SEE testing at NSRL and operational modes for the proposed HEET facility

Kevin A. Brown, brownk@bnl.gov

Brookhaven National Laboratory, Upton, NY 11973, USA

ECE Dept., Stony Brook University, Stony Brook, NY 11794, USA

Team:

Petra Adams, Bhawin Dhital, Wolfram Fischer, Eiad Hamwi*, David Inzalaco, Lucy Lin*, Trevor Olsen, Michael Sivertz

Brookhaven National Laboratory

* Cornell University group led by Prof. Georg Hoffstaetter

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Topics

- What is space weather?
- What does it mean to simulate space weather?
- What metrics are used by experiments?
- The NASA Space Radiation Laboratory (NSRL)
- The proposed High Energy Effects Test facility (HEET)

APS DPB Newsletter article:

https://engage.aps.org/dpb/resources/newsletters

Why simulate Space Weather?

Space Weather

Charged Ionizing Radiation

Outer-Space is filled with it

Solar Proton Events

Trapped protons in Van Allen Belts

Galactic Cosmic Radiation

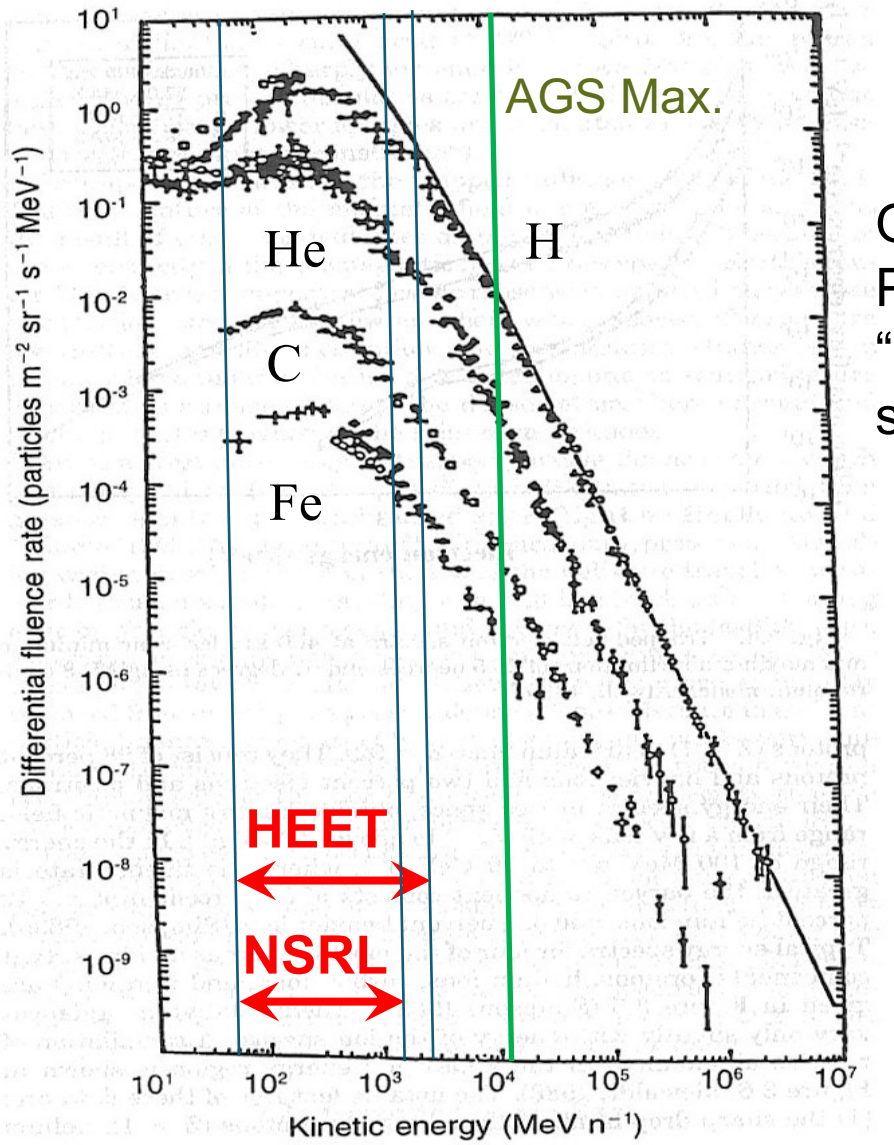


Fig. 3.5. Typical energy spectra for protons, helium ions, carbon ions, and iron ions from "top to bottom," respectively, at solar minimum. The solid line is the local interstellar spectrum (Simpson, 1983a).

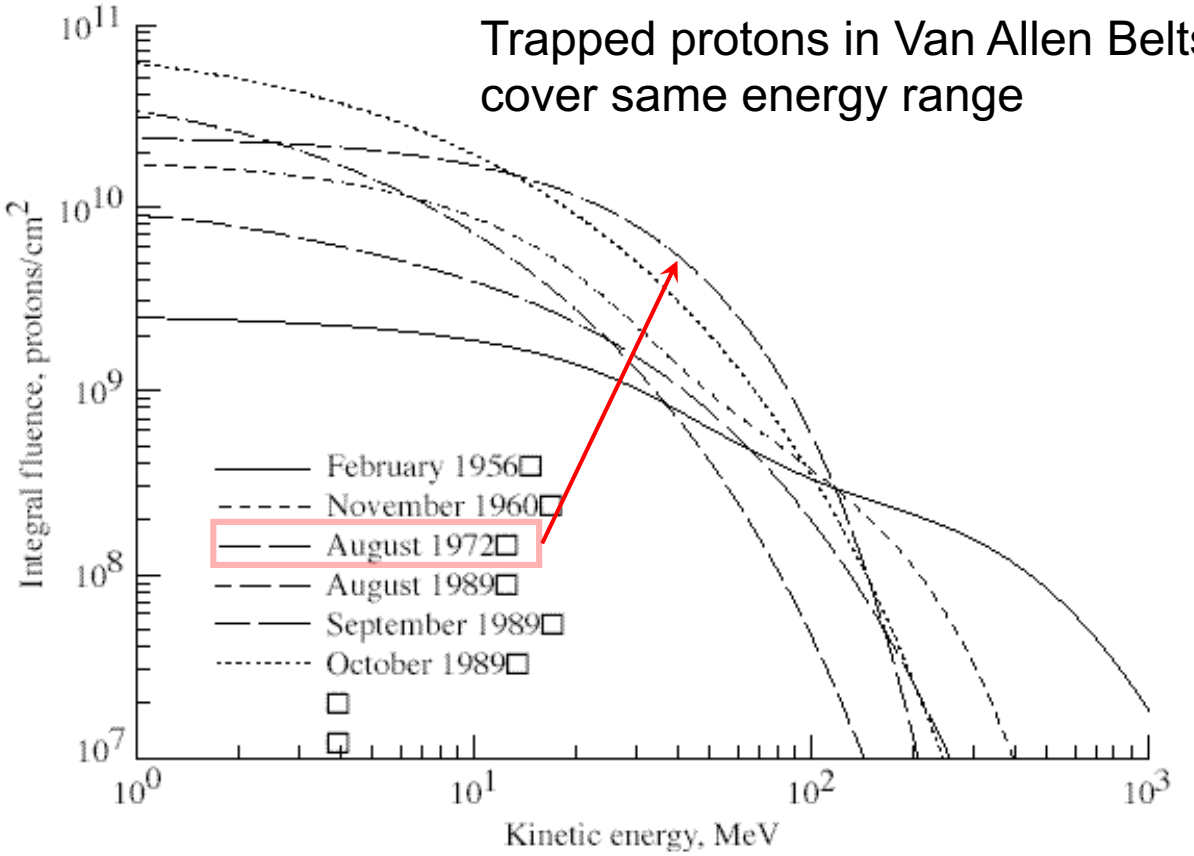
On a Pleasant "day" in space.

Figures reproduced from:

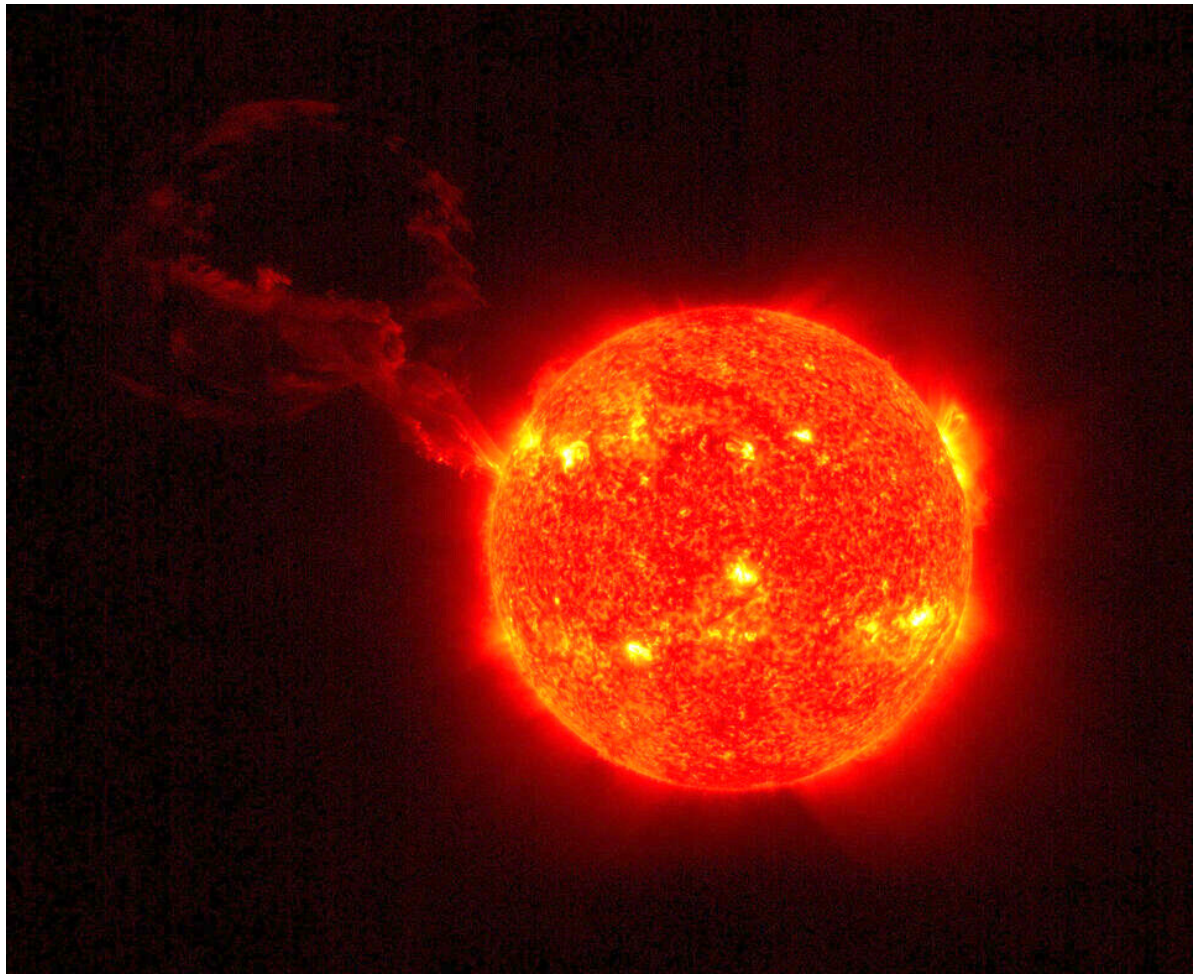
1.Mewaldt, R.A., "Elemental Composition and Energy Spectra of Galactic Cosmic Rays", Interplanetary Particle Environment, JPL Publications 88-28, edited by J.~Feynman and S.~Gabriel, NASA Jet Propulsion Laboratory, Pasadena, CA, 1988

2.Simpson, J.A., "Elemental and Isotopic Composition of the Galactic Cosmic Rays", Annual Reviews of Nuclear and Particle Sciences, Vol. 33, 1983, p.706

Solar Proton Events => Coronal Mass Ejections



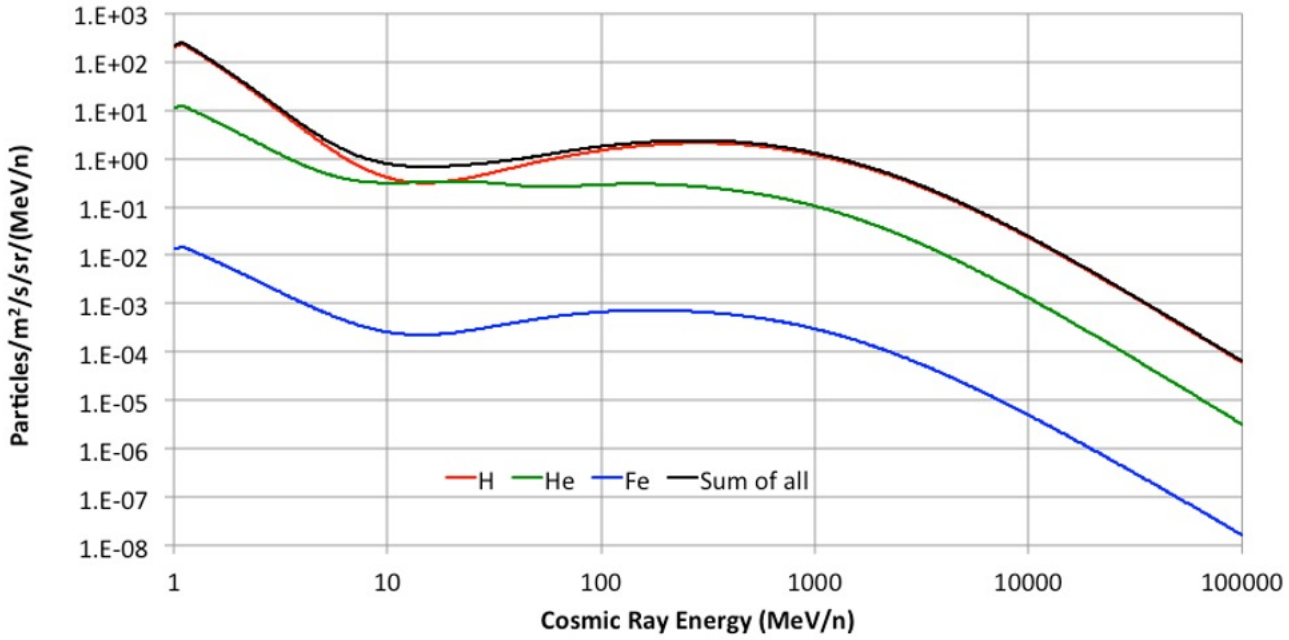
Large solar proton event integral fluence spectra at 1 AU.

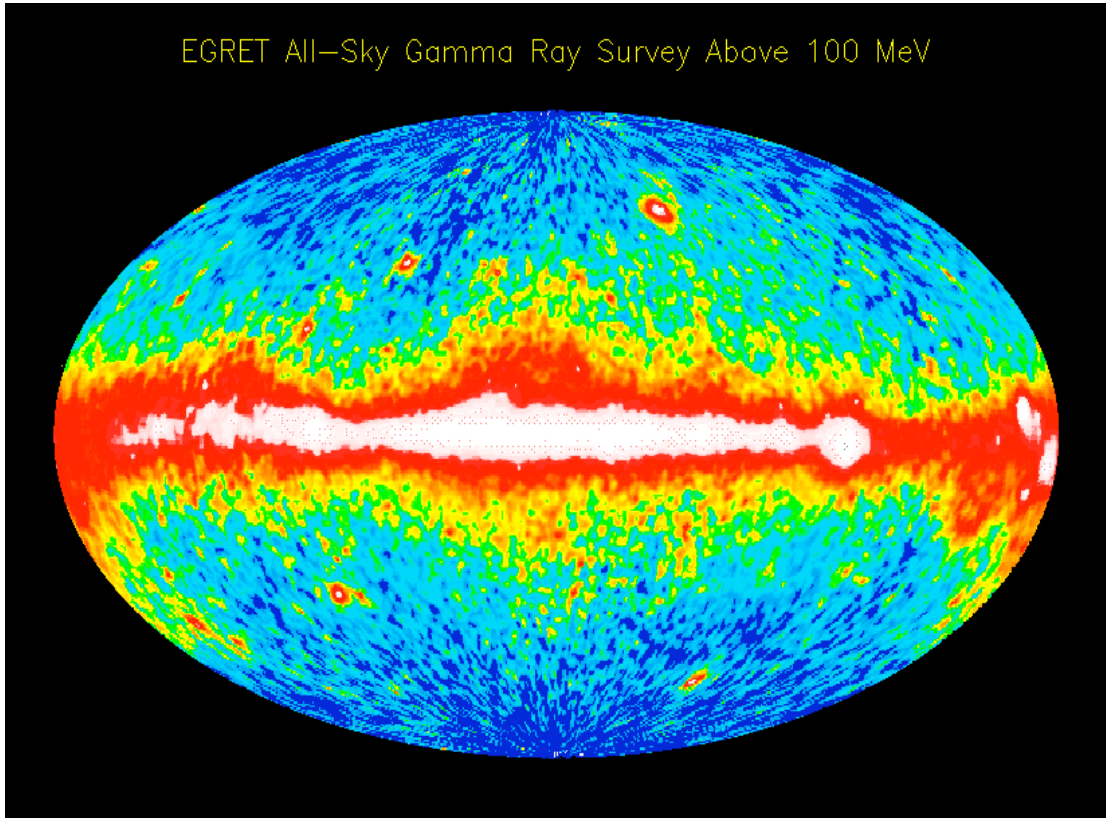


The storm caused widespread electric- and communication-grid disturbances through large portions of North America as well as satellite disruptions. On 4 August 1972 the storm caused the accidental detonation of numerous U.S. naval mines near Haiphong, North Vietnam. The coronal mass ejection (CME)'s transit time from the Sun to the Earth is the fastest ever recorded. (from Wiki: August 1972 solar storms)

Galactic Cosmic Rays = HZE Particles

Spectra* for H, He, Fe and sum of all ions in vacuum of space





EGRET All-Sky Gamma Ray survey - bright emission along Galactic Plane is due to cosmic-ray interactions with interstellar matter.

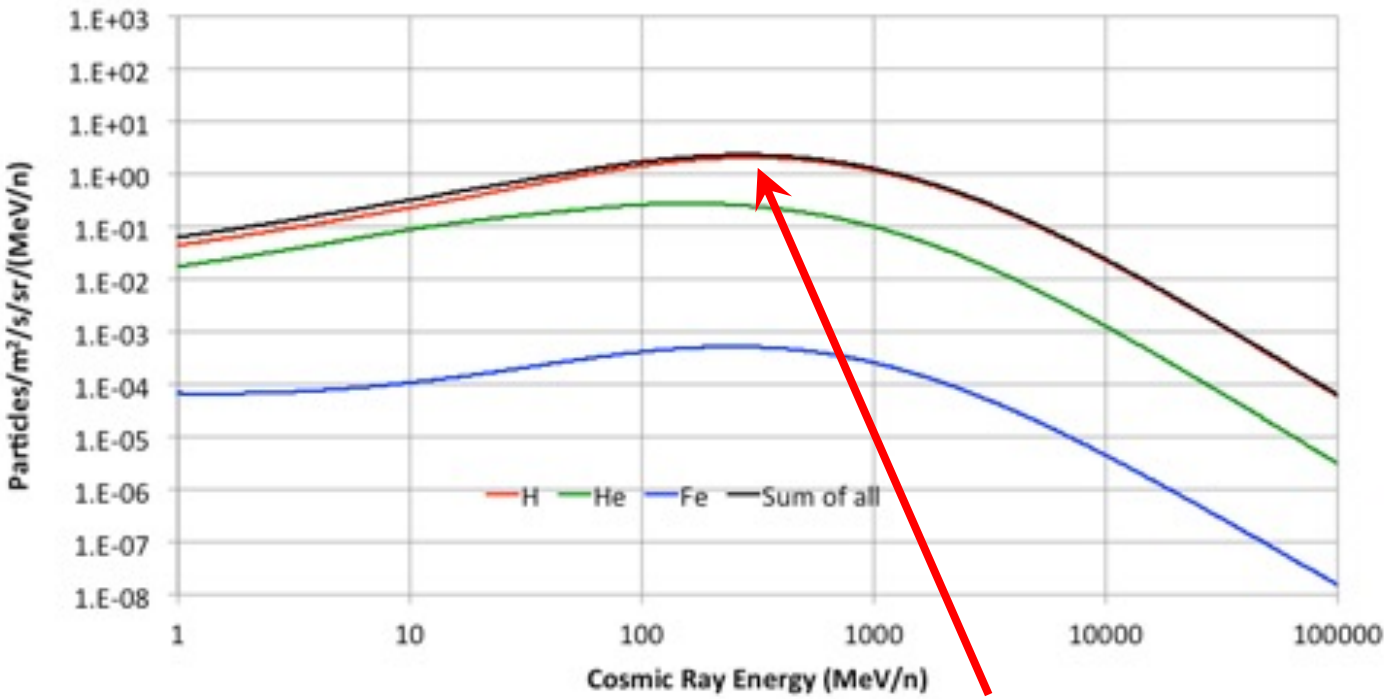
https://heasarc.gsfc.nasa.gov/docs/cgro/cgro/egret_allsky.html

*from Creme96 simulation at Geosynchronous Earth Orbit

Galactic Cosmic Rays = HZE Particles

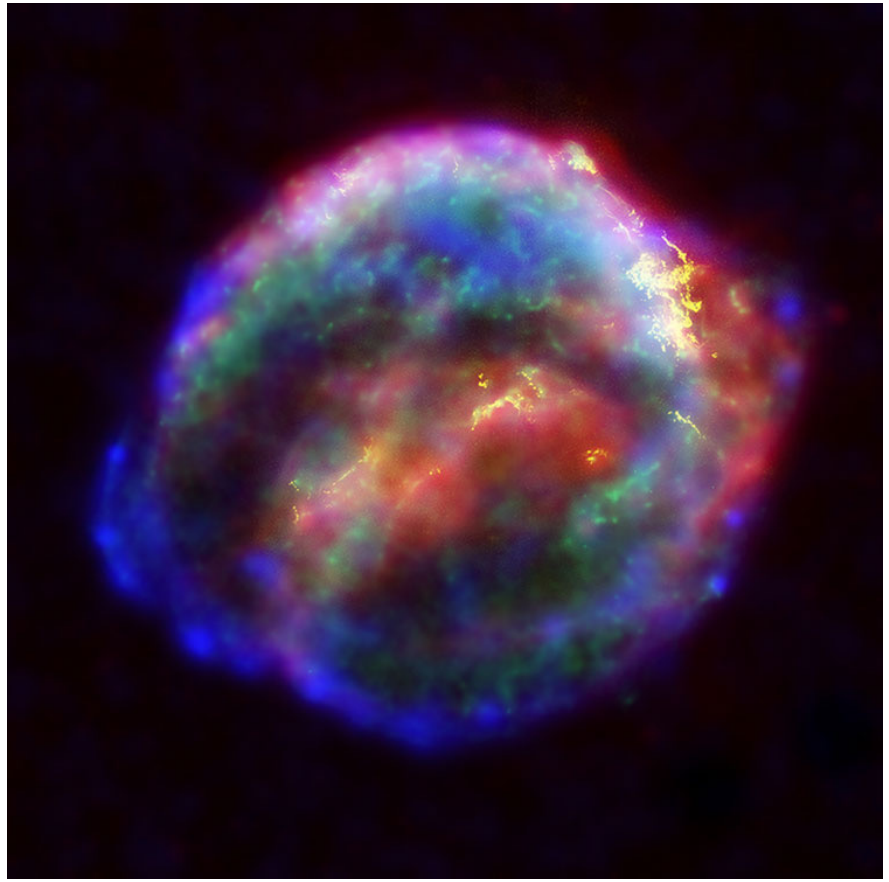
Spectra inside spacecraft:

(8mm thick Aluminum “shielding”)



Peak Energy is around 300 MeV/n for all ion species

Kepler’s 1604 Supernova Remnant



Credit: NASA, ESA & JHU APL (Chandra, Hubble and Spitzer)

*from Creme96 simulation at Geosynchronous Earth Orbit

Simulating space weather

General Requirements

Independent of the system being studied, whether radiobiology, radiation effects in materials, single event effects in electronics, or something else, what does an accelerator have to provide?

- Beams of protons and ions
- Energies from 10's of MeV/nucleon to 1 GeV/nucleon or higher
- Beam flux from 10 - 10^6 particles/(cm^2-sec)
- 3D uniform beams
- Time continuous beams

Experiments think in terms of LET

LET = Linear Energy Transfer

The rate of ionization energy deposition per unit of path length

$$LET = \frac{dE_{EM}}{ds}$$

s is along the path of the particle.

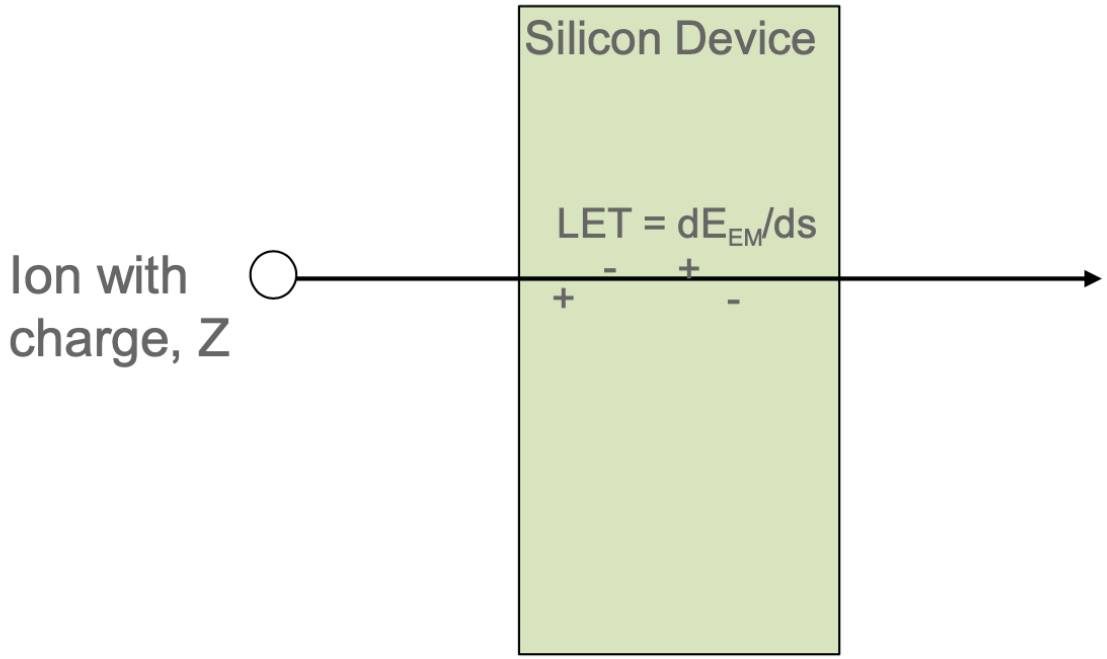
LET units

- MeV·cm2/mg

Think of it as:

- MeV/(mg/cm^2)
- MeV/(cm · mg/cm^3)→dE/(ds*δ)

Energy deposited per unit of length normalized by density of the target material



LET depends on

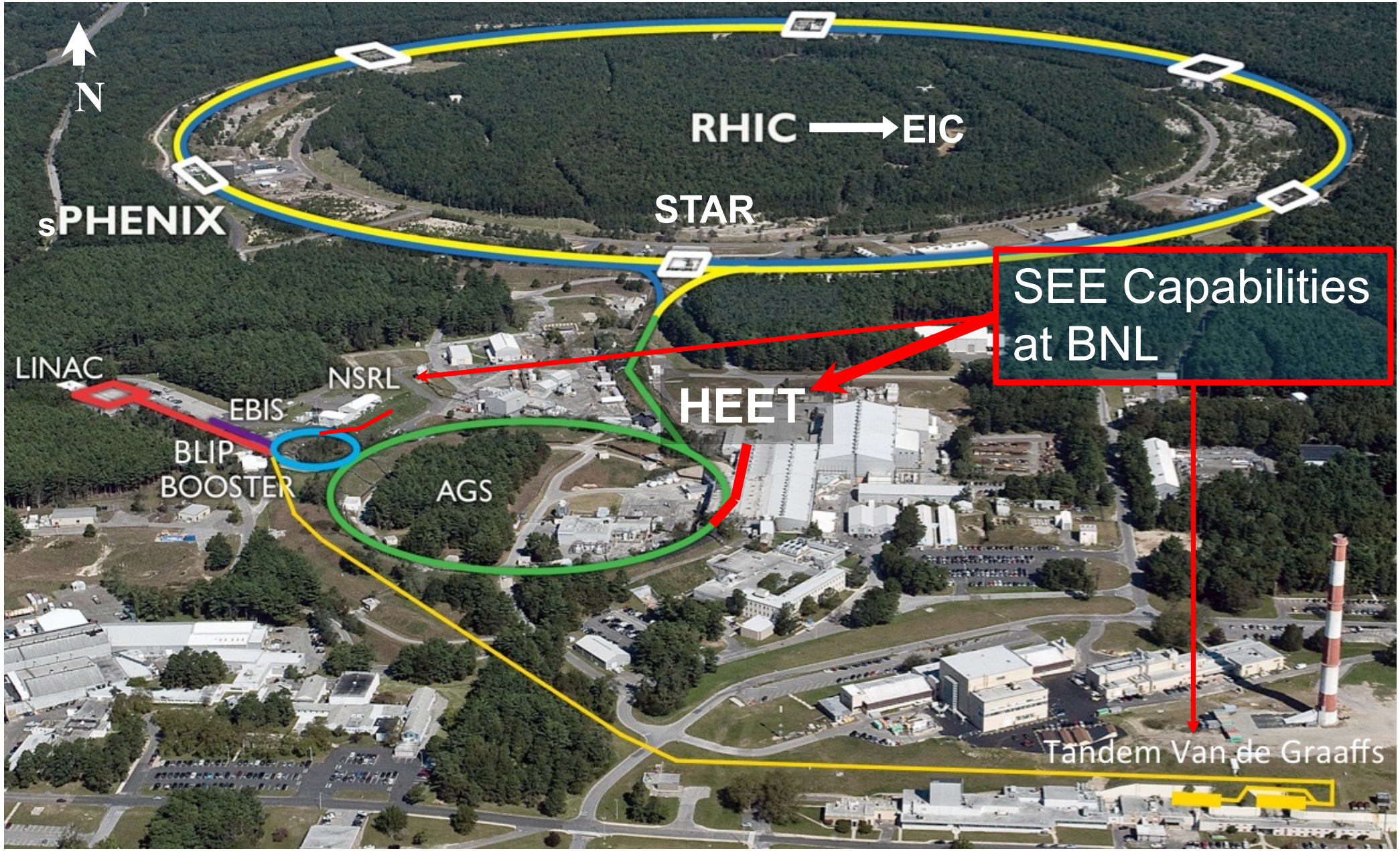
- Charge of ion, Z
- Target Material
- Energy of ion

Single Event Effect in electronics (SEE)

Permanent?	Name		Description
Non-destructive "Soft" Error	SEU	Single Event Upset	Bi-stable circuit element, e.g. memory cell, flips state due to charge pulse
	SEFI	Single Event Functional Interrupt	An SEU that occurs in a control register thereby changing the operating characteristics of a microcircuit
	SET	Single Event Transient	Spurious pulses in analog circuitry
Destructive "Hard" Error	SEL	Single Event Latchup	High current state caused by ion turning on a parasitic structure in a microcircuit. Clears only through power cycle.
	SEB	Single Event Burnout	High current state in power transistors, diodes.
	SEGR	Single Event Gate Rupture	Breakdown of the gate oxide of power MOSFET due to a single ion strike.
	SEDR	Single Event Dielectric Rupture	Large current through a dielectric driven by the voltage across the dielectric. Caused by ion passage temporarily lowering resistance of the dielectric.

From Megan Casey, NASA Goddard Space Flight Center

The NASA Space Radiation Laboratory



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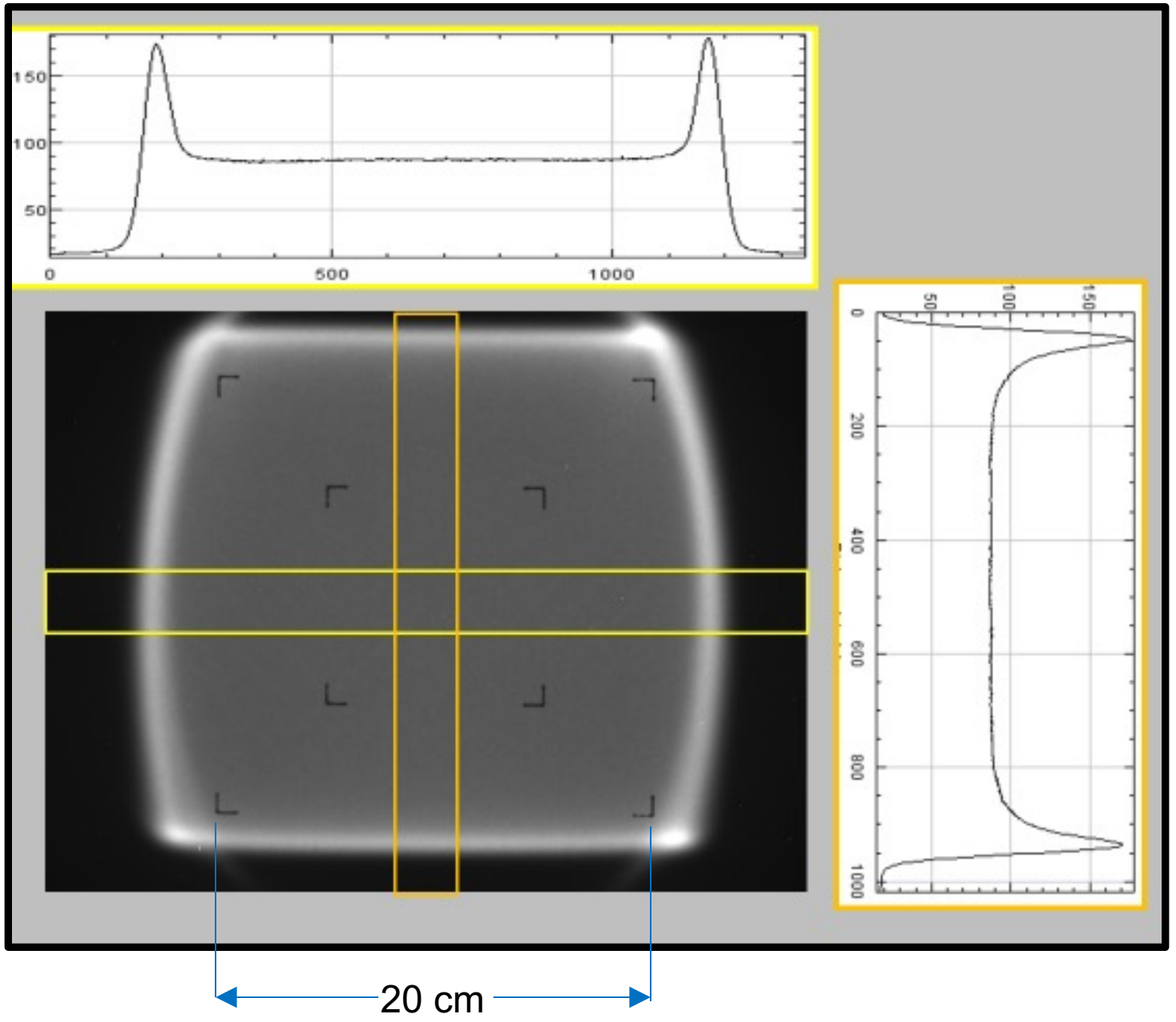
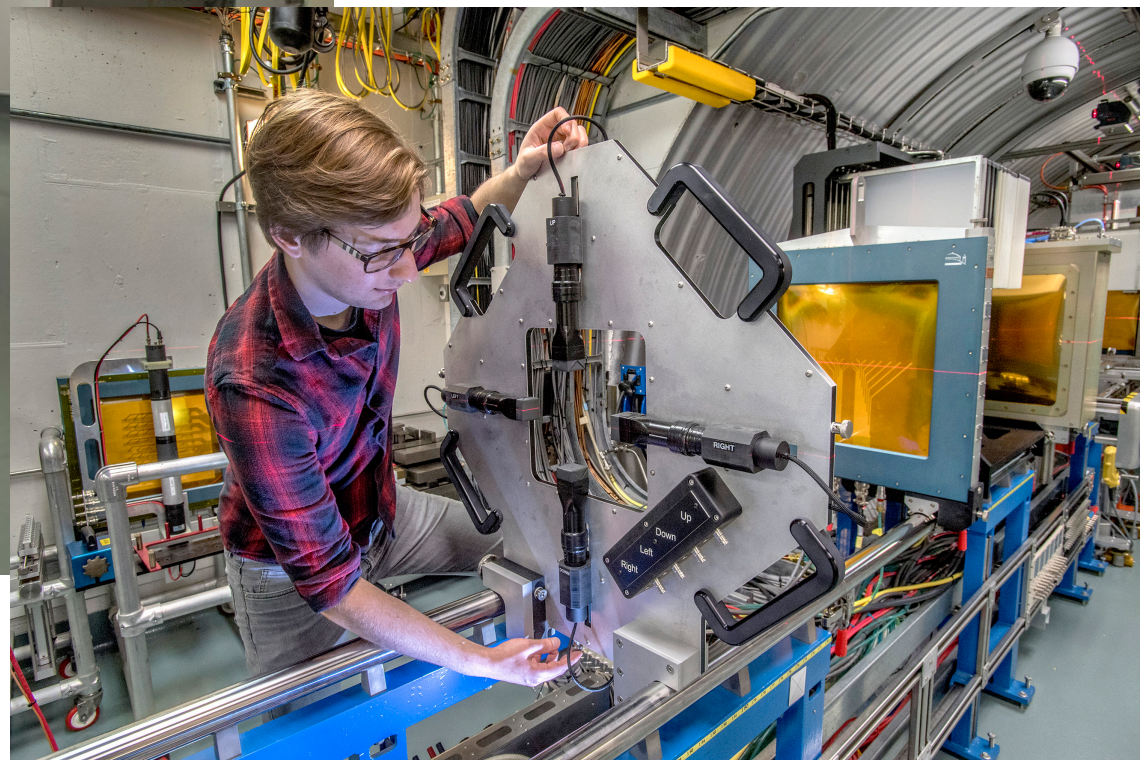
Beam distribution

- Typical beam profile, captured on the Digital Beam Imager (DBI), and analyzed using **ImageJ**. This is an image formed from one full spill.
- The projections show the beam spatial distribution to be within a few % of the mean in the area between the outer “ears”.





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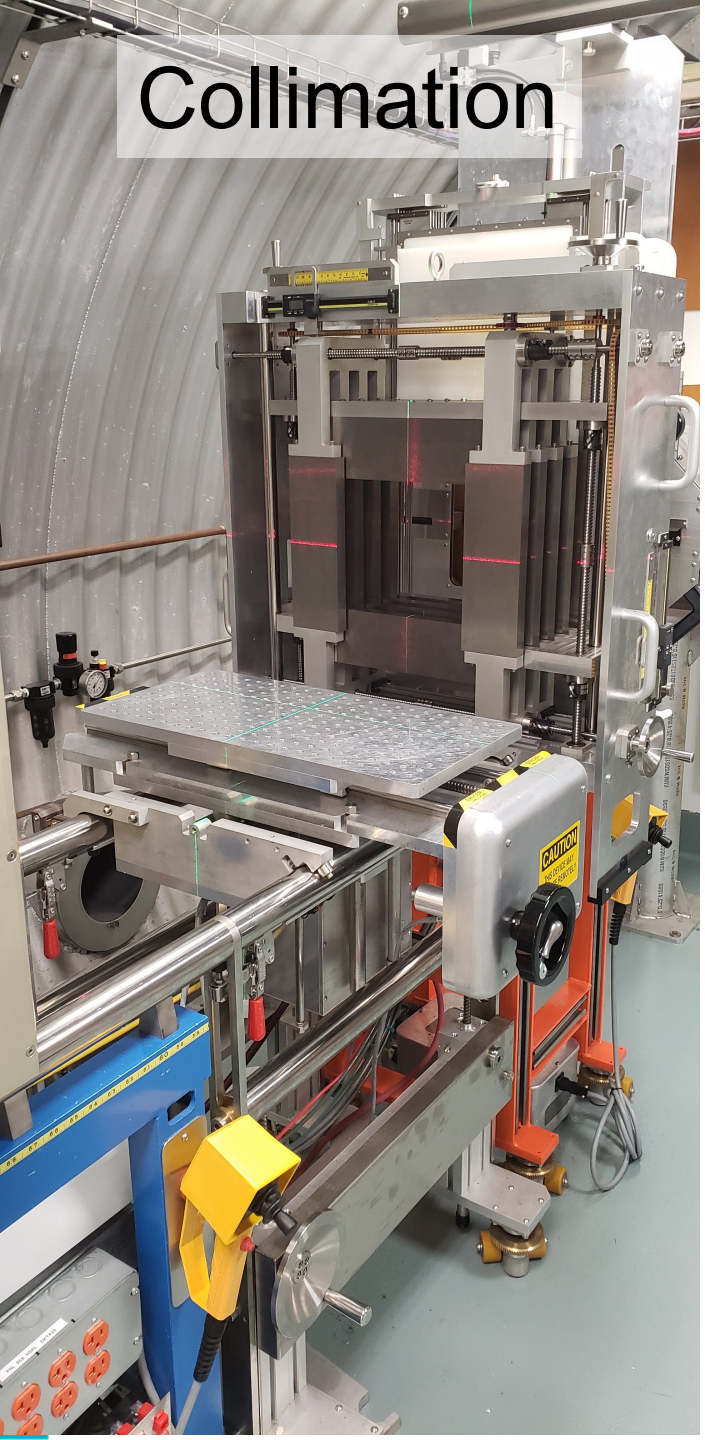
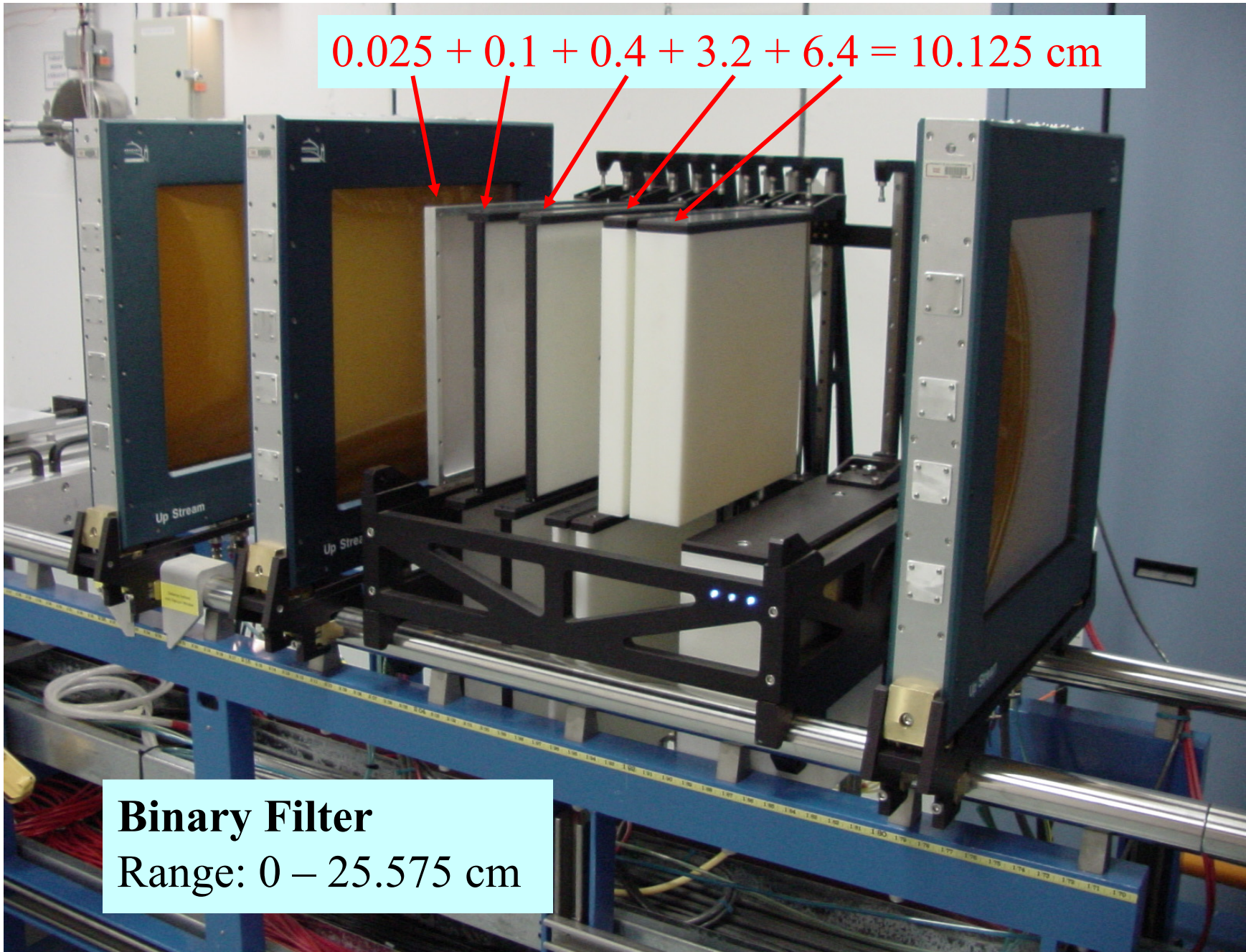
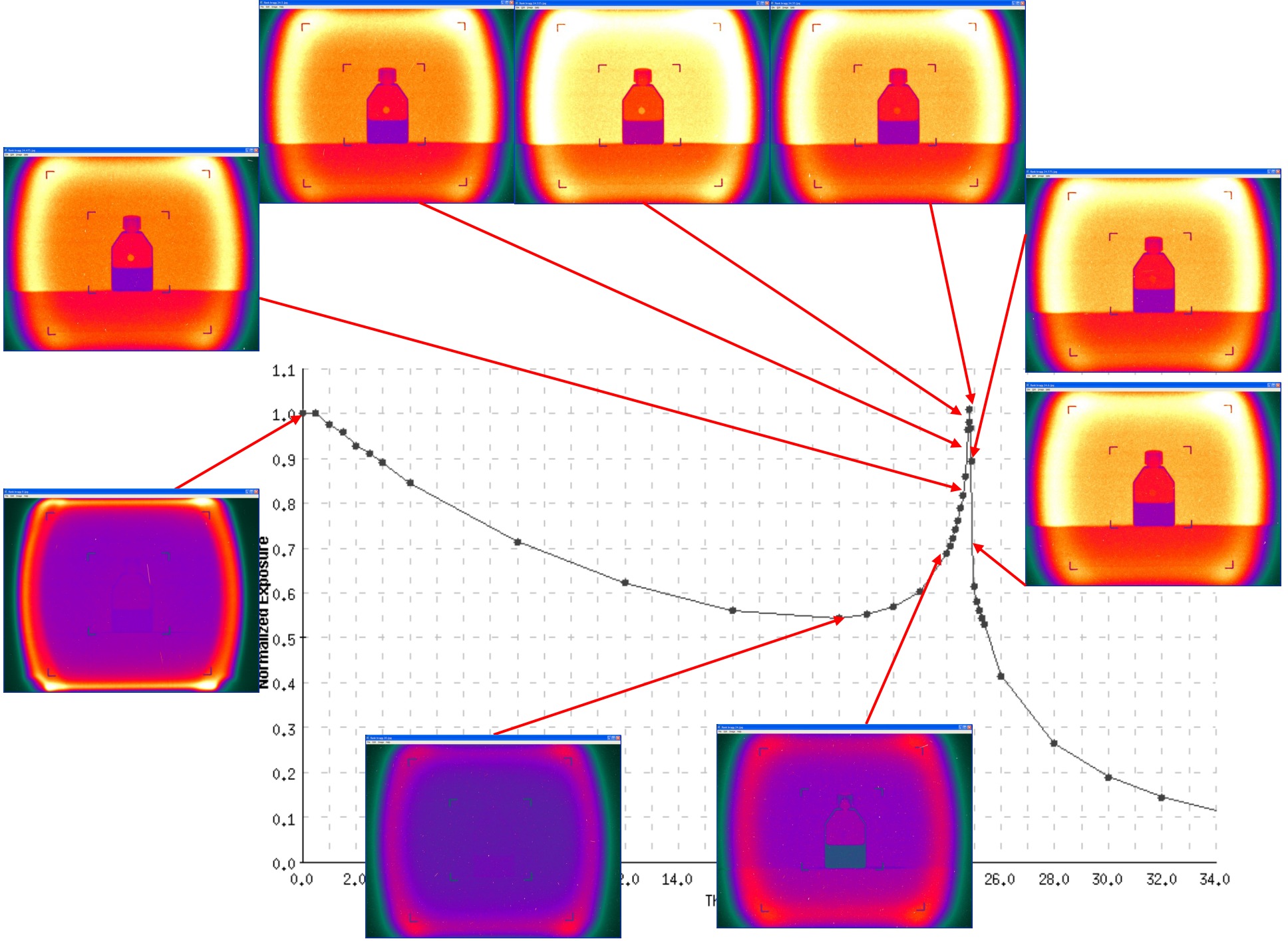


Energy Measurement, Degrader, Variable Bragg



NSRL is the only facility that can provide high energy ions >40MeV/n in the USA



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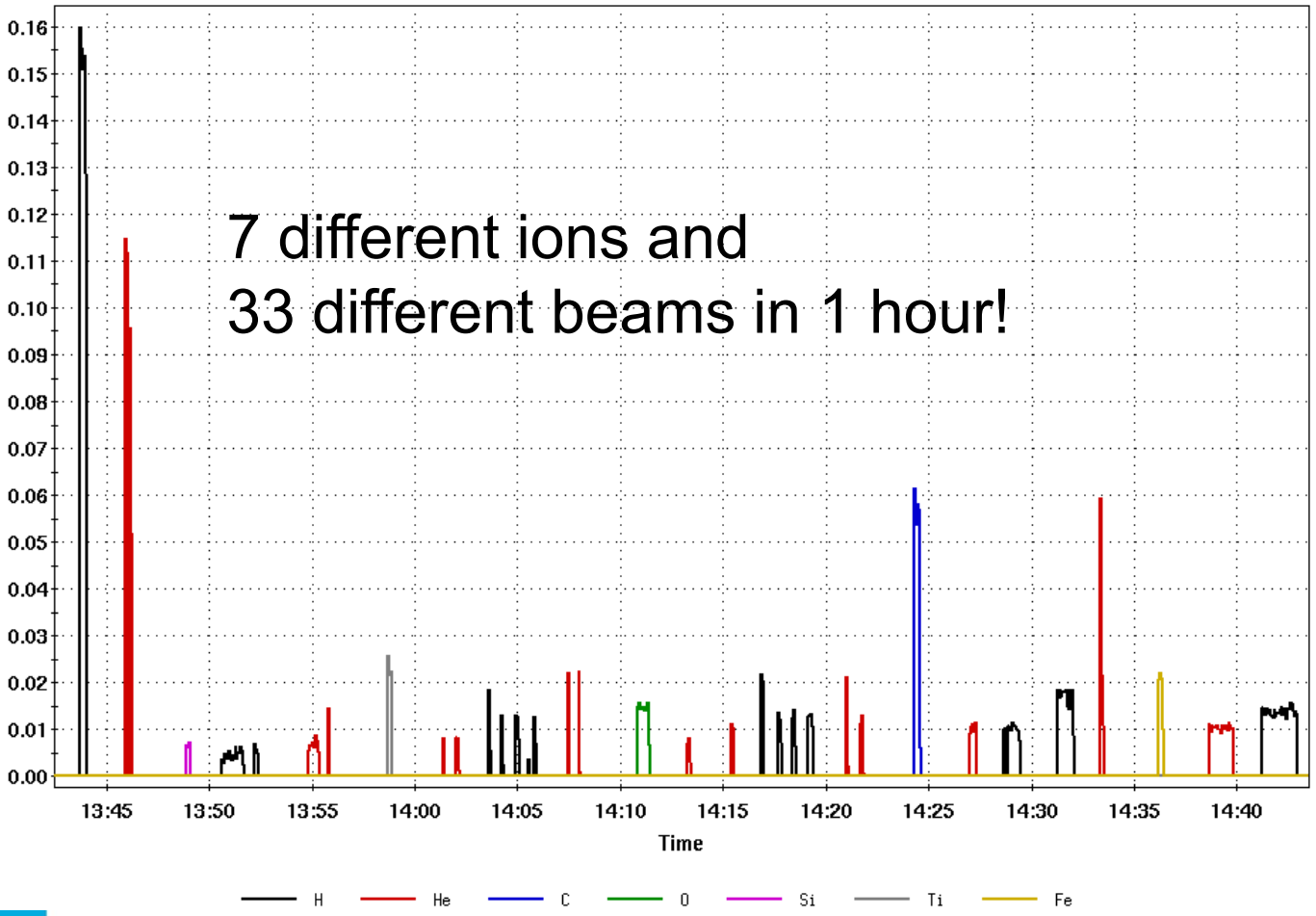
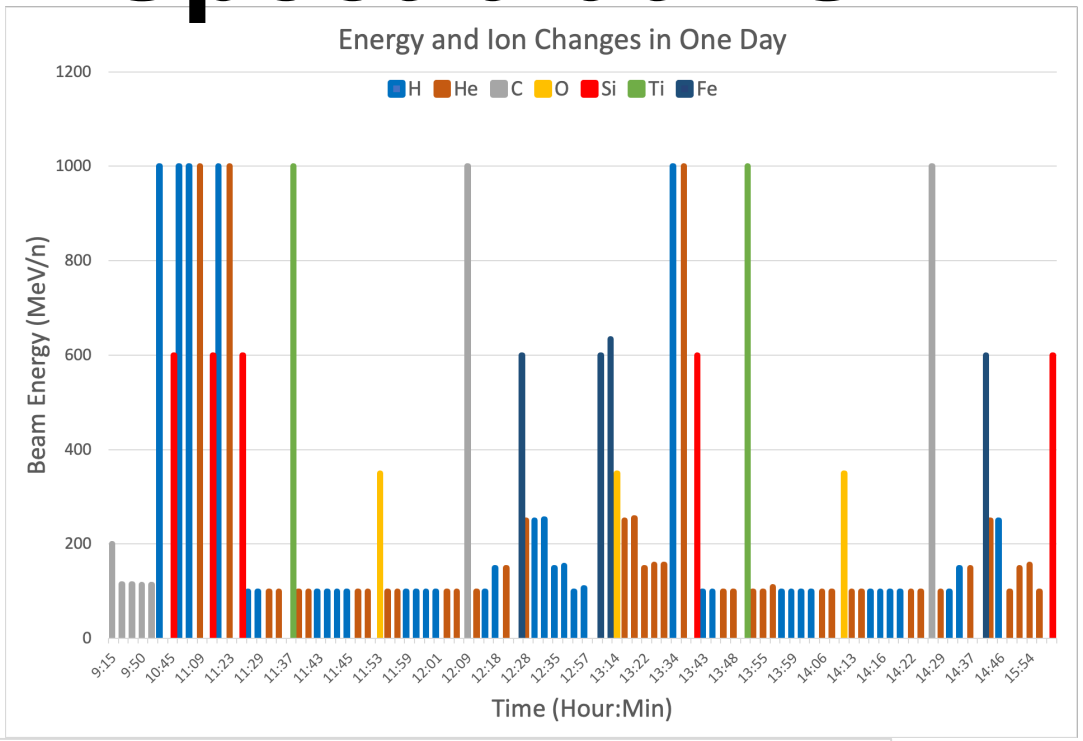
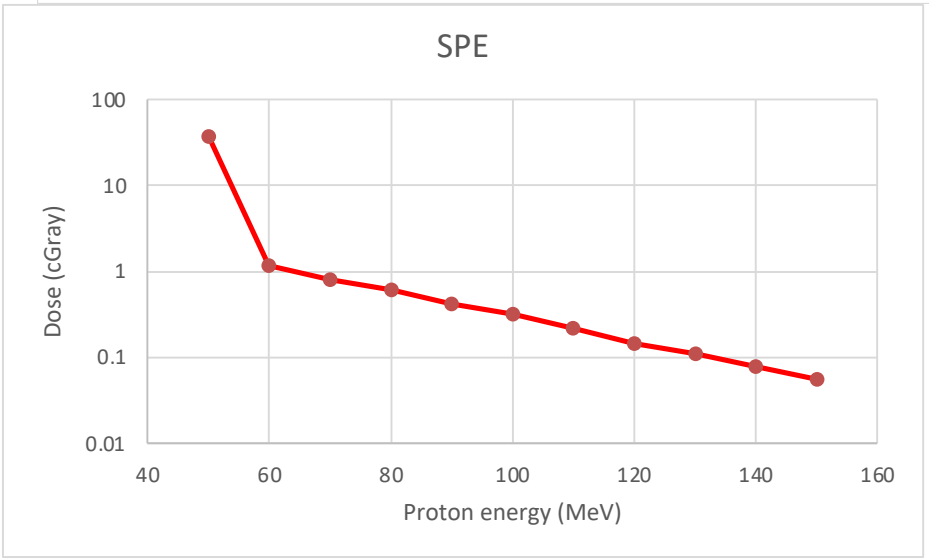
Delivered GCR and SPE Spectra at NSRL







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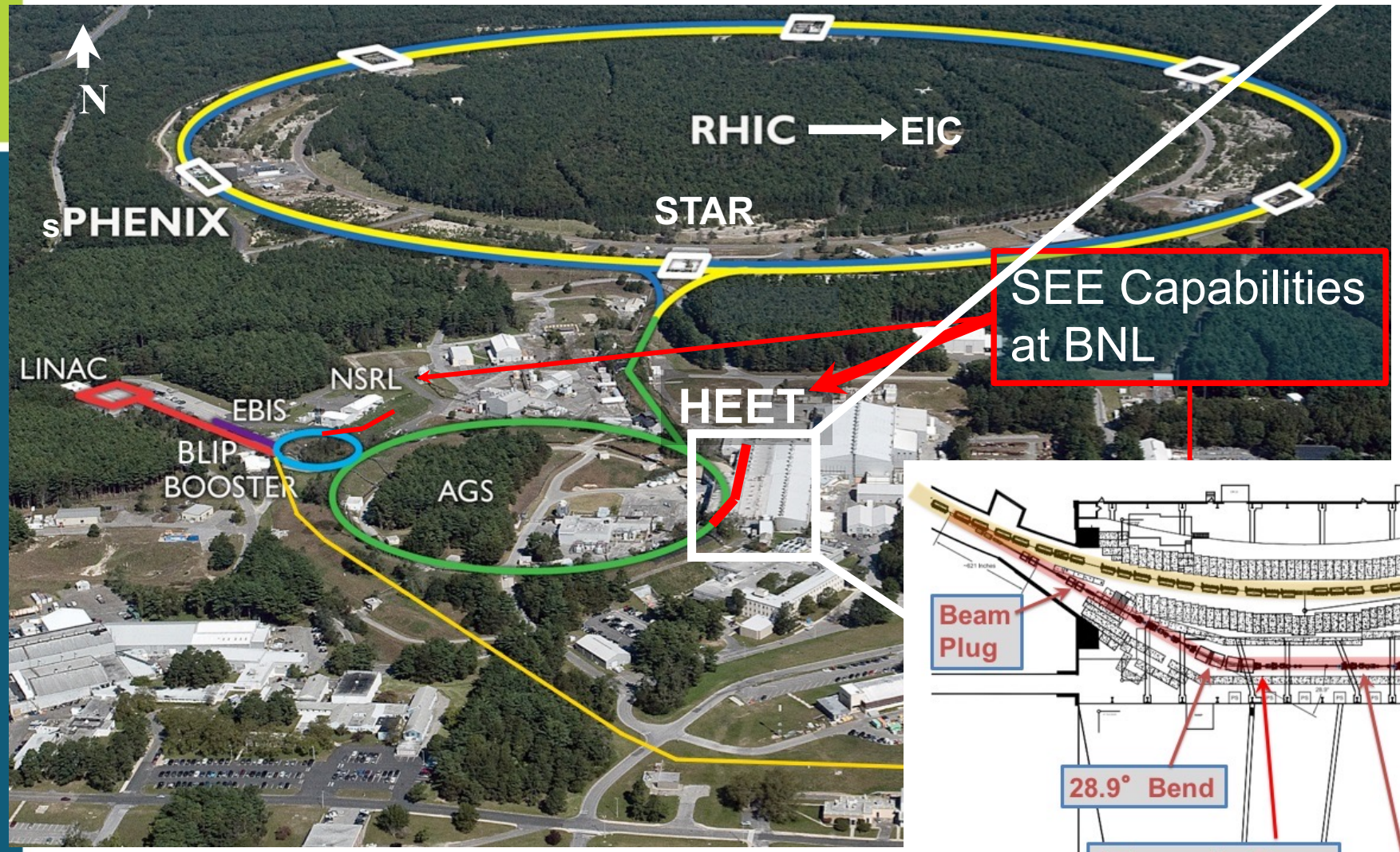
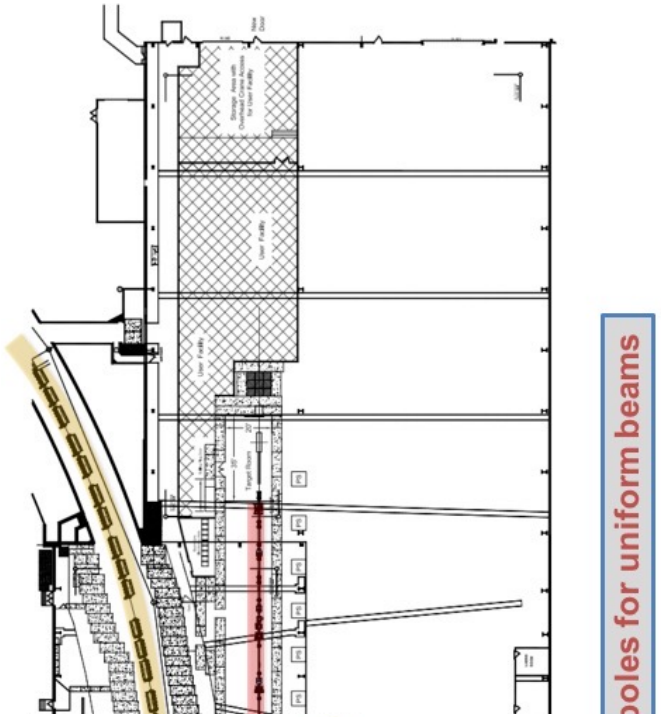
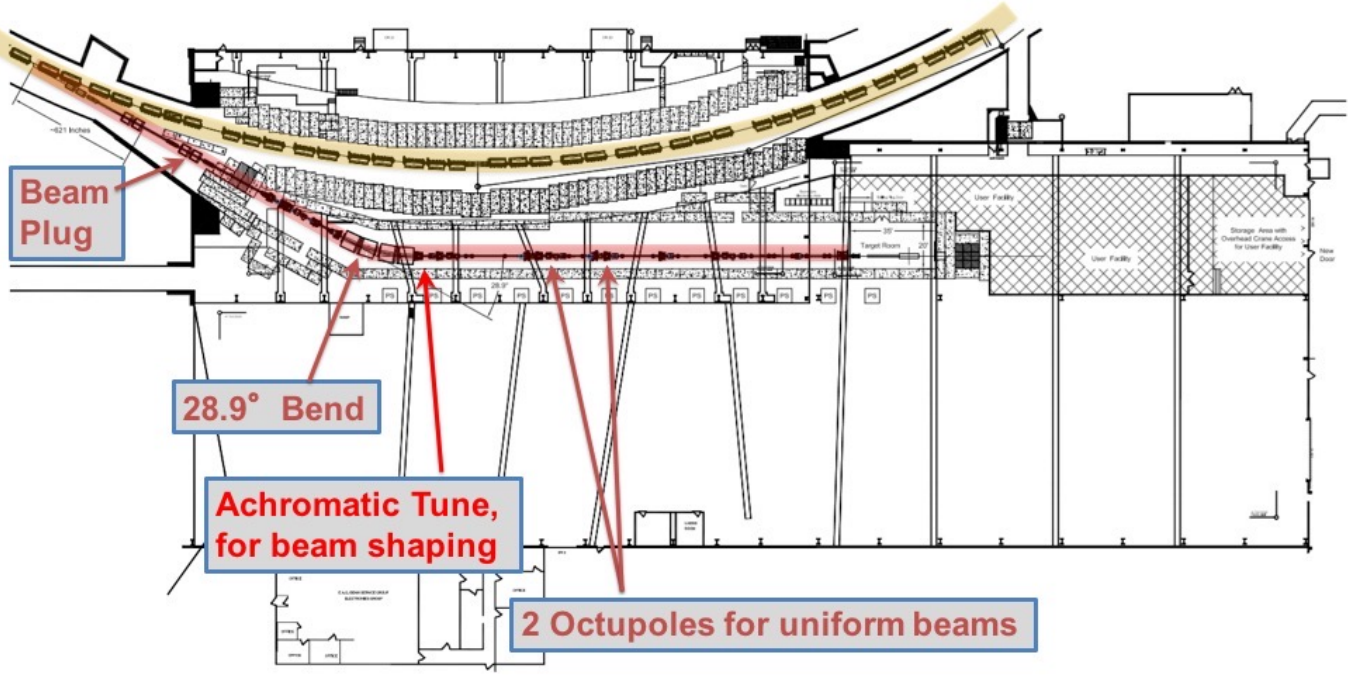
The proposed High Energy Effects Test facility







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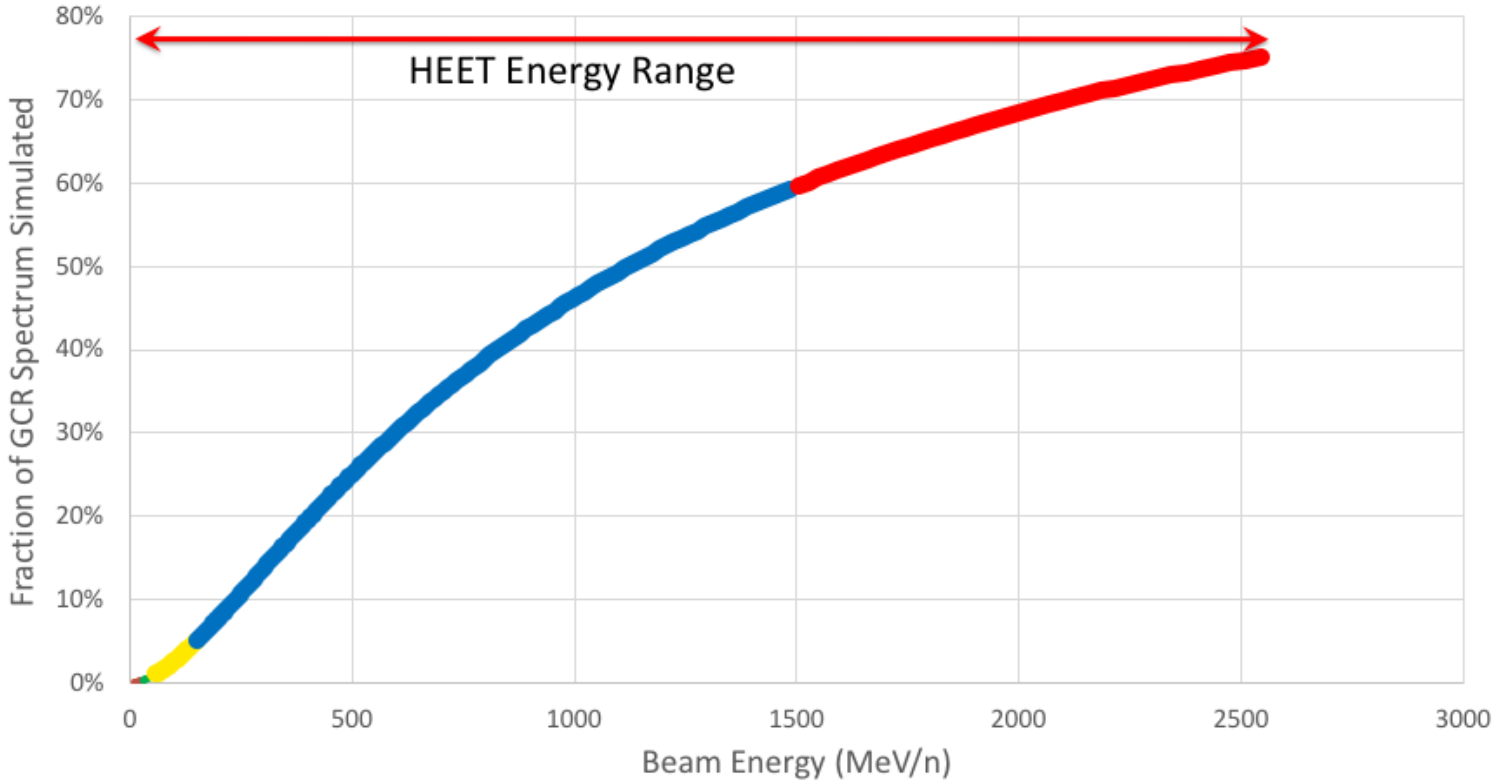
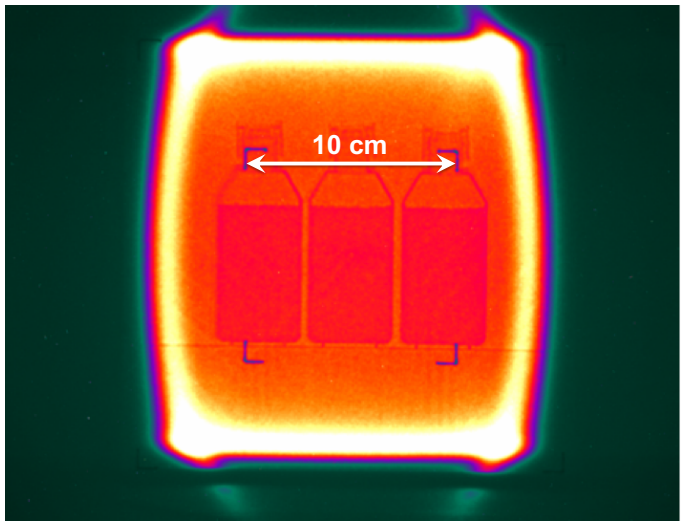
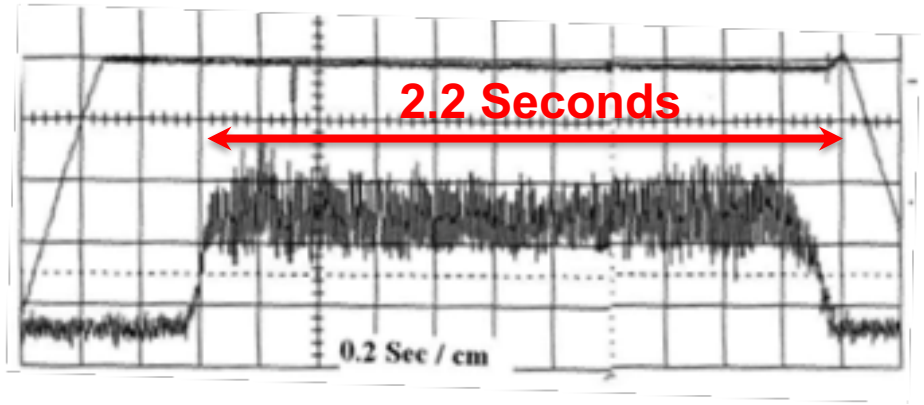
HEET Energy Range and Beams



Note:
GCR = Galactic Cosmic Ray
SPE = Solar Particle Event

- LBNL
- Tandem
- TAMU
- NSCL
- NSRL
- AGS

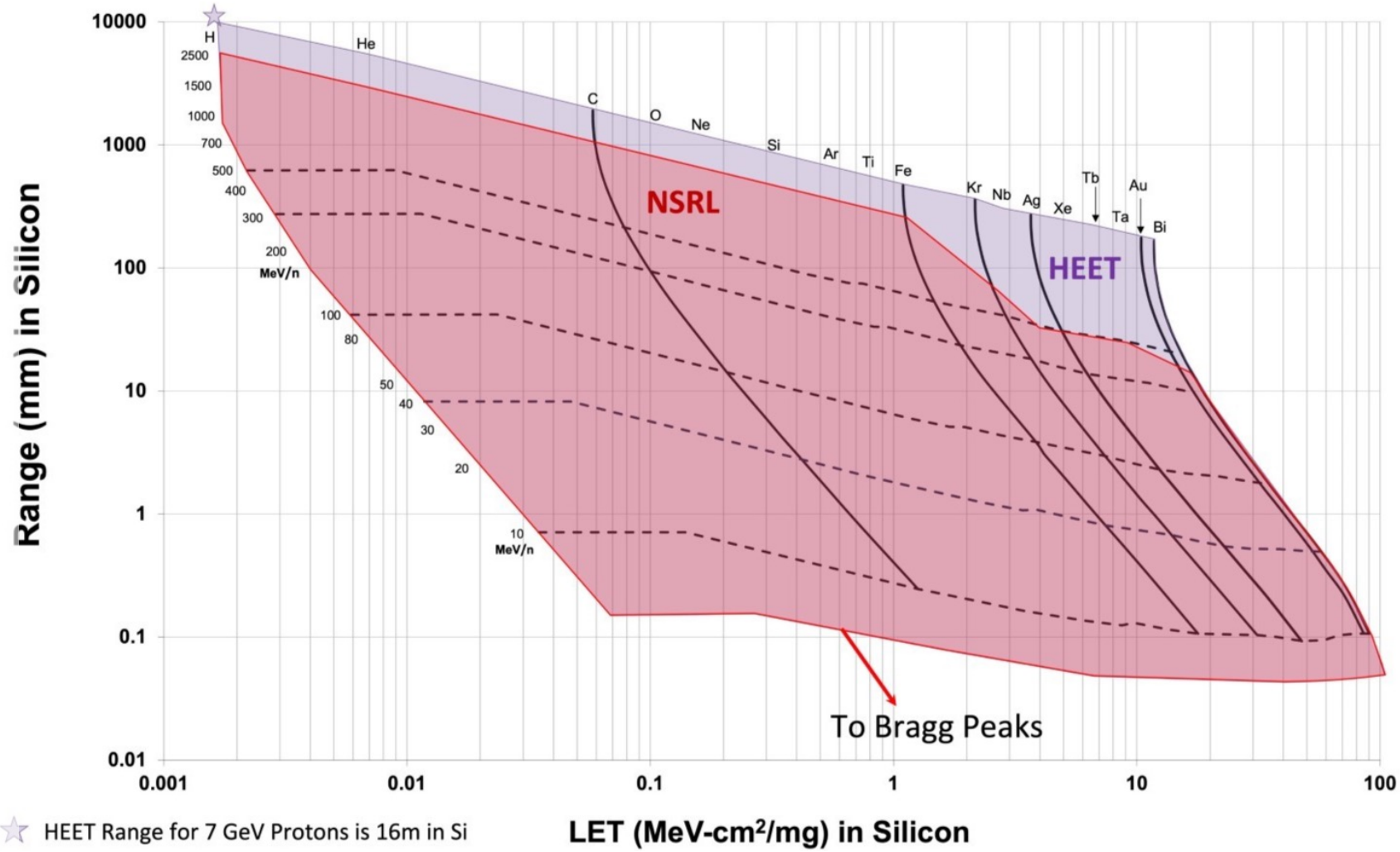




Note 1) The GCR Spectrum does not include the solar cosmic rays which are predominantly low energy protons.
Note 2) The GCR Spectrum used here is from a cosmic ray simulation routine that is commonly used in the industry. It is called CRÈME, and these data came specifically from CRÈME96. See footnote: https://creme.isde.vanderbilt.edu/
Note 3) The GCR Spectrum has been transported through 300 mils (7.62 mm) of "Aluminum shielding" which filters out soft stuff.

HEET Facility will provide:

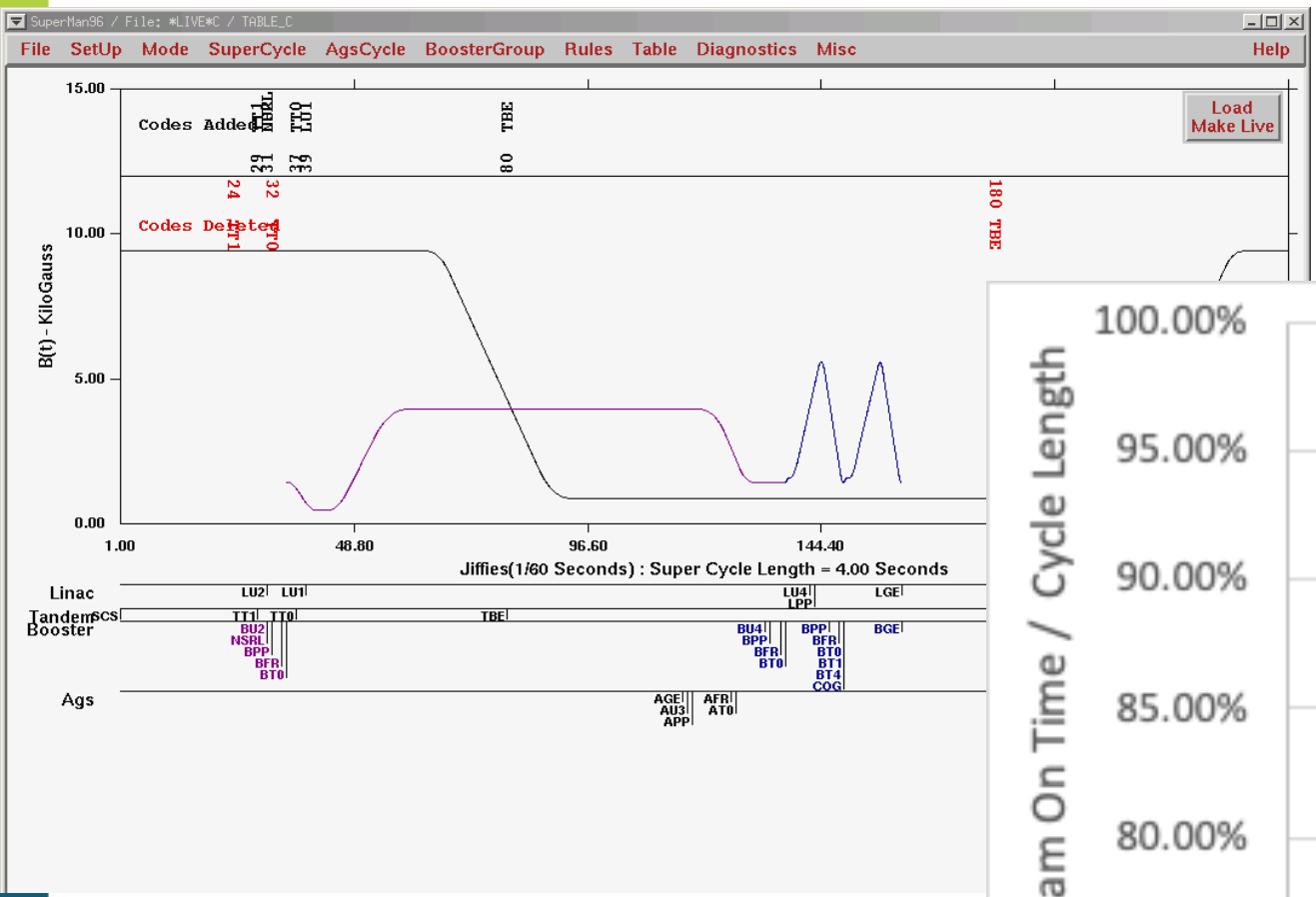
- 3D Uniform beams with spatial dimensions as large as 20x20 cm^2
- Simulation of SPE and GCR
- High LET with deep range probes
- Protons and full range of ion beams
- A few MeV/n to 2500 MeV/n beams
- Full experimental support



Modes of operations

The combination of having two synchrotrons (the Booster and the AGS) AND a Laser Ion Source at EBIS, allows us to do things nobody else can do!

1. Normal operation is to do first stage of acceleration in the Booster, transfer the beam(s) to the AGS, accelerate to desired energy, and extract to the HEET beamline
2. To increase the intensity, multiple beams can be transferred to the AGS before acceleration – allowing for x2 and up to x6 more intensity and perhaps more to be extracted to HEET
3. For lower energies (approx. 200 MeV/n and below), the Booster can handle all the acceleration and the AGS will act as a 'stretcher' ring = No acceleration. Beam is injected, debunched, and immediately extracted, enabling **extremely long beam spills**. This goes beyond what cyclotrons can deliver, since the beams will have no rf structure
4. With the ability to do multiple beam transfers from the Booster to the AGS with different ions from EBIS, we can also match the beam 'rigidity' ($B\rho=p\ k/Q$) for ions and deliver 'mixed fields' of ions in a single spill


SuperMan96 / File: *LIVE*C / TABLE_C
File SetUp Mode SuperCycle AgsCycle BoosterGroup Rules Table Diagnostics Misc Help
Load
Make Live
Codes Added
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B(t) - KiloGauss
15.00
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5.00
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48.80
96.60
144.40
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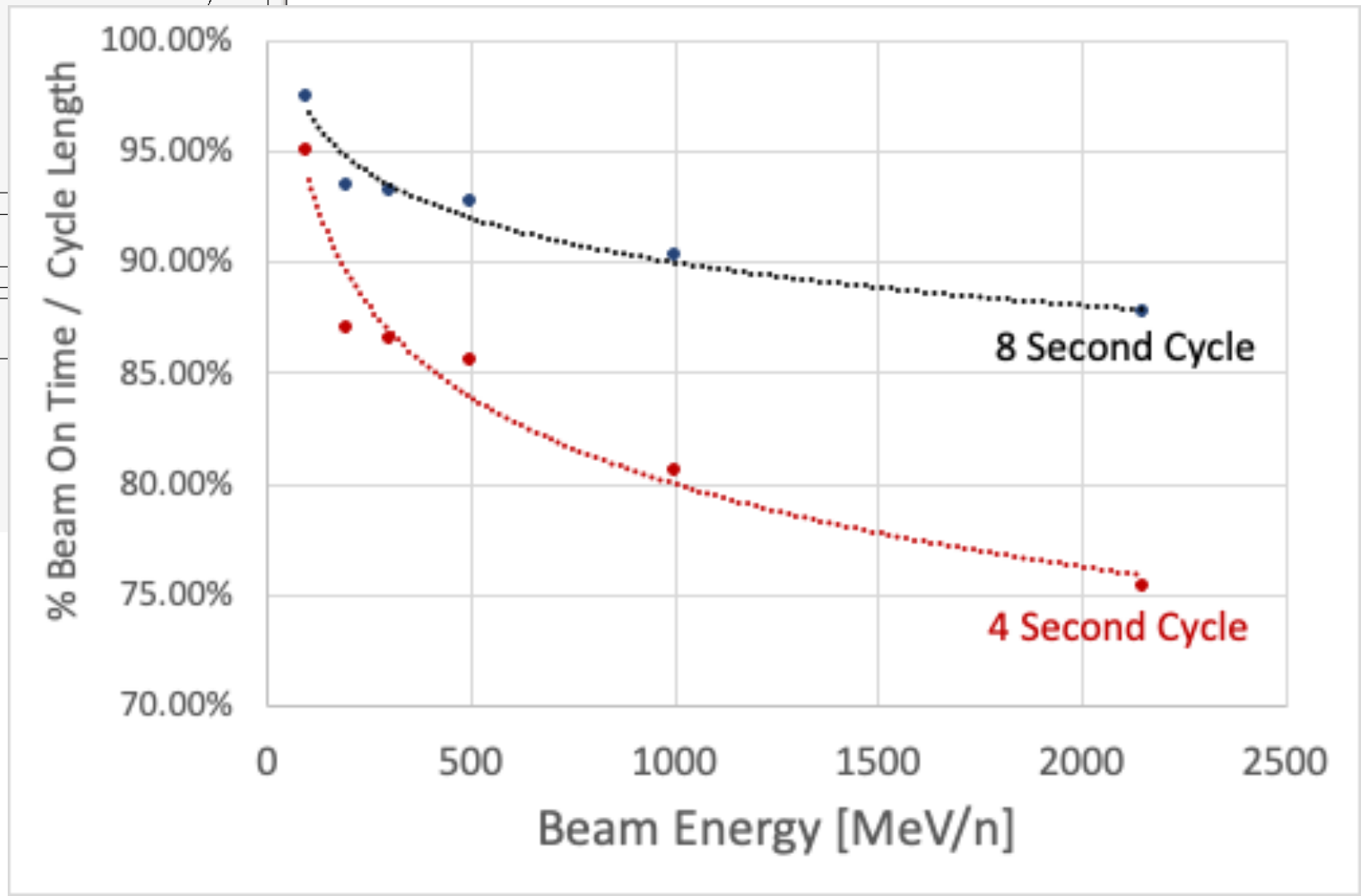
Linac
Tandem
Booster
Ags
TBE
180 TBE


% Beam On Time / Cycle Length
100.00%
95.00%
90.00%
85.00%
80.00%
75.00%
70.00%
0
500
1000
1500
2000
2500
Beam Energy [MeV/n]
8 Second Cycle
4 Second Cycle

Thoughts to Take Home

- Space Weather has a strong impact on all systems that we send into space and beyond the Earth's protective envelope
- Accelerators can simulate space weather, but the demands are different from other types of physics experiments
  - Simulate SPE – means being able to quickly/actively change energy
  - Simulate GCR – means being able to quickly change ion species
  - Measurements – must be able to measure and communicate in terms of LET and damage = significant challenge is how to communicate High Energy Effects
- Electronics testers are starved for beam time, all over the world