Physics 100 – Module 1

Materials Science and Materials Analysis using a Particle Accelerator

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My Background:

In the department for 12 years

7th time teaching Physics 100.

Teach primarily

- Physics 110/111 (Physics for the Life Sciences)
- Physics 120 (Physics for Majors and Engineers)
- Physics 210 (Medical Physics)
- Physics 300 (Modern Experimental Techniques)

Background continued…

- I am a theoretical physicist who was trained in waveguide theory

  Production, propagation, and diffraction of x-rays (a type of electromagnetic wave) through glass capillary fibers.

  Includes surface roughness and x-ray attenuation effects.

- I am also an experimental physicist who runs the particle accelerator.

  Environmental pollution studies with aerosols/liquids

  Environmental pollution near airports

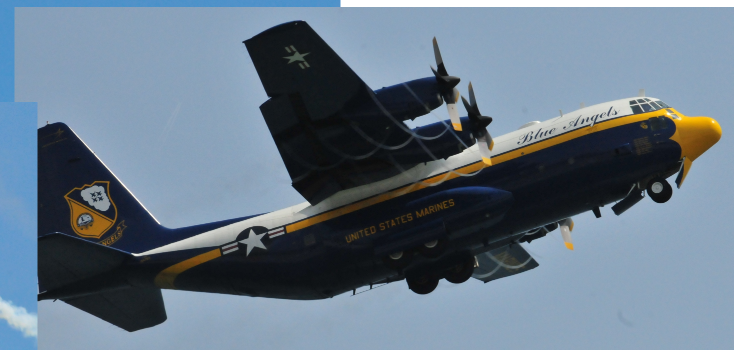
  Medical and Health Physics issues – Hg in Fish/metal distribution in tissues

  Soil contamination – Mud Samples

  Art and Archeometry

  At some point – Forensics/paleontology/medical applications

My physics hobbies…

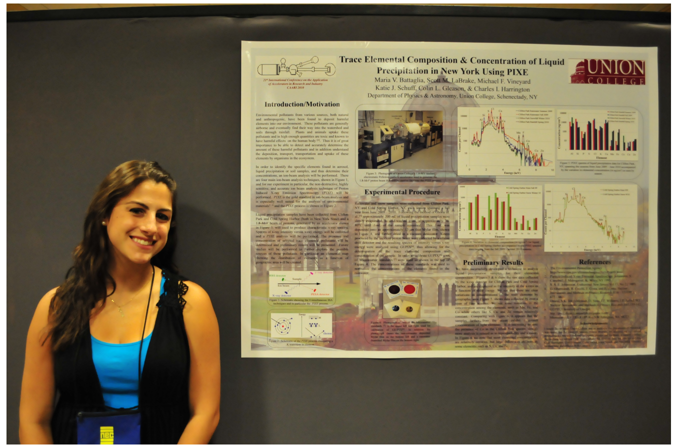


Fluid Mechanics
Aerodynamics
Flight and Flight Mechanics
Aircraft Photography

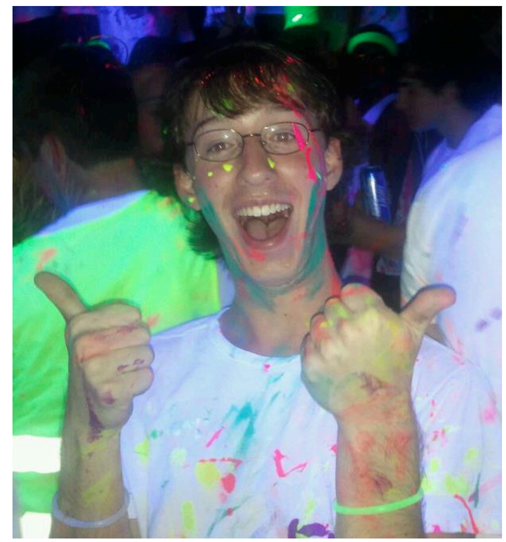
Motion and Gravity

The Union College Ion Beam Analysis Laboratory

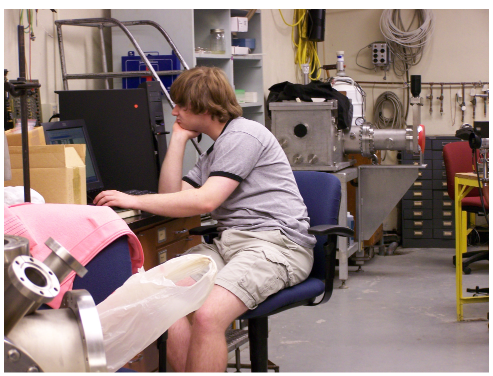
Chad & Colin are now graduate students (at SUNY Buffalo and University of South Carolina), who worked on the analysis of atmospheric aerosols by PIXE/PIGE/RBS/PESA.



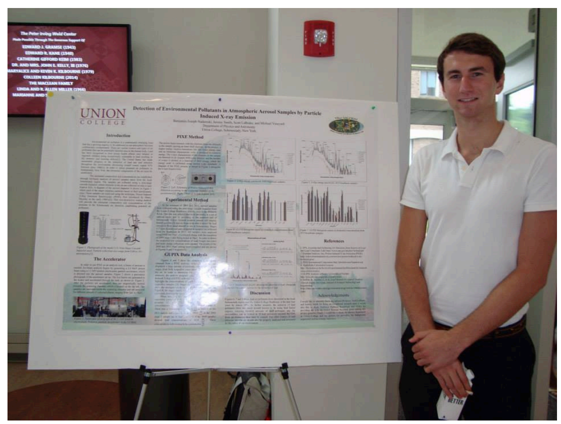
Maria is a 2nd year medical student who worked on liquid precipitation samples and on the development of a procedure for looking at the distribution of metals in animal (skate) tissues. Here she is at CAARI, an international accelerator conference in Fort Worth Texas



Jeremy is a senior (and former PHY100 student) who is working on his senior thesis on the accelerator studying lead emissions from small airplanes at Schenectady airport.



Colin is a graduate student at Penn State who worked on the analysis of atmospheric aerosols by RBS/PESA.



Ben is a sophomore (and last year took PHY100) who is looking at lead pollution near airports.

Some past and present research students

What does the *UCIBAL* study?

Environmental Pollution

Solids – soils, trees, tissues
Liquids – water, wines, blood
Gas – atmospheric aerosols

http://www.offthehoof.co.uk/2013/03/how-to-avoid-environmental-pollution/

http://www.conserve-energy-future.com/wp-content/uploads/2013/04/Smoke_from_airplane.jpg

http://ocean.nationalgeographic.com/ocean/critical-issues-marine-pollution/

Game Plan….

•We're going to use a what?

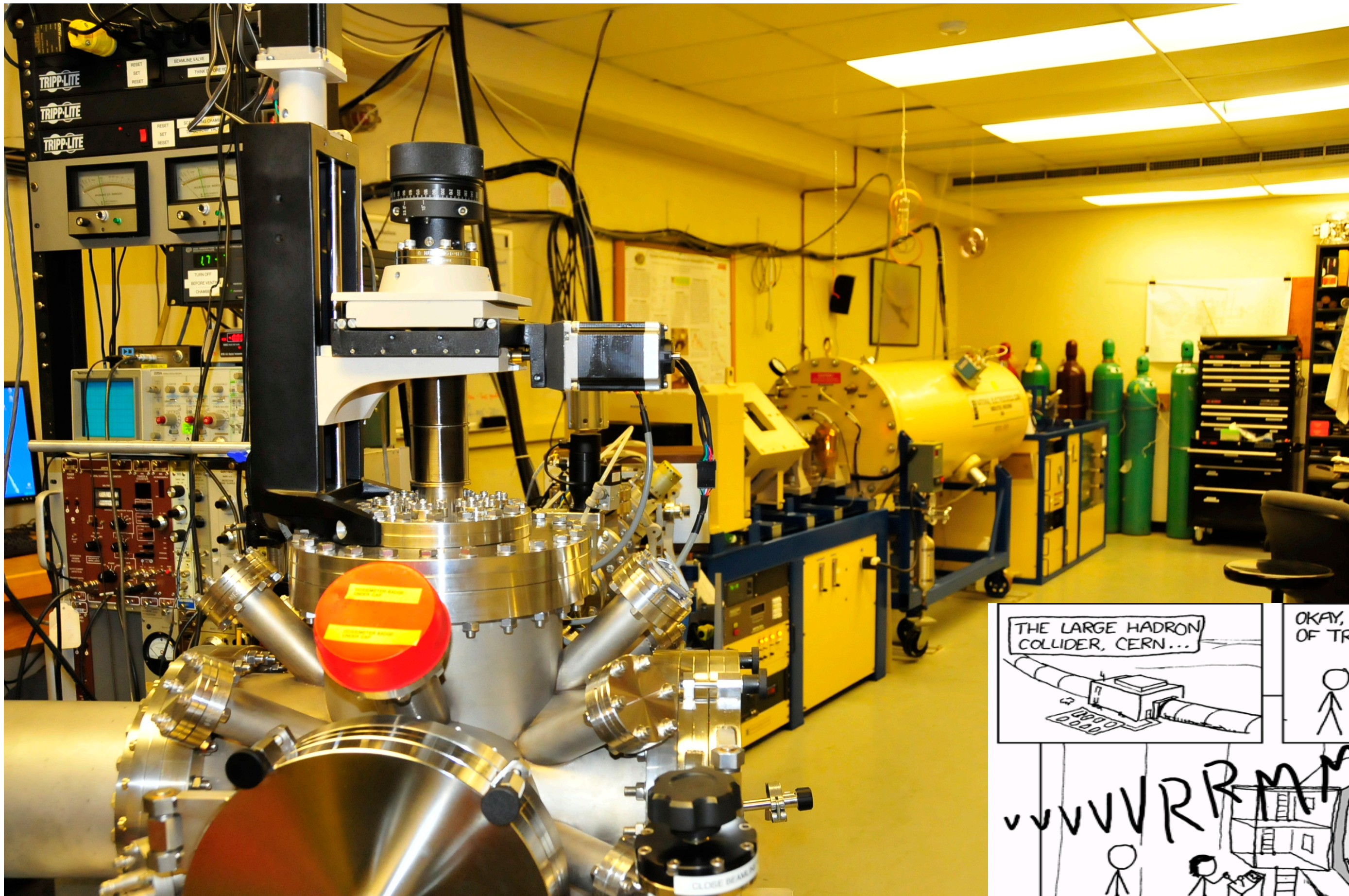
•Accelerator – What it is, What it does. Energy and velocity calculations.

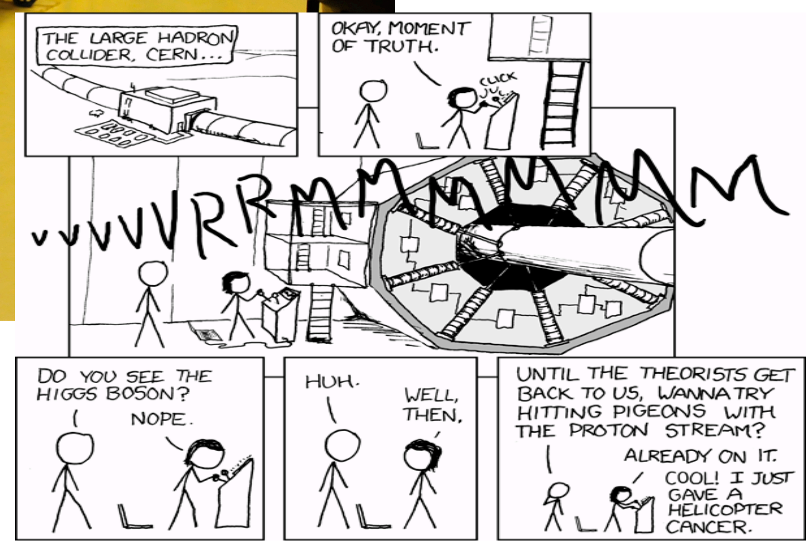
•*PIXE* – Basics, Theory and Sample calculations.

•Modifications to the *PIXE* Theory.

•Materials Analysis of a sample using *PIXE* and the accelerator.

We’re going to use a what? A particle accelerator?



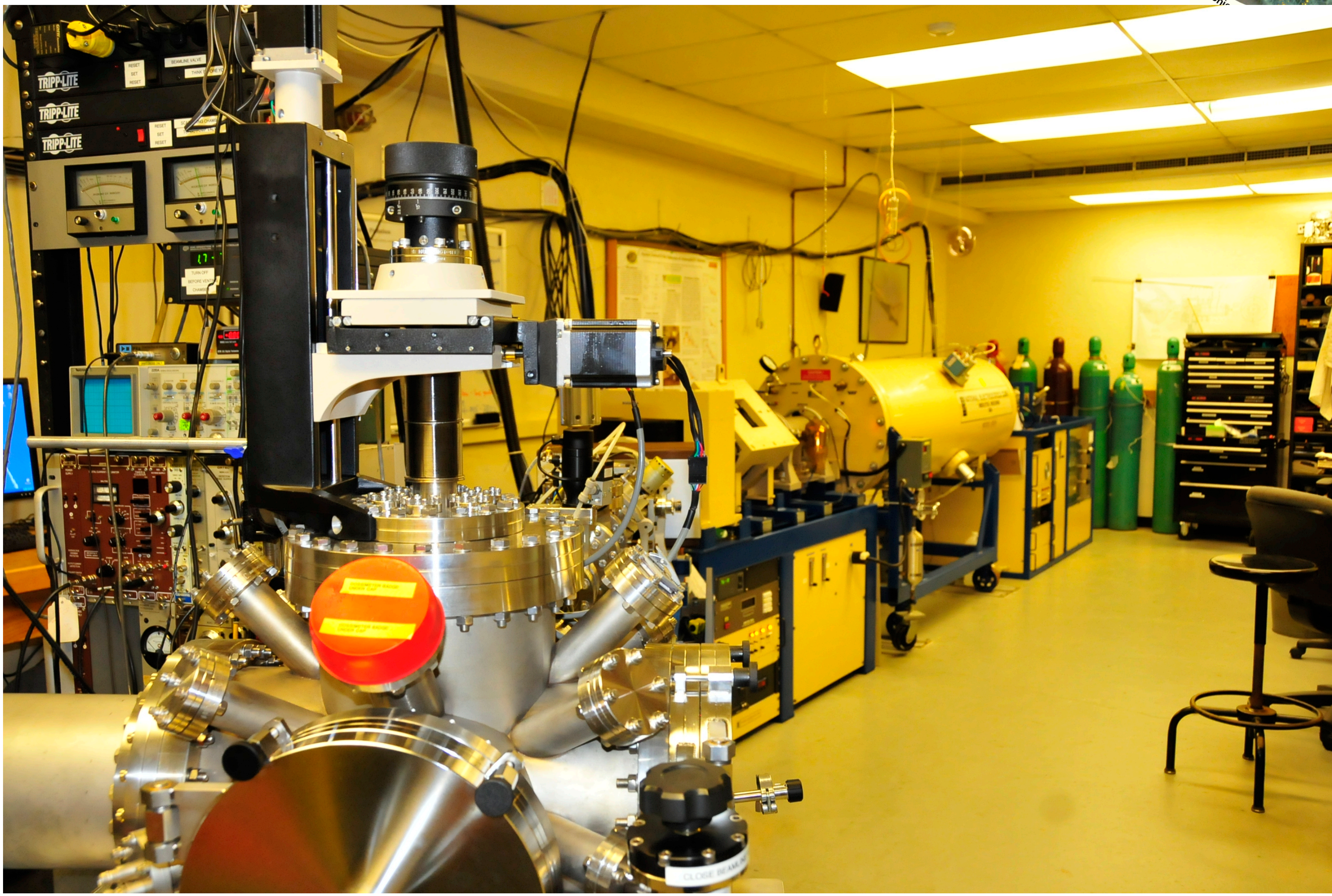


http://sciencegeekgirl.com/files/2008/12/large_hadron_collider1.png?w=300

The Pelletron Particle Accelerator

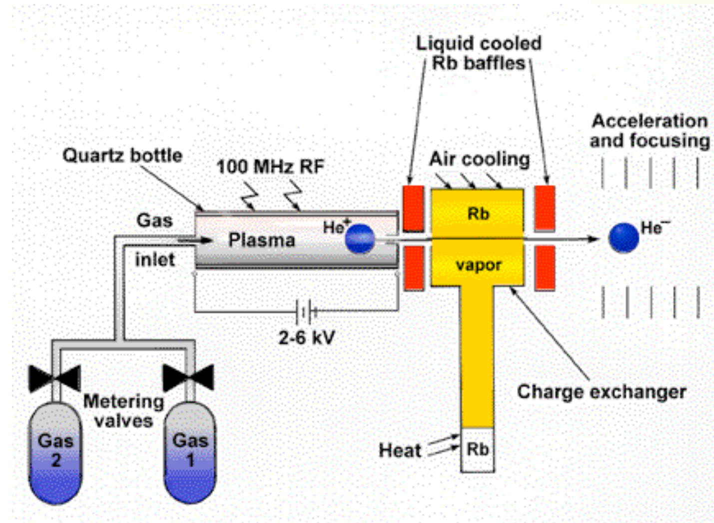
- Built by the National Electrostatics Corporation
- Acquired in 1991
- Replaced 450 kV Van-de-Graff accelerator
- Our accelerator has 4 main components
    - Ion production
    - Two-Stage (tandem) acceleration of ions
    - Steering of ions
    - Scattering chamber

The Pelletron Particle Accelerator



The Source: Ion Production

- H or He gas is bled into the gas inlet.
- 100MHz Radio Frequency (RF) electromagnetic energy is dumped into the quartz bottle which produces H^+, He^+, He^{++} and other ions.
- A potential difference of about 6kV (for He) or 3kV (for H) is applied across the bottle.
- This accelerates the ions out into the charge exchanger.

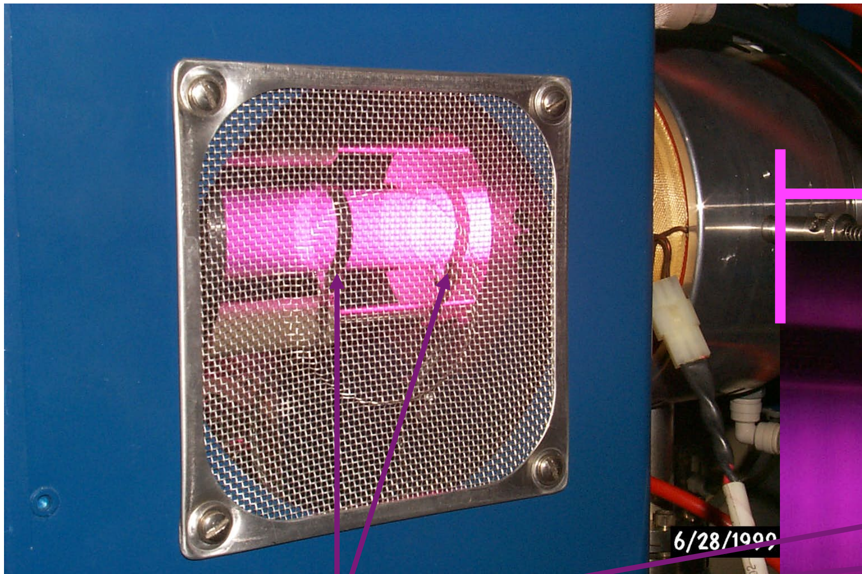


http://www.pelletron.com

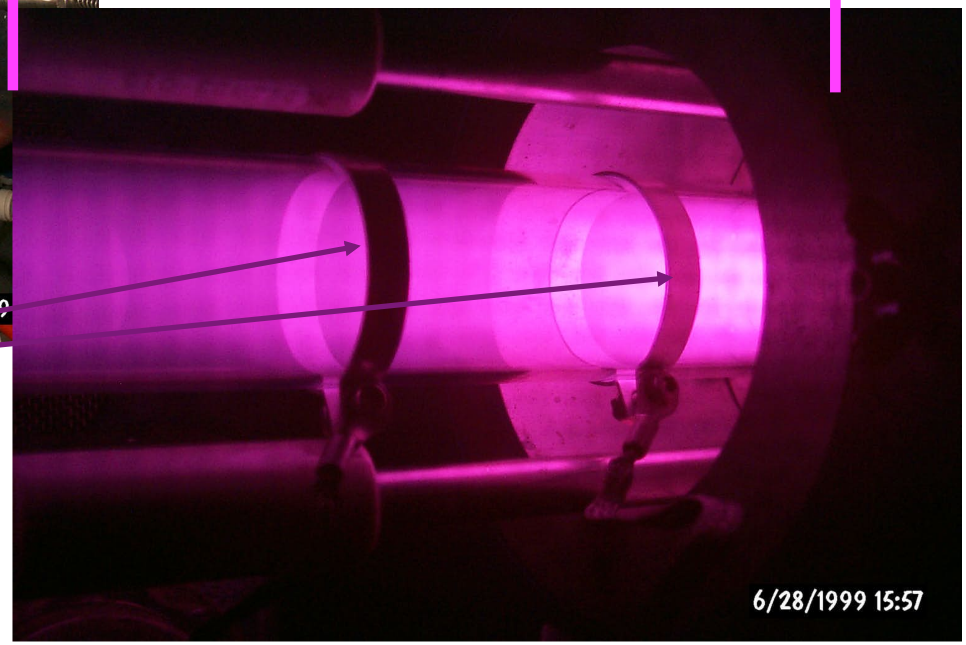
- The H^+ or He^+ charges pass through a low density Rubidium (Rb) vapor and through charge-exchange collisions pick up extra negative charges.
- The H^- or He^- charges continue on into the accelerator.
- Of course there are other ions that are also accelerated (N^-, O^-, ...)

The UCIBAL
Union College Ion-Beam Analysis Lab

Ion Production and Plasma Source



ΔV = 3kV to 6kV



Looking into the back end bottle. The metal bands are what couples the RF source to the bottle.

Characteristic glow of a hydrogen plasma.

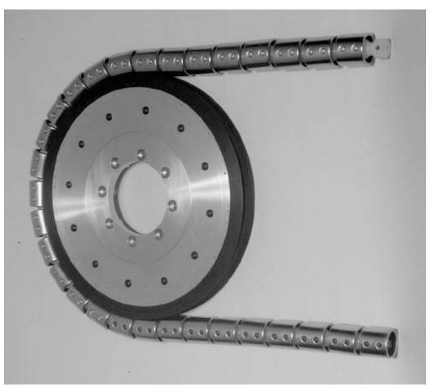
The Low Energy End of the Accelerator

Ion Source or Low-Energy end of the accelerator showing the Rubidium furnace and cooling system. The H^+ plasma is the faint pink glow.

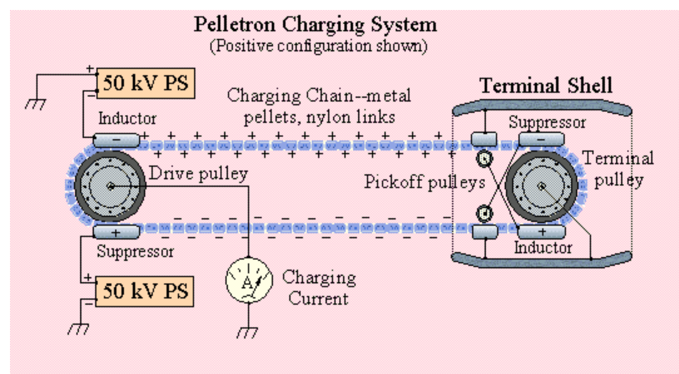
Wide view of ion source. This also has a *Faraday cup* in view. The faraday cup is designed to count the number of charges and determine the beam current.

Tandem acceleration of ions

- The negative ions are accelerated toward the center of the pressure tank by a 1.1 MV difference in potential between the low-energy end and the terminal.
- The center of the pressure tank (the terminal) is made positive with respect to the charge exchanger.
- The potential difference is developed by the Pelletron Charging system, which consists of metal pellets and insulating connectors.
- The terminal is charged by induction and is a very stable and reliable system.



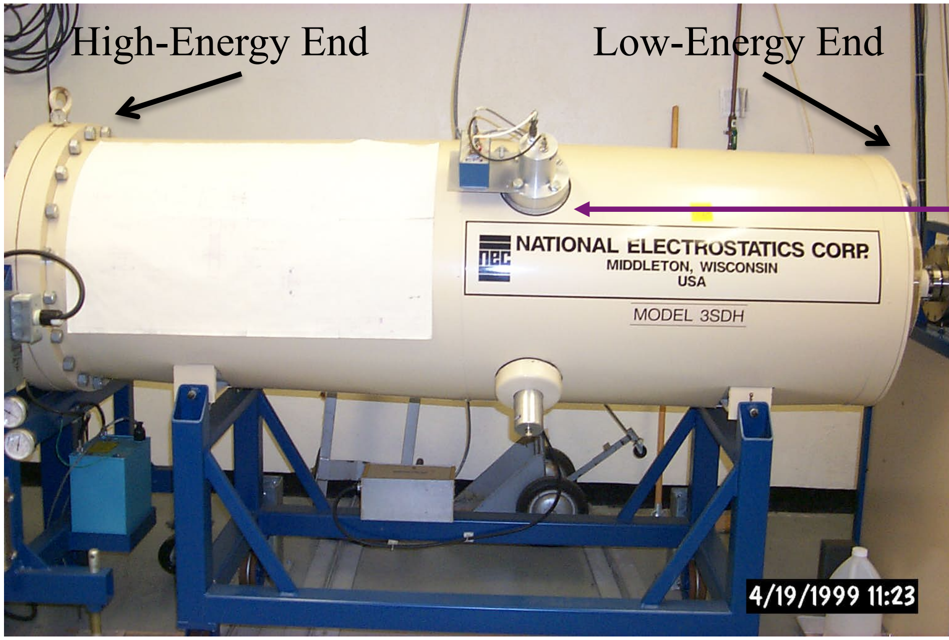
Pelletron Chains



Pelletron Charging System by NEC

http://www.pelletron.com/charging.htm

The Accelerator



• The chain is housed inside of this tank.

• The terminal is in the center.

• From right edge of the photo (the low-energy end) to the terminal a *1.1MV* is applied.

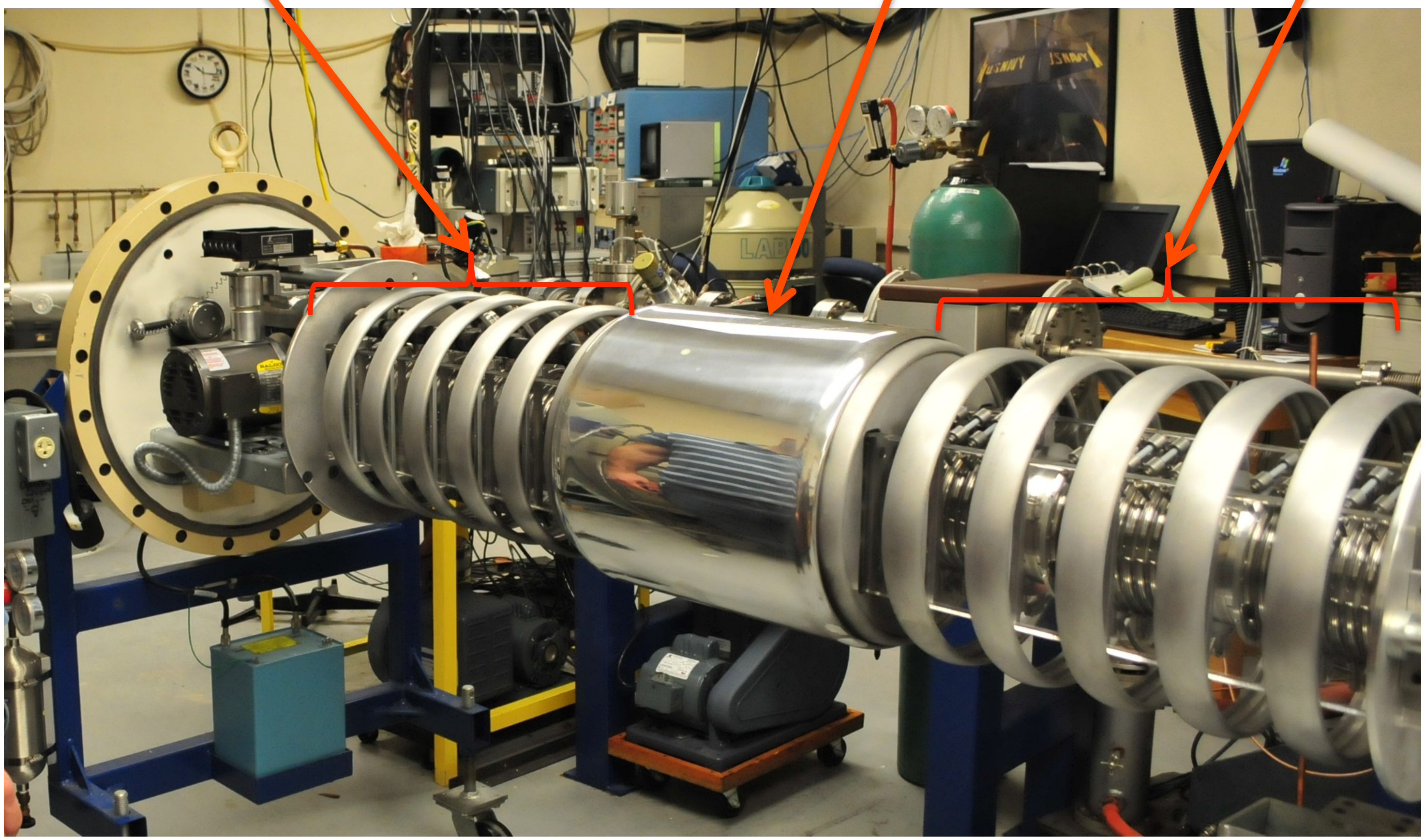
• From the terminal to the high-energy end there is another *1.1MV* difference in potential.

• Nitrogen gas is bled from the left end of the photo to the terminal to pull off the added negative charges through anther charge-exchange collision.

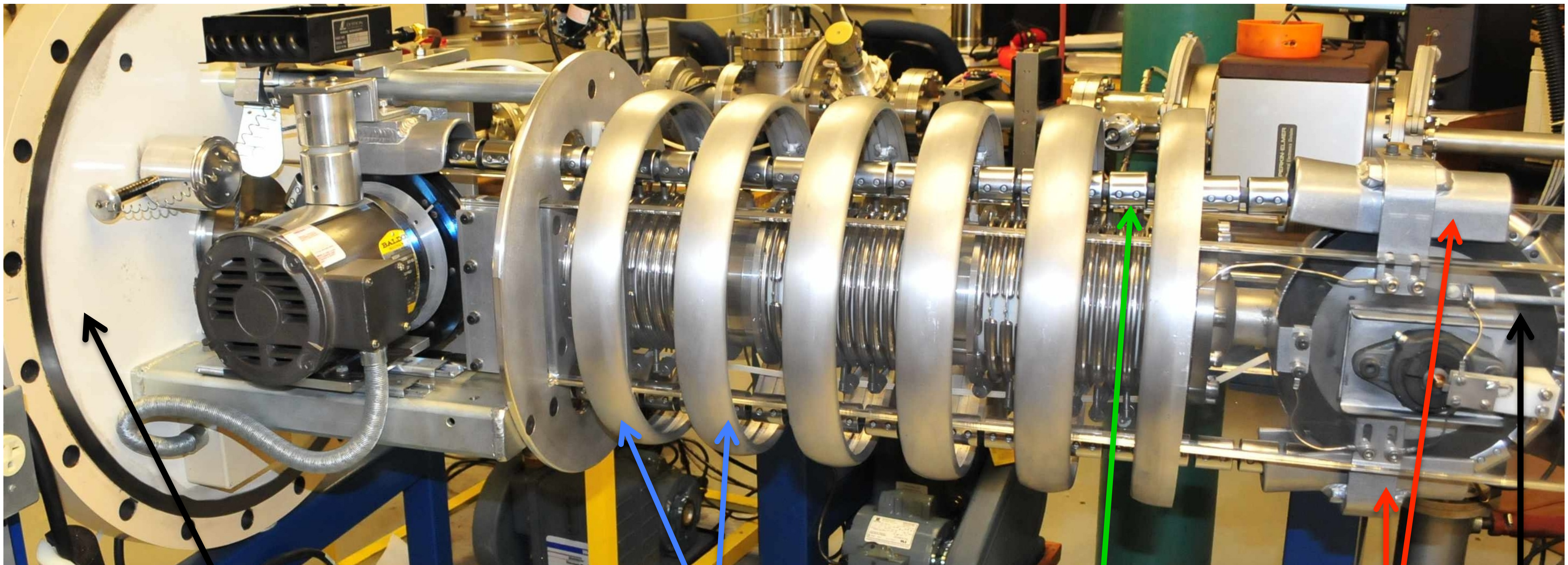
• The resultant positive particle is accelerated away from the terminal back down *1.1MV* towards the left edge and thus produces a tandem acceleration of the ion species.

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

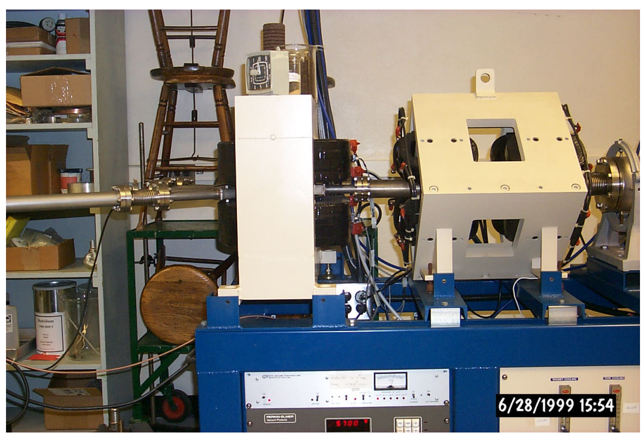
A Pellet

Inductors

Terminal Shell

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 $\vec{F} = q\vec{v} \times \vec{B}$



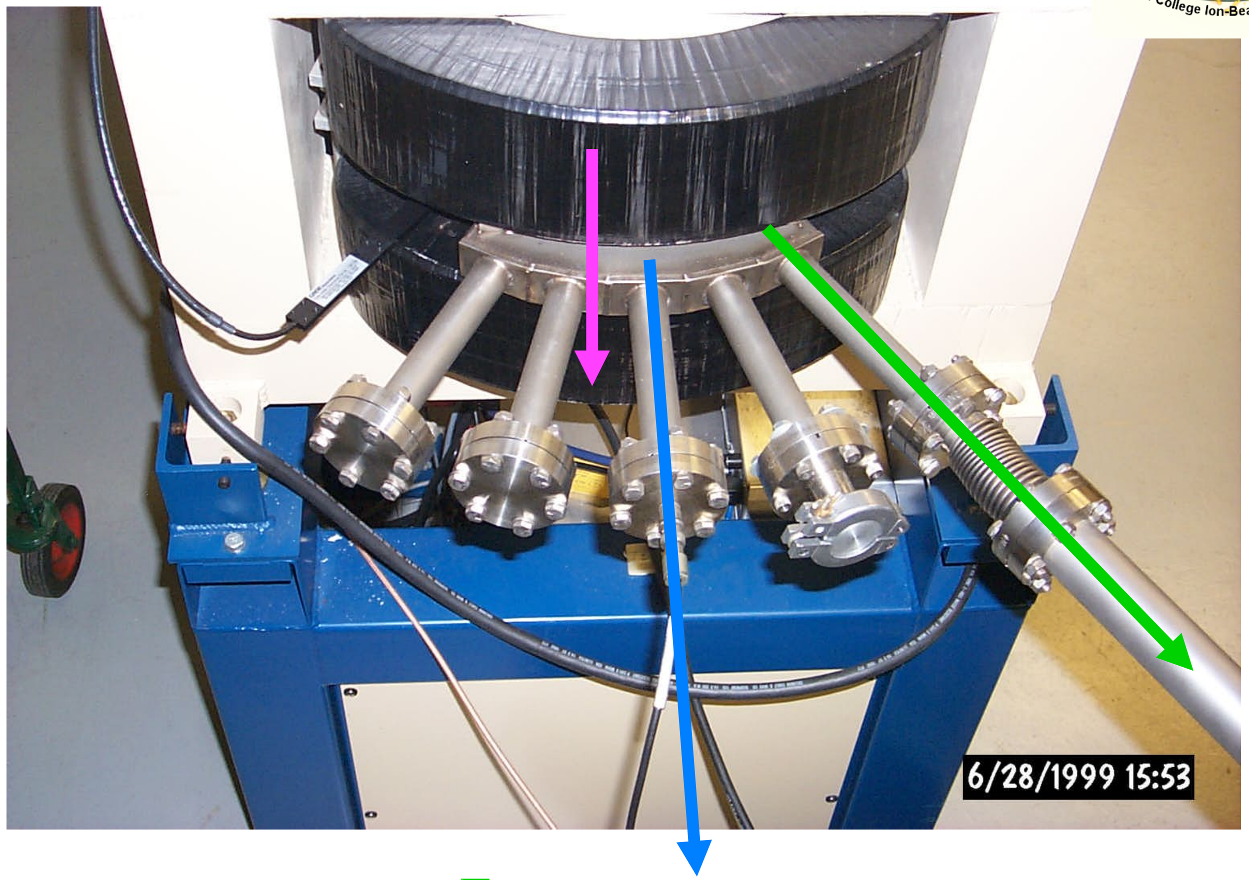
Side view of steering and quadrapole magnets

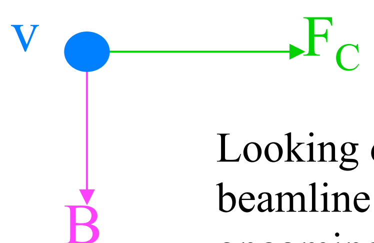
Steering of Ions

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

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

$$W_i = q\Delta V = 1e \times 2.2kV = 2.2keV$$

$$W_i = \Delta KE$$

$$W_i = 2.2keV \times \frac{1.6\times10^{-19}J}{1eV} = 3.52\times10^{-16}J = KE_f - KE_i = KE_f$$

$$3.52\times10^{-16}J = \frac{1}{2}m_p v_p^2$$

$$\therefore v_p = \sqrt{\frac{2\times3.52\times10^{-16}J}{1.67\times10^{-27}kg}} = 6.49\times10^5 \tfrac{m}{s}$$

A Couple of Quick Calculations

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

$$W_{total} = \sum_{j=1}^{N} w_i = \sum_{j=1}^{N} q\Delta V_{i,f} = w_{source} + w_{low-energy} + w_{high-energy}$$

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

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

$$\therefore KE_f = 2.2MeV \times \frac{1.6 \times 10^{-19} J}{1eV} = 3.52 \times 10^{-13} J$$

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

$$KE_f = \frac{1}{2} m_p v_p^2 \rightarrow v_p = \sqrt{\frac{2KE_f}{m_p}} = \sqrt{\frac{2 \times 3.52 \times 10^{-13} J}{1.67 \times 10^{-27} kg}} = 2.05 \times 10^{7} \tfrac{m}{s}$$