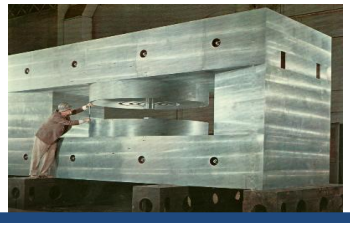
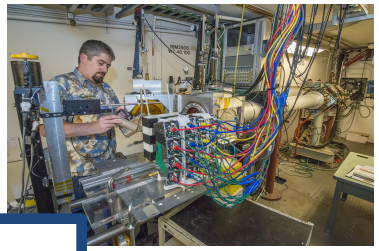
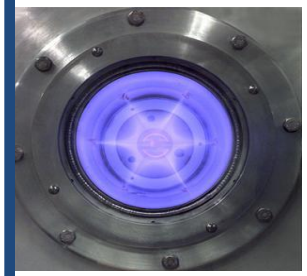
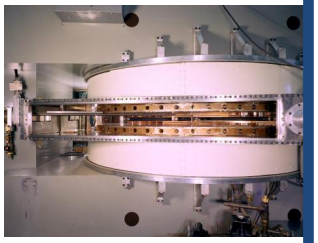
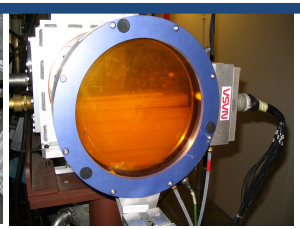
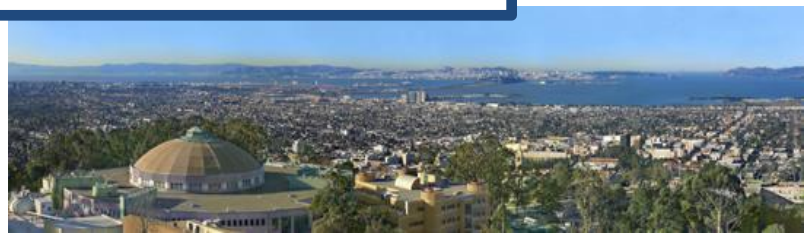
The Berkeley Accelerator Space Effects (BASE) Facility



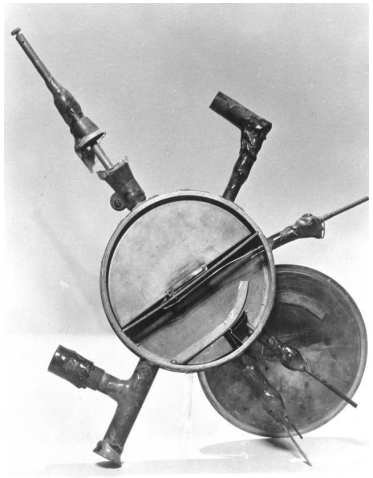
88-Inch Cyclotron

Mike Johnson

Lawrence Berkeley National Laboratory

Berkeley Lab - Bldg. 88

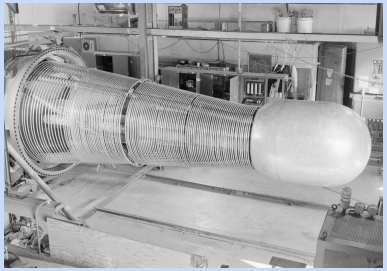
What is a “Cyclotron”?



The first cyclotron (4 inches in diameter)

A cyclotron is a type of particle accelerator consisting of a magnet and a high frequency oscillator, with *ions* travelling in a spiral pattern.

The 184-inch Cyclotron

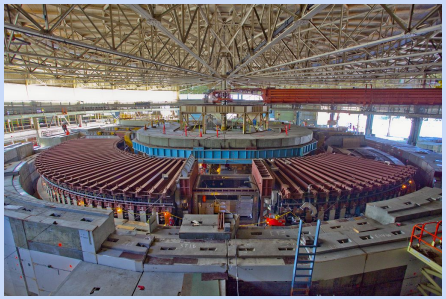


Van de Graaff

Other types of particle accelerators include:

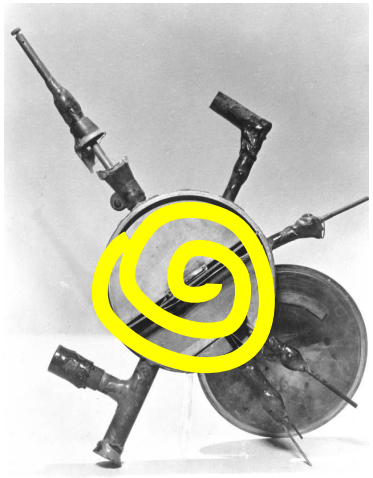
- Van de Graaff accelerators
- Linear accelerators (“linacs”)
- Synchrotron accelerators

Linear Accelerator



Synchrotron

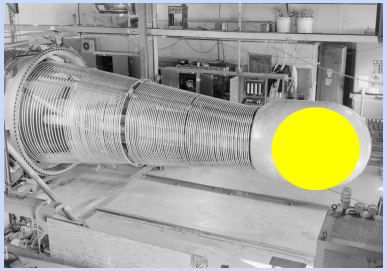
What is a “Cyclotron”?



The first cyclotron (4 inches in diameter)

A cyclotron is a type of particle accelerator consisting of a magnet and a high frequency oscillator, with *ions* travelling in a spiral pattern.

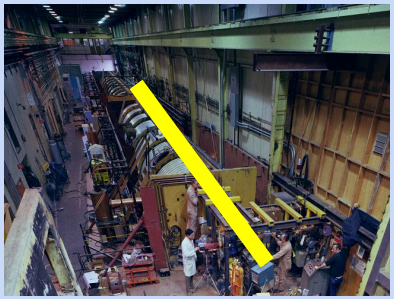
The 184-inch Cyclotron



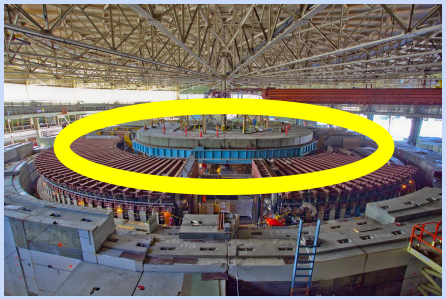
Van de Graaff

Other types of particle accelerators include:

- Van de Graaff accelerators
- Linear accelerators (“linacs”)
- Synchrotron accelerators



Linear Accelerator



Synchrotron

Accelerators Simplified

Donut Hole

Van de Graaff

Churro

Linear Accelerator

Donut

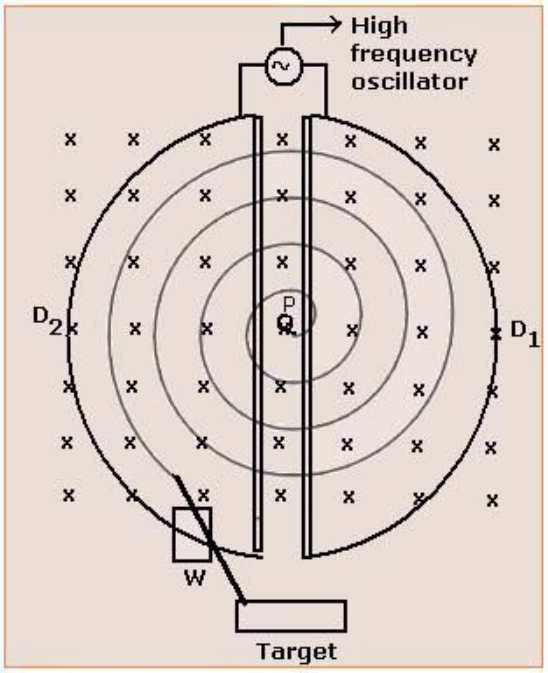
Synchrotron

Cinnamon Roll

Cyclotron

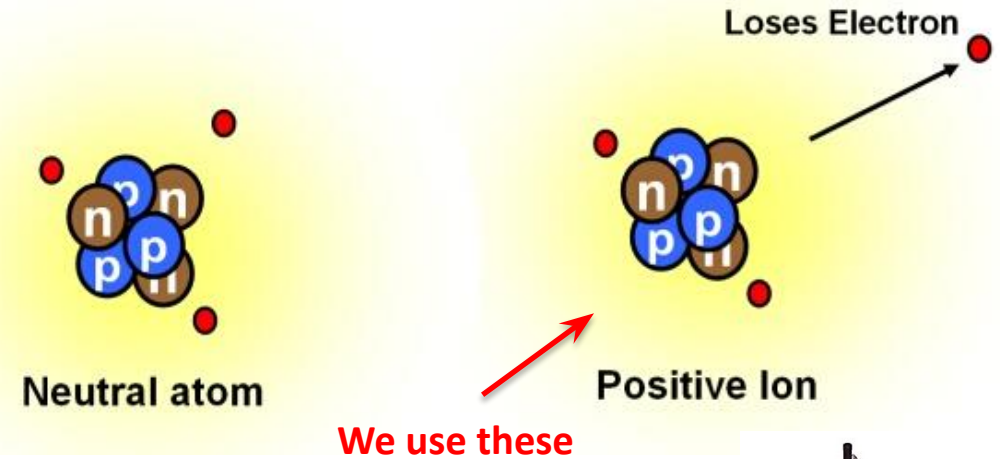
This is us!

How does a cyclotron work?



Cyclotron operation

Distorted TV picture from electrons taking a curved path in the presence of a magnetic field



We use these

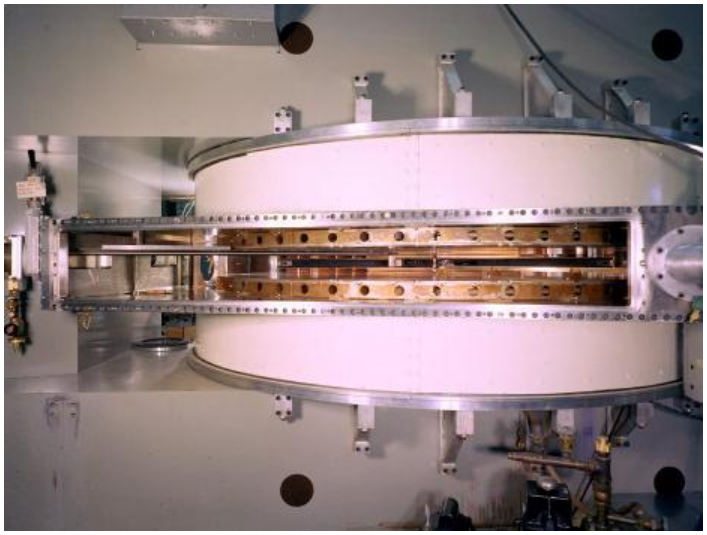
1.) Ions are injected in the center and travel in a curved trajectory due to the magnetic field

2.) Ions get periodic 'kicks' of electromagnetic energy to increase their velocity, causing them to spiral outward

3.) Once the ions reach the outer orbit, they are pulled out with a high voltage and sent to the experiments

Tetherball

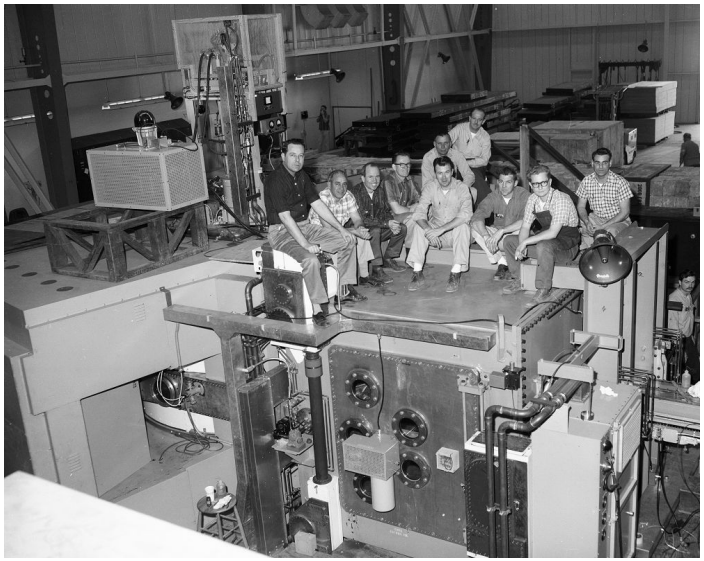
The 88-Inch Cyclotron



88-Inch Cyclotron

- 300 tons of metal
- First beam in Dec. 1961
- Capable of accelerating hydrogen through uranium
- Ions reach a third of the speed of light and travel 100 to 600 orbits

Cyclotron dee removal



Sitting on top of the RF Tank in the early days

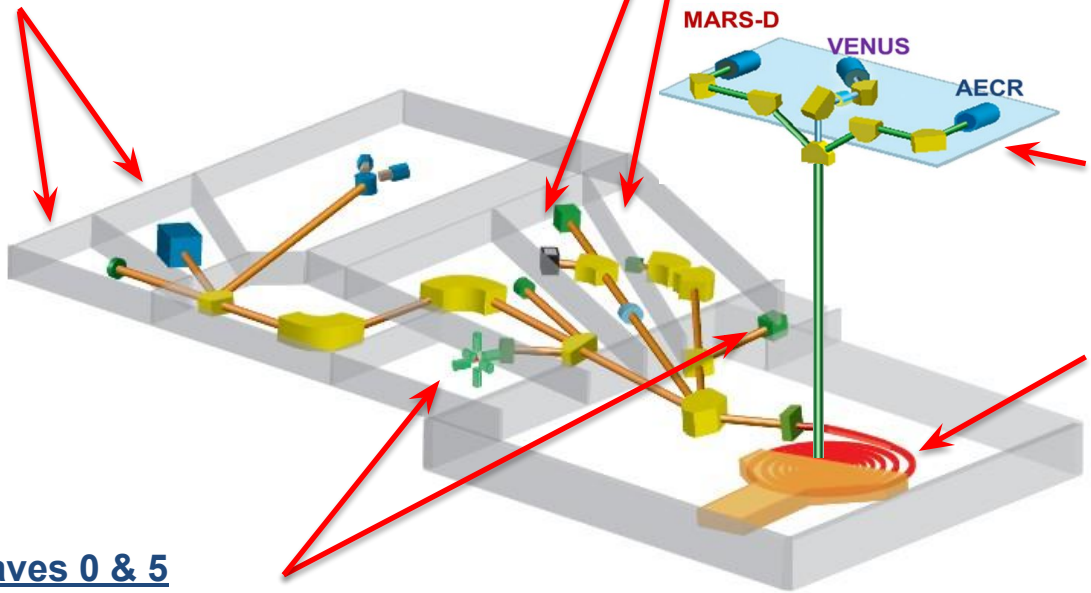
Cyclotron Map & Current Research

Caves 1 & 2

- **Berkeley Gas-filled Separator (BGS)**
- Superheavy element research - search for new elements & isotopes, chemistry

Caves 4A & 4B

- **BASE Facility**
- Heavy ion cocktails and protons for radiation effects testing



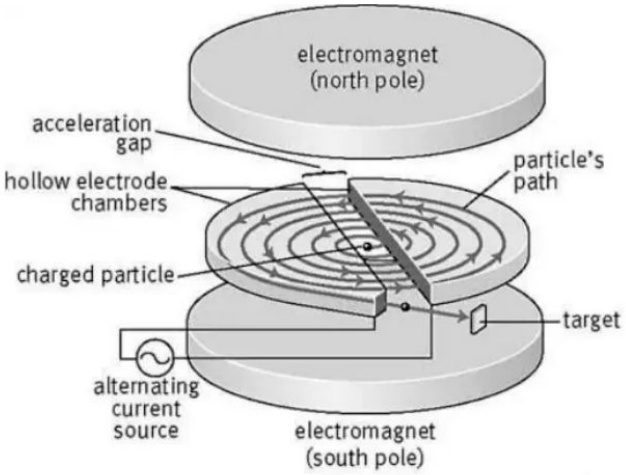
Ion Sources

88-Inch Cyclotron

Caves 0 & 5

- **Nuclear Data Group**
- Neutron beams from deuterons

Ion Sources



m v = q *B* r

We can change this one!

m = ion mass

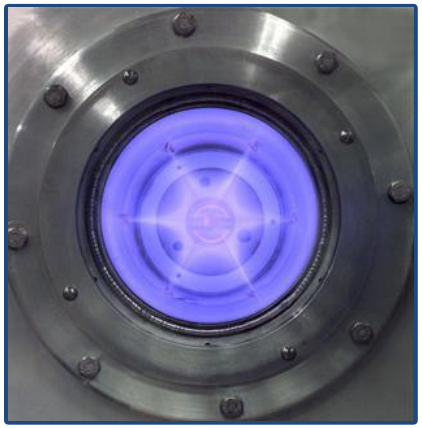
v = ion velocity

r = orbital radius

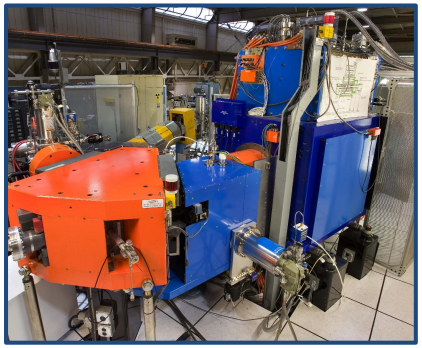
q = ion charge

B = magnetic field

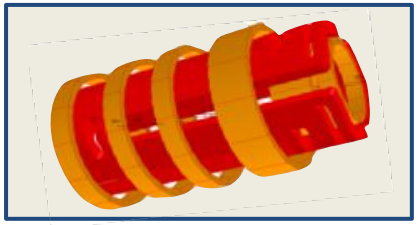
Can't change these easily



Plasma



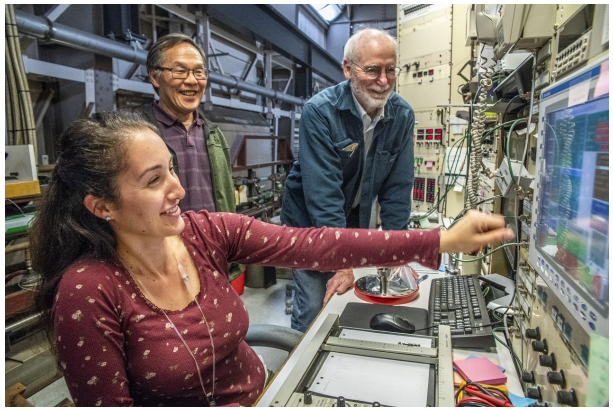
VENUS ion source



Under development: MARS ion source

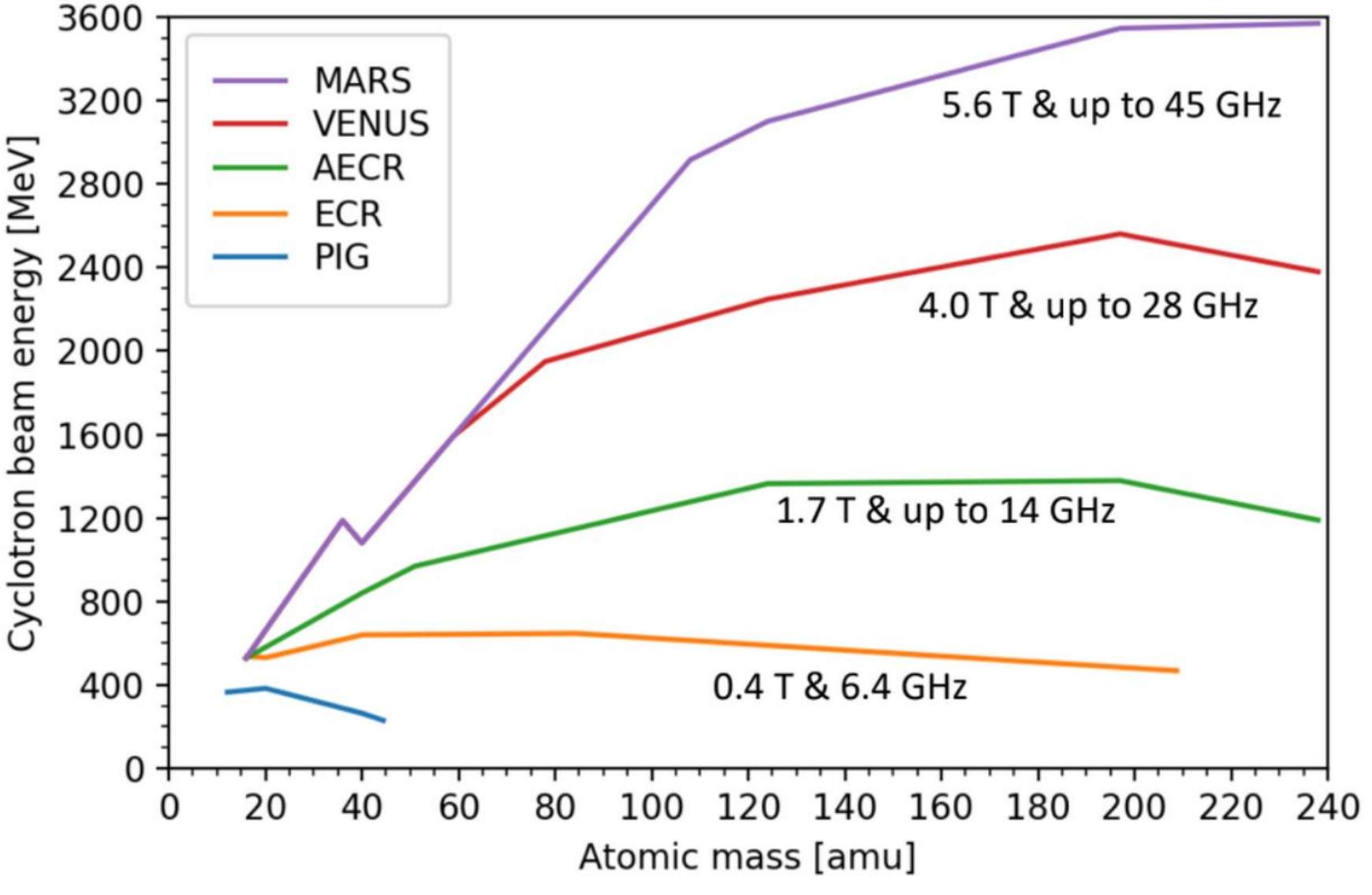
Why ECR ion sources?

- Higher current beams
- Higher energy beams
- More simultaneous beams
- Improved reliability



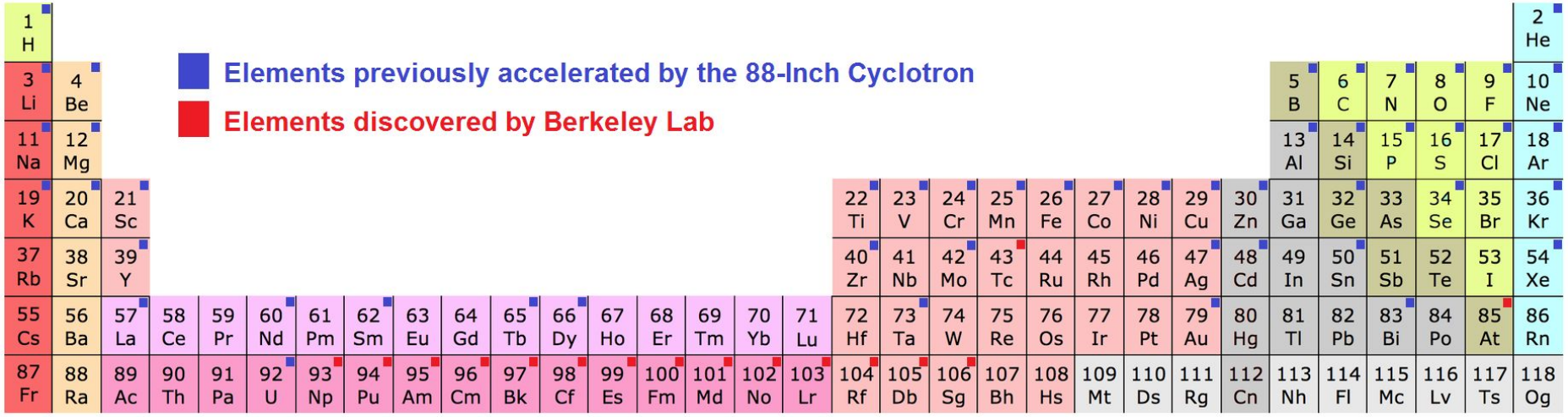
Tuning the VENUS ion source

Ion Source Evolution



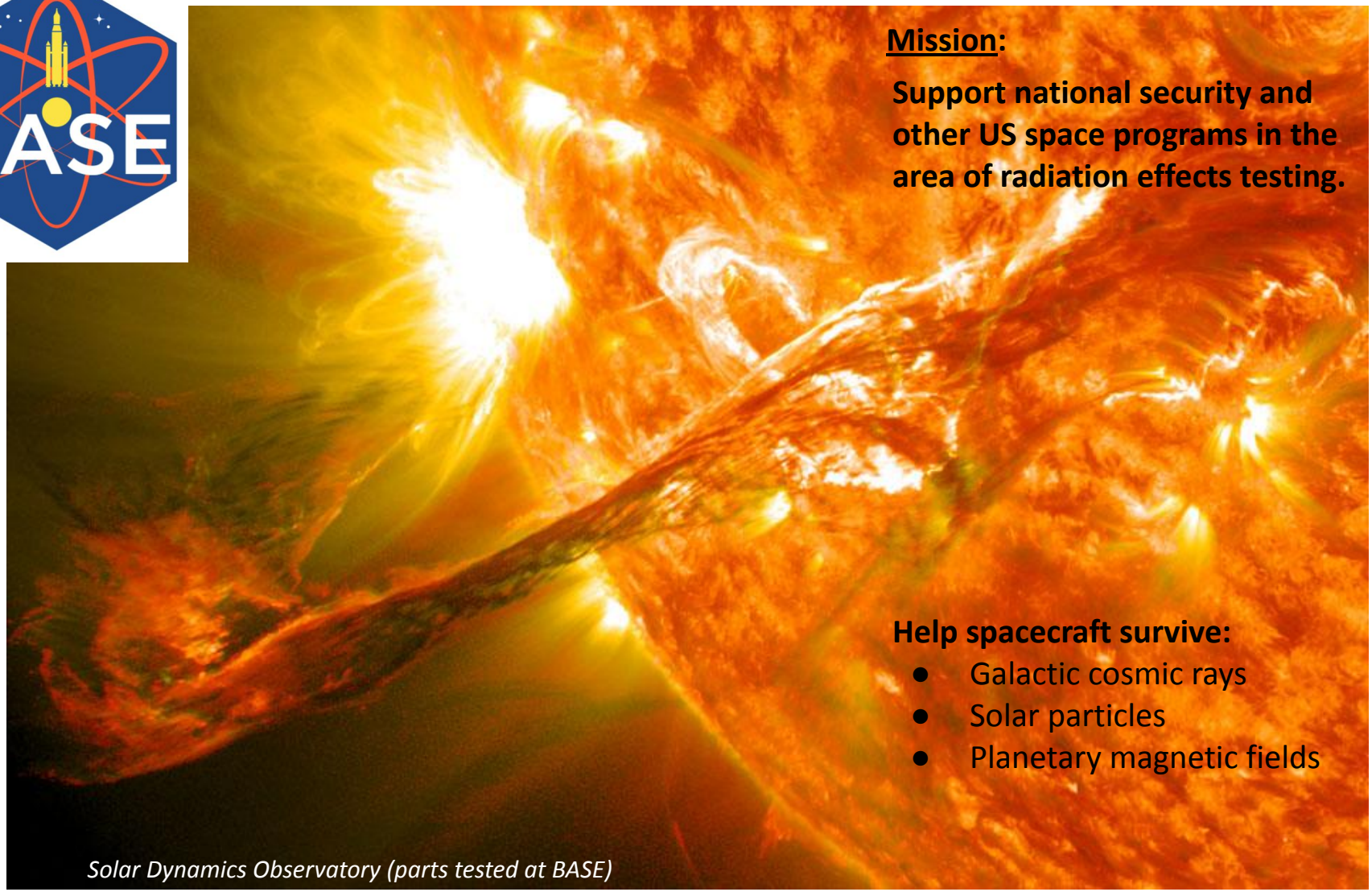
Elements Accelerated

Periodic Table of the Elements



Most of these elements can't be accelerated without our ECR ion sources!

Berkeley Accelerator Space Effects (BASE) Facility



Mission:

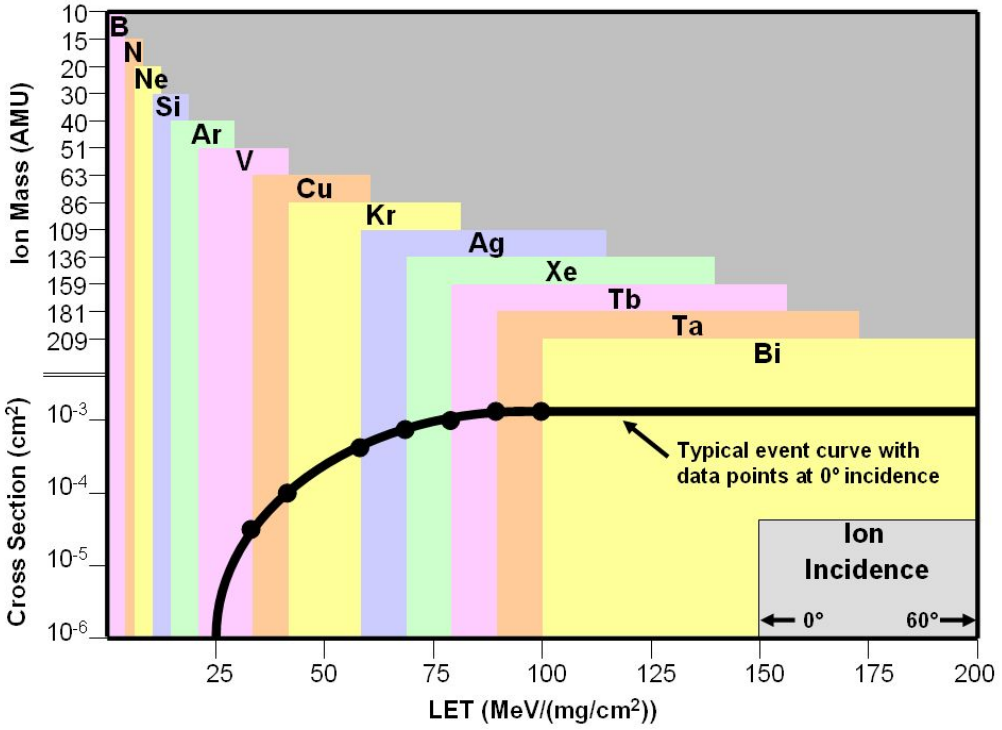
Support national security and other US space programs in the area of radiation effects testing.

Help spacecraft survive:

- Galactic cosmic rays
- Solar particles
- Planetary magnetic fields

Solar Dynamics Observatory (parts tested at BASE)

Cocktail Beams



Why cocktail beams?

- To efficiently deposit *different amounts of energy* into electronics parts for Single Event Effects (SEE) testing

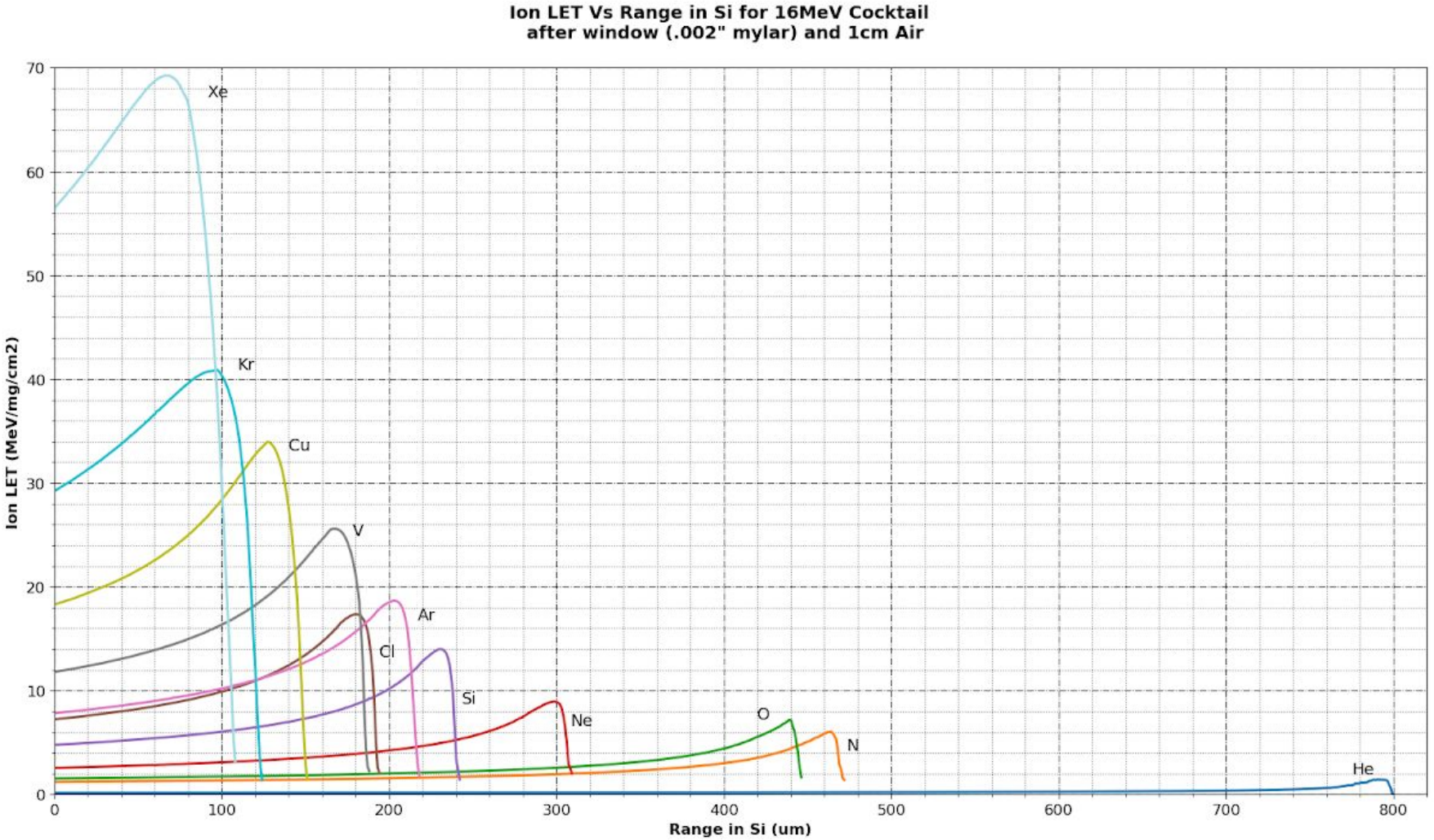
What is a 'cocktail'?

- Unique to cyclotrons with ion sources
- Multiple ions injected simultaneously
- Ions are selected and separated by simply changing cyclotron frequency
- Cyclotron + ion sources = **3 minutes** to change ions (instead of 4 hours)

Standard cocktail beams

- 4.5, 10, 16, 20 MeV/nuc (heavy ion)
- 30 & 32.5 MeV/nuc (light ion)

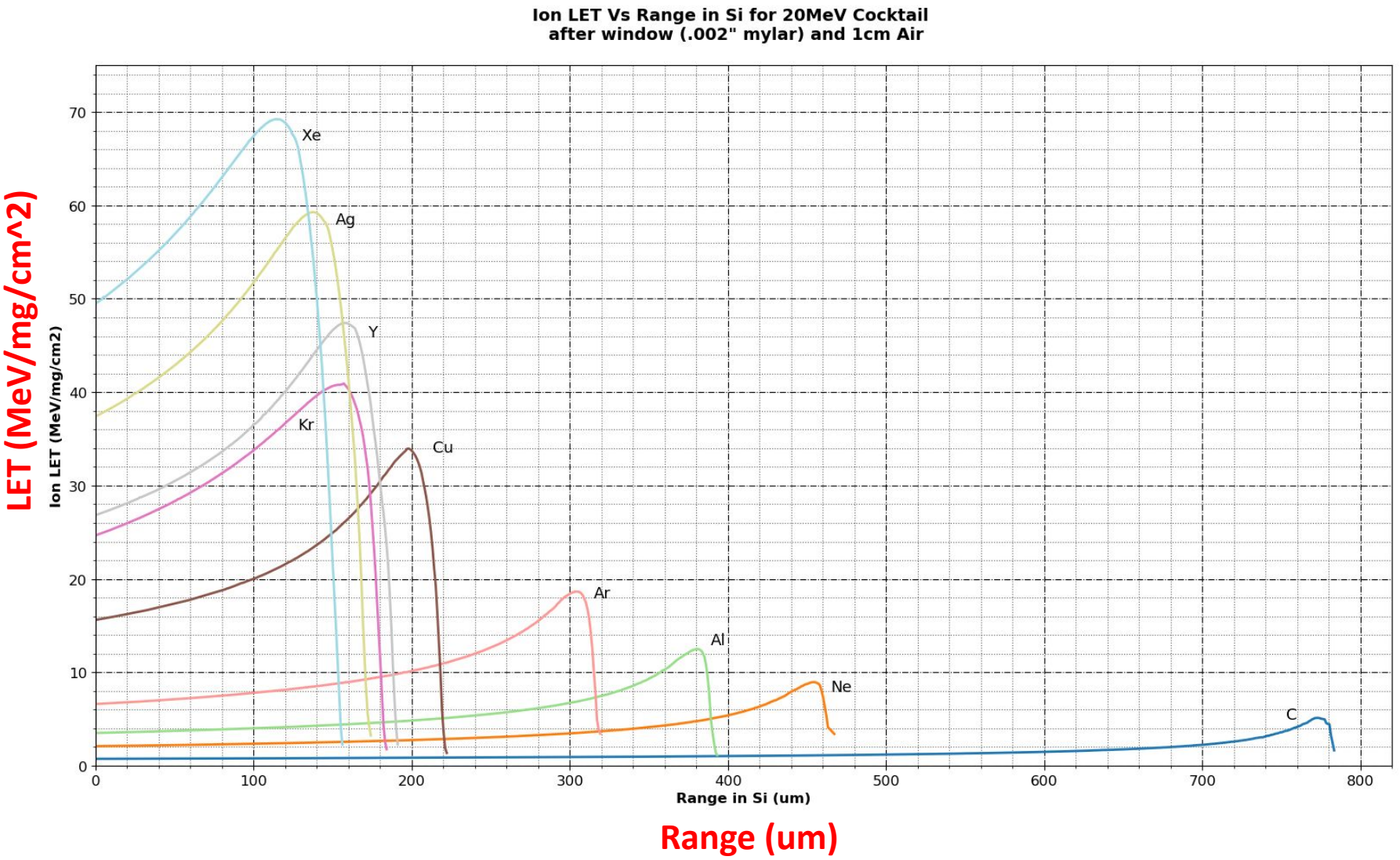
Bragg Curves - 16 AMeV (in air)



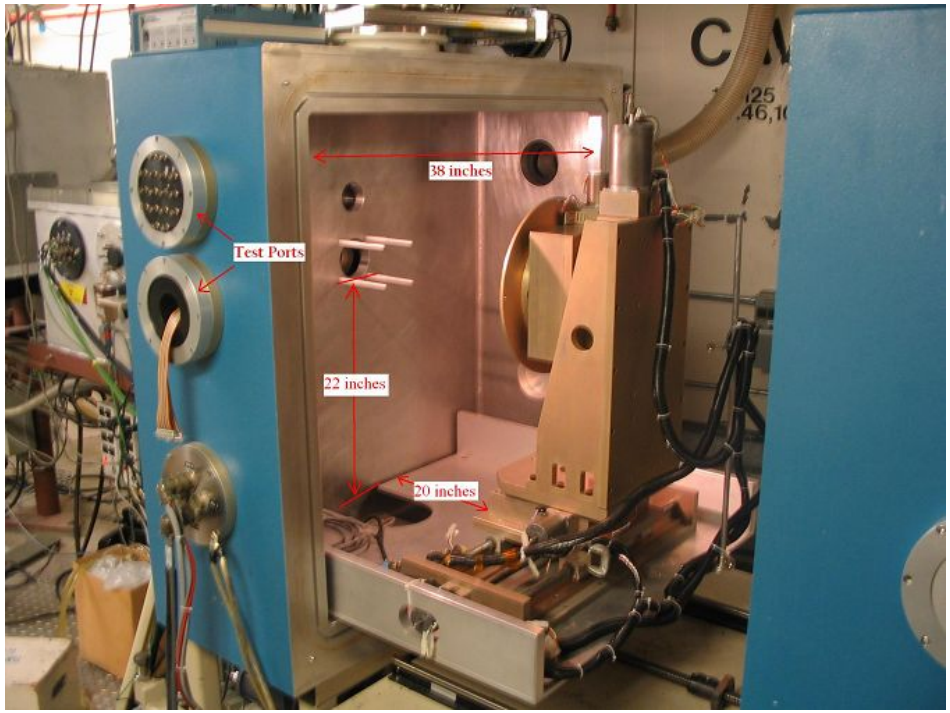
LET (MeV/mg/cm^2)

Range (um)

Bragg Curves - 20 AMeV (in air)



Heavy Ion Station Details



Vacuum chamber and motion table

Flux densities 1E2 - 1E7 ions/cm^2/sec

Photomultiplier tube dosimetry

Remote motion table positioning

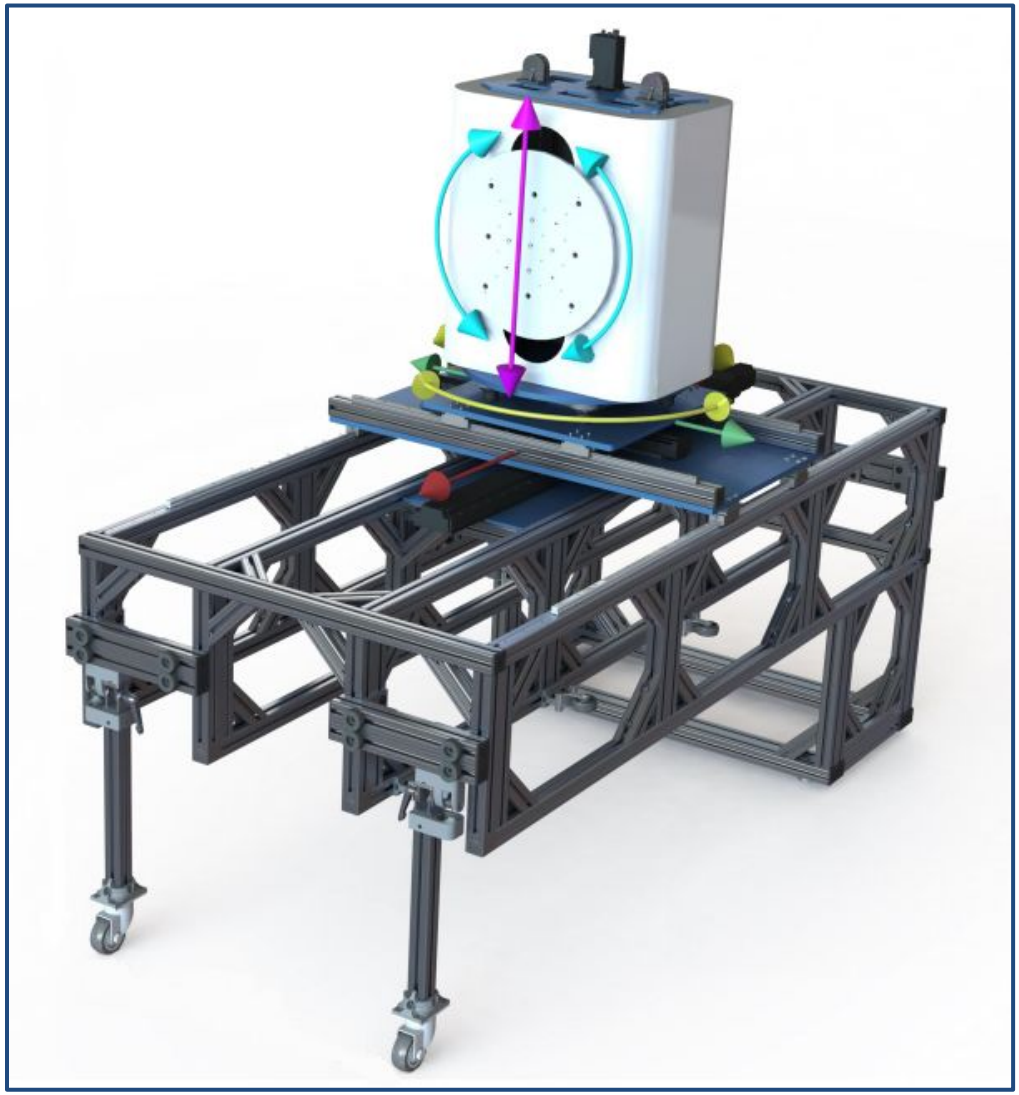
Remote laser alignment

Vacuum chamber:

- One-button operation
- Pumps down in 4 minutes
- Multiple feedthroughs available

Cooling/heating plate available

Heavy Ion In-Air Stage

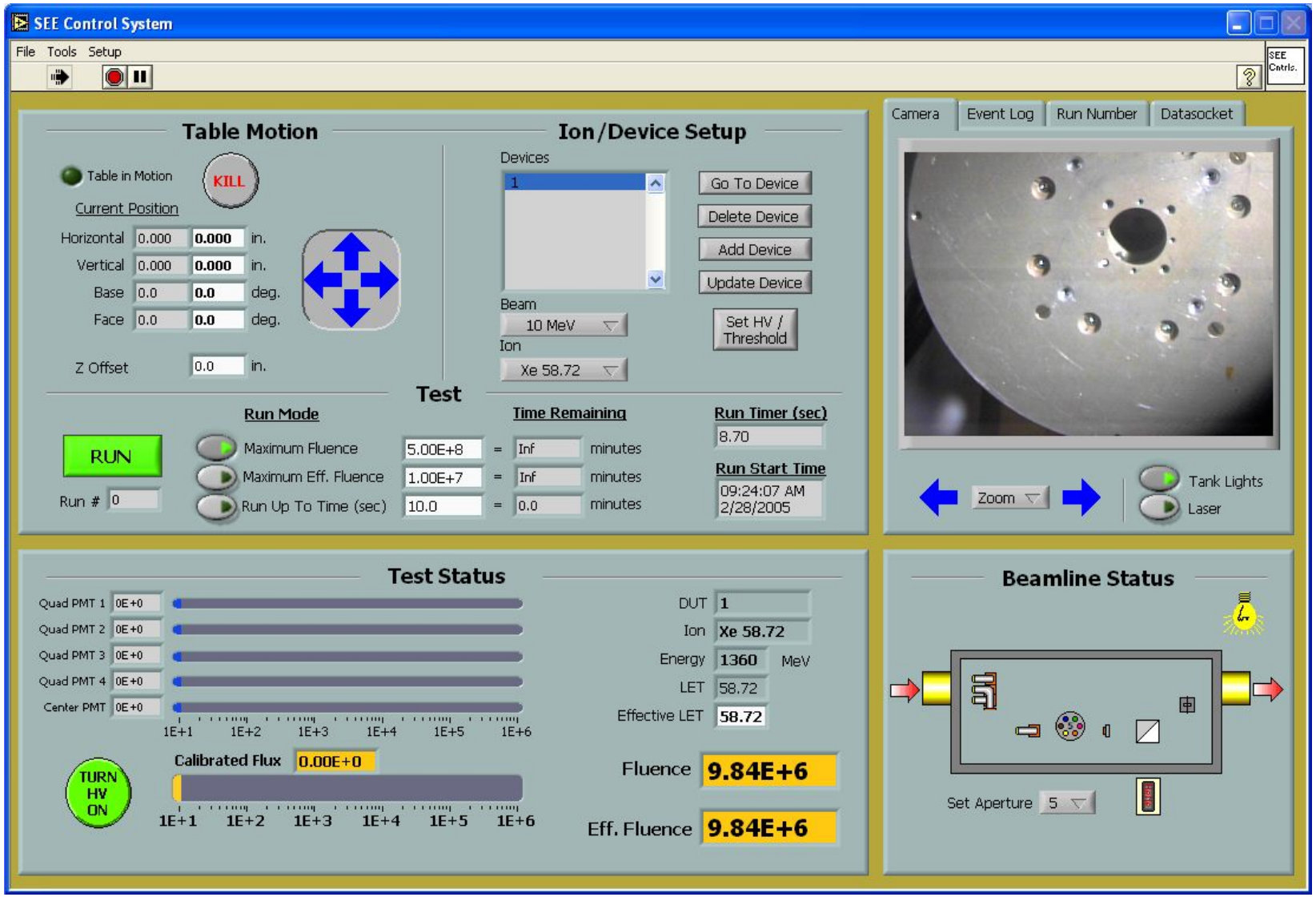


In-Air Stage

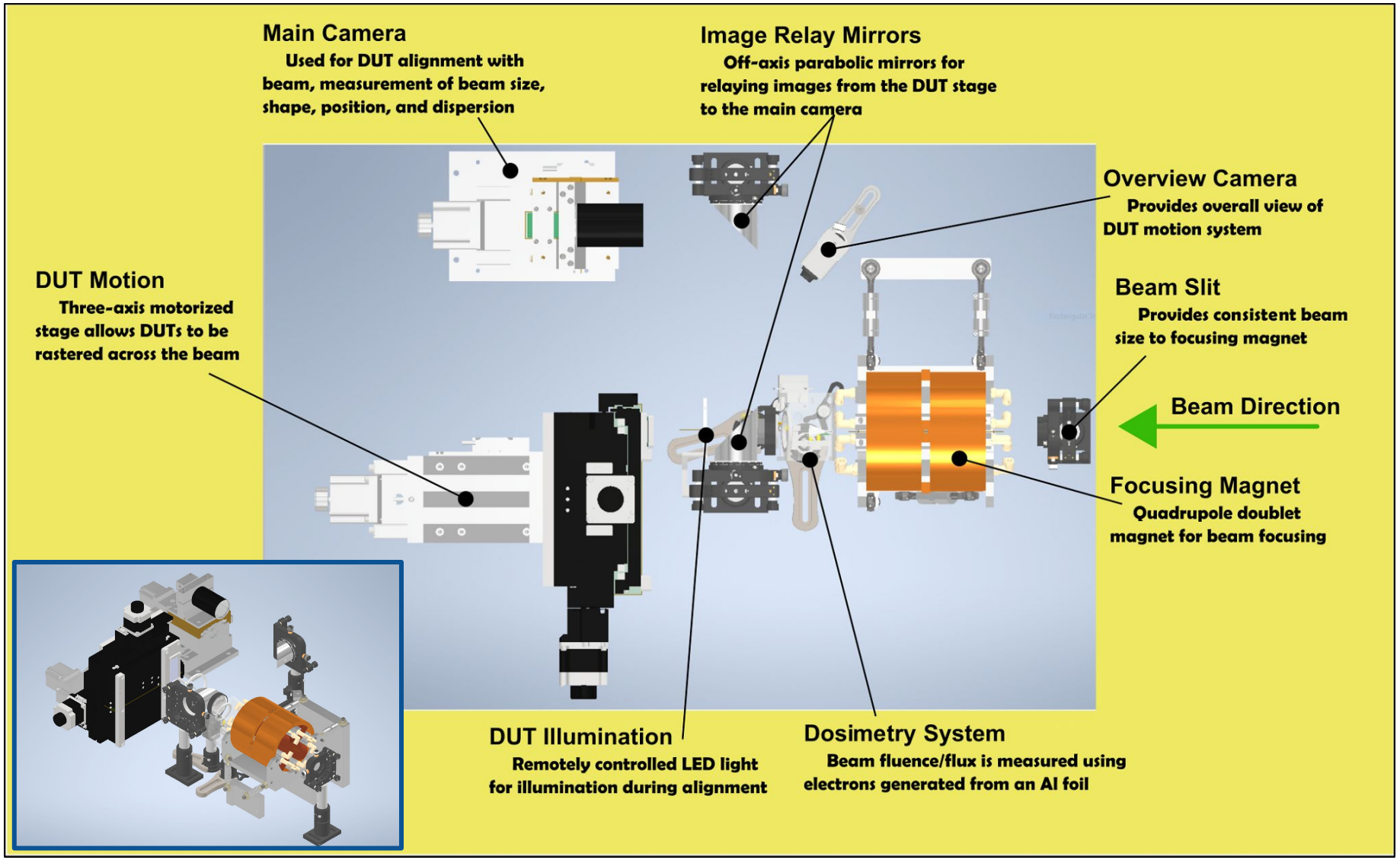
New: In-Air Stage

- Driven by user need for a modern in-air test station
- Versatile:
  - can be used with standard mounting fixtures from other facilities

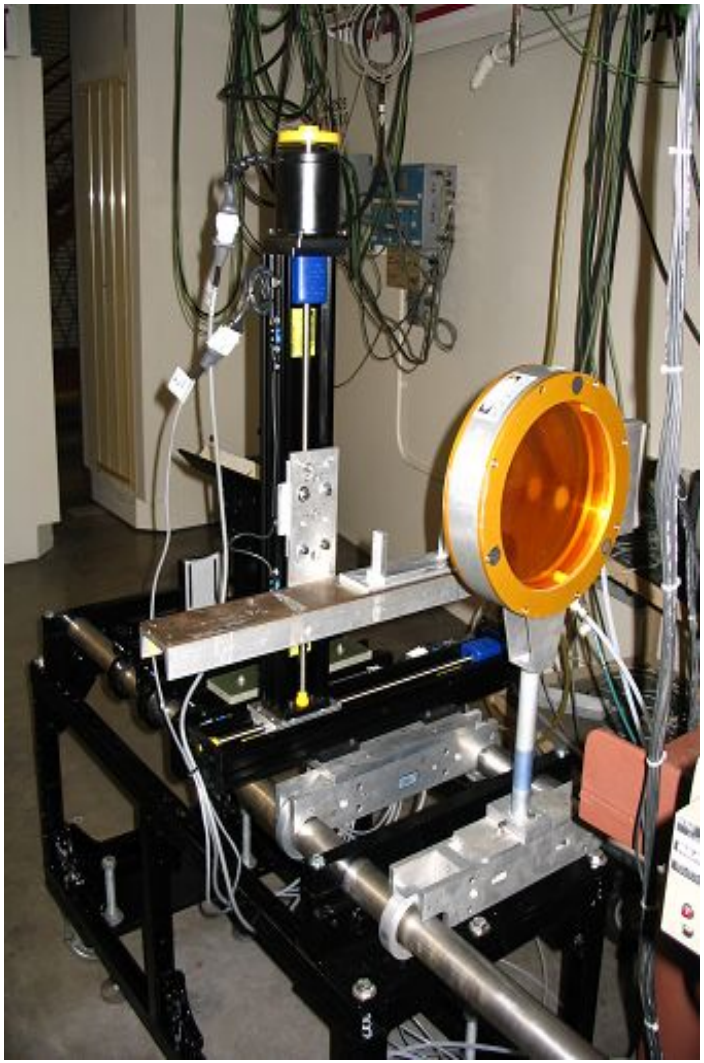
SEE Software



Microbeam

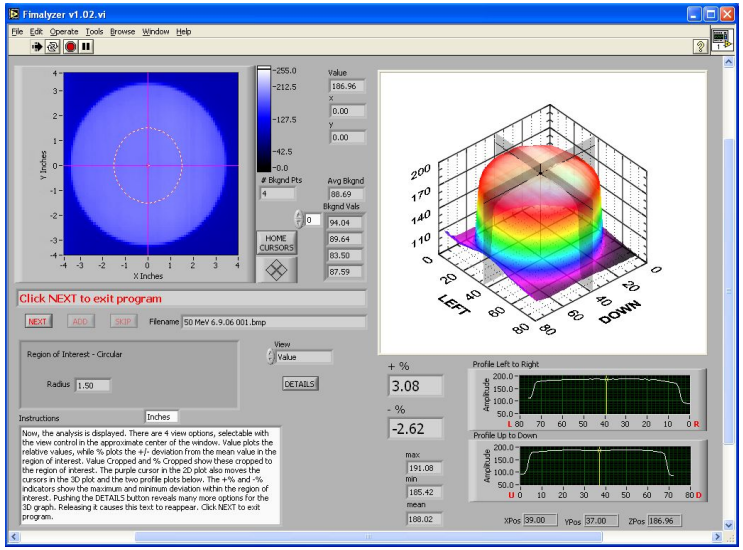

Main Camera
Used for DUT alignment with beam, measurement of beam size, shape, position, and dispersion
Image Relay Mirrors
Off-axis parabolic mirrors for relaying images from the DUT stage to the main camera
Overview Camera
Provides overall view of DUT motion system
DUT Motion
Three-axis motorized stage allows DUTs to be rastered across the beam
Beam Slit
Provides consistent beam size to focusing magnet
Beam Direction
Focusing Magnet
Quadrupole doublet magnet for beam focusing
DUT Illumination
Remotely controlled LED light for illumination during alignment
Dosimetry System
Beam fluence/flux is measured using electrons generated from an Al foil

Protons



Ion Chamber & Translator Table

- In-air: 10 to 60 MeV
- Vacuum: 1 to 10 MeV
  (performed in Cave 4B next door)
- Standard flux densities:
  1E6 to 3E8 protons/cm^2/sec
- 6-inch, 5-mil kapton window with ion chamber dosimetry and laser alignment



Filmalyzer QA software

Neutrons

Neutrons & Nuclear Data

- Pulsed, high intensity neutron beams
- Broad spectral range: 50 keV to 62 MeV
- Energy centered at roughly half of the beam energy (deuterons)
- Samples places as little as 1 cm away
- Variable flux density of up to 2.75×10^{12} neutrons/sr/s @ 10 uA and 33 MeV

Recent Work

- Scintillator characterization
- Neutron damage studies
- Cross-section measurements
- Medical isotope research
- Fission yield measurements
- Neutron inelastic scattering measurements

BASE Facility Users

Who uses BASE?

- NASA
- Dept. of Defense
- Defense Contractors
- Semiconductor Manufacturers
- Private Space Companies
- Telecom & Satellite Companies
- Universities
- National Laboratories
- Small Businesses

What type of work is performed?

- Chip testing
- Detector characterization
- Materials & shielding studies
- Biomed research

xEMU Space Suit

The 88-Inch Cyclotron

"Instead of an attic with a few test tubes, bits of wire and odds and ends, the attack on the atomic nucleus has required the development and construction of great instruments on an engineering scale."

"No individual is alone responsible for a single stepping stone along the path of progress, and where the path is smooth, progress is most rapid."

"Let us cherish the hope that the day is not far distant when we will be in the midst of this next adventure."

- Ernest Lawrence

Thank you

cyclotron.lbl.gov

Single Event Effects

Single-Event Effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic-particle strike.

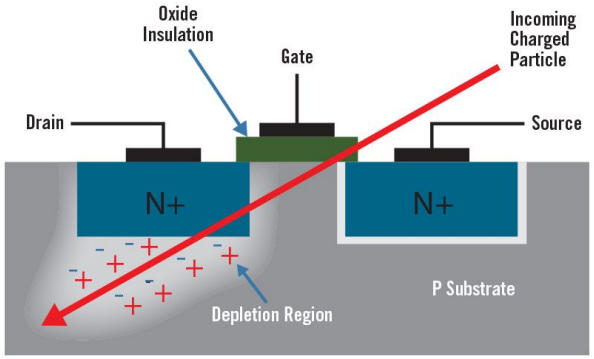
Examples of Single Event Effects:

Single-Event Upset (SEU): A soft error caused by a single ionizing particle striking a sensitive node.

Single-Event Latchup (SEL): An abnormal high-current state with loss of device functionality; requires cycling power to restore operation.

Single-Event Burnout (SEB): High-current state in a device that results in catastrophic failure.

Single-Event Functional Interrupt (SEFI): A soft error affecting a device's internal control signals that causes it to reset, lock-up, or otherwise malfunction.



Courtesy of COTS Journal

Causes of SEE's:

-Cosmic rays
-Solar
-Natural isotopes
-Van Allen belts
-Nuclear weapons

Sampling of Upsets, Unclassified (1970s & 80s)

Spacecraft	Failure
Intelsat IV	TTL Flip-FLop
Voyager	CMOS Memory
Pioneer VENUS	TL RAM, PMOS Shift Register
TIROS-N	Potential CMOS RAM SEL
DMSP	NMOS Memory
SDS	64-bit TTL Schottky RAM
GPS	NMOS Memory
SMM	Fast Bipolar Memory
Landsat D	Memory & possible CMOS SEL
Galileo	Possible CMOS PROM SEL
LES 8 & LES 9	TTL Flip-Flop

88-Inch Contributions to Space Exploration

Apollo 17 (experiment with lunar soil sample)

Solar Terrestrial Relations Observatory (STEREO)

Solar Dynamics Observatory (SDO)

Parker Solar Probe

Genesis (Solar Wind Sample Return)

Messenger (Mercury)

Pioneer Venus

Van Allen Probes

IMAGE/Explorer 78

Landsat

Global Positioning System (GPS)

Lunar Reconnaissance Orbiter (LRO)

Mars Pathfinder

Mars Polar Lander

Mars Climate Orbiter

Mars Exploration Rover (MER) / Spirit & Opportunity

Mars Science Laboratory (MSL) / Curiosity Rover

Mars Atmosphere & Volatile Evolution (MAVEN)

Mars 2020 / Perseverance & Ingenuity

Mars Odyssey

Phoenix (Mars)

ExoMars

InSight (Mars) Lander

Dawn (Asteroid Belt)

Galileo (Jupiter)

Juno (Jupiter)

Europa Clipper (Jupiter)

Cassini-Huygens (Saturn)

Voyager (Jupiter, Saturn, Uranus, Neptune)

New Horizons (Pluto)

Orion

Space Shuttle

Orion Multi-Purpose Crew Vehicle

International Space Station (ISS)

James Webb Space Telescope

Spitzer Infrared Telescope Facility

Swift Gamma-Ray Burst Mission

Stardust (Comet Sample Return)

Deep Space 1

Atlas Launch Vehicles

Delta Launch Vehicles

xEMU Space Suit

...and many more!

Ingenuity helicopter