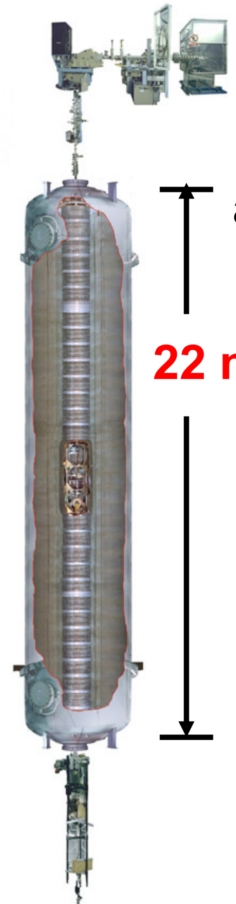
Australian National University

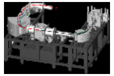
Trends in Accelerator Mass Spectrometry (AMS)

Keith Fifield
Department of Nuclear Physics
ANU



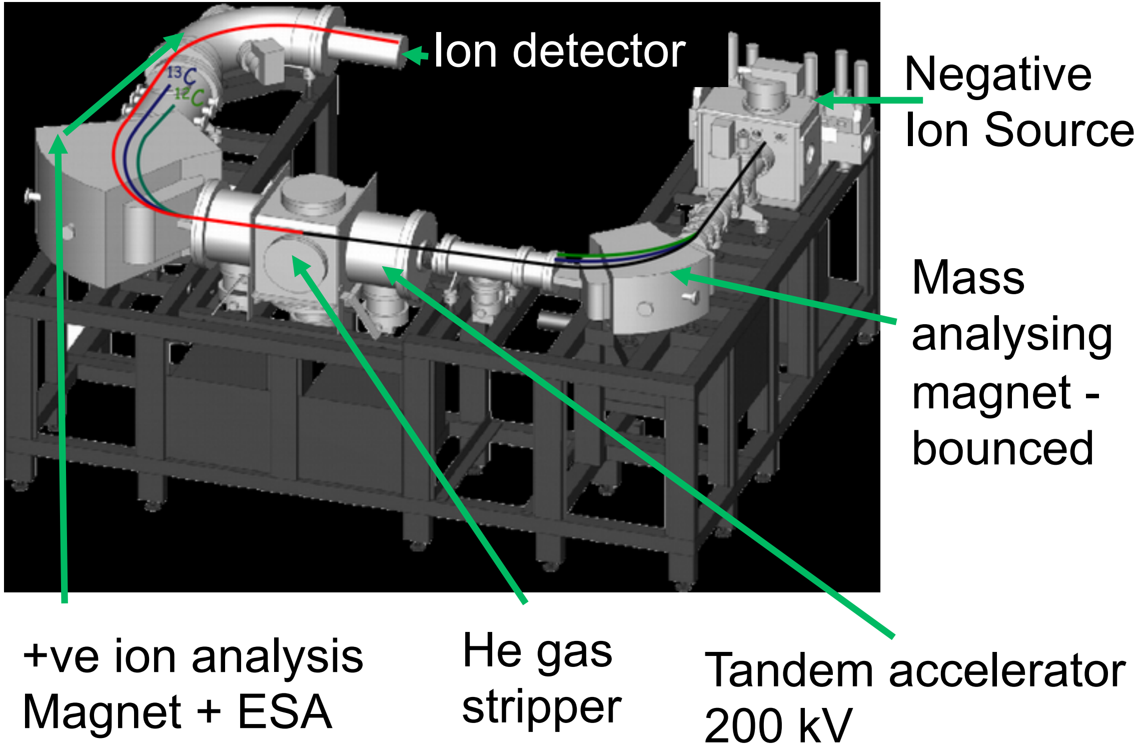
15 MV 14UD accelerator at ANU

22 m



Mini Radiocarbon dating system (MICADAS)
2.5m x 3.0m

MICADAS – ETH Zürich



Australian National University

Essential features of an AMS system

1. Negative ion source – can provide discrimination against isobars. E.g. $^{14}C^-$ and $^{26}Al^-$ are stable, whereas $^{14}N^-$ and $^{26}Mg^-$ are not.

2. Dissociation of molecules, e.g. $^{13}CH^-$, $^{12}CH_2^-$, and conversion to positive ions so that subsequent analysis selects only ^{14}C. Requires acceleration to sufficient energy for high yield of positive ions.

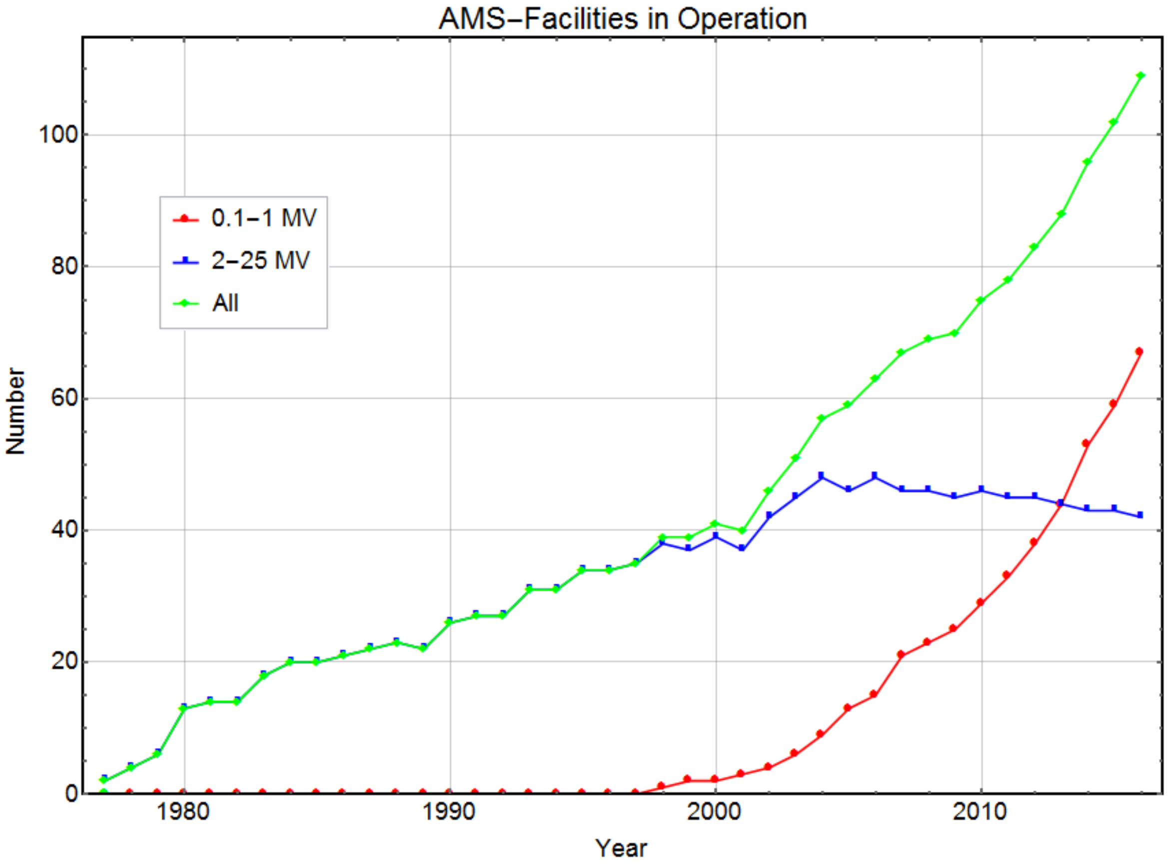
3. Where the ion source does not provide isobar discrimination, e.g. ^{36}Cl and ^{36}S, further acceleration to an energy at which ion identification techniques from nuclear physics can be used.

AMS's debt to Nuclear (and Atomic) Physics

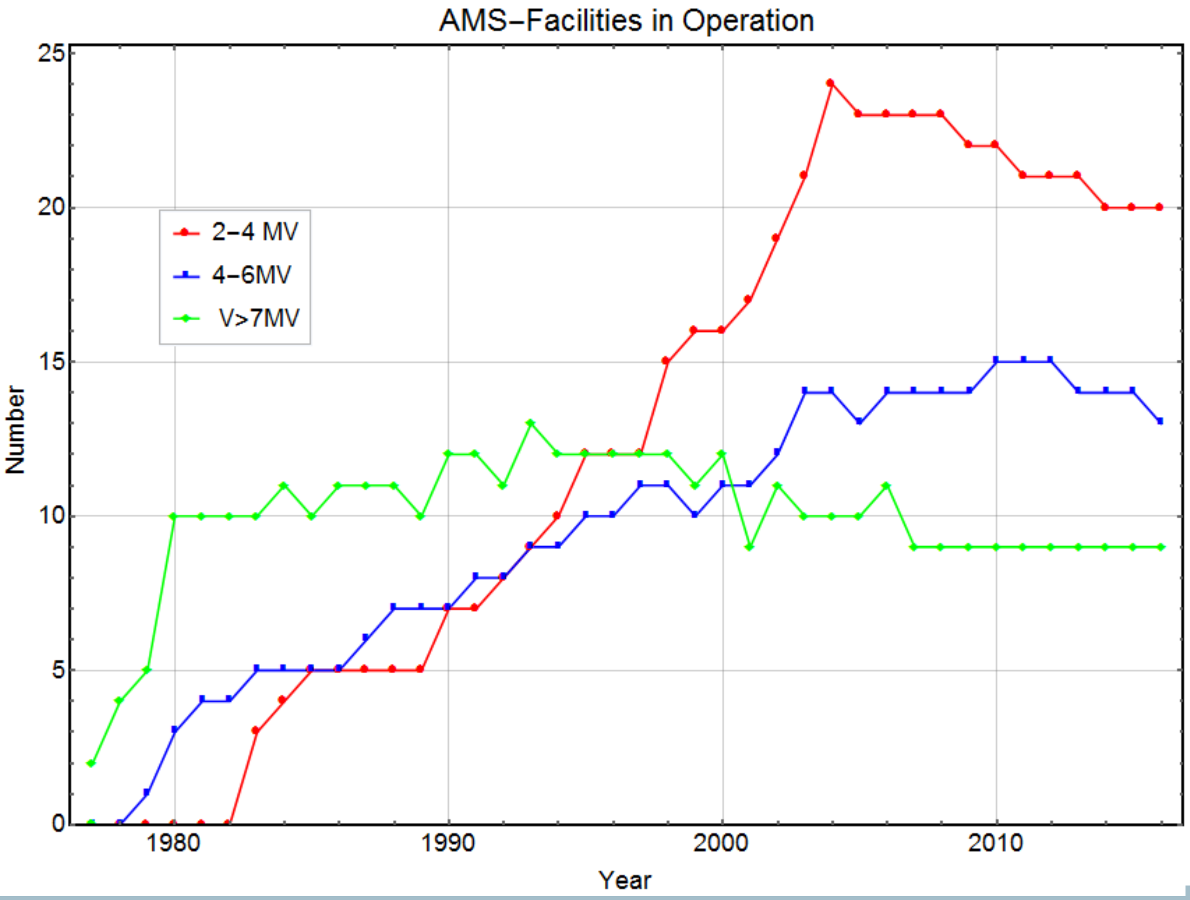
- Negative ion sources
- Tandem electrostatic accelerators, including foil and gas strippers
- Detectors – ionization chambers, silicon detectors, TOF
- Isobar separation techniques – absorbers, degraders, gas-filled magnet.
- Measurements of charge state distributions and charge-changing cross sections

Not all one way, however: AMS → Nuclear Physics

- Ion source development
- Gas stripper development
- Automation

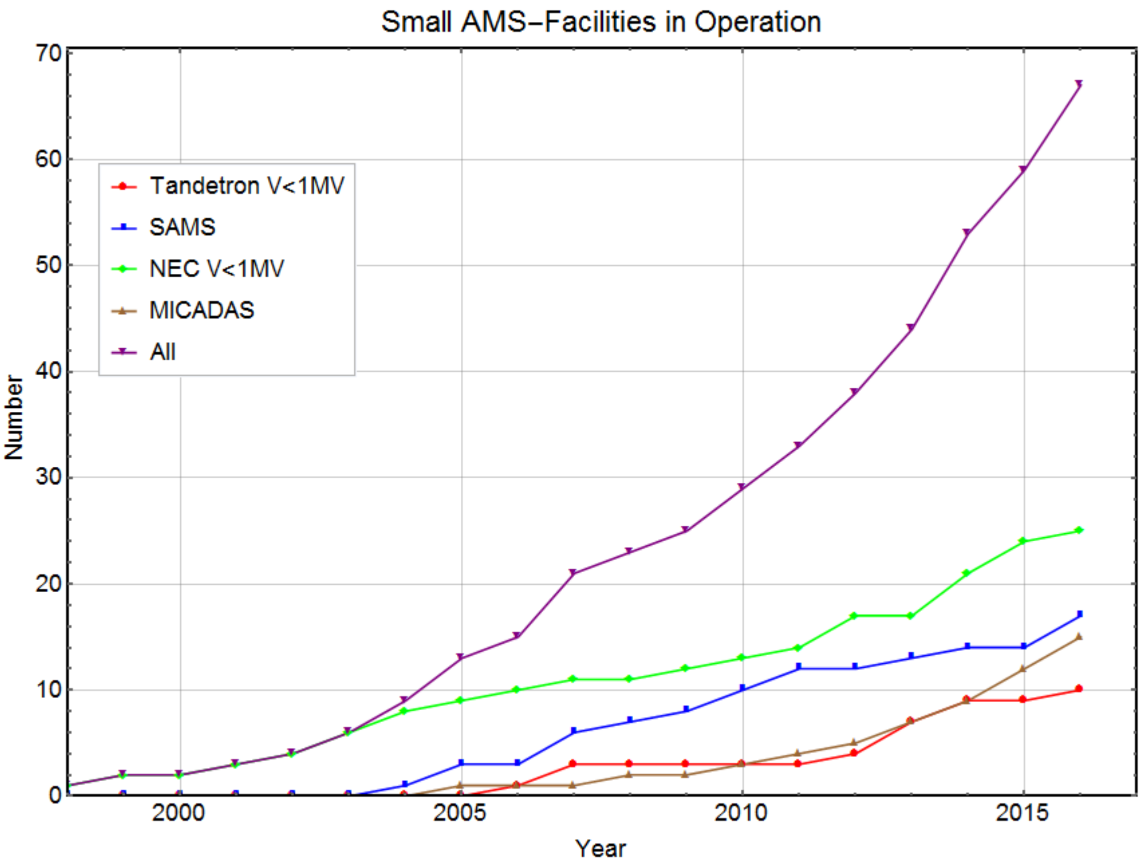


- 107 facilities in total
- 64 used for ^{14}C only.



Notes:

- V>7 MV – highly versatile. Feasibility and sensitivity.
- V= 4-6 MV – versatile. Can do most isotopes.
- V=2-4 MV – versatile, but many used only for ^{14}C.



Notes

1. SSAMS and MICADAS – ^{14}C only.
2. Others more versatile – ^{10}Be, ^{26}Al, ^{41}Ca, ^{129}I, actinides (Pu, ^{236}U).

In Australia:

V>7 MV:

- 14UD (15MV) at ANU
- ANTARES (9 MV) at ANSTO

V = 4-6 MV

- SIRIUS (6 MV) at ANSTO

V = 2-4 MV

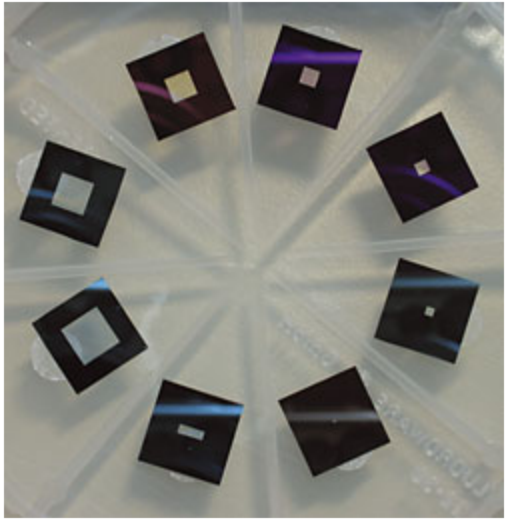
- STAR (2 MV) at ANSTO

V ≤ 1 MV

- VEGA (1 MV) at ANSTO
- SSAMS (0.25 MV) at ANU

Tranformative developments

1. **Silicon nitride foils** for detector windows and degraders. Thickness down to 30 nm, area 8x8 mm^2. Extremely uniform.

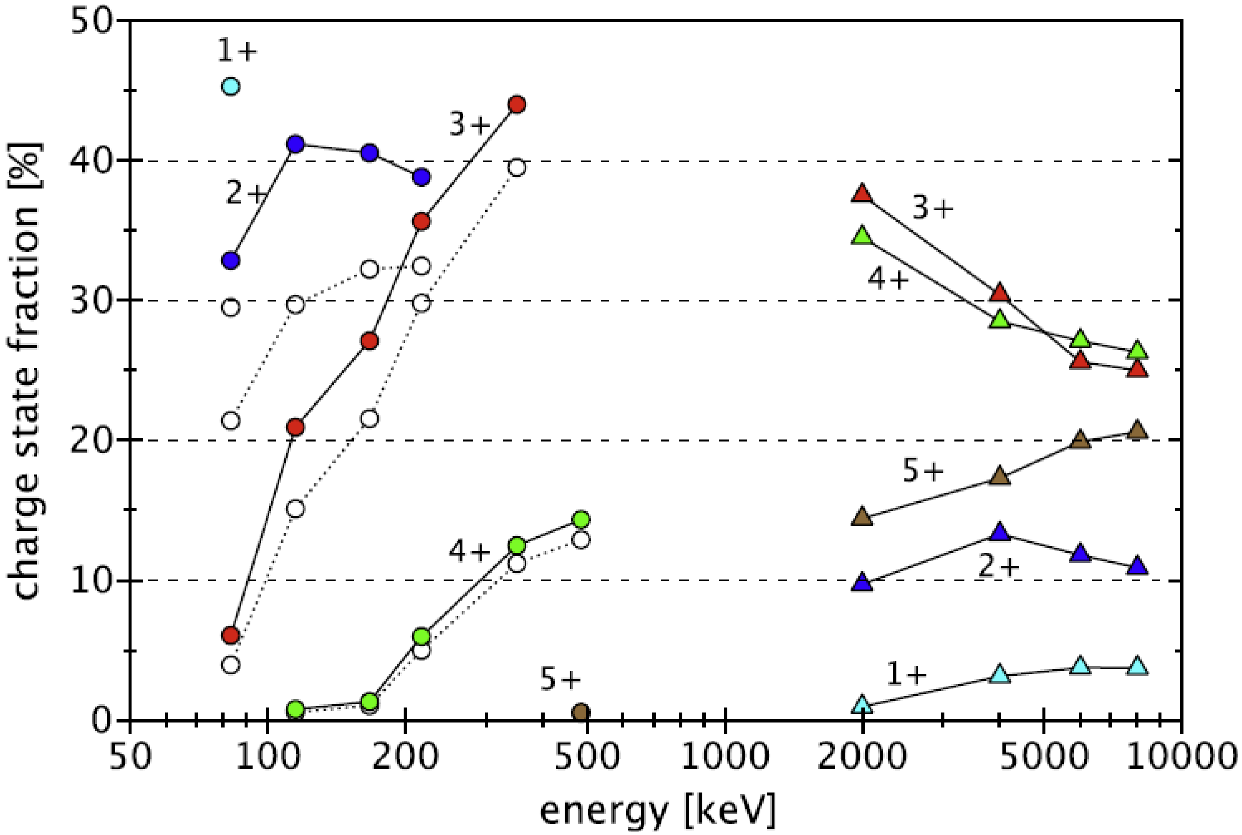


Manufactured by Silson in UK

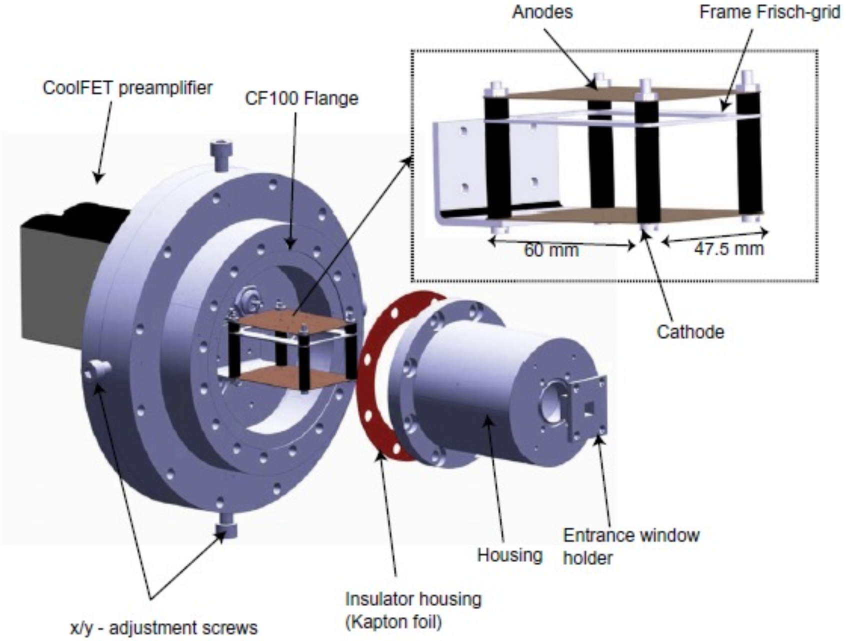
Australian National University

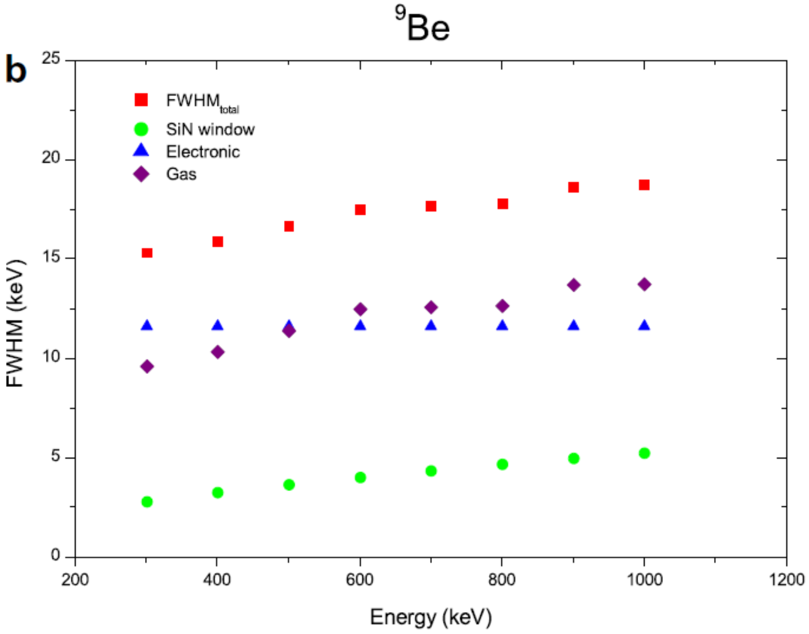
2. Helium stripping.

- Less scattering than argon.
  E.g. for the SSAMS at ANU , ^{14}C transmission from 34% to 48% when switched from argon to helium.
- Higher stripping yield in high charge states.
  E.g. U^{3+} > 40% at 0.3 - 1 MeV. Exploited by new ANSTO 1 MV system (VEGA).


charge state fraction [%]
energy [keV]
1+
2+
3+
4+
5+
0
10
20
30
40
50
50
100
200
500
1000
2000
5000
10000

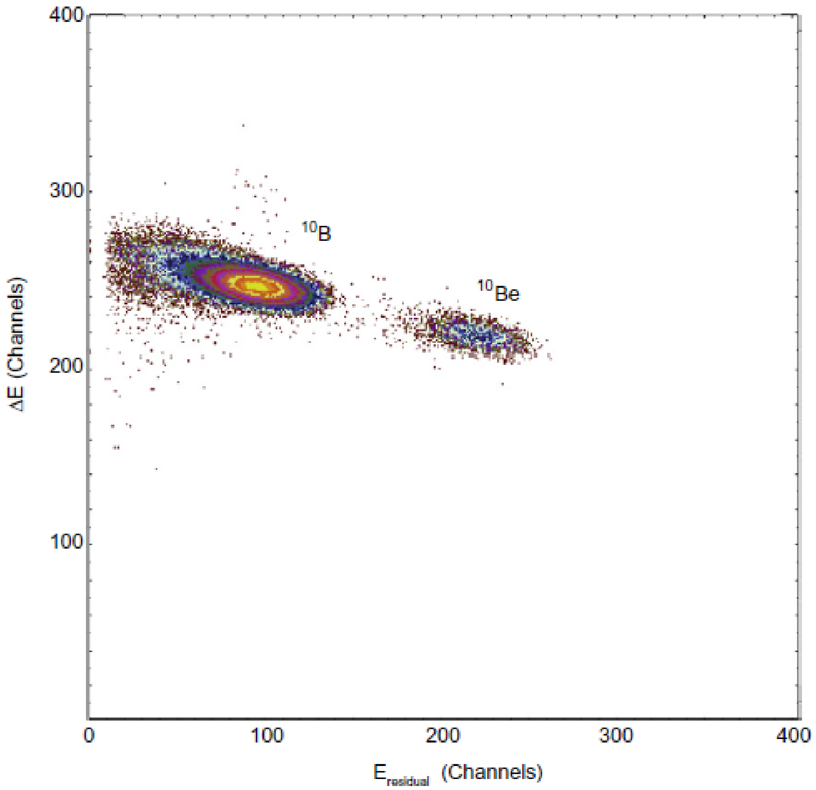
3. Ionisation detector developments – silicon nitride foils and low-noise via design and preamps.





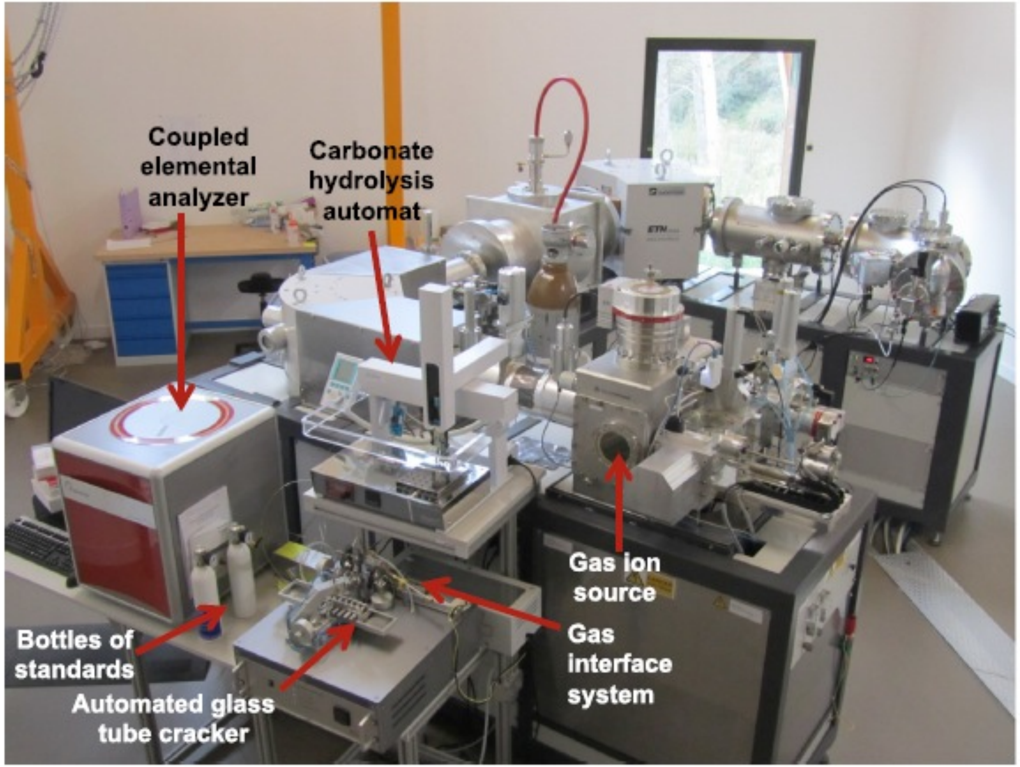
Contributions to resolution for Be ions

Separation of 750 keV ^{10}Be and ^{10}B

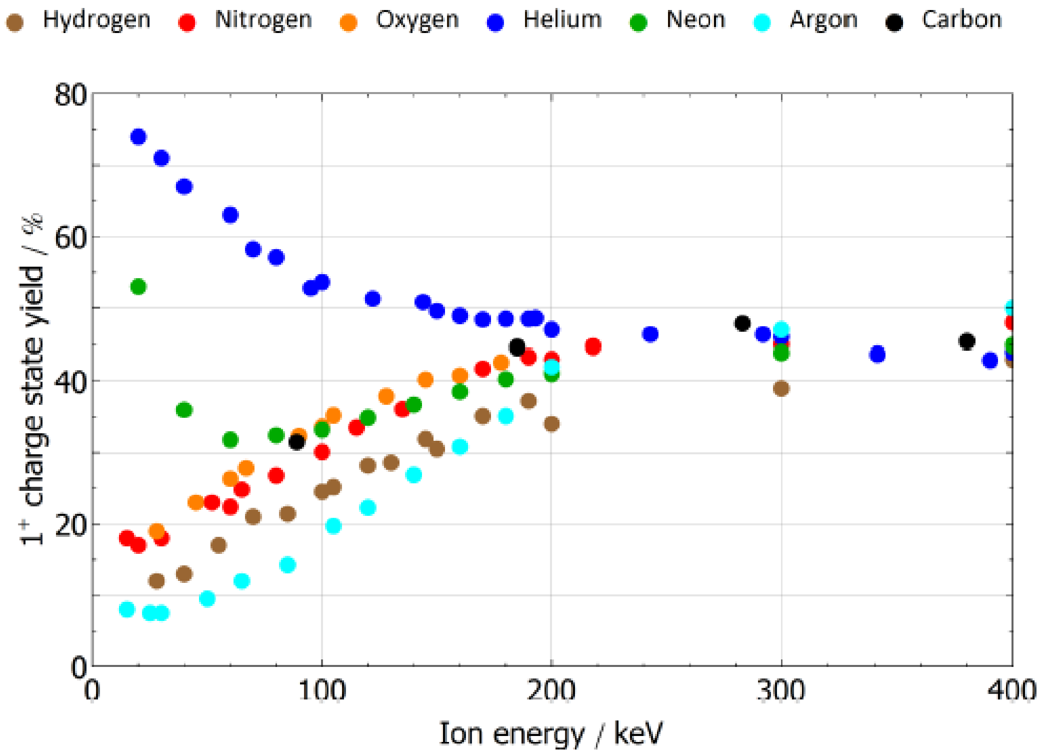


4. **CO_2 gas sources** for ^{14}C

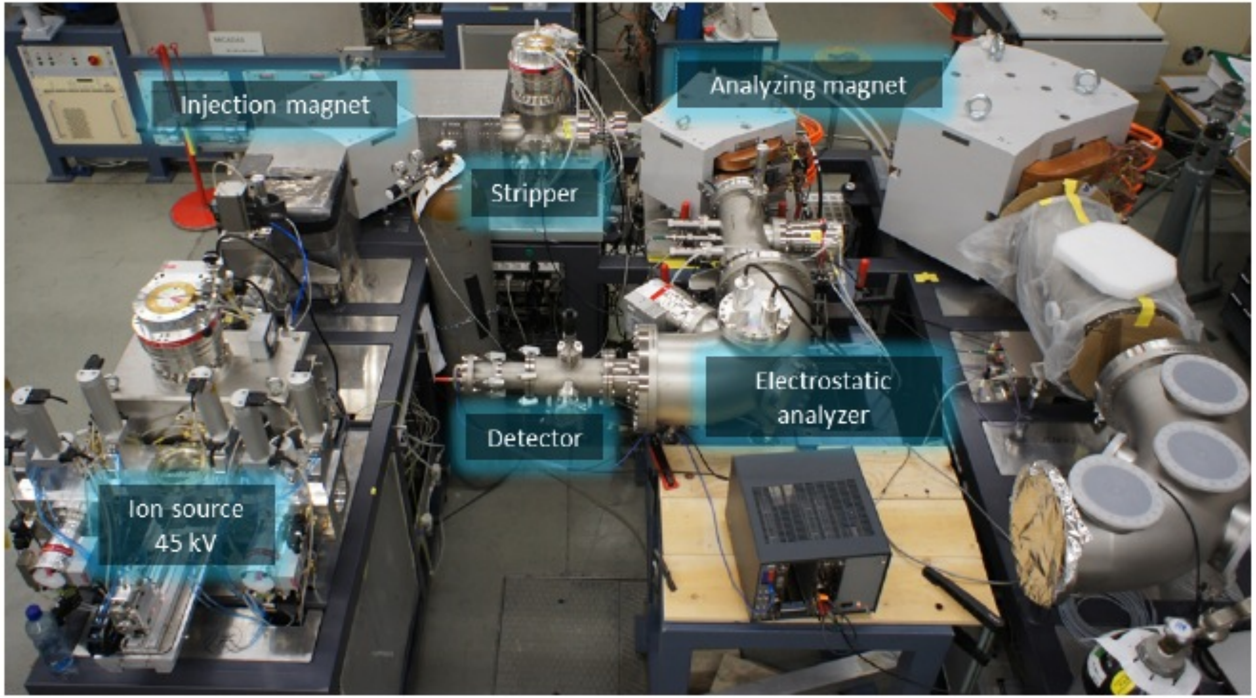
- Allows very small samples (<5 μg) – compound specific ^{14}C.
- May be coupled to automated CO_2 production systems. E.g. elemental analyser for charcoal, 'gas bench' for carbonates, laser ablation.



MICADAS system at CEREGE, Aix-en-Provence, France



Yield of 1$^+$ ‘carbon’ ions after stripping in various gases as function of energy



myCADAS – AMS without the ‘A’

Isobar separation prior to the accelerator

A. Photo-detachment. Vienna.

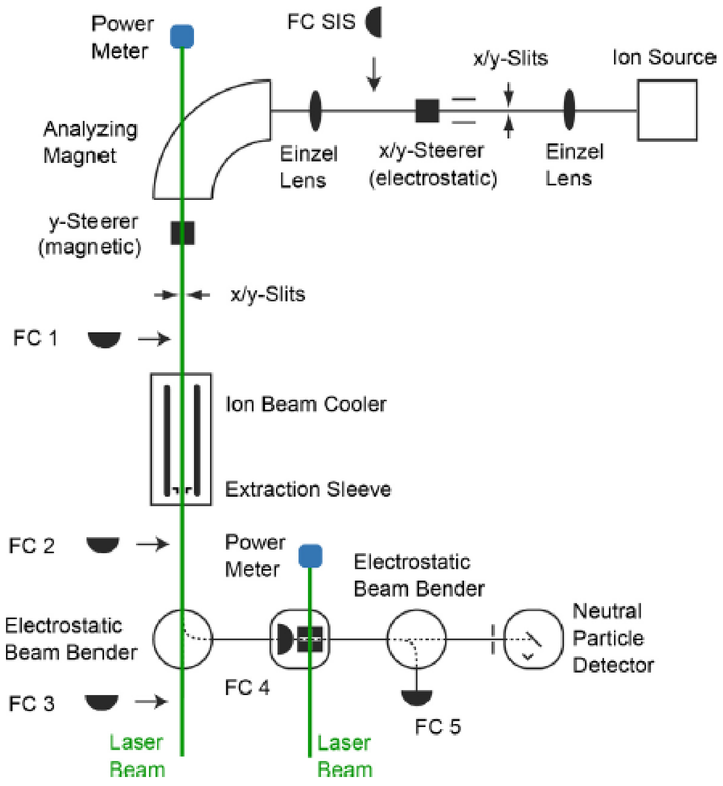
Electron affinities:

$^{36}Cl^{-}$ – 3.62 eV

$^{36}S^{-}$ – 2.08 eV

Nd:YAG laser 532 nm = 2.33 eV

Long interaction time by decelerating and then cooling negative ions to eV energies in He gas in RFQ.



B. Electron transfer reactions. Ottawa.

At eV energies

$^{36}S^{-} + NO_2 \rightarrow {}^{36}S + NO_2^{-}$

Rate constant 1.3×10^{-9} cm^3/s

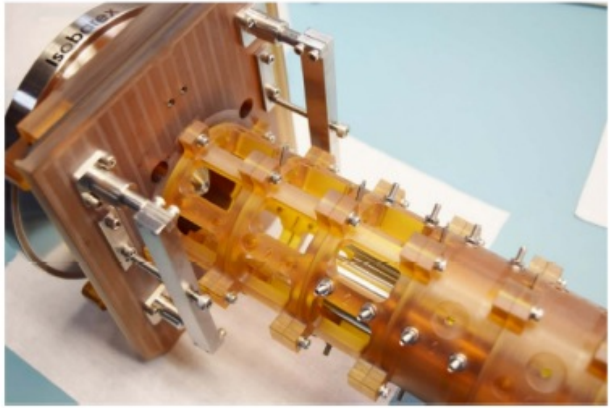
$^{36}Cl^{-} + NO_2 \rightarrow {}^{36}Cl + NO_2^{-}$

Rate constant $<6 \times 10^{-12}$ cm^3/s

Again, use gas-filled RFQ to cool beam to eV energies.

a

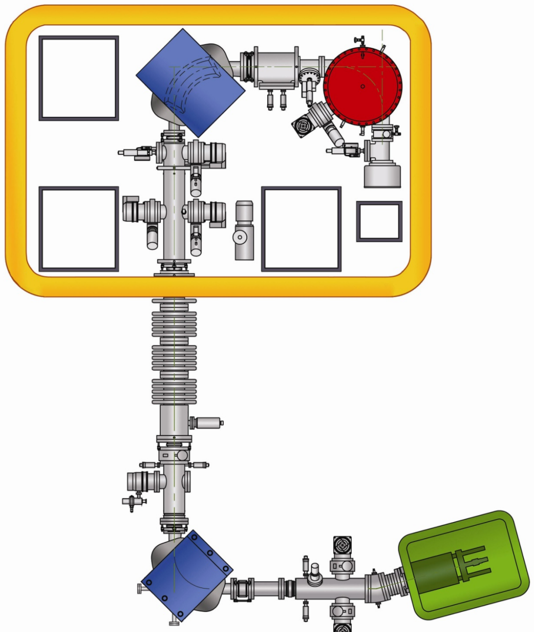
b



A multi-isotope AMS system at only 300 kV? ETH

- MICADAS accelerator successfully scaled up to 300 kV
- Problems with helium as stripper gas have been solved
- Ultra-thin and ultra-uniform silicon nitride foils available
- Second magnet in HE analysis system reduces background
- Detectors are good enough to separate 450 keV ^{10}Be from ^{10}B
- ^{10}Be, ^{26}Al, ^{41}Ca, ^{129}I, actinides (^{239,240,242,244}Pu, ^{236}U, ^{237}Np)

And Thanks



Single Stage Accelerator Mass Spectrometer - SSAMS

Applications:

^{14}C

- Archaeology
- Chronologies – marine and lake cores for palaeoclimate reconstruction
- Environmental tracing – much uses ‘bomb pulse’
    - Oceanography
    - Carbon cycle – soils
- Biomedicine – drug testing

^{10}Be ($T_{½}$ 1.4 Ma) and ^{26}Al (0.7 Ma) – 'Cosmogenic' isotopes

- 'Exposure dating' – glacial advance and retreat, river and wave-cut terraces, landslides. Palaeoclimate and landscape evolution
- Erosion – landscape evolution
- Chronologies of marine crusts and cores beyond ^{14}C

^{36}Cl (0.3 Ma)

- Exposure dating and erosion
- Hydrology – dating and tracing groundwater
- Artificial tracer – oil field tracing

Actinides – Plutonium and ^{236}U

- Human-induced erosion.
- Tracing of releases from accidents and reprocessing
- Oceanography

Isotopes for nuclear astrophysics:

- ^{60}Fe – produced in supernova and deposited on earth. Sensitivity $^{60}Fe/^{56}Fe < 10^{-16}$ required. Needs gas-filled magnet and high energy (170 MeV) to discriminate against ^{60}Ni.
- Cross-sections for reactions of astrophysical importance, e.g. $^{92}Zr(n,\gamma)^{93}Zr$. Irradiate ^{92}Zr at a neutron facility, e.g. SARAF in Israel, and measure the ^{93}Zr produced by AMS. High-energy and GFM to discriminate against ^{93}Nb.

Charge state distribution for carbon ions in argon gas.