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# Surrey Ion Beam Centre: the EPSRC "MRF" for Ion Beam Applications

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The Surrey Ion Beam Centre (SIBC) has been sponsored as a National Centre for research in the UK since 1978. It underpins more than £40M of active UK research grants at any one time on a range of subject areas but mostly to support micro-electronics radiation damage studies. It was part of large European infrastructure project (SPIRIT) providing access to ion beam equipment across Europe. In 2002 it was awarded the Queens Anniversary prize for research achievement in Ion Implantation and Optoelectronics. The citation which accompanies the award says "*For over thirty years the University has been recognized as a pre-eminent institution in the field of ion implantation and optoelectronics. Its innovative research into these key technologies has had an outstanding impact on the development of the modern electronics industry worldwide."* The SIBC works actively with industry, developing bespoke processes and services, particularly for the photonics industry and provides ion beam facilities to ~20 companies across the world. It operates a stringent quality control program and is one of the few ion beam laboratories in the world to operate under ISO 9001 certification.

The SIBC has become one of the world leaders in the field of ion beam research. In the 1970's and early 80s it pioneered the rapid thermal annealing technique[1] which is now universally used by the semiconductor industry, in the 80's it developed [2,3] "radiation hard" silicon on insulator substrates for space and military applications and for a time was the world's only supplier of these substrates. In the 1990s it developed DataFurnace [4] a computer algorithm to enable quantified analysis using ion beam techniques (one of 2 recognised by the IAEA). The Ion Beam Analysis DataFurnace is a computer code to extract *elemental depth profiles* from Rutherford backscattering and related ion beam analysis spectra. It is able to solve the inverse problem ("given the spectrum, what is the profile") *automatically*, without user intervention. In the 1990's the SIBC also began its work on silicon photonics, beginning with research on $\beta FeSi_2$ [5] in silicon and later combing this work with defect engineering [6]. This led to the formation of a spinout company SiLight Technologies and a prestigious European Research Council grant.

More recently in the field of microelectronics the SIBC has worked on novel approaches to activate dopants for shallow junction devices [7]. The SIBC has also looked to widen its approach and apply its techniques to new areas of research. This has included the biomedical applications of ion beams [8], where a network led by the SIBC was instrumental in bringing the clinical community together to make a case for particle therapy in the UK – three new proton therapy units are now in the process of being built in the UK after much lobbying. With colleagues in Japan, the IBC has pioneered the development of a new analytical technique – MeV SIMS [9-10], this has the potential to produce high molecular mass concentration maps in ambient pressure conditions with high spatial resolution. This is not currently possible using any other technique. The IAEA are involved in promoting and developing this technique worldwide. Recently the IBC has used the capabilities afforded by its DataFurnace algorithm to initiate work with Forensic service providers, the police and Home Office and similar establishments across mainland Europe. This has led to ion beam techniques being recognised as potentially of use for high impact crime cases. In 2007 the IBC received ISO9001 accreditation and is now actively pursuing ISO 17025 certification for its Ion Beam Analysis protocol.

Total IBA [11] has now been developed from DataFurnace and is a very powerful new ion beam analysis characterisation technique enabling the unambiguous depth profiling of very complex thin films, and in principle making chemical tomography of small samples feasible. This new method, which we have been instrumental in developing, fully exploits the complementary information available from the photon and particle methods.

Over the years the SIBC has developed its portfolio of industrial users. Work with these companies is done via means of a non-disclosure agreement. What the company wishes to achieve is first established and then a process is developed to meet these needs. Sometimes the process is then shipped out to the company in question but more often, batches of wafers are sent to the SIBC for the bespoke implantations and processing required. A turnaround time of typically 3-5 days is achieved meaning that the IBC supplies expert services to companies across the world. The SIBC also supplies bespoke consultancy when required. It runs with a relatively robust business model attracting approximately equal funding from UK research councils, the EU and industry.

The Vertical Beam Line for Cell Irradiation

Semiconductor end station

The Ion Implantation Facility & Clean Room

Beam lines from 2MV Tandem

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# Ion Beams in the UK….

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# the EPSRC “MRF” for Ion Beam Applications

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# The Proposed UK Virtual Ion Beam Centre:

- **Surrey**
  - Implantation and IBA facility
- **Huddersfield**
  - Miami (in-line TEM) and MEIS facility
- **Manchester**
  - Gamma ray and neutron irradiation emulation facility

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# Surrey Ion Beam Centre

## The People

**The core staff are:**

**Prof. Roger Webb** (director)
Prof Russell Gwilliam
Prof Kevin Homewood
Dr Chris Jeynes
Dr Geoff Grime

**Liaison support staff are:**

Dr Julien Colaux
Dr Nianhua Peng
Dr Keith Heaseman

**Admin Support is provided by:**

Karen Arthur

**Technical Support is provided by:**

Alex Royle
Mark Browton
Adrian Cansell

**Research Staff:**

Dr Vladimir Palitsin
Dr Luke Antwis
Dr Lucio Dos Santos Rosa
Dr Ellis Moura Stori Rosa
Ms Lidija Matjacic

**Visiting Staff:**

Prof Karen Kirkby
Dr Brian Jones
Dr Mike Merchant
Dr Charlie Jeynes
Dr Julien Demarche

**Other associated staff include:**

Prof Paul Sellin
Prof John Watts
Prof David Bradley
Dr Melanie Bailey

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# USERS

## Other EU Universities accessing the Surrey IBC in the past 5 years include:

## UK Universities Accessing the Surrey IBC in the past 5 years include:

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## National Centres and Organisations accessing the IBC in past 5 years include:

## Companies & Organisations accessing the IBC in past 5 years include:

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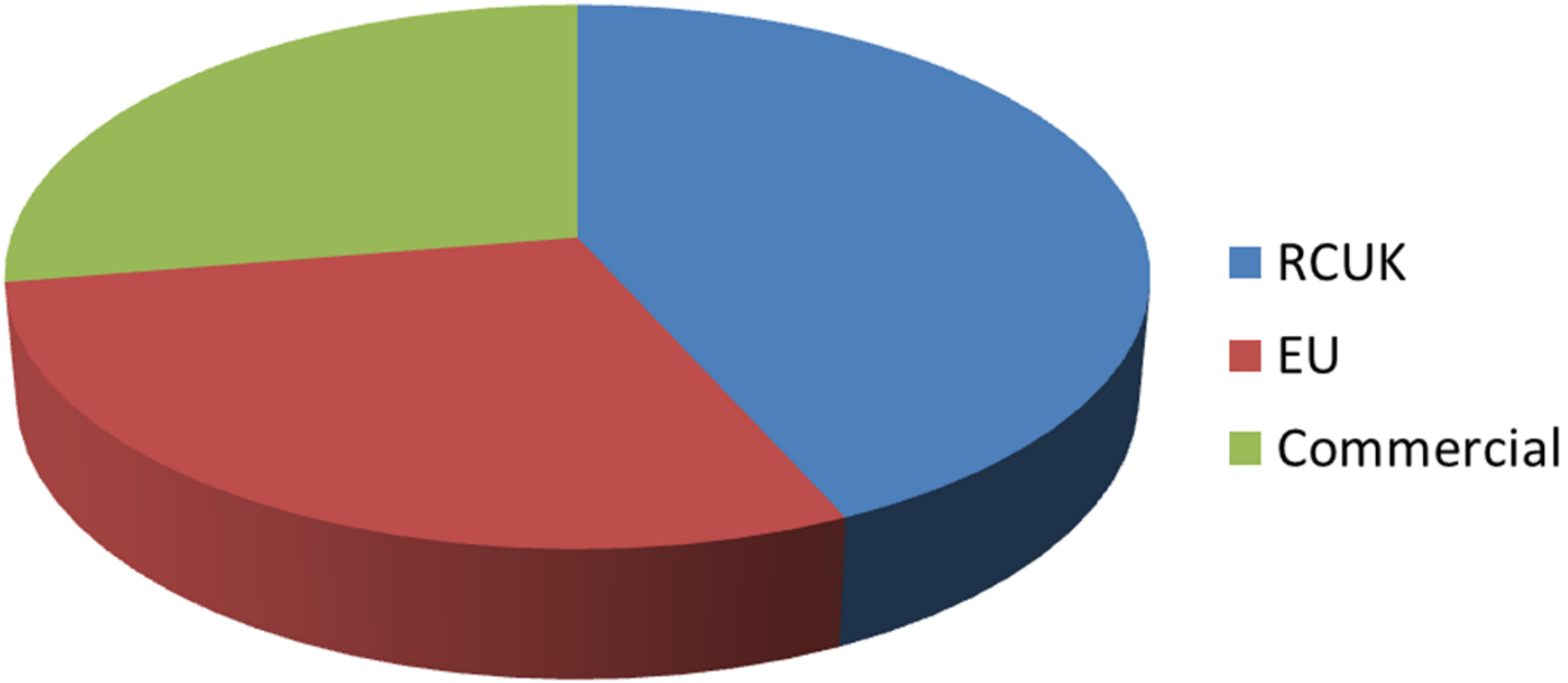
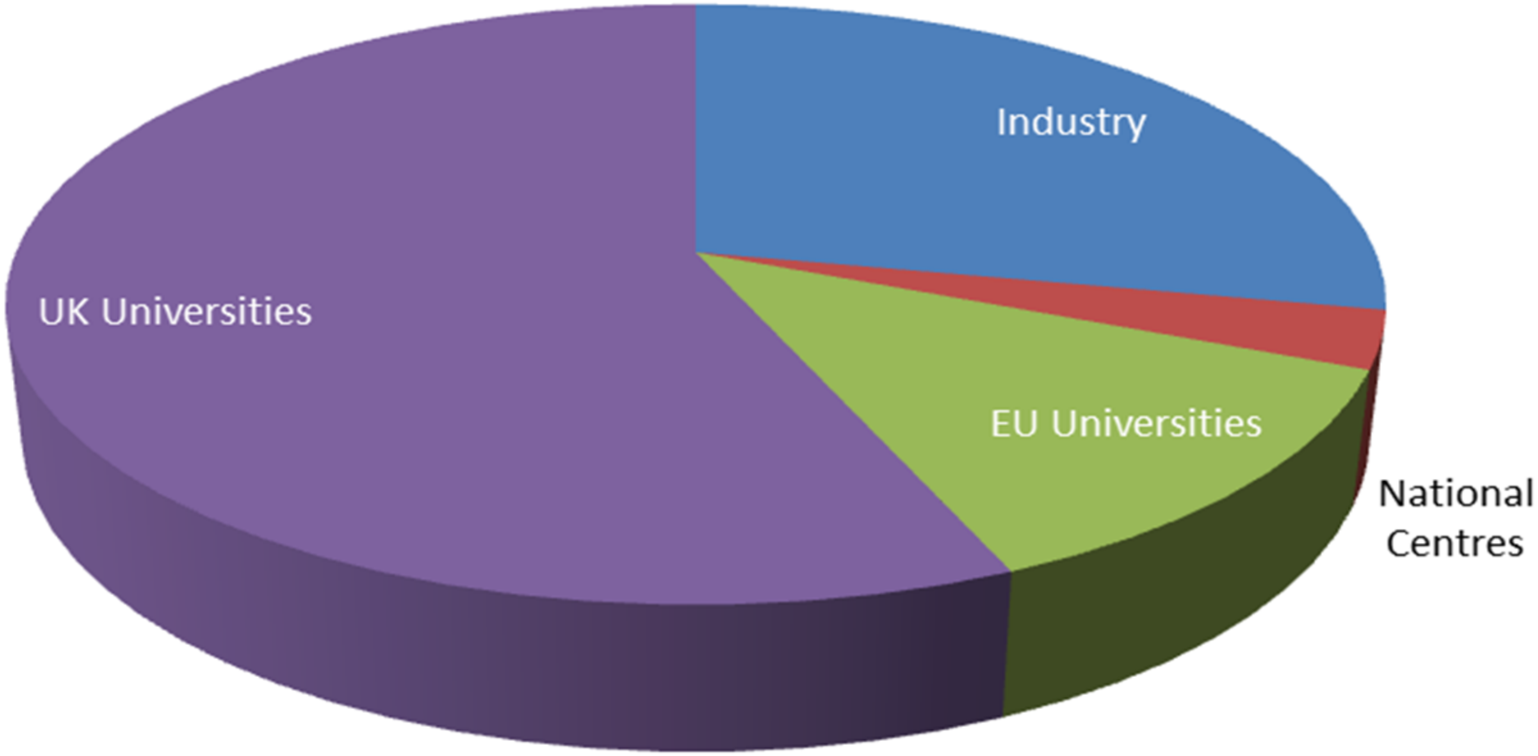
# *Breakdown of Funding at Surrey IBC over the past 5 years*

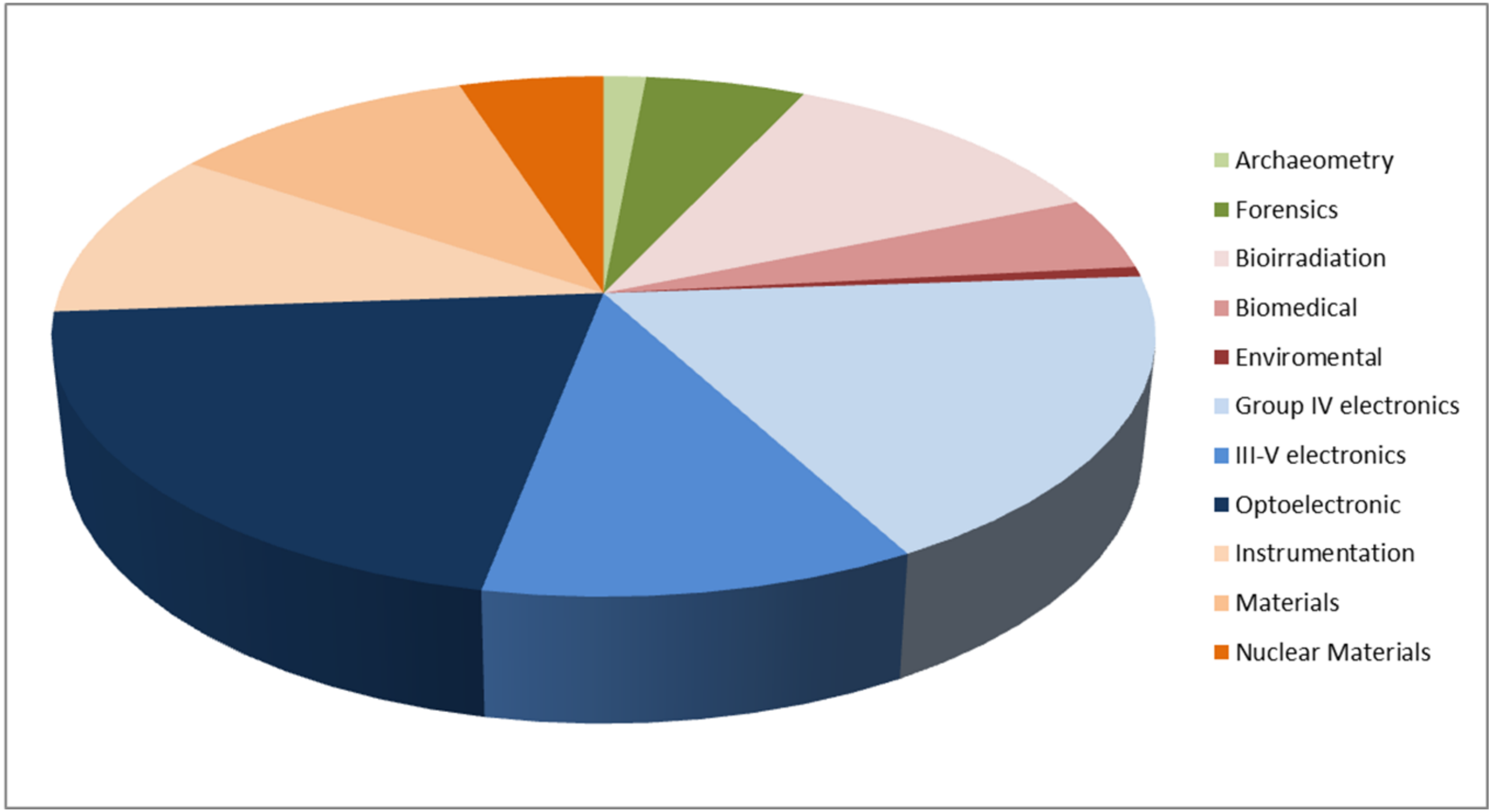


# Breakdown of Beam Time Usage at Surrey IBC over the past 5 years



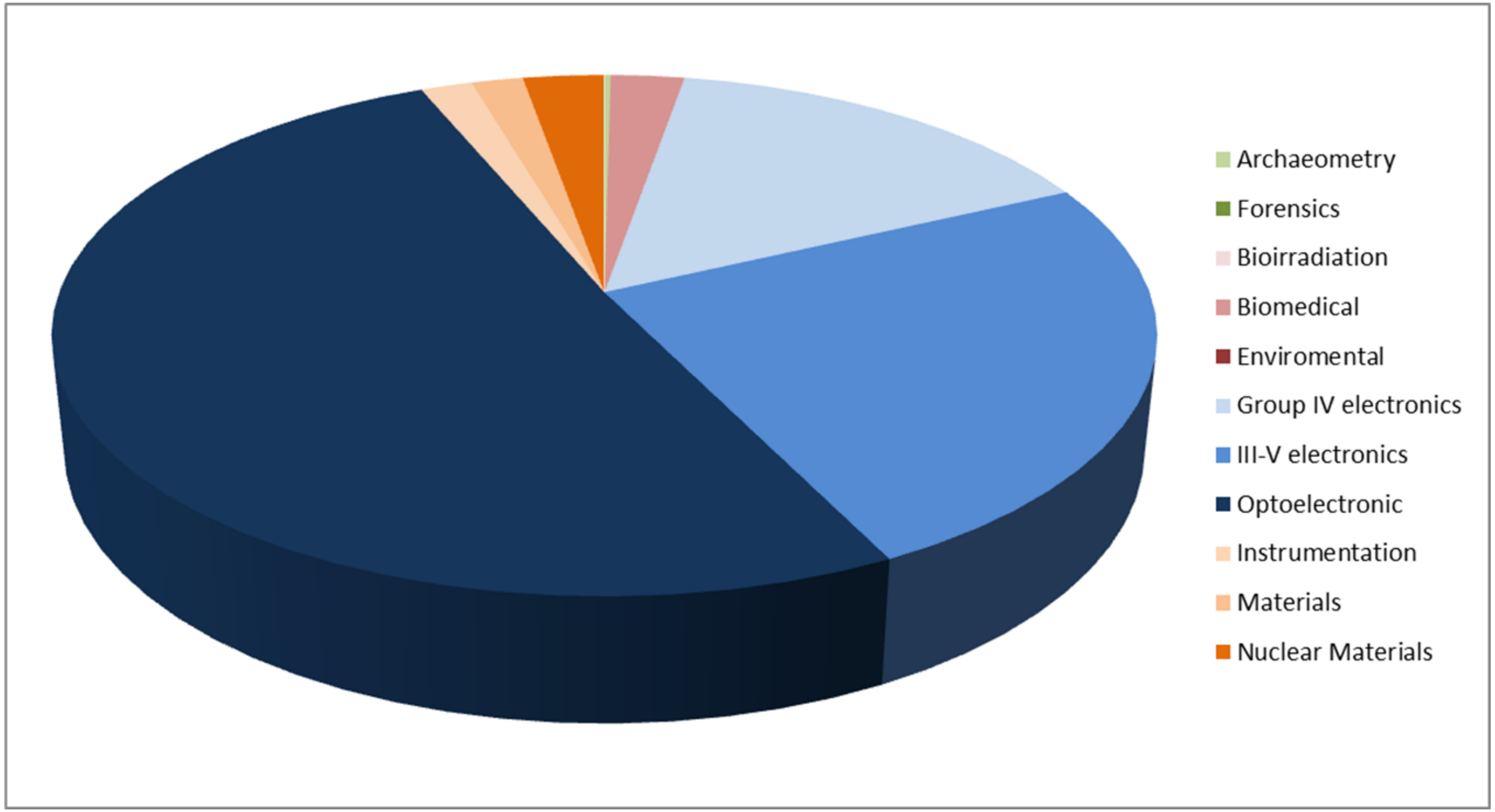
# Breakdown of Beam Time Used by Project Type

# All Funding Sources - 50% semiconductors



# Breakdown of Beam Time Used by Project Type

# Commercially Funded - 91% semiconductors



# Quality Assurance and Standards

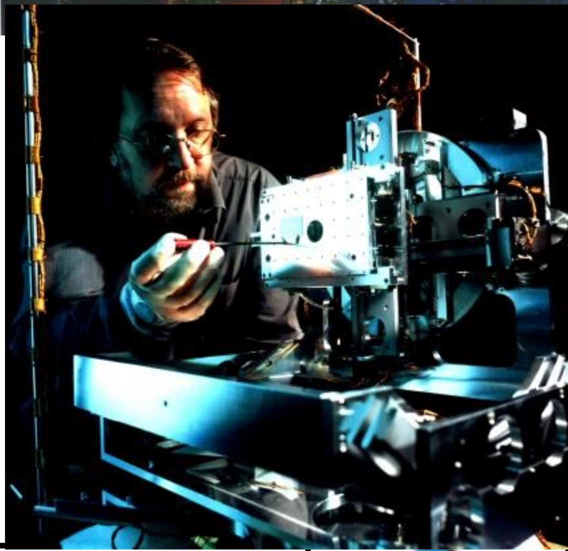
- *Extensive QA program*
- *ISO9001 certified since 2008*
- Working with both NPL and PTB on various fundamental studies
- ISO17025 accreditation for high accuracy RBS awarded 2015

Certification No. 181855

8943

# Surrey Ion Beam Centre

- **Investment**
  - **Support**
    - £5M investment in machines and beam lines
    - Approx £1.5M per annum support
    - 2 academics
    - 8 RAs (including 2 senior RAs)
    - 3 technicians + 1 secretarial
  - **Technology Transfer**
    - 32 University departments around the UK
    - 53 local and international companies
    - 15 PhD projects
    - Supporting >50 EPSRC grants worth >£50M



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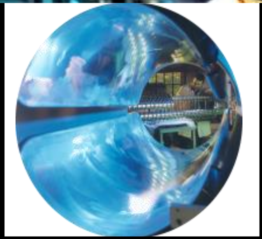

# Surrey Ion Beam Centre

- **Controllable Materials Modification**
  - Facilities
    - 0.4-2MV High Energy Implanter
    - 2-200kV High Current Implanter
    - Implantation 2keV⇒4MeV (up to 10mA)
    - Sample size mm$^2$ to 40cmx40cm
    - Hot (1000$^o$C) or cold (~10K)
    - Sample Chambers in class 100 clean room
    - Plasma/thermal processing and metrology

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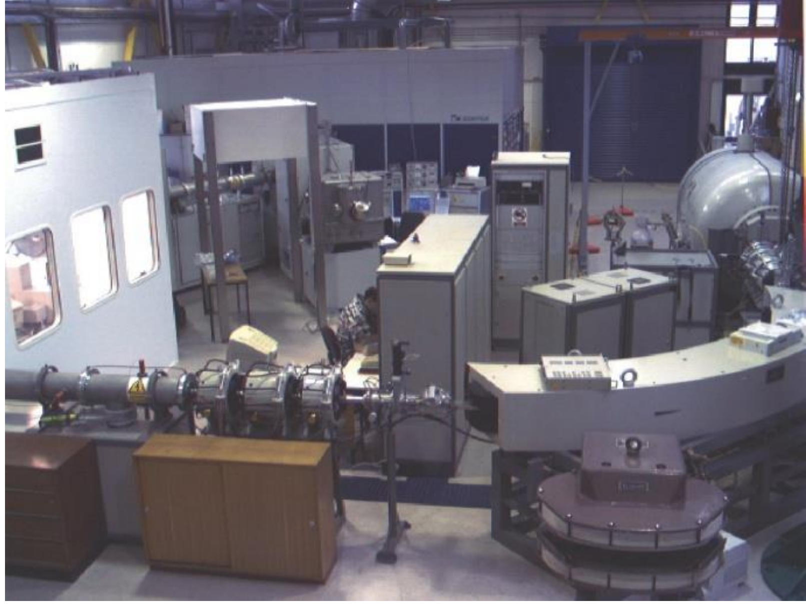
# Surrey Ion Beam Centre

- **Controllable Materials Modification**
  - **Applications**
    - Ion Beam Synthesis
    - Ion Implantation
    - Defect Engineering
    - Proton beam lithography (on Tandem accelerator)

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# Huddersfield Miami Facility

- **Implanter with In situ TEM**
  - **Facilities**
    - JOEL 2000FX TEM
    - 2-100keV Implanter
    - Temperature stage -173-1000$^{o}$C
  - **Applications**
    - Nuclear Radiation damage
    - Ion Implantation
  - **Staff**
    - Steve Donnelly
    - Johnathan Hinks
    - Graeme Greaves

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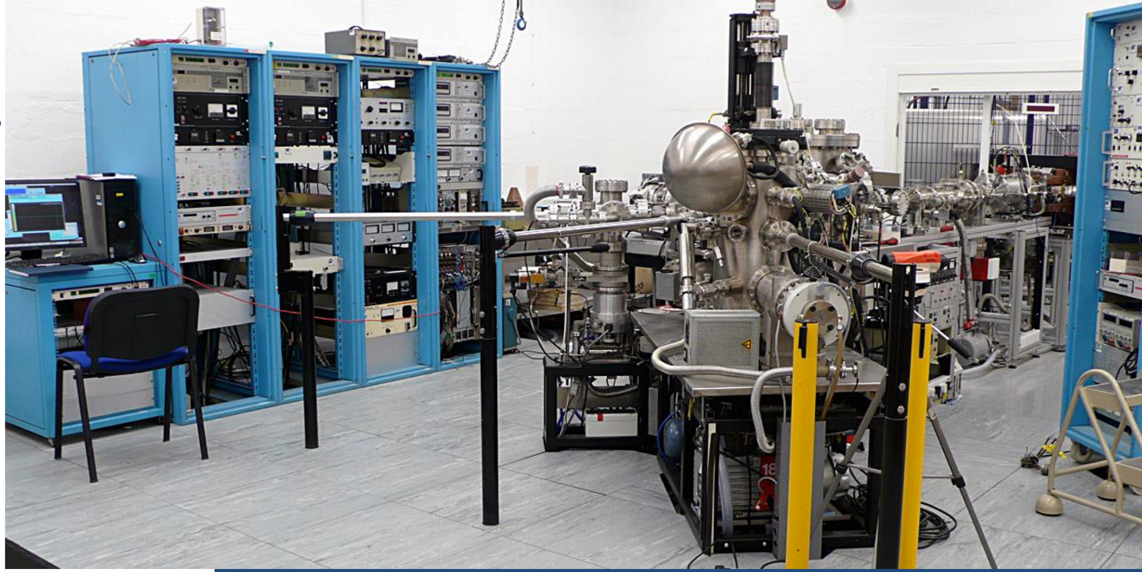
# Huddersfield MEIS Facility

- **Medium Energy Ion Scattering**
  - **Facilities**
    - 50-200keV Accelerator
    - LEED Auger
    - Temp range 300-1300K
  - **Applications**
    - High Resolution Depth Profiling
    - Channelling for damage studies
  - **Staff**
    - Jaap Van Den Berg
    - Roger Barlow



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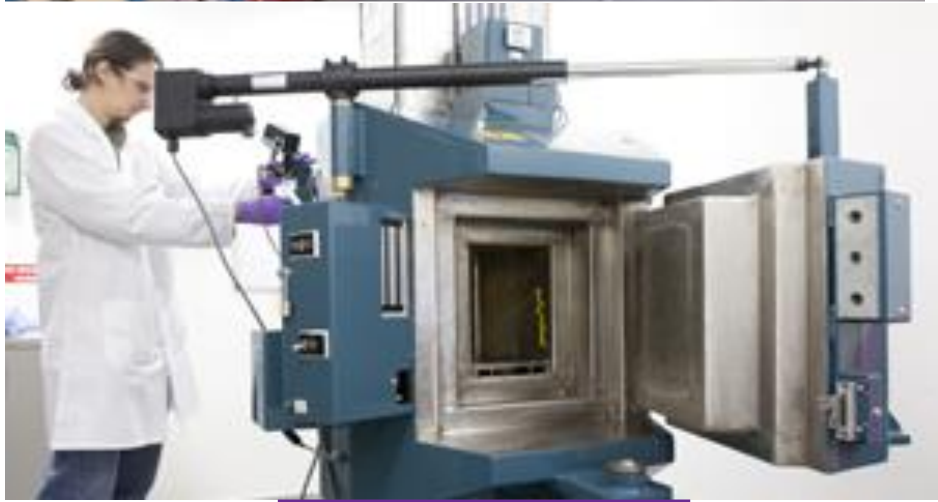
# Manchester Dalton Institute

- **Cumbria Nuclear User Facility**
  - **Facilities**
    - 5MV Tandem Accelerator
    - $^{60}$Co gamma source – 4-100Gy/min
    - Temp range 300-1300K
    - Installing 2.5MV Tandem for dual beam work
  - **Applications**
    - Radiation Damage Studies
    - Nuclear Irradiation
  - **Staff**
    - Simon Pimblott
    - Andy Smith
    - Nick Mason



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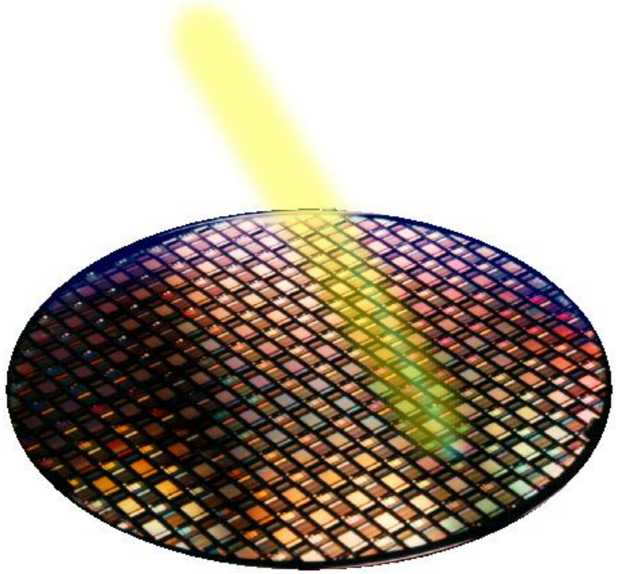
# Ion Implantation



**The charge on the ion** can be collected so that each ion can be counted as it enters the material ensuring precise control on **quantity**

**The charge on the ion** enables a single isotopic mass to be selected in a magnetic field providing **high purity**

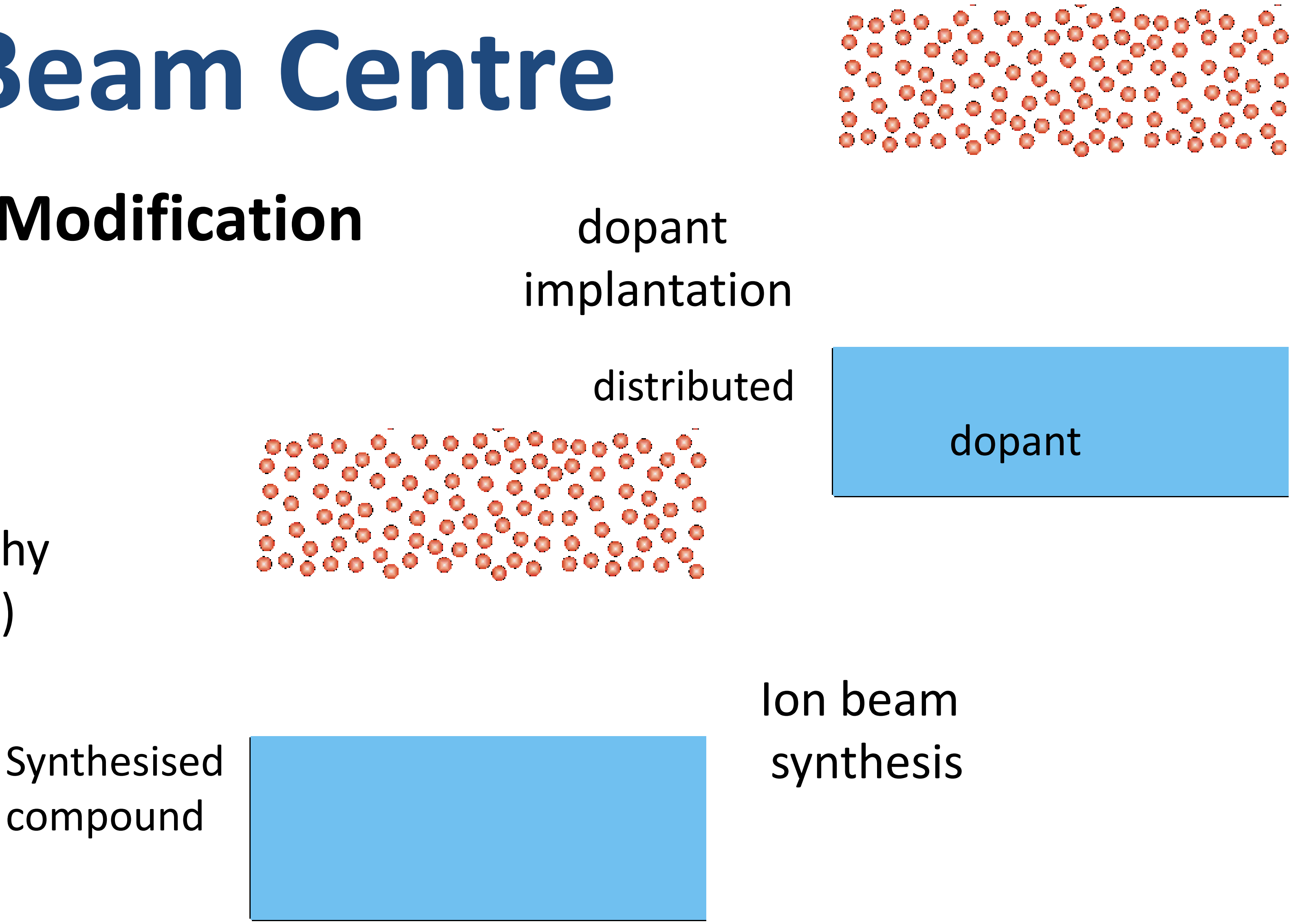
**The charge on the ion** enables the particles to be accelerated by a potential gradient. The velocity of each particle is identical and when they reach the target surface will embed themselves to a **well determined depth**.

**The charge on the ion** enables the ion beam to be raster scanned across a target (like an old fashioned CRT display) producing a **very uniform** spread across the sample under irradiation.



# Surrey Ion Beam Centre

- **Controllable Materials Modification**
  - **Applications**
    - Ion Beam Synthesis
    - Ion Implantation
    - Defect Engineering
    - Proton beam lithography (on Tandem accelerator)



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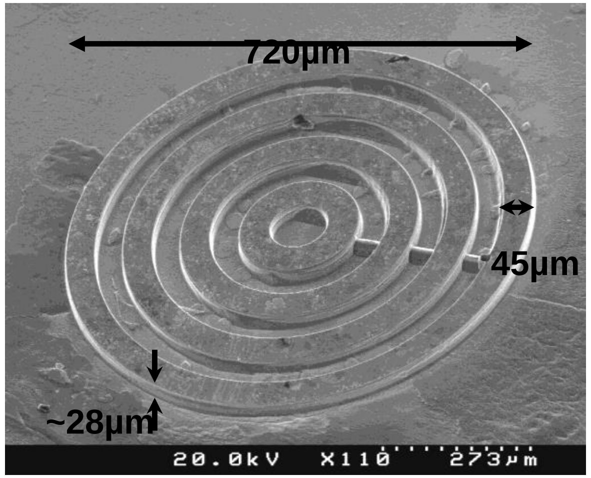
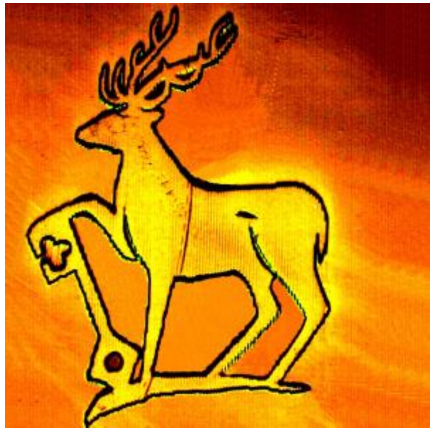
- **Controllable Materials Modification**
  - **Applications**
    - Proton Beam Lithography
      - Like e-beam lithography
      - MeV protons set photo resist
      - But heavy ions:
        - don't scatter like electrons
        - And can be focussed to ~50nm
        - Penetrate to 40um
      - Potential for 1000:1 aspect ratio structures
      - Can also direct write into semiconductors to knock out carriers and decrease electro-chemical etch rate.




*SEM image of a concentric circle structure produced by 2MeV protons in GaAs*



*University Logo in GaAs*



# Surrey Ion Beam Centre

- **Advanced Materials Analysis**
  - **Facilities**
    - 2MV Tandem
    - Techniques include RBS, EBS, ERD, PIXE, PIGE, NRA, IBIL, IBIC
    - **NEW** MeV SIMS
    - Sub micron size micro-beam with full scanning
    - Channelling Spectroscopy for damage analysis
    - Fully automated collection and analysis
    - External Beam for vacuum sensitive samples
    - Horizontal nanobeam (30nm) in construction
    - Vertical nanobeam for cell (in culture) irradiation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- **Advanced Materials Analysis**
  - **Applications**
    - Thin Film Depth Profiling
    - 3-D elemental composition and mapping
    - Protein Analysis
    - Forensics, Archaeometry
    - Disorder Profiling of Crystals
    - Radio biology
    - Analysis of cells in culture

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# Bio-Irradiation Facility

**Facilities for bio-irradiation**

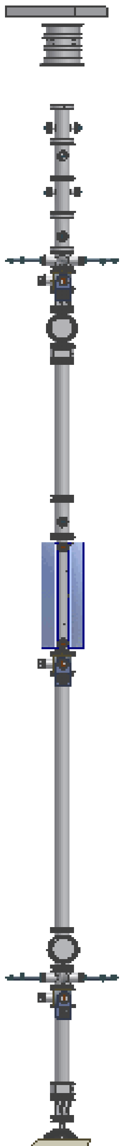
- Targeted (~100nm) single ion irradiation
- End Station in Cat 2 biological clean room
- Vertical Arrangement to allow irradiation of living cells in liquid cultural
- ~10,000 cell irradiations per hour
- Ions up to Ca from 2MVTandem
- Environmental chamber, incubators etc.

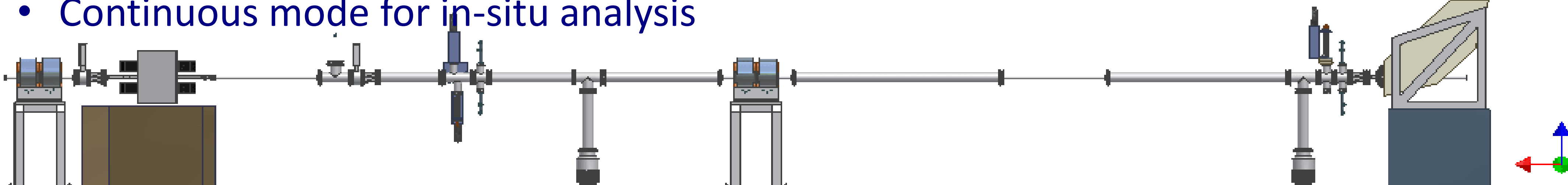
**Facilities for Protein Analysis**

- Analysis by microPIXE
- To determine the heavy metal constituents in some proteins – can be difficult via other methods
- ppm sensitivity

**Applications**

- Cell Irradiation
- Proton/hadron therapy research
- Continuous mode for in-situ analysis





# What happens when the ion beam hits the target?

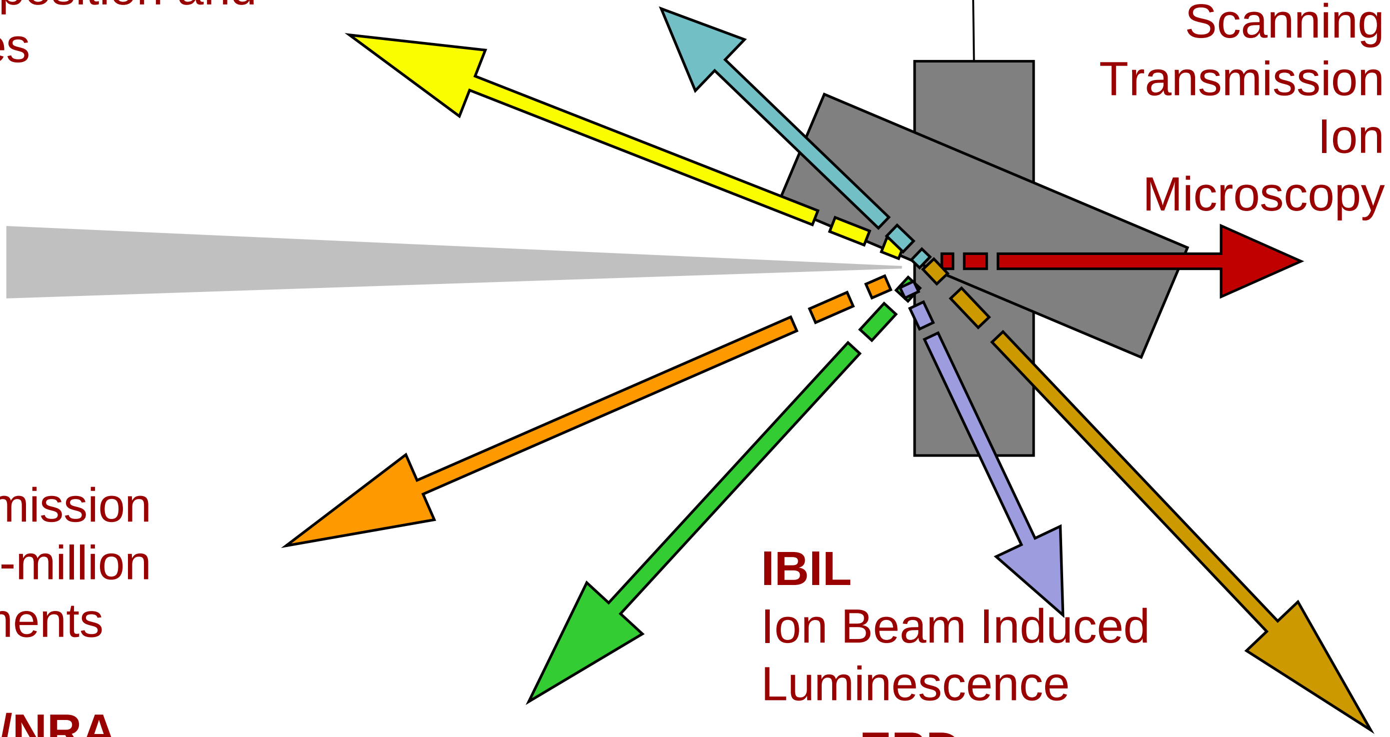
**RBS**
Energy of scattered protons or He give light element composition and elemental depth profiles

**MeV SIMS**
Using heavy ions molecular material can be desorbed and anaylsed using ToF MS

**IBIC**
Ion Beam Induced Charge

**STIM**
Scanning Transmission Ion Microscopy

Fast moving, charged particles MeV ions



**PIXE**
Characteristic X-ray emission Simultaneous part-per-million detection of trace elements from Na to U

**PIGE/NRA**
Nuclear reactions give charac-teristic gamma rays and/or particles from light nuclei (e.g. Li, B, F)

**IBIL**
Ion Beam Induced Luminescence

**ERD**
Forward recoil of target atoms (particularly good for H profiling)

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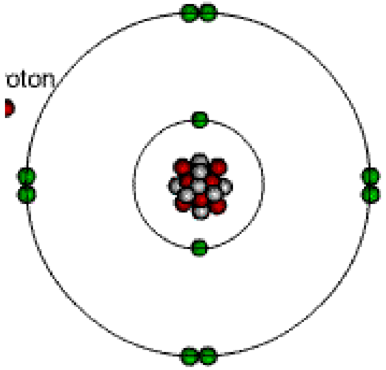
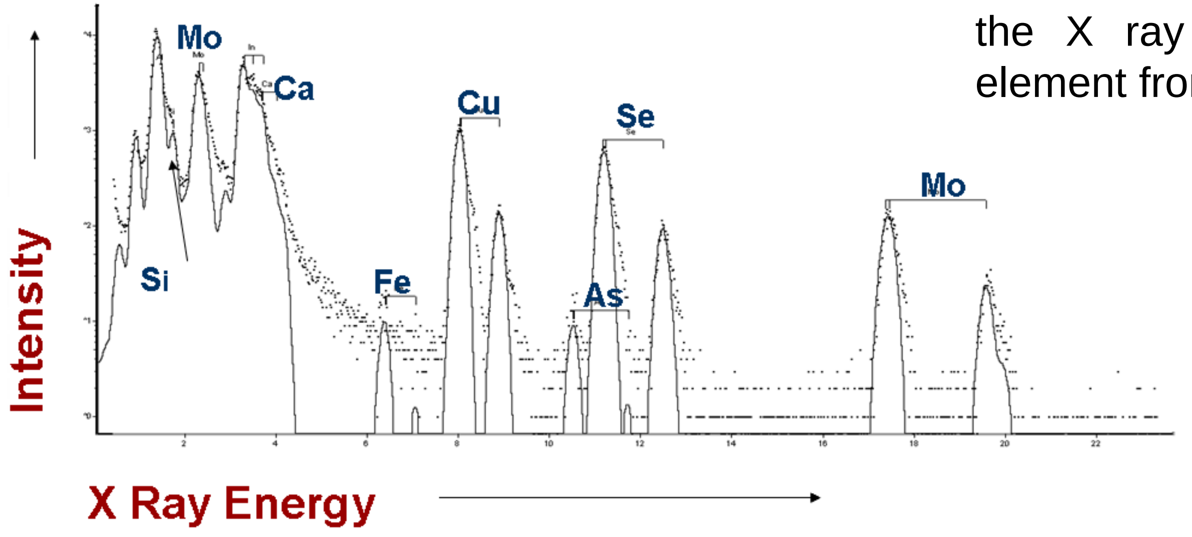
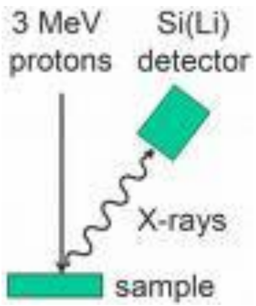
# What is PIXE…?



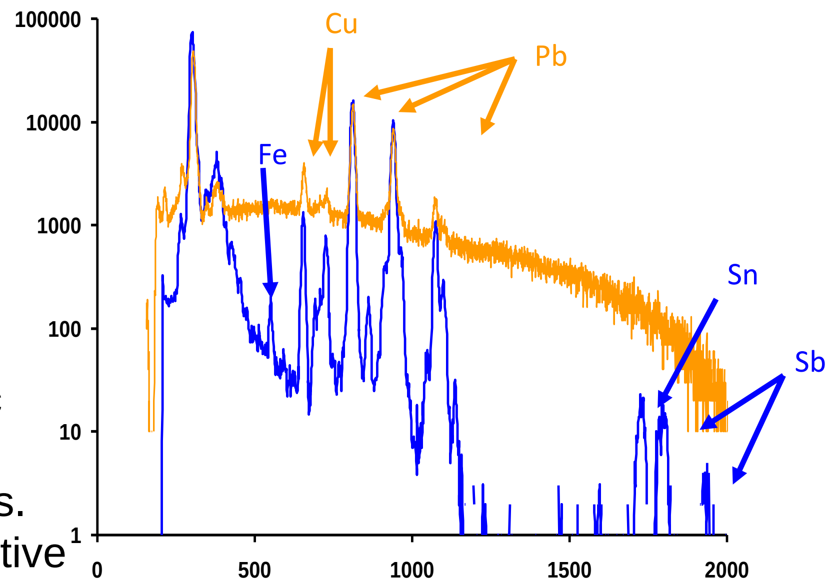
**Particle Induced X-ray Emission**

- The ion beam can cause ionisation of target atoms (i.e. the removal of an electron) as shown in the figure on the left.
- This leaves a vacancy in one of the electron shells
- An electron from an outer electron shell jumps down to fill the gap
- An X ray is emitted, the energy of which is equal to the difference in the energy levels.
- Since different atoms have a different number of protons, the spacing of the energy levels for different atoms is different, and therefore the X ray energy is characteristic of the element from which it originated



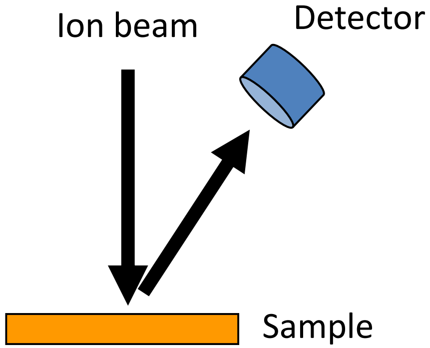



# Benefits of PIXE & PIGE

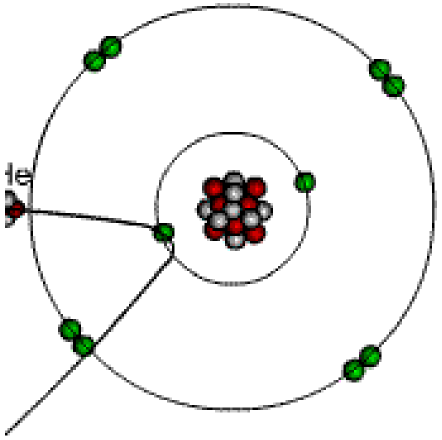



- PIXE can be used to detect elements in the periodic table **from Na to U (Li, B, F** etc. with PIGE**)**
- The sensitivity is at the **ppm level** for most elements.
- The figure on the right shows how much more sensitive PIXE (blue) is to trace elements than the electron micro-probe (yellow), **no brehmsstrahlung**
- The analysis can be carried out **in air or in vacuum**. This allows the non-destructive analysis of large and/or vacuum sensitive objects.
- There is usually **no need for any sample preparation**
- PIXE analysis gives absolute quantification. There is no need to compare to standards.
- The accuracy of the technique is ~5%.
- In PIXE analysis, we simultaneously collect a backscattered particle spectrum. This gives us complementary information that we can use to determine depth profiles of the major elements.

# What is RBS?

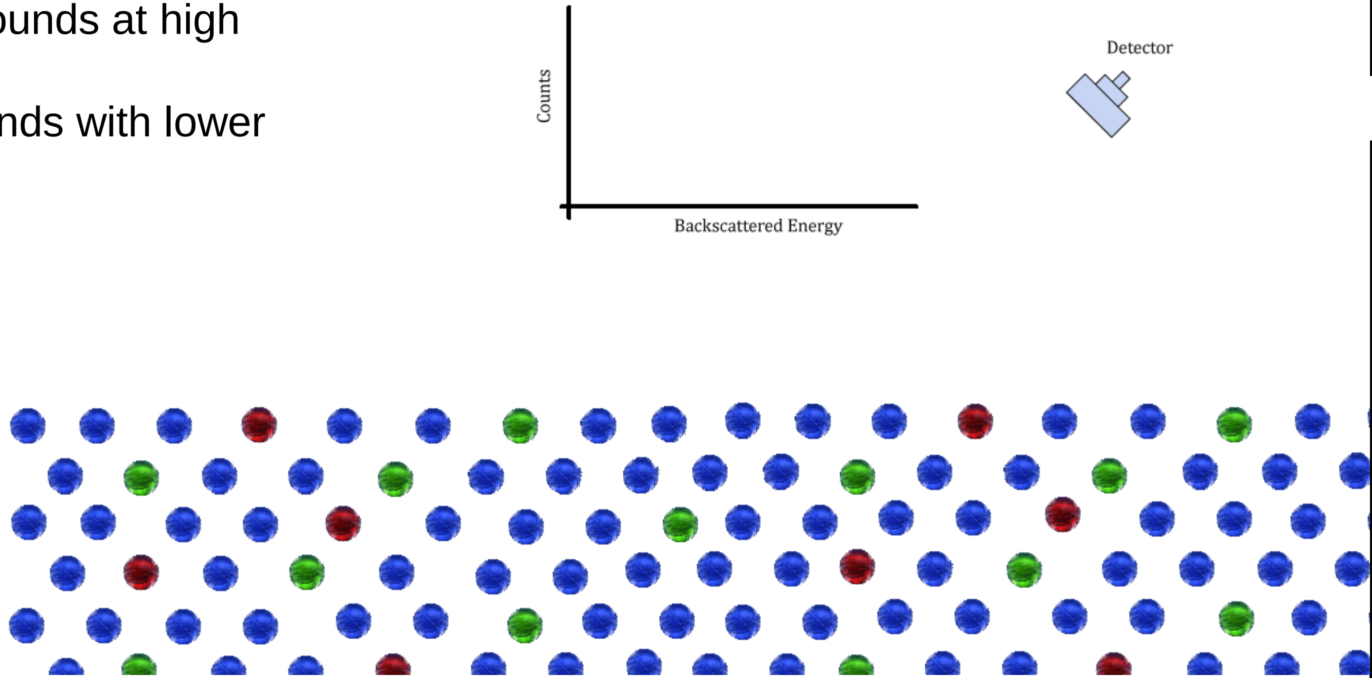



- RBS determines compositional information about a sample:
  - ***Which*** atoms are present and ***where*** are they?
- Rather than an alpha source like Rutherford, we use a more convenient ion beam from an accelerator
- We detect backscattered particles and their energy
- Ions are repelled by the positively charged nucleus, and scattered backward.
- The particle detector measures the energy of the backscattered particles.
- For high beam energies (EBS) the ion penetrates the nucleus,  and the scattering probability is modified.



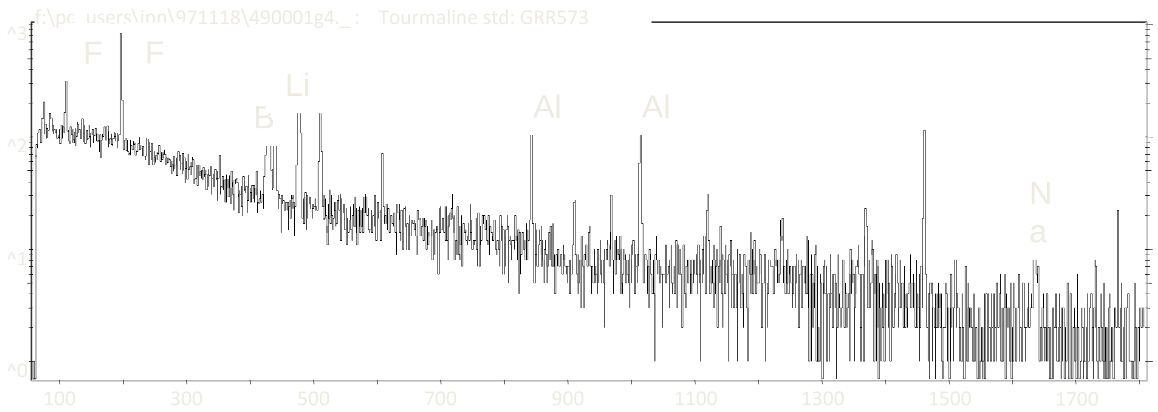
# How to interpret a RBS Spectra

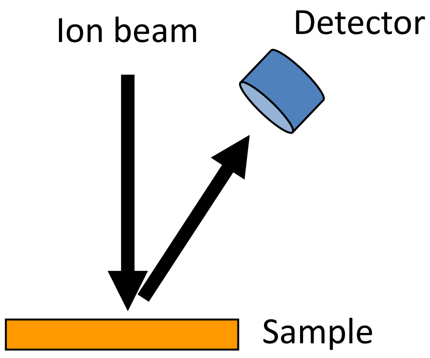
- The energy of the backscattered particle depends on the depth in the sample at which it was backscattered
- As the particle travels through the sample, it loses energy through collisions with the target electrons
- These collisions don't really affect the particle's direction, just its speed (i.e. kinetic energy)
- The energy of the backscattered particle also depends on the mass of the atom it hit
- If it hits a heavy atom, it rebounds at high energy
- If it hits a light atom, it rebounds with lower energy

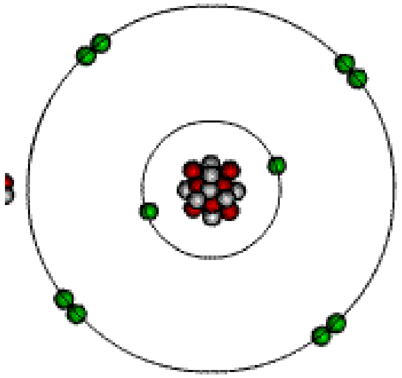


# What is NRA/PIGE?

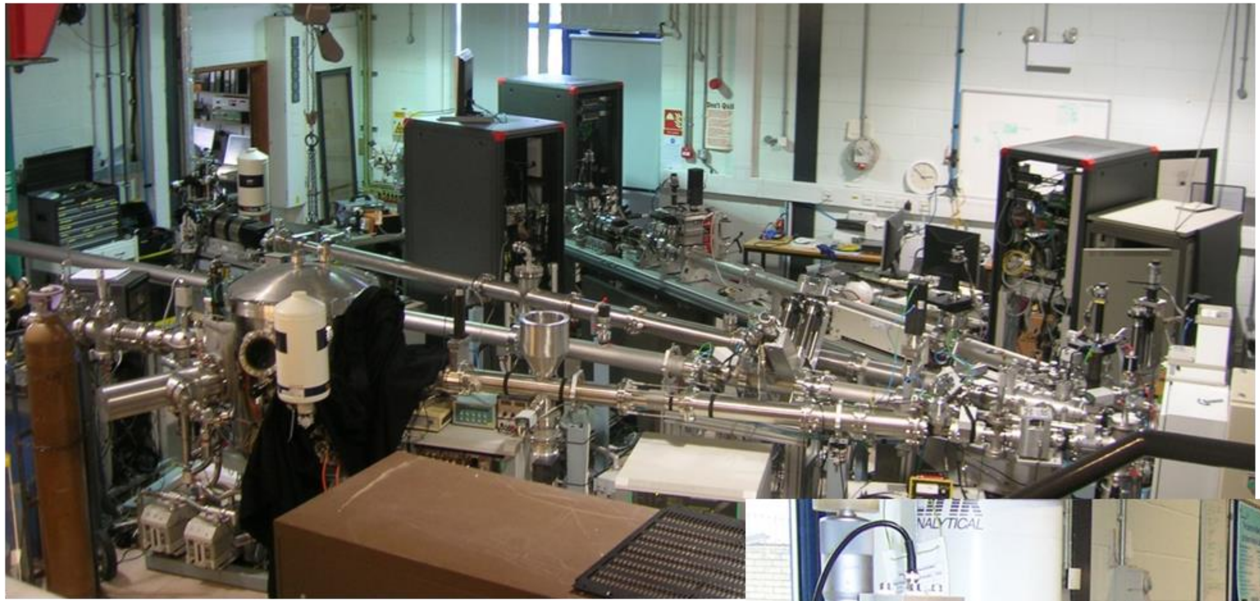
- **NRA** or **Nuclear Reaction Analysis** uses accelerated nuclei to penetrate the nucleus of a target atom causing a nuclear reaction in the target nucleus and the emission of a particle (or a gamma ray in **PIGE**) whose energy is characteristic of the target element.
- The technique is particularly useful for **identifying light elements** that are difficult to "see" with PIXE.
- **Resonant reactions** can be used which occur at particularly sharp interaction energies. As the mono-energetic beam slows gradually as it enters the target, these resonant reactions occur only at determinable depths. Hence by varying the energy of the initial beam it is possible to **depth profile** using this technique.



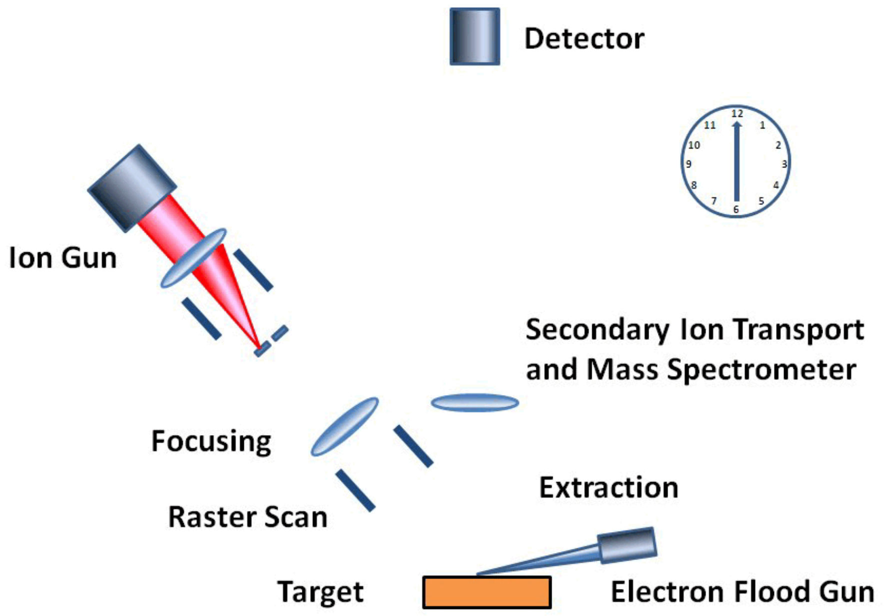
# Ion Beam Mapping



Ions from
accelerator

Magnets for
focussing

# What is MeV ToF-SIMS…?



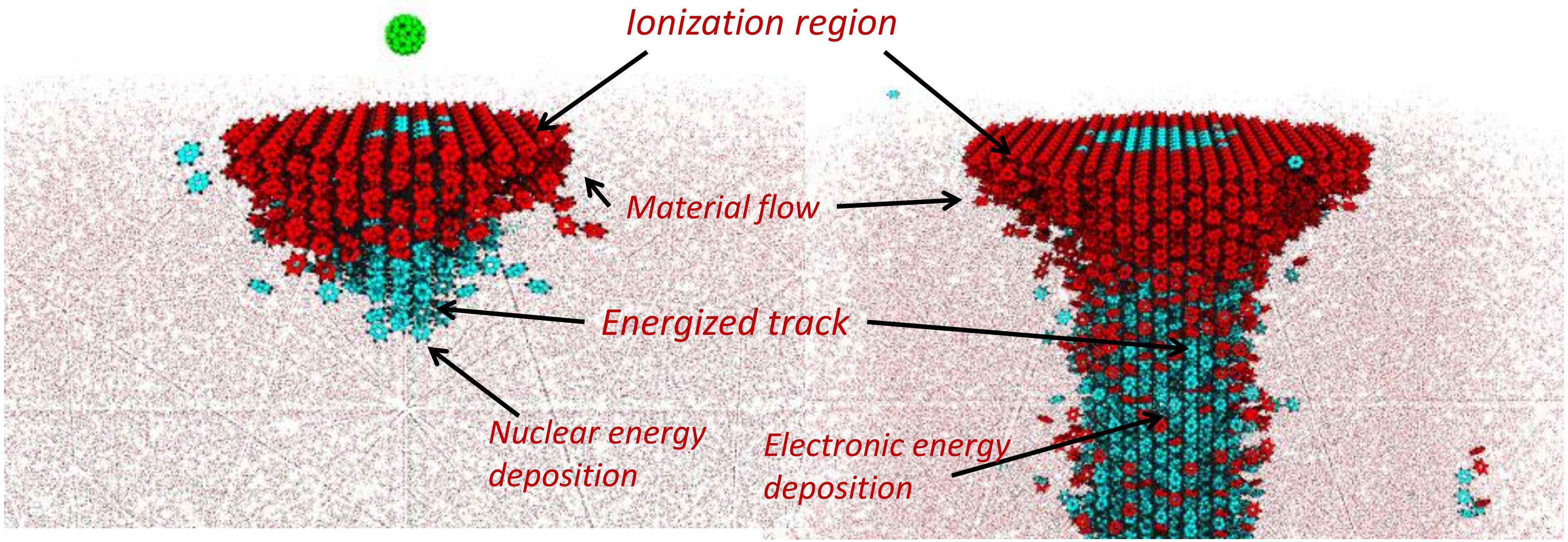

- MeV ToF-SIMS is a surface analysis technique used to look at the elemental and molecular composition on the surface of a sample
- For this analysis a high-energy beam of ions (MeV primary ion beam) is focussed on the surface and its energy is deposited in the uppermost layers causing atoms and molecules to be sputtered
- Some of these sputtered atoms become ionised
- The secondary ions are accelerated into a mass spectrometer and the time they take to travel through the detector is used to determine their charge-to-mass ratios
- This technique is used to measure a spectrum with a mass range made up of elements (and their isotopes) ranging from hydrogen to heavy molecules (e.g. proteins) consisting of thousands of atoms

# Comparing keV and MeV-SIMS

## MD Simulations - Organics

After 4ps plot **original** positions of benzene molecules **moved up** and **broken**

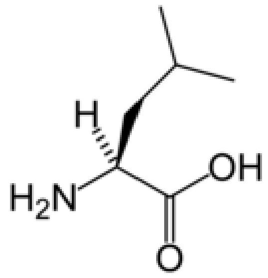
**10keV $C_{60}$ impact in frozen benzene** | **MeV simulation**




**keV Cluster SIMS**
*Fragmentation due to nuclear collisions*

**MeV SIMS**
*Fragmentation due to ionisation and vaporisation*

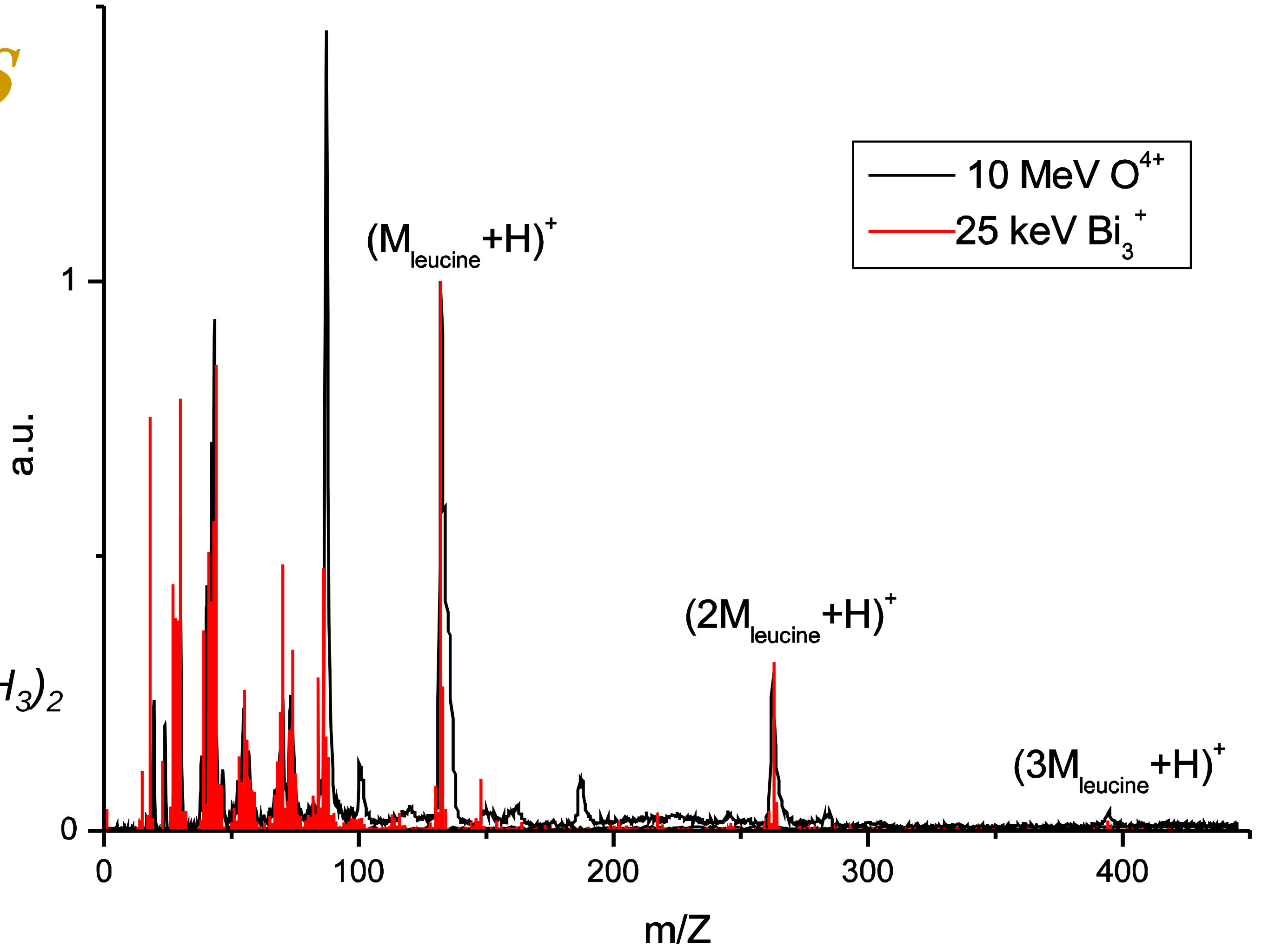
# *Comparing keV and MeV-SIMS*




*Leucine*

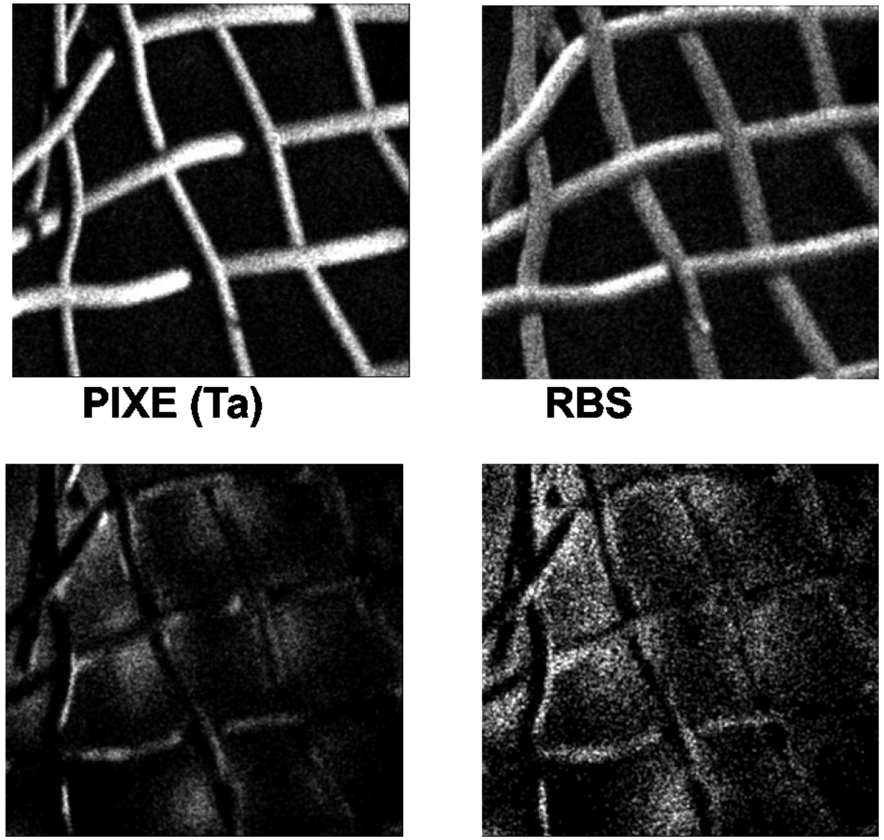
*$HO_2CCH(NH_2)CH_2CH(CH_3)_2$*

*131.17 g/mol*



# Combining SIMS, PIXE, & RBS

- Because of the high primary ion energies used in MeV ToF-SIMS, we also measure PIXE and RBS spectra simultaneously
- PIXE gives elemental information when the primary ion excites the atoms by releasing an inner-shell electron
- RBS measures the backscattered particle energy to give elemental depth profile information



PIXE (Ta) RBS

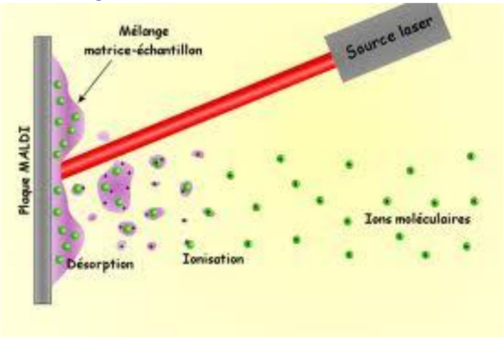
SIMS (m/z = 73) SIMS (m/z = 180)

# Why Use MeV Ions?

## Imaging Ambient Pressure Techniques

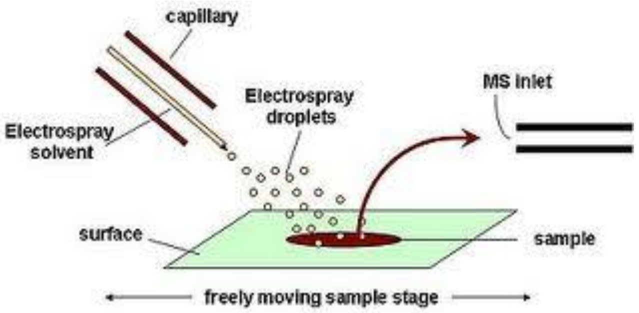
### MALDI – Matrix Assisted Laser Desorption Ionization

- 10$\mu$m spatial resolution determined by spatial resolution of the laser spot
- Marks the sample

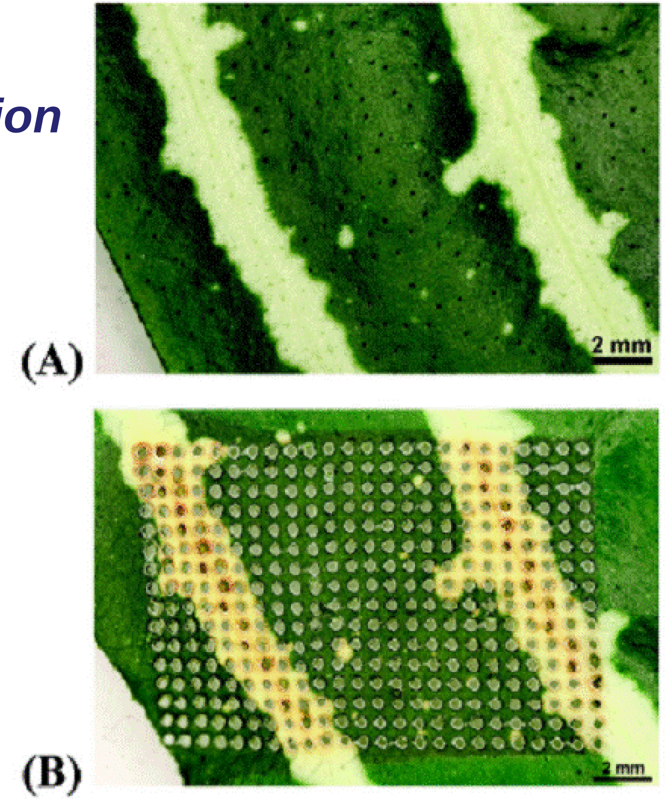



### DESI – Desorption Electro Spray Ionization

- 100$\mu$m spatial resolution determined by spatial resolution of the spray
- Marks the sample and sprays surroundings



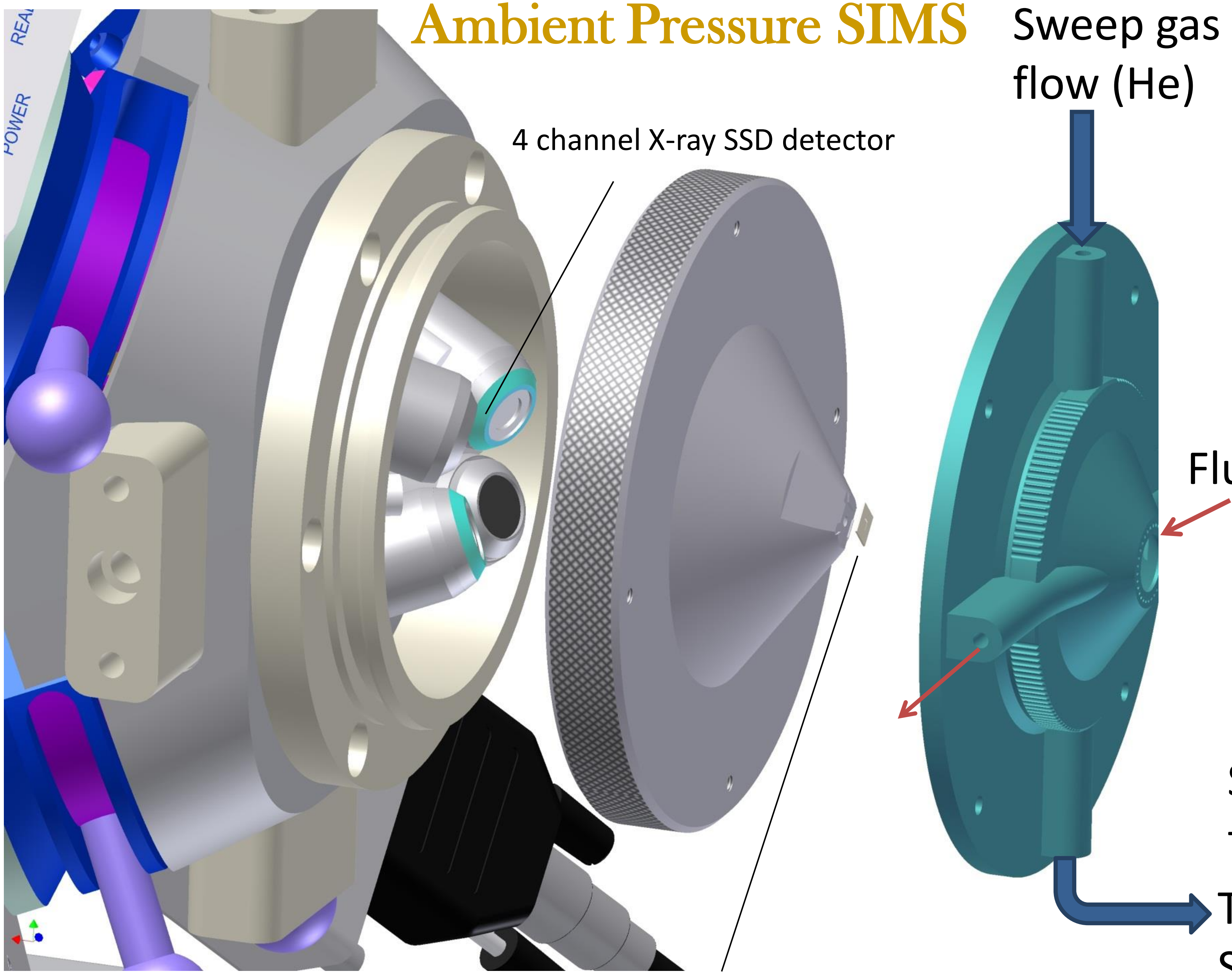

BEFORE




AFTER

*R.A.Ketola, T.Mauriala, European Journal of Pharmaceutical Sciences 46 (2012) 293-314*

# Ambient Pressure SIMS




**100nm thick Silicon Nitride membrane.**
Primary beam comes through;
X-Rays from target come back through to X-ray SSD detector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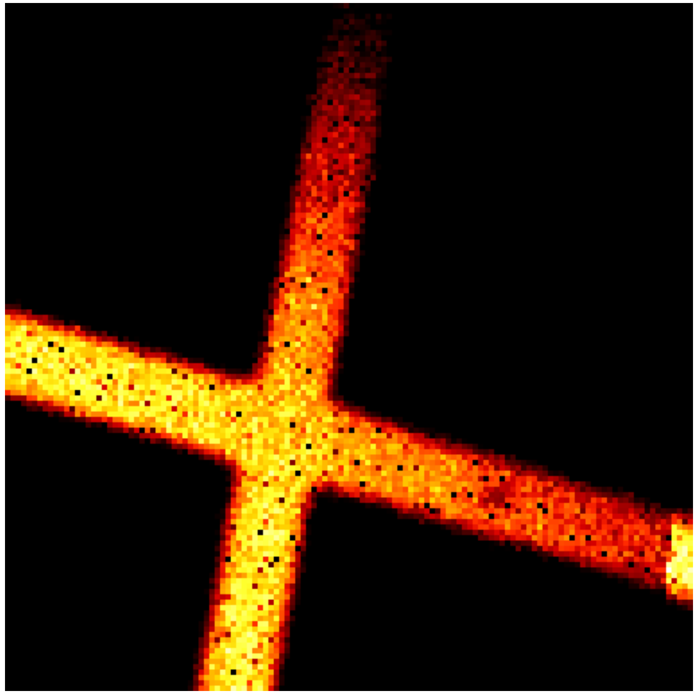
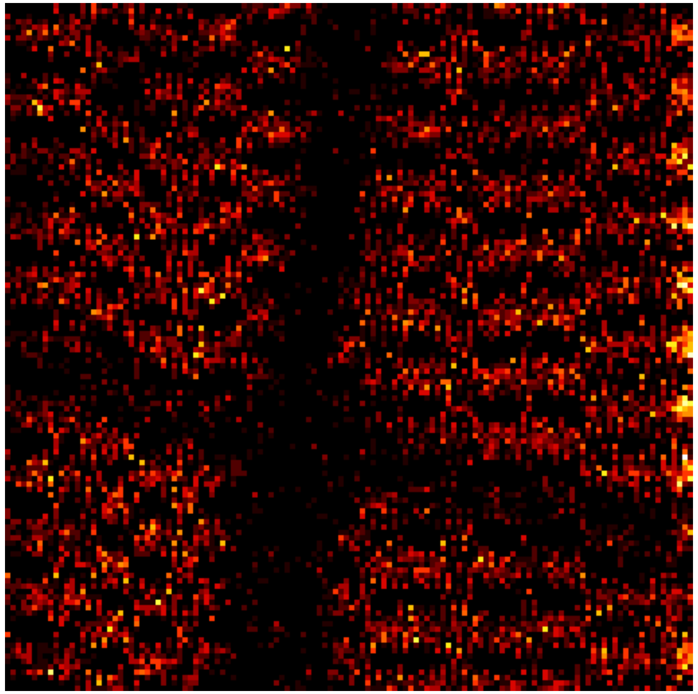
# *First Fully Ambient MeV-SIMS Image*

After demonstrating success in the vacuum system with MeV-SIMS SUR his attempting to employ MeV-SIMS in fully ambient conditions using an external beam.

Using an 8.8MeV $O^{3+}$ beam at ~4um resolution we have recorded the first fully ambient MeV-SIMS molecular image



a) Cu PIXE Map



b) PTFE molecular map

*Aliasing due to scanning of quadrapole mass spectrometer*

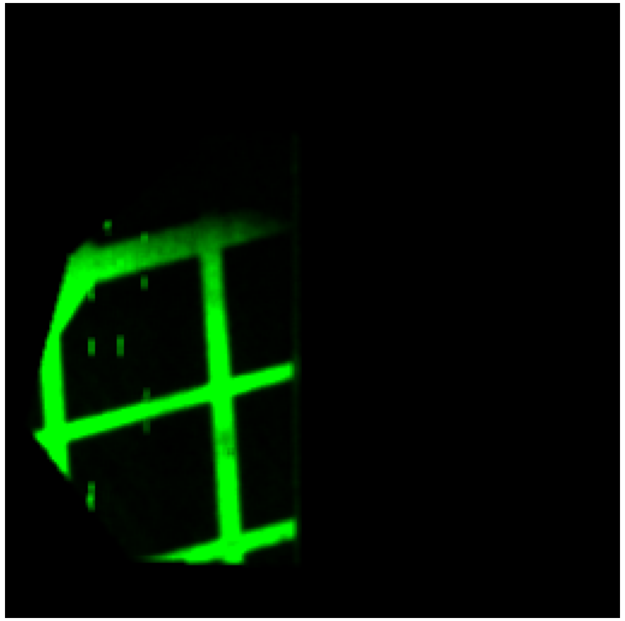
# Second Fully Ambient MeV-SIMS Image

After repairing accelerator and stopping QMS from scanning….

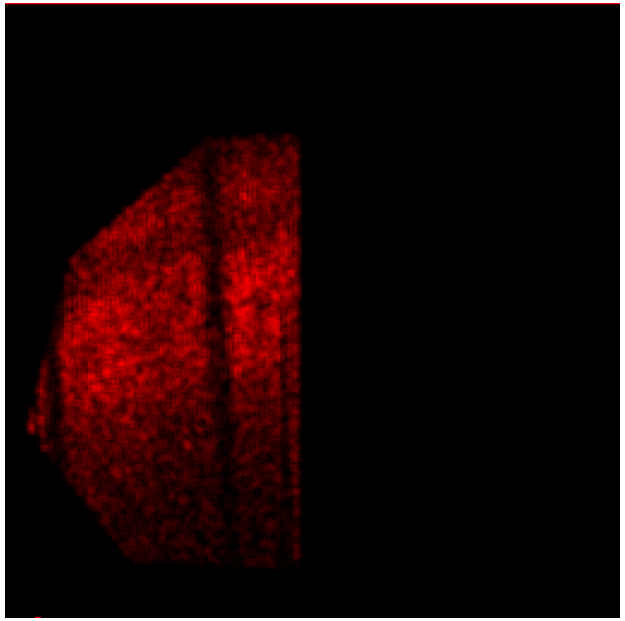
Using an 8.8MeV $O^{3+}$ beam at ~4um resolution.

No aliasing, but non uniform response due to alignment issues

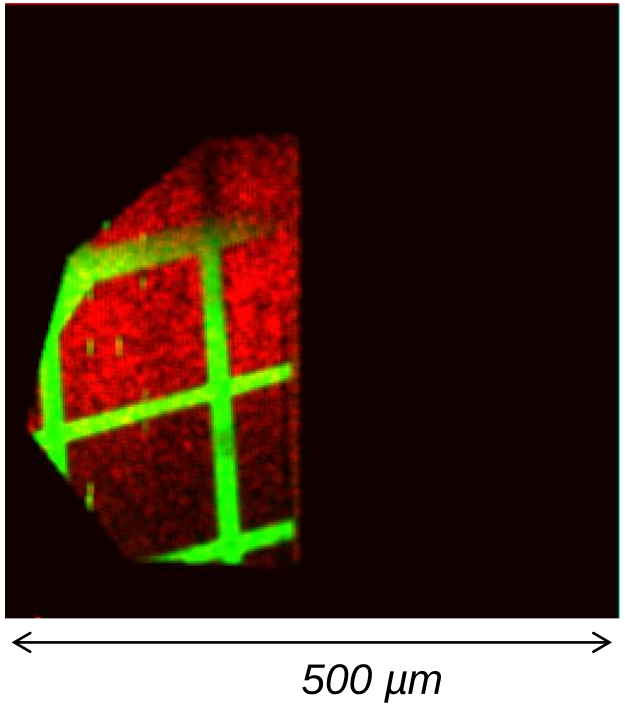
X-ray detector only sees bottom left and SIMS sees middle brighter



a) Cu PIXE Map



b) PTFE molecular map

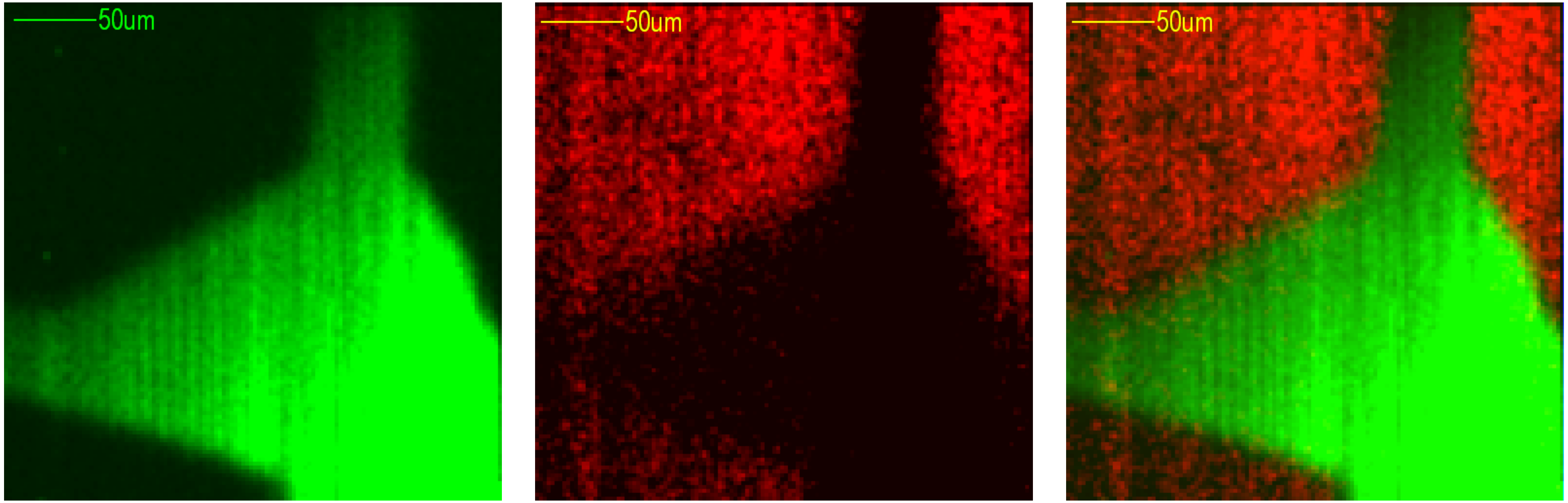


# Third Fully Ambient MeV-SIMS Image

After repairing accelerator and stopping QMS from scanning….

Using an 8.8MeV $O^{3+}$ beam at ~4um resolution.

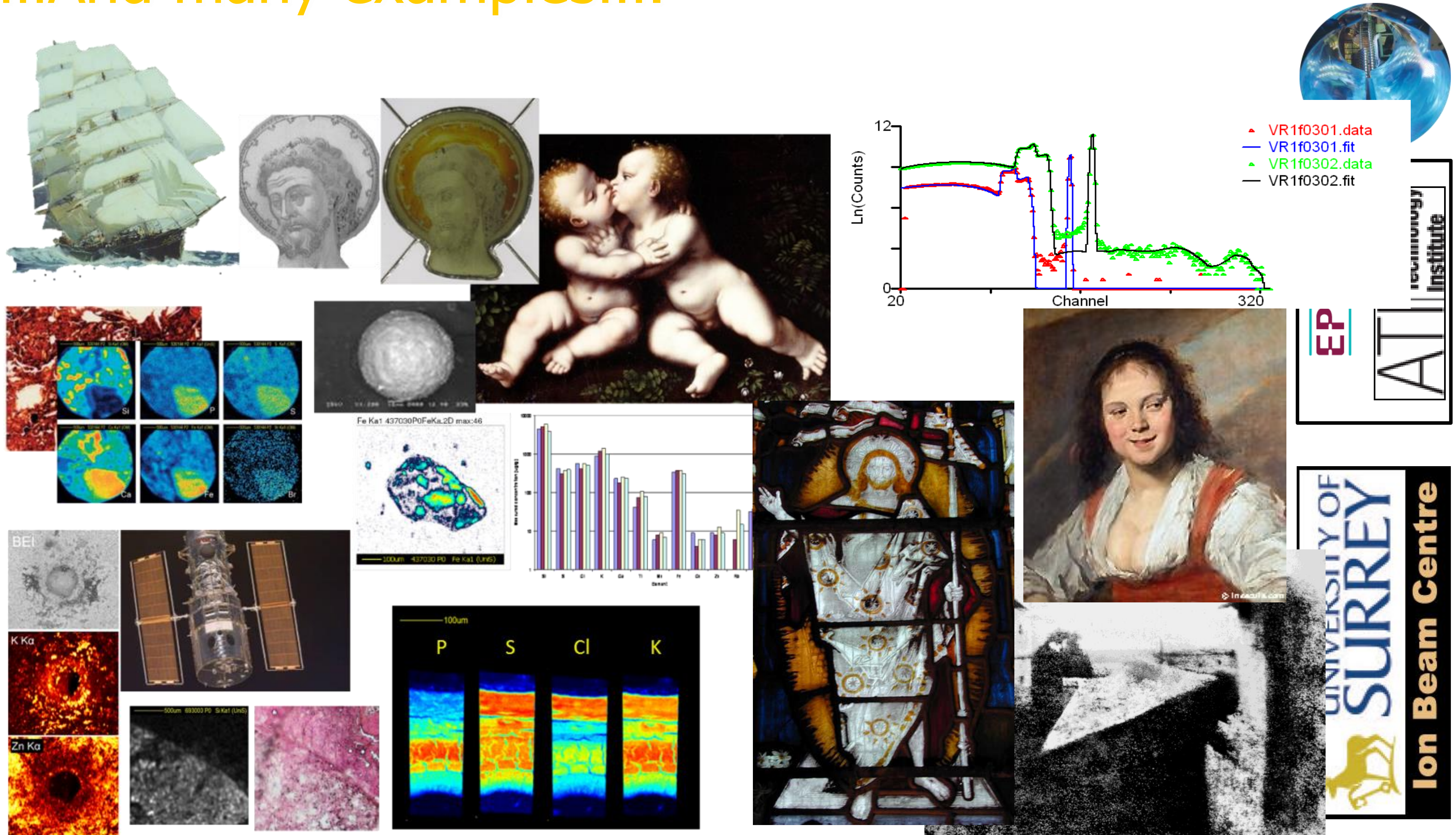
Zoom in to avoid visibility issues and things improve…




a) Cu PIXE Map

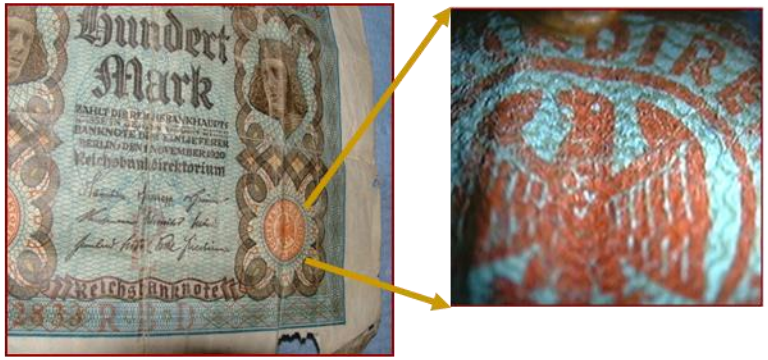
b) PTFE molecular map

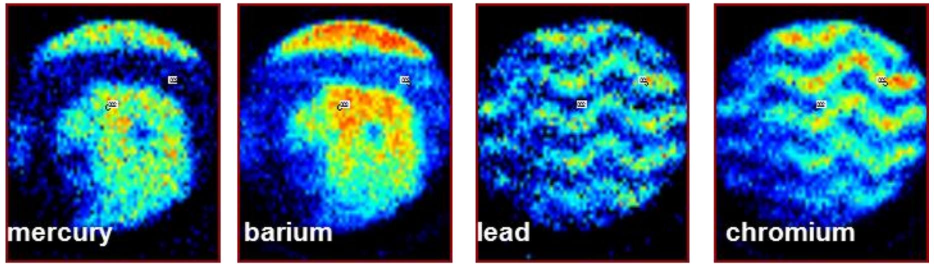
# …And many examples….



# Elemental mapping using ion beams

- The current Surrey microbeam can be focussed to 1-2um
- New nanobeam (currently under construction) will allow elemental mapping down to <200nm resolution




Red ink (head of eagle)

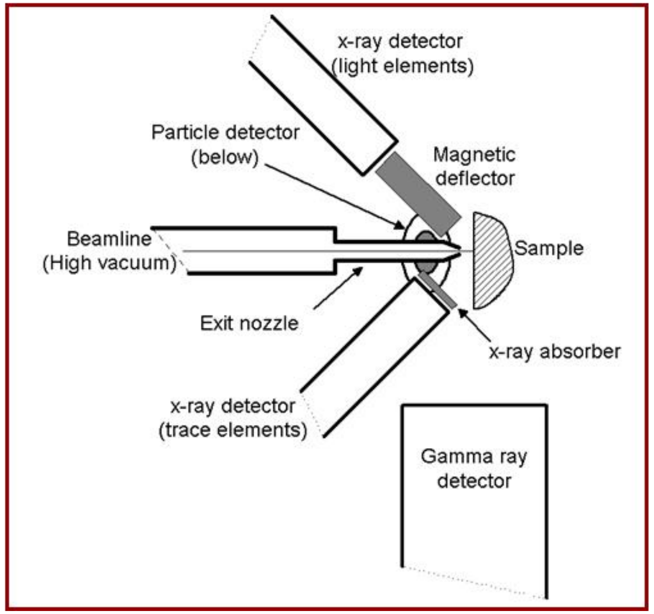
Green ink (wavy lines)

Analysis in air of a 1920's 100 Reichsmark note,

Surrey Ion Beam Centre

# Why Use Ion Beams?

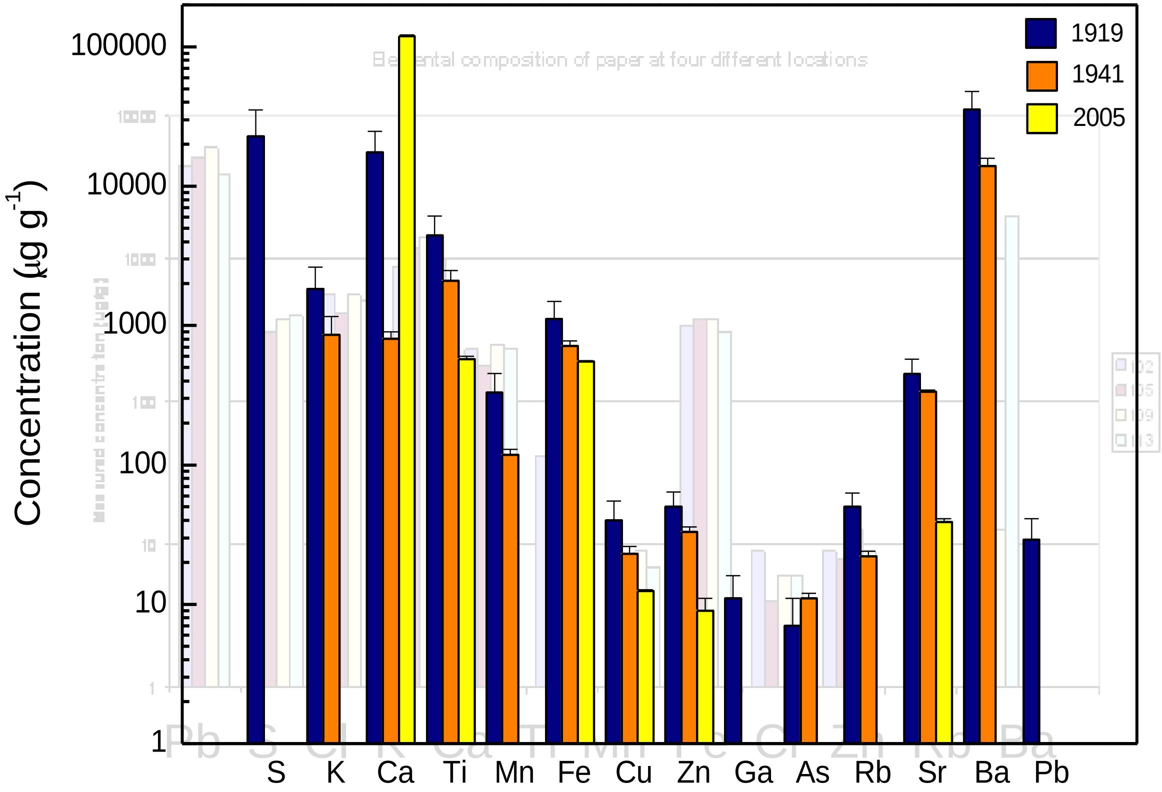
- Analysis does not destroy the samples
- Very high sensitivity to small quantities of material
- Most samples do not need any preparation treatments prior to analysis
- Analysis can be performed in air with an external beam




# Ion beams in police casework

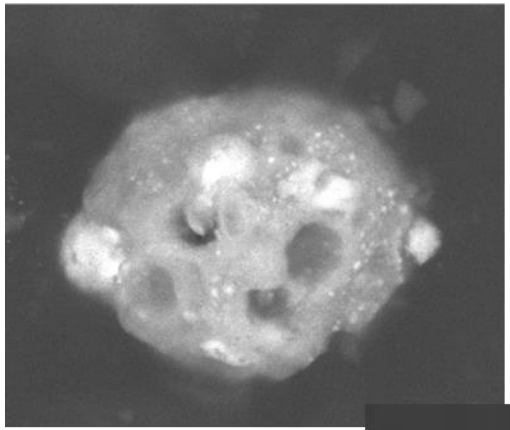
- June 2008, Surrey IBC
- Document from a murder investigation
- Ion beams were used to establish the age of the document
- i.e. was it current (>2006) or old (c1960?)

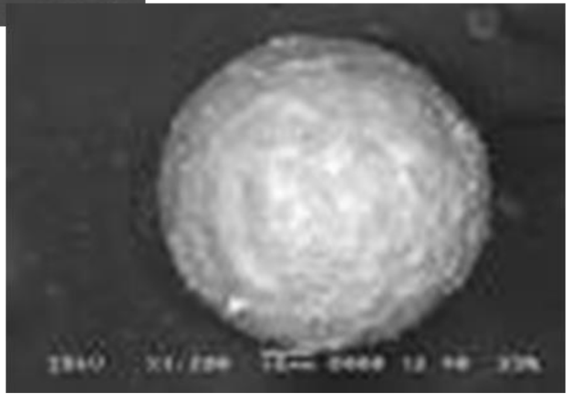
Manso et al (Nucl. Instr. Meth. Res. B, 580 (2007), 732-734)




- The paper contained many impurities
- Note in particular S, K, Ba, Pb, Rb
- Water is now much cleaner and modern paper no longer contains such heavy elements

# Gunshot Residue

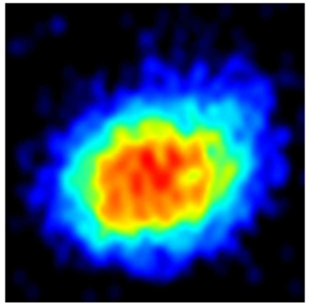


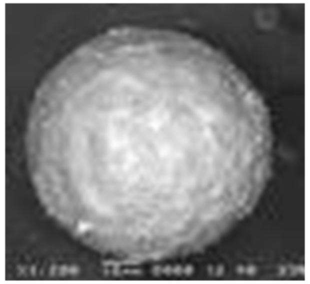


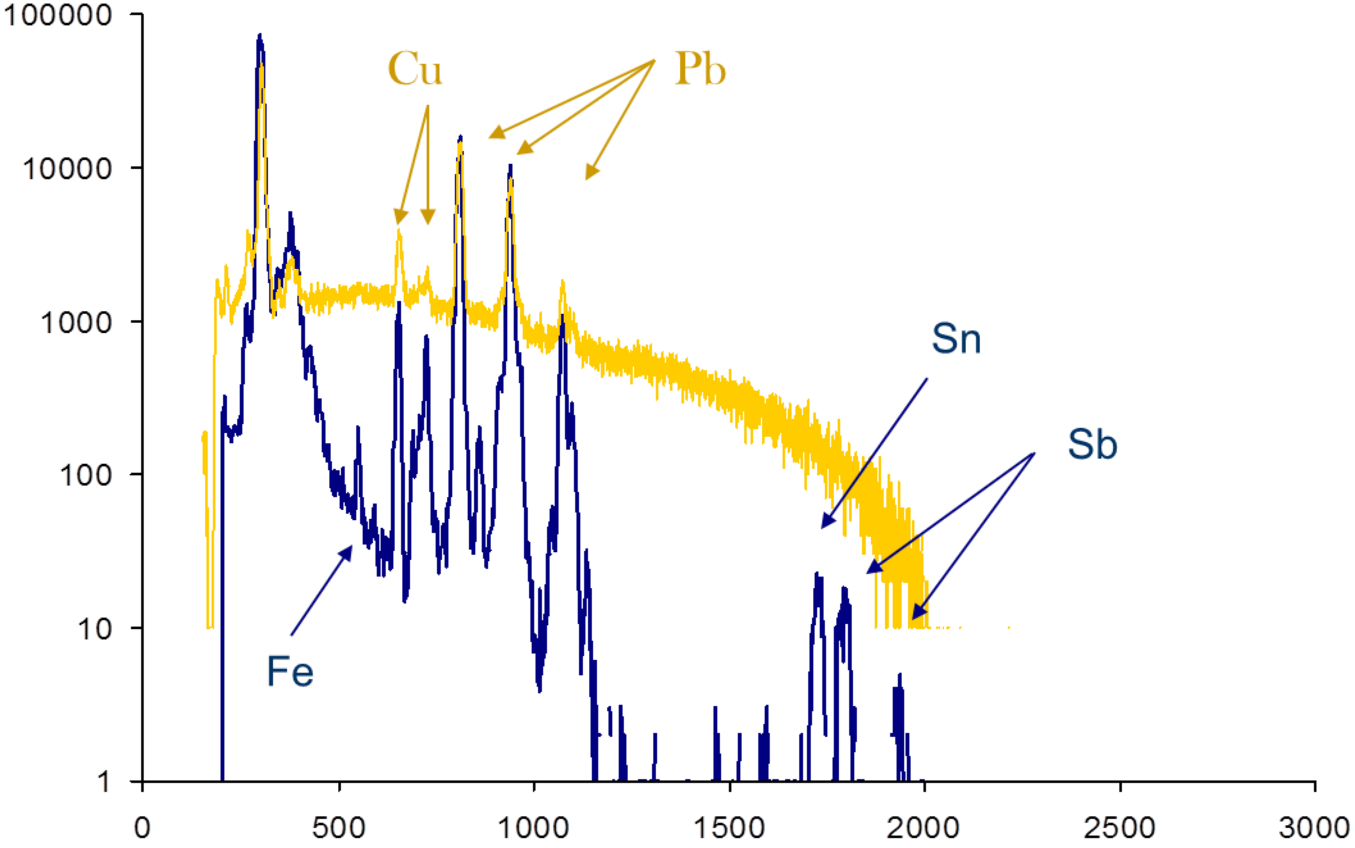
Gunshot residue (GSR) particles :

primer, bullet, bullet jacket, cartridge casing, gun barrel

# Ion Beams vs Conventional Methods





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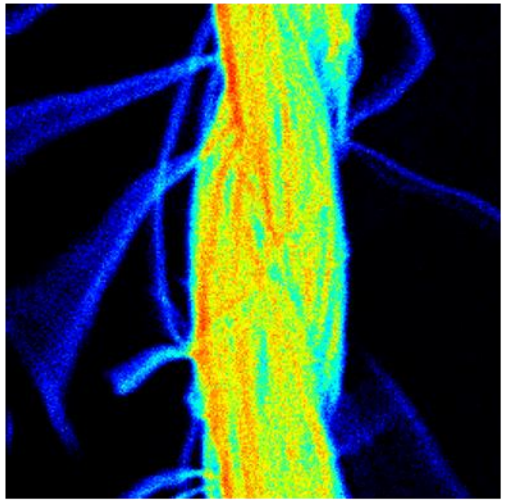
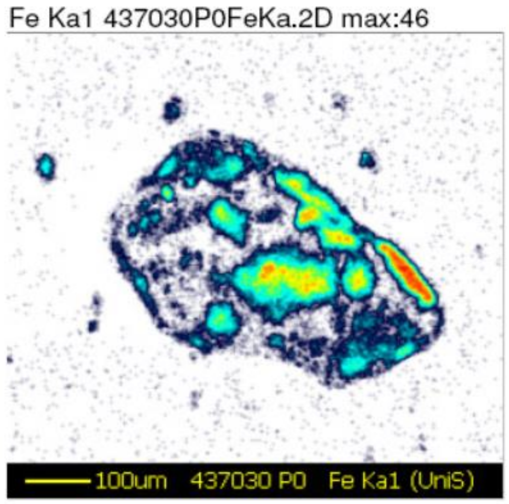
## Current work with the Italian Carabinieri

- Can we be certain we have gunshot residue and not some environmental particle?
- Can we reliably distinguish different types of gunshot residue?
- Can we tell if gunshot residue is from the arresting officer or from the suspect?
- What happens if the suspect changes to a new type of cartridge? Does this affect our analysis?
- Lead free ammunition – GSR must contain
  Pb, Ba & Sb (and shape – brake linings) by definition??

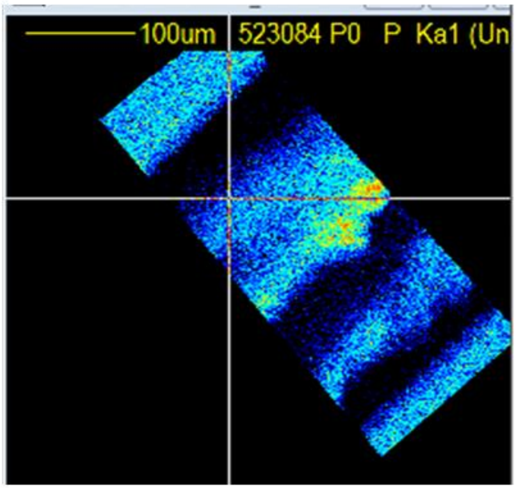
# Other types of trace evidence being studied at Surrey…



Fibres



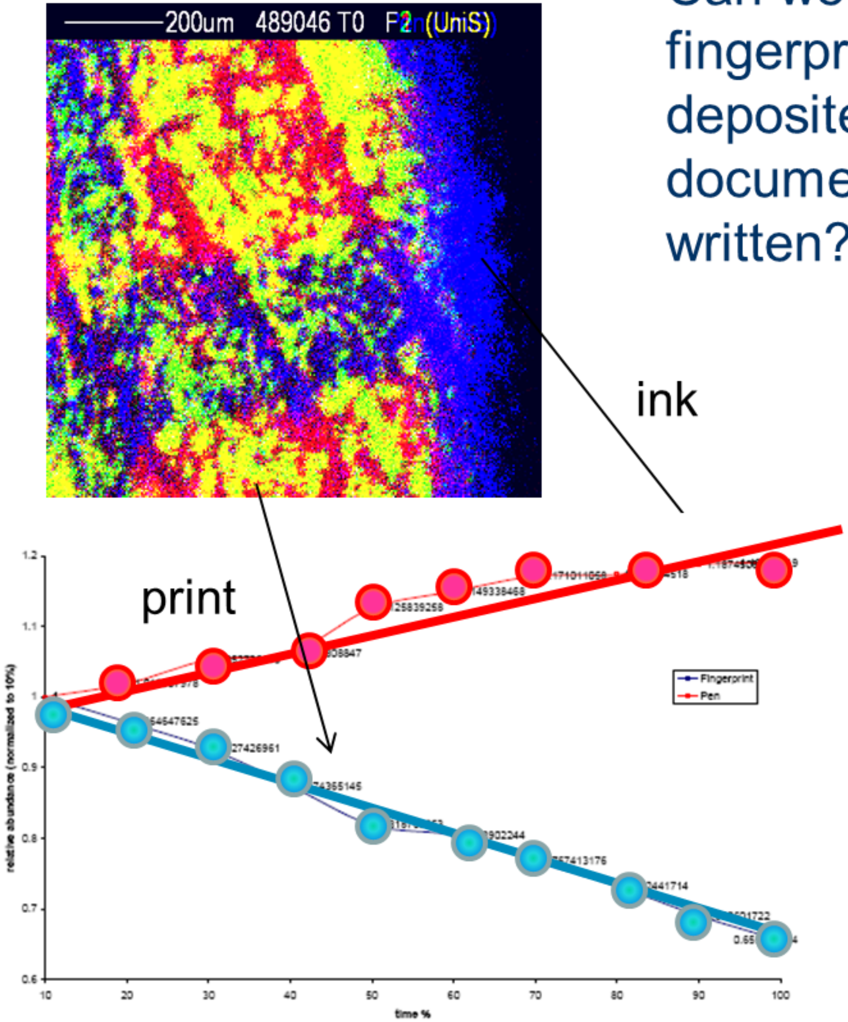

Soil particles




Car paint layers

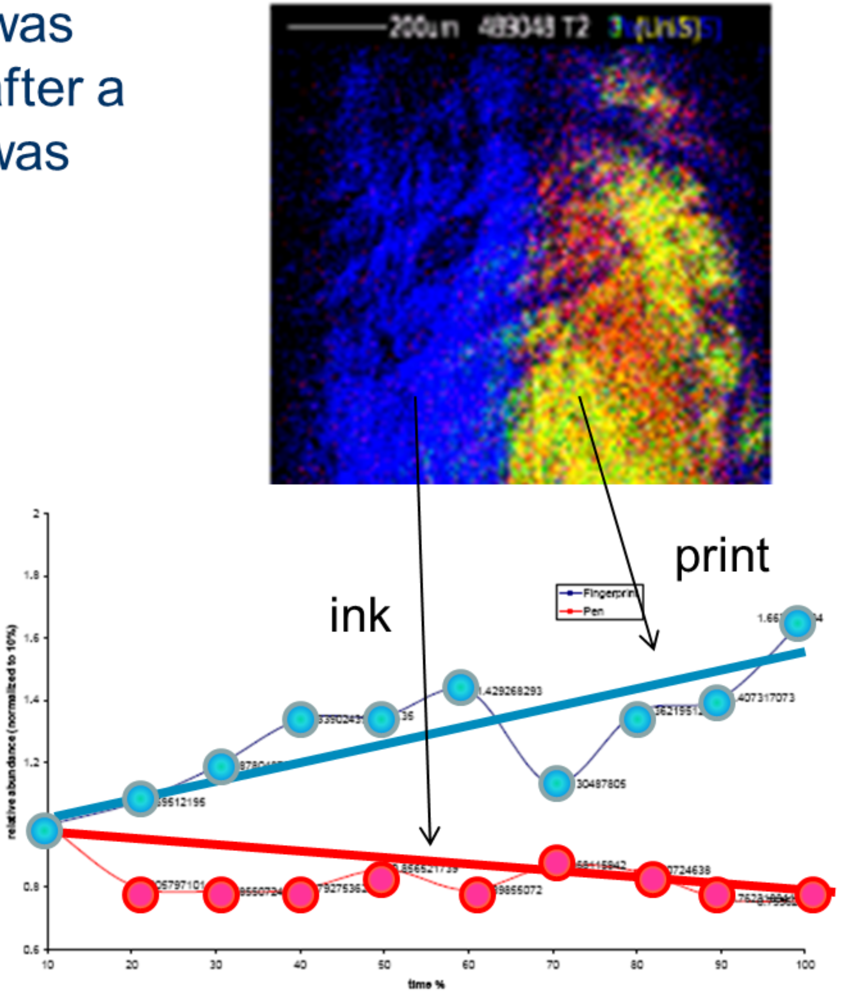
# .... & fingerprints

Print over ink




Can we prove a fingerprint was deposited after a document was written?

Ink over print




Count rate with time changes suggest print is over pen.

# Art Forensics

Ion beam analysis used as part of TV programme

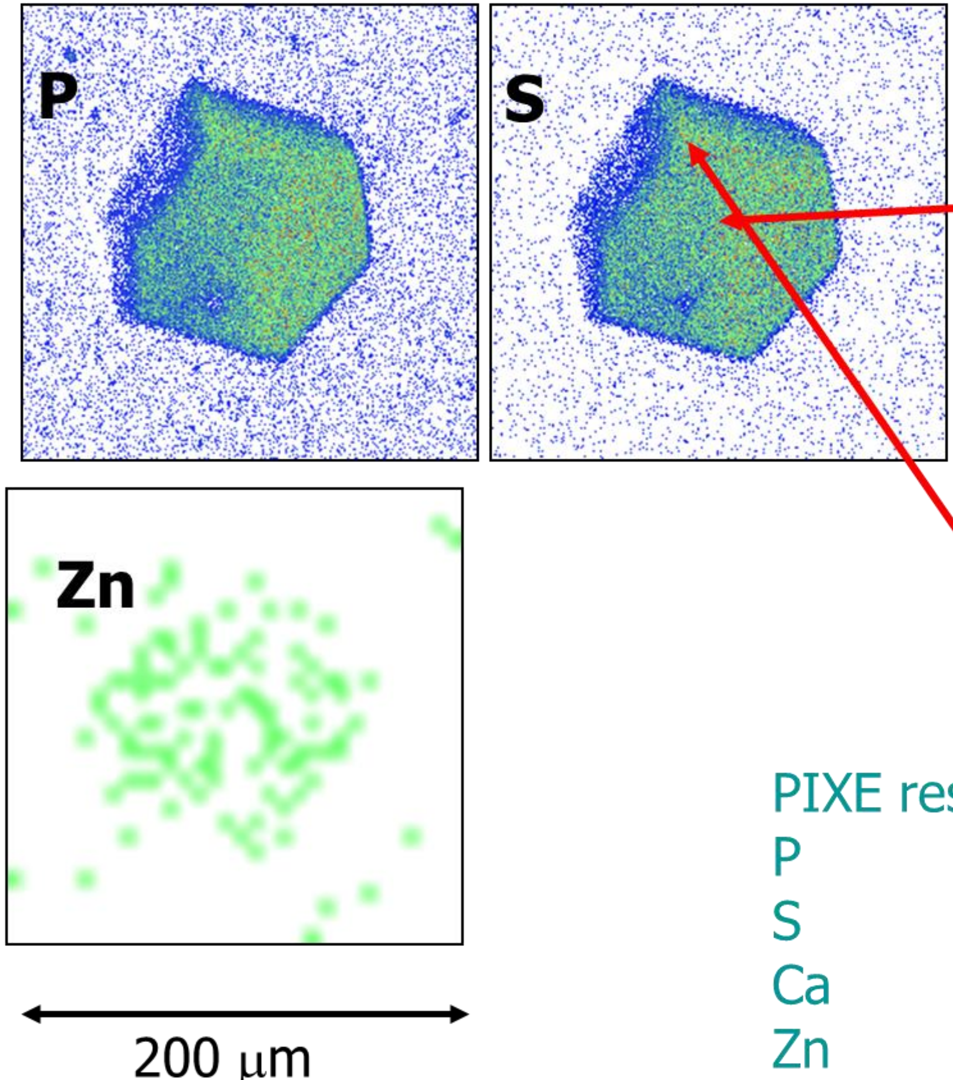
- A 'Leonardesque' painting
- Was it painted by Leonardo Da Vinci?

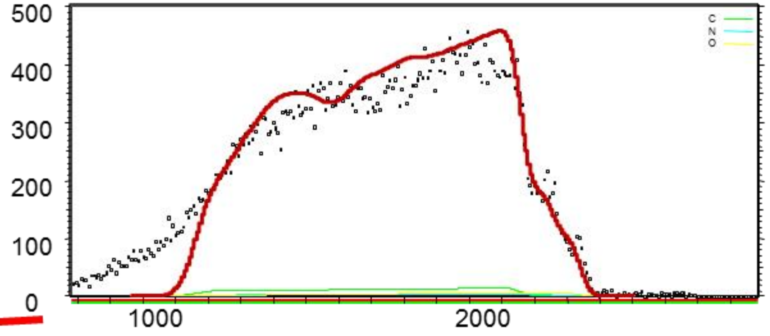
## Trace element analysis

- White pigment corresponds to 16th Century Italy
- Green/brown pigment corresponds to 16th Century organo-Cu compounds
- White pigment on the back (catalogue number) was Northern European

# Analysis of Proteins

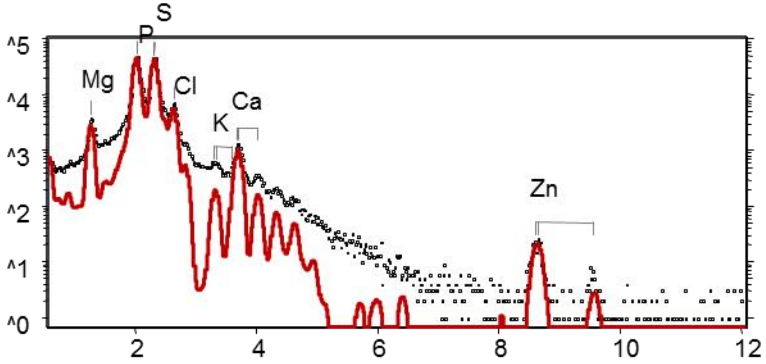
Blue Tongue Virus crystal




RBS fit:

$C_4N_{1.25}O_{1.43}$ 20.7μm




PIXE results:

| | |
|---|---|
| P | 1.49% |
| S | 1.17% |
| Ca | 350ppm |
| Zn | 90ppm |

| | |
|---|---|
| Ca:S | 0.02:1 atoms |
| Zn:S | 0.004:1 atoms |
| P:S | 1:1 atoms |

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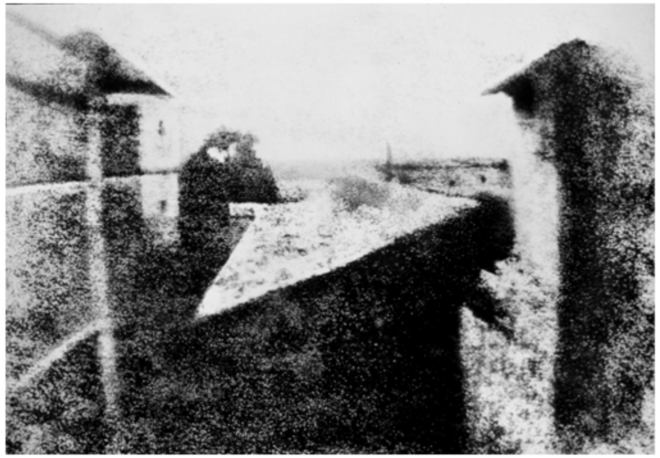
# Simultaneous PIXE and RBS

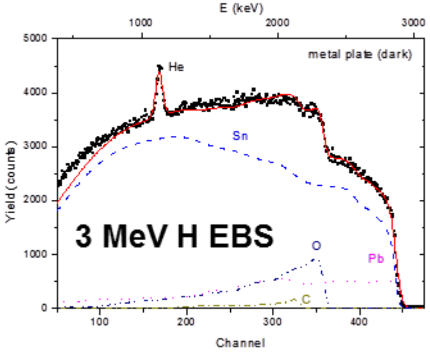
C. Pascual-Izarra (Madrid), N. P. Barradas, M. A. Reis (Lisbon),
C. Jeynes (Surrey), M. Menu, B. Lavdrine, J. J. Ezrati, S. Röhrs (Louvre)

Nucl. Instrum. Methods B261, 426-429 (2007)

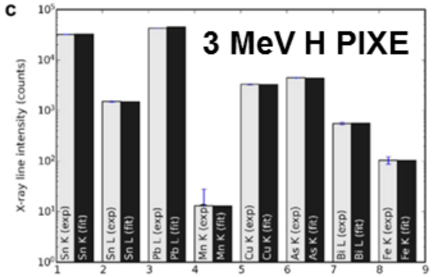


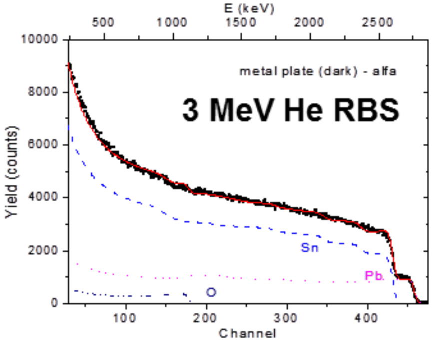
Niepce's first Heliography:
Paysage à Saint-Loup de Varennes (1827)

**Corrosion products demonstrated by PIXE/RBS/EBS to be tin oxide in a tin/lead matrix**

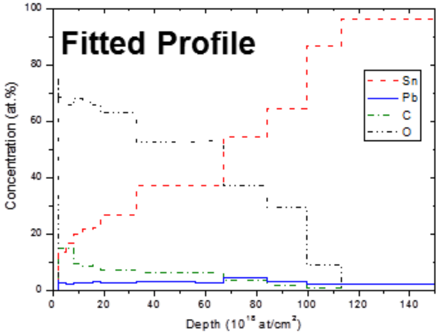



Fitted RBS spectrum for 3 MeV $H^+$ beam on the dark spot (corroded area). Calculated partial spectra for each element are also shown




Fitted RBS spectrum for 3 MeV $^4He^+$ beam on the dark spot (corroded area). Calculated partial spectra for each element are also shown

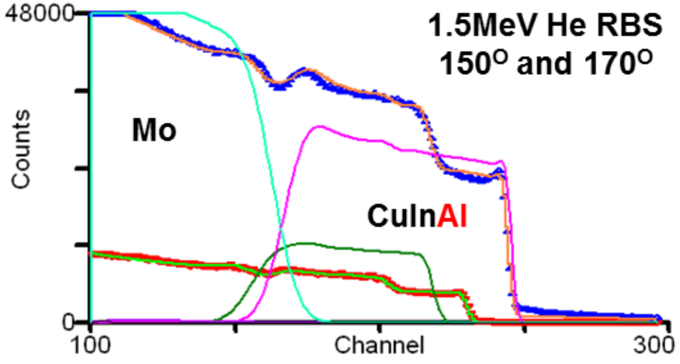


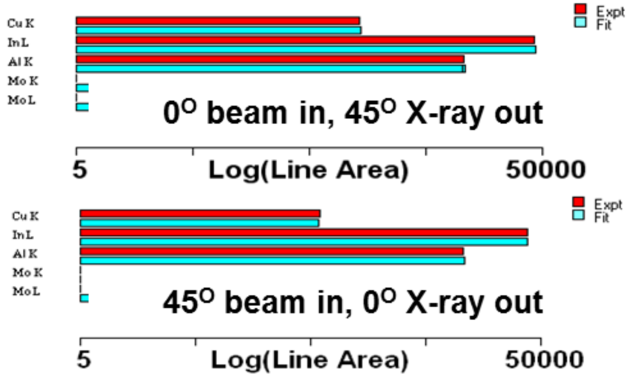

Concentration profiles for the dark spot (corroded area), as obtained from a simultaneous fit to 3 MeV proton PIXE and RBS, and 3 MeV alpha RBS.

# Characterisation of thin film chalcogenide PV materials using MeV ion beam analysis

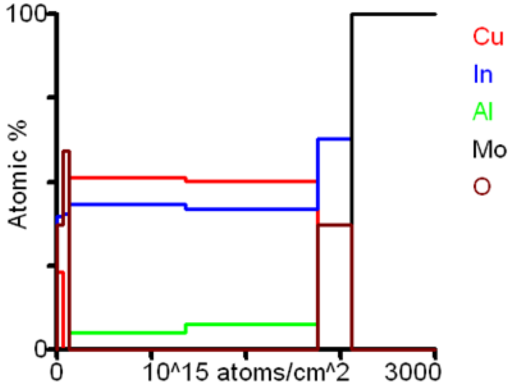
**Chris Jeynes, G.Zoppi, I.Forbes, M.J.Bailey, N.Peng**

***IEEE Proceedings of Supergen Conference***, **Nanjing, April 2009, DOI:10.1109/SUPERGEN.2009.5348162**




**He-PIXE simulated by equivalent-velocity H-PIXE**




- CIAS semiconductor on Mo electrode
- Precursor material (not selenided yet)
- Al invisible in backscattering
- Strong layering: PIXE uninterpretable without profile independently available
- Differential PIXE to profile Al
- Essential to fit roughness (non-uniform thickness) to reproduce RBS spectra
- Good fit essential for reliable profile

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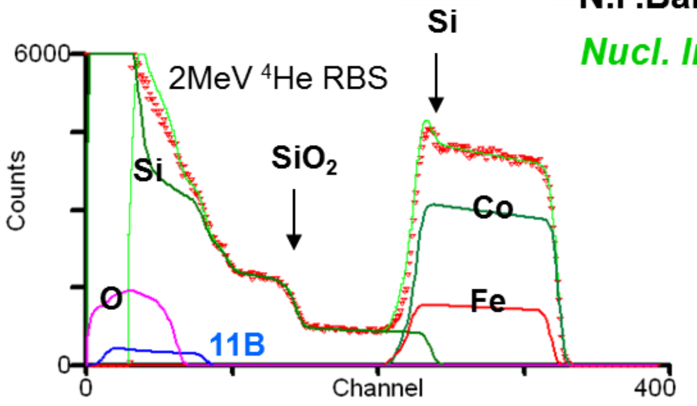
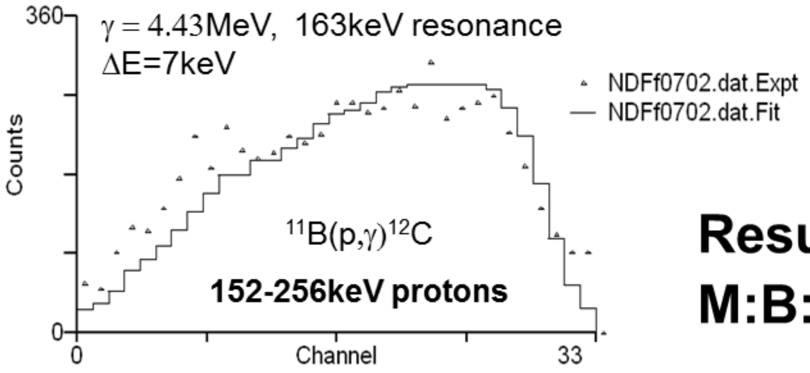
# NRP (PIGE) of metal boro-silicide sample

N.P.Barradas, R.Mateus, M.A.Reis, I.Vickridge *et al*

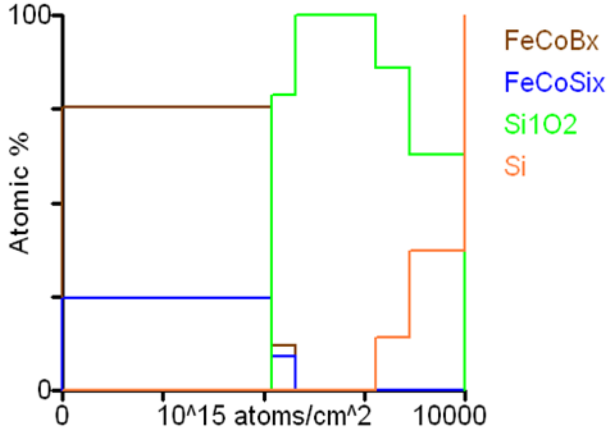
*Nucl. Instrum. Methods* B268, 2010, 1829-1832 (Lisbon & Paris)




- **Sample structure from RBS (boron content poorly determined)**
- **Co/Fe=3.8 from 2.2MeV PIXE**
- ***Direct PIGE signal for B with a proton beam scanned 0.1-0.3 MeV***




**Result is:**
**M:B:Si = 26:58:16**




***DataFurnace integrates RBS/PIXE/PIGE for self-consistent analysis***

# PIGE

# Elastic Recoil Detection

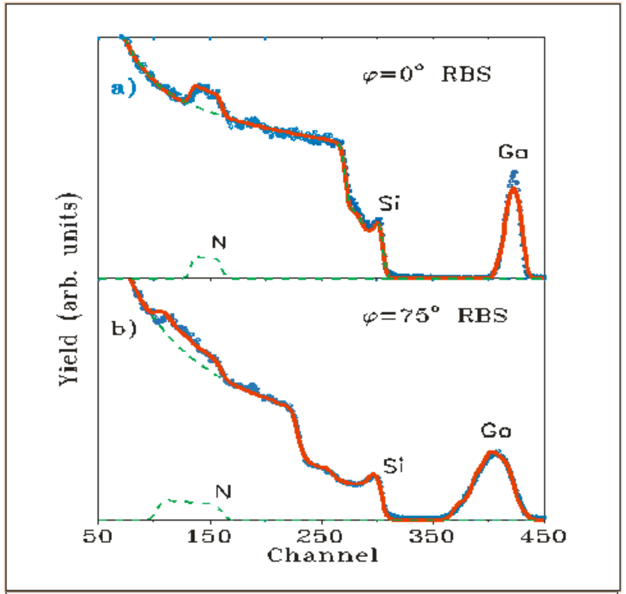
1.5MeV $^4$He RBS

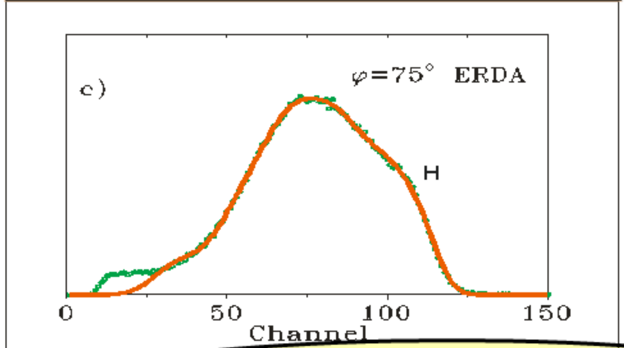
Normal incidence

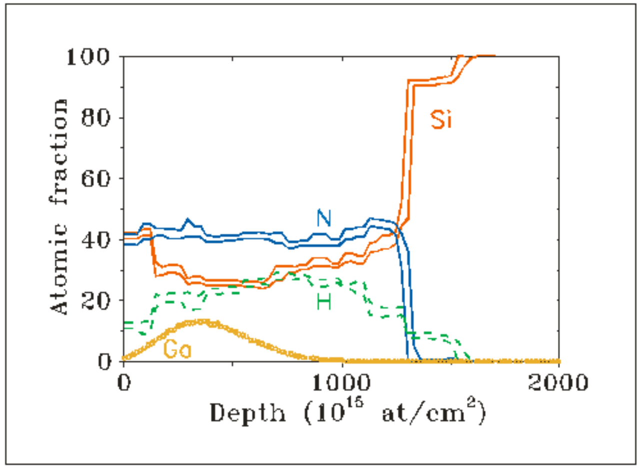
Glancing incidence

Simultaneous with:

ERD




$SiN_x$:H on Si

Ga implant to form a-$GaN_x$?

**Barradas *et al*, NIM B148, 1999, 463**

Depth profile with uncertainties

Using DataFurnace software

**Jeynes *et al* J.Phys.D <u>36</u>, 2003, R97**

ERD

**Bayesian Inference for uncertainties**
**Multiple spectra**

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# Summary - TOTAL IBA

## *Simultaneous SIMS, PIXE and BS*

***PIXE strength***

- High sensitivity
- Excellent specificity

***BS strength***

- Traceable accuracy
- Excellent depth resolution

***SIMS strength***

- Surface Sensitive
- Molecular Concentration

***PIXE weakness***

- Poor traceability
- Poor depth resolution
- No molecular information

***BS weakness***

- Low sensitivity
- Poor mass resolution

***SIMS weakness***

- Matrix effects
- Poor traceability

*NB: PIXE information depth is significantly larger than for BS & SIMS*

*NBB: XRF information depth is significantly larger than for PIXE*

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