Production of the first ^{163}Ho implanted micro-calorimeters for the HOLMES experiment.

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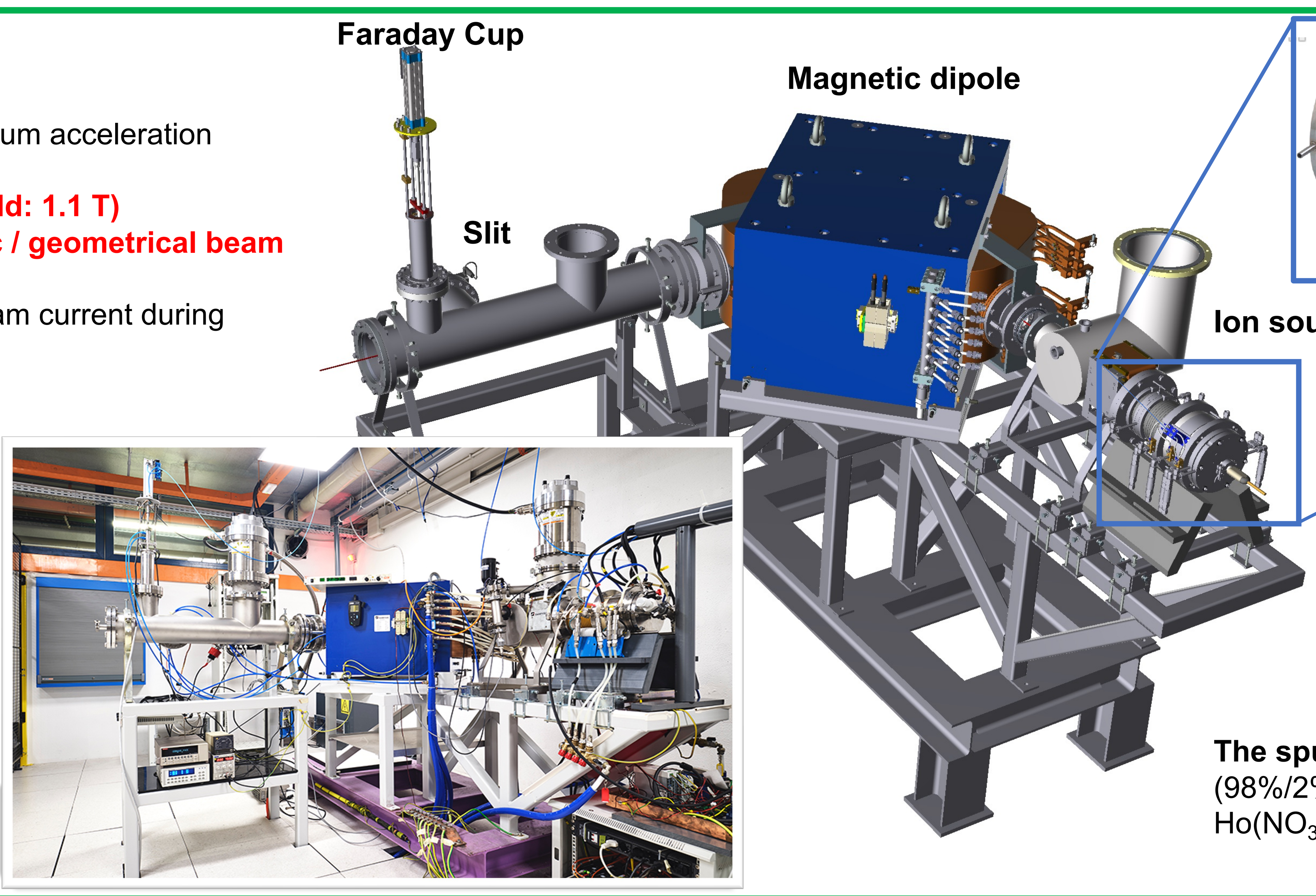
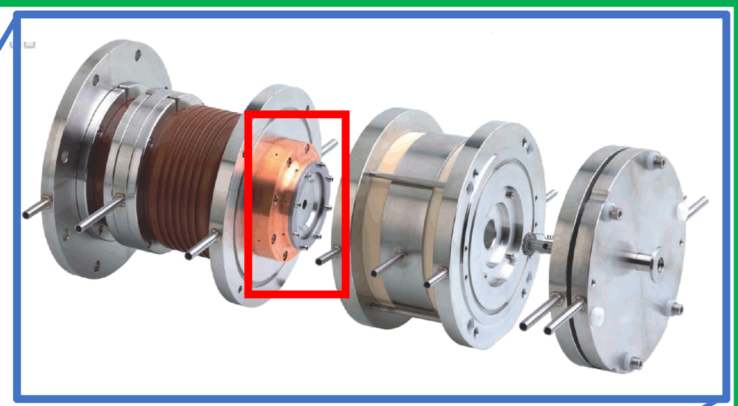
The HOLMES experiment aims to directly measure the ν mass studying the ^{163}Ho electron capture decay spectrum, developing arrays of TES based micro-calorimeters implanted with O(10^2 Bq/detector) ^{163}Ho atoms. In order to embed the ^{163}Ho source inside the detector, removing at the same time contaminants from other isotope, a dedicated implantation / beam analysis system has been set up and commissioned in Genoa's laboratory. After an intensive campaign of tests and calibration, the commissioning was completed in 2023 and we were able to implant the first set of arrays with an expected activity of 1 Bq / detector. In this work, the commissioning of the machine and results concerning the production of the first set of implanted TES will be shown. These detectors are currently taking the first physics data set of HOLMES. Moreover, future implanter upgrade needed to increase the maximum achievable activity on the TES array will be described.

The HOLMES ion implanter:

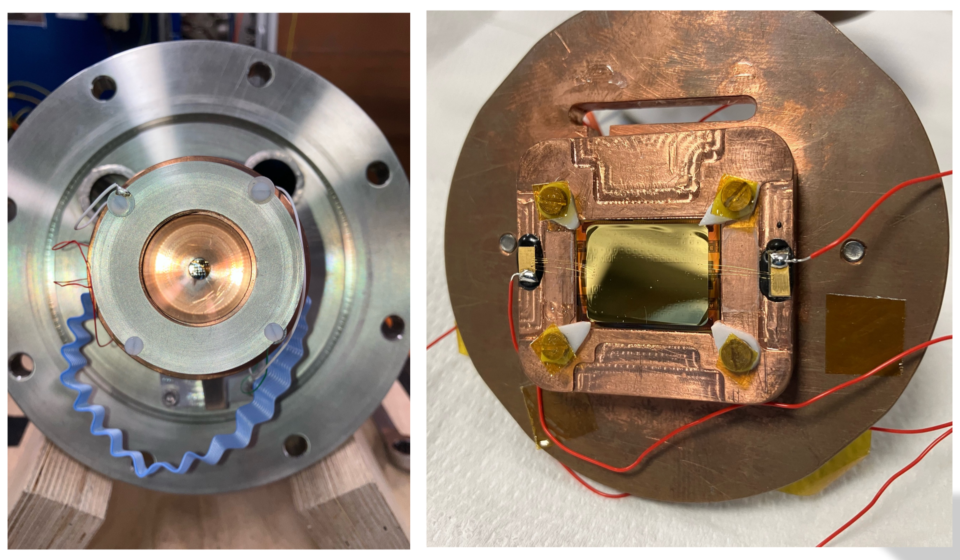
It is made by:

- **an argon Penning sputter ion source** (maximum acceleration energy: 50 keV);
- **a magnetic dipole mass analyzer (max. B field: 1.1 T)**
- **a Faraday cup and a slit for beam diagnostic / geometrical beam selection**;
- **a target holder**, able to measure impinging beam current during implantation run.





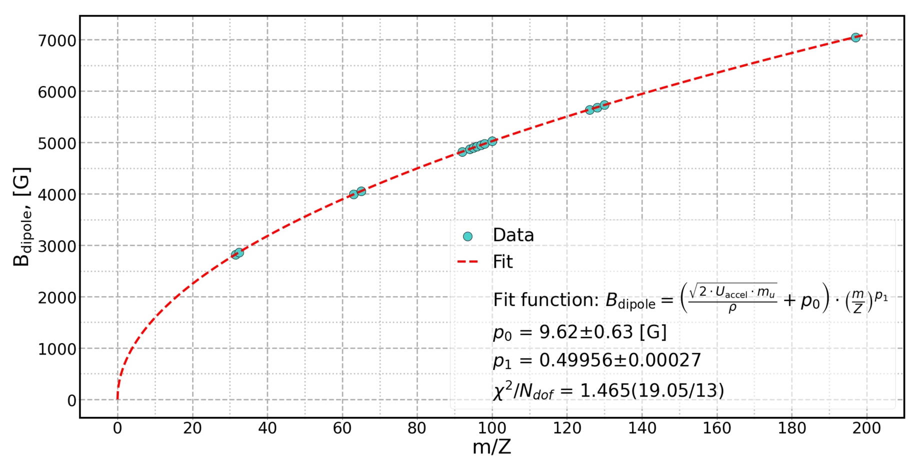
Faraday cup and target holder

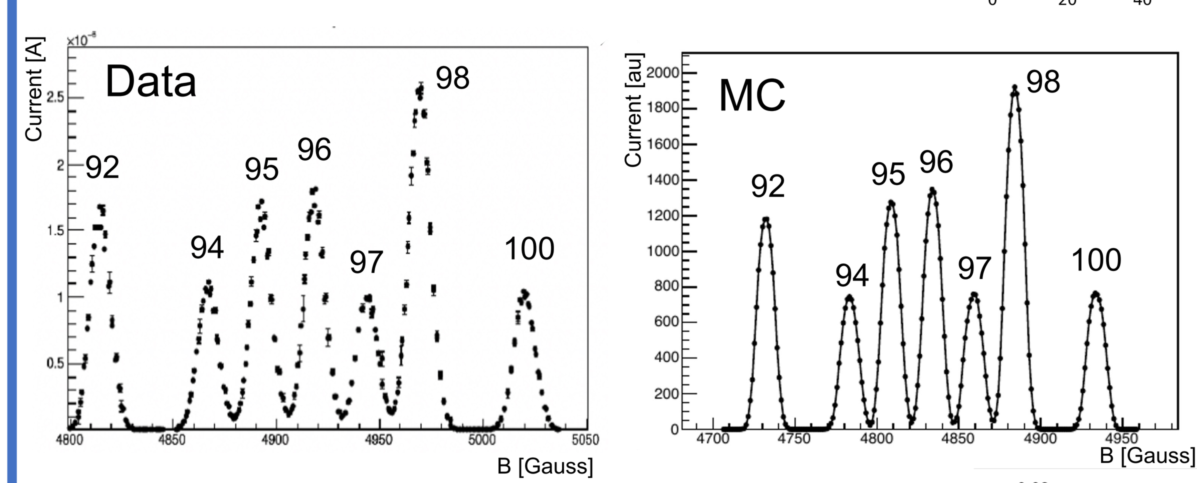


The sputter target consists of a Zr/Bi (98%/2%) sintered matrix on which a $Ho(NO_3)_3$ solution is "dripped" and dried.

Implanter commissioning:

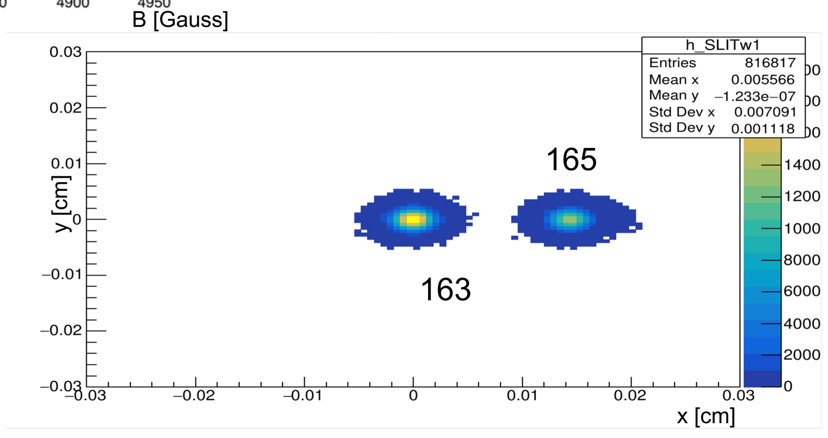
We use multiple peaks from Cu, Au and Mo to obtain a B vs M/Q relation and take into account for misalignment.

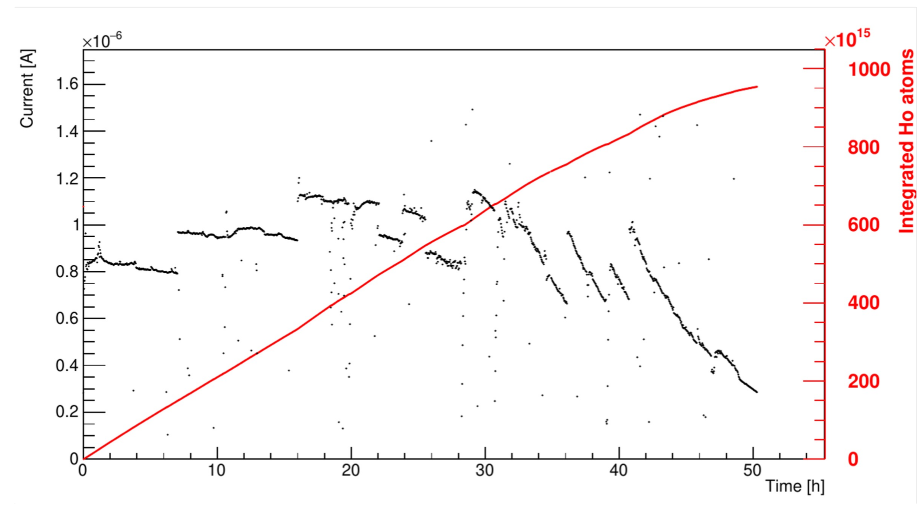




Multi-peaks element (like Mo) used to extract beam size (σ ~ 1.3 mm) and cross check MC simulation reliability.

163 vs 165 a.m.u. separation evaluated by MC simulation → expected to be about 15mm at slit plane → 166 a.m.u. expected to be ~ 22mm away from 16.3

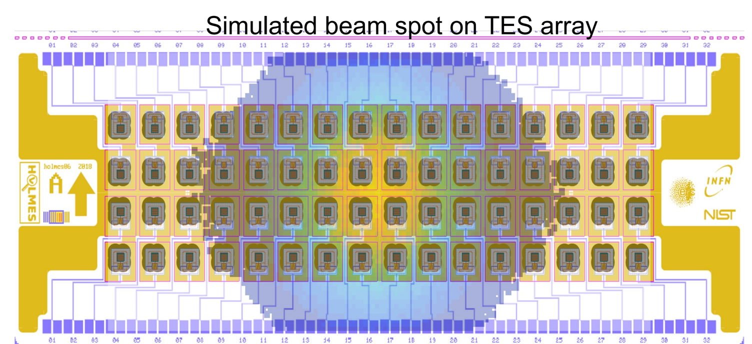


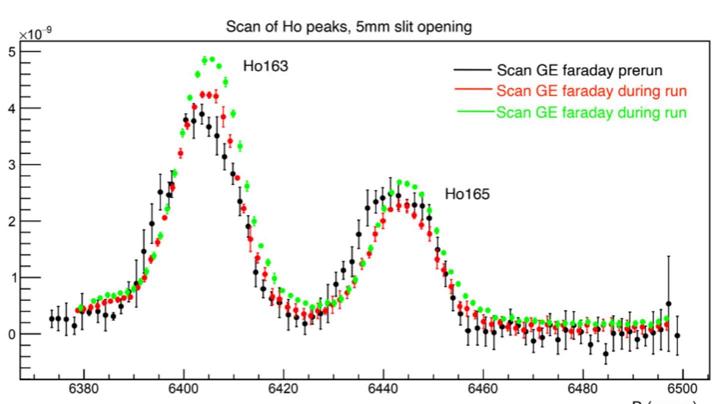


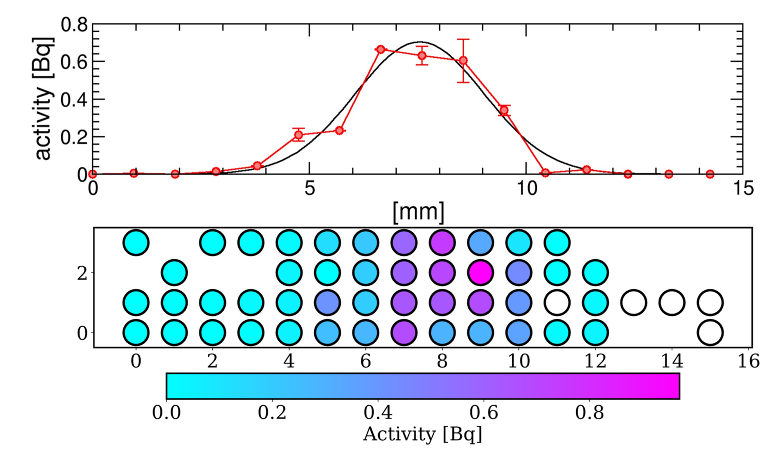
Extraction efficiency evaluated using ^{165}Ho, by acquiring long run (~ 50 h) up to a total consumption of a target, then comparing the integrated charge w.r.t. the ^{165}Ho content in target. ε ~ 0.2 %, enough to proceed to first implant.

First implantation and results:

We evaluated geometrical efficiency on a single spot (beam at fixed position) implantation by means of MC simulations.



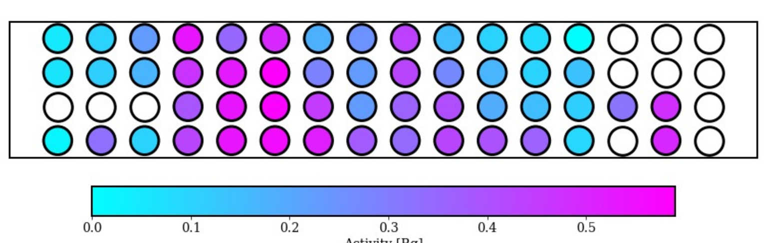


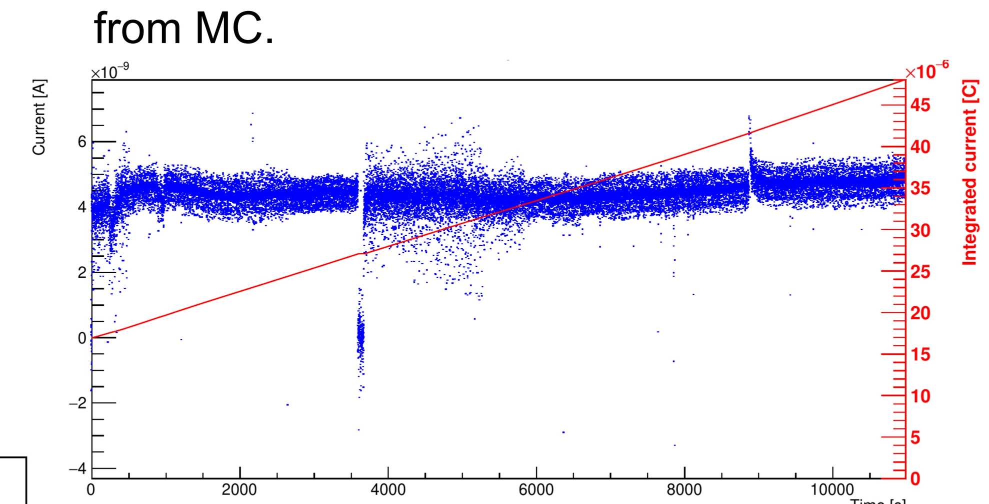


Activities on each TES were measured and a factor 2 discrepancy w.r.t. expectation was found: this is under study. A beam size of σ ~ 1.5 mm has been evaluated.

^{163}Ho / ^{165}Ho mass separation measured on data during implantation run : ~ 45 G, corresponding to ~15 mm, as expected from MC.

Finally, we implanted an array with 4 aligned spot in to get a near homogeneous distribution of activity in the TES.

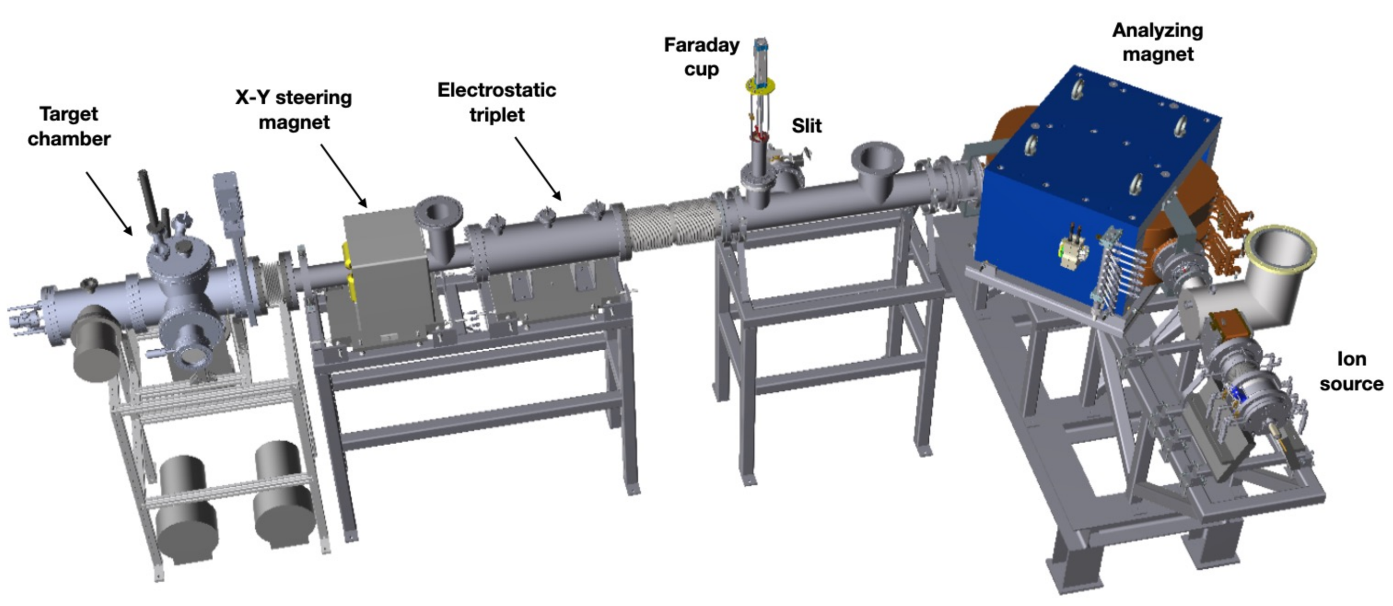


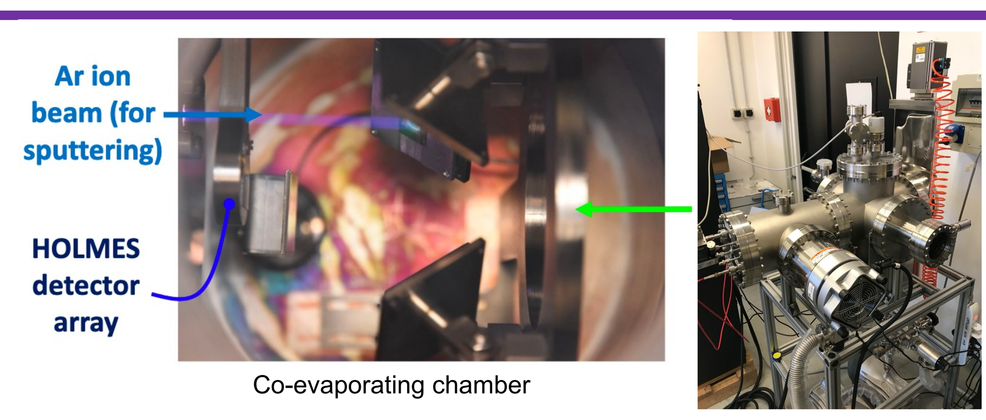


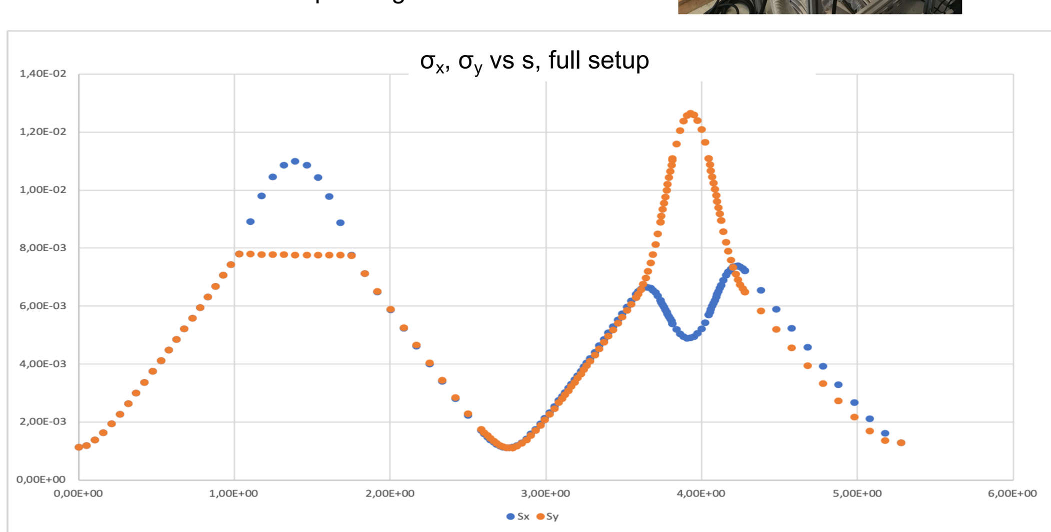
^{163}Ho beam current was measured on-line during implantation: we expected to have ~2Bq on central TES.

Even in the "multi-spot" implantation we found a discrepancy between expected and implanted activity, which will be investigated in the next runs.

Next steps: machine upgrade







To increase the maximum achievable activity and obtain a more effective beam handling, an upgrade of the beam line is currently on going. The setup will be extended by adding a quadrupole triplet, a x-y steering magnet and a target chamber to allow co-evaporation of Au during Ho implantation. With this configuration we expect to be able to get a beam size of σ ~ 1.1 mm.

Moreover, to increase the source extraction efficiency, we have to improve the ion source as well. Currently, we plan to move from a sputter based one to a resonant laser ionization source. R&D is on going.