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РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

Two-phase emission liquid xenon detector RED100 for rare events search at ground level laboratory

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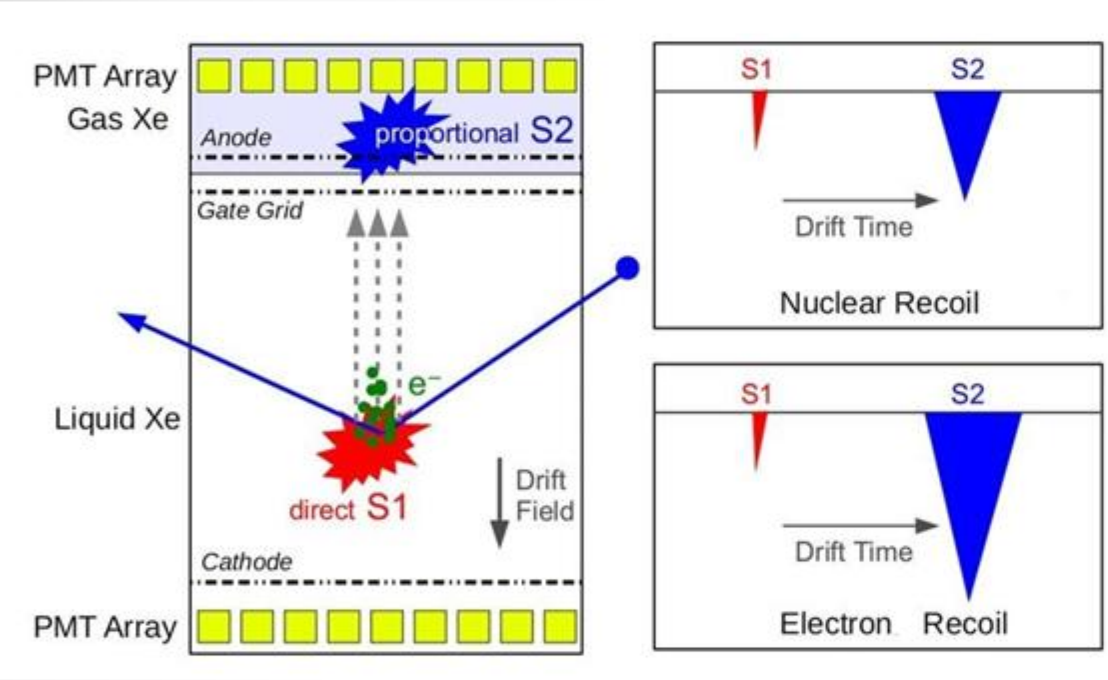
Two-phase emission liquid xenon detector



S1 - scintillation
S2 **-**proportional scintillation(electroluminescence): measurement of e- charge extracted from the liquid to the gas

S2/S1 ratio depends on the recoil type

Position sensitivity:
-X and Y from the S2 light distribution across the PMT array
-Z from drift time (delay between S1 and S2)

LXe advantages:

Self-shielding, high Z, high density, no intrinsic backgrounds, scalability

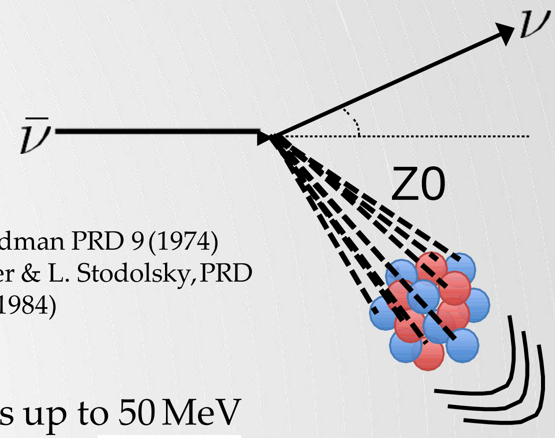
These detectors found wide application in detection of rare events (mostly in WIPMs search)

Coherent elastic neutrino-nucleus scattering (CEνNS)

Neutrino elastically scatters off a nucleus via Z0 exchange

Flavour blind
No threshold
Predicted by the SM

Observed for the first time in 2017 D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017).



D.Z. Freedman PRD 9 (1974)
A. Drukier & L. Stodolsky, PRD 30, 2295 (1984)

Neutrinos with energies up to 50 MeV satisfy coherence condition $Q \lesssim \frac{1}{R}$

$$\frac{d\sigma}{dE_r} = \frac{G_F^2}{4\pi} Q_w^2 M \left(1 - \frac{ME_r}{2E_\nu^2}\right) F^2(Q^2)$$

G_F – Fermi constant

$F(Q^2)$ – form factor at four-momentum Q

$Q_W = N - (1-4\sin^2(\theta_W))Z$ – weak charge for a nucleus with N and Z, θ_W – weak mixing angle; $\sin^2(\theta_W) \approx 0.22 \Rightarrow Q_W \sim N$;

High cross-section but tiny nuclear recoil energies:

$$\sigma \sim 4.2\times10^{-45}\, N^2\, (E/\text{МэВ})^2\ \text{см}^2$$

$$\langle E_r \rangle = 716\ \text{eV}\ \frac{(E_\nu/\text{MeV})^2}{A}$$

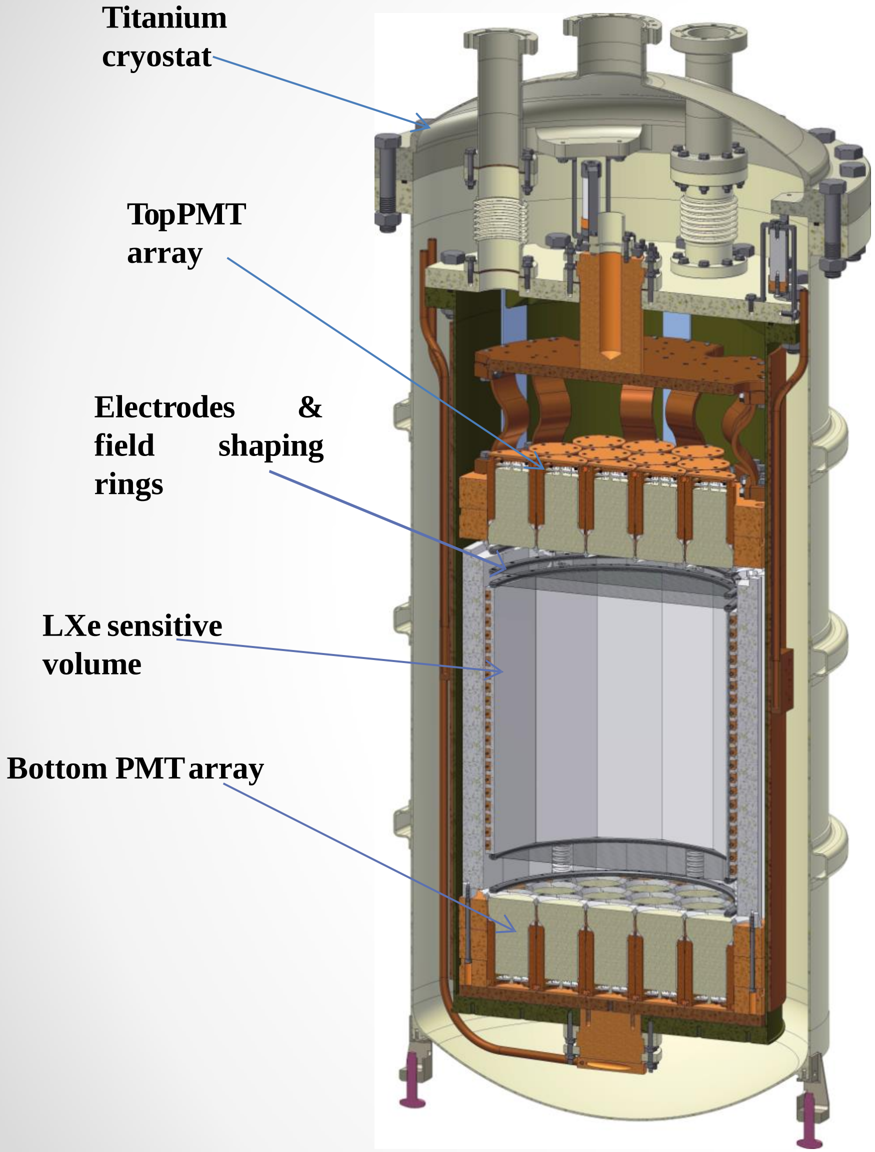
in keV region for spallation sources;

in sub-keV region for nuclear reactors

Motivation:

Test of the SM, probe of neutrino NSI
Important in supernova processes
Dark-matter direct-detection background
Monitoring of nuclear reactors

RED-100



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

Contains ~200 kg of LXe, ~100 kg in FV.

The sensitive volume ~ 40 cm in diam

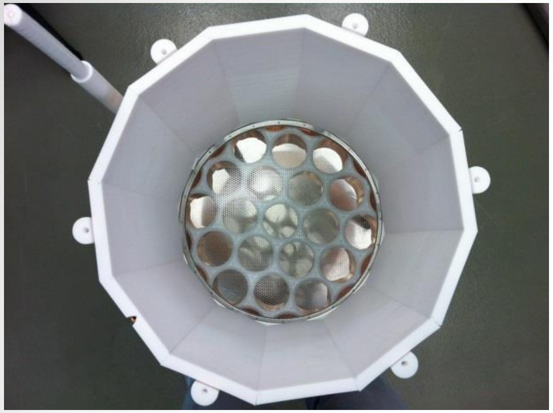
~ 42 cm in height, is defined by the top and bottom optically transparent mesh electrodes and field-shaping rings.

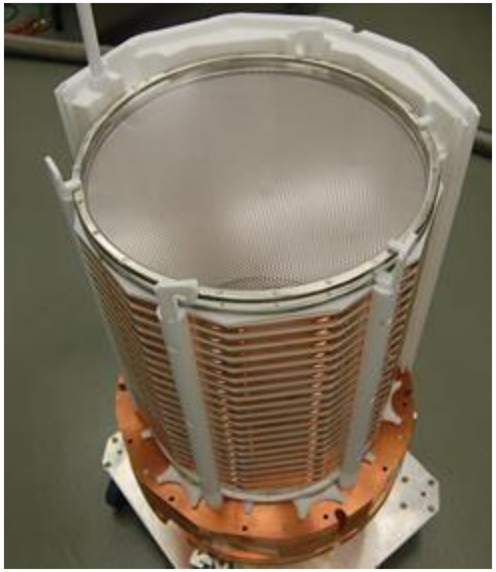
PMTs are Hamamatsu R11410-20 (low-background); 38 in total (2 x 19)

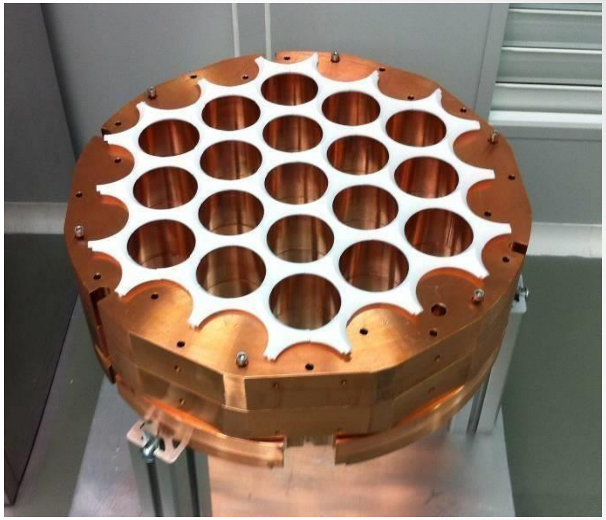
Electroluminescence gas region – 1 cm.

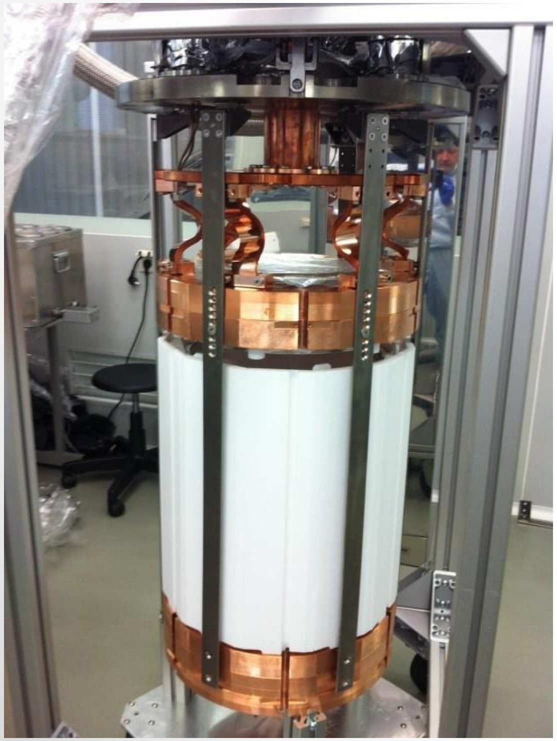
RED100 setup at the Laboratory for Experimental Nuclear Physics

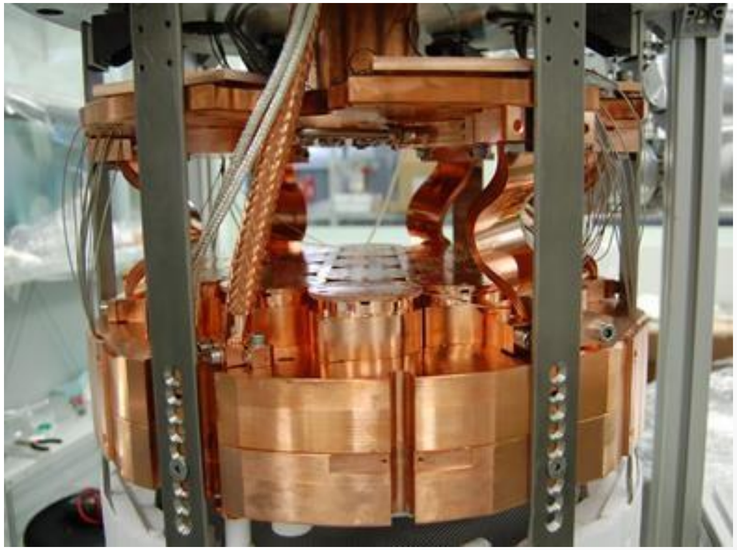
RED-100 internals assembling



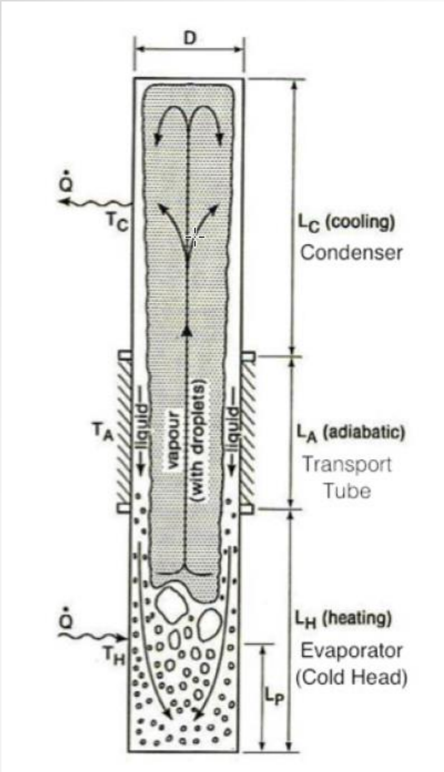








Cryogenics

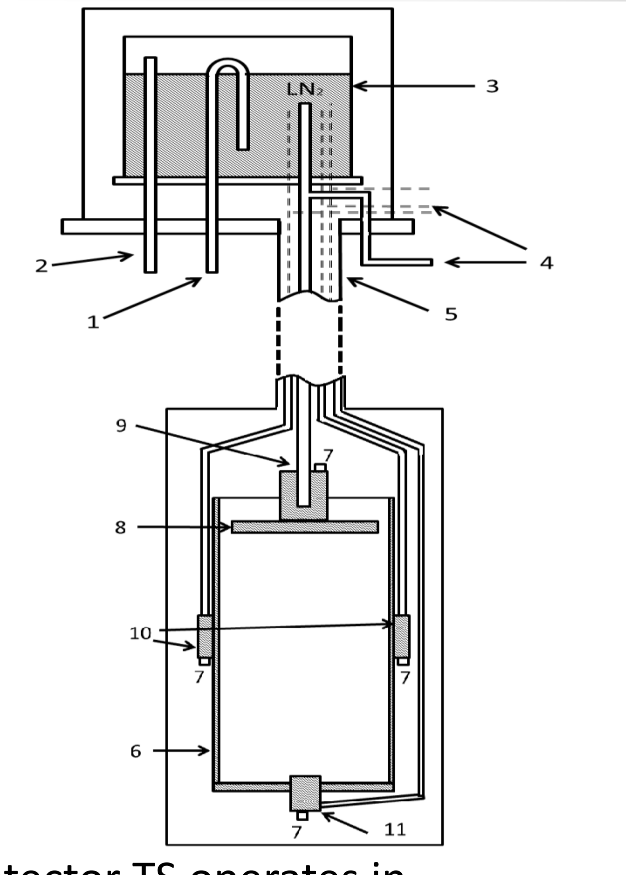


RED-100 cryogenics is based on a two-phase tubular thermosyphon:

-Stable operation at LXe temperature ~165-170 K

-No mechanical vibrations

-Low radioactivity near detector

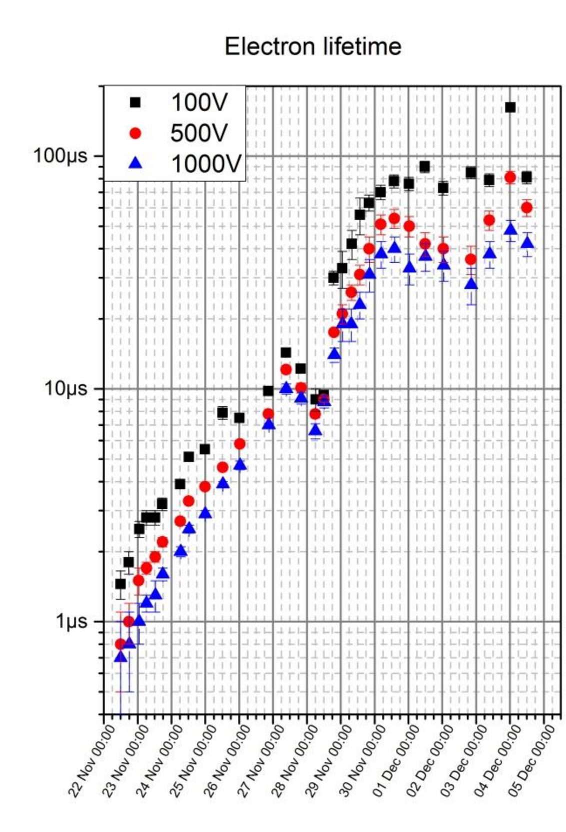


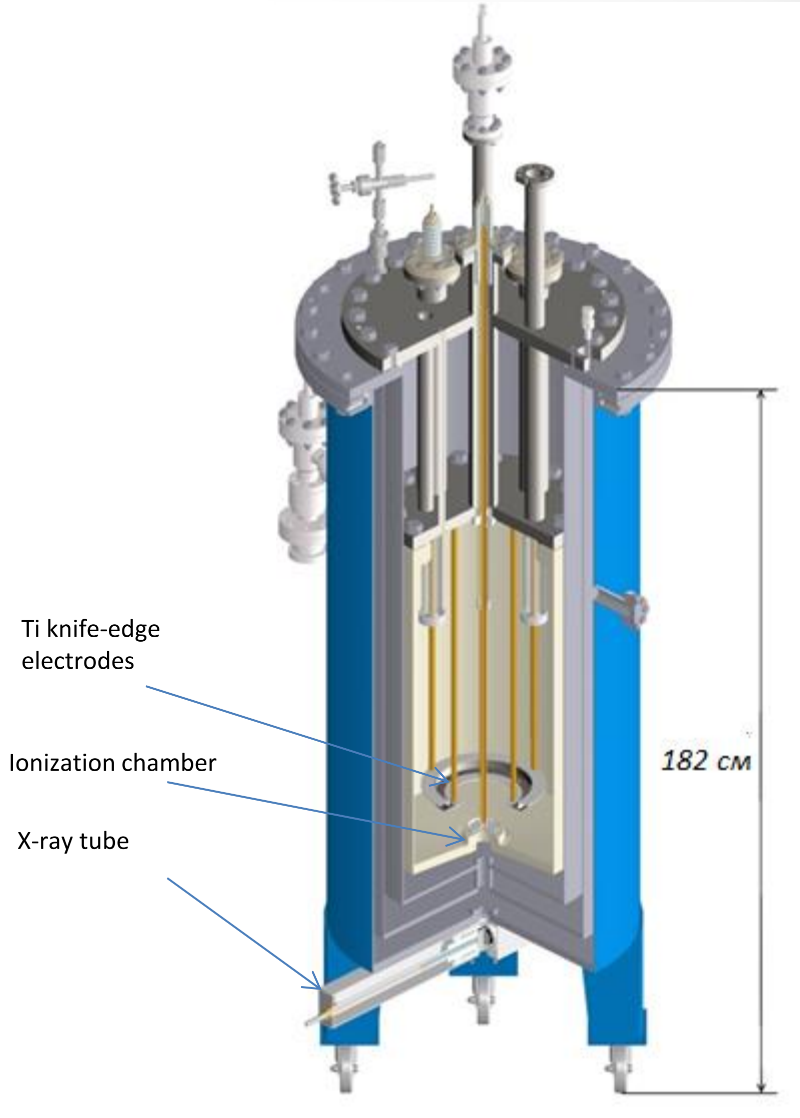
Liquid nitrogen is used as a coolant. To get LXe temperature detector TS operates in dynamic mode

In RED-100 we use four thermosyphons which provide ~400 W of cooling power

Xenon purification

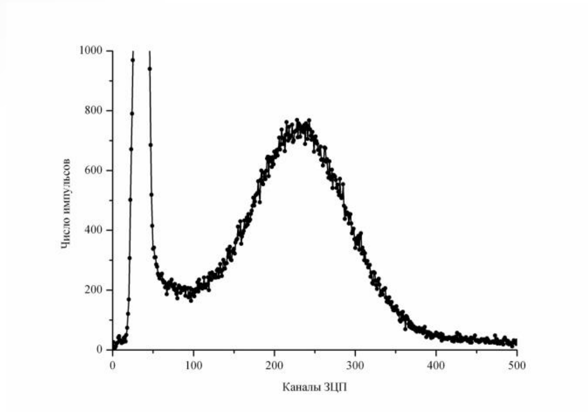
In RED-100 we use xenon that was originally processed in centrifuges to extract Xe-136 isotope for EXO-200.
It was found out that our gas was contaminated with high molecular electronegative impurities after this procedure.
Moreover, commercial SAES hot getters are not able to get rid of these impurities.

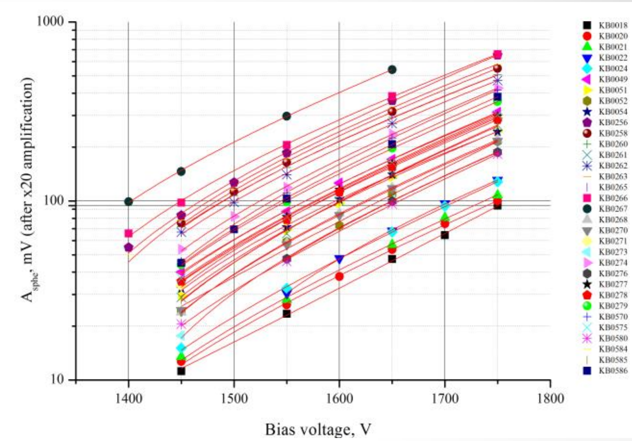




Thus, ~200 kg of xenon were purified to electron lifetime ~100 µs by spark discharge technology in «Mojdodyr» setup by production of titanium nanoparticles

Photomultiplier tubes

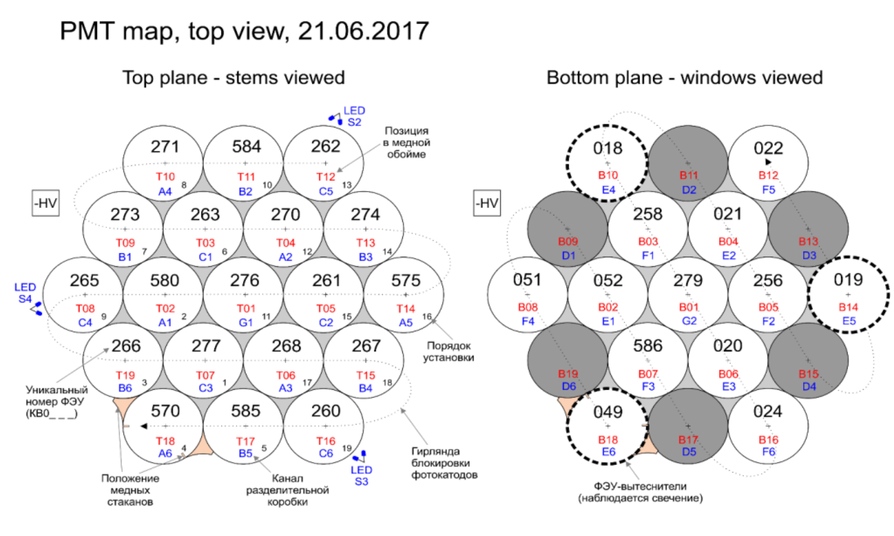




All 32 PMTs were characterized (single electron response, noise) to optimize layout in PMT arrays

3-inch Hamamatsu R11410-20 PMTs:

Operate in LXe
Low background
High gain 3,5× 10^6
QE ~30% at 175 VUV light



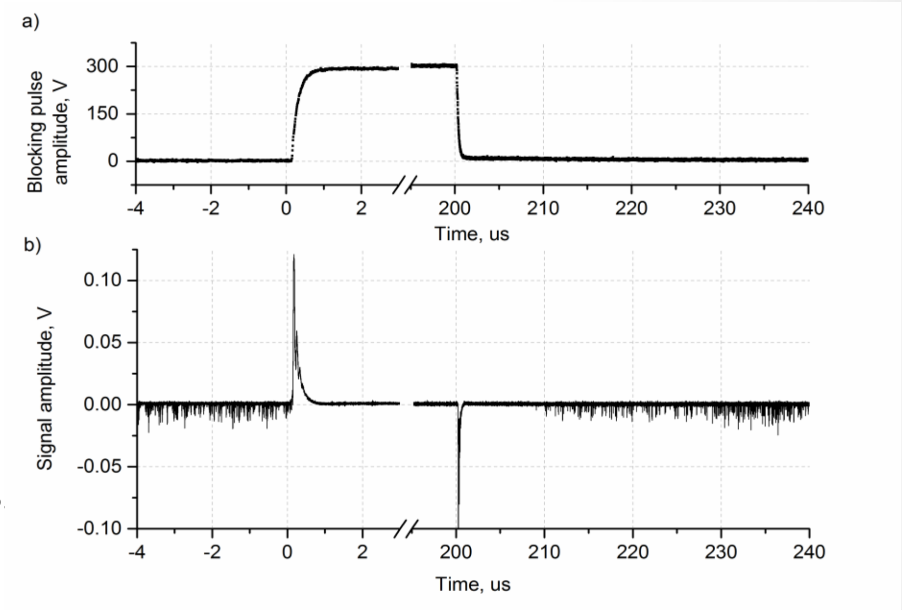
20 MΩ individual voltage dividers on Cirlex® boards
Positively biased

Two-phase emission detector at ground level laboratory

High muon flux at sea level leads to serious PMT ageing

Cosmic Muon deposits ~240 MeV in RED-100
One muon interaction leads to

N_{phe}=8,2 ×10^8 phe/PMT
$C = N_{phe}$× g ×q_e= 4,6×10^{-4} C/s

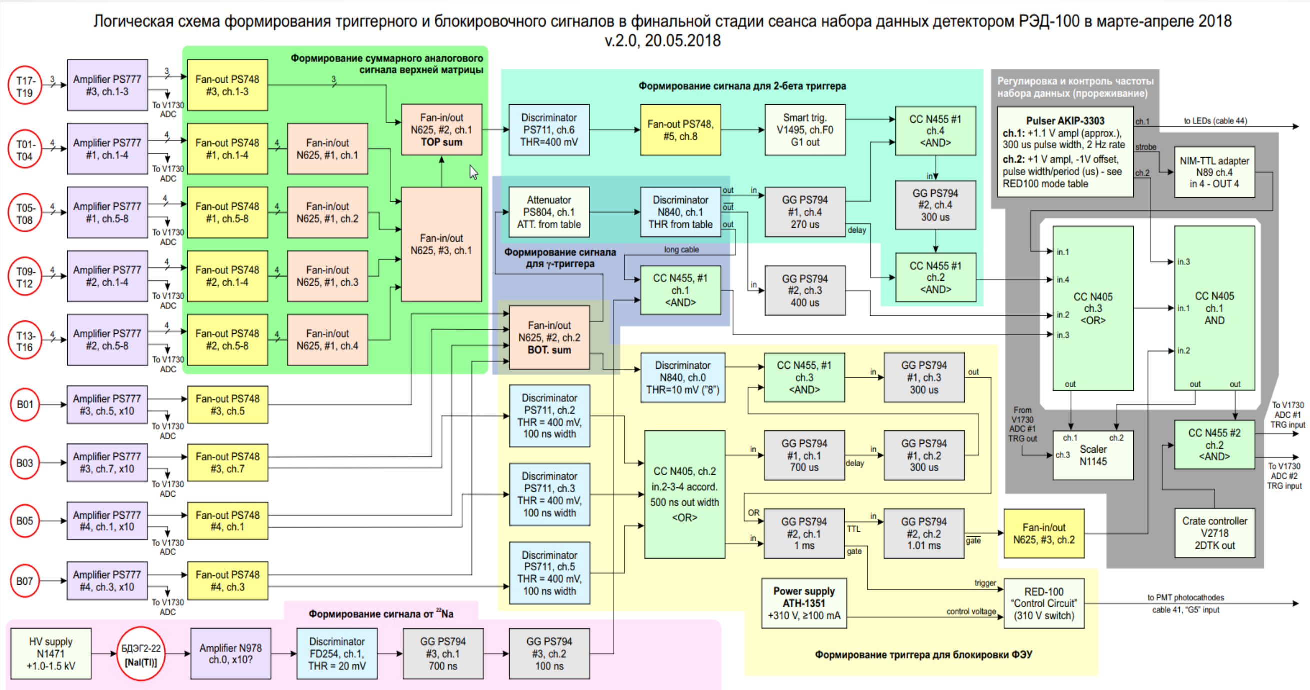


Charge density at the photocathode (recalculated to the anode) may reach 10 C/cm2 per year
Deterioration can begin with charge densities of ~1 C/cm2

Jinno, T., Mori, T., Ohshima, T., Arita, Y., Inami, K., Ihara, T., Nishizawa, H., and Sasaki, T., arXiv: 1010.1057v1 [physics.insdet], 2010.
Barnyakov, M.Yu. and Mironov, A.V., J. Instrum., 2011, vol. 6, p. C12026.
DOI:10.1088/17480221/6/12/C12026

Pulse ~+300 V is sent to photocathode. This allows to close a gap between photocathode and the first dynode to prevent further electron multiplication. Pulse is triggered by intense S1 signal

Electronics@DAQ



No preamplifiers needed

CAEN V1730 FlashADC digitizers:

- -16 channels
- -high speed – 2 ns sampling
- -two input ranges – 2 / 0.5 V
- -big dynamic range – 14 bits

Trigger is based on CAEN V1495 multipurpose board. Allows to count SPE signals in time window for low signals like SE

DAQ written in C++ Linux and saves data directly to ROOT files

Experimental run March-April 2018

~30 hours is required to cool down the detector (~4 K/h)

~200 kg of xenon were condensed within 2,5 days (~3kg/h)

Detector was thermostabilized at T=168 K

Working pressure P=1.30±0.02 bar

Voltage of 17,5 kV was applied to cathode (maximum electric field in LXe is ~420 V/cm)

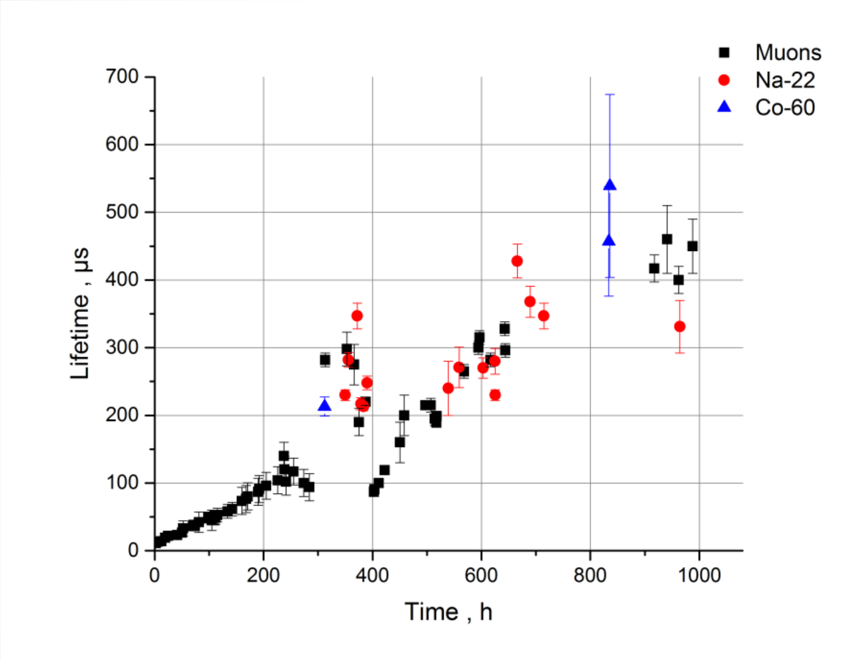
Maximum applied voltage between gate and anode is 9,5 kV

PMT operated at a gain corresponding to 1 spe/mV

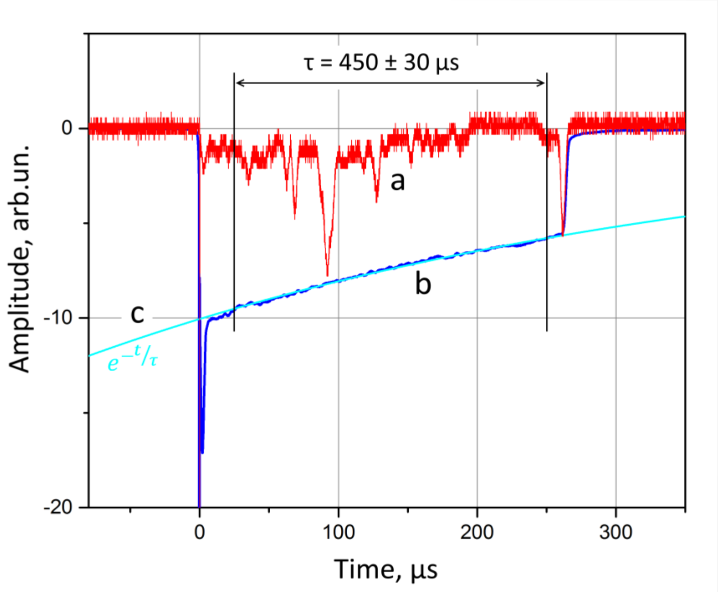
Detector operated during almost two months -> Lots of acquired data

Data analysis in progress now

Xenon purification by circulation through SAES getters



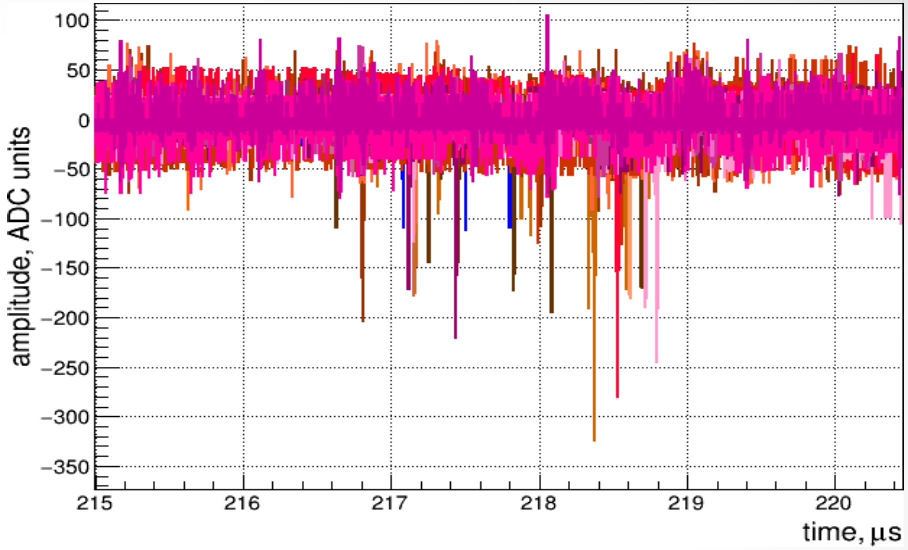
Typical cosmic muon signal



~450 µs electron lifetime was achieved after 1,5 months of continuous xenon circulation at rate of ~3 kg/hour

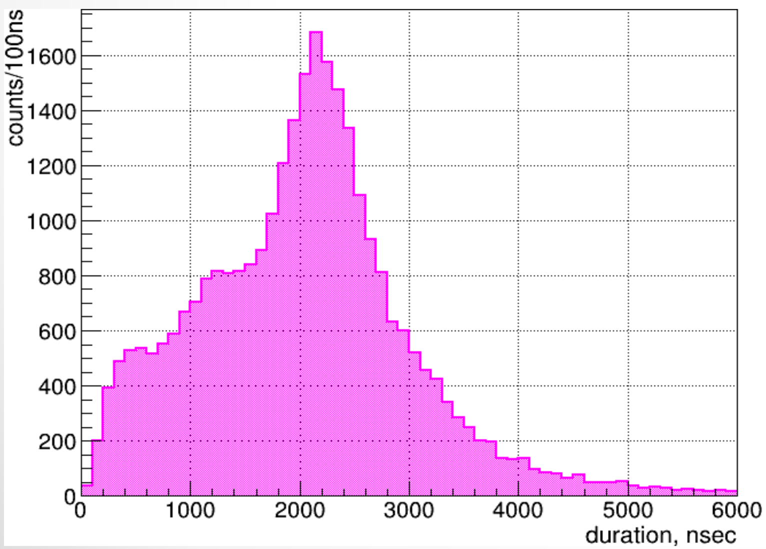
Sensitivity to single electrons

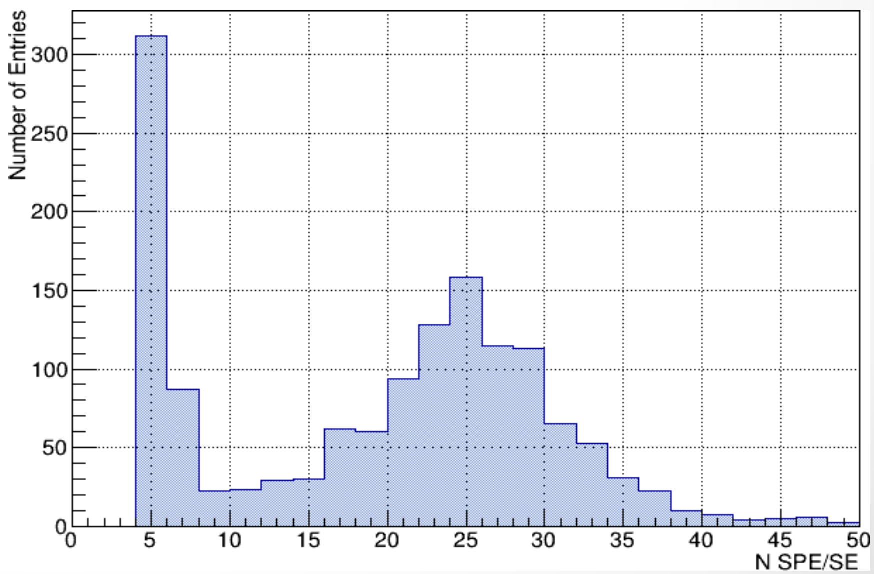
The number of single photoelectrons (SPE) per SE is defined by the light-collection efficiency.
Typical value of SPE/SE for two-phase detectors is several tens.



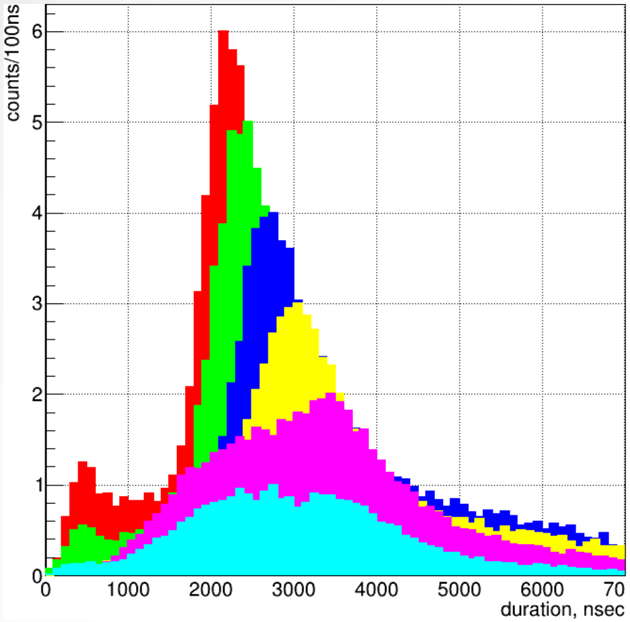
1SE rate ~10 kHz (No drift field)
2SE rate ~ 10 Hz
3SE rate ~ 10^{-2} Hz
SE rate with drift field ~200 kHz
«Electron shutter» efficiency to be tested soon

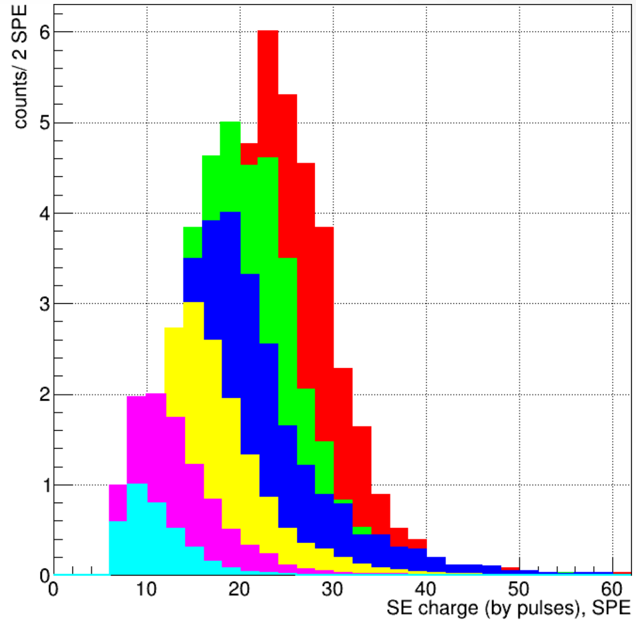
For 1.7-2.8 µs interval
6.6 kV/cm in gas

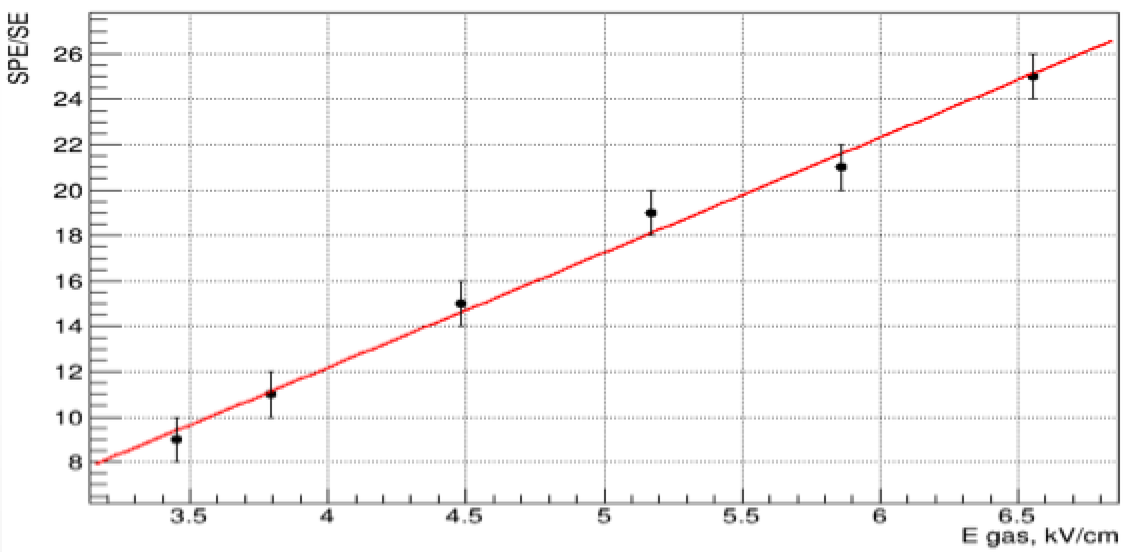




Sensitivity to single electrons



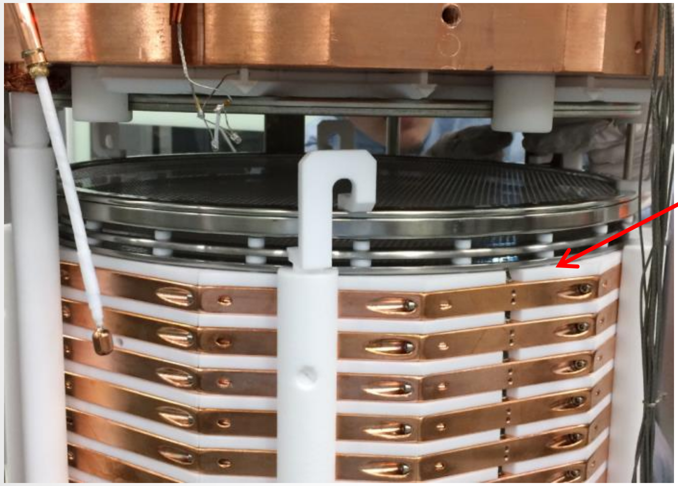


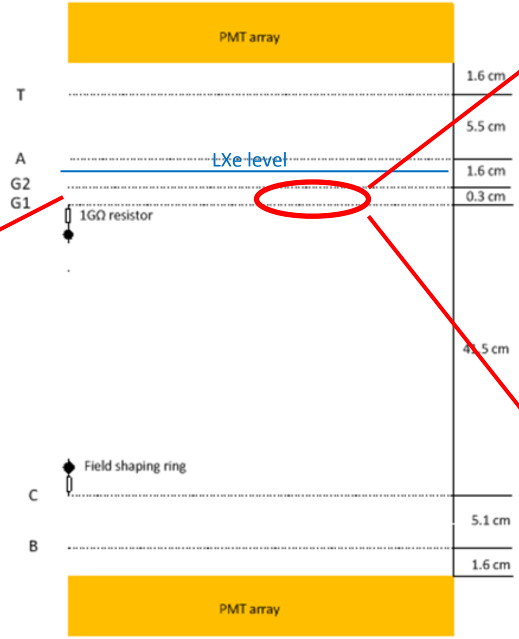


SPE/SE dependance on electric field in gas phase

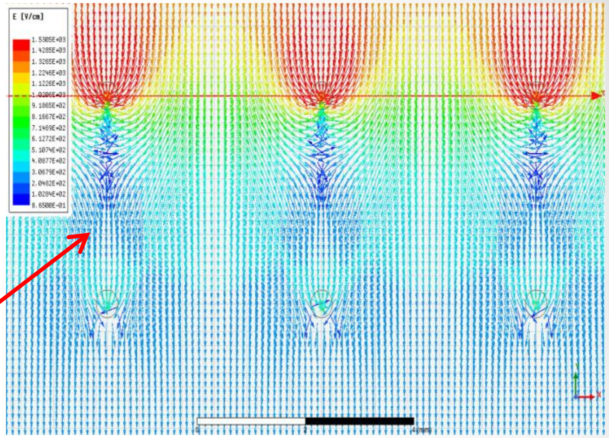
Two-phase emission detector at ground level laboratory

There is no significant overburden in CEvNS experiment
Muon rate in RED-100 is ~25 Hz (at sea level)
Spontaneous single electron emission increases with radiation load
SE noise is almost indistinguishable from CEvNS events
«Electron shutter» was designed to decrease SE rate

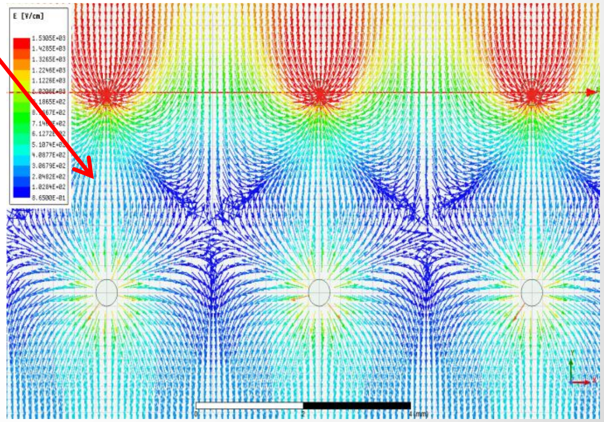




«Electron shutter» open

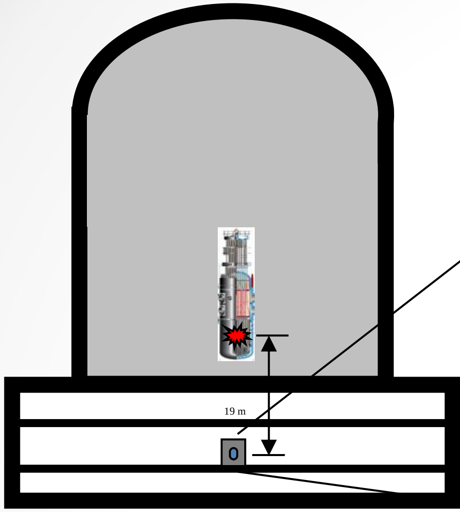


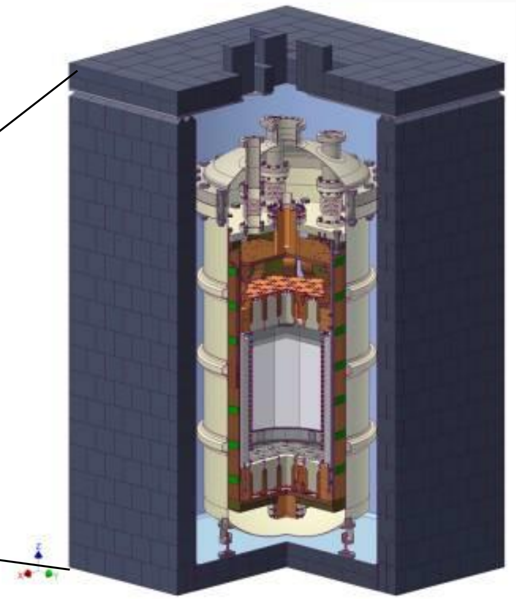
«Electron shutter» closed



When muon or gamma interacts with LXe ~ +300 V pulse ~250 µs is sent to G1 grid
Triggered by intense S1 signal

CEvNS experiment at reactor





γ and n shield:
10 ÷ 15 cm Pb
+ ~15 H_2O

19 м from reactor core

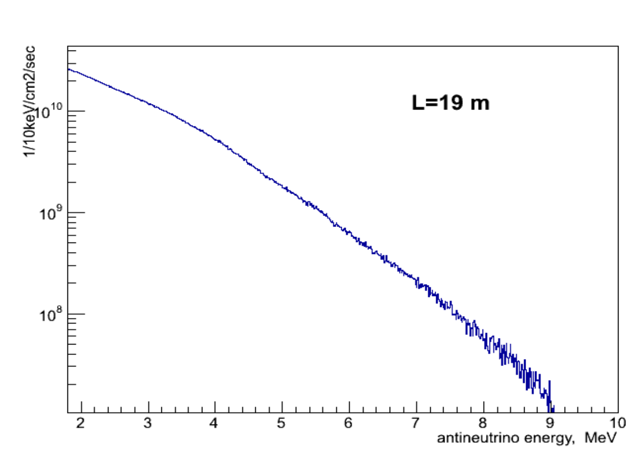
Antineutrino flux at this place - $1.35 \cdot 10^{13}$ $cm^{-2}s^{-1}$

Kalinin Nuclear Power Plant,
Udomlya, Russia

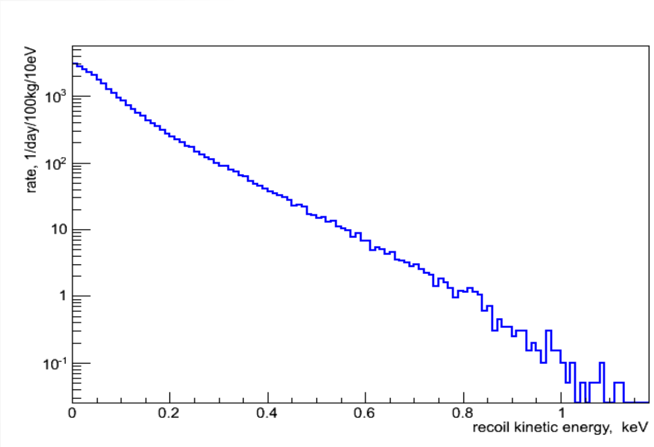
50 m.w.e. provide
reduction factor in
cosmic muon flux ~5

Experiment is funded by Russian Science Foundation under contract #18-12-00135

Energy spectra

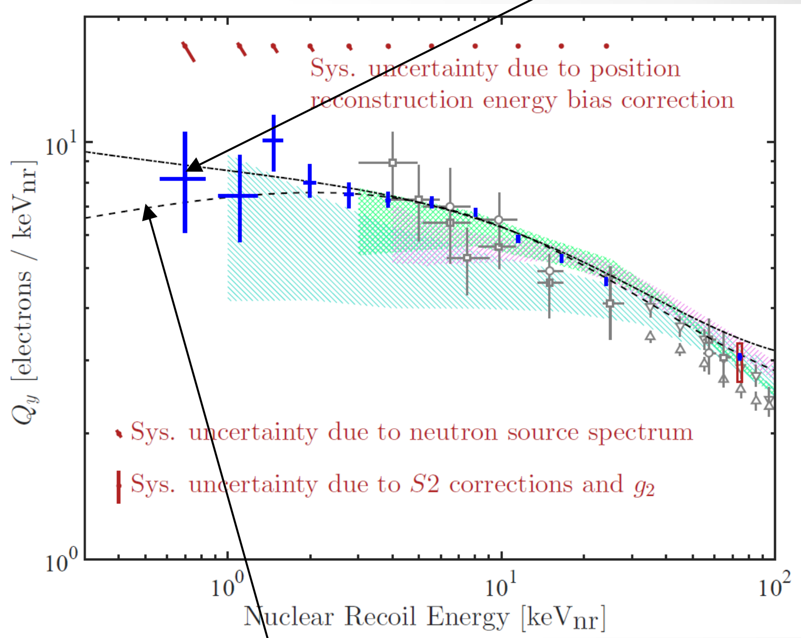


Reactor energy spectrum



Xe recoil energy spectrum for reactor $\tilde{\nu}_e$ lies in sub-kev region

LUX data

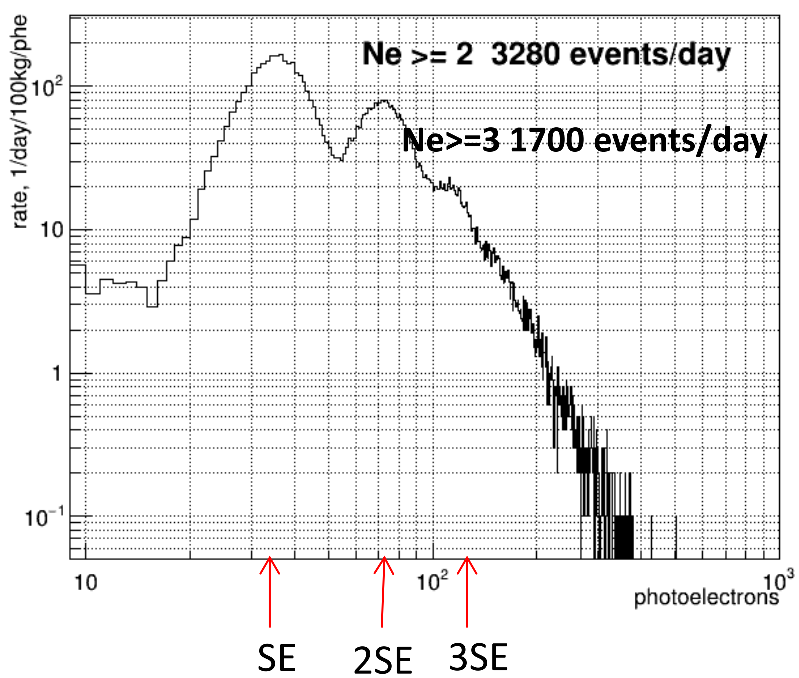


NEST – Noble Element Simulation Technique

Ionization yield for NR in sub-keV region is 7-8 e-/keV

Expected results

Estimated event rate of RED-100 detector for CEνNS is ~ 3300 events/day



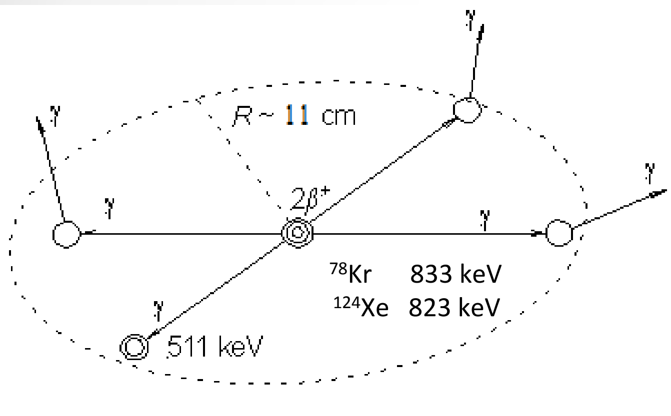
The major n-background induced by cosmic ray muons is expected to be at the same level

So, the effect can be seen in reactor on and off mode

Search for double positron neutrinoless beta decay

$$2\beta^+0\nu: \quad {}^{124}_{54}Xe \rightarrow {}^{124}_{52}Te + 2e^+ \qquad {}^{78}_{36}Kr \rightarrow {}^{78}_{34}Se + 2e^+$$

$$2\beta^+2\nu: \quad {}^{124}_{54}Xe \rightarrow {}^{124}_{52}Te + 2e^+ + 2\nu \qquad {}^{78}_{36}Kr \rightarrow {}^{78}_{34}Se + 2e^+ + 2\nu$$



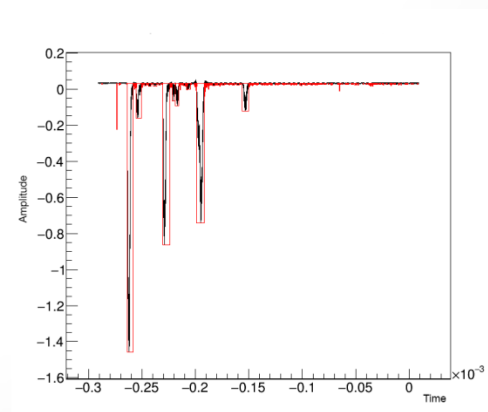
	P(%)	M(A,Z) − M(A,Z−2), keV	$T_{1/2}$, theor. years [1]		$T_{1/2}$, exp. years [2]	
			$(2\beta+)_{0\nu}$	$(2\beta+)_{2\nu}$	$(2\beta+)_{0\nu}$	$(2\beta+)_{2\nu}$
^{78}Kr	0,355	2846	$(1.0\text{-}1.7) \times 10^{28}$	$(4.9\text{-}15.8) \times 10^{25}$	$> 2\times10^{21}$	
^{124}Xe	0,0952	2865	$(2.3\text{-}7.7) \times 10^{28}$	$(1.7\text{-}38)\times 10^{26}$	4.2×10^{17}	2.0×10^{14}

2 β+ event must have larger multiplicity than gammas with the same energy (~ 2800 keV)
Gamma bckg can be rejected at a trigger level by threshold on multiplicity

The event of 2 β+ event must have the very unique signature:
- the central vertex from 2 positrons and four 1-st points of interaction of 511-keV annihilation gammas
- all of them are lying in one plane

^{78}Kr can be dissolved in LXe in amount of ~1 kg
Experiment can be performed at ground level laboratory

Example waveform of multi-vertex event
(DAQ triggered when total EL length > 16 μs)



Conclusion

Two phase liquid xenon detector RED-100 was constructed at Laboratory for Experimental Nuclear Physics of NRNU MEPhI

The first experimental run showed that RED-100 works properly

The experiment on observation CEvNS is possible at KNPP. RED-100 can be transferred to this site this year

THANK YOU FOR YOUR ATTENTION


Прозрачность затвора в РЭД 100 при расстоянии между сетками 3 мм
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Прозрачность затвора, %
4 300,00
4 350,00
4 400,00
4 450,00
4 500,00
4 550,00
4 600,00
Напряжение на нижней сетке, В