Physics 100 – Module 1

Materials Science and Materials Analysis using a Particle Accelerator

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My Background:

In the department for 13 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 220 (Introduction to Quantum Mechanics)
- 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 – Pb pollution

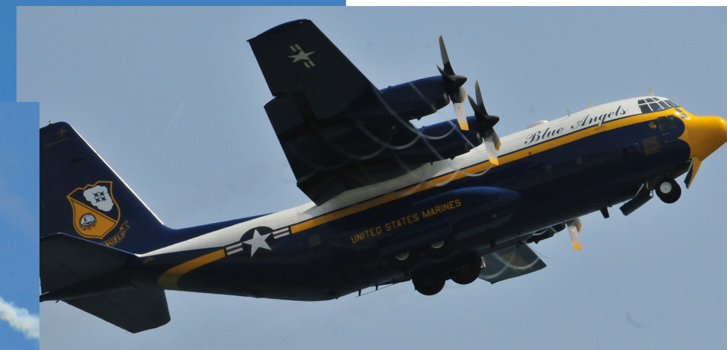
Medical and Health Physics issues – Hg in Fish/metal distribution in tissues

Soil contamination – Mud Samples

Art and Archeometry

At some point – Forensics/paleontology/medical applications

My physics hobbies…

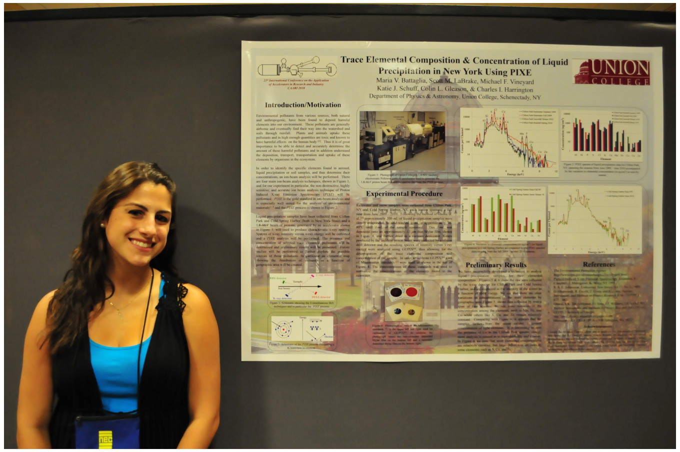


Fluid Mechanics
Aerodynamics
Flight and Flight Mechanics
Aircraft Photography

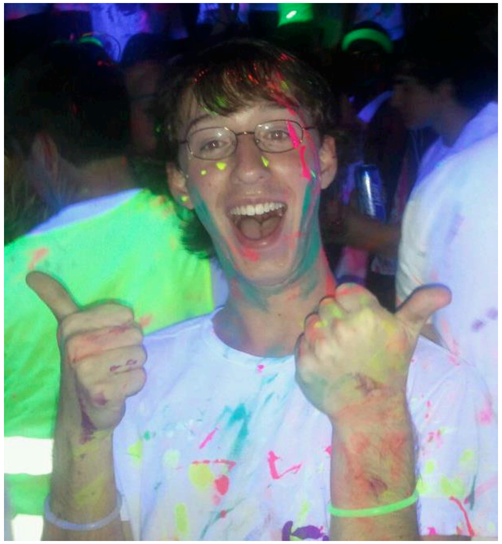
Motion and Gravity

*The **Union** **College** **Ion** **Beam** **Analysis** **Laboratory***

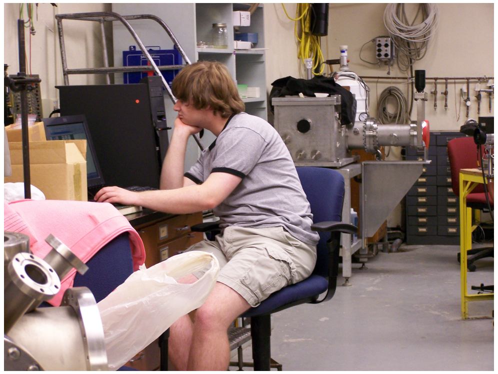
Chad & Colin are now graduate students (at SUNY Buffalo and University of South Carolina), who worked on the analysis of atmospheric aerosols by PIXE/PIGE/RBS/PESA.



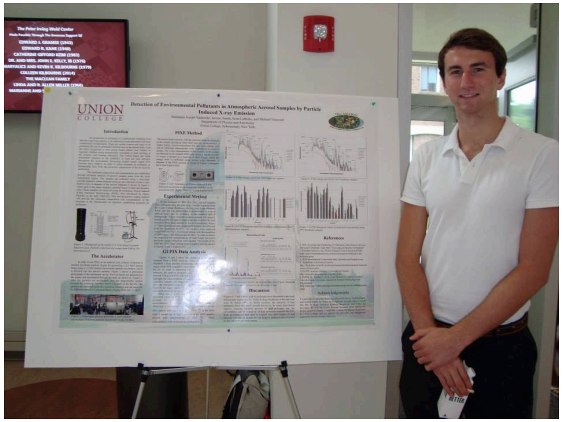
Maria is a 3rd year medical student who worked on liquid precipitation samples and on the development of a procedure for looking at the distribution of metals in animal (skate) tissues. Here she is at CAARI, an international accelerator conference in Fort Worth Texas



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



Colin is a 2nd year graduate student at Penn State who worked on the analysis of atmospheric aerosols by RBS/PESA.



Ben is a junior 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?

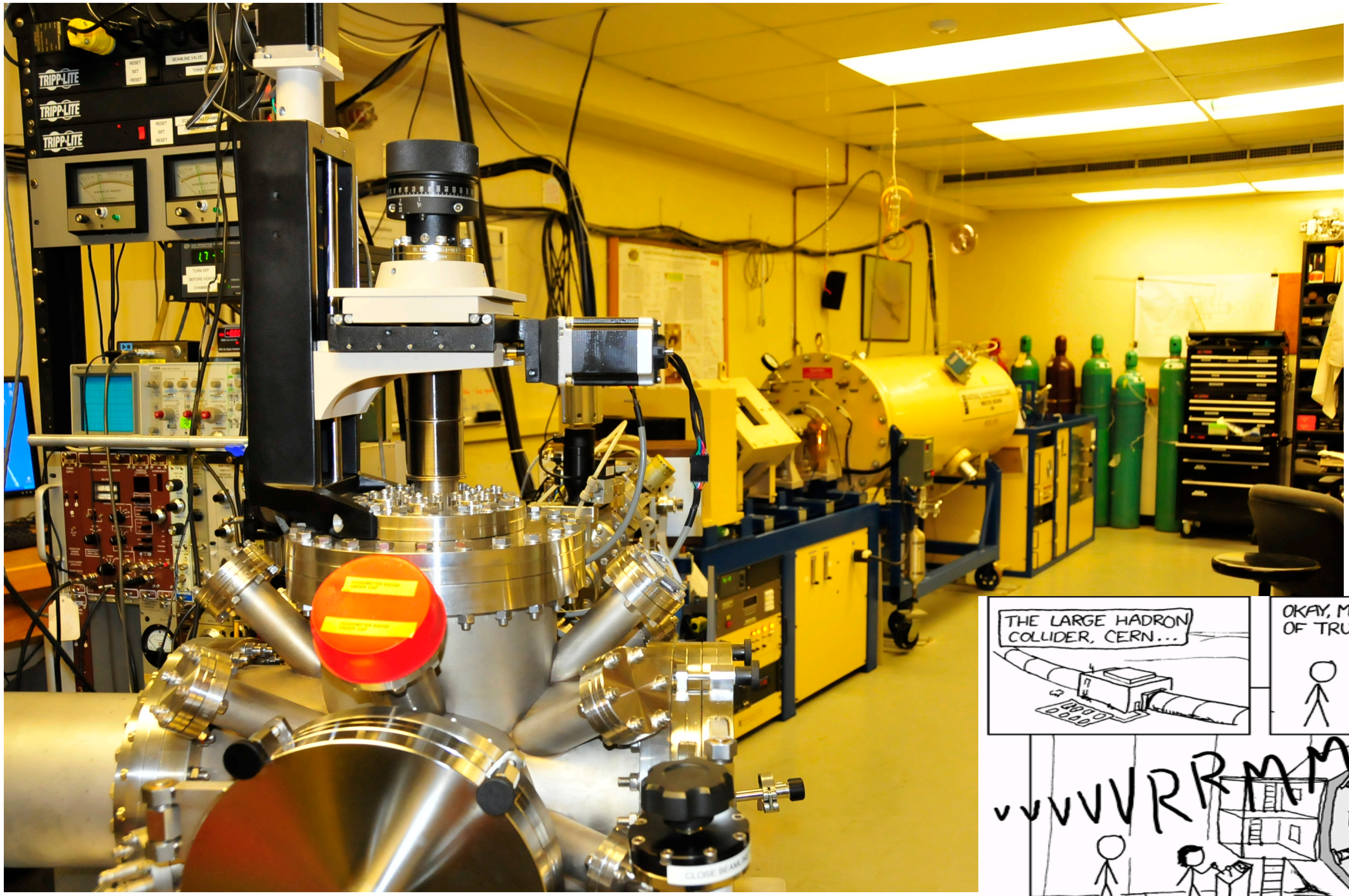
•Accelerator – What it is, What it does. Energy and velocity calculations.

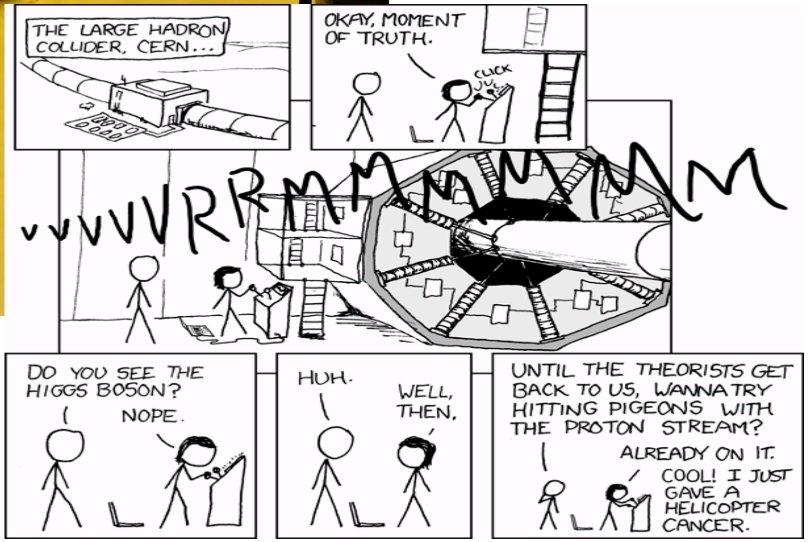
•*PIXE* – Basics, Theory and Sample calculations.

•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?



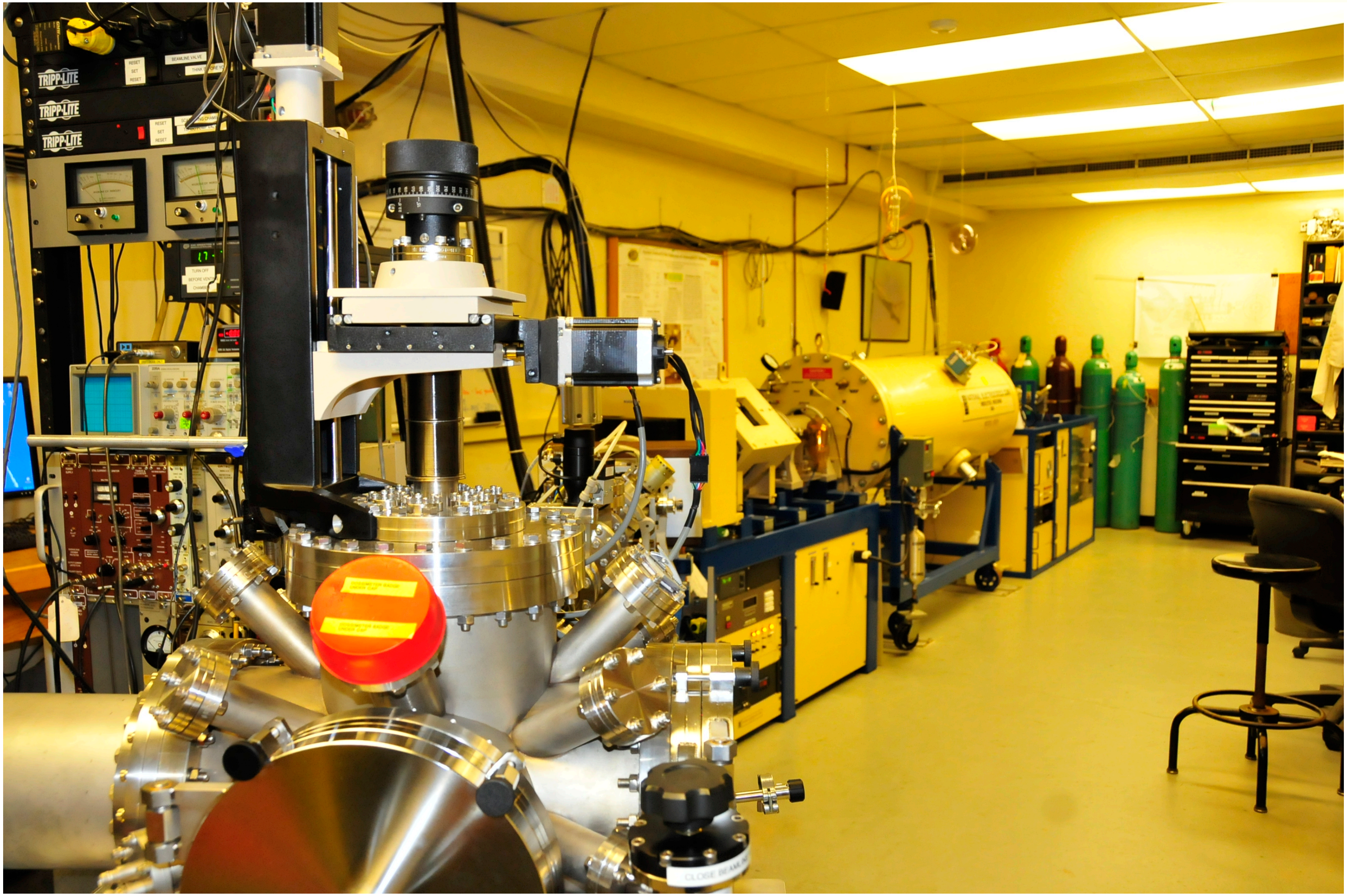


http://sciencegeekgirl.com/files/2008/12/large_hadron_collider1.png?w=300

The Pelletron Particle Accelerator

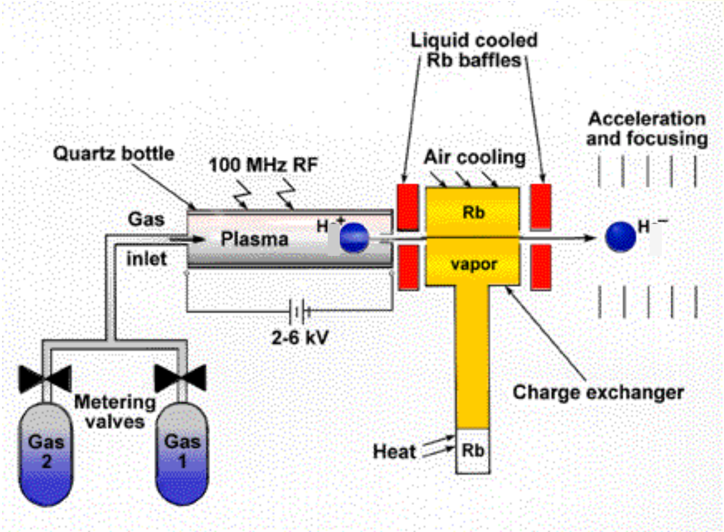
- Built by the National Electrostatics Corporation
- Acquired in 1991
- Replaced 450 kV Van-de-Graff accelerator
- In the process of writing a grant proposal for ~1.2 million dollars for a new accelerator which if funded would be installed in 2016.
- Our current accelerator has 4 main components
  - Ion production
  - Two-Stage (tandem) acceleration of ions
  - Steering of ions
  - Scattering chamber

The Pelletron Particle Accelerator



The Source: Ion Production

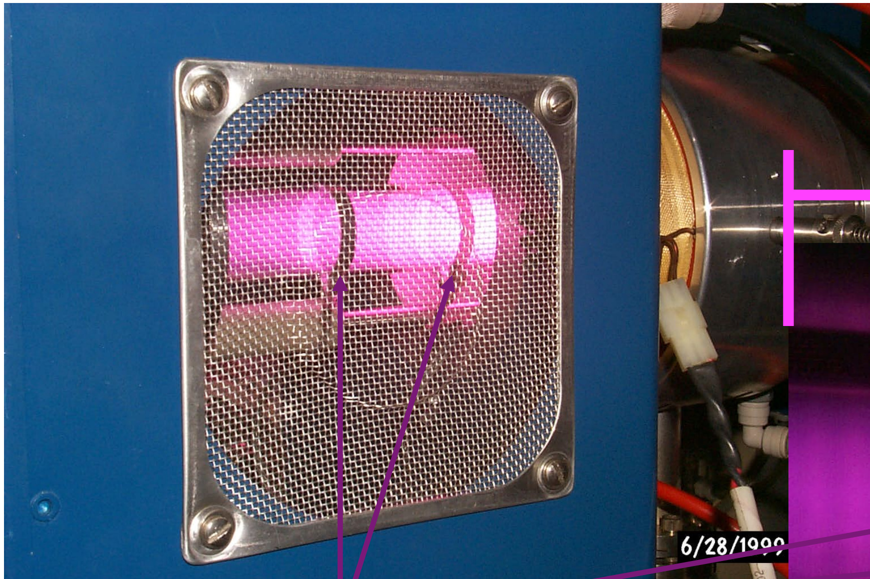
- H or He gas is bled into the gas inlet.
- 100MHz Radio Frequency (RF) electromagnetic energy is dumped into the quartz bottle which produces H^+, He^+, He^{++} and other ions.
- A potential difference of about 3.6kV for H or He is applied across the bottle.
- This accelerates the ions out into the charge exchanger.



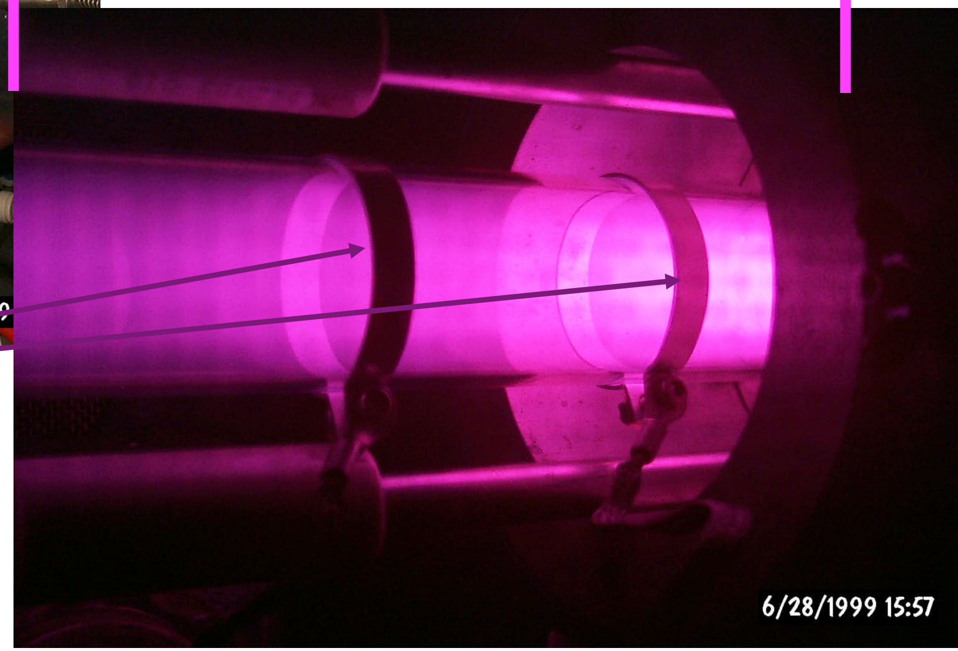
http://www.pelletron.com

- 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^-, ...)

Ion Production and Plasma Source



DV = 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

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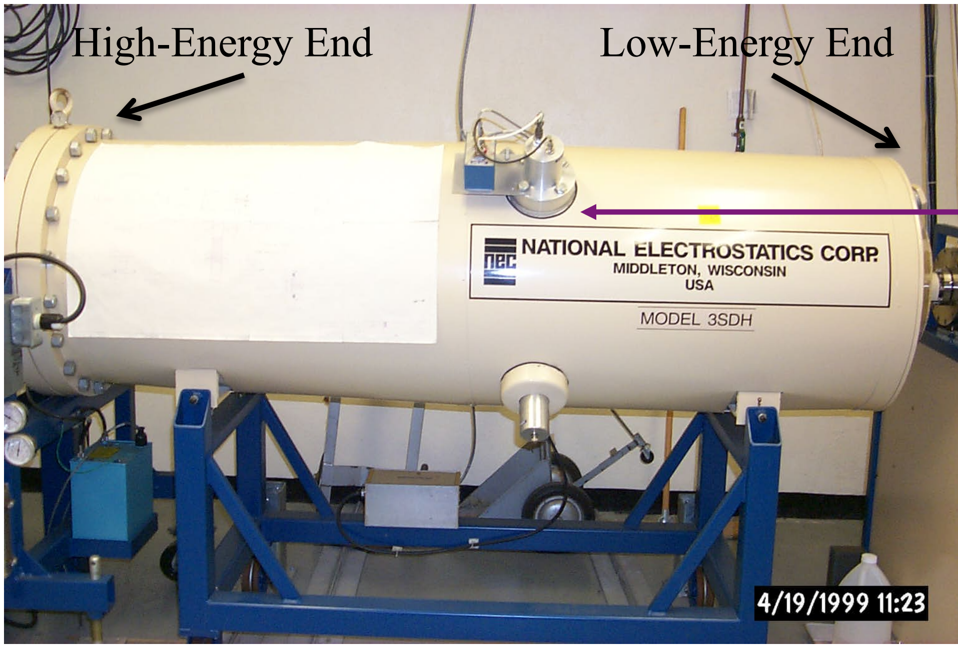
Union College Ion-Beam Analysis Lab

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.

The Accelerator



• 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 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.

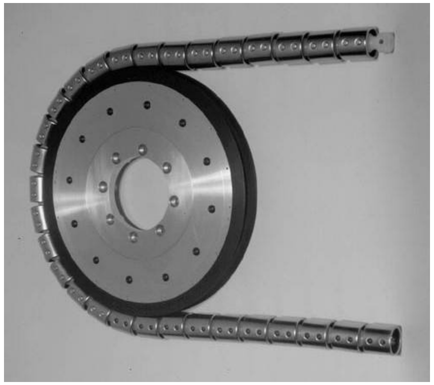
Tandem acceleration of ions

• 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.

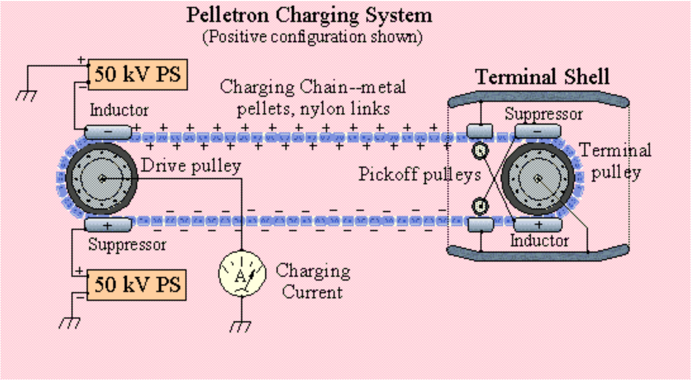
• The center of the pressure tank (the terminal) is made positive with respect to the charge exchanger.

• 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

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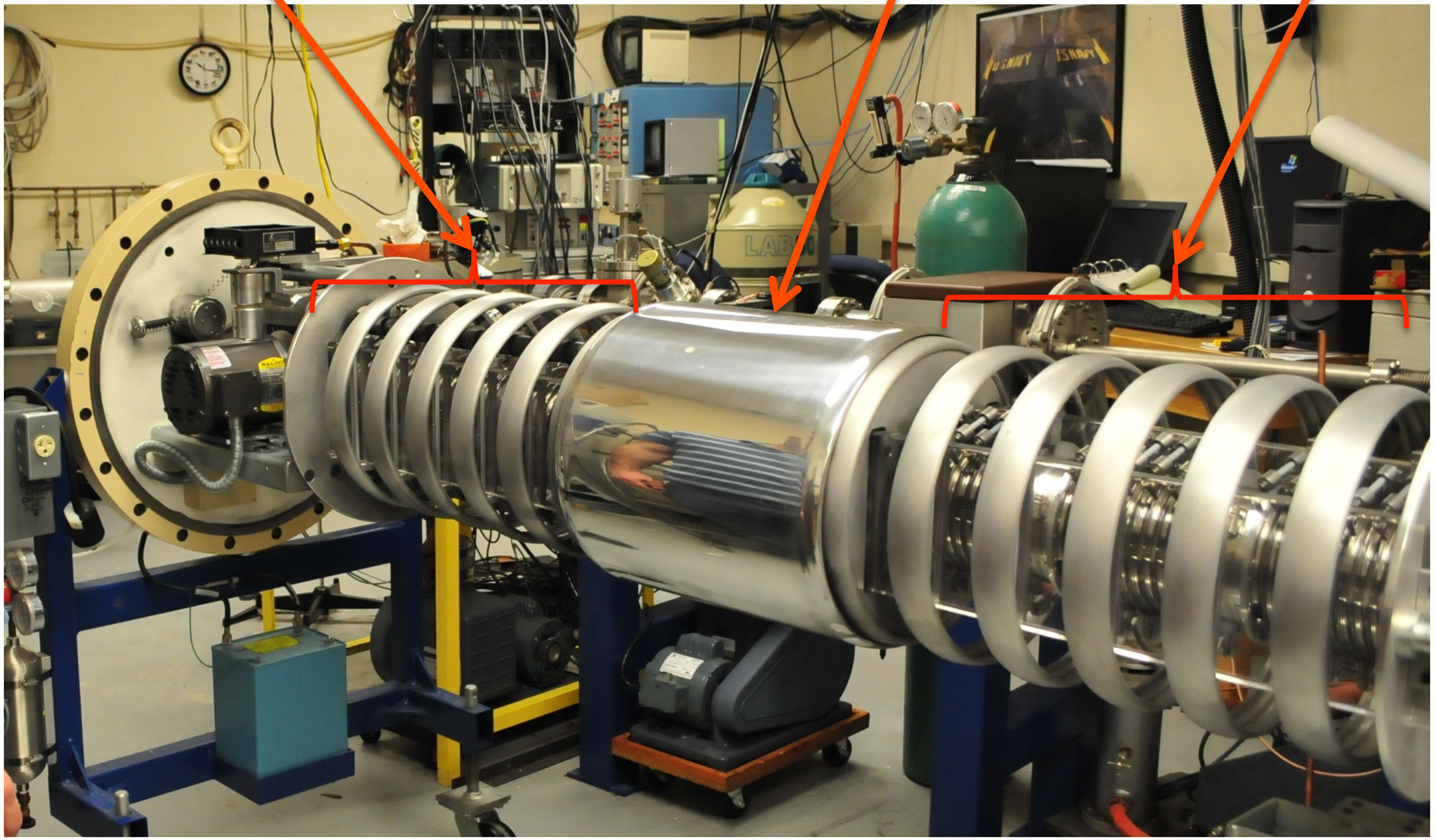
The Accelerator – What's inside the tank…

High Energy Column Terminal Shell Low Energy Column



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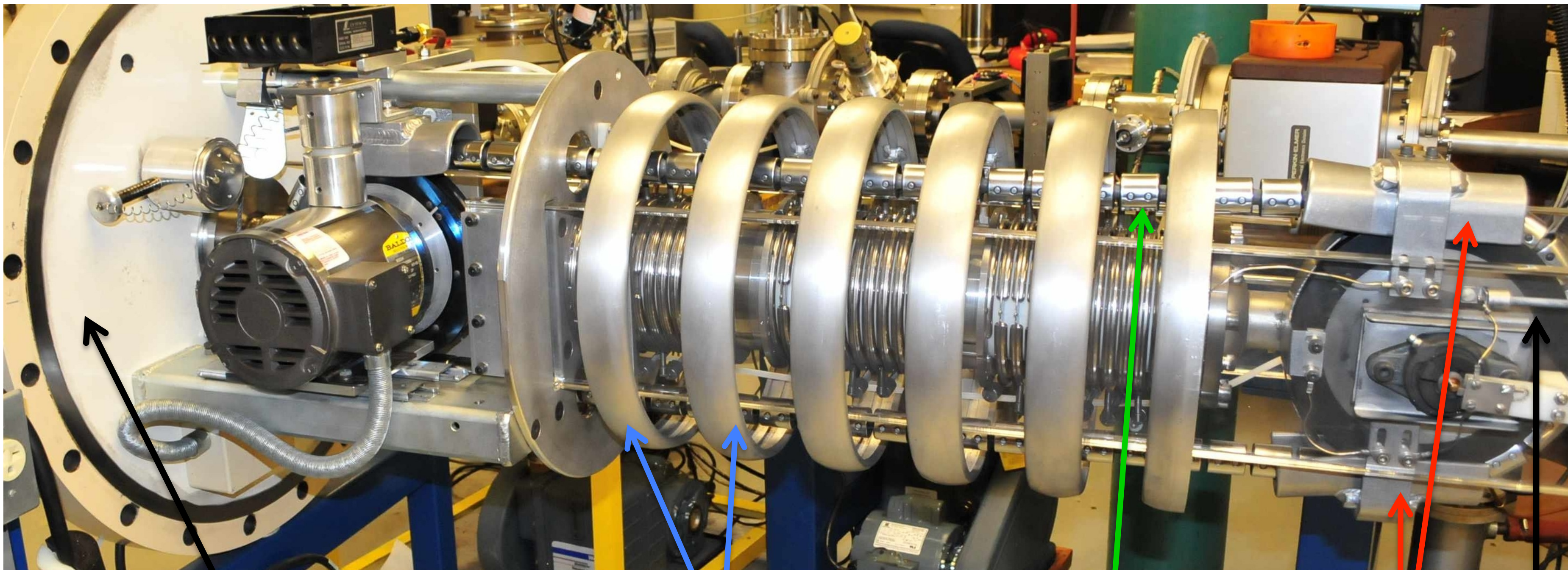
The Accelerator – What's inside the tank…



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:**

$$\text{Work} = W = q\Delta V_{\text{accelerating}} = 1eV = 1e \times \frac{1.6\times10^{-19}\,\text{Coulombs}}{1e} \times 1\text{Volt} = 1.6\times10^{-19}\,\text{Joules}$$

- **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?

$$W_i = q\Delta V = 1e \times 3.6kV = 3.6keV$$

$$W_i = \Delta KE$$

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

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

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

A Couple of Quick Calculations

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

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

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

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

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

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.