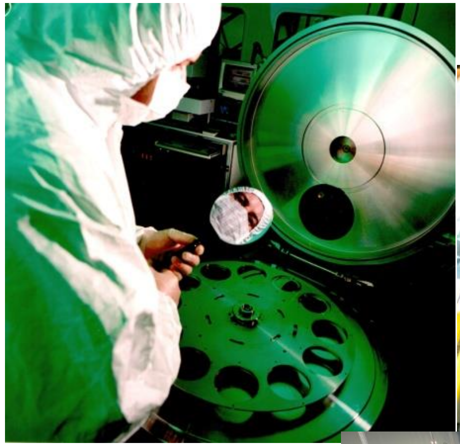
The UK National Ion Beam Centre

EPSRC

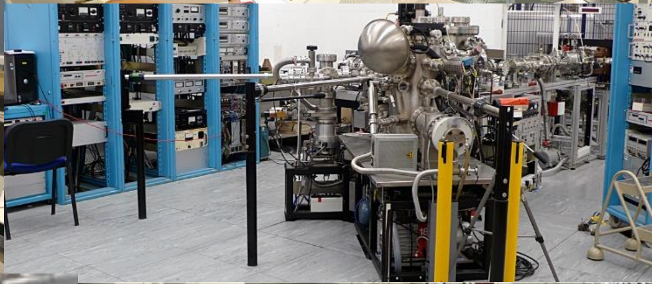
University of Surrey Ion Beam Centre

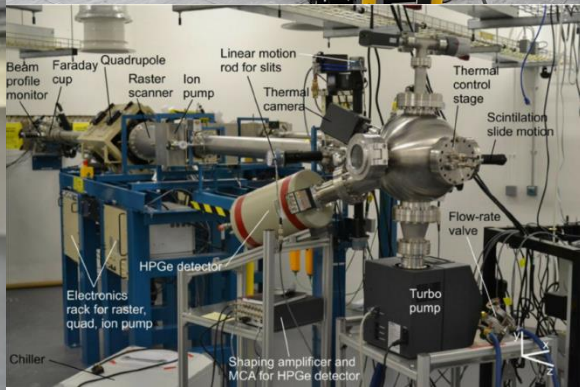
University of Huddersfield
Inspiring tomorrow's professionals

MANCHESTER 1824
The University of Manchester



Roger Webb
University of Surrey
Ion Beam Centre

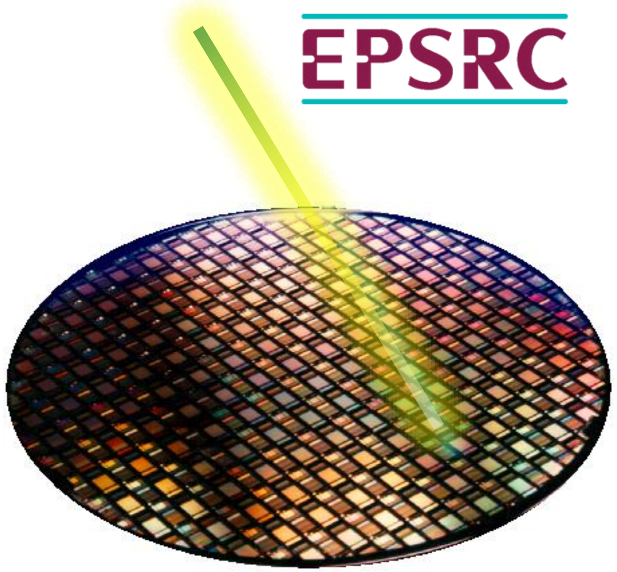




www.uknibc.co.uk

Ion Implantation

EPSRC



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.

Ion Beam Analysis

EPSRC

What happens when the ion beam hits the target?

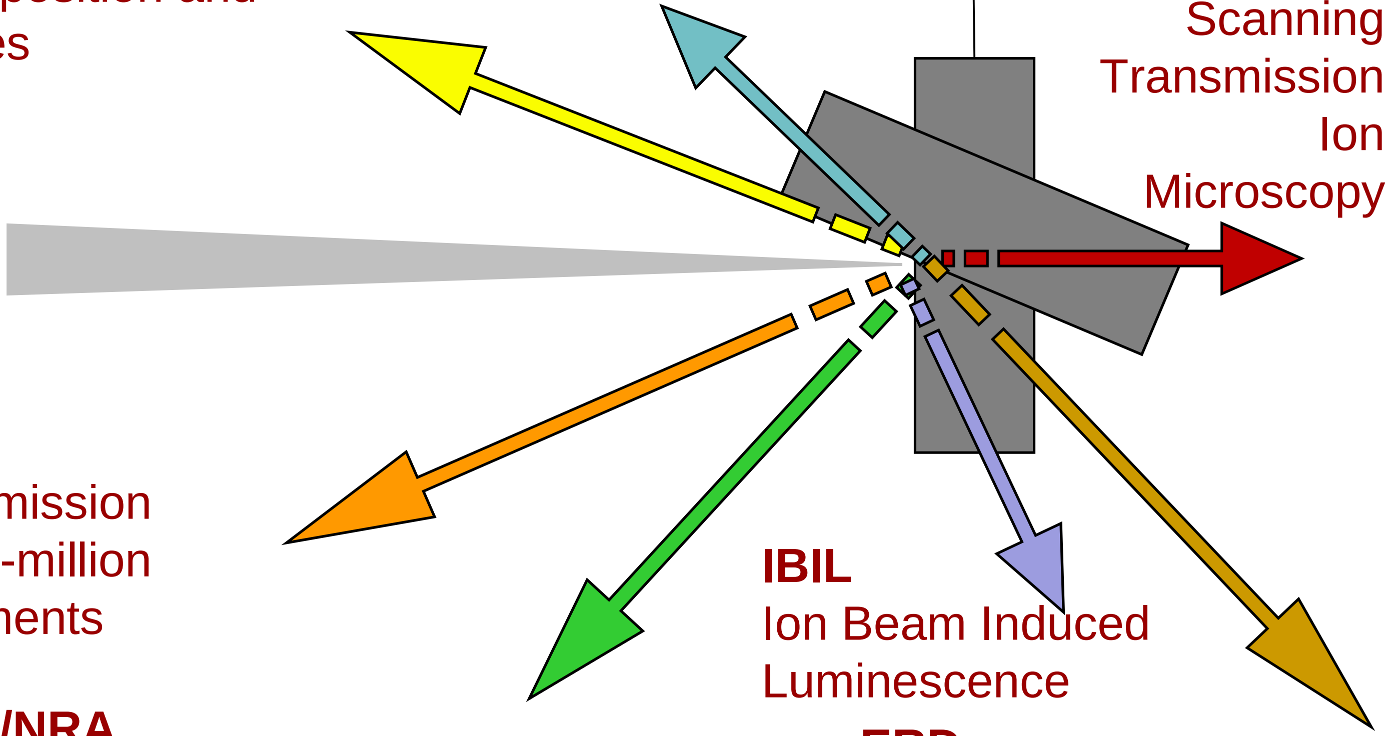
RBS
Energy of scattered protons or He give light element composition and elemental depth profiles

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)

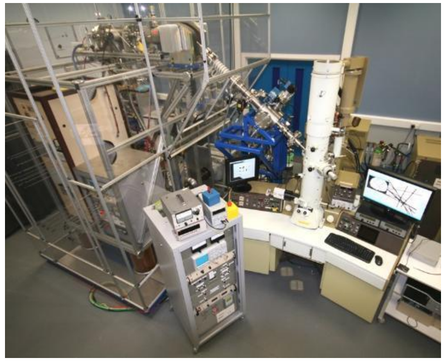
The UK National Ion Beam Centre

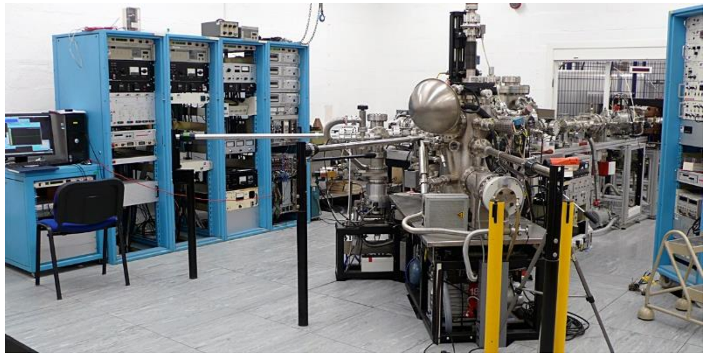
EPSRC

UNIVERSITY OF SURREY
Ion Beam Centre

University of HUDDERSFIELD
Inspiring tomorrow's professionals

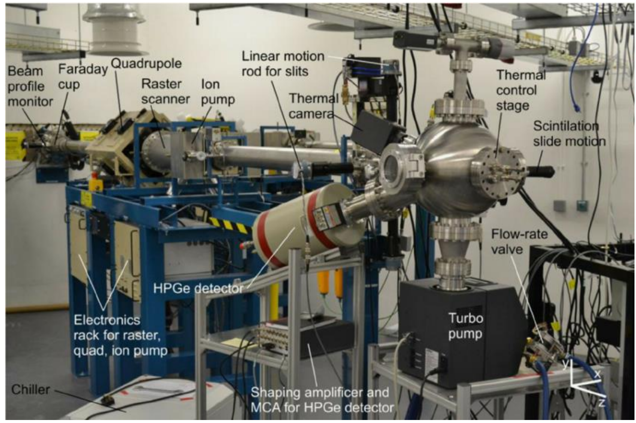
Bringing together 3 ion beam facilities in the UK





MANCHESTER 1824
The University of Manchester

An EPSRC Mid Range Facility



www.uknibc.co.uk

Huddersfield Miami Facility

EPSRC

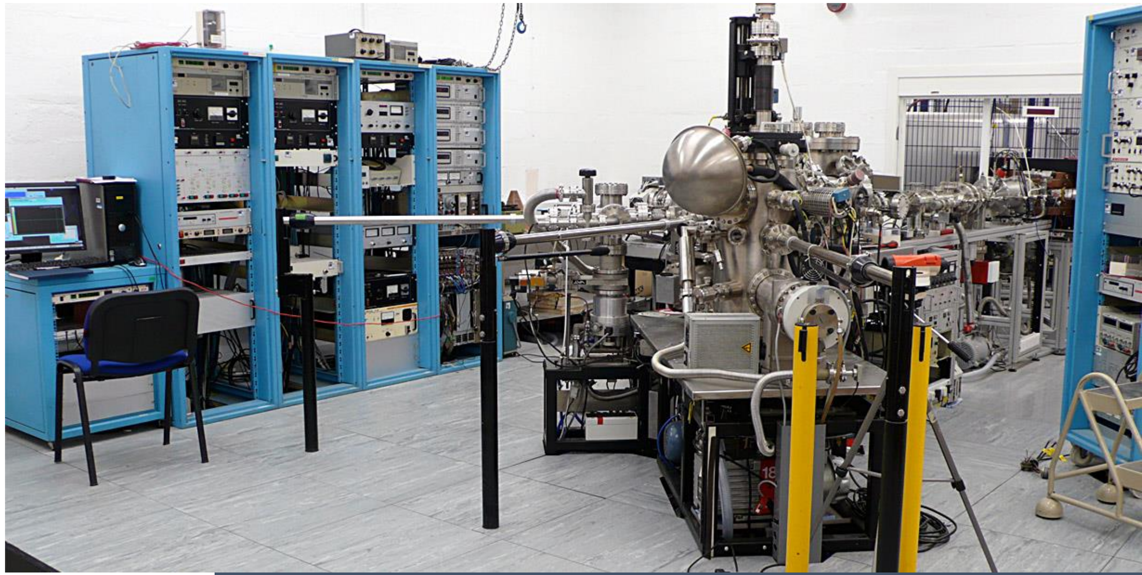
- **Implanter with In situ TEM**
  - **Facilities**
    - JOEL 2000FX TEM
    - 2-100keV Implanter
    - Temperature stage -173-1000^{o}C
  - **Applications**
    - Nuclear Radiation damage
    - Ion Implantation
  - **Staff**
    - Steve Donnelly
    - Johnathan Hinks
    - Graeme Greaves

University of
HUDDERSFIELD
Inspiring tomorrow's professionals

www.uknibc.co.uk

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



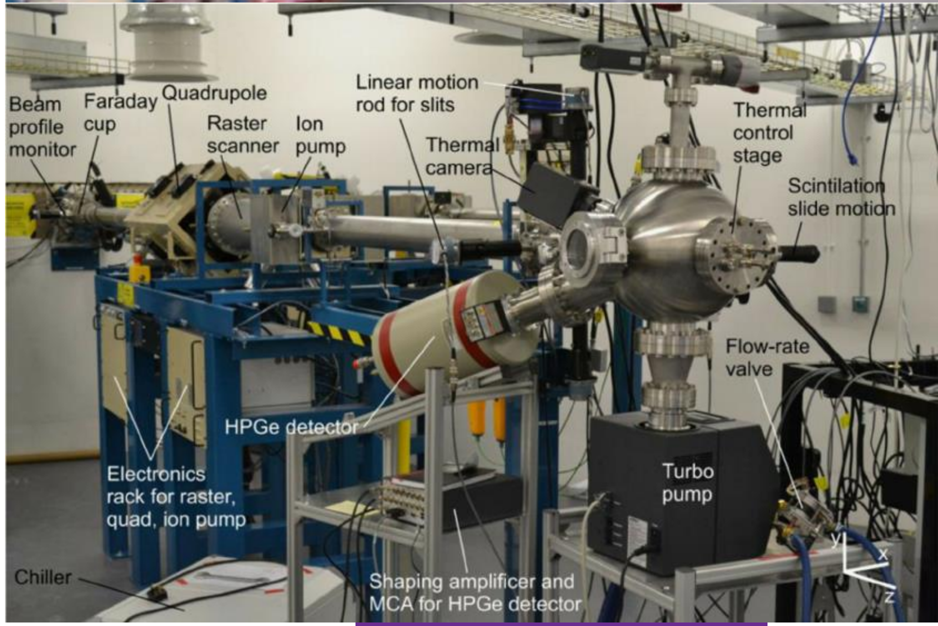
EPSRC

University of HUDDERSFIELD
Inspiring tomorrow's professionals

Manchester Dalton Institute

EPSRC

- **Cumbrian 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

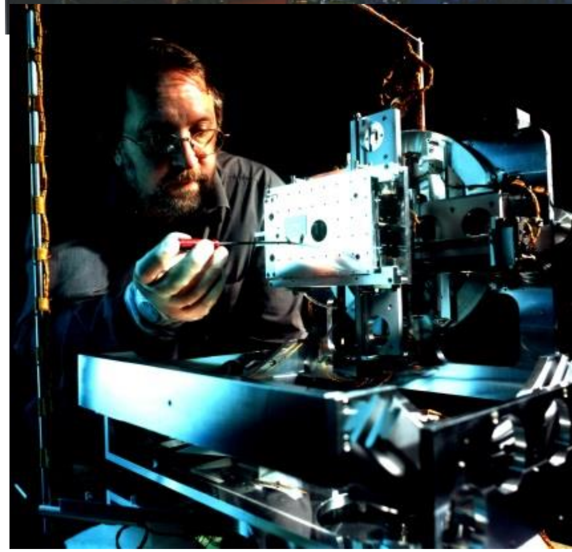


MANCHESTER 1824
The University of Manchester

www.uknibc.co.uk

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



EPSRC

UNIVERSITY OF SURREY
Ion Beam Centre

www.uknibc.co.uk

Surrey Ion Beam Centre

EPSRC

- **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

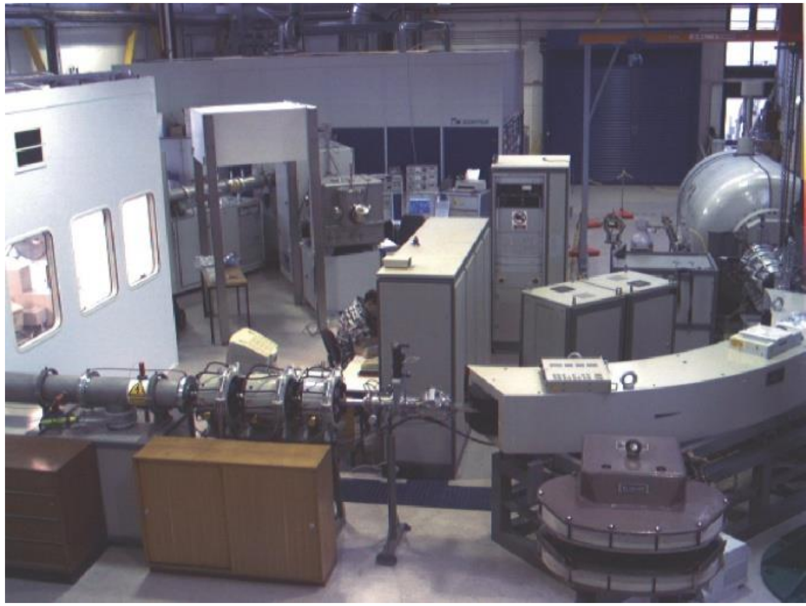
UNIVERSITY OF SURREY
Ion Beam Centre

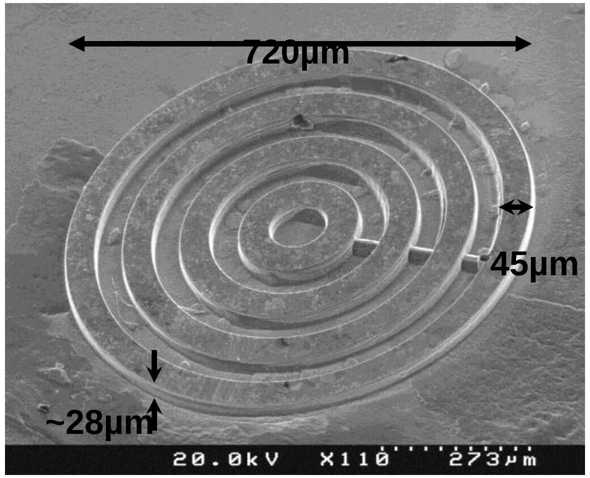
www.uknibc.co.uk

Surrey Ion Beam Centre

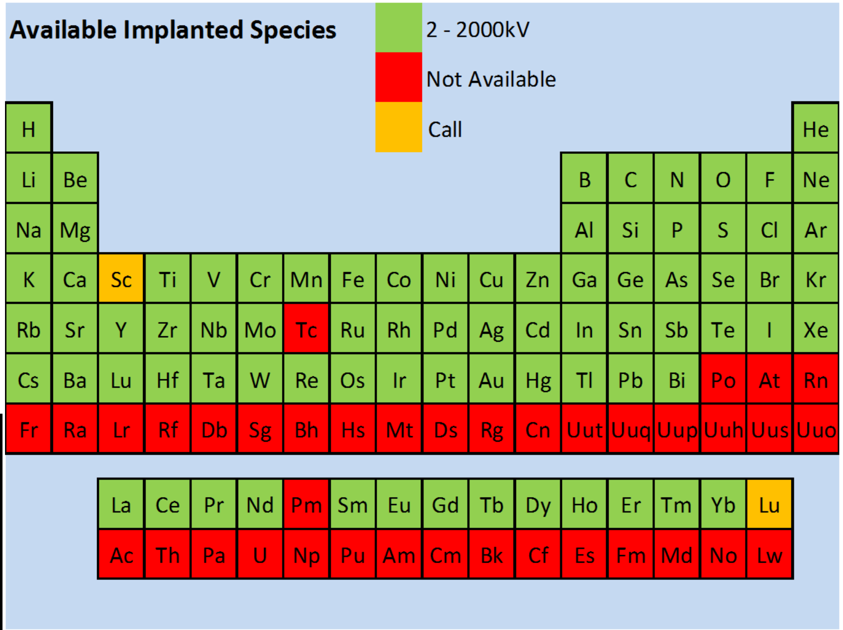
EPSRC

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





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



UNIVERSITY OF SURREY
Ion Beam Centre

www.uknibc.co.uk

Surrey Ion Beam Centre

EPSRC

- **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

UNIVERSITY OF SURREY
Ion Beam Centre

www.uknibc.co.uk

Surrey Ion Beam Centre

EPSRC

- **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

UNIVERSITY OF SURREY
Ion Beam Centre

www.uknibc.co.uk

Surrey Ion Beam Centre

Bio-Irradiation Facility

Facilities for bio-irradiation

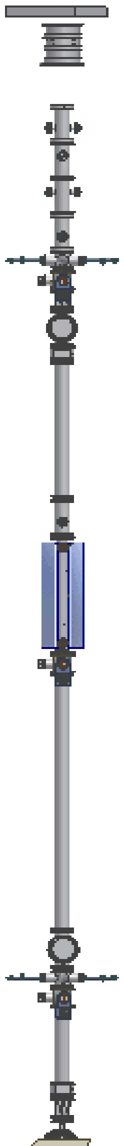
- Targeted (~100nm) single ion irradiation
- End Station in Cat 2 biological clean room
- Vertical Arrangement to allow irradiation of living cells in liquid cultural
- ~10,000 cell irradiations per hour
- Ions up to Ca from 2MVTandem
- Environmental chamber, incubators etc.

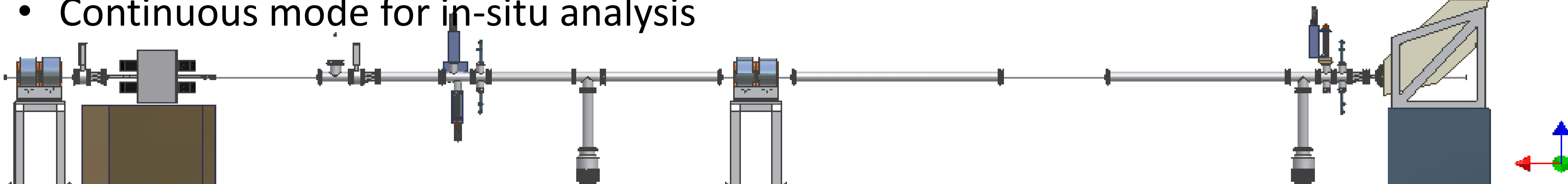
Facilities for Protein Analysis

- 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





www.uknibc.co.uk

Surrey Ion Beam Centre

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

THE BRITISH ASSESSMENT BUREAU ISO9001
Certification No. 181855

ilac-MRA UKAS CALIBRATION
8943

Surrey Ion Beam Centre

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:

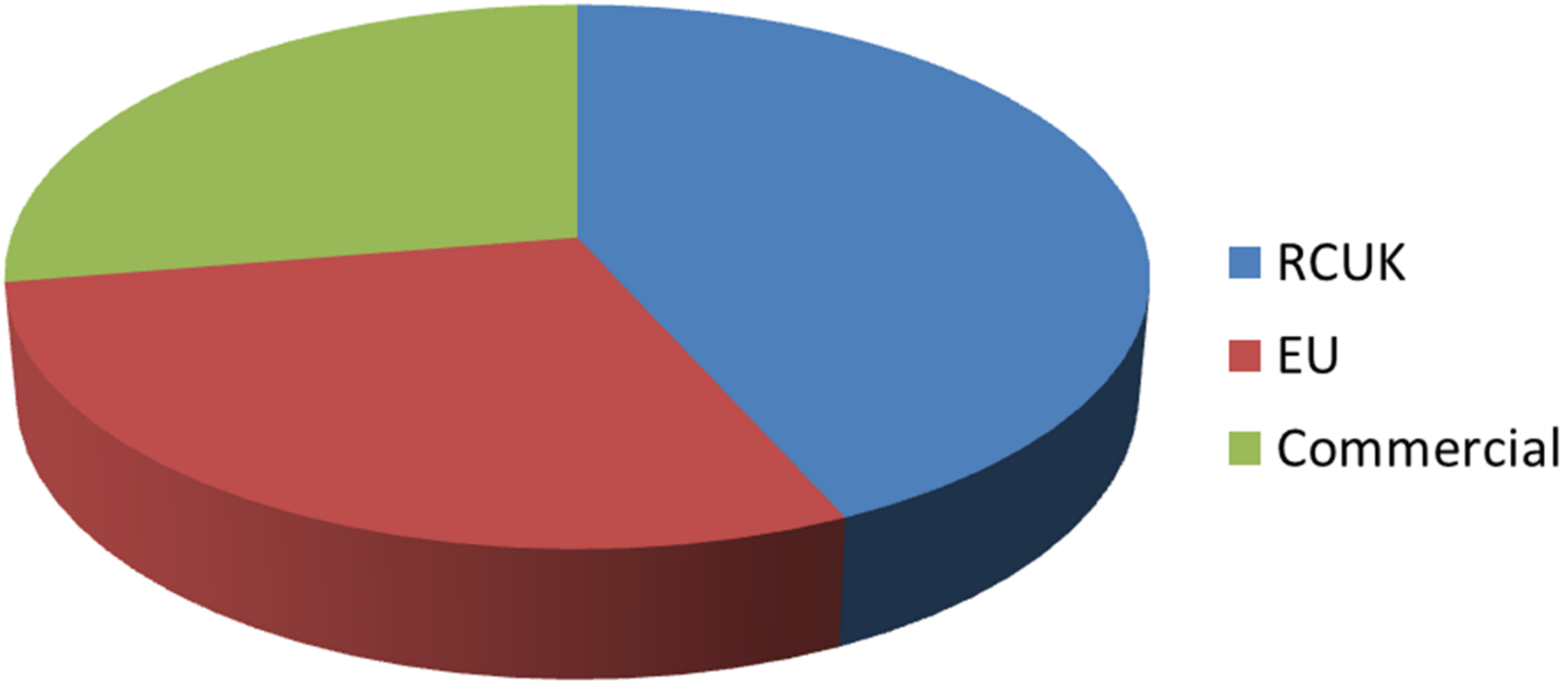
National Centres and Organisations accessing the IBC in past 5 years include:

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

www.uknibc.co.uk

Surrey Ion Beam Centre

Breakdown of Funding at Surrey IBC over the past 5 years



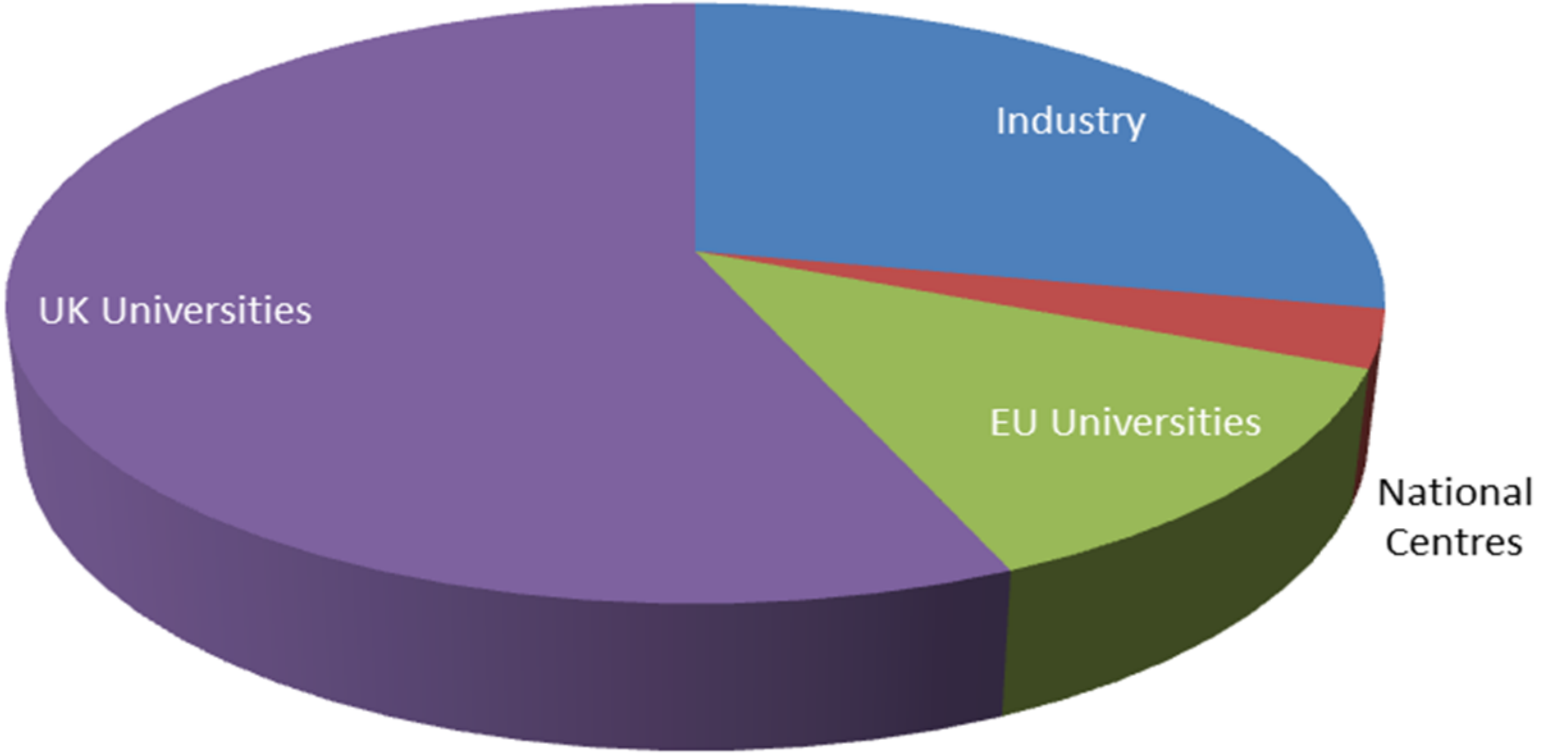
www.uknibc.co.uk

Surrey Ion Beam Centre

UNIVERSITY OF SURREY Ion Beam Centre

EPSRC

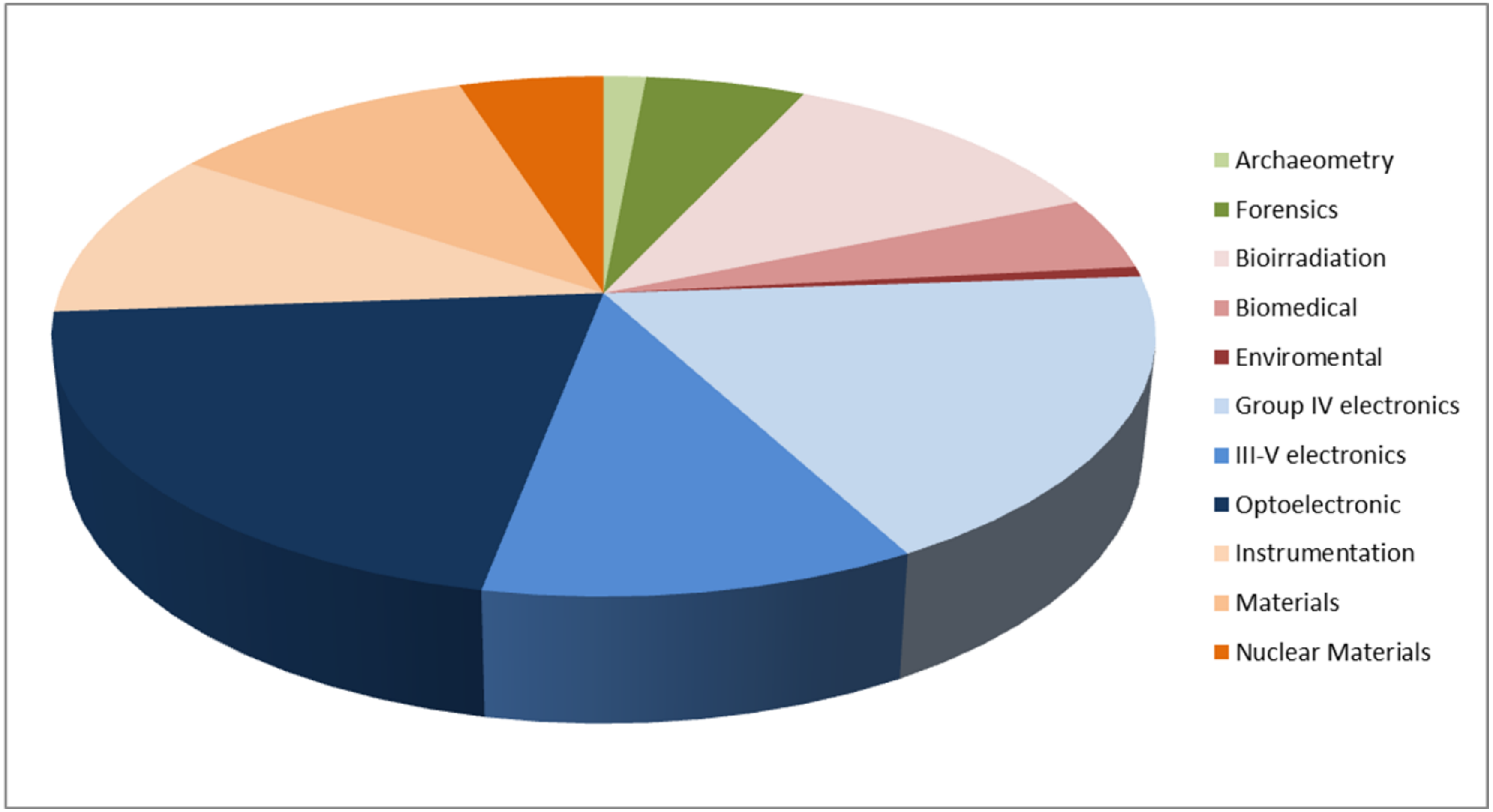
Breakdown of Beam Time Usage at Surrey IBC over the past 5 years



Surrey Ion Beam Centre

Breakdown of Beam Time Used by Project Type

All Funding Sources - 50% semiconductors

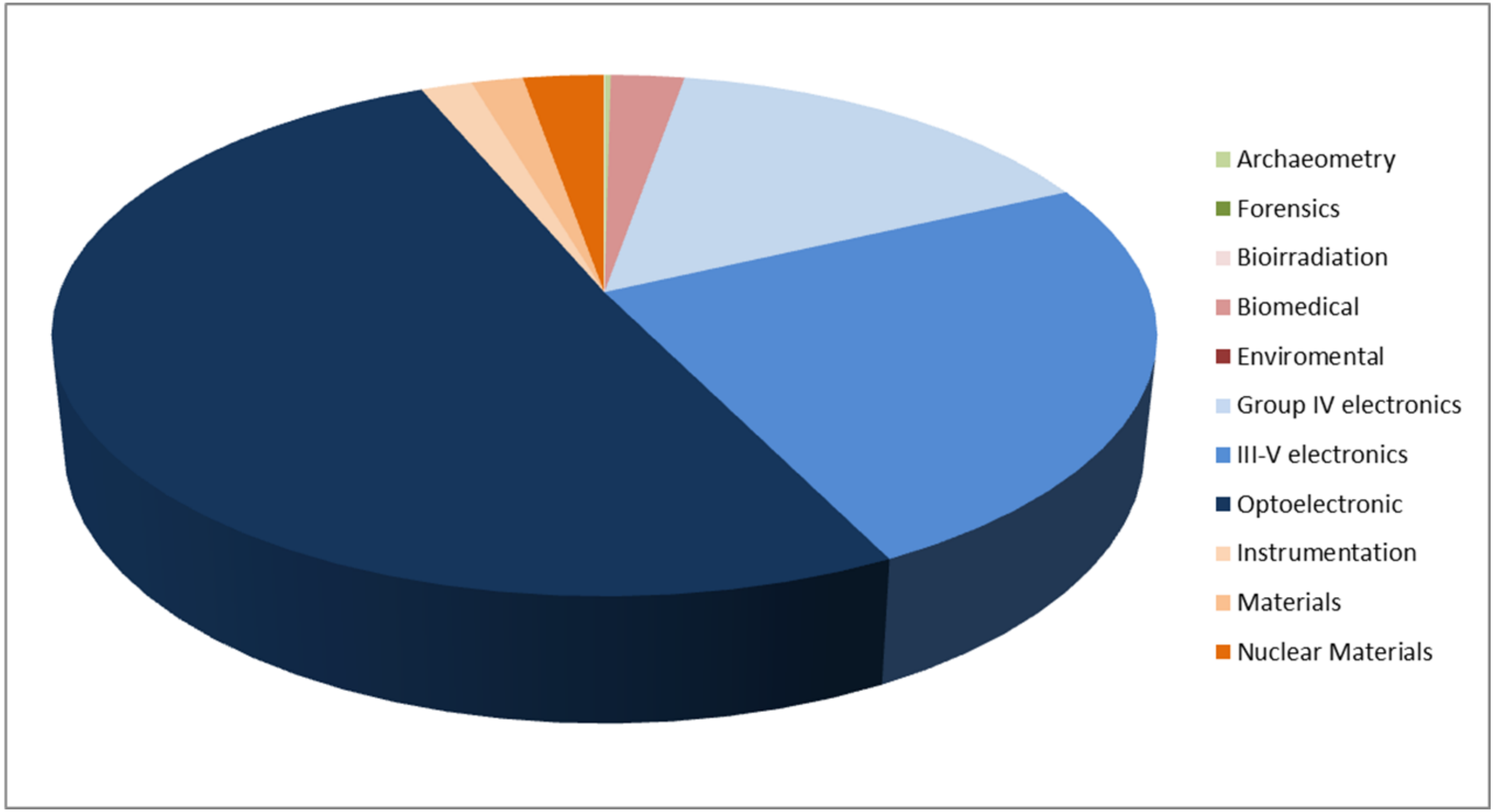


www.uknibc.co.uk

Surrey Ion Beam Centre

Breakdown of Beam Time Used by Project Type

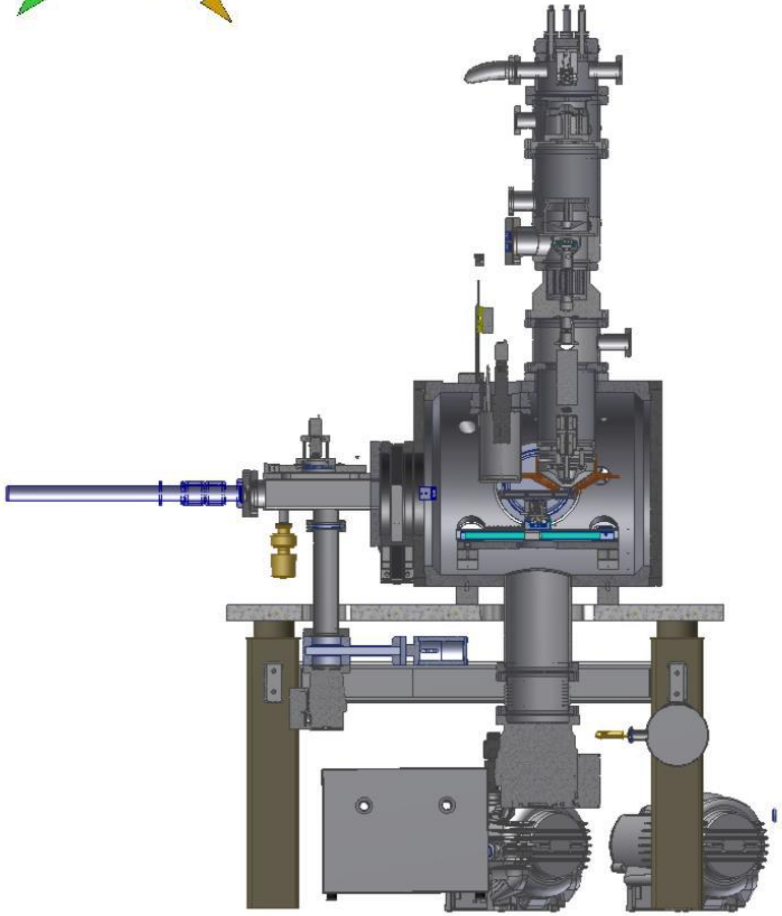
Commercially Funded - 91% semiconductors



www.uknibc.co.uk

Future Developments:

- **SIMPLE** – Single Ion Implanter for Quantum Technology applications
- **DAPNE** – 1um molecular sampling attached to orbitrap MS coupled with 1um trace element mapping
- **Hot Cell** – installation in progress
- **Dual beam** end station – in progress
- **200mm beam** line on 2MV implanter – expected end 2017



The UK National Ion Beam Centre

EPSRC

Getting Access:

There are five mechanisms through which users can gain access to these facilities:

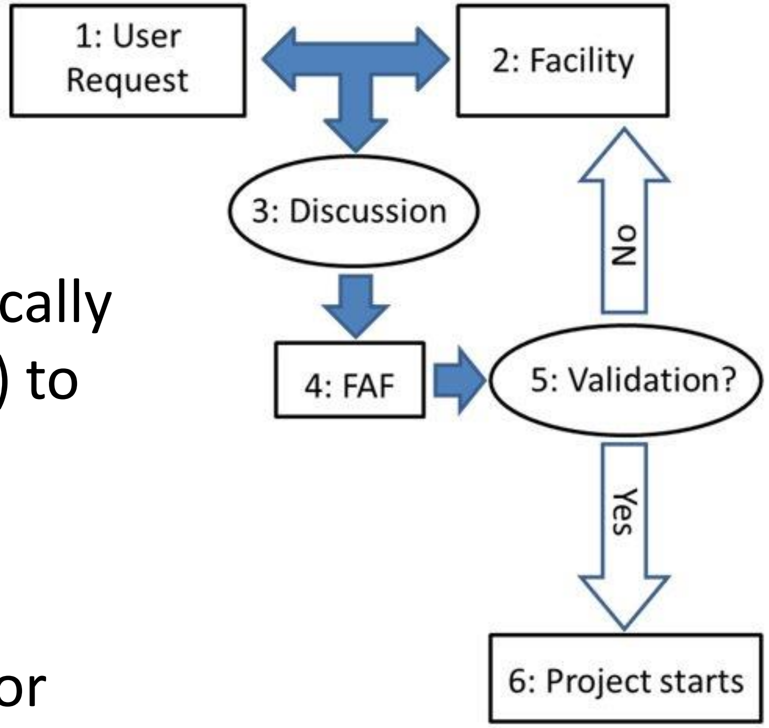
Commercial - the user pays for usage through the normal commercial route of each facility

Existing EPSRC grants without time - access granted via a simple validation process.

New EPSRC Application – access is requested as part of a EPSRC application. If the grant is awarded then access will be automatically provided by the UKNIBC – we supply Technical Assessment (FAF) to go with your application.

EPSRC Students. EPSRC funded students can access the UKNIBC in their own right.

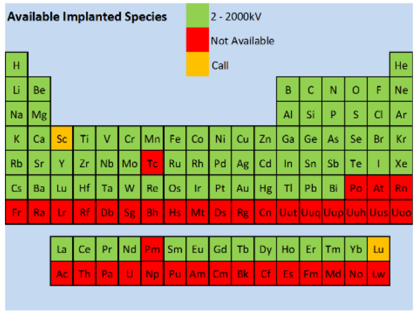
Pump Priming. A proportion (10%) of UKNIBC time is earmarked for new projects that have no current EPSRC support.



www.uknibc.co.uk

Summary

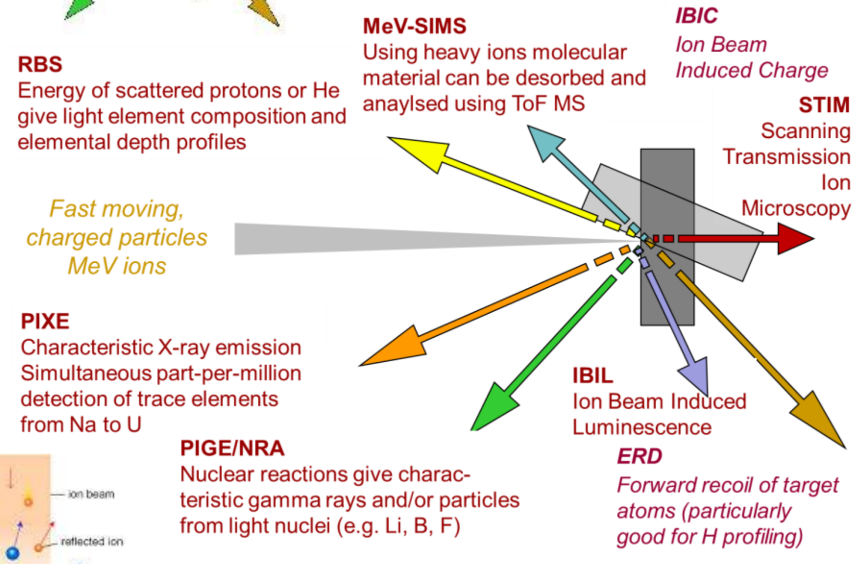
Ion Implantation for Controllable Materials Modification
- 2keV – 4MeV energy range
- 10K to 1000K implant temperature
- Class 100 clean room

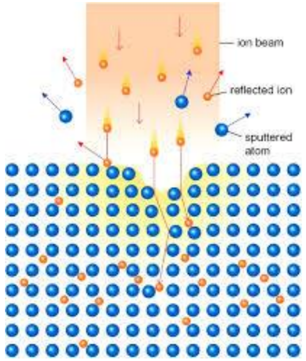


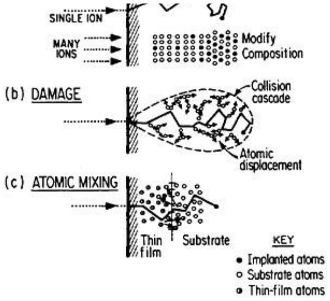
Ion Irradiation for Radiation Damage studies
- in-situ TEM
- Hot Cell for active material irradiation

Bio-irradiation for biological implications of radiation damage
- Vertical Beam line for irradiation in living cells in media
- Single ion delivery into single cell

Ion Beam Analysis
- PIXE, EBS, RBS, ERD, PIXE,PIGE, NRA, IBIL, IBIC, MeV-SIMS
- in vacuum and in full ambient
- micro beams for mapping ~1um
- MEIS for high depth resolution







Surrey
- Implantation and Ion Beam Analysis facility

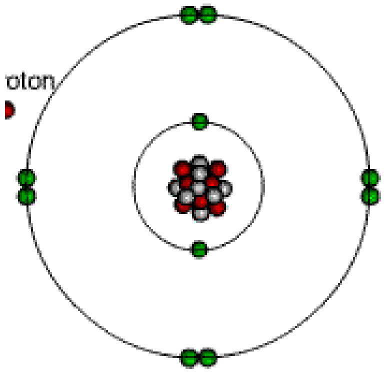
Huddersfield
- Miami (in-line TEM) and MEIS facility

Dalton Cumbrian Facility - Manchester
- Neutron irradiation emulation facility with hot cell

www.uknibc.co.uk

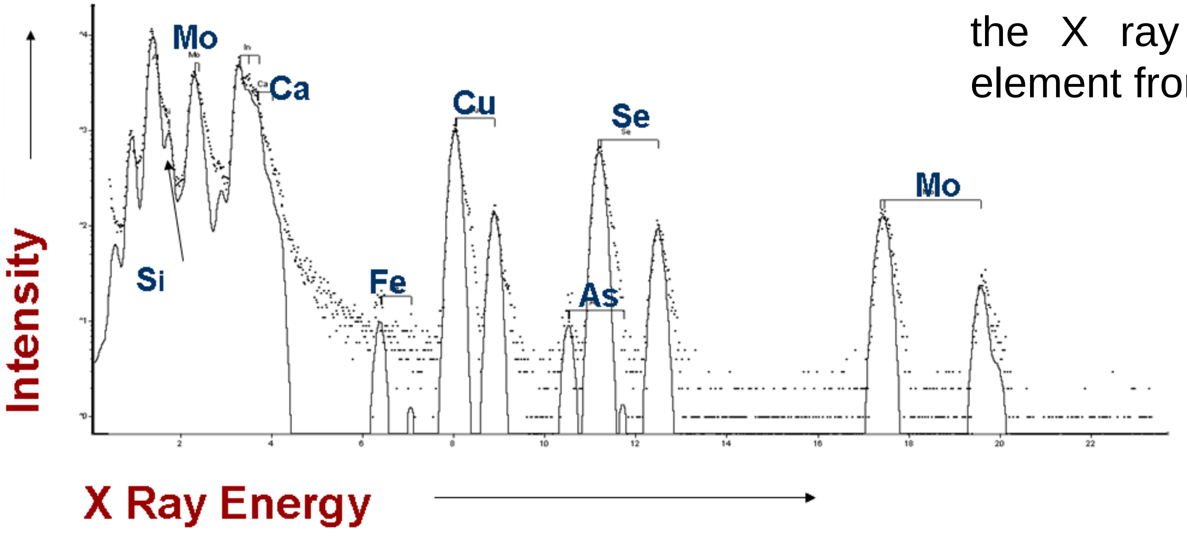
- Additional slides…

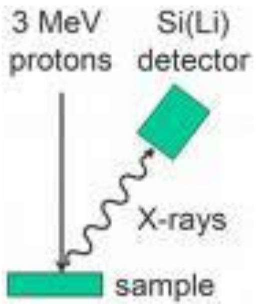
What is PIXE…?



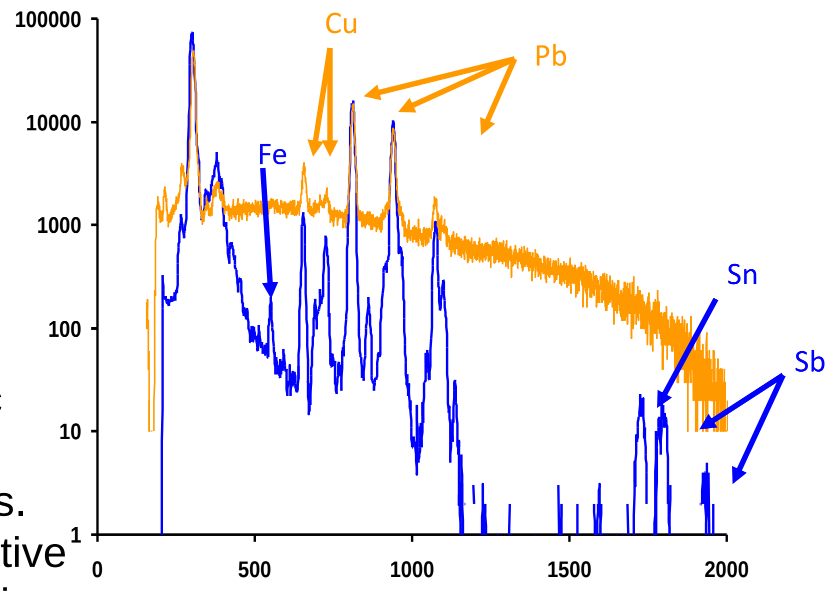
Particle **I**nduced **X**-ray **E**mission

- 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





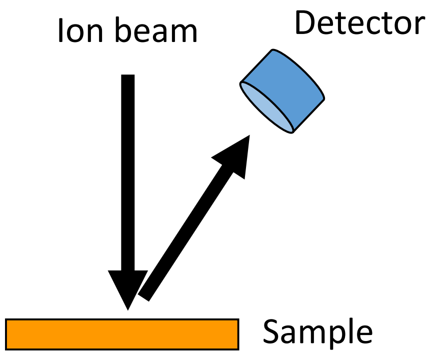
Benefits of PIXE & PIGE

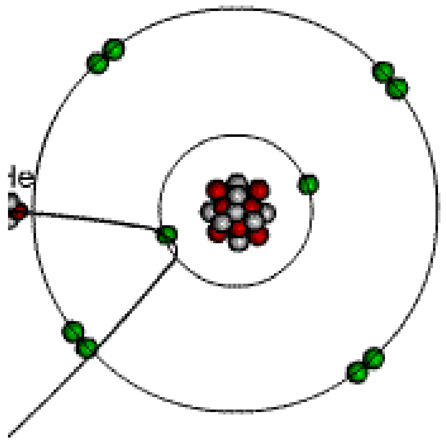


- PIXE can be used to detect elements in the periodic table **from Na to U (Li, B, F** etc. with PIGE**)**
- The sensitivity is at the **ppm level** for most elements.
- The figure on the right shows how much more sensitive PIXE (blue) is to trace elements than the electron micro-probe (yellow), **no 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?

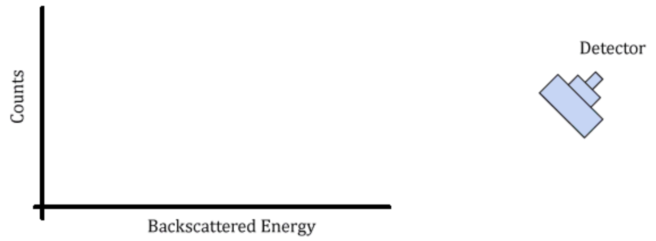
- RBS determines compositional information about a sample:
  - ***Which*** atoms are present and ***where*** are they?
- Rather than an alpha source like Rutherford, we use a more convenient ion beam from an accelerator
- We detect backscattered particles and their energy
- Ions are repelled by the positively 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.

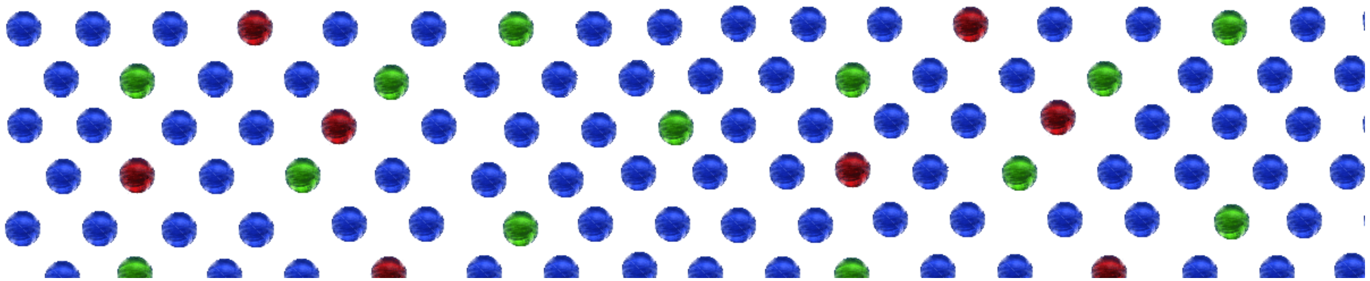




How to interpret a RBS Spectra

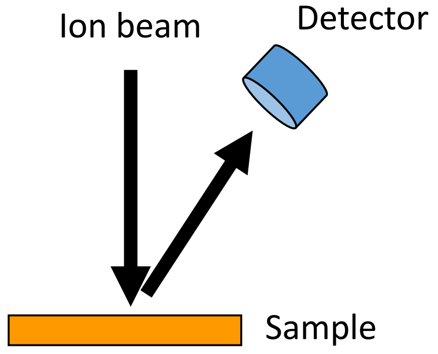
- The energy of the backscattered particle depends on the depth in the sample at which it was backscattered
- As the particle travels through the sample, it loses energy through collisions with the target electrons
- These collisions don’t really affect the particle’s direction, just its speed (i.e. 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

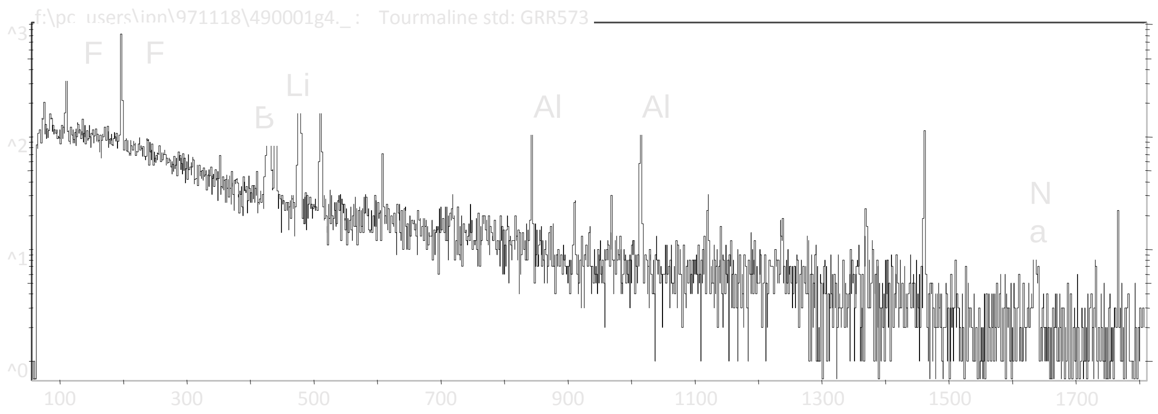


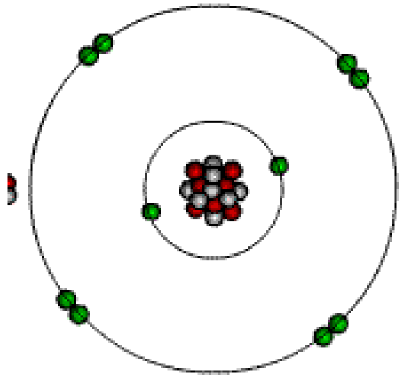


What is NRA/PIGE?

- **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.

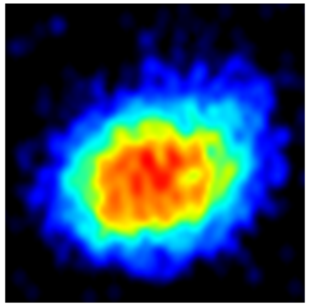


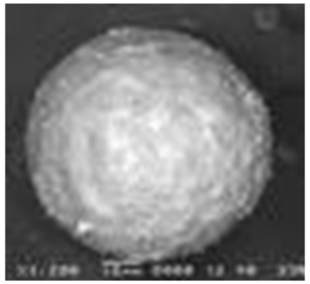


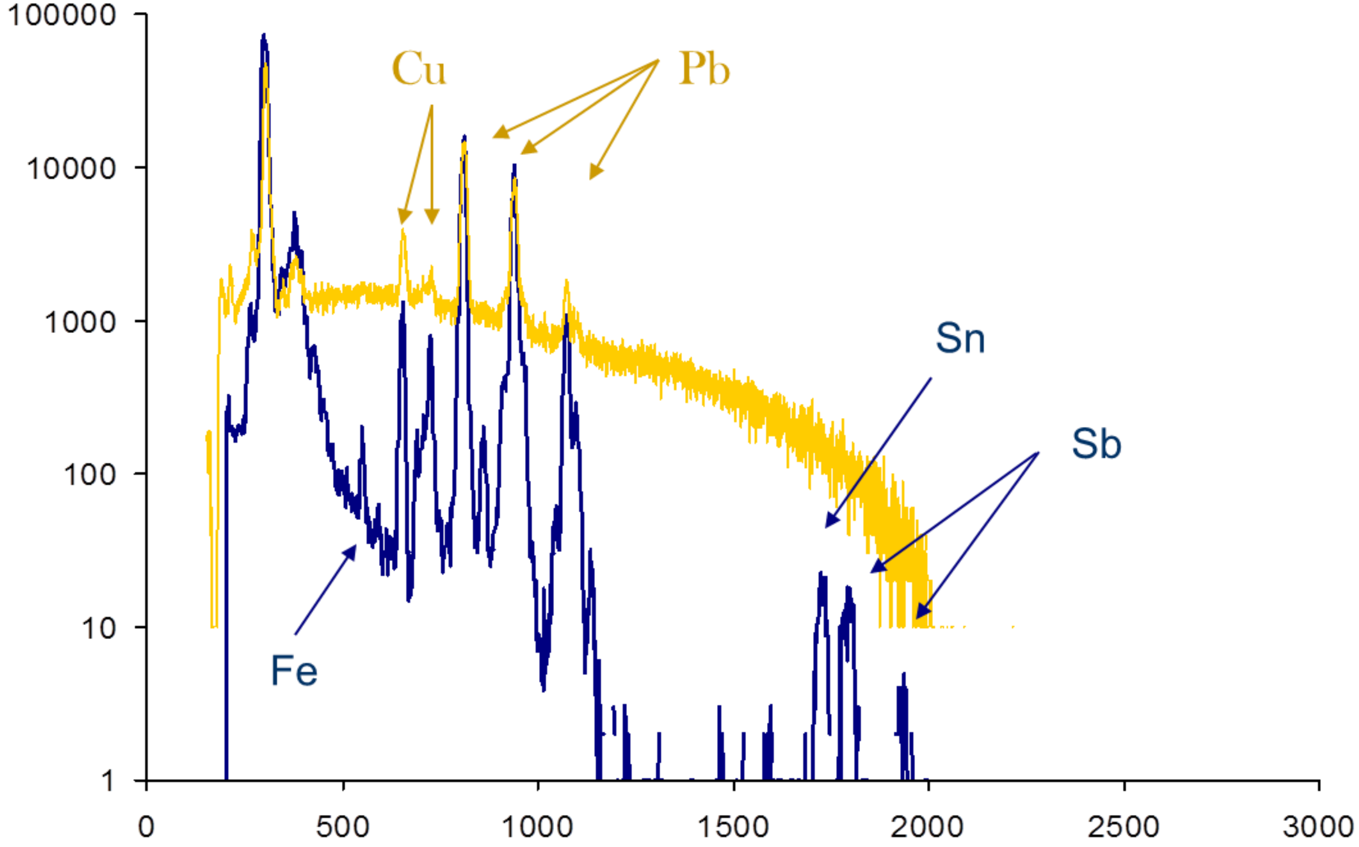


EPSRC

Ion Beams vs Conventional Methods

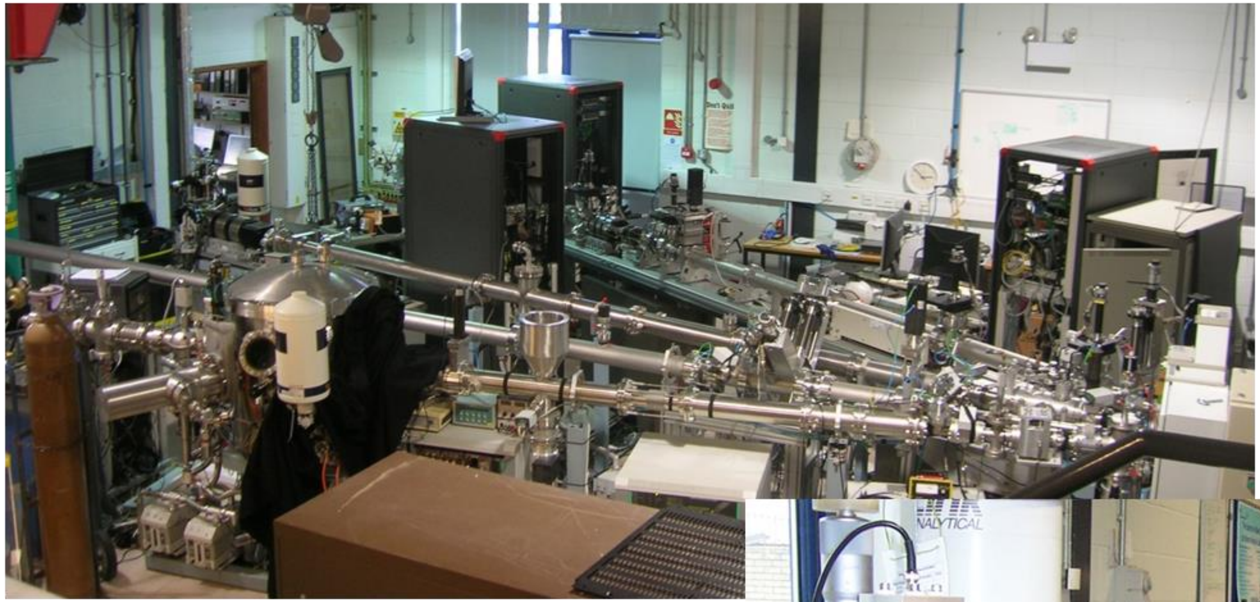






EPSRC

Ion Beam Mapping



Ions from accelerator

Magnets for focussing