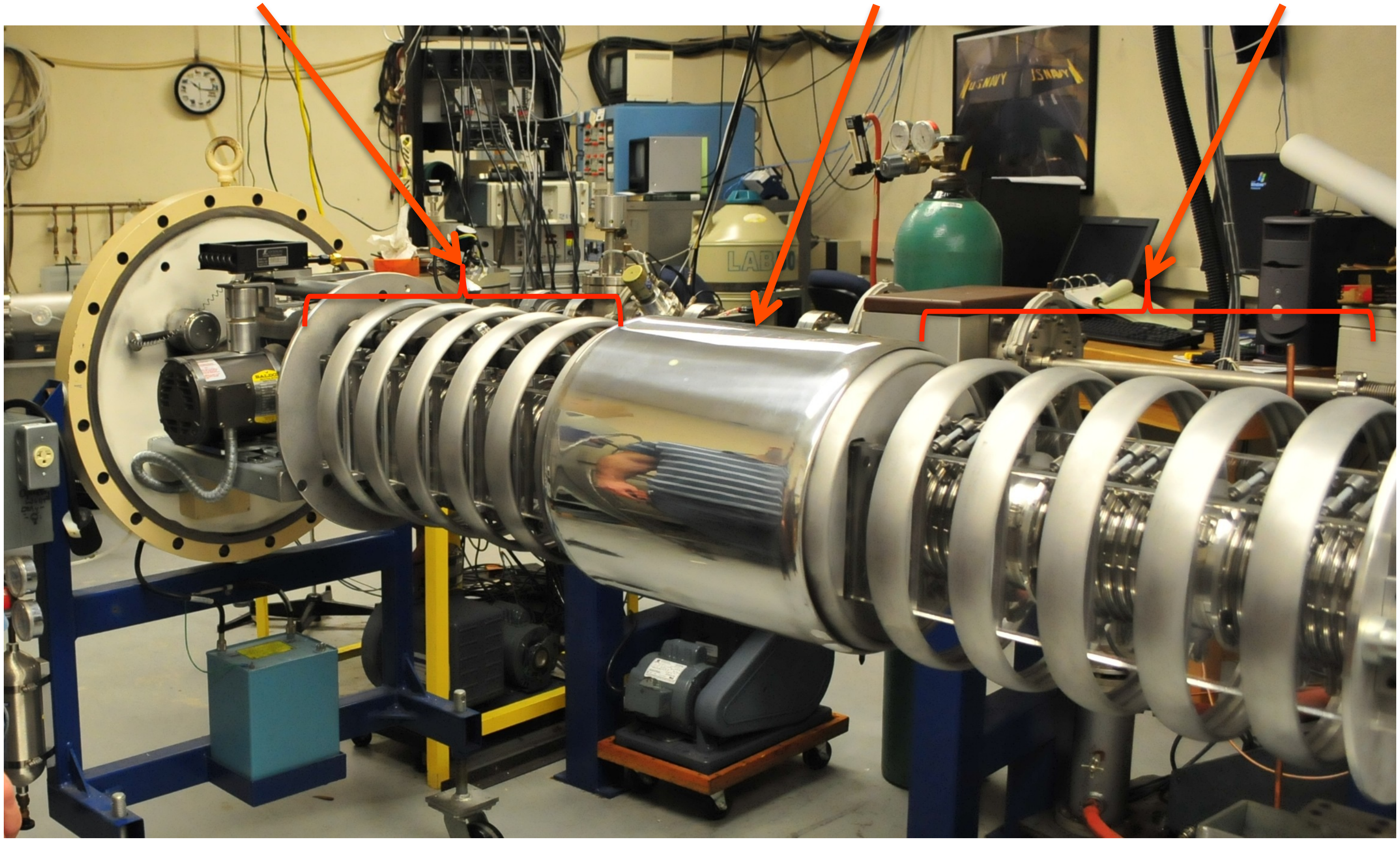
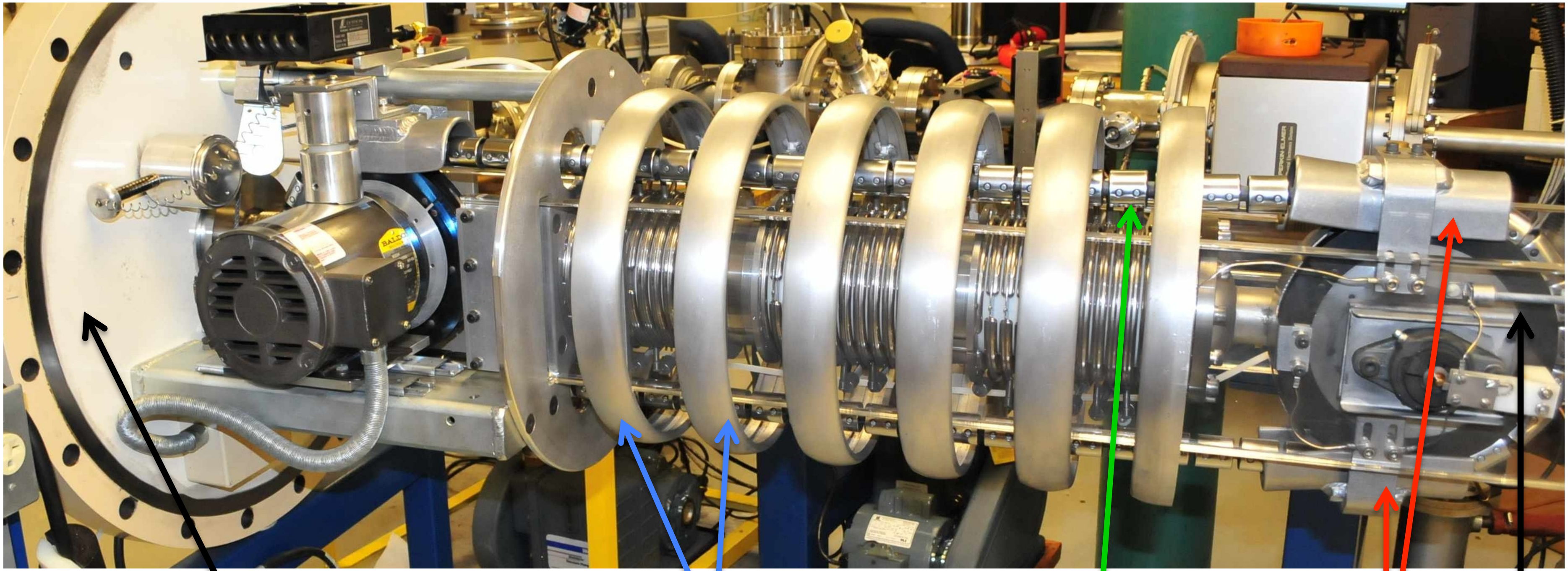
The Accelerator – What's inside the tank…

High Energy Column Terminal Shell Low Energy Column



The Accelerator – What's inside the tank…



High-energy end of accelerator

Accelerating Rings

A Pellet

Inductors

Terminal Shell

Units:

Typically work is expressed in units of kiloelectron volts (keV) or Megaelectron volts (MeV). What are these?

- **First let's consider accelerating a charged particle from rest to some speed *v*.**
- **The work done is a product of the charge and the accelerating potential that the charge passes though.**
- **It is like a ball rolling down a hill. There is a conversion of *potential energy* at the top of the hill to *kinetic energy* at the bottom of the hill. The ball starts from rest and at the bottom of the hill has a speed *v* and thus a *kinetic energy* associated with its motion. So too does the charge.**
- **It is repelled away from a like charge at the top of the potential hill and attracted to an opposite charge at the bottom of the potential hill**

$$\text{Work} = W = |q\Delta V| = \left(1e^{-}\right)\times\left(1\text{Volt}\right) = 1\text{electron}\times\text{Volt} = 1eV$$

Units:

- **Each elementary charge has *1.6x10^{-19} Coulombs* worth of charge. Therefore the work done can also be written as:**

$$\text{Work} = W = q\Delta V_{\text{accelerating}} = 1eV = 1e \times \frac{1.6\times 10^{-19}\,\text{Coulombs}}{1e} \times 1\text{Volt} = 1.6\times 10^{-19}\,\text{Joules}$$

- **An electron-volt is a unit of energy**
- **And our conversion is that *1eV = 1.6x10^{-19} J.***
- **By the work-kinetic energy theorem, the work done accelerating the charge changes the kinetic energy from zero (the charge is initially at assumed to be at rest) to some speed *v* given by**

$$\text{Work} = \Delta\text{Kinetic Energy} = \Delta KE = \frac{1}{2} m_{ion} v_{ion}^{2}$$

A Couple of Quick Calculations

How fast is the proton traveling when it leaves the ion source?

$$W_i = -q\Delta V = -\left(1e \times \left(0kV - 3.6kV\right)\right) = 3.6keV$$

$$W_i = \Delta KE$$

$$W_i = 3.6keV \times \frac{1.6\times10^{-19}J}{1eV} = 5.76\times10^{-16}J = KE_f - KE_i = KE_f$$

$$5.76\times10^{-16}J = \frac{1}{2}m_p v_p^2$$

$$\therefore v_p = \sqrt{\frac{2\times5.76\times10^{-16}J}{1.67\times10^{-27}kg}} = 8.31\times10^5\,\tfrac{m}{s}$$

A Couple of Quick Calculations

What is the kinetic energy of the proton after it leaves the accelerator?

$$W_{total} = \sum_{j=1}^{N} w_j = -\sum q\Delta V = w_{source} + w_{low-energy} + w_{high-energy}$$

$$W_{total} = -\left\{1e^{+} \times \left(0kV - 3.6kV\right) + \left(-1e^{-}\right) \times \left(1.1MV - 0MV\right) + 1e^{+} \times \left(0MV - 1.1MV\right)\right\}$$

$$W_{total} = KE_f = 3.6keV + 1.1MeV + 1.1MeV = 2.2036MeV \approx 2.2MeV$$

$$\therefore KE_f = 2.2MeV \times \frac{1.6\times10^{-19}J}{1eV} = 3.52\times10^{-13}J$$

What is the speed of the proton after it leaves the accelerator?

$$KE_f = \frac{1}{2}m_p v_p^2 \rightarrow v_p = \sqrt{\frac{2KE_f}{m_p}} = \sqrt{\frac{2\times3.52\times10^{-13}J}{1.67\times10^{-27}kg}} = 2.05\times10^{7}\,\tfrac{m}{s}$$

A Couple of Quick Calculations

Comment:

Generally one needs to worry about the speeds of these particles and how they compare to the speed of light.

- Need to include Relativistic effects?
- In other words does the measured speed of the proton equal the theoretical speed of the proton?

This is hard to do… so, we set a limit… and we define a relativistic limit to be when the velocity of the object is less than *one-tenth* the speed of light ($c \sim 3x10^8$ *m/s*) then we do not have to worry about relativistic effects.

Here the velocity is $2.05x10^7$ m/s which is *0.069* times the speed of light, less than the limit, so no relativistic effects.

Steering of Ions

- The steering magnets are a momentum filter (or here, a really crude mass spectrometer.)
- A momentum filter is a device which separates charged particles based on their momentum (or kinetic energy, which is proportional to their momentum).
- When a charged particle passes through a magnetic field with a component of its velocity perpendicular to the magnetic field, the charge will feel a force and it will move in the direction of the applied force.
- The magnetic force is given by $\vec{F} = q\vec{v} \times \vec{B}$

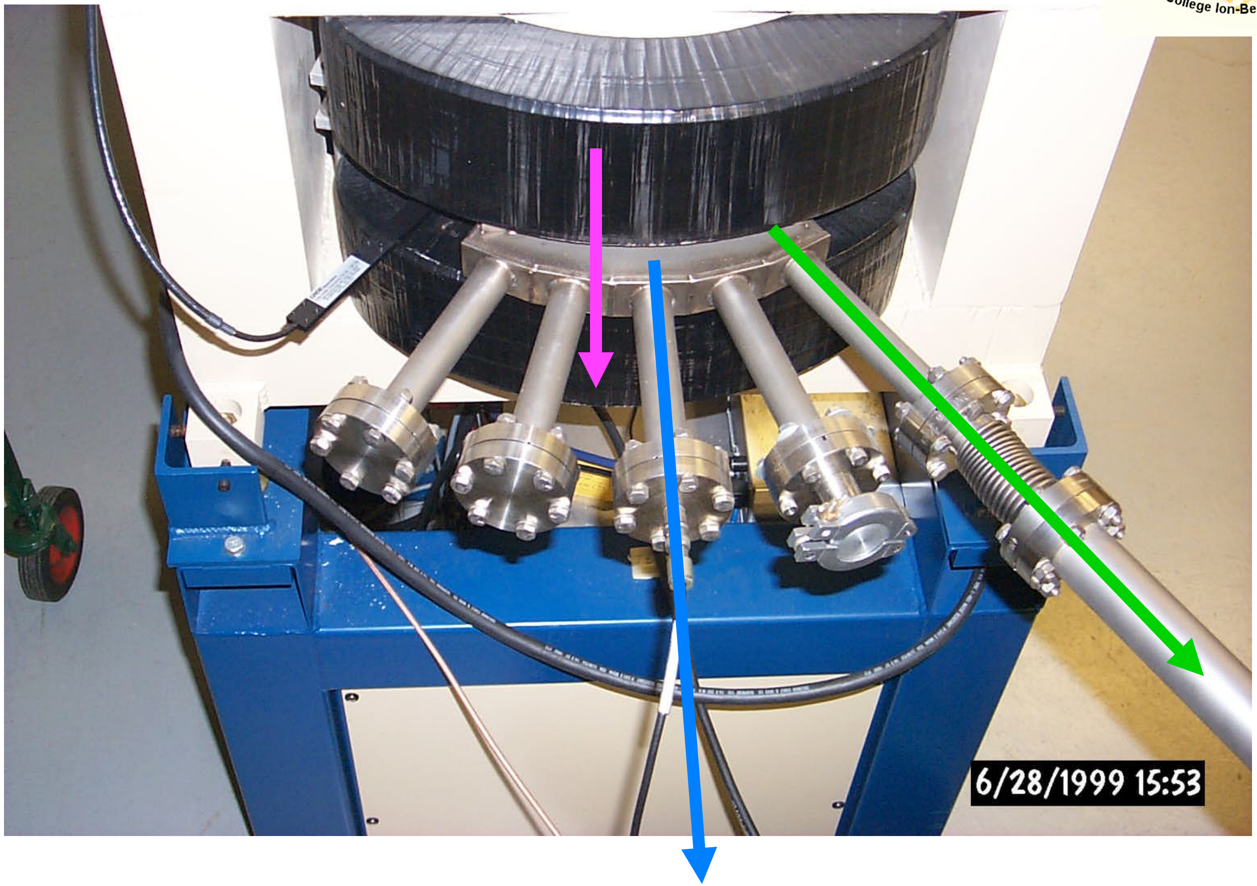
Side view of steering and quadrapole magnets

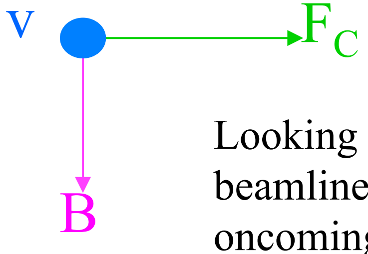
Steering of Ions

B points straight down to the floor from the upper to the lower magnet.

The velocity vector of the charges is coming out of the machine at you. This is called the zero-degree beamline.

Choosing the field appropriately (to match the particle's energy bends the charges to your right and down the 30^{o} beamline.





Looking down the beamline at the oncoming charge

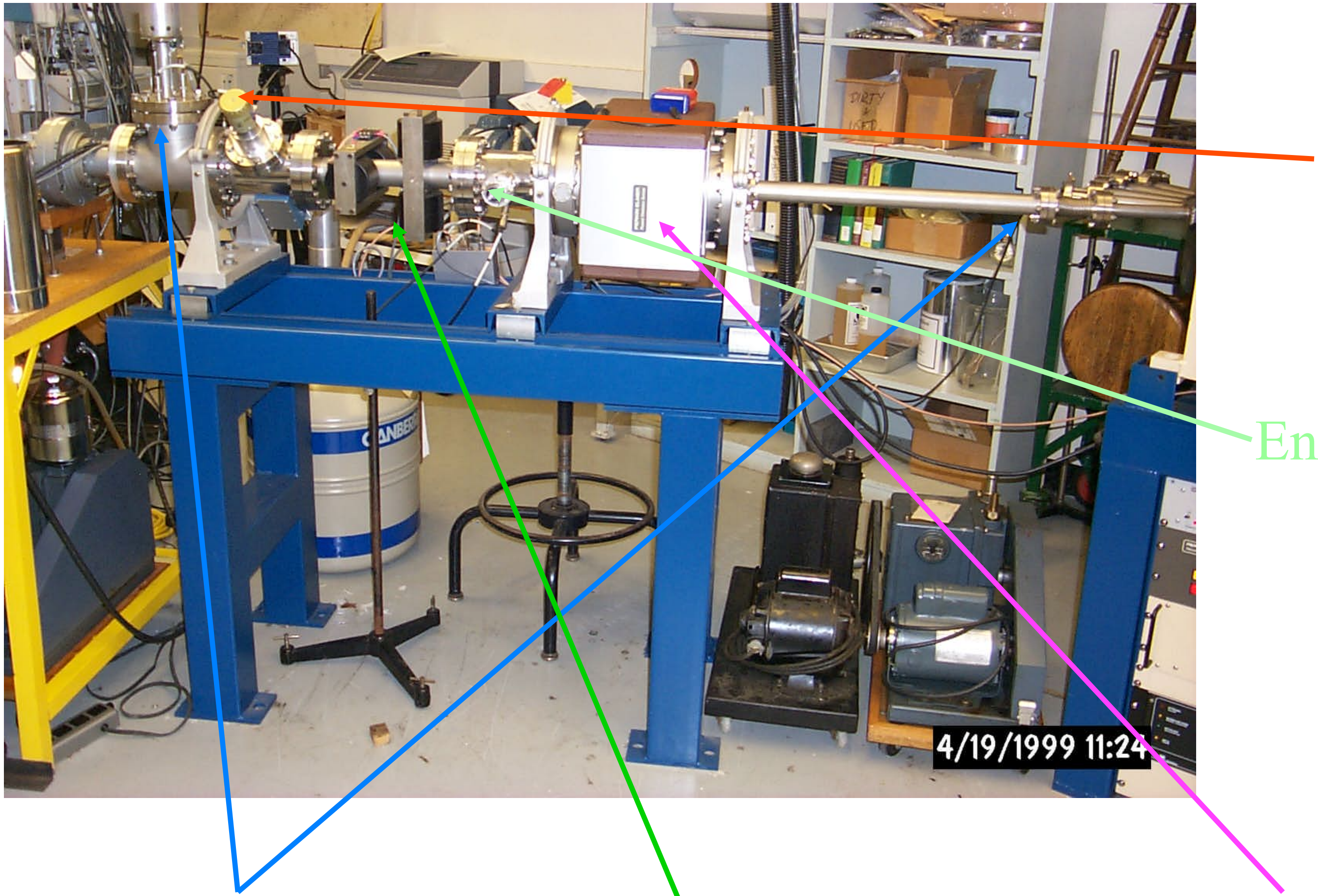
A Couple of Quick Calculations

- So, we've accelerated the proton and calculated its energy and speed.
- Now can we steer it in the magnetic field? If so, what is its orbital trajectory, or radius?
- The proton feels a force given by $\vec{F} = q\vec{v} \times \vec{B}$.
- This makes the particle travel in a circle of radius *r* due to the centripetal force it feels. $F_B = F_C \rightarrow qv_pB = \frac{m_p v_p^2}{r}$

$$r = \frac{m_p v_p}{qB} = \frac{1.67 \times 10^{-27} kg \times 2.05 \times 10^7 \frac{m}{s}}{1.6 \times 10^{-19} C \times 0.6214 T} = 0.344 m = 34.4 cm$$

- Once the charges leave the magnetic field the force vanishes and they continue in a straight line toward the scattering chamber.

A few odds and ends on the way to the scattering chamber….



Beam profile monitor

Energy controller

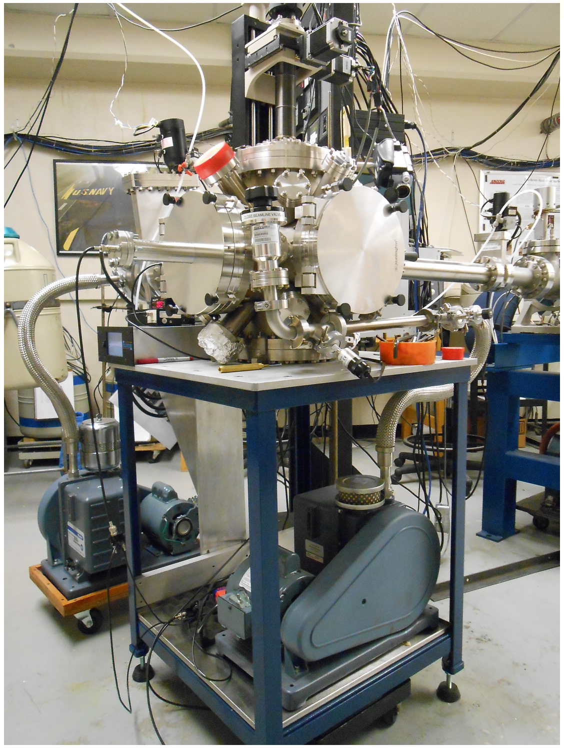
Faraday cups

Ion pump (not in use)

Horizontal and Vertical steering magnets

The scattering chamber

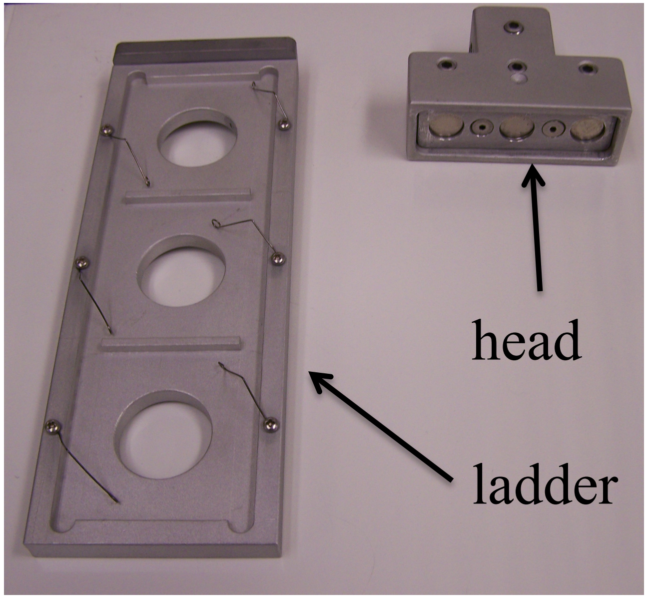
This is where the experiments are done.

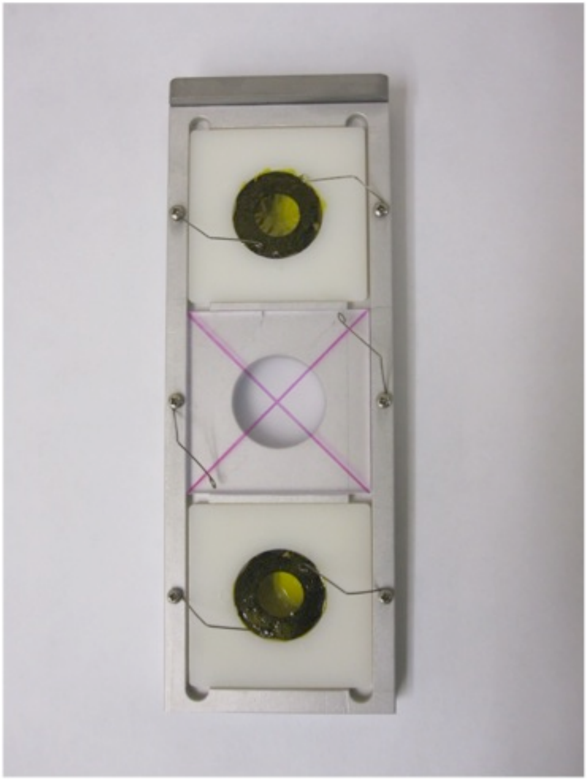


- The scattering chamber is a 10” multi-port Conflat system with a 3-axis target manipulator mounted on top.

- Samples are placed inside and can be moved horizontally in a plane, vertically, and rotated about a central axis.

Target Ladder Assembly



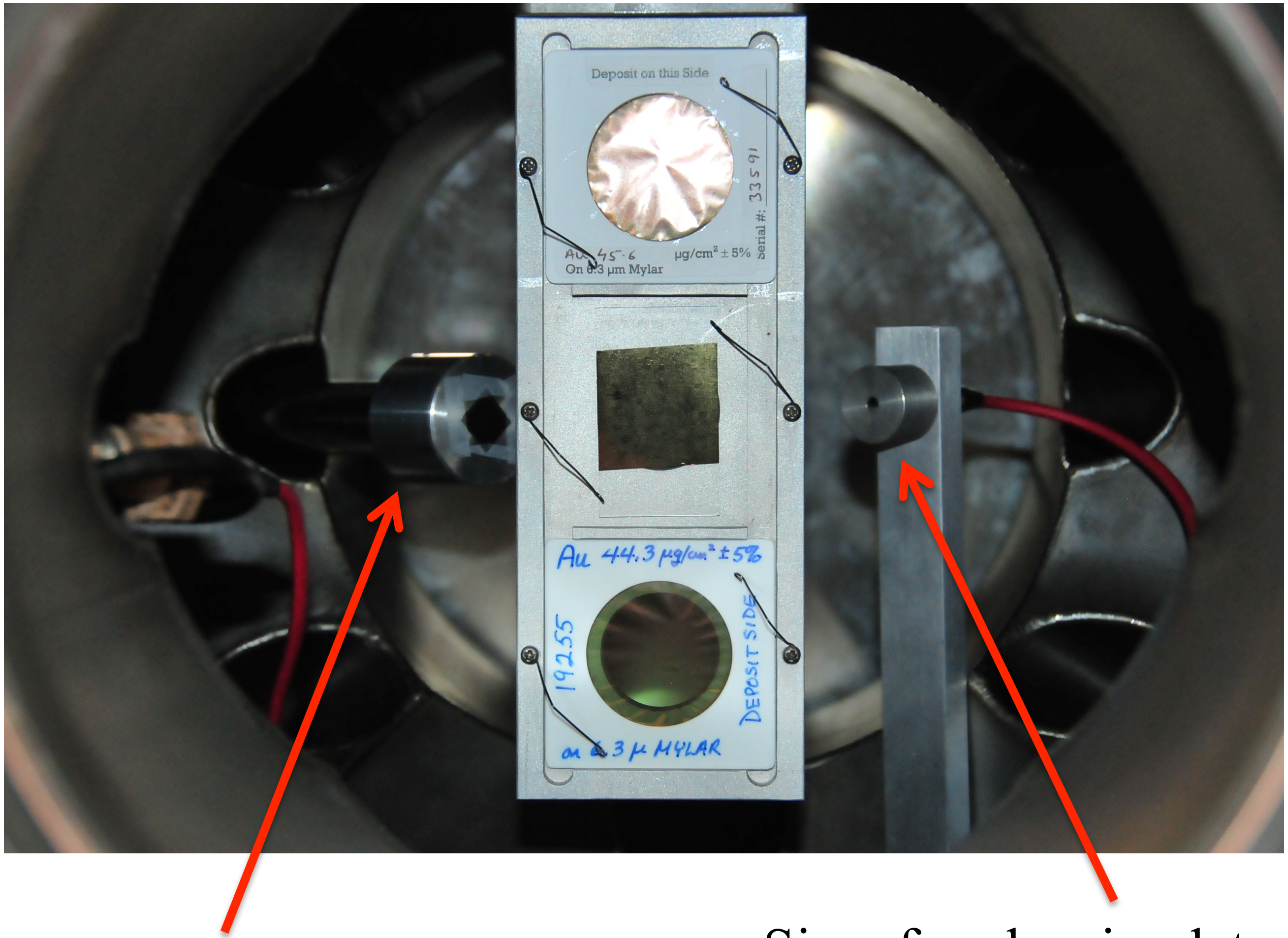


- Inside of the scattering chamber is the target ladder assembly. It is attached to the target manipulator by a “head” by a shaft (not shown) and the ladder is magnetically coupled to the head.

- Three targets at a time may be analyzed using the ion beam.

Inside the scattering chamber

The ion beam enters facing you and passes thought the targets



X-ray detector (for *PIXE*)

Si surface barrier detector (for *RBS & ERDA*)

Uses of a particle accelerator

Materials Analysis

Environmental Samples

Mass spectrometry

Nuclear reactions

Nuclear structure

Medicine

Nuclear Medicine

Biochemistry

Paleontology

Forensic science.

Art restoration and archeometry