A gas ionization chamber and time-of-flight detector for heavy ion elastic recoil detection analysis

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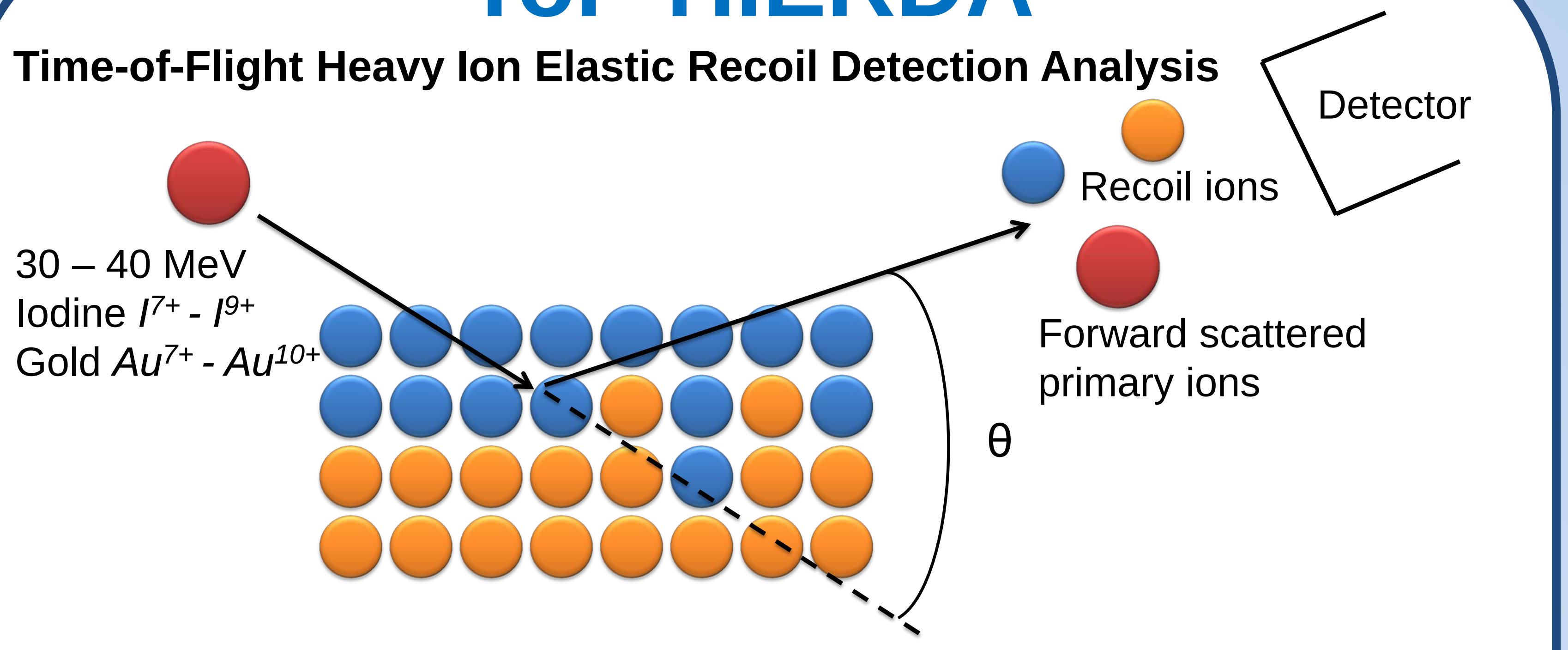
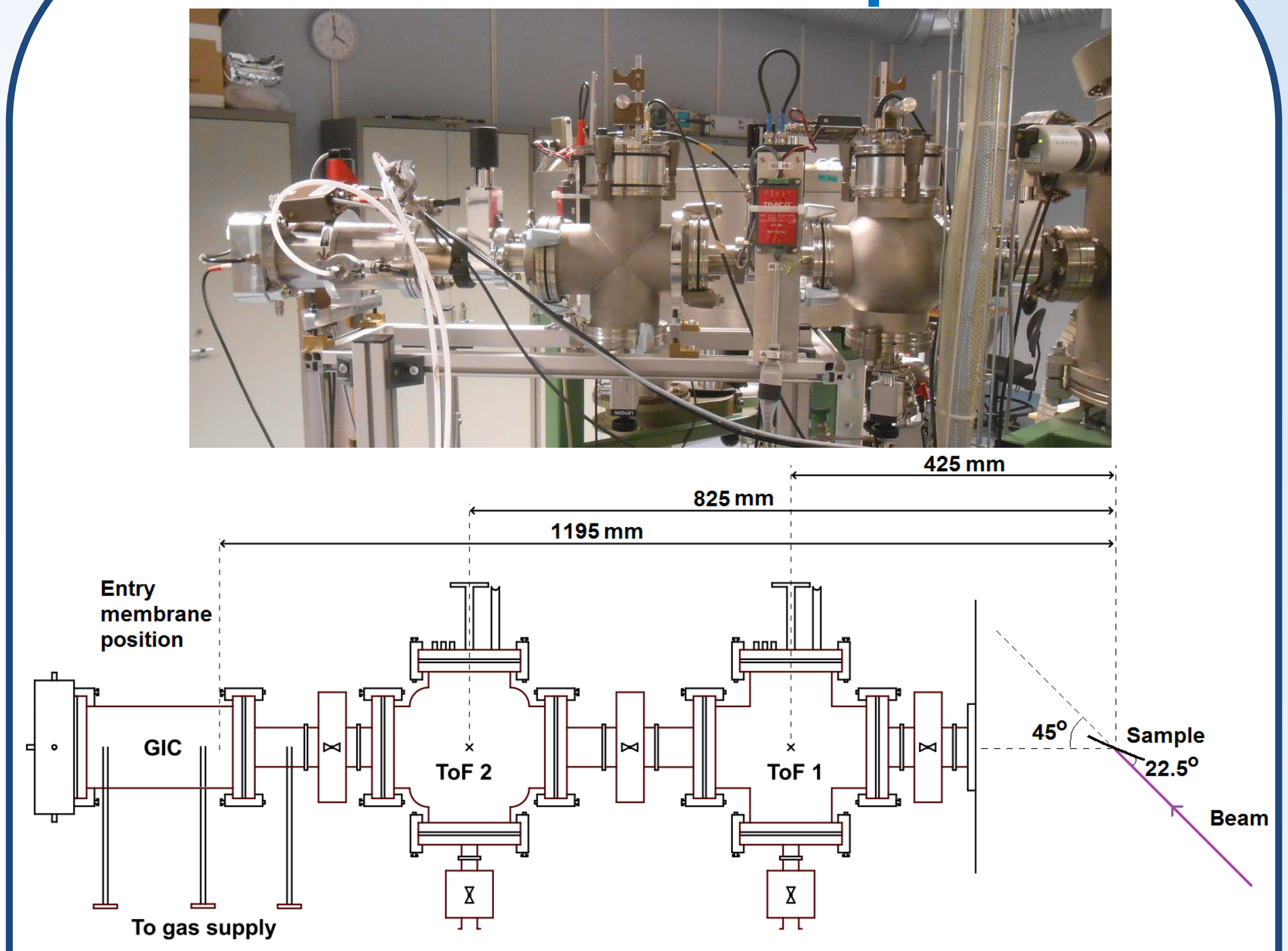
ToF-HIERDA

Time-of-Flight Heavy Ion Elastic Recoil Detection Analysis



ToF-HIERDA is a surface analysis method in which a sample is exposed to a beam of heavy ions (analyzing beam) with energy up to a few tens of MeV. The angle between the beam and the sample surface is small, typically 22.5 ^{0}. Particles knocked out from the surface (recoil ions) have their velocity and energy measured. Knowing these quantities gives the mass of each ion. Since the collision kinematics are known, the measured energy can also be used to infer the energy lost as ions pass through the sample material. From the energy loss, the depth of origin of each detected ion is calculated. The end result is a set of concentration depth profiles for all elements in the first micrometer beneath the surface of the sample.

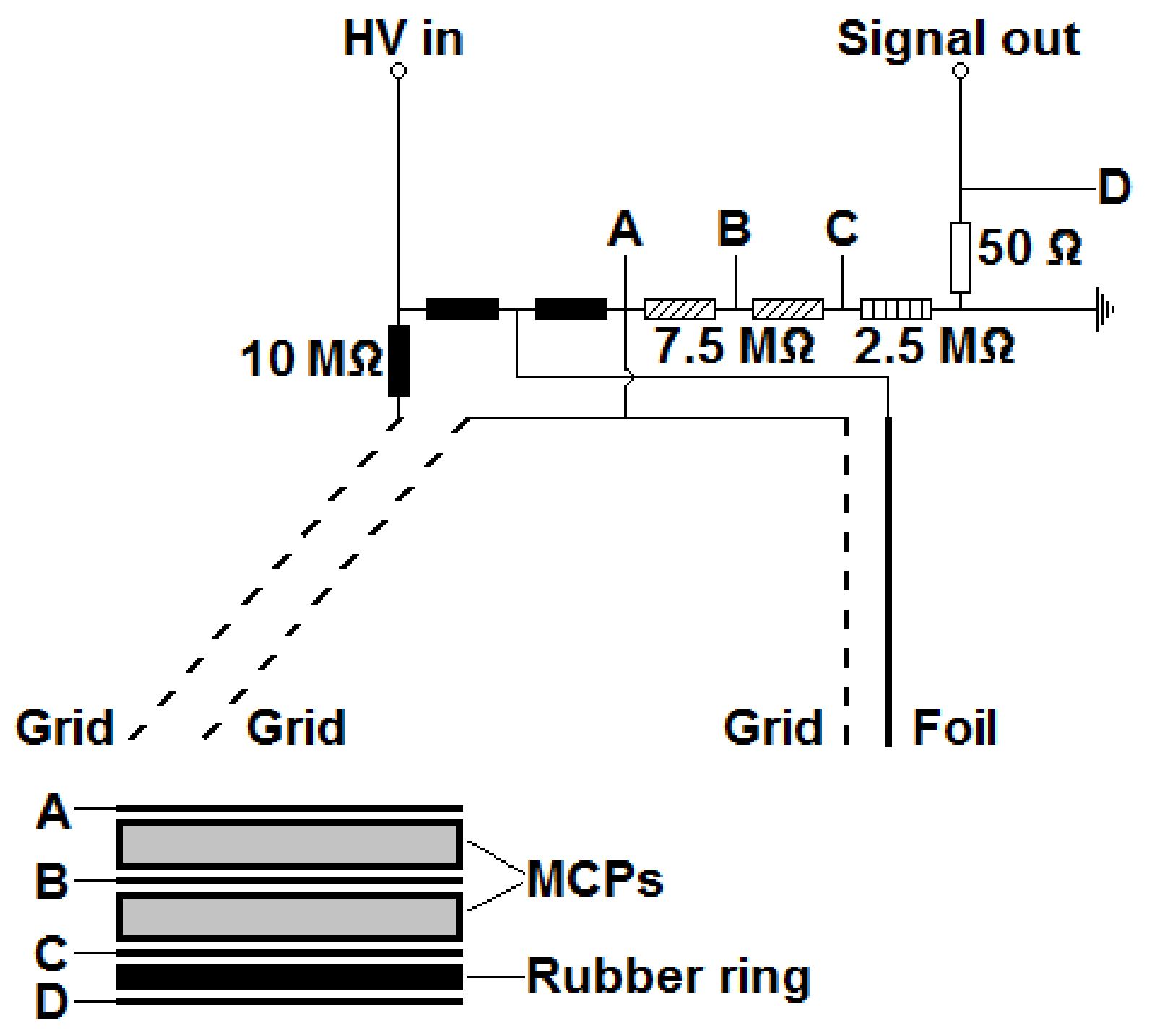
Detector setup



Schematic drawing (lower) and photograph (upper) of the detection system. The analyzing beam hits a sample in a chamber at the right side of the depicted region and the detection system is placed at 45^0 with respect to the forward beam direction. Two time-of-flight (ToF) detectors, with a flight distance of 400 mm between them are used to record the velocity of recoil ions. The gas ionization chamber (GIC) to the left stops the ions in isobutane at 30 mbar and records their energy.

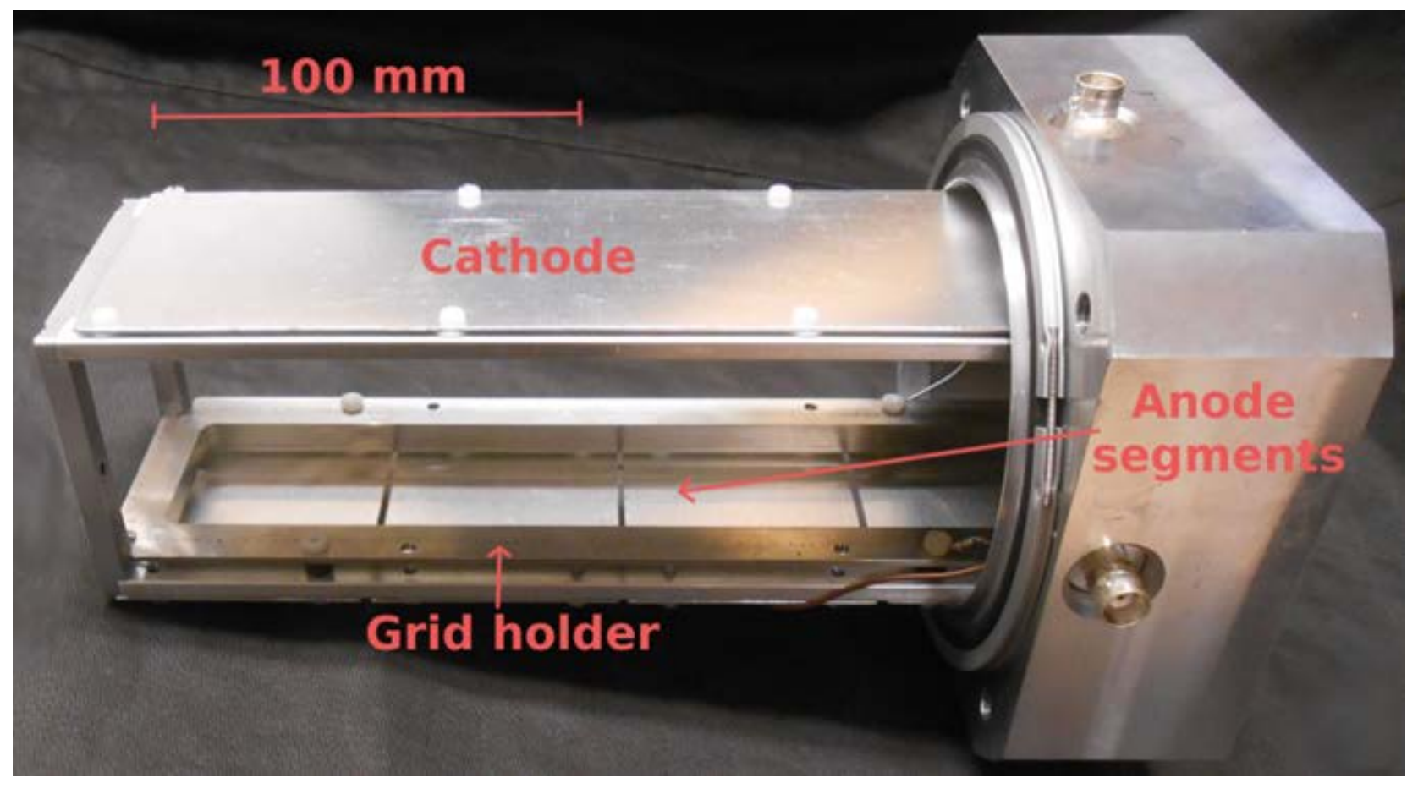
Features

Time-of-flight



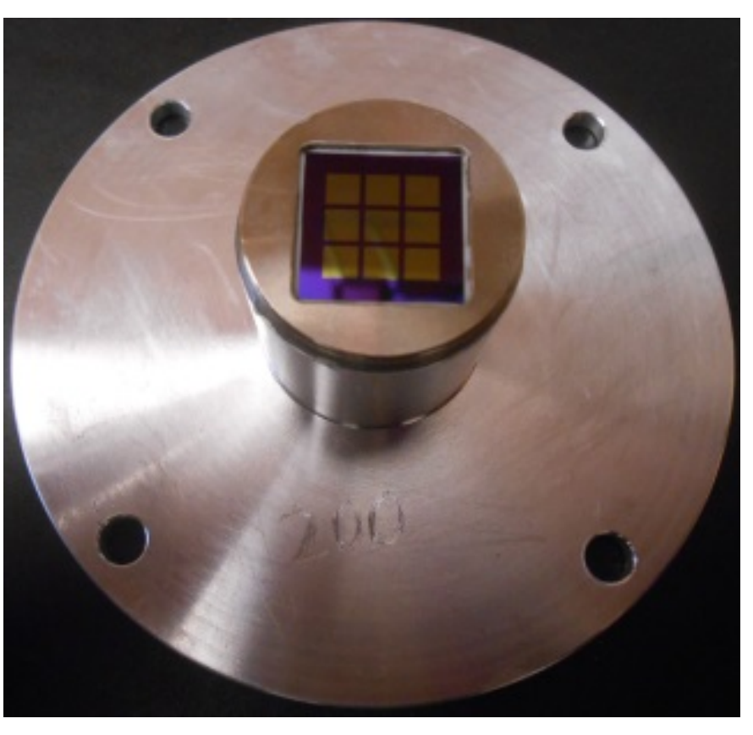
In each ToF detector the ions pass through a 22 nm thick carbon foil (5 µg of carbon per cm^2) and cause a number of electrons to be ejected. These electrons are accelerated towards a pair of microchannel plates in order to amplify the signal. The signals from both detectors are used as start- and stop signals for a time to amplitude converter whose output is therefore dependent on the flight time.

Gas ionization chamber

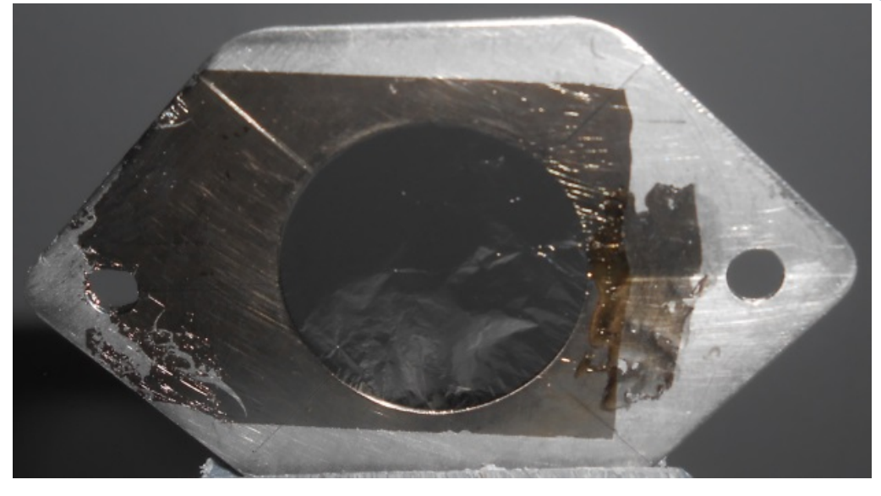


The GIC can be thought of as a gas filled capacitor. When an ion enters the gas volume, it creates electron/ion pairs by colliding with gas molecules along its trajectory. An applied voltage causes electrons to be attracted to the anode and ions to be pushed towards the cathode. The resulting voltage drop across the capacitor is dependent on the ion energy. A grid above the anode helps improve energy resolution. The anode is divided into 4 segments used to register parts of the energy signal [1]. This gives a stopping power based identification of ions and therefore resolves nuclear charge number.

Membranes



To isolate the pressurized region in the GIC from the vacuum maintained in the rest of the system, a 75 nm thick silicon nitride window is used. Ions enter the detector through the window which is kept as thin as possible to minimize the ions' energy loss. Energy straggling in the window limits the overall resolution of the detection system.

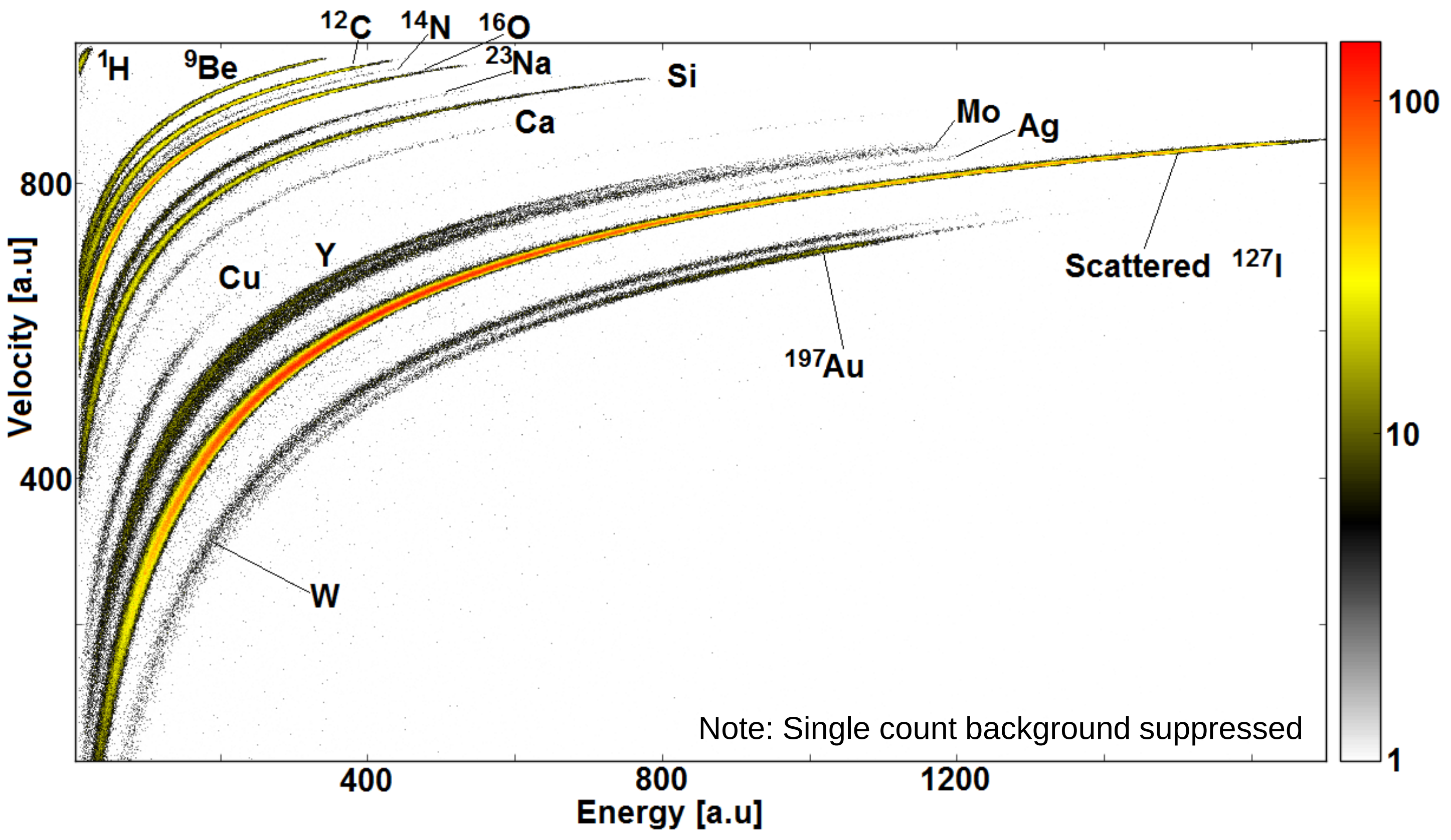


The carbon films in the ToF detectors do not have to sustain a pressure gradient and as such they can be kept thinner than the GIC entry window. Their effect on resolution is limited.

Performance

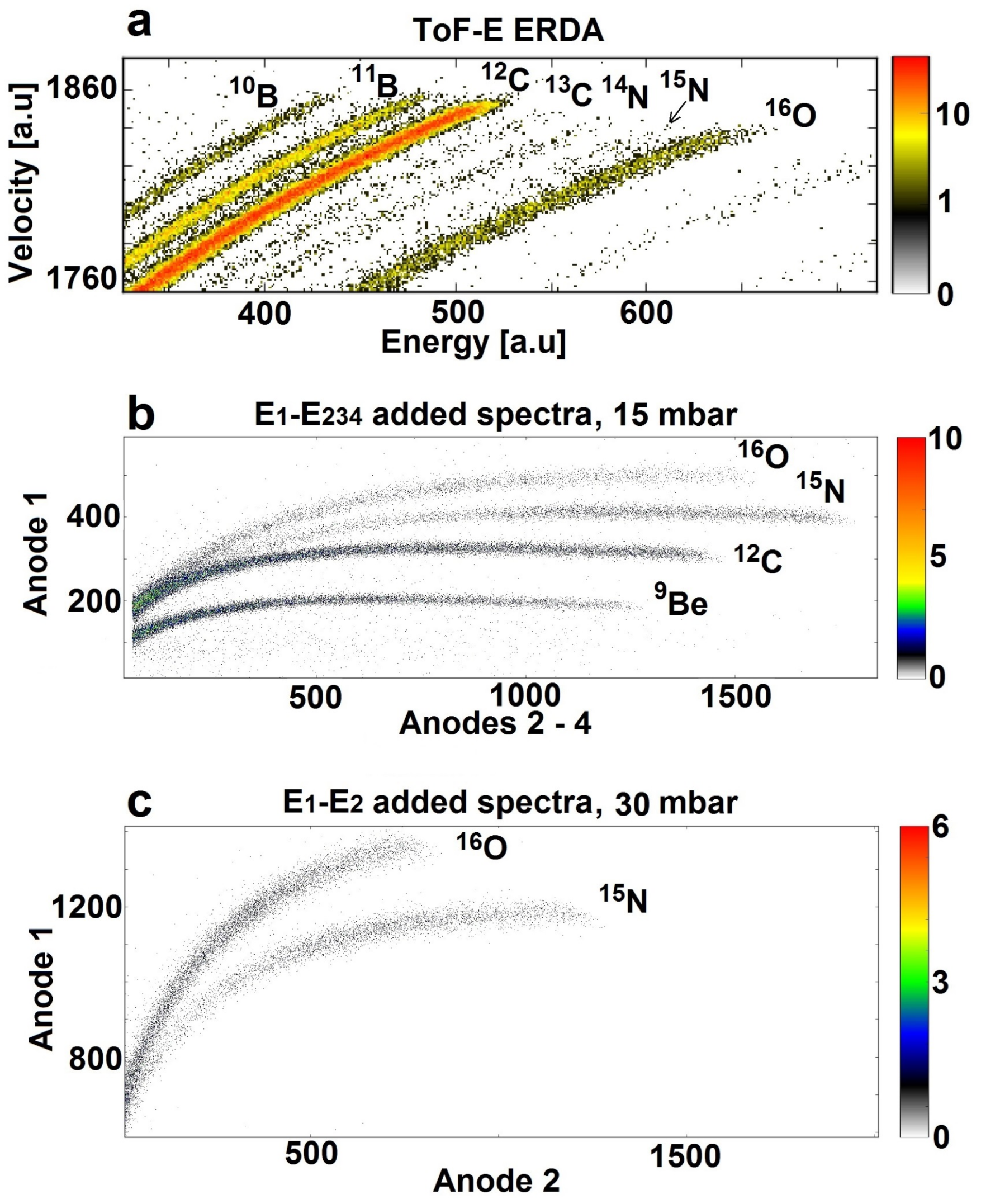
ToF/Energy: mass identification

By connecting all anode segments in the GIC in parallell one measures the full energy of recoil ions. The figure below shows a 2D histogram with the full energy on the x-axis and the time-of-flight signal on the y-axis for a series of ToF-HIERDA measurements on reference samples containińg a range of both light and heavy elements. The color scale gives the number of counts in each channel. Apart from the elements found in the reference samples, there is also a signal corresponding to forward scattered iondine ions from the analyzing beam. Using the detection system in this way is thought of as regular ToF-HIERDA and it has the benefit of usually being able to quantify all elements present in a sample in one run.



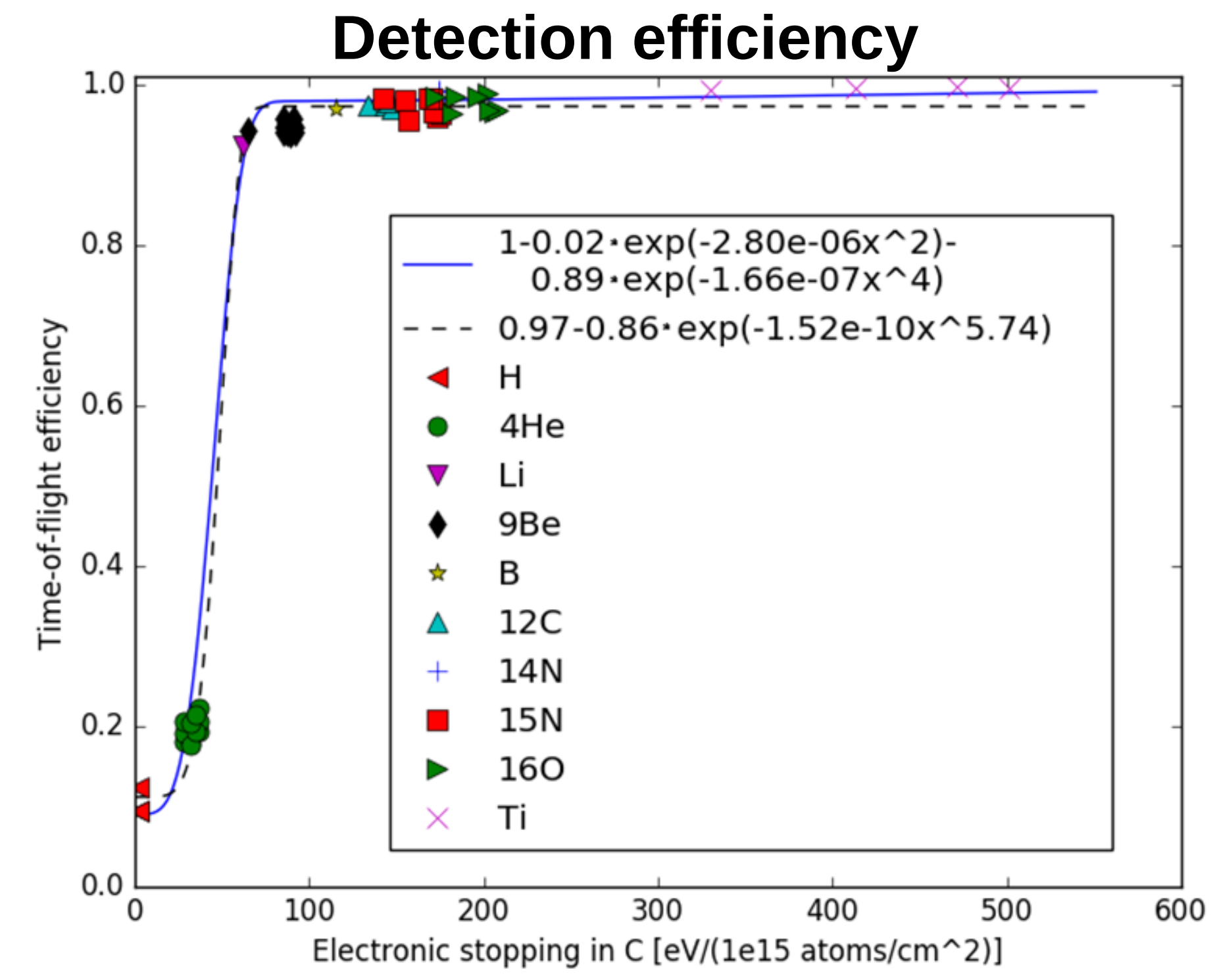
Note: Single count background suppressed

Partial energy signals: stopping power identification



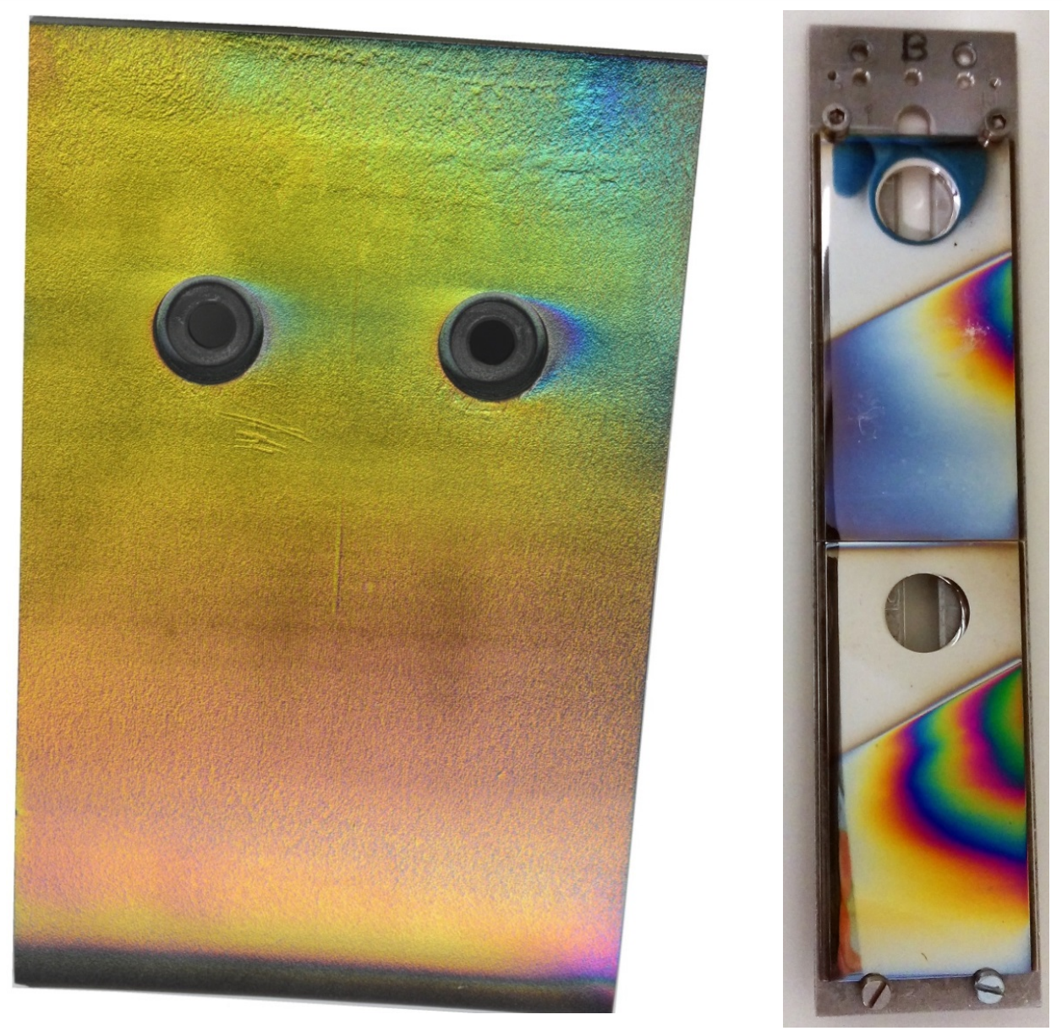
If one wants to measure small amounts of an isotope when there is a large amount of some other isotope of similar (or same) mass present, the method based on full energy is inadequate. Here, that method is compared to using the partial energy signals from the anode segments in the GIC to separate signals from ^{15}N and ^{16}O. Fig. **a** shows a ToF/energy spectrum containing those two signals among others. Figs. **b** and **c** instead show separation of elements based on plotting different partial energy signals against each other. By using the detection system in this way, a clearer separation between ^{15}N and ^{16}O is obtained.

Detection efficiency



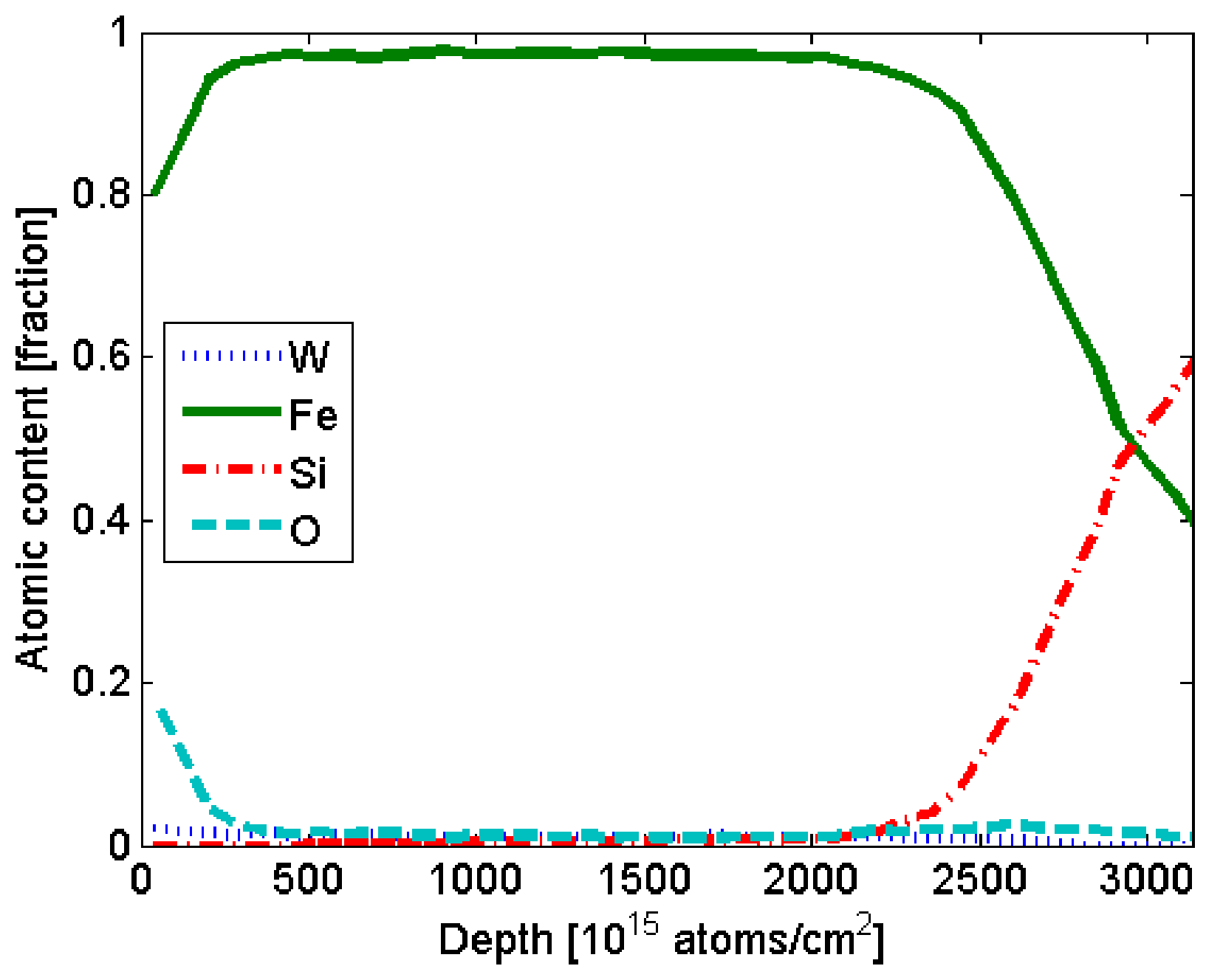
If the interaction of an ion with the carbon film in either ToF detector produces too few electrons (or none at all), the flight time will not be registered and the count is lost. This effect must be compensated for not to under-estimate the amount of light elements.

Fusion applications



Plasma facing components such as limiter tiles (left) and instrument covers (right) can be probed for deposited material with ToF-HIERDA. Metal mirrors used for diagnostics are studied to compare the thickness and composition of deposited layers to changes in reflectivity. Low activation steels are examined to quantify surface enrichment of tungsten after deuterium sputtering.

Typical result from ToF-HIERDA



This figure shows the elemental composition depth profiles of an iron and tungsten film deposited on silicon. Such films are used for studies of sputtering. In this case the film is oxidized at the surface.

[1] P. Ström et al., A combined segmented anode gas ionization chamber and time of flight detector for heavy ion elastic recoil detection analysis, Rev. Sci. Instrum. **87** (2016), 103303

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