



Utilization of the RBI Tandem Accelerator Facility for Analytical Applications

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Utilization of Accelerators, Vienna, 4-8 May 2009**

Satellite meeting II: Particle Accelerators in Analytical and Educational Applications





Laboratory for Ion Beam Interactions,
Rudjer Boskovic Institute, Zagreb, Croatia:

I. Bogdanovic Radovic, M. Bogovac, I. Bozicevic, S. Fazinic, A. Gajski,
M. Jaksic (head), M. Karlusic, Z. Pastuovic, Z. Perisa, Z. Siketic,
N. Skukan, D. Spanja, T.Tadic, I. Zamboni Micanovic

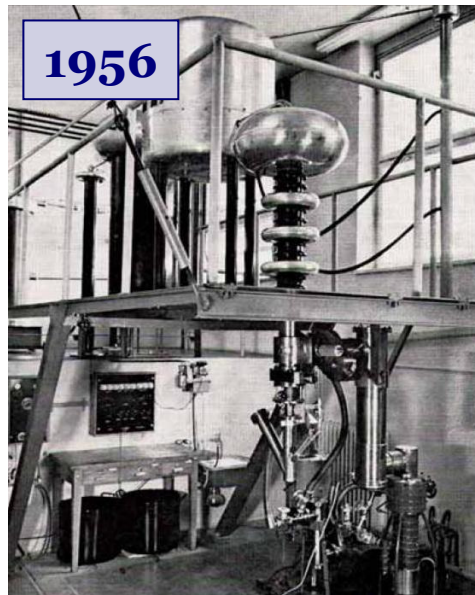
Faculty of Engineering, University of Rijeka:
L. Mandic

Department for Conservation and Restoration, Academy of Fine Arts:
V. Desnica

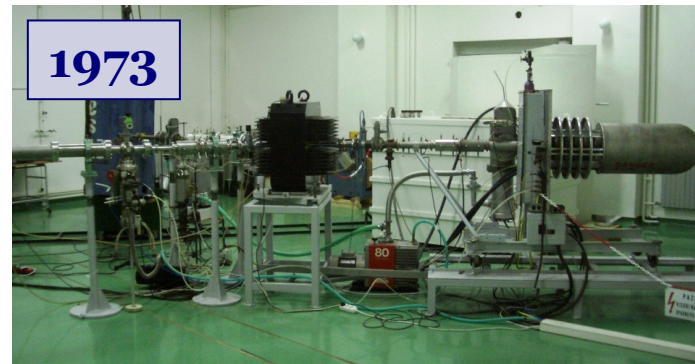
Croatian Conservation Institute, National Science Laboratory
M. Braun, D. Mudronja



History – accelerators of the R. Bošković Institute



1956



1973

1956 - 200 keV neutron generator
1973 - 350 keV neutron generator
(Still in use)



1987



1962

1962 – 1987. Cyclotron
(20 MeV deuterons)
2009 - 18 MeV proton
cyclotron (PET isotopes)

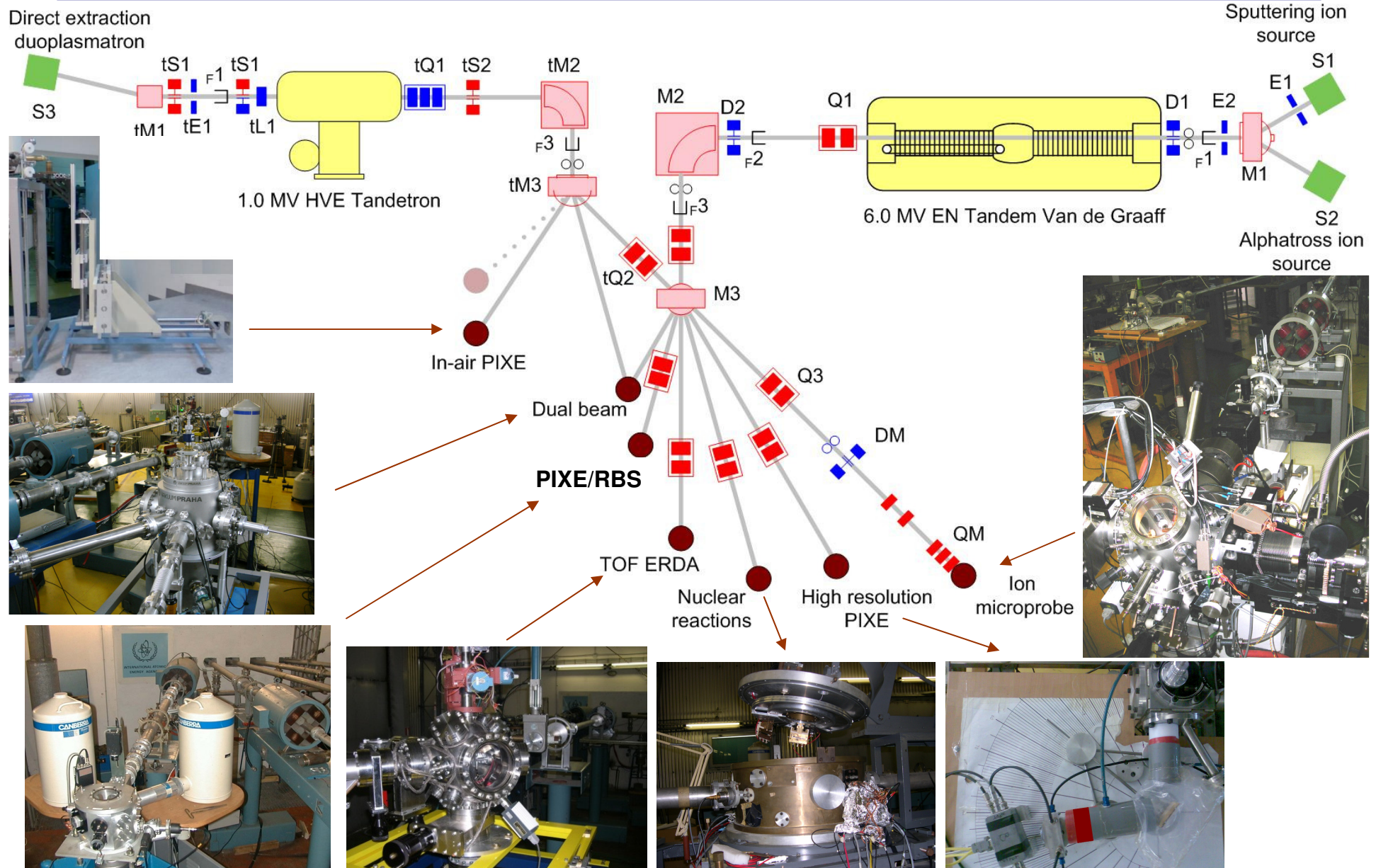
1987 – 6 MV EN Tandem
2005 - 1 MV Tandetron



2005



Tandem accelerators facility





RBI Laboratory for Ion Beam Interactions

Interactions of accelerated ion beams with materials

Fundamental processes

- Stopping of ions in solids and related effects
- Inner shell ionization and X-ray emission processes
- Ion scattering
- Nuclear reactions

Developments

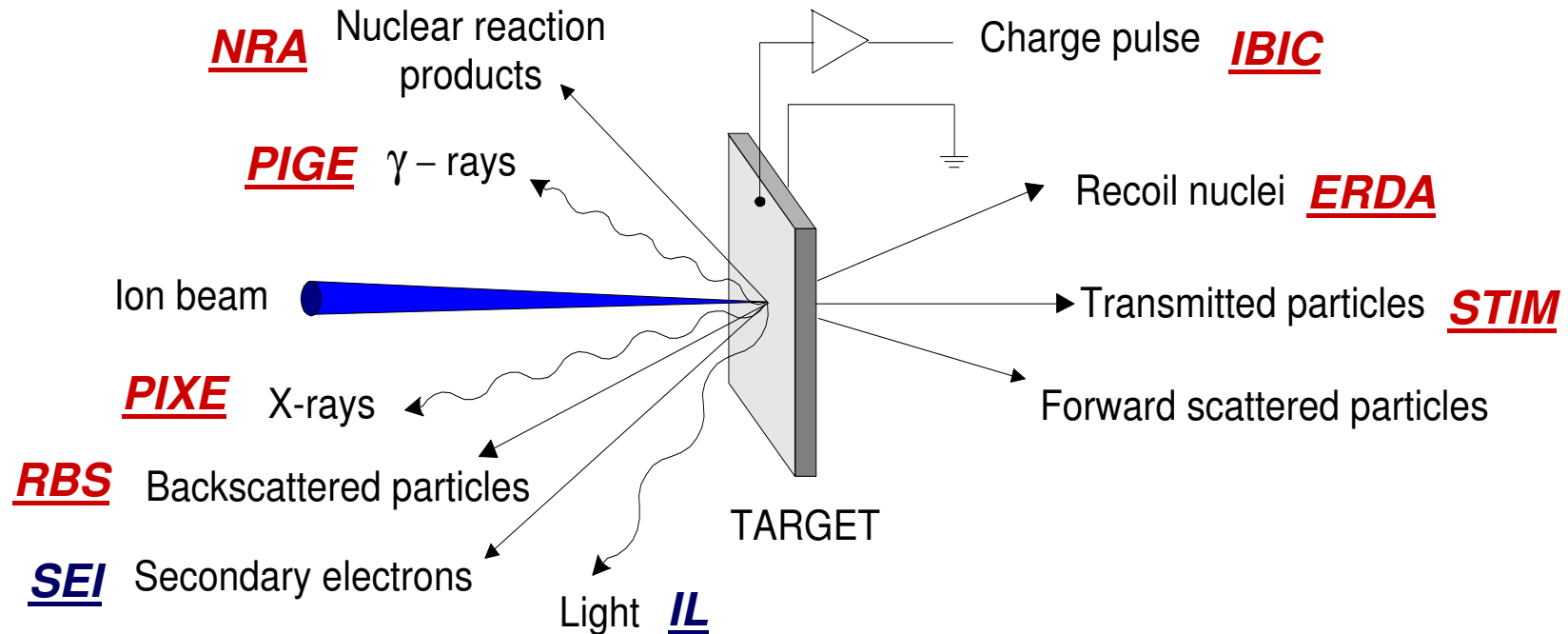
- data acquisition and control software and hardware (SPECTOR)
- accelerator computer control (including remote operation)
- design and constructions of end-stations

Applications

- Material characterisation (analysis) by IBA
- Material modifications



Ion Beam Analysis (IBA)



Concentrations and/or depth profiles:

Elements - x-rays (PIXE)
 - backscattered particles (RBS)
 - recoiled ions (ERDA)

Isotopes - gamma-rays (PIGE)
 - nuclear reactions (NRA)

Density variations – transmitted ions (STIM)

Charge transport – ion beam induced current (IBIC)

Chemical bonds – light (IL), x-rays (high –resolution)

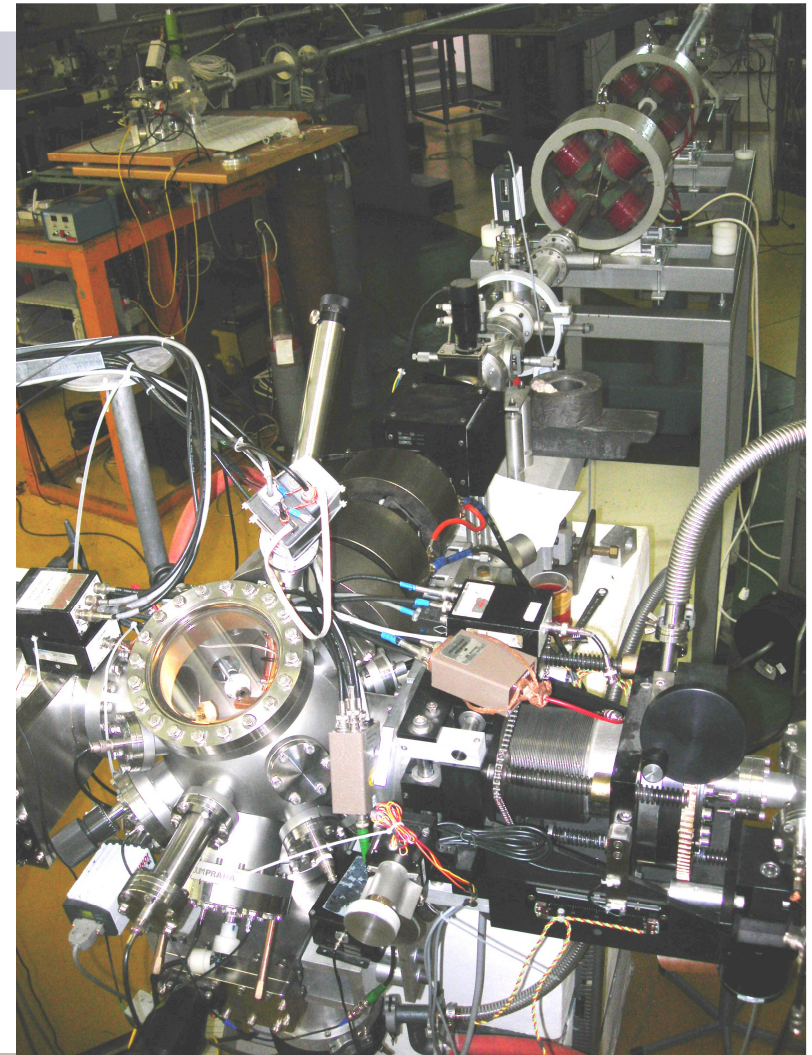
Crystal structure – channeling RBS, STIM, PIXE

Morphology – secondary electrons (SEI)

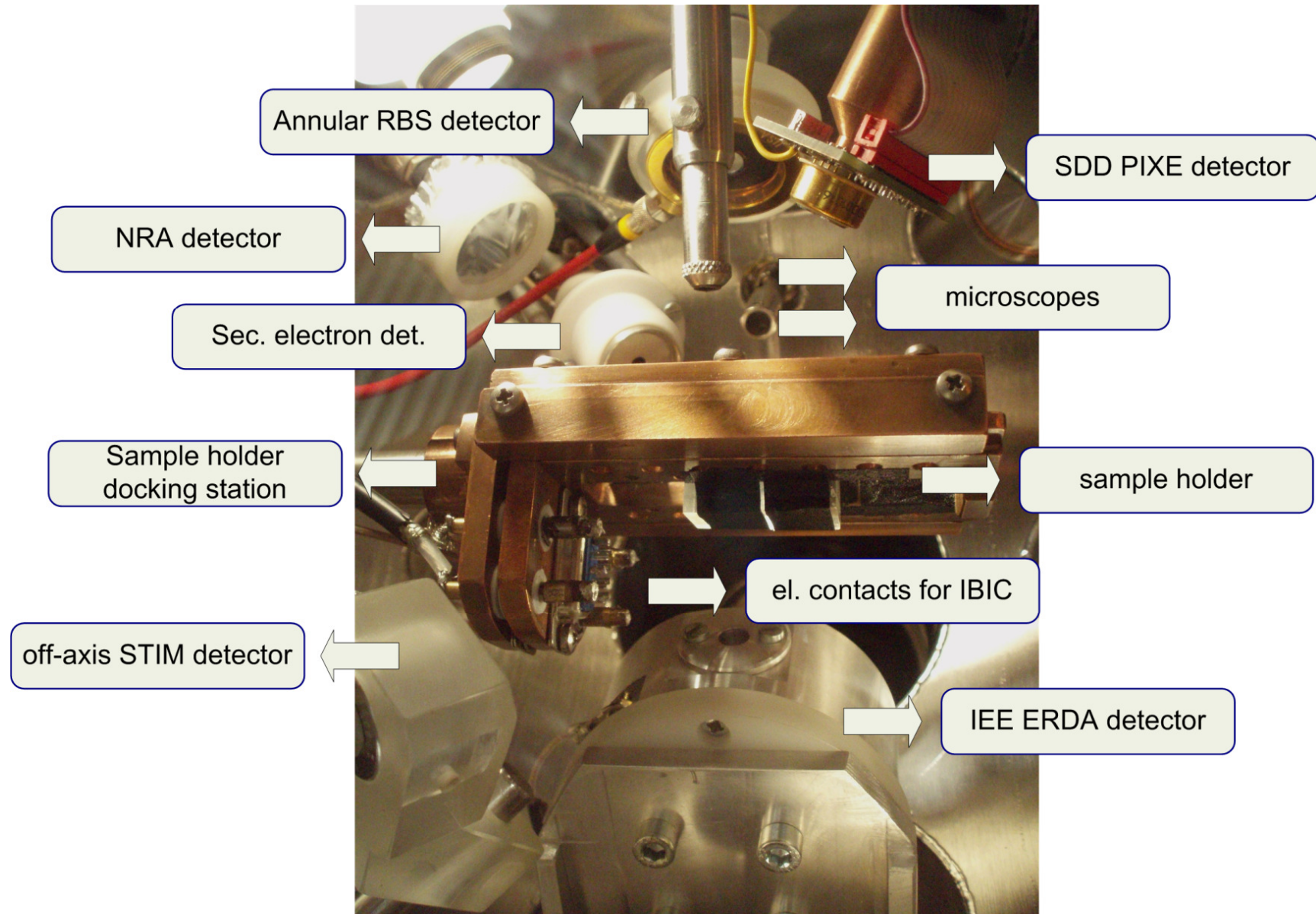


Ion (nuclear) microprobe

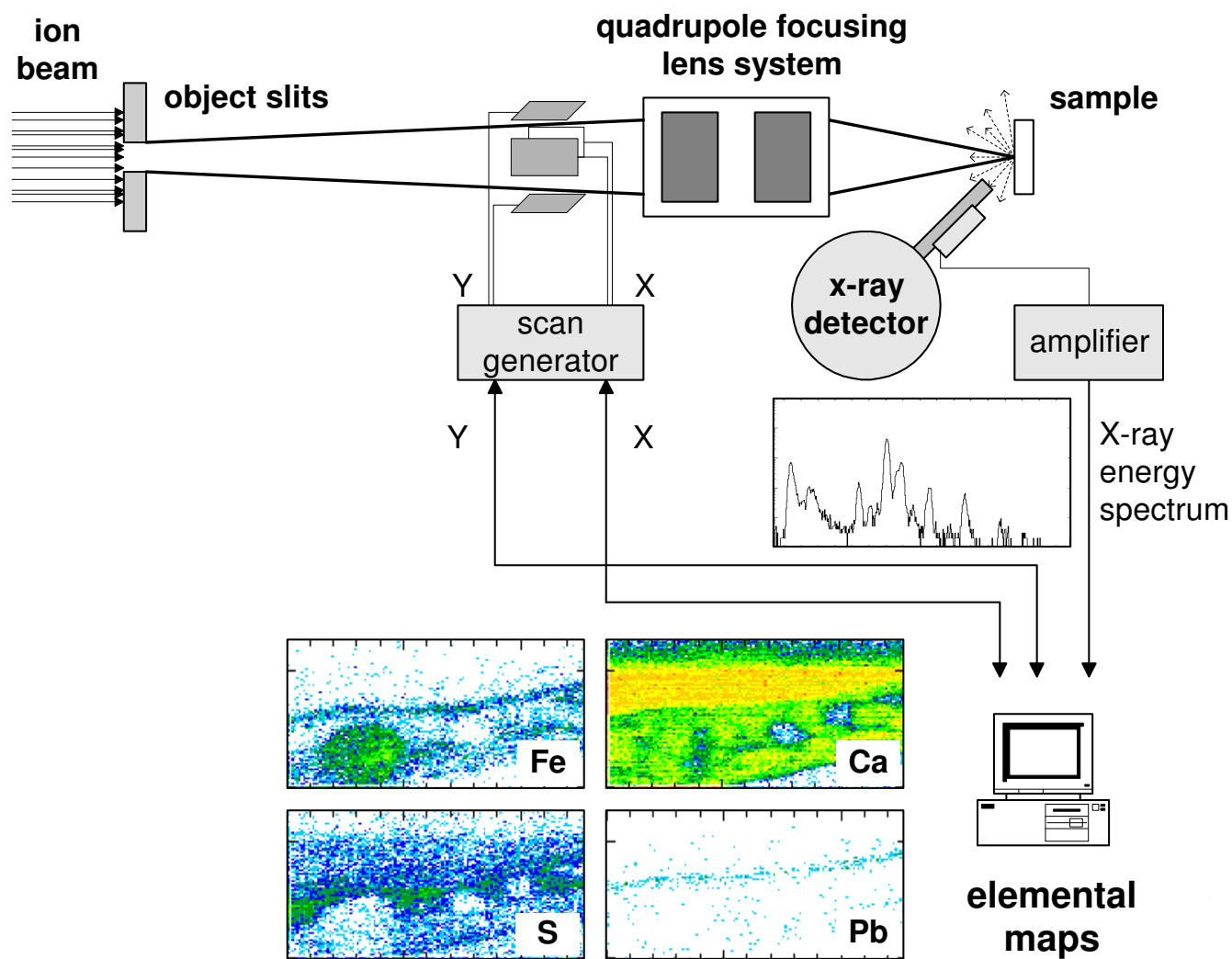
- PIXE, RBS, ERDA,
 - IBIC, STIM
 - Coincidence scattering
 - Ion hit detection (SE & IL)
-
- Focusing system – quintuplet
 - $ME/q^2 < 25$
 - Equal demagnification
 - $0.5\ \mu\text{m}$ – smallest beam size



microprobe - inside the vacuum chamber



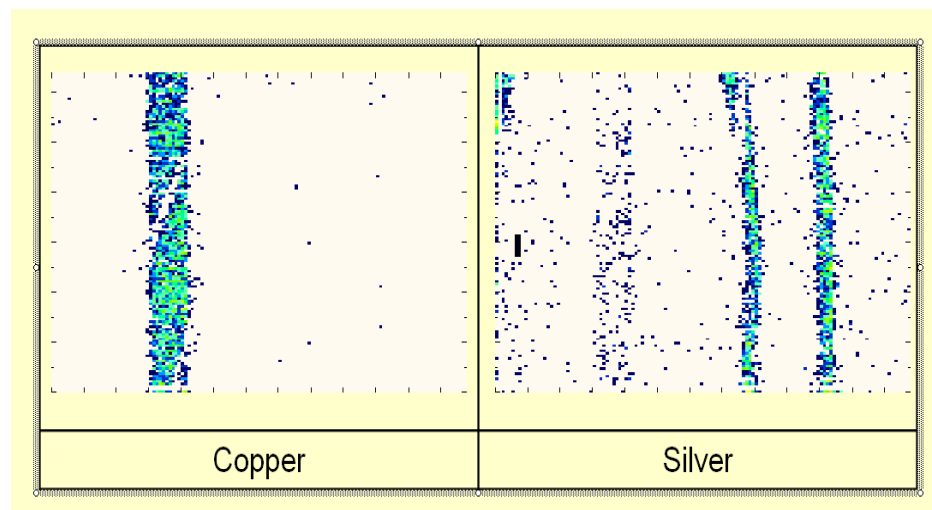
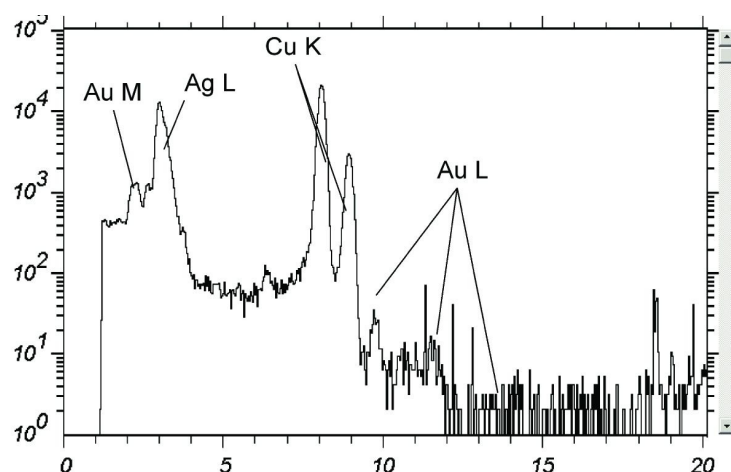
Microprobe



Example: Analysis of metal threads of a 17th century church textile with PIXE at the microprobe

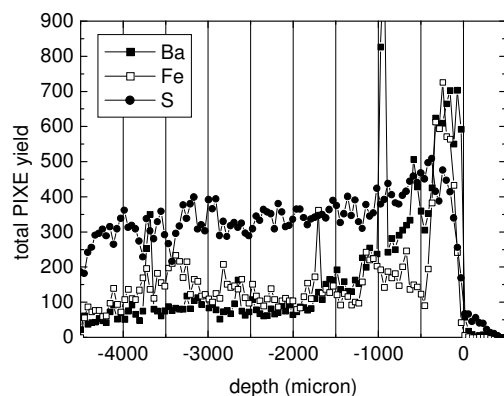


The left lamina contains more copper, whereas the two right ones are silver laminas.

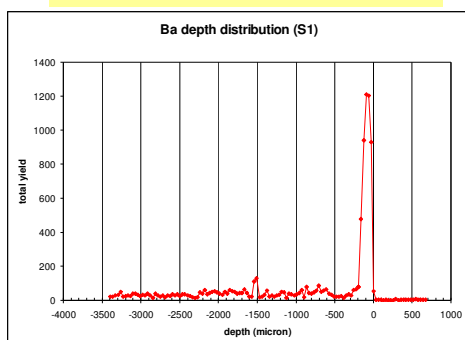


Example: Analysis of stone samples at the microprobe

Conservation of St. Marko church portal



Portal sample P1

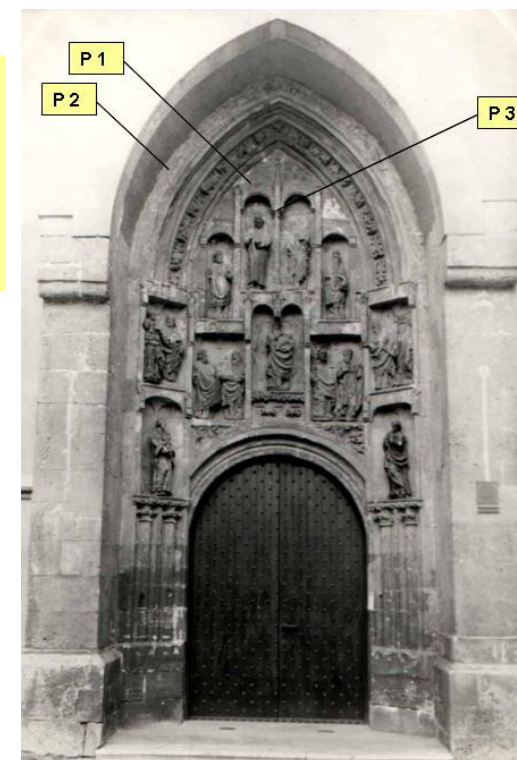


Sandstone sample treated in laboratory

Florentine method of cleaning and consolidation by soaking the stone in ammonium carbonate and barium hydroxide was used.

Barium and sulfur concentration level variations with depth have been determined in samples taken from the portal after the treatment.

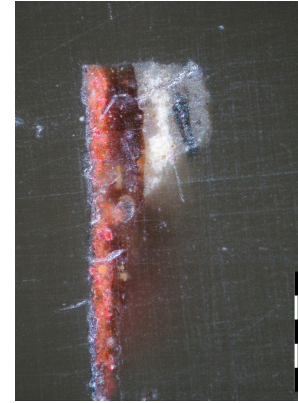
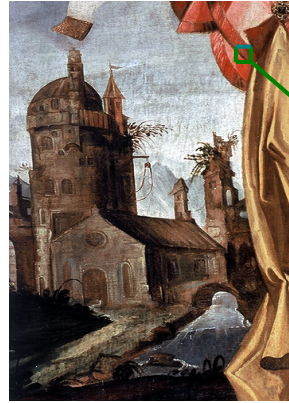
In addition, Ba depth profiles in sandstone treated by three different ways were measured.



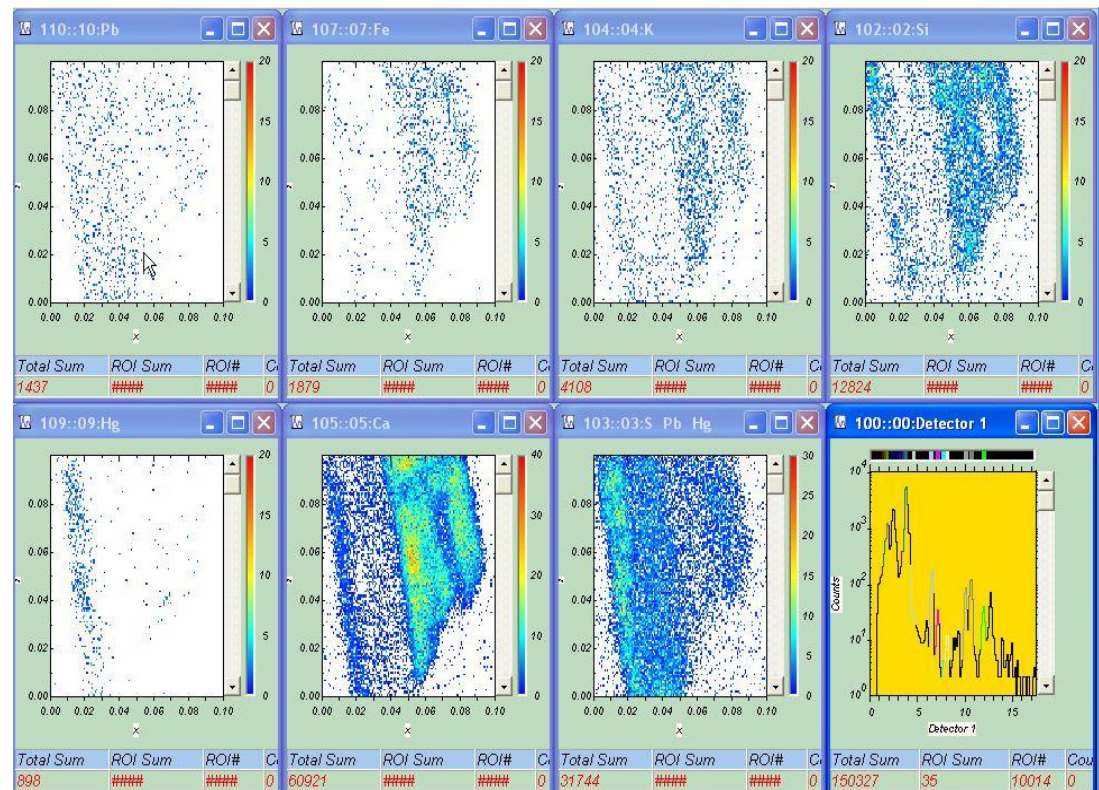
Analysis of pigment layers at the microprobe



The light red layer exhibits high Hg and S concentrations (HgS – cinnabar), while the dark red layer beneath shows presence of Pb, Al, Ca, but without Hg (either minium, or carmine).



2D element distribution of the pigment cross section sample taken from the red area of the painting.



Examples: Analysis of pigment layers at the microprobe

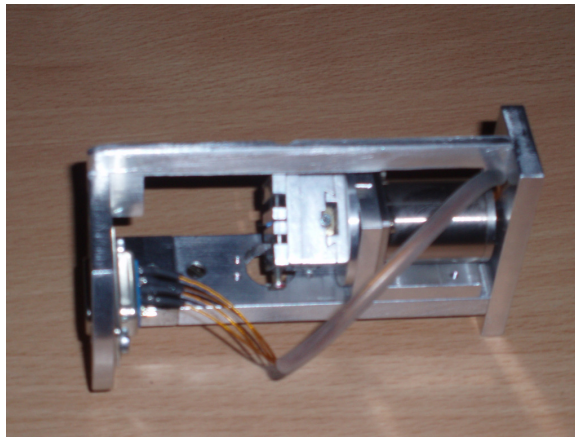


Microsamples are the same as ones needed for optical microscopy techniques. Method is non-destructive and samples may be re-used.

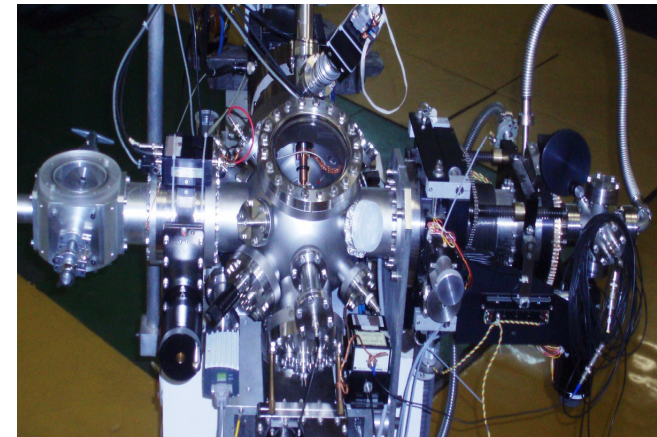
We analyse between 50 to 100 such samples per year.



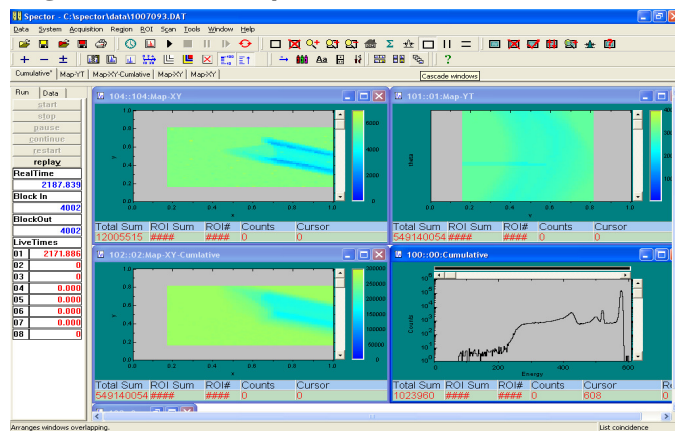
Example 2: STIM tomography module



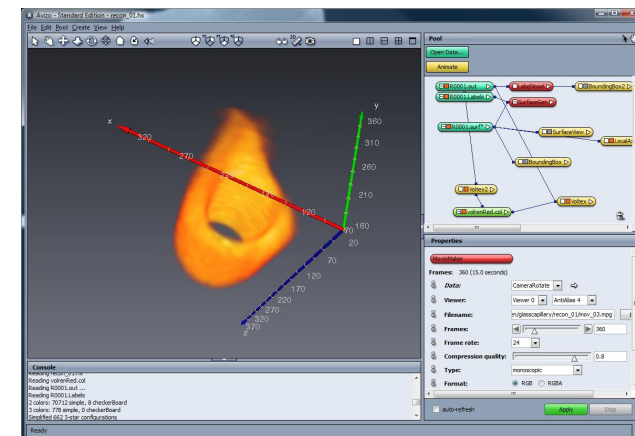
(1) Sample positioning on the axis of stepper motor using microscope



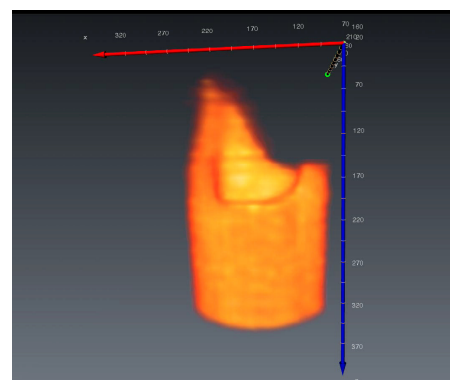
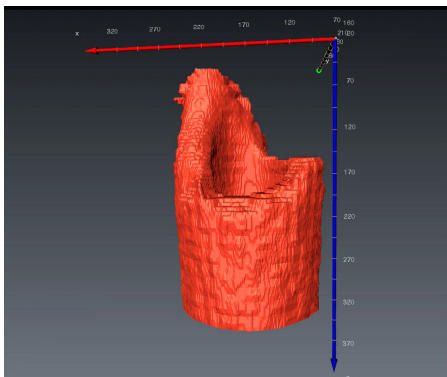
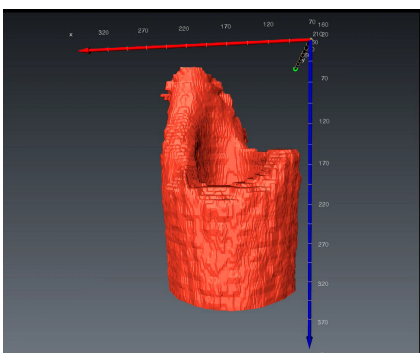
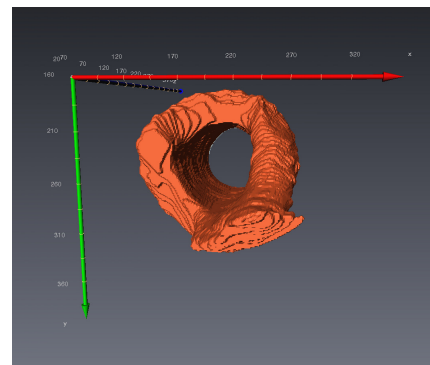
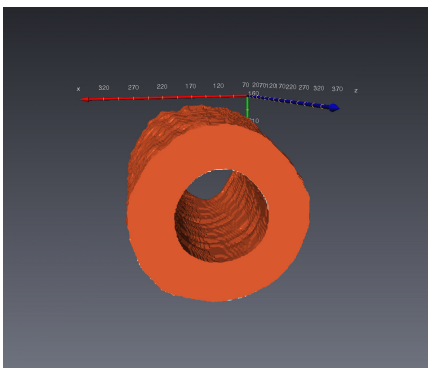
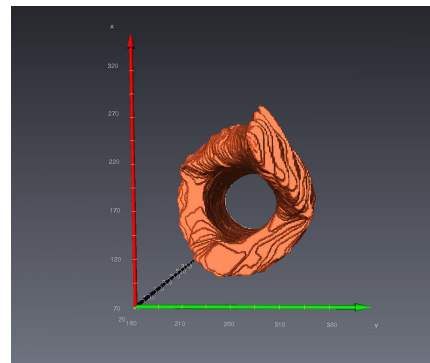
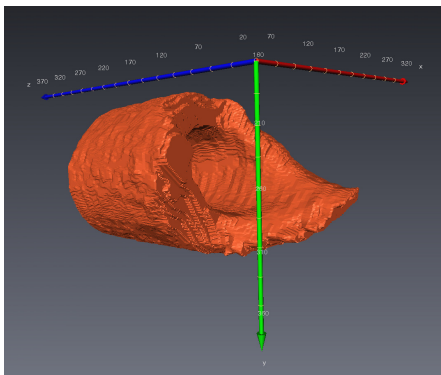
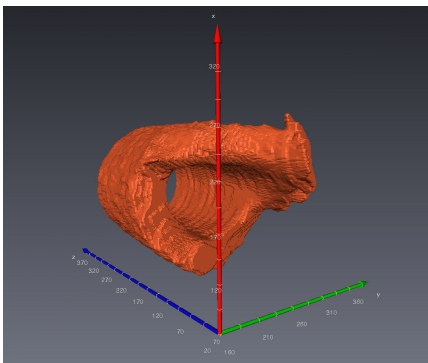
(2) Loading into the chamber



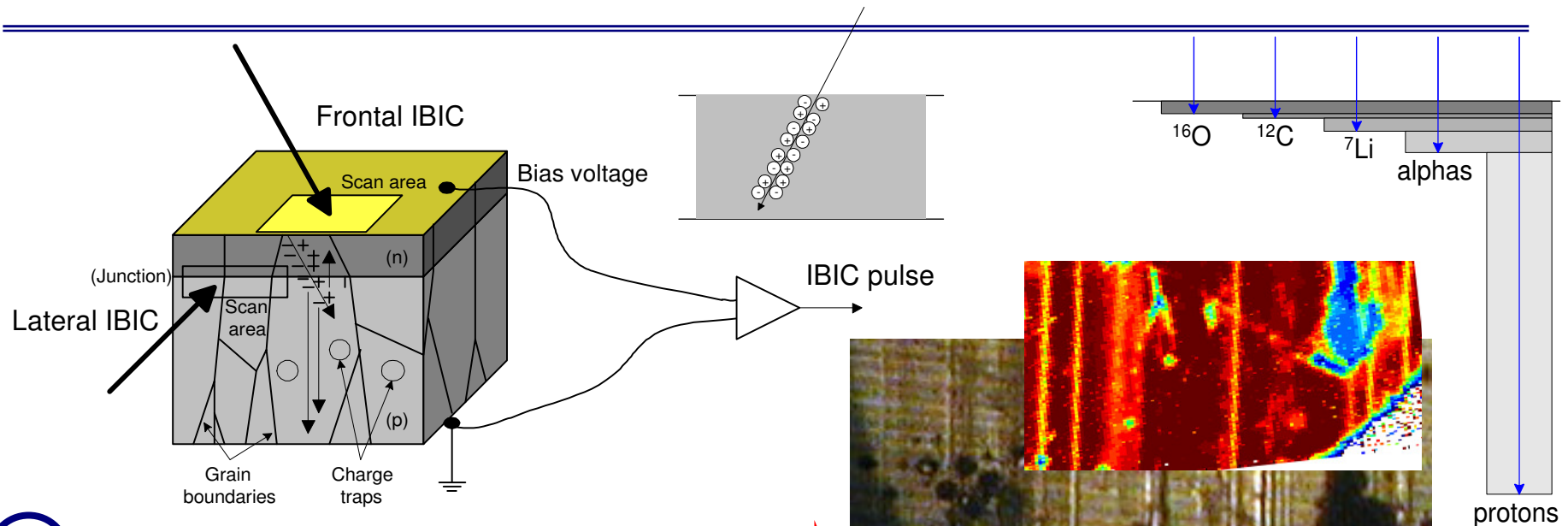
(3) Measurement



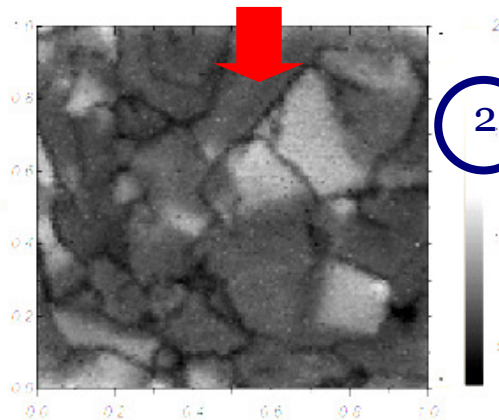
(4) Reconstruction and visualization



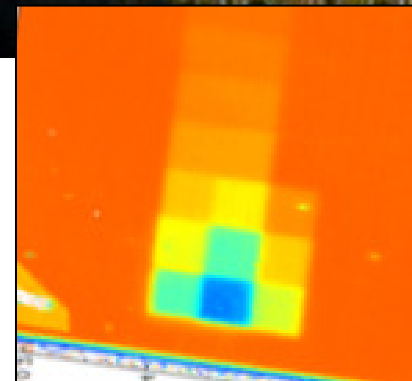
Single ions – tool for **charge injection** and **probe** for micro - **imaging of charge transport** properties



1. Imaging of electronically active defects in Si, CVD diamond, CdTe, GaAs,



2. Creation /structuring of defects → change of charge transport properties: the example of Si pin diodes



PIXE/RBS scattering chamber

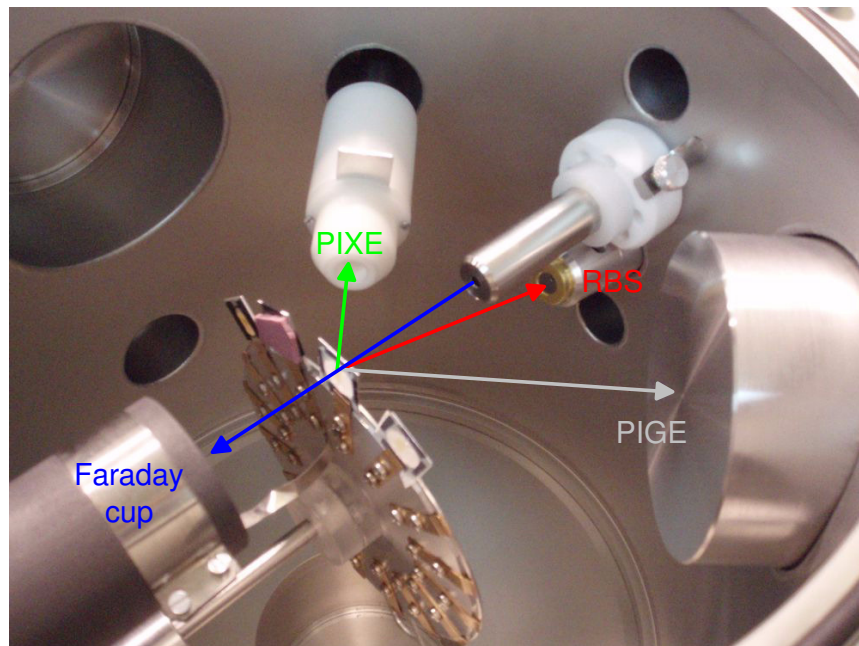


**PIXE, RBS, PIGE detectors
simultaneous measurements**

SPECTOR data acquisition

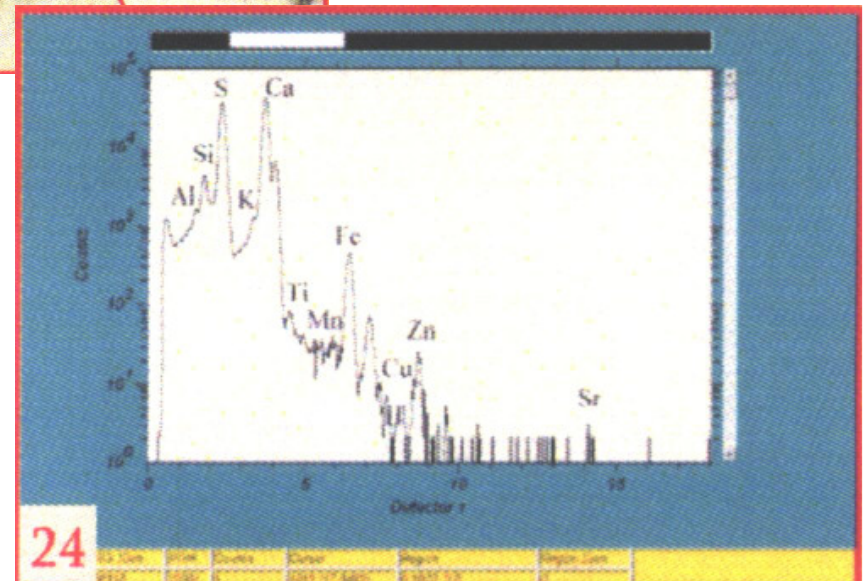
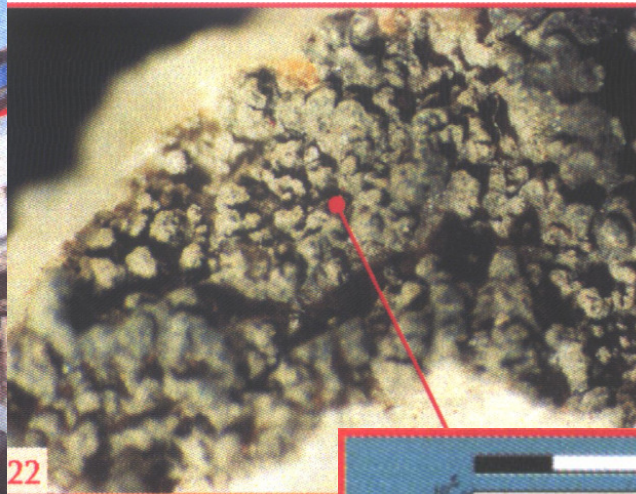
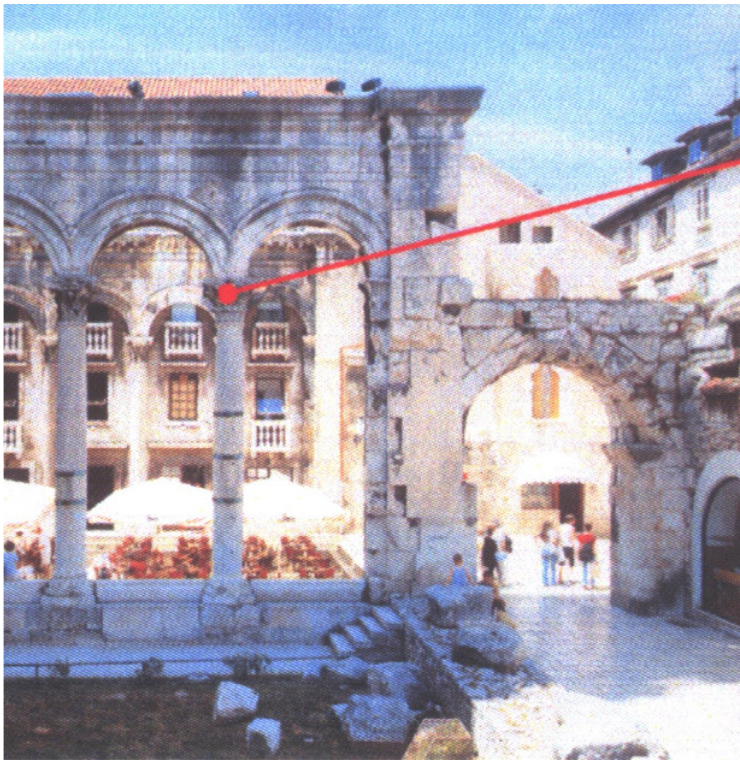
**+ computer controled sample
changer**

Beam shape is defined by the
collimators (beam defining slits)
and is usually from 1 to 8 mm

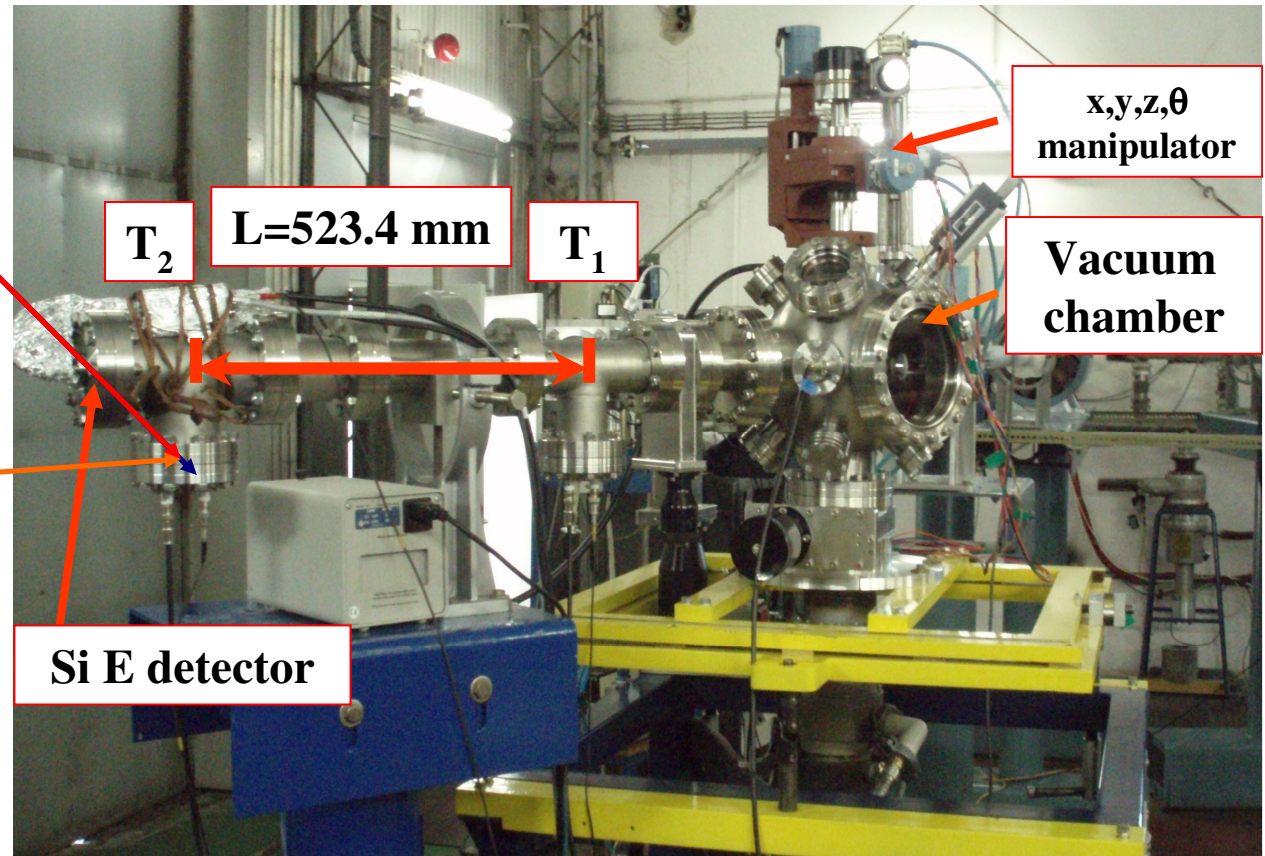
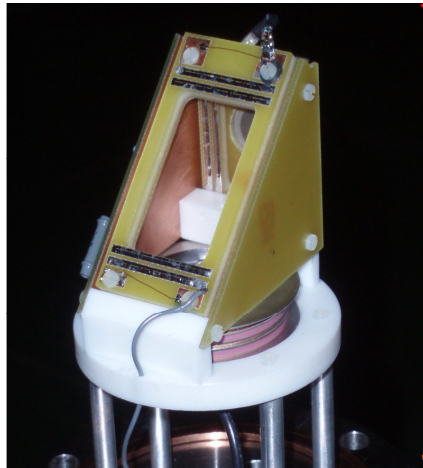


Example: Analysis of samples taken from the surface of the stone material of the Roman remains in Split

Samples analysed in vacuum at the IBA end-station



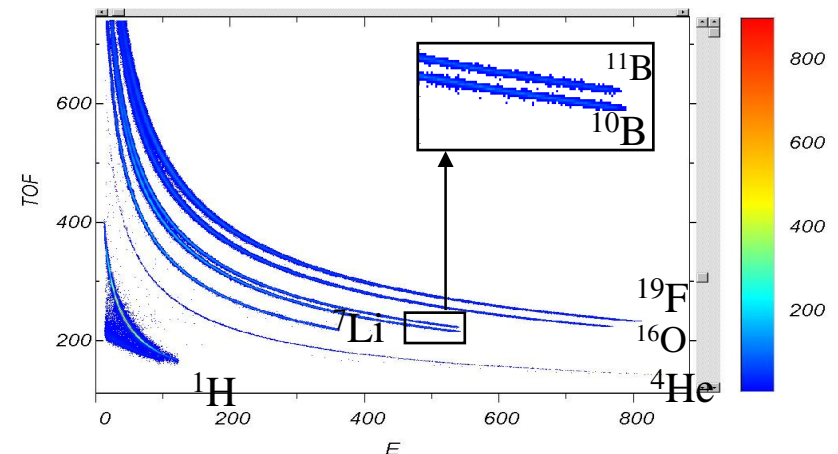
Time of flight ERDA spectrometer



$$TOF = T_1 - T_2 = l \left(\frac{M_2}{2KE_0} \right)^2$$

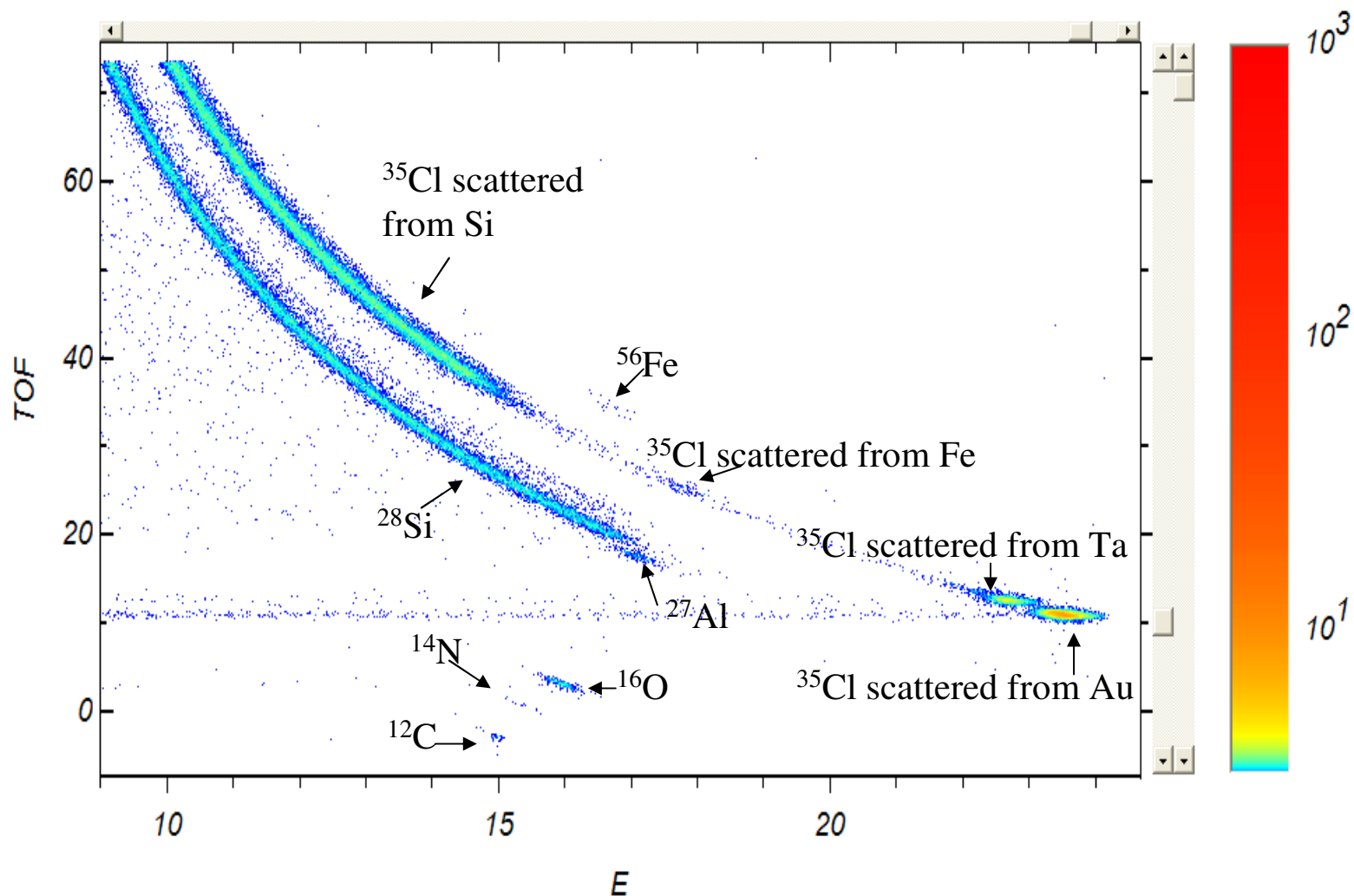
$$K = \frac{4M_1M_2 \cos^2 \phi}{(M_1 + M_2)^2}$$

- o ERDA (Elastic Recoil Detection Analysis)
- o TOF (time of flight) system for separation of scattered from recoiled ions (v, E)
- o Depth resolution down to 5 nm
- o Ion beams – Cl, I (energies 10-50 MeV)
- o Resolution of isotopes up to $M = 28$



TOF-ERDA Spectrum example

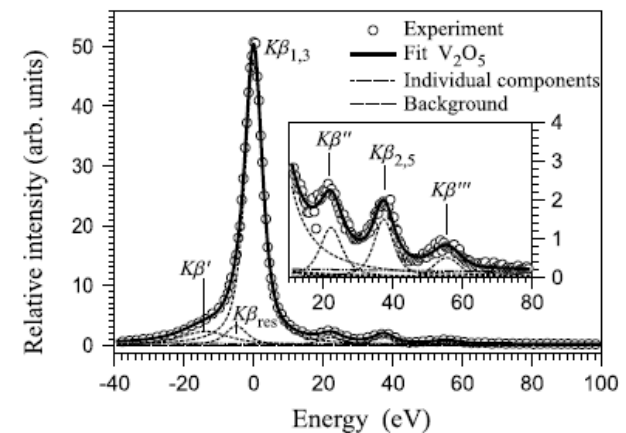
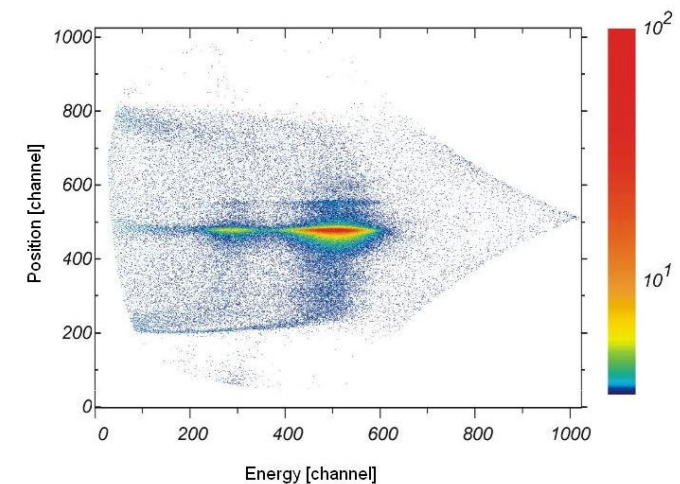
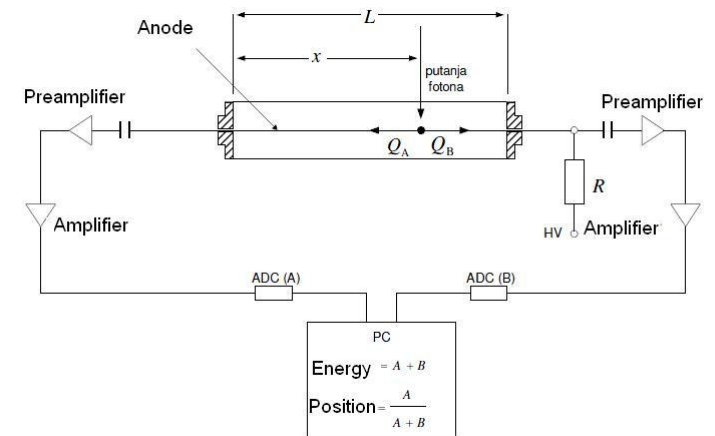
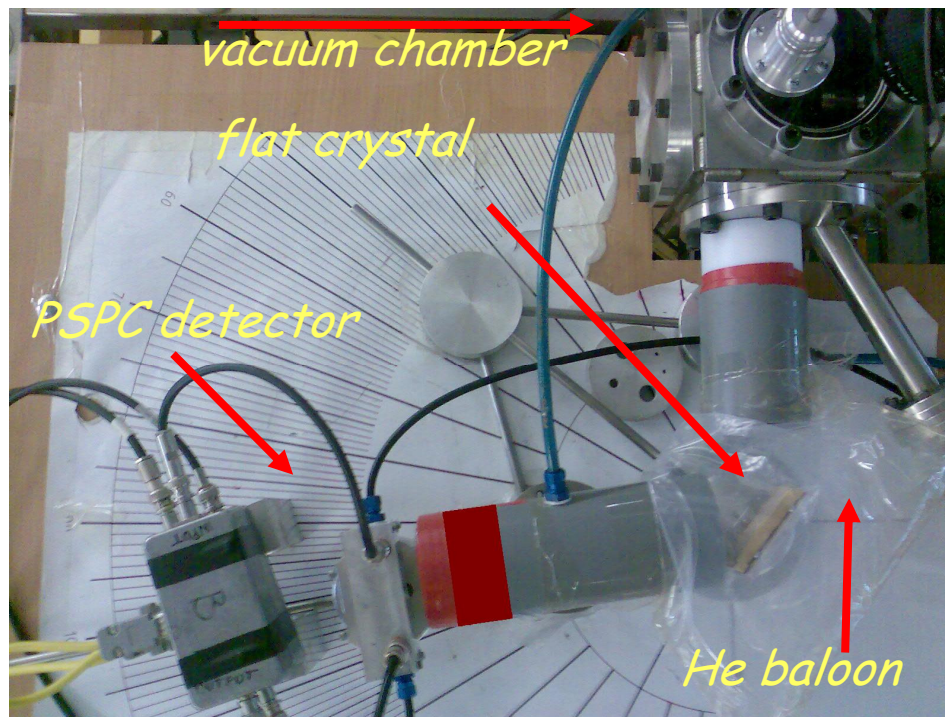
Coincidence spectrum (E and TOF coincidence) obtained by bombarding *Si/20Å Ta/100 Å AlNO/20Å Au Round robin sample* by 35 MeV ^{35}Cl
Sample tilt angle $\theta_{\text{in}} = 17.5^\circ$



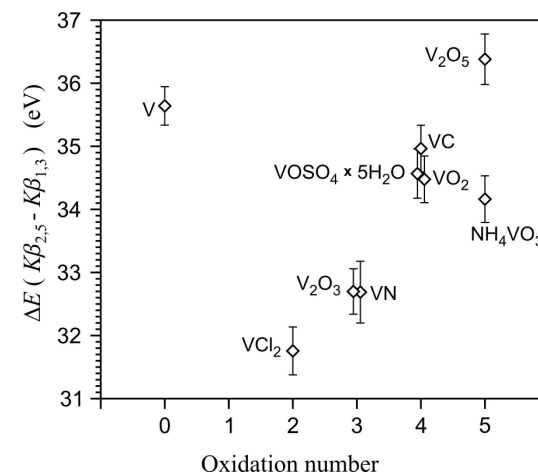
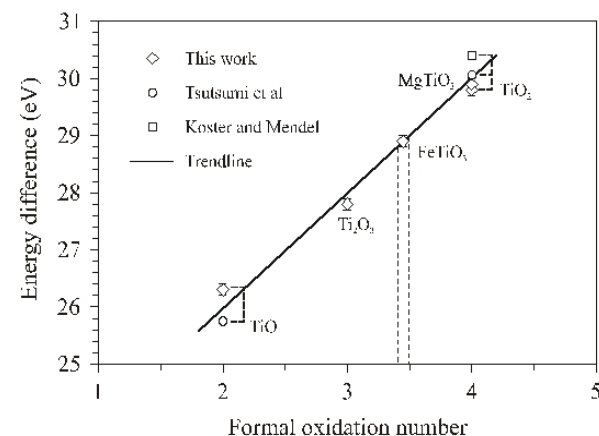
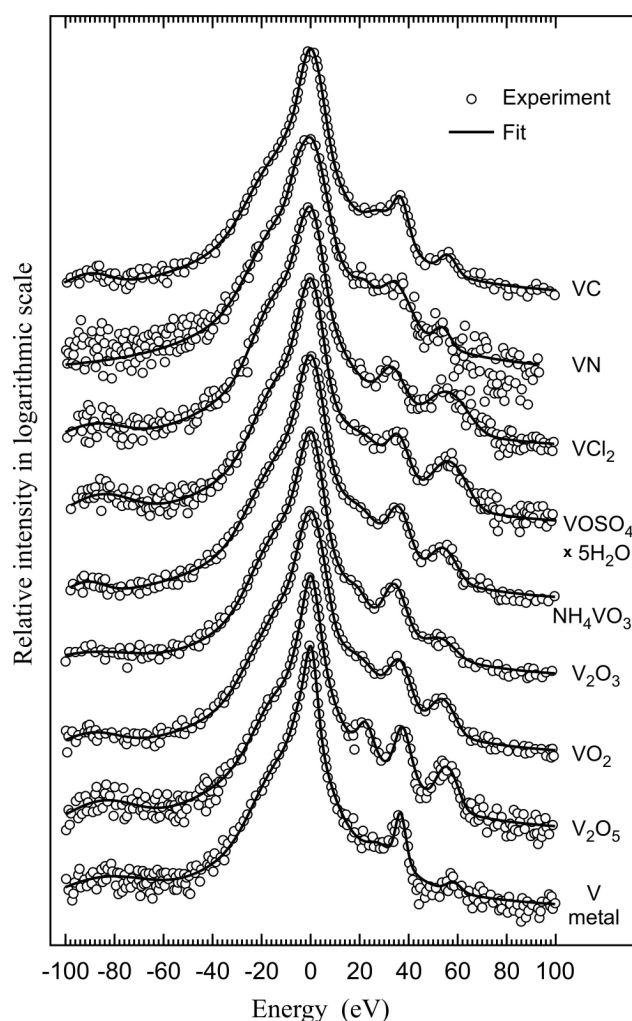
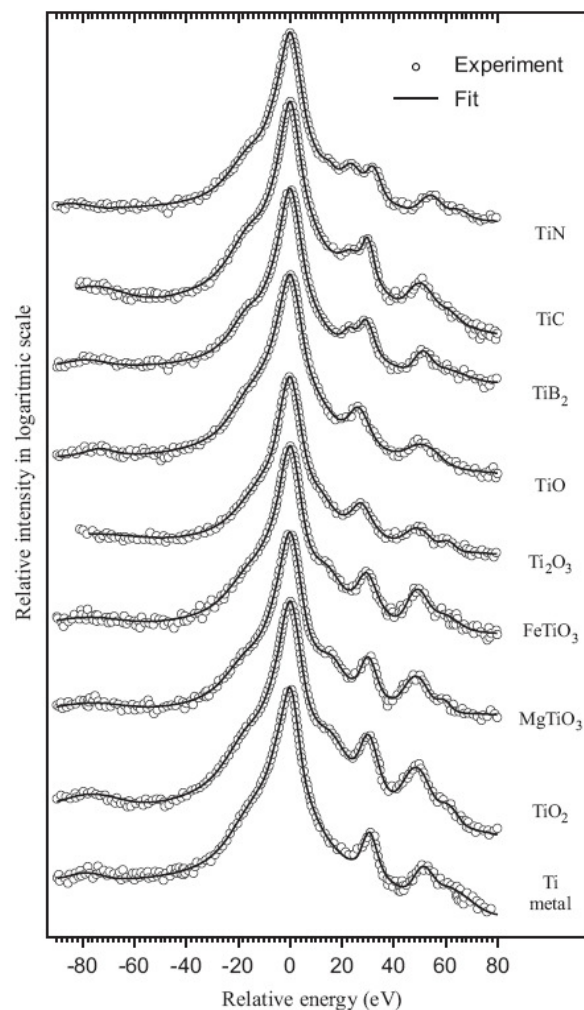
High Resolution PIXE

Simple high resolution wavelength
dispersive crystal spectrometer
with position sensitive proportional
counter.

Data acquisition by SPECTOR.

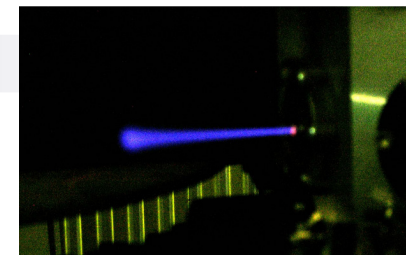


Example: High Resolution PIXE measured spectra of selected Ti and V compounds to investigate chemical effects on $K\beta$ X-ray spectra



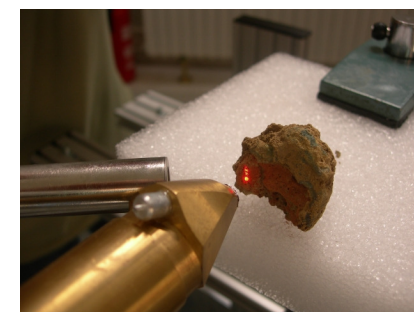
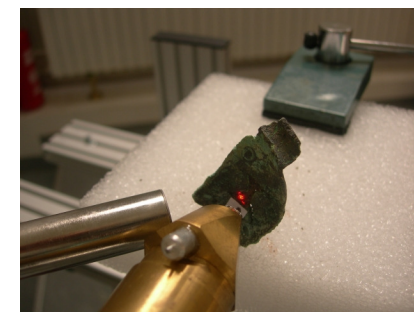
PIXE analysis in air

For large/bulky objects and samples that cannot be exposed to vacuum



Examples: Analysis of alloys

Analysis in air



file uzorak

705231 Kaptol-G. T-6 kaciga
 705232 Kaptol-G. T-6 PN80 drška mača (crvenkasta površina)
 705233 isto (zelenkasta površina)
 705234 Kaptol-G. T-6 korice mača
 705235 štrb.13.06.05. PN3, SJ1/2, B48, vjerG.104, pixe, A, 1,20g
 705236 4029-Sl.Brod, SEOM KNEMIDA

Spektar	Si	P	S	Cl	K	Ca	Fe	Cu	Sn	Pb
705231	1		0.4	0.2			0.9	73.8	17	3.2
705232	1.6			1			2.1	57.6		34.4
705233	6.2	0.5	0.5	0.3	0.3	0.5	5.6	71.2	0.9	10.3
705234	1.9		0.3	0.4			0.1	78.0	15.0	1.5
705235	5.3	9.0	2.7			5.2	1.4	6.4	29.0	32.8
702356	1.4	1.6	0.2	0.8			0.3	66.5	25.0	1.6



Ruđer Bošković Institute, Zagreb, Croatia



Example: Analysis of pigments at the in-air end-station

Fiorentino / white	C(%)
<i>AlK</i>	1.66
<i>SiK</i>	1.05
<i>P K</i>	0.31
<i>S K</i>	0.03
ClK	3.20
K K	0.91
CaK	2.34
<i>TiK</i>	0.00
FeK	1.22
<i>CuK</i>	0.06
<i>BaLA</i>	0.00
PbLA	78.66



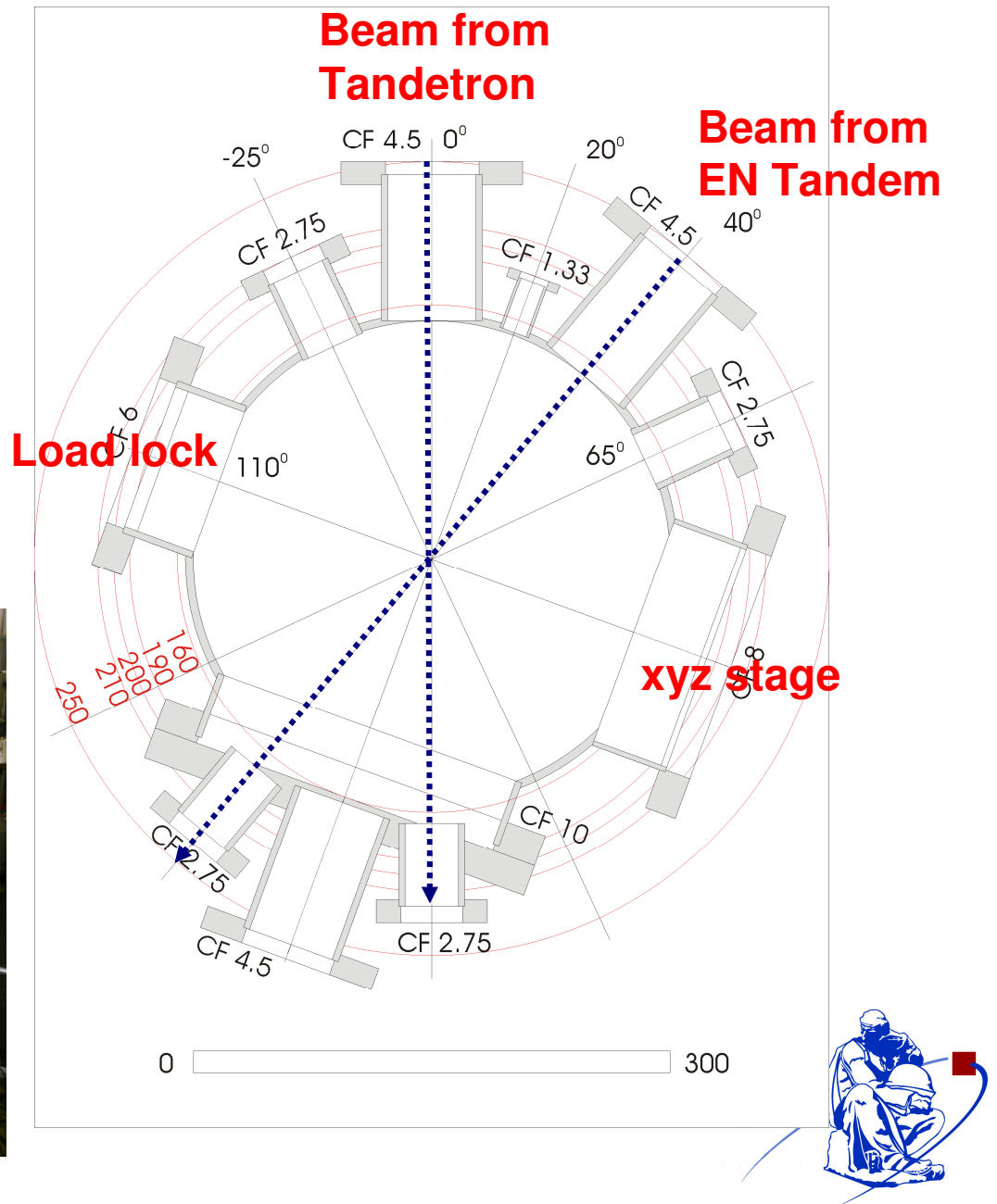
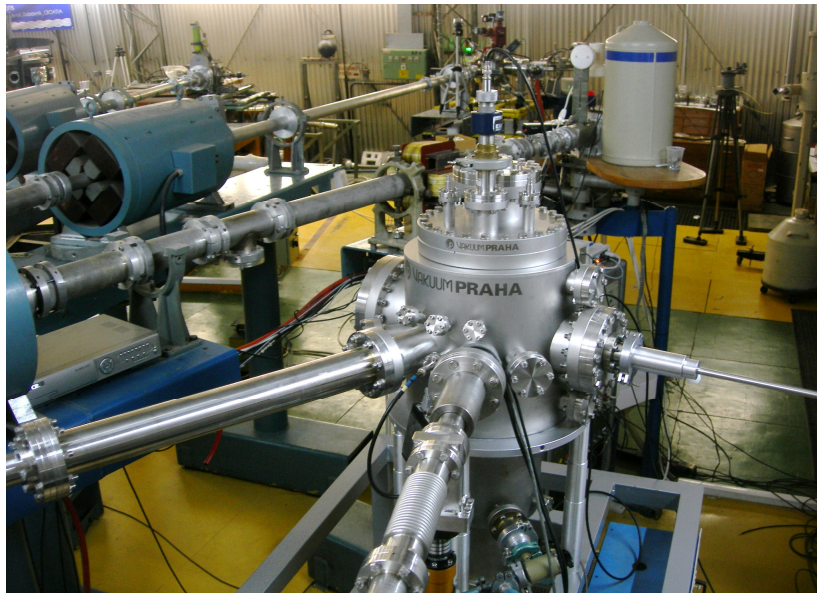
Fiorentino / blue	C(%)
<i>AlK</i>	1.31
SiK	1.29
<i>P K</i>	0.36
S K	2.67
ClK	0.75
K K	0.35
CaK	1.17
<i>TiK</i>	0.08
FeK	1.05
CuK	50.09
BaLA	5.48
PbLA	18.81



New 'dual beam' chamber

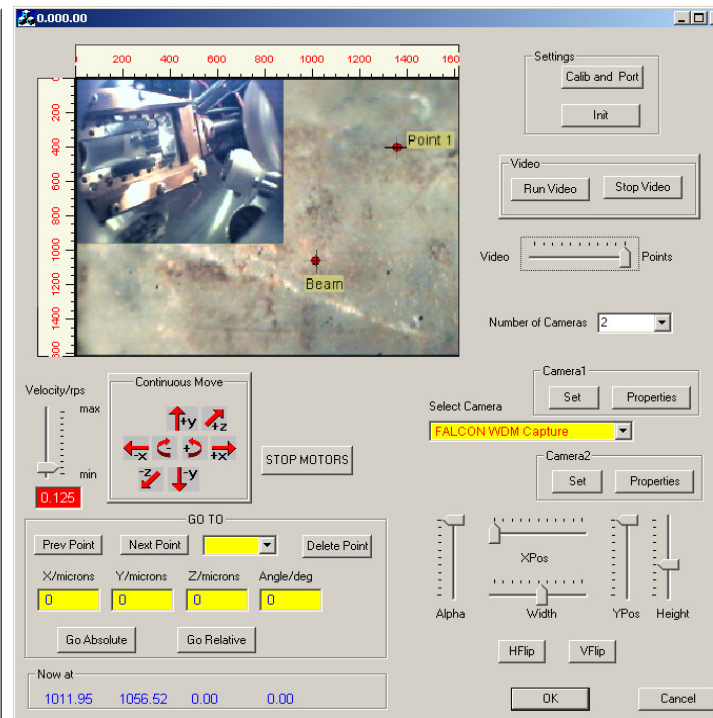
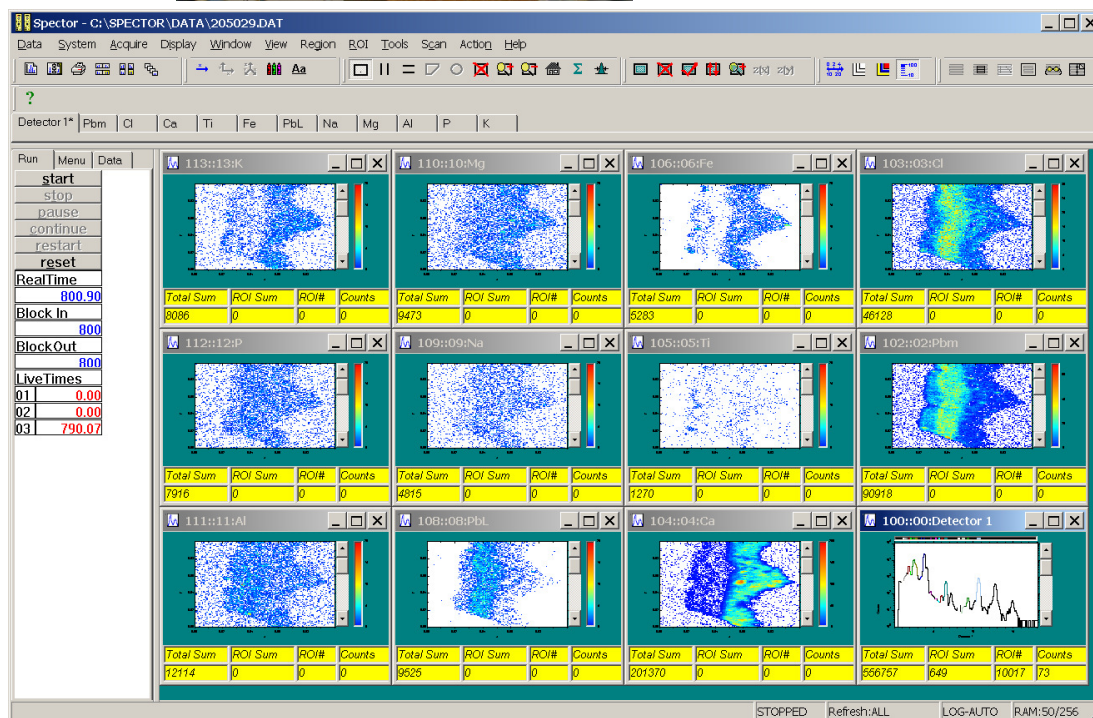
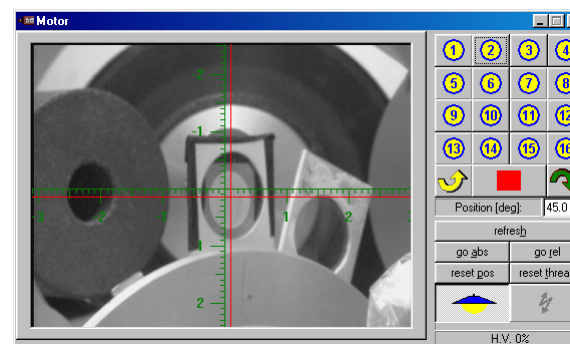
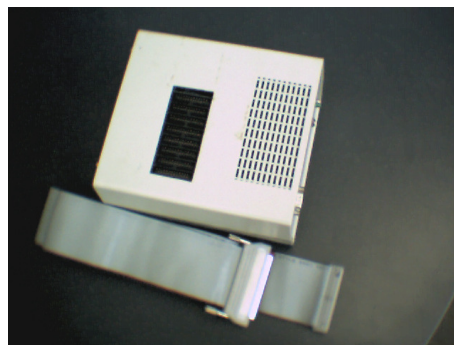
(still under
construction)

simultaneous
modification + analysis

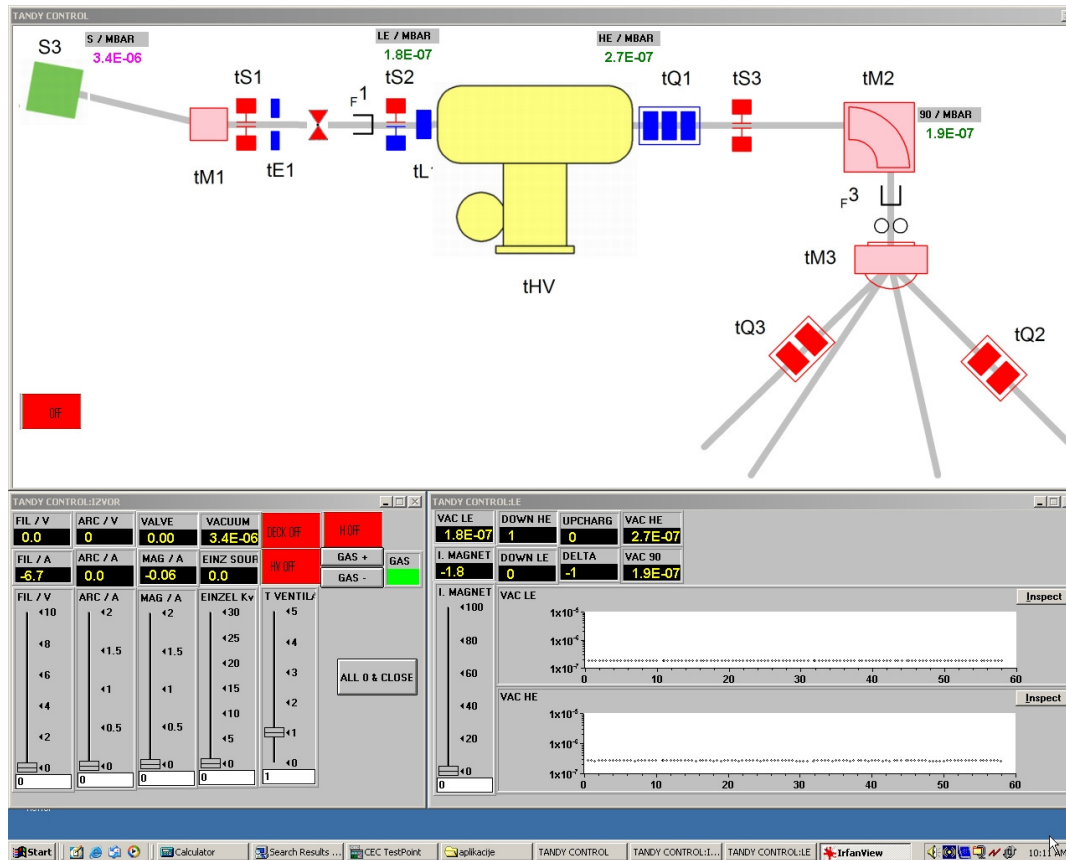




SPECTOR – home made Data acquisition /target positioning & beam scanning software



Computer control – ACCEL6 for EN Tandem Van de Graaff and ACCEL1 for Tandetron accelerator



- 16 bit AD/DA modules (controls for ion sources, accelerator and beam optics system)
- 8 digital inputs, 8 digital outputs
- Controls are based on TESTPOINT

Capabilities:

- Remote control (from remote computers)
- Reads beam optics parameters from previous experiments
- Calculates changes of parameters for change of energy and/or ion
- Security interlock system



Remote experiments on accelerator

Performance of experiments by expert users

- Access to accelerator control console
- Sample positioning and beam scanning
- Data acquisition

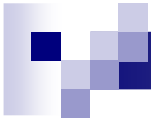
Education and training for users unfamiliar with technique

- Viewer to accelerator control console
- Beam controls on/off
- Access to sample changer and data acquisition with limited access
- On-line tutorial

Examples

- IAEA trainees (in collaboration with the IAEA Seibersdorf Laboratory)
- Laboratories starting PIXE
- Remote Universities without experimental facilities





Thank you
