NASA Space Radiation Laboratory

Adam Rusek (rusek@bnl.gov)

April 13st, 2021

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science

Designed and Built for NASA Radio-Biology Work

What that means:

- Large uniformly distributed beam (±3%).
- Space relevant ions and energies (100–1500 MeV/n).
- Good local controls and monitoring of beam shape, uniformity, beam intensity.
- Dose based cutoff (±0.1%).
- User controlled cutoff.
- Device controlled cutoff.
- Custom cutoff.
- NIST traceable calibration(±2%).
- Beam energy measurement by bragg curve.
- *All these make the system very useful for electronics testing.*

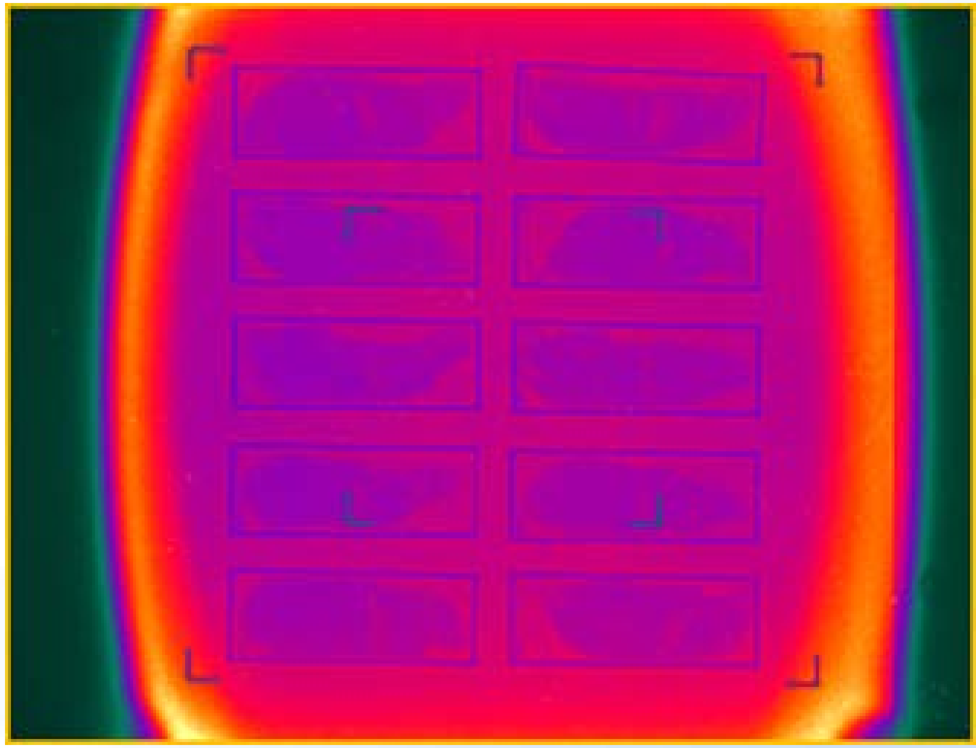
Further developments:

- Rapid ion and energy changes, motivated by the development of the Galactic Cosmic Ray Simulator. We are able to switch ions and energies, sending pre-developed archives to all parts of the machine, from EBIS through the Booster to the NSRL beam line in a matter of 3-4 minutes.
- Beam monitoring for low rates (scintillation counters).
- Scintillation counter-based cutoff.
- Beam start and stop signals for use by investigators.
- *We haven't done, nor are we equipped to do classified work.*

It also means that there is a reason the facility is not available to electronics testing year-round.

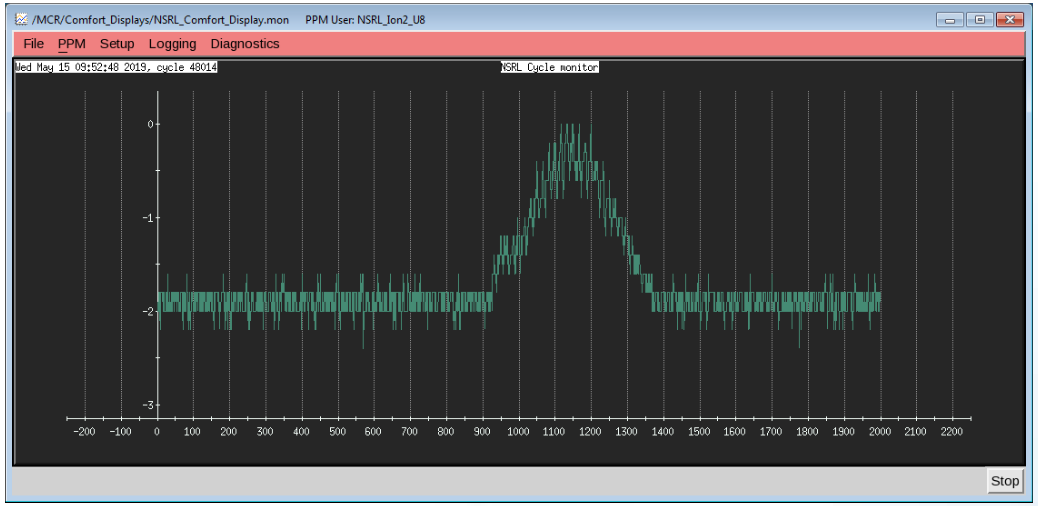
Beam structure, time and space

- The beam is delivered to us in *spills,* that is, there is a 300-500 ms long beam pulse every 4-6 seconds.
  - The time between spills is determined by RHIC, with whom we share the Booster.
- The beam can be made small – 1 cm diameter round beam for higher energies (>500 MeV/n), several cm diameter for lower energies.
- The beam can be made large – up to 60x60 cm^2 square beam (*very special setup*).
- The beam can be collimated just before the device under test (DUT).

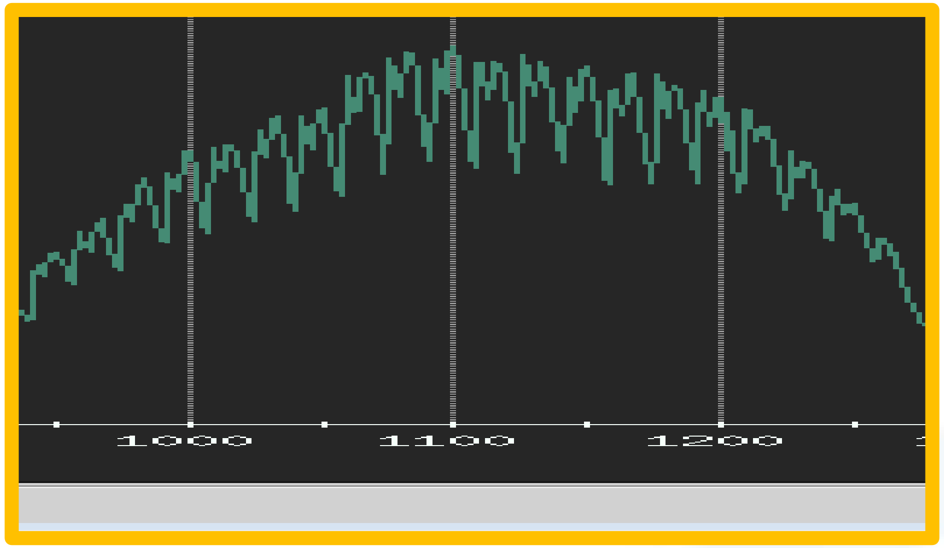


Beam time structure

- The spills here are about 400 ms long.
- There is a 60 Hz modulation of the beam and higher multiples of 60 on top of that.
- The ion chamber that produces these images. has a several ms response, so image is smoother than reality.



Fe 1000 MeV/n

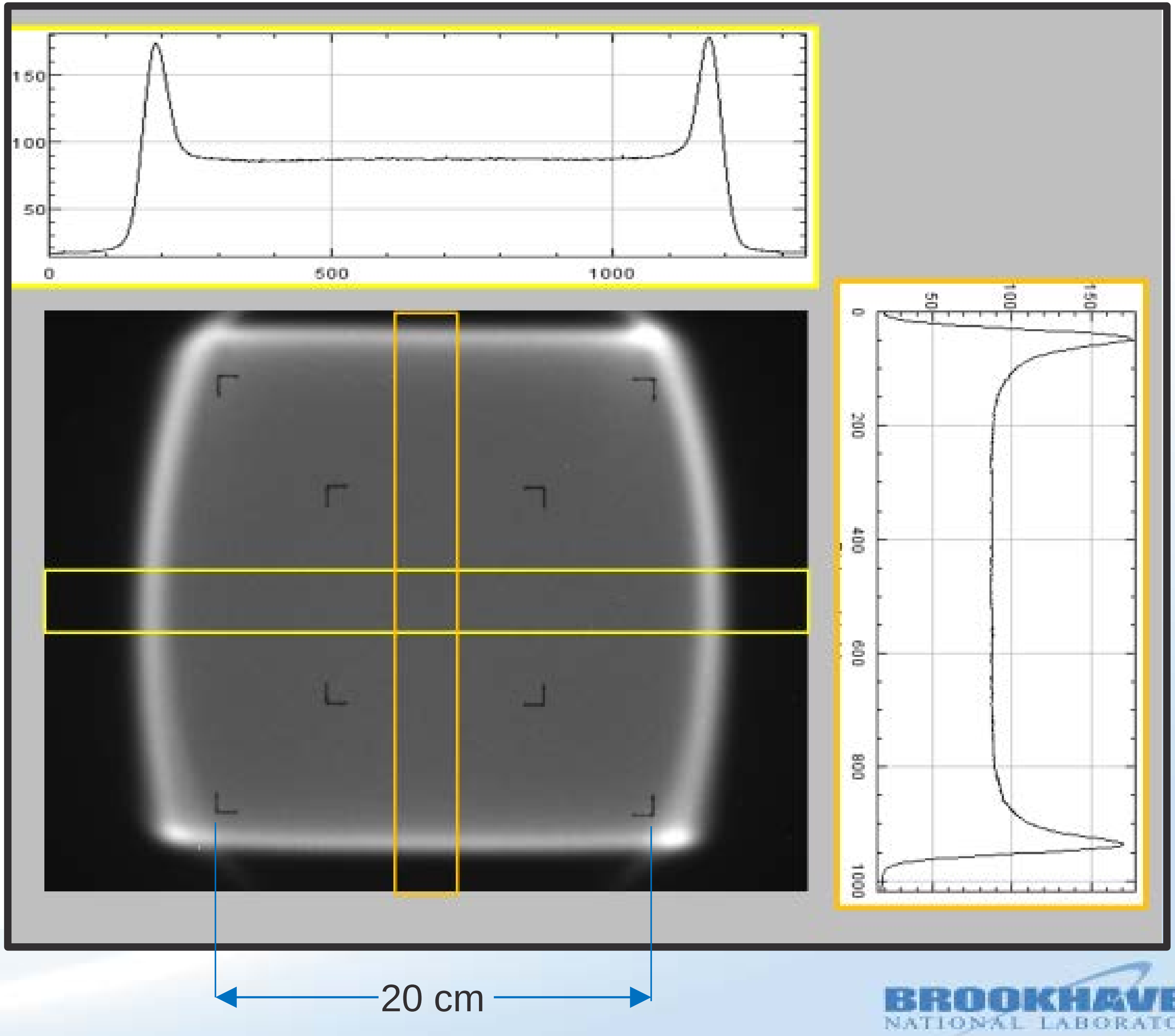


Kr 720 MeV/n

https://www.bnl.gov/nsrl/userguide/time-structure-in-beam.php

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".



List of ions delivered, to date*

The list can be expanded, and in fact we are working on adding Terbium to the list (it fills the gap between Xe and Ta and has essentially a single isotope), as well as Bismuth (High charge, essentially single isotope).

*Some of the ions on the list were used only once, or only developed in the machine, never having been used. For example, Li, Be, B, Cl and Ca. They appear on the list for bragging rights.

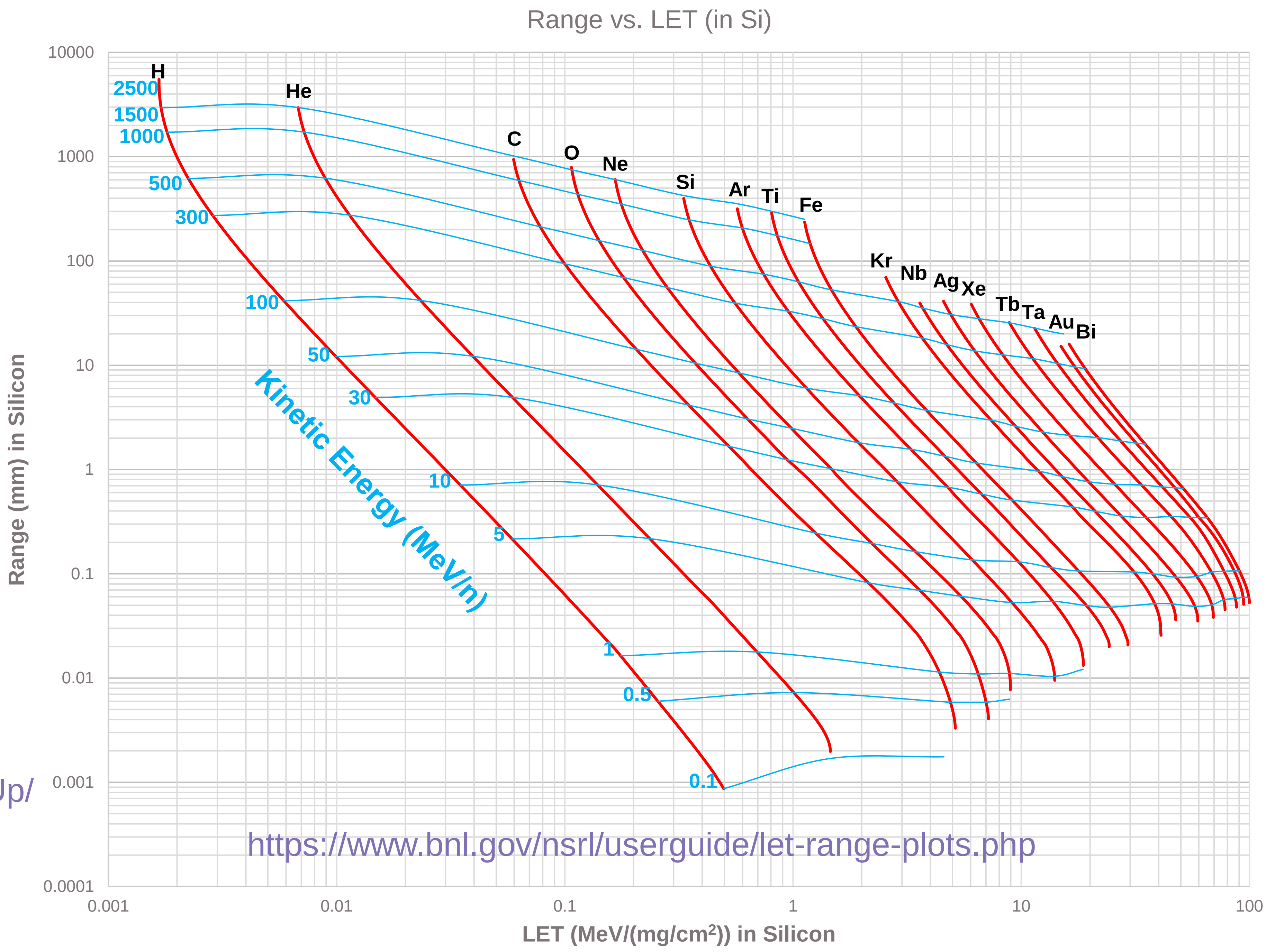
Ion	Z	A	Max energy (MeV/n)
H	1	1	2500
He	2	4	1500
Li	3	7	1500
Be	4	9	1500
B	5	10,11	1500
C	6	12	1500
O	8	16	1500
Ne	10	20	1000
Si	14	28	1000
Cl	17	35	1000
Ar	18	40	1000
Ca	20	40	1000
Ti	22	48	1000
Fe	26	56	1000
Kr	36	84	720
Nb	41	93	520
Ag	47	107	570
Xe	54	129	590
Tb	65	159	500
Ta	73	181	470
Au	79	197	400
Bi	83	209	400

https://www.bnl.gov/nsrl/userguide/beam-ion-species-and-energies.php

Range of various ions in silicon, plotted against their LET in silicon.

Note that the ranges in Si are high – no need for de-lidding, nor is it necessary to work in vacuum.

SRIM lookup tool:
https://www.bnl.gov/nsrl/StackUp/

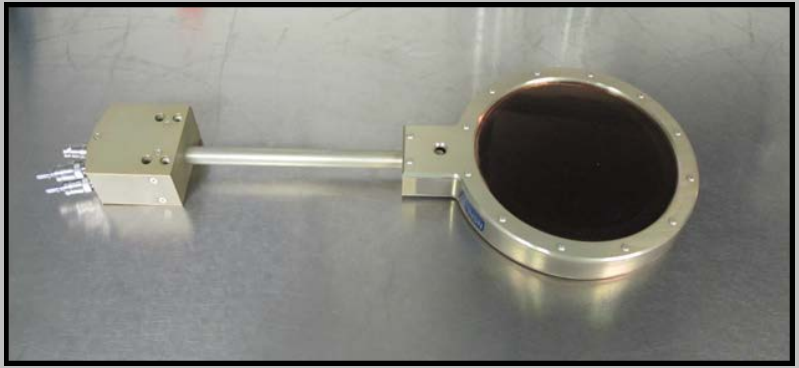


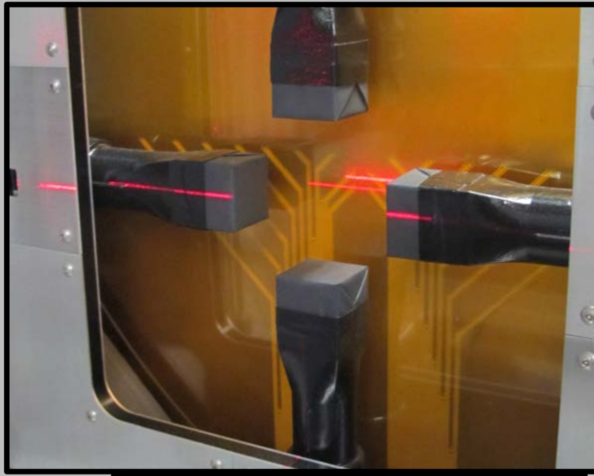
Properties of the NSRL Facility

- ~20 different ion species with maximum energies ranging from 2500 MeV protons to 400 MeV/n gold. The energies are continuously variable and accurately known.
- Beam size from 1 cm (fwhm) round to 60x60 cm^2 (usable area) square.
- Beam uniformity is ~97%.
- Beam rates Range from 10^2 – 10^7 per cm^2 per spill. ***Rates depend on beam size, ion species, and energy***.
- Penetration depth in Si can be adjusted from cm to sub mm.
- Beam intensity changes within seconds, ion species and ion energy changes in less than 4 minutes (***if archives prepared in advance***).
- Beam cutoff can be dose-based, scintillation-counter-based, or user defined and controlled.

Tools of the trade

- **X-Y lift tables. 300 lb capacity, local and remote-controlled.**
- **Rotational table. 300 lb capacity, local and remote-controlled.**
- **Ion chambers for beam cutoff. Calibrated against NIST traceable calibration chambers or scintillation counters – users' choice.**
- **Polyethylene binary-filter for moderating beam energy. Also used for measuring beam energy (range).**
- **Collimators. Copper (shown), W bricks, adjustable W collimator (under construction).**
- **Height-adjustable rails to accommodate oversized targets.**
- **Scintillation counters for beam monitoring.**
- **Plenty of hardware to fix targets on beam line.**
- **Cooling and heating of DUT, by air.**
- **Engineering support.**





Testing Electronics at NSRL

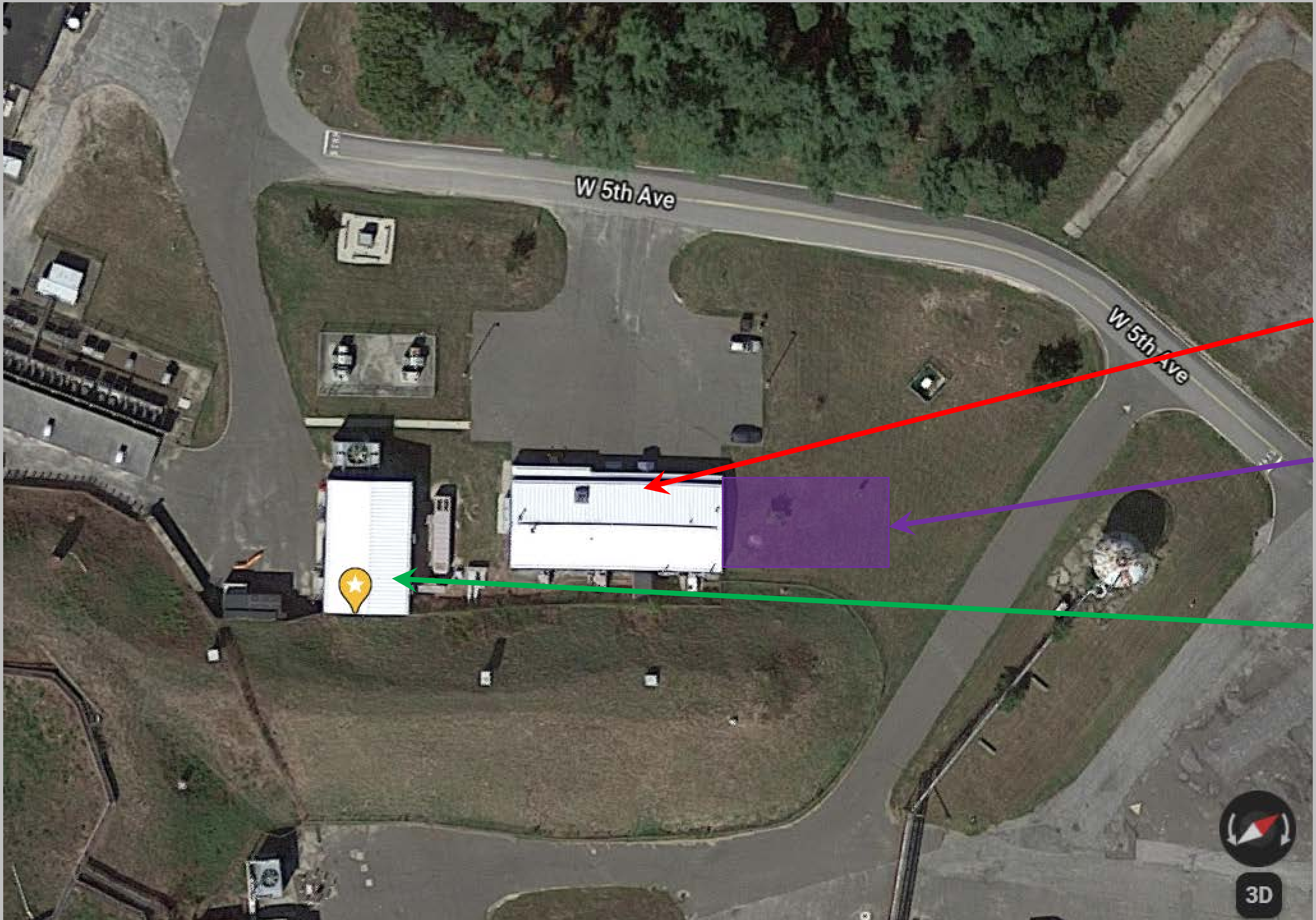
- Purpose of test
  - Radiation hardness/resistance?
  - Mitigation or recovery from SEU?
  - System, assembly, flight configuration testing?
- Taking full advantage of the facility's capabilities
  - Make use of high kinetic energy beam (penetrating, not stopping).
  - Carry out only work that cannot be done better elsewhere (better use of time).
- We are avalable to help with all issues pertaining to testing at NSRL
  - Beam ion and energy choices.
  - Experimental design, layout, support needs, etc.

Expanding Support for Electronics Testing

1. Increasing throughput at NSRL.
   1. Addition to the building.
   2. Additional staff, at least during MDA runs.
2. New beam line, in the AGS experimental hall.
   1. Next talk, by K. Brown of BNL.

Increasing Throughput at NSRL

- There are about 4 winter months during which there are no NASA activities.
- We will require an average of two days per week when no beam is delivered to users, to allow time between groups and for beam preparation.
    - Time between groups is independent of the number of shifts run during each day.
    - Each group has different beam needs, which results in much time spent preparing them.
- The day between groups can be reduced to a few hours if we have a place to put multiple groups and handle their shipments – an addition to the NSRL support building.
- The time spent preparing beams can be at least partially eliminated by standardizing the ion/energy combinations as well as beam sizes, so that we can use the same beams for all groups (or the majority thereof).

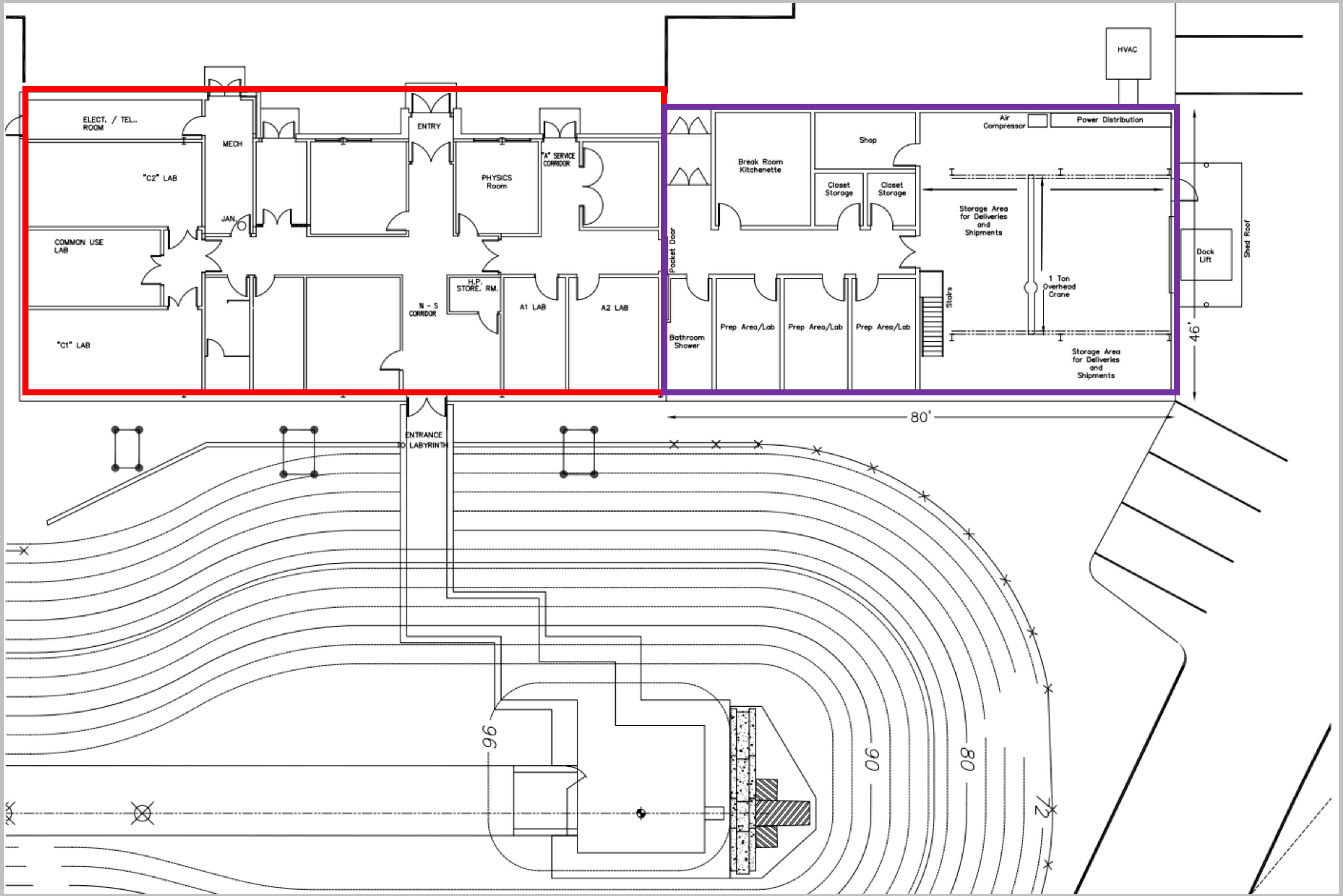


The NSRL Support Building

Support Building (958)

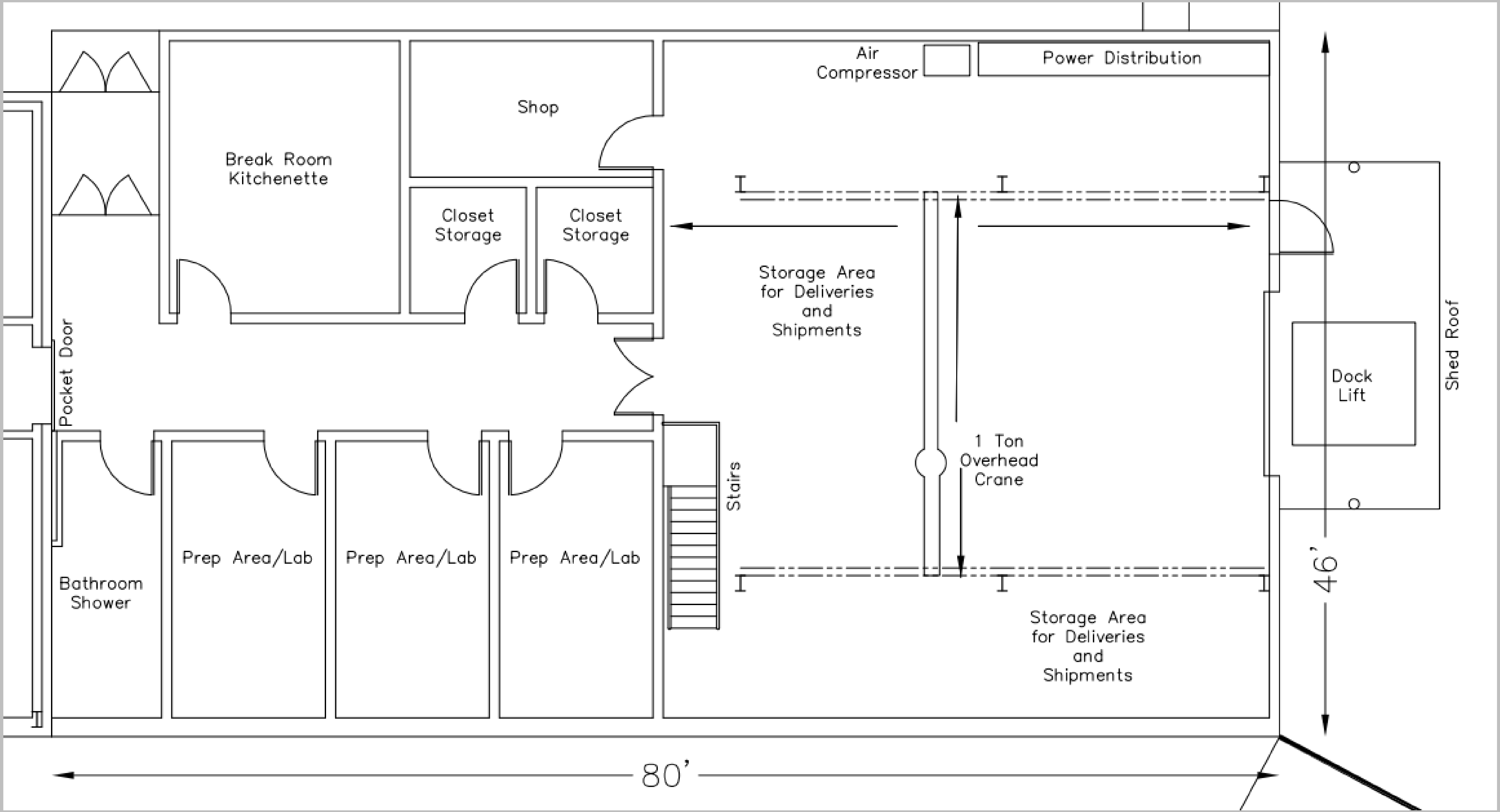
Proposed addition to 958

Power supply building, currently used for storing users' shipments.



Existing Support Building

Proposed Extension


Air Compressor
Power Distribution
Shop
Break Room Kitchenette
Closet Storage
Closet Storage
Storage Area for Deliveries and Shipments
Pocket Door
Stairs
1 Ton Overhead Crane
Dock Lift
Shed Roof
Prep Area/Lab
Prep Area/Lab
Prep Area/Lab
Bathroom Shower
Storage Area for Deliveries and Shipments
46'
80'

Summary

- NSRL is a unique facility.
  - High energy ion beams – no need for de-lidding or work in vacuum.
  - Good spatial distribution control, good dose (fluence) control.
  - Flexible beam-cutoff options, including user issued signal-based cutoff.
  - Dedicated support staff, available during all activities at the facility, as well as for consultation on all ion-beam and experimental planning and setup issues.
  - Engineering support available.
- NSRL does have schedule limitations.
  - 4 winter months during which there are no NASA experiments are (roughly) the only large time window available for SEE testing.
  - One way to improve the use of time within this window may be the expansion of the user support building. It will enable us to accommodate multiple groups in the queue for beam and handle the equipment they ship in and out of the facility.
- An additional facility at BNL will greatly increase testing capacity – Next talk.