Development and commissioning of the ion implanter for the HOLMES experiment.

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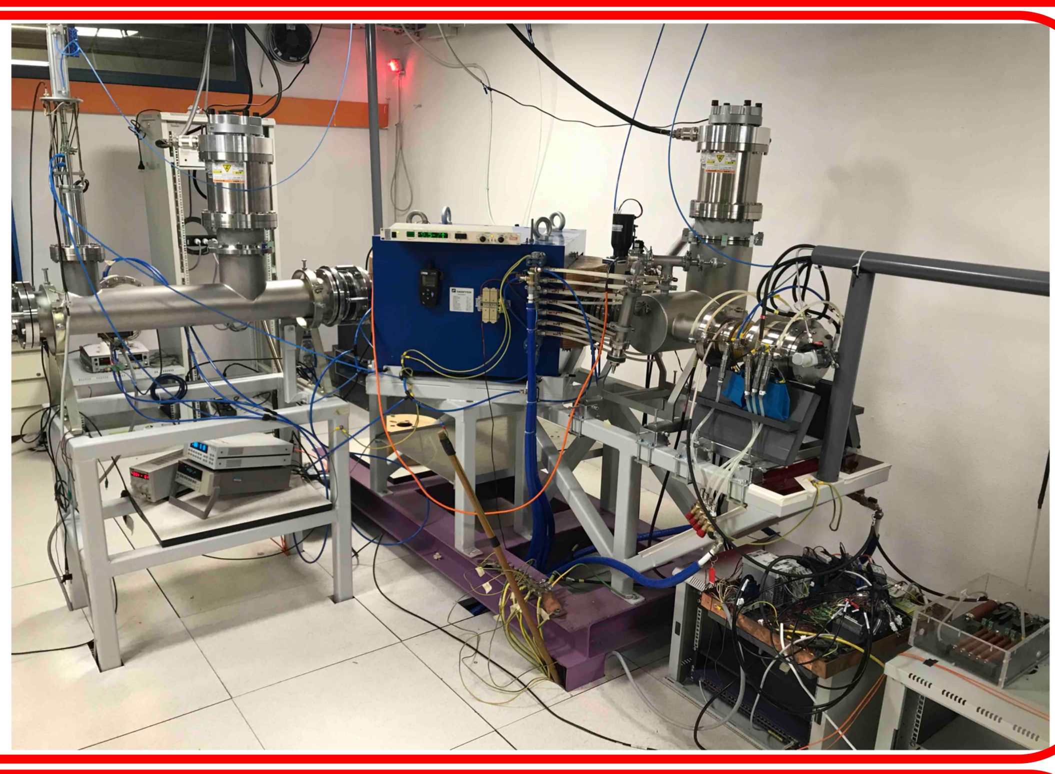
The HOLMES experiment aims to directly measure the ν mass studying the ^{163}Ho electron capture decay spectrum, developing arrays of transition edge sensors based micro-calorimeters implanted with O(10^2 Bq/detector) Ho atoms. The embedding of the source inside detectors is a crucial step of the experiment. Because ^{163}Ho is produced by neutron irradiation of a ^{162}Er sample, the source must be separated from a lot of contaminants. A chemical process removes every species other than Ho, but it is not sufficient to remove all background sources: in particular, ^{166m}Ho beta decay can produce fake signal in the region of interest. For this reason a dedicated implantation / beam analysis system has been set up and commissioned in Genoa's laboratory. It is designed to achieve more than 5σ separation @163/166 a.m.u. simultaneously allowing an efficient Ho atoms embedding inside microcalorimeter absorbers. Its main components are a 50 kV sputter-based ion source, a magnetic dipole and a target chamber. A specially dedicated co-evaporation system has been designed to "grow" the gold microcalorimeter absorber during the implantation process, increasing the maximum achievable activity which can be embedded. The machine performances in terms of achievable current, beam profile and mass separation have been evaluated by means of commissioning runs using Cu, Mo, Au and ^{165}Ho beams. A special care has been given to the search of an effective way to populate source plasma with Ho ions obtained from different Ho compounds, testing different target fabrication techniques. In this work, the machine development and commissioning will be described.

The ion implanter…

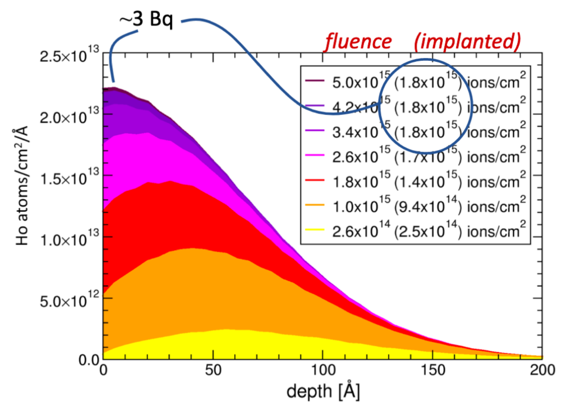
The main components of the machine are:

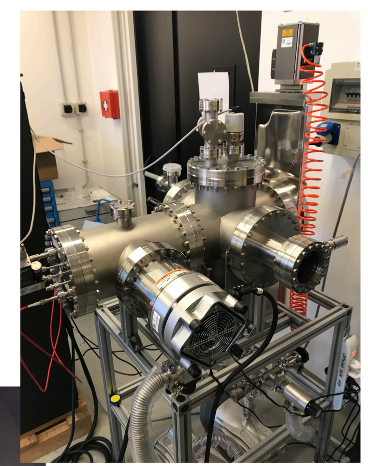
- **an argon Penning sputter ion source** with an acceleration section allowing to reach a maximum energy of 50 keV;
- **a magnetic dipole mass analyzer** with magnetic field up to 1.1 T;
- **a Faraday cup and a slit**;
- **a target chamber**, designed to allow simultaneous co-evaporation of Au (needed to encapsulate ^{163}Ho in the absorber).

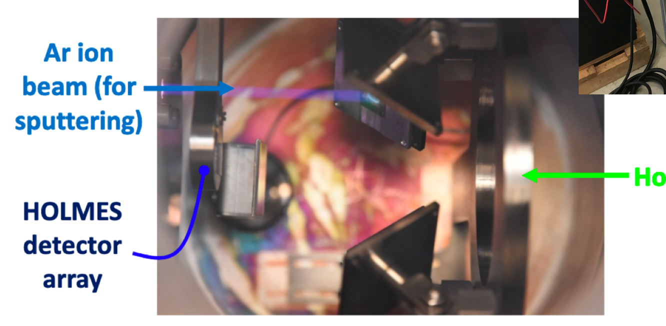


…and the target chamber

Ho concentration in absorbers saturates because after a while incoming Ho will start to sputter the already deposited one. This effect could be compensated by allows Au co-evaporation. Moreover, at the end of the process a final 1 μm Au layer will be deposited to fully encapsulate the Ho source. A dedicated chamber has been designed and commissioned.

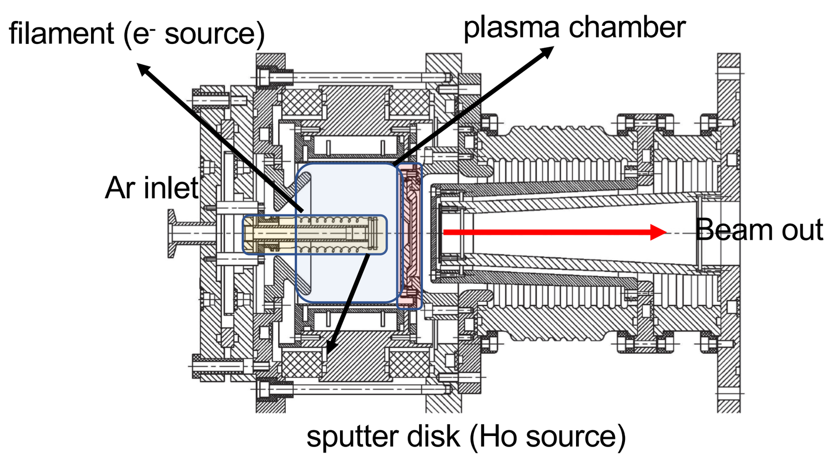






The ion source…

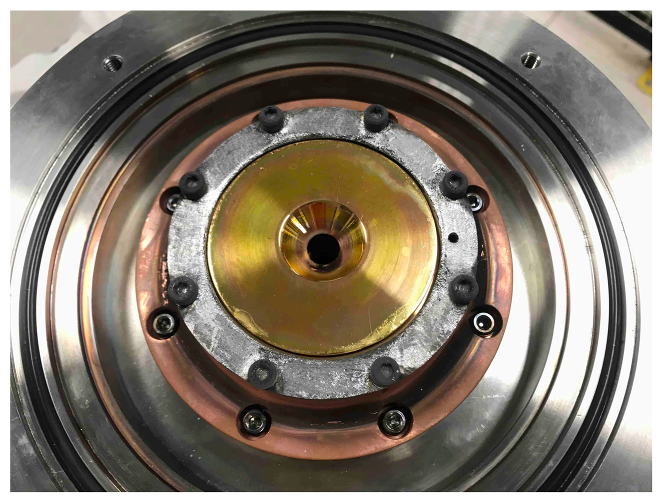
An argon Penning ion source with magnetic multipole/reflex ("bucket") configuration of the discharge chamber, allowing the creation of a quiet, cold and stable plasma of large cross section with densities suitable to form high-current and high-brightness ion beams. The possibility to mount a negatively-biased metal disk (sputter target) inside the discharge chamber in front of the outlet hole allows to populate the plasma with metal atoms of our choise sputtered off the disk.



…and the sputter target

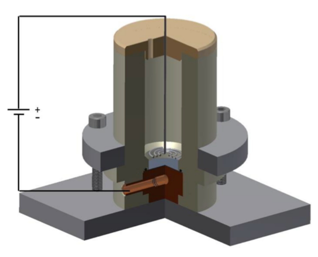
The sputter target consists mainly of a «bulk» target (materials under study: Ti and Mo) on which Ho compound has to be embedded. Currently we are testing 3 techniques for sputter target fabrication:

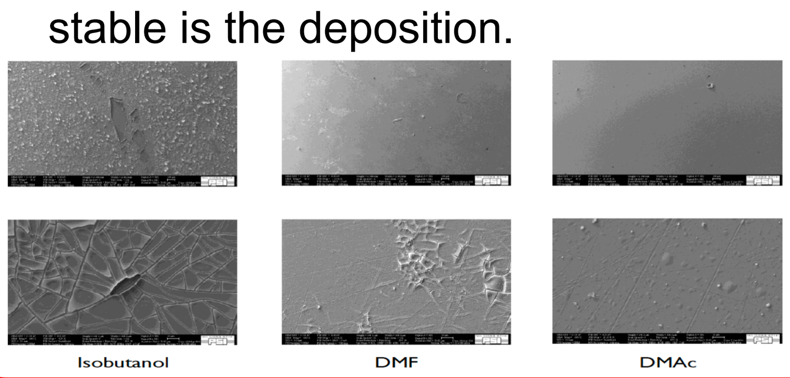
1. Molecular plating (PSI);
2. Sintered target (Chem. Department, UniGE);
3. Molecular plating + coupled reduction on Pd substrate (PSI)



Molecular plating

- High yield (> 90%) electrodepositon from an organic solvent;
- Produces very thin and uniform layer;
- Uniformity depends on solvent: the lower the vapour pressure is, the more stable is the deposition.





Sintered target

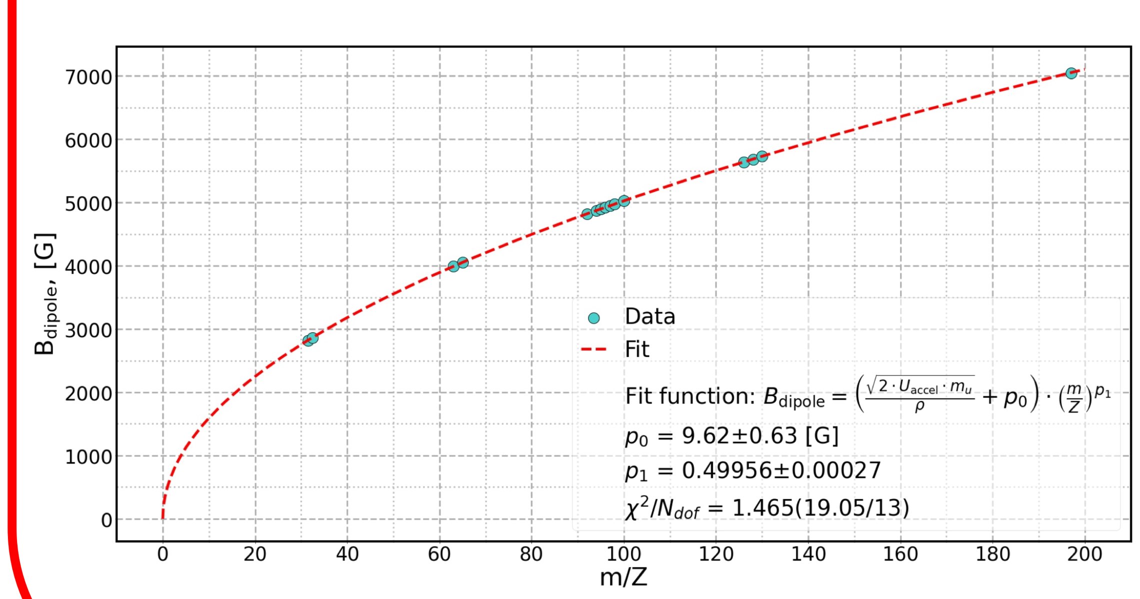
Sintered sputter target: including Ho (Ho(NO_3)$_3$) in a metallic mixture of Zr and Y fine-grained powder (95% to 5%). The compound is prepared in Ar atmosphere to prevent metal oxidation and then is compressed at 350 bar/cm² inside a specially designed mould. The obtained target is heated at 1000°C in a low-oxygen environment for 3 hours to improve the mechanical properties of the sinter.

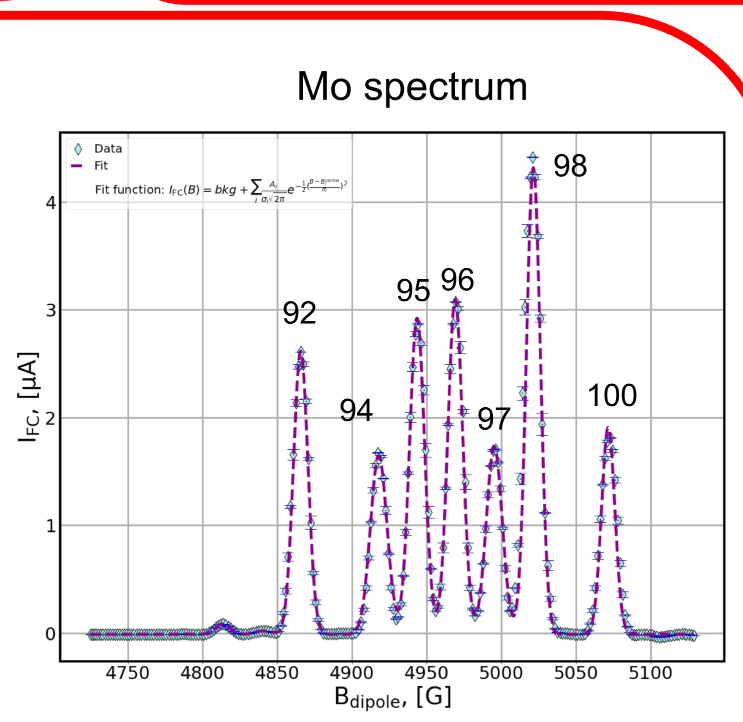
Coupled reduction on molecular plating:

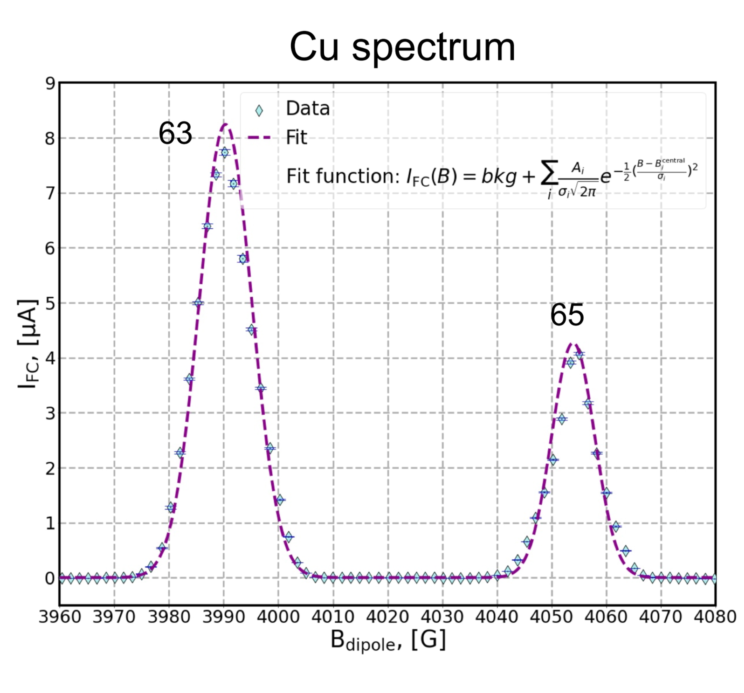
Coupled Reduction (CR): Ho reduction and diffusion into backing material (substrate) due to thermodynamically favourable formation of intermetallic compound. Start from a thin layer deposited by molecular plating on a thin (25μm) Pd substrate. Target is then fixed on a bulk Mo holder.

Implanter calibration:

The machine is calibrated using peaks from Ar, Cu, and Mo. These materials are always available (Ar from the discharge operating gas, Cu from sputter target bulk, Mo from source anode). From those peaks one could obtain a field vs M/Q relation and correct for misalignment: a small offset in magnetic field corresponding to ~ O(mm) radial beam shift has been measured and corrected. 165 a.m.u. peak is expected to be at 6458 G (@25 keV acceleration energy). Adjacent peak separation at 63 a.m.u. (from copper data) is 31 G, corresponding to 15 mm evaluated on MC simulation. Extrapolation to 163 a.m.u. / 166 a.m.u. gives 18.8 mm separation. Vertical alignment has been checked by scanning steering magnet currents.







Some results @165 a.m.u.:

- Tests with different natural ^{165}Ho-containing targets (molecular plating on bulk Cu, Ti-Ni-Sn-Ho sinter, Zr / Y sinter) show clear peak, O(10 nA - 100 nA), at 165 a.m.u.
- Fabrication of a target which could provide a stable current is not straightforward: i.e., using molecular plated target w are able to sustain a O(10 nA) current for less then 2 hours…
- Target warm-up could be an issue? Deposited material could be suddenly evaporated? More studies ongoing…
- Best current-stability: O(200 nA) over ~15 h, with Ho(NO_3)$_3$ on Zr-Y sinter target.
- Coupled reduction of Ho on Pd substrate to be tested soon.
- Next milestone: implant of first 64-TES array with low dose ^{163}Ho (≈ 1 Bq) without focusing.