

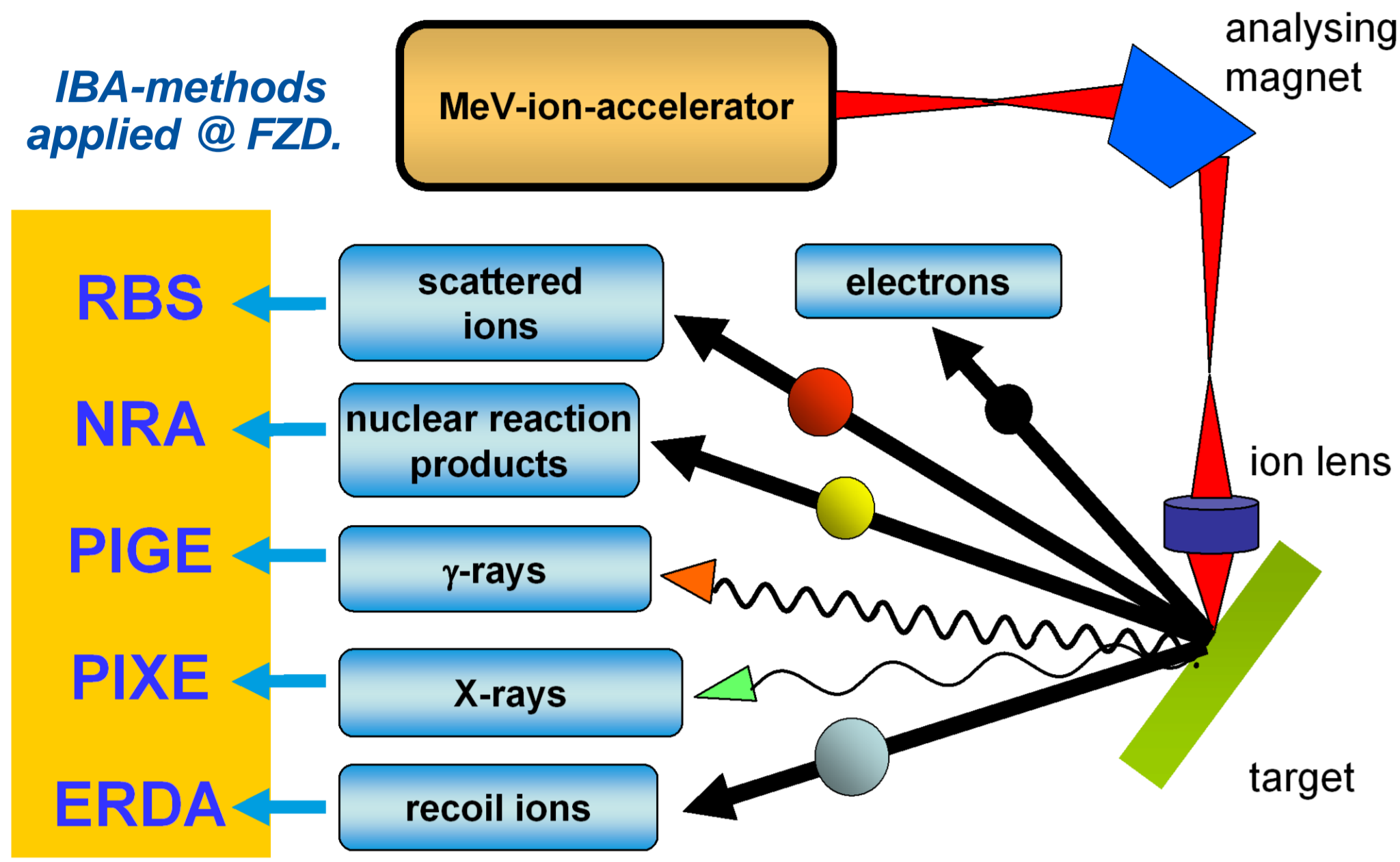
Accelerator mass spectrometry (AMS) and ion beam analysis (IBA) with the new 6 MV accelerator at FZ Dresden-Rossendorf

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Ion beam analysis @ FZD

Since more than 30 years ion beam analysis (IBA) is performed at the Forschungszentrum Dresden-Rossendorf (FZD) for the determination of element distributions. Due to continuous upgrades of the different experimental set-ups, we are able to routinely perform:

- Rutherford Backscattering Spectrometry (RBS) & Channeling (C-RBS)
- Nuclear Reaction Analysis (NRA)
- Elastic Recoil Detection Analysis (ERDA)
- Particle-Induced X-Ray Emission (PIXE)
- Particle-Induced Gamma-Ray Emission (PIGE)



State-of-the art with "old" accelerators [1]

Most of our applications lie within material sciences. We are able to measure non-destructively "all natural" elements, i.e. hydrogen to uranium, most elements with lateral, some even in 3-D resolution with the following typical parameters (highly depending on matrix and elements):

depth resolution	0.5 - 30 nm
depth range	nm - μm
lateral resolution	few μm
usual mapping area	2 x 2 mm ²
maximum sample size	3 x 10 cm ² (vacuum) & "unlimited" (external beam)
detection limits	10 $\mu\text{g/g}$ (H) / 1 $\mu\text{g/g}$ (F) 500 $\mu\text{g/g}$ - 1% (He-O) 10-100 $\mu\text{g/g}$ (Na-U)

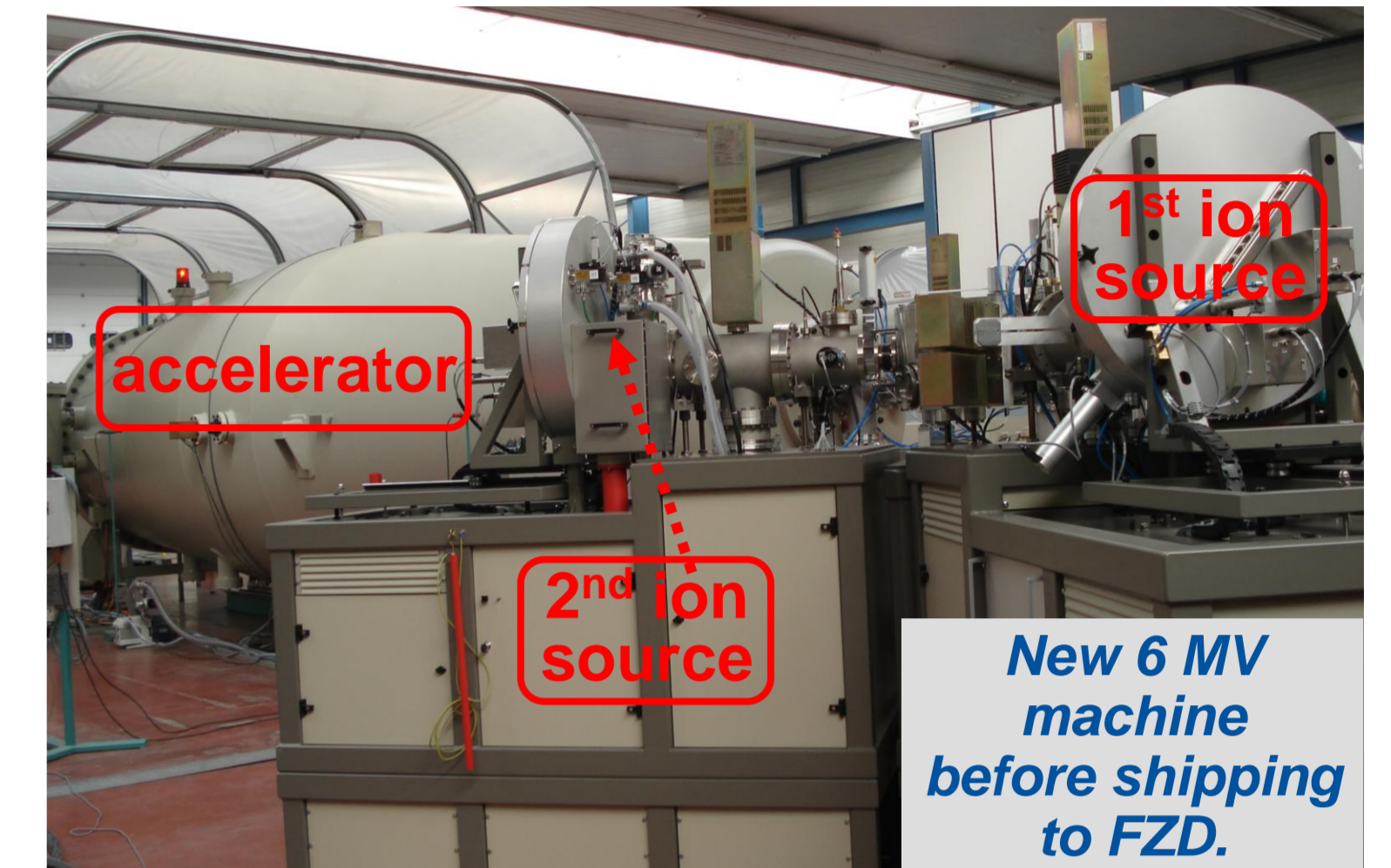
For some elements, e.g. H/D, isotope analysis is possible.

Outlook for "new" 6 MV accelerator

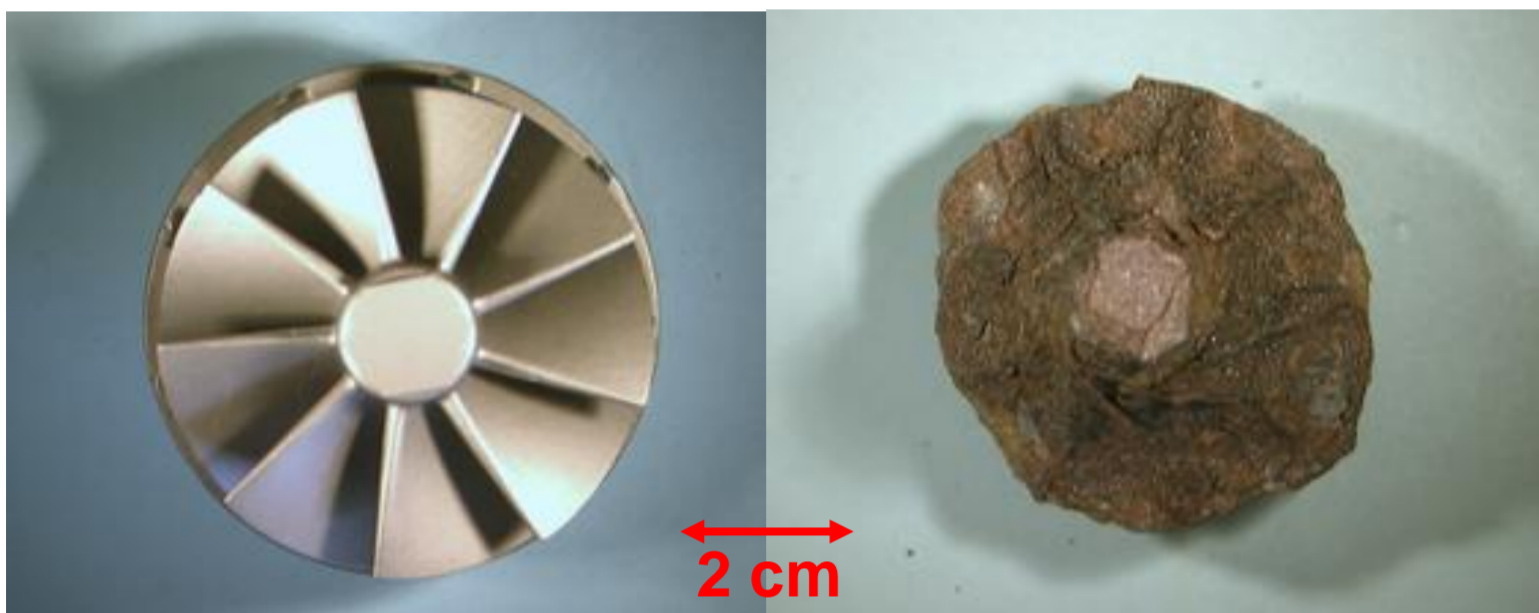
In summer 2009, the old van-de-Graaff 5 MV accelerator will be replaced by the latest 6 MV Tandatron model [2], which is even more sophisticated than the lately installed 5 MV version in France [3]. Our new accelerator will need less maintenance allowing more beam time for real measurements with respect to our old one. It might be also possible to expand from two to three 8-hour-shifts a day with the new fully automatic system.

Scientifically, the main advantages for IBA are an increased depth range by a factor of two for ERDA and improved detection limits for NRA. The high energy resolution allows analysis of outstanding depth resolution and provides the ion optical requirements for a MeV-ion nanoprobe for selective in vivo-irradiation of cell nuclei at the nanometre-scale.

In addition, the machine will be installed with special equipment for accelerator mass spectrometry (AMS) [4].

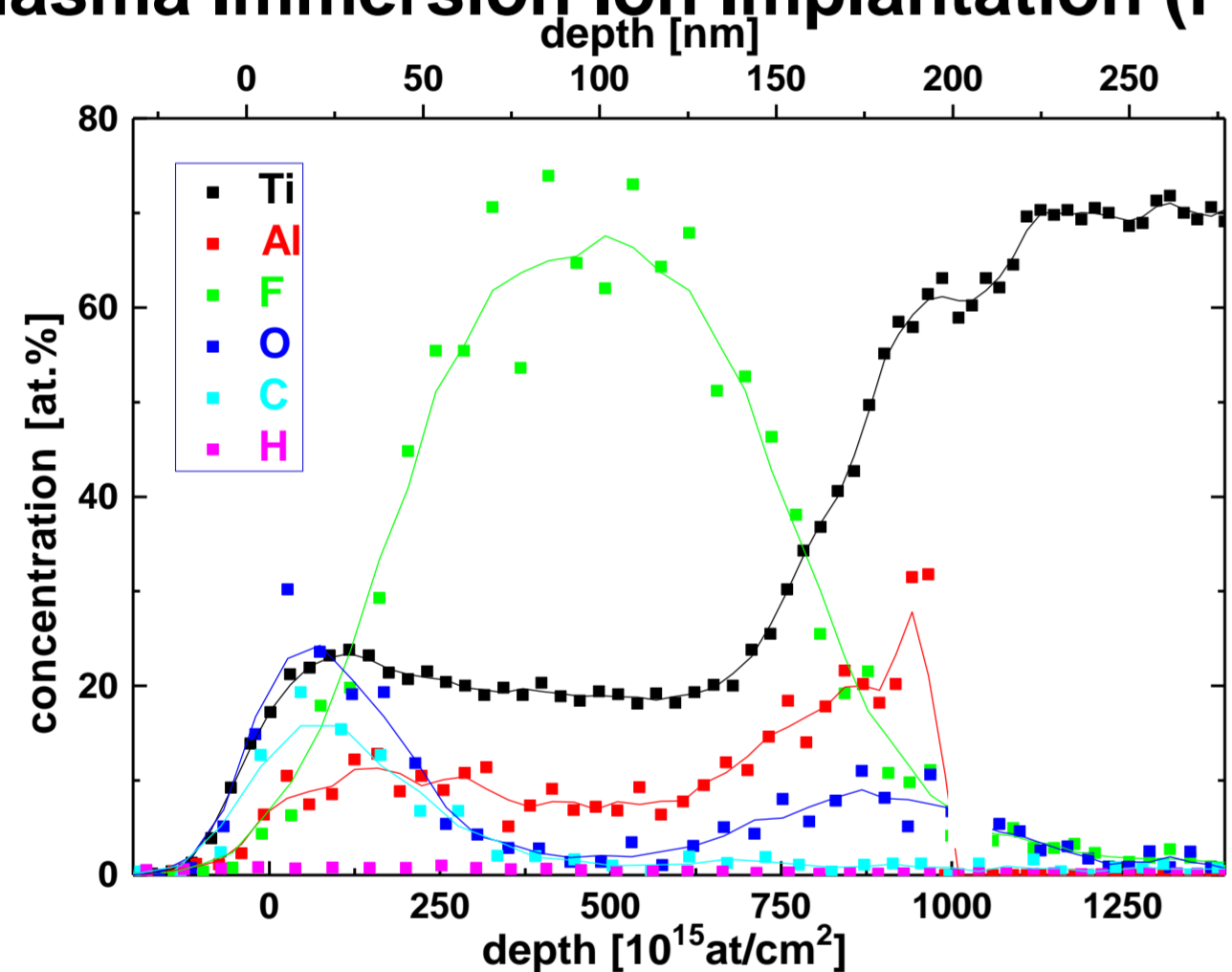


Improving the corrosion resistance at high temperatures by fluoridation



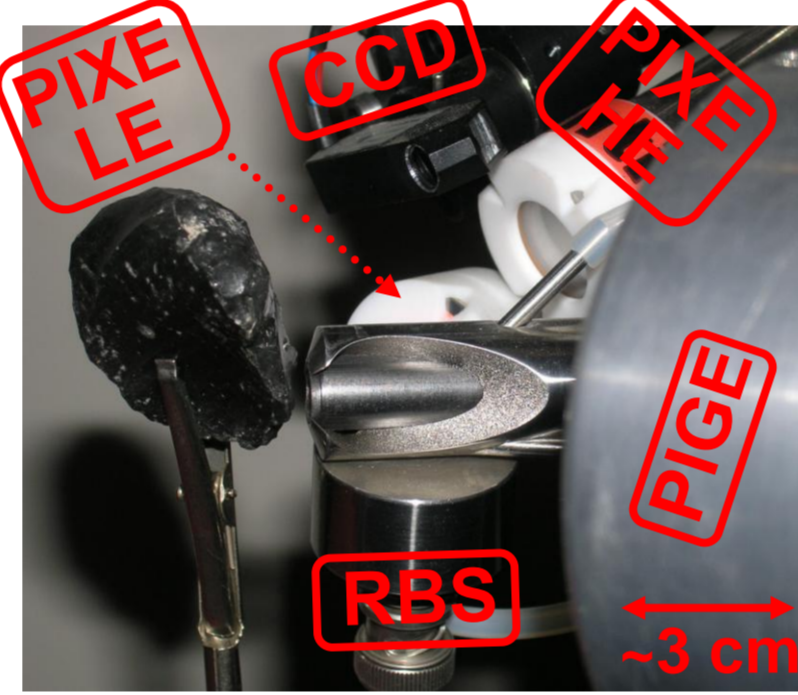
A turbocharger made of TiAl alloy before (left) and after (right) oxidation in air at 1200°C for 50 days.

possible treatment against corrosion: Plasma Immersion Ion Implantation (PIII) of F



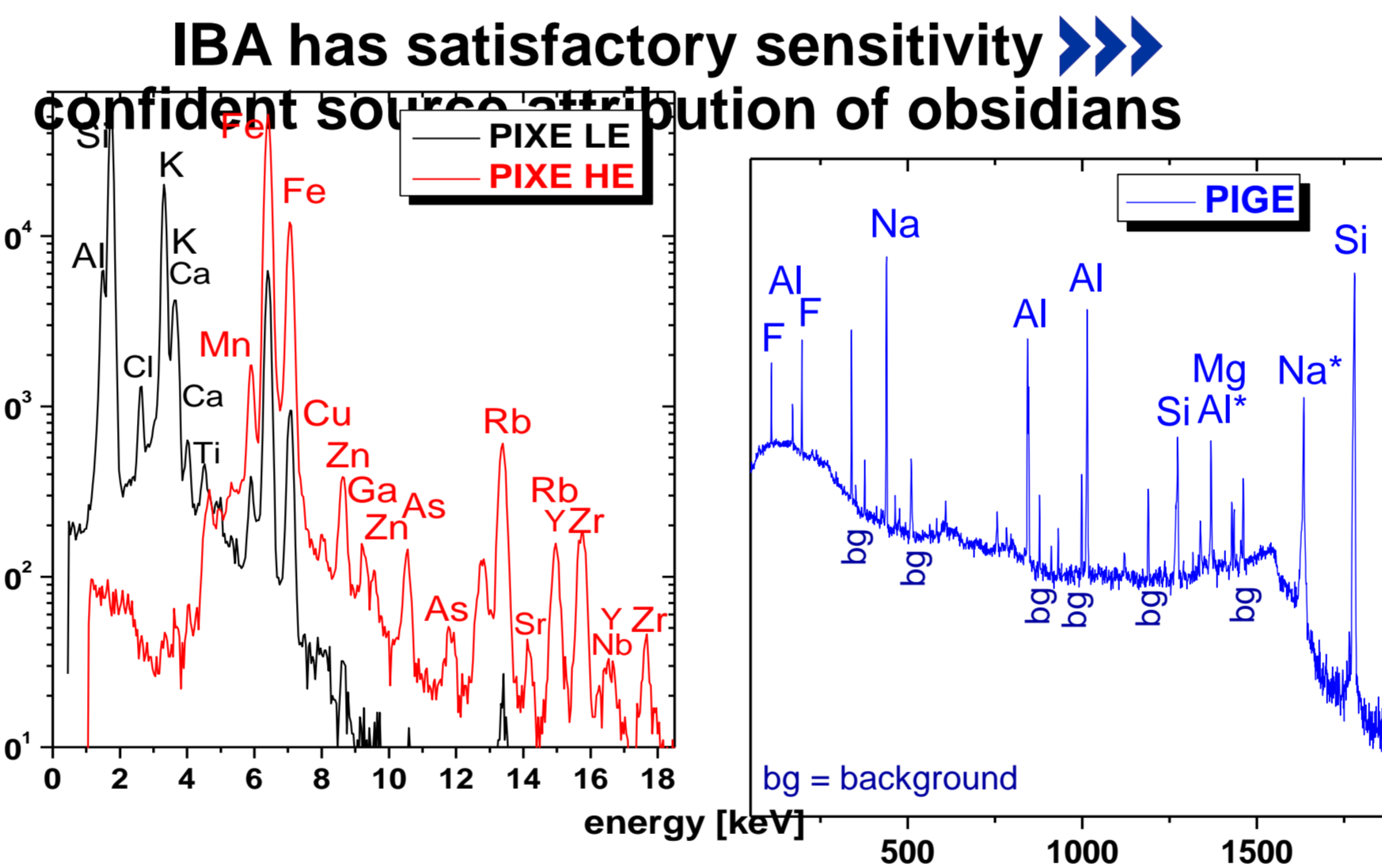
Depth profiles of main elements of TiAl alloy "after processing with F by PIII" measured by ERDA [5].

Selection of IBA applications Provenance studies on archaeological obsidian



Obsidian sample in front of external proton beam (1 mm ϕ) with PIXE-, PIGE- and RBS-detectors.

good agreement between non-destructive IBA and corresponding destructive LA-ICP-MS results



PIXE- and PIGE-spectra simultaneously measured from an Obsidian sample [6]. (p,p γ)-reactions for PIGE-peaks (exception: *(p, α)).

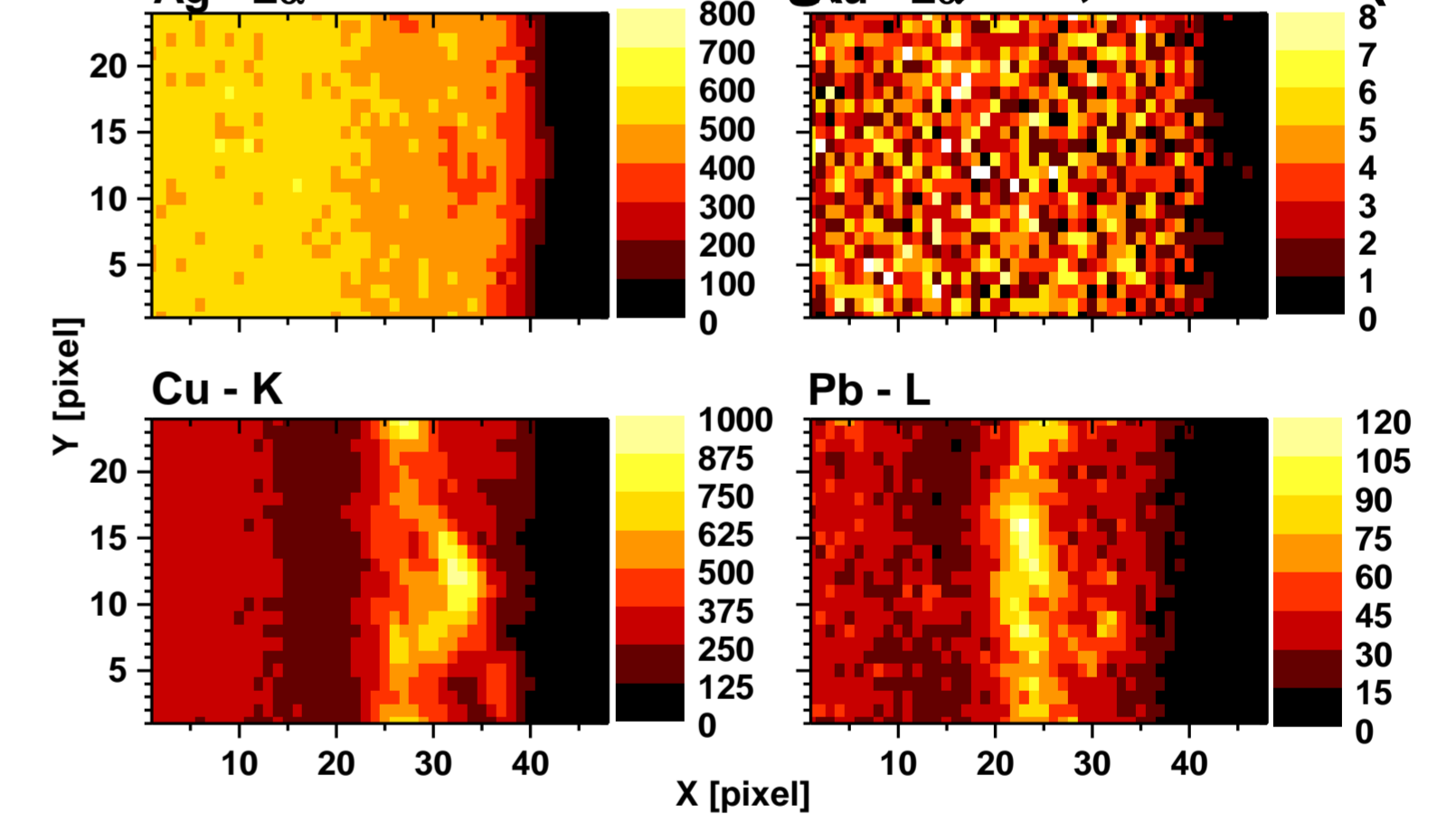
Silver Coins of the Ottoman Empire



Excavation site @ Becin, near Ephesos, Turkey (left) & coins in the state of excavation (right).

comparison of μ -XRF, SEM/EDX & PIXE for same sample: silver coin of Mehmed III. (1595-1603)

μ -XRF: Ag, Cu, Pb
SEM/EDX: Ag, Cu, Pb + Au (0.6%)
PIXE: Ag, Cu, Pb, Au + Bi (0.03%)



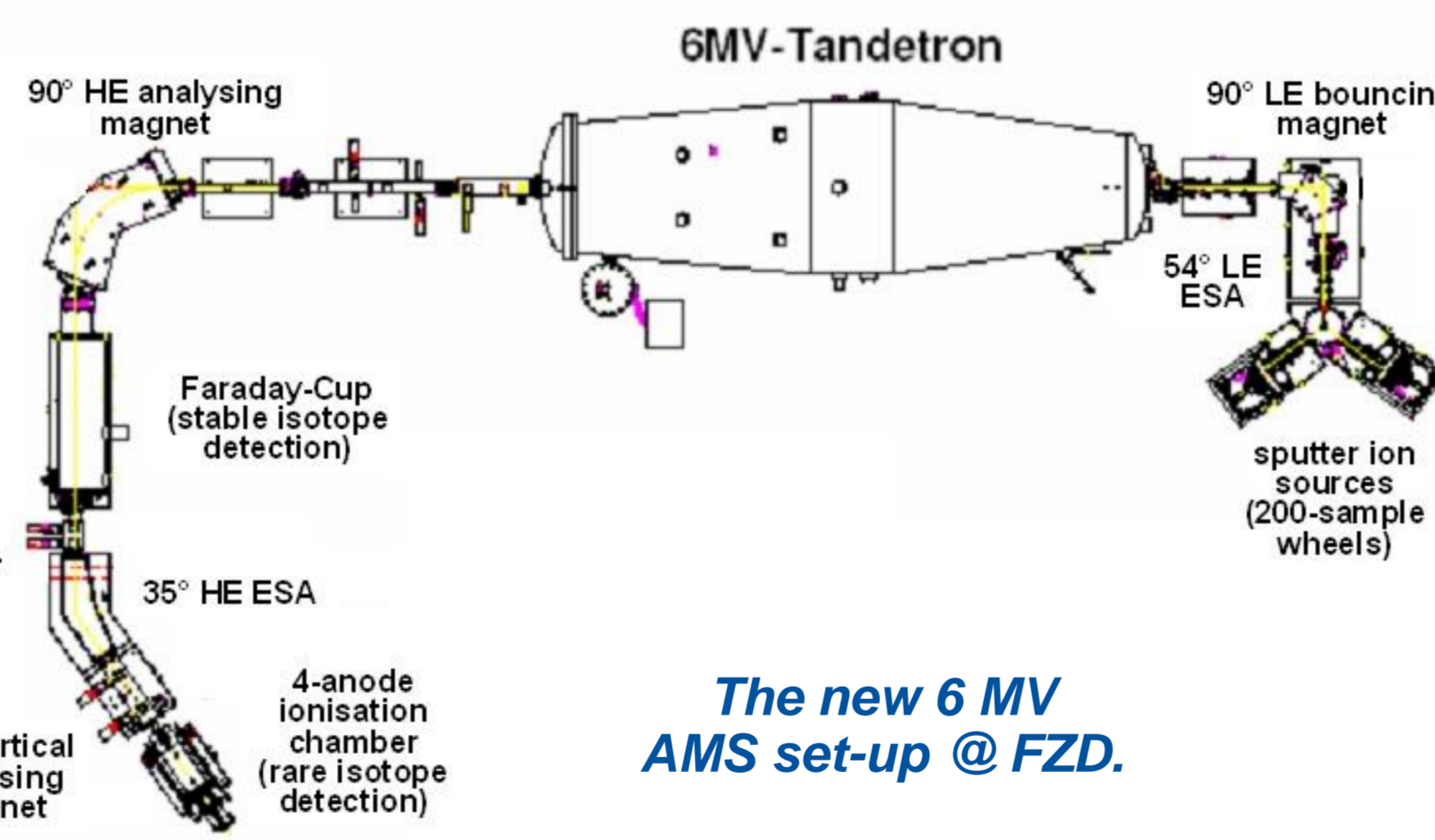
2-D elemental distributions deduced from individual PIXE-spectra (beam- ϕ : 2-3 μm ; scanning area \sim 110 μm x 35 μm) [7].

AMS

There is a main advantage of using a high-energy accelerator for mass spectrometry: The background and interfering signals, resulting from molecular ions and ions with similar masses (e.g. isobars) are nearly completely eliminated. Thus, AMS generally provides much lower detection limits (typical isotope ratios 10^{-10} - 10^{-15}) in comparison to conventional mass spectrometry. Our AMS system will offer excellent measurement capabilities also for external users.

In contrast to common low-energy AMS facilities in Europe, which have mainly specialized in radiocarbon analyses (¹⁴C), the FZD-AMS is the first modern-type facility in the EU that will run at a terminal voltage of 6 MV.

Especially in environmental and geosciences, the determination of long-lived ($t_{1/2}$ > 0.3 Ma) cosmogenic radionuclides like ¹⁰Be, ²⁶Al, and ³⁶Cl became more and more important within the last decades [8]. Using these nuclides dating of mass movements, e.g. volcanic eruptions, rock avalanches, earth quakes, and glacier movements is possible.



The new 6 MV AMS set-up @ FZD.

Detection limits of AMS can be as low as 20,000 atoms/g or 10^{-9} Bq.

Elements, which are routinely measurable using a large accelerator like the one at FZD, are marked in red in the periodic system of elements. Those elements with at least one long-lived radionuclide with a half-life longer than 10 years are marked in orange and can be measured by a more-sophisticated approach.

Due to the low precision of AMS (% to ‰), stable isotopes of elements marked in yellow can only be measured if the ratios are highly different from natural isotope ratios. Probably, other MS methods yield better results at normal isotope ratios.

H																He		
Li	Be	B	C	N	O	F	Ne											
Na	Mg	Al	Si	P	S	Cl	Ar											
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	112	113	114	115	116		118	

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

* only one long-lived radioactive isotope / no stable isotope \rightarrow very sophisticated set-up

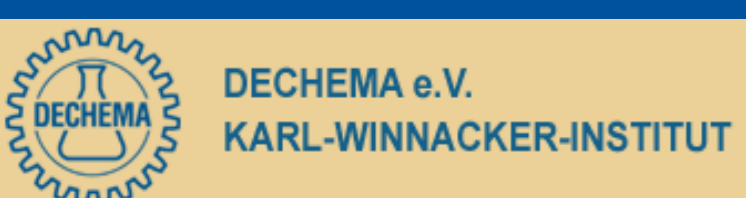
References

[1] <http://www.fzd.de/fwia>. [2] A. Gott dang et al., NIMB 190 (2002) 177. [3] M.G. Klein et al., NIMB 266 (2008) 1828. [4] <http://www.fzd.de/ams>. [5] U. Kreissig et al., NIMB 136-138 (1998) 674. [6] R. Bugoi et al., NIMB 226 (2004) 136. [7] M. Schreiner et al., IBA-2005-Abstract. [8] J.C. Gosse and F.M. Phillips, Quat. Sci. Rev. 20 (2001) 1475. [9] <http://www.fzd.de/aim>.

Acknowledgments

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in cooperation with:



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Forschungszentrum
Dresden Rossendorf

External researchers can apply for access to the AIM (Center for Application of Ion Beams in Materials Research) @ FZD [9].