An EBIS-based RHIC Preinjector - Overview

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This talk – **<u>why</u>** EBIS is needed.
The next three talks will show **<u>how</u>** we'd do it.

Ed Beebe – Test EBIS Results
Sasha Pikin – Design of the EBIS for RHIC
Deepak Raparia – RFQ & Linac

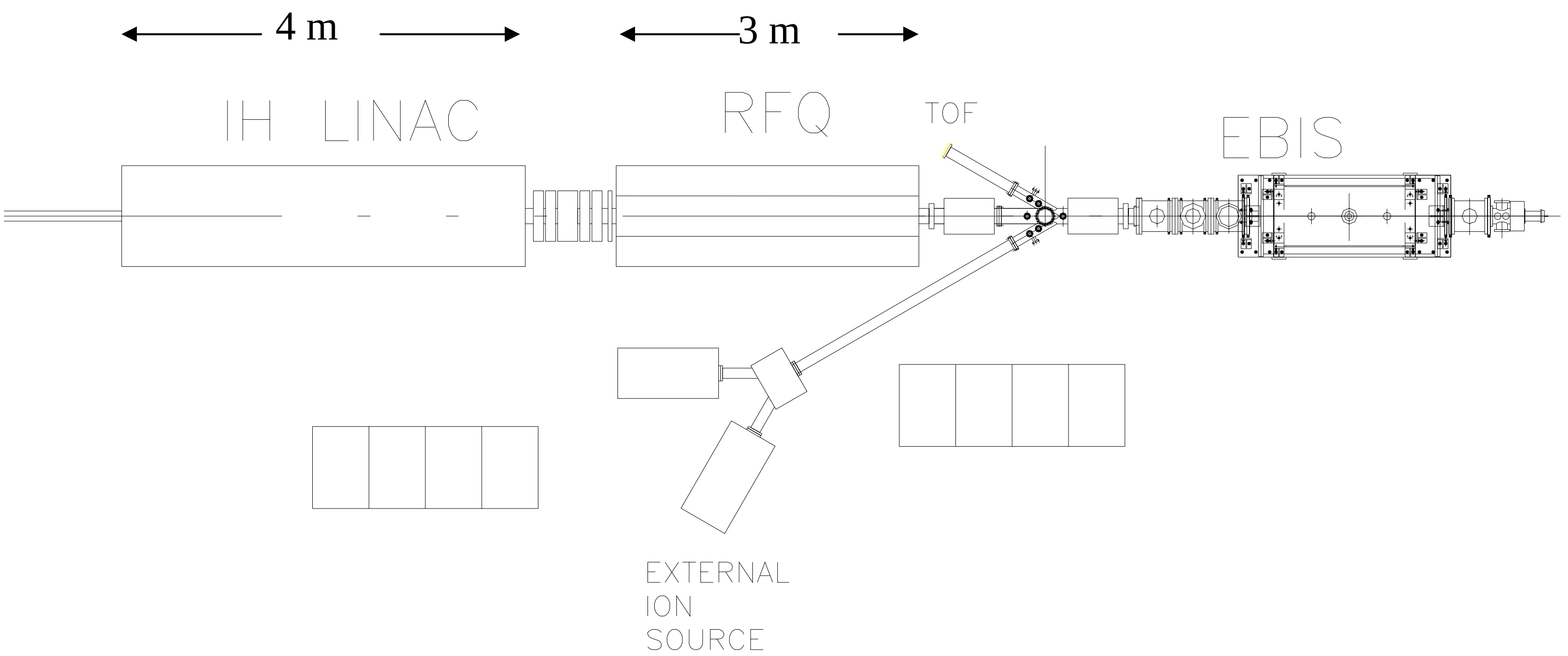
EBIS - Overview

BNL has proposed an initiative for new pre-injector for RHIC based on the Laboratory's development of an advanced Electron Beam Ion Source (EBIS).

The new preinjector would consist of an EBIS high charge state ion source, a Radio Frequency Quadrupole (RFQ) accelerator, and a short linac.

Presently, one or two ~35-year old Tandem Van de Graaff accelerators are used for RHIC pre-injection, but the recent advances in the state of the art in EBIS performance by more than an order of magnitude now make it possible to meet RHIC requirements with a modern linac-based preinjector.

Proposed Linac–Based RHIC Preinjector



RFQ: 8.5 - 300 keV/u; 100 MHz

Linac: 0.3 - 2.0 MeV/u; 100 MHz

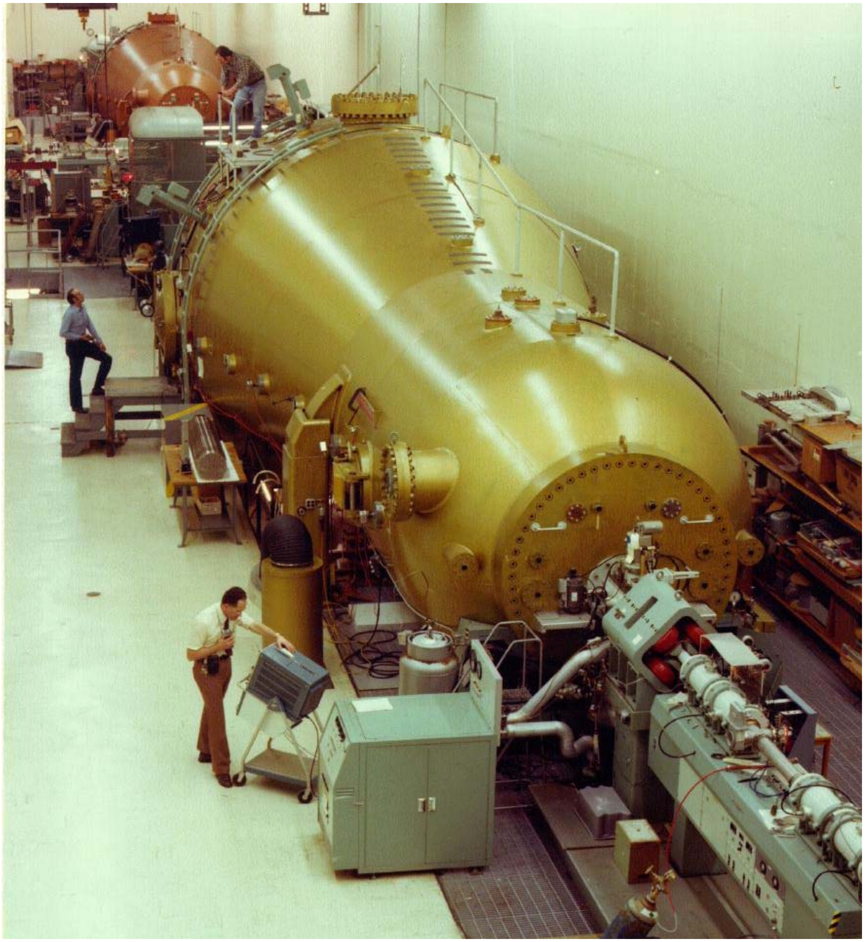
The EBIS preinjector offers the following benefits:

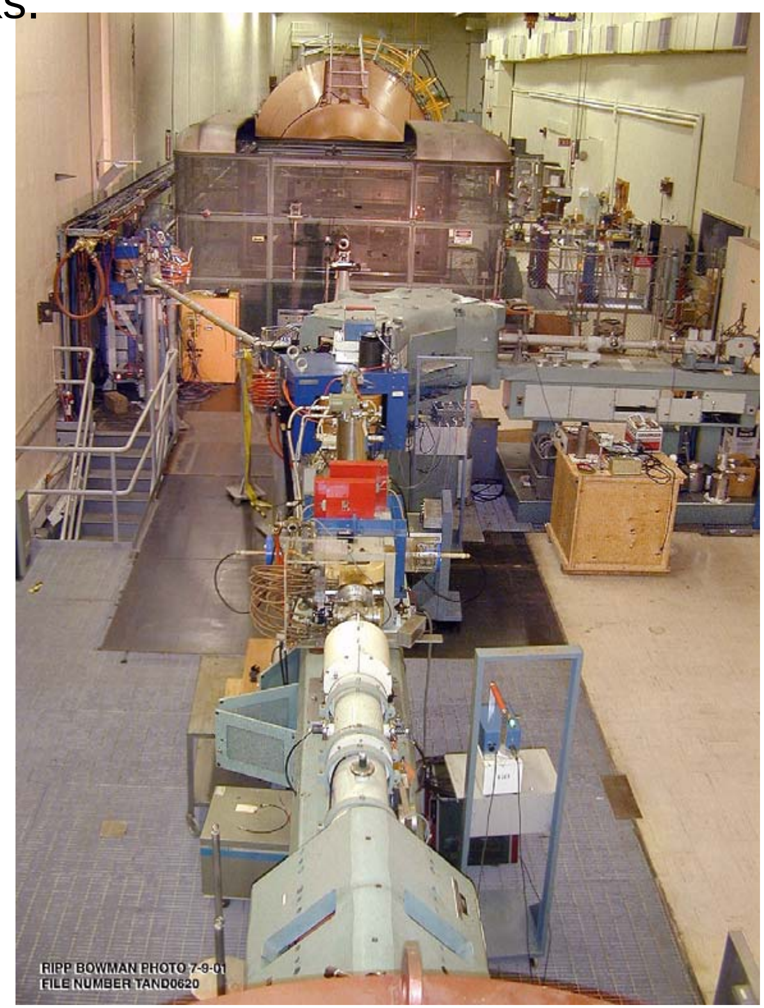
- Improvements in reliability, setup time, and stability should lead to increased integrated luminosity in RHIC
- Reduced operating costs, and avoidance of ~ 6 M$ in reliability-driven investments in the tandems
- Elimination of two stripping stages and an 860 m long transport line, leading to improved performance
- Simplification of Booster injection (few turn vs. present 40 turn)
- Increased flexibility to handle the multiple simultaneous needs of RHIC, NSRL, and AGS
- Capability to provide ions not presently available, such as noble gas ions (for NSRL), uranium (RHIC), or, with additional enhancements, polarized ^3He (eRHIC)
- Simpler technology, robust, more modern (Tandem replacement parts becoming difficult to get)

The list of benefits on the previous slide does not effectively convey our concerns with the Tandems, and the cost and effort required to operate and maintain them.

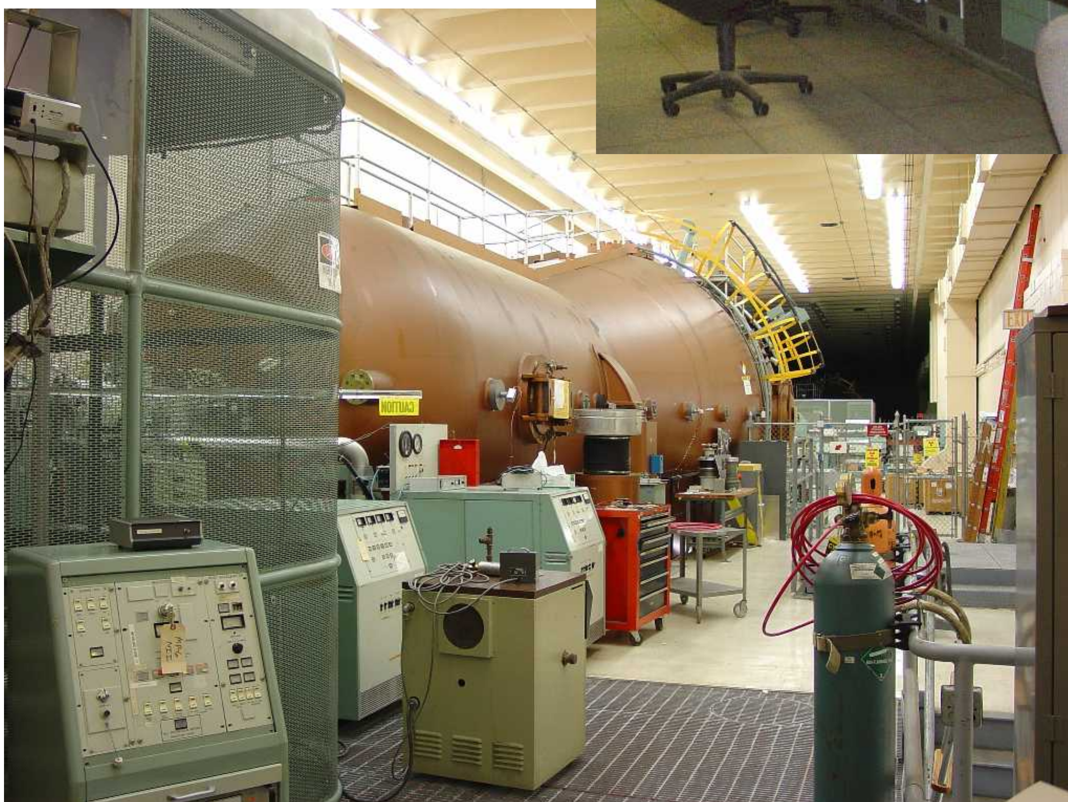
One needs to understand the size of the Tandem facility, the number and size of the support systems, and the age of its components, in order to better appreciate the great simplification the EBIS Preinjector offers.

Each tank is 81' L x 18' diameter. 11,250 cu. ft. of insulating gas at ~ 180 psi. The gas handling system, mostly original equipment from 1966, consists of large pumps, compressors, gas dryers, control valves, gauges, relief valves, heat exchangers, and underground storage tanks.



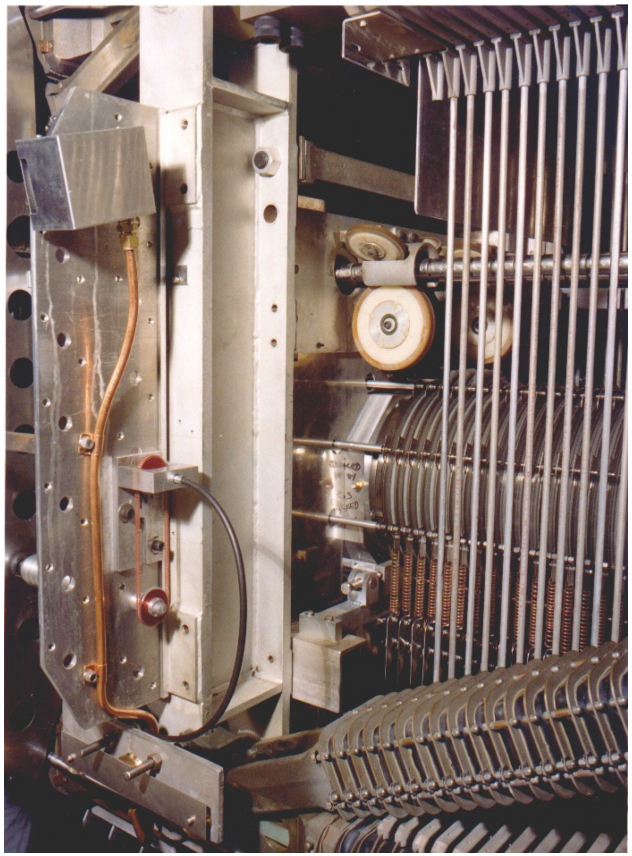


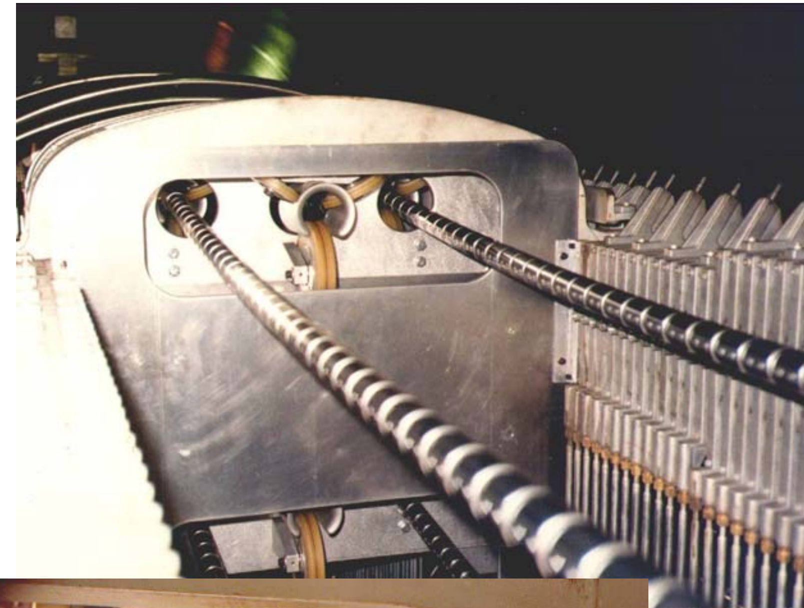
Controls – original equipment (1970). Dials control micropositioners, turning lucite rods going to ps's at HV. Readbacks are cameras aimed at meter at HV.

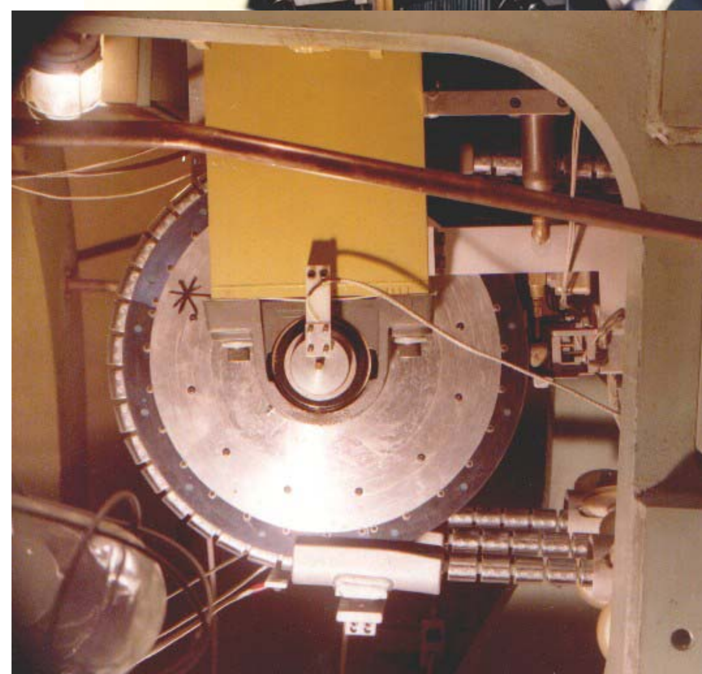


Because of the high sensitivity at Booster injection to the settings on many of these devices, machine reproducibility becomes difficult, and one instead needs to perform frequent retuning. In addition, automatic monitoring of device statuses is impossible.

Internally, lots of components –
chains, pulleys, motors, alternators, resistors (>1000), vacuum pumps, foil holders, gas bleeds, steerers, lenses, ….



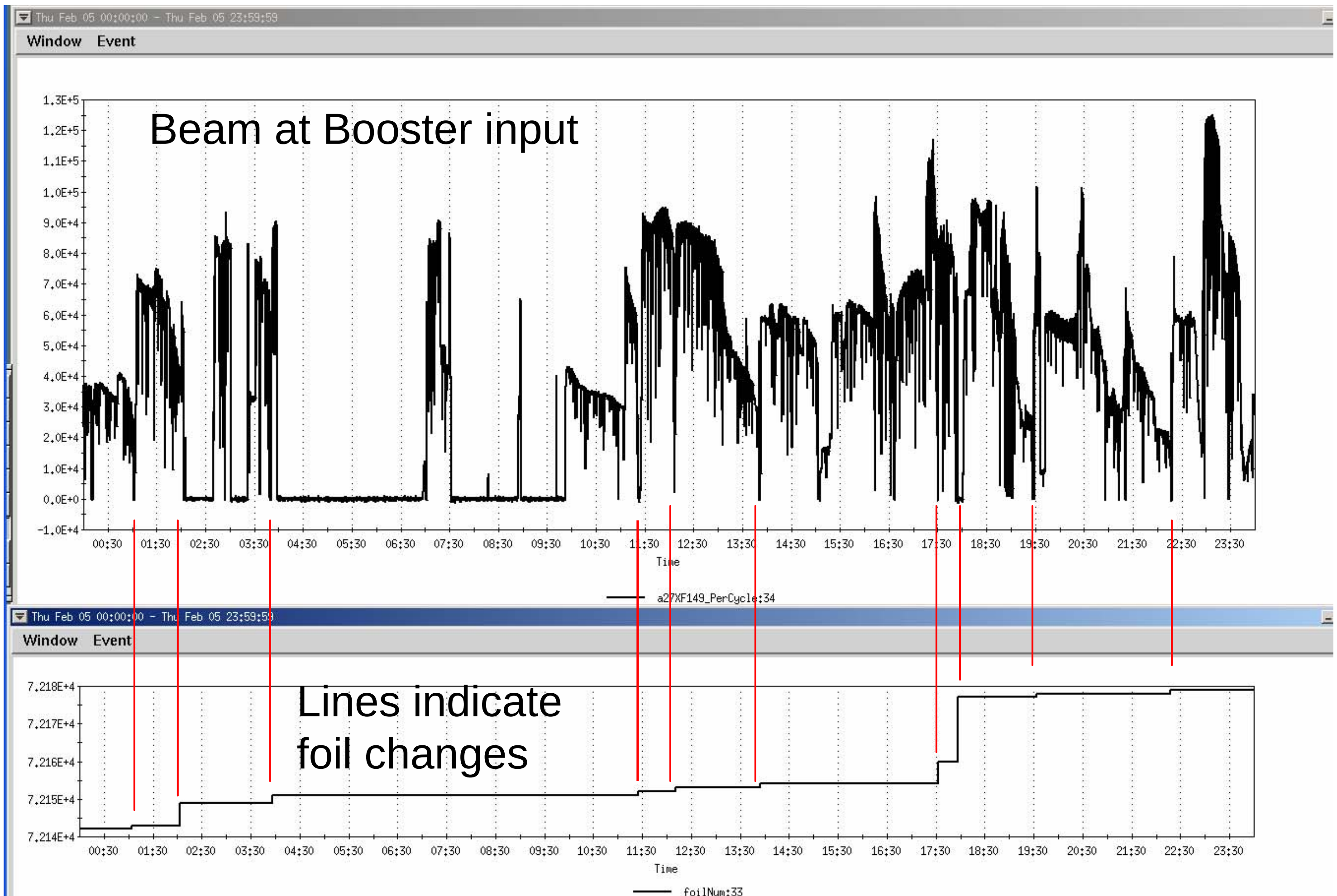


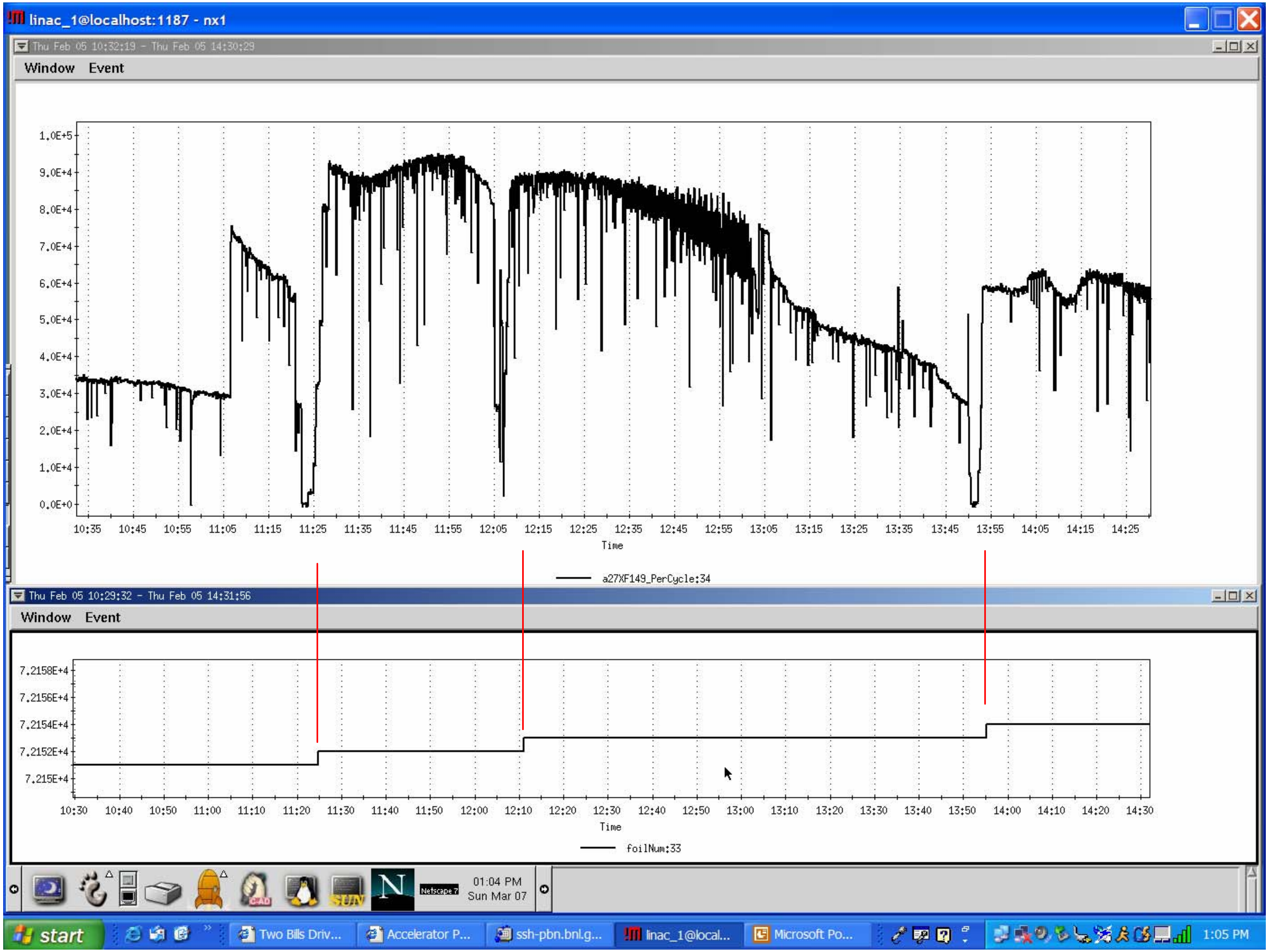


<u>Stripping Foils</u> – 2 stripping stages required for the Tandem: Au^{-} ☾ Au^{12+} in the terminal; Au^{12+} ☾ Au^{32+} at the high energy end.

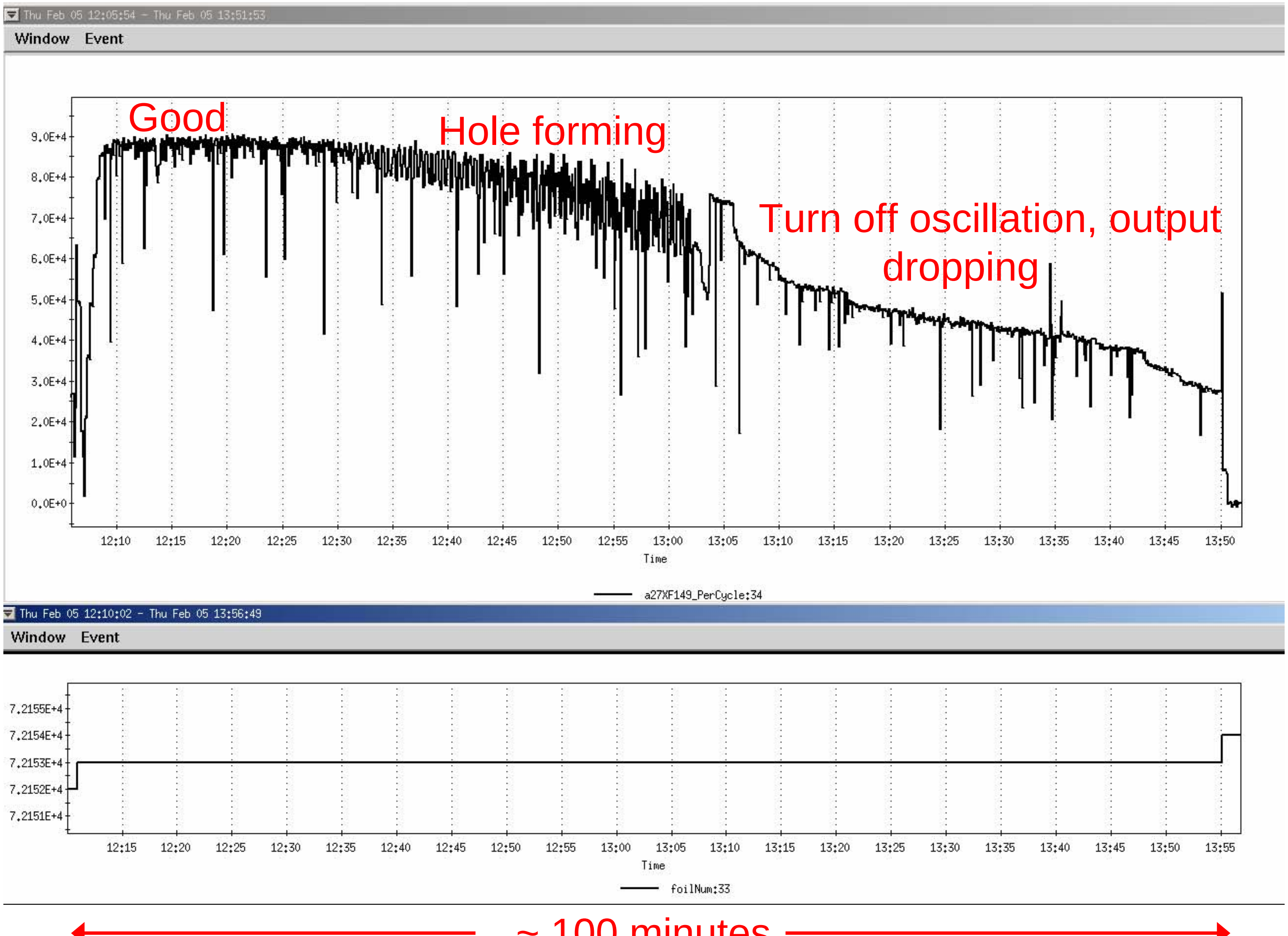
With EBIS, <u>no stripping</u> is required before the Booster.

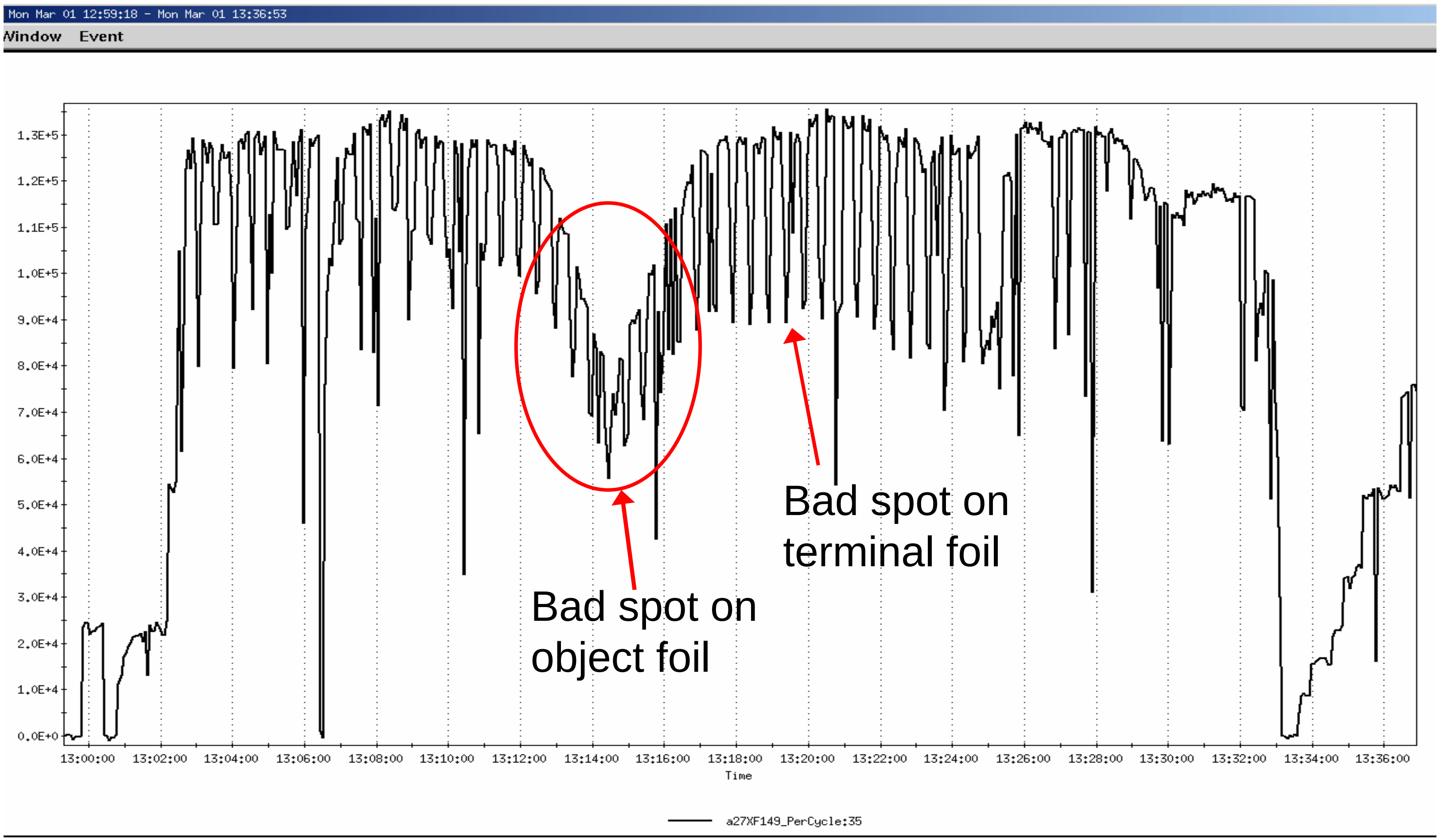
Beam evolution through 24 hours; 11 terminal foils




linac_1@localhost:1187 - nx1
Thu Feb 05 10:32:19 - Thu Feb 05 14:30:29
Window Event
Time
a27XF149_PerCycle:34
Thu Feb 05 10:29:32 - Thu Feb 05 14:31:56
Window Event
Time
foilNum:33

Evolution of a terminal stripping foil





The continuous changes in both terminal and object foils means that considerable attention is required of a Tandem operator just to maintain optimum intensity.

Tandem sparks – it's going to happen occasionally. (Unfortunately, sometimes they cause further damage).

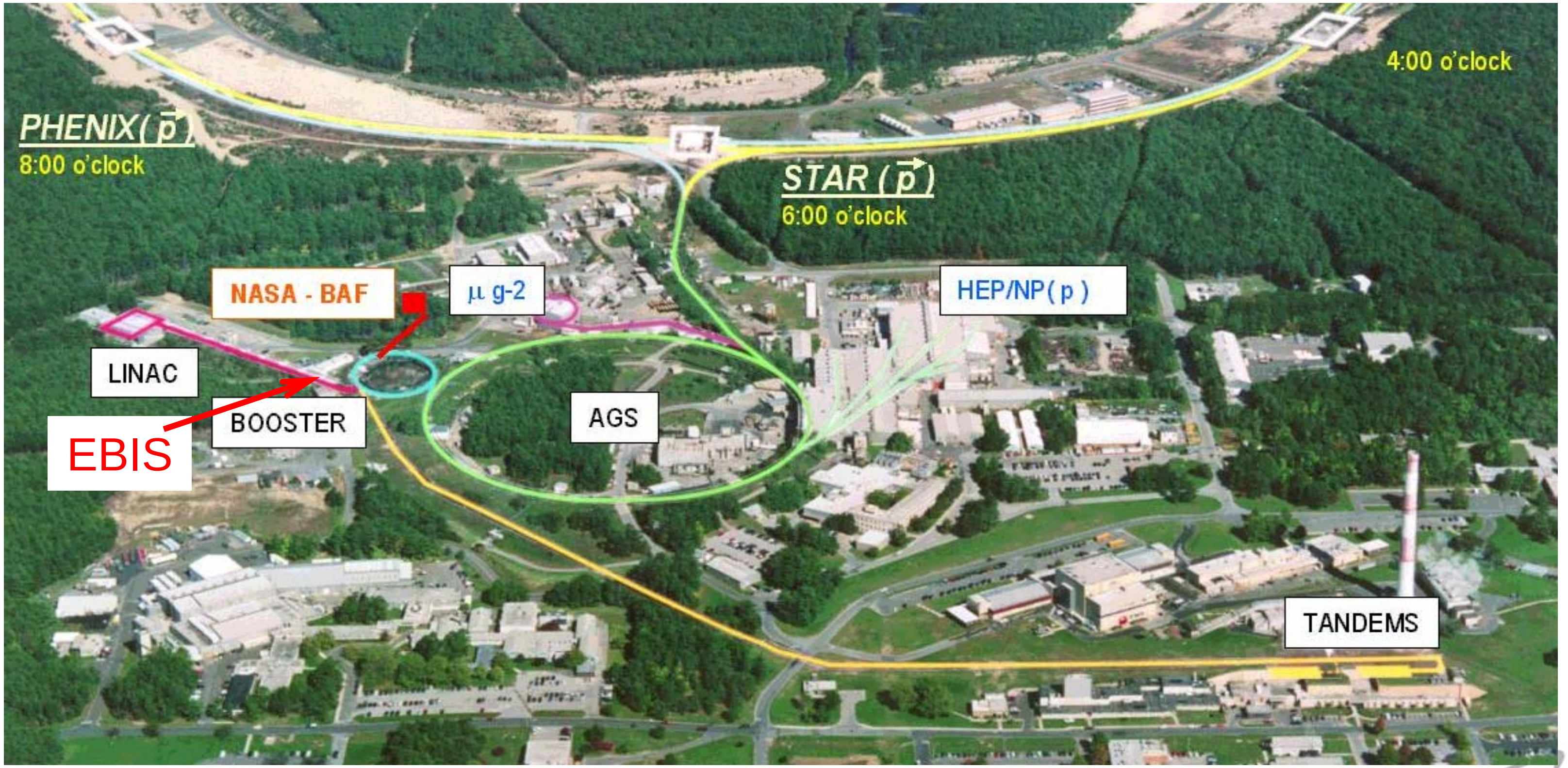
Jan 3 2004 6:30:19: Tandem Sparked
Jan 3 2004 7:05:59 Summary: Physics ran for 9.3 hours this shift along with 2.5 hours of Machine setup. One hour of machine setup was used in the middle of the store for gap cleaning. As of the end of shift, Tandem has recovered from a spark, RHIC is back at injection, and CAS is investigating blue acceleration cavity #1.
Jan 8 2004 4:07:17: Tandem Sparked
Jan 8 2004 4:50:52: Tandem has recovered from the spark.
Jan 11 2004 9:24:05: Tandem Sparked (MP7).
Feb 3 2004 1:39:37: Tandem reported that MP7 has sparked.
Feb 3 2004 2:00:19: Tandem has just recovered from a spark. The blue ring is having difficulties with beam being injected into the wrong bucket.
Feb 6 2004 8:15:02: Tandem spark.
Feb 6 2004 11:00:00: C. Carlson reported that Tandem has sparked several times this morning. Tandem personnel have reduced the voltage on MP7. Tandem is currently providing beam, but Booster input is significantly low (100e8 ions.)
Feb 6 2004 6:30:10: Tandem personnel reported that MP7 sparked.
Feb 6 2004 6:40:37: Tandem reported that MP7 sparked again. They estimate that beam will be off for one hour.
Feb 6 2004 8:02:36 Summary:
Physics ran for 4.17 hours this shift. Tandem personnel spent several hours restoring MP7 after multiple sparks this shift. As of the end of the shift, Tandem is recovering from
Feb 6 2004 8:34:49: Tandem spark.
Feb 6 2004 11:04:20: Tandem spark.
Feb 7 2004 7:02:36 Summary: Physics ran for 4.1 hours this shift. The first half of the shift consisted of many failures including Tandem sparks, RHIC QLI's, RHIC lead flow trips and Booster main magnet power supply trips. Eventually the rings were filled and ramped and a store was established. The PHOBOS interaction point was lowered vertically by 7 mm at the beginning of the store. A blue quench finished the store and recovery is underway. Tandem switched to MP6 this shift for RHIC injection due to all the sparking in MP7. As of the end of the shift beam is available but at lower intensity. Tandem personnel continue to optimize the machine. The RhicInjection program steering corrections do not work.
Feb 7 2004 9:54:00:
In addition, Tandem is continuing to work on increasing the output from MP6. After briefly discussing the possibility of switching back to MP7, K. Yip, J. Alessi, and I have decided to allow Tandem to work on increasing the intensity from MP6. The Tandem operators believe that they can restore much if not all of the intensity that was previously being delievered from MP7. MP7 will require prolonged downtime to fix the sparking problems.

Feb 22 2004 5:33:39: Tandem spark.
Feb 22 2004 5:59:40: Tandem has recovered from the spark.
Mar 3 2004 3:10:47 Summary: Scheduled maintenance ran all shift. Work with gold beam in the booster was hampered by several tandem sparks throughout the day. As of the end of the shift RHIC sweeps have begun, Linac is running, booster low-level RF work is underway and the AGS access continues.
Mar 3 2004 4:50:14: Tandem has sparked again. There appear to be temperature problems related to recent change in weather that are creating difficulties.
Mar 4 2004 10:15:48: Tandem spark.
Mar 4 2004 1:03:26: Tandem spark.
Mar 4 2004 1:47:05: Tandem spark.
Mar 4 2004 2:35:26: Tandem spark.
Mar 4 2004 7:04:32 Summary: Physics ran for 5.3 hours this shift; machine development ran for 4 hours. As of the end of the shift work continues in RHIC with a 6 bunch ramp using the merge setup. Setup for the bunch merge scheme ran behind the second store but was interrupted by several tandem sparks. Setup work for the Booster D6 septum and correction continued, but it was still necessary to tune the D6 correction winding to restore optimal performance after running the septum on and off sequences several times.
Mar 5 2004 12:30:00: Tandem spark. Tandem operators are working to recover.
Mar 5 2004 1:57:00: Tandem sparked once again, but they are currently estimating 11 minutes before recovery is complete.
We conduct a hysteresis ramp while waiting for Tandem to recover.
Mar 5 2004 3:07:18: Tandem reports that they are having significant problems with beam stability. They report that the beam is erratic and conjecture that it may be caused by a power supply, by problems with the foil mechanism, or by residual sparking. They also indicate that they have expended their supply of conditioned foils and would have to condition foils immediately before use. They continue to investigate.
Mar 5 2004 3:08:52: Tandem sparks again.
Mar 5 2004 4:24:09: Tandem spark.
Mar 5 2004 7:08:14 Summary: Physics ran for 6.13 hours in RHIC and BLIP ran for 12 hours. Two physics stores were achieved in RHIC, the second of which continues as of the end of the shift. Establishment of the second store was hampered by several Tandem sparks that required a significant amount of time to recover from. During this time, polarized proton work progressed in the Booster and AGS.
Tandem sparking occurred all throughout the shift, and impeded establishment of a second RHIC physics store. The problem has been particularly acute in recent days.
Mar 5 2004 9:03:04: RHIC at injection; tandem spark.
Mar 6 2004 12:01:14: Tandem spark.

Tandem to Booster transport line is 860 m long.

44 quadrupoles
71 steering dipoles
6 large dipoles
25 multiwires
20 Faraday cups
Dozens each of pumps, vacuum valves, vacuum gauges, etc.

The transport from the EBIS to the Booster will be only 30 m long!



All beams from the Tandems must start as negative ions. EBIS can produce <u>any</u> type ions. (As a future upgrade, the EBIS could be an ideal ionizer for polarized ^{3}He).

With the EBIS, one will be able to switch between beam species on a pulse-to-pulse basis, for running asymmetric beams in RHIC, or RHIC & NSRL. With the Tandem, pulse-to-pulse switching requires the use of <u>both</u> Tandems (and the transported beams must have the same rigidity).

Concern that the Tandem was not the best long-term solution for RHIC preinjection led us to investigate alternatives. Linac-based preinjectors are much more conventional, and offer many advantages, but an ion source which could deliver intermediate charge state heavy ions of the required intensity did not exist.

Following a very successful ion source development program at BNL (factor of 20 improvement in intensity), we have now demonstrated that an EBIS can meet RHIC requirements, and are ready to proceed with a new preinjector. The required RFQ and short linac are very straightforward.

Real concern – worked long and hard on EBIS – Success!

the Bulletin

BROOKHAVEN NATIONAL LABORATORY

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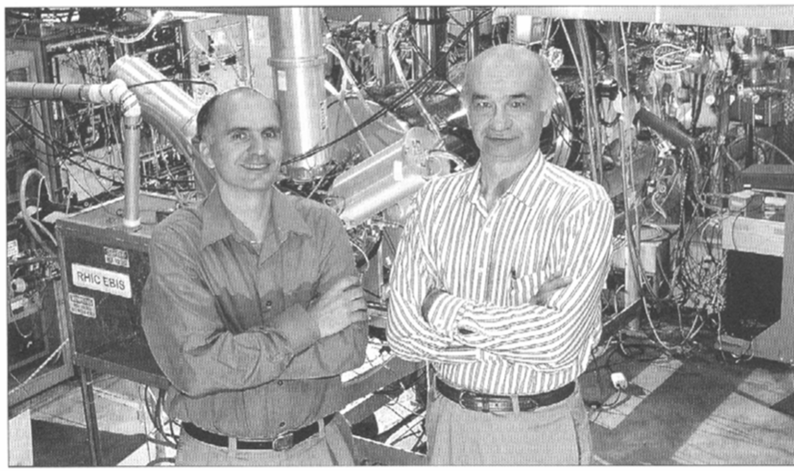
Edward Beebe and Alexander Pikin Win 'Brightness Award' For Achievement in Ion Source Physics, Technology

Edward Beebe and Alexander Pikin, physicists in the Collider-Accelerator Department, have been awarded the Ion Source Prize, known as the "Brightness Award," which recognizes and encourages innovative and significant recent achievements in the fields of ion source physics and technology.

The two physicists received the award on September 9, at the Tenth International Conference on Ion Sources, held in Dubna, Russia. Donated by Bergoz Instrumentation of Saint Genis Pouilly, France, the award consists of $6,000, to be shared by the two winners, and a certificate for each.

An ion is an atom that has a net excess or deficit of electrons, allowing it to be manipulated by electric and magnetic fields. Ions are accelerated to nearly the speed of light for physics research in accelerators, such as the Relativistic Heavy Ion Collider (RHIC). Funded by the DOE's Office of Science, Nuclear Physics, Beebe and Pikin have developed and tested a new high-intensity version of a source that produces highly charged heavy ions, called an electron beam ion source. The number of ions generated by this source is twenty times more than in previous designs. BNL plans to eventually use a version of this source for ion injection into RHIC. In addition, the new ion production method may be adapted for use in other particle accelerators, such as the Large Hadron Collider at CERN, the European laboratory for particle physics.



Roger Stoutenburgh

Edward Beebe (left) and Alexander Pikin stand in front of the electron beam ion source that they developed and tested at Brookhaven Lab.

Since 1970, two accelerators at Brookhaven, known as the Tandem Van de Graaff, have provided researchers with heavy ions. The new method for producing ions would require only a small linear accelerator, about one-tenth the size of the Tandem Van de Graaff.

The new combination of ion source and accelerator will provide enhanced performance and will be easier to operate and maintain than the current method for ion production. The new source is able to directly create and accelerate highly charged positive ions. In contrast, the Tandem must begin by accelerating negative ions; stripping foils are then used to make the highly charged positive ions required for RHIC experiments. In addition, the new source is more versatile than the current method, since it can produce ion beams of any species.

For more information, see www.bnl.gov/bnlweb/pubaf/pr/2003/bnlpr090903a.htm.

— Diane Greenberg

Received at 10th International Conference on Ion Sources (Dubna)

BNL EBIS performance represents more than an order of magnitude improvement over past EBIS sources.

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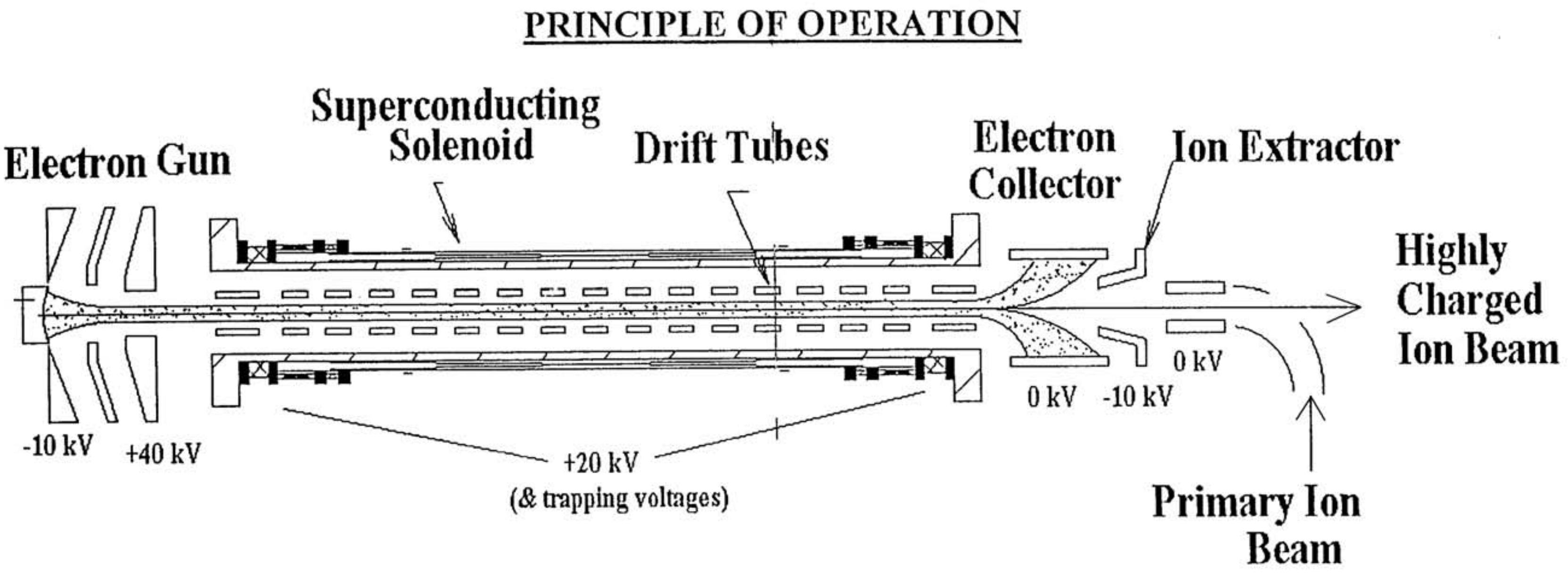
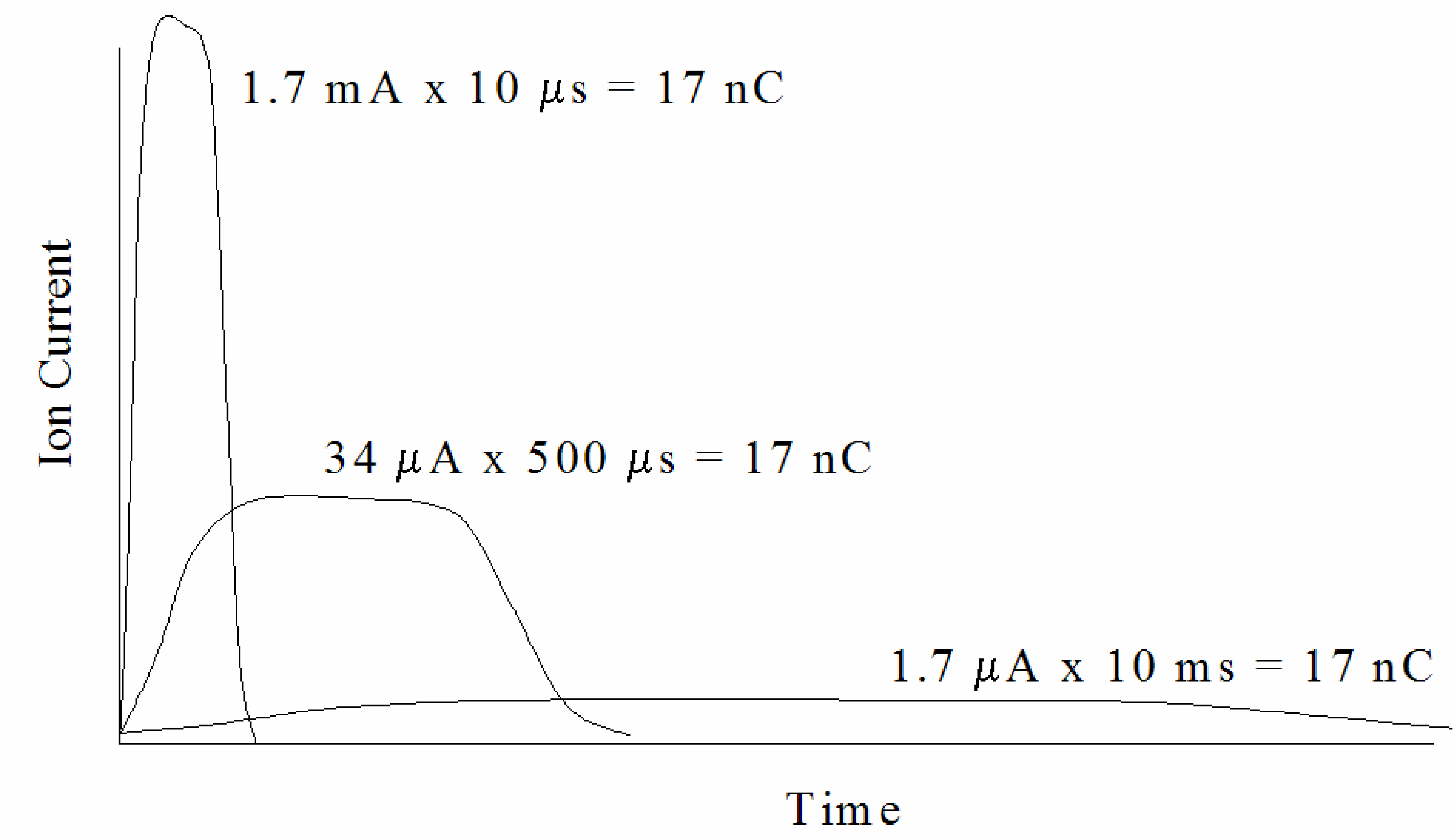


Radial trapping of ions by the space charge of the electron beam.
Axial trapping by applied electrode electrostatic potentials.

Ion output per pulse is proportional to the trap length and electron current.
Ion charge state increases with increasing confinement time.

Ions are extracted from an EBIS in pulses of constant charge; one has control over the pulse width

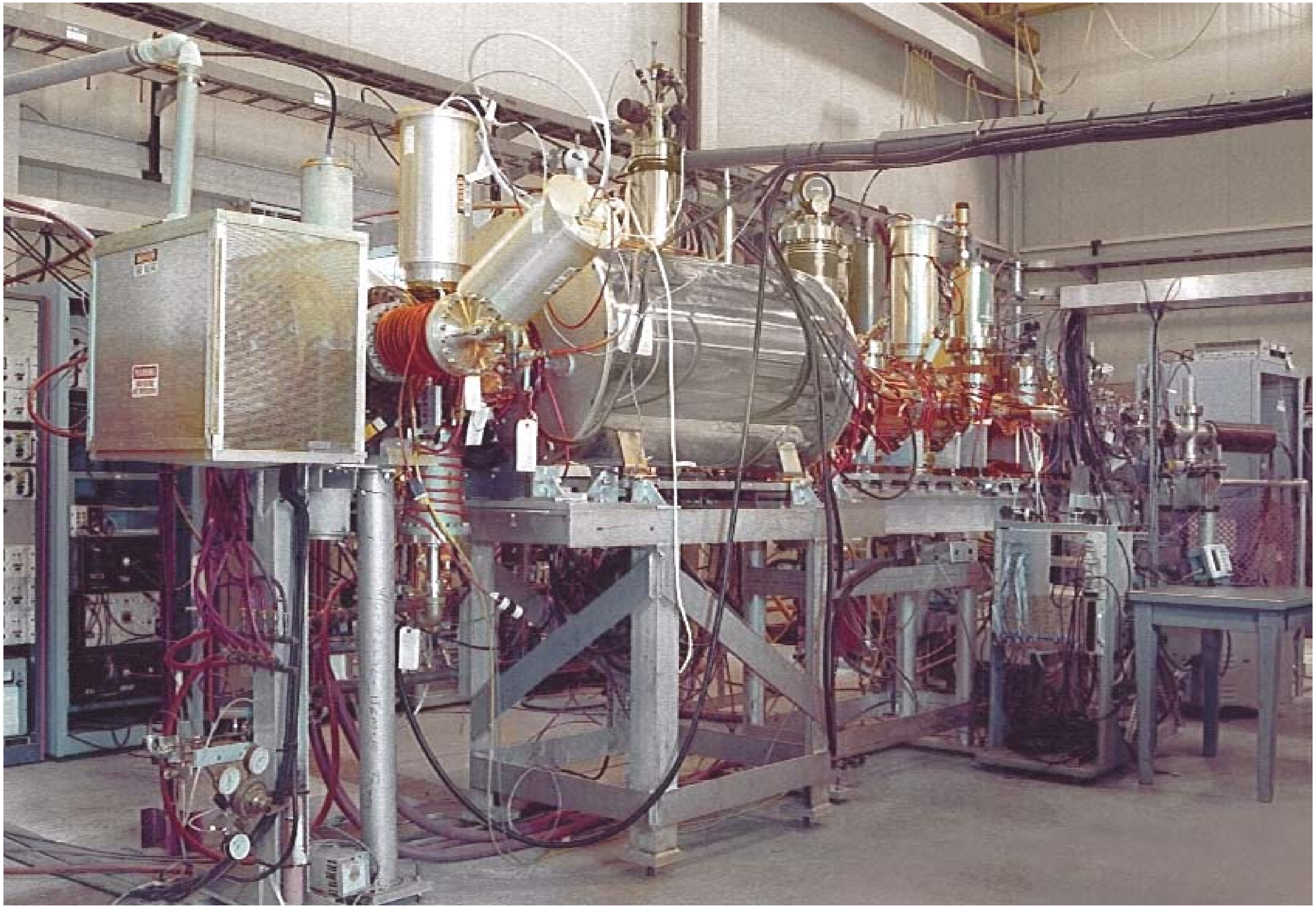


Advantages of an EBIS (vs. LIS, ECR)

- **An EBIS can produce any type ions – from gas, metals, etc., and is easy to switch species (pulse-to-pulse!)**
- **One has control over the charge state produced (easy to get intermediate charge states, such as Au^{32+} or U^{45+})**
- **One has control over pulse width, extracting a fixed charge – can better match to synchrotron requirements**
- **EBIS produces a narrow charge state distribution (≥ 20% in the desired charge state), so there is less of a space charge problem in the extraction and transport of the total current**
- **The scaling laws are understood**
- **The source is reliable, and has excellent pulse-to-pulse stability, long life**

Our R&D now shows that an EBIS meeting the RHIC requirements can be built. (mA's of Au^{32+} !)

EBIS Test Stand



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RHIC EBIS

Design changes relative to the Test EBIS, needed to meet RHIC requirements:

1. Longer SC solenoid and ion trap region
2. Collector design for higher average power

Improvements to increase operational reliability and safety margin:

3. Collector design for higher peak power
4. Electron gun capable of 20 A operation
5. Increases to the solenoid bore and maximum field

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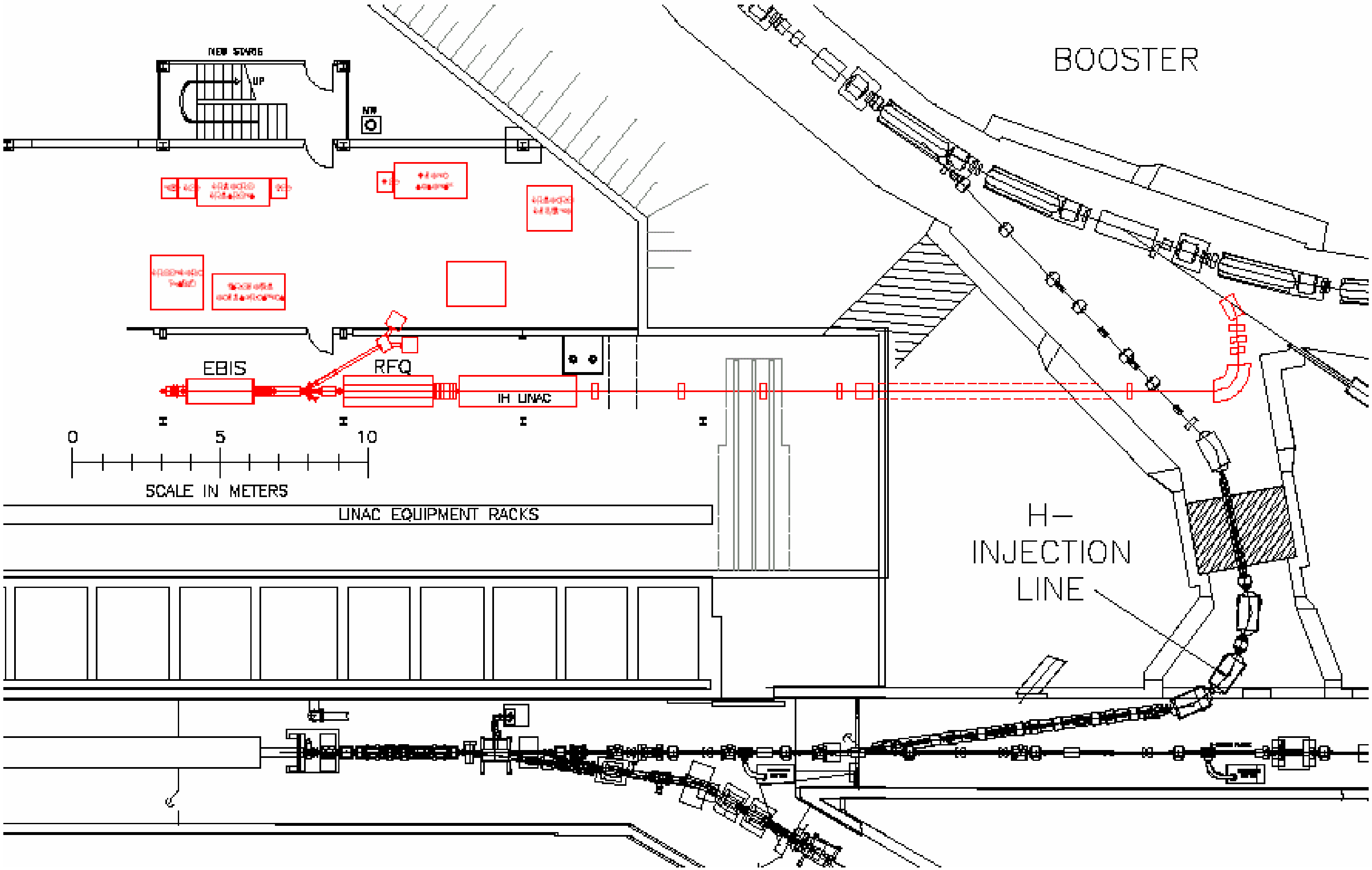
Proposed location at the end of the 200 MeV linac



EBIS 3-Year Construction Effort in FY '04$K

	FY05	FY06	FY07	FY08	Total
Pre-R&D					
R&D		898	408		**1306**
CDR	200				
PED/EDIA		1992	1284		**3276**
Cons		2623	3530	5266	**11419**
Preops/Commissioning		26	262	263	**551**
TEC		4615	4813	5266	**14694**
TPC		5539	5483	5528	**16550**
Planned redirect		3025	2948	2963	**8936**
Needed New Funds (TPC-redirect)		2514	2535	2565	**7614**

SUMMARY

- The EBIS initiative, a linac-based preinjector, is based on a modern technology, which will be simpler to operate and easier to maintain than the Tandems and will have the potential for future performance improvements.

- It will provide a robust and stable preinjector, which is important for the successful operation of the injectors.

- The RHIC EBIS design has been verified by the present EBIS operating at BNL.

- No significant improvement in performance is required, other than the straightforward scaling of ion output with an increase in trap length. The RFQ and linac are very similar to devices already operating at other labs.

NSRL Requirements

Species	Q	Q/m	E (Bster) (GeV/u)	Ions/pulse (NSRL)	EBIS Preinj.
^{12}C	6	0.5	1.23	12×10^9	28×10^9
^{28}Si	14	0.5	1.23	4×10^9	6×10^9
^{56}Fe	21	0.375	1.1	1×10^9	4×10^9
^{63}Cu	22	0.35	1.04	1×10^9	4×10^9
^{197}Au	32	0.162	0.3	2×10^9	2.7×10^9

All charge states can be reached in EBIS within a 100 ms confinement time.

EBIS can produce any ion species (including noble gases).