NATIONAL RESEARCH NUCLEAR UNIVERSITY "MEPhI"

Laboratory for Experimental Nuclear Physics

RED Collaboration

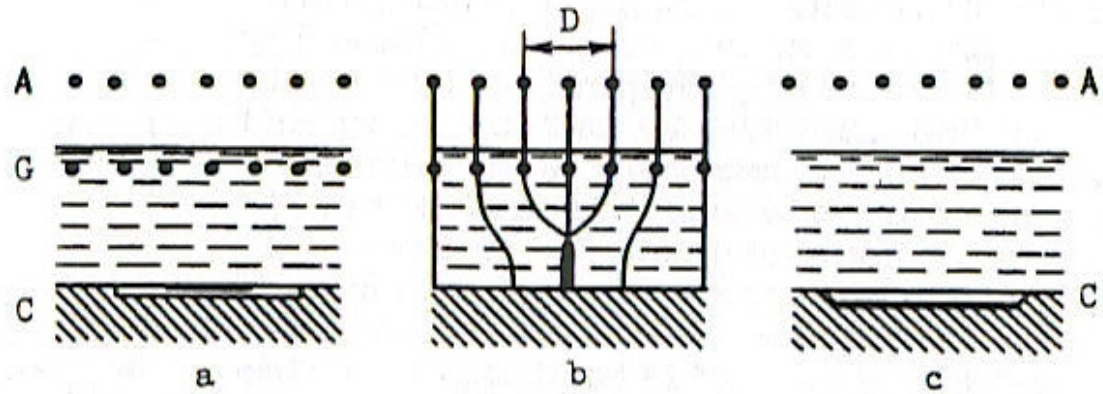
Development of RED100 liquid xenon emission detector for observation of coherent neutrino scattering

Alexander Bolozdynya

2013

Emission Detectors

1969-70 Emission Method of Particle Registration

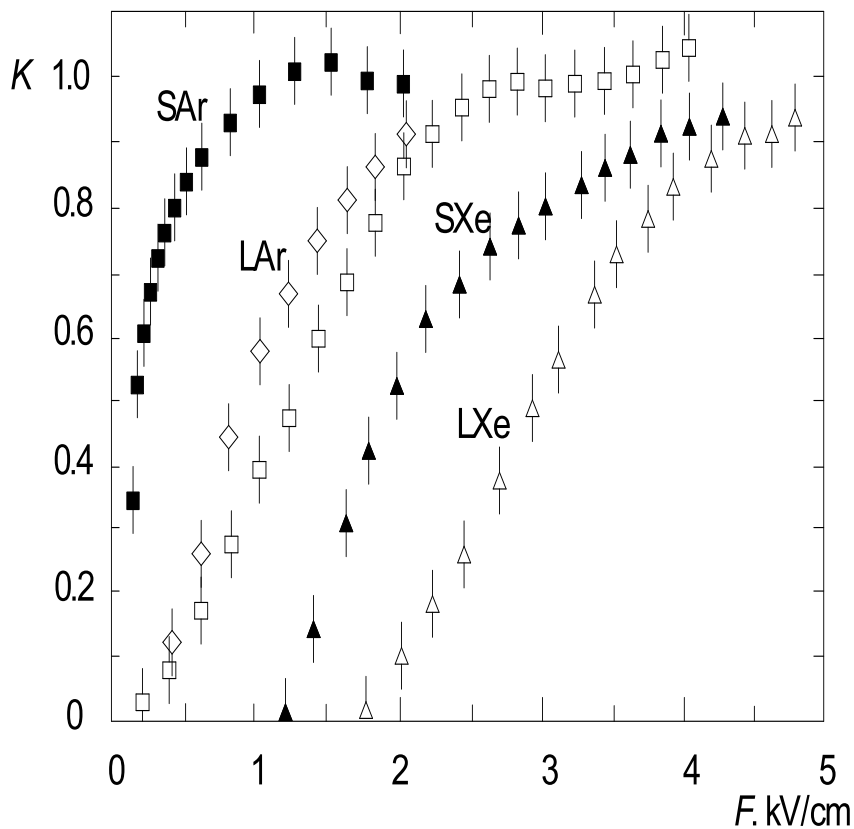


Boris A. Dolgoshein

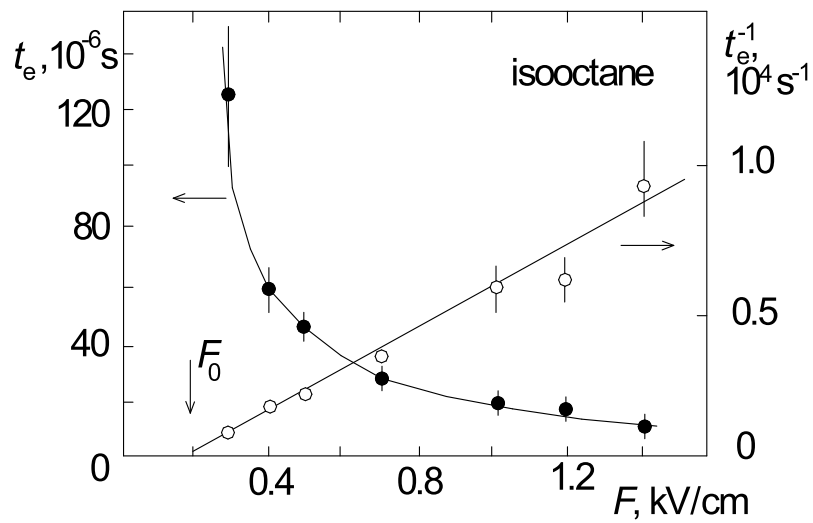
Boris U. Rodionov

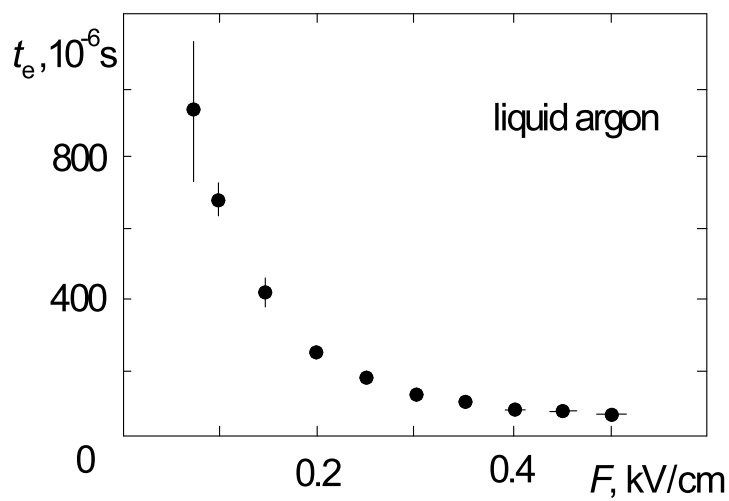
Vadim N. Lebedenko

Probability of the quasi-free electron emission from non-polar dielectrics



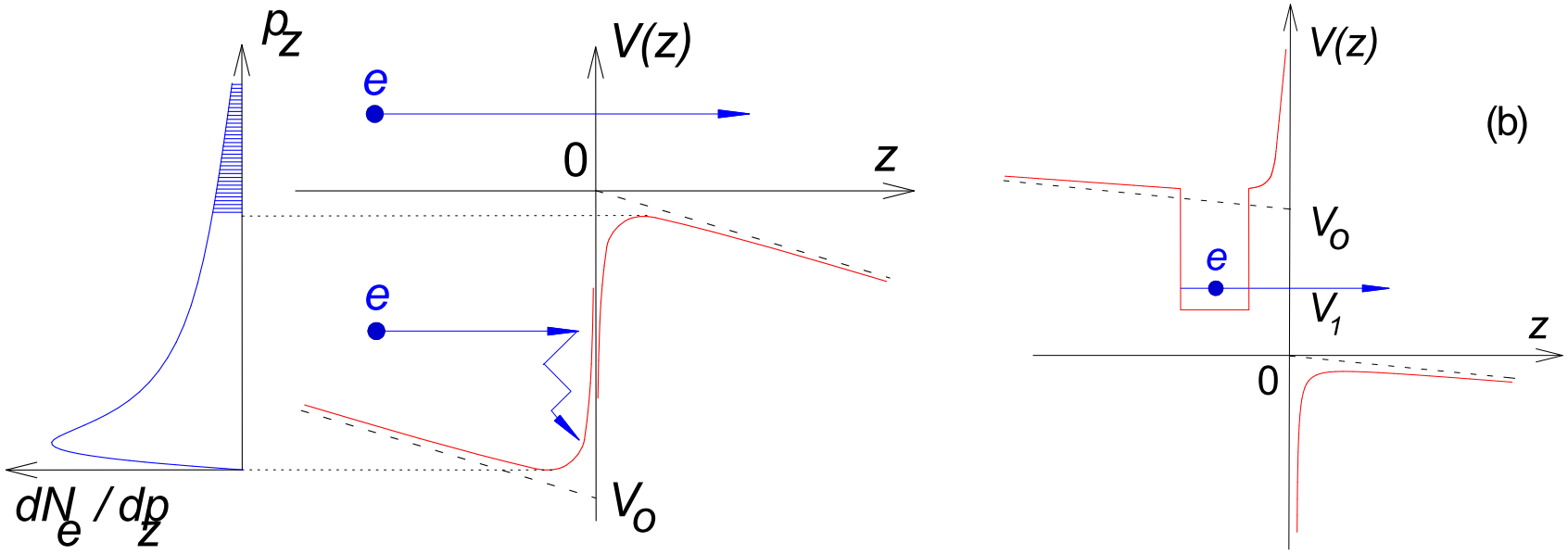
$$K = \int_{p_z > p_0} \alpha\beta f(\vec{p})d\vec{p} \Big/ \int f(\vec{p})d\vec{p}$$





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

Quasi-free electron emission from nonpolar dielectrics



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

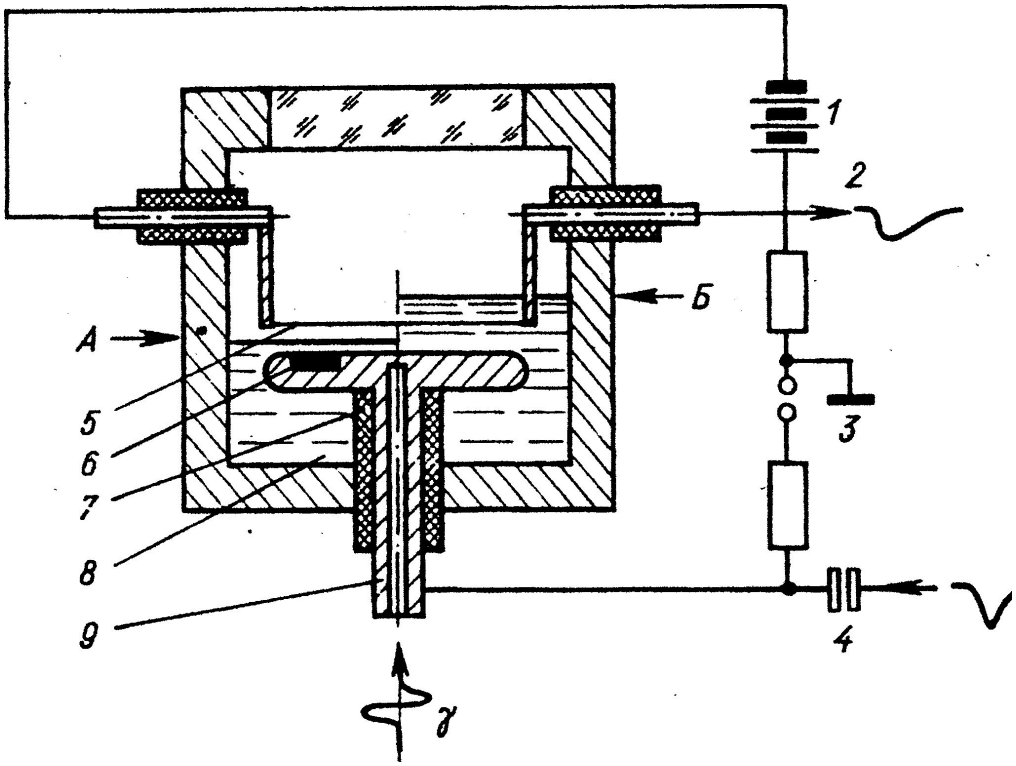
$$V_2(z) = -eF_2 z + eA_2, z > 0$$

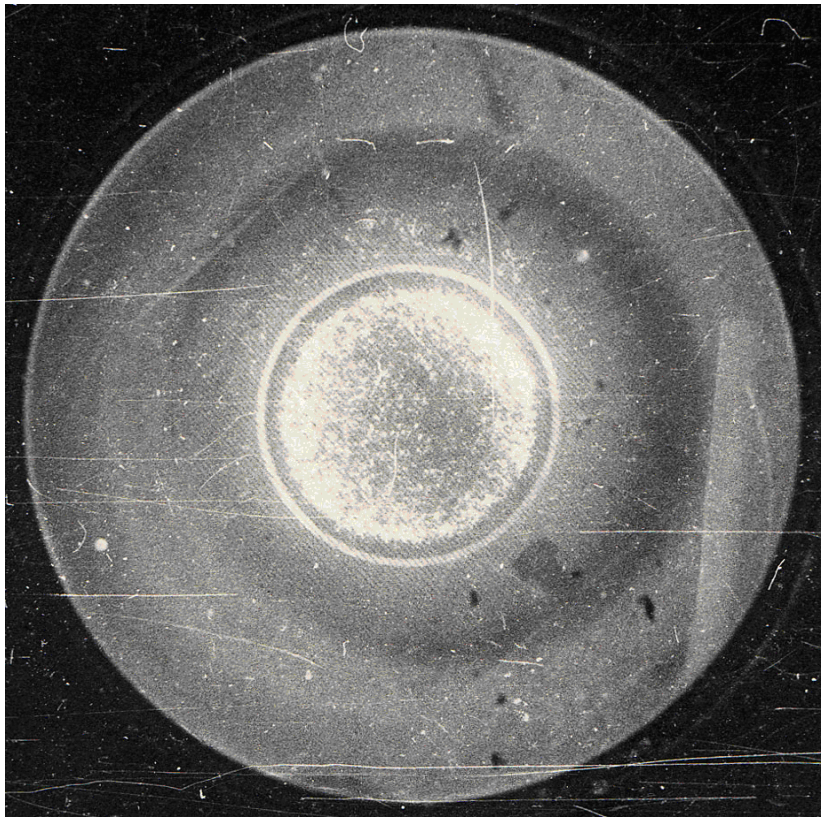
$$A_{1,2} = -e(\varepsilon_1 - \varepsilon_2) / \left[4\varepsilon_{1,2}(z + \xi z/|z|)(\varepsilon_1 + \varepsilon_2)\right]$$

	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)

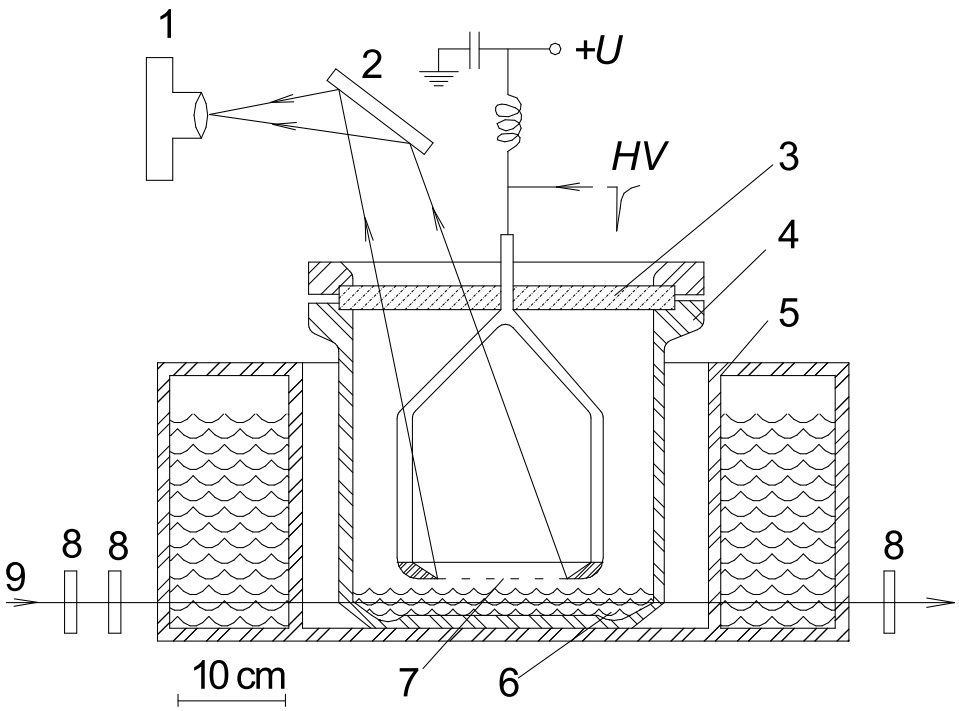
Note: n-H – normal hexane, iso-O - isooctane, TMP - thetramethylepentane

1970-73 Emission Spark Chamber

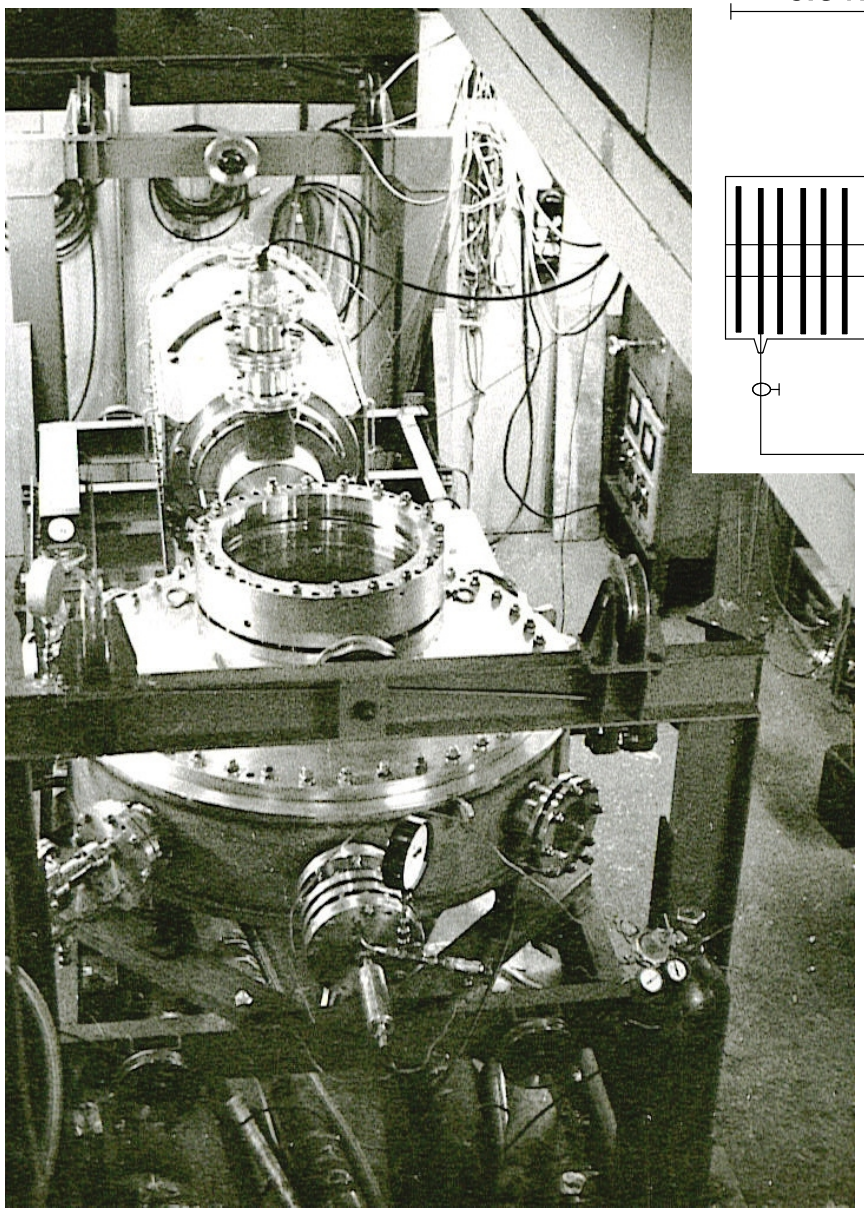


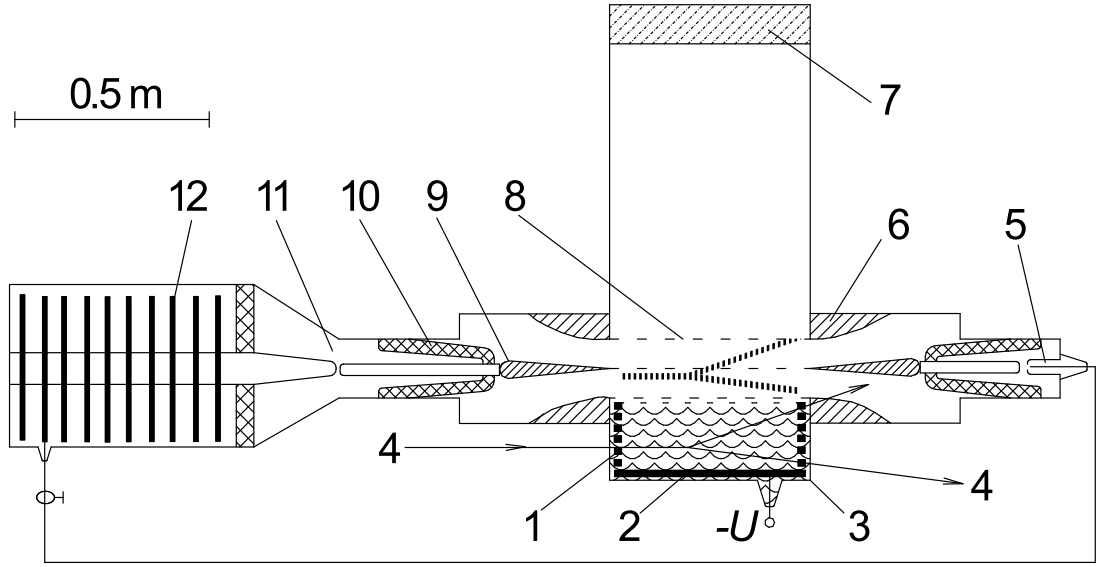


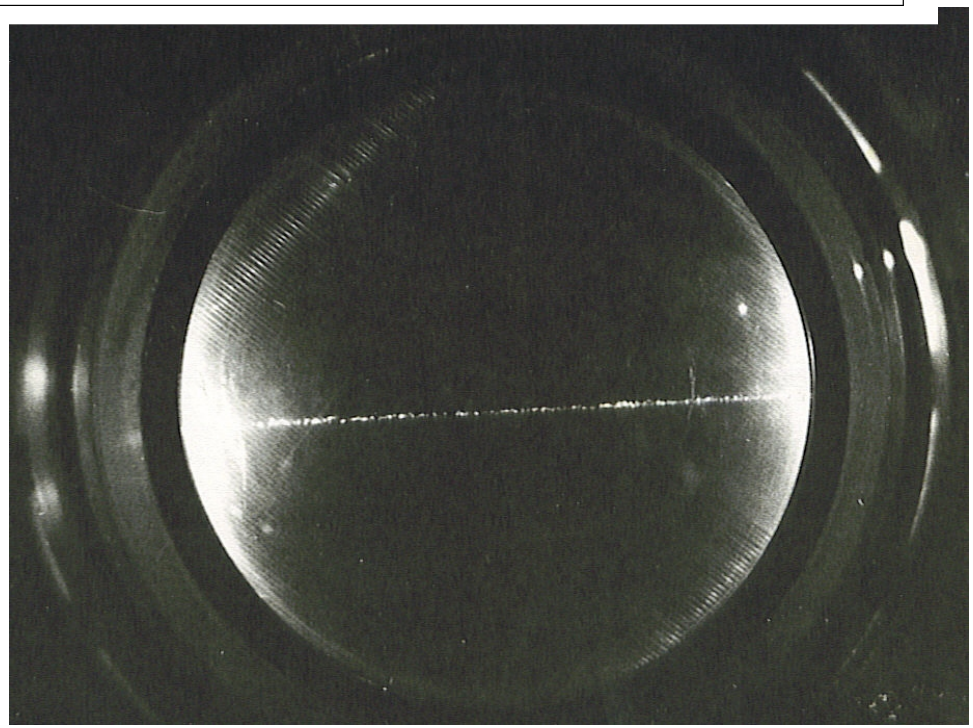
1977 Emission Streamer Chamber



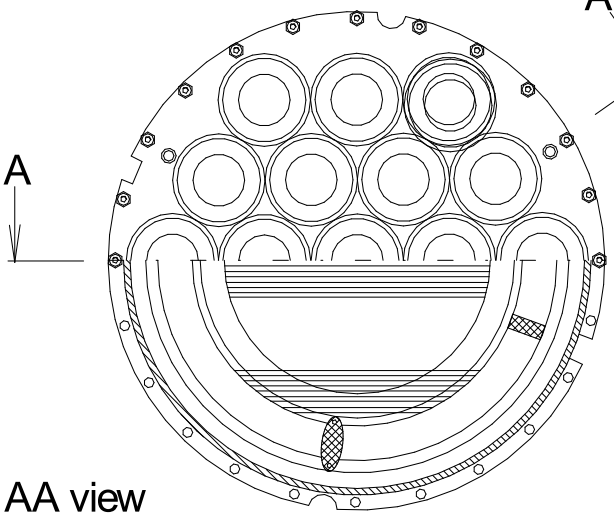
1980-1990

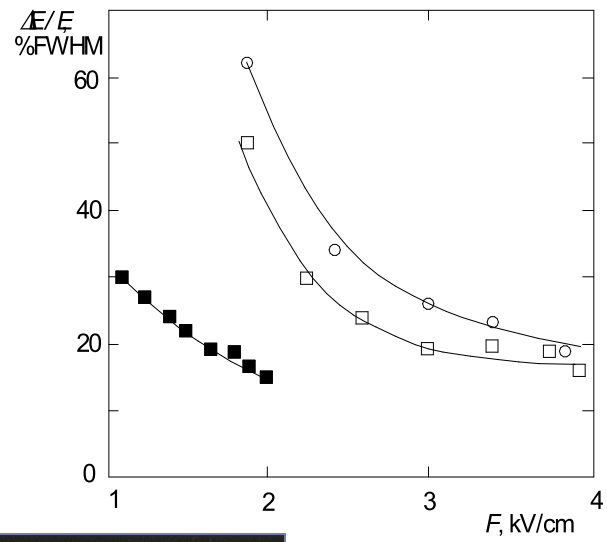




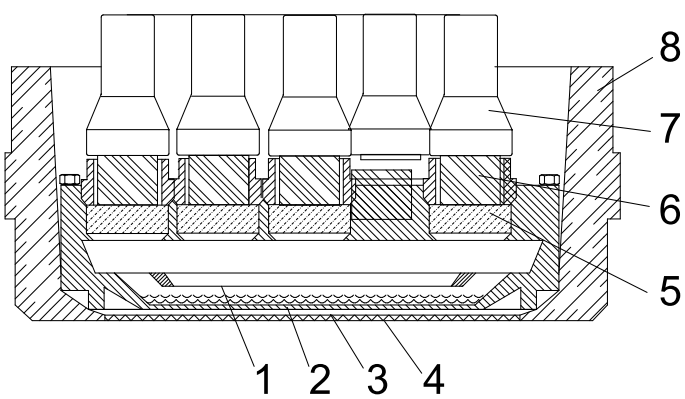


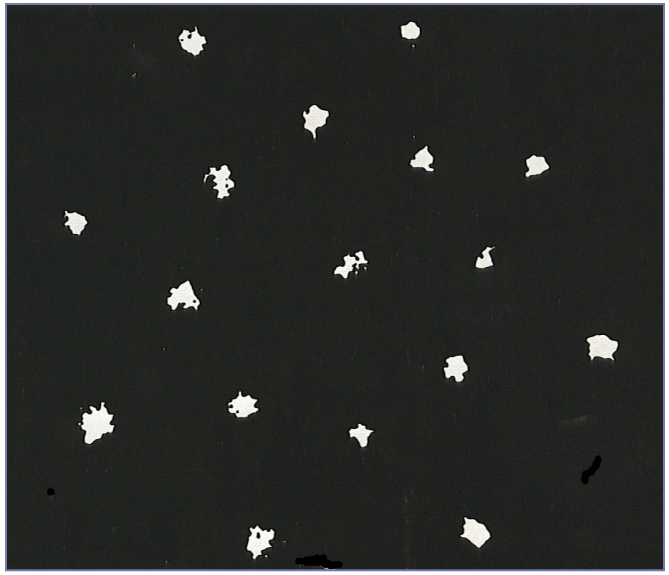
1983 Emission Electroluminescence Camera



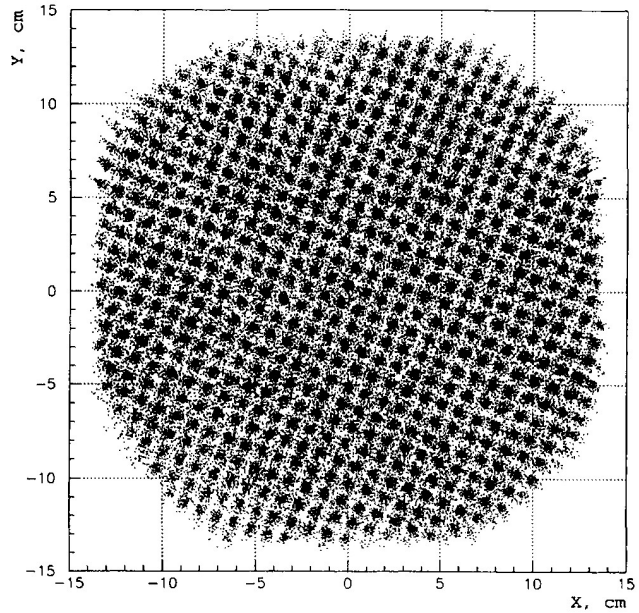


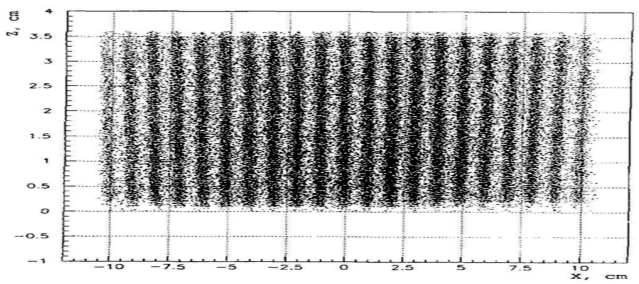
AA view

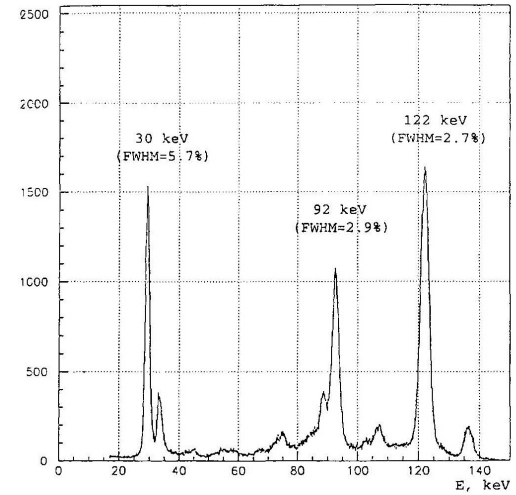


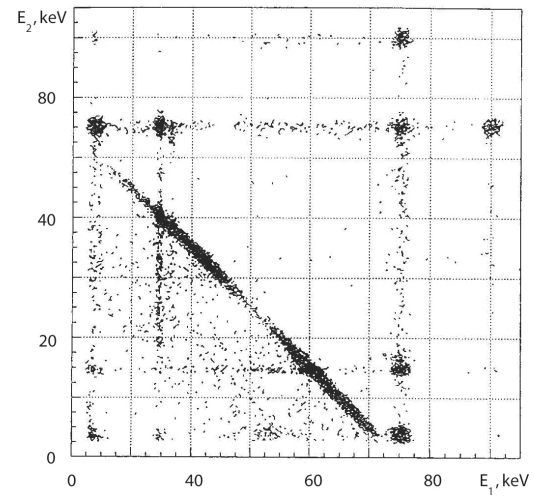


1994-95 3D EL gamma camera

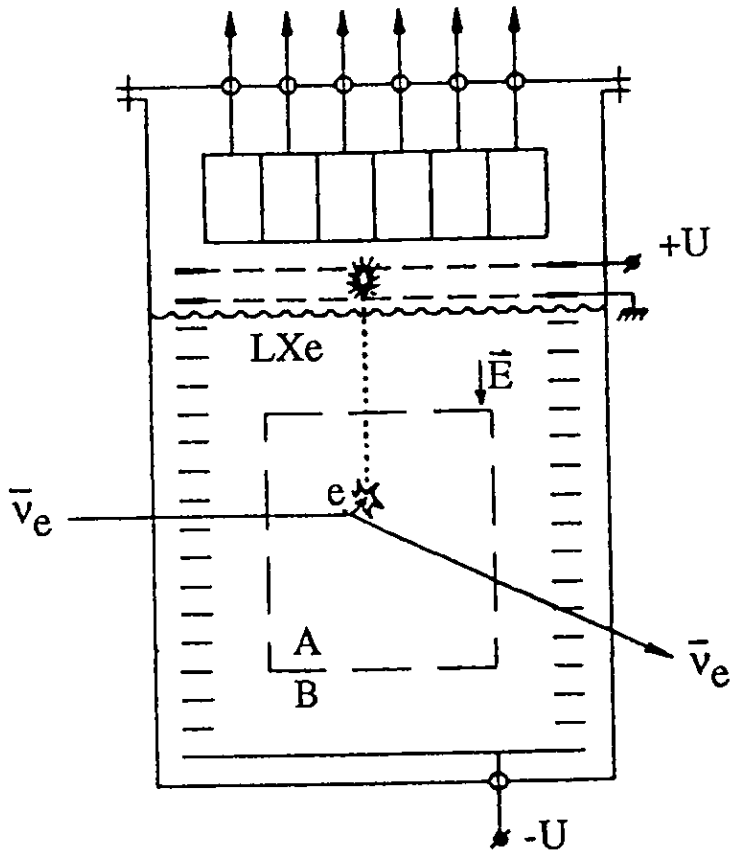








“Wall-less” emission detector



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

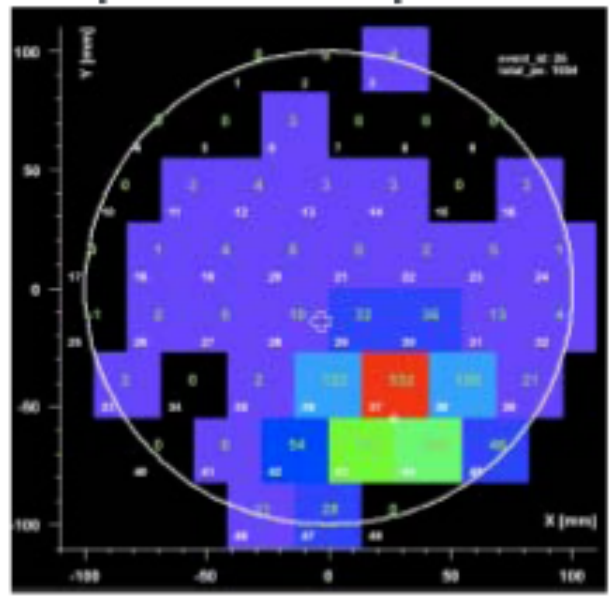
Fig.4. LXe time-projection scintillating drift chamber as wall-less detector for measurements of magnetic momentum neutrino.

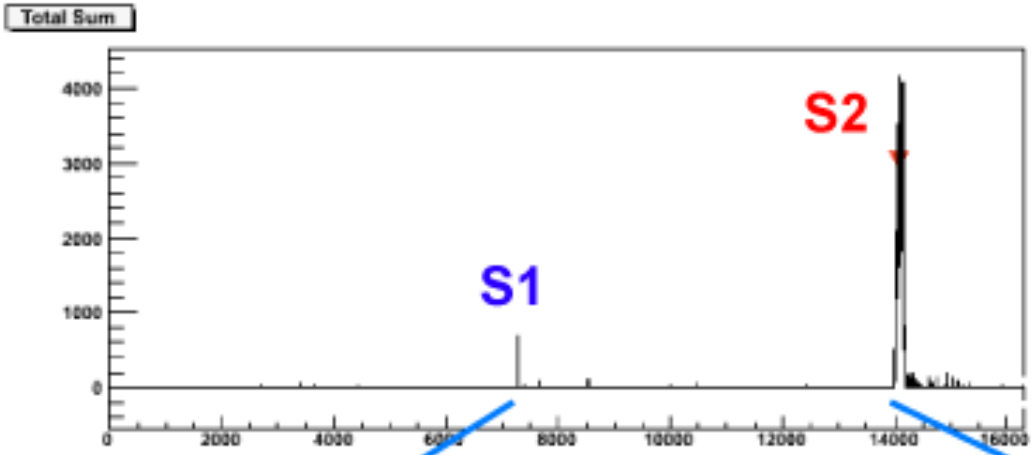
Bolozdynya, Egorov, Miroshnichenko, Rodionov.*IEEE Trans. Nucl. Sci.* v.42, n.4 (1995) 565-569

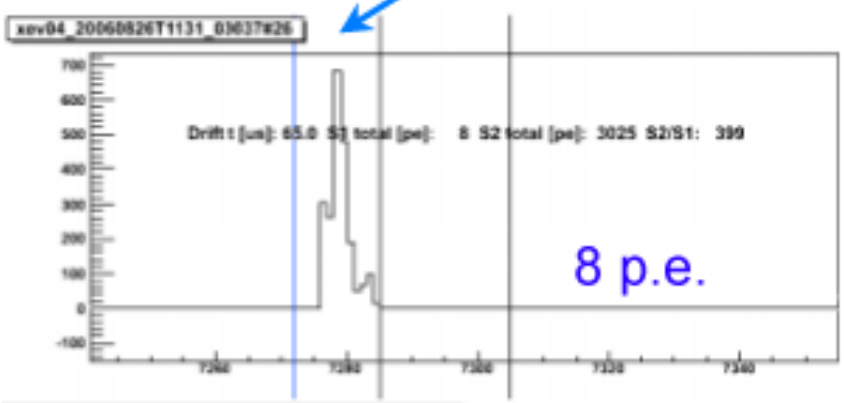
Real signals from XENON10 LXe emission detector

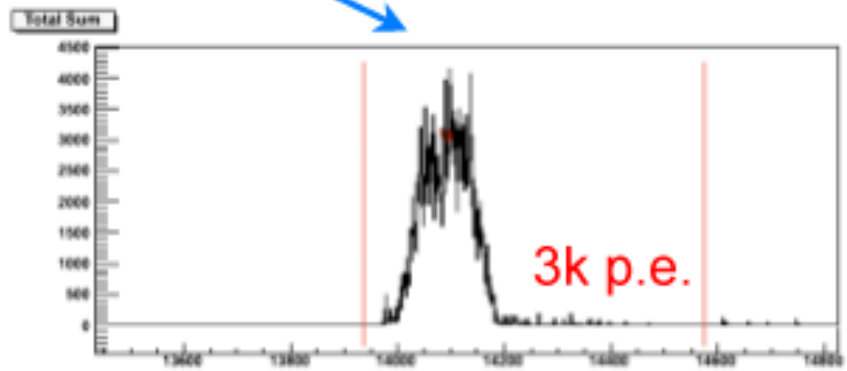
4 keV$_{ee}$ event; S1: 8 p.e => 2 p.e./keV

Hit pattern of top PMTs

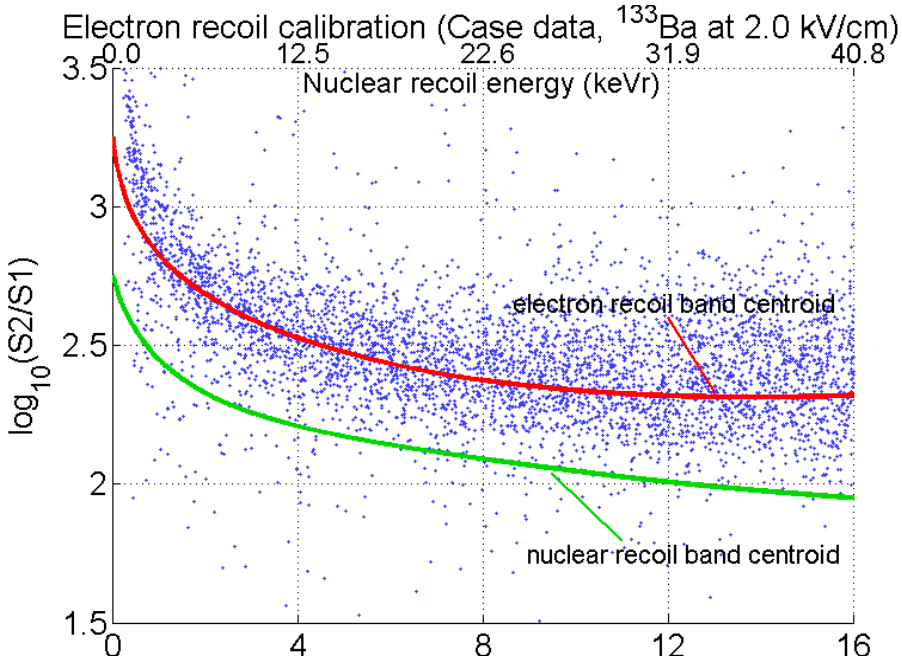


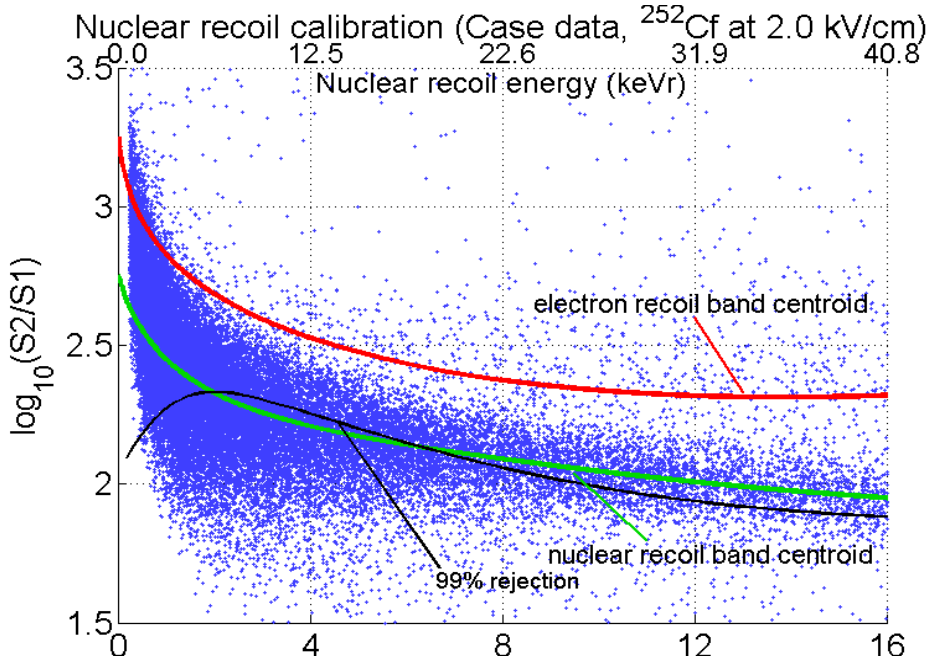






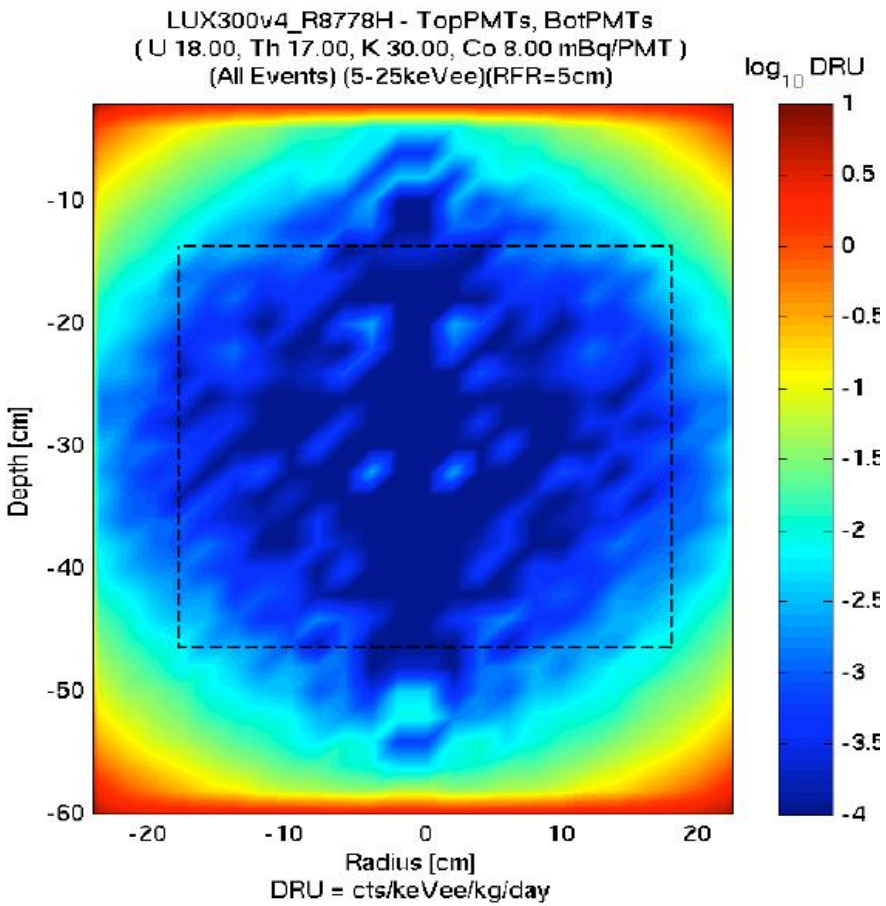
Separation of gamma and nuclear recoil signals

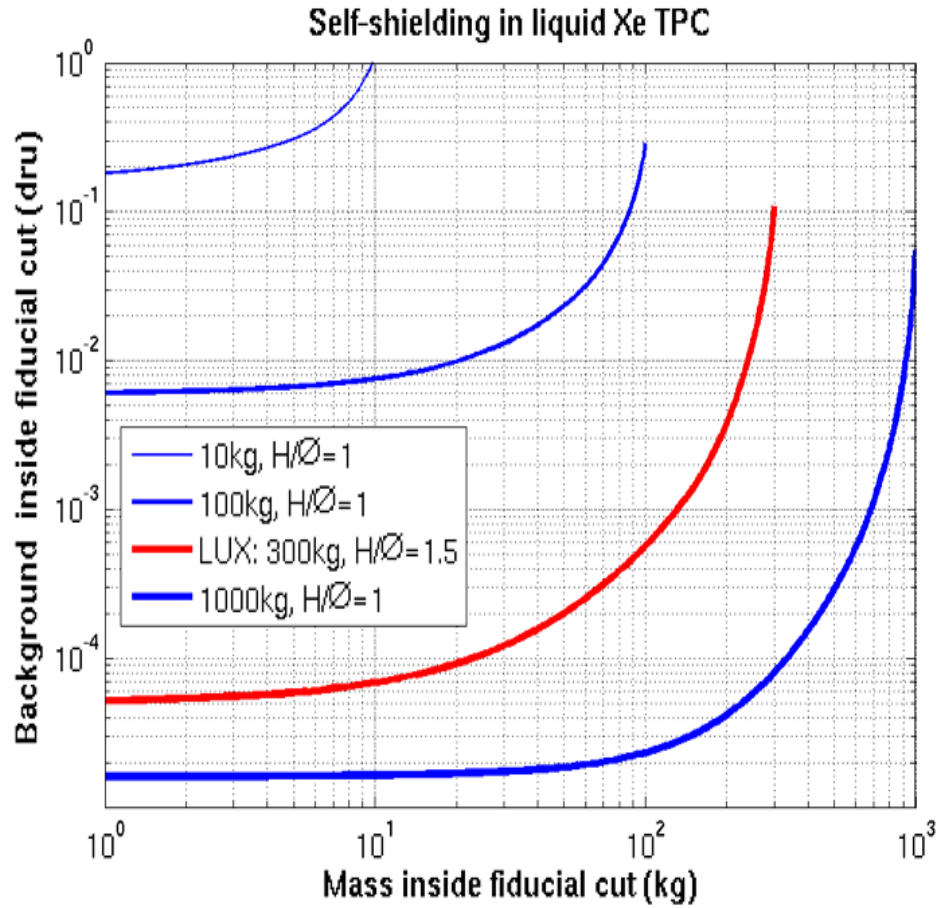




Energy, keVee

Self-shielding





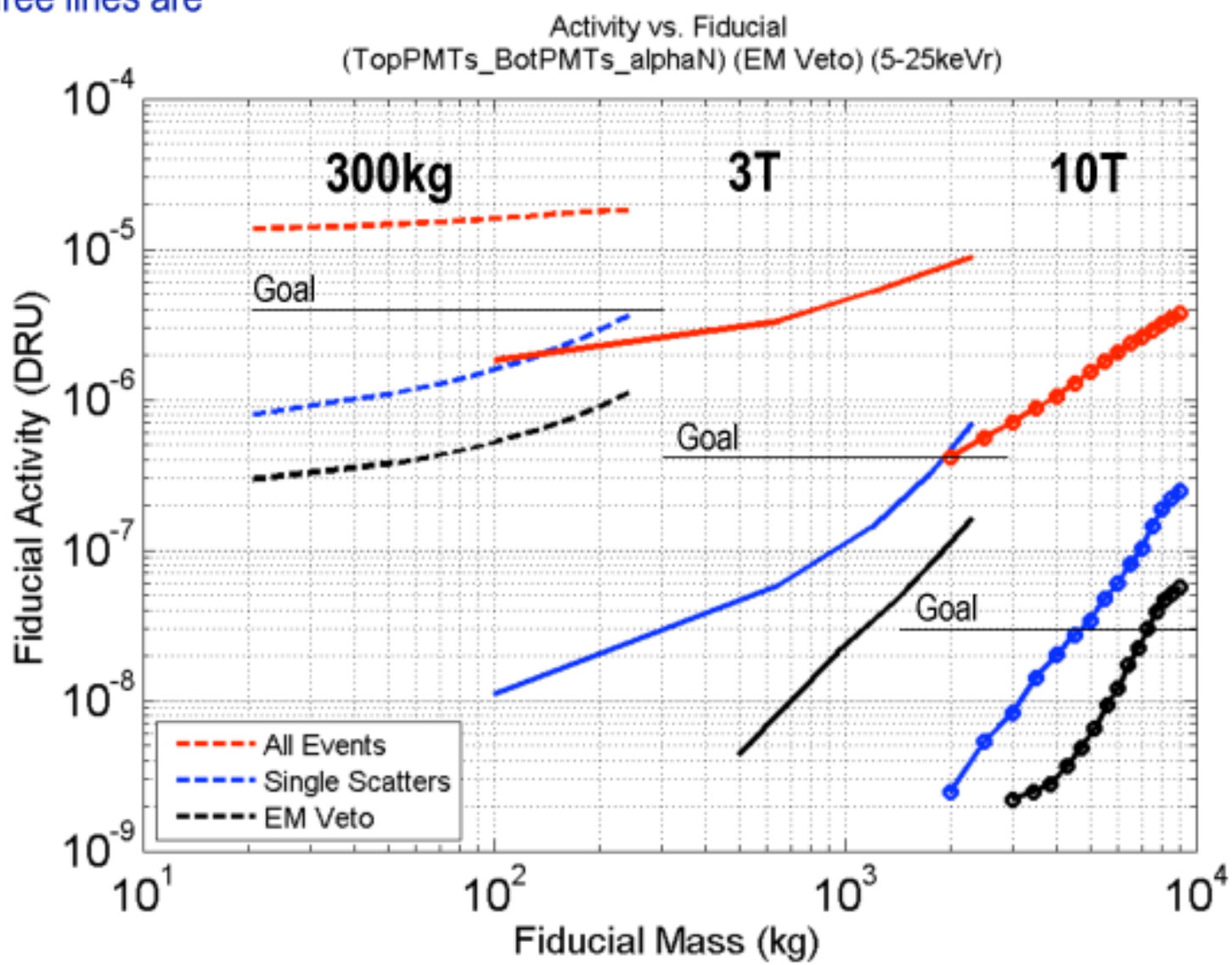
LXe

Neutron Activity vs. Fiducial Mass

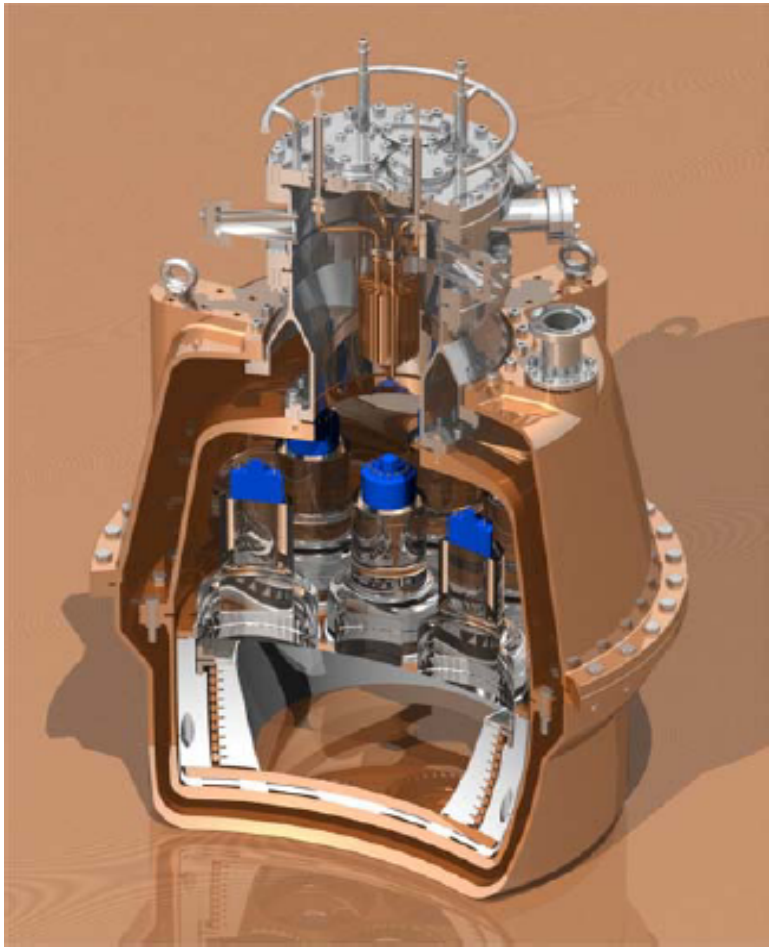
- For each detector, three lines are plotted:
  - All Fiducial Events (Red)
  - Single Scatters Only (Blue)
  - Single Scatters, after EM-component Veto (Black)

Neutrons reduced by factor 20x using multiple vertex cut

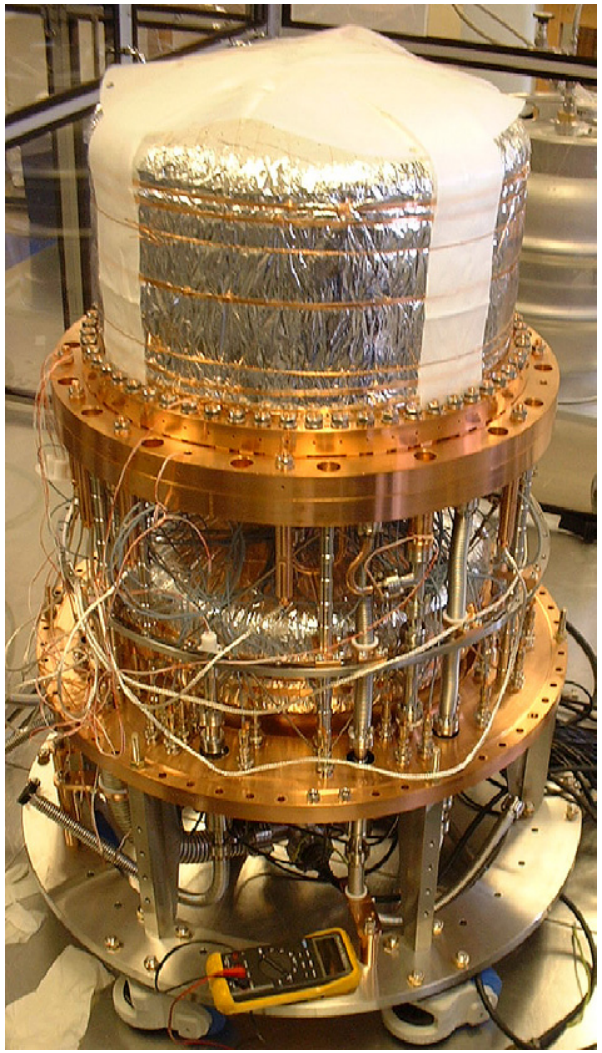
Single Phase - XMASS and DEAP/ CLEAN cannot exploit this well for low energy neutrons, so must work much harder on n activity



ZEPLIN @ Boulby mine 2004-2009

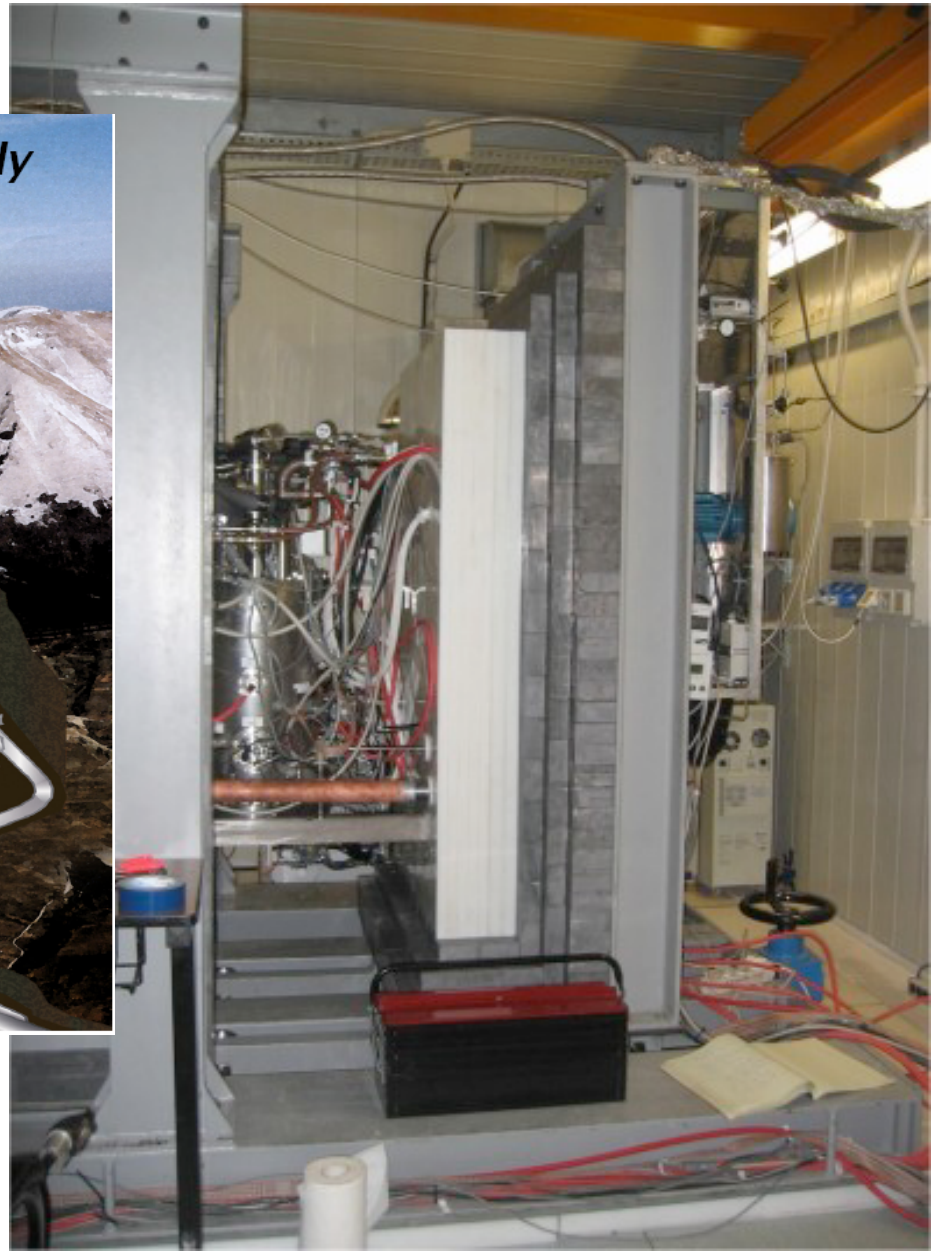


ZEPLIN-II

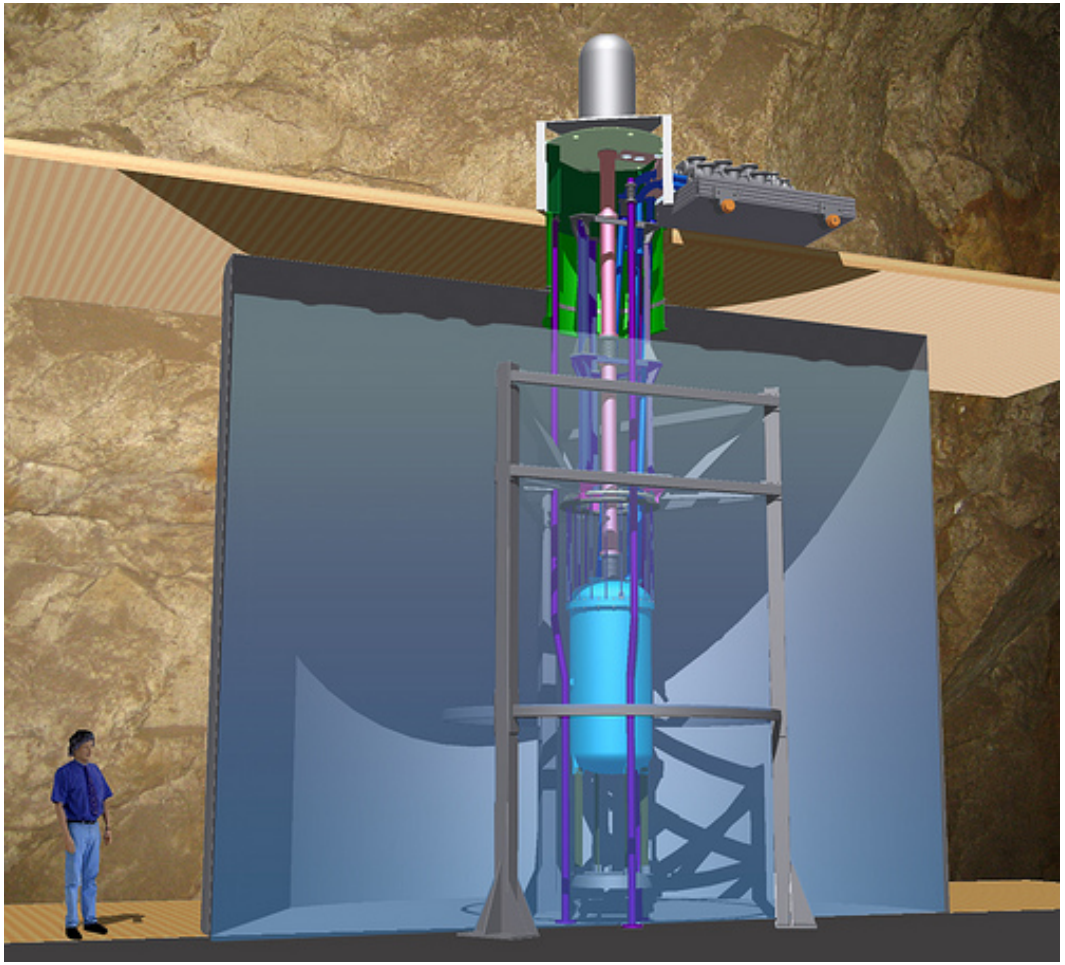


ZEPLIN-III

XENON at Gran Sasso Lab 2005-now



LUX at Homestake mine (USA)

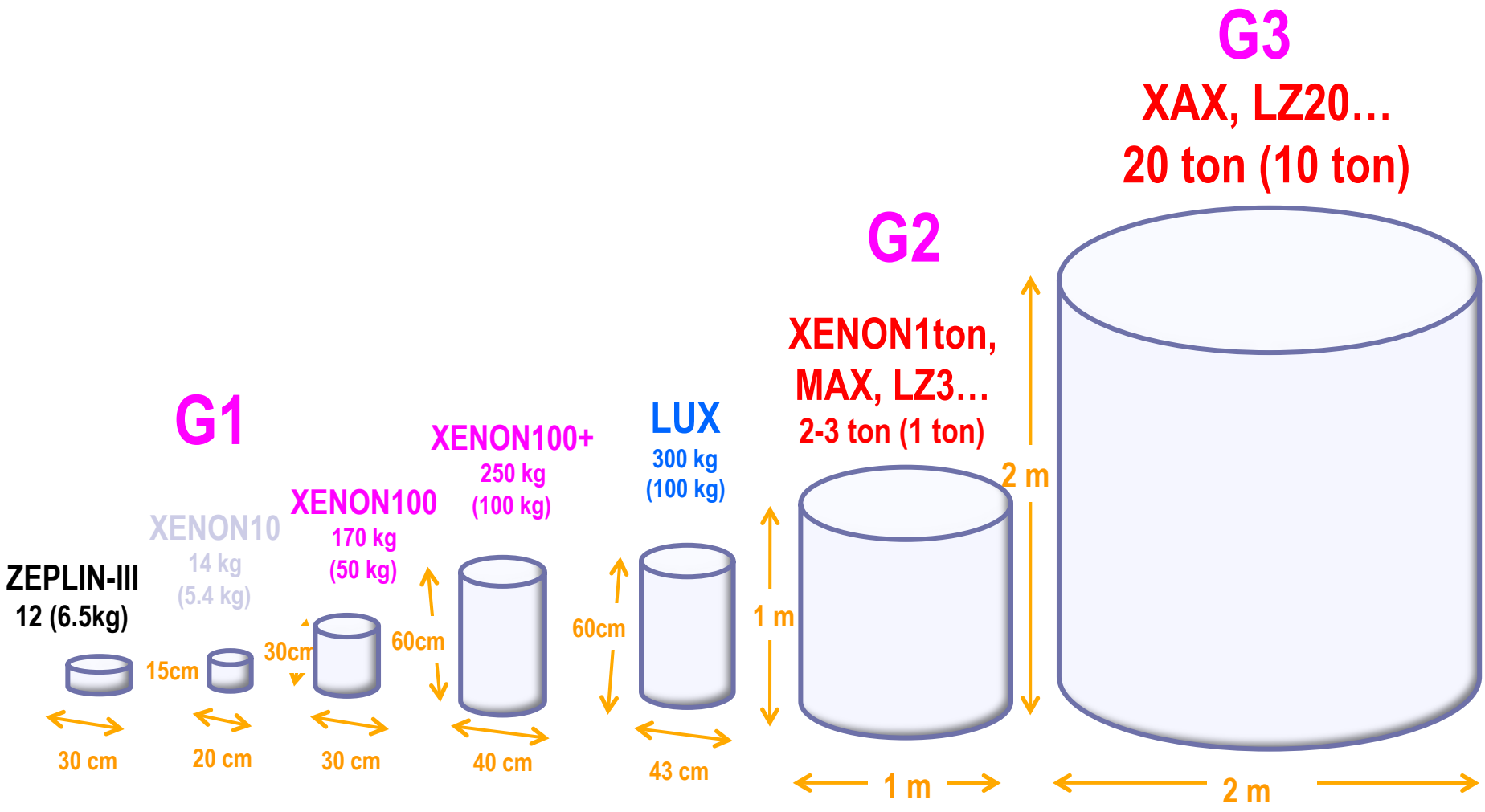


Emission WIMP detectors

Project	Detector mass, Total/Feducial, kg	Sensitivity, $10^{-44}cm^2$	Location, Years on duty	Status	Ref.
XENON10	25/5 LXe	8.8 @ 100 GeV/c^2 5.5 @ 30 GeV/c^2	GS, 2006-07	Completed	a
XENON100	100/10 LXe	0.2 @ 100 GeV/c^2	GS, 2008-13	Active	b
ZEPLIN II	31/8 LXe	66 @ 55 GeV/c^2	BM, 2006-07	Completed	c
ZEPLIN III	12/6.5 LXe	0.18 @ 55 GeV/c^2	BM, 2008-11	Completed	d
LUX	300/100 LXe	0.07 @ 100 GeV/c^2	H	u/c	e
WARP10	10/2.6 LAr	75 @ 100 GeV/c^2	GS, 2006-2007	Completed	g
WARP100	100 LAr	1 @ 100 GeV/c^2	GS	u/c	g

Notes:
BM – Boulby mine (England); GS – Gran Sasso Underground Laboratory (Italy); H – Homestake DUSEL (South Dakota); u/c – under construction; a – Angle et al., 2007; b – Aprile and Baudis, 2009; c – Alner et al., 2007; g – Benetti et al., 2008

WIMP emission detector generations



Р Э Д

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

LENP

RED collaboration

Russian Emission Detectors

Р Э Д

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

A.I. Bolozdynya[1], D.Yu. Akimov[2], I.S. Alexandrov[2], V.I. Aleshin[3], N.T. Antonov[5], V.A. Belov[2], A.E. Bondar[4], A.F. Buzulutskov[4], A.A. Burenkov[2], A.V. Derbin[5], V.V. Dmitrenko[1], A.G. Dolgolenko[2], E.S. Drachnev[5], O.Ya. Zeldovich[2], S.V. Ivakhin[1], A.K. Karelin[2], M.A. Kirsanov[1], A.G. Kovalenko[2], V.I. Kopeikin[3], A.V. Kuchenkov[2], E.A. Litvinovich[3], I.N. Machulin[3], V.P. Martemyanov[3], V.N. Muratova[5], N.N. Nurakhov[3], M.D. Skorokhvatov[3], V.N. Stekhanov[2], S.V. Sukhotin[3], V.G. Tarasenkov[3], G.V. Tikhomirov[1], Yu.A. Tikhonov[4], A.V. Etenko[3], A.S. Chepurnov[6]

[1]National Nuclear Research University «MEPhI», Moscow
[2]SSC RF Institute for Theoretical and Experimental Physics, Moscow
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[4]Institute of Nuclear Physics SB RAS, Novosibirsk
[5]Petersburg Nuclear Physics Institute RAS, Gatchina
[6]Institute of Nuclear Physics MSU, Moscow

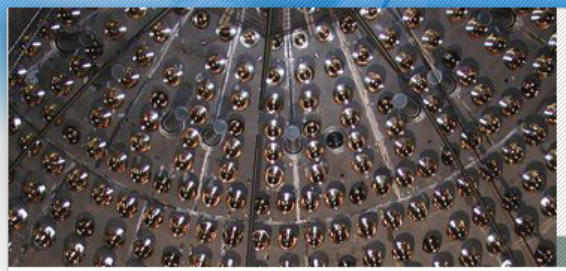
http://enpl.mephi.ru/

Лаборатория эксперимен...

Файл Правка Вид Избранное Сервис Справка

VLP SkTech Почта МИФИ ФЦП К NEWSru Y РНЛ Гр-экс СБ VoIP ЦЯМ ЛЭЯФ Страница Безопасность Сервис

Национальный исследовательский ядерный университет "МИФИ"



Лаборатория экспериментальной ядерной физики НИЯУ МИФИ

Лаборатория

- Общая информация
- Руководитель
- Фотоальбом
- Пресса о нас
- Рабочее совещание нейтрино-2012

Научная программа и деятельность

- Общая информация
- Отчёты и публикации
- Семинары
- РЭД-100
- Эксперимент на реакторе ИРТ МИФИ
- Закрытая зона

Грант правительства РФ 2011-2013

- Задачи
- Рабочие материалы 2012

Полезные ссылки

- Borexino Experiment
- KamLAND
- ZEPLIN-III
- EXO
- XMASS

Новости лаборатории

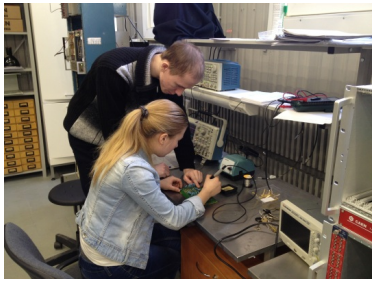
- 2013-02-25 04:09:09: Conference in Novosibirsk, Russia: Dark Matter, Dark Energy and Their Detection
- 2013-02-13 17:30:20: Репортаж с места установки детектора LUX
- 2013-01-22 09:01:48: Итоги 2011-2012 годов, новая структура лаборатории, планы на 2013 год
- 2013-01-07 08:29:36: Информационное сообщение о продлении научных исследований победителей конкурсного отбора 2010 года в рамках реализации постановления Правительства Российской Федерации от 9 апреля 2010 г. № 220.
- 2013-01-07 08:22:54: РЭД-100 в журнале "Nature"

Все новости

Stuff:
Doctors of Science -2
PhDs – 10
Faculty - 12
PhD students – 6
Students – 10

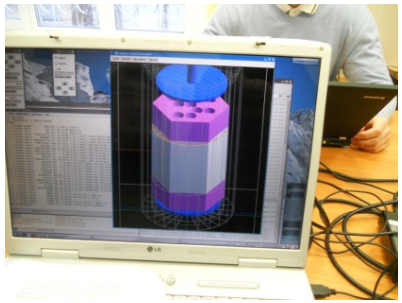
Laboratory for Experimental Nuclear Physics of NRNU MEPhI

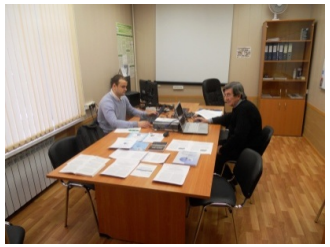
Advanced detectors lab of 326.8 m^2 area (bldg.24) including clean room of 1000 class, cryogenics, LN_2 generator, lab work-shop



5 offices of 70 m^2 total

Experimental facility at the Horizontal Experimental Channel #10 of the research reactor IRT MEPhI

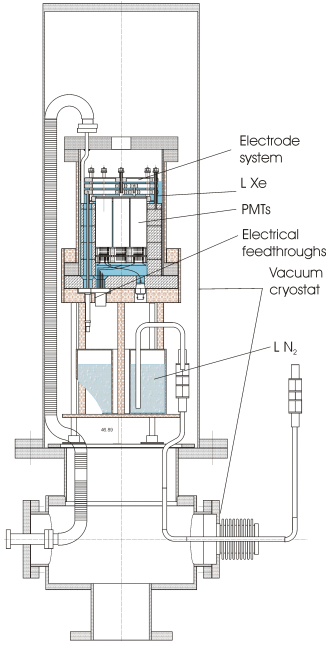




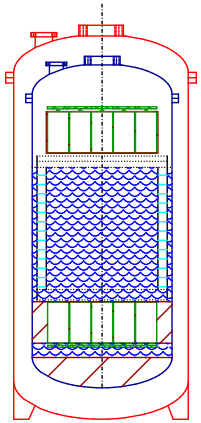
Modern digital and analog electronics, computer network

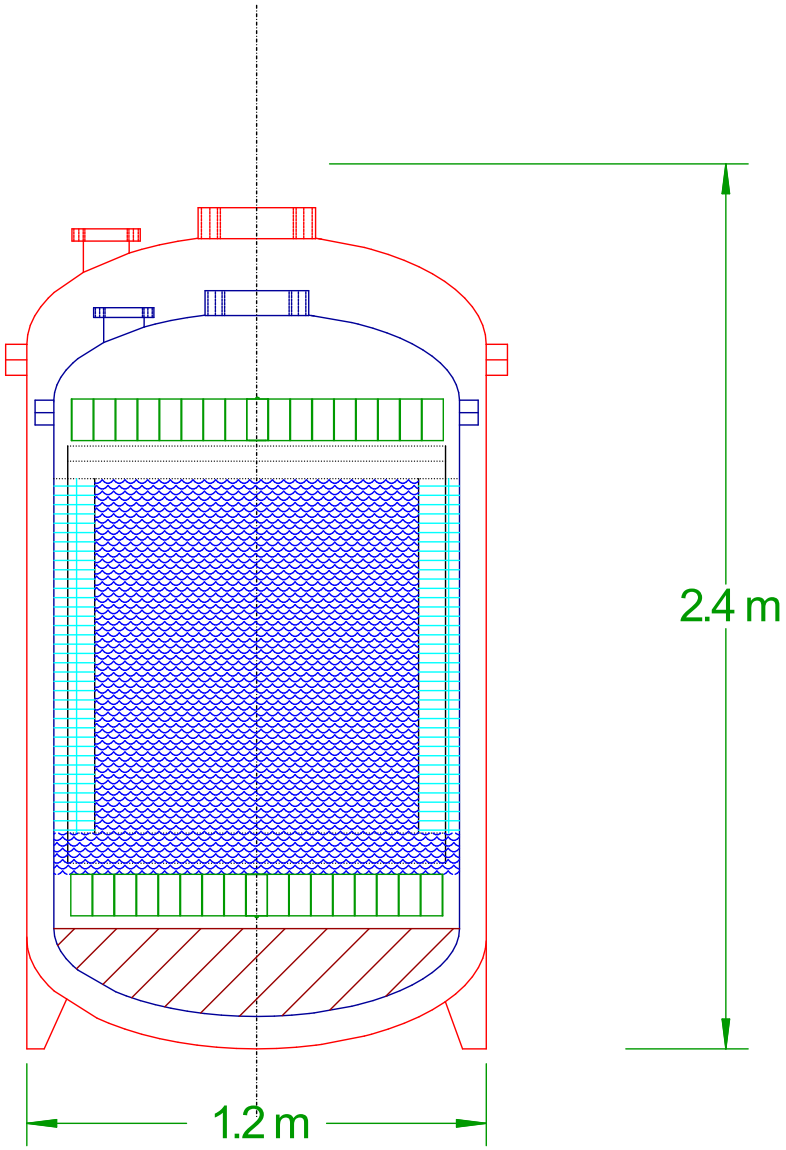
RED-3000

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР



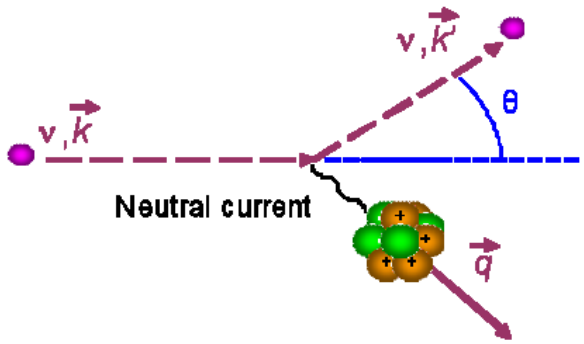
RED-100

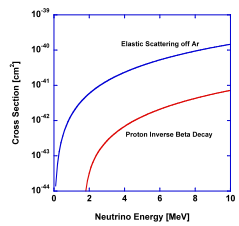




Coherent Neutrino Scattering

Coherent neutrino scattering off heavy nuclei





Large cross-section

$$\sigma_{\text{elastic}} = \frac{G_F^2}{4\pi} N^2 E_\nu^2$$

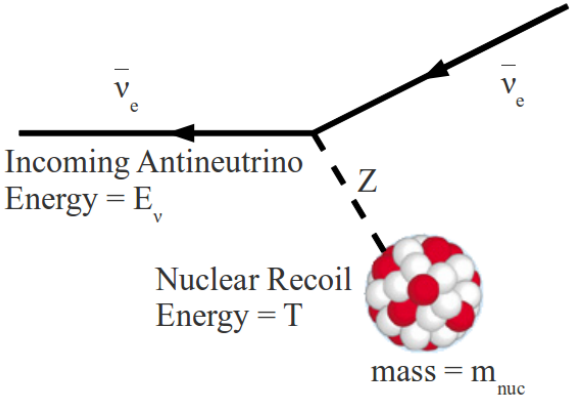
$$\approx 0.4 \times 10^{-44}\,\text{cm}^2 A^2 E_\nu (\text{MeV})^2$$

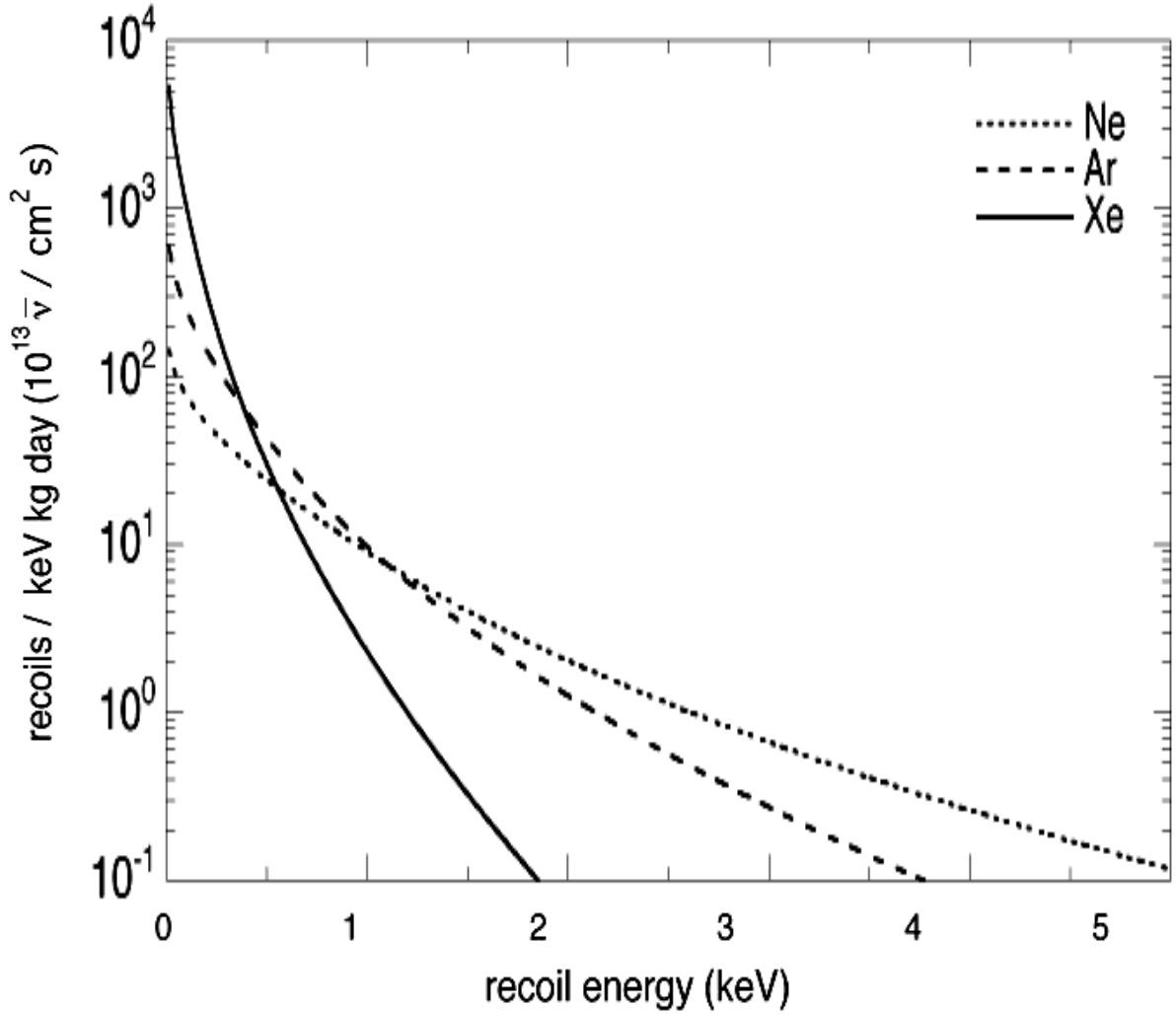
$$p + \bar{\nu}_e \rightarrow e^+ + n$$

Small recoil energies

$$< E_{\text{recoil}} > \; = \; 716\,\text{eV}\,\frac{E_\nu^2(\text{MeV})}{A}$$

Recoil spectra from reactor e-antineutrino

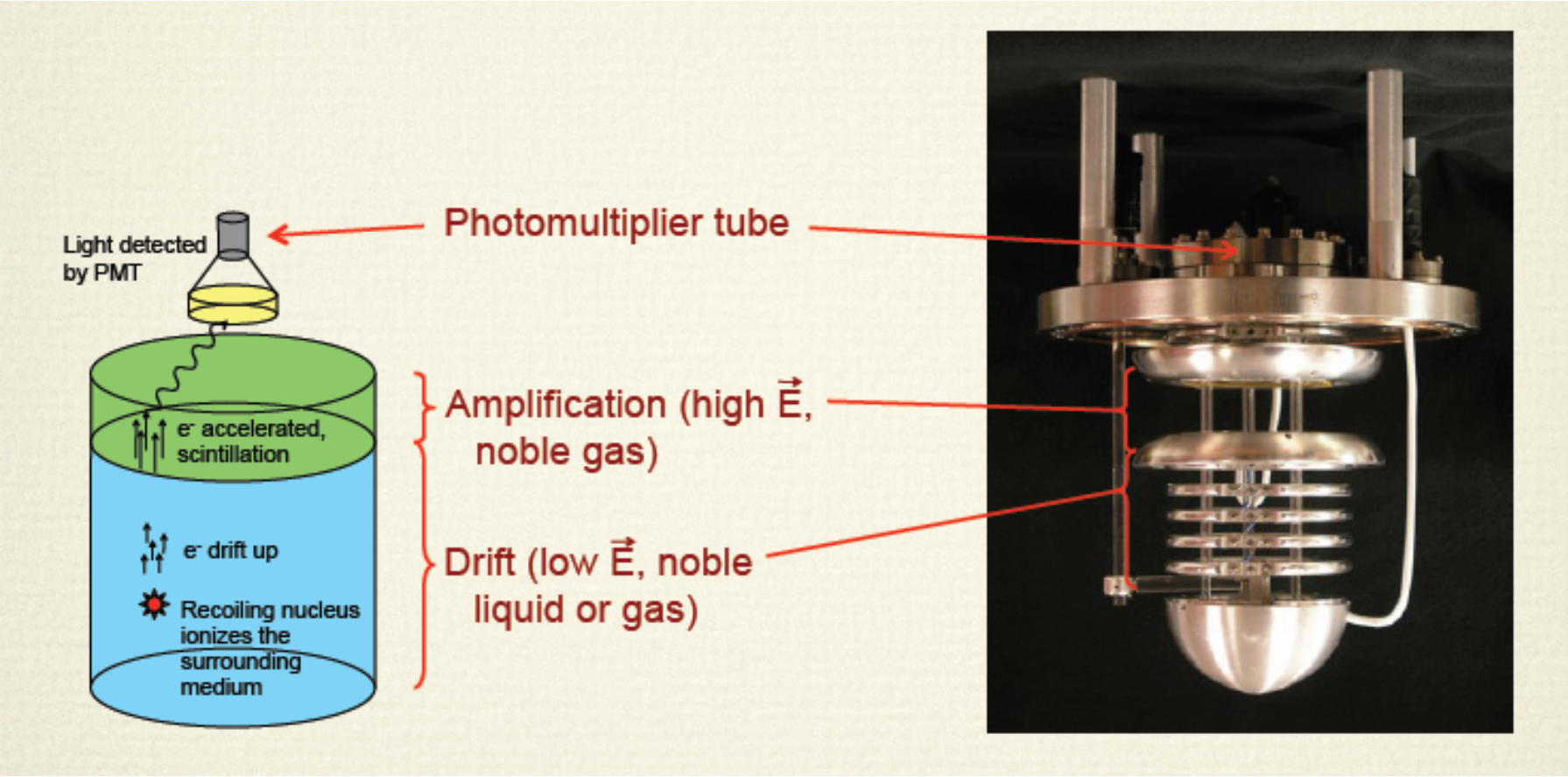




P. S. Barbeau, J. I. Collar, J. Miyamoto, and I. Shipsey

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

LAr detector @ LLNL

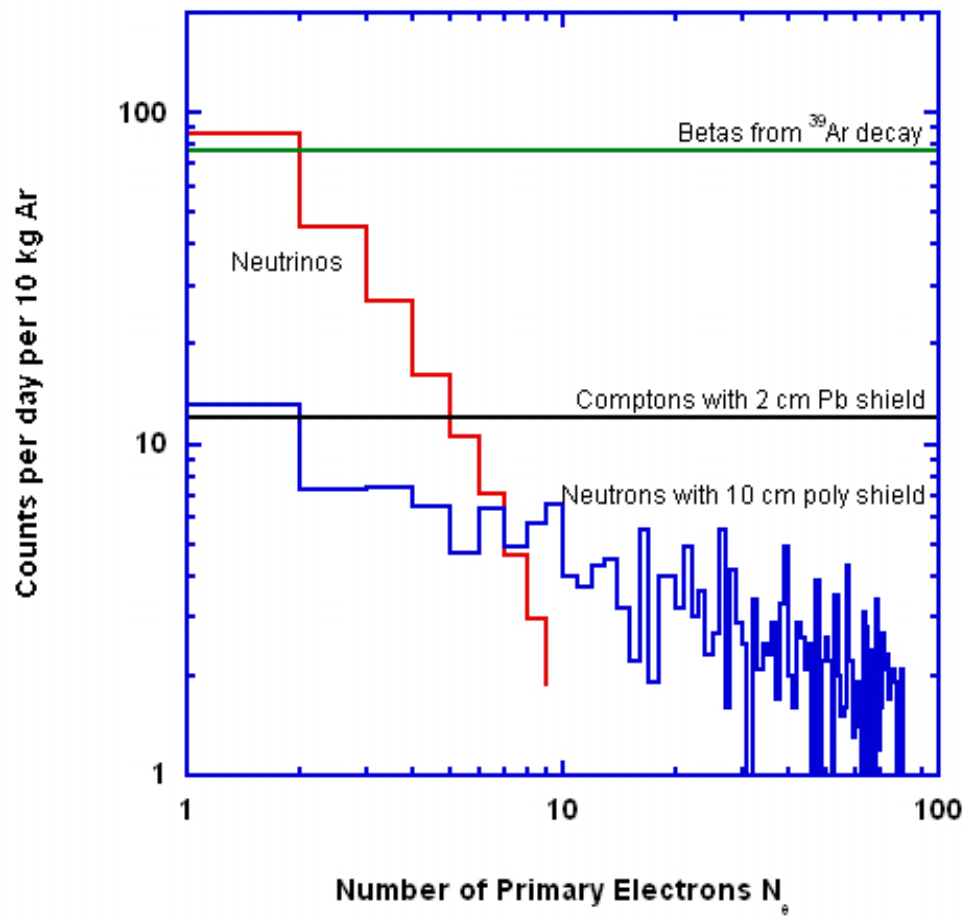


Hagmann, C. and Bernstein, A. (2004).
Two-phase emission detector for measuring coherent neutrino-nucleus scattering,
IEEE Trans. Nucl. Sci. 51, pp. 2151-2155.

10 kg Ar, 25 m standoff, 3.4 GWt
Signal: estimated after quenching: 1-10 free e-

Monte Carlo Simulation of signal and backgrounds in 10 kg Ar, per day

Signal Rate	**~200 per day (1 or more liquid e-)**
Background Rates	counts/ dy/10 kg
Dominant: 39Ar (sim.; depleted Ar reduces 20x)	1000
External U/Th/K : (sim., after 2 cm Pb shield)	~ 100
External neutrons: (sim. after 10 cm borated poly shield,)	~ 20
Internal gammas: (as measured in XENON10):	~ 50 per day @ 3 keVee; but ~1 Hz of single liquid electrons

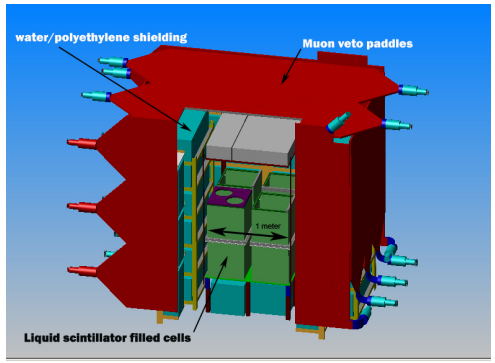


Shield: Inner: 2cm Lead
Outer: 10cm borated polyethylene

Rates in plot and table simulated@ 20 mwe

Flux of reactor antineutrinos:

10^{13} $\overline{\nu}$ / *(cm^2 sec)*



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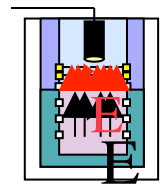


LLNL-SNL Reactor Monitor: 1 Tonne
(San Onofre, Calif.)

2-phase Argon coherent scatter detector : 10 kg
(Proposed)

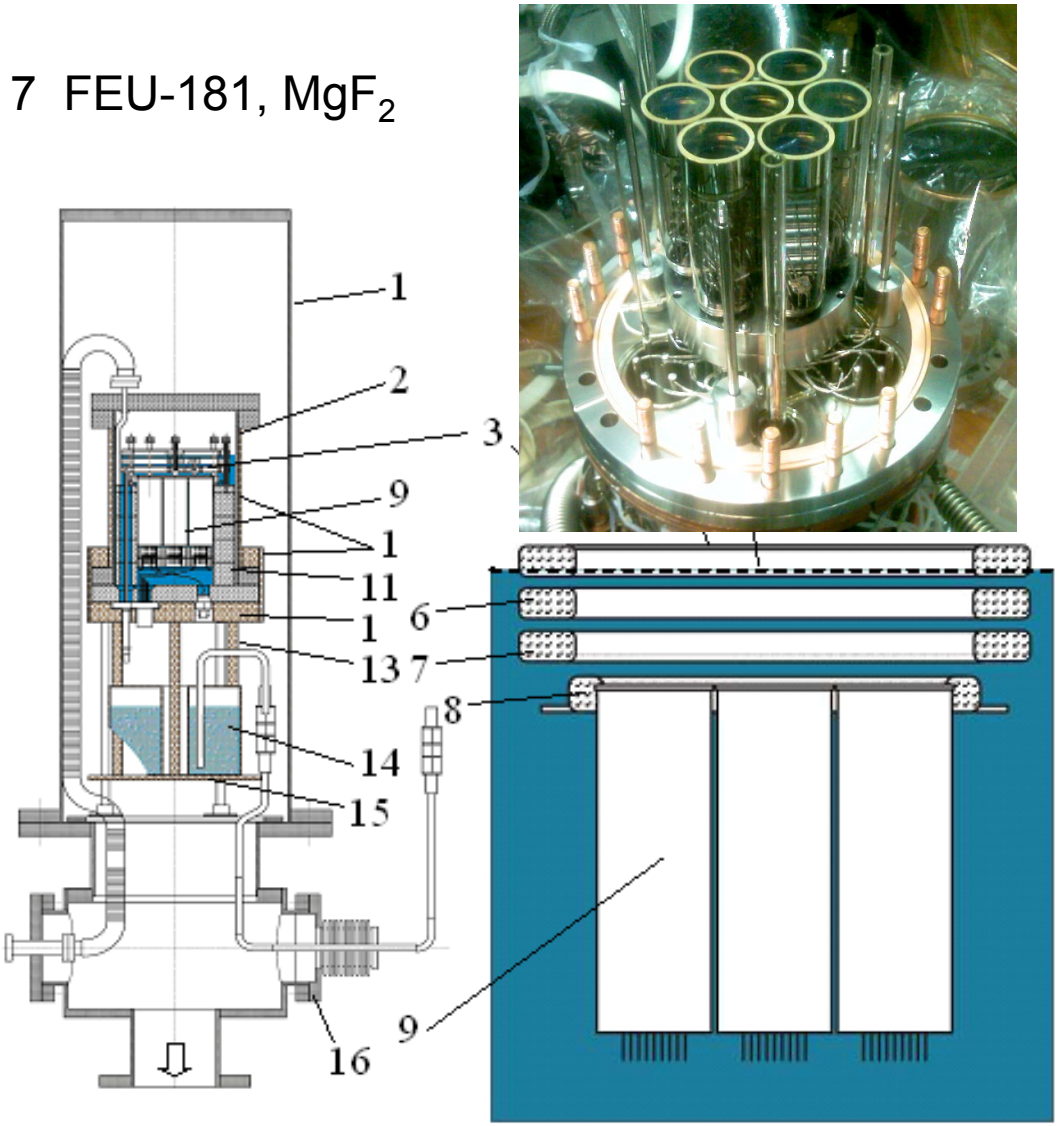
Both detectors would report similar rates

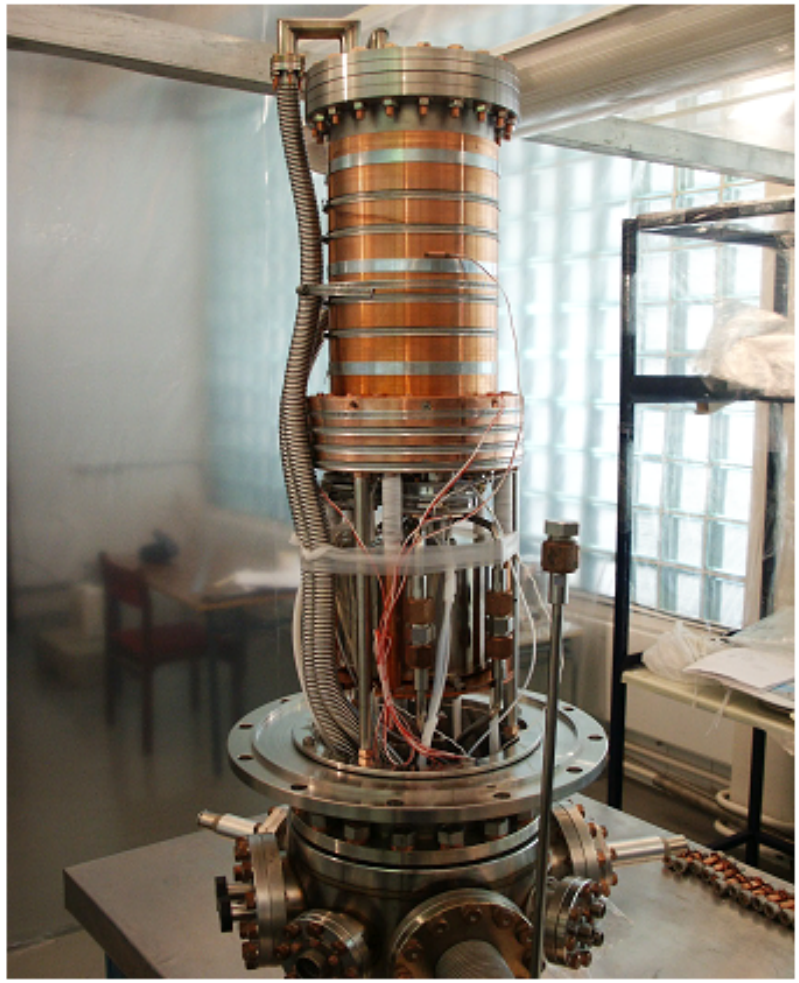
2-phase detector 100 times smaller!

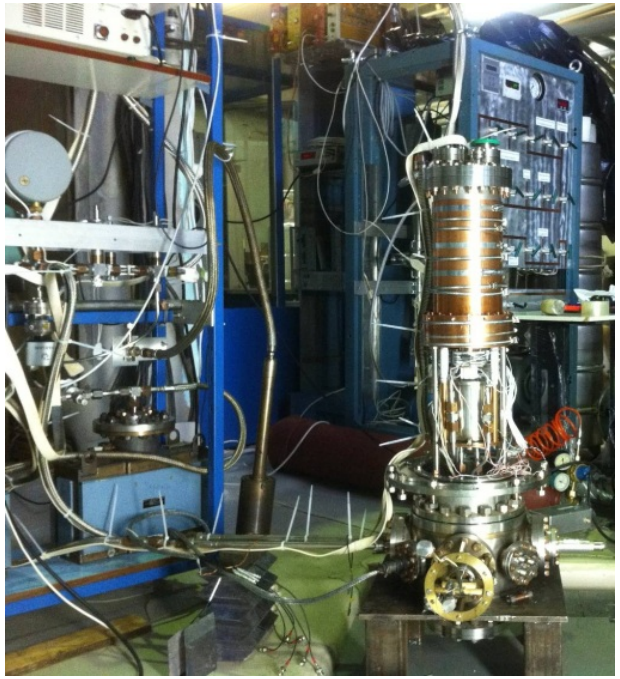
RED-1

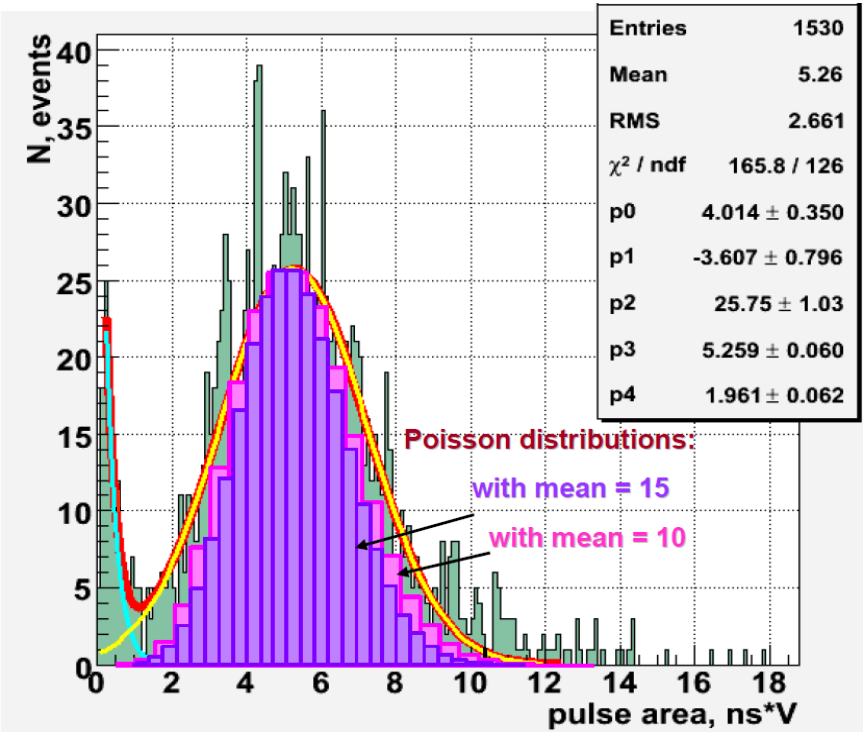
RED-1 @ Research reactor of NRNU MEPhI

7 FEU-181, MgF_2

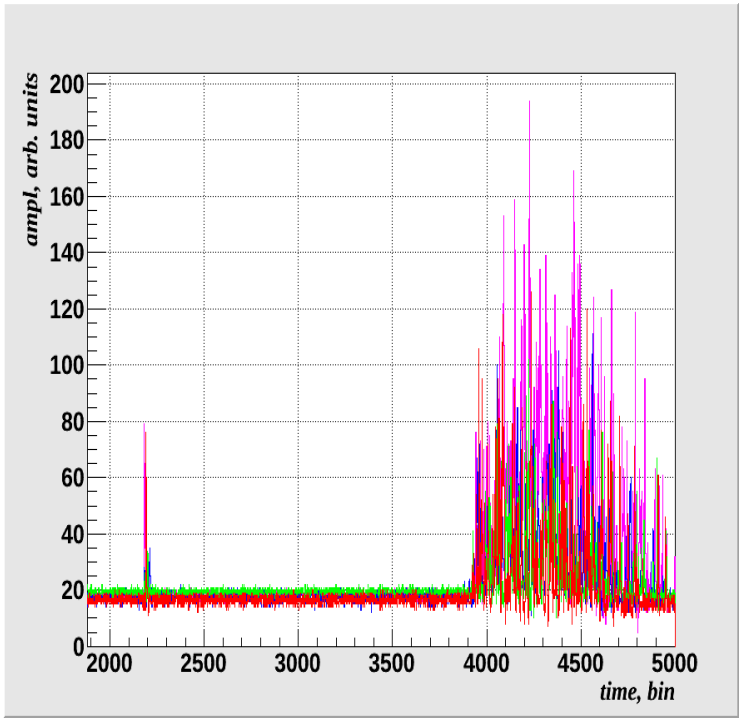








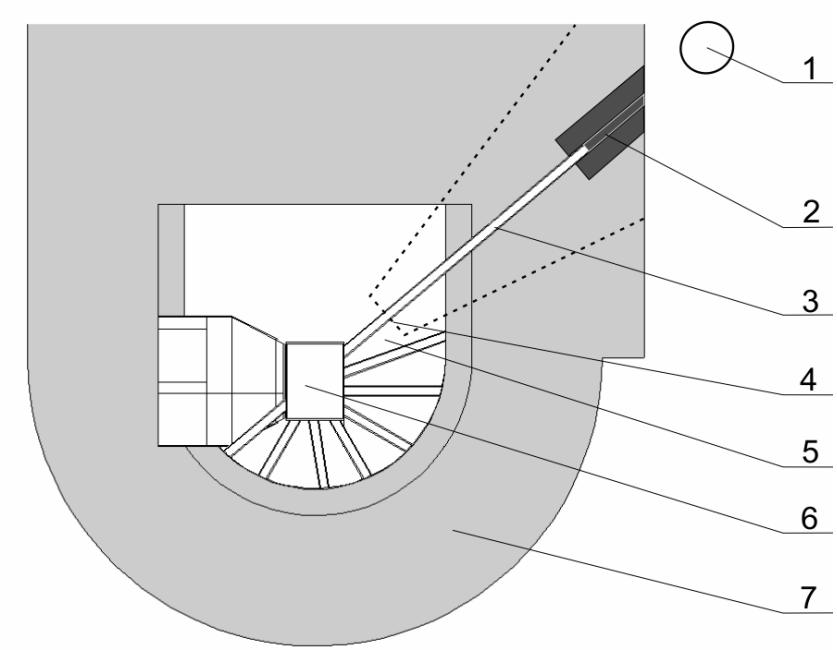
Distribution of EL (S2) signals generated by single emitted electrons (green). Maximum of the Gauss fit is 15 ± 5 photoelectrons.
Poisson distribution for 10 and 15 expectations are shown in pink and violet, respectively.



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.

2.5 MW
Research reactor IRT MEPhI



1 – RED-1

2 – Fe/Al filter

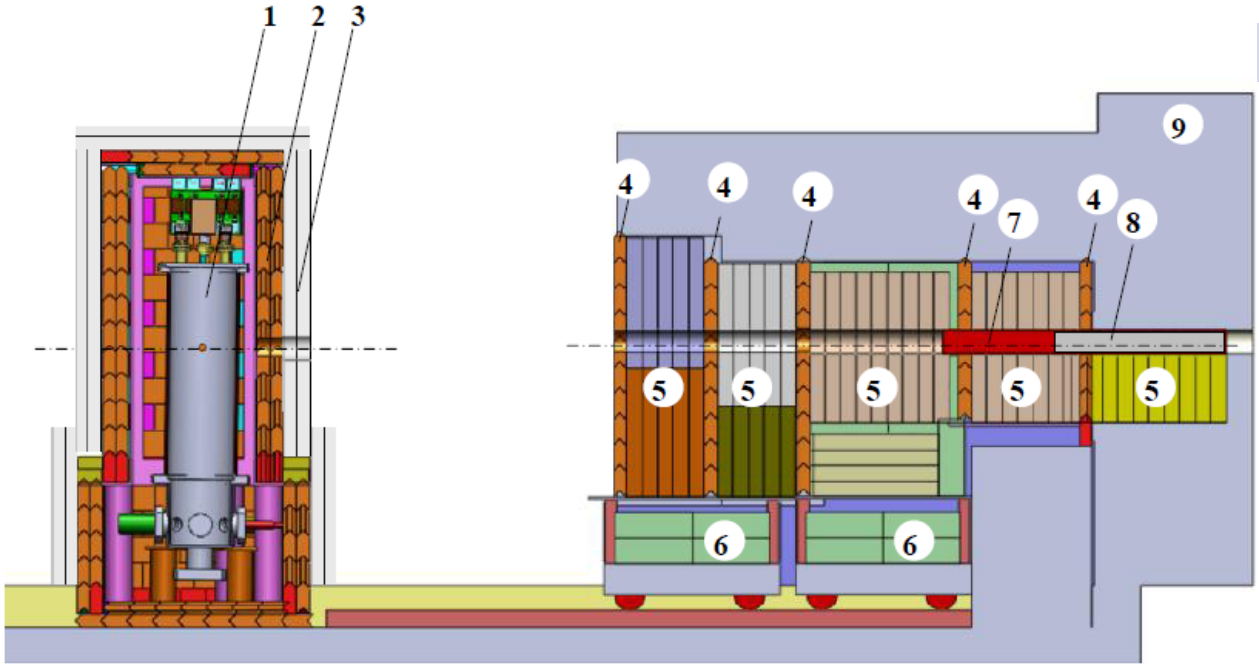
3 – horizontal neutron channel GEK10

4 – starting point of MCNP simulations

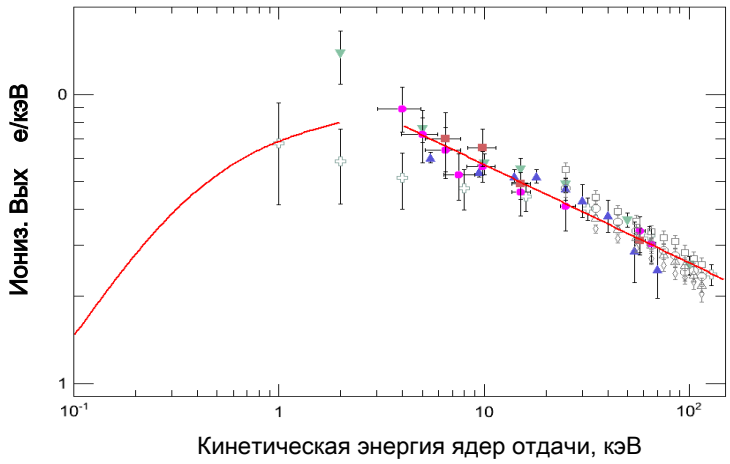
5 – cooling water pool

6 – active zone

7 – heavy concrete shielding

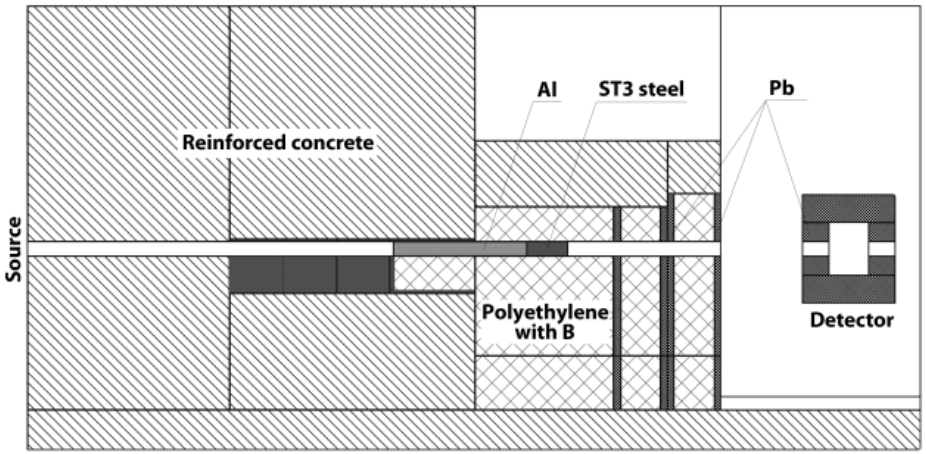


1 – детектор РЭД-1; 2, 3 - защитные слои 10 см свинца и 10 см борированного полиэтилена; 4 - свинцовые слои 5 см; 5 - полиэтиленовые слои 5 см; 6 - парафин; 7,8 – фильтр 30 см Fe и 70 см Al; 9 - бетонная защита реактора.



Удельный ионизационный выход для ядер отдачи с энергией < 1 кэВ неизвестен. Его измерение является основной целью нашего эксперимента на ГЭК-10

Al/Fe filter



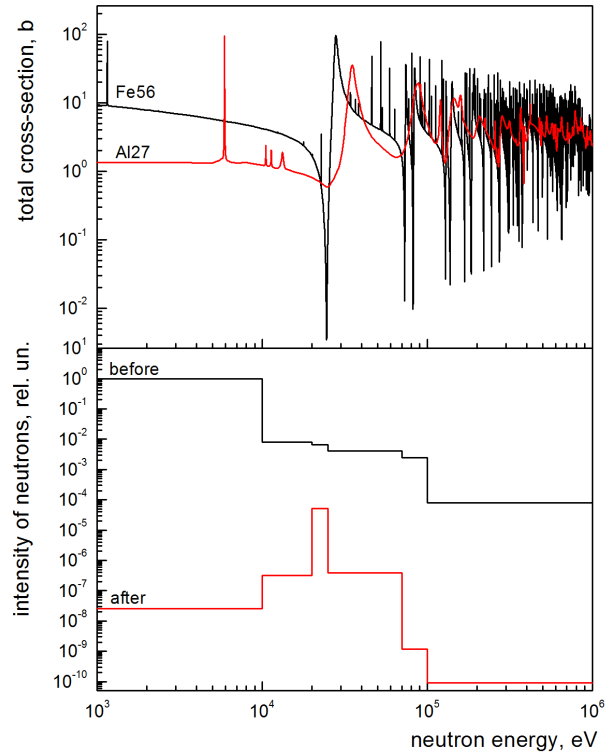
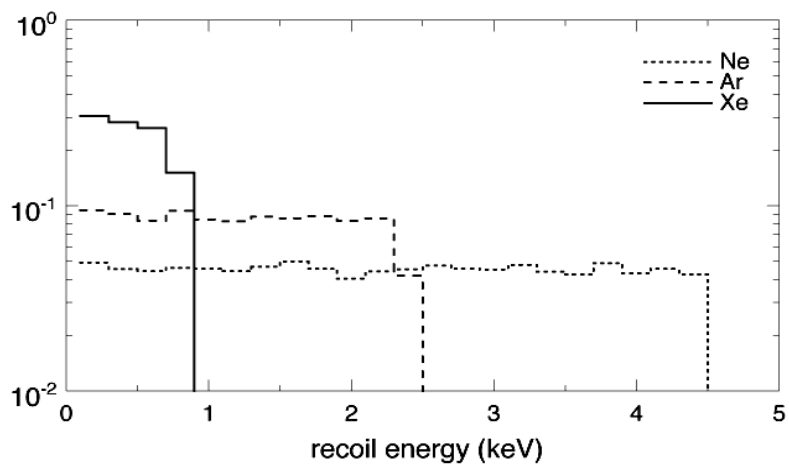
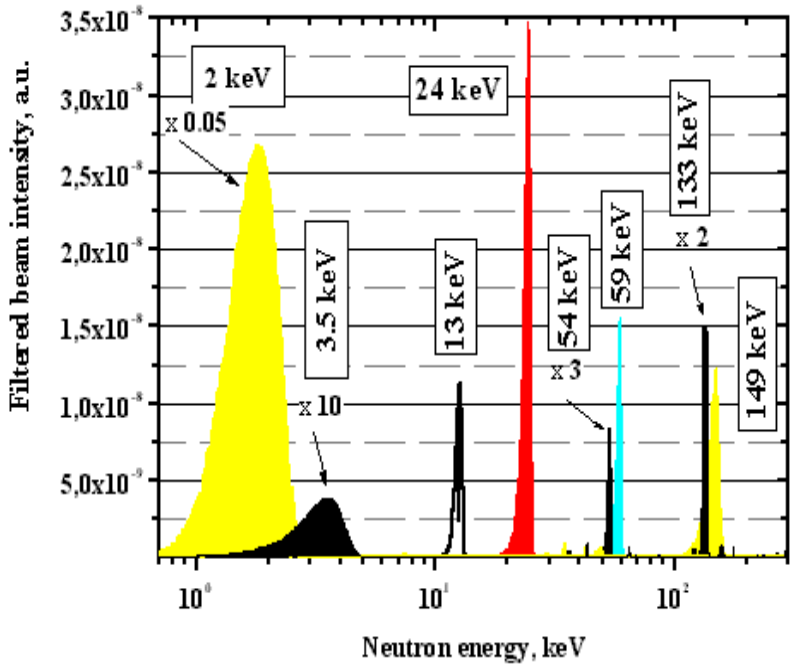


Table 1. Values of signal-to-background ratio

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





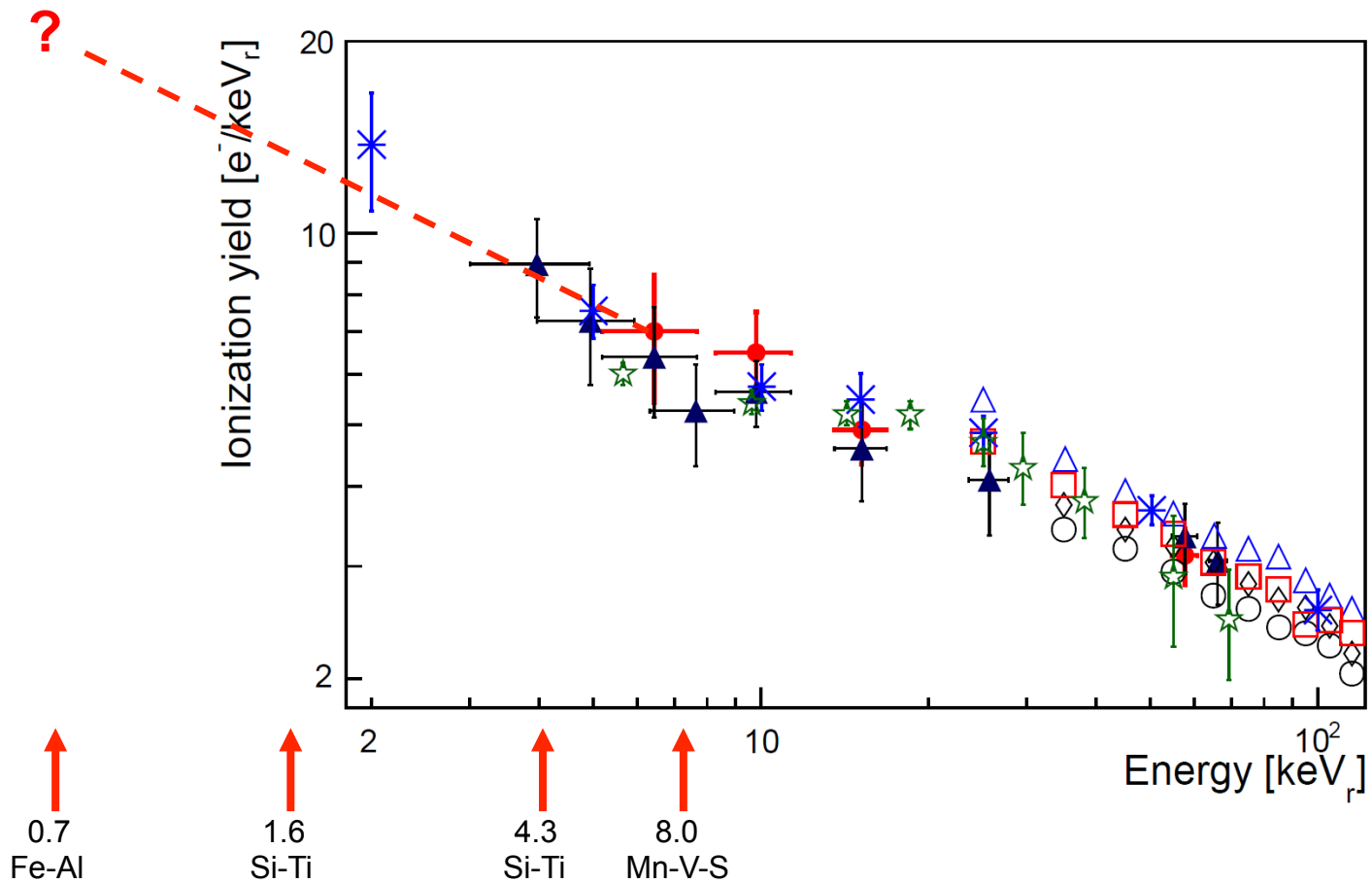
2 ±0.7 keV filter (g/cm²)						
^{10}B (85%)	Sc	^{60}Ni	^{54}Fe	S	^{59}Co	Al
0.2	104.6	80.2	39.35	56.0	26.7	0.54

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

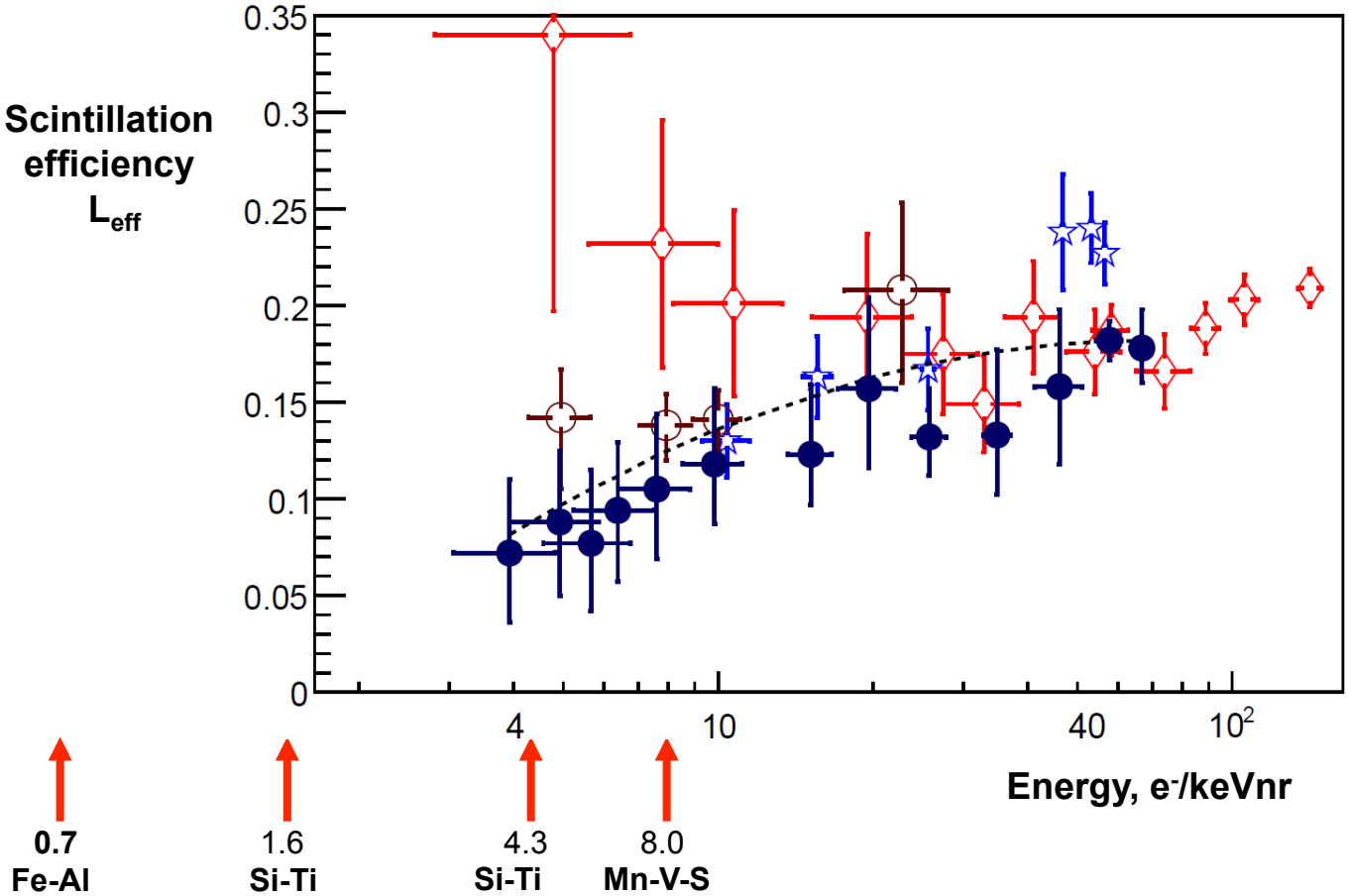
54 ±2 keV filter (g/cm²)			
^{10}B (85%)	Si	S	Al
0.2	144.926	36.7	10.796

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

O.Gritsai, The 3rd International Conference Current Problems in Nuclear Physics and Atomic Energy (NPAE-Kyiv2010) 7 -12 June, 2010, Kyiv, Ukraine



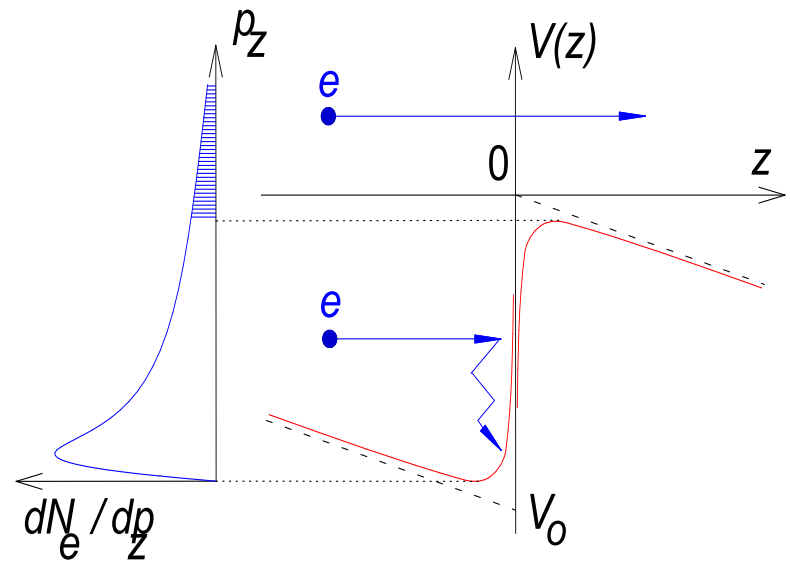
Ionization yield of liquid xenon for nuclear recoils and transmission maximum of interference neutron filters marked with red arrows



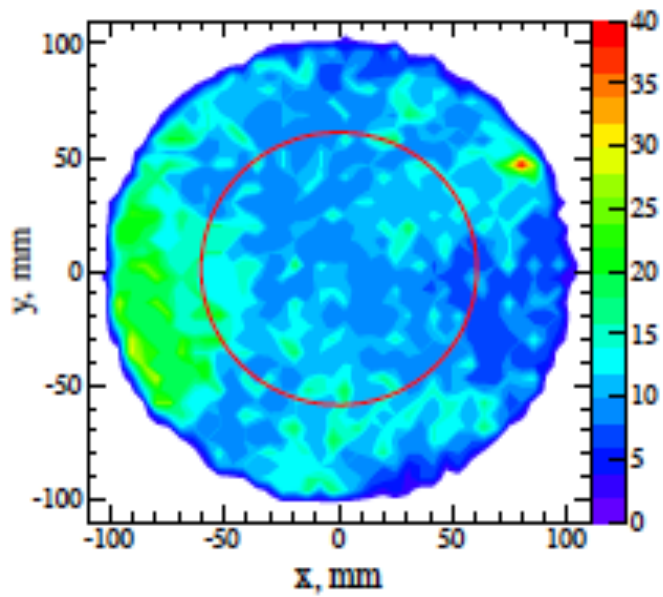
Relative scintillation efficiency of LXe

Single Electron Noise

Observation of single electron noise



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



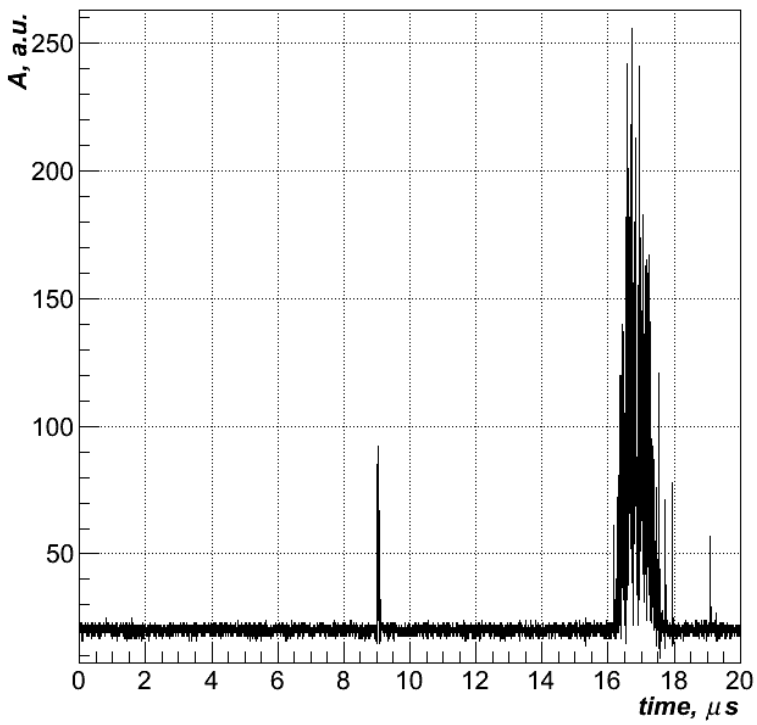
SE background rate:

- **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 count rate could be reduced by cleaning interface with tangential electric field**

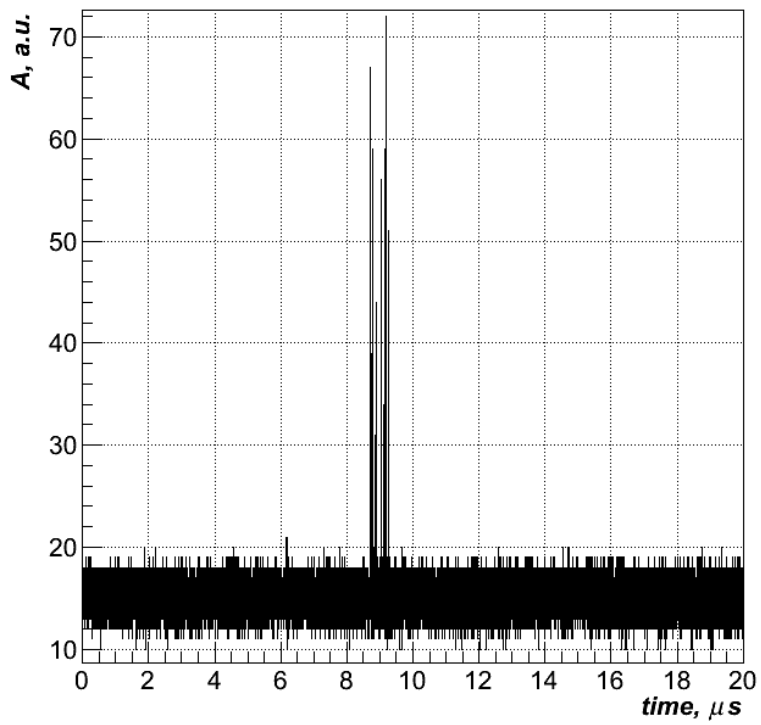
x-y positions of single electron events in a 12 kg emission LXe detector ZEPLIN-III installed in the underground lab

Santos – arxiv 1110.3056v1

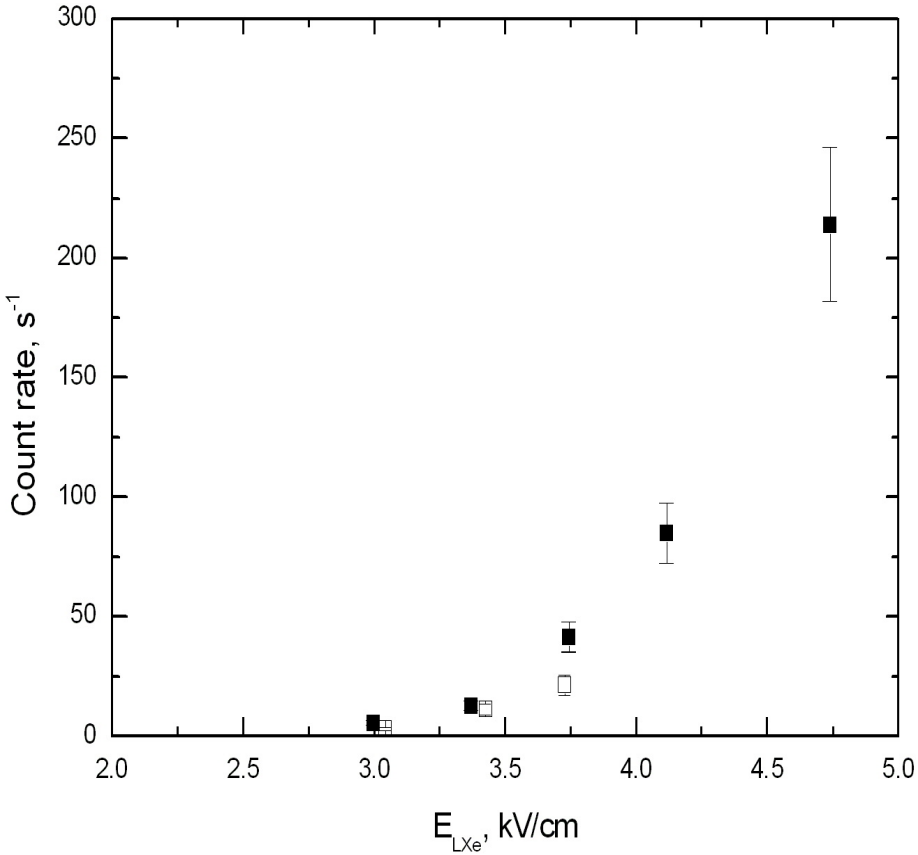
Waveforms associated with gamma ray (a) and single electron emission (b) acquired from the RED1 detector



(a)

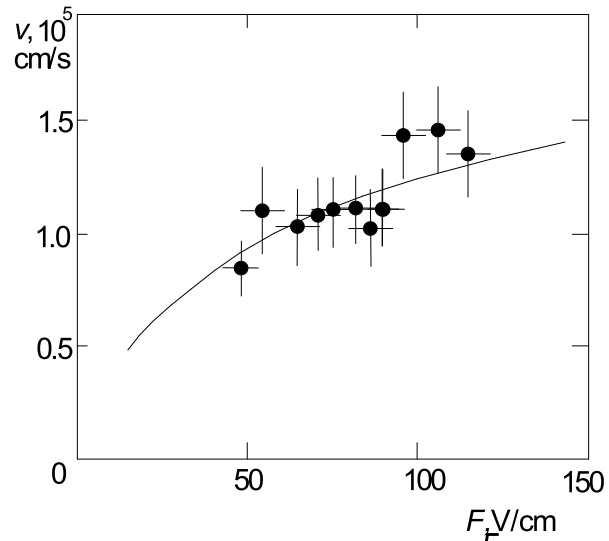


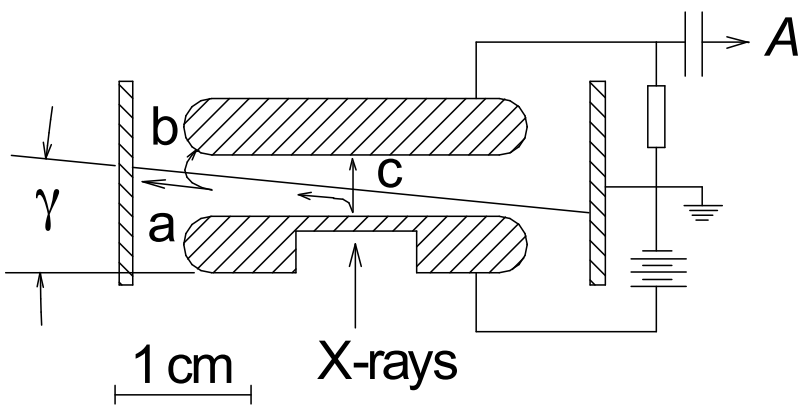
(b)

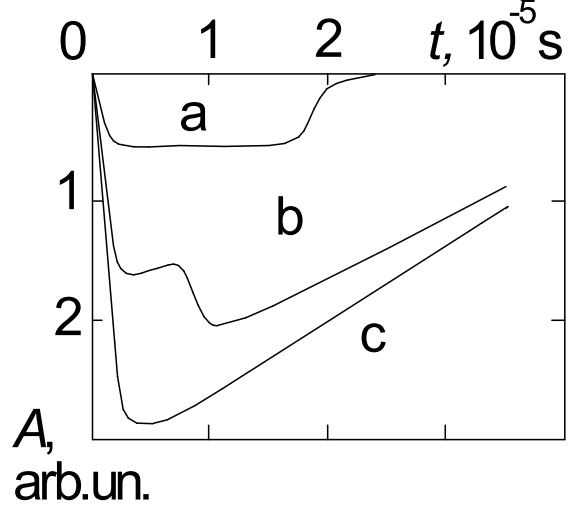


Typical single-electron noise count rate associated with a natural radioactive background measured in RED1.

E_t - cleaning the interface



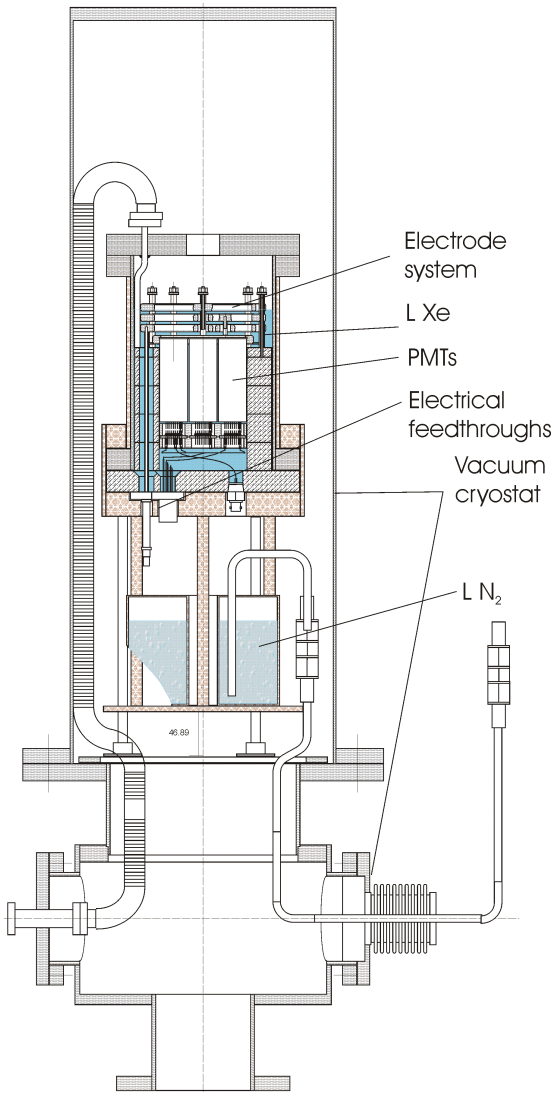




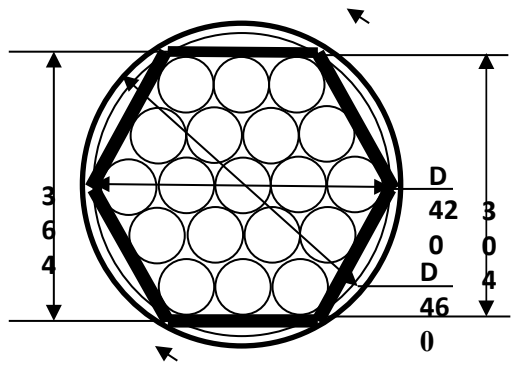
С. Анисимов и др.,Письма в ЖЭТФ, 40 (1984) 829-832

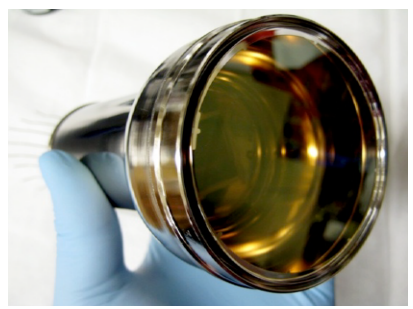
RED-100

RED-1

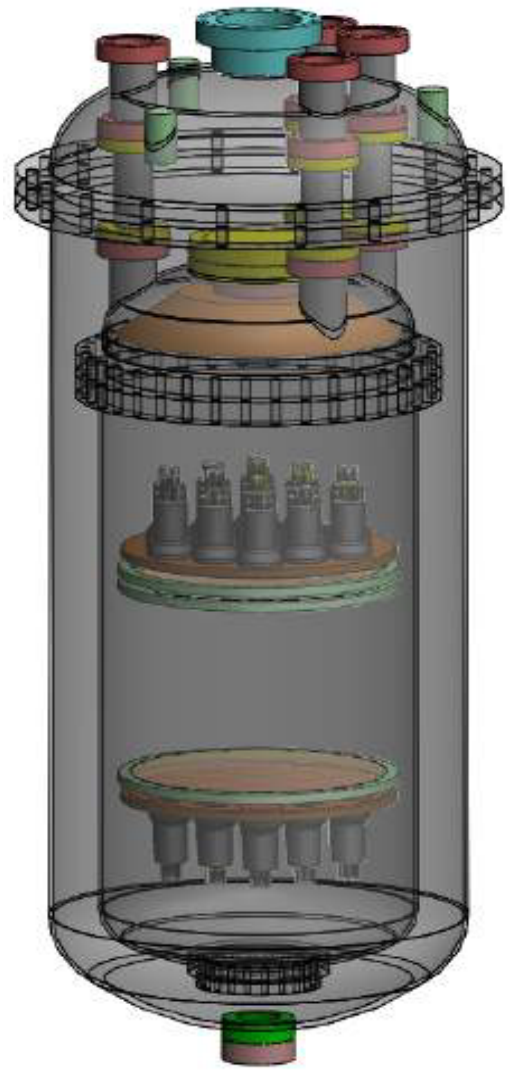


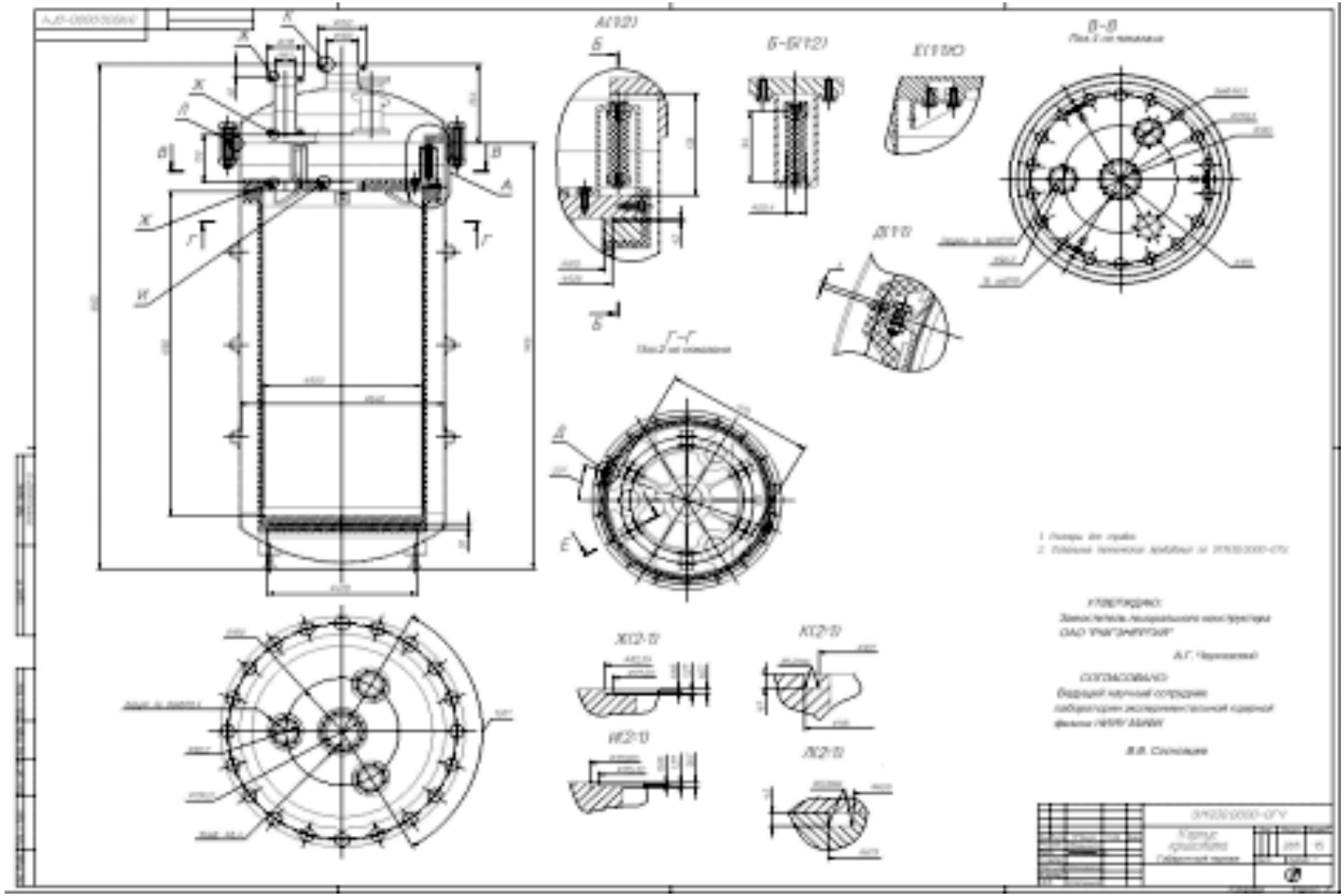
RED-100



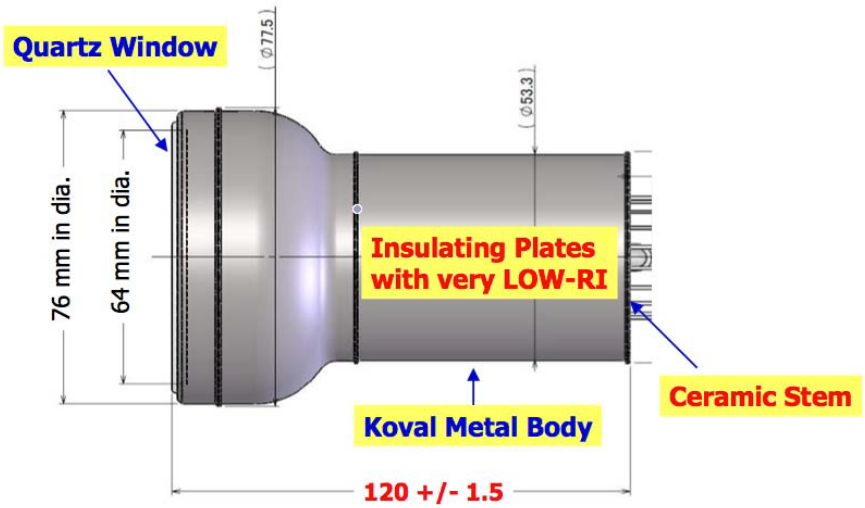


Hamamatsu R11410





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



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

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, mBq/kg	2	1	4	1	0.5

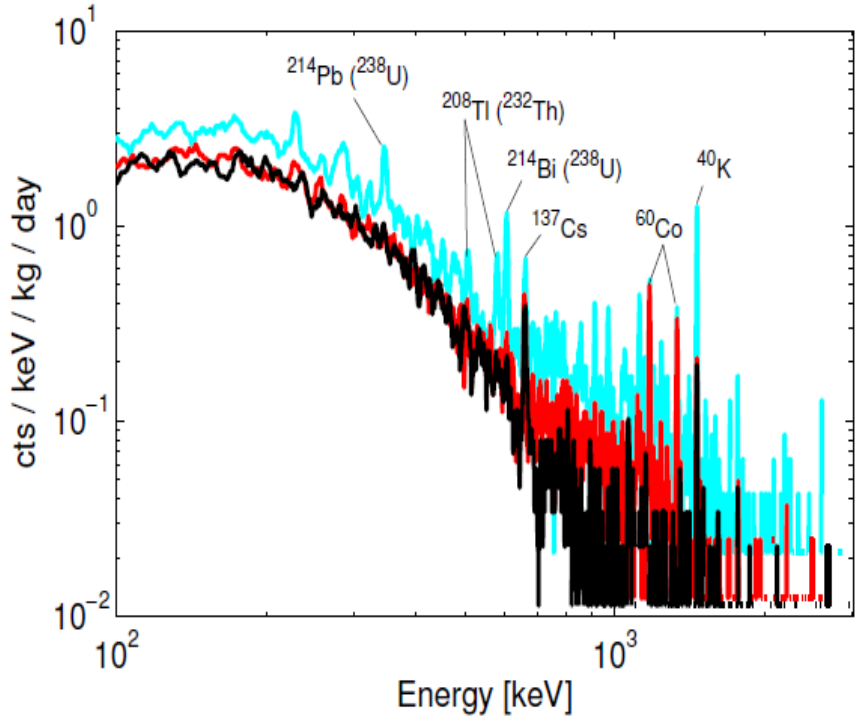
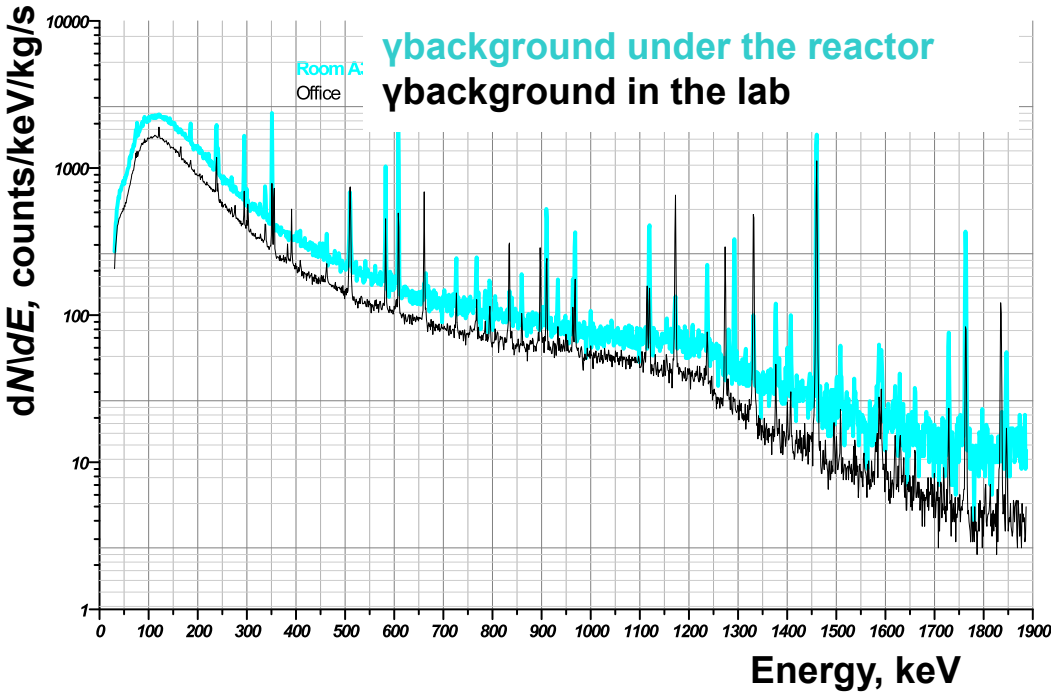
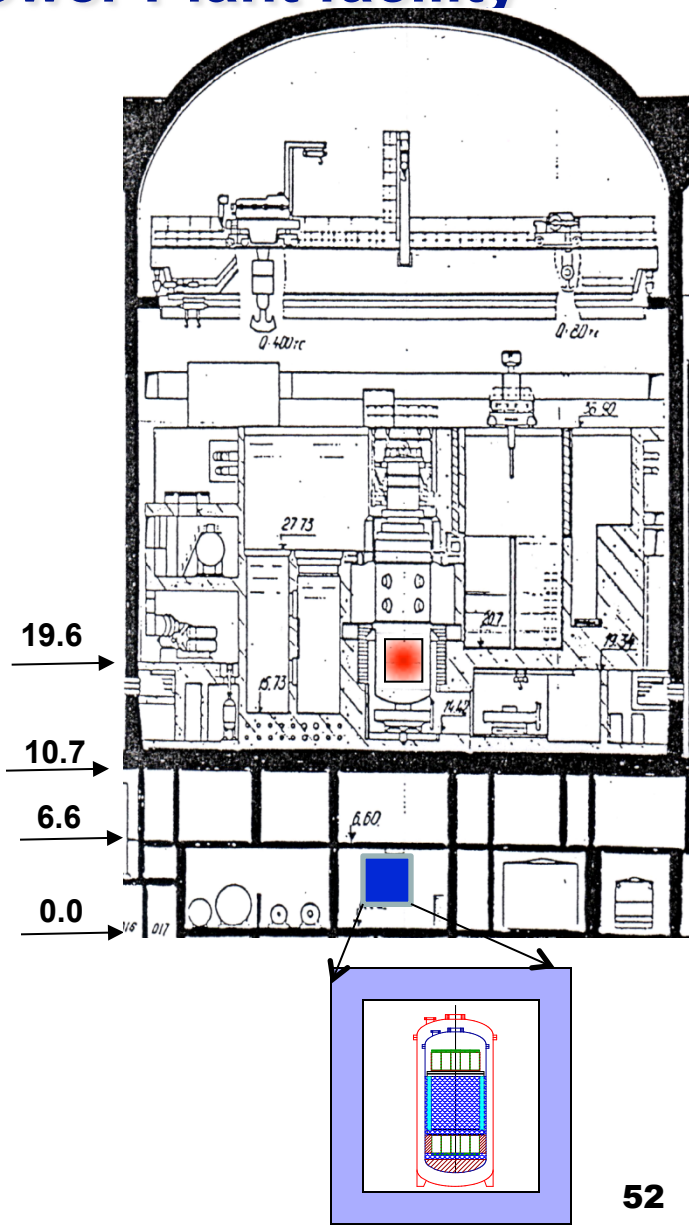


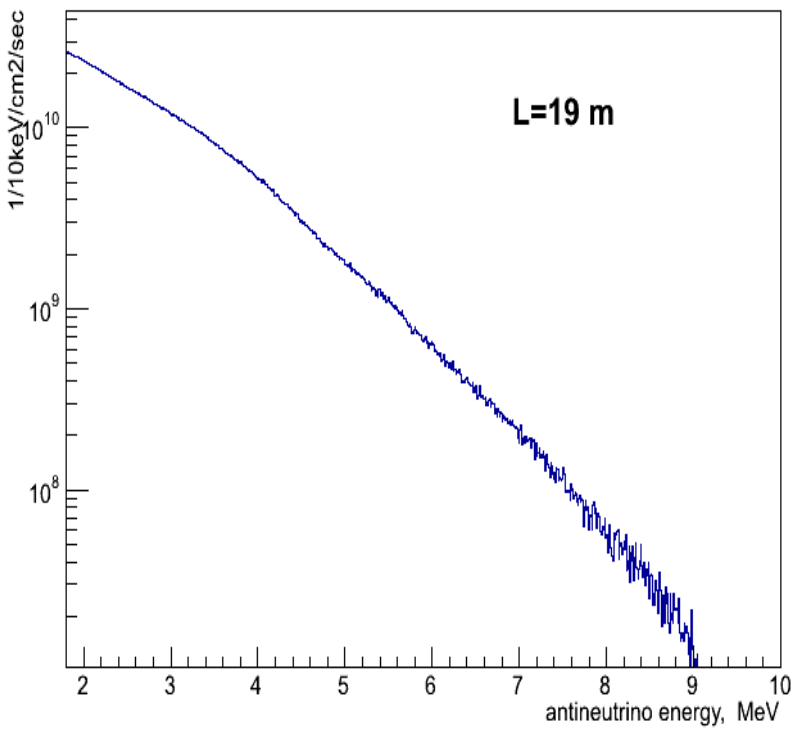
Figure 3. SOLO counting spectra for R8778 (14 live days, blue) and R11410 MOD (19 live days, red) PMTs, superimposed with a sample background run (21 live days, black). Strong lines in the R8778 spectrum indicate the presence of ^{238}U, ^{232}Th, ^{40}K and ^{60}Co. The reduced activity of the R11410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

RED-100 @ the Kalinin Nuclear Power Plant facility

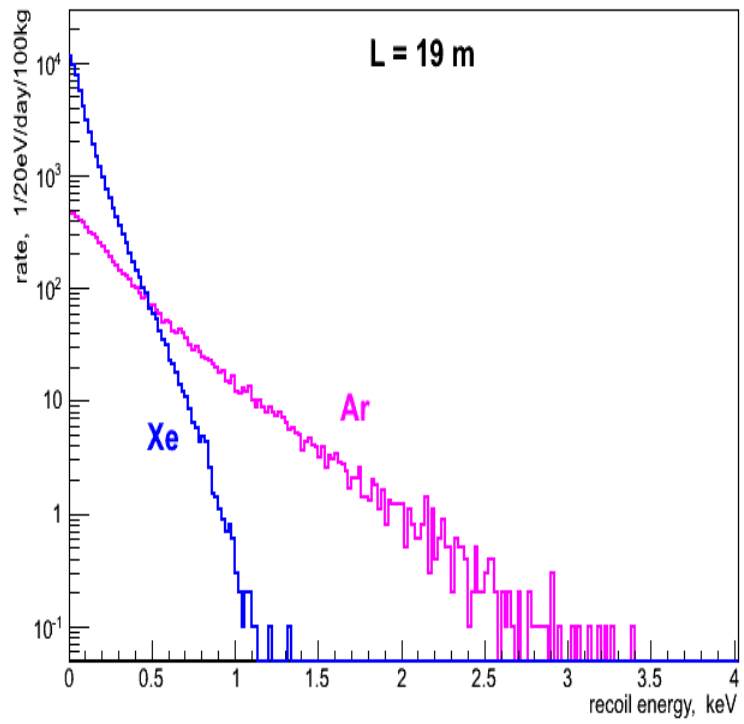




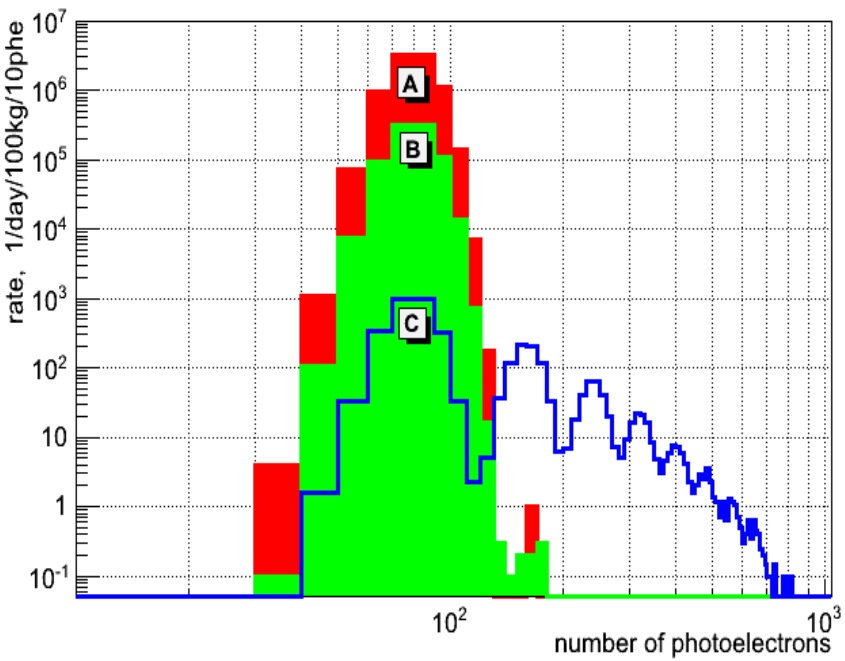
Antineutrino Spectrum

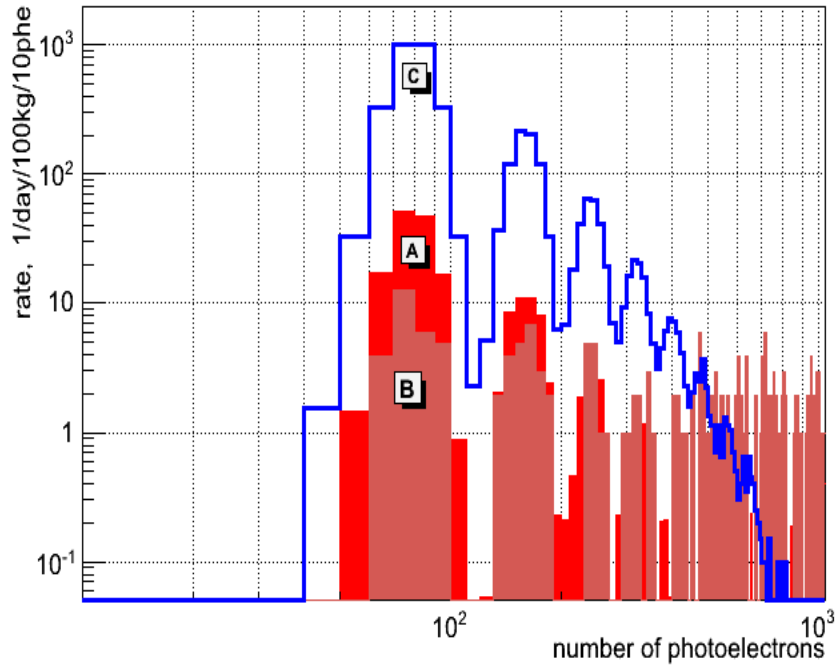


Count Rate



Kalinin' NPP facility: $\Phi_{antineutrino}$ = 1.35*10^{13} cm^{-2}s^{-1}





Signal/Noise

A: f_{SEE}=100Hz

B: f_{SEE}=10Hz

C: Signal

CR (>3 phe) = 433/day/100 kg LXe

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

Signal/Background

A: detector components

B: neutrons

C: Signal

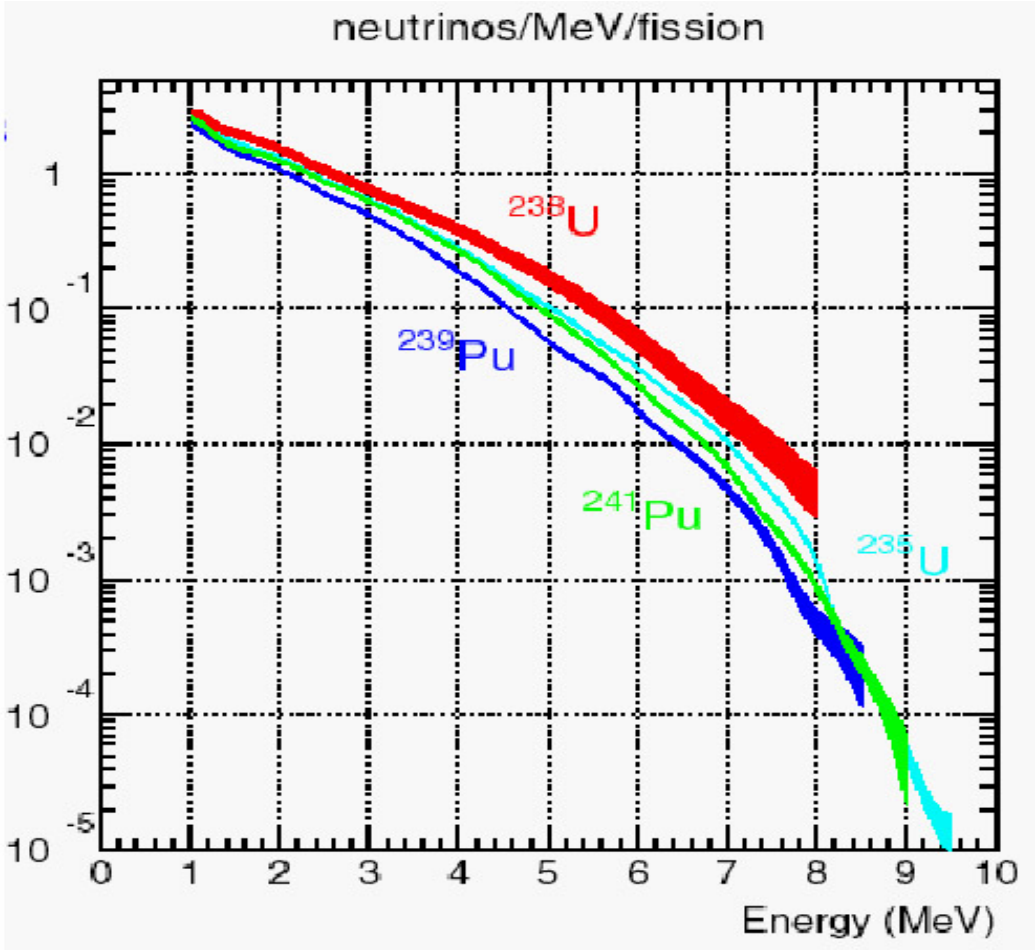
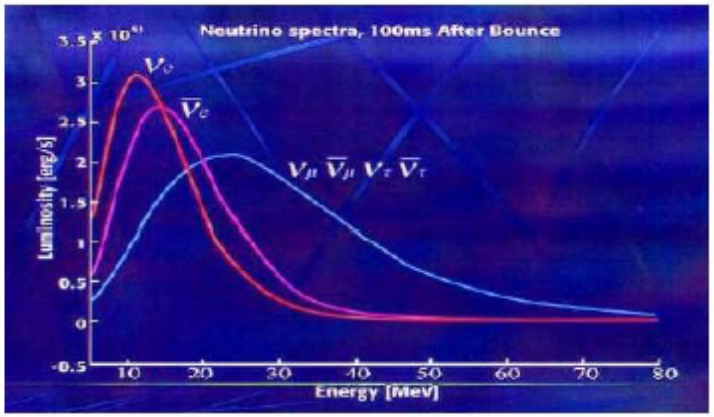
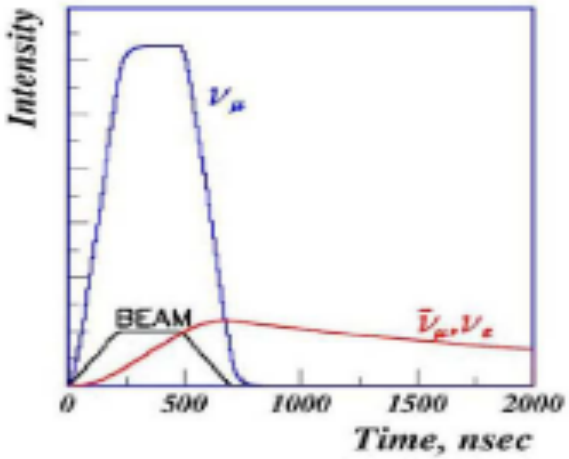


Fig. 4.2. Neutrino spectra from fission of ^{235}U, ^{239}Pu, ^{241}Pu (measured), and ^{238}U (calculated).

Experiment at the SNS facility



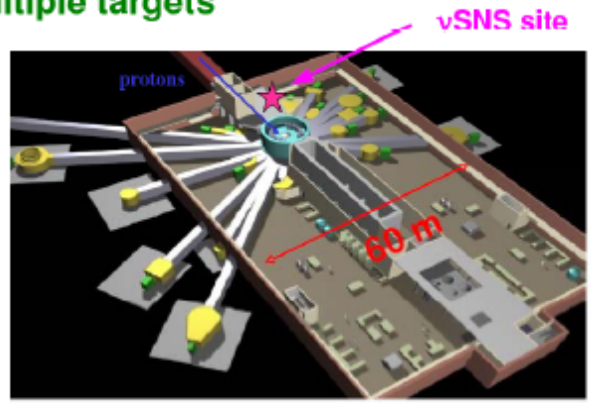


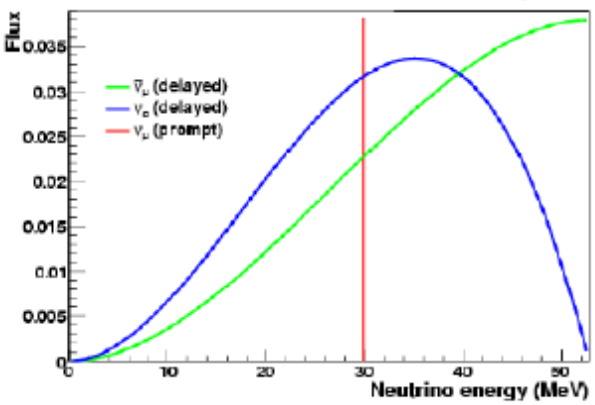
NuSNS (Neutrinos at the SNS)

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

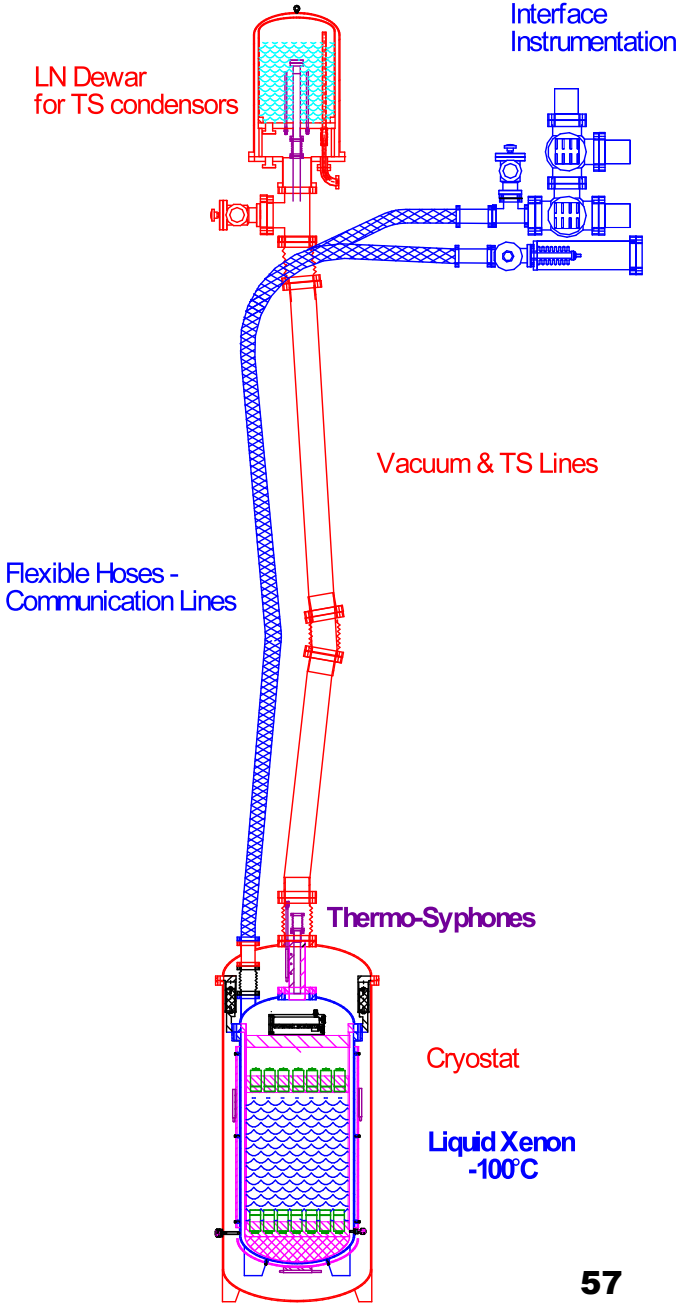
$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$ — 3-body decay: range of energies between 0 and $m_\mu/2$ DELAYED (2.2 μs)

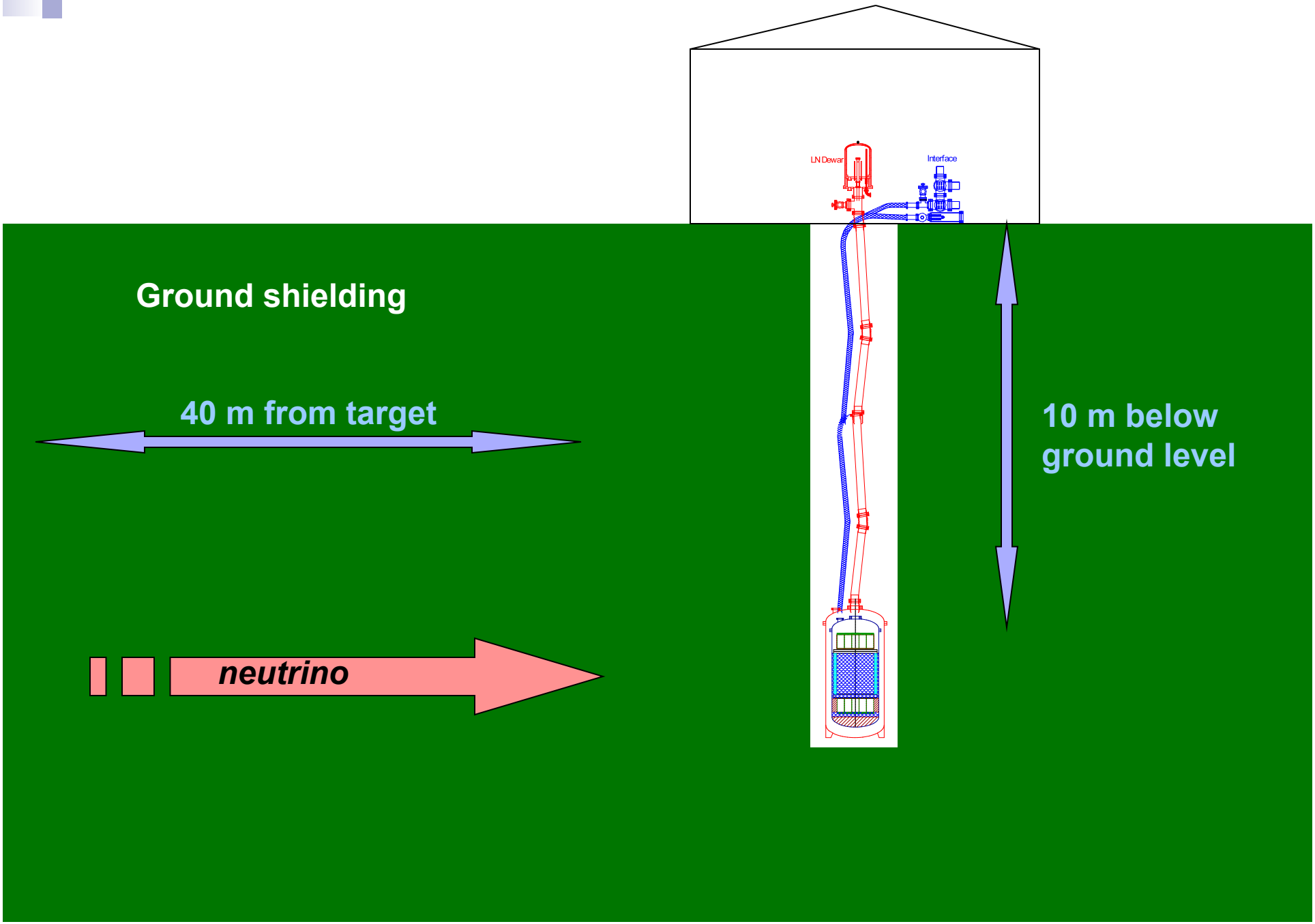
A neutrino facility with capability to measure multiple targets



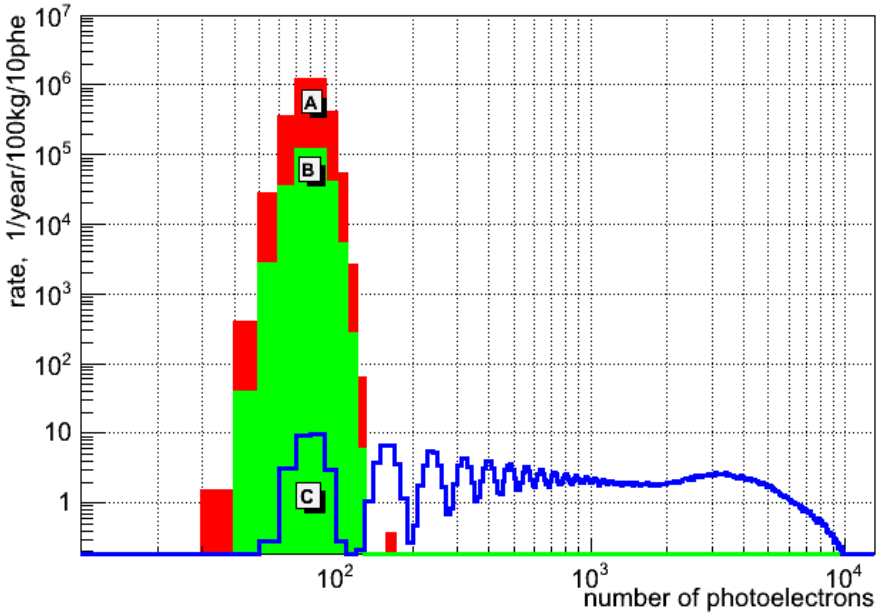


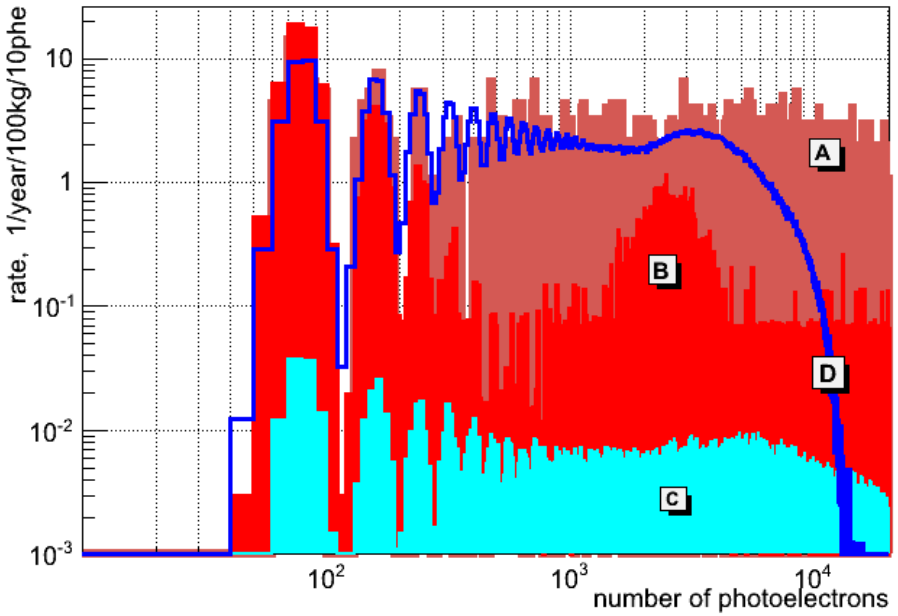
Well-logging RED100 detector




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

A: f_{SEE}=100Hz

B: f_{SEE}=10Hz

C: Signal

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

Signal/Background

A: Neutrons from cosmic rays

B: Components of RED100

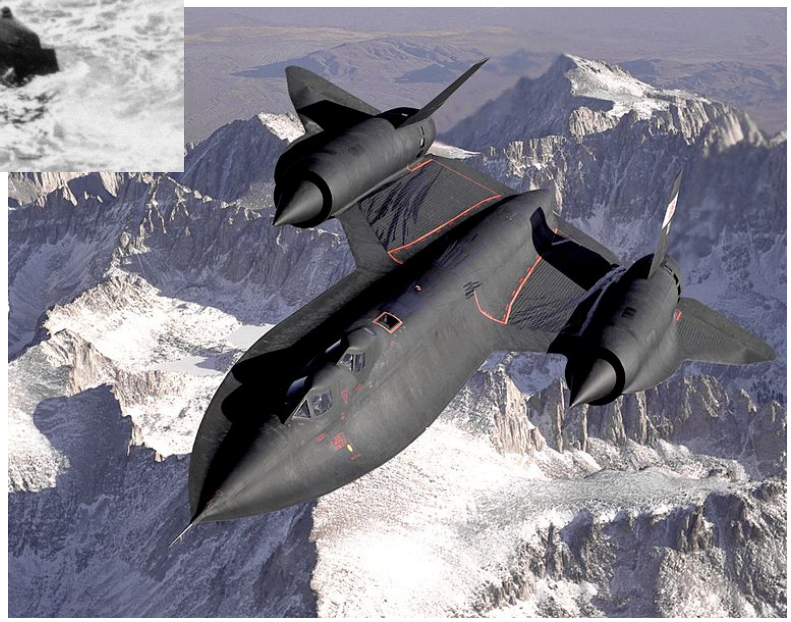
C: Neutrons from SNS

D: Signal

Conclusion

- ***Emission two-phase detectors*** are promising technology for detecting and investigation of Coherent Neutrino Scattering
- ***CNS*** is interesting for basic science and possibly for non-proliferation applications
- ***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 to low-ionization events
- Recently established experimental facilities allow development of LXe emission detectors for observation of CNS

Russian Titanium

"Komsomolets" submarine ("Mike")

SR-71B ("Black Bird")