Integration and Optimization of the Muon-Induced X-ray Emission Technique at PSI

Xiao Zhao[1], Michael Heiss[1], Francisco Garcia[2], Issa Briki[1] , Gianluca Janka[1] , Maxime Lamotte[1] , Thomas Prokscha[1]

[1]PSI Center for Neutron and Muon Sciences CNM, 5232 Villigen PSI, Switzerland
[2]Helsinki Institute of Physics, University of Helsinki, 00014 Helsinki, Finland

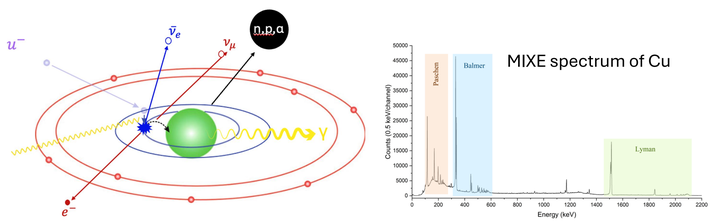
Muon-Induced X-ray Emission

When muons are implanted into the target material:

- Low energy muon is captured by the atom in higher excited states:

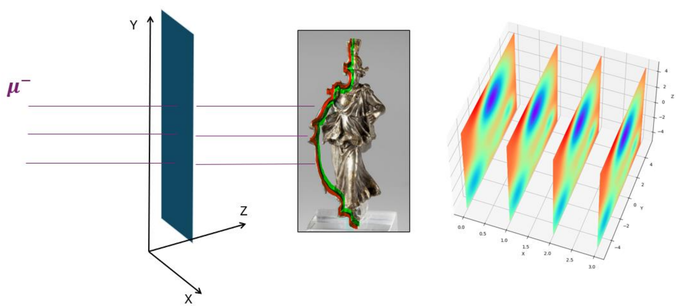
$$n_\mu \approx \sqrt{\frac{m_\mu}{m_e}} \approx 14.$$

- Cascades down to $n_\mu = 1$ while emitting X-rays characteristic to the element / isotope.
- Muon is unstable and decays : $\mu^- \rightarrow e^- + \bar{\nu_e} + \nu_\mu$. or
- Muon is captured by nucleus: : $\mu^- + p \rightarrow \nu_\mu + n$ (+ ~10-20 MeV),
- Nucleus loses excess energy by emitting (some combination of) n, p, α, γ.



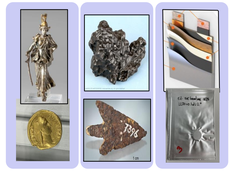
Novel Elemental Analysis Technique

- Non-destructive.
- Depth-resolved from surface to bulk (~ µm to ~ cm).
- Sensitivity to basically all elements (often even isotopes, indication of chemical states).
- Possibility for tomography.

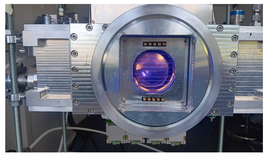


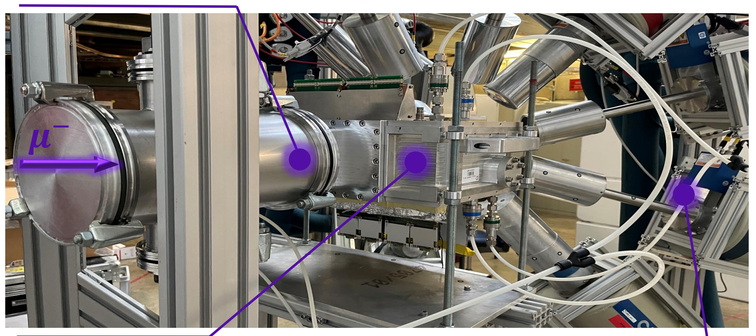
Samples

- Archeological artifacts
- Meteorites
- Batteries



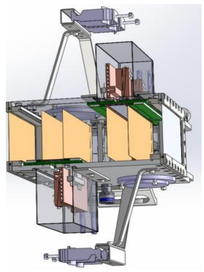
Experimental Setup





Segmented Tagger Detector

- 10 independent segments
- 67x 67mm entrance window
- High repetition rate

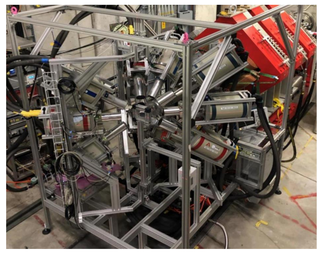


Twin-GEM TPC HGB4

- Precision Tracking and Endpoint Localization.
- Low-material-budget gas mixture (He/CO_2 90:10) to reduce multiple scattering and improve spatial resolution.

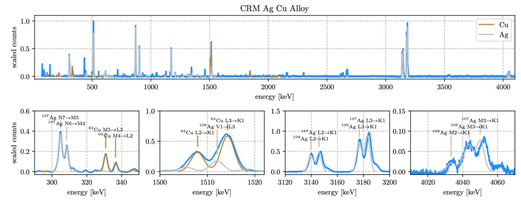
GIANT

- Capture characteristic X-rays and gamma rays to obtain precise elemental spectra.
- Fully automatic LN_2 cooling system.



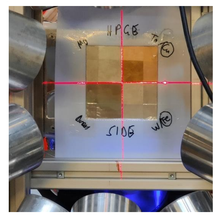
Smart Analysis of MUonic x-Rays with AI

- Software package for fully automated analyses of MIXE spectra.
- Aims to providing online analysis immediate feedback to users.
- Based on cutting-edge, efficient AI methods for rapid results.

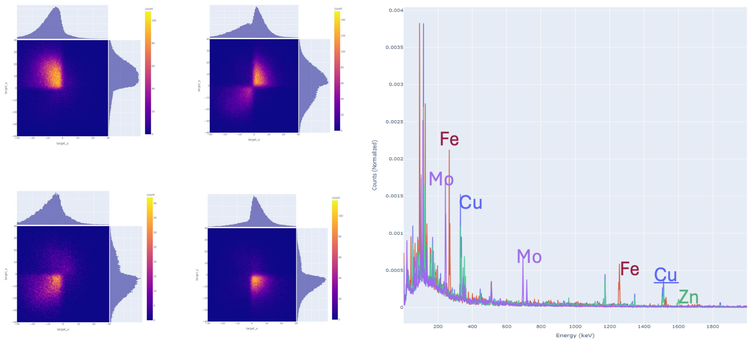


Elemental Imaging

A layered sandwich sample is used to obtain the spatial resolution of elemental imaging of MIXE-Tomography.



- Resolution @60 MeV/c (Ar/CO2 75:25 gas)
- X : 1.083 ± 0.113 mm
- Y : 1.357 ± 0.172 mm
- Mainly due to the multiple scattering effect in air and materials.
- Lower density gas He/CO2 90:10 used in 2024 MIXE campaign.



References

[1] K. Nagamine, Cambridge University Press, 2003.
[2] L. Gerchow et al., Review of Scientific Instruments, 2023, 94, 1089-7623.
[3] F. García et al., NIM-A, 2018, 884, 18-24.