Automating Control of the Beams for the NASA Space Radiation Laboratory (NSRL)

K.A. Brown,

S. Binello, M. Costanzo, T. D'Ottavio,

J. T. Morris, J. Jamilkowski,

S. Nemesure, R. Olsen, C. Theisen

Collider Accelerator Department, BNL

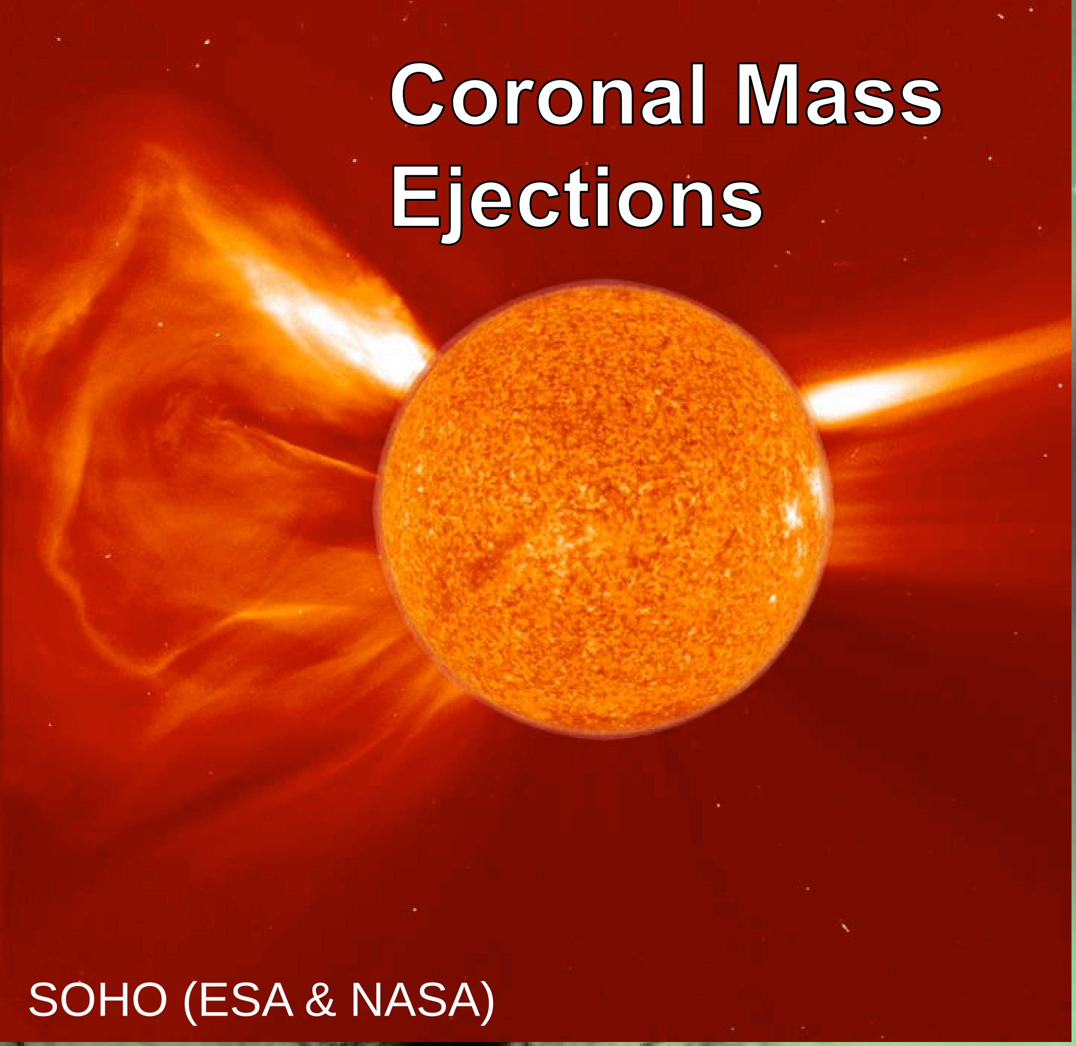
BROOKHAVEN NATIONAL LABORATORY

Outline

- The NASA/BNL Space Radiation Program (2 slides)
- The NSRL Facility (2 slides)
- Operations (2 slides)
- Beam Characteristics (2 slides)
- Uniform Beams (3 slides)
- Solar Particle Simulator (2 slides)
- GCR Simulator (4 slides)
- Summary (2 slides)

SPACE WEATHER

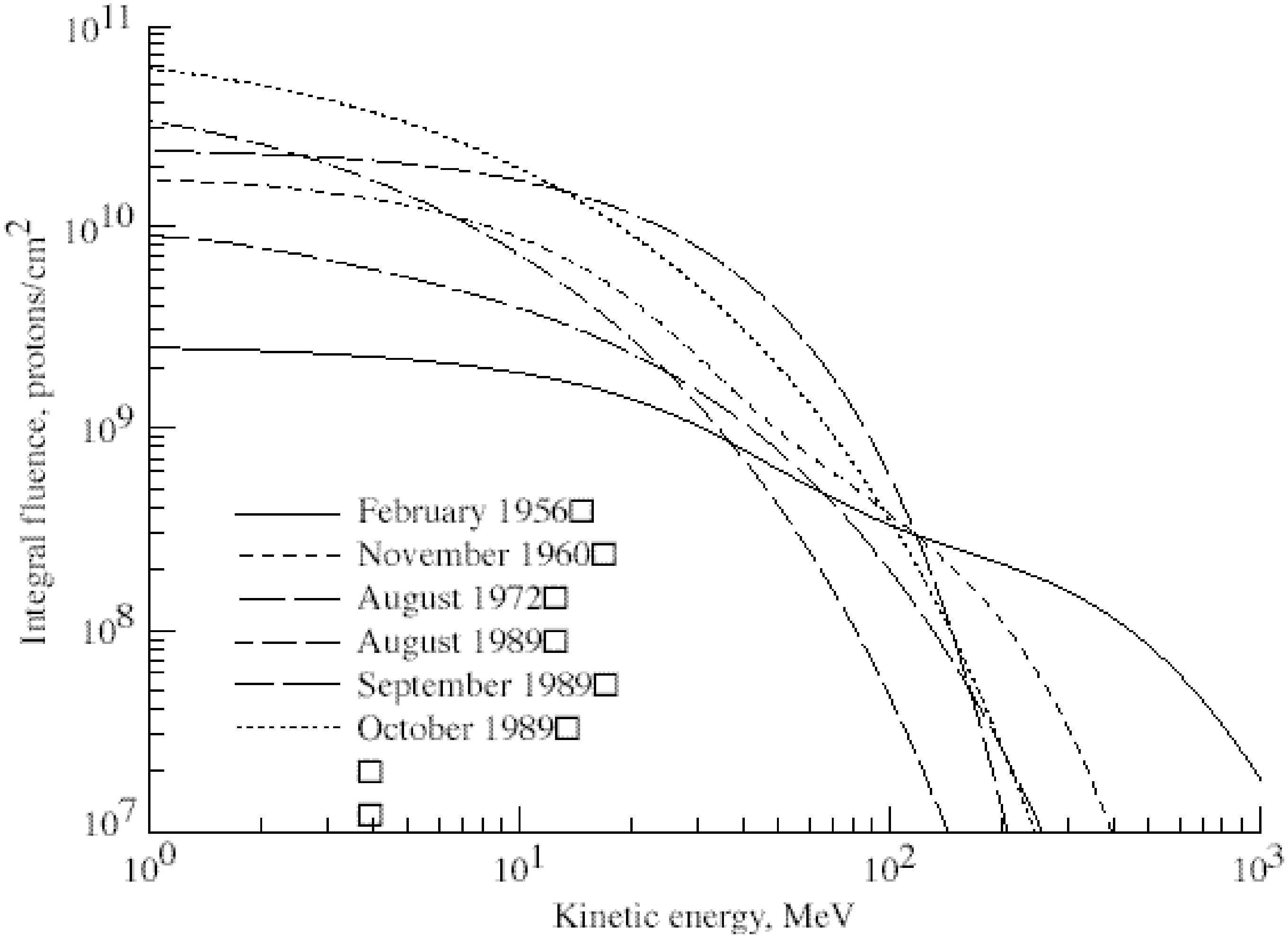
SPACE WEATHER



SOHO (ESA & NASA)

Coronal Mass Ejections

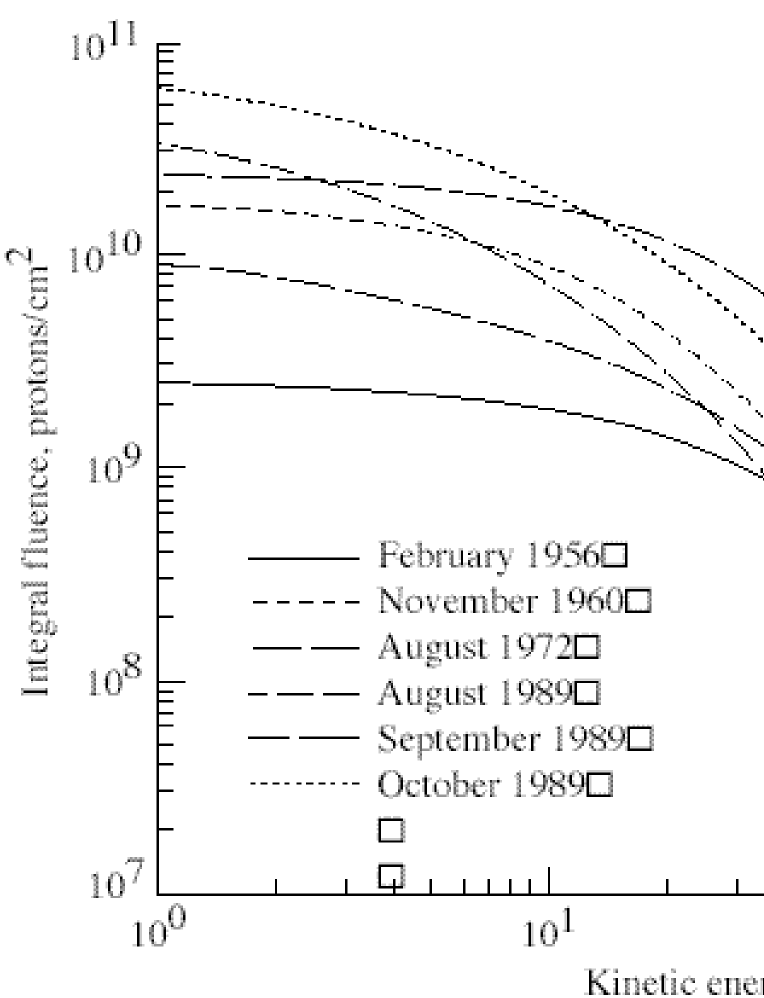
SPACE WEATHER



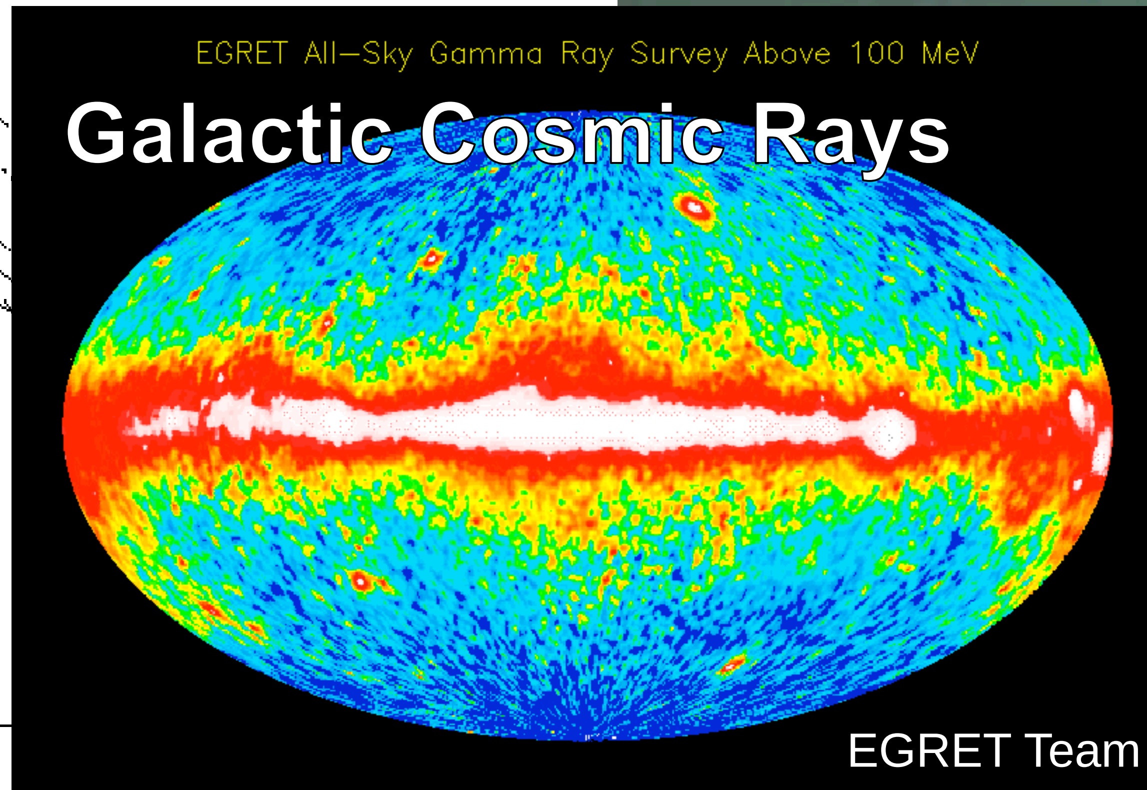
. Large solar proton event integral fluence spectra at 1 AU.

Coronal Mass Ejections

SPACE WEATHER



. Large solar proton event integral fluence spectra at 1 AU.



Galactic Cosmic Rays

EGRET Team

Heavy Ions

Charged

Ionizing Radiation

Outer-Space is full of them

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

Heavy Ions

Charged

Ionizing Radiation

Outer-Space is full of them

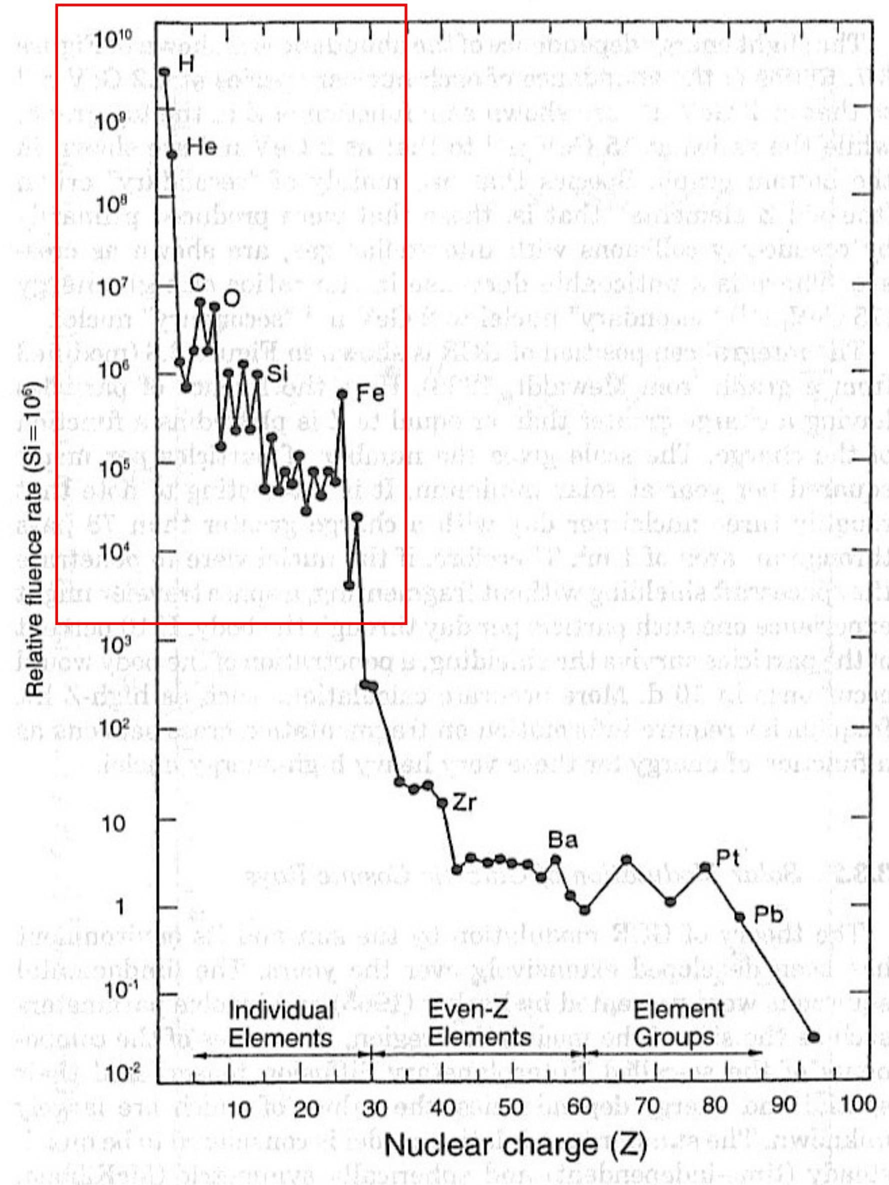


Fig. 3.6. Nuclear composition of GCR (~2 GeV n^{-1}) (Mewaldt, 1988).

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

Heavy Ions

Charged

Ionizing Radiation

Outer-Space is full of them

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

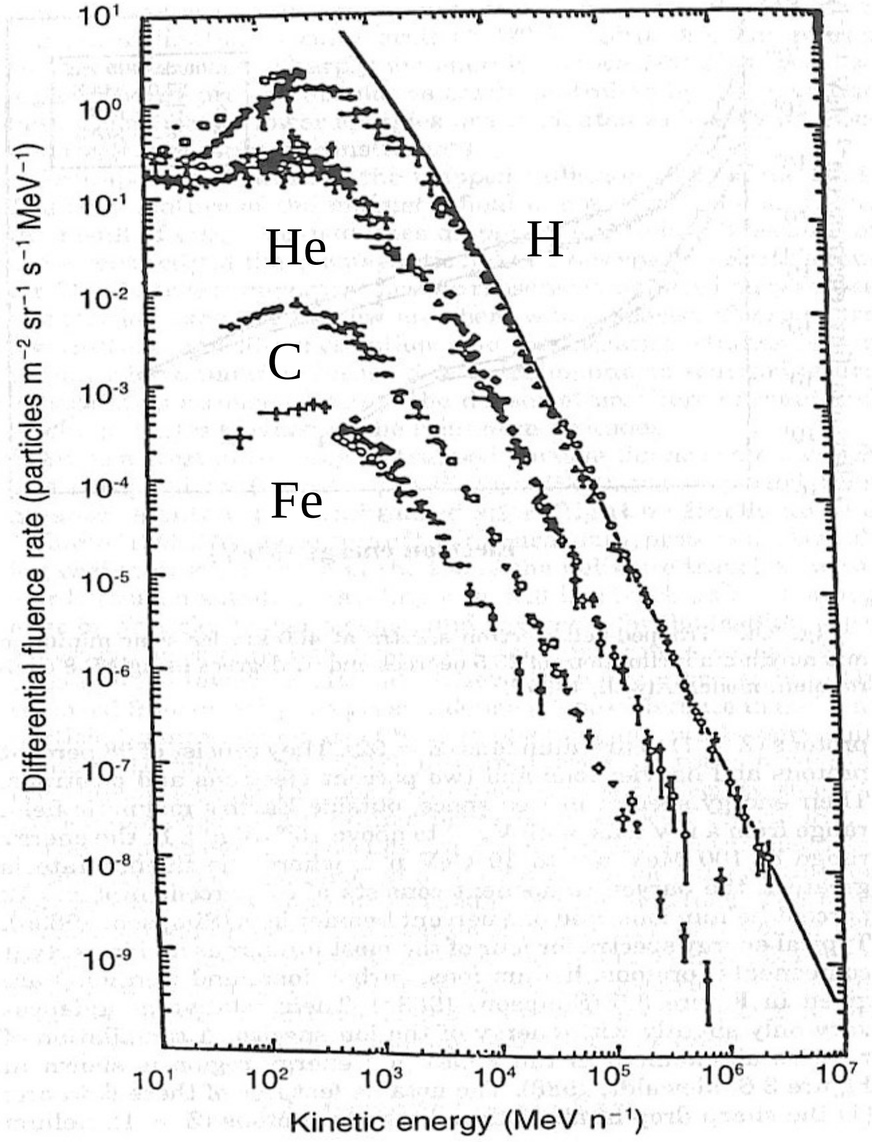


Fig. 3.5. Typical energy spectra for protons, helium ions, carbon ions, and iron ions from "top to bottom," respectively, at solar minimum. The solid line is the local interstellar spectrum (Simpson, 1983a).

Heavy Ions

Charged

Ionizing Radiation

Outer-Space is full of them

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

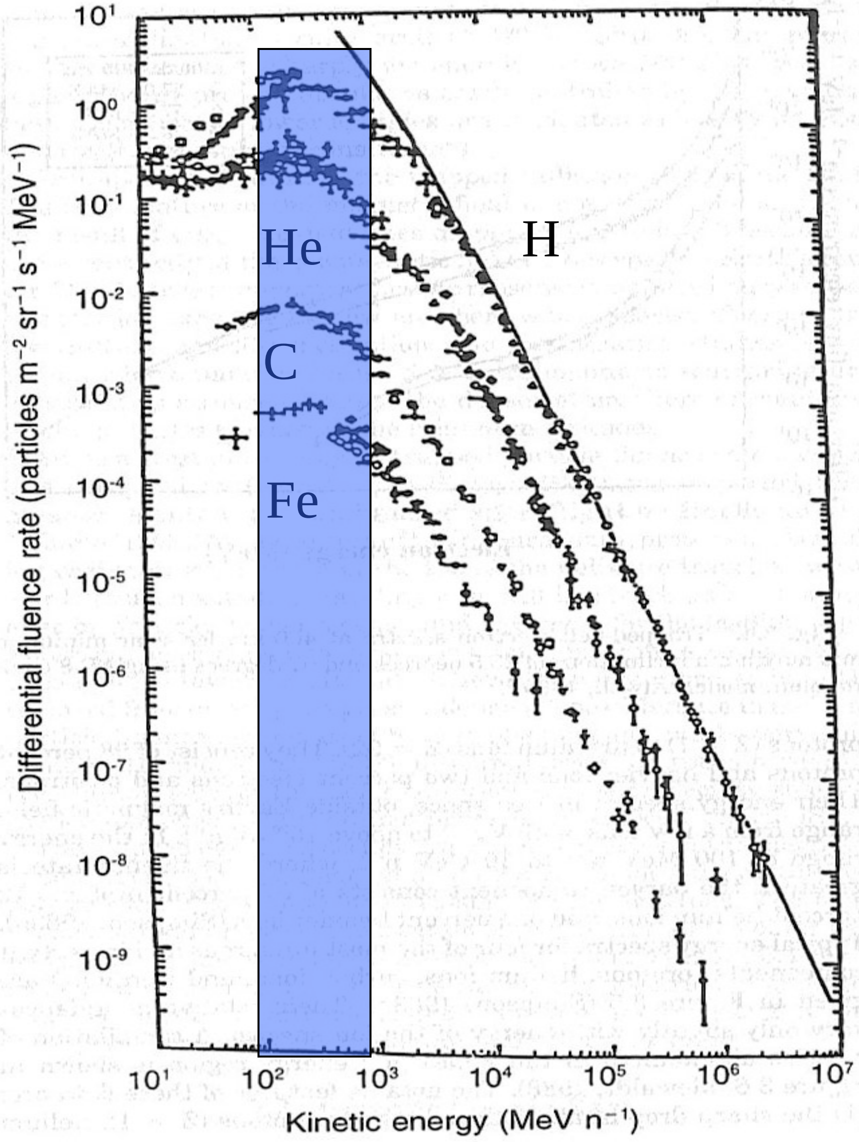


Fig. 3.5. Typical energy spectra for protons, helium ions, carbon ions, and iron ions from "top to bottom," respectively, at solar minimum. The solid line is the local interstellar spectrum (Simpson, 1983a).

Heavy Ions

Charged

Ionizing Radiation

Outer-Space is full of them

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

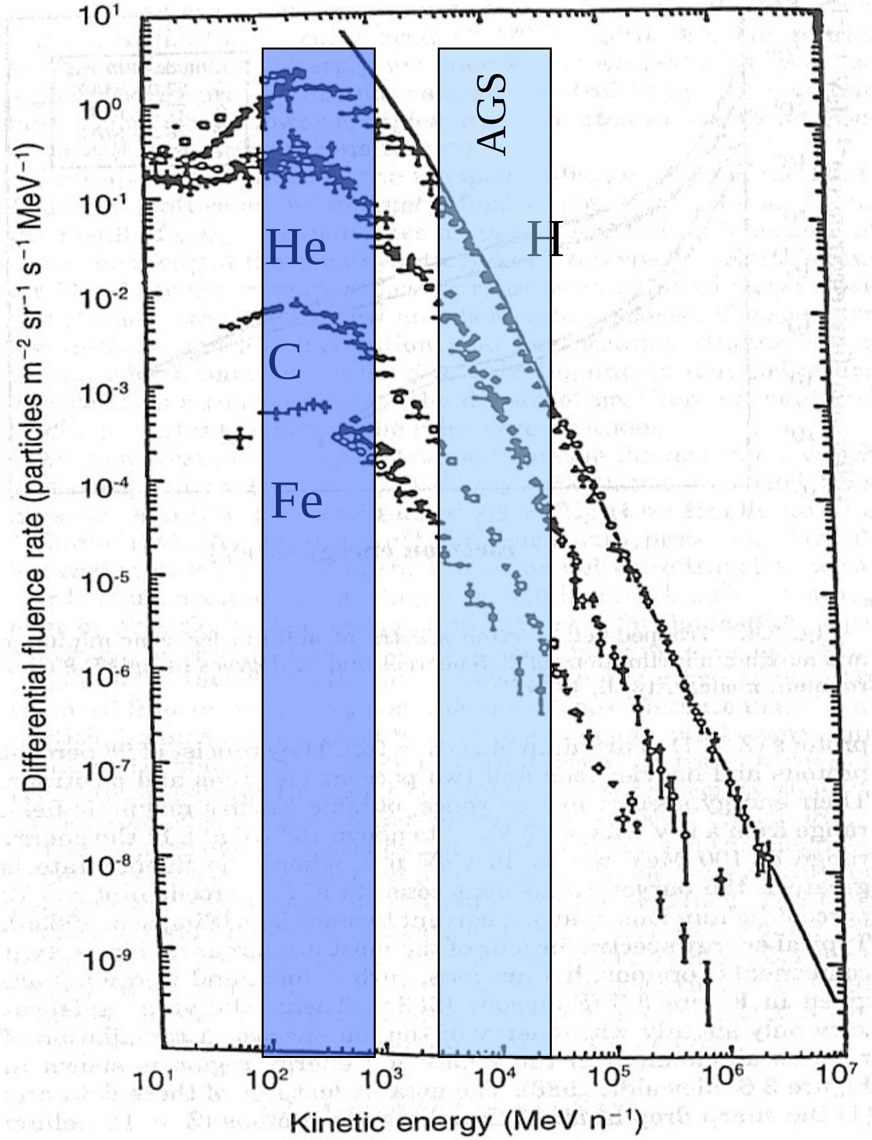
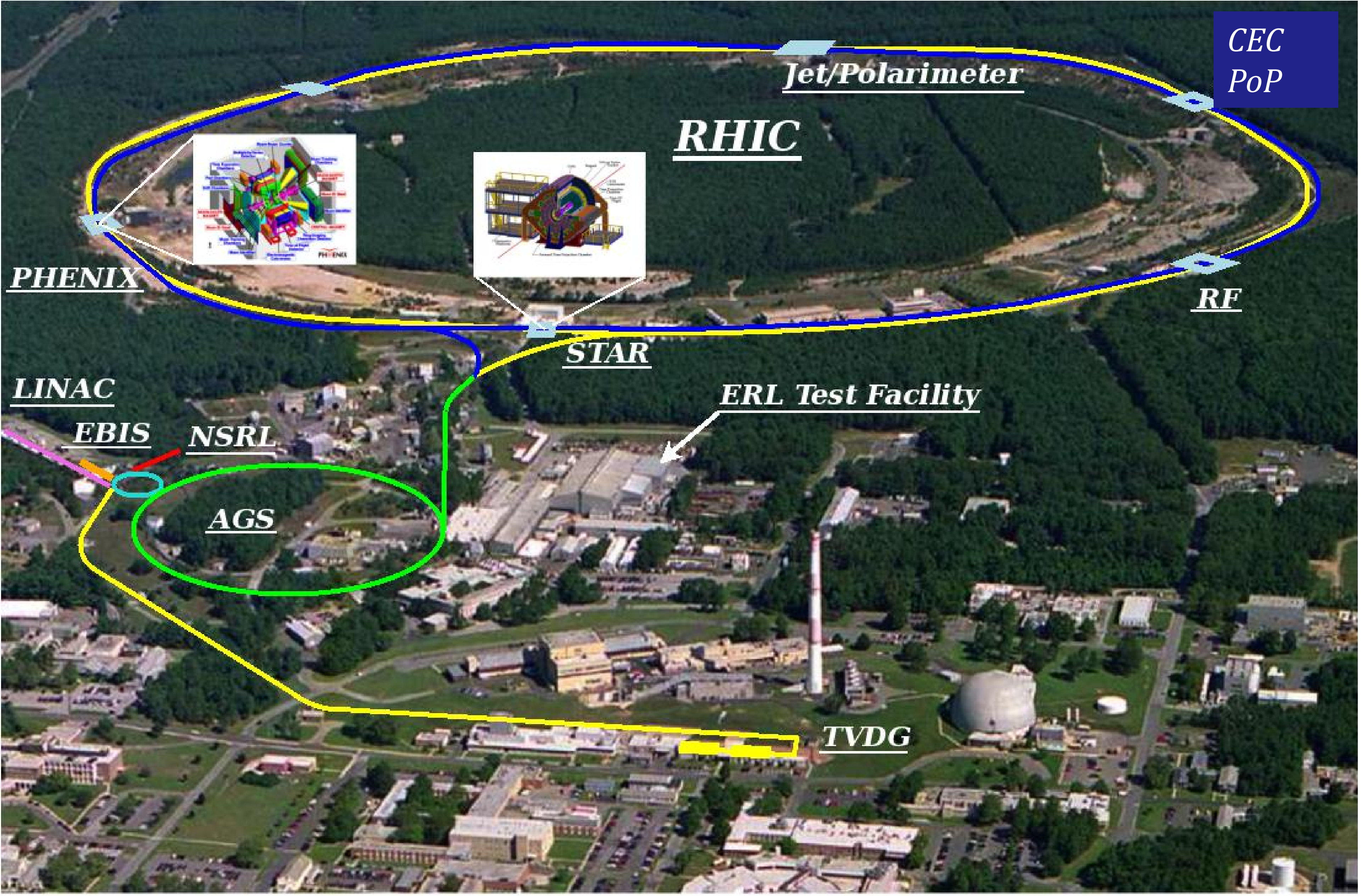
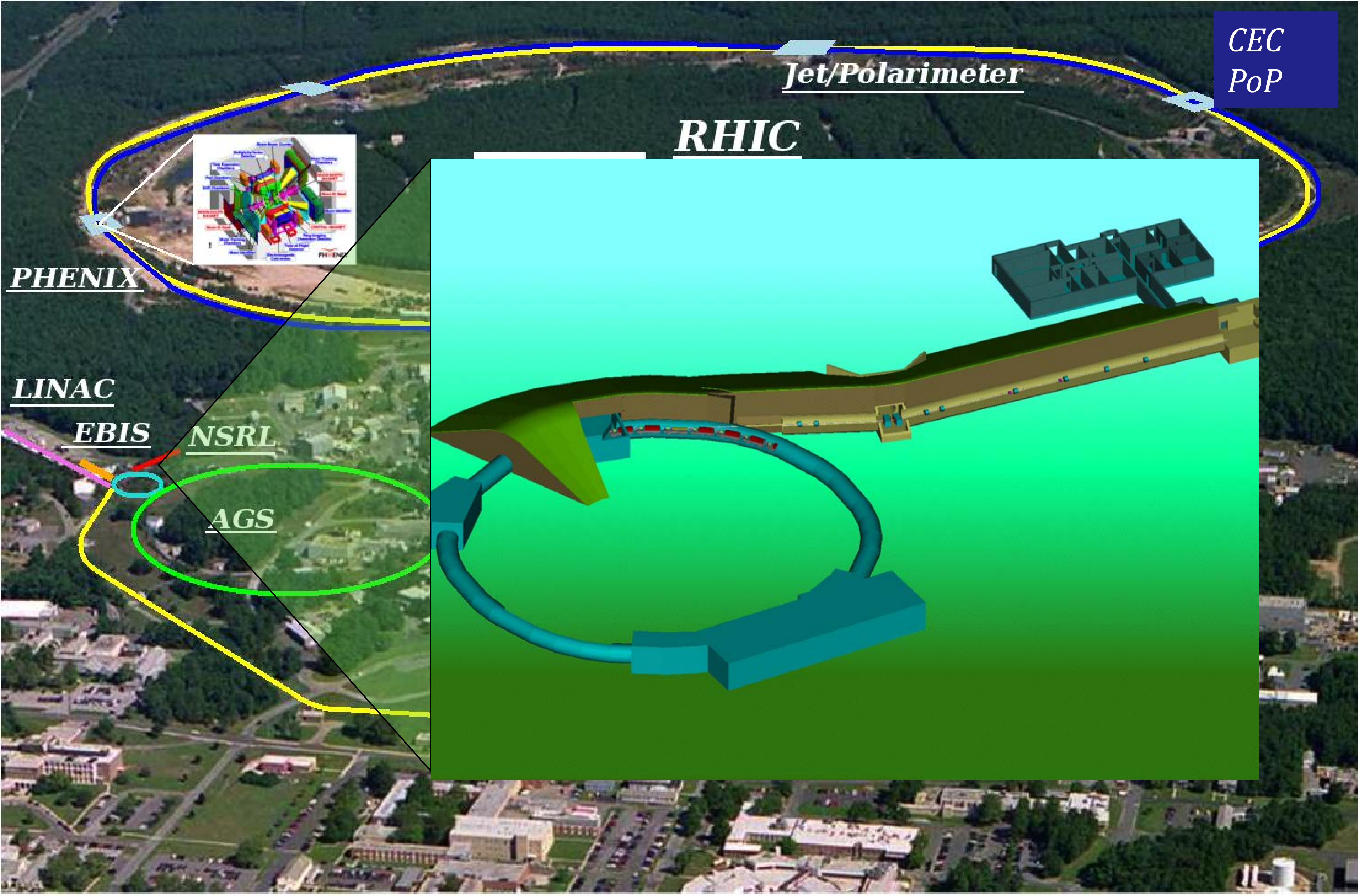


Fig. 3.5. Typical energy spectra for protons, helium ions, carbon ions, and iron ions from "top to bottom," respectively, at solar minimum. The solid line is the local interstellar spectrum (Simpson, 1983a).

Outline

- The NASA/BNL Space Radiation Program (2 slides)
- The NSRL Facility (2 slides)
- Operations (2 slides)
- Beam Characteristics (2 slides)
- Uniform Beams (3 slides)
- Solar Particle Simulator (2 slides)
- GCR Simulator (4 slides)
- Summary (2 slides)


CEC
PoP
Jet/Polarimeter
RHIC
PHENIX
RF
STAR
LINAC
ERL Test Facility
EBIS
NSRL
AGS
TVDG


CEC
PoP
Jet/Polarimeter
RHIC
PHENIX
LINAC
EBIS
NSRL
AGS

NSRL Target Room

BROOKHAVEN
NATIONAL LABORATORY

Outline

The NASA/BNL Space Radiation Program (2 slides)

The NSRL Facility (2 slides)

Operations (2 slides)

Beam Characteristics (2 slides)

Uniform Beams (3 slides)

Solar Particle Simulator (2 slides)

GCR Simulator (4 slides)

Summary (2 slides)

Schedules

8 am 8:59	set-up Protons	22	8 am 8:59	set-up Iron	23	8 am 8:59	BOOSTER WORK		8 am 8:59	set-up Iron	25	8 am 8:59	set-up Oxygen	26	8 am 8:59
9:00 9:59	Nelson A		9:00 9:59	Nelson A		9:00 9:59			9:00 9:59	Aroumougame C		9:00 9:59	Kronenberg C		9:00 9:59
10:00 10:59	Turker A		10:00 10:59	Aroumougame C		10:00 10:59			10:00 10:59			10:00 10:59			10:00 10:59
11:00 11:59			11:00 11:59			11:00 11:59			11:00 11:59	Beam Development Rusek		11:00 11:59	Grabham C		11:00 11:59
12 pm 12:59	Semones P		12 pm 12:59	Turker A		12 pm 12:59	set-up Iron	24	12 pm 12:59			12 pm 12:59			12 pm 12:59
1:00 1:59			1:00 1:59			1:00 1:59	Rabin A		1:00 1:59			1:00 1:59	Rabin A		1:00 1:59
2:00 2:59			2:00 2:59	Semones P		2:00 2:59			2:00 2:59			2:00 2:59			2:00 2:59
3:00 3:59			3:00 3:59			3:00 3:59	Zhu C & A		3:00 3:59	wrap-up	24	3:00 3:59	Limoli C & A		3:00 3:59
4:00 4:59	wrap-up	21	4:00 4:59			4:00 4:59			4:00 4:59			4:00 4:59			4:00 4:59
5:00 6 pm			5:00 6 pm			5:00 5:59	wrap-up	23	5:00 6 pm			5:00 5:59	Wilson C		5:00 5:59
			6:00 6:59			6:00						6:00			6:00 6:59
			7:00 7:59			7:00						7:00			7:00 8 pm
			8:00 8:59			8:00									
			9:00 9:59			9:00									
			10:00 11 pm	wrap-up	22	10:00									

Short experiments with many different beam requirements.

1. Intensities from as low as a few hundred ions/pulse to maximum deliverable.
2. Each experiment requires different beam sizes/characteristics.
3. Each experiment may require different beam energies.

BROOKHAVEN NATIONAL LABORATORY

Electron Beam Ion Source (EBIS)

The source of heavy ions for all NSRL and RHIC programs.

All ion species including noble gas ions (NSRL), uranium (RHIC) and polarized He^3 (eRHIC) (~ 1-2 □10^{11} charges/bunch with $\varepsilon_{N,rms}$ = 1-2 μm)

Operated reliably for NSRL with He^{+}, He^{2+}, Ne^{5+}, Ne^{8+}, Ar^{11+}, Ti^{18+}, Fe^{20+}

Provided *Au* and *U* for RHIC in 2012

For Controls:

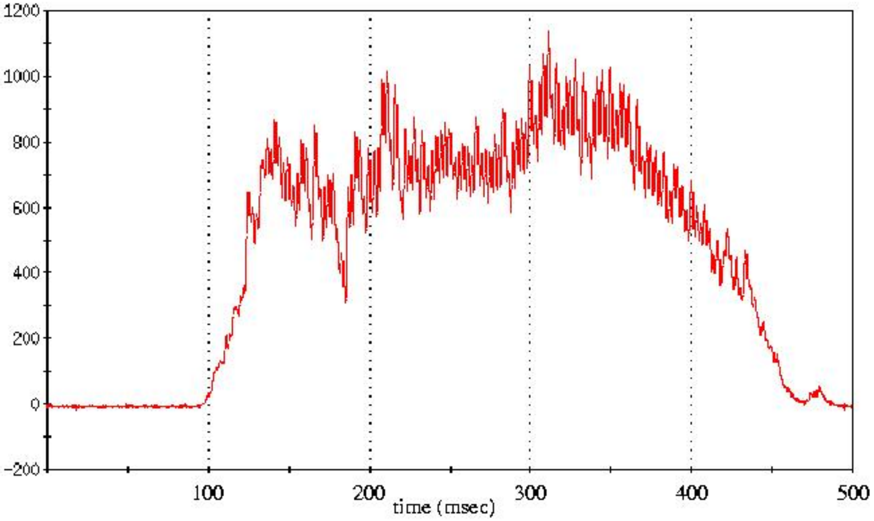
- 5 Hz PPM Operation (Capability to switch ion species at 5 Hz)
- Standard hardware interfaces
- New applications for project specific controls

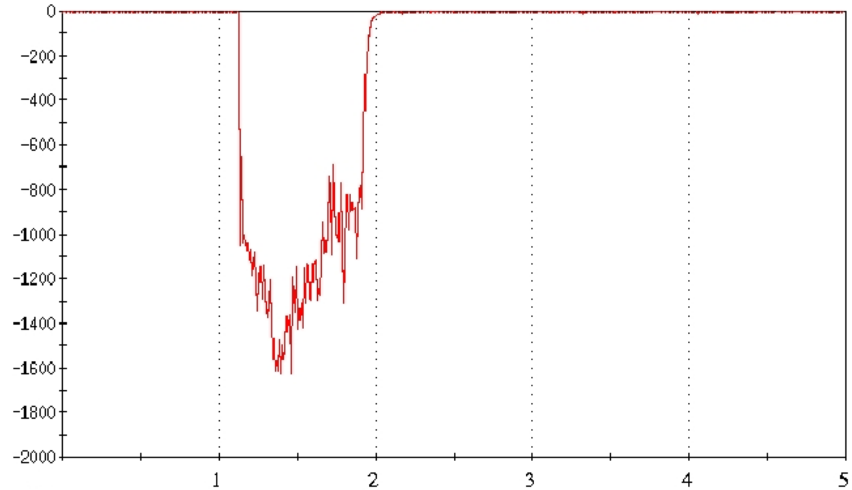
Operations

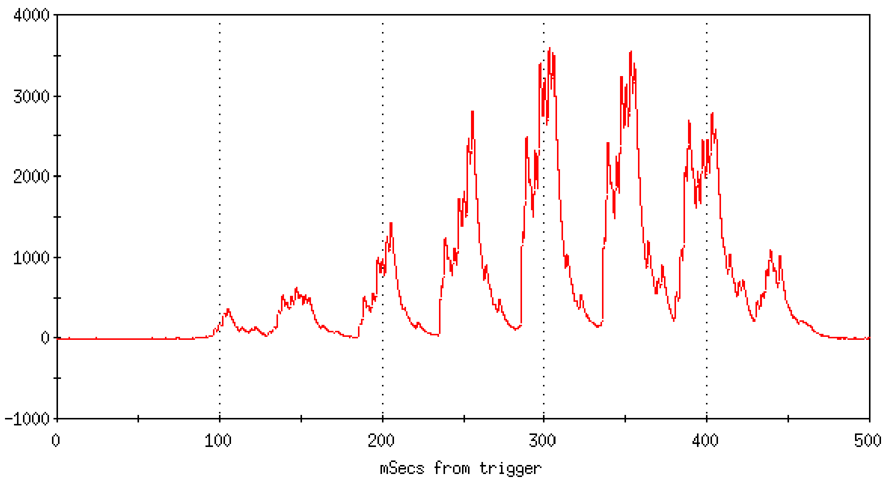
A Sampling of Beams Delivered

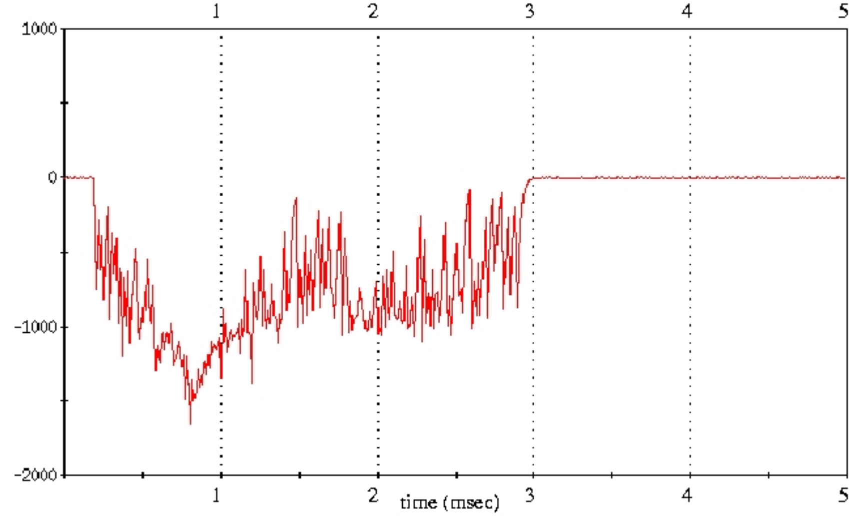
Ion Species	Energy (MeV/nucleon)	Max. Intensity (ions/spill)
p	50 - 2500	6.4×10^{11}
C-12	65 - 1000	1.2×10^{10}
O-16	50 - 1000	4.0×10^{9}
Si-28	93 - 1000	3.0×10^{9}
Cl-35	500 - 1000	2.0×10^{9}
Ti-48	150 - 1100	8.0×10^{8}
Fe-56	50 - 1000	2.0×10^{9}
Au-197	76 – 165	1.0×10^{7}

Different kinds of Beam Spills Delivered





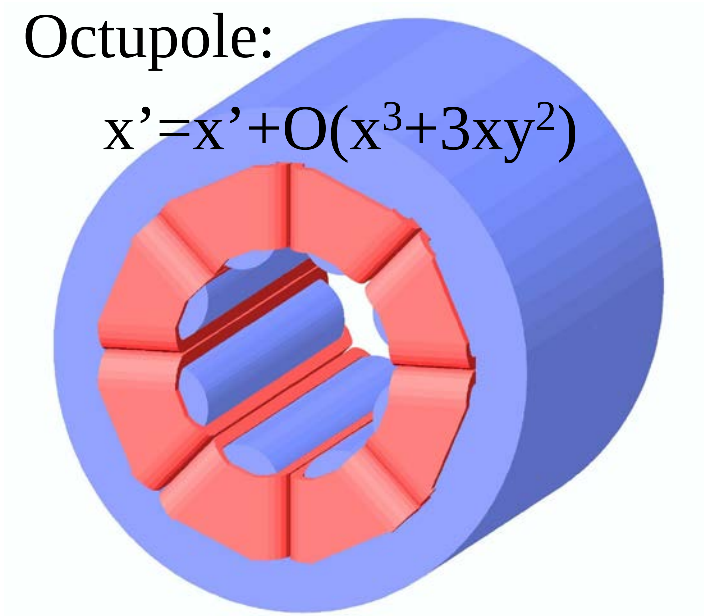


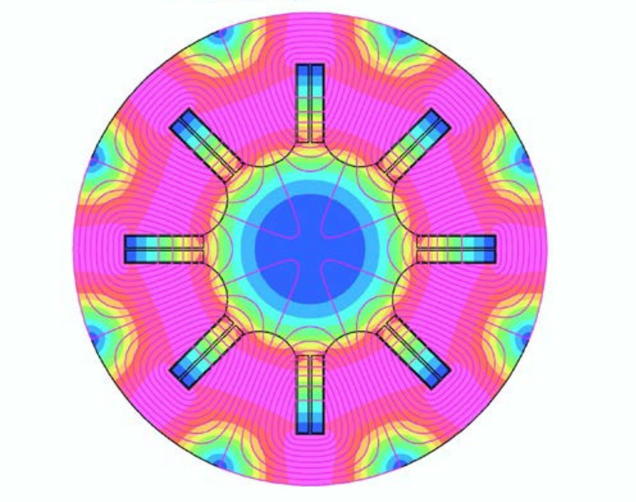


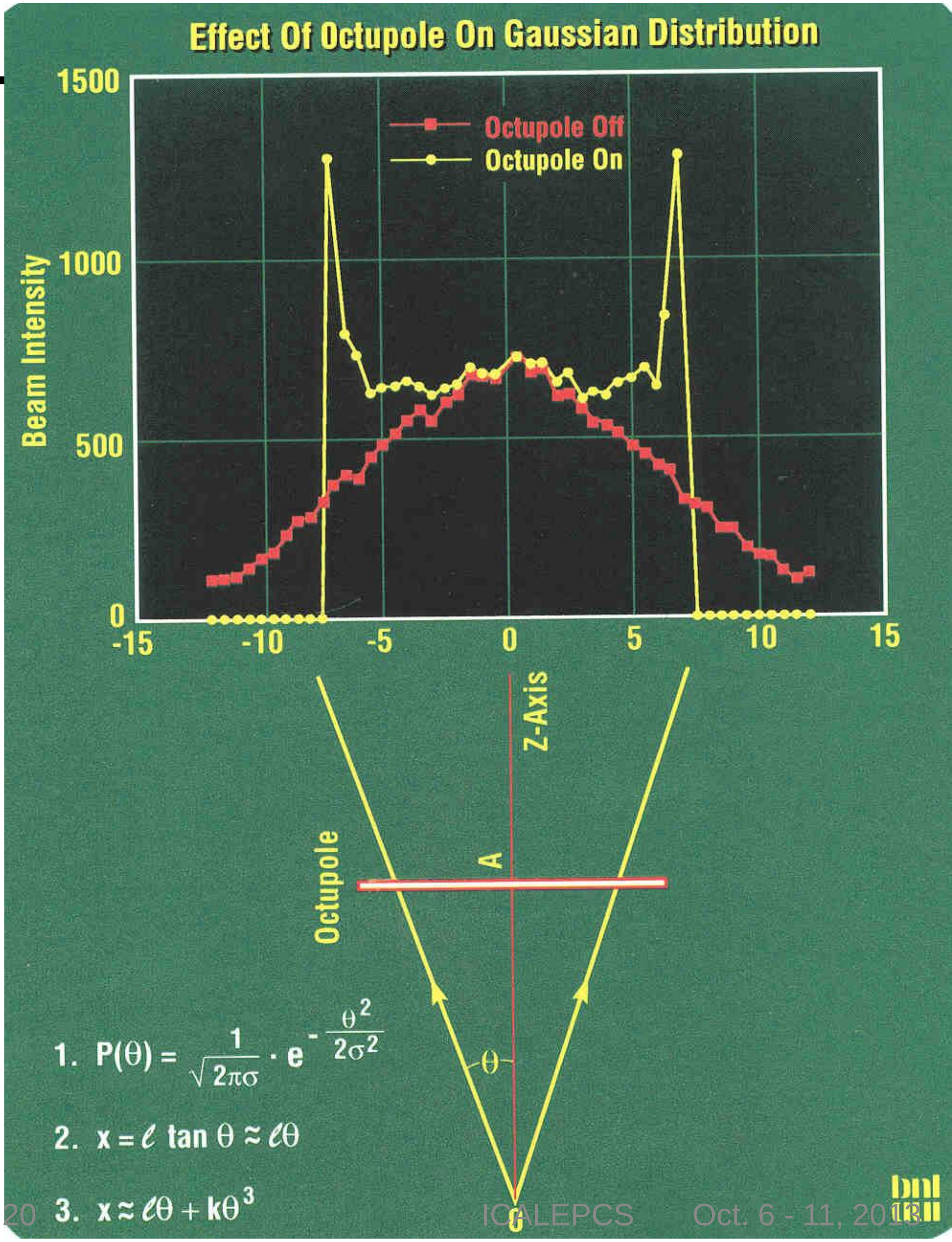
Uniform Beams

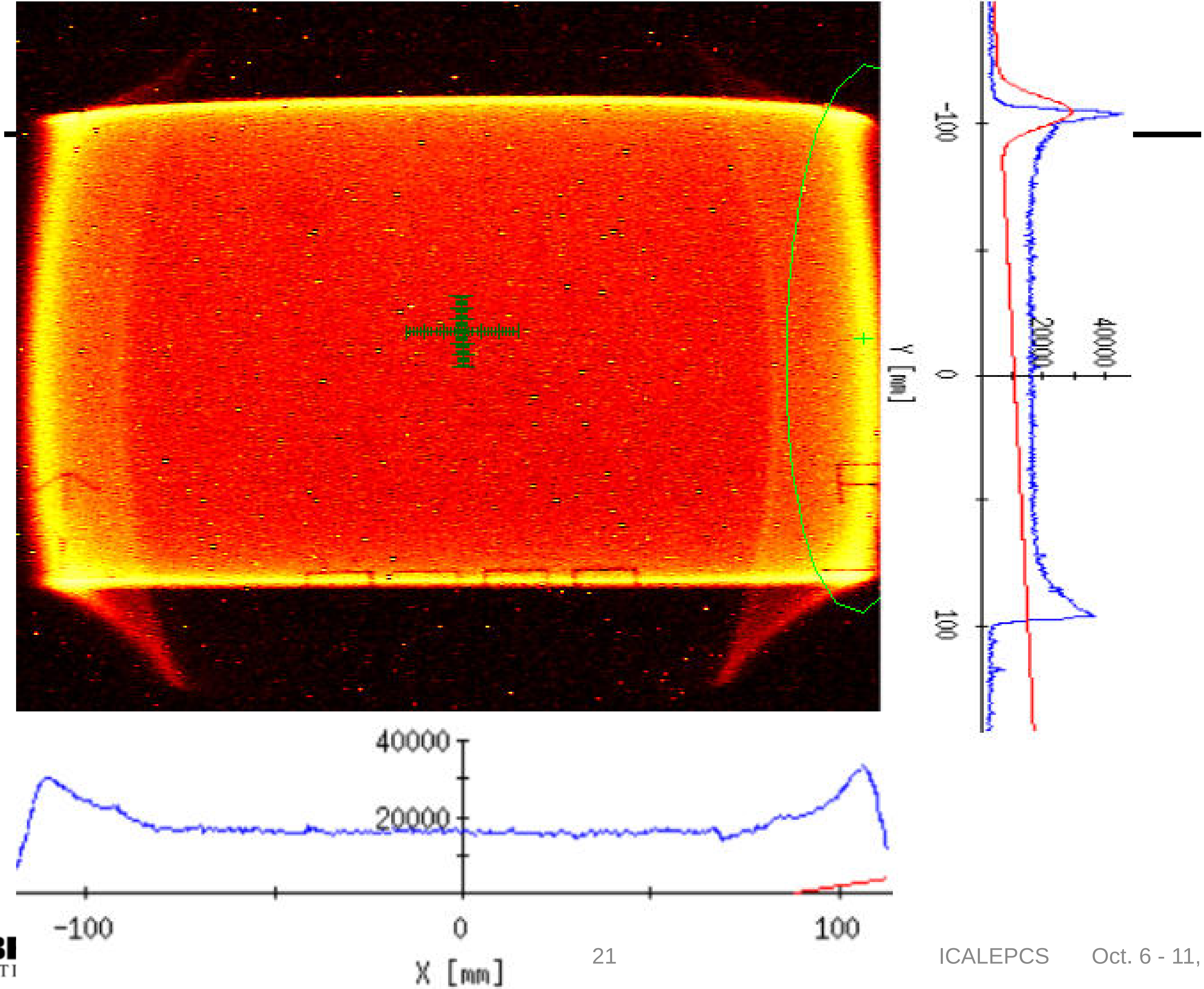
Octupole:

$$x' = x' + O(x^3 + 3xy^2)$$

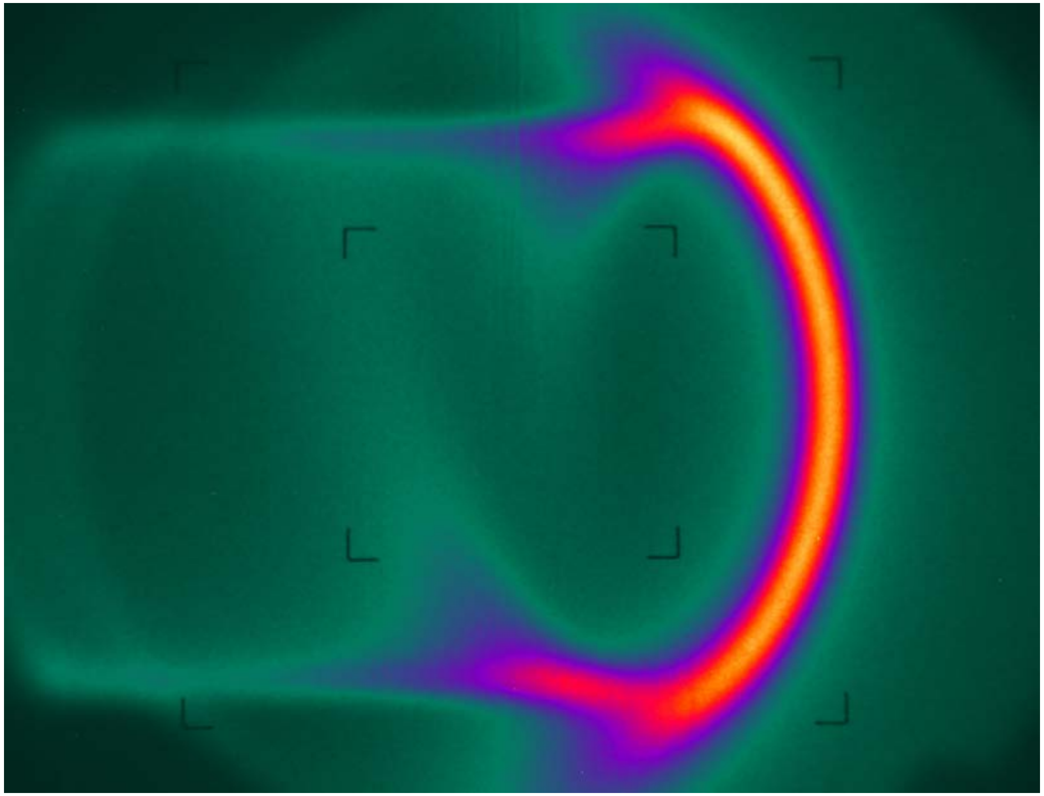


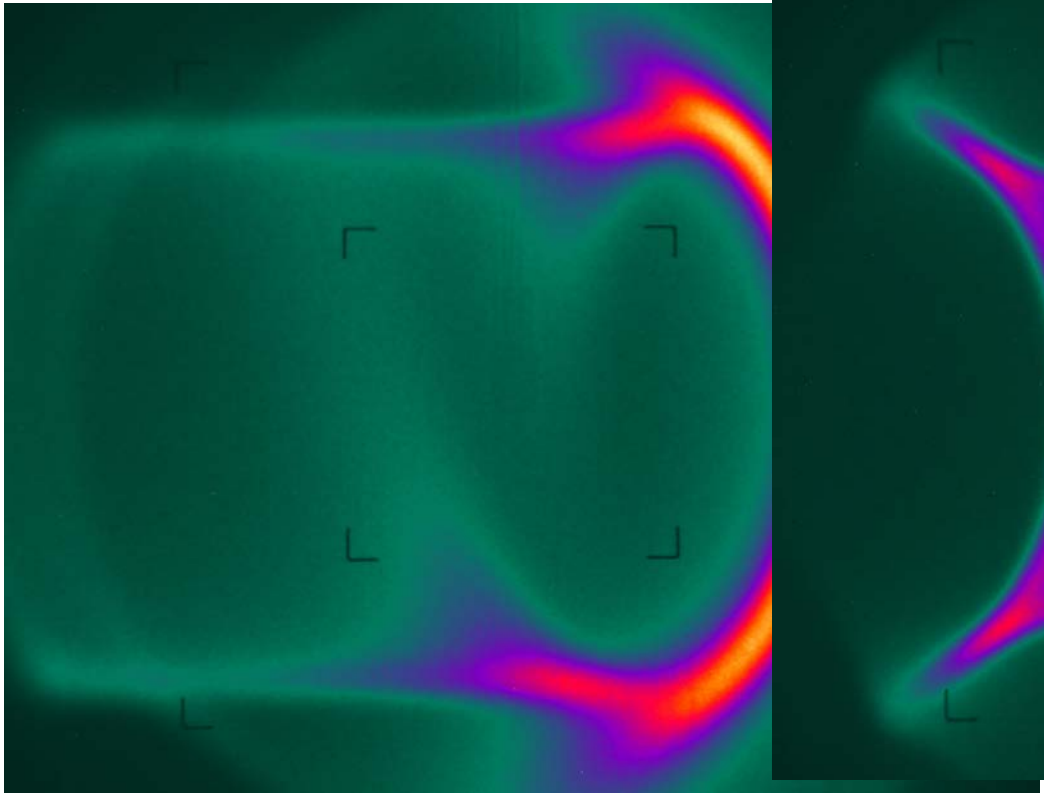


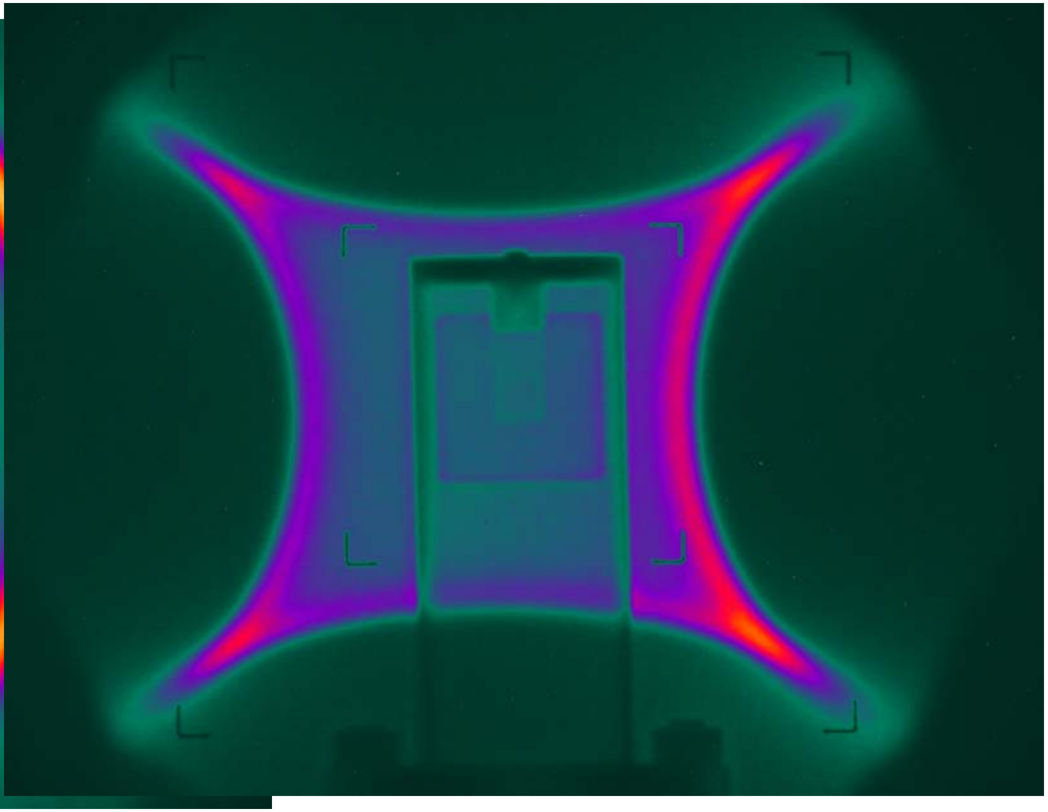


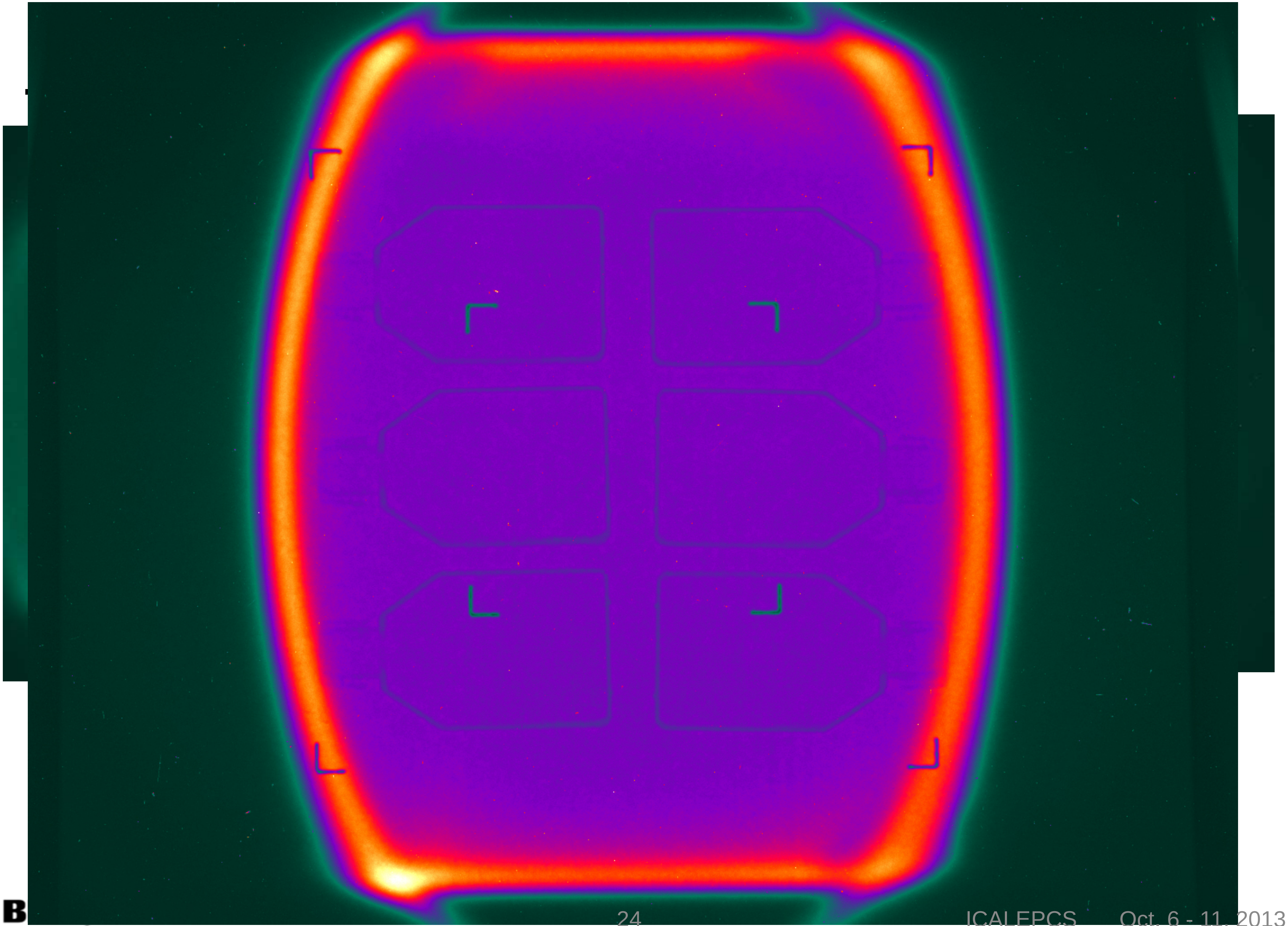


-100
0
100
Y [mm]
20000
40000
X [mm]









Outline

The NASA/BNL Space Radiation Program (2 slides)

The NSRL Facility (2 slides)

Operations (2 slides)

Beam Characteristics (2 slides)

Uniform Beams (3 slides)

Solar Particle Simulator (2 slides)

GCR Simulator (4 slides)

Summary (2 slides)

SPE: What happens?

Goal: A single target is to get irradiated with a single beam (i.e., protons) over many energies, to simulate exposure to a Solar particle event.

- The dosimetry system determines the dose delivered to the target for each energy and sends a trigger to inhibit the beam when the desired dose is reached
- With beam disabled, the accelerator state is automatically modified to go to the next energy
  - Booster main magnet cycle is scaled to next energy
  - Beam line magnets are scaled
  - Booster extraction is scaled for next energy
  - Note: Scaling is not just simple linear factors – saturation, hysteresis, etc.
- Beam is re-enabled to continue the exposure

- In practice, energy setups are created and saved in advance and the system just loads a saved setup to switch energy. This saves time and is more reliable and reproducible

SPE: Tools developed.

- Tape (sequencing) system used for RHIC (event driven system for injecting, initiating ramping, and setting RHIC store conditions) was modified to work with the Booster systems
- Tape system initiates Booster Main Magnet scaling, using known model of Booster main magnet systems (to get correct current and voltage references).
- Booster optics controls were modified to allow automatic scaling, to keep betatron tunes constant when the Main Magnet field was scaled.
- Tool was developed to automatically scale the extraction and beam line magnets.
- Tape sequences were written

- While we did plan on building a higher level interface – it wasn't needed.
  - Tape is able to run event driven
  - Re-enabling beam: desire from operations was to keep this part manual.

GCR: What is supposed to happen?

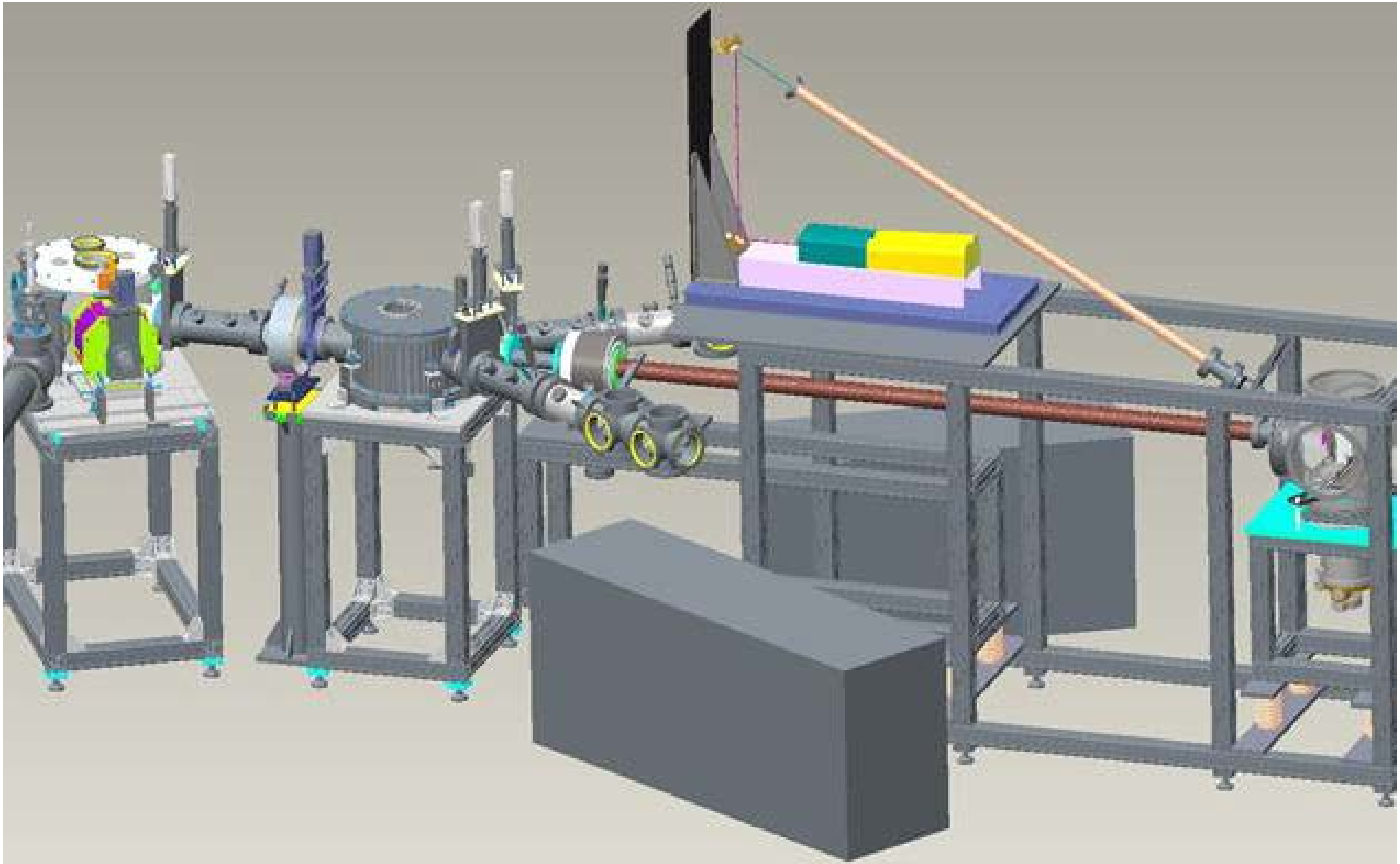
Goal: A single target is to get irradiated with *multiple* beams (i.e., protons, Fe, C, O, Si, etc) over many energies, to simulate exposure to a Galactic Cosmic Ray event.

- Works in the same manner as the SPE simulator, except now a new ion is selected from EBIS
  - Need to change EBIS automatically for new ion species
  - Need to scale Booster injection
  - New RF parameters
  - Keep orbit corrected for new ion species (different beam rigidity during the acceleration ramp)
  - Dosimetry system (which measures delivered dose), needs to calculate dose correctly for new species

GCR: What's needed?

- **EBIS Laser Ion Source**
  - New project, needs "standard" controls
  - Extending existing EBIS applications to include Laser Ion Source
  - Laser target motion control – constantly/slowly moving to keep fresh spot
  - Laser profile and power monitoring
- **Tools to properly adjust EBIS parameters for new species selected**
  - Timing changes mostly
  - EBIS RF parameters for new ions species
- **Tools to properly adjust Booster Injection – fast and reliably**
  - Beam Velocities are always the same – scaling for changes in Rigidity
  - New Booster (all digital) LLRF – greater flexibility and controllability
  - Feedback/feed-forward systems to get beam injected into the correct field
  - Automating Booster configuration parameter changes
  - Automatically change species specific calibrations (e.g., beam current)

Laser Ion Source



Features of the Laser Ion Source

- Many targets are contained within the source enclosure = multiple ions selection from a single source
- Translation table allows selecting new targets (new ion species), or a clean area on an existing target.
- Switching time is limited by translation table
  - {investigating switching by moving the laser pulse (i.e., mirror rotation)}
- Laser stability is very important – makes for very tight timing constraints.

- How it works:
  - Laser produces an ablation plasma from surface of target
  - Plasma properties – charge states, current and ion energies – depend on laser power density.
  - 1+ charge ions are selected, accelerated, and transported to EBIS solenoid.

Outline

The NASA/BNL Space Radiation Program (2 slides)

The NSRL Facility (2 slides)

Operations (2 slides)

Beam Characteristics (2 slides)

Uniform Beams (3 slides)

Solar Particle Simulator (2 slides)

GCR Simulator (4 slides)

Summary (2 slides)

NASA's Summary

NSRL capabilities need to evolve from early work on track segment irradiations for a few select HZE nuclei and protons towards validation and counter-measure design studies with realistic SPE and GCR simulations

Challenges include

- Better understanding of temporal dependence of biological models for extended duration or fractionated exposures
- Mixed-field design using energy switching, multiple ion sources, and complex degrader (shielding) configurations
- Dosimetry needs for mixed fields including secondary neutrons for a Mars surface simulation

NASA expects to utilize NSRL beyond original 15-to-20 year plan, which may require unforeseen upgrades and replacements to facility over its lifetime

Future Capabilities

Laser Ion Source will provide

•Multiple ions from one source

•“Fast” automatic switching of ions delivered to NSRL

GCR Simulator (Mixed field at mixed energies)

- Multiple ions on single target exposure
- Exposures over long periods (single target exposed to multiple ions/energies over many hours).

Thank You !

Backup Slides

NSRL's Capabilities

1. Beam energies from 0.05 to 1 GeV/n with any ion that can be produced at EBIS, protons from the LINAC.
2. Lowest intensities operated ~10^2 ions/cm^2/cycle
3. Smallest beams around 1 cm, smaller possible (not uniform, Gaussian). Largest beams around 20x20 cm^2 uniform. Work is ongoing to make even larger uniform beams.
4. Fast extracted & slow extracted beams, with very short to very long beam spills.
5. Mixed field of protons and ions on a single target
6. Solar particle simulator
    1. Large range of ion energies over single irradiation
    2. Fast, automated energy changes

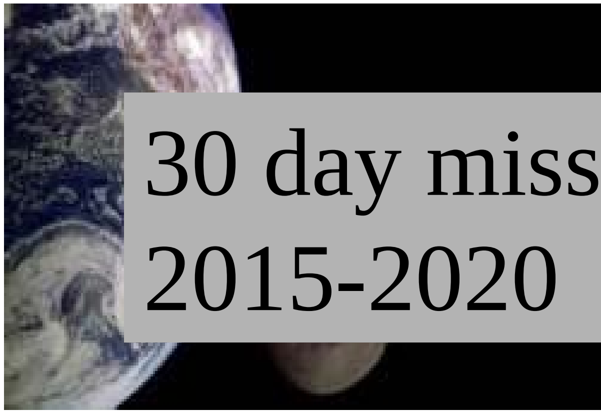
The NASA Program

- Solar particle event simulation
  - Major peak of SPE's is over a 5-15 hour window
  - Dose-rates ~1-100 rad/hr
  - Mixed-energies corresponding to primary spectrum and slowing down spectrum in tissues
    - Small secondary neutron and recoil ion component
- Dose-rate from GCR
- Mixed- Z and E exposures
  - Each shielding configuration of spacecraft leads to a varying Z and E composition.
  - There is a need to use the EBIS facility to define a "GCR simulation field representative of Energy Deposited and Z composition of GCR
  - Several "GCR reference fields" will be needed:
    - Earth-Mars transit field
    - Mars surface representative field
  - Mixed fields must be reproducible

Human Environments in Space

Present

Future

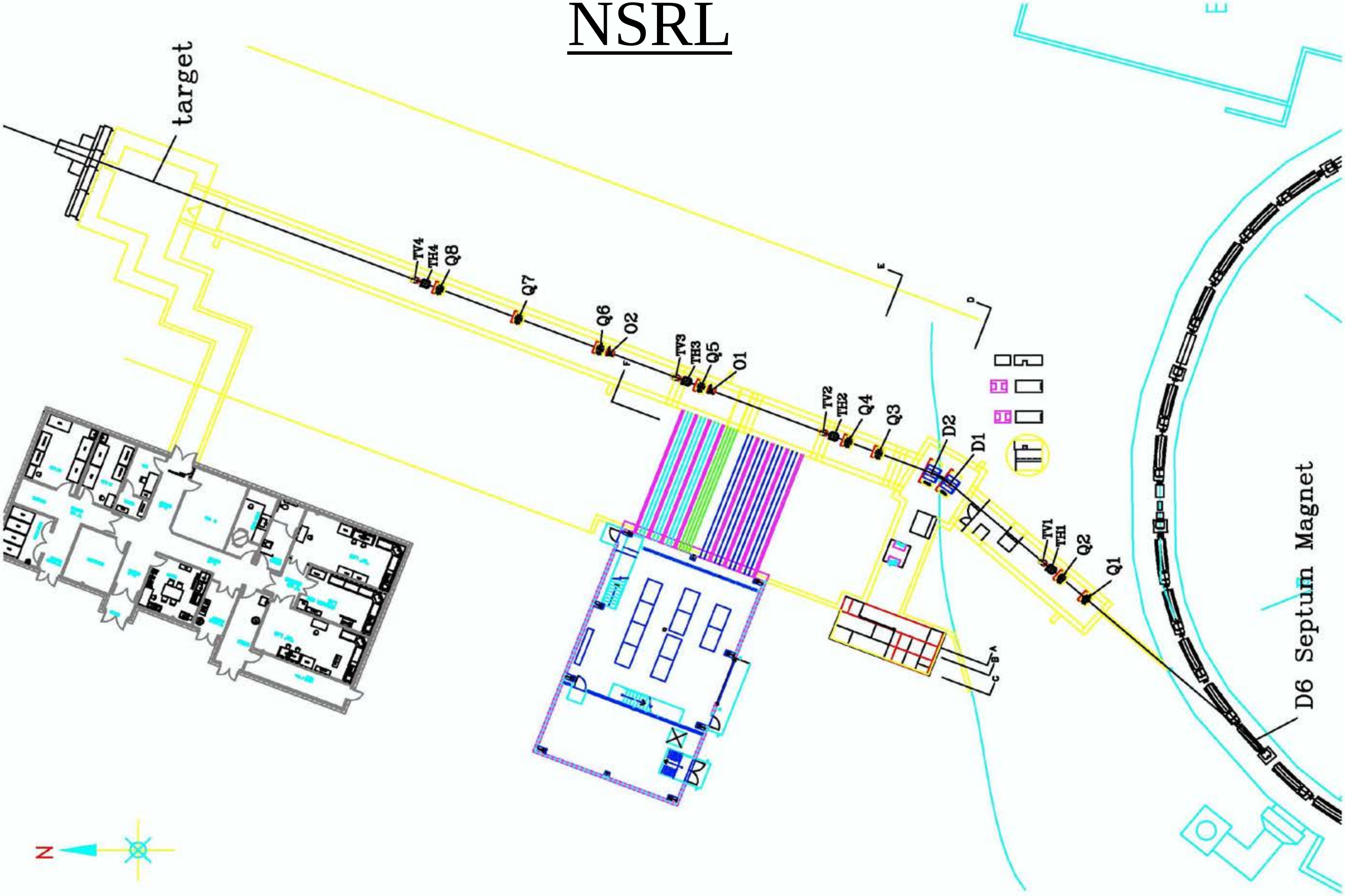


30 day mission,
2015-2020

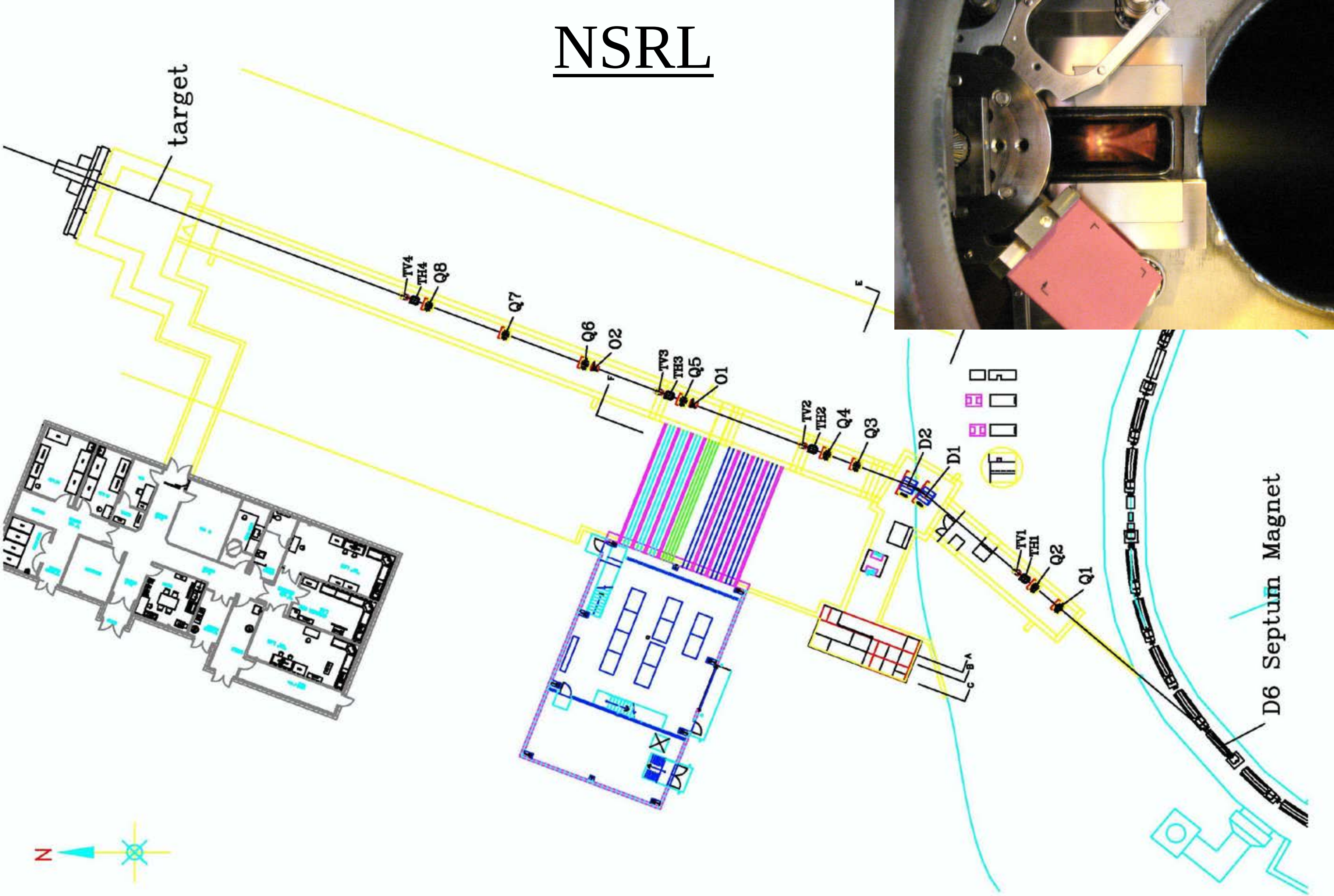
1 year mission:
(215 days, 2006)

30 month mission,
2025-2030

NSRL

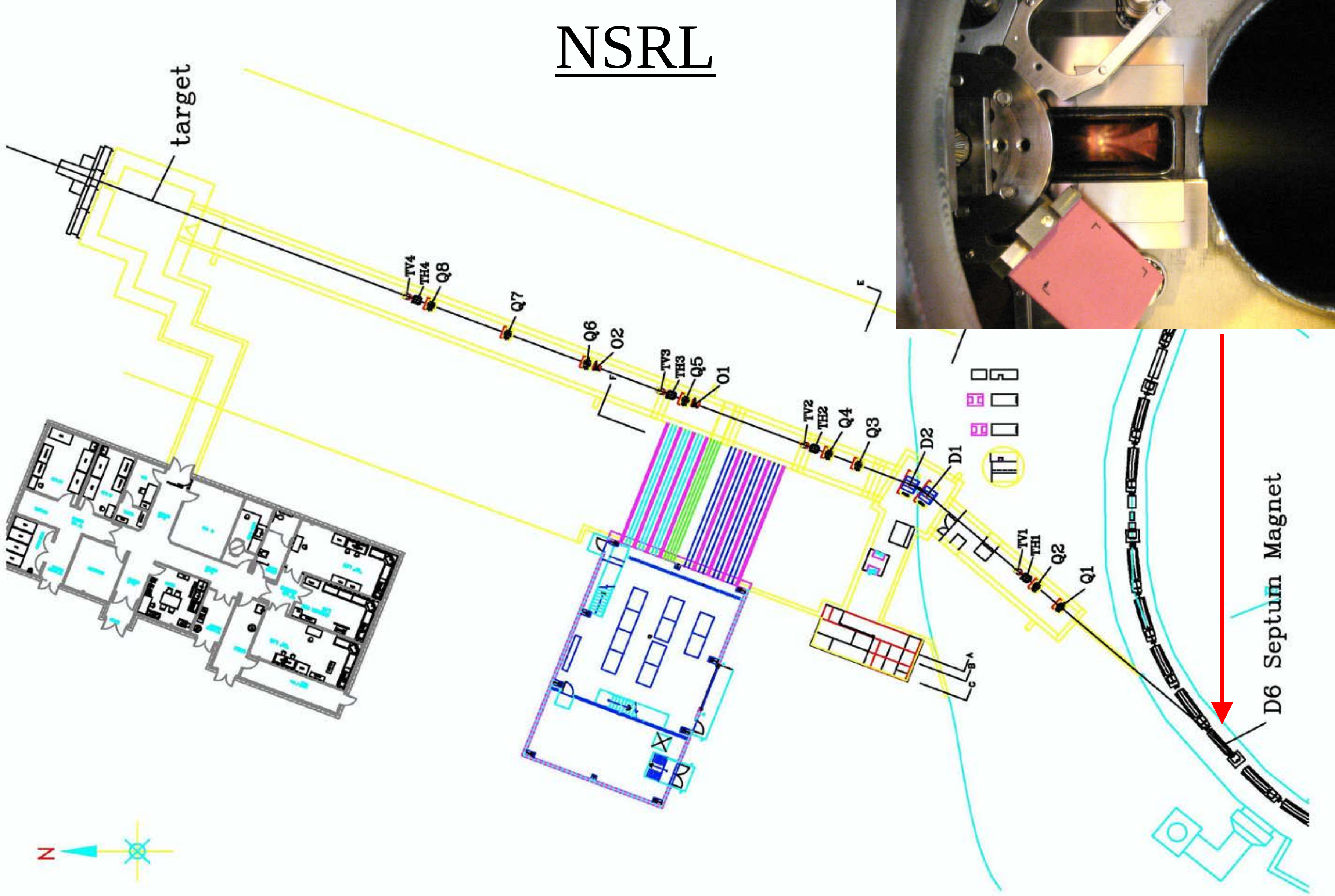

target
TV4
TH4
Q8
Q7
Q6
O2
TV3
TH3
Q5
O1
TV2
TH2
Q4
Q3
D2
D1
TV1
TH1
Q2
Q1
D6 Septum Magnet
N

NSRL

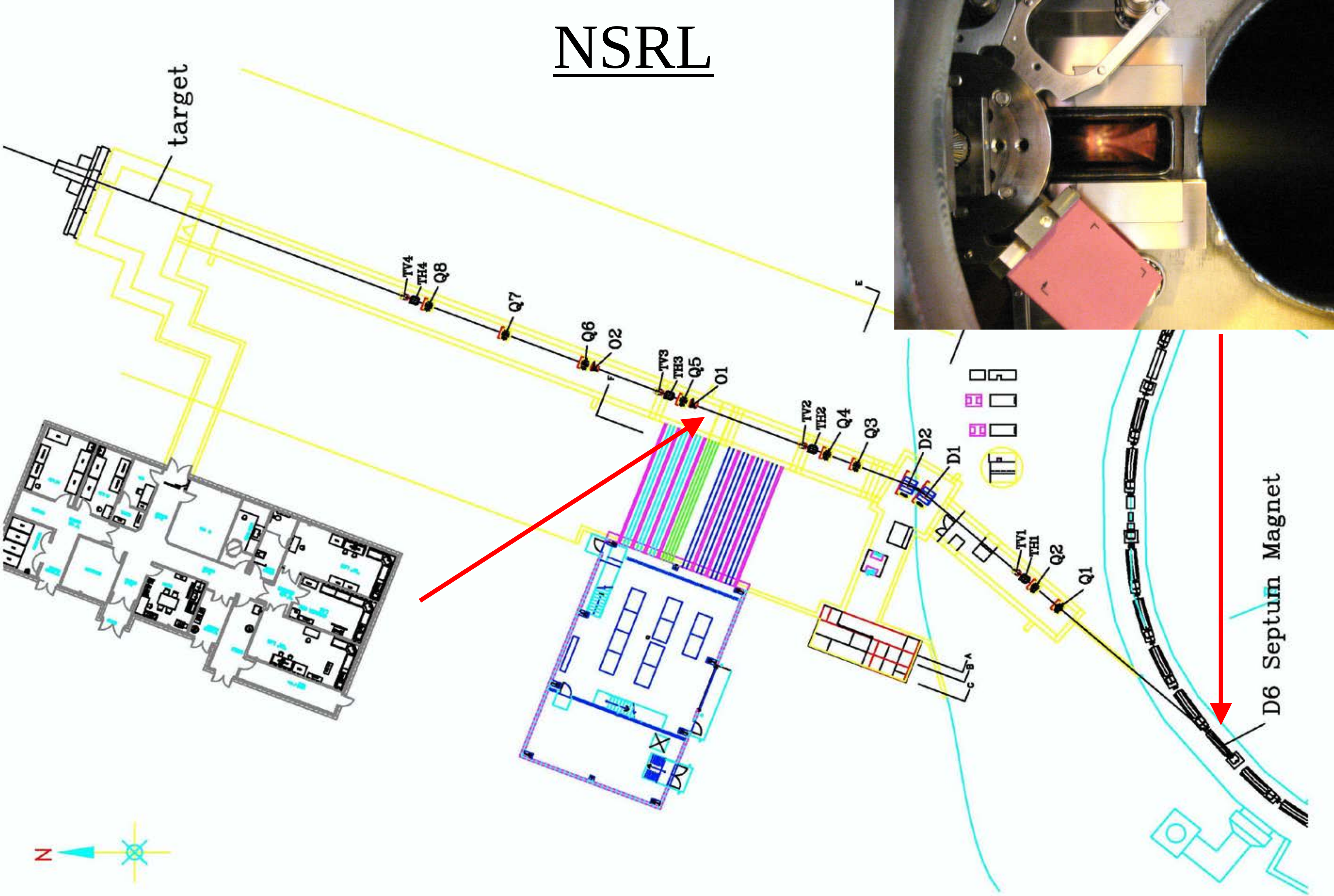


target
TV4
TH4
Q8
Q7
Q6
O2
TV3
TH3
Q5
O1
TV2
TH2
Q4
Q3
D2
D1
TV1
TH1
Q2
Q1
D6 Septum Magnet
N

NSRL

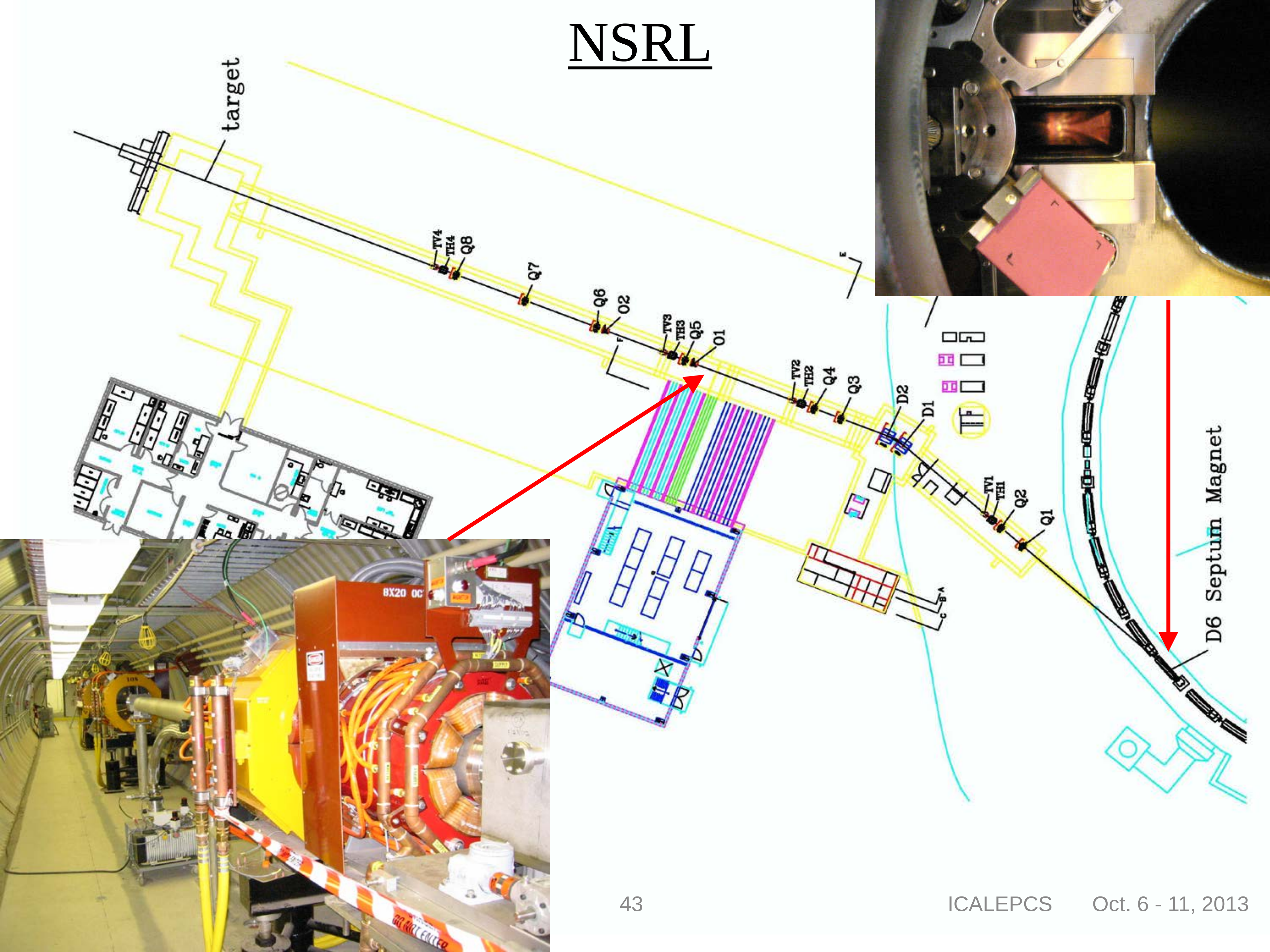

target
TV4
TH4
Q8
Q7
Q6
O2
TV3
TH3
Q5
O1
TV2
TH2
Q4
Q3
D2
D1
TV1
TH1
Q2
Q1
D6 Septum Magnet
N

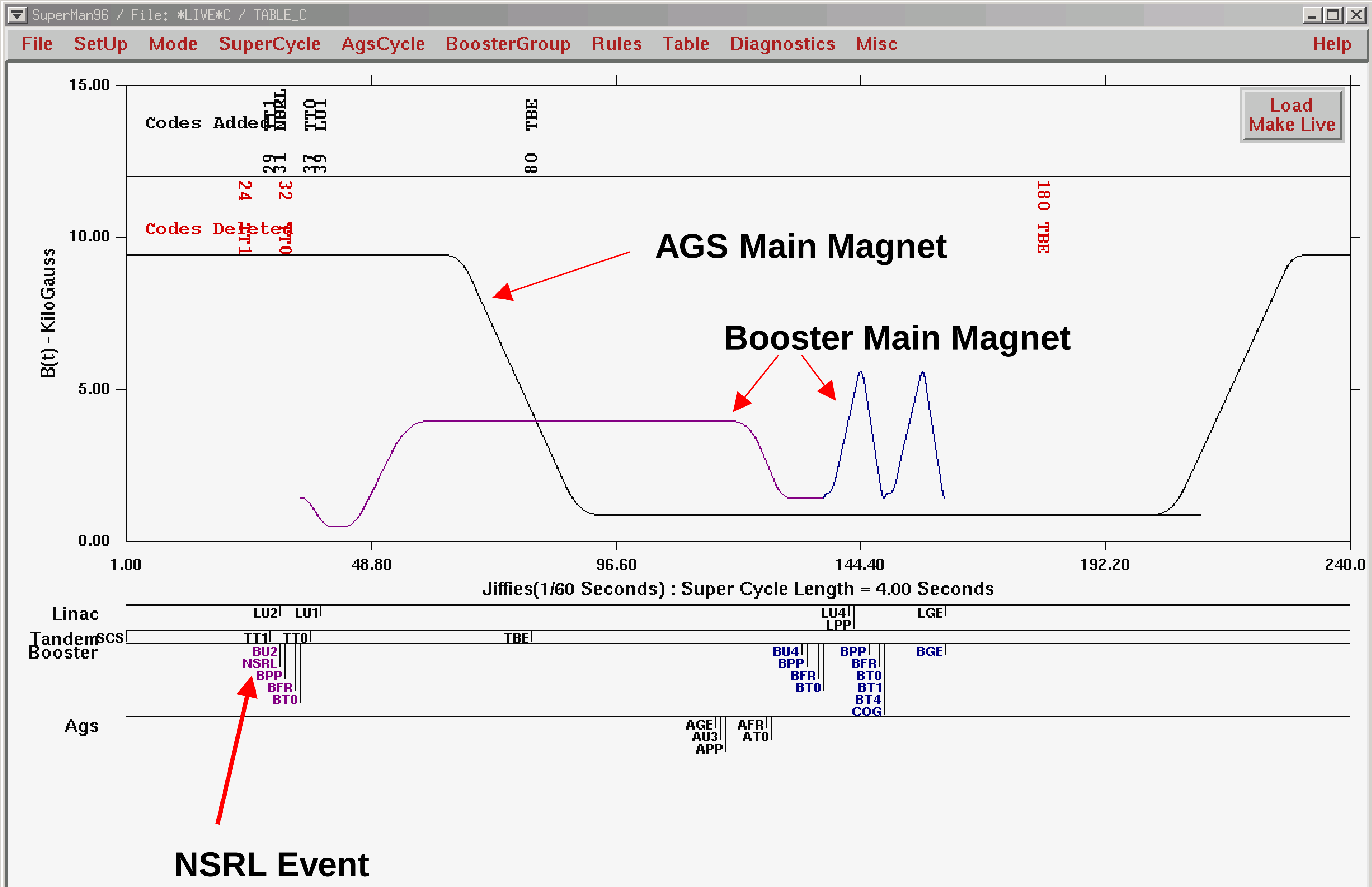
NSRL



target
TV4
TH4
Q8
Q7
Q6
O2
TV3
TH3
Q5
O1
TV2
TH2
Q4
Q3
D2
D1
TV1
TH1
Q2
Q1
D6 Septum Magnet
N

NSRL


target
TV4
TH4
Q8
Q7
Q6
O2
TV3
TH3
Q5
O1
TV2
TH2
Q4
Q3
D2
D1
TV1
TH1
Q2
Q1
D6 Septum Magnet


SuperMan96 / File: *LIVE*C / TABLE_C
File SetUp Mode SuperCycle AgsCycle BoosterGroup Rules Table Diagnostics Misc Help
Load
Make Live
Codes Added
Codes Deleted
AGS Main Magnet
Booster Main Magnet
B(t) - KiloGauss
15.00
10.00
5.00
0.00
1.00
48.80
96.60
144.40
192.20
240.0
Jiffies(1/60 Seconds) : Super Cycle Length = 4.00 Seconds
Linac
Tandem
SCS
Booster
Ags
NSRL Event

Electron Beam Ion Source [EBIS]