Laboratory Calibration of Low-Energy ENA Instruments for Space Science

Jonathan Gasser,* André Galli, and Peter Wurz

Space Research and Planetary Sciences, University of Bern

* contact: jonathan.gasser@unibe.ch

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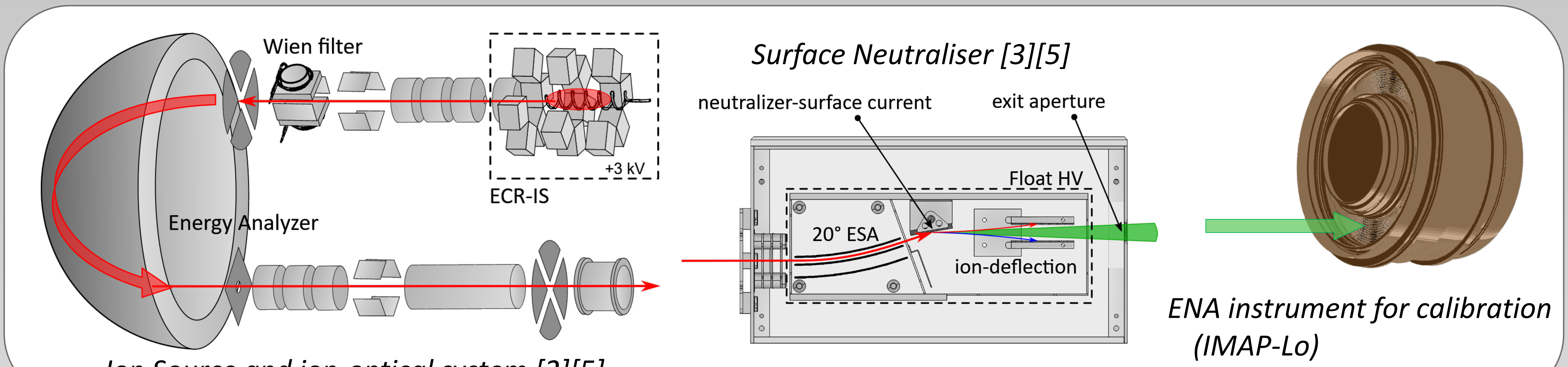

Figure 1: Schematic of ENA instrument calibration with the laboratory neutral atoms beam source [5].

MOTIVATION

What is interesting about low-energy ENA ?

Imaging of Energetic Neutral Atoms (ENA) is a well-established observation technique in space research. It allows in situ and remote observation of space plasma populations from planetary magnetospheres to the heliosphere and interstellar medium. For example, the upcoming Interstellar Mapping and Acceleration Probe (IMAP) mission [1] will observe the global heliosphere and its interaction with the local interstellar medium in great detail. There are three ENA instruments included, of which IMAP-Lo covers the low-energy range. It is of particular interest as the heliospheric ENA energy distribution peak and observed interstellar neutrals populations fall into this range.

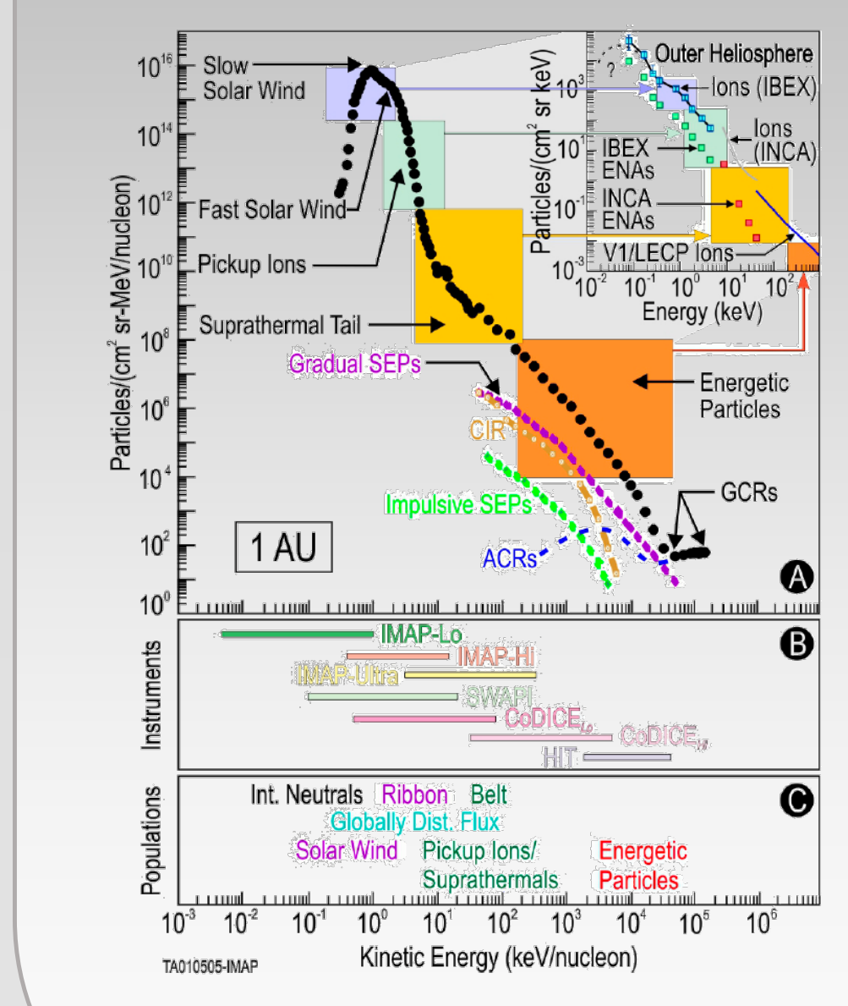

Figure 2: heliospheric ENA energy spectrum, IMAP instrument ranges, and populations. [1]

Calibration – why is it important?

Detection and imaging of ENA in space is generally challenging, as neutral atoms have to be charged up prior to their electrical analysis and detection in the instrument. This requirement limits the overall throughput and geometric factor of spaceborne ENA imaging instruments – especially ENA at energies below a few 100 eV:

Low-energy ENA are scattered at grazing incidence angle off a charge-state conversion surface. The conversion efficiency for light atoms is just a few percent (up to about 15% for oxygen), and the scattering process introduces considerable angular divergence, lowering the throughput of the ENA instrument's ion-optics system.

Moreover, particle fluxes from the sources are usually low ($\lesssim 100\ cm^{-2}sr^{-1}eV^{-1}$), which typically leads to very low ENA count rates.

Thus, thorough instrument calibration in a dedicated test facility is a crucial step in the development and testing.

FACILITY

The MEFISTO calibration facility [2] at Uni Bern is well suited to carry out calibrations of low-energy ENA instruments:

It provides laboratory neutral atom beams of all species of interest at the relevant low-energy range from 3 keV down to as low as 10 eV.

- large (1.20m x 1.40m) vacuum test chamber for instrument calibration
- 5-axis hexapod motion table
- 2.45 GHz microwave-induced electron-cyclotron resonance (ECR) ion source
- Collimated ion beams from any atomic species
- 3 keV/q ion beam extraction (up to 100 keV/q)
- Beam guiding system and beam scanner
- Calibrated Surface Neutraliser [3][5]

METHODS

The required low-energy laboratory ENA beams are obtained from respective ion beams via surface neutralisation in a dedicated neutralization stage. [3] Calibration beams of the species relevant for heliospheric and interstellar ENA observations are readily available.

Surface Neutraliser

- On-surface neutralization of ion beams
- Energy adjustment by float retarding potential and electrostatic analyser (20° ESA, see *figure 1*)
- Ion-deflection plates
- Real-time monitoring of neutral beam intensity by pA-meter surface current measurement
- **Calibrated fluxes and neutral beam energies** [5] for relevant species: **H, D, He, O, Ne**

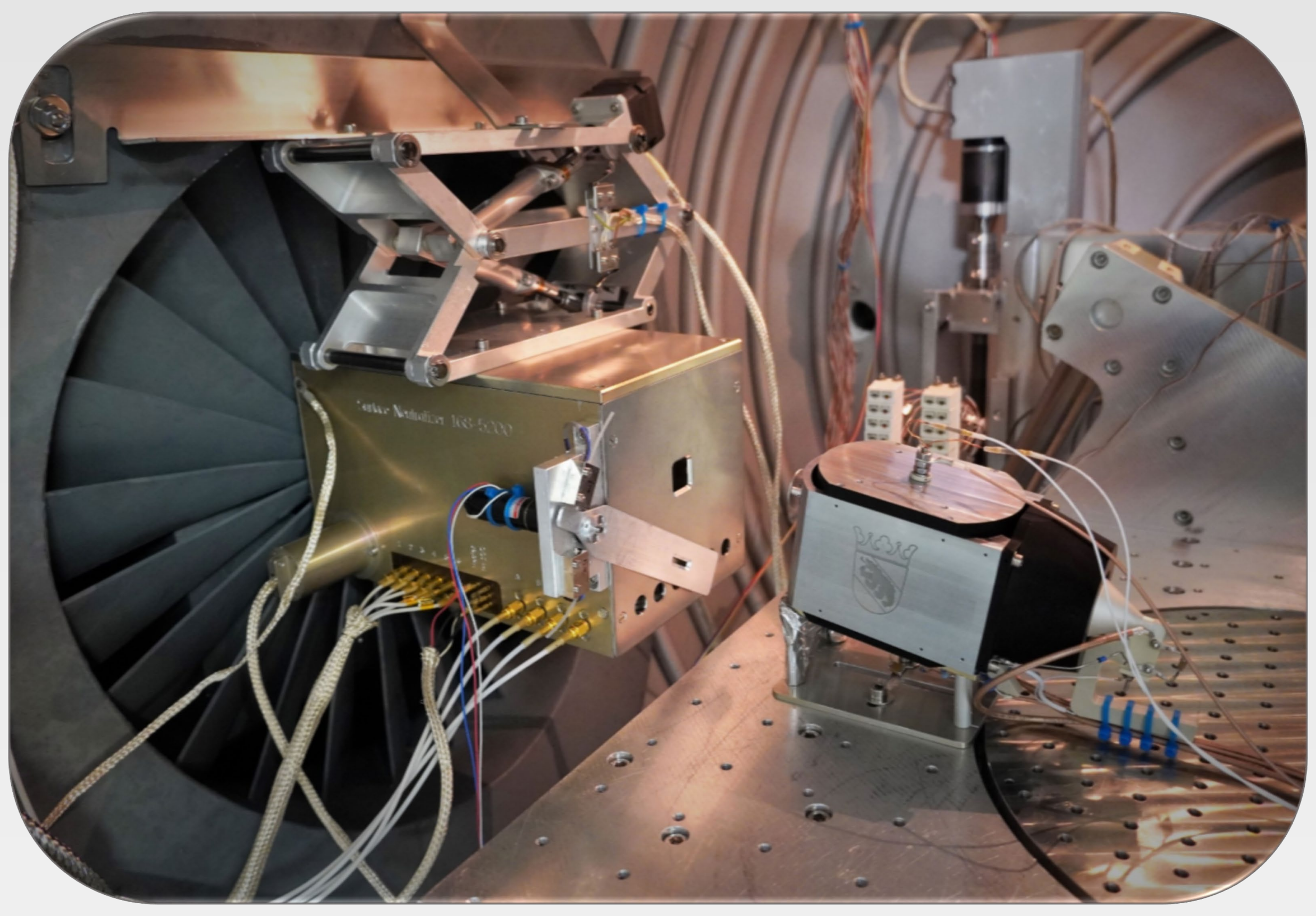

Figure 3: ABM on hexapod table, and neutraliser in MEFISTO test chamber.

Effects of surface neutralisation

- Reduction in beam energy
- Increase in angular divergence
- Species- & energy-dependent efficiency & throughput

→ Characterisation of produced neutral beams needed.

→ Developed novel ABM lab device [4] for low-energy laboratory neutral beam calibration

Absolute Beam Monitor (ABM)

- Surface scattering of neutral beam
- Coincidence event detection of secondary electrons (start) and scattered atoms (stop)
- Measured neutral beam fluxes independent of detection efficiency (absolute)!
- Measured coarse neutral beam energy from start-stop ToF distributions

RESULTS

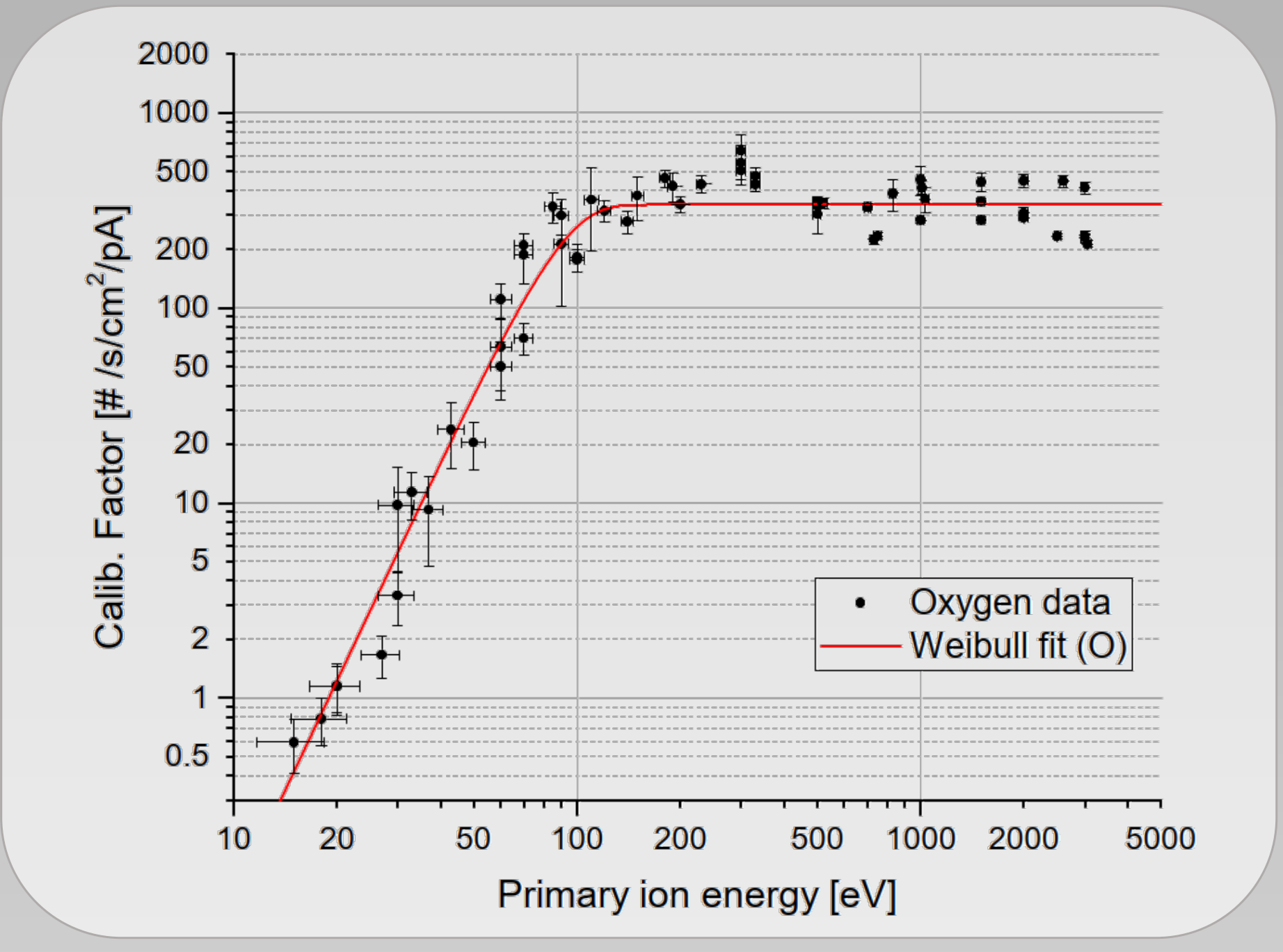

Figure 4: Neutral beam flux calibration [5] with ABM: oxygen as an example.

Neutral beam calibration with ABM

The ABM serves as a primary calibration standard for the characterisation of low-energy neutral atom beams [5]:

- applied in MEFISTO to measure the neutrals beam flux F_n
- experimentally determined species- and energy-dependent ratio of neutrals flux to surface current I_{ncs}

→ Calibration Factor $CF(E_{ion}) = F_n \ / \ I_{ncs}$ *(figure 4)*

→ Relative beam energy loss determined *(figure 5)*

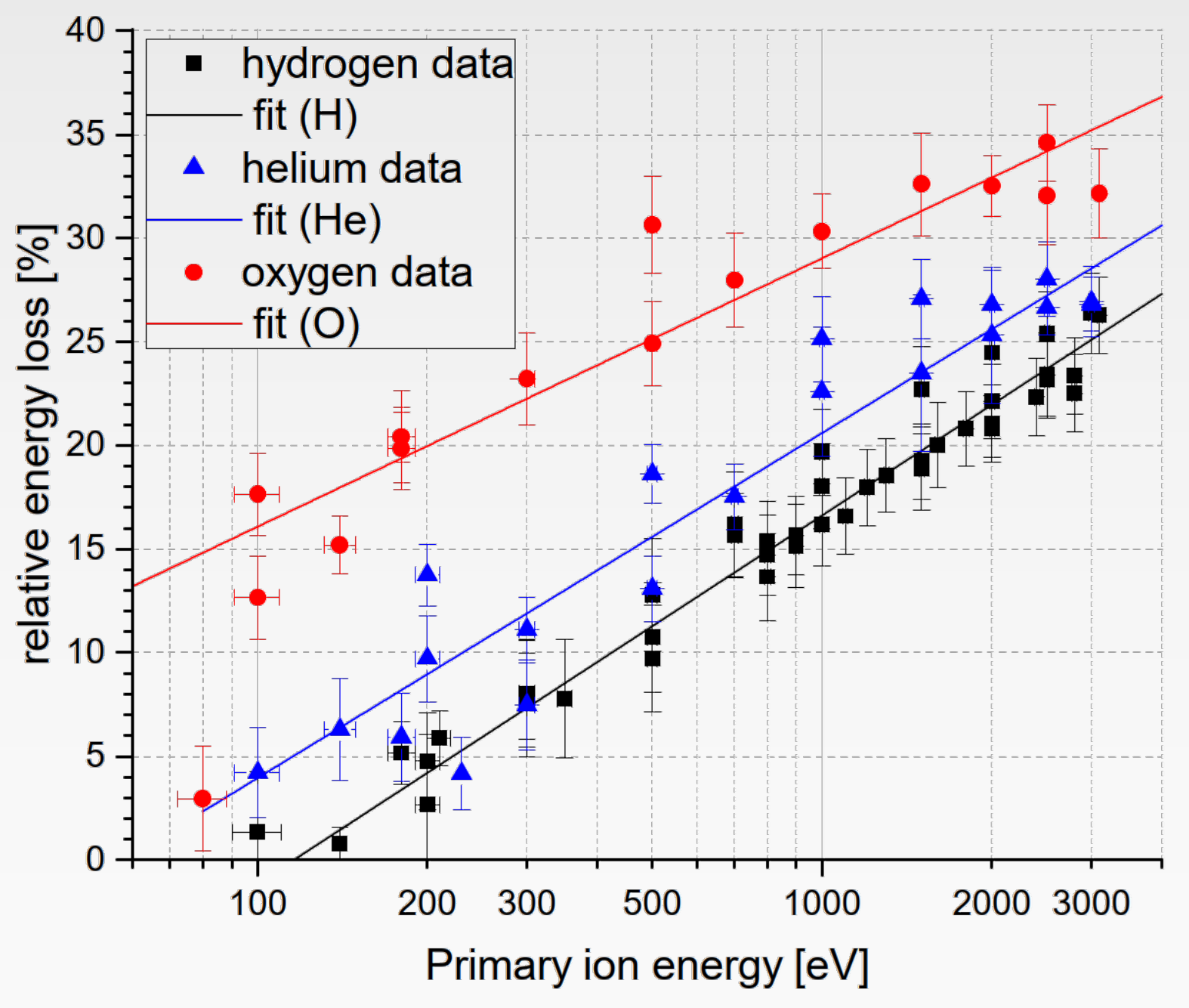

Figure 5: beam energy reduction in the surface neutraliser [5]

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