Alexander Bolozdynya

(NRNU MEPhI)

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

Two-phase emission detector RED100 for investigation of coherent scattering neutrino off heavy atomic nuclei

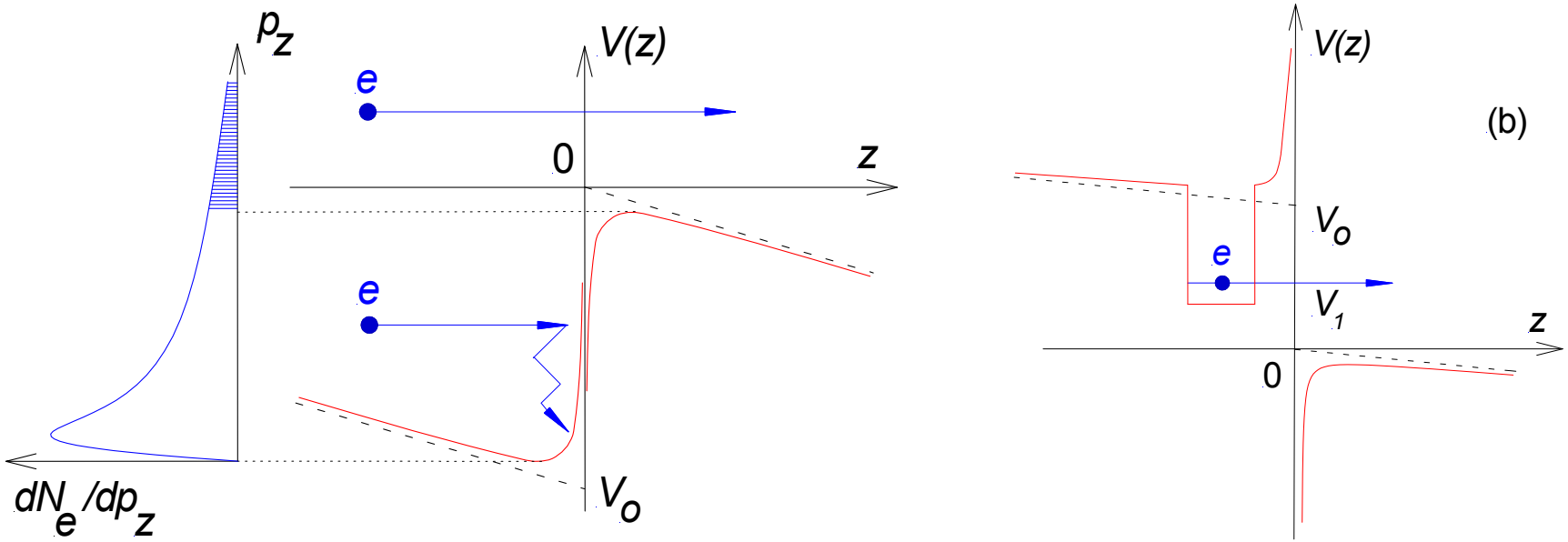
CREDO

RED is focused on development of two-phase noble gas emission detector with 100 kg mass of working media which to be used for detection of neutrino coherent scattering on heavy nuclei. The detector will have single-electron sensitivity to ionization and could be considered for observation 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.

As part of the program, the liquid xenon 5 kg model of the detector will be tested at the horizontal channel of the IRT MEPhI 2.5 MW research reactor in order 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 will be formed with aluminum-iron interferential filter.

Quasi-free electron emission from nonpolar dielectrics

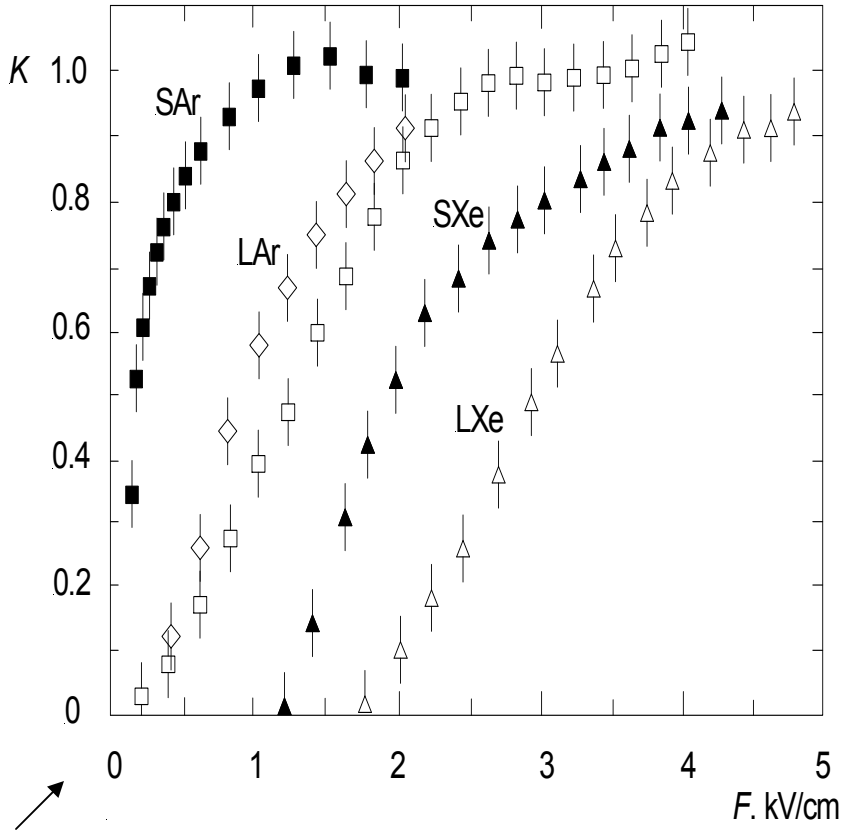


$$V_1(z) = V_0 - eF_1 z + eA_1, z < 0$$

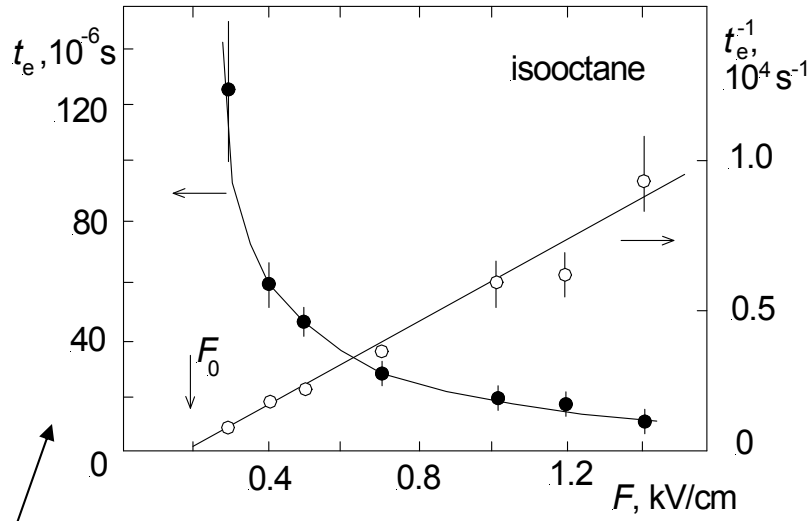
$$V_2(z) = -eF_2 z + eA_2, z > 0$$

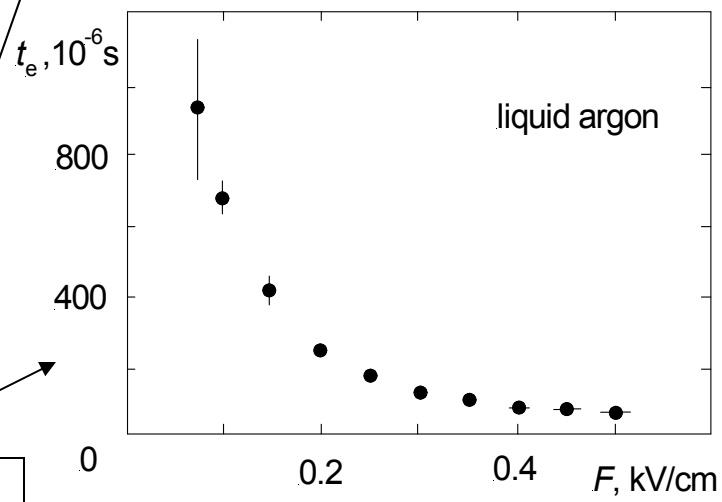
$$A_{1,2} = -e(\varepsilon_1 - \varepsilon_2) / \left[4\varepsilon_{1,2}(z + \xi z/|z|)(\varepsilon_1 + \varepsilon_2)\right]$$

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



Hot electron emission





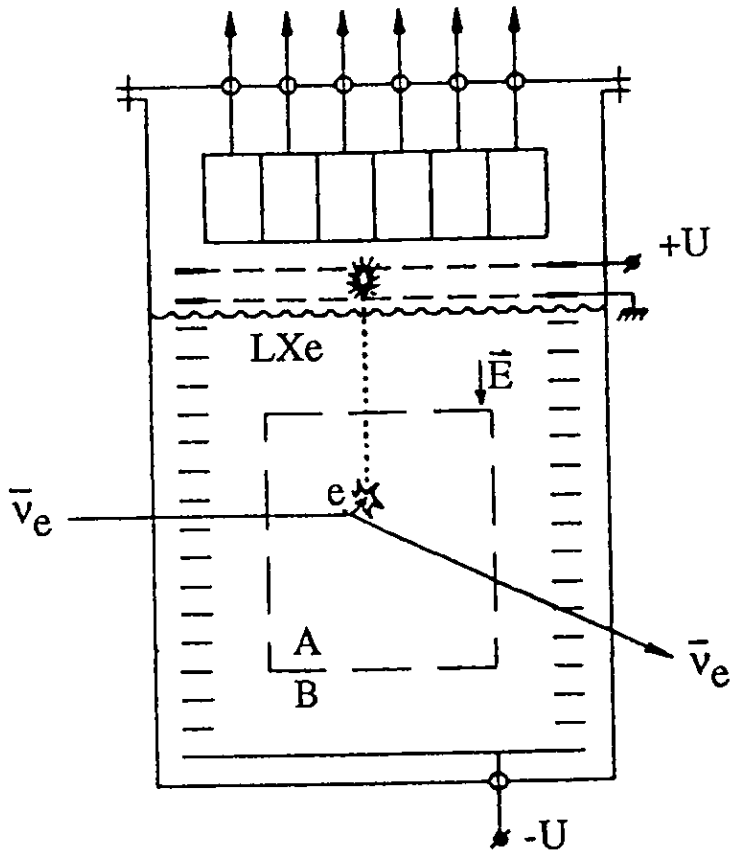
Thermoelectron emission

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

	T, K	*μo* , *cm2/V/s*	*Vo* , eV	*Ec* , kV/cm	*Eo* , kV/cm	*te*
Emitters of cold electrons						
L^{4}He	1-2	0.03	+1			10 s (100V/cm)
L n-H	300	0.09	+0.09	100	0.03	
L iso-O	300	7	-0.18	90	0.15	20 μs (1kV/cm)
L TMP	297	24	-0.3	50		
LAr	84	475	-0.21	0.2		700μs (100 V/cm)
SNe	24	600	+1.1			
Emitters of hot electrons						
LCH$_4$	100	400	-0.18	1.5	<4	
SCH$_4$	77	~1000	0		<1.5	< 0.1 μs (>1kV/cm)
LAr	84	475	-0.21	0.2	0.25	< 0.1 μs (>0.3kV/cm)
SAr	83	1000	+0.3 (6K)		0.1	< 0.1 μs (>100V/cm)
LKr	116	1800	-0.4	0.08	1.6	< 0.1 μs (>1.6kV/cm)
SKr	116	3700	-0.25 (20K)		0.98	< 0.1 μs (>1kV/cm)
LXe	161	2200	-0.61	0.05	1.75	< 0.1 μs (>1.8kV/cm)
SXe	161	4500	-0.46 (40K)		1.25	< 0.1 μs (>1.3kV/cm)

Note: n-H – normal hexane, iso-O - isooctane, TMP - thetramethylepentane

“Wall-less” emission detector



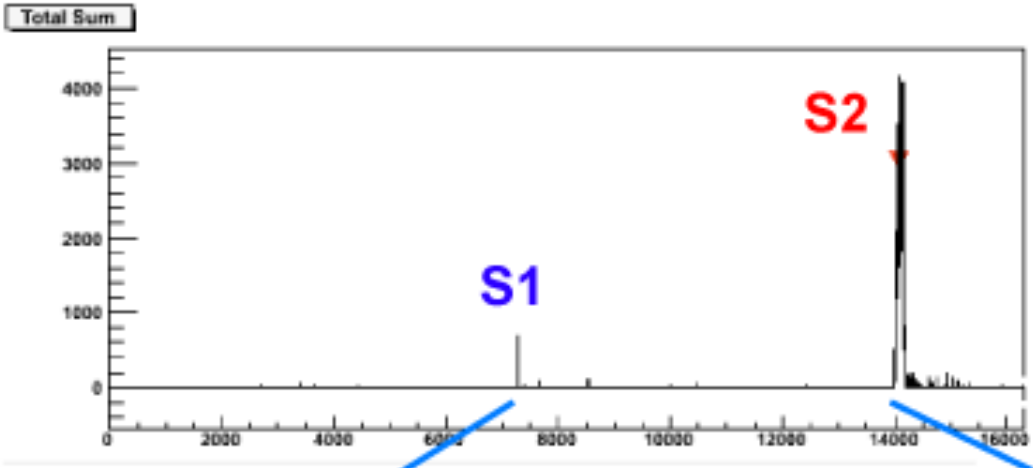
- Sensitive to single ionization electrons
- Two signals from ionization and excitation of atoms
- «Selfshielding»
- Large mass working media

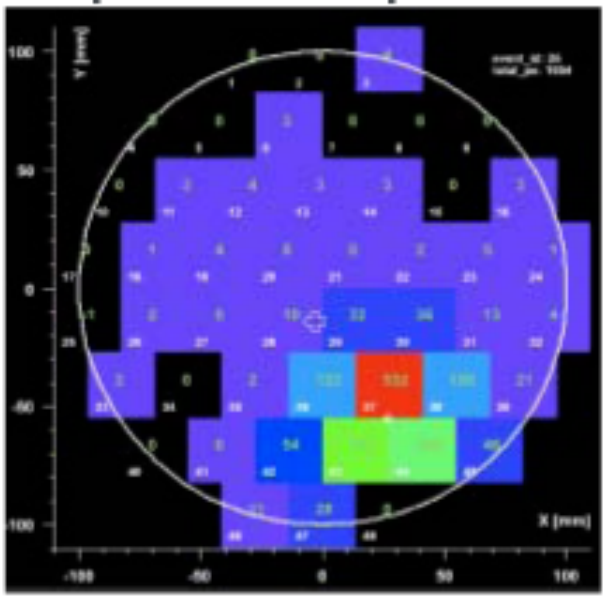
Fig.4. LXe time-projection scintillating drift chamber as wall-less detector for measurements of magnetic momentum neutrino. Bolozdynya, Egorov, Miroshnichenko, Rodionov.*IEEE Trans. Nucl. Sci.* v.42, n.4 (1995) 565-569

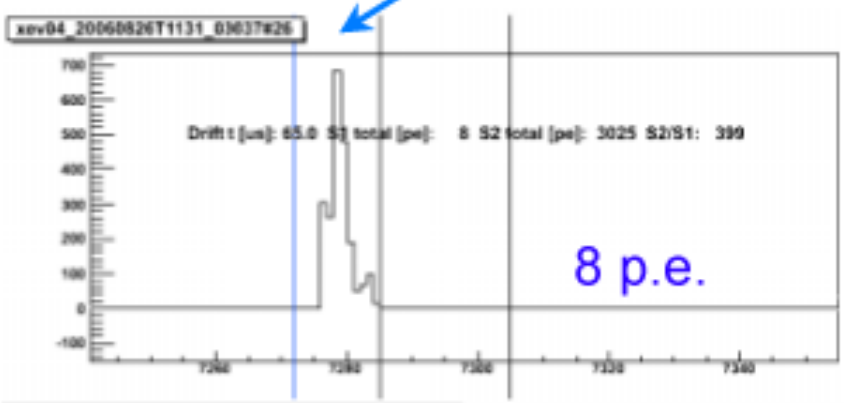
Real signals from XENON10 LXe emission detector

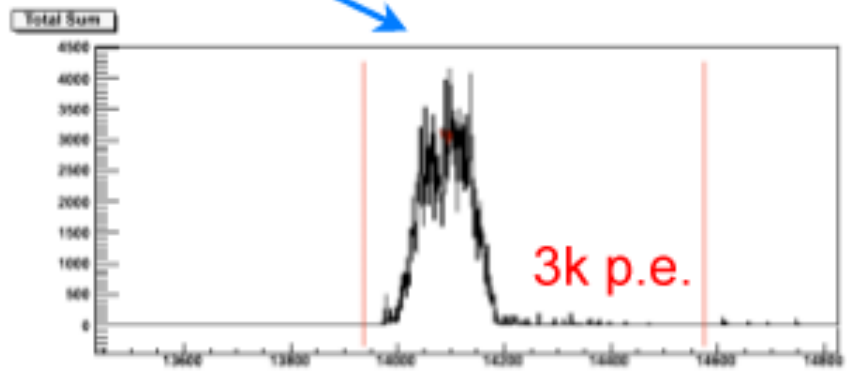
4 keV$_{ee}$ event; S1: 8 p.e => 2 p.e./keV

Hit pattern of top PMTs

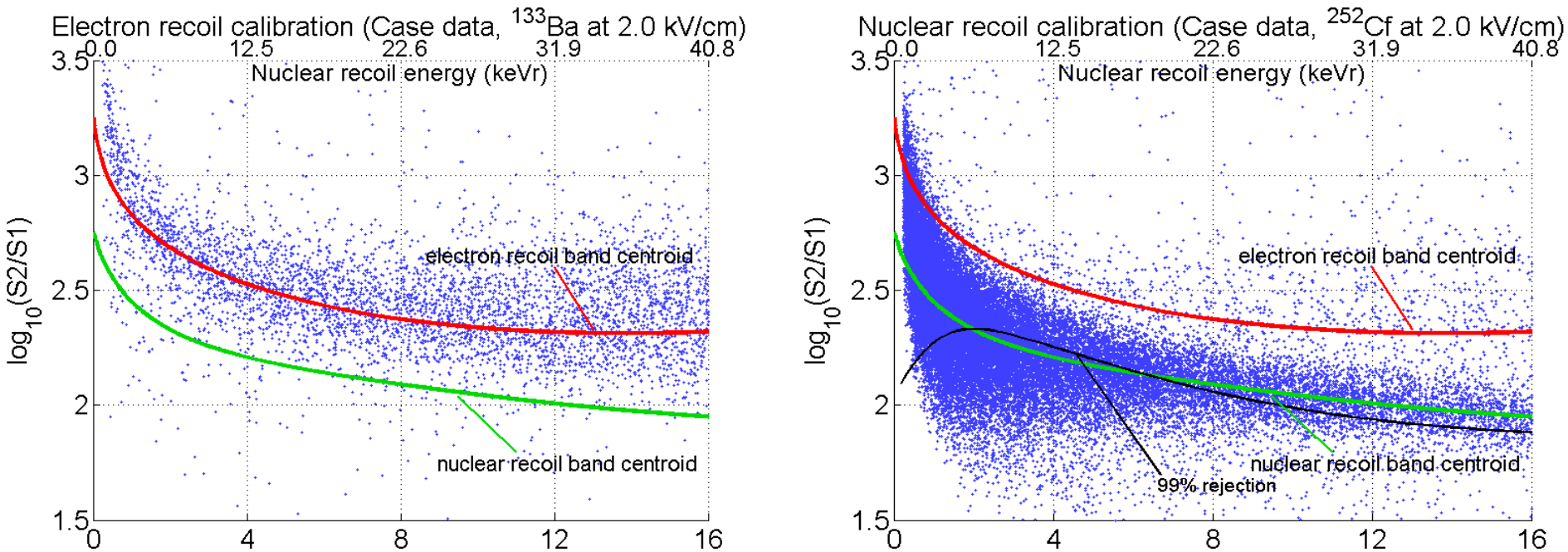








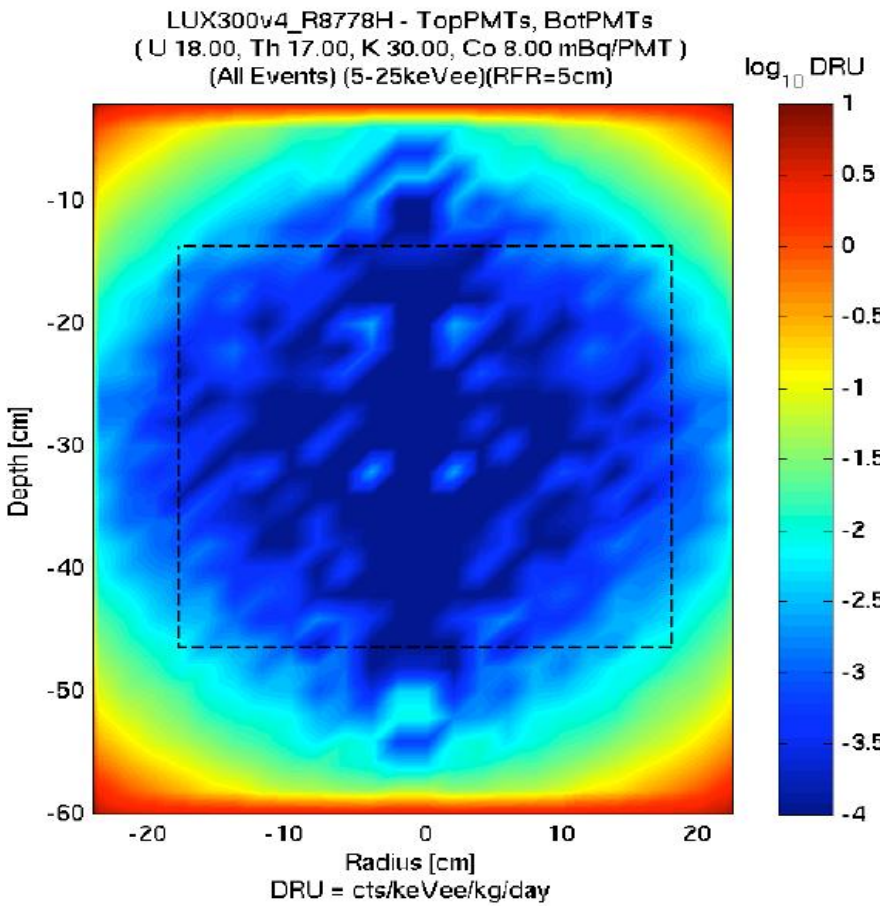
Separation of gamma and nuclear recoil signals

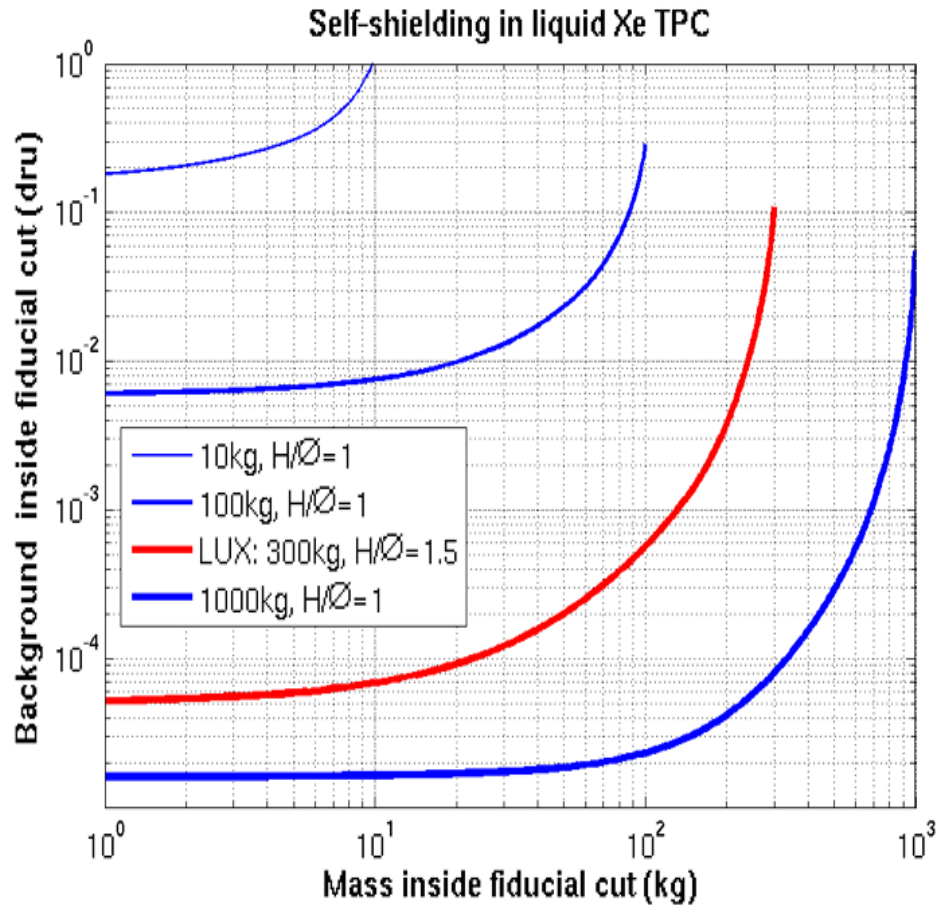


Energy, keVee

Shutt et al. *Nucl. Instr. & Meth.. A* v.579 (2006) 451-453

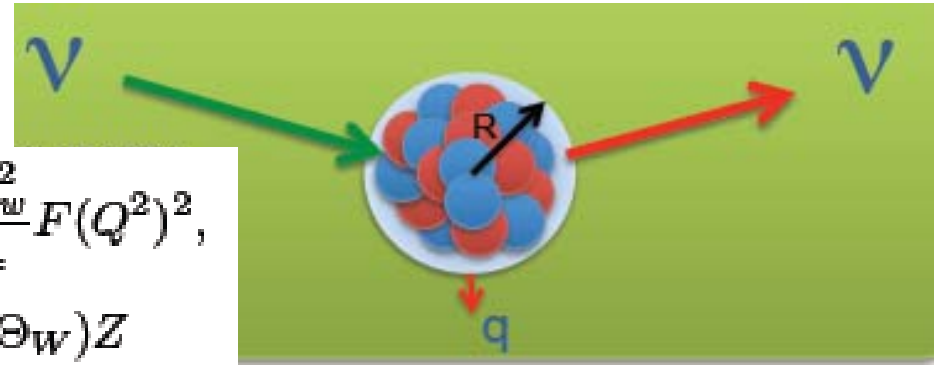
Self-shielding





Courtesy of Richard Gaitskell & Collaboration LUX

Coherent neutrino scattering off heavy nuclei



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

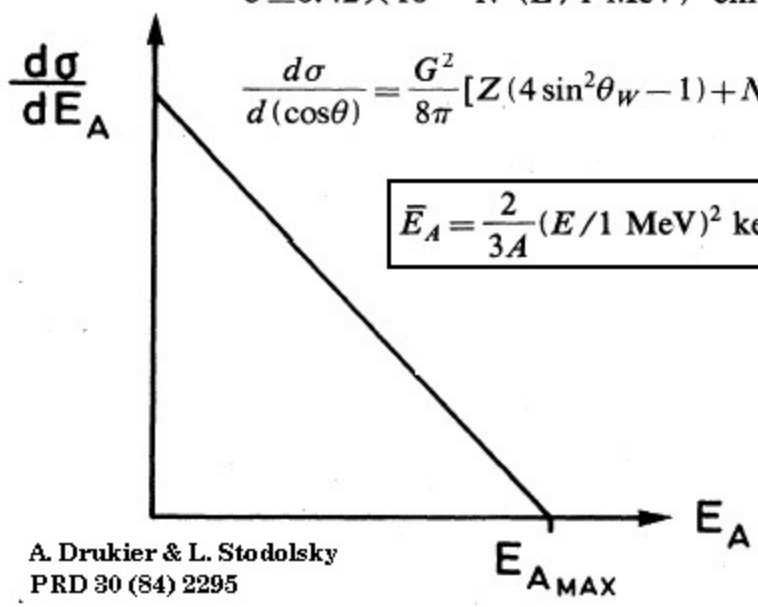
$$Q_w = N - (1 - 4\sin^2\Theta_W) Z$$

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

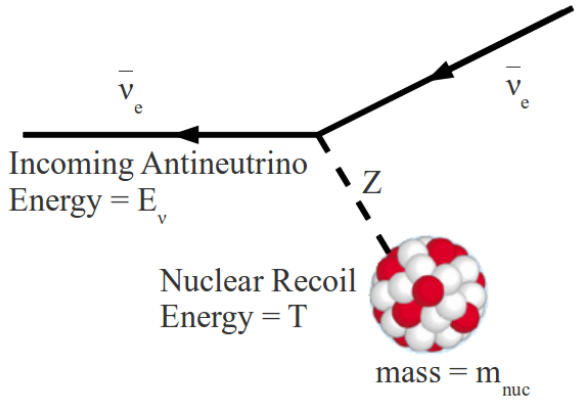
$$\sigma \simeq 0.42 \times 10^{-44} N^2 (E/1\ \text{MeV})^2\ \text{cm}^2$$

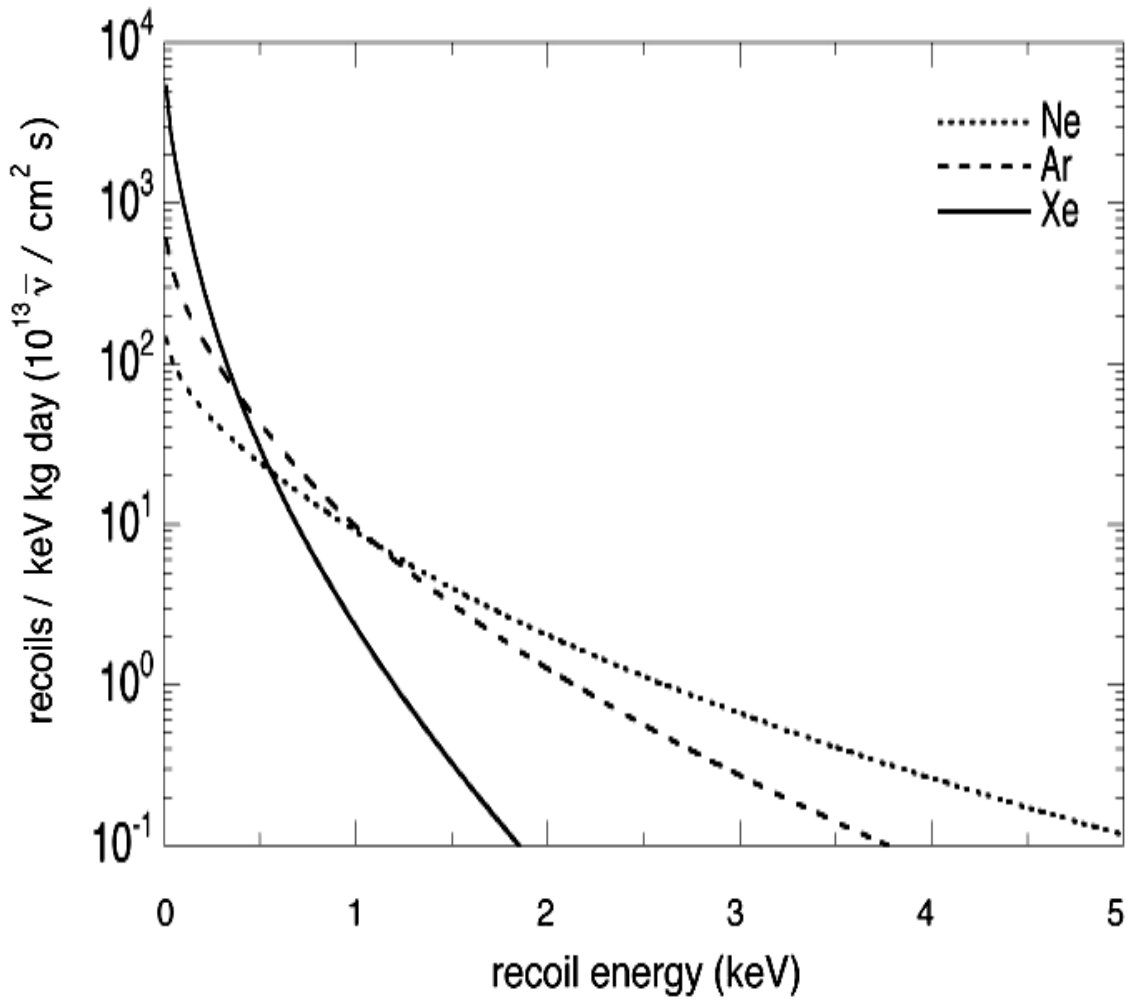
$$\frac{d\sigma}{d(\cos\theta)} = \frac{G^2}{8\pi}[Z(4\sin^2\theta_W - 1) + N]^2 E^2 (1+\cos\theta)$$

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



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



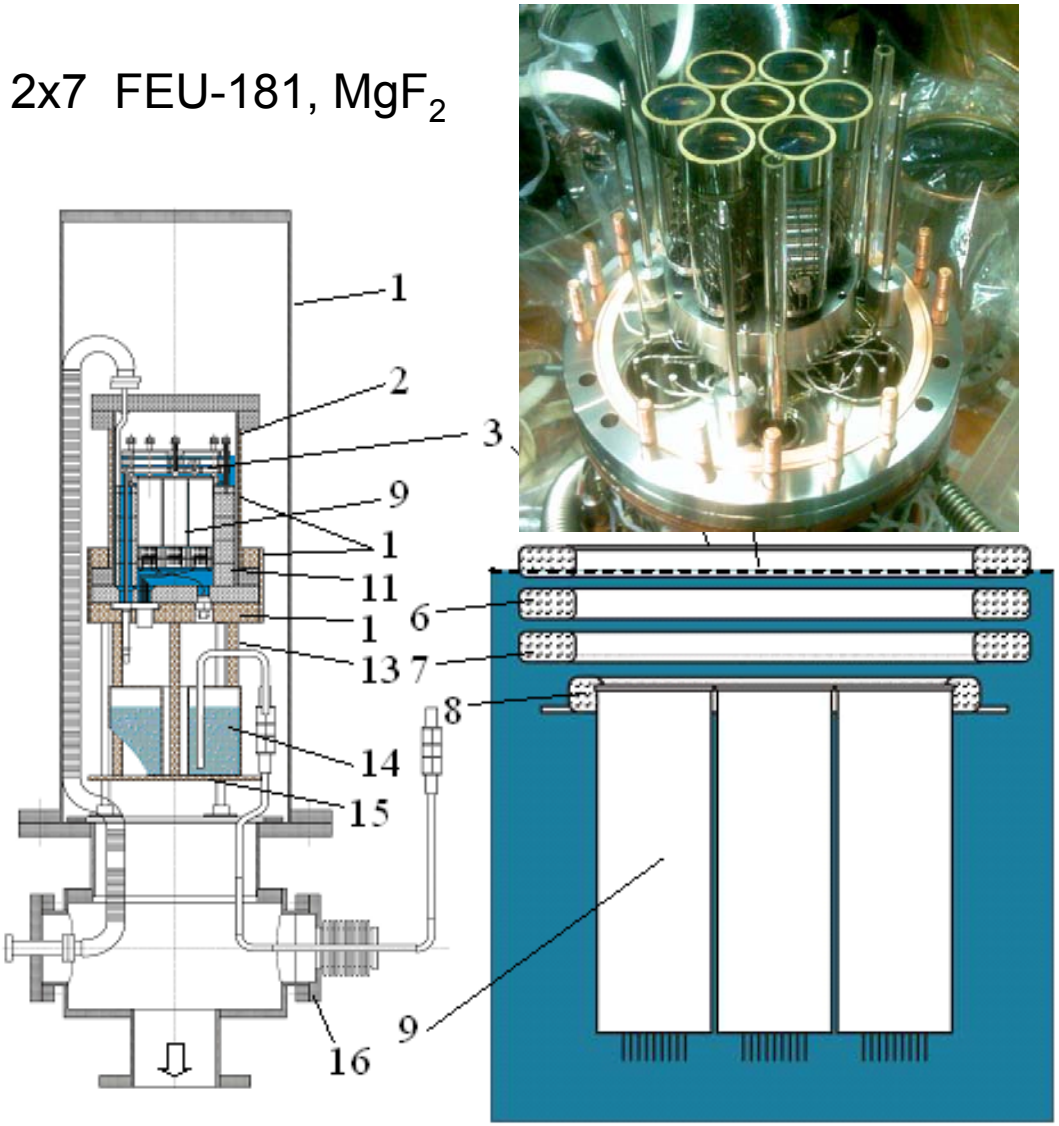


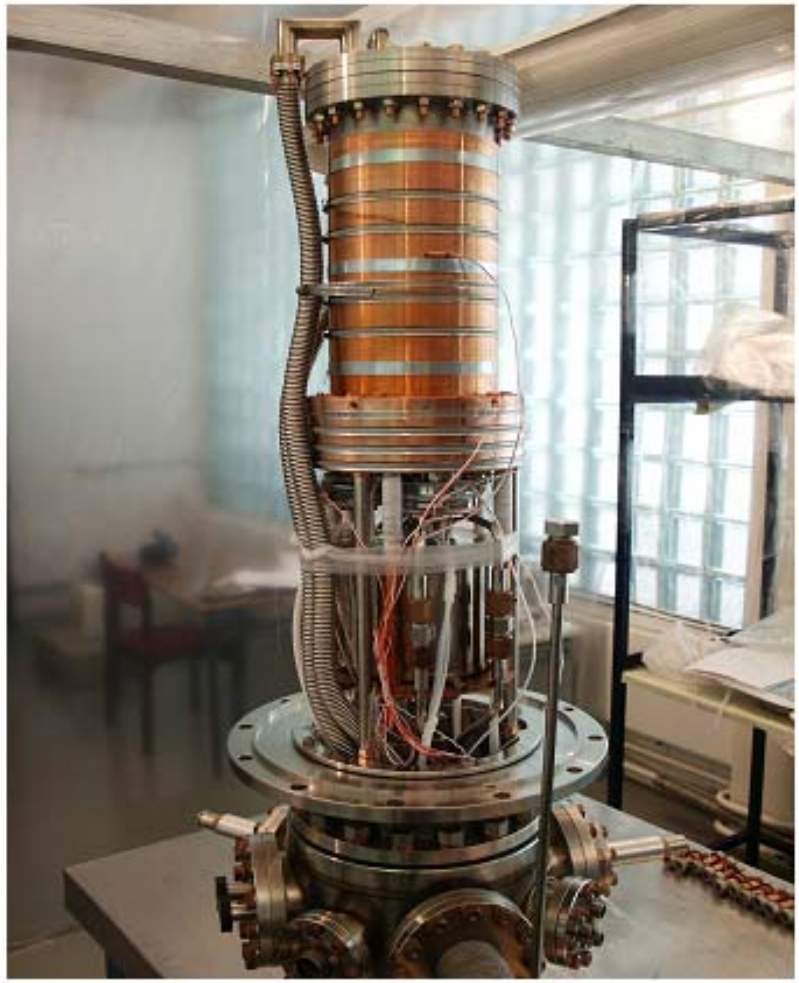
P. S. Barbeau, J. I. Collar, J. Miyamoto, and I. Shipsey

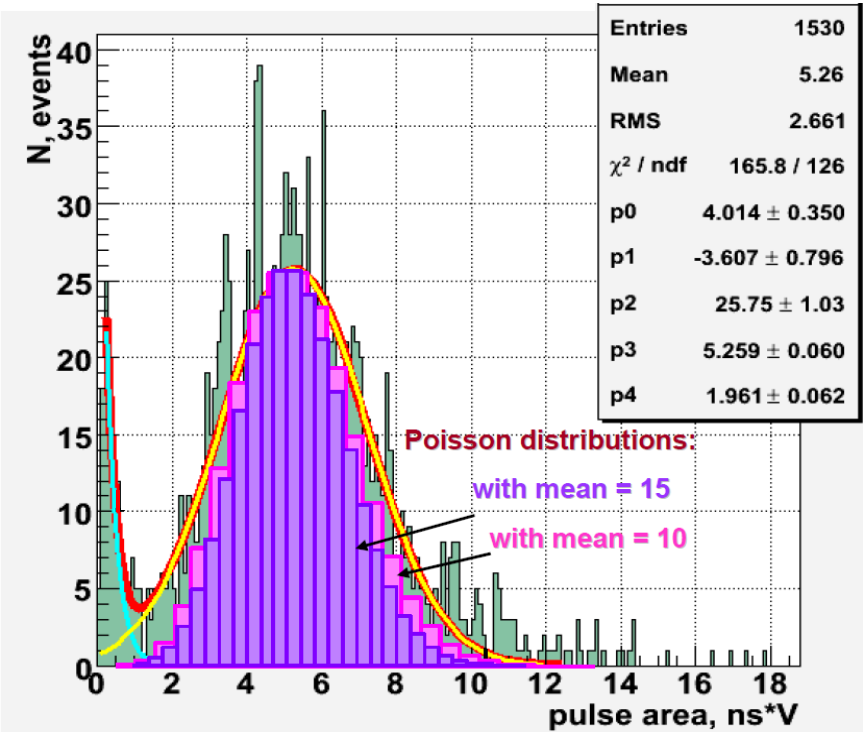
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 50, NO. 5, OCTOBER 2003

RED-1

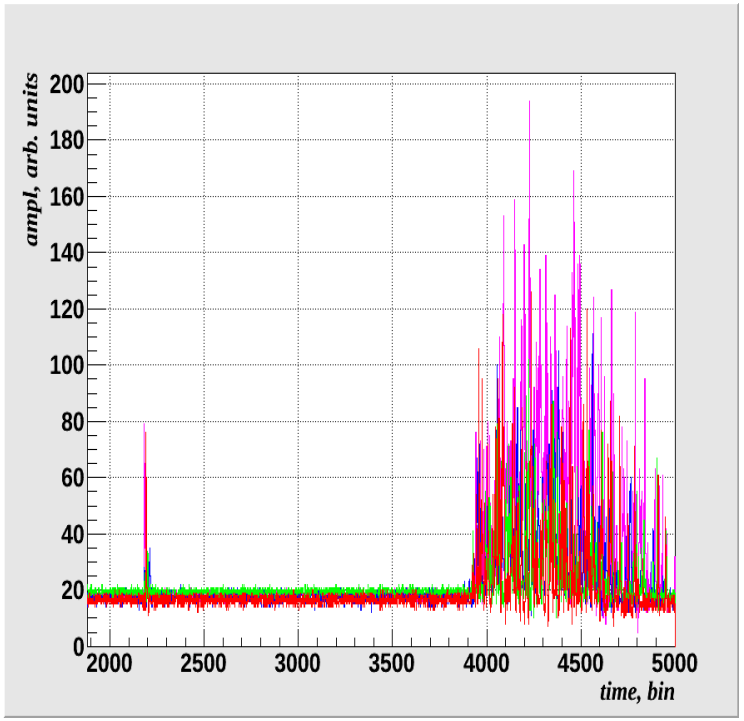
2x7 FEU-181, MgF_2







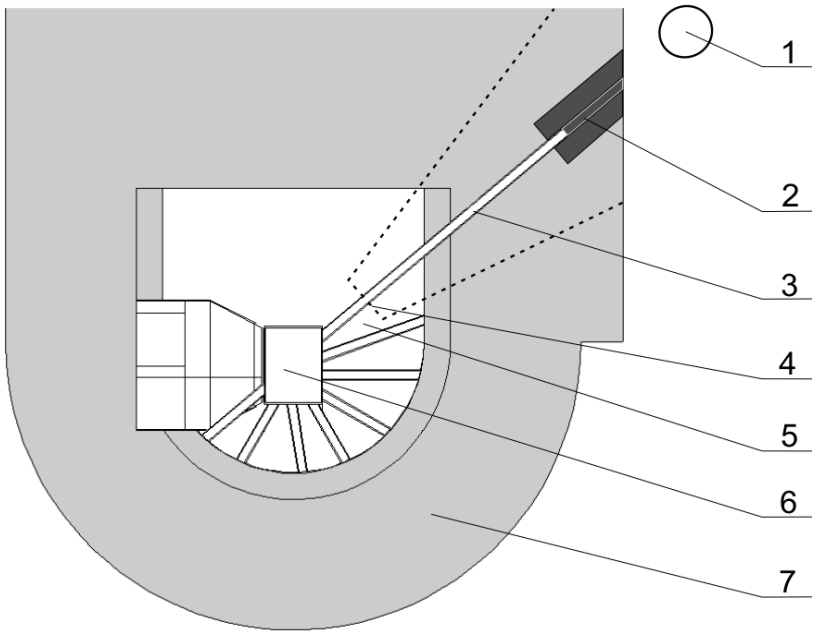
Distribution of EL (S2) signals generated by single emitted electrons (green). Maximum of the Gauss fit is 15 ± 5 photoelectrons.
Poisson distribution for 10 and 15 expectations are shown in pink and violet, respectively.



Typical gamma event in RED-1

A.Burenkov, D.Akimov et al.
Ядерная физика 72: 693-701, 2009; Phys. Atom. Nucl. 72: 653-661, 2009.

Research reactor IRT MEPhI



1 – RED-1

2 – Fe/Al filter

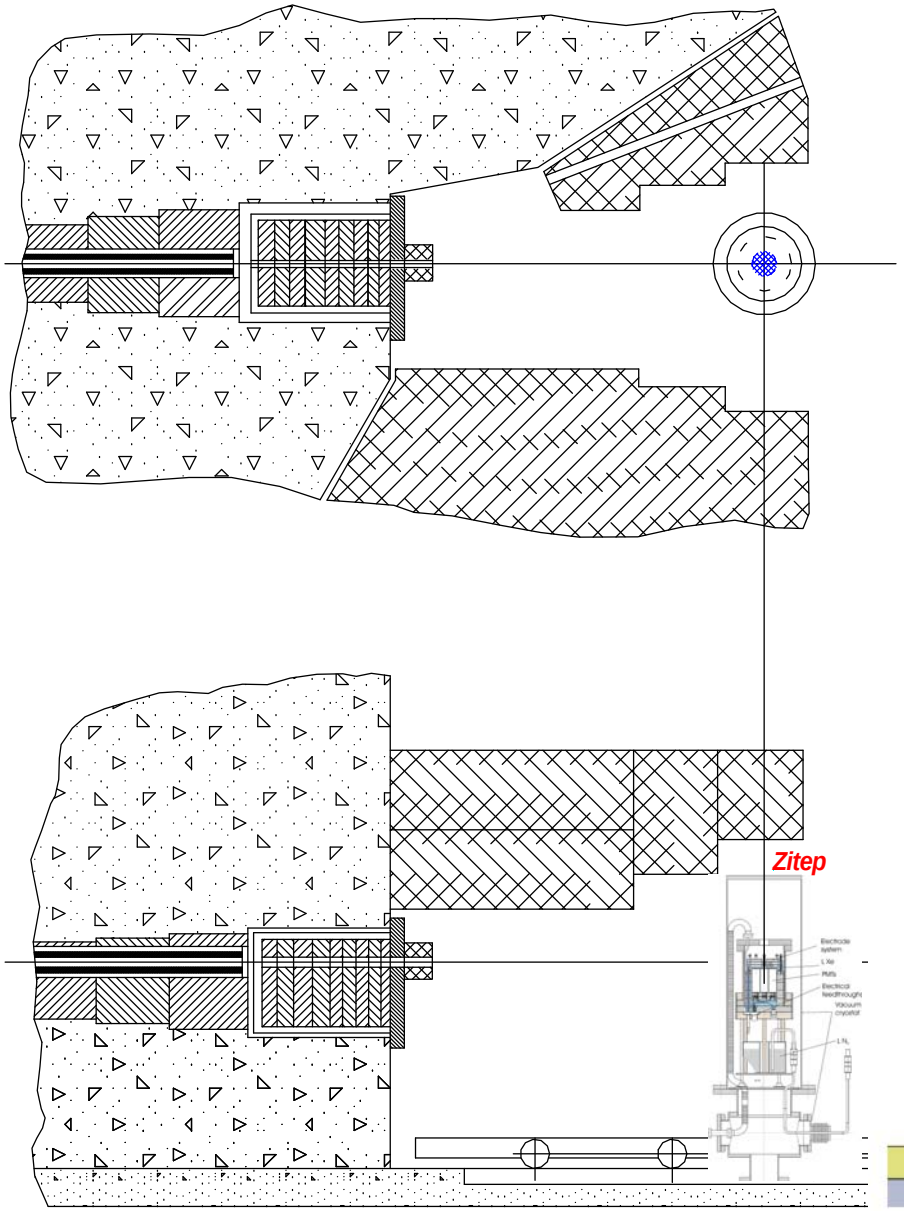
3 – horizontal neutron channel GEK10

4 – starting point of MCNP simulations

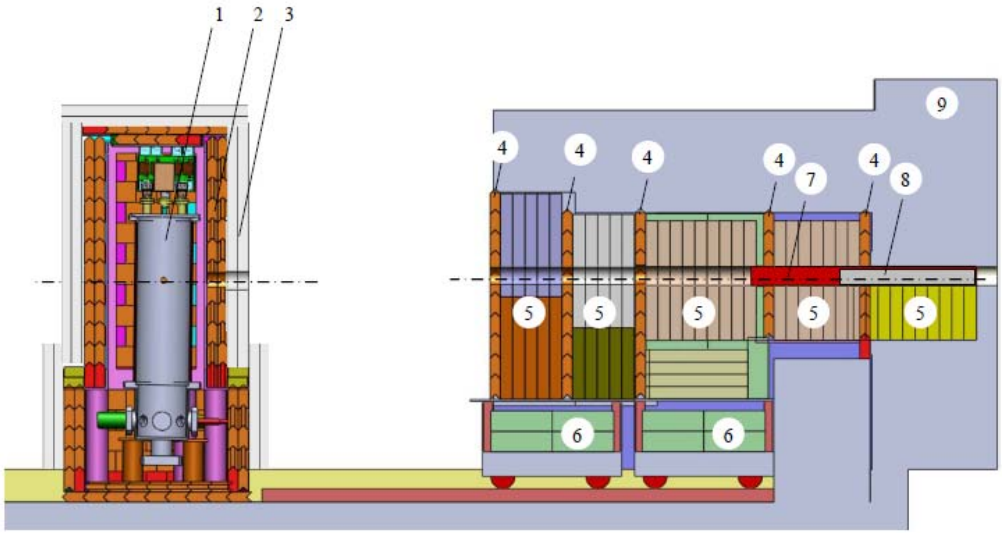
5 – cooling water pool

6 – active zone

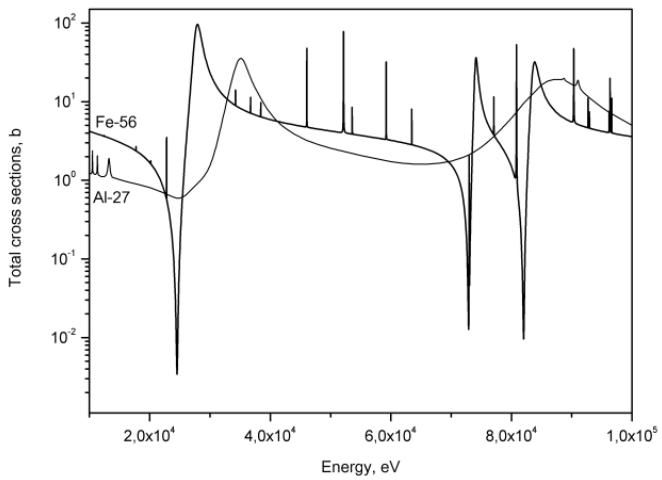
7 – heavy concrete shielding

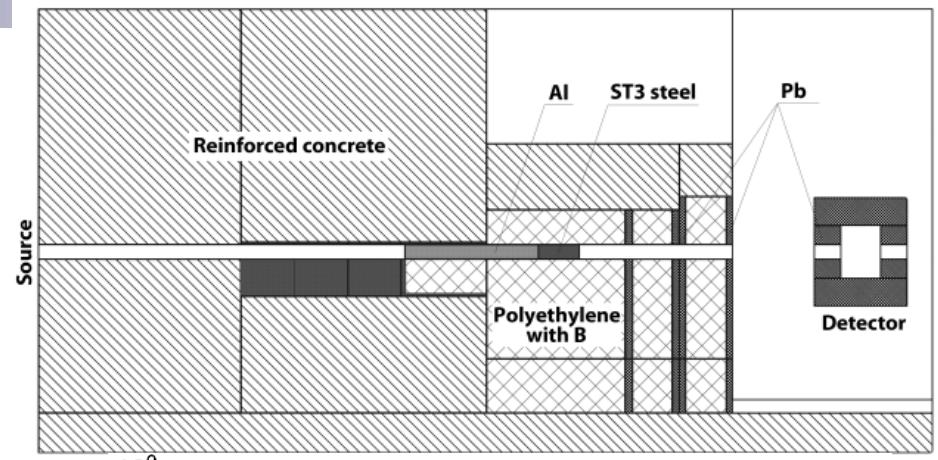


RED-1 at GEK-10 IRT MEPhI



Al/Fe filter





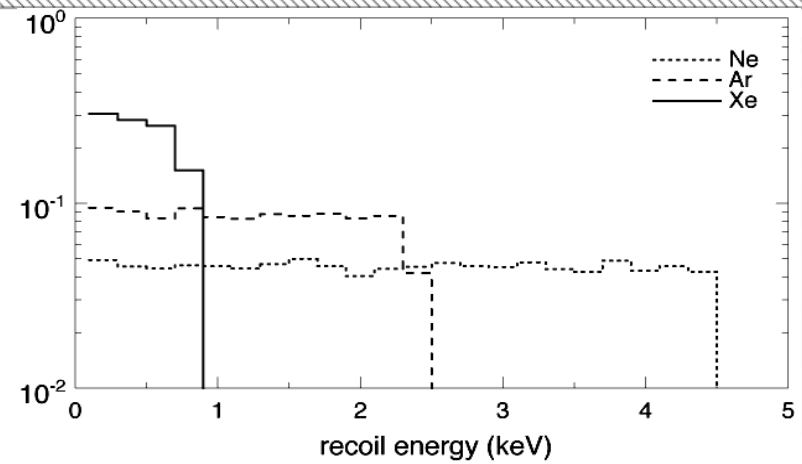
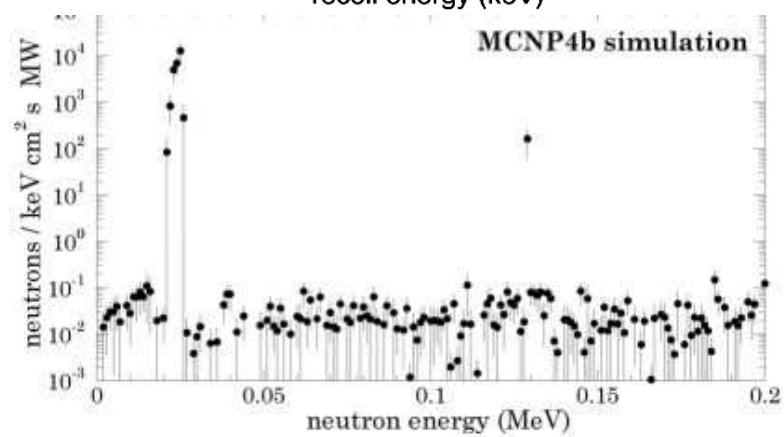
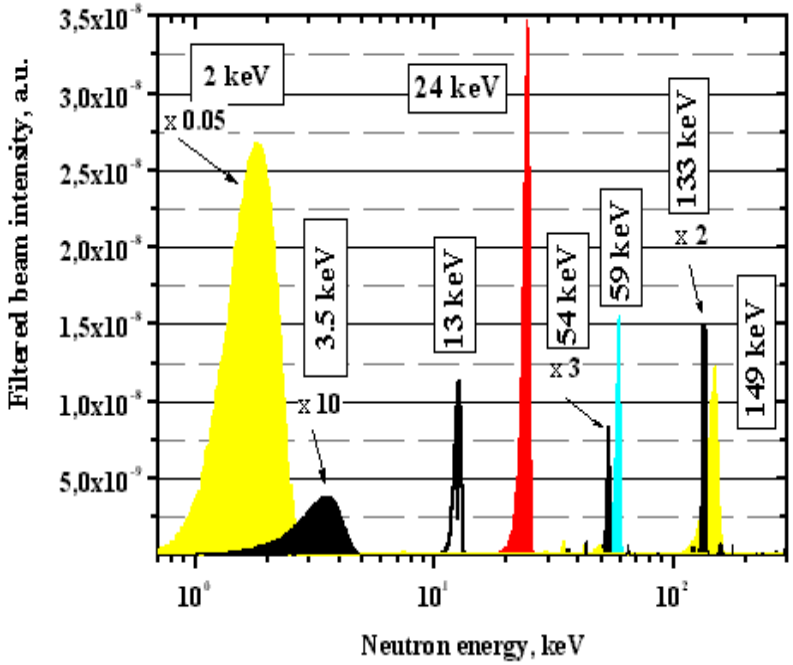


Table 1. Values of signal-to-background ratio

Models of GECh-10 channel with real geometries of the environment:	Signal-to-background ratio
without any radiation shielding	0.01
with radiation shielding of the channel only	39.10
with radiation shielding of the channel and the detector	34.10



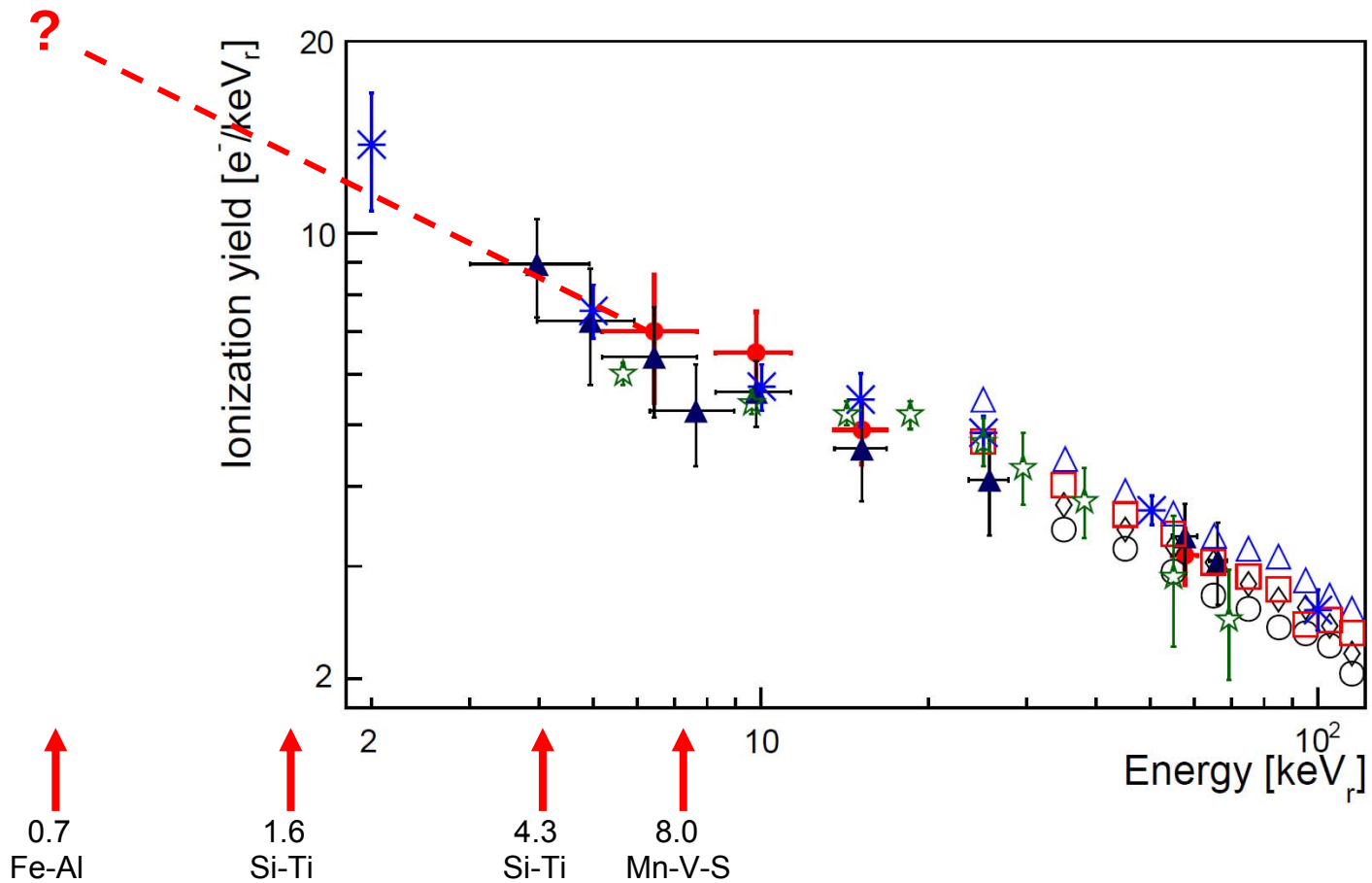


2 ±0.7 keV filter (g/cm²)						
^{10}B (85%)	Sc	^{60}Ni	^{54}Fe	S	^{59}Co	Al
0.2	104.6	80.2	39.35	56.0	26.7	0.54

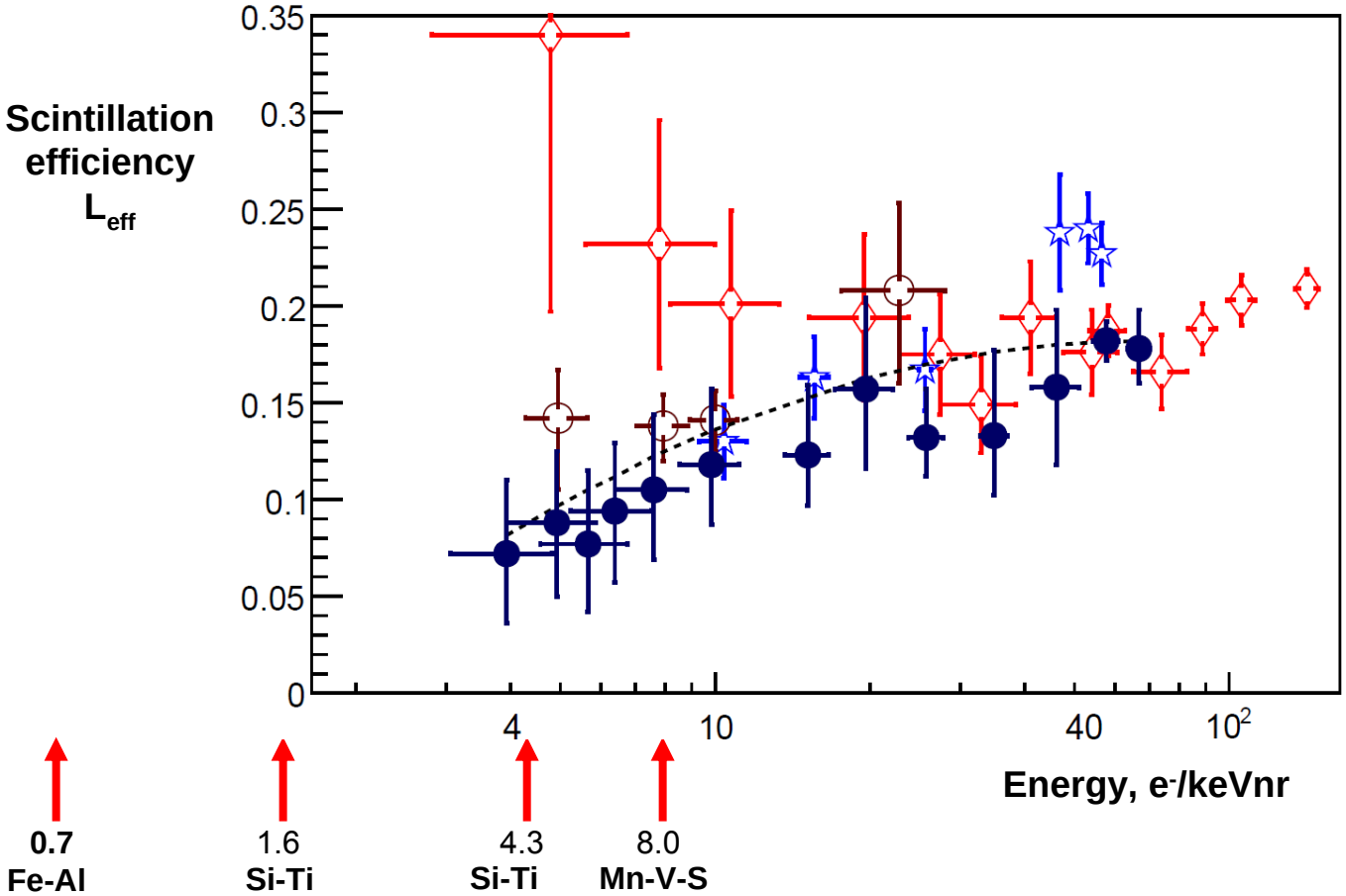
24 ±0.96 keV filter (g/cm²)			
^{10}B (85%)	S	Fe	Al
0.95	16.35	236.1	99.86

54 ±2 keV filter (g/cm²)			
^{10}B (85%)	Si	S	Al
0.2	144.926	36.7	10.796

133 ±1.4 keV filter (g/cm²)					
^{10}B (85%)	^{52}Cr	^{58}Ni	^{60}Ni	Si	Al
0.2	95.94	194.06	3.1157	93.08	0.54

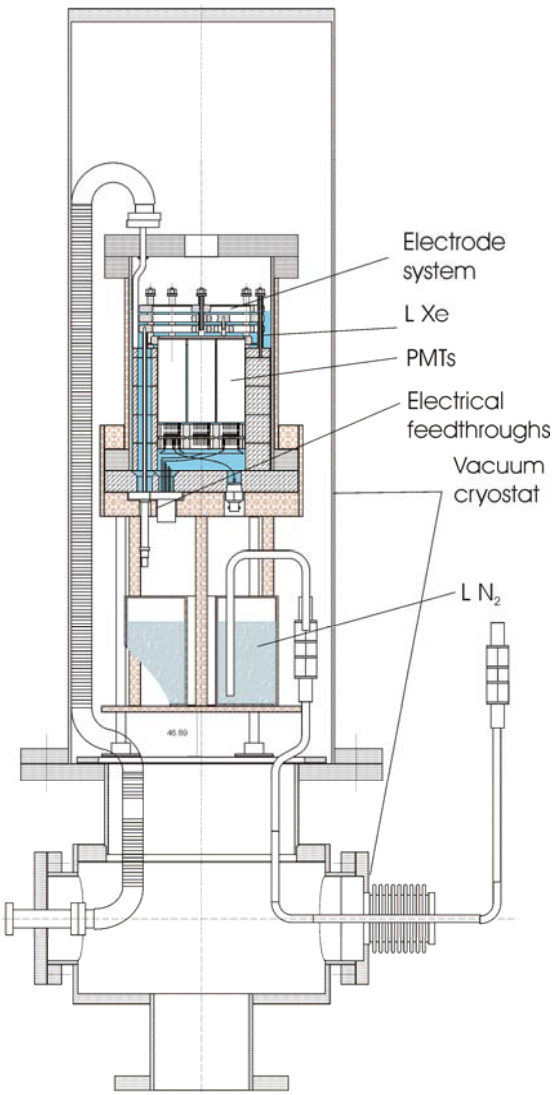


Ionization yield of liquid xenon for nuclear recoils and transmission maximum of interference neutron filters marked with red arrows

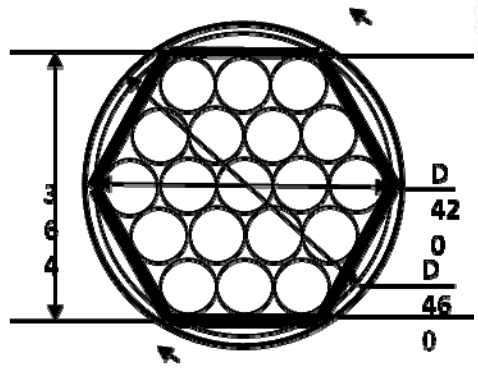


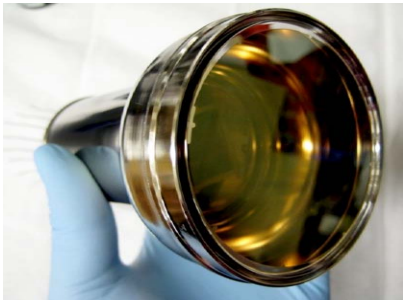
Relative scintillation efficiency of LXe

RED-1

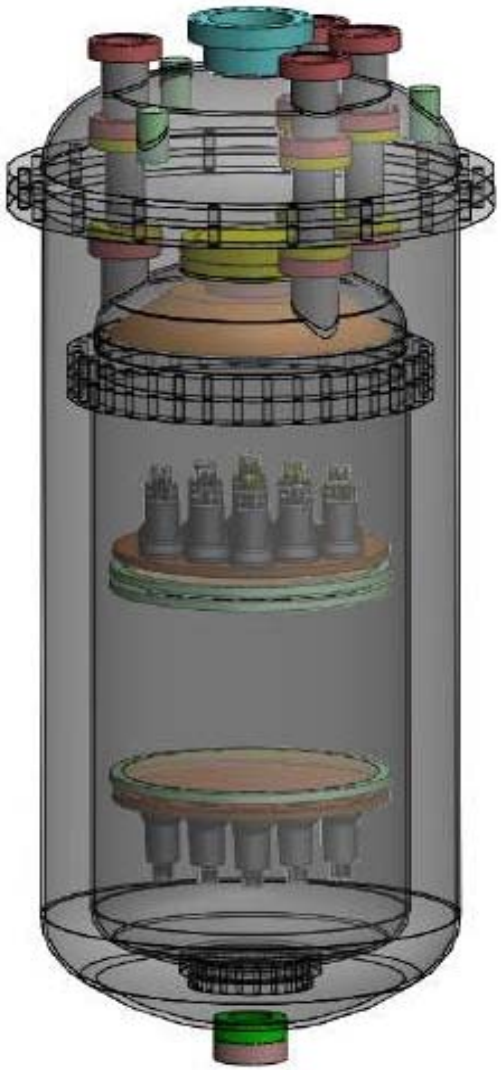


RED-100

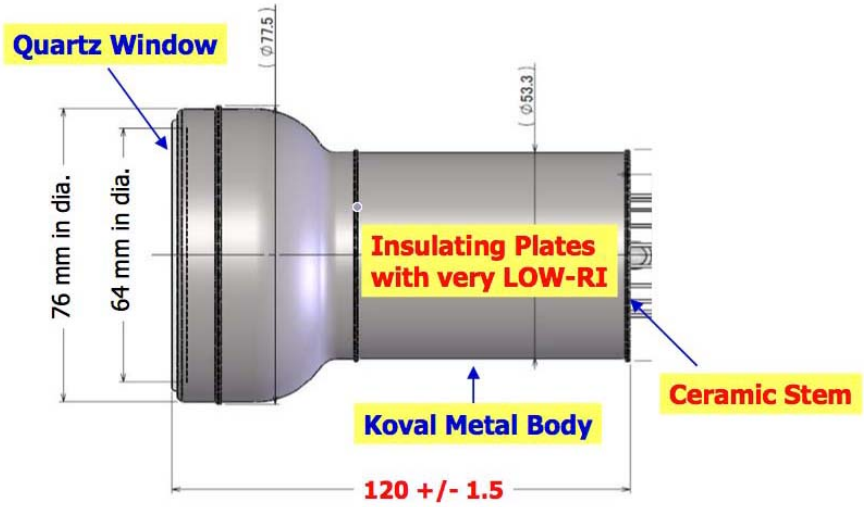




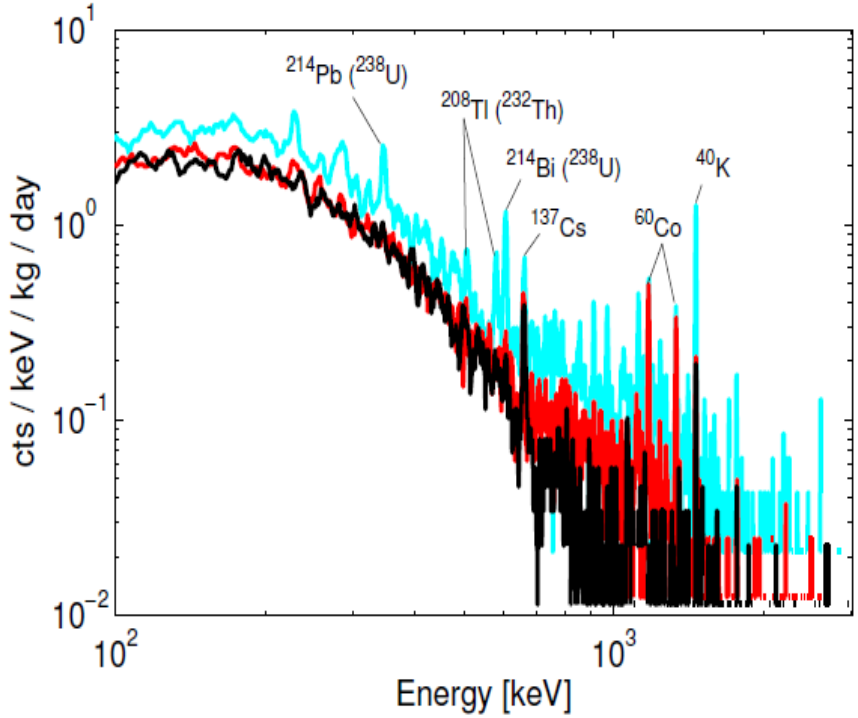
Hamamatsu R11410



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



Copyright © Hamamatsu Photonics K.K. All Rights Reserved.

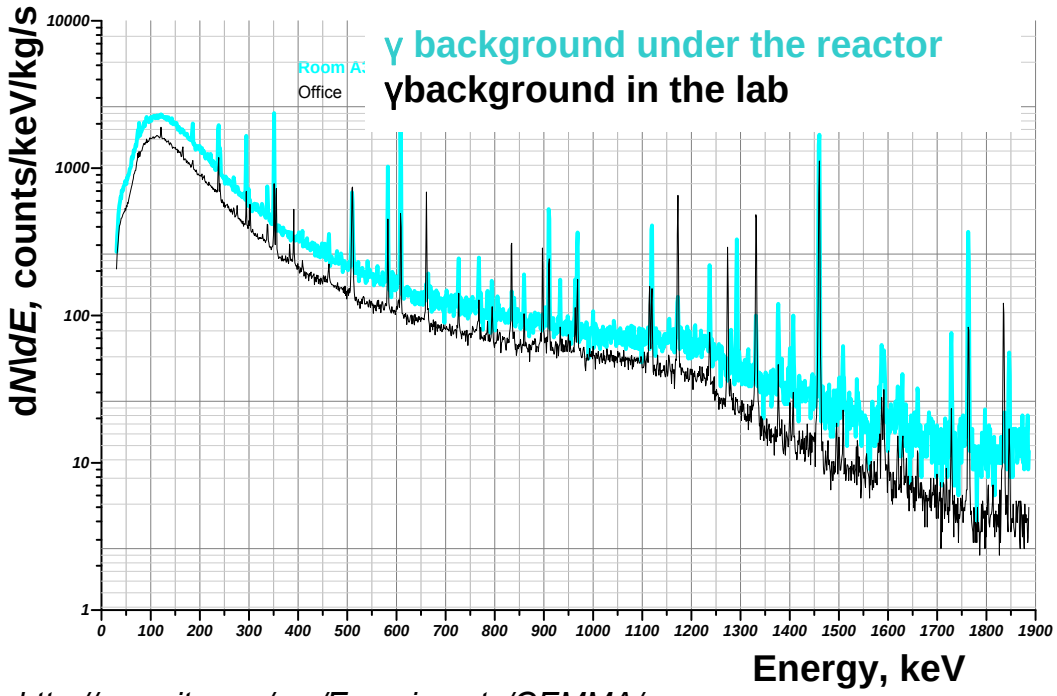


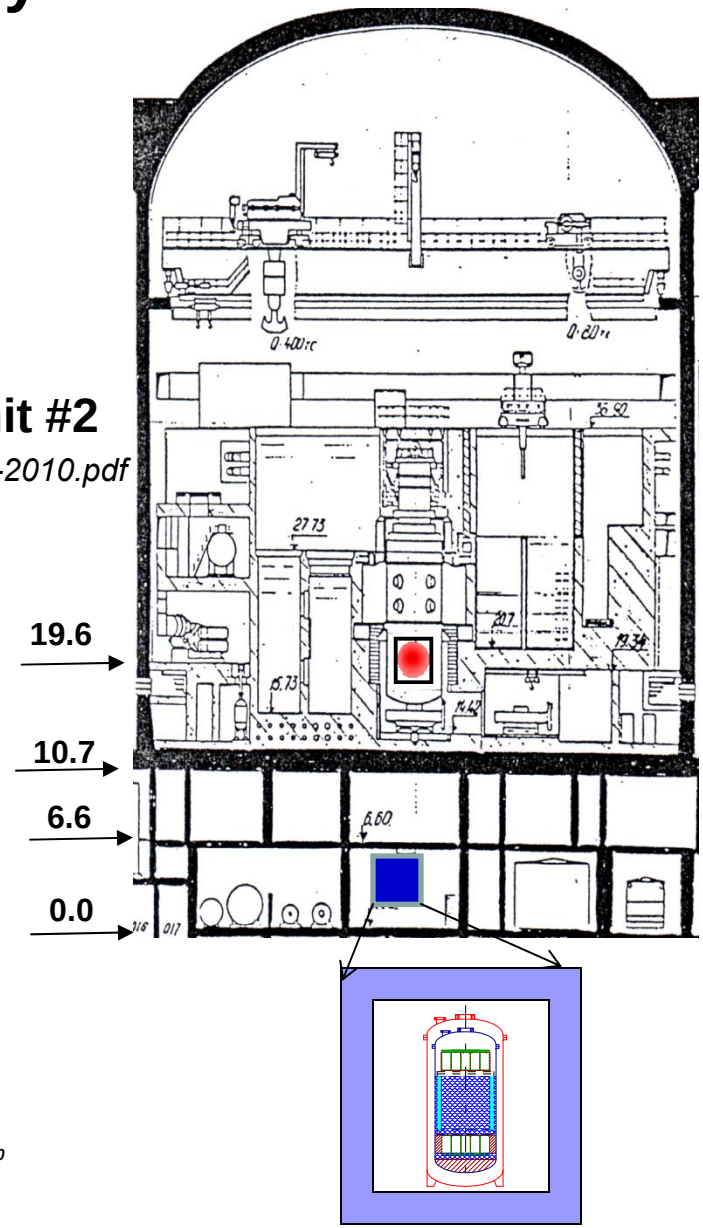
ure 3. SOLO counting spectra for R8778 (14 live days, blue) and R11410 MOD (19 live days,) PMTs, superimposed with a sample background run (21 live days, black). Strong lines in the 778 spectrum indicate the presence of ^{238}U, ^{232}Th, ^{40}K and ^{60}Co. The reduced activity of the 1410 MOD is readily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

Kalinin nuclear power plant facility

Reactor unit #2

http://nuclphys.sinp.msu.ru/neutrino/Medvedev-02-11-2010.pdf





http://www.itep.ru/rus/Experiments/GEMMA/

Reactor Neutrinos

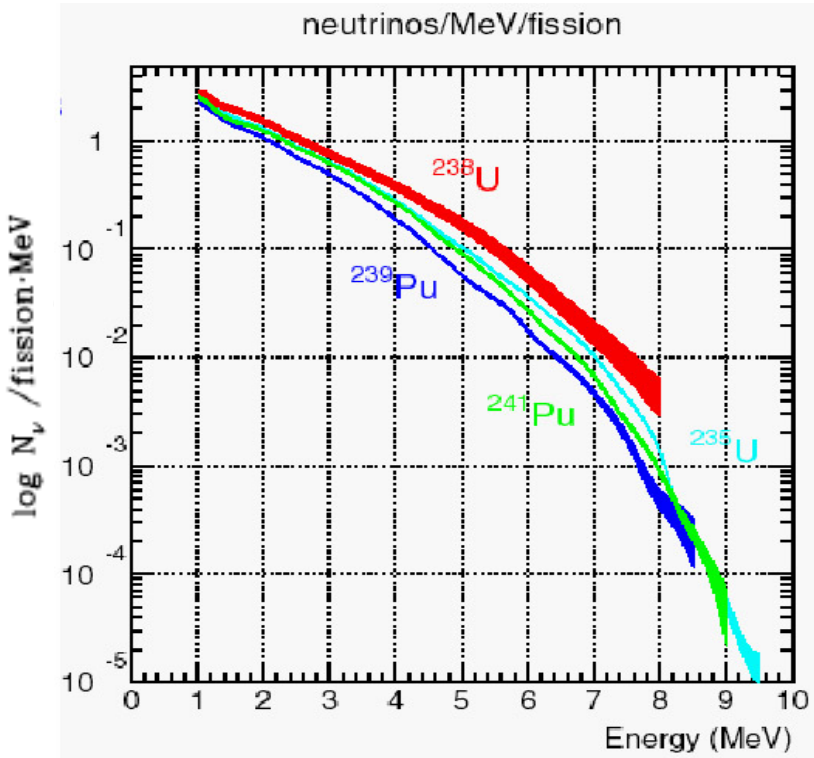
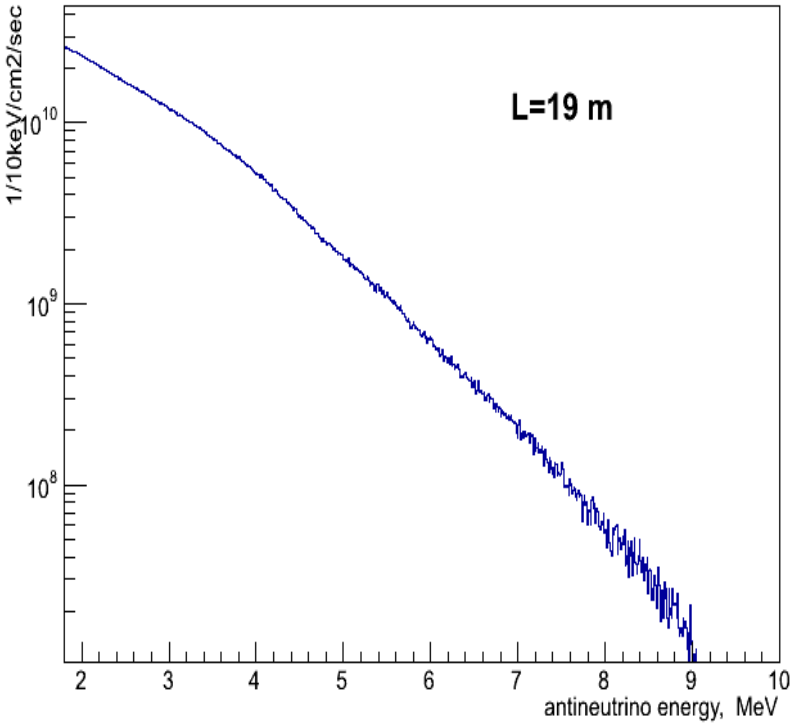
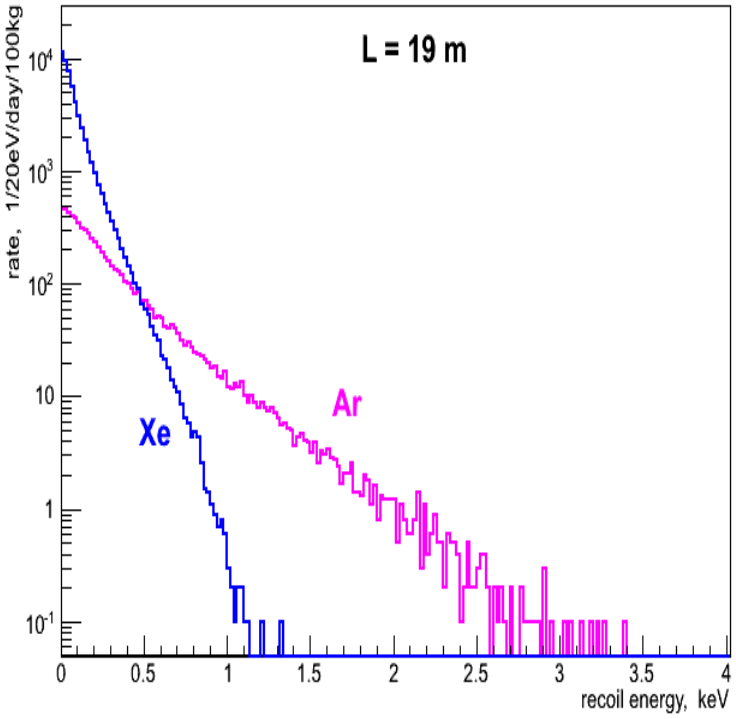


Fig. 4.2. Neutrino spectra from fission of ^{235}U, ^{239}Pu, ^{241}Pu (measured), and ^{238}U (calculated).

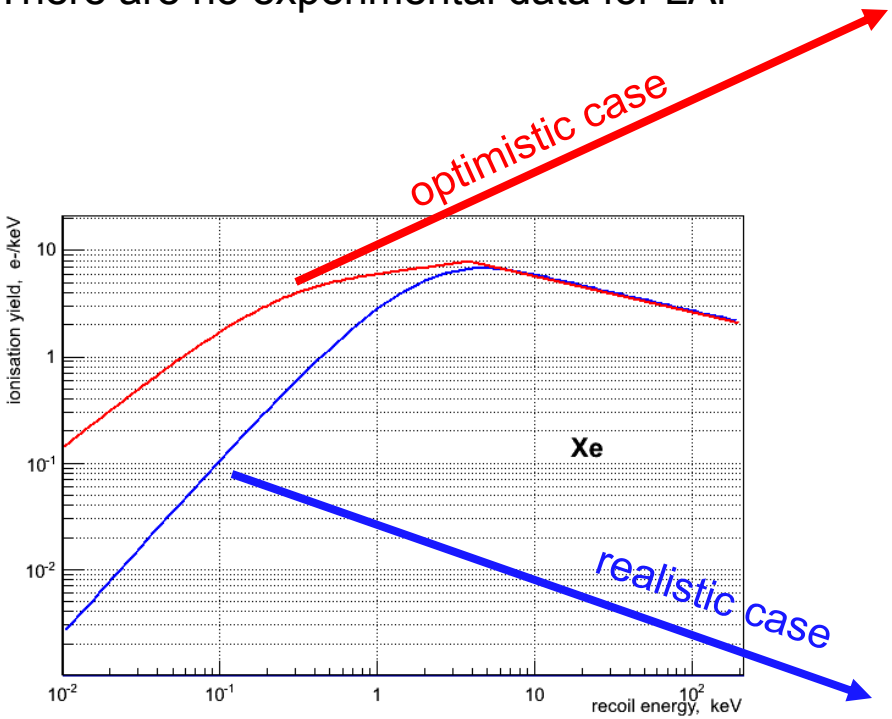
Antineutrino Spectrum

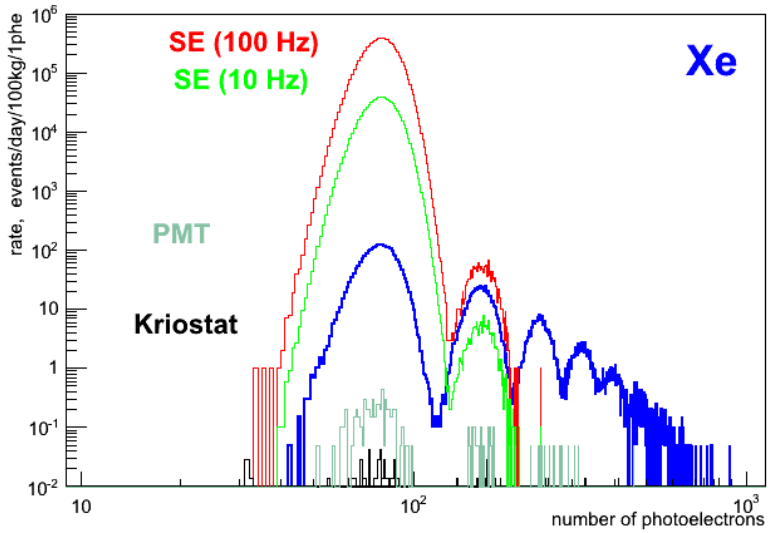


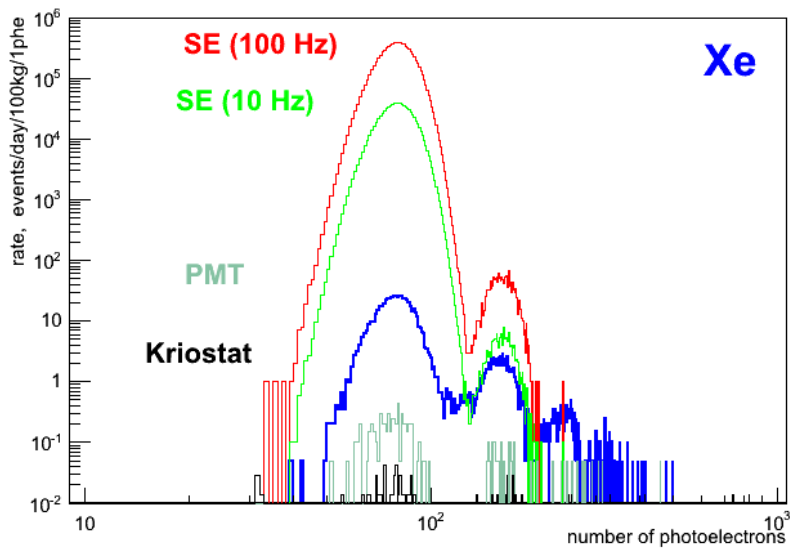
Count Rate



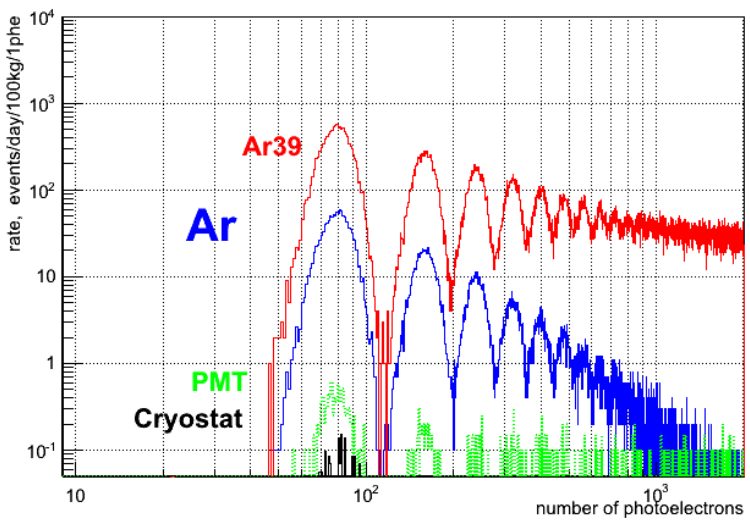
Experimental data on ionization yield for NR are available for ≥4 keV for LXe.
There are no experimental data for LAr

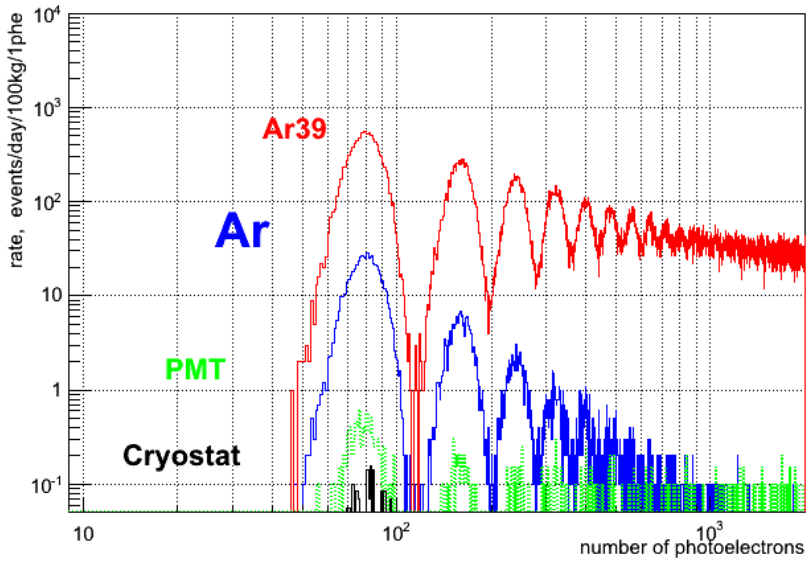






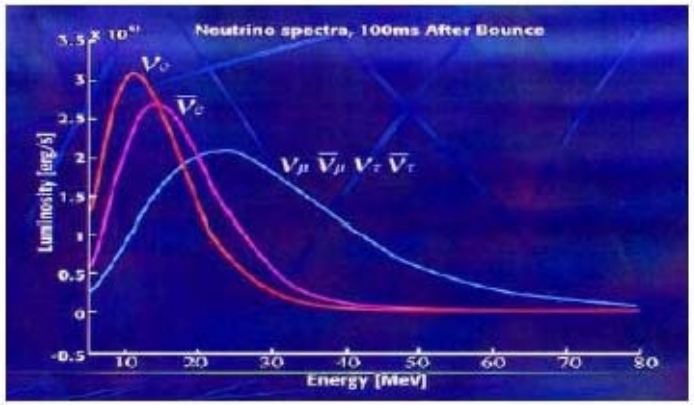
For LXe we used a fit of the existing data with 12.5·*E-0.34 (E in keVnr) for E > 4 keV and for* E < 4 keV a smooth function going to “0”

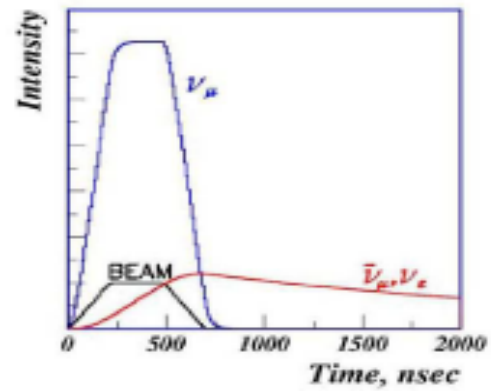




For LAr we used the same dependence but reduced by *Wi LXe /Wi LAr ratio*

SNS

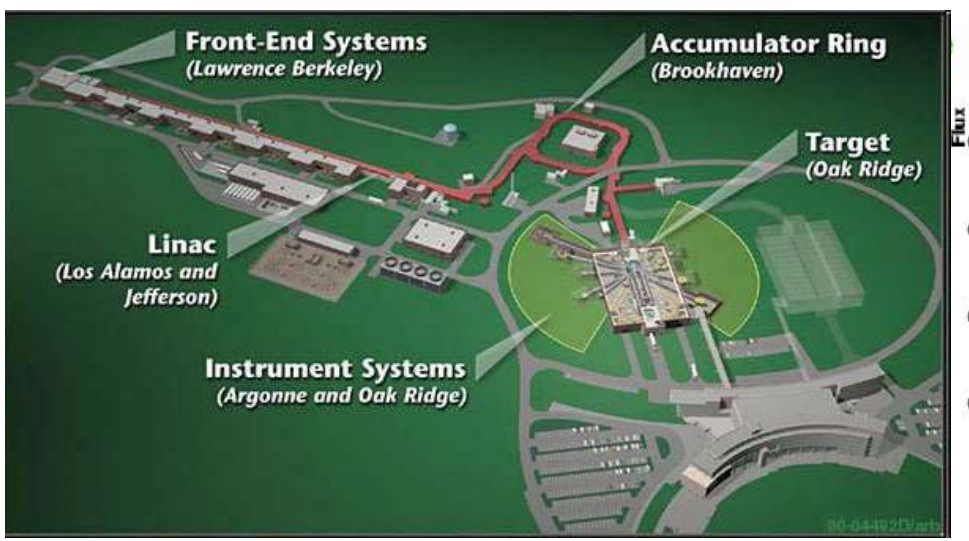


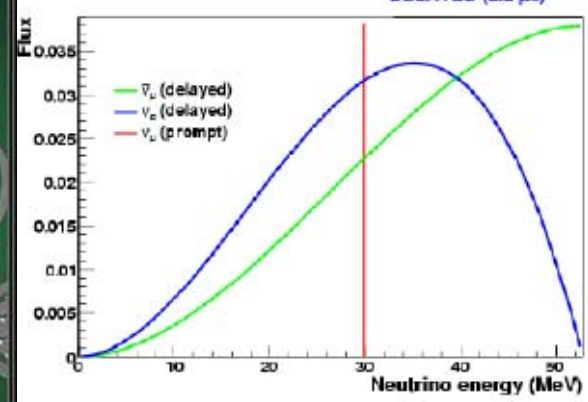


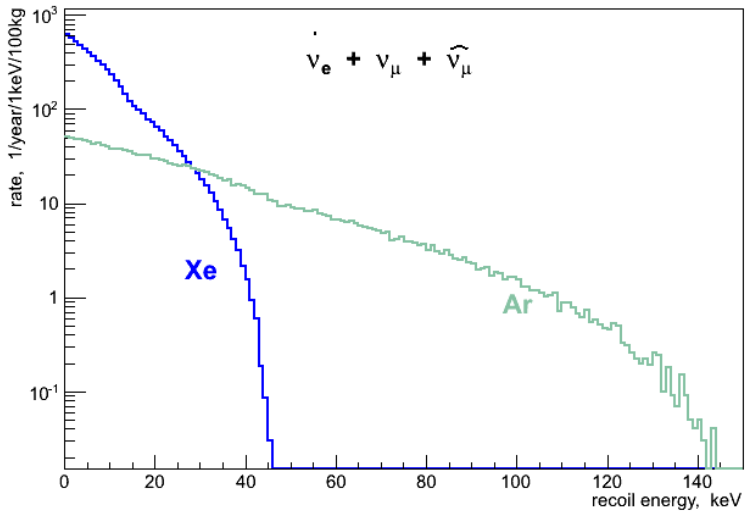
NuSNS (Neutrinos at the SNS)

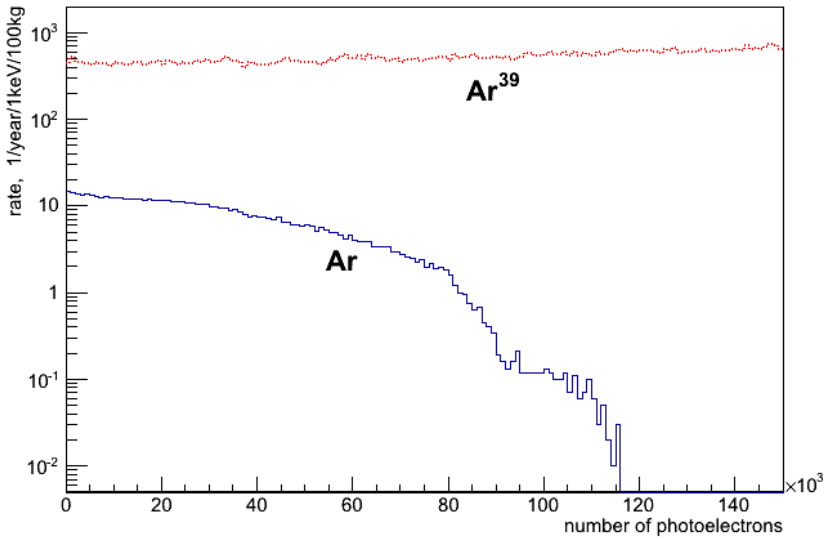
$\pi^+ \rightarrow \mu^+ + \nu_\mu$ — 2-body decay: monochromatic 29.9 MeV ν_μ PROMPT

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

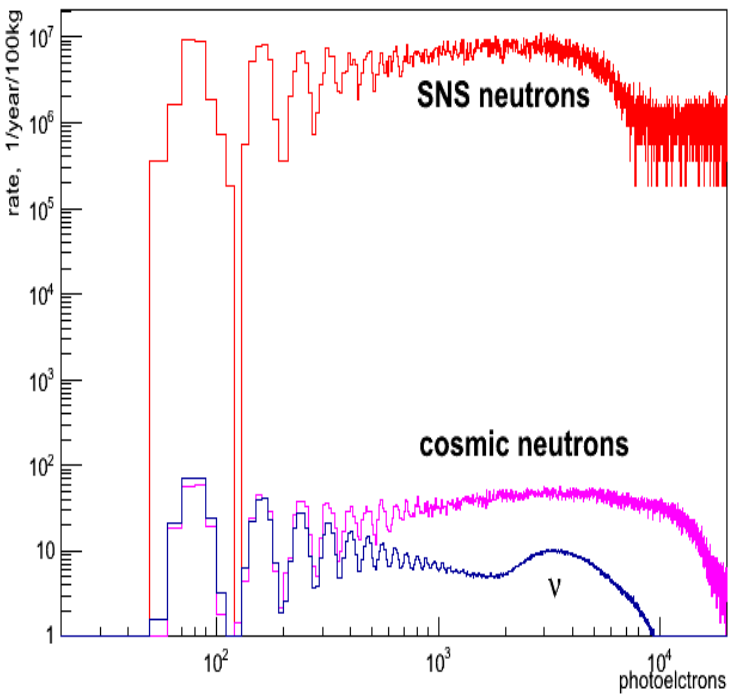





rate, 1/year/1keV/100kg
recoil energy, keV
Xe
Ar


rate, 1/year/1keV/100kg
number of photoelectrons
Ar39
Ar

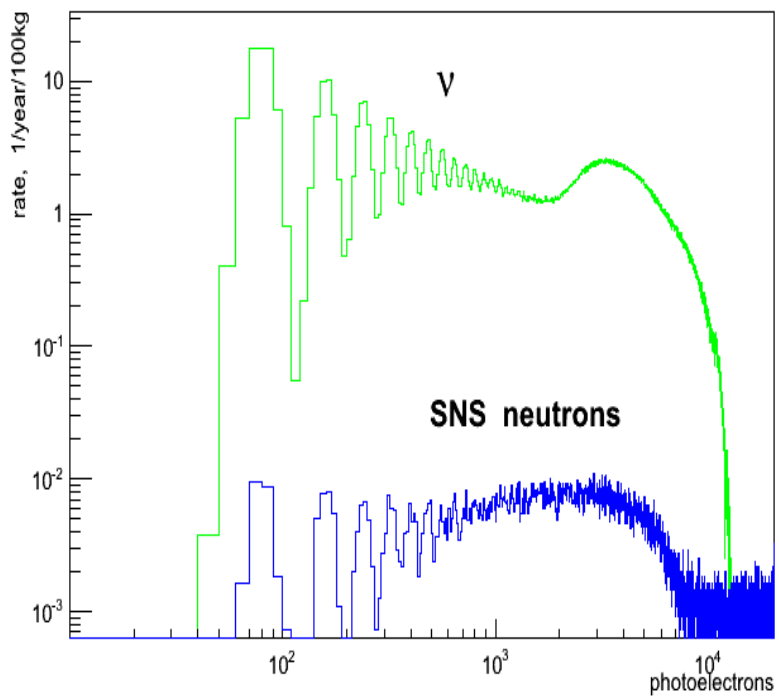
RED-100 @ SNS



20 m from the target of SNS

Cosmic neutron background is suppressed by factor 1000 due to duty cycle.

Effect = 6000 events/year

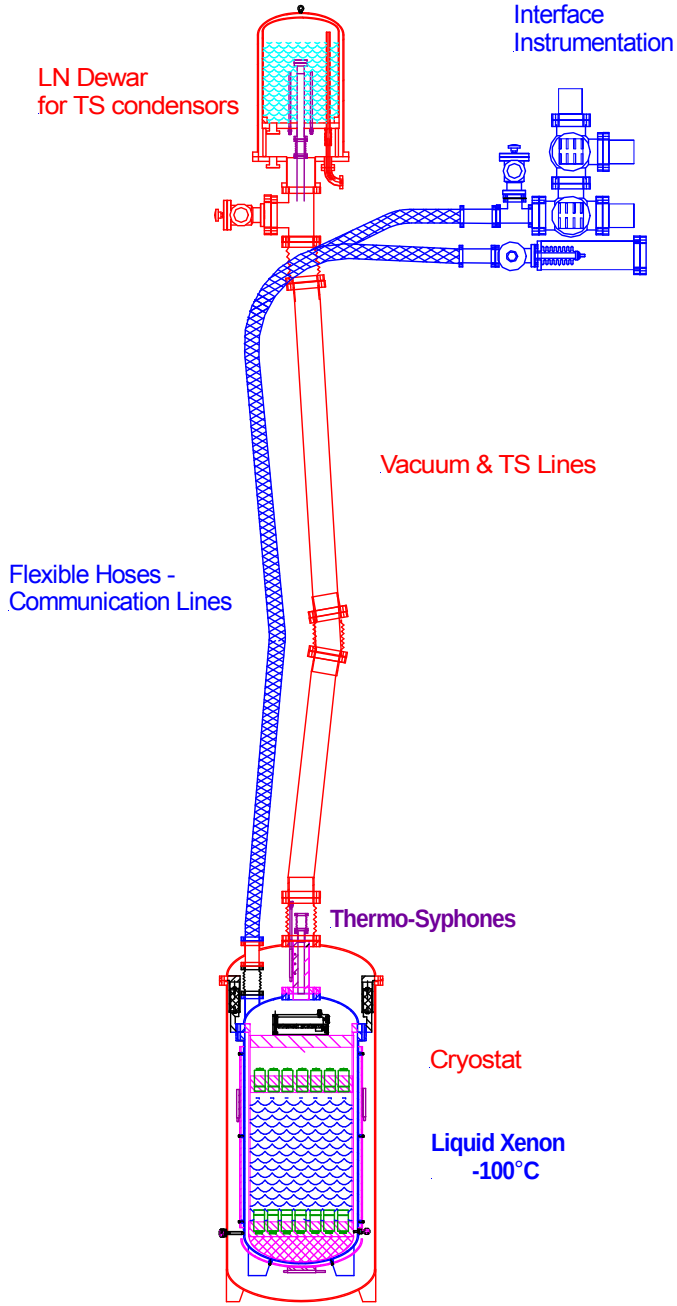


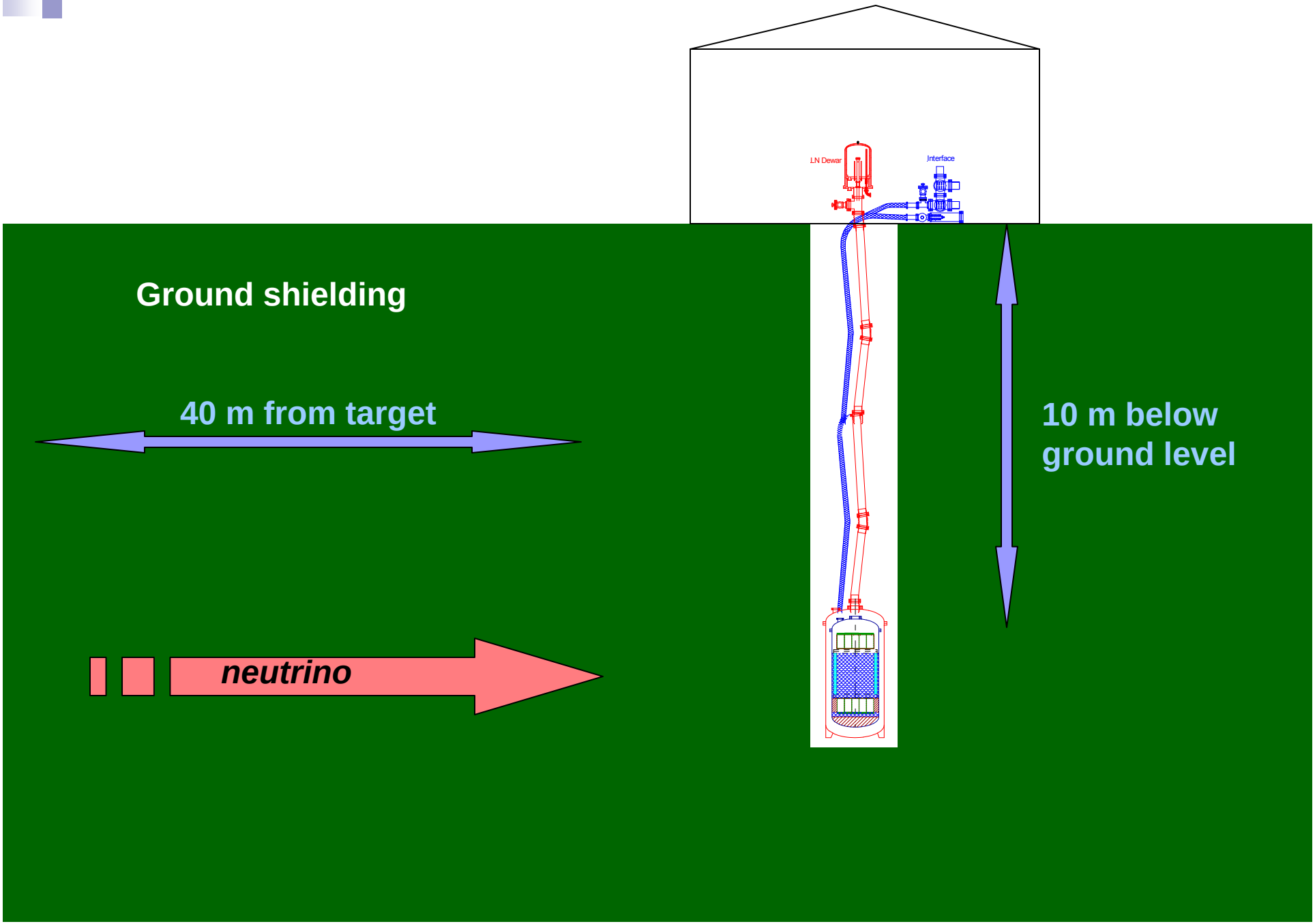
40 m from the target of SNS

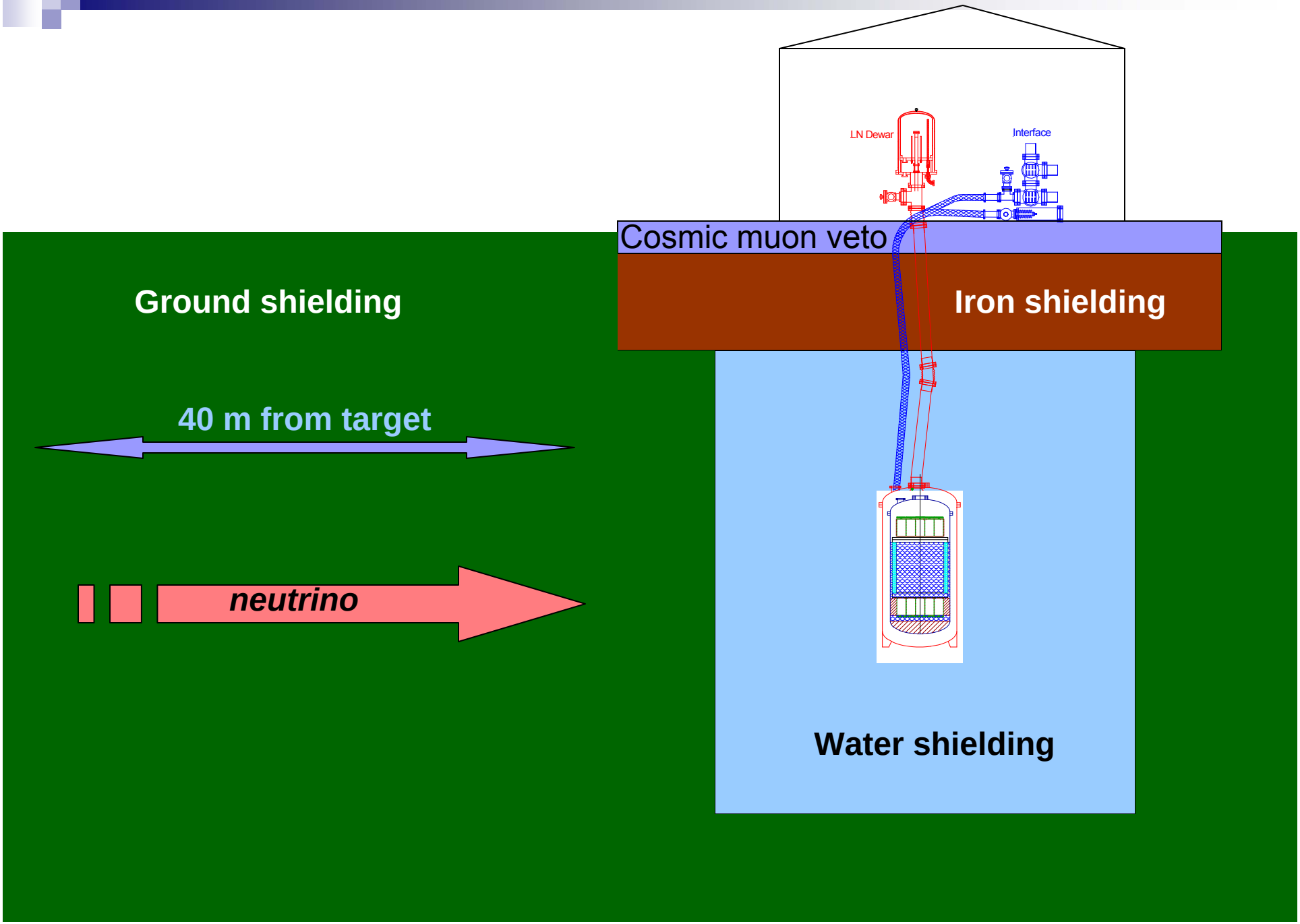
SNS neutron bckgr suppressed by factor 10^9 due to ground shielding

Effect =1470 events/year

Well-logging detector

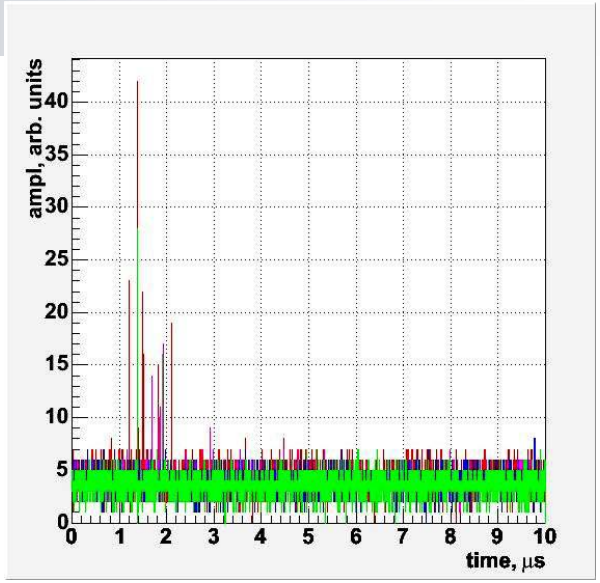


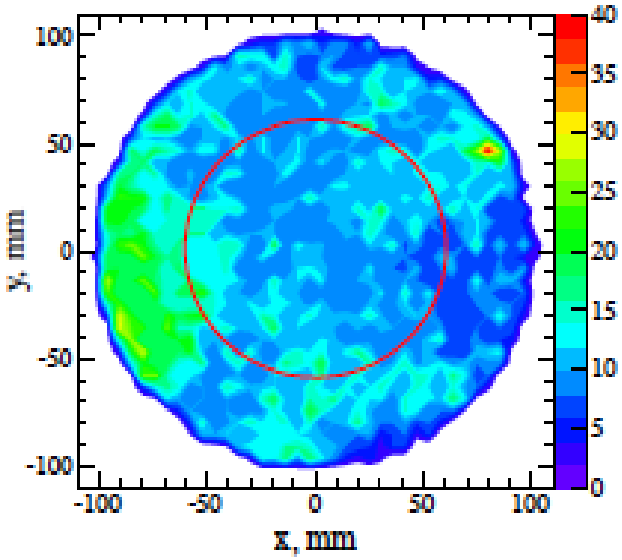

LN Dewar
Interface
Ground shielding
40 m from target
10 m below
ground level
neutrino


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

Single electrons background

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





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

Santos – arxiv 1110.3056v1

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

Conclusion

- Coherent Neutrino Scatter (CNS) is interesting for basic science - and possibly for non-proliferation applications
- Emission two-phase detectors look suitable for detecting CNS
- Measurement of the ionization yield for nuclear recoils below ~keVr energies is a key element toward the observation of CNS
- Single-electron noise is a factor limiting sensitivity of LXe emission detectors
- At reactor for signal $N_e \geq 2$: LXe 20-400 d^{-1} ; LAr 400-700 d^{-1}
- At SNS for signal $N_e \geq 2$: LXe 1400 d^{-1} ; LAr 400 d^{-1}