PAUL SCHERRER INSTITUT

PSI

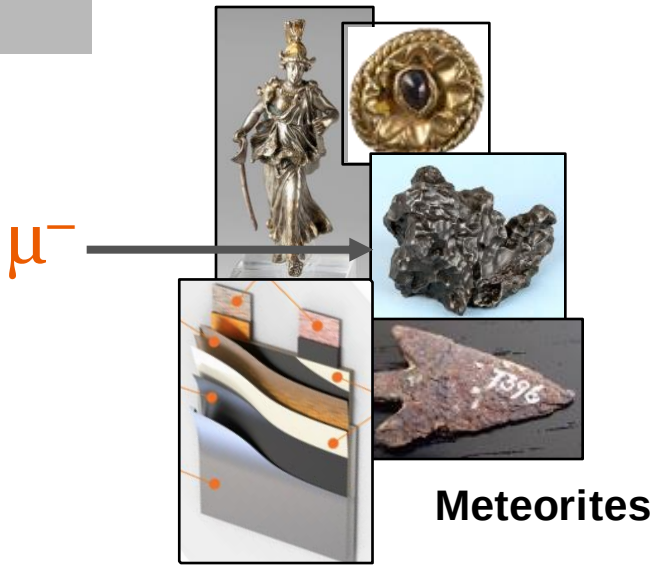
Michael Heiss :: MIXE :: Paul Scherrer Institute

MIXE @ PSI:
Measurement System Overview and New Developments

BRIDGE2023, 19.10.2023

MIXE: Muon Induced X-ray Emission

Archeological artifacts



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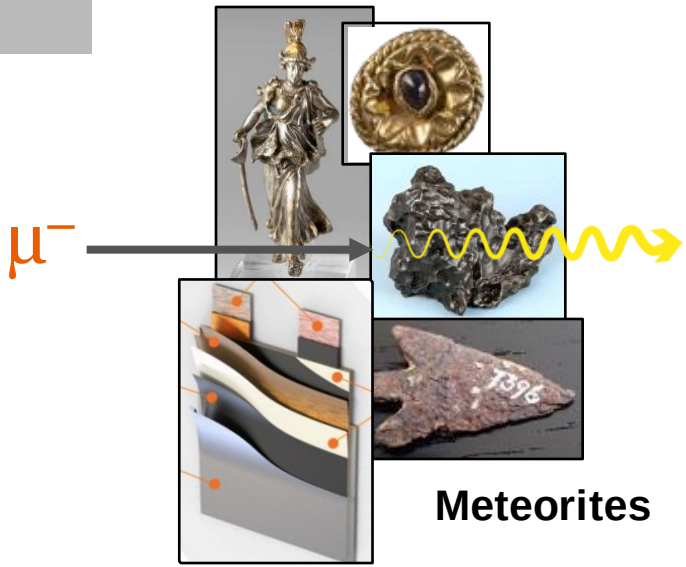

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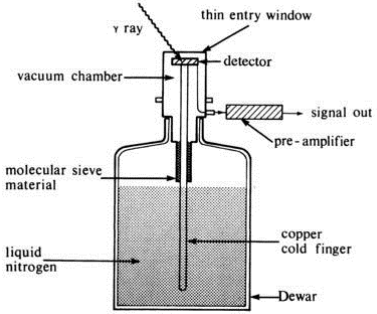
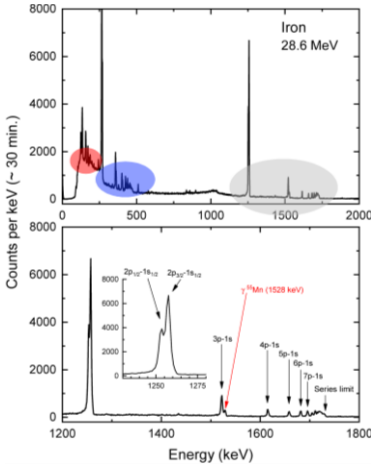


High Purity Germanium Detectors



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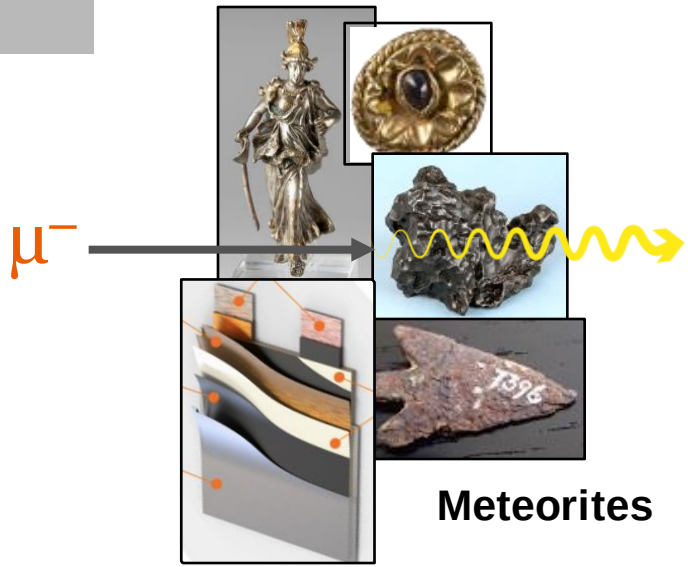

μ^-

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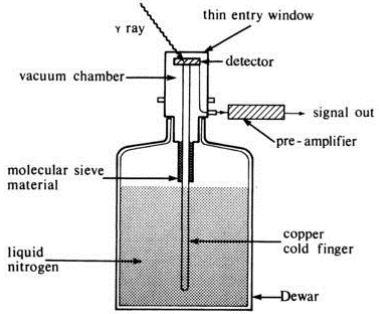

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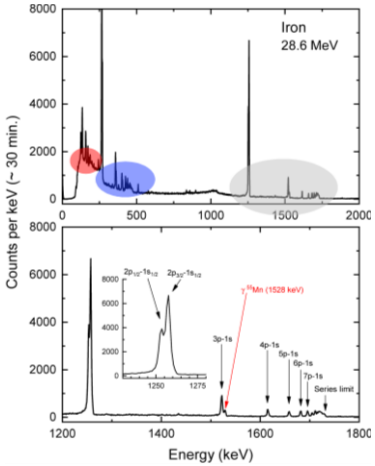

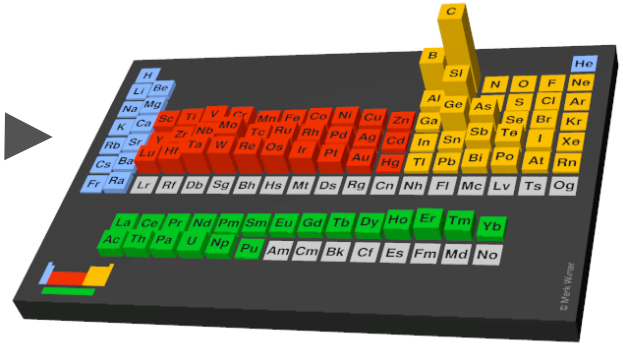

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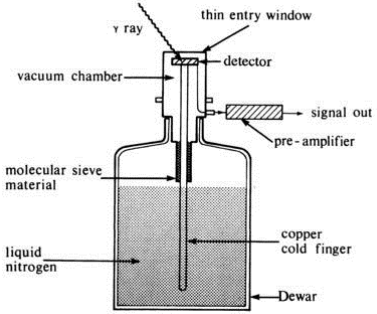

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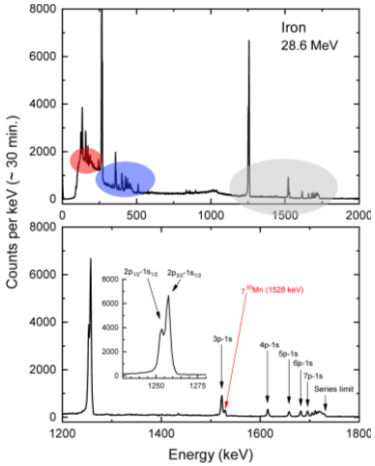

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see poster by S. Biswas

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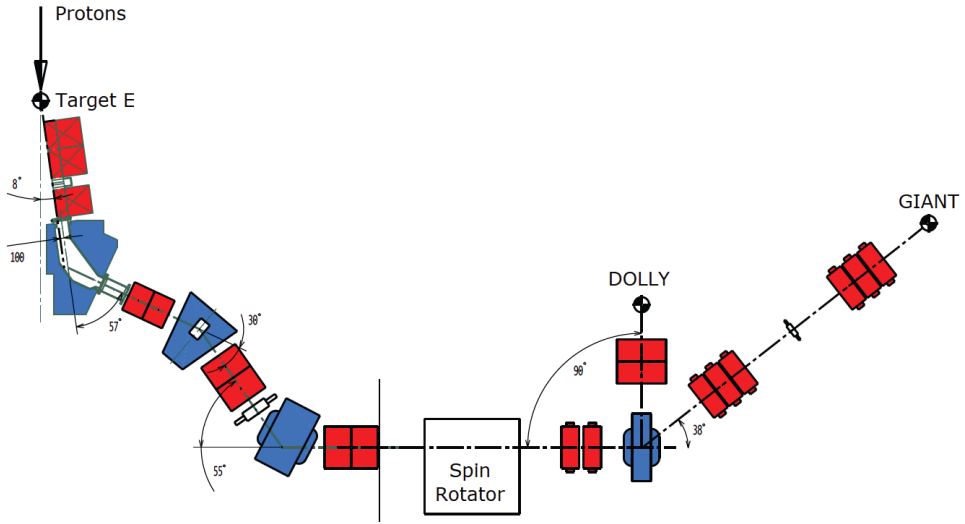
Overview:
MIXE Experimental Setup

MIXE at beamline πE1

- High intensity π beamline at target E
  - cloud μ^- from π^- decay
  - Typical μ^- momenta: 15-60 MeV/c



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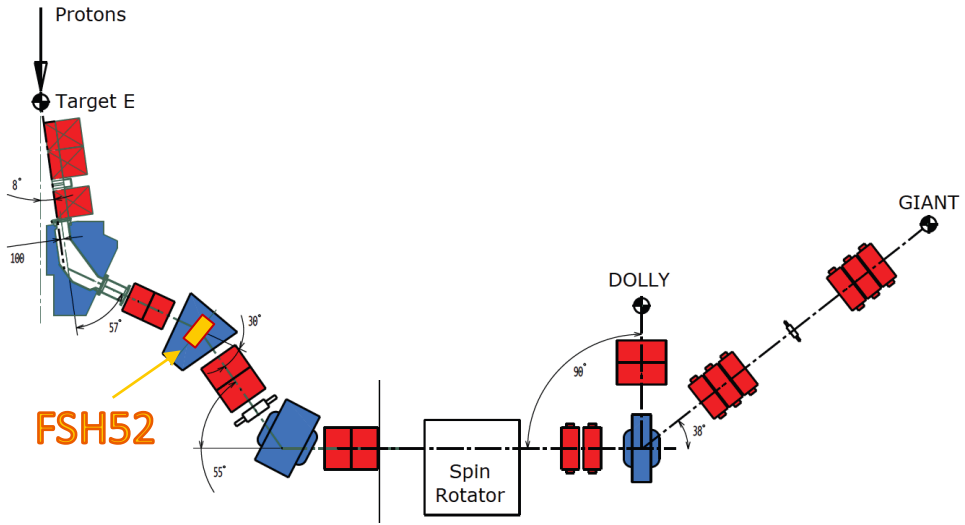

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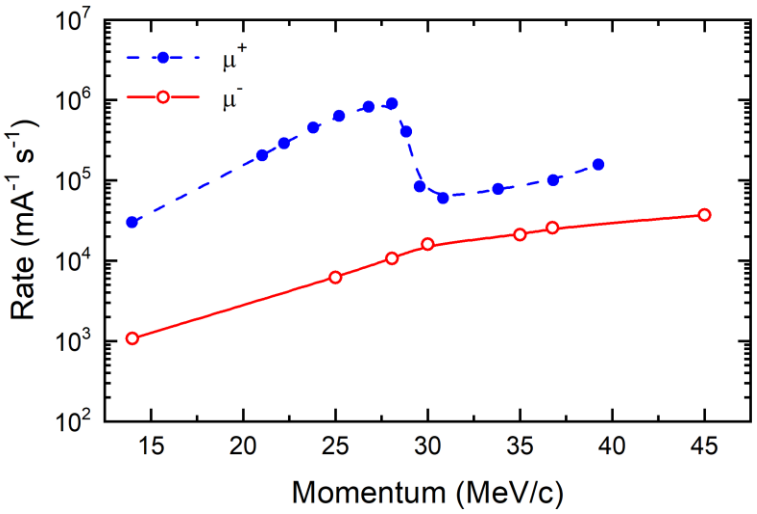

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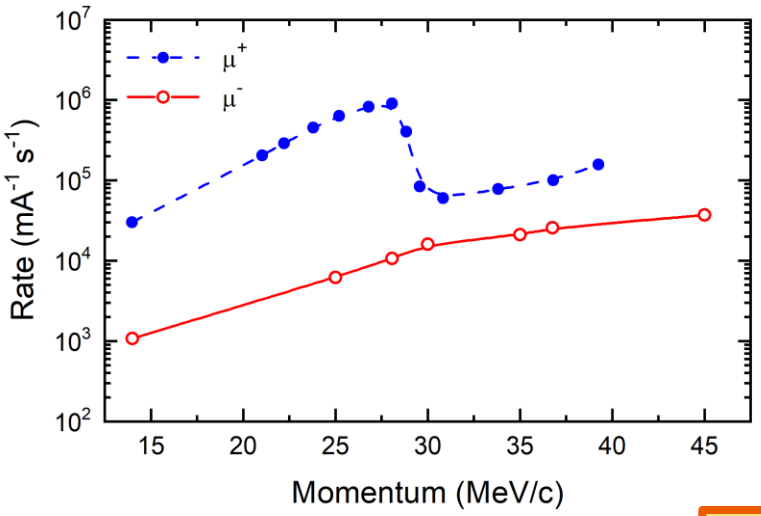

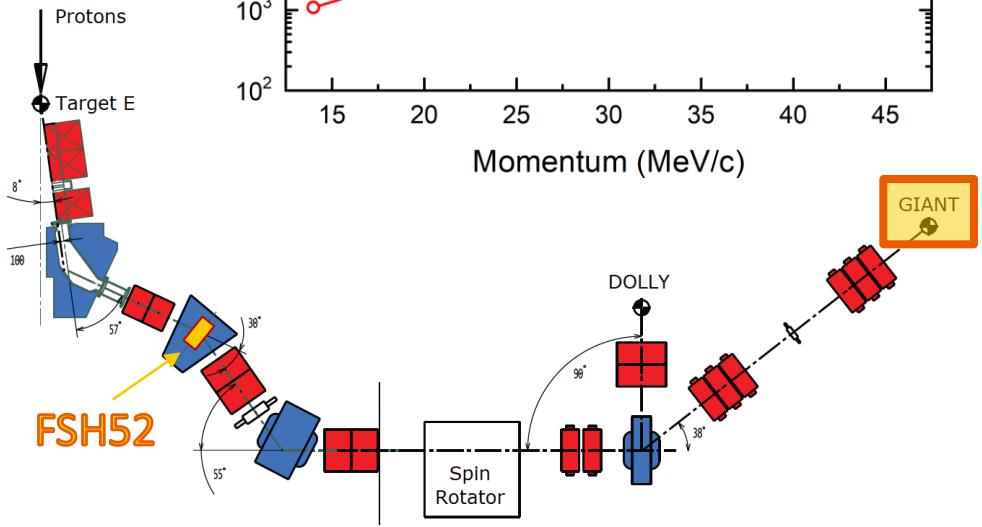

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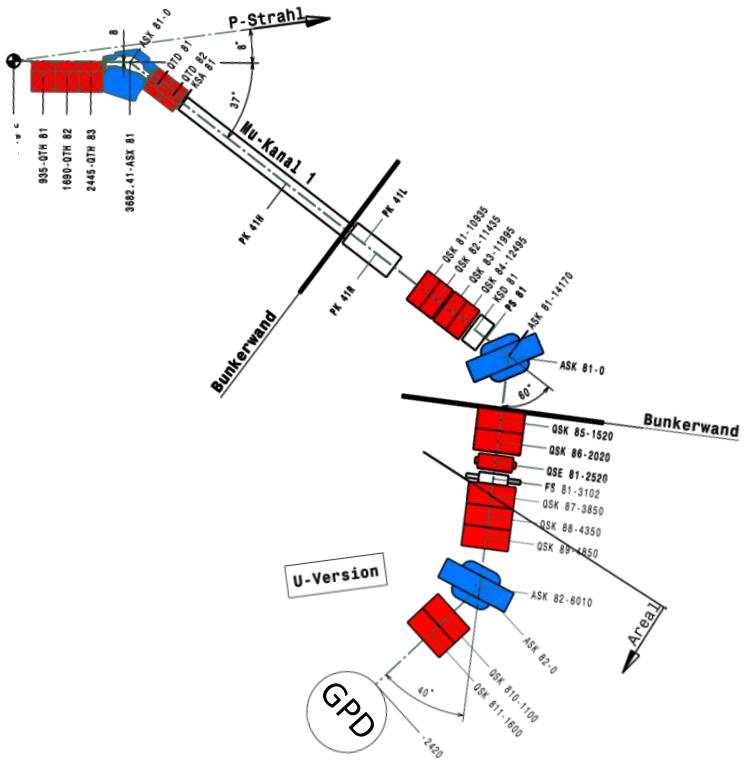
- All past MIXE campaigns hosted at πE1.2
  - non-permanent installation
  - approx. 3 weeks beam time per year

Future: MIXE at beamline μE1?



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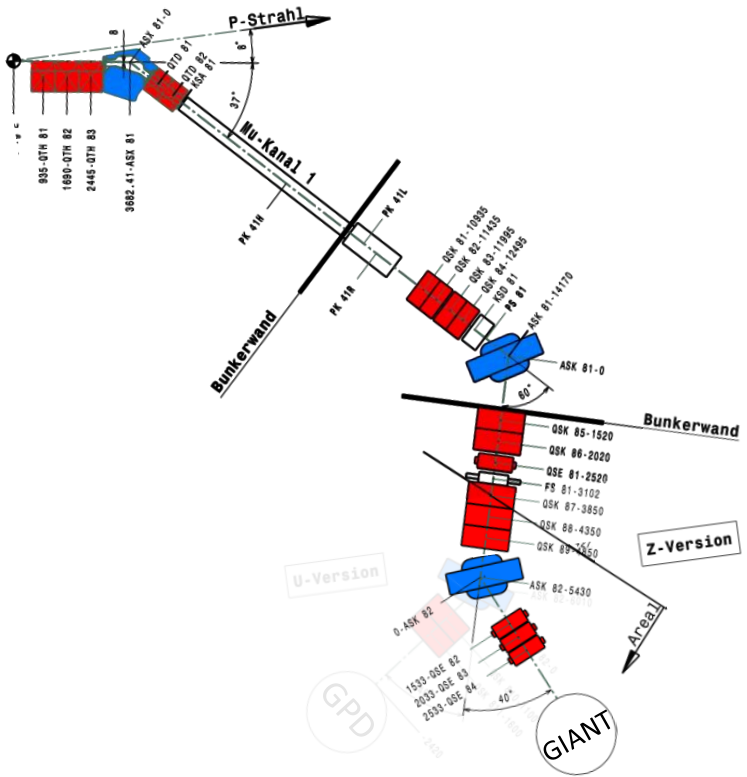

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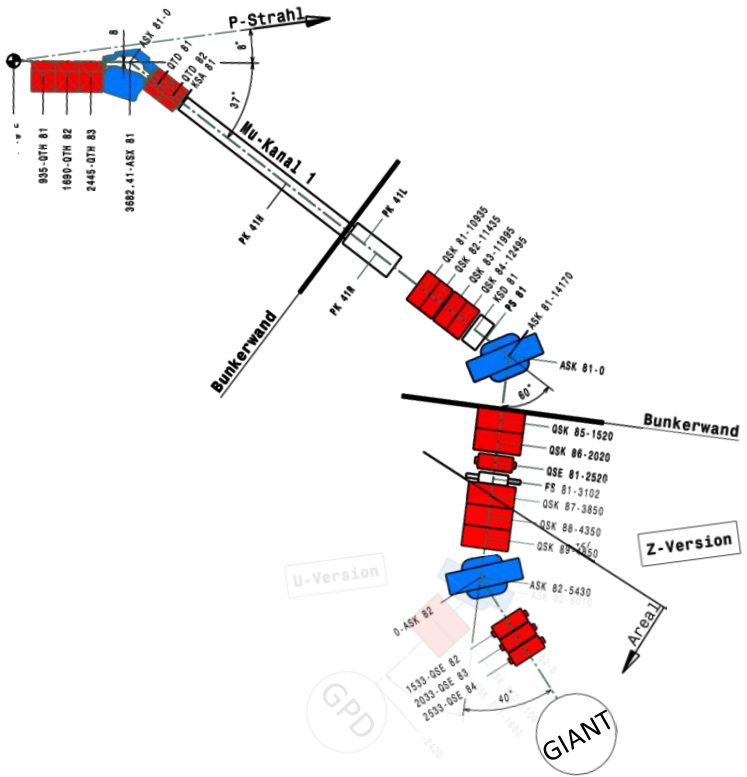

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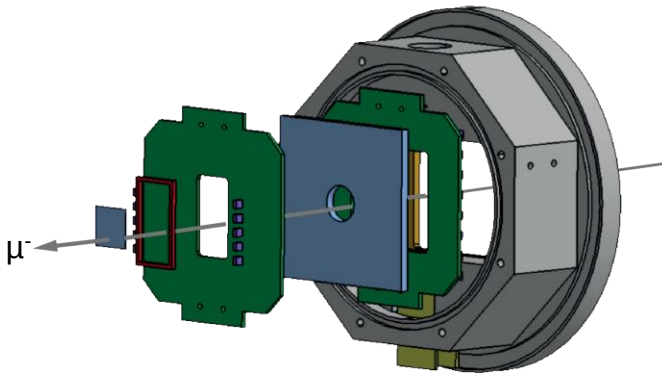
- Preliminary beam simulations very promising
- Low momenta require warm-bore magnet
  - *represents quite significant investment*
  - would introduce new capabilities for studies much closer to surface

Muon Tagging & Beam Port

- Tagging Detector (developed for muX experiment)
  - reduces uncorrelated BKG
  - allows for discrimination of nuclear capture events
  - BC-400 plastic scintillators (Counter and Veto)
  - SiPM readout using custom electronics



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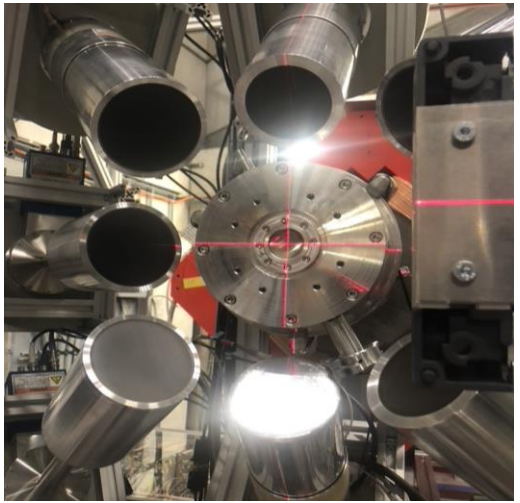
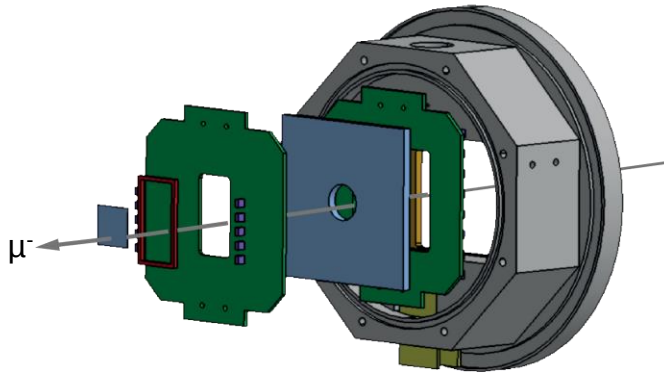
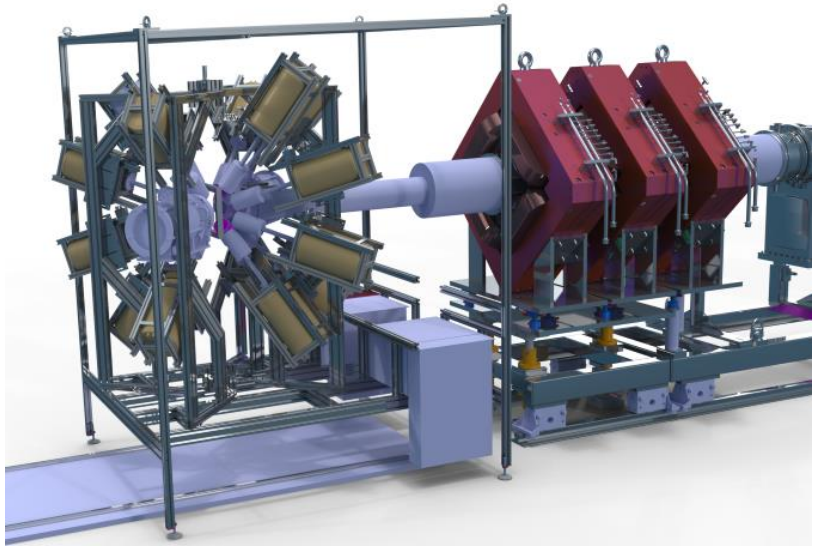




- Beam Port
  - 10μm titanium foil window
  - beam extraction to sample in air
    - approx. 10 cm distance
  - system of collimators available for sample spot measurements

The GIANT Setup – Hardware Design



GIANT

German**I**um **A**rray for **N**on-destructive **T**esting

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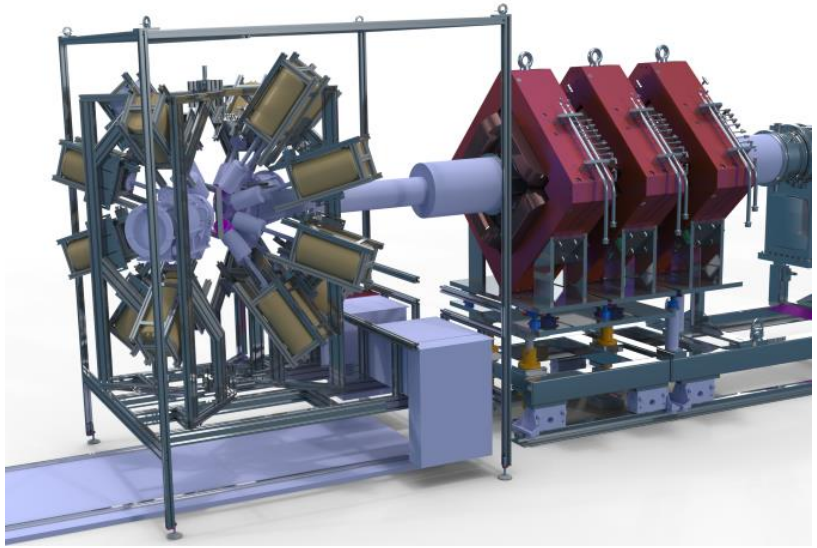

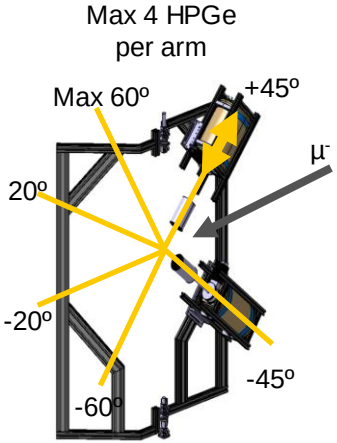

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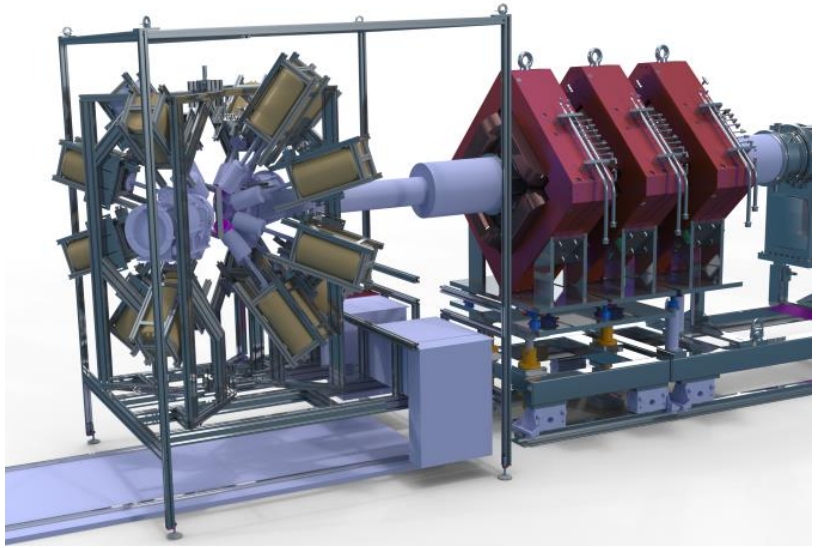

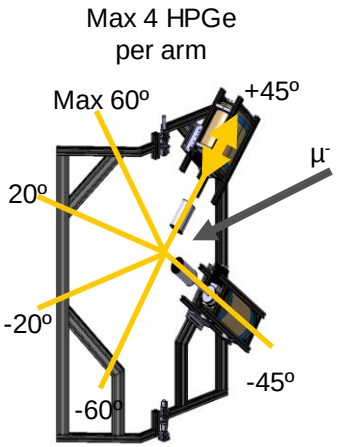

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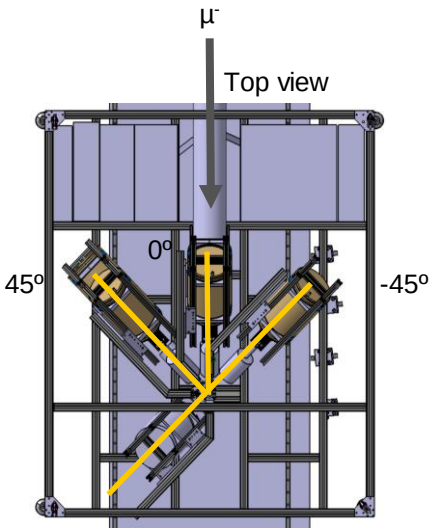

Continuous 0º - 340º

Min Step 35º

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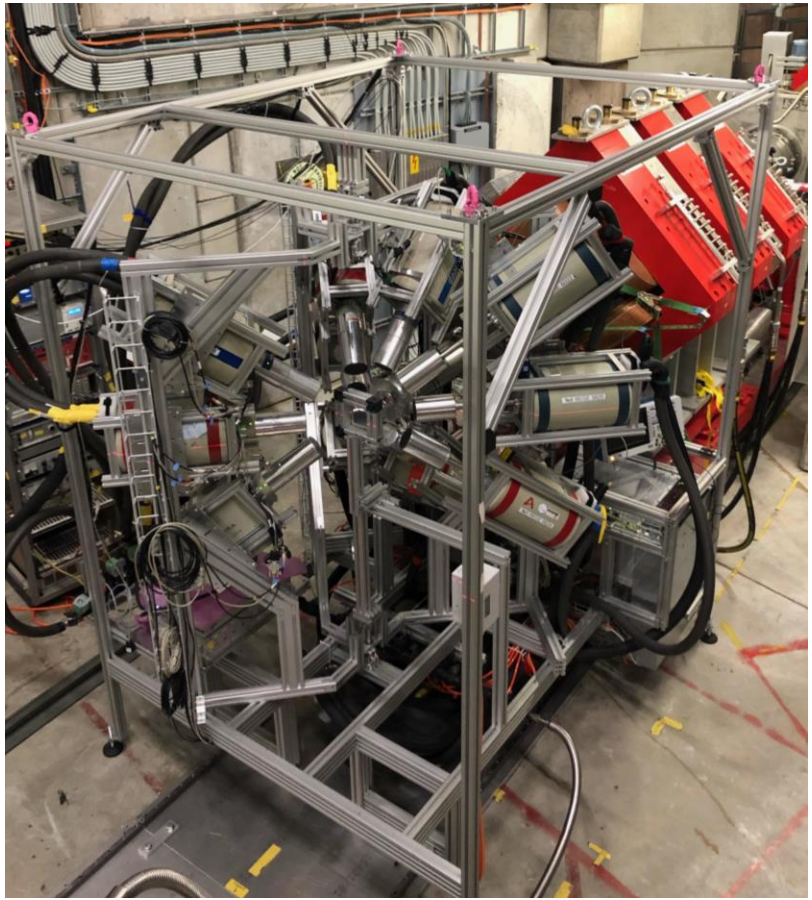

- (Nearly) complete setup
  - 8 freely rotating arms (currently 5)
  - 4 BigMac HPGe per arm
  - up to 30 HPGe detectors
    - currently ~12 detectors
  - shared between multiple experiments

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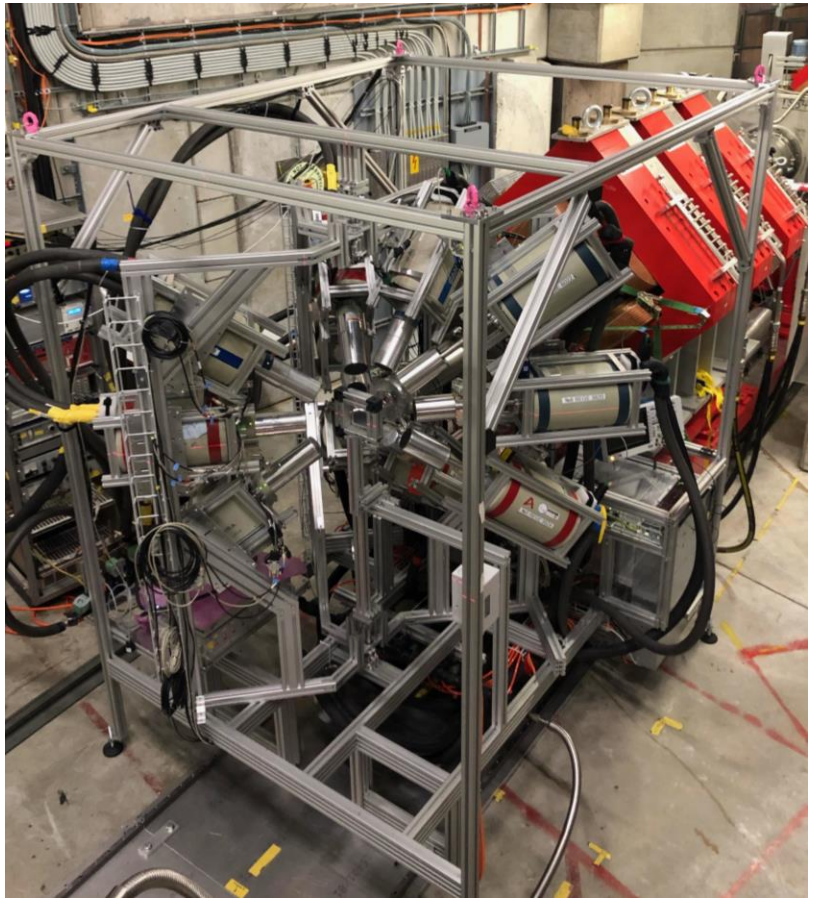

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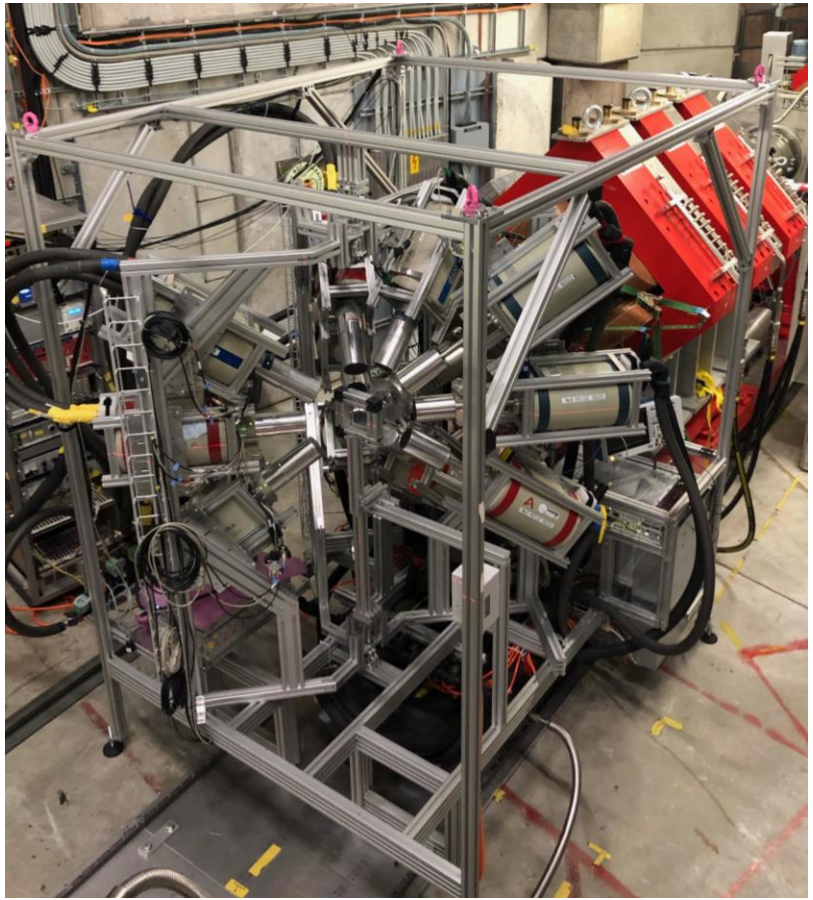

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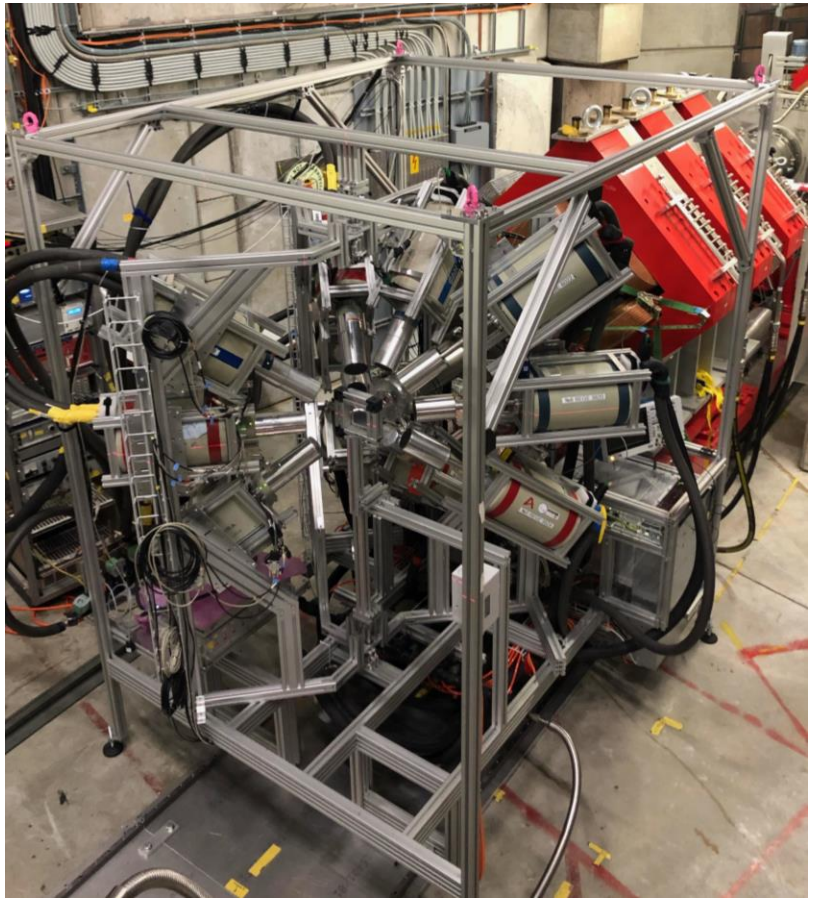

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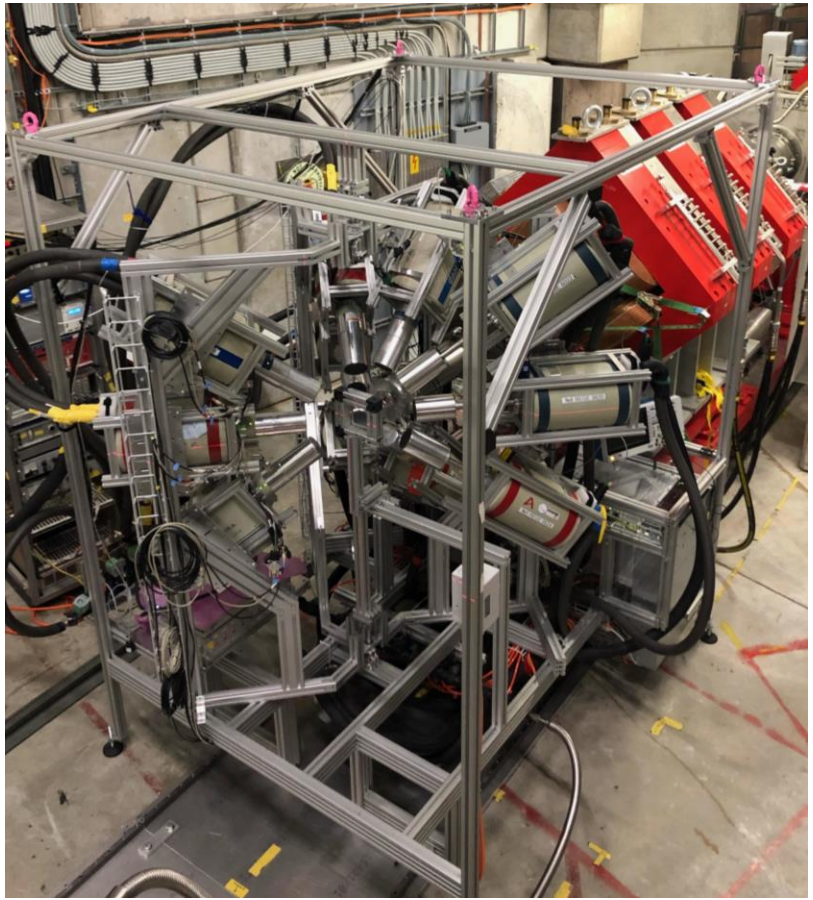

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- Sample station twin in control room
  - Mounting & Alignment “prefab”
  - Roughly 5 min sample change

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  - multiple devices chainable (external clock available)

New Developments: Towards MIXE Tomography

Characterization of Beam Spot

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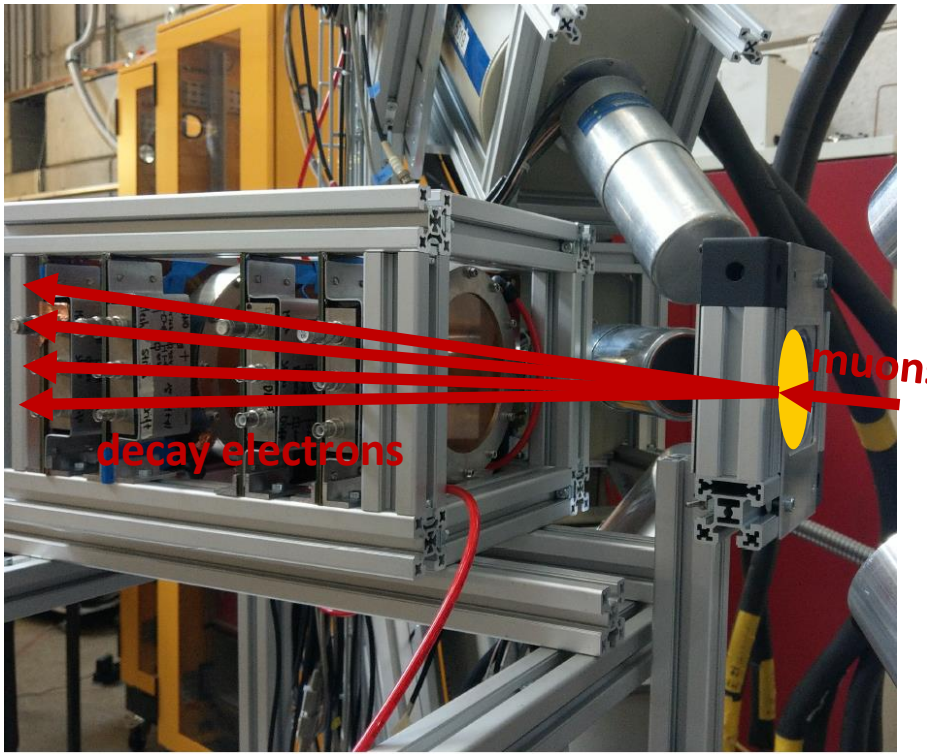

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Momentum (MeV/c)	σ_x (mm)	σ_y (mm)
25	22.06(18)	23.54(18)
33	17.52(3)	18.07(3)
35	16.55(3)	17.24(3)
45	14.45(6)	14.34(6)

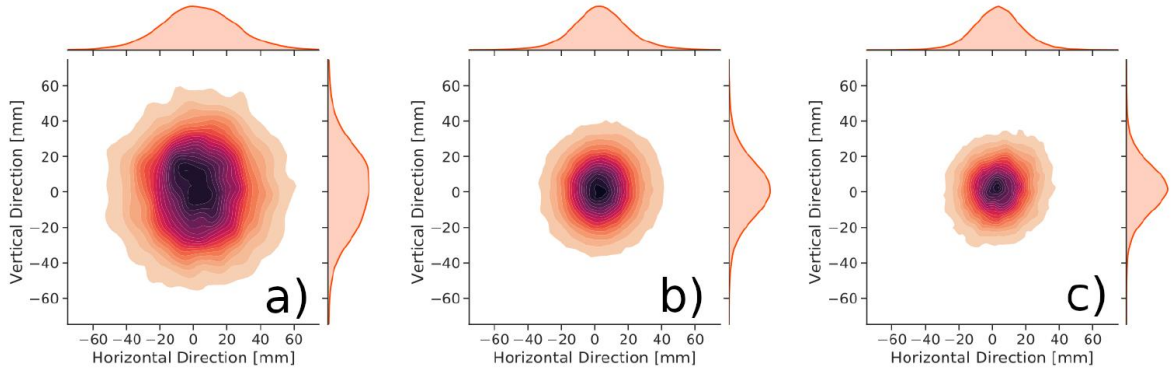
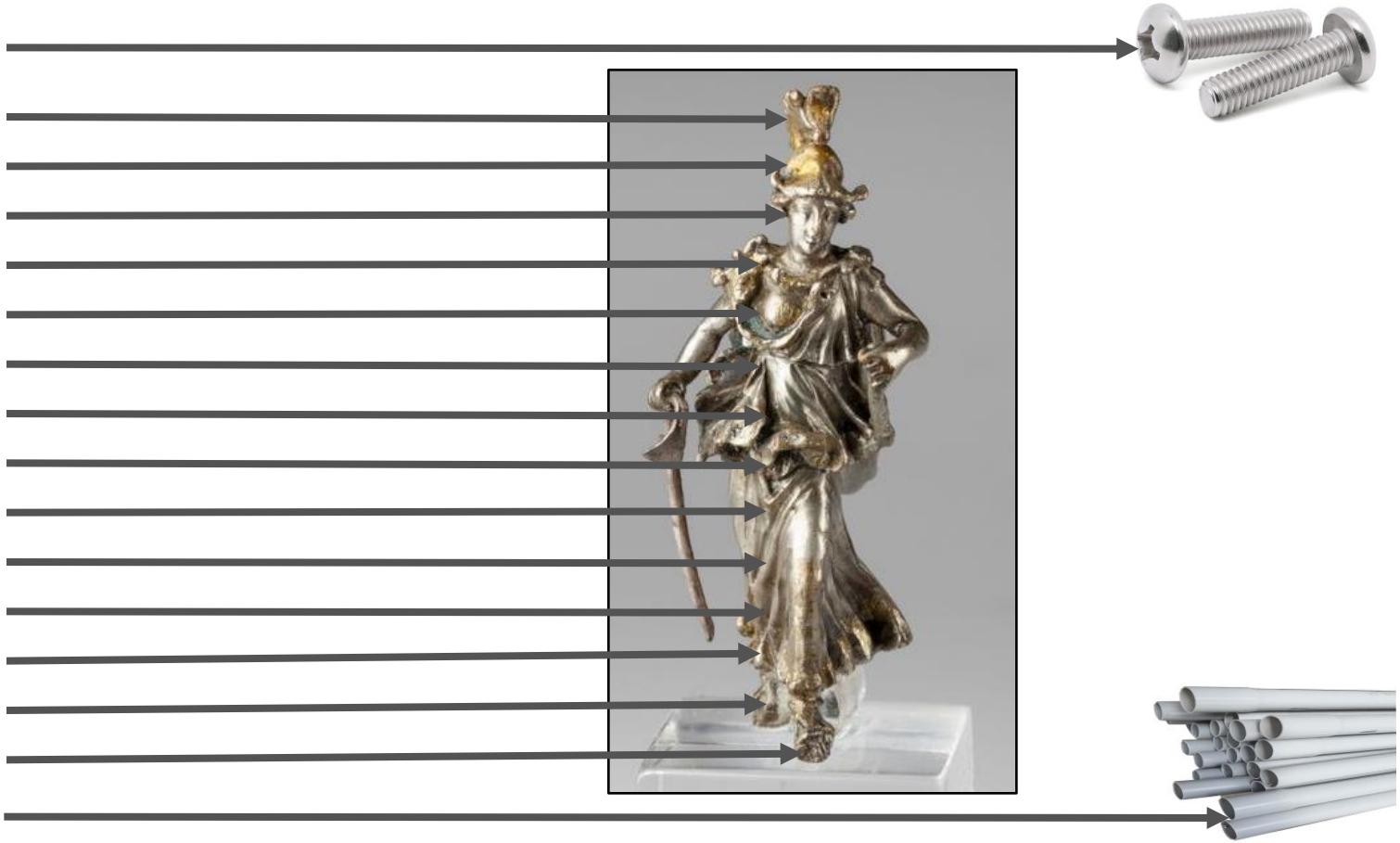


Figure 5: Beam spots on target during the MIXE campaign in 2022 May in πE1 for different momenta: (a) 25 MeV/c, (b) 35 MeV/c and (c) 45 MeV/c .

Tracking for MIXE – Motivation

μ^-



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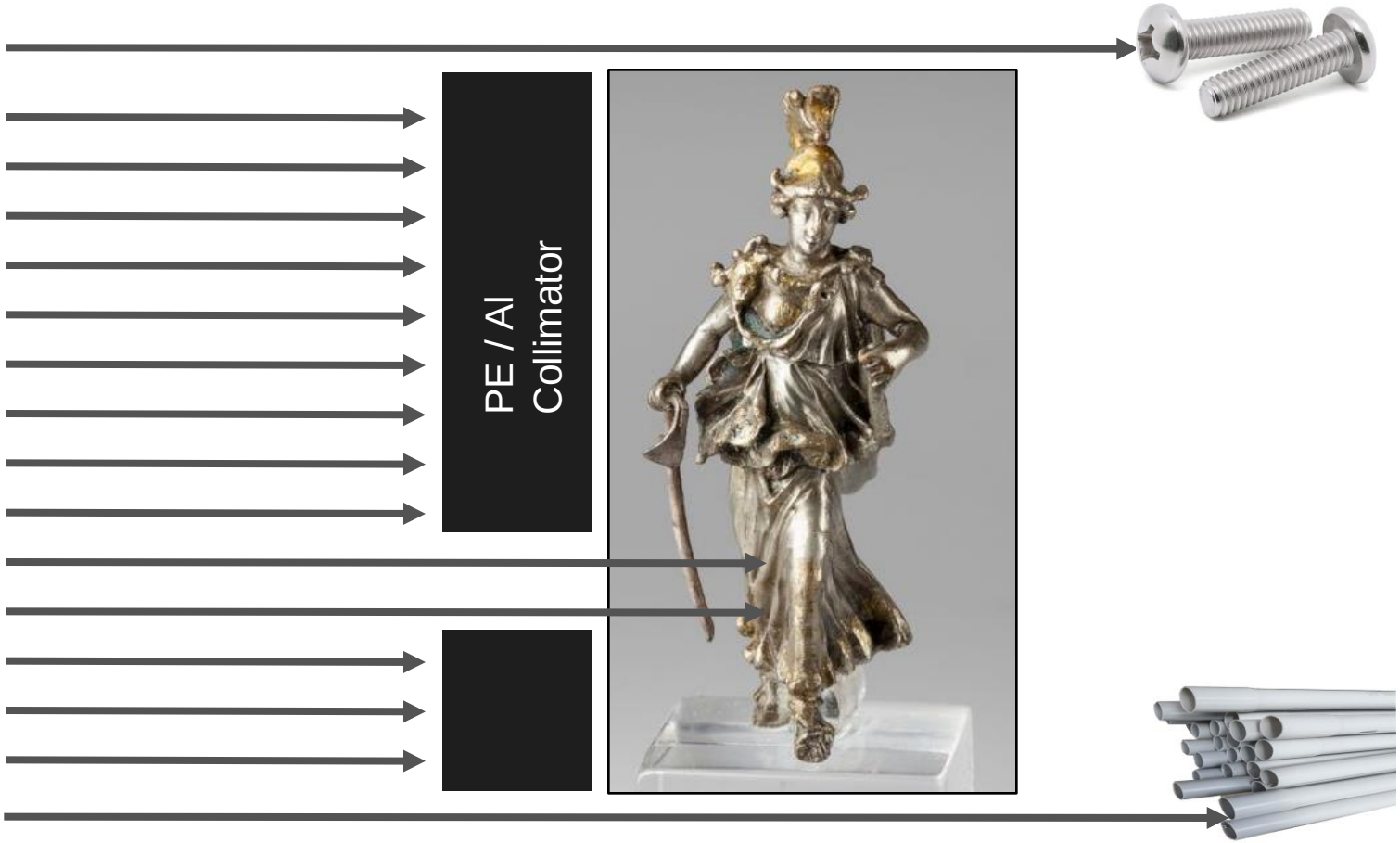

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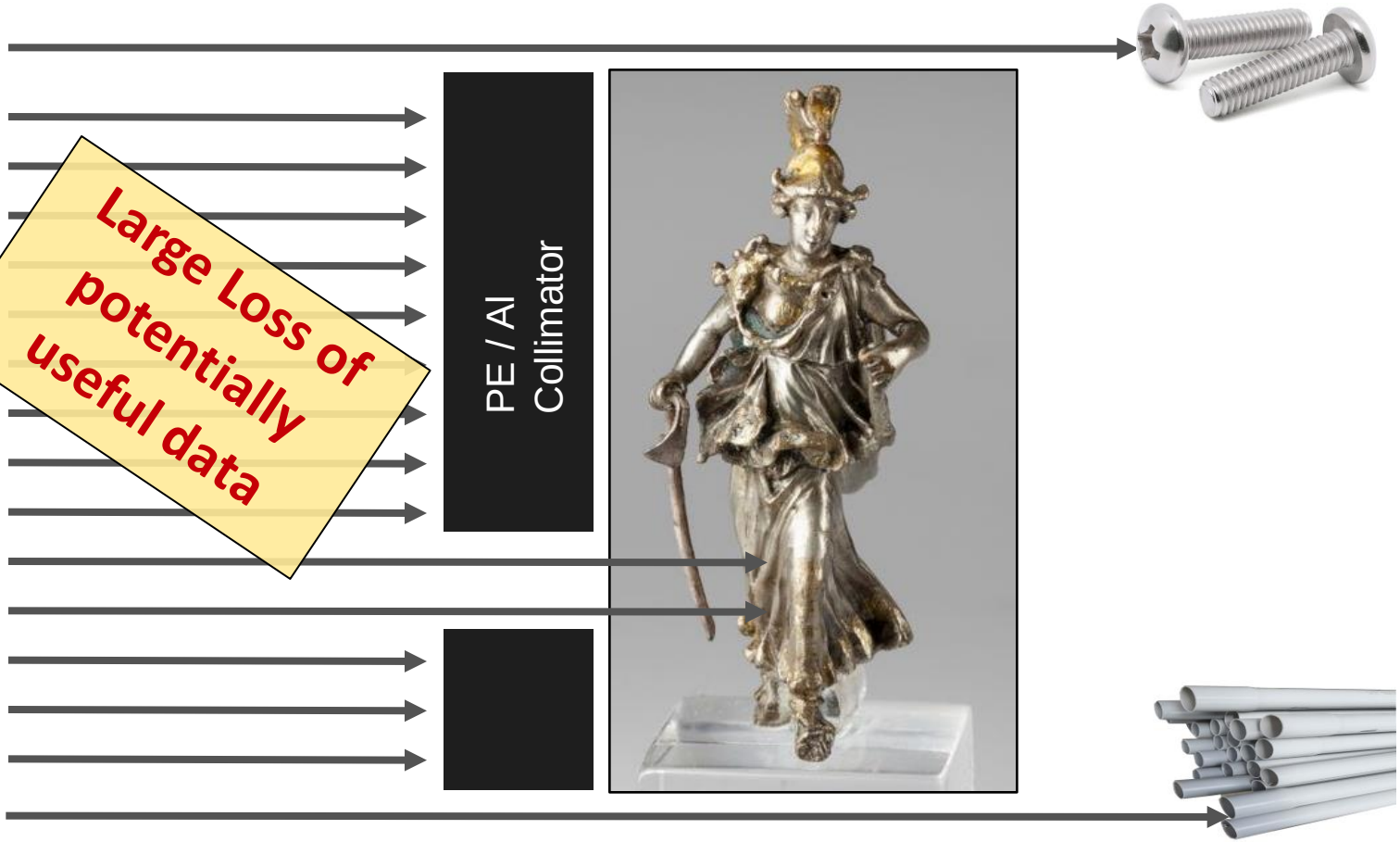

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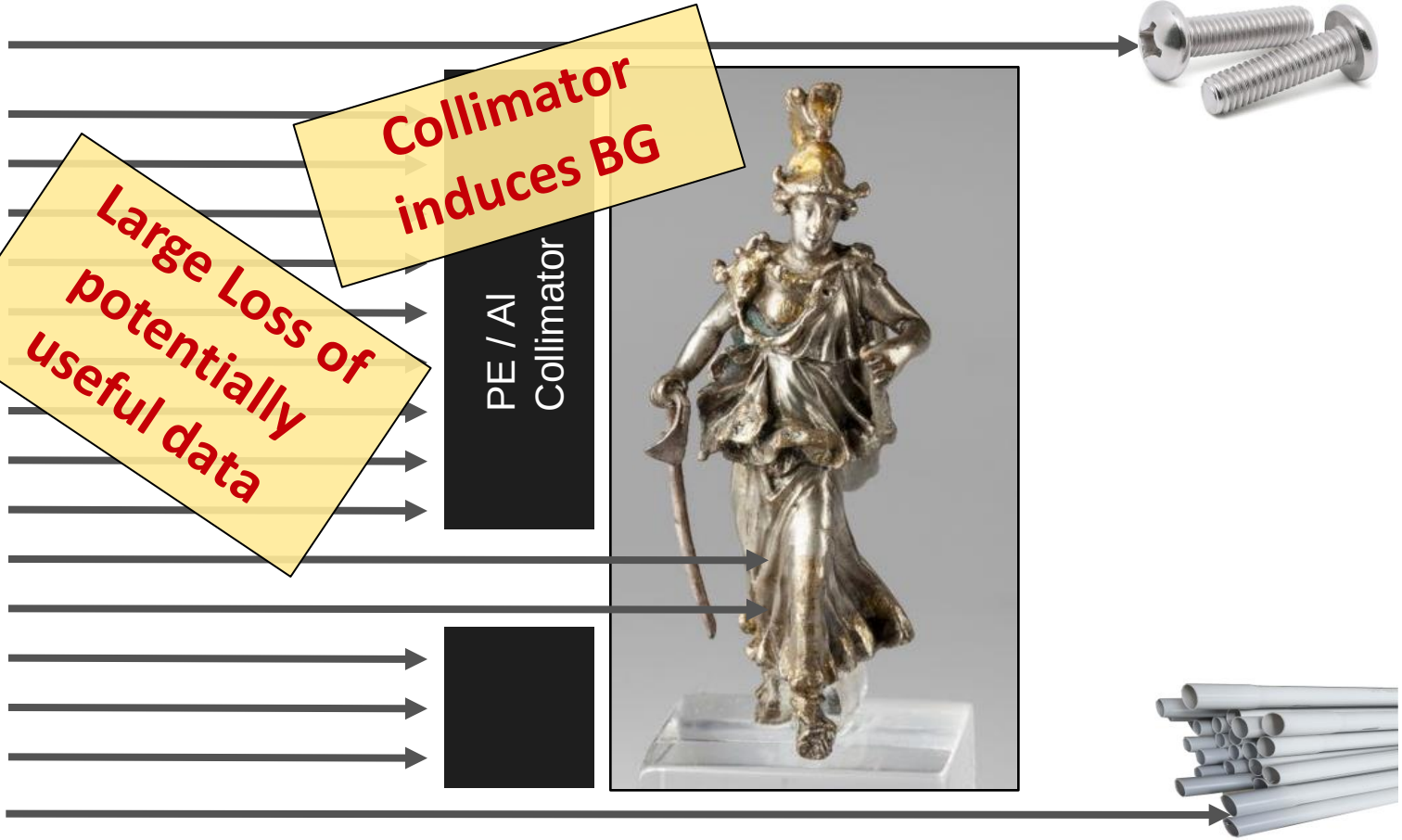

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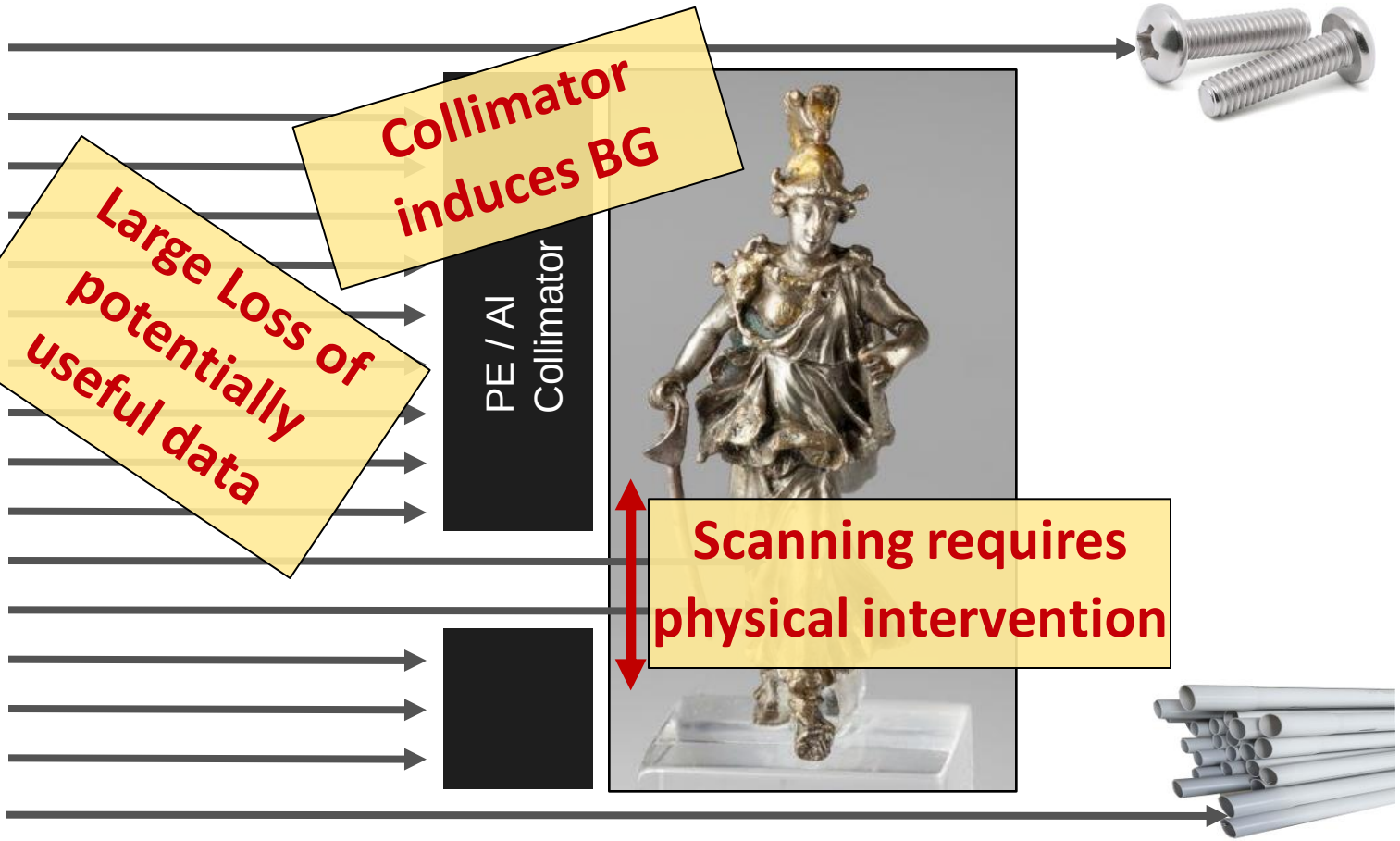

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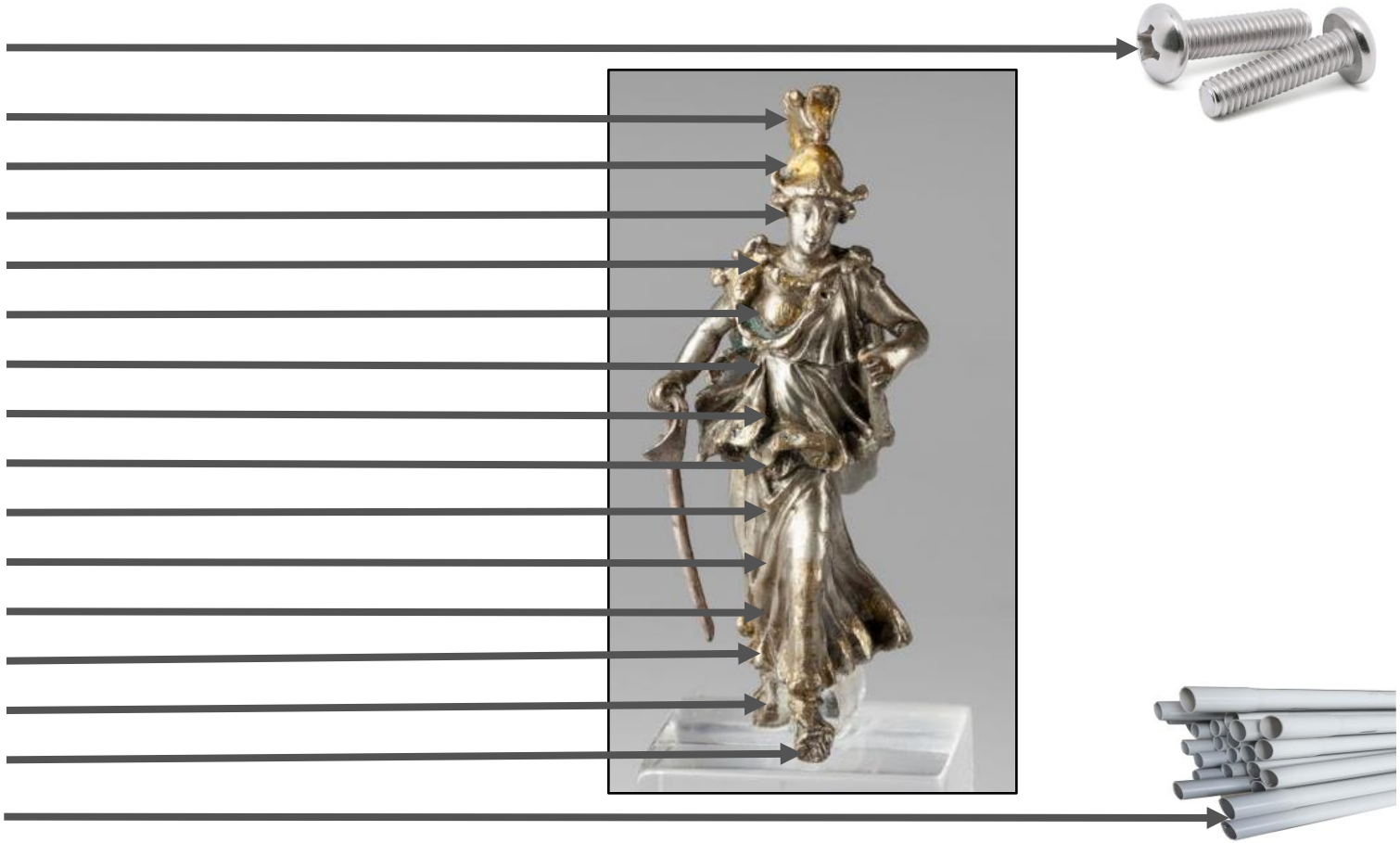

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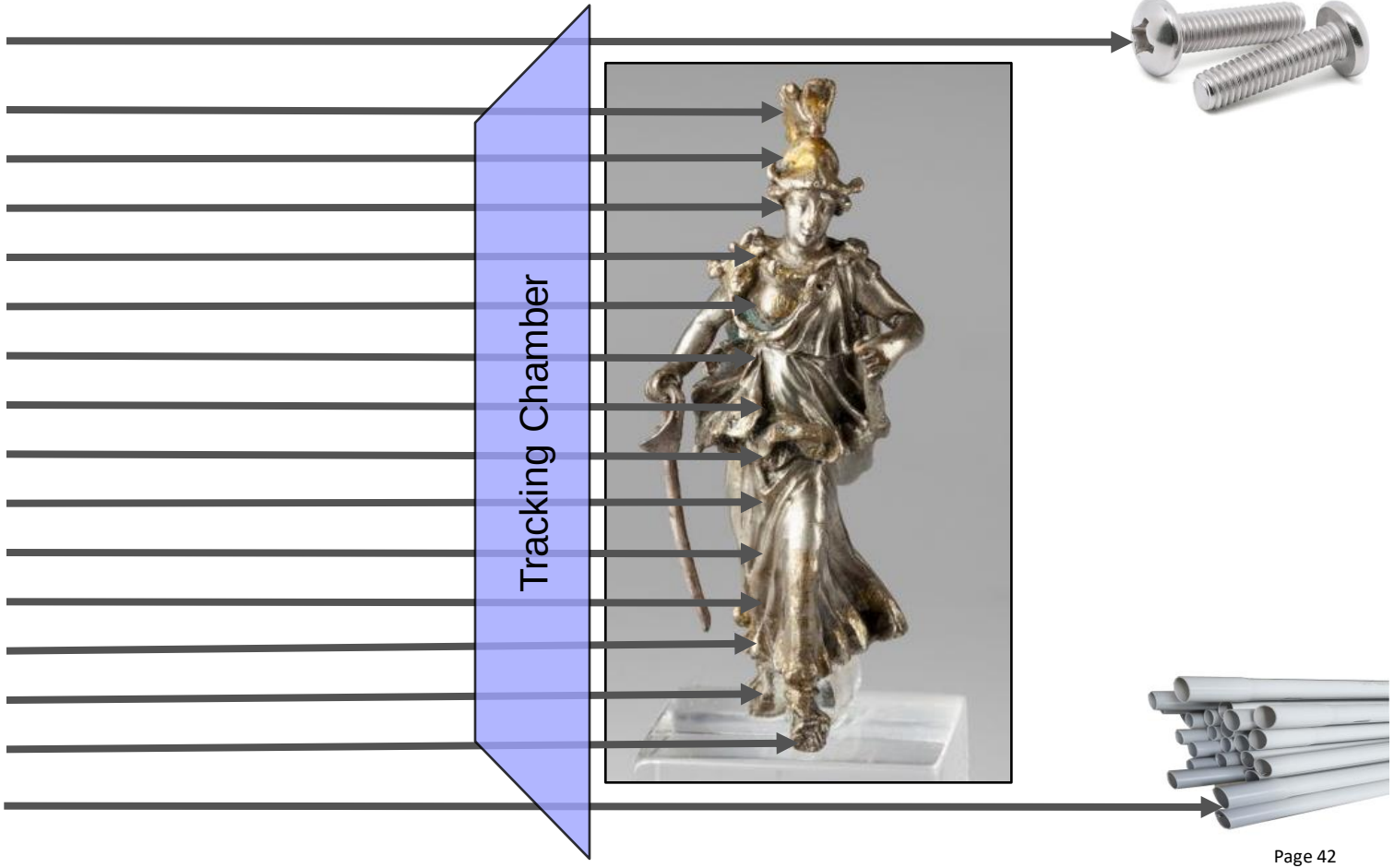

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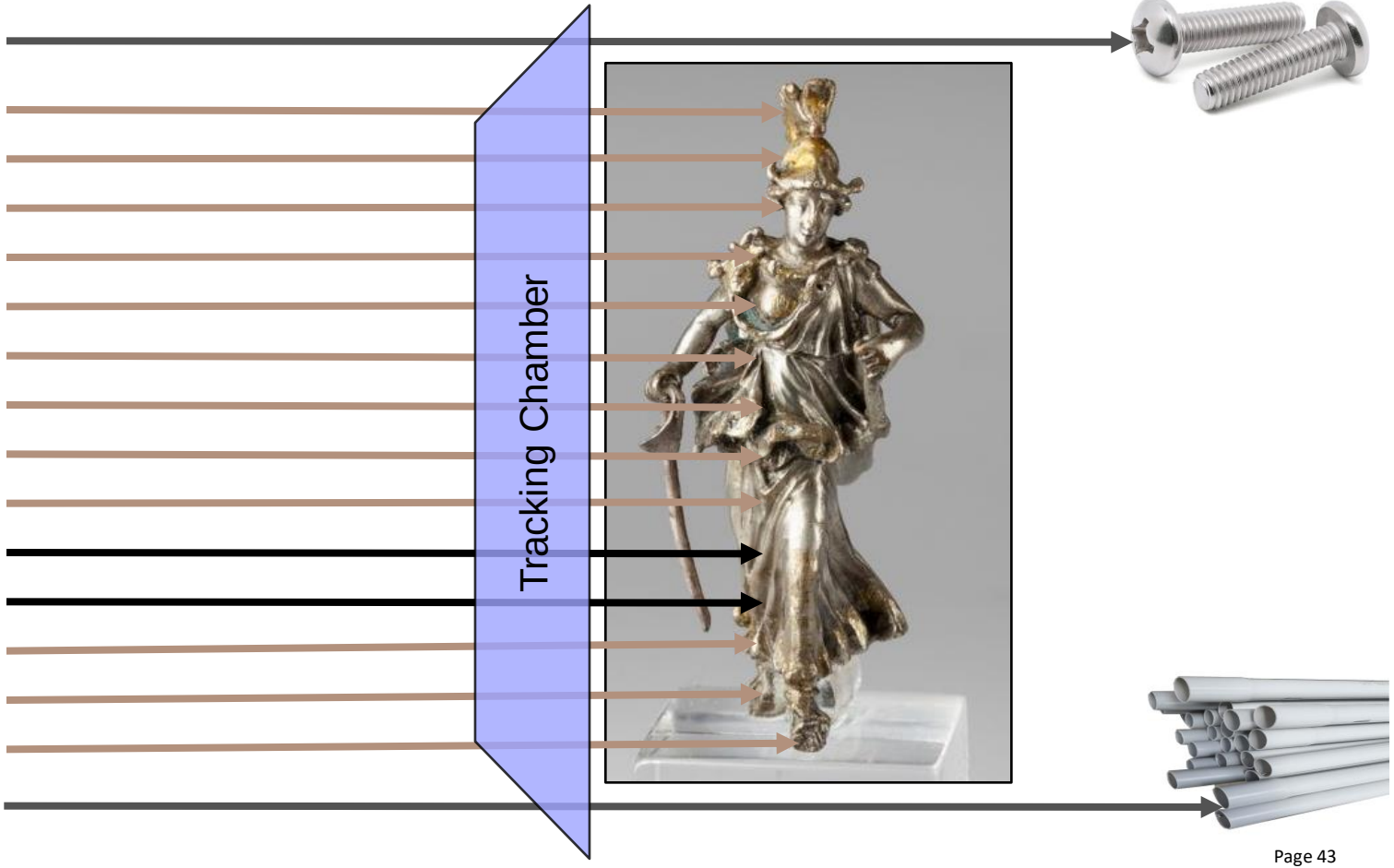

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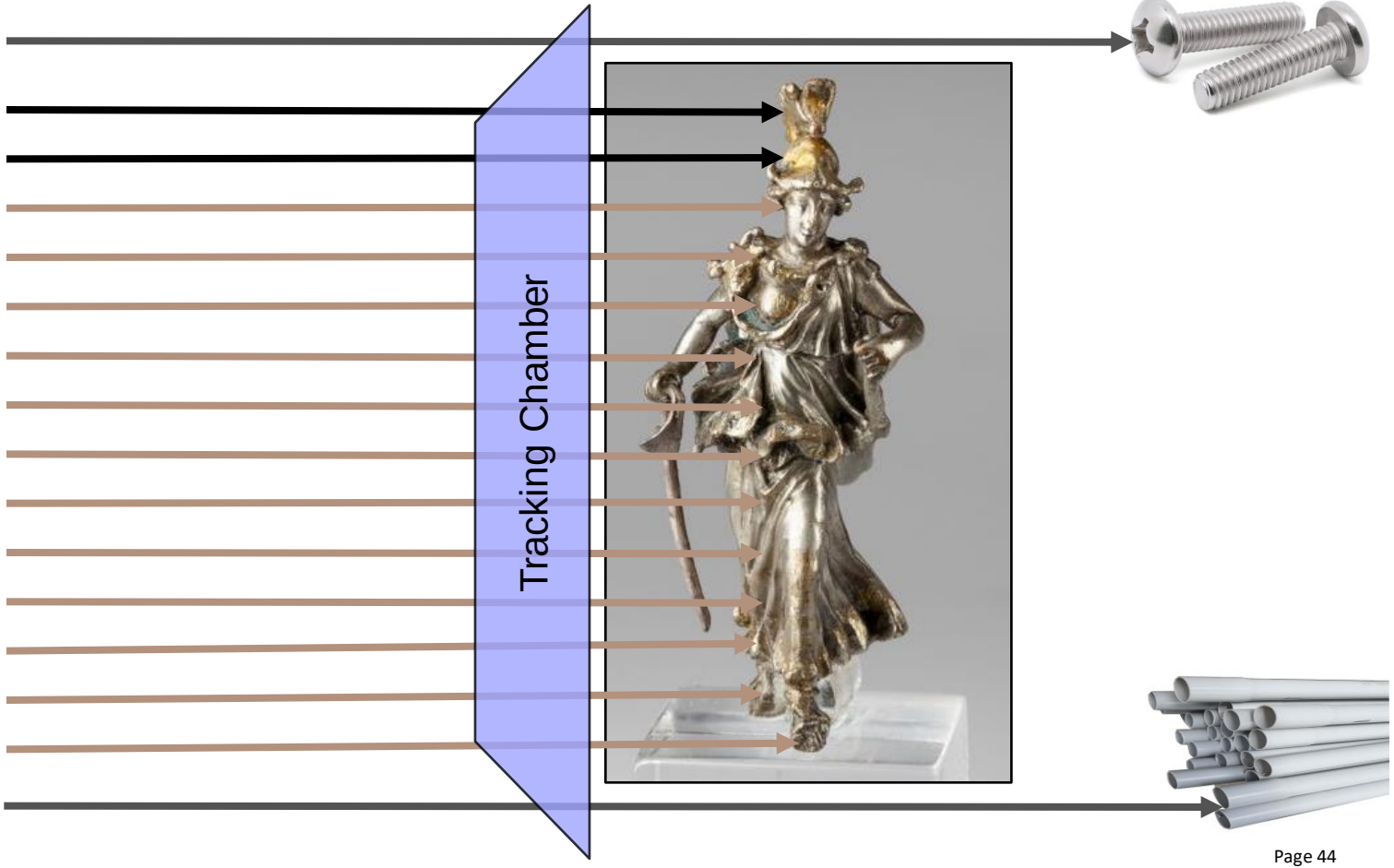

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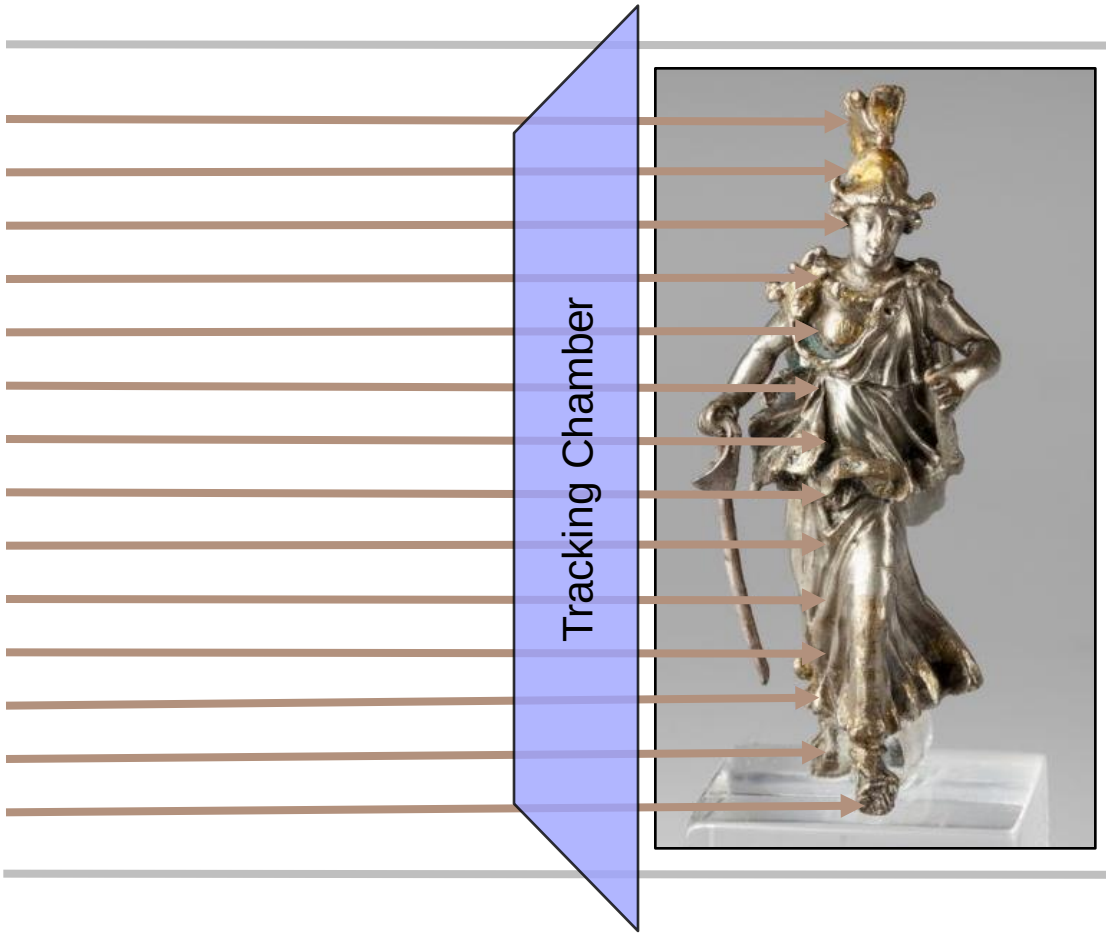
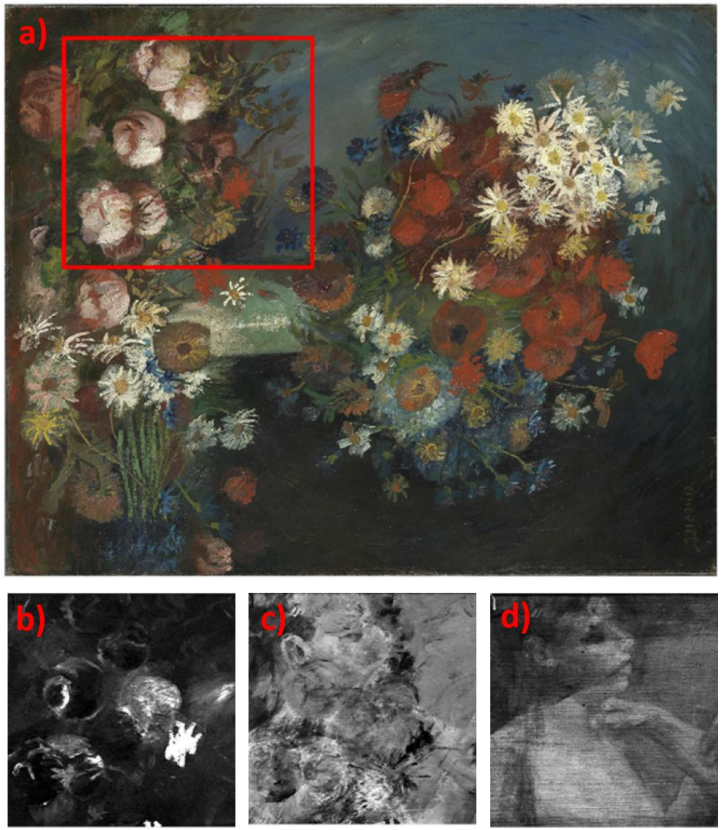


Novel technique: Non-destructive element (isotope) sensitive tomography!



a) Vincent van Gogh's Flower Still Life with Meadow Flowers and Roses, summer 1886 (Kröller–Müller Museum, Otterlo, the Netherlands), rotated for illustration purposes.

b) Hg fluorescence signal of the area in the red box, flowers are visible.

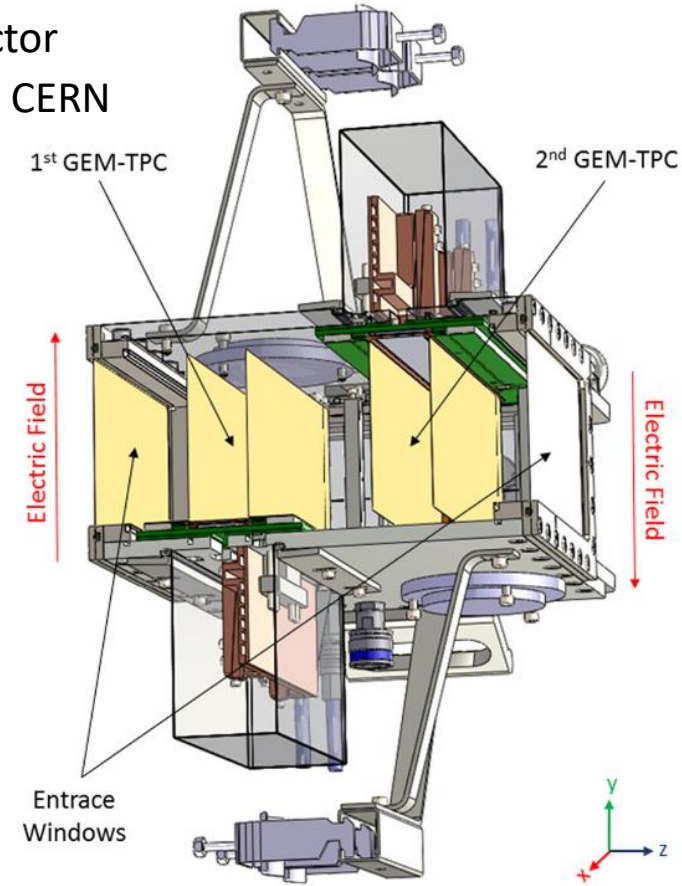
c) Zn fluorescence signal of the same area, hints of a human face visible.

d) Zn fluorescence measured from the back of the painting with less absorption, revealing the human face as part of an overpainted wrestling scene..

M. Alfeld and J. A. C. Broekaert, Spectrochimica Acta Part B 88, 211- 230 (2013)

Twin GEM-TPC Tracking chamber

- Opportunity to work with existing prototype detector
  - Collaboration with F. Garcia (U Helsinki) & RD51, CERN
  - Designed for heavy ion tracking @ GSI/FAIR



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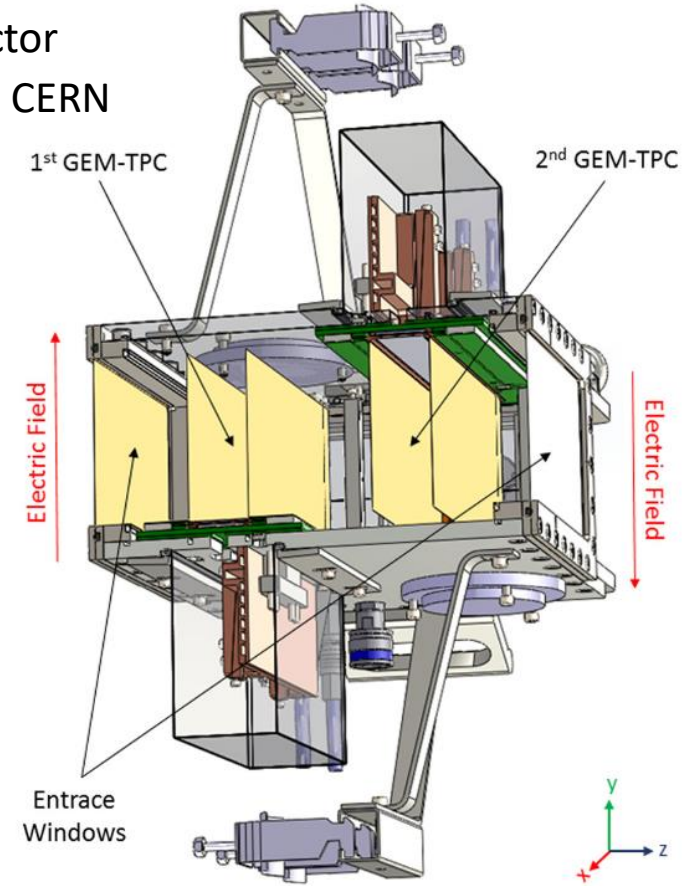
  - GEM stack amplification stage
  - 1D strip readout – 1024 in total
  - X position given by cluster on strips
  - Y position by drift time(s)
  - Tested with Ar/CO2 and P10 (Ar/CH4)



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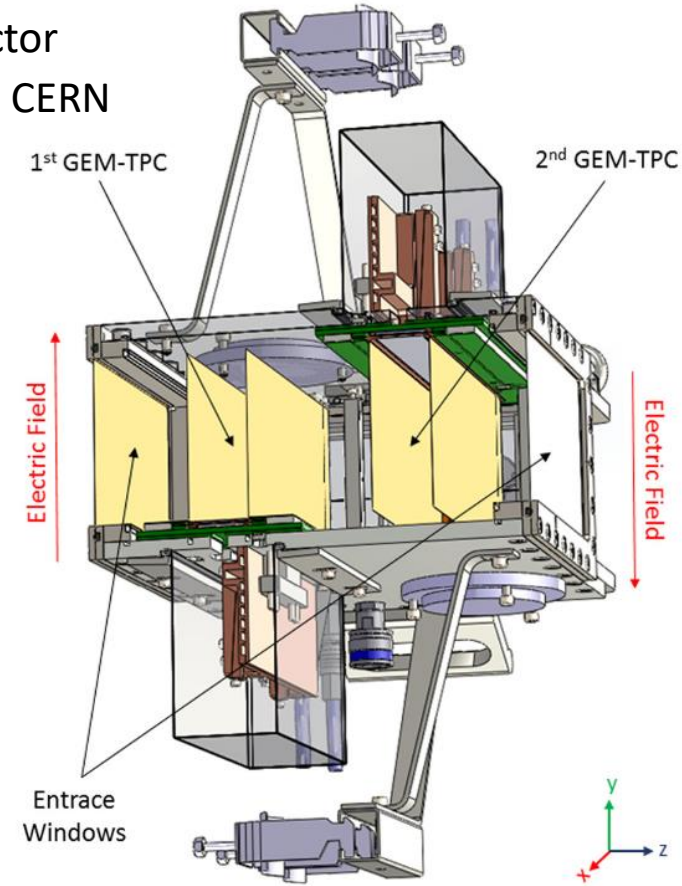
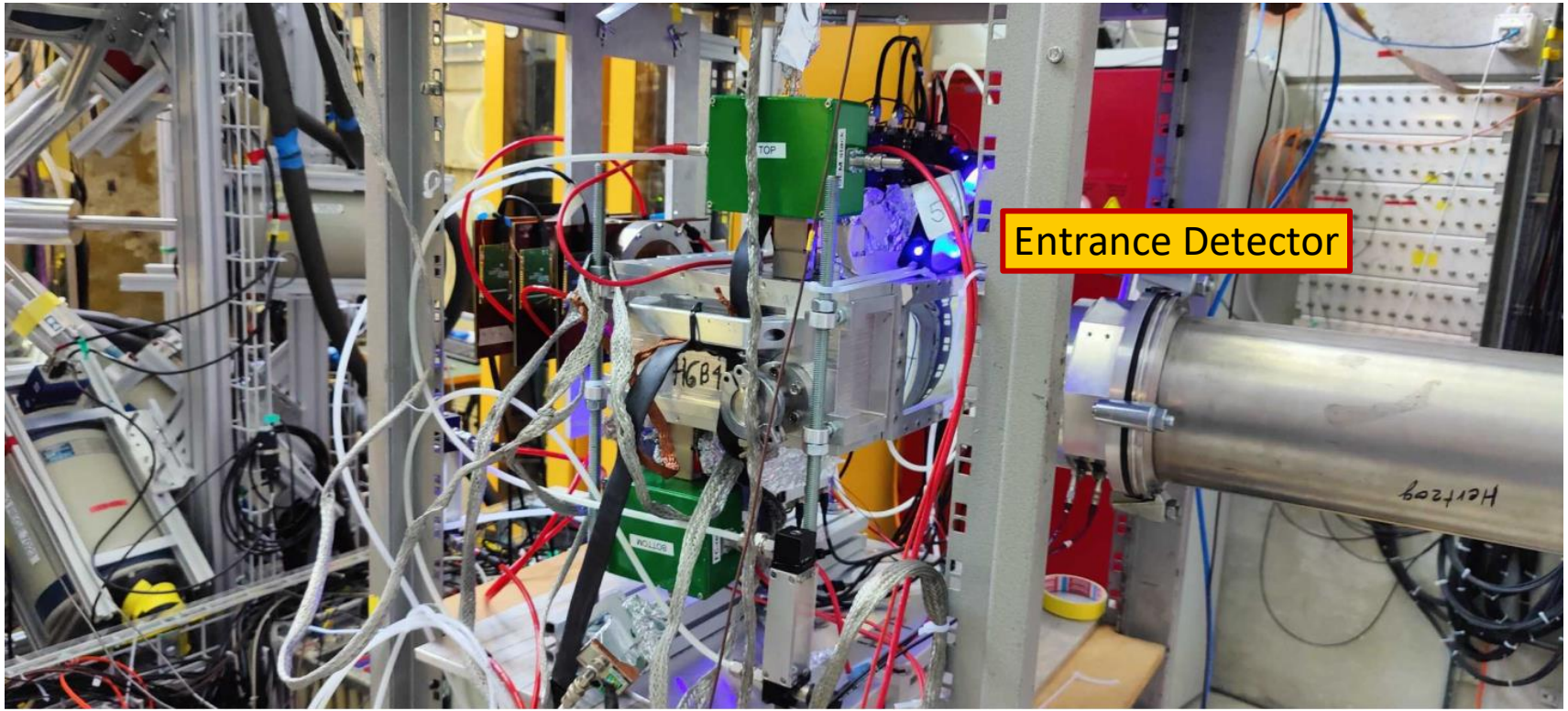
  - 1D strip readout – 1024 in total
  - X position given by cluster on strips
  - Y position by drift time(s)
  - Tested with Ar/CO2 and P10 (Ar/CH4)
- Separate readout system
  - based on SRS DAQ with VMM3a ASICs
  - extreme rate capability (not required for MIXE)
  - continuous readout
  - challenging synchronization with MIXE DAQ



First Tracker Measurements: May 2023



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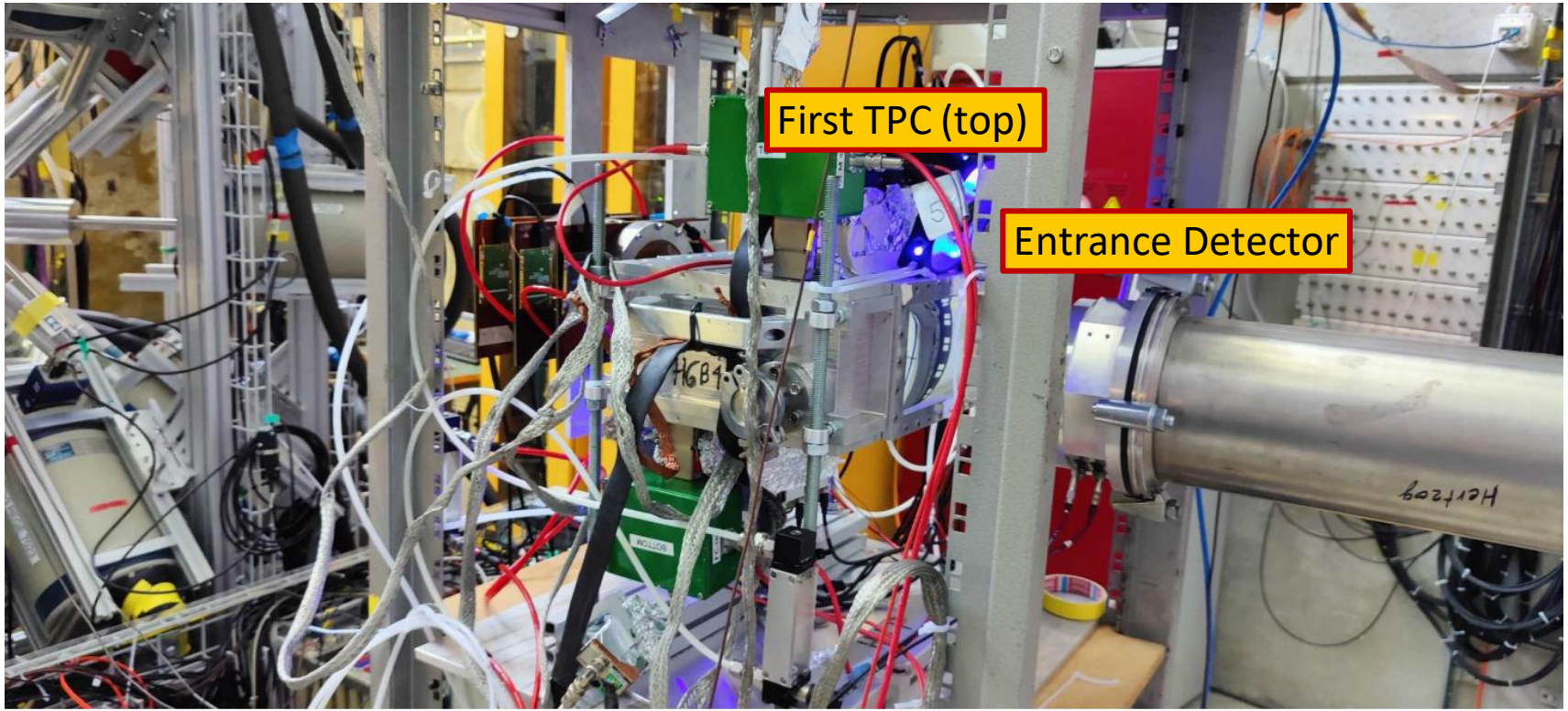

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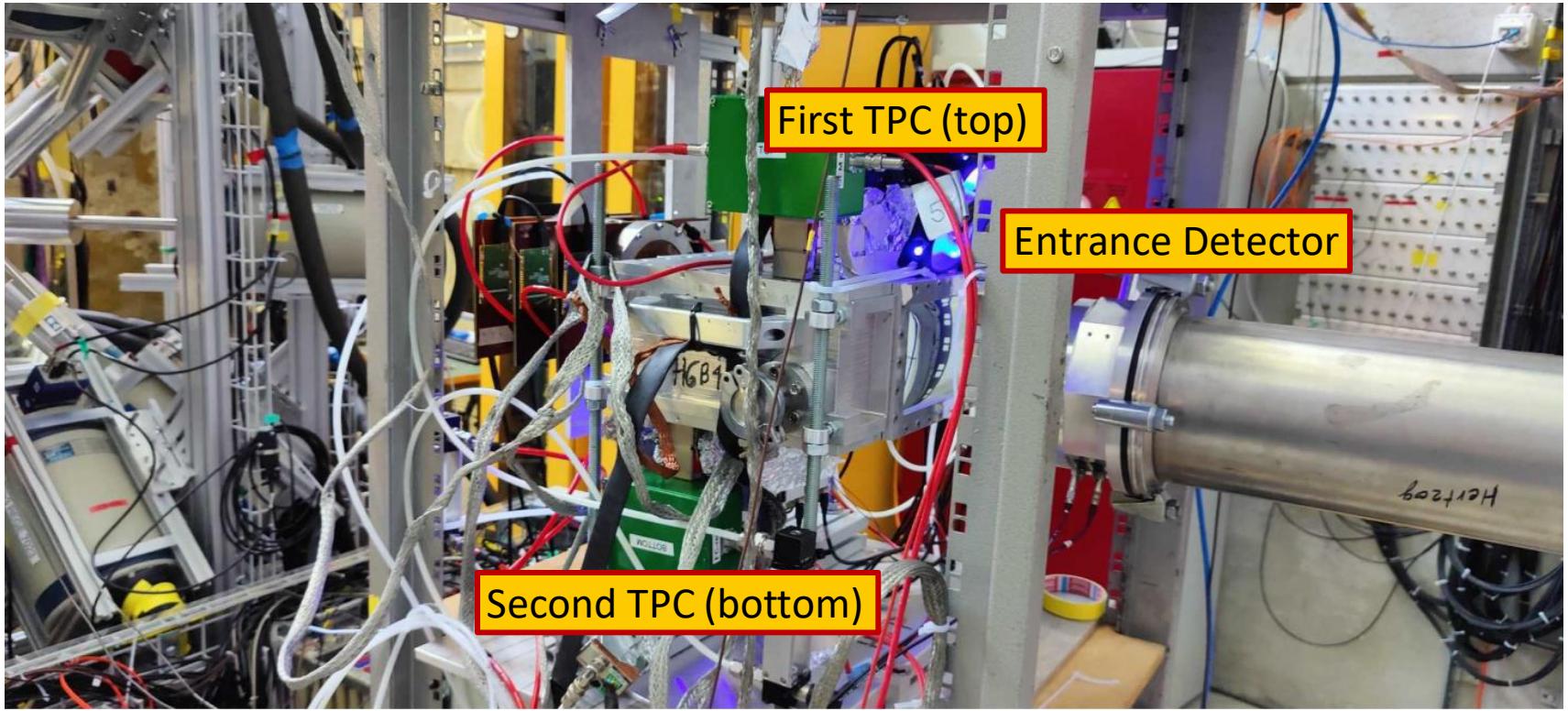

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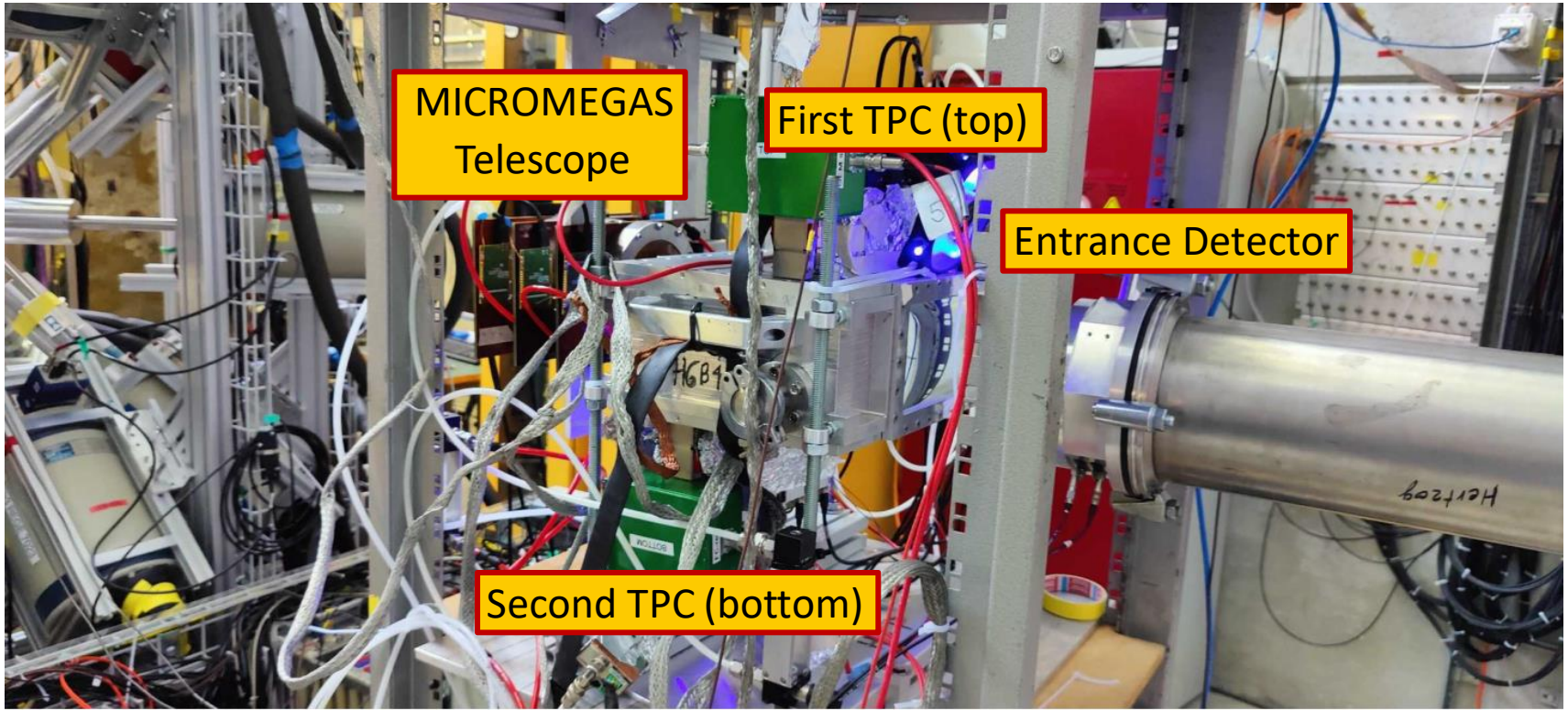
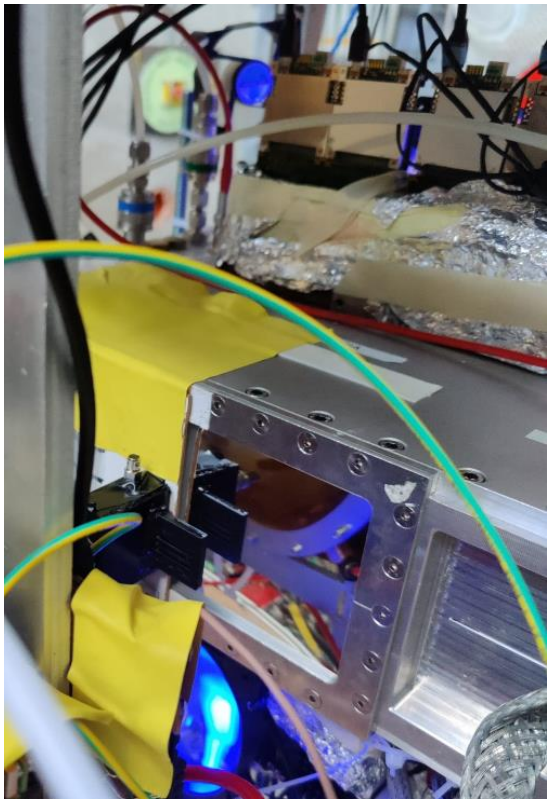


Drift time calibration – Fiber Detector

- Assembled, tested and mounted new detector
  - precision 3D printed (35um) mounting structure
  - 3 scintillating fibers in exactly 4mm distance
  - high speed SiPM premounted on readout board



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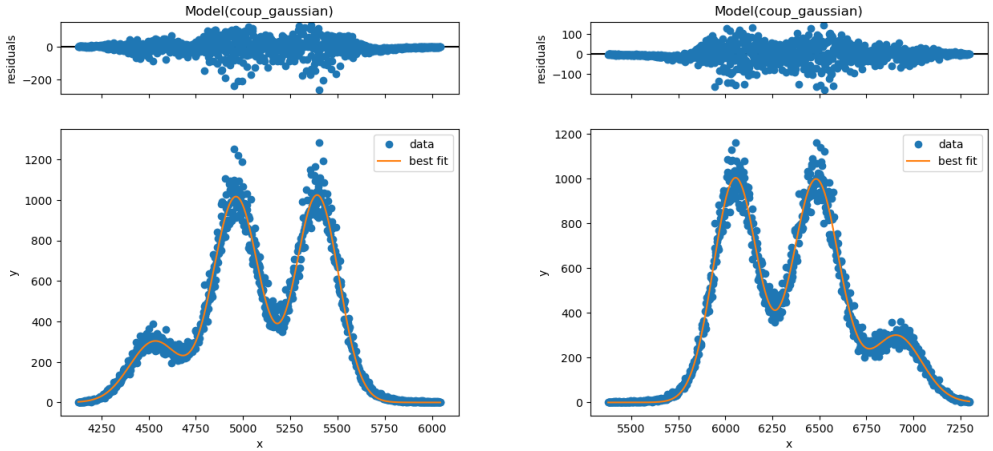
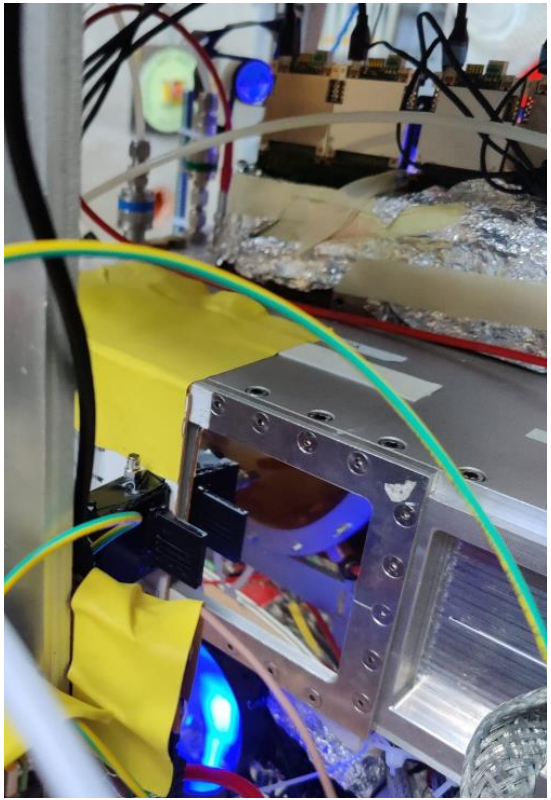
- *Drift time calibration successful!*
  - cut on parallel tracks (constant sum of drift time)
  - drift velocity: (9.30 +/- 0.03) mm/us





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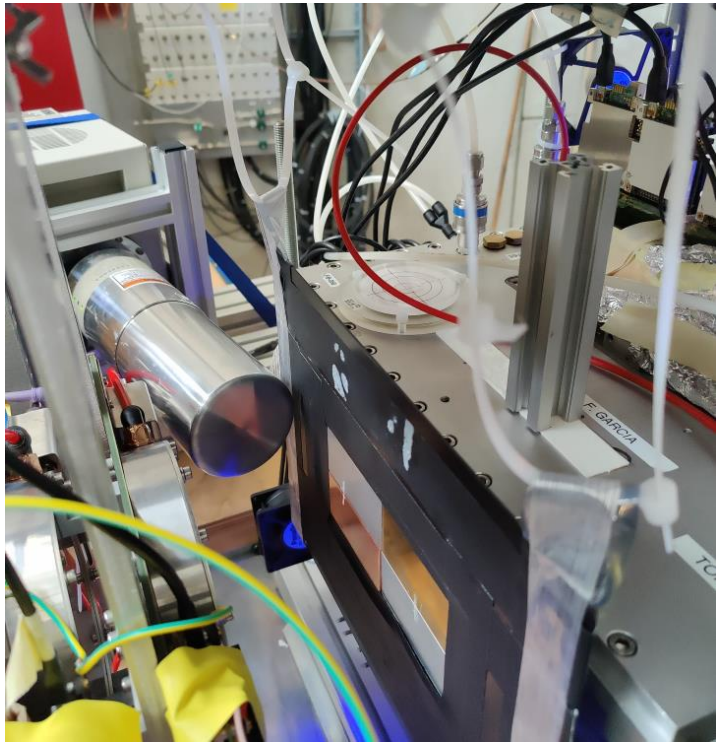

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  - Stainless: Fe (66%), Cr (18%), Ni (12%)
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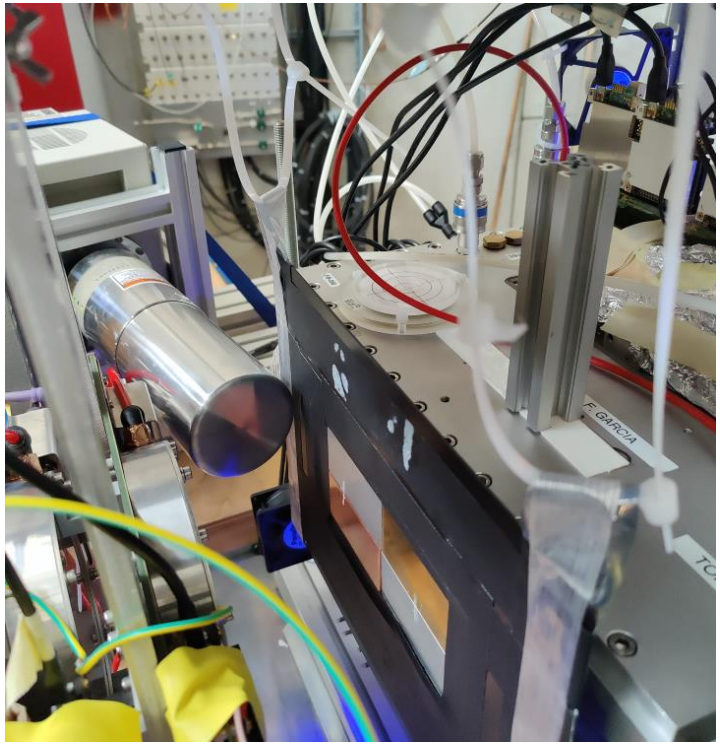

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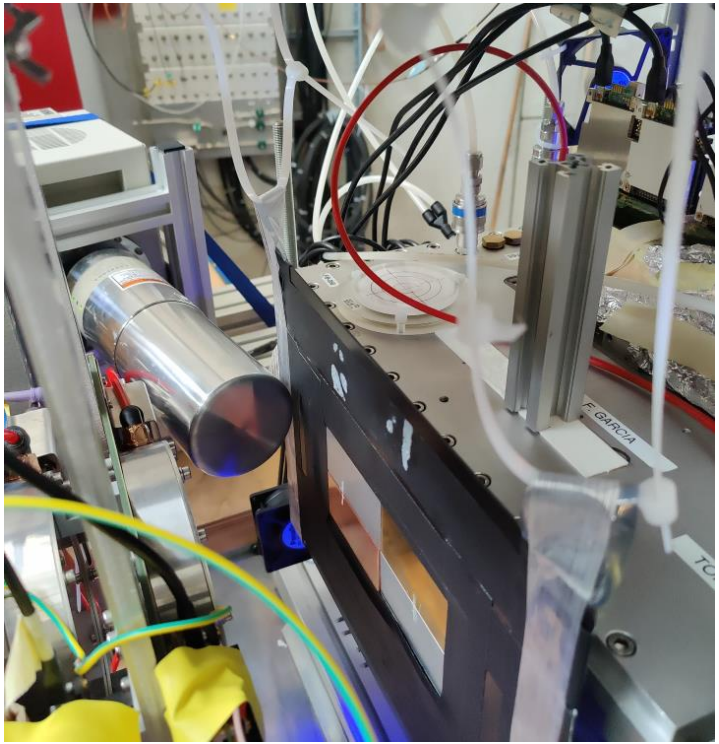

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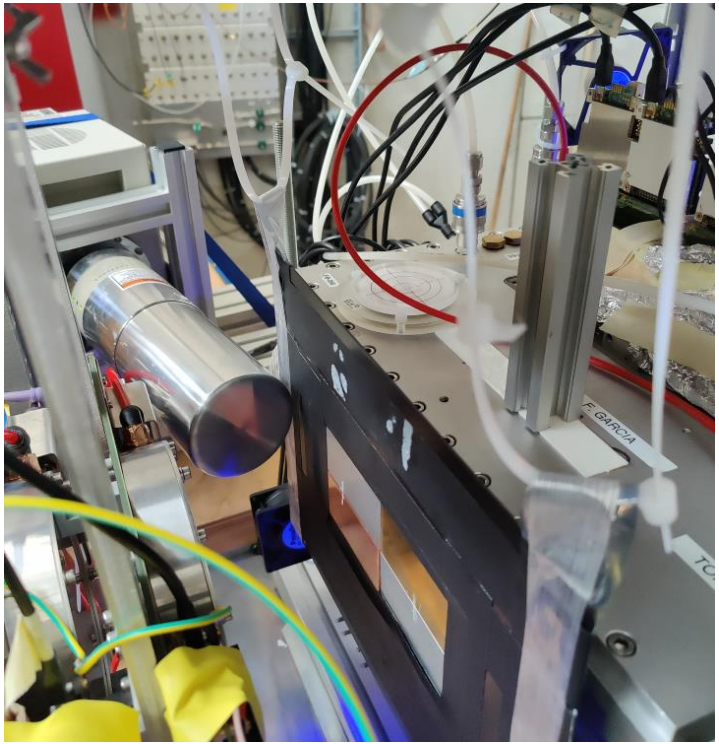

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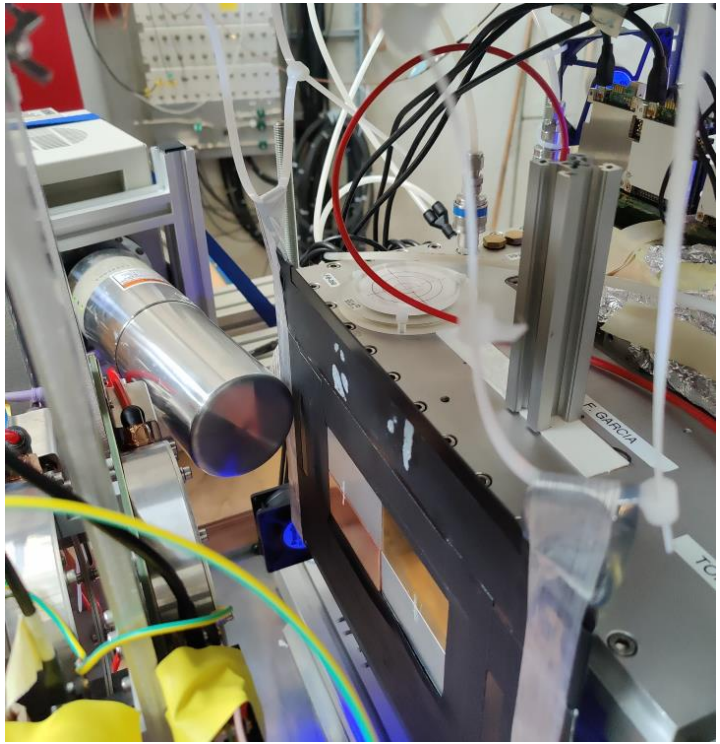
- Last night of beamtime! Time for 2 runs:
  - High rate: ~4 hours, approx. 20 kHz
  - Low rate: ~9 hours, approx. 8 kHz

low multiplicity in tracker – simpler analysis



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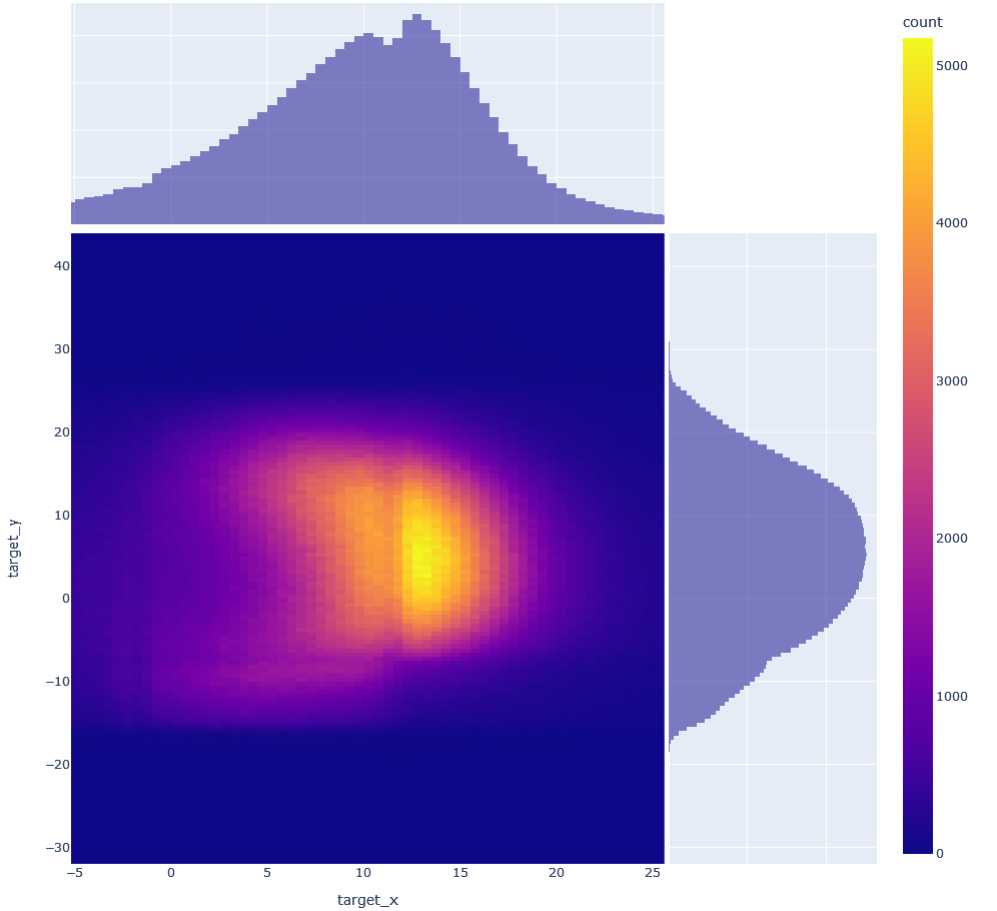

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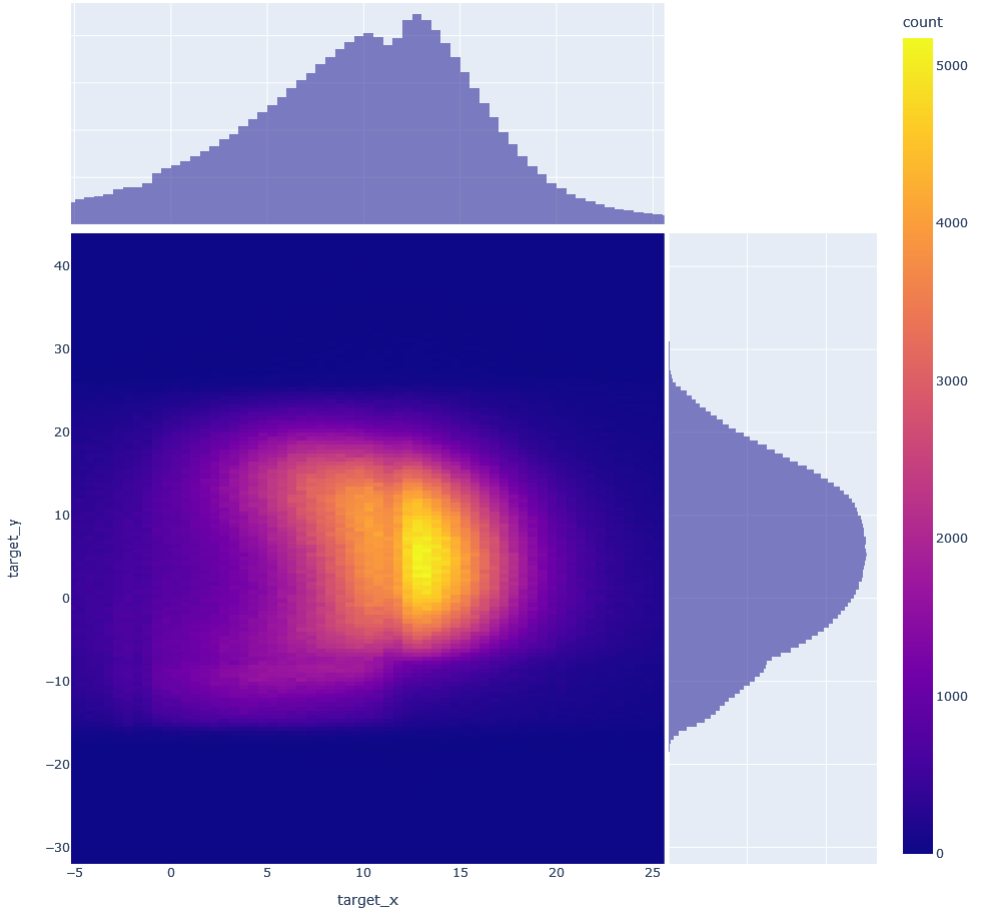

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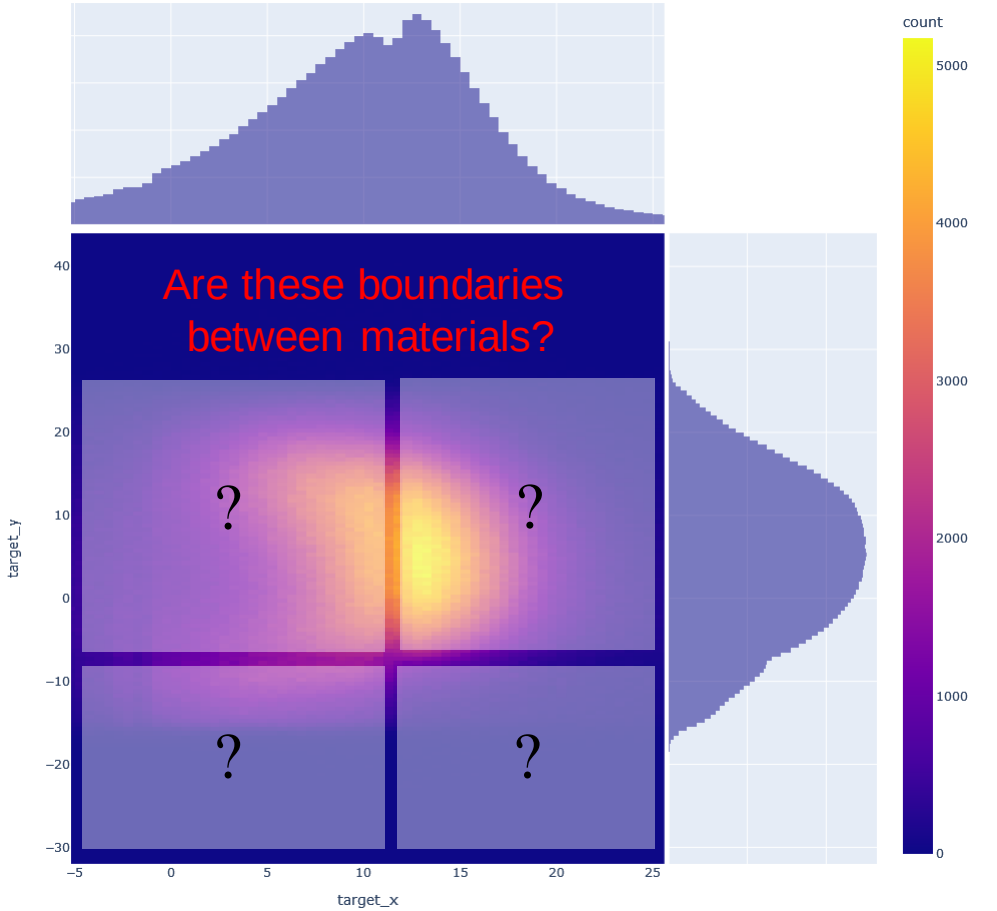

Material ID: Upper Right Quadrant

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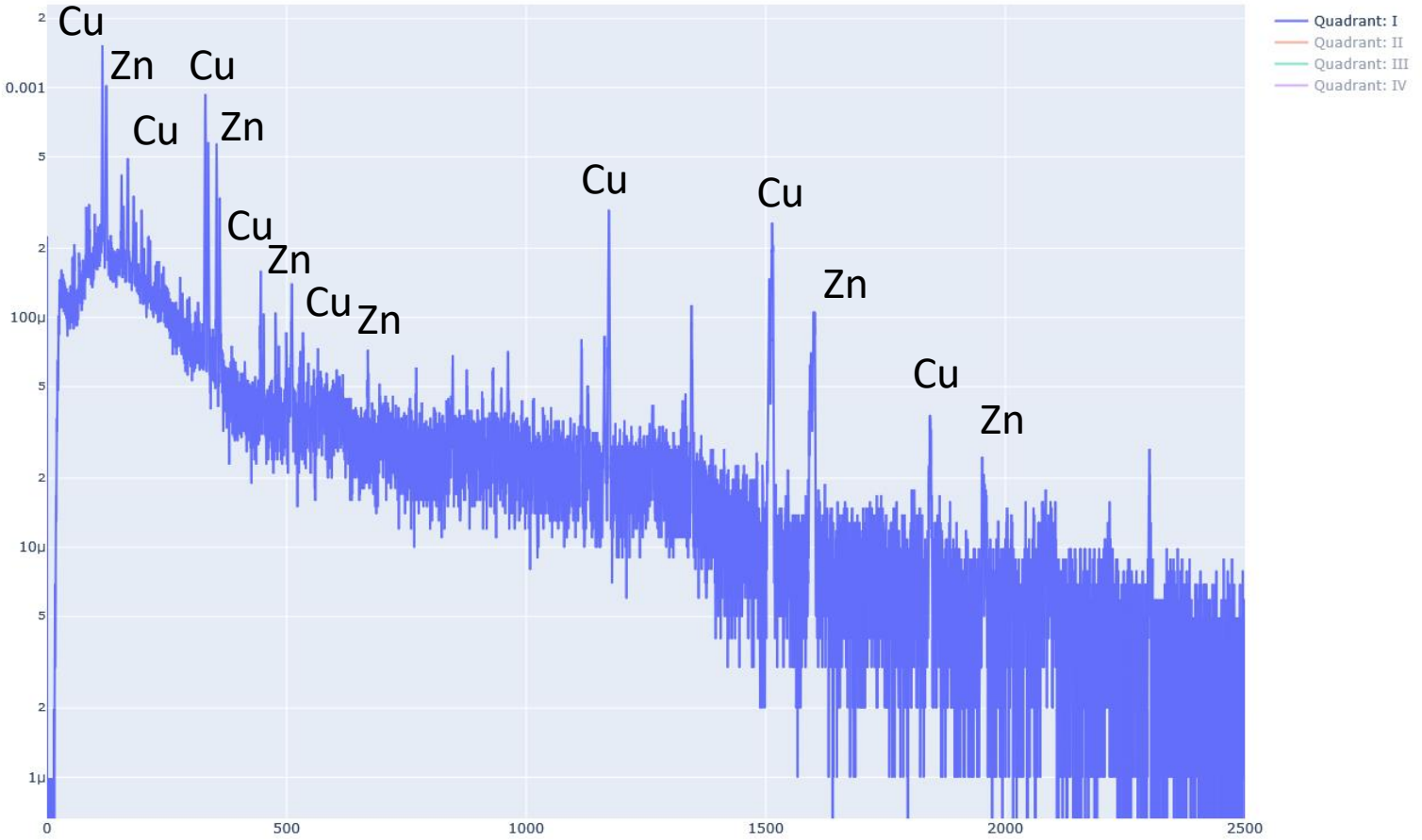

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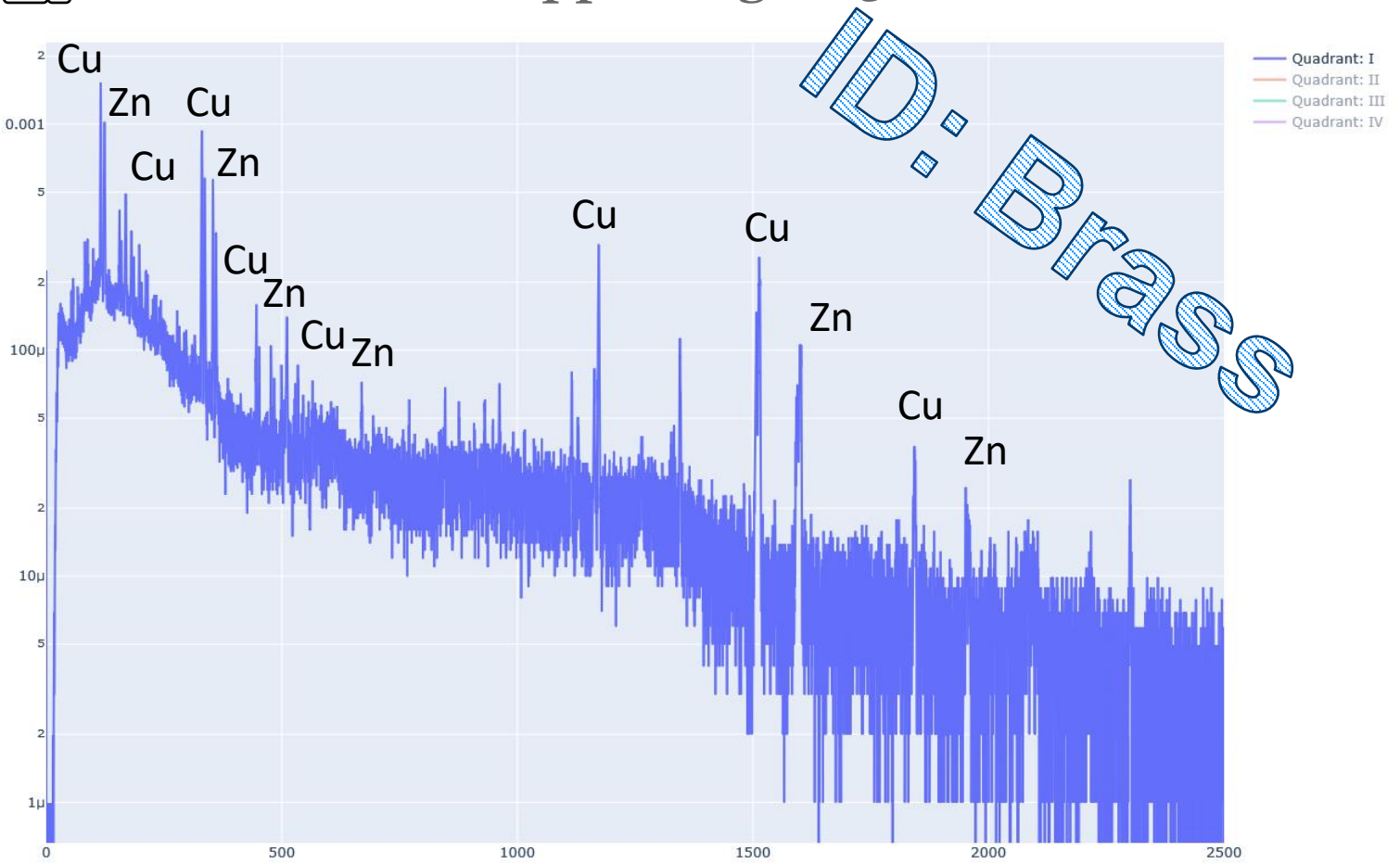

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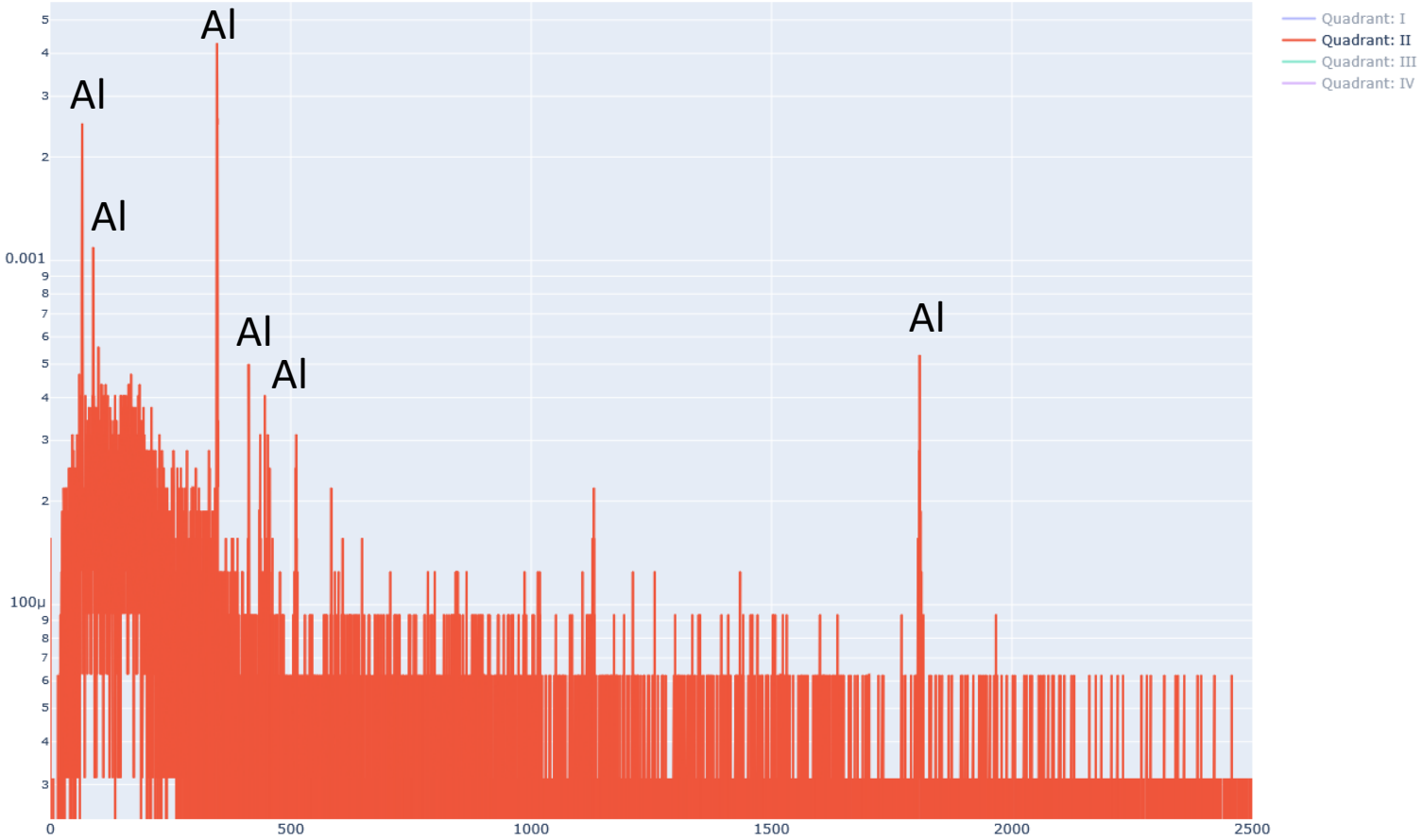

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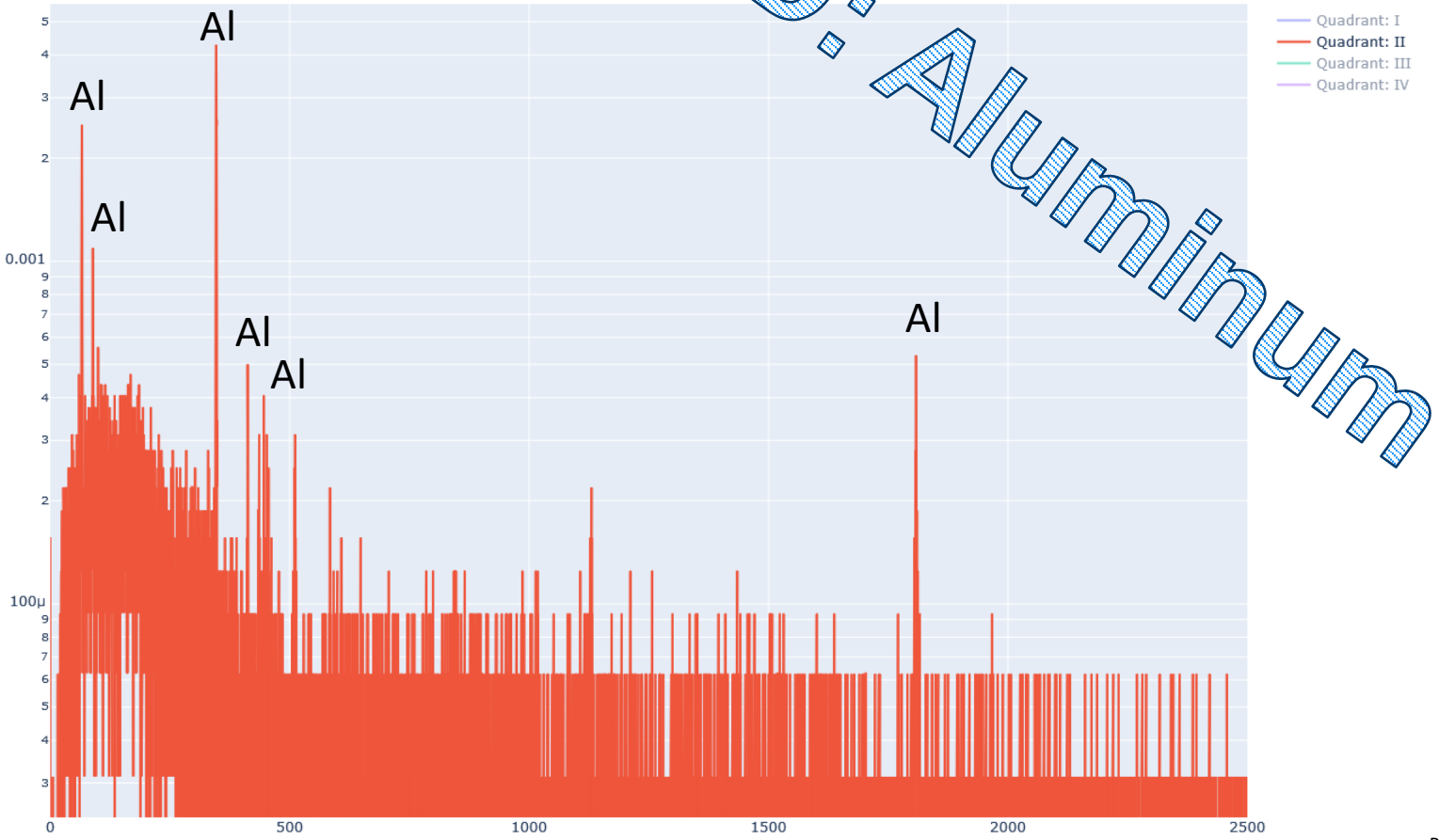

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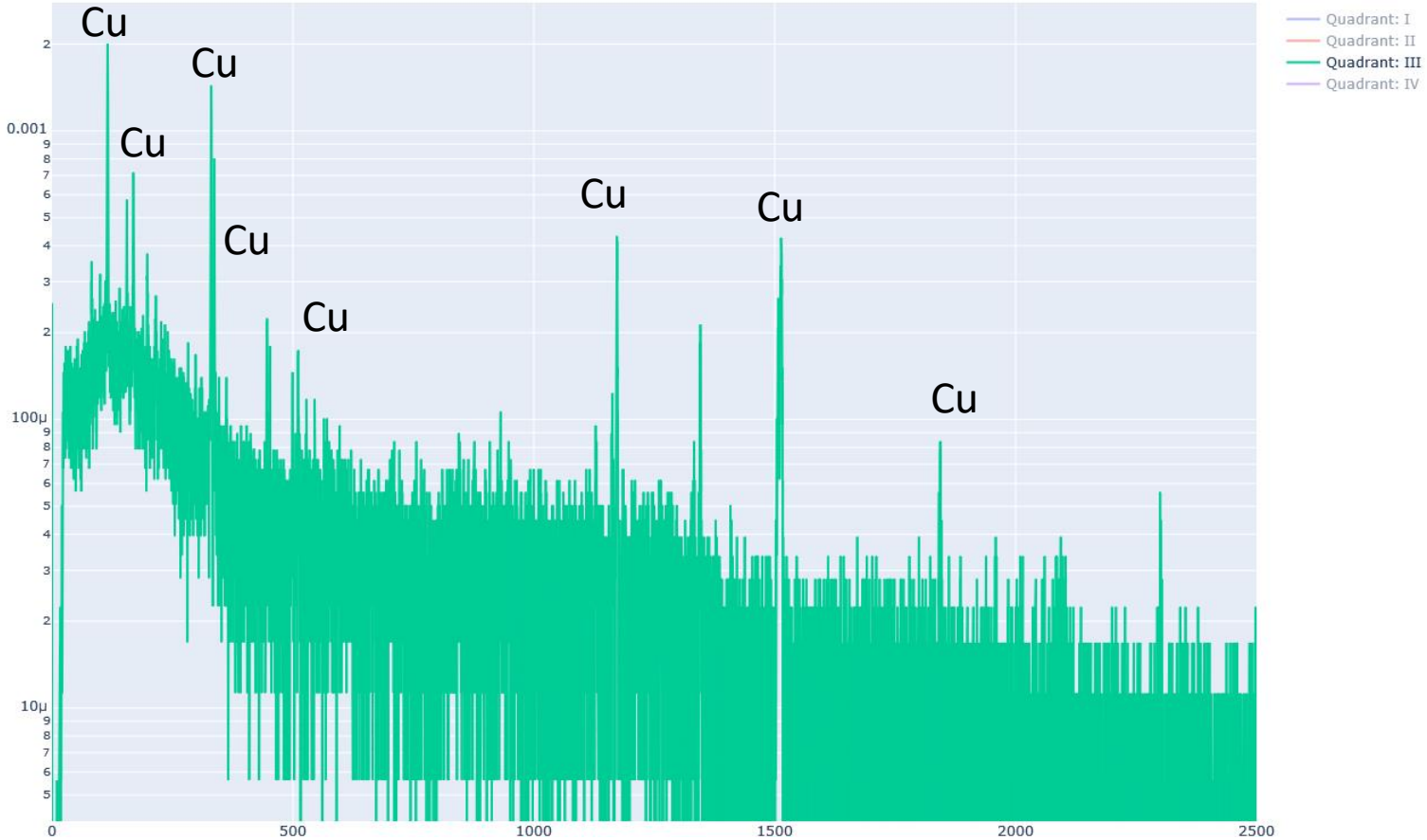

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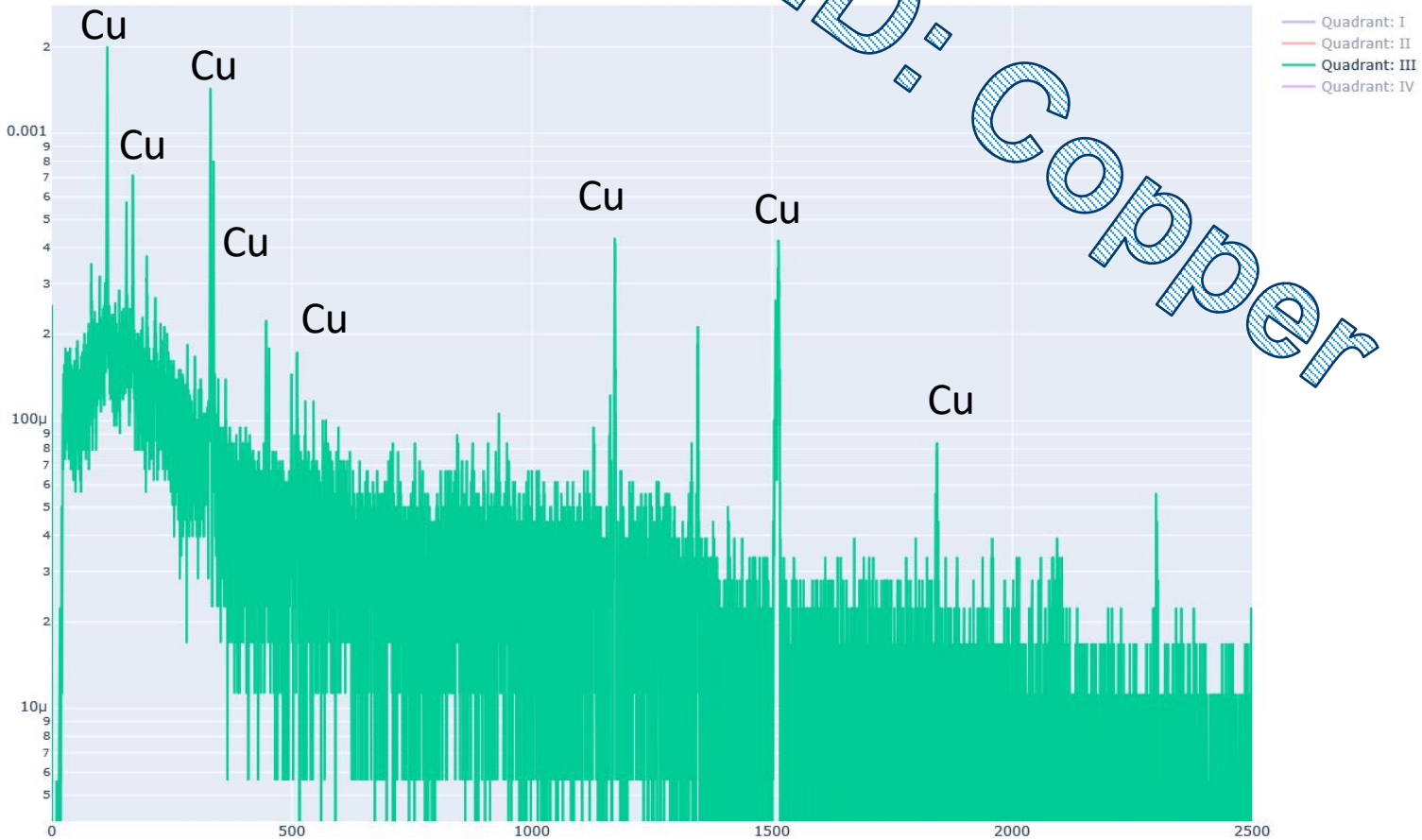

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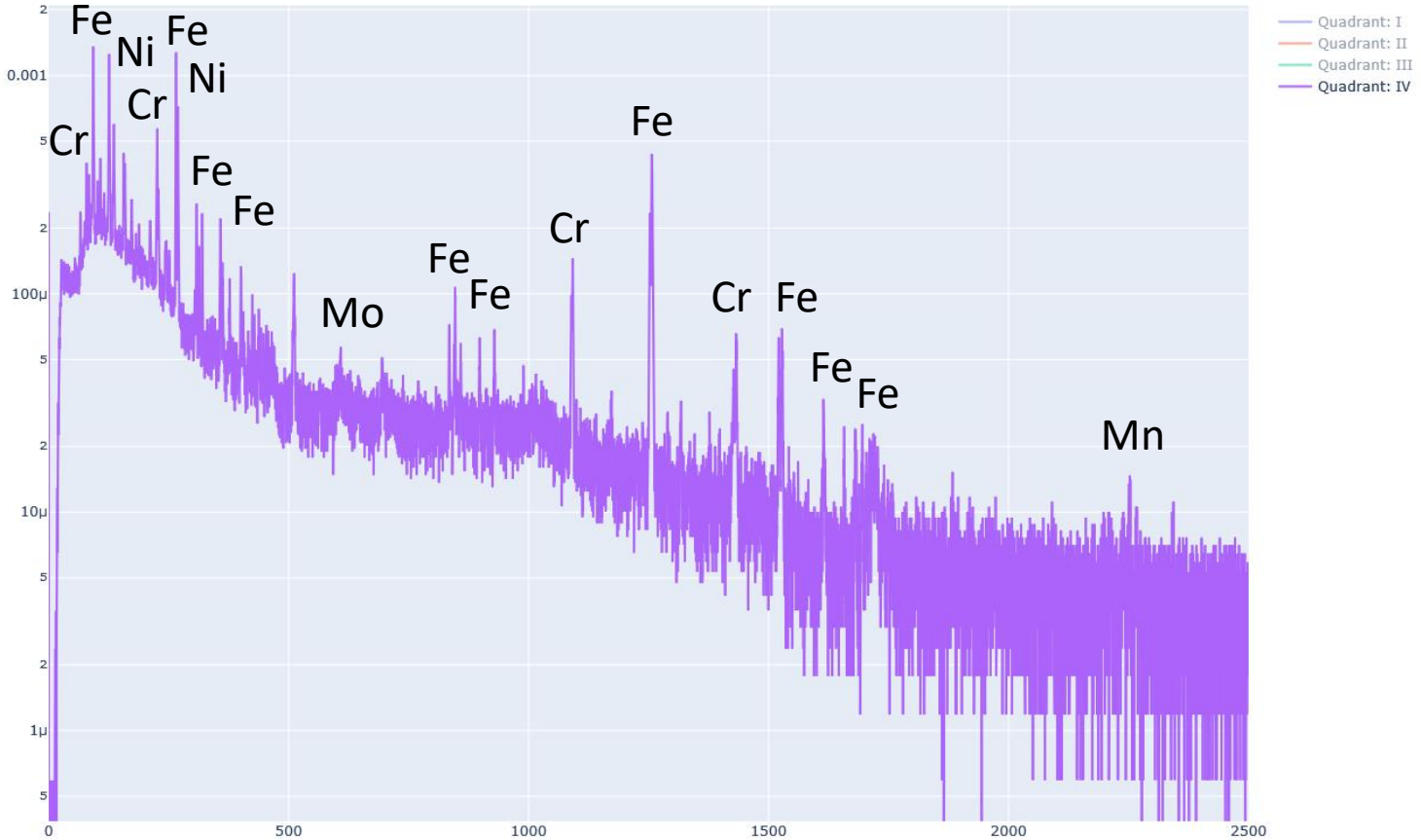

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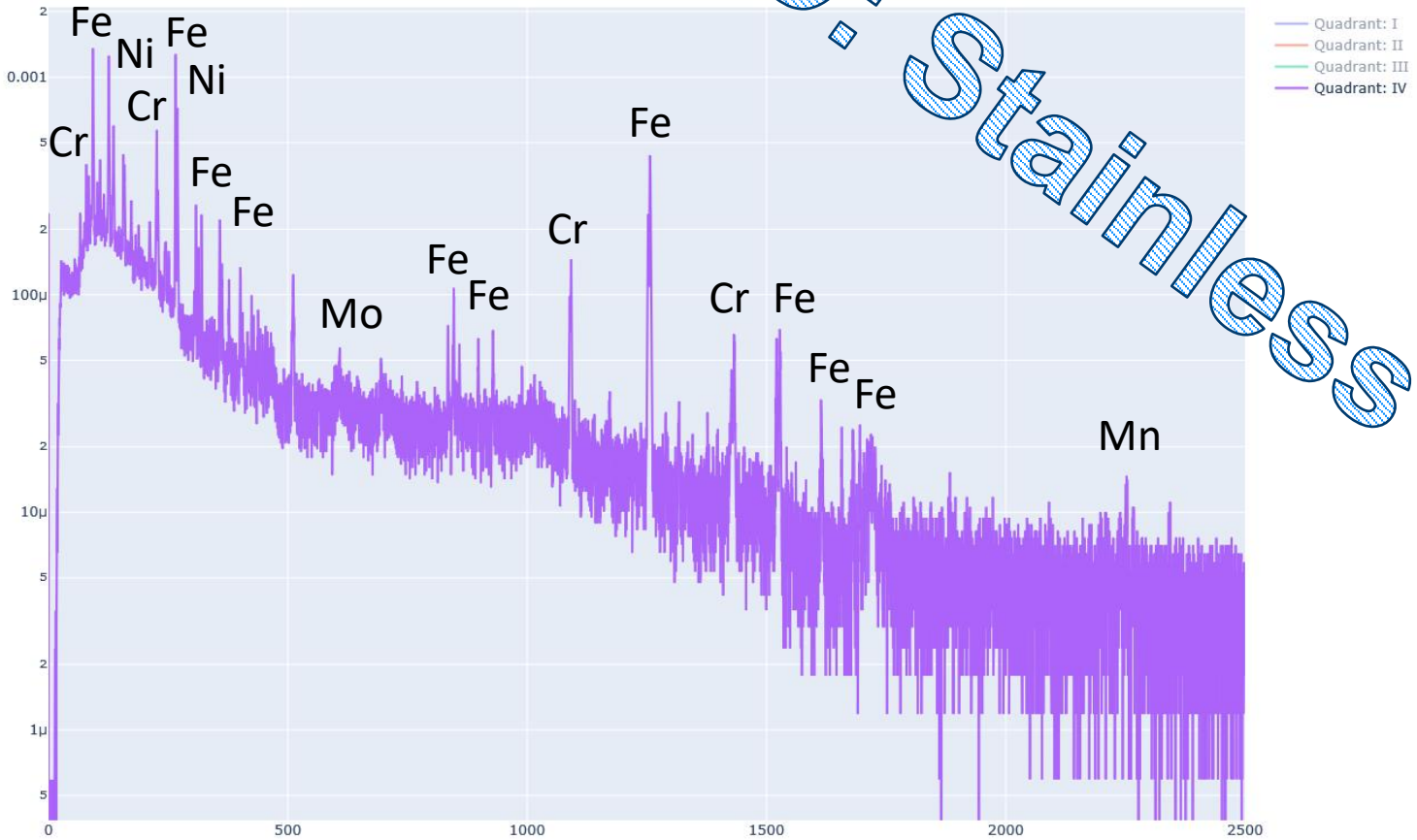

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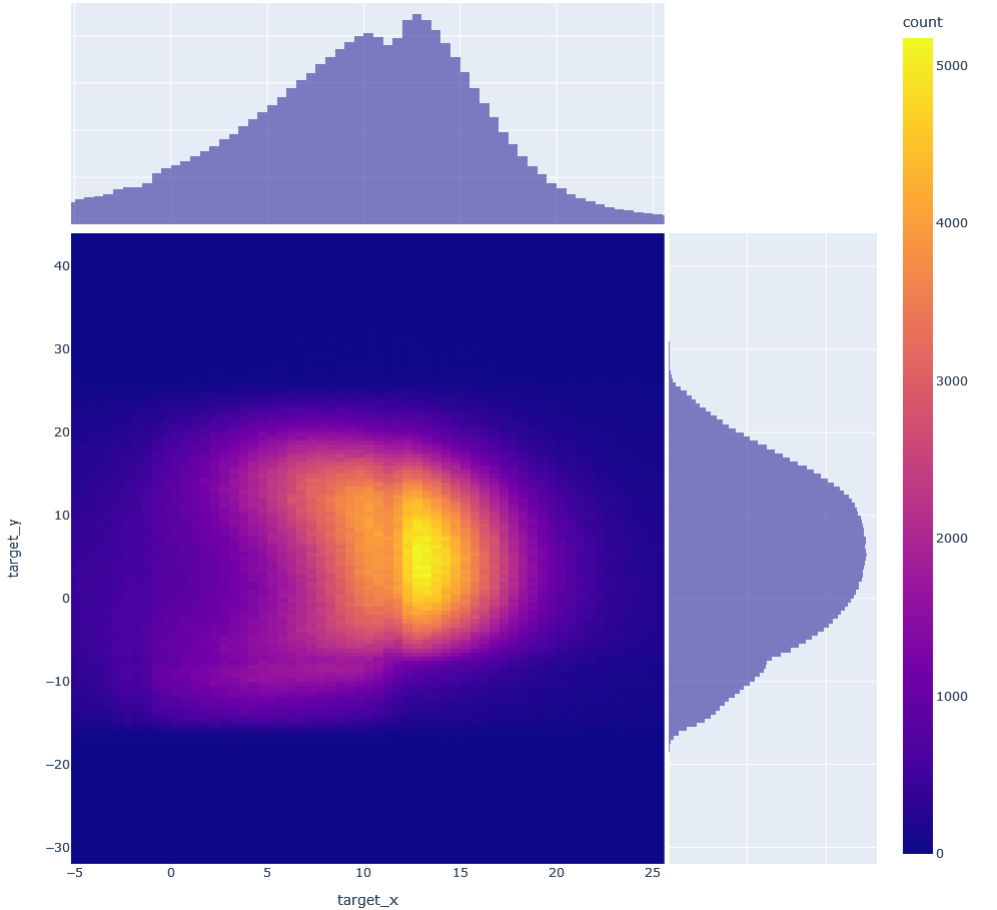

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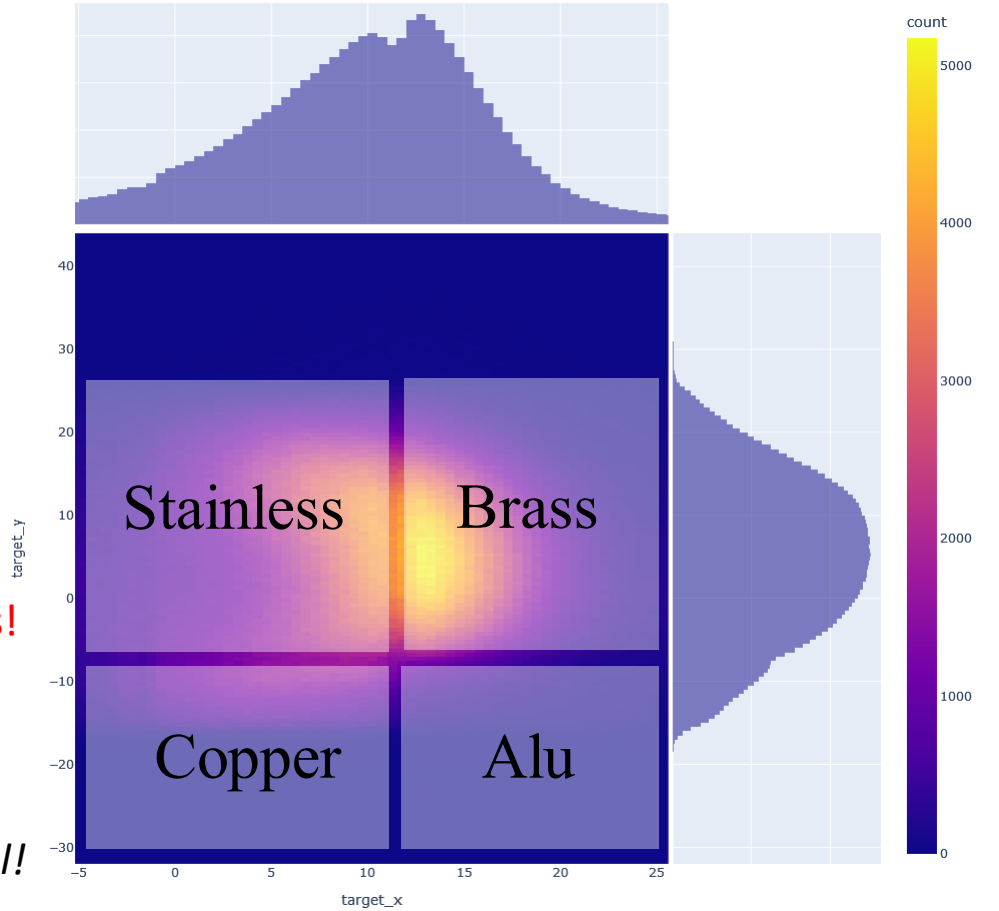
- Clear boundaries between materials!
  - cutting 2mm around boundary
    → 4 distinct spectra w/o overlap
  - combined resolution ~1.6 mm
    - *5cm ArCO2, 1cm Air, 2mm metal!*



Next step: Elemental (isotopic) imaging

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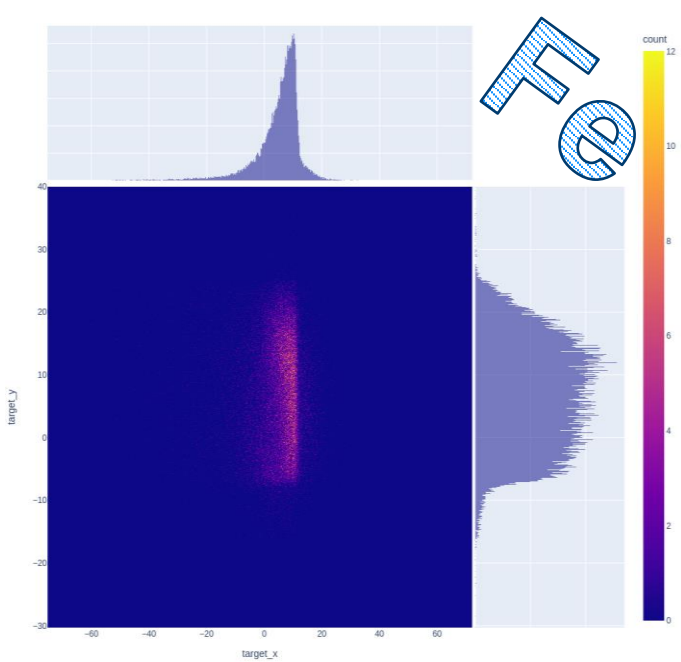

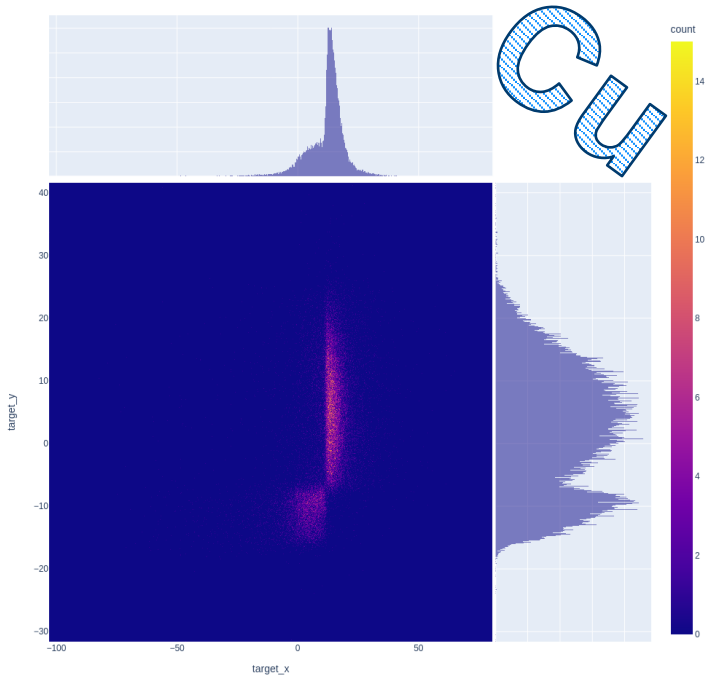

Preliminary conclusions

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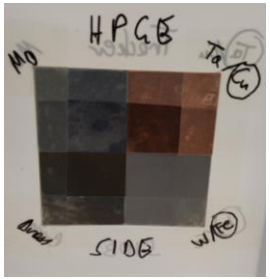
- *Major step towards element (or even isotope) sensitive 3D tomography*
  - first experiment showing this imaging technique/capability
  - momentum scans will provide depth information!
- Multiple scattering in the gas is a strongly limiting factor
  - *We need low density mixture, e.g. $HeCO_2$ (90/10)!*
  - Preparations underway to test with this mixture later this year
  - Development in collaboration with RD51/CERN

Improvements in September Beamtime

- Improved reference target
  - pure metals (except brass)
  - layered to check depth resolution
  - optimized total thickness
  - reproducible, more stable mounting
  - central alignment on beamspot



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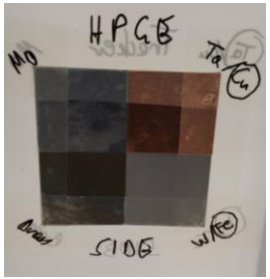

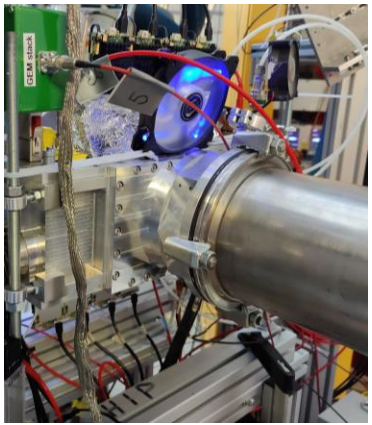

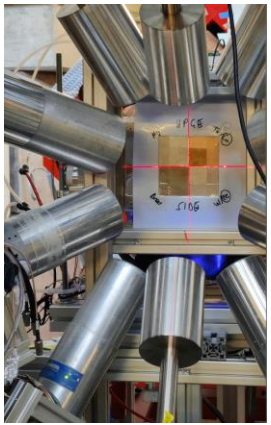

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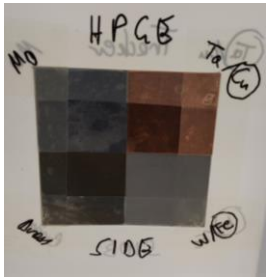
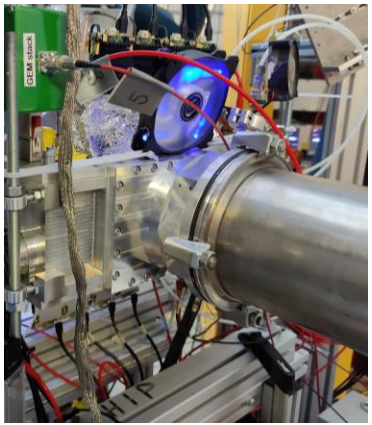
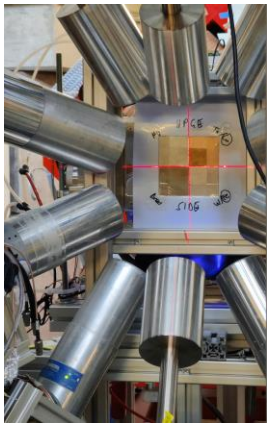
- Depth scanning to resolve material interfaces
  - 50, 52.5, 55, 57.5, 60, 65 MeV/c



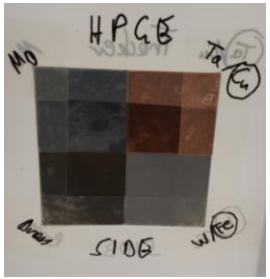


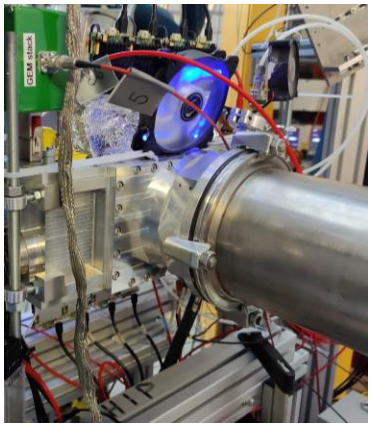


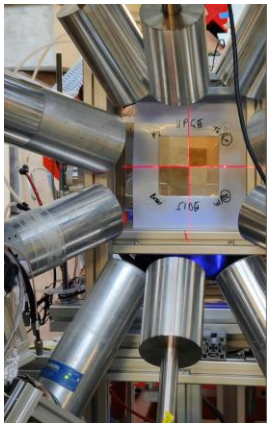
Improvements in September Beamtime

- Improved reference target
  - pure metals (except brass)
  - layered to check depth resolution
  - optimized total thickness
  - reproducible, more stable mounting
  - central alignment on beamspot
- Improved experimental setup
  - Tracker flanged directly on beampipe
  - factor 10 more HPGe detectors
- Depth scanning to resolve material interfaces
  - 50, 52.5, 55, 57.5, 60, 65 MeV/c
- Analysis ongoing!

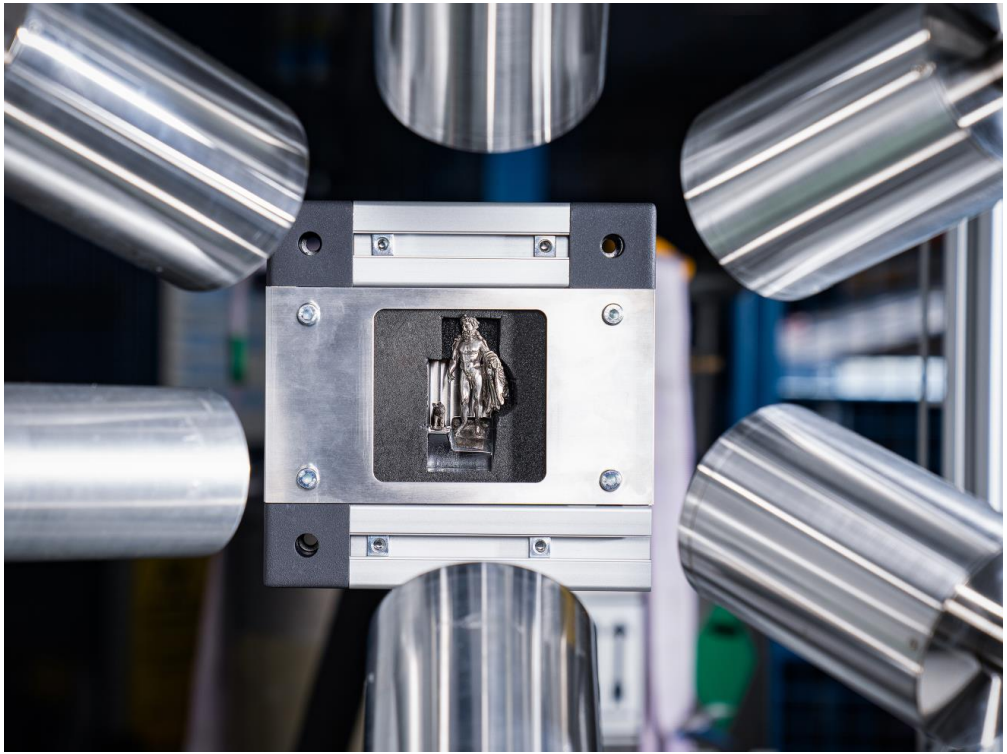
Stay tuned!







Thank you for your attention!



Any Questions, Comments or Suggestions?

Additional Materials

Synchronization difficulties

- Two separate DAQs:
  - SRS/VMM3a for Tracker
  - MIDAS/VME/SIS3316 for HPGe
- Multiple signals for synchronization in both DAQs
  - 1 kHz reference from signal generator
  - proton current (semi-regular)
  - entrance detector
- *However: multiple issues severely complicate sync!*
  - no common clock for ASICS → relative clock drift
  - tracker DAQ (readout?) sometimes drops events
  - different chunks missing in both DAQs (when new files start)

Fixed!

Event selection criteria (low rate run)

- Good events require the following:
  - Entrance detector shows muon without veto firing
  - Top and Bottom TPC each show a single cluster each within 10us window
  - HPGe fires within 1us after tagging
- Rate reduction
  - 8 kHz tagging rate (60 MeV/c, slits to minimum)
  - ~0.2 kHz events survive selection criteria
    - solid angle coverage of HPGe ~5%
    - tracker efficiency ~90% without multiplicity
- Improvements possible
  - require tag or matching hits in tracker with drift time sum
  - allow multiple hits in tracker