The SoLid experiment: Search for sterile neutrinos at the SCK-CEN BR2 reactor

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TAUP 2017

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

SNOLAB

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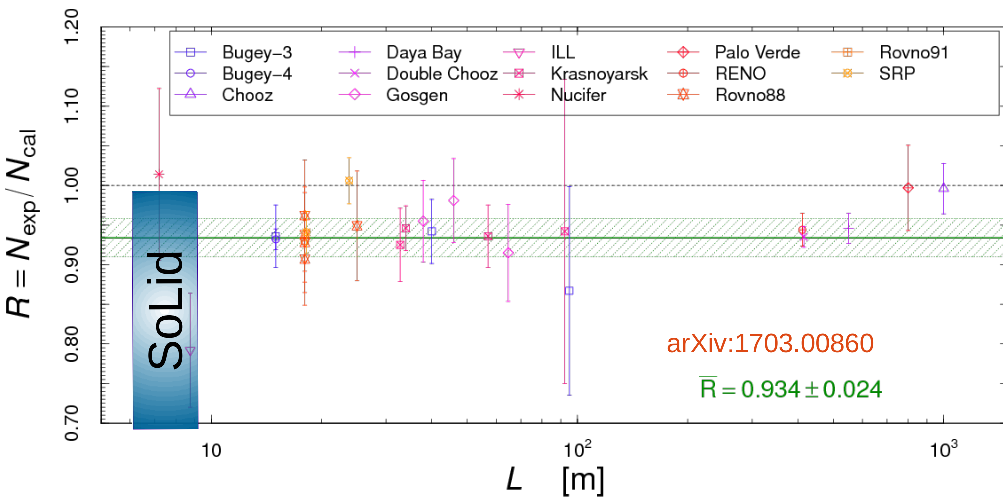
Université Laurentienne Laurentian University

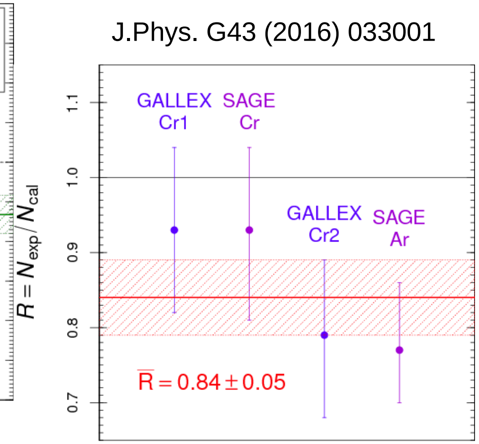
Outlook

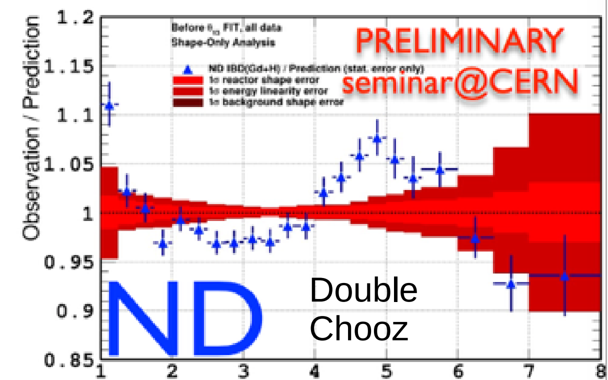
- Motivations
- Detector technology concept
- Construction and Quality Assurance (QA)
- Expected physical results
- Summary

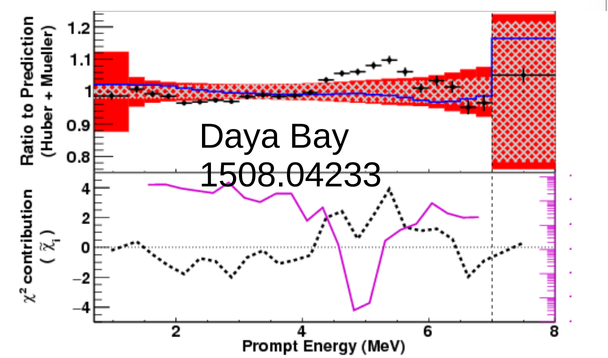
Physics Motivations

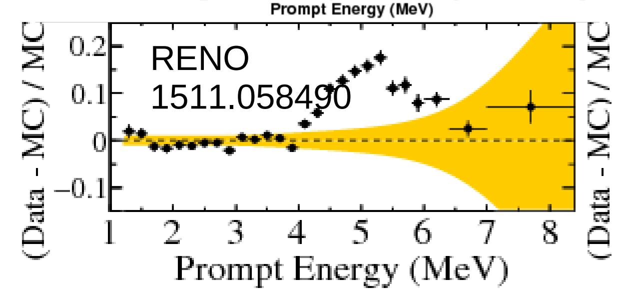
- **Anomalies:** The **reactor antineutrino anomaly** and **gallium anomaly** both show discrepancies wrt expectations at ~3σ level
  - Oscillations into a **light sterile neutrino state** ($\Delta m^2 \sim 1$ eV^2) could account for such deficits









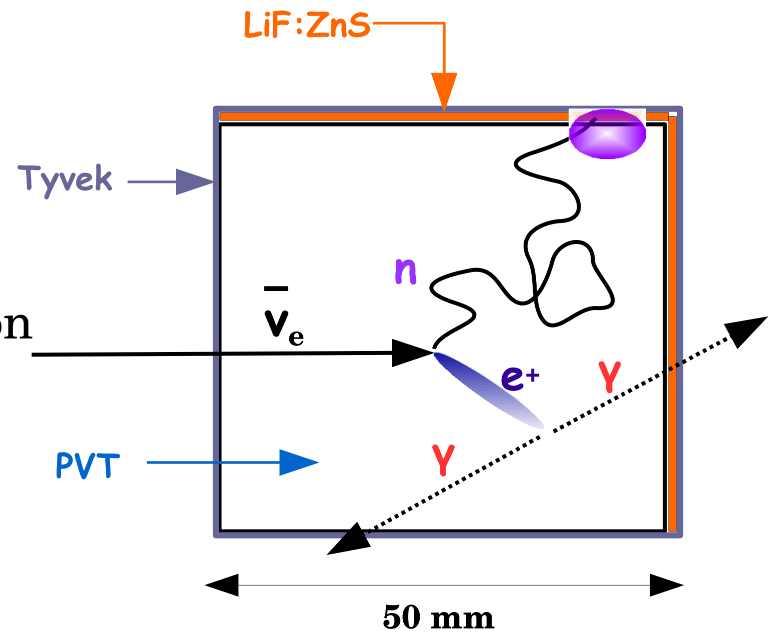


- **Distortion** observed around **5 MeV** ("bump") in the reactor **antineutrino** energy **spectrum**
  - Hints point to $^{(235)}$U (1609.03910, 1608.04096, 1512.06656)
- **SoLid goals:**
  - RAA: Search for an **energy distortion** pattern at short baselines
  - 5 MeV "bump": Provide a **new** measurement of ^{235}U fuel **antineutrino spectrum** with a different detection technology

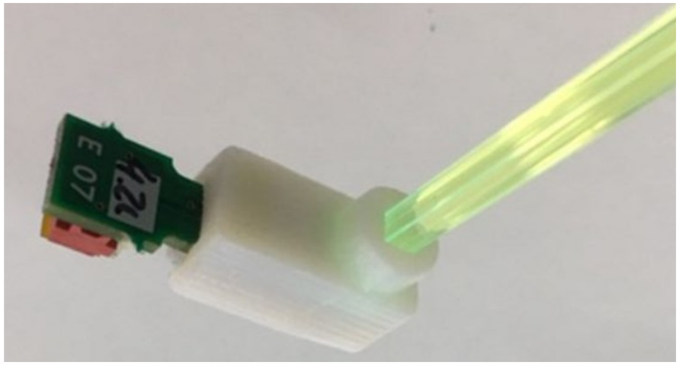
The SoLid technology

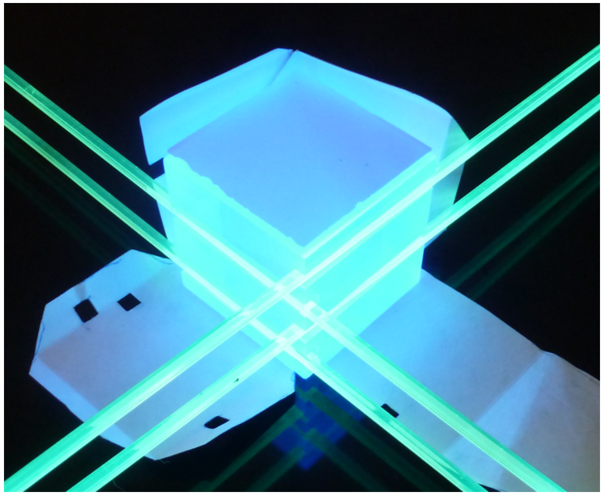
- Inverse beta decay: $\bar{\nu}_e + p \rightarrow e^+ + n$
- 3D highly **segmented composite detector**
  - 5 cm x 5 cm x 5cm **PVT** cubes
    - e^+ interaction
  - 2 layers / cube of **LiF:ZnS**(Ag) for neutron detection
    - Neutron capture on Li in ZnS layer :

      $n + {}^6Li \rightarrow {}^3H + \alpha + 4.78$ MeV
  - Signals of n and e/γ very different
    - → PSD discrimination + neutron trigger
- Cubes optically separated (tyvek)
- WLS fibers + SiPM to read out signals



JINST, Vol. 12, 2017, arXiv:1703.01683

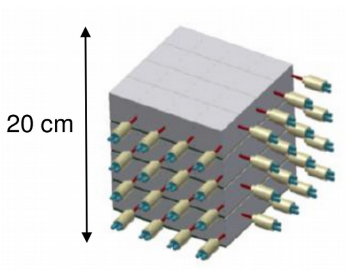




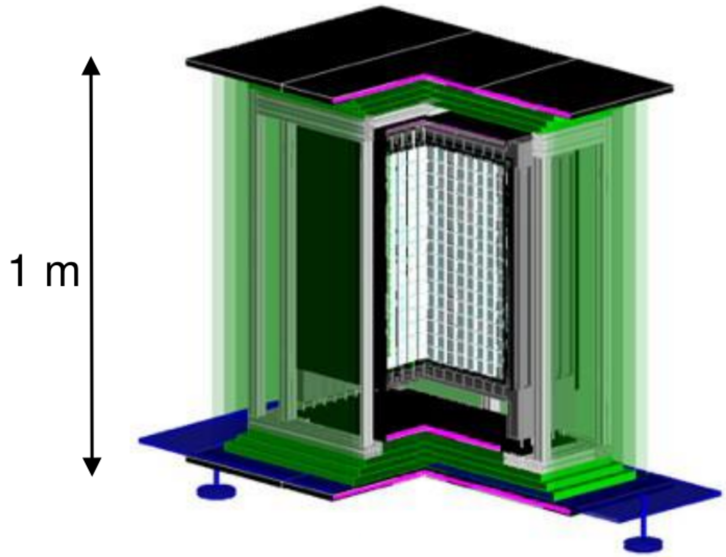
Validation of technology

- From prototype to full scale detector

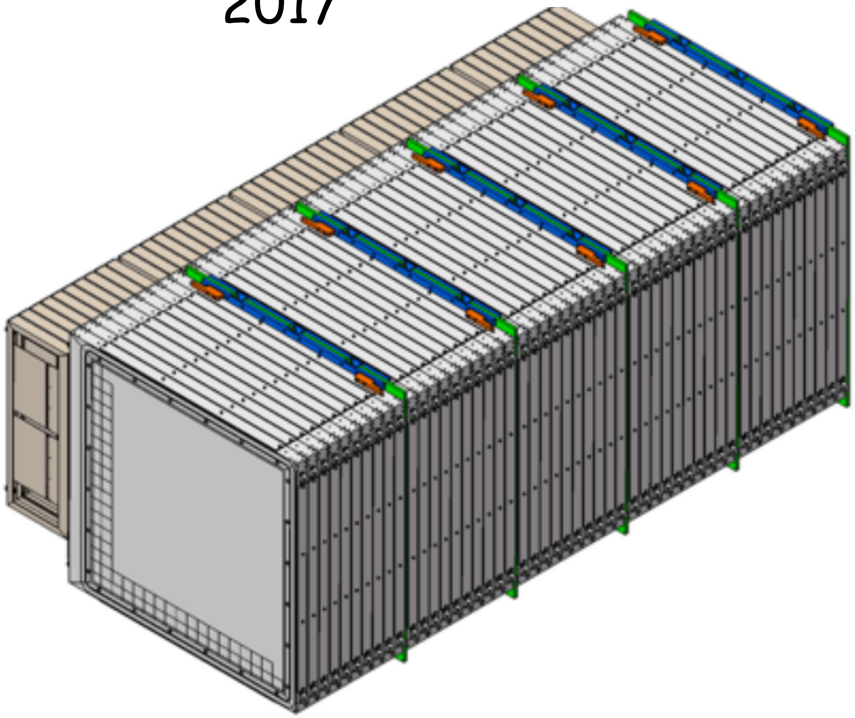
2013



2014-2015



2017

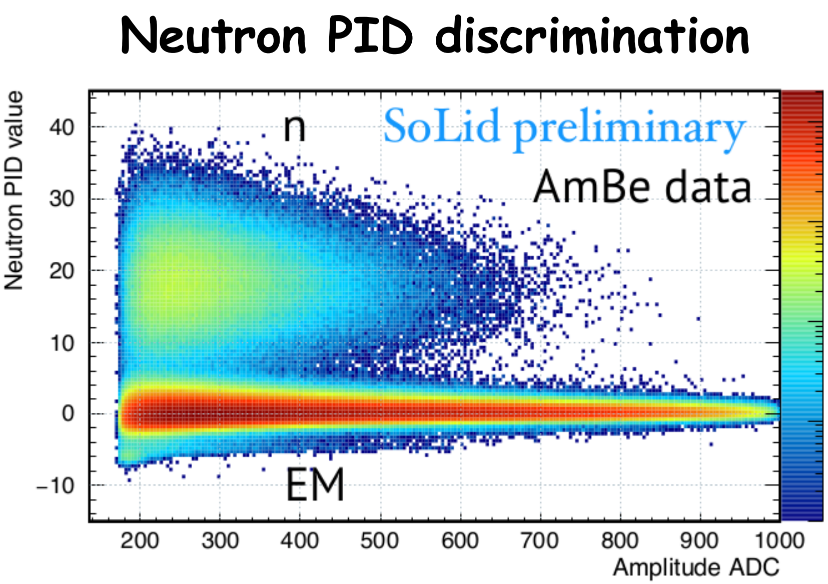


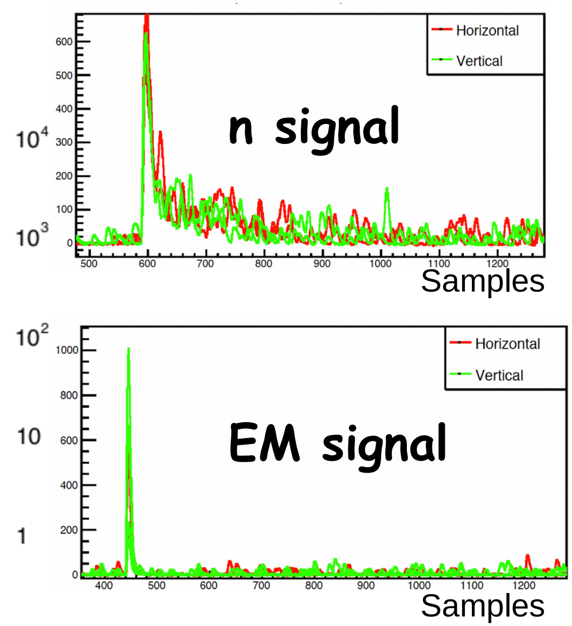
NEMENIX (8 kg)
- Prof of **concept**
- Neutron PID

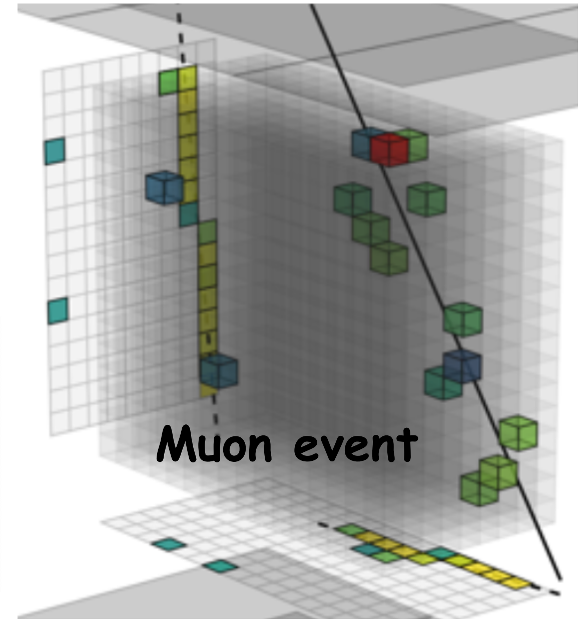
SM1 (288 kg)
- Real **scale system**
- Prove power of **segmentation**
- Test **scalability** and **production**

SoLid Phase 1 (1600 kg)
- 13 k cubes read out by 3.2 k channels
- **Performance optimized**
- **Spectrum measurement**
- **Oscillation search**

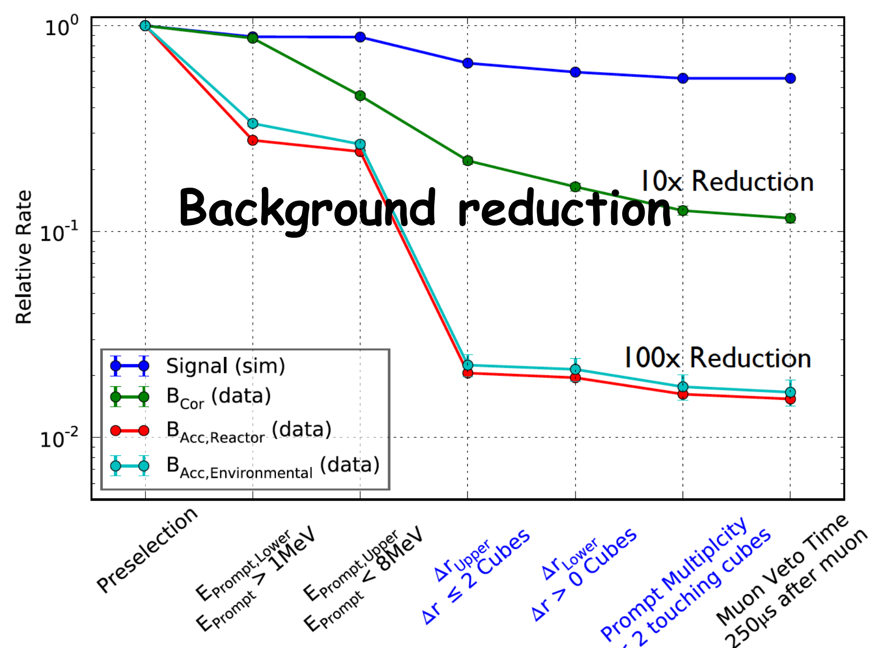
Validation of technology (SM1 at BR2)

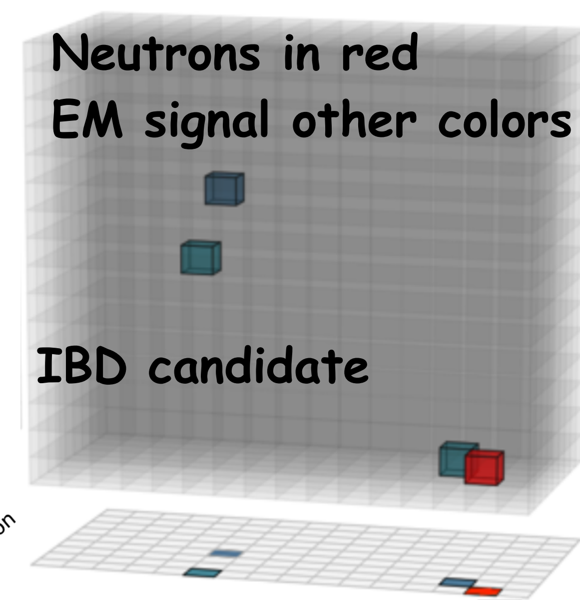






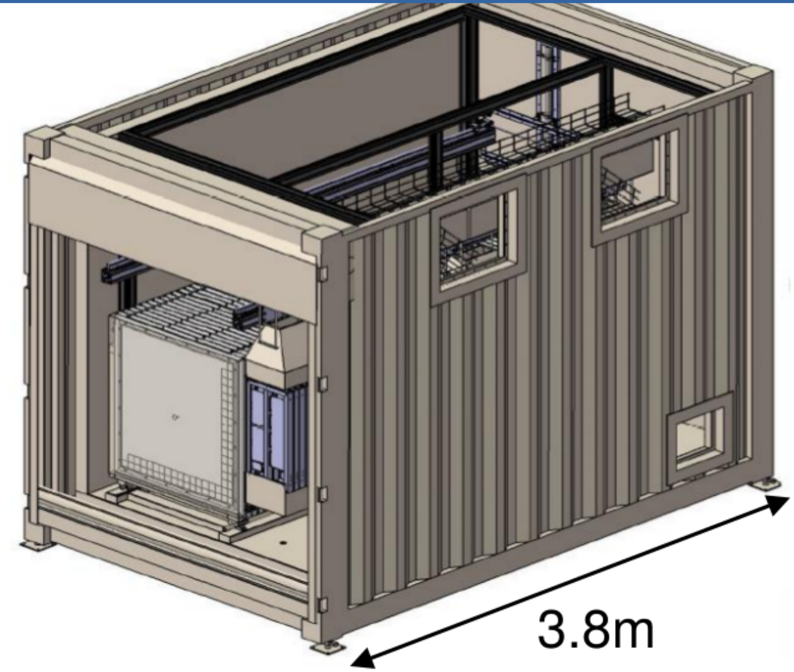
- ✔ Particle identification validated
- ✔ **Neutron discrimination** power confirmed
- ✔ **Background reduction** based on segmentation validated

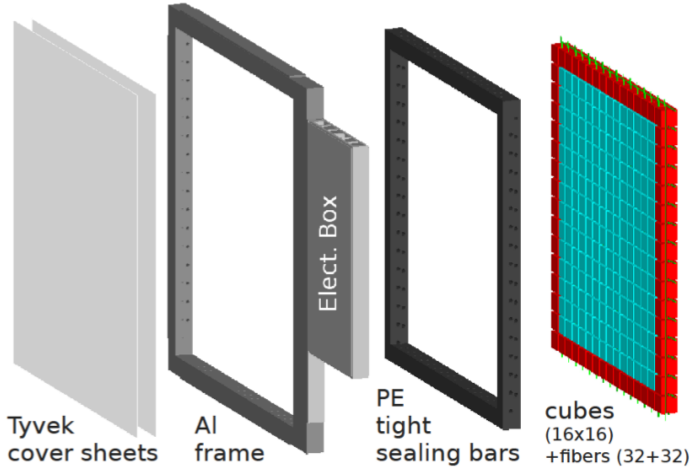


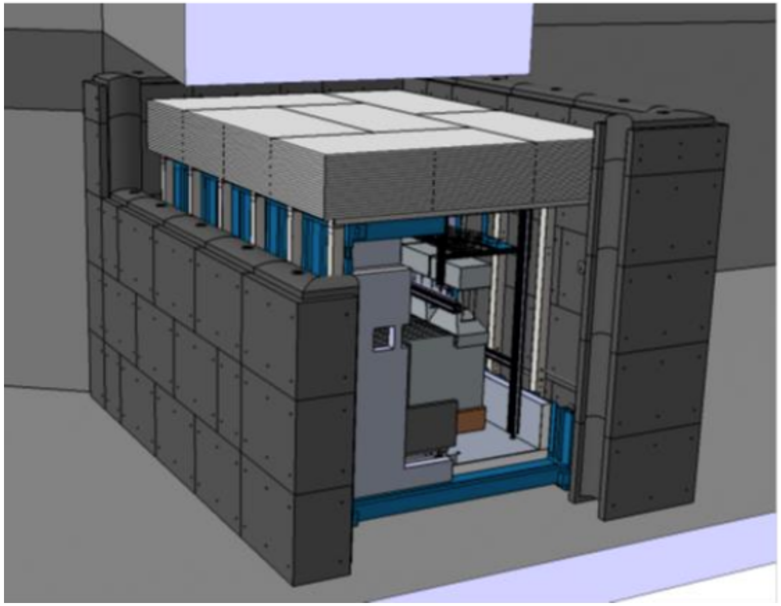


The SoLid (1600 kg) detector

- **5 Modules** of 10 planes
  - Planes of 16x16 cubes
- 4 x (fiber + SiPM + Mirror) per cube
- Automated calibration system
- Container (2.4x2.6x3.8 m) for **cooling at 5 °C**
  - Reduction of dark count rate
- **Shielding:**
  - Water wall: 50 cm thick, 3.4 m high, 28000 kg
  - Polyethylene ceiling: 50 cm thick, 6000 kg



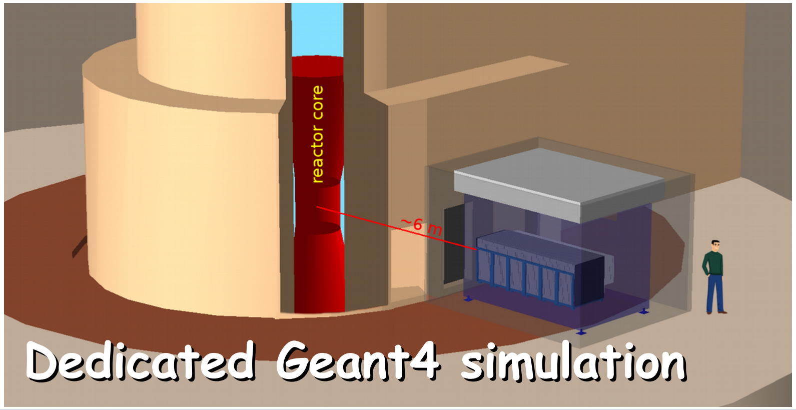




The BR2 site and reactor

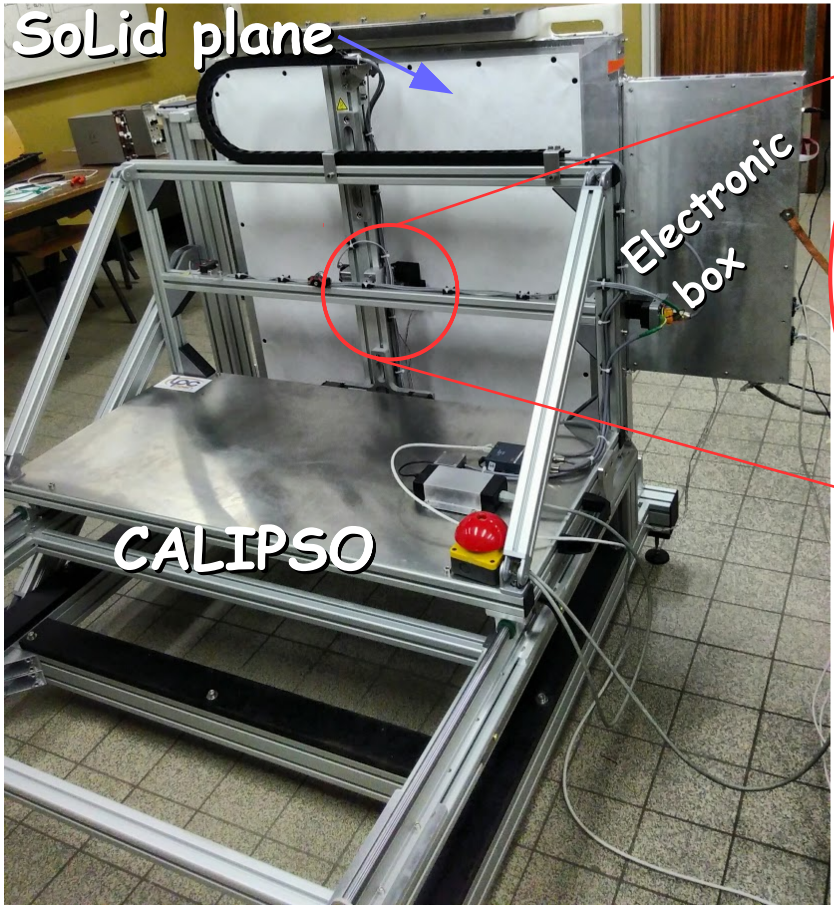
Best fit RAA → Oscillation length of 3 m for 3 MeV ν 's ⇒ **Compact source**

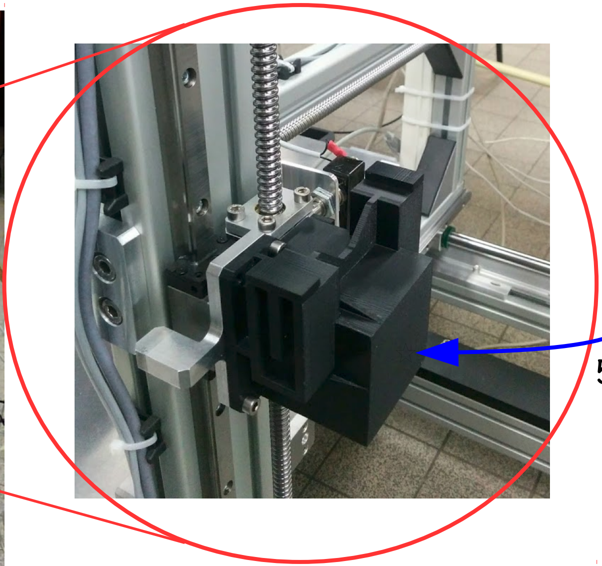
- **Compact** reactor **core** Φ < 50 cm, h = 90 cm
  - Baselines : 6 → 9 m
- Thermal power: 50-80 MW
- Highly ^{235}**U enriched** (93.5 %)
- 150 days per year duty cycle
  - Reactor off data for background estimation and subtraction
- **No nearby experiments**
- **Low background** (neutron, γ)



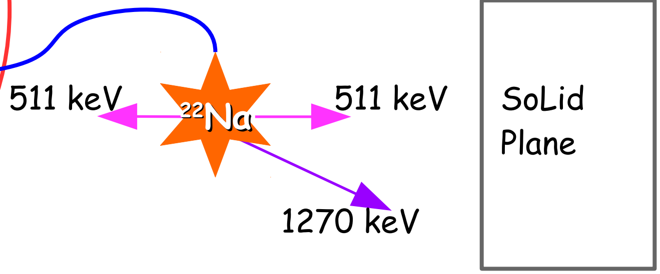
SoLid phase 1 commissioning status

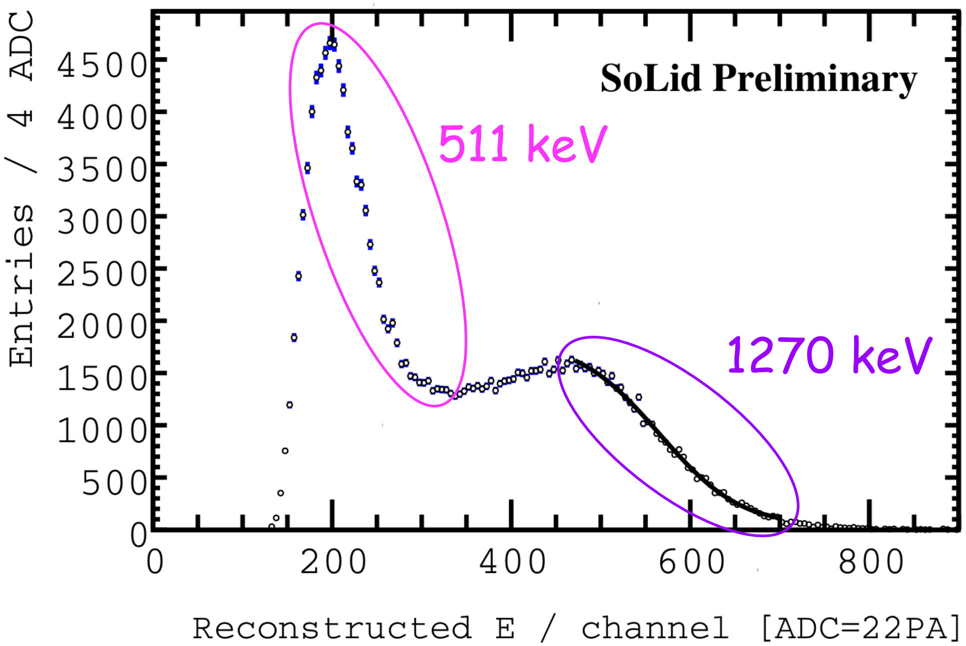
Quality assurance and calibration





External cube with ^{22}Na
→ **pure samples** for calibration





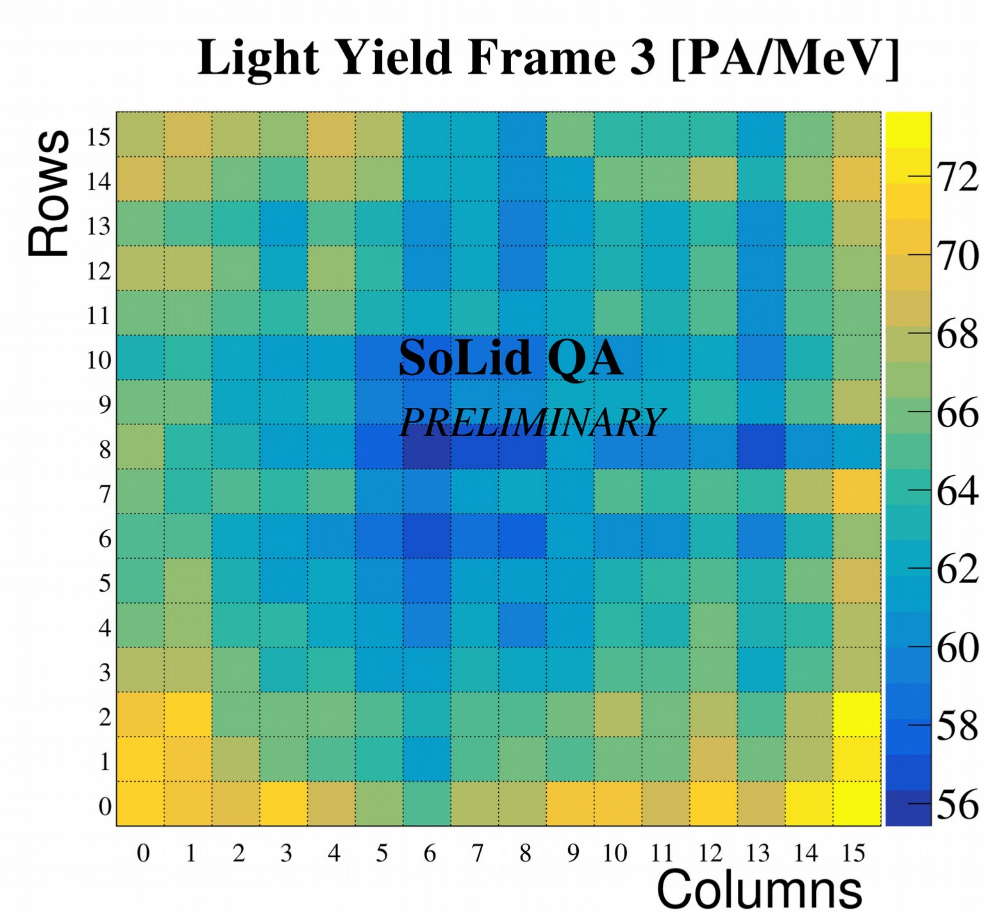
CALIPSO
- Automated system for QA
- Source placed in front of each cube

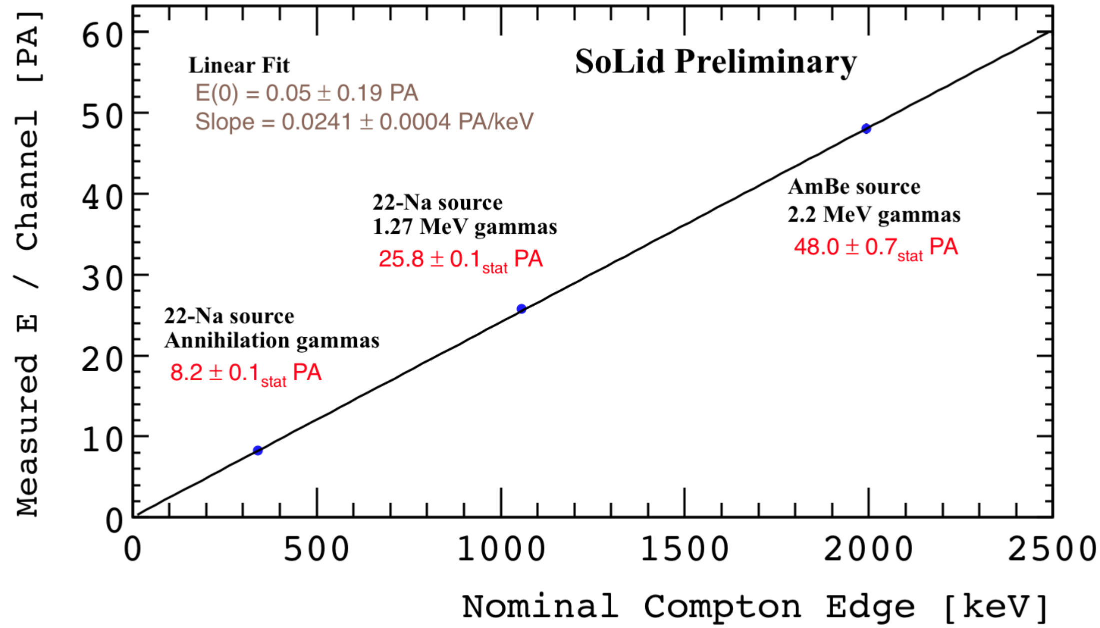
CROSS
- In situ calibration

All frames scanned with n/γ sources to **validate** light yield, n **response**, n capture efficiency

Linearity and light yield

- **Gamma** sources to asses the **LY**
  - **Exceeds** SoLid **requirements**
    (40 PA/MeV → >60PA/MeV !)
- **Homogeneous** response
  - Can be improved with correction from attenuation length



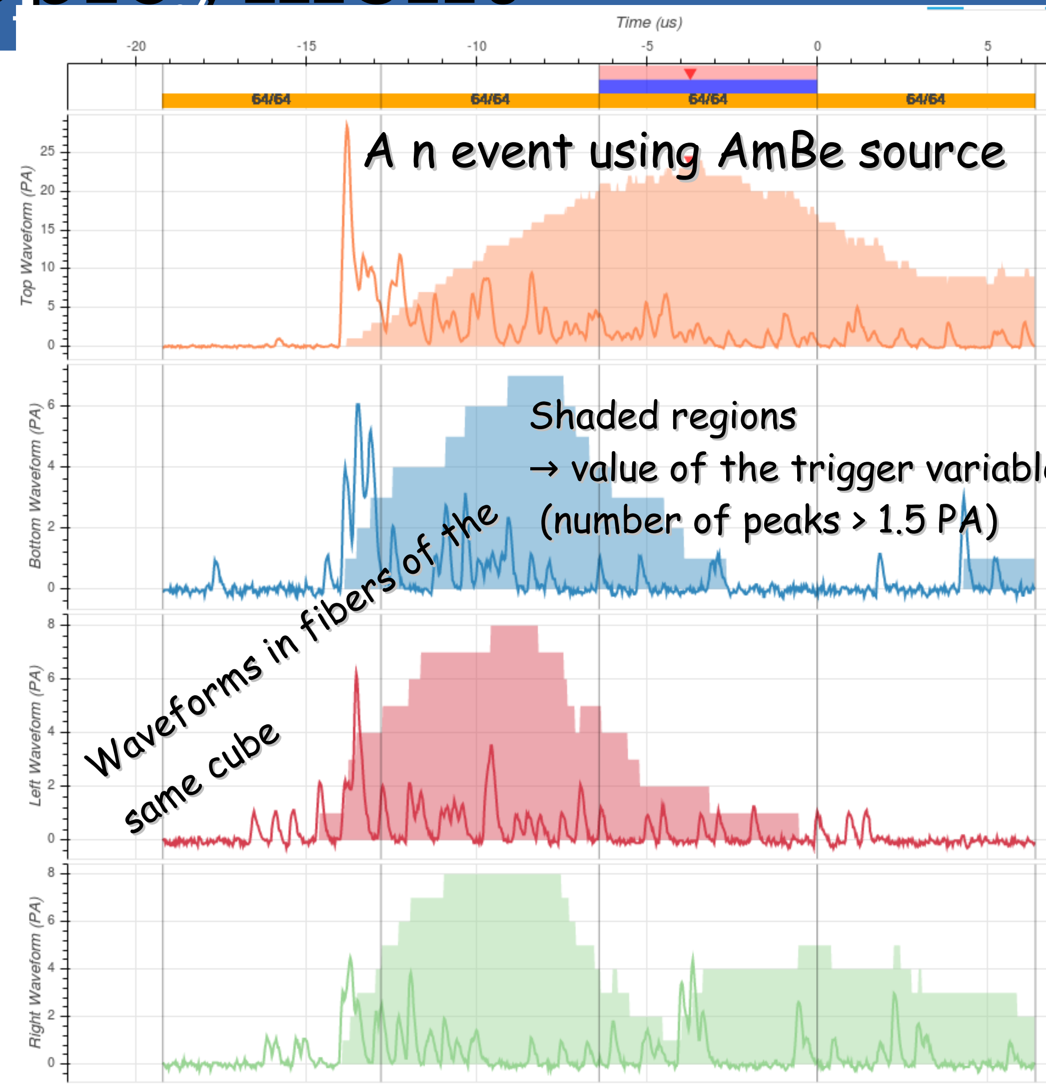


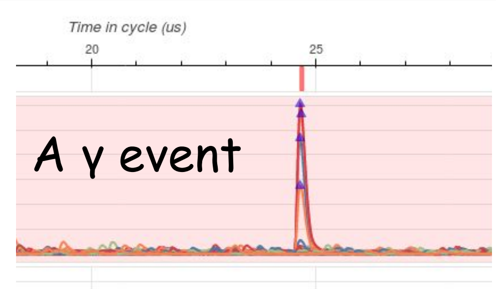
- Initial measurement of energy linearity response
  - **Linear response** of PVT from ~ 340 keV – 2000 keV
- Several γ / e⁻ / n sources (^{22}Na, ^{137}Cs, ^{207}Bi, ^{60}Co, ^{252}Cf, AmBe) + μ to add more calibration points in the future

Neutron trigger deployment

- Dedicated **neutron trigger** for neutrino detection.
  - Implemented in FPGAs.
  - Based on **peak counting**.
  - Combined with **large buffer** for prompt detection→ high IBD efficiency.
- Recently deployed with CALIPSO
  - **Fulfills** SoLid **requirements**

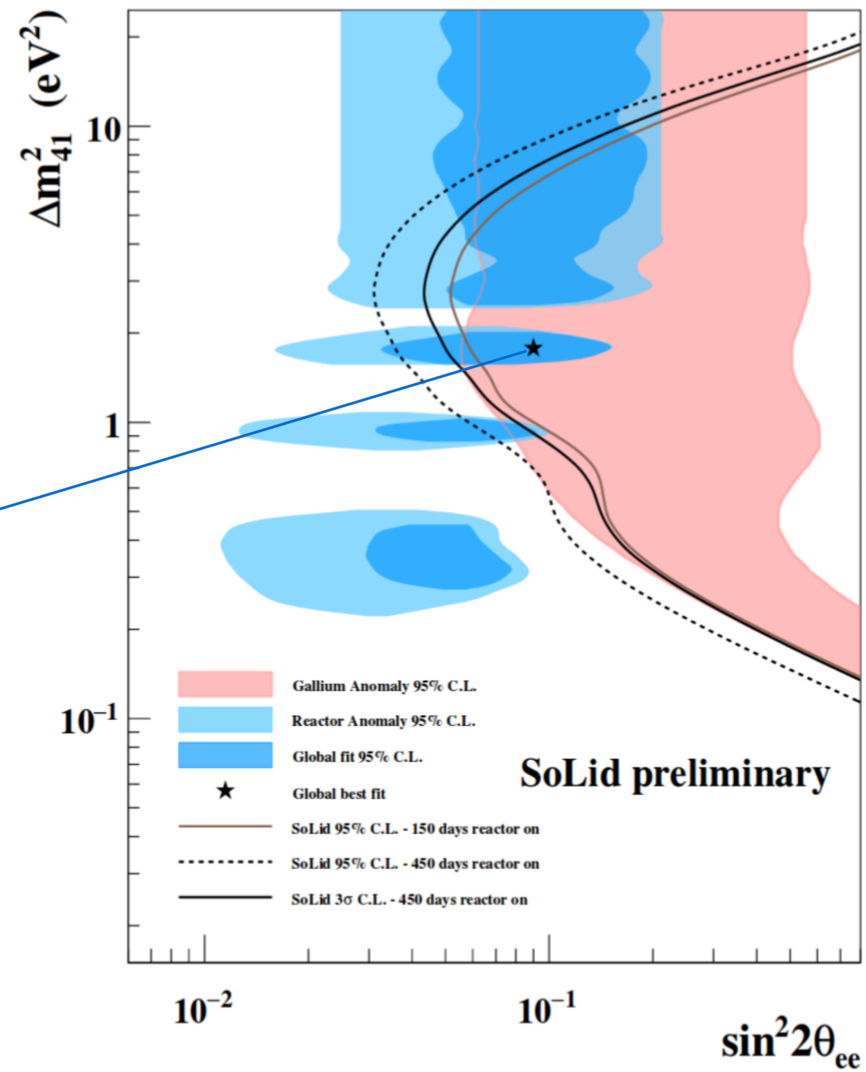
    (n trigger eff > 60 %)

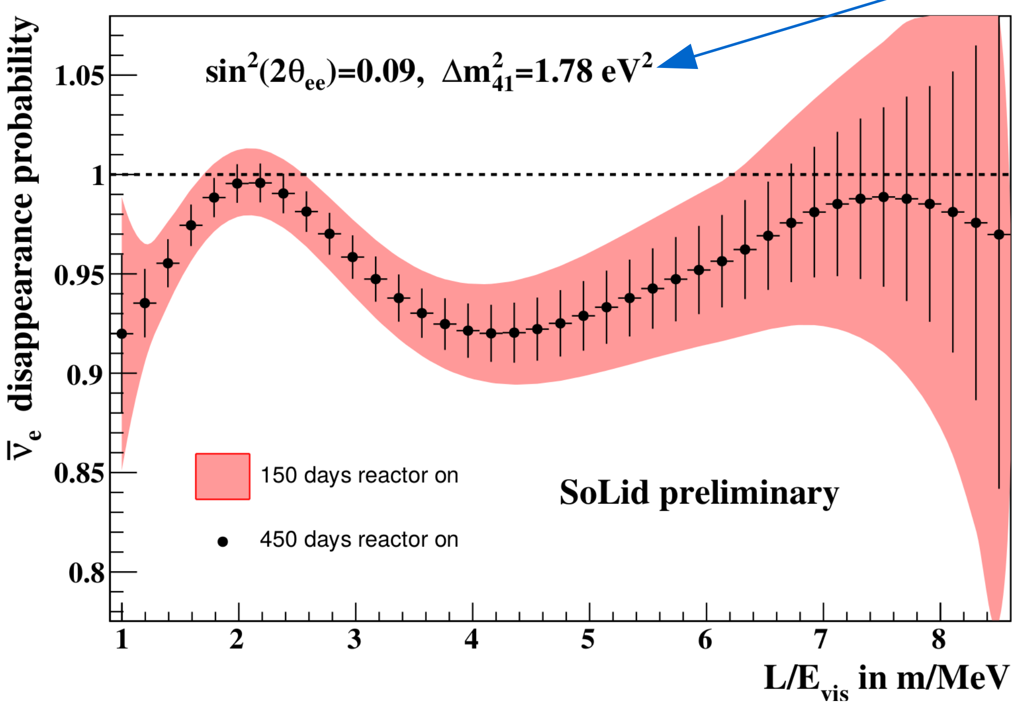




Expected physics results

- Baselines: 6 – 9 m
- Energy resolution 14% / √E
- IBD eff: 30%
- Thermal power: 60 MW
- S:B of 3:1
- 5 Modules
- 450 days of reactor ON





New measurement of **ν spectrum** of **^{235}U**

First physics results expected by 2018

Summary

- **New** detector **concept** [JINST 12 (2017) no.04, arXiv:1703.01683]
  - Robust n/e-γ discrimination
  - High segmentation for background reduction
- **Construction** of SoLid phase 1 (1600 kg) **ongoing**
- Several upgrades to **reduce background**
- **Quality assurance ongoing**: Light yield + neutron trigger **meets (exceeds!) SoLid requirements**
  - Light yield > 60 PA/MeV
  - Neutron trigger efficiency > 60 %
- **Data taking** expected by September **2017**
- First **physics results** expected by **2018**

Thanks for your attention

The SoLid Collaboration

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

Universiteit Antwerpen

lpc caen

VUB Vrije Universiteit Brussel

LPC Particules pLasmas Univers applicationS – Laboratoire de Physique de Clermont

Universiteit Gent

LAL Laboratoire de l'Accélérateur Linéaire

SCK•CEN Studiecentrum voor Kernenergie – Centre d'Étude de l'Énergie Nucléaire

Subatech

University of Bristol

Imperial College London

University of Oxford

VirginiaTech Invent the Future

Stay tuned !