



Ion Source Development for AMS at WHOI

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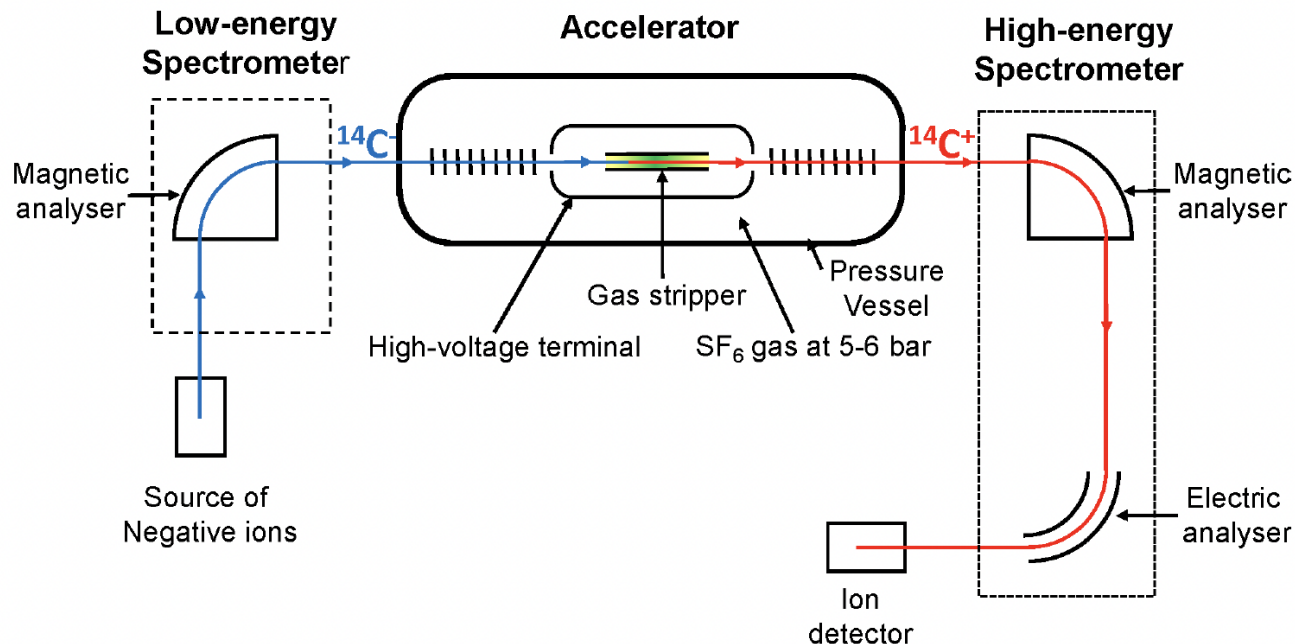
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What is AMS?

- Accelerator mass spectrometry (AMS) is a method to count atoms of rare, long-lived radioactive isotopes (like ^{14}C) by accelerating ions to high kinetic energies using an accelerator and separating isotopes by mass.



One of two AMS systems at WHOI



CFAMS System

Why a negative ion source?

Why electrostatic tandem acceleration?

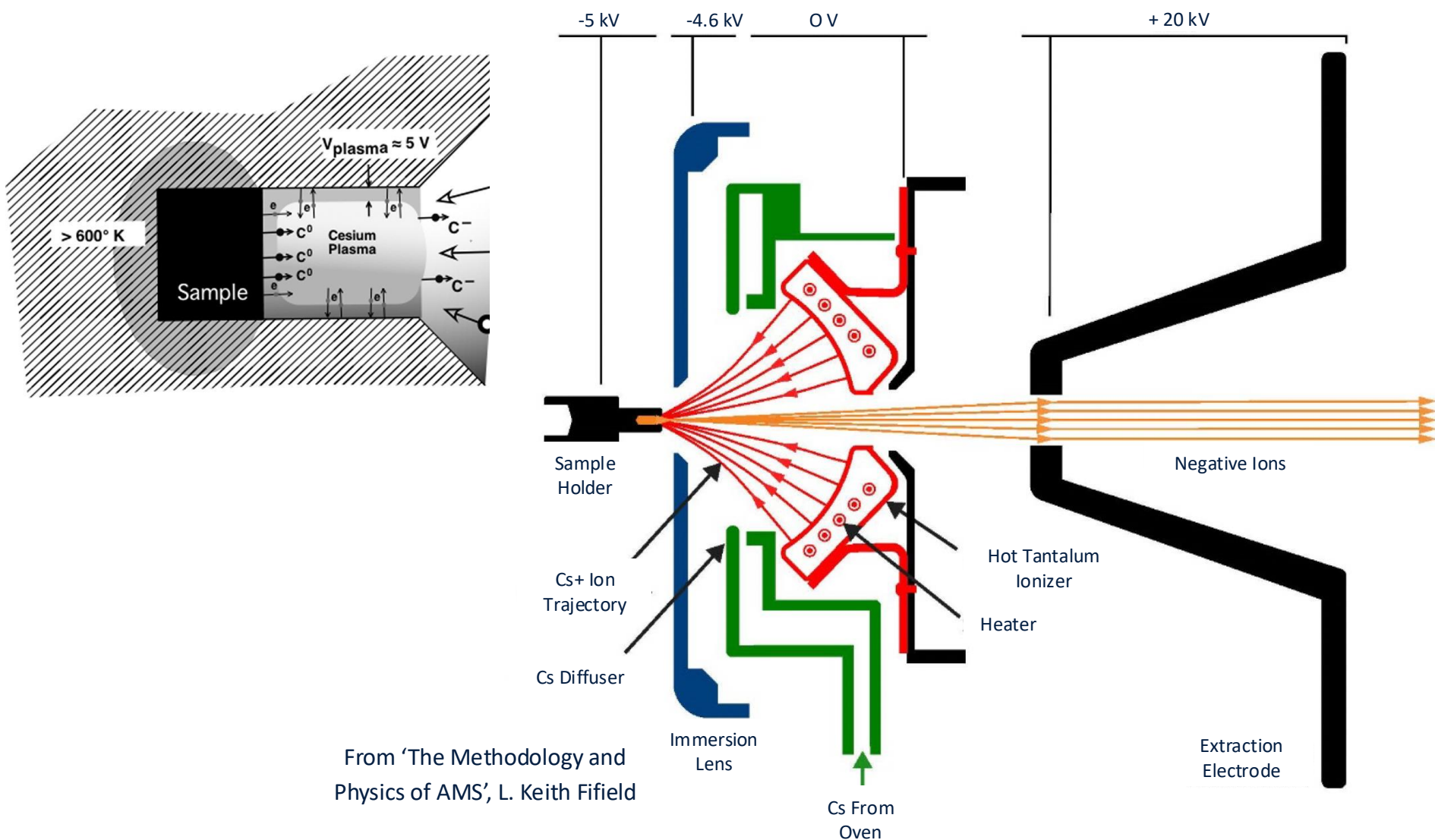
- AMS uses a negative ion source to eliminate background interference from isobars.

The best example of this is that ^{14}N does not form a stable negative ion. If ^{14}N made a negative ion, radiocarbon dating using AMS would not be possible.

- An accelerator because molecular breakup in the high voltage terminal stripper eliminates molecular ions.

For example, in ^{14}C AMS, the terminal stripper destroys interfering $^{12}\text{CH}_2$ and ^{13}CH molecules.

Principle of the Negative Ion Cesium Sputtering Source



From 'The Methodology and Physics of AMS', L. Keith Fifield

Important Metrics for a Negative Ion Source

- Ion Current

At 100 μA of $^{12}\text{C}^-$, the ^{14}C count rate from a modern sample is ~ 300 cps.
Hence, to get to a total of 250,000 counts (0.2%) takes ~ 14 minutes

- Efficiency

A 30 μg , 11,500 year old sample has $\sim 370,000$ ^{14}C atoms.

With a 10% source efficiency and 50% stripping efficiency, we can only detect a maximum of $\sim 18,000$ ^{14}C atoms (0.7%).

- Beam Emittance

Need a reasonably small beam emittance. Too large a beam emittance and isotope fraction becomes a problem.

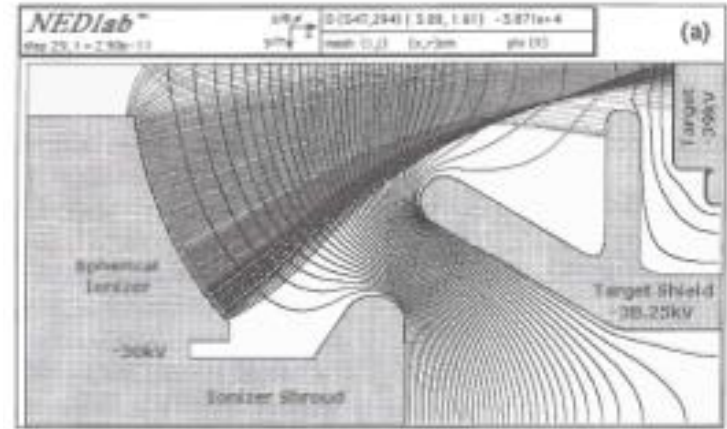
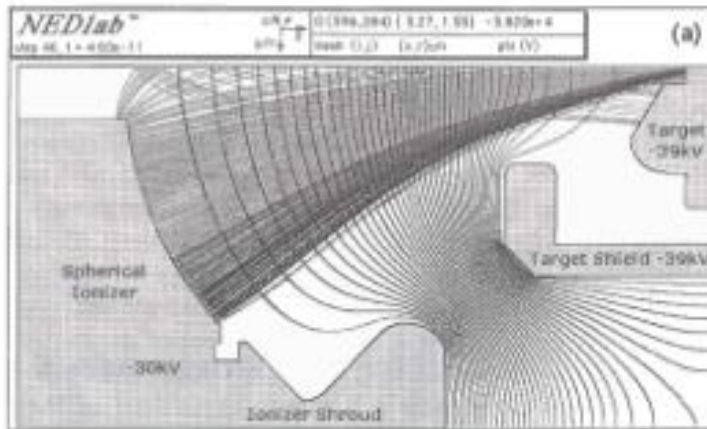
The accelerator stripping canal diameter is typically the limiting factor.

Ion Source Modeling

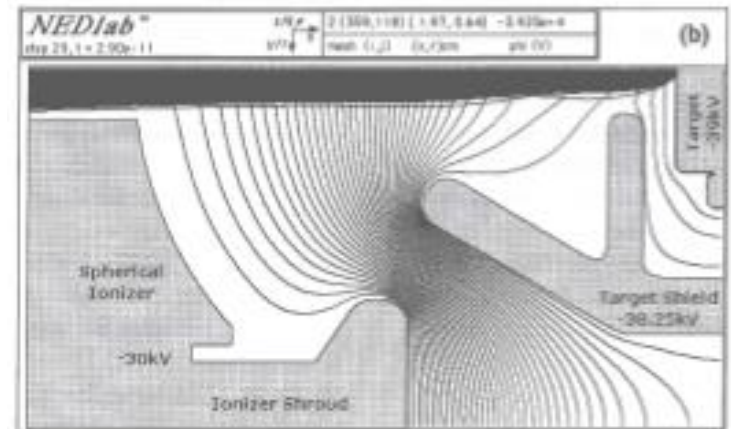
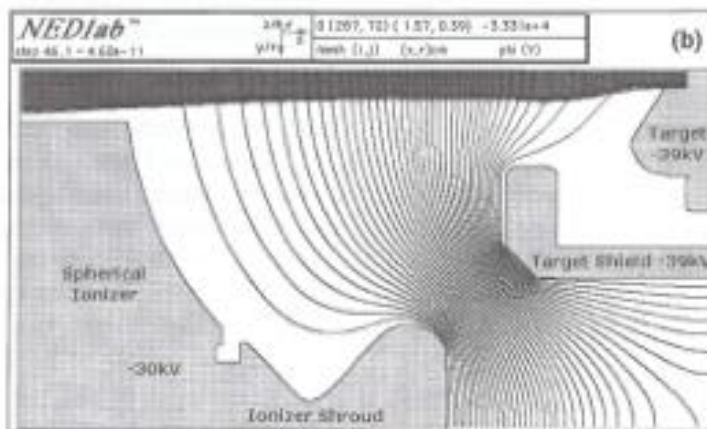
- Numerical Electrodynamics Laboratory (NEDLab). A 2.5-dimensional (cylindrical or Cartesian) particle and field simulation software.
- Important considerations:
 - Child's Law modeling (Cs^+ from ionizer)
 - Ion emission with thermal energy distribution and randomized angles
 - Space charge

Ion Source Modeling

Cs⁺



C⁻

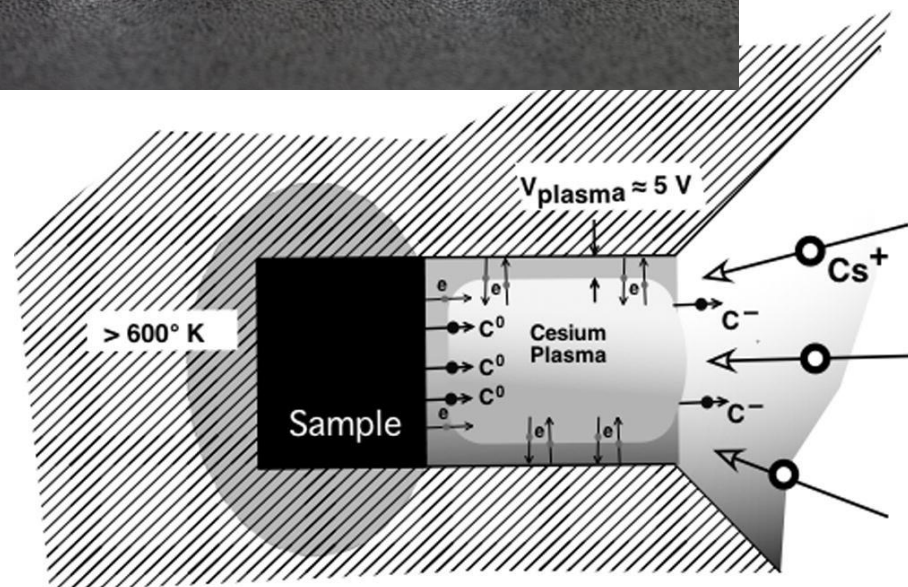
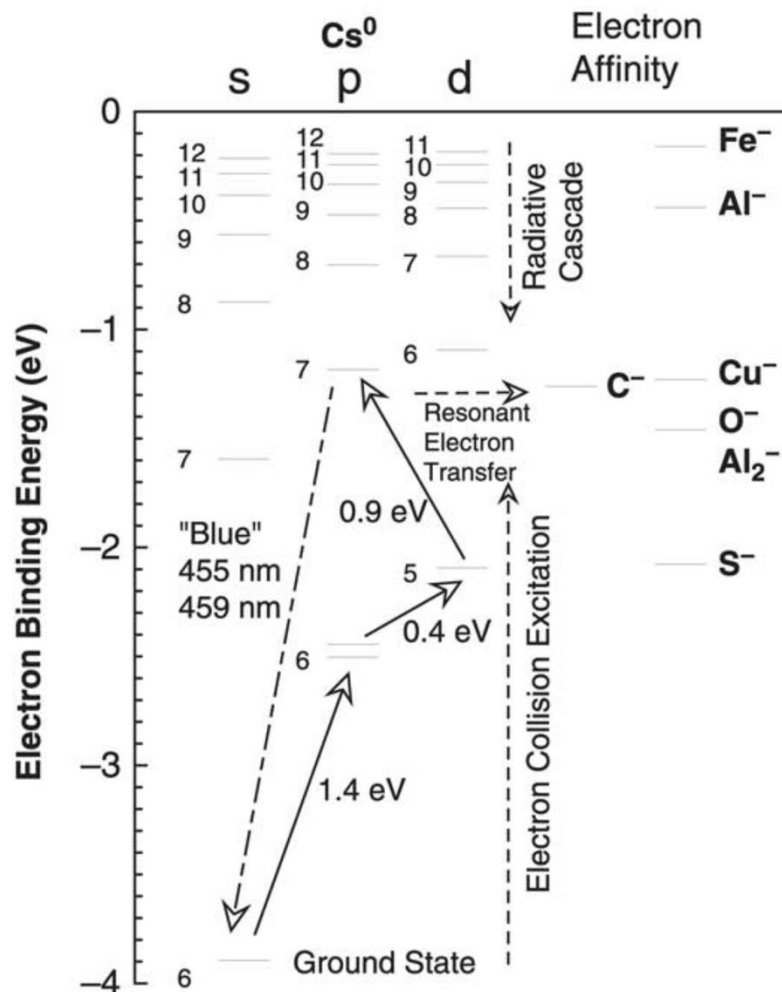


Old electrode geometry

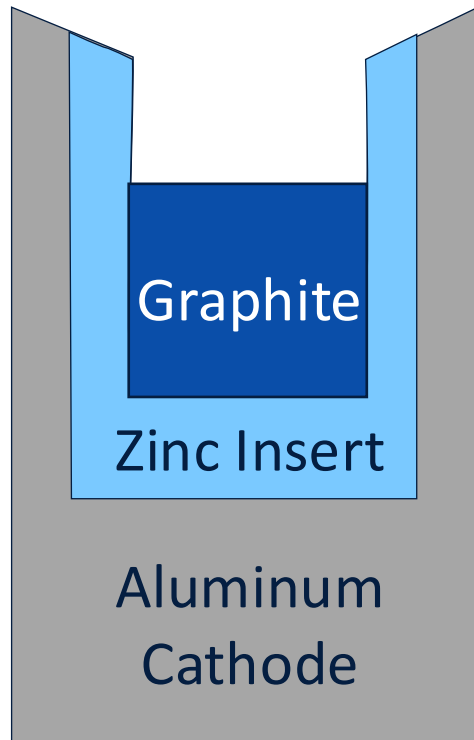
New electrode geometry

Model predicted 2X Current. In practice, currents increased from $\sim 200 \mu\text{A}$ to $\sim 370 \mu\text{A}$.

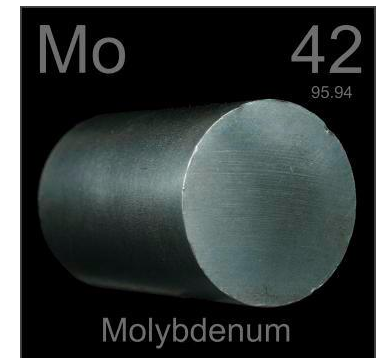
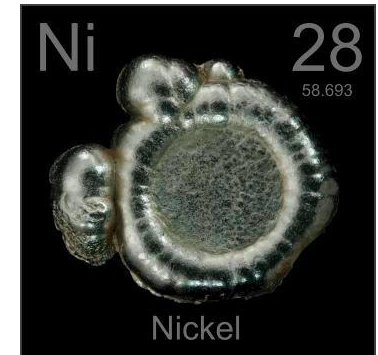
Ionization potentials of Cs compared to the electron affinities of C and other elements,



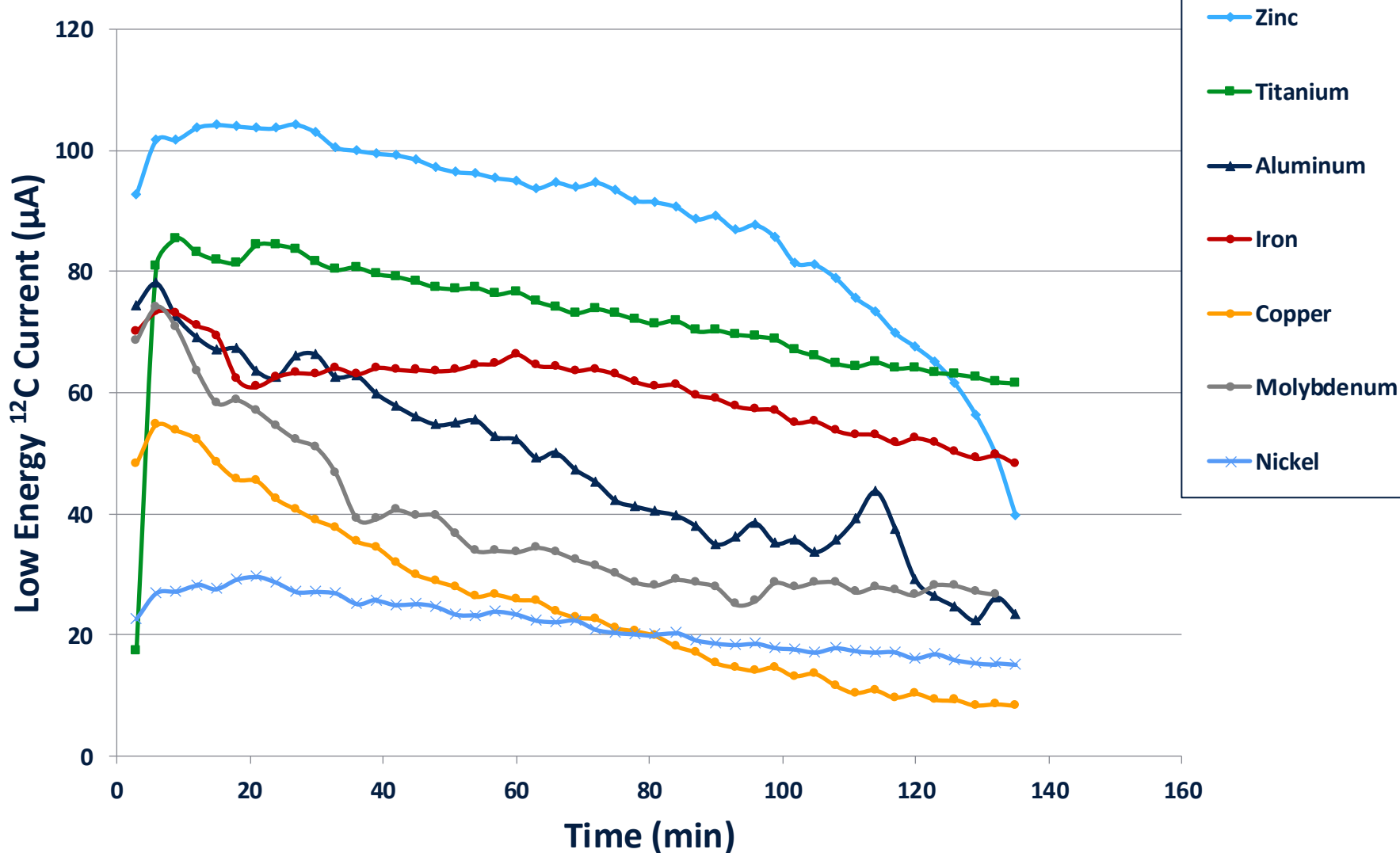
Different Cathode Material



Cross-section of
NOSAMS cathode with
zinc insert.

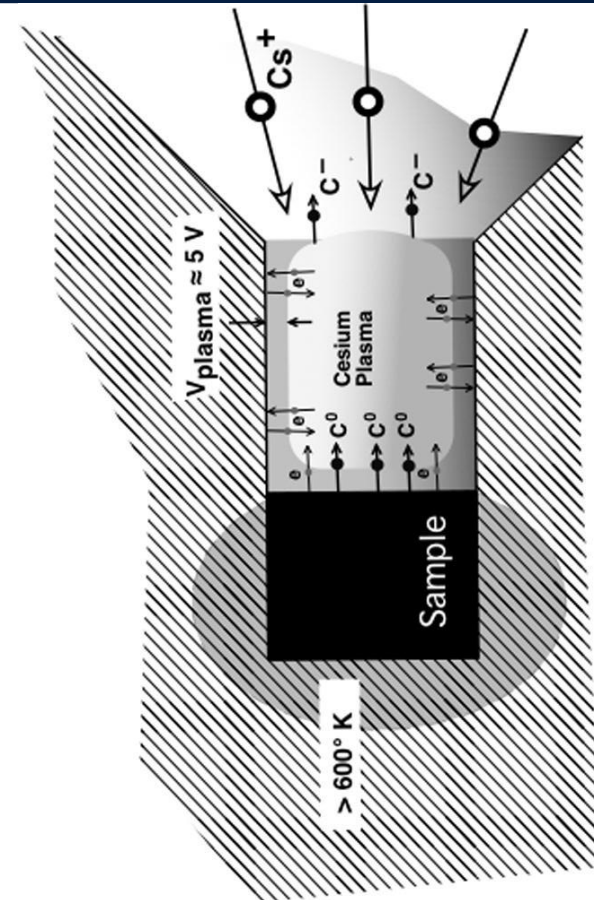


Different Cathode Material



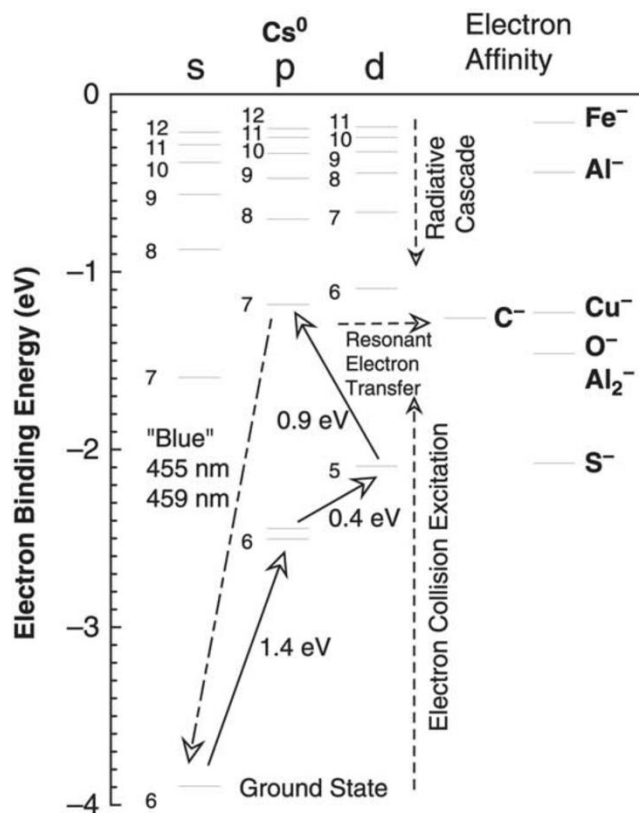
Different Cathode Material

Insert Material	Electron Affinity (eV)	Ion Source Efficiency
Zinc	-	19.60%
Titanium	0.085	20.60%
Iron	0.153	16.60%
Aluminum (Al ₂)	0.433 (1.461)	11.80%
Molybdenum	0.747	10.30%
Nickel	1.157	5.00%
Copper	1.236	5.50%

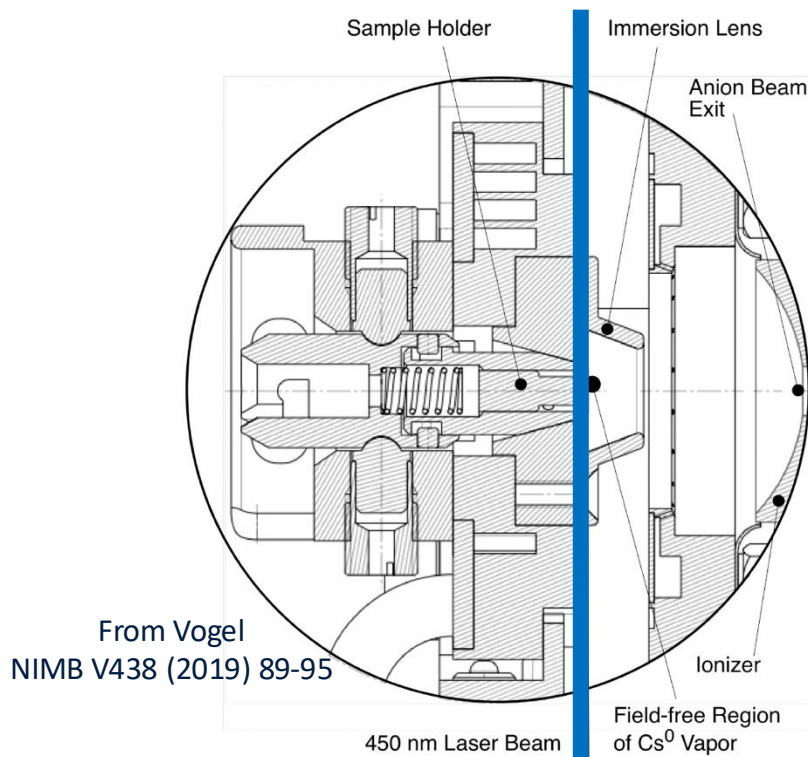


Cross section of a sample holder with sample being sputtered by Cs⁺ beam.

LASER Assisted Sputtering



From Vogel and Giacomo
Radiocarbon V59 (2017) 957-965



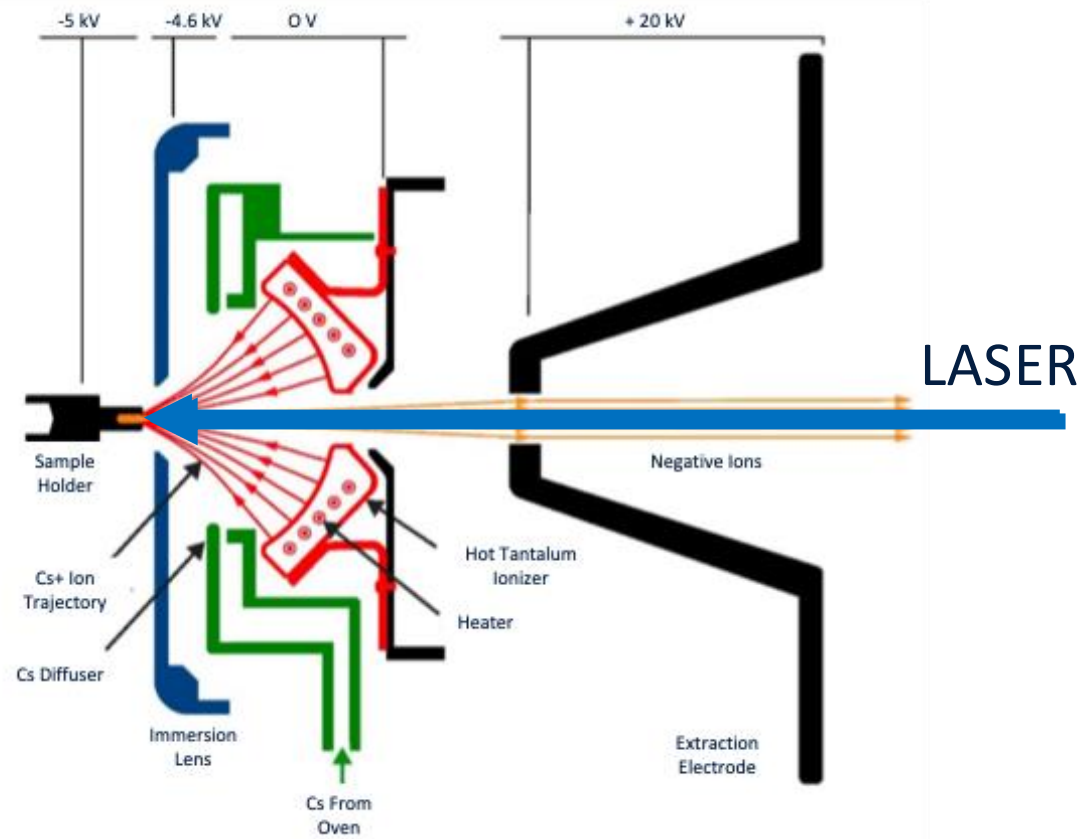
450 nm 5 W LASER

10-15% Increase in
negative ion current

LASER Assisted Sputtering



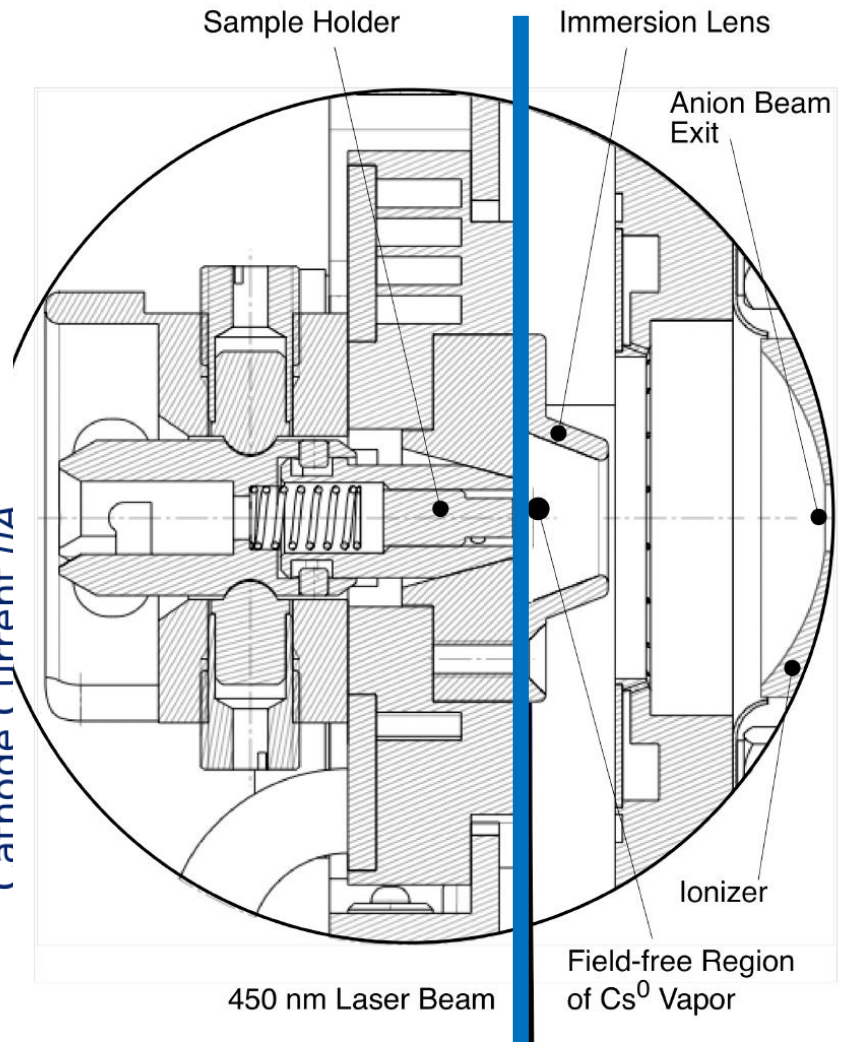
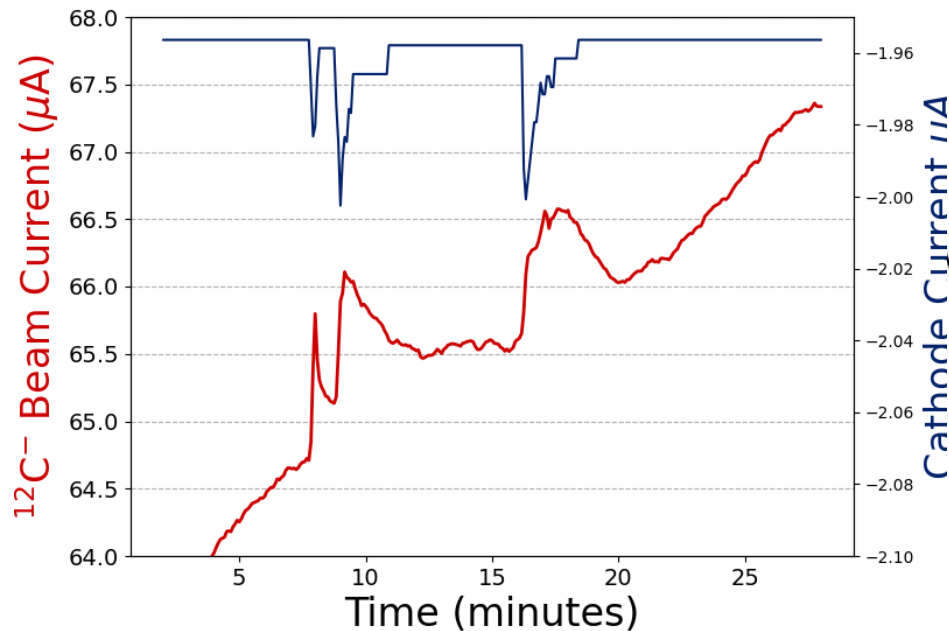
450 nm 5 W LASER



No increase in
negative ion current

LASER Assisted Sputtering

- 2-3% Increase in negative ion current



450 nm 5 W LASER

Summary

- The development of AMS was/is intimately linked to negative ion cesium sputter sources.
- The development of negative ion cesium sputter sources was/is intimately linked to the development of AMS.
- Despite decades of development, the ion source remains the most maintenance-intensive and least-understood component of an AMS system.

Thank you

