Van de Graaff

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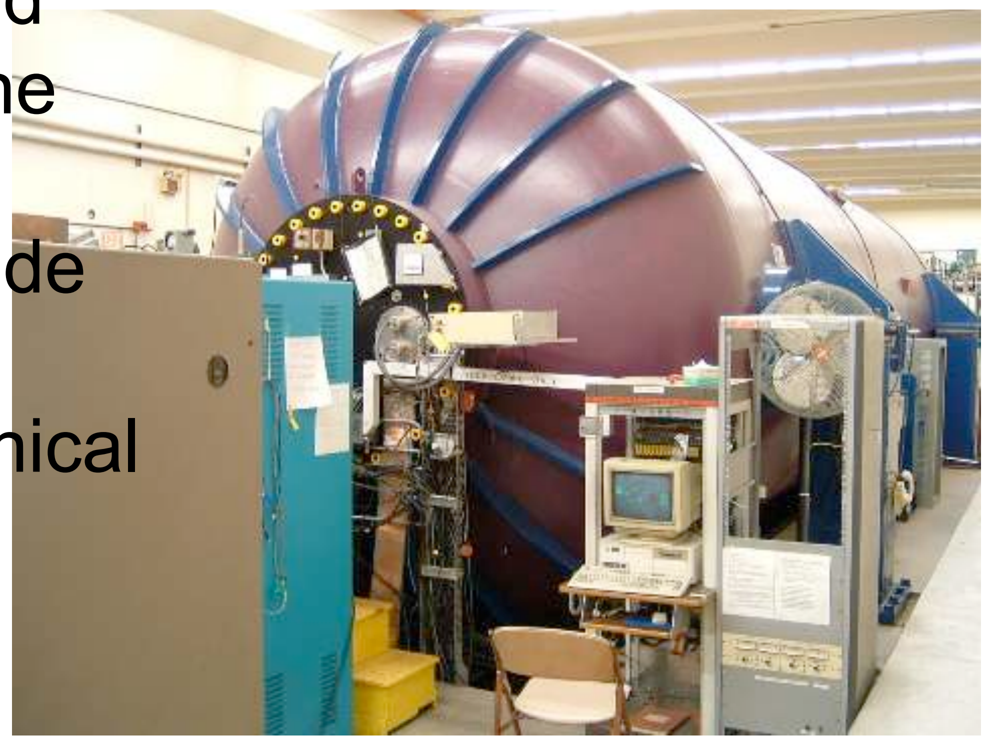
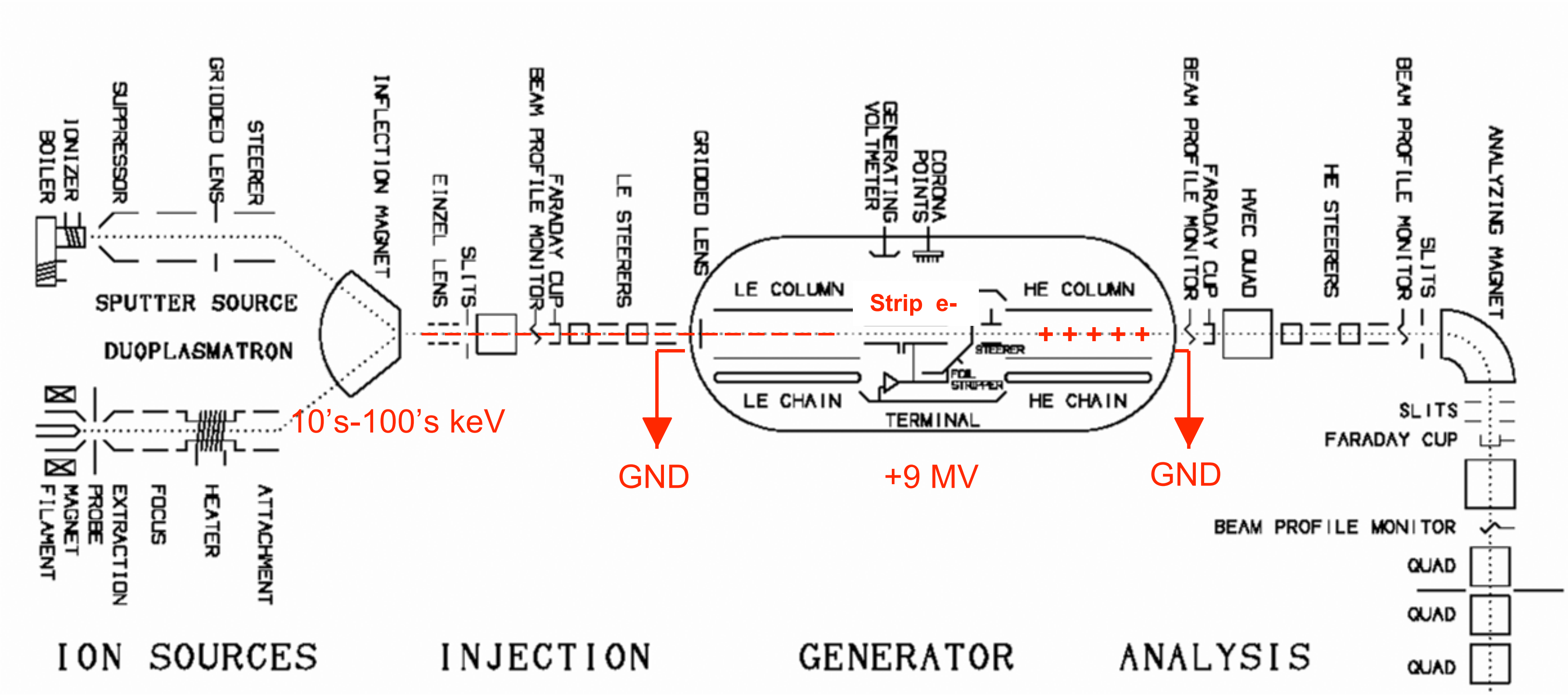
Van de Graaff

- With special thanks to Dick Seymour and Greg Harper at the University of Washington Van de Graaff for much-appreciated technical guidance (and friendship)!



Van de Graaff



The "Tandem"

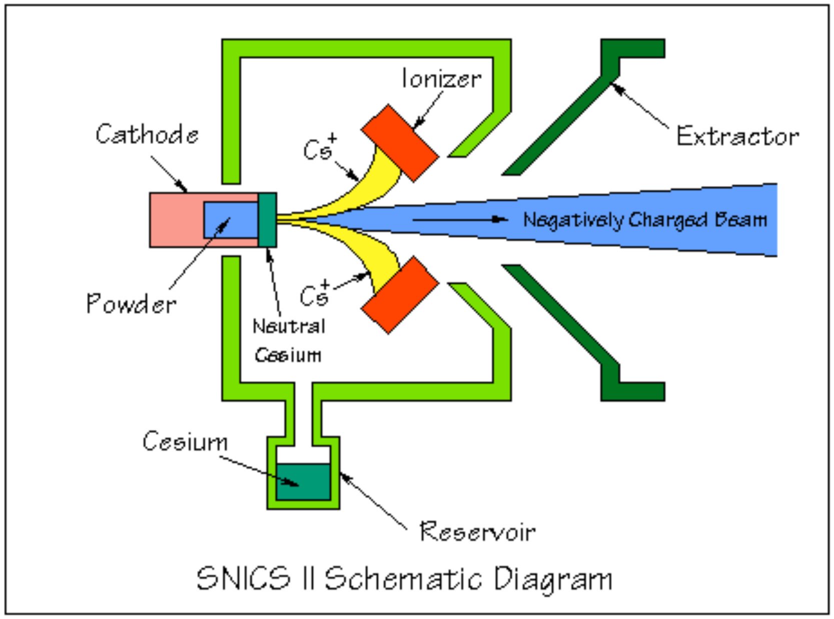
- The accelerator is a Model FN Tandem van de Graaff purchased from High Voltage Engineering of Burlington, Massachusetts
- The name "Tandem" arises from the two accelerations (one before stripping and one after) that the ion beam experiences

Negative ion sources

- Sputter ion source
- Duoplasmatron

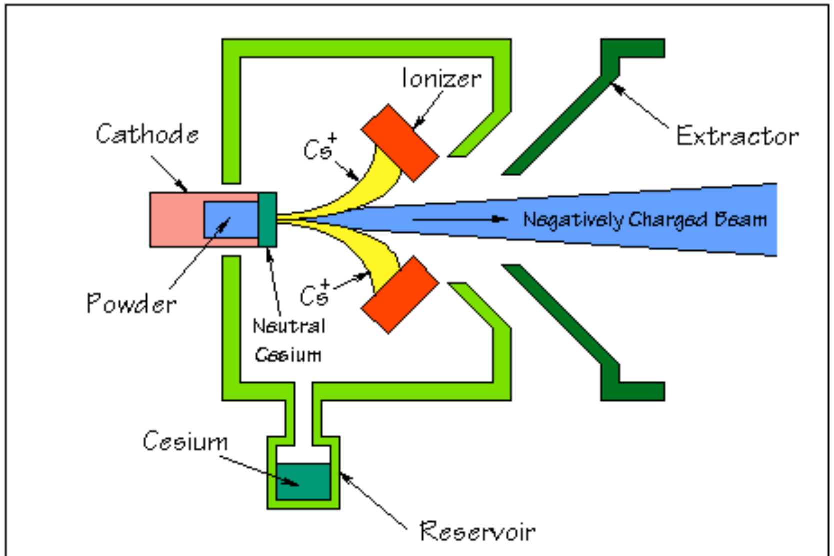
Sputter ion source

- A reservoir of cesium is heated to approximately 120 °C to form cesium vapor
- The vapor rises from the reservoir in vacuum to an enclosed region between the cathode, which is cooled, and the ionizer, which is heated
- Some of the cesium condenses onto the cool surface of the cathode, while some of the cesium comes in contact with the surface of the ionizer and is immediately "boiled away".



Sputter ion source

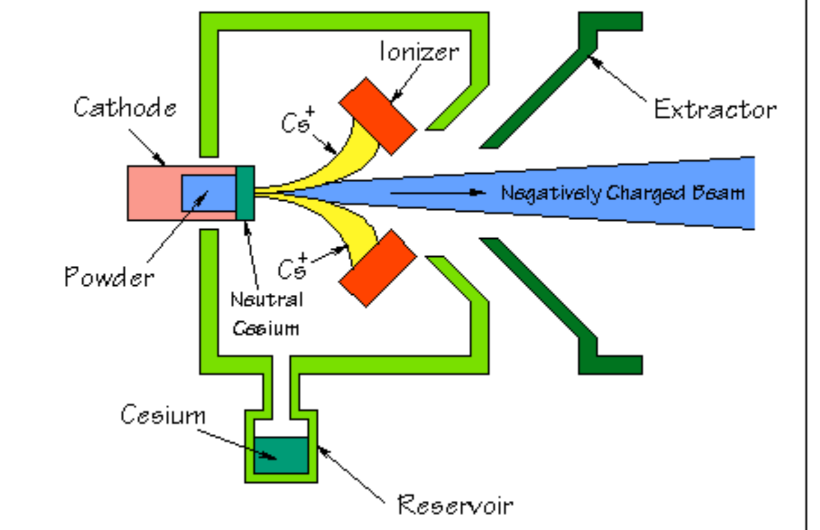
- The positively charged cesium ions leaving the ionizer are accelerated toward and focused onto the cathode, sputtering material from the cathode at impact
- Some of the sputtered material gains an electron in passing through the cesium coating on the surface of the cathode and forms the negatively charged beam.



SNICS II Schematic Diagram

Sputter ion source

- Since the entire source is operated below ground potential, the negative beam is accelerated out of the source and is available for injection into the Van de Graaff accelerator



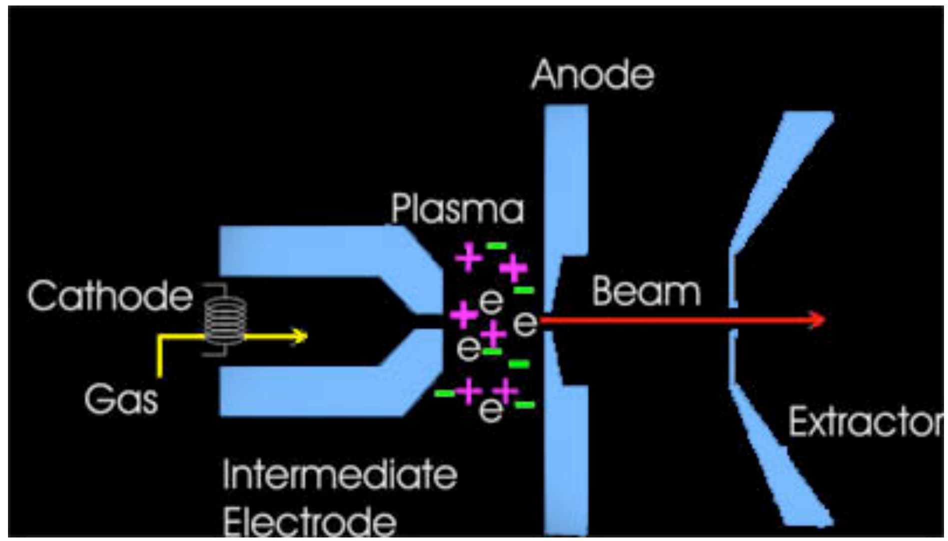
SNICS II Schematic Diagram

Duoplasmatron

- Free electrons are produced by boiling them off of a heated cathode

- Gas containing atoms of desired beam are injected into the chamber between the cathode and anode

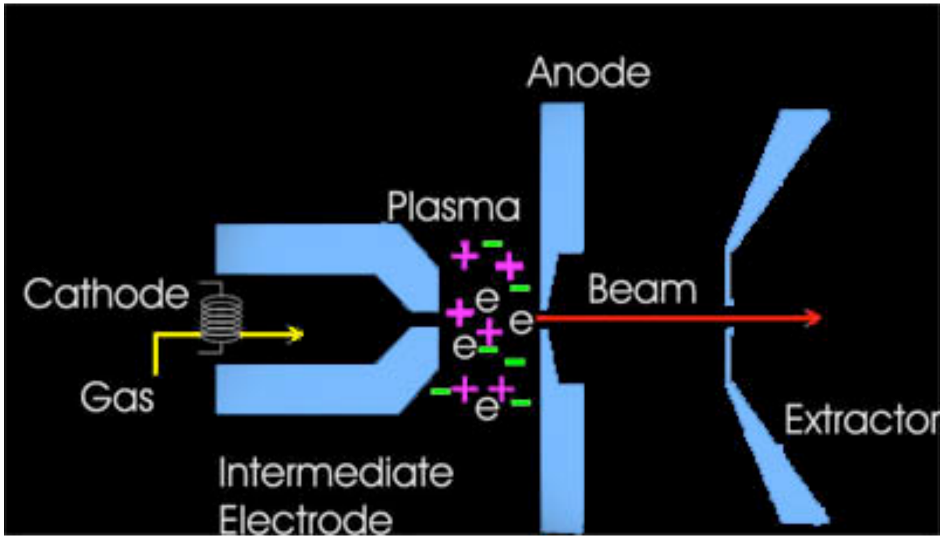
- As the electrons fly toward the anode, they collide with the atoms of the gas, producing ions.



Duoplasmatron

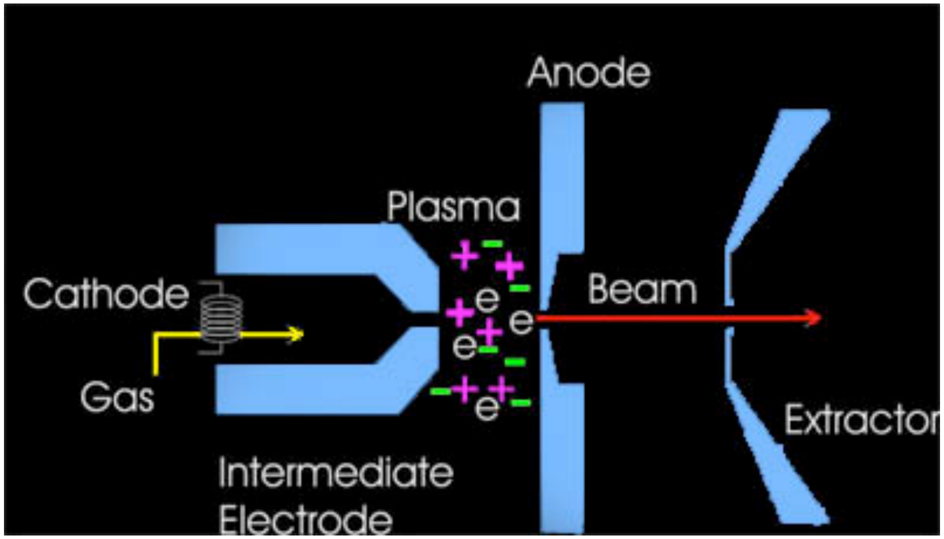
- An electron can either be absorbed by the atom thereby creating a negative ion, or it can knock an electron off of the atom producing a positively charged ion

- The ions are then focused by the shape of the electric fields into a dense plasma in the region just before the anode aperture



Duoplasmatron

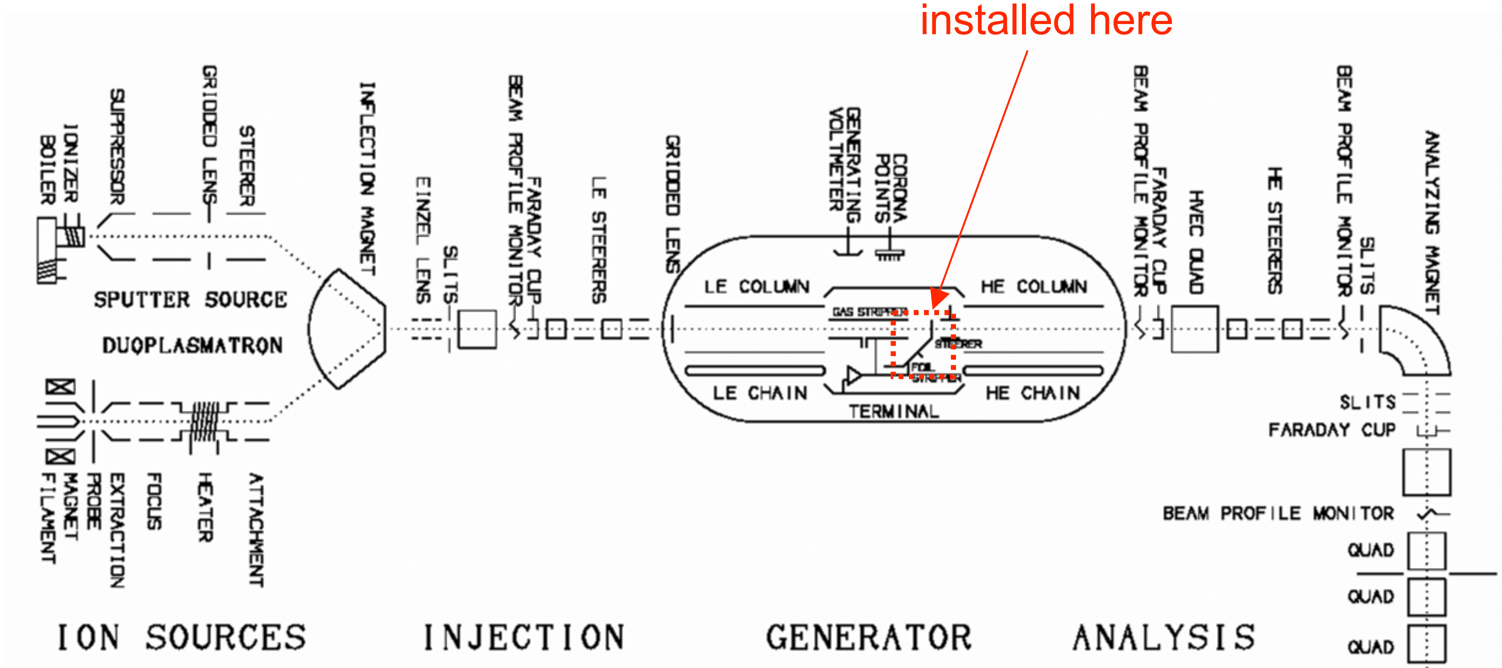
- The plasma bulges slightly through the anode aperture forming an "expansion ball".
- The negative ions are then selected by an extractor which is at ground potential
- The ions form a beam flowing into the beam tube toward the accelerator



Terminal ion source

- A terminal ion source provides an intense beam of Helium-3 at a relatively low energy
- It is exchanged with the foil stripper mechanism to switch between single-ended and tandem operation

He-3 source would be
installed here



Beam transport

- From the ion sources, the ions drift to the low-energy end of the Van de Graff

- Beam is steered and focused along the way

Low energy end

- The beam enters the low energy end of the 40-foot long Van de Graaff tank
- The steel vessel is filled with compressed CO_2, which serves as an insulator (many Van de Graaffs use SF_6)

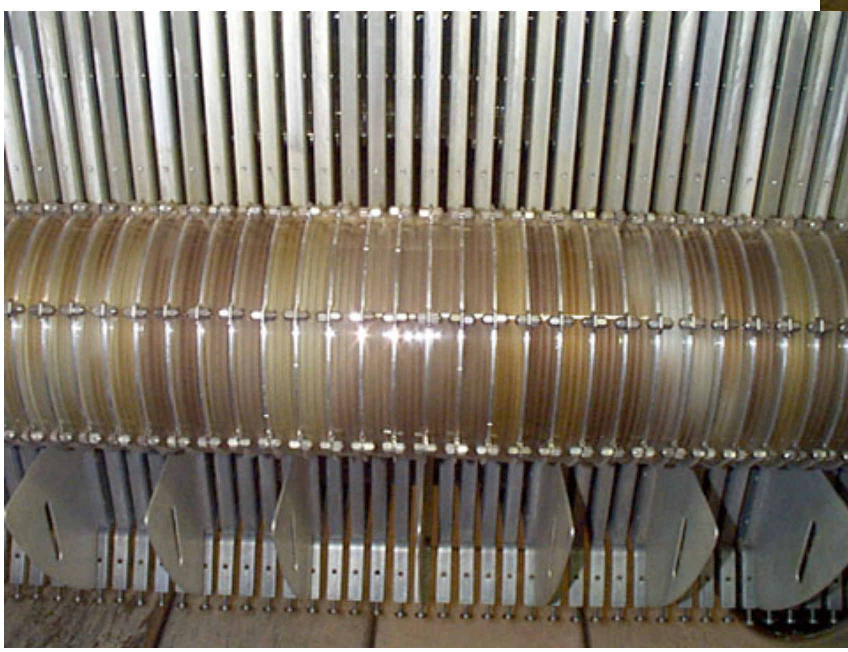
Middle

- Actuator for corona points

Inside the tank

Corona points

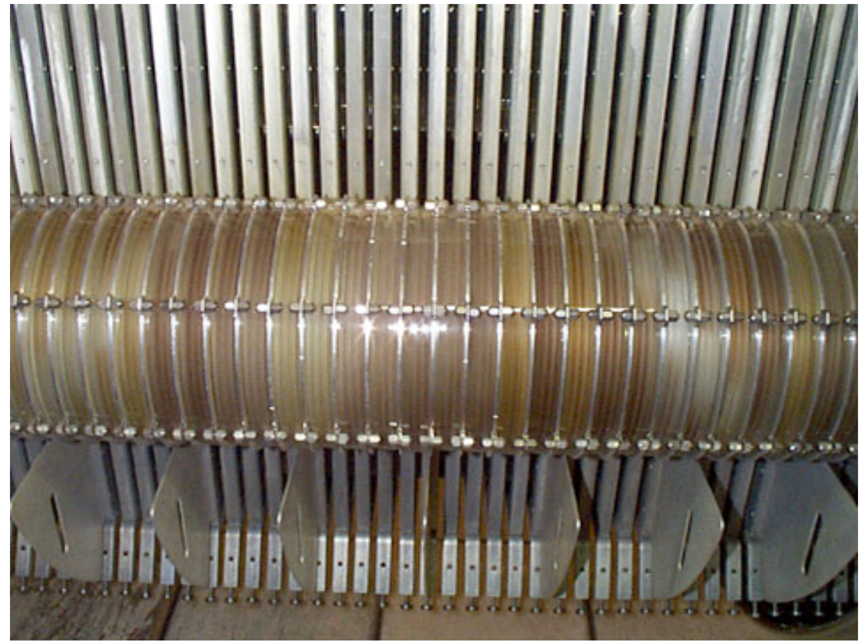
LE and HE columns



Inner part of a column

Accelerating column Part 1

- 9 MV divided along the columns by 600 MΩ resistors to provide a constant accelerating gradient
- Series of ~200 metal plates and glass insulators
- Note spark gaps used to minimize radiation damage to the glass insulators



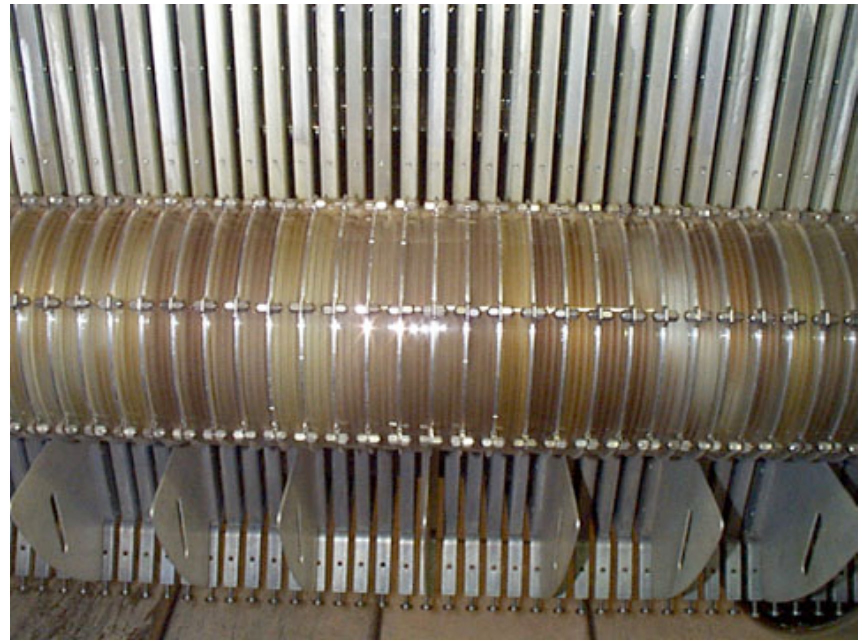
Accelerating column Part 2

- Tubular stainless steel hoops surround each plate
- The hoops preserve the equipotential of the field at each column plate
- Note, for operation, the floorboards, lights, and people must be removed!

Column focusing Part 1

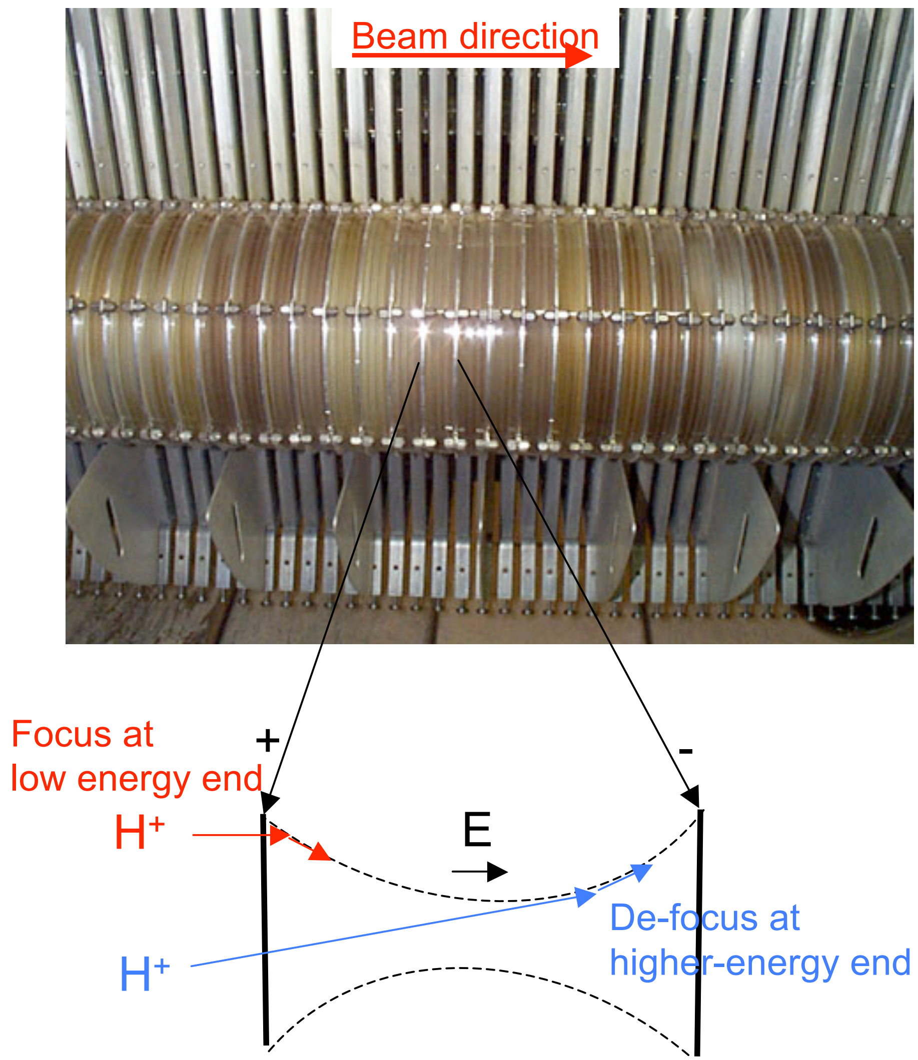
- The strongest focusing lens in the column is the fringe field region that exists outside the first accelerating plane

- The equipotential surfaces bulge out in this region and the radial field forms a strong lens.



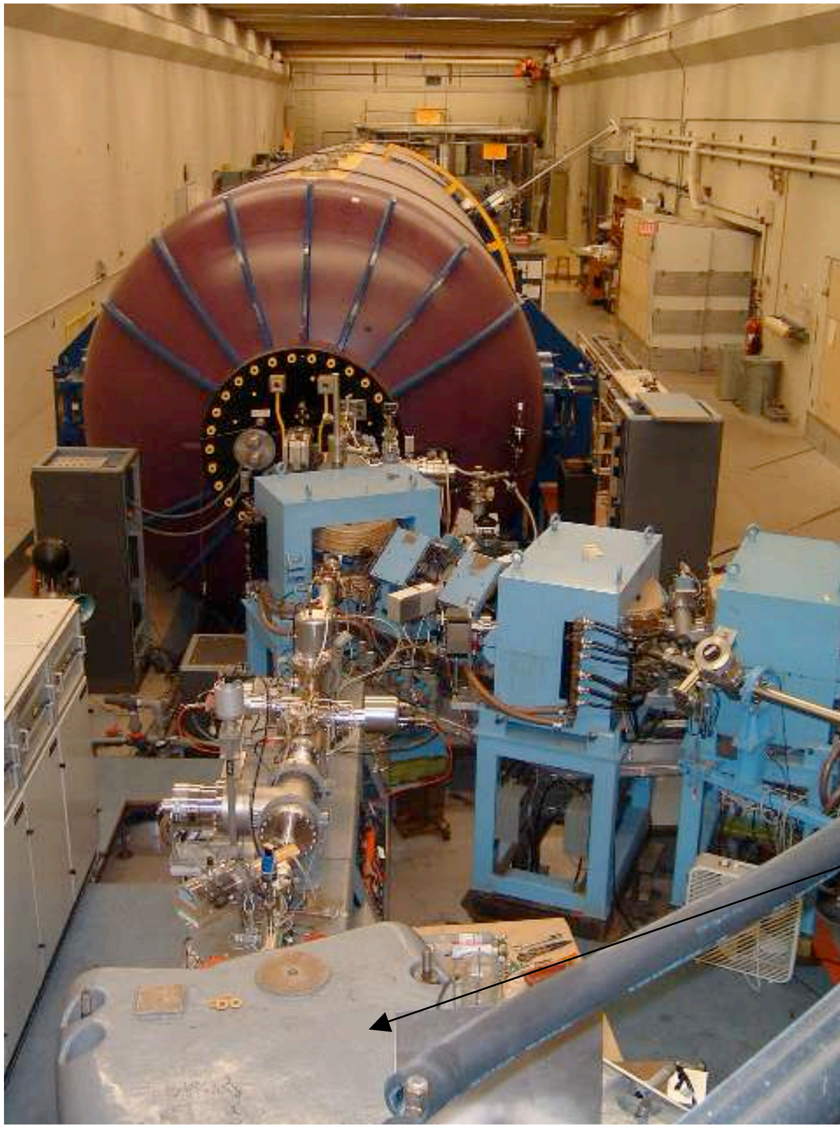
Column focusing Part 2

- The rest of the focusing effect of the column is as shown to the right
- Focusing at the upstream end of each gap and defocusing at the downstream end of each gap results in *net focusing,* because the beam is a bit higher-energy downstream
- In other words, the focusing effect is always greater than the defocusing effect



High energy end

High energy end



Beam is bunched and sent to superconducting linear accelerator

Analyzing magnet to select energy for beam that will not be further-accelerated

Analyzing magnet

- The field of the 90° bend is of order 1 Tesla
- The bend radius is of order 1 meter
- Know desired q,m, and v
- Set corresponding B
- B is regulated by an NMR probe

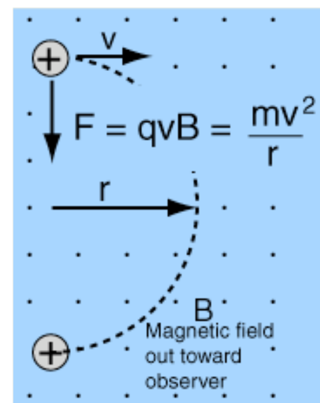
$$r = \frac{mv^2}{qvB} = \frac{mv}{qB}$$ Radius of path produced by magnetic field

If the velocity v is produced by an accelerating voltage V:

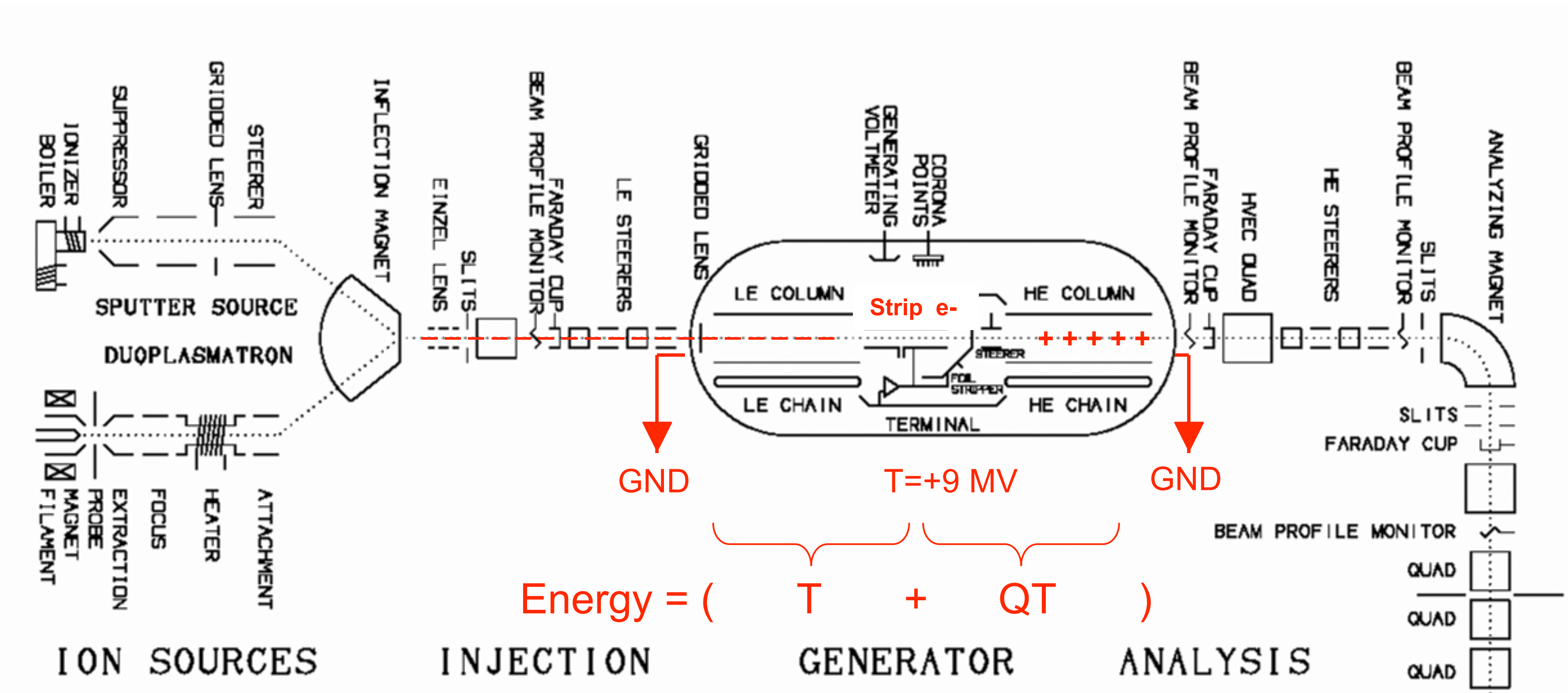
$$\frac{1}{2}mv^2 = qV \; ; \quad v = \sqrt{\frac{2qV}{m}}$$

Substitution gives:

$$r = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

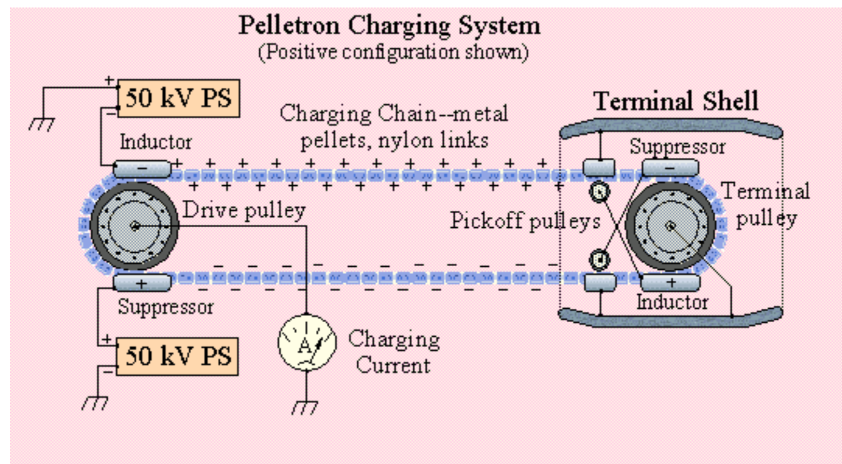


Beam energy


BOILER
IONIZER
SUPPRESSOR
GRIDDED LENS
STEERER
SPUTTER SOURCE
DUOPLASMATRON
INFLECTION MAGNET
EINZEL LENS
SLITS
BEAM PROFILE MONITOR
FARADAY CUP
LE STEERERS
GRIDDED LENS
GENERATING VOLTMETER
CORONA POINTS
LE COLUMN
Strip e-
HE COLUMN
STEERER
FOIL STRIPPER
LE CHAIN
TERMINAL
HE CHAIN
BEAM PROFILE MONITOR
FARADAY CUP
HVEC QUAD
HE STEERERS
BEAM PROFILE MONITOR
SLITS
ANALYZING MAGNET
SLITS
FARADAY CUP
BEAM PROFILE MONITOR
QUAD
QUAD
QUAD
FILAMENT
MAGNET
PROBE
EXTRACTION
FOCUS
HEATER
ATTACHMENT
GND
T=+9 MV
GND
Energy = (T + QT)
ION SOURCES
INJECTION
GENERATOR
ANALYSIS

Charging system

- The amount of variation in the terminal voltage depends on the mode of operation
- GVM mode
  - FWHM = (1 + charge) * 1000 V
- Slit Mode
  - FWHM = (1 + charge) * 500 V
- The 2 modes will be described after providing a bit of necessary background in the next few slides



Variation in energy

- The Pelletron charging chain was developed in the mid 1960s as an improvement over the older Van de Graff charging belts

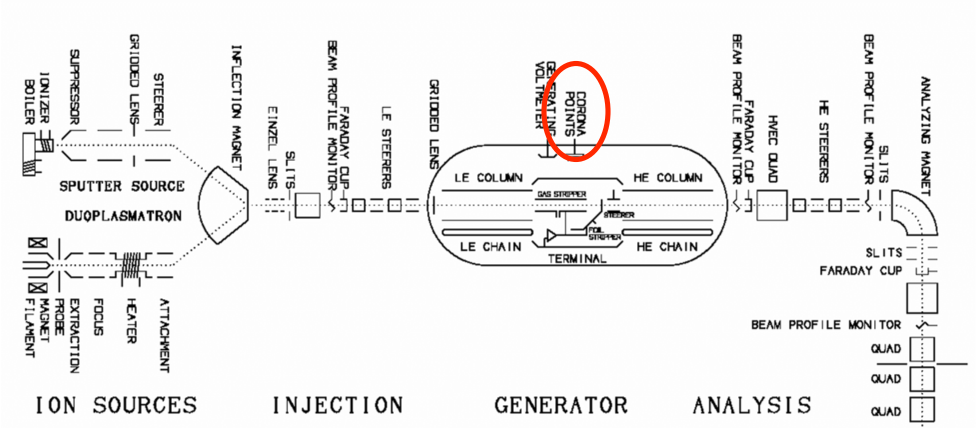
- These belts suffered from terminal voltage instability, susceptibility to spark damage, and they generated belt dust which necessitated frequent cleaning inside the accelerator tank

- The belt in the University of Washington’s Van de Graaff was replaced with a Pelletron in about 1995

Corona points

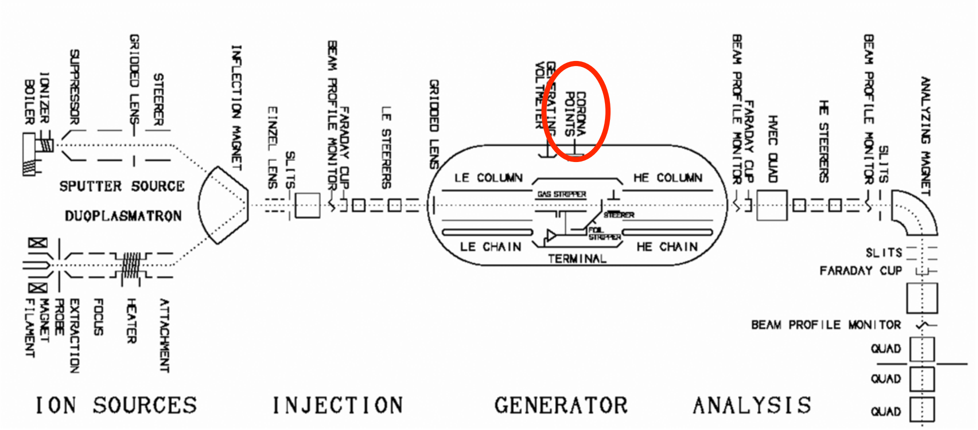
- Equilibrium must be established between the charge brought to the terminal by the belt or pelletron chain and that which flows from the terminal to ground through the column resistors

- This is done via the corona points, a collection of about a dozen sharp metal needles attached to the end of a moveable arm



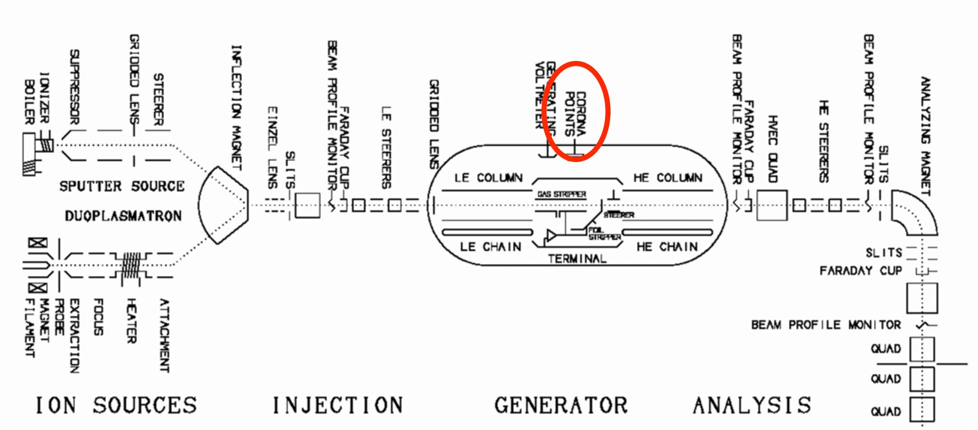
Corona points

- The arm is mounted in the tank wall opposite the terminal so that the points can be extended toward or extracted away from the terminal
- During operation, the corona points are moved close enough to the terminal so that a coronal discharge begins at the points
- This discharge causes charge to flow from the terminal through the corona points



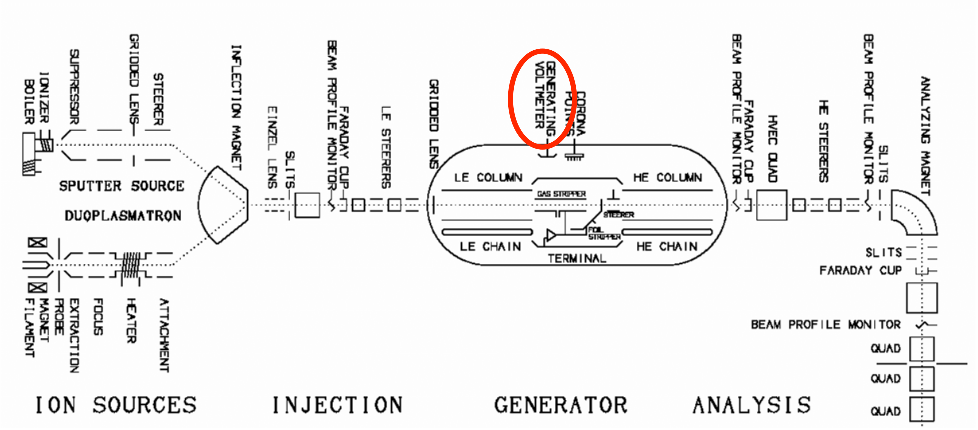
Corona points

- A variable resistor within the electrical circuitry connected to the corona points is adjusted to increase or decrease the charge extracted from the terminal so that a constant terminal voltage is maintained



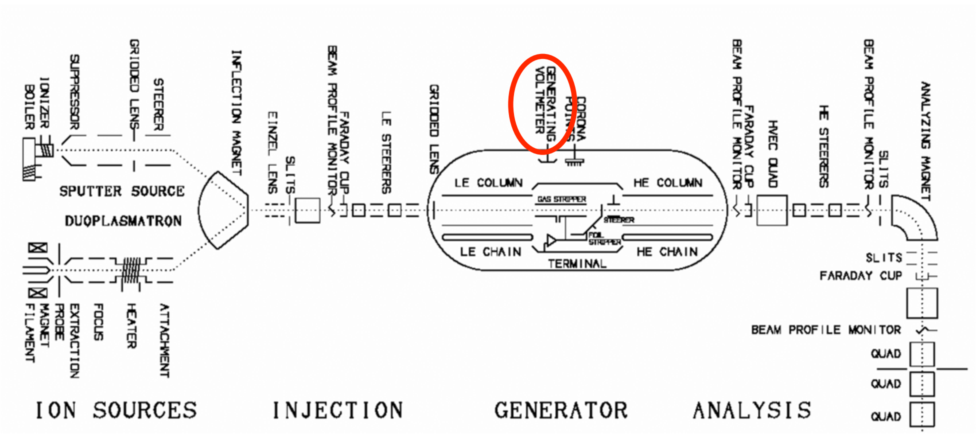
GVM

- The terminal voltage is measured continuously by a generating voltmeter (GVM)
- The GVM has a set of stationary metal vanes mounted behind a set of rotating metal vanes.



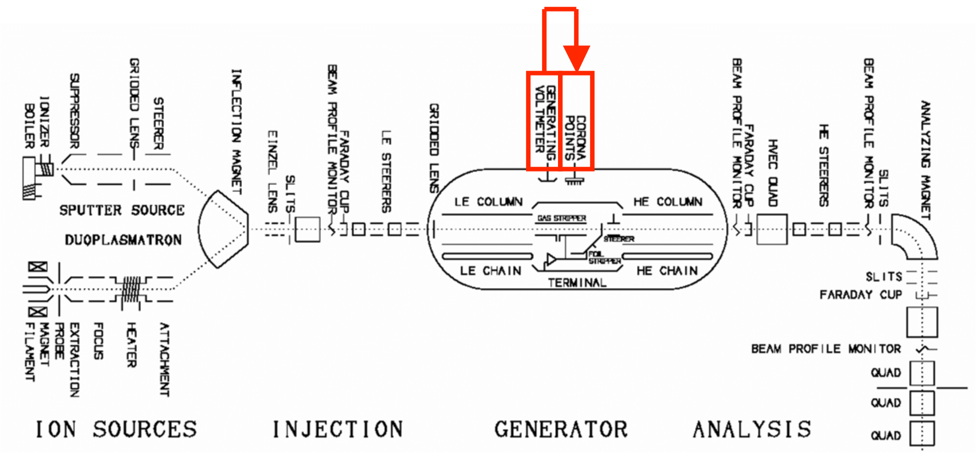
GVM

- The GVM is exposed to the E field of the terminal
- The capacitance of the GVM varies as the vanes rotate
- This capacitance measurement can be used to determine the terminal voltage



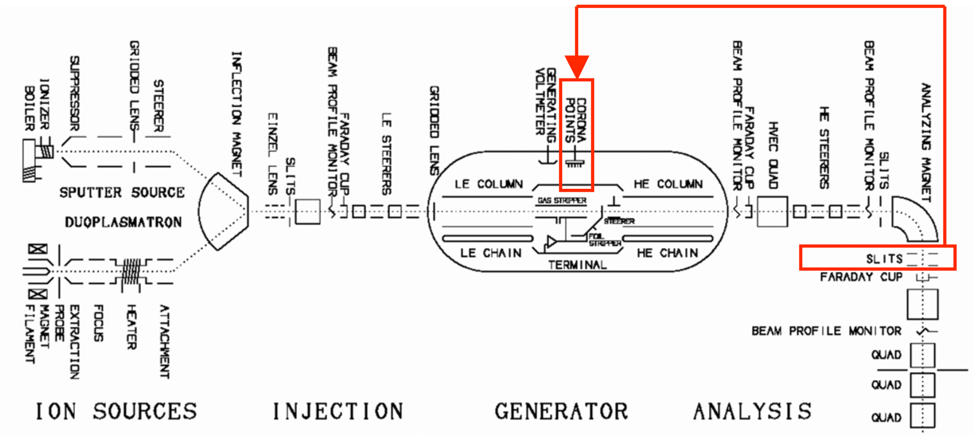
GVM mode

- Output of GVM is compared to a reference set by the operator to the desired terminal voltage
- The error signal created from the difference between the reference and the GVM is used to adjust the variable resistor in the corona points assembly which causes the terminal voltage to change until the reference and GVM signals agree



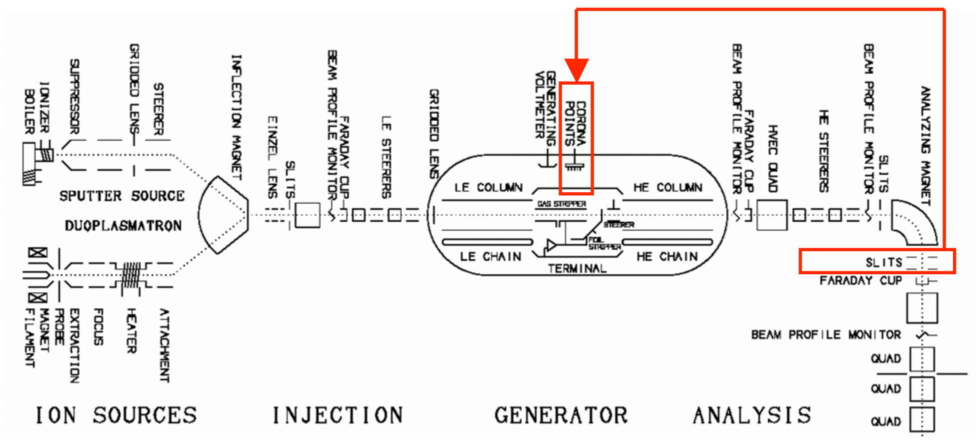
Slit mode

- An error signal is generated by a set of slits located at the exit of the 90º analyzing magnet.
- The B field in the analyzing magnet is set so to allow only the beam with the desired energy to complete the 90º degree bend
- The beam with the desired energy will pass through the slits.
- The slits are set to intercept a small amount of beam, so a well-centered beam will strike both slits equally.

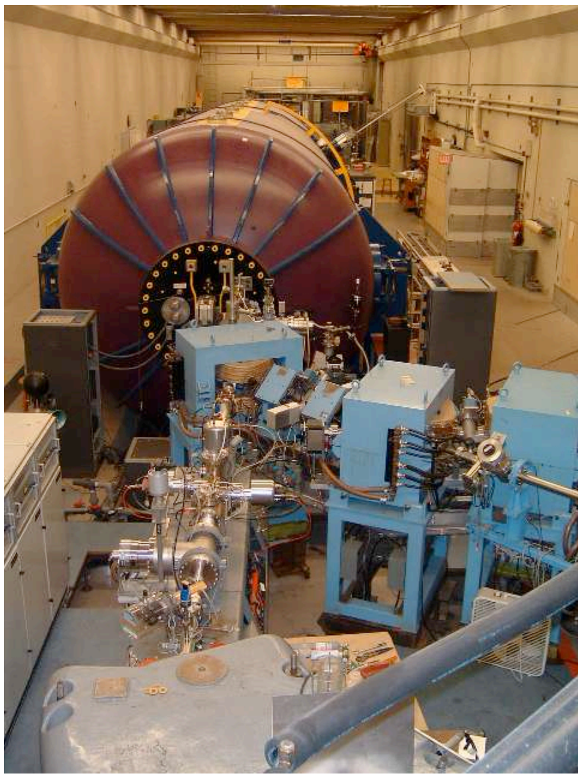


Slit mode

- If the beam energy varies slightly due to variations in the terminal voltage, the beam will not have the correct energy to traverse the 90º bend, and more beam will strike one of the analyzing slits than the other
- An error signal is generated based on the difference in the slit current readings
- This signal is then used to adjust the variable resistor in the corona points assembly



High energy end



Analyzing magnet
for beam that will not
go to the linac

Superconducting
linear Booster

Each pipe leads to one of the
target areas in the target rooms.

Quarter-wave SRF cavities

- The Booster is comprised of 2 sizes of quarter-wave SRF cavities
- The SRF cavities are made of Cu plated with Pb
- Pb is superconducting at 4K
- Linear accelerator operates at 50 MHz

Target room

- Targets, spectrometers, detectors, etc.

Door to control room

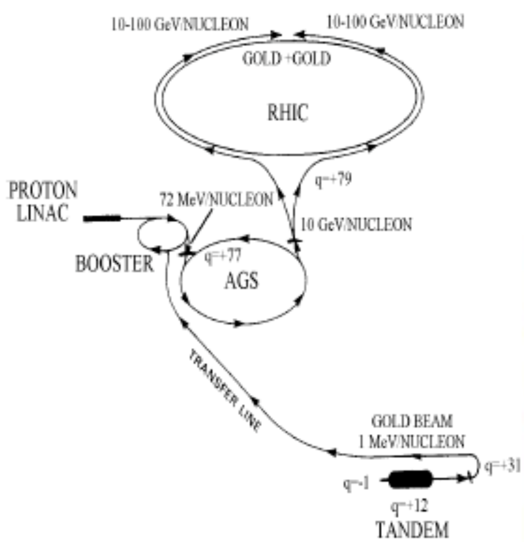
- 6-foot-thick door between Van de Graaff and control room

Control room

Van de Graaff controls

Booster controls

Uses of Van de Graaffs



Tandem Van de Graaff
serves as an injector for RHIC

- Nuclear physics
- Injectors for high energy heavy ion accelerator (like RHIC)
- Study of space radiation effects, in particular, Single Event Upset (SEU) Testing and Spacecraft Instrument Calibration.