SoLid short baseline reactor anti-neutrino experiment

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Mathieu BONGRAND
for the SoLid Collaboration

CNRS/IN2P3 - Université Paris-Sud - LAL Orsay

2017/10/17

Motivations for SoLid experiment

SoLid technology and SM1 results

SoLid Phase I (1.6 t) detector construction

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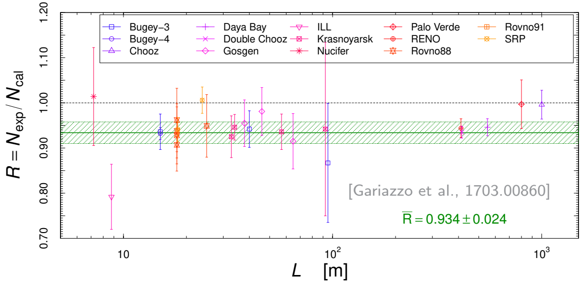
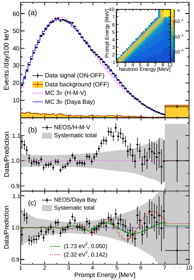
Physics motivations

Short-baseline neutrino oscillations anomalies:

- reactor anti-neutrino $\overline{\nu}_e$ deficit of 2.8σ
- gallium radioactive source ν_e deficit of 2.9σ
- LSND $\overline{\nu}_\mu \to \overline{\nu}_e$ appearance of 3.8σ

could be explained by oscillations to sterile neutrino with $\Delta m^2 \sim 1$ eV^2



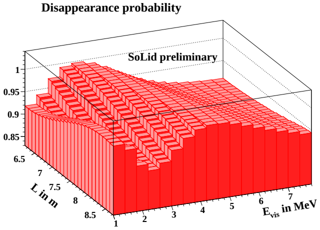


[NEOS, 1610.05134]

Recent facts:

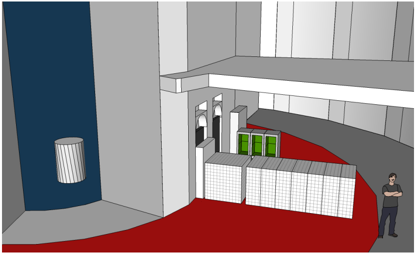
- 5 MeV bump in the reactor anti-neutrino energy spectrum
- Flux deficit is different for the 4 parent fission isotopes and ^{235}U seems to be the main source of the anomaly [Daya Bay, 1704.01082]
- New results (MINOS, IceCube, Daya Bay, DANSS, NEOS) don't rule-out sterile neutrino hypothesis [Gariazzo et al., 1703.00860 & Dentler et al., 1709.04294]

SoLid challenges



Detector for oscillation search:

- fine segmentation
- good energy resolution and linearity
- safety implications
  (data rates, building access, no flammable liquids)



Anti-neutrino source:

- compact reactor core
- very short-baseline (< 10 m)
- ON/OFF periods
- ^{235}U fuel

Backgrounds reduction:

- topological reconstruction of IBD and background events
- particle identification (e^+, γ, n, μ)
- use of passive low density shielding (H_2O, PE)

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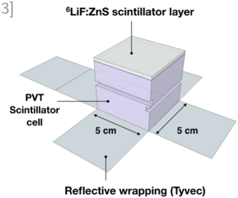
SoLid detection principle

[SoLid, JINST 12 P04024 2017, 1703.01683]

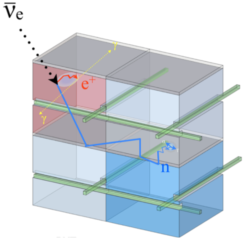
Anti-neutrinos detected through
inverse beta decay (IBD) in the plastic scintillator

$\overline{\nu}_e + p \rightarrow e^+ + n \qquad (E_{\overline{\nu}_e} > 1.8 \text{ MeV})$



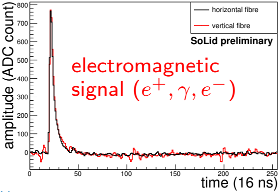
Prompt positron signal:

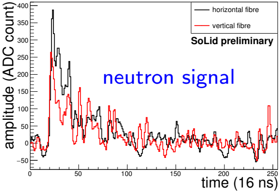
- localize the interaction point
- gives the anti-neutrino energy
- annihilation γ can help e^+ identification



Delayed neutron capture in ^{6}LiF:ZnS:

- $n + {}^6Li \rightarrow {}^3H + \alpha \qquad + 4.78$ MeV
- well localized inorganic scintillator (not like γ signal)
- pulse shape discrimination (same readout)





BR2 nuclear site

Compact research reactor:

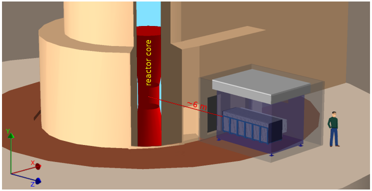
- ϕ 50 cm - h 90 cm
- fuel 93.5 % of ^{235}U
- thermal power 50-80 MW_{th}
- duty cycle 150 days/y
  ($\sim$ 1 month cycles)

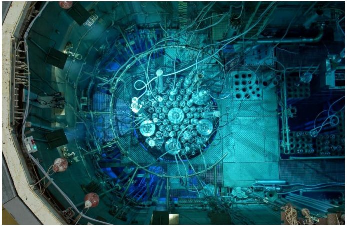
Low background site:

- low neutron and gamma fluxes
- no surrounding experiments
- overburden 10 m.w.e.

SoLid at the reactor core level:

- baseline 6 $\rightarrow$ 9 m
- complete GEANT4 simulation

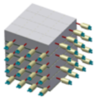




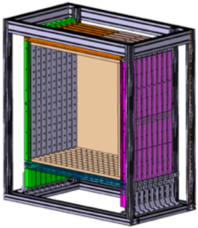
SoLid timeline

Prototypes and full scale detector constructions

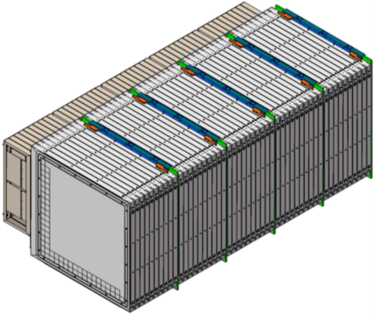
2013



2014-15



2016-17



NEMENIX (8 kg)

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

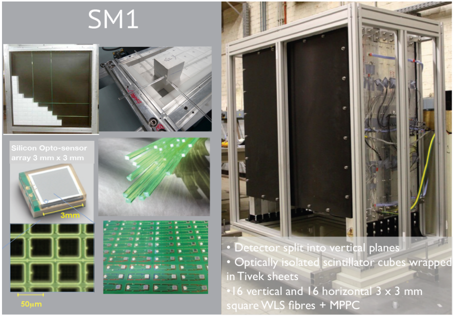
SM1 (288 kg)

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

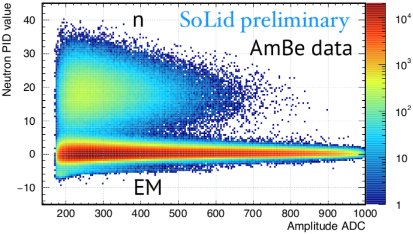
SoLid Phase I (1.6 t)

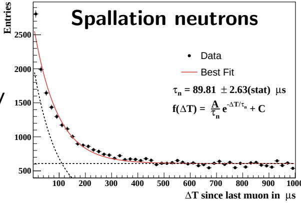
- 16×16×50 cubes
- 3200 channels
- optimized performances
- energy spectrum measurement
- oscillation search

SM1 (288 kg)



Neutron PID

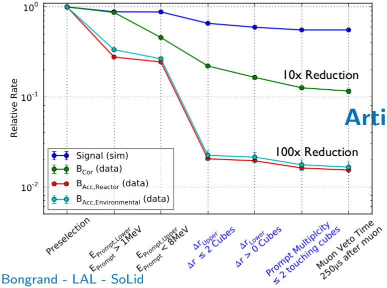




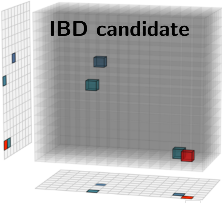
Light-yield ∼25 PE/MeV

$\sigma_E/\sqrt{E} = 20\%$

Background reduction



Article coming soon!



Motivations for SoLid experiment

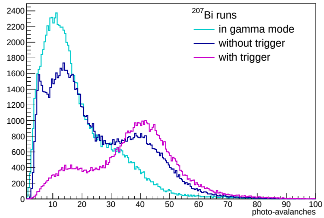
SoLid technology and SM1 results

SoLid Phase I (1.6 t) detector construction

Light-yield improvements for SoLid Phase I

Many aspects were optimized to improve light-yield and plane uniformity:

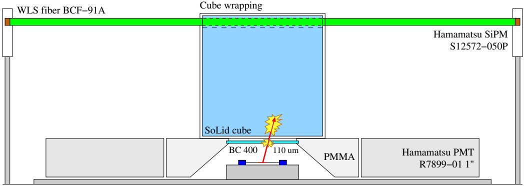
- double clad fiber
- thicker Tyvek reflector
- cube machining
- Al-mylar fiber-end mirror
- 4 fibers + 4 SiPMs / cube
- SiPM voltage



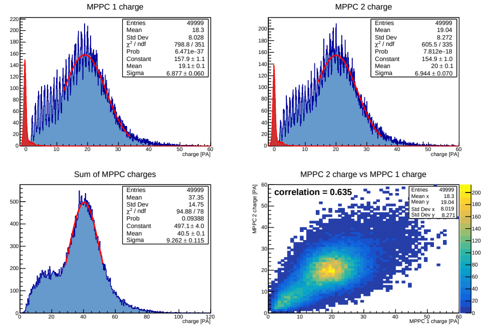
Light-yield increased by a factor $\sim$3 in the test setup conditions

Result of $\sim$50 PE/MeV demonstrating the target

$$\sigma_E/\sqrt{E} = 14\%$$



^{207}Bi: 1 MeV electrons

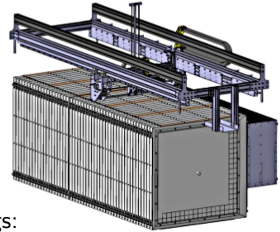


See D. Boursette's Poster - **Article in preparation**

SoLid Phase I (1.6 t)

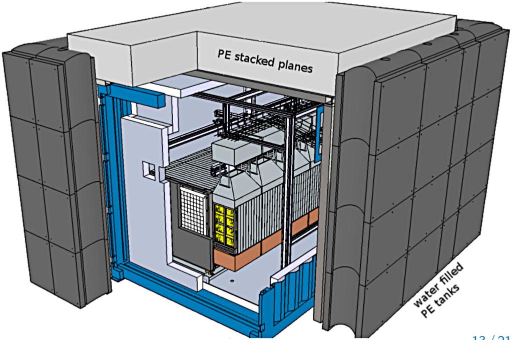
Container 2.4×2.6×3.8 m^3:

- 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



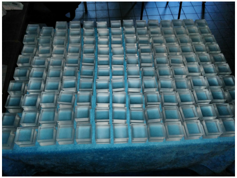
Shieldings:

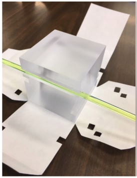
- water walls: 50 cm thick, 3.4 m high, 28 t
- polyethylene ceiling: 50 cm thick, 6 t
- cadmium sheets

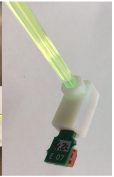


SoLid Phase I construction status

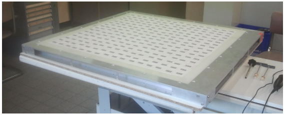
SoLid detector construction started in 12/2016 is now already completed !

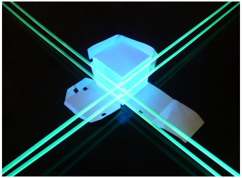


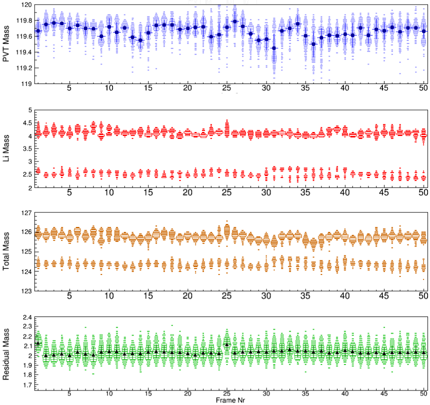




All the cubes components were precisely weighted and all the production informations are stored in database





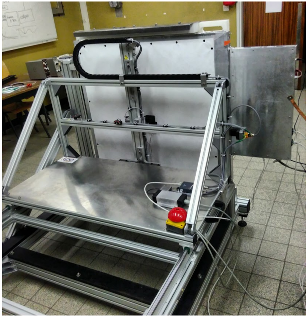


Planes qualification: Calipso

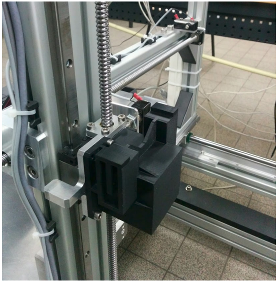
Calipso automated robot for XY scanning of SoLid planes with calibration sources

Check quality and uniformity of the detector construction

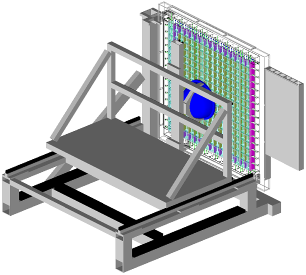
Gives already a good knowledge of the detector before installation at BR2



Gamma mode:
^{22}Na source with an active calibration head for coincidences



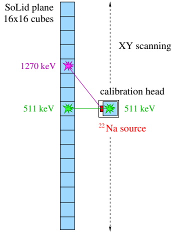
Neutron mode:
polyethylene collimator and ^{252}Cf source

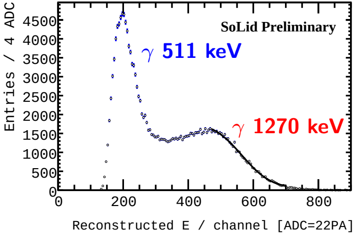


Planes qualification: gammas in PVT

16×16 cubes of the planes scanned in 4 h (30 s per cube) with Calipso

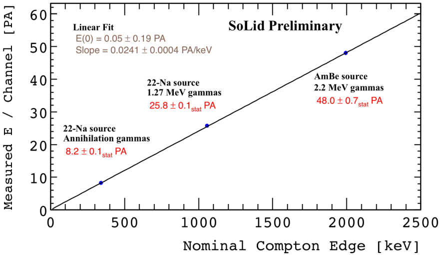
No background thanks to the coincidences with the ^{22}Na calibration head

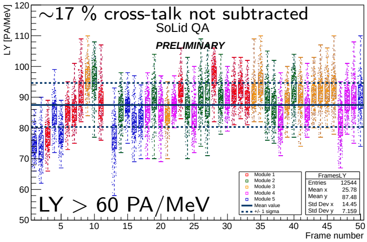




Minor construction problems were identified and fixed

Preliminary results show **very good linearity, light-yield and uniformity !**





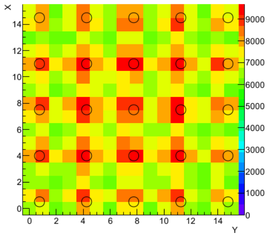
Planes qualification: neutrons in ZnS

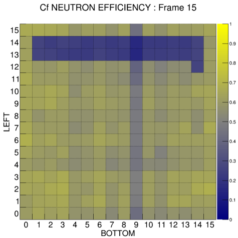
^{252}Cf calibration with PE collimator on 25 positions per plane in 3 h

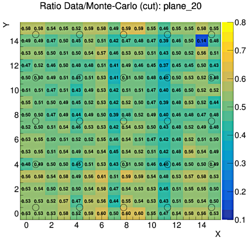
One bad ^{6}LiF:ZnS batch identified and replaced

Only 1/12800 cubes where 1 neutron screen was missing has been replaced

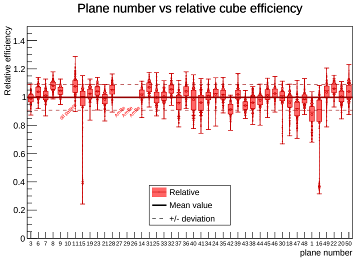
GEANT4 simulation







Neutron capture time reduced to $\tau \sim 65$ μs with 2 screens / cube and capture efficiency is 66 % (GEANT4 simulations)



Very good uniformity of the neutron detection efficiency

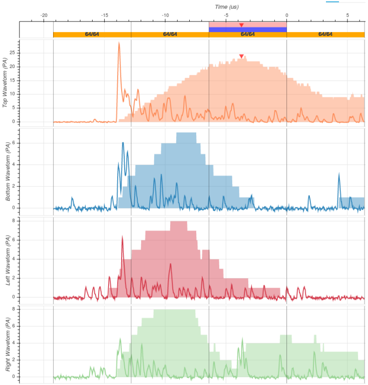
$\boldsymbol{\sigma_{\epsilon_n} \sim 10\ \%}$

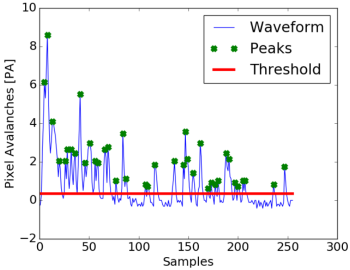
Neutron trigger

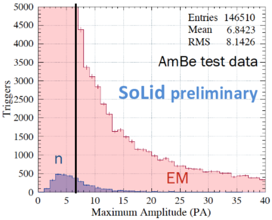
SM1 used a threshold trigger at 6.5 PA (data rate driven)

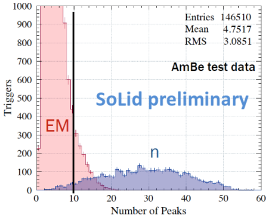
SoLid is implementing a neutron trigger:

- counting the number of peaks
- directly in the FPGA
- commissioning with calipso





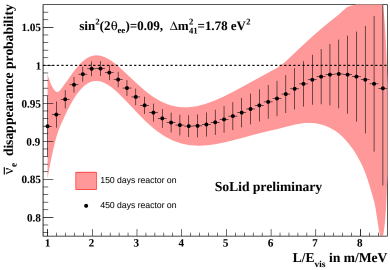


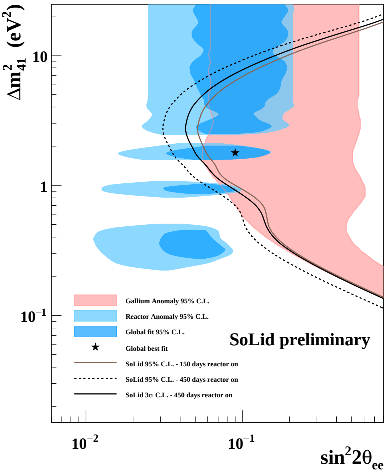


Large buffer to collect prompt signals in ±500 μs and 5 planes around the neutron delayed signals

SoLid experiment sensitivity

- Baseline 6-9 m
- Thermal power 60 MW_{th}
- Detector dimensions $0.8 \times 0.8 \times 2.5$ m^3
- Detector mass 1.6 t
- Energy resolution $\sigma_E/\sqrt{E} = 14$ %
- IBD efficiency 30 %
- Signal to background 3:1
- Background spectrum taken from SM1





Conclusion

- SoLid experiment consists of an innovative hybrid scintillator technology to search for reactor anti-neutrino oscillations to a sterile neutrino
- BR2 research reactor offers very good conditions for a very short baseline experiment
- SM1 results have validated the technology and demonstrated background rejection thanks to the fine segmentation
- Light-yield studies on a dedicated test setup improved the light-yield to reach an energy resolution of $\sigma_E/\sqrt{E} = 14$ %
- SoLid Phase I detector (1.6 t) construction is now completed
- All the detector planes have been calibrated with Calipso: the light-yield seems better than expected and the neutron detection efficiency is good
- Integration of the detector at BR2 in November before the last reactor cycle of 2017
- Data taking is coming !

In memory of Edgar Koonen 

The SoLid Collaboration

4 countries **12 institutes** **~50 people**

Universiteit Antwerpen

lpc caen

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Laboratoire de Physique de Clermont

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