Experimental capabilities for applied nuclear science at the 88-Inch Cyclotron

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NSD
NUCLEAR
SCIENCE
DIVISION

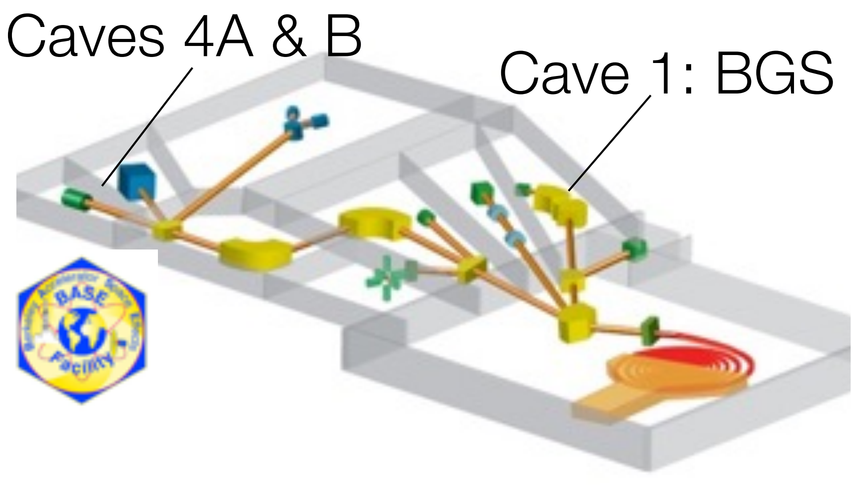
U.S. DEPARTMENT OF ENERGY

UNIVERSITY OF CALIFORNIA

Questions

1. What are the capabilities at your lab?
   - particle microamp
   - most anything on the periodic table
   - Facilities: BGS, gamma decay counting, BASE
   - protons: up to 55 MeV
   - deuterons: up to 65 MeV
   - He3: up to 170 MeV
   - alphas: up to 130 MeV
   - neutron beams: 8-30 MeV
2. Are there specific limitations in the types of experiments that can be run at your lab?
   - E/A=5-10 MeV for heavy
   - E/A = 14 MeV for medium
   - E/A = 32 MeV for lighter heavy-ion beams
3. What is required to run an experiment at your lab?
   - Local Cyclotron Advisory Committee (CAC)
   - $1400/hr
   - Rad worker 1 training online, Bldg OJT (20 min. onsite)

88-Inch Cyclotron Dual Mission

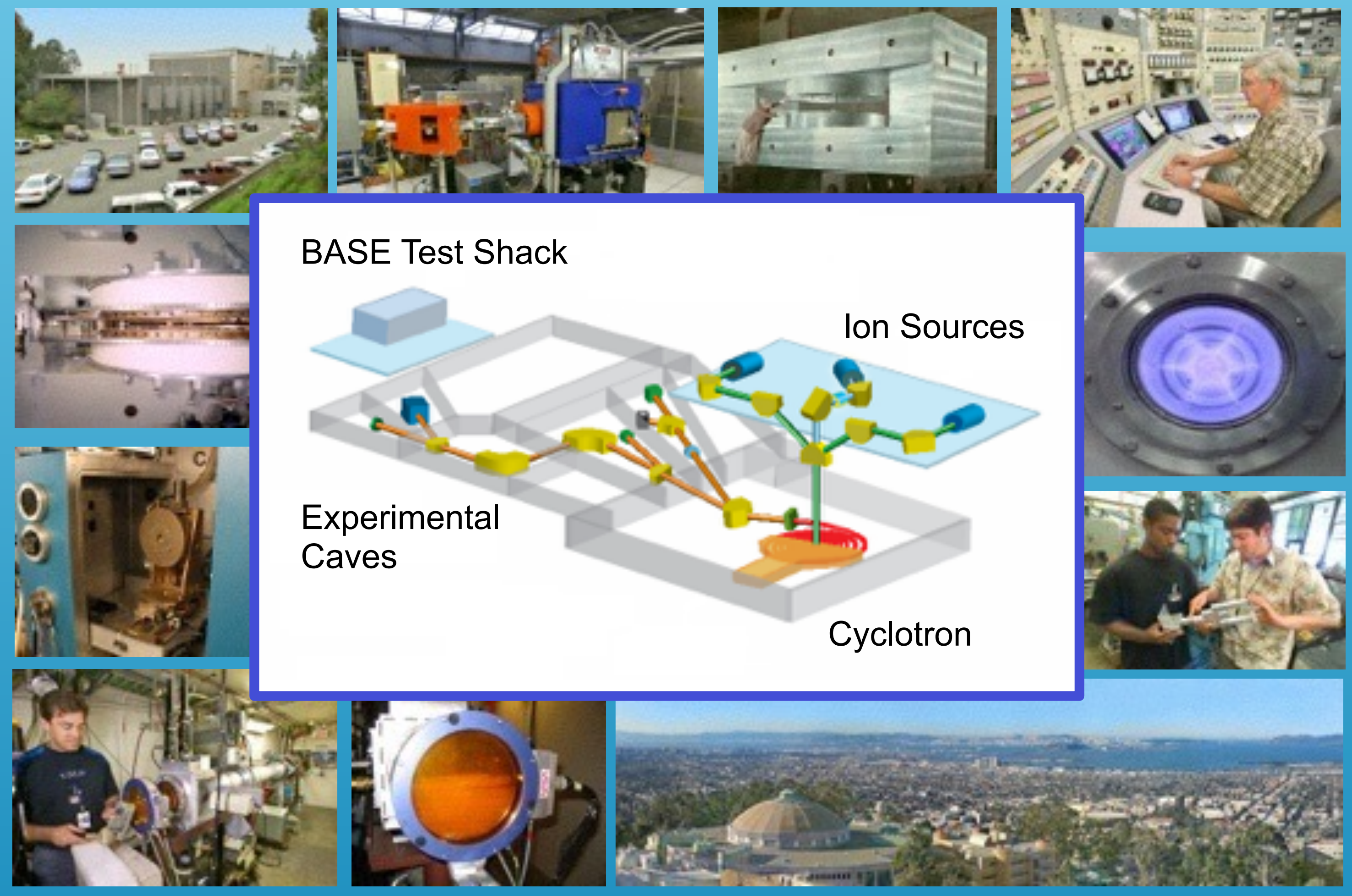


Users: ~ 350
Light Ions: Protons up to 55 MeV
^{3}He up to 170 MeV
Heavy Ions: 5 To 32 AMeV

- Conduct world-class science: Berkeley Gas-filled Separator (BGS), super-heavy element program
- Support national security and other US space programs in the area of radiation effects testing: <u>B</u>erkeley <u>A</u>ccelerator <u>S</u>pace <u>E</u>ffects (BASE) Facility

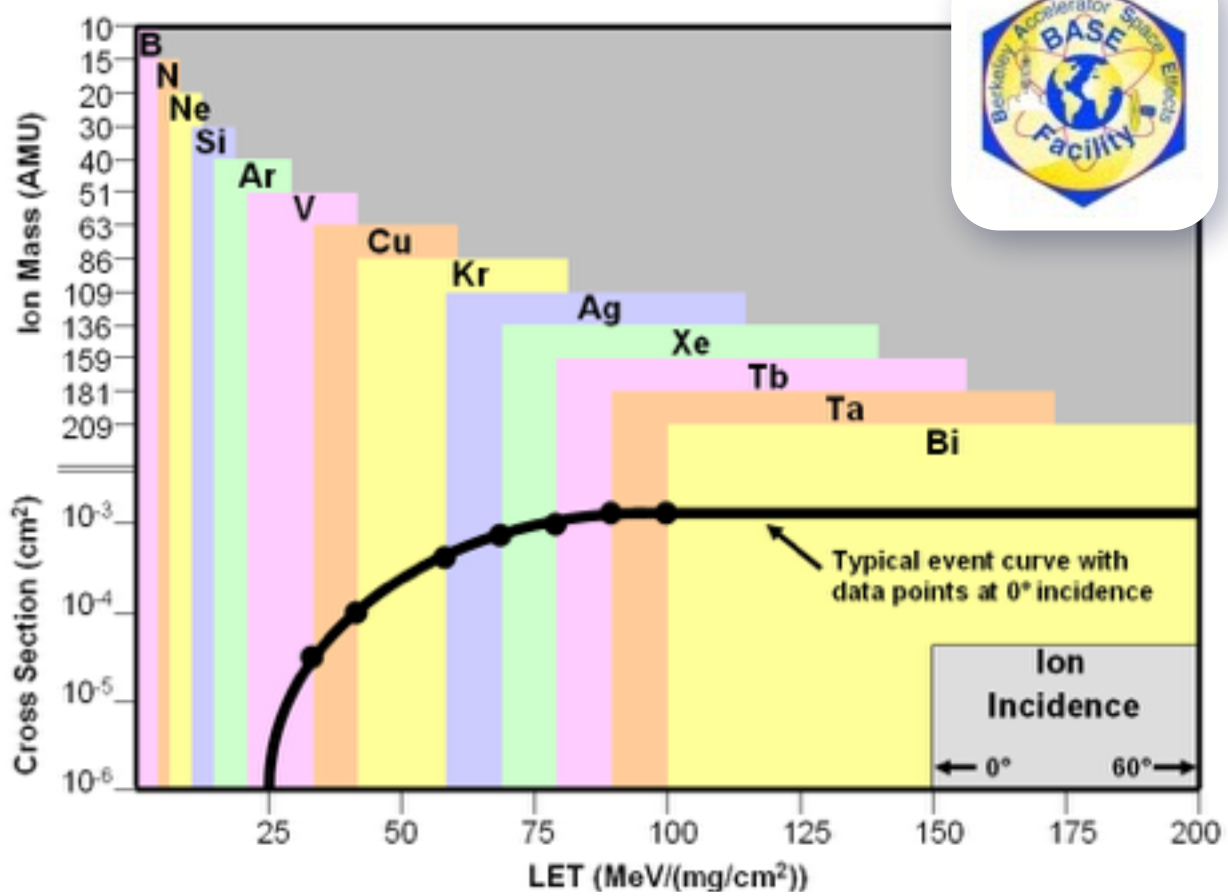
BASE Facility and mission

- BASE = Berkeley Accelerator Space Effects
- Mission: Support national security and other US space programs in the area of radiation effects testing.
- protons: 1-55 MeV
- Standard Cocktail Beams: 4.5, 10, and 16 AMeV



BASE Cocktails

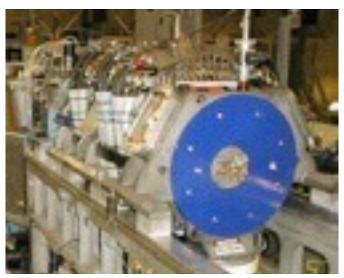
- What is a “Cocktail”?
  - Multiple ions injected in to the Cyclotron, which we can then select and separate by simply changing the frequency of the cyclotron.
- Why do BASE users want “Cocktails”?
  - Typically, to obtain data correlating event cross sections to linear energy transfer (LET).



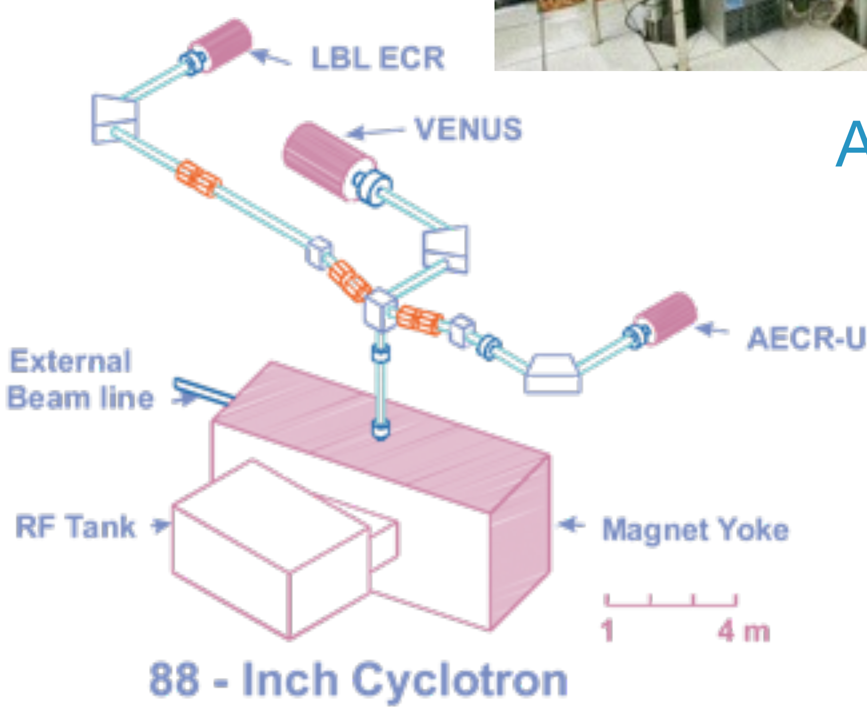
Large ion selection combined with **3-minute ion changes** saves users a significant amount of time.

88-inch accelerator

6.4 GHz ECR



VENUS: 18+28 GHz



AECR: 10+14 GHz

High Intensity Light Ions

Protons to 55 MeV

^{3}He to 170 MeV

Heavy Ions

5 To 32 MeV/nucleon

$0.2 \leq Q/M \leq 0.5$

Mass Resolution

1/3000

$$\frac{E}{M} = \left(\frac{Q}{M}\right)^2 \times K$$

→ Medium to very high charge states of every element from H to U

World-leading ECR ion source group

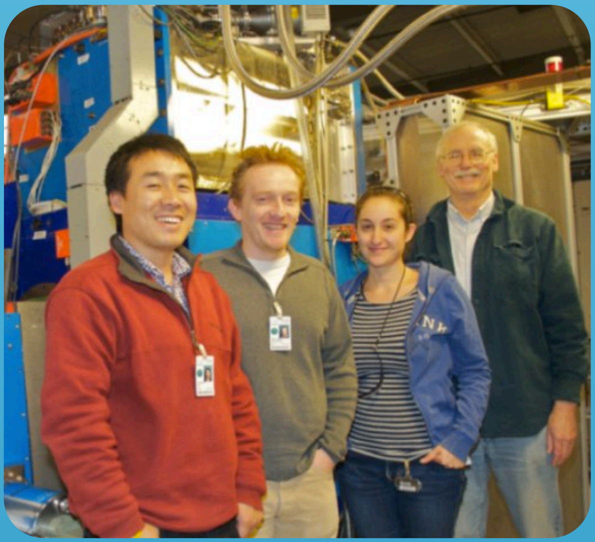
VENUS records

Ion	Chg	Intensity (eμA)
^{4}He	2+	11,000
^{16}O	6+	3,000
^{40}Ar	11+	860
^{209}Bi	31+	300
^{209}Bi	50+	5.3
^{238}U	33+	440
^{238}U	50+	13
^{40}Ca	11+	400

Why these records are important...

FRIB needs very high intensity high-charge-state beams.

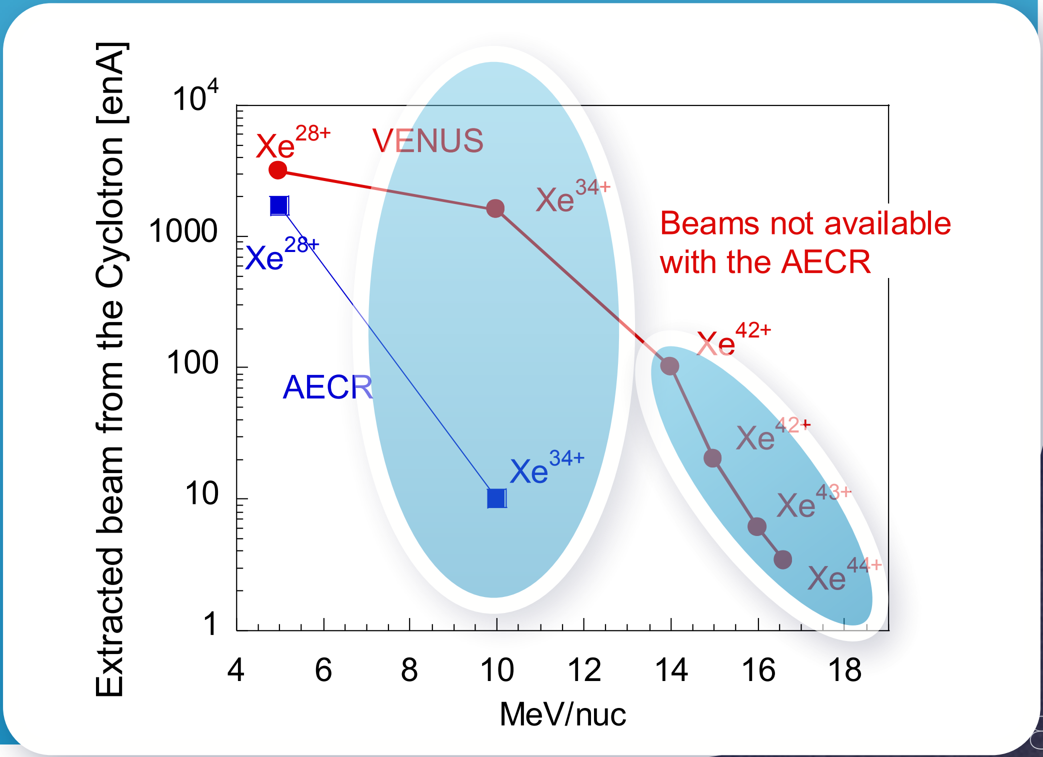
- Low emittance beams for high intensity transmission (super heavy studies)



Collaboration with MSU

$^{238}U^{33+}$: 430 μA

- BASE community can use the tails for higher LET in the cocktail
  - Xe in the 16 AMeV cocktail
  - Bi or Au in the 10 AMeV cocktail



Future heavy ion accelerators begin here:

Next generation ECRIS for intense heavy ion beams

Engineering
NSD
AFRD

Superconducting Electron Cyclotron Resonance ion sources (ECRIS) are being developed at LBNL that provide improved performance and significant cost savings for accelerator facilities in the US and around the world. Significant gains can be made for radioactive beam facilities, high density physics research, and super-heavy element studies with more intense, higher charge state beams.

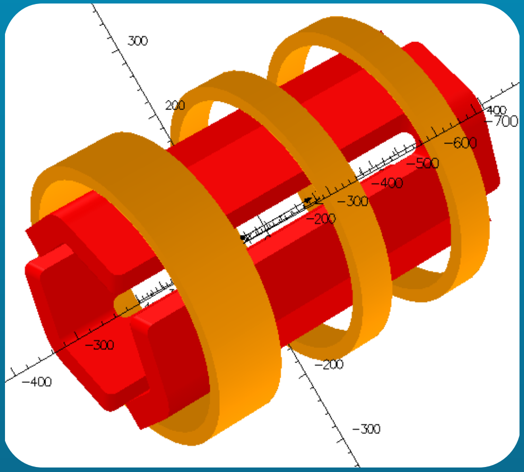
Current state of the art: VENUS

Recent milestone:

$^{238}U^{33+}$: 430 eμA

Prototype ion source for FRIB

A path forward: **MARS** (Mixed Axial and Radial field System)



MARS: proof of principle of the new magnetic structure for next generation ECRIS

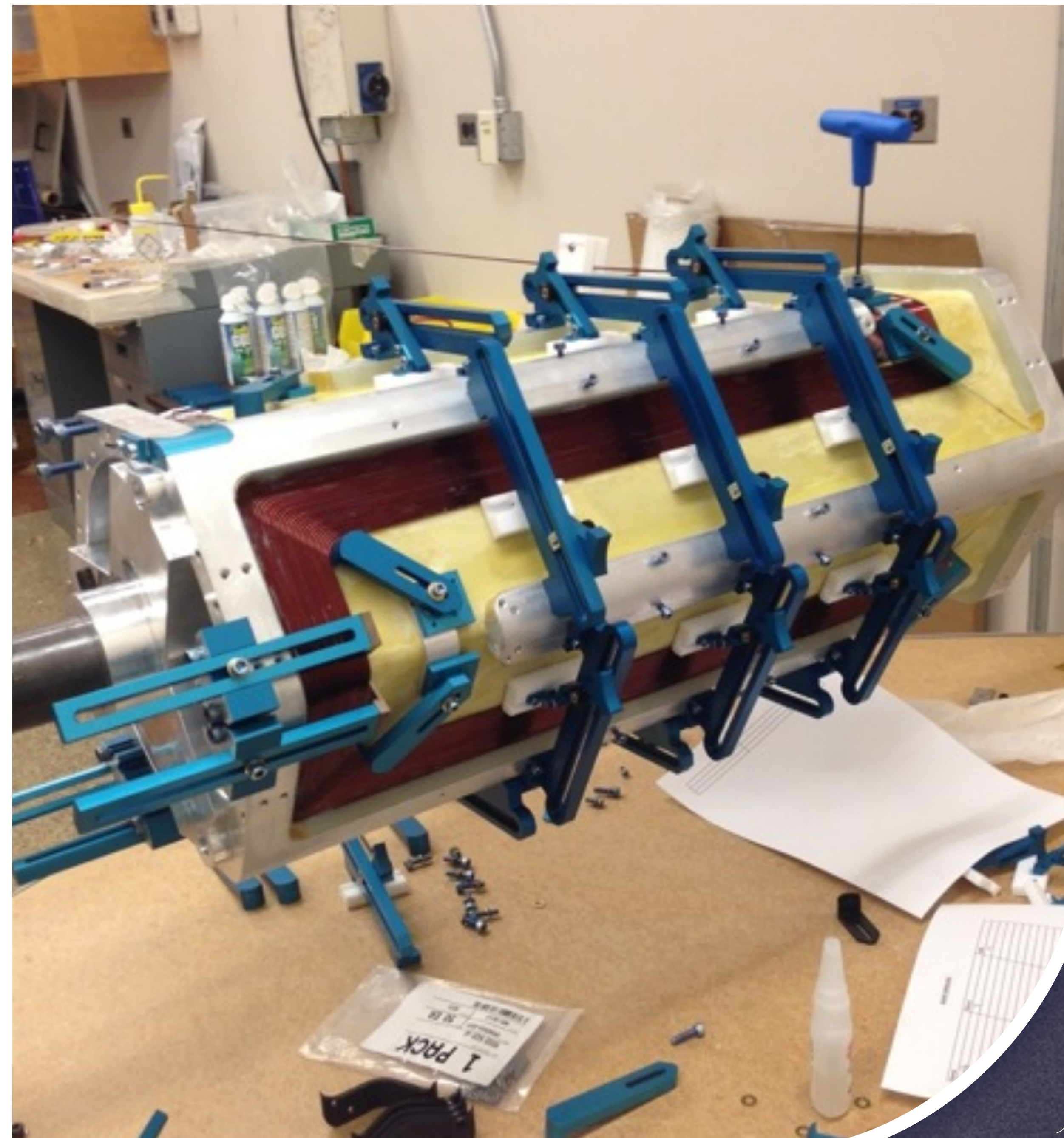
MARS will bridge to next generation ECRIS technologies with a novel closed-loop super-conducting coil. This scheme for generating higher magnetic fields will be tested in MARS and will ultimately allow for new ion source designs with improved performance far beyond that of VENUS.

	VENUS	MARS
B on axis (T)	4	3.6
B radial (T)	2.2	3.3
Frequency (GHz)	28	18-28

Goal: emA of high charge state Bi & U beams

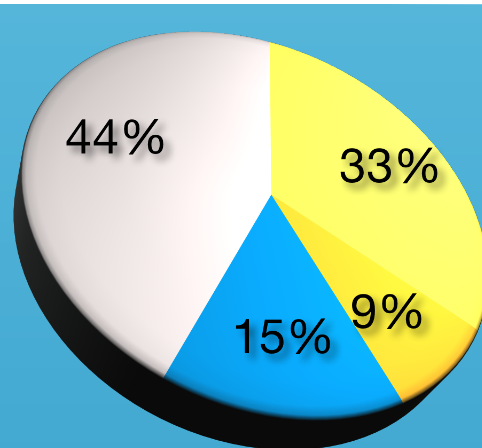
MARS windings: a test

- Field maps
- Test potting techniques
- Wind with NbTi to build a MARS demonstrator, up to 45 GHz



Beam time distribution in FY12

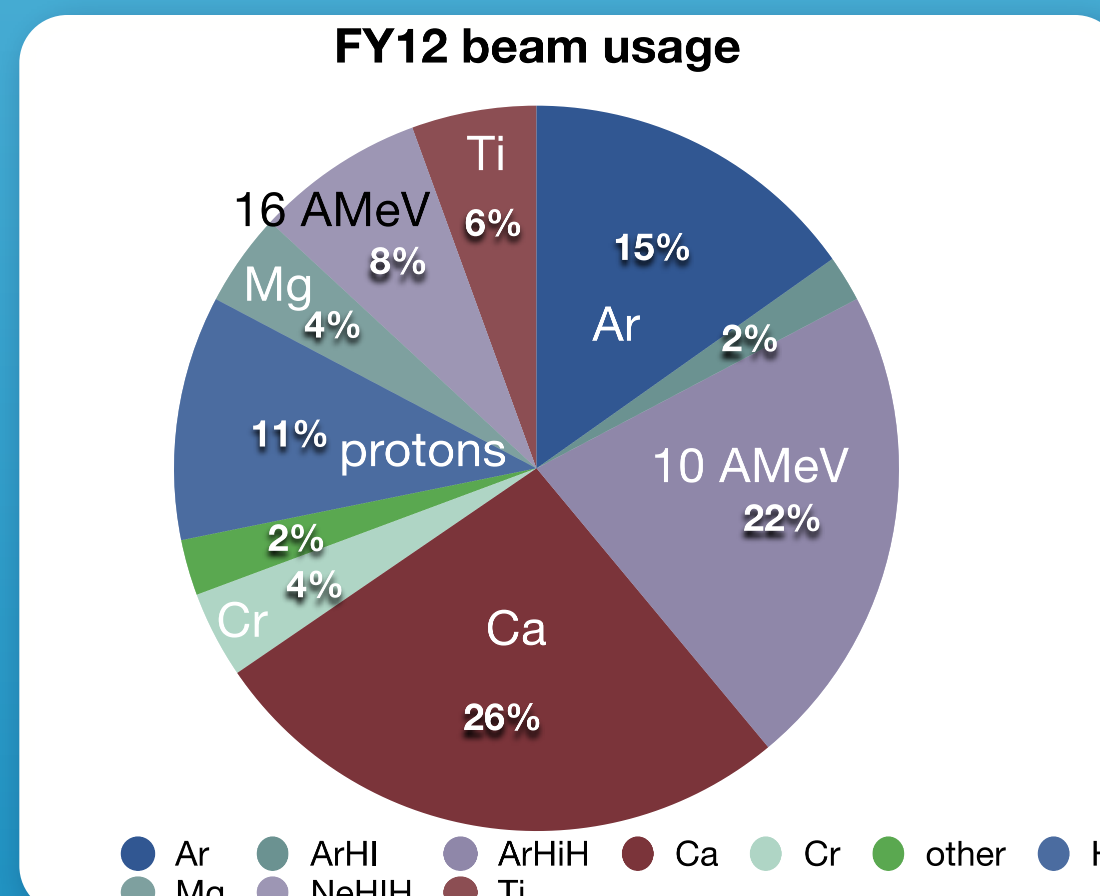
- BASE
- Recharge
- Beam development
- Nuclear Science



5425 hours of 10/4 operation

Availability: 94%

- 46 experiments for BASE (~300 customer visits)
- 9 experiments for NSD: ^{48}Ca for GRETINA@BGS

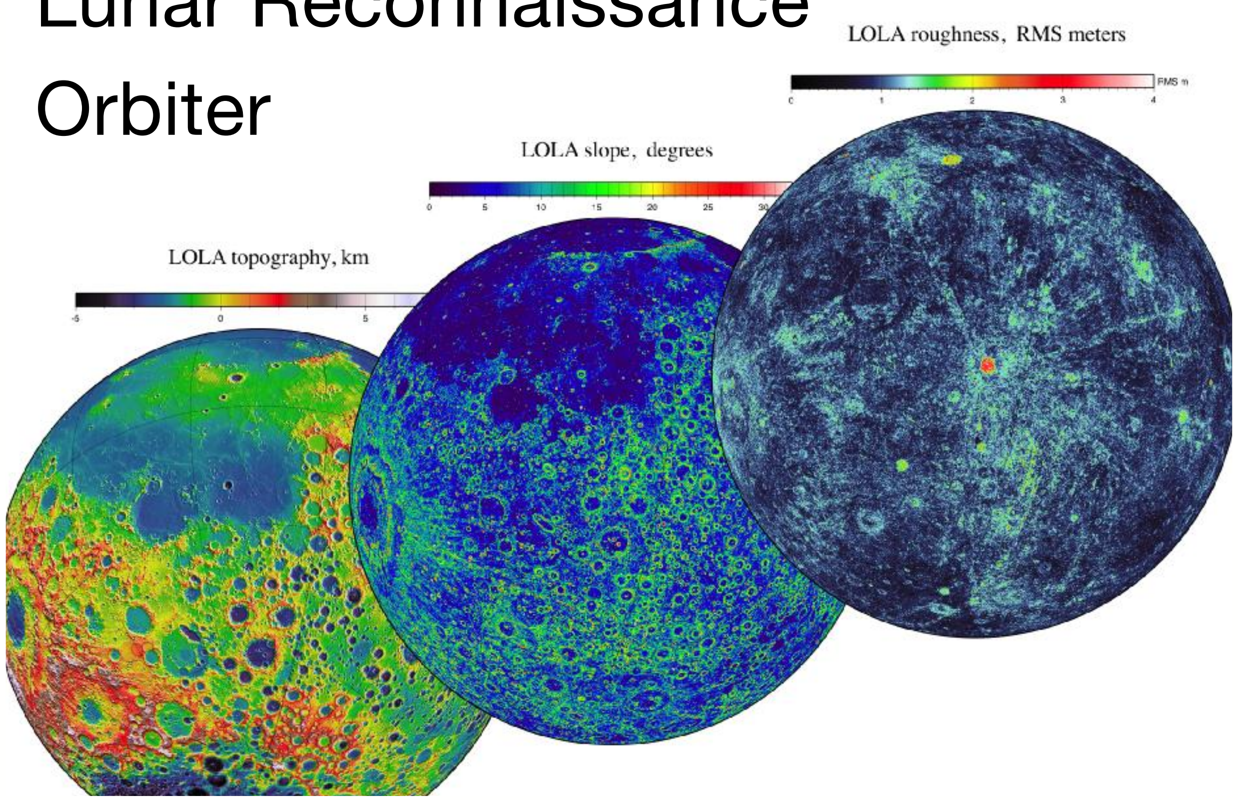


Users

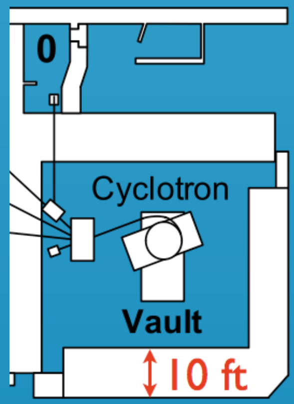
Aerospace Corp.
Aeroflex
Micro-RDC
Honeywell
Microsemi
MIT – Lincoln
Silicon Space Technology
Xilinx
Situs Logic
Ultracomm
Moog, Inc.
International Rectifier
LBNL
LLNL
Sandia National Lab
National Semiconductor
BAE
Cypress Semiconductor
Intersil
Texas Instruments
Space Micro
Zephyr
ITT Exelis
Broadcom
Linear Technology
Georgia Tech
ASIC Advantage
Rochester Inst. of Tech.
NASA Johnson
NASA Goddard
NASA Ames
NASA Jet Propulsion Lab
United Launch Alliance
Northrup Grumman
Vanderbilt U.
Boeing
Ball Aerospace
NRL

Neutron beam

Lunar Reconnaissance Orbiter



- Characterize new neutron scintillator materials for basic and applied research (LLNL)



- Stopped d beams in the vault. Break-up neutrons at zero degrees in to Cave 0.
  - Intensities: 10^6 n/cm^2/sec
  - Energies: 8-30 MeV
  - Beam sweeper
- Use light-ion reactions, ^{7}Li(p,n)^{7}Be and d(d,n)^{3}He, to produce nearly monoenergetic neutrons
- Darren Bleuel's talk Friday

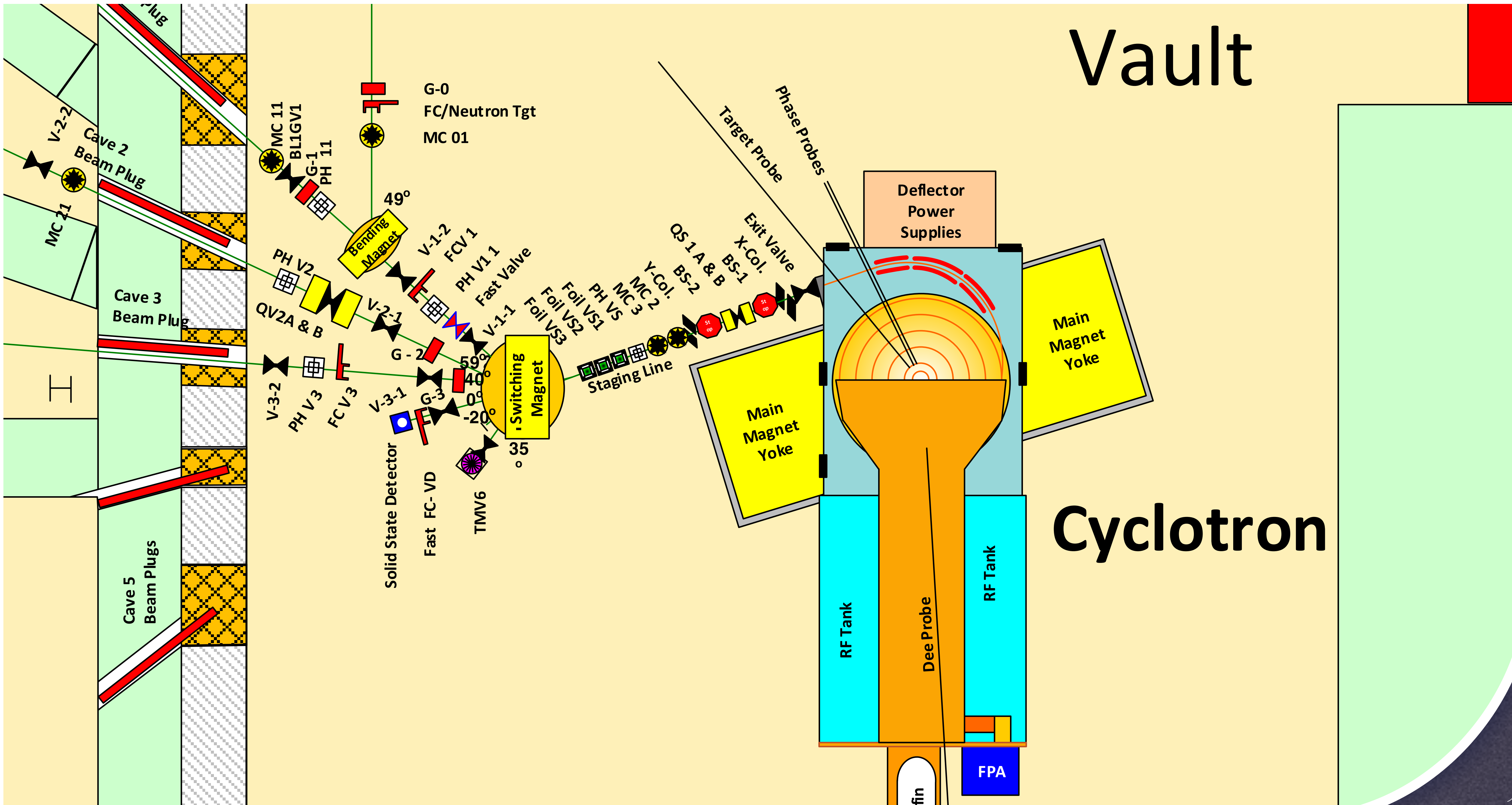
Cyclotron capabilities (now)

- 10’s of microamps of light ions (H, D, He3, alphas)
  - protons: 3-55 MeV
  - deuterons: 2-65 MeV
  - He3: up to 170 MeV
  - alphas: up to 130 MeV
  - neutrons: 8-30 MeV
- Particle microamps of heavy ions (up to 32 MeV/nucleon)

Cyclotron capabilities (future & past)

- Cyclotron started as an internal target machine:
  - Few mA of beam
- If we need to **extract** intense light ion beams: negative ions and stripping

Cyclotron: internal targets



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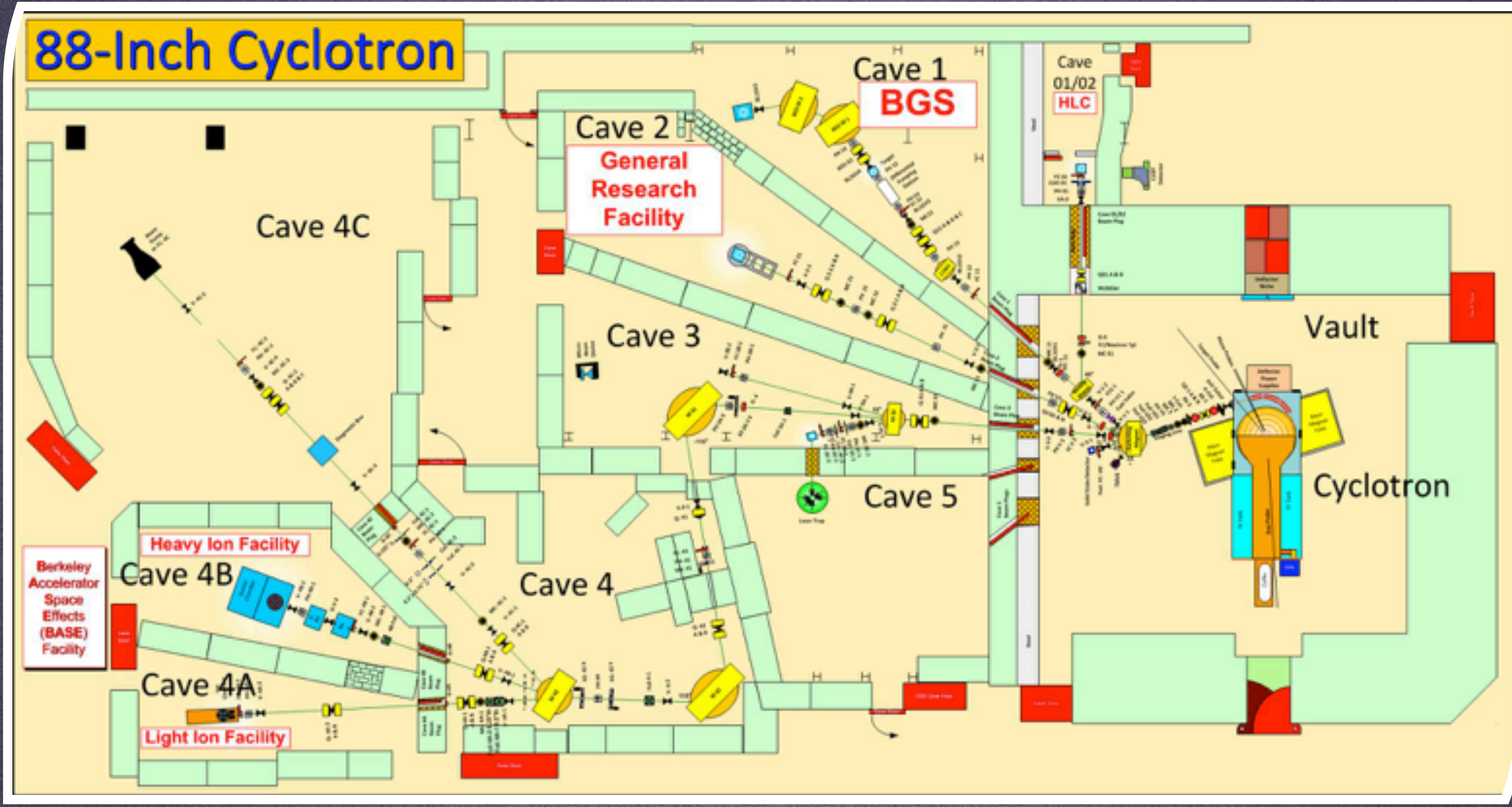
88-Inch Cyclotron
Cave 1
BGS
Cave 01/02
HLC
Cave 2
General Research Facility
Cave 4C
Cave 3
Vault
Cave 5
Cyclotron
Heavy Ion Facility
Berkeley Accelerator Space Effects (BASE) Facility
Cave 4B
Cave 4
Cave 4A
Light Ion Facility