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Cross sections structure research at INR spallation neutron source installation INES

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Installation INES at the TOF 50 meter base of the pulsed spallation neutron source RADEX

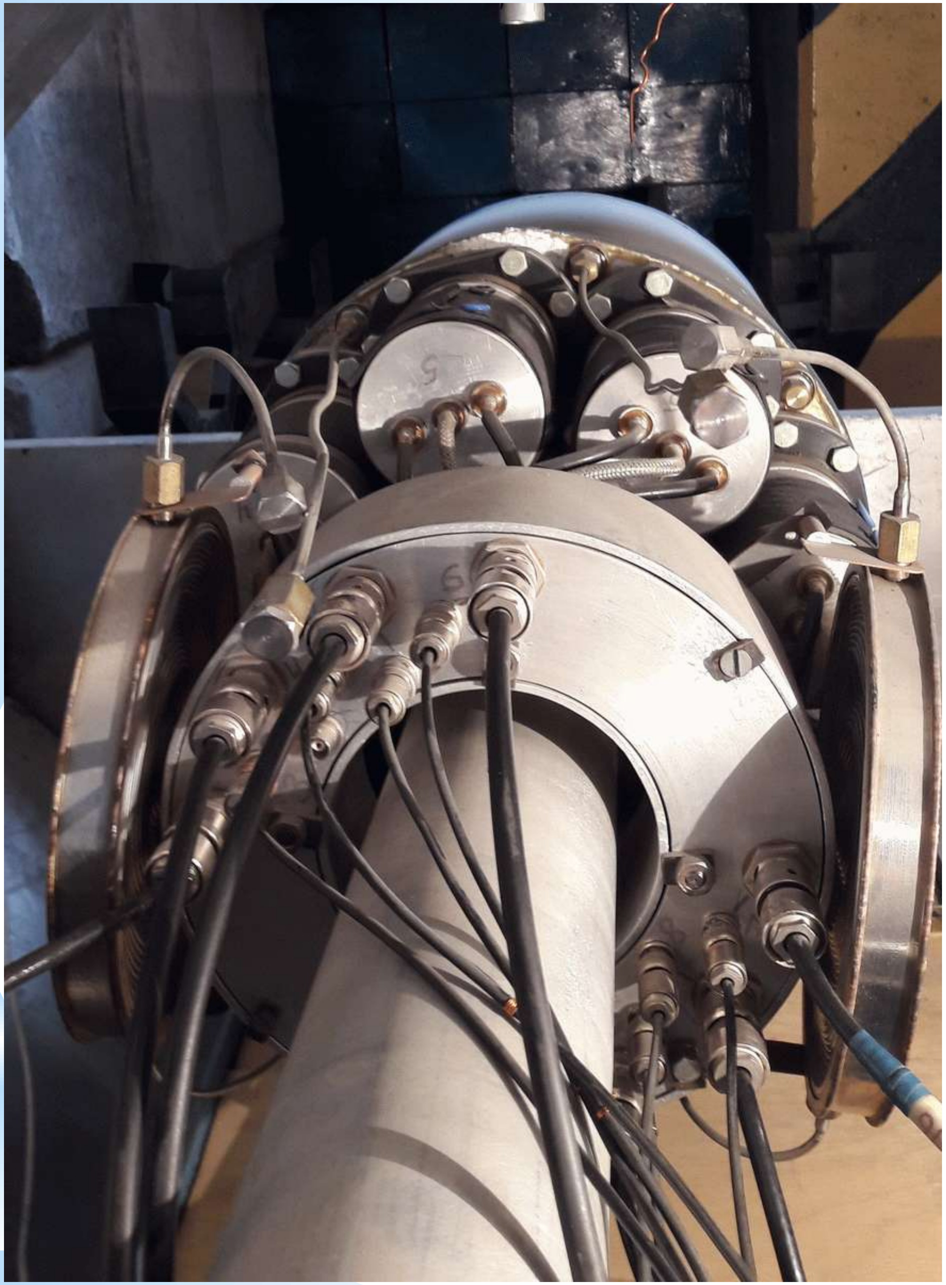
Installation INES is created to investigate neutron cross sections and make measurements of effective group cross sections for metal alloys and other nuclear reactor materials, which were made using enriched isotopes.

Effectiveness of measurements grow due to making two types of experiments: both absolute cross sections measurements and comparable measurements, using as a calibration pattern the same alloy material, made using usual chemical elements of natural isotope composition.

- *92 chemical elements before and including uranium (Z=92)*
- *83 of them have stable isotopes and available in nature in enough quantities to become construction materials*
- *21 of them are mono-isotope*
- *23 of them have 2 stable isotopes*
- *39 have even Z value due to what they have three and more stable isotopes*
- *Thus, 62 chemical elements in nature are isotope mixtures which can be separated and used in nuclear technics as alloys with perfected qualities. Their group cross sections depend on separation quality and must be measured experimentally*

Group cross sections are used by calculation programs, codes, as a start data for calculation of nuclear reactors, radiation shield and their properties in different conditions.
As an example, widely used stainless steel alloy consists of four elements: chromium, nickel, titanium and iron which have 18 isotopes in different quantities. During calculation of 28-group effective alloy cross sections, it's necessary to calculate sum of 18 isotopes resonance structure, also at energies higher then resolved resonances area, their interference, Doppler-effect and internal block-effect. Isotope composition of alloy is also known with definite accuracy.

INES allows to get experimental group cross sections for alloys, produced by industry for usage in cores of nuclear reactors. This gives an opportunity to compare and check precise theoretical calculation results.



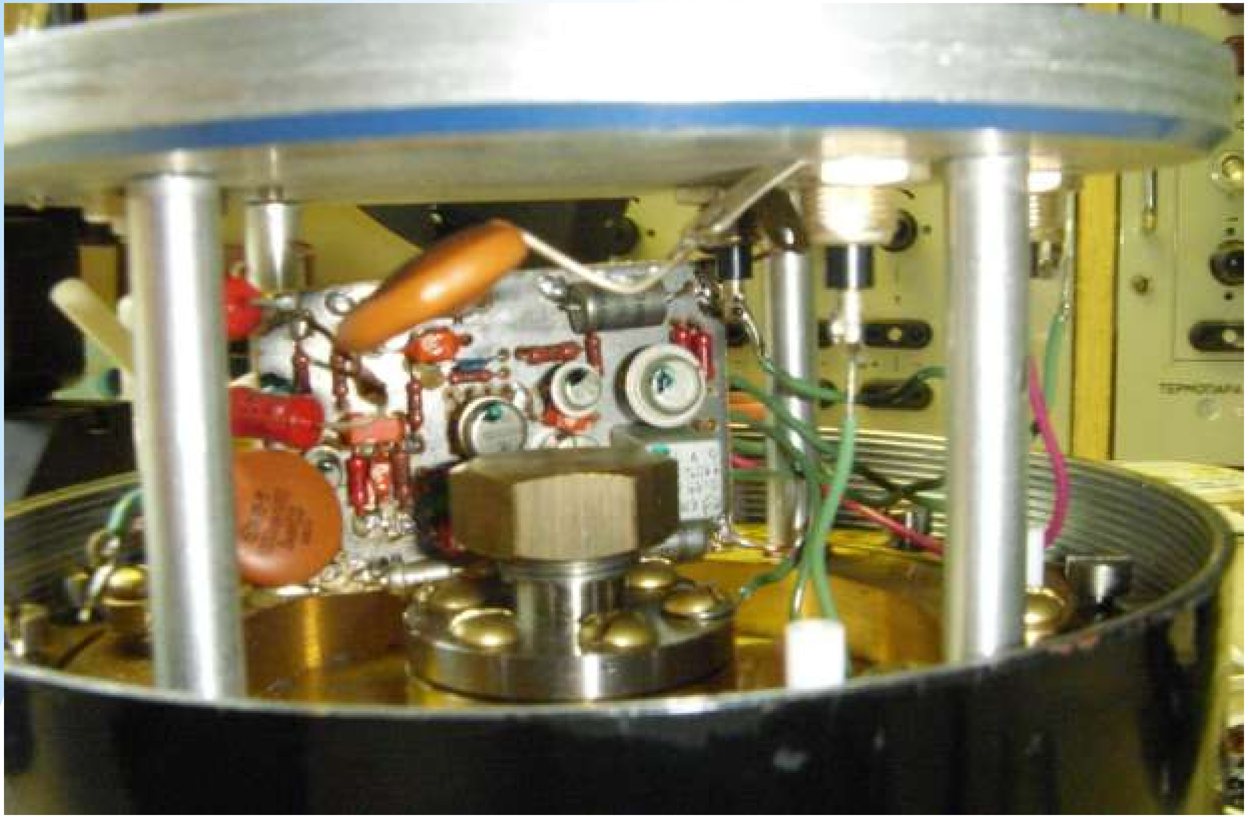
Liquid scintillator 8-channel detector, used at 50 meters flight base of pulsed spallation neutron source RADEX

8-sectional liquid (n, γ) detector has pulse length **30 nanoseconds** and allows usage of coincidence multiplicity method to extract (n, γ) cross sections also in energy region upper then resolved resonances. Effect and background can be distinguished also in upper energy groups.

During measurements INR proton linac was working with parameters:
Energy of protons **209 MeV**
Pulsed current **10 mA**
Frequency **50 Hz**
Pulse duration **1 mks**

Thus, pulsed beam power was **2 MW** at mean current **0.5 mkA**, which provided intensity **5E12** neutrons/s.

At the 50 meter TOF base, neutron flux **13000 n/(cm2 * s)** was measured.



He3 monitor counter:
* previously used front-end electronics (shown on the picture), created for measurements at IBR-30 pulsed (4mks) reactor, had pulse length 6 mks and maximum load 80 kHz

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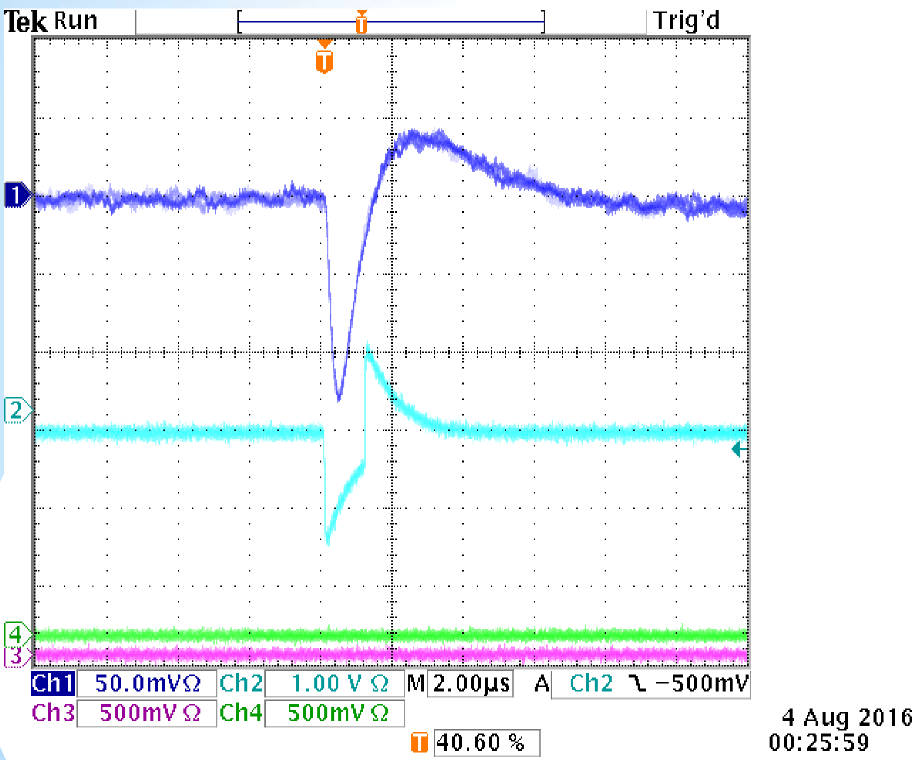
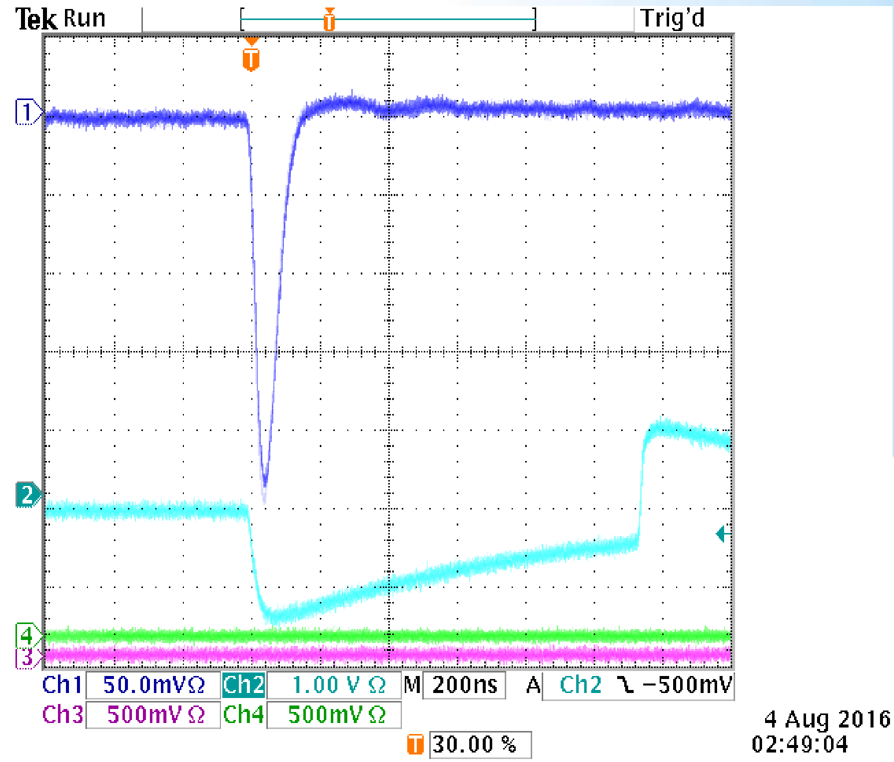
*** For measurements with accelerators, which provide smaller pulse length, in cooperation with John Scarley (New York University) we created new front-end electronics. New amplifier design uses modern electronic element base.**

***He-3 detector, equipped with it, provides pulse length 350 nanoseconds, the same as the shortest INR proton linac beam.**

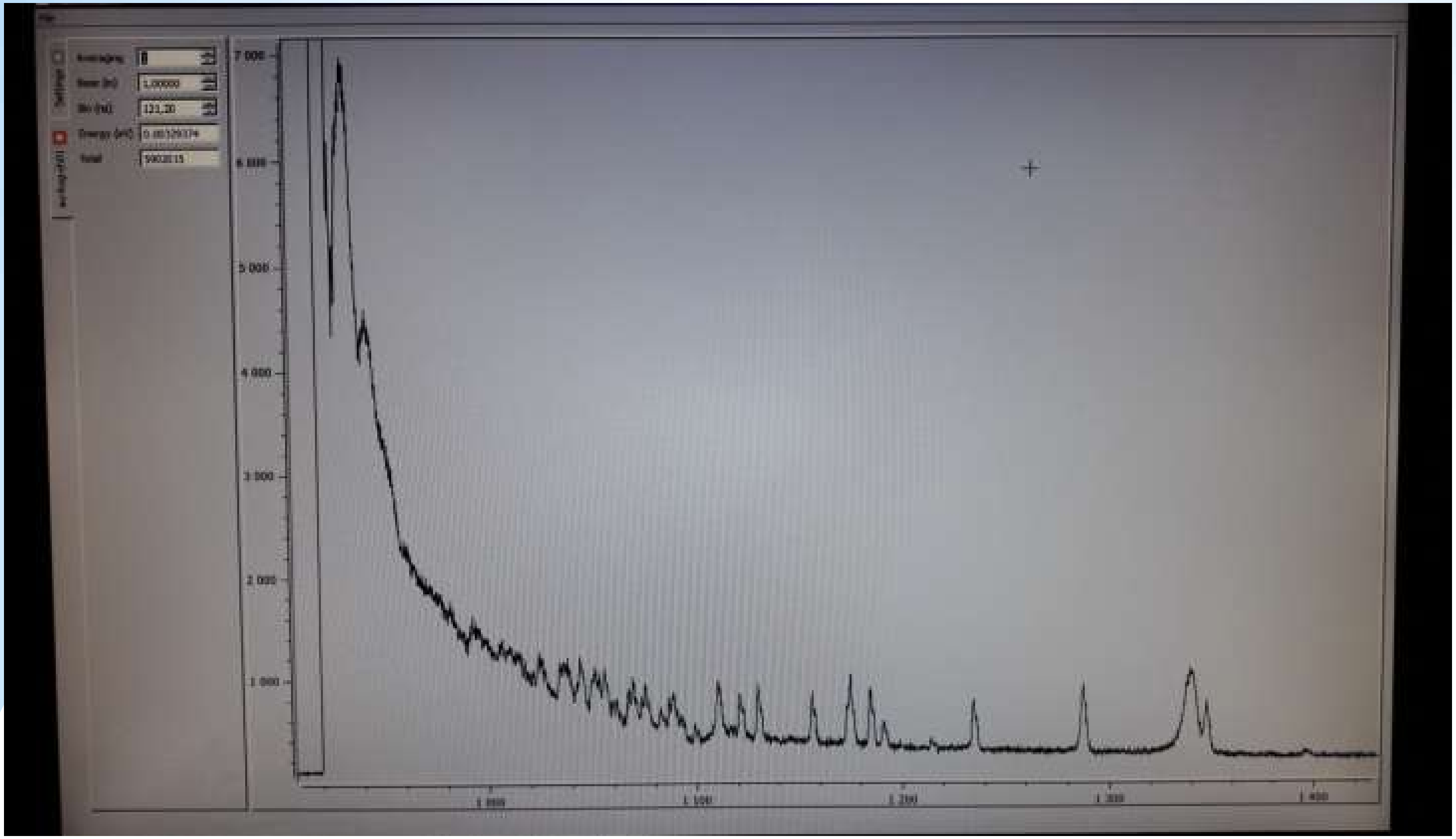
*** Maximum work load of He3 monitor with new front-end electronics was measured using Cf-252 neutron source, its value is approximately 900 kHz**

Properties of preamplifier signals:
old version (left side) and new device (right side).





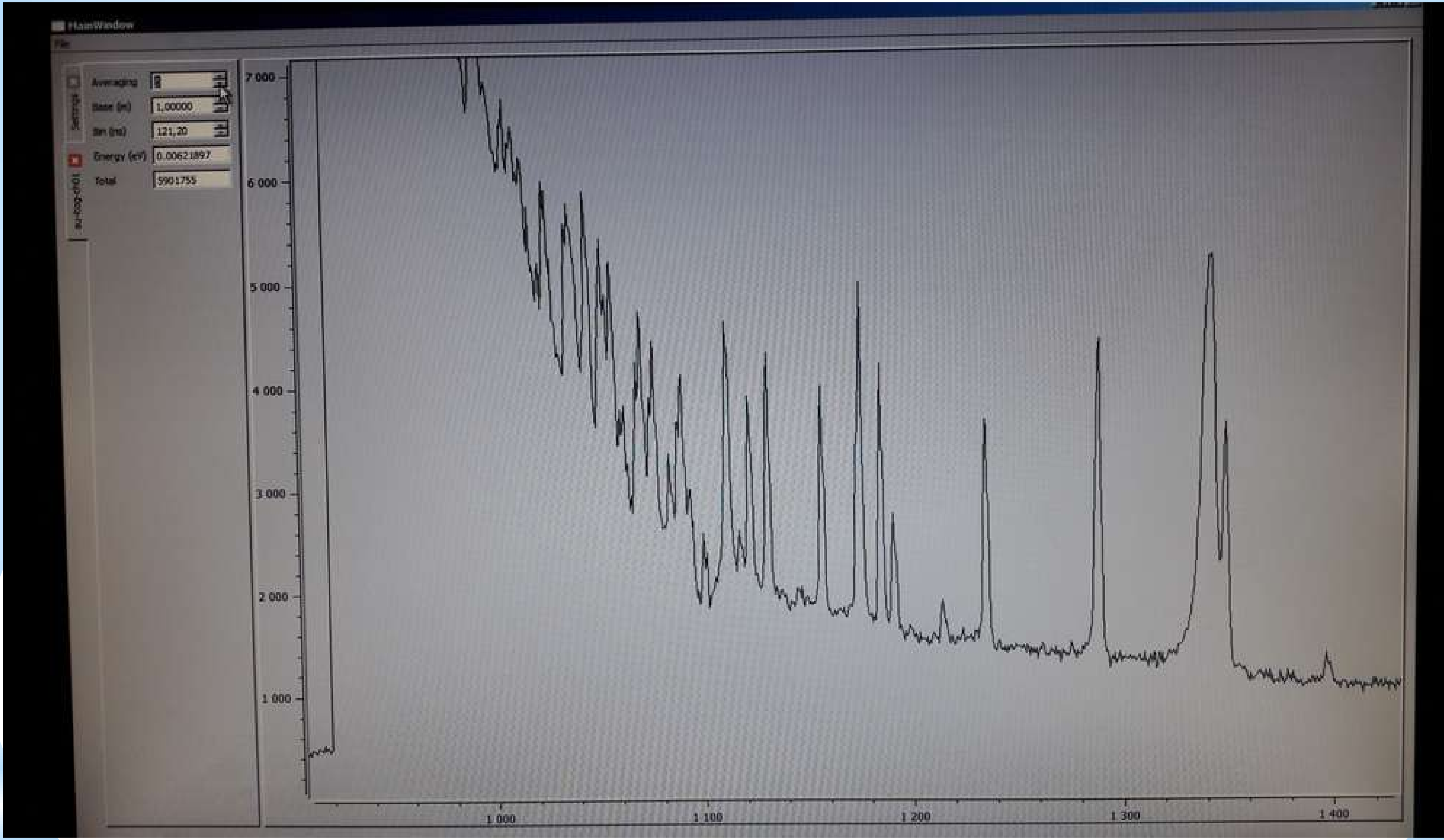
Entering signals are the same in both cases and are shown on lower curves.
Resulting signals are shown on upper curves.
Scale is 2 mksek/div for old amplifier (left side)
and 200 nanosec/div for John Scarley design (right picture).



As results of measurements we get experimental spectra:
on X axis is number of channel ‘N’, on Y axis is count in the channel number ‘N’.

TOF spectra of Au-197 is shown.

Screen of new Data Collection System is shown.
This system with channel width 133 nanoseconds was created in our group under the direction of professor $\boxed{\text{Yu.V. Grigoriev}}$ **and currently all the institute is using it for measurements.**

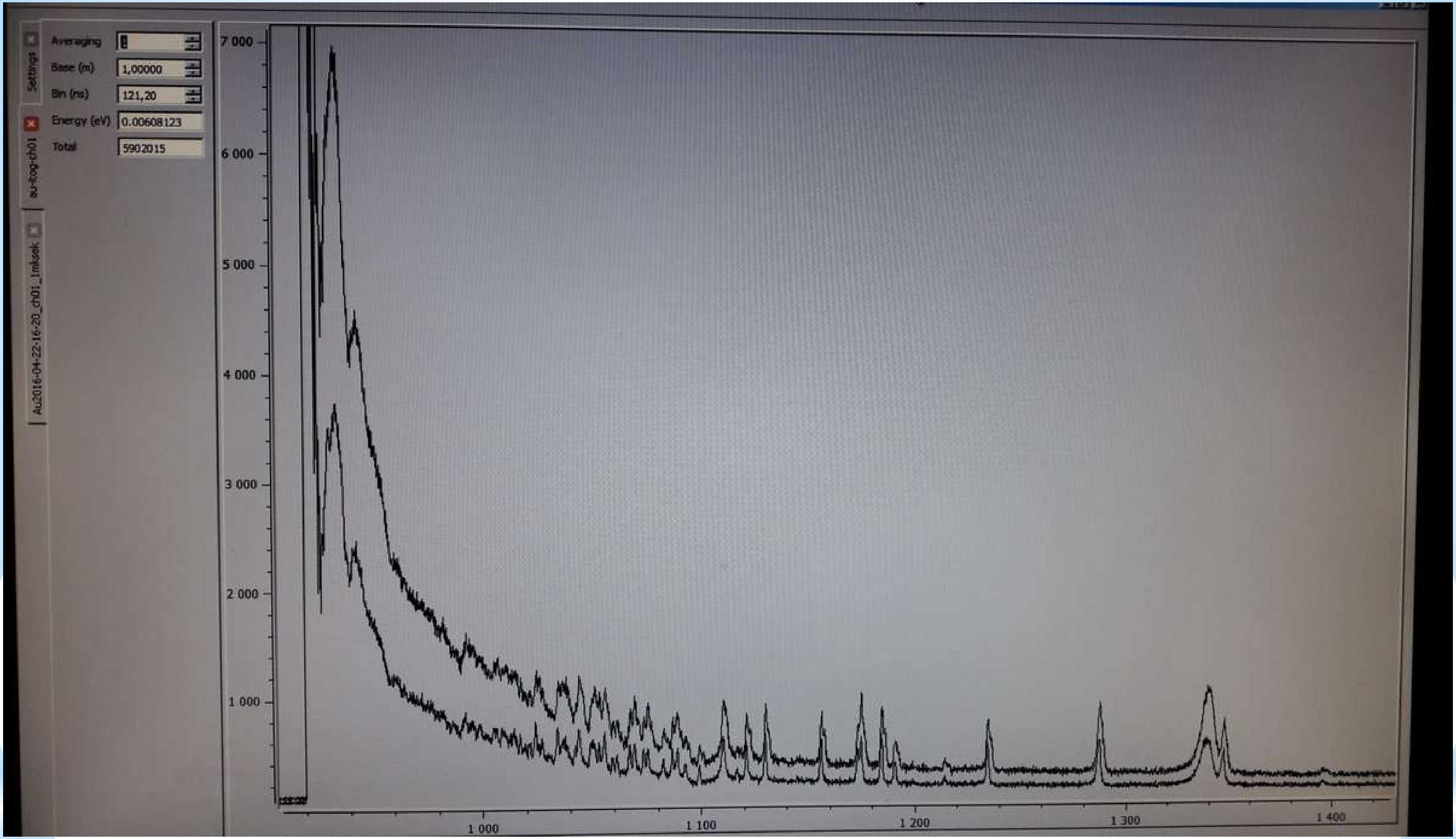


Resonance structure of Au-197 was measured on 50 meter TOF base of INR RADEX pulsed spallation neutron source. Beam length was 1 mksek, data collection system's channel width was chosen 133 nanoseconds.

This choice provided energy resolution 22 nanosec/meter and acceptable measurement time.

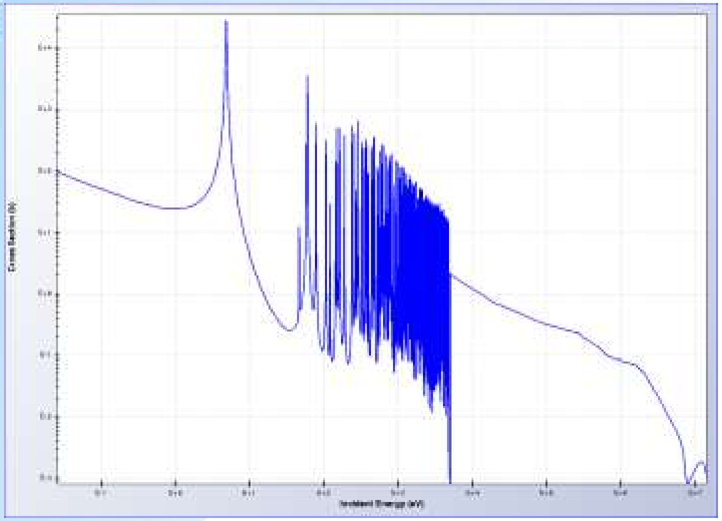
All the 50 Hz spectrum includes 150375 channels, part of spectrum is shown.

Right Au-197 resonance is 46.44 ev, at the left side shown curve corresponds to 2.2 keV.



Au-197 spectra with different statistics from different sections of 8-sectional liquid (n,γ) detector are shown. For group cross sections calculations, we currently add all 8 curves from 8 sections.

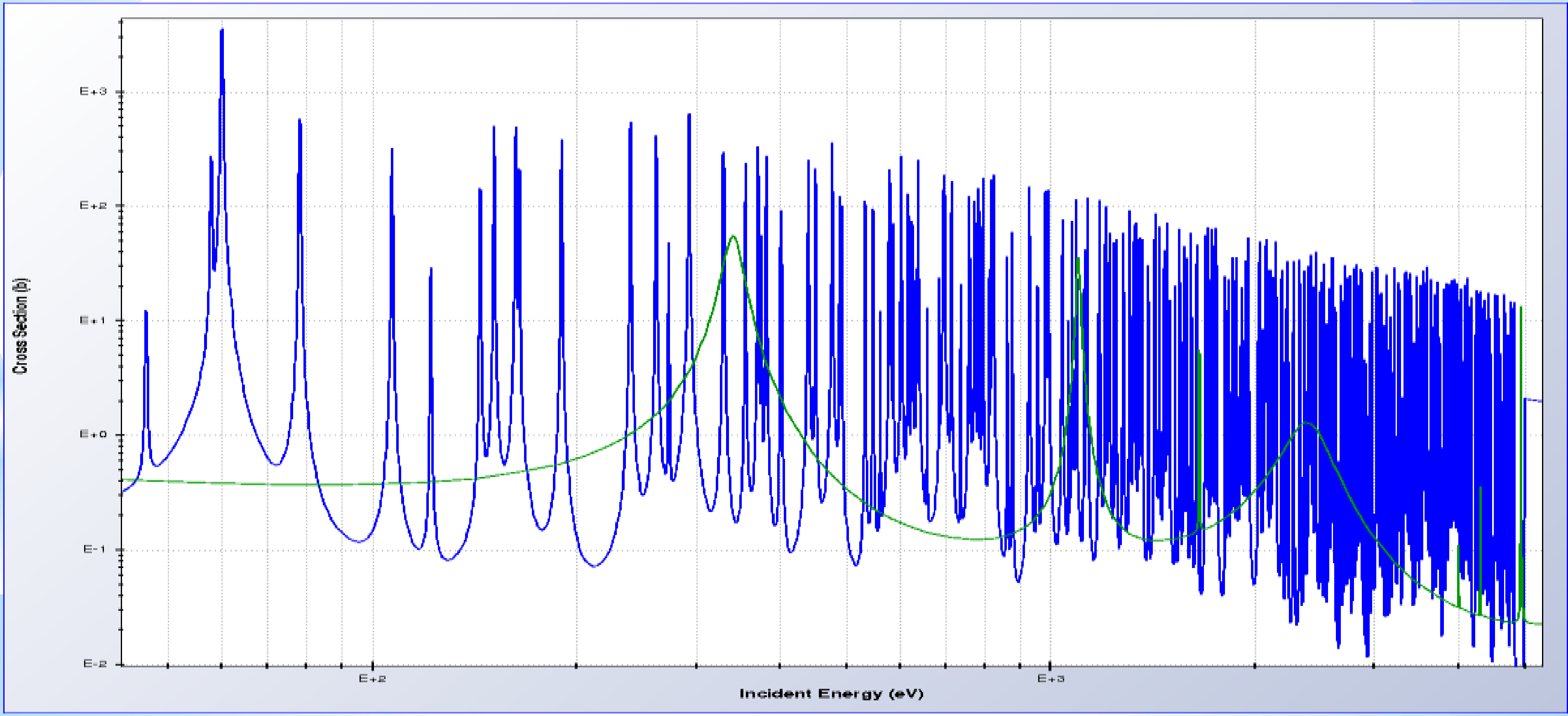
New electronic data collection system, which allows multiplicity method, is currently under construction.

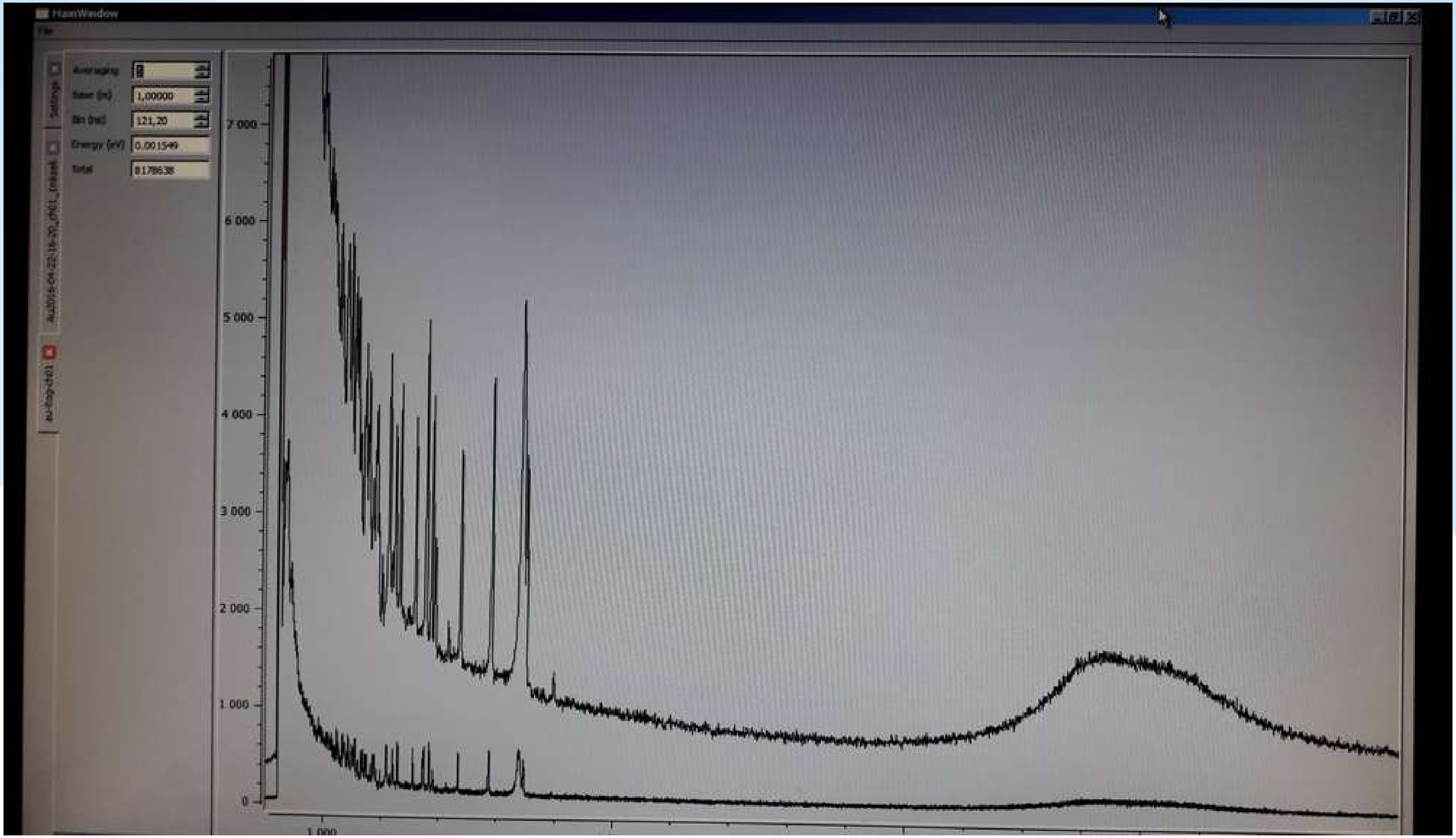


ENDF/B-VII.1 (USA, BNL) data for (n,γ) of Au-197

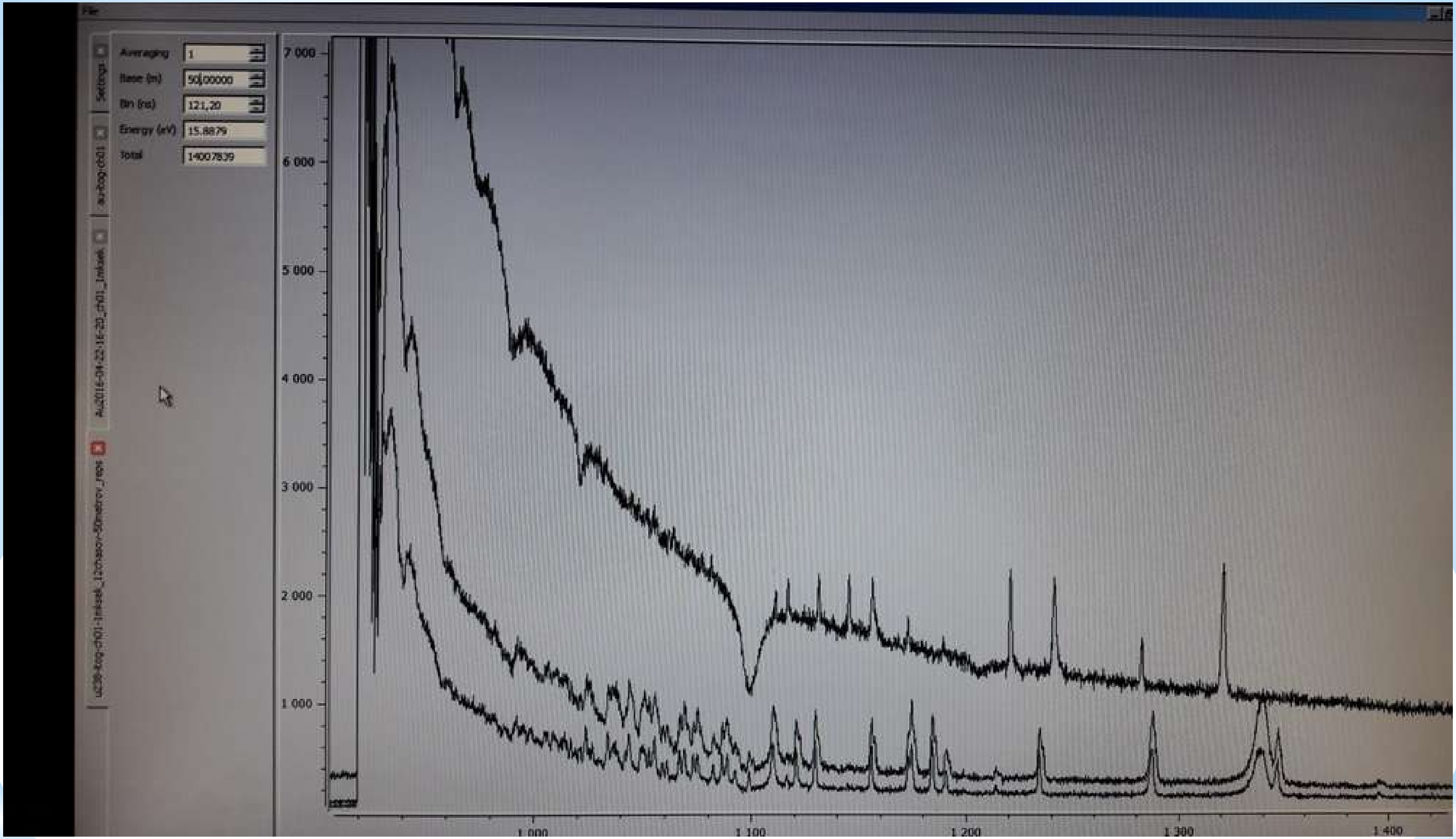
Resolved resonances are up to 5 keV.

So as Manganese-55 was used as a filter during our measurements, it’s resonances at 337 eV and at 2327 eV are shown on the second picture.

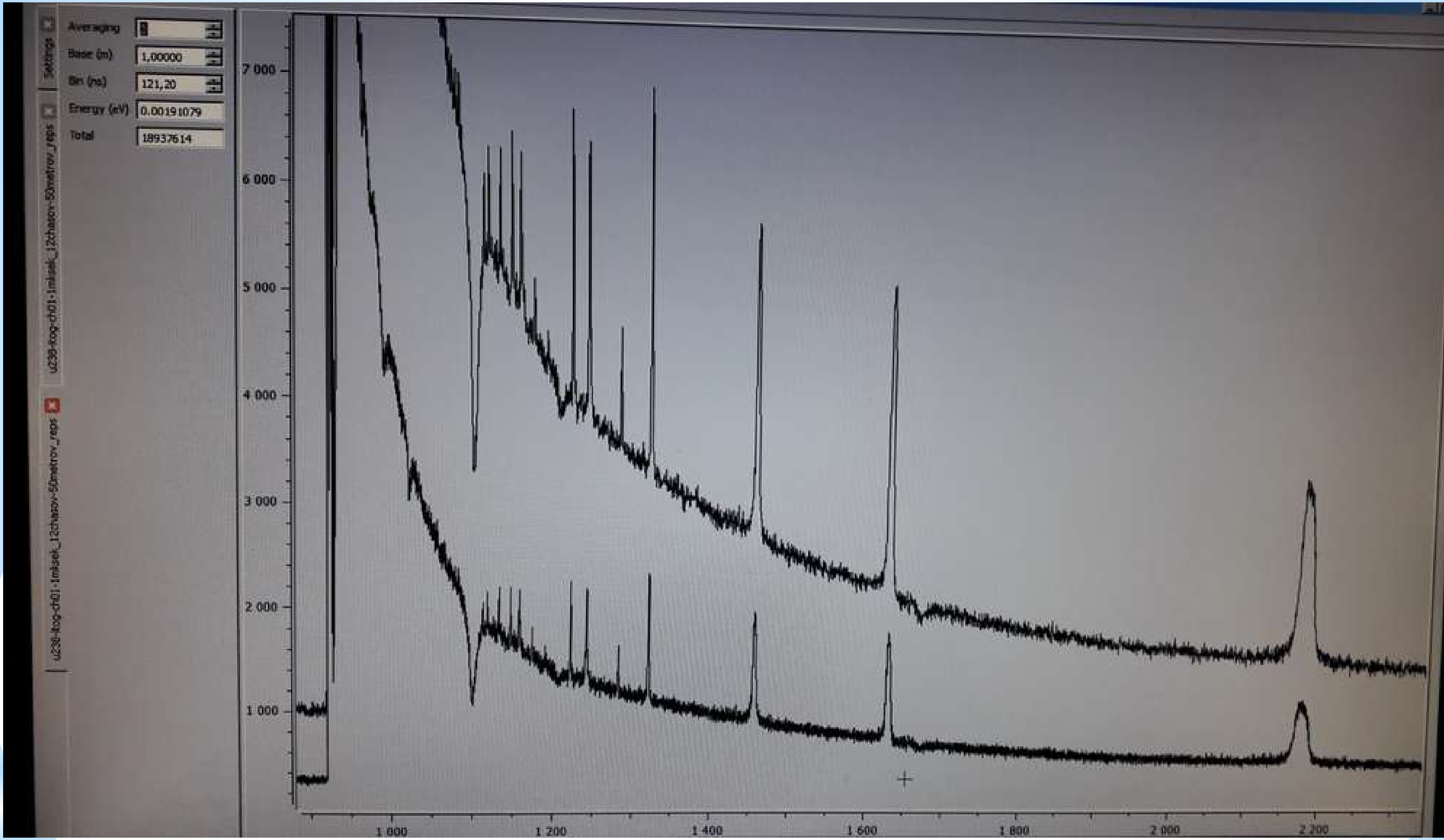




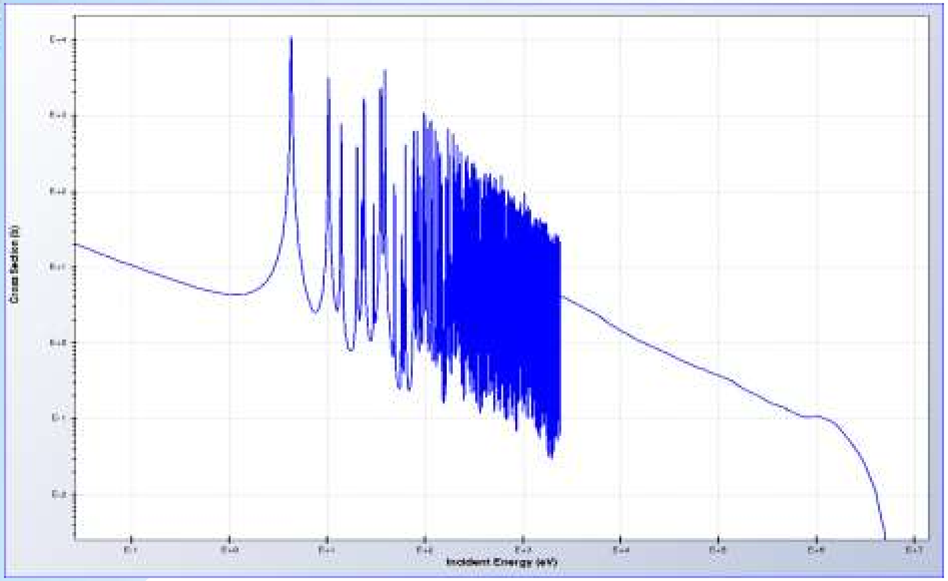
Software of new data collection system allows to see spectrums with averaging of 'X' selected number of neighboring channels. This option allows to see the spectrum with 'X' smaller value of (nanosec/meter) parameter, during that exceeding of useful signal above background rises into the factor 'X'.
For example, TOF spectra of Au-197 is the same on both curves.
On spectrum with averaging we can observe 46.44 eV resonance (first in left group) and lower resonance of Au-197 at 4.9 eV, which has big value of internal block-effect due to big (n,γ) cross section and big thickness of gold plate, which was used for measurements.



Upper curve: Uranium 238 with Mn-55 filter
Lower curves: Au197 with different statistics.
Resonance of Mn55 filter is observable at 337 ev.
Energy resolution 22 nanosec/meter allows to see strong resonances at neutron energies up to few keV



Uranium-238 spectra with different statistics.
In the right corner resonance 6.8 eV is observed, in the left Mn-55 resonance at 337 eV.
After deleting the background, resonance structure can be distinguished up to few keV.

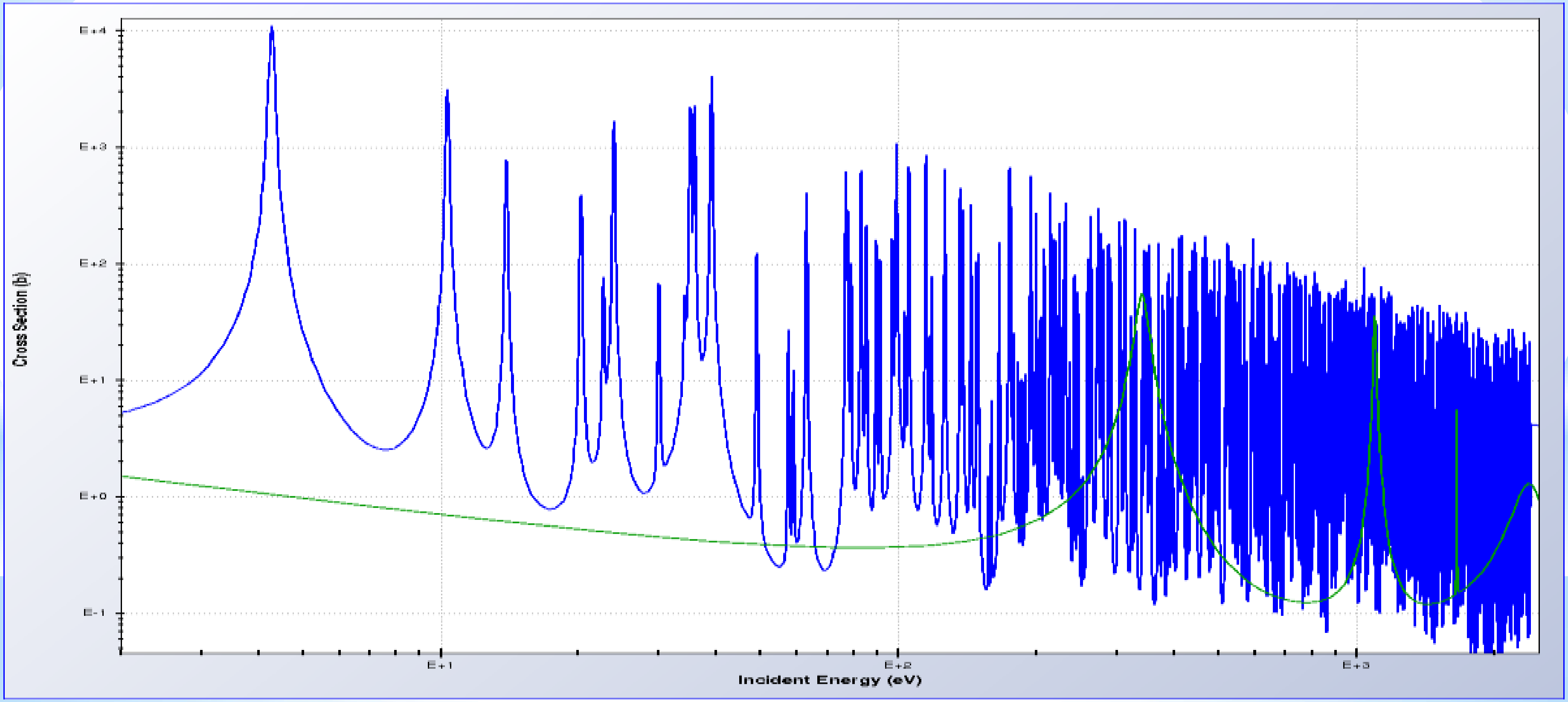


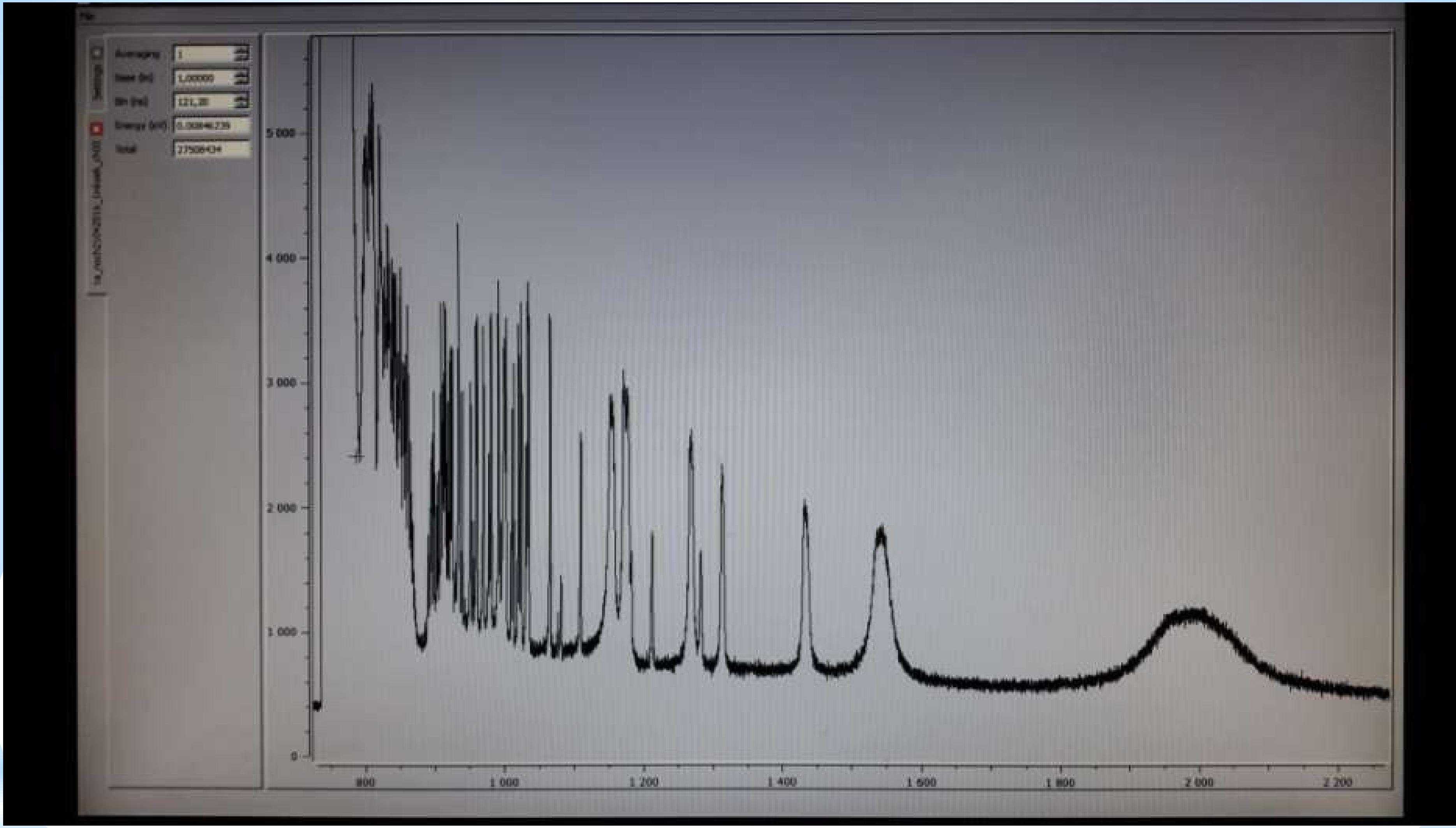
ENDF/B-VII.1 (USA, BNL) data for (n,γ) of Ta-181
Resolved resonances are up to 2.3 keV.

Manganese-55 was used as a filter in our measurements, it’s resonances at 337 eV and at 2327 eV are shown on the second picture.

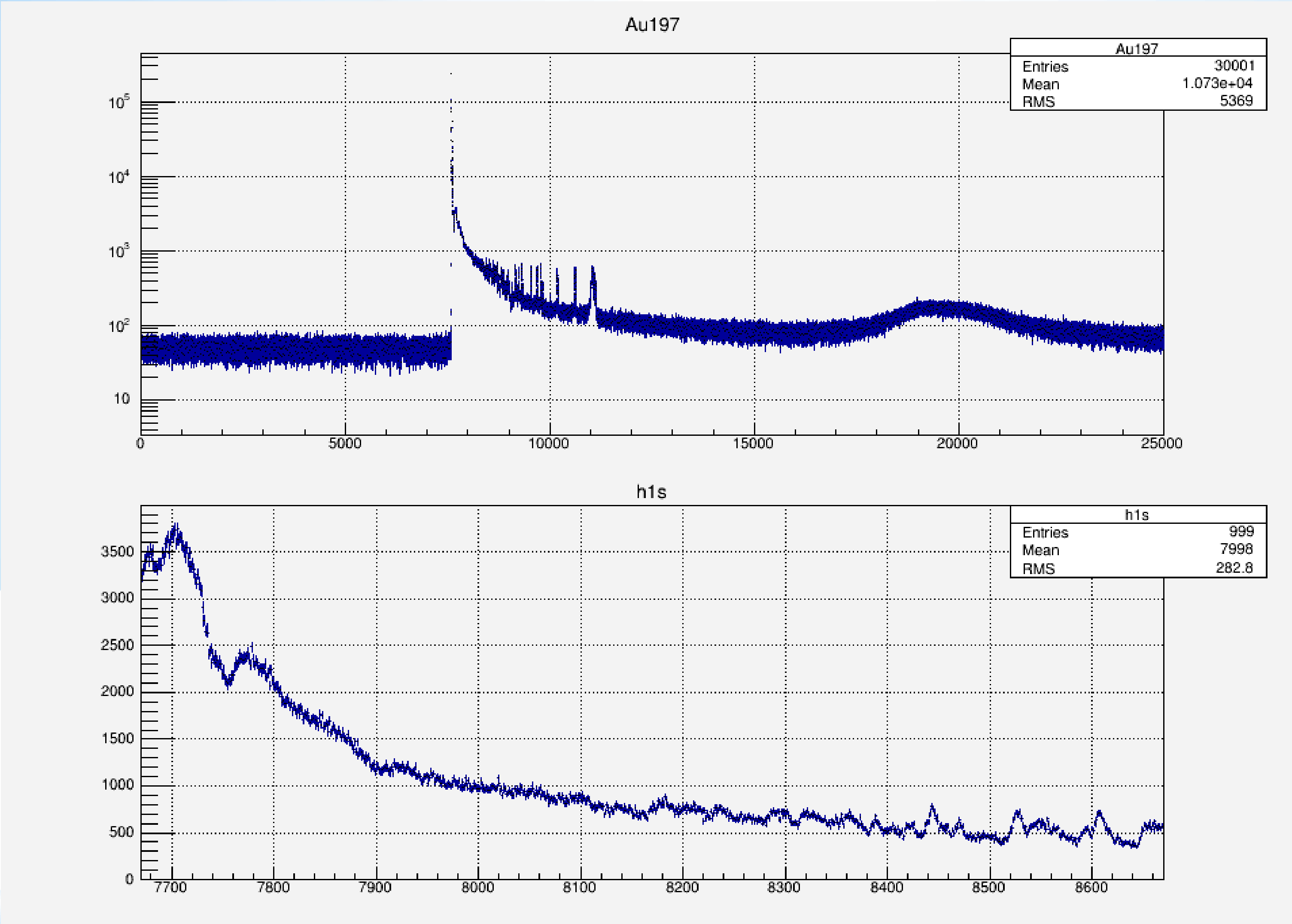
Energy borders of left picture are from thermal neutrons 0.0253 eV to 14 MeV.

Energy borders of second picture are from lowest Ta-181 resonance to upper limit of resolved resonances interval





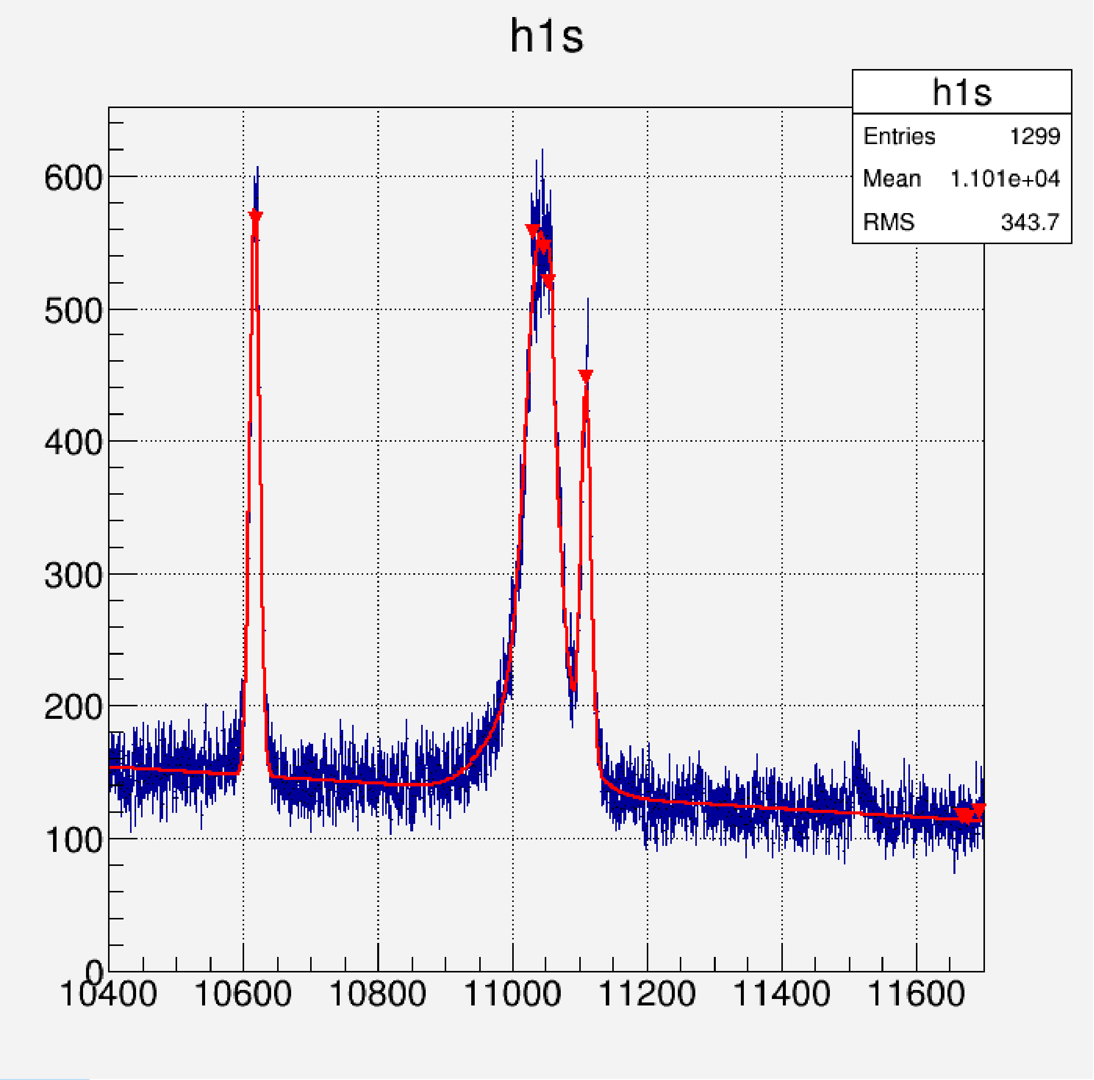
The same Ta-181 raw data spectrum in our measurements.
Lower resonance is not sharp: it has big value of internal block-effect due to big thickness of Ta-181 metal plate, which was chosen to be used in measurements for providing visibility of upper resonances, considering definite measurement time.
Resonance structures of Ta-181, U-238 and Au-197 were used for calibration of installation INES.



Screen of the program for preliminary observation of experimental TOF spectra

Resulting product of TOF measurements is a table of 28 (or 299 in BNAB-93 standard) group cross section values, which are used by reactor calculation programs as initial data.

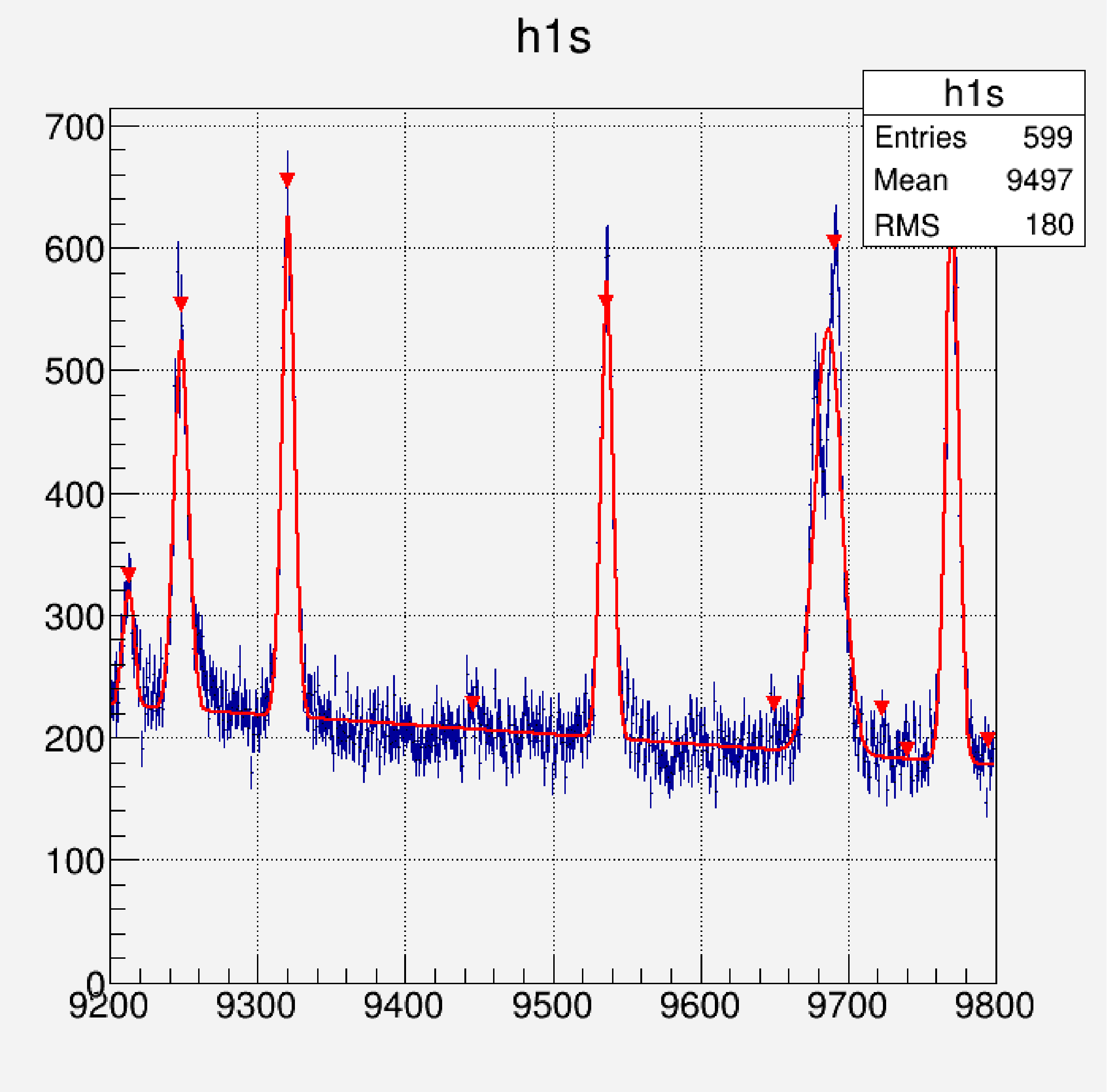
To get these group cross sections values using TOF spectra as a raw material, few new programs (on language C++) during current year were written.



This program is analyzing TOF spectra by method of form, considering that form of resonance in ideal case is determined by Breit-Wigner formulae.
Program marks candidate peaks by red markers, and after that is trying to find resonance parameters for them. For the case when calculation converges, program is painting red curve above candidate peaks, which are recognized as resonances by chosen parameter which can be changed inside program. For example, minimum disconverge value and exceeding of signal above background.

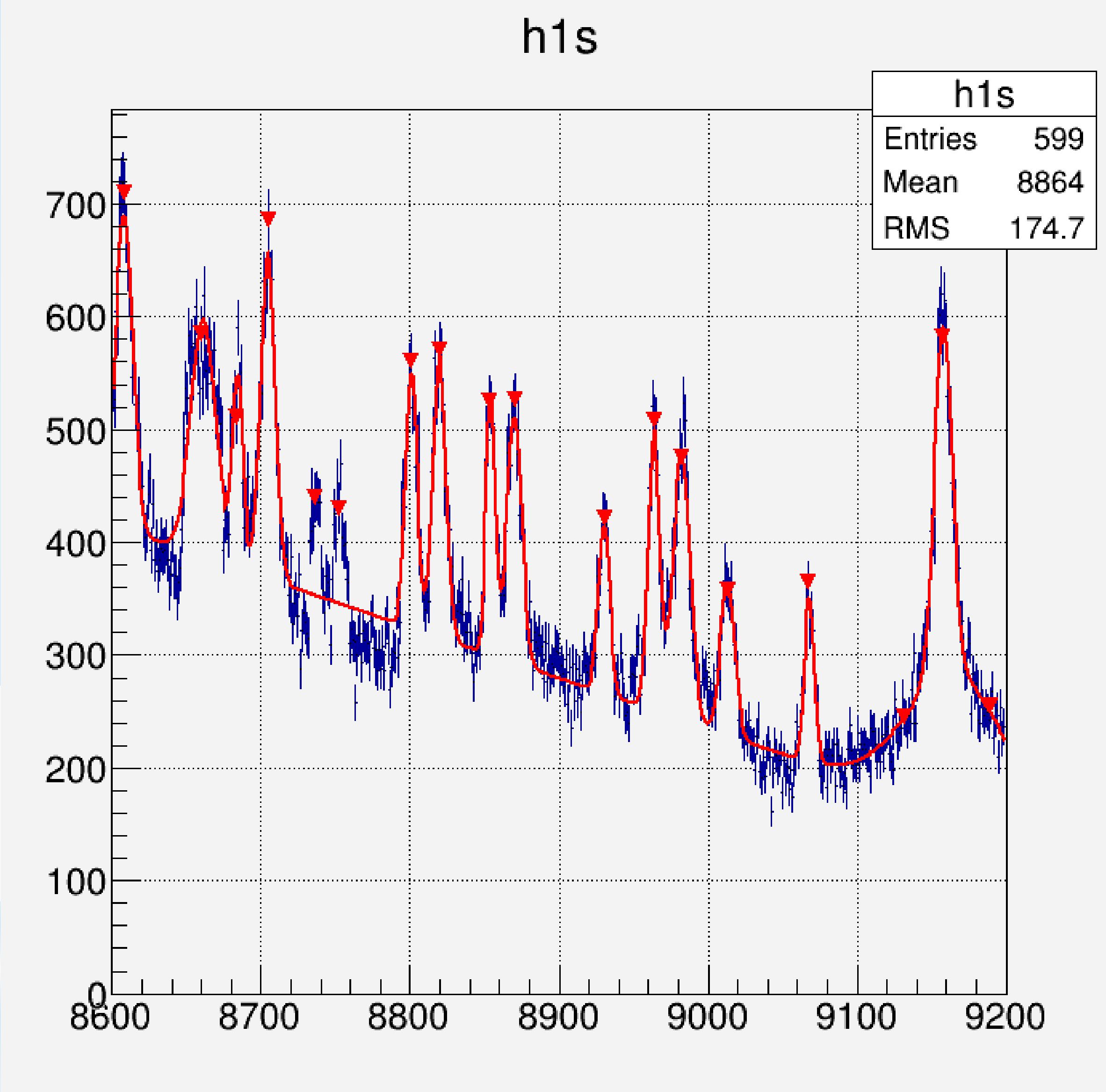
In practice, if we use usual computers or notebooks, interval of number of channels on X axis must be chosen small enough, few percent of all 150,000 channel 20 msec interval. In other case program is calculating very long time.

Example of TOF Au-197 spectra recognition process.
At chosen analysis parameters, resonances at 57.92 eV, 60.1 eV and 78.27 eV and their resonance parameters are automatically determined while resonance 46.44 eV is missed (right corner).
It's definition requires another (signal/background) value inside C++ program, which will require longer work time of the same computer.



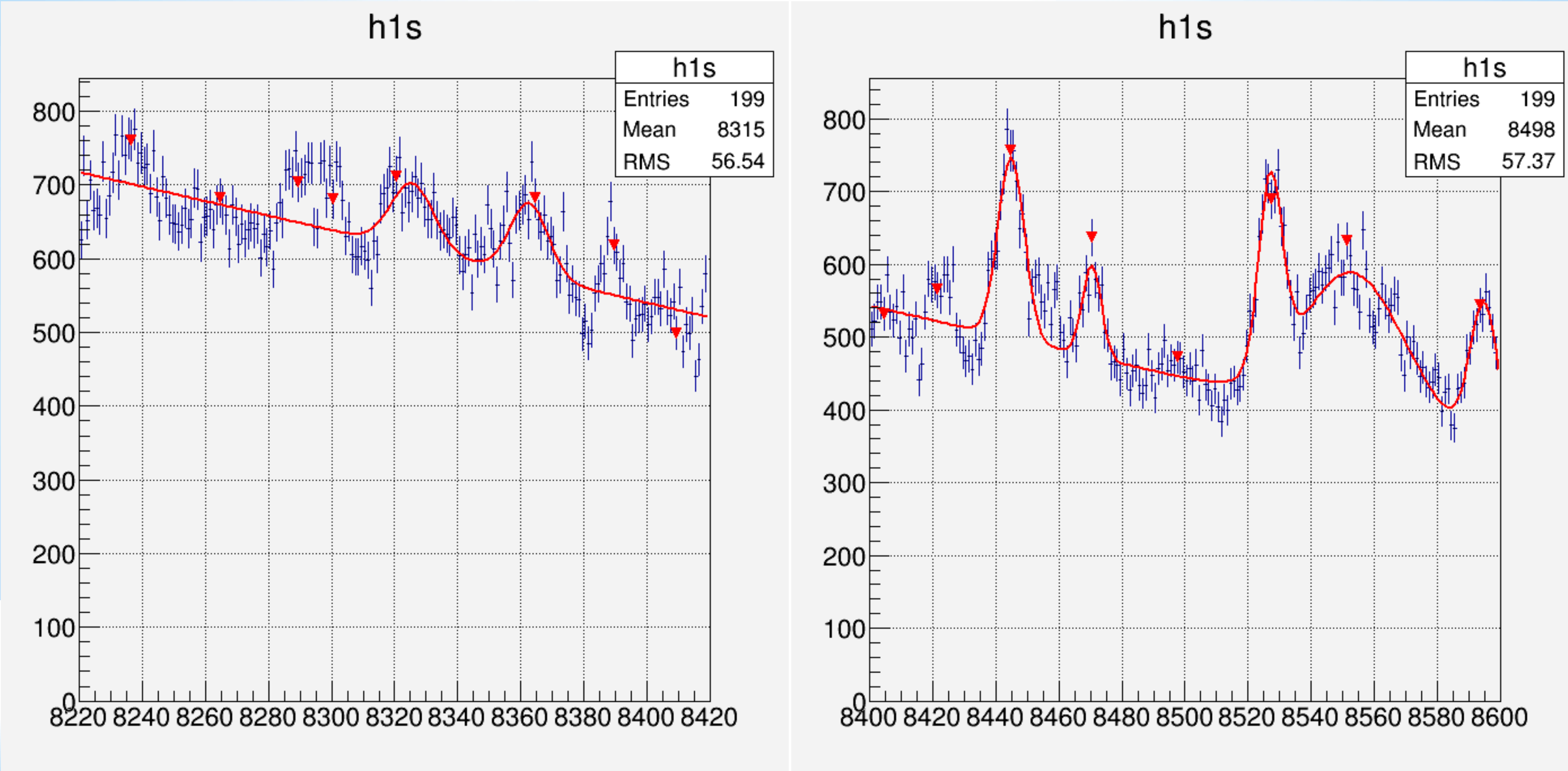
Varying program parameters allows extract resonance parameters during availability of the background.

Au-197 TOF spectra, on 'X' axis are numbers of channels, each is 133 ns. Interval between neutron energies 151.4 eV (right resonance) and 273.8 eV (left resonance)



Screen of the C++ program for automatic recognition of experimental TOF spectra resonances.

Work process is shown in interval between 293.4 eV and 695.3 eV, two obvious resonances in the interval are missing. Their definition required another criteria value of (signal/background), which required more amount of computer work time.

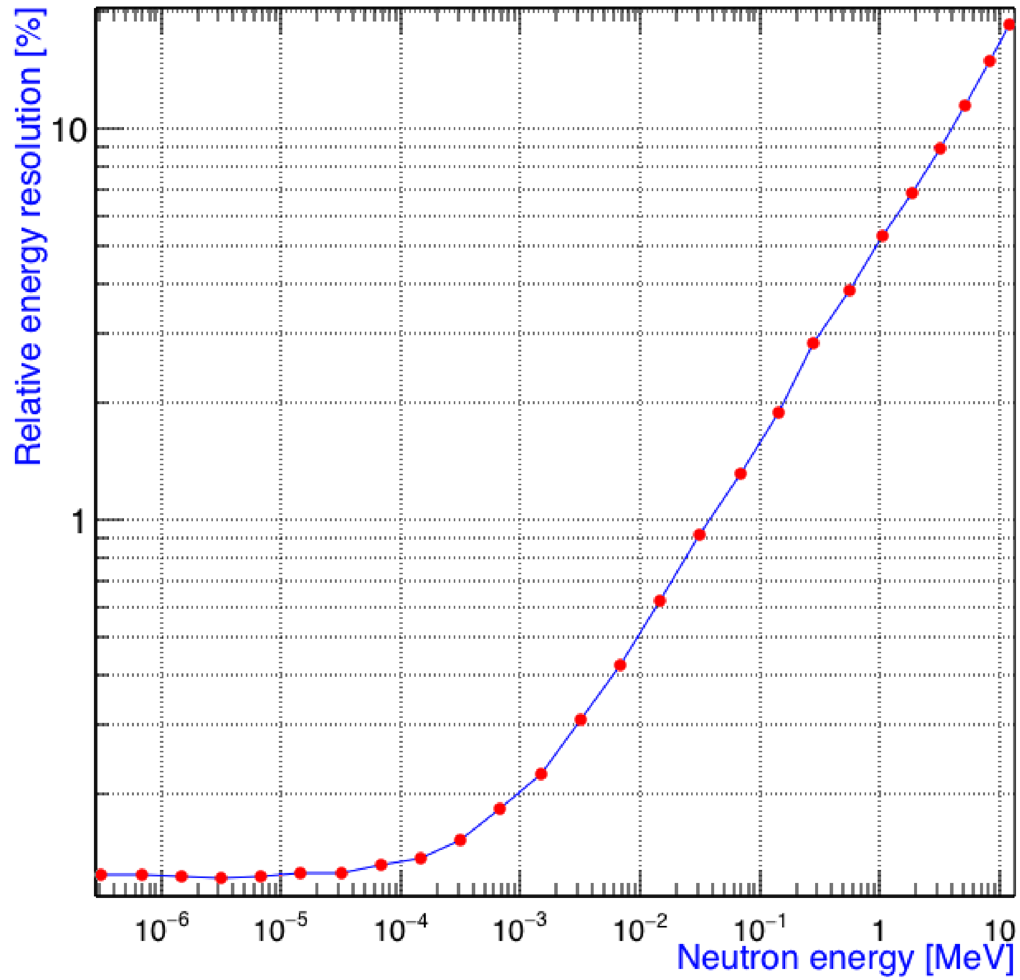


Left interval border of Au-197 TOF spectra, with quality 22 (ns/meter), is 1740 eV, right is 698.4 eV

At energies, which are high for this spectrometer energy resolution and measured nuclide (Au-197) resonance levels energy distribution density, can be recognized only strong resonances: those, which has big capture cross section at the peak energy and big energy width at half-altitude. For others better resolution and (or) bigger statistics are required.

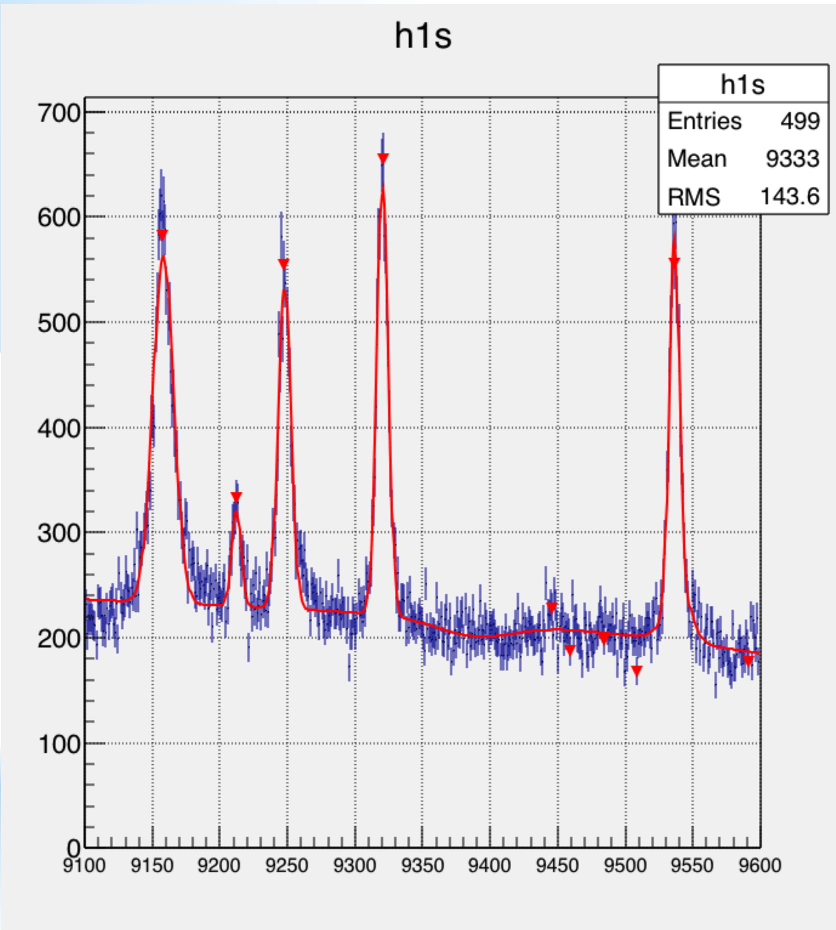
Energy resolution at 50 meters flight base during measurements with proton beam 1 mksek

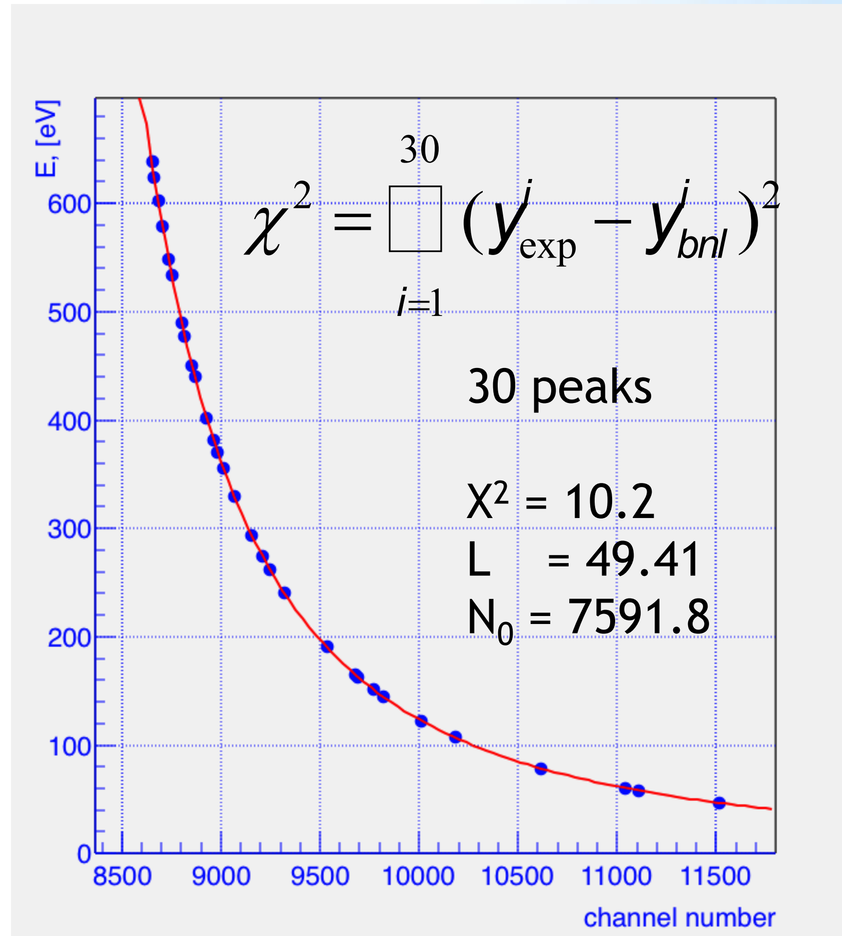
- $\delta T_{tot}^2 = \delta T_p^2 + \delta T_n^2 + \delta T_s^2 + \delta T_{tdc}^2 + \delta T_d^2$
- $\delta T_p = 0.25\ \mu s$
- $L_{det} = 10$ cm
- ➔ $\delta E/E = 0.12\%$
- $L_{det} = 30$ cm
- ➔ $\delta E/E = 0.36\%$

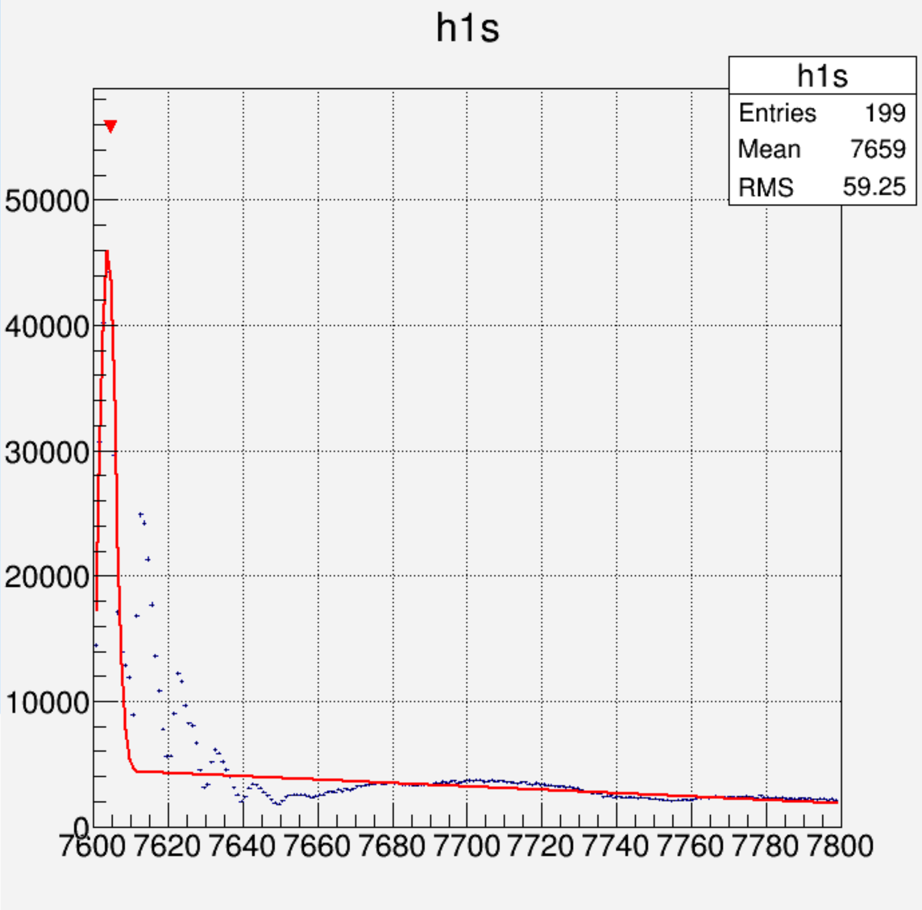


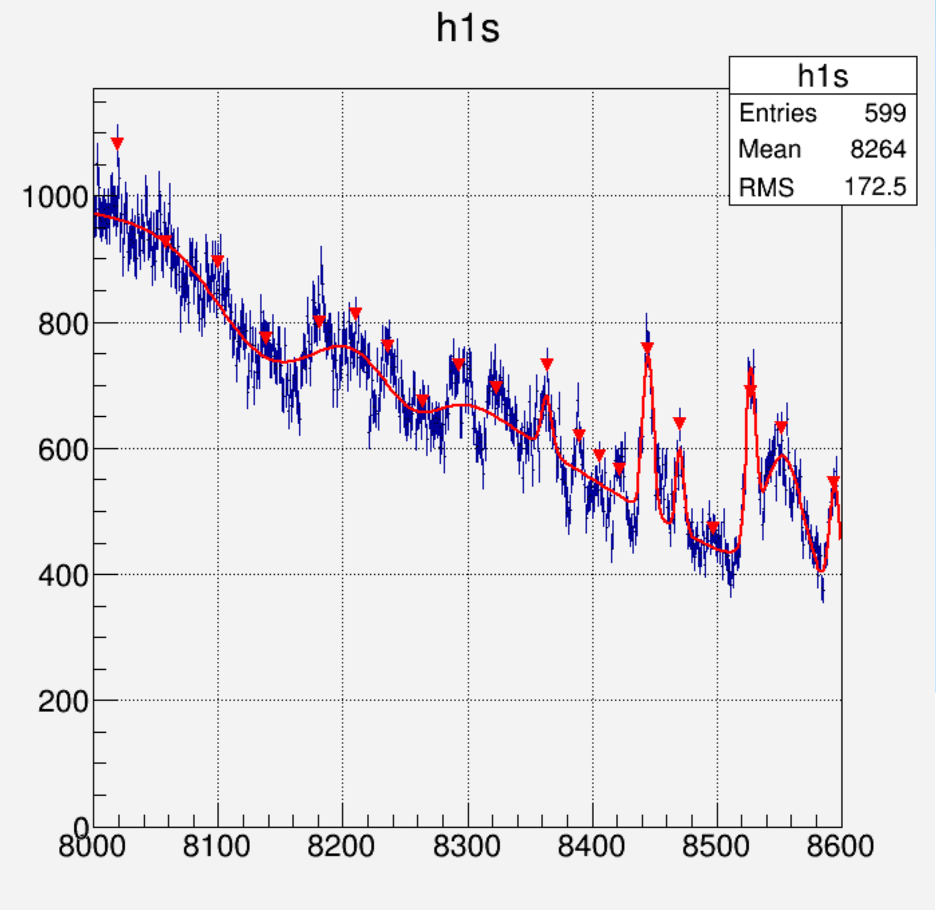
Reconstruction of Au197 peaks

$$E_i = 2.94\ 10^5\ L^2/(N_i - N_0)^2$$





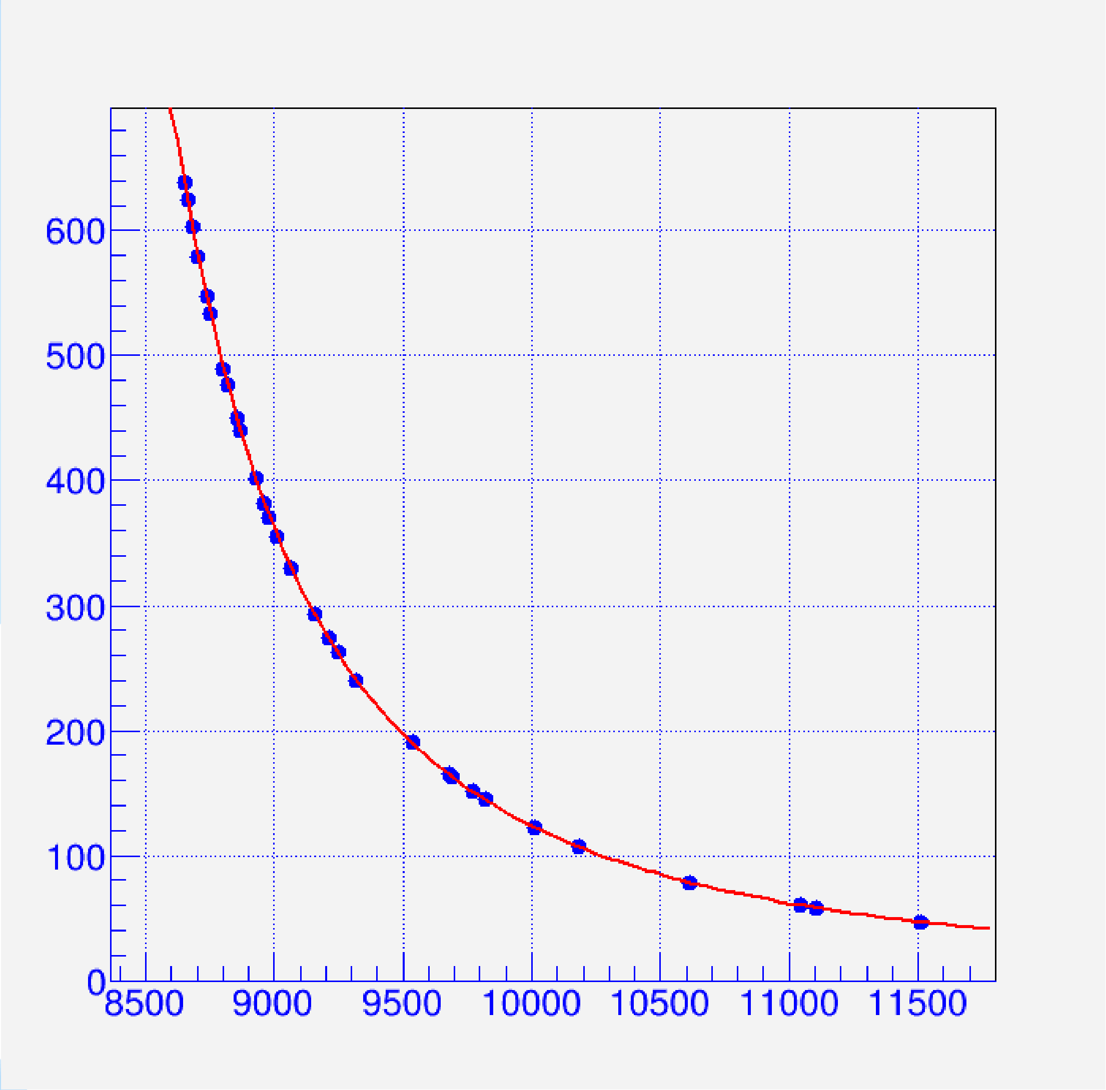




On the right picture, TOF spectrum energy border is 4000 eV.
On the left picture, neutron flash is shown.

Left picture demonstrates importance of struggle with electromagnetic transients at high energies: 6 waves with period 1.3 microseconds are visible. This occurs with some parameters of front-end electronics, due to reflections when TTL signal is send to ~ 100 meters between detector and data collection system. Measurements of resonance structure in high Mega electron Volts energies region require higher energy resolution.

At the same time, as we can see, calibration proves that Installation INES provides group total, group capture and (when multiplicity blocks will be ready) group fission cross sections for alloys, made with usage of separated isotopes.



Installation INES (Investigation of Neutron Experimental Spectra) calibration results. Screen of the calibration program, written in C++.

Red curve is theoretical correlation between channel number 'N' (X axis) and energy measured in Electron-Volts 'E' (Y axis), which is calculated using start channel number (N=7592) and TOF flight base length L=49.41 meters.

Blue marks are resonance positions from experimental TOF Au-197 spectra, after work of automatical resonance parameters definition program. Good correlation is observed

Installation INES calibration curve.
On 'X' axis is number of channel (133 nanoseconds each),

On 'Y' axis is neutron energy in eV.
Blue marks are gold (isotope Au-197) resonances.

Thank you for attention!