

# The SoLid short baseline neutrino detector

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SoLid

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Les deux infinis

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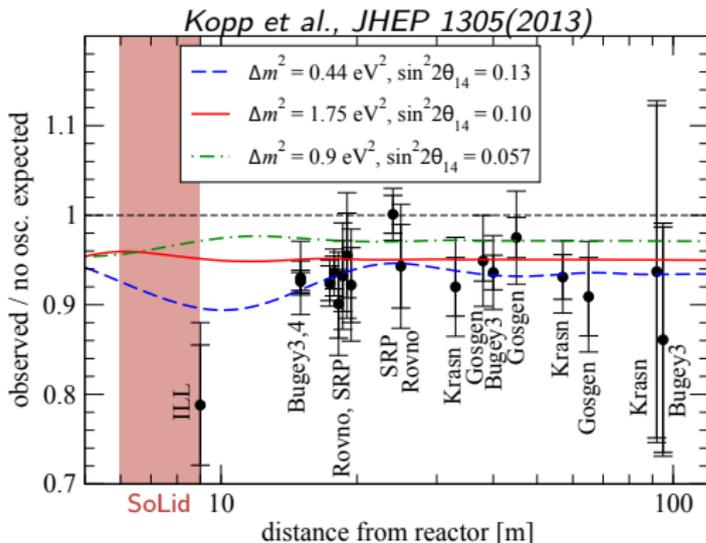
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## Physics motivation

### Reactor anomaly:

- ▶ Disagreement between neutrino flux prediction and measurements
- ▶ 3+1 oscillation neutrino hypothesis with a fourth "sterile" neutrino



## Experimental challenge

What are we looking for ?

**Absolute/relative neutrino rate and energy spectrum distortion at short baseline**

Experimental constraints:

Reactor:

- ▶ Compact reactor core
- ▶ Reactor fuel composition understanding
- ▶ As close as possible
- ▶ Security and safety consideration

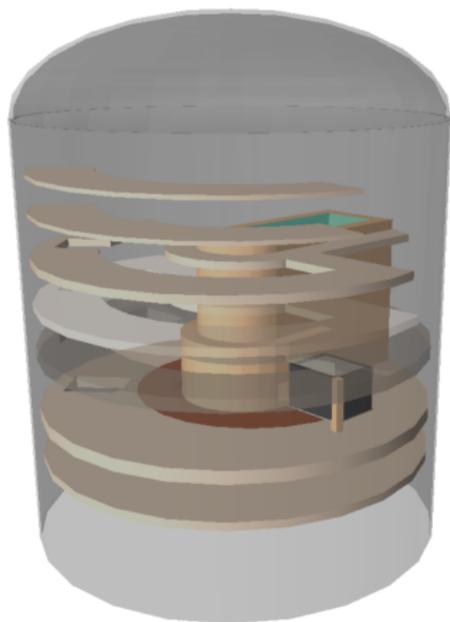
Detector:

- ▶ High energy resolution
- ▶ High spatial resolution
- ▶ Homogeneous and well calibrated
- ▶ Effective background rejection

## SoLid overview

### BR2 @ SCK-CEN (Mol, Belgium):

- ▶ Nuclear research reactor
- ▶ High Enriched Uranium (HEU):  $^{235}\text{U}$  (93.5 %)
- ▶ Compact:  $\varnothing_{\text{eff}} = 50 \text{ cm}$ ,  $h = 90 \text{ cm}$
- ▶ Baseline:  $6.2 \rightarrow 8.7 \text{ m}$



## SoLid overview

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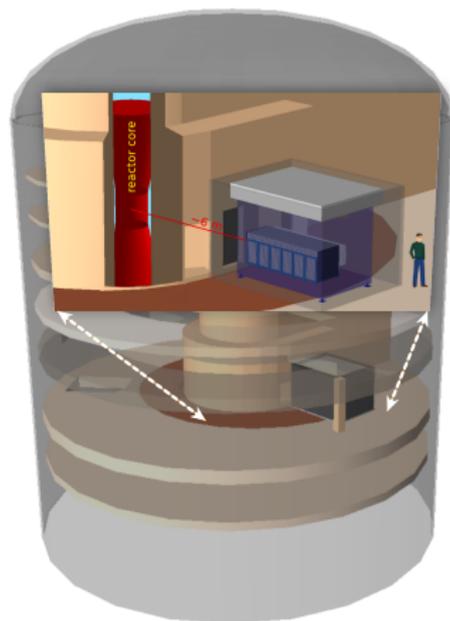
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### Detector: 1.6 ton:

- ▶ Dual solid scintillators
- ▶ Highly segmented
- ▶  $\nu_e$  interaction rate: 1000/day

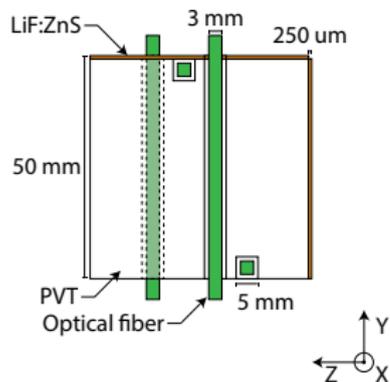
#### Goals:

- ▶ Neutrino efficiency  $\approx 30 \%$
- ▶ Signal/Background  $\approx 3$
- ▶ Energy resolution:  $\frac{\sqrt{E}}{E} \approx 14 \%$



Y. Abreu et al. , A novel segmented-scintillator antineutrino detector, JINST, Vol. 12 .  
April 2017, arXiv:1703.01683

## SoLid design

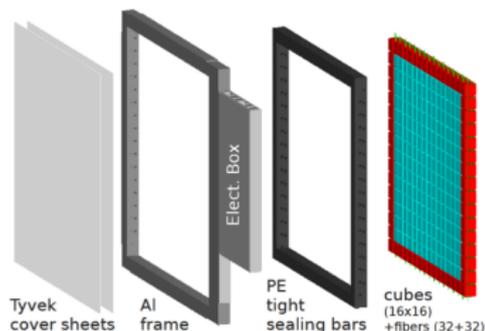


### Cube ( $5 \times 5 \times 5 \text{ cm}^3$ )

- ▶ Plastic scintillator cube: PVT ( $\tau \approx 5 \text{ ns}$ )
- ▶ 2 neutron scintillator screens LiF:ZnS ( $\tau \approx 5 \mu\text{s}$ )
- ▶ Optically isolated by Tyvek

### Readout

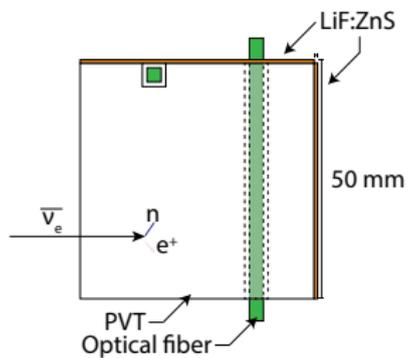
- ▶ Optical fibers : 2 horizontals(X) and 2 verticals(Y)
- ▶ Silicon-Photo-Multiplier (SiPM/MPPC)
- ▶ Reflector on the other side



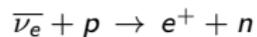
### Plane

- ▶  $16 \times 16$  cubes
- ▶ 64 Readout channels
- ▶ 50 planes (Z segmentation) grouped per 10 (module)

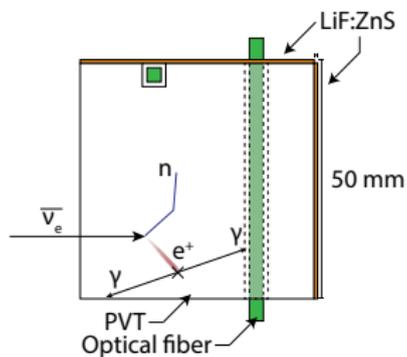
## Detection principle: composite scintillators



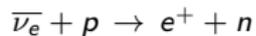
► Inverse beta decay:



## Detection principle: composite scintillators



- ▶ Inverse beta decay:



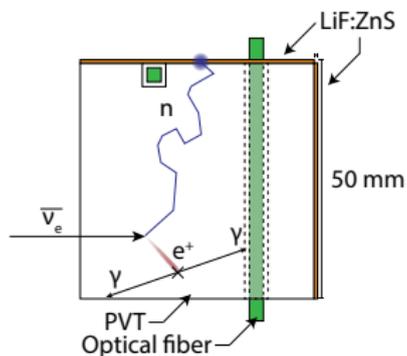
- ▶ Prompt event:

positron in PVT scintillator

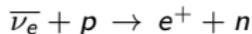
$$E_{e^+} \in [0 : 10] \text{ MeV}$$



## Detection principle: composite scintillators



- ▶ Inverse beta decay:

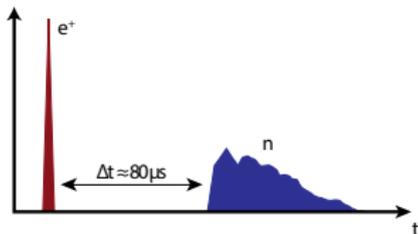


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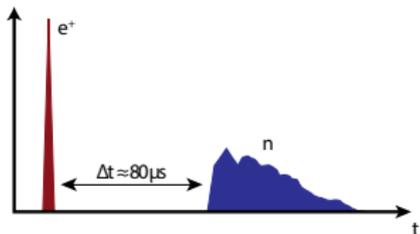
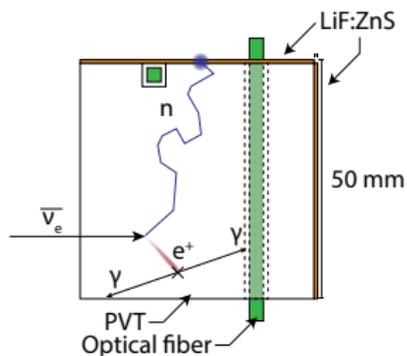
positron in PVT scintillator  
 $E_{e^+} \in [0 : 10] \text{ MeV}$

- ▶ Delayed neutron capture:

Thermalisation in PVT  
Capture on  ${}^6\text{LiF} : \text{ZnS}$   
 $n + {}^6\text{Li} \rightarrow \alpha + t$



## Detection principle: composite scintillators



- ▶ Inverse beta decay:



- ▶ Prompt event:

positron in PVT scintillator  
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- ▶ 2 Particles, 2 scintillators:

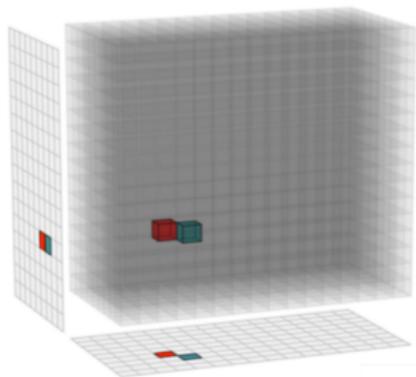
**Pulse Shape Discrimination**  
 **$\Delta t$  coincidences**

## Detection principle: highly segmented

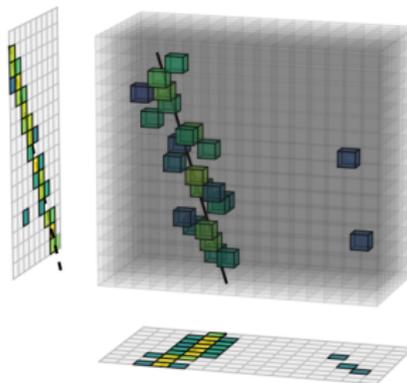
3D topology reconstruction ( $8000 \text{ voxels}/\text{m}^3$ ):

- ▶ Background identification and rejection

### IBD candidate

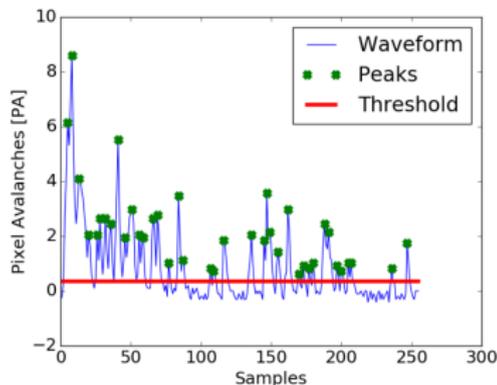


### Muon candidate



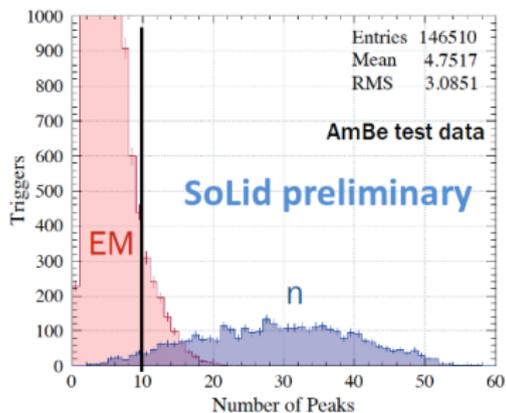
SM1 results

## Trigger system



#Peaks over threshold trigger (PSD) :

- ▶ Neutron trigger at electronic level
- ▶ Count #peaks in a time window
  - ▶ Optimized hardware usage



Good separation between EM ( $\gamma$ , e...) and neutrons:

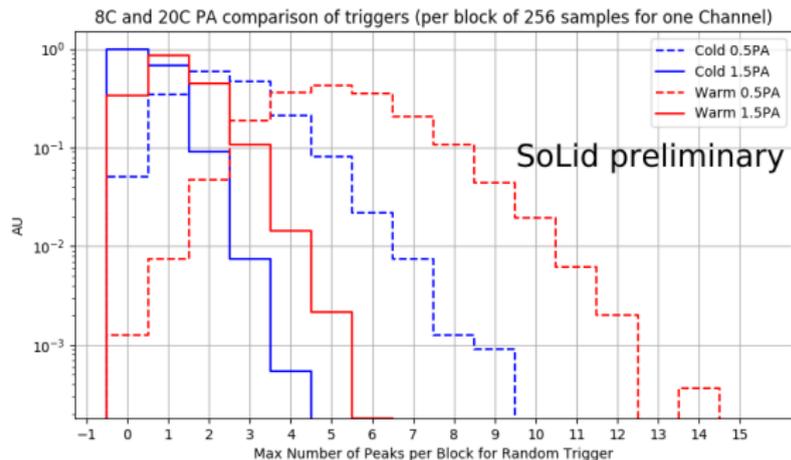
- ▶ Expected neutron reconstruction efficiency:  $\approx 70\%$
- ▶ Good purity (low EM contamination)

## SiPM cooling

Cooled Container:

- ▶ Whole detector at 5° C
- ▶ Dark count decrease by 10

#Peaks over threshold is very sensitive to darkcount:



**Decrease threshold to reach 70% efficiency**

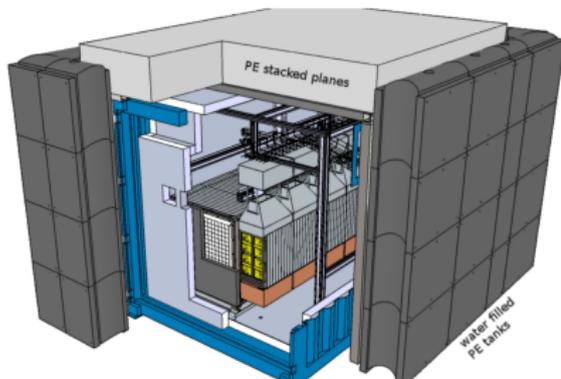
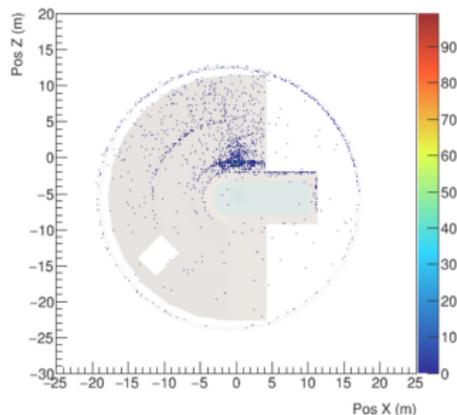
# Background shielding

Monte-Carlo model for cosmic background:

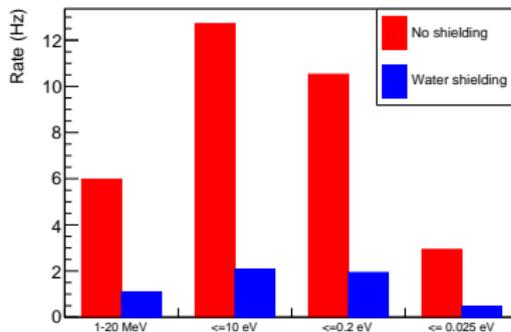
- ▶ Cosmic generator
- ▶ Validated with SM1(prototype) measurements

Passive shielding (50 cm):

- ▶ Stop  $\approx 80\%$  of cosmic neutron (MC)
- ▶ Also efficient for reactor neutrons and gamma

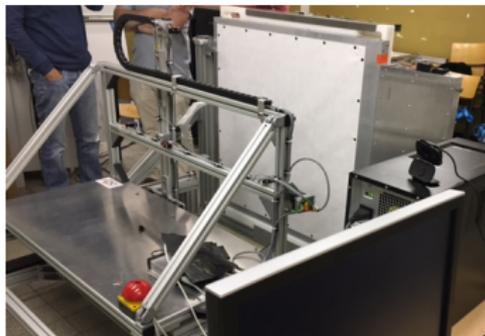
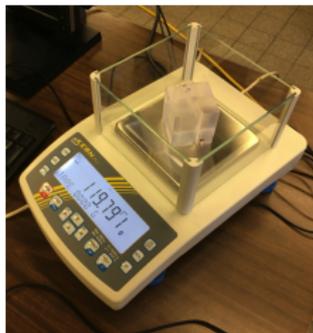


Cosmic neutron entering the detector (Monte-Carlo with 2 modules)



# Construction & Quality Assurance

Real "detector factory" @Gent: 12 800 cubes, 3 200 channels, 50 planes



## Calibration *in-situ*

Radioactive sources:

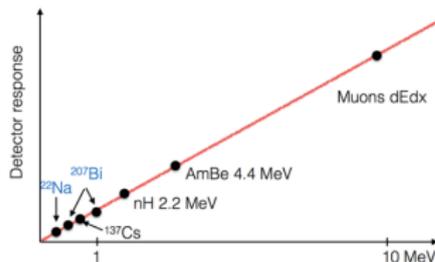
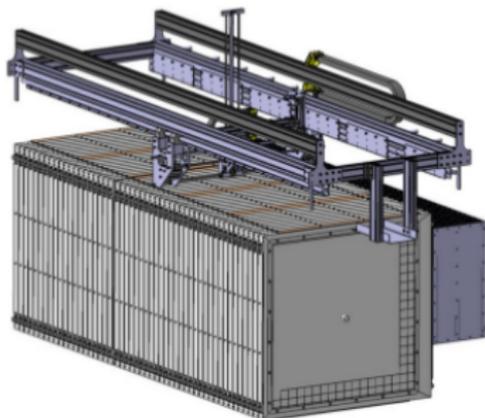
- ▶ Automatized robot in X,Y and Z(CROSS)
- ▶ Sources insertion between modules
  - ▶ neutrons: AmBe and Cf ( $\pm 1\%$ , calibrated @NPL)
  - ▶  $\gamma$ ,  $e^-$ :  $^{22}\text{Na}$ ,  $^{137}\text{Cs}$ ,  $^{207}\text{Bi}$

Neutron induced  $\gamma$ :

- ▶  $n + {}^1\text{H} \rightarrow {}^2\text{H} + \gamma$ ,  $E_\gamma = 2.2\text{ MeV}$
- ▶  $\alpha + {}^9\text{Be} \rightarrow {}^{12}\text{C} + n + \gamma$ ,  $E_\gamma = 4.4\text{ MeV}$

Muon:

- ▶  $\frac{dE}{dx} \approx 2\text{ MeV/cm}$
- ▶ Reconstruction efficiency > 97% (SM1)



## Timeline

- 2013-2015 → Small size - Real size prototype (NEMENIX - SM1):  
successful run !
- november 2016-mid 2017 → SoLid phase 1 construction
- july-august 2017 → Installation @BR2
- may-september 2017 → Quality assurance (@Gent) & commissioning (@BR2)
- september 2017 → Physics data taking (2 years minimum)

Y. Abreu et al. , A novel segmented-scintillator  
antineutrino detector, JINST, Vol. 12 . April 2017

Neutrino physics talk tomorrow (9h30), F. Yermia

Project funded by:



# Thanks

