Alexander Bolozdynya

(NRNU MEPhI)

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

RUSSIAN EMISSION DETECTOR

2012

RED (Russian Emission Detector) Collaboration

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CREDO

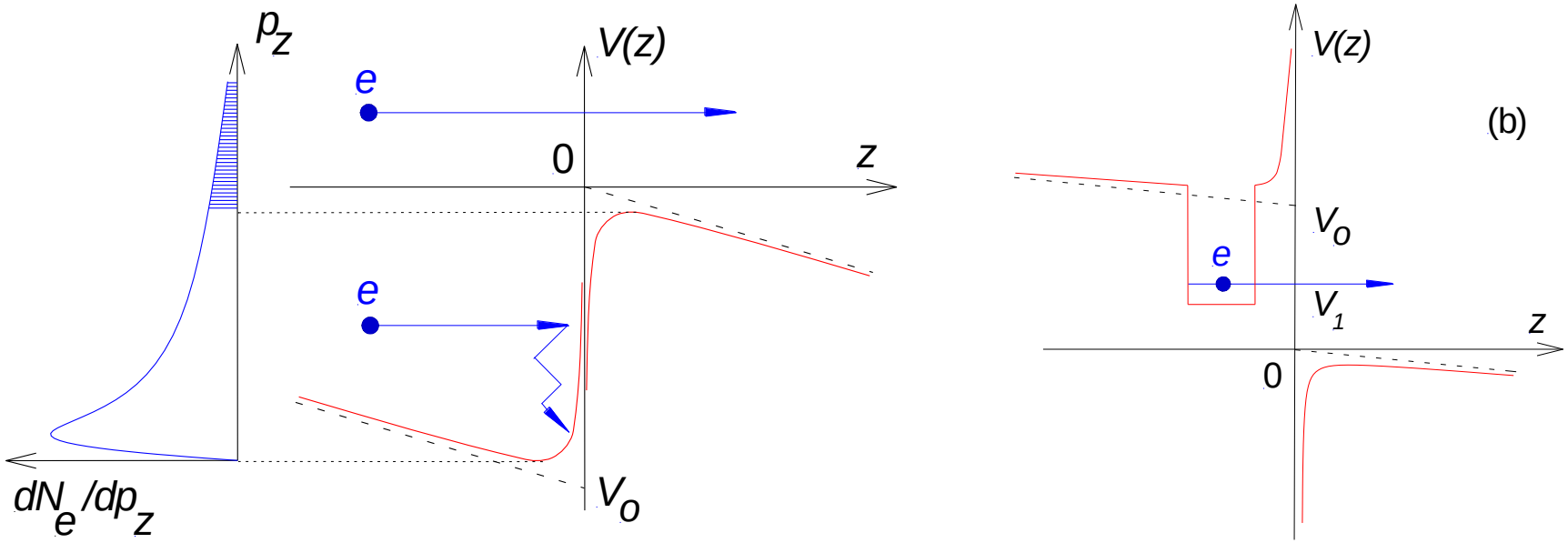
RED is focused on development of two-phase noble gas emission detectors with single electron sensitivity to ionization and >100 kg mass of working media

As part of the program, the liquid xenon 5 kg model of the detector RED-1 is going to be tested at the horizontal channel of the IRT MEPhI 2.5 MW research reactor. The primary goal is to investigate scintillation and ionization yield of liquid xenon stopping heavy nuclear recoils in the range of kinetic energy of below 1 keV. The quasi-monochromatic neutron beam with average energy of 24±1.5 keV and $10^3 cm^2 s^{-1}$ flux density has to be formed with aluminum-iron interferential filter.

RED-100 is being developed for detection of neutrino coherent scattering off heavy nuclei. Beyond probing the Standard Model the coherent scattering can be used for development of a new generation of neutrino detectors monitoring active core of industrial nuclear reactors on the subject of Pu to U ratio.

Emission Detectors

Quasi-free electron emission from nonpolar dielectrics

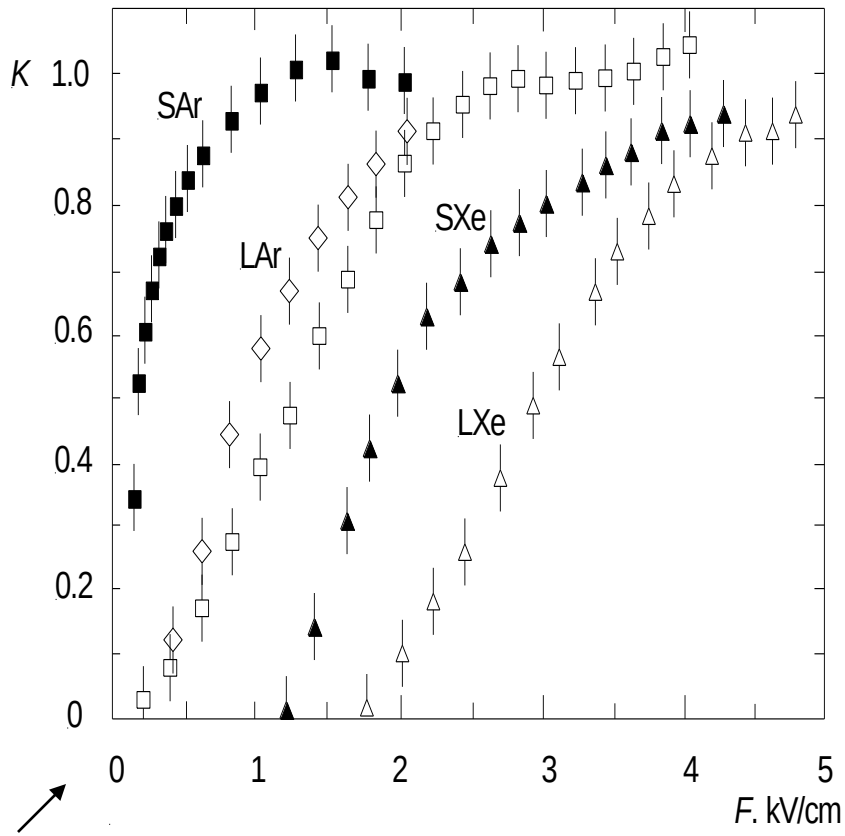


$$V_1(z) = V_0 - eF_1 z + eA_1, z < 0$$

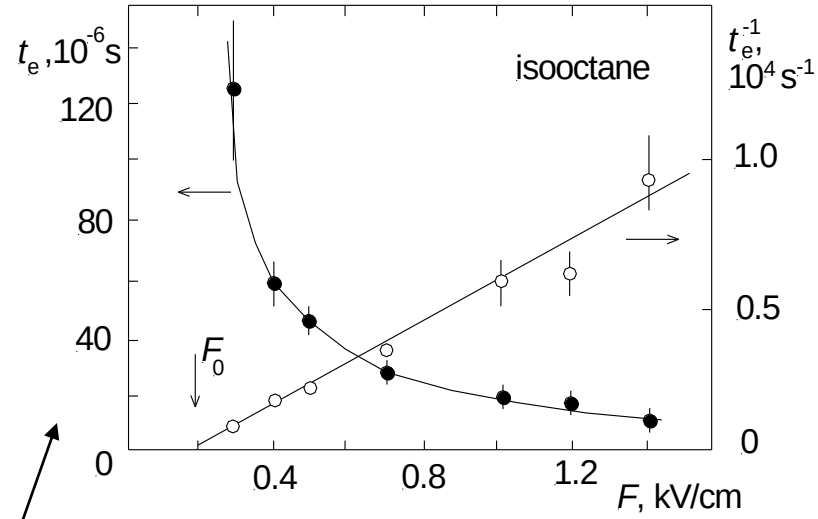
$$V_2(z) = -eF_2 z + eA_2, z > 0$$

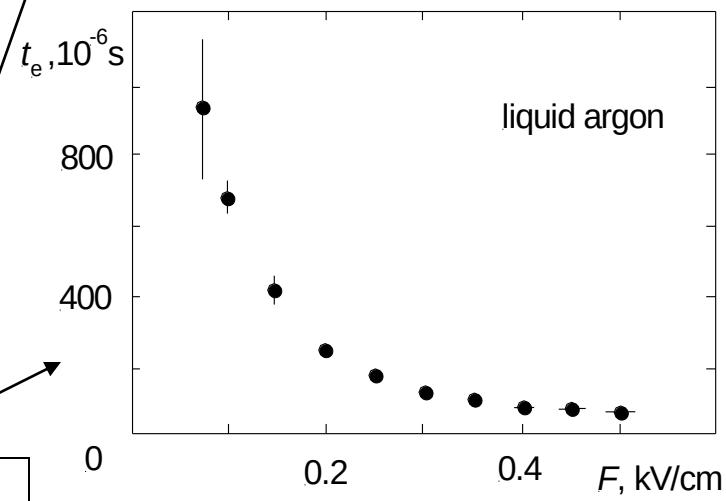
$$A_{1,2} = -e(\varepsilon_1 - \varepsilon_2) / \left[4\varepsilon_{1,2}(z + \xi z/|z|)(\varepsilon_1 + \varepsilon_2)\right]$$

Probability of emission of quasi-free electrons from some non-polar dielectrics



Hot electron emission

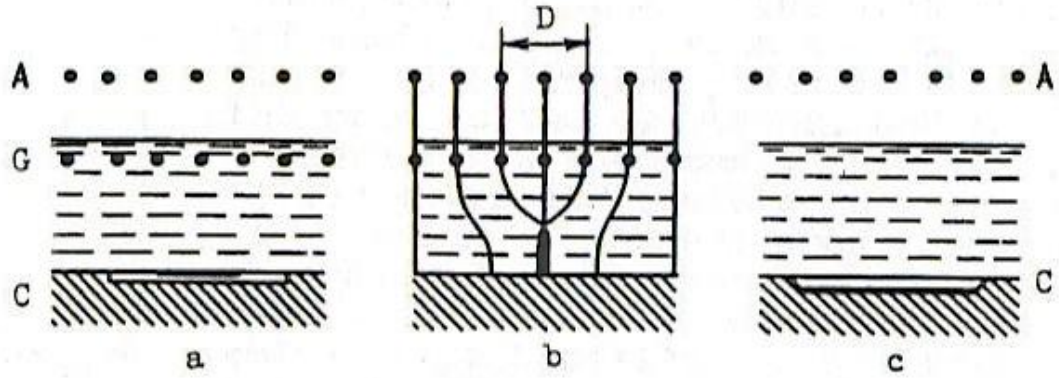




Thermoelectron emission

$$t_e \sim (\Lambda / v_d) \exp\{[V_0 - 2eA_1^{1/2}(1 + A_2^{1/2} / A_1^{1/2})F^{1/2}] / k_B T\}$$

1969-70 Emission method of detection

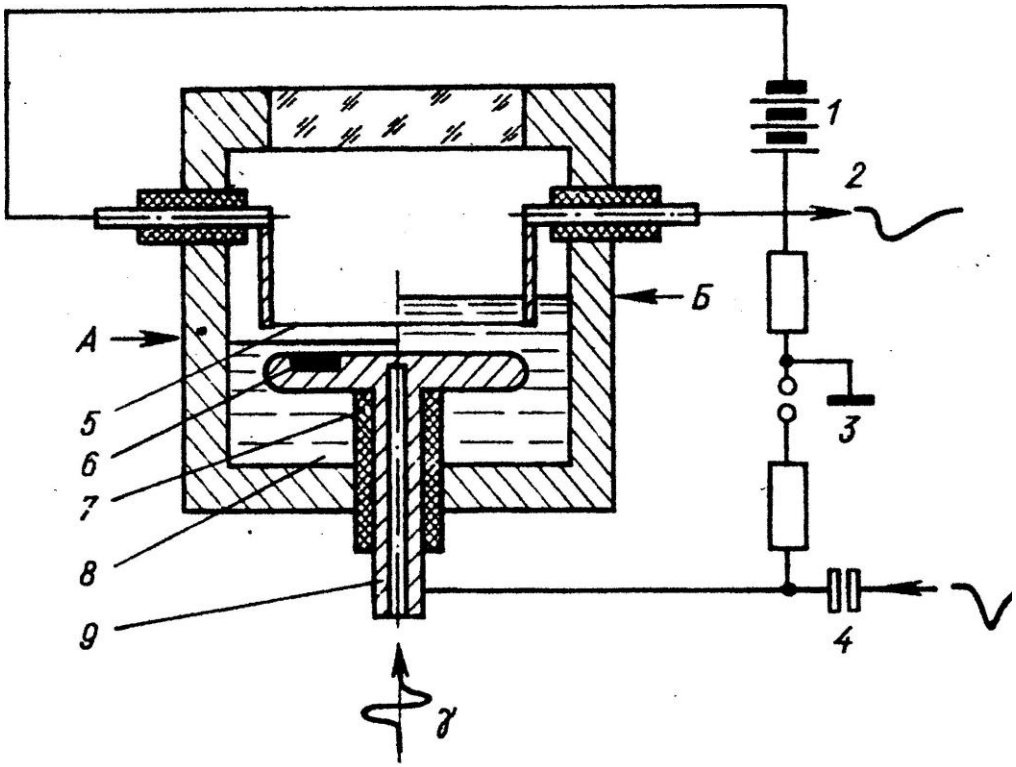


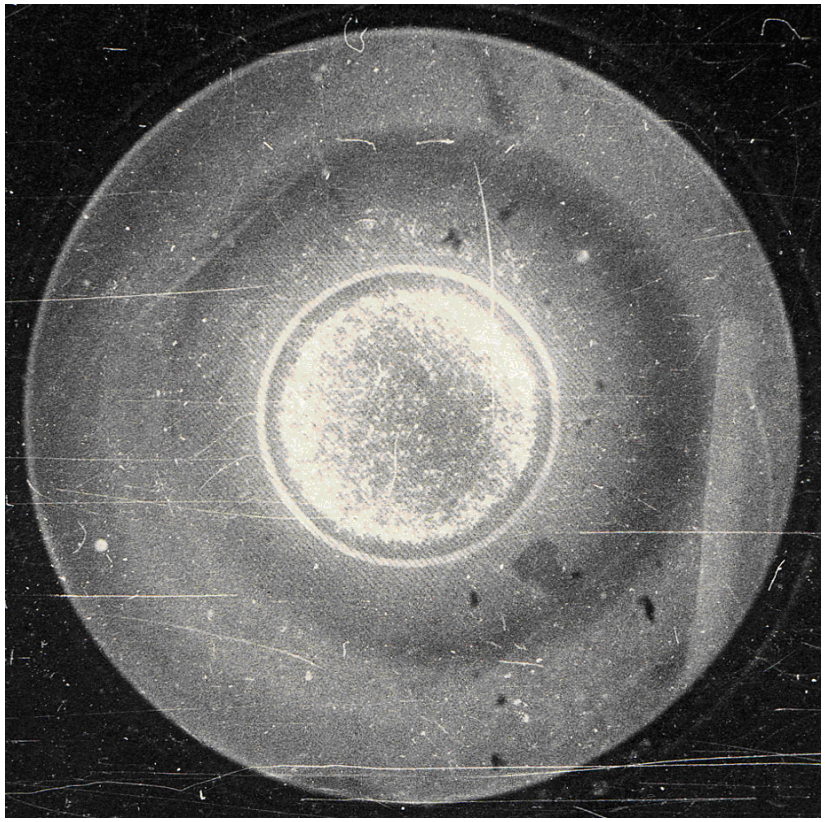
B.A. Dolgoshein

B.U.Rodionov

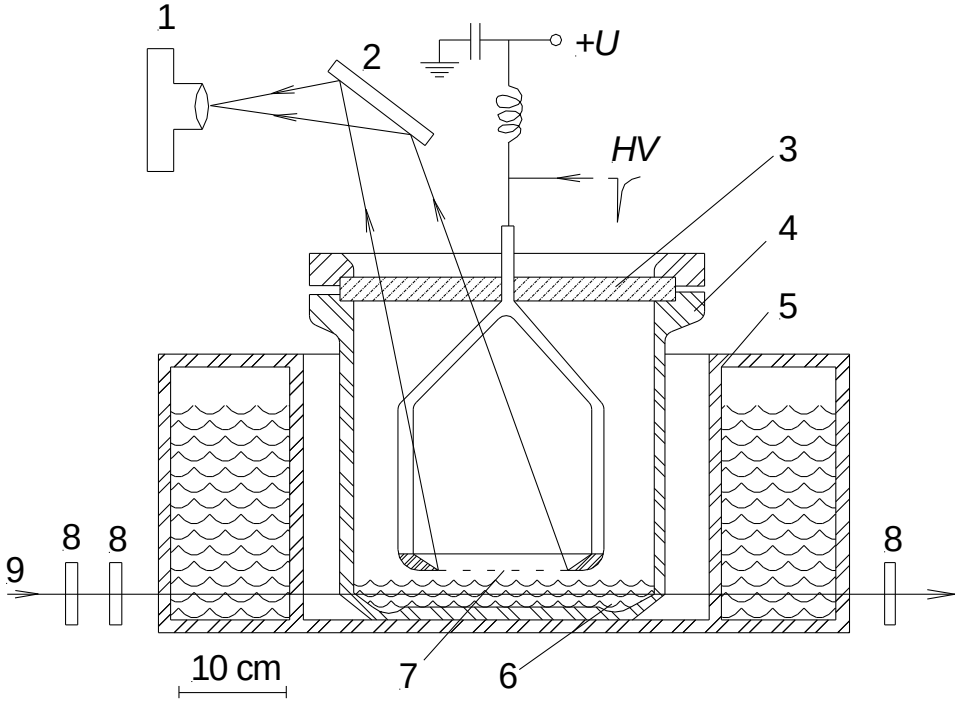
V.N.Lebedenko

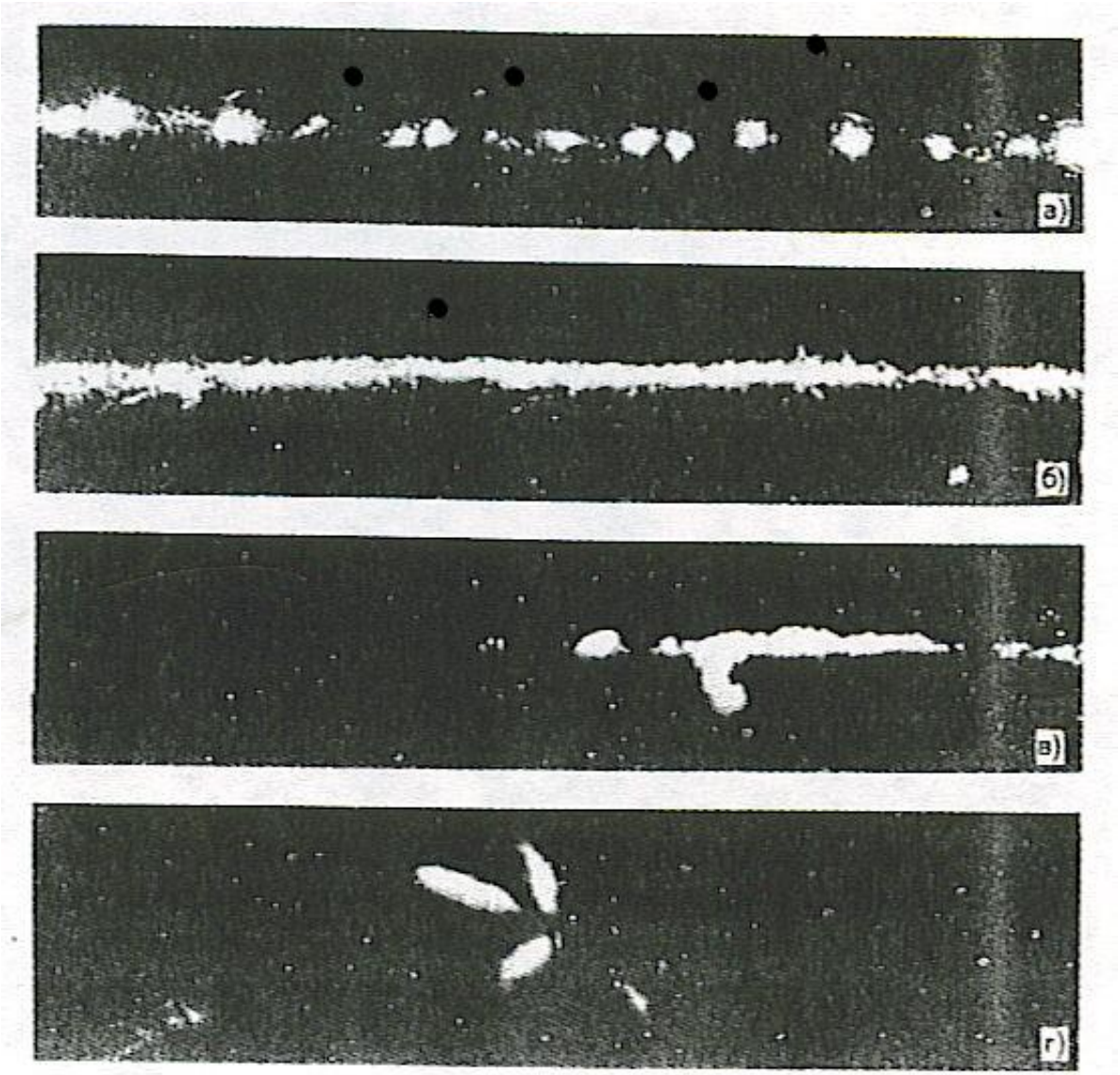
1970-73 Emission Spark Chamber





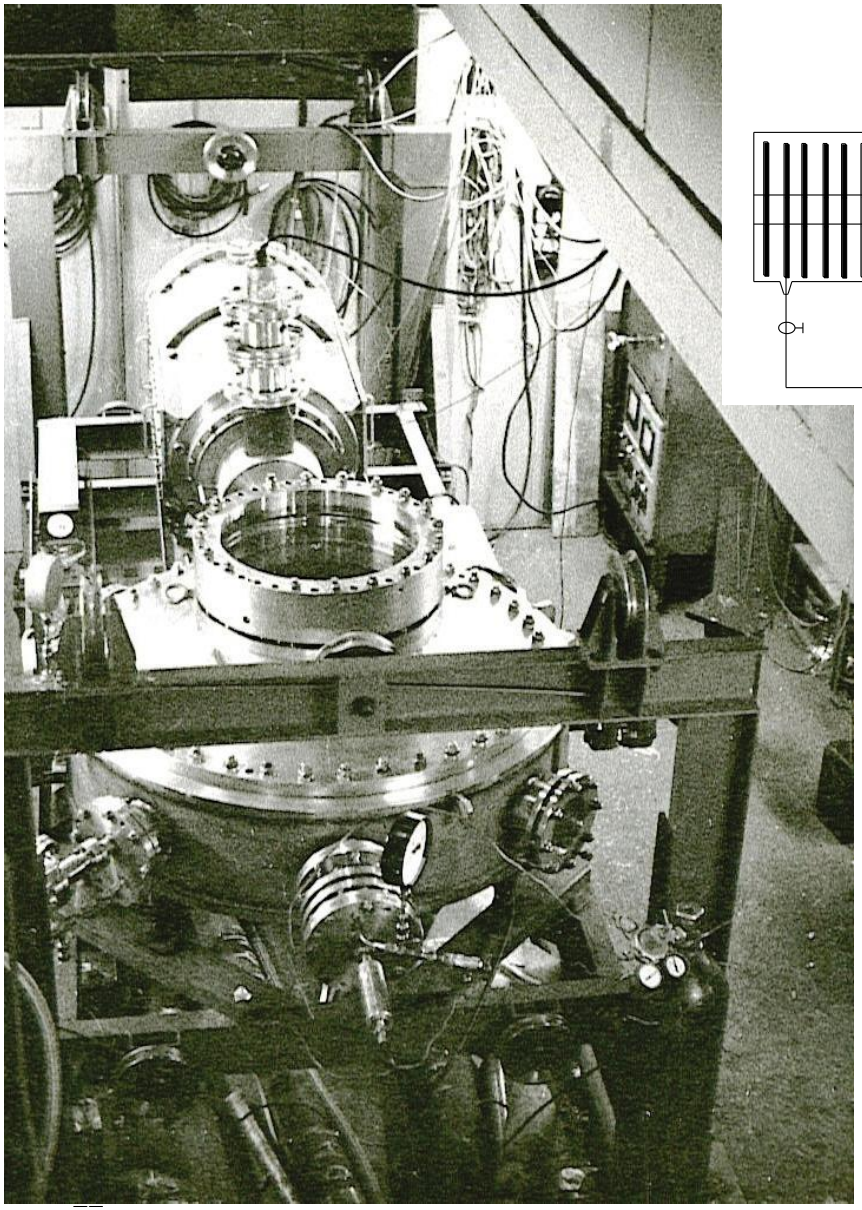
1977 Emission streamer chamber

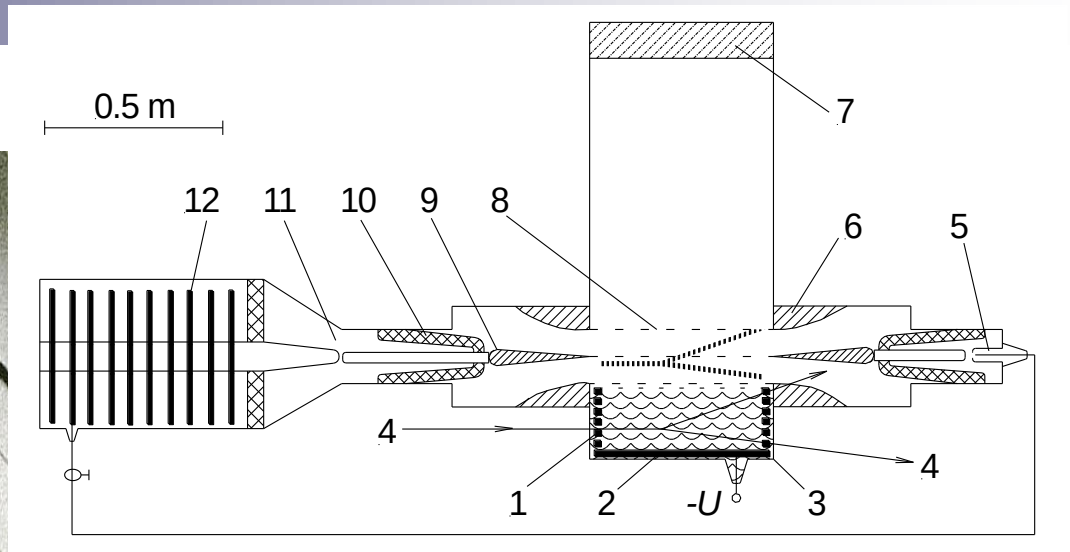


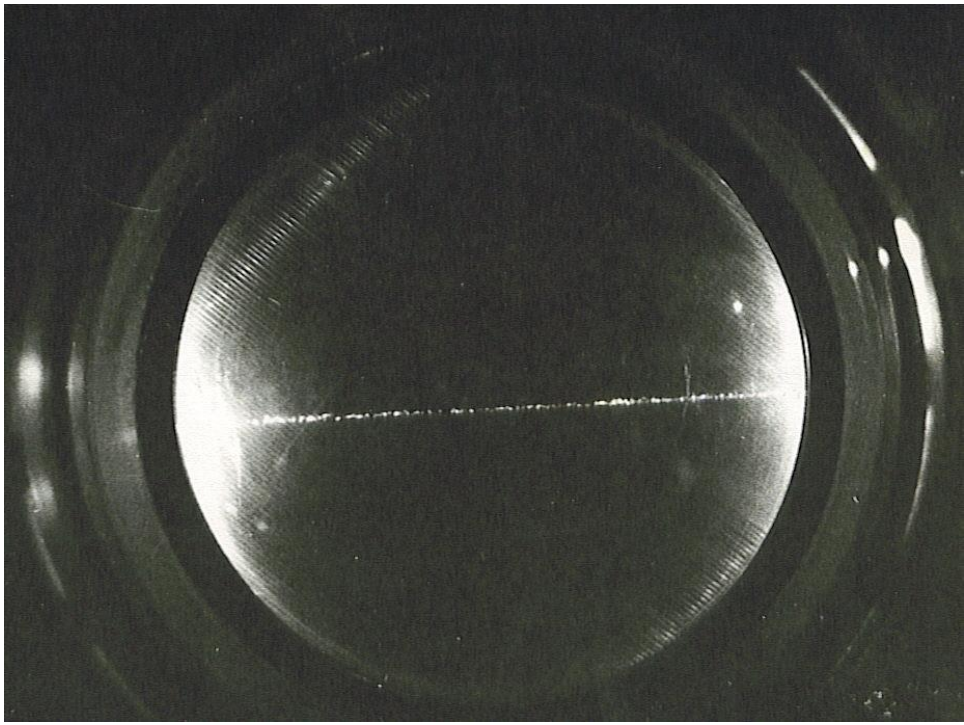


Bolozdynya, Miroshnichenko, Rodionov e.a. *JETP Lett.* 25 (1977) 401

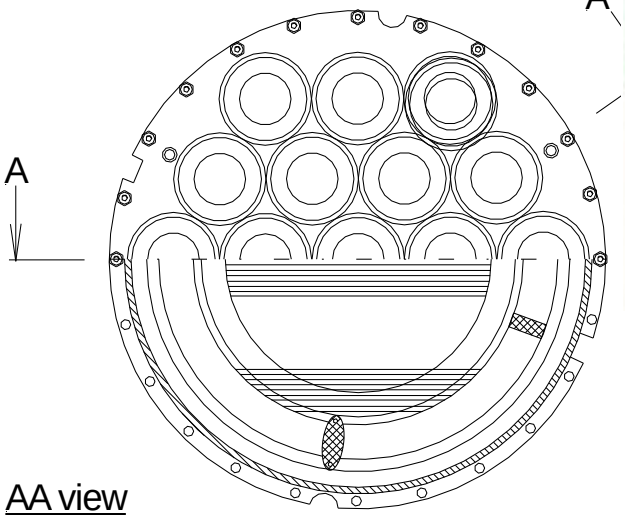
1980-1990

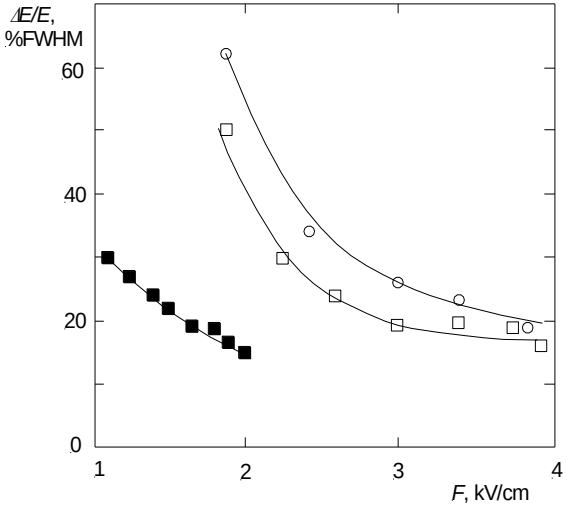




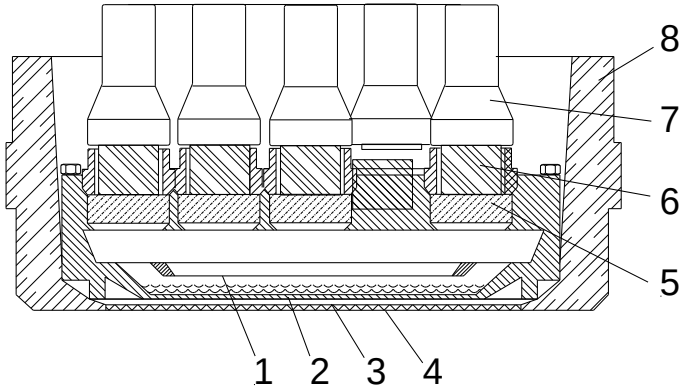


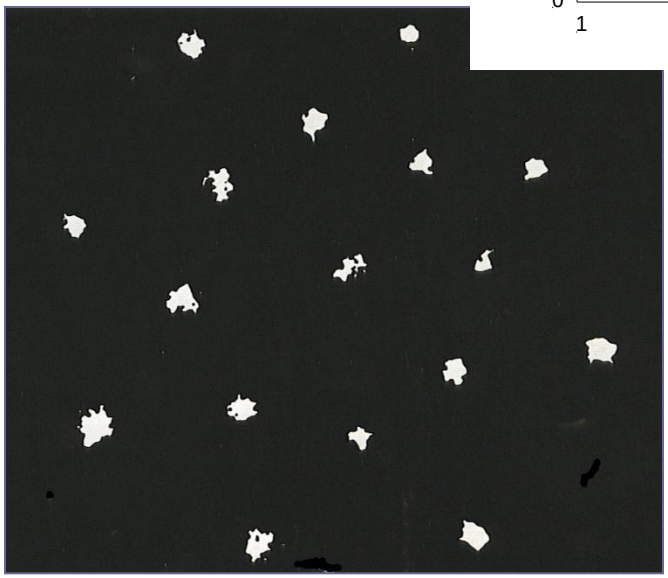
1983 Emission Electrolum. Chamber





AA view



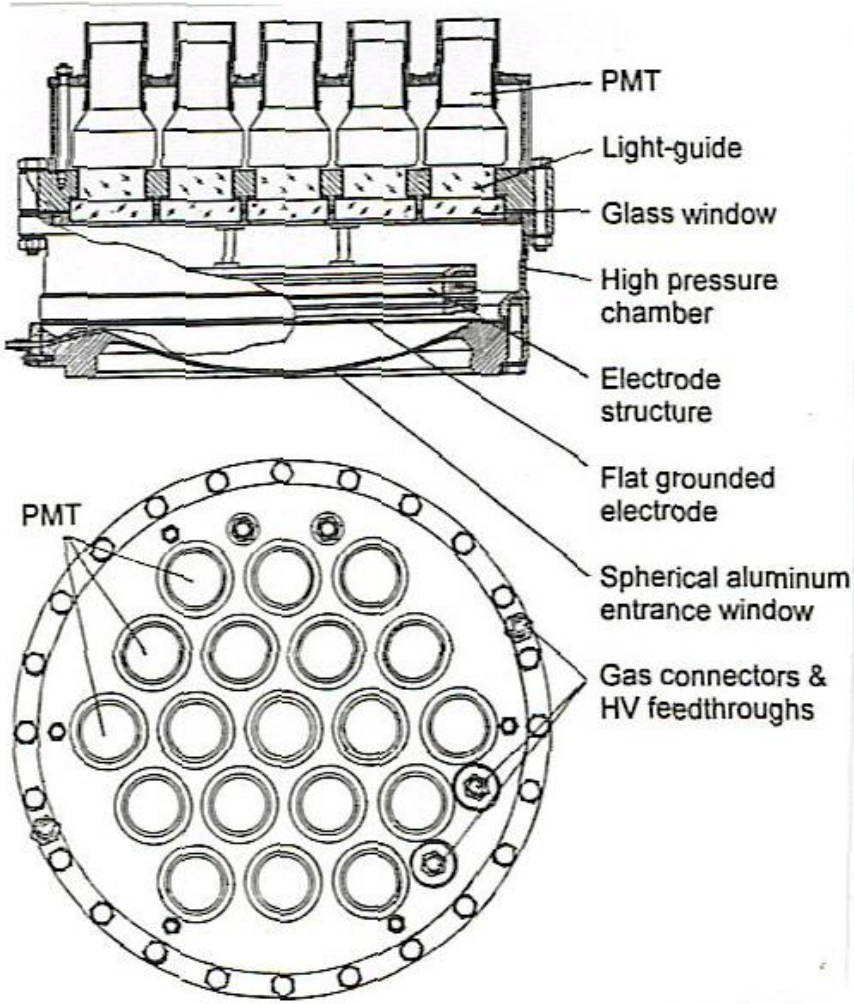


Egorov, Rodinov, Bolozdynya e.a. *NIM* 205 (1983) 373

HPXe Gamma Camera

SDC-19 @ SIEMENS

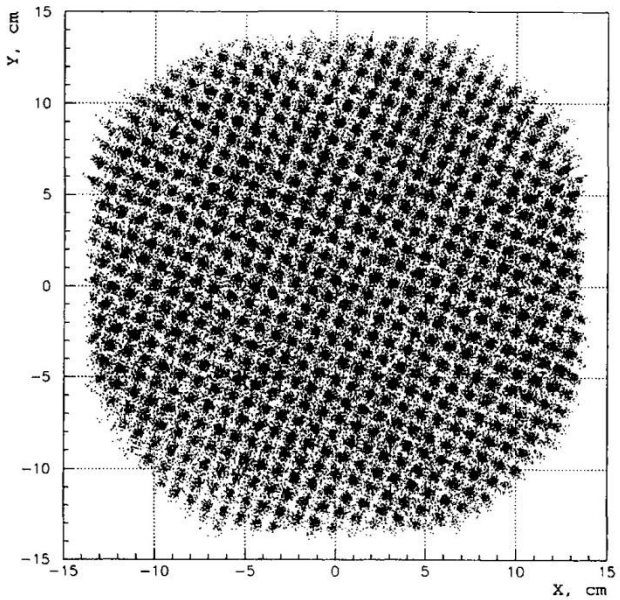
1995



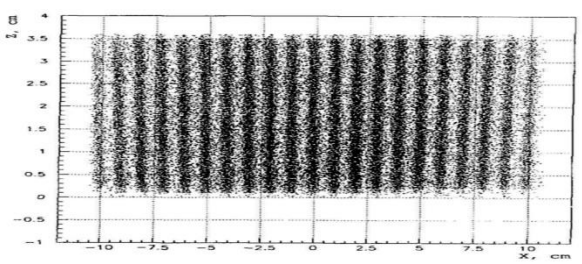
Array of nineteen 3" dia. photomultipliers installed behind glass windows, 9 bar Xe

Bolozdynya, Egorov, Kuchenkov e.a. *NIM A* 385 (1997) 225

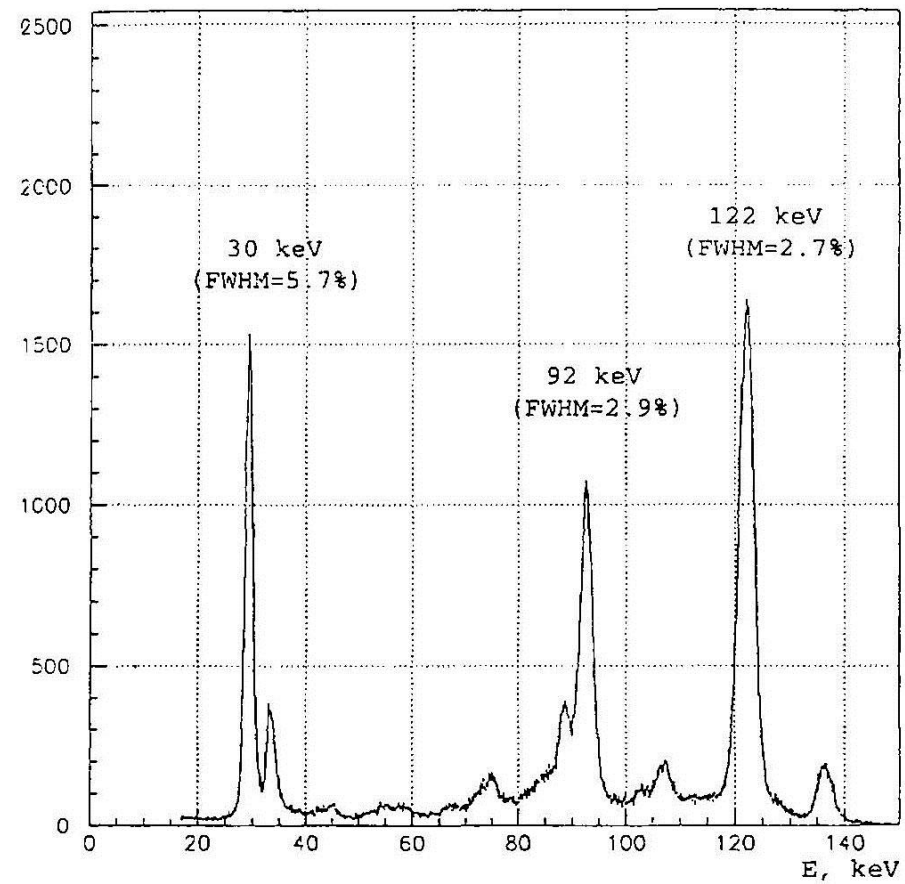
1995



XY image of lead mask



ZX image of lead mask

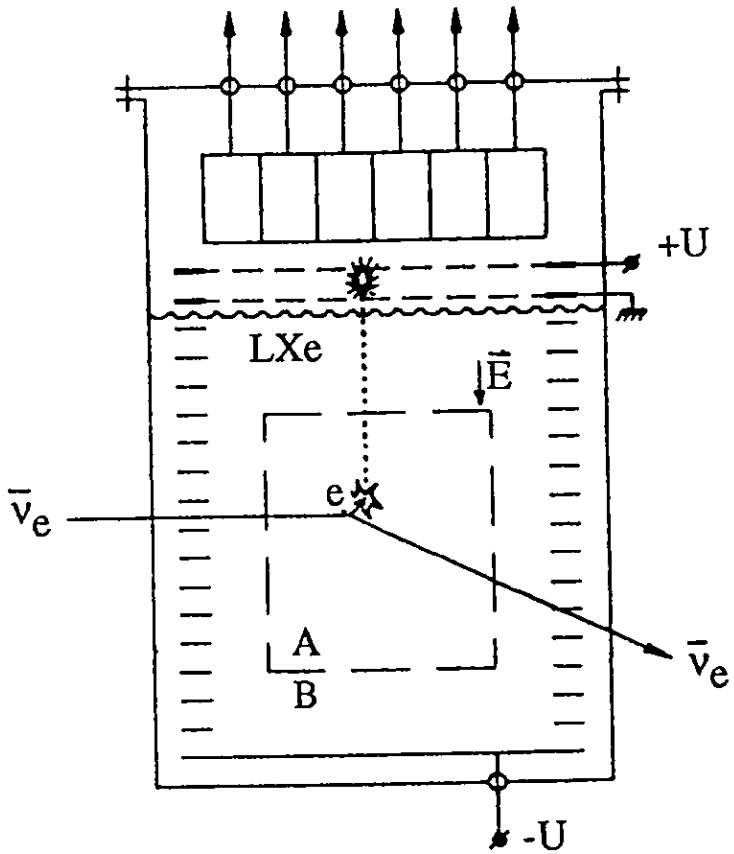


Measured spectrum of ^{57}Co

Bolozdynya, Egorov, Kuchenkov e.a. *NIM A* 385 (1997) 225

“Wall-less” emission detectors

“Wall-less” emission detector



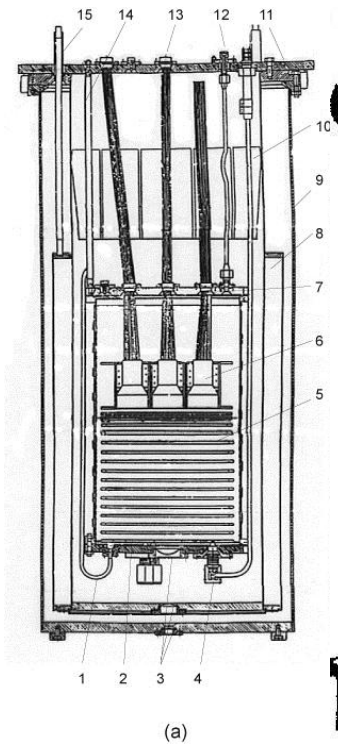
- Sensitive to single ionization electrons
- Two signals from ionization and excitation of atoms
- «Selfshielding»
- Large mass working media

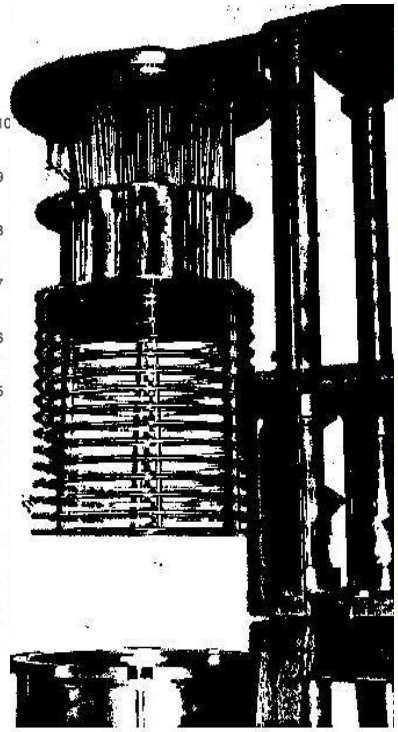
Fig.4. LXe time-projection scintillating drift chamber as wall-less detector for measurements of magnetic momentum neutrino.

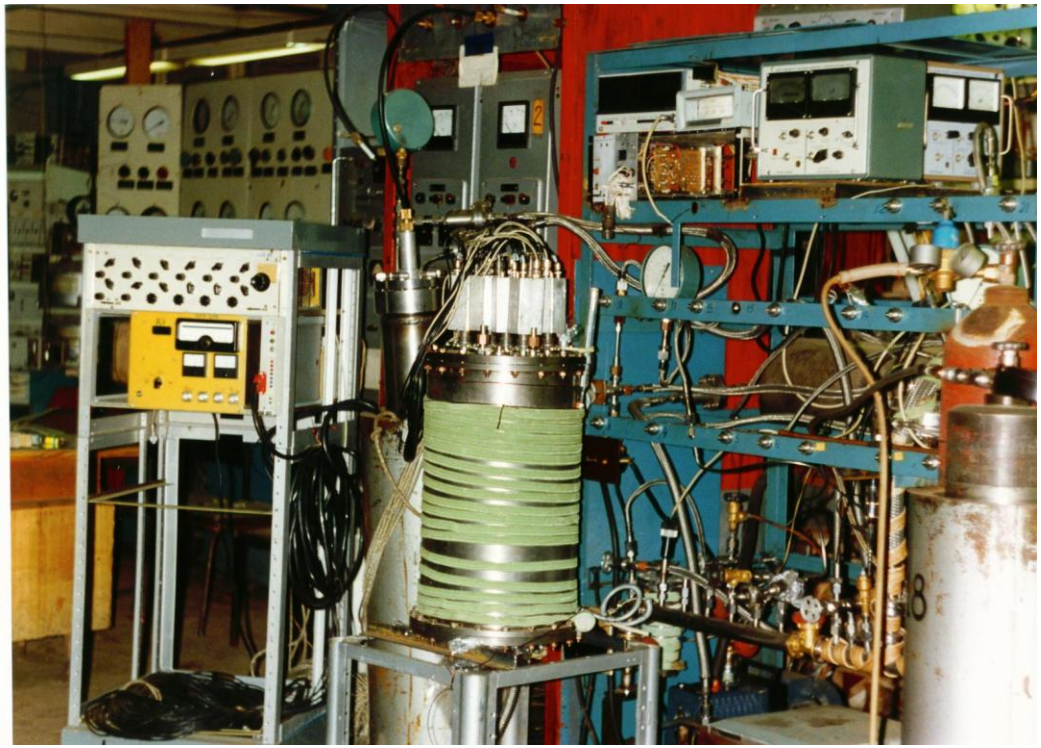
Bolozdynya, Egorov, Miroshnichenko, Rodionov.*IEEE Trans. Nucl. Sci.* v.42, n.4 (1995) 565-569

ITEP – magnetic momentum neutrino project

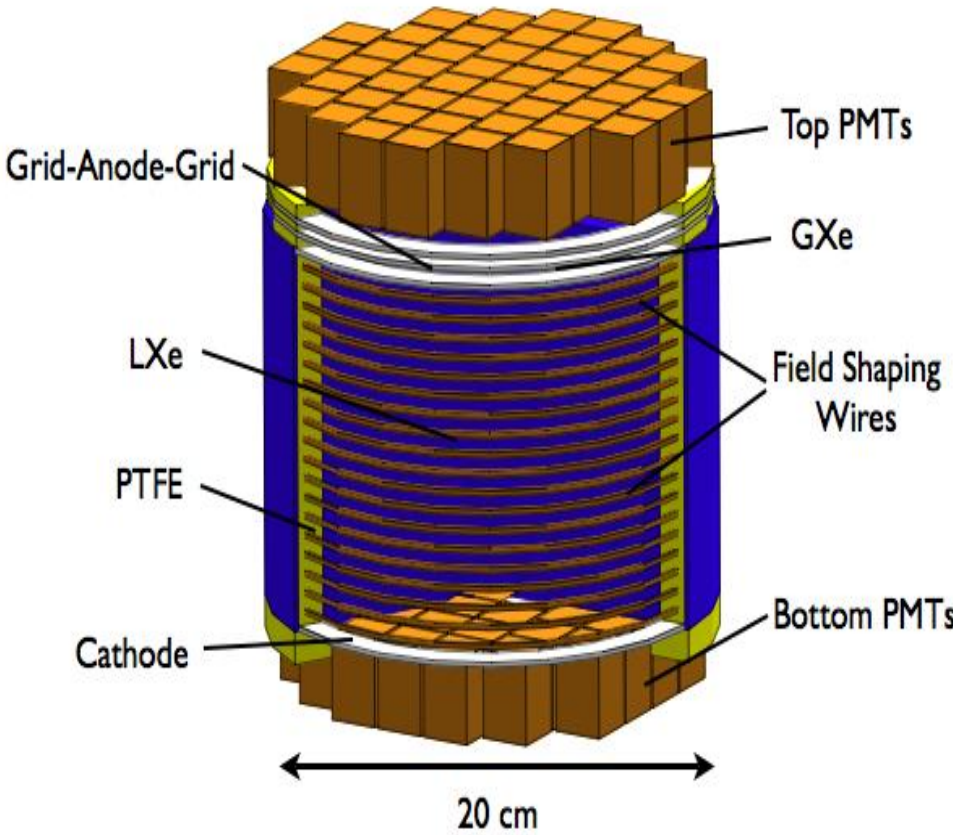
1992-1996



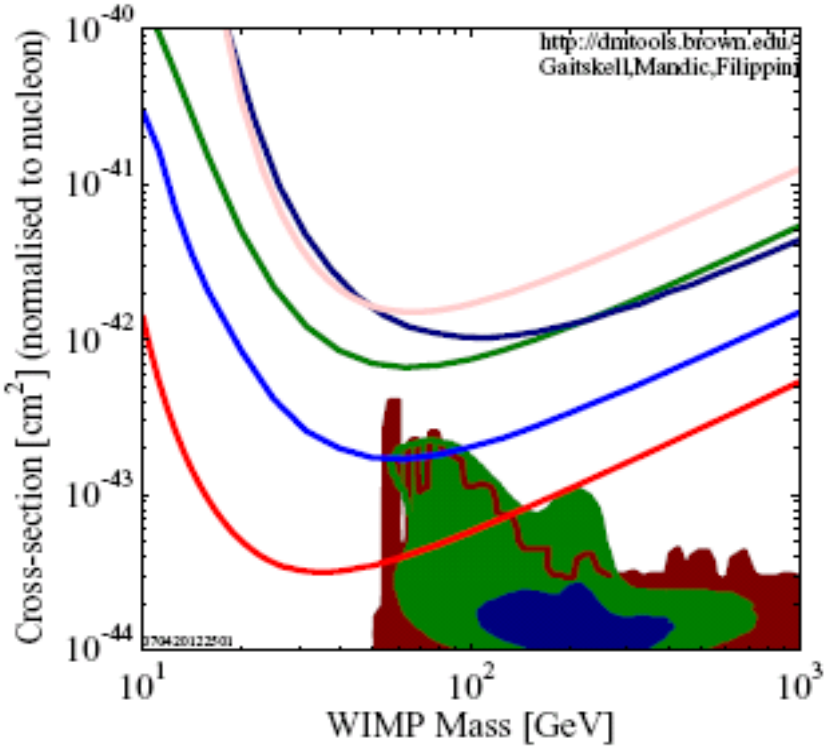




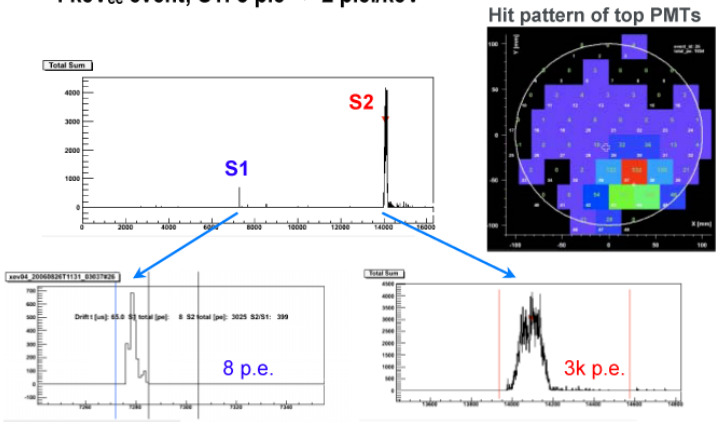
Xenon 10 – New best limit in 2007



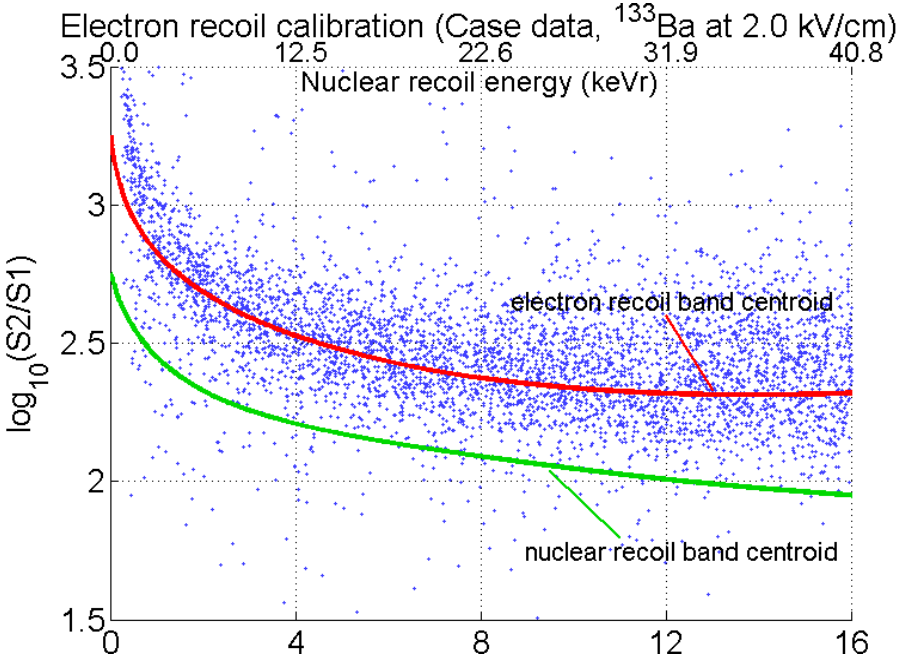
26 kg LXe

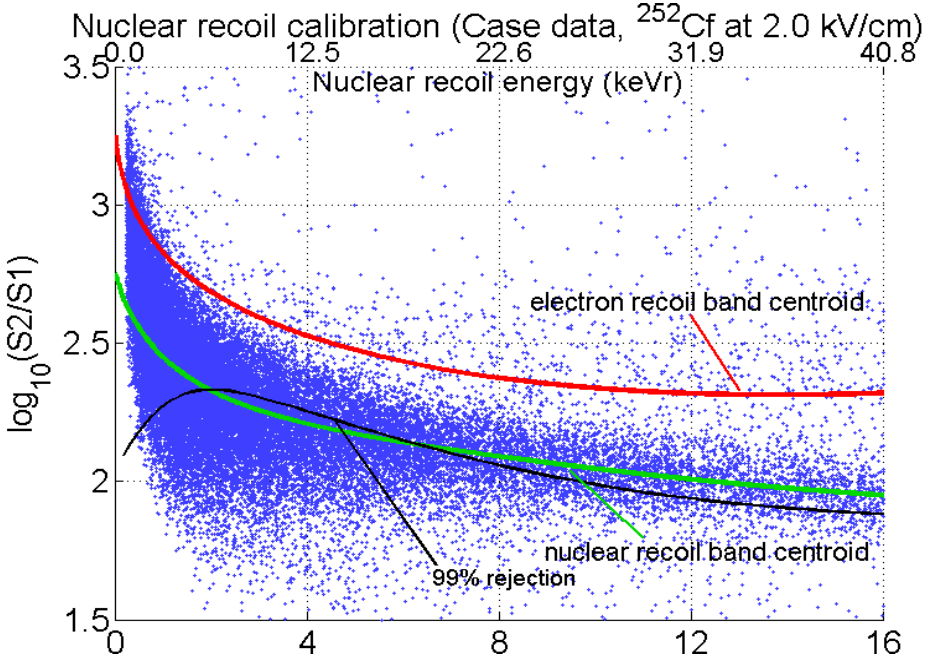


4 keV$_{ee}$ event; S1: 8 p.e => 2 p.e./keV



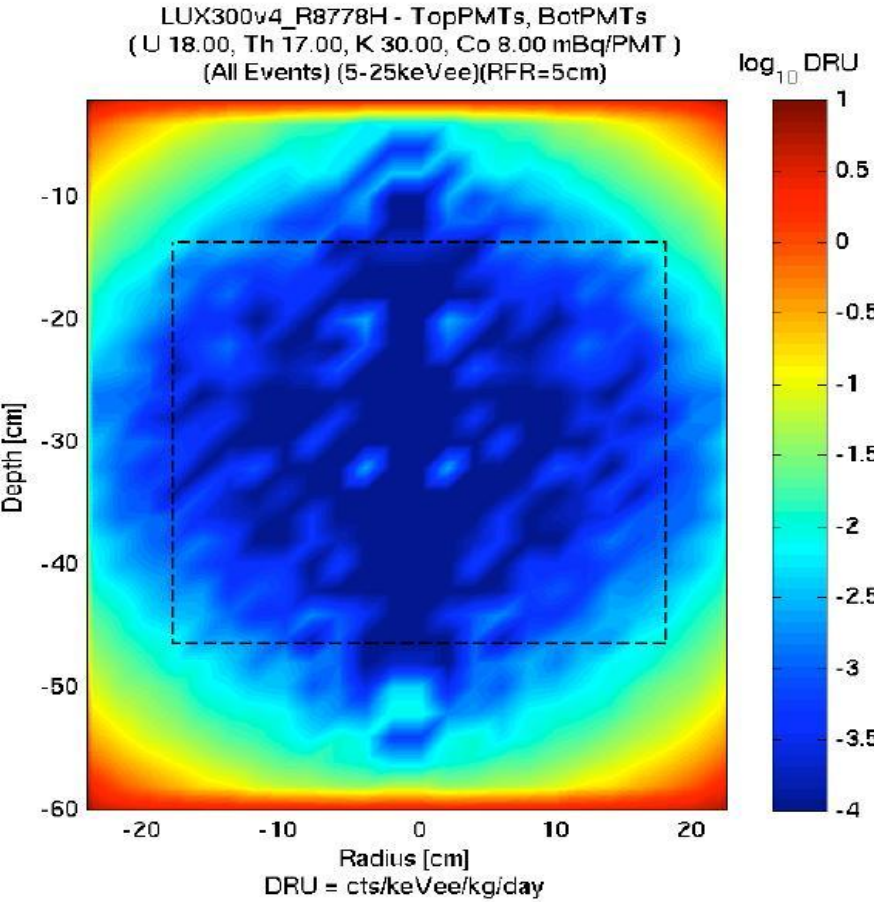
Separation of gamma and nuclear recoil signals

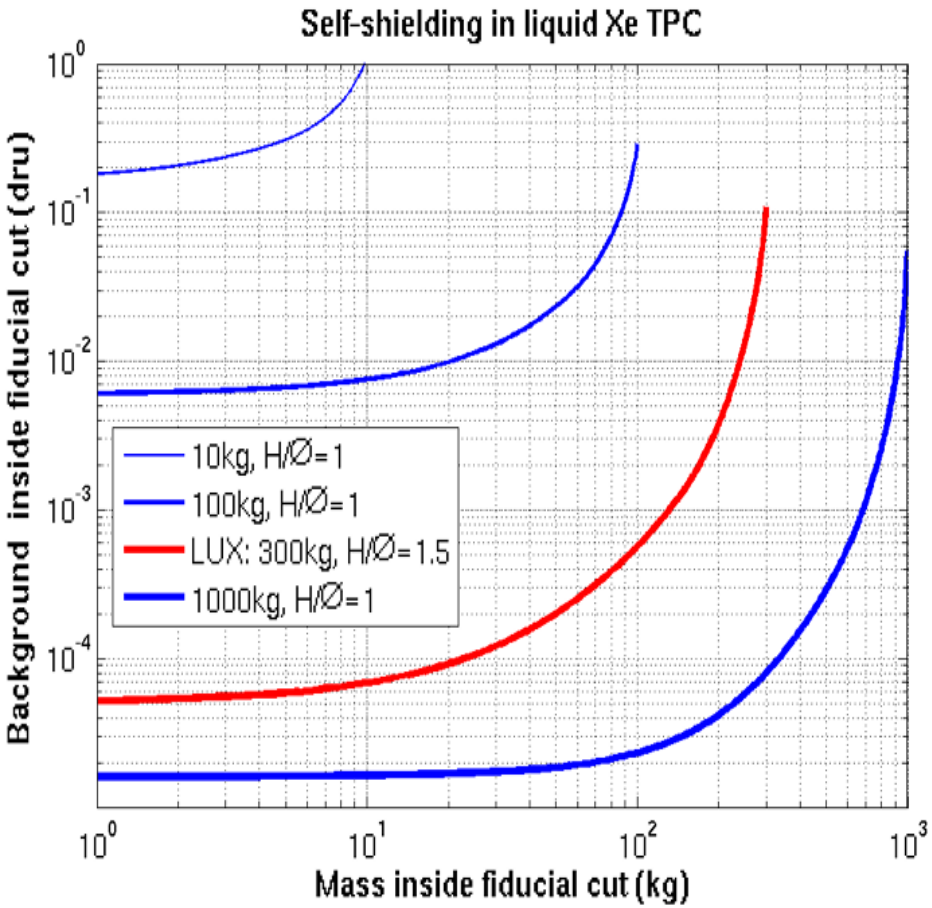




Energy, keVee

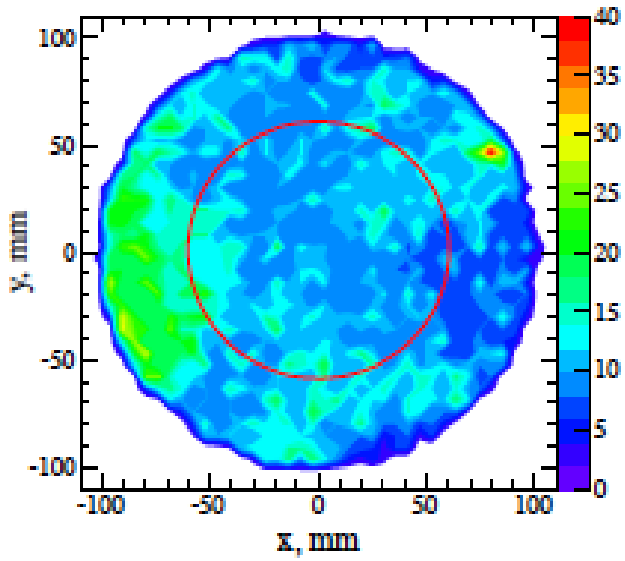
Self-shielding





Single electrons background

Spontaneous single electron emission observed in ZEPLIN-III, Xenon-10, RED-1



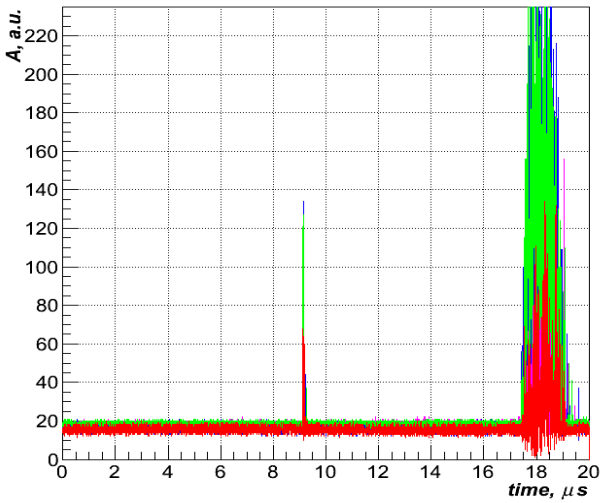
SE background rate:

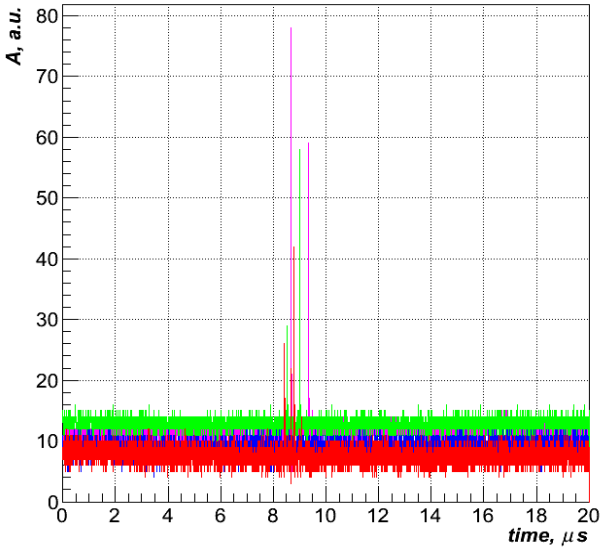
- **strongly depends on potential barrier at the interface**
- **depends on intensity of radioactive background (5 Hz spontaneous rate in ZEPLIN-III, 40 Hz in RED-1)**
- **Single electron events could be suppressed by cleaning interface with tangential electric field**

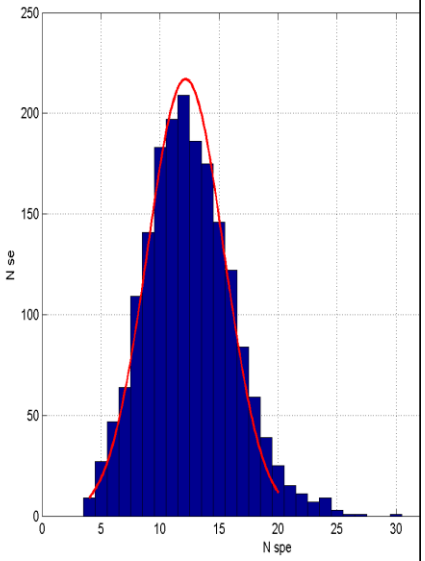
x-y positions of single electron events in a 12 kg emission LXe detector ZEPLIN-III installed in the underground lab

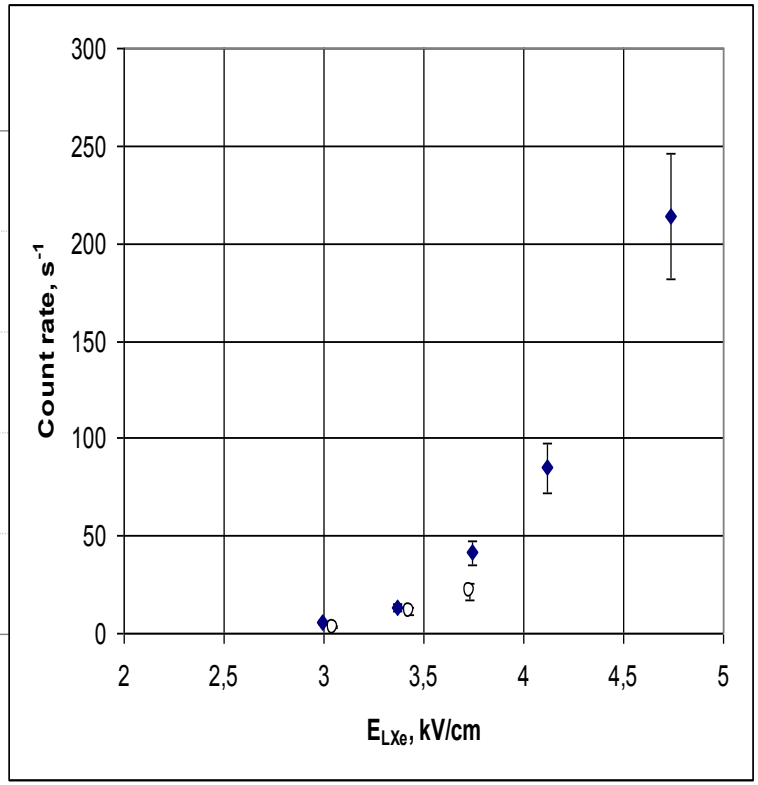
Santos – arxiv 1110.3056v1

Single electron noise measured in RED-1 detector

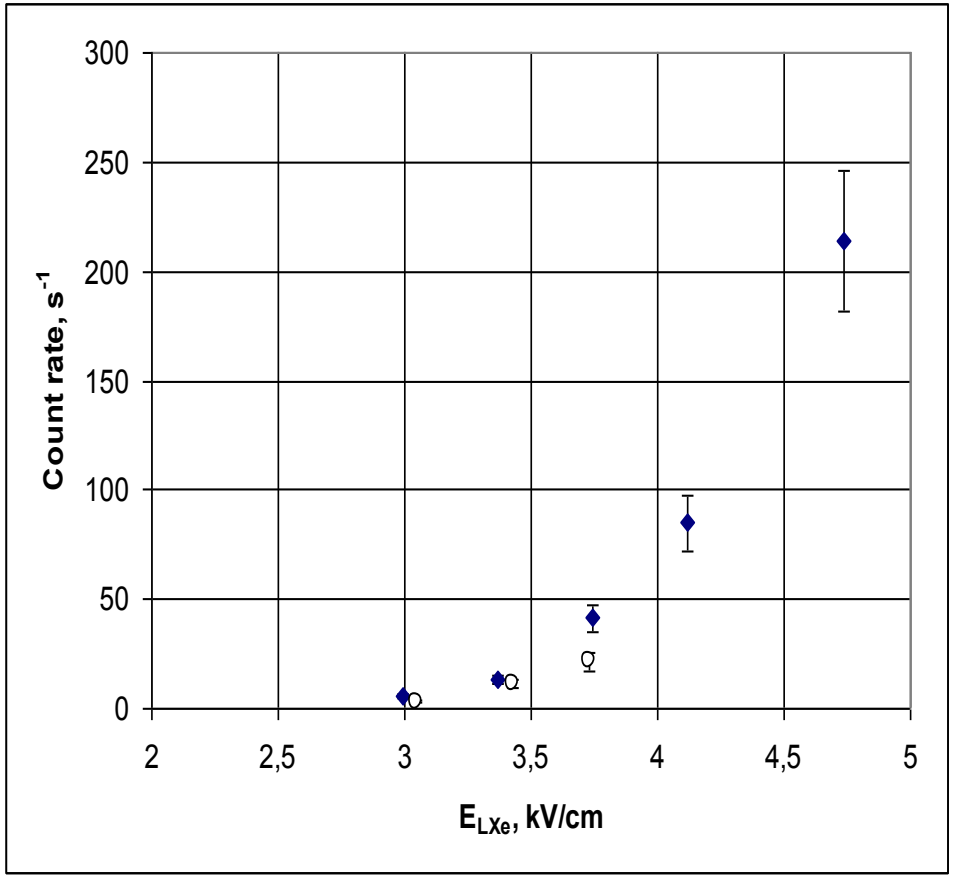






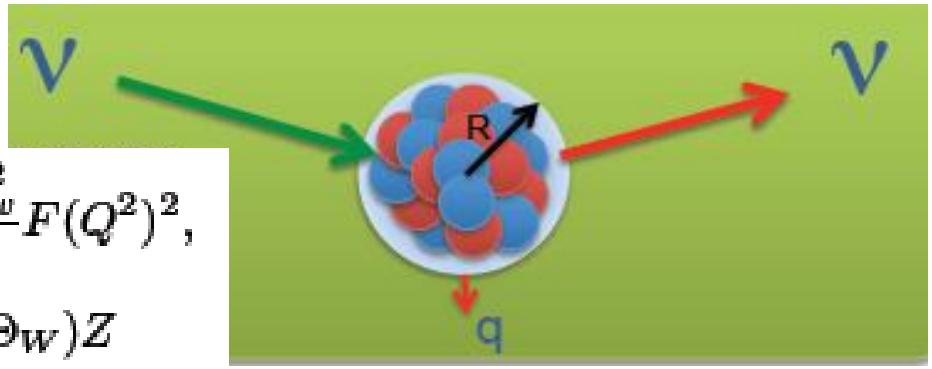


Single electron noise rate associated with radioactive background measured in two different runs



Coherent Neutrino Scattering

Coherent neutrino scattering off heavy nuclei



$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{Q_w^2}{4} F(Q^2)^2,$$

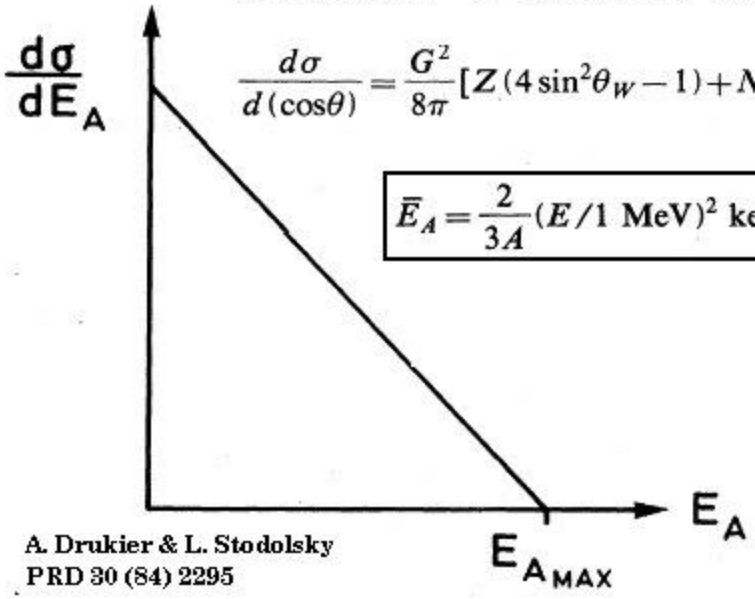
$$Q_w = N - (1 - 4\sin^2\Theta_W) Z$$

Phys Rev D 30, Vol 30, No11 (1984)
Phys Rev D 68, 023005 (2003)

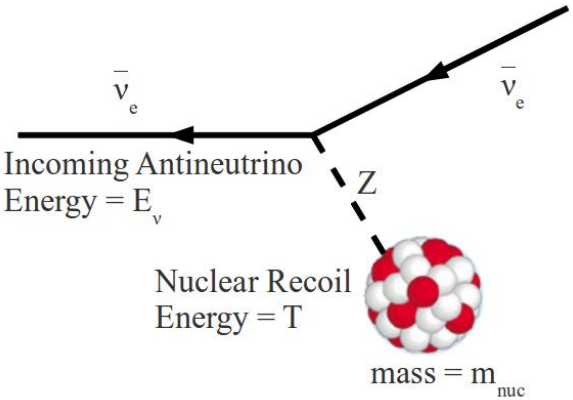
$$\sigma \simeq 0.42 \times 10^{-44} N^2 (E/1\ \text{MeV})^2\ \text{cm}^2$$

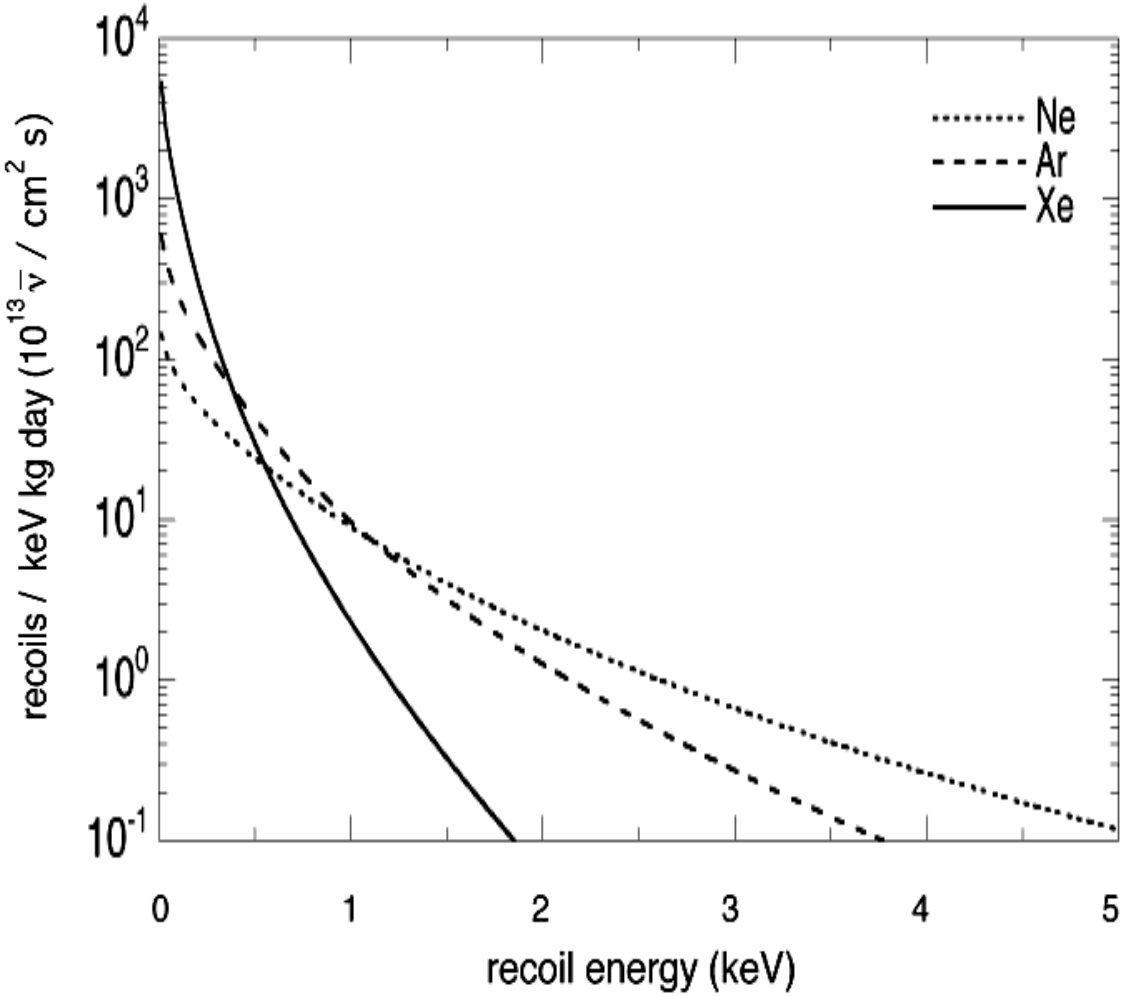
$$\frac{d\sigma}{d(\cos\theta)} = \frac{G^2}{8\pi}[Z(4\sin^2\theta_W - 1) + N]^2 E^2 (1+\cos\theta)$$

$$\bar{E}_A = \frac{2}{3A}(E/1\ \text{MeV})^2\ \text{keV}$$



A. Drukier & L. Stodolsky
PRD 30 (84) 2295

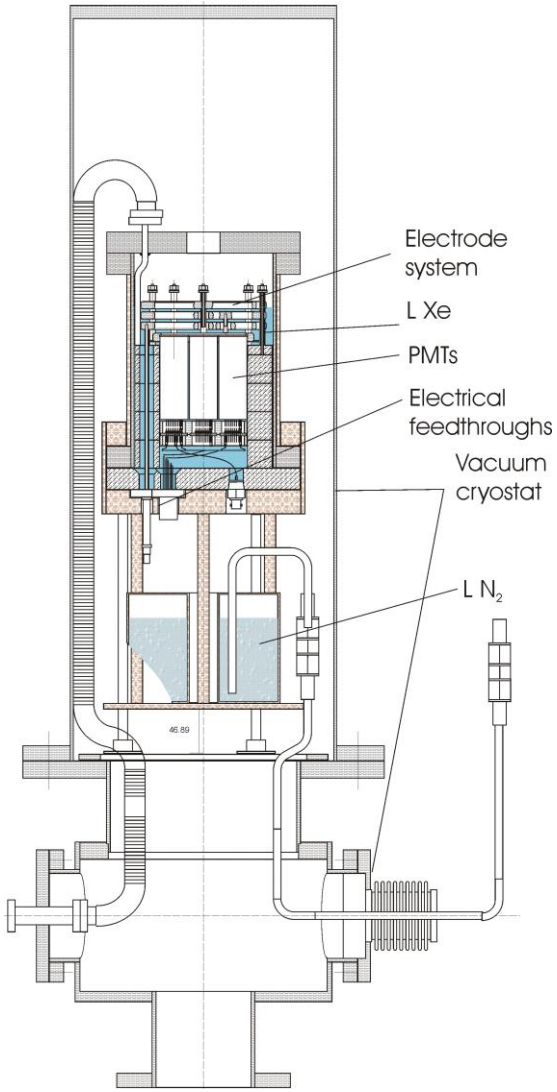




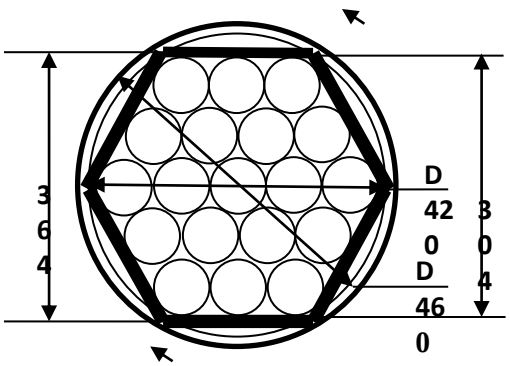
P. S. Barbeau, J. I. Collar, J. Miyamoto, and I. Shipsey

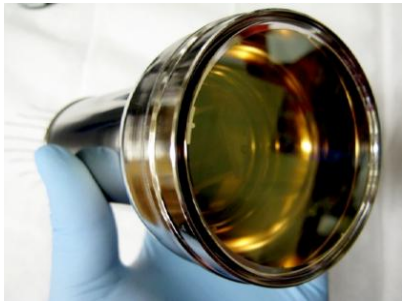
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 50, NO. 5, OCTOBER 2003

RED-1

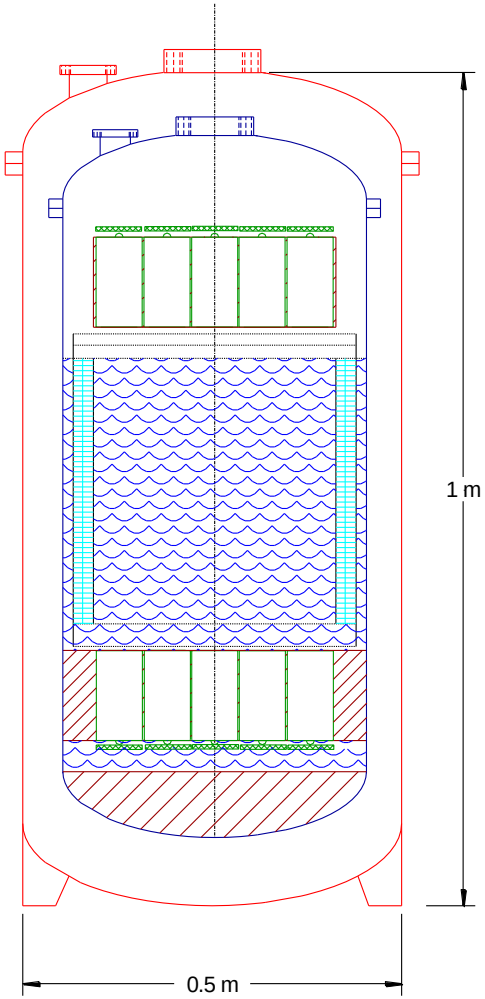


RED-100

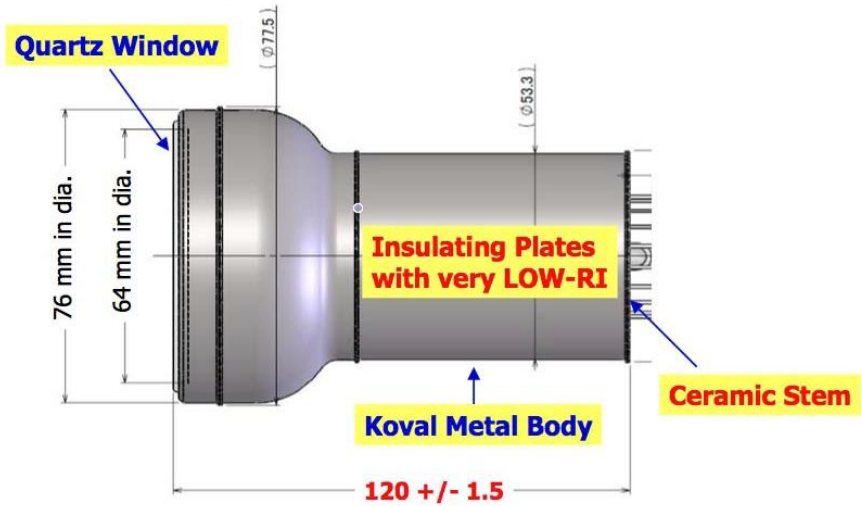




Hamamatsu R11410



The Hamamatsu R8778 PMT, used in the LUX experiment (left), and the R11410



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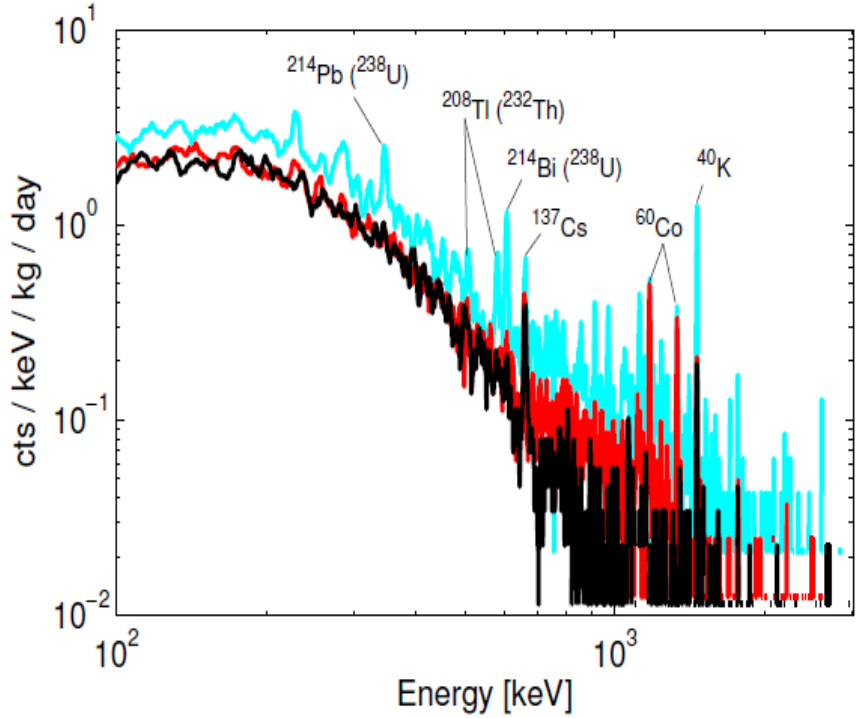
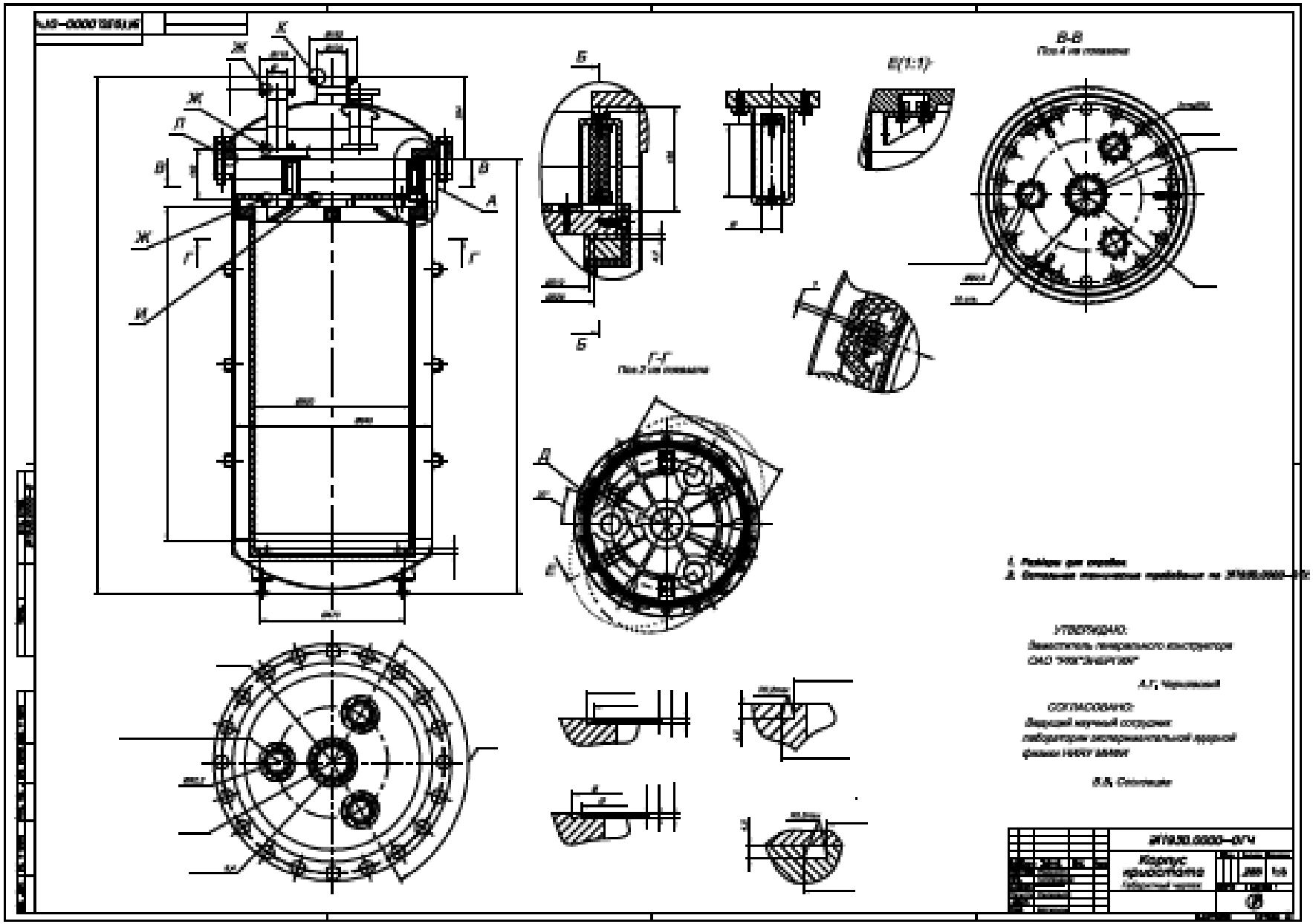
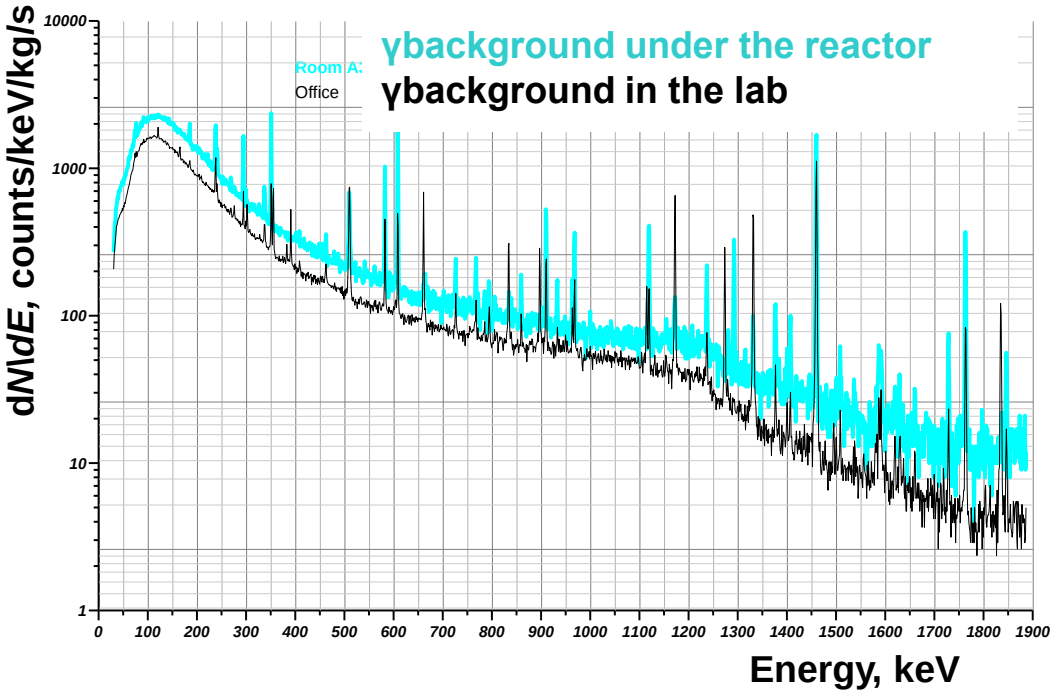
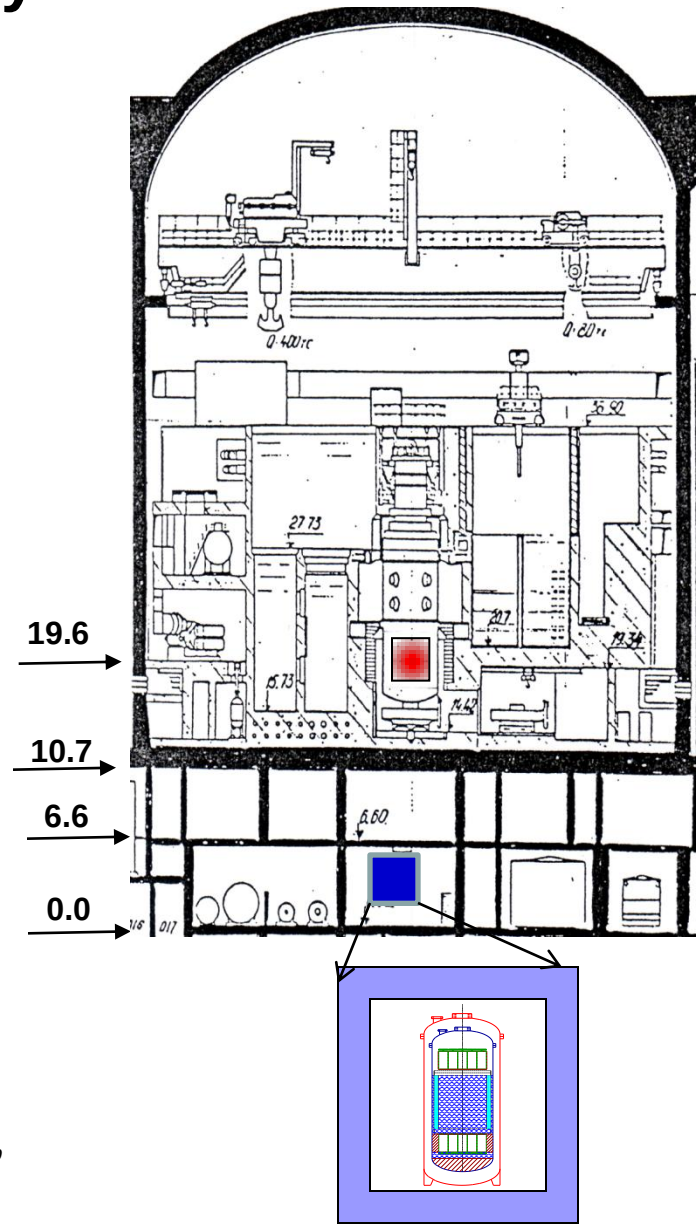


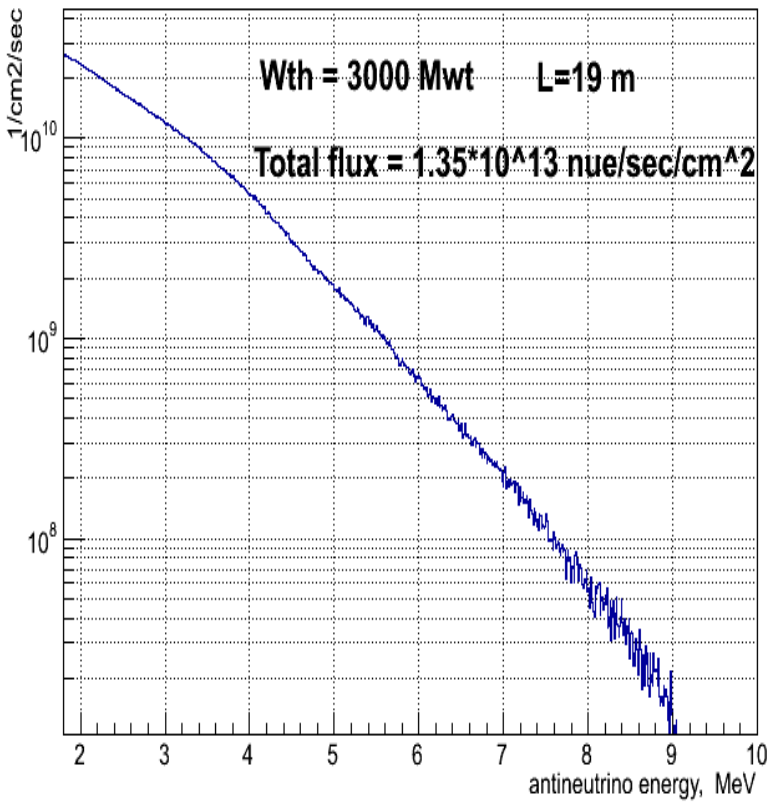
gure 3. SOLO counting spectra for R8778 (14 live days, blue) and R11410 MOD (19 live days,) PMTs, superimposed with a sample background run (21 live days, black). Strong lines in the 778 spectrum indicate the presence of ^{238}U, ^{232}Th, ^{40}K and ^{60}Co. The reduced activity of the 1410 MOD is readily apparent from the lack of distinct features in comparison with the R8778.

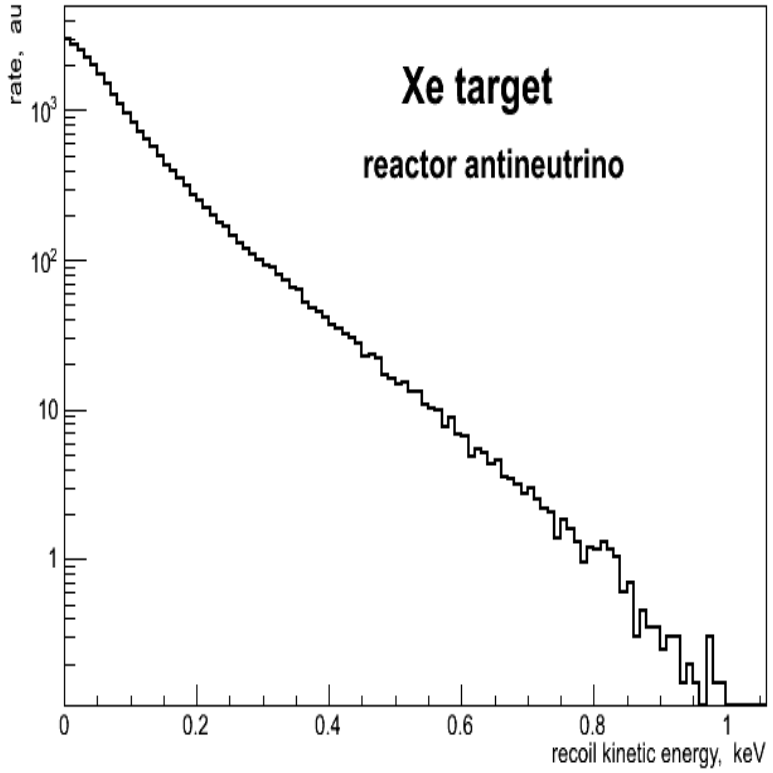

В-В
Г-Г
УТВЕРЖДАЮ:
СОГЛАСОВАНО:
Корпус
приостата

Kalinin nuclear power plant facility

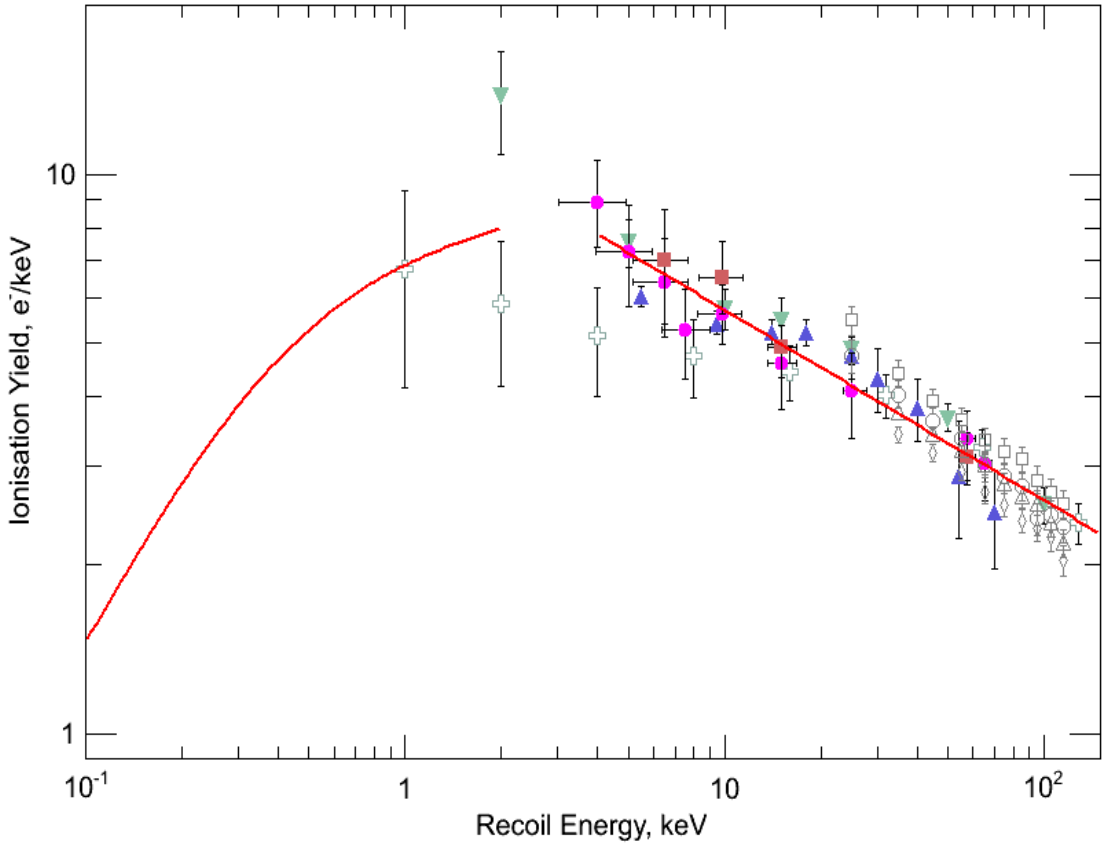





Wth = 3000 Mwt L=19 m
Total flux = 1.35*10^13 nue/sec/cm^2
1/cm2/sec
10^{10}
10^{9}
10^{8}
2
3
4
5
6
7
8
9
10
antineutrino energy, MeV


Xe target
reactor antineutrino
rate, au
10^{3}
10^{2}
10
1
0
0.2
0.4
0.6
0.8
1
recoil kinetic energy, keV

Detector response



P.Sorensen, et al., arxiv : 1011.6439
P.Sorensen, et.al., NIM A601 (2009) 339
P.Sorensen, et.al., arxiv : 0807.0459
A.Manzur, et.al., Phys.Rev.C81 (2010) 25808
E.Aprile, et.al., Phys.Rev.Lett 97 (2006) 81302

Conditions

Reactor

P = 3000 MW

L = 19 m

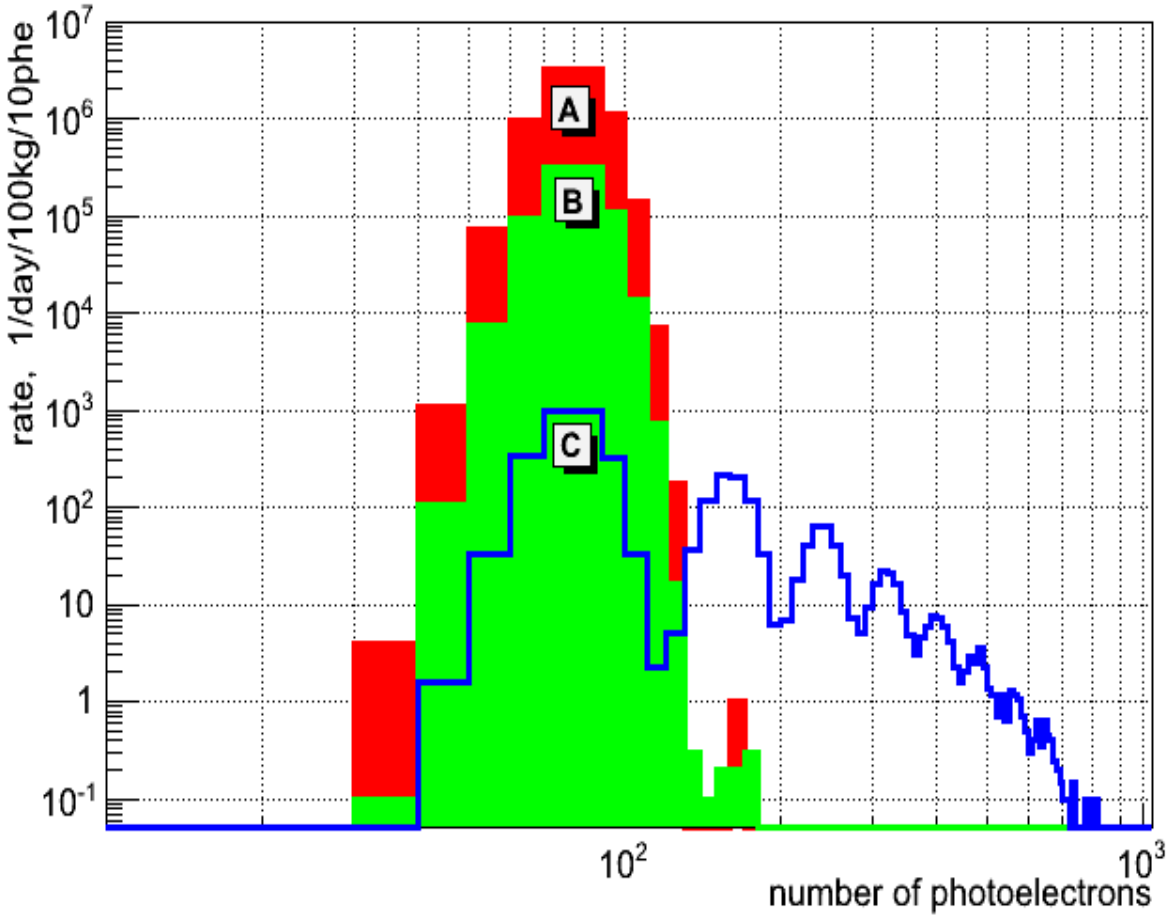
$\Phi = 1.35 \cdot 10^{13}\ cm^{-2}s^{-1}$

Detector

Fiducial ~100 kg Xe

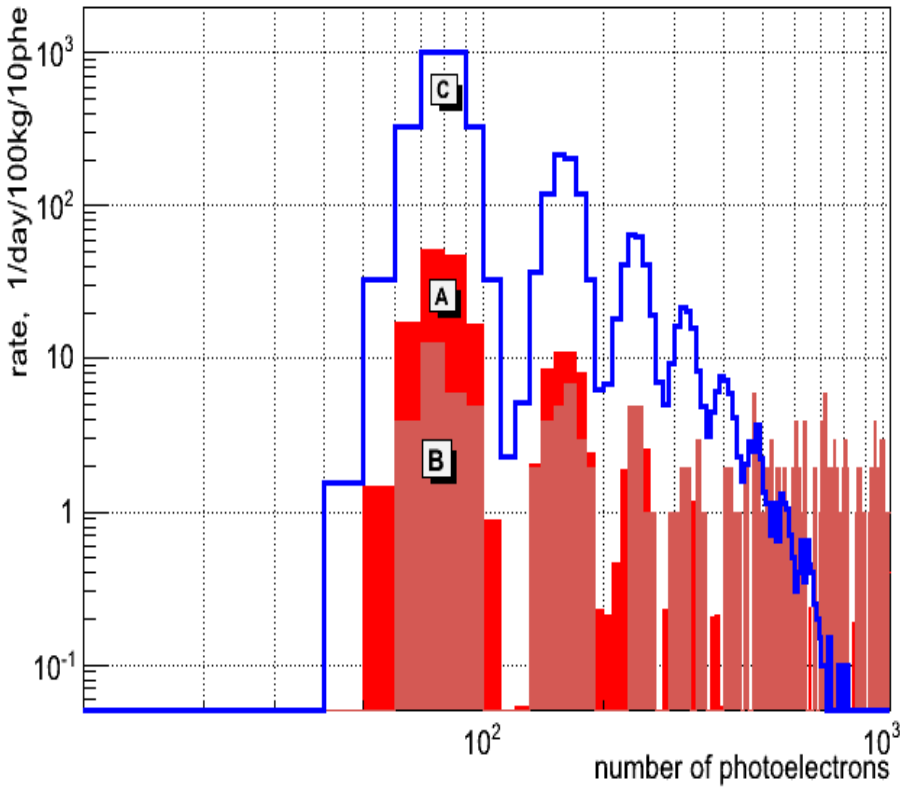
PMT QE ~ 30%

Sensitivity ~ 80 phe/e-



Simulated count rate in the RED100 detector located at 19 meters from the KNPP reactor core associated with the 100 Hz (A) and 10 Hz (B) single electron emission noise and with the neutrino coherent scattering (C).

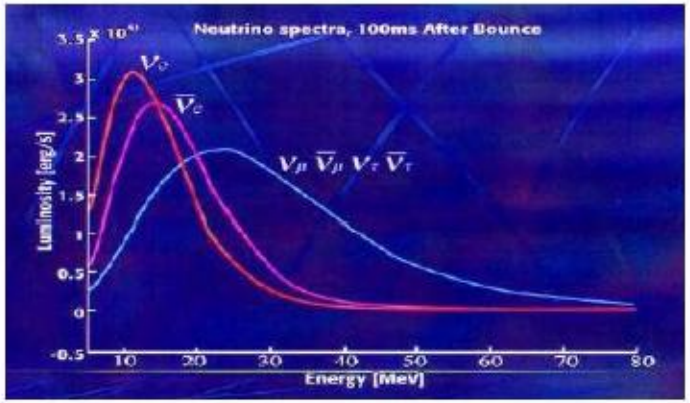
For ≥3e rate 433 events/day

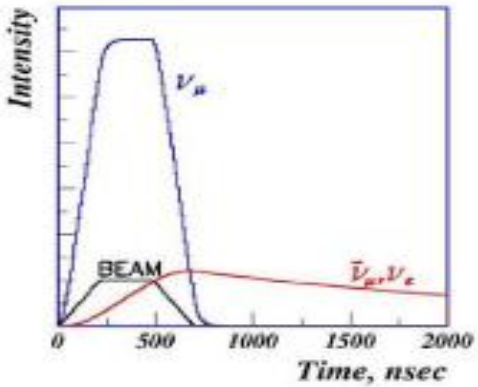


Component (material)	^{238}U	^{232}Th	^{40}K	^{60}Co	^{137}Cs
PMT mBq/unit	0.4	0.3	8.3	2.0	
Cryostat (Titanium) mBq/kg	0.2	0.25	0.93		
Reflector (Teflon) mBq/kg	2	2	15	5	1
PMT support/heat exchanger (Copper) mBq/kg	2	1	4	1	0.5

Simulated count rates of backgrounds caused by radioactivity of detector components (A), by neutrons from cosmic rays (B) in comparison with the count rate from the neutrino coherent scattering (C) in the RED100 detector located at 19 meters from the KNPP reactor core.

SNS



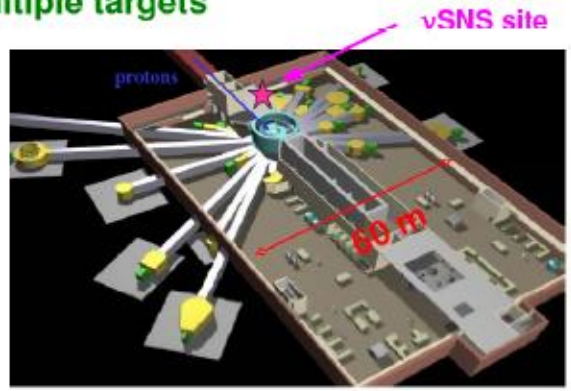


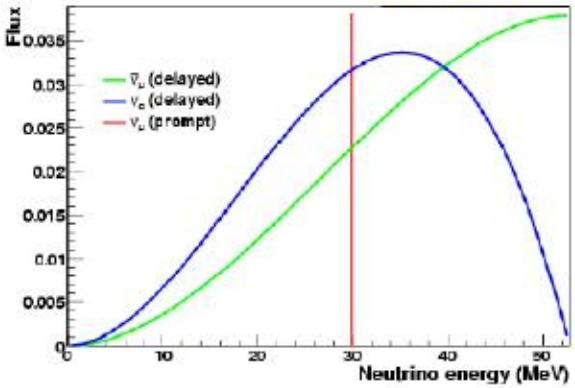
NuSNS (Neutrinos at the SNS)

$\pi^+ \rightarrow \mu^+ + \nu_\mu$ 2-body decay: monochromatic 29.9 MeV ν_μ PROMPT

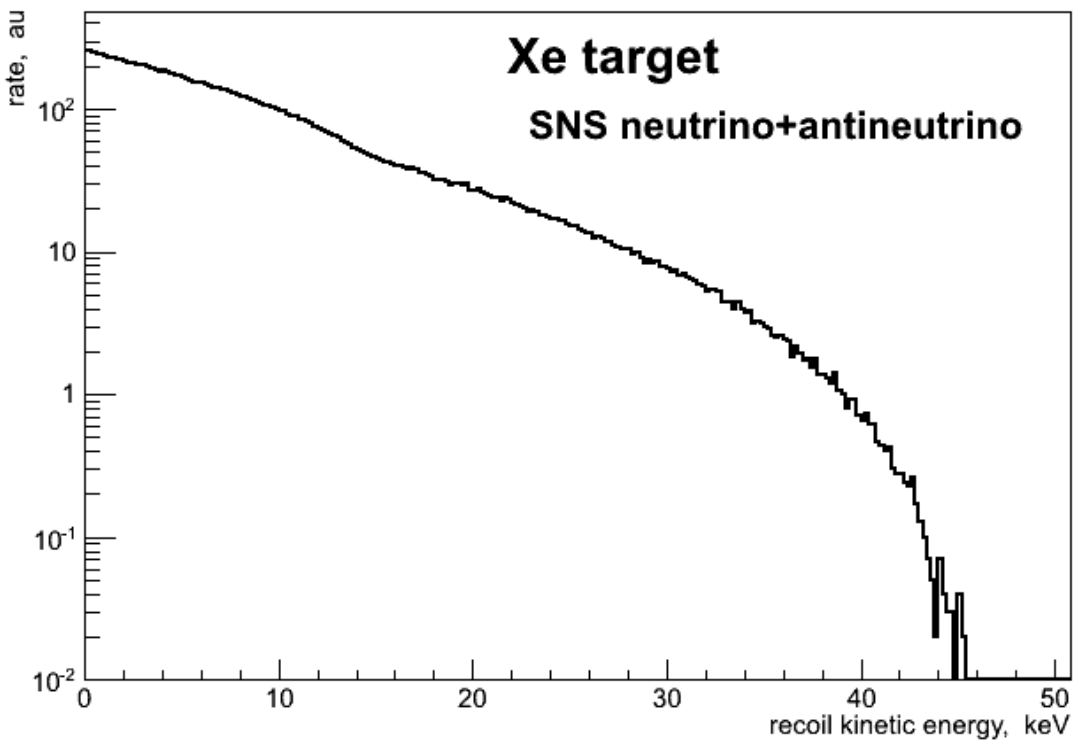
$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$ 3-body decay: range of energies between 0 and $m_\mu/2$ DELAYED (2.2 μs)

A neutrino facility with capability to measure multiple targets

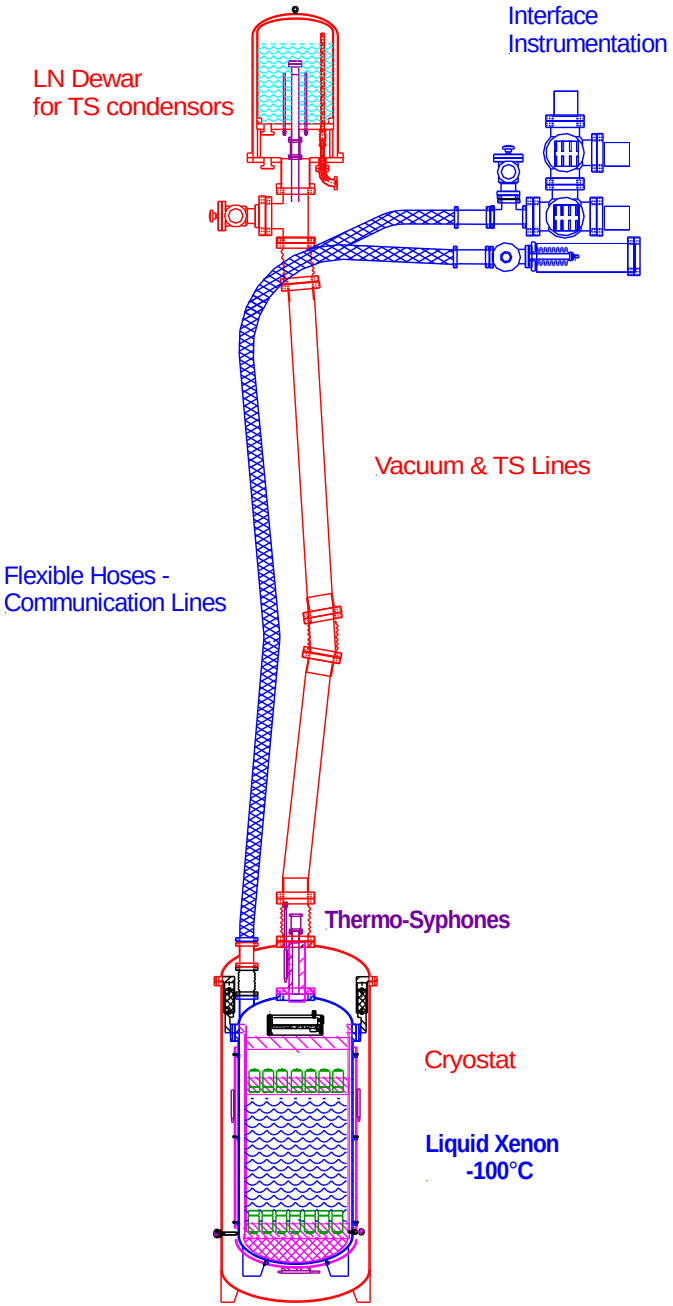




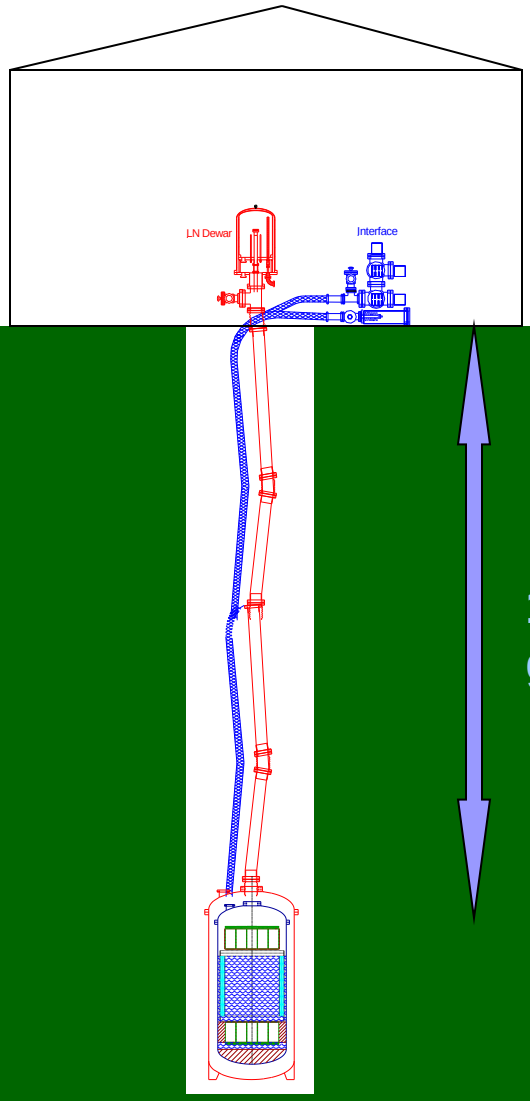
Coherent Neutrino Scattering



Well-logging detector



RED-100 @ SNS

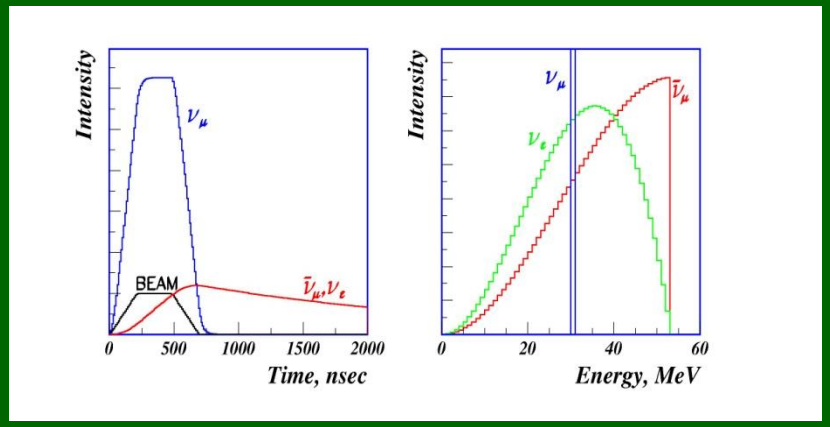


Ground shielding

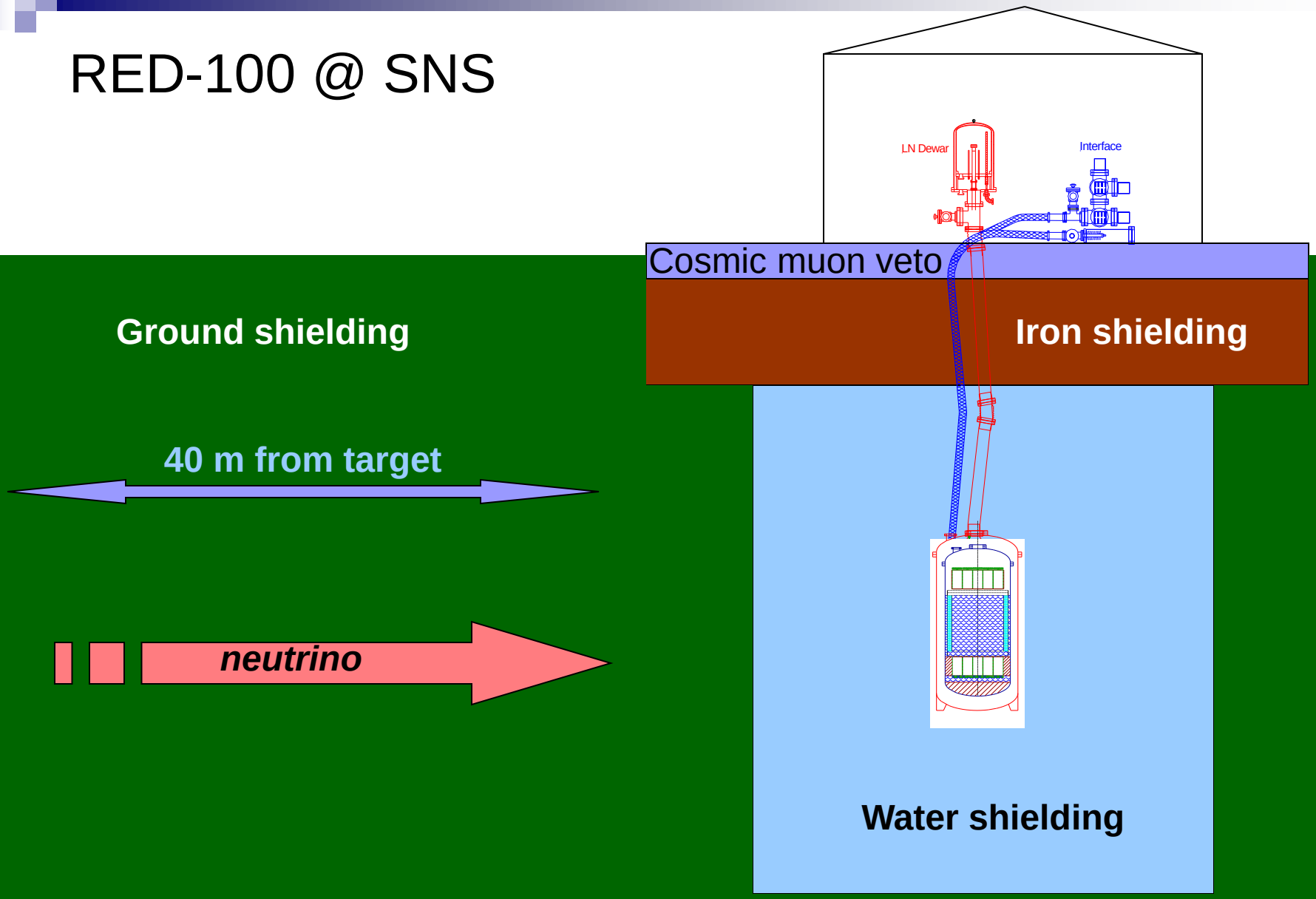
40 m from target

neutrino

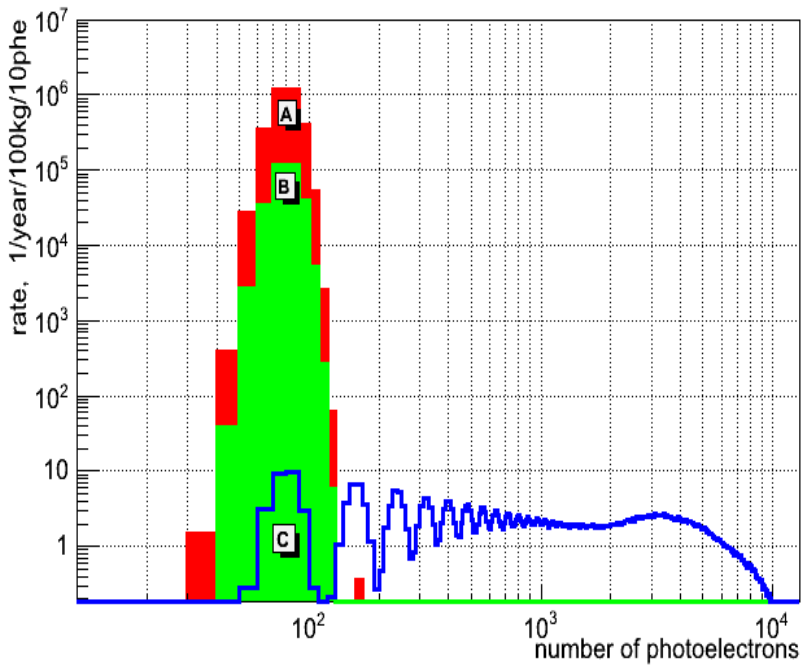
10 m below ground level



RED-100 @ SNS


LN Dewar
Interface
Cosmic muon veto
Iron shielding
Ground shielding
40 m from target
neutrino
Water shielding

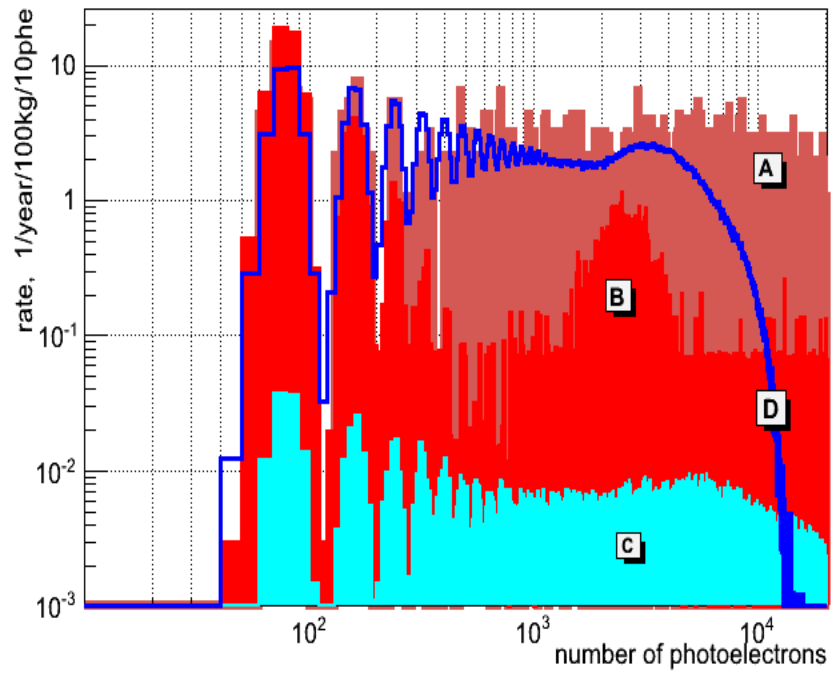
RED-100 @ SNS



40 m from the target of SNS

Simulated count rate in the RED100 detector located at 20 m depth in ground and at 40 meters from the SNS target associated with the 100 Hz (A) and 10 Hz (B) single electron emission noise and with the neutrino coherent scattering (C).

For ≥3e annual rate 1400 events



40 m from the target of SNS

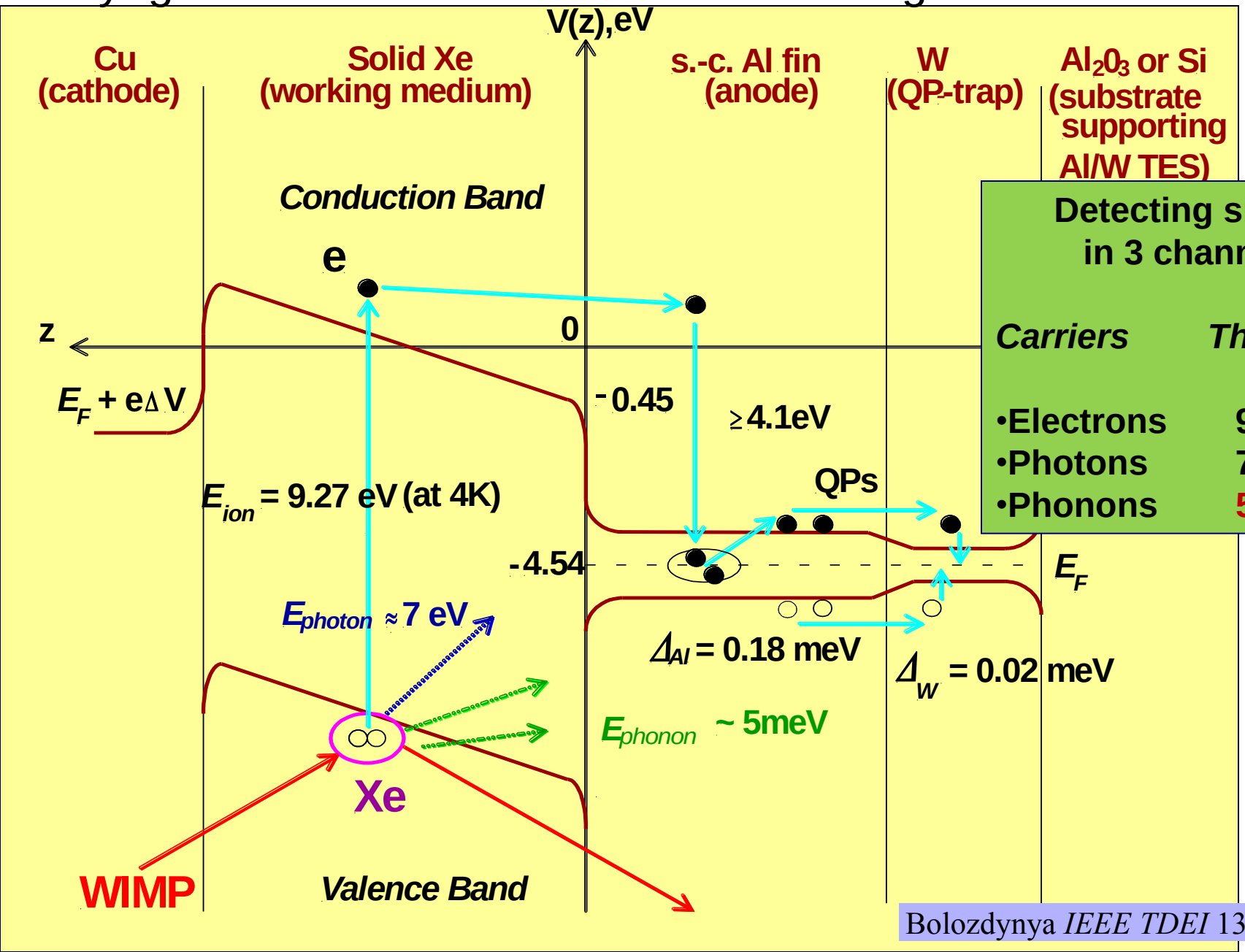
Simulated count rate in the RED100 detector located at 20 m depth in ground and at 40 meters from the SNS target caused by neutrons from cosmic rays (A), by radioactivity of detector components (B), by background neutrons generated by the SNS (C) in comparison with the count rate from the neutrino coherent scattering (D).

Conclusion

- Emission two-phase detectors look suitable for detecting Coherent Neutrino Scatter (CNS)
- Measurement of the ionization yield for nuclear recoils below ~keVr energies is a key step toward the experiment on observation of CNS
- Single-electron noise is a factor limiting sensitivity of LXe emission detectors

Cryogenic Xe Detector with Transition Edge Sensors

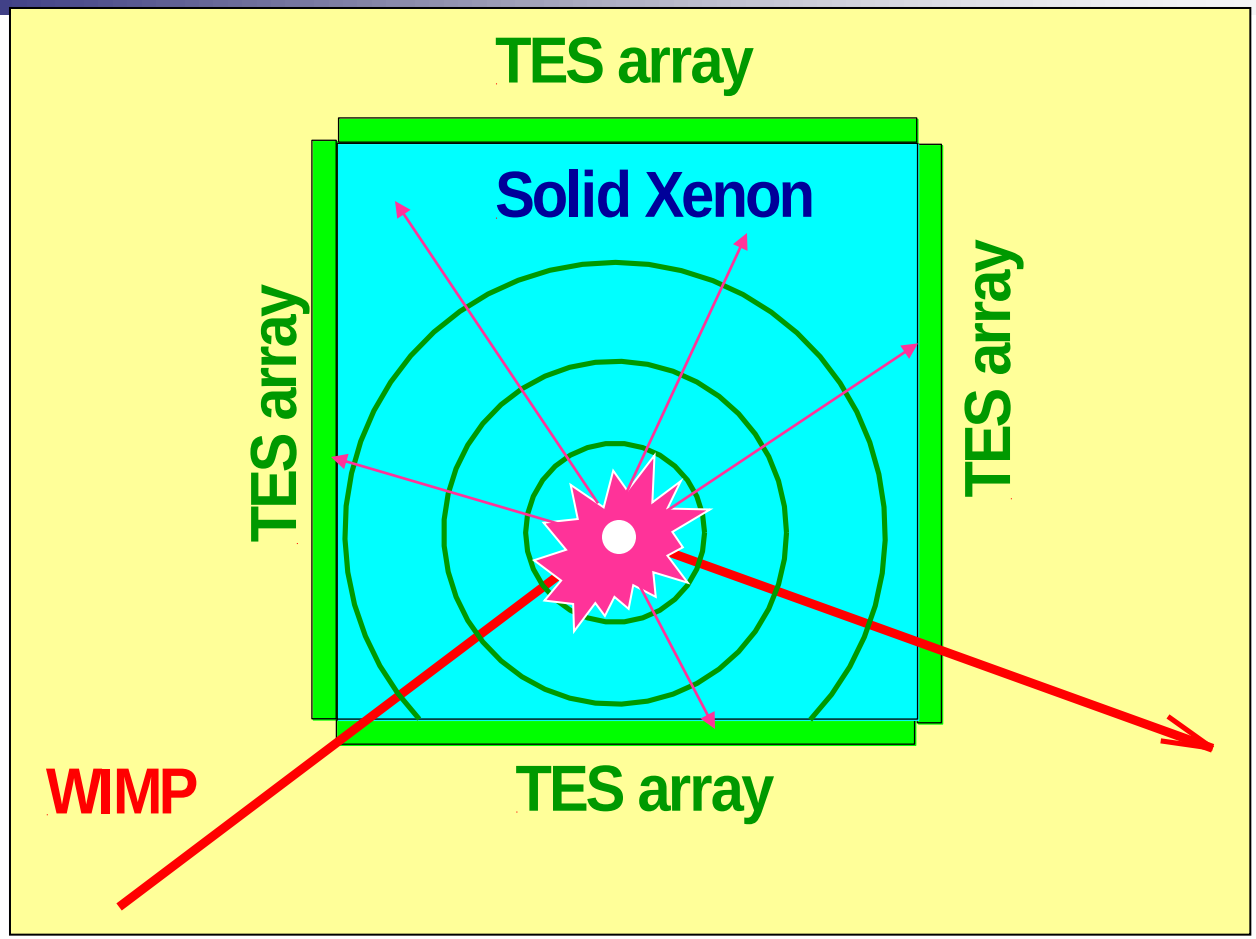
SXe



Detecting signal in 3 channels:

Carriers	*Threshold*
•Electrons	9.27eV
•Photons	7 eV
•Phonons	5 meV !!

Bolozdynya *IEEE TDEI* 13 (2006) 616



DETECTING SCINTILLATION AND PHONONS

- No electrical field → effective recombination
- First signal = **photons** → trigger
- Delayed signal = **phonons** → *Energy*
- Time analyses → *X, Y, Z*