First result of the experimental search for the 2K-capture of ^{124}Xe with the copper proportional counter

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$$^{124}_{54}\boldsymbol{Xe} \xrightarrow{2e_k} {}^{124}_{52}\mathrm{Te}^{**} + 2\boldsymbol{\nu}\,(2{,}865(7)\,\boldsymbol{MeV})$$

Theory:

$T_{1/2}^{ee} = 7{,}0 \cdot 10^{21}\,yr.$ $\quad$ O.A.Rumyantsev, M.Urin 1998 y.[1]

$N_{2k} \sim 0{,}73 N_{ee}$ $\quad$ W.Bambynek 1977 y[2]

$T_{1/2}^{2k} = 1.08 \cdot 10^{22}\,yr.$ $\quad$ O.A.Rumyantsev, M.Urin 1998 y.[1]

$T_{1/2}^{2k} = 3{,}9 \cdot 10^{23}\,yr.$ $\quad$ M.Aunola, J.Suchonen 1996 y.[3]

[1] – O.A. Rumyantsev and M.N. Urin, Phys. Lett. B 443, 51 (1998)
[2] – W. Bambynek et al. Rev. Mod. Phys., Vol.49 No. 1, January 1977
[3] – M. Aunola and J. Suhonen, Nucl. Phys. A 602, 133 (1996)

Te*	Te*		
e_a	e_a	$0.142^2 = 0.020$	
e_a	K	} 0.246	
K	e_a		
K	K	$0.857^2 = 0.734$	

$K_{ab} = 31.8$ keV

$E_{2k} = 63.6$ keV

$\omega_k = 0.857$ - characteristic quantum

$\omega_e = 0.142$ - Auger electron

Te**-----------------> Te*+ Te*

$K_{ab} = 31.81$ keV,

$K_{\alpha 1} = 27.47$ keV 52.2%

$K_{\alpha 2} = 27.20$ keV 27.7%

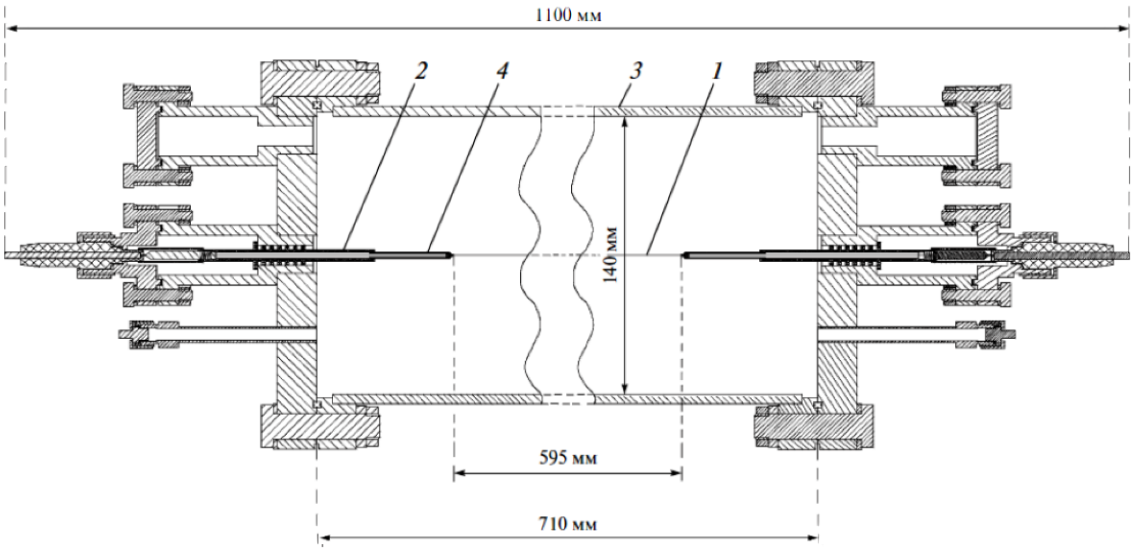
$K_{\beta 1} = 30.99$ keV 16.2%

$K_{\beta 2} = 31.70$ keV 3.9%

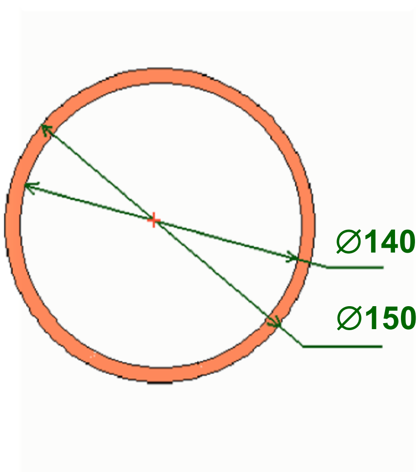
The energies of characteristic photons and an Auger-electron in 2K-capture are determined under the assumption that the filling of the double vacancy of K-shell in one atom is identical to filling two K-shell vacancies, each in a separate atom; the total energy release being 63.8 keV.

The probability of the emission of two characteristic X-ray photons and auger electron equal to 73,4%.

Schematic view of Proportional Counter



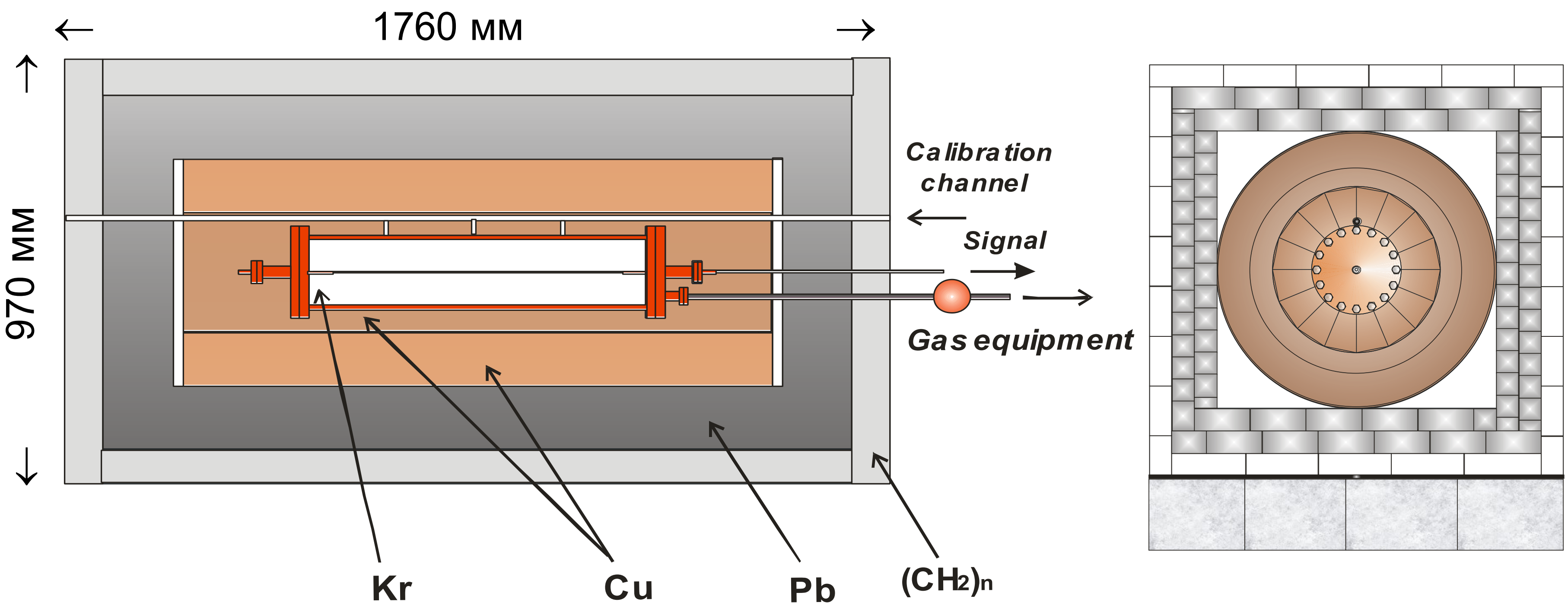
1.- Anode wire, 2.- Insulator, 3.- Cathode , 4. - Copper tubes.



Cross-section of the counter
+ - anode

1. Body's material	Cu
2. Total length, mm	1160
3. Fiducial length, mm	595
4. Outer diameter, mm	150
5. Inner diameter, mm	137
6. Central anode material, mm	g.p.tan., 0.010
7. Total volume, l	10.37
8. Fid. Volume, l	8.77
9. Pressure, at	4.609
10. Capacity, pF	31
11. Anode wire resistance , Ohm	613

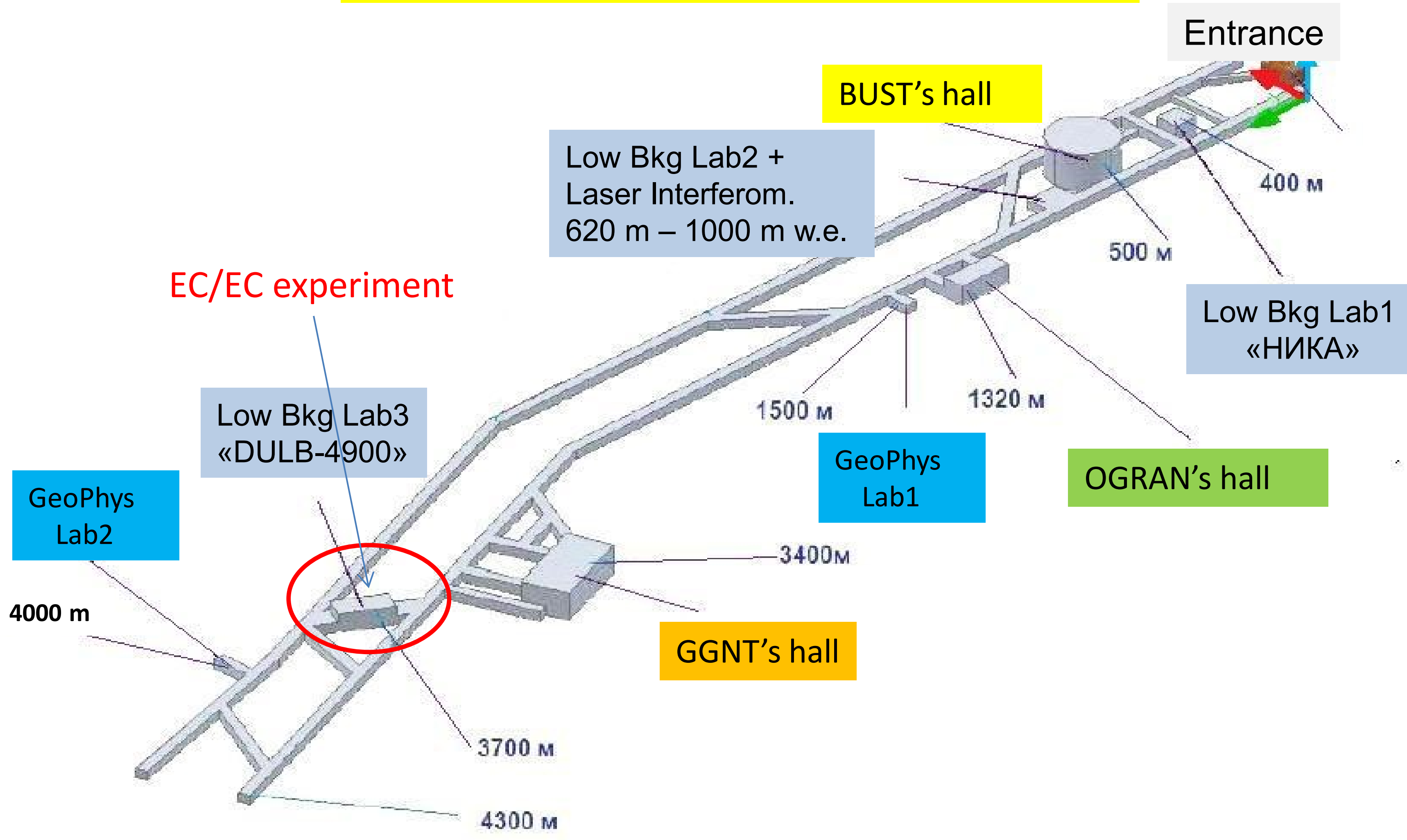
Low background shield



18 cm copper
15 cm lead
8 cm borated polyethylene

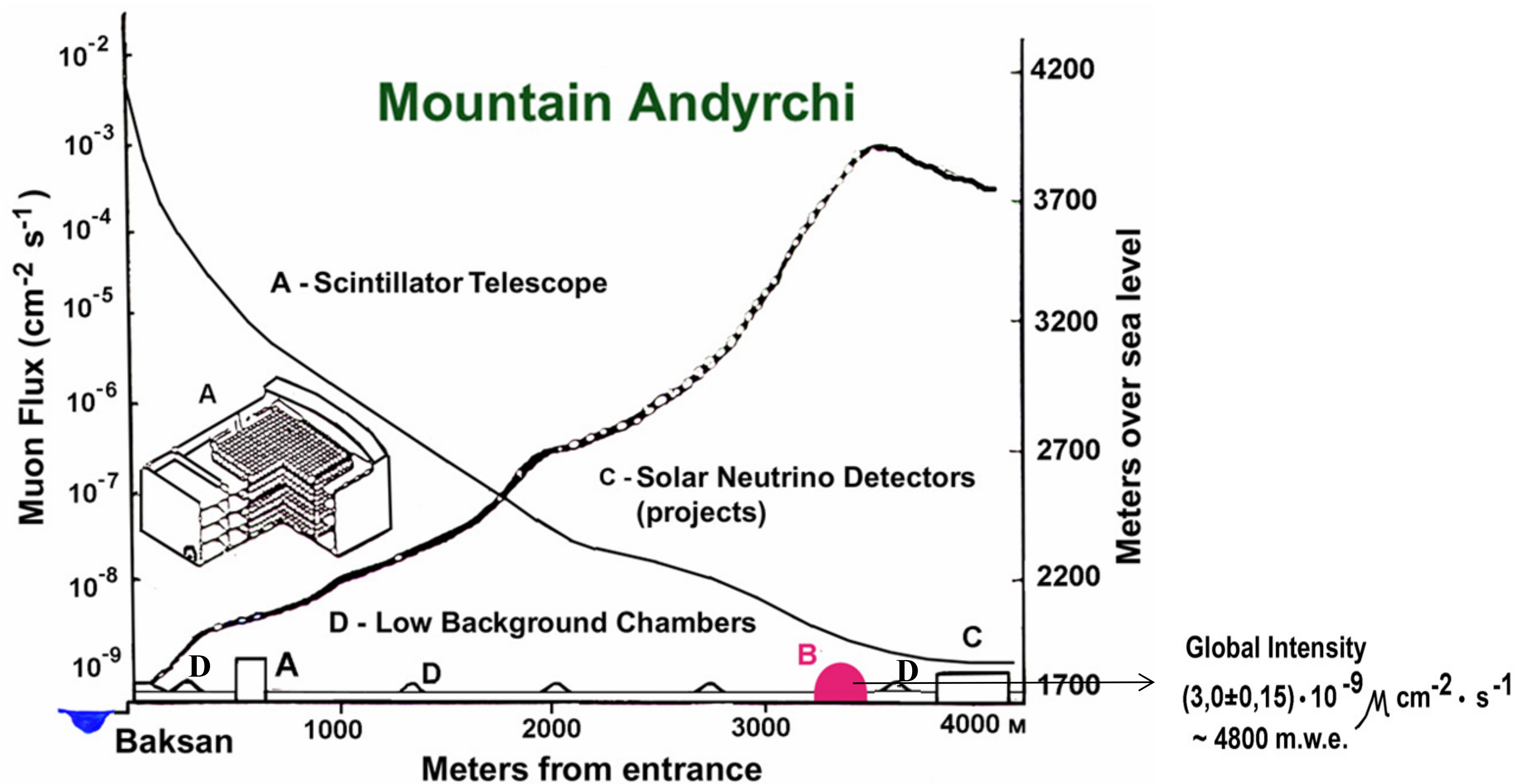
View of installation

General view of underground objects of BNO



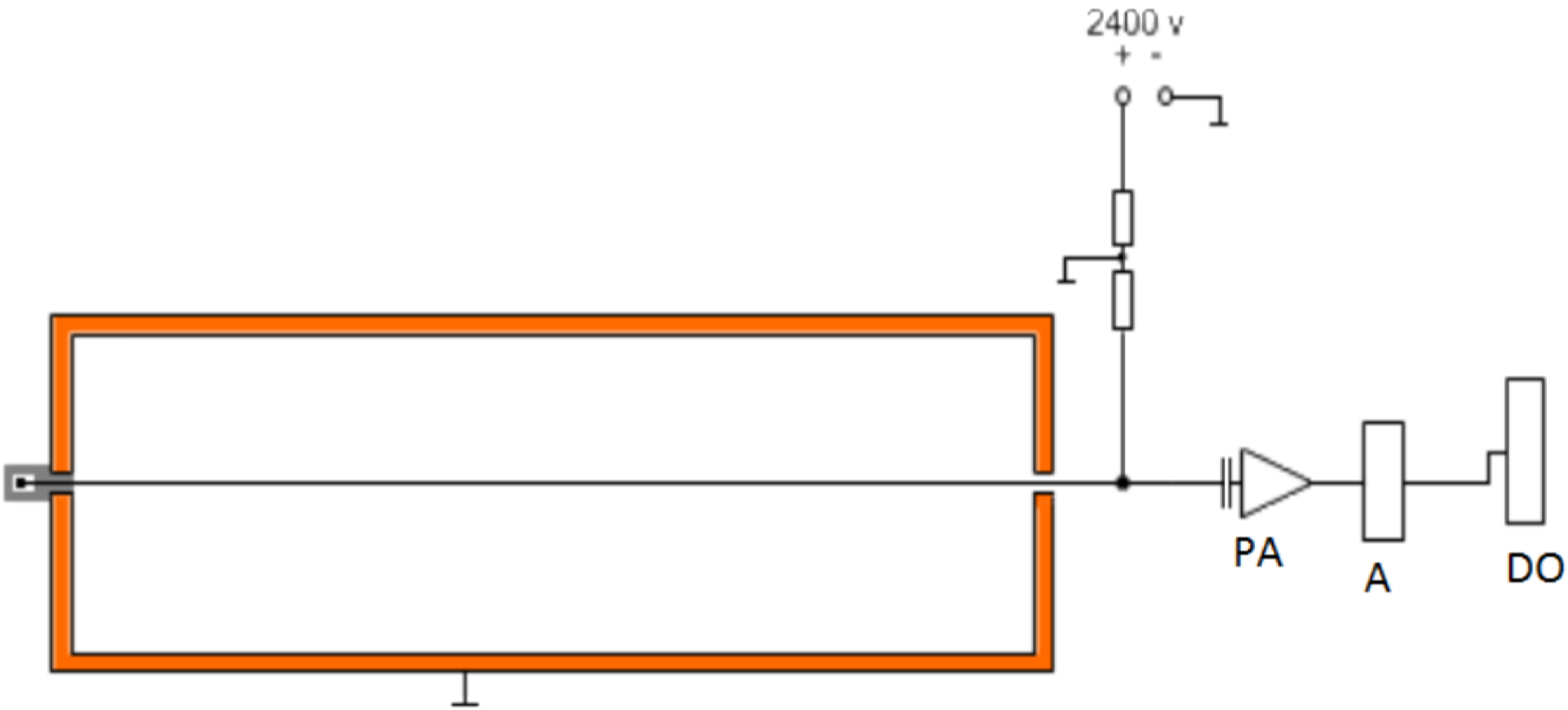
Underground Laboratories of the BNO INR RAS

General view of underground objects of BNO



Schematic view of a section of the Andyrchy slope along the adit (write scale) and dependence of underground muon flux on the laboratory location depth (left scale).

Electric scheme of the setup



PA – preamplifiers, A – amplifiers, DO – digital oscilloscope.

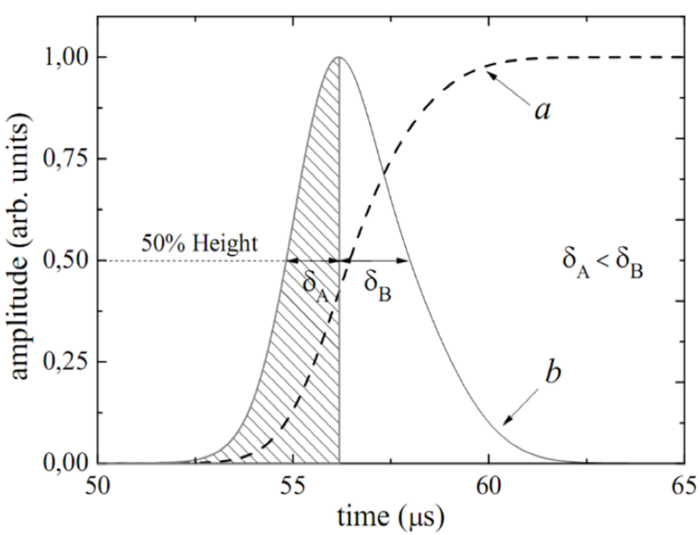
Current pulse normalizing

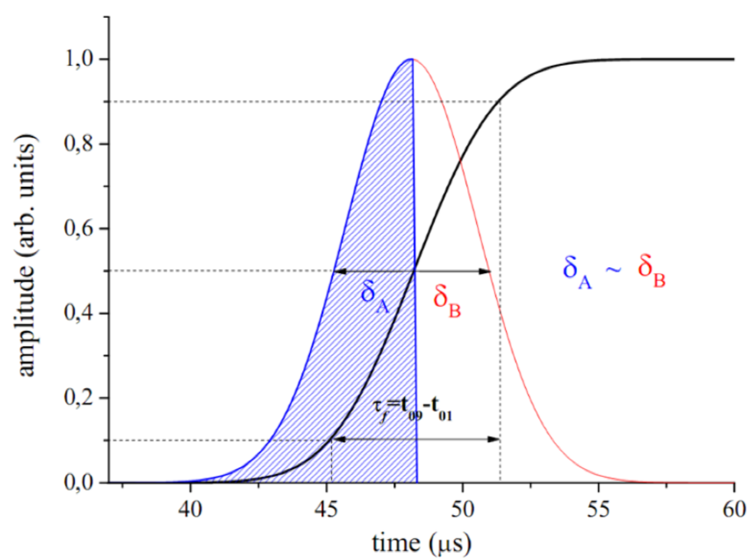
The current signal produced as a result of gas amplification has an asymmetric form.

The output pulse shape is defined by the superposition of induced charges from single electron avalanches distributed in time and intensity according to: the shape of the current pulse from primary ionization electrons, the shape of a pulse from an individual avalanche, and a finite time of the CSA self-discharge. The last two parameters are responsible for the asymmetry of the output current pulse. The output current pulse can be transformed to a symmetric shape by taking into account the analytical dependence of the amplitude of the output voltage pulse generated by a point (in projection onto the radius at the boundary of the gas amplification region) group of primary ionization electrons as a function of time and discharge constant of the output storage capacitor.

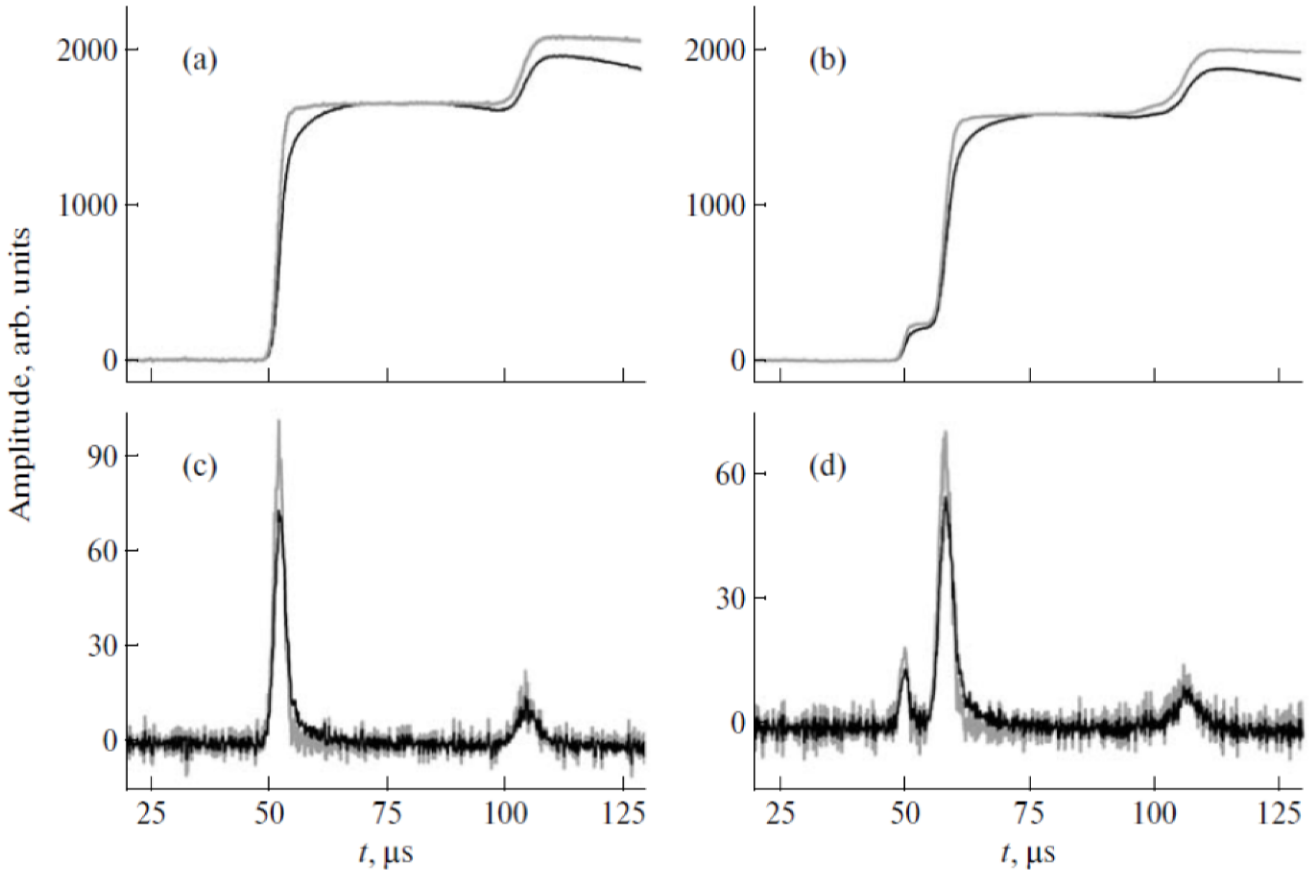
The obtained form of a signal one can describe by a set of Gaussian curves and thus determine the charge that was deposited in separate components of a multipoint event. The calculated area of an individual Gaussian should correspond to the charge (energy) of the corresponding point-like ionization.

$$V_k(t_i) = K_{1C} n_k \exp\left(-\frac{t_i + B}{RC}\right) \times \left\{ \ln\left(1 + \frac{t_i}{B}\right) + \frac{t_i}{RC} + \frac{t_i^{\,2}}{2 \times 2!(RC)^2} + \ldots \right\} + K_{EC} n_k \exp\left(-\frac{t_i}{RC}\right),$$

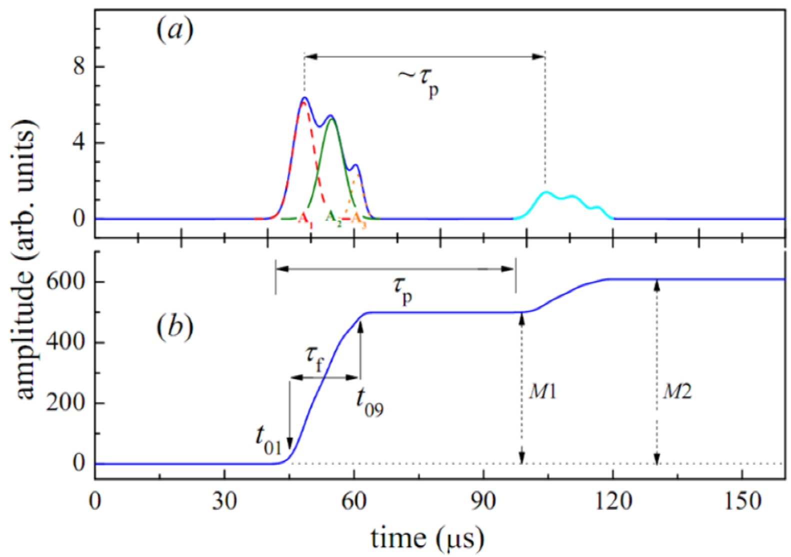




Examples of pulses (dark lines) of two types of events: (a) for photoabsorption of an 88-keV photon with an escape of electrons only (a single-point event), (b) simultaneous escape of a 12.6-keV characteristic photon Kr and a photoelectron [88.0 keV-12.6 keV = 75.4 keV (a two-point event)]. The calculated, area-normalized current pulses of primary ionization electrons are shown with light lines in Figs. c and d, while the respective voltage (charge) pulses obtained by integrating these current pulses are depicted with light lines in Figs. a and b.

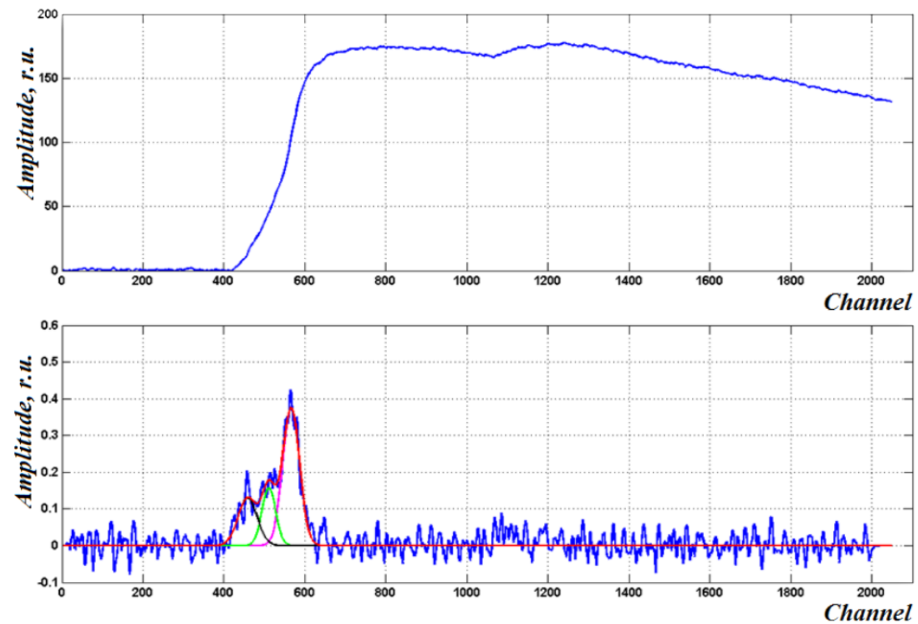


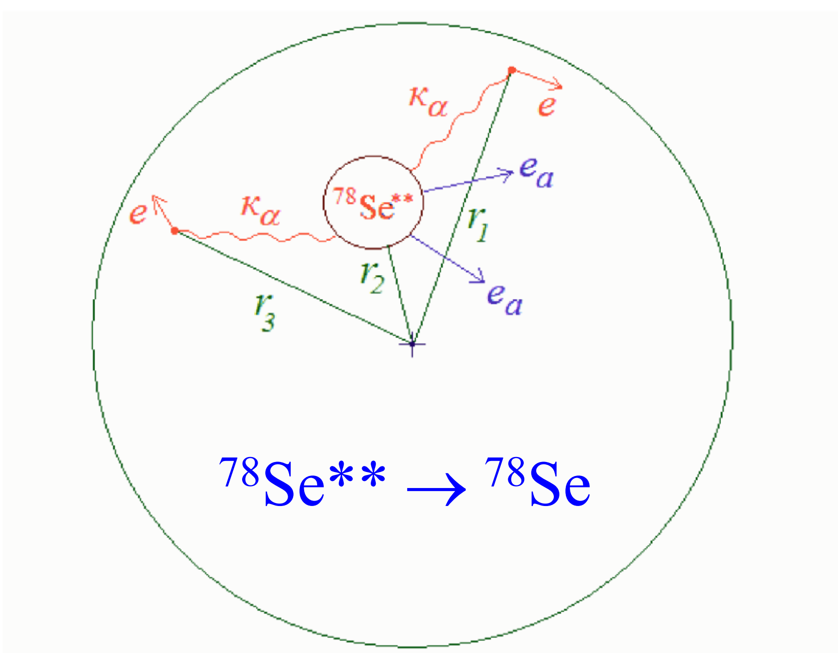
Three-point pulse



$$\begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix} \Rightarrow \begin{Bmatrix} q_0 \\ q_1 \\ q_2 \end{Bmatrix}$$

λ=((M2-M1)/M1)·100





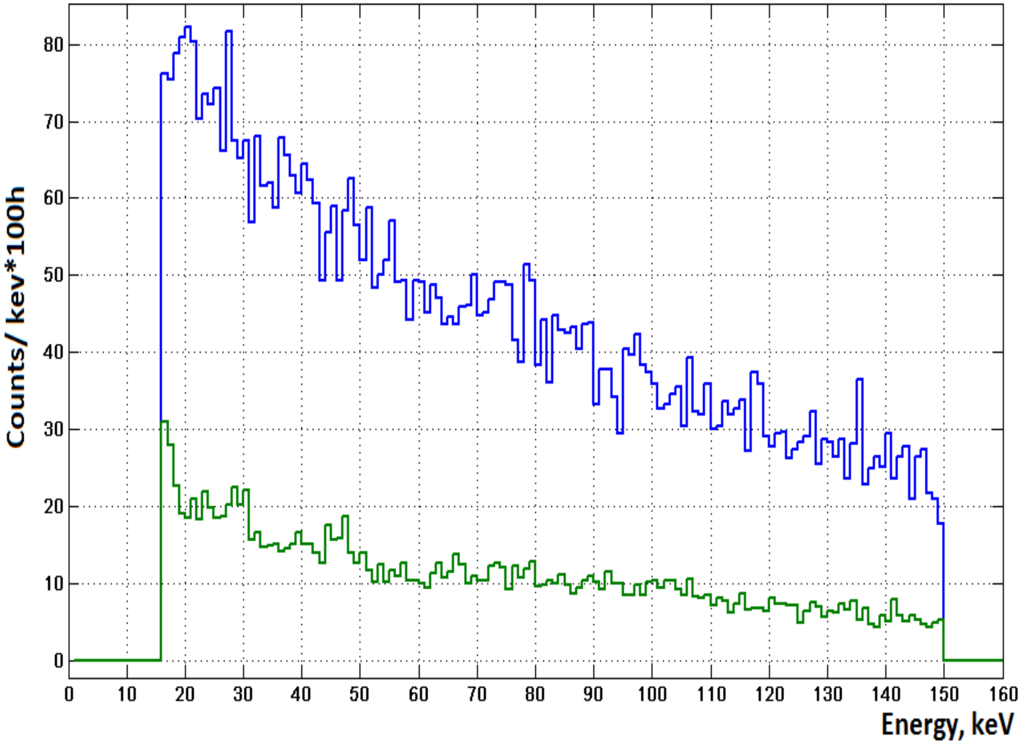
^{124}Xe – sample

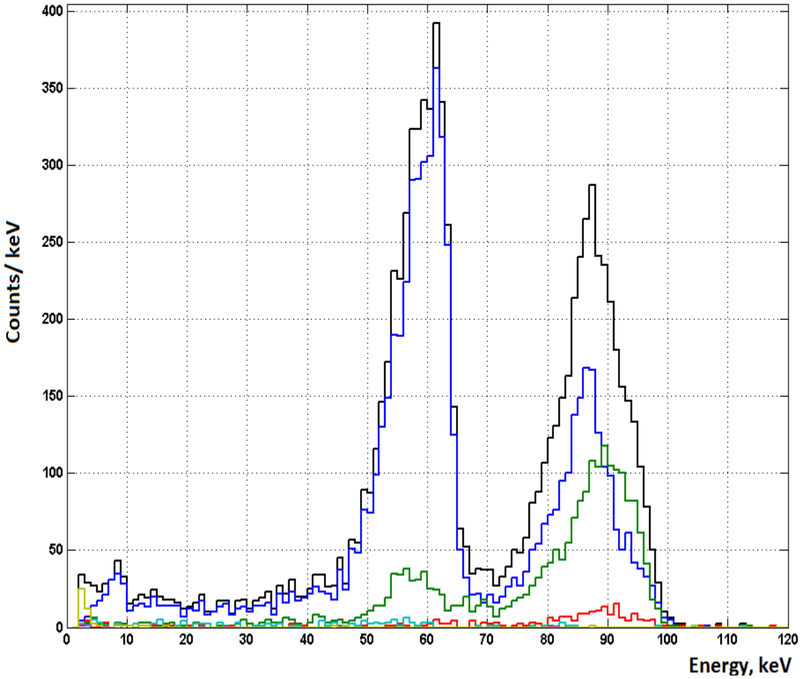
^{124}Xe – sample, (total ~12 l, ^{124}Xe ~ 7,6 l ≈ 44 gr)

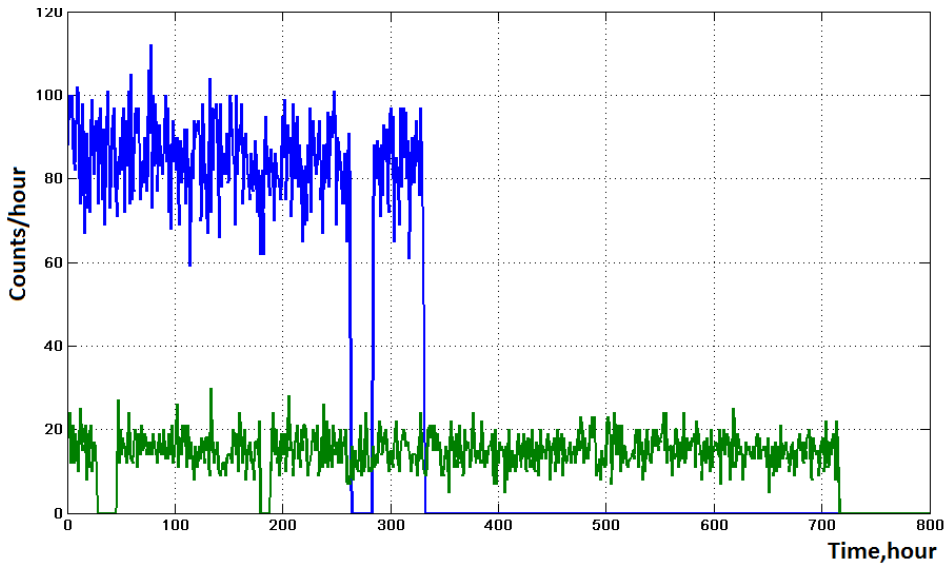
Isotope / Sample	124 l	126 l	128 l	129 l	130 l	131 l	132 l	134 l	136 l
Sample №1a ~1.98 l	1.02	0.381	0.519	$3.1\cdot10^{-4}$	$1.32\cdot10^{-4}$	$3.76\cdot10^{-5}$	$1.8\cdot10^{-5}$	$1.8\cdot10^{-5}$	$1.8\cdot10^{-5}$
Sample №2 ~1.27 l	1.13	0.013	0.034	$6.1\cdot10^{-4}$	$1.2\cdot10^{-4}$	$3.6\cdot10^{-5}$	$3.6\cdot10^{-5}$	$3.5\cdot10^{-5}$	$3.5\cdot10^{-5}$
Sample №3 ~3.56 l	1.6	1.93	0.00103	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.7\cdot10^{-5}$	$6.7\cdot10^{-5}$	$6.6\cdot10^{-5}$	$6.5\cdot10^{-5}$
Sample №4 ~3.1 l	1.50	1.4	0,12	$6{,}7\cdot10^{-4}$	$5{,}8\cdot10^{-4}$	$5{,}8\cdot10^{-4}$	$5{,}8\cdot10^{-4}$	$5{,}8\cdot10^{-4}$	$5{,}8\cdot10^{-4}$
Sample №5 ~1.32 l	1.11	$4\cdot10^{-3}$	$7{,}5\cdot10^{-5}$	$5\cdot10^{-5}$	$5\cdot10^{-5}$	$5\cdot10^{-5}$	$5\cdot10^{-5}$	$5\cdot10^{-5}$	$5\cdot10^{-5}$
Sample №6 ~1.31 l	1.31	$1.6\cdot10^{-4}$	$1.3\cdot10^{-5}$	$1.26\cdot10^{-5}$	$1.25\cdot10^{-5}$	$1.24\cdot10^{-5}$	$1.23\cdot10^{-5}$	$1.21\cdot10^{-5}$	$1.19\cdot10^{-5}$

^{85}Kr ~50 ppm

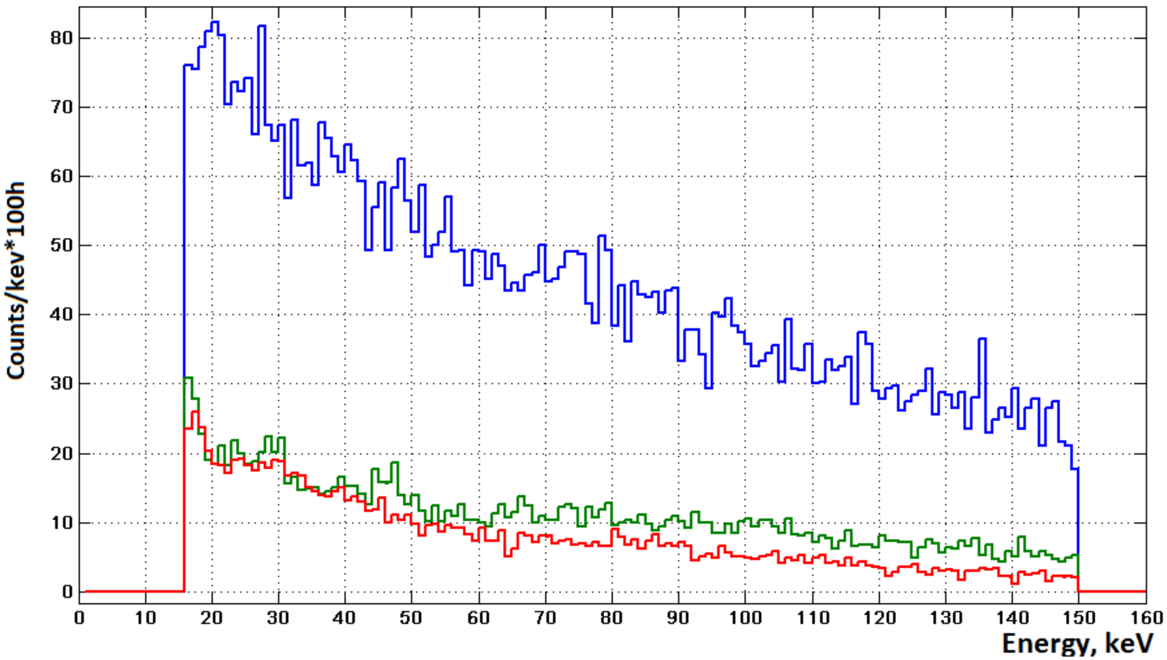
Spectrum of ^{124}Xe with ^{85}Kr







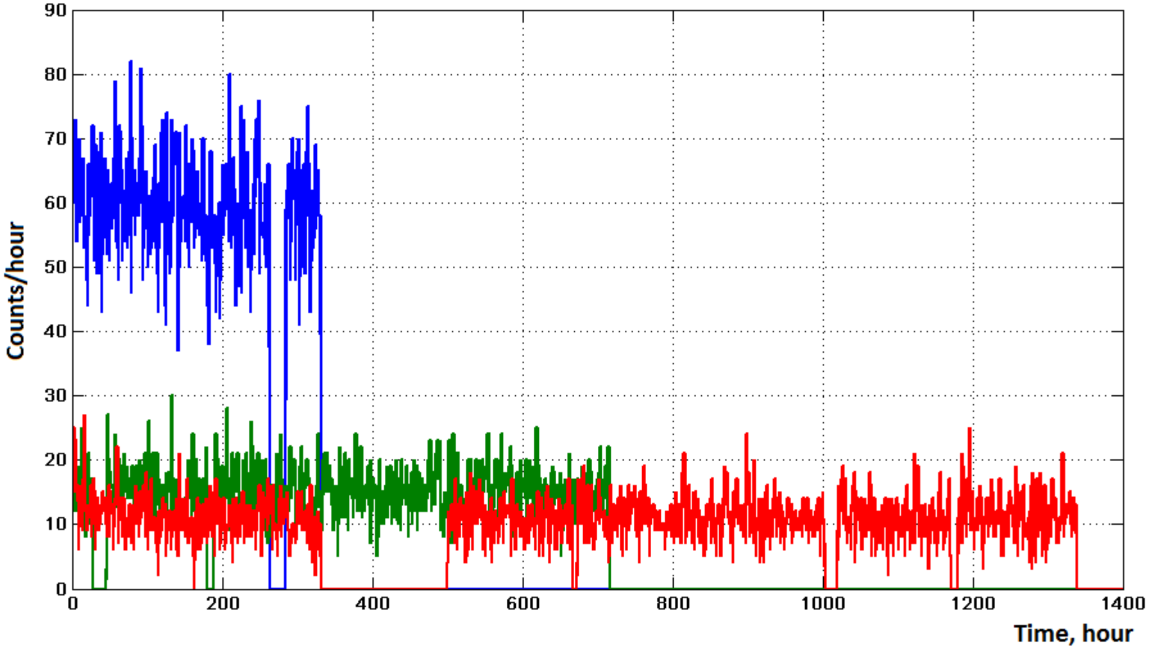
Spectrum of ^{124}Xe after separation from ^{85}Kr



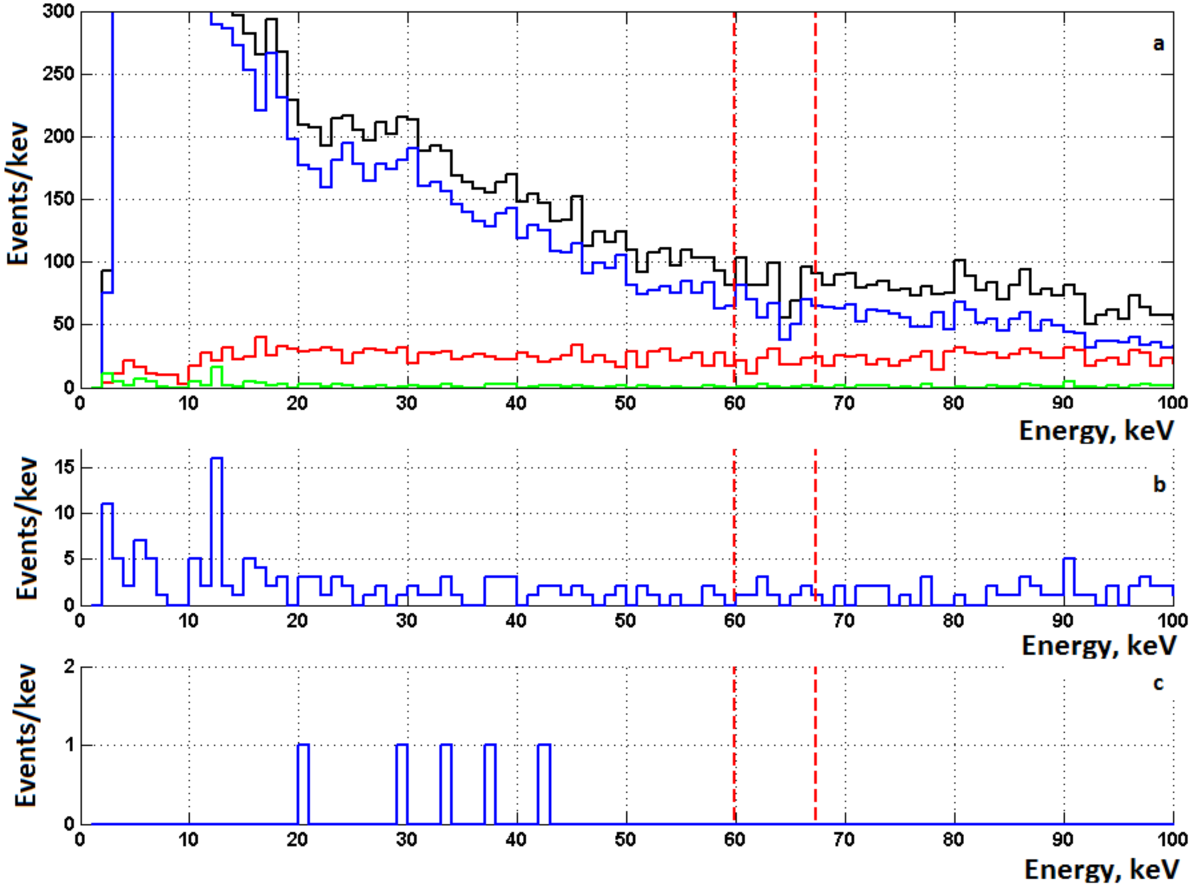
Blue – [^{124}Xe+^{85}Kr]
Green – ^{nat}Xe
Red – [^{124}Xe – ^{85}Kr]

Count rate :

Blue – [^{124}Xe+^{85}Kr]
Green – ^{nat}Xe
Red – [^{124}Xe – ^{85}Kr]



First result in ^{124}Xe 2K-capture experiment



Black – All events

Blue - one point events

Red – two point events

Green – three point events

Three point events under condition: $m_1/m_2 \geq 0.7$

Three point events under condition: $m_1/m_2 \geq 0.7$

$5keV \leq m0 \leq 13keV$

From G.J. Feldman & R.D. Cousins, for n_0=0 and b=0

90% C.L. μ=0.00÷2.44 →2.44 for 1130h.→
→N_{eff} = 21,3744 yr $^{-1}$

$$T_{1/2} \geq \frac{\ln 2 \cdot N \cdot p_3 \cdot \varepsilon_p \cdot \varepsilon_3}{N_{exp}}$$

$$N = 2.59 \cdot 10^{23}$$

$$p_3 = 0.735$$

$$\varepsilon_p = 0.09$$

$$\varepsilon_3 = 0.422$$

$$T_{1/2}^{2\nu 2K}(g.s. \to g.s) \geq 4.67 \cdot 10^{20}\ yr\ (90\%\, C.L.)$$

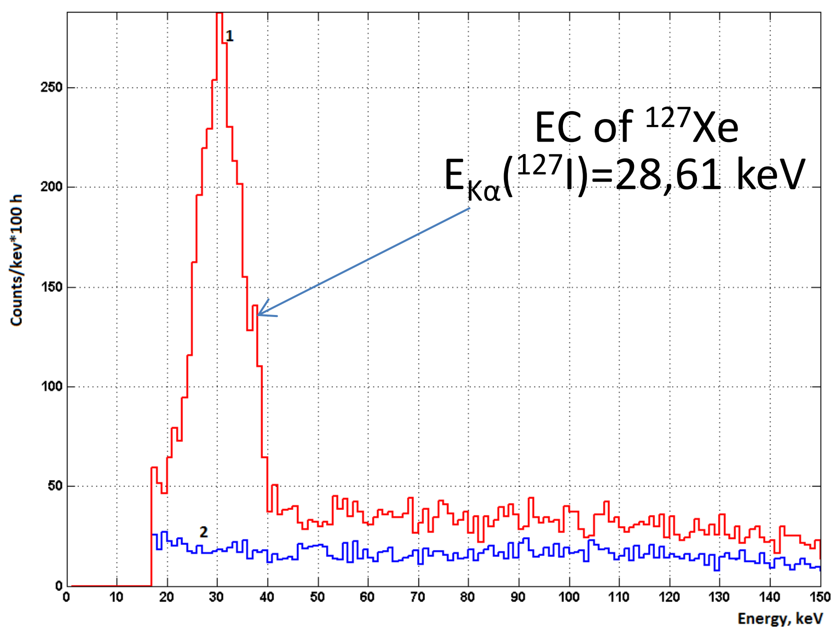
$$S = 1.46 \cdot 10^{21}\ yr\ (90\%\, C.L.)$$

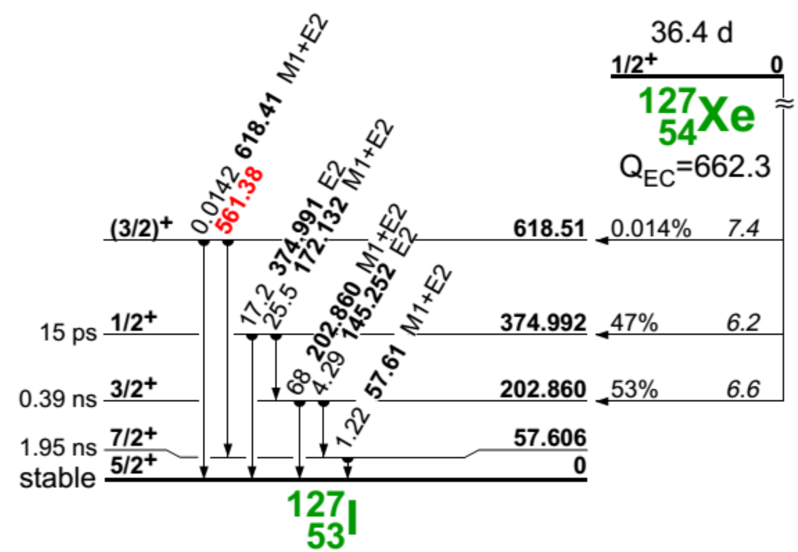
For ε_p=0.809 P=4.8 atm.

^{124}Xe – "No Name" sample №7

^{124}Xe – sample, (total ~58 l, ^{124}Xe ~ 4.33 l ≈ 23.96 gr), ^{126}Xe ~ 15.24 l ≈ 85.7 gr

Isotope Sample	124 l	126 l	128 l	129 l	130 l	131 l	132 l	134 l	136 l
Sample "unmarketable wastes" ~58 l	*4.33*	*15.24*	*24.174*	*14.033*	*0.0511*	*0.0394*	*0.0168*	*0.0606*	*0.0543*

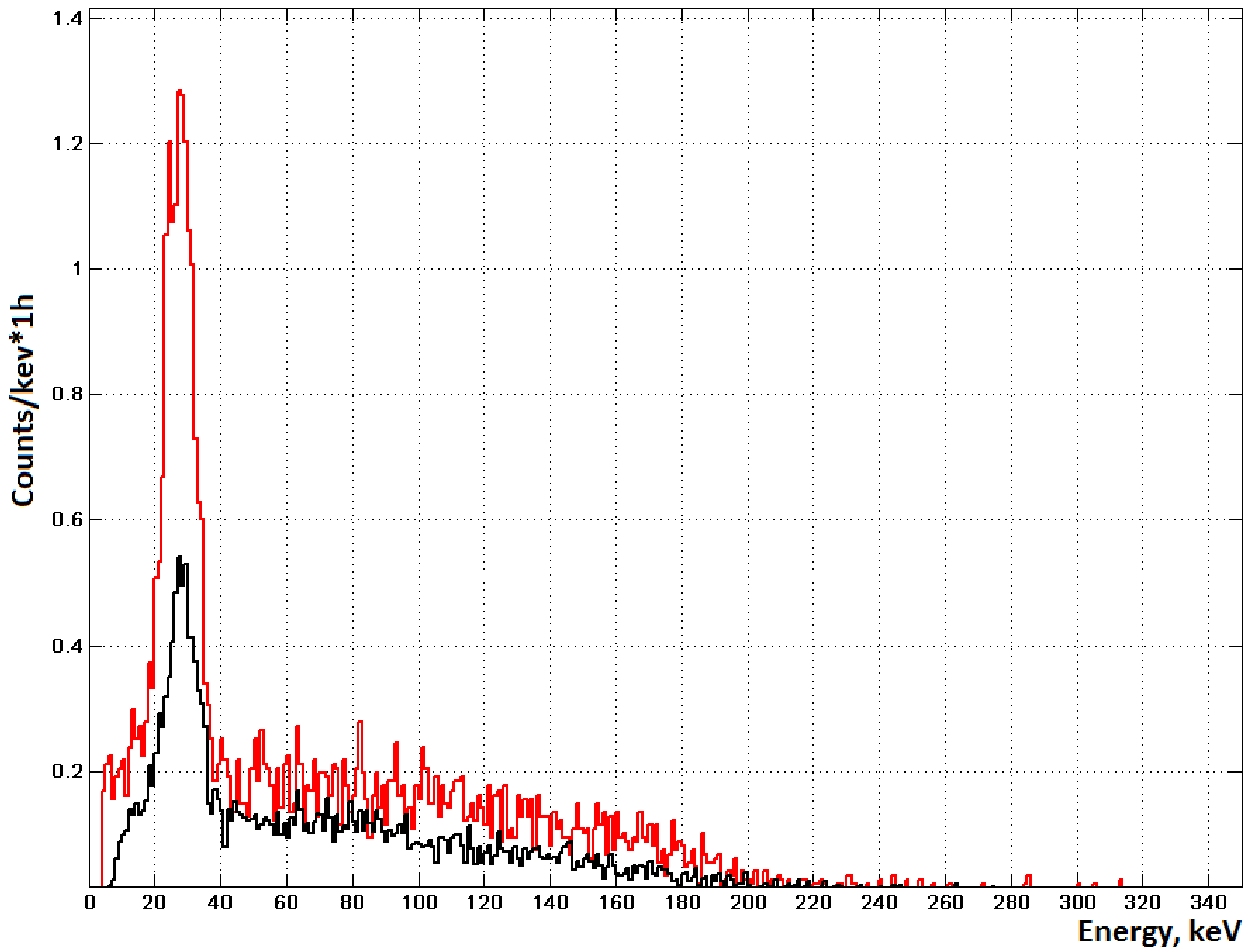




1. - *Spectrum of ^{124}Xe+^{126}Xe*
2. - *Spectrum of ^{nat}Xe*

Background spectrum of ^{124}Xe with internal source ^{127}Xe

The spectra are normalized to one hour.



Red spectrum is taken in the first 148 hours of measurement.
Black spectrum is taken in the last 300 hours.

Estimates on the half-life of 2K-capture of Xe-126

Measuring Double-Electron Capture with Liquid Xenon Experiments

D.-M. Mei, I. Marshall, W.-Z. Wei, and C. Zhang

arXiv:1310.1946v3

From the analysis of XENON100 data

$$T_{1/2}^{2\nu 2K} \geq \frac{\ln 2 \cdot f_k \cdot \varepsilon \cdot a \cdot \frac{M \cdot N_A}{A} \cdot \Delta T}{\mu_{up}}$$

$$\mu_{up} \cong \alpha \cdot \sqrt{B}$$

$$B = b \cdot \Delta T \cdot \Delta E$$

Mass of liquid xenon, kg	*34*
Isotope abundance, %	*0.09*
Live time, day	*225*
Background index, event/keV/day	*0.18*
K-shell fluorescence yield (ω_k)	*0.875*
$f_k = \omega^2_k$	*0.766*
Efficiency at 63.6 keV	*0.9*
Energy resolution(σ/*E*) *at 63.6reV,%*	*7.0*
The region of interest ΔE	*7.94*
Reaction Q value, keV	*896*

$$T_{1/2}^{2\nu 2K} \geq 1.47 \cdot 10^{21}\ yr\ (90\% C.L.)$$

Thank You!