BASE Operations

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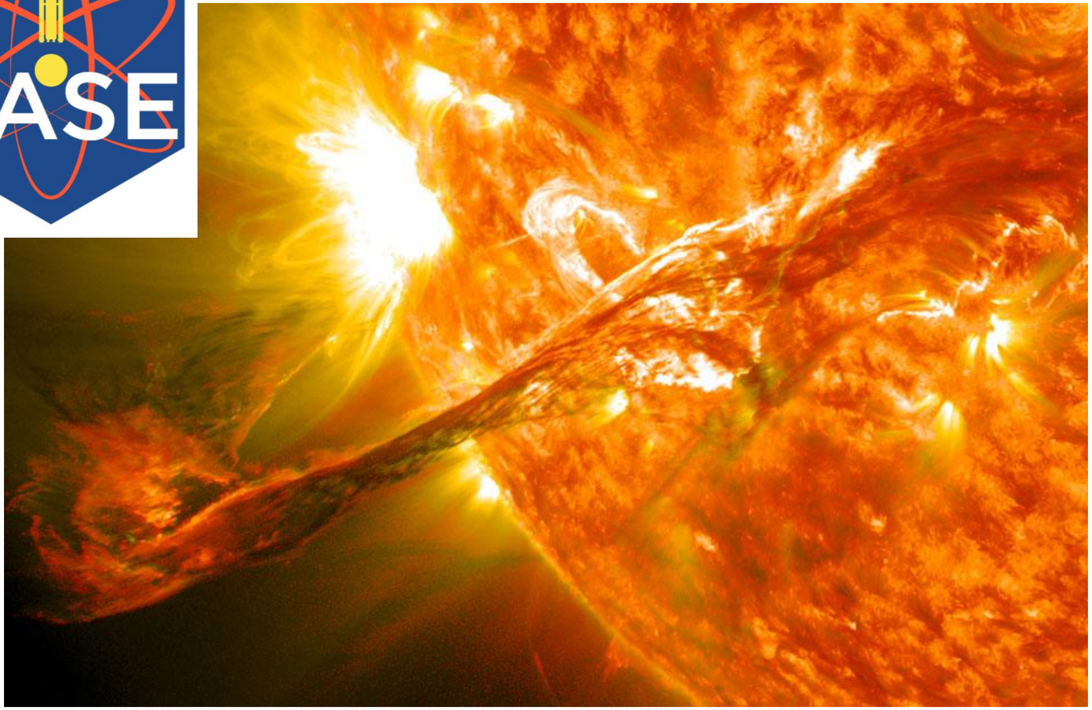
BASE Facility Mission



Solar filament, accompanied by a coronal mass ejection (CME), captured by the Solar Dynamics Observatory (SDO) in September of 2012. Parts for SDO were tested at the BASE Facility.

Mission:

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

- Almost all American (and many foreign) spacecraft and commercial aircraft have had one or more parts tested at the 88-Inch Cyclotron BASE Facility.

Radiation Effects at the 88

Pre-1979: Carrington Event, Explorer I, Operation Argus, Starfish Prime, Test 184, Hughes, Intel

1979: The *very first “single event effects” test in the world* is performed at Berkeley Lab’s 88-Inch Cyclotron.

1984: The first U.S.-based Electron Cyclotron Resonance (ECR) ion source begins operation at the 88-Inch Cyclotron, leading to the development of “cocktail” beams.

1990: A second ion source, the AECR, comes online at the 88-Inch Cyclotron.

2004: USAF and NRO begin partial support of the 88-Inch operating budget, resulting in an Interagency Agreement.

2008: VENUS ion source comes online at the 88-Inch and begins delivering beam to BASE users.

2015: National Space Weather Action Plan and National Space Weather Strategy implemented.

2016: NRO withdraws from the Interagency Agreement. Space weather presidential executive order.

2018: National Academies study “Testing at the Speed of Light” is published. NASA joins the U.S. Air Force in providing partial funding support for the 88-Inch Cyclotron.

2019: Electromagnetic Pulse (EMP) executive order.

2020: USAF withdraws from the Interagency Agreement. The Missile Defense Agency (MDA) begins using the newly-available beam time.

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.

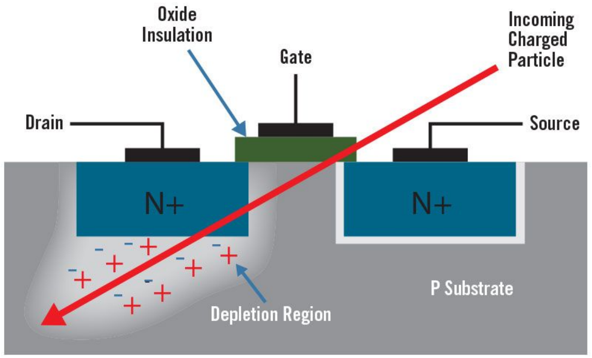
Examples of Single Event Effects:

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

BASE Facility Layout & Capabilities

Heavy Ions, Low Energy Protons, Microbeams

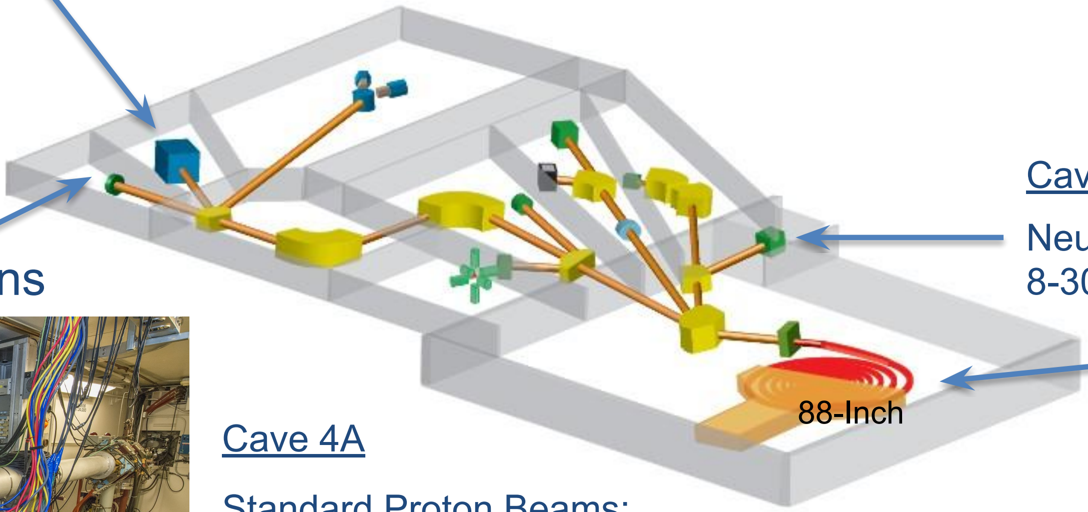
Cave 4B

Standard Cocktail Beams:
4.5, 10, 16, & 20 AMeV

available in air

Low Energy Protons:
1-10 MeV

88 BASE Facility Beams:
- Heavy Ions
- Light Ions
- Protons
- Low Energy Protons
- Neutrons
- Microbeams



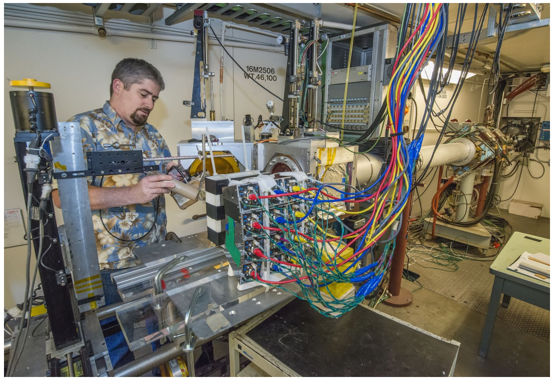
available in-air

Cave 0

Neutrons:
8-30 MeV

Cyclotron

Light Ions, Protons

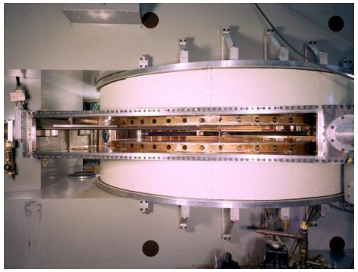


Cave 4A

Standard Proton Beams:
10-60 MeV

Light Ion Cocktails:
30 and 32.5 AMeV

available in-air



Heavy Ion Software

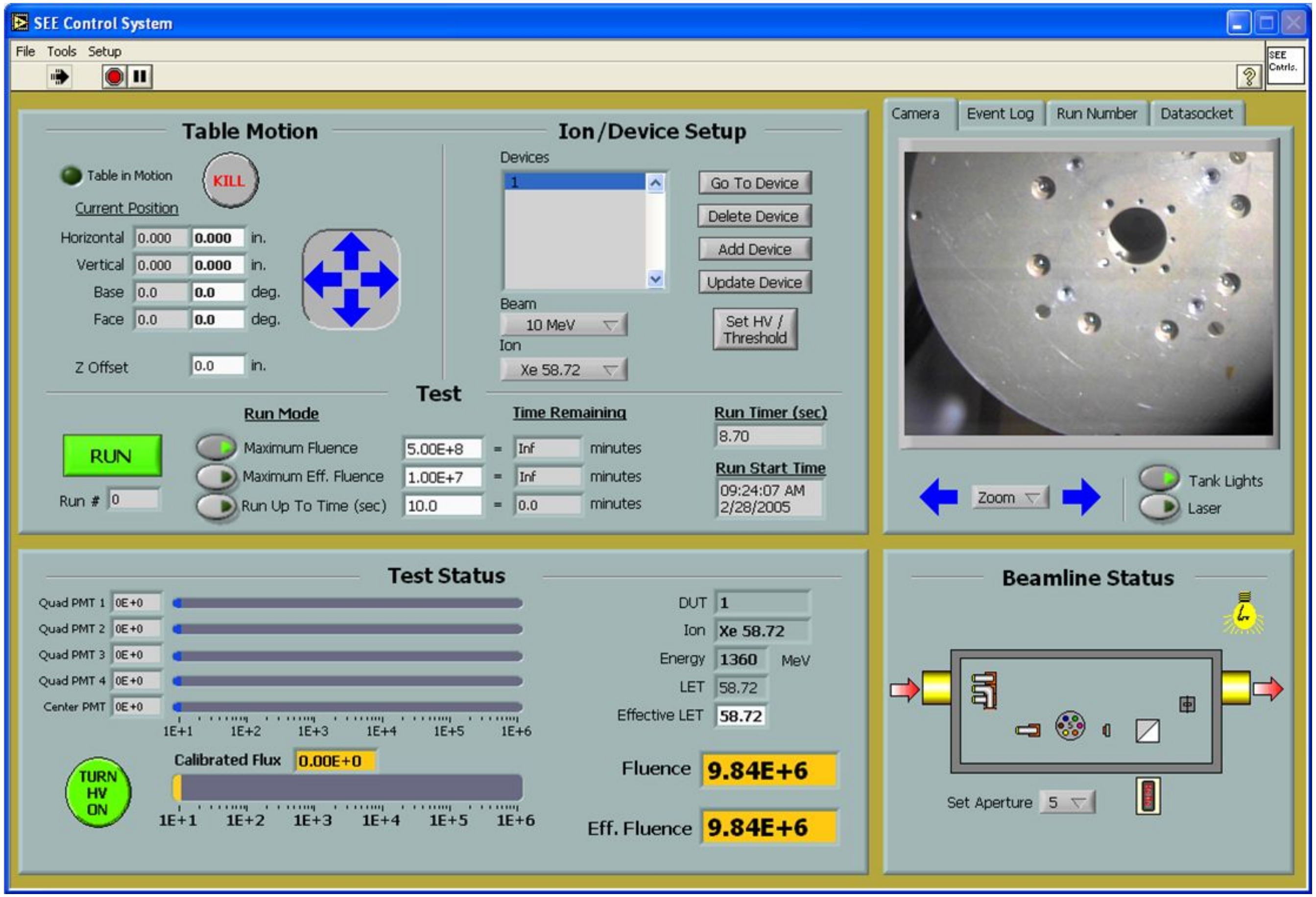


Table in Motion

Current Position

Horizontal 0.000 0.000 in.
Vertical 0.000 0.000 in.
Base 0.0 0.0 deg.
Face 0.0 0.0 deg.
Z Offset 0.0 in.

Devices: 1
Beam: 10 MeV
Ion: Xe 58.72

Run # 0

Run Mode			Time Remaining	
Maximum Fluence	5.00E+8	=	Inf	minutes
Maximum Eff. Fluence	1.00E+7	=	Inf	minutes
Run Up To Time (sec)	10.0	=	0.0	minutes

Run Timer (sec): 8.70

Run Start Time: 09:24:07 AM 2/28/2005

Quad PMT 1 0E+0
Quad PMT 2 0E+0
Quad PMT 3 0E+0
Quad PMT 4 0E+0
Center PMT 0E+0

Calibrated Flux 0.00E+0

DUT 1
Ion Xe 58.72
Energy 1360 MeV
LET 58.72
Effective LET 58.72

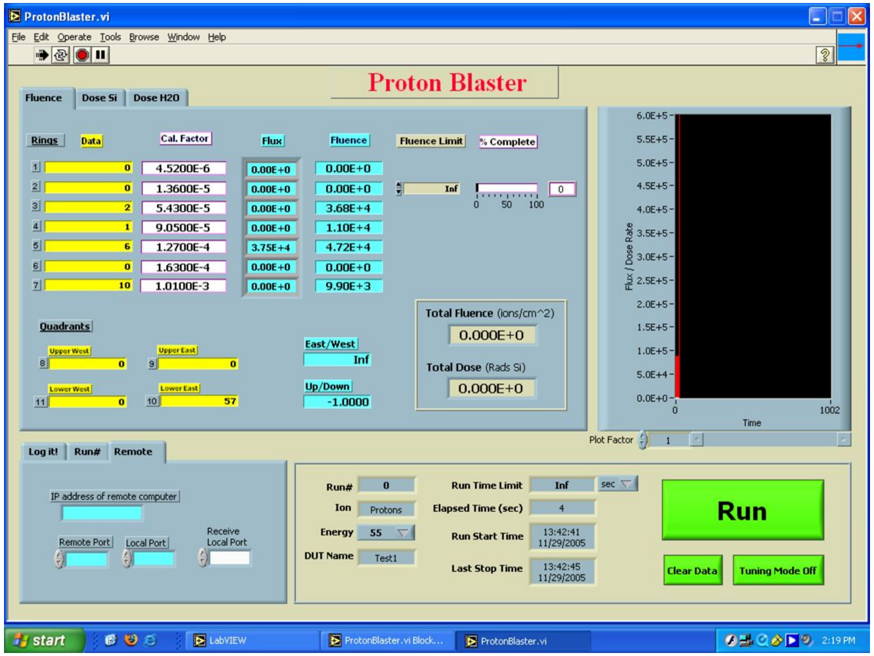
Fluence 9.84E+6

Eff. Fluence 9.84E+6

Set Aperture 5

Software used to control the heavy ion beam. It was designed to be extremely intuitive and user-friendly.

Proton Software



Rings	Data	Cal. Factor	Flux	Fluence
1	0	4.5200E-6	0.00E+0	0.00E+0
2	0	1.3600E-5	0.00E+0	0.00E+0
3	2	5.4300E-5	0.00E+0	3.68E+4
4	1	9.0500E-5	0.00E+0	1.10E+4
5	6	1.2700E-4	3.75E+4	4.72E+4
6	0	1.6300E-4	0.00E+0	0.00E+0
7	10	1.0100E-3	0.00E+0	9.90E+3

Fluence Limit: Inf

% Complete: 0

Quadrants

	Quadrant	Data
8	Upper West	0
9	Upper East	0
11	Lower West	0
10	Lower East	57

East/West: Inf

Up/Down: -1.0000

Total Fluence (ions/cm^2): 0.000E+0

Total Dose (Rads Si): 0.000E+0

Plot Factor: 1

IP address of remote computer

Remote Port

Local Port

Receive Local Port

Run#: 0

Ion: Protons

Energy: 55

DUT Name: Test1

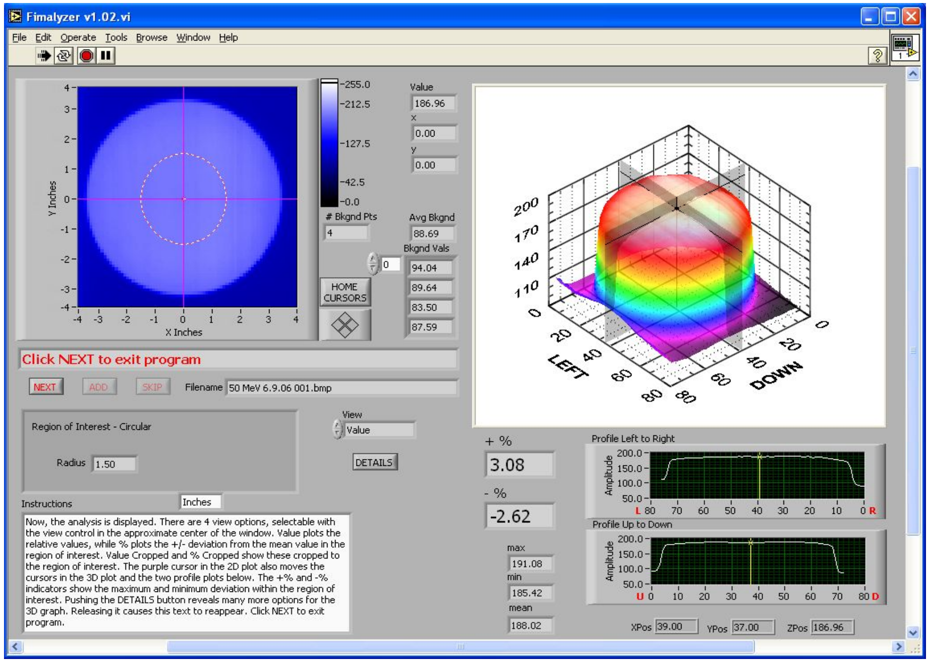
Run Time Limit: Inf sec

Elapsed Time (sec): 4

Run Start Time: 13:42:41 11/29/2005

Last Stop Time: 13:42:45 11/29/2005

Software used to control the proton beam.



Value: 186.96

x: 0.00

y: 0.00

Bkgnd Pts: 4

Avg Bkgnd: 88.69

Bkgnd Vals: 94.04, 89.64, 83.50, 87.59

Click NEXT to exit program

Filename: 50 MeV 6.9.06 001.bmp

Region of Interest - Circular

Radius: 1.50

View: Value

Instructions

Inches

Now, the analysis is displayed. There are 4 view options, selectable with the view control in the approximate center of the window. Value plots the relative values, while % plots the +/- deviation from the mean value in the region of interest. Value Cropped and % Cropped show these cropped to the region of interest. The purple cursor in the 2D plot also moves the cursors in the 3D plot and the two profile plots below. The +% and -% indicators show the maximum and minimum deviation within the region of interest. Pushing the DETAILS button reveals many more options for the 3D graph. Releasing it causes this text to reappear. Click NEXT to exit program.

+ %: 3.08

- %: -2.62

max: 191.08

min: 185.42

mean: 188.02

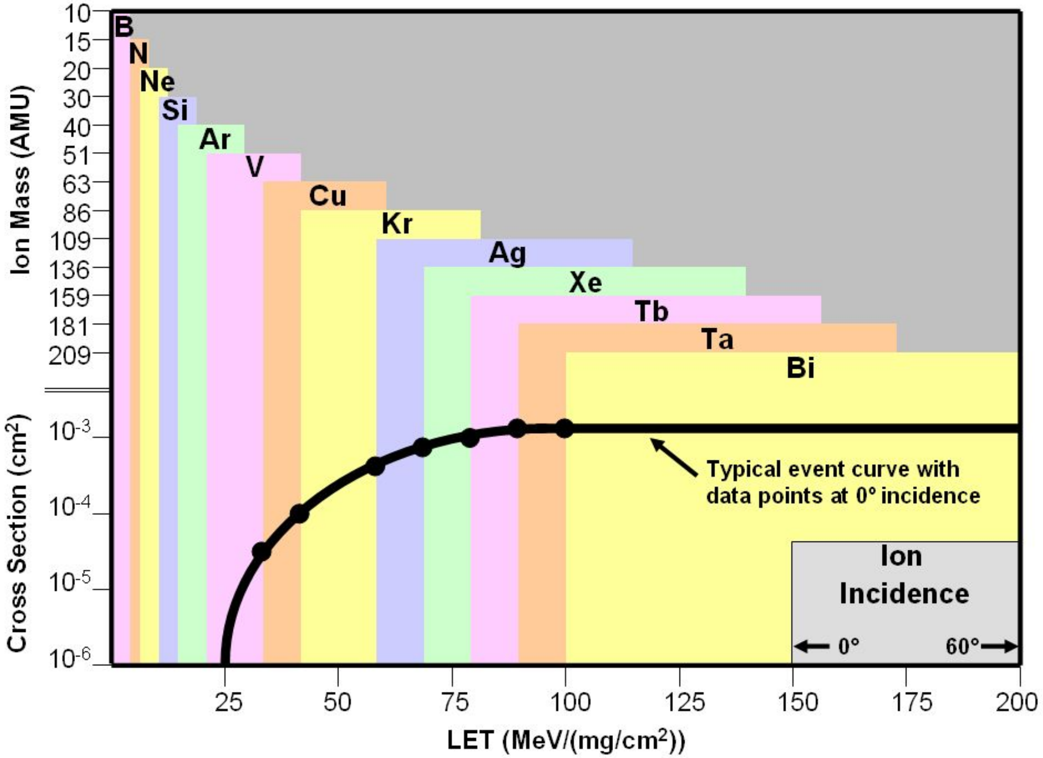
XPos: 39.00

YPos: 37.00

ZPos: 186.96

Software used to scan ion beam film exposures of the beam to measure uniformity.

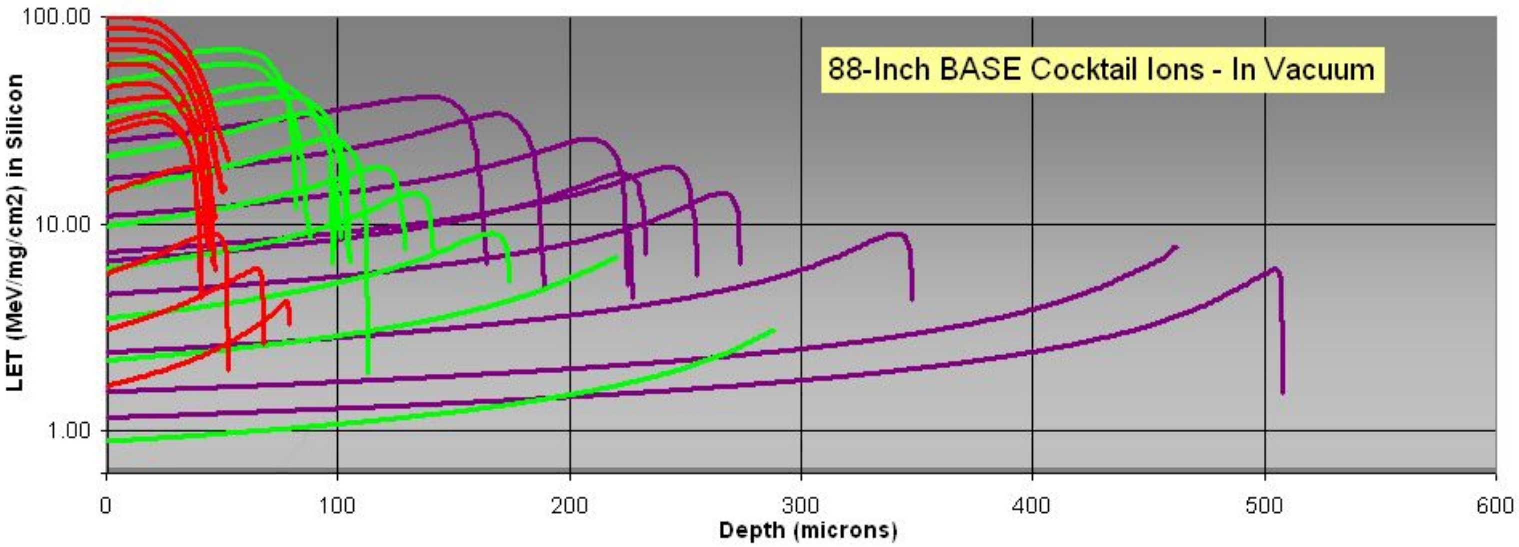
BASE Cocktails



What is a 'cocktail'?

- Multiple ion species are injected into the Cyclotron simultaneously, which are then selected and separated by simply changing the frequency.
- Normally, it would take hours to retune the Cyclotron to a new ion. With our ion sources, we can change ions in less than 3 minutes.

BASE Cocktails



<u>Legend</u>:
4.5 AMeV
10 AMeV
16 AMeV

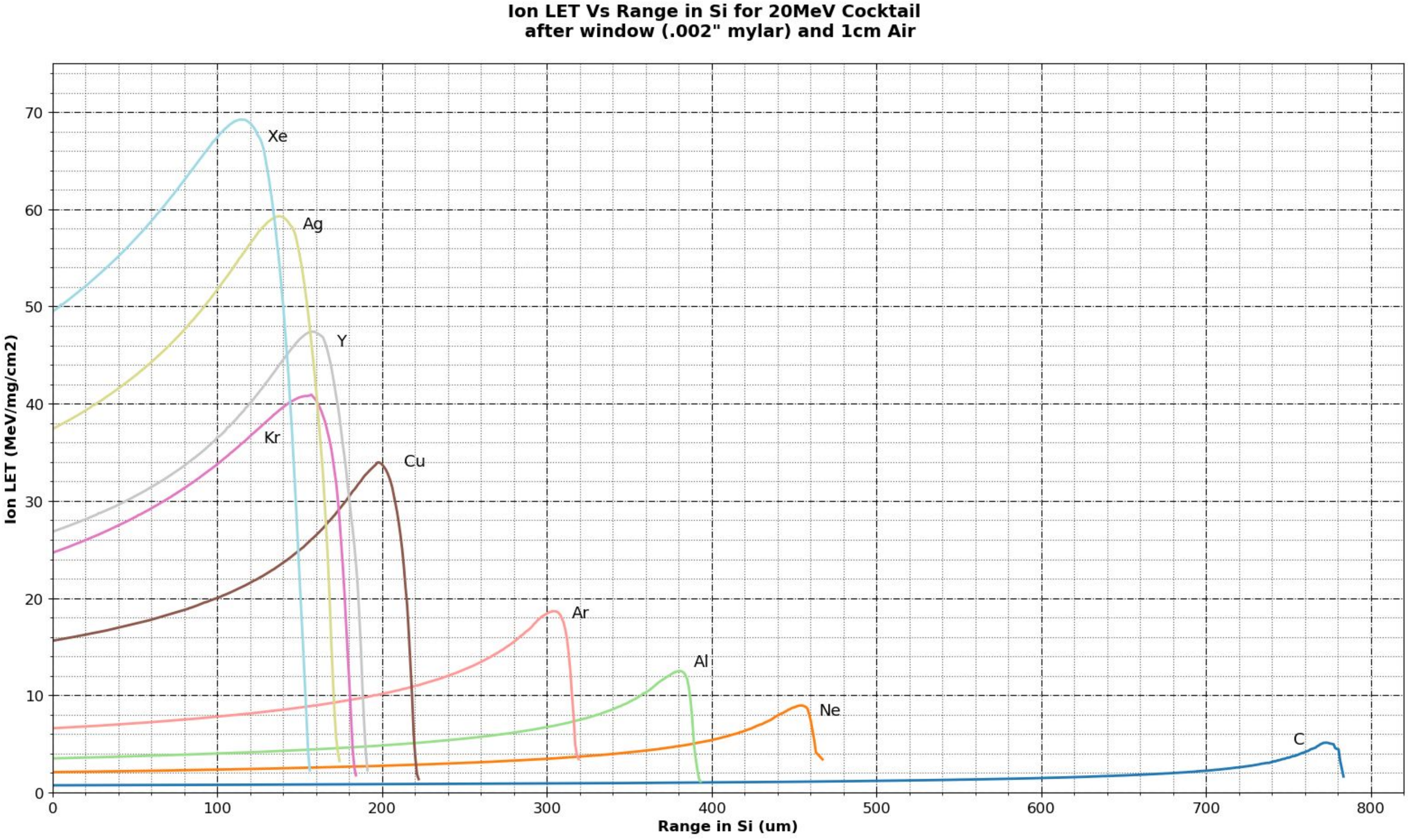
All three are refined and running smoothly

<u>NEW</u>:
20 AMeV

Still a few growing pains

- Cocktails allow users to deposit the right amount of energy at the desired depth.
- High LET ions are the most difficult to tune out of the machine, but thanks to ion source and Cyclotron improvements, we can achieve very high fluxes for even our heaviest ions.

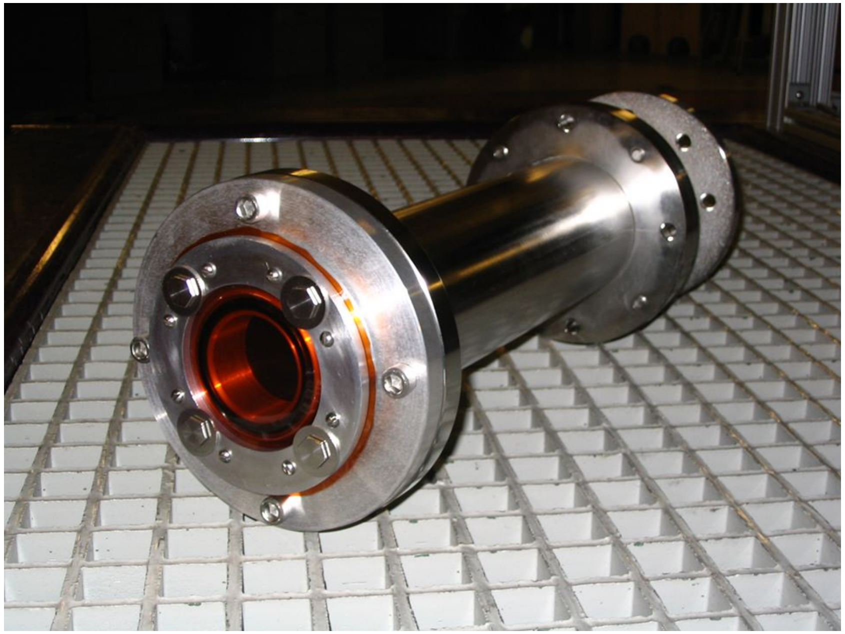
Bragg Curves - 20 AMeV (in-air)



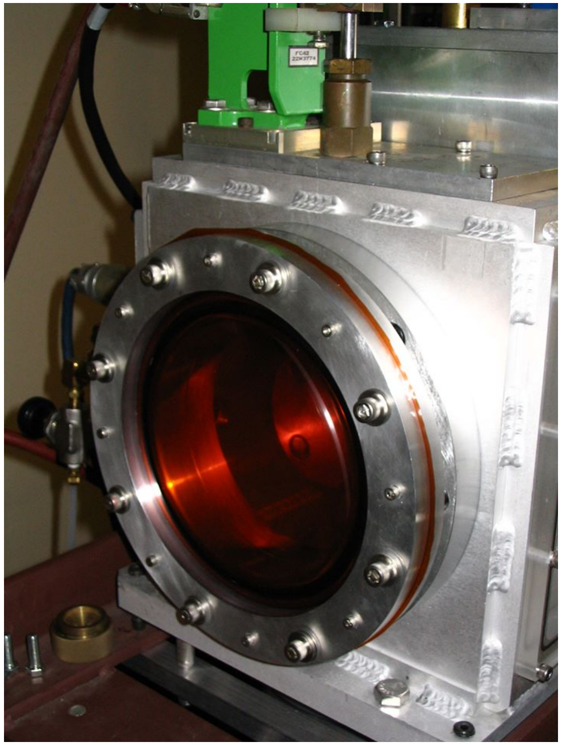
LET (MeV/mg/cm^2)

Range (um)

Custom In-air Windows



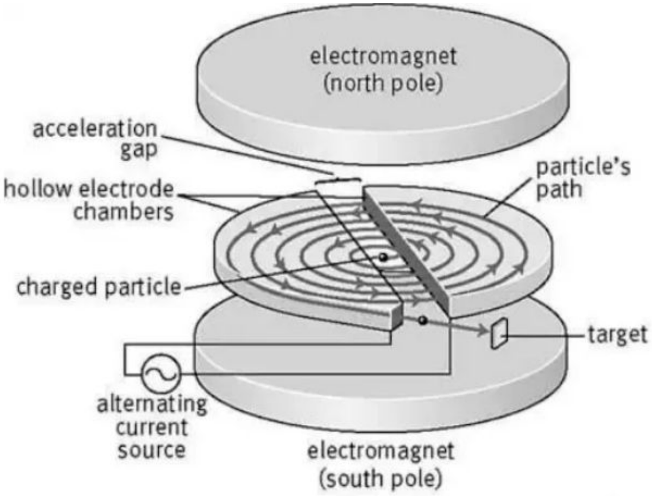
Heavy ion window designed to minimize air gap and allow some ability to test at angles.

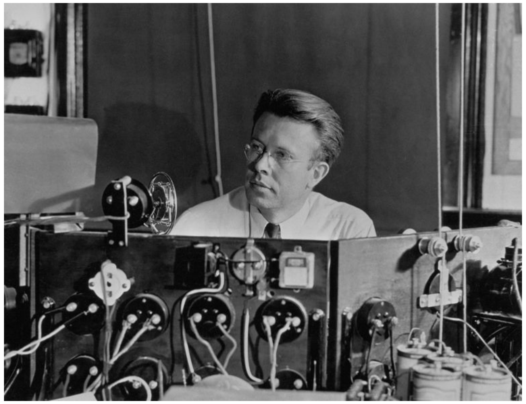


Proton window designed to maximize exposure area.

Useful Cyclotron Equations

Berkeley Lab's 184-Inch Cyclotron, the largest single-magnet cyclotron ever built.





Ernest O. Lawrence at the controls of the 37-Inch Cyclotron.

$$E/A = k\,(q/A)^2$$

E = energy

A = atomic mass of ion

k = "k-value" (maximum rigidity)

q = ion charge

$$m\,v \;=\; q\,B\,r$$

LBNL

UC Davis

Texas A&M

m = ion mass

v = ion velocity

r = orbital radius

q = ion charge

B = magnetic field

$$f \;=\; \frac{q\,B}{2\,\pi\,m}$$

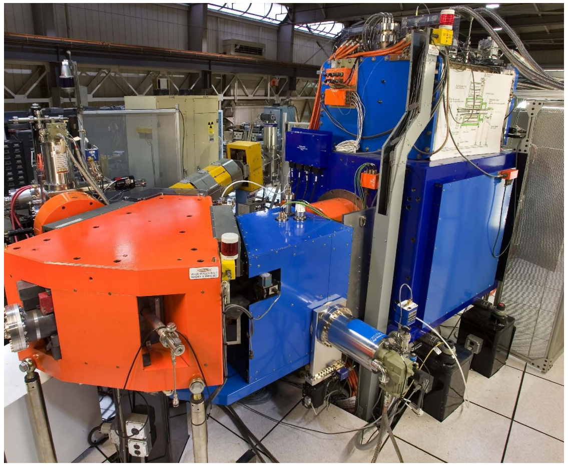
f = cyclotron resonance frequency

q = ion charge

B = magnetic field

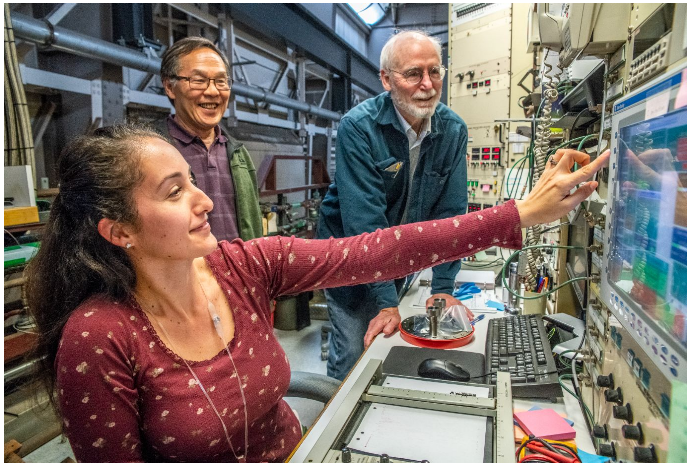
m = ion mass

Importance of Ion Sources



Example: GOLD in the 10 AMeV Cocktail

- Au-197, charge state of +52
- Generated by both oven and sputter probe
- LET = 85.76 MeV/mg/cm^2, range = 105.9 microns
- Made possible thanks to VENUS ion source

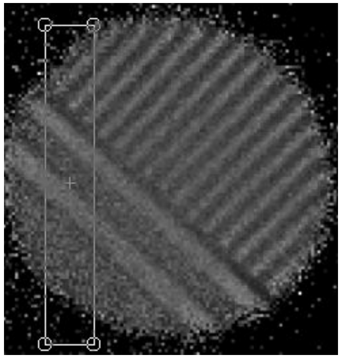


Other BASE beams now possible due to VENUS:

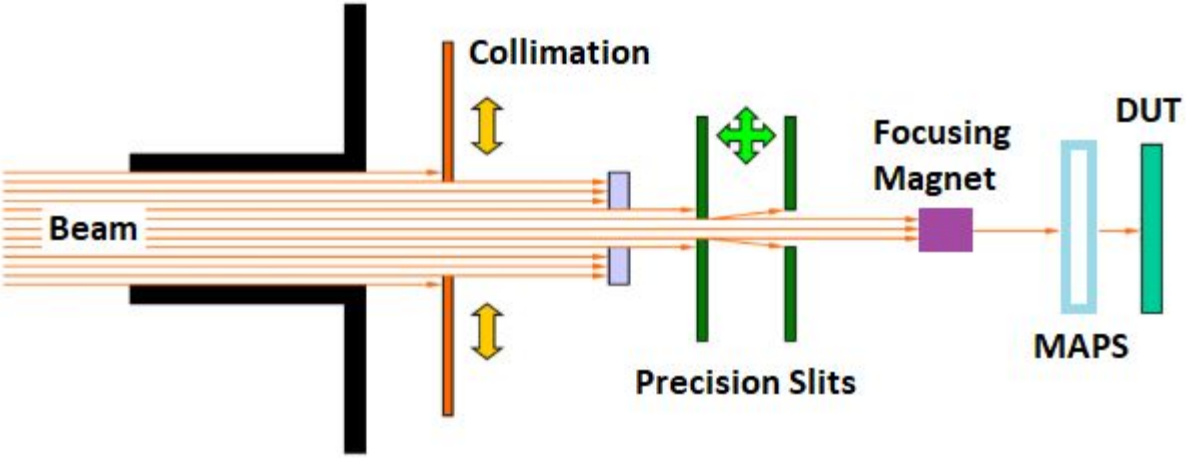
- 16 & 20 AMeV xenon
- Most of the 20 AMeV cocktail
- New cocktail >25 AMeV w/krypton?

BASE Microbeams & MAPS

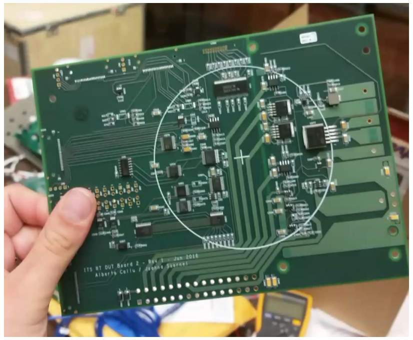
- Semiconductor parts are becoming more miniaturized.
- Need to be able to isolate and probe *small sections* of chips; NASA interest.
- 88-Inch is unique in being able to provide the highly parallel beams needed.
- Grad student project: combine previous collimator, precision slits, and focusing magnet efforts to produce a submicron beam.
- Monolithic Active Pixel Sensor (MAPS), developed for STAR Heavy Flavor Tracker, to be used for positioning microbeams.



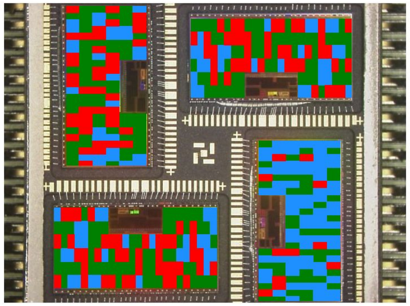
5 um resolution



ALICE-LHC Studies at BASE



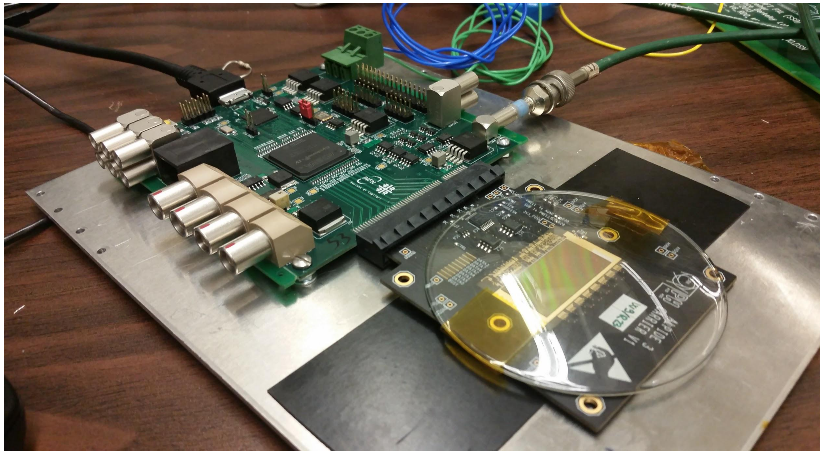
Power Board Components

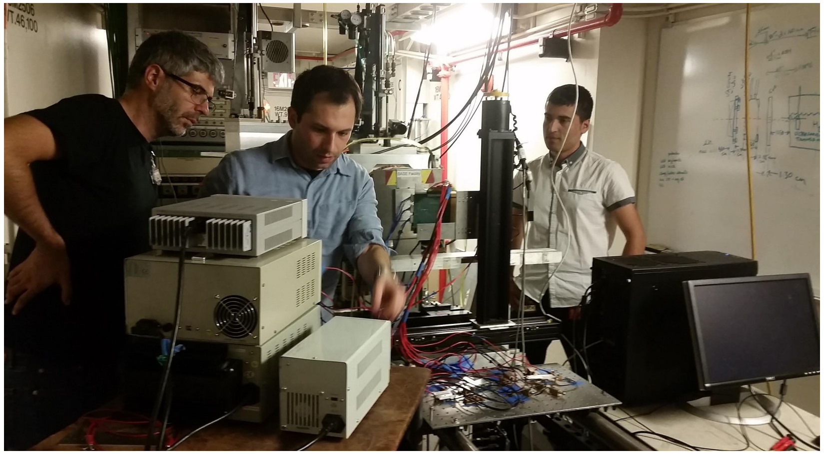


LHC SEU Detector

ALICE Inner Tracking System Upgrade

- BASE heavy ions used for MAPS Single Event Latch-up studies.
- BASE protons used for MAPS Single Event Upset studies.
- BASE used for rad hardness studies for power board components.
- SEU detector tests conducted at BASE for use at LHC.





88-Inch Contributions to Space Exploration

Apollo 17 (experiment with lunar soil sample)
Solar Terrestrial Relations Observatory (STEREO)
Solar Dynamics Observatory (SDO)
Solar Probe Plus
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 Rovers
Mars Science Laboratory (MSL) / Curiosity Rover
Mars Atmosphere & Volatile Evolution (MAVEN)

Mars Odyssey
Phoenix (Mars)
ExoMars
InSight (Mars) Lander
Dawn (Asteroid Belt)
Galileo (Jupiter)
Europa Clipper (Jupiter)
Cassini-Huygens (Saturn)
Voyager (Jupiter, Saturn, Uranus, Neptune)
New Horizons (Pluto)
Stardust (Comet Sample Return)
Deep Space 1 (Comet & Asteroid Flyby)
Atlas Launch Vehicles
Delta Launch Vehicles
Space Shuttle

Orion Multi-Purpose Crew Vehicle
International Space Station (ISS)
James Webb Space Telescope
Spitzer Infrared Telescope Facility
Swift Gamma-Ray Burst Mission
Wide Field Infrared Survey Telescope
Restore-L (Robotic Servicing)

Organizations Using BASE

The Aerospace Corp.
Naval Research Lab
Aeroflex
Micro-RDC
Honeywell
Microsemi
Silicon Space Technology
Xilinx
Linear Technology
Moog, Inc.
International Rectifier
Lawrence Berkeley Natl. Lab
Lawrence Livermore Natl. Lab
Los Alamos Natl. Lab
Sandia National Labs
Xsis Electronics
Save, Inc.
Raytheon
Semicoa
Japanese Space Agency (JAXA)

Cypress Semiconductor
Texas Instruments
Space Micro
Exelis
Broadcom
Georgia Tech
Rochester Inst. of Technology
MIT – Lincoln Laboratory
Caltech
Lockheed Martin
University of Colorado
Johns Hopkins University APL
Robust Chip
ThermoFisher Scientific
3D Plus
L-3 Communications
ITT
University of Wisconsin
Intel
European Space Agency (ESA)

SpaceX
Blue Origin
Google
NASA Ames
NASA Johnson
NASA Goddard
NASA Jet Propulsion Lab
United Launch Alliance
Northrop Grumman
Vanderbilt University
Boeing
Ball Aerospace
SEAKR
Peregrine Semiconductor
National Semiconductor
Semicoa
ST Electronics
NAVSEA Crane
LaRosa Engineering
Space Vector Corp.
JD Instruments

Beam Time Allocation

1. Determine the total beam time hours for the fiscal year from funding agencies (DOE, NASA, etc.).

2. Determine if there are any large maintenance items requiring more time (cooling tower replacement).

3. Layout the draft calendar with run and shutdown slots.

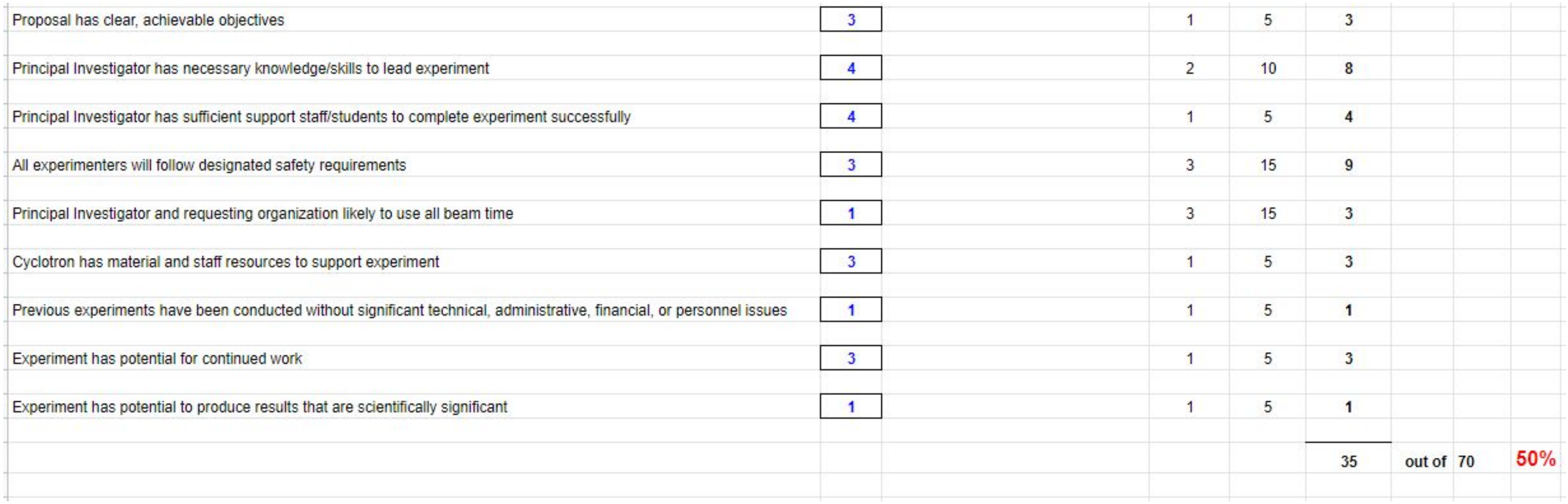
4. Determine the number of hours of allocated beam time for each funding agency & their priorities (BGS, medical isotopes, BASE, etc.).

5. Adjust calendar layout for researchers needing extended runs (2-month runs for BGS).

6. Obtain buy-in from all funding agency stakeholders.

7. Sell any remaining available beam time to outside (recharge) users.

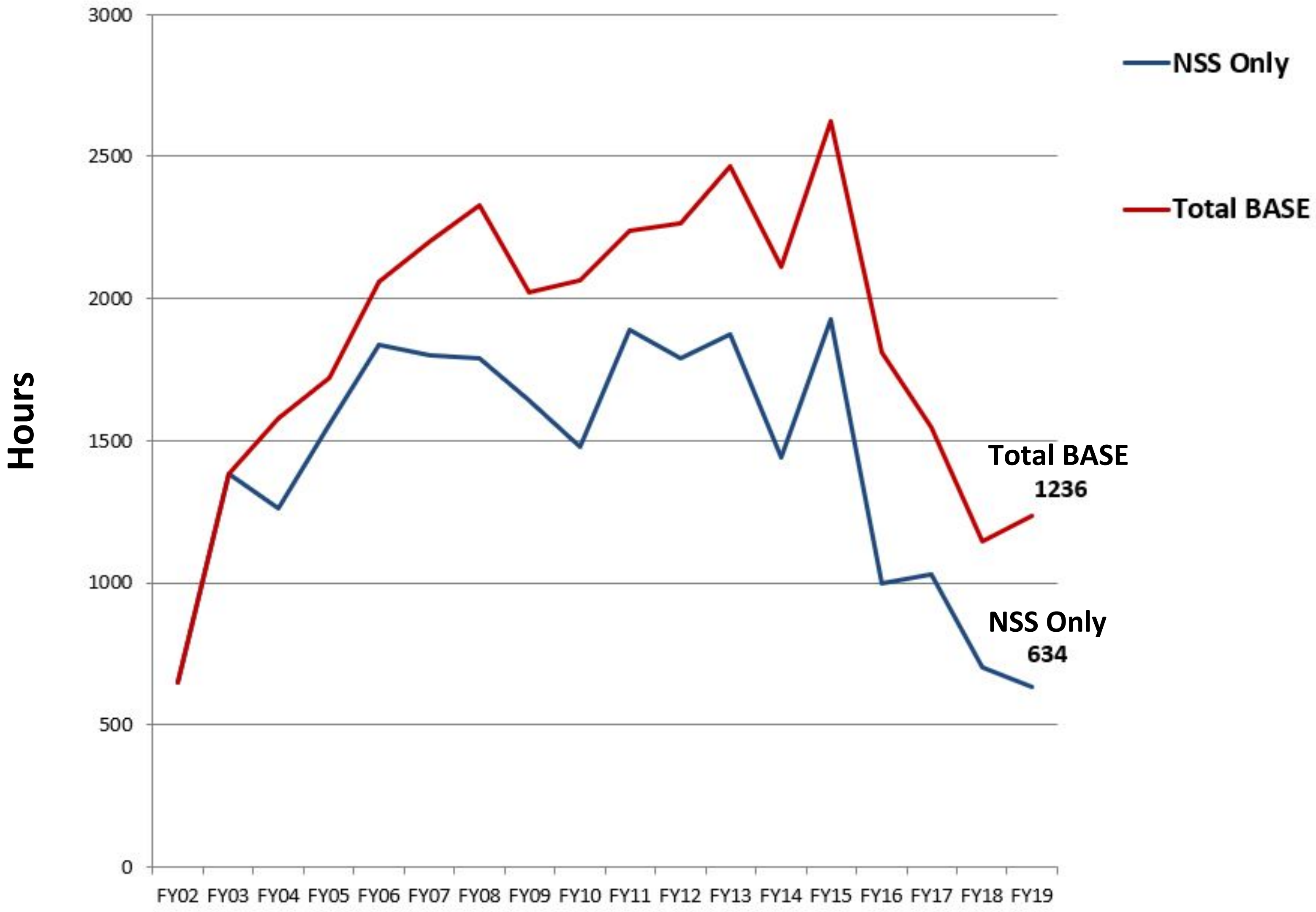
Proposal Evaluation Form



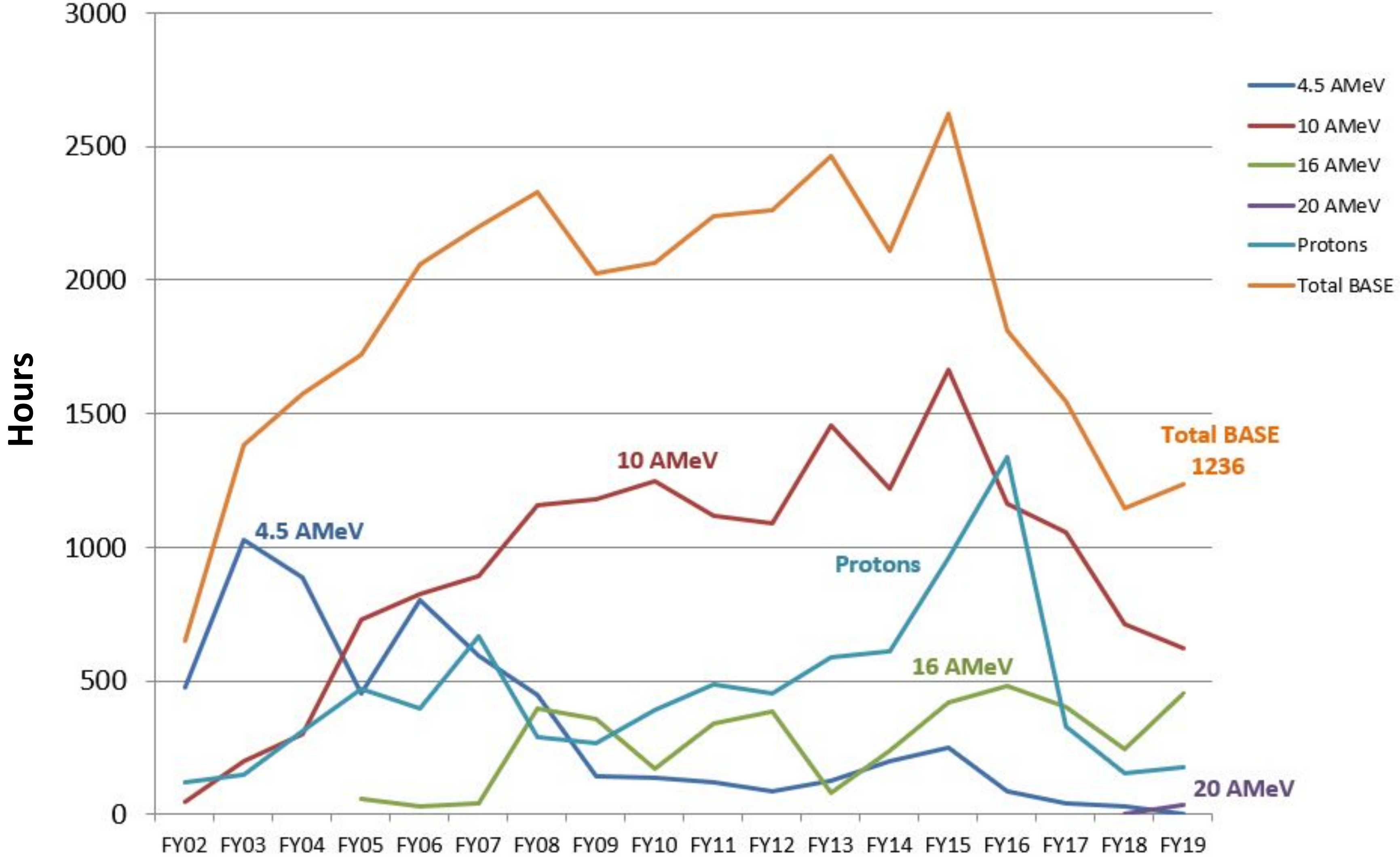
Proposal has clear, achievable objectives	3	1	5	3			
Principal Investigator has necessary knowledge/skills to lead experiment	4	2	10	8			
Principal Investigator has sufficient support staff/students to complete experiment successfully	4	1	5	4			
All experimenters will follow designated safety requirements	3	3	15	9			
Principal Investigator and requesting organization likely to use all beam time	1	3	15	3			
Cyclotron has material and staff resources to support experiment	3	1	5	3			
Previous experiments have been conducted without significant technical, administrative, financial, or personnel issues	1	1	5	1			
Experiment has potential for continued work	3	1	5	3			
Experiment has potential to produce results that are scientifically significant	1	1	5	1			
				35	out of	70	50%

Used as a guide to evaluate **BASE / RECHARGE** users.

Trends


Hours
3000
2500
2000
1500
1000
500
0
FY02
FY03
FY04
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
NSS Only
Total BASE
Total BASE
1236
NSS Only
634

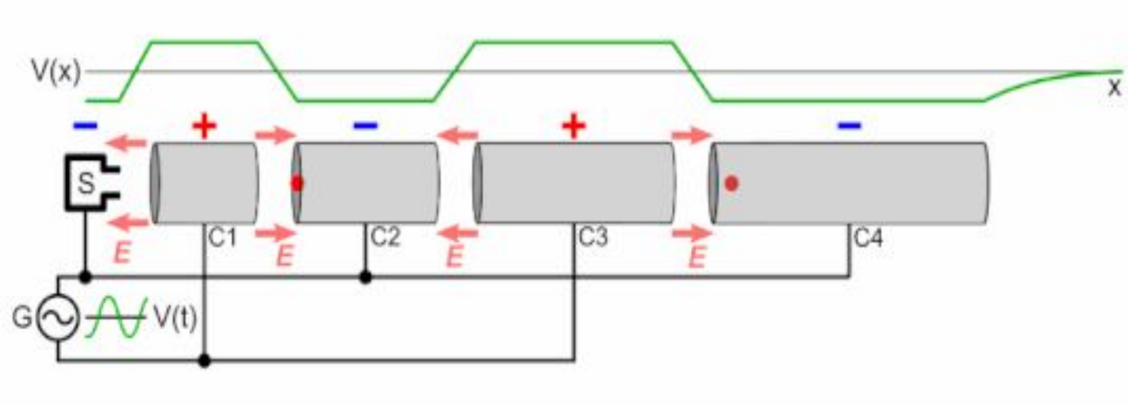
Trends



Hours
3000
2500
2000
1500
1000
500
0
FY02
FY03
FY04
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
4.5 AMeV
10 AMeV
16 AMeV
20 AMeV
Protons
Total BASE
Total BASE
1236
10 AMeV
4.5 AMeV
Protons
16 AMeV
20 AMeV

Opportunities: Booster LINAC

- Design & build a booster LINAC that would connect to the output of the cyclotron
- LINAC would provide higher energies for radiation effects testing, while cyclotron would still be able to run lower energies for current nuclear science research
- Higher energies would be able to get through thicker silicon overlayers
- Potential to eliminate (very expensive) chip de-lidding AND ability to test as you fly
- Collaboration between 88-Inch Cyclotron and SLAC
- Air Force, NASA have expressed strong interest; a proposal has been submitted to USAF



LINAC
Beam Direction →

High-energy
Beam Output

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