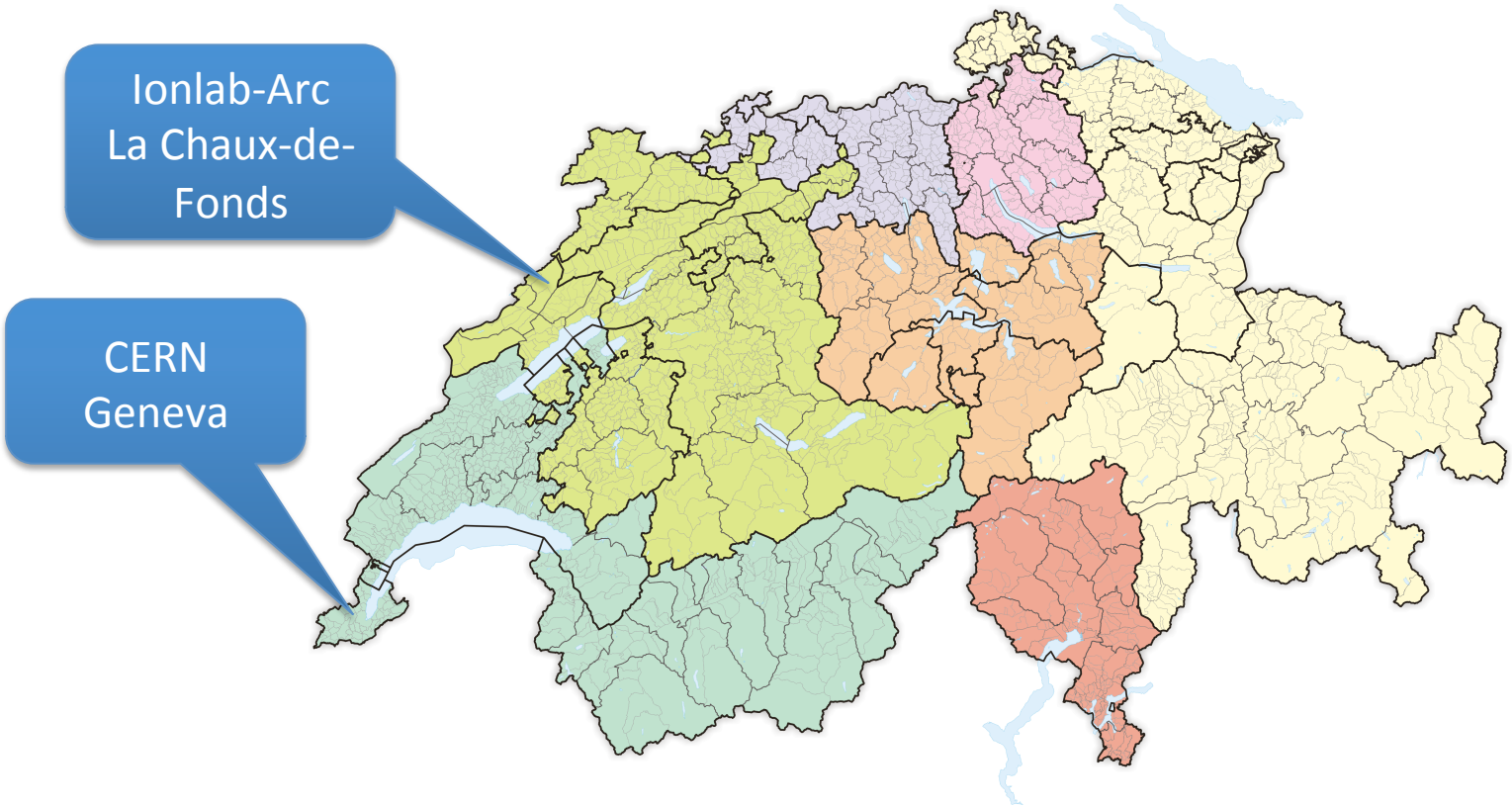
MeV ions for materials surface characterization and large area micro and nanostructuring

Harry J. Whitlow

Institut des Microtechnologies Appliquées Arc
Haute Ecole Arc Ingénierie
Eplatures-Grise 17
CH-2300 la Chaux-de-Fonds
Switzerland

Accelerator laboratories in Western Switzerland



Economic perspective

- > 10 000 ion accelerators have been produced over last 30 years
- Annual sales of ion accelerators 1 BCHF/year
- Market value of devices produced with accelerators 300 BCHF/year

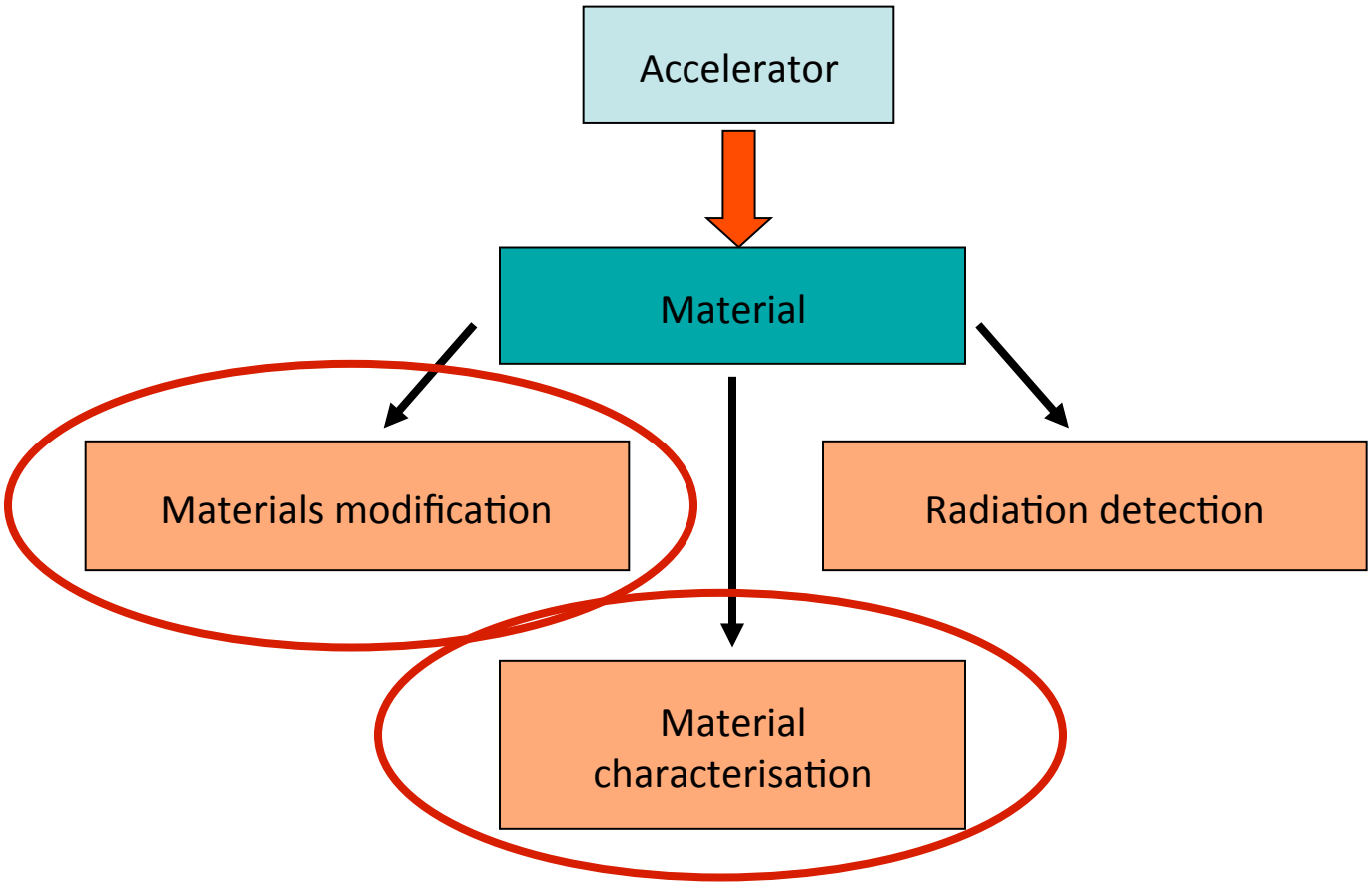
- 24000 particles accelerators for materials applications over past 60 years
- +17 000 electron accelerators for cancer therapy
- 1100 new systems a year – market value 2.2 BCHF/year
- 500 BCHF/year added value from accelerators

Source: R.W. Hamm, M.E. Hamm, (eds); *Industrial Accelerators and their application;* (World Scientific, Singapore, 2012)

- Sales of Swiss watchmaking industry in 2011: 35 BCHF
  Source: F. Eschmann*; W The Journal about high-end watches*, 27 Nov. 2012

n.b. Billions are US billions

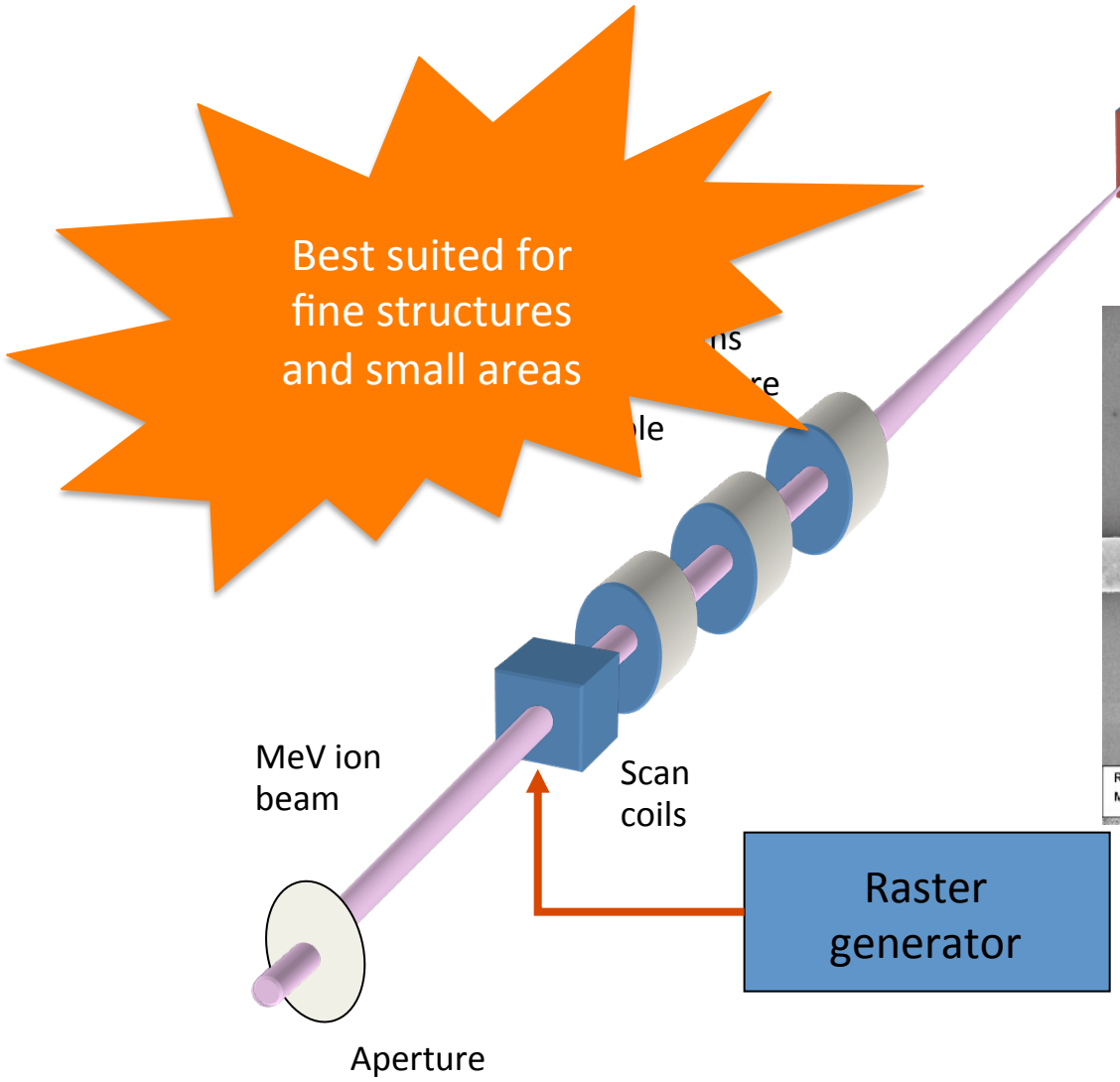
Interaction of MeV ions with materials

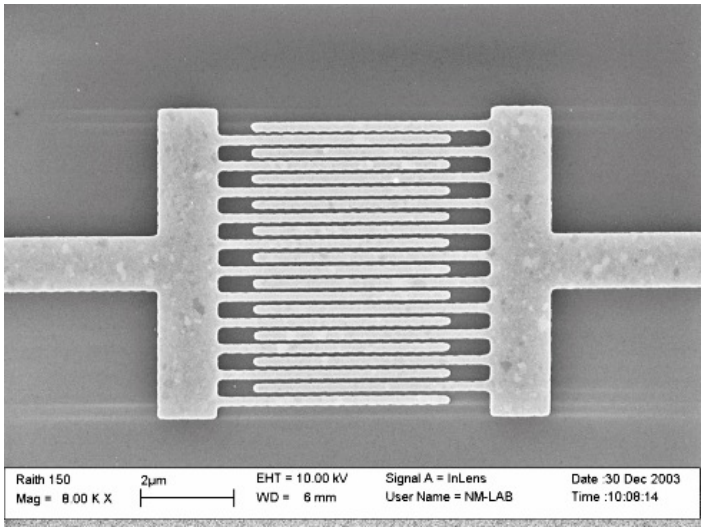


Surface layer structuring of with ion beams

Georgius Agricola, *De re metallica*, 1556

Proton Beam Writing (PBW) with a focused beam

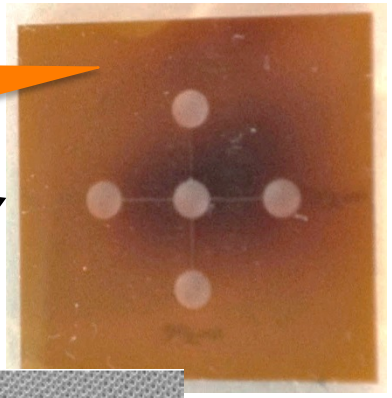


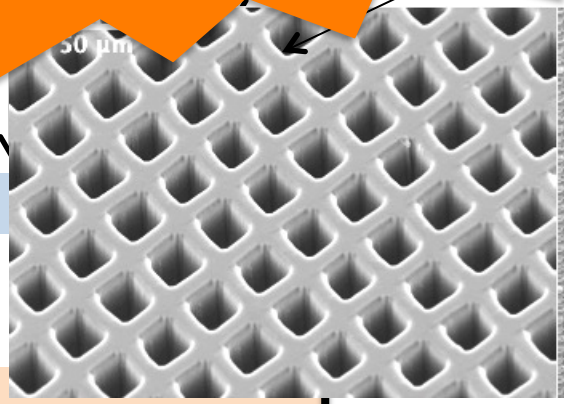


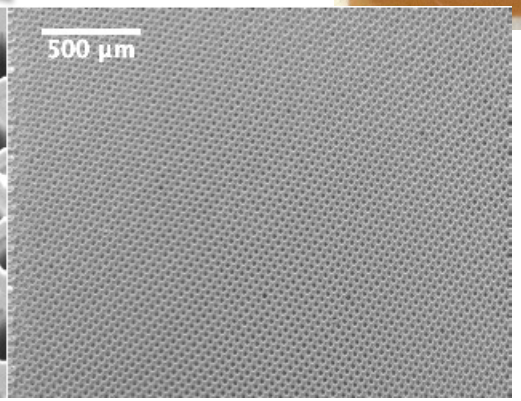
H. J. Whitlow, M. L. Ng, V. Auželytė, I. A. Maximov, J. A. van Kan, A. Bettiol and F. Watt *Lithography of high spatial-density biosensor structures with sub-100 nm spacing by MeV proton beam writing with a minimal proximity effect.* Nanotechnology 15 (2004) 223.

MeV ion projection lithography

Suited for:
- Large areas
- Non planar substrates
- Roll-to-roll processing



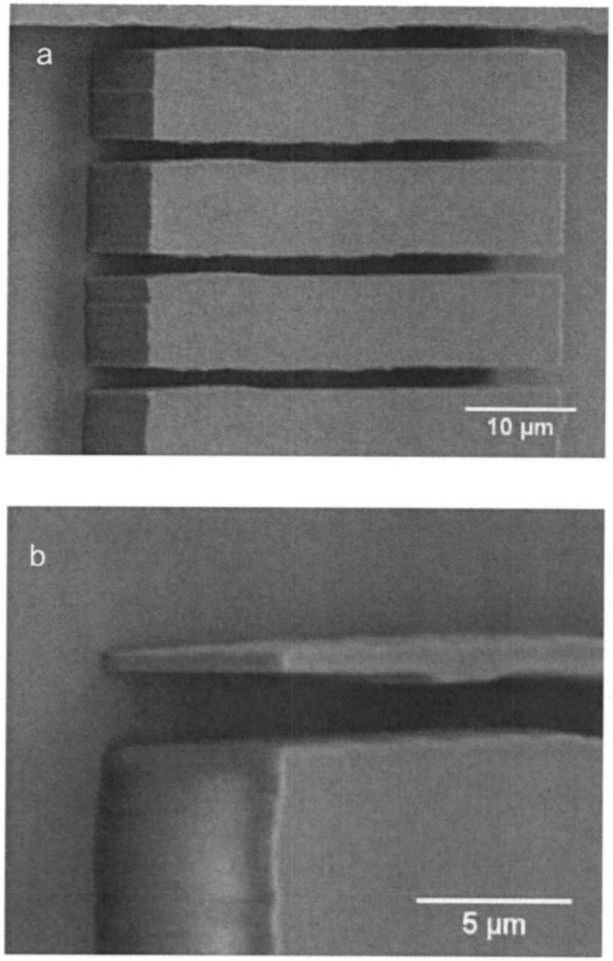




Substrate

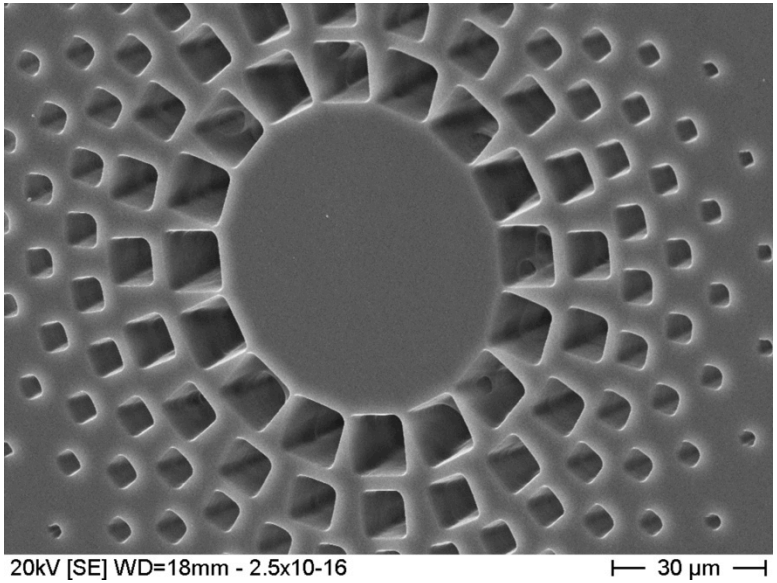
Developer

High aspect ratio patterns by MeV ion beam lithography



N. Puttaraksa, S. Gorelick, T. Sajavaara, M. Laitinen, S. Singkarat, and H. J. Whitlow, *Programmable proximity aperture lithography with MeV ion beams.* J. Vac. Sci. Tech. B 26(2008)1732.

FIG. 7. (a) SEM image of 1.6 μm wide channels. (b) SEM image of a detail of the smallest structure (a 700–800 nm thick freestanding wall) produced by using 3 MeV $^{4}He^{2+}$ ions in a 7.5 μm thick PMMA.

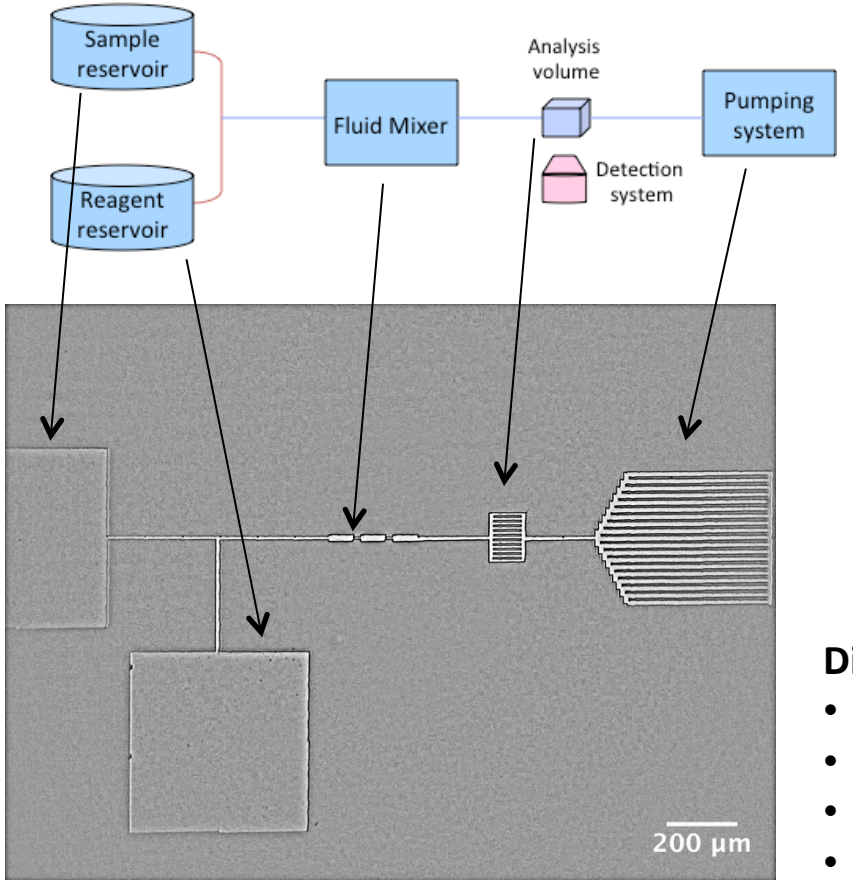


Lithographic pattern produced at IMA using a stencil mask technique in conjunction with heavy ions.

S. Brun, V. Savu, S. Schintke, E. Guibert, H. Keppner, J. Brugger, H. J. Whitlow, *Application of Stencil Masks for Ion Beam Lithographic Patterning*, Nucl. Instrum. Methods B 306(2013)292.
http://dx.doi.org/10.1016/j.nimb.2012.12.064

MeV ion beam lithography for lab-on-chip microfluidics

Schematic illustration of a 2-antibody immunoassay sensor based on microfluidics

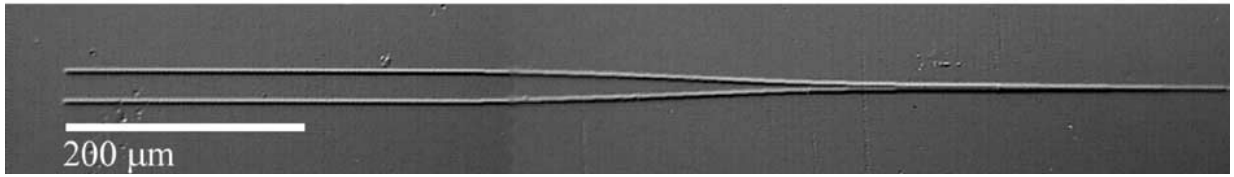


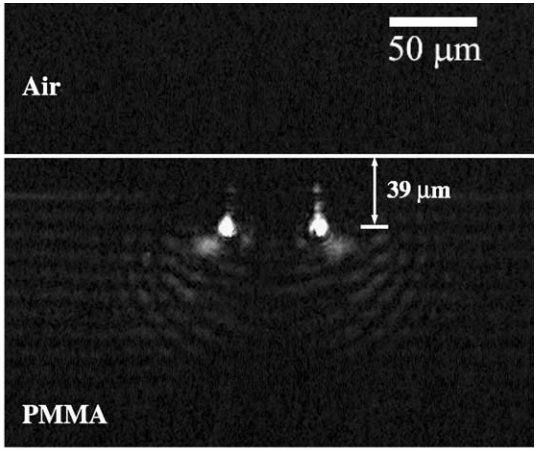
Unpublished results: L.P. Wang, L.K. Gilbert and H. J Whitlow

Direct write fast prototyping

- Lab-on-chip test-kits
- Pharmaceutical delivery
- Pharmaceutical testing
- Nanofluidics
- Optical, electrical, magnetic readout

Waveguide- and diffractive optics

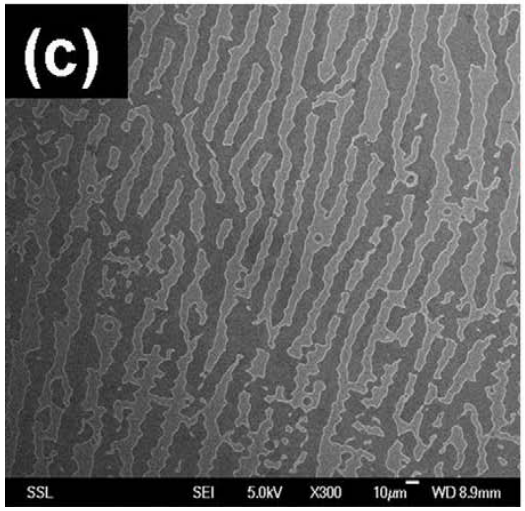


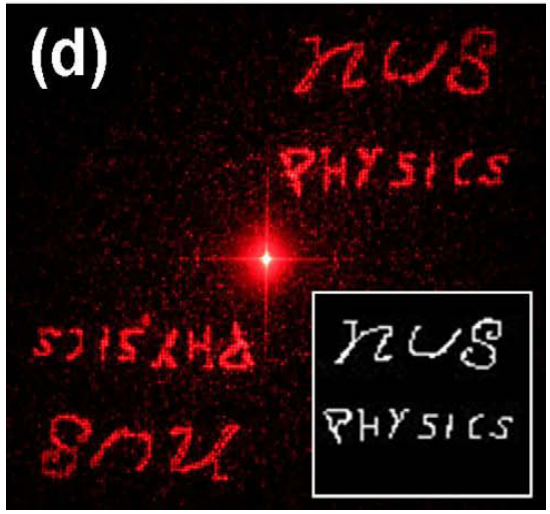


Y-branch waveguide written directly in PMMA using MeV protons. (a) waveguide structure, (b) Intensity of emitted 633 nm radiation.

T. C. Sum, A. A. Bettiol, H. L. Seng, I. Rajta, J. A. van Kan and F. Watt, *Proton Beam Writing of Passive Waveguides in PMMA ,* Nuclear Instruments & Methods B210 (2003) 266-271

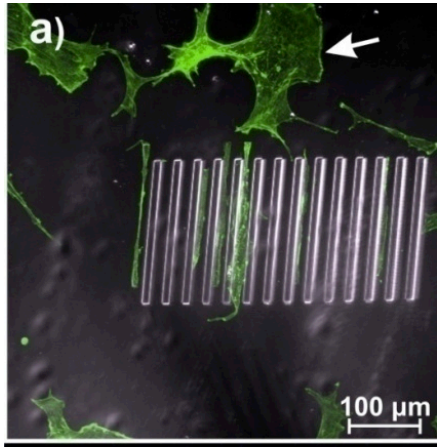
Y.S. Ow, M.B.H. Breese, Y.R. Leng, S. Azimi, E.J. Teo, X.W. Sun, *Micromachining of amplitude and phase modulated reflective computer generated hologram patterns in silicon*, Nuclear Instruments and Methods in Physics Research B 268 (2010) 1416–1421.

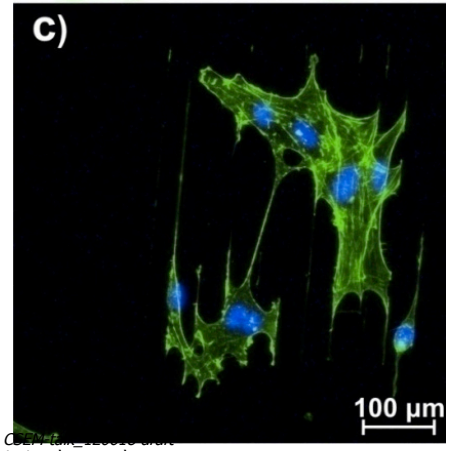




Flexible micro- and nanofabrication for biomedicine and agriculture

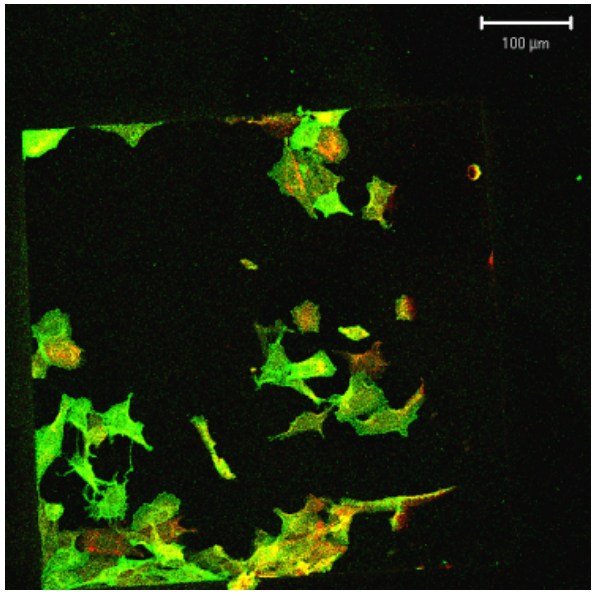
Cell-growth substrates





S. Gorelick, P. Rahkila, A. Sagari A.R., T. Sajavaara, S. Cheng, L. B. Karlsson , J. A. van Kan, H.J.Whitlow *Growth of bone-cells on lithographically modified surfaces.* Nucl. Instrum. Methods B 260 (2007)130.

Micro-spotting plates and cell pattern printing

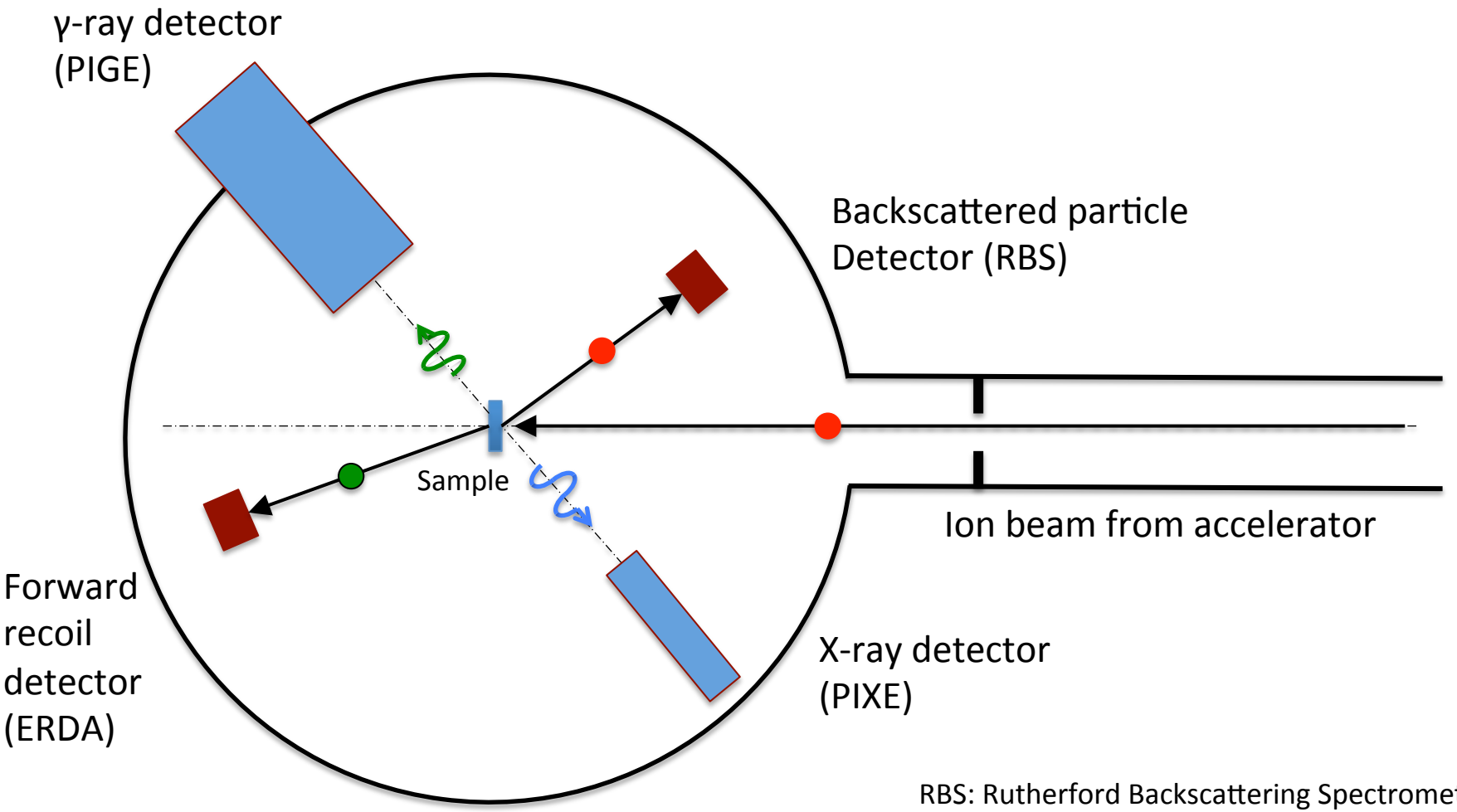


S. Sangyuenyongpipat , V. Marjomäki, S. Ikonen, T. Sajavaara A. Sagari A.R., S. Gorelick, M. Laitinen, L.P. Wang, H. J. Whitlow, *Development of micro-contact printing of osteosarcoma cells using MeV ion beam lithography*, Nucl. Instrum. Meth. B 267(2008)2306.

Materials analysis with ion beams

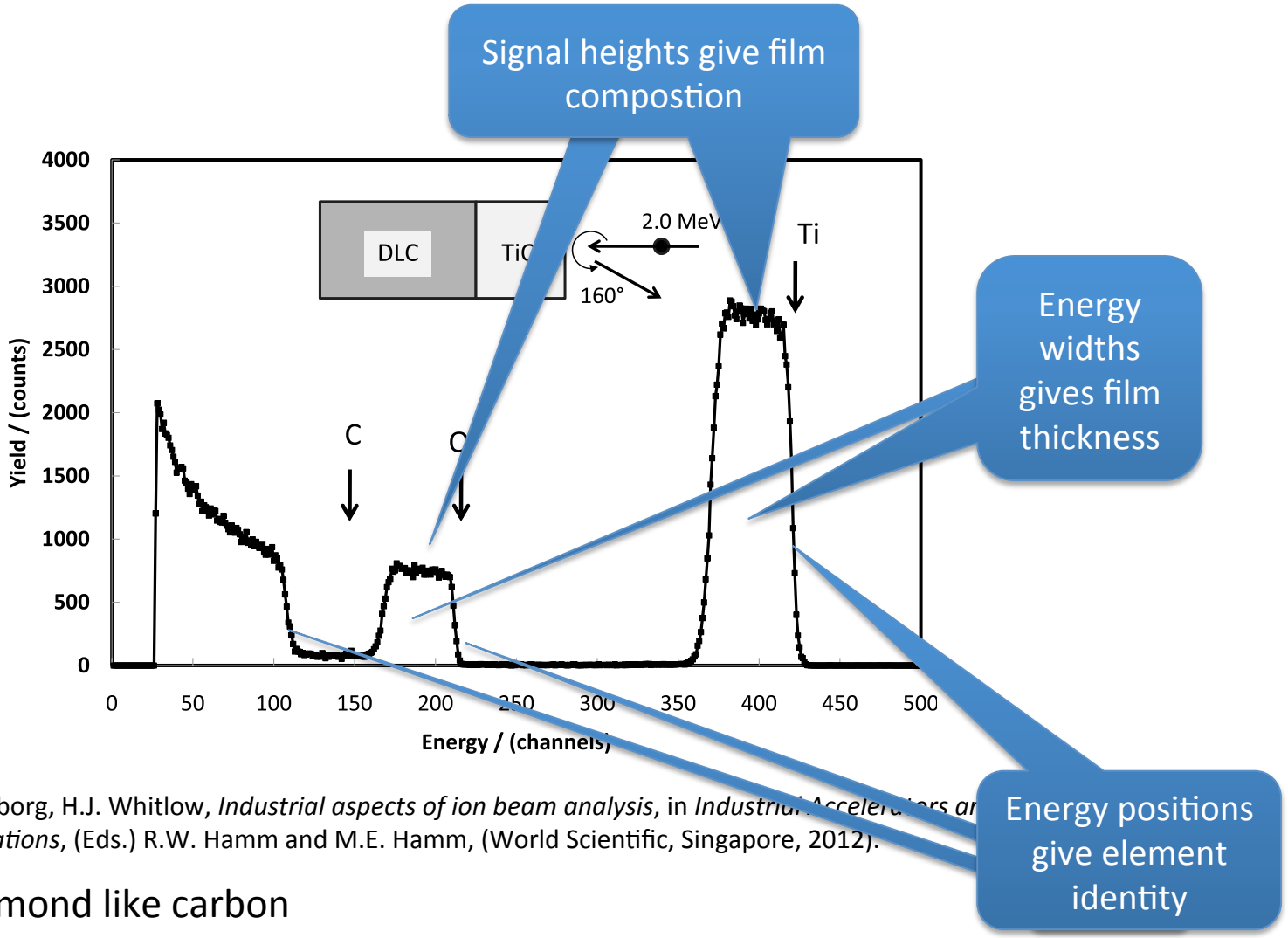
Georgius Agricola, *De re metallica*, 1556

Ion beam analytical signals



RBS: Rutherford Backscattering Spectrometry
PIXE: Particle induced X-ray Emission
PIGE: Particle induced γ-ray emission
ERDA: Elastic Recoil Detection Analysis

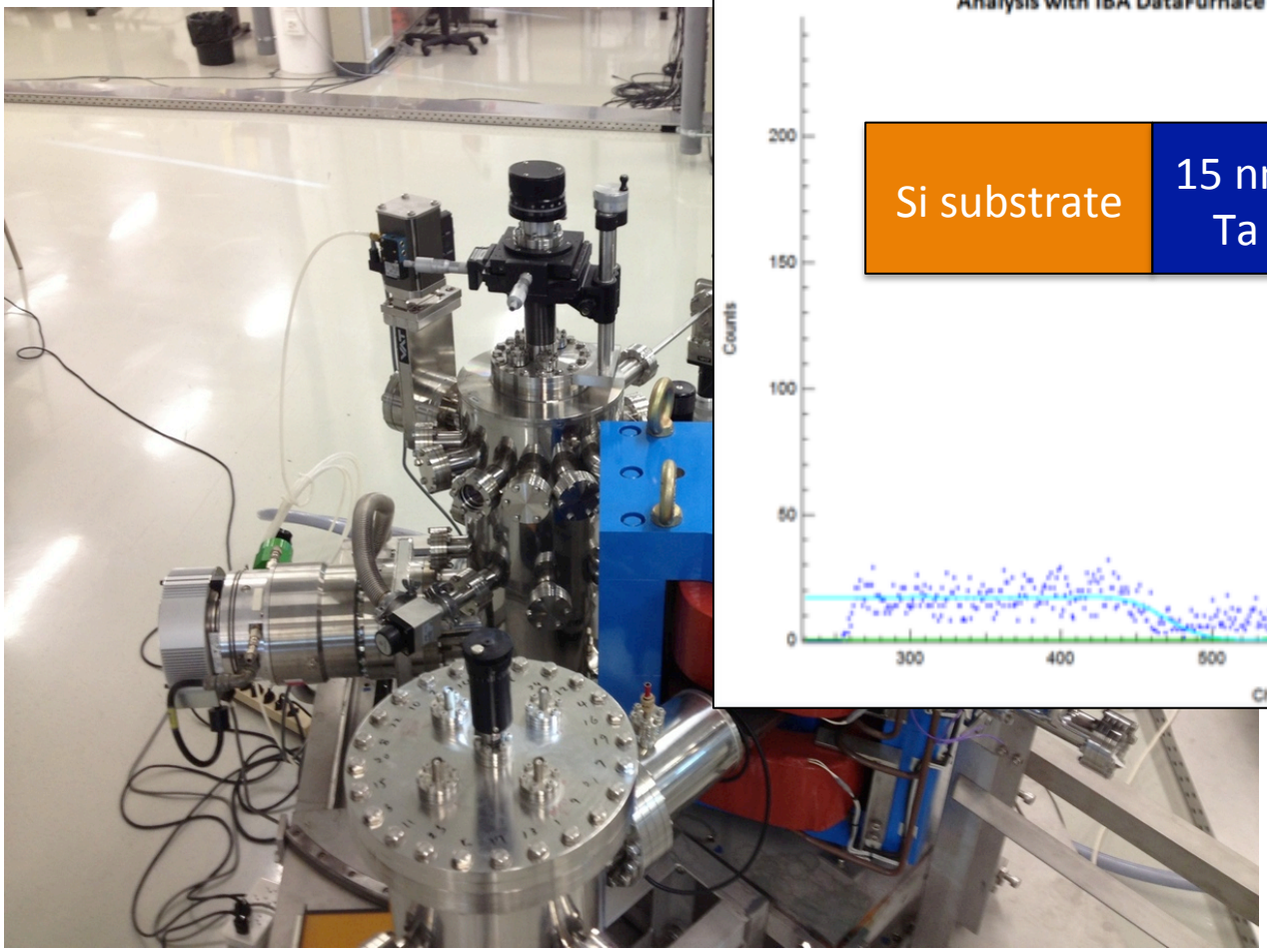
RBS of a TiO_2 film on DLC*

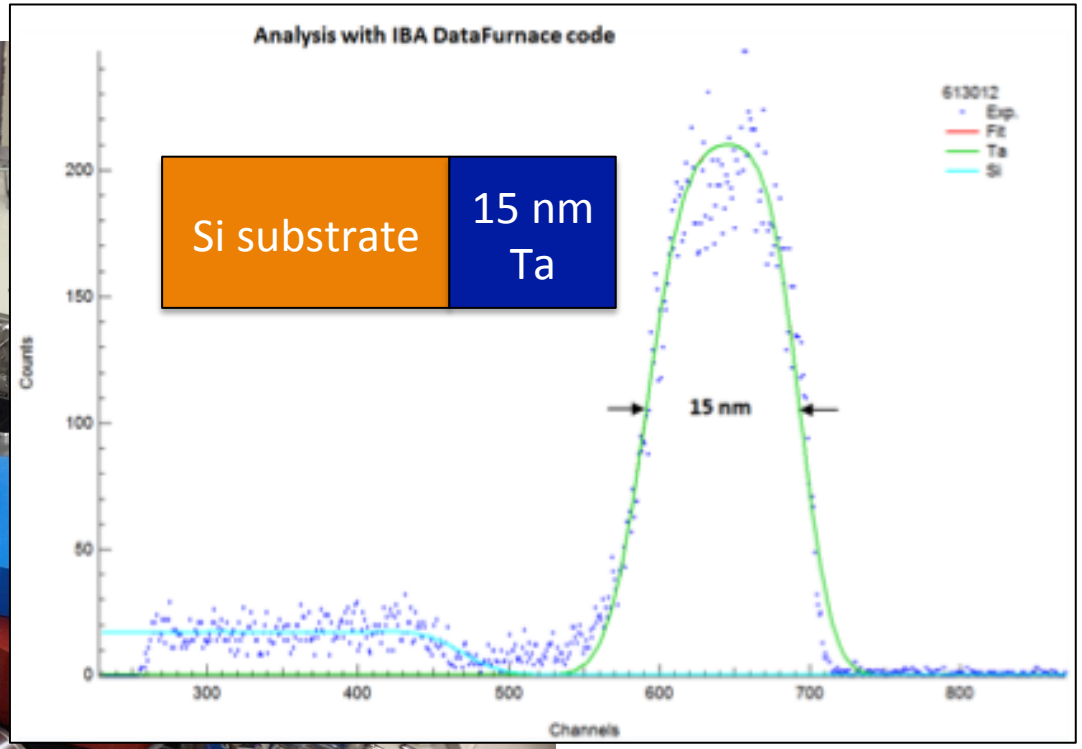


R. Hellborg, H.J. Whitlow, *Industrial aspects of ion beam analysis*, in *Industrial Accelerators and their applications*, (Eds.) R.W. Hamm and M.E. Hamm, (World Scientific, Singapore, 2012).

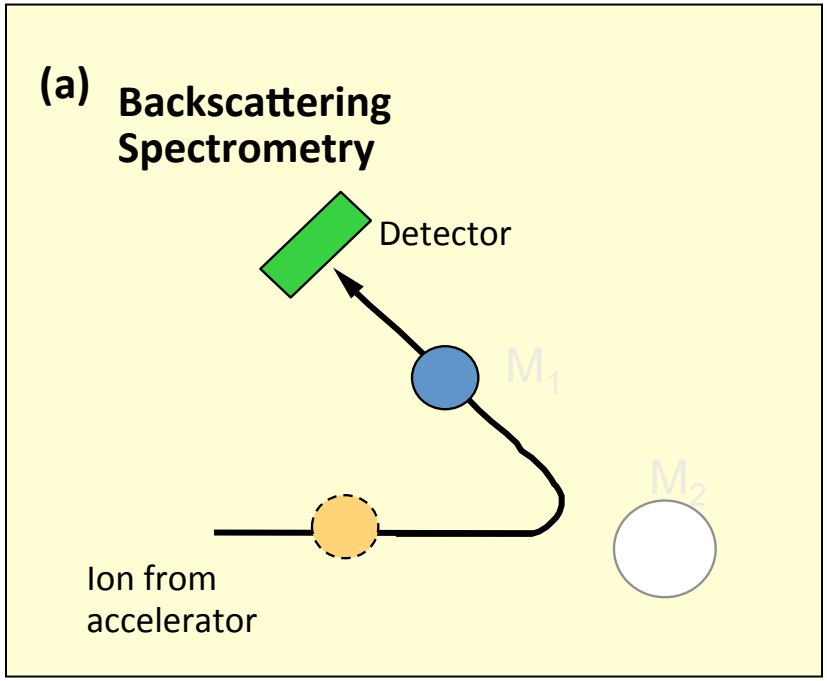
* DLC = diamond like carbon

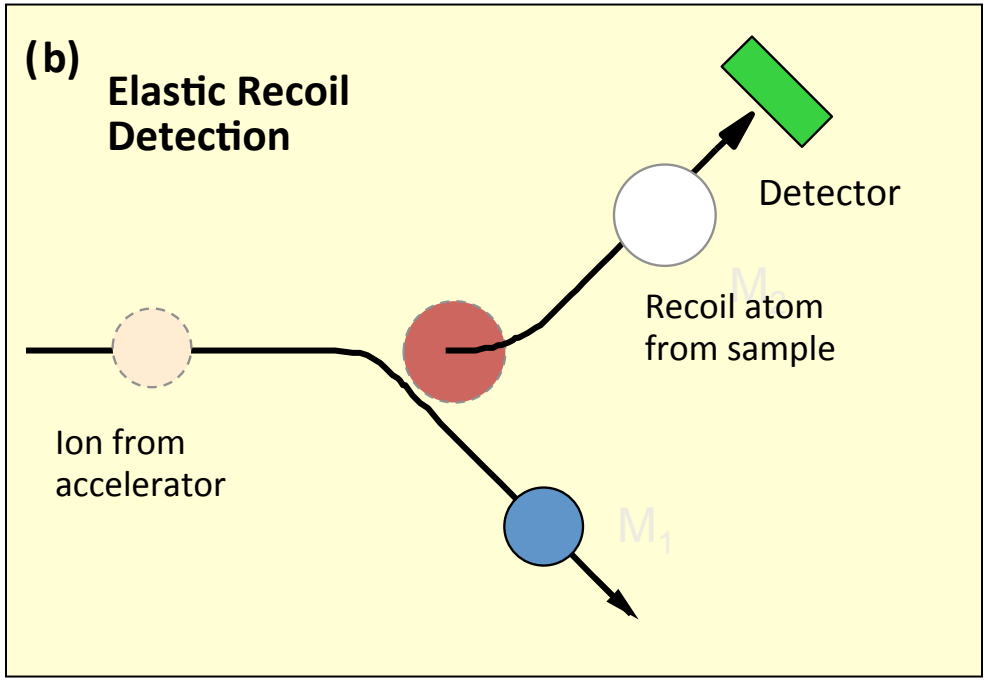
IONLAB-Arc High resolution magnetic RBS / ToF-E ERDA spectrometer
(under commissioning)





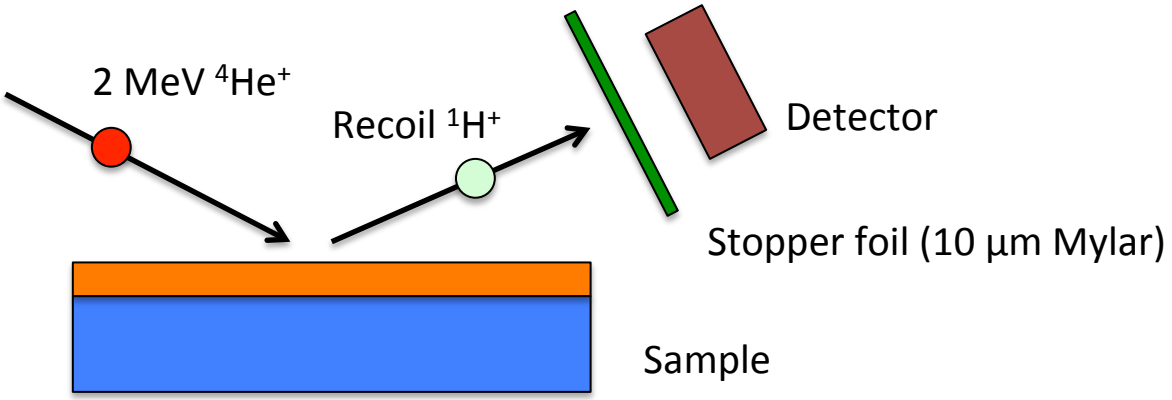
RBS vs. ERDA

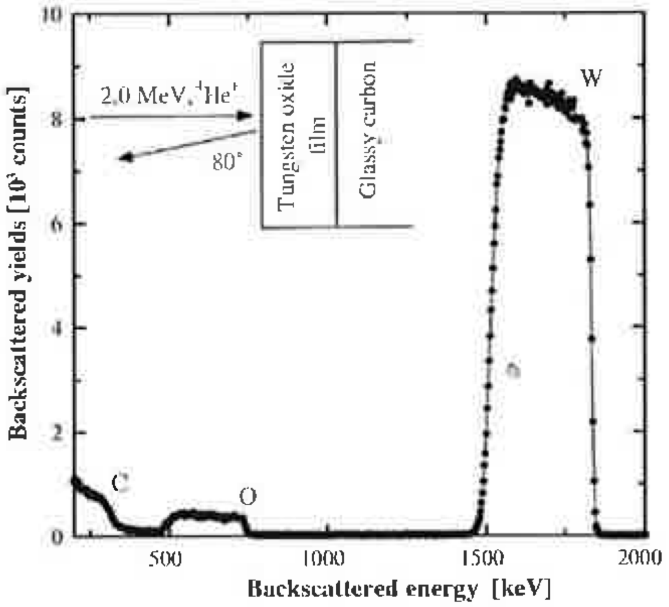


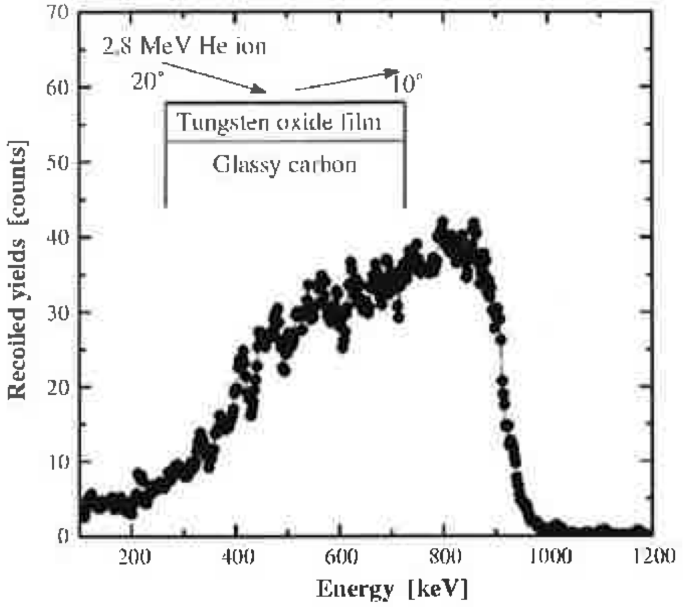


- **RBS**
  - Detected particle is ion from accelerator ion source
  - Depth and mass information encoded on detected particle energy
- **ERDA**
  - Detected particle is target atom
  - Depth information encoded on energy
  - Isotopic identity carried directly by recoil

ERDA measurement of hydrogen

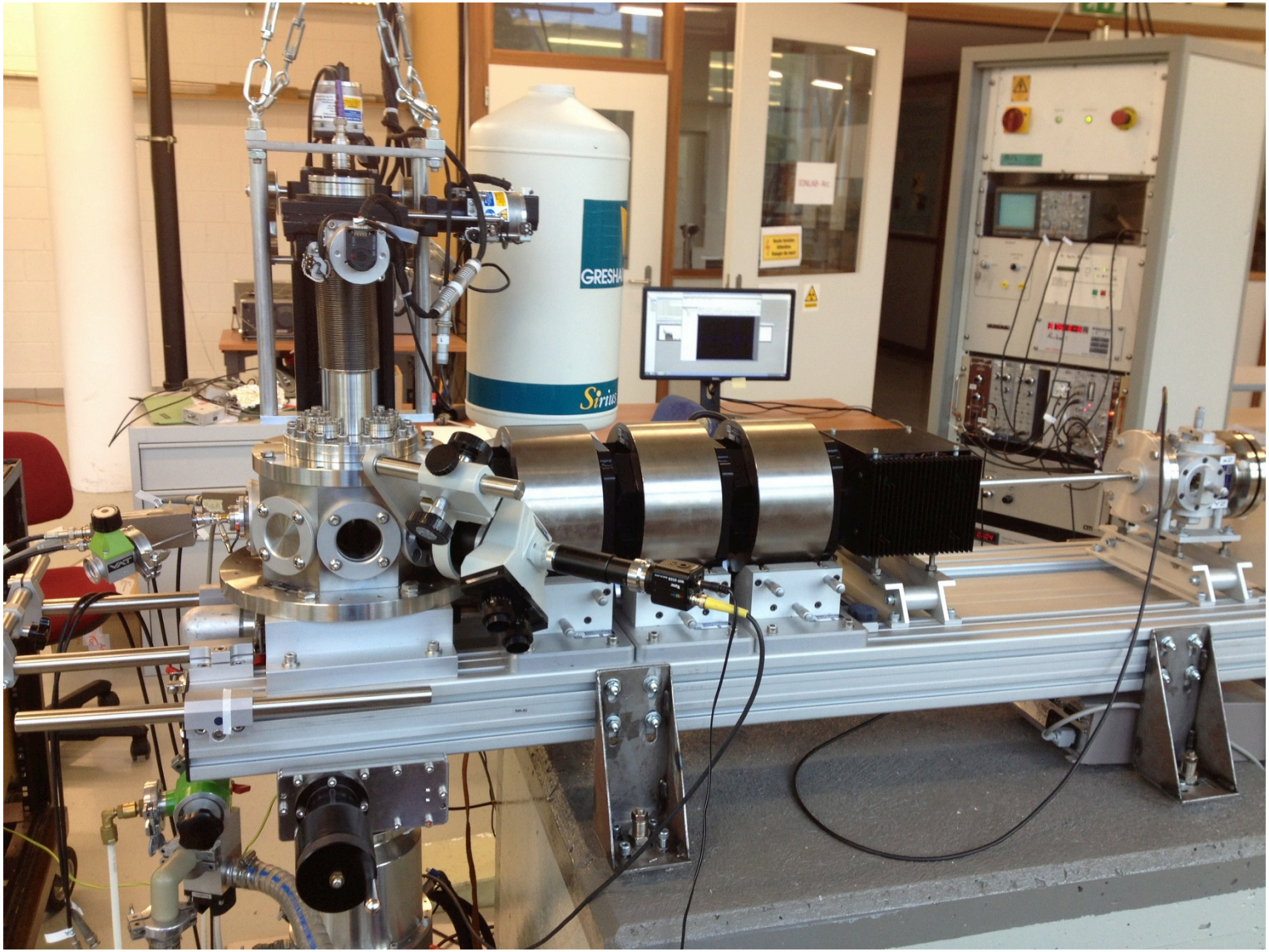




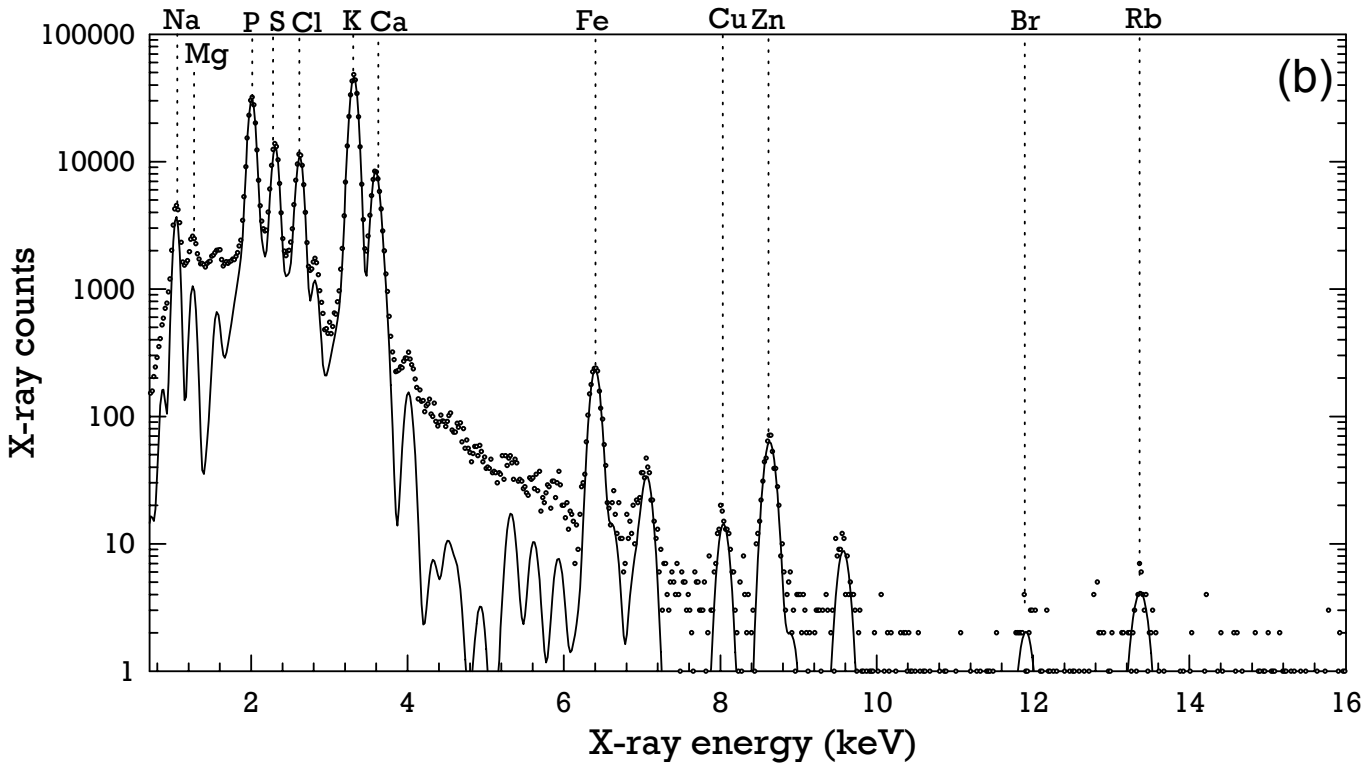


T. Sajavaara in, H. J. Whitlow, Y. Zhang and R. Hellborg (eds.) *Ion beams in nanoscience and –technology*, (Springer, Heidelberg, 2010)

Instrument de microscopie par ions MeV



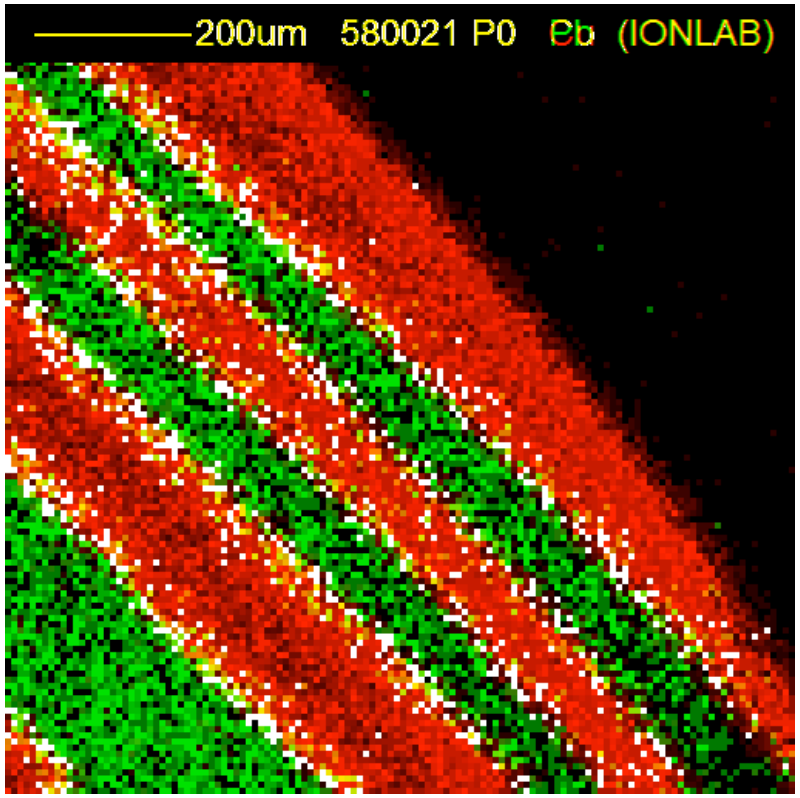
Example PIXE spectrum



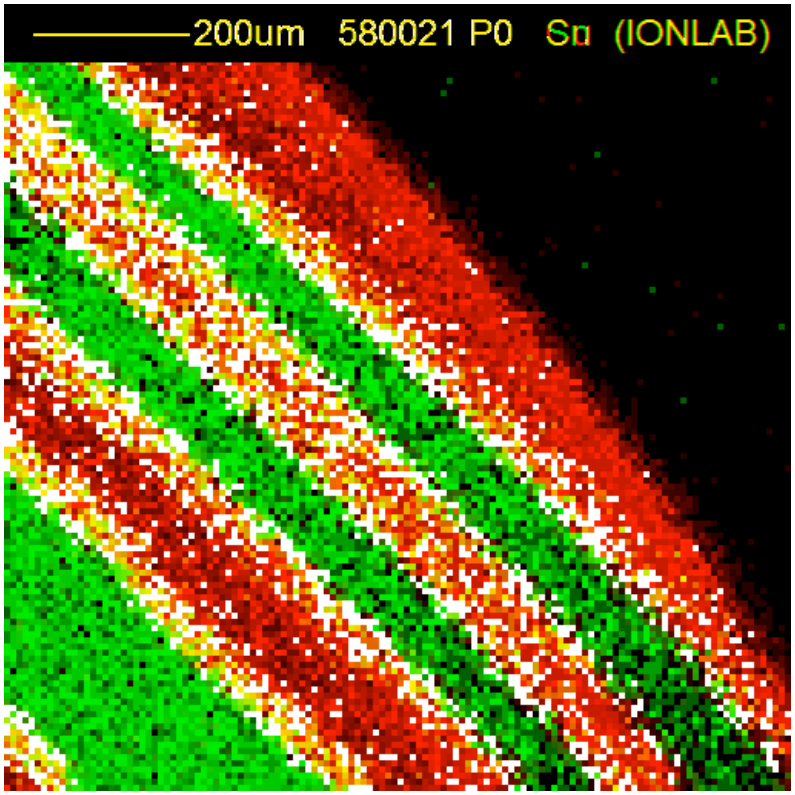
2 MeV H^+ PIXE spectrum from 20 µm section of rat brain tissue. The peaks correspond to the different characteristic X-ray from different elements in the sample.

H.J. Whitlow and M.-Q. Ren *Ion Beam Analysis in Biomedicine*, in: *Ion Beam Analysis; principles and applications,* (eds) M. Nastasi, J.W. Meyer and Y. Wang, CRC Press (In press).

Colocalised X-ray maps of Pb-Sn solder wetting copper



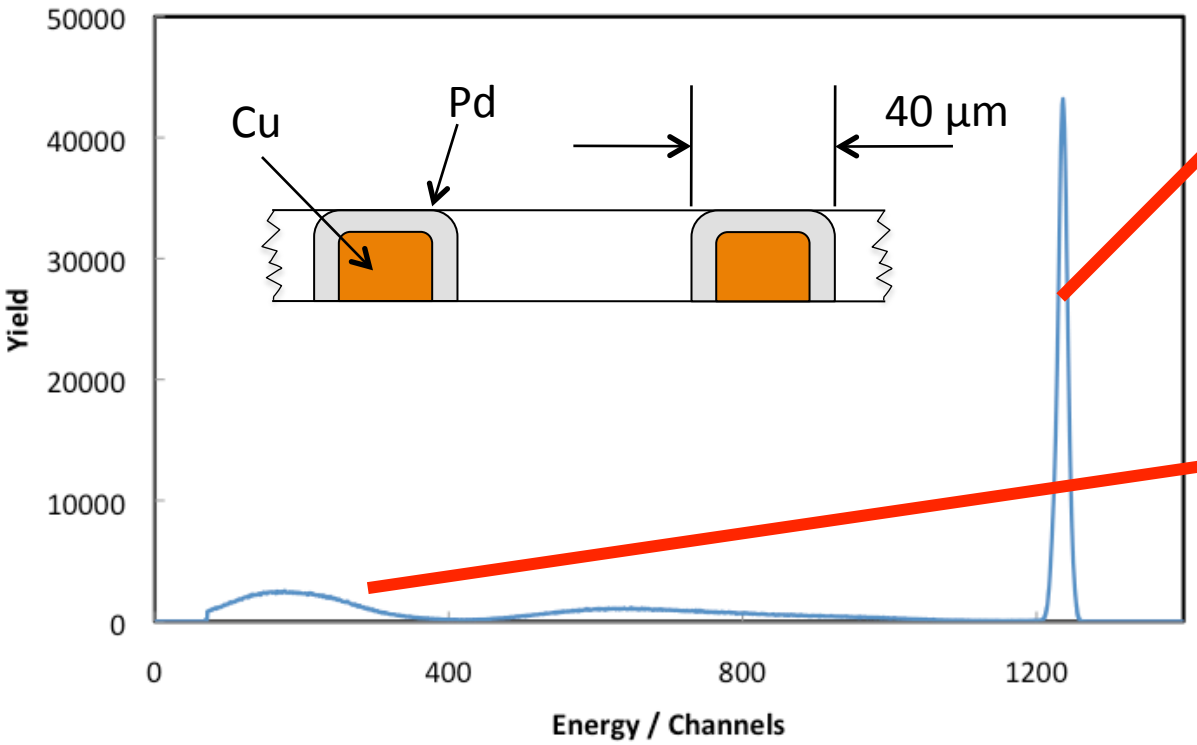
Red: Cu
Green: Pb
White: co-localised Cu and Pb

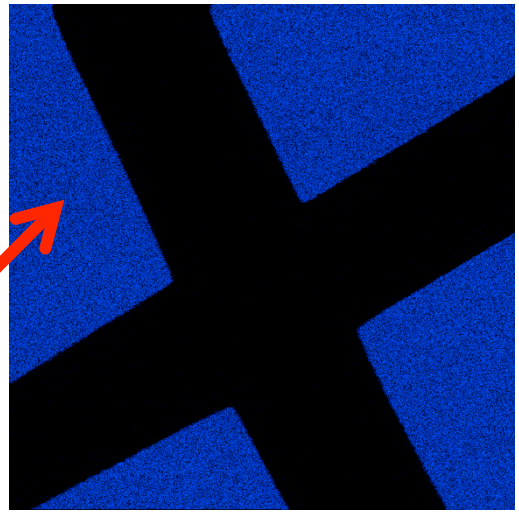


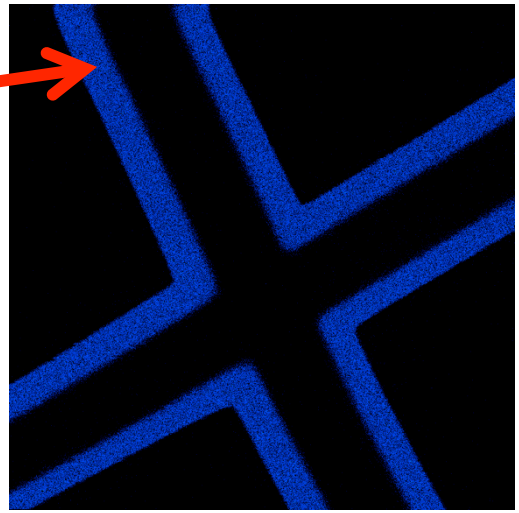
Red: Cu
Green: Sn
White: co-localised Sn and Pb

Unpublished work: E. Guibert, P. Jeanneret and H.J. Whitlow, 2012

STIM image of Re coated Cu grid







Harry J. Whitlow, Minqin Ren, Xiao Chen, Thomas Osipowicz, J. A. van Kan, Frank Watt (unpublished data)


Thanks for your attention!