqrt{E}$=14 %
- IBD efficiency 30 %
- Signal to background 3:1
- Background spectrum taken from measurements with SM1 at BR2 in 2015

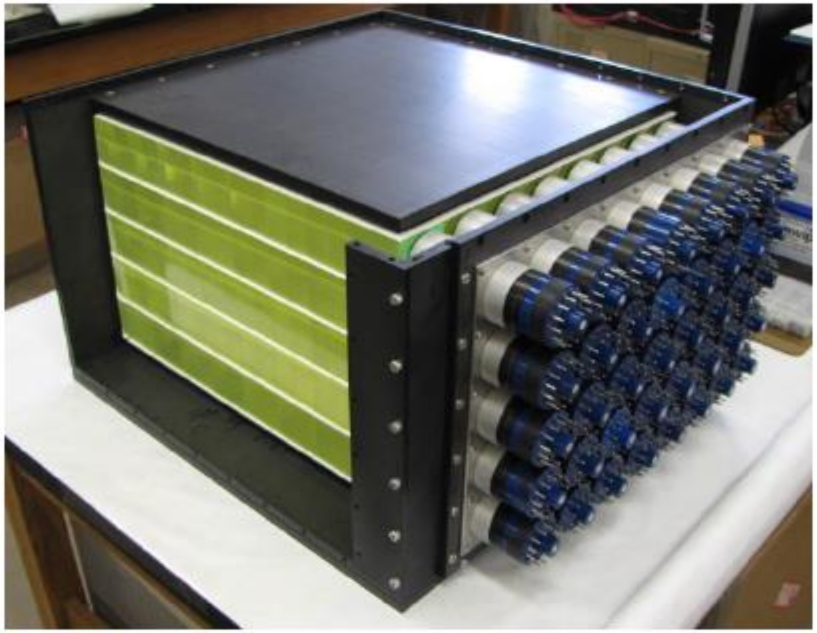




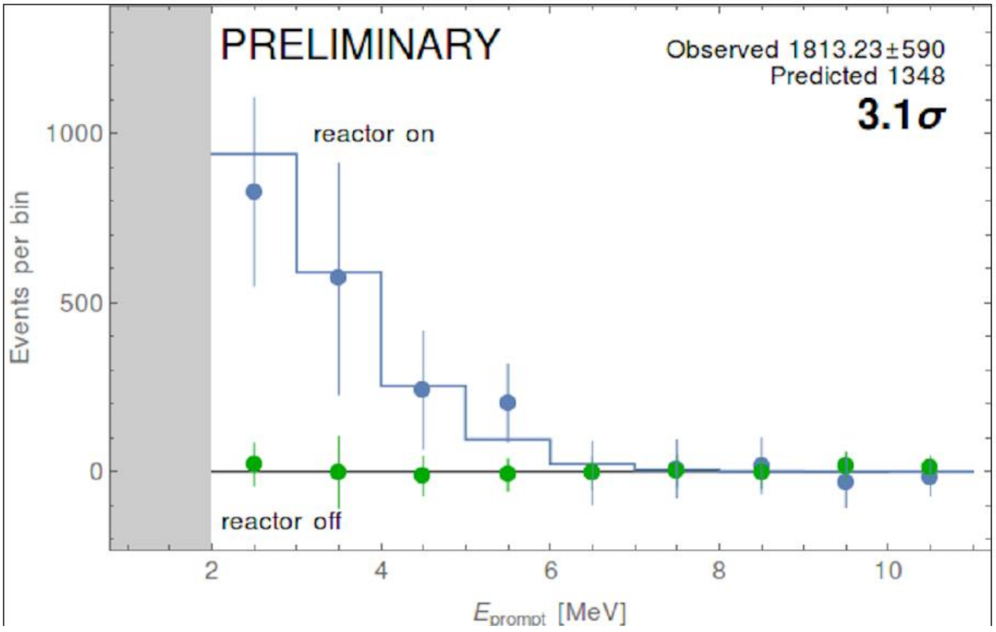


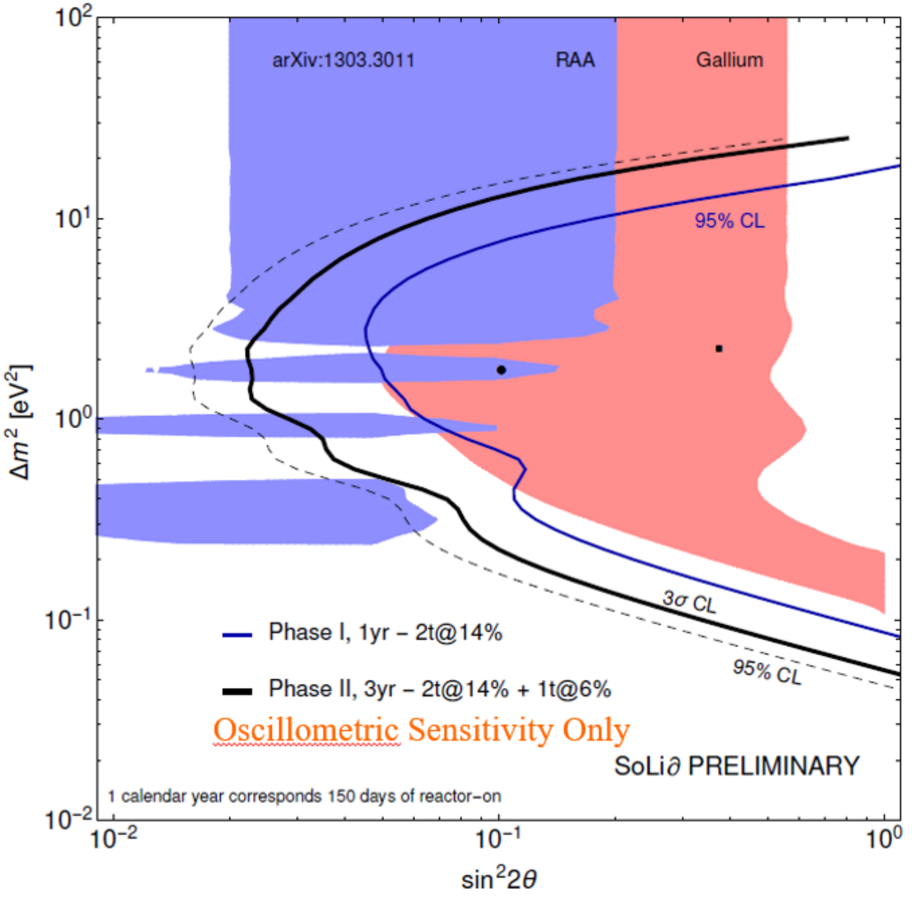
Beyond phase 1

- Possibility to extend SoLid1 with:
  - 1 extra module (320 kg extra fiducial mass)
  - 1-2 ton CHANDLER detector running alongside
- CHANDLER:
  - Raghavan Optical Lattice: wl. Shifter in Plastic and readout via total internal reflection
  - LiZnS sheets sandwiched in layers
  - Aiming at $\sigma_E/\sqrt{E}$=6 %
  - 1-2 Ton detector to be funded
- Mini-CHANDLER:
  - 2x8x5 readout channels
  - Deployed at North Anna 2.9 GW at 25 m since June 2017



Chandler performance





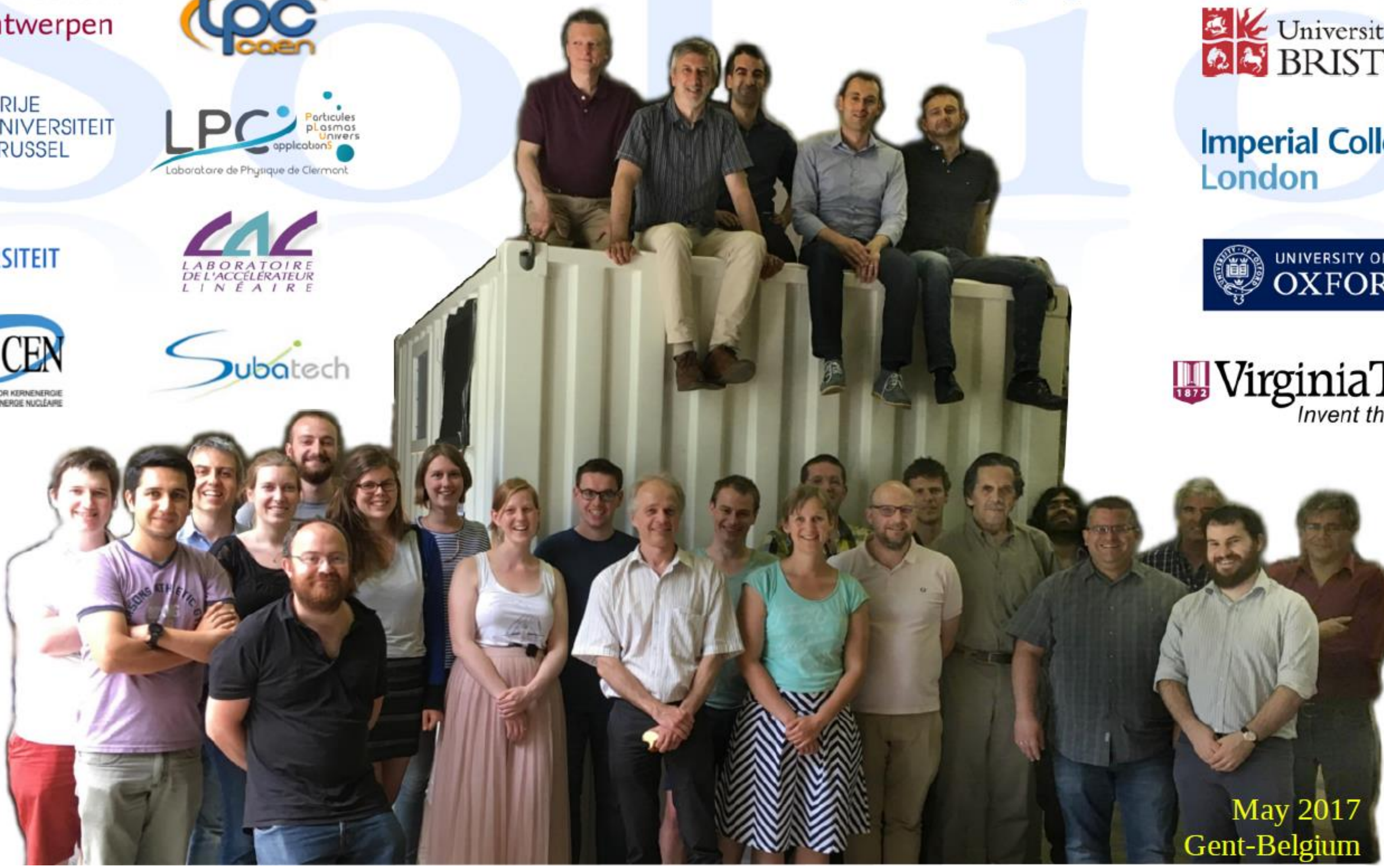
Conclusion

- SoLid has constructed Phase 1: a 1.6 Ton full scale detector with he aims of performing oscillation searches in 2018
- Sensitivity using this fiducial mass comparable with other experiments being staged
- Quality assurance and calibration measurements show excellent performance : uniformity, light yield, efficiencies, …
- Backgrounds are already well understood and properly modeled using 2015-2016 data
- Phase 1 detector deployed at BR2 reactor since end October 2017
- BR2 reactor currently running at 60 MW_{th}
- Analysis tools and software, including reactor antineutrino spectrum predictions at the ready
- 4 out of 5 modules being commissioned as we speak, showing excellent performance:
  - 99% channels up and equalized,
  - various triggers deployed, including IBD
  - Cooldown of detector in progress
- Phase 2 based on improved energy resolution showing promising potential using small demonstrator
- Look out for news in the very near future

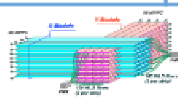
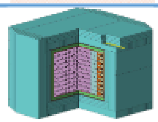
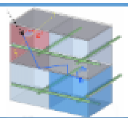
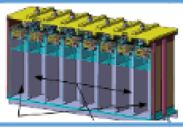
The SoLid Collaboration

4 countries 12 institutes ~50 people

Universiteit Antwerpen
Vrije Universiteit Brussel
Universiteit Gent
SCK•CEN Studiecentrum voor Kernenergie Centre d'Étude de l'Énergie Nucléaire
LPC Caen
LPC Laboratoire de Physique de Clermont
LAL Laboratoire de l'Accélérateur Linéaire
Subatech
University of Bristol
Imperial College London
University of Oxford
Virginia Tech Invent the Future



Short Baseline Reactor Experiments*

Experiment		Reactor Power/Fuel	Overburden (mwe)	Detection Material	Segmentation	Optical Readout	Particle ID Capability
DANSS (Russia)		3000 MW LEU fuel	~50	Inhomogeneous PS & Gd sheets	2D, ~5mm	WLS fibers.	Topology only
NEOS (South Korea)		2800 MW LEU fuel	~20	Homogeneous Gd-doped LS	none	Direct double ended PMT	recoil PSD only
nuLat (USA)		40 MW ^{235}U fuel	few	Homogeneous ^{6}Li doped PS	Quasi-3D, 5cm, 3-axis Opt. Latt	Direct PMT	Topology, recoil & capture PSD
Neutrino4 (Russia)		100 MW ^{235}U fuel	~10	Homogeneous Gd-doped LS	2D, ~10cm	Direct single ended PMT	Topology only
PROSPECT (USA)		85 MW ^{235}U fuel	few	Homogeneous ^{6}Li-doped LS	2D, 15cm	Direct double ended PMT	Topology, recoil & capture PSD
SoLid (UK Fr Bel US)		72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm multiplex	WLS fibers	topology, capture PSD
Chandler (USA)		72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm, 2-axis Opt. Latt	Direct PMT/ WLS Scint.	topology, capture PSD
Stereo (France)		57 MW ^{235}U fuel	~15	Homogeneous Gd-doped LS	1D, 25cm	Direct single ended PMT	recoil PSD