The RED-100 experiment
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&
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The main goal of the RED experiment is to detect CE\textsubscript{ν}NS at NPP
A coherent elastic neutrino-nucleus scattering (CEνNS): $\nu + A \rightarrow \nu' + A'$

It was predicted theoretically 45 y ago:


but has never been observed experimentally until recently (2017 ) because of the very small energy transfer

Neutrino interacts via exchange of Z with the nucleus as a whole, i.e. coherently;
This takes place when the transferred momentum is of an order or smaller than the inverse nuclear radius

$E_\nu \approx 50$ MeV
CEvNS cross-section

\[ \frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} M_W^2 \left( 1 - \frac{MT}{2E^2}\nu \right) F_{\text{nucl}}^2(Q^2) \]

where \( F_{\text{nucl}}(Q^2) \) – nuclear form factor (FF), \( E_\nu \) – neutrino energy, \( T \) – nucl. recoil energy

\[
Q_W = [Z(1 - 4\sin^2\theta_W) - N] \approx N,
\]

\( Z \) – protons, \( N \) - neutrons

\[
\sin^2\theta_W \sim 0.25 \quad \Rightarrow \quad \sigma \sim N^2.
\]

\( \theta_W \) – Weinberg angle

Ar - Next talk of A. Kumpan for the 1-st result

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


At a reactor:

Ge detectors: CoGeNT, TEXONO, vGeN, CONUS
Low-temp. bolometers: RICOCHET, MINER, v-cleus
CCD: CONNIE

Noble liquid detectors: LAr Livermore, LXe ITEP&INR, LXe ZEPLIN-III

At a spallation neutron source:

at ISIS: LXe ZEPLIN-III
at SNS: CLEAR (LAr), COHERENT: LAr, Ge, CsI [Na]

taking data

Data taking completed

at LANSCE-Lujan Facility: Coherent CAPTAIN-Mills
Commissioning Dec 2019
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
Two-phase emission detection technique is very suitable for CEνNS 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 1970s!

Photodetectors (photomultipliers)
\( \tilde{\nu}_e \) energy spectrum from nuclear reactor

This is very challenging task, but feasible!
We considered “optimistic” and “realistic” scenarios.

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

Now

Ionization yield for sub-keV nuclear recoils

NEST – Noble Element Simulation Technique

New data by LLNL
arXiv:1908.00518
Single electron detection

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

Proposals on CEvNS detection:

ITEP&INR LXe:

ZEPLIN-III Collaboration LXe:
The RED-100: the laboratory tests are under way in MEPHi

RED-100 is a two-phase noble gas emission detector. Contains ~200 kg of LXe, ~160 kg in sens. volume, ~100 kg in FV.

The sensitive volume 38 cm in diam., 41 cm in height, is defined by the top and bottom optically transparent mesh electrodes and field-shaping rings.
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
RED-100 detector assembling
**1st stage:** LXe was purified by a spark-discharge method with “Mojdodyr”: D.Yu. Akimov et al., Instrum. Exp. Tech. 60 (2017) no.6, 782

X-ray tube as a source of ionization electrons for e\(^{-}\) lifetime measurements

**2nd stage:** Purification was performed by continues circulation of Xe through RED-100 and SAES

Electron lifetime was measured by cosmic muons passed through the detector:

Average energy deposition from cosmic muons is practically uniform

**RED-100 performance: LXe purity**

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 \( \gtrsim 50 \mu s \) for \(~200\) kg of LXe
RED-100 performance: SE

SE is a cluster of individual SPEs (single photo electrons) with a typical duration of ~ 2 µs.
From S2 distribution ONLY,

\[ N_{SE} = \frac{22\text{Na peak pos. area}}{SE area} \]

\[ N_E \text{ – from NEST @ } E_{dr} = 0.217 \text{ kV/cm} \]

\[ N^*_E \text{ – corrected for electron lifetime} \]

\[ EEE = \frac{N_{SE}}{N^*_E} = 0.54 \pm 0.08 \]

\[ @ E_{extr} = 3.0 \pm 0.1 \text{ kV/cm} \]
RED-100 performance: "spontaneous" SE

The rate is proportional to the total charge rate in the detector

P. Sorensen, K. Kamdin
JINST 13 (2018) no.02, P02032

"Spontaneous" SE noise is caused by overlapping of the SE tails of the energetic events (mostly muons).

Two components:
1\textsuperscript{st} – short, but more intense, caused by emission of the electrons trapped at LXe surface.
2\textsuperscript{d} – 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)
RED-100 performance: "spontaneous" SE

To minimize the 1st component, an electron shutter is introduced (G2 – G1).

Positive pulse (~300 V millsec. duration) is applied to G1, and the charge is collected to it.

Pulse generator is triggered by muon scintillation.

Then, the only ~1-cm part of LXe above G2 produces the undersurface charge.

The use of shutter allowed us to reduce the SE rate by a factor of ~3

However, the "spontaneous" SE rate is quite high: ~ 250 kHz in our ground-level lab. (no overburden, no shielding)

Example of waveform:

At the site of KNNP (Kalinin Nuclear Power Plant), it will be reduced by a factor of ~5
Antineutrino flux at this place - $1.35 \times 10^{13}$ cm$^{-2}$s$^{-1}$

$\gamma$ and $n$ shield:
5 cm Cu + ~60 cm H$_2$O

Neutron flux

KNPP 60 - 70°  KNPP vert.

KNPP – Kalinin Nuclear Power Plant

Image by J.I. Collar
Assembling the whole setup is currently in progress in MEPhI lab.
Estimation of CE$_{\nu}$NS count rate at KNPP

ME – multielectron events – accidental coincidences of SE is the main instrumental background of a two-phase emission detector

**Taken into account:**
- New data on ionization yield in LXe for NR
- $\text{EEE} = \frac{N_{SE}}{N^*_E} = 0.54 \pm 0.08$
- Factor of 5 reduction of muon rate $\Rightarrow$ 50 kHz spontaneous SE rate
- Poisson flow of spontaneous SE
- Cut on "non-pointness" of event – selection of only point-like events

<table>
<thead>
<tr>
<th>ME value in electrons</th>
<th>Estimated ME background at KNPP, events/160kg/day</th>
<th>Expected CE$_{\nu}$NS 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$\cdot$10$^7$</td>
<td>1.8$\cdot$10$^7$</td>
</tr>
<tr>
<td>3</td>
<td>4.4$\cdot$10$^5$</td>
<td>0.9$\cdot$10$^5$</td>
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<tr>
<td>4</td>
<td>2.7$\cdot$10$^3$</td>
<td>348</td>
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<tr>
<td>5</td>
<td>13.7</td>
<td>1.1</td>
</tr>
<tr>
<td>6</td>
<td>5.7$\cdot$10$^{-2}$</td>
<td>3.0$\cdot$10$^{-3}$</td>
</tr>
</tbody>
</table>

We can detect CE$_{\nu}$NS with threshold of $\sim$ 4 SE
Further steps to improve CEνNS/bckg

1 To increase EEE by increasing extraction (G2-A) electric field ⇒ CEνNS signal ↑, however SE rate ↑, 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
2020 Laboratory tests in full-shield configuration; preparing for shipment, paperwork, and shipment & deployment

2021 Getting started & Data taking

2022 Data analysis
CONCLUSION

1 First ground-level laboratory tests of the RED-100 detector was carried out. The main technical results are:
   • Excellent LXe purity is achieved – electron lifetime of ~ milliseconds
   • Electron extraction efficiency (EEE) = 0.54 ± 0.08 @ 3.0 ± 0.1 kV/cm
   • SE gain of 29+6.2 SPE is obtained
   • The electron shutter was tested: the spontaneous SE rate reduced but still high

2 Estimations based on our tests show that the detection of the CEνNS events is feasible at the site of Kalinin NPP with a threshold corresponding to ~ 4 SE

The results of the first lab. test : 2020_JINST_15_P02020

NEW COLLABORATORS ARE WELCOME!

THANK YOU FOR ATTENTION!
Backup slides
Worldwide CEνNS map

CAPTAIN-Mills
By electric field part of electrons are extracted from the track; recombination is suppressed. Suppression depends on dE/dX. Ratio of SC/EL is different for different kind of particles.

For the Dark Matter search: