Status of the RED-100 experiment

Rudik D. G.
NRNU MEPhI

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Our goal is to detect and study CEvNS @ close vicinity of reactor core with RED-100 detector

Supported by

* Science and innovations Rosatom
Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

Predicted more than 40 years ago within Standard Model (SM)


\[
\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1 + \cos \theta) \frac{(N - (1 - 4\sin^2 \theta_W)Z)^2}{4} F^2(Q^2) \propto N^2
\]

where $G$ – Fermi constant, $Z$ – number of protons, $N$ – number of neutrons, $F(Q^2)$ – nuclear form factor, $Q$ – momentum transfer, $k$ – neutrino energy, $\theta_W$ – Weinberg angle

First observations:

Cs & I - Experimental point by COHERENT: Science Vol. 357 (2017) 1123

CEvNS around the World
RED-100

- Two-phase noble gas emission detector
- Contains $\sim 200$ kg of LXe ($\sim 100$ kg in FV)
- 38 PMTs
  Hamamatsu R11410-20 (19 in each PMT array)
- Thermosyphon-based cooling system ($\text{LN}_2$)
RED-100: schematic layout of grids and PMTs

Sizes of the drift volume and distances between grids are in mm.

T and B – top and bottom grounded grids, A – anode grid, G1 – electron shutter grid, G2 – extraction grid, C – cathode grid
Two-phase emission detector technique

Very suitable for CEvNS study. It combines the advantages of gas detectors: the possibility of proportional or EL amplification, XYZ positioning, and the possibility to have the large mass!

This method was proposed by Russian scientists in MEPhI in 1970:


Two-phase emission detector with PMT matrices for rare events study:

Single Electron (SE) detection

- Capability to detect single ionization electrons (SE) was demonstrated
- Projects for CEvNS with LXe two-phase detectors appeared

Proposals on CEvNS detection:

- ZEPLIN-II (LXe)
  - arXiv:0708.0768
- ITEP two-phase LXe prototype
  - Phys. Atom. Nucl. 72 (2009), #4, 653
- ZEPLIN-III (LXe)
  - arXiv:1110.3056
  - JHEP 1112 (2011) 115

ITEP&INR LXe:
- JINST 4 (2009) P06010
  - arXiv:0903.4821

ZEPLIN-III Collaboration LXe:
RED-100 assembling

• RED-100 was assembled and tested in the MEPhI laboratory

Electronegative impurities catch the ionization electrons

Purification in two stages
1\textsuperscript{st}: spark discharge technique with “Mojdodyr”
2\textsuperscript{nd}: continues circulation of Xe through RED-100 and SAES

Electron lifetime of several milliseconds was achieved

Xenon was contaminated by highly-electronegative impurities presumably due to the use of a special fluorine-containing high-molecular-weight lubricant in gas centrifuges.

After purification, the achieved lifetime $\geq 50\,\mu$s for $\sim 200$ kg of LXe
RED-100 performance: SE

- SE is a cluster of individuals SPEs (single photo electrons)
- Typical duration $\sim 2 \mu s$
- $\sim 30$ SPE/SE for RED-100

![Typical single electron (SE) signal](image1.png)

Different colors $\rightarrow$ different PMTs

![Distribution of SE duration](image2.png)

Distribution of SE duration

![Distribution of SE area](image3.png)

Distribution of SE area
• Gamma calibration was done
• Position reconstruction tested
• LRF obtained for the top PMT plane
• Electron extraction efficiency (EEE)
  • S2-based only
  • $N_{SE} = 22\text{Na peak position/SE area}$
  • $N_E$ – from NEST @ $E_{dr} = 0.217$ kV/cm
  • $N_E^*$ – corrected for electron lifetime
  • $\text{EEE} = N_{SE}/N_E^* = 0.54 \pm 0.08$ @ $E_{extr} = 3.0 \pm 0.1$ kV/cm

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**Gamma calibration**

- Energy calibration of $^{60}\text{Co}$ and $^{22}\text{Na}$ sources.

**Position reconstruction for $^{22}\text{Na}$**

- Reconstruction of $^{22}\text{Na}$ decay events in the detector.

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**Electron Extraction Efficiency (EEE)**

- Calibration results showing $\text{EEE}$ as a function of electric field.

**LRF example**

- Lateral position resolution for a specific event.
RED-100 performance: “spontaneous” SE

- An increasing of SE rate after energy deposition in liquid noble gas detector was observed by several groups

- Two components:
  1. Short, but more intense, caused by emission of the electrons trapped at LXe surface
  2. Long, but less intense; unknown mechanism, decreases with time as purity increase; possibly, catching and releasing electrons by impurities (correlation with purity of LAr was also observed in DS50)

- Electron shutter in RED-100
  - To minimize 1st component
  - Muon is a trigger
  - SE rate was reduced by factor of about 3
  - Still high SE rate of the second component (250 kHz) in the lab
  - Expecting reduction at the site of KNPP in a factor of about 5

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**Observed in ZEPLIN-III:**


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**D.Yu. Akimov et al., Two-phase emission low-background detector (in Russian), Utility model patent RU 184222 U1, 2018**
RED-100 at KNPP

• KNPP – Kalinin Nuclear Power Plant
• 19 m from the reactor core
• Antineutrino flux
  \( \sim 1.35 \times 10^{13} \text{ cm}^{-2}\text{s}^{-1} \)
• \( \sim 65 \text{ m.w.e. in vertical direction} \)
• Passive shielding:
  • 5 cm Cu
  • \( \sim 60 \text{ cm H}_2\text{O} \)
Passive shielding

Assembled and tested in MEPhI

Copper shielding

Water tank
Passive shielding

• Restrictions in space and kg/m² at KNPP
• 5 cm Cu and ~ 60 cm water
• Reduction of gamma background in a factor of ~ 700 according to tests and MC
• MC for neutron background reduction is on going
Estimation of CEvNS count rate at KNPP

- Main background \(\rightarrow\) accidental coincidence of several spontaneous SE

- But:
  - CEvNS events are point-like events
  - Background is mostly NOT point-like

- Simple point-like cut was tested, and it works!

- More about it and about the development of better point-like cut in the next talk (Olga Razuvaeva: Point-like events searching in RED-100)

<table>
<thead>
<tr>
<th>ME value in electrons</th>
<th>Estimated ME background at KNPP, events/160kg/day</th>
<th>Expected CEvNS count rate at KNPP, events/160kg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no cut</td>
<td>point-like</td>
</tr>
<tr>
<td>2</td>
<td>5.3\times10^7</td>
<td>1.8\times10^7</td>
</tr>
<tr>
<td>3</td>
<td>4.4\times10^5</td>
<td>0.9\times10^5</td>
</tr>
<tr>
<td>4</td>
<td>2.7\times10^3</td>
<td>348</td>
</tr>
<tr>
<td>5</td>
<td>13.7</td>
<td>1.1</td>
</tr>
<tr>
<td>6</td>
<td>5.7\times10^{-2}</td>
<td>3.0\times10^{-3}</td>
</tr>
</tbody>
</table>

We can detect CEvNS with threshold of \(\sim 4\) SE

Taken into account:
- Recent data on ionization yield in LXe for NR
- \(\text{EEE} = \frac{\text{NSE}}{N*E} = 0.54 \pm 0.08\)
- Factor of 5 reduction of muon rate \(\Rightarrow 50\) kHz spontaneous SE rate
- Poisson flow of spontaneous SE
Despite COVID-19 situation we are in time!

2020
- October: improvement of water tank and its test; packing the detector and all the stuff; preparing for shipment
- November: shipment to KNPP; background measurements on site

2021
- Winter: deployment; background measurements and analysis
- Spring: start of data taking

2022
- Data analysis
- Prolongation of experiment (?)
Conclusion

• RED-100 was assembled and tested @ MEPhI
  • Excellent electron lifetime of several milliseconds
  • Electron extraction efficiency = 0.54 ± 0.08 @ 3.0 ± 0.1 kV/cm
  • SE gain is about 30 SPE/SE
  • The electron shutter was tested: the spontaneous SE rate suppressed but still high

• Estimations based on our tests show the possibility to detect CEvNS at KNPP with a threshold of ~ 4 SE (progress is ongoing)

• The results of the first lab test are available: Akimov D. Yu., et al. JINST 15.02 (2020): P02020

• We are in time: shipment to the KNPP by the end of this year!
Backup
CEvNS around the World
In Dark Matter search experiments, the progress of setting limits has increased significantly when liquid noble gas detectors (two-phase) started operation.

1st proposal (in 2004); LAr detector

C. Hagmann and A. Bernstein,
Two-Phase Emission Detector for Measuring Coherent Neutrino-Nucleus Scattering

From Akimov D. talk @ INSTR20
Ionization yield for sub-keV nuclear recoils

7 years ago
There were no data < 4 keV_{nr}

Now
LUX data

We considered “optimistic” and “realistic” scenarios

NEST – Noble Element Simulation Technique

New data by LLNL
arXiv:1908.00518

From Akimov D. talk @ INSTR20
Energy spectrum

$\bar{\nu}_e$ energy spectrum from nuclear reactor

L=19 m

Xe and Ar nuclear recoil spectra

L = 19 m

region of few ionisation electrons

This is very challenging task, but feasible!
1 To increase EEE by increasing extraction (G2-A) electric field $\Rightarrow$ CEvNS signal $\uparrow$, however SE rate $\uparrow$, but not significantly

For this purpose, additional Teflon isolator is installed between G2 and A

2 To introduce smart blocking for the muon events: the higher muon deposited energy, the longer blocking time of the shutter (up to several hundred ms)

3 To study the influence of LXe purity on the rate of spontaneous SE events

4 To improve algorithm of point-like events selection
Background measurements with NaI[Tl]

- Calibrated NaI[Tl] detector was used for the background study
- Thick Cu+Pb shielding was used to get internal + muons background
  - 15 cm of Pb from the bottom
  - At least 15 cm Cu from each side
  - 5 cm Pb belt
- Publication is under preparation