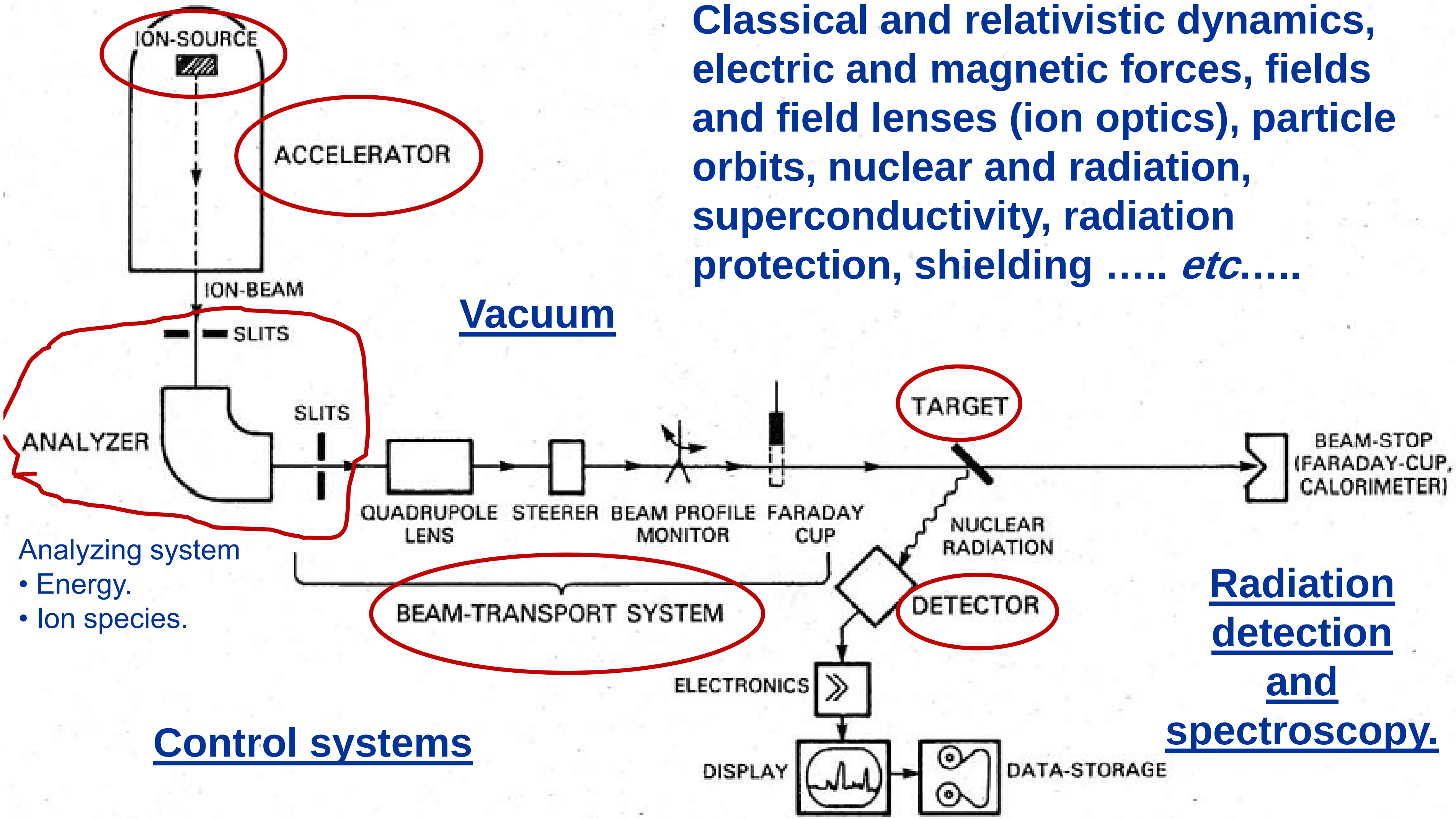
Example => Relevant Physics

Physics:
Classical and relativistic dynamics, electric and magnetic forces, fields and field lenses (ion optics), particle orbits, nuclear and radiation, superconductivity, radiation protection, shielding ….. *etc.*….



Vacuum

Analyzing system
- Energy.
- Ion species.

Control systems

Radiation detection and spectroscopy.

Categories

- Linear or circular.
- Electrostatic or RF (acceleration mechanism).
- DC or pulsed and bunched. TOF applications.
- Accelerate leptons or hadrons.
- Accelerate stable or radioactive beams.
- …..

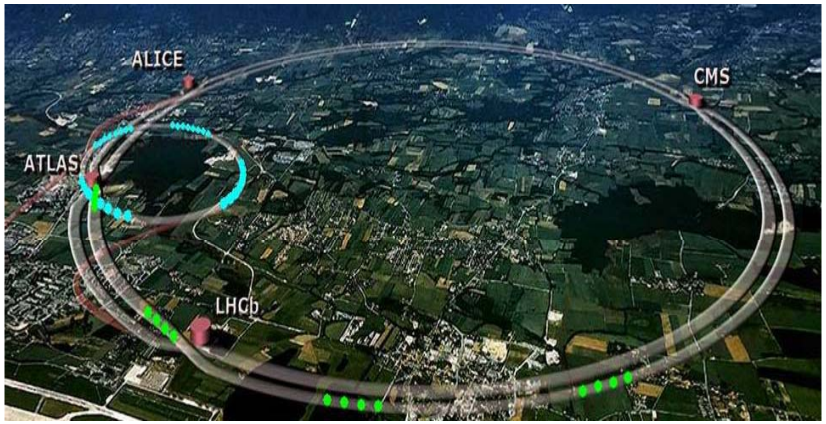
Simple accelerator: X-ray tube.

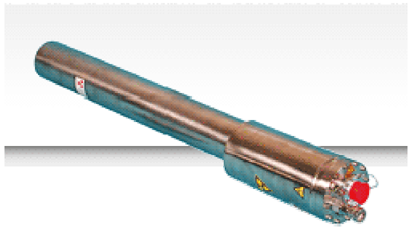
Applications – Vast Field

- Accelerator applications ► Broad field.
  - High energy physics.
  - Nuclear physics and nuclear astrophysics.
  - Radiotherapy and hadron therapy.
  - Ion implantation, solid state and condensed matter physics. RBS and Channeling.
  - Industrial processing and NDT.
  - Chemistry, Biology and Biomedical.
  - Neutron generators.
  - Spallation neutron sources, transmutation and ADS.
  - Radioisotope production (^{18}F …).
  - Archaeology.
  - AMS.
  - ………

Big Science

Multiple uses





Vast Field

- Broad range of beam parameters:
  - Beam currents: nA to MA. (Beam intensity ppp).
  - Pulse: < ns to steady state.
  - Accelerated particles: *e* to heavy ions (Linac to GSI).
  - Energy: eV to TeV. (Livingston Chart).
  - Life time of particles.
  - Coherency, emittance, luminosity, brilliance, brightness.
  - …….
- Different technologies.
- Van de Graaff, tandem, pelletron, dynamitron, betatron, tevatron, resonant cavities, linac, cyclotron, synchrotron, storage ring, microtron……

Example on Requirements

- **Nuclear physics** experiments (nuclear reactions).
  - ~100 μA – mA.
  - < 1 keV energy spread at MeV ion energy. (<100 eV not needed, thermal motion of target).
  - Vary energy over a wide range (few hundred keV to multi MeV) with ~ 0.1 keV energy step.
  - Maintain high current over the full energy. Usually the range is $E/E_{max} \cong 0.1-1.$ (A challenge is at low energies).
  - Experimental setup. Detect outgoing particles. Low cross sections imply experimental challenges.

Course Strategy

In view of the above: we will work "**parallel**" on the following:

- Physics of acceleration, beam transport, beam optics, *etc* …
- Technologies.
- Applications.
- Spectrometry.
- Radiation protection concepts.

Very Basic Physics

Lorentz's Force

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

Change in energy

$$T = qV$$

Charge state

Circular path

$$r = \frac{mv}{qB}, \qquad \vec{v} \perp \vec{B}$$

HW 1

Exercise 1.1

In Lee

Momentum rigidity

$$Br = \frac{mv}{q} = \frac{p}{q}, \qquad \vec{v} \perp \vec{B}$$

Read Ch. 2 of Humphries, Chs. 1&2 in Wiedemann.

Electrostatic Accelerators

Overview

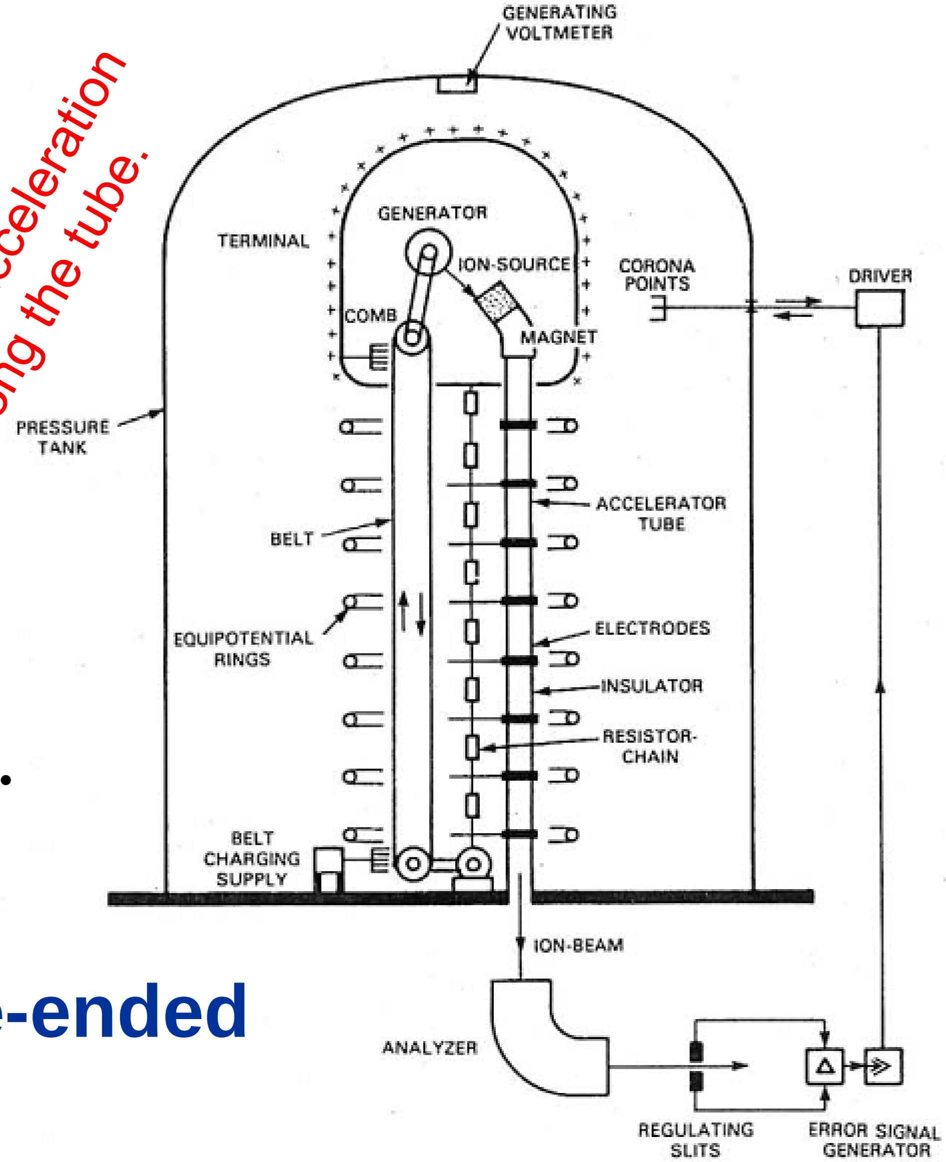
Van de Graaff

- **Insulating belt transports +ve charge to the terminal (Faraday cage) whose $V=Q/C$. Therefore, $dV/dt=I_{belt}/C$, possibly 1 MV/s.**
- **I_{belt} is in equilibrium with current drains:**

$$I_{belt} = I_{beam} + I_{ins} + I_{cor} + I_{res}.$$

1 mA maximum

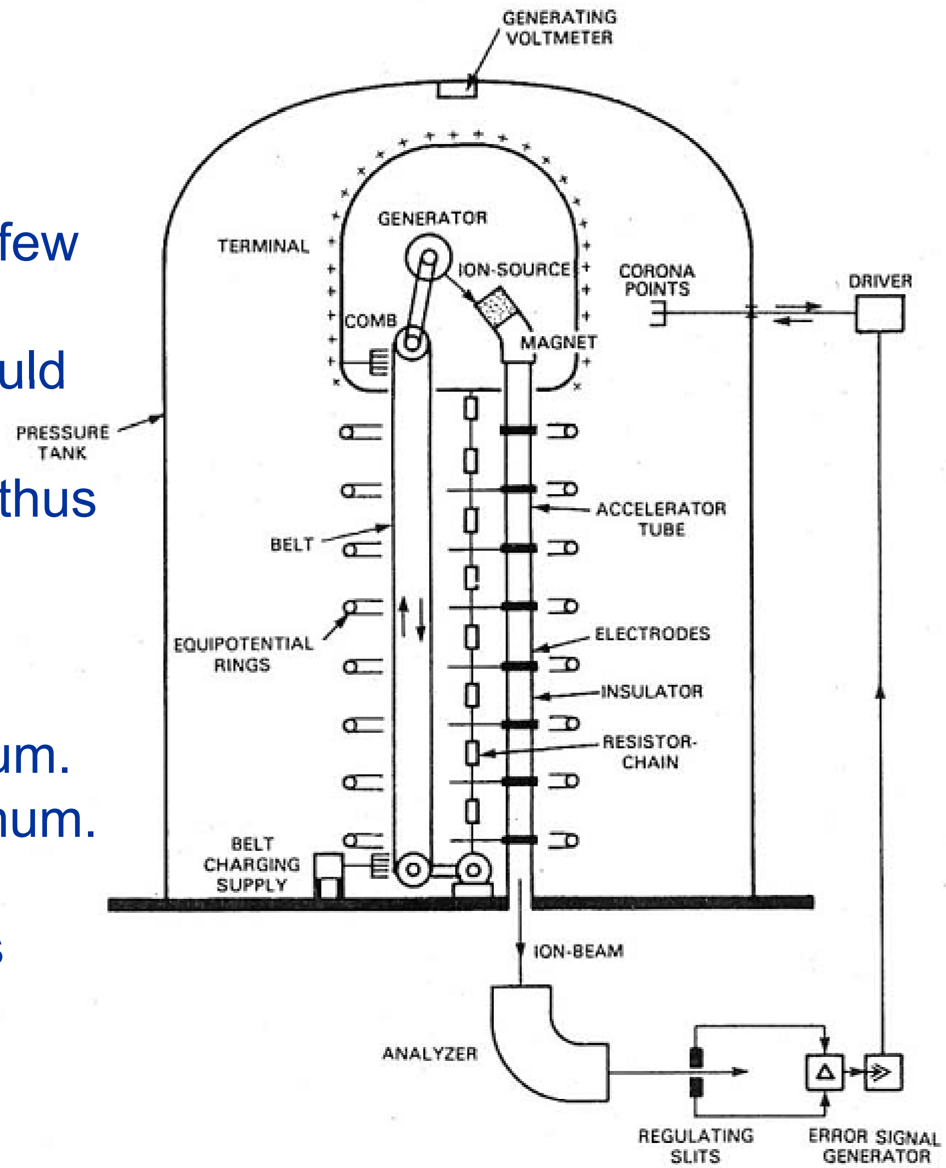
Uniform acceleration along the tube.



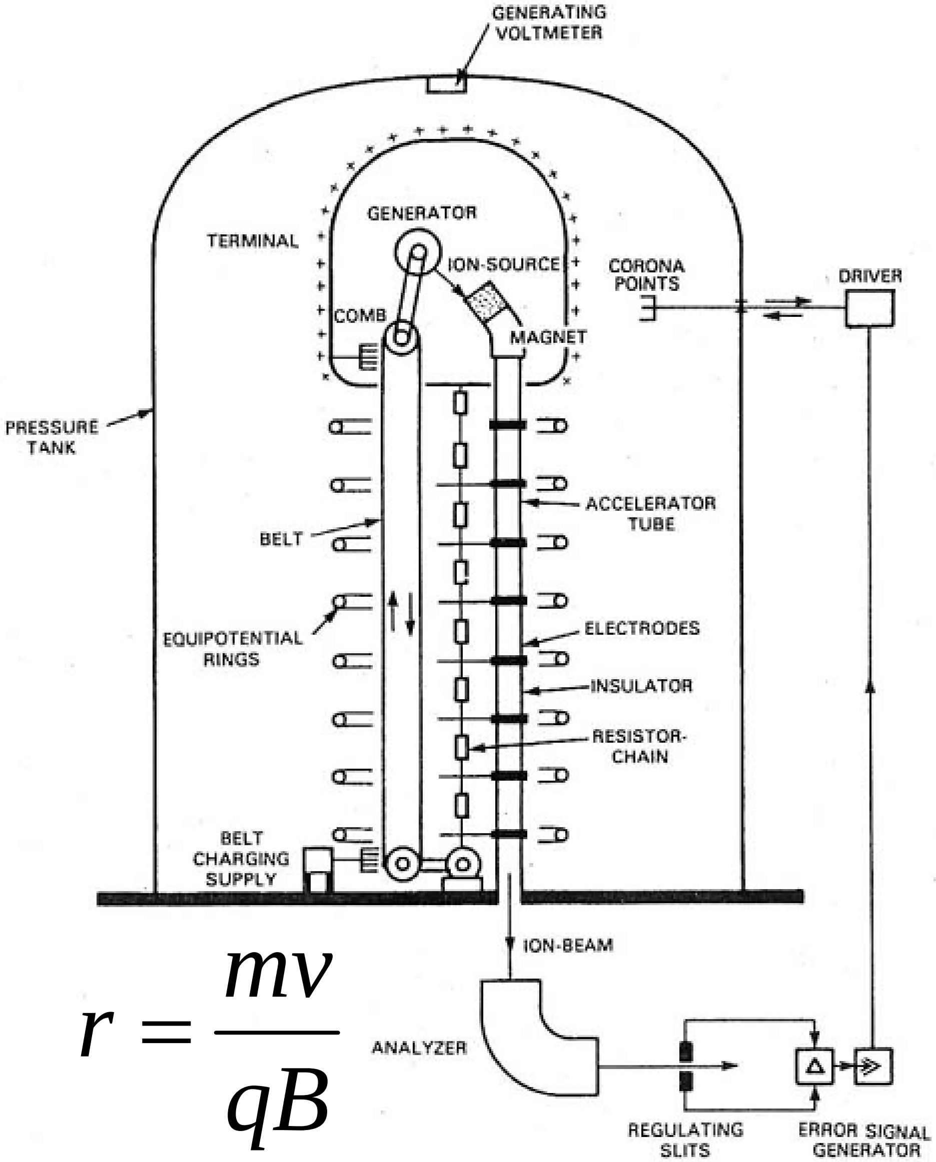
Single-ended

Van de Graaff

- Electrodes: electrostatic lenses.
- Focal length?
- Focusing. Diameter at exit of tube ~ few mm.
- Electric field along tube and belt should be uniform, thus corona rings.
- Field gradients should be minimum, thus radius of curvature of structures, even dome, should be large.
- Dry air ► sparking at 30 kV/cm.
- Dome radius of 1 m ► 3 MV maximum.
- Practically, no dry air ► 1 MV maximum.
- Larger domes or better use a high-pressure tank filled with insulating gas (SF_6 at typically 6 bar).
- Gas used at JUVAC?



Van de Graaff

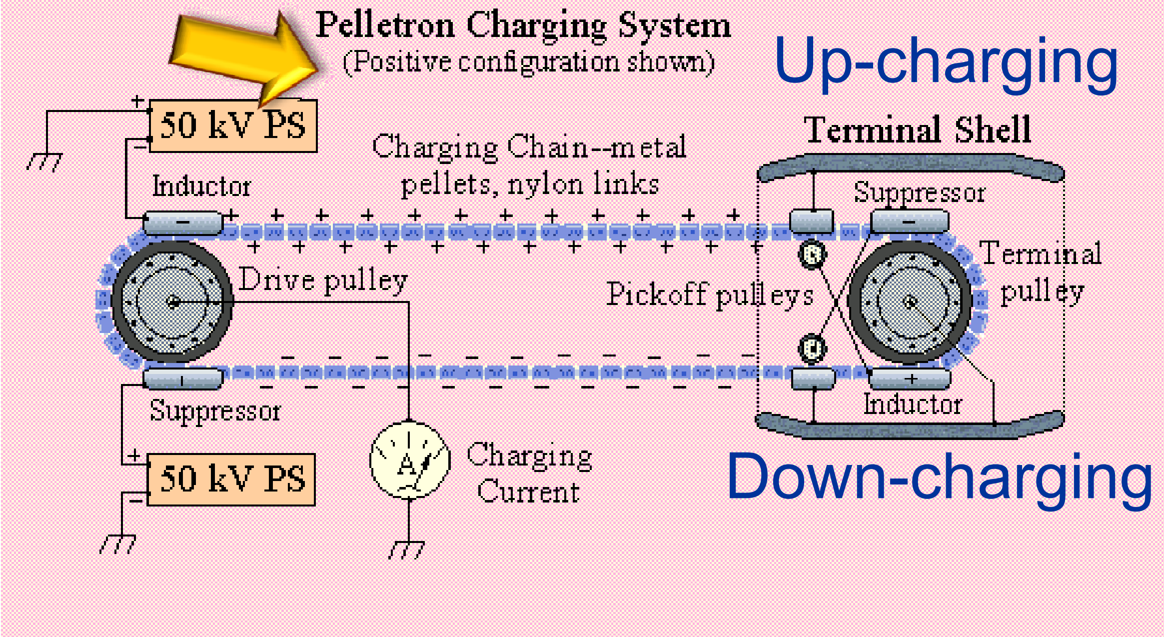


$$r = \frac{mv}{qB}$$

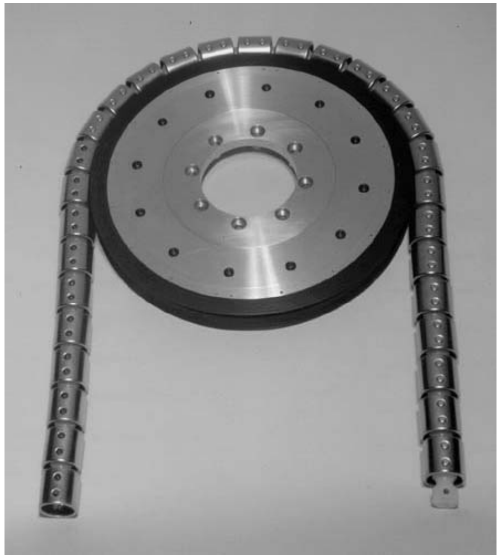
- V ↑ ► beam bending ↓ ► higher current at one slit ► error signal moves corona points closer to terminal ► I_{cor} ↑ ► V ↓.
- Singly charged molecular hydrogen *vs.* proton beam. A factor of $(1/2)^{1/2}$. Can control the system using molecular hydrogen. Usage of unwanted impurities!
- Belt ► Instability in terminal voltage V, belt dust and spark damage.

Dynamitron and Pelletron.

Pelletron



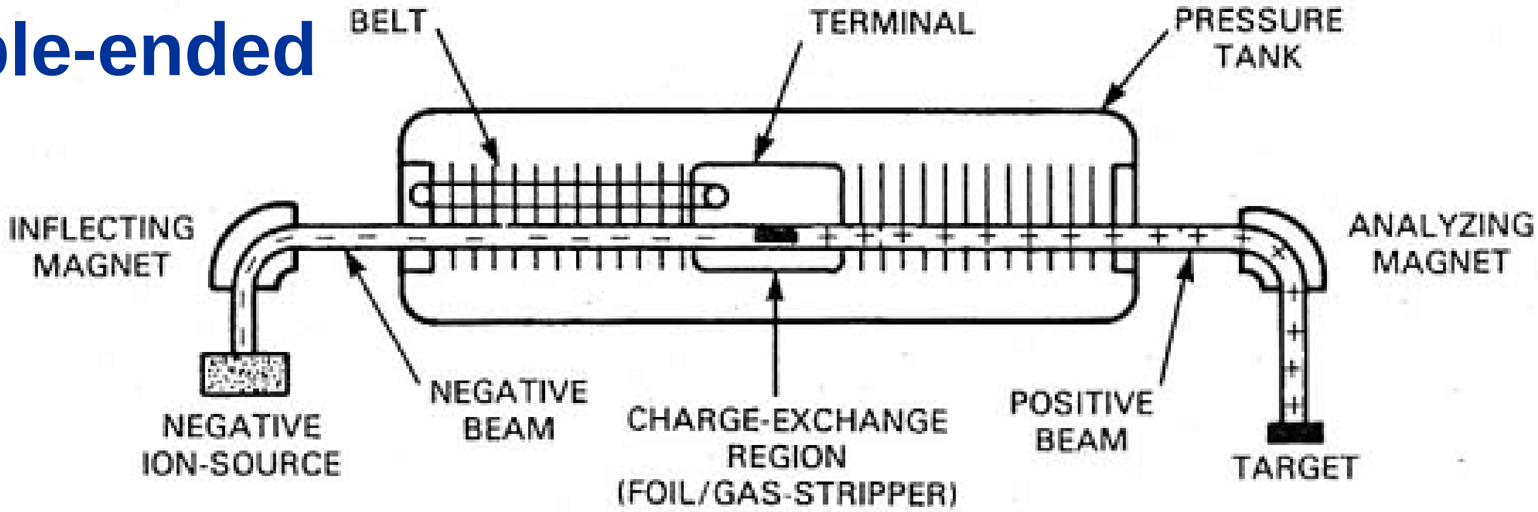
http://www.pelletron.com/charging.htm



• Pelletron chain is made of metal pellets connected by insulating nylon links and charged by induction (no rubbing contacts).

Tandem

Double-ended



Singly charged –ve ions.

$T=eV$ $T=eV\,(1+q)$

- Achieve higher energies. How much?
- Ion source at ground ► outside the tank ► accessible.
- Van de Graaff or Dynamitron or Pelletron.

http://isnap.nd.edu/html/research_FN.html