NATIONAL RESEARCH NUCLEAR UNIVERSITY MEPhI
(Moscow Engineering Physics Institute)

Laboratory for Experimental Nuclear Physics
http://enpl.mephi.ru/

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

The RED-100

Search for elastic coherent neutrino scattering off atomic nuclei at the Kalininskaya Nuclear Power Plant

Rudik Dmitry

AAP Workshop

CEA 2014

Outline:

- RED Collaboration
- RED-1 & obtained results
- RED-100 & Kalininskaya Power Plant
- Conclusion

2010

Russian Emission Detectors

Р Э Д

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

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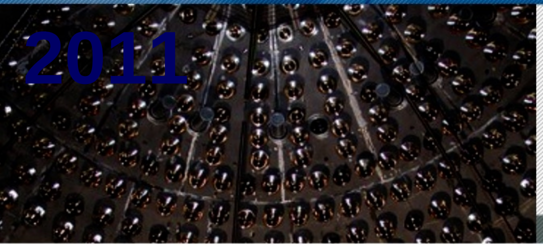
National Research Nuclear University, "MEPhI"



Laboratory for Experimental Nuclear Physics of NRNU MEPhI

LENP

D.Sc. -2
PhDs – 10
Faculty - 12
PhD students – 6
Students – 10

Laboratory

- General information
- Head of the lab
- Posters
- Photo Album
- Press about us
- Library
- Open House

Scientific program and activities

- General information
- Publications
- Seminars
- **Workshops**
- Carried out research activities
- RED-100
- The experiment at the reactor IRT MEPhI
- Restricted area

Grant of the Russian government in 2011-2013

- Tasks 2013
- Tasks 2012

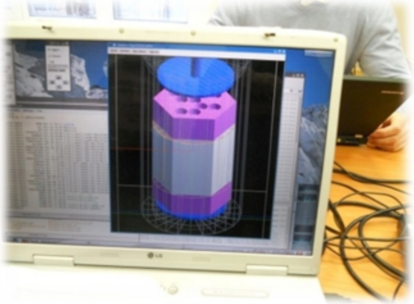
News of the Lab

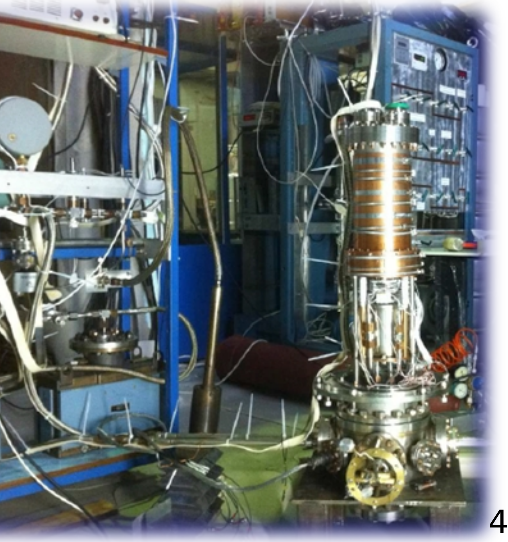
12 November 2014: **Мемориальные мероприятия, посвящённые памяти Б.А. Долгошеина**
...

8 October 2014: **Цикл лекций по современно**
...

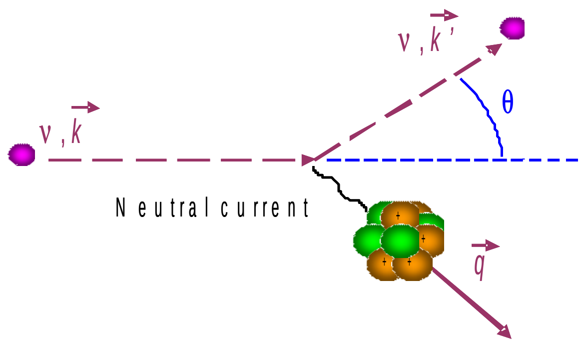
19 September 2014: **ЛЭЯФ в Фотохронике ИТА**
...

17 July 2014: **Next-Generation Dark Matter Ex**





Coherent neutrino scattering off heavy nuclei

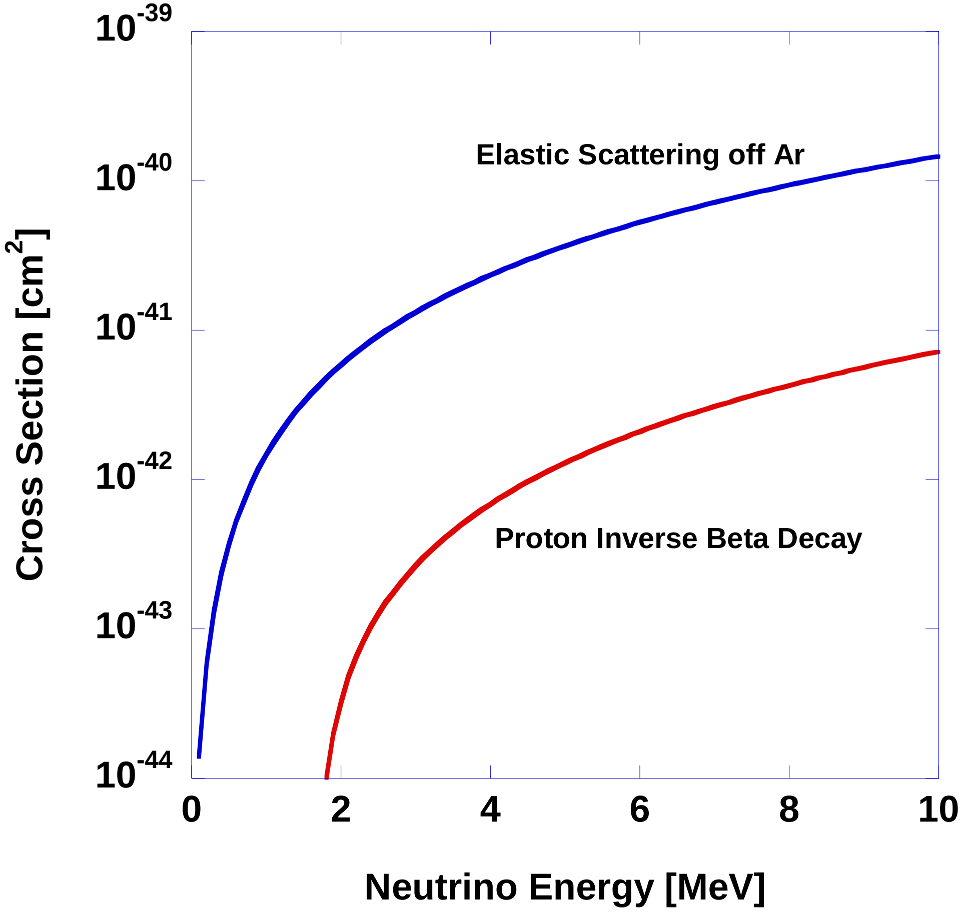


Large cross-section

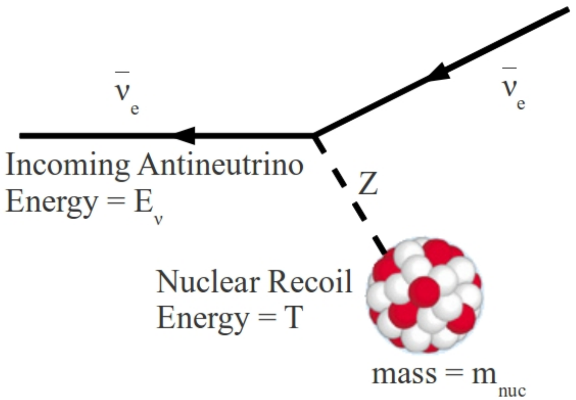
$$\sigma_{\text{elastic}} = \frac{G_F^2}{4\pi} N^2 E_\nu^2$$
$$\approx 0.4 \times 10^{-44}\,\text{cm}^2 A^2 E_\nu(\text{MeV})^2$$

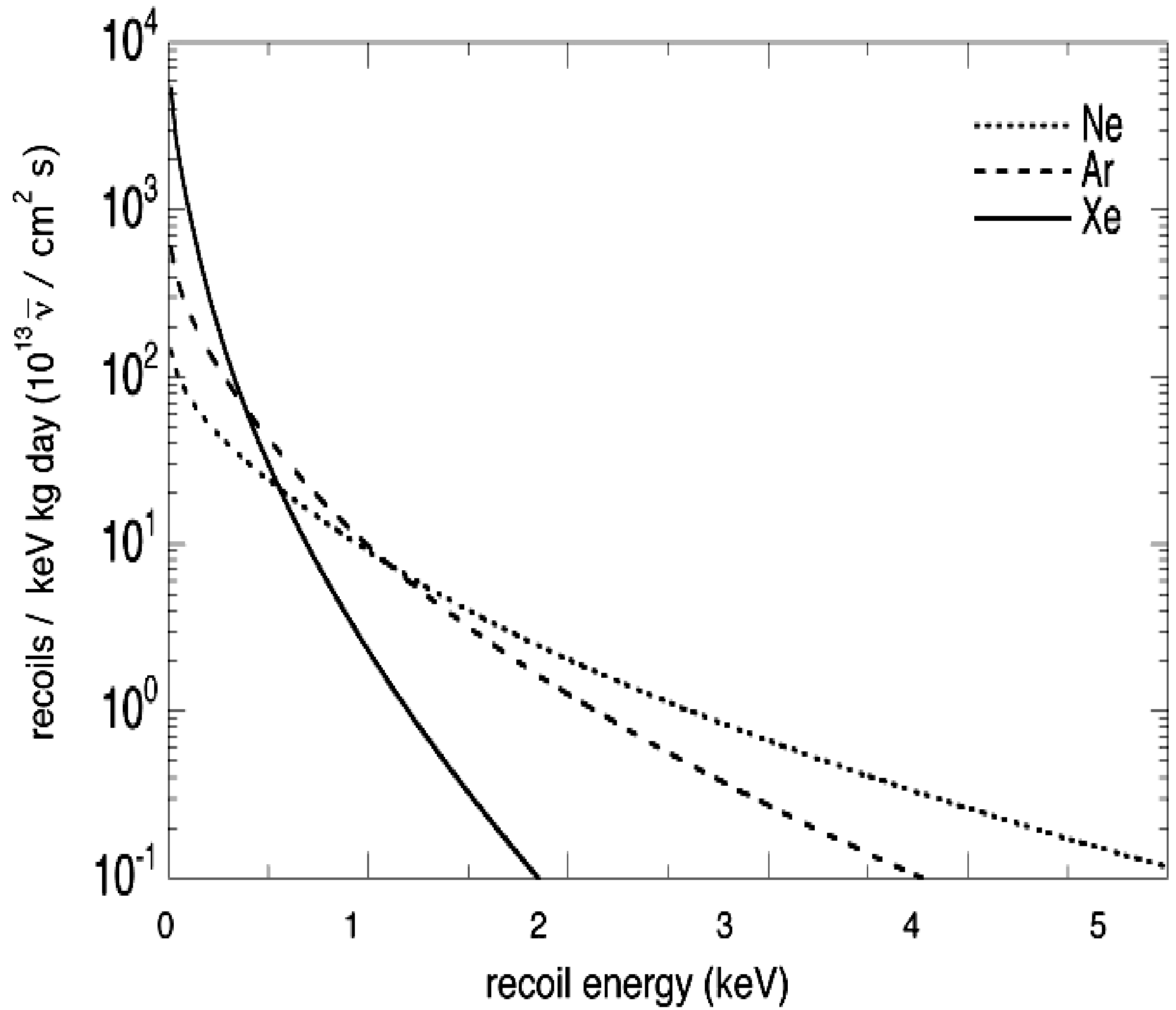
Small recoil energies

$$E_{\text{recoil}} \leqslant 716\ \text{eV}\ \frac{E_\nu^2(\text{MeV})}{A}$$



Recoil spectra from reactor e-antineutrino

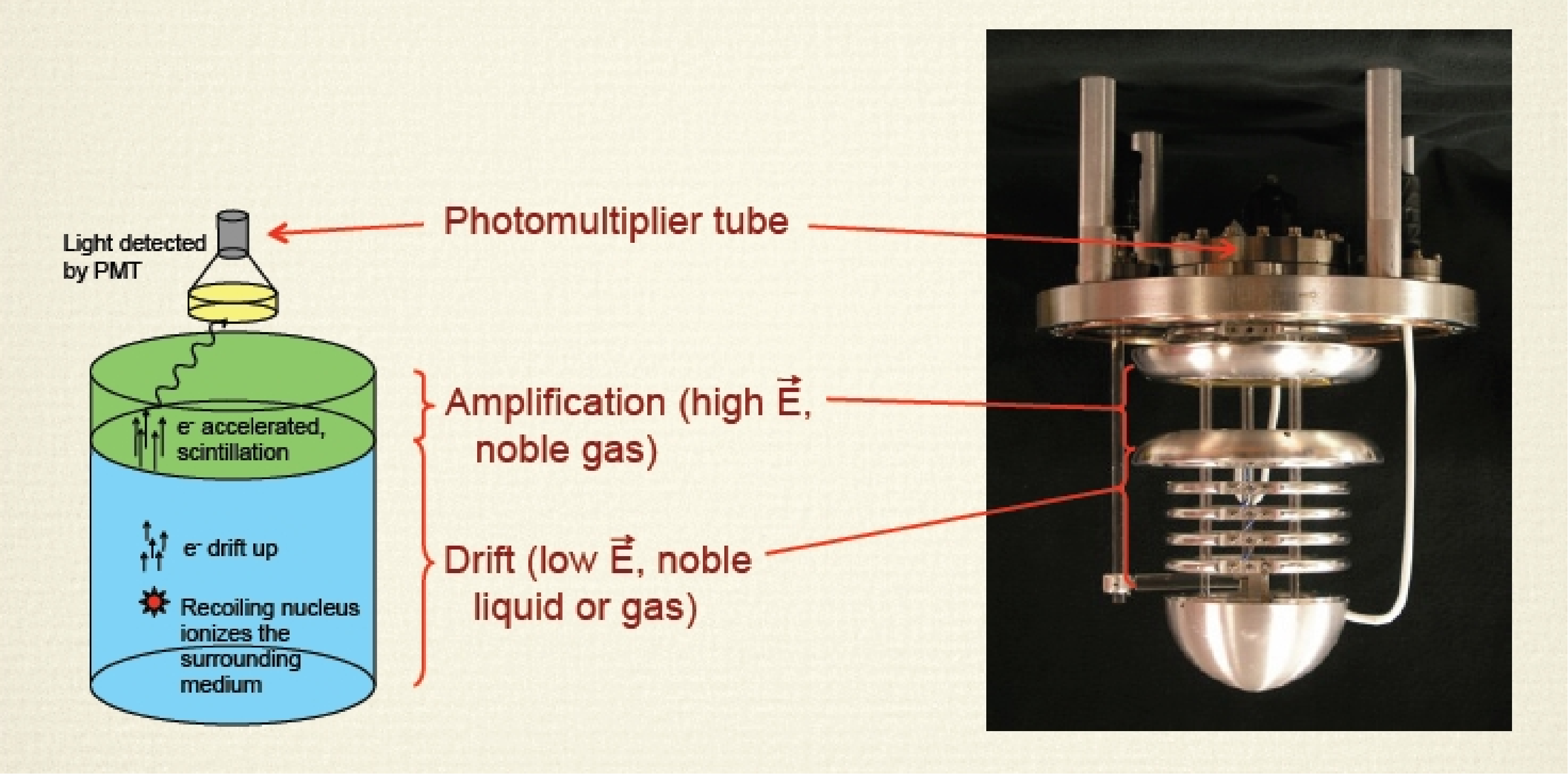




P. S. Barbeau, J. I. Collar, J. Miyamoto, and I. Shipsey

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

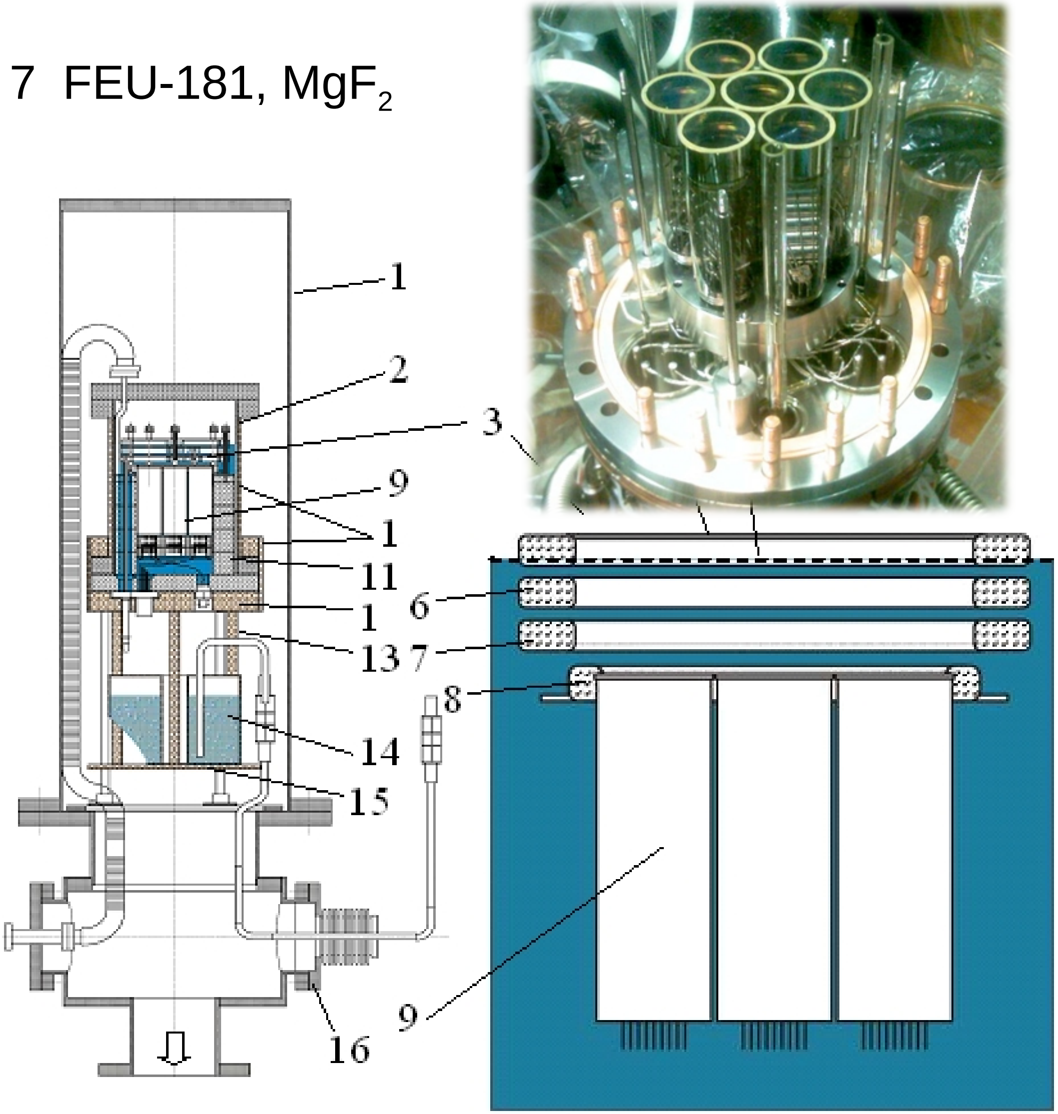
LAr detector @ LLNL

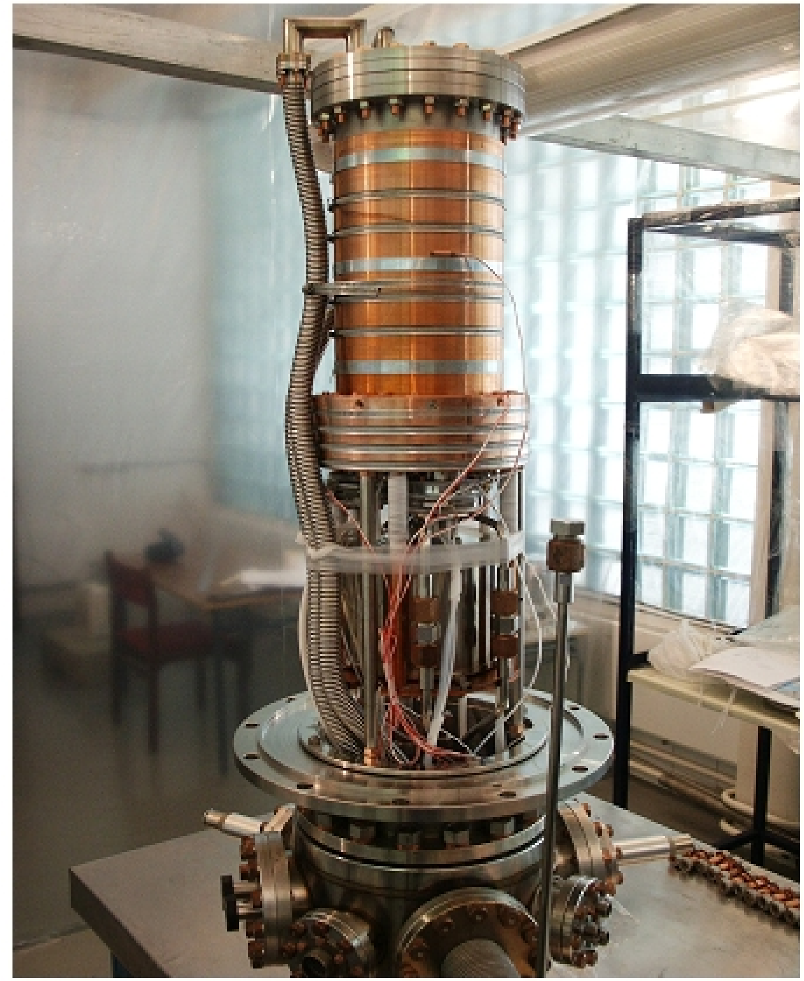


C.Hagmann and A.Bernstein.
Two-phase emission detector for measuring coherent neutrino-nucleus scattering,
IEEE Trans. Nucl. Sci. 51(2004)2151-2155.

LXe RED-1 & Research reactor of MEPhI

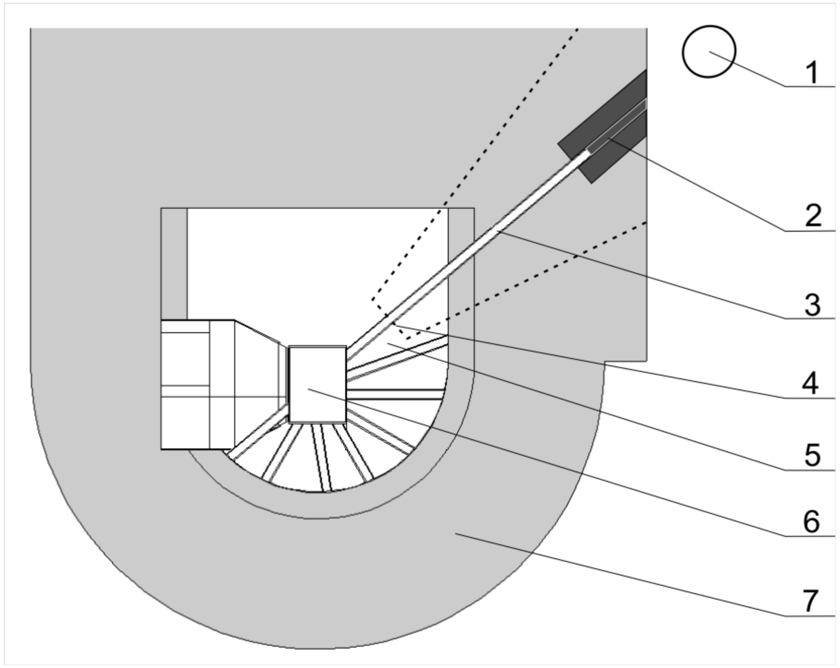
7 FEU-181, MgF_2





arXiv:1212.1938

2.5 MW
Research reactor IRT MEPhI



1 – RED-1

2 – Fe/Al filter

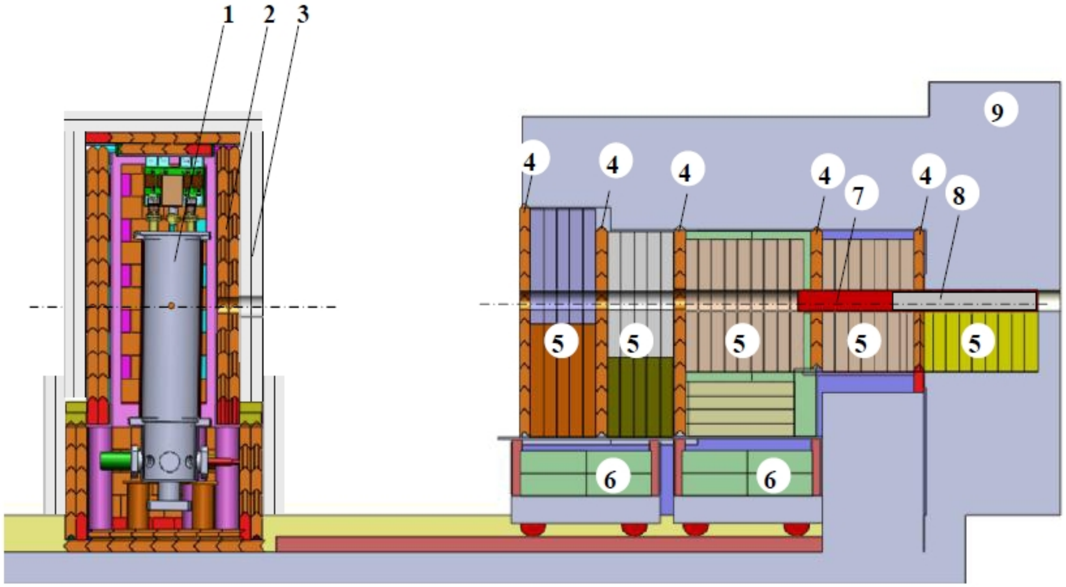
3 – horizontal neutron channel GEK10

4 – starting point of MCNP simulations

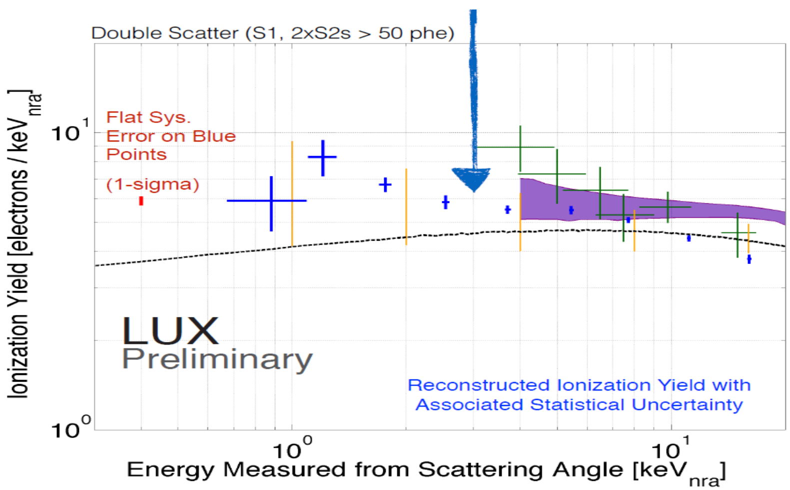
5 – cooling water pool

6 – active zone

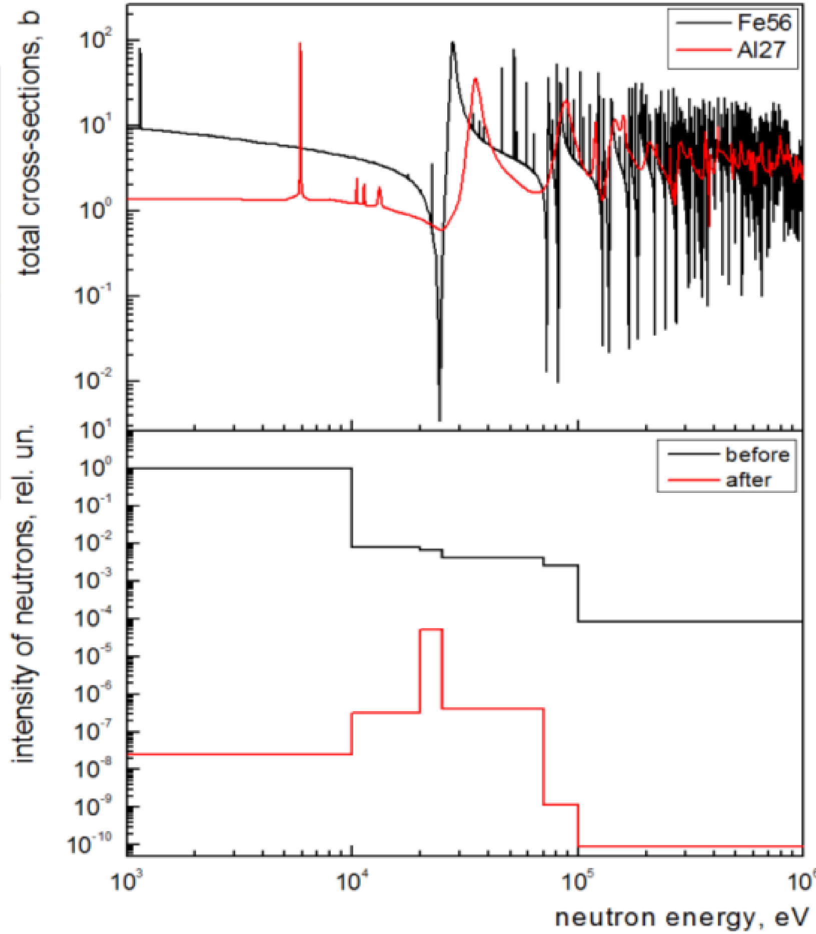
7 – heavy concrete shielding



1 – detector RED-1; **2, 3** - shield 10 cm lead & 10 cm borated polyethylene; **4** — lead slice 5 cm; **5** polyethylene slice - 5 cm; **6** - paraffin; **7,8** – filter 30 cm Fe & 70 cm Al; **9** — reactor's concrete shield.



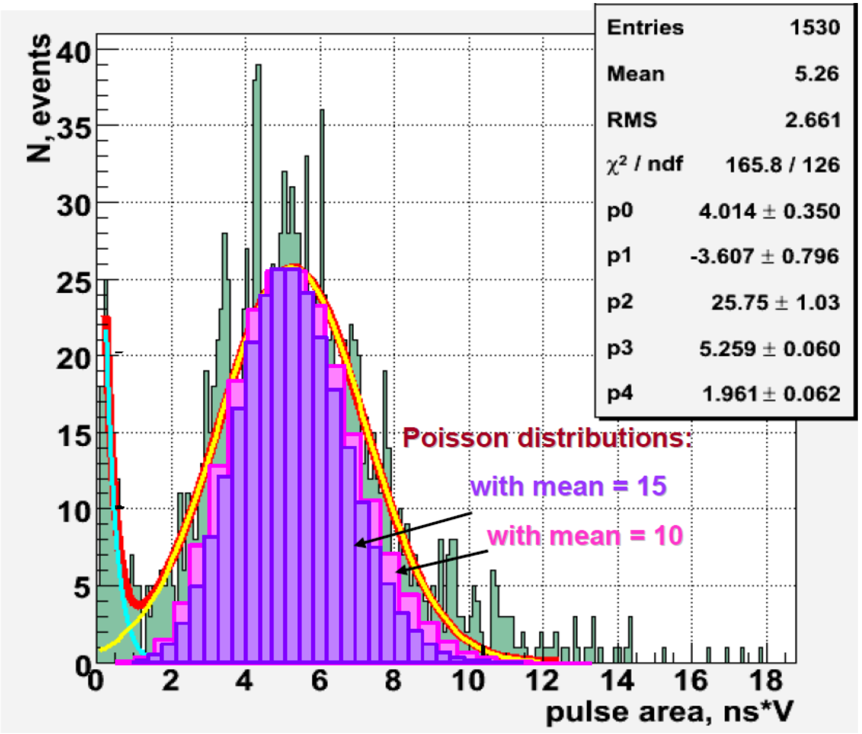
Specific ionization yield for the nuclear recoil with energy < 1 keV isn't known. Its obtainig is the main goal of our experiment at the MEPhI reactor.



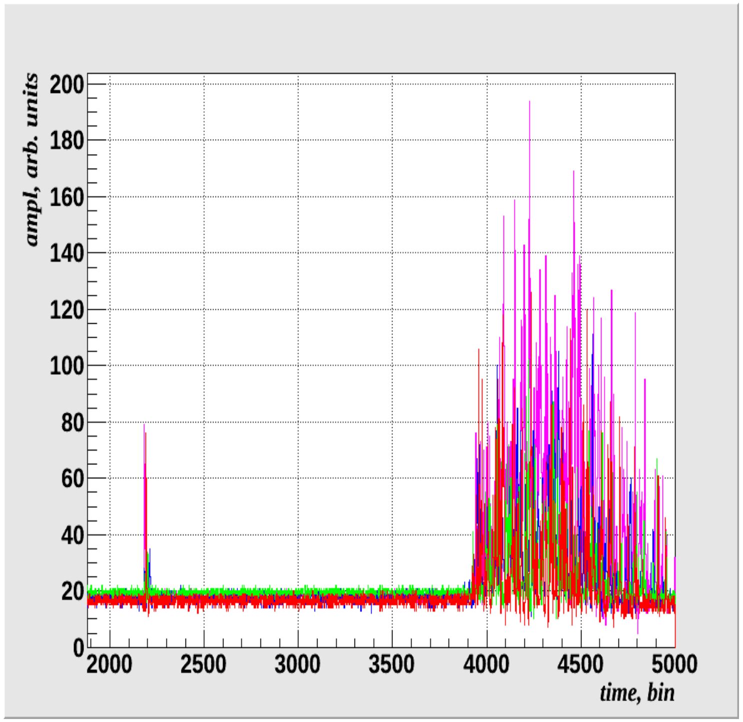
Neutron total cross section of ^{27}Al and of ^{56}Fe (upper plot) and simulated neutron beam spectra before and after passing the filter (bottom plot).

arXiv:1212.1938

Detection of Single Electrons

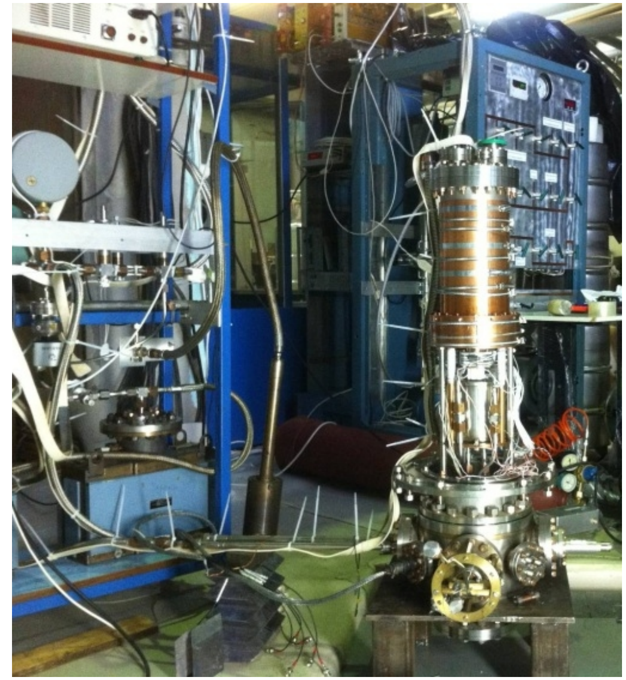


Distribution of EL (S2) signals generated by single emitted electrons (green). Maximum of the Gauss fit is 15 ± 5 photoelectrons.
Poisson distribution for 10 and 15 expectations are shown in pink and violet, respectively.



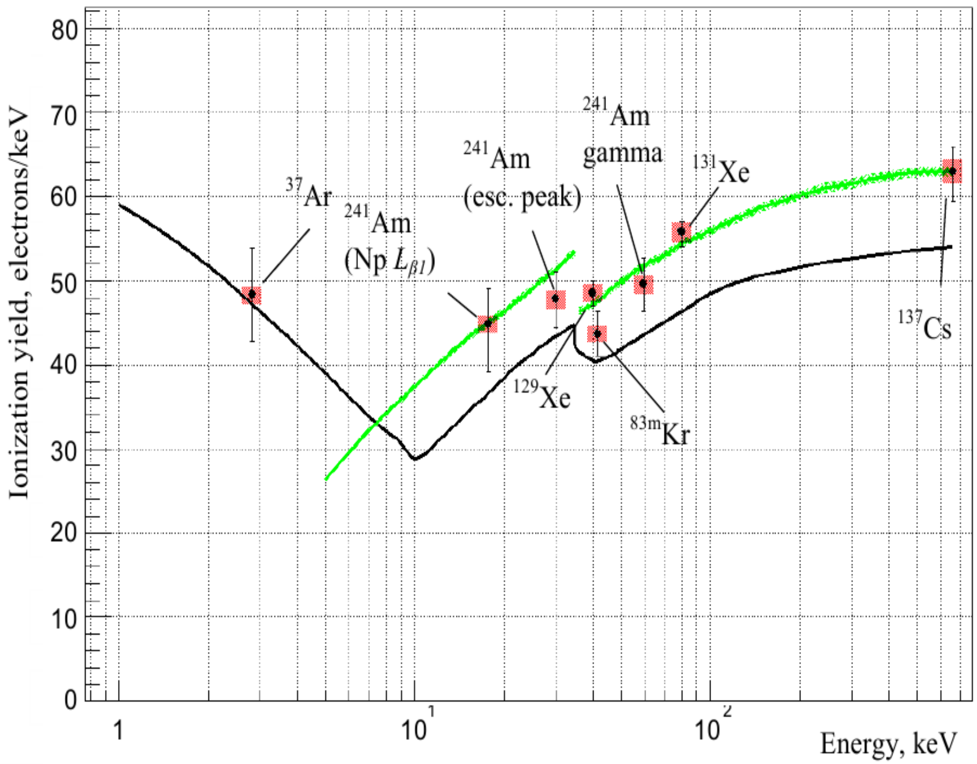
Typical gamma event in RED-1

A.A. Burenkov et al **Phys.Atom.Nucl. 72** (2009) 653-661,
Yad. Fiz. 72 (2009) 693-701
Doi: 10.1134/S1063778809040103



Obtained results

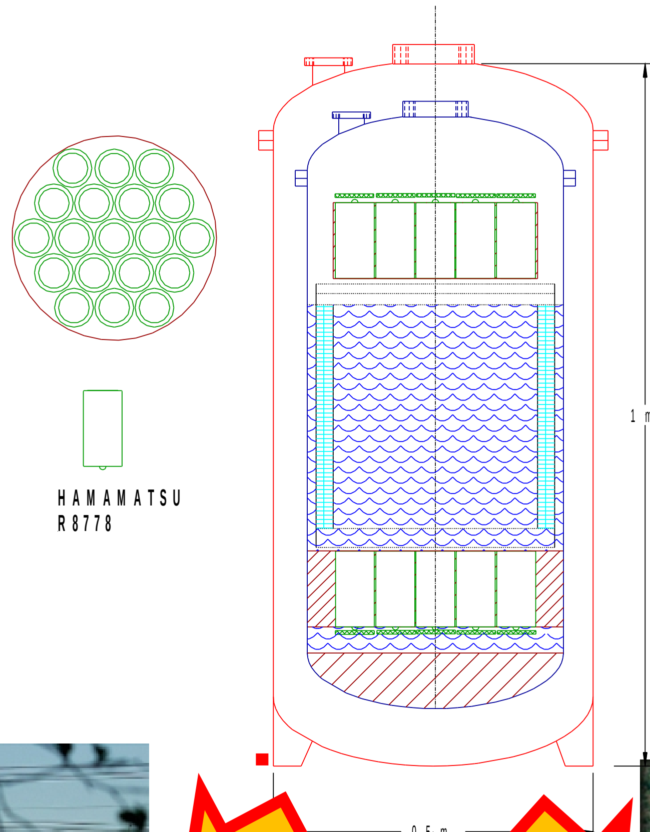
Experimental data for the ionization yield of LXe for electron recoils and theoretical predictions



D.Yu. Akimov et al 2014 JINST 9 P11014
doi:10.1088/1748-0221/9/11/P11014

Source	Energy, keV	Ionization yield, e-/keV
^{37}Ar	2.82	48.3 ± 5.7 (syst.)
^{241}Am, Np $L_{\beta 1}$	17.75	44.9 ± 2.7 (stat.) $^{+3.3}_{-5.1}$ (syst.)
^{241}Am, esc. peak (59.5-29.5 keV)	30	47.8 ± 0.7 (stat.) $^{+3.3}_{-3.4}$ (syst.)
^{129}Xe	40	49.0 ± 0.4(stat.) ± 1.7 (syst.)
^{83m}Kr	41.5	43.7 ± 0.1 (stat.) ± 2.8 (syst.)
^{241}Am	59.5	49.5 ± 0.1(stat.) ± 3.4 (syst.)
^{131}Xe	80	55.6 ± 0.8 (stat.) $^{+1.6}_{-1.9}$ (syst.)
^{137}Cs	662	63.0 ± 0.2 (stat.) $^{+3.2}_{-3.8}$ (syst.)

RED-100

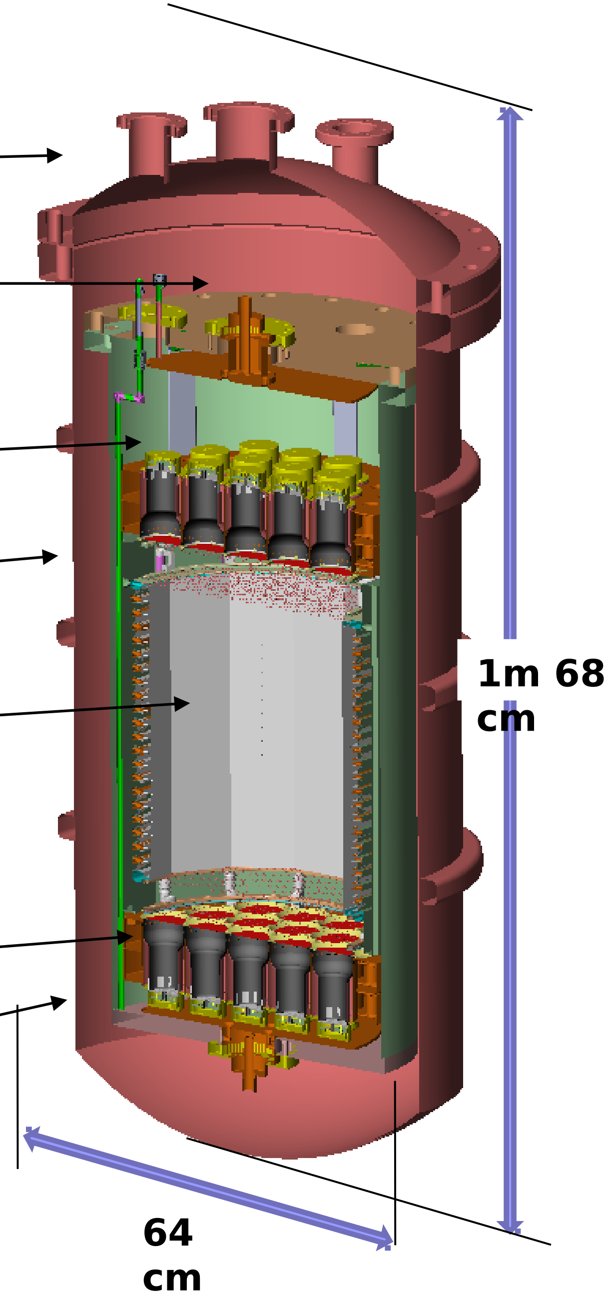


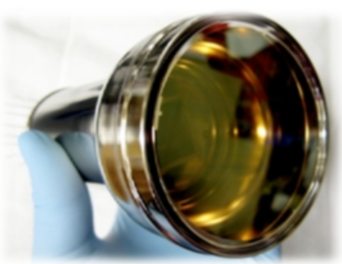
Kalininskaya NPP

OAK RIDGE National Laboratory

USA

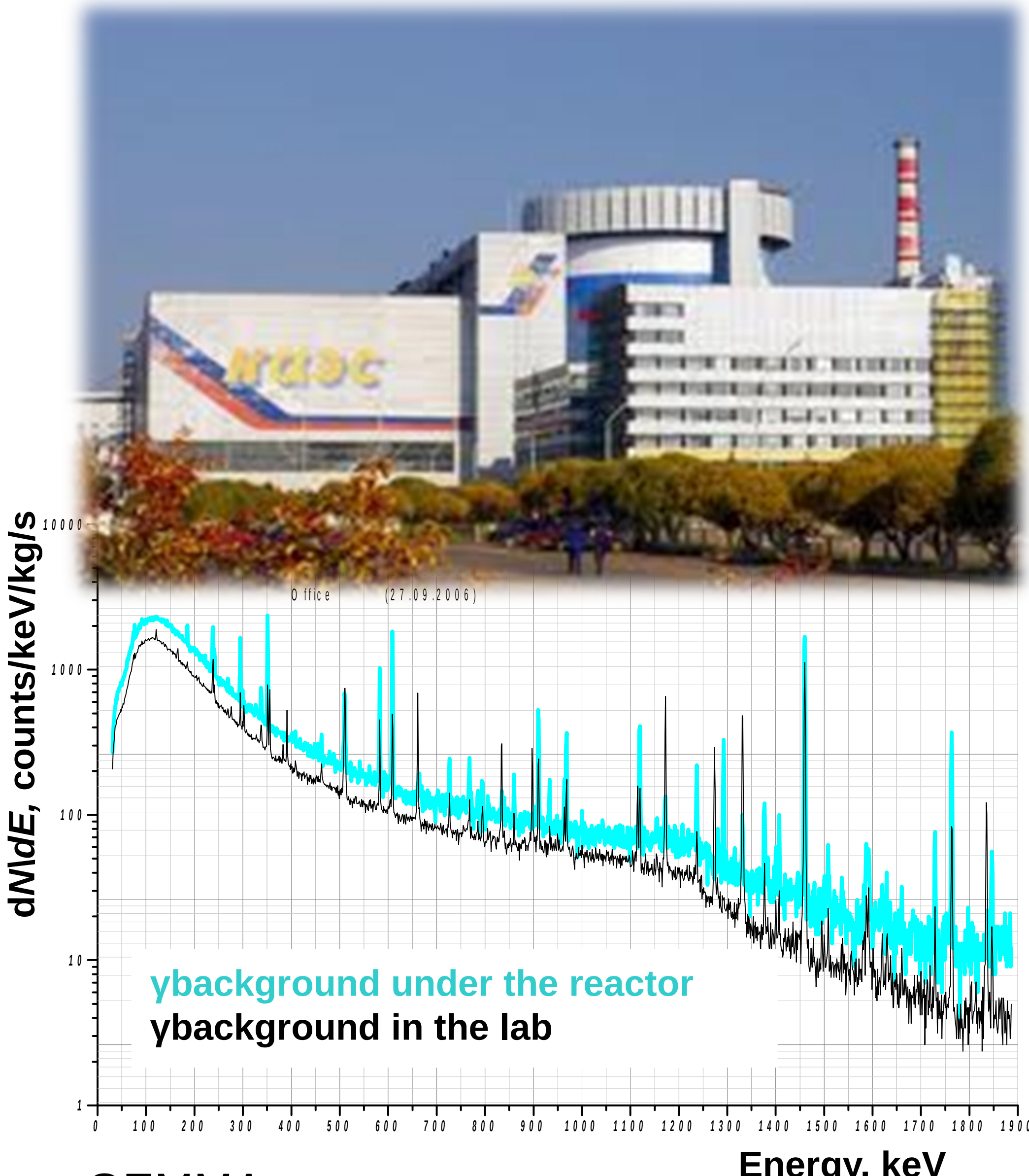
RED-100

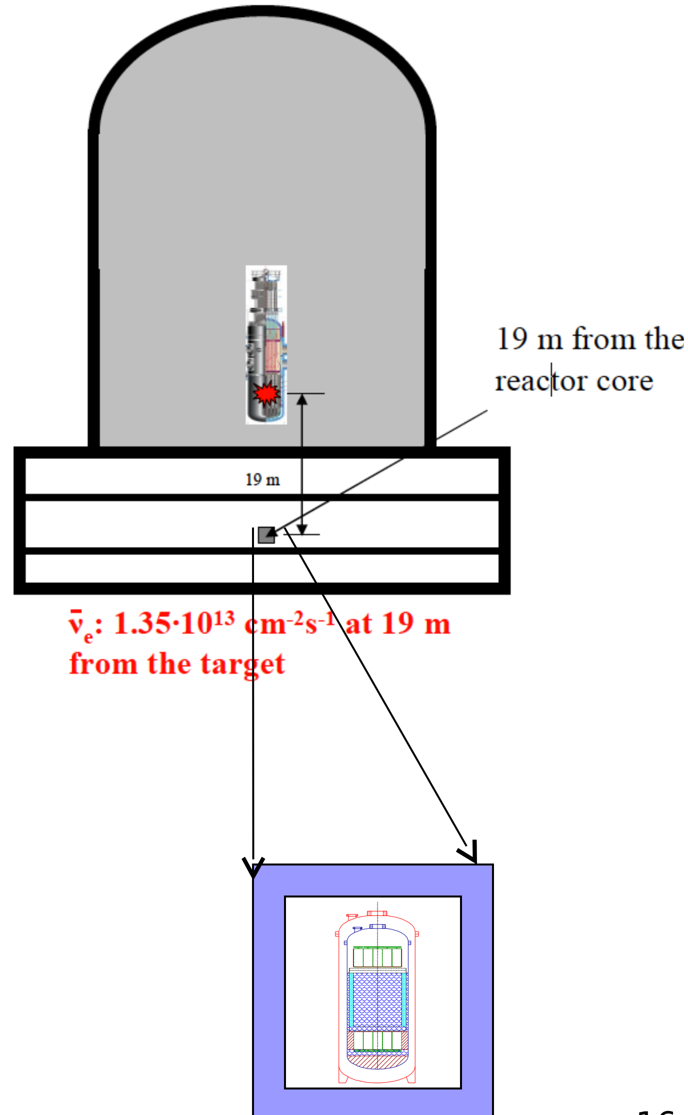




Hamamatsu R11410-20

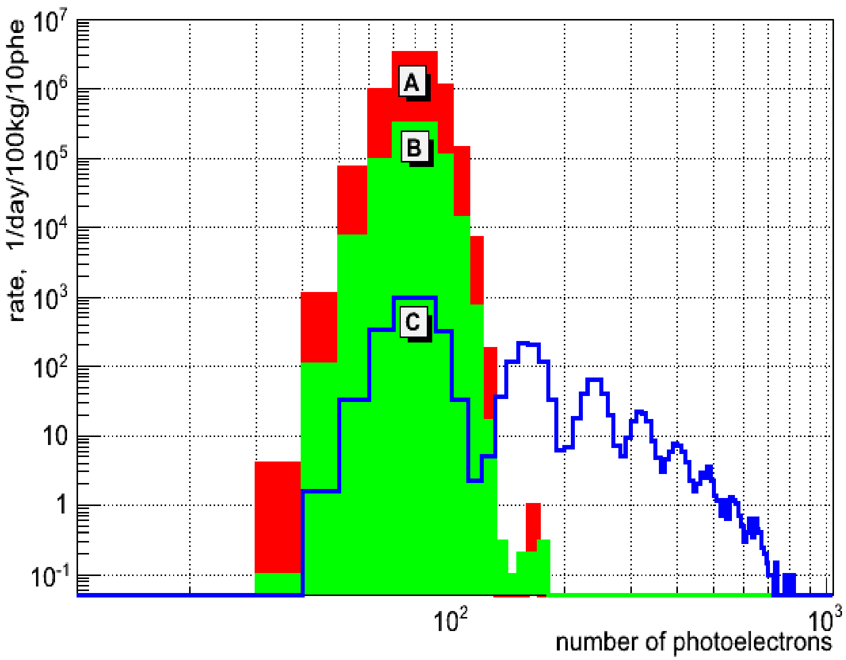
Kalininskaya Nuclear Power Plant (Udomlya)





GEMMA

Kalininskaya NPP facility: $\Phi_{antineutrino} = 1.35 \cdot 10^{13}$ cm^{-2}s^{-1}



Signal/Noise

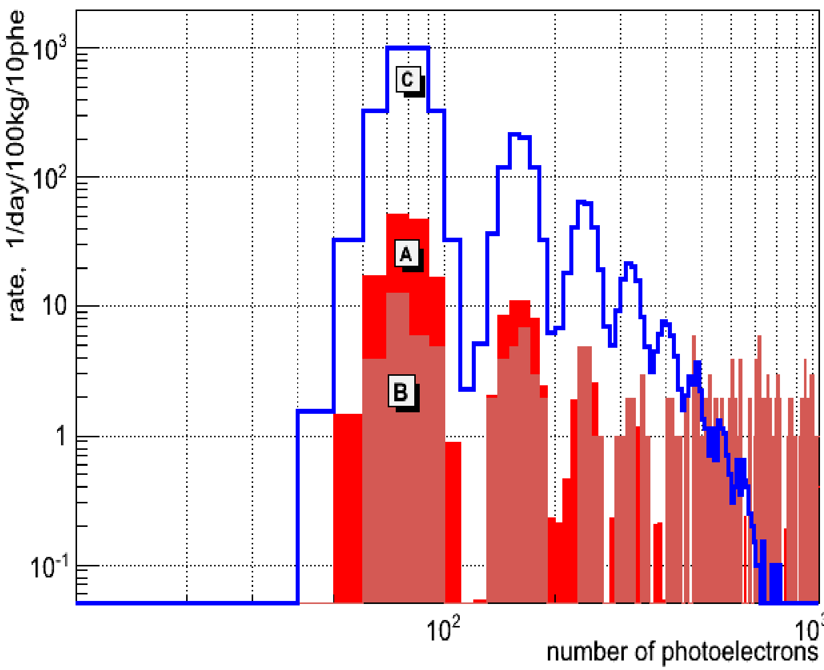
A: f_{SEE}**=100Hz**

B: f_{SEE}**=10Hz**

C: Signal

CR (>2 e) = 433/day/100 kg LXe

CR (*E*>1,8 MeV) = 27000/day/100kgLXe



Signal/Background

A: detector components

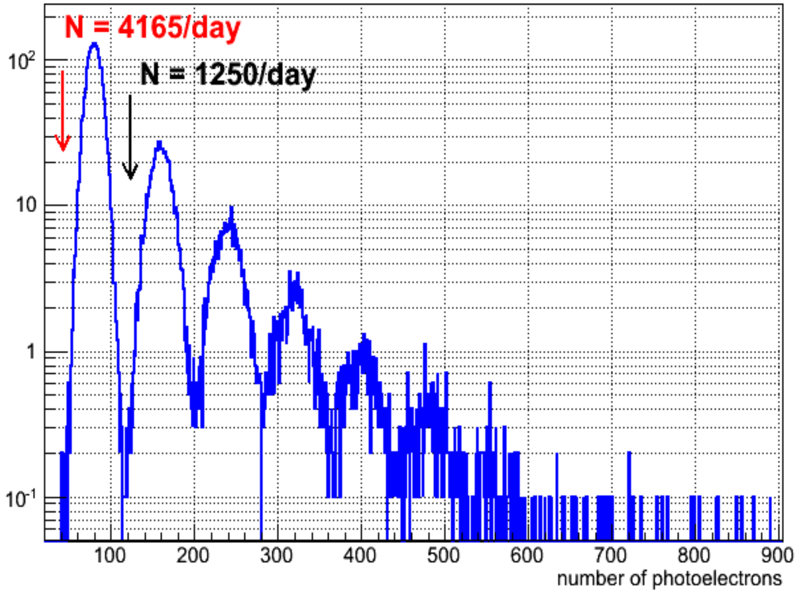
B: neutrons

C: Signal

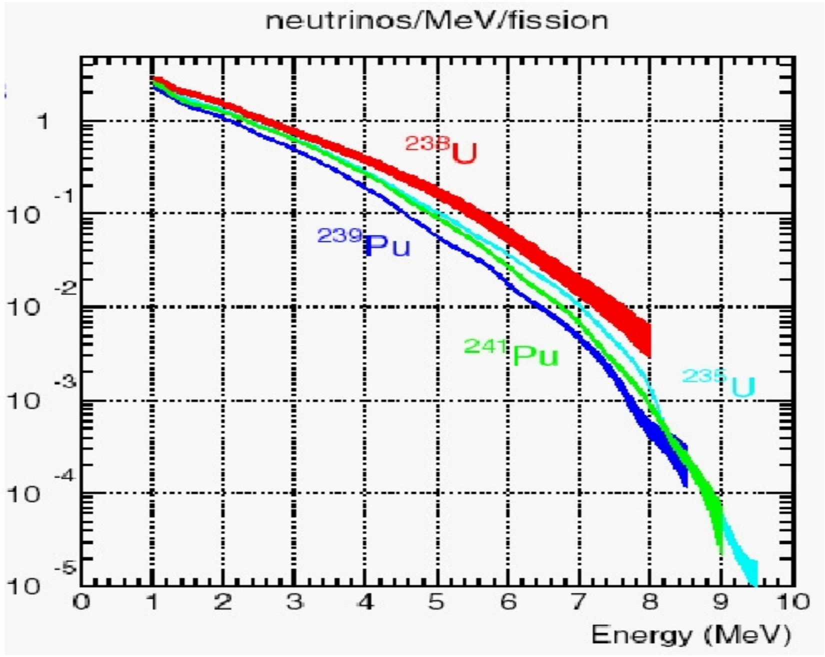
arXiv:1212.1938

Monitoring nuclear reactors

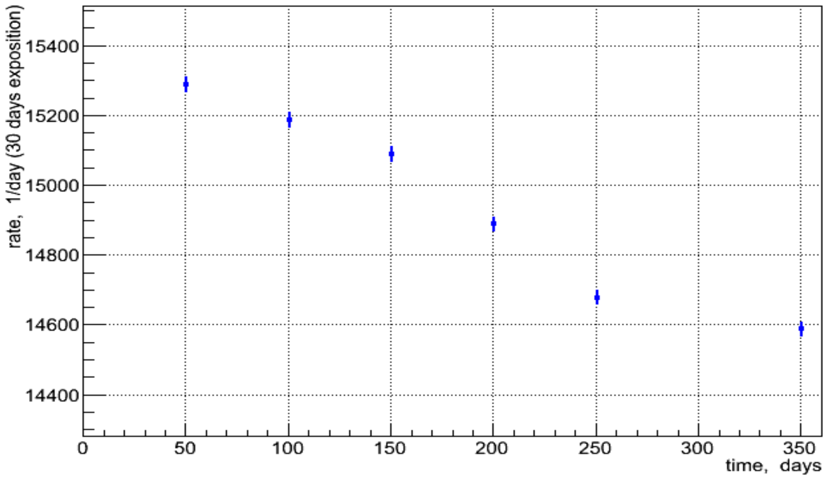
LWR, 3GWt, L = 19m



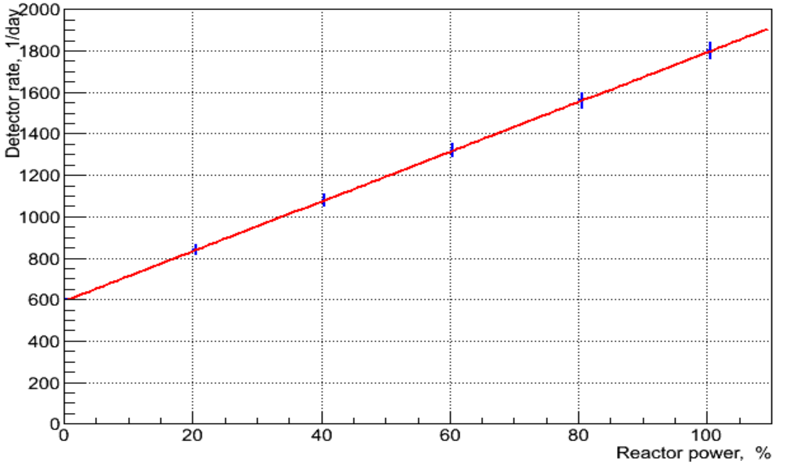
Detector response



Neutrino Spectra from fusions



Antineutrino flux evolution



Daily power monitoring

Conclusion

- ***Emission two-phase detectors*** are much promising technology to search for the Coherent Neutrino Scattering (*CNS)* effect
- ***CNS*** is interesting for fundamental Physics and for non-proliferation applications
- ***Capability to measure weak ionization*** from nuclear recoils below 1 keV energies is a key element toward the observation of CNS
- ***Obtained results by RED-1*** of low energy recoils region show an ability of such detectors to search for CNS effect
- ***RED-100*** experimental installation is under development for observation of CNS and for development of a highly sensitive method of NPP monitoring

Р Э Д

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

Thank you for your attention!

Our contacts:

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  - akimov_d@me.com - Dmitry Akimov
  - Rudik.dmitry@mail.ru - my e-mail

Backup

Electronics: RUN2013

Signals from PMTs

Fast preamplifiers

A remote control switch.

0.5 or 5 gain possibility

Low sensitivity channel

CAEN V1720 12-bit

(4 ns sampling)

From a fraction of a SPE to ~10^5 SPE!

High sensitivity channel

8-channel Phillips Scientific 772

Struck SIS3350 12-bit (2 ns sampling)

Calibration sources

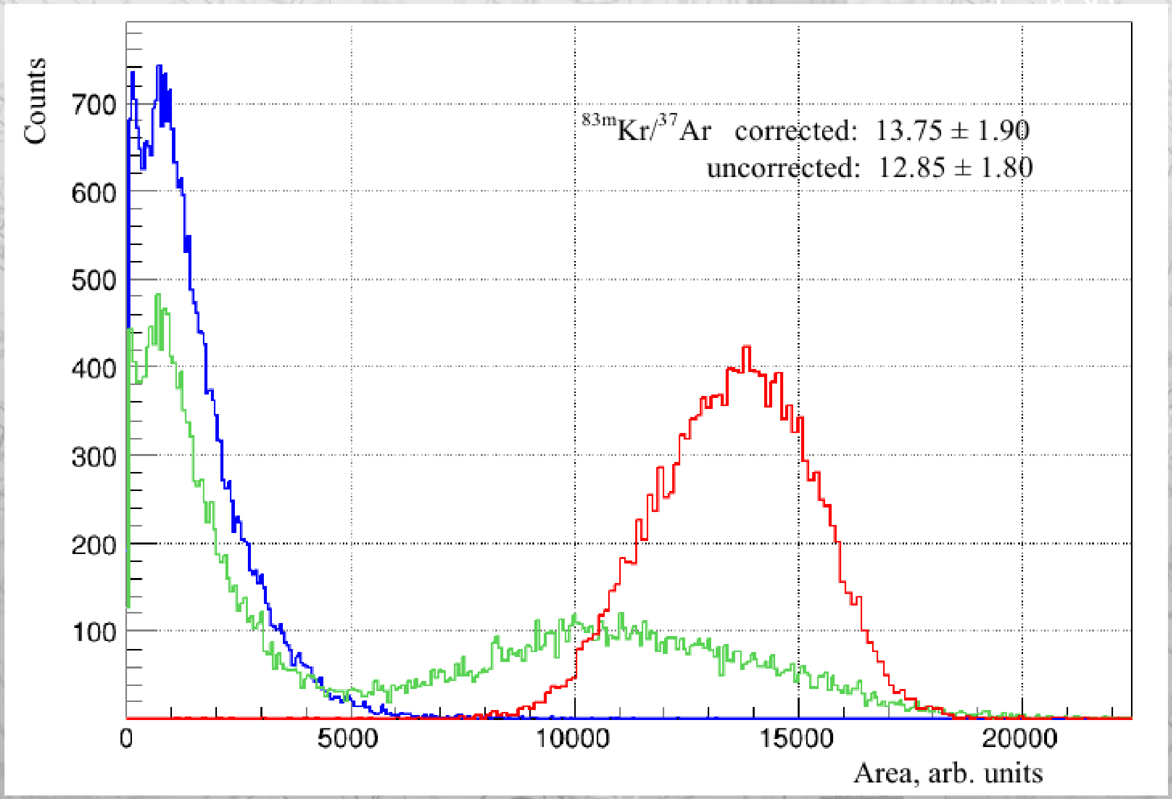
Table of energy lines and corresponding radioactive sources

Energy, keV	2.82	13.9	17.2	30	39.6	41.5	59.5	80.2	662
Isotope	^{37}Ar	^{241}Am	^{241}Am	^{241}Am	^{129}Xe	^{83m}Kr	^{241}Am	^{131}Xe	^{137}Cs
Description	EC, Auger	gamma	gamma	escape peak	n-gamma	IC, gamma, Auger	gamma	n-gamma	gamma
RUN2009	–	+	+	+	–	+	+	–	–
RUN2013	+	–	–	–	+	+	–	+	+

^{83m}Kr line was used as a reference point to combine results of both datasets

Data analysis: ^{37}Ar

Distribution of S2 signal areas of 37Ar and 83mKr events; red - events from the 83mKr runs, blue – events from 37Ar runs, green – events from the runs with both 37Ar and 83mKr in the detector (without lifetime correction).



Weighted average of krypton to argon ratio is

13.3 ± 1.3

The evaluated from ^{37}Ar data free electron lifetime is 16 ± 5 μs.

Ionization yield: W_i

$W_i = 15.6 \pm 0.3$ eV (for MeV ^{207}Bi electrons and γ)

T. Takahashi, S. Konno, T. Hamada et al., Phys. Rev. A12 (1975) 1771,
Average energy expended per ion pair in liquid xenon

$W_i = 16.5 \pm 0.8$ eV (for 122 keV ^{57}Co γ)

M. Horn, V. A. Belov, D. Yu. Akimov et al., Phys. Lett. B705 (2011) 471,
Nuclear recoil scintillation and ionisation yields in liquid xenon from ZEPLIN-III data

$W_i = 14.27 \pm 0.30$ eV ← $(1 + 0.06) * W = 13.46 \pm 0.29$ eV

T. Shutt, C.E. Dahl, J. Kwong et al., NIM A579 (2007) 451,
Performance and fundamental processes at low energy in a two-phase liquid xenon dark matter detector

$W_i = 13.6 \pm 0.2$ eV

I. M. Obodovskii and S. G. Pokachalov, Sov. J. Low Temp. Phys. 5 (1979) 393,
Average ion pair formation energy in liquid and solid xenon

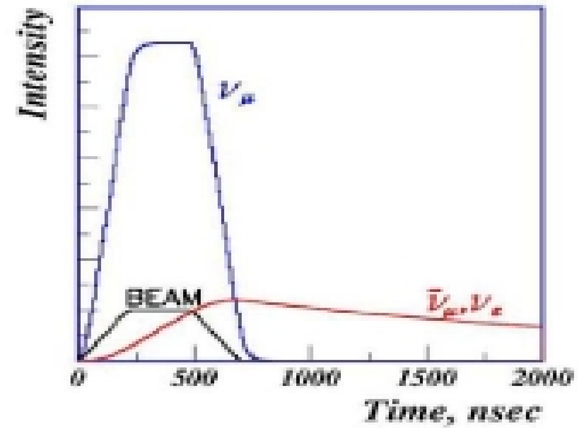
$W_i = 14.84$ eV ← $(1 + 0.06) * W = 14$ eV

E. Aprile J. Angle, F. Arneodo et al., Astropart. Phys. 34 (2011) 679,
Design and performance of the XENON10 dark matter experiment

Spallation Neutron Source (ORNL)

Proton beam energy – 0.9 - 1.3 GeV
Intensity - 9.6 · 10^{15} protons/sec
Pulse duration - 380ns(FWHM)

Repetition rate - 60Hz
Total power – 1.3 MW
Liquid Mercury target

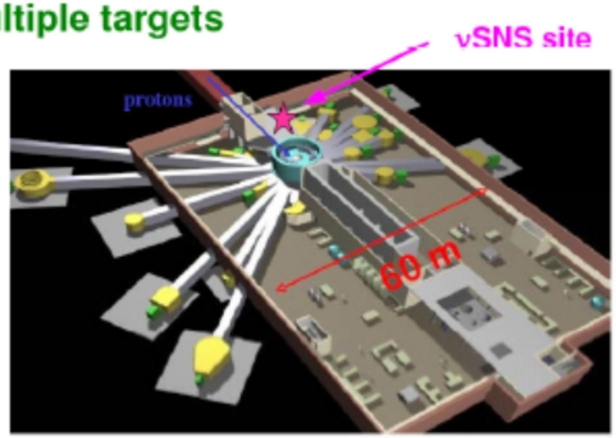


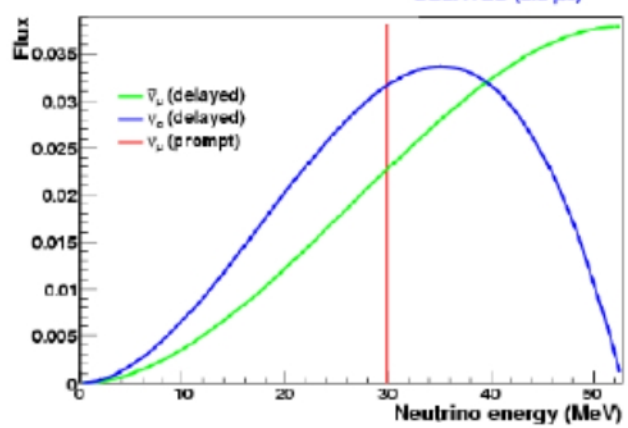
NuSNS (Neutrinos at the SNS)

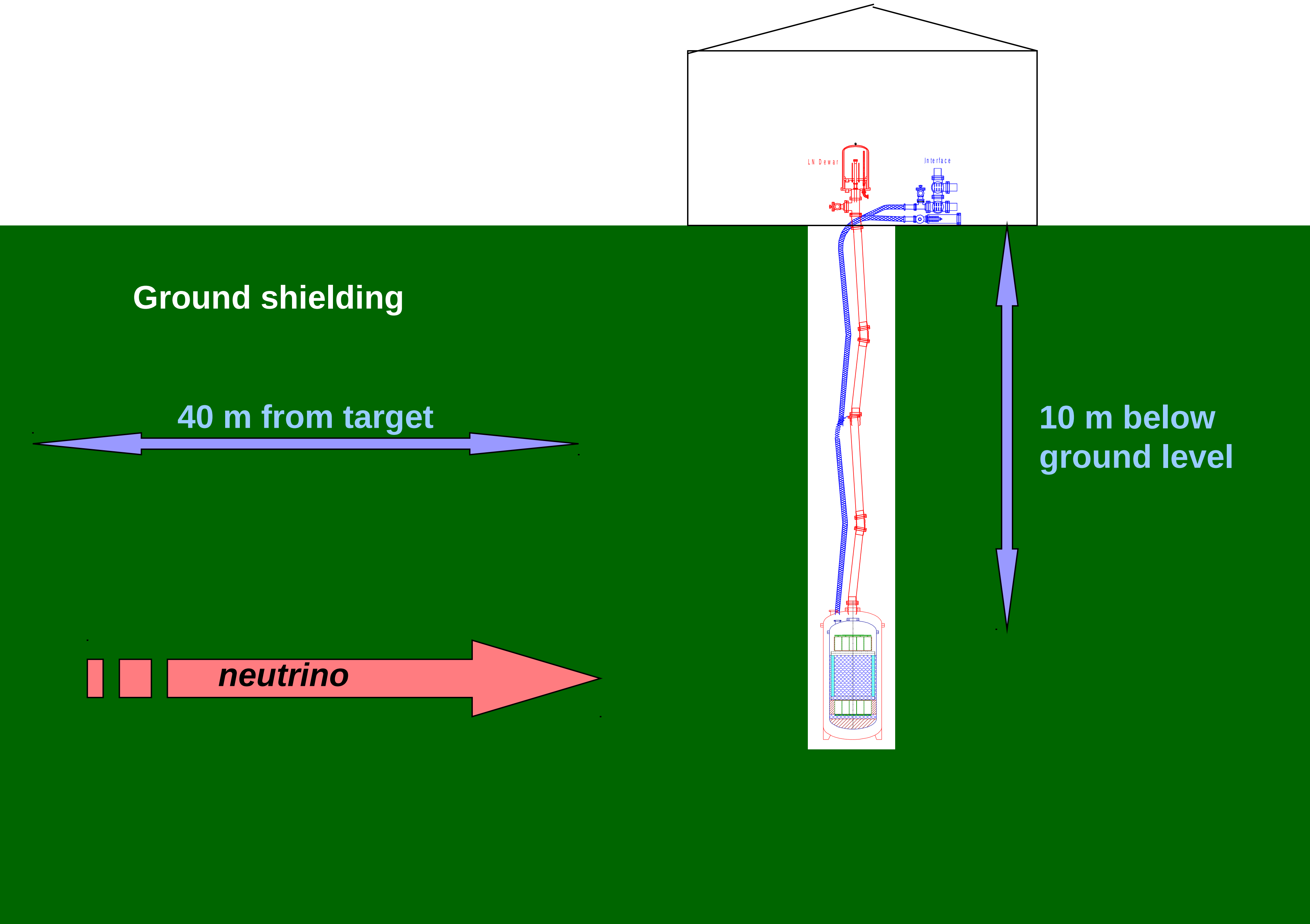
$\pi^+ \to \mu^+ + \nu_\mu$ 2-body decay: monochromatic 29.9 MeV ν_μ PROMPT

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

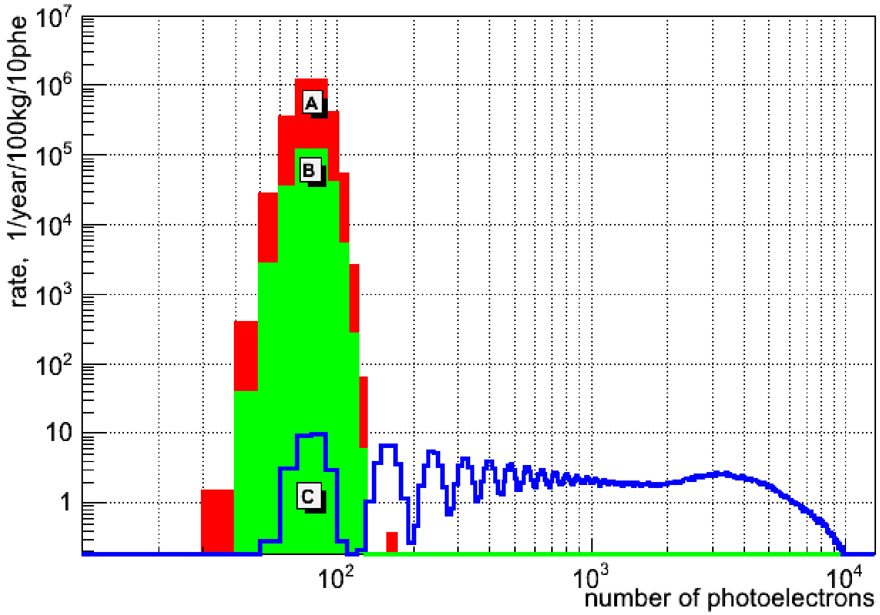
A neutrino facility with capability to measure multiple targets



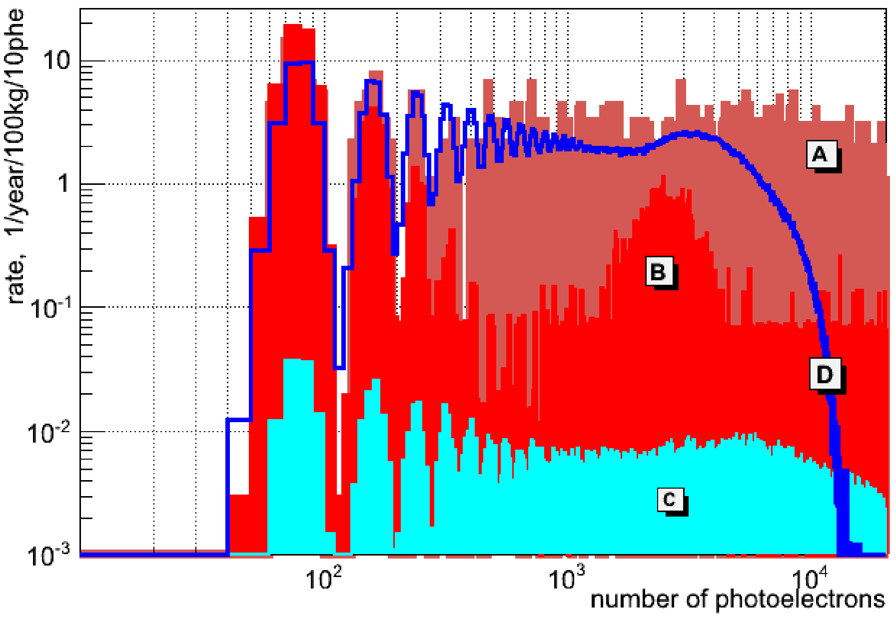



LN Dewar
Interface
Ground shielding
40 m from target
10 m below
ground level
neutrino

RED-100 @ 40 m from the SNS target



Signal/Noise



Signal/Background

A: f_{SEE}**=100Hz**

B: f_{SEE}**=10Hz**

C: Signal

CR (>3 phe) = 1470/year/100 kg LXe

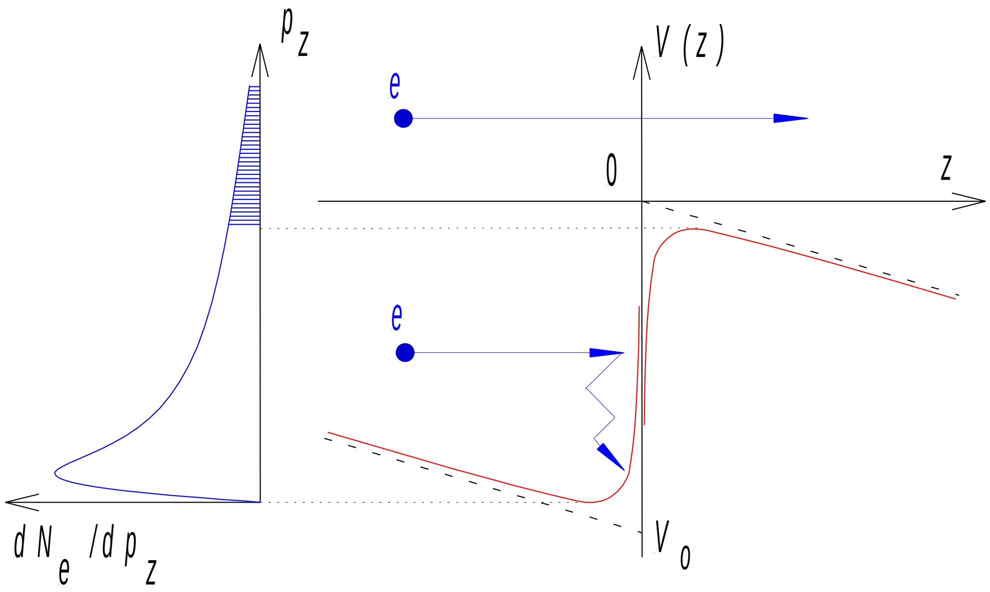
A: Neutrons from cosmic rays

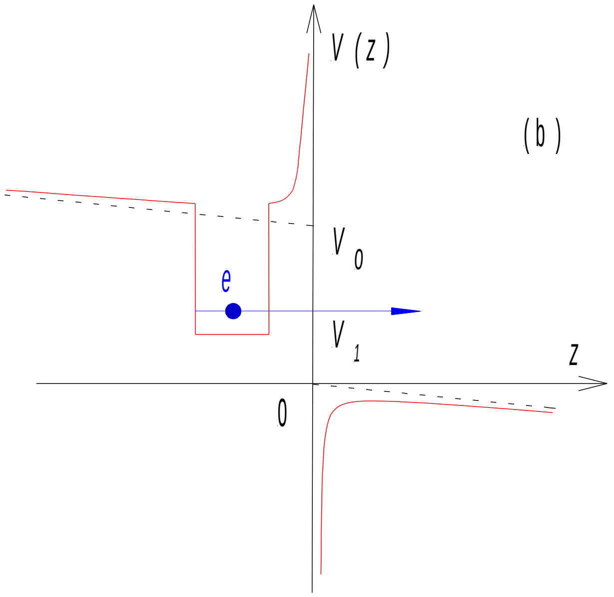
B: Components of RED100

C: Neutrons from SNS

D: Signal

Quasi-free electron emission from nonpolar dielectrics





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

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

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