Exposition of the RED-100 two-phase emission detector at the Kalinin NPP for the study of coherent elastic neutrino scattering off Xenon nuclei

Alexander Bolozdynya for RED collaboration

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НАУКА И ИННОВАЦИИ РОСАТОМ *

RSF Russian Science Foundation

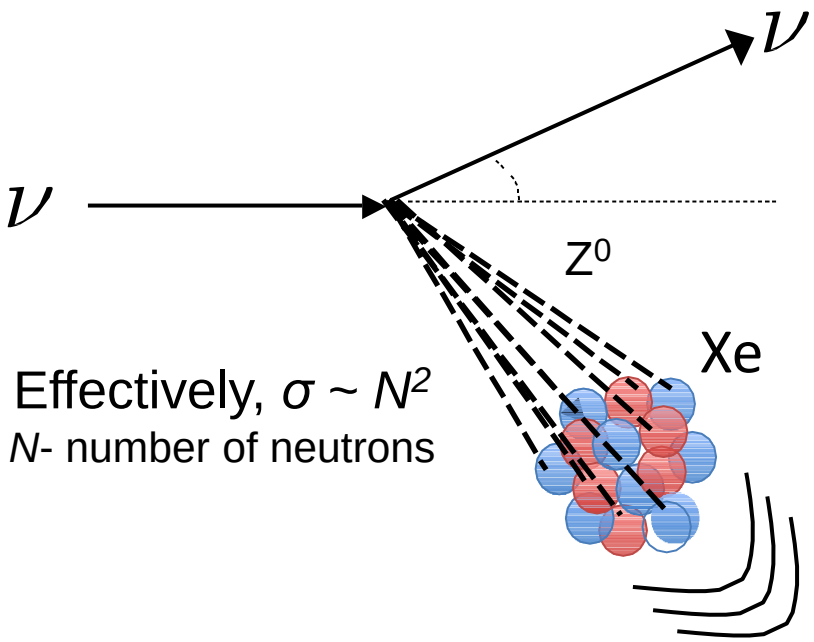
RFBR RUSSIAN FOUNDATION FOR BASIC RESEARCH

MEPhI

* Science and innovations Rosatom

The goal

Detection of reactor antineutrinos via *coherent elastic neutrino-nucleus scattering* (*CEνNS*) off *Xe* nuclei



Effectively, $\sigma \sim N^2$
N- number of neutrons

Predicted 48 years ago
[D.Z. Freedman et al. PRD 9(1974)1389]

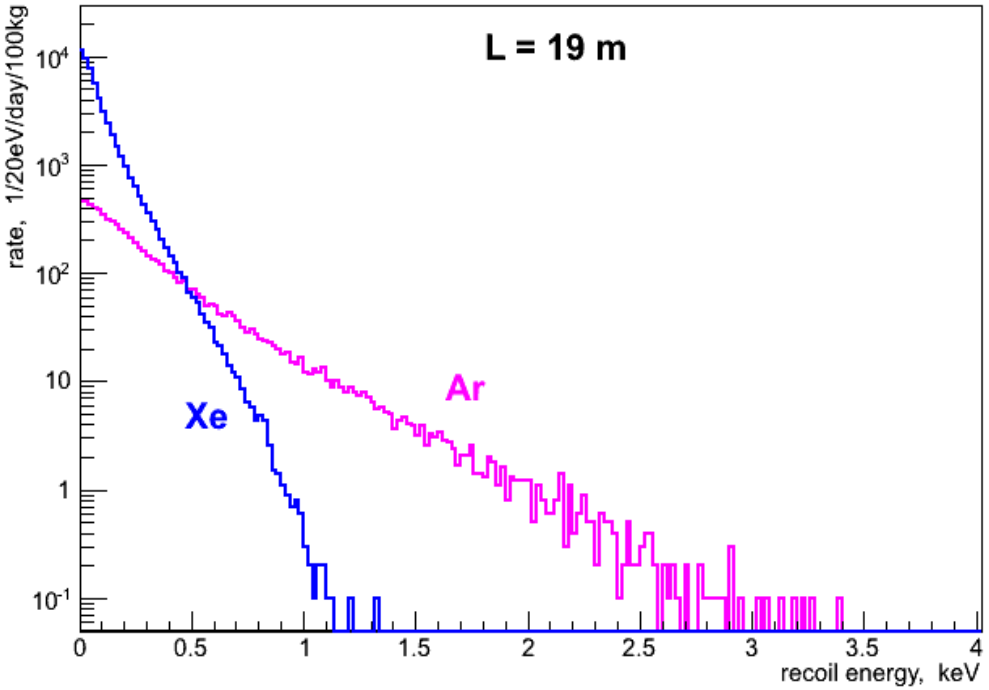
First observation by COHERENT at SNS (Oak Ridge) in 2017
[D.Akimov et al. Science 357(2017)6456]

For *Xe* averaged reactor $\bar{\nu}_e$ energy spectrum $\langle\sigma\rangle \approx 7 \cdot 10^{-41}\ cm^2$ is 700 larger than that for the inverse beta-decay $\tilde{\nu} + p \rightarrow e^+ + n$

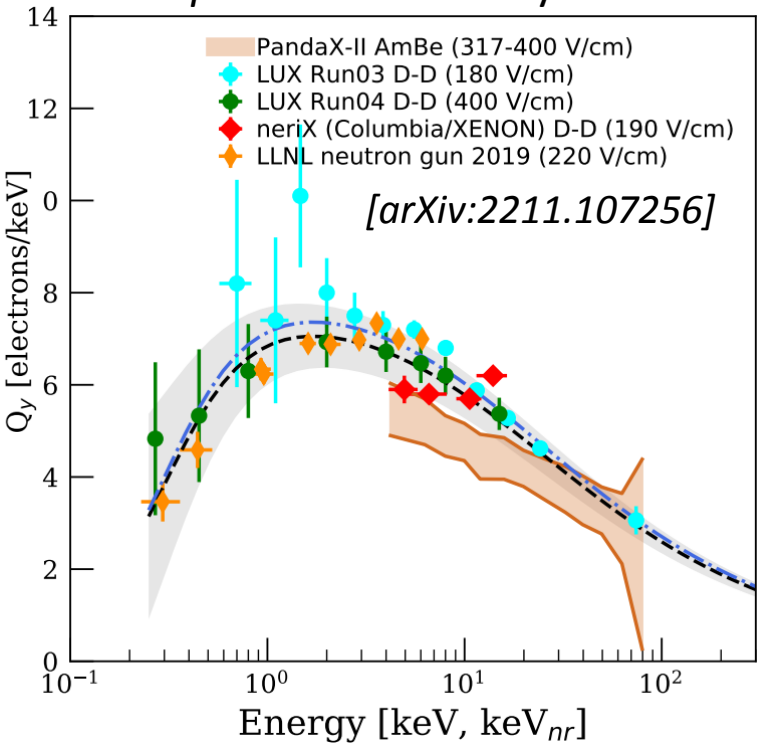
Expected signals in search for *CEvNS* off Xe nuclei at Kalinin NPP

Challenge: only low energy nuclear recoils (***<1 keV*** for *Xe*) are observable

CEvNS nuclear recoil spectrum at KNPP



Liquid Xe ionization yield



Signal in Liquid Xenon = a few ionization electrons !

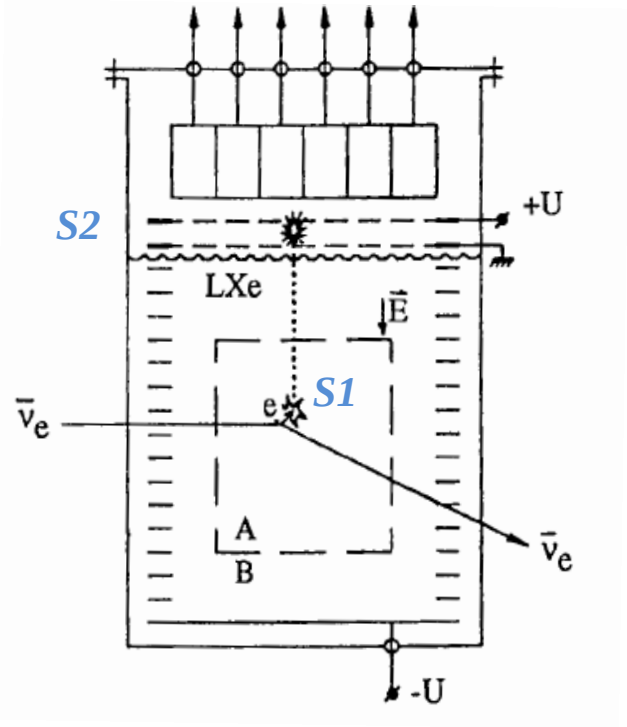
Ionization electrons at 200 V/cm	1	2	3	4	5	6
Events/day/100 kg* (L=19 m, KNPP)	788	500	219	94	41	19

* before taking into account e-capture by impurities and efficiency of e-extraction from liquid

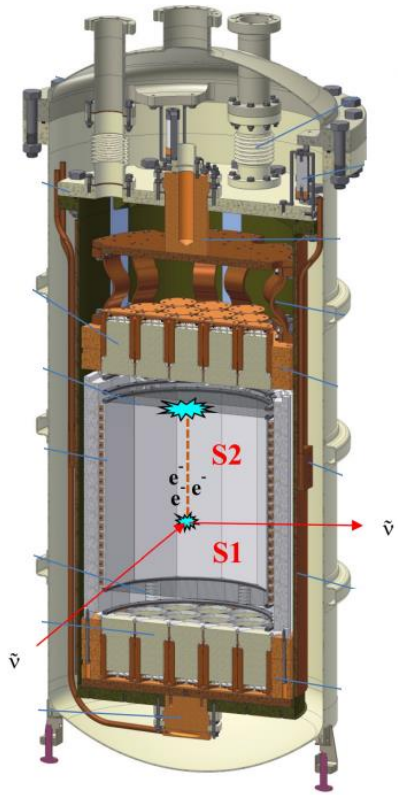
A “wall-less” two-phase emission detector

- S1 (scintillation) and S2 (ionization) for energy and position reconstruction
- Sensitive to single ionization electrons
- Large mass of sensitive medium
- “Self-shielding” effect

First publication of the idea:
[A.Bolozdynya, V.Egorov, B.Rodionov, V.Miroshnichenko. IEEE TNS 42(1995)565]



The RED-100 detector
[D.Akimov et al. JINST 15(2020)P02020]



Light collection:
- 19 PMTs top at the top
- 7 PMTs at the bottom

Sensitive volume:
- 380 mm diameter
- 415 mm high
- about 100 kg of LXe

Field:
- 200 V/cm drift field
- 2.85 kV/cm extraction
- “Electron shutter” *[Patent RU 184222 U1, 2018]*

Assembling RED-100 in MEPhI

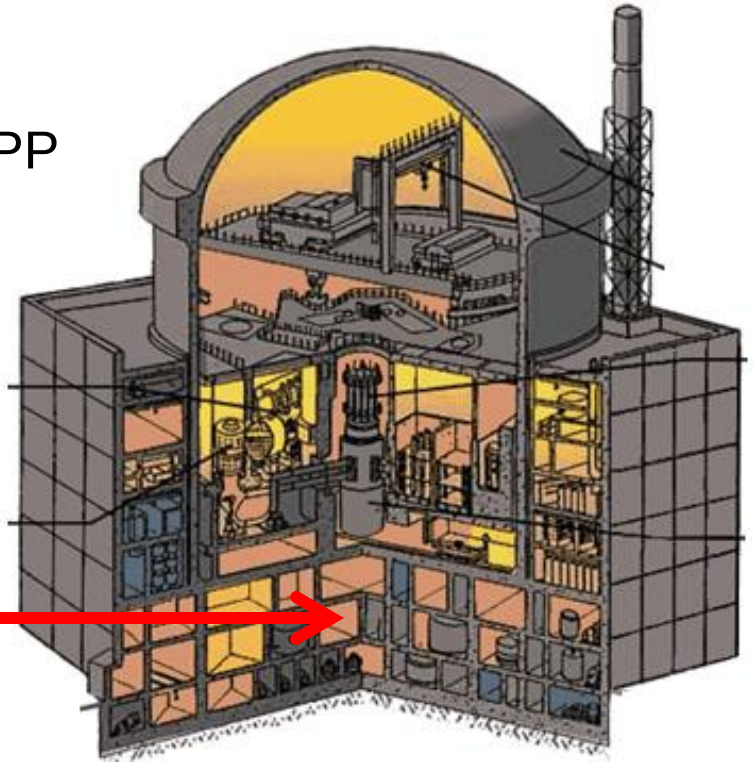
Laboratory for Experimental Nuclear Physics

Kalinin Nuclear Power Plant (KNPP)

Exposition site: the 4th Power Unit of KNPP

- 19 m from the reactor core
- ~65 m.w.e. in vertical direction
- $\bar{\nu}_e$ flux is ~$1.35 \cdot 10^{13}$ $cm^{-2}s^{-1}$

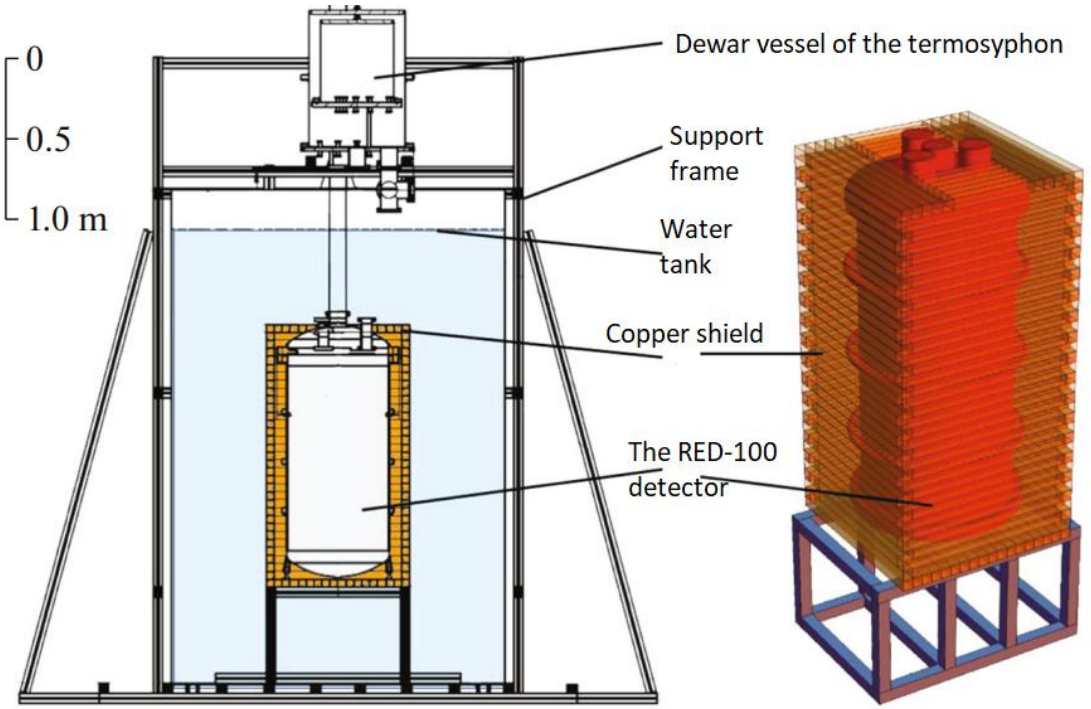
Location of RED-100



Deployment at KNPP

[JINST 17 (2022) T11011]

The setup was deployed at KNPP
in February – May of 2021



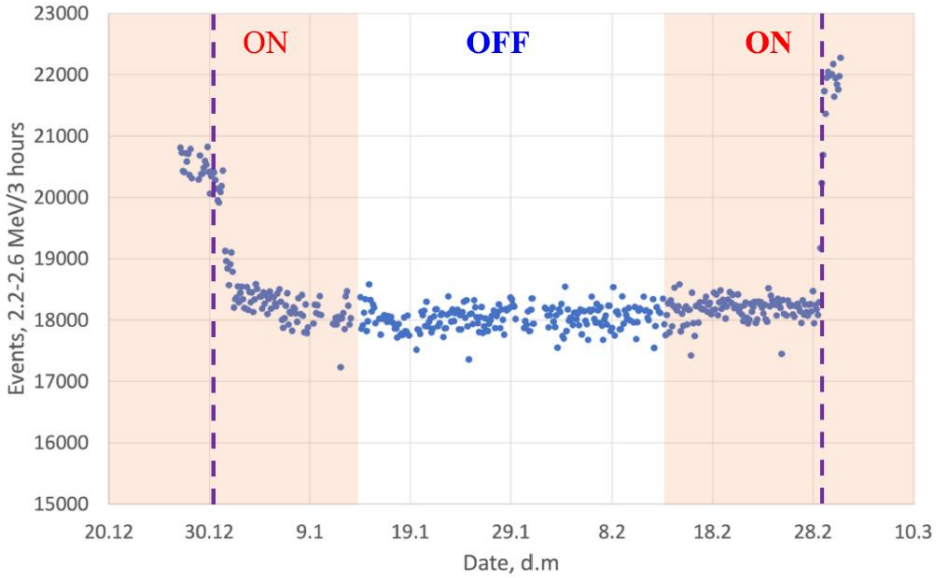
The passive shield consists of copper (~5 cm)
and water (70 cm) layers

RED-100 at KNPP

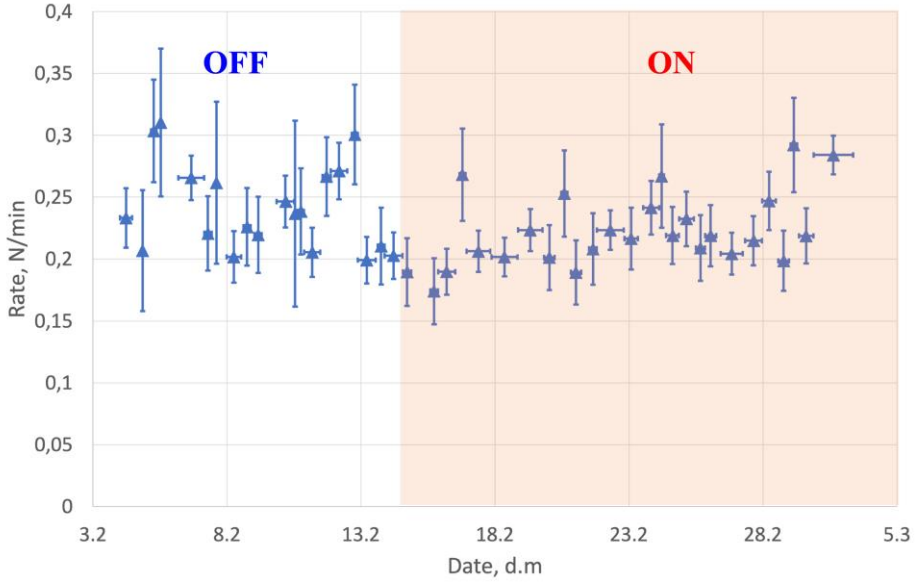
May-July ‘21: meas. of backgrounds in the room, Xe purification, initial tests
Aug-Oct ‘21: technical break, express analysis
Nov-Dec ’21: Xe purification
Jan-Feb ’22: setting up the trigger, scientific data acquisition

Radiation background measurements

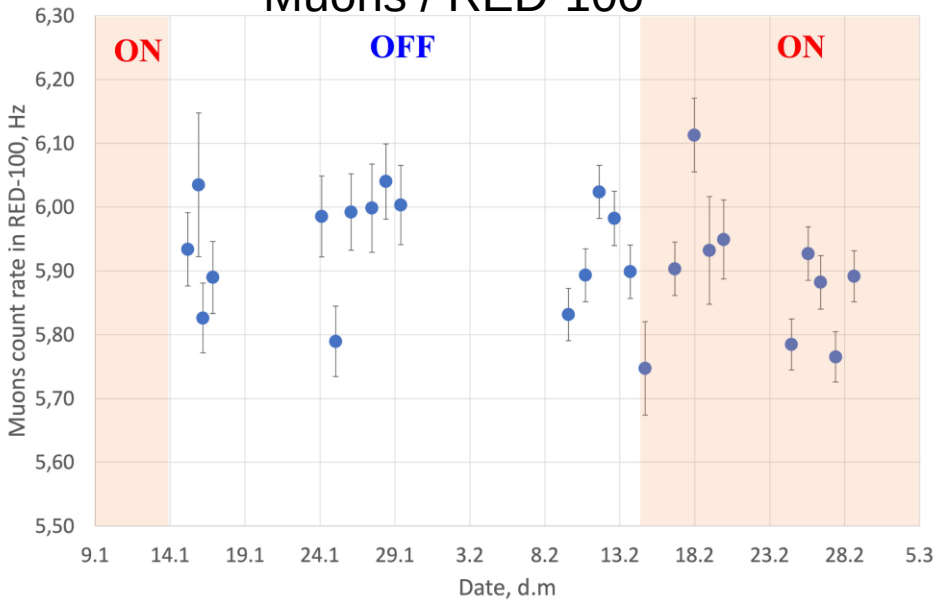
Gamma / NaI[Tl]



Neutrons / BICRON (BC501A) LS



Muons / RED-100

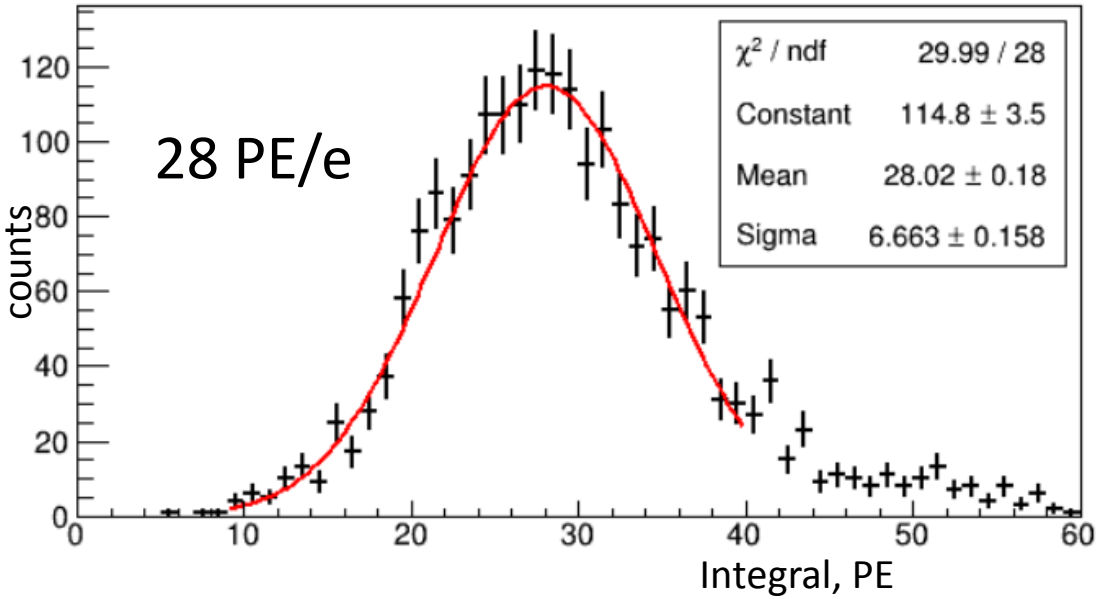


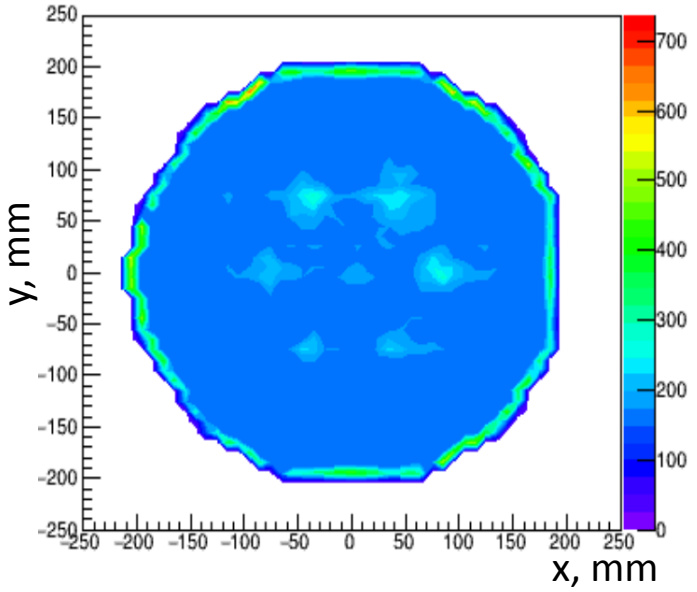
General Conclusions

1. ***Gammas***: x5 larger, than that in lab. (suppressed in 700 by the shielding)
2. ***Neutrons***: about the same for ON/OFF
3. ***Muons***: x8 suppressed rel. to lab., approx. the same rate for ON/OFF
4. ***Radon***: ~100 Bq/m^3

Single electron response of RED-100

“Spontaneous” single electron noise *SE* (S2 signals from single electrons extracted from the liquid) are correlated in time with a large energy depositions from cosmic muons and may appear several milliseconds after the “parent” event is happened.





~40 kHz of single electron noise is measured at KNPP that is factor 6 lower, than that observed in the lab (compare with factor 8 reduction in the muon rate)

Main source of background in 2-5 electrons region is associated with coincidences of *SE*s in time and space. A lower than expected discrimination power of a cut based on the likelihood of the light distribution in the PMT array is found.

A possible reason of this effect is spatial correlations of *SE* sources.

Selection of CEvNS candidates

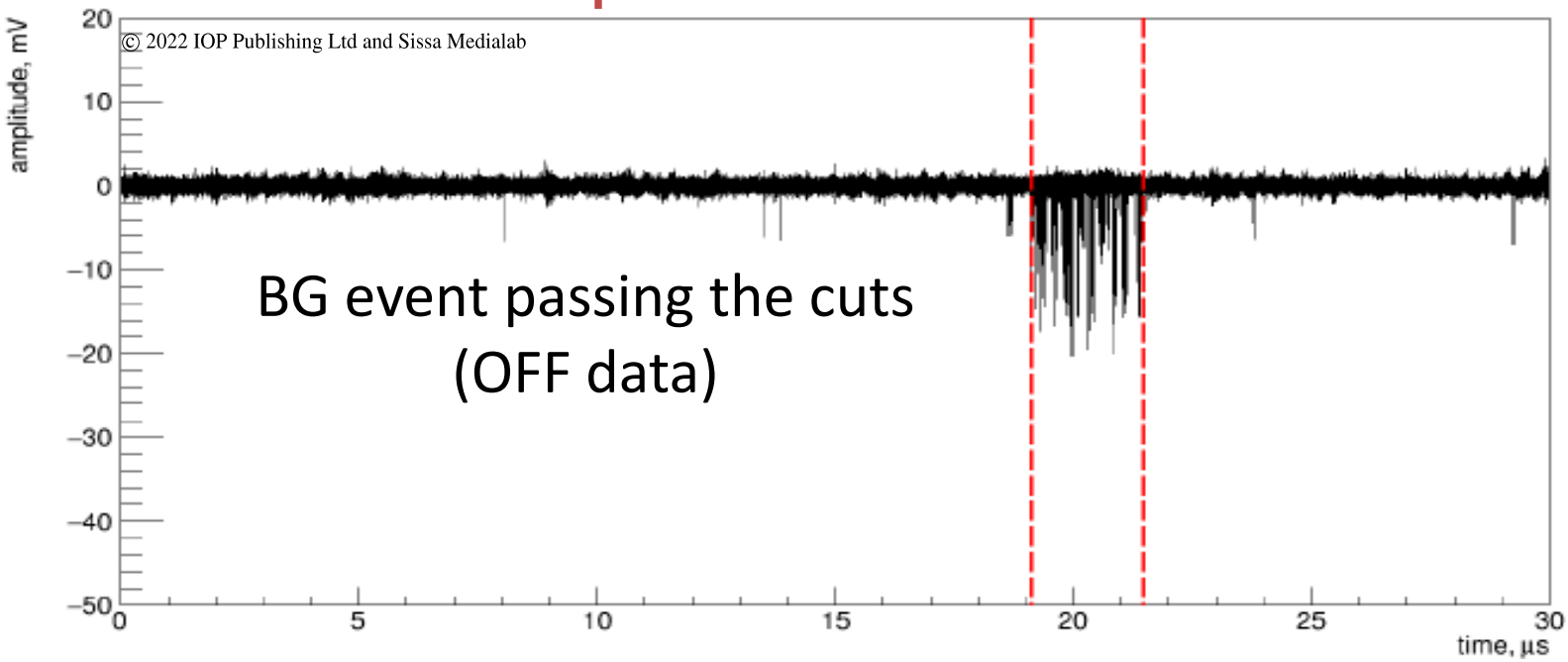
(See the talk presented by Olga Razuvaeva)

CEvNS candidates: S2-like clusters of PE selected in neural network analyses of data

Looking at the OFF data to optimize and fix selections before looking at ON

Parameters to get optimal SIG/sqrt(BG):

- shape
- length
- coordinates
- likelihood of light distribution over PMT array



Preliminary results: the BG is ~2-3 orders of magnitude larger than that expected. An upper limit of *CEvNS* cross-section is expected to be tens time larger than that predicted by Standard Model.

CONCLUSIONS

1. At the first time about 100kg-massive liquid noble gas detector has been tested in conditions of a modern NPP with an ionization signal sensitivity down to a few electrons.

2. Effectively stable radiation background has been achieved at the site in ON & OFF reactor modes.

3. There are acquired data at the both ON & OFF reactor modes.

4. Currently, the efficiency of *CEvNS* events selection is lower than that expected due to unpredictively high *SE* coincidence background.

5. The upper limit on *CEvNS* rate will be found soon by ongoing analyses.

6. Liquid Argon is under consideration as an alternative working medium because it provides higher energy of *CEvNS* nuclear recoils that may improve separation of useful events from *SE* coincidence background.

R E D
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