Neutrino Physics Session
ICNFP 2019 - Kolymbari, Crete

Status of the SoLid experiment at the BR2 reactor

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Outline

1. The SoLid experiment
   - Experimental program
   - Reactor site
   - Detector technology

2. Data reconstruction and BGs
   - Energy scale calibration
   - Data reconstruction
   - Main backgrounds
   - Background data/MC

3. Antineutrino detection
   - IBD selection cuts
   - Predicted S:B
   - Analysis status
SoLid goals

**MOTIVATION**

- Probe the reactor anomaly deficit and search for oscillation at very short baseline: $L \approx 10 \text{ m} \Leftrightarrow \Delta m^2 \approx 1 \text{ eV}^2$

- Resolve discussion on spectral features observed by previous reactor experiments

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*Kopp et al., JHEP 1305 (2013)*

*Double Chooz Collaboration, arXiv:1901.09445*
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APPROACH

- Using plastic scintillator with linear energy response
- Use of segmentation to allow for topological event information (BG reduction) and measurement of potential oscillations in E and L
- Using a compact core with highly enriched $^{235}\text{U}$ fuel
BR2 reactor site

- Compact research reactor at SCK•CEN: \( \varnothing \, 50 \, \text{cm} - H \, 90 \, \text{cm} \)
- Highly enriched fuel: \( 93.5\% \, ^{235}\text{U} \)
- Operating power at \( 50-80 \, \text{MW} \)
- 6 cycles of \(~1\) month each: \(~150\) days per year
- SoLid baseline at \( 6-9 \, \text{m from core} \)
- At ground level \( \rightarrow \) low overburden
SoLid detector technology

- Stacked PVT cubes of (5x5x5) cm³ for electromagnetic signal (ES) detection
- Each covered with two $^6\text{LiF:ZnS(Ag)}$ screens for nuclear signal (NS) detection
- Wrapped in reflective Tyvek paper
- X/Y wavelength shifting fibre arrays, read out by SiPMs

→ Pulse shape discrimination
→ Time and spatial event signature
SoLid Phase I detector

- Planes are filled with 16x16 detection cells
- Planes are grouped per 10 in a module
- 5 movable modules on rail system
  - 1.6 tonnes sensitive mass
  - Closest approach to core of 6.2m
- Housed in container, cooled to 10°C
- Instrumented with remotely operated calibration system (CROSS)
- Passive shielding (50 cm):
  - Sides: water bricks
  - Roof: HDPE slabs
SoLid Phase I detector
Energy scale calibration

- Calibration with crossing muons (*wip*)
- Calibration with sources using CROSS
  - Very good data/MC agreement
  - Energy scale determination using two methods:
    - Kolmogorov-Smirnov test
    - Klein-Nishina analytical fit

- Consistent results over large energy range
- Light yield of 96 PA/MeV (12% at 1 MeV stochastic term)

K-S test $^{22}\text{Na}$

$E_Y = 1.27\text{MeV}$

MC best K-S $\sigma_E$

Data best K-S LY

Linearity Calibration

- Muon Calibration Results
- 22-Na Source
- Bi Source
- AmBe Source
- Best linear fit
  - slope $= [24.11 \pm 0.26] \text{PA/MeV}$
0. Different trigger types for first selection
   ➔ **Threshold**: XY coincidence > 2 MeV
   ➔ **Neutron**: PSD algorithm for neutrons
   ➔ **Random**: Full detector readout at 1 Hz

1. Time clustering to group signals from different fibres

2. Pulse shape discrimination used in offline reconstruction to divide signals in 3 streams:
   NS - ES - Tracks

3. Make correlations between prompt ES and delayed NS signals

Data reconstruction
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Main backgrounds

Fast Neutrons

Muon spallation and/or cosmic ray air showers create fast neutrons

- neutron recoil mimics ‘prompt ES’
- neutron capture is ‘delayed NS’

BiPo

Contamination from $^{238}\text{U}/^{230}\text{Th}$ series in $^{6}\text{LiF:ZnS(Ag)}$ screens and in the air:

$^{214}\text{Bi} \rightarrow ^{214}\text{Po} \rightarrow ^{210}\text{Pb}$, with $T_{1/2}(\text{Po}) = 164 \mu s$

- $\text{e}^-$ from $^{214}\text{Bi}$ mimics ‘prompt ES’
- $\alpha$ from $^{214}\text{Po}$ mimics ‘delayed NS’
Background MC: Fast neutrons

Combined model fit of spallation (42%) and atmospheric neutrons (58%), matches data very well in the ΔT and ΔR distributions.
Background MC: BiPo

MC/Data comparisons of $\Delta T$, $\Delta R$ and prompt E distributions show BiPo background is well understood.
IBD selection cuts

1. Most effective:
   1. PSD for neutron & α in ZnS
   2. Spatial distance between ES and NS (ΔX, ΔY, ΔZ)
   3. Difference in energy balance between “max E” (ES1) cubes
Predicted S:B

- Current cut menu results in IBD efficiency of ~15% (WIP!)
- Signal based on MC calculated number of 1087 IBD interactions/day
- Bg based on 7.28 days of reactor off data

SoLid preliminary

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Analysis status

1. Good progress in developing a precise reconstruction and first IBD selection.

2. The data analysis is ongoing and focuses on topological information for background reduction.

3. Expect further improvement on S:B figure with lower energy threshold.

4. Further developing the oscillation and ‘5 MeV bump` analysis.
Thank you for your attention.

Does anyone have any questions?

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Credits

The members of the SoLid Collaboration and their institutes.

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BACK-UP SLIDES
SoLid Phase I Timeline

- December 2016: STARTED CONSTRUCTION
- November 2017: DETECTOR SHIPMENT & INSTALLATION AT BR2
- December 2017: DETECTOR COMMISSIONING AT BR2 WITH 4 MODULES
- April 2018: START DATA TAKING WITH FULL PHASE I DETECTOR
- Today: ANALYSIS OF 6 REACTOR CYCLES
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<td>SoLid detector technology</td>
<td>1703.01683</td>
<td>2017 JINST 12 P04024</td>
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<td>SM1 prototype performance</td>
<td>1802.02884</td>
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<td>SoLid readout system</td>
<td>1812.05425</td>
<td>Submitted to JINST</td>
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**SoLid Publications**
Detector design
Detector energy response

Energy reconstruction and MC simulation validated against calibration runs with $^{22}$Na (work in progress).
Energy scale stability

- Based on muon dE/dx distribution (average over full detector)
- Shows good stability of energy scale over data taking period
Main backgrounds

BiPo

- Contamination from $^{238}\text{U}/^{232}\text{Th}$ series in LiF:ZnS(Ag) screens:
  
  $^{214}\text{Bi} \rightarrow ^{214}\text{Po} \rightarrow ^{210}\text{Pb}$

  gives $\beta$ and $\alpha$ with $T_{1/2}(\text{Po}) = 164$ μs

- Use PSD capabilities of ZnS scintillator for neutron/alpha discrimination

- Use difference in signal topologies (i.e. distribution over neighbouring cubes) between IBD and BG events
IBD selection cuts

- Muon and NS multiplicity veto
- $\Delta x, \Delta y, \Delta z, \Delta r$ topological cuts
- $1.5 \text{ MeV} < \text{prompt E} < 20 \text{ MeV}$
- Energy balance + BiPonisher cut
- Fiducial cut on outer layer
- $0 < \Delta t < 150 \mu s$

IBD signal Monte Carlo

33% prompt eff
- Discrimination between neutron and alpha, based on integral shape from ZnS.
- AmBe data set is taken in a very close volume around the source to increase purity
- BiPo is selected using delta t (side band) and topological cuts.