SoLid: An innovative antineutrino detector for searching oscillations at the SCK•CEN BR2 reactor

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SoLid

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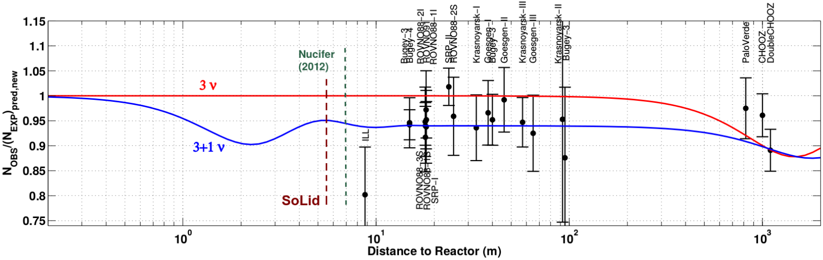
Outline

- The Reactor Antineutrino Anomaly
- The SoLid experiment
- Submodule 1 design and performance
- Outlook of the SoLid detector

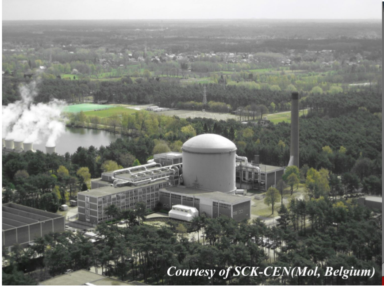
The Reactor Antineutrino Anomaly

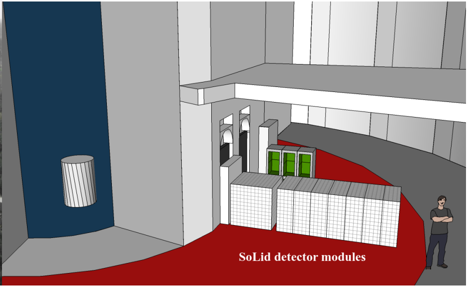


K.N. Abazajian, et al., arXiv:1204.5379v1, 2012

- Previous experiments at short baselines are systematically shifted from the expected values of $\overline{\nu}_e$ flux.
- New experiments at shorter distances are required
- A possible hint for new physics ...

The SoLid Experiment





- Search for short baseline neutrino oscillations
  - Precise position and energy measurement
  - Existence of a fourth massive “sterile” neutrino?
- Precise measurement of the $\overline{\nu}_e$ spectrum of ^{235}U from 5.5 m @ BR2
- Demonstrate its applicability to reactor monitoring safeguard.
- Doing short baseline measurements is particularly challenging due to the background conditions (muon induced + reactor)

BR2 reactor at SCK•CEN

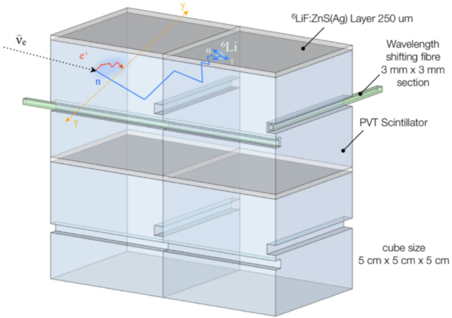
- Research reactor
  - Highly enriched in ^{235} U
  - Neutrino flux ($\sim 10^{19}\nu/s$)
  - Compact core (d $\sim$ 50 cm)
  - Well shielded core (low background)
  - Thermal power between 40 – 80 MW
- Reactor hall allows baselines from 5.5 to 10 m
- 150 days per year duty cycle
  - Reactor off data for background estimation and subtraction

Detection principle

Detection through the Inverse Beta Decay (IBD)

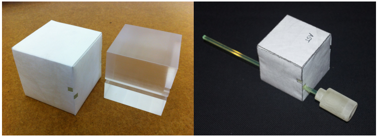
$$\overline{\nu}_e + p \rightarrow e^+ + n$$

$$n +^6 Li \rightarrow \; ^3H + \alpha + 4.78 MeV$$

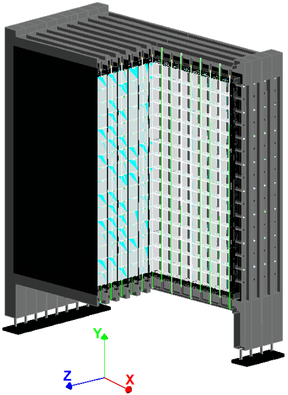


Composite scintillator

- PVT Cubes of 5x5x5 cm + ^{6}Li:ZnS(Ag).
- Cubes are optically separated (Wrapped with Tyvek)

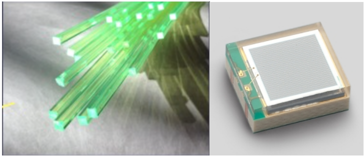


Detector Submodule 1 (SM1): 2014-2015



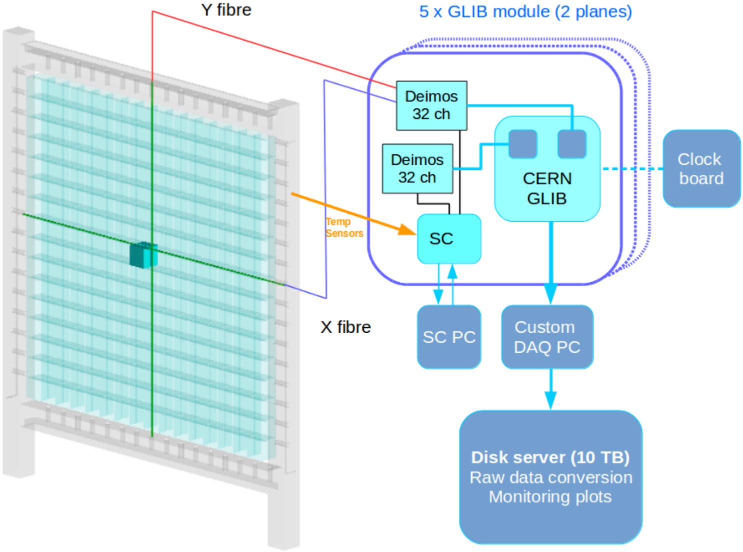
- 16 x 16 x 9 PVT Cubes + $^{6}Li:ZnS(Ag)$.
- 9 detector frames of Al with HDPE internal reflectors

- High segmentation
  - Spatial resolution of IBD vertex
  - Allow exploitation of IBD event topology
  - Background rejection
- Light collected with WLS fibers and multi–pixel photon counters (MPPCs) Hamamatsu S12572-050P



- 288 readout channels
- $\approx$ 290 kg

Detector Submodule 1 (SM1): 2014-2015

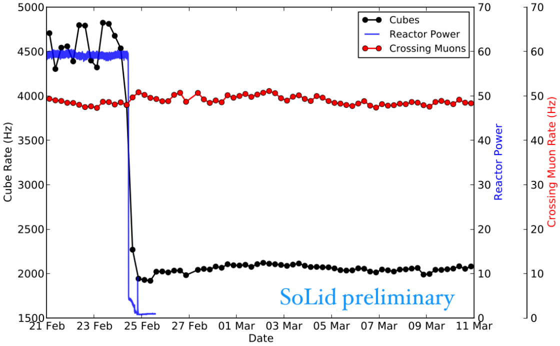


Detector Submodule 1 (SM1): 2014-2015

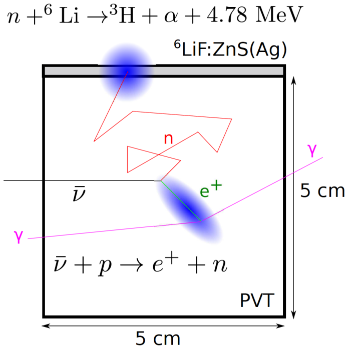
- ADC: 62.5MHz rate (16 ns sample)
- Light yield $\sim$ 25 PA/MeV (X+Y)
- Energy resolution of 20 % at 1 MeV
- 50 ns coincidence window (X&Y)
- Threshold at 0.6 MeV
- Trigger algorithms
  - Trigger by threshold and coincidence
  - Random trigger

SM1 run at BR2

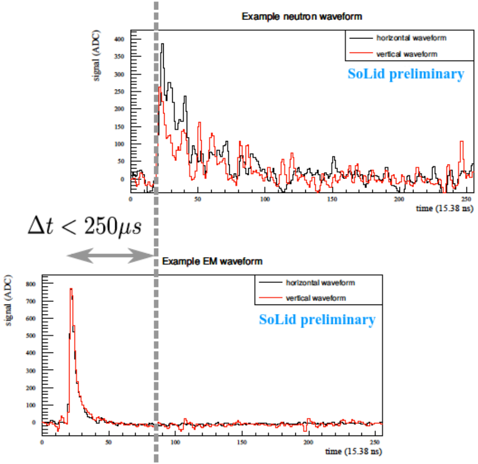
- Data from Dec 2014 to March 2015
  - 3 – 4 days Reactor on
  - ∼ 1 month Reactor off
- Detector calibration
  - ^{60}Co, ^{137}Cs and cosmic muons for energy calibration
  - AmBe and ^{252}Cf for neutron calibration



Detector particle discrimination



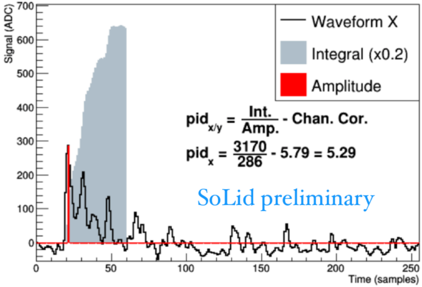
Prompt-delayed coincidence

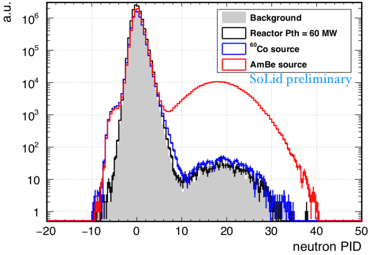


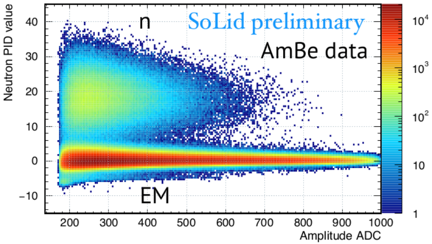
Particle discrimination capabilities based on the pulse shape difference between the ^{6}Li:ZnS(Ag) and PVT.

Neutron Identification Algorithm

- Particle identification based on the pulse shape.
  - Integral / Amplitude
- The $^{6}Li:ZnS$ neutron discrimination power is confirmed.

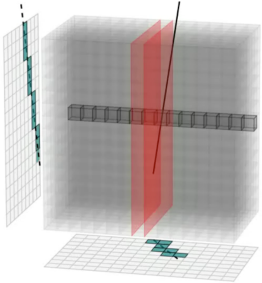




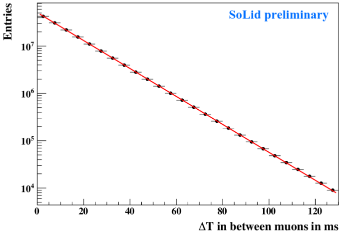


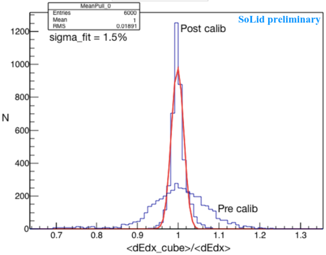
Detector response to cosmic muons

- Muon tracks can be reconstructed due to detector segmentation
  - In-situ calibration and monitoring with dE/dx



R_μ = 69.42 ± 0.01(stat) Hz

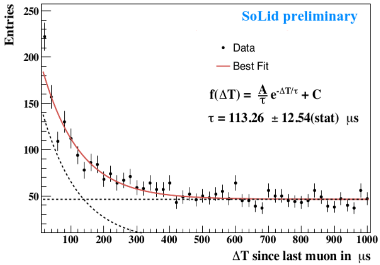




Background rejection capabilities

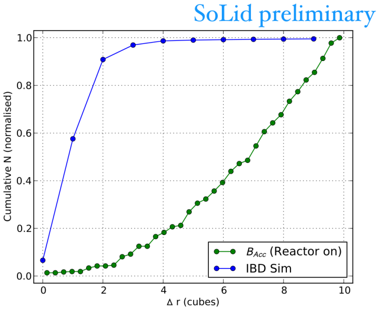
Muons passing the detector making fast neutrons:

- Correlation between muons and neutrons is observed



- Rejection of muon correlated background
    - Muon Veto cut

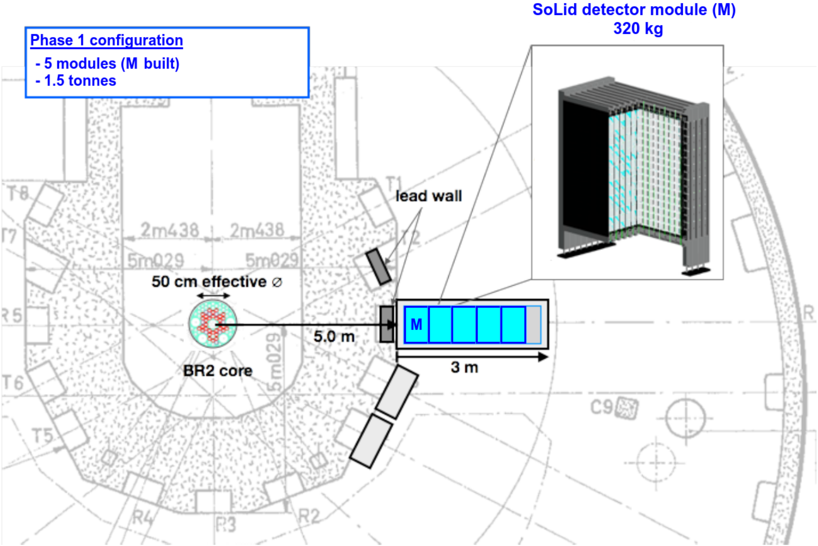
SoLid particular cut: Δr can be chosen to retain most of the signal and cut hard on Accidental backgrounds (B_{Acc})



Δr for B_{Acc} (Data) and neutrinos (Simulation)

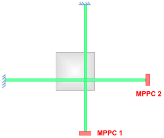
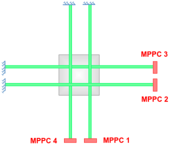
SoLid detector: Phase I (2016-2017)

Experimental set up

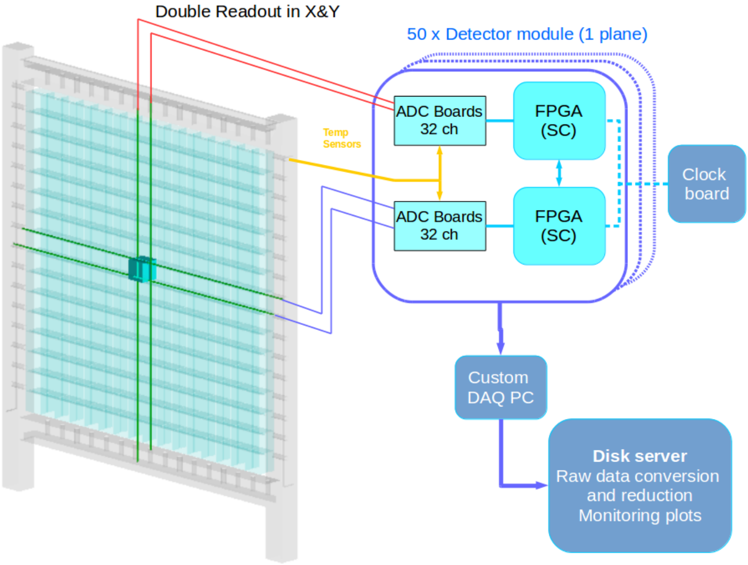


SoLid detector: Phase I (2016-2017) vs SM1

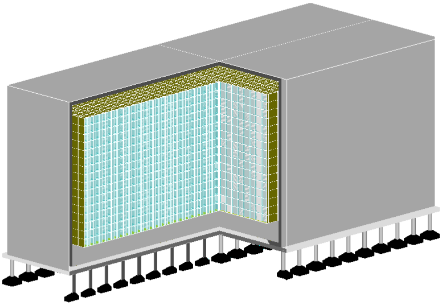
Improvement in light yield and readout

	Setup	Description
SM1		• Thin tyvek • Single cladding fibre • Single readout • Light yield: 25 PA/MeV (Cube)
Solid Phase 1		• Thick tyvek • Multi cladding fibre • Double readout • Light yield increase in $\sim$ x1.8

SoLid detector: Phase I (2016-2017)

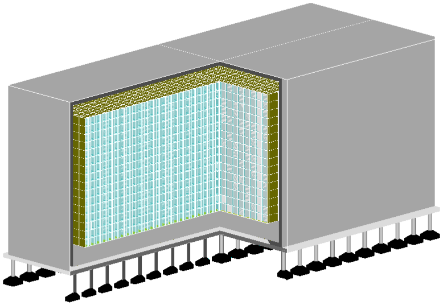


SoLid detector: Phase I (2016-2017)



- Double electronic readout compared to SM1
  - Reduce dark count rate (noise)
  - Increase the light yield
  - Better energy resolution: $\sim 14 - 16$ % at 1 MeV
  - 3200 readout channels
- Trigger algorithms
  - Neutron waveform trigger with zero suppression readout
  - Threshold trigger
  - External trigger

SoLid detector: Phase I (2016-2017)



- The SoLid detector will be constructed in a modular way during 2016.
- Data will be taken in search mode over one year, starting on the second half of 2016.

Summary and Outlook

- The SoLid submodule 1 run has been successful
  - Excellent neutron ID
  - Probe of background rejection capabilities
  - Data analysis is still ongoing
- Improved detector design for Phase 1.
  - Better detector sensitivity and energy resolution
  - Improvement on trigger algorithm
  - A very sensitive search for antineutrino disappearance using a new generation of compact detector is expected
- Phase 1 construction will be done in a modular base
  - Planned to run in search mode over one year, starting on the second half of 2016.

SoLid Collaboration

4 Countries, 10 Institutions, $\sim$ 50 people

SCK•CEN

Universiteit Antwerpen

Vrije Universiteit Brussel

UNIVERSITEIT GENT

LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

lpc caen

Subatech

UNIVERSITY OF OXFORD

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VirginiaTech Invent the Future