Перспективы использования газового детектора ионизирующего излучения с порогом ниже 1 кэВ для изучения реакторных антинейтрино

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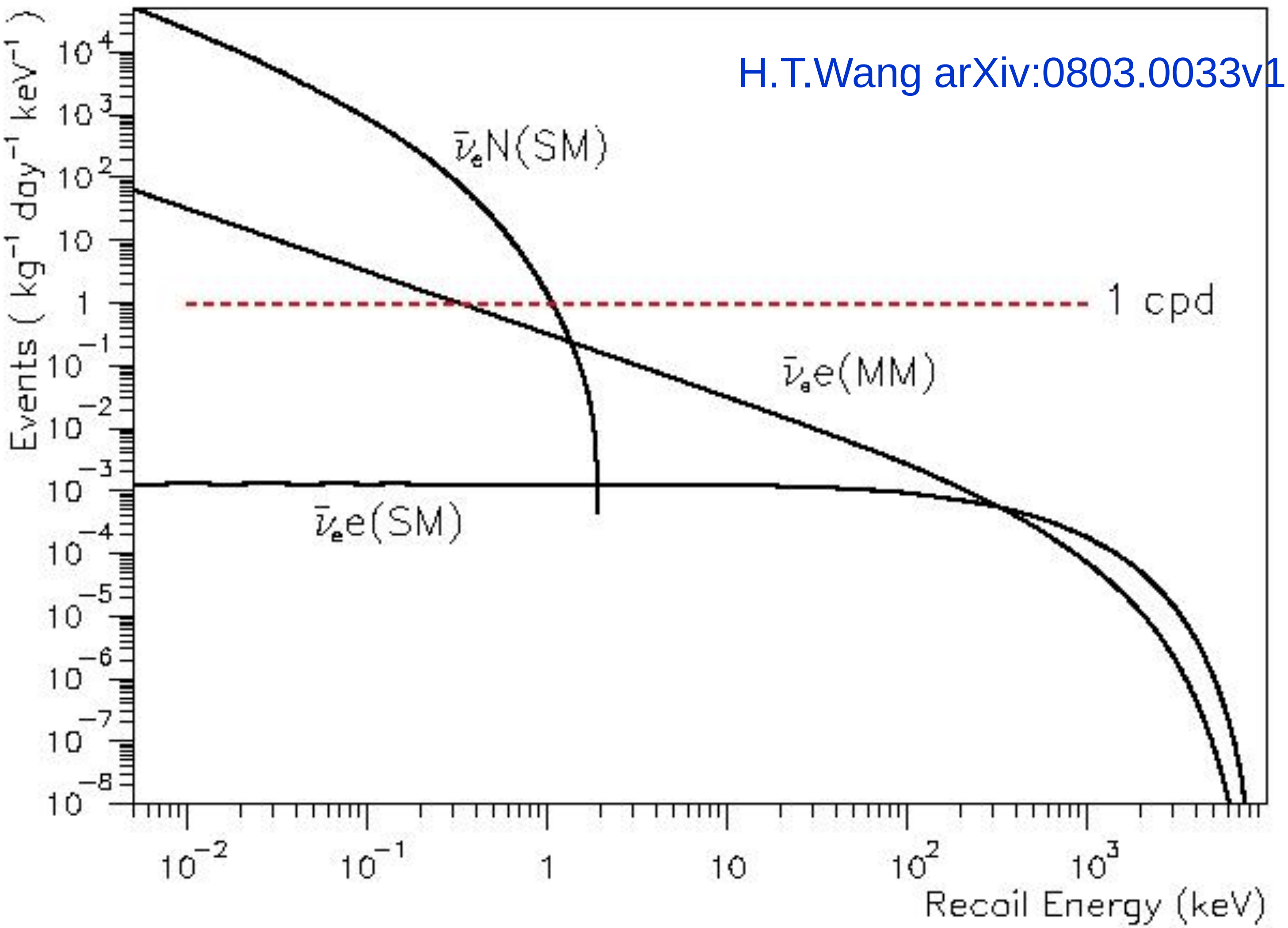
А.В.Копылов, И.В.Орехов, Е.П.Петров, В.В.Петухов, А.Е. Соломатин
ОЛВЭНА ИЯИ РАН 2012

Идея проста:
сделать детектор антинейтрино
от реактора размером с настольную лампу.

Что можно сделать
на коротком (5 лет)
временном
интервале?

С порогом ниже 1 кэВ ?

При малых энергиях отдачи скорость счета будет достаточна, чтобы снять спектр от антинейтрино от реактора.



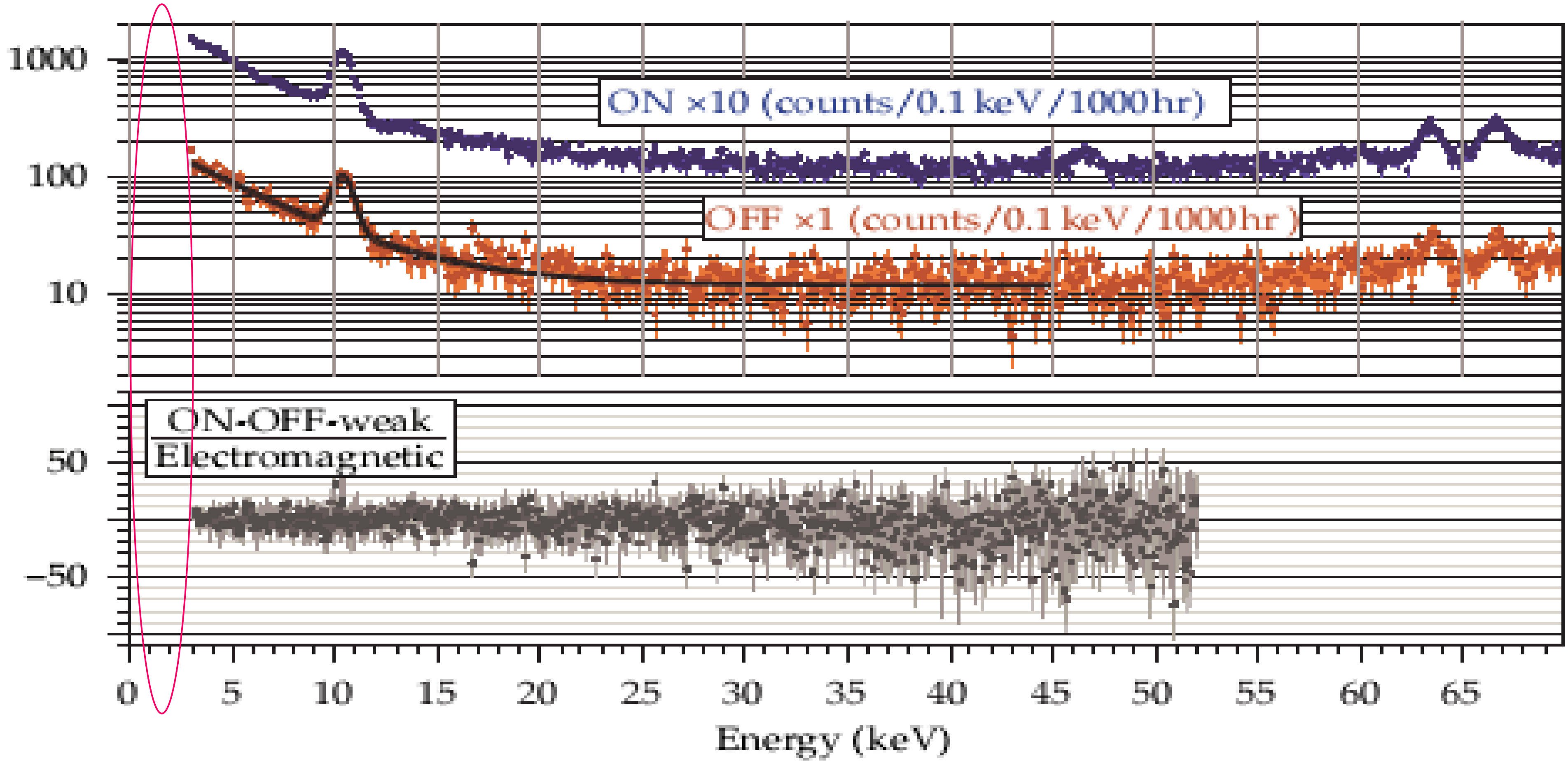
Вклад от магнитного момента

$$\sigma_{\nu e} = \pi r_0^2 \mu_\nu^2 \left[\ln\left(\frac{E_{e\ \max}}{T} \right) + \frac{T}{E_{e\ \max}} - 1 \right]$$

- Полное сечение рассеяния нейтрино на электроне, связанное с магнитным моментом нейтрино, здесь *T* – порог регистрации электронов отдачи, *Ee max* = *Ev(2Ev/(2Ev + m_e))* – максимально возможная энергия электронов отдачи (*Ee max* ≈ *Ev* при *Ev* >> m_e), r_0 – классический радиус электрона
- Квадратичная зависимость от магнитного момента!

С порогом ниже 1 кэВ?

Первый (и последний!) кэВ, где эффект от антинейтрино еще не измеряли.



Фрагменты спектра при включенном и выключенном реакторе (вверху) и их разность, нормированная на сечение электромагнитного взаимодействия (внизу)

A.G.Beda et al. (GEMMA) *The Results of Search for the Neutrino Magnetic Moment in GEMMA Experiment* Advances in High Energy Physics **2012** (2012) 350150.

Когерентное рассеяние на ядрах мишени

- **D.Z.Freedman PRD 9, 1389 (1974);**
  D.Z.Freedman, D.N.Schramm, and D.L.Tubbs, Ann.Rev.Part.Sci. 27, 167 (1977)]

- **A.Drukier and L.Stodolsky *Principles and applications of a neutral-current detector for neutrino physics and astronomy* Phys.Rev.D 33, p.p.2295-2309 (1984)**

- Процесс идет с малой передачей импульса и потому нейтрино взаимодействует в фазе со всеми нуклонами ядра. Рассеяние идет по каналу нейтрального тока через обмен Z_0 -бозоном со всеми нуклонами и по этой причине не зависит от аромата нейтрино. Сечение пропорционально квадрату числа нейтронов в ядре. Удельный темп счета (в *кг-1сутки-1*) довольно велик и пропорционален атомному весу мишени

- **Предложено в 70х, часто обсуждалось и никем пока не наблюдалось!**

Unrealized proposals
(from P.S.Barbeau, J.I.Collar, O.Trench 2007 JCAP09(2007)009)

[3] P.S. Barbeau *et al.*, IEEE Trans. Nucl. Sci. **50** (2003) 1285.

[4] B. Cabrera *et al.*, Phys. Rev. Lett. **55** (1985) 25; A. S. Starostin and A. G. Beda, Phys. Atom. Nucl. **63** (2000) 1297; H.T. Wong, Nucl. Phys. B (Procs. Suppl.) **138** (2005) 333; A.G. Beda, Nucl. Instr. Meth. **A531** (2004) 161.; C. Hagmann and A. Bernstein, IEEE Trans. Nucl. Sci. **51** (2004) 2151; I. Giomataris *et al.*, hep-ex/0502033; S.A. Golubkov *et al.*, Instr. Exp. Tech. **47** (2004) 799; K. Scholberg, Phys. Rev. **D73** (2006) 033005; C. Braggio *et al.*, Nucl. Instr. Meth. **A568** (2006) 412; A. Bueno *et al.*, Phys. Rev. **D74** (2006) 033010; A. Bondar *et al.*, physics/0611068.

В физике главное – не идея.
Идею можно позаимствовать у другого.
В физике главное – это искусство экспериментатора. Этого нельзя позаимствовать, но именно это обеспечивает успех.

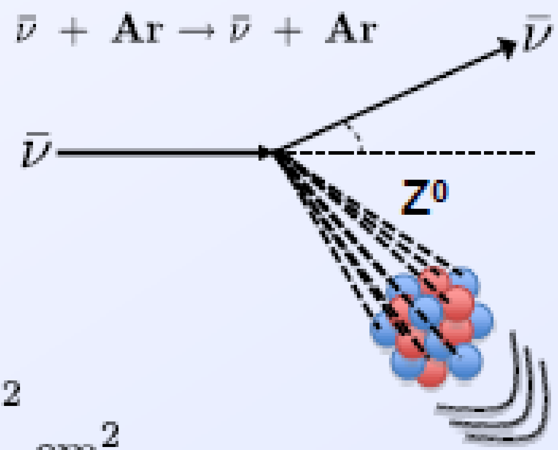
Рэймонд Дэвис.

Raymond Davis

Coherent Neutrino Scattering (CNS)

A neutrino elastically scatters on a nucleus via Z0 exchange with all nucleons

- flavor blind, no threshold
- predicted by the SM, long-sought
- **high cross-section:**



$$\sigma_{\rm cs} \simeq \frac{G^2 N^2}{4\pi} E_\nu^2 \simeq 0.42 \times 10^{-44} N^2 \left(\frac{E_\nu}{\rm MeV}\right)^2 {\rm cm}^2$$

- **But low recoil energy:**

$$\langle E_r \rangle = 716\,{\rm eV}\ \frac{(E_\nu/{\rm MeV})^2}{A}$$

Sources of < 50 MeV neutrinos

- Reactors
- spallation sources
- supernovae
- the Sun

A.Bernstein, NOW2011

Вклад от когерентного рассеяния дифференциальный

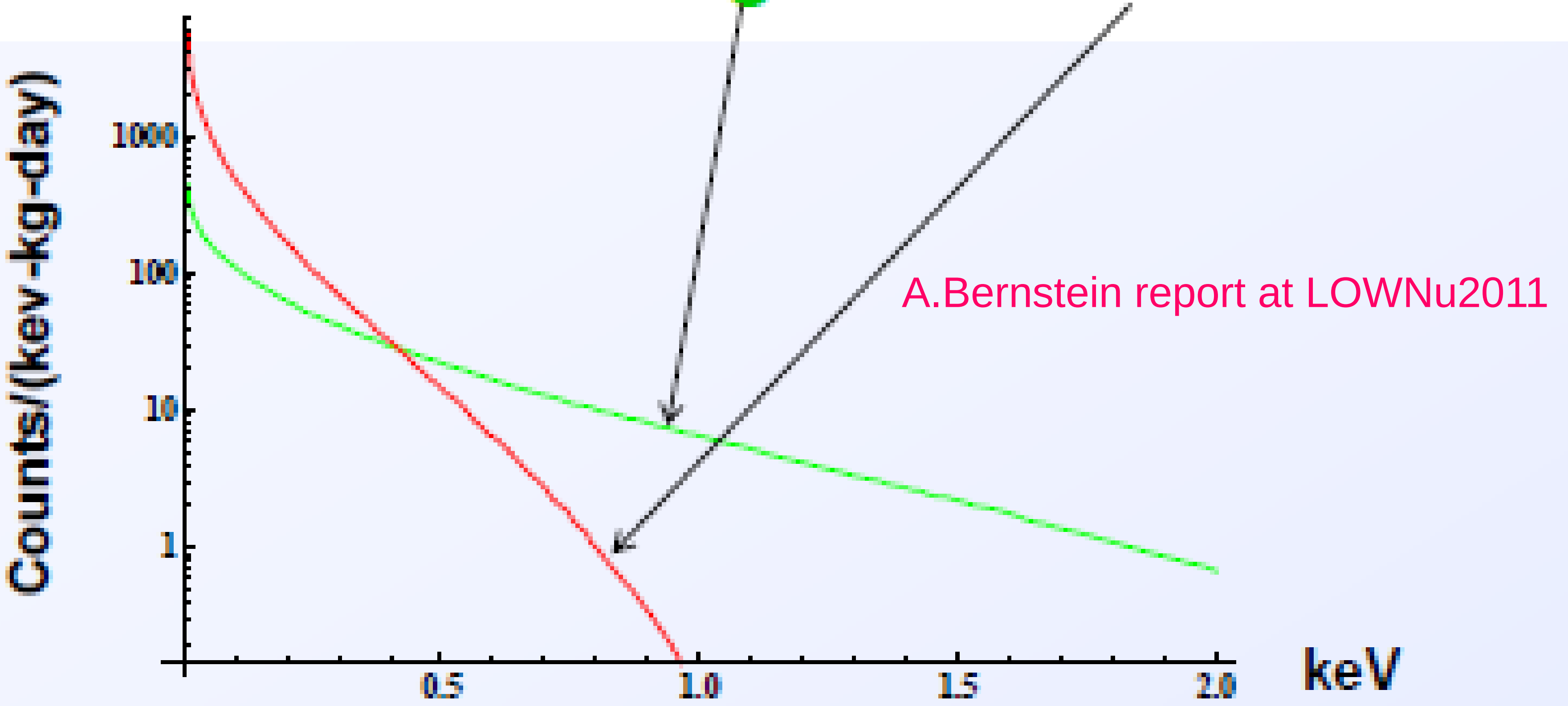
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M \left(1 - \frac{MT}{2E_\nu^2}\right) F\left(Q^2\right)^2$$

$$Q_W = N - \left(1 - 4\sin^2\theta_W\right) Z$$

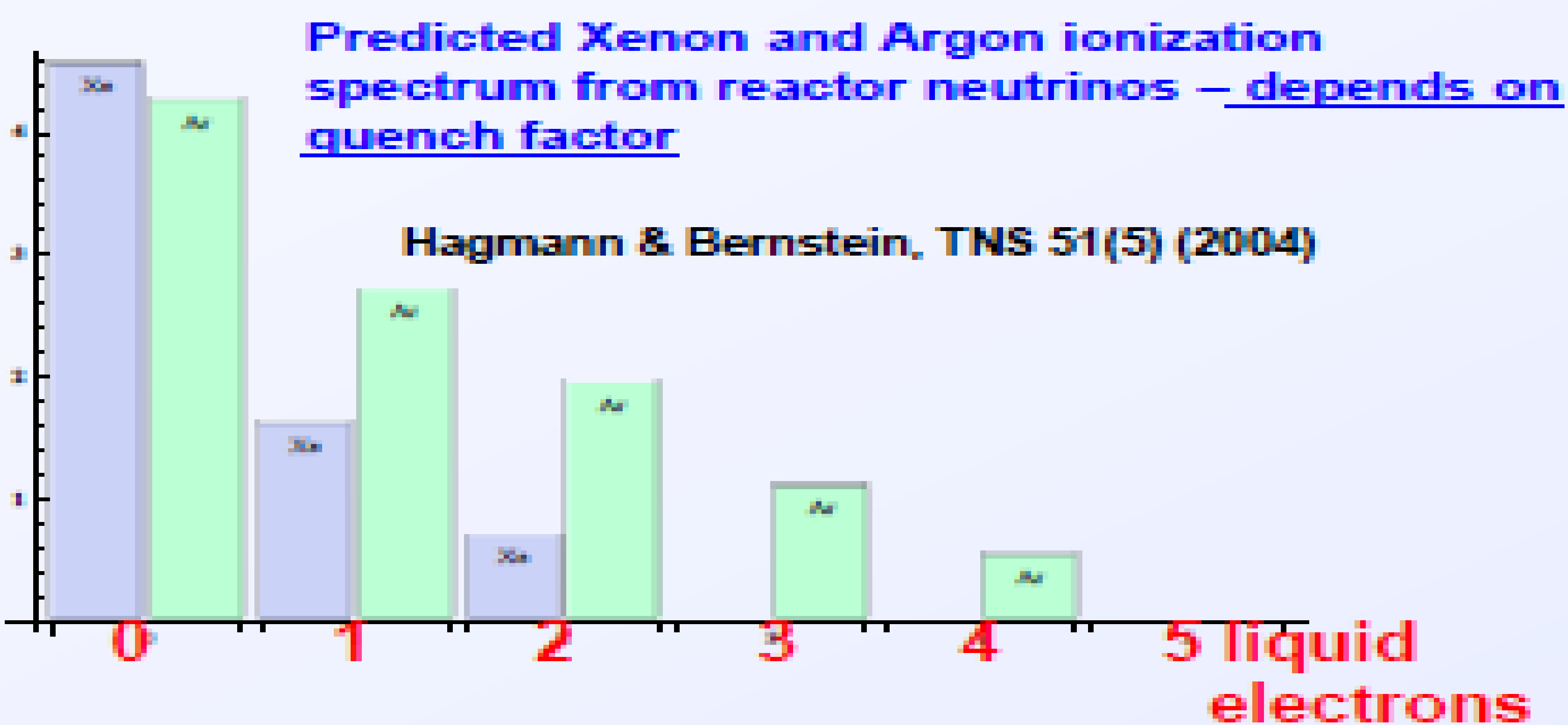
- *Z* – заряд ядра, *N* – количество нейтронов, M – масса ядра
- T – энергия отдачи ядра
- $sin^2\theta_W \approx 0.22$.

Энергия отдачи ядра мала. Для легких ядер (Ar) больше доля событий с энергией отдачи свыше ~400 эВ, чем для тяжелых (Xe)

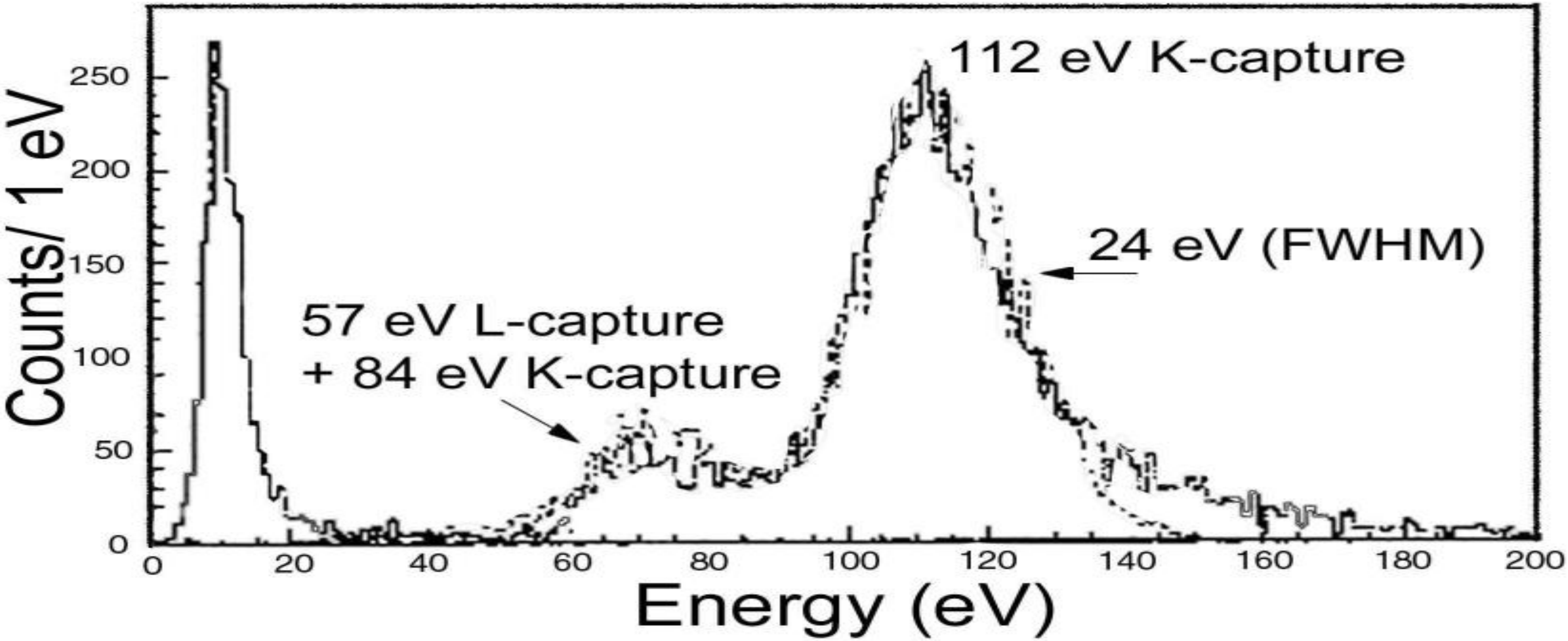
The recoil energy spectrum of reactor antineutrinos in argon and xenon



Электроны от ионизации в аргоне и ксеноне.
Для измерения магнитного момента лучше подходит ксенон, для регистрации когерентного рассеяния нейтрино на ядрах – аргон.
Хорошо иметь сразу два детектора на одном пучке и сравнивать…

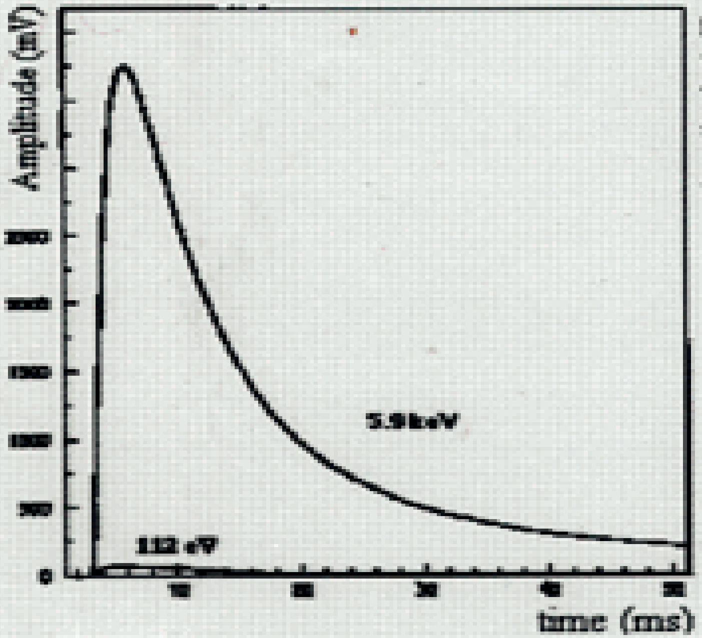


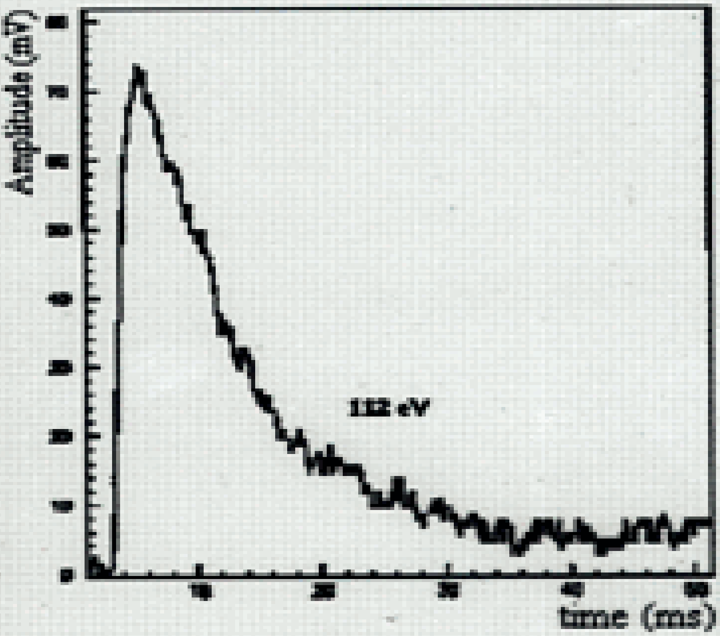
Порог 40 эВ реален!



M.Galeazzi, G.Gallinaro, F.Gatti, P.Meunier, S.Vitale, A.V.Kopylov, V.V.Petukhov, E.A.Yanovich, G.T.Zatsepin Phys.Lett. B, 1998. v.398, p.187

Pulse shape





The pulses have a well defined shape which allows a <u>pulse shape analysis</u> in order to discriminate real pulses from noise with an efficiency of 100%.

Direct Measurement of the L/K Ratio in ^{7}Be Electron Capture

P. A. Voytas,[1] C. Ternovan,[1] M. Galeazzi,[2] D. McCammon,[2] J. J. Kolata,[3] P. Santi,[3] D. Peterson,[3] V. Guimarães,[3] F.D. Becchetti,[4] M. Y. Lee,[4] T. W. O'Donnell,[4] D. A. Roberts,[4] and S. Shaheen[4,5]

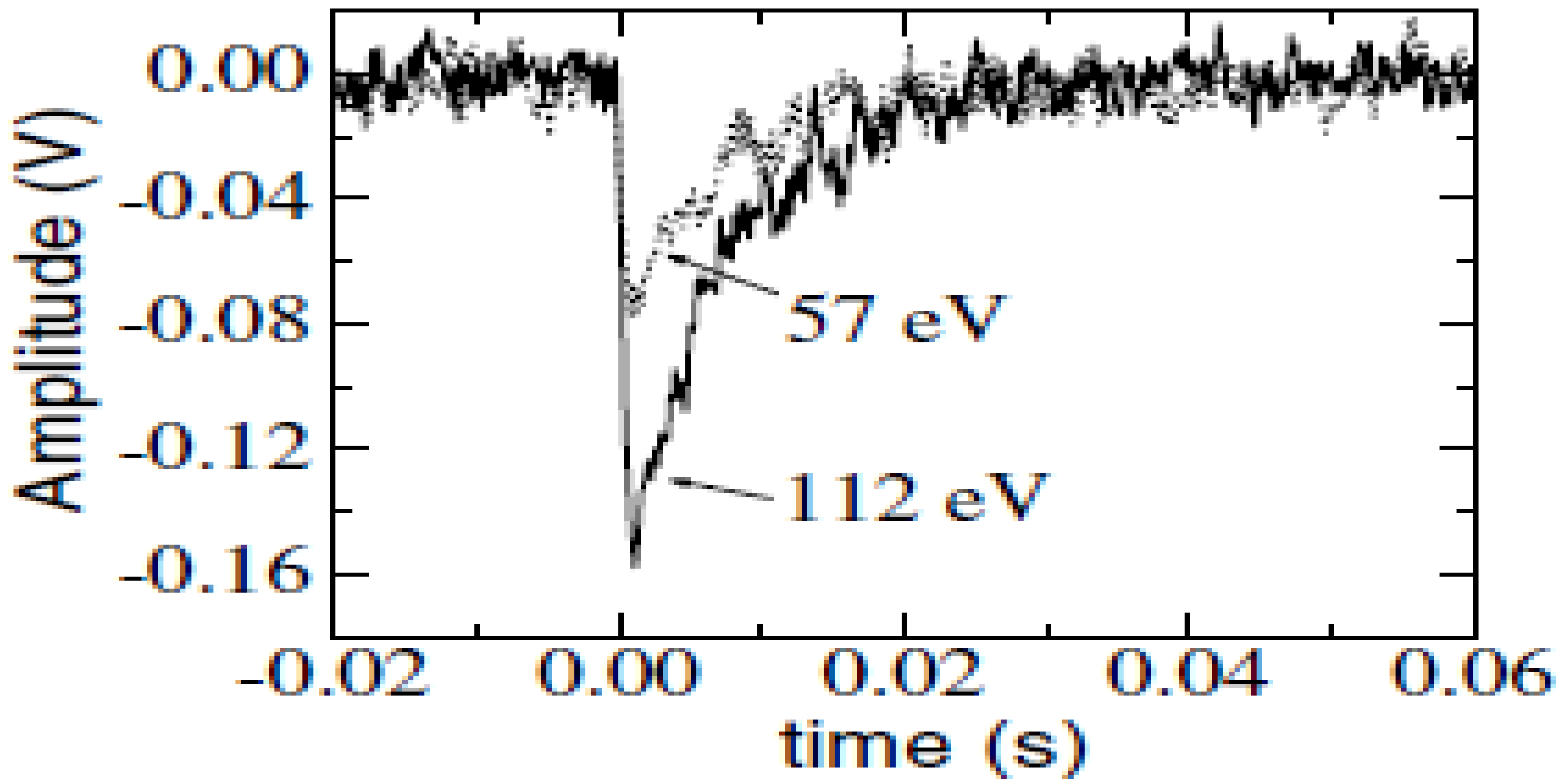
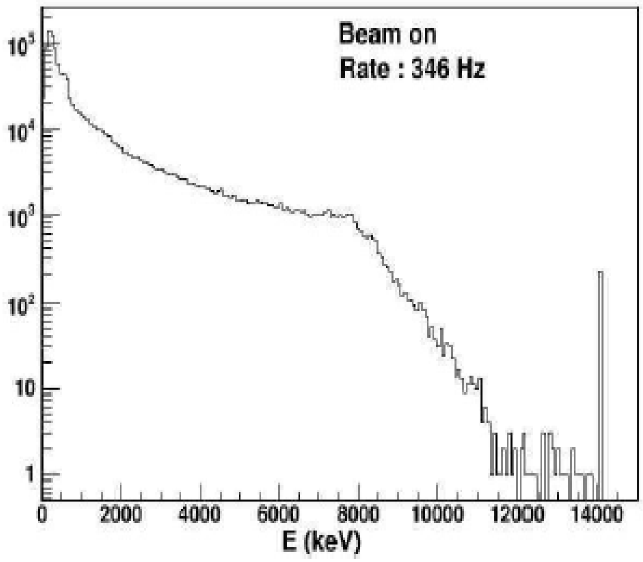


FIG. 2. Example pulses from the microcalorimeter showing noise levels and the characteristic time constant.

Gamma background with 3” NaI(Tl) : Reactor ON

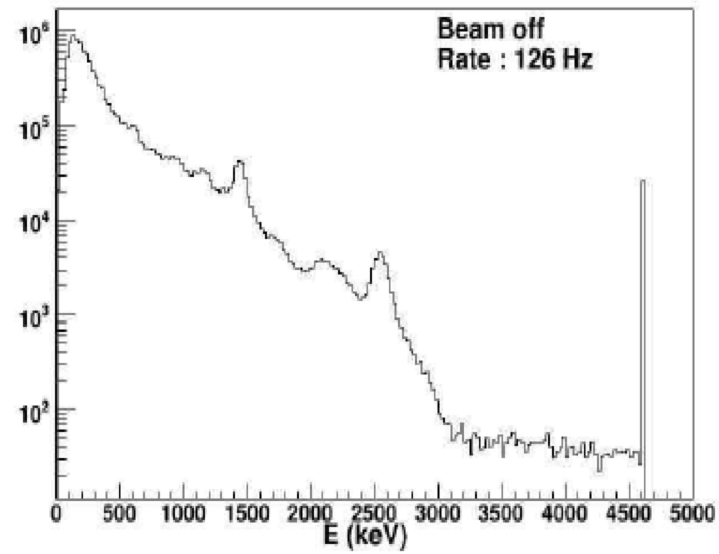
20



- Rate for E>1 MeV : 100 Hz (x10 bg) – higher energy gammas from reactor.
- The shielding container seem to have leakage.

Gamma background with 3” NaI(Tl) : Reactor Off

19



E>1 MeV ; 10.6 Hz

KOREAN EFFORTS ON REACTOR ANTINEUTRINO PHYSICS

Yeongduk Kim
Sejong University
For HANARO-SBL collaboration.

2011. 11.10. LowNu 2011

P.S.Barbeau, J.I.Collar, O.Trench

II. A FIRST COHERENT NEUTRINO DETECTOR

The Low-Background Detector Development group at the Enrico Fermi Institute has investigated several new technologies, each in principle capable of meeting the three goals (energy threshold, background and minimum detector mass) required for a successful measurement of this mode of neutrino interaction in a power reactor. In this paper we concentrate on what is presently considered the most promising path towards this measurement. The prototype described here exhibits an effective mass of 475 g, sufficient for a measurement of the cross section. The technology is however readily scalable to a mass O(10) kg, necessary for most of the applications mentioned above, in the form of a small array of detectors.

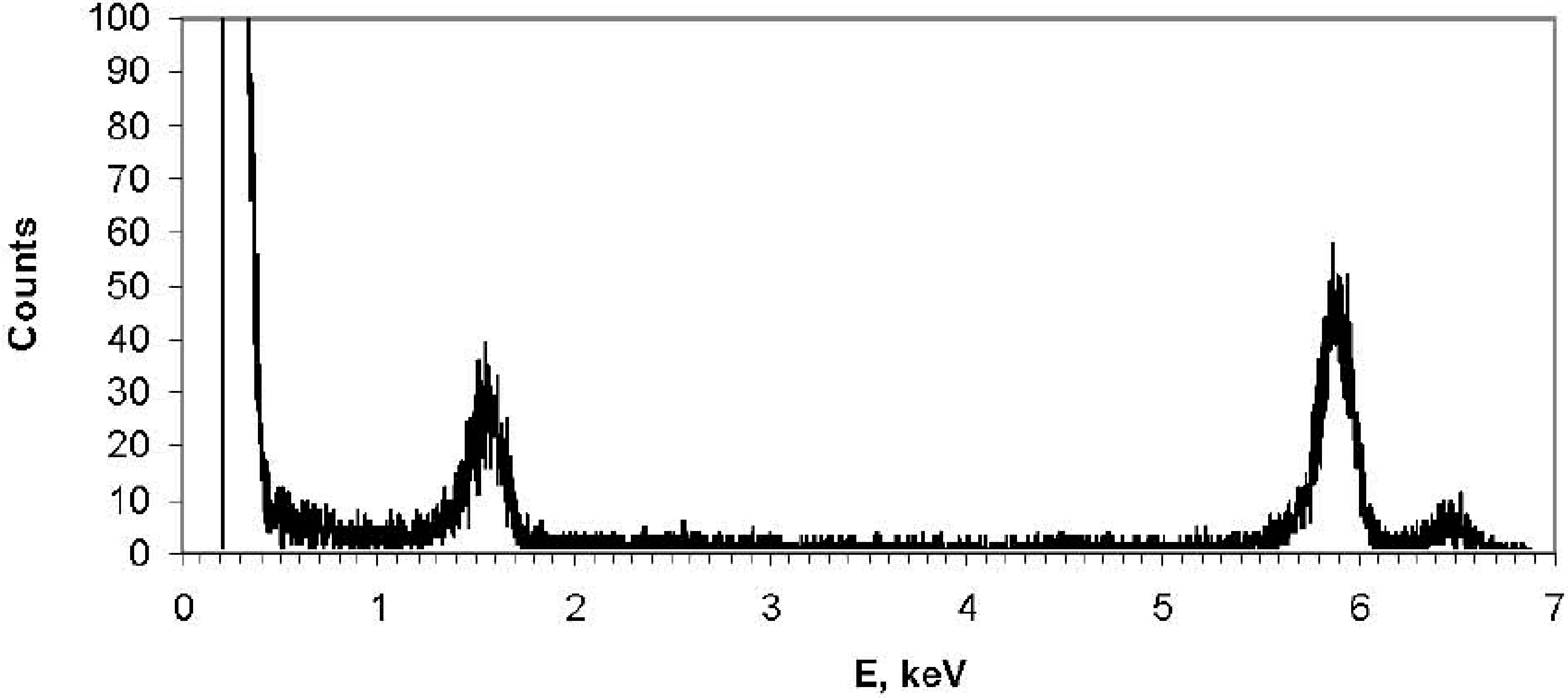
С газовым детектором (Xe,Ar) это достижимо

A noise level of 270 eV (resulting in a threshold two to three times higher) would still be insufficient for a reactor experiment looking for coherent neutrino scattering. However, a number of improvements could in principle reduce this to a threshold ~100 eV or even lower in such a large detector, which would yield a comfortable signal rate for present purposes. Since a large fraction of the noise figure in the seminal work of [17] was due to the electronic characteristics of the field effect transistors (JFETs) available 20 years ago, it seemed timely to reconsider this approach in the light of the most recent technology. A number of possible improvements were envisioned:

С газовым детектором с высоким $(>10^4)$ КГУ эту проблему можно обойти!

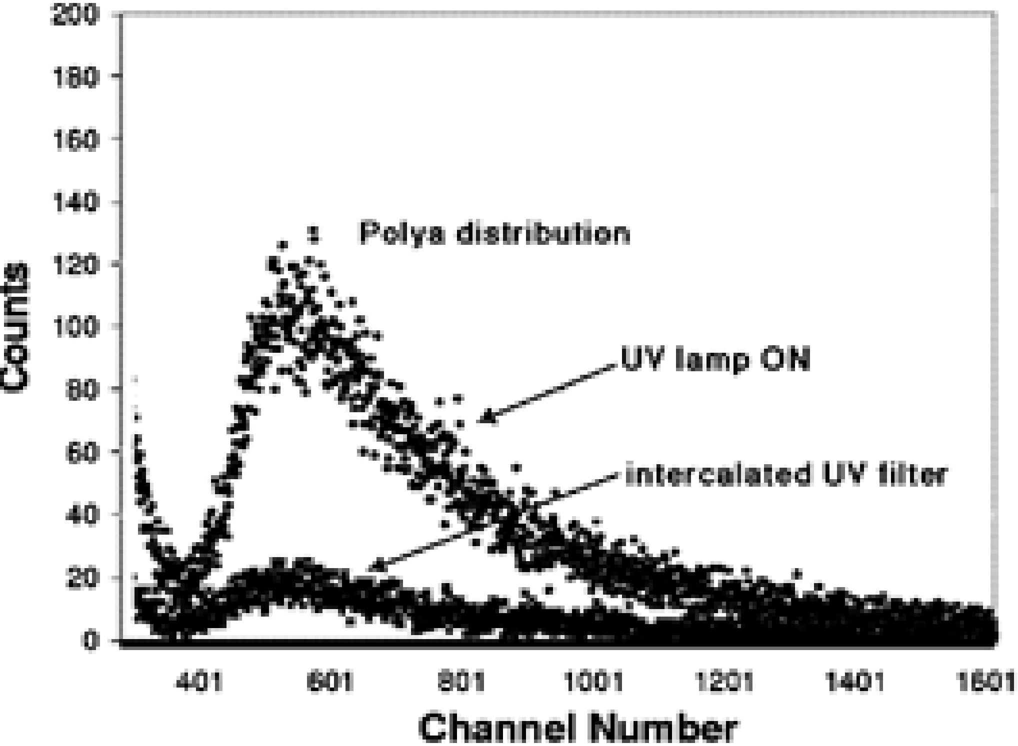
Status

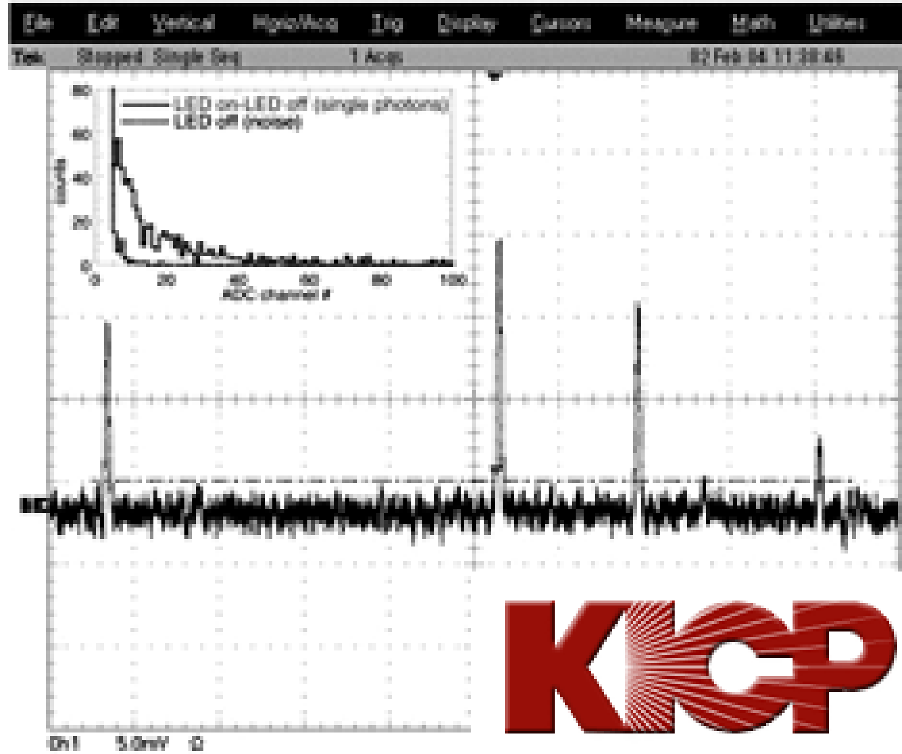
Calibration spectrum in Dubna with (Fe-55, Al) source
Achieved energy threshold is ~350 eV



Development of Low Energy Threshold HPGe Detectors at JINR

Evgeny Yakushev
The project of Department of Nuclear Spectroscopy and Radiochemistry, JINR, MEPHI Session 2012



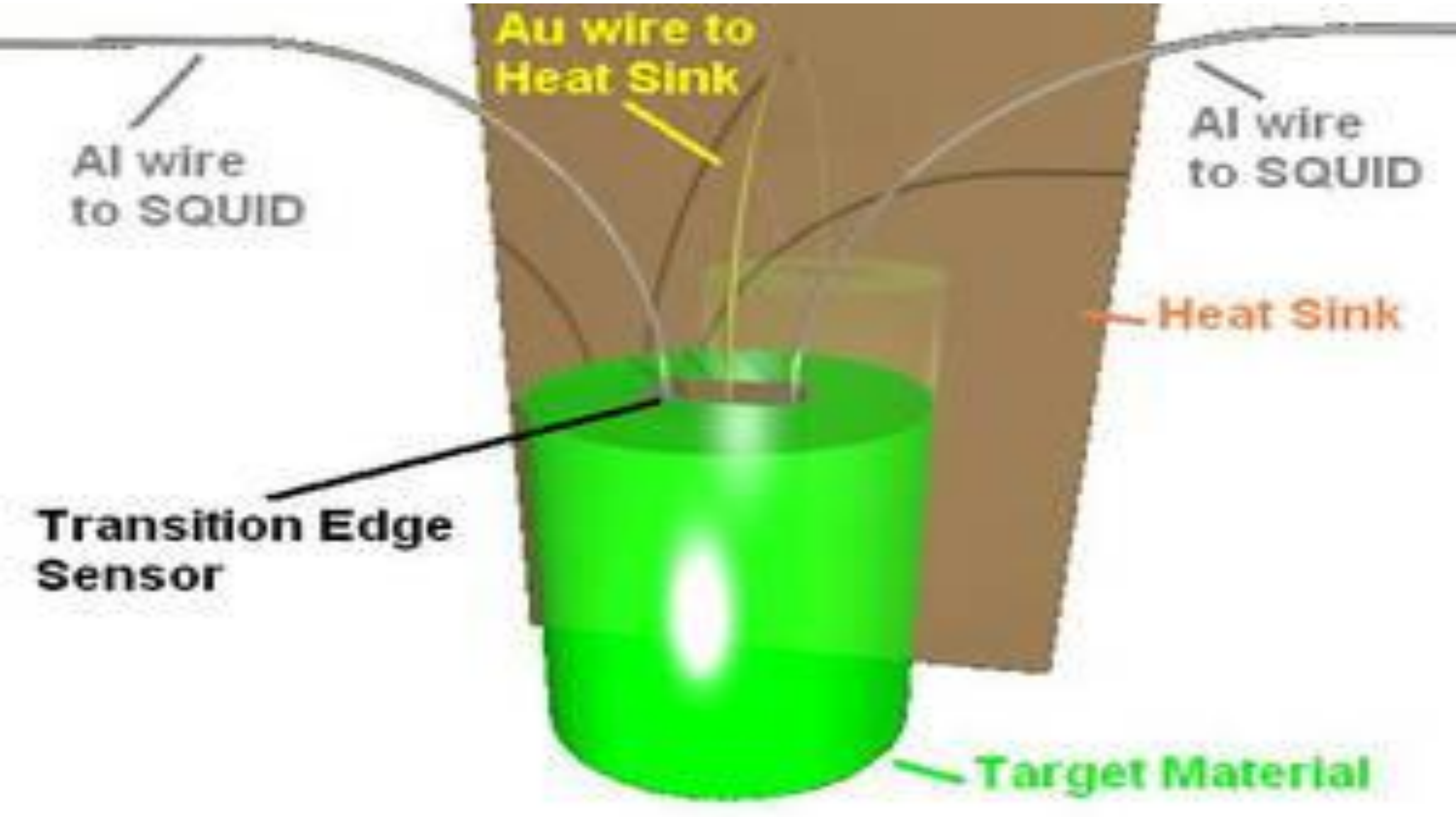


Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

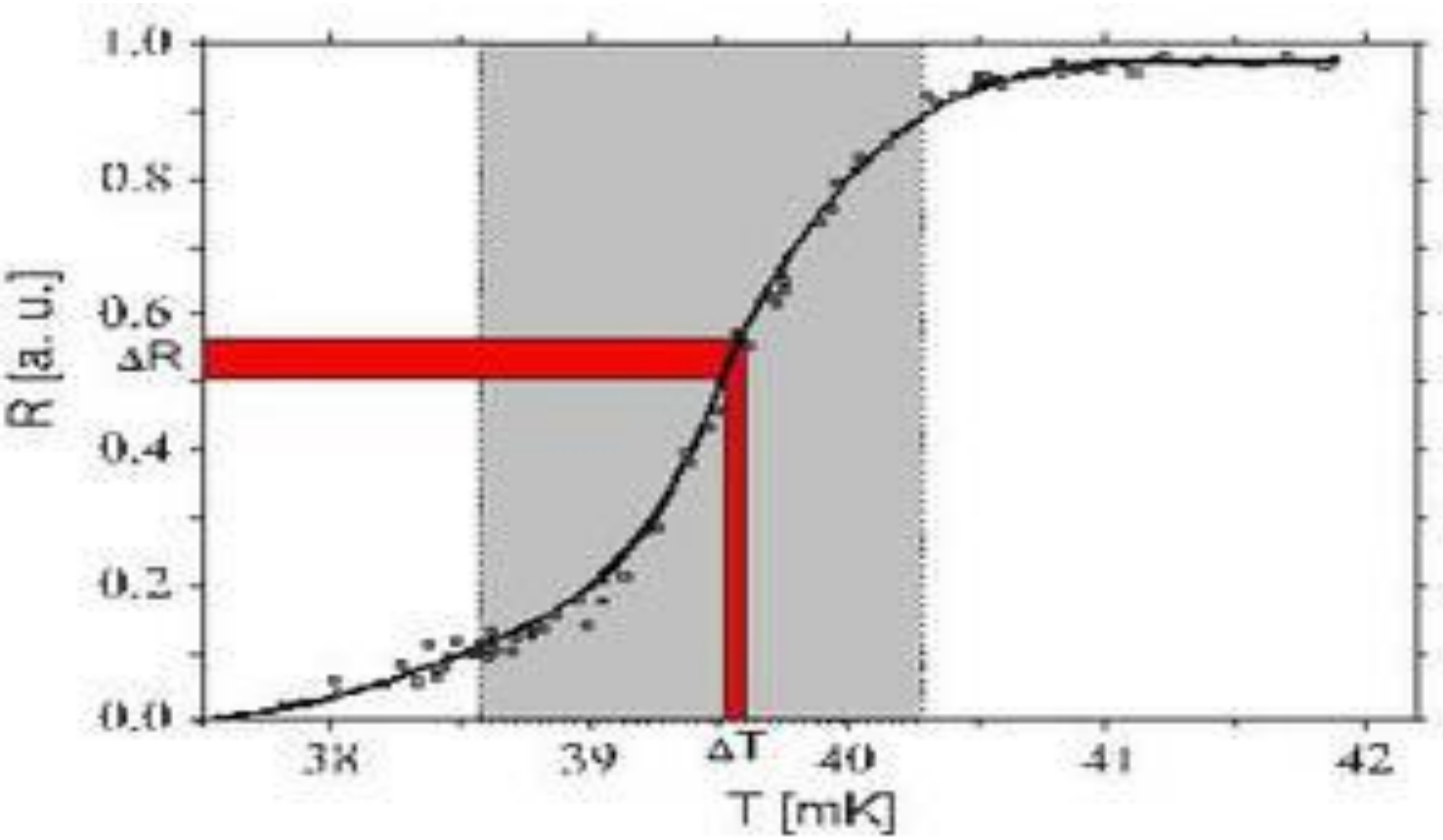
Left: single electron spectrum (showing a typical polya distribution) in P-5 gas using a quadruple university of chicago-3m gas electron multiplier.
Right: single photon pulses from a 10-12 filtered LED on a cooled large area avalanche photodiode (1.6 cm diameter, advanced photonix). Cryogenic operation of laapds produces a substantial reduction in their noise (inset) and gains of a few thousand while still in proportional mode,facilitating single-photon

detection with a very high quantum efficiency (>70%).

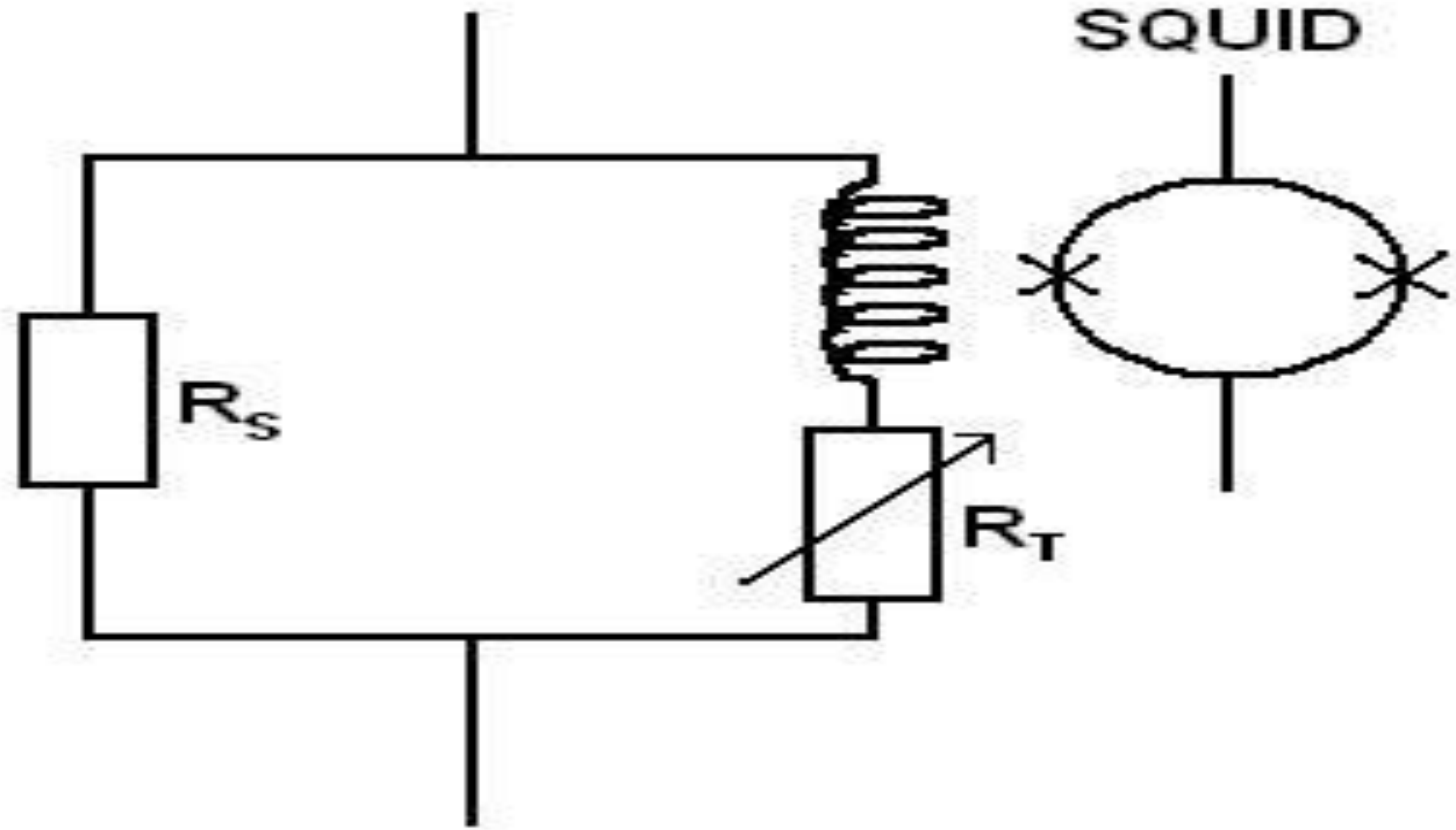
Coherent Neutrino Nucleus Scattering (CNNS) with cryogenic detector



phase transition of a superconducting film



electric curcuit diagram for the resistance measurement with the SQUID



The resistace of the superconducting film (→ RT in the figure below) is measured with a SQUID (**S**uperconducting **QU**antum **I**nterference **D**evice), which is a very sensitive sensor for magnetic fields. As the electric curcuit diagram below shows, the SQUID measures the magnetic field produced by a coil, which has the same current as the superconducting film.

- **Outlook**
- If we succeed in developing a cryogenic detector with the specifications mentioned above (low energy threshold, good energy resolution and **a massive target of several 100 g**), the detector should be placed to an area with a very high neutrino flux of at least about **10^{13}neutrinos/cm^{2} s**. Such a place could be in the vicinity of a nuclear power plant with a thermal power of 2 GW.

SN neutrino detection via coherent scattering using the spherical proportional counter (SPC)

G. Tsiledakis

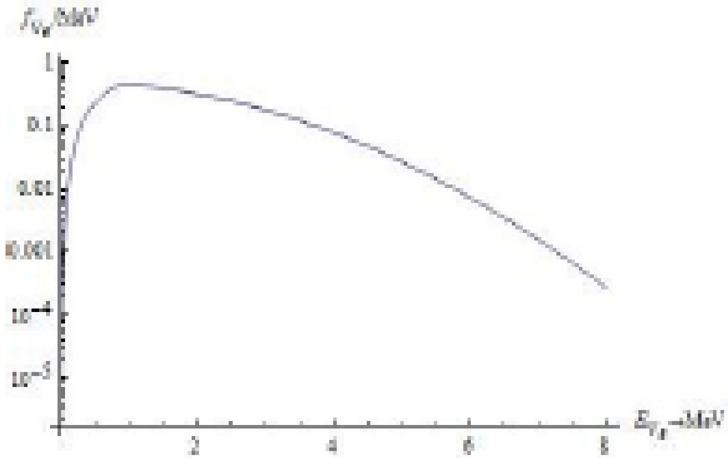
E. Bougamont[1], P. Colas[1], J. Derre[1], A. Dastgheibi-Fard, I. Giomataris[1], G. Gerbier[1], M. Gros[1], N. Grouas, P. Loiza, P. Magnier[1], J. P. Mols, X.F. Navick[1], P. Salin[3] I. Savvidis[2], G. Tsiledakis[1], J. D. Vergados[4]

1: IRFU Saclay, 2: Univ. of Thessaloniki, 3: APC Univ. of Paris, 4: Univ. of Ioannina

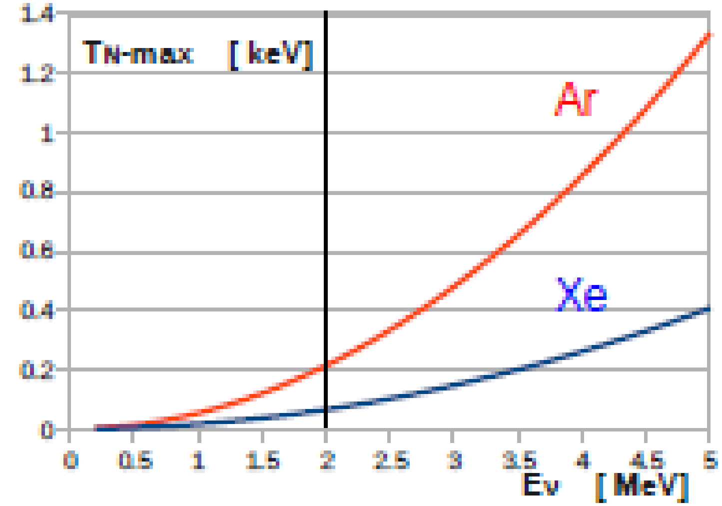
Friday 22/07/2011--Phenomenology and Detection Session

IRFU (Institute of Research into the Fundamental Laws of the Universe) Saclay (France)

But this coherent ν - A elastic scattering has never been observed...



Typical reactor electron antineutrino spectrum



Recoil energies are tiny!

$$T_N = 2\, m_N (E_\nu \cos\theta)^2 / \{(m_N + E_\nu)^2 - (E_\nu \cos\theta)^2\}$$

Energy ν = 2 MeV ~ <Eν> at nuclear reactor

→Xe ==> T_{max}=66 eV

→Ar ==> T_{max}=215 eV

A. Druikier, L. Stodolsky, Phys.Rev.D30:2295,1984, JI Collar, Y Giomataris - NIMA471:254-259,2000, H. T. Wong, arXiv:0803.0033-2008, PS Barbeau, JI Collar, O Tench - Arxiv preprint nucl-ex/0701012, 2007

Spherical Proportional Counter

- SPC at Saclay

- **Simplicity of design**
- **Cheap**
- **Single channel to read-out a large volume**
- **Low detector C < 0.1 pF ==> very-low electronic noise**
- **Large variety of gases – low to high p**
- **Robustness**
- **Good energy resolution**
- **Low energy threshold**
- **Efficient fiducial cut (rise time)**

Sub-keV calibration sources (i)

Am-241 source – April 2010

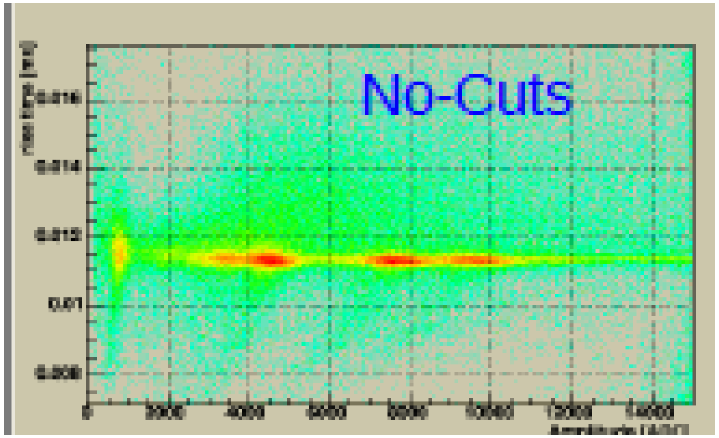
$^{241}Am \to (^{237}Np)^* + {}^{4}He + 5.6\,MeV$ α

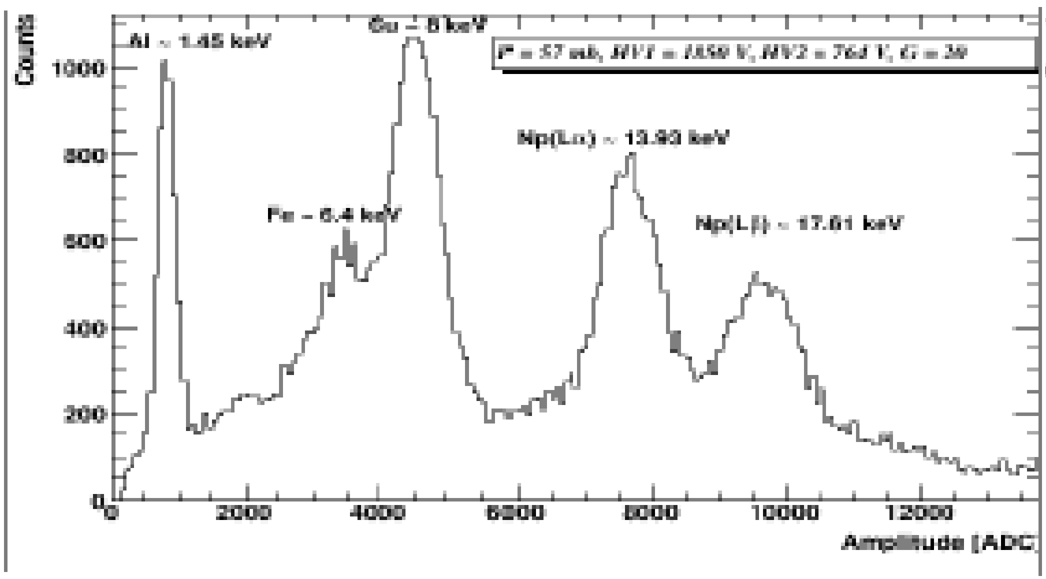
Np-237 decays with γ ~ 59.5 keV and L rays

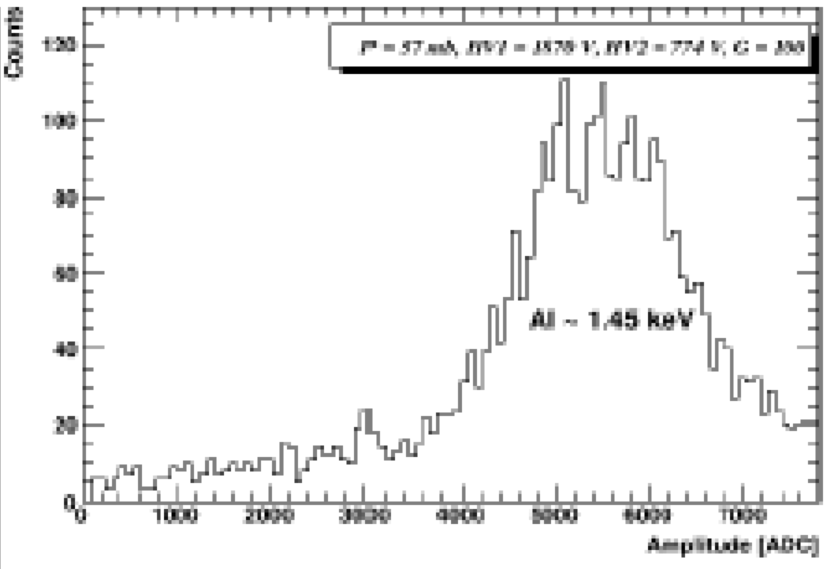
Source attached to sensor-rod

Source covered by thin foils

20μm Al foil ≈ α range







Flat background at low E

arXiv:1010.4132 [physics.ins-det], 2010

Summary

- A new spherical detector is developed with large mass and low sub-keV energy threshold
- Good energy resolution, robust, cheap and stable
- Very low detection threshold ~ 30 eV (single electrons sensitivity)
- ν – A coherent elastic scattering under reach
- Can be served as a low cost Supernova demonstrator
- A world wide network of several detectors is advertized

Neutral Current Coherent Cross Sections- Implications on Gaseous Spherical TPC's for detecting SN and Earth neutrinos

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Abstract. The detection of galactic supernova (SN) neutrinos represents one of the future frontiers of low-energy neutrino physics and astrophysics. The collapse of a neutron star liberates a gravitational binding energy of about 3×10^{53} erg, 99% of which is transferred to neutrinos and antineutrions of all the flavors and only 1% to the kinetic energy of the explosion. In other words, a core-collapse supernova represents one of the most powerful sources of neutrinos and antineutrinos of all flavors in the Universe. The neutron coherence of neutral currents (NC) allows quite large cross sections in the case of neutron rich targets, which can be exploited in detecting earth and sky neutrinos by measuring nuclear recoils. These (NC) cross sections are not dependent on flavor conversions and, thus, their measurement will provide useful information about the neutrino source. In particular they will yield information about the primary neutrino fluxes, i.e. before flavor conversions in neutrino sphere. The advantages of large gaseous low threshold and high resolution time projection counters (TPC) detectors will be discussed. These are especially promising since they are expected to be relatively cheap and easy to maintain. The information thus obtained can also be useful to other flavor sensitive

Journal of Physics: Conference Series 309 (2011) 012031

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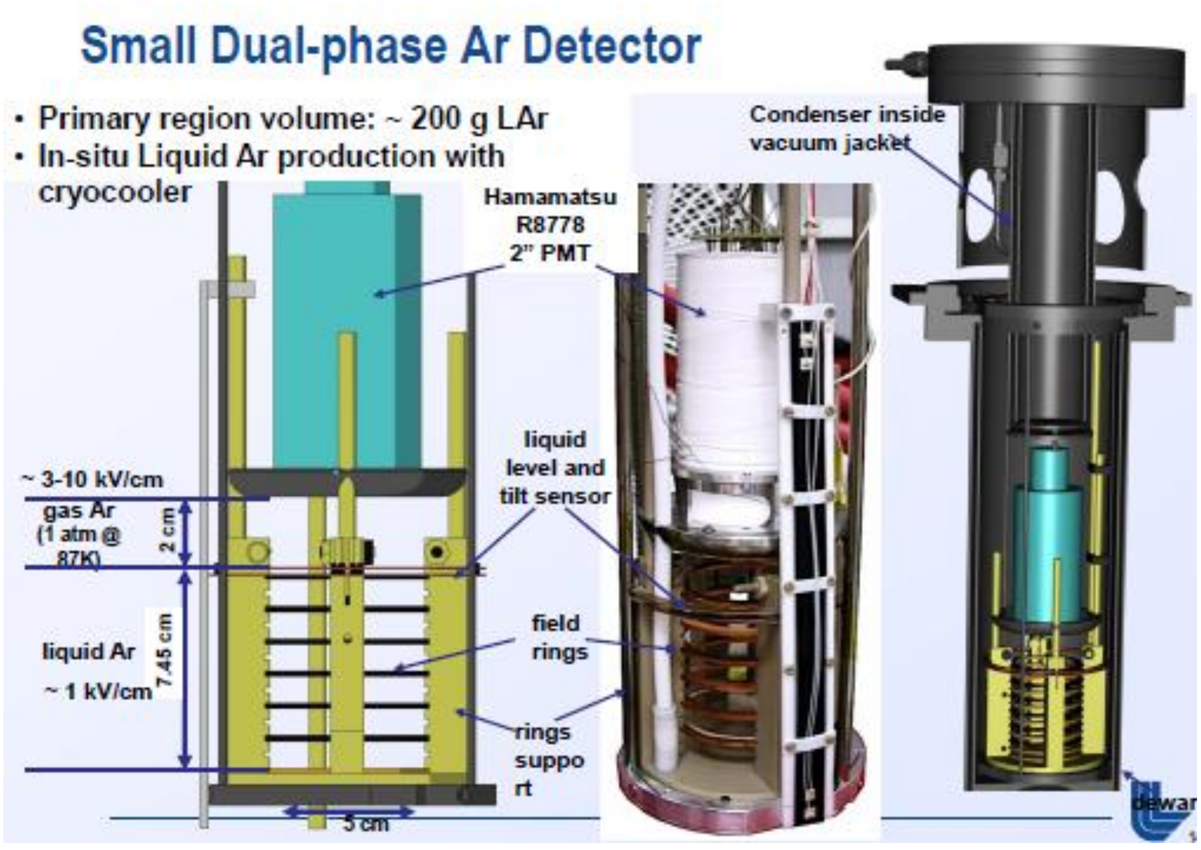
5. Conclusions

From the above results one can clearly see the advantages of a gaseous spherical TPC detector dedicated for SN neutrino detection. The first idea is to employ a small size spherical TPC detector filled with a high pressure noble gas. An enhancement of the neutral current component is achieved via the coherent effect of all neutrons in the target. Thus employing, e.g., Xe at 10 Atm, with a feasible threshold energy of about 100 eV in the recoiling nuclei, one expects between 700 and 900 events for a sphere of radius 5m. Employing ^{40}Ar one expects between 200 and 300 events but with a vessel of larger radius (R=10m). If necessary, this detector can be tested with Earth neutrino sources, which have a neutrino spectrum analogous to that of a SN.

The second idea is to build several such low cost and robust detectors and install them in several places over the world. First estimates show that the required background level is modest and therefore there is no need for a deep underground laboratory. A mere 100 meter water equivalent coverage seems to be sufficient to reduce the cosmic muon flux at the required level (in the case of many such detectors in coincidence, a modest shield is sufficient). The maintenance of such systems, quite simple and needed only once every few years, could be easily assured by universities or even by secondary schools, with only specific running programs.

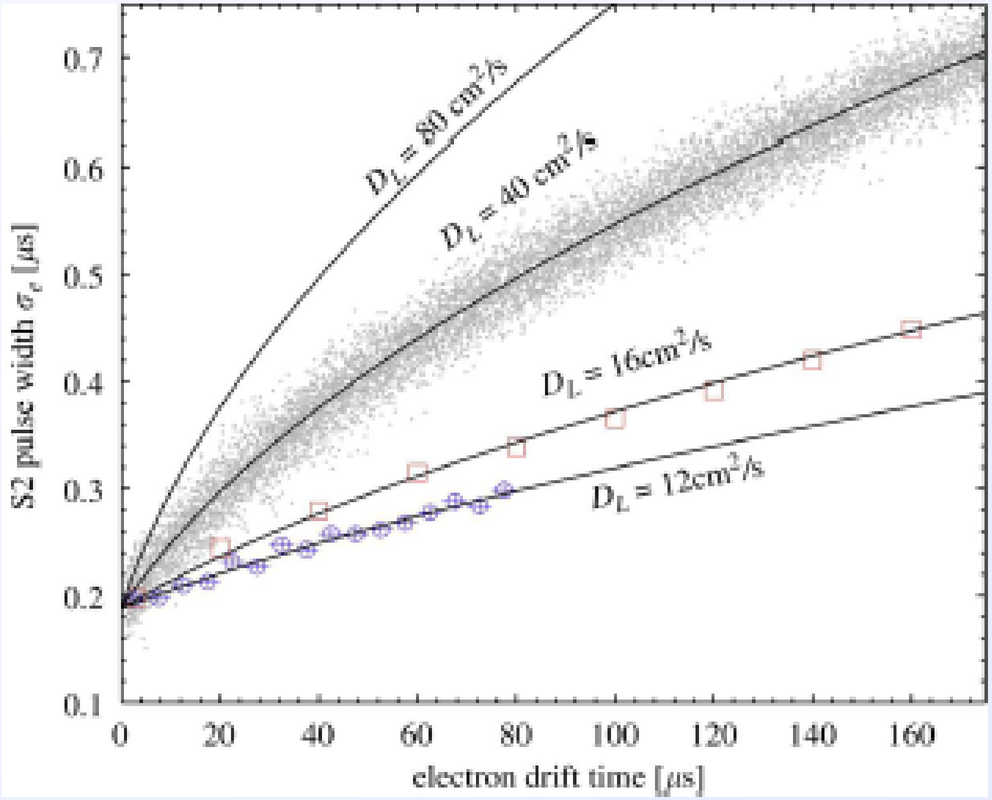
Перспективы двухфазного детектора для регистрации антинейтрино от реактора ?

A.Bernstein report at LOWNu2011



Перспективы двухфазного детектора для регистрации антинейтрино от реактора?

Time Projection breaks down at low energy: recover z position by diffusion



P.Sorensen - arXiv:1102.2865

Without a starting flash of light, we need a way to reconstruct vertical position

Answer: measure the transverse width of the electron cloud

(but it won't work for one electron…)

A.Bernstein Report at LOWNu2011

DUSEL at Homestake mine

PHYSICAL REVIEW D **84**, 013008 (2011)

Coherent neutrino scattering in dark matter detectors

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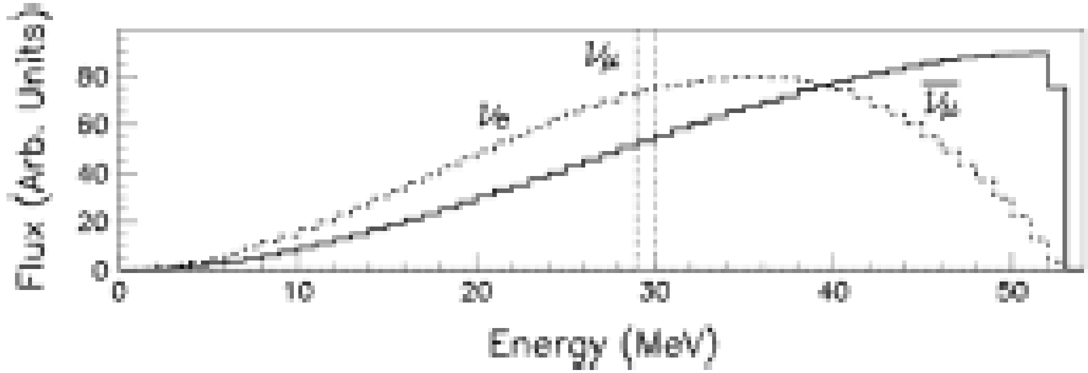
(Received 31 March 2011; published 15 July 2011)

Coherent elastic neutrino-nucleus and weakly interacting massive particle-nucleus interaction signatures are expected to be quite similar. This paper discusses how a next-generation ton-scale dark matter detector could discover neutrino-nucleus coherent scattering, a precisely-predicted standard model process. A high-intensity pion- and muon- decay-at-rest neutrino source recently proposed for oscillation physics at underground laboratories would provide the neutrinos for these measurements. In this paper, we calculate raw rates for various target materials commonly used in dark matter detectors and show that discovery of this interaction is possible with a 2 ton · year GEODM exposure in an optimistic energy threshold and efficiency scenario. We also study the effects of the neutrino source on weakly interacting massive particle sensitivity and discuss the modulated neutrino signal as a sensitivity/consistency check between different dark matter experiments at the Deep Underground Science and Engineering Laboratory. Furthermore, we consider the possibility of coherent neutrino physics with a GEODM module placed within tens of meters of the neutrino source.

DOI: 10.1103/PhysRevD.84.013008 PACS numbers: 13.15.+g, 25.30.Pt, 95.35.+d

In order to be reasonably concrete, we study a set of experimental designs inspired by proposals for the Deep Underground Science and Engineering Laboratory (DUSEL). We note that the detector designs are not very different from those under consideration at other underground laboratories and that the results can be easily scaled. For the neutrino source, we assume a DAR configuration produced by high-intensity cyclotrons which are now under development [18,19] and proposed for DUSEL [20].

DAR neutrinos are known to be an excellent source for neutrino-nucleus coherent scattering experiments [2,3]. The neutrinos are produced with relatively low energies (< 52.8 MeV), a range where coherent neutrino scattering dominates all other cross sections by about an order of



800 МэВ протоны
1 МВт мощность пучка
4x10²² нейтрино в год каждого аромата
Duty factor 13(20)%

FIG. 1. Energy distribution of neutrinos in a DAR source, from Ref [21].

DAR: pion and muon Decay At Rest

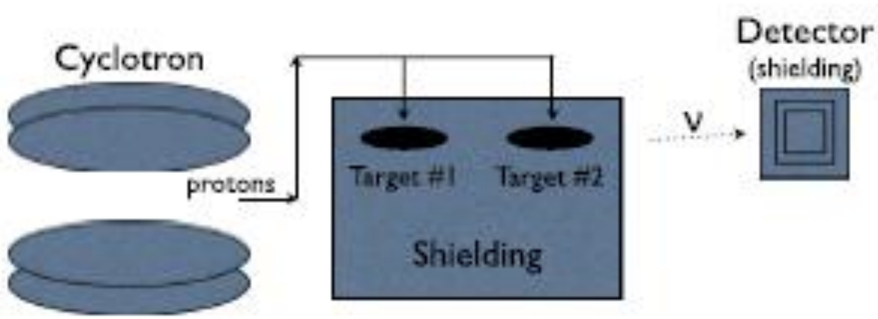
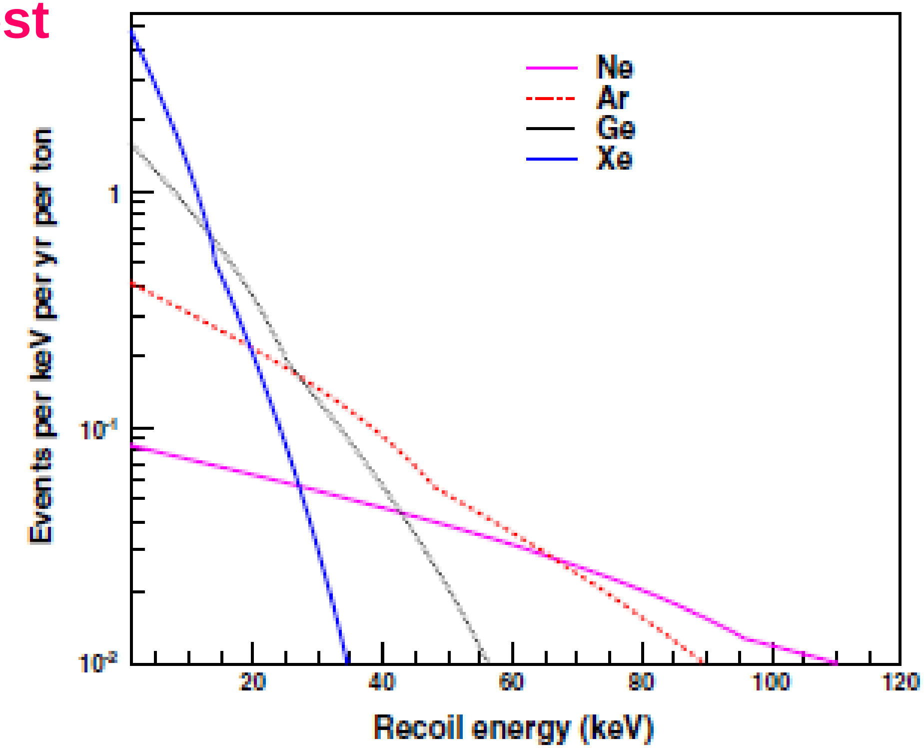
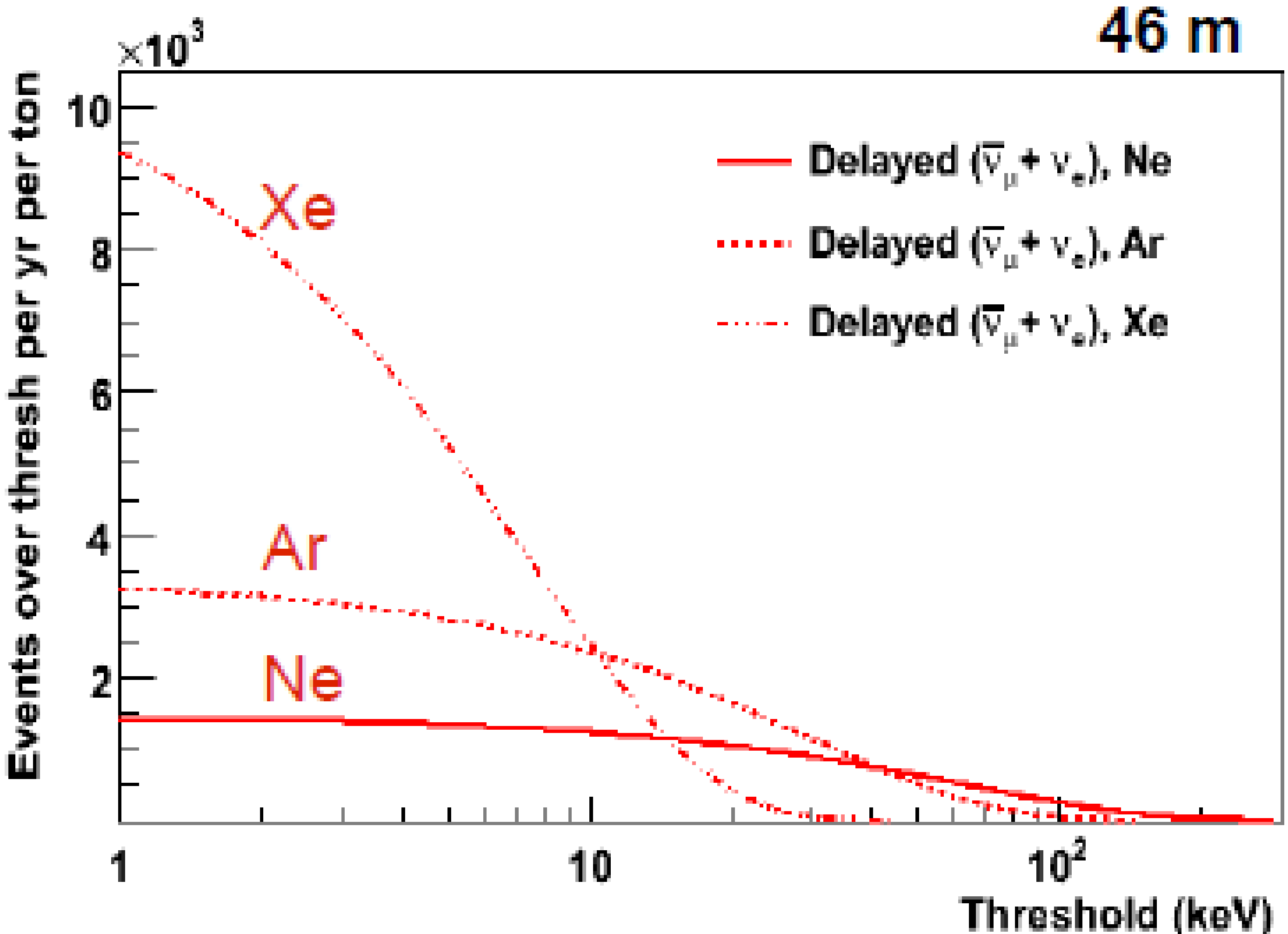


FIG. 2 (color online). A schematic of the experimental configuration.



Integrated SNS yield for various targets



Lighter nucleus ⇒ expect fewer interactions, but more at higher energy

K.Scholberg Spallation Source 2012

target design for GEODM is an array of 300 ~ 5 kg Ge crystals operated at 40 mK with a total target mass of

A coherent neutrino interaction discovery in GEODM could be achieved with a 2 ton-year exposure. About 2.0 detected coherent neutrino events/ton/year over a background of 0.03 events/ton/year are expected in a GEODM-style detector at a 2.3 km baseline, given optimistic assumptions for energy threshold and detection efficiency. Even in a conservative (baseline) scenario, with energy threshold and efficiency reasonably consistent with CDMS II, evidence for coherent neutrino scattering could be obtained with a 4.5 ton-year exposure. In addition, a 10 kg fiducial mass GEODM-derived detector brought within 20 m of the neutrino source could collect about 1350 events with a 50 kg · year exposure. Such a sample would be good for a <5% flux-averaged total cross section measurement uncertainty and significant tests of the standard model.

Commendations for *Nature* News & Comment in the 2012 Online Media Awards Find out more

NATURE | NEWS FEATURE

After the Higgs: The new particle landscape

A.Suzuki NOW_Sept_2012

Physicists are planning the pow detail.

Matthew Chalmers

29 August 2012

ILLUSTRATION BY BREN

Going global

If a linear collider is to be approved in the next few years, says Evans, it will probably not be built at CERN. Despite the European lab's wealth of technical and political infrastructure, it has its hands full with the LHC, which isn't even scheduled to reach its design energy of 7 TeV per beam until 2014 and is also scheduled to undergo a luminosity upgrade around 2022. “I'd bet that the highest priority of the European strategy workshop will be continuing to exploit and upgrade the LHC,” says John Womersley, chief executive of Britain's Science and Technology Facilities Council, which controls the country's spending on particle physics.

The United States is also an unlikely site for a new collider, says Fermilab director Pier Oddone, who is chair of the International Committee for Future Accelerators. “Something drastic would have to change,” he says. After the closure of Fermilab's 2-TeV Tevatron collider, the energy frontier crossed from the United States to Europe. So the current US strategy is to concentrate on the 'intensity frontier', studying rare particle interactions produced by, for example, intense beams of neutrinos. And yet, says Oddone, “we had a fairly severe budget cut at the beginning of this year and had problems fitting in a facility [a long-baseline neutrino experiment] that costs one-tenth of the ILC”. Oddone says that it would also be “very difficult” at this time for the United States to contribute much to a lepton collider built elsewhere.

Many observers think that by far the strongest candidate to host the next project is Japan. After all, notes Evans, Japan made a significant contribution to the LHC in the mid-1990s when the project was under financial strain. “Perhaps it's time for Europe to return the favour,” he says. The Japanese premier made positive references to the ILC in December 2011, just after the first preliminary sightings of the new boson were announced. There is a scent of extra funds, because the new accelerator is being discussed as part of a broader economic plan to boost regions devastated by the March 2011 earthquake; the idea is to make it the hub of an 'international city' comprising other research laboratories, industrial zones and education centres. And as Japanese particle physicists update their five-year roadmap this year, the ILC remains at the top of their new-project wish-list. Specifically, explains Atsuto Suzuki, director-general of the KEK laboratory in Tsukuba, the community's recommendation was that “Japan should take leadership of the early realization of an electron–positron linear collider should a particle such as a Higgs boson be confirmed at the LHC”.

PHYSICAL REVIEW D **86**, 013004 (2012)

Measuring active-to-sterile neutrino oscillations with neutral current coherent neutrino-nucleus scattering

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(Received 20 January 2012; published 2 July 2012)

Light sterile neutrinos have been introduced as an explanation for a number of oscillation signals at $\Delta m^2 \sim 1$ eV^2. Neutrino oscillations at relatively short baselines provide a probe of these possible new states. This paper describes an accelerator-based experiment using neutral current coherent neutrino-nucleus scattering to strictly search for active-to-sterile neutrino oscillations. This experiment could, thus, definitively establish the existence of sterile neutrinos and provide constraints on their mixing parameters. A cyclotron-based proton beam can be directed to multiple targets, producing a low-energy pion and muon decay-at-rest neutrino source with variable distance to a single detector. Two types of detectors are considered: a germanium-based detector inspired by the SuperCDMS design and a liquid argon detector inspired by the proposed CLEAR experiment.

The accelerator and detector location is envisioned close to a large water- or scintillator-based detector [44–49]. The neutrino flux normalization uncertainty at each baseline is conservatively expected at 1.5%, given a $\mathcal{O}(100$ kton$)$ device. We assume the flux has been constrained to this level by an independent measurement of ν-electron scattering with a large detector assumed to be running concurrently. The 1.5% uncertainty estimate takes into

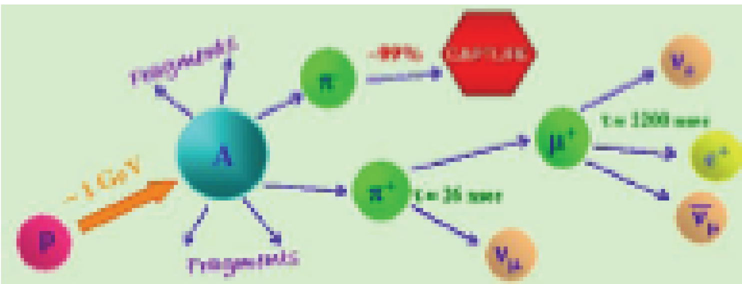
CDMS and CLEAN or CLEAR

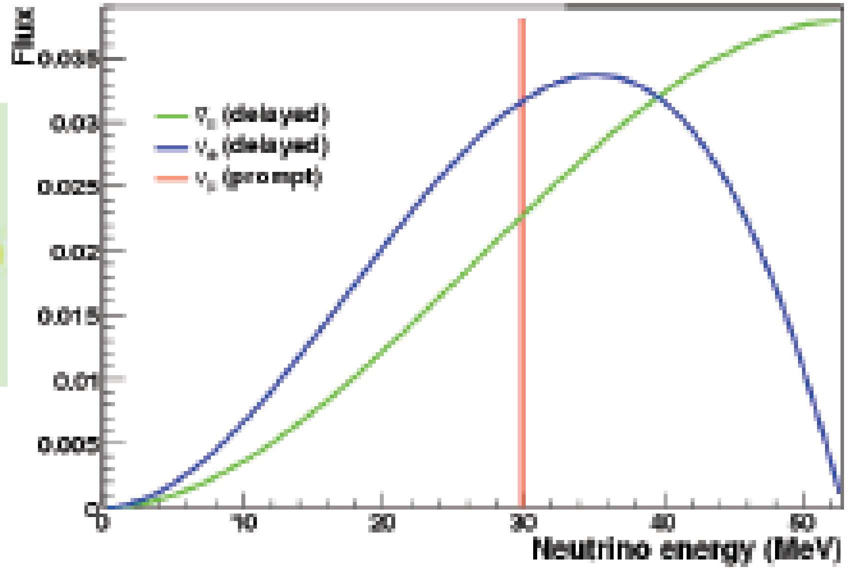
Figures 5 and 7 show that, despite the difference in fiducial mass, the 100 kg germanium detector performs slightly better than the 456 kg liquid argon one. The difference is in part due to the difference in nuclear recoil energy threshold; 10 keVr for germanium, 30 keVr for argon. This emphasizes the fact that a low detector energy threshold is important for obtaining a high-statistics sample of coherent neutrino scattering events as the rate is dominated by events with very low-energy recoils ($\lesssim$ 10 keVr).

1 eV^2. Depending on the detector technology and run scenario, the experiment described is sensitive to the LSND best-fit mass splitting at the level of 3–5σ and can probe large regions of the LSND and reactor anomaly allowed regions. The experiment offers a pure and unique analysis of neutrino oscillations that is complementary to charged current-based appearance and disappearance searches.

Expected neutrino spectrum

F. Avignone and Y. Efremenko, J. Phys. G: 29 (2003) 2615-2628





$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

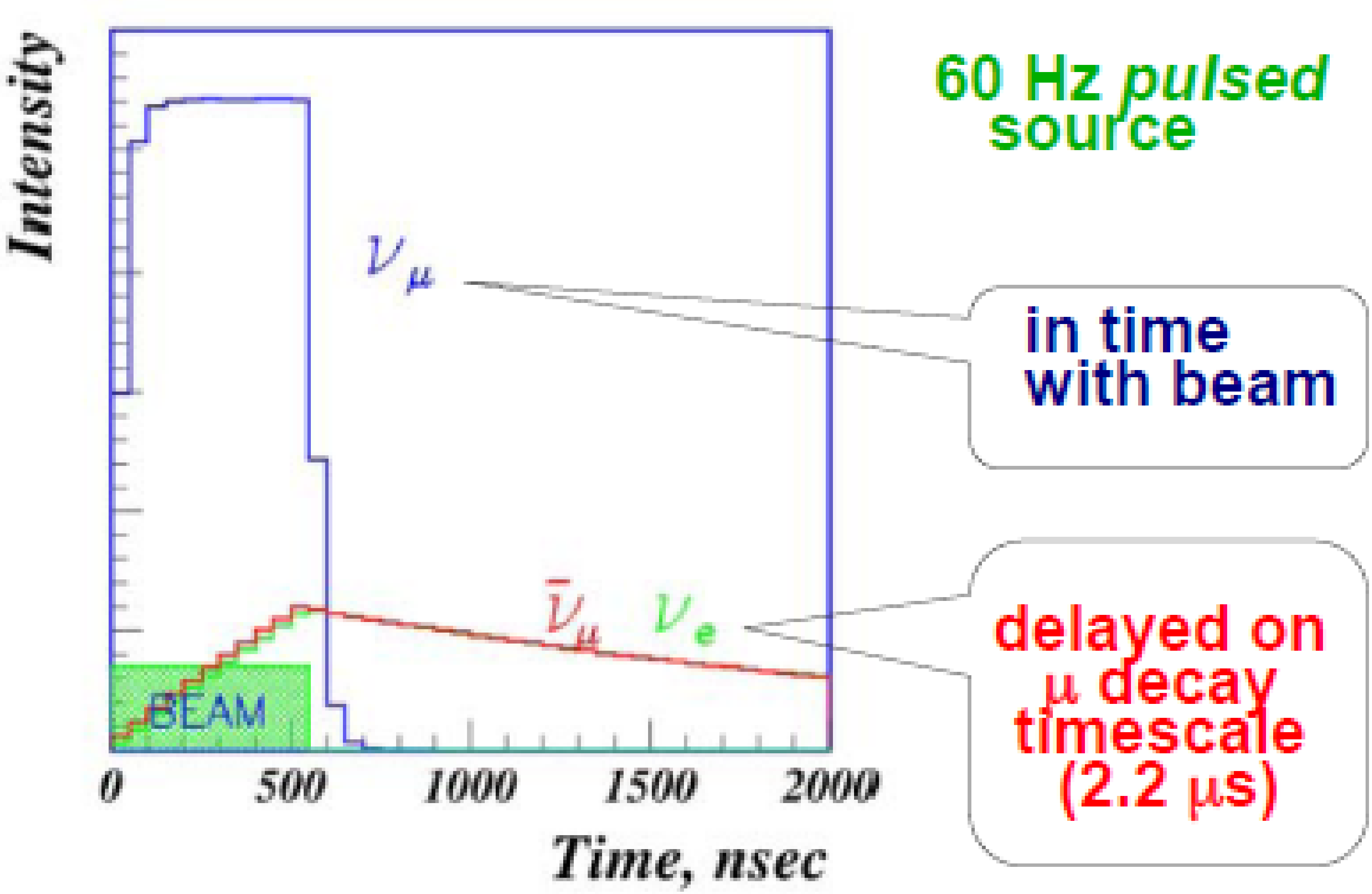
$$\downarrow$$

$$\mu^+ \longrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies between 0 and $m_\mu/2$
DELAYED (2.2 μs)

Neutrino flux: few times 10^7 /s/cm^2 at 20 m ~0.13 per flavor per proton

Time structure of the source

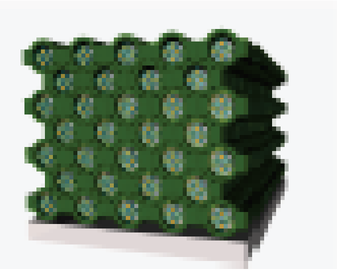


Background rejection factor ~few x 10^{-4}

Summary

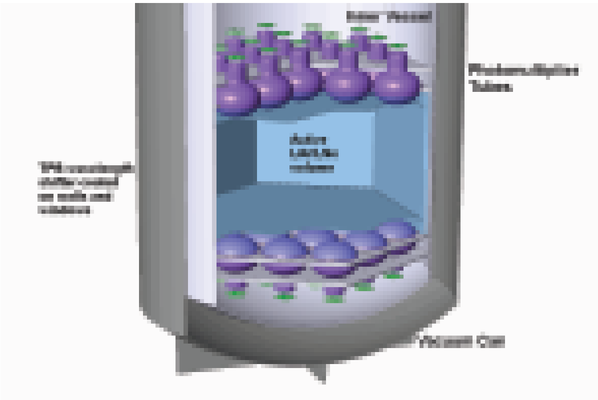
The SNS at ORNL will provide a high-intensity stopped-pion neutrinos in the fews tens of MeV range

This is ideal for studiesof supernova-relevant neutrino-nucleus interactions!



Cross-section studies valuable for understanding of supernova processes, and supernova ν

Another possibility is detection of coherent elastic neutrino-nucleus scattering: huge rate, but low energy recoils; now within reach of new low-threshold technology developed for dark matter searches



The SNS is the best neutrino source in the world in the few tens of MeV range; let's not waste it!

→ start with a ton-scale detector for cross-sections?

3.1. The Inner Noble Liquid Detector

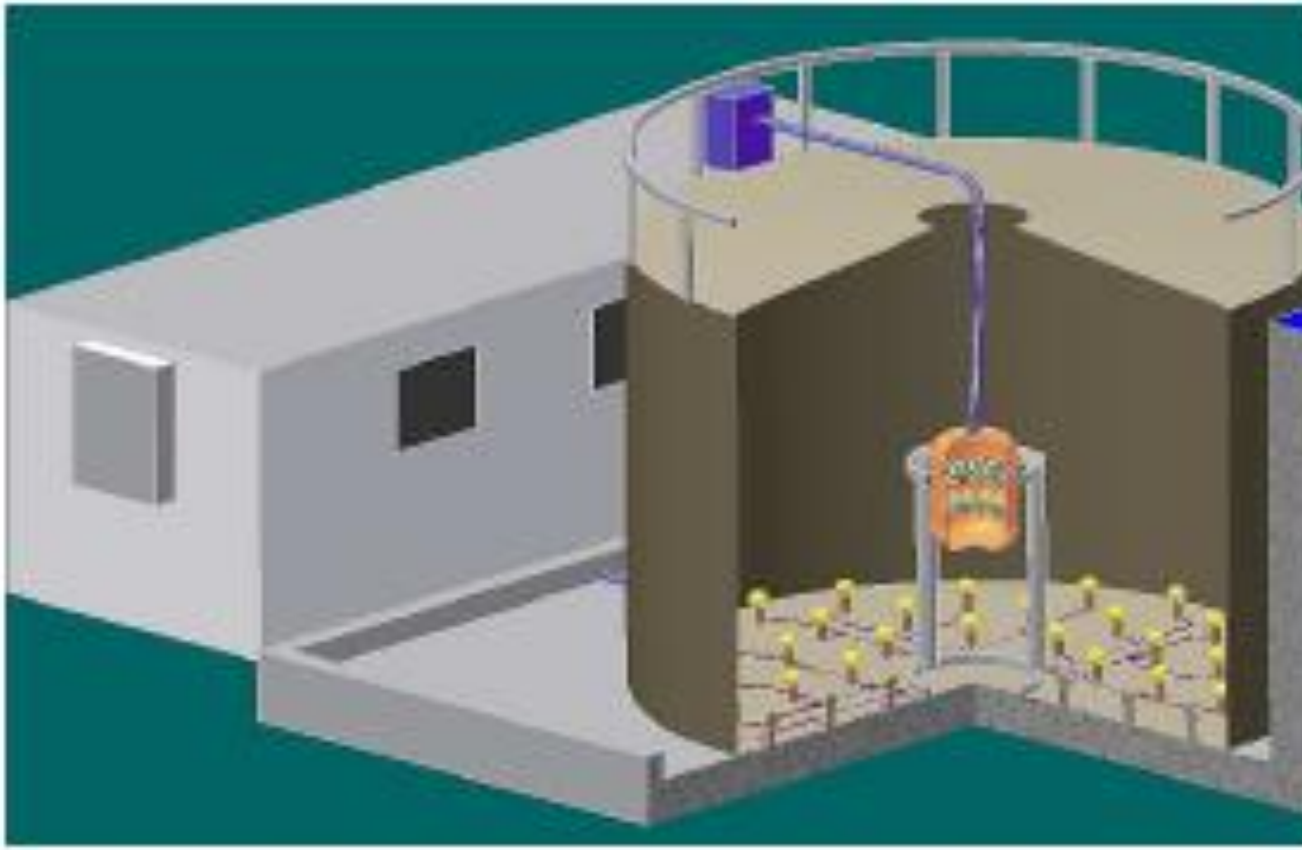


Figure 5: CLEAR experiment concept. The cryogenic inner detector enclosed in a vacuum vessel will be positioned inside a tank of water, which provides neutron shielding and an active muon veto by detection of Cherenkov radiation with an array of PMTs.

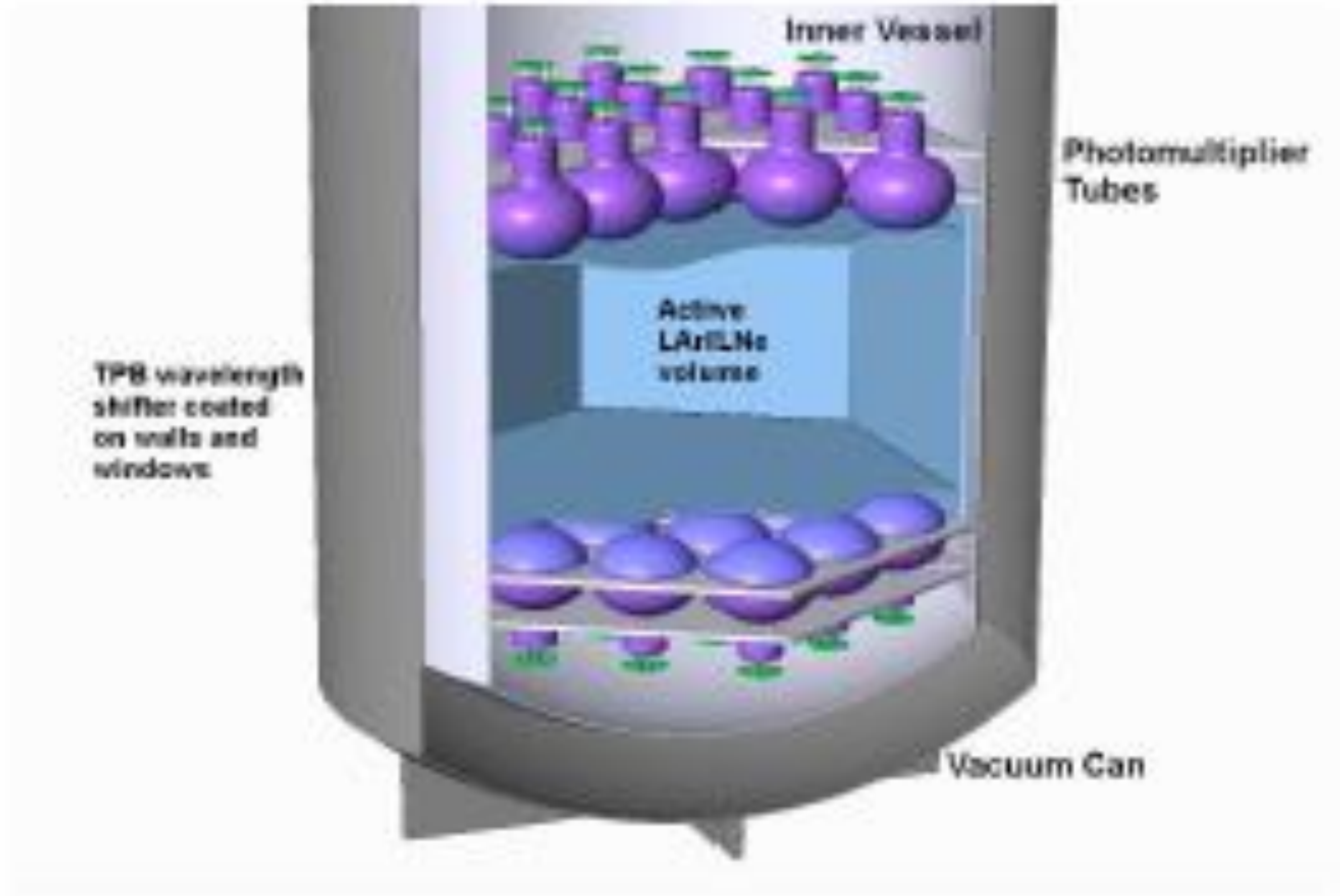


Figure 6: The inner detector, containing an active target of LAr or LNe viewed by photomultipliers, as described in the text.

4. Summary

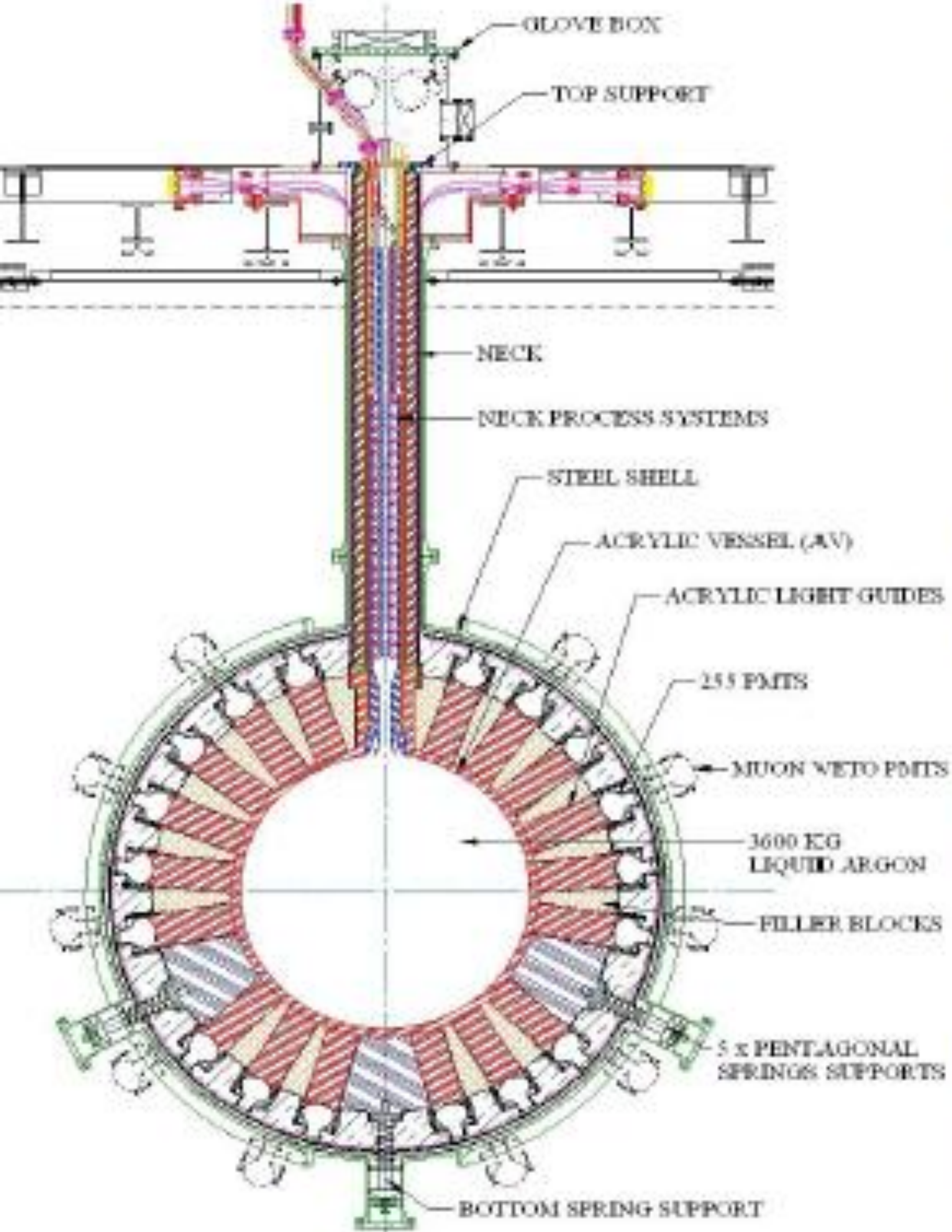
The SNS creates an intense neutrino source in the few tens of MeV energy range. The CLEAR experiment aims to measure coherent elastic ν-A scattering by siting a single-phase noble liquid scintillation detector 46 m from the SNS neutrino source. The planned active target mass is 456 kg of LAr or 391 kg of LNe. Non-beam-related backgrounds include cosmic rays, internal and external radioactivity, radon, and ^{39}Ar (for argon); all of these may be well characterized using data outside of the beam window. Beam-related neutron backgrounds, which cannot be rejected using the beam time window, have been shown using extensive simulations to be comfortably small. The absolute rate can be measured with $\sim$12-13% uncertainty.

Experimental Program at SNO

Experiment	Solar ν	0νββ	Dark Matter	Super nova	GeoNu	Other	Space Allocated	Status	Expt Lead
SNO+	X	X		X	X		SNO Cavern	Construction	
PICASSO			X				Ladder Labs	Running	
DEAP-1			X				J-Drift	Running	
DEAP-3600			X				Cube Hall	Construction	
MiniCLEAN			X				Cube Hall	Construction	
COUPP-4			X				J-Drift	Running	
COUPP-60			X				Ladder Labs	2011	
SuperCDMS			X				Ladder Labs	2012	
HALO				X			Phase III Stub	Construction	
PUPS						Seismic	Various Locations	Completed	


DEAP-3600
MiniCLEAN
Single phase liquid argon
10-46 cm2 @ 100GeV

DEAP-3600 Detector



3600 kg argon target (1000 kg fiducial) in sealed ultraclean Acrylic Vessel

Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction

Large area vacuum deposition source for TPB wavelength shifter deposition

255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)

50 cm light guides + PE shielding provide neutron moderation

Detector in 8 m water shield at SNOLAB

DEAP-3600 Design Parameters and Background Target Levels

Parameter	Value
Light Yield	8 photoelectrons per keV_{ee}
Nuclear Quenching Factor	0.25
Analysis Threshold	15 keV_{ee}, 60 keV_r
Total Argon Mass (Radius)	3600 kg
Fiducial Mass (Radius)	1000 kg
Position Resolution at threshold (conservative, design spec)	10 cm
Position Resolution at threshold (ML fitter)	5 cm
Background	**Target**
Radon in argon	< 1.4 nBq/kg
Surface α's (tolerance using conservative pos. resolution)	< 0.2 $\mu Bq/m^2$
Surface α's (tolerance using ML position resolution)	< 100 $\mu Bq/m^2$
Neutrons (all sources, in fiducial volume)	< 2 pBq/kg
Bg events, dominated by ^{39}Ar	< 2 pBq/kg
Total Backgrounds	**< 0.6 events in 3 Tonne-y**

arXiv/1203.0604 Boulay IDM 2012

Summary

- DEAP-3600 has good physics sensitivity, $8x10^{-47}$ cm^2 (conservative cuts-based analysis, more sophisticated analysis and Depleted Argon allow enhanced low mass sensitivity)

- Extensive radiopurity control and QA program for all components, in particular all fabrication steps of inner Acrylic Vessel

- Most detector components at SNOLAB in September 2012

- Detector Installation, Assembly and Commissioning until late 2013

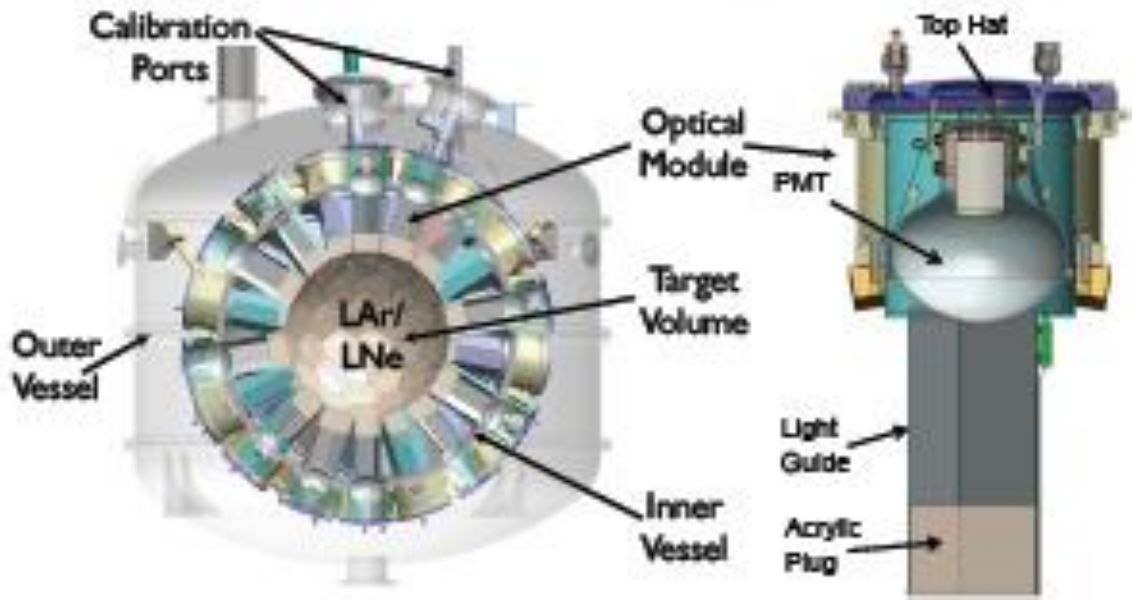
- Technology can be scaled to very large target masses, > 100 tonnes or 10^{-48} cm^2 Sensitivity. Current focus on DEAP-3600 commissioning, some modest R&D underway

- Surface contamination easier to mitigate with larger detector (using Position Reconstruction)

- Larger detector (100's tonnes) will require Depleted Argon

MiniCLEAN Modular Design

- 4π coverage to maximize light-yield at threshold …
  - 3D Position Reconstruction
  - Particle-ID via Pulse-shape discrimination
- Radon-free assembly …
- "Cold" design allows both LAr & LNe …
- No electric fields … PMTs only active component …
- Fast signals (τ_3 = 1.6 μs) avoid pulse-pileup in LAr …



PHYSICAL REVIEW D 68, 023005 (2003)

Supernova observation via neutrino-nucleus elastic scattering in the CLEAN detector

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(Received 5 February 2003; published 28 July 2003)

Development of large mass detectors for low-energy neutrinos and dark matter may allow supernova detection via neutrino-nucleus elastic scattering. An elastic-scattering detector could observe a few, or more, events per ton for a galactic supernova at 10 kpc (3.1×10^{20} m). This large yield, a factor of at least 20 greater than that for existing light-water detectors, arises because of the very large coherent cross section and the sensitivity to all flavors of neutrinos and antineutrinos. An elastic scattering detector can provide important information on the flux and spectrum of ν_μ and ν_τ from supernovae. We consider many detectors and a range of target materials from ^{4}He to ^{208}Pb. Monte Carlo simulations of low-energy backgrounds are presented for the liquid-neon-based Cryogenic Low Energy Astrophysics with Noble gases detector. The simulated background is much smaller than the expected signal from a galactic supernova.

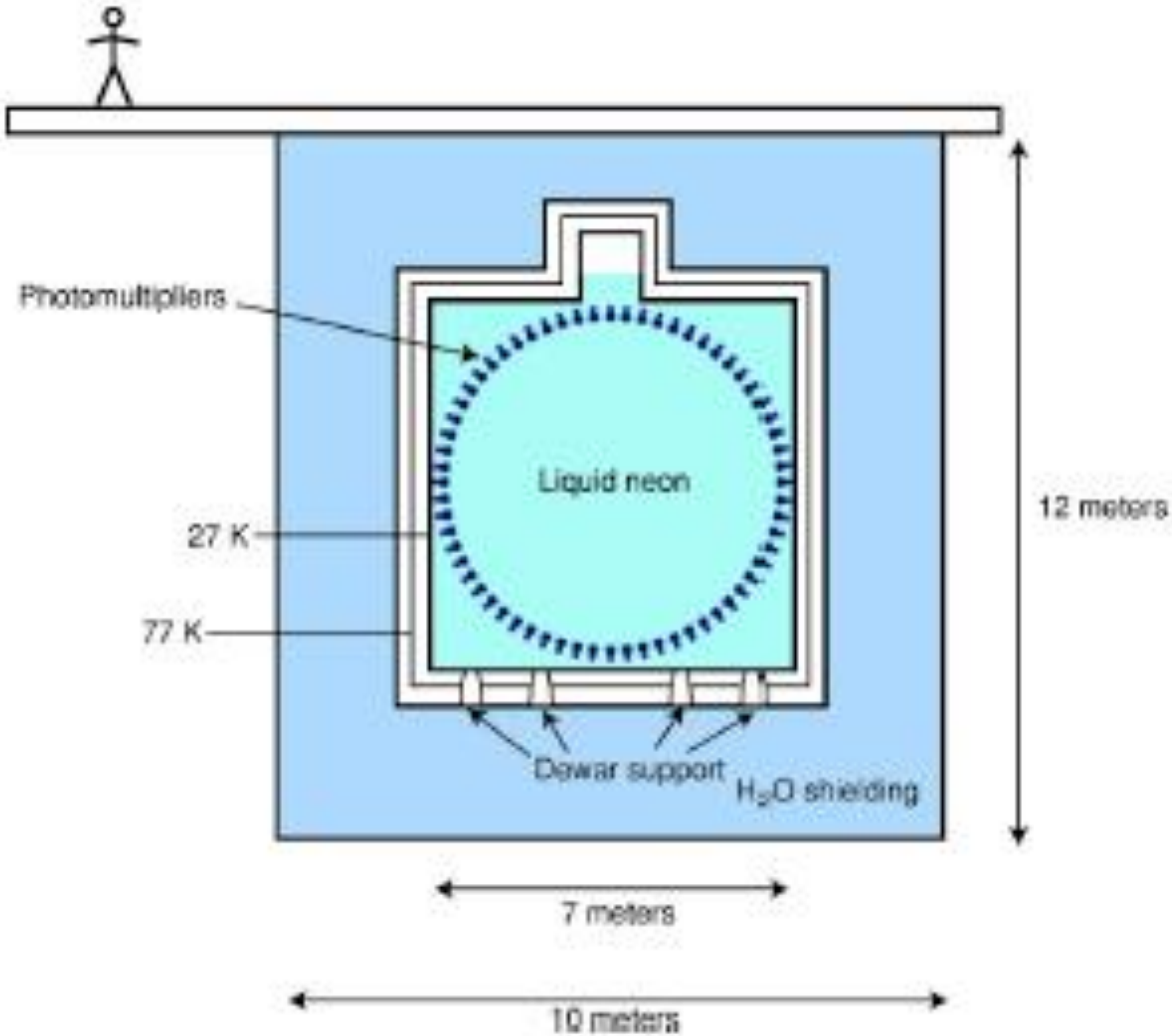


FIG. 3. Diagram of CLEAN.

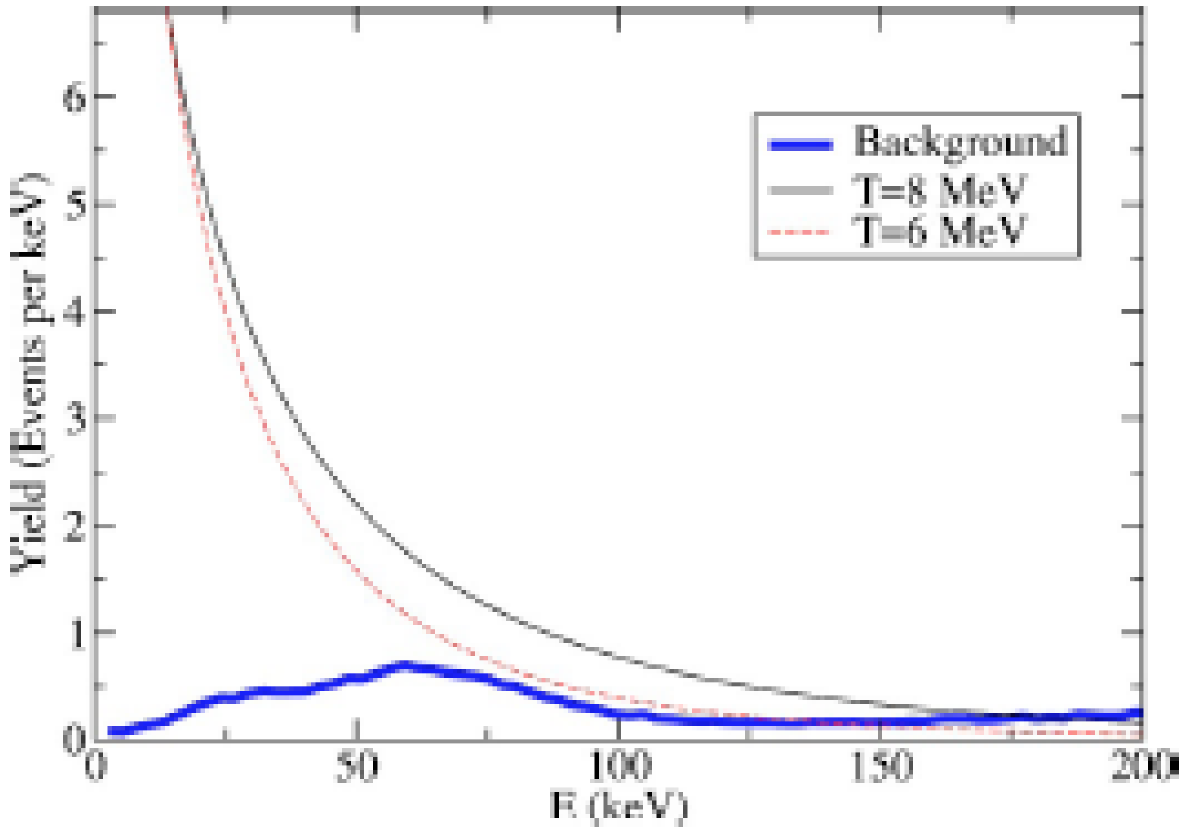
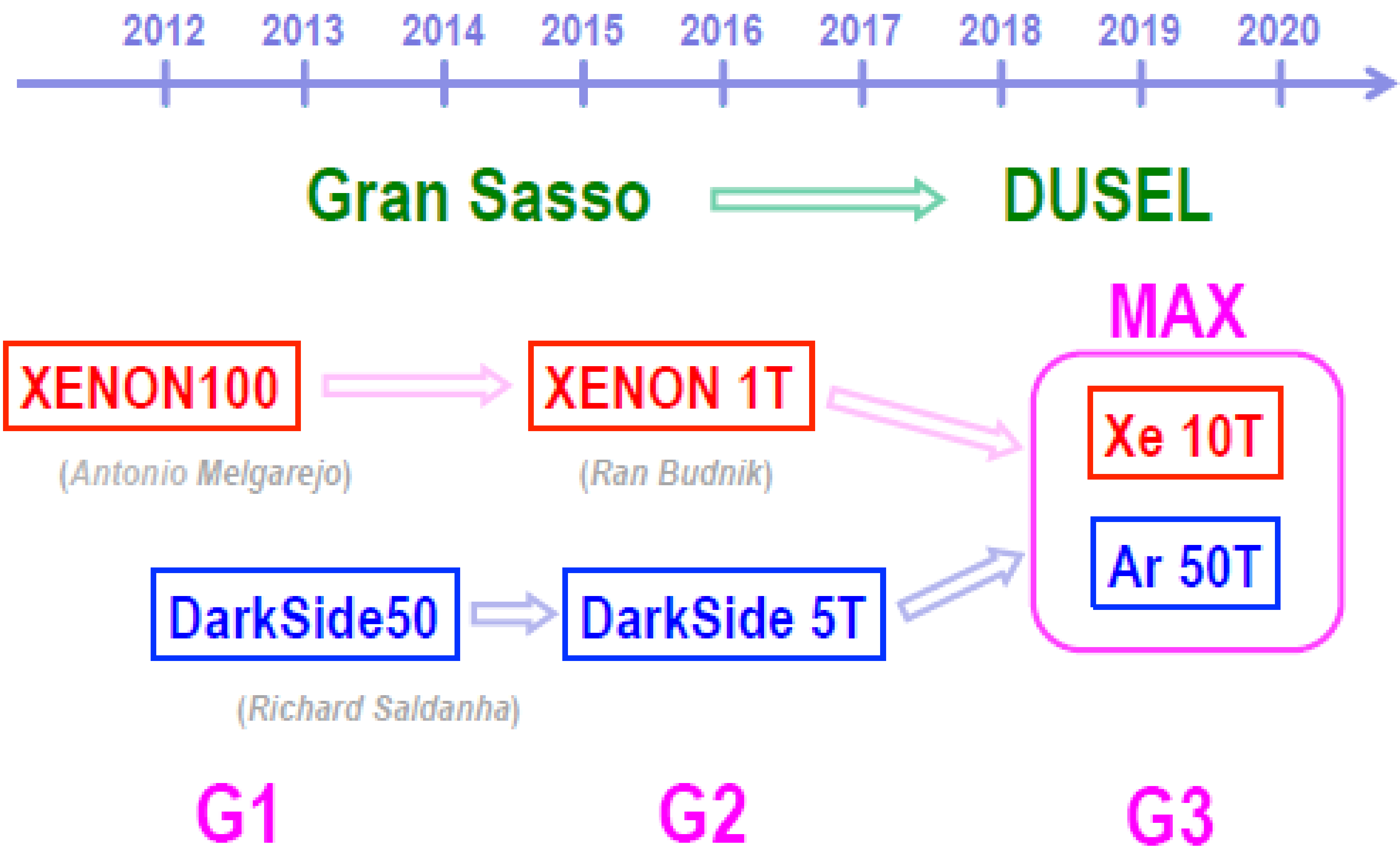


FIG. 4. Yield for full a 100 ton fiducial mass of CLEAN versus recoil kinetic energy E. The solid curve is the expected supernova signal assuming a distance of 10 kpc and a ν_x temperature $T_{\nu_x} = 8$ MeV. The dashed curve assumes $T_{\nu_x} = 6$ MeV. Finally, the thick curve is the predicted background from the Monte Carlo simulation assuming an observing time of 10 sec.

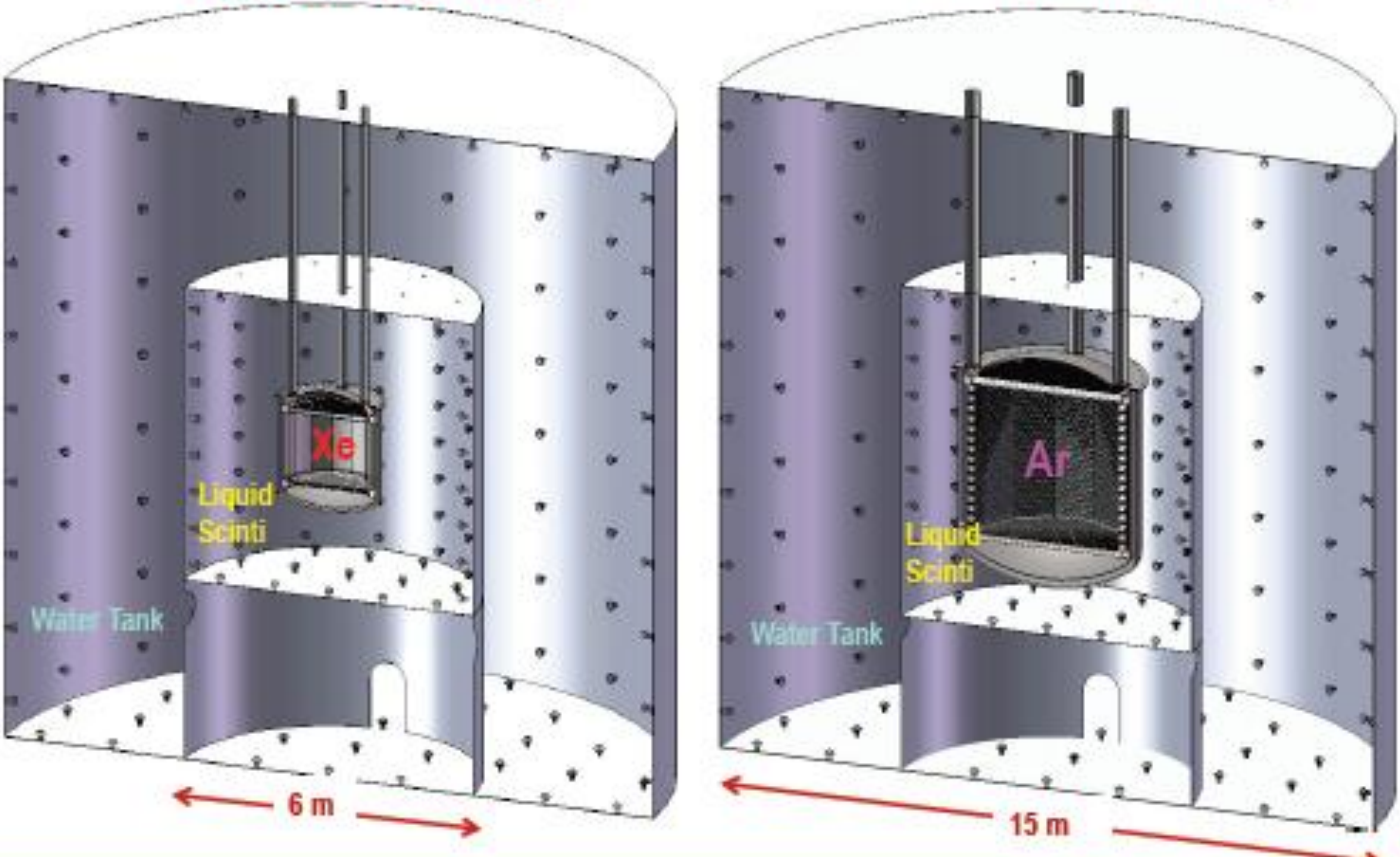
Roadmap to MAX



MAX G3 Detector

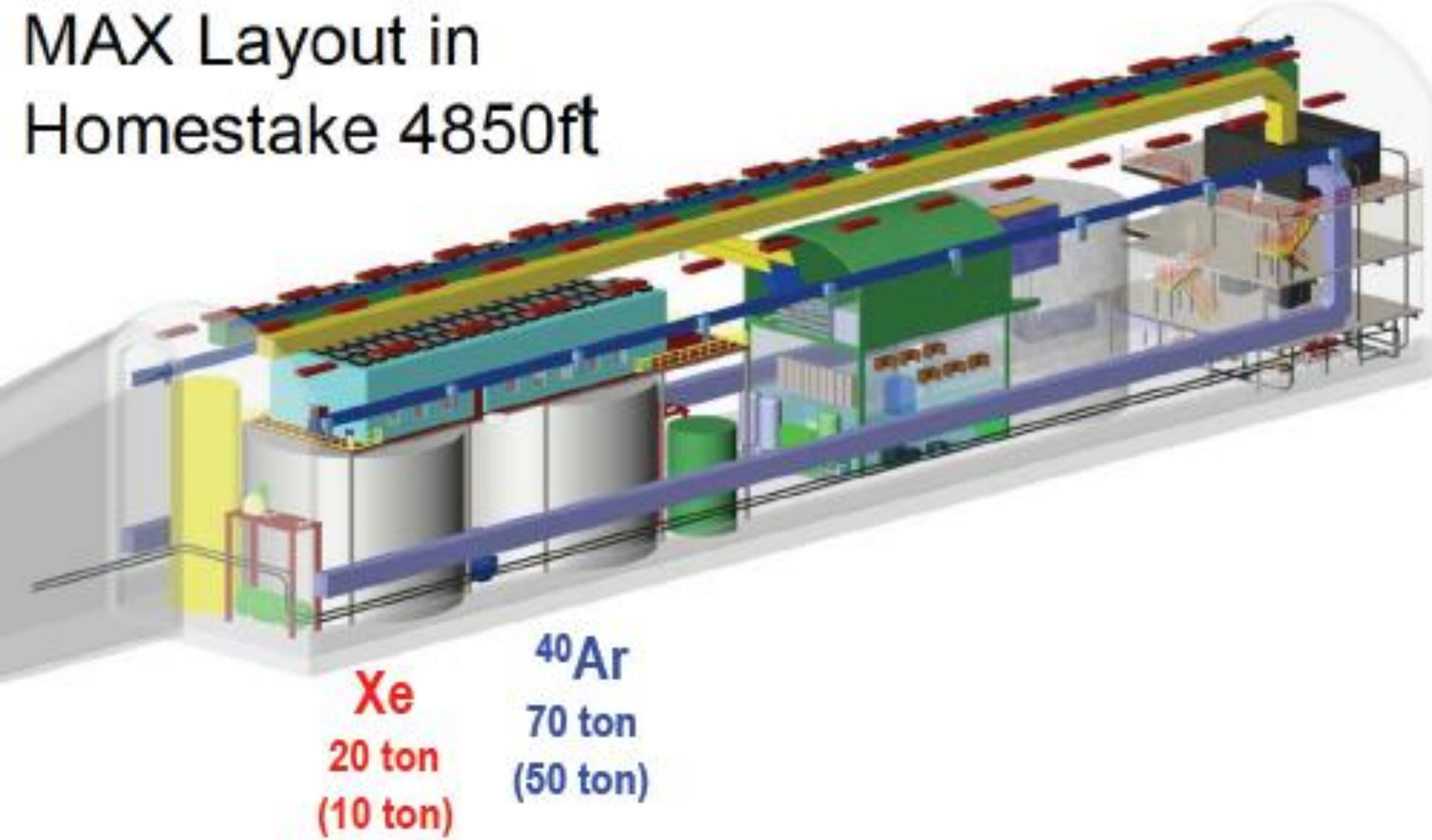
Xe 20 ton (10 ton)

^{40}Ar 70 ton (50 ton)



MAX G3 Detector (at DUSEL)

MAX Layout in Homestake 4850ft



Резюме:

Резко возросшая активность по разработке низкопороговых детекторов есть несомненное свидетельство, что здесь в течение ближайших 5 (максимум 10) лет будет достигнут прорыв.

Хотим ли мы участвовать в этой работе?

P.S.Barbeau, J.I.Collar, O.Trench

II. A FIRST COHERENT NEUTRINO DETECTOR

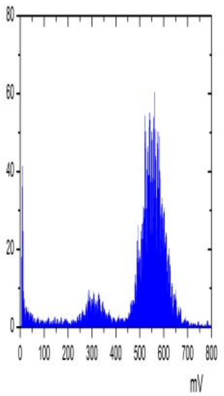
The Low-Background Detector Development group at the Enrico Fermi Institute has investigated several new technologies, each in principle capable of meeting the three goals (energy threshold, background and minimum detector mass) required for a successful measurement of this mode of neutrino interaction in a power reactor. In this paper we concentrate on what is presently considered the most promising path towards this measurement. The prototype described here exhibits an active mass of 475 g, sufficient for a measurement of the cross section. The technology is however readily scalable to a mass O(10) kg, necessary for most of the applications mentioned above, in the form of a small array of detectors.

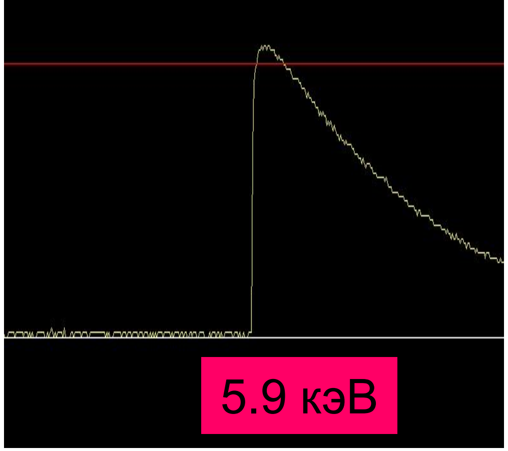
С газовым детектором (Xe,Ar)
это достижимо

A noise level of 270 eV (resulting in a threshold two to three times higher) would still be insufficient for a reactor experiment looking for coherent neutrino scattering. However, a number of improvements could in principle reduce this to a threshold ~100 eV or even lower in such a large detector, which would yield a comfortable signal rate for present purposes. Since a large fraction of the noise figure in the seminal work of [17] was due to the electronic characteristics of the field effect transistors (JFETs) available 20 years ago, it seemed timely to reconsider this approach in the light of the most recent technology. A number of possible improvements were envisioned:

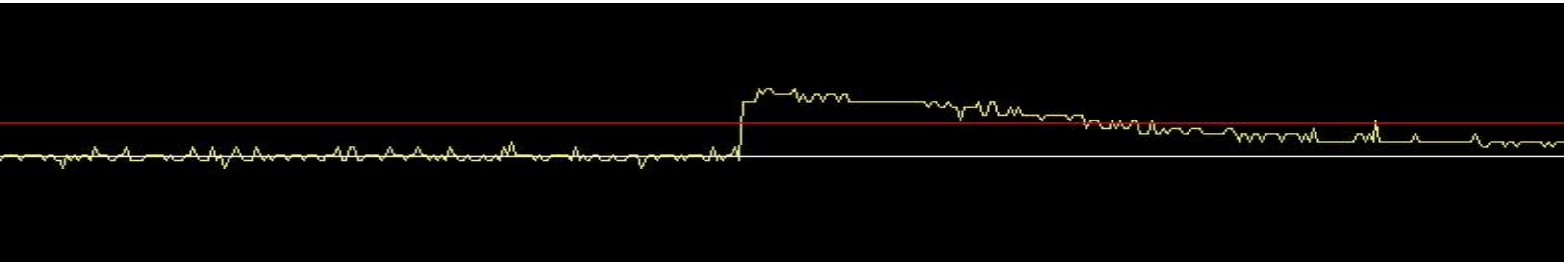
С газовым детектором с высоким ($>10^4$) КГУ эту проблему можно обойти!

Форма импульса и возможность дискриминации шумов
КГУ = 2×10^4

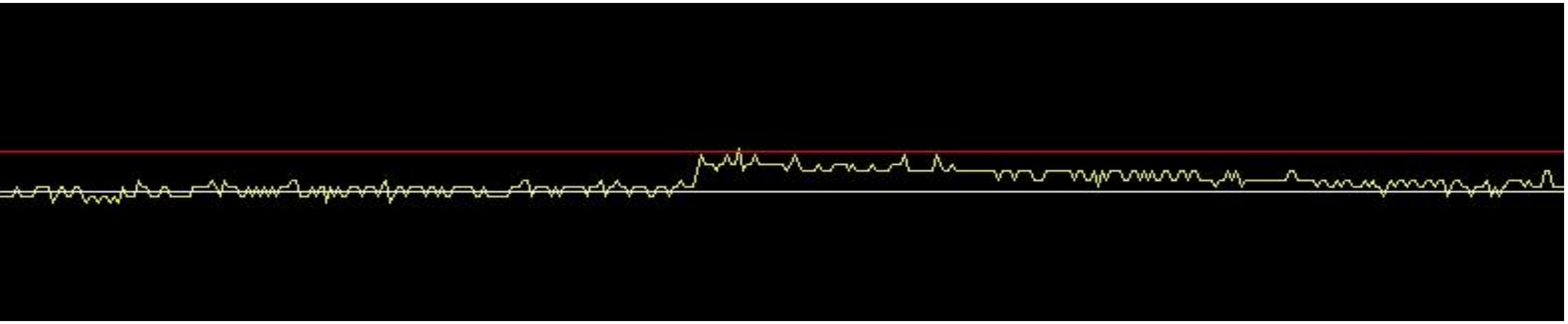




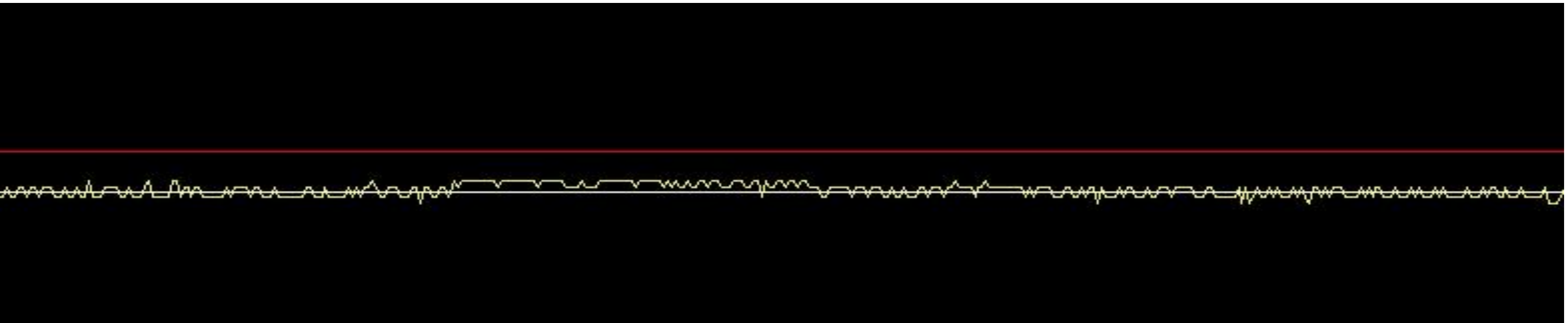
Кадр 400 мксек



90eV

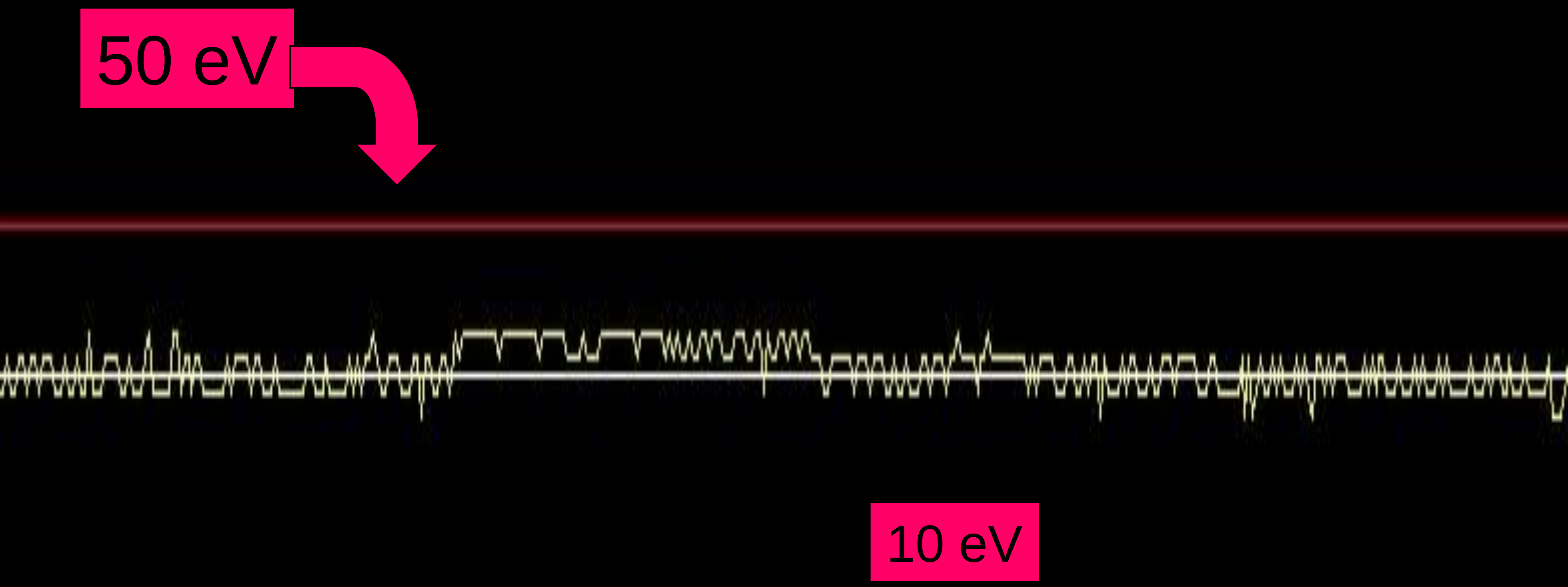


40 eV

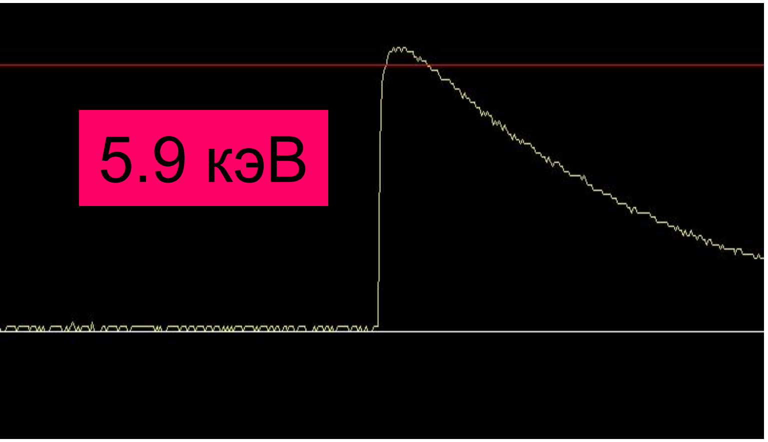


10 eV

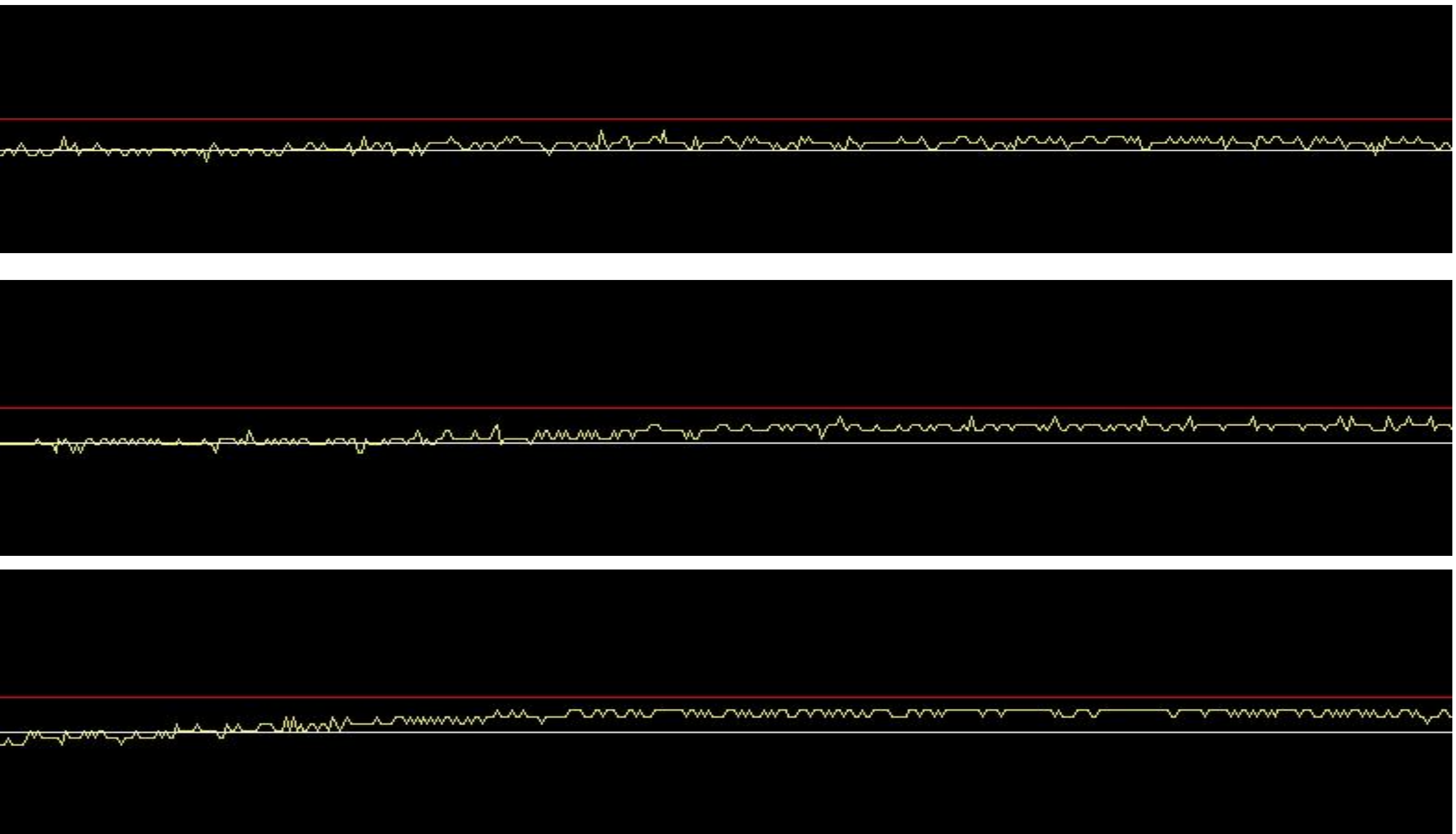

450 eV
Фронт импульса: 1 бин – 1 мксек
P-10, 900 мбар, D = 37 mm, d = 20 мк
HV = 1800 V, КГУ = 2x10^4
При 3 бар и HV = 2600 V КГУ = 2x10^4


50 eV
10 eV

Форма импульса и возможность дискриминации шумов



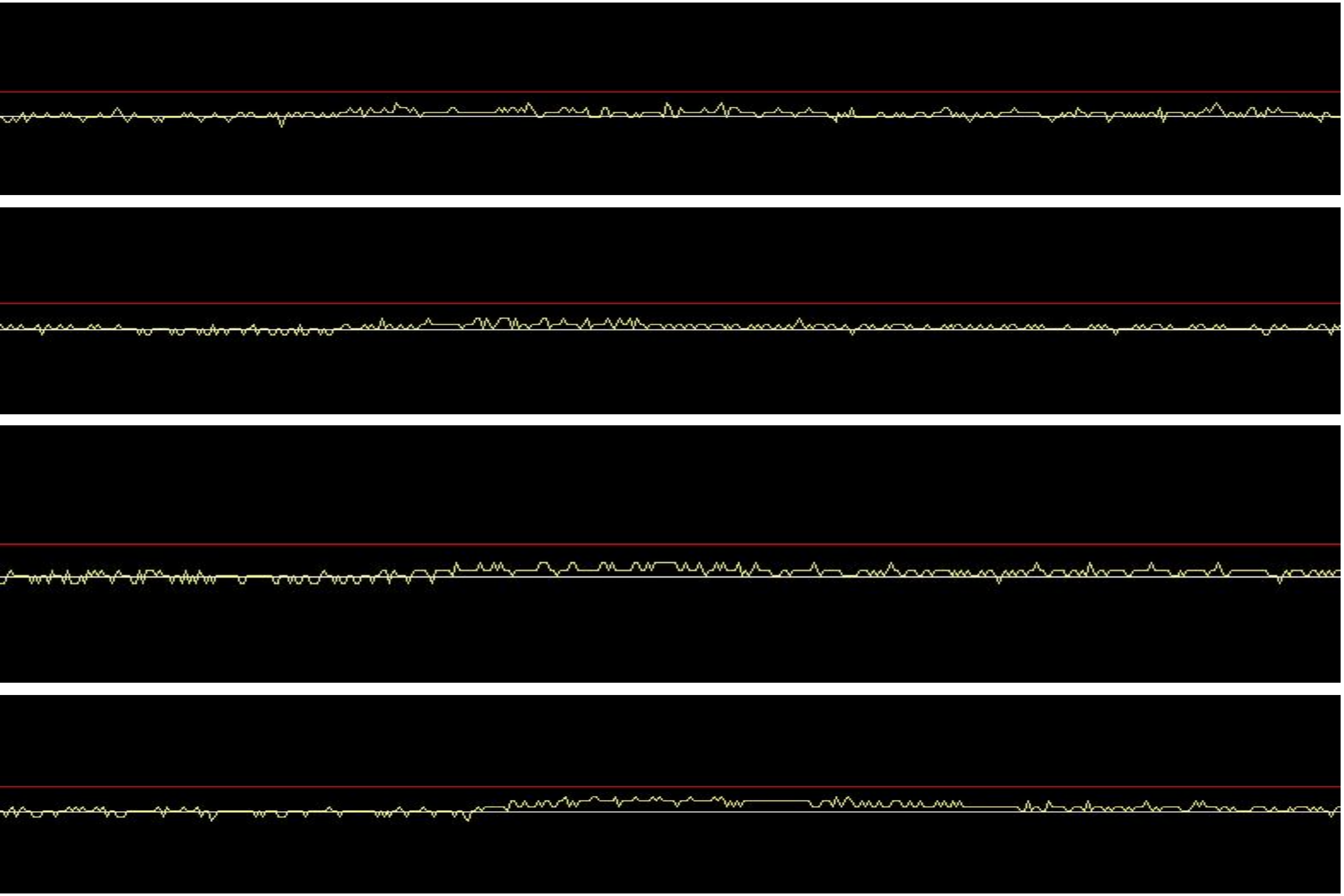
Кадр 400 мксек



э/м наводки

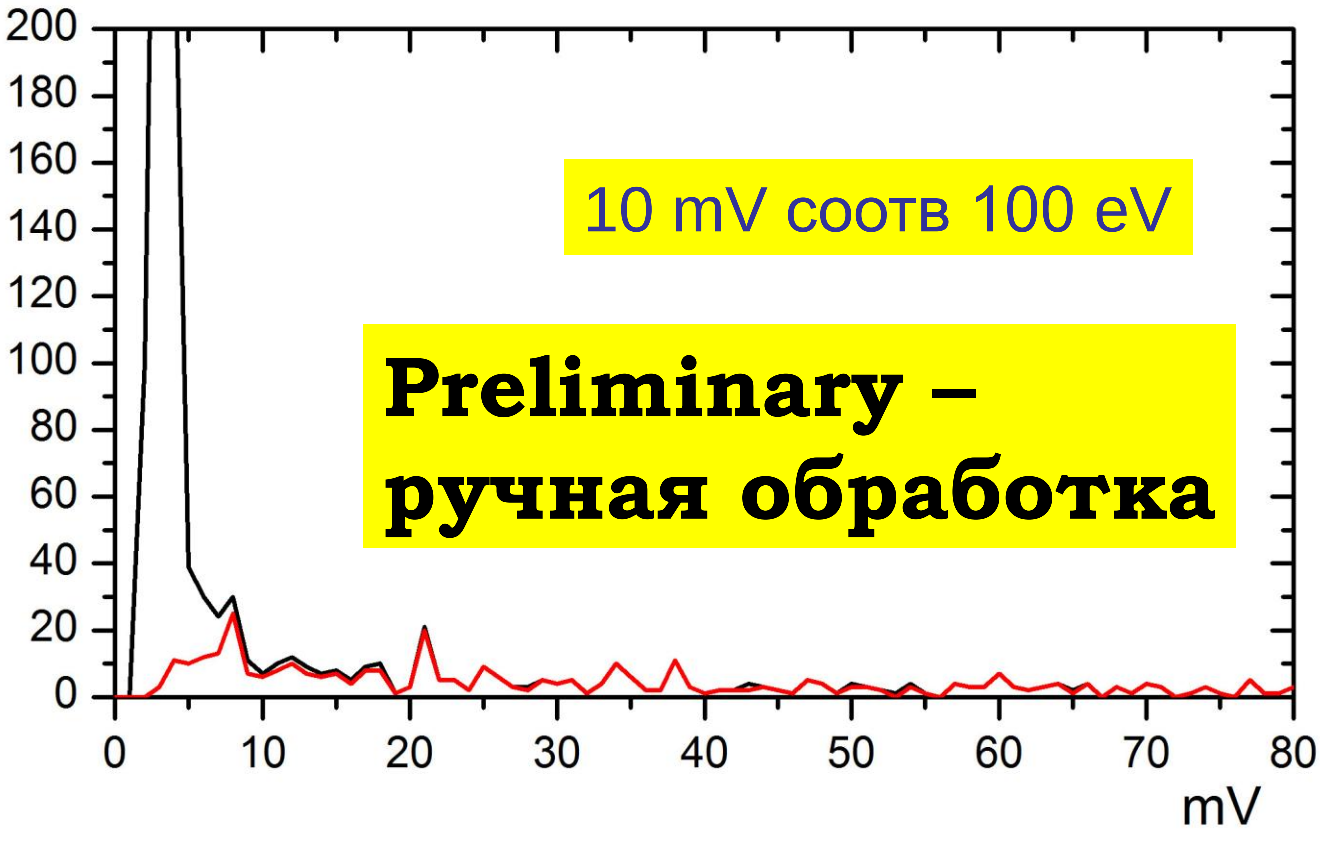
Форма импульса и возможность дискриминации шумов

Кадр 400 мксек



Микрофоника

Эффект от дискриминации по форме импульса. Импульсы малой амплитуды от 55Fe.

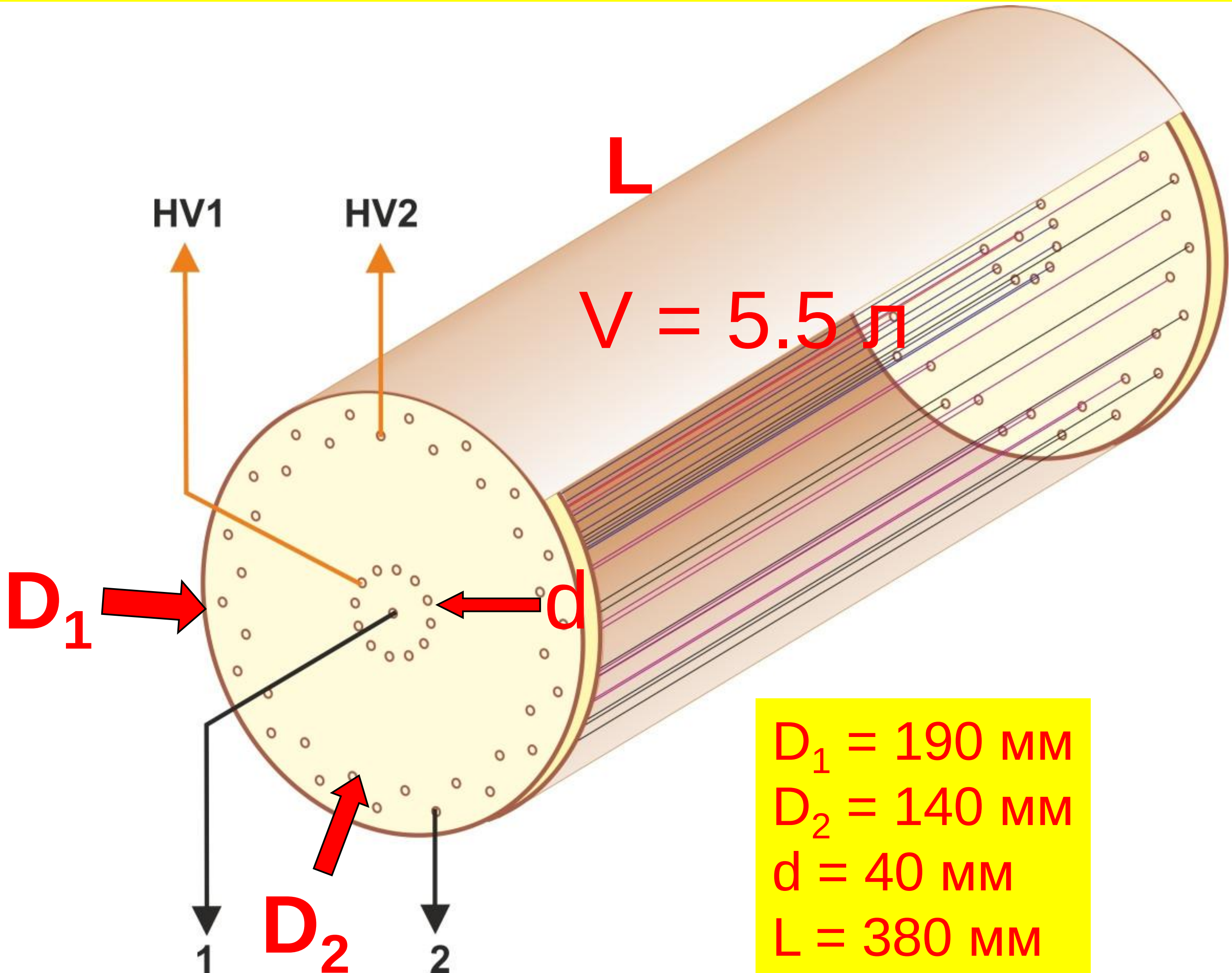


Задача на ближайшее будущее?

Создать такой детектор, для которого внутри защиты собственный темп счета в области от 30 эВ до 1 кэВ будет, по крайней мере, не выше нескольких десятков событий на кг мишени в сутки.

Это – задача №1!

Низкофоновый вариант с активной и пассивной (от флуоресценции от материала корпуса) защитой, центральным детектором с высоким КГУ и с дрейфовым промежутком для увеличения массы рабочего газа при P=5 атм и более.



D_1 = 190 мм
D_2 = 140 мм
d = 40 мм
L = 380 мм

Изготовлен, в стадии сборки

Что сделано?

- Разработана концепция газового детектора с низким (менее 1 кэВ) порогом.
- Изготовлен и находится в стадии сборки сам детектор.
- Разработана методика дискриминации шумов по форме импульса.

Заключение

- Газовый детектор с низким (менее 1 кэВ) порогом регистрации ионизирующего излучения - это хорошая возможность за сравнительно короткое время (примерно 5 лет) сделать весьма существенный прорыв в исследовании антинейтрино от реакторов в том числе, в регистрации когерентного рассеяния антинейтрино на ядрах мишени..
- Наряду с другими перспективными подходами к решению этой задачи, такими как разработка криогенных и полупроводниковых детекторов, а также экспериментов с нейтрино от распада остановившихся π-мезонов и мюонов это может стать одним из самых результативных направлений на последующие 5 лет.
- Для нас эта задача тем более является привлекательной, поскольку в России мы не располагаем и, по-видимому, уже не будем располагать другими сильноточными источниками нейтрино, кроме как ядерные реакторы.

Конец первой серии