Heavy Neutral Leptons @ Solid

Searching For Long Lived Particles at the LHC.
6th workshop of the LHC LLP community.

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At 6 m from the reactor core.

Baselines: 6.5 → 9 m.

3D highly segmented composite detector.

Detector is taking data since 2 years.
Belgian reactor (BR2) : source of neutrinos

- **Source : Nuclear reactor**
  - Compact reactor core $\Phi < 50\text{ cm}$, $h = 90\text{ cm}$.
  - Power : 80 MW.
  - Composition : Highly enriched 235U.

- **Period of Data Taken :**
  - Reactor on : 150 days per year cycle.
  - Reactor off : data collection for background study.

- **Expected anti neutrino flux :**
  - $8.5 \times 10^{19}$ neutrino per second.
Detector configuration

- 5 Modules.
- 10 planes per module.
- 1 plane = 16*16 cubes.
- 1 cube = 5cm*5cm*5cm PVT scintillator.
- 2 layers of $^6\text{LiF:ZnS(Ag)}$ per cube.
**Main physics goal**

- **Inverse Beta Decay (IBD):**
  \[\bar{\nu}_e + p \rightarrow e^+ + n\]

- **Neutron captured in $^6$Li:**
  \[n + ^6\text{Li} \rightarrow ^3\text{H} + \alpha\]

- **ZnS-PVT pulse shape discrimination:**
  - Positron-neutron identification

- **Time and space coincidence:**
  - Background rejection

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Main physics goal

- Probe the so called reactor anomaly deficit.
- Search for oscillation to sterile neutrinos at very short baseline:
  \[ L \approx 10 \text{ m} \leftrightarrow \Delta m^2 \approx 1 \text{ eV}^2 \]
- Good sensitivity.
- Covers part of the most important region.


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Opportunity for HNLs:

- Sensitivity range:
  - 1.022 MeV up to ~ 9 MeV.

- Expected HNLs flux:

\[ \frac{d\phi_{\nu_3}}{dE_{\nu}} = \theta(E_{\nu} - m_{\nu}) |U_{e3}|^2 \sqrt{1 - \left( \frac{m_{\nu}}{E_{\nu}} \right)^2} \frac{d\phi_{\nu_e}}{dE_{\nu}}. \]

- Decay Rate: leptonic channels

\[ \Gamma_{\ell_1\ell_2\nu_{\ell_2}} \equiv \Gamma(N_4 \to \ell_1^- \ell_2^+ \nu_{\ell_2}) = \frac{G_F^2}{192\pi^3} |V_{\ell_14}|^2 m_4^5, \]

- The proper lifetime from the uncertainty principle:

\[ \tau_0 = \frac{\hbar}{\Gamma} \propto \frac{1}{|V_{\ell_14}|^2 m_4^5} \]

LLP particles, some of them decay in SoLid.

~35% BR to e+e-\nu
Signal production

- **Generator in place:**
  - Generator tool: Pythia8: particle gun using the muon matrix element.
  - Anti neutrino energy spectrum from BR2 as input.
  - Decay position simulated following the:
    - The decay rate formula.
    - The kinematic of the initial neutrino.
Signal: Trigger efficiency

- Threshold trigger with 2 fibers in coincidence in place.
  - Triggers on electromagnetic signal with energy above 2MeV.
  - 1 vertical plane (x,y) read out with a time window of 6.4us.
Signal vs background rate

◆ Signal Rate:
  ❏ Expected signal Rate is: 1Hz-1mHz

◆ Most important backgrounds:
  ❏ Proton recoil from fast neutrons.
  ❏ Cosmic muons.
  ❏ External gammas.

<table>
<thead>
<tr>
<th>Background</th>
<th>Fast neutrons</th>
<th>Cosmic muons</th>
<th>External gammas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rate</td>
<td>3.87 Hz</td>
<td>260 Hz</td>
<td>1 kHz</td>
</tr>
<tr>
<td>Rate*</td>
<td>0.92 Hz</td>
<td>10.4 Hz</td>
<td>10 Hz</td>
</tr>
</tbody>
</table>

➢ To deal offline with Rate* applying cuts:
  1. Fiducial volume: most of the background is at the edge.
  2. Energy cut.
  3. Timing.
  4. Topology.

⇒ Preliminary studies show that background can be kept under control.

* Rate after: water shielding, reconstruction efficiency and without neutron tag.
**Constraints**

- **Direct constraints:**
  - Main constraints from the kinematic of the Beta decay: experimental constraints study.
  - Stronger constraint for LNV senario.

- **Cosmological constraints:**
  - Strong tension mainly with BBN.
SoLid sensitivity range: 1.022 MeV up to ~ 9 MeV.

Previous results from the experiment at the nuclear power reactor of Bugey.

Expect to do better than the Bugey results.
- Higher trigger efficiency.
- Better technology.

Very promising results due to the specific topology of HNL signal.

C. Hagner, et al., PhysRevD.52.1343
Thanks for your Attention!