27-th International Seminar on Interaction of Neutrons with Nuclei
Dubna, Russia, June 10 – 14, 2019

Measurement of capture and total neutron cross sections of Au, Ta and In isotopes with proton flash duration 250 nanoseconds at installation INES

R.M.Djilkibayev, D.V.Khliustin, I.A.Vasilyev

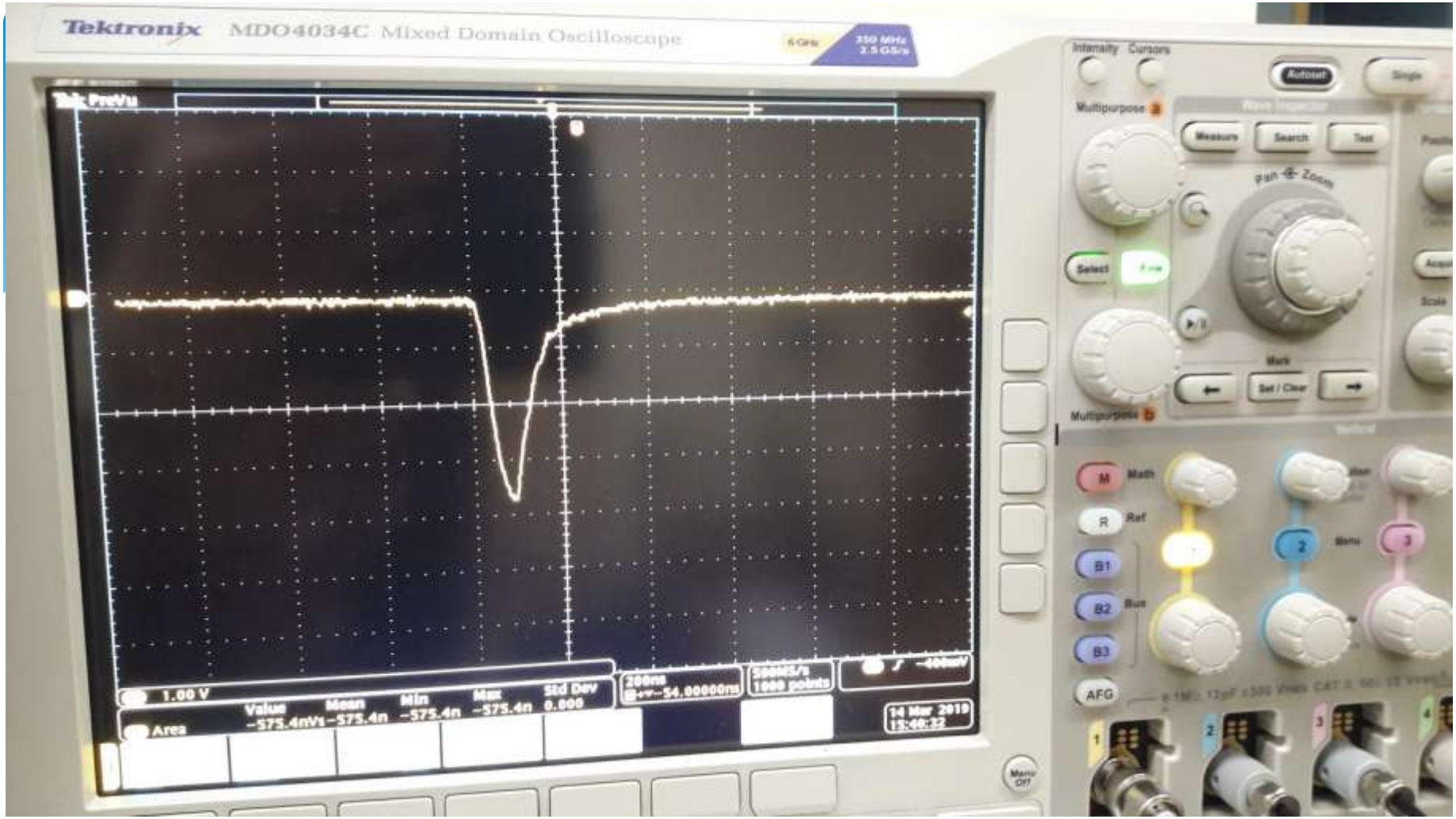
Institute for Nuclear Research Russian Academy of Sciences, Moscow, Russia
denhlustin@gmail.com

INR RAS proton linac

* During measurements the accelerator worked with parameters:
  Energy of protons 267 MeV
  Pulsed current 10 mA
  Pulse duration 250 nanoseconds
  Frequency 50 Hz
* Neutron flux into 4 Pi was 2E12 neutrons/sec

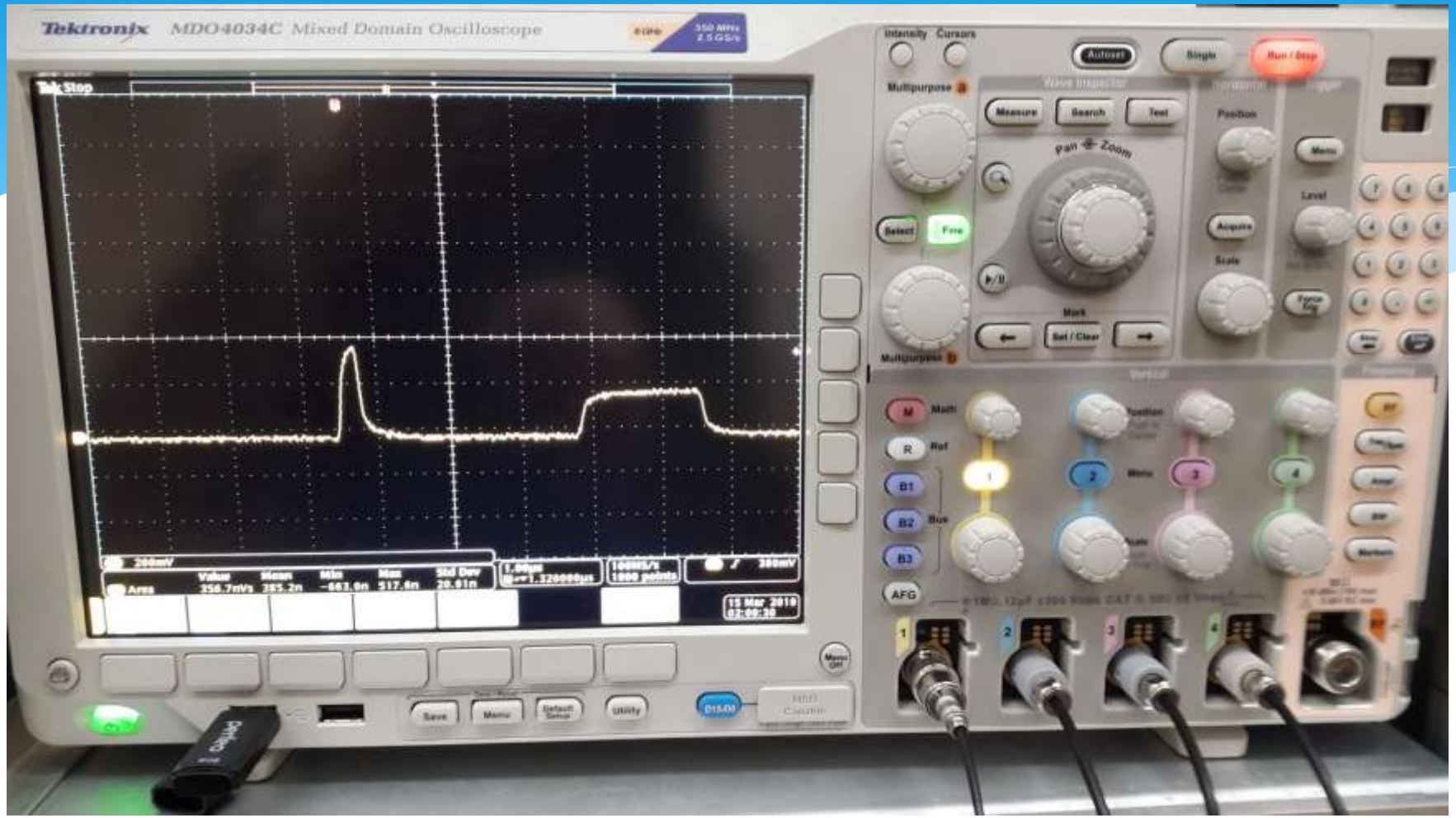
Preparing of the experiment at 50 meter TOF base

For measurements we used 8-sectional liquid (n,gamma) detector based on photomultipliers FEU-110 with pulse duration 30 nanoseconds and 4-atmosphere Helium-3 detectors SNM-18: 4 of them as proton beam intensity monitors and four for transmission functions measurements.



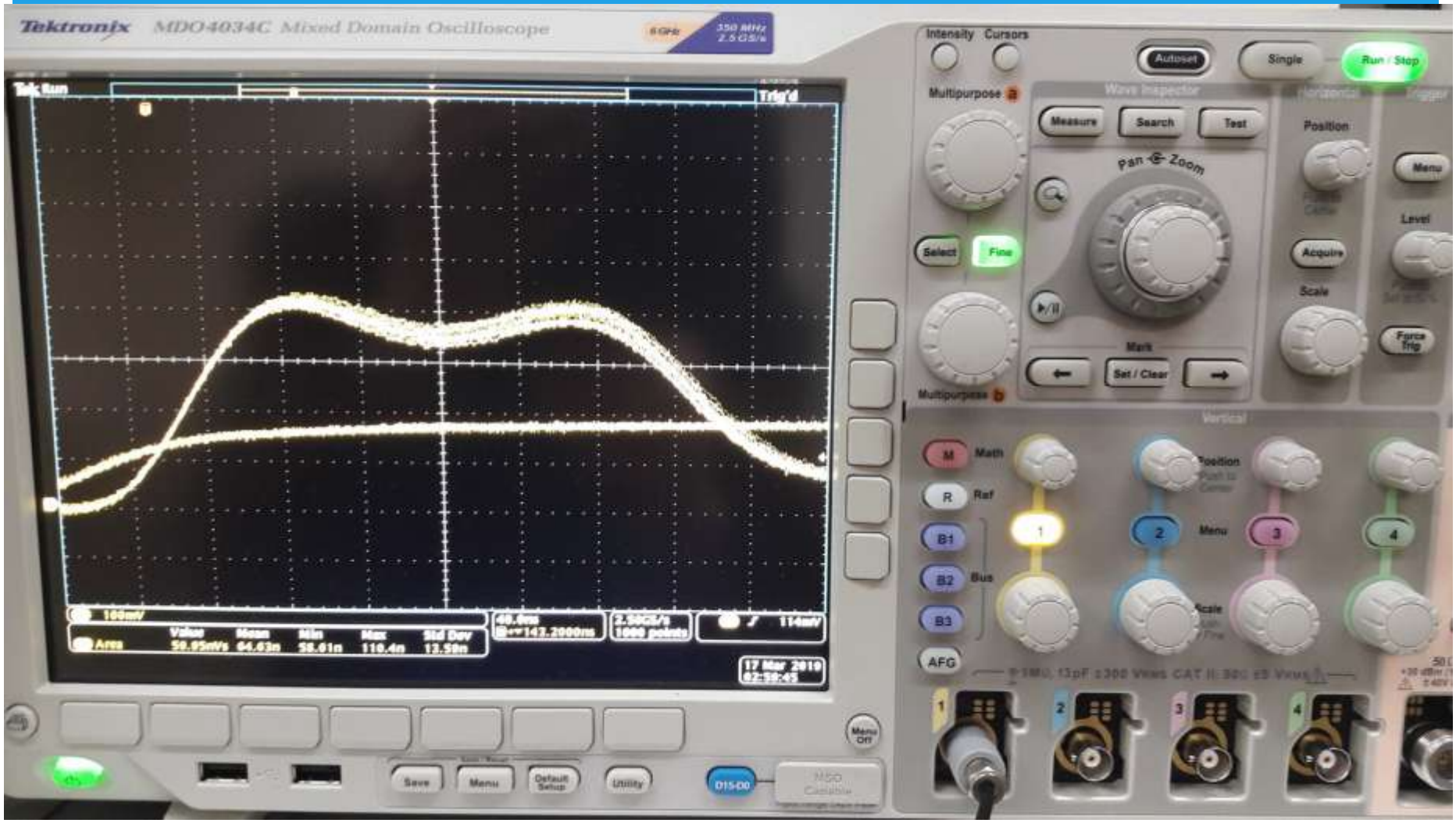
Scintillator detector's pulse, measured after pre-amplifier is shown. It is 80 nanoseconds on half altitude. During turning the Co-60 gamma ray source was placed into the detector. Before measurements it's necessary to make amplitude characteristics of all 8 sections equal to each other, especially in gamma ray multiplicity mode which allows to distinguish effect and background in the unresolved resonances region at high neutron energies.

Proton pulse 250 nanoseconds



During year 2018, proton pulse duration 250 nanoseconds was achieved. It is smaller than period of proton's circulation inside 109 meter storage ring with project stored current 10 Amperes, which is now under construction. Successful and stable acceleration of 250 ns beam was a necessary step in creation of a storage ring with low gamma activation of equipment.

Proton beam turning before the experiment



* After turning, process of which is shown, proton beam have one central peak and 10 mA of intensity. Time axis grid is 40 nanoseconds per division. Pulse duration on the picture is 270 ns on half altitude, during measurements accelerator operated with 250 nanoseconds beam.

Laser collimation process of the experimental beam channel is shown. Vacuum neutron guide aperture is 200 mm, also four He-3 monitors and 8-sectional scintillator detector are observable.

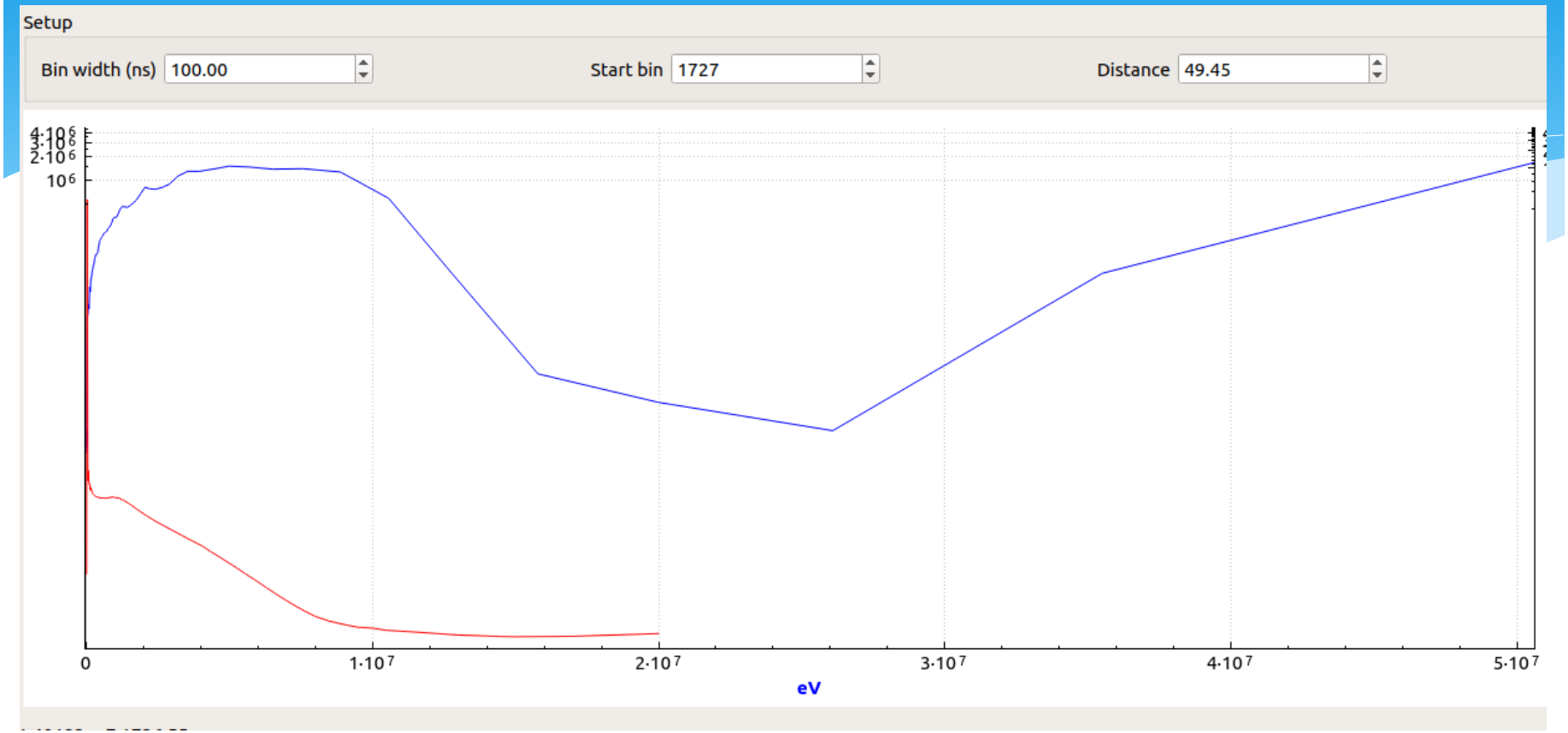
* Proton pulse duration 250 nanoseconds consists of 50 elementary accelerator's RF field bunches, so as frequency of Alvaretz accelerator's part is 198.2 MHz.
* Combined with TOF base 50 meters, data acquisition system's channel width 100 nanoseconds and 80 ns of detector's pulse, installation INES spectrometer achieved resolution factor 6 nanoseconds/meter.
* Neutron flux intensity provided ability to achieve about one TOF spectra each 12 hours of measurements.

* *On the pictures below we show, what is possible to observe with achieved energy resolution 6 ns/m.*

Fast multi-MeV part of TOF spectrum: proton flash is resolved

* On experimental curve we can see, that cascade neutrons with energies up to 267 MeV and gamma background at 50 meter base are separated from spallation neutrons.
* Spectrum of spallation neutrons is similar to fission spectrum and has bigger average neutron energy, significant amount of neutrons has energies up to 10 MeV.
* 14-MeV neutrons pass 50 meters during 1 mks, this time is bigger then proton flash duration and gamma rays have enough time to escape from the spectrometer channel.

Neutron energy region between maximums of spallation and cascade neutrons

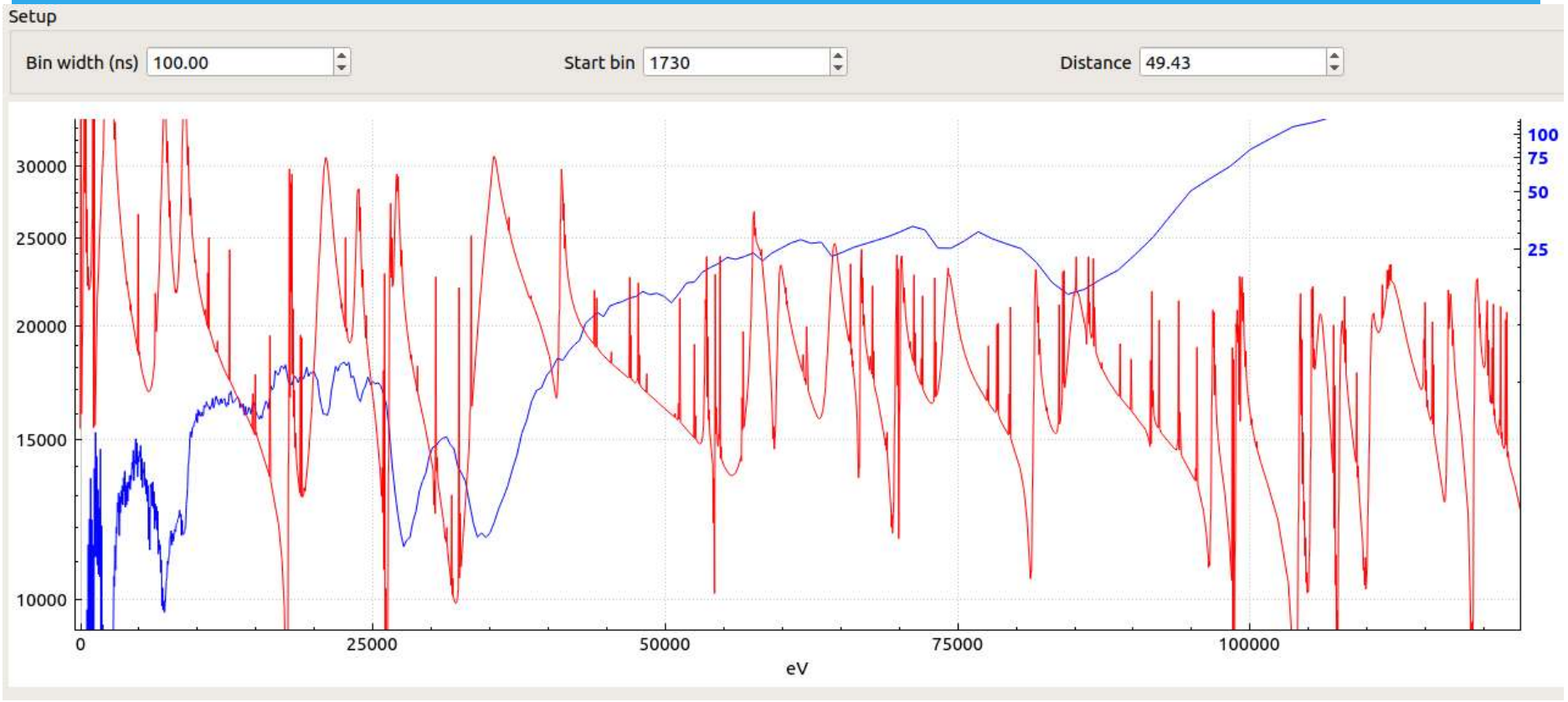


* All cascade neutrons are arriving into 10 channels of the data acquisition system, which was used in mode of 100 ns steps.
* Fast neutron part of spectrum is distributed into 90 channels of the data acquisition system, in energy borders between 140 keV and 14 MeV. Energy resolution is high enough for group cross sections measurements for all energy groups of ABBN-78 neutron cross section constants system, and for majority of groups of new 299-group system ABBN-93.

Spectrum of pulsed neutron source Radex with Mn55 filter

* Resonance structure of Mn55 is resolved up to 125 keV. Mn55 (n,gamma) cross section is shown by red line with right vertical axis in barns. Experimental spectra is shown by blue line between neutron energies 20 and 130 keV.

Energy region up to 125 keV

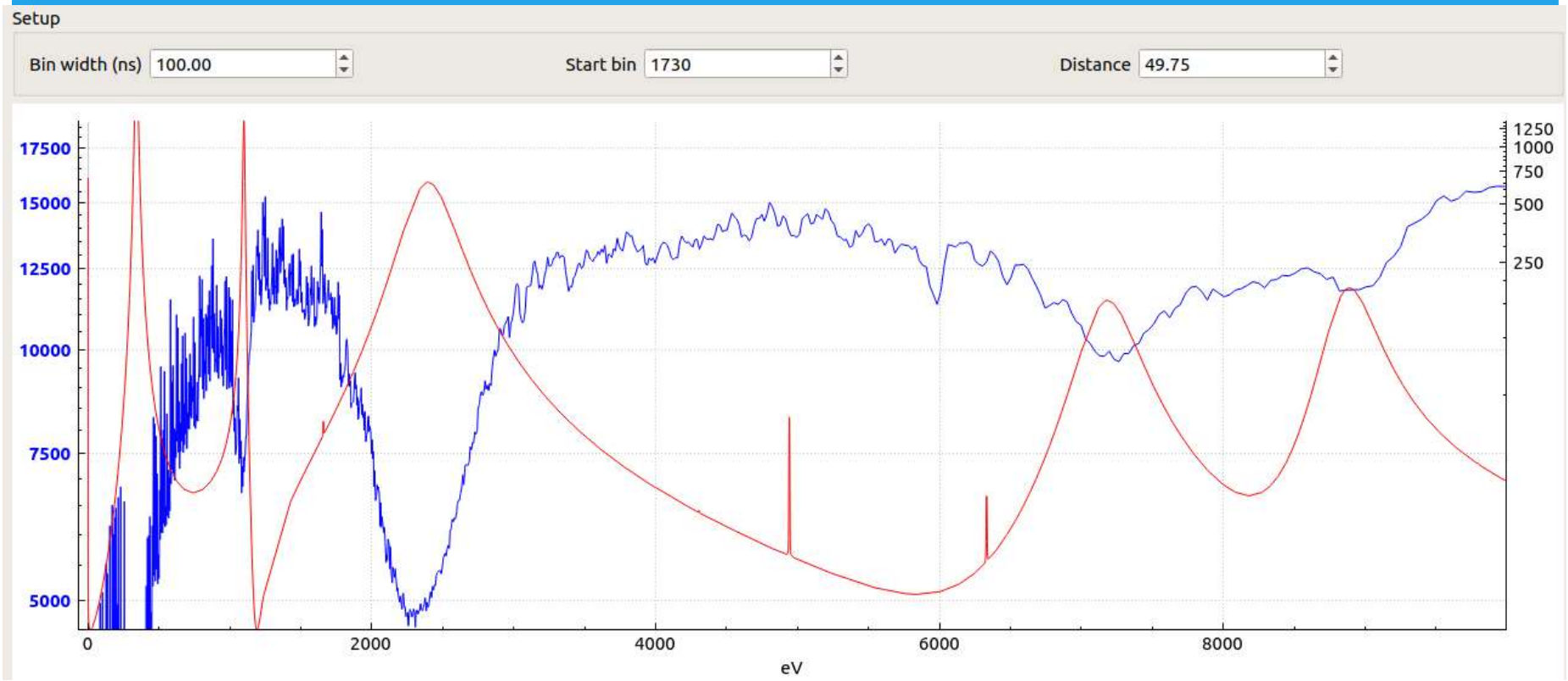


Absorption of neutron flux by Mn55 capture resonances around 73000 eV and 85000 eV is observable. Measurements with Mn55 filter were done to determine the background, they are necessary to extract group cross sections from experimental spectra.

Energy region up to 22 keV with Mn55 beam filter

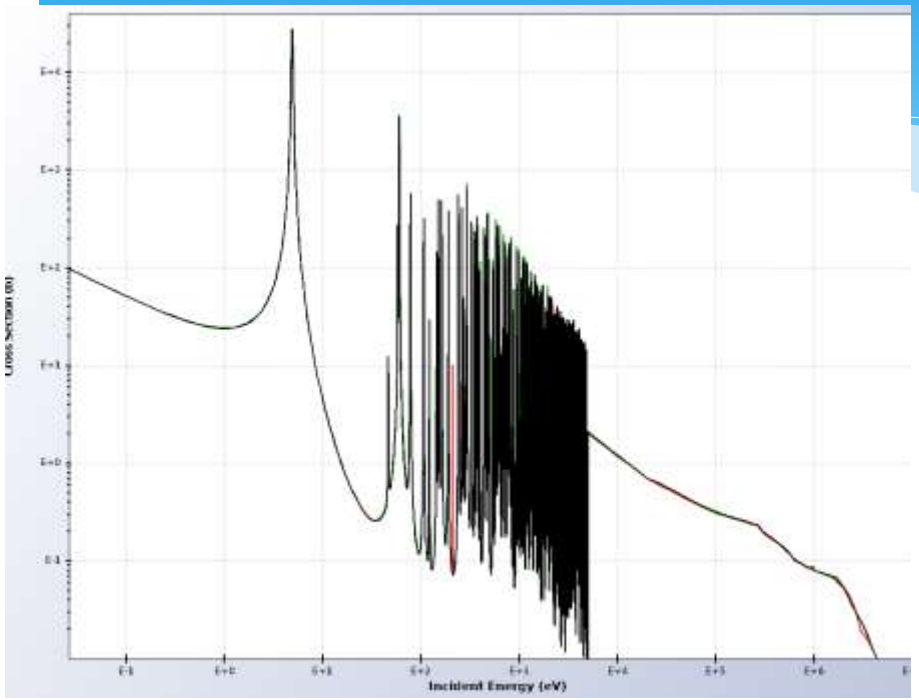
Red curve is Mn55(n,gamma) cross section, barns on right axis
Blue curve is Radex beamline spectra with Mn55 filter, counts on left axis

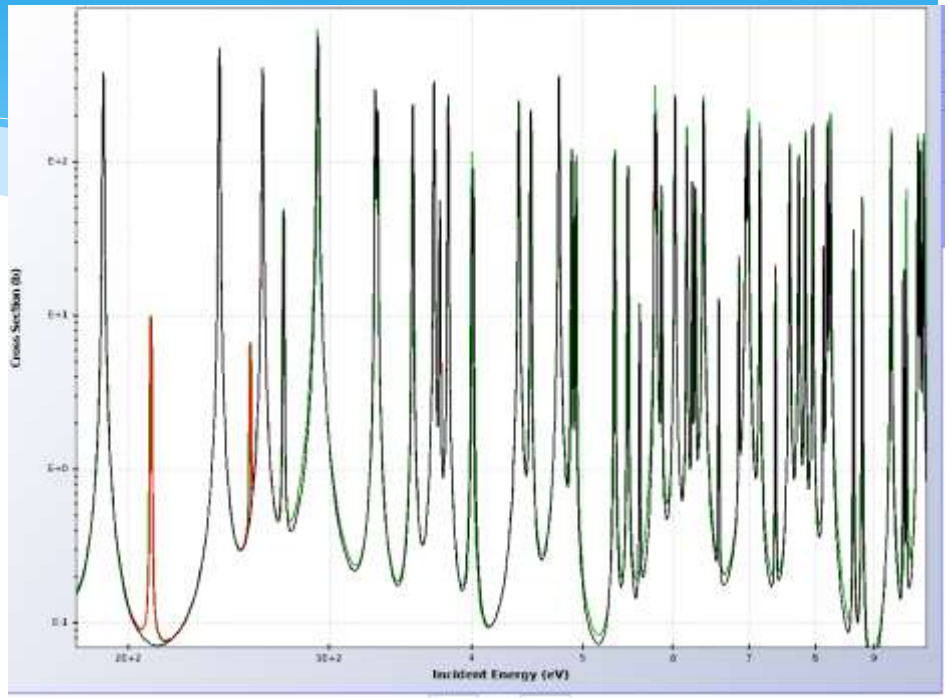
Energy region up to 10,000 eV



- Mn resonances at 336 eV, around 1100 eV, 2400 eV, 7500 eV and 9000 eV are observable on both curves.
- Radiator pattern on this curve is Indium target, resolved energy areas in the best world data source ENDF/B-VII.1 for them are:
  below 2000 eV for In115 and below 850 eV for In113.

Au197: disputable resonances according to ENDF/B-VII.1, JEFF, ROSFOND, JENDL-4 and our measurements

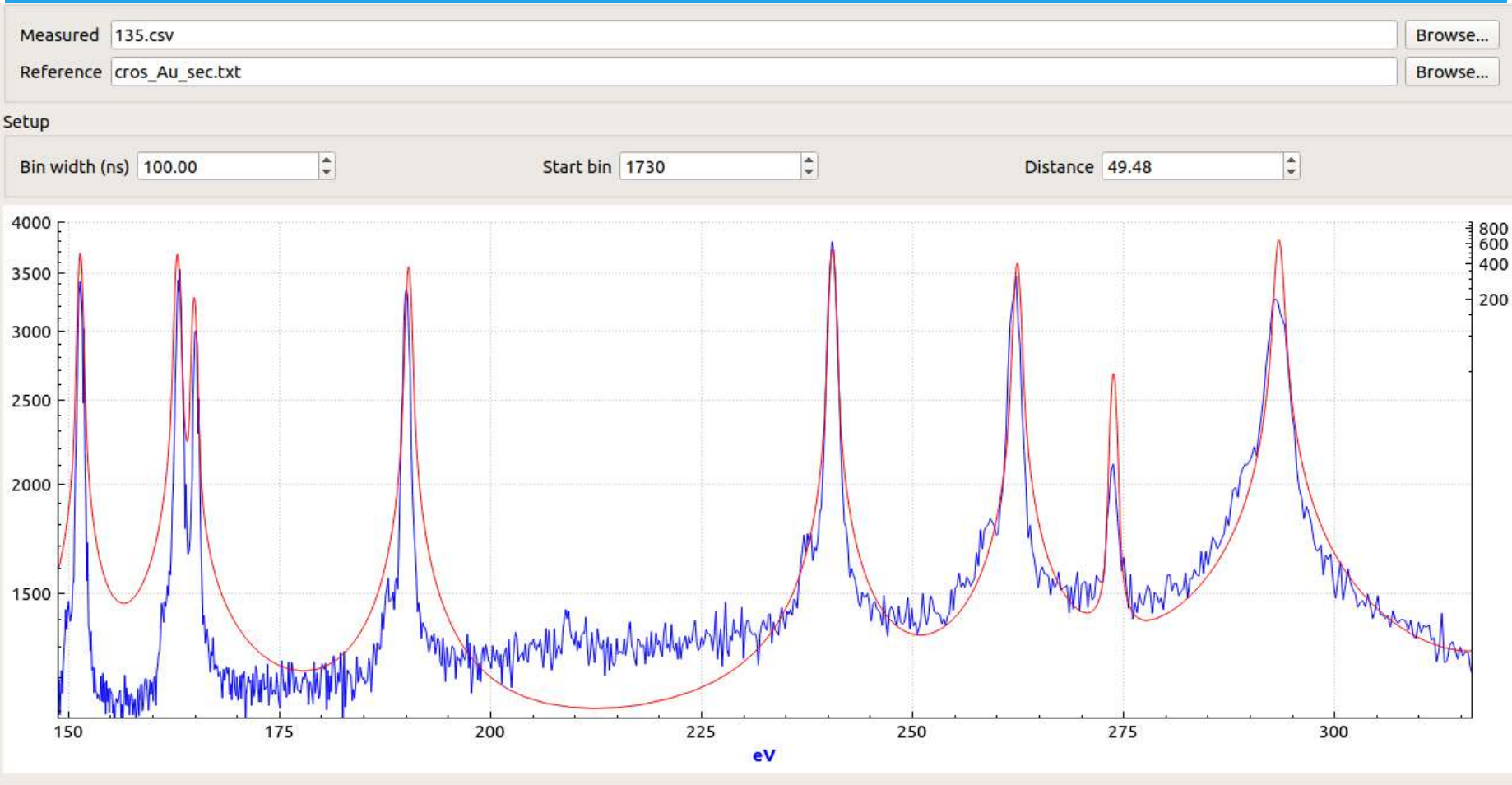




Au-197 isotope is often used for calibration as a standard. However, in 4 world data systems – ENDF, JEFF, ROSFOND and JENDL still available differences: debatable resonances at
209 eV, 256 eV, 561 eV, 955 eV, 1021 eV, 1252 eV, 1893 eV.

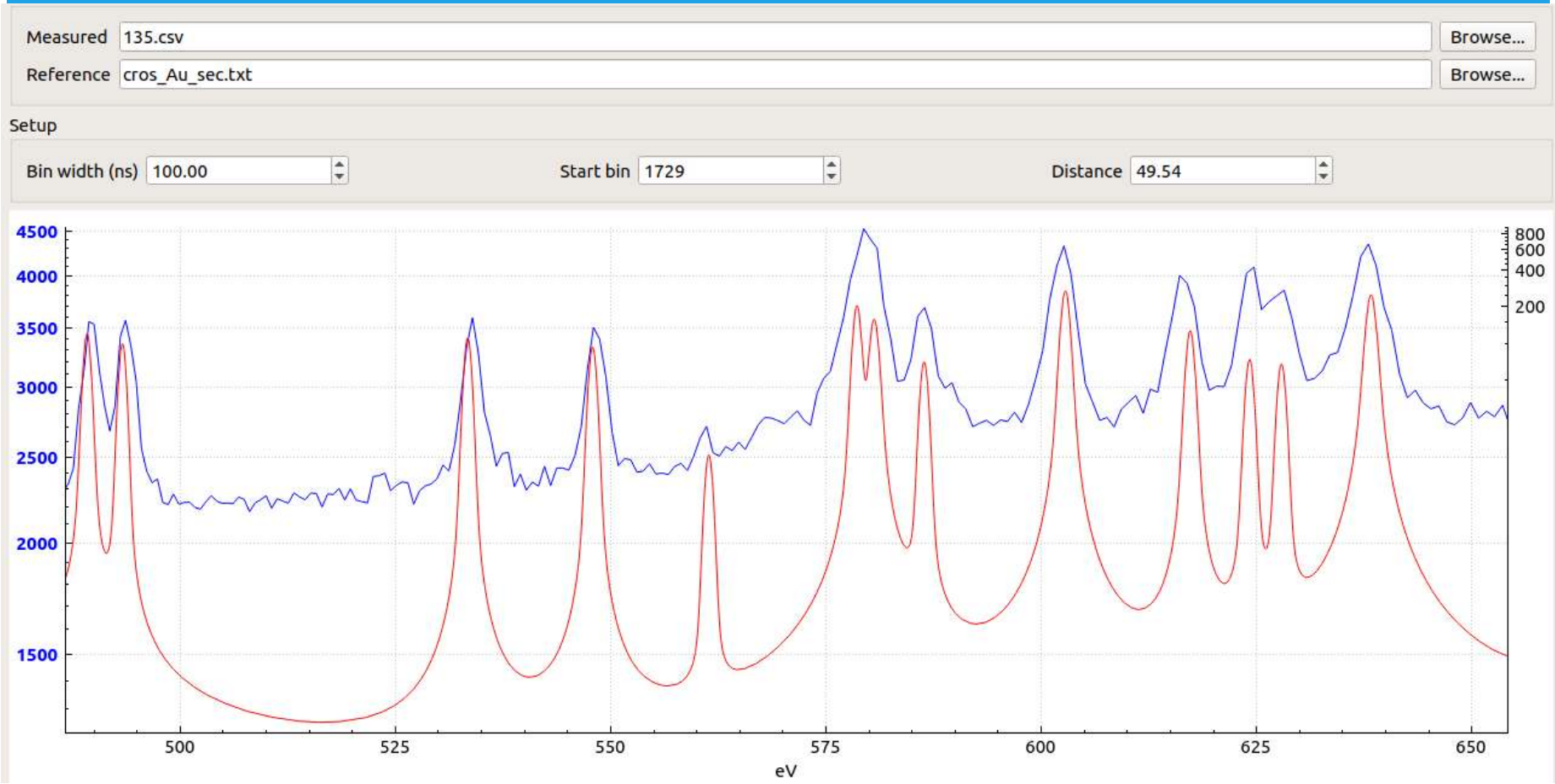
79-Au-197(n,γ) ENDF/B-VII.1
79-Au-197(n,γ) JEFF-3.1
79-Au-197(n,γ) JENDL-4.0
79-Au-197(n,γ) ROSFOND

Au-197 cross capture 150<En<315 eV



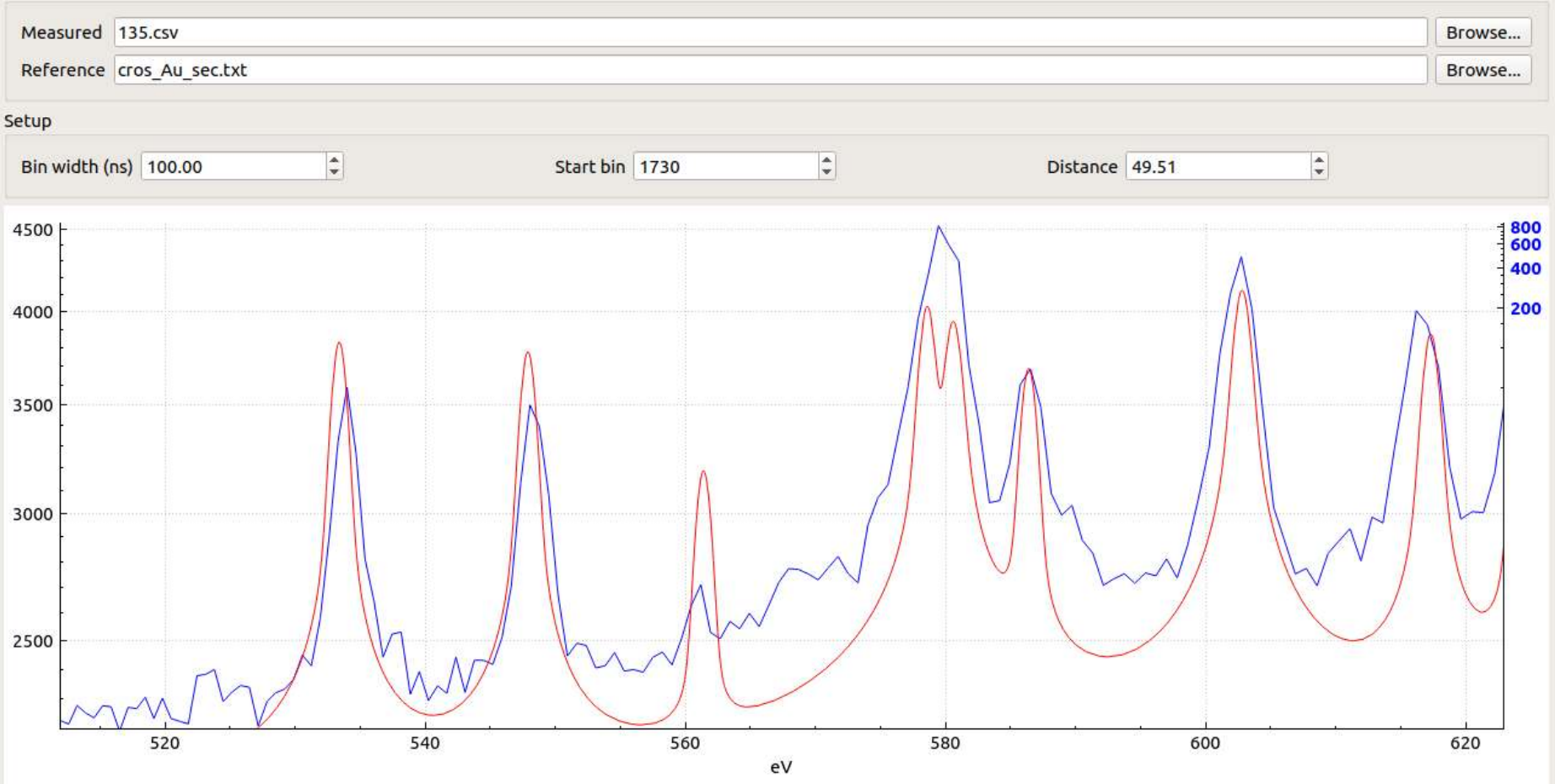
* Resonance 209 eV exists, 256 eV not obvious

Existance of Au-197 resonance at 561 eV is proved



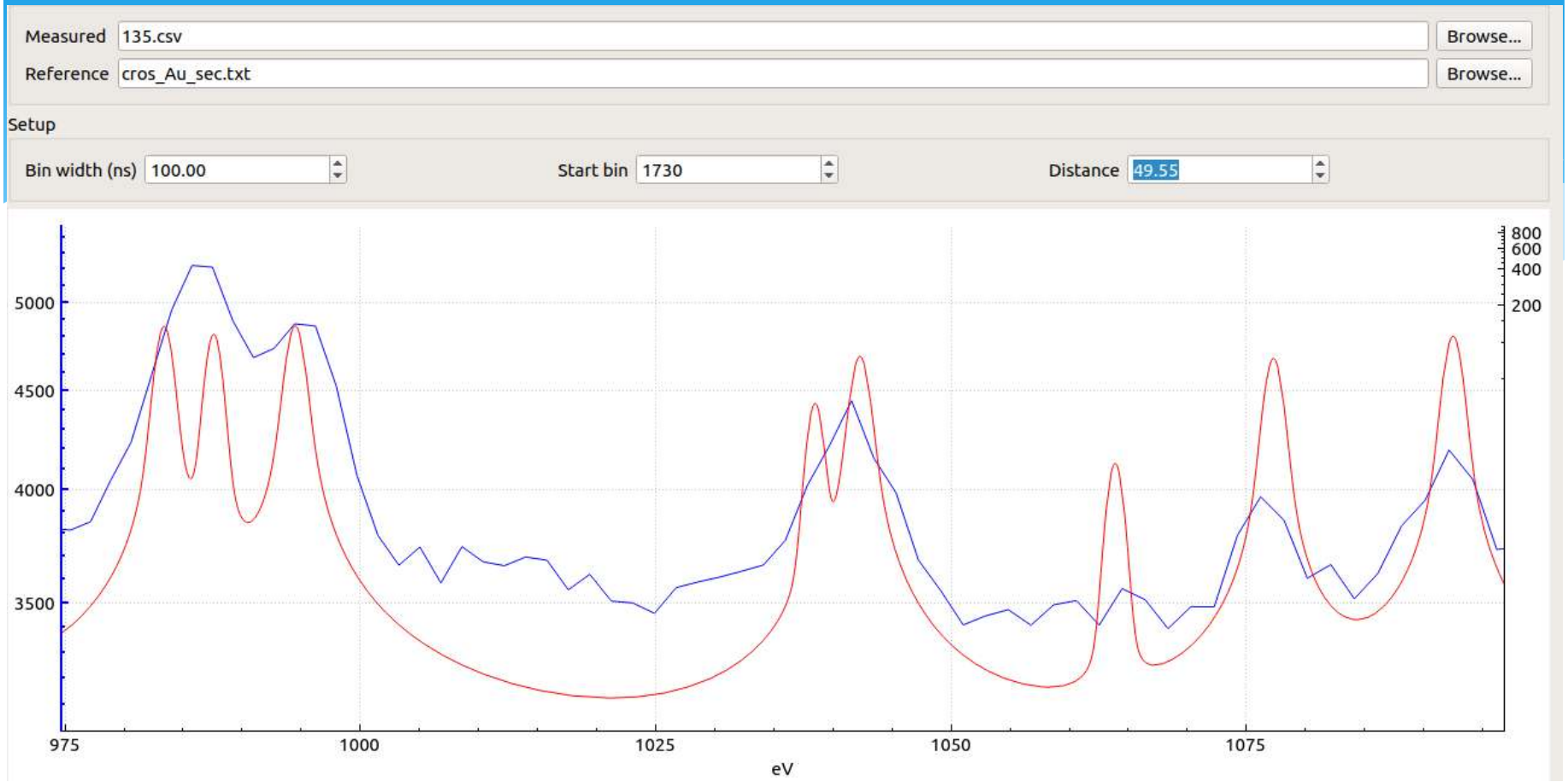
Au-197 capture resonance at 561 eV exists

Au-197 (n,gamma) resonance at 561 eV



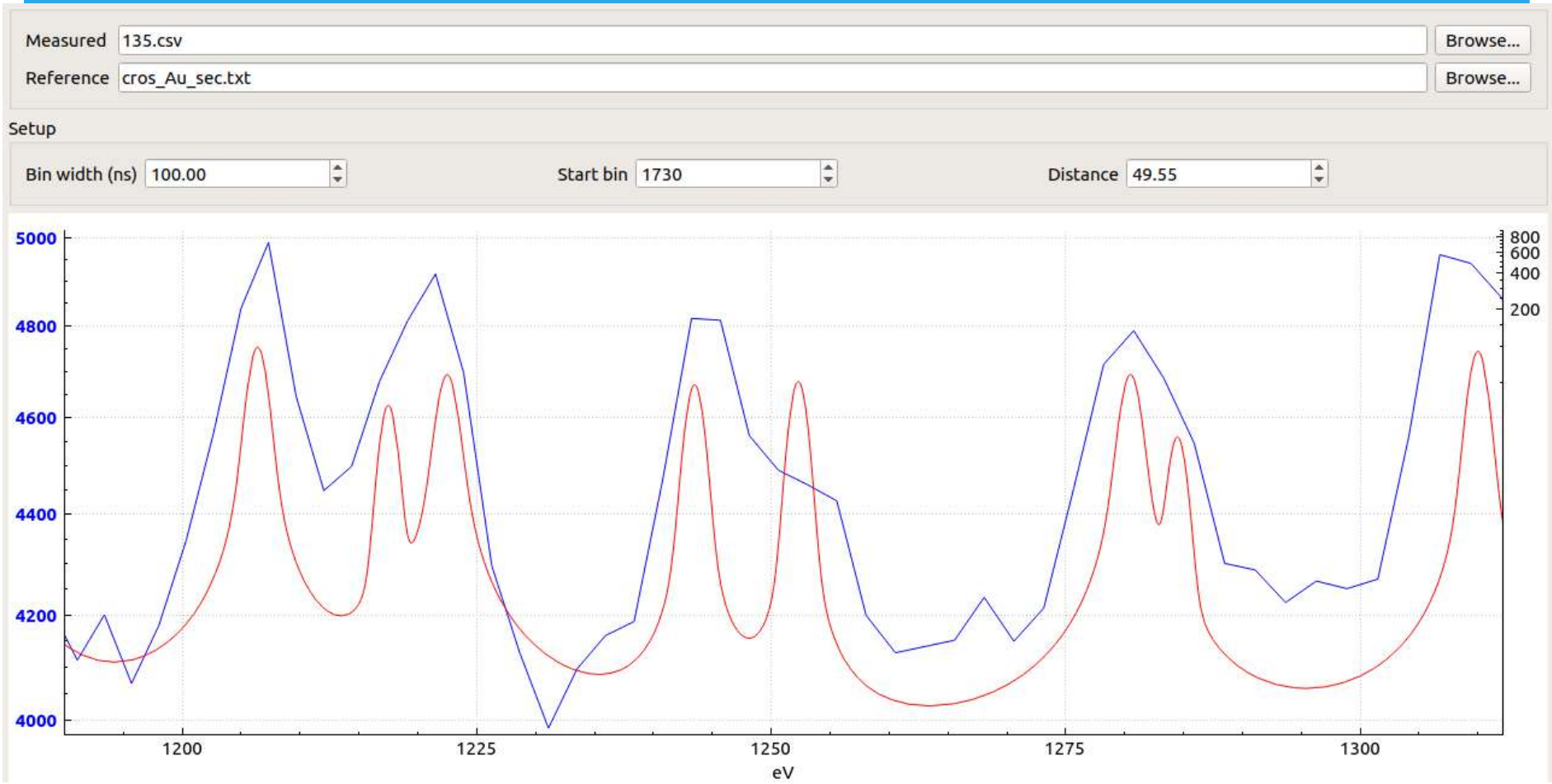
* Bigger scale of disputed Au197 capture resonance at 561 eV.

Disputed Au-197 resonance at 1023 eV



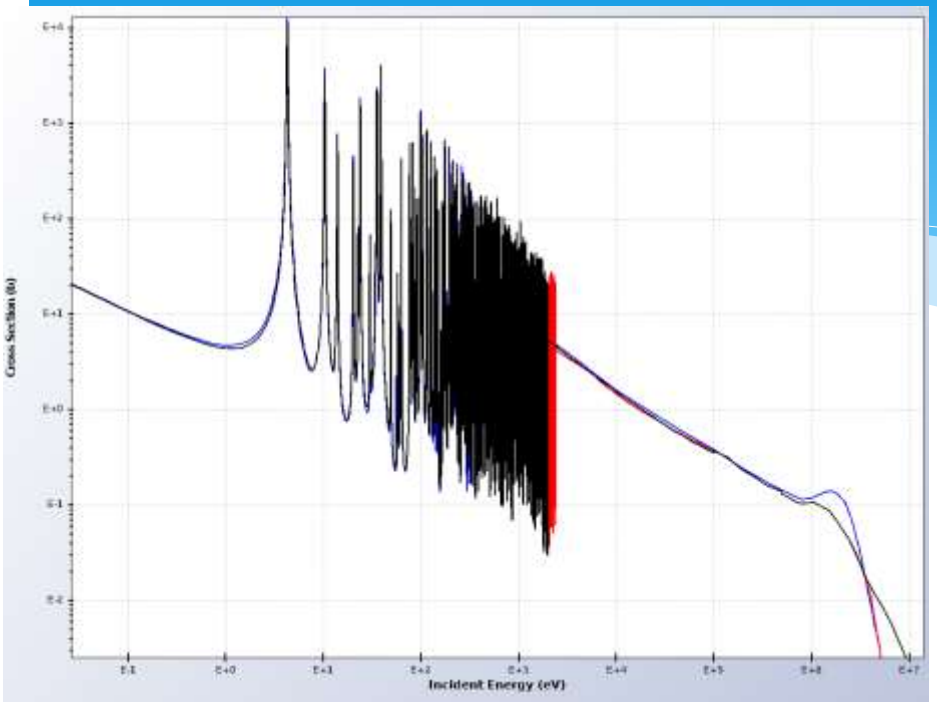
* Resonance at 1023 eV is not obvious

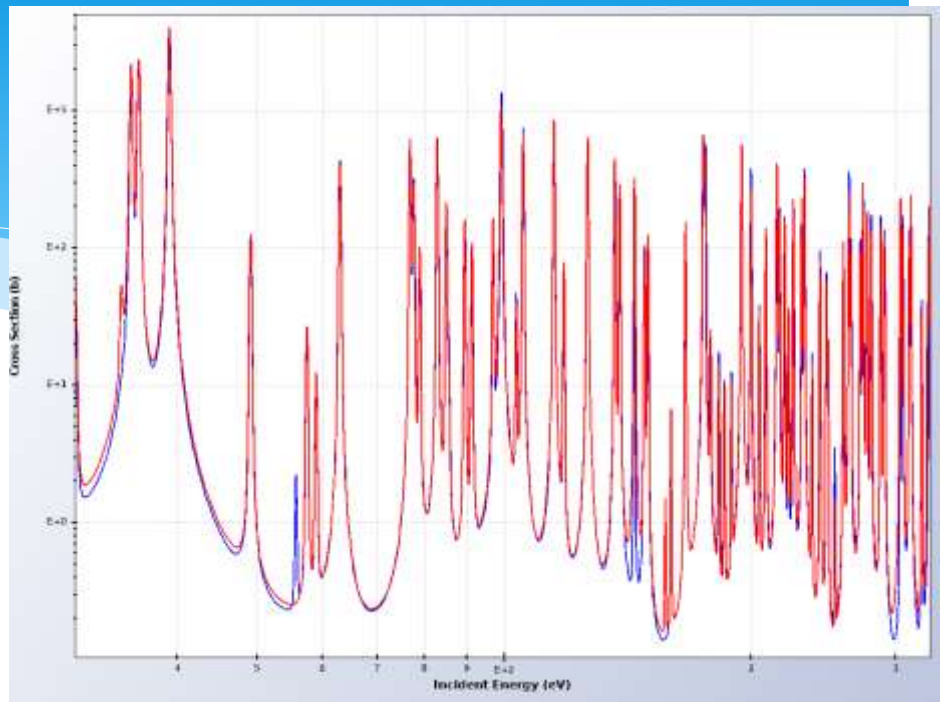
Neutron energy area between 1200 and 1300 eV



* Resonance at 1252 eV exactly exists.
* Resonance structure of Au197 cross section is measured up to 4800 eV. Higher then 1893 eV (resonance exists on our spectra) all databases are similar. Probably, they used one and the same experimental work as a source. According to our data, exists Au197 capture resonances at 209 eV, 561 eV, 1252 eV, 1893 eV and not exists available in some data files at 256 eV, 955 eV, 1021 eV.

Ta181 pattern-radiator with Mn55 filter and ENDF/B-VII.1 as a reference source



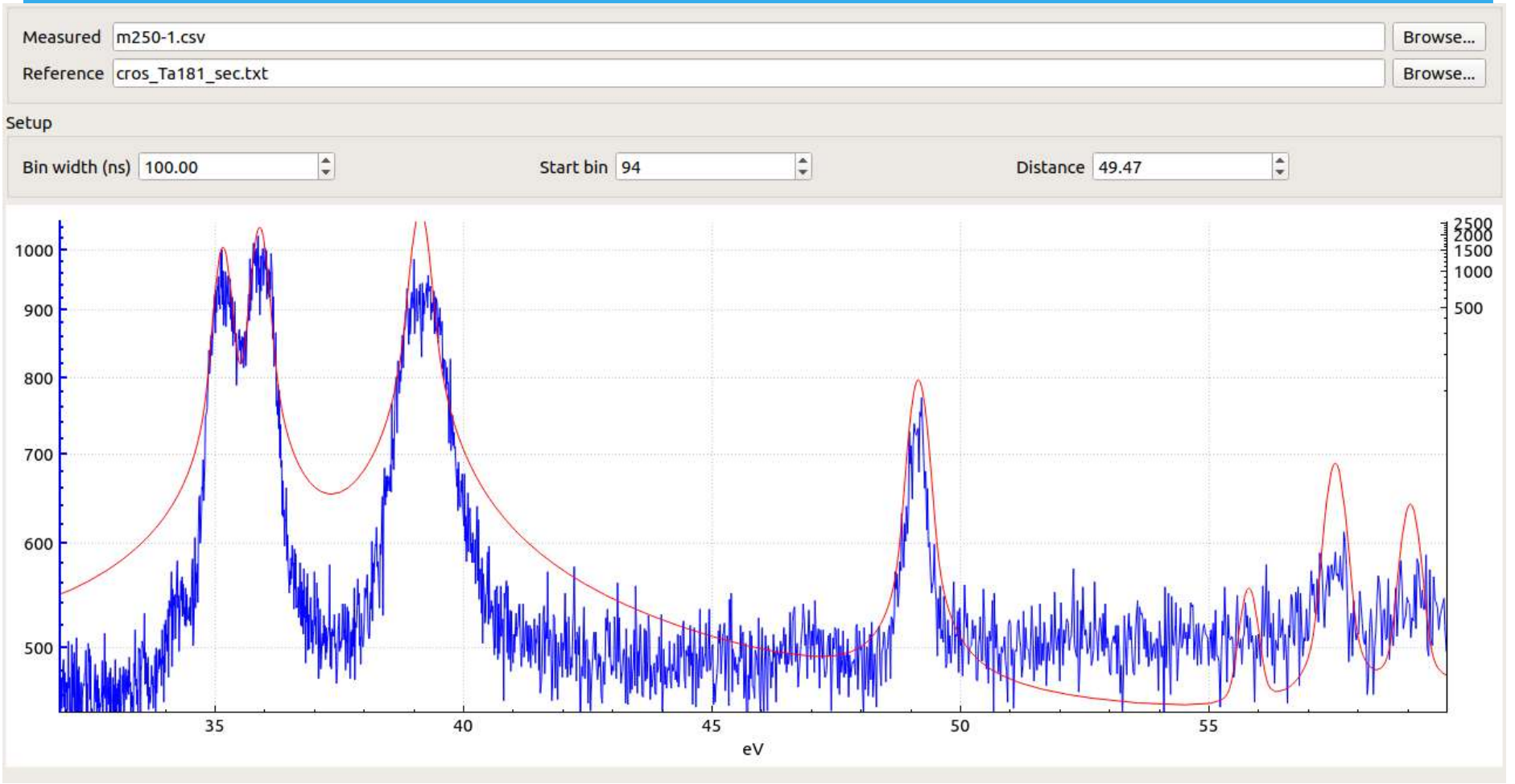


Resonance structure of Ta181 is resolved up to 2400 eV.
Below 330 eV difference between four world data bases is in existance of 3 resonances: at 34 eV, 55.8 eV and 157 eV. Also resonance parameters of 144 eV and 304 eV in different sources are different.

73-Ta-181(n,γ) ENDF/B-VII.1
73-Ta-181(n,γ) JEFF-3.1
73-Ta-181(n,γ) JENDL-4.0
73-Ta-181(n,γ) ROSFOND

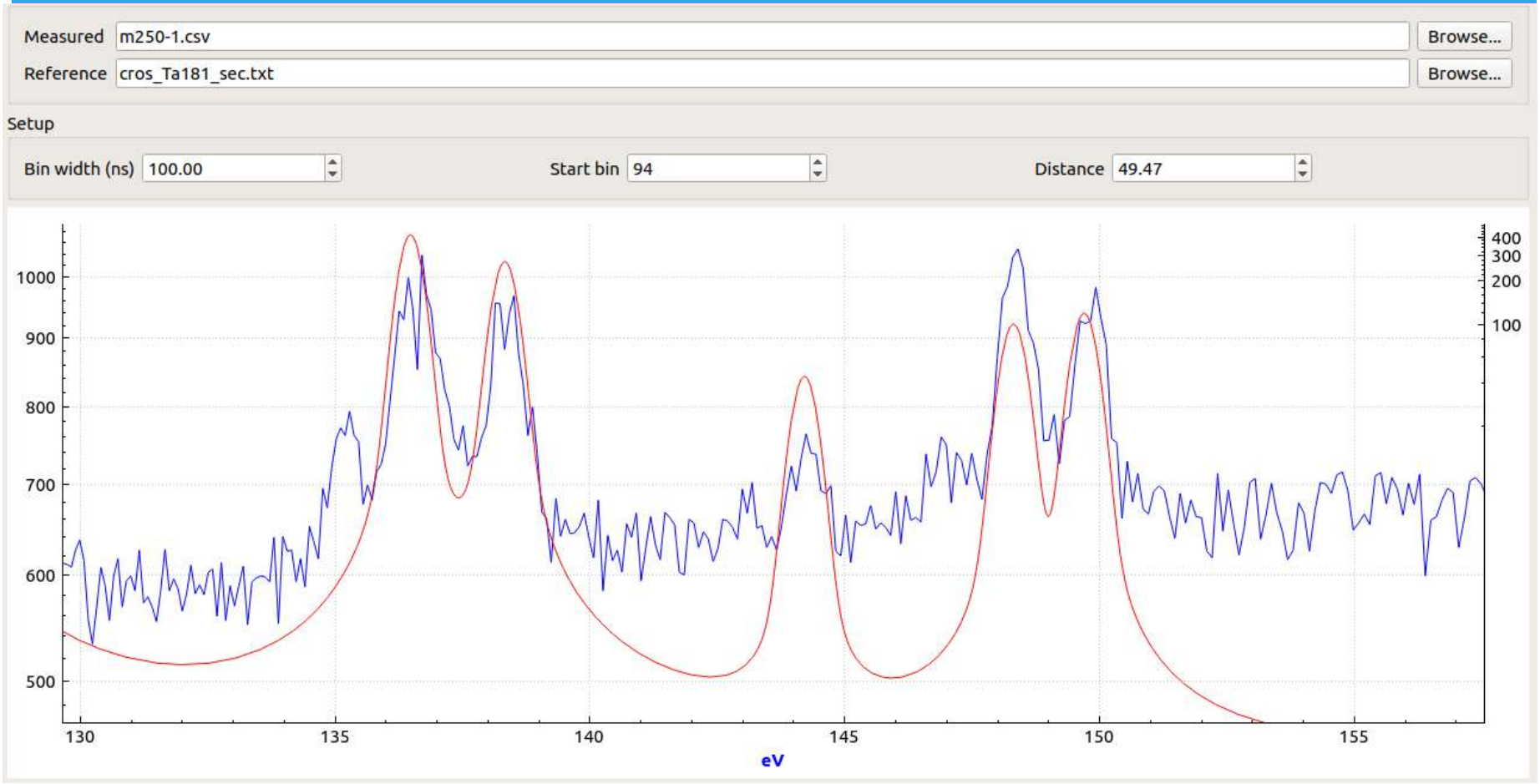
Higher then 330 eV all world data bases for Ta-181 (n,gamma) are similar, probably they are based on one and the same source.

Ta181 (n,gamma) spectrum between 32 and 60 eV



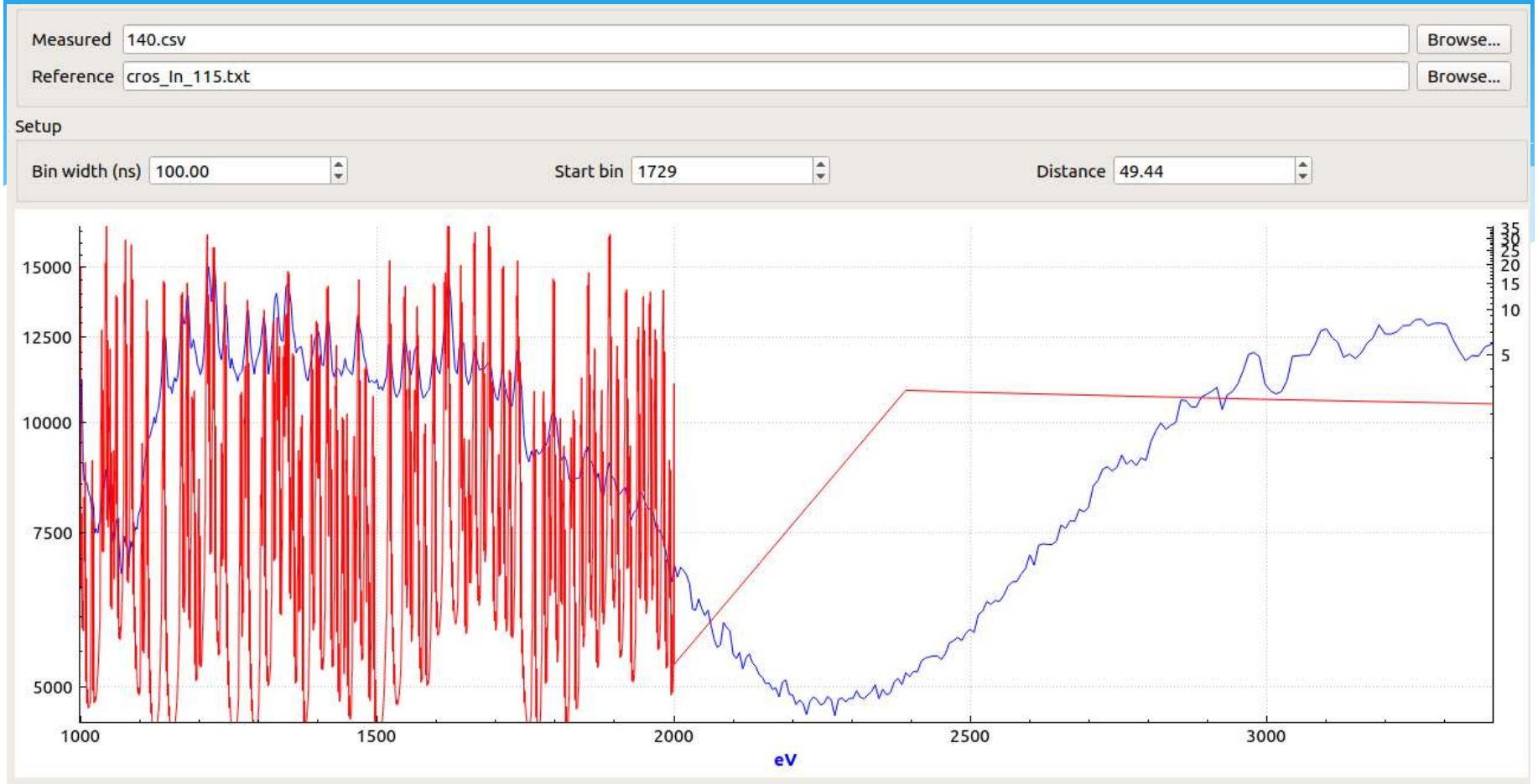
* Ta181 (n,gamma) resonance at 34 eV exactly exists,
* Ta181 (n,gamma) resonance at 55.8 eV is abcent

Disputed cross section of Ta-181 resonance at 144 eV



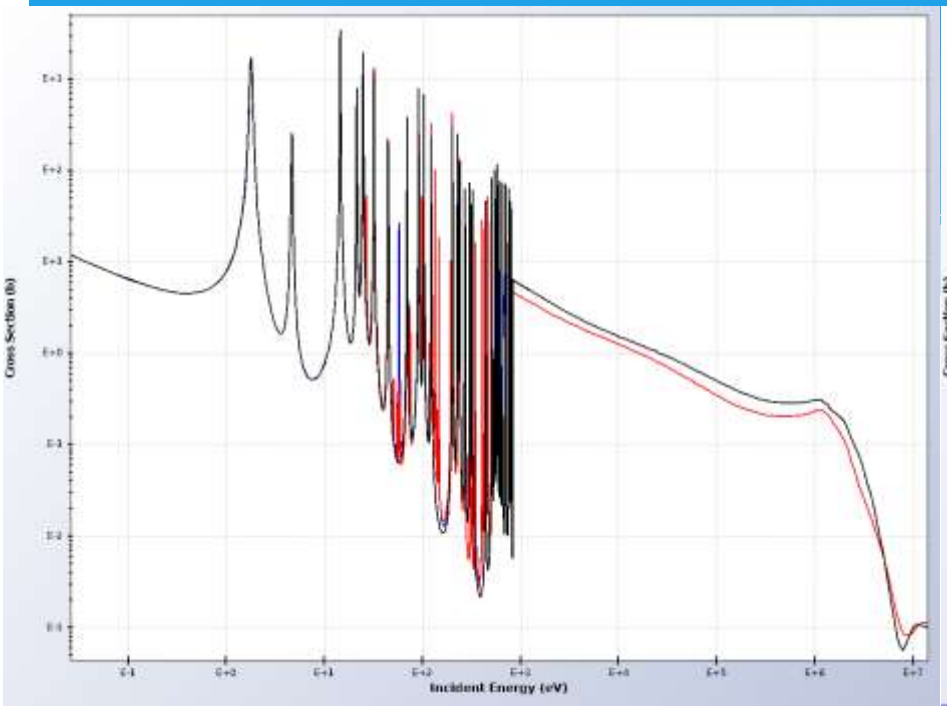
* Resonance at 144 eV is lower that others, this fact is also disputed between four world data bases. Resonance at 157 eV is abcent.

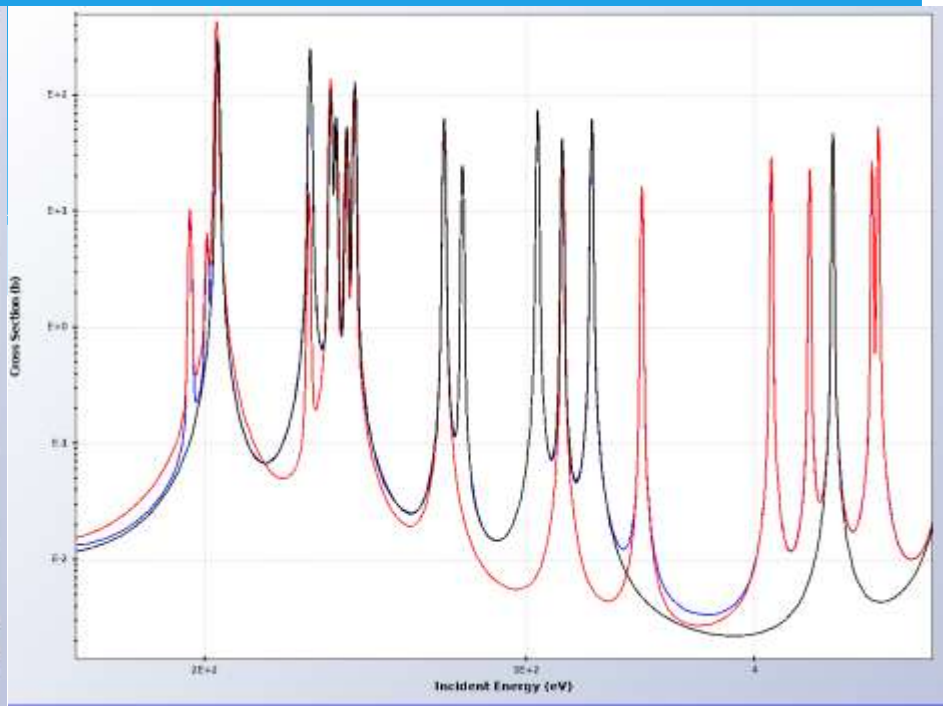
Natural Indium isotope mixture pattern-radiator with Mn55 filter



* Natural Indium consists of two isotopes: In-113 (4.23%) and In-115 (95.77%)
* Red curve is ENDF/B-VII.1 data in barns with axis from right side
* Blue color is experimental spectra, counts per channel on left axis

Indium In-113 (n,gamma) resolved resonances

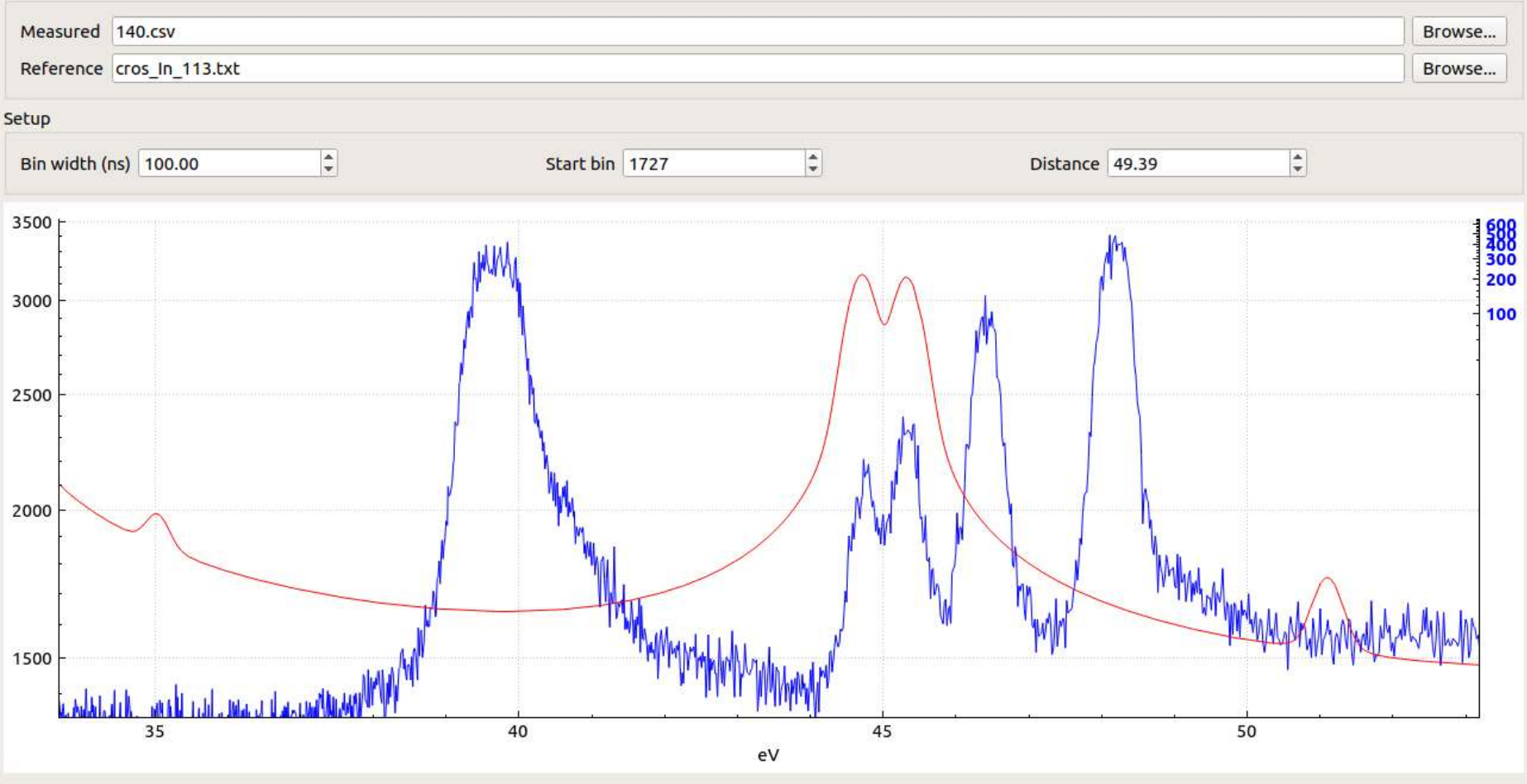




* In the best world nuclear data, currently
  In-115 resolved resonance area is up to 2000 eV,
  In-113 up to 850 eV

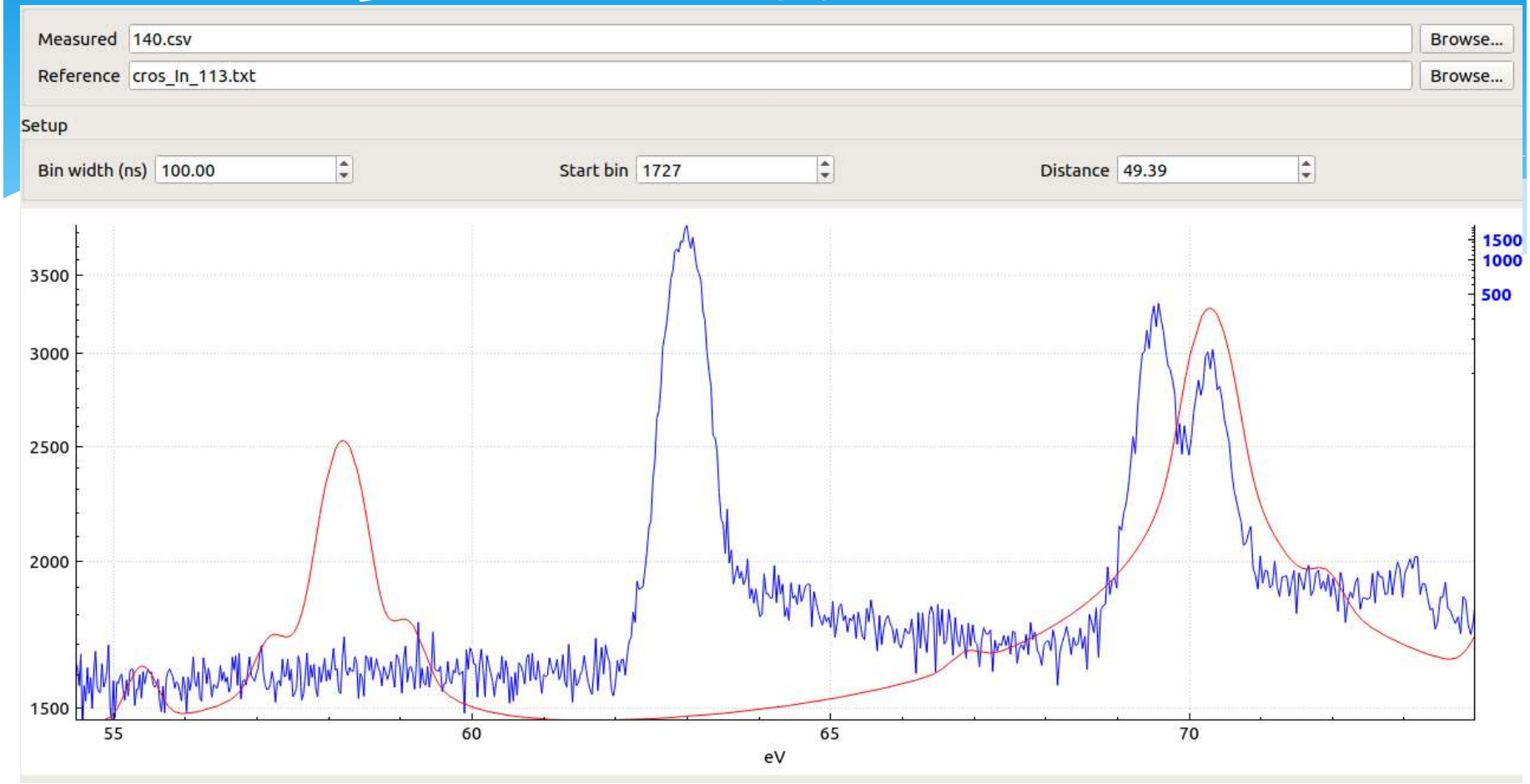
49-In-113(n,γ) ENDF/B-VII.1
49-In-113(n,γ) JEFF-3.1
49-In-113(n,γ) JENDL-4.0
49-In-113(n,γ) ROSFOND

Disputed In113 resonance at 51 eV



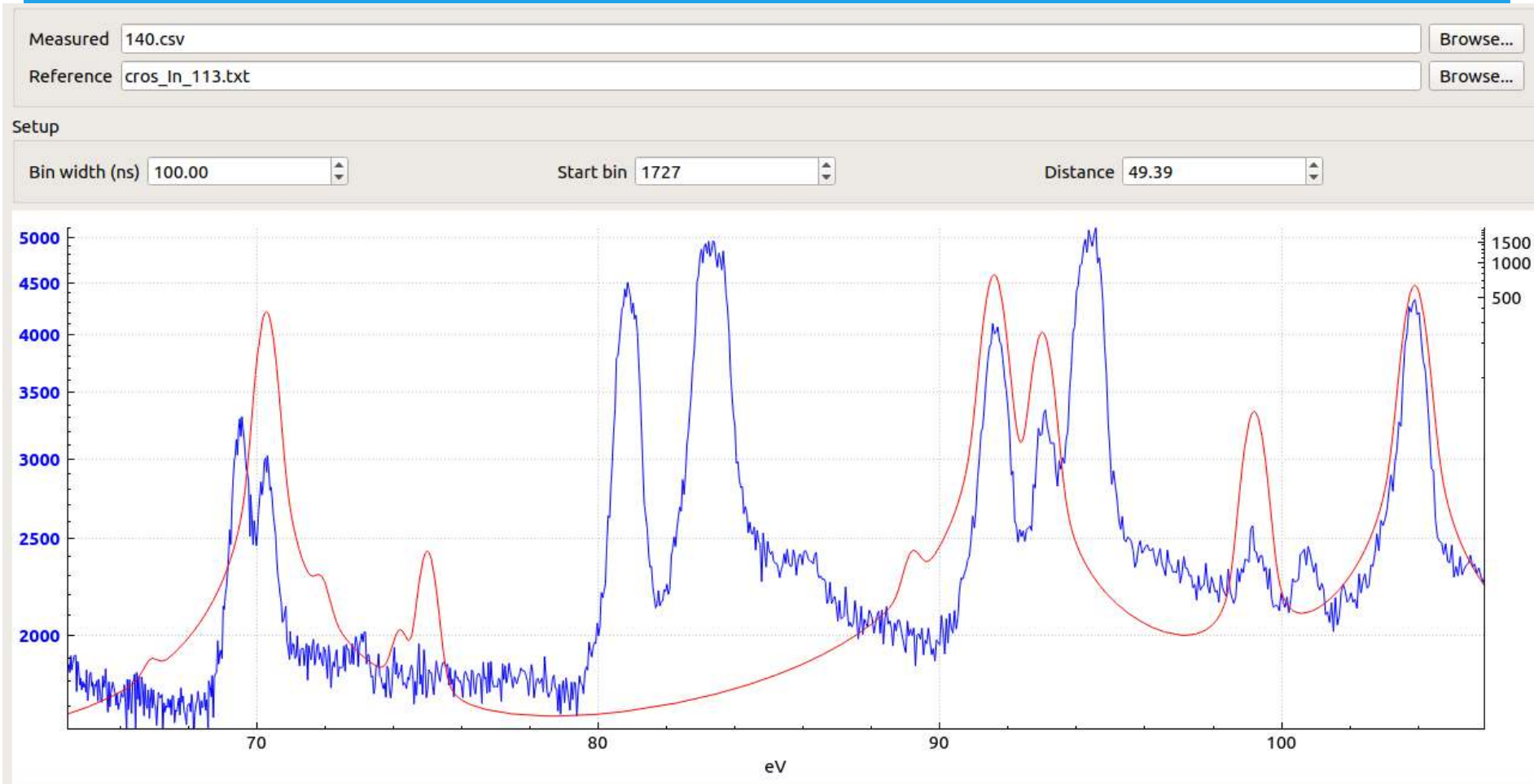
* In-113 resonance at 51 eV is abcent
* Resonances, that coincidences with resonances of red curve, are In-113(n,gamma)
* Resonances on blue spectra, which does’nt repeat red line, are In-115 isotope

In-113 between 55 eV and 74 eV



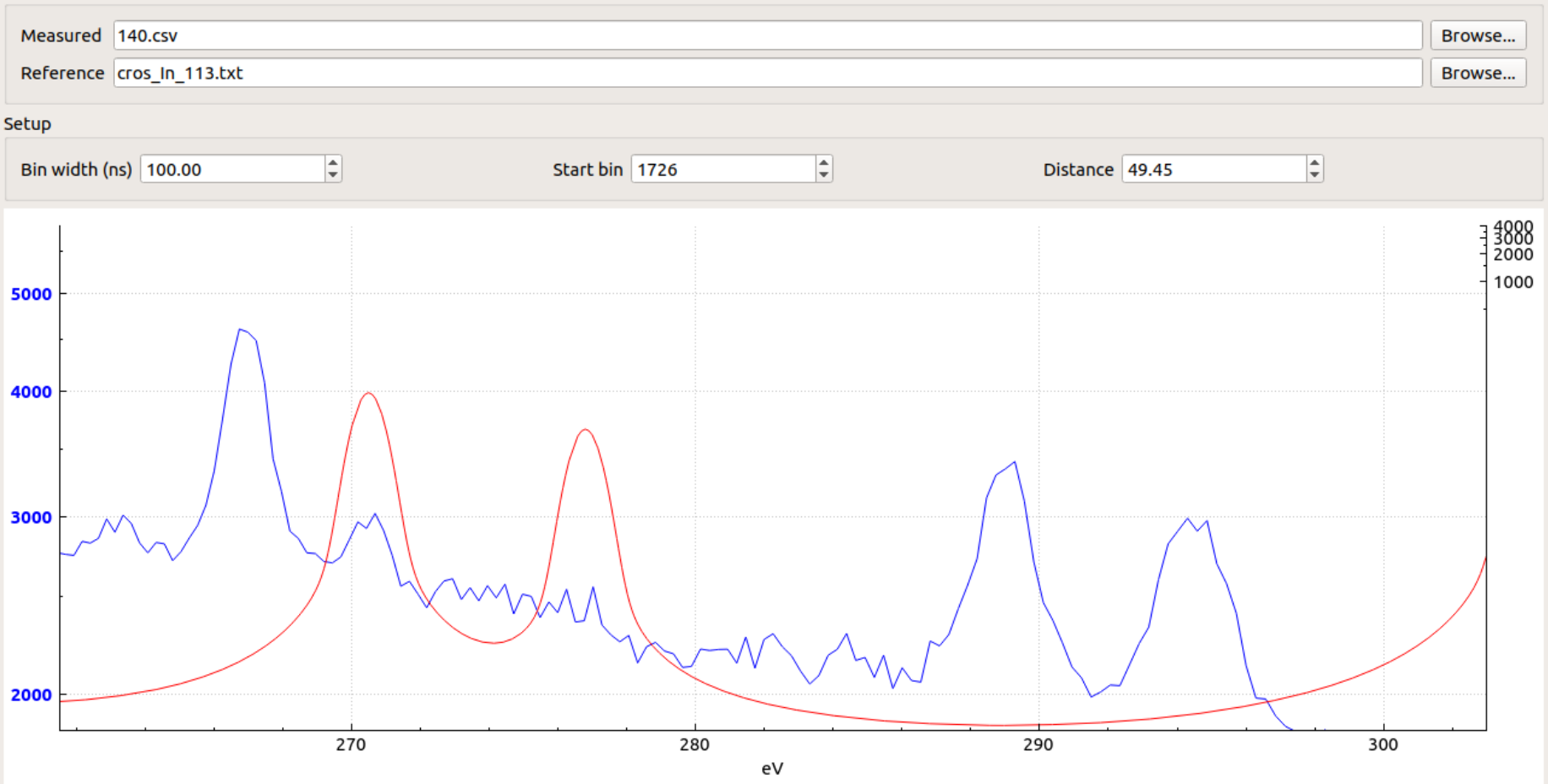
* In-113 disputed resonances at 67 eV and 71,8 eV exists.
* Debated in some data files resonances at 55,4 eV; 57,2 eV; 58,2 eV; 59,1 eV does’nt exist.

In-113 between 64 eV and 106 eV



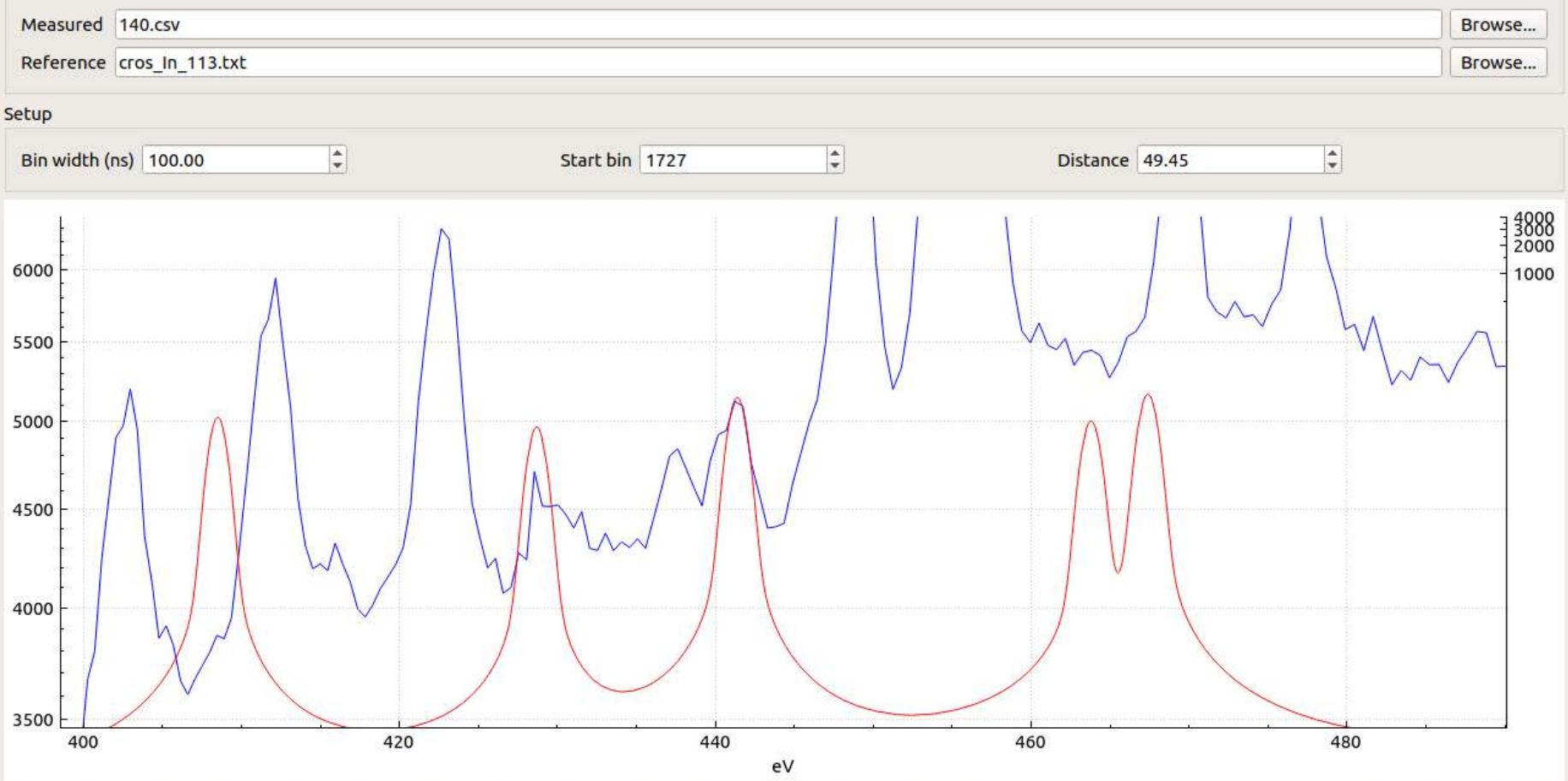
* In-113 debated resonances at 67 eV; 71,8 eV; 75 eV; 99,1 eV exists.
* In-113 disputed resonances at 74,4 eV; 89,3 eV does'nt exist.

In-113 (n,gamma) between 260 and 302 eV



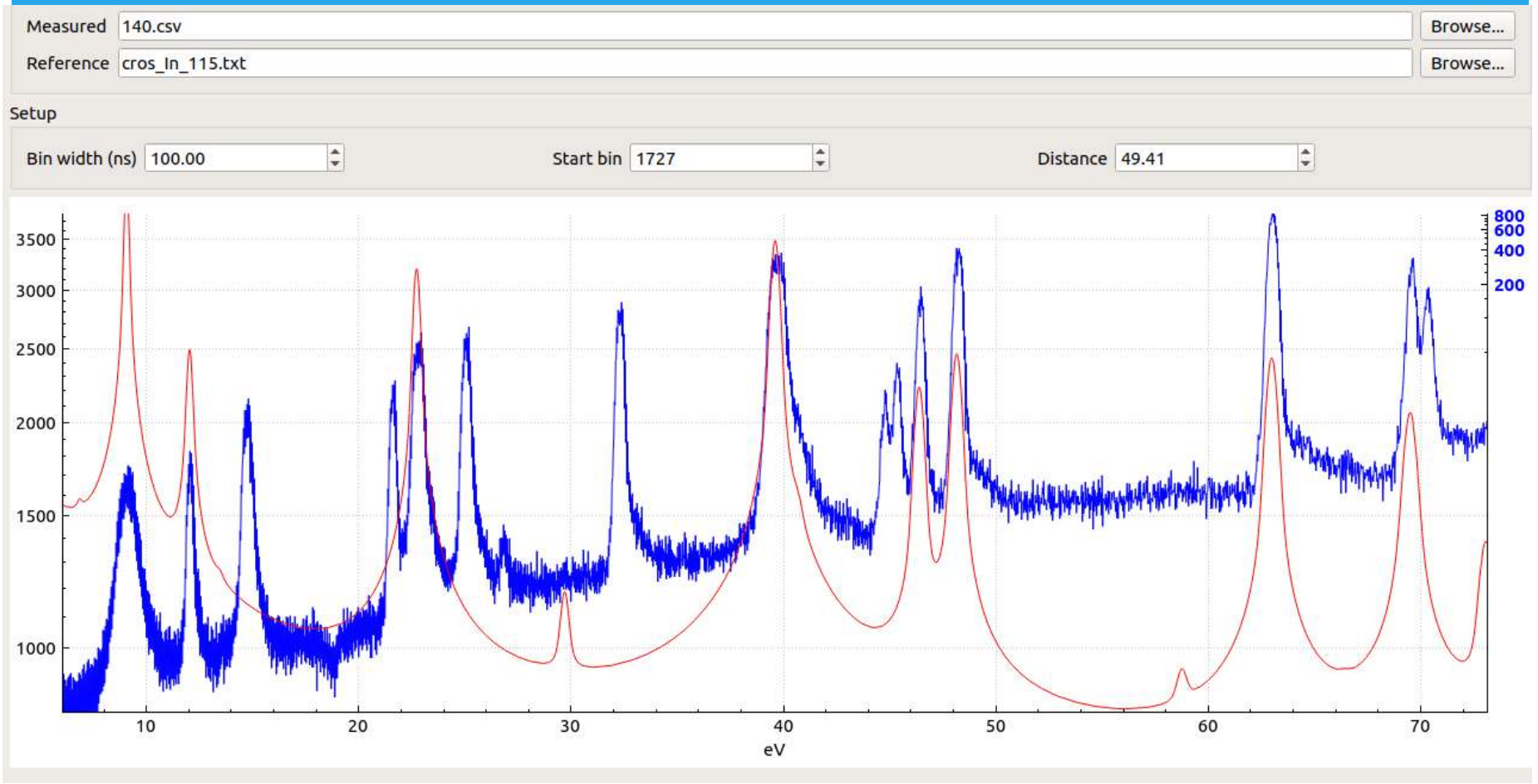
- In-113 resonances exist at 134 eV; 147,6 eV; 196,3 eV; 200,8 eV; 463,7 eV; 467,4 eV;
- In-113 resonances not exist at 119,3 eV; 142,4 eV; 276,7 eV; 408,5 eV.
- Higher then 470 eV up to border of resolved area at 813 eV, between four world data bases there is no difference. Exists probability, that all they used one and the same experimental work as a source of data.

In-113 between 400 and 490 eV



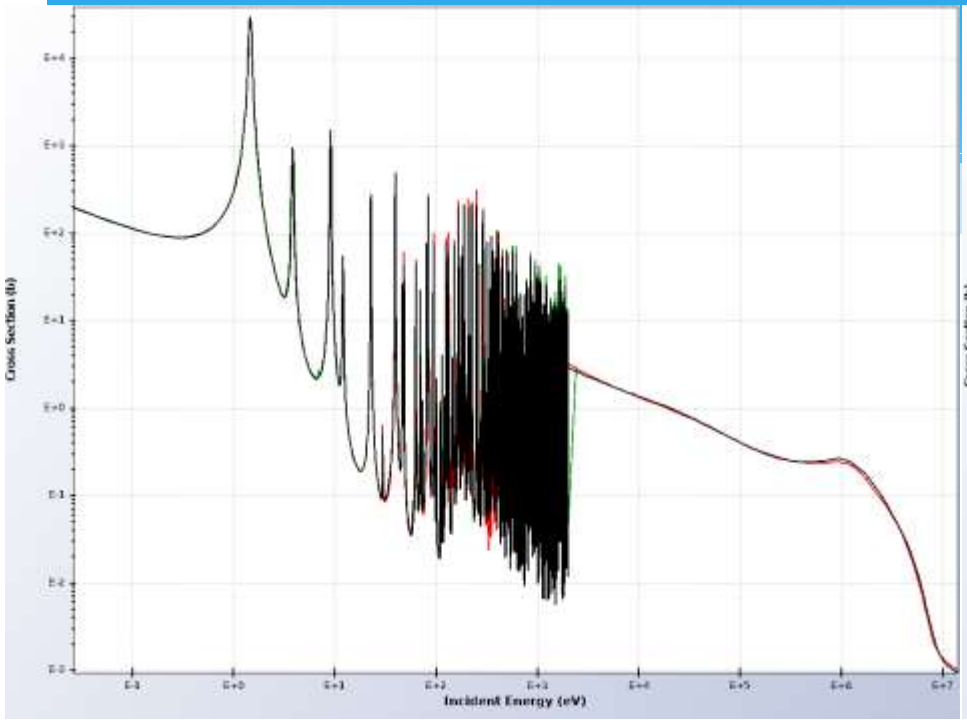
* In-113 disputed resonances at 463,7 eV and 467,4 eV exists, resonance at 428,8 eV is strong and obvious. Resonance at 408,5 eV does'nt exist.
* Big resonances on the blue curve belongs to In-115.

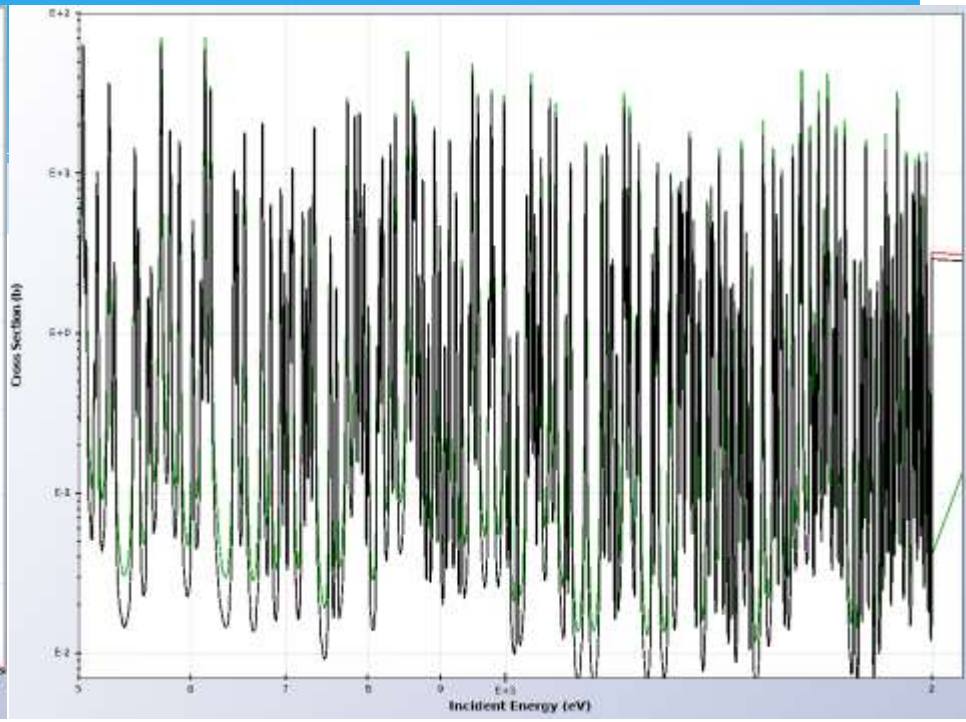
In-115 pattern ENDF/B-VII.1 and our data are shown



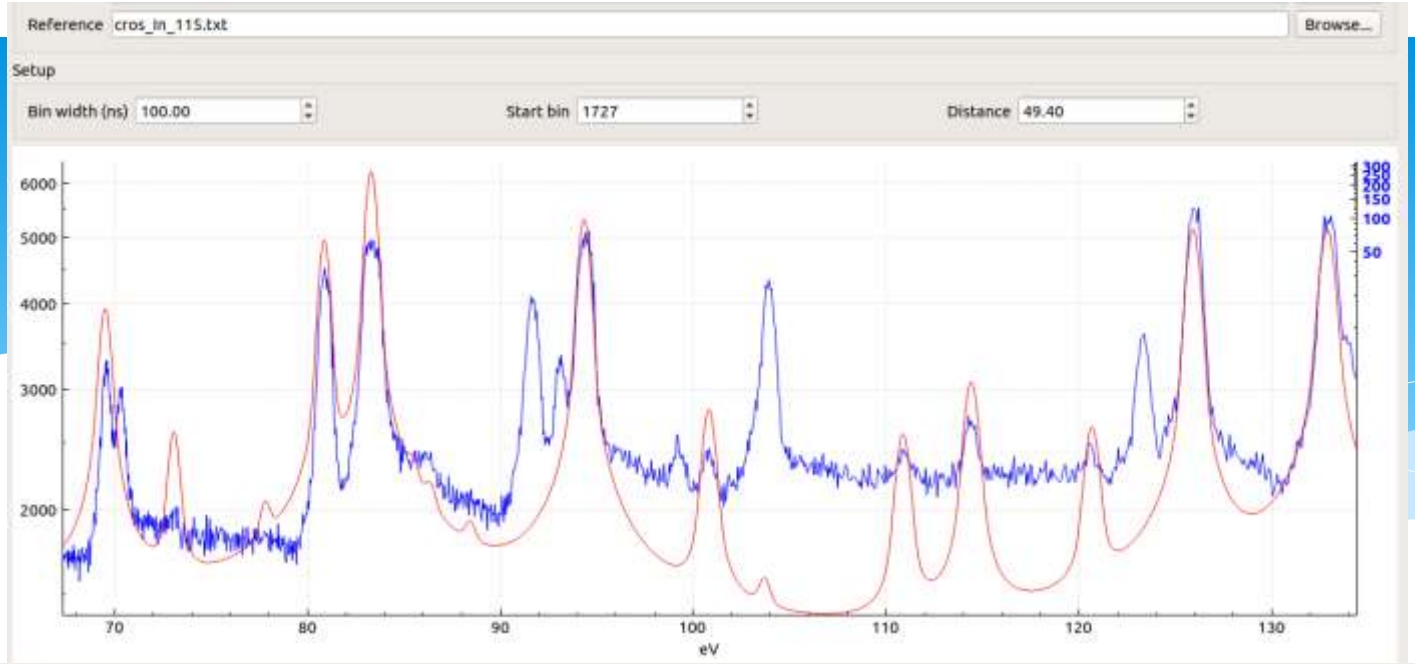
- In-115, neutron energies between 6 eV and 73 eV: all resonances on their places.
- High resonances on blue spectra, which are not in coincidence with red line, belongs to In-113 isotope.

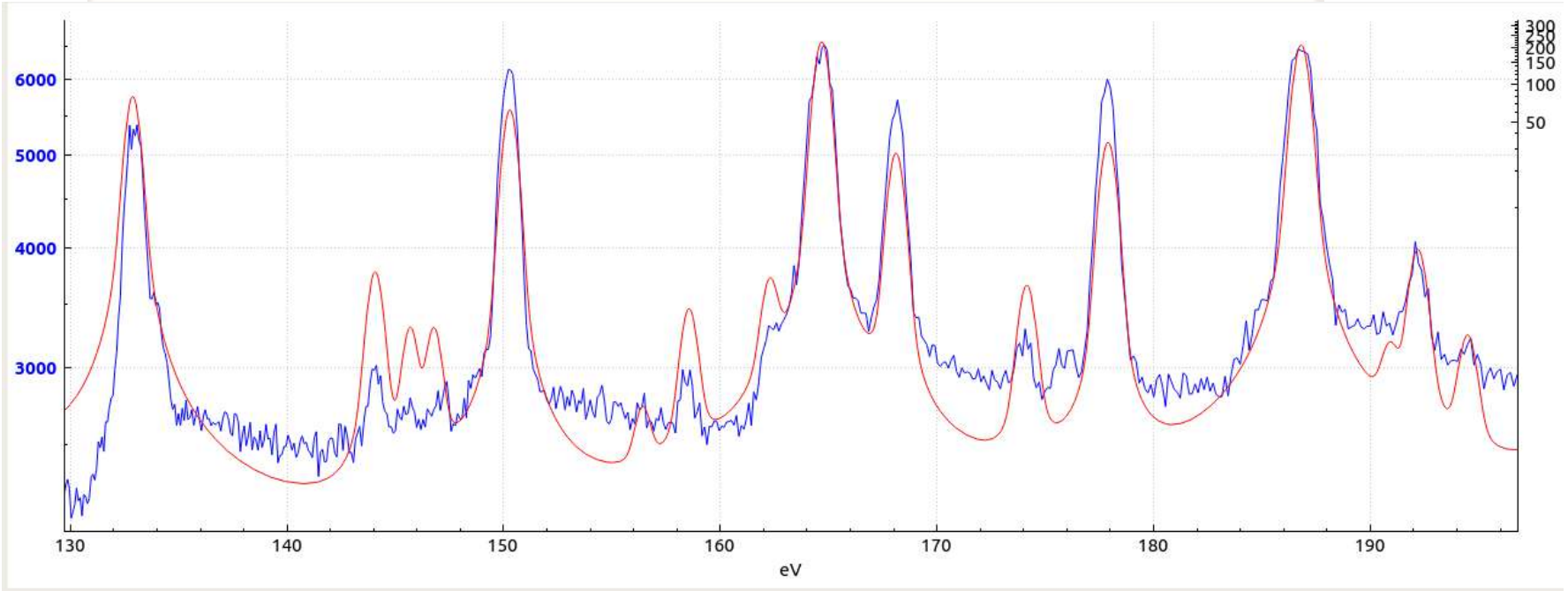
Indium In-115 isotope



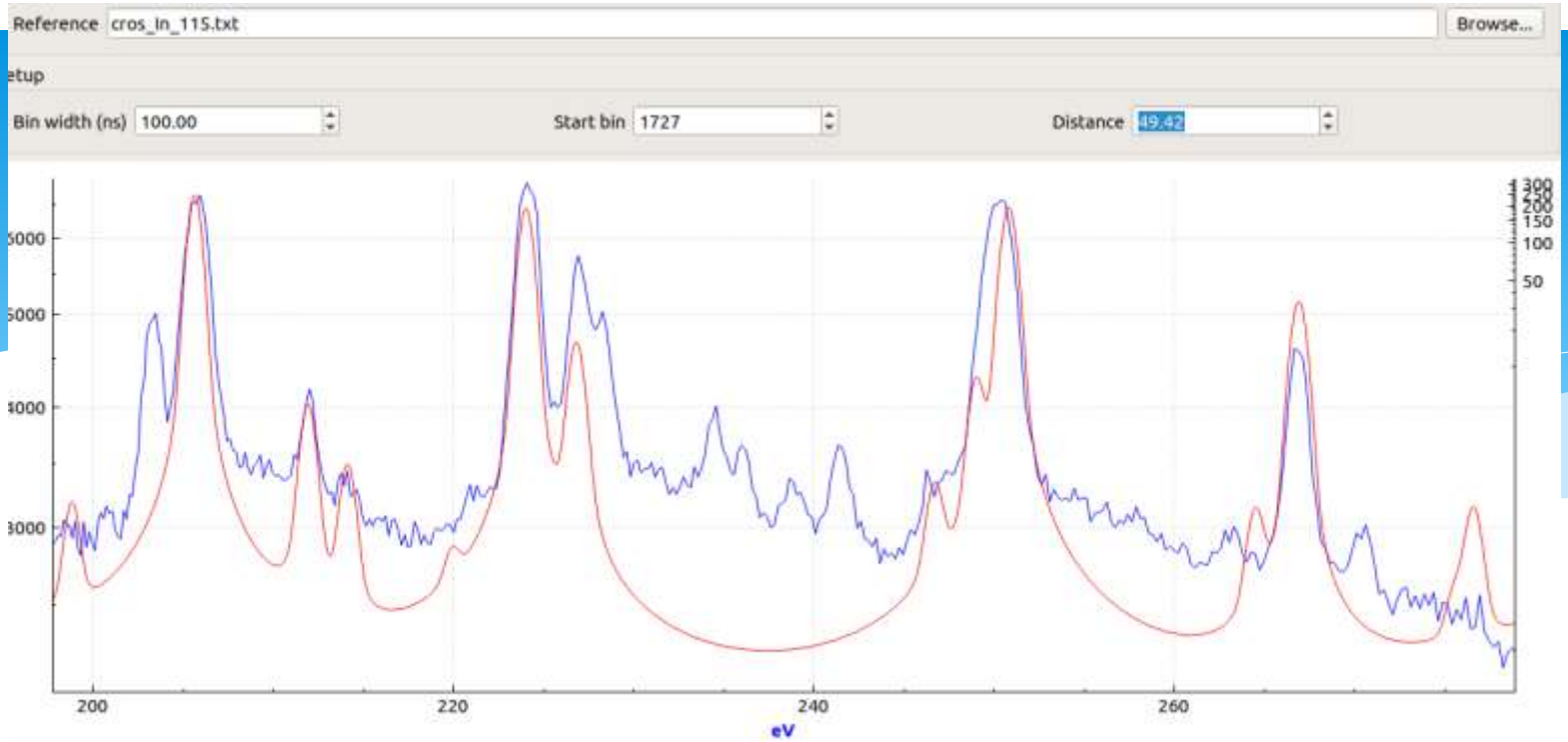


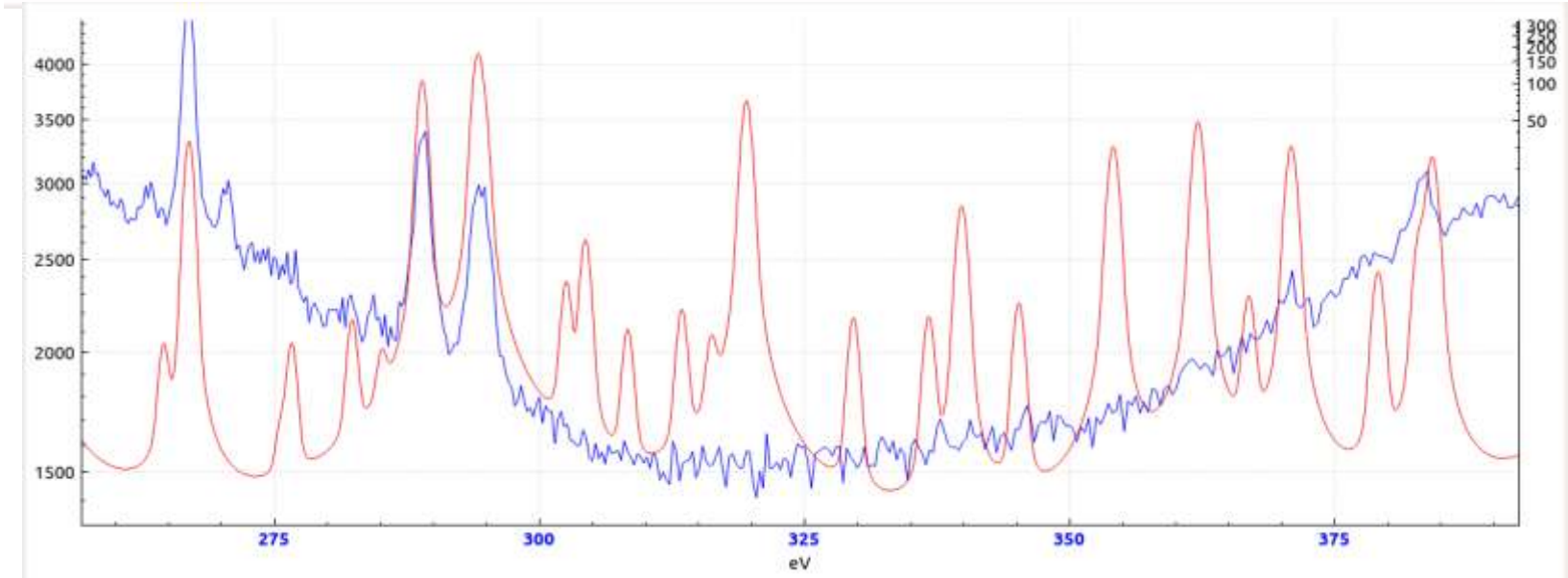
* Resonance structure of In-115 isotope is resolved by four world data bases up to 2000 eV. Between 500 eV and 2000 eV all they are similar without differences, probably one and the same experimental data source was used.
* Below 500 eV exists great amount of differences of all kinds: missing resonances, resonances from admixtures, debated cross section and even debated energy position of the resonance.
* We present Preliminary data below on pictures





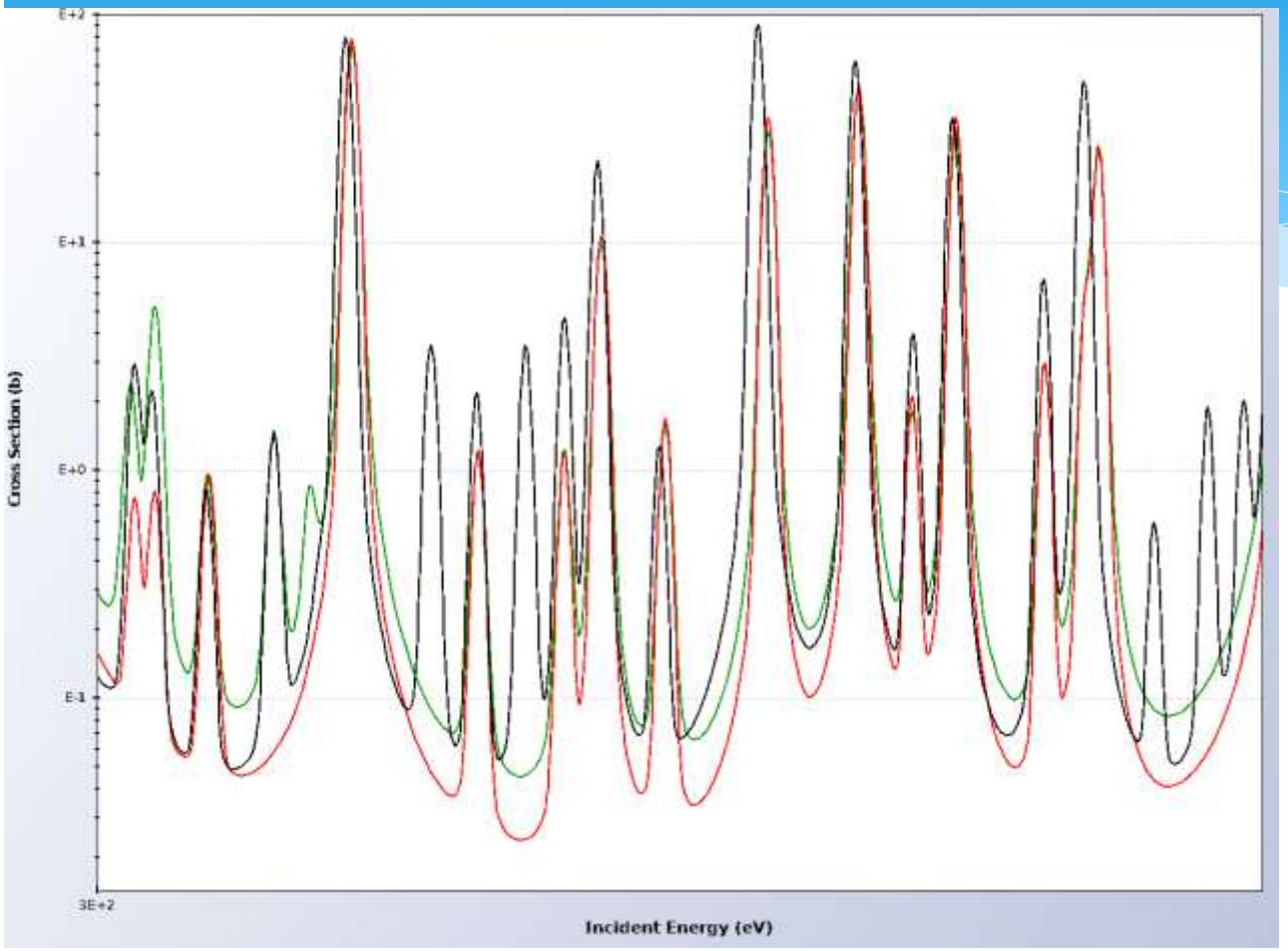
* In-115 debated resonances exactly exists at 86 eV; 104 eV; 123 eV; 162 eV;



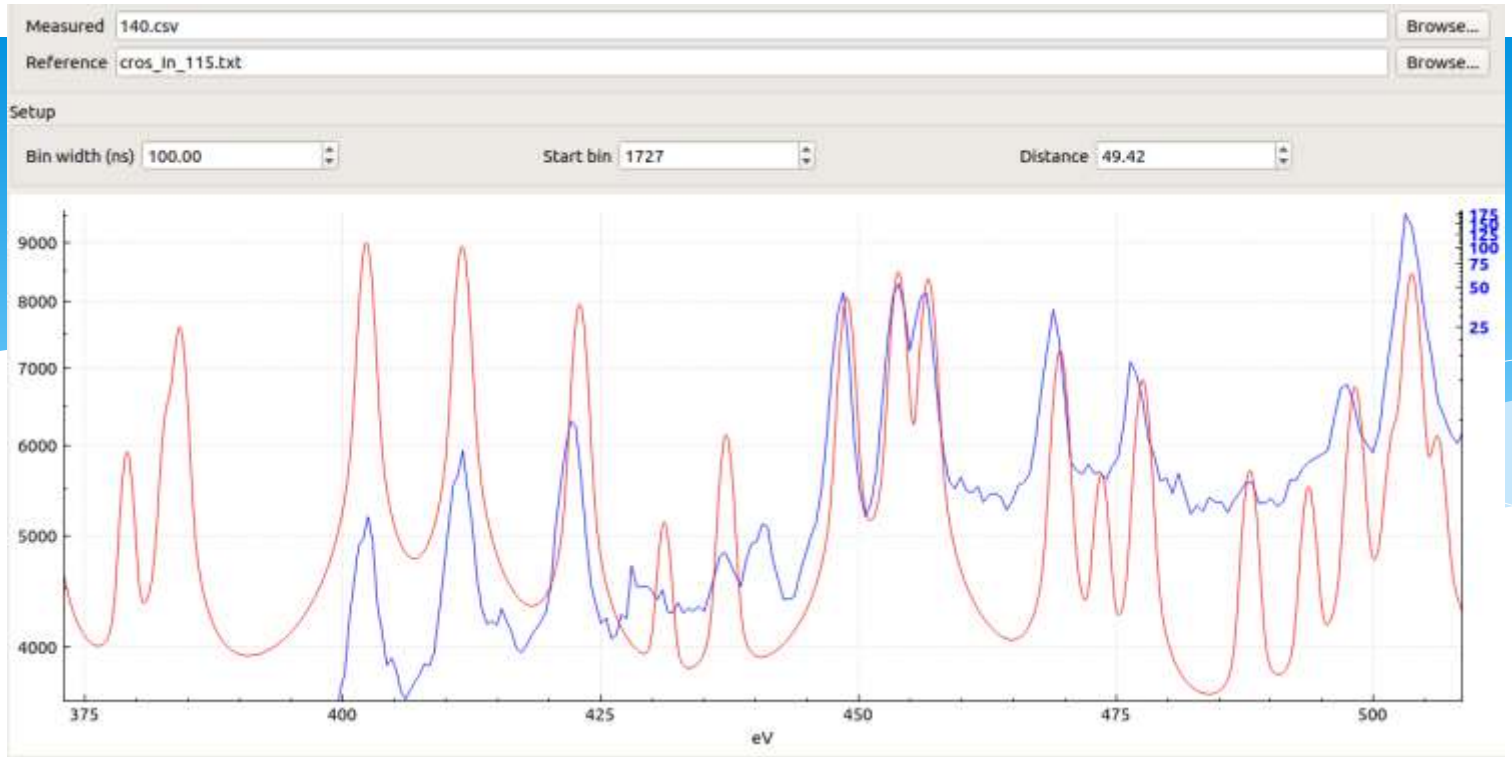


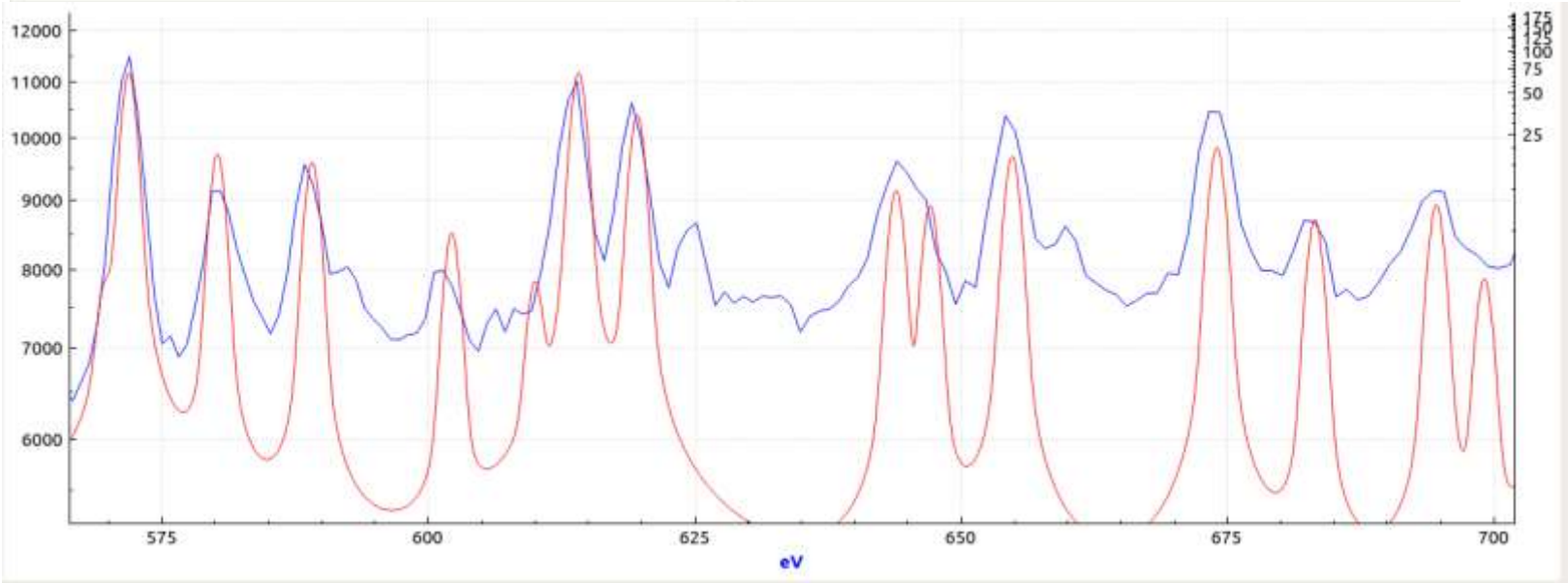
* On lower picture neutron flux cut by Mn55 filter is shown. Filter was used to determine the background function of neutron energy.

In-115 (n,gamma) best world data

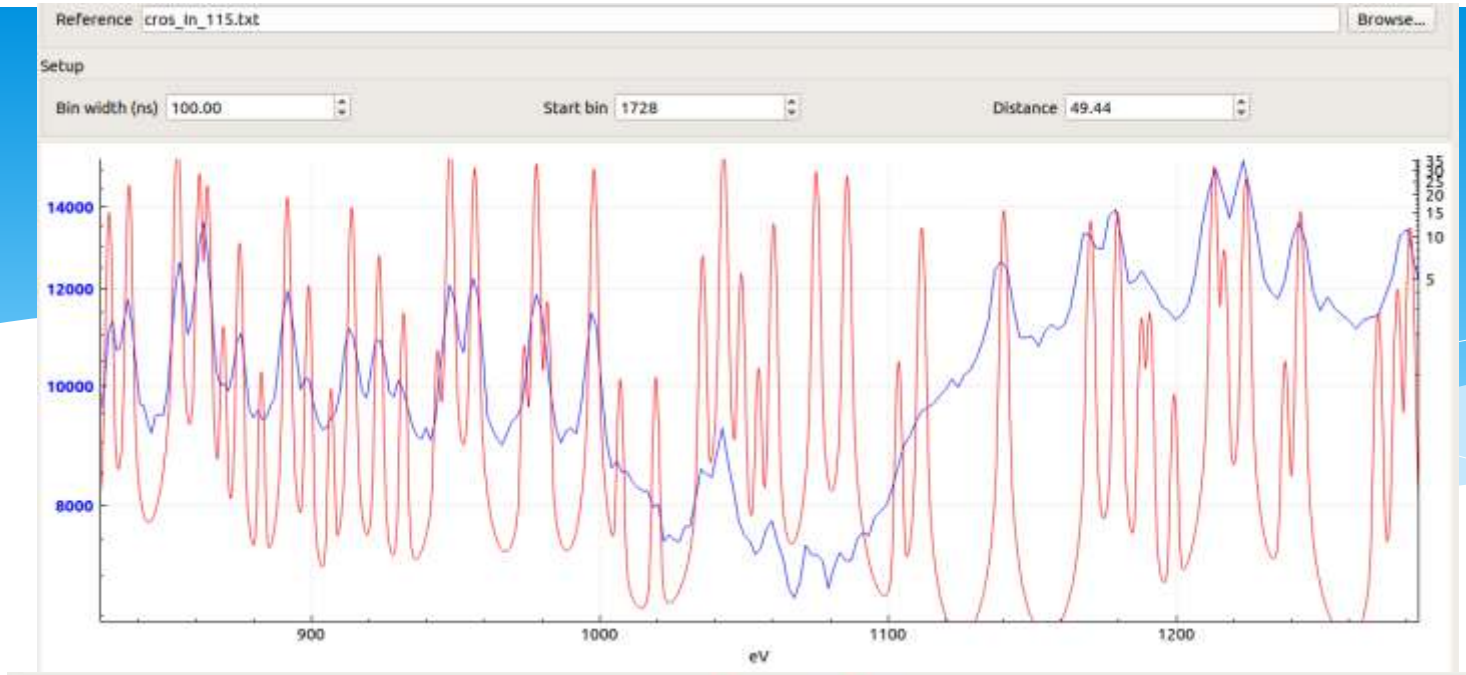


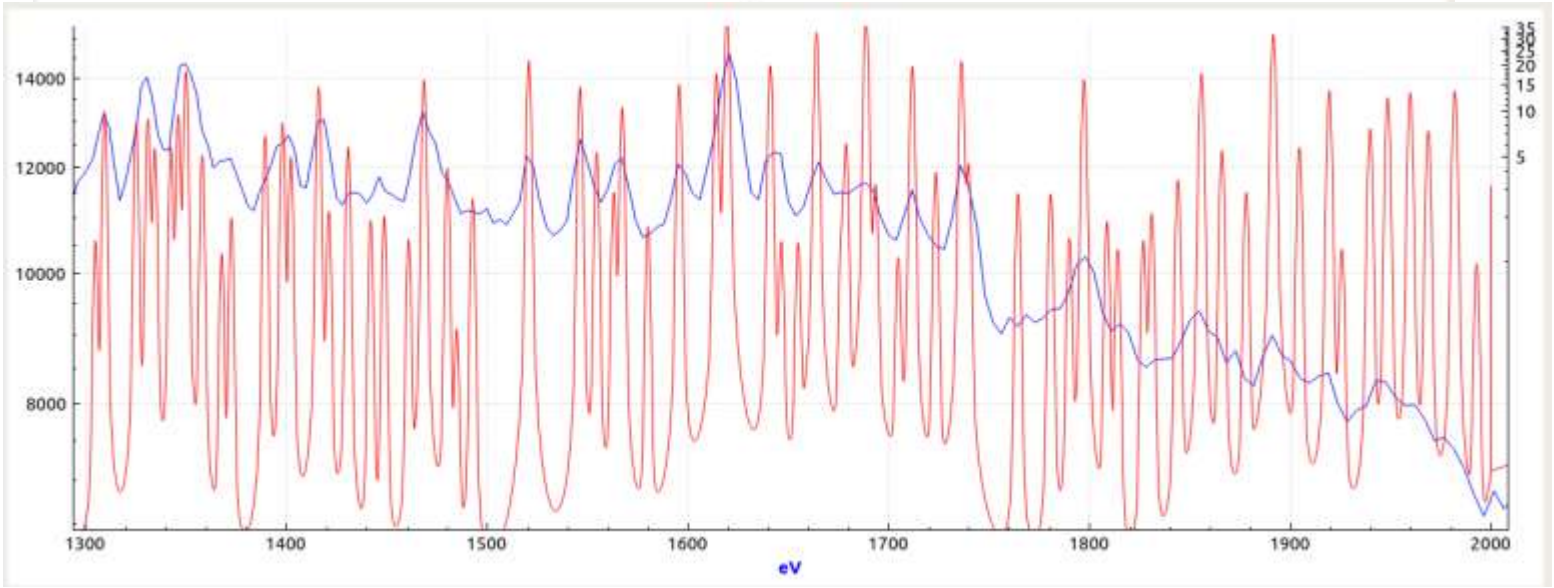
* In-115 (n,gamma) BNL data between 300 eV and 500 eV





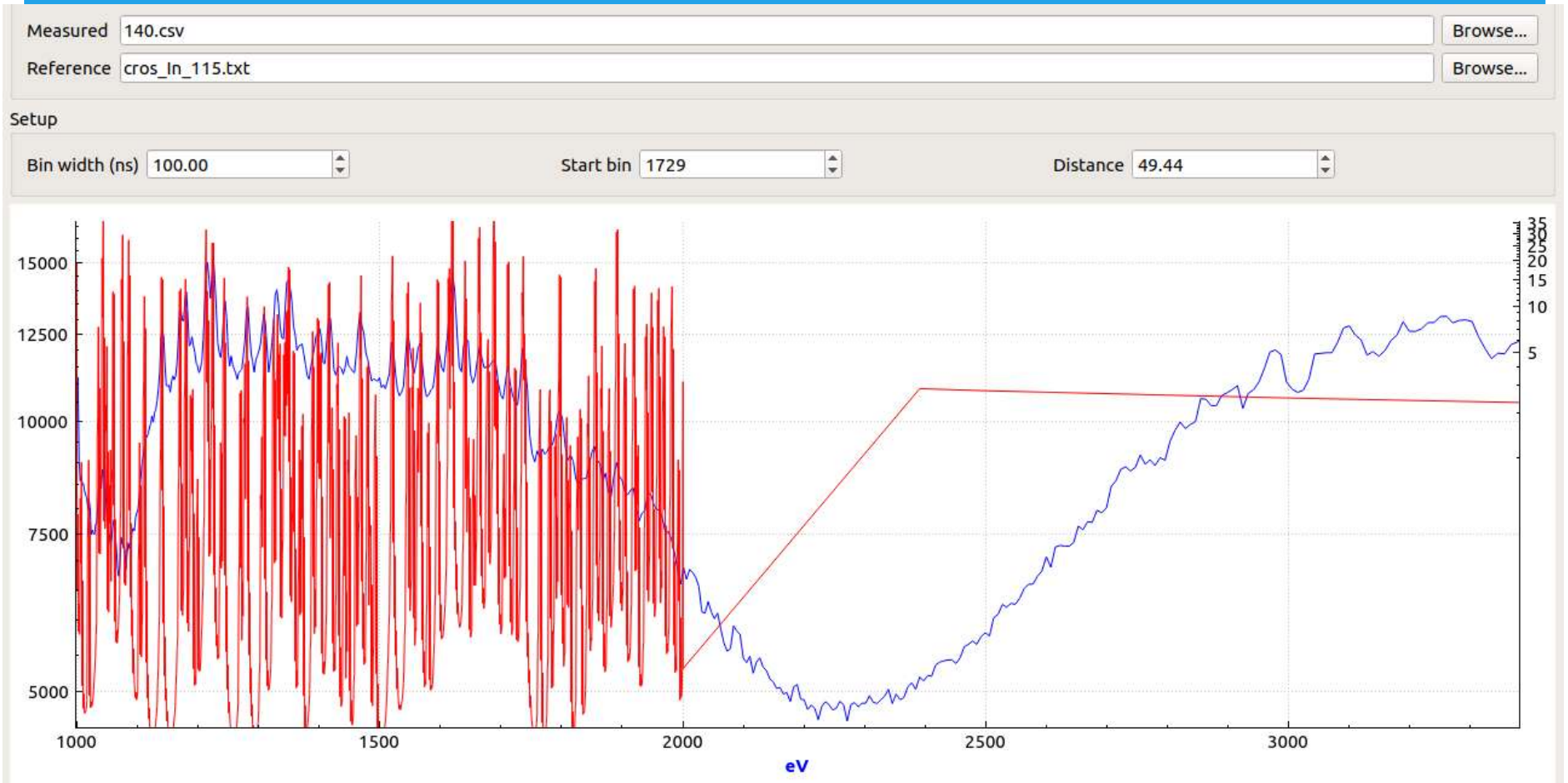
* In-115 definitely has some of disputed resonances in the interval 375 – 700 eV





* In ENDF/B-VII.1 for In-115 area of unresolved resonances is started from neutron energy 2000 eV, we distinguish resonance structure up to comparable energy level.

Summary



* During years 2018 and 2019 resonance structures of Au-197, Ta-181, In-113 and In-115 were measured using installation INES at 50 meter TOF base of INR RAS pulsed spallation neutron source RADEX.
* New data on resonance structure achieved by INR RAS in order to contribute international efforts to increase precision of world nuclear neutron data files.

Acknowledgements

Authors express their thanks to INR RAS Director Kravchuk L.V. for support of this work, Vice-director Feschenko A.V. for providing accelerator beam time, academician RAS Tkachev I.I. for fruitful discussions and new oscilloscope, team of the accelerator department for high stability of proton beam, team of chemistry department for high purity of Tantalum and Indium metal patterns.