The SoLid experiment

EOS Solstice meeting

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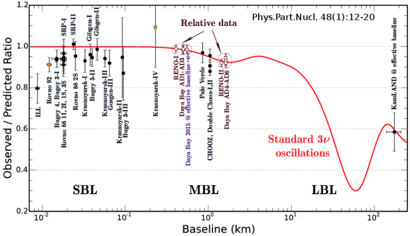
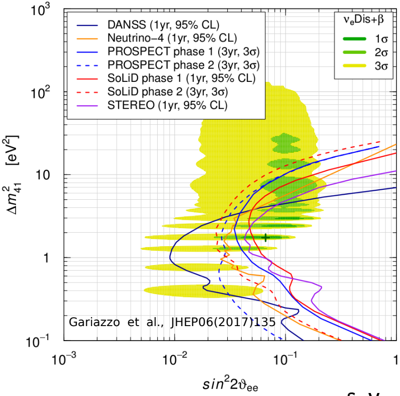
20 December 2018

Universiteit Antwerpen

SoLid

SoLid goals

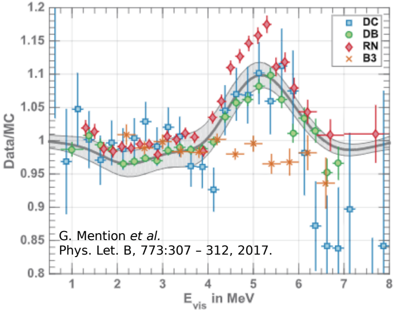




Goals

1. Resolve the reactor antineutrino anomaly
   - Observed $\bar{\nu}_e$ deficit at short baseline
   - Propose $\sim$ 1 eV sterile neutrino as explanation
   - Detect from disappearance pattern
   - SoLid observes reactor as close as 6.2 m

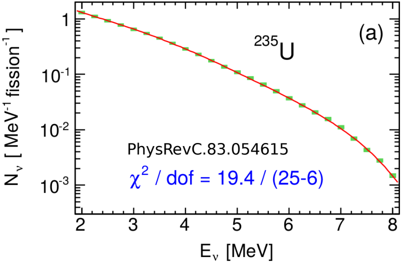
SoLid goals

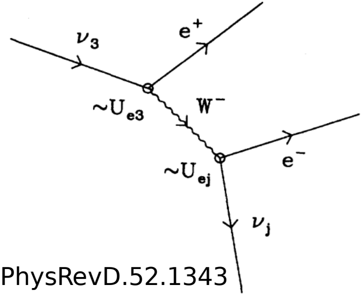


Goals

1. Resolve the reactor antineutrino anomaly
2. Observe the 5 MeV bump
   - Observed $\bar{\nu}_e$ excess at $E_{vis} \approx 5$ MeV
   - Size of excess seems fission fraction dependent
   - SoLid observes 93.5% enriched ^{235}U reactor

SoLid goals



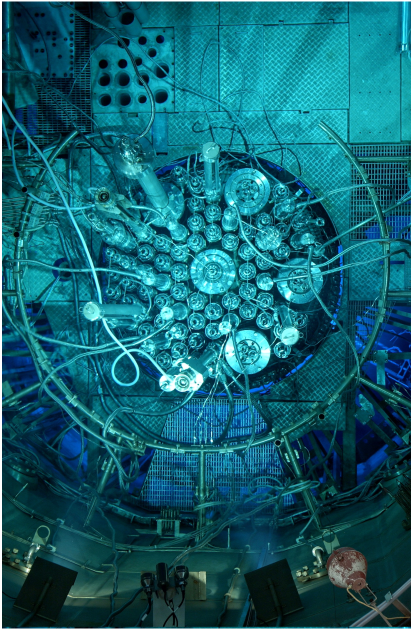


PhysRevD.52.1343

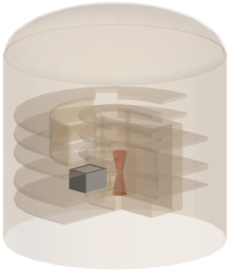
Goals

1. Resolve the reactor antineutrino anomaly
2. Observe the 5 MeV bump
3. Search for heavy neutral leptons (HNL)
   - $\bar{\nu}_e$ can oscillate to any mass state kinematically allowed
   - Able to probe HNL up to $\sim$ 9 MeV
   - Decay products of HNL can be observed
   - Physics program extension

The BR2 reactor



- 60 MW_{therm} nuclear reactor
  $\rightarrow \sim 10^{19}\ \bar{\nu}_e\ s^{-1}$
- Falling energy spectrum, up to 9 MeV
- Twisted compact core
  $\rightarrow$ Ideal for oscillation search
- Experimental hall starting at 5 m from reactor core

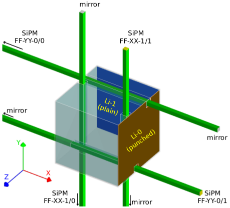


The SoLid detector

Observe neutrinos through inverse beta decay

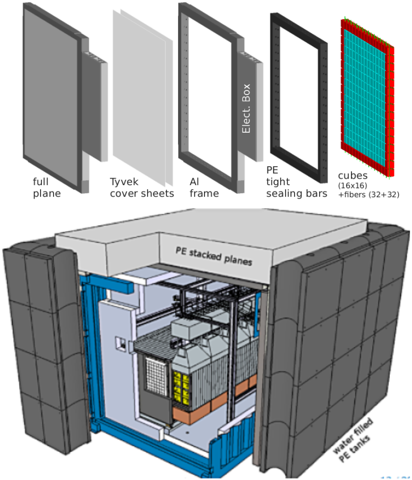
$$\bar{\nu}_e + p \rightarrow n + e^+$$

using a voxelised hybrid scintillator detector.



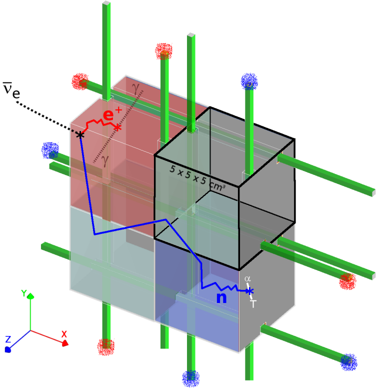
- **Hybrid:** Combination of PVT and ZnS(Ag) scintillators
  - **PVT:** Bulk of the detector.
    Detect positron, gammas and crossing muons
  - **ZnS(Ag):** Localized, doped with ^{6}LiF
    Capture and detect neutron: $n + {}^6\text{Li} \rightarrow {}^3\text{H} + \alpha$
  - Scintillator identification by PSD
- **Voxelized:** Provides location information
  - $5 \times 5 \times 5$ cm^3 cubes
  - Optical isolation via Tyvek

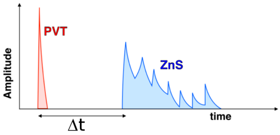
The SoLid detector



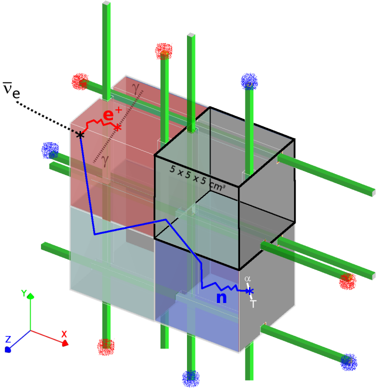
- 16 × 16 cube planes
- 50 planes (1.6 ton)
- Light extraction via XY grid of wavelength shifting fibres
- Fibres read out via SiPMs in frame structure
- Detector in cooled container, surrounded by 0.5 m of shielding (H_2O and HDPE)

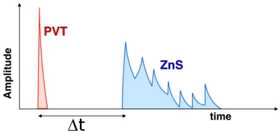
Neutrino interaction

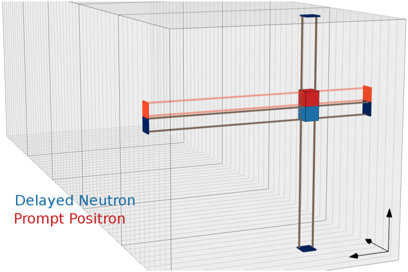


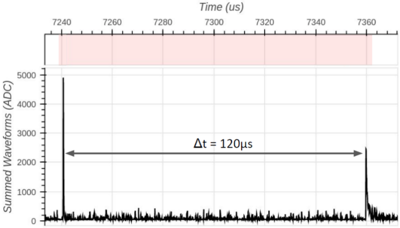


1. Neutrino interacts
2. Positron scintillates in PVT
3. Neutron captures on ^{6}Li after thermalization
4. α and ^{3}H scintillate in ZnS(Ag)


$\bar{\nu}_e$
e+
γ
γ
5 x 5 x 5 cm³
n
α
T
Y
X
Z


PVT
ZnS
Amplitude
time
Δt


Delayed Neutron
Prompt Positron

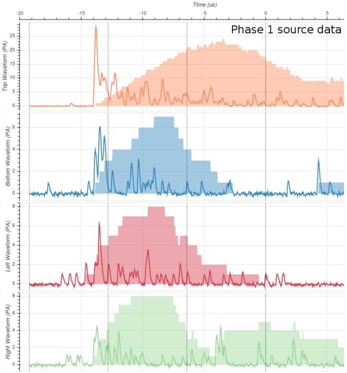

Time (us)
7240
7260
7280
7300
7320
7340
7360
Summed Waveforms (ADC)
5000
4000
3000
2000
1000
0
Δt = 120μs

Neutrino detection

- Sea level neutrino detector next to a nuclear reactor
  - $\rightarrow$ High rate of EM background (γ, μ)
  - $\rightarrow$ Make use of positron-neutron coincidence, trigger on neutron signal

Neutron trigger

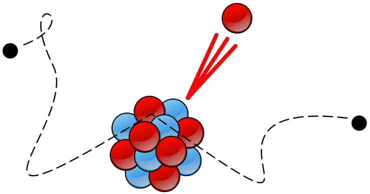
- Large time constant of ZnS(Ag) gives rise to long signals
  $\rightarrow$ lots of peaks
- Count peaks over threshold (PoT)
- Consider neutron if channel PoT value exceeds threshold
- Read buffer (500 μs back) over several planes (3 both sides) for positron signal



Correlated backgrounds

- Cosmic ray muon crosses the detector
- Spallation on material $\rightarrow$ high energy neutron
- Neutron thermalizes and captures
    - Initial collisions of sufficient energy for proton scintillation
    - Nearly identical time constant to IBD
- Apply muon veto

- Cosmic ray induced
    - Muon spallation



Correlated backgrounds

- Cosmic ray interaction creates neutrons high up in the atmosphere
- High energy neutron reaches the detector
- Neutron thermalizes and captures
    - Sufficient energy in initial collisions for proton scintillation
    - Nearly identical time constant to IBD
- No corresponding muon

- Cosmic ray induced
    - Muon spallation
    - Atmospheric neutrons

Correlated backgrounds

- Part of the Uranium decay chain
- Both environmental and contamination

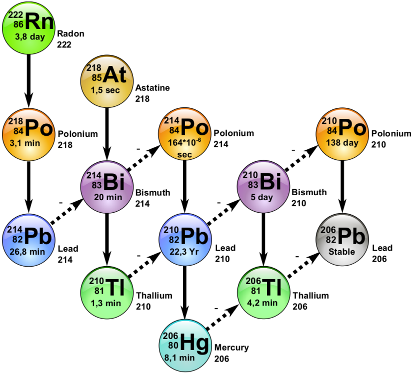
1. ^{214}Bi $\rightarrow$ ^{214}Po + e^-
   - e^- in PVT, very similar to IBD prompt
   - $Q_\beta = 3.2$ MeV

   $\langle E_{vis} \rangle = 2.5$ MeV

2. ^{214}Po $\rightarrow$ ^{210}Pb + α
   - α in ZnS(Ag), very similar to IBD delayed
   - $t_{1/2} = 164\ \mu$s

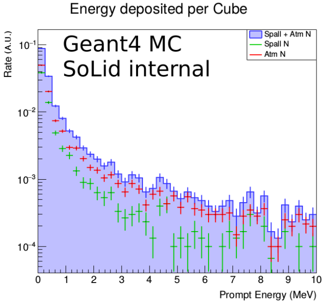
   $\tau_{IBD} = 64\ \mu$s

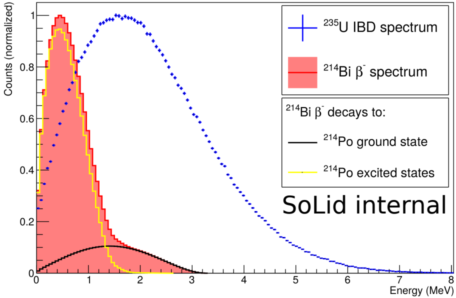
- Cosmic ray induced
  - Muon spallation
  - Atmospheric neutrons
- $\beta - \alpha$ decay chains



Neutrino observation

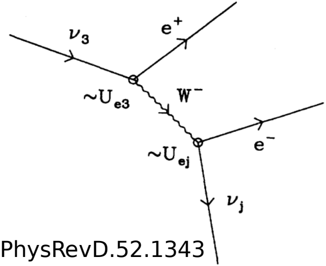
- Stable data taking since April,
  accumulated over 100 days of reactor on data
- Excess consistent with expectations has been observed
  (internal results, not yet public)
- Working on characterization of correlated backgrounds,
  in particular at low energies





HNL search

- Not the design goal
- Initial phases of analysis
- No neutron involved
  - → Have to rely on secondary trigger for HNL data: threshold trigger



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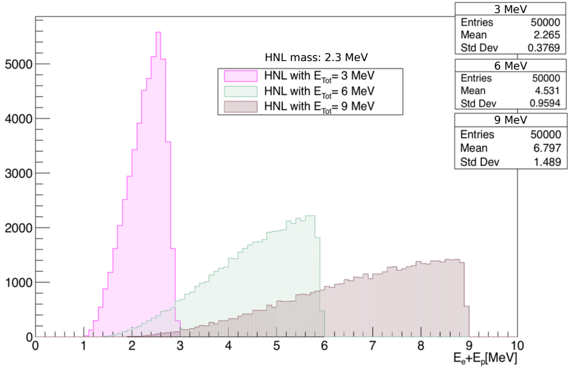
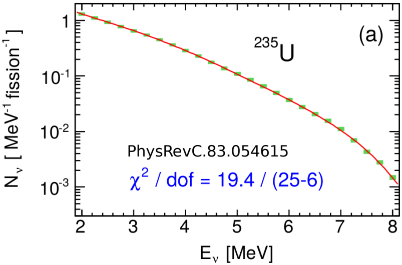
Threshold trigger

- 2.5 MeV threshold
- Simple XY coincidence requirement
- Reads entire plane (64 channels) for 6.4 μs
- Designed for muons

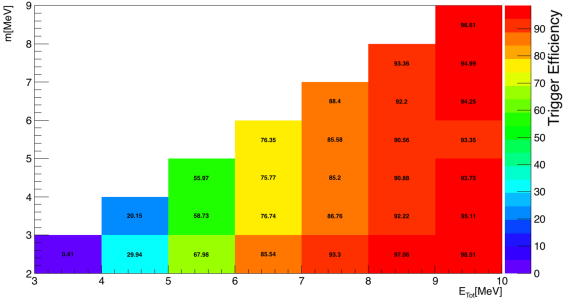
HNL event topology

1. $\bar{\nu}_e$ from reactor oscillates to HNL
2. HNL decays
3. Emission of e^-, e^+ and ν from decay point
   - ν carries away energy invisibly, e^+ and e^- carry the rest
   - Due to relatively low energy and cube size, signal is mostly contained in one or two cubes (except e^+ decay gammas)



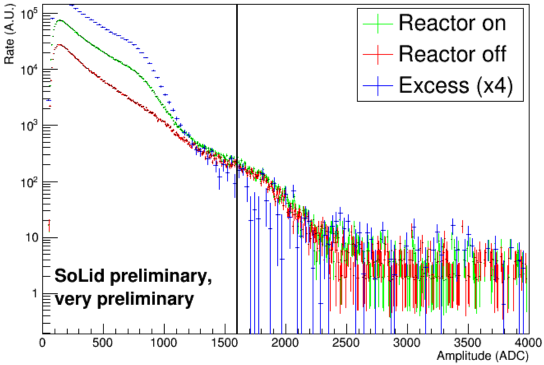


- Trigger efficiency, no reconstruction
- Efficiency dominated by neutrino energy, not HNL mass
- Reducing threshold trigger level gives access to exponentially more neutrinos



HNL backgrounds

- e^+e^- scintillation is a single signal
  $\rightarrow$ no correlated backgrounds
- Neutrino correlated backgrounds are accidental for HNL
  $\rightarrow$ Require muon and neutron veto
- Relatively quiet environment



Conclusion

- Collecting data since April
- First looks at data are very promising, neutrinos are coming soon
- First steps in heavy neutral lepton analysis taken