The ETH Zurich Laboratory of Ion Beam Physics

Hans-Arno Synal
**Mission Statement of the Laboratory**

LIP is a national and international center for

- Accelerator Mass Spectrometry (AMS) 80%
- Ion Beam based Material Sciences (IBA) 20%

**Mission of the Laboratory:**

- Fundamental research of processes in ion beams physics within a trans-disciplinary context between methods and applications.
- Development of novel instrumentation base on latest research results.
- Exploit existing and new developed infrastructure to play a key role in applications of ion beam technology.
- Provide our Infrastructure to external users (Service Laboratory)
  - Perform analyses
  - Produce Instrumentation under research collaboration agreements
- The LIP is taking part within the educational program of ETH
  - Lectures at ETH and other Universities
  - Bachelor-, Master-, Diploma- and Doctoral Theses
Beautiful examples of radiocarbon dating applications

"Ozi" the Ice Man
3350 – 3110 BC

The Shroud of Turin
1260 – 1390 AD

"Temple" Scroll
97 BC – 1 AD

A Copy of "Mona Lisa"
1430 -1480 AD

Bamiyan Afghanistan
590 AD - 645 AD

The "Turin" Textile sample

NuPECC Meeting Basel 12th June 2015
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run time statistics
RBS
ERDA
HIBS
PIXE
Channeling
NRA
Ion Beam Modification
Capillary Microprobe
Cluster Irradiation
SuperSIMS
MeV SIMS under Development
Measurement hall
500 kV Pelletron based multi-nuclide AMS system

- Routine $^{10}$Be (all possible applications).
- Routine and experimental $^{26}$Al measurements.
- $^{41}$Ca for biomedical application.
- Routine $^{129}$I environmental monitoring and nuclear safeguards.
- Versatile actinide program (Th, U, Pu, Pa, Cu, Am,..).

Improved performance

- additional magnet at HE-end
- higher transmission with He stripping
- Optimized gas ionization detectors

The “mother” of all compact AMS facilities
200 kV vacuum insulated $^{14}$C dedicated AMS system

- “working horse” routine $^{14}$C program
- Unattended operation with low maintenance
- High throughput: 4650 graphite, 3000 CO$_2$ samples (<50 µg) in 2014
- Overall measurement uncertainty: 1.5-2 ‰ (modern sample)
- Hybrid ion source for solid graphite and gaseous CO$_2$ samples

“MICADAS” the most compact AMS system in the World
Developments of measured samples 1982-2014

150'000 AMS analyses since 1982

- 10Be
- 26Al, 36Cl, 41Ca, 129I, Ac
- 14C
The World of AMS facilities in 2015

124 AMS facilities

- National Electrostatic Corporation
- High Voltage Engineering Europe
- ETH Zurich
- Large Tandem / exotic systems

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Commercial AMS systems

High Voltage Engineering Europa B.V.
Amsterdamseweg 63, 3812 RR Amersfoort, P.O. Box 99, 3800 AB Amersfoort, The Netherlands
Phone: +31 33 4619741  Fax: +31 33 4615291  E-mail: info@highvoltage.com  Web: www.highvoltage.com

System layouts

5.0 MV Tandem AMS with Bouncer

5-6 MV

3.0 MV Tandem AMS with Bouncer

3 MV

3.0 MV Tandem AMS with Recombinator

1 MV

National Electrostatics Corporation
Middleton, Wisconsin, USA

5-6 MV

3 MV

500 kV

250 kV SSAMS
$^{14}\text{C}$ charge state yield & accelerator size

**Traditional AMS**
2.5 - 9 MV

*Coulomb disintegration*

Fraction of ions in charge state

<table>
<thead>
<tr>
<th>Charge State</th>
<th>Energy / keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100 - 1000</td>
</tr>
<tr>
<td>1+</td>
<td>1000 - 10000</td>
</tr>
<tr>
<td>2+</td>
<td>1000 - 10000</td>
</tr>
<tr>
<td>3+</td>
<td>1000 - 10000</td>
</tr>
<tr>
<td>4+</td>
<td>1000 - 10000</td>
</tr>
</tbody>
</table>

Energy / keV

www.ams.ethz.ch
Traditional 3-6 MV AMS systems

- Leibniz AMS 3 MV facility, Kiel, GER
- HZDR 6 MV Tandetron AMS facility, Rossendorf, GER
- VERA AMS 3 MV facility, Vienna, Austria
Charge state yield of $^{14}$C ions in Ar gas

Compact AMS
0.2 - 1 MV

Multiple ion gas collisions

Traditional AMS
2.5 - 9 MV

Coulomb disintegration

Fraction of ions in charge state

Energy / keV

0% 20% 40% 60% 80%

0 1+ 2+ 3+ 4+
**Stripping Process**

Injected negative mass 14 ions

\[ \begin{align*}
14\text{C}^- & = 1 \\
13\text{CH}^- & = 10^8 \\
12\text{CH}_2^- & = 10^9
\end{align*} \]

negative ions

Stripper

positive ions

q=1-, 0, 1+, 2+, 3+, ...

\[ \begin{align*}
{}^{13}\text{CH}^q & \quad {}^{13}\text{C}^q \\
{}^{12}\text{CH}_2^q & \quad {}^{12}\text{C}^q \\
\text{H}^q & \quad {}^{14}\text{C}^q
\end{align*} \]

\[ \sum \Phi_q \rho (q) q = 1, 0, 1+, 2+, 3+, .. \]

- Electron-loss
- Electron capture
- Break-up of molecules
- Energy straggling
- Angular straggling

**Charge state distribution**

\[ \begin{align*}
{}^{14}\text{C}^- \\
{}^{13}\text{C}^- \\
{}^{12}\text{C}^- \\
{}^{13}\text{CH}^- \\
{}^{12}\text{CH}_2^- \\
\text{H}^- \\
\text{H}^+ \\
\text{H}^{++} \\
\text{H}^{+++} \\
\text{..}
\end{align*} \]
Compact AMS Systems (1 MV-500KV)

Tandy AMS facility, Zurich, CH

ETH Zürich
Inside view of a MICADAS acceleration system
He-stripping to enhance system performance: AixMICADAS

in collaboration with: Aix-Marseille University Collège de France

performance:
• 48 % transmission
• > 90% ion optical transmission
• stable operation conditions
Introducing permanent magnets in AMS instruments

collaboration with:

- Arnd Braurichter
- Franz Boedker
- Leif Baandrup

- Göran Possnert
- Mehran Salehpour

permanent materials have a strong temperature dependence of magnetic field strength

Why shall we get away from a well established concept?

1) Simplified installation
2) No cooling water required
3) Significant reduction in operating costs

energy consumption of magnets:
5 - 10 kW @ 3000 h/year
energy costs: ~0.3 $/kWh → 4500-9000 $/yr
GreenMICADAS developed at ETHZ

Wall plug 3x400 V/16 A

compact lab-sized instrument
  – automatic operation
  – simple operation
  – no open high voltages
  – low maintenance costs

First System installed in 2014 at University of Uppsala
Second System became operational this week (CEA-Saclay)
Two more are under construction (University of Bristol, ETH Zurich)
Discoverers of Accelerator Mass Spectrometry (1977)

AMS-Heros
A.E. Litherland
K.H. Purser
H.E. Gove

not in picture
E. Nelson
G. Raisbeck
R. Muller

The New York Times

NEW YORK, THURSDAY, JUNE 9, 1977

A New Method of Carbon-14 Dating Expected to Double Science's Range

Der Rochester, NY(USA) Teilchenbeschleuniger

erster $^{14}$C Nachweis
Can we go any further?
He areal density of $\approx 0.5\mu g / cm^2$ should be sufficient to get rid of molecules

\[ \sigma / (10^{-16} \text{ cm}^2) \]

*stripping energy / keV*
Angular straggling

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N2

He

Energy / keV

half angle beam acceptance / mrad

68%
80%
95%

68%
80%
95%

www.ams.ethz.ch
Charge state yield: $^{12}$C in He

Further details: Poster AAT39; Sascha Maxeiner
A pure mass spectrometer for $^{14}$C detection

**Experimental platform (prototype instrument)**

- Investigate physical processes
- Optimize operation conditions
- Find best suited ion optical conditions
- Test designs for a dedicated $^{14}$C mass spectrometer

**myCADAS**

**Configuration:**
- Magnet
- Stripper
- Magnet
- ESA

**Transmission:** 35-38% @ 45 keV
Background and detection level

-7kV bias at vacuum chamber

2-D Scan: Analyzing magnet / ESA

- Clear identification of $^{14}$C ions
- $^{14}$C peak shows e/q – p/q correlation
- $\approx 35\%$ transmission
- $\approx 70\%$ $^{14}$C detection efficiency
Moor’s Law in AMS

- well established technology
- further developments for routine operation of specific applications

- FN-Tandem McMaster
- MP-Tandem Rochester
- EN-Tandem ETH, Oxford, Lower Hutt, Utrecht, Erlangen, ...
- IONEX Arizona, Oxford, Gif-sur-Yvette, ...
- HVEE-Tandetron Woods Hole, Groningen, Kiel, ...
- ETH-Compact: Zurich
  - NEC: Georgia, Poznan, Irvine
- NEC-SSAMS Lund, ANU, SUERC, ...
- ETH-MICADAS Zurich, Davis, Mannheim, ...
- ETH-μICADAS Zurich

\[ \text{14C ion energy / MeV} \]

\[ \text{Year / AD} \]
Scientific instruments for AMS and IBA

Ionplus AG produces high-quality and user-friendly instrumentation for accelerator mass spectrometry (AMS) and ion beam analysis (IBA).