The RED-100 status update

V.Belov

(on behalf of RED collaboration)

ITEP & MEPhI

The Magnificent CEvNS workshop, Nov 9-11, 2019

CEvNS

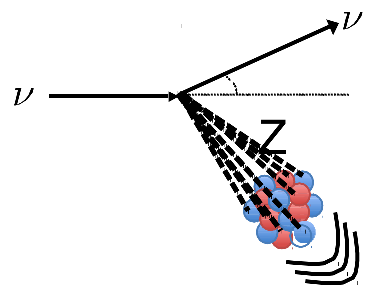
A coherent elastic neutrino-nucleus scattering (CEνNS): $\nu + A \rightarrow \nu' + A'$

It was predicted theoretically 40 years ago:

D.Z. Freedman, D.N. Schramm, and D.L. Tubbs.
Ann. Rev. Nucl. Part. Sci. 27, 167 (1977)

Also see:

Kopeliovich V.B., Frankfurt L.L., JETP Lett. 19 145 (1974)



Only recently it was observed experimentally because of the very low energy transfer

D.Yu. Akimov et al., Science 357 no.6356, 1123-1126 (2017)

A neutrino interacts via exchange of Z with a nucleus as a whole, coherently up to E_ν~ 50 MeV

A general behaviour is $\sigma \sim N^2$

For Xenon $\sigma \approx 7 \cdot 10^{-41}$ cm^2 averaged over energy spectrum of reactor antineutrinos: 0 – 10 MeV

Proposals and experiments worldwide

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 (LAr, Ge, CsI(Na))

Taking data (LAr)

Data taking completed (CsI(Na))

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

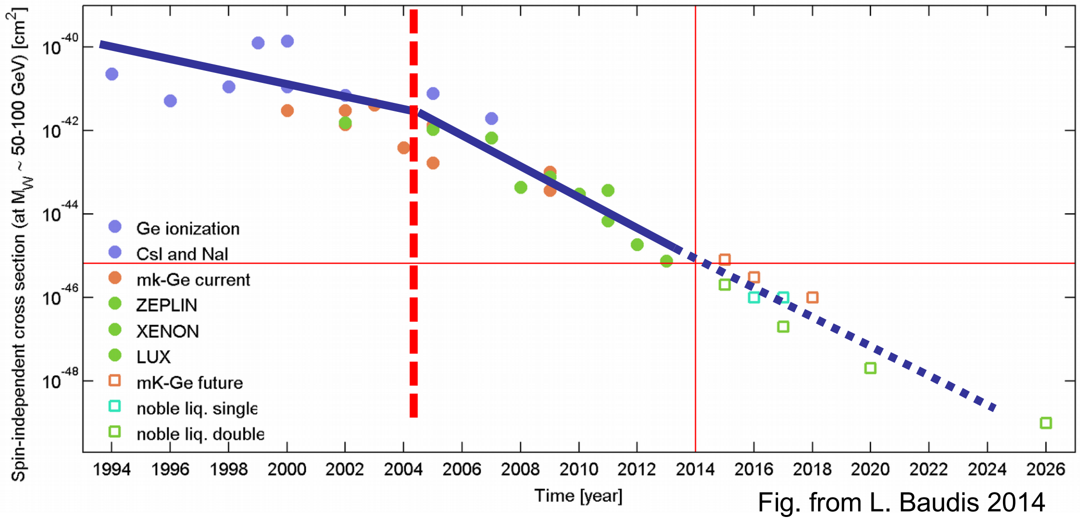
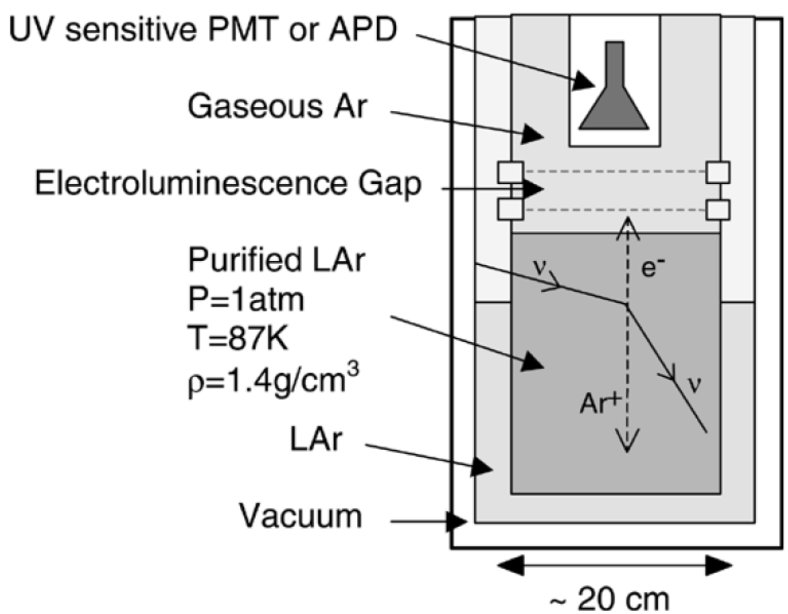


Fig. from L. Baudis 2014

1st proposal (in 2004); LAr detector



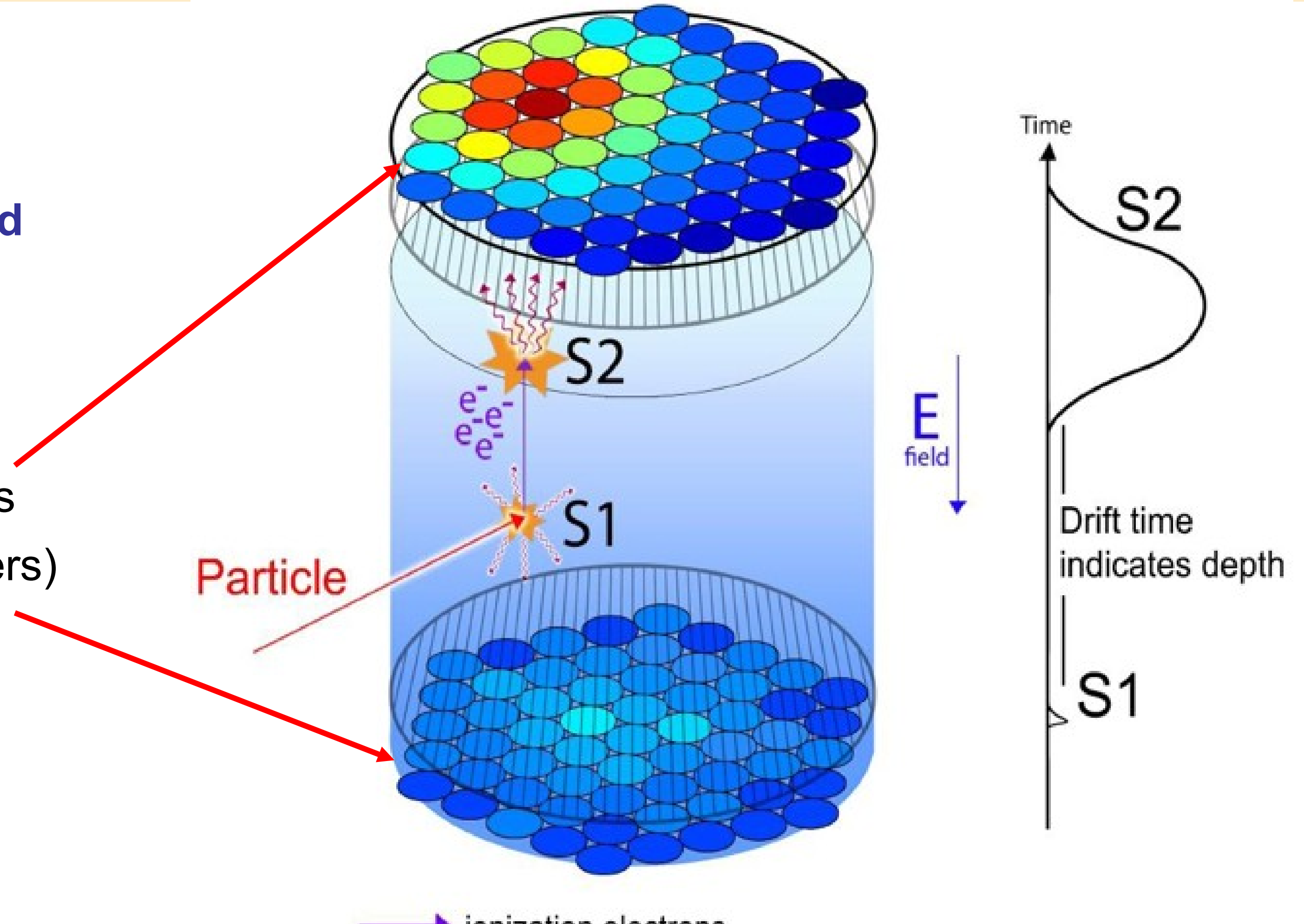
C. Hagmann and A. Bernstein, **Two-Phase Emission Detector for Measuring Coherent Neutrino-Nucleus Scattering**
IEEE Trans.Nucl.Sci. 51 (2004) 2151

Two-phase emission detector

It combines the advantages of gas detectors: the proportional amplification regime for EL, 3D reconstruction, and the possibility to have the large mass!

This method was proposed at MEPhI in 1970s!

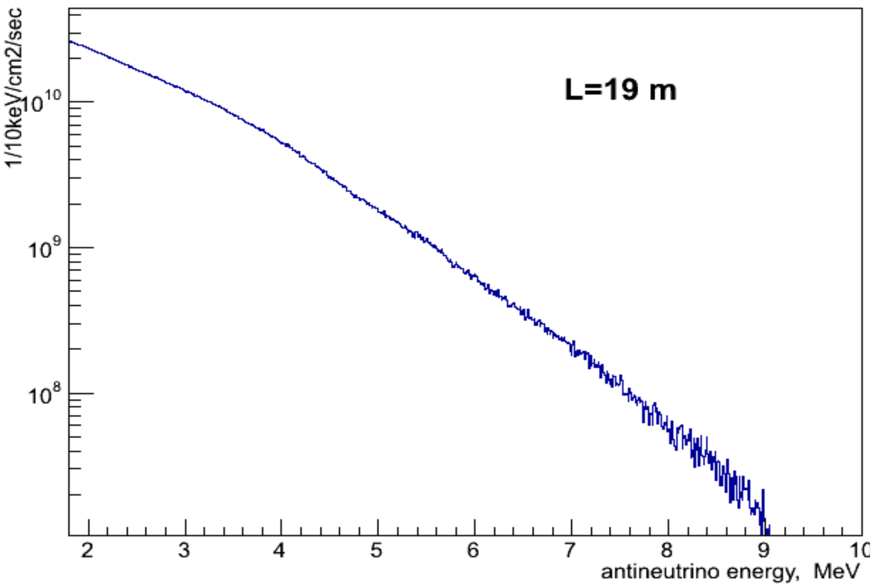
Photodetectors
(photomultipliers)



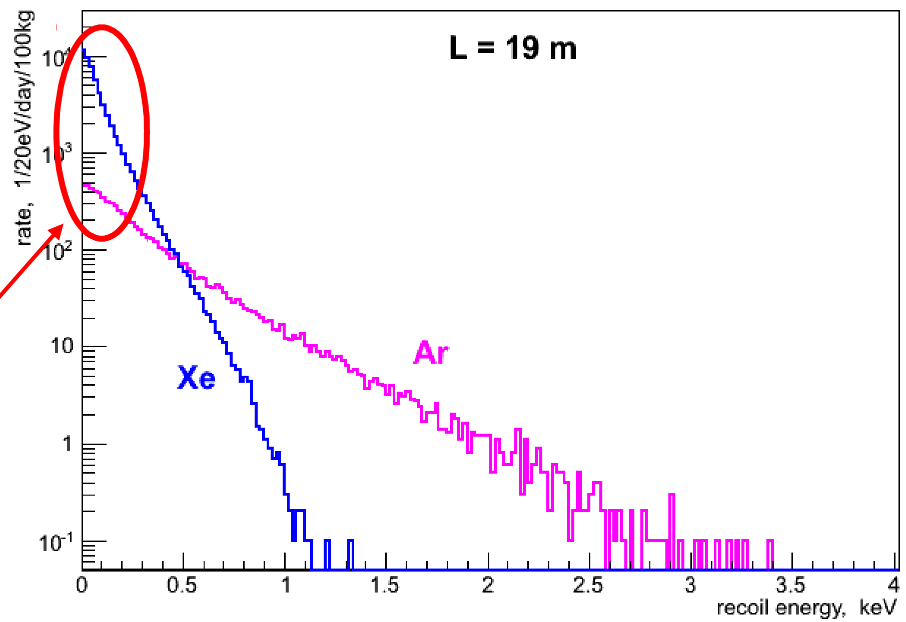
LUX Collaboration
Image by CH Faham (Brown)

Signal energy region

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



Xe and Ar nuclear recoil spectra



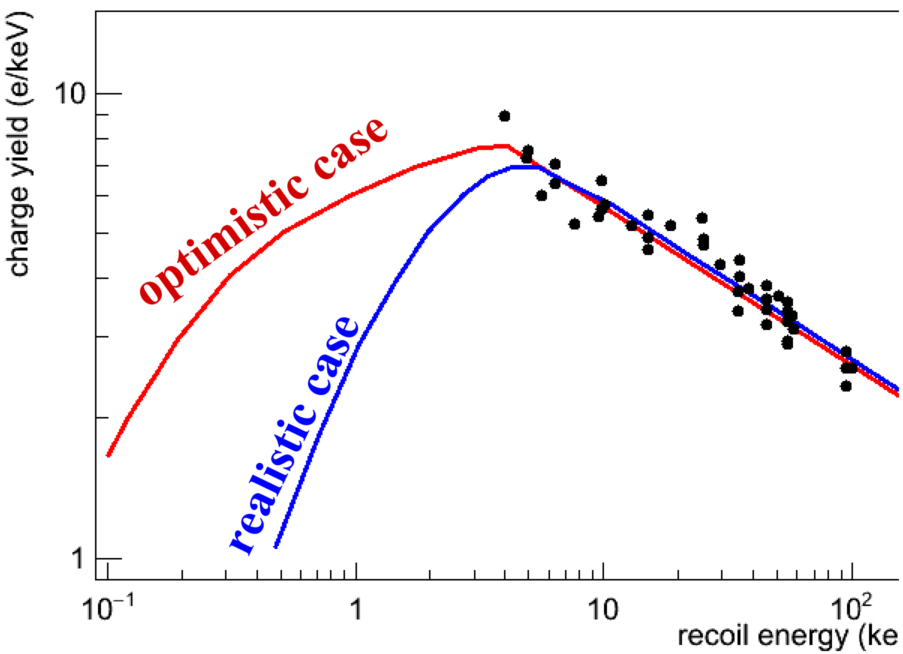
region of few ionisation electrons

This is very challenging task, but feasible!

Ionization yield for sub-keV nuclear recoils

7 years ago

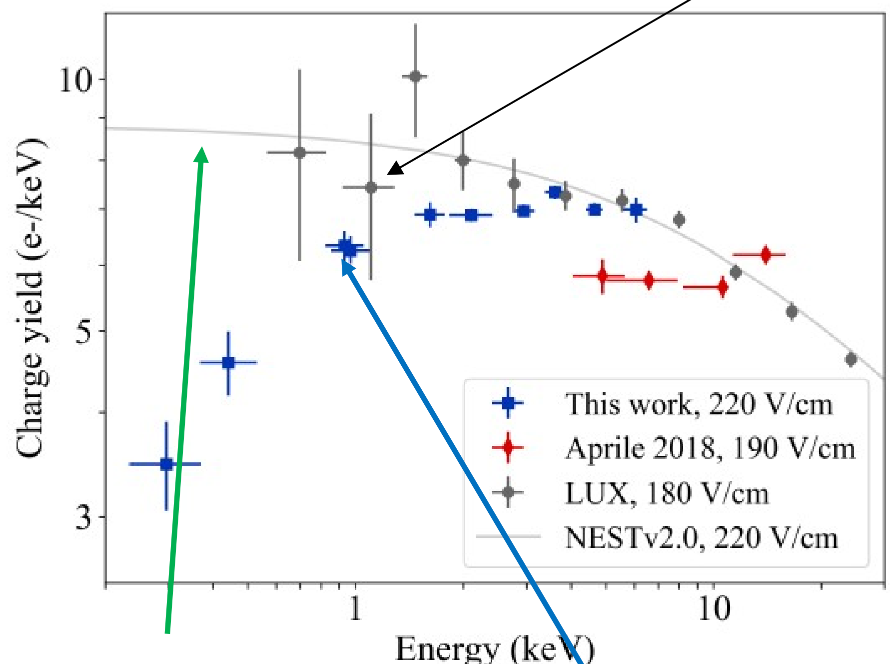
There were no data < 4 keV$_{nr}$



We concidered
"optimistic" and "realistic" scenarios

Now

LUX data

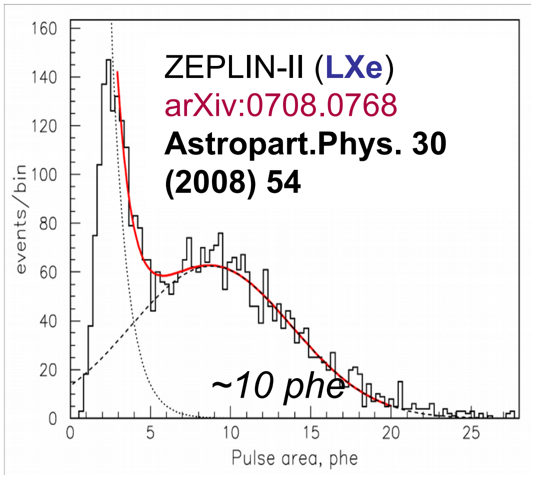


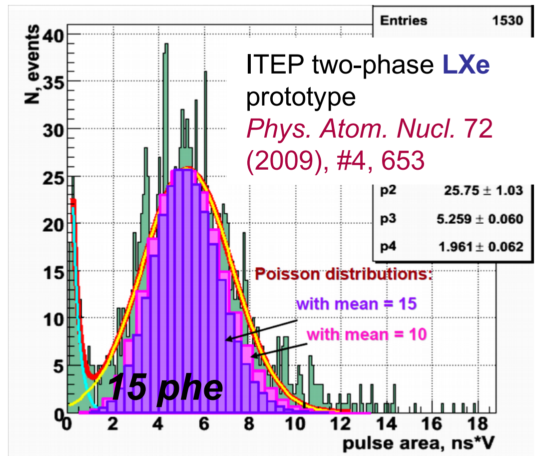
NEST – Noble Element Simulation Technique

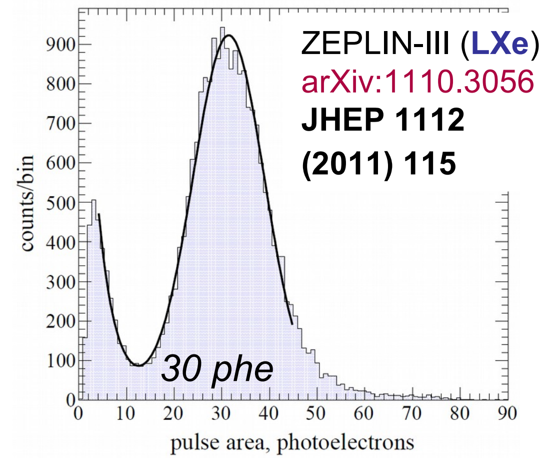
New data by LLNL arXiv:1908.00518

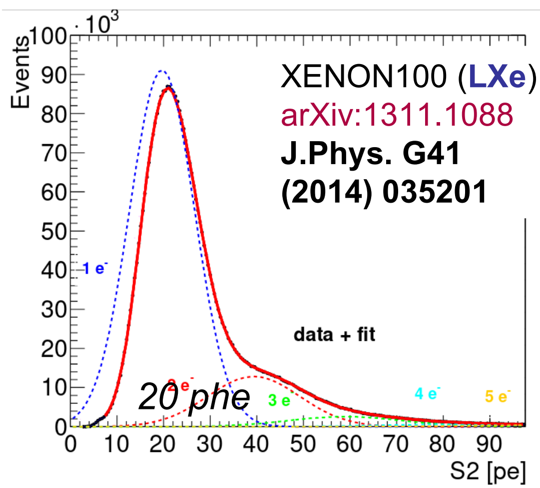
Single electron detection

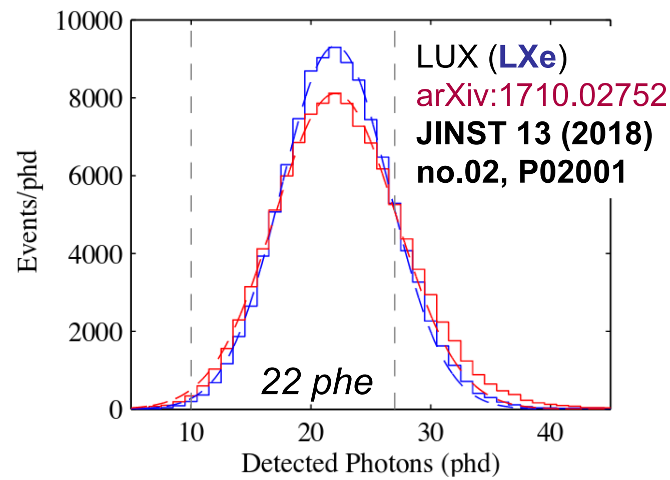
Projects for CEvNS with LXe two-phase detectors appeared after
the capability to detect single ionization electrons (**SE**) was demonstrated:







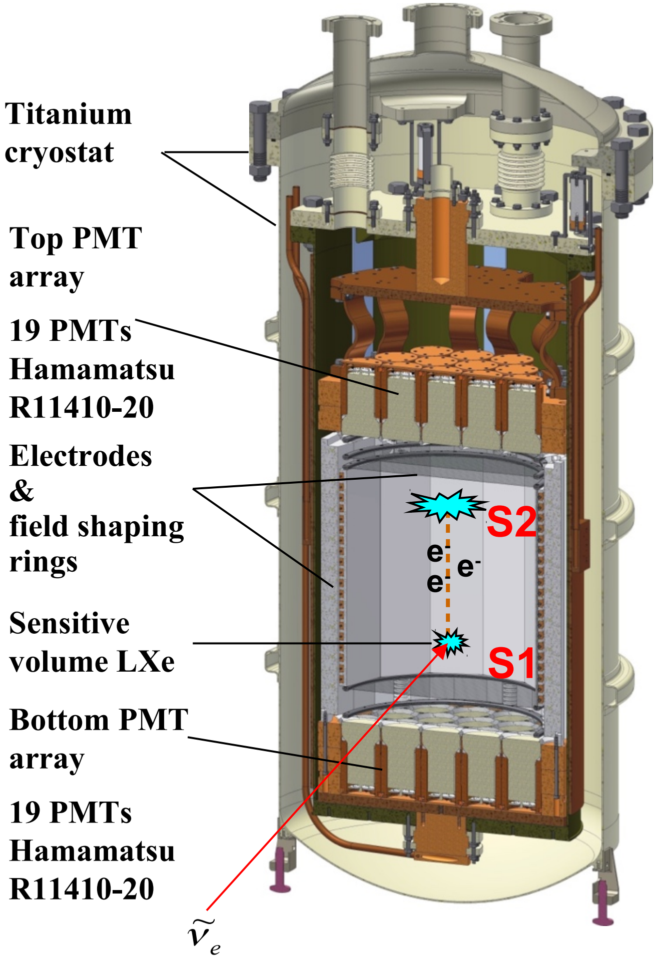


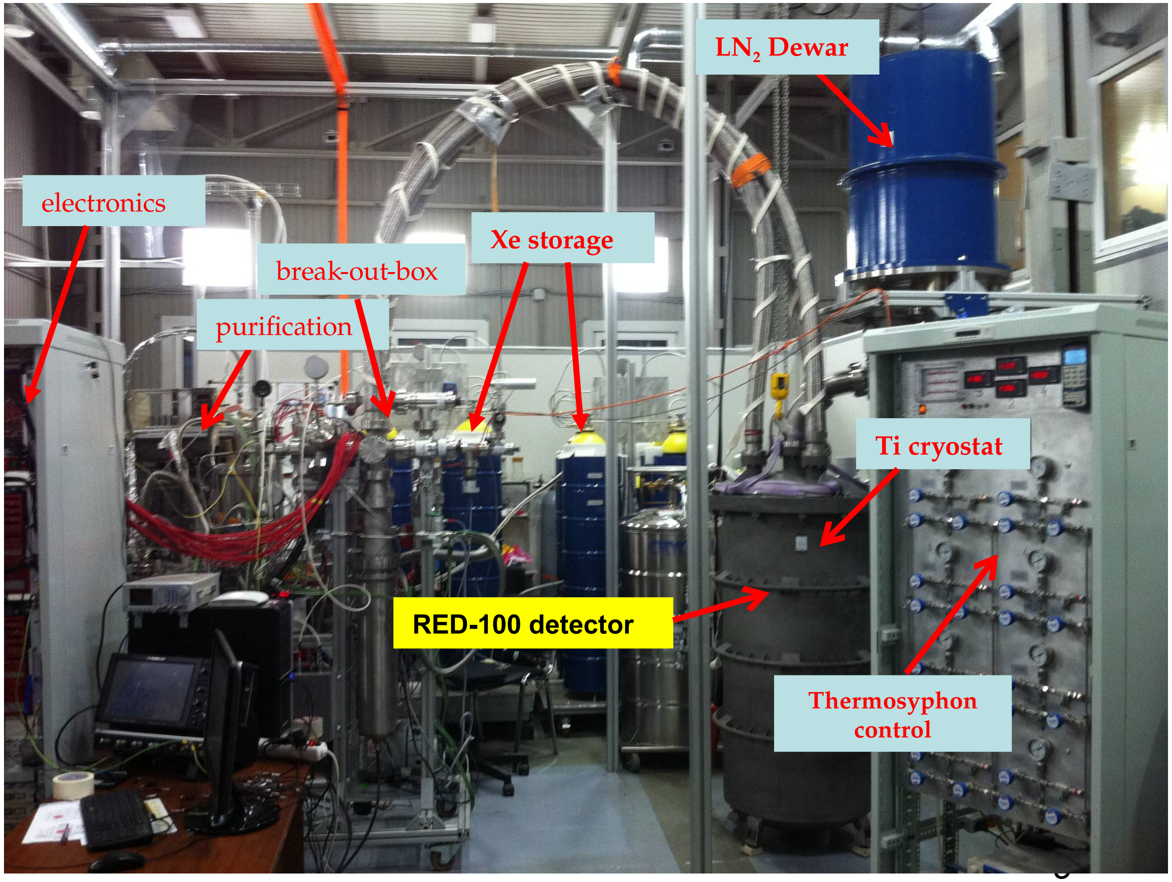


The RED-100: tests are underway at MEPhI

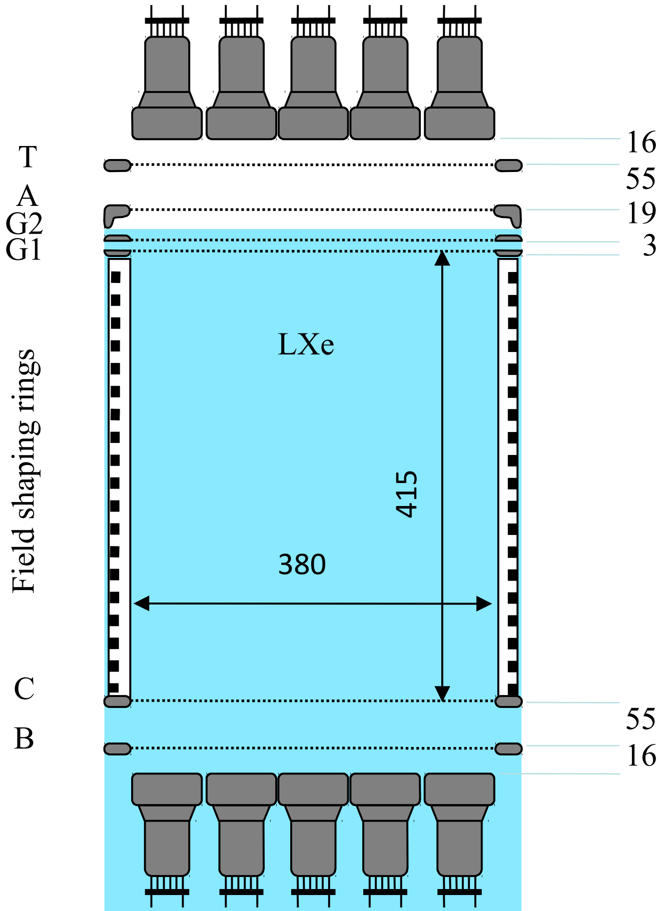
RED-100 is a two-phase noble gas emission detector. Contains ~200 kg of LXe, ~160 kg in sens. volume, ~100 kg in FV.

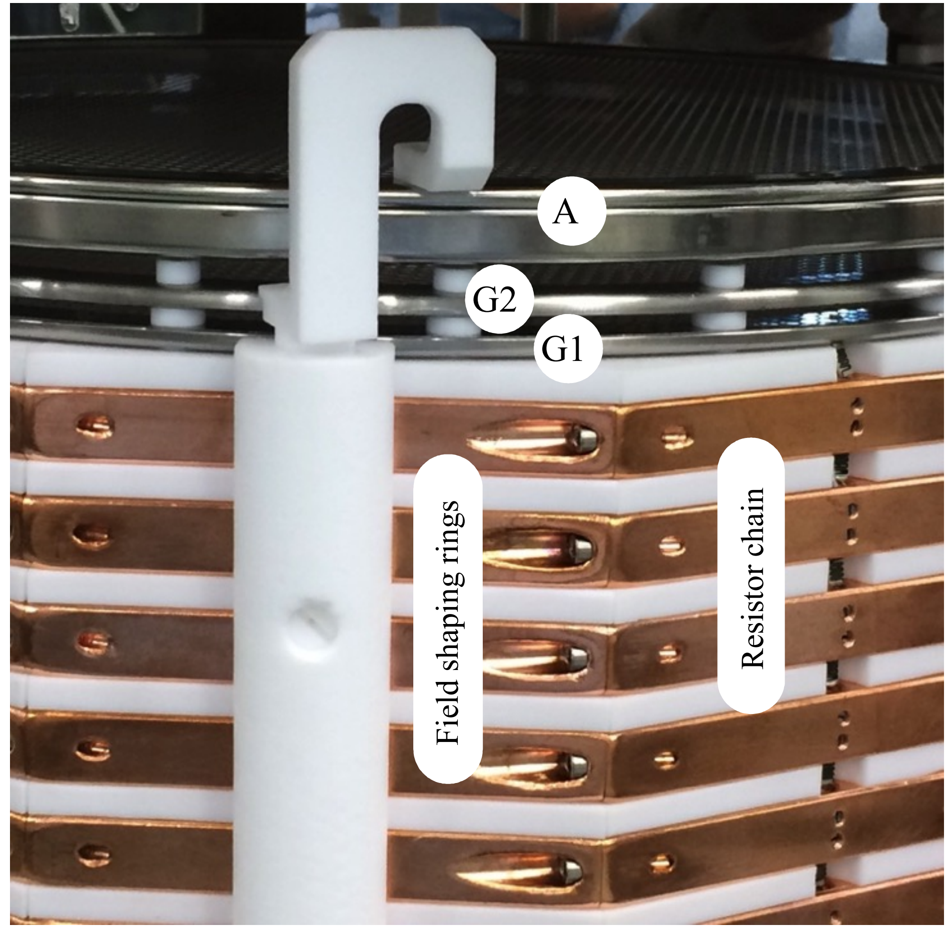
The sensitive volume 38 cm in diam., 41 cm in height, is defined by the top and bottom optically transparent mesh electrodes and field-shaping rings.





Schematic layout of grids and PMTs





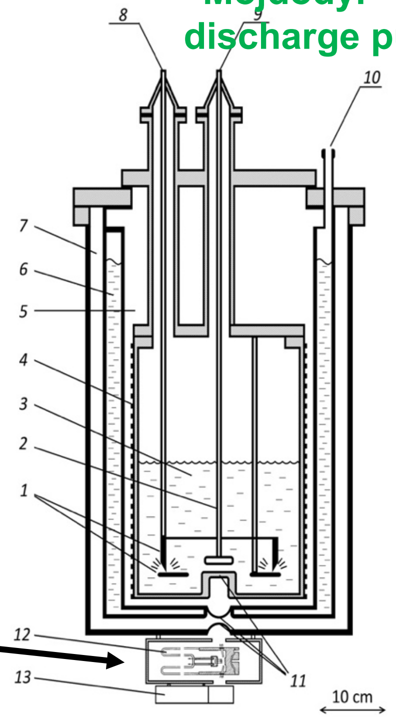
Sizes of the drift volume and distances between grids are in mm.

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

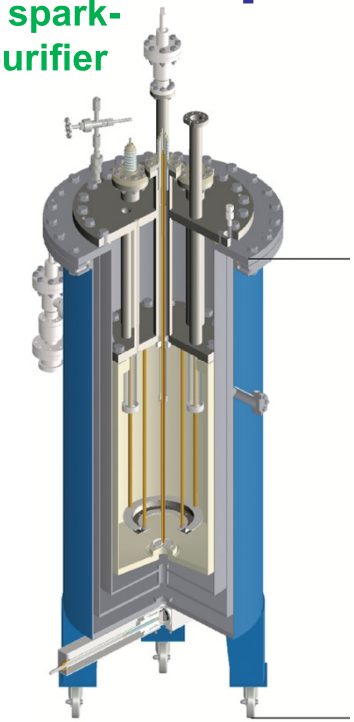
RED-100 performance: LXe purity

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



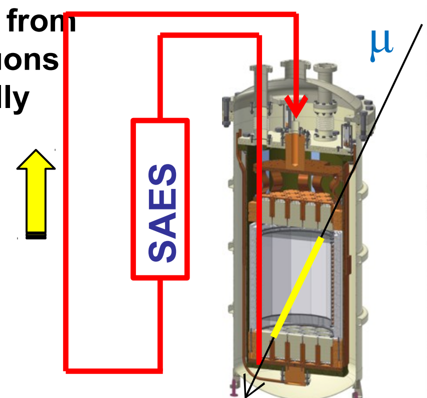
Xenon was contaminated by highly-electronegative impurities presumably due to the use of a special fluorine-containing high-molecular-weight lubricant in gas centrifuges.

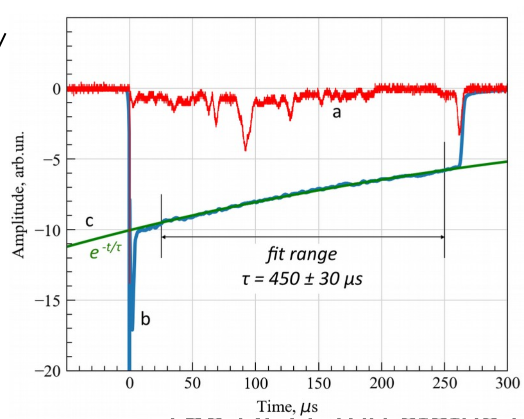
After purification, the achieved lifetime ≳ 50 μs for ~200 kg of LXe

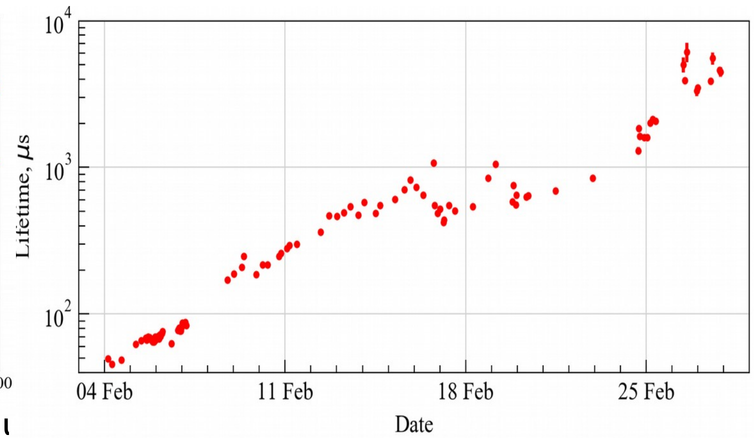
2d stage: Purification was performed by constant circulation of Xe through RED-100 and SAES

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

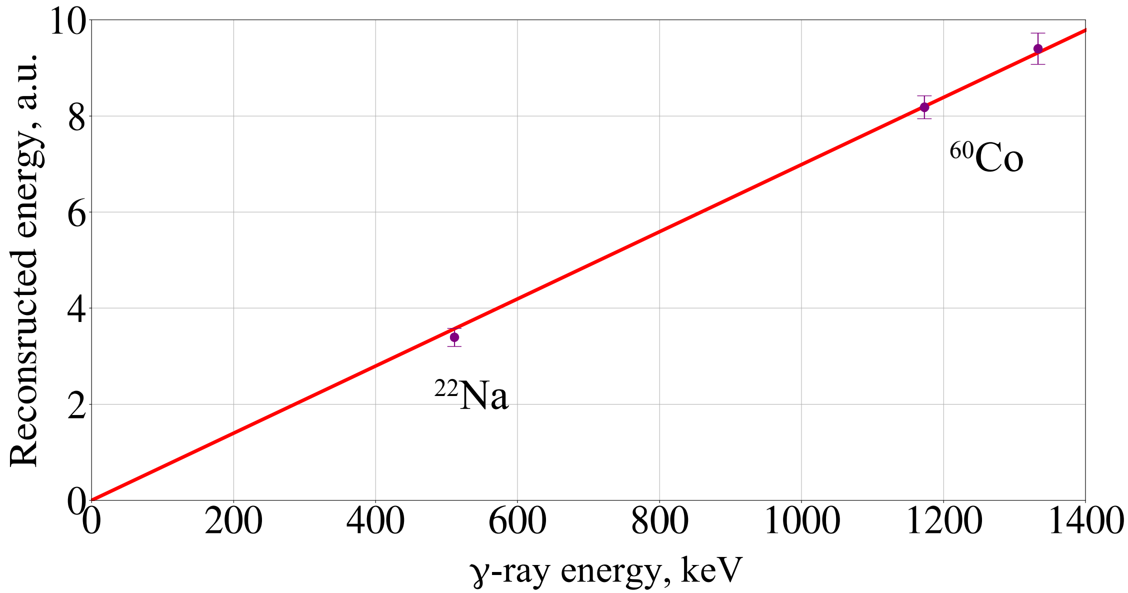
Average energy deposition from cosmic muons is practically uniform







RED-100 performance: gamma-calibration



Electron extraction efficiency (EEE)

From S2 distribution ONLY,

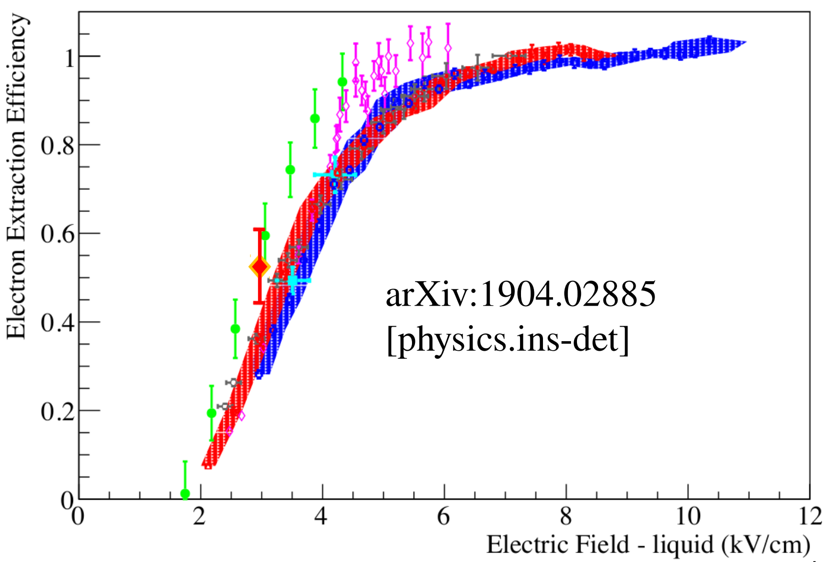
N_{SE} = ^{22}Na peak pos. area / SE area

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

N^*_E – corrected for electron lifetime

EEE = N_{SE} / N^*_E = 0.54 ± 0.08

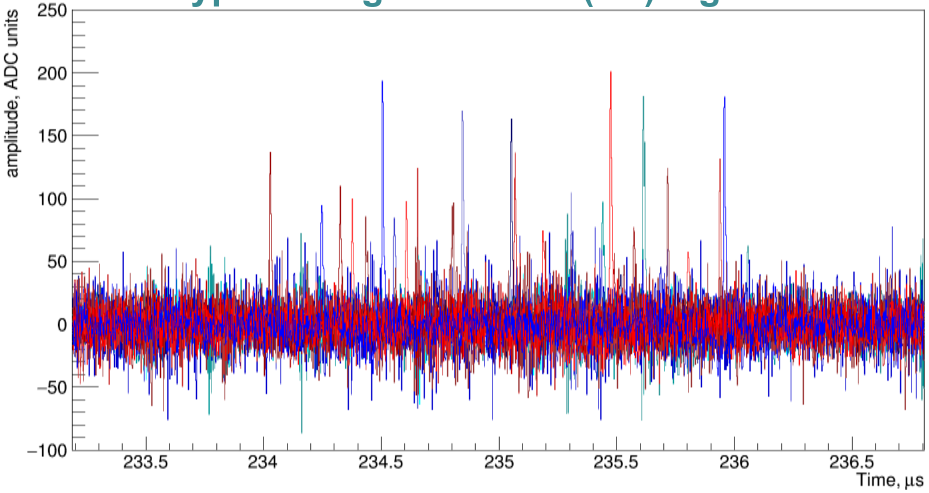
@ E_{extr} = 3.0 ± 0.1 kV/cm

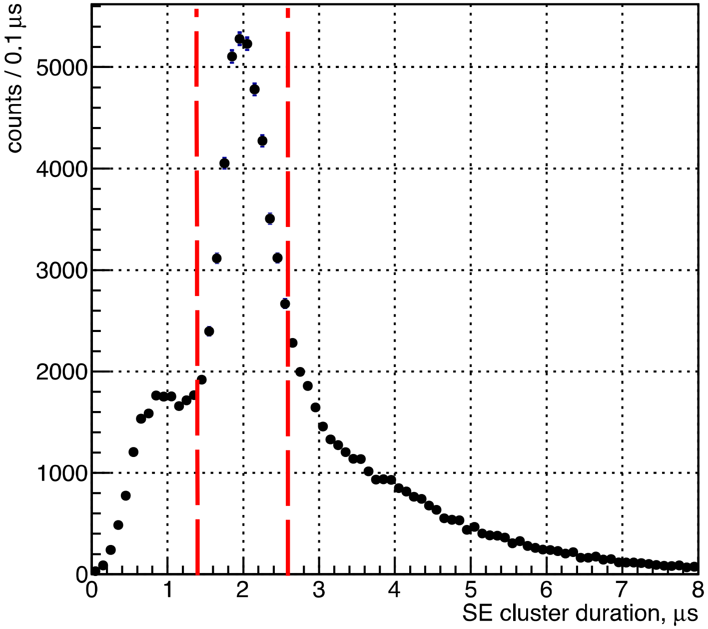


RED-100 performance: SE

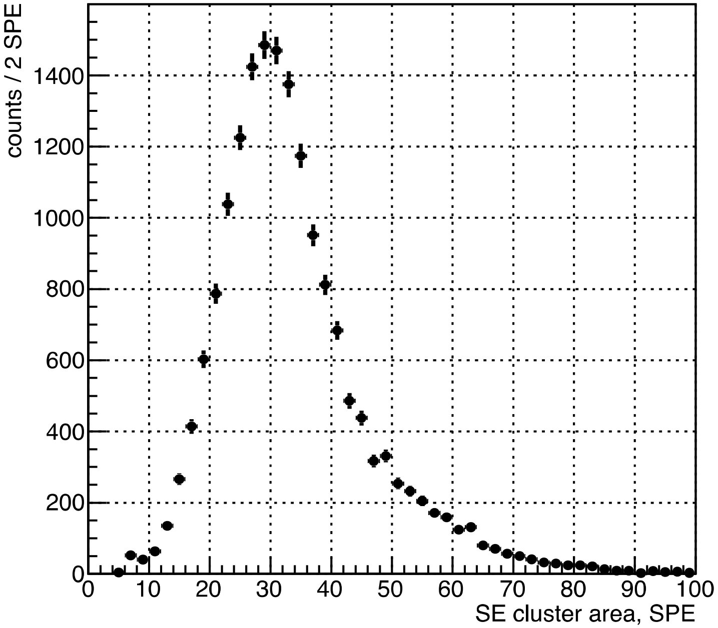
SE is a cluster of individual SPEs (single photo electrons) with a typical duration of ~ 2 µs

Typical single electron (SE) signal





Distribution of SE duration

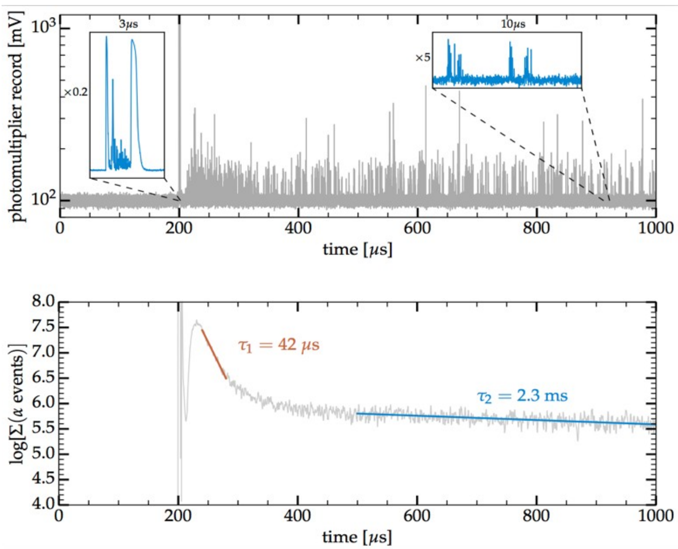


Distribution of SE area

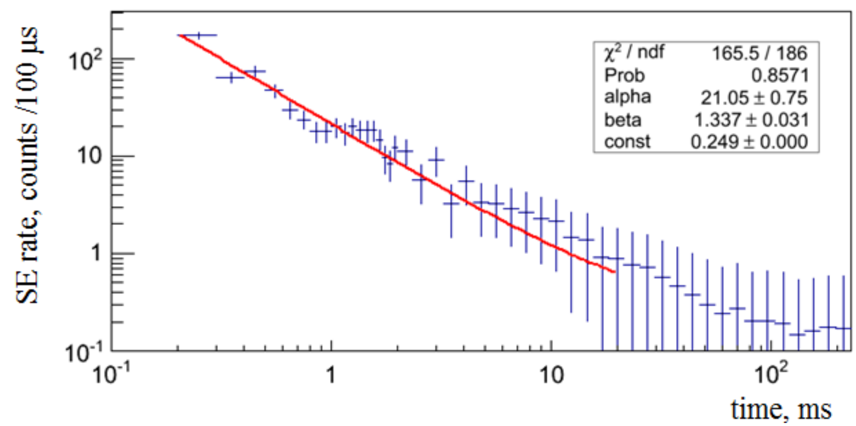
RED-100 performance: "spontaneous" SE

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



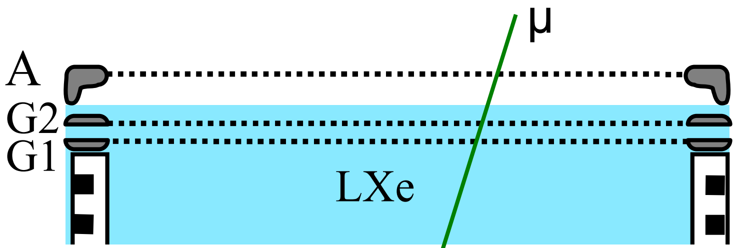
JINST 11 (2016) no.03, C03007



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

Two components:
1^{st} – short, but more intense, caused by emission of the electrons trapped at LXe surface.
2^{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: electron shutter

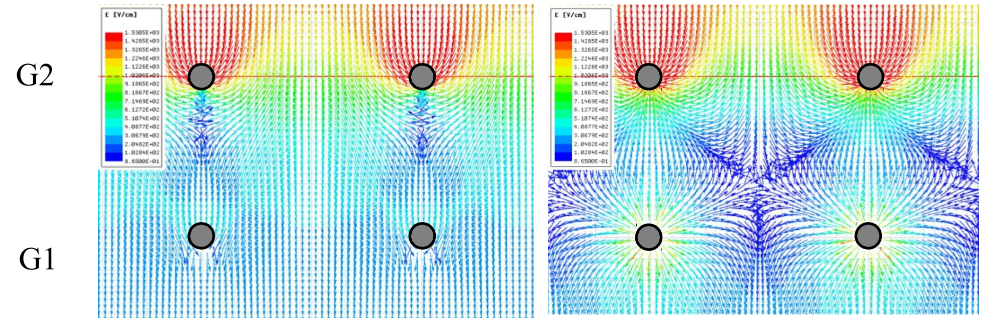


Positive pulse (~300 V millisec. duration) is applied to G1, and the charge is collected to it.

Pulse generator is triggered by muon scintillation.

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

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

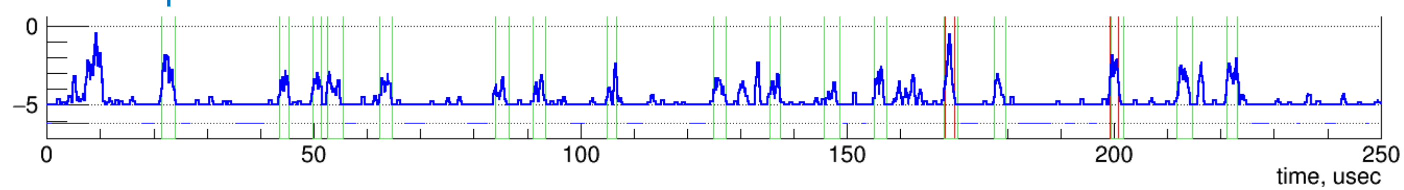


open: $U_{G2} - U_{G1} = 50$ V closed: $U_{G2} - U_{G1} = -250$ V

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

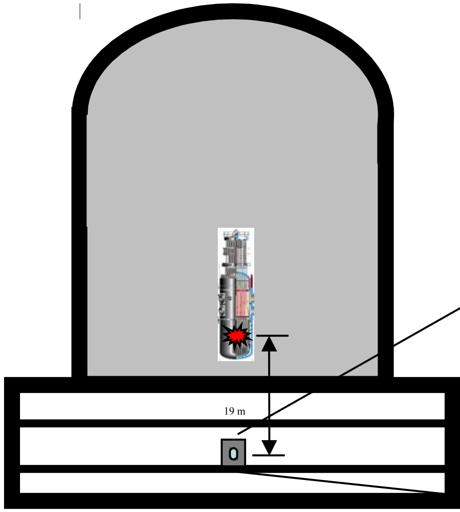
However, the "spontaneous" SE rate is quite high: ~ 250 kHz in our ground-level lab. (no overburden, no shielding)

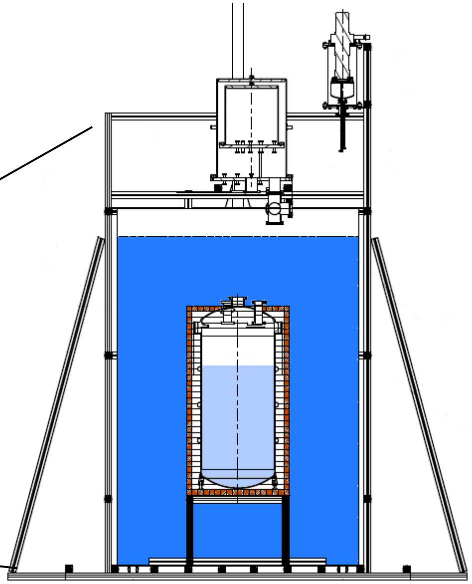
Example of waveform:



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

RED-100 at KNPP





γ and n shield:
5 cm Cu + ~60 cm H_2O

19 m from core

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

Neutron flux

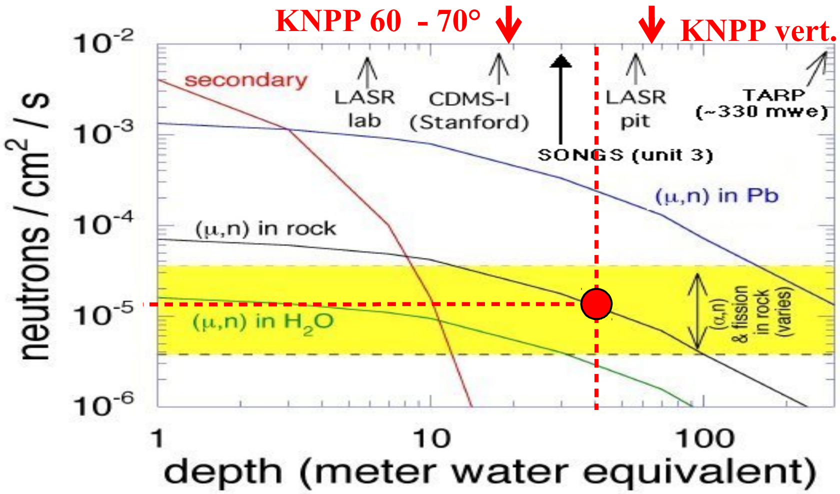


Image by J.I. Collar

Estimation of CEvNS count rate at KNPP

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

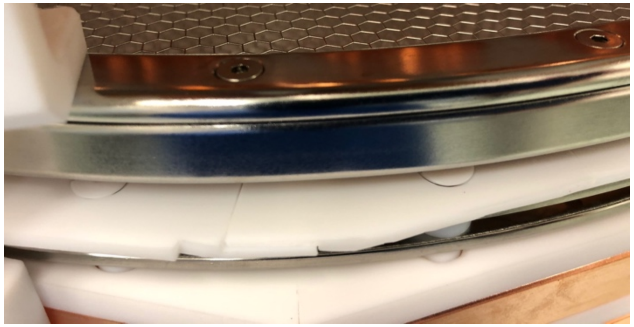
Taken into account:

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

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 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 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 Study the influence of LXe purity on the rate of spontaneous SE events

4 Develop better algorithms for point-like events selection

Conclusion

► **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**

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

► **Further steps to improve CEνNS/bckg were discussed**

NEW COLLABORATORS ARE WELCOME!

The RED collaboration:

National Research Nuclear University "MEPhI" (Moscow Engineering Physics Institute)
A.I. Bolozdynya, D.V. Gouss, Dj.Ed. Kdib, A.V. Khromov, A.V. Kumpan, V.V. Moramzin, A.V. Shakirov, V.V. Sosnovtsev, A.A. Vasin

Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Center "Kurchatov Institute"
D.Yu. Akimov, V.A. Belov, A.M. Konovalov, A.G. Kovalenko, E.S. Kozlova, A.V. Lukyashin, O.E. Razuvaeva, D.G. Rudik, G.E. Simakov

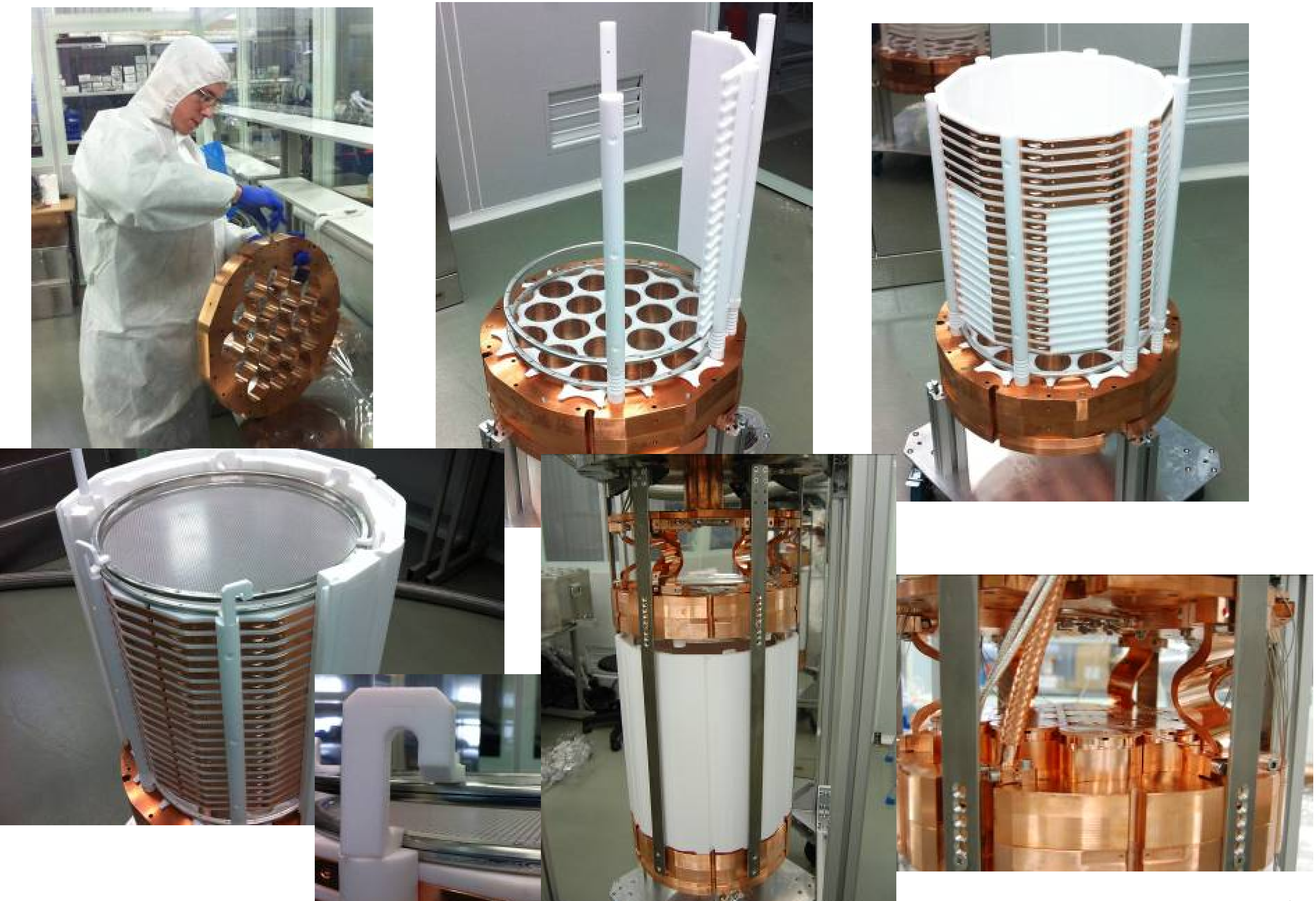
Joint Institute for Nuclear Research,
A.V. Galavanov, Yu.V. Gusakov

National Research Center "Kurchatov Institute"
A.V. Etenko

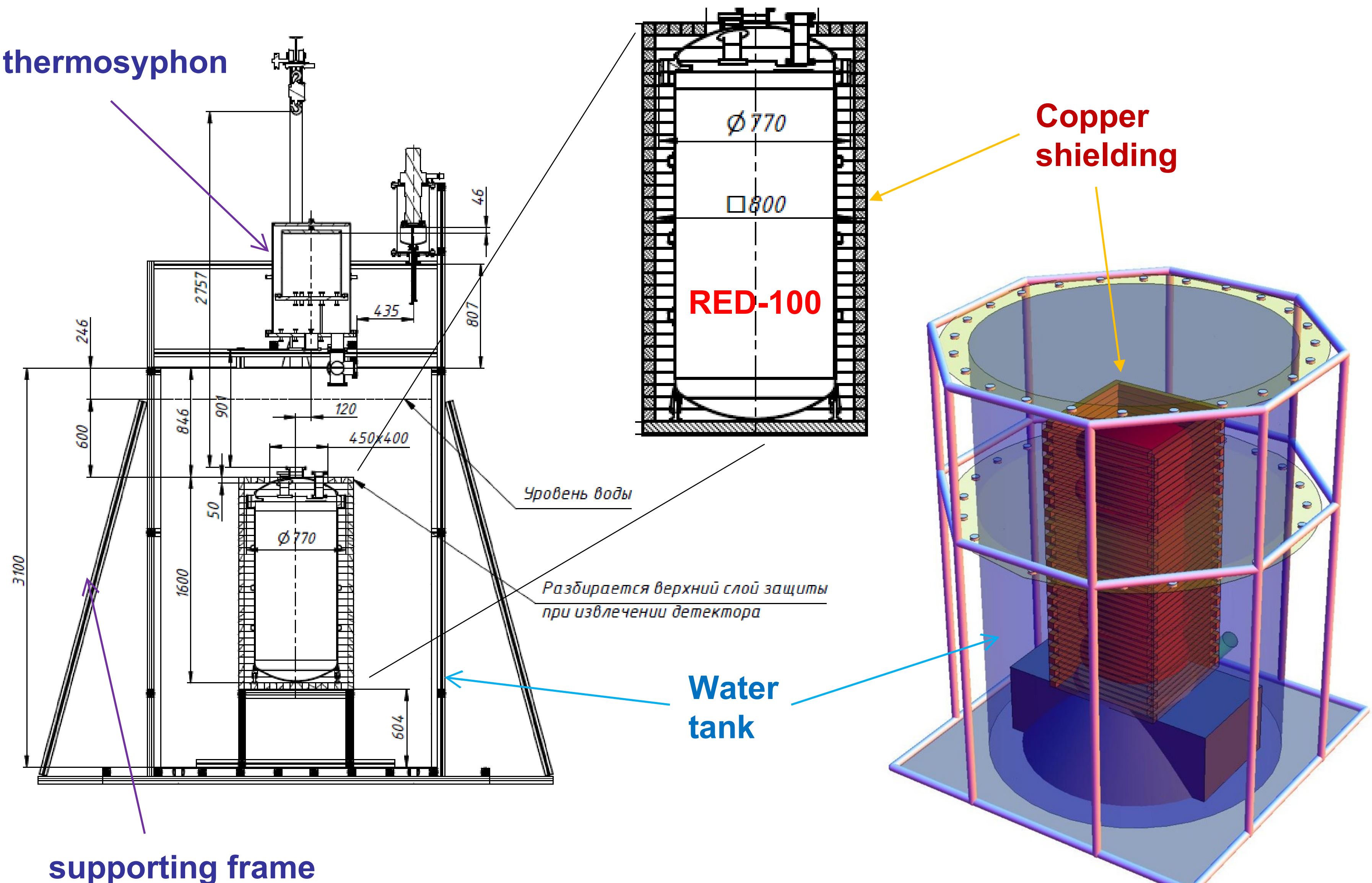
University of Tennessee,
Yu.V. Efremenko

Institute for Nuclear Research,
V.N. Kornoukhov, Yu.A. Melikyan

RED-100 detector assembly



RED-100 in passive shielding

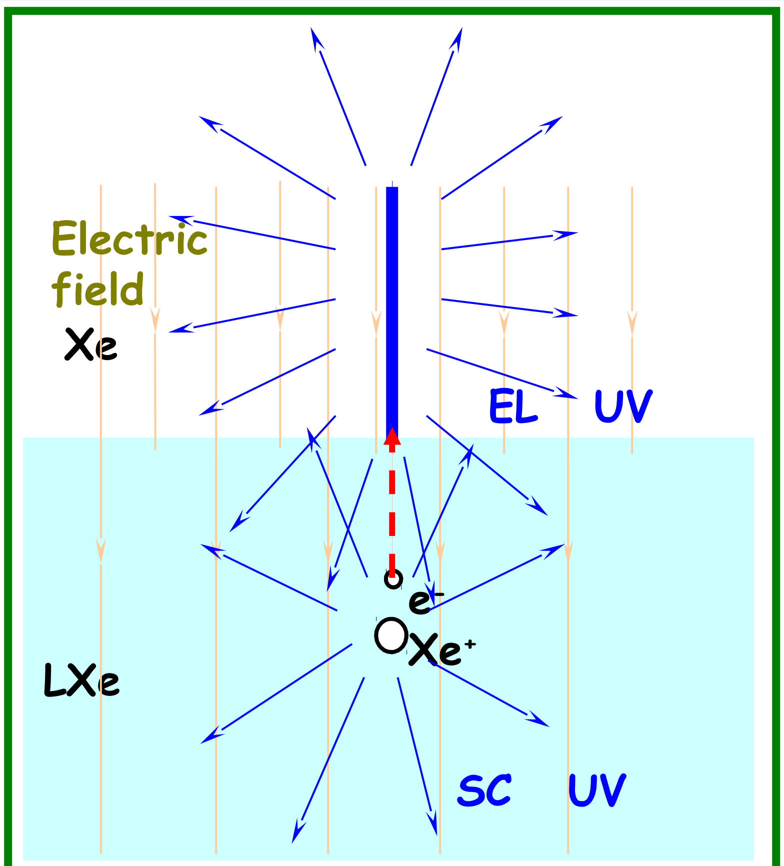


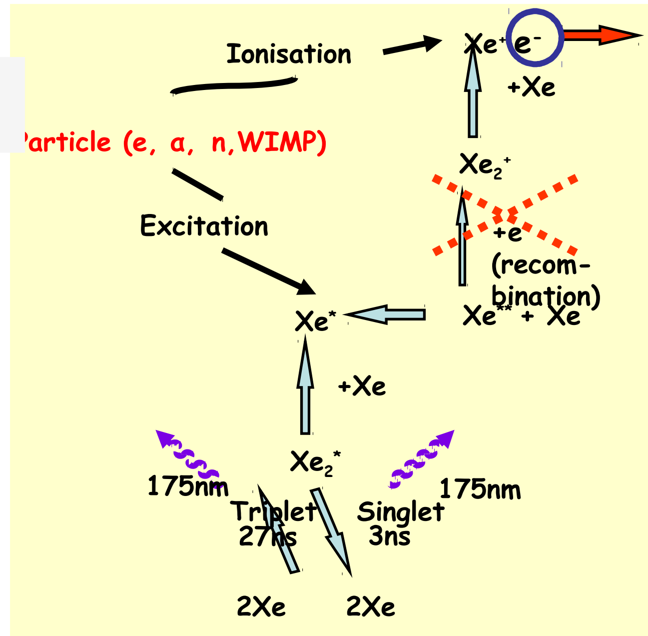
Two-phase detector

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