38th International Conference on High Energy Physics
August 3 - 10, 2016, Chicago

SoLid: A compact detector for very short-baseline neutrino experiments

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for the SoLid collaboration

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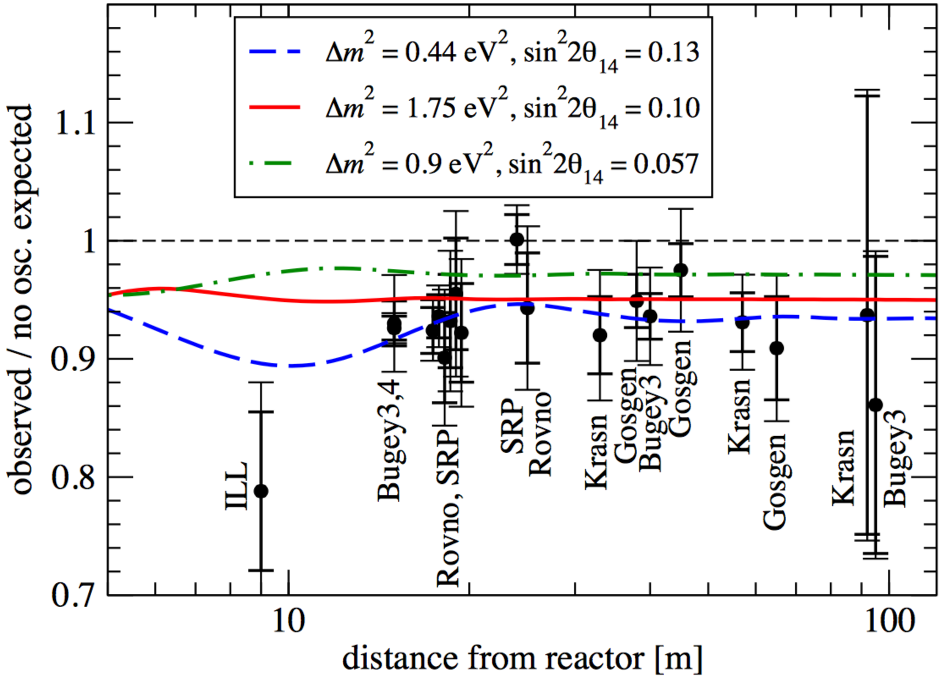
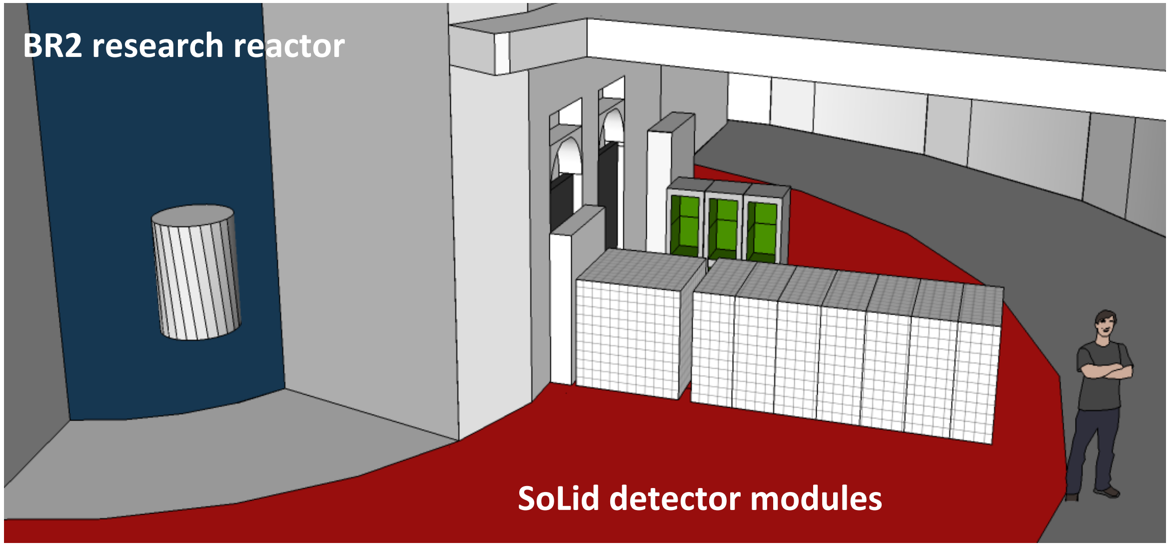
Motivation

Kopp et al., JHEP 1305(2013)



- Re-analysis of past reactor experiments, with improved flux
  - ~ 6% deficit in the number of detected antineutrinos
  - Supporting indication from source calibration runs in gallium detectors
- *Could this be the hint of an additional sterile neutrino ?*

The SoLid experiment at SCK•CEN



- **SoLid is a very short-baseline experiment, designed to resolve the Reactor Antineutrino Anomaly**
  - Installed at the BR2 research reactor in SCK•CEN (Mol, Belgium)
  - Long detector module that covers a wide baseline range ~ 5.5 - 10 m
- **Measurement of the ^{235}U flux and spectrum**
  - Help to understand the 5 MeV "bump" seen by Daya Bay, Double Chooz and RENO
  - Demonstrate reactor antineutrino safeguards for non-proliferation

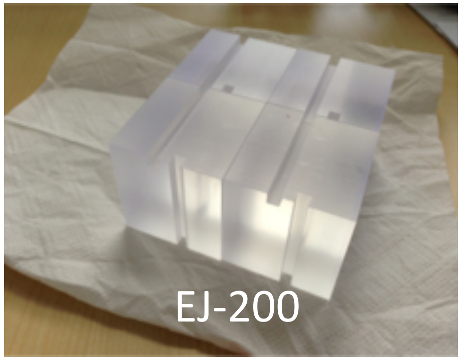
The SoLid collaboration

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

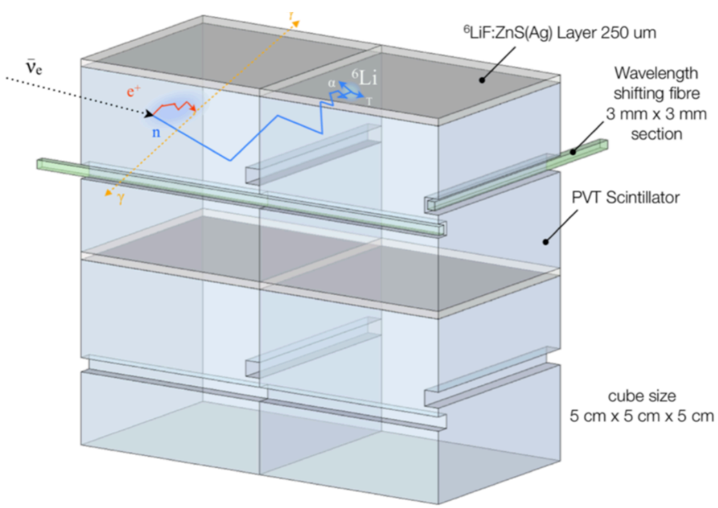
Challenges

- **Small oscillation effect (10%)**
  - Large statistics, good understanding of systematics
- **Requires compact reactor core (d < 1 m)**
  - A few meters oscillation length
- **Cover a large baseline range (5.5 - 10 m)**
  - Good vertex and energy resolution
- **Control of background is the key**
  - Close proximity to a nuclear reactor
  - Low overburden (almost on surface)

Detector concept

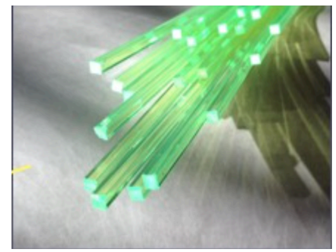


- $5 \times 5 \times 5$ cm^3 PVT cubes
- Non-flammable scintillator

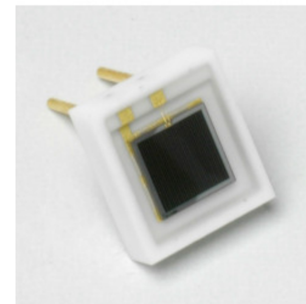


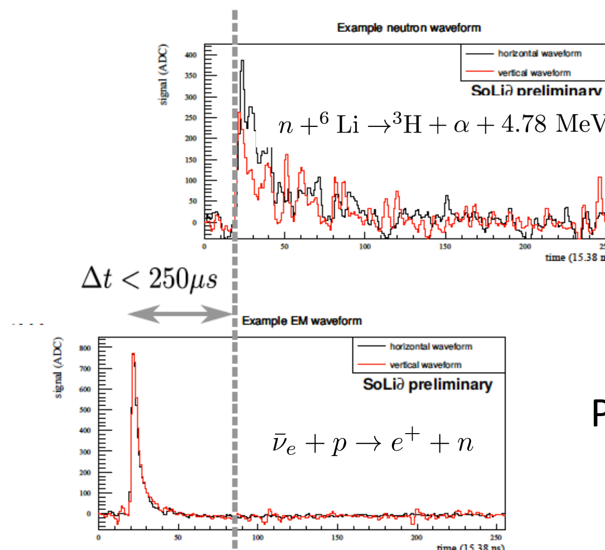
- Adjacent planes of cubes

- Cubes are optically separated (wrapped in Tyvek)
- ^{6}LiF:ZnS(Ag) for neutron identification
- Light collected through optical fibers and silicon photomultipliers (SiPMs require low-voltage)



Squared BCF-91A fiber



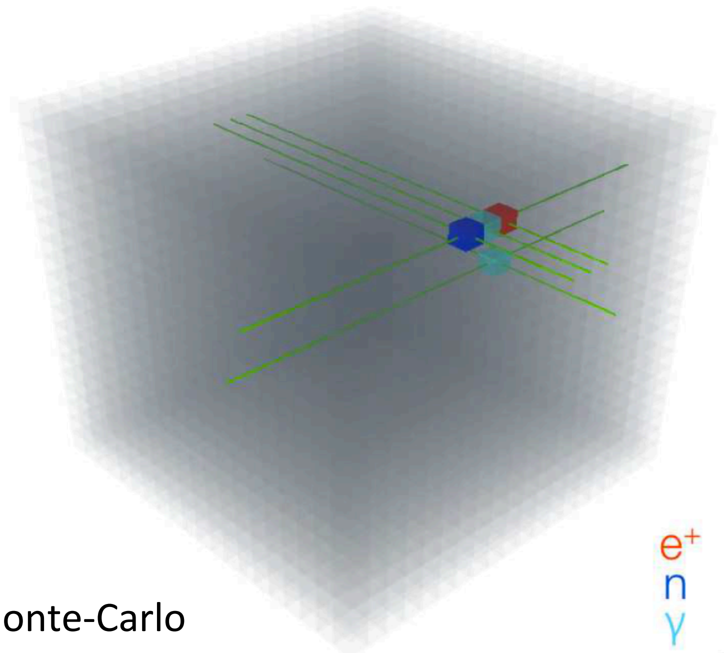


Delayed signal

Prompt signal

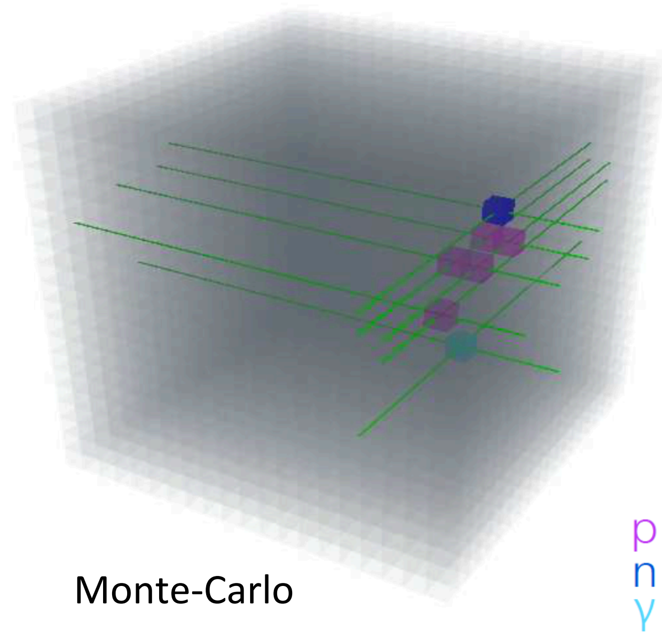
Event topology in SoLid

Inverse beta decay event



Monte-Carlo

Fast neutron event

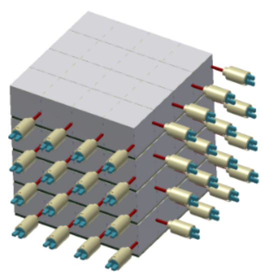


Monte-Carlo

– High granularity allows for signal localization and thus enhances significantly background rejection
– Fast neutron rejection possible through event topology

Detector development

NEMENIX, 2013



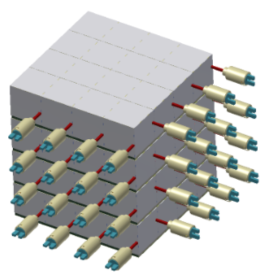
64 cubes totally
8 kg active mass

Proof of principle

- Validate neutron identification
- Demonstrate prompt-delayed signal selection
- Background measurement

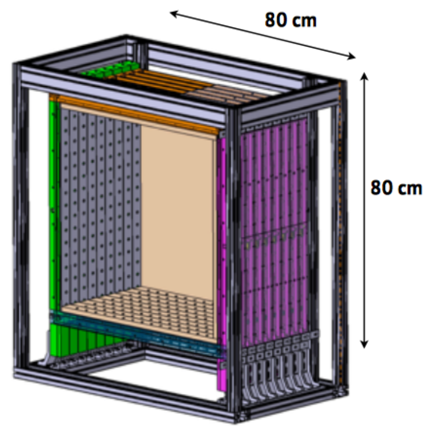
Detector development

NEMENIX, 2013



64 cubes totally
8 kg active mass

SM1 prototype,
2014 -2015



9 planes of 16 × 16 cubes
288 kg active mass

Proof of principle

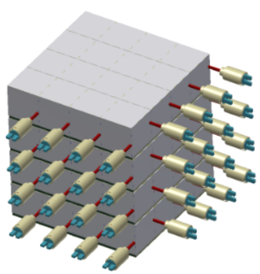
- Validate neutron identification
- Demonstrate prompt-delayed signal selection
- Background measurement

First large scale prototype

- Demonstrate scalability and test production schedule
- Probe background rejection
- Analysis tools, physics results

Detector development

NEMENIX, 2013



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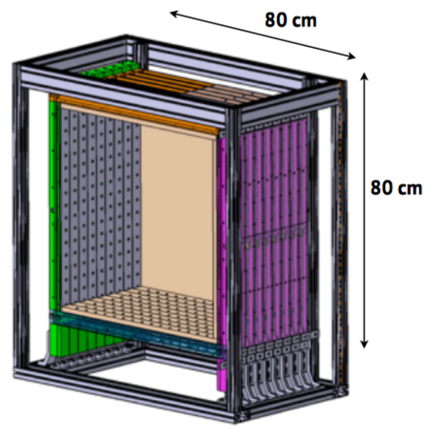
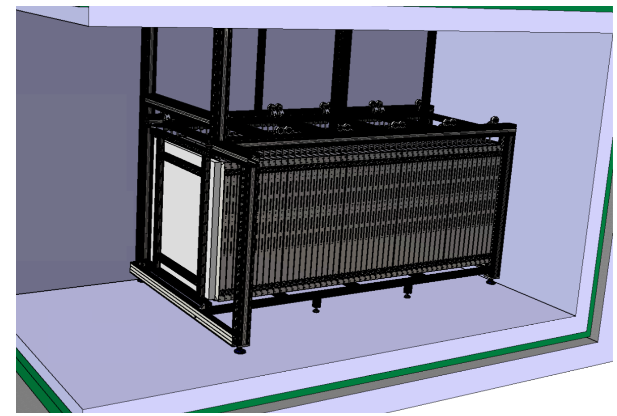
SM1 prototype,
2014 -2015



9 planes of 16 × 16 cubes
288 kg active mass

Phase I detector, 2016



50 planes of 16 × 16 cubes
1.6 tons active mass

Proof of principle

- Validate neutron identification
- Demonstrate prompt-delayed signal selection
- Background measurement

First large scale prototype

- Demonstrate scalability and test production schedule
- Probe background rejection
- Analysis tools, physics results

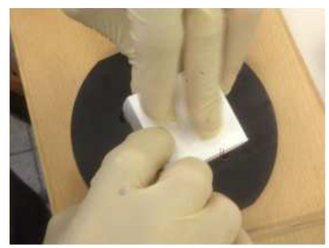
Real scale system

- Improved design
- Implement neutron trigger
- Perform high precision measurements

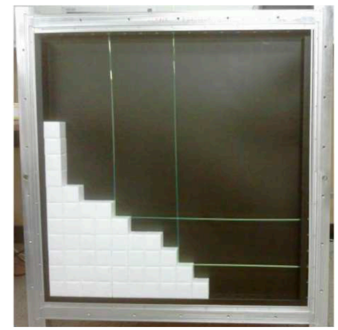
SM1 prototype

- 3000 cubes machined and assembled
  - Wrapped with Tyvek and carefully weighted
  - Number of protons determined with better than 1 % accuracy



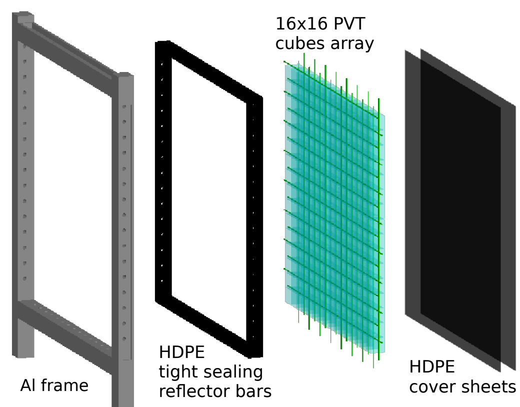


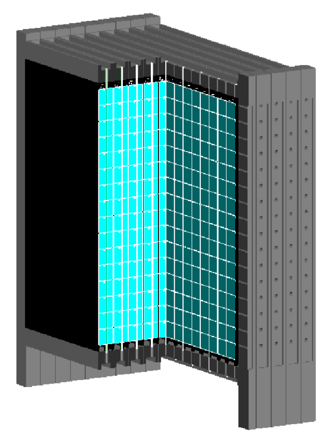
Plane under construction



Assembled plane

- 16 × 16 PVT cubes grouped together to form a single plane
  - Mechanical support with aluminum frame
  - HPDE to reduce neutron dissipation





9 planes totally, 288 kg
288 readout channels
80 × 80 × 45 cm

Deployment at BR2

SM1 at Gent

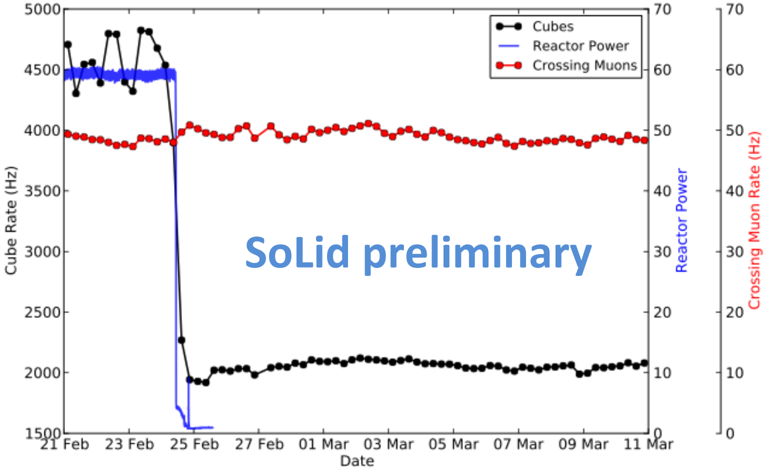
Eppur si muove

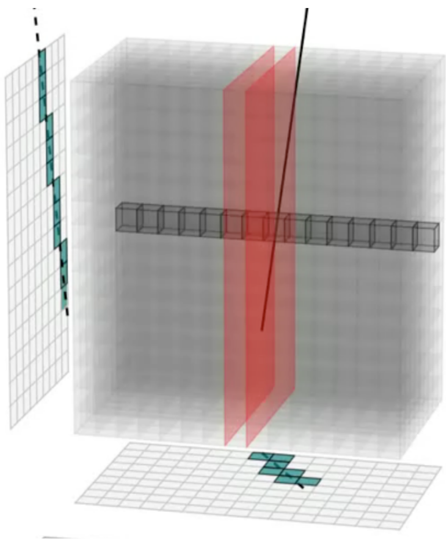
Installation at BR2

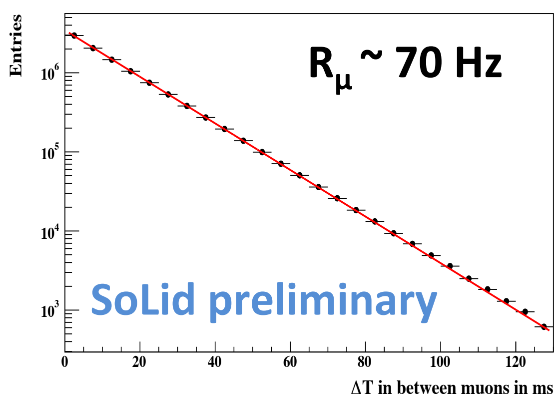
November 2014

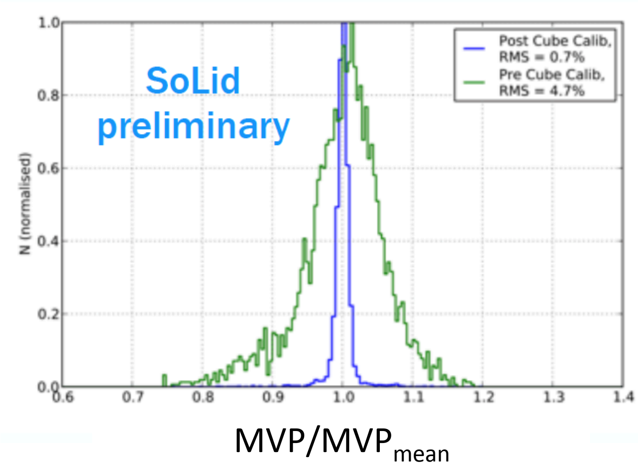
Data taking and calibration with muons

- SM1 took data for several weeks
  - 3 - 4 days reactor on
  - ~ 1 month reactor off
  - Calibration runs with ^{60}Co, AmBe and ^{252}Cf sources
- Channel equalization (gains and attenuation) using crossing muons

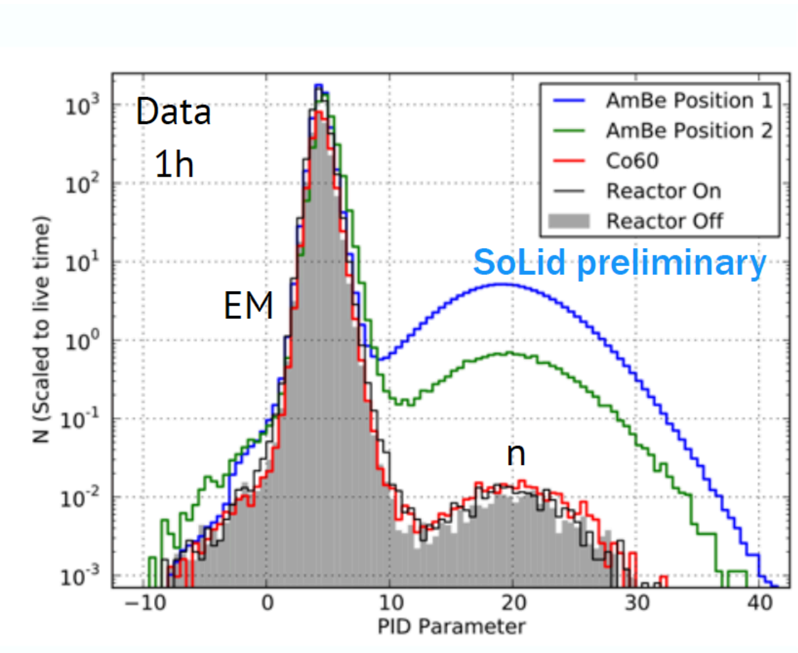


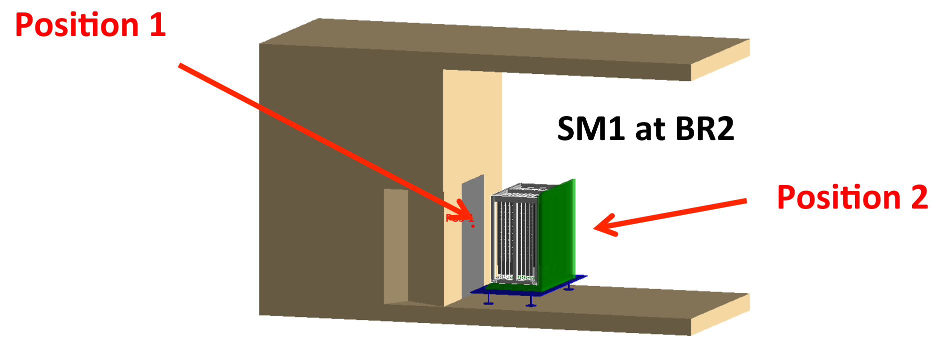




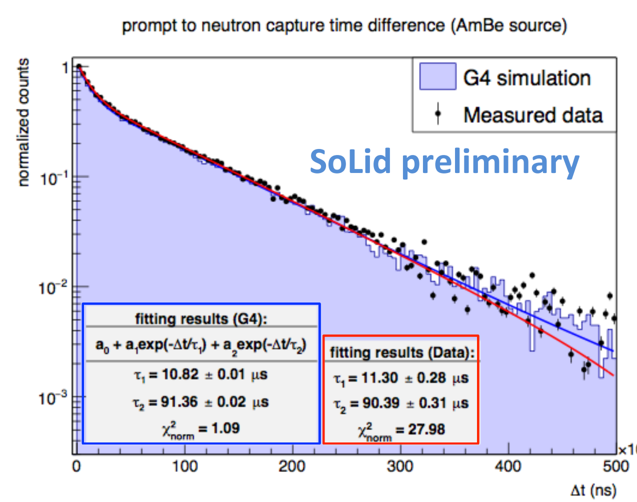


Neutron identification





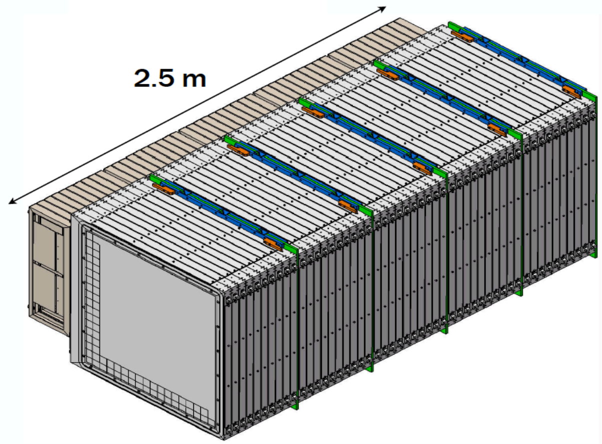
- Calibration runs with AmBe source
  - AmBe is a fast neutron emitter
- Study prompt-delayed coincidence
  - Time-space correlation, neutron efficiency, etc…



- Excellent neutron identification
  - Tail-to-total algorithm using information from both channels
- Can distinguish a neutron in millions of signals !

Phase I detector

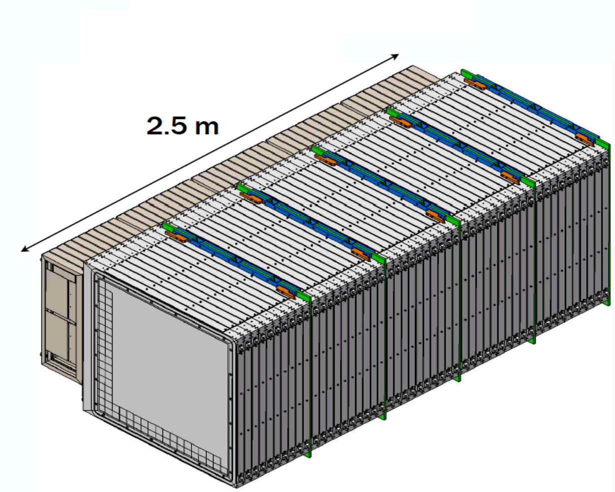
Construction phase has started



- 5 modules of 10 planes, 16 × 16 cubes
- 50 planes totally, 12800 cubes
- Temperature controlled system
- 3200 readout channels, max 0.5 TB per day

Phase I detector

Construction phase has started



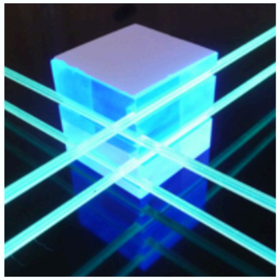
- 5 modules of 10 planes, 16 × 16 cubes
- 50 planes totally, 12800 cubes
- Temperature controlled system
- 3200 readout channels, max 0.5 TB per day

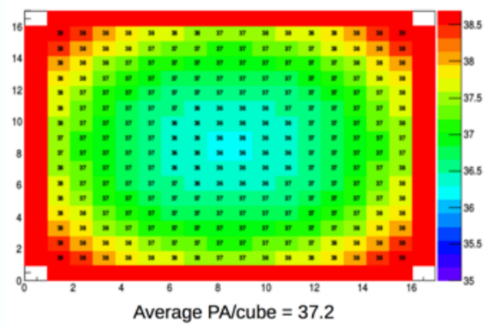
Neutron detection efficiency

- Additional LiF:ZnS sheets
  - Increases ^{6}Li capture efficiency from 51% to 66%
  - Reduces capture time from 105 µs to 66 µs
- New screens with improved transparency

Light yield and uniformity

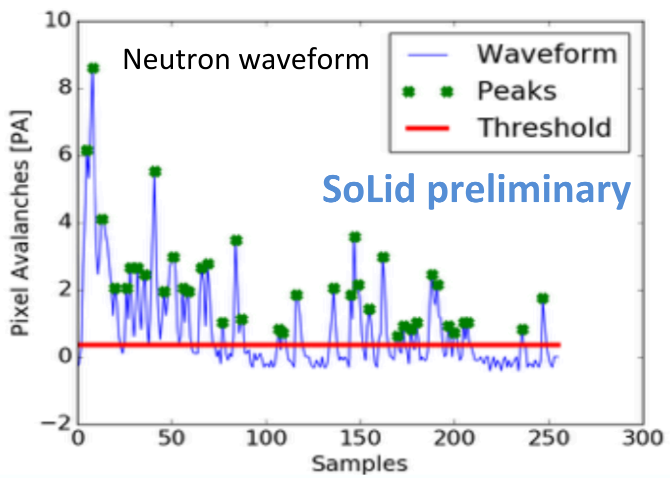
- Four fiber readout
  - 37 PA/MeV, 66% increase with respect to SM1
  - 7% variation of light yield across the detector



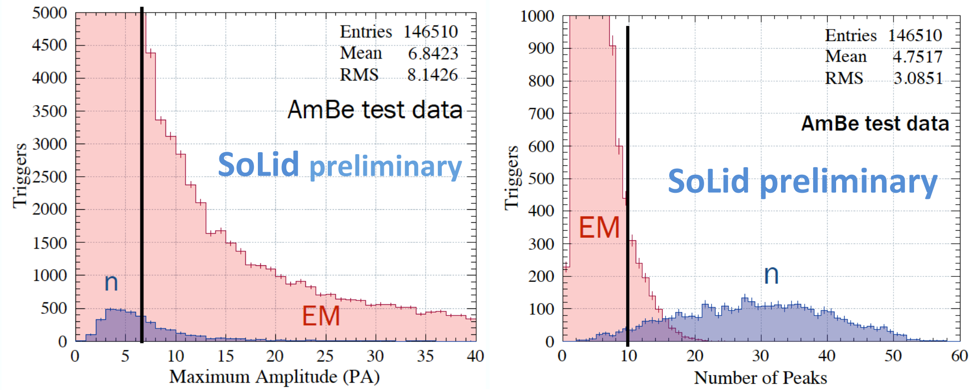


Neutron trigger

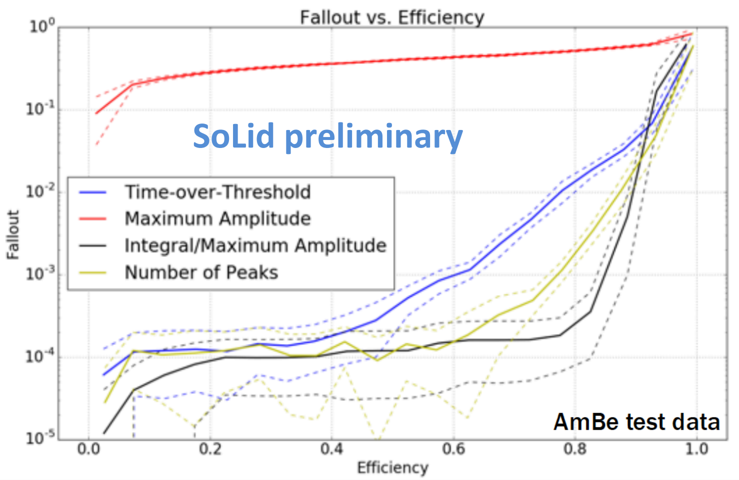
- SM1 had a rather low neutron detection efficiency of ~ 5%, due to high trigger threshold (6.5 PA)



Neutron (n) and electromagnetic (EM) signals



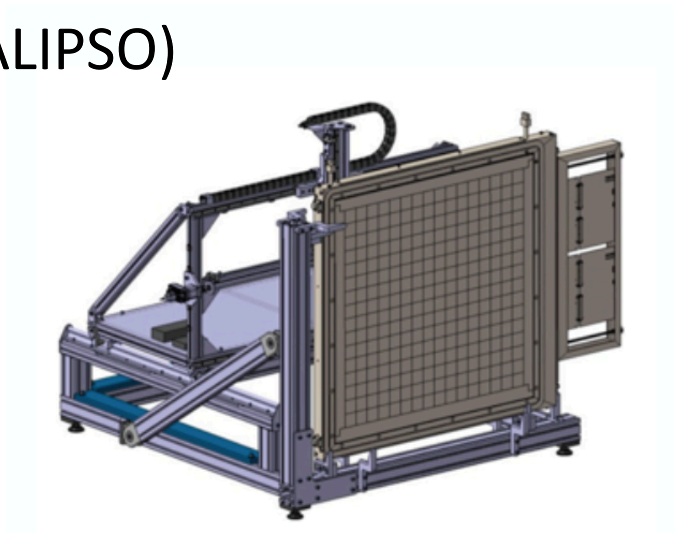
- Phase I detector is designed to have a neutron selection at the trigger level (implemented at the firmware level)
  - Buffer time ± 500 μs and ± 2 planes around a neutron event
  - Zero suppression threshold at 1.5 PA
  - Reduces dramatically the amount of data
  - Retains high IBD efficiency



- We expect n detection efficiency of ~ 70%

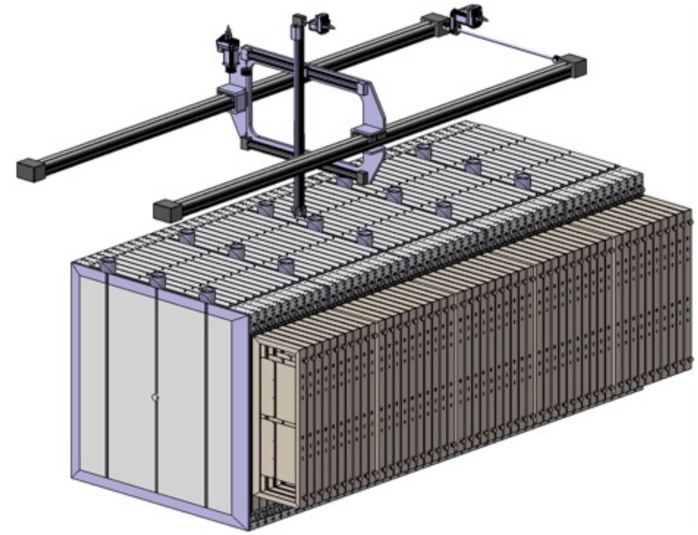
Detector calibration

Off-site calibration system (CALIPSO)



- Plane characterization and commissioning
- Cube to cube equalization
- Neutron and EM signals benchmark

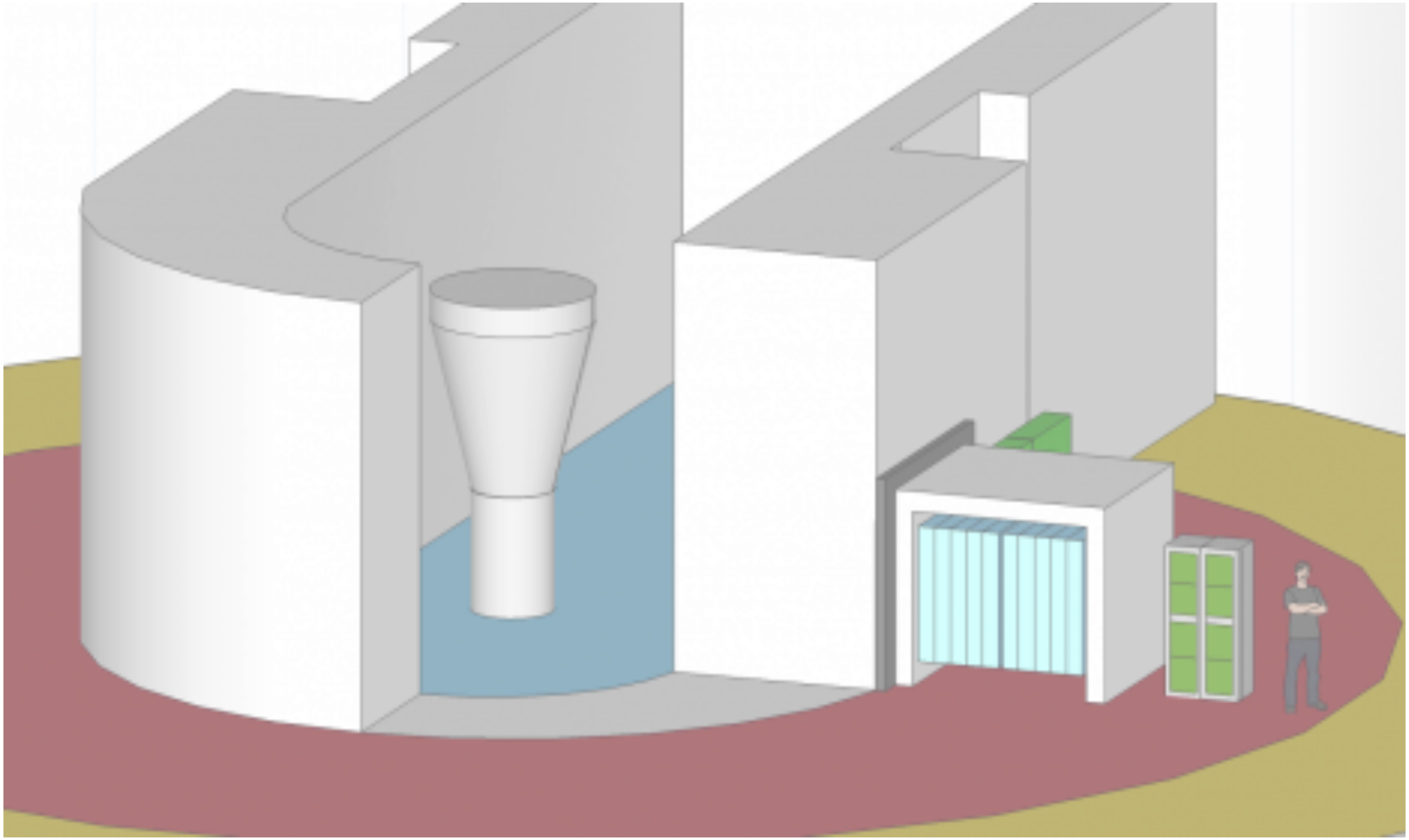
In-situ calibration system (CROSS)



- In-situ radioactive sources deployment
- Precise energy scale and neutron detection efficiency determination

Ending themes

- The SoLid experiment will make a very sensitive search for $\overline{\nu}_e$ disappearance using a novel detector design
- SM1 operation has been very successful
  - Excellent EM/neutron identification
  - Low background at BR2 has been confirmed
  - Precise calibration with muons (cube equalization ~1.5%)
  - *Data analysis talk by Dan Saunders (4/08, Neutrino Physics session) and poster by Ianthe Michiels (6/08, Poster session)*
- Entered construction phase fro the 1.6 ton detector
  - Funded by FWO, Hercules (BE), ERC (EU) and ANR (FR) grants
  - *Detector technology and construction poster by Celine Moortgat (6/08, Poster session)*
- Detector commissioned and deployed in BR2 by early 2017



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