Liquid Xenon Detector for CEνNS
From RED-100 to RED-1000

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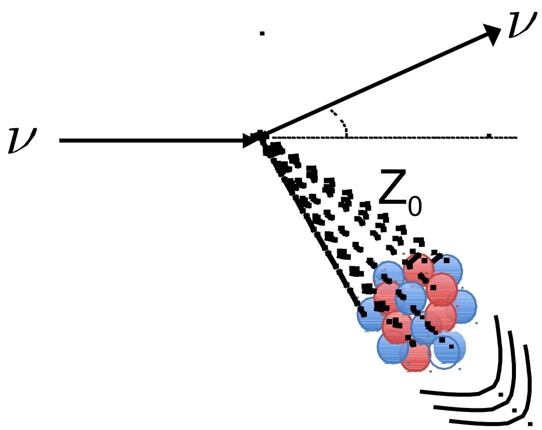
*** SSC RF ITEP of NRC "Kurchatov Institute", ** NRNU Moscow Engineering and Physics Institute**

CEνNS

A coherent elastic neutrino-nucleus scattering (CEνNS):

$$\nu + A \rightarrow \nu + A$$



It is allowed by Standard Model and was predicted theoretically in 1974

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

but has never been observed experimentally because of very low energy transfer

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

CEvNS attempts

There were several proposals for the discovery of this effect

At a nuclear reactor

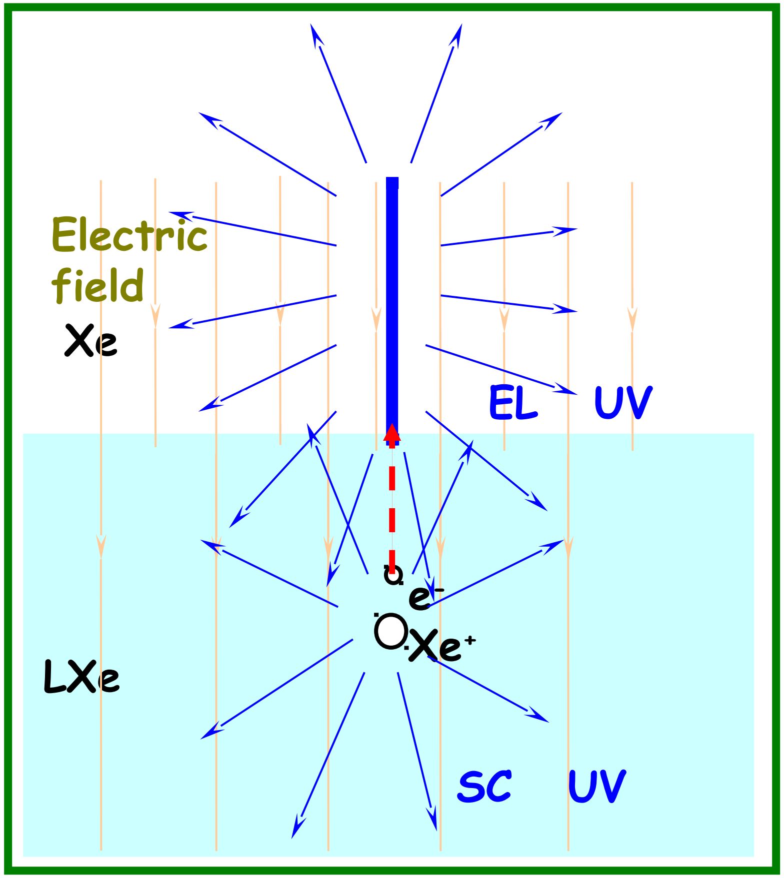
- **Ge detectors**
  - **CoGeNT** *(USA)*, **TEXONO** *(Taiwan)*, *JINR Dubna,*
- **Noble gas detectors**
- **Noble liquid detectors**
  - **LAr Livermore, LXe ITEP&INR, LXe ZEPLIN-III**
- **Bolometric detectors**

At a spallation neutron source

- **LXe ZEPLIN-III (ISIS)**
- **CLEAR (SNS)**
- **COHERENT (SNS)**
  - **LXe, Ge, CsI**

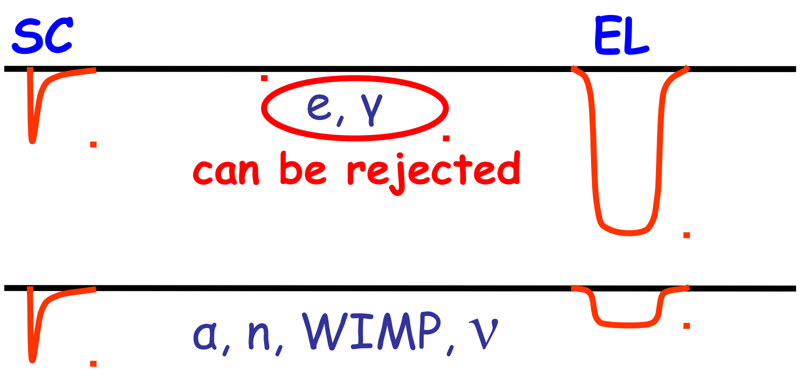
Two-phase detector

Originally introduced:
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

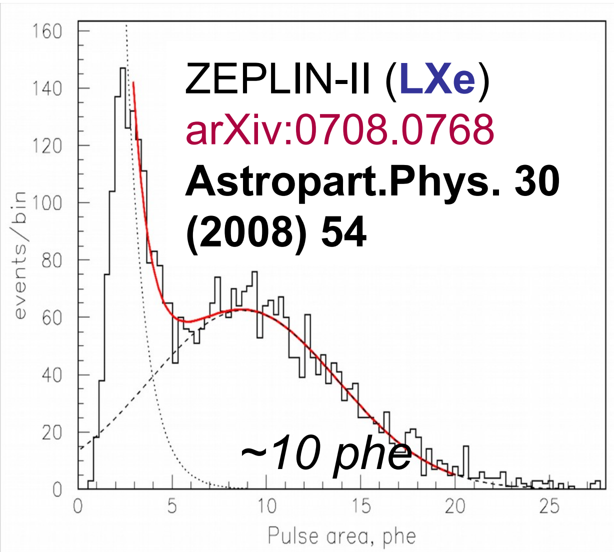


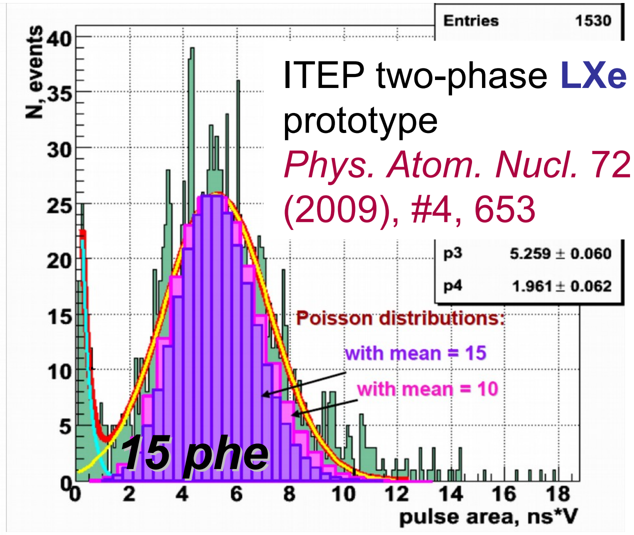
It combines the advantages of gas detectors and the possibility to have the large mass!

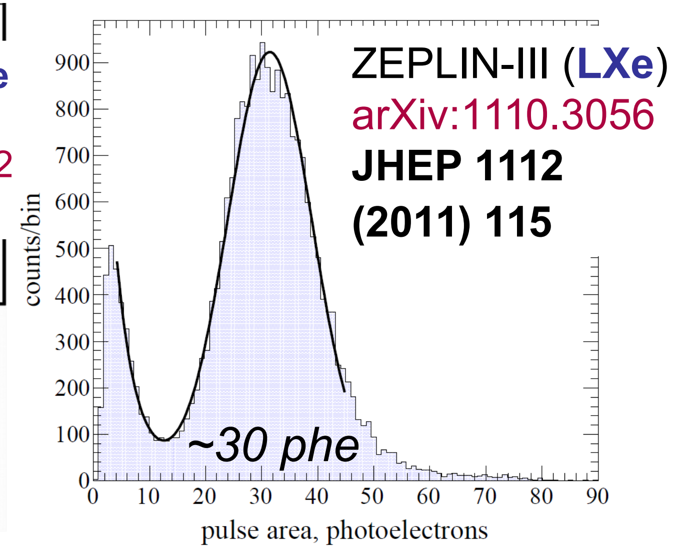
Main features:
- detect scintillation + ionisation
- proportional amplification in EL
- 3d position reconstruction
- ratio SC/EL can distinguish kinds of particles
- wall-less detector construction

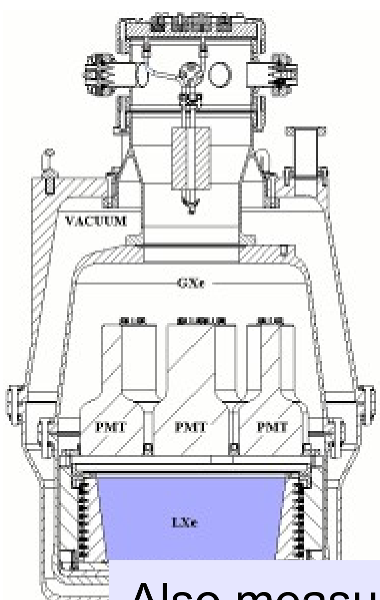


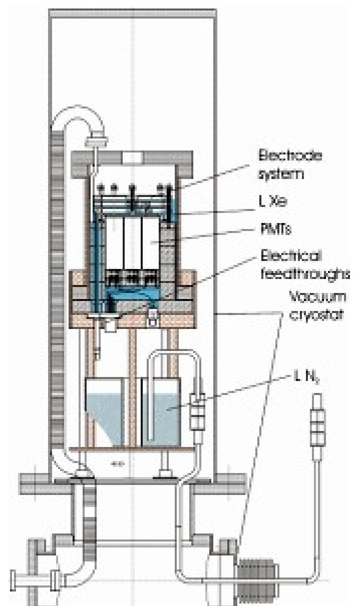
Superior in sensitivity down to a single ionisation electron

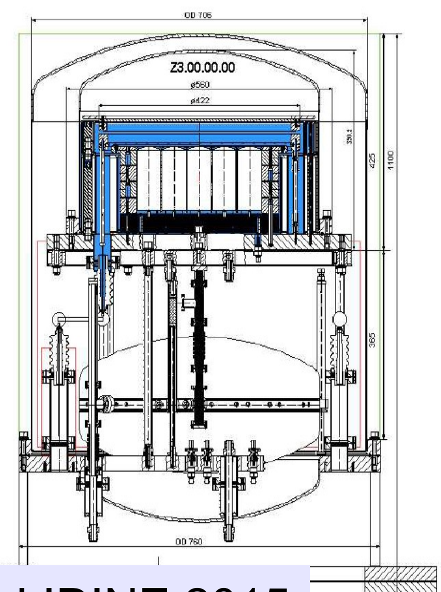










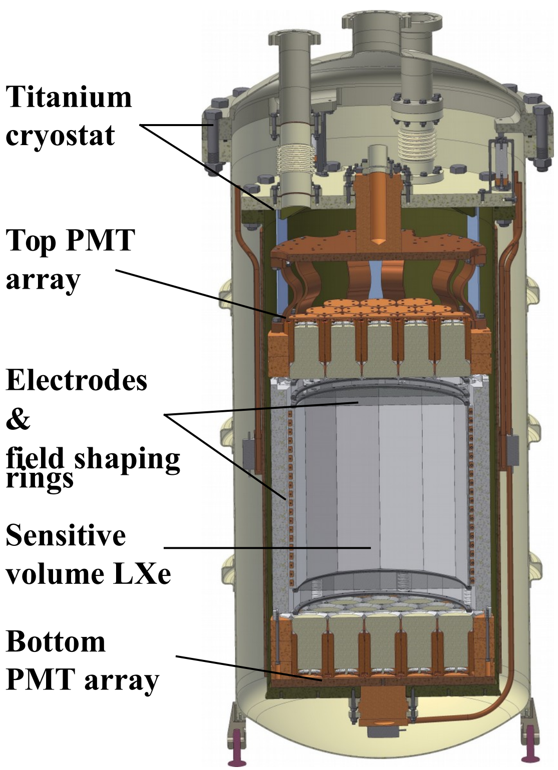


Also measured by PIXeY ~34 phe, D.McKinsey, conf. LIDINE 2015

Р Э Д

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

RED-100 (~100 kg of LXe in FV, ~250kg total) Russian Emission Detector



RED-100 is a two-phase noble gas emission detector. Contains ~250 kg of LXe, ~100 kg in FV.

The sensitive volume is a cylinder ~ 45 cm in diameter and ~ 45 cm in height

Confined by the top and bottom optically transparent grid electrodes and field-shaping rings behind a teflon reflector.

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

Drift field in liquid is ~ 0.5 ÷ 1 kV/cm

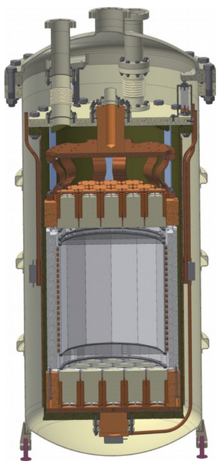
Field in gas (EL region) is ~ 7 ÷ 10 kV/cm

The expected *number of photoelectrons per one ionisation electron* extracted to the gas phase ~ 80.

RED project

The history started in 2011 when we got 5M$ grant from Russian MES

Two options in LOI for the search for CEνNS



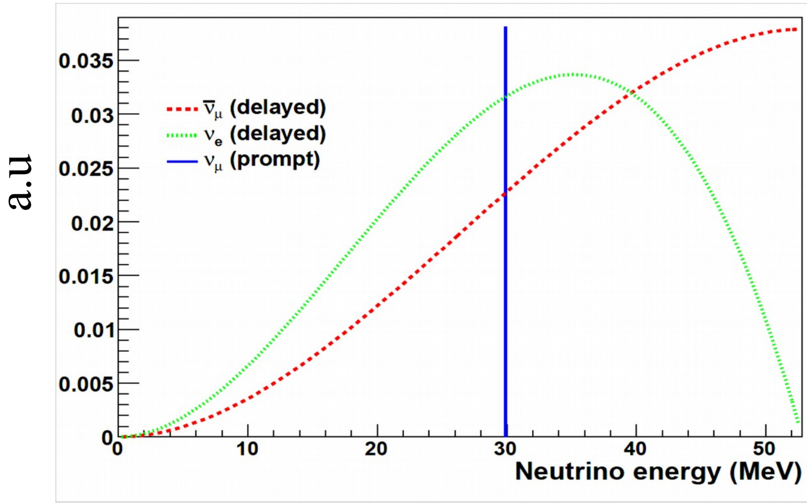
Spallation neutron source (SNS, Oak Ridge National Laboratory, USA)
~ 30 m away

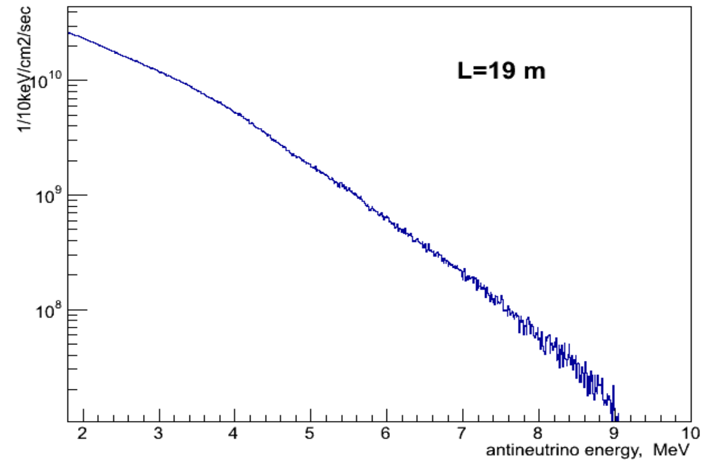
JINST 8 (2013) P10023
arXiv: 1212.1938

Kalinin Nuclear Power Plant, Udomlia, RF
~ 20 m away

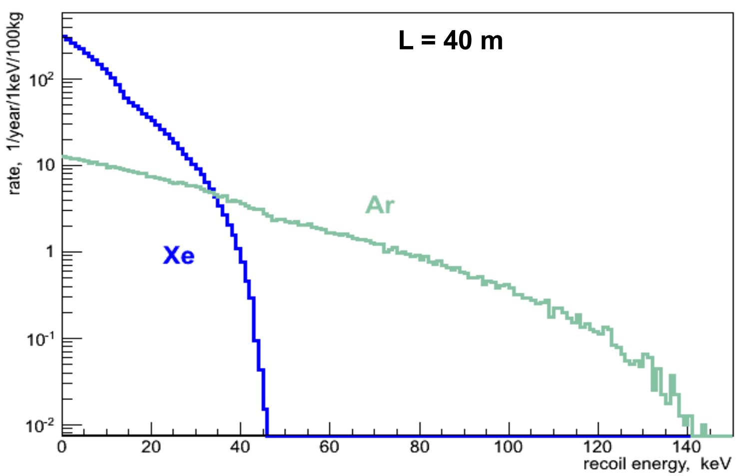
ν and recoil energy spectra

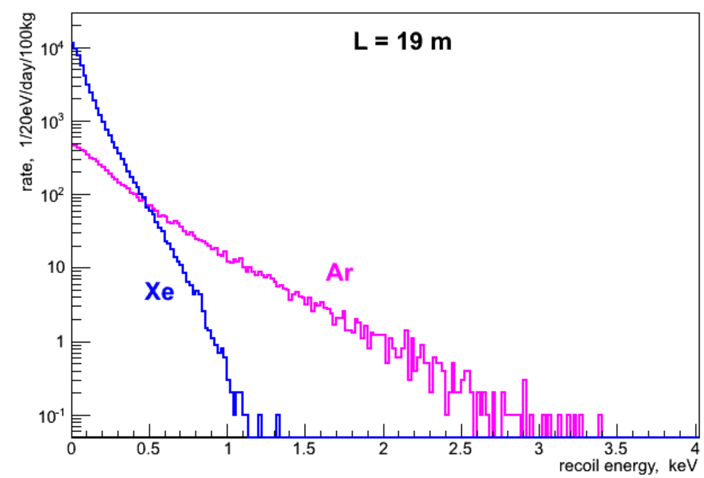
SNS ν energy spectra **Reactor**





Xe and Ar n.r. spectra





Here we suppose Q_y = 8 e^- / keV from B.Lenardo et al. arXiv: 1412.4417

In Mar 2014 the COHERENT collaboration established

COHERENT SNS

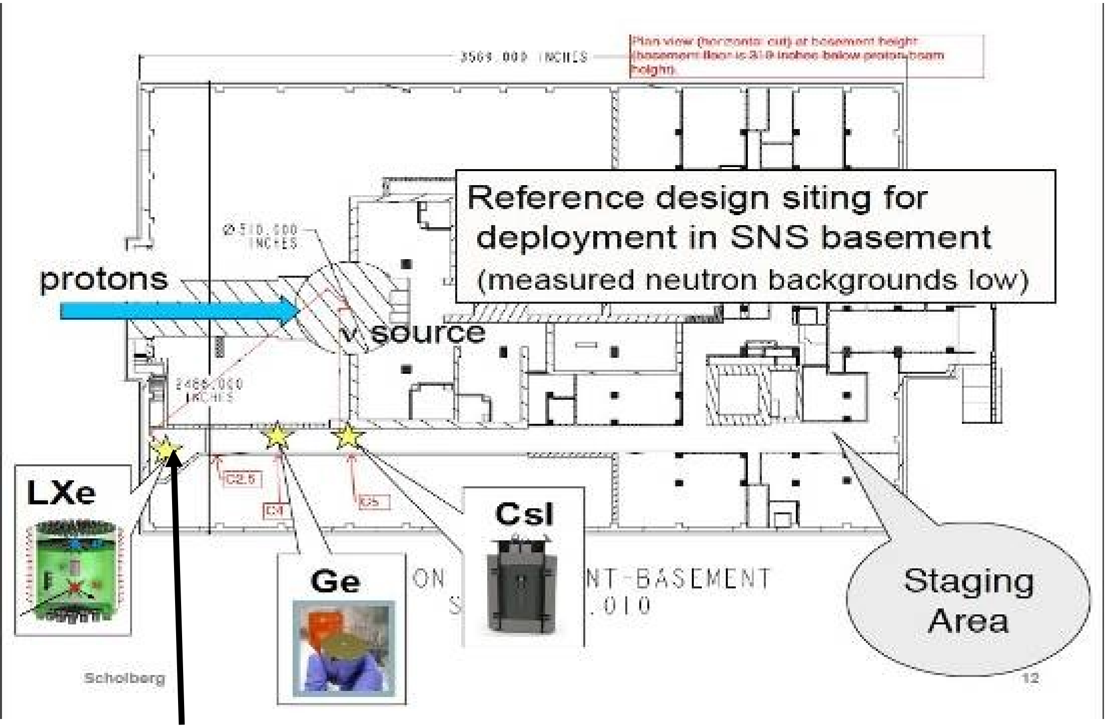
The goal is the discovery of CEνNS using three different detection techniques at SNS:

LXe – RED-100

Ge – Majorana detectors

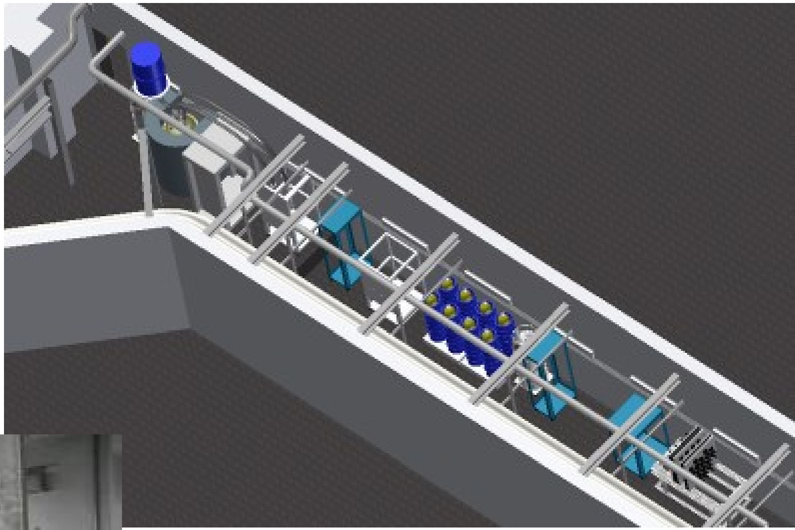
CsI(Na) crystals (CsI and Xe targets has close neutron numbers)

Experimental site at SNS



ν flux ~10^7 cm^{-2}s^{-1} @ 30m

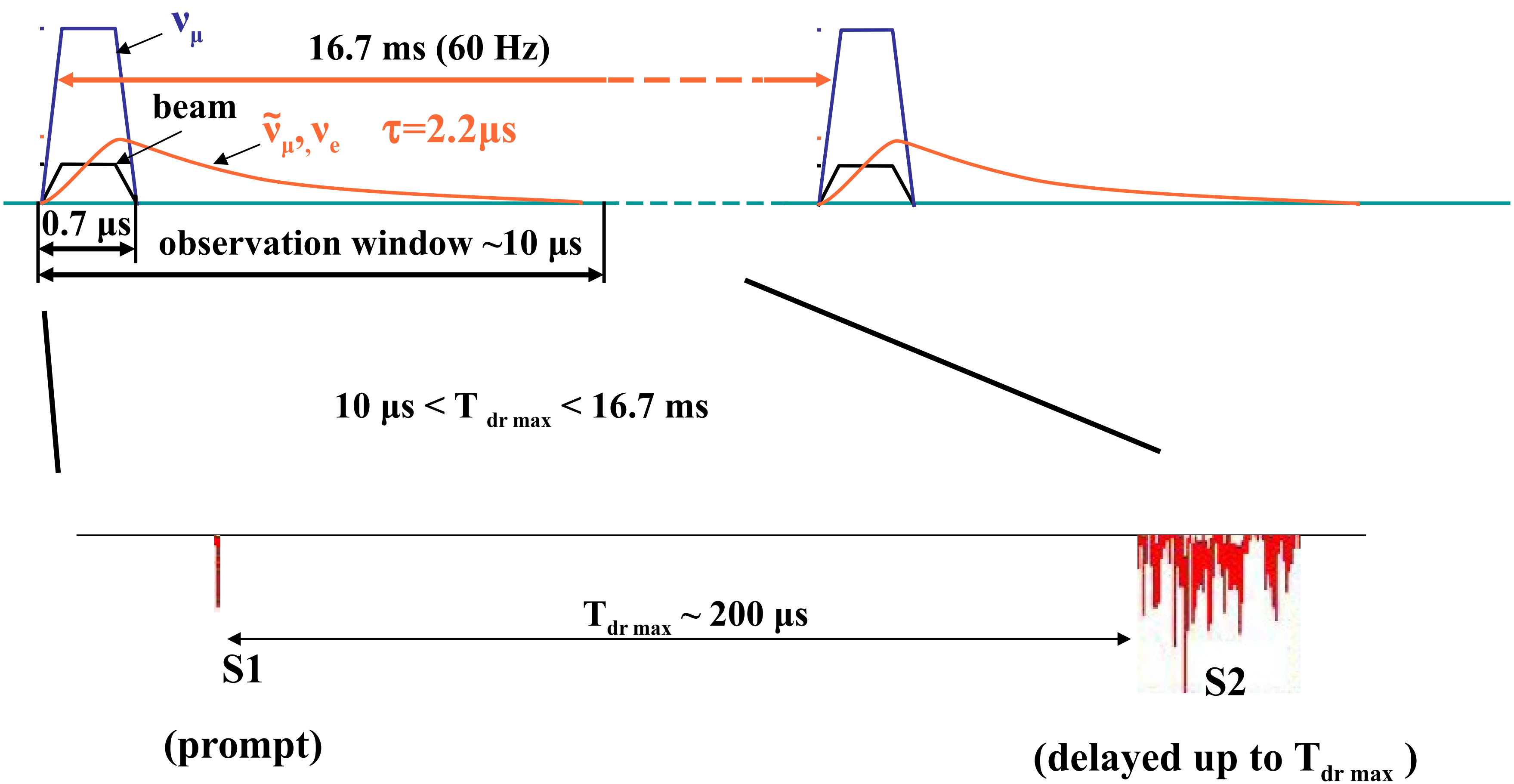
Basement hallway is neutron-quiet place:
beam-related neutron flux is four orders of magnitude lower in compare to that at the experimental floor.
In addition, 8 m.w.e. overburden.



Timing at SNS

SNS pulsed beam is an essential factor in background reduction!

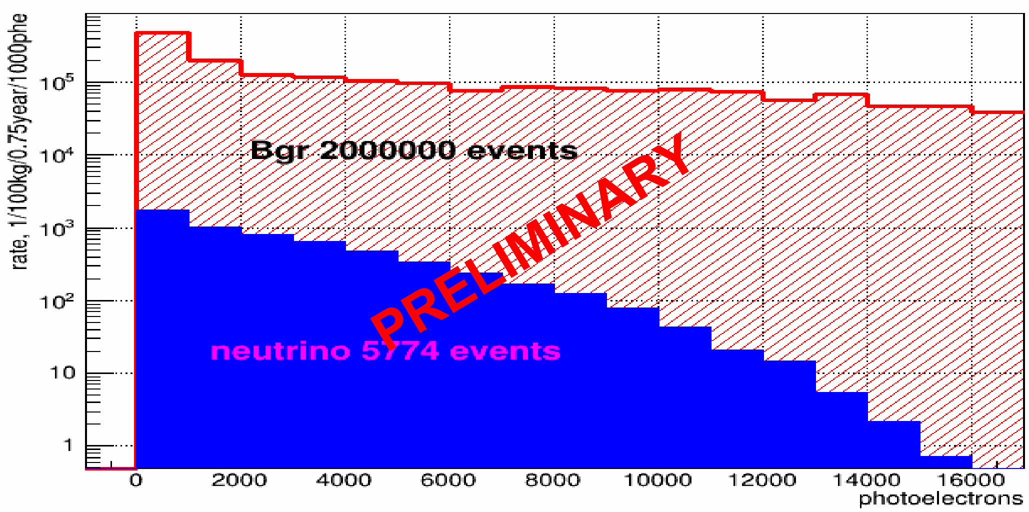
Duty factor = 10 μs/16.7 ms ≈ 1/1600



Unfortunately timing is possible only with S1

Expected gamma-background at SNS

Background modeling for the experimental site (basement)

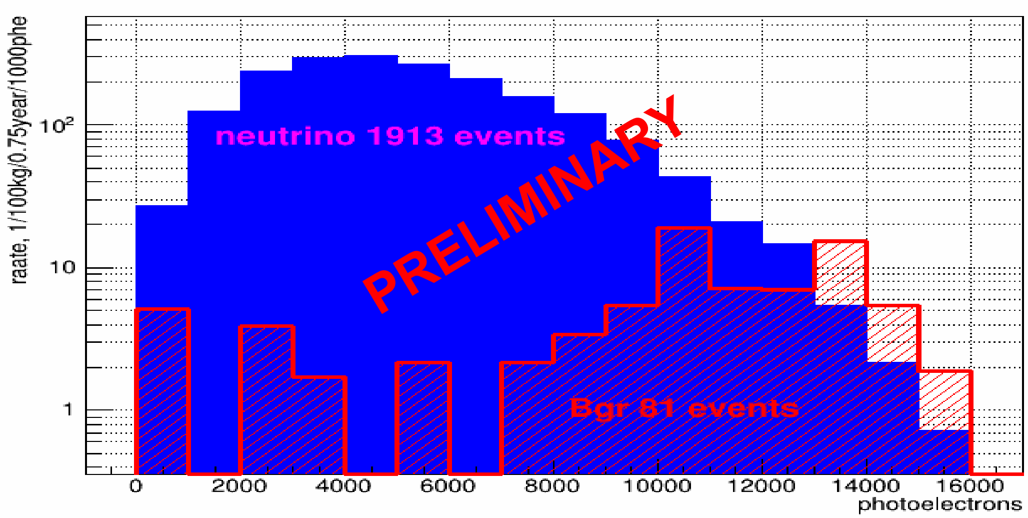


Example of the most serious γ- background from the cryostat

External bckg is shielded by 100 mm Pb

Exposition – 9 months

Without duty factor



gamma

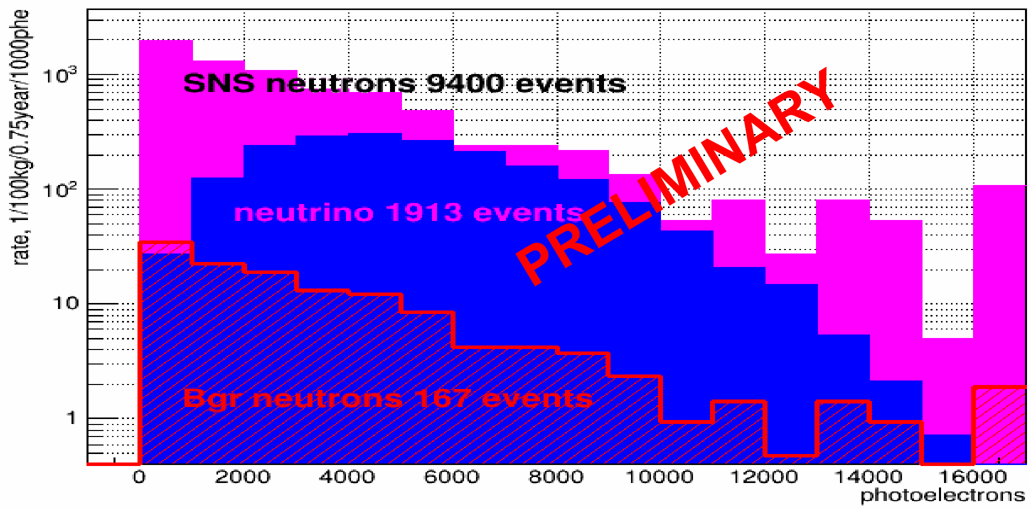
ν-N

With duty factor 1/1600 and with selection S1 ≥ 2 phe

Expected neutron-background at SNS

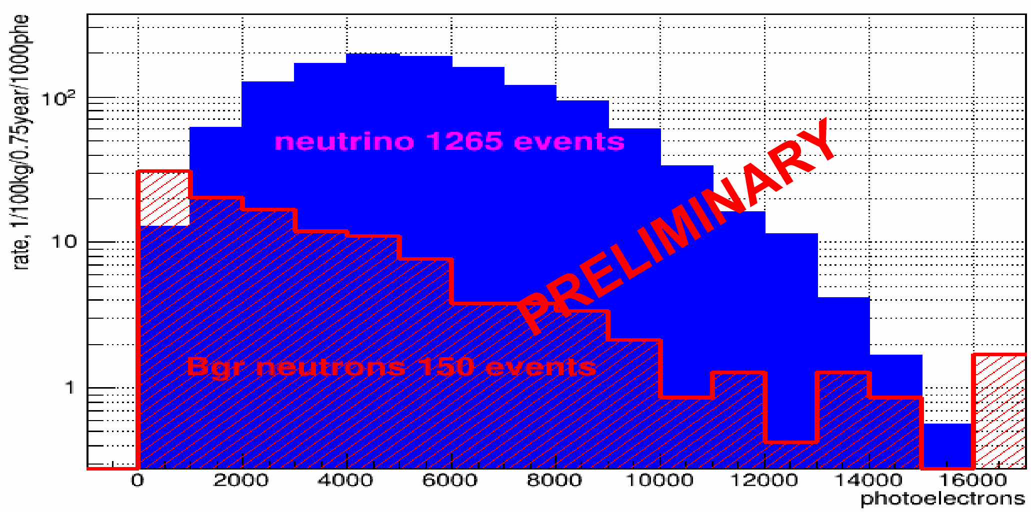
The neutron background simulation is based on the measured neutron flux in the basement

Exposition – 9 months



With duty factor ~1/1600, with selection S1 ≥ 2 phe

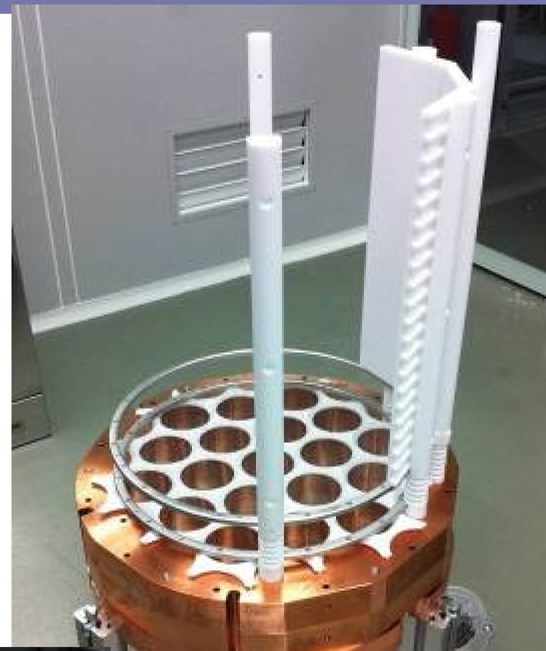
n-N n associated with beam
n-N n not associated with beam
ν-N

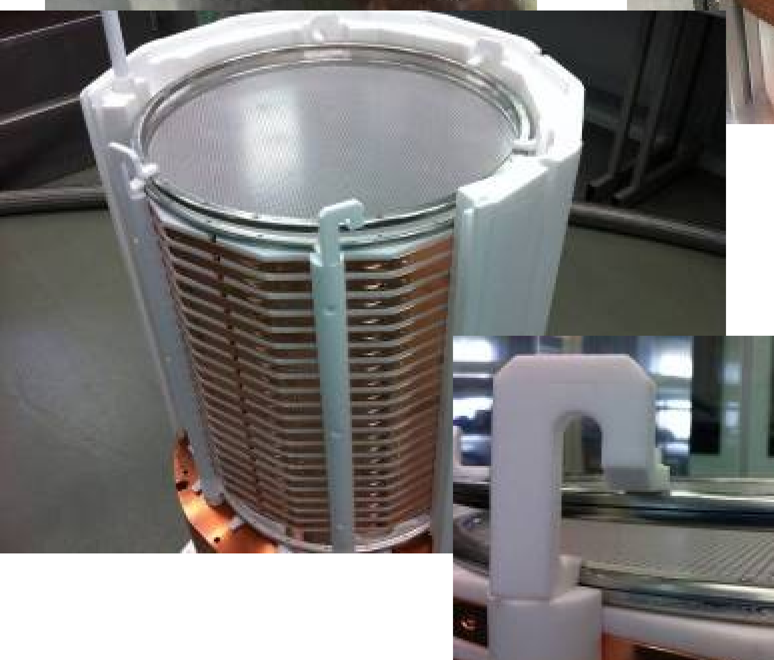


With duty factor ~1/1600, with selection S1 ≥ 2 phe, and with time selection > 1 μs after start of the SNS pulse

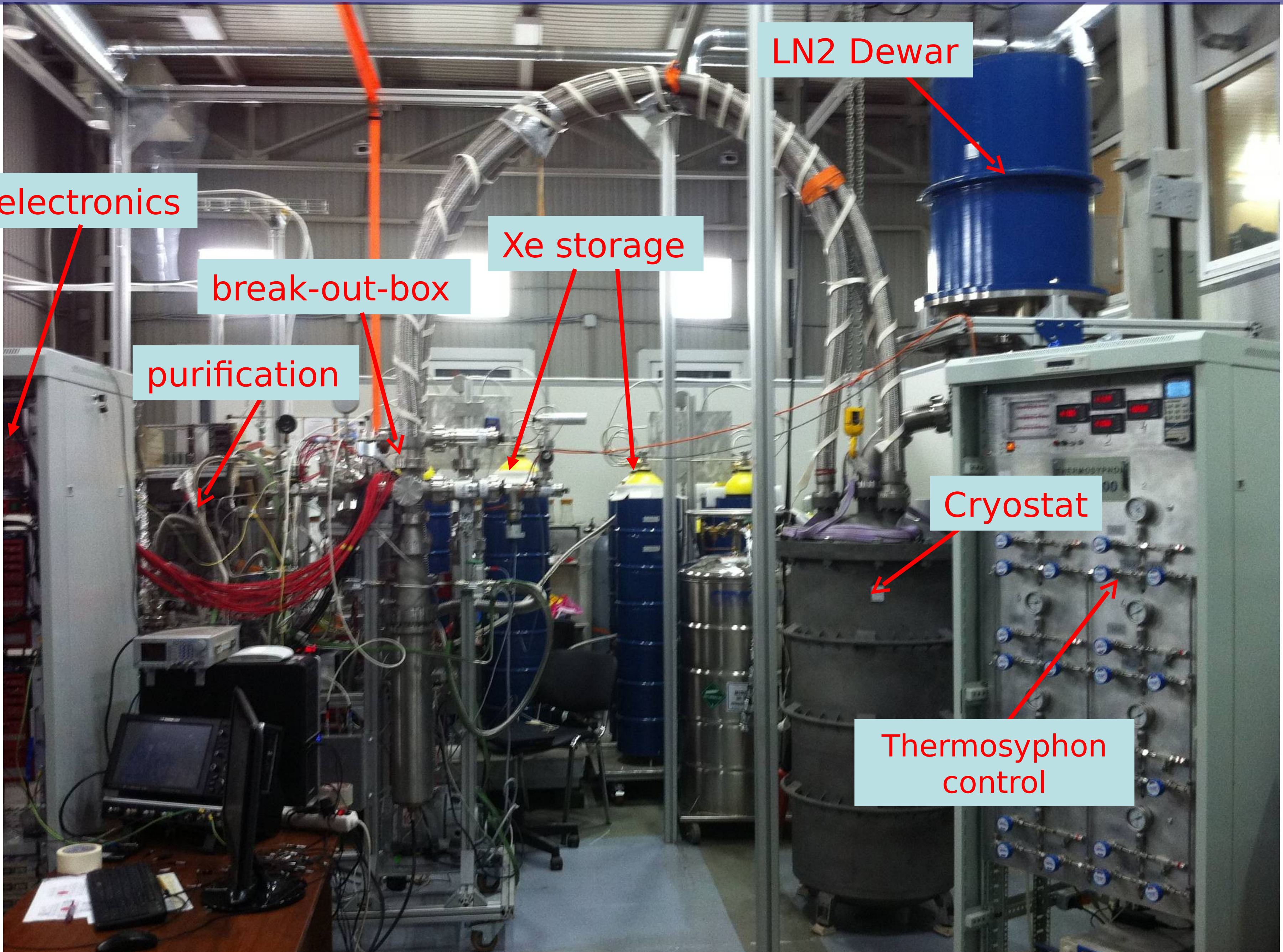
Unfortunately, the ν_μ prompt component is lost in this case

RED-100 detector assembling





RED-100 detector in the lab



Beyond COHERENT

What can we do after the discovery of CEνNS?

At present, there is an intensive work around the world on development of the next generation of relatively compact neutrino detectors for nuclear reactor monitoring

WHY CEνNS IS ATTRACTIVE FOR REACTOR MONITORING?

Because of $\sigma \sim N^2$

For coherent neutrino scattering on Xe nucleus $\langle\sigma\rangle \approx 7\cdot10^{-41}$ cm^2

For inverse beta decay (IBD) on proton, $\tilde{\nu} + p \rightarrow e^{+} + n$ $\langle\sigma\rangle \approx 1\cdot10^{-43}$ cm^2

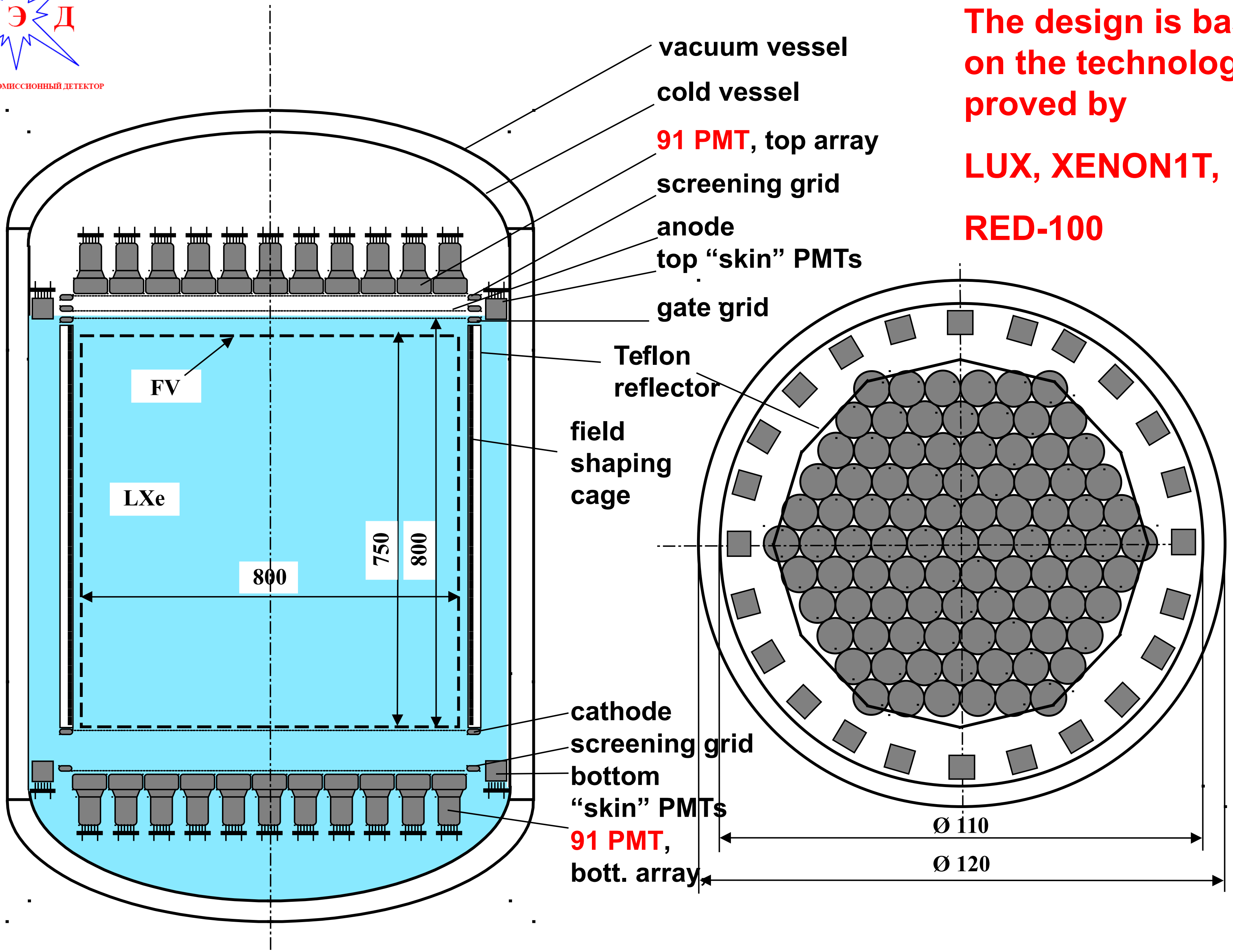
DANSS, KASKA, iDREAM, Nucifer, CORMORAD are based on IBD

The study was started in late 70s by Kurchatov Institute at Rovno NPP.

Similar study was done at San Onofre NPP

Also, reactor as a neutrino source is interesting for physics because it emits pure electron antineutrino

RED-1000 schematic design (~1000 kg of LXe in FV)



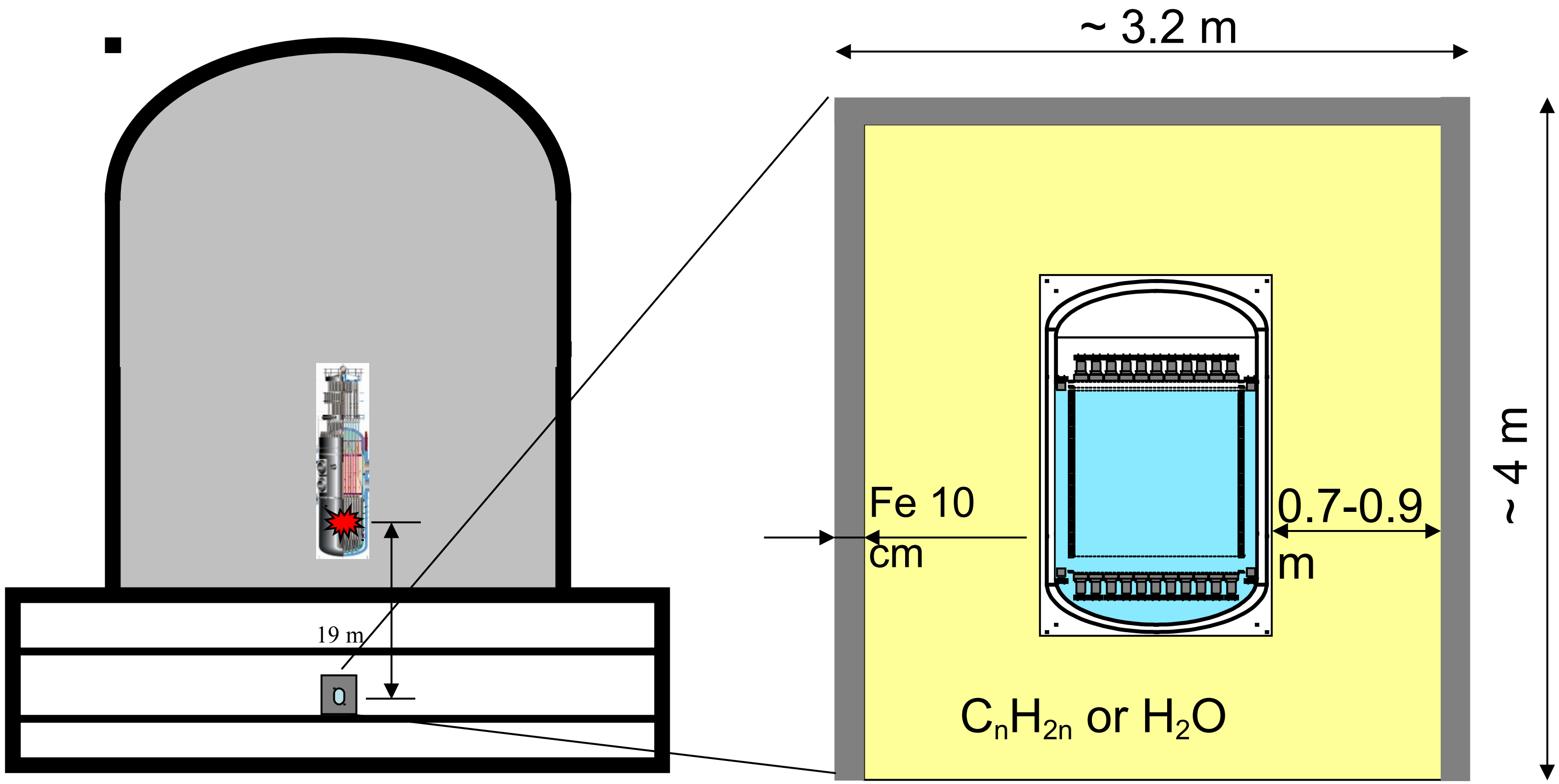
The design is based on the technology proved by

LUX, XENON1T,

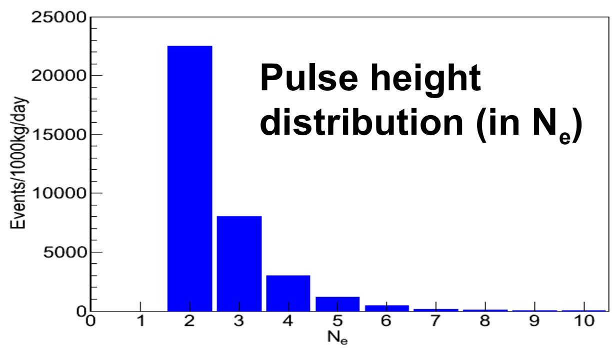
RED-100

Layout of RED-1000 at WWER-1000 reactor (KNNP)

What can we do with this detector?



At this location: $\tilde{\nu}$ flux = $1.35\cdot10^{13}$ $cm^{-2}s^{-1}$; μ flux is reduced by factor ~5



Count rate **~ 35k** events/day (trigger on $N_e \geq 2$)

0.4 Hz; like a Geiger counter!

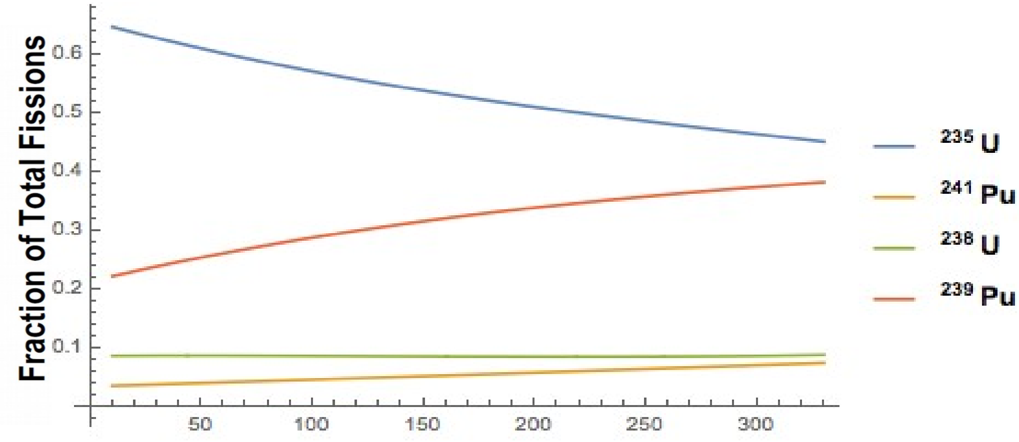
~ 13k events/day (trigger on $N_e \geq 3$)

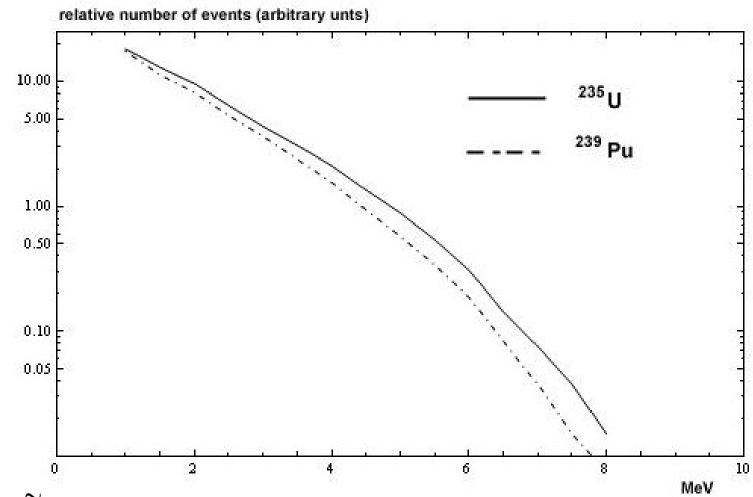
This is enough for DAILY monitoring of power with statistical accuracy ~ 0.5%; $N_e \geq 2$

(~ 0.88%; $N_e \geq 3$)

What can we do using this detector?

Fuel composition monitoring





201.7 MeV / fiss. ^{235}U
210.0 MeV / fiss. ^{239}Pu

$\tilde{\nu}$ energy spectra for ^{235}U and ^{239}Pu

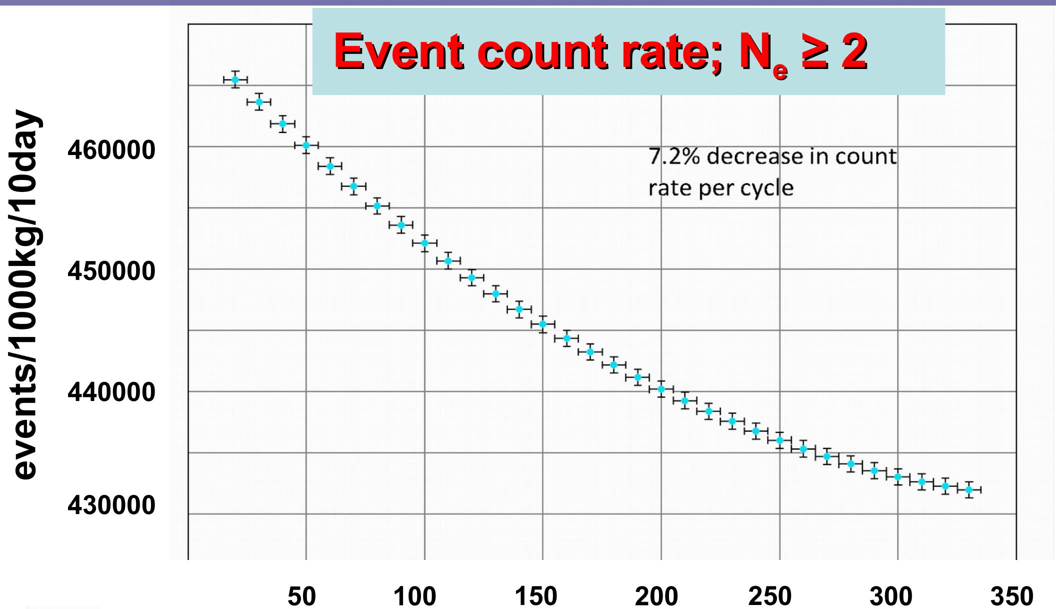
This results in decreasing (at constant power) of $\tilde{\nu}$ flux by ~ 0.15% /10 days
count rate by ~ 0.2% /10 days

$N_e \geq 2$: $3.5 \cdot 10^5$ events/10day **=> statistical accuracy ~ 0.17%**

$N_e \geq 3$: $1.3 \cdot 10^5$ events/10day **=> statistical accuracy ~ 0.28%**

Detector CAN see variation of the $\tilde{\nu}$ flux
due to fuel burn-up in real time

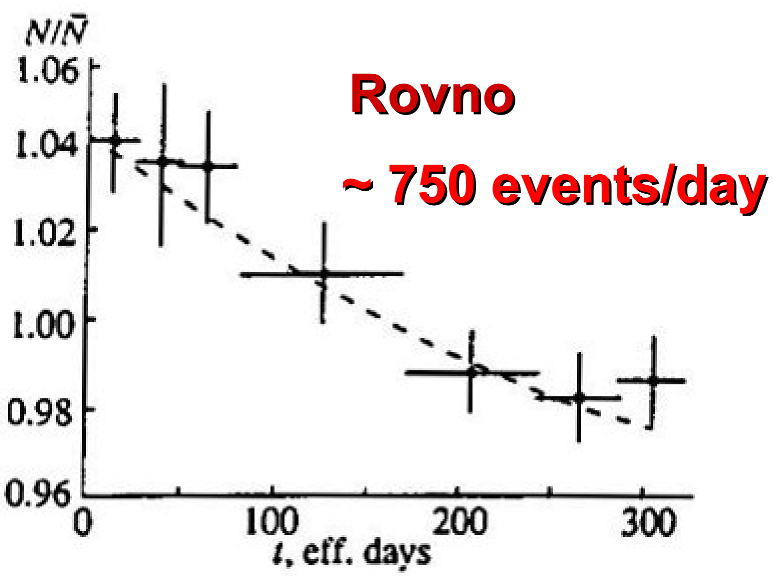
What can we do using this detector?

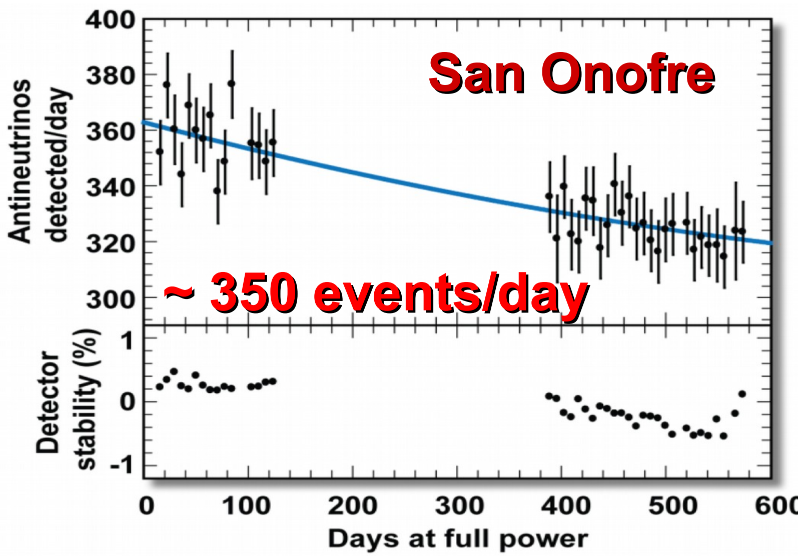


Precise measurement of the count rate evolution!

This should be compared with IBD detectors

at the same place (19m), 1-ton IBD detectors (30% eff.) will have <2000 events/day
a new generation (DANSS claims 70% eff.) might rise to ~ 3000–4000 events/day





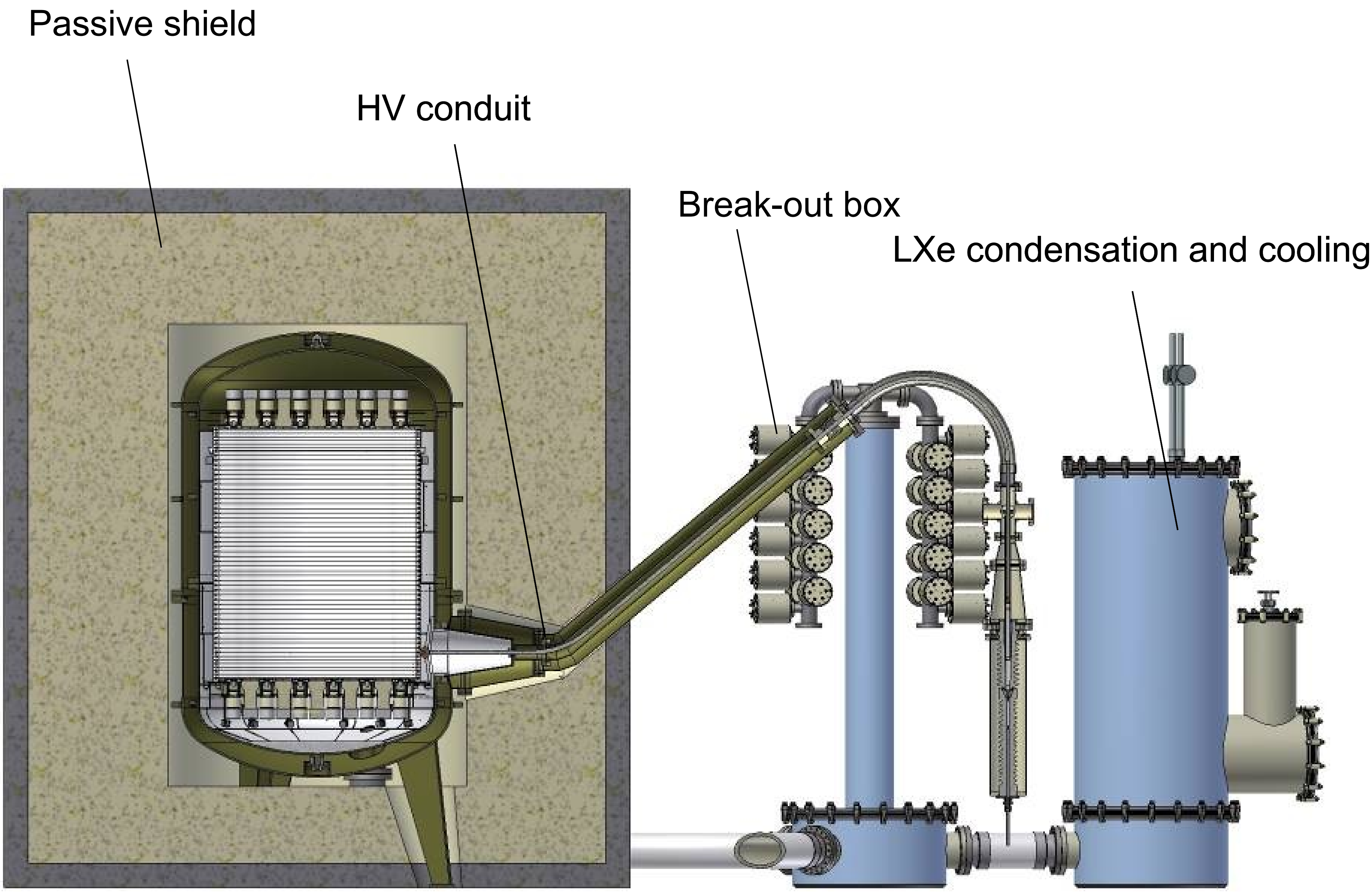
SUMMARY

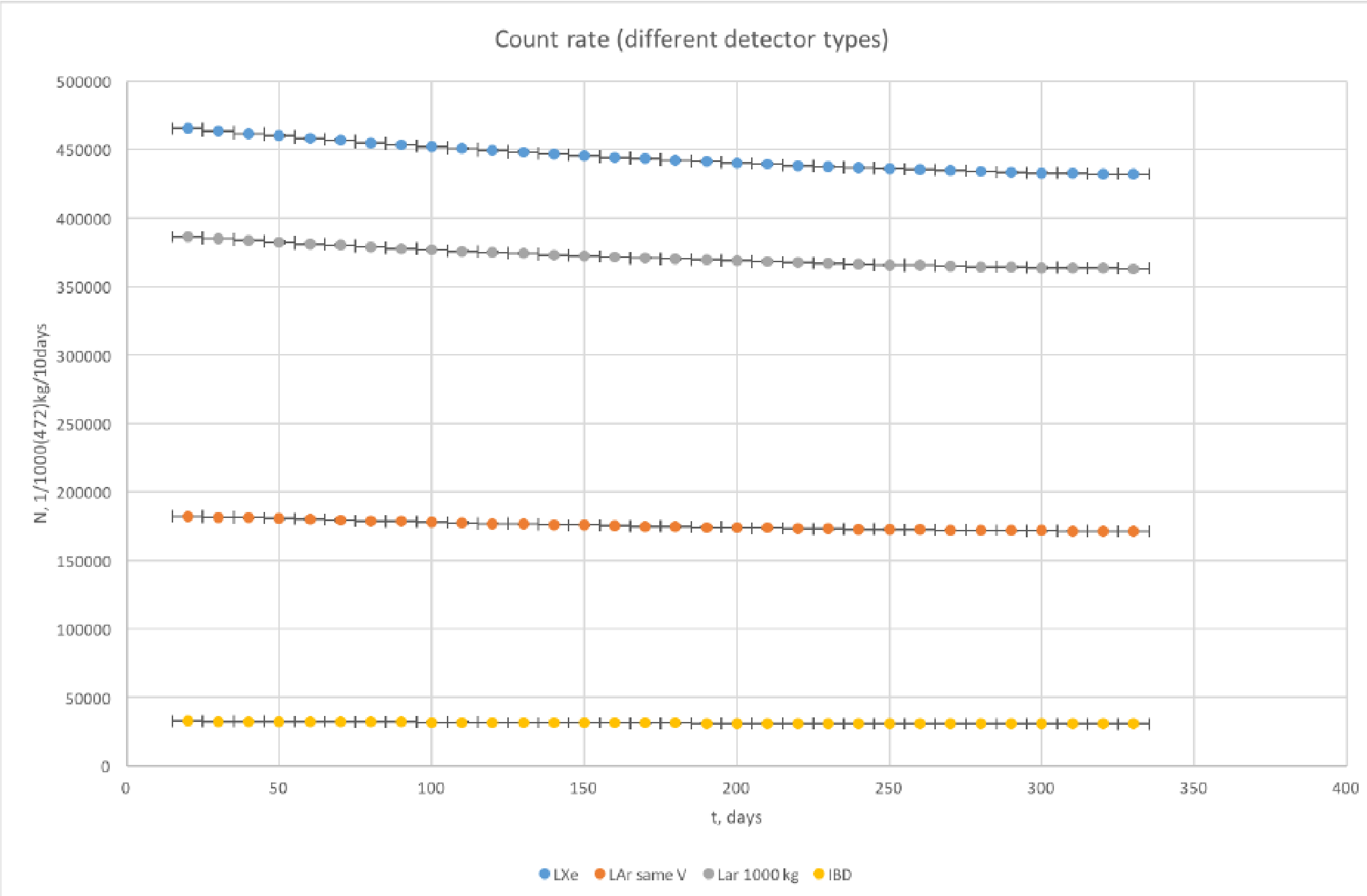
- RED-100 detector as a part of COHERENT experiment is capable to detect the CEνNS with the high signal-to-noise ratio

- After discovery of this process, the technique of RED-100 can be scaled up to a ton-mass detector RED-1000 for nuclear reactor monitoring

- Statistical accuracy of neutrino flux measurements (for 10-day intervals) will be of the same magnitude as the variation of the neutrino flux due to fuel burn-up: observation of fuel burn-up in real time

Engineering design of RED-1000





Count rate (different detector types)
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
N, 1/1000(472)kg/10days
0
50
100
150
200
250
300
350
400
t, days
LXe
LAr same V
Lar 1000 kg
IBD