NATIONAL RESEARCH NUCLEAR UNIVERSITY MEPhI
(Moscow Engineering Physics Institute)

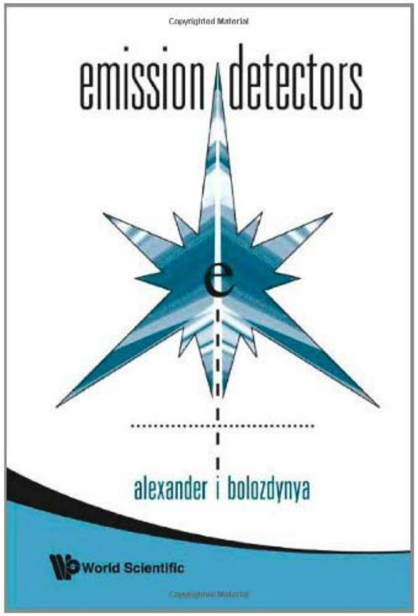
Laboratory for Experimental Nuclear Physics
http://enpl.mephi.ru/

Александр Болоздыня

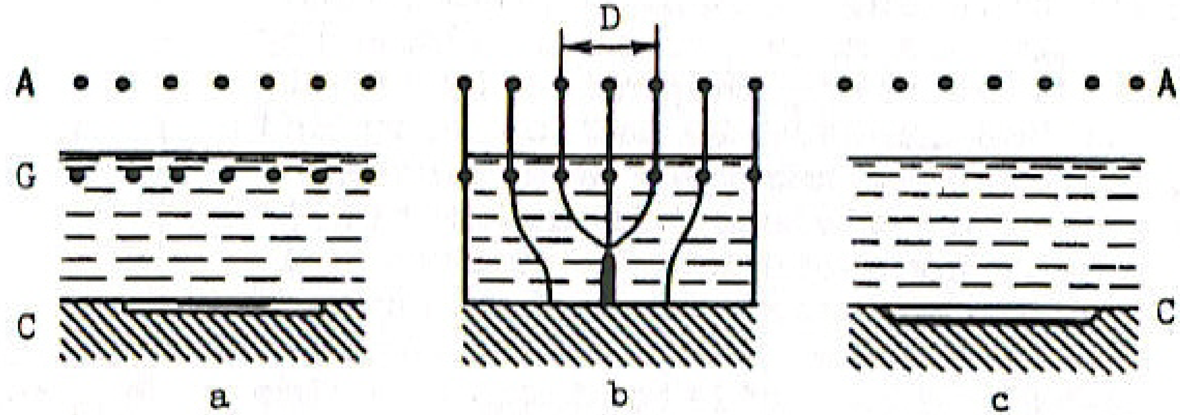
Эмиссионный детектор РЭД100 для наблюдения когерентного рассеяния нейтрино на ядрах Xe

5 декабря 2016 г.
ИЯИ РАН
Троицк

ANCIENT HISTORY
OF EMISSION DETECTORS

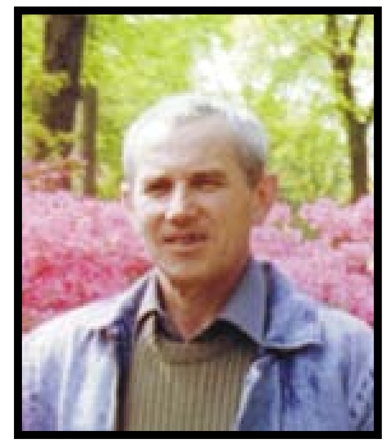


1969-70 MEPhI: Two-phase emission detection principle



Boris Dolgoshein

Boris Rodionov

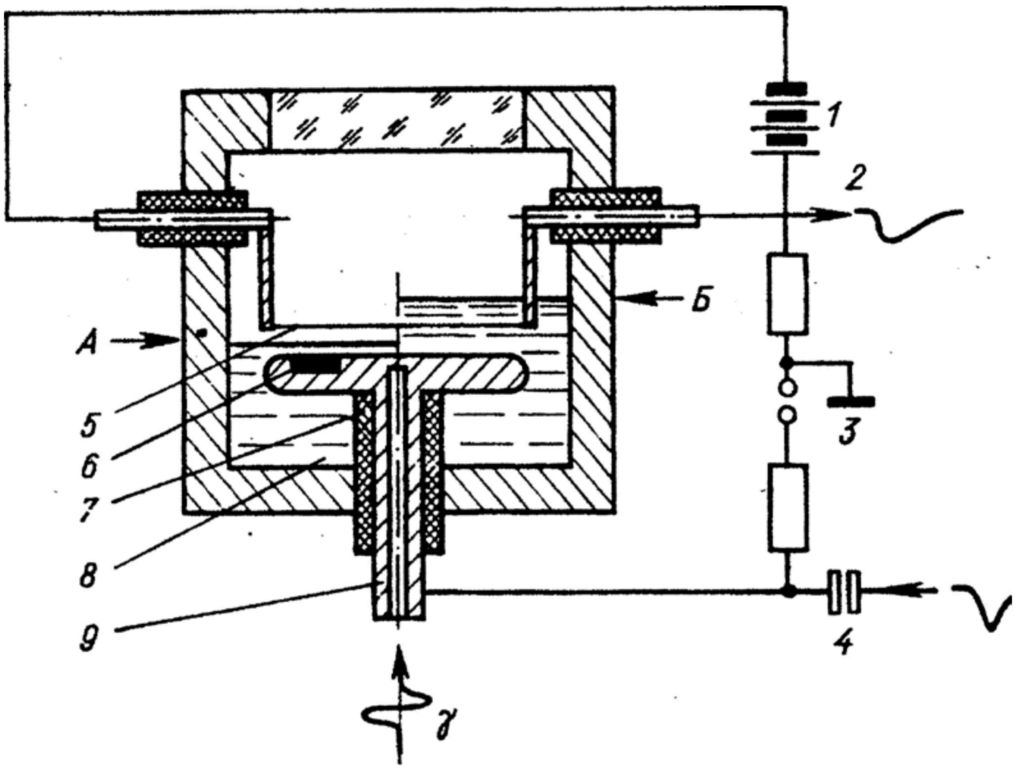


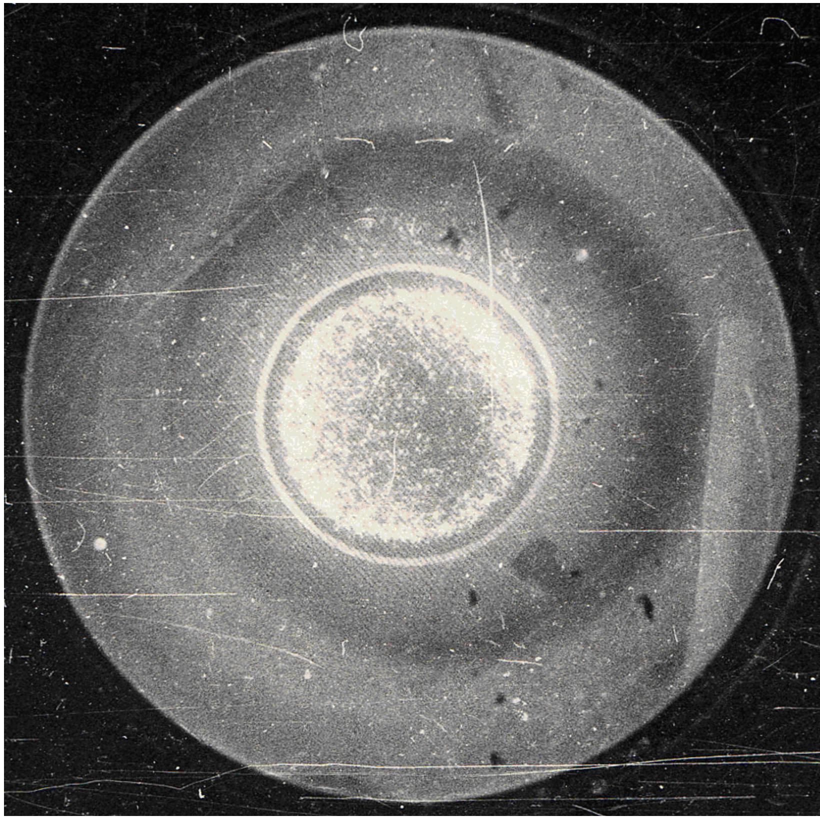
Vadim Lebedenko

Долгошеин Б.А., Лебеденко В.Н. и Родионов Б.У. Новый метод регистрации треков ионизирующих частиц в конденсированном веществе, Письма в ЖЭТФ, 1970, т.11, стр. 351-353.

Hutchinson G. W. (1948). Ionization in liquid and solid argon, *Nature*, 162, pp. 610-611.

1970-73 MEPhI: LAr Emission Spark Chamber

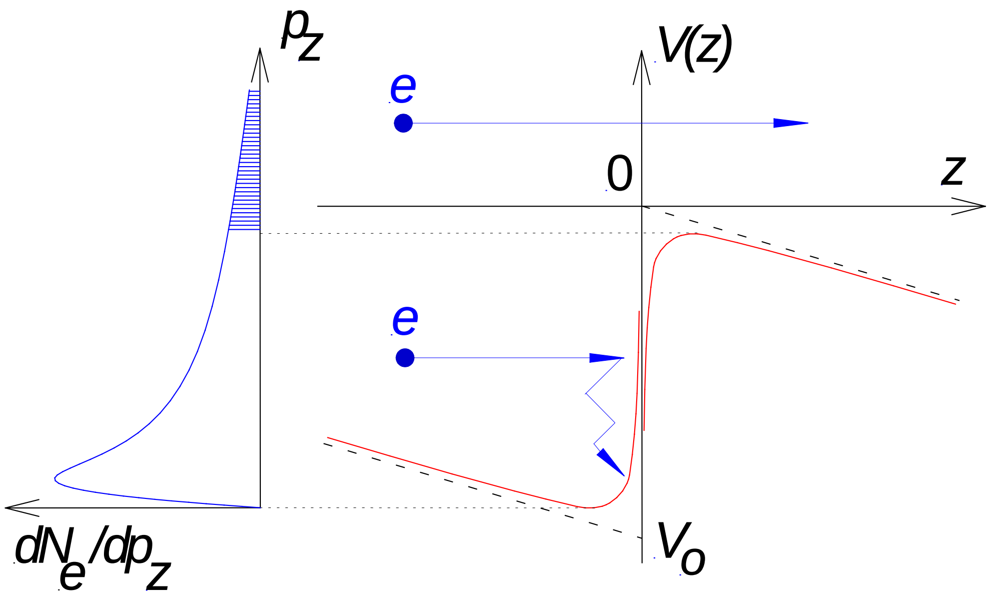


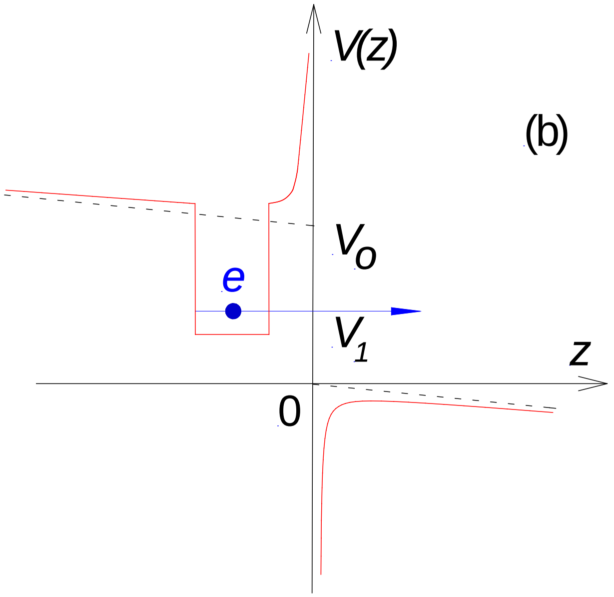


B.A. Dolgoshein, V.N. Lebedenko, B.U. Rodionov. JETP Lett. 11 (1970)513-516

B.A. Dolgoshein, A.A. Kruglov, V.N. Lebedenko, V.P. Miroshnichenko, B.U. Rodionov.
Physics of Elementary Particles and Atomic Nuclei (in Russian) 4(1973)167-186

Electron emission from nonpolar dielectrics



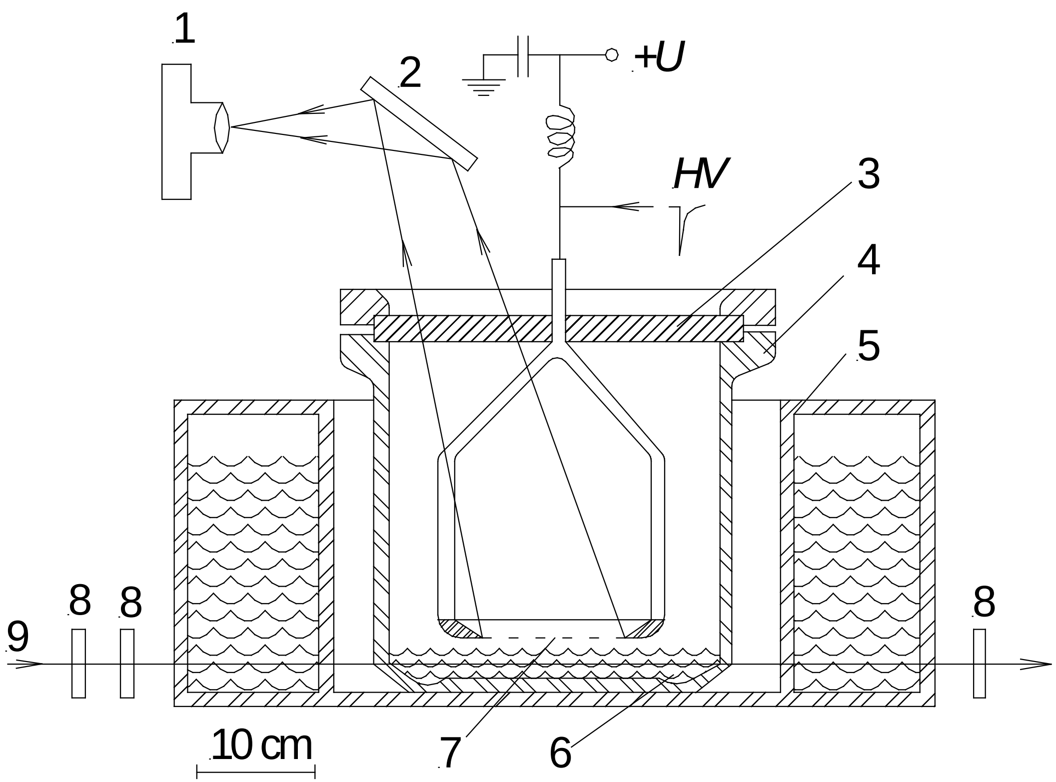


$$V_1(z) = V_0 - eF_1 z + eA_1, z < 0$$

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

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

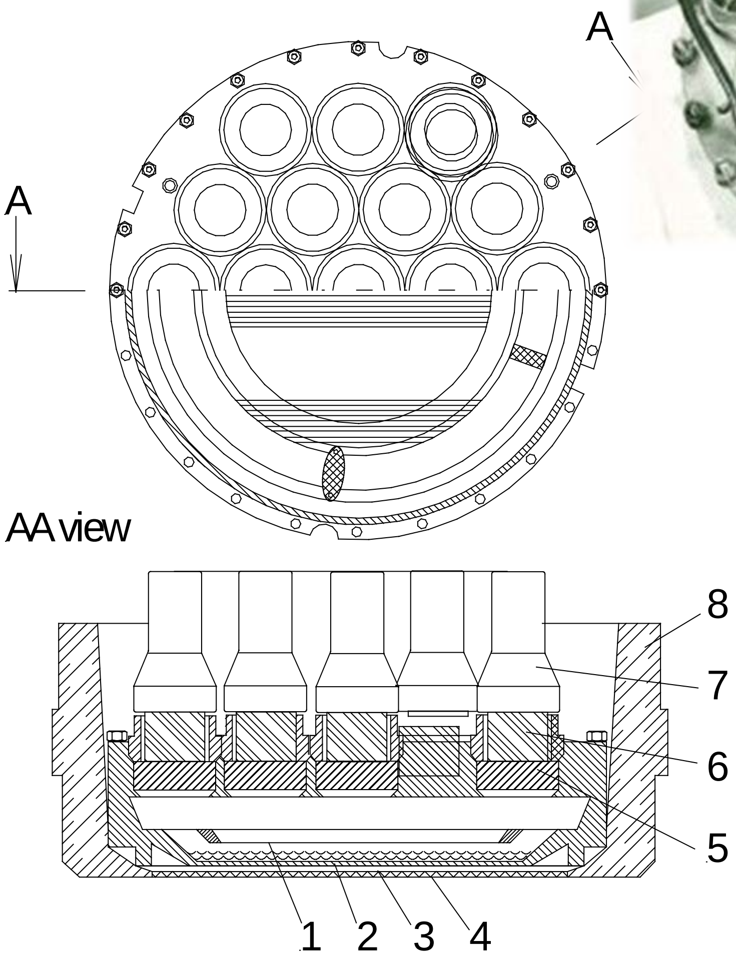
1977-1979 MEPhI-ITEP: SKr emission streamer chamber

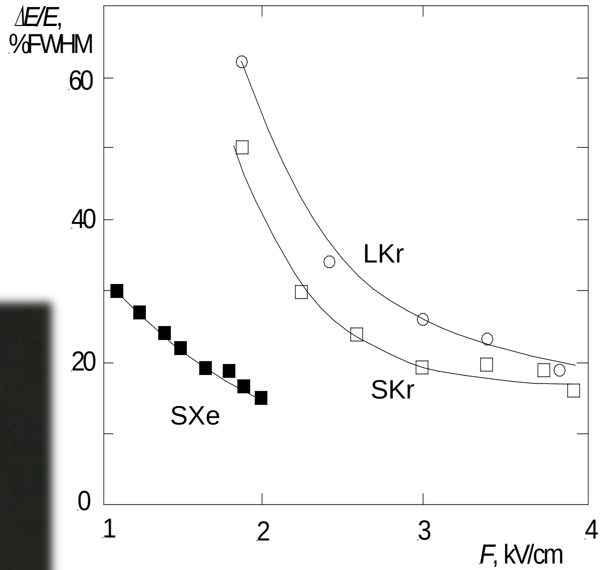


Bolozdynya, A.I.; Egorov, O.K.; Korshunov, A.A., Sokolov, L.I., Miroshnichenko, V.P., and Rodionov, B.U. (1977). The first observations of particle tracks in condesed matter obtained by the emission method, *Pis'ma Zhurnal Eksp. Teor. Fiz., 25*, pp. 401-404 (in Russian).

Bolozdynya, A. I., Egorov, O. K., Miroshnichenko, V. P., Rodinov, B. U. and Shuvalova, E. N. (1980). A new possibility to search for low-ionizing particles, *Elementarnye Chastitsy i Kosmicheskie Luchi,* 5, Moscow: Atomizdat, pp. 65-72 (in Russian).

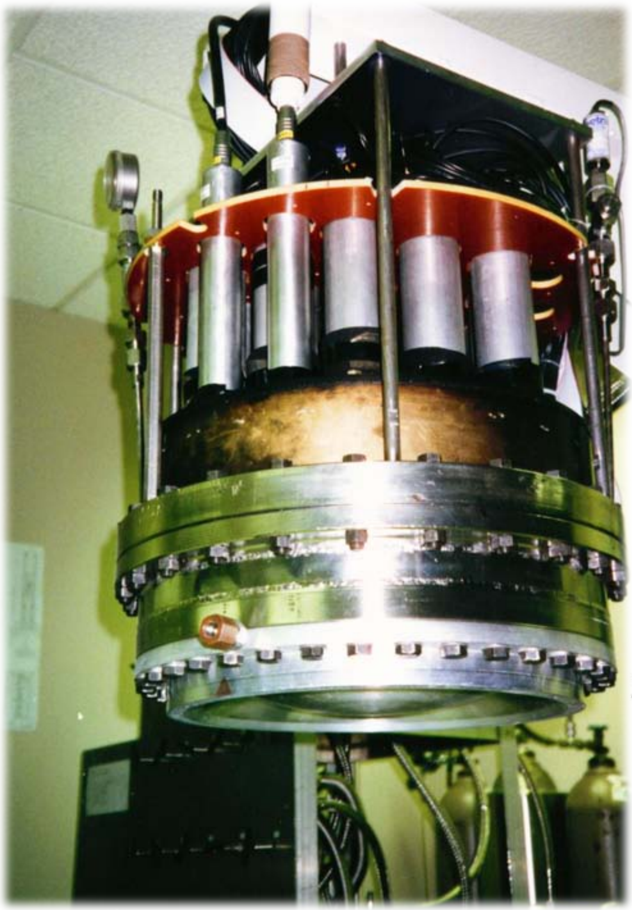
1982-1985 MEPhI-ITEP: 2D SXe emission gamma camera

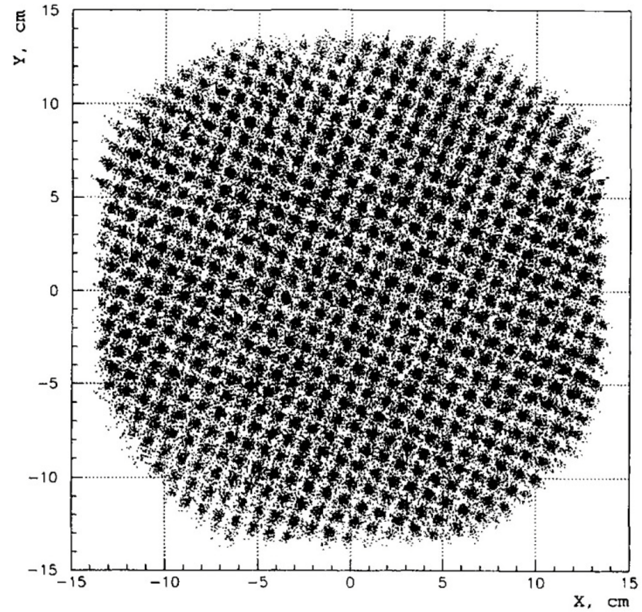


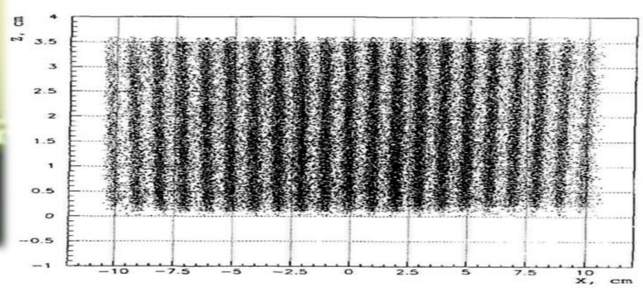


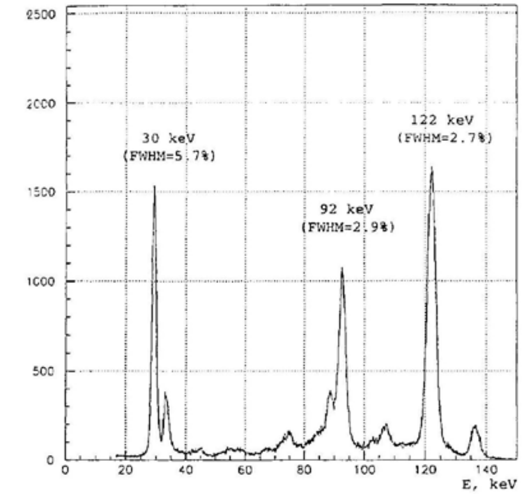
Egorov, V. V., Miroshnichenko, V. P., Rodionov, B. U., Bolozdynya, A. I., Kalashnikov, S. D. and Krivoshein, V. L. Electroluminescence emission gamma-camera, *Nucl. Instrum. Meth.* 1983, v.205, pp. 373-374.

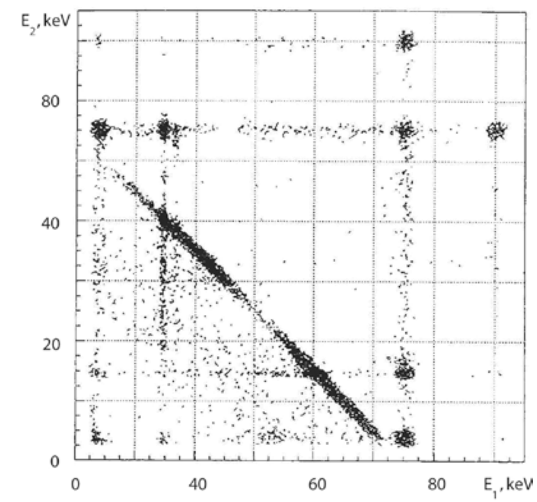
1994-95 MEPhI-ITEP-SIEMENS: 3D HPXe gamma camera











Bolozdynya A., Egorov V., Koutchenokov A., Safronov G., Smirnov G., Medved S. and Morgunov V. A high pressure xenon self-triggered scintillation drift chamber with 3D sensitivity in the range of 20–140 keV deposited energy, *Nucl. Instrum. Meth. A,* 1997, v.385, pp. 225-238.

1995 MEPhI-ITEP: Idea of the “wall-less” detector

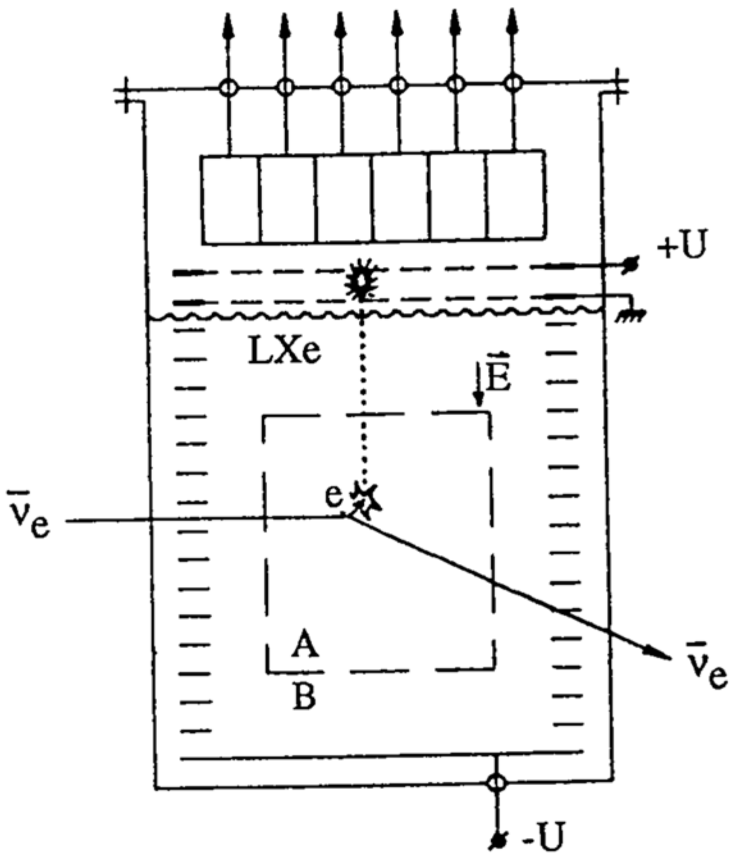
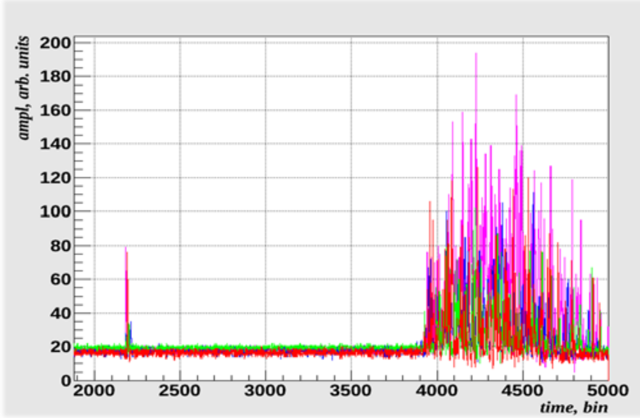


Fig.4. LXe time-projection scintillating drift chamber as wall-less detector for measurements of magnetic momentum neutrino.

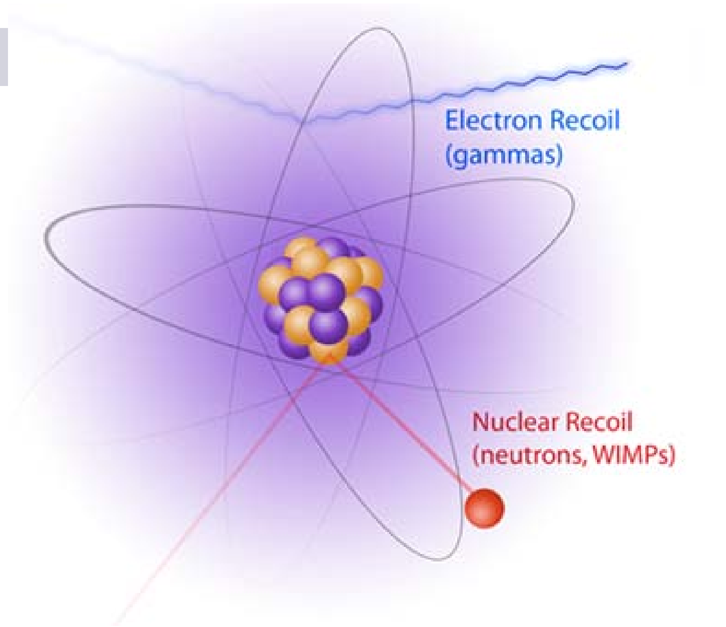


- sensitive to single electrons
- two signals: Sc&EL or S1 & S2
- self-shielding
- massive
- can be used to search for rare and low-ionization signals

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

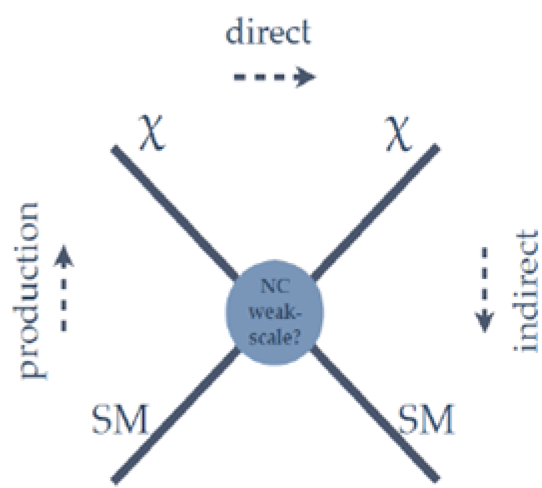
MODERN HISTORY
OF EMISSION DETECTORS

Searching for WIMPs



1. Direct detection (scattering XS)

- **Nuclear (atomic) recoils from elastic scattering**
- (annual modulation, directionality, A- & J-dependence)
- Galactic DM at the Sun's position – our DM!
- Mass measurement (if not too heavy)



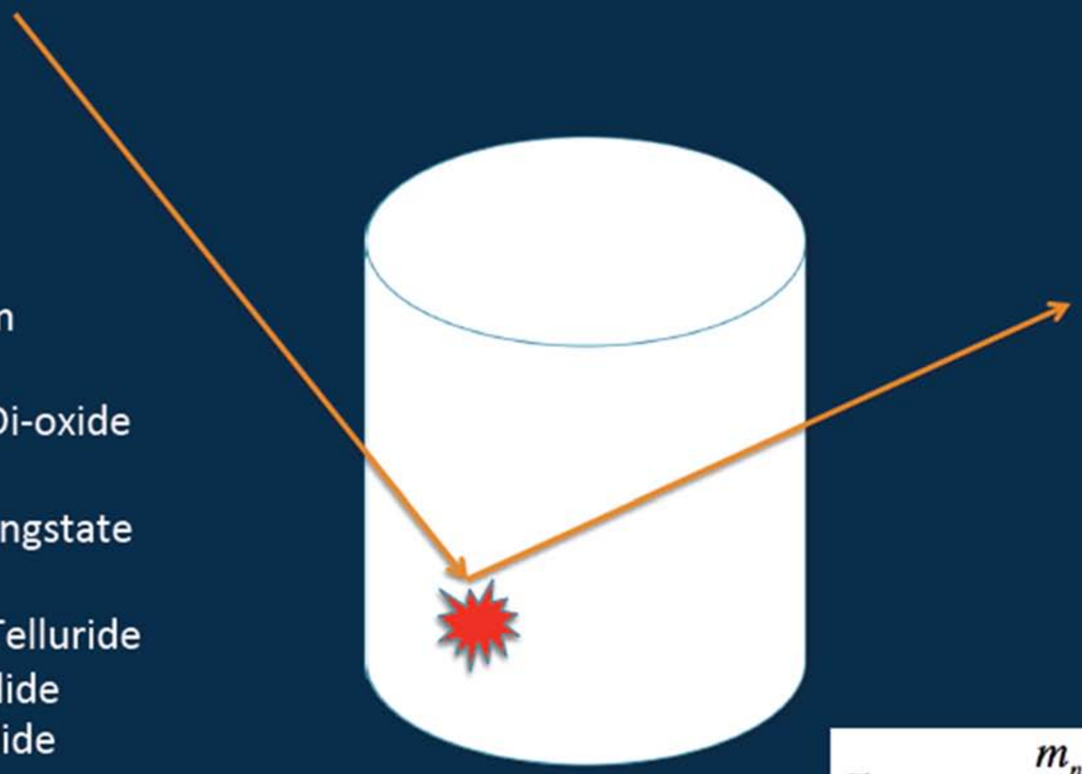
2. Indirect detection (decay, annihilation XS)

- High-energy cosmic-rays, γ-rays, neutrinos, etc.
- Over-dense regions, annihilation signal $\propto n^2$
- Challenging backgrounds

3. Accelerator searches (production XS)

- Missing transverse energy, monojets, etc.
- Good place to look for particles…
- Mass measurement poor, at least initially
- Can it establish that new particle is the DM?

Direct detection

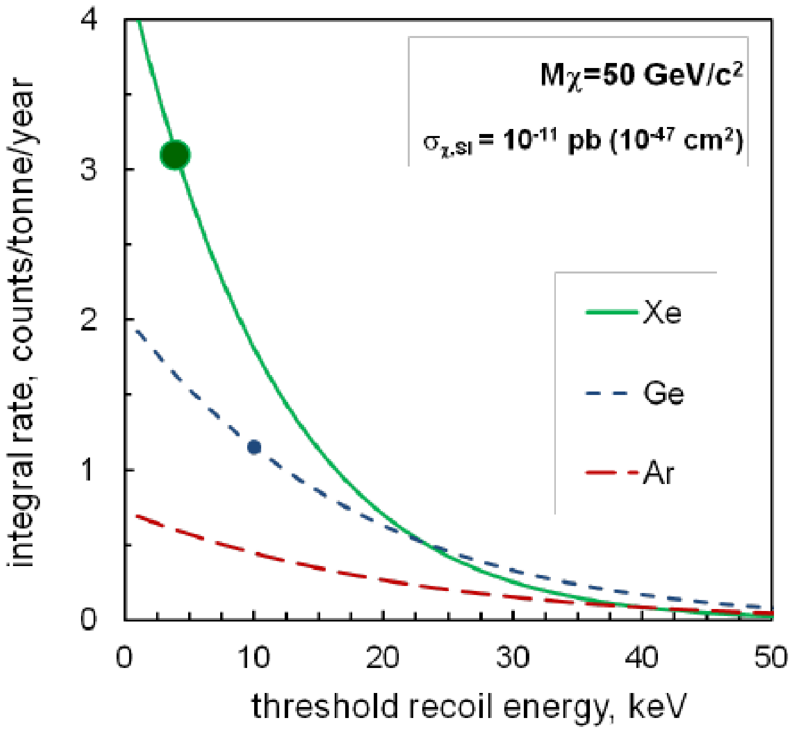


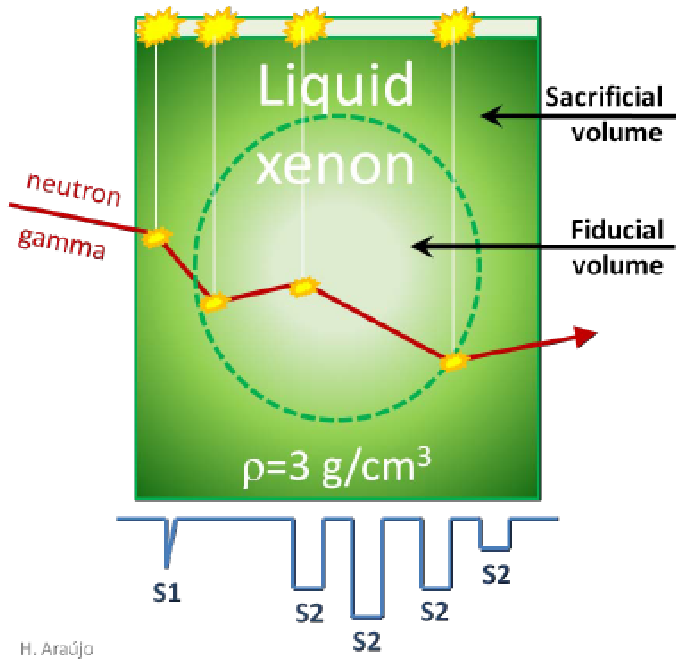
Germanium
Saphire
Tellurium Di-oxide
Xenon
Calcium Tungstate
Argon
Cadmium Telluride
Sodium Iodide
Cesium Iodide
And more

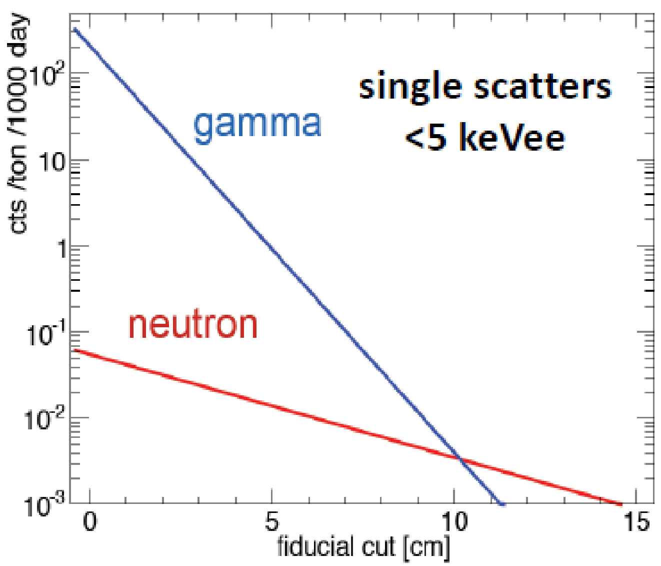
$$\sigma_{nucleus} = \frac{m_n + M_w}{m_n^2 (A + m_n)^2} A^4 \sigma_{nucleon}$$

The interaction produces ionization and/or phonons or and/or Scintillation light, even noise pulses.

Two-phase LXe approach







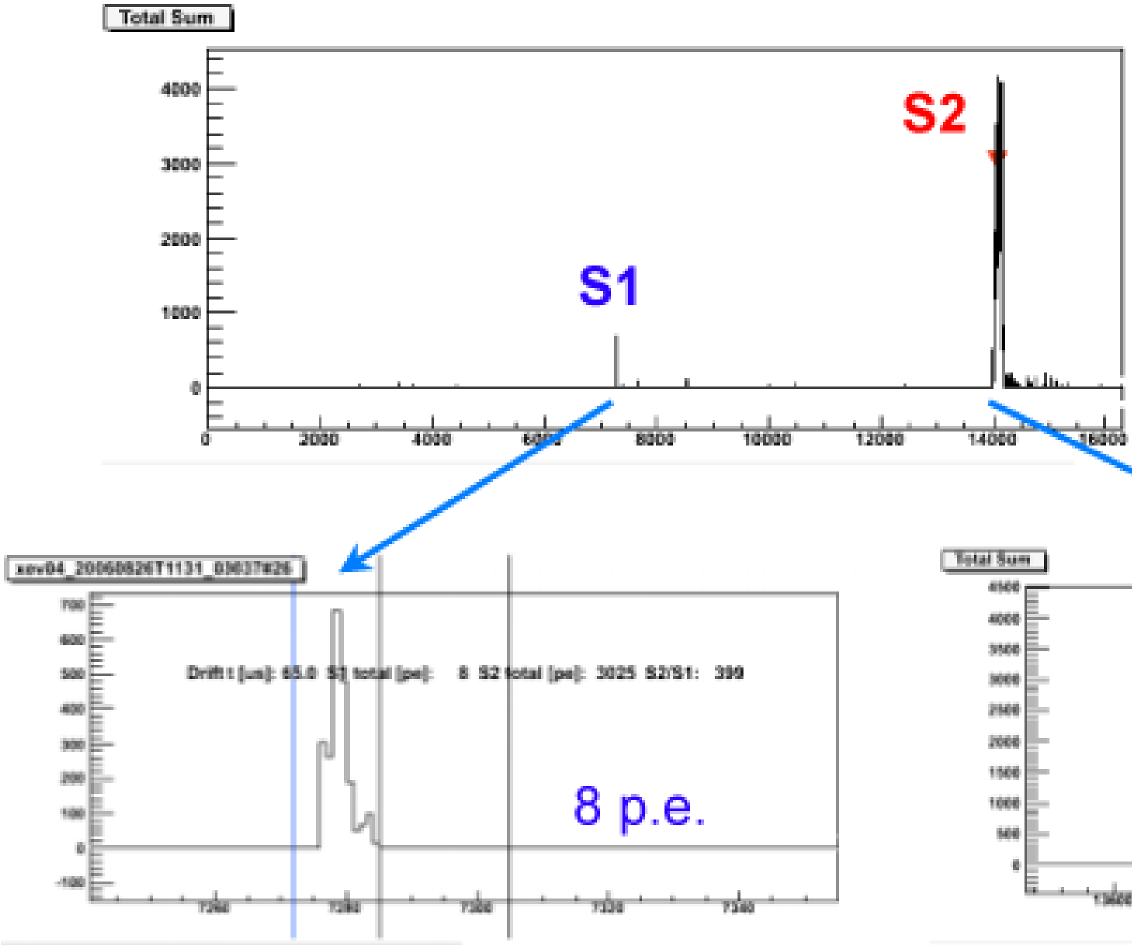
Searches for RARE *and* LOW ENERGY events: a very challenging combination

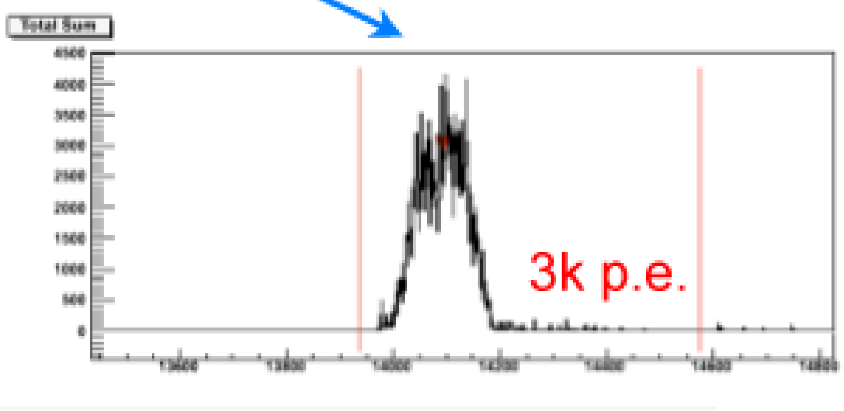
H. ARAUJO

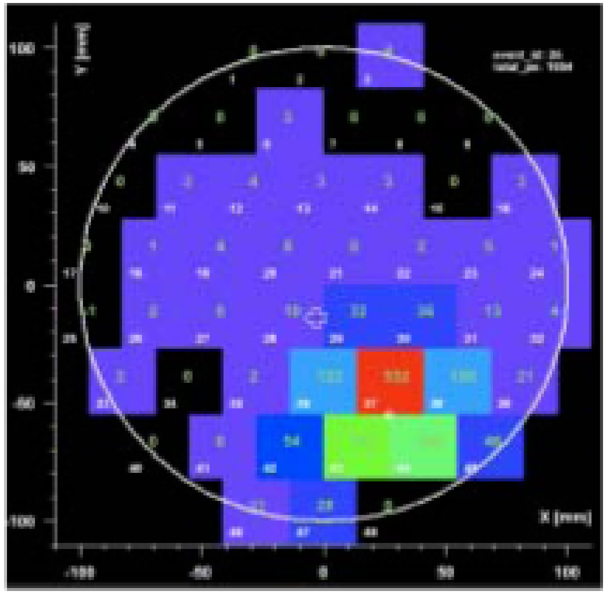
Real signals from XENON10 LXe emission detector

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

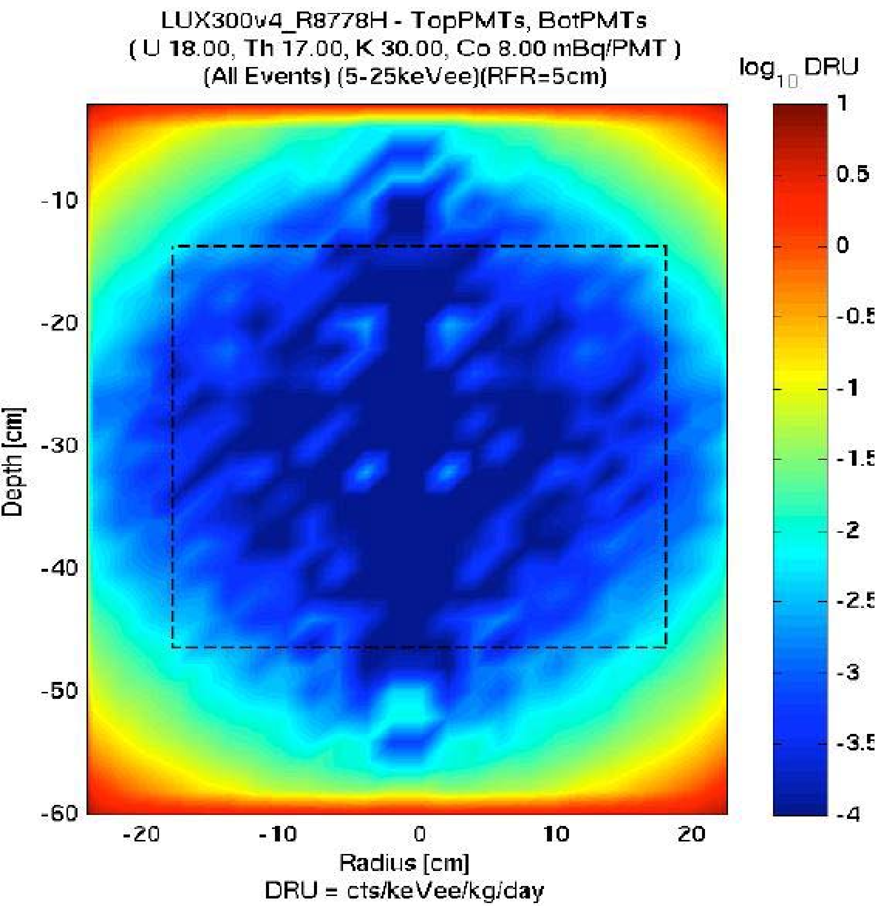
Hit pattern of top PMTs

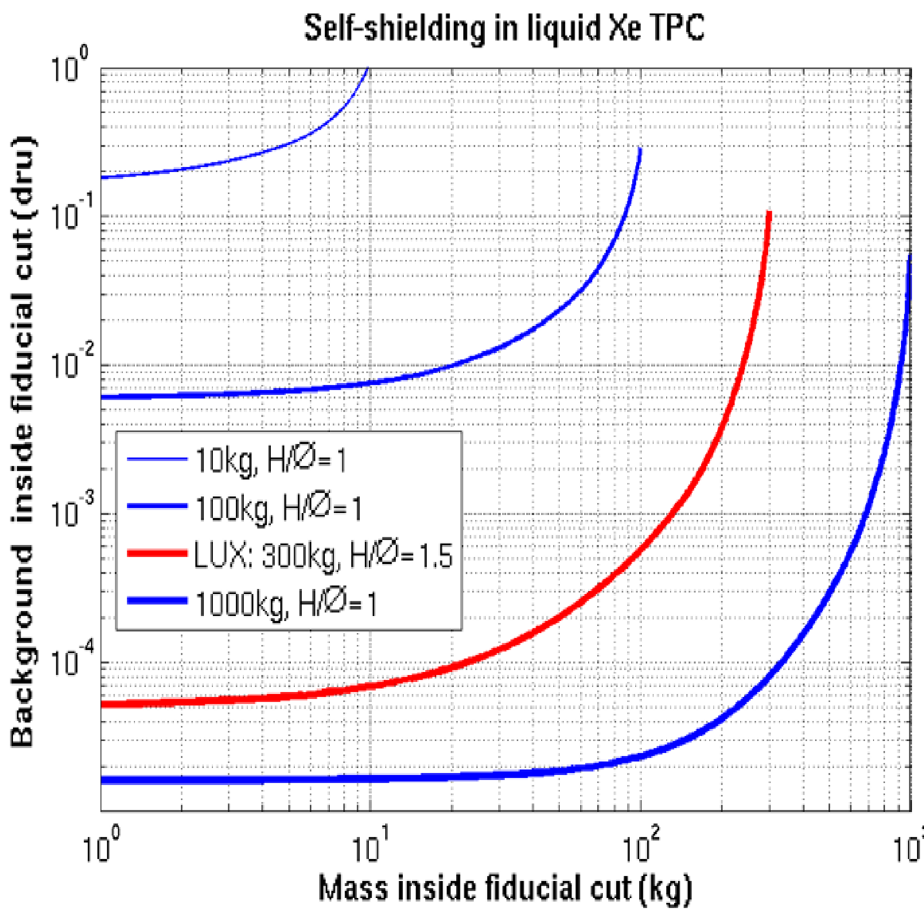




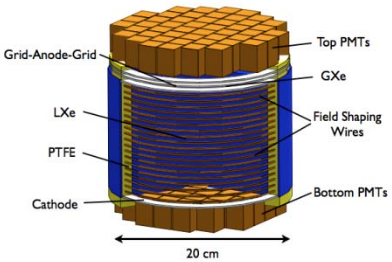


Self-shielding effect

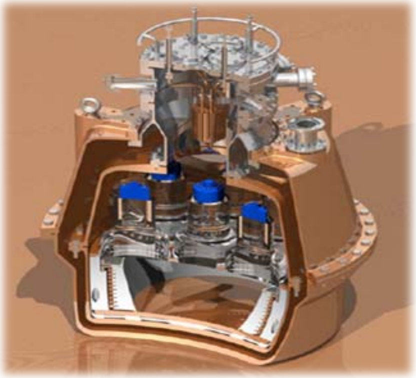




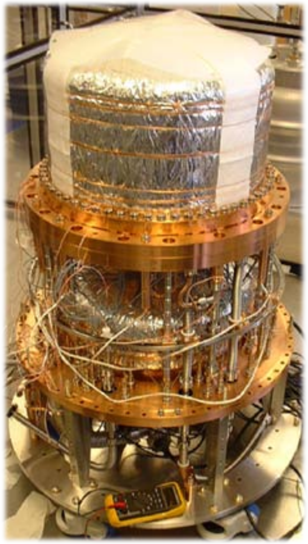
2003-2016 G1 LXe emission WIMP detectors



XENON10



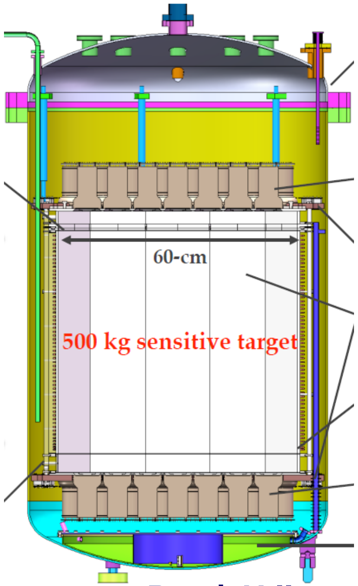
ZEPLIN II



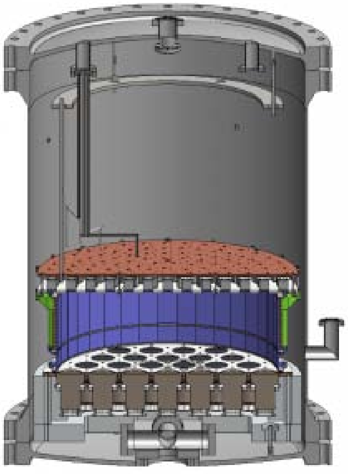
ZEPLIN III

LUX

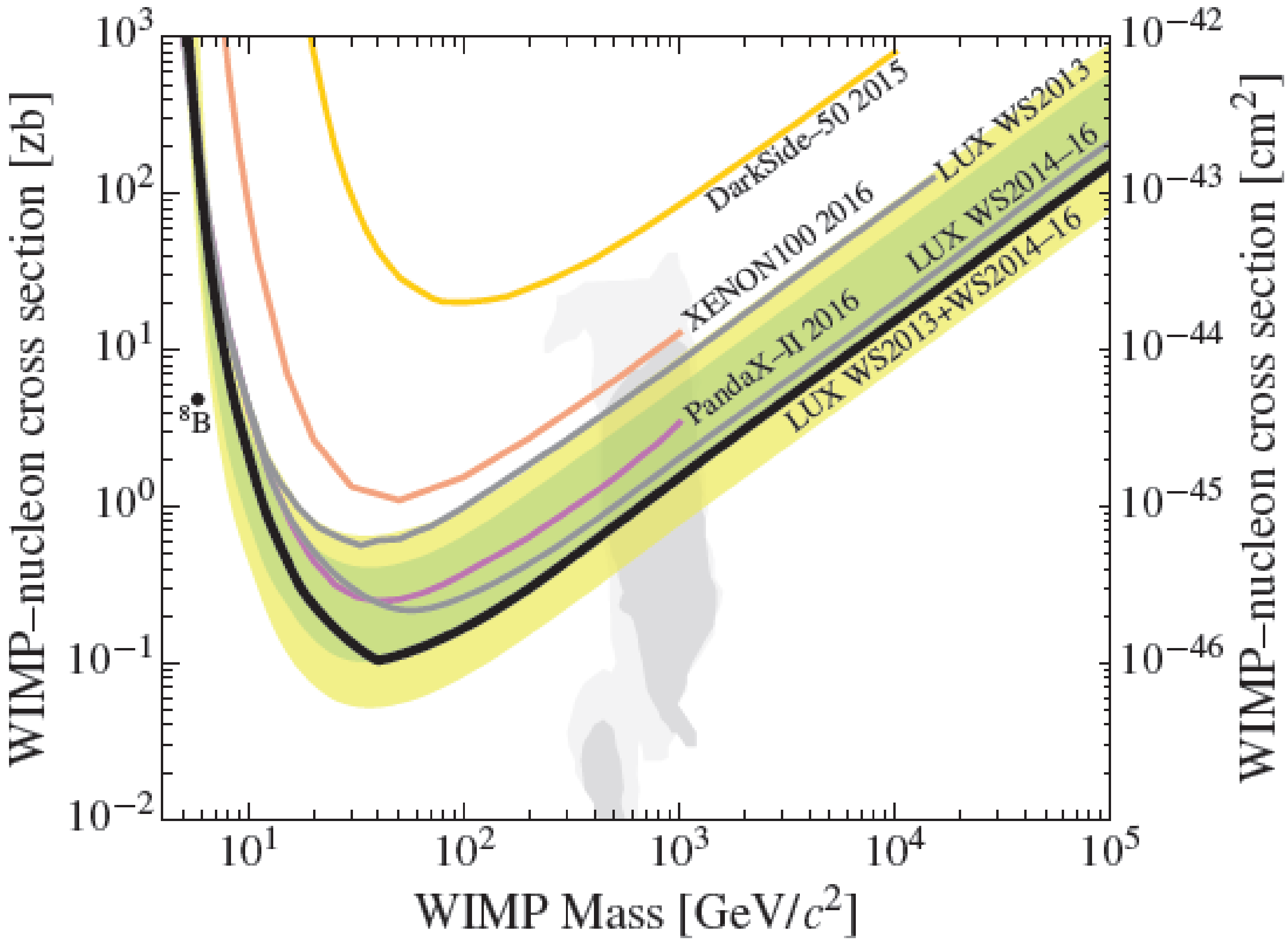
XENON100



PandaX-II



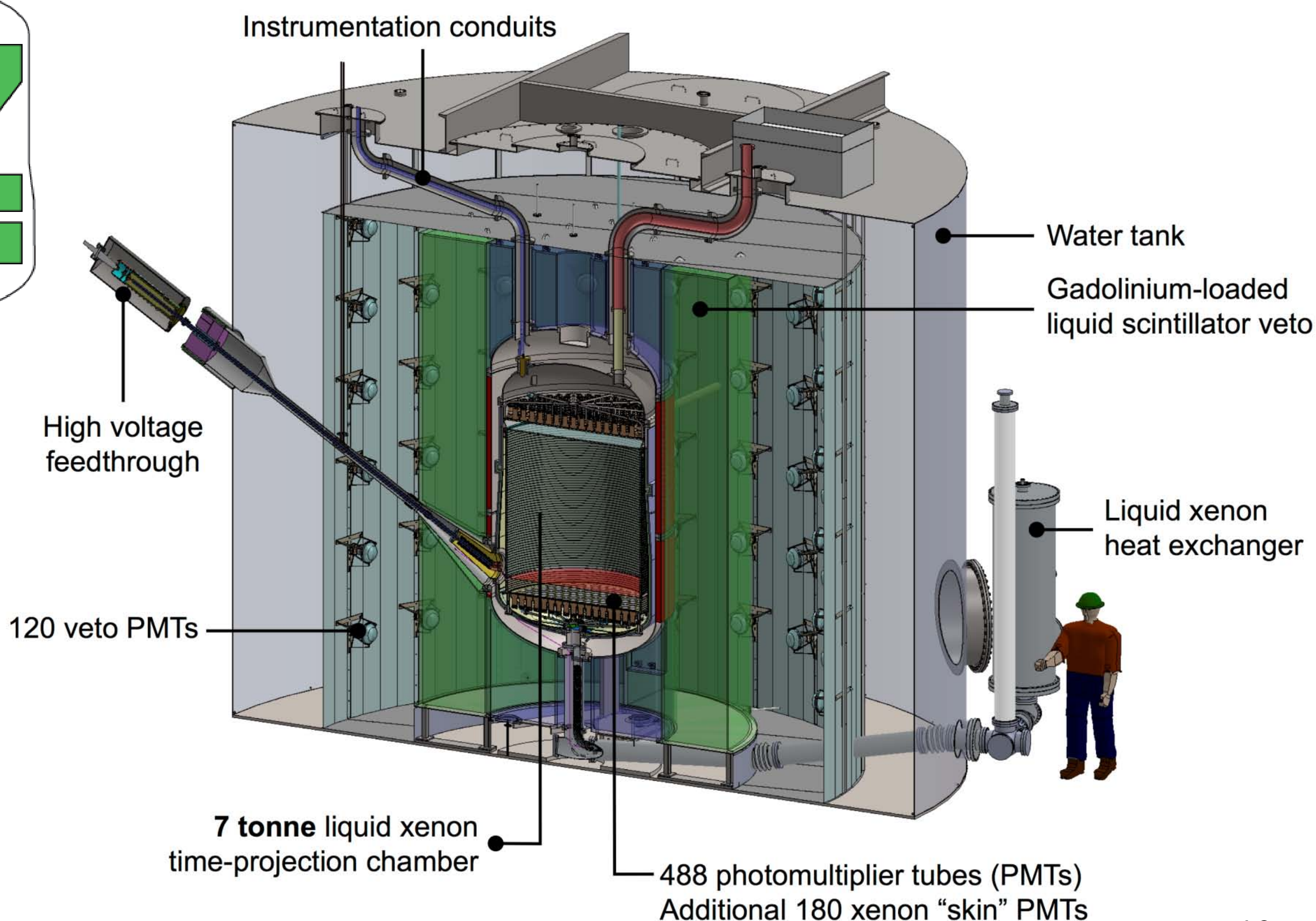
PandaX-I

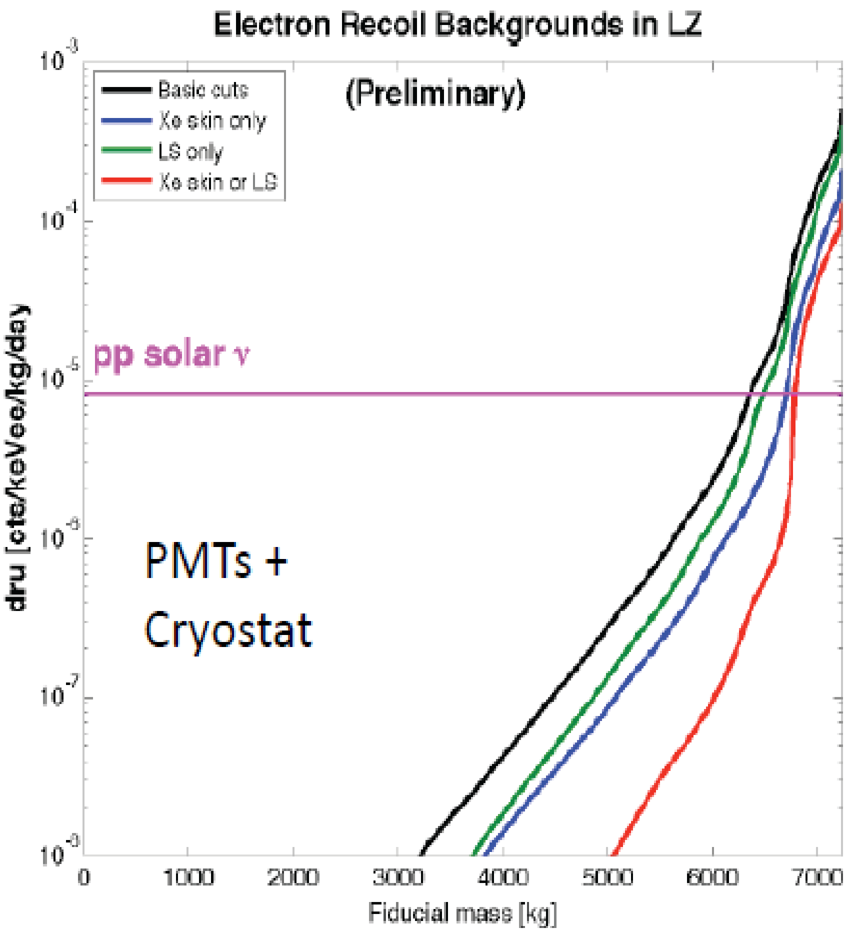


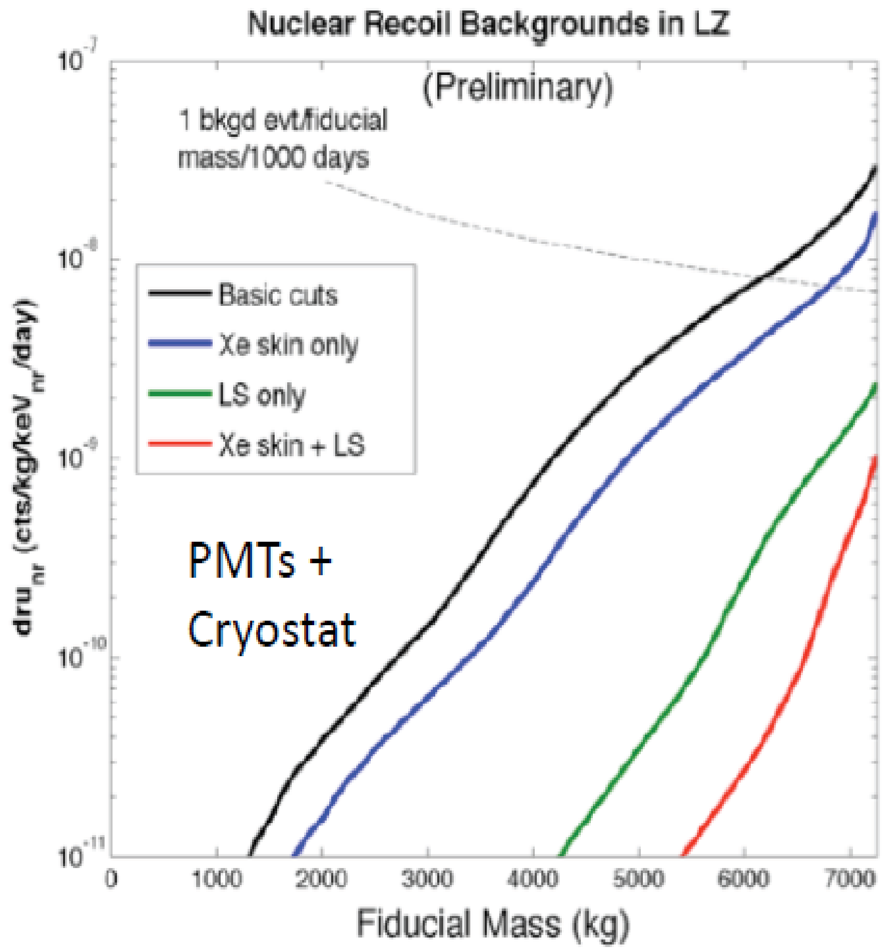
arXiv:1608.07648v2 [astro-ph.CO] 13 Oct 2016

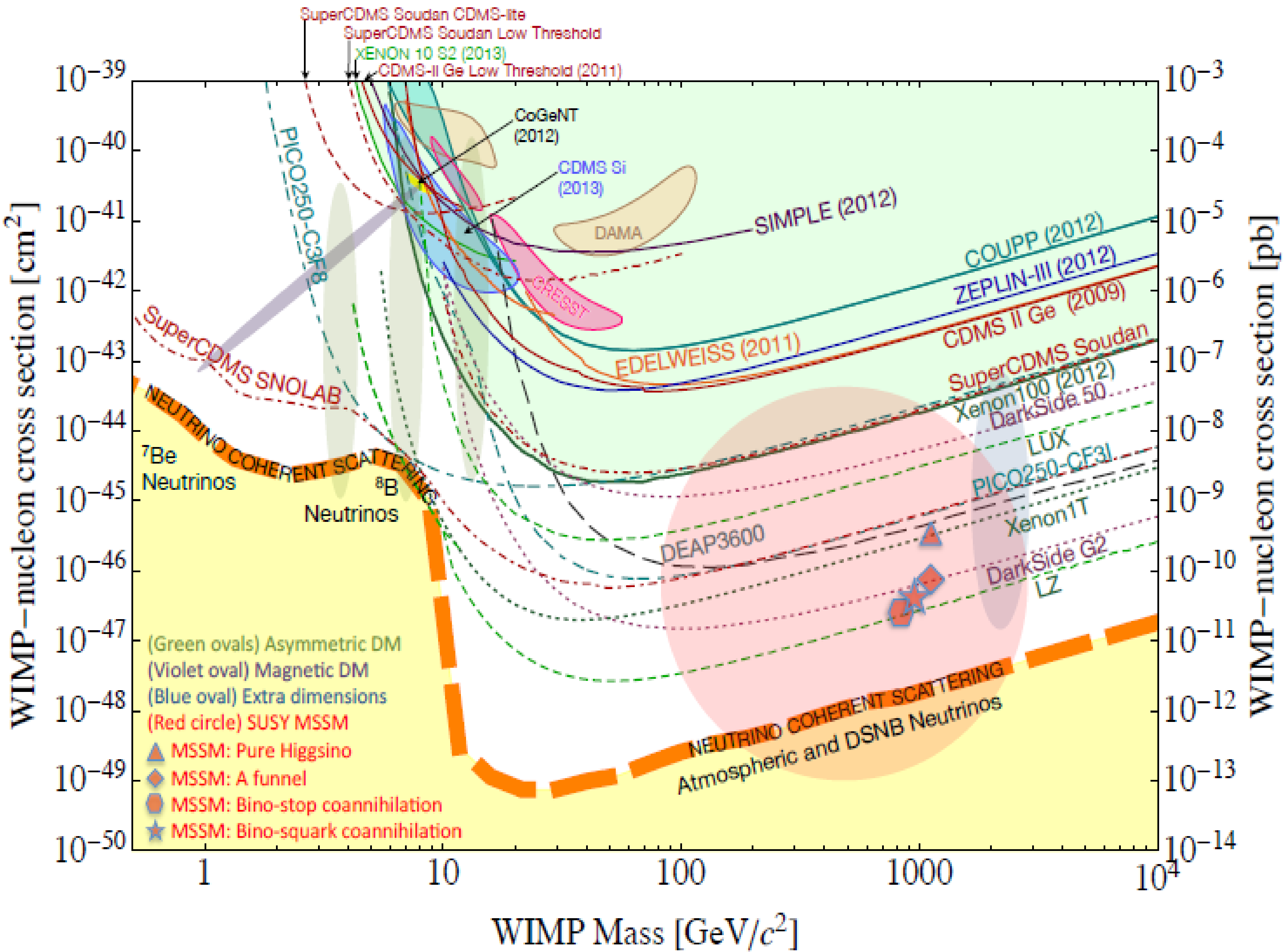
From G1 to G3

2015-2025 G2 generation experiment LZ (LUX/ZEPLIN)



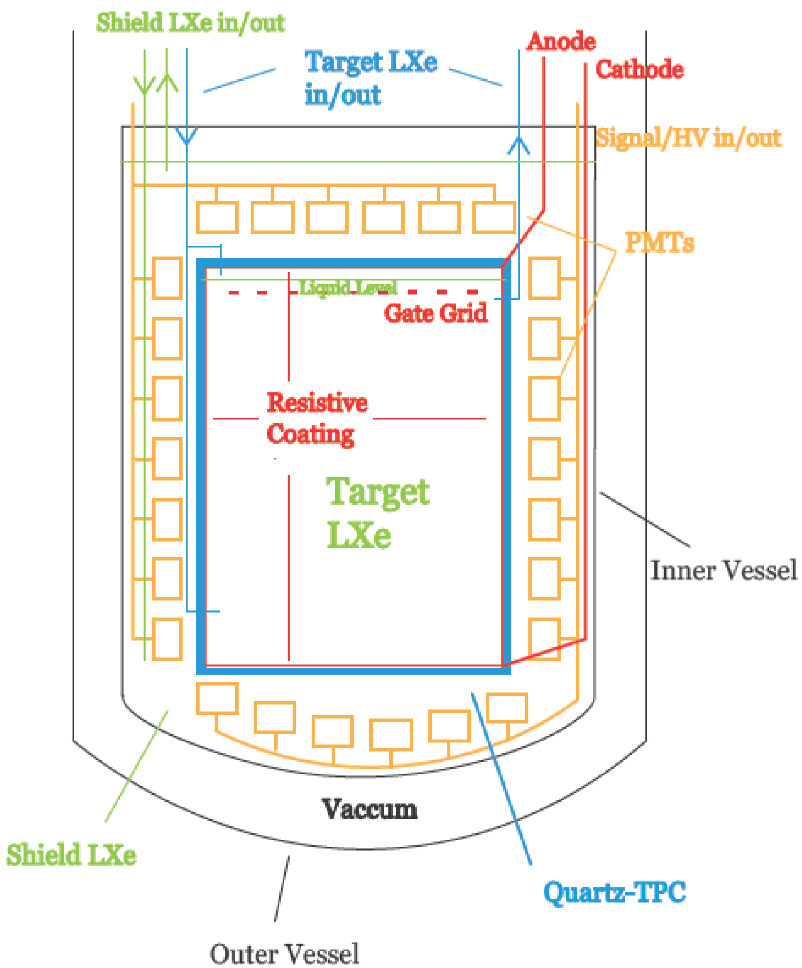

Electron Recoil Backgrounds in LZ
(Preliminary)
Basic cuts
Xe skin only
LS only
Xe skin or LS
pp solar ν
PMTs +
Cryostat
dru [cts/keVee/kg/day]
Fiducial mass [kg]
0
1000
2000
3000
4000
5000
6000
7000


Nuclear Recoil Backgrounds in LZ
(Preliminary)
1 bkgd evt/fiducial
mass/1000 days
Basic cuts
Xe skin only
LS only
Xe skin + LS
PMTs +
Cryostat
Fiducial Mass (kg)
0
1000
2000
3000
4000
5000
6000
7000

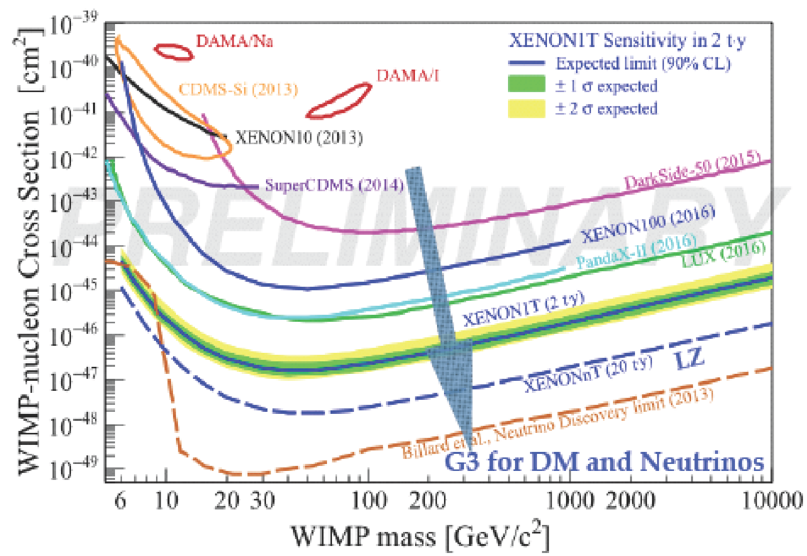


SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
CRESST
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
DEAP3600
PICO250-C3F8
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c²]

A Conceptual Design for G3 Liquid Xe Experiment for DM and Neutrino Physics (R&D, 2016-2021)



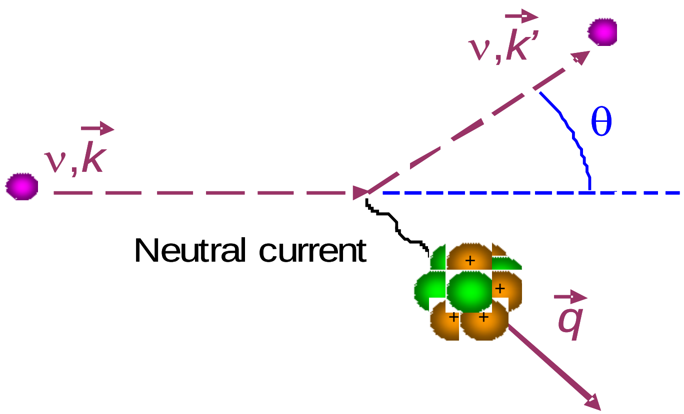
- **Large target mass:** 30 T LXe target
- **Low energy threshold** (keV): high photon detection efficiency
- **Ultra-low background**: significant reduction of Rn background by separating the target and shield volumes

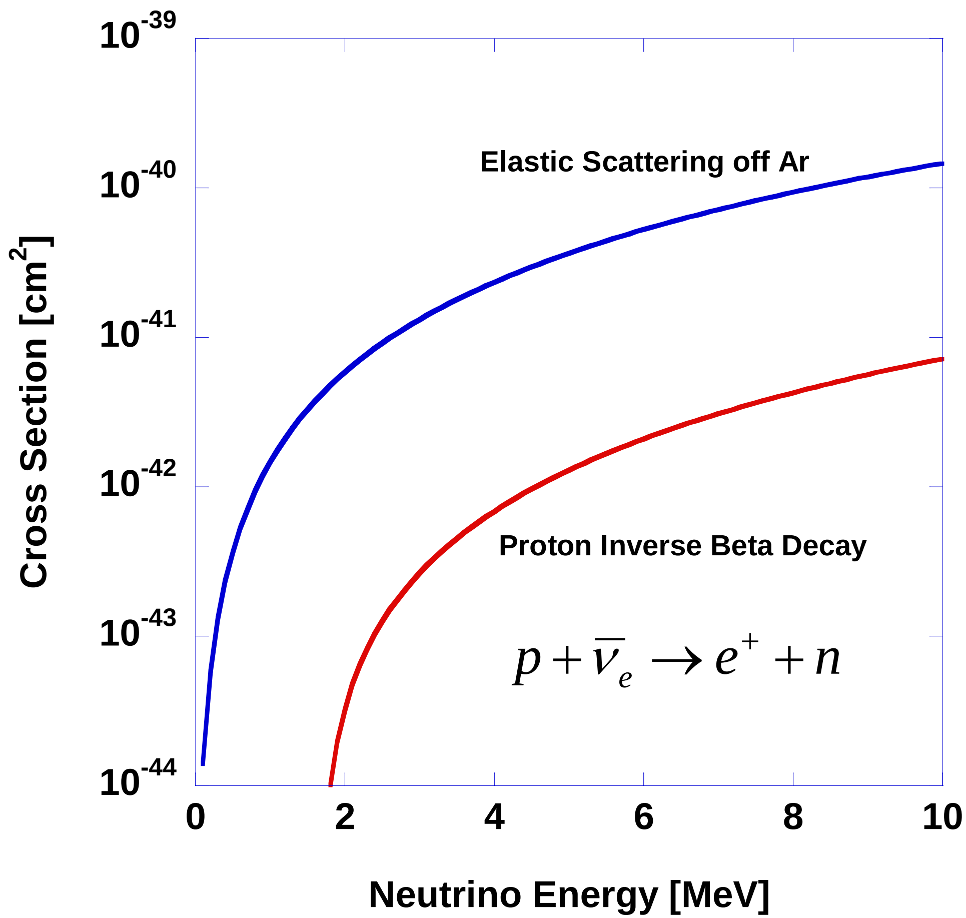


Kaixuan Ni
UCSD Xe-DM Group

NEW GENERATION OF NEUTRINO DETECTORS

Coherent neutrino scattering off heavy nuclei





Large cross-section

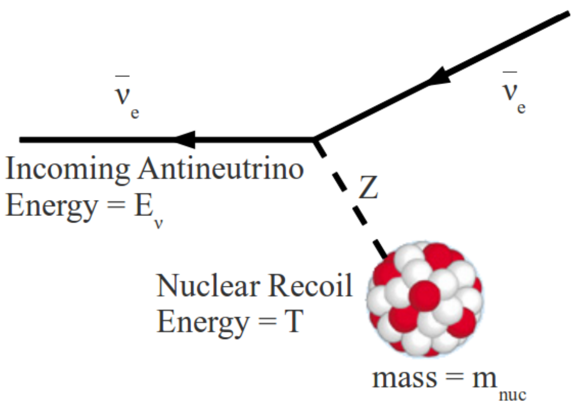
$$\sigma_{\text{elastic}} = \frac{G_F^2}{4\pi} N^2 E_\nu^2$$

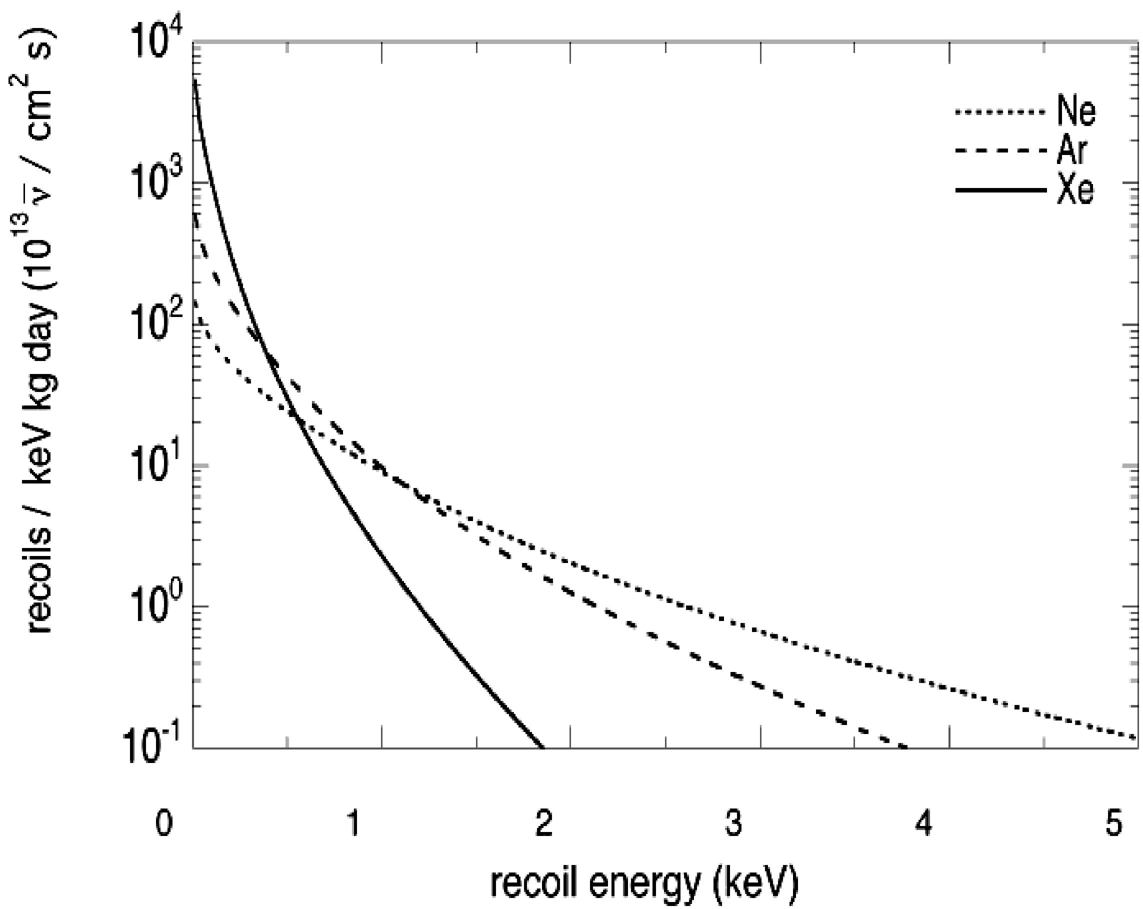
$$\approx 0.4 \times 10^{-44}\,\text{cm}^2 A^2 E_\nu(\text{MeV})^2$$

Small recoil energies

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

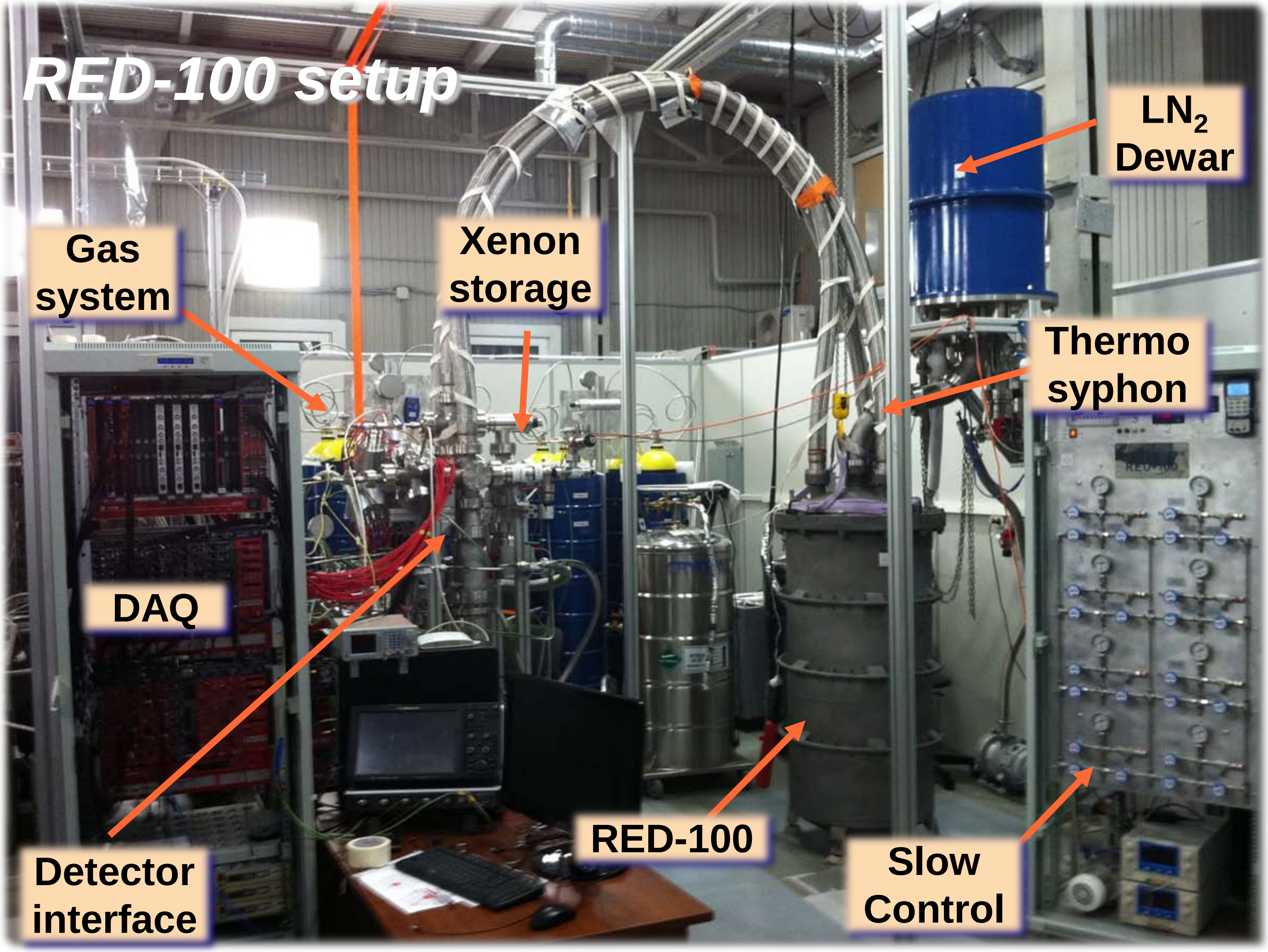
Recoil spectra from reactor e-antineutrino

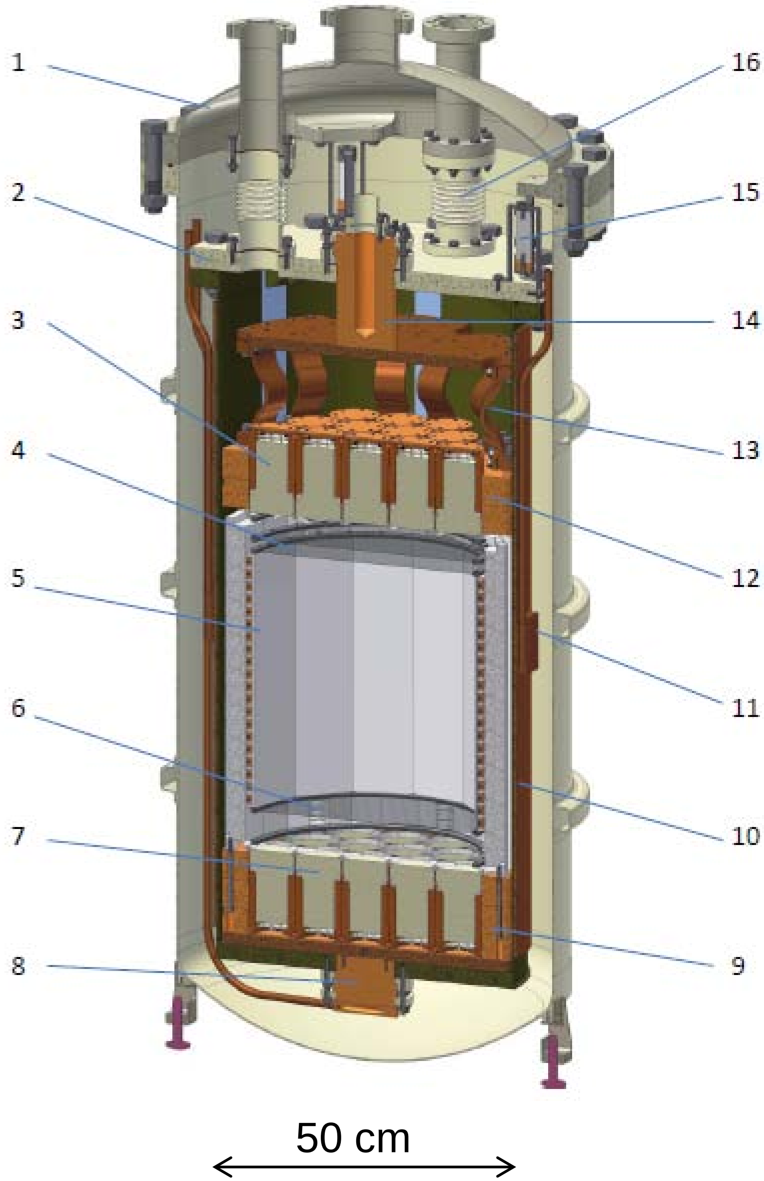




P. S. Barbeau, J. I. Collar, J. Miyamoto, and I. Shipsey

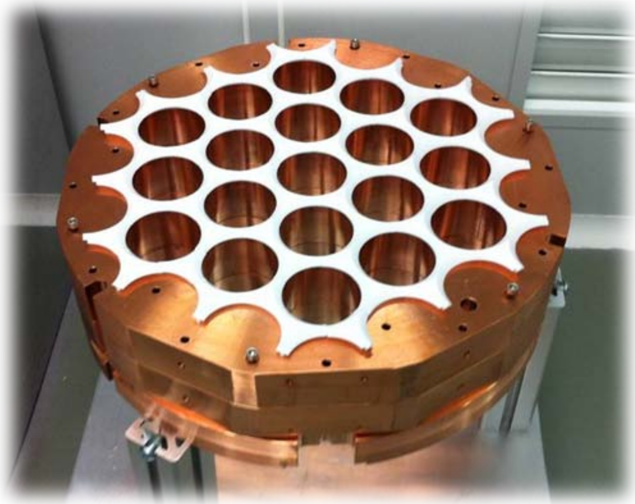
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 50, NO. 5, OCTOBER 2003

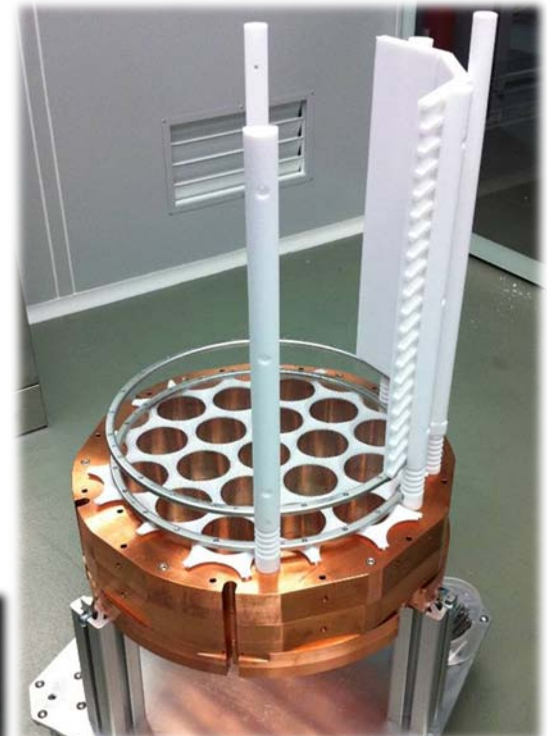

RED-100 setup
LN2 Dewar
Gas system
Xenon storage
Thermo syphon
DAQ
Detector interface
RED-100
Slow Control

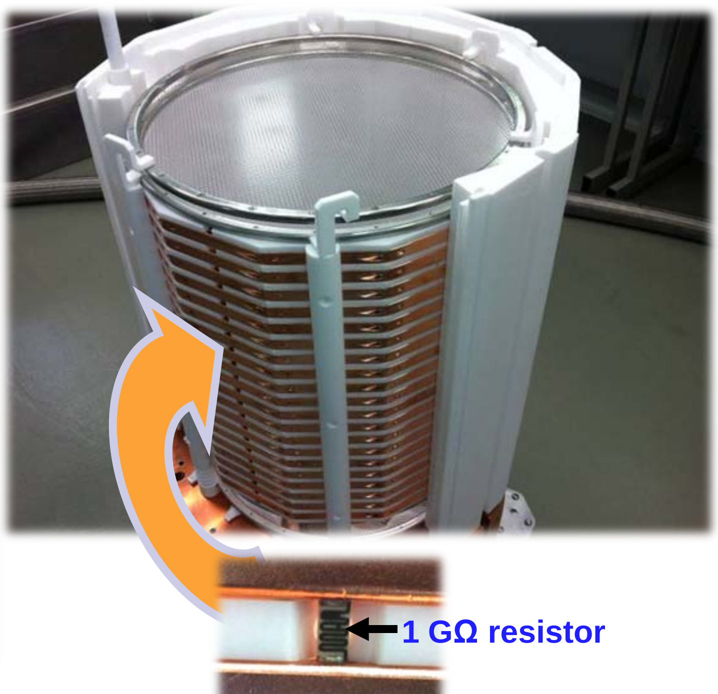


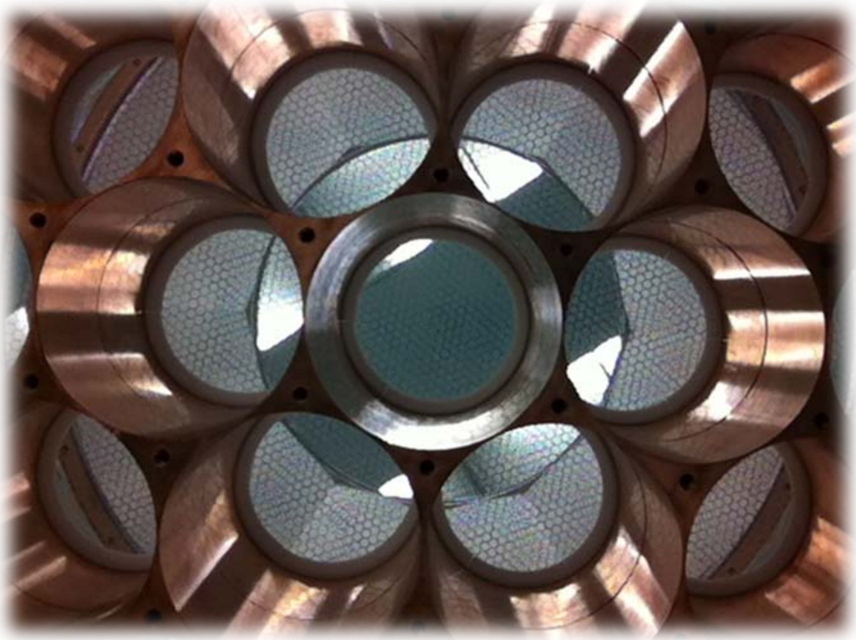
Устройство детектора РЭД-100:

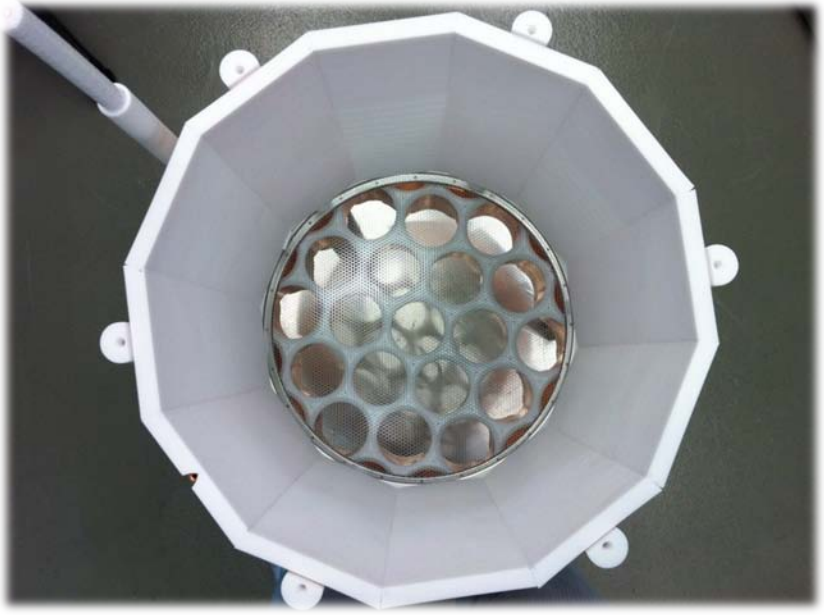
1 – внешний (тёплый) сосуд криостата,
2 – внутренний (холодный) сосуд криостата,
3 – верхняя матрица из девятнадцати ФЭУ типа HAMAMATSU R11410-20,
4 – сетчатый анод и вытягивающая сетка,
5 – рабочий объем, окруженный тефлоновым отражателем со встроенными полезадающими электродами,
6 – сетчатый катод,
7 – нижняя матрица из девятнадцати ФЭУ,
8 – нижний центральный теплосъемник с термосифоном,
9 – медная обойма для нижней матрицы ФЭУ,
10 – медный кожух холодного сосуда криостата,
11 – один из двух боковых теплосъемников с термосифонами,
12 – медная обойма верхней матрицы ФЭУ,
13 – гибкий тепловой мост,
14 – верхний центральный теплосъемник с медным диском, на котором конденсируется ксенон,
15 – теплоизолирующий подвес на основе материала Vespel,
16 – сильфонная тепловая развязка на трубопроводе для вывода кабелей.



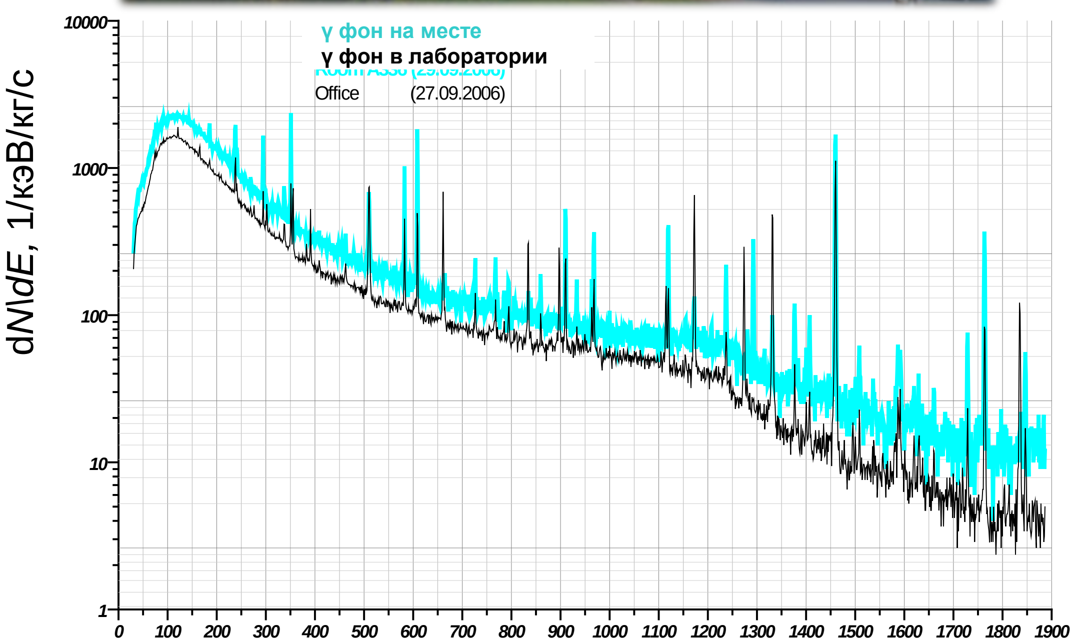


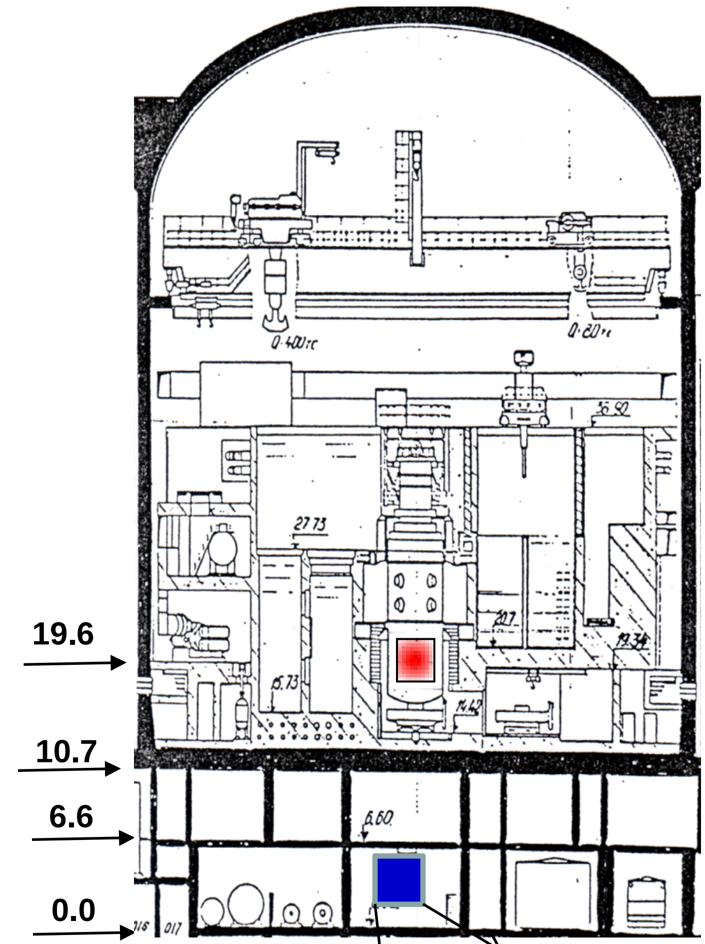

1 GΩ resistor

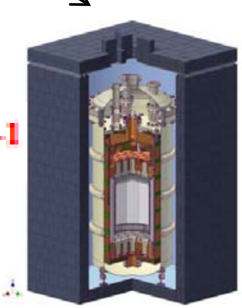


Калининская АЭС как место постановки эксперимента



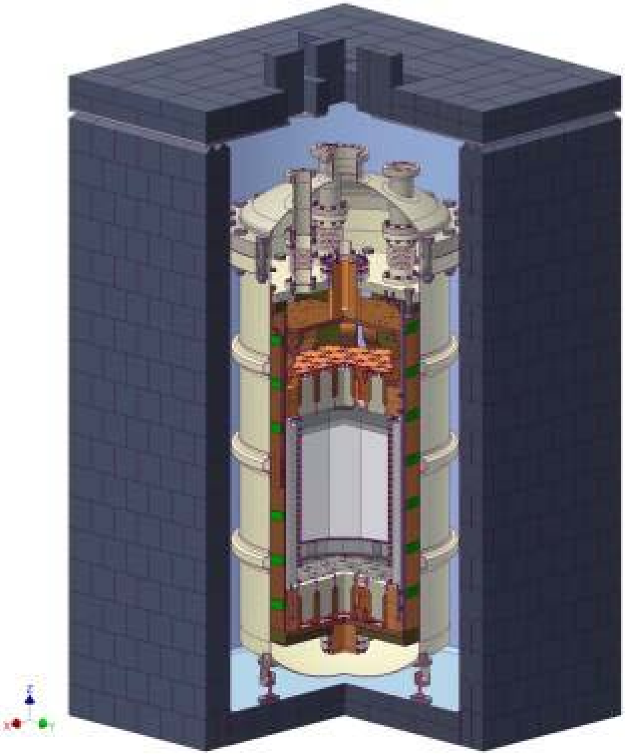


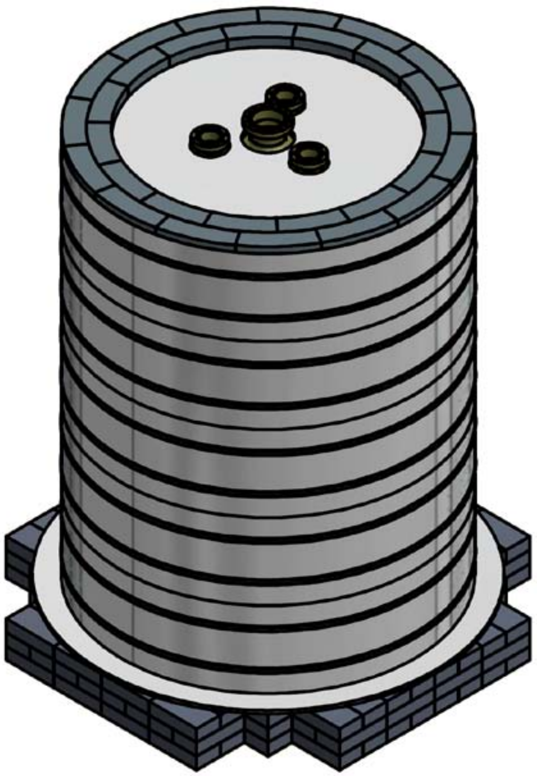
$\bar{\nu}_e$: $1.35 \cdot 10^{13}$ $cm^{-2}s^{-1}$



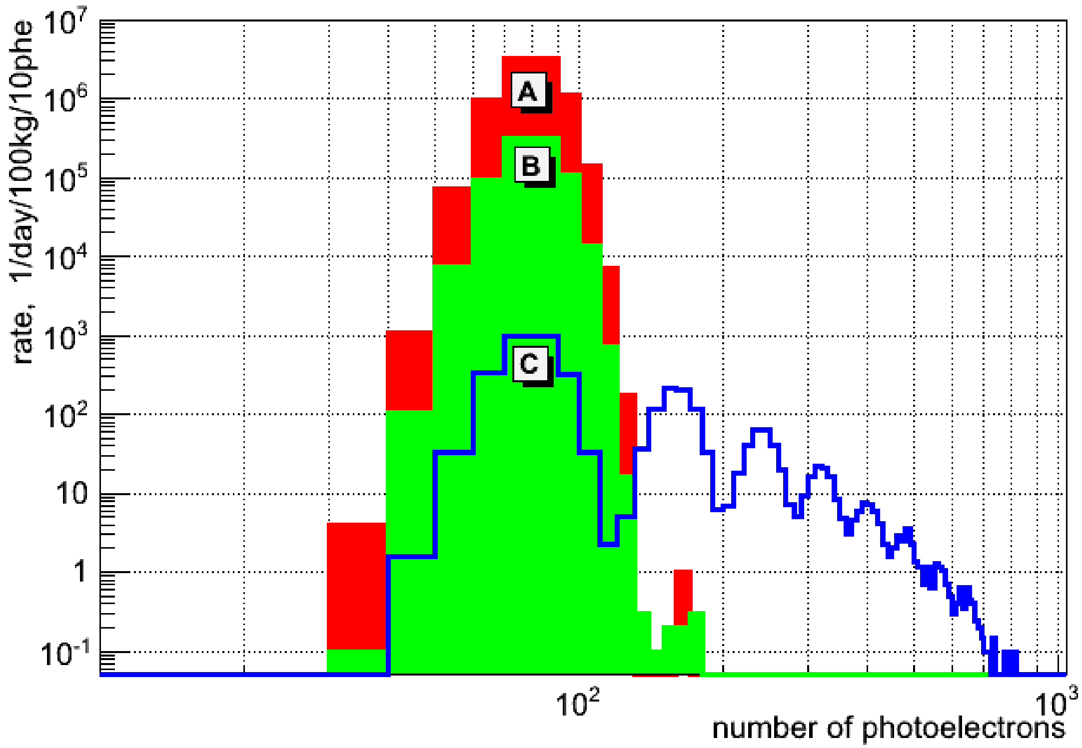
http://www.itep.ru/rus/Experiments/GEMMA/

Варианты пассивной защиты для РЭД-100





10 ÷ 15 cm Pb + 15 cm H_2O



Simulations of a single electron noise in RED-100 at 100 (A) and 10 (B) Hz in comparison to the effect (C)

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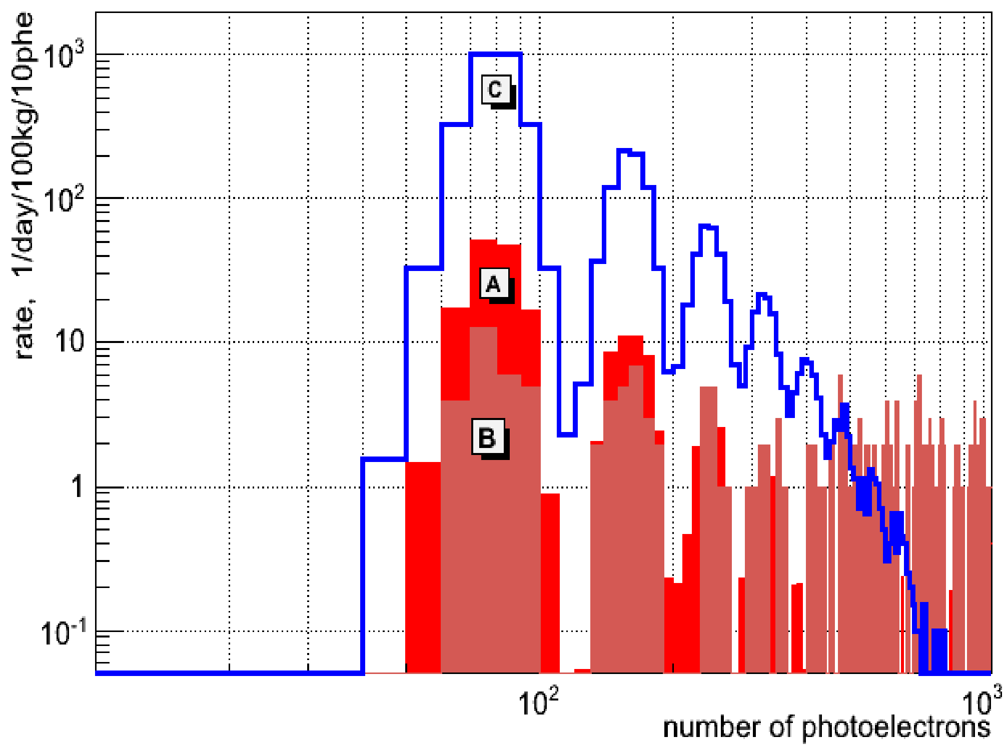

Simulations of radioactive background (A), cosmogenic neutrons (B) and effect (C)

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

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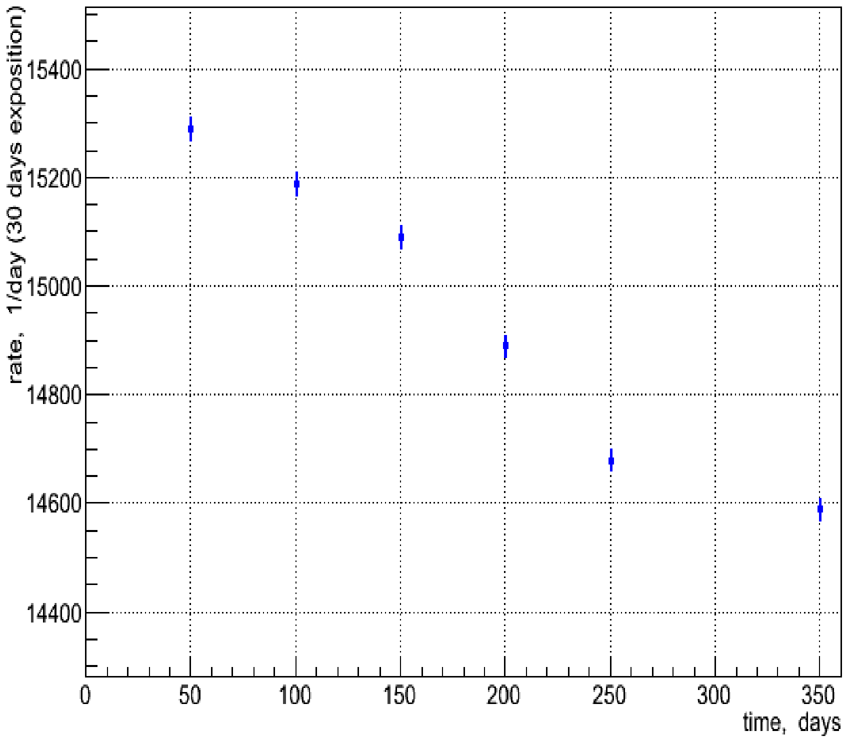

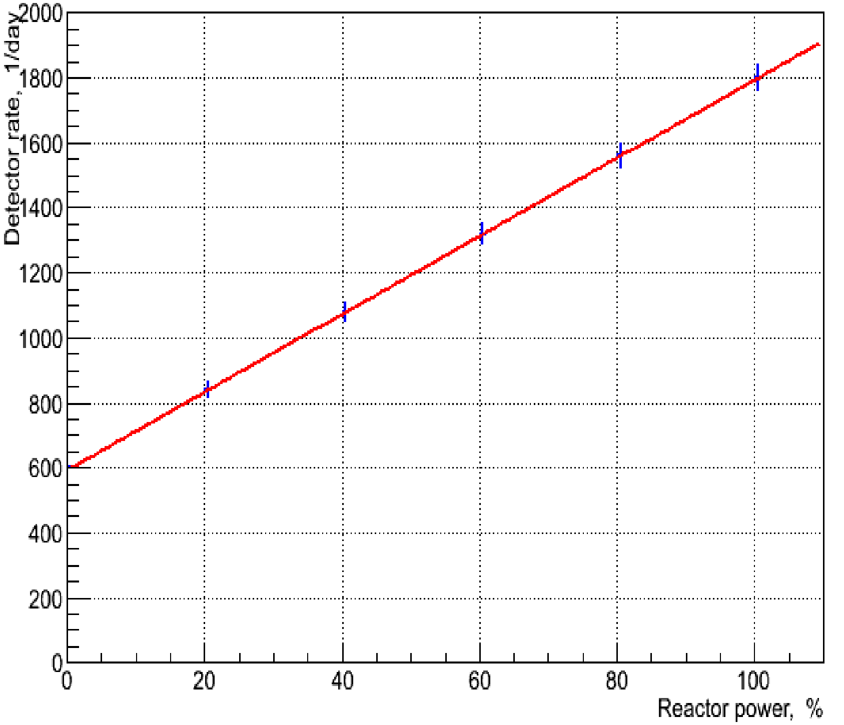

Preliminary simulation of antineutrino flux evolution (on the left site) during the 350 days of reactor cycle and simulation of reactor power monitoring (on the right site) using the coherent neutrino scattering and RED-100 as a tool

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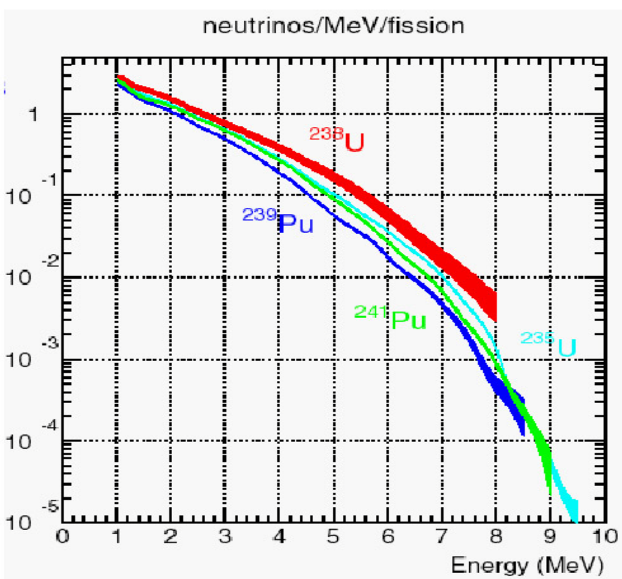
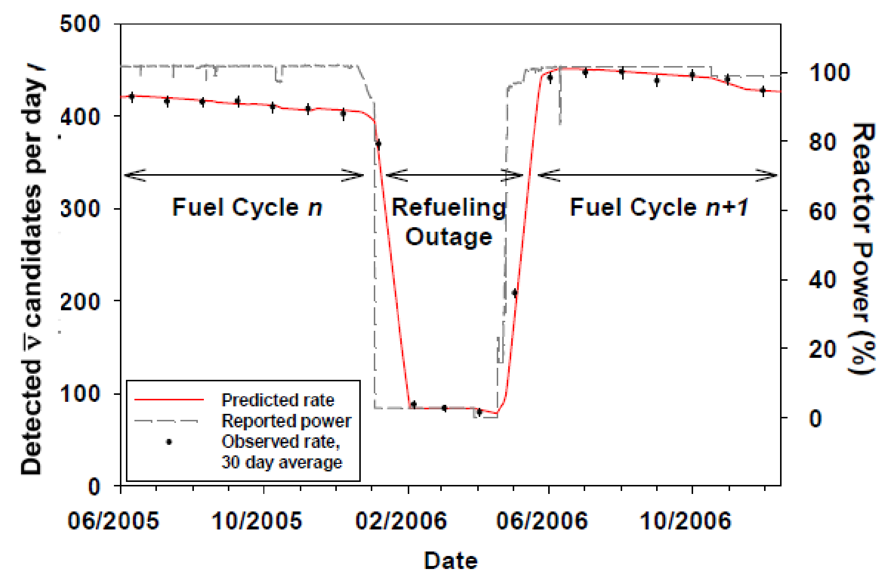
Monitoring nuclear reactors



Neutrino Spectra from fusions



Conclusion

1. Two-phase emission detectors originally proposed at MEPhI is the most promising technology to search for low-ionization and rare events

2. LXe emission detectors of G2 generation shall either unambiguously detect WIMPs or rule out all current theoretical predictions for WIMP existence

3. LXe detector of the G3 generation will be used for multiple purposes including detection of double beta neutrinoless decay and Solar neutrinos.

4. RED-100 LXe detector can be used for the first observation of the coherent neutrino scattering in 2018-2019