EBIS Status and Plans

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.

EBIS Status and Plans

EBIS (i.e. Linac-based preinjector)

What is it? Status of the development?

What advantages does it offer ?

How it addresses the weak points, concerns of the present Tandems

Cost, schedule

BNL Tandems

Have been operating for ~ 33 years.
Have been used for injection into AGS or Booster for ~ 17 years!

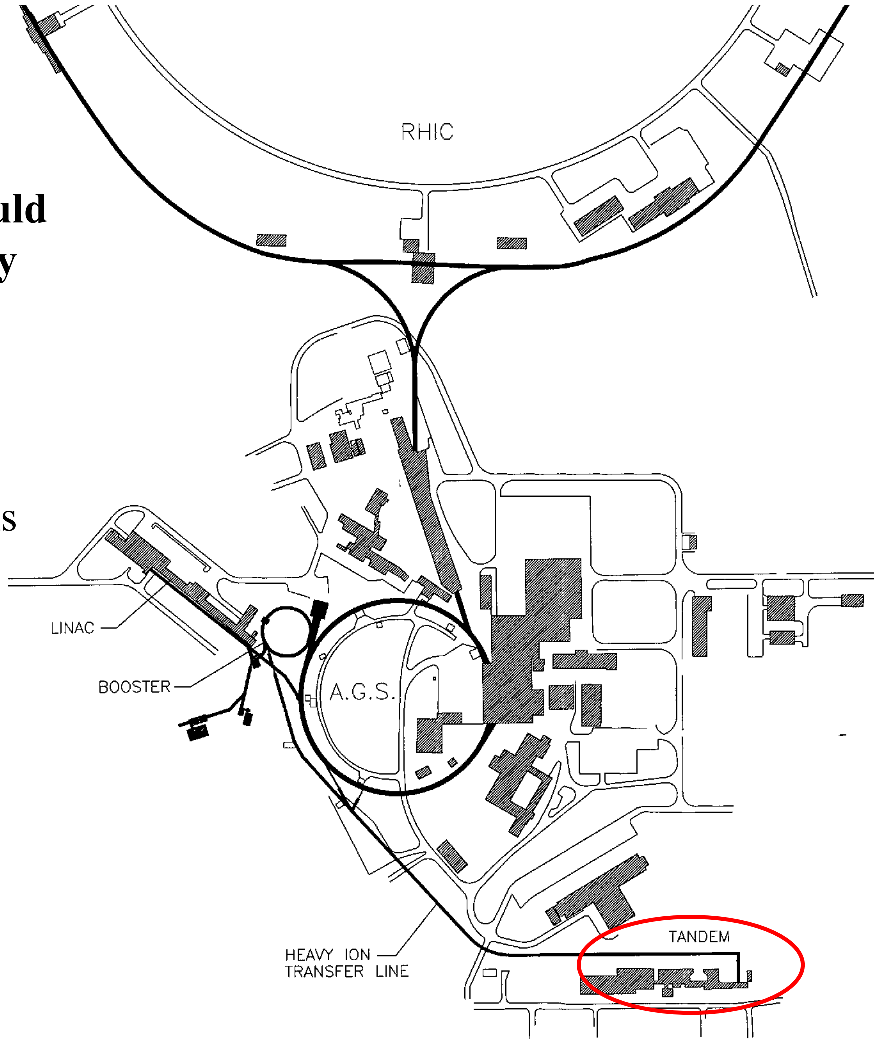
The use of the tandems as preinjectors was a very difficult task, and a tremendous success.
Present reliability is quite remarkable, but equipment is becoming old, obsolete, and there are limitations in performance.

Is there now a better alternative?

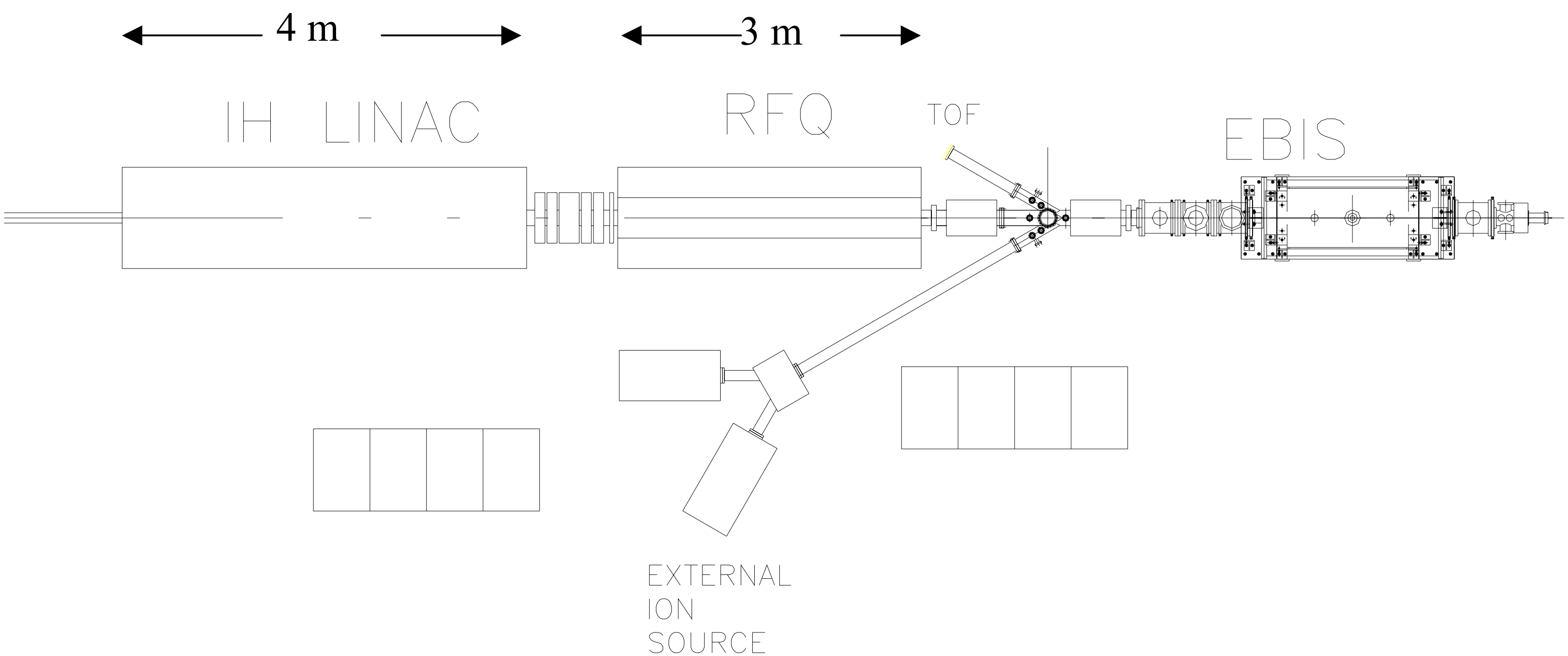
Heavy Ion Preinjector for RHIC

The Tandem Van de Graaff is the present RHIC preinjector. Until our recent EBIS development, it was the only option which could meet RHIC requirements, and while presently it is quite reliable, it has disadvantages -

- 860 m transport line to Booster
- Stripping foils at terminal and high energy lead to intensity & energy spread variations
- Injection over > 40 turns is required
- Limitations on ion species (must start with negative ions)
- High maintenance, manpower
- Obsolete equipment requires upgrading

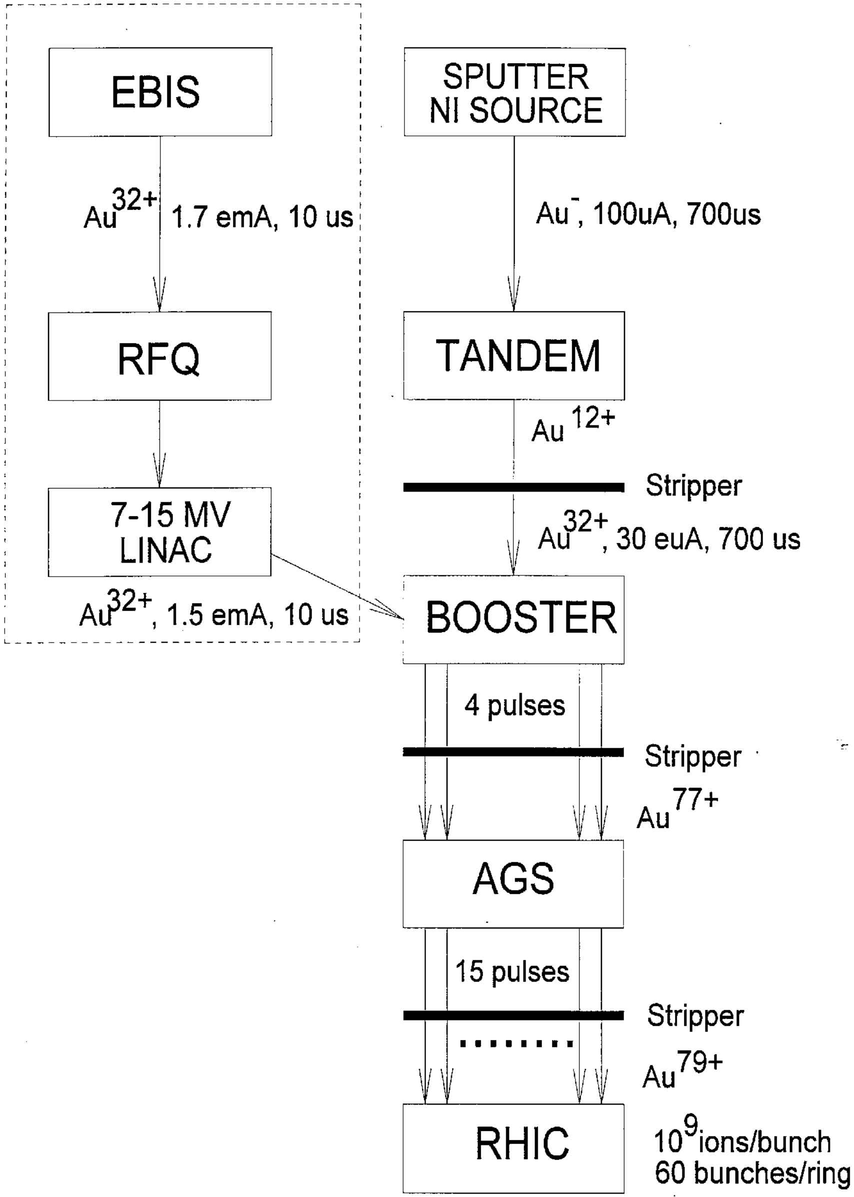


Proposed Linac–Based RHIC Preinjector



RFQ: 8.5 - 300 keV/u; 100 MHz

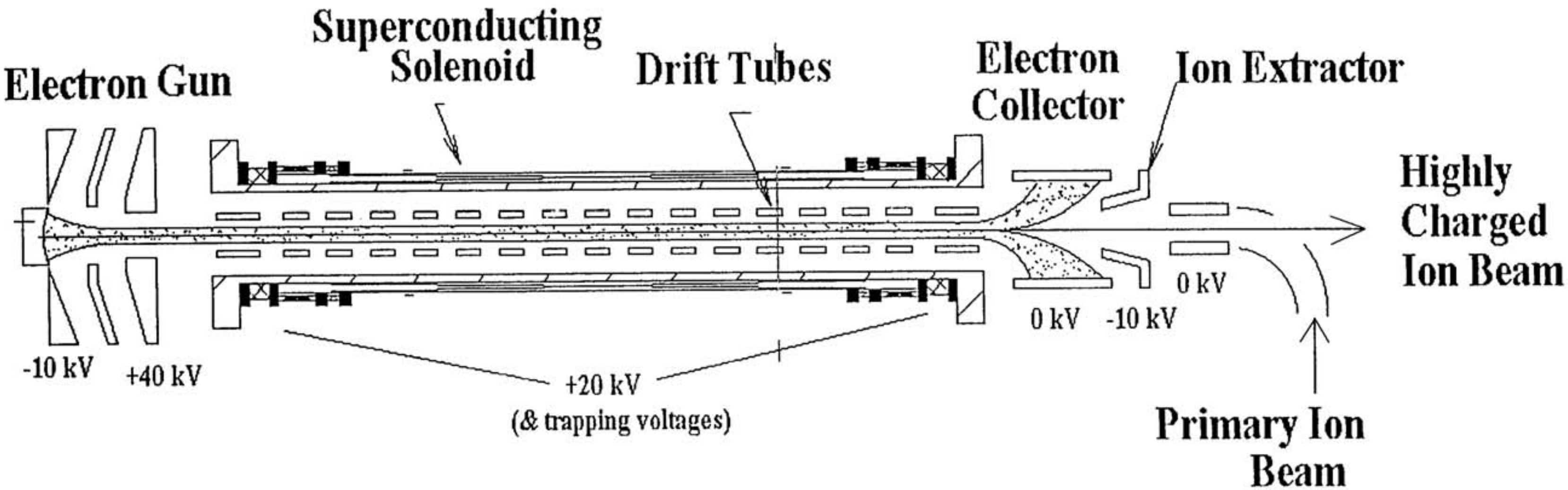
Linac: 0.3 - 2.0 MeV/u; 100 MHz



Advantages of the new preinjector:

- Simple, modern, low maintenance
- Lower operating cost
- Can produce any ions (U, $He^3\uparrow$)
- Higher Au injection energy into Booster
- Fast switching between species
- Short transfer line to Booster (30 m)
- Few-turn injection
- No stripping needed before the Booster
- Expect future improvements to lead to higher intensities

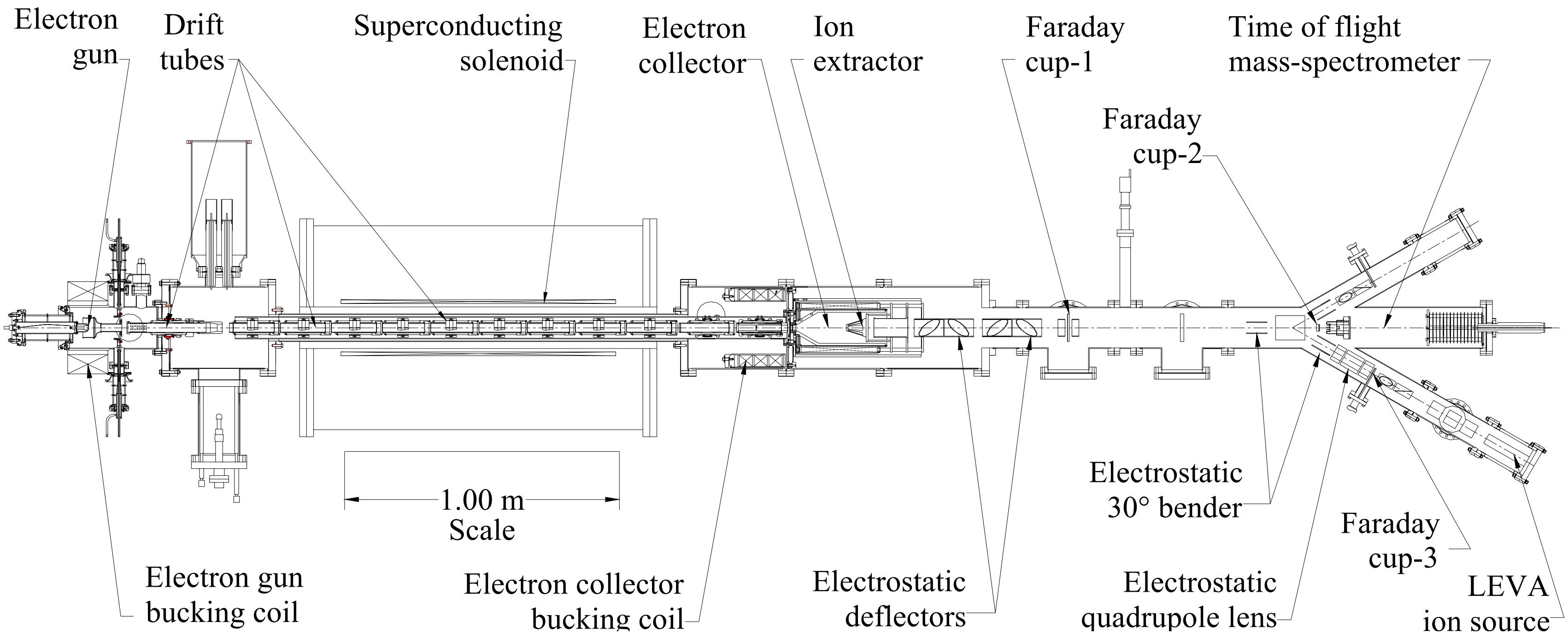
PRINCIPLE OF OPERATION

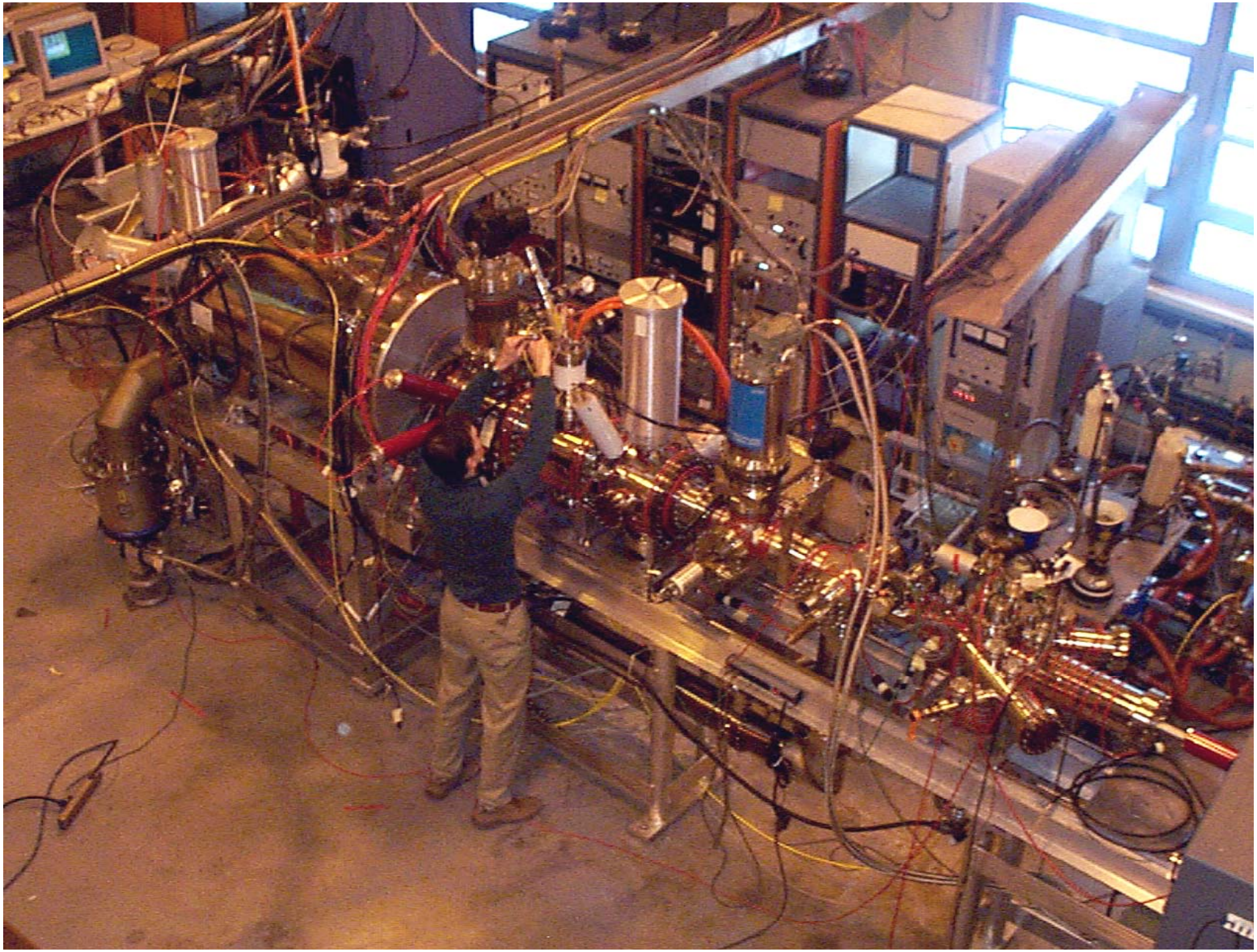


Radial trapping of ions by the space charge of the electron beam.
Axial trapping by applied electrode electrostatic potentials.

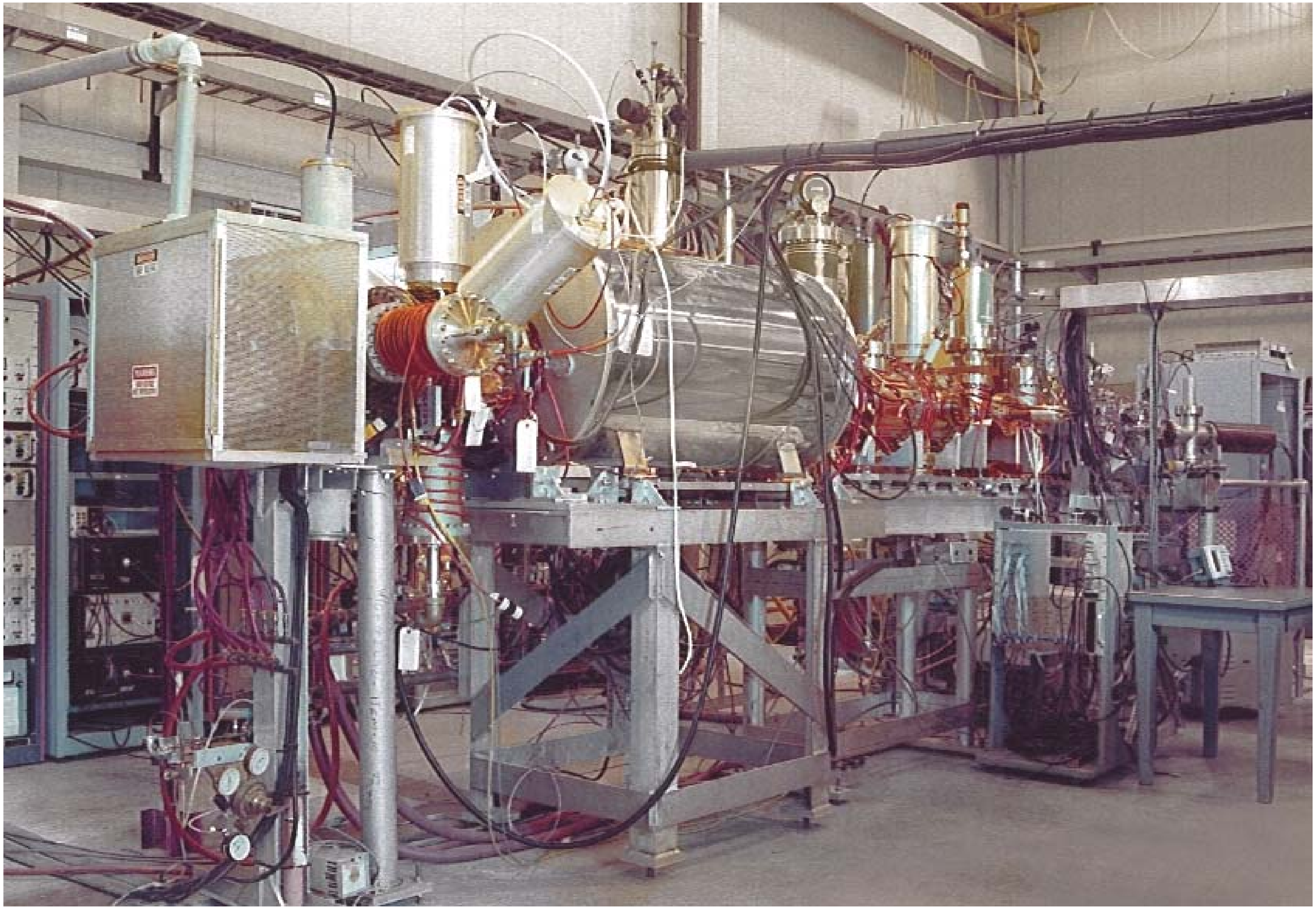
Ion output per pulse is proportional to the trap length and electron current.
Ion charge state increases with increasing confinement time.

EBIS Test Stand - showing ion injection, and extraction to TOF





EBIS Test Stand



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Test EBIS R&D Goals

Demonstrate operation with the full required electron beam (i.e. 10 A, ~ 20 times greater than previous EBISs).

With ½ the final required trap length, demonstrate all expected performance (½ ion yield, full charge state, etc.)

Bottom line – all goals were achieved.

(This was not trivial, but I will skip the discussion of the many successful detailed design choices)

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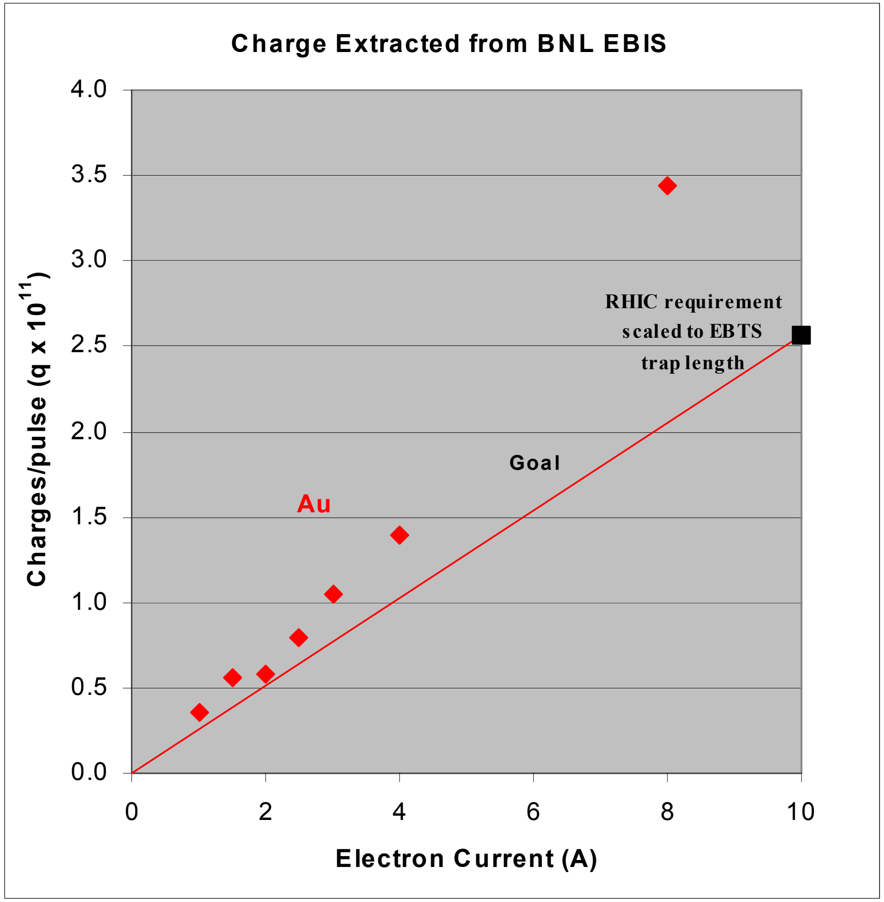
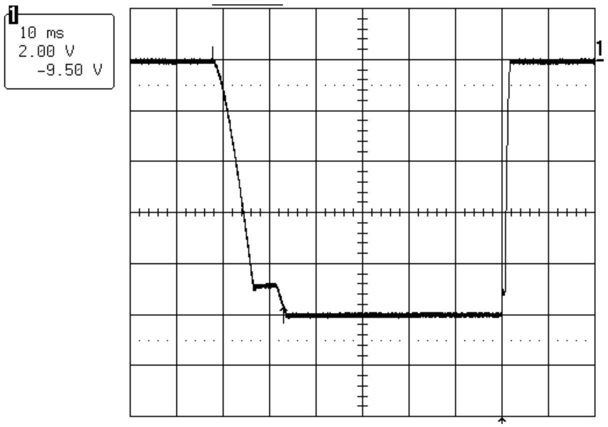
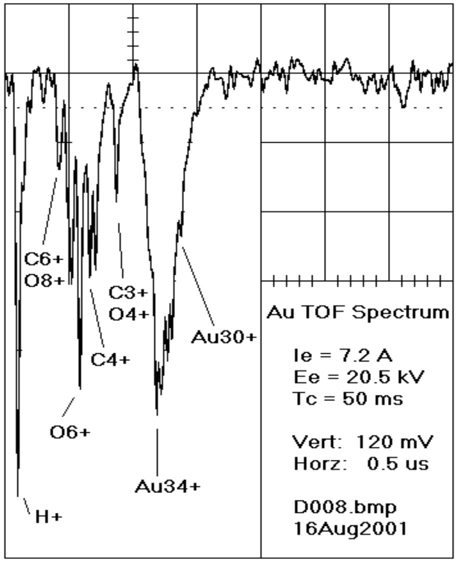
Results from Test EBIS (½ Length of RHIC EBIS)



5.5 x 10^{11} charges/pulse are required for RHIC. By doubling the EBIS trap length to 1.5 m, we will exceed this requirement. (The ion yield has been shown to scale linearly with trap length).

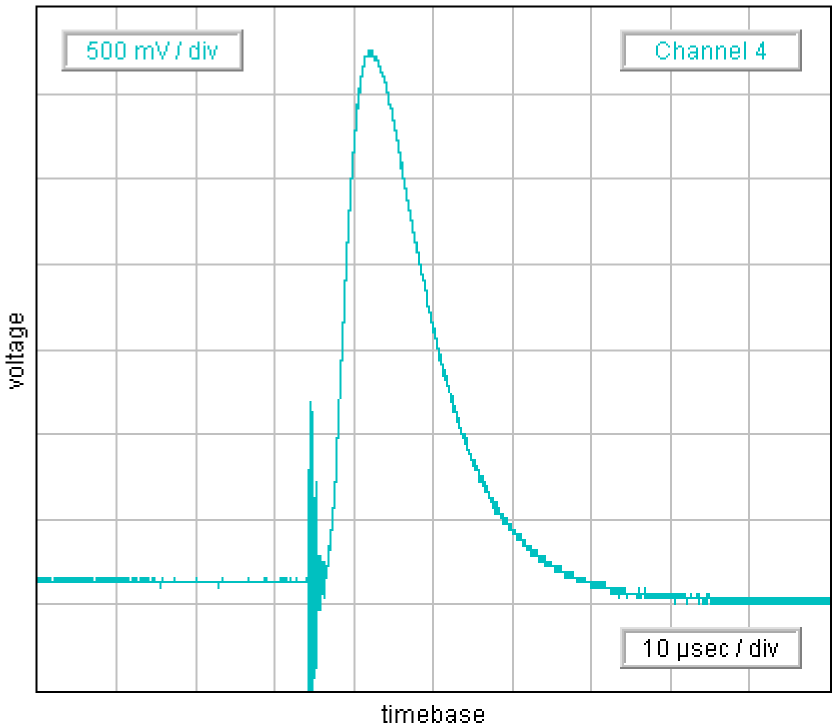


10 A, 50 ms Electron Beam Pulse



Time-of-flight spectrum peaked at Au 34+

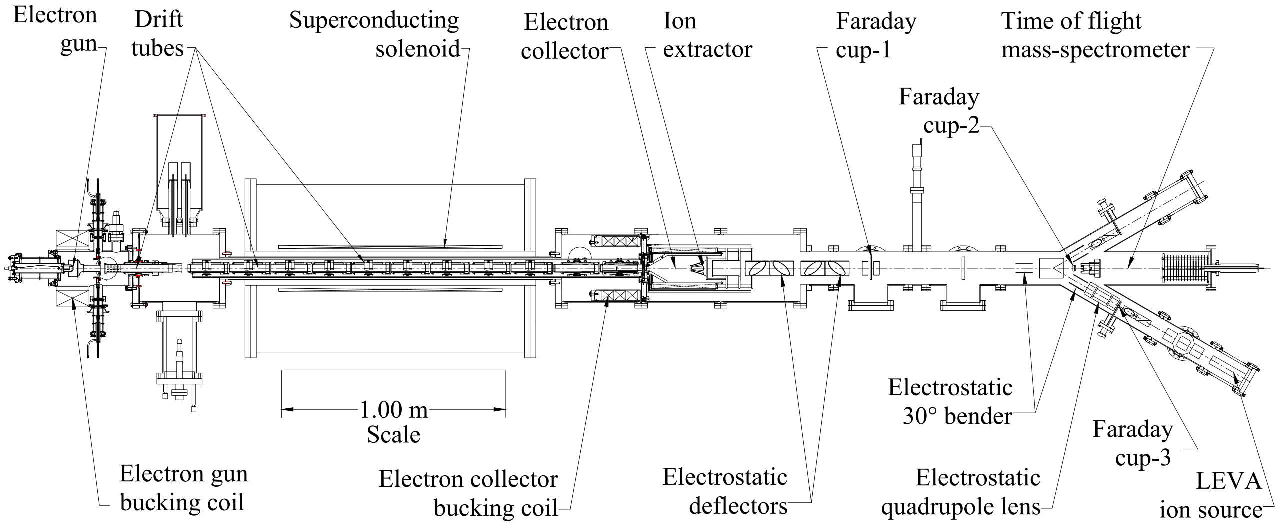
Fast Extraction of Ions from the EBTS
(for single turn injection into Booster)



A 3.2mA, 12µs FWHM, (40nC) ion pulse was obtained at the source exit toroid using a 6.8A e-beam and Au external ion injection, after a 15ms confinement. (85 nC required for RHIC)

Faster extraction has been obtained earlier by applying a gradient to the well floor during extraction. In the future, the pulse shape will be tailored by applying an appropriate voltage pulse to the well.

Results from Test EBIS (½ of RHIC EBIS)



	RHIC Requirements	Achieved
E-beam current	10 A	10 A
E-beam energy	20 keV	20 keV
Yield of pos. charges	5.5×10^{11} (Au, 10 A, 1.5m)	3.2×10^{11} (Au, 8 A, 0.7m)
Pulse length	≤ 40 µs	20 µs
Yield of Au^{33+}	3.4×10^{9}	> 1.5×10^{9}

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the Bulletin

BROOKHAVEN NATIONAL LABORATORY

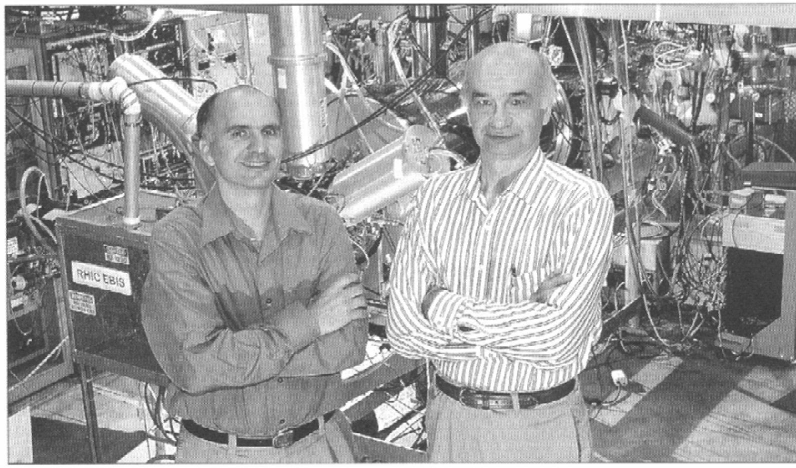
Vol. 57 - No. 35 October 10, 2003

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



Roger Stoutenburgh 00040903

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

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.

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.

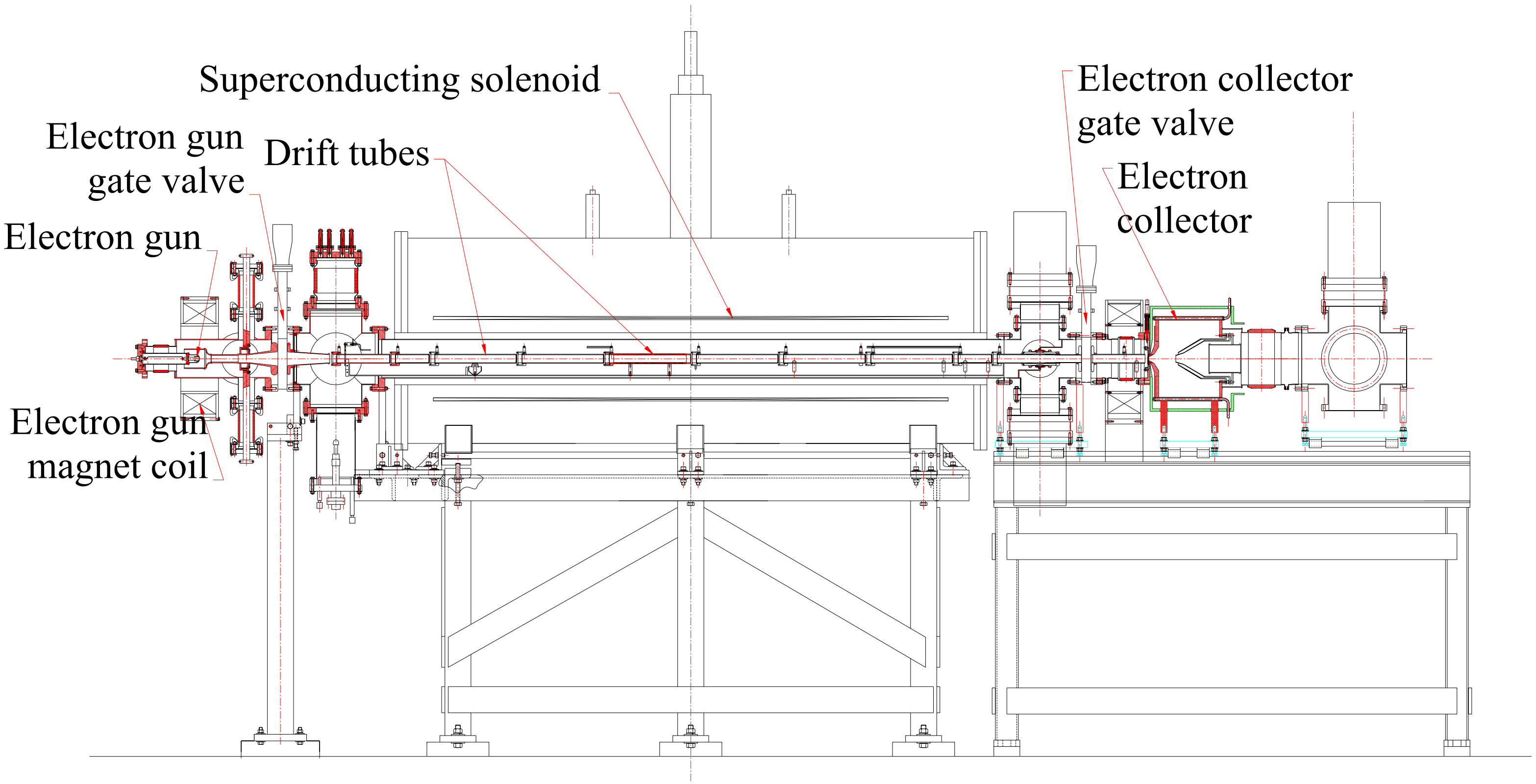
For more information, see www.bnl.gov/bnlweb/pubaf/pr/2003/bnlpr090903a.htm.

— Diane Greenberg

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

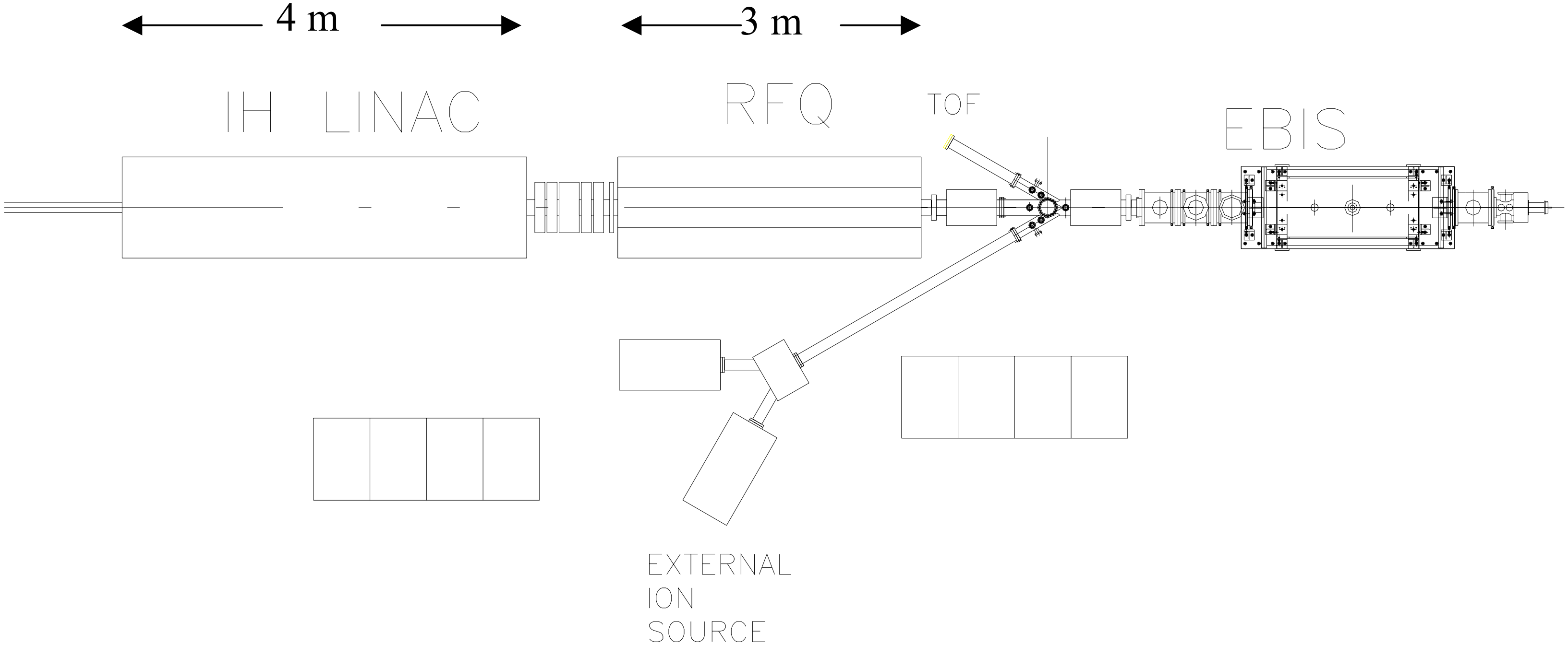
EBTS performance represents more than an order of magnitude improvement over past EBIS sources.

Schematic of EBIS for RHIC



The primary difference in the RHIC EBIS, compared to EBTS, is the doubling of the trap length to double the ion output. Other new features we plan to incorporate into the final EBIS will be made in order to make the final EBIS more robust.

Proposed Linac-based RHIC Preinjector



RFQ: 8.5 - 300 keV/u; 100 MHz

Linac: 0.3 - 2.0 MeV/u; 100 MHz

RFQ Parameters

Parameters	BNL	CERN	Units
Type	4-rod	4-rod	
Q/m	0.16-0.5	0.12	
Input Energy	8.5	2.5	keV/amu
Output Energy	300	250	keV/amu
Frequency	101.28	101.28	MHz
Max rep rate	10	10	Hz
Length	2.96	2.5	Meters
Number of cells	236		
Aperture Radius	0.006	.0045	Meters
Voltage	92	70	kV
E (surface)	20.8	≤ 23	MV/m
RF Power	< 350	< 350	kW
Acceptance	1.7	> 0.8	pi mm mrad (nor)
Input Emittance	0.35		pi mm mrad, nor, 90%
Output Emittance (trans)	0.375		pi mm mrad, nor, 90%
Output Emittance (longit)	0.75		pi MeV deg
Transmission	97	93	%
Bravery factor	1.8	≤ 2	Kilpatrick

Linac

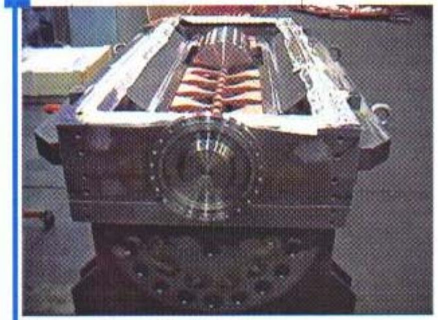
IH Linac, very similar to the first tank of the CERN Pb linac, is our baseline:

Table6: Main parameters of the IH linac

Parameters	**BNL**	**CERN Tank 1**	**Units**
Q/m	0.18-0.5	0.12	
Input energy	0.300	0.250	MeV/amu
Output Energy	2.0	1.87	MeV/amu
Frequency	101.28	101.28	Mhz
Max rep rate	10	10	Hz
length	4.0	3.57	Meters
Input emittamce	0.55		pi mm mrad, norm,90%
Output emittance	0.61		pi mm mrad, norm,90%
Output energy spread	20.0		keV/amu
transmission	100		%

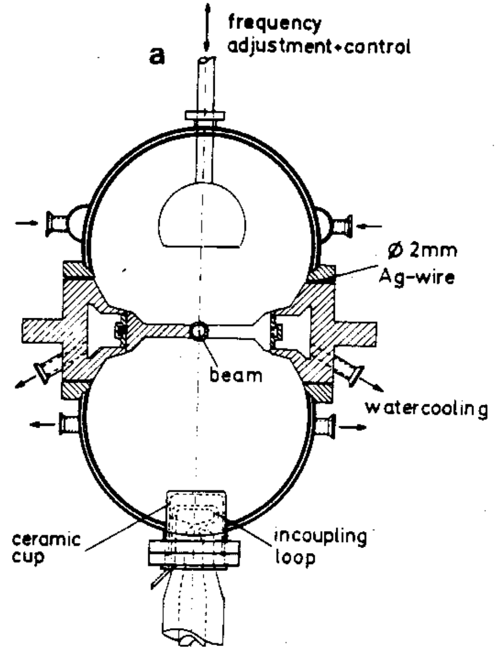
The other linac option, a superconducting linac similar to ATLAS, has been set aside for now due to its higher cost.

IH-Resonator for the REX-ISOLDE Project



Mid section with drift tubes

Section with drift tubes during measurement of the resonance frequency



Watercooled top section of the IH-Resonator

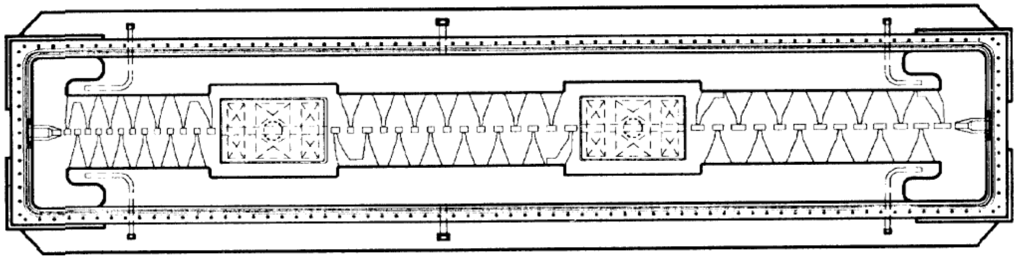
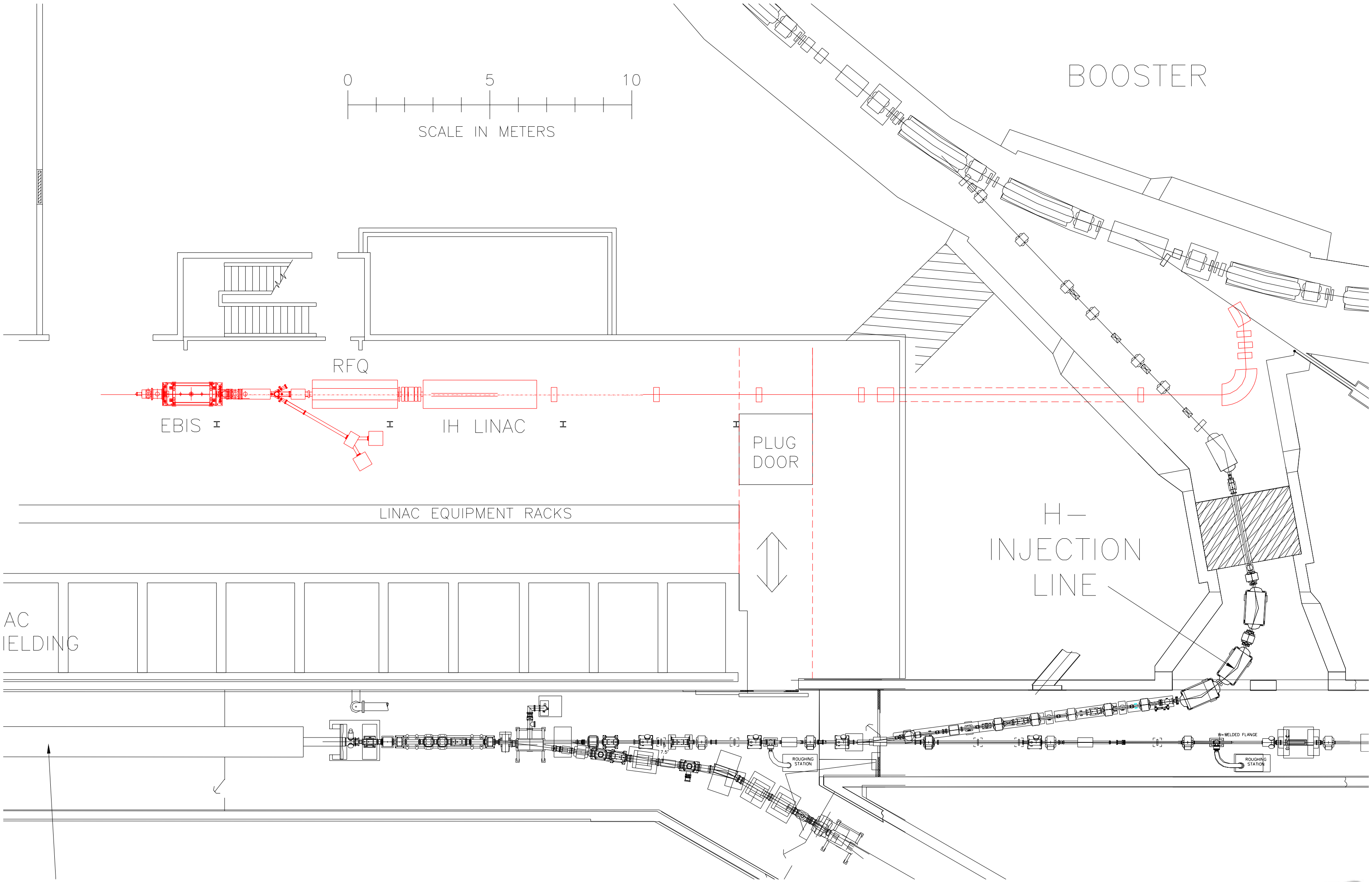


Fig. 3b) Top view on the middle part of the GSI-cavity.

Layout in the Linac Lower Equipment Bay

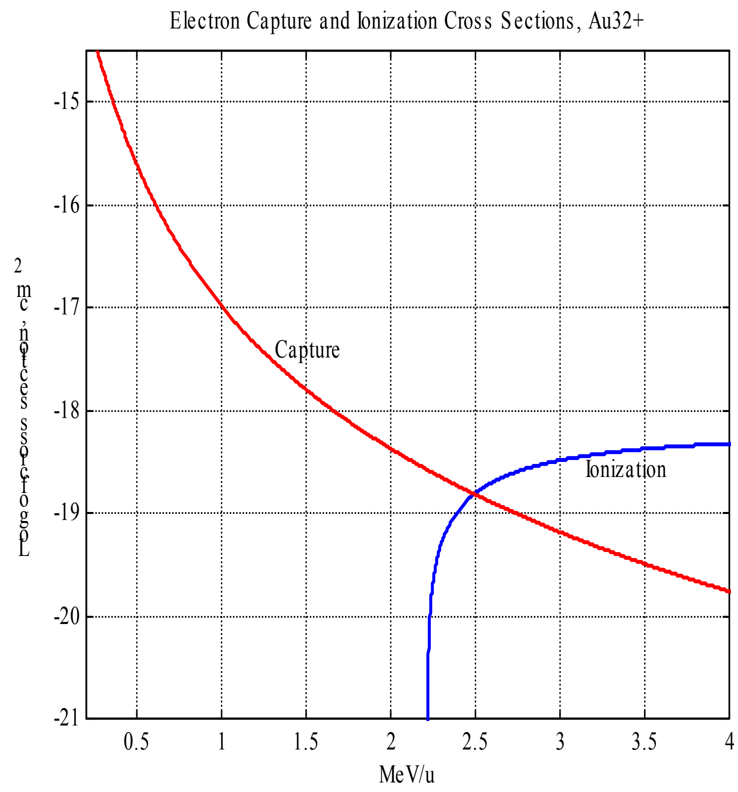


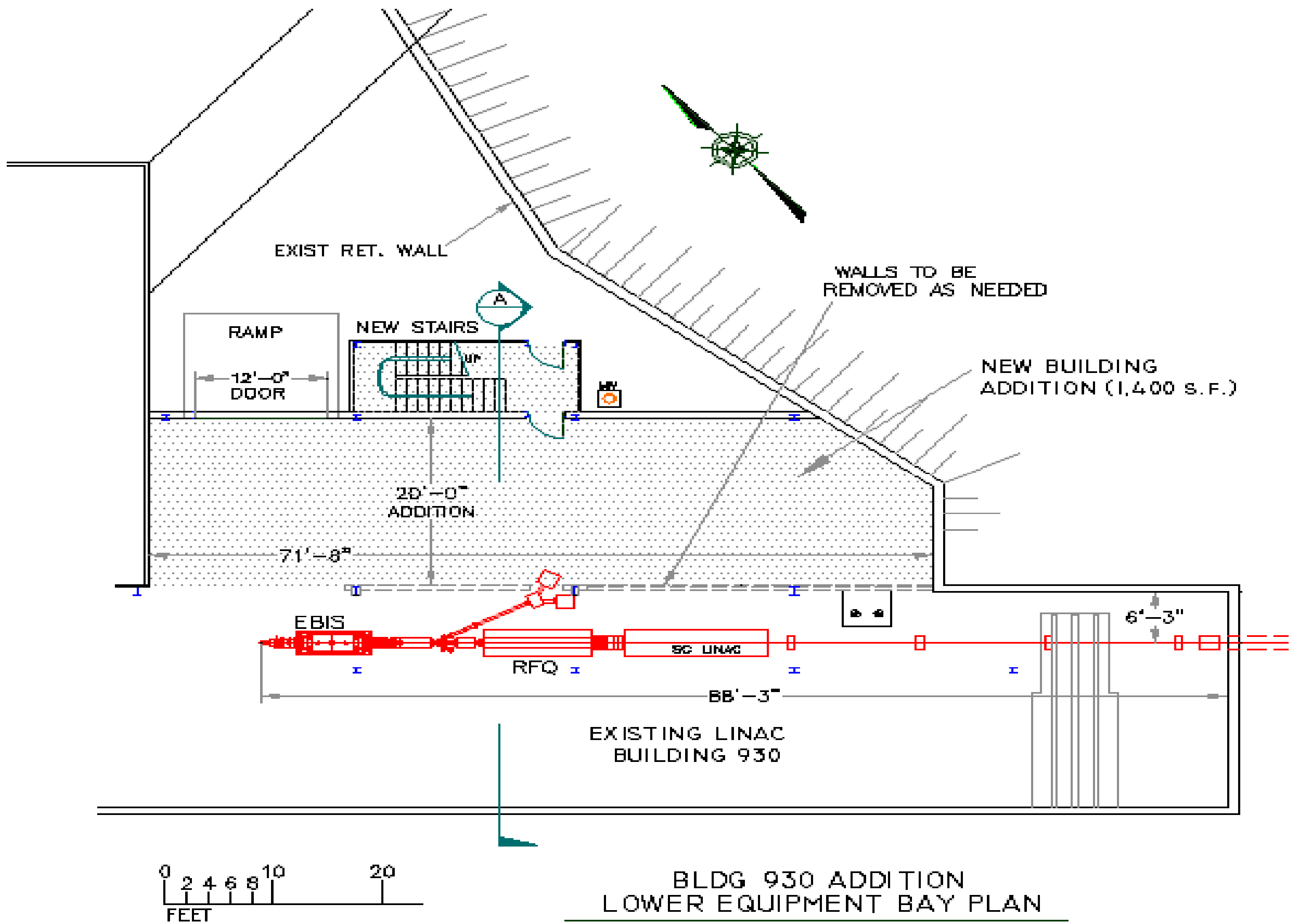
Booster Injection

With 1-4 turn injection, emittance in Booster will be smaller than from tandem (>40 turns)

With dp/p = ±0.05%, requirements for longitudinal emittance in Booster are satisfied.

At 2 MeV/u, capture cross section reduced by factor of 40 relative to tandem.





BLDG 930 ADDITION
LOWER EQUIPMENT BAY PLAN

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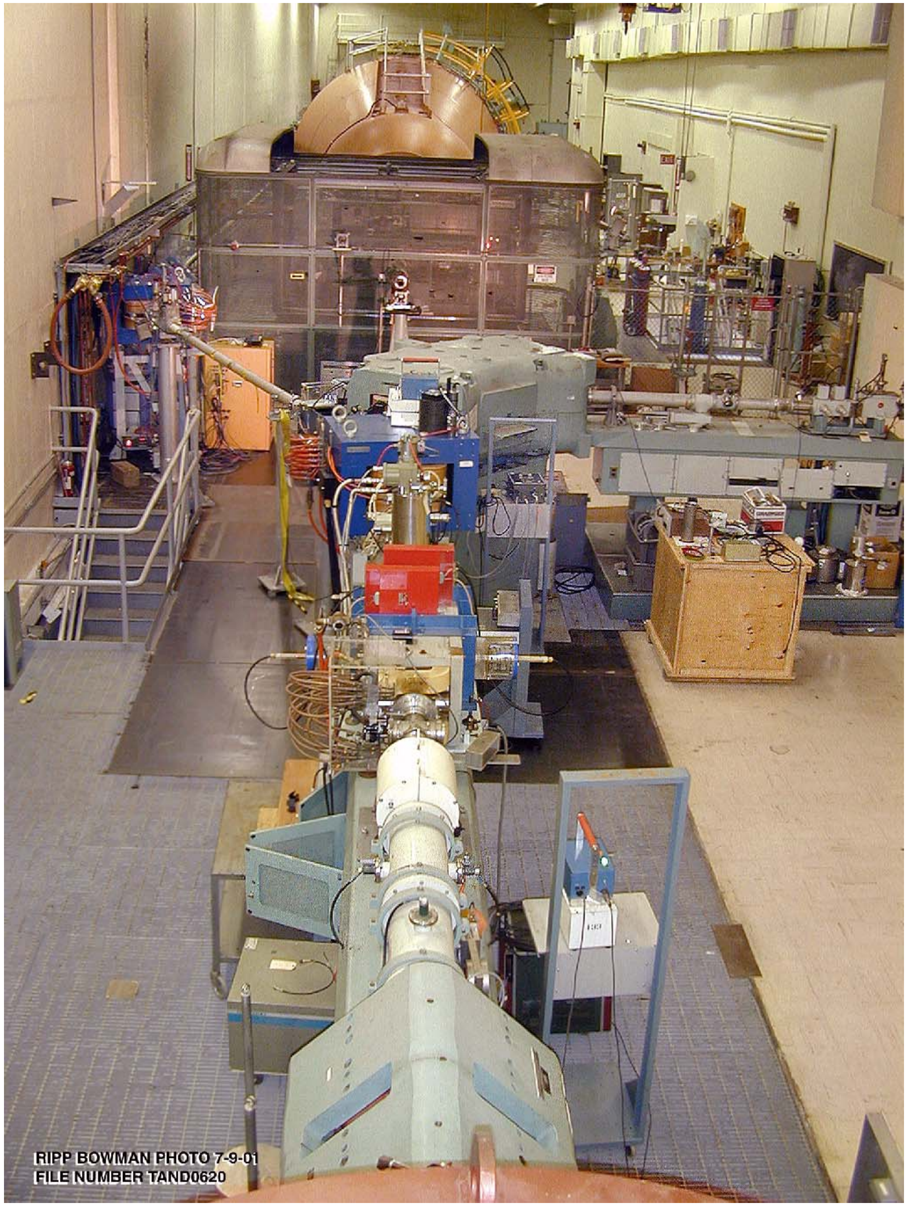

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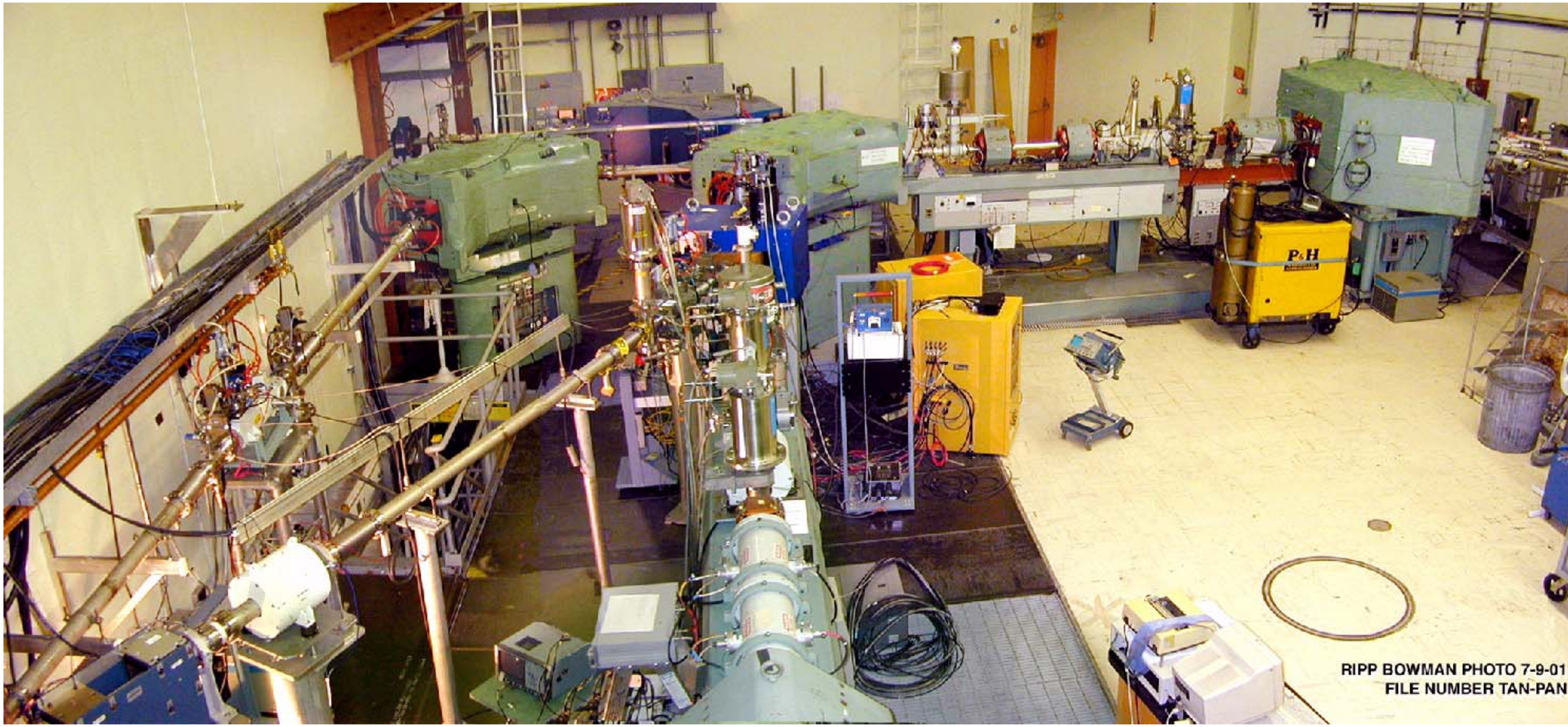

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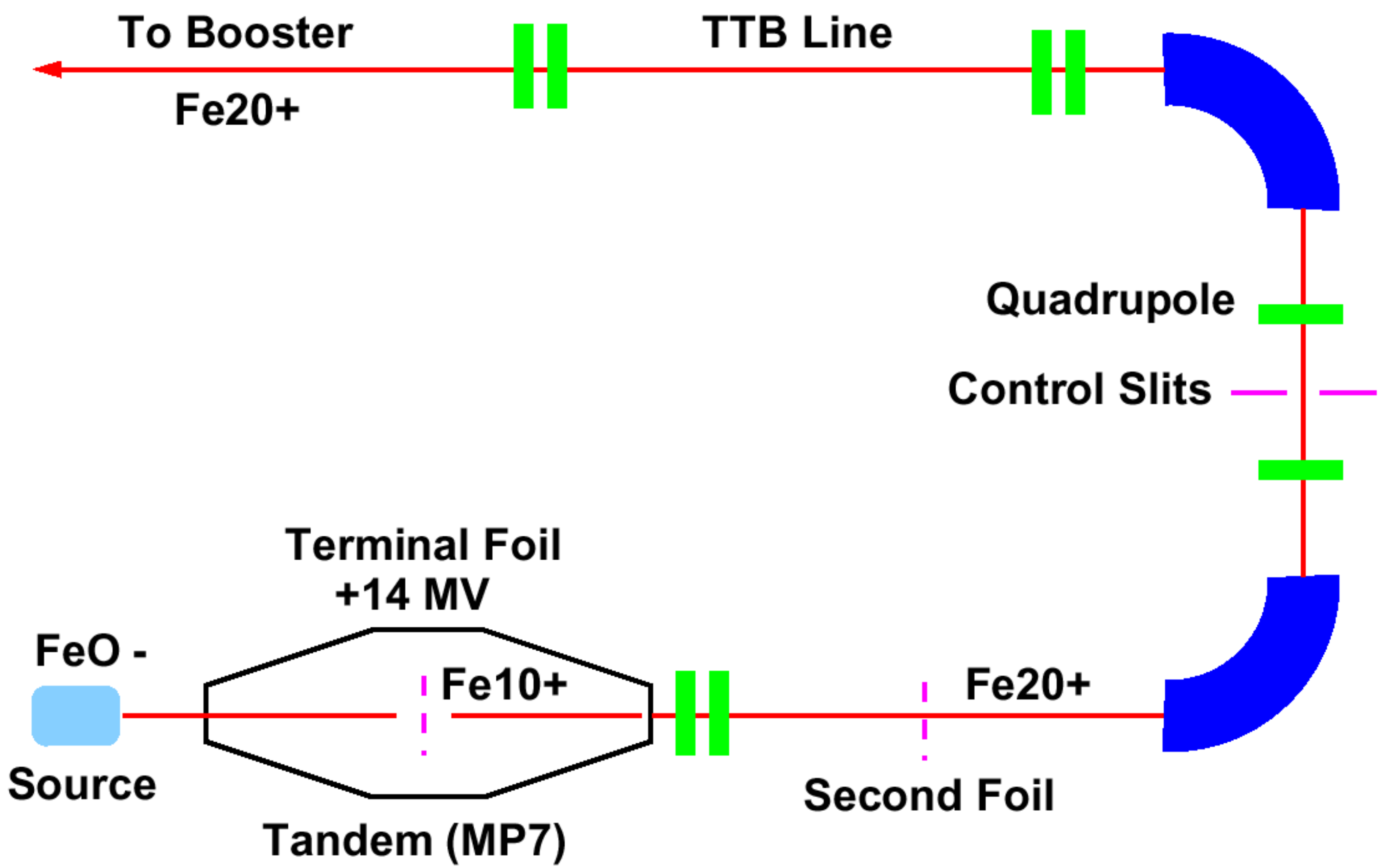
Almost all accelerator supplies and controls are original, not computer controllable. It is becoming difficult to get spares.



All beams from the Tandems must start as negative ions. (EBIS can produce any type ions)

Two stripping stages required for most ions.

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Example of foil holder

Object foils (thicker)

Stripping Foils

Intensity vs. time: Foils change (thicken, then break). This increases energy spread over time. Beamline and Tandem transmission decrease.

There are both terminal and object foils which are changing with time. Good and bad foils, good or bad spots on a foil, etc. So maintaining peak intensity takes constant attention.

Foil lifetime decreases with increasing intensity, so while one tries to deliver the maximum intensity when *really* required, the preference is to operate at reduced intensities whenever possible to reduce foil consumption. (Unfortunately, this conflicts with the desires of some to continuously optimize Booster and AGS).

EBIS will produce directly the desired charge state, with no stripping required before the Booster.

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PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NASA - BAF
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

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!

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 ^{3}He (eRHIC)
- Simpler technology, robust, more modern (Tandem replacement parts becoming difficult to get)

Given such importance, the Laboratory will provide a substantial two-part contribution. The first part is to utilize the extraordinary construction project overhead rate of 14%, waiving the standard overhead rate of 39.2%. This reduces the TPC by ~ $3.1M. The second part is the contribution of $3.3M of RHIC operations funds and $6.4M of AIP funds over the three-year funding profile. This would reduce the TPC from $20.6M to $17.5M, leaving a $7.8M funding requirement in new Nuclear Physics Budget Authority and a $9.7M contribution from RHIC.

There are two proposed scenarios:

Preferred - Construct EBIS in three years to rapidly achieve the above advantages and operations cost savings. This proposes that Nuclear Physics provide an increment of ~ $2.6M per year beginning in FY ’05. The infusion of new funding provides the financial wherewithal for the Laboratory to utilize the extraordinary construction rate. Additionally, it is a very reasonable financial partnership, wherein RHIC Operations contributes $9.7M, Nuclear Physics $7.8M and BNL contributes $3.1M in reduced overhead costs. Completion would be expected in FY ’07.

Construct EBIS in a nominal 5 – 6 year period. In the event that substantial Physics funds are not available, the project must be extended. BNL still desires to begin in FY ’05, using RHIC AIP and Operating funds at the same level as above. However, in the absence of new funding, it will not be possible to include the extraordinary construction rate due to the adverse impact on overhead budgets. Completion will not be achieved until FY ’10.

BNL strongly urges pursuit of option (a) as the most mutually beneficial approach.

ELECTRON BEAM ION SOURCE (EBIS)
Budget Authority - AY Dollars in Millions

	1	*2*	*3*	*4*	*5*	*6*	
	2005	***2006***	***2007***	***2008***	***2009***	***2010***	***TOTAL***
A: EBIS Preferred Plan*							
Lab. C-AD Contribution							
Operating	1.1	1.1	1.1				3.3
A I P	2.1	2.1	2.2				6.4
Total	3.2	3.2	3.3				9.7
Add'l NP Program Funds	2.5	2.6	2.7				7.8
TOTAL Preferred Plan	**5.7**	**5.8**	**6**				**17.5**
B:EBIS Extended Plan**							
Lab. C-AD Contribution							
Operating	1.1	1.1	1.1	1.1	1.1	1.1	6.6
A I P	2.1	2.1	2.2	2.2	2.2	2.2	13
Total	3.2	3.2	3.3	3.3	3.3	3.3	19.6
Add'l NP Program Funds	0.3	0.3	0.3	0.3	0.3	0.3	1.8
TOTAL Extended Plan	**3.5**	**3.5**	**3.6**	**3.6**	**3.6**	**3.6**	**21.4**

* Preferred Program - BNL can grant extraordinary Overhead rates reducing the TPC ~$3.1M

** Extended Plan - BNL cannot extend extraordinary Overhead rate due to impact on Lab Overhead pools

CONCLUSION

Achieving sufficient integrated luminosity is essential to the success of most RHIC experiments. This places considerable demands on the ion source and injectors. 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 will be very similar to the present EBTS 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.