“First result of the experimental search for the 9,4keV solar axions reactions with ^{83}Kr in the copper proportional counter”

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“Axions are among the most fascinating particles on the long list of those proposed but not yet observed or ruled out. Their existence would provide an elegant resolution of the strong CP problem. Even more exciting is the possibility that the missing mass needed to close the universe is composed of axions, and that axions are «cold dark matter» which seems to be necessary for galaxy formation. ...”
Mark Srednicki, “Axion couplings to matter (I). CP-conserving parts”, Nucl. Phys. B260 (1985) 689-700.

“...the composite axion is a particular example of a “hadronic” axion, resulting from a theory where only exotic fermions carry $U(1)_{PQ}$ charges. Hadronic axions don't couple to leptons, which are neutral under $SU(3)xU(1)_{PQ}$. Nor do they couple to heavy quarks, which are integrated out of the theory above 1GeV, where QCD gets strong. Hadronic axions will still couple to nucleons as well as to photons. ...”
David B. Kaplan, “Opening the axion window”, Nucl. Phys. B260 (1985) 215-226.

“The most attractive solution of the strong CP problem is to introduce the Peccei-Quinn global symmetry which is spontaneously broken at energy scale f_a. The original axion model assumed that f_a is equal to the electroweak scale. Although it has been experimentally excluded, variant “invisible” axion models are still viable in which f_a is assumed to be very large. ... Such models are referred to as hadronic and Dine-Fischler-Srednicki-Zhitnitskii axions. ....”
Shigetaka Moriyama, “Proposal to search for a monochromatic component of solar axions using ^{57}Fe”, Phys. Rev. Lett. v.75 №8 (1995) 3222-3225.

Proposal to Search for a Monochromatic Component of Solar Axions Using ^{57}Fe

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A new experimental scheme is proposed to search for almost monochromatic solar axions, whose existence has not been discussed heretofore. The axions would be produced when thermally excited ^{57}Fe in the Sun relaxes to its ground state and could be detected via resonant excitation of the same nuclide in a laboratory. A detailed calculation shows that the rate of the excitation is up to order 1 event/day kg ^{57}Fe. The excitation can be detected efficiently using bolometric techniques.

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The most attractive solution of the strong *CP* problem is to introduce the Peccei-Quinn global symmetry which is spontaneously broken at energy scale f_a [1]. The original axion model assumed that f_a is equal to the electroweak scale. Although it has been experimentally excluded, variant "invisible" axion models are still viable in which f_a is assumed to be very large; since coupling constants of the axion with matter are inversely proportional to f_a, experimental detection becomes very difficult. Such models are referred to as hadronic [2] and Dine-Fischler-Srednicki-Zhitnitskiĭ (DFSZ) [3] axions. At present, these invisible axions are constrained by laboratory searches, and by astrophysical and cosmological arguments. One frequently quoted window for f_a, which escapes all the phenomenological constraints, is $10^{10}-10^{12}$ GeV. Besides this, there

^{57}Fe can be a suitable axion emitter for the following reasons: (i) ^{57}Fe has an $M1$ transition between the first excited state and the ground state; (ii) the first excitation energy of ^{57}Fe is 14.4 keV, which is not too high compared with the temperature in the center of the Sun ($\sim$1.3 keV) [9]; and (iii) ^{57}Fe is one of the stable isotopes of iron (natural abundance 2.2%), which is exceptionally abundant among heavy elements in the Sun [10]. If the axion exists, strong emission of axions is expected from this nuclide.

These monochromatic axions would excite the same nuclide in a laboratory, because the axions are Doppler broadened due to thermal motion of the axion emitter in the Sun, and thus some axions have energy suitable to excite the nuclide.

Energy loss due to the axion emission in the Sun

$$\delta E\left(T\right)=N\frac{2\exp\left(-\beta_T\right)}{1+2\exp\left(-\beta_T\right)}\frac{1}{\tau_\gamma}\frac{\Gamma_a}{\Gamma_\gamma}E_\gamma,$$

where:

$$\frac{\Gamma_a}{\Gamma_\gamma}=\frac{1}{2\pi\alpha}\frac{1}{1+\delta^2}\left[\frac{g_0\beta+g_3}{\left(\mu_0-1/2\right)\beta+\mu_3-\eta}\right]^2$$

$$g_0=-7.8\cdot10^{-8}\left(\frac{6.2\cdot10^6}{f_a/GeV}\right)\left(\frac{3\mathrm{F}-D+2\mathrm{S}}{3}\right)$$

$$m_a=\frac{\sqrt{z}}{1+z}\frac{f_\pi m_\pi}{f_a}=1\mathrm{eV}\frac{\sqrt{z}}{1+z}\frac{1.3\cdot10^7}{f_a/GeV}$$

$$g_3=-7.8\cdot10^{-8}\left(\frac{6.2\cdot10^6}{f_a/GeV}\right)\left(\left(D+F\right)\frac{1-z}{1+z}\right)$$

Axion flux from the Sun at the Earth

$$\frac{d\Phi\left(E_a\right)}{dE_a}=\frac{1}{4\pi R_E^2}\int_0^{R_o}\frac{1}{\sqrt{2\pi}\sigma\left(T\right)}\exp\left[\frac{-\left(E_a-E_\gamma\right)^2}{2\sigma\left(T\right)^2}\right]\cdot\frac{\delta E\left(T\right)}{E_\gamma}\rho\left(r\right)4\pi r^2dr$$

Shigetaka Moriyama, “Proposal to search for a monochromatic component of solar axions using ^{57}Fe”, Phys. Rev. Lett. v.75 №8 (1995) 3222-3225.

Rate of the excitation per nucleus:

$$R_N = A \sigma_{0,a} \Gamma_{tot} \frac{\pi}{2}$$

$$\sigma_{0,a} = 2\sigma_{0,\gamma} \frac{\Gamma_a}{\Gamma_\gamma}$$

For Kr-83 the excitation rate is:

$$R\left[g^{-1}\, day^{-1}\right] = 7.417 \cdot 10^{-12} \left(\frac{k_a}{k_\gamma}\right)^6 \cdot \left(\frac{m_a}{1\mathrm{eV}}\right)^4,$$

where k_a and k_γ denote impulses of axions and photons, respectively.

(K. Jakovčić et al., arXive:nucl-ex/0402016v1)

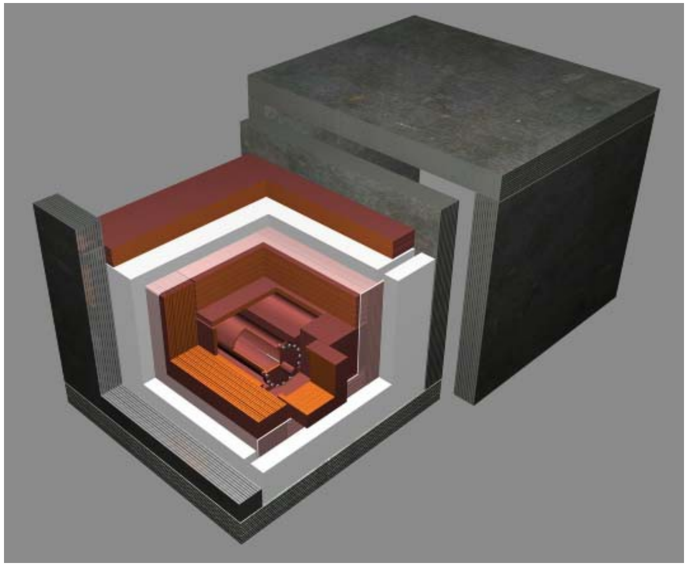
Nuclide	Photosphere abundance, $\log_{10}s$ (normalized to $\log_{10}s(H)=12.00$)	1-st excitation level, keV (transition)
Fe-57	5.78	14.41 (M1+E2)
Kr-83	2.34	9.40 (M1+E2)
Li-7	?	477.6 (M1+E2)

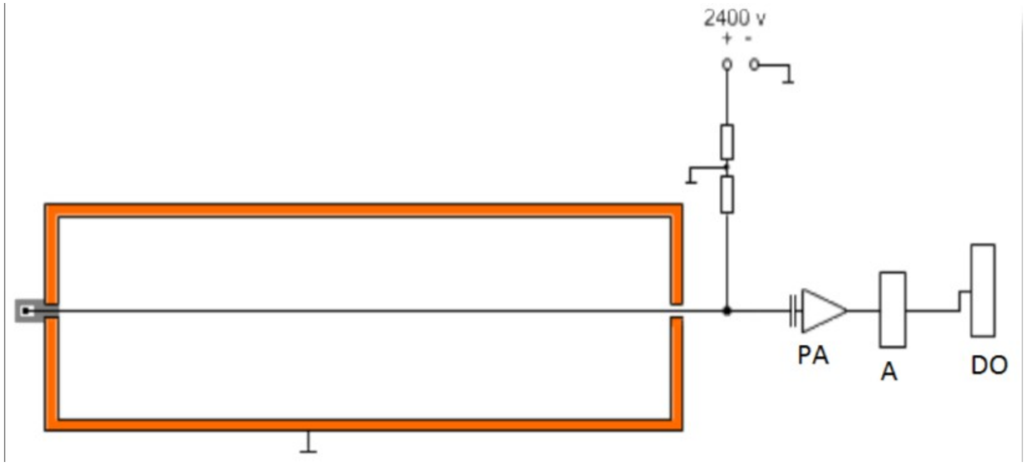
Previous results of a search for Hadronic (KSVZ) axions

	Reference (nuclei)	Result
1	M. Krcmar et al., arXive:nucl-ex/9801005v2 (Fe-57)	≤745eV
2	K. Jakovčić et al., arXive:nucl-ex/0402016v1 (Kr-83)	≤5,5keV
3	A.V. Derbin et al., Eur. Phys. J. C (2009) 62:755-760 (Fe-57)	≤159eV
4	F.A. Danevich et al., arXive:nucl-ex/0811383v2 (Fe-57)	≤1,6keV
5	P. Belli et al., Nucl. Phys. A (2008) 806:388-397 (Li-7)	≤13,9keV
	W.C. Haxton and K.Y. Lee, Phys. Rev. Lett. 66 (1991) 20:2557-2560 (Red-Giant Evolution)	≈3÷20eV

Experimental setup at BNO INR RAS

Detector	proportional counters
Passive shield	23cm Pb, 8cm PolEth, 20cm Cu
Working media	99.55% Kr + 0.45% Xe (58% of Kr-83)
Inner diameter	134 mm
∅ of the anode wire	10 μm
Fiducial length	595 mm
Gas pressure (Kr)	5.6 bar





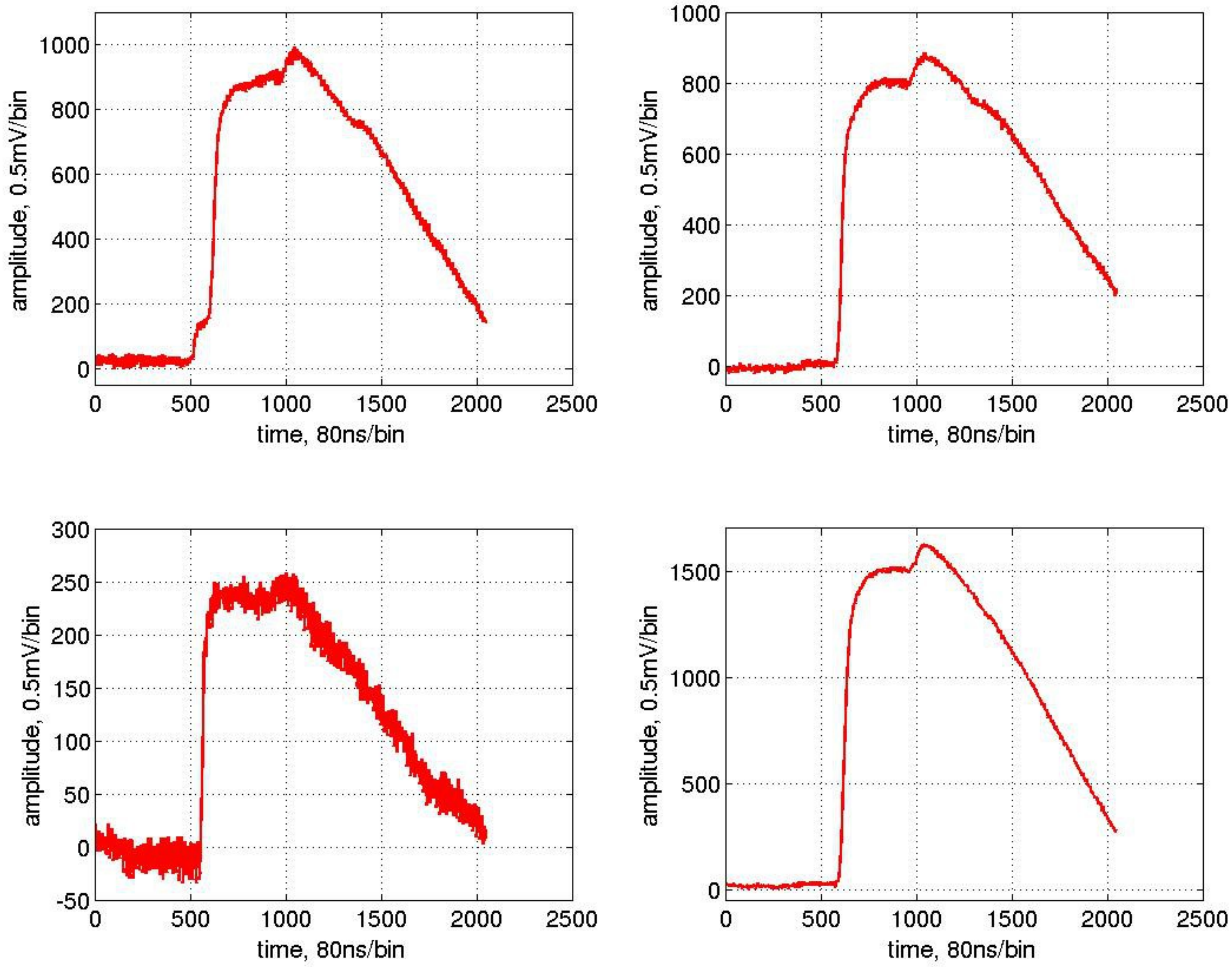
Electric scheme of the setup

PA – preamplifier

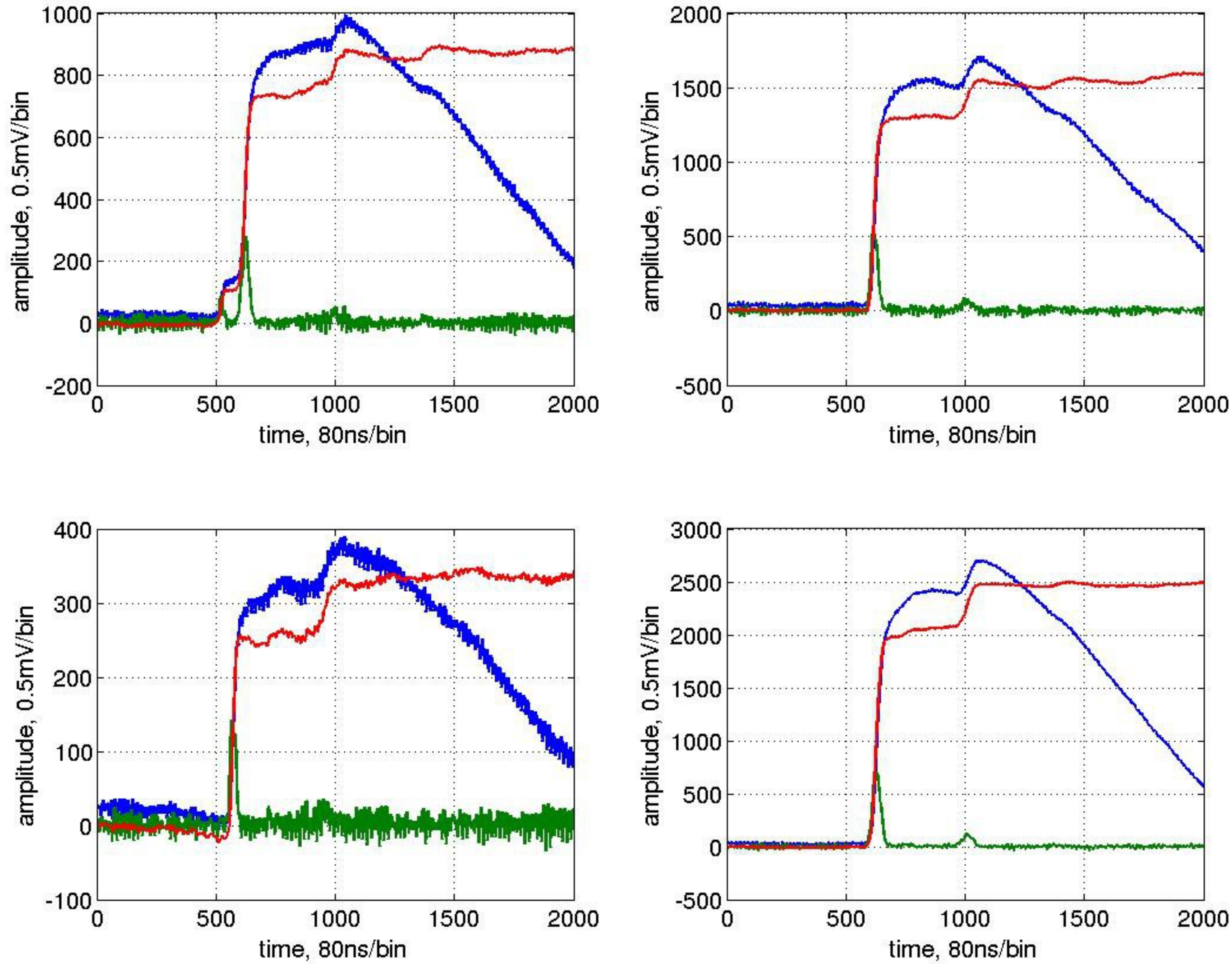
A1 – amplifier

DO – digital oscilloscope

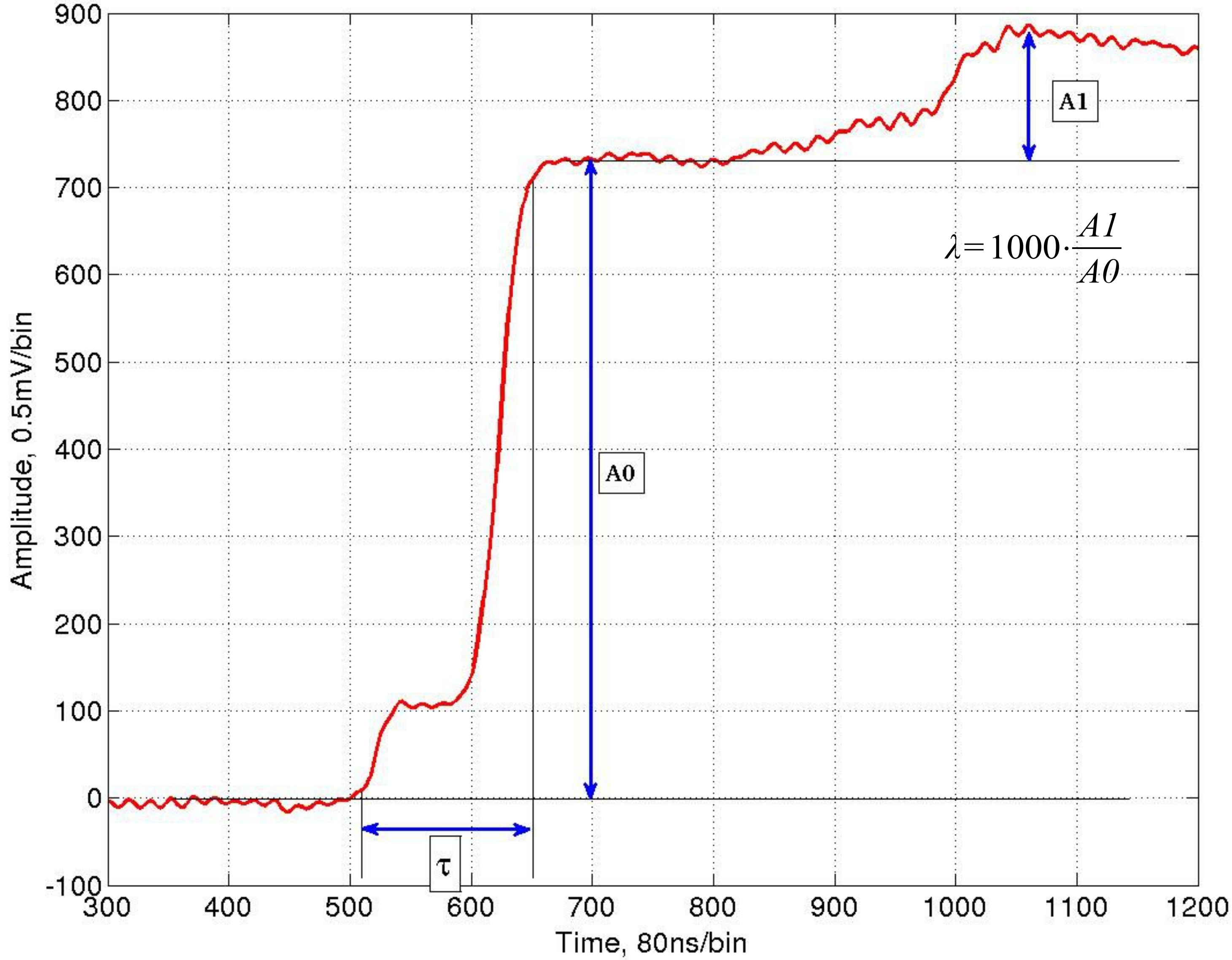
Samples of pulses from the proportional counter



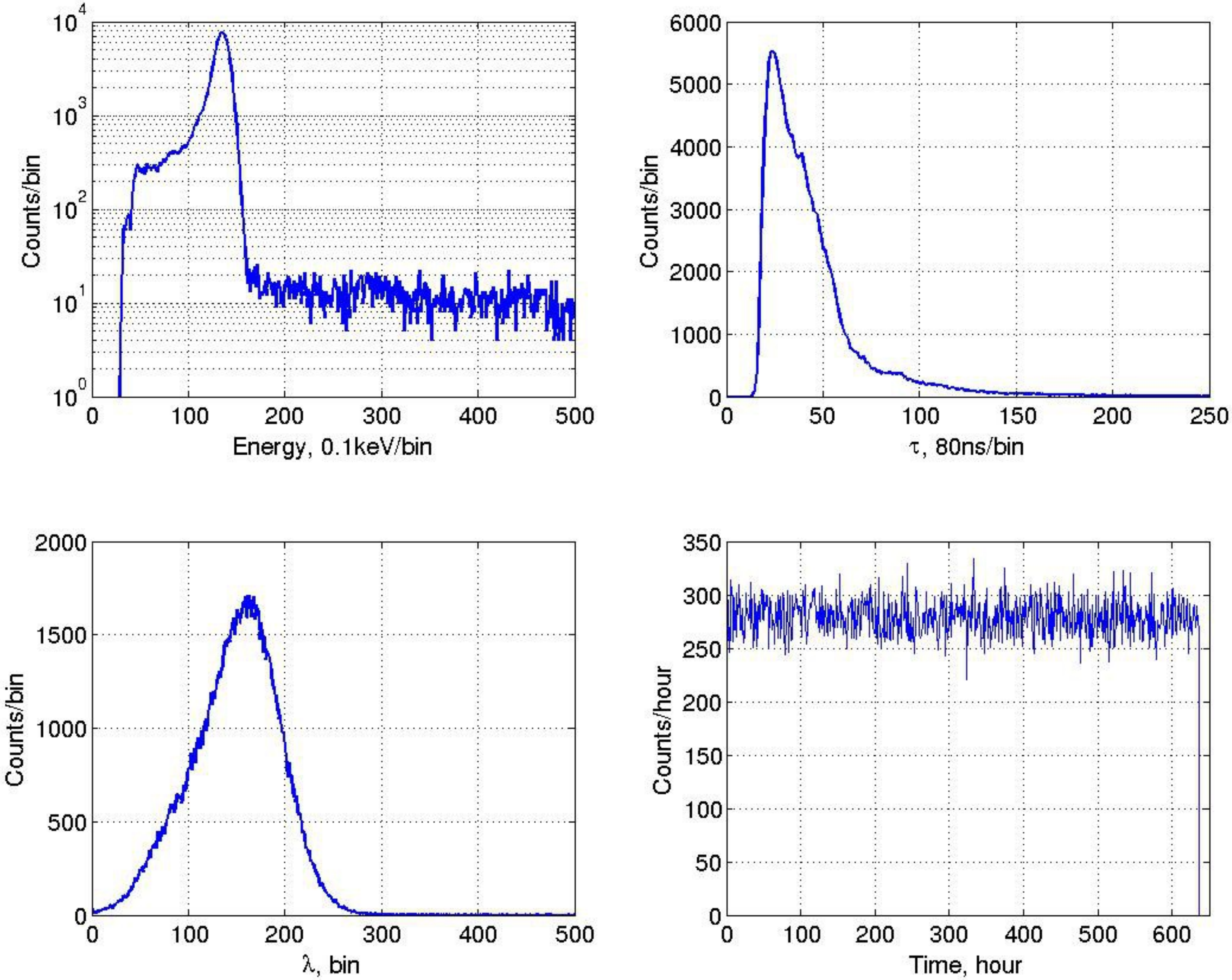
Samples of pulses from the proportional counter



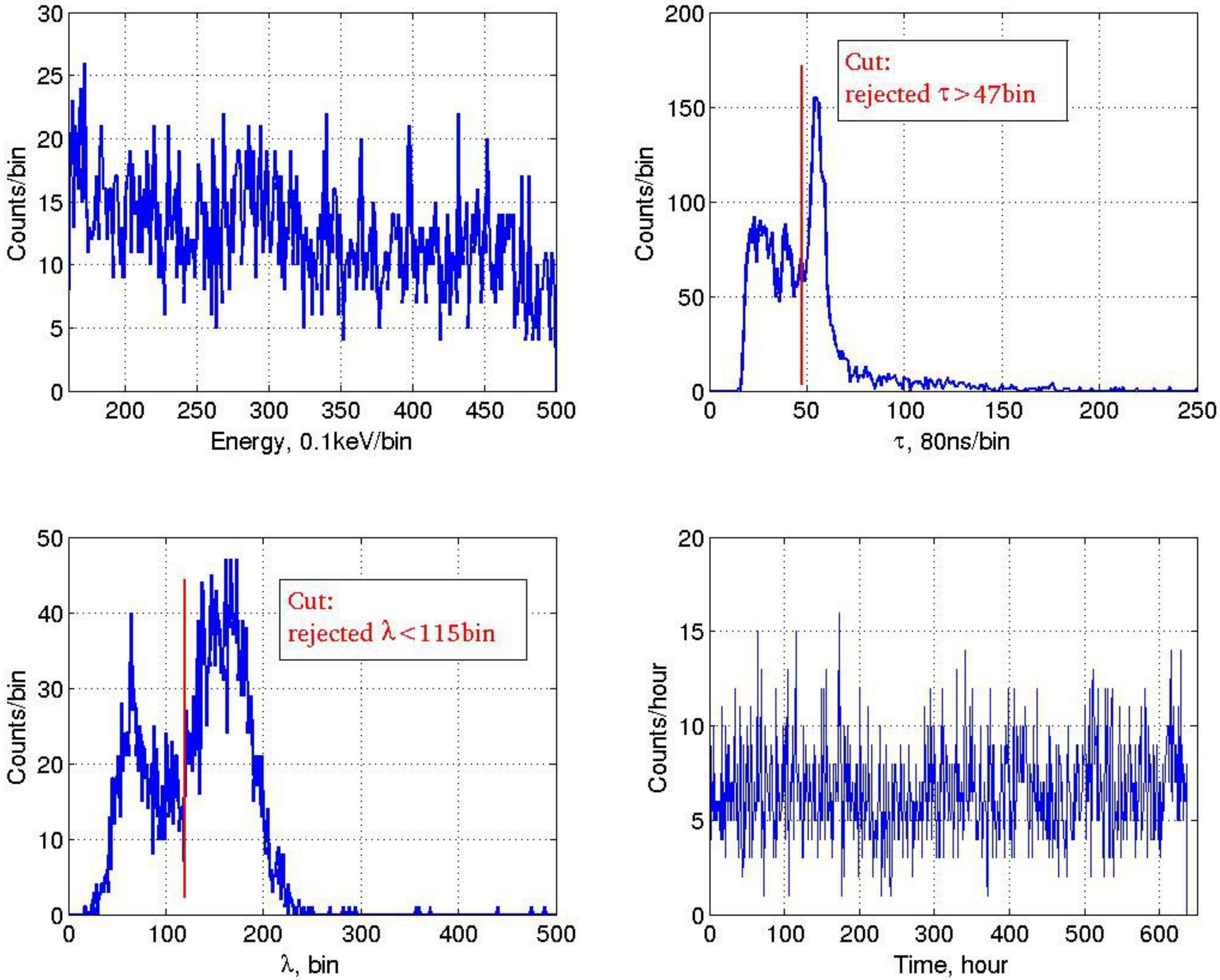
Pulse parameters



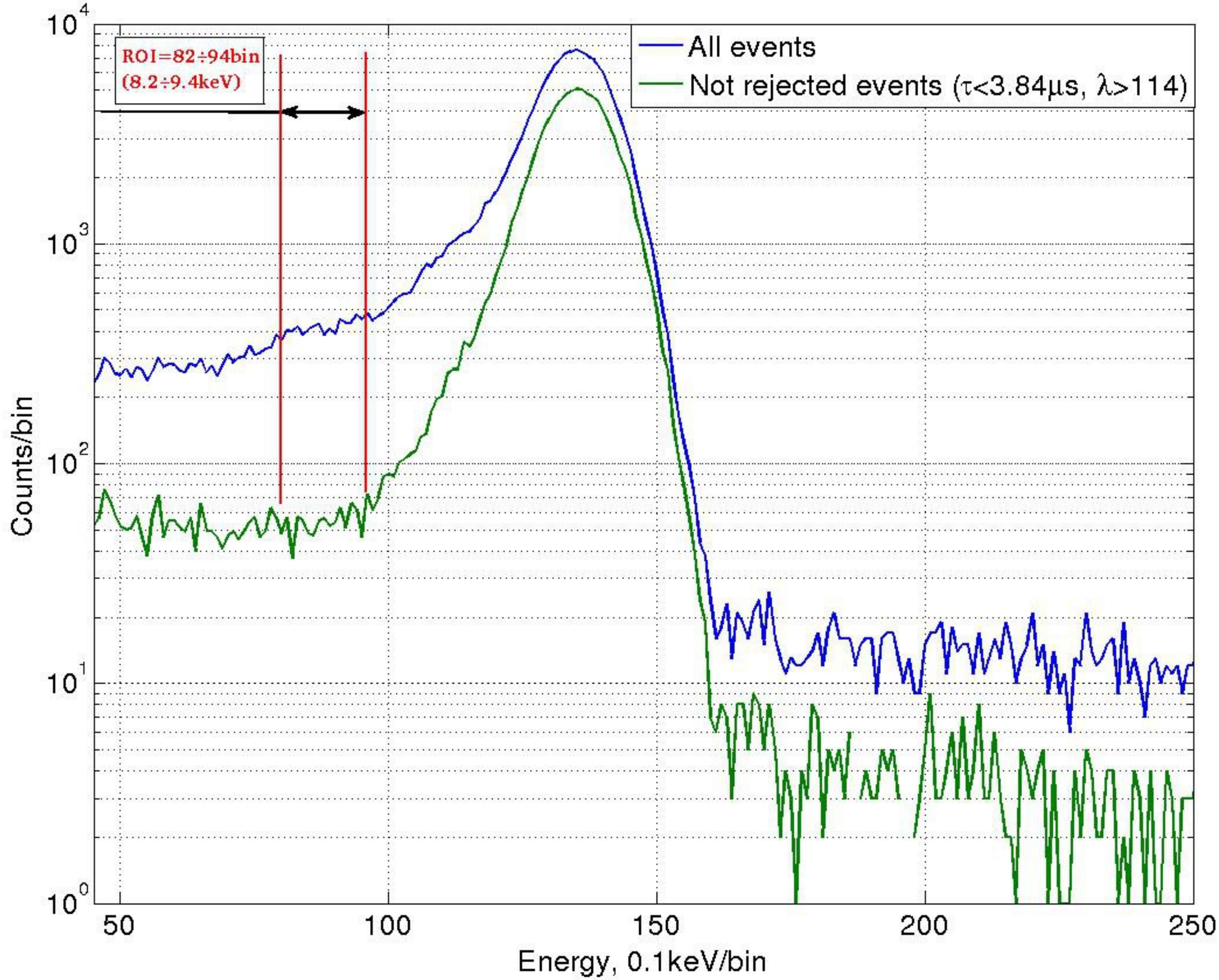
Distribution of the events (all statistics)



Distribution of the events (events with E>16keV)



Registration efficiency after cut



Under 13.5keV peak:
41.4% - single side events (13.5keV Auger electrons),
58.6% - multiside events (~1.6keV Auger electrons + 11.9keV Photons)

Energy resolution for 13.5keV
11.7% (1.58keV)

In the 9.4±1.2keV window
95% of Axion events

ROI 8.2-9.4keV
47.5% of Axion-events

Background in ROI - 703 events
Measurement time - 26.5days
Mass of Kr-83 - 101g

Detection efficiency after applying cuts:

$$\varepsilon_\lambda = 0.91 \qquad \varepsilon_\tau = 0.94 \qquad \varepsilon_E = 0.475$$

Excitation rate of Kr-83 nucleus:

$$R \leqslant \frac{2\cdot\sqrt{2\mathrm{B}}}{m_{Kr}\cdot t_{meas}} \cdot \frac{1}{\varepsilon_\lambda} \cdot \frac{1}{\varepsilon_\tau} \cdot \frac{1}{\varepsilon_E} = \frac{75}{101\cdot 26.5} \cdot \frac{1}{0.91} \cdot \frac{1}{0.94} \cdot \frac{1}{0.475} = 0.069\, g^{-1} d^{-1}$$

Result:

$$\frac{m_a}{(1\text{eV})} \leqslant \left(\frac{R}{7.417\cdot 10^{-12}}\right)^{\frac{1}{4}} \cdot \left(\frac{k_a}{k_\gamma}\right)^{-\frac{3}{2}} = 311\, eV \cdot \left(\frac{k_a}{k_\gamma}\right)^{-\frac{3}{2}}$$

$$m_a \leqslant 311\, eV$$

Estimated sensitivity of the setup at two years of measurements:

$$m_a \leqslant 164\, eV$$

Plans:

- to buy ~ 200g Kr-83 (99.9% enrichment) to reduce the background dueto Kr-81 decay by factor of ~500
- hope to get sensitivity m_a<100eV in two years of measurements

THANKS!