Two-phase emission detector RED100 for investigation of coherent scattering neutrino off heavy atomic nuclei
RED is focused on development of two-phase noble gas emission detector with 100 kg mass of working media which to be used for detection of neutrino coherent scattering on heavy nuclei. The detector will have single-electron sensitivity to ionization and could be considered for observation of neutrino coherent scattering off heavy nuclei.

Beyond probing the Standard Model the coherent scattering can be used for development of a new generation of neutrino detectors monitoring active core of industrial nuclear reactors on the subject of Pu to U ratio.

As part of the program, the liquid xenon 5 kg model of the detector will be tested at the horizontal channel of the IRT MEPhI 2.5 MW research reactor in order to investigate scintillation and ionization yield of liquid xenon stopping heavy nuclear recoils in the range of kinetic energy of below 1 keV. The quasi-monochromatic neutron beam with average energy of 24±1.5 keV and $10^3$cm$^2$s$^{-1}$ flux density will be formed with aluminum-iron interferential filter.
Quasi-free electron emission from nonpolar dielectrics

\[ V_1(z) = V_0 - eF_1 z + eA_1, z < 0 \]
\[ V_2(z) = -eF_2 z + eA_2, z > 0 \]
\[ A_{1,2} = -e(\varepsilon_1 - \varepsilon_2) / [4\varepsilon_{1,2} (z + \xi z / |z|)(\varepsilon_1 + \varepsilon_2)] \]
Probability of emission of quasi-free electrons from some non-polar dielectrics

\[ t_e \sim \left( \frac{\Lambda}{v_d} \right) \exp \left\{ \left[ V_0 - 2eA_1^{1/2} \left( 1 + A_2^{1/2} / A_1^{1/2} \right) F^{1/2} \right] / k_B T \right\} \]
<table>
<thead>
<tr>
<th></th>
<th>T, K</th>
<th>( \mu_o ), cm(^2)/V/s</th>
<th>( V_o ), eV</th>
<th>( E_c ), kV/cm</th>
<th>( E_o ), kV/cm</th>
<th>( t_e )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emitters of cold electrons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L^4\text{He} )</td>
<td>1-2</td>
<td>0.03</td>
<td>+1</td>
<td></td>
<td></td>
<td>10 s (100V/cm)</td>
</tr>
<tr>
<td>( L , n-H )</td>
<td>300</td>
<td>0.09</td>
<td>+0.09</td>
<td>100</td>
<td>0.03</td>
<td></td>
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<tr>
<td>( L , \text{iso-O} )</td>
<td>300</td>
<td>7</td>
<td>-0.18</td>
<td>90</td>
<td>0.15</td>
<td>20 ( \mu )s (1kV/cm)</td>
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<tr>
<td>( L , \text{TMP} )</td>
<td>297</td>
<td>24</td>
<td>-0.3</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L , \text{Ar} )</td>
<td>84</td>
<td>475</td>
<td>-0.21</td>
<td>0.2</td>
<td></td>
<td>700( \mu )s (100 V/cm)</td>
</tr>
<tr>
<td>( SNe )</td>
<td>24</td>
<td>600</td>
<td>+1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Emitters of hot electrons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>( L , \text{CH}_4 )</td>
<td>100</td>
<td>400</td>
<td>-0.18</td>
<td>1.5</td>
<td>&lt;4</td>
<td>&lt; 0.1 ( \mu )s (&gt;1kV/cm)</td>
</tr>
<tr>
<td>( S , \text{CH}_4 )</td>
<td>77</td>
<td>~1000</td>
<td>0</td>
<td>&lt;1.5</td>
<td>&lt;0.1 ( \mu )s (&gt;0.3kV/cm)</td>
<td></td>
</tr>
<tr>
<td>( L , \text{Ar} )</td>
<td>84</td>
<td>475</td>
<td>-0.21</td>
<td>0.23</td>
<td>&lt;0.1 ( \mu )s (&gt;1kV/cm)</td>
<td></td>
</tr>
<tr>
<td>( S , \text{Ar} )</td>
<td>83</td>
<td>1000</td>
<td>+0.3 (6K)</td>
<td>0.1</td>
<td>&lt;0.1 ( \mu )s (&gt;100V/cm)</td>
<td></td>
</tr>
<tr>
<td>( L , \text{Kr} )</td>
<td>116</td>
<td>1800</td>
<td>-0.4</td>
<td>0.08</td>
<td>1.6</td>
<td>&lt;0.1 ( \mu )s (&gt;1.6kV/cm)</td>
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<tr>
<td>( S , \text{Kr} )</td>
<td>116</td>
<td>3700</td>
<td>-0.25 (20K)</td>
<td>0.98</td>
<td>&lt;0.1 ( \mu )s (&gt;1kV/cm)</td>
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<tr>
<td>( L , \text{Xe} )</td>
<td>161</td>
<td>2200</td>
<td>-0.61</td>
<td>0.05</td>
<td>1.75</td>
<td>&lt;0.1 ( \mu )s (&gt;1.8kV/cm)</td>
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<tr>
<td>( S , \text{Xe} )</td>
<td>161</td>
<td>4500</td>
<td>-0.46 (40K)</td>
<td>1.25</td>
<td>&lt;0.1 ( \mu )s (&gt;1.3kV/cm)</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** n-H – normal hexane, iso-O - iso-octane, TMP - thetramethylepentane
“Wall-less” emission detector

- Sensitive to single ionization electrons
- Two signals from ionization and excitation of atoms
- «Selfshielding»
- Large mass working media

Fig. 4. LXe time-projection scintillating drift chamber as wall-less detector for measurements of magnetic momentum neutrino. Bolozdynya, Egorov, Miroshnichenko, Rodionov. IEEE Trans. Nucl. Sci. v. 42, n. 4 (1995) 565-569
Real signals from XENON10 LXe emission detector

4 keV$_{ee}$ event; S1: 8 p.e. => 2 p.e./keV

Hit pattern of top PMTs

8 p.e.

3k p.e.
Separation of gamma and nuclear recoil signals

Energy, keVee

Self-shielding

Courtesy of Richard Gaitskell & Collaboration LUX
Coherent neutrino scattering off heavy nuclei

\[ \frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1 + \cos\theta) \frac{Q_w^2}{4} F(Q^2)^2, \]

\[ Q_w = N - (1 - 4\sin^2\Theta_W)Z \]


\[ \sigma \approx 0.42 \times 10^{-44} N^2 (E/1 \text{ MeV})^2 \text{ cm}^2 \]

\[ \frac{d\sigma}{d\cos\theta} = \frac{G^2}{8\pi} \left[ Z(4\sin^2\theta_W - 1) + N \right] E^2 (1 + \cos\theta) \]

\[ \bar{E}_A = \frac{2}{3A} (E/1 \text{ MeV})^2 \text{ keV} \]

A. Drukier & L. Stodolsky
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RED-1

2x7 FEU-181, MgF$_2$
Distribution of EL (S2) signals generated by single emitted electrons (green). Maximum of the Gauss fit is $15 \pm 5$ photoelectrons. Poisson distribution for 10 and 15 expectations are shown in pink and violet, respectively.

**Research reactor IRT MEPhI**

1 – RED-1
2 – Fe/Al filter
3 – horizontal neutron channel GEK10
4 – starting point of MCNP simulations
5 – cooling water pool
6 – active zone
7 – heavy concrete shielding
Al/Fe filter

Table 1. Values of signal-to-background ratio

<table>
<thead>
<tr>
<th>Models of GECh-10 channel with real geometries of the environment:</th>
<th>Signal-to-background ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>without any radiation shielding</td>
<td>0.01</td>
</tr>
<tr>
<td>with radiation shielding of the channel only</td>
<td>39.10</td>
</tr>
<tr>
<td>with radiation shielding of the channel and the detector</td>
<td>34.10</td>
</tr>
<tr>
<td>Filter Energy (keV)</td>
<td>Materials</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>2 ±0.7</td>
<td>10B (85%)</td>
</tr>
<tr>
<td>24 ±0.96</td>
<td></td>
</tr>
<tr>
<td>54 ±2</td>
<td>10B (85%)</td>
</tr>
<tr>
<td>133 ±1.4</td>
<td>10B (85%)</td>
</tr>
<tr>
<td>144.926</td>
<td></td>
</tr>
<tr>
<td>194.06</td>
<td></td>
</tr>
<tr>
<td>3.1157</td>
<td></td>
</tr>
<tr>
<td>93.08</td>
<td></td>
</tr>
<tr>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>
Ionization yield of liquid xenon for nuclear recoils and transmission maximum of interference neutron filters marked with red arrows.
Scintillation efficiency $L_{\text{eff}}$

Relative scintillation efficiency of LXe
The Hamamatsu R8778 PMT, used in the LUX experiment (left), and the R11410

![Image of PMT and graph]

Figure 3. SOLO counting spectra for R8778 (14 live days, blue) and R11410 MOD (19 live days, red) PMTs, superimposed with a sample background run (21 live days, black). Strong lines in the 778 spectrum indicate the presence of $^{238}$U, $^{232}$Th, $^{40}$K and $^{60}$Co. The reduced activity of the 1410 MOD is readily apparent from the lack of distinct features in comparison with the R8778.
Kalinin nuclear power plant facility

Reactor unit #2

http://www.itep.ru/rus/Experiments/GEMMA/

γ background under the reactor
γ background in the lab

http://www.itep.ru/rus/Experiments/GEMMA/
Reactor Neutrinos

Fig. 4.2. Neutrino spectra from fission of $^{235}\text{U}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$ (measured), and $^{238}\text{U}$ (calculated).
Antineutrino Spectrum

$\text{L=19 m}$

Count Rate

$\text{L = 19 m}$
Experimental data on ionization yield for NR are available for $\geq 4$ keV for LXe. There are no experimental data for LAr.

For LXe we used a fit of the existing data with $12.5 \cdot E^{-0.34}$ ($E$ in keVnr) for $E > 4$ keV and for $E < 4$ keV a smooth function going to “0”
For LAr we used the same dependence but reduced by \textit{Wi LXe /Wi LAr ratio}
SNS

NuSNS (Neutrinos at the SNS)

Front-End Systems (Lawrence Berkeley)
Accumulator Ring (Brookhaven)
Linac (Los Alamos and Jefferson)
Instrument Systems (Argonne and Oak Ridge)

2-body decay: monochromatic 29.9 MeV $\nu_e$
PROMPT

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_\mu + \nu_e$

3-body decay: range of energies between 0 and $m_e$
DELAYED (2.2 $\mu$s)

Neutrino energy (MeV)

Flux
RED-100 @ SNS

20 m from the target of SNS

Cosmic neutron background is suppressed by factor 1000 due to duty cycle.

Effect = 6000 events/year

40 m from the target of SNS

SNS neutron background suppressed by factor $10^3$ due to ground shielding

Effect = 1470 events/year
Well-logging detector

LUX at Homestake
Interface

Ground shielding

40 m from target

10 m below ground level

neutrino
Ground shielding

40 m from target

neutrino

Iron shielding

Cosmic muon veto

Water shielding
Single electrons background

Spontaneous single electron emission observed in ZEPLIN-III, Xenon-10, RED-1

SE background rate:

- strongly depends on potential barrier at the interface
- depends on intensity of radioactive background (5 Hz spontaneous rate in ZEPLIN-III, 40 Hz in RED-1)

Single electron events could be suppressed by cleaning interface with tangential electric field

XY-positions of single electron events in a 12 kg emission LXe detector ZEPLIN-III installed in the underground lab

Santos – arxiv 1110.3056v1
Conclusion

- **Coherent Neutrino Scatter (CNS)** is interesting for basic science - and possibly for non-proliferation applications.
- **Emission two-phase detectors** look suitable for detecting CNS.
- **Measurement of the ionization yield** for nuclear recoils below \( \sim 1 \text{keVr} \) energies is a key element toward the observation of CNS.
- Single-electron noise is a factor limiting sensitivity of LXe emission detectors.
- At reactor for signal \( N_e \geq 2 \): LXe 20-400 d\(^{-1}\); LAr 400-700 d\(^{-1}\).
- At SNS for signal \( N_e \geq 2 \): LXe 1400 d\(^{-1}\); LAr 400 d\(^{-1}\).