KU LEUVEN

Ion beam analysis: a family of versatile techniques for materials characterization

André Vantomme

Quantum Solid-State Physics,
KU Leuven, Belgium

Pushing the boundaries of advanced materials characterization, SIM²MRC, Leuven, 3 June 2022

Ion beam analysis in materials science

a family… → case dependent combination (total IBA)

…of complementary techniques

compositional depth profile

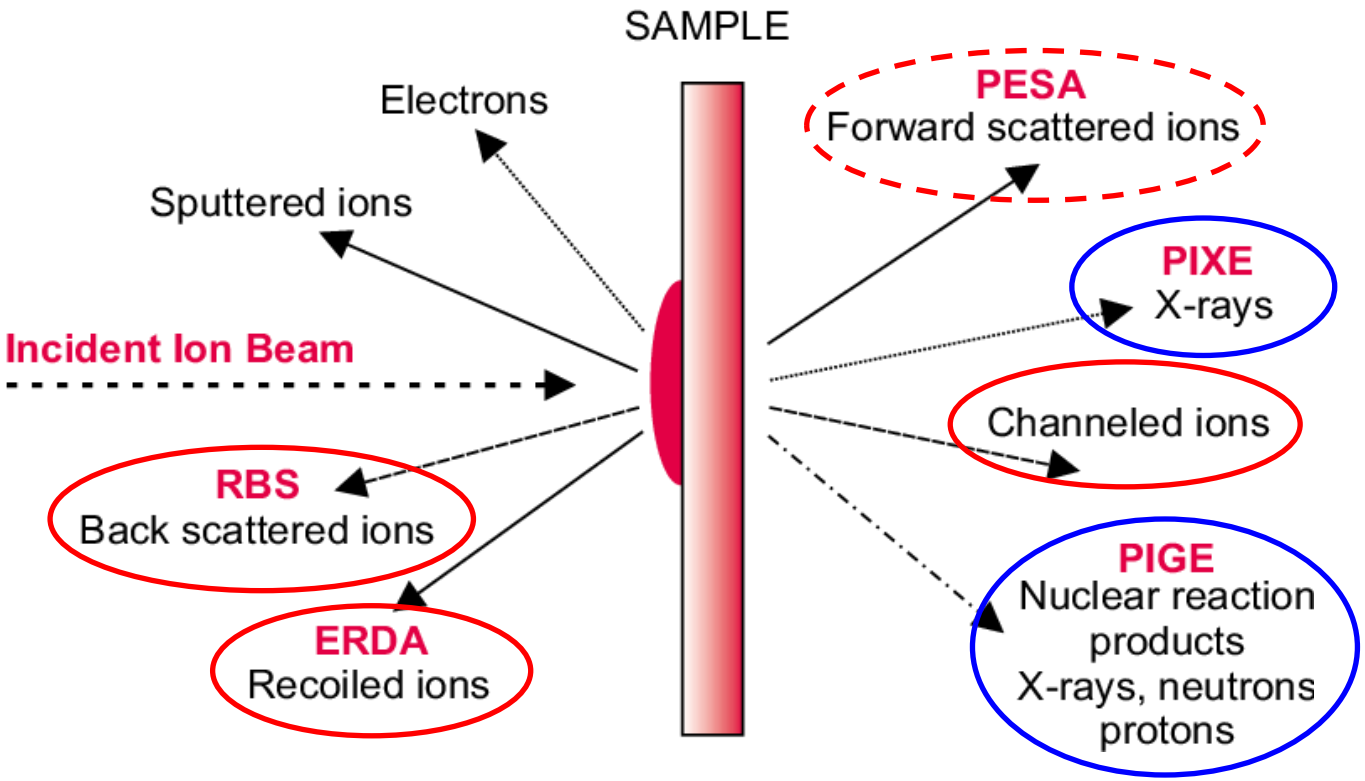
+ crystalline structure (channeling)

wide range of materials/samples

from thick coatings (up to 1 μm) to nanoparticles

KU LEUVEN

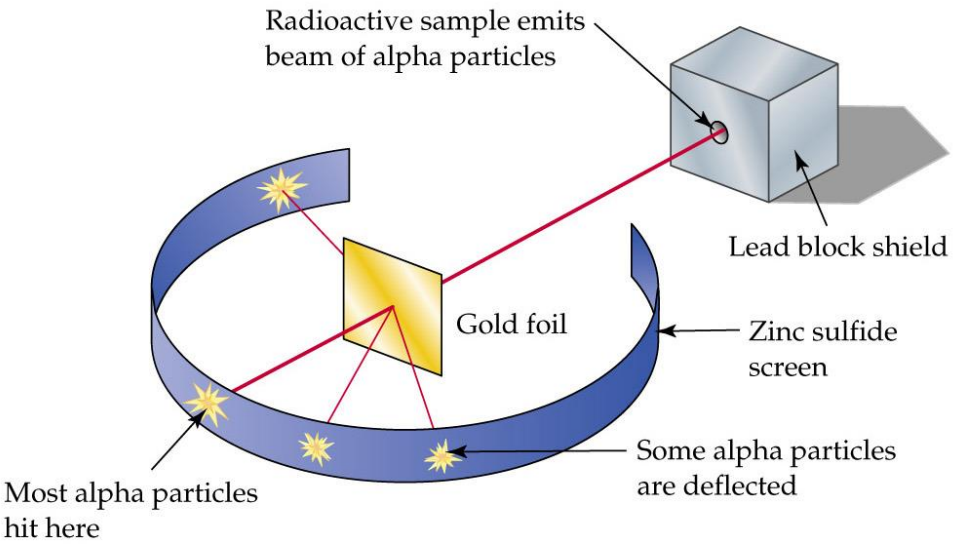
Ion beam analysis



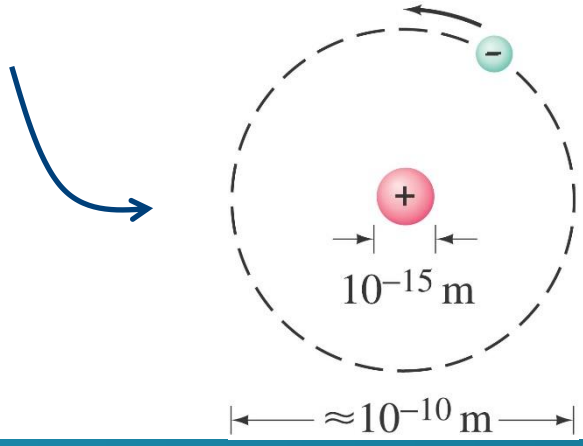
key: interaction between ion and solid

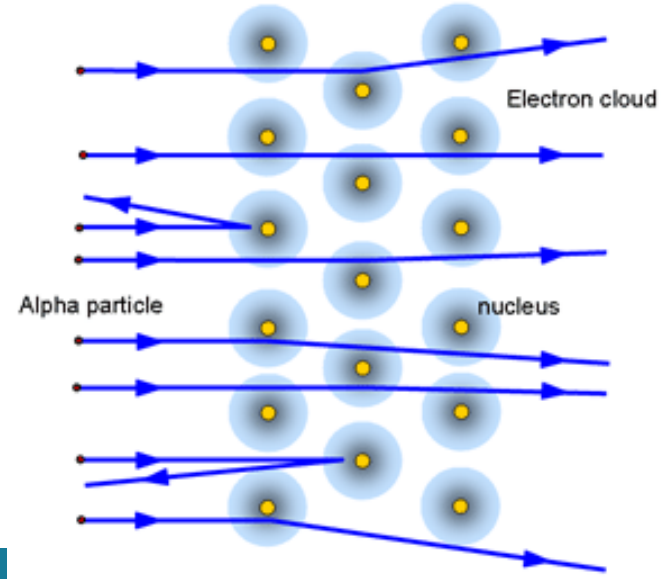
Pioneering experiment

interaction of ions with atoms



Ernest Rutherford (H. Geiger – E. Marsden)





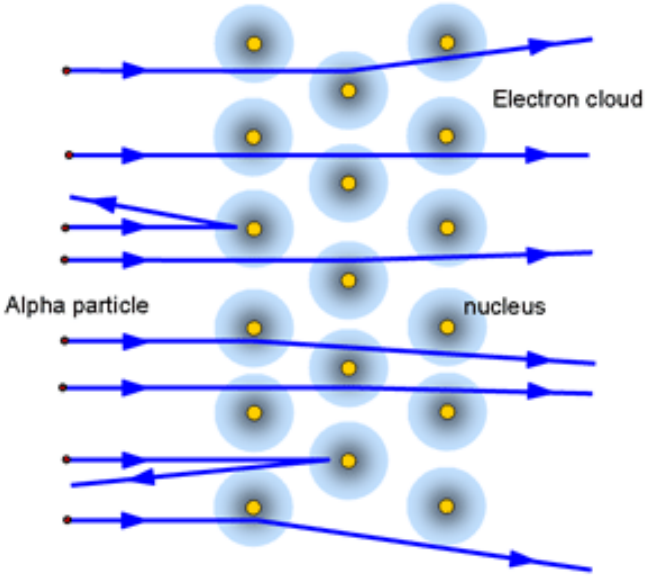
Pioneering experiment

interaction of ions with nuclei and with electrons

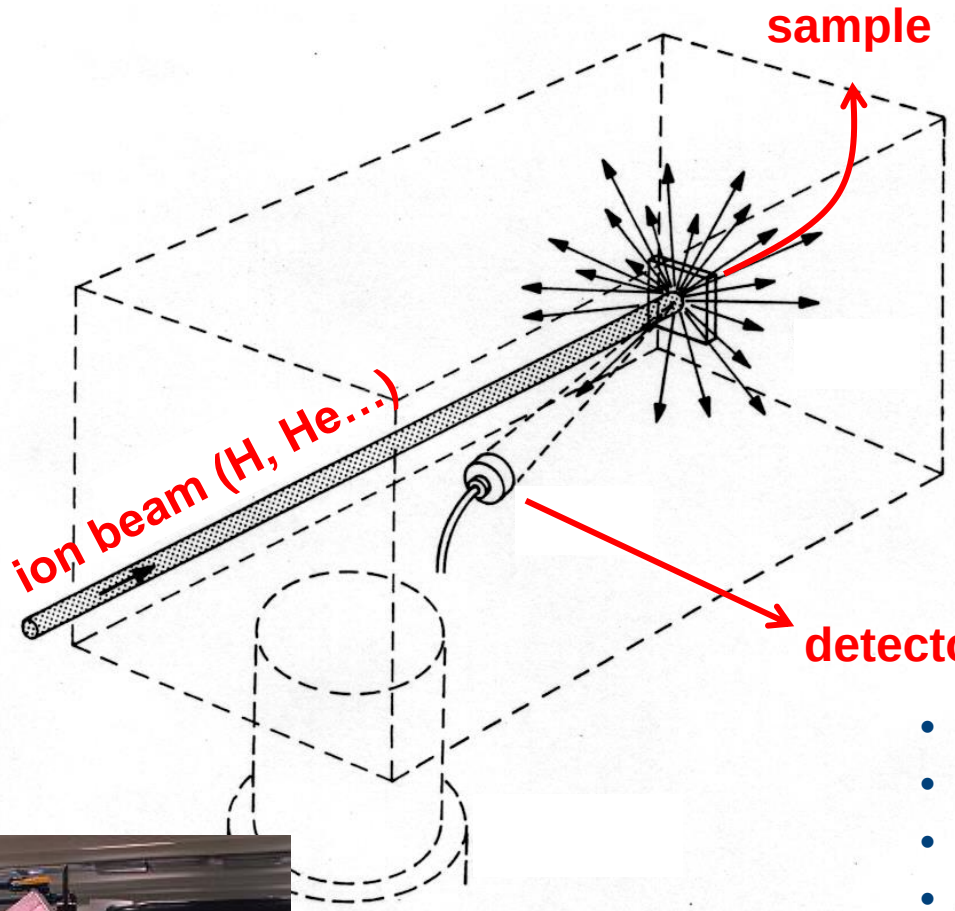
interaction via scattering/recoil or energy loss/excitation

- conservation of momentum
- conservation of energy
- conservation of angular momentum
- Rutherford model
- Bohr model
- …

quantitative
(standardless)



Concept of ion beam analysis

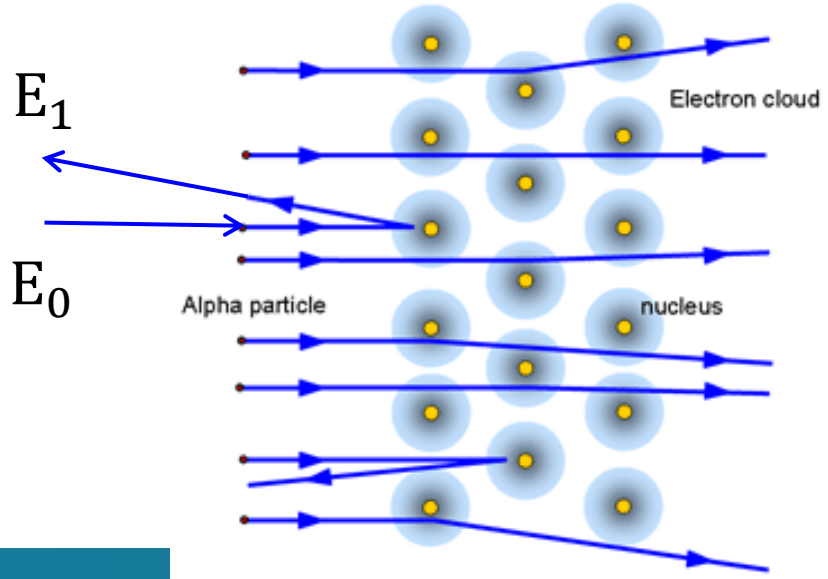


- ions
- electrons
- X-rays
- γ-ray
- …

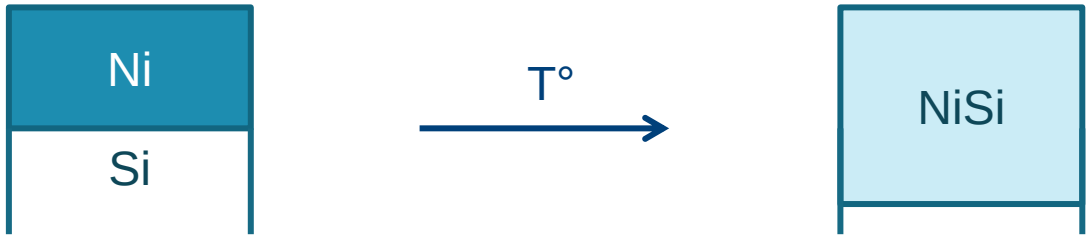
Rutherford backscattering spectrometry

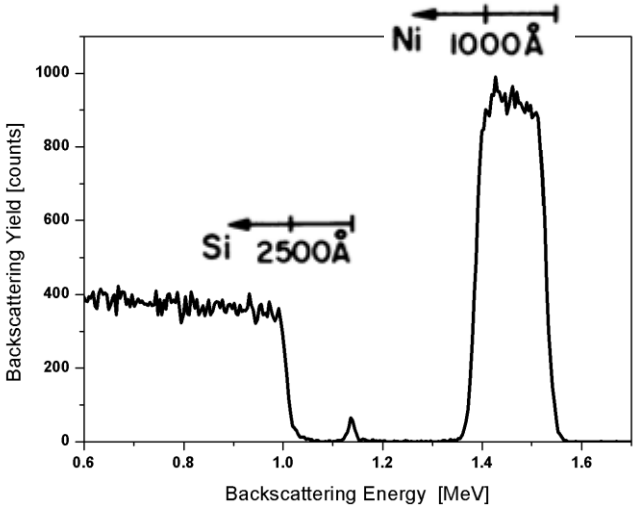
1. energy transfer during the collision of M_1 and M_2 (kinematic factor) → **identity (M_2)** of the target atoms
2. cross section in central force field (scattering cross section) → **concentration** of target atoms
3. energy loss of particle (stopping cross section) → **depth** profiles

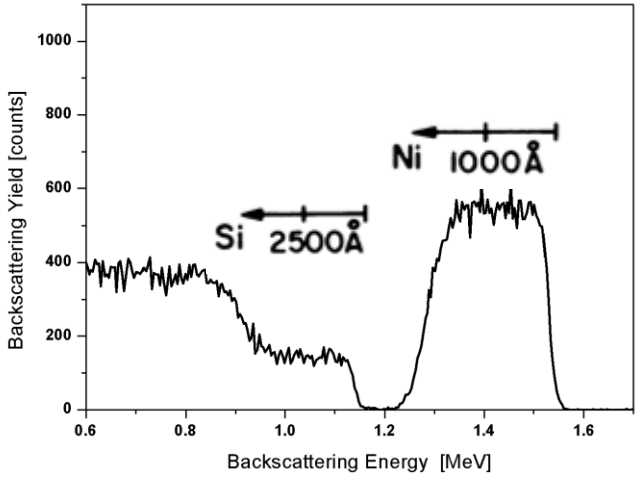
compositional depth profile



Rutherford backscattering spectrometry





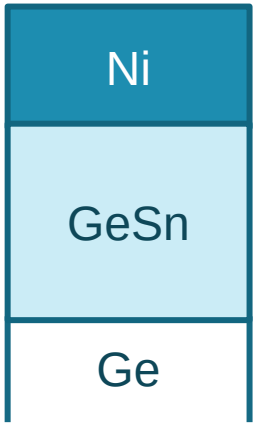


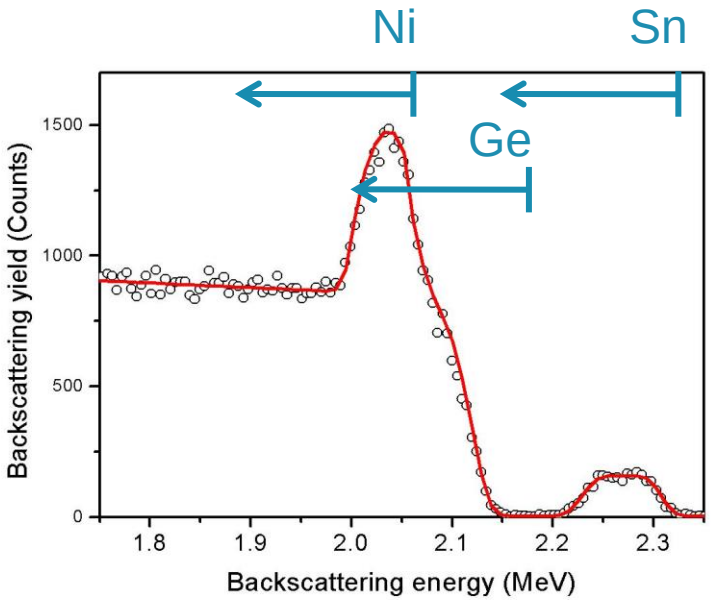
- correct phase identification
- correct thickness analysis
- no matrix nor chemical effects

- no chemical information
- potential overlap of signals…

KU LEUVEN

Rutherford backscattering spectrometry





- correct phase identification
- correct thickness analysis
- no matrix nor chemical effects

- no chemical information
- potential overlap of signals…

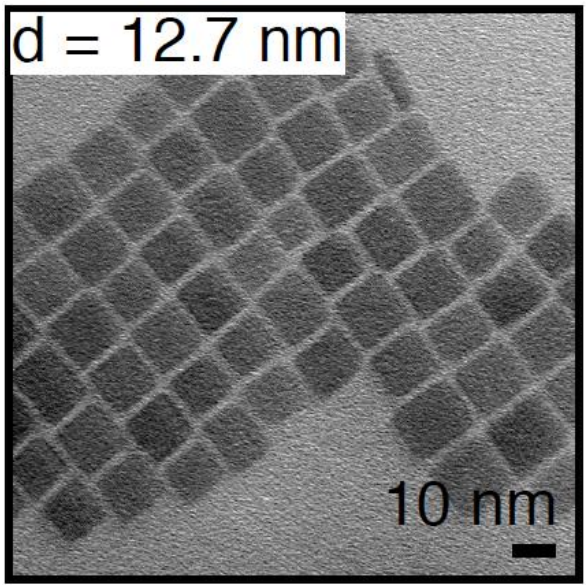
KU LEUVEN

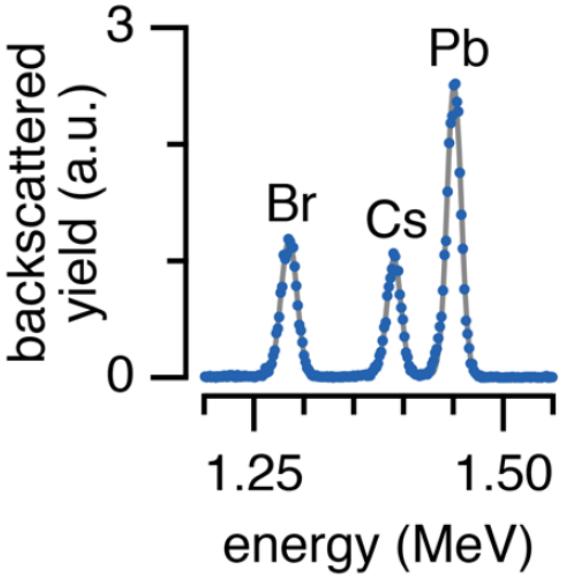
Composition of a nanoparticle

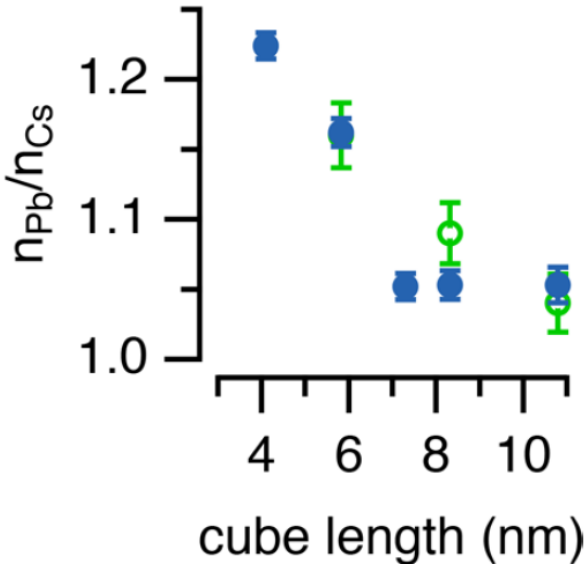
too small for a nanobeam: by far more recoil than scatter events

- exact composition? stoichiometric?
- terminated by excess metal cations?

$CsPbBr_3$





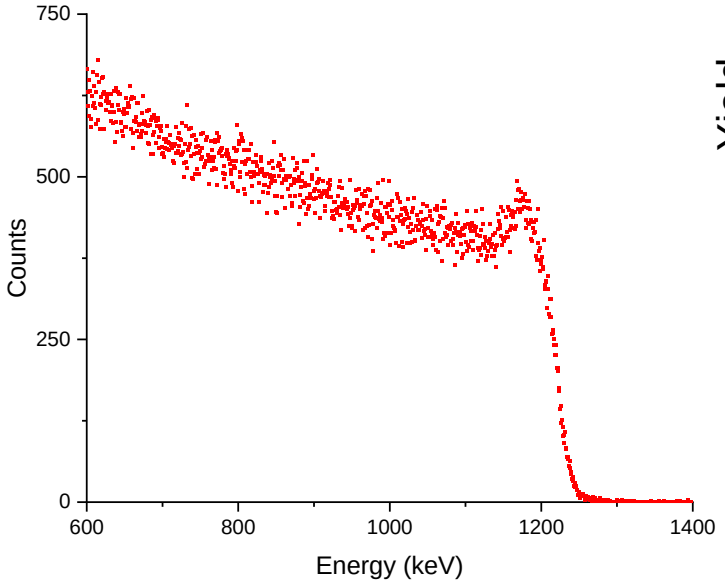


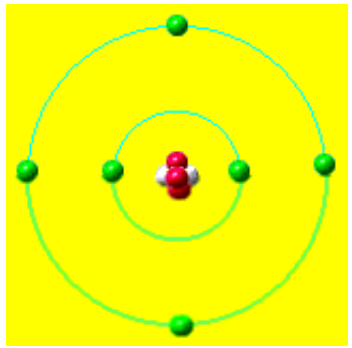
J. Maes *et al.*, J. Phys. Chem. Lett. 9 (2018) 3093

PIXE: particle induced X-ray emission

ZnO doped
with Co and Mn

25	26	27	28	29	30
Mn	Fe	Co	Ni	Cu	Zn



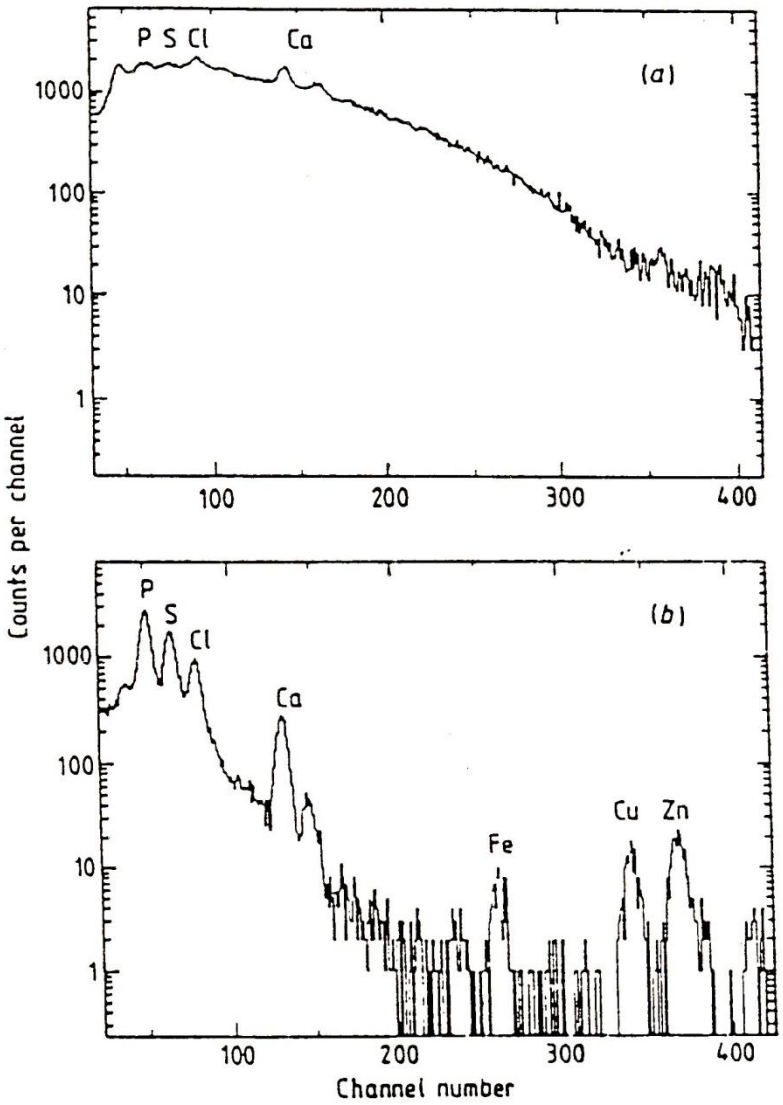


Courtesy: K.J. Kirkby, Univ. of Surrey, Ion Beam Center

KU LEUVEN

PIXE vs. EMA

EMA (electron)



PIXE (proton)

easier beam focus

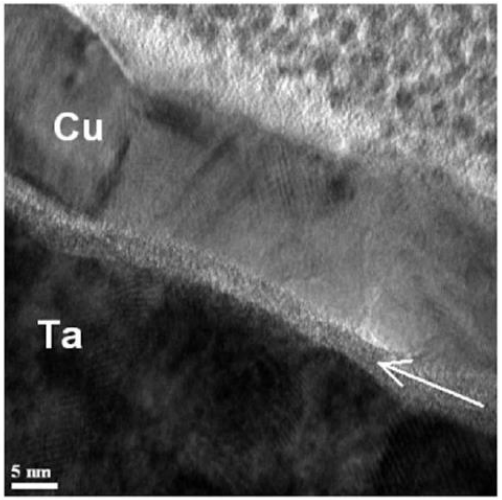
less Bremsstrahlung

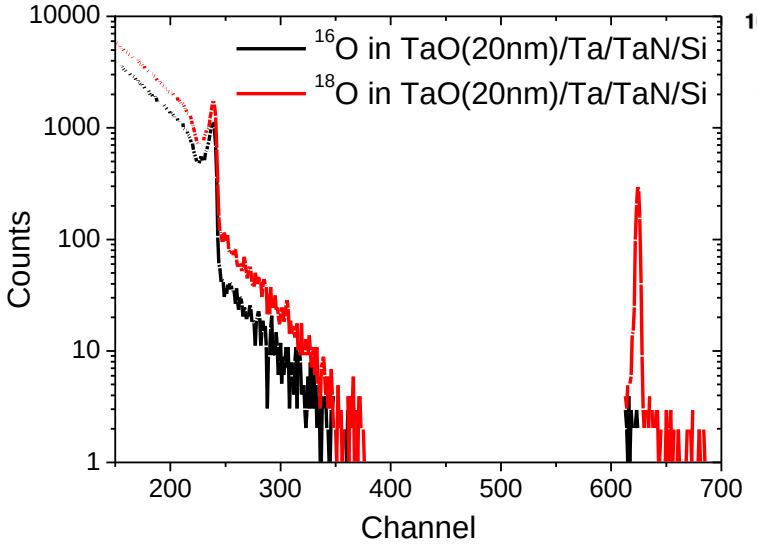
NRA: nuclear reaction analysis

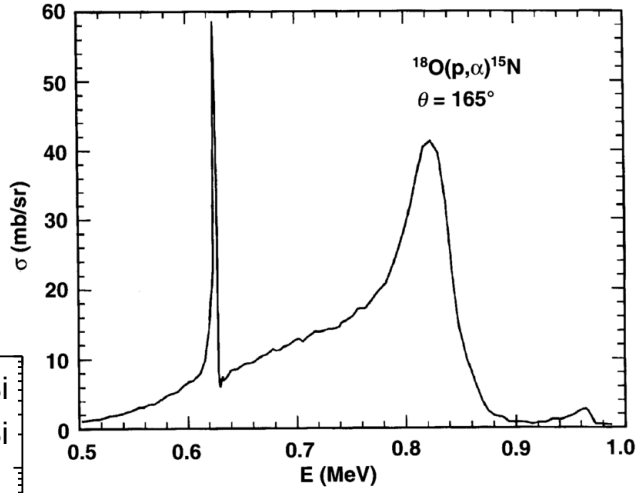
Ta oxidation in high vacuum: $^{18}O(p,\alpha)^{15}N$ resonance (629 keV)

natural abundance: 0.21 %

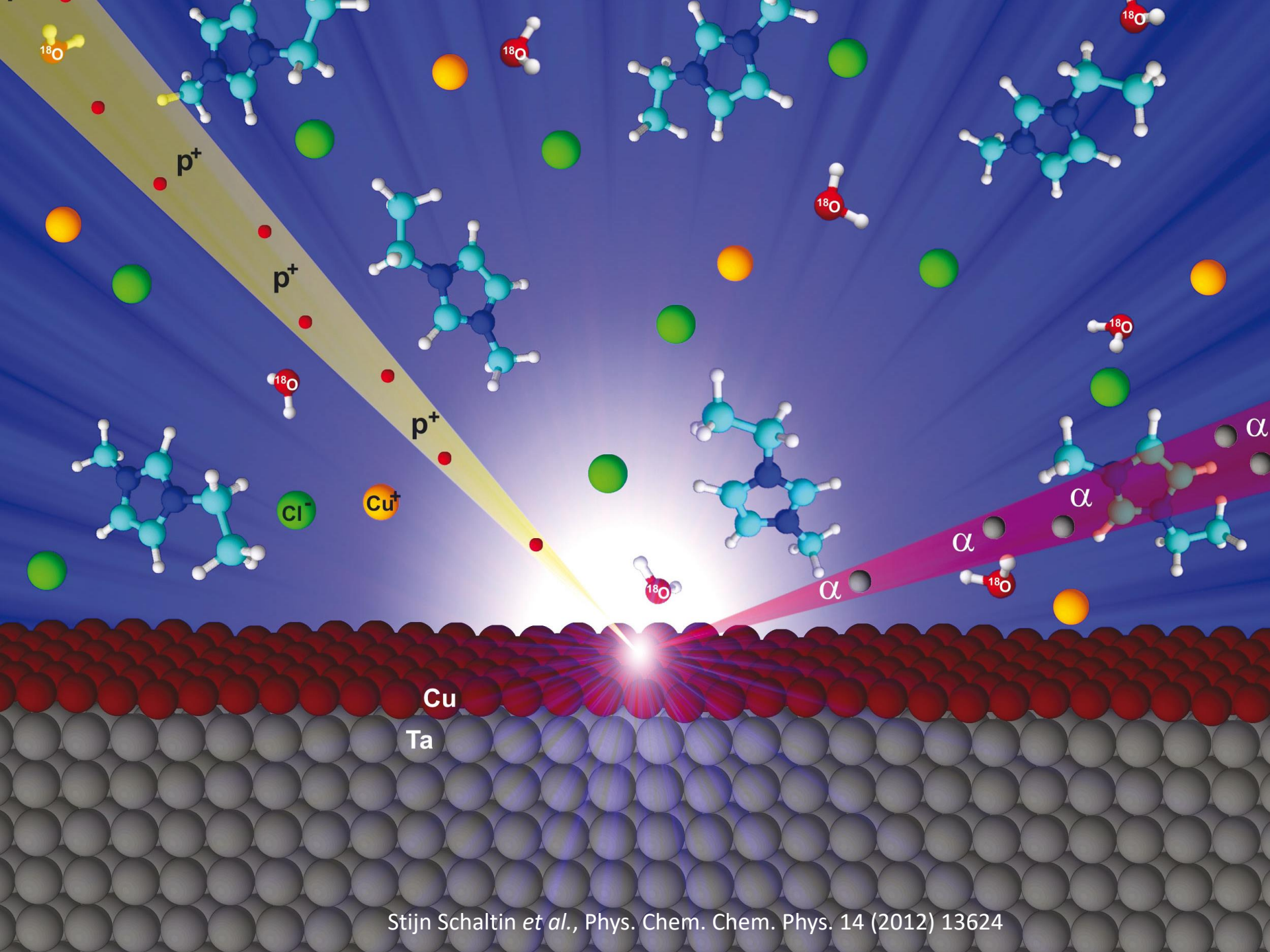
Direct electroplating of copper on tantalum from ionic liquids







Stijn Schaltin *et al.*, Phys. Chem. Chem. Phys. 14 (2012) 13624



Stijn Schaltin *et al.*, Phys. Chem. Chem. Phys. 14 (2012) 13624

IBA: strengths and limitations

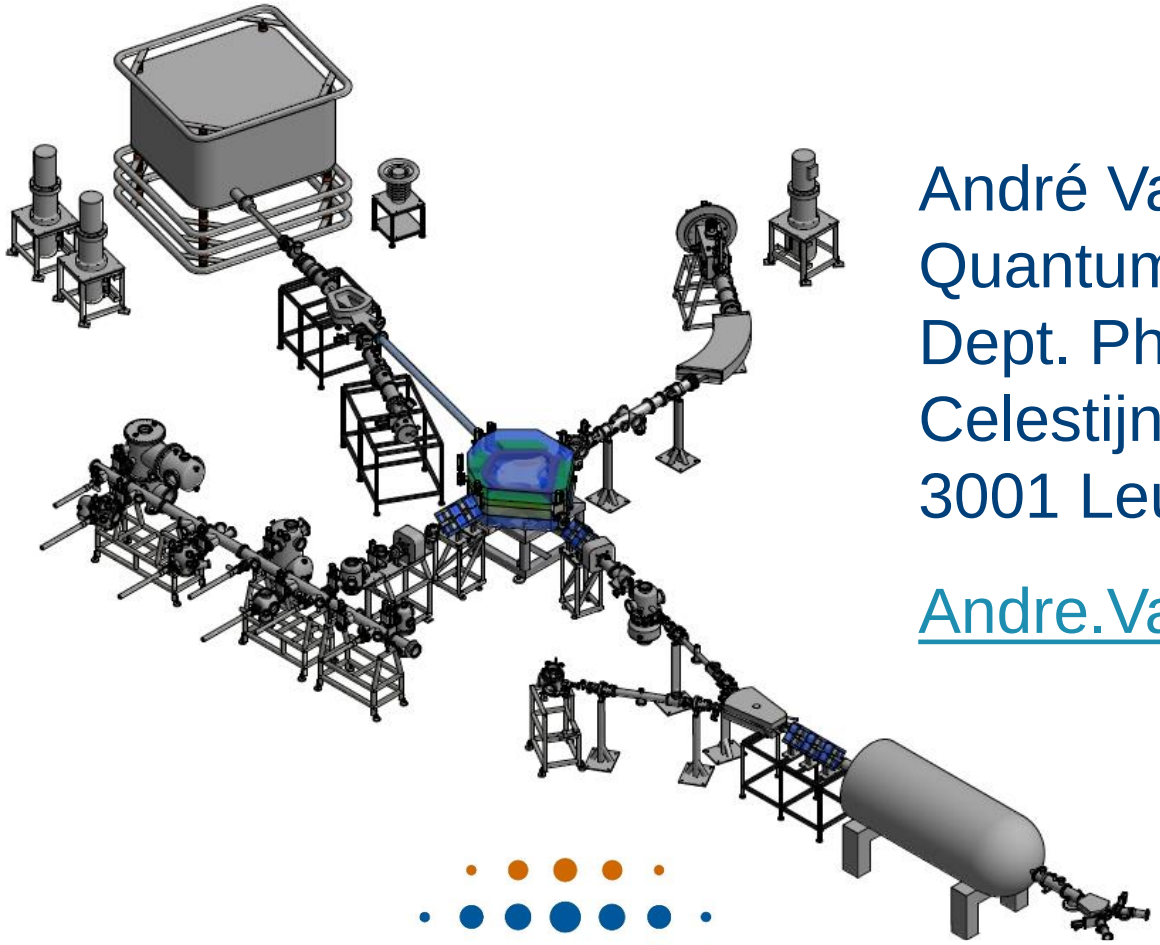
RADIATE

\+
- very versatile – determining compositional depth profile
- from the surface to (a few) μm deep
- quantitative – based on fundamental conservation laws
- independent of matrix, chemistry…
- *in situ* (during heating, laser irradiation…)

\-
- mm-sized ion beam (but: use ensembles)
- mass resolution (but: PIXE, NRA…)
- individual techniques may lack sensitivity in specific cases (but: use complementary techniques – TOTAL IBA)

KU LEUVEN

Ion and Molecular Beam Laboratory



André Vantomme
Quantum Solid-State Physics
Dept. Physics and Astronomy
Celestijnenlaan 200D
3001 Leuven

Andre.Vantomme@kuleuven.be

RADIATE

Research And Development with Ion Beams – Advancing Technology in Europa

KU LEUVEN