



Australian Government

Ansto

Ion Beams and Accelerators

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Overview of Talk

- MV positive ion accelerators
- Ion Beam Analysis (IBA)
- Future facilities

Already discussed synchrotrons & cyclotrons ...

Now look at **positive ion accelerators**,

- Electrostatic linear, megavolt systems

Accelerating ions such as:-

proton- H^+ , alpha- He^{2+} , gases- Ne^+ , Ar^+ , Kr^+ ..., solids- C^{3+} , Ti^{2+}

(in fact ions from most elements in the periodic table)

If these ions 'fall' through megavolt (MV) potential then they will have energies of mega-electron volts (MeV).

Accelerators Methods

Examples of megavolt systems are the two accelerators at ANSTO:-

STAR - Small Tandem for Applied Research, 2MV arrived 2003, \$3M

ANTARES - Australian National Tandem for Applied Research, 10MV arrived 1989, valued around \$10M

Two primary techniques:-

IBA - Ion beam analysis

AMS - Accelerator mass spectrometry, isotopic dating

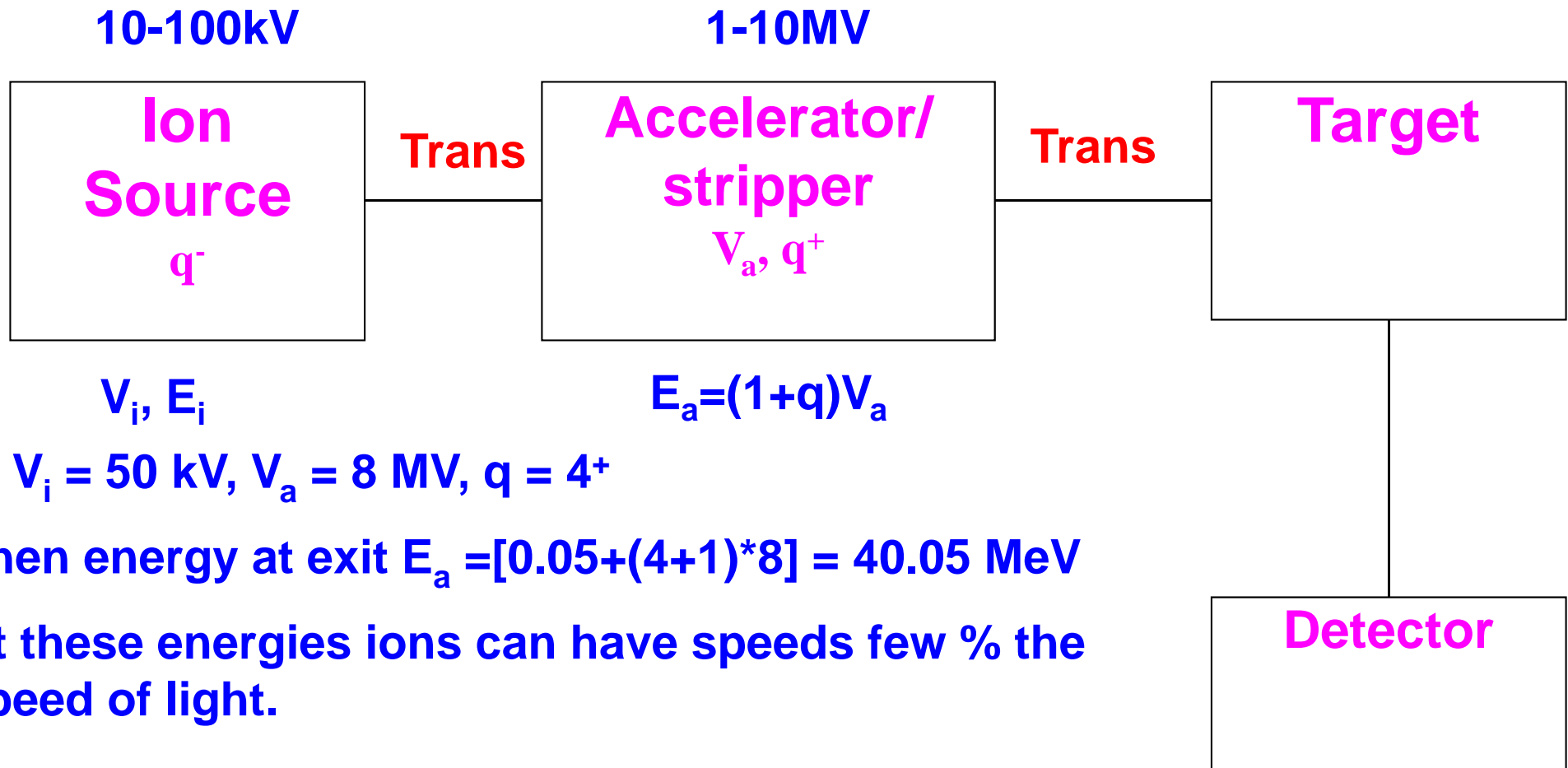
Why accelerators?:-

Both techniques very sensitive ($\mu\text{g/g}$), isotopic ratios $1:10^{15}$

Analyse very small samples - pg to μg , atomic layers, individual atom counting.

Several minutes analysis times per sample, often non-destructive.

Ion Acceleration & Transport



If $V_i = 50$ kV, $V_a = 8$ MV, $q = 4^+$

Then energy at exit $E_a = [0.05 + (4+1)*8] = 40.05$ MeV

At these energies ions can have speeds few % the speed of light.

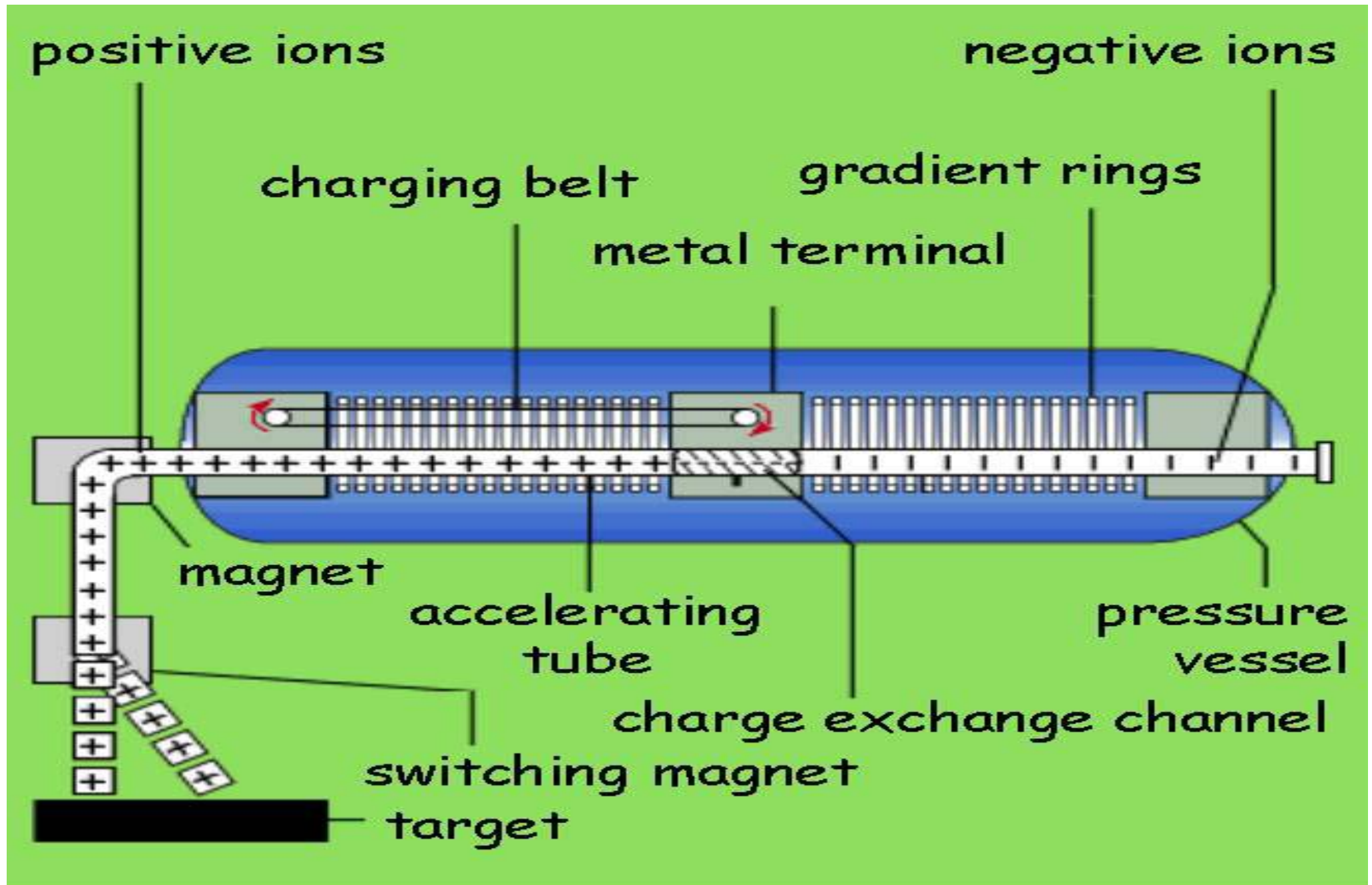
Currents:

$$1 \text{ pA} = 6 \times 10^6 \text{ ions/ sec (q=1)}$$

$$100 \text{ } \mu\text{A} = 6 \times 10^{14} \text{ ions/ sec (q=1)}$$

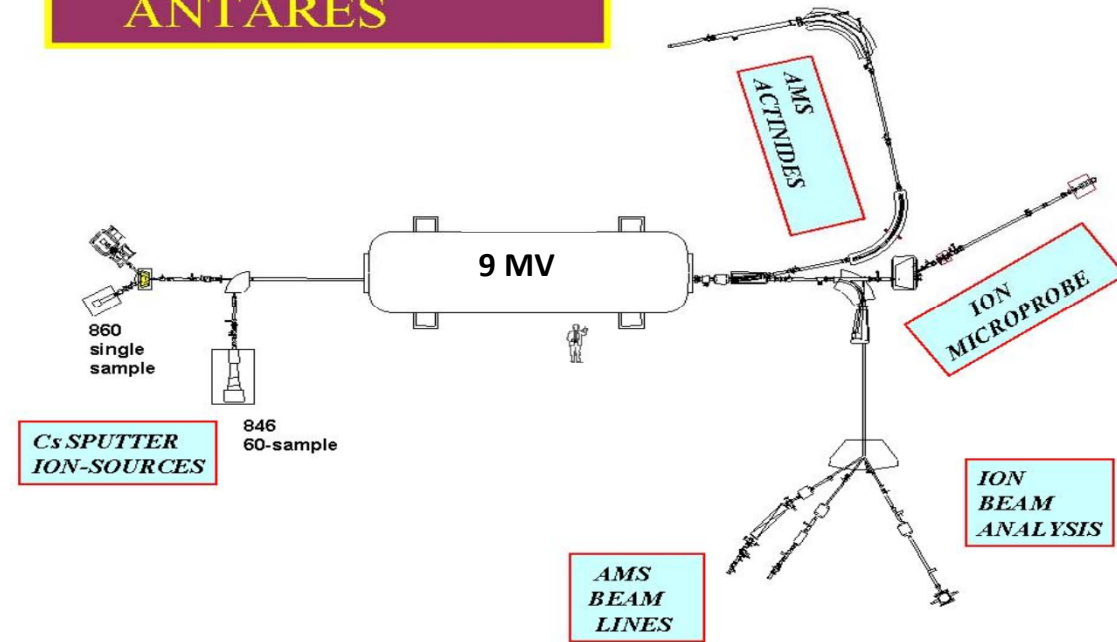
Small currents produce many ions/ sec!

What might these accelerators look like?



ANTARES Accelerator

ANTARES



- ❖ 9 MV HVE Tandem.
- ❖ 3 ion sources for ions H-U.
- ❖ 2 IBA beamlines, heavy ion microprobe, heavy ion ERDA, RToF.
- ❖ 3 AMS beamlines, small sample, actinides, ^{10}Be , ^{26}Al , ^{14}C .

Can be accessed directly thru ANSTO or from Universities thru AINSE

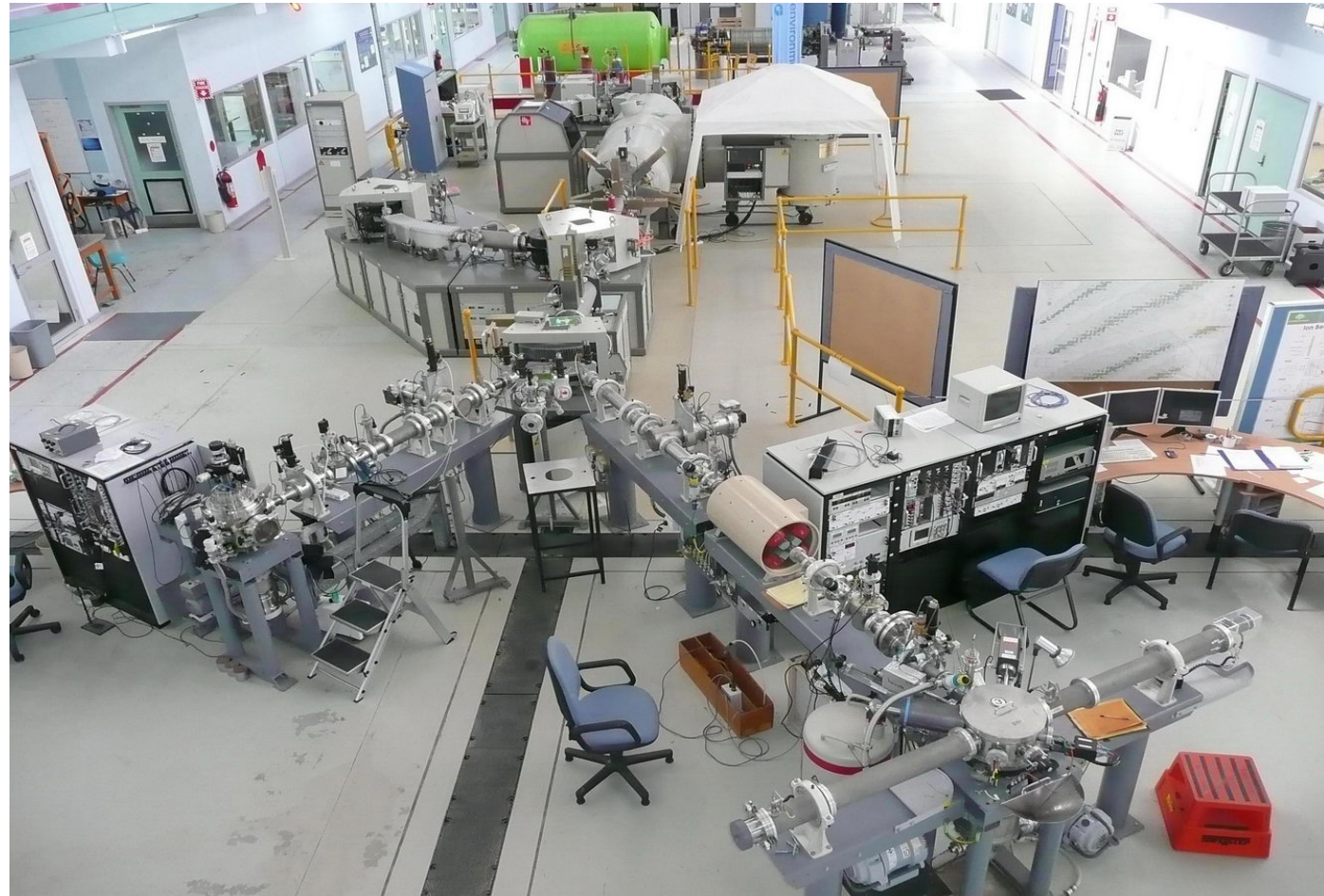
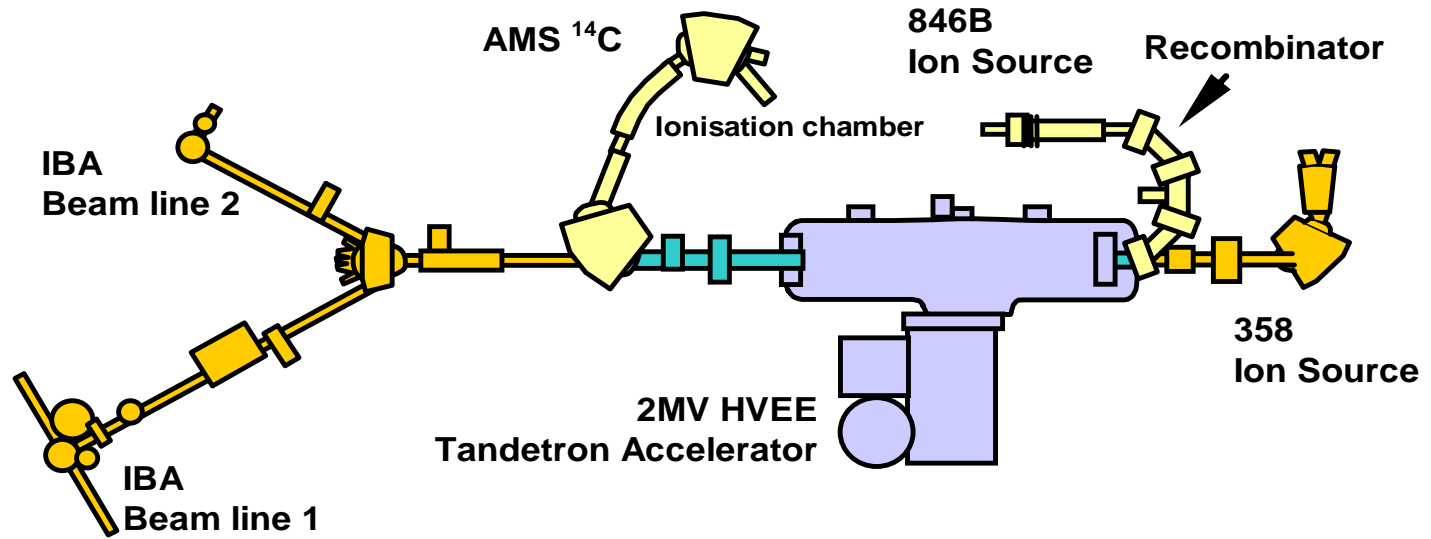
High Energy Beam Hall at ANSTO Tandem



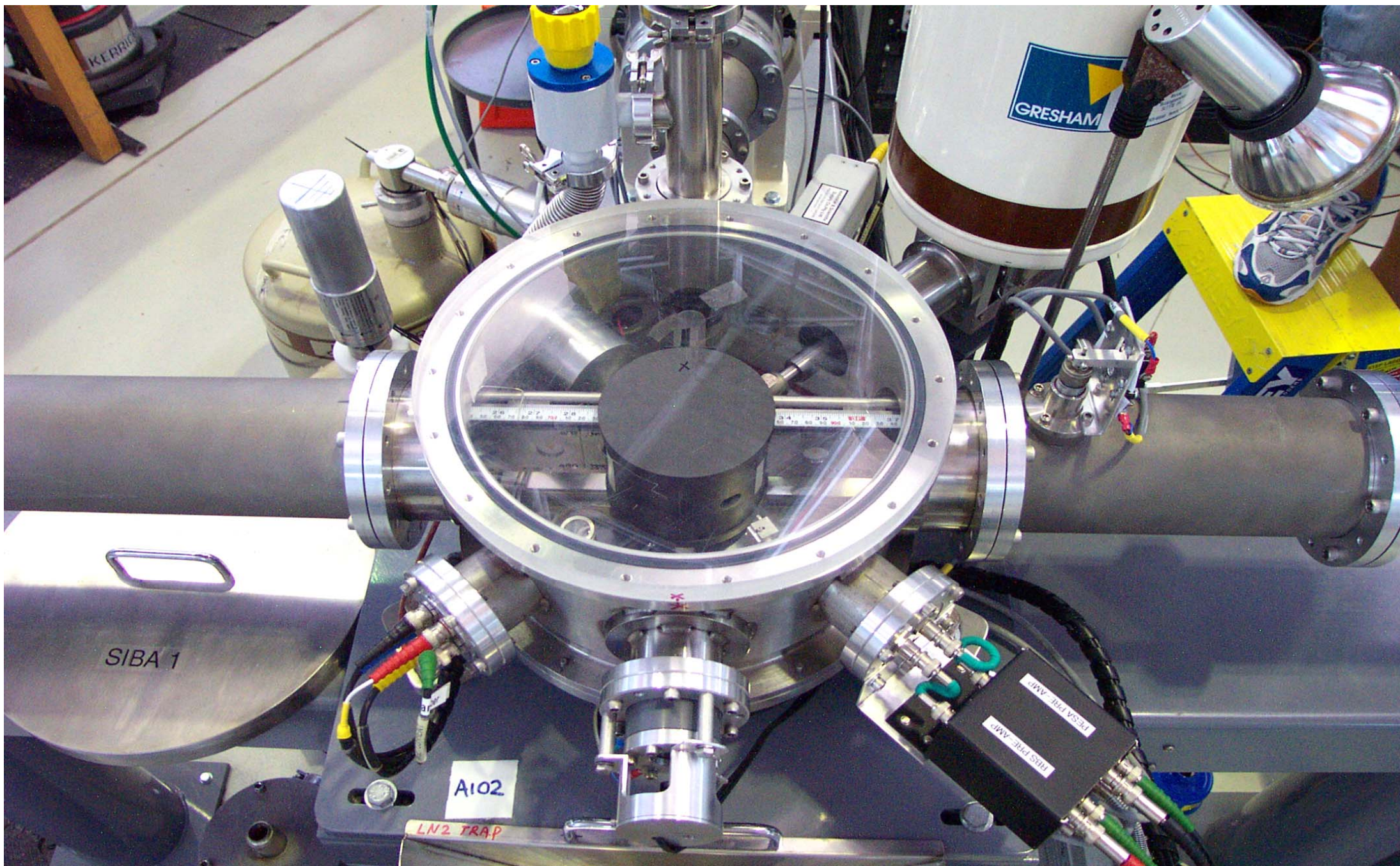
These are fairly complex machines!

STAR Accelerator

- ❖ 2MV HVE Tandatron
- ❖ 2 Duoplasmatron ion sources for H, He
- ❖ 1 Sputter ion source for heavy ions
- ❖ 2 IBA beamlines, PIXE, PIGE, RBS, PESA, ERDA
- ❖ ^{14}C AMS



Typical IBA and PIXE end stations and chamber



Accelerator Based Ion Beam Techniques

2MV STAR Accelerator

PIXE, PIGE, RBS, ERDA beamline



Beams of high energy ions (p, He, C....) fired into sample surfaces.

Interactions with $e^- \Rightarrow$ X-rays **PIXE** (Al-U)

nucleus \Rightarrow γ -rays **PIGE** (Li, F, Na..)

\Rightarrow scattered and recoiled particles **RBS, ERDA, RTof** (H, C, N, O,...)

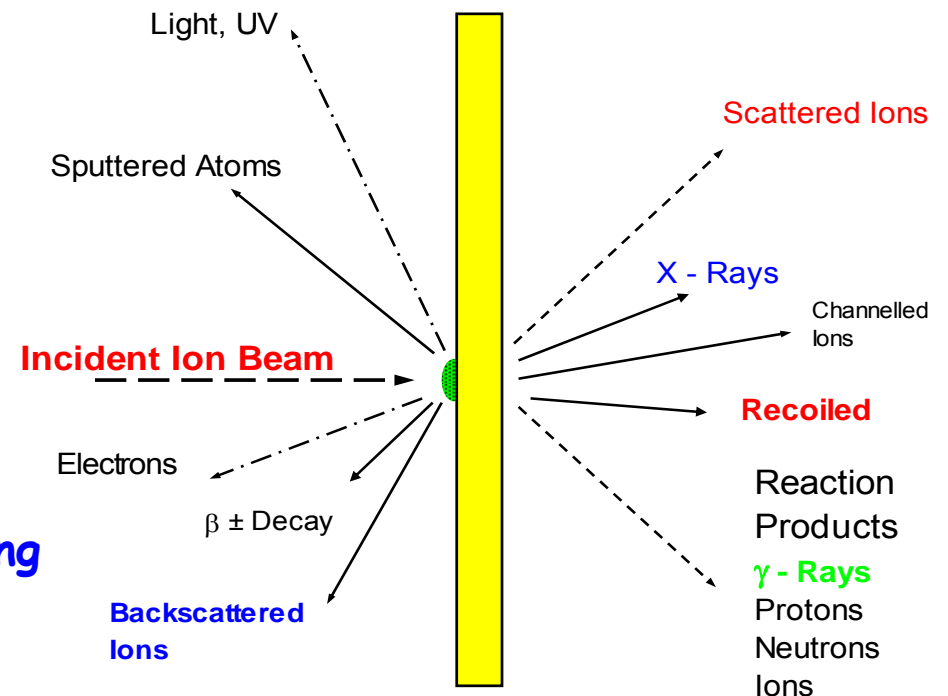
IBA techniques cover Periodic Table (H to U).

Very sensitive ($\mu\text{g/g}$) on small samples (pg).

Fast (<5mins), essentially non destructive as counting individual atoms/ ions/ photons.

Have between 100-120 external visitors/ year

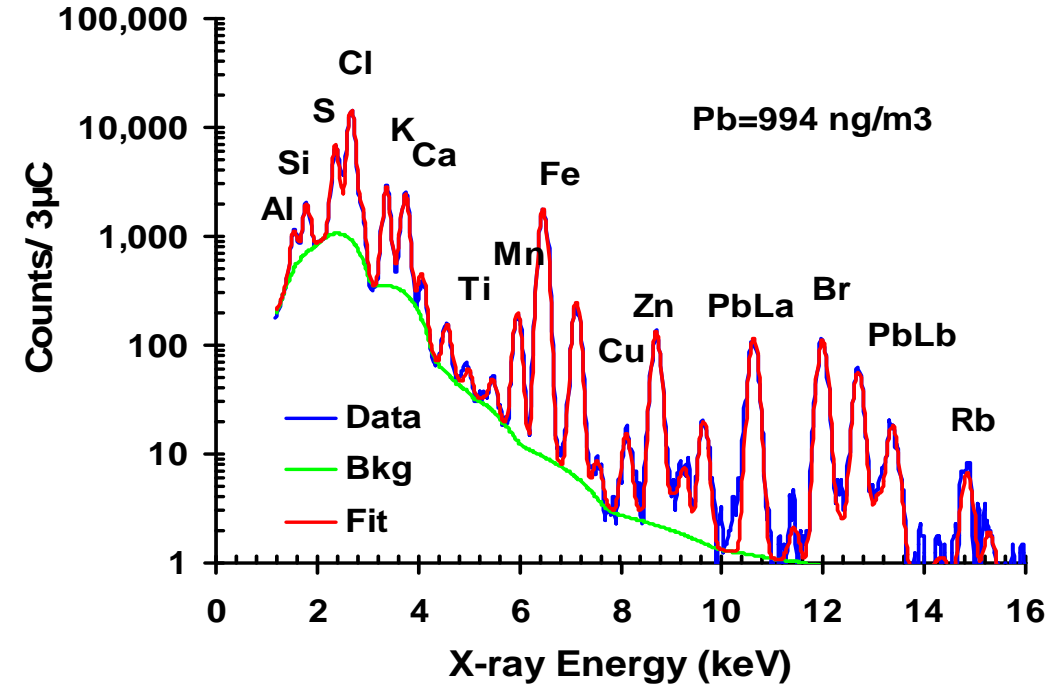
Interact with all 37 Australian Universities



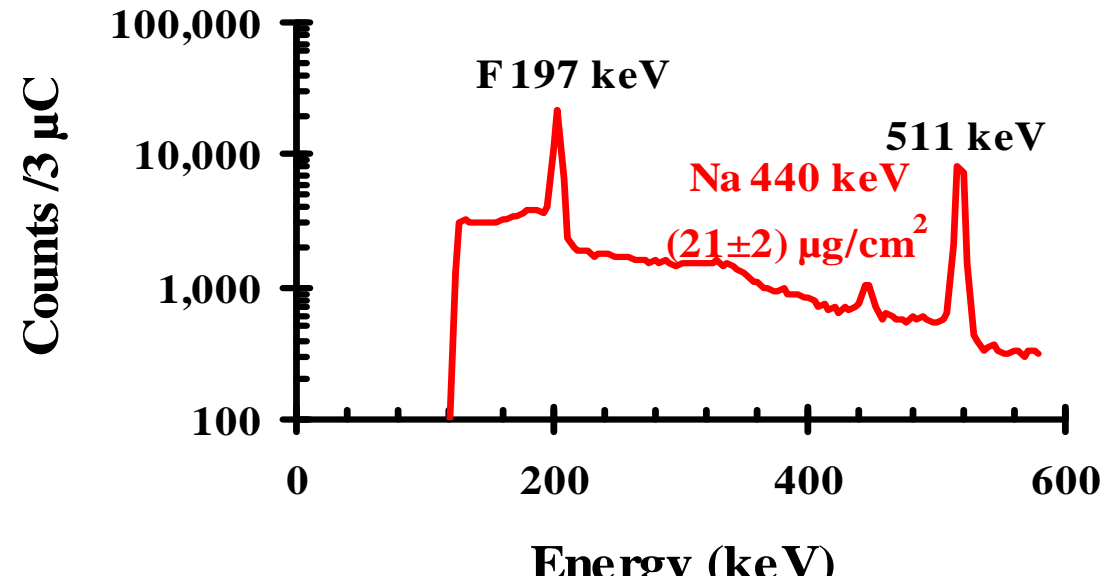
Sample

Ions travel few % speed of light through the target

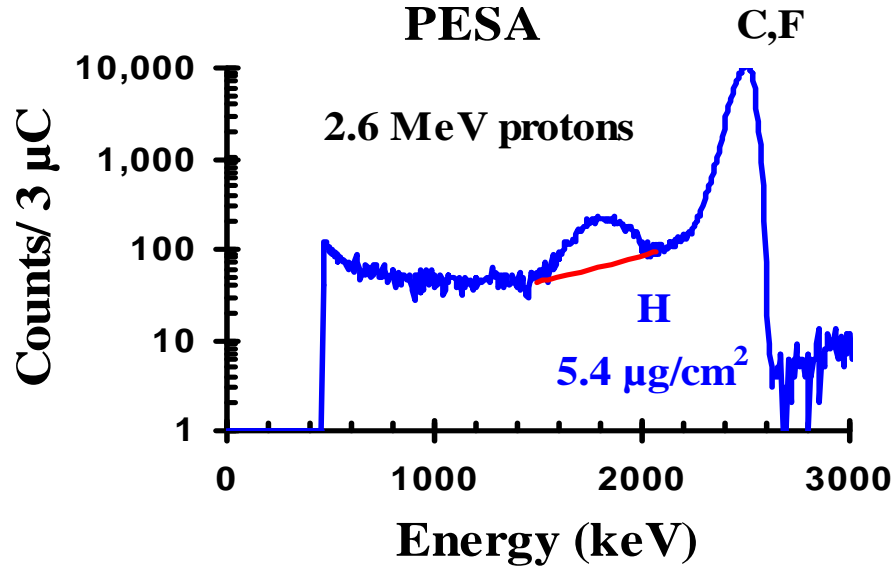
PIXE



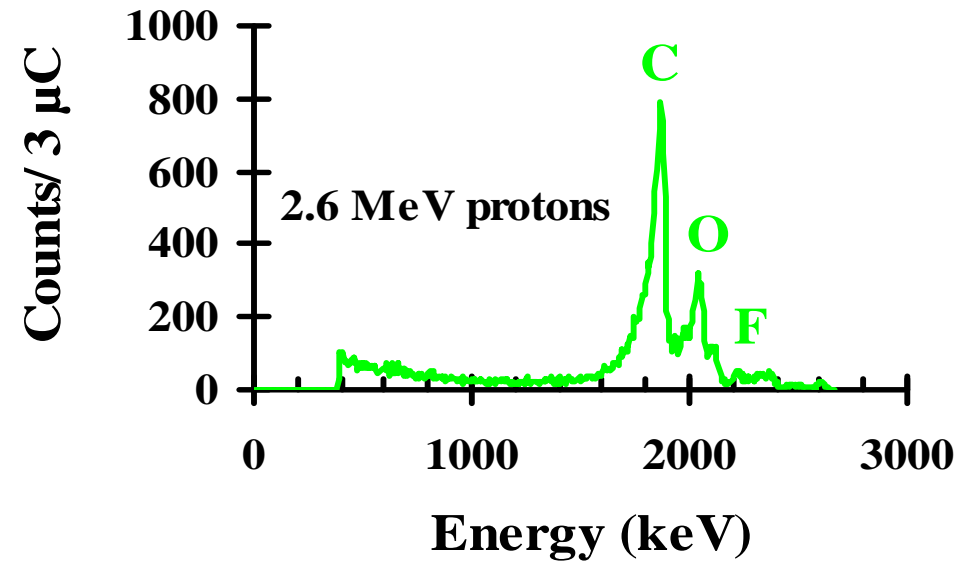
PIGE



PESA



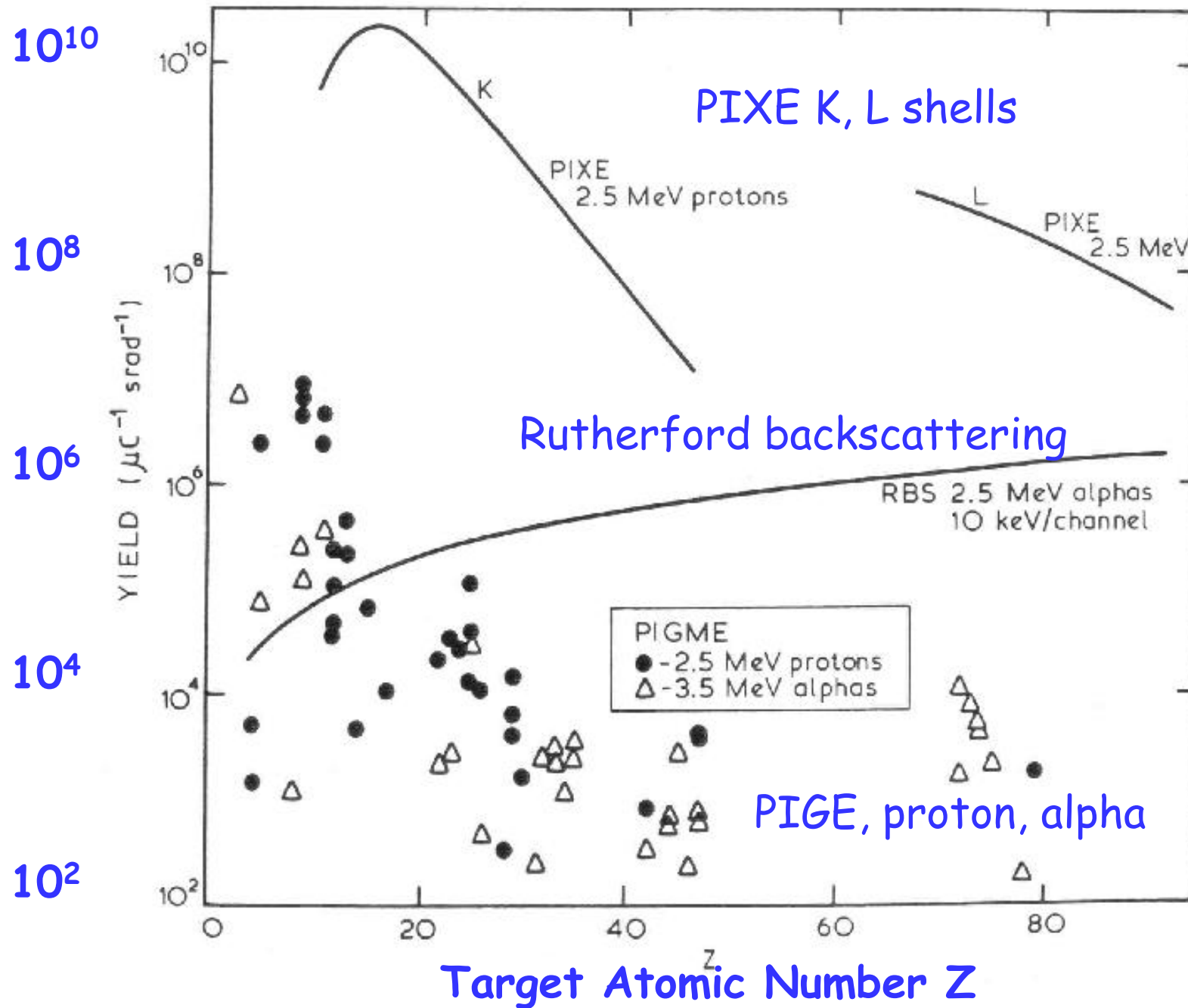
RBS



Four techniques cover most of the periodic table from H to U

10nA for 5 mins of 2.6 MeV protons = $3\mu\text{C}$

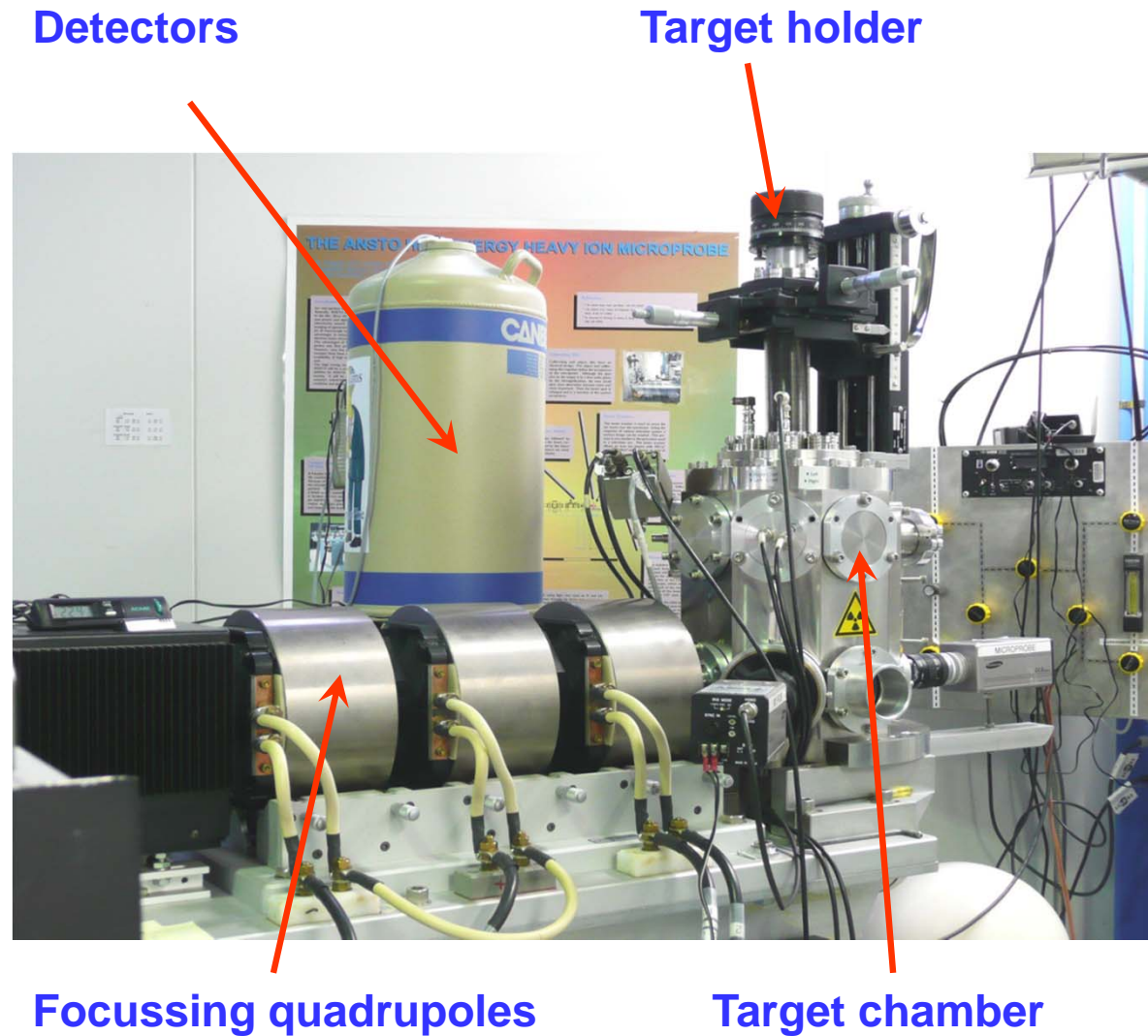
Relative Yields for PIXE, PIGE, RBS



Ions beams can be focussed, Heavy Ion Microprobe

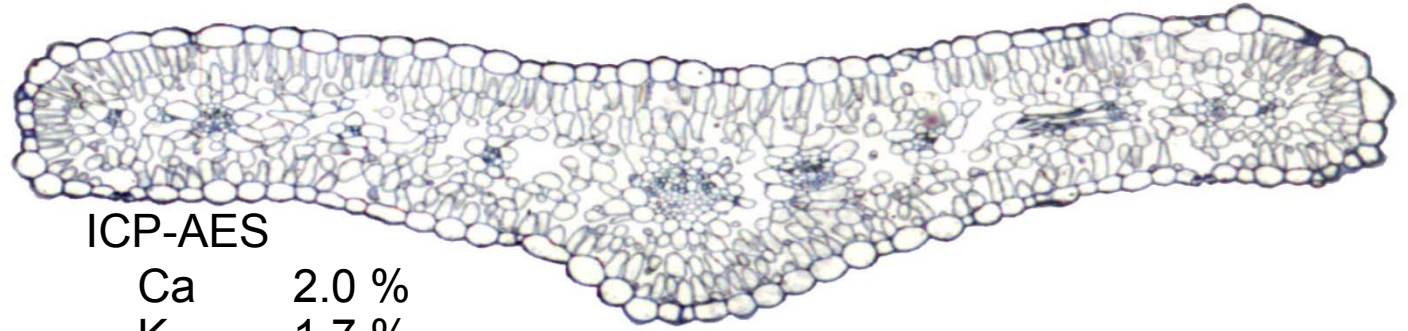
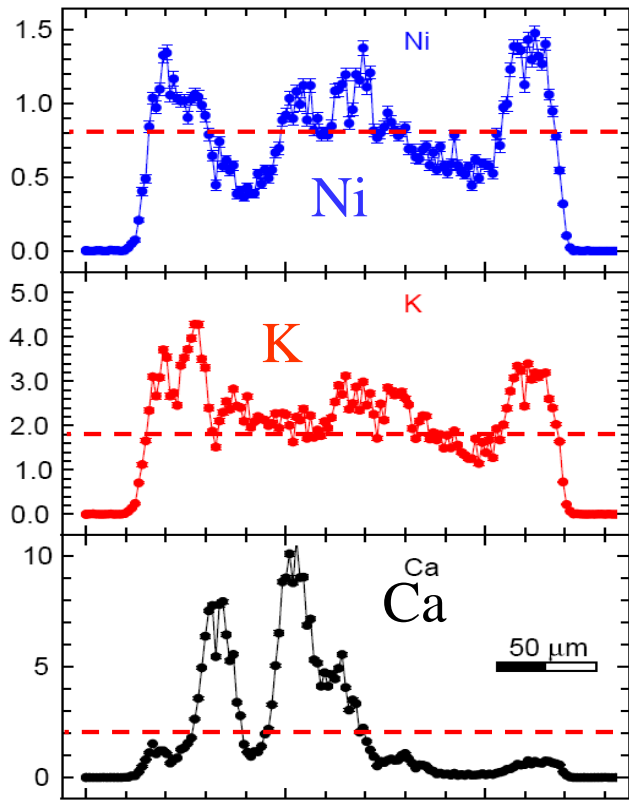
Key application areas are:

- **Environmental** - elemental characterisation, biological tissue, biota, solid materials
- **Minerals characterisation** - 2D micro-mapping in mineral deposits, plant systems, microelectronics
- **Materials analysis** - thin film analysis, ion beam induced currents (IBIC).



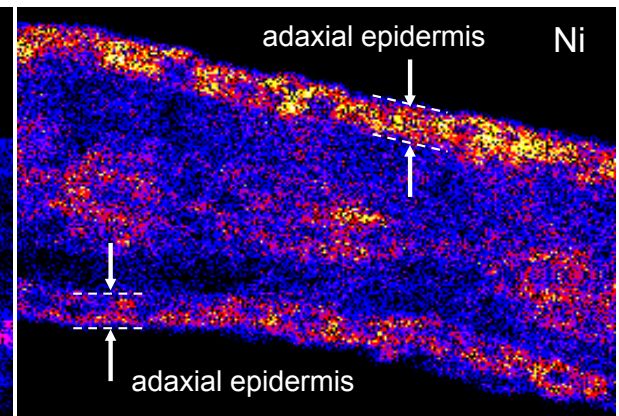
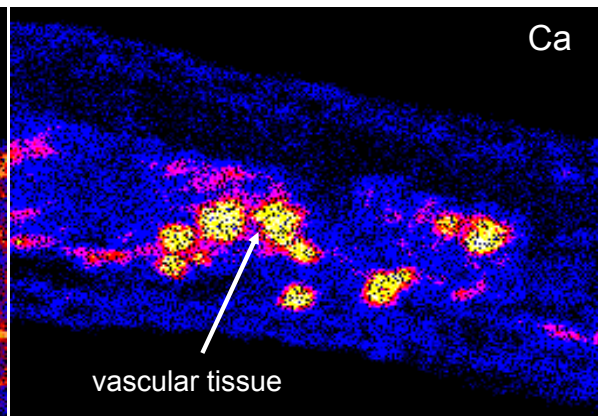
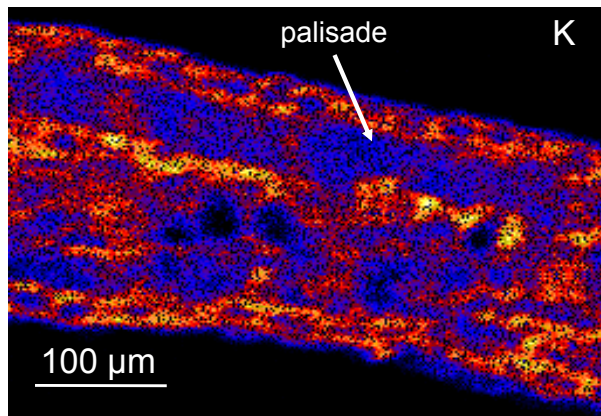
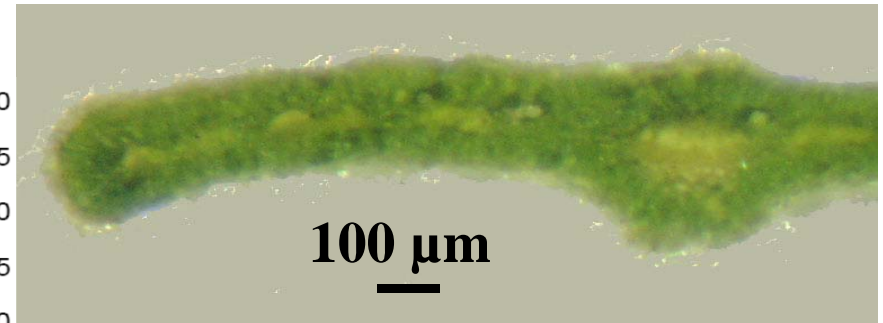
Microprobe can focus 100MeV Iodine beams into $1 \times 1 \mu\text{m}$ spot sizes

Leaf sections for Ni accumulator



ICP-AES

Ca	2.0 %
K	1.7 %
Ni	0.8 %



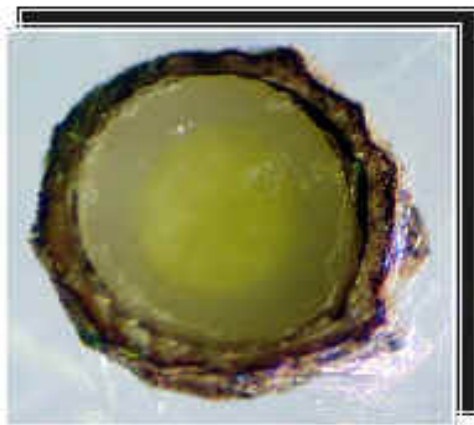
3MeV proton scans

Takes up to 4% Ni by dry weight

Hybanthus Floribundus subsp. floribundus

Seeds of *Stackhousia tryonii* as seen by Ion Microprobe

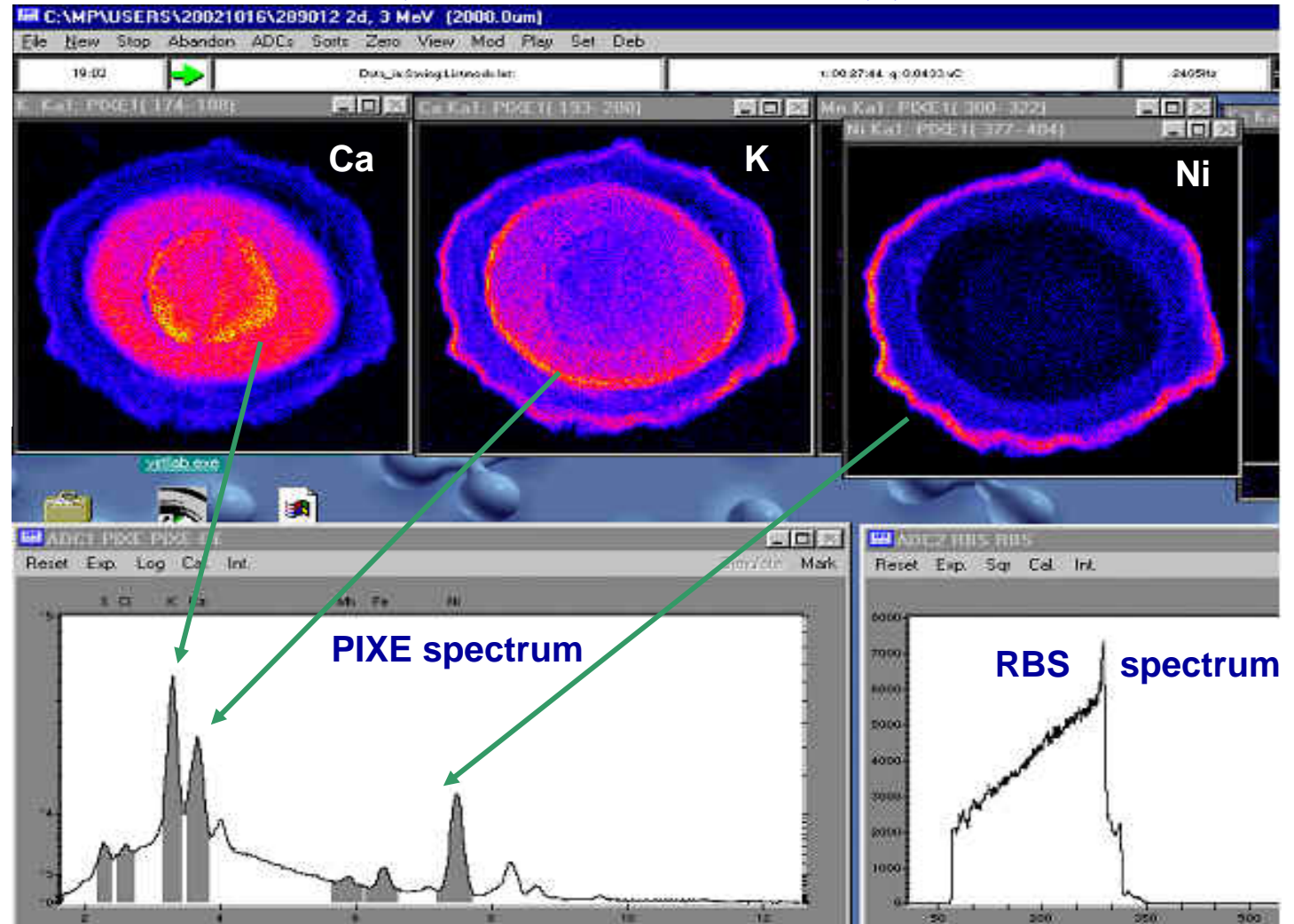
This native Australian plant is a very efficient Ni accumulator.
Can accumulate up to 4% Ni of dry body weight!!



Seed

1500 x 1500 μm^2

Microprobe elemental mapping



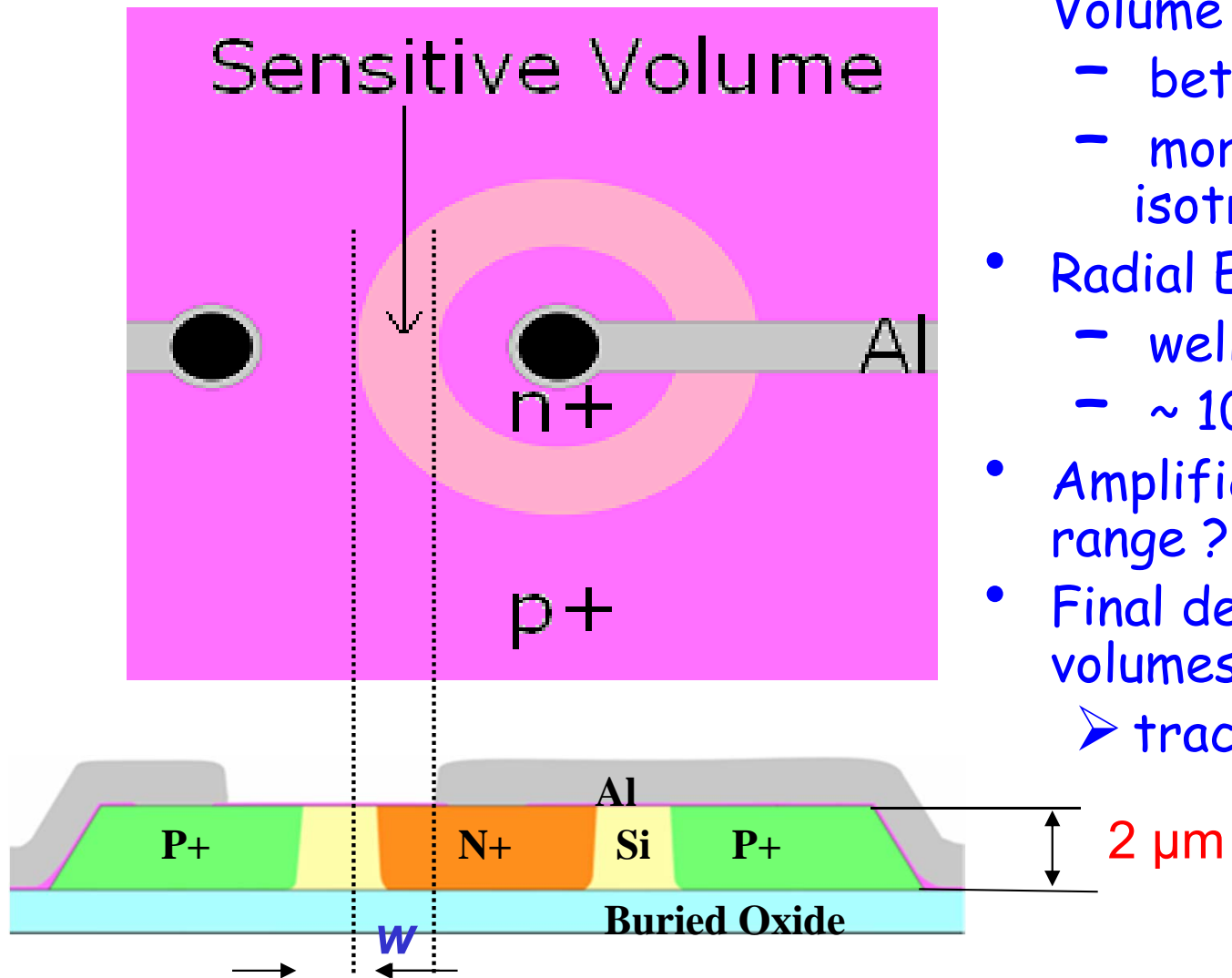
Study of Sensitive Volume in μ -Dosimeters

- Study charge collection variations with
 - Location of ion strike on the device
 - Stopping power of the ion
 - Bias applied to micro-dosimeter
- IBIC using 3 MeV H^+ , 9 MeV He^{2+} , 25 MeV C^{4+}
 - ⇒ Improved dosimetry
 - ⇒ Improved cancer treatment

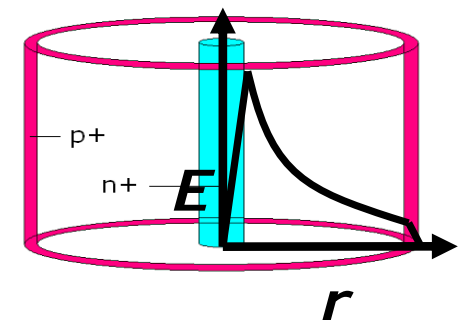
Applications

- Cancer treatment modalities which utilise high energy loss ions for radiation therapies (proton & heavy ions)

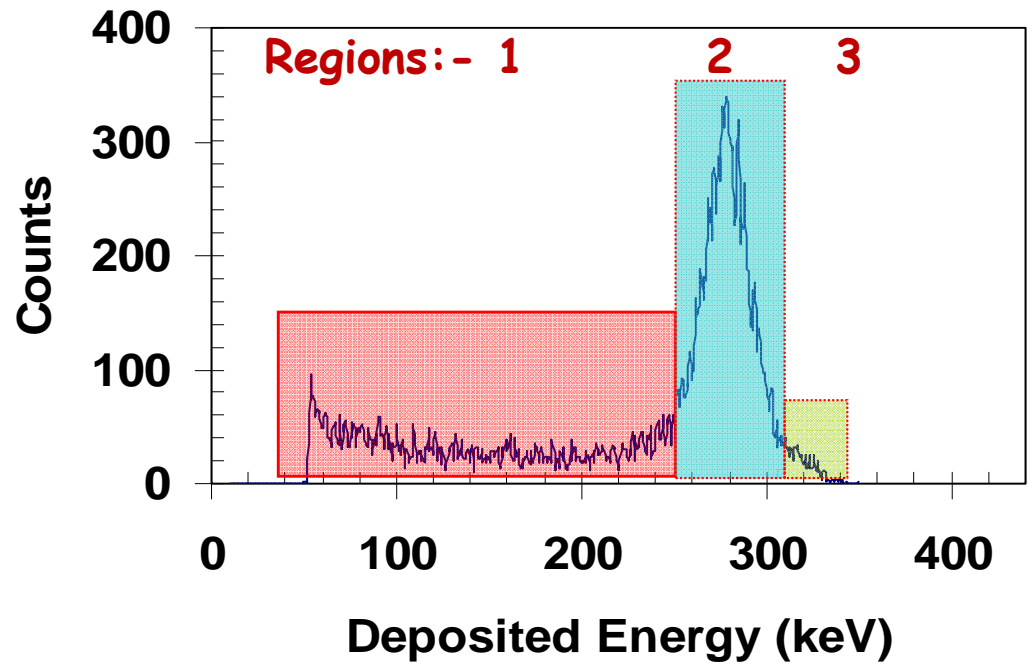
Design of 2nd Generation Micro-dosimeter



- Isolated 3D Cylindrical Sensitive Volume
 - better approx. of ideal sphere
 - more uniform response to isotropic field
- Radial Electric Field
 - well defined sensitive volume
 - ~ 100 % charge collect. effic.
- Amplification = increased dynamic range ?
- Final device: Rows of sensitive volumes in 2D array.
 - track structure



IBIC for 2 μm device (single cell)

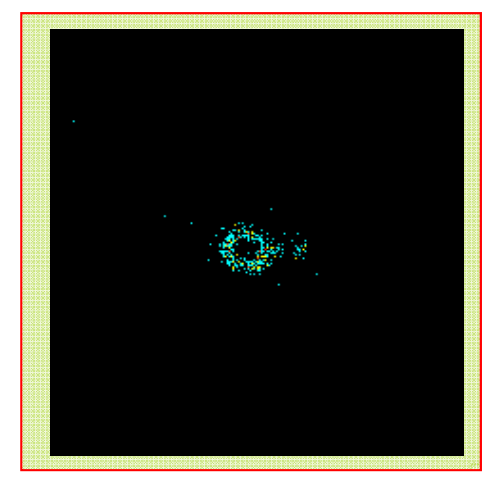
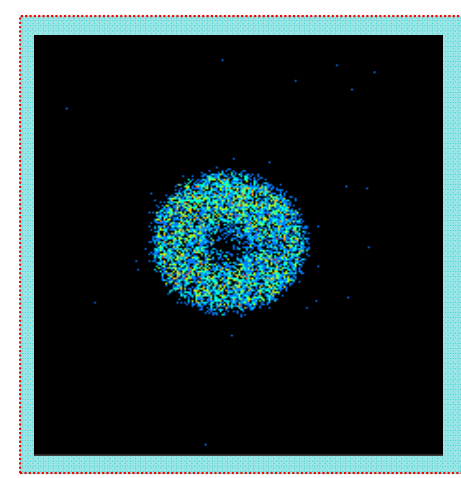
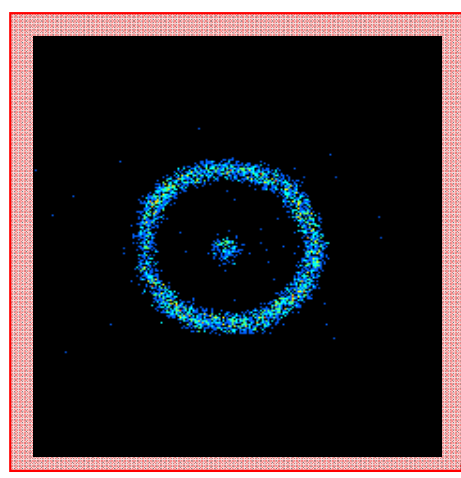
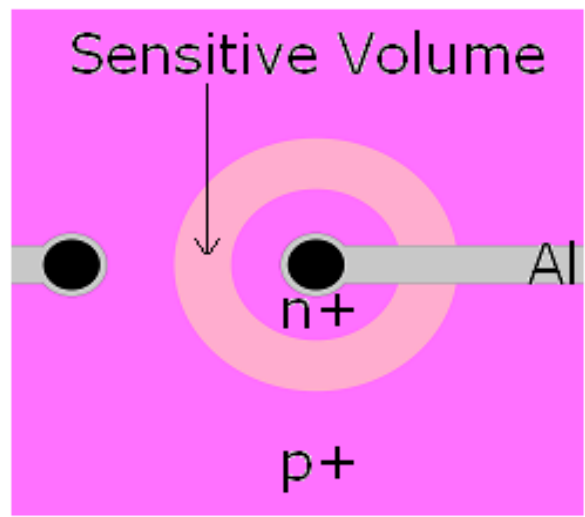


Can select regions by selecting ions and energies of interest.

Low energy: charge recombination within highly doped p^+ and n^+ regions

Peak: dull energy collection due to drift of charge under applied E-field.

High energy: enhanced charge Collection correlates with Al contact



Regions:-

1

2

3

Accelerator Research using IBA

- Hydrogen technology: enhanced H implantation capability and H depth profiling (NRA)
- Radiation hardness of multi layered structures (Ti-Al-C)
- Bio-Polymers: Gd and Sr irradiation for antiseptic wound dressing
- Radiation damage of nuclear materials for fission and fusion first wall studies
- Micro-beam irradiation of biological systems (including single cells)
- Enhanced 2D and 3D X-ray mapping capability-heavy ion confocal microprobe
- Combine ion beam implantation/characterisation for a thin film studies
- Heavy metal pathways in biological systems
- Fine particle atmospheric pollution characterisation and source apportionment studies

Cover all disciplines from Archaeometry to Zoology (A-Z)

Future Accelerator Science at ANSTO

In 2009-10 budget ANSTO received additional Federal Government funding \$25M + \$10M from ANSTO to develop Centre for Accelerator Science (CAS).

The IBA component of this includes a new 6MV Tandem accelerator with 4 IBA beam lines.

- Heavy ion ERDA
- High energy, heavy ion implantation
- Confocal microprobe
- NRA and high resolution RBS

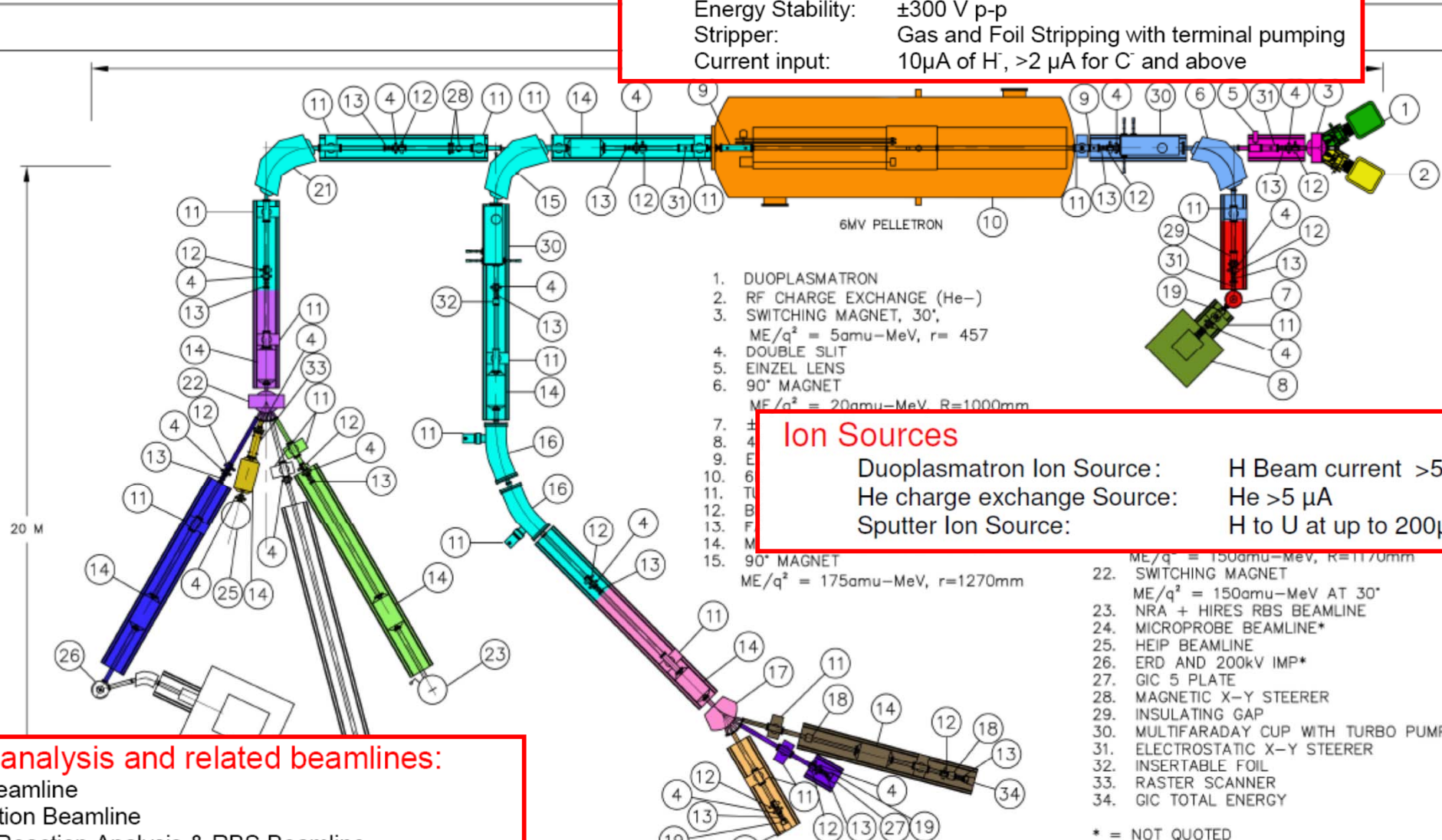
The AMS component includes a new dedicated 1MV tandem and a new AMS beamline on the 6MV Tandem for,

- Highest precision, throughput, efficiency and best background for AMS
- Highest efficiency actinides analysis

Proposed 6 MV NEC Tandem

6 MV Accelerator:

Automated, computer controlled 6 MV tandem
 Energy Stability: ± 300 V p-p
 Stripper: Gas and Foil Stripping with terminal pumping
 Current input: $10\mu\text{A}$ of H^+ , $>2\mu\text{A}$ for C^- and above



1. DUOPLASMATRON
2. RF CHARGE EXCHANGE (He^-)
3. SWITCHING MAGNET, 30° ,
 $ME/q^2 = 5\text{amu-MeV}$, $r = 457$
4. DOUBLE SLIT
5. EINZEL LENS
6. 90° MAGNET
 $ME/q^2 = 20\text{amu-MeV}$, $R=1000\text{mm}$
7. \pm
8. 4°
9. E
10. 6
11. T
12. B
13. F
14. M
15. 90° MAGNET
 $ME/q^2 = 175\text{amu-MeV}$, $r=1270\text{mm}$
22. SWITCHING MAGNET
 $ME/q^2 = 150\text{amu-MeV}$, $R=1170\text{mm}$
23. NRA + HIRES RBS BEAMLINE
24. MICROPROBE BEAMLINE*
25. HEIP BEAMLINE
26. ERD AND 200kV IMP*
27. GIC 5 PLATE
28. MAGNETIC X-Y STEERER
29. INSULATING GAP
30. MULTIFARADAY CUP WITH TURBO PUMP
31. ELECTROSTATIC X-Y STEERER
32. INSERTABLE FOIL
33. RASTER SCANNER
34. GIC TOTAL ENERGY

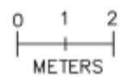
Ion Sources

Duoplasmatron Ion Source: H Beam current $>50\mu\text{A}$
 He charge exchange Source: He $>5\mu\text{A}$
 Sputter Ion Source: H to U at up to $200\mu\text{A}$

4 ion beam analysis and related beamlines:

ERDA Beamline
 Implantation Beamline
 Nuclear Reaction Analysis & RBS Beamline
 Microprobe Beamline $1\mu\text{m}$ or better for ions from H to Br

- Item 2.6
- Item 2.7
- Item 2.8
- Item 2.14
- Item 2.15
- Item 2.16



3 AMS beamlines:

gas detector for ^{10}Be , ^{36}Cl , etc
 TOF for ^{129}I , etc
 Gas-filled magnet (not shown) for ^{26}Al , etc

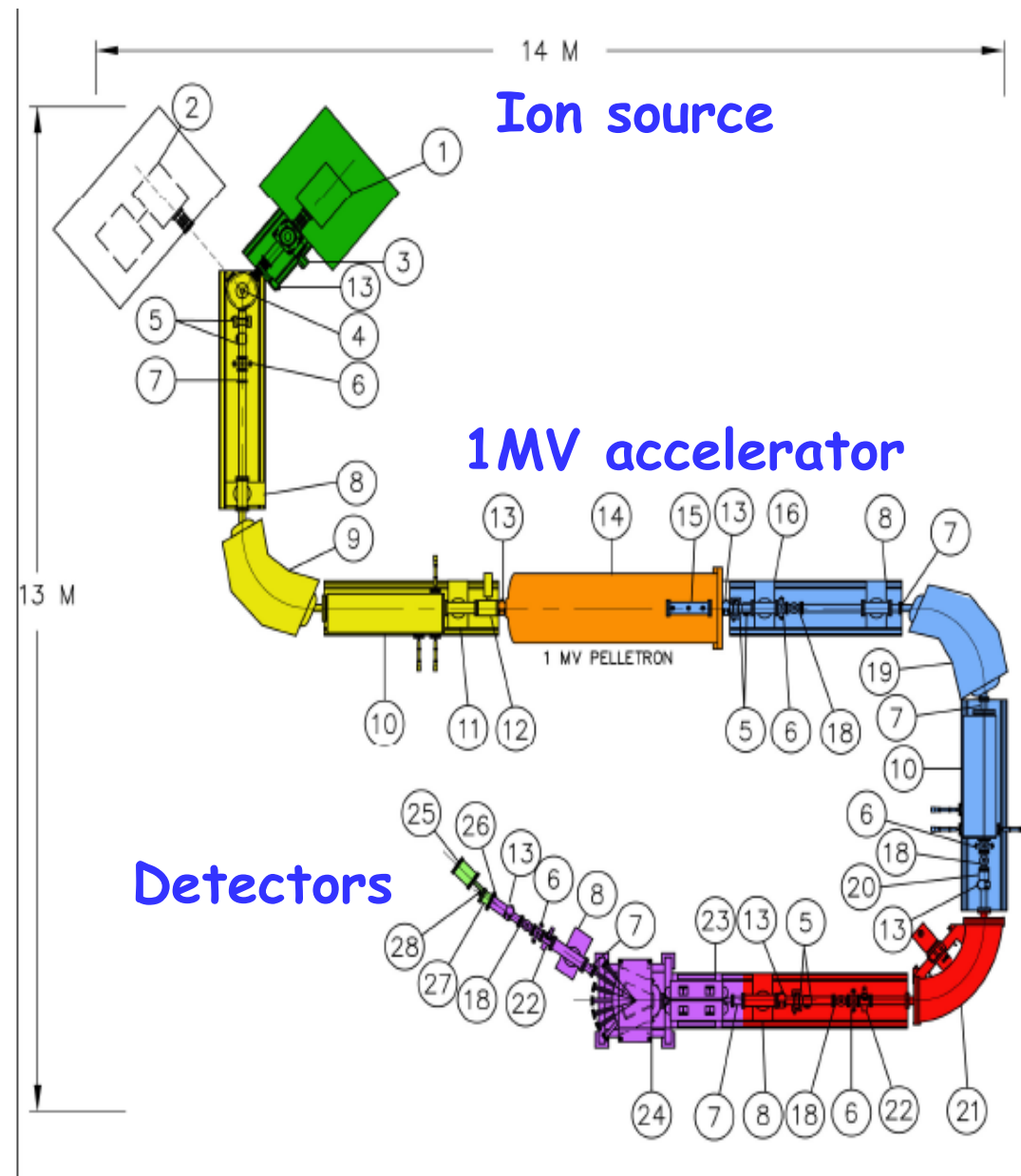
* = NOT QUOTED

ELECTROSTATICS CORPORATION MIDDLETON, WISCONSIN	
6MV PELLETRON AMS/IBA ANSTO	
DWG NO. ANSTO 6MV	LOC CV

Compact AMS 1MV NEC

Arriving at ANSTO
September 2013.

- Custom-built to our specification taking into account recent overseas developments
- Optimised for ^{14}C performance - highest precision, throughput and best background.
- Highest efficiency actinides analysis
- Allow for future development possibilities



Accelerator Science at ANSTO

Accelerator based R&D at ANSTO is based on **IBA** and **AMS** techniques. It is world class, leading edge, exciting and innovative and has outcomes across many different disciplines from **Archaeometry** to **Zoology**. Over 100 scientists/ users/ year from Australian Universities, R&D organisations and industry.

With the development of the Centre for Accelerator Science (**CAS**) and increased interactions with other Australian accelerator centres (ANU, Melb Uni Synchrotron) the future looks very promising.

For more information contact David Cohen

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