

PAUL SCHERRER INSTITUT



Alex Amato :: Paul Scherrer Institute

# Sinergia Deepμ Project: Status and Perspective

MIXE mid-term meeting, 05.12.2022, Blue City Hotel -- Baden

# Some history...

- **First basic tests in 2018:** (Alex, Hubertus, MuX collab.)
- **March 2019:**  
First discussions (Alex, Arndt, Lilian and Beda).
- **June 2019:**  
First proposal submitted on 6<sup>th</sup> June: *DEEPμ: A non-destructive and depth resolved element analysis technique using elementary particles -- development and applications*  
→ **July 2019:** “Nicht eintreten” (administrative) decision
- **December 2019:**  
Second version with Markus Peter as PI for Augusta Raurica.
- **June 2020:**  
Acceptance by the SNSF → 1.459 MCHF awarded (minor cut of 100 kCHF)  
New budget accordingly
- **September 2020:**
  - Official start of the project (01.09)
  - Kick-off Meeting (03.09, Zoom)
  - Hiring campaigns

## Kickoff Meeting September 3, 2020

### Tentative Program:

09:30	--	09:40	<i>Welcome and short presentation of the participants</i>	<b>All</b>
09:40	--	09:55	<i>Administrativ and Management Matter</i>	<b>Alex Amato</b>
09:55	--	10:05	<i>Presentation of the "external" partners (LTP/PSI and Osaka)</i>	<b>Alex Amato</b>
10:05	--	10:50	<i>Presentation of the technique and first results</i>	<b>PSI</b>
10:50	--	11:05	<i>Presentation of the Project by Augusta Raurica</i>	<b>Markus Peter</b>
11:05	--	11:20	<i>Presentation of the Project by EMPA</i>	<b>Arndt Remhof</b>
11:20	--	11:35	<i>Presentation of the Project by Uni Bern</i>	<b>Beda Hofmann</b>
11:35	--	12:15	<i>Discussion + beamtime 2019</i>	<b>All</b>

# People working for the project

## **Funded by project:**

- Ryo Asakura (PhD student and after Postdoc, Empa, 01.09.2020 → 31.03.2022)
- Isabel Megatli (PhD student, Augusta Raurica, 01.01.2021 → ...)
- Lars Gerschow (Postdoc, PSI, 18.01.2021 → 31.03.2021, 60%)
- Sayani Biswas (Postdoc, PSI, 01.02.2021 → ...)
- Edouard Querel (Postdoc, Empa, 01.05.2022 → ...)

## **Not funded by project (but 100% involved):**

- Lars Gerschow (Postdoc, PSI, 01.04.2021 → 31.07.2022, 60% and later 100%)
- Carlos Vigo (Postdoc, PSI, 01.02.2022 → 30.06.2022, 60%)
- Gianluca Janka (Postdoc, PSI, 01.08.2022 → 31.12.2022, 100%)
- Michael Heiss (Postdoc, PSI, 01.12.2022 → 30.11.2022, 100%)
- Cong Chen (PhD student, IHEP and PSI, 01.12.2022 → 30.11.2022, 100%)

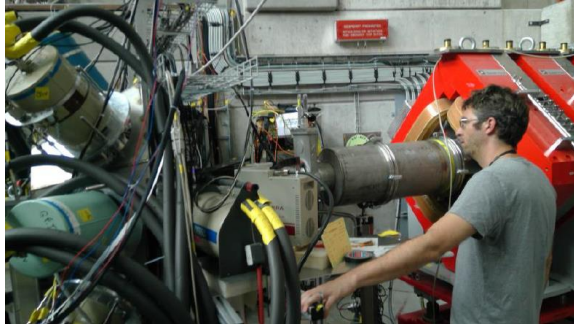
# Some achievements

## Instrument

MuX instrument(s) parasitic mode → “shaky” setup → GIANT → **Talk of Gianluca**

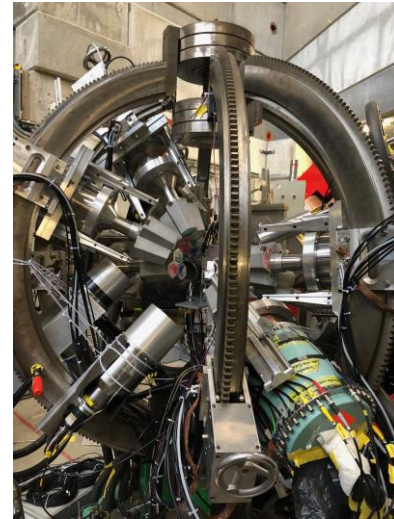
## Campaigns

**2018:** July: First quick tests using MuX setups (MuX collab. Detectors)



**2019:** November: Tests + Measurements using MuX setup (CERN detectors)

- Bronze standard, Coins, Fibula,



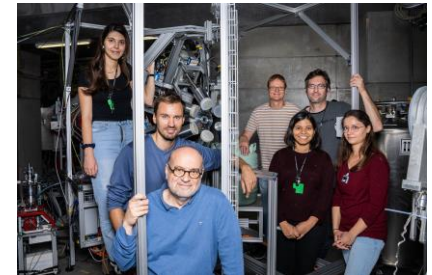
# Some achievements

**2020:** November: Tests + Measurements with “shaky” setup...

- Menorah ring, coins, chemical compounds, lead isotopes, meteorites, battery

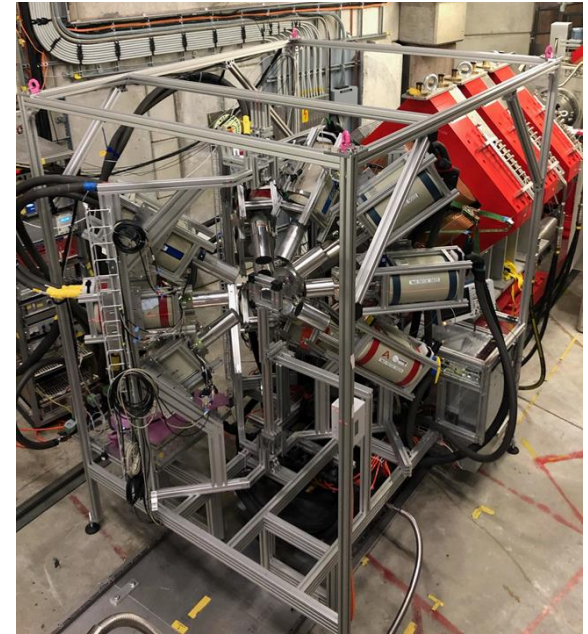
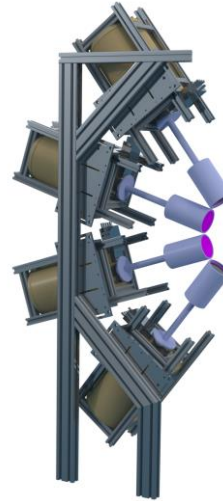
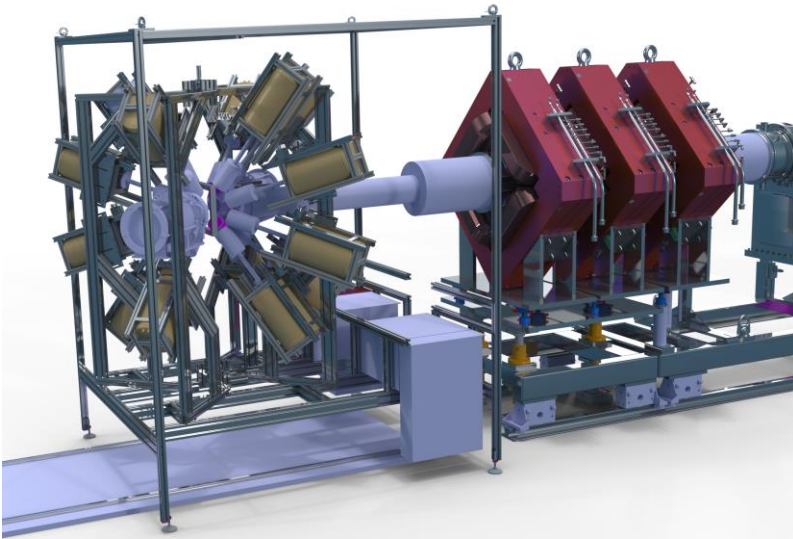


**2021:** October + December: First measurements with GIANT Findings, Battery,



# Some achievements

**2022:** May + August-September: GIANT with even more detectors  
Real “production”... Also sample from ANAXAM, Geneva, etc...



Our setup also used by particle physicists → synergies...

# Some achievements

## **Between campaigns:**

- Improvement of the hardware
  - Analysis
  - User “friendliness” of the experimental control and analysis
  - Publications + conferences
  - Start of simulations
  - Write proposals for additional funding...
- 
- **Tests to use another beamline →  $\mu$ E1 (see also work related to tasks of Cong)**



## Outreach (Publications + Conferences):

- **Publication:**

1. *Characterization of a Continuous Muon Source for the Non-Destructive and Depth-Selective Elemental Composition Analysis by Muon Induced X- and Gamma-rays*, S. Biswas et al., *Applied Sciences*, **12**, 2541–2541 (2022).
2. *Thermal and Electrochemical Interface Compatibility of a Hydroborate Solid Electrolyte with 3 V-Class Cathodes for All-Solid-State Sodium Batteries*, R. Asakura et al., *ACS Applied Materials & Interfaces*, **13**, 55319–55328 (2021).
3. *Germanium Array for Non-destructive Testing (GIANT) setup for Muon Induced X-ray Emission (MIXE) at the Paul Scherrer Institute*, L. Gerchow et al., <https://arxiv.org/abs/2210.16161>, submitted to *Rev. Scientific Instr.* (2022).
4. *The non-destructive investigation of a late antique knob bow fibula (Bügelknopffibel) from Kaiseraugst/CH using Muon Induced X-ray Emission (MIXE)*, S. Biswas et al., submitted to *Heritage Science* (2022).
5. *An arrowhead made of meteoritic iron from the Late Bronze age settlement of Mörigen, Switzerland and its possible source*, B. A. Hofmann et al., under preparation (2023).
6. *Battery...*, S. Biswas et al., under preparation (2023).
7. ...

## Outreach (Publications + Conferences):

- **Conferences + Seminars:**
- **20th Swiss Geoscience Meeting**, 2022, Lausanne, CH  
Talk, Applied physics research with Muon-Induced X-Ray Emission (MIXE) at PSI
- **7th ARCH RNT Symposium (Archaeological Research & New Technologies)**, 2022, Kalamata, Greece  
Poster: Precious Metals from Augusta Raurica – Archaeological and archaeometrical investigations using non-invasive X-rays
- **28th Annual Meeting of the European Association of Archaeologists (EAA)**, 2022, Budapest, Hungary  
Poster: Precious Metals from Augusta Raurica – Archaeological and archaeometrical investigations using non-invasive X-rays
- **15 International Conference on Muon Spin Rotation, Relaxation and Resonance**, 2022, Parma, Italy  
Talk: Muon-Induced X-ray Emission (MIXE) at PSI
- **Seminar at the KTH (Sweden)**, 2022, Stockholm, Sweden  
Talk: Use of muons to investigate materials: Not only  $\mu$ SR..., but also the Muon-Induced X-ray Emission (MIXE) Technique
- **KEK – PSI Workshop on Muon and Neutron related Technologies and Research**, 2022, PSI, CH  
Talk: Negative Muons (PSI) -- MIXE
- **PSI Seminar – LMX**, 2022, PSI, CH  
Talk: Muon-Induced X-ray Emission Technique: Non-destructive and depth-sensitive technique for elemental analysis
- **Jahresversammlung Arbeitsgemeinschaft für die Provinzialrömische Forschung in der Schweiz (ARS)**, 2021, Fribourg, CH  
Talk: Métaux précieux à Augusta Raurica – Les investigations archéologiques et archéométriques
- **Master- und Doktorandenkolloquium**, 2021, Köln, Germany  
Talk: Tiefe Einblicke in römerzeitliches Metallhandwerk – Annäherungen an die Myon-Röntgenfluoreszenzanalyse am Beispiel Augusta Rauricas

# Some achievements

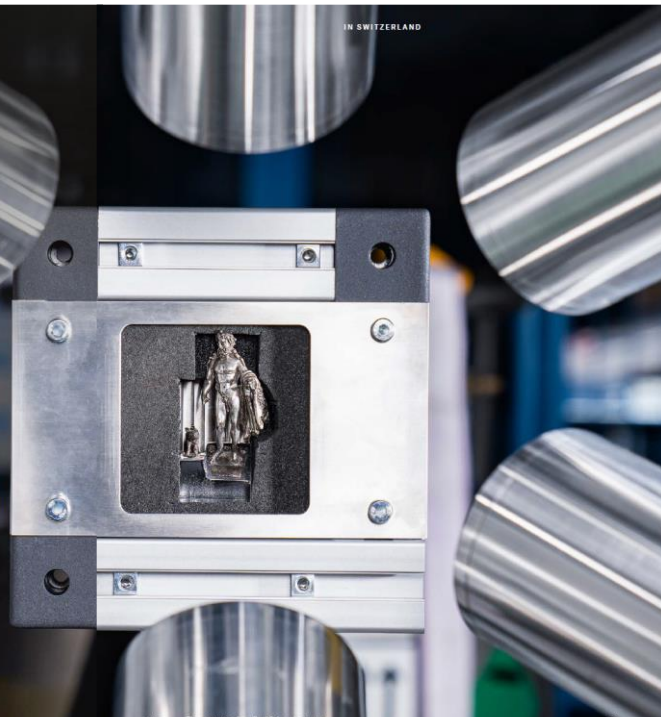
## Outreach (Publications + Conferences):

- **Broader Public:**
- **5232 PSI Publication**

## Hercules and batteries, X-rayed

For ancient artefacts and modern technologies alike, examination methods that leave the object completely intact are required. For this, researchers at PSI use elementary particles called muons and are developing a new experimental method that is useful for archaeology and can also answer questions relevant to battery development.

Text: Barbara Vonarburg



Placed in cut-to-fit foam: A six-centimetre-tall silver statuette of the Greek hero Hercules, accompanied by a mythological bear, waits to be examined with muons.

By hand, two researchers are putting the final touches on preparations to transport a measuring instrument. For security, the apparatus – developed and assembled by a research group at PSI over the past ten months – is framed by a set of rods roughly two and a half metres high. “This instrument will enable us to non-invasively determine the chemical composition of a sample,” explains Lars Gerchow, who was responsible for designing it. For this, the researchers will need special elementary particles called muons.

Gerchow, his colleague Sayani Biswas, and others lending a helping hand are in the large hall housing PSI’s muon source. Muons are naturally occurring elementary particles that are pervasive as part of cosmic radiation. “On average, a muon rains down on us every second,” the physicist explains. Nevertheless, at PSI these particles are generated artificially with the help of a large accelerator.

The measuring instrument is ready to be moved to its intended place – a delicate task that requires an indoor crane. The crane operator receives instructions from the ground by radio, and then the instrument is hoisted aloft.

### Gold and silver from a Roman settlement

In the control room, from which the physicists will monitor the muon experiment, archaeologist Isabel Megatli is making the final preparations for her mis-

“We were able to show that Minerva and Hercules are made of a high-quality silver alloy.”

Isabel Megatli, research associate at the Roman settlement of Augusta Raurica.

determine which mine was the source of the metal ores used. “And we can also expose counterfeiters,” Megatli says, “as aluminium, for example, has only been processed since the 19<sup>th</sup> century.”

### Fingerprint of the elements

Physicist Sayani Biswas explains how the experiment will work. “We have a sample, and we send negatively charged muons to it.” An atom in the sample captures a muon. Now, in place of an electron, a muon is orbiting the atom’s nucleus. At first it is in an excited state, and then it falls stepwise to its ground state. In the process, X-rays are emitted. The energy of this radiation is characteristic for the type of atom. In other words, the element that has

Science-Switzerland  
8,950 followers  
View full page

**#Muons | Non-Destructive Method to Determine Chemical Composition of Samples** | A team of researchers from the Paul Scherrer Institut PSI, the Roman settlement of Augusta Raurica, Empa, and the Naturhistorisches Museum Bern, with financial support from the SNSF Swiss National Science Foundation, recently developed a new experimental method, which makes it possible to non-invasively determine the chemical composition of a given sample with the help of elementary particles called muons.

To achieve this, physicist Sayani Biswas explains that they begin by sending negatively charged muons to a sample, where they are subsequently captured by atoms. There, the muons progressively fall from an excited state to their ground state as they orbit the nucleus of their respective atom, while simultaneously emitting X-rays, whose energy is characteristic for the type of atom – in other words, the element that has captured the muon. This in turn enables the team to determine the elementary composition of materials deep inside the sample.

Using this method, the team were not only able to examine precious gold and silver objects that were excavated in Augusta Raurica – one of the most important Roman sites in Switzerland – but also to investigate how a lithium-ion battery ages through use, thereby highlighting the exciting potential of this novel method for the study of ancient artefacts and modern technologies alike.

**Promoted**

- Tenable Exposure Platform**  
Know the cyber exposure of every asset on any platform.
- Year-end crunch? Find 2022 closing with talent on Upwork who are eager to help you succeed.
- HBS EDUCATION**  
In-person and virtual. Sharpen your leadership skills and advance your career. Learn more.

**Similar pages**

- SNSF Swiss National Science Foundation**  
Research  
201-500 employees  
+ Follow
- Swissnex**  
International Affairs  
51-200 employees  
+ Follow

- **SNF has a long backlog ...**  
Our Financial report of September 2021 still not looked at...
- **Everything seems to be under control...**
- **Rest of PSI budget:**
  - possibility to have a muon tracking device
  - additional detectors
- **Additional funding obtained so far**
  - Strategic focus areas – ETH Board: “Advanced Manufacturing”: 70 kCHF
  - PSI NUM+LMU: about 50 kCHF

**My thanks go to**

All of you + Lilian +  
Lars + Carlos

