The RED-100 experiment

D. Akimov (RED collaboration)
NRNU MEPhI
&
NRC “Kurchatov institute” ITEP

RUSSIAN EMISSION DETECTOR

The International Conference "Instrumentation for Colliding Beam Physics" (INSTR20), Novosibirsk, Russian Federation, 24 - 28 February, 2020

RUSSIAN EMISSION DETECTOR

The RED collaboration is currently represented by:

D.Yu. Akimov[a,b], V.A. Belov[a,b], A.I. Bolozdynya[a], Yu.V. Efremenko[f], A.V. Etenko[a,d], A.V. Galavanov[a,c], D.V. Gouss[a], Yu.V. Gusakov[a,c], Dj.Ed. Kdib[a], A.V. Khromov[a], A.M. Konovalov[a,b,e], V.N. Kornoukhov[a,g], A.G. Kovalenko[a,b], E.S. Kozlova[a,b], A.V. Kumpan[a], A.V. Lukyashin[a,b], Yu.A. Melikyan[a,g], V.V. Moramzin[a], O.E. Razuvaeva[a,b], D.G. Rudik[a,b], A.V. Shakirov[a], G.E. Simakov[a,b,e], V.V. Sosnovtsev[a], A.A. Vasin[a]

[a] *National Research Nuclear University "MEPhI" (Moscow Engineering Physics Institute), Moscow, 115409, Russia*

[b] *Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Center "Kurchatov Institute", Moscow, 117218, Russia*

[c] *Joint Institute for Nuclear Research, Dubna, Moscow region, 141980, Russia*

[d] *National Research Center "Kurchatov Institute", Moscow, 123098, Russia*

[e] *Moscow Institute of Physics and Technology (State University), Moscow, 117303, Russia*

[f] *University of Tennessee, Knoxville, TN 37996-1200, USA*

[g] *Institute for Nuclear Research, Moscow, 117312, Russia*

The main goal of the RED experiment is to detect CEνNS at NPP

CEνNS

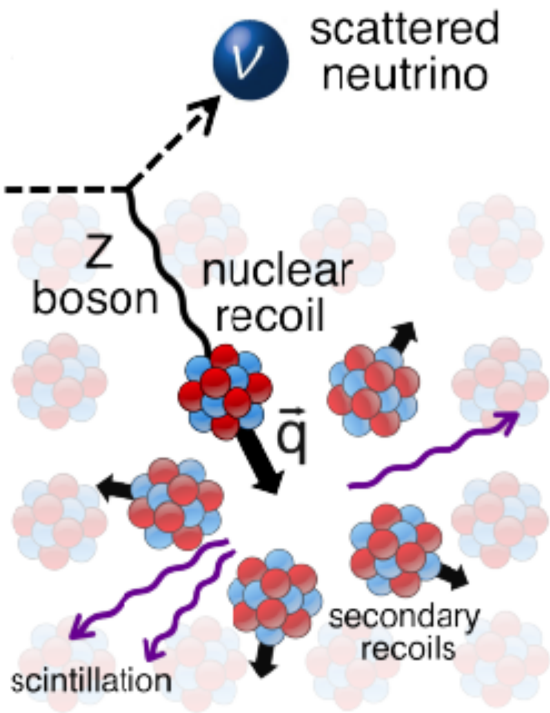
A coherent elastic neutrino-nucleus scattering (CEνNS): $\nu + A \rightarrow \nu' + A'$

It was predicted theoretically 45 y ago:

D.Z. Freedman, Coherent effects of a weak neutral current, Phys. Rev. D 9 (1974) 1389

As well, Kopeliovich V B, Frankfurt L L JETP Lett. 19 145 (1974); Pis'ma Zh. Eksp. Teor. Fiz. 19 236 (1974)

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

$E_\nu \lesssim 50$ MeV

CEνNS cross-section

$$\frac{d\sigma}{dT}_{coh} = \frac{G_F^2}{4\pi} M Q_W^2 \left(1 - \frac{MT}{2E_\nu^2}\right) F_{\rm nucl}^2(Q^2)$$

where $F_{\rm nucl}(Q^2)$ – nuclear form factor (FF), E_ν – neutrino energy, T – nucl. recoil energy

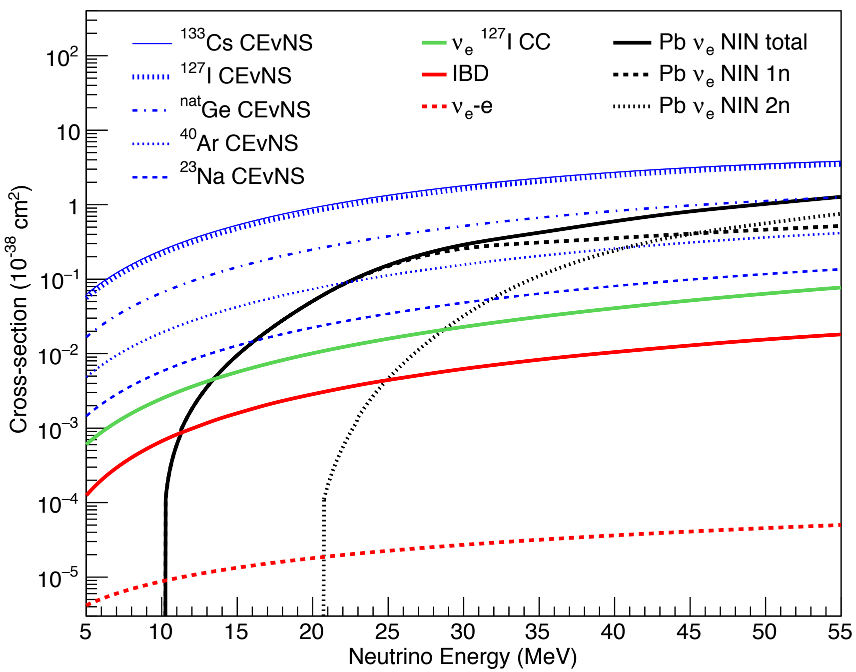
$$Q_W = [Z(1-4\sin^2\theta_W) - N] \approx N,$$

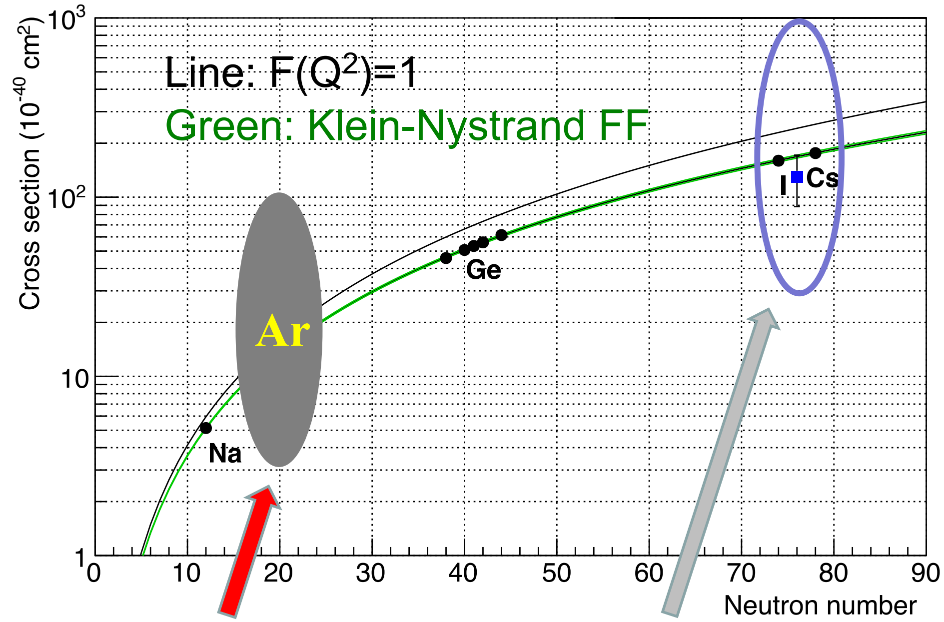
weak nucl. charge

Z – protons, N - neutrons

Θ_W – Weinberg angle

$\sin^2\Theta_W \sim 0.25$ ⇒ $\sigma \sim N^2$.





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

1-st proposal: A. Drukier, L. Stodolsky Phys. Rev. D 30 2295 (1984)
detector based metastable superconducting grains for solar neutrino and other applications

At a reactor:

Ge detectors: CoGeNT, TEXONO, νGeN , CONUS
Low-temp. bolometers: RICOCHET, MINER, ν-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:

taking data **LAr, Ge, CsI [Na]** **Data taking completed**

at LANSCE-Lujan Facility: Coherent CAPTAIN-Mills
Commissioning Dec 2019

Liquid noble gas detectors

In Dark Matter search experiments, the progress of setting limits has increased significantly when liquid noble gas detectors (two-phase) started operation

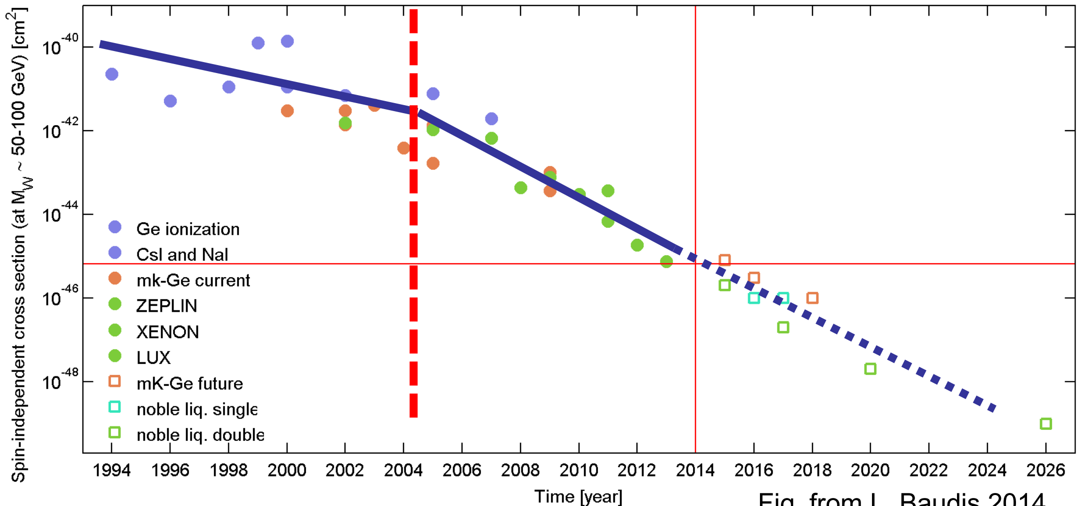
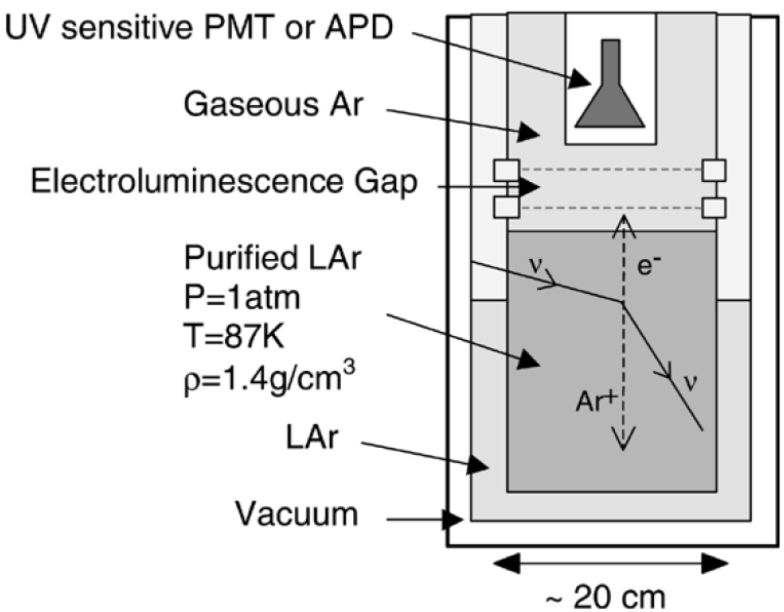


Fig. from L. Baudis 2014

1st proposal (in 2004); LAr detector



C. Hagmann and A. Bernstein,
Two-Phase Emission Detector for Measuring Coherent Neutrino-Nucleus Scattering
IEEE Trans.Nucl.Sci. 51 (2004) 2151

Two-phase emission detection technique

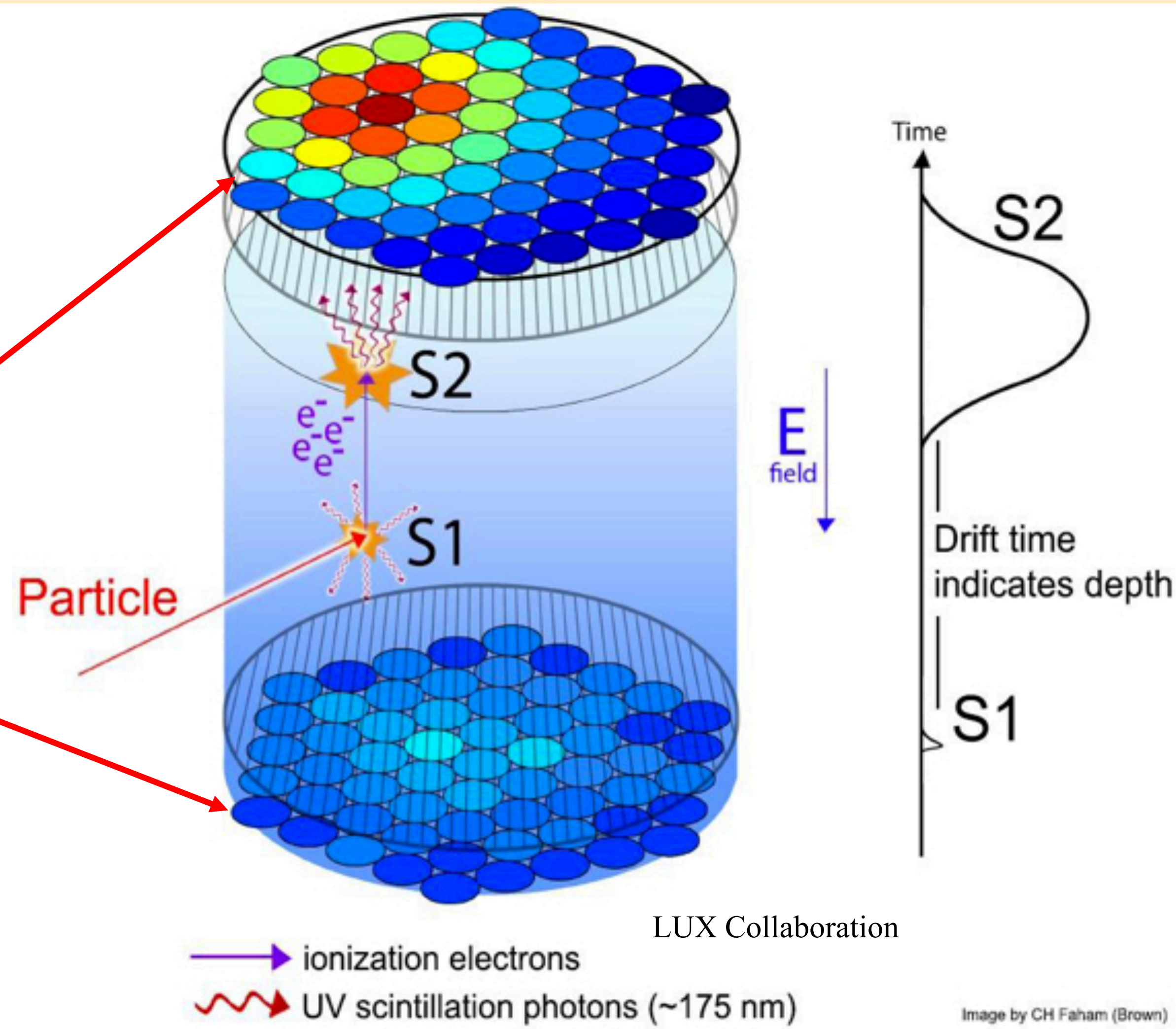
is very suitable for CEνNS study

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

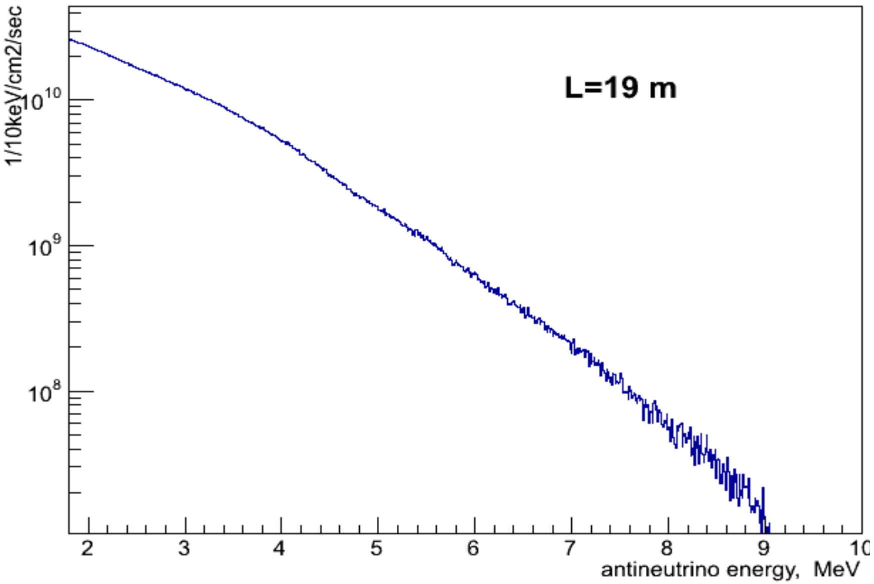
(photomultipliers)



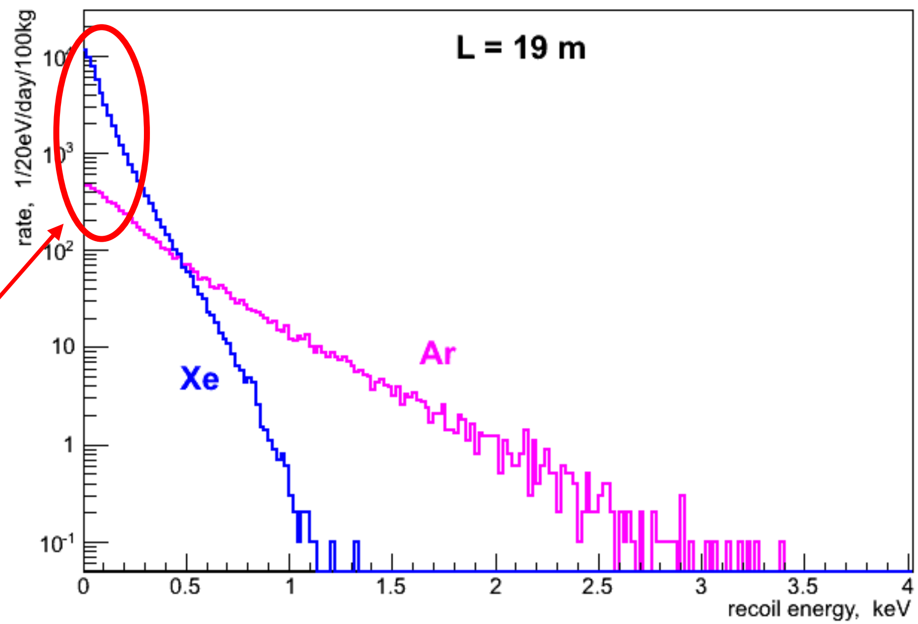
LUX Collaboration

Energy spectra

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



Xe and Ar nuclear recoil spectra



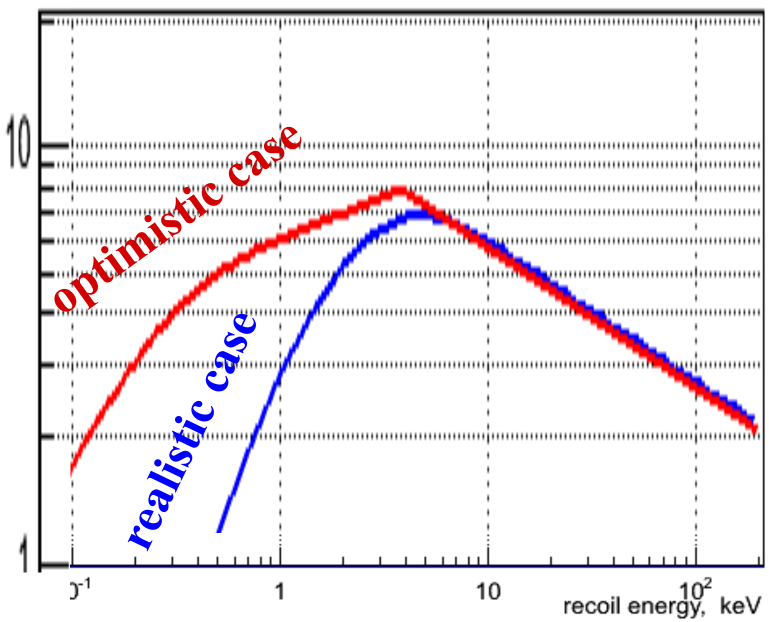
region of few ionisation electrons

This is very challenging task, but feasible!

Ionization yield for sub-keV nuclear recoils

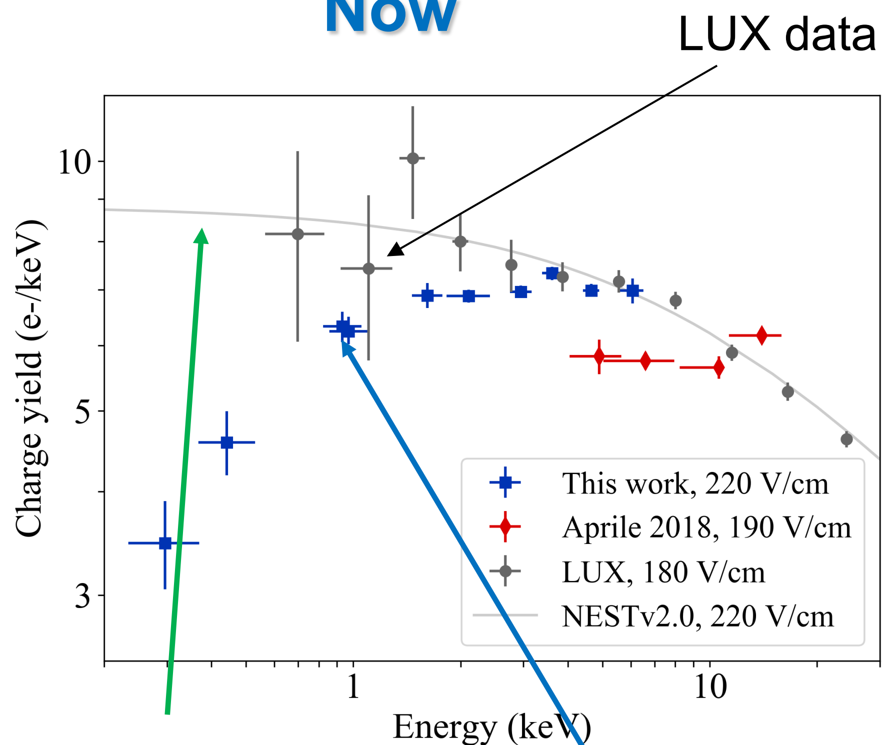
7 years ago

There were no data < 4 keV_{nr}



We considered
"optimistic" and "realistic" scenarios

Now



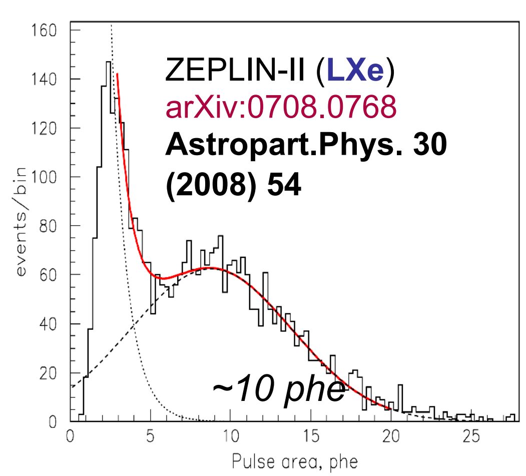
NEST – Noble Element Simulation Technique

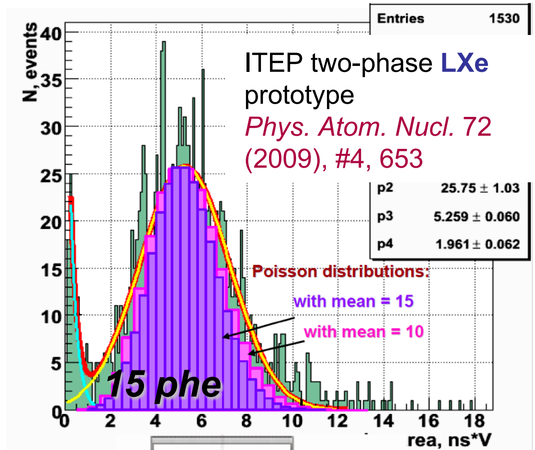
New data by LLNL

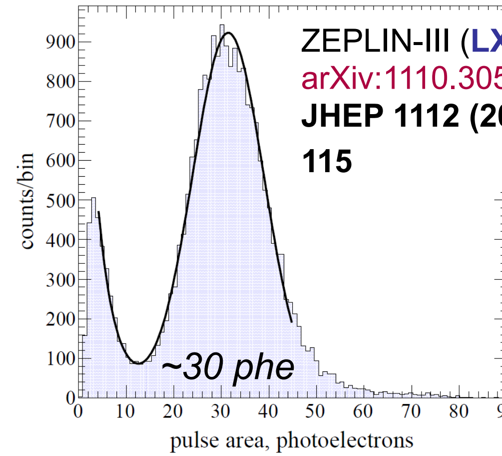
arXiv:1908.00518

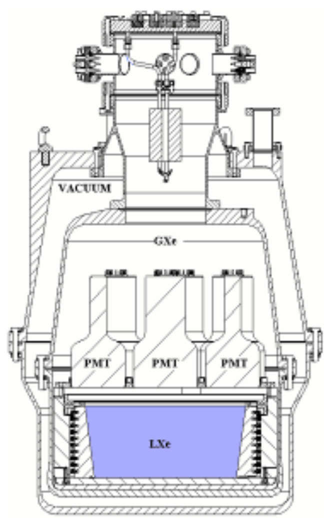
Single electron detection

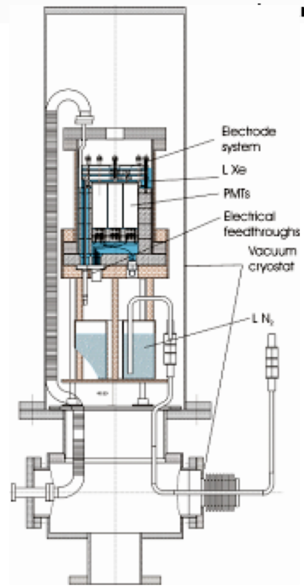
Projects for CEvNS with LXe two-phase detectors appeared after the capability to detect single ionization electrons (**SE**) was demonstrated:

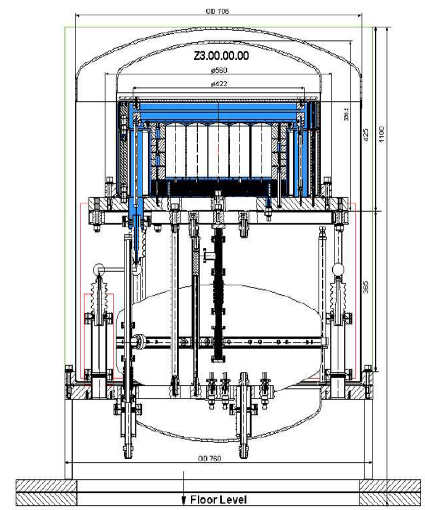












Proposals on CEvNS detection:

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

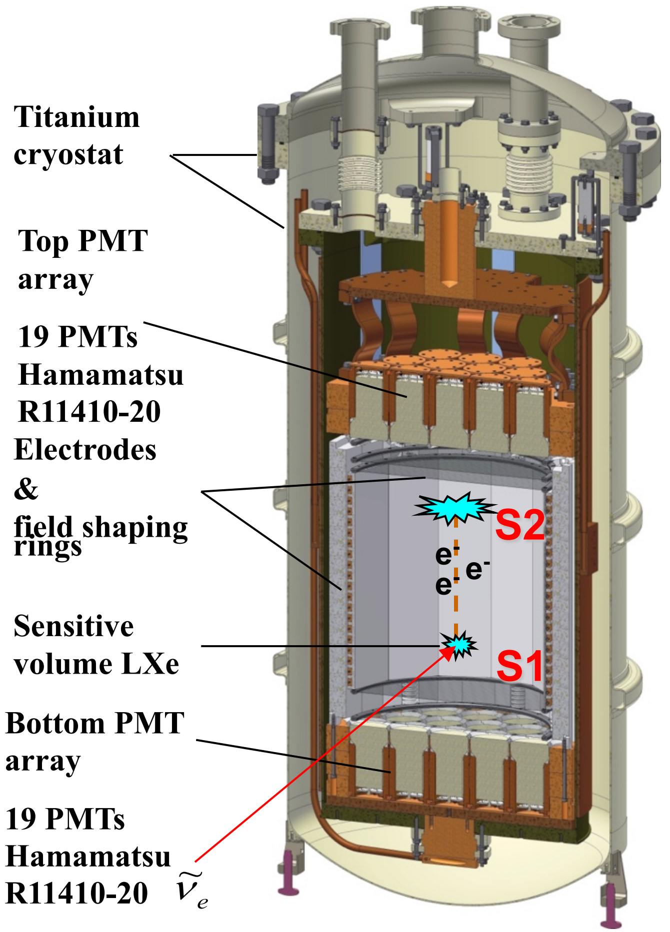
ZEPLIN-III Collaboration LXe:
JHEP 1112 (2011) 115 [arXiv:1110.3056].

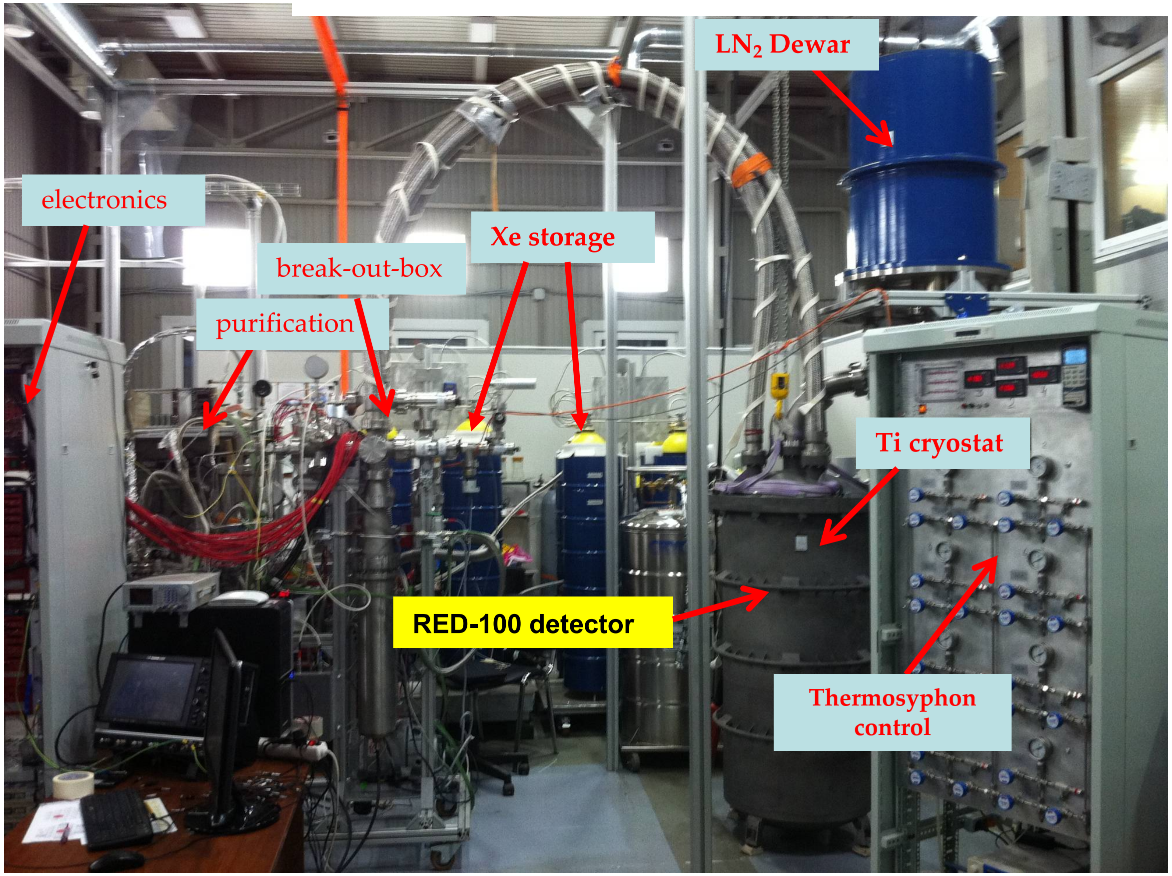
The RED-100: the laboratory tests are under way in MEPhI

RED-100 is a two-phase noble gas emission detector.

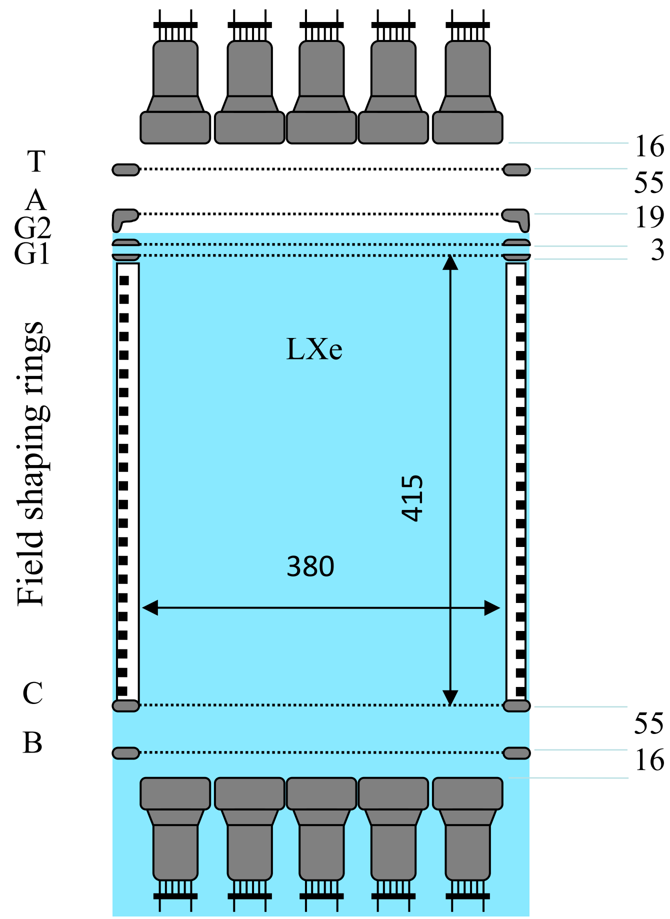
Contains ~200 kg of LXe, ~160 kg in sens. volume, ~100 kg in FV.

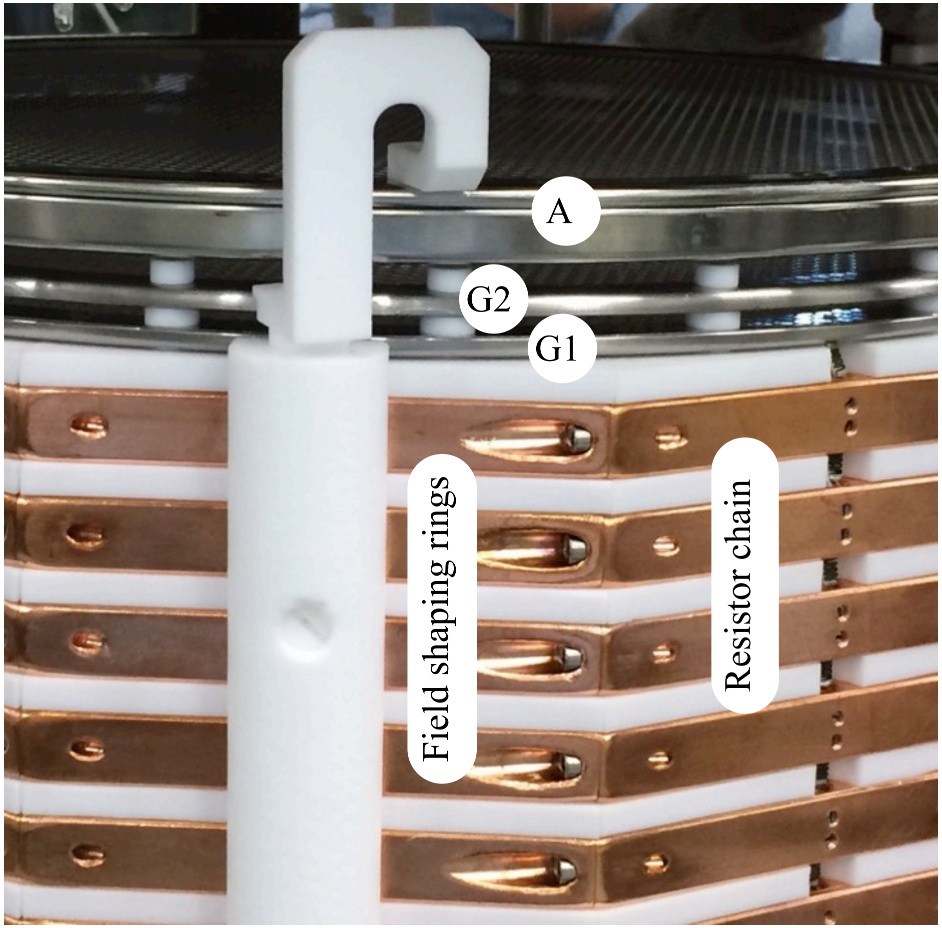
The sensitive volume 38 cm in diam., 41 cm in height, is defined by the top and bottom optically transparent mesh electrodes and field-shaping rings.





Schematic layout of grids and PMTs

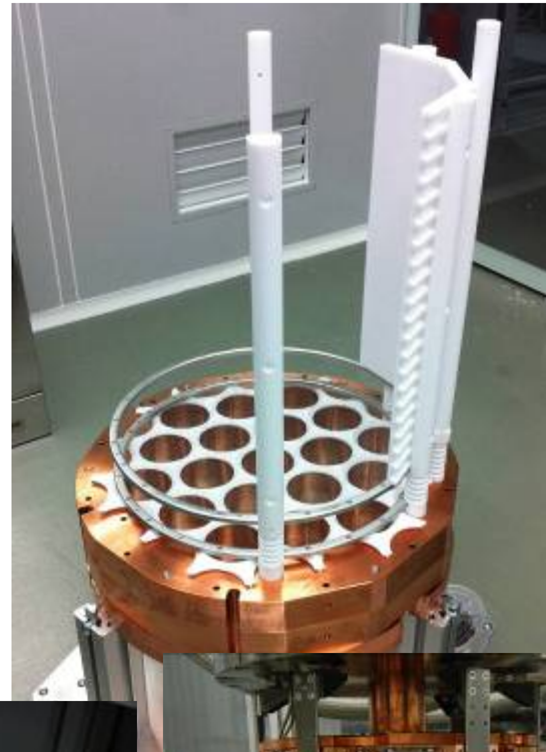
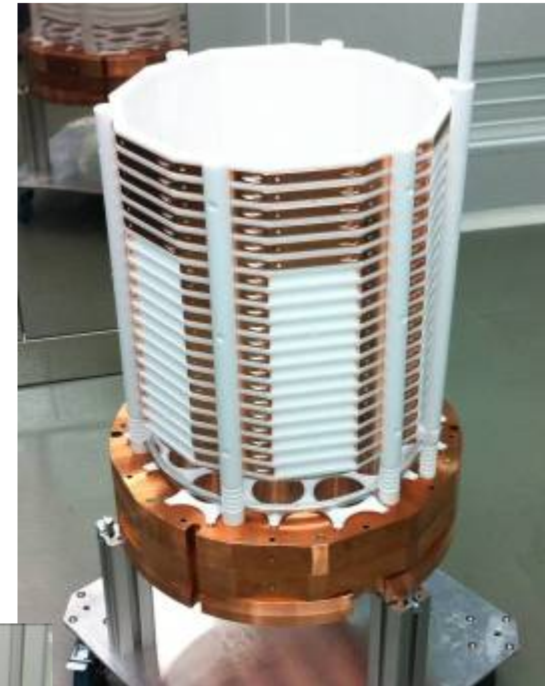




Sizes of the drift volume and distances between grids are in mm.

T and B – top and bottom grounded grids,
A – anode grid,
G1 – electron shutter grid,
G2 – extraction grid,
C – cathode grid

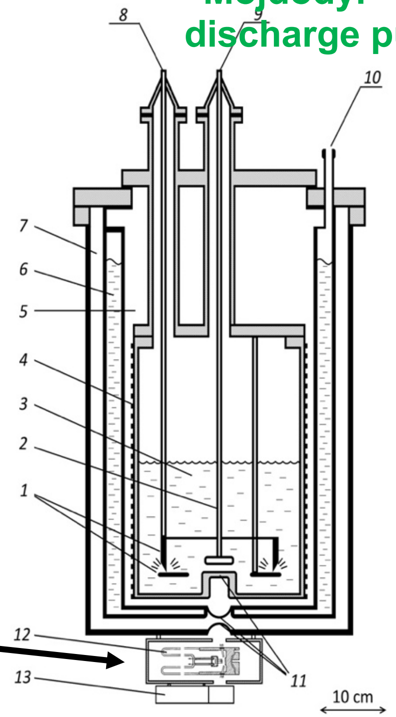
RED-100 detector assembling

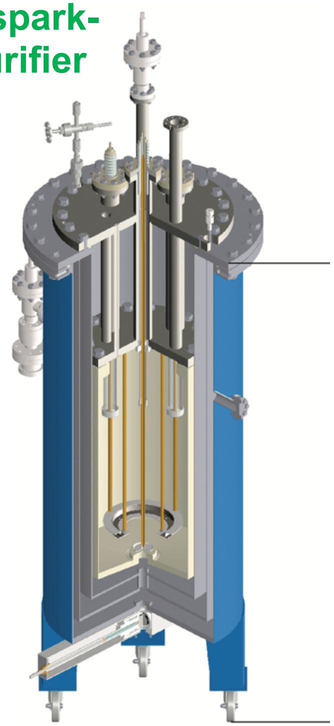





RED-100 performance: LXe purity

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

"Mojdodyr" spark-discharge purifier





X-ray tube as a source of ionization electrons for e- lifetime measurements

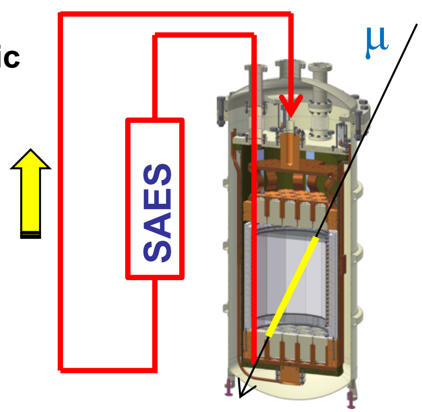
Xenon was contaminated by highly-electronegative impurities presumably due to the use of a special fluorine-containing high-molecular-weight lubricant in gas centrifuges.

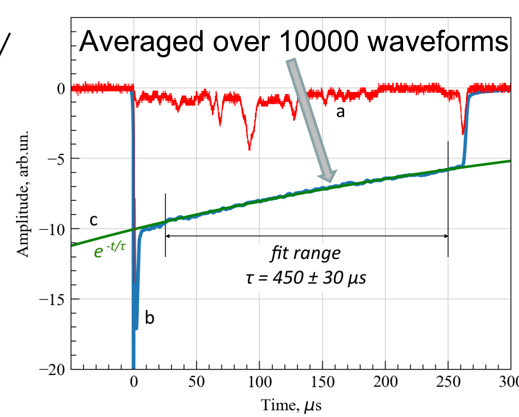
After purification, the achieved lifetime ≳ 50 μs for ~200 kg of LXe

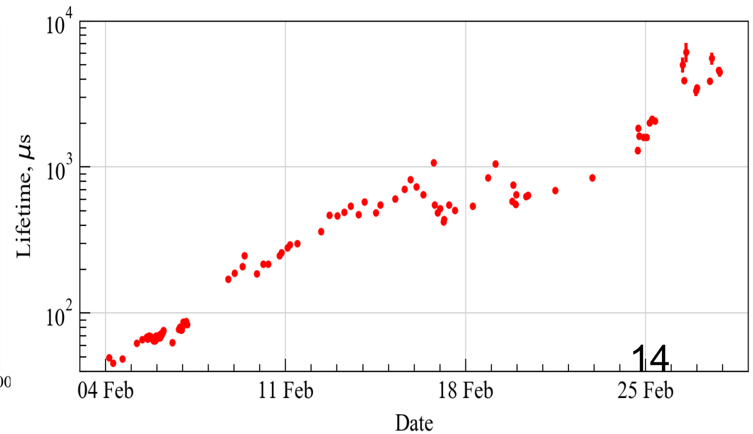
2d stage: Purification was performed by continues circulation of Xe through RED-100 and SAES

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

Average energy deposition from cosmic muons is practically uniform



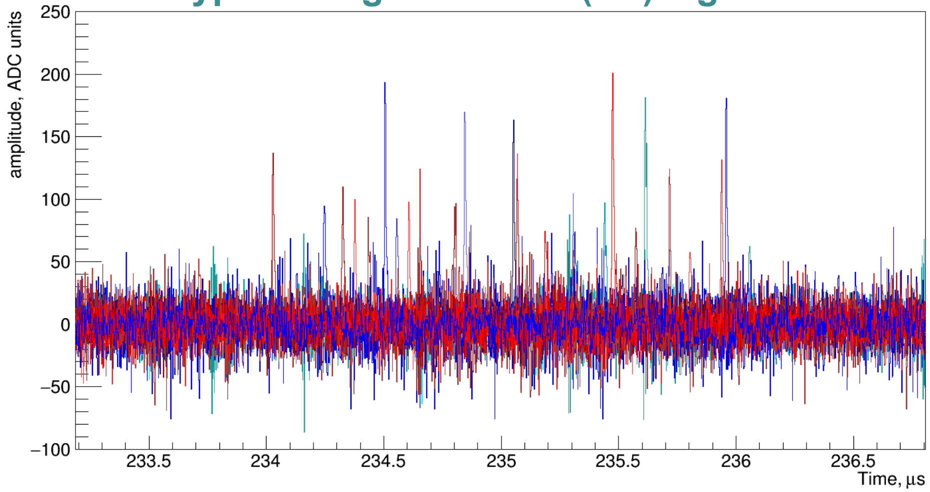


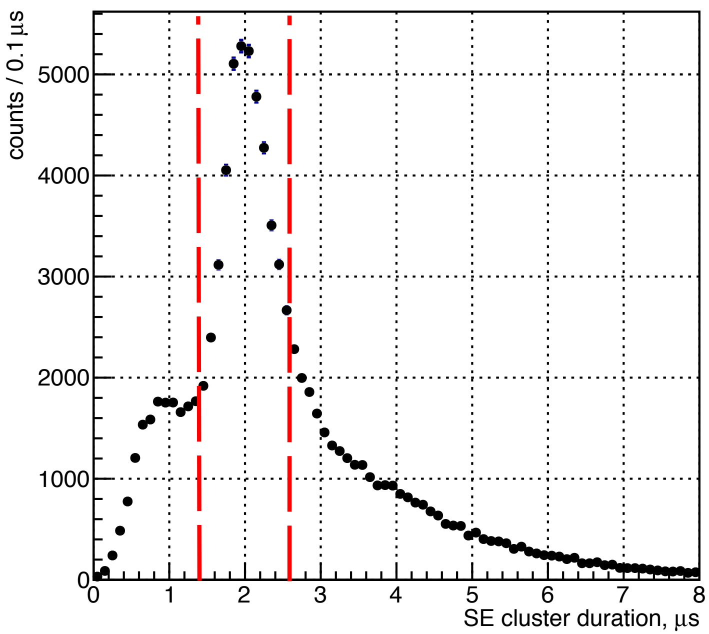


RED-100 performance: SE

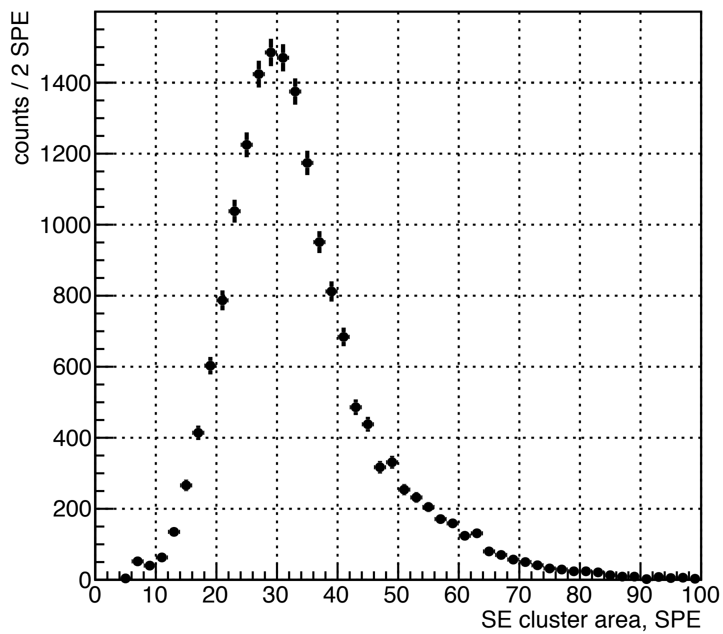
SE is a cluster of individual SPEs (single photo electrons) with a typical duration of ~ 2 μs

Typical single electron (SE) signal





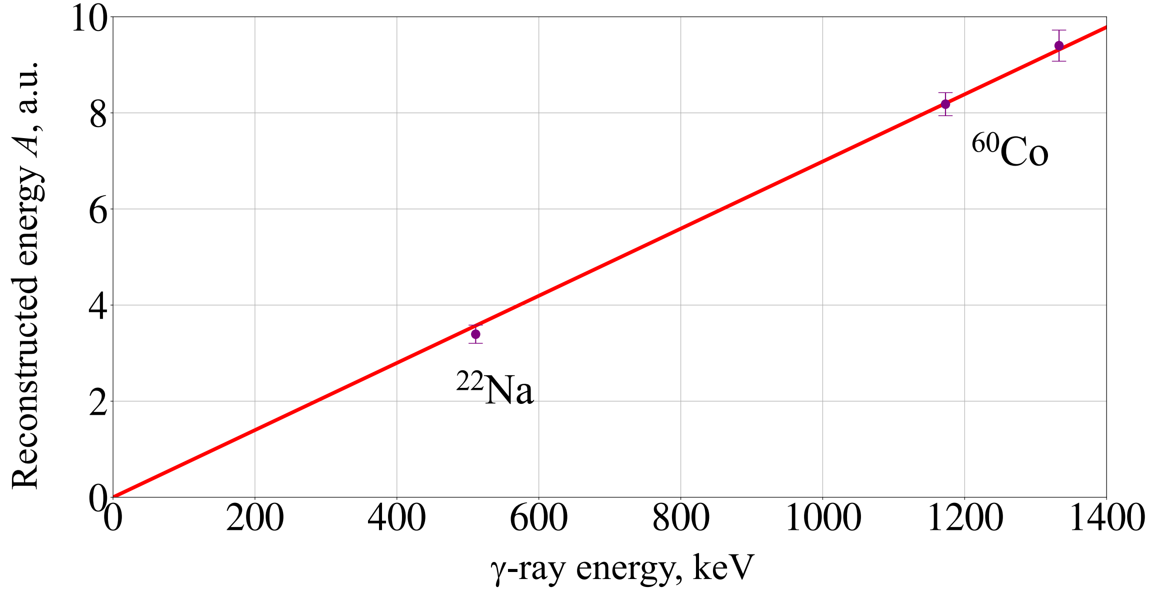
Distribution of SE duration



Distribution of SE area

RED-100 performance

Gamma- calibration



Electron extraction efficiency (EEE)

From S2 distribution ONLY,

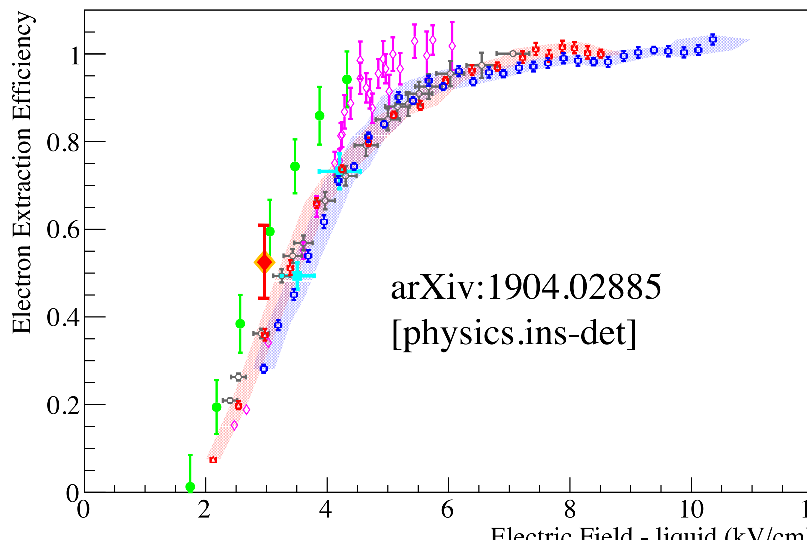
N_{SE} = ^{22}Na peak pos. area / SE area

N_E – from NEST @ E_{dr} = 0.217 kV/cm

N^*_E – correct ed for electron lifetime

EEE = N_{SE} / N^*_E = 0.54 ± 0.08

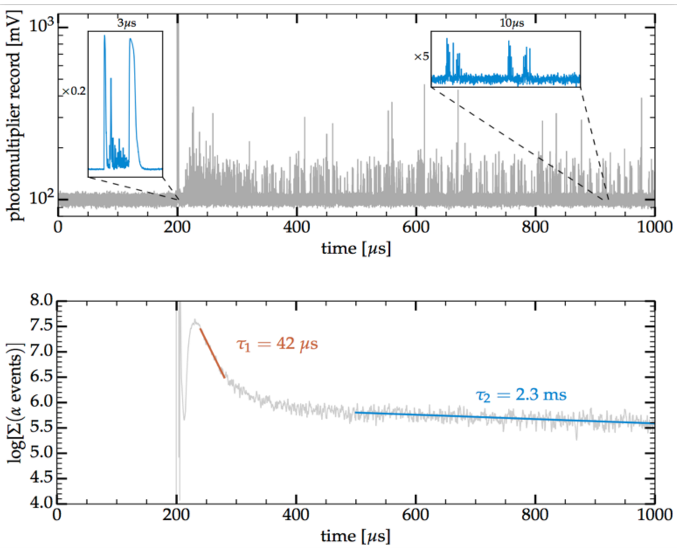
@ E_{extr} = 3.0 ± 0.1 kV/cm



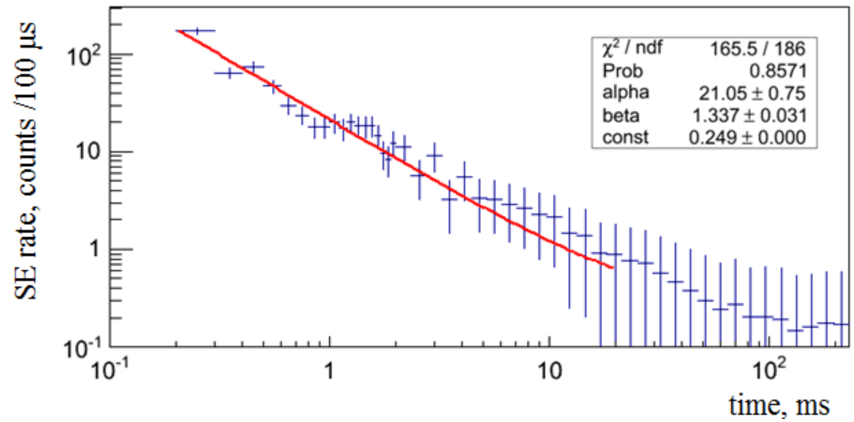
RED-100 performance: "spontaneous" SE

Observed in ZEPLIN-III:
JHEP 1112 (2011) 115, arXiv:1110.3056 [physics.ins-det]
The rate is proportional to the total charge rate in the detector

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



JINST 11 (2016) no.03, C03007

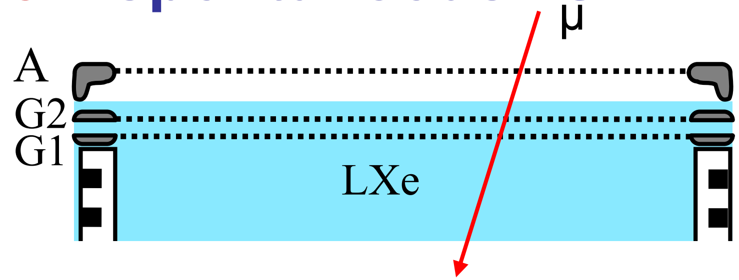


"Spontaneous" SE noise is caused by overlapping of the SE tails of the energetic events (mostly muons).

Two components:
1st – short, but more intense, caused by emission of the electrons trapped at LXe surface.
2d – 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

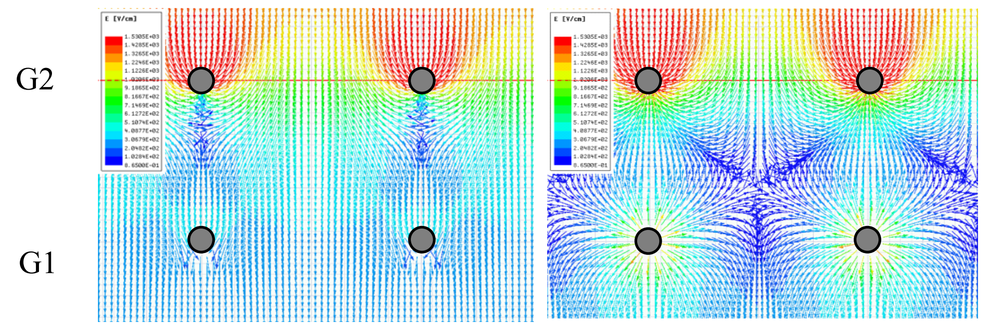
To minimize the 1st component, an electron shutter is introduced (G2 – G1).



Positive pulse (~300 V millisec. 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.

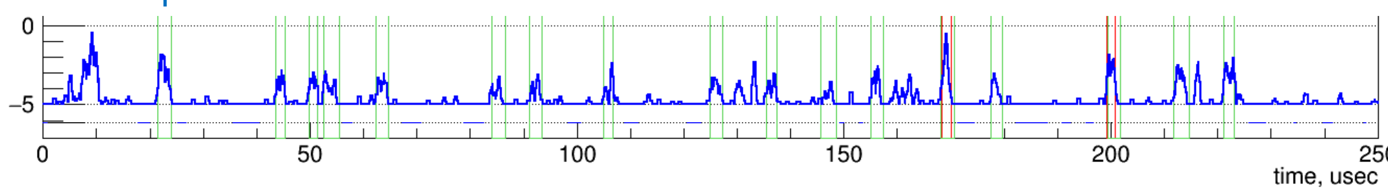


open: $U_{G2} - U_{G1} = 50$ V closed: $U_{G2} - U_{G1} = -250$ V

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

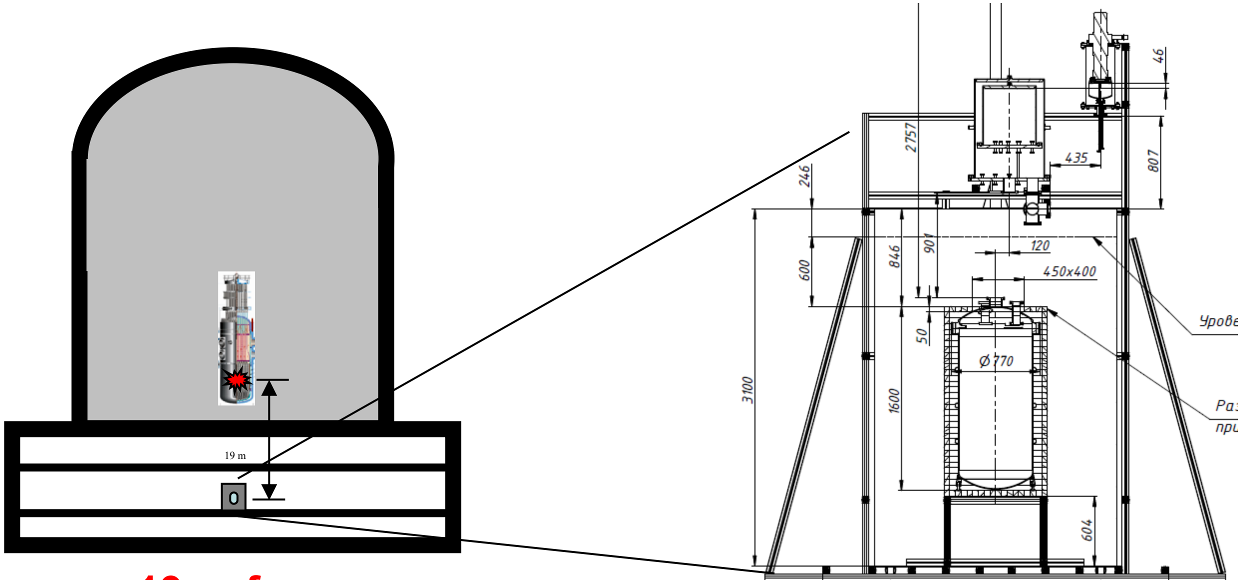
However, the "spontaneous" SE rate is quite high: ~ 250 kHz in our ground-level lab. (no overburden, no shielding)

Example of waveform:



At the site of KNNP (Kalinin Nuclear Power Plant), it will be reduced by a factor of ~5

RED-100 at KNPP



19 m from core

Antineutrino flux at this place - $1.35 \cdot 10^{13}$ $cm^{-2}s^{-1}$

γ and n shield:
5 cm Cu + ~60 cm H_2O

KNPP – Kalinin Nuclear Power Plant

Neutron flux

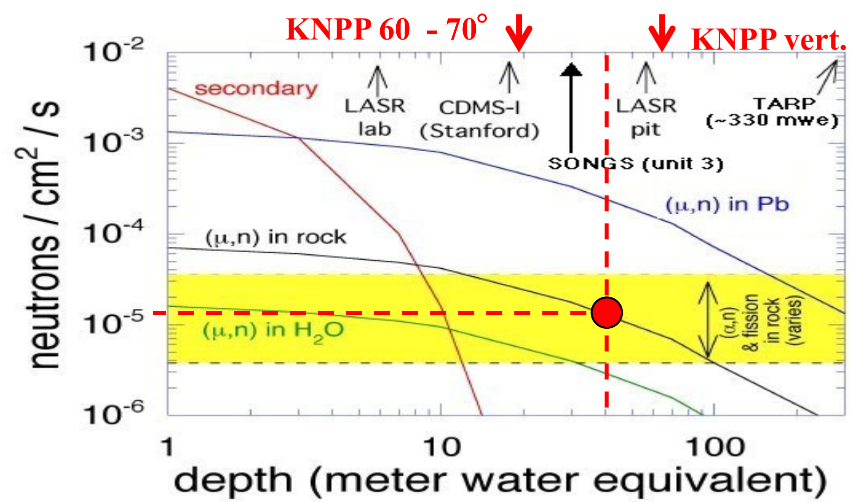
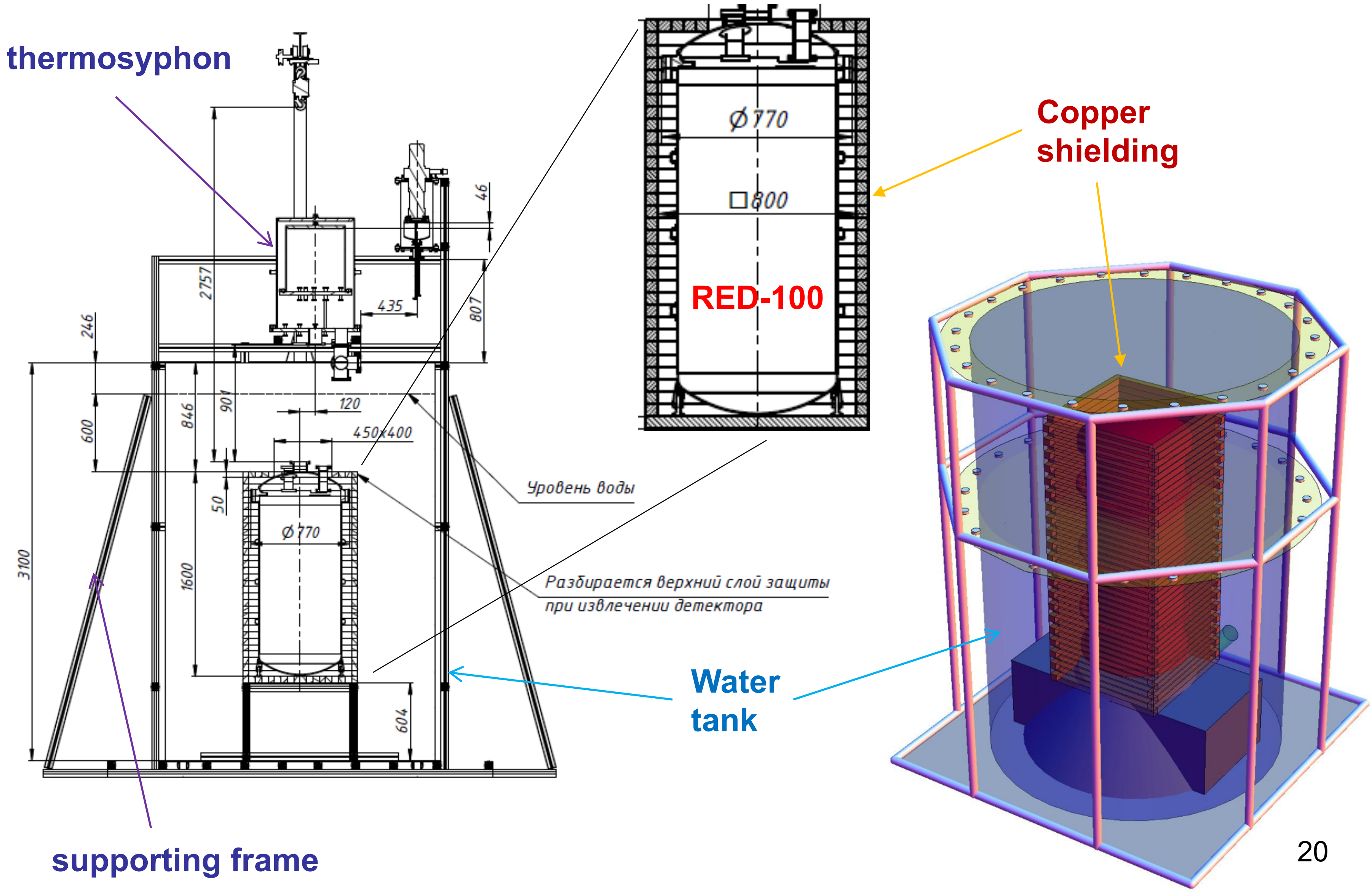
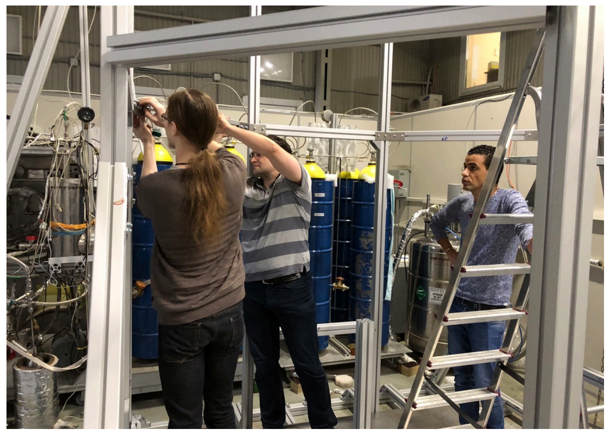
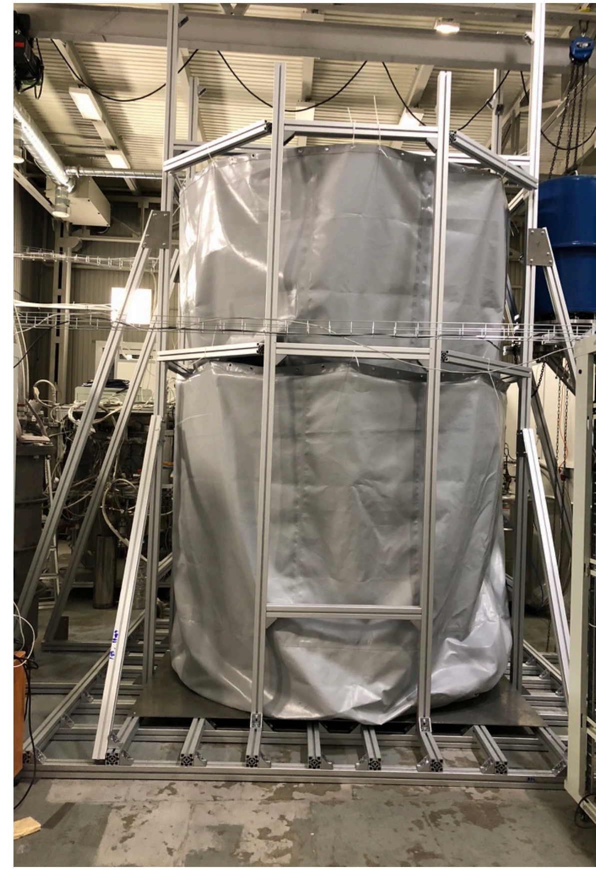


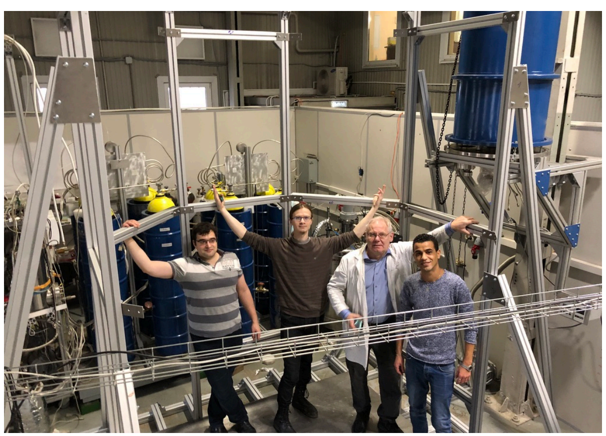
Image by J.I. Collar

RED-100 in passive shielding









Assembling the whole setup is currently in progress in MEPhI lab.

Estimation of CEνNS count rate at KNPP

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

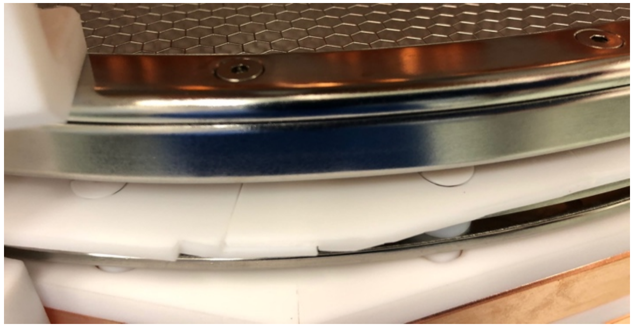
Taken into account:

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

ME value in electrons	Estimated ME background at KNPP, events/160kg/day		Expected CEνNS count rate at KNPP, events/160kg/day	
	no cut	point-like	no cut	point-like
2	$5.3\cdot10^7$	$1.8\cdot10^7$	465	283
3	$4.4\cdot10^5$	$0.9\cdot10^5$	129	79
4	$2.7\cdot10^3$	348	35.5	21.7
5	13.7	1.1	10.6	6.4
6	$5.7\cdot10^{-2}$	$3.0\cdot10^{-3}$	1.9	1.2

We can detect CEνNS with threshold of ~ 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

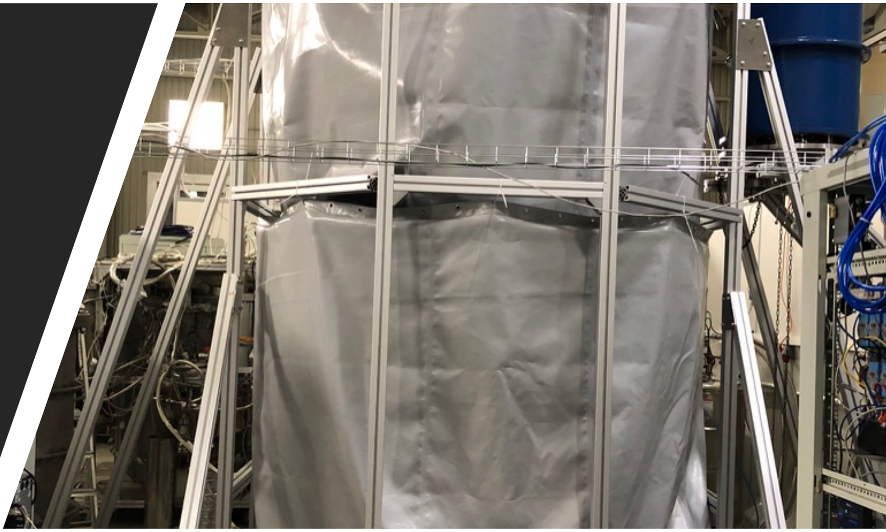
2 To introduce smart blocking for the muon events: the higher muon deposited energy, the longer blocking time of the shutter (up to several hundred ms)

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

4 To improve algorithm of of point-like events selection

TIMELINE

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

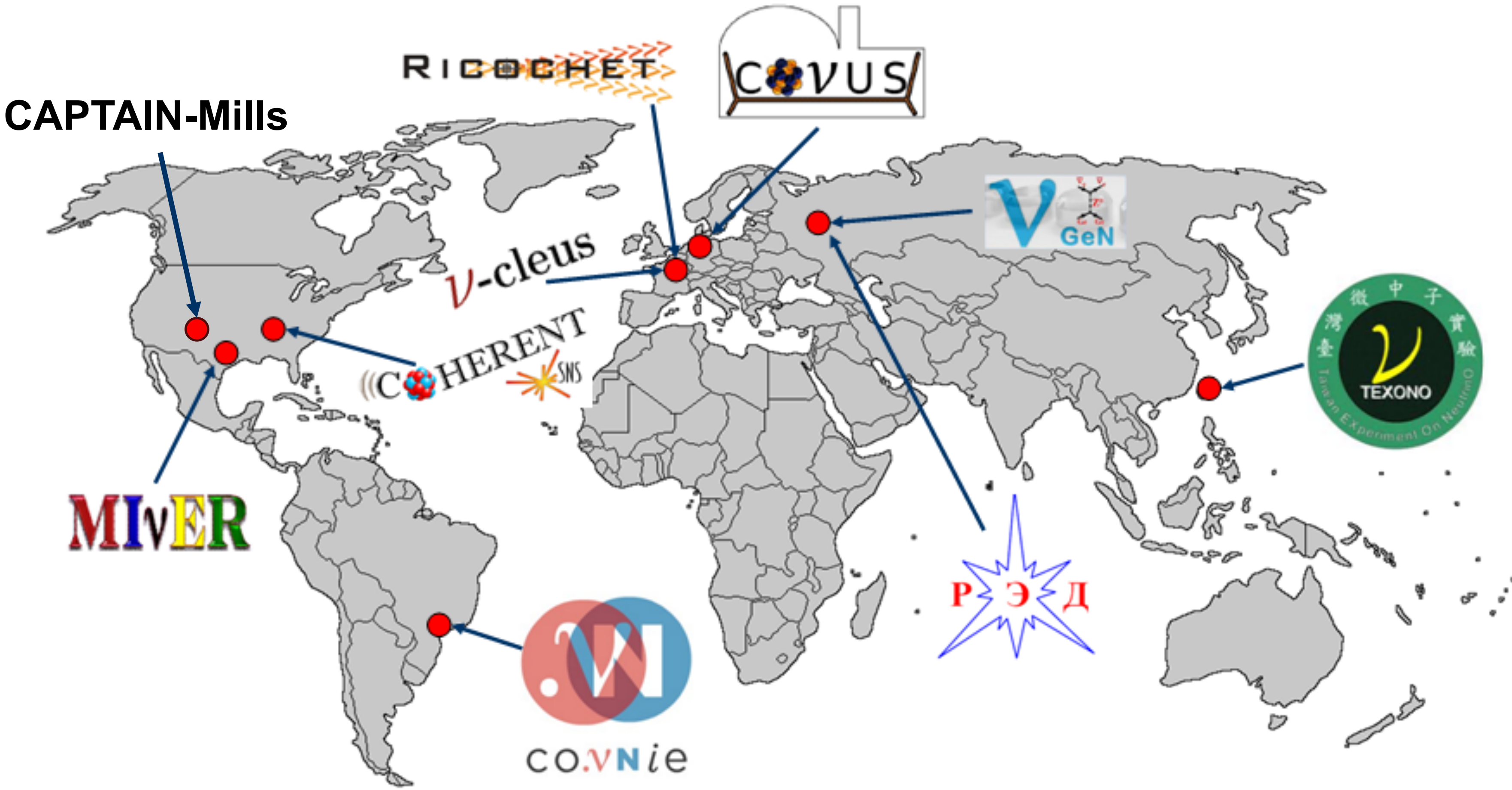
The results of the first lab. test : 2020_JINST_15_P02020

NEW COLLABORATORS ARE WELCOME !

THANK YOU FOR ATTENTION !

Backup slides

Worldwide CEνNS map

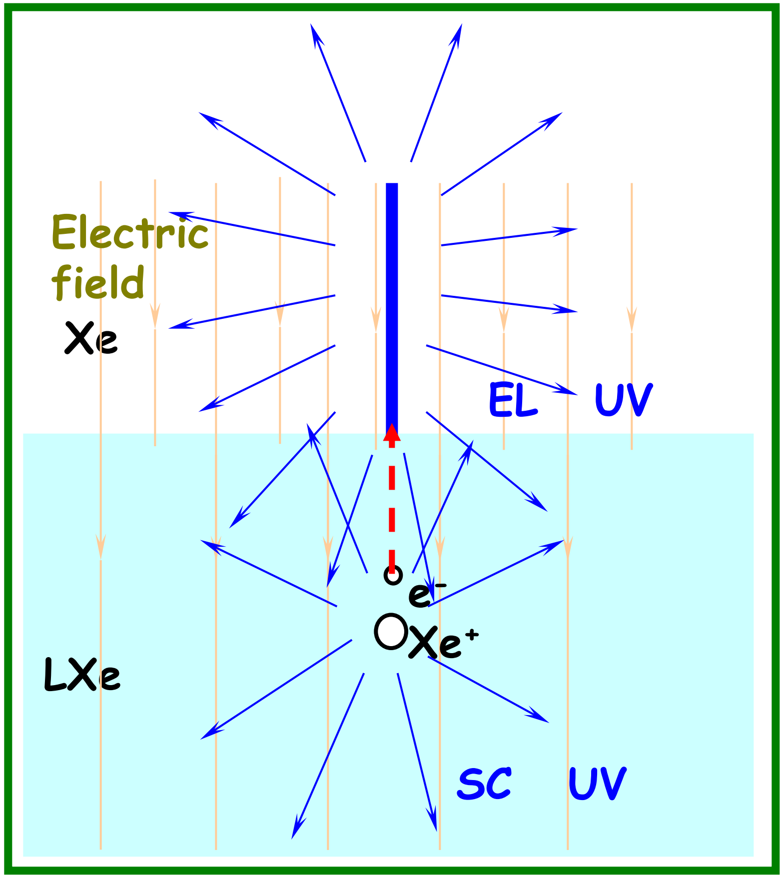


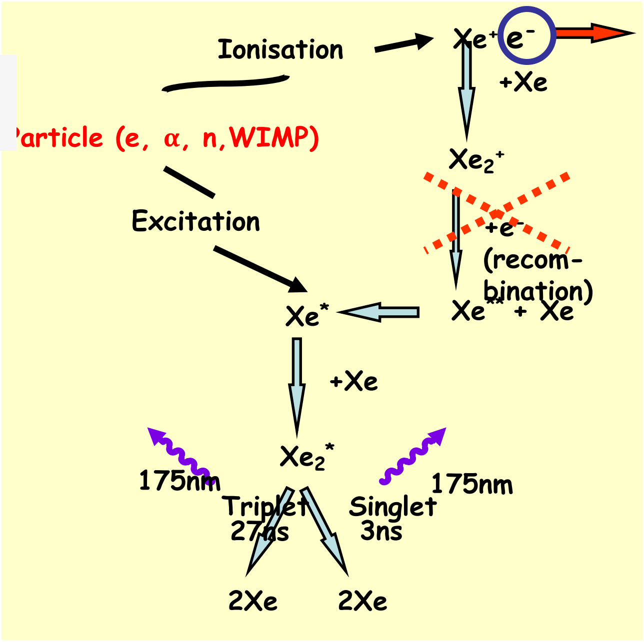
Two-phase detector

Detection principle

B.A. Dolgoshein, V.N. Lebedenko, B.U. Rodionov, JETF Letters (in Russian), 1970, v. 11, p. 513

For the Dark Matter search:
A.S. Barabash and A.I. Bolozdynya, JETF Letters (in Russian), 1989, v.49, p. 359





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