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Muonic atom X-Ray Emission Spectroscopy (μ XES) and X-Ray Fluorescence (XRF): comparison for application to metallic archaeological samples

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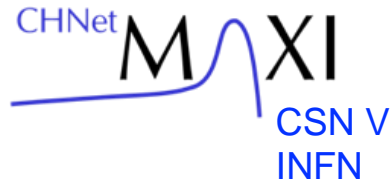
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OUTLINE

*CHNet-MAXI experiment funded by INFN:
Muonic Atom X-ray and prompt gamma spectrometry for
non-destructive Isotopic analysis for cultural heritage.*



Preliminary study:
XRF (X-Ray Fluorescence) vs **μ XES** (*Muonic Atoms Emission X-Rays Spectroscopy*)

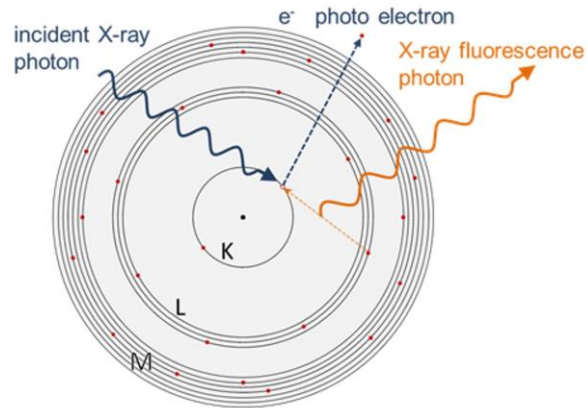


Case study: Historical Portuguese Coin



METHODS

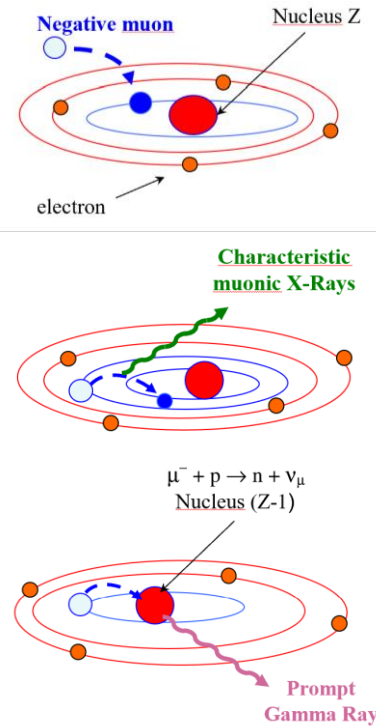
XRF (X-Ray Fluorescence)



Both:

- Non-invasive and non-destructive technique
- Qualitative and quantitative analysis
- Based on the emission of characteristic X-rays

μ XES (Muonic Atoms Emission X-Rays Spectroscopy)



Muonic Atom formation: muon capture in atomic muonic orbital.

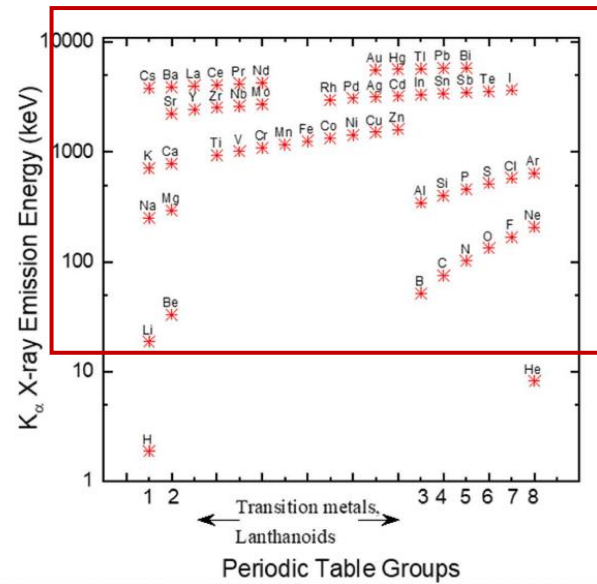
Muonic Cascading process: emission of high energy **characteristic muonic X-Rays**.

Natural decay/muon capture by nucleus with Prompt Gamma Ray emission.

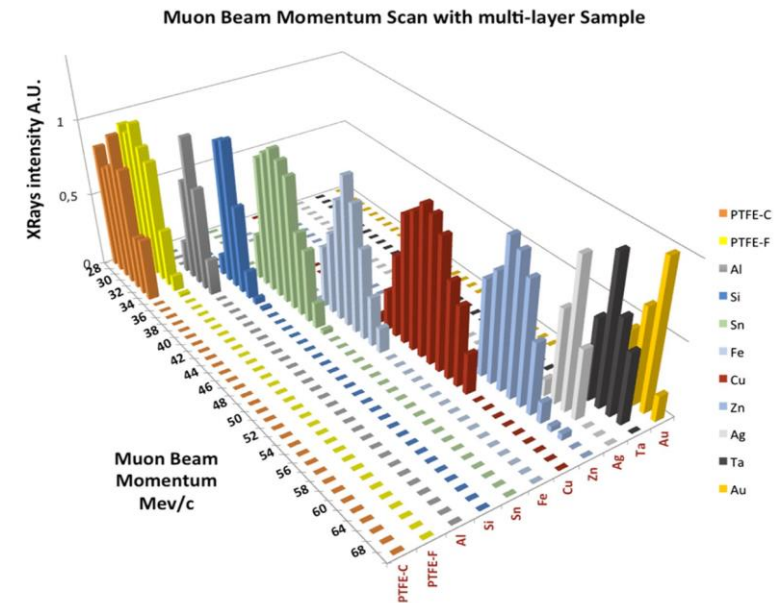
METHODS

μ XES (*Muonic Atoms X-Rays Spectroscopy*)

- High energy characteristics X-rays (10 keV - 10 MeV)
- Applicable to every element from Li to U: simultaneous multi-elemental analysis



- Depth profile



Materials

Portugues Coin, late XVIII century

- Different kind of coin (Reis): Copper/Bronze (5,10, 20, 40 reis) and Silver (60, 80, 120, 200, 400 reis) coin
- Visible in our coin is the number “LXXX” (thus 80 reis) and the name of Queen Mary I who reigned from 1777 to 1799.

The main interest of the analysis conducted on this coin is to cross-check it with various nuclear surveys to reveal its exact composition and to assess whether it has undergone surface enrichment in silver.

Why analysis with XRF and μ XES?

- Non-destructive
- No cleaning necessary
- Depth profile with μ XES



Materials

Instrument:

- XRF Portable instrument – Brucker Tracer 5
- μ XES @ISIS Facility

Calibration:

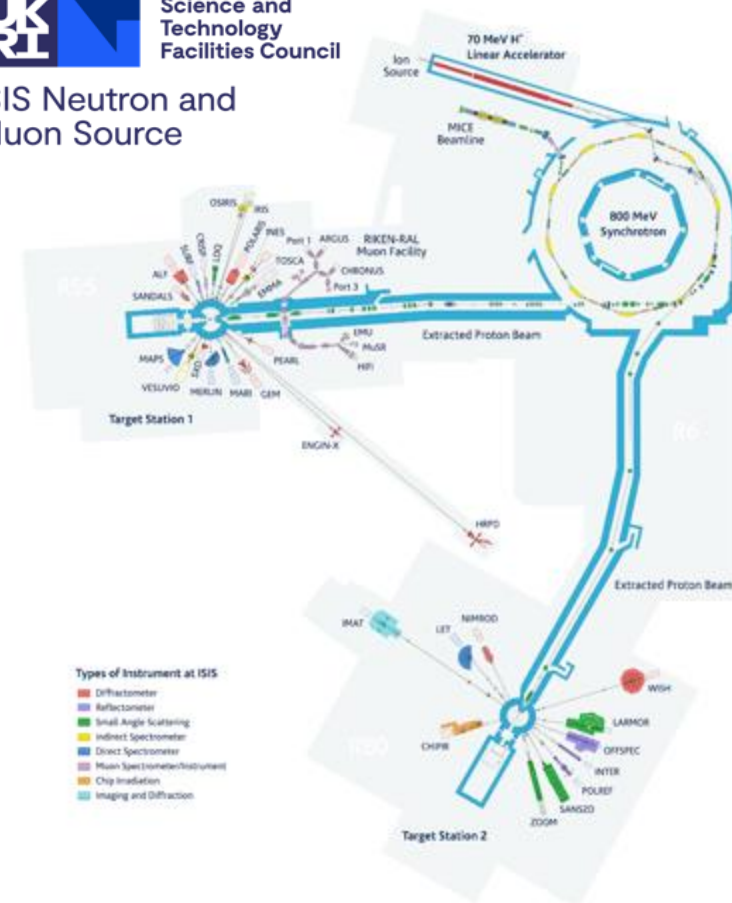
- certified metal standard (copper alloys)

Sample:

- Portugues Coin, late XVIII century



ISIS Neutron and Muon Source



XRF Measures – Data elaboration

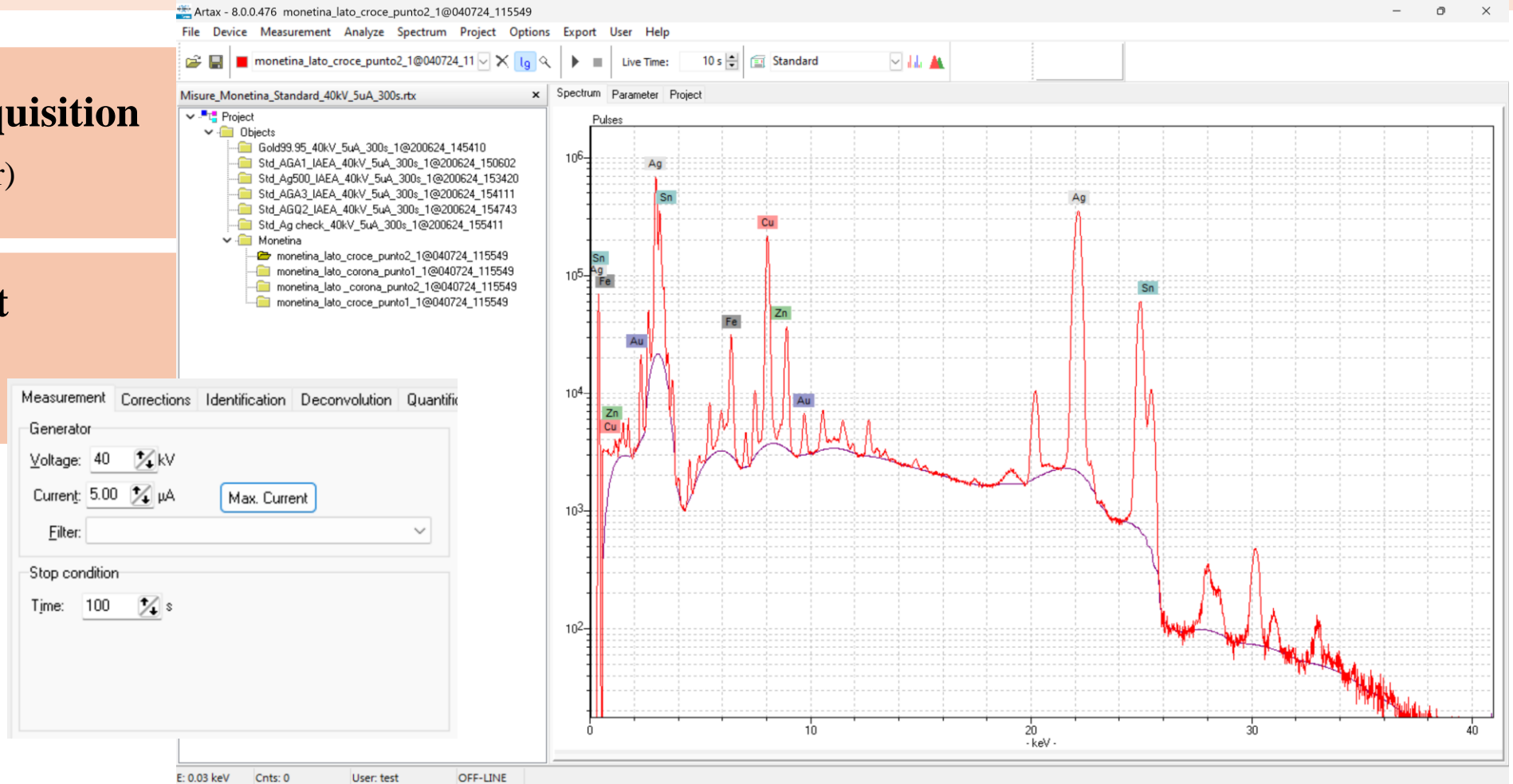
Spectra acquisition

Artax (Bruker)

Spectra Fit

InterSpec

(open source)

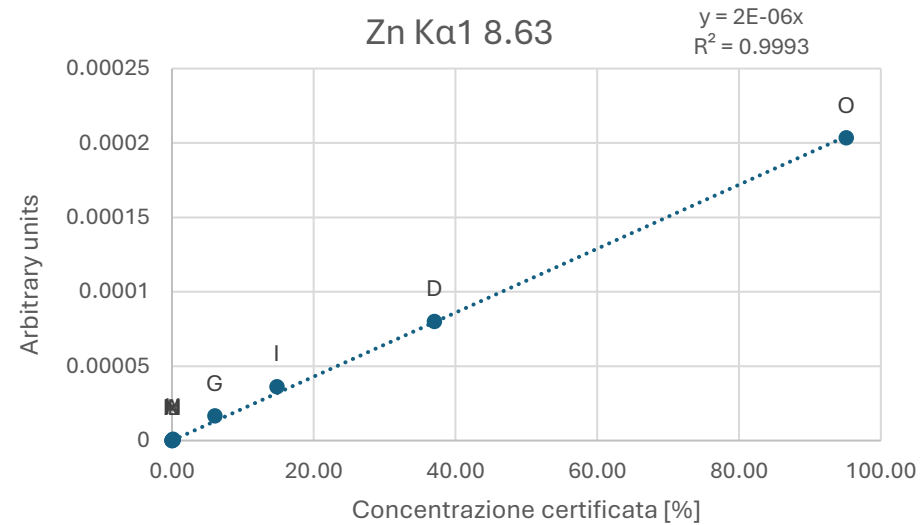


XRF Measures – Data elaboration

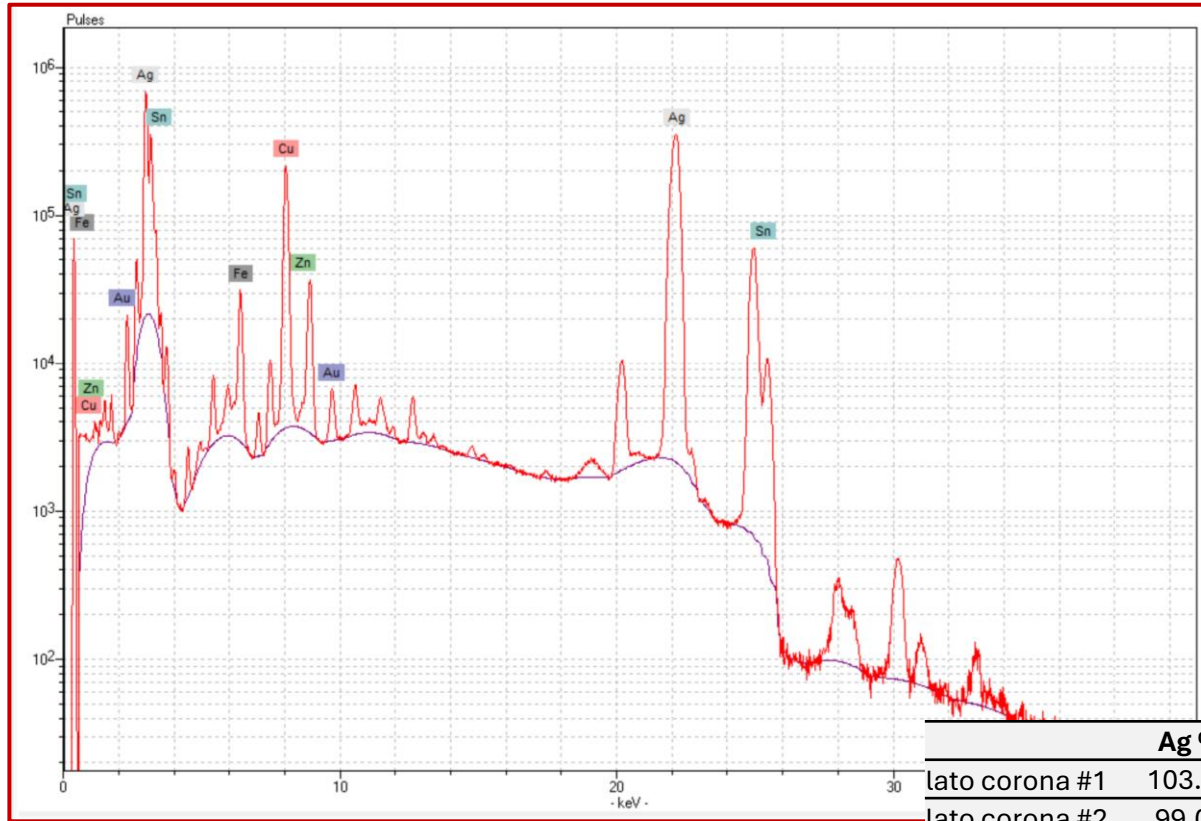
Nome file	Zn Certif. [%]	Unc.	Zn Ka1 8.63	Unc.	Totale conteggi	Unc	Real time [s]	Zn Ka1 8.63 Normalizzata	Unc
BCR691_A	G	6.02	2.77E+06	1.84E+03	4.47E+08	2.11E+04	374	1.65E-05	1.10E-08
BCR691_B	I	14.80	6.65E+06	2.75E+03	4.77E+08	2.18E+04	385	3.61E-05	1.50E-08
BCR691_C	M	0.06			2.61E+08	1.62E+04	386	0.00E+00	0.00E+00
BCR691_D	H	0.15	1.61E+05	9.05E+02	4.41E+08	2.10E+04	373	9.79E-07	5.50E-09
BCR691_E	L	0.16	7.35E+04	6.22E+02	4.58E+08	2.14E+04	378	4.25E-07	3.59E-09
Pb_Therm_Ref	A	0.01			3.16E+08	1.78E+04	347	0.00E+00	0.00E+00
Cu_elect	N	6.5E-04	1.74E+04	6.86E+02	4.84E+08	2.20E+04	389	9.26E-08	3.65E-09
BCR361_Zn	O	95.12	3.54E+07	6.27E+03	4.58E+08	2.14E+04	380	2.03E-04	3.72E-08
Brass_Cu63/Zn37	D	37.00	1.48E+07	3.99E+03	4.77E+08	2.18E+04	387	7.99E-05	2.19E-08

Normalization

$$\frac{\text{Peak area}}{\text{Total counts} * \text{Real time}}$$



XRF Measures – Data elaboration



Spot area = 8 mm

	Ag %	Au %	Cu %	Fe %	Pb %	Sn %	Zn %	tot
lato corona #1	103.33	0.33	10.32	-	0.50	4.3E-05	0.06	114.54
lato corona #2	99.06	0.42	10.95	-	0.29	4.0E-05	0.04	110.76
lato croce #1	100.56	0.47	10.18	-	0.47	4.2E-05	0.23	111.91
lato croce #2	97.60	0.38	10.37	-	0.43	4.0E-05	0.08	108.86

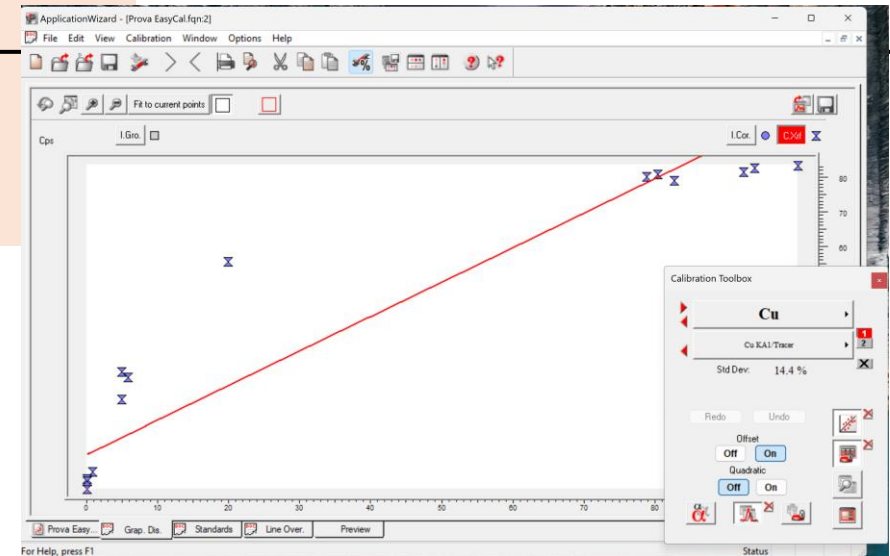
XRF Measures – Data elaboration

EasyCal
(Bruker)

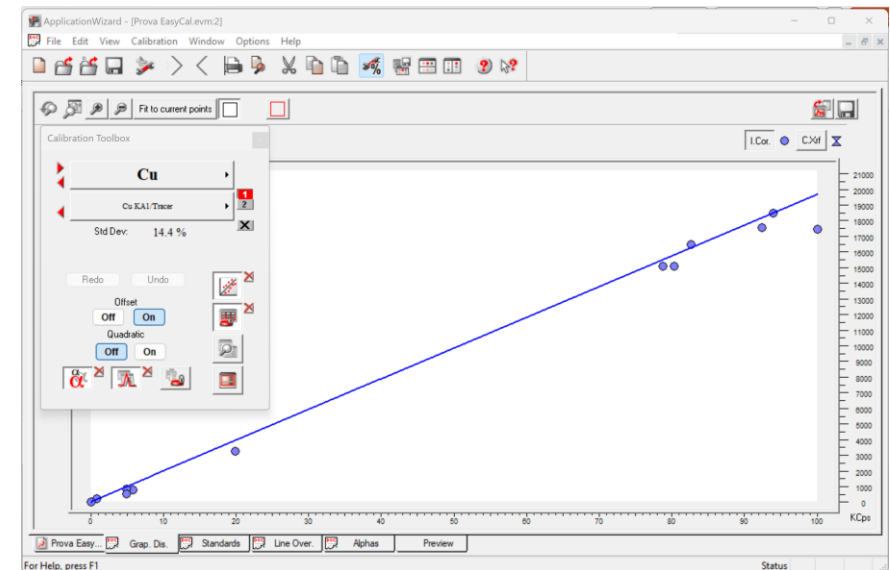
Matrix Correction

$$I_i = m_i * c_i \times \left(1 + \sum_{j \neq i} \alpha_{ij} * c_j \right)$$

- i is the element of interest, c_i is its concentration and I_i is the measured intensity of the line of i used for the evaluation.
- m_i is the calibration coefficient for the considered line.
- The c_j are the concentration of the other elements.
- α_{ij} is an integral expression that depends on all the concentrations, and that **represents the influence of j on the intensity measured for i** ; it is called «inter-element coefficient» or «**matrix coefficient**».



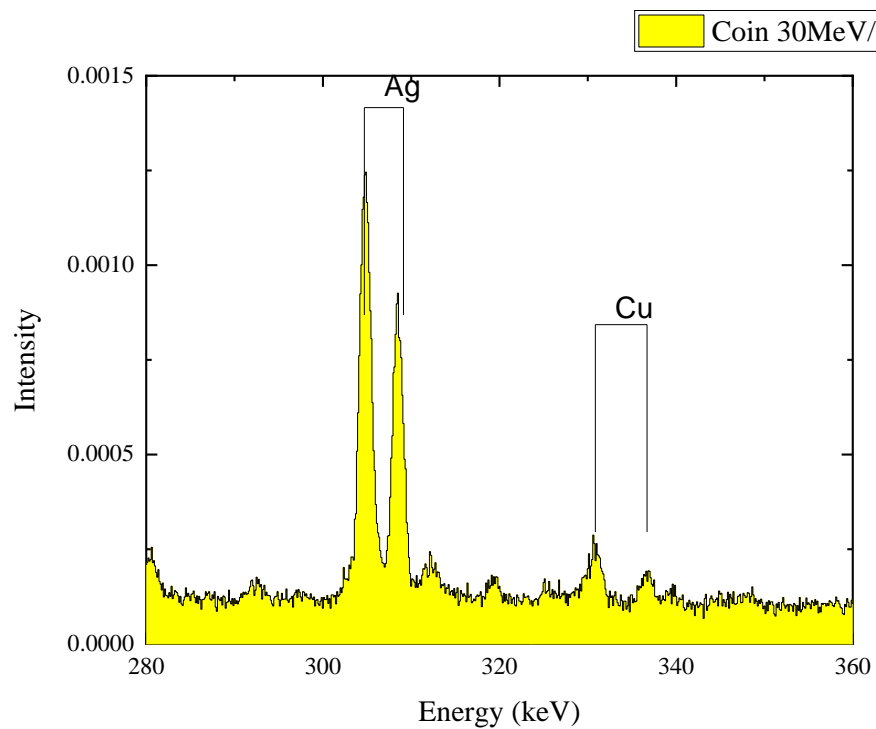
Before Matrix Correction



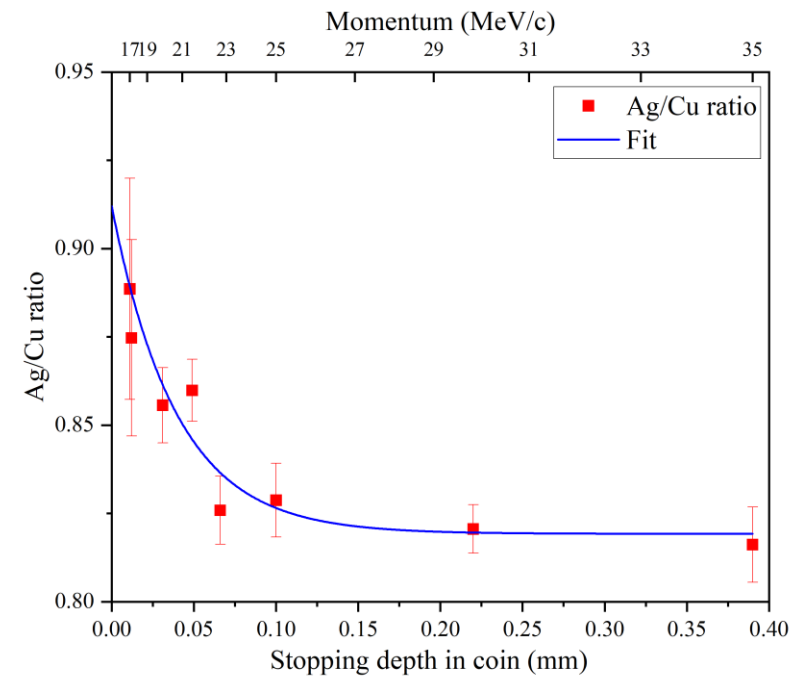
After Matrix Correction

μ XES Measures – Data elaboration

Qualitative analysis and Depth profile



Silver and Copper peak



Depth profile

Results

In Future...

XRF

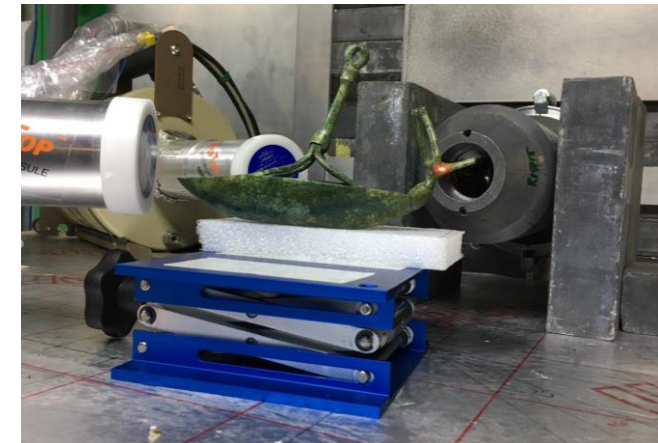
- Qualitative Analysis:
Au, Ag, Cu, Fe, Pb, Sn, Zn
- Quantitative analysis:
 - Excel: without matrix correction



Complete XRF calibration:

- Iron calibration
- Quantitative analysis with EasyCal

Next sample: Nuragic Votive Ship



μXES

- Qualitative analysis:
Ag, Cu, Fe
- Depth profile



Calibration for
quantitative analysis

Thanks for the attention!