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U.S. DEPARTMENT of ENERGY

Fixed Target Options and Parameters at the AGS

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Collider-Accelerator Department, Brookhaven National Lab.

Outline

Overview of AGS Extraction systems

Replicating the Space Environment in the lab

Beam Transport Options

Beam Quality and methods to improve duty factor

Options for NP fixed target experiments

Summary

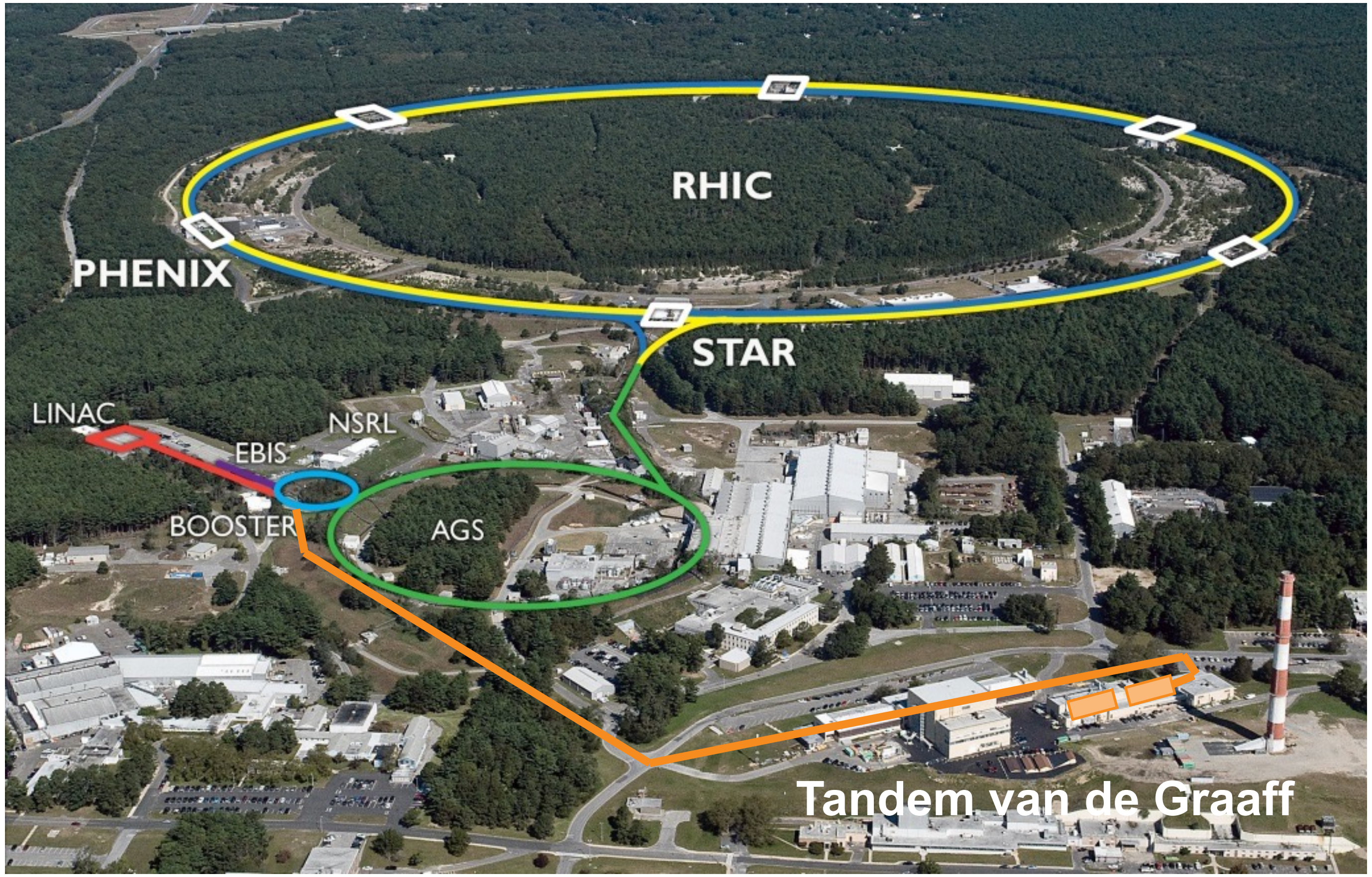
BNL RHIC Accelerator Complex

Accelerator Rings

	Circumference [m]
Booster	201
AGS	807
RHIC	3833

Typical Top Energies [GeV/N]

	Au	Pol. Protons
Linac (H^-)	--	0.2
Booster	1	2
AGS	10	24
RHIC	100	255



Heavy Ions	Protons
E-beam Ion Source (EBIS)	OPPIS (polarized)
Tandem Van de Graaf	High-intensity H^- (unpolarized)

Note:
Tandem and EBIS can supply protons, as well.

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Slow Extraction at the AGS

March 1968: first SE for HEP, $3Q_H=26$
- Simple system with no ES septum

1972: 200 MeV LINAC (previous was 50 MeV), H+ injection to AGS

1979: first ES septum installed

1979: new multi-hall switchyard (3 lines)

1980's: pre-Booster era, H- injection to AGS
- Intensities 1.0 – 1.6 x 10^{13} protons/pulse
- Extraction momentum 25-29 GeV/c
- Spills 1 – 2 sec., repetition periods 2.4 - 4.0 sec.
- Extraction inefficiency 3 – 5 %
- Began doing heavy ion experiments (NPP)

1990's: post-Booster era
- Intensities 5.0 – 7.6 x 10^{13} protons/pulse
- Extraction momentum 25.5 GeV/c (to improve uptime)
- Similar spills and rep periods, more optimization on duty factor
- Extraction inefficiency 2 – 3 %
- Problem! Higher losses in switchyard beam transport

2002: program ends. RHIC era.

1963 (work started in 1961)

THE CPS RESONANT EXTRACTION SYSTEM

H. G. Hereward

CERN

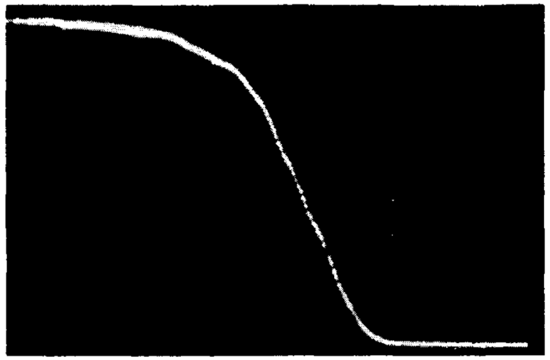

Fig. 2. Internal beam current as function of time during resonant spill-out.

1967

Improvement of the Emittance in the Resonant Beam Ejection

Y. Kobayashi and H. Takahashi

Institute for Nuclear Study, University of Tokyo

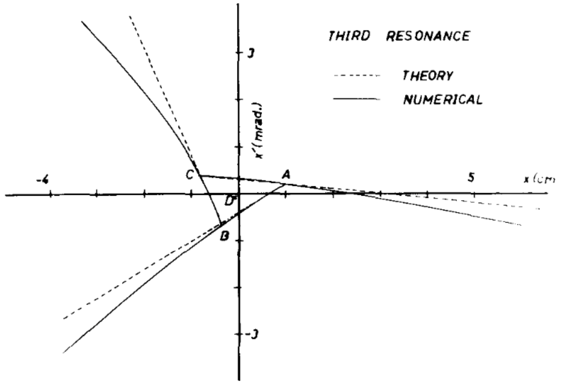

Fig. 3 A separatrix for a third resonance at K_1, where A, B and C are unstable fixed points and D is a stable fixed point. $g_1 = -0.2102$ and $g_2 = g_3 = 0$

$$H = -\frac{\varepsilon}{2}(X'^2 + Y'^2) + \frac{\beta\sqrt{A^2+B^2}}{3} X'(X'^2-3Y'^2).$$

The Kobayashi Hamiltonian

$$H(x,x',s) = \frac{1}{2}(x'^2 + K_x x^2) + \frac{S(s)}{6}x^3.$$

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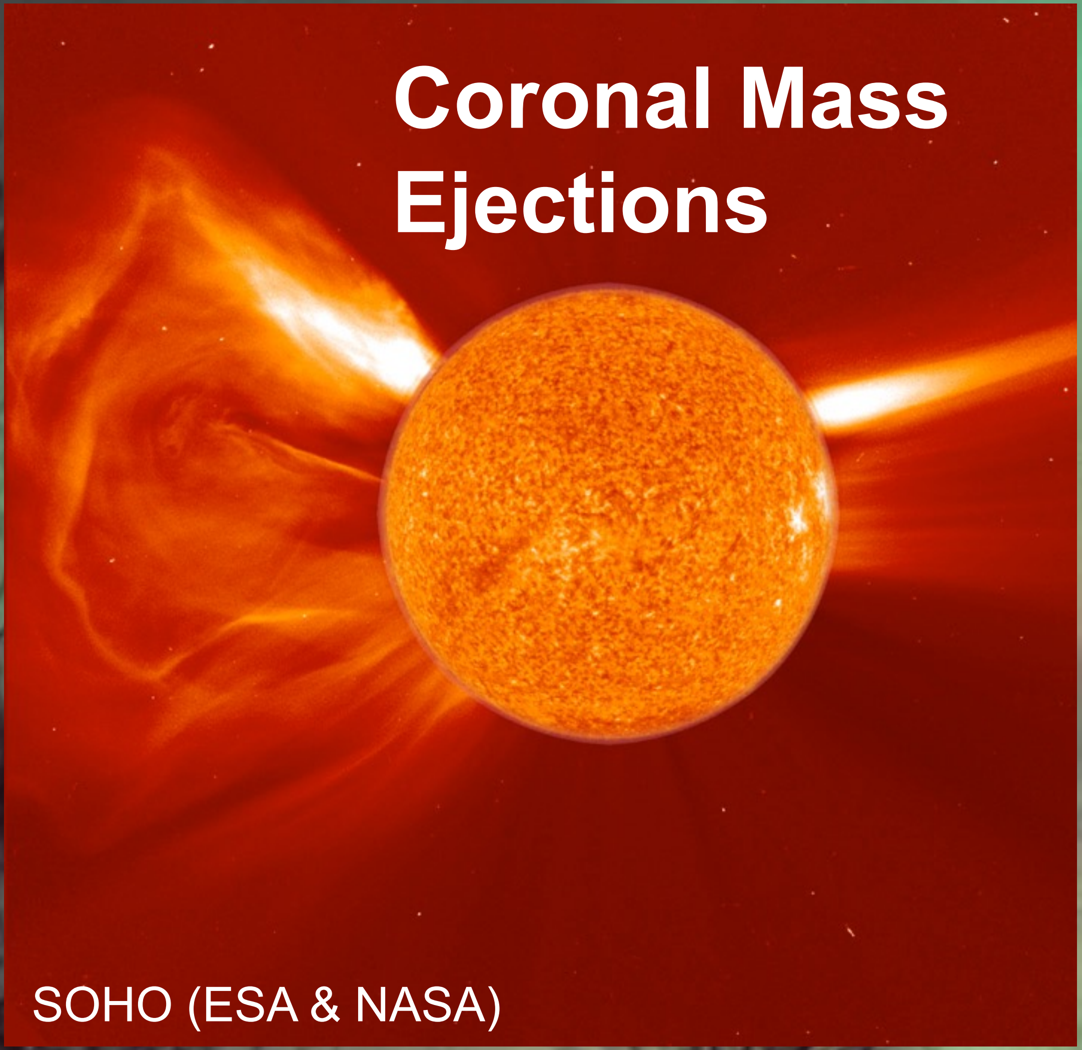
Replicating the Space Environment in the lab

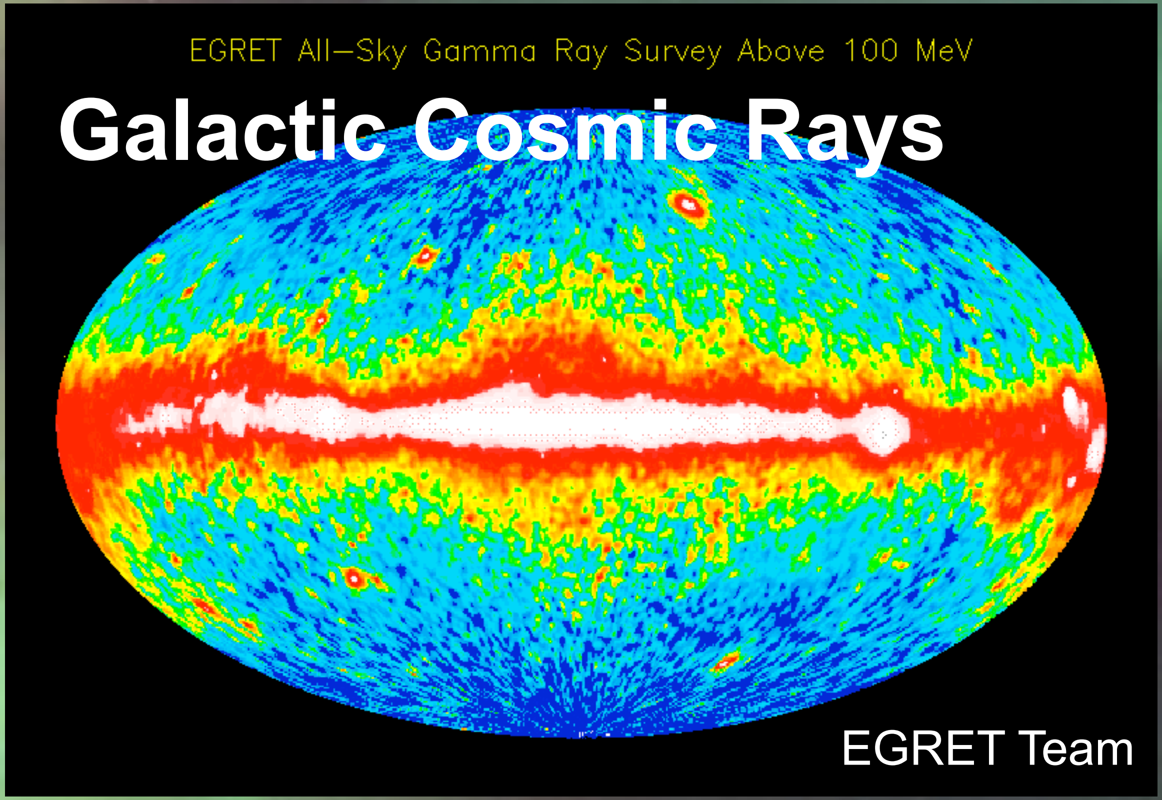
SPACE WEATHER

SPE: Solar Particle Events = Coronal Mass Ejections

GCR: Galactic Cosmic Rays
= particles from outside the solar system



SOHO (ESA & NASA)



EGRET Team

Space is filled with charged ionizing radiation.

Why is it important?

Things we put in space encounter two types of radiation effects

- Continuous bombardment from high energy particles is called cumulative dose and can lead to equipment failures
- Single event effects are a single particle hitting a sensitive part, such as a cell in computer memory or even the microprocessor

As we see in current events, there is a new space race taking place and we will soon see people going to the moon and beyond.

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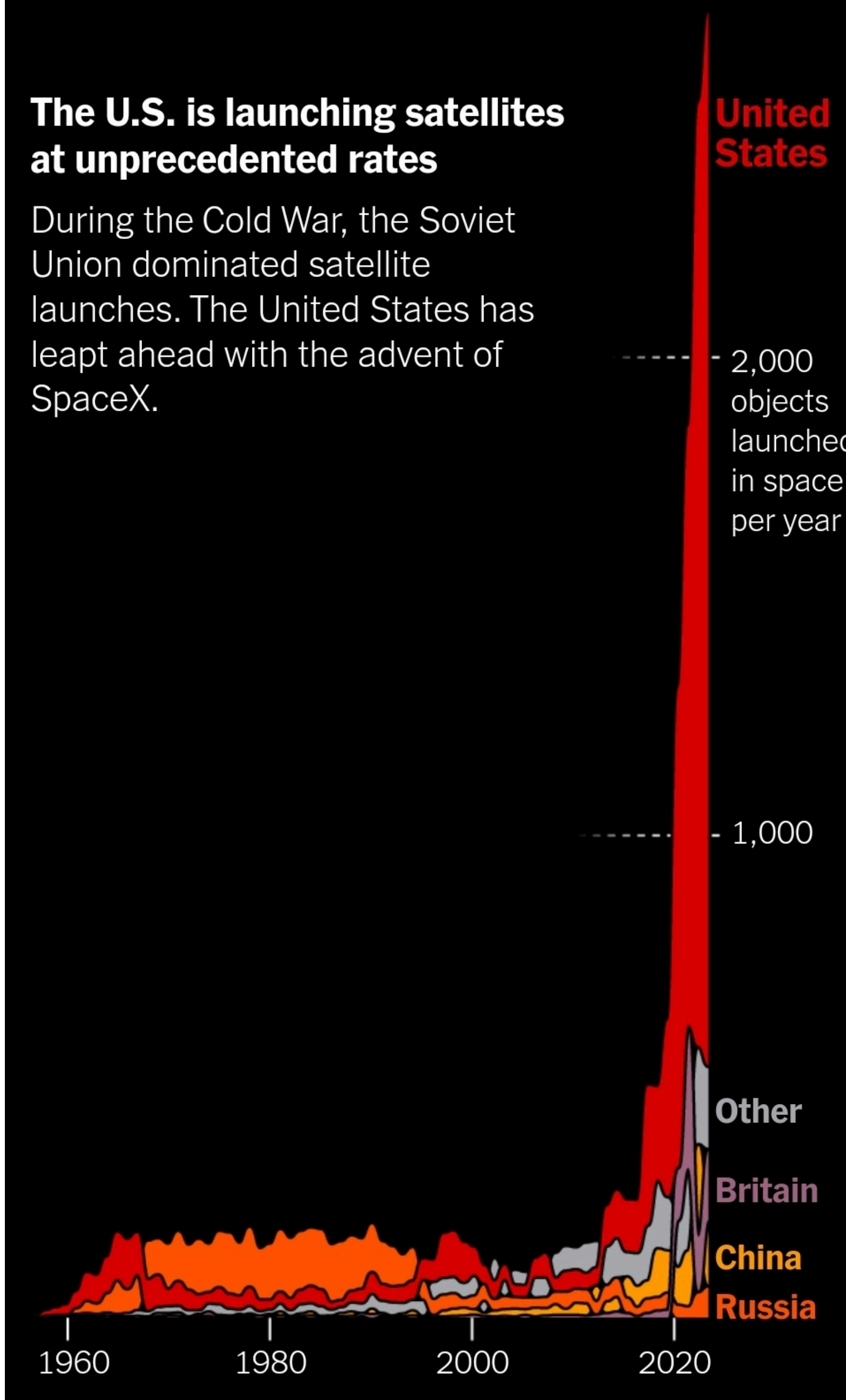
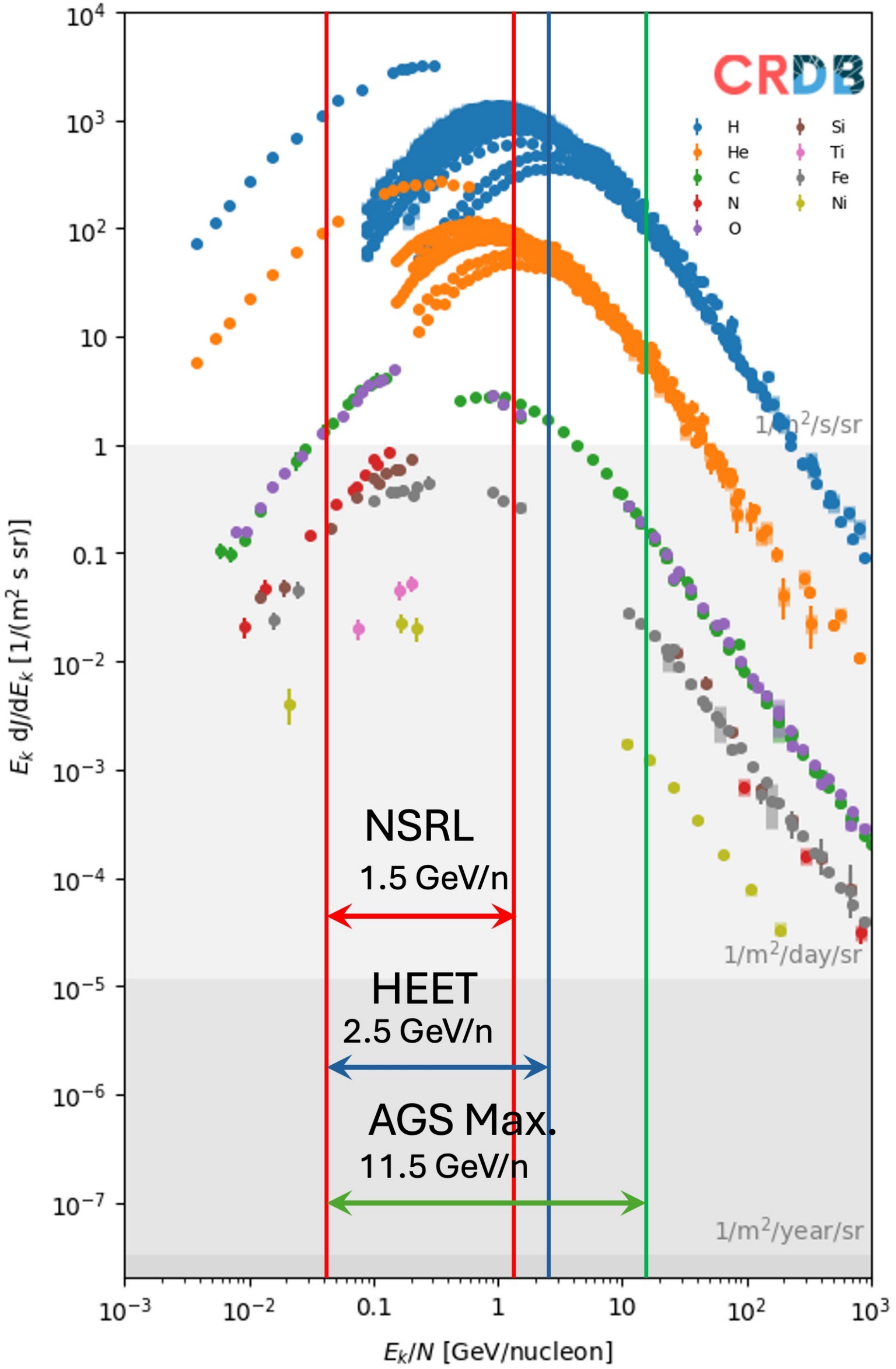
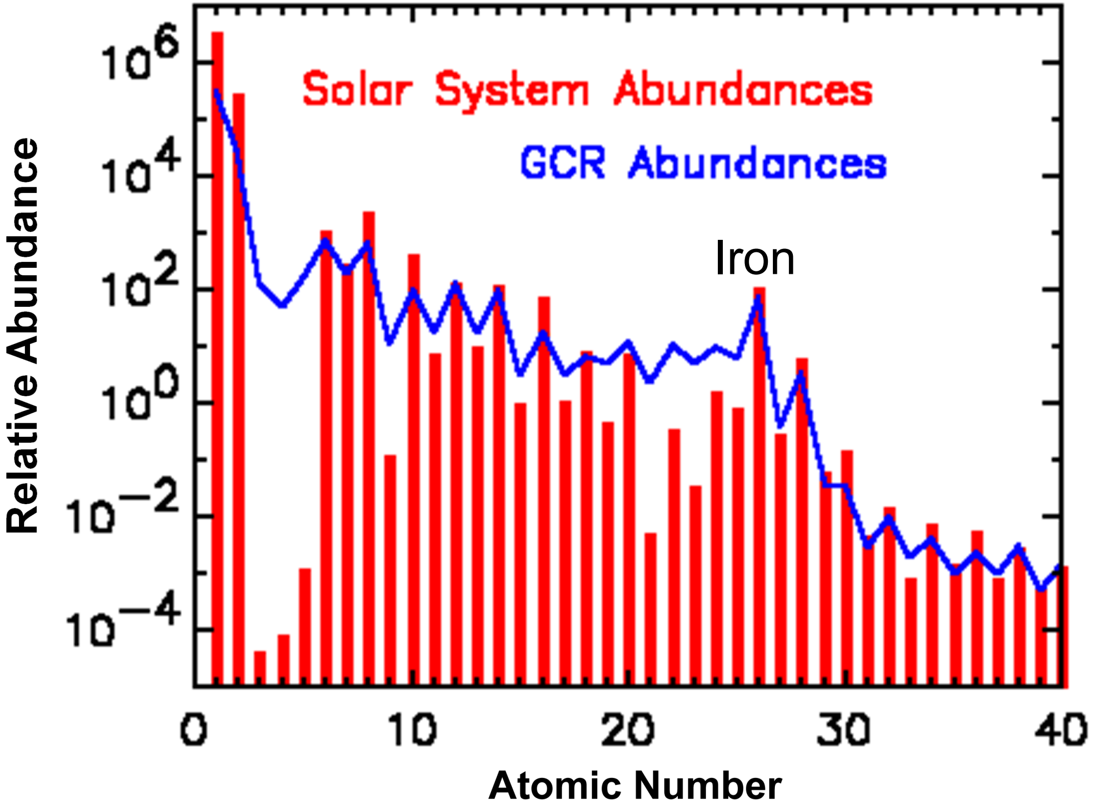
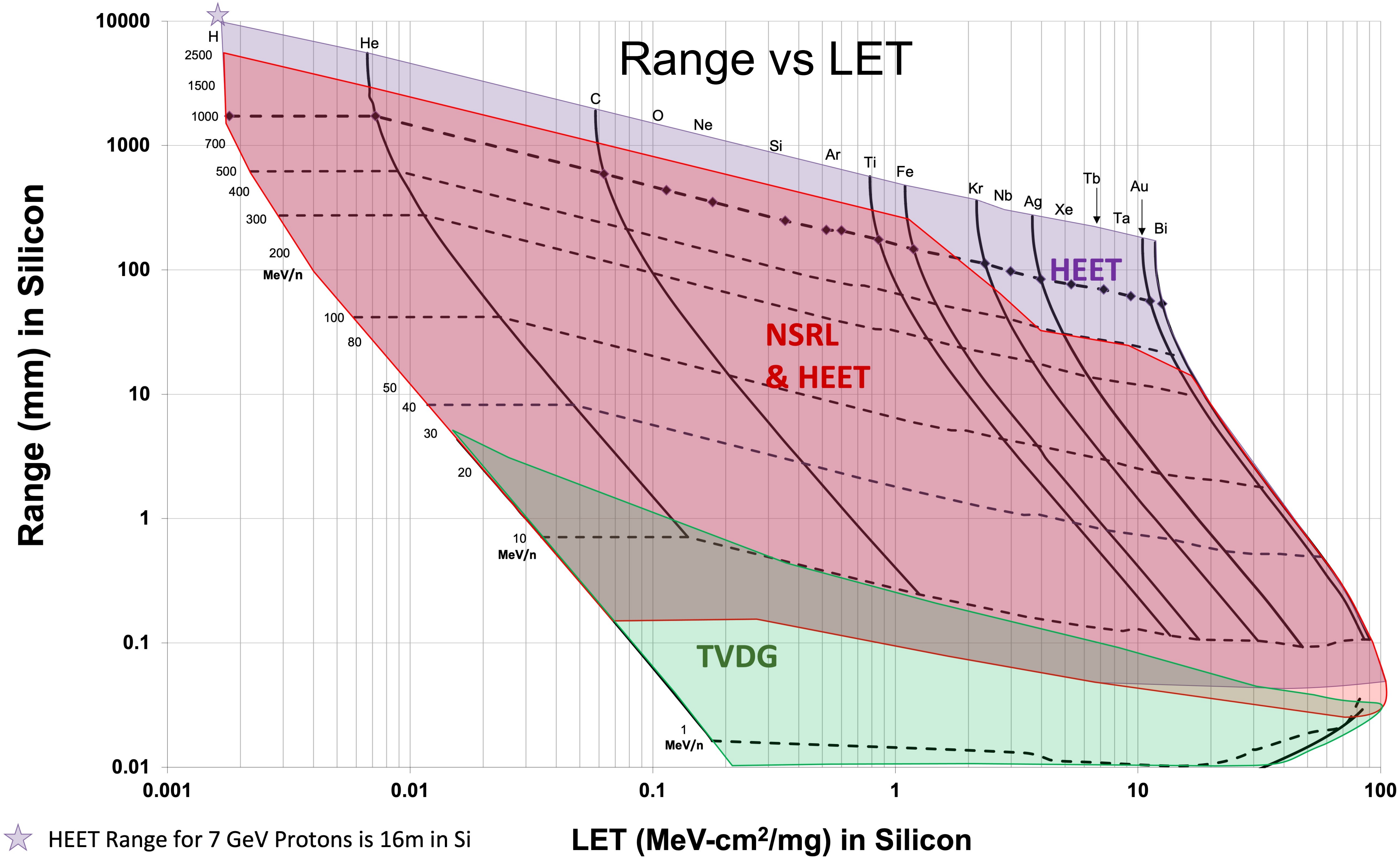




- GCR is Composed of all naturally occurring elements
  - 90% hydrogen
  - 9% helium
  - 1% heavier ions
- Generally similar to solar abundances but secondary products due to interstellar GCR fragmentation smooths out abundances



https://imagine.gsfc.nasa.gov/



☆ HEET Range for 7 GeV Protons is 16m in Si

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Overview of AGS Extraction systems

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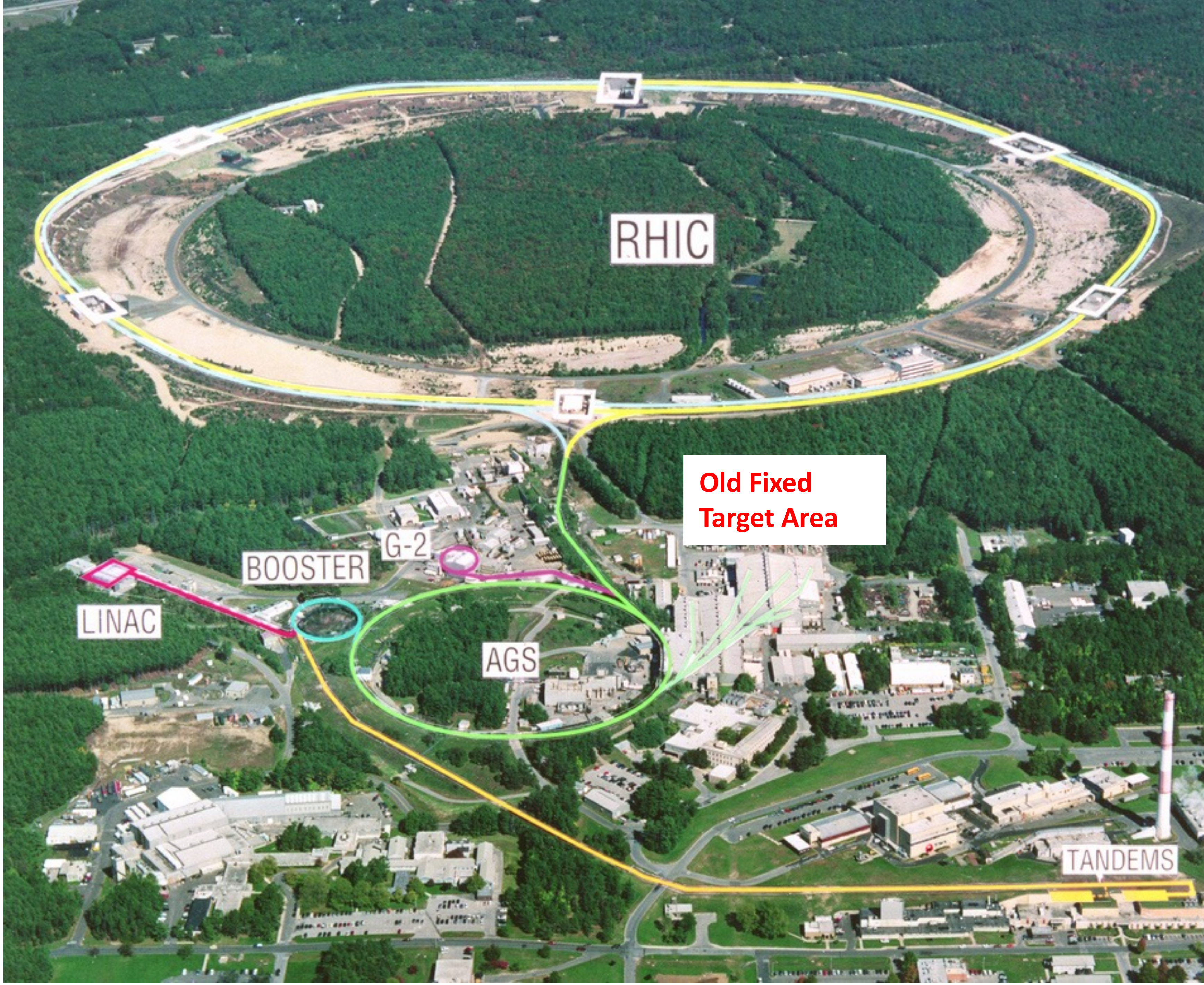
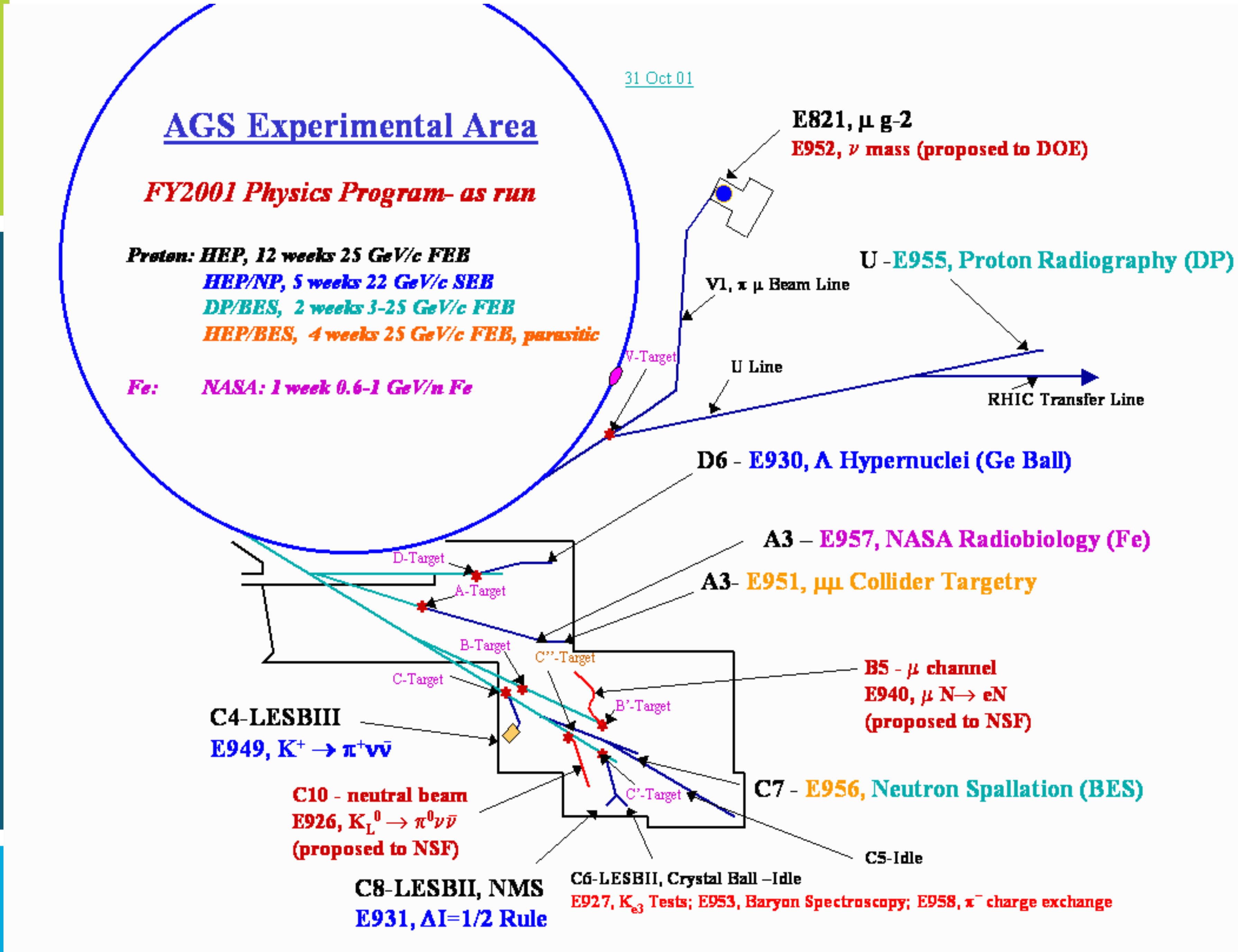
An old image but shows 3 things.

1. Fixed target Area (912)
   - Slow extracted beams
   - Single bunch fast beam
   - Micro & mini-bunched SX
2. G-2 with fast single bunch
   - 12 bunches, 33msec apart
3. AtR, with fast single bunch to RHIC

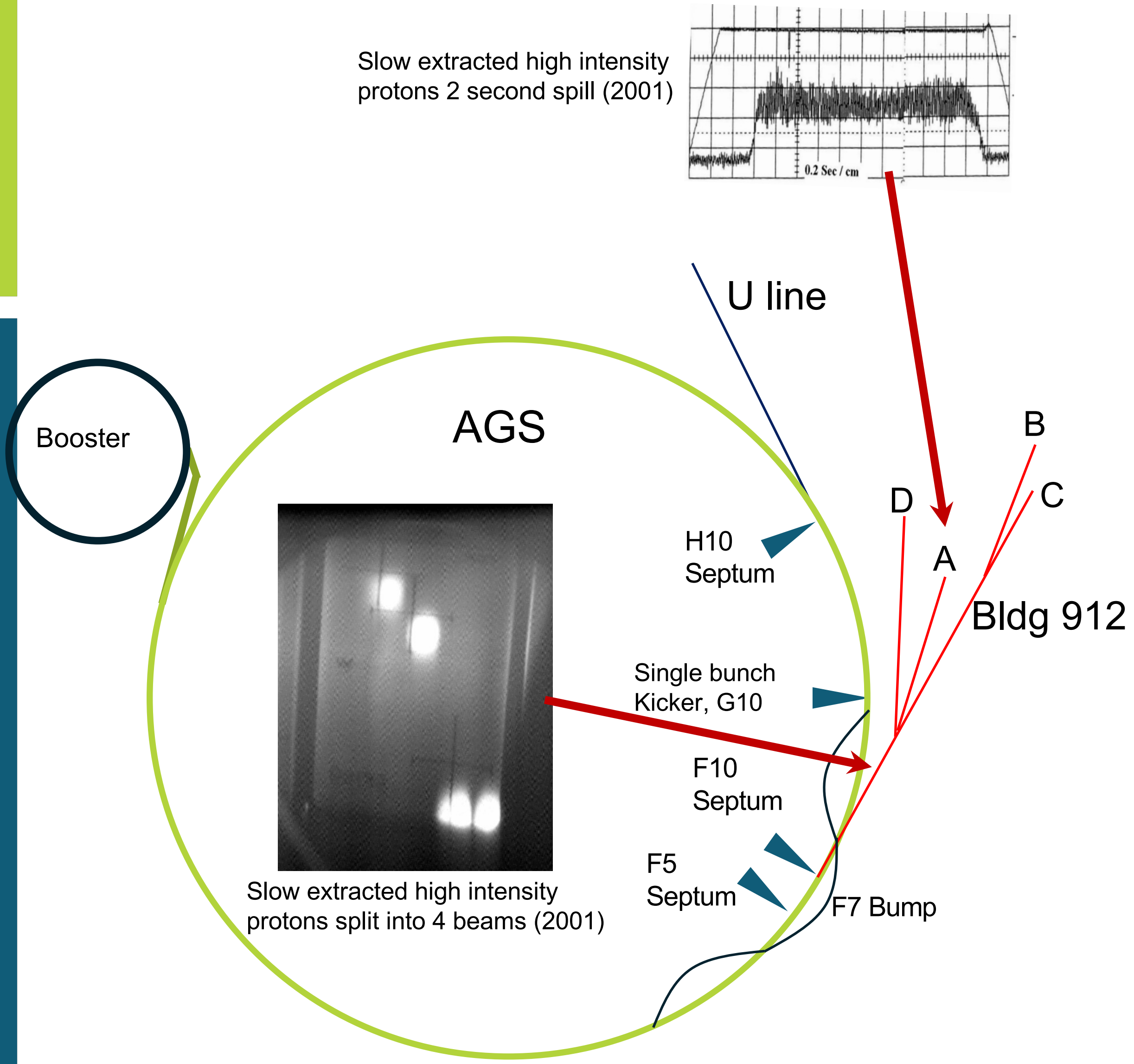




We used to handle a large variety of experiments.

After 2002

- all HEP experiments ended
- NP experiments ended with RHIC startup
- NASA moved to new facility off the AGS Booster
- G-2 finished
- Radiography ran 1 year



Ways to extract beam from the AGS

1. Fast beams (single bunches)
   To Uline via G10 kick into H10 Septum
   OR
   To 912 (A,B,C, or D) via G10 kick into
   F5 and F10 Septa (requires correct horizontal tune)

2. Slow extracted beams (1 – 2 seconds long)
   To 912 via F5 and F10 septa

3. Slow extracted modes
   Bunched beam slow extraction

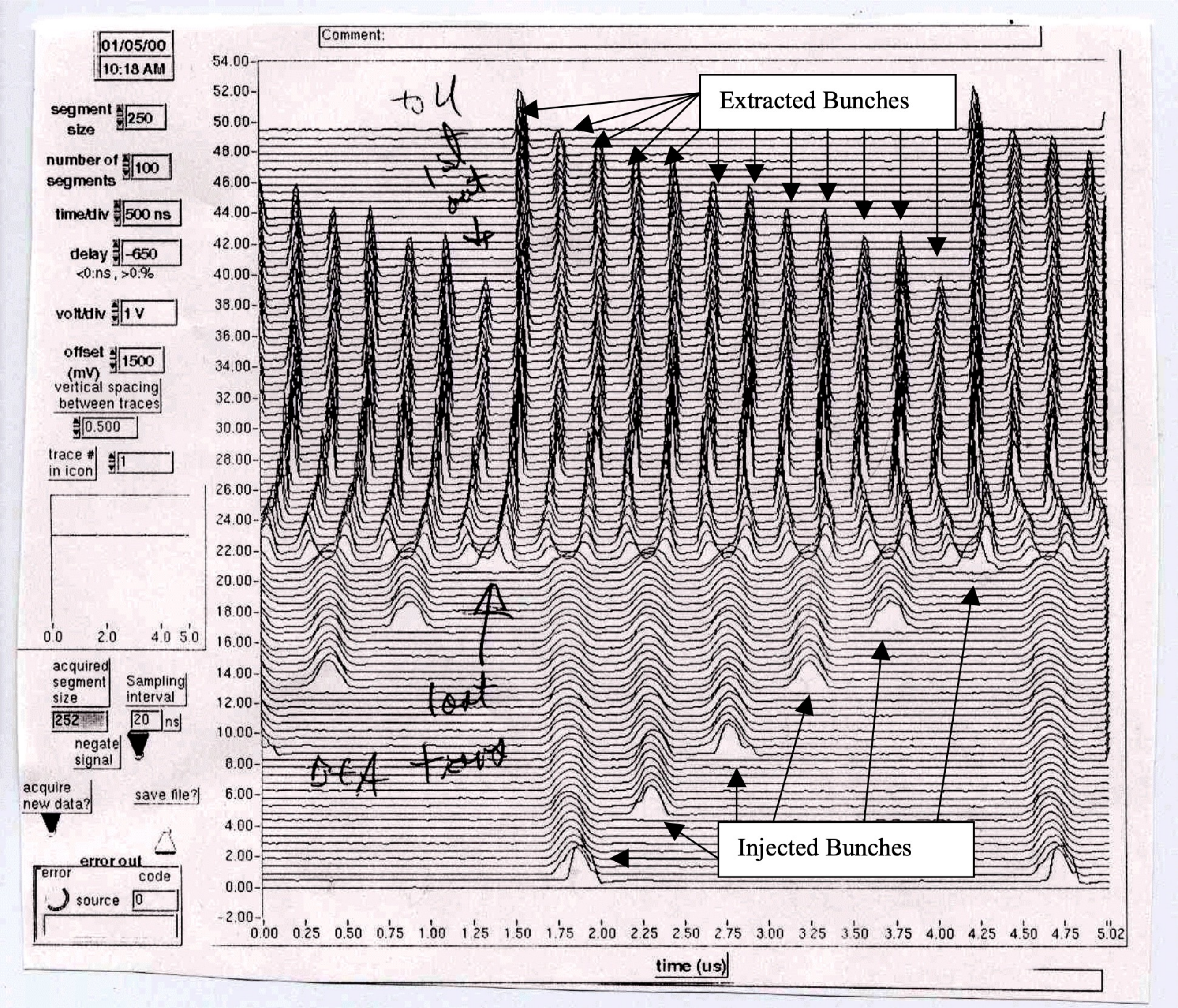
   Micro-bunched beam slow extraction

We do not have the ability to extract full turn. This would require a new kicker magnet.

A little on Fast Extracted Beams

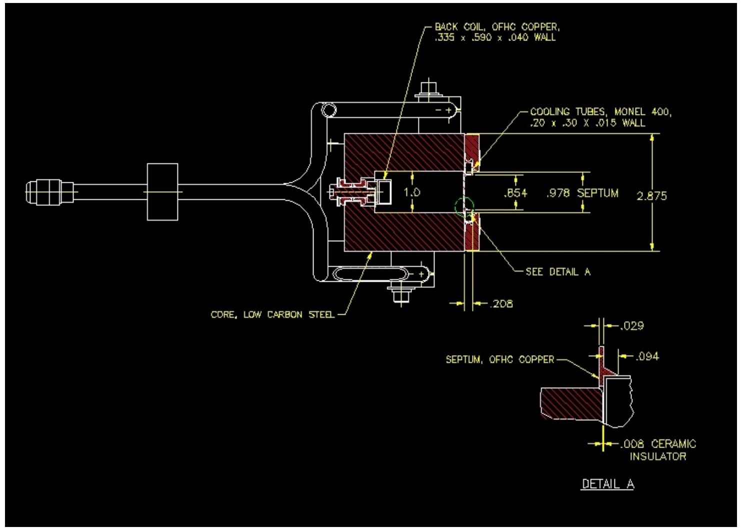
For G-2, p=24 GeV/c protons

- we ran ~6x10^{12} p / bunch
- Bunches were about ~80 nsec long (at the baseline)
- Single Bunches extracted at 30 Hz
- Au ions can be extracted in a similar way, but for RHIC they are transferred on demand, cogged for bucket-to-bucket transfer.

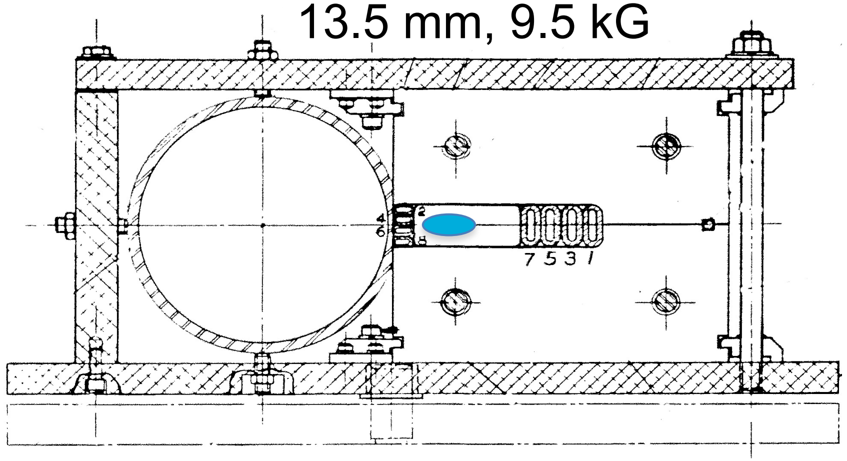


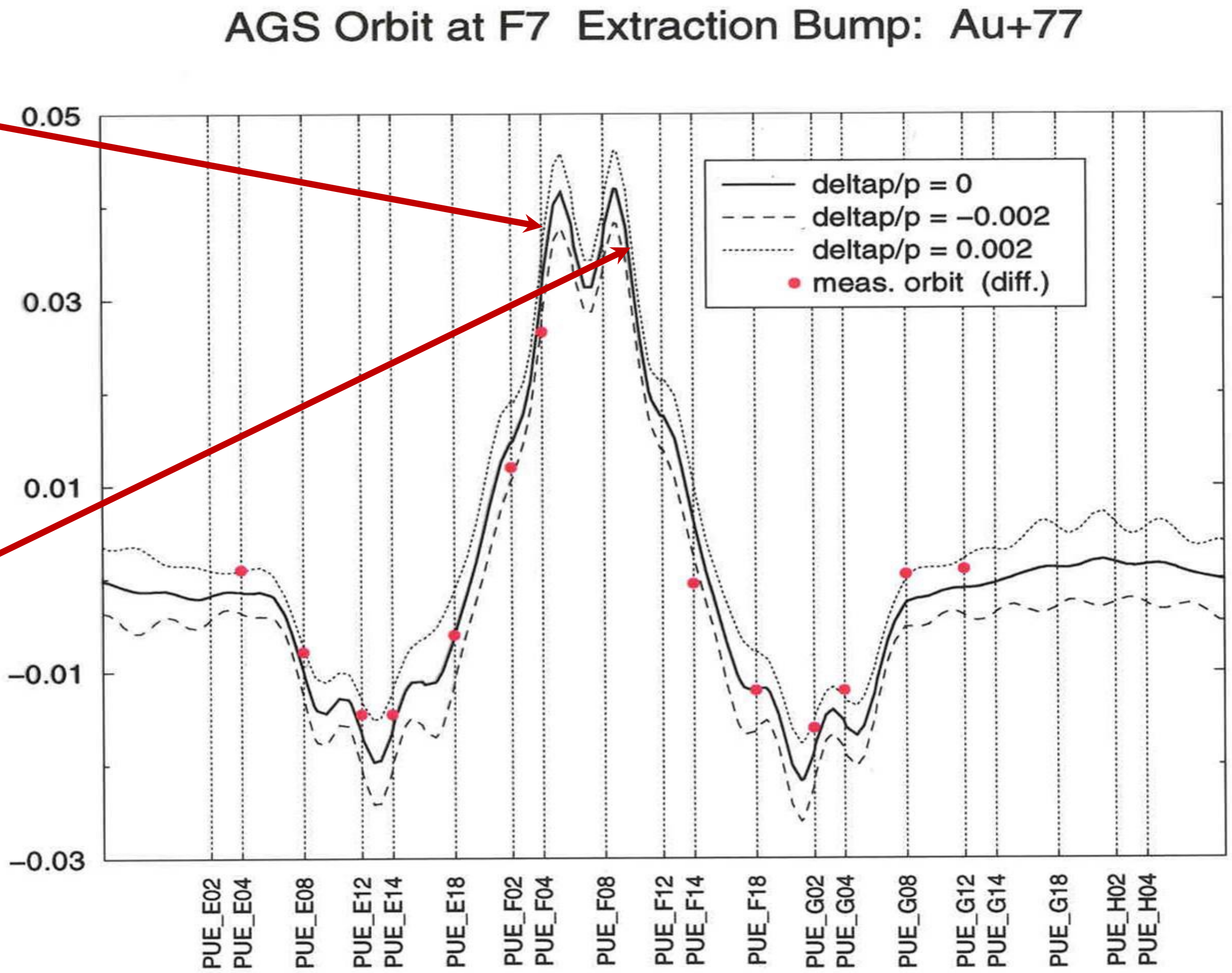
Overview of AGS Slow Extraction

Thin Septum
0.76 mm, 1.5 kG



Thick Septum
13.5 mm, 9.5 kG





AGS Performance History

PROTON BEAM	FY94	FY95	FY96	FY97 SEB	FY97 FEB (g-2)	FY98/99 SEB	FY98/99 FEB (g-2)	FY2000 FEB (g-2)
Beam Energy	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV
Peak Beam Intensity	40 x 10^{12} ppp	63 x 10^{12} ppp	62 x 10^{12} ppp	62 x 10^{12} ppp	46 x 10^{12} ppp	72 x 10^{12} ppp	58 x 10^{12} ppp	61 x 10^{12} ppp
Total protons accelerated	0.3 x 10^{20}	1.1 x 10^{20}	0.9 x 10^{20}	0.4 x 10^{20}	0.1 x 10^{20}	0.9 x 10^{20}	0.4x 10^{20}	0.5x 10^{20}
Spill Length/Cycle Time	1.0 sec/3.8 sec	1.6 sec/3.6 sec	1.6 sec/3.6 sec	1.6 sec/3.6 sec		2.8 sec/5.1 sec		
-> Duty Cycle	26%	44%	44%	44%		55%		
Spill Structure Modulation (peak-average) /average	50%	20%	20%	20%		20%		
Average Availability /Best Week	~83%	82%/ 93%	76% / 92%	71% / 79%	58 % / 67 %	71% / 88%	55 % / 83 %	74 % / 87 %

HEAVY ION BEAM	Au	Au	Au	Au	Fe (NASA)	Au	Fe (NASA)	
Beam Energy /nucleon	11 GeV	11 GeV	11 / 4 / 2 GeV	11 / 8 / 6 GeV	1.0 / 0.6 GeV	11 GeV	1.0 / 0.6 GeV	
Peak Beam Intensity	2 x 10^8 Au/p	2 x 10^8 Au/p	4 x 10^8 Au/p	17 x 10^8 Au/p	20 x 10^8 Fe/p	9 x 10^8 Au/bunch		36 x 10^8 Fe/p
Spill Length/Cycle Time	1.0 sec/3.8 sec	1.0 sec/3.8 sec	1.4 sec/3.6 sec	1.5 sec/4.0 sec		1.2 sec/3.0 sec		
-> Duty Cycle	26%	26%	39%	38%		40 %		
Spill Structure Modulation (peak-average) /average	50%	20%	<20%	<20%		<20%		
Average Availability	~85%	90%	80%	82 %	96 %	81 %	90 %	

Intensity range of AGS (today)

AGS intensity in recent years driven entirely by RHIC needs; higher per bunch intensity, polarization, not a lot of concern for high bunch number per cycle

(unpolarized) Proton intensity and number of bunches per cycle not pushed since g-2 (~2002)

- 12 bunches/cycle, $6x10^{12}$/bunch
- This would require (re) development

Intensity of new species in AGS generally needs to be studied: main limitations are initial source production intensity and stripping foil efficiency (many of the species on the NSRL Booster list have not been stripped/injected into AGS)

Species	"Routine" highest intensity/bunch	Bunches/AGS cycle
Pol.Protons	$3x10^{11}$	1
Gold	$3x10^{9}$	2
Cu	$4x10^{9}$	2
Al	$1x10^{10}$	2

Per bunch intensities achievable with 'normal' efforts (i.e. for a RHIC run)

Beam transport options

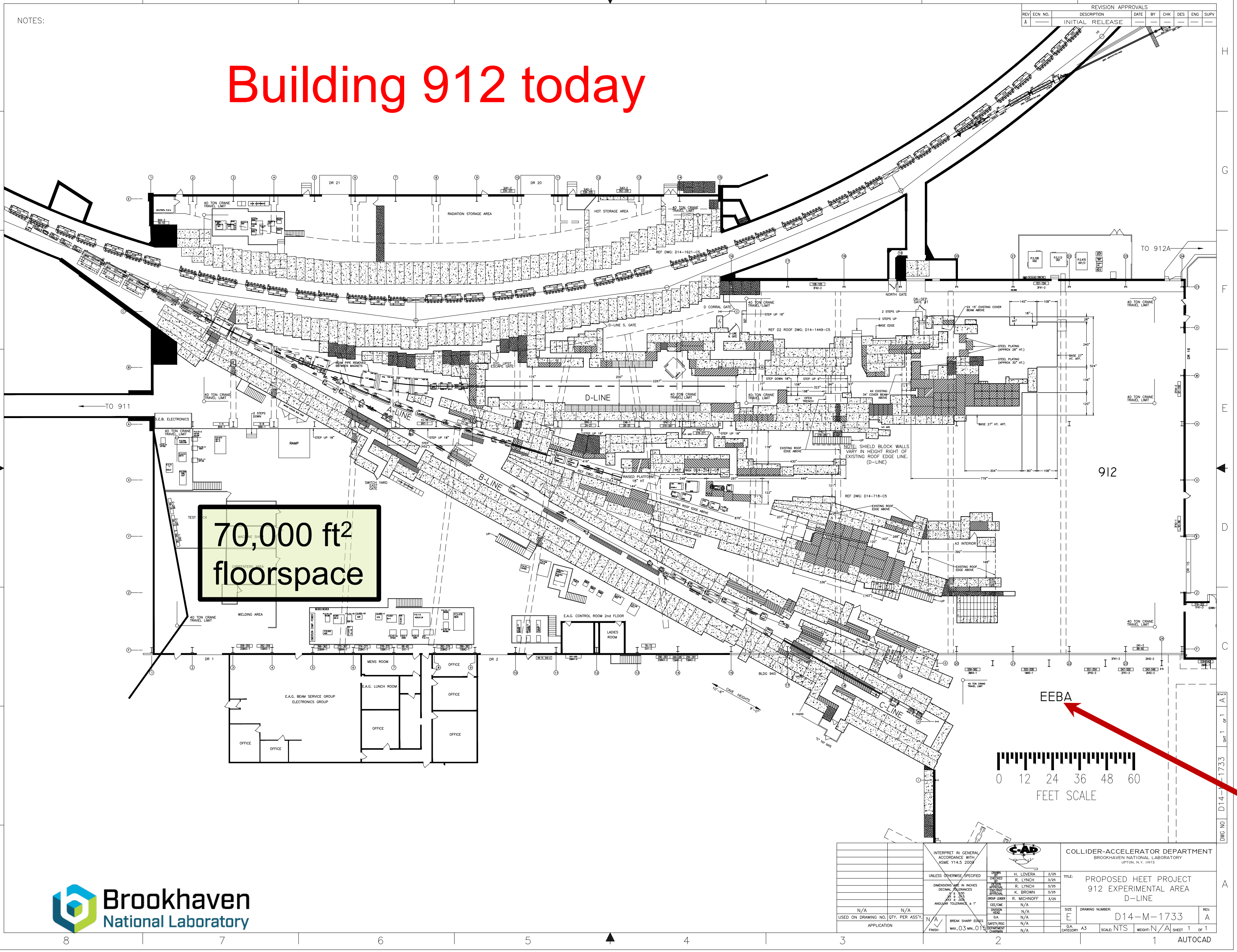
Status

Slow extraction from AGS has been disabled, to re-enable we need

1. New thin and thick septa (have one still) magnets and power supplies
2. F7 bump reinstalled with new cables and new PS
3. 4 sextupole magnets powered with new PS
4. New active filter (to reduce spill ripple)
5. New vacuum pipe from F10 to F12, for extraction channel (have old one)
6. Refurbished magnets in 912
7. Refurbished and some new PSs for magnets
8. New vacuum systems
9. New instrumentation

Getting all this back in place and operating will take ~3 years

Building 912 today



Most of the old switchyard is still in place.

But,

Not operated in 25 years.

All formed experiments and detectors have been removed.

Some magnets have been removed, to repurpose and use for other applications.

Electrical infrastructure does not meet code – needs upgrading before running.

EEBA no longer available!

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Options

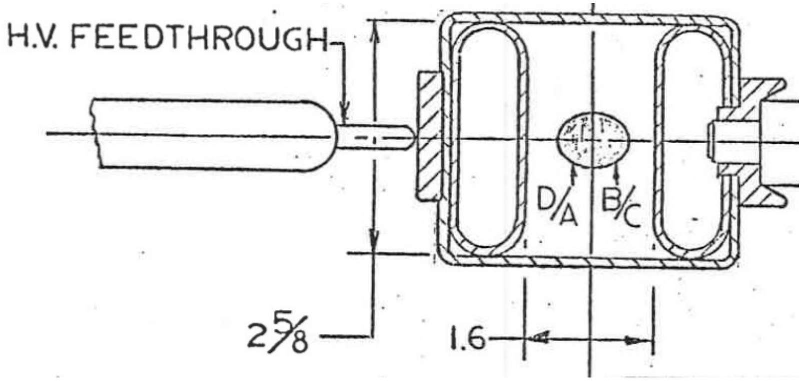
We could do split beams again, but we could simplify the design.

- How many beamlines are needed?
- We could look into horizontally splitting, rather than vertical
- Handling momentum dispersion will be an issue. Would want to design achromatic tune and split where D=D’=0 (oddly enough, this is simpler).

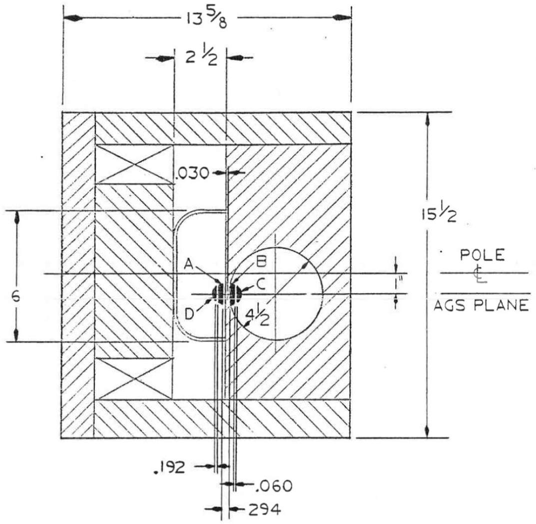
We could eliminate splitters and use a switching magnet

- If each beamline has a different purpose this is the best option
- Can NP experiments share a single target?

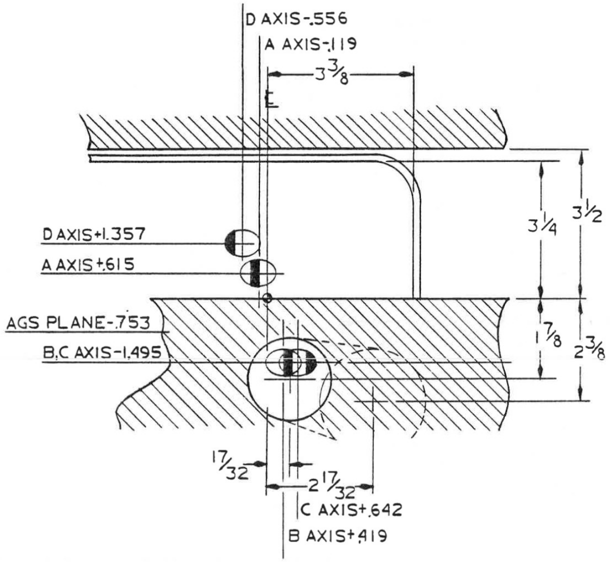
Electrostatic splitter



Thin Lambertson



Thick Lambertson



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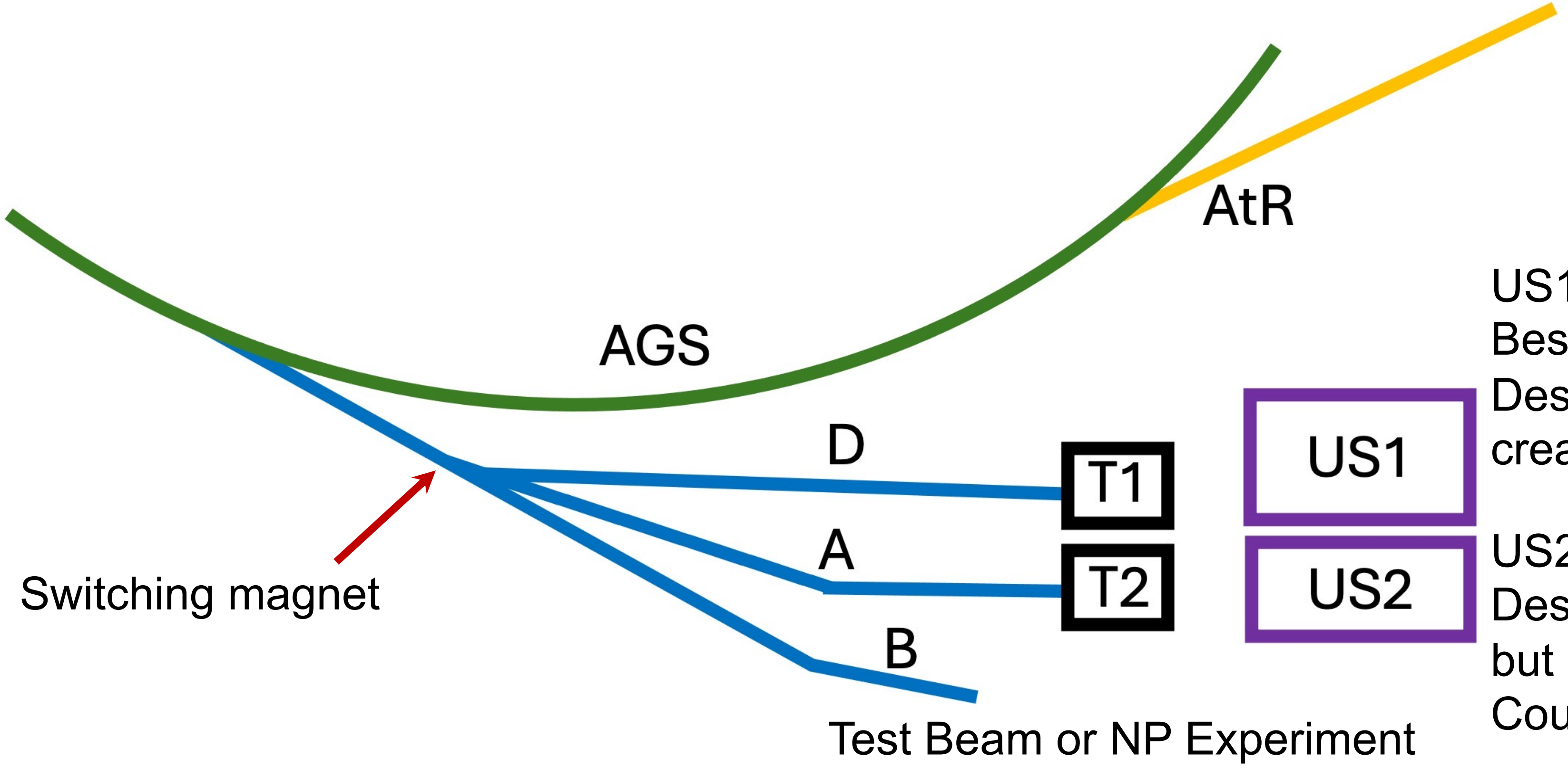
For Example: 3 different Users



US1 might be electronics testers
Best use of Dline is for low energies
Designed to give large uniform beams
created using octupole magnets

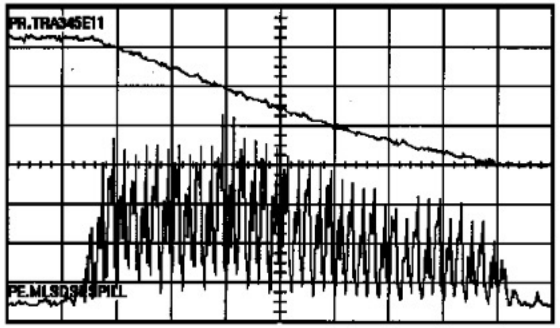
US2 may be anything
Designed to give large uniform beams
but by rastering a small beam.
Could deliver small beams on a target.

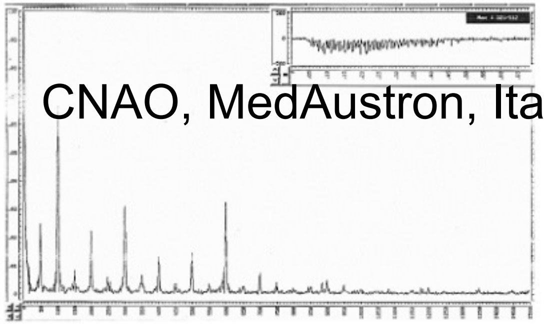
Beam Quality and methods to improve duty factor

Main beam quality issues to consider

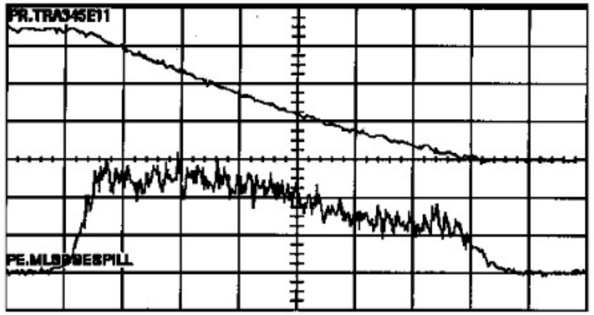
- Spill quality
  - Historically it was around 30-40% modulated
  - Modulation comes from tune ripple in the AGS (ripple on power supplies modulate the betatron tune during extraction)
  - Active filter (on AGS Main magnet PS) helps
  - Additionally, adding a high frequency quadrupole and modulate will remove the ripple structure (have such system Booster, R&D project)
- Beam size and shape
  - small Gaussian shaped beams (~ a few mm diameter)
  - Making very small beams increases the angular divergence – so a careful analysis of the beam parameters is needed to inform the optics design
- Beam Motion on target
  - Historically a challenge in the switchyard. No dispersion control.
  - Two ways to fix it: ramp dipoles with spill or design achromatic tune.

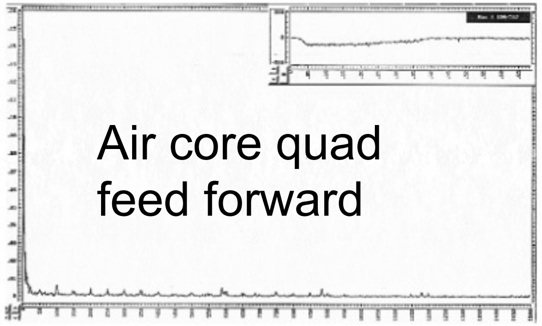
Samples of Spills



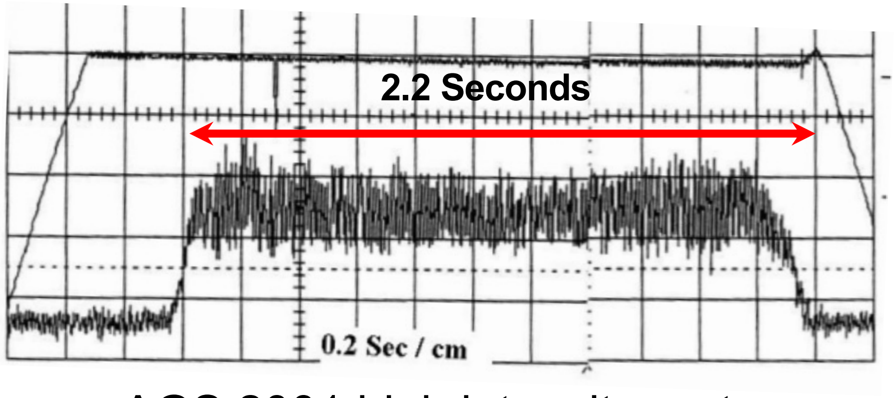


CNAO, MedAustron, Italy

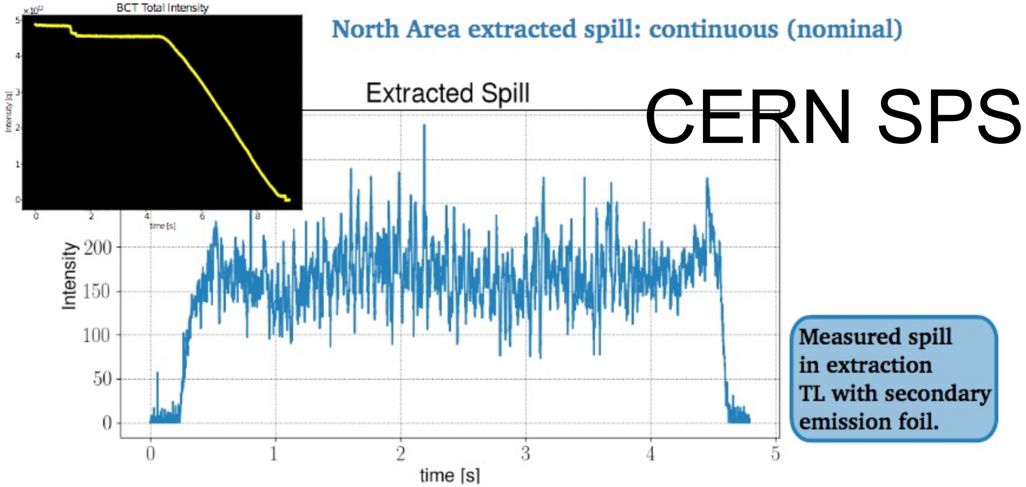




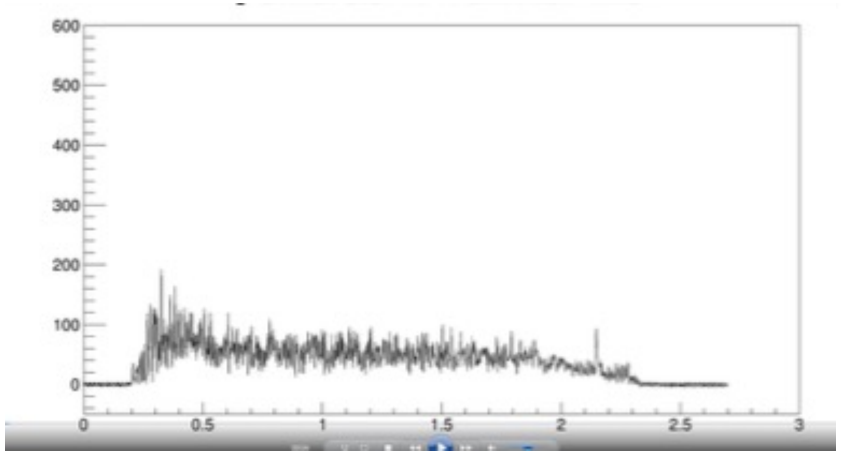
Air core quad feed forward

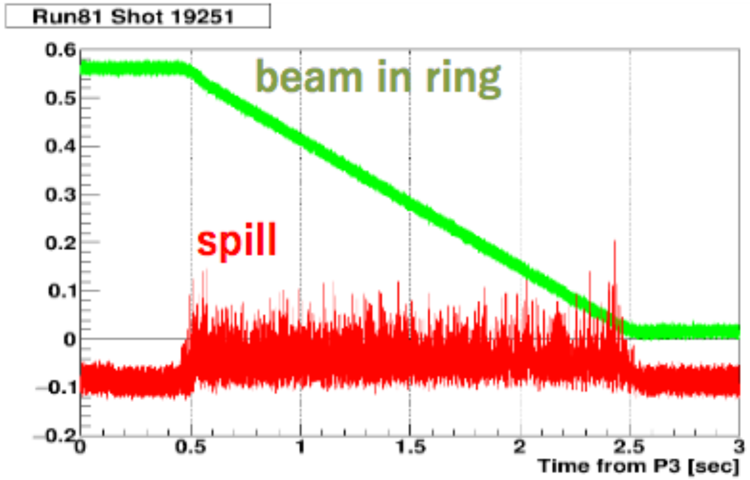


AGS 2001 high intensity protons



CERN SPS

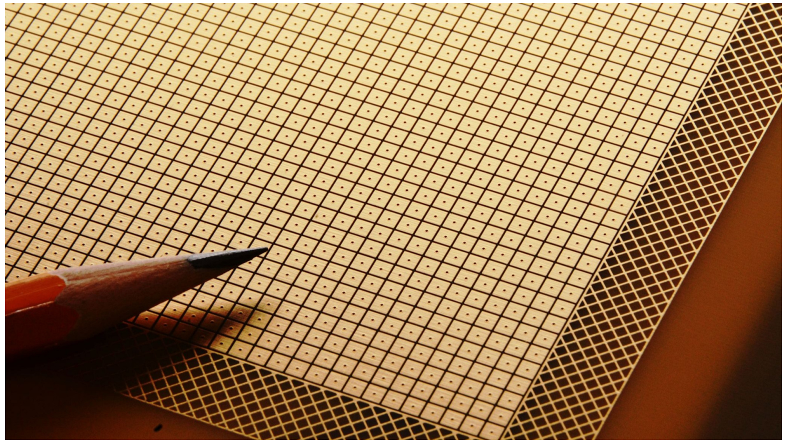




JPARC has some unique problems, due to operation with zero chromaticity.

Beamline instrumentation: commercial ion chambers

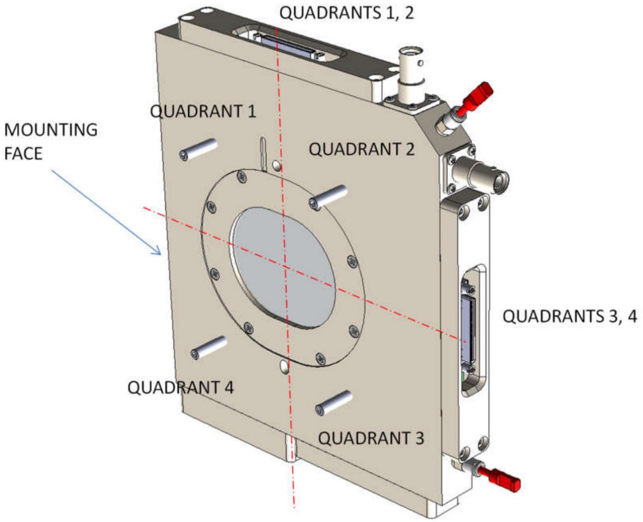
Pyramid Technical Consultants make a wide array of devices.
We have a large 25x25 cm unit with pretty big pixels in a 16x16 array.
We have plans for a 16x16 cm unit with 1 cm pixels. We hope to end up with a wide range of both thin and thick detectors fairly soon, but with 16x16 pixels in all cases.

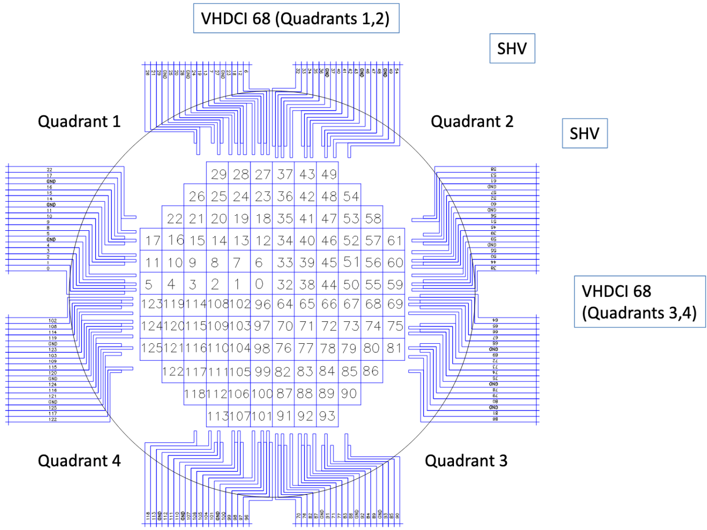


Pixelated 2D-Sensing Thin-film Ionization Chamber

Features

- Choice of readout electrode pattern area: 42 mm diameter with 3.8 mm pixel pitch, 28 mm diameter with 2.5 mm pixel pitch
- Low insertion length: 20 mm face to face
- Ionization chamber with 120 pixel readout for position and shape monitoring
- Ultra-thin film windows and electrodes permit "always in beam" applications with minimal beam scattering
- HV loopback for bias voltage validation
- Operable with atmospheric air or flow-through gas mixture
- Integrated environmental sensors
- Integrated replaceable desiccant
- Compatible with I128, I128S and I6400 readout electronics





https://ptcusa.com/

Options for NP fixed target experiments

What's available?

Ions'?

- NSRL has used
  C, Ne, Si, Cl, Ar, Ti, Fe, Kr, Nb, Ag, Xe, Tb, Ta, Au, W, Bi, Th
- RHIC has used
  d, Al, O, Cu, Zr, Ru, Au, U
- Old SEB => mostly Au at 11 GeV/n/c

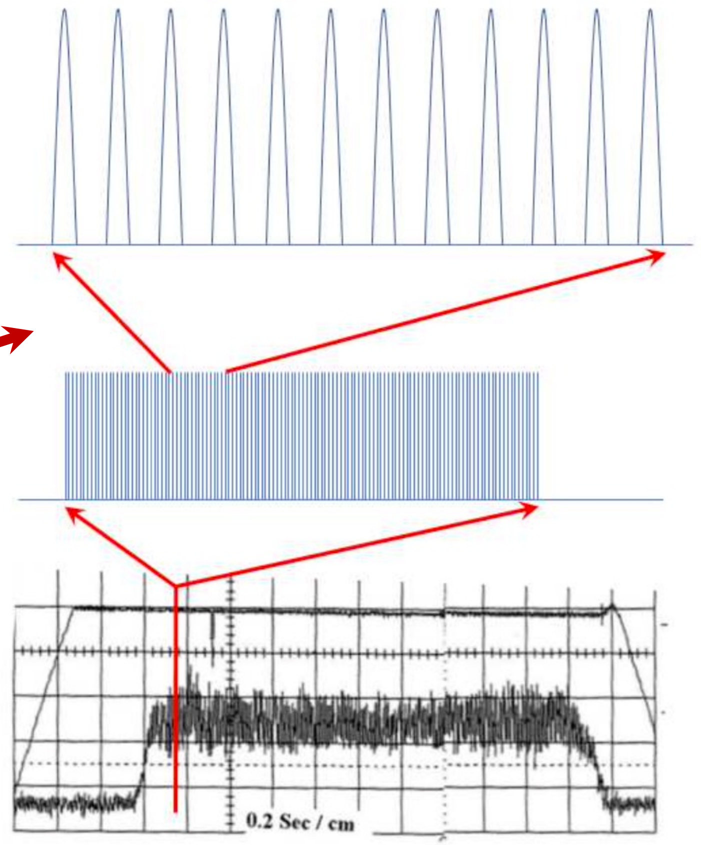
Energies?

- AGS can run as high as Bρ = 100 Tm (roughly 28 GeV/c protons or 10.8 GeV/n Au)
- Lower energies are possible, but beam size gets bigger. However, we might get down to ~10 Tm, or ~1.2 GeV/n for Au. Beam will be x3 larger, so likely higher losses.
- d => 14 GeV/n and He3 => 19 GeV/n (fully stripped in AGS)

Operation Modes to Switchyard

Once Extraction to switchyard is re-established

- Slow extraction from the AGS with 2- to 4-second-long spills
  - Options:
  - Completely debunched, smooth constant flux
  - bunched beam SX, to get 0.2 - 2.5 μsec bunch spacings – simulate collider beams
  - Possible microbunched beam, but will require high freq RF
    (e.g., <1 nsec bunches w/ 10 – 40 nsec spacing)
- Fast Extracted single bunches (like G-2, but to the switchyard beamlines)



1.5M micro-bunches, <500,000> ions/bunch

Scheduling

- RHIC operations to end some time between Dec 2025 and Apr 2026
  - RHIC equipment removal to commence immediately to begin ~10 year construction effort for the Electron-Ion Collider

- BLIP, NSRL operation to continue in the intervening years
  - Requires only sources and Booster in stretches of several weeks to a few months throughout the year

- AGS to be operated for (on average) two months a year for development
  - Exact distribution of time not at all settled, funding contingent (longer, less frequent blocks better?)
  - Development time planned mostly for polarized species
    - Principally: development of polarized ^3He. Dominates the time, requires new equipment in Booster and challenging AGS setup. Only the second polarized species in AGS.
    - Commissioning new systems: Polarization resonance correction schemes, TBT BPMs, upgraded tune meter

  - Other AGS efforts, like test beams, not currently allotted

Summary

- We have a long history of delivering many kinds of beams to experiments from the AGS.
- Slow extraction from the AGS is currently disabled. Will require $10's of millions to resurrect beam in building 912.
- We have many questions, but much depends on experimental requirements and how well AGS capabilities can match those requirements.
- If we started today, it would take a few years to have beam.

Questions (from me)

We assume interest is in polarized beams, d, and He3 ions.

Does community want K.E. = 10.8 GeV/n Au beams?

Can a cheap new detector be built from old STAR/sPHENIX parts?

What kind of targets are needed? Polarized? Jets? Solid?

How long to get a detector installed?

Please note: assume a schedule of 3 years to get beam in 912.