EBIS and LION

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+ many others

- Run 14 – EBIS and LION
- A few words on considerations for running various species
- Work this summer
- Brief – polarized helium 3

Quick summary for Run 14

- For RHIC, EBIS ran ~24/7 from January 25 – July 7.
- Starting 3/25, in parallel with RHIC, EBIS also provided all beams for NSRL (except protons).
  - 9 species (C, O, Si, Ti, Fe, Kr, Ta, Au, ^{3}He)
  - no restrictions on NSRL running

    (this changed during helium 3 running → 4 days from Tandem)
- The Laser Ion Source (LION) provided many 1+ beams for injection into EBIS. (Others came from the hollow cathode ion source).
- EBIS is used in all cases for raising ions to the required high charge state.
- EBIS ran unattended for much of the time.
- No maintenance except SC solenoid helium fills every ~3 weeks (done during stores).

Things which were better this year:

- Fixed collector ps loose wires and lockout relay – eliminated spurious trips
- Took anode ps PSI's off the HV platform (function now comes over analog light links from ground for both treks). Electrical noise was causing electron beam pulse stretching, pressure bursts, leading to trip-offs of the beam
- Remote on-off removed from several ps's, including anodes (noise would turn ps's off, but wouldn't show as a malfunction).
- Omar Gould's "auto reset" for electron beam.

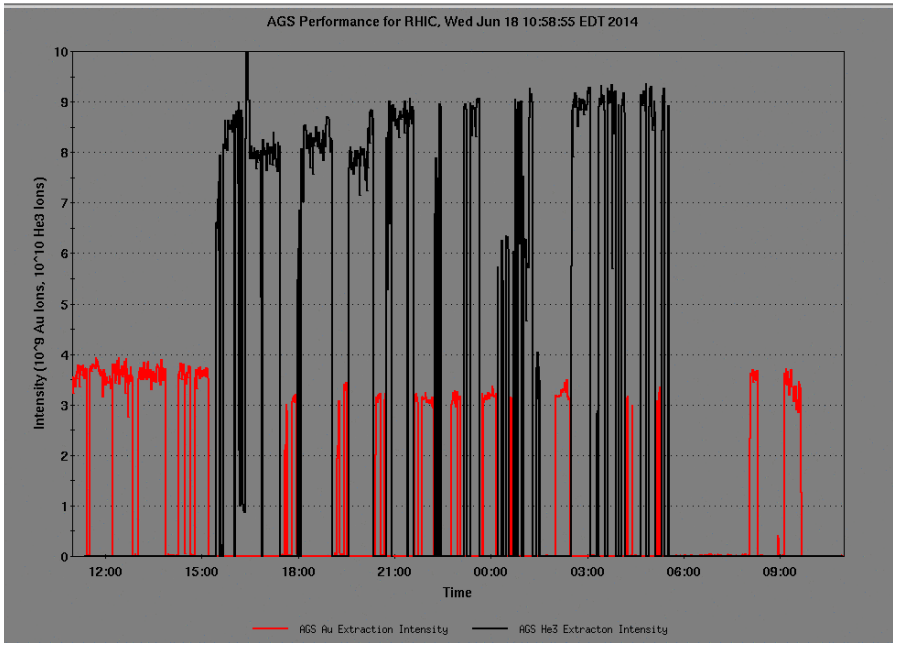
As a result of the above, unattended operation went well.

Very few failures during the run. (but an RFQ ps trip every ~36 hours was annoying). *Thanks to CAS for the many resets.*

Au-^{3}He Running

- Very unique – $^3He^{2+}$ and Au^{32+}, from 1 source, 1 minute apart - highlighted the great versatility of the EBIS
  - The excellent gas efficiency of EBIS was important, since ^{3}He is expensive and supply is limited
- Switching between Au and He went much better than expected.
  - John Morris – script for pressure regulation; Greg Marr - TAPE sequence.

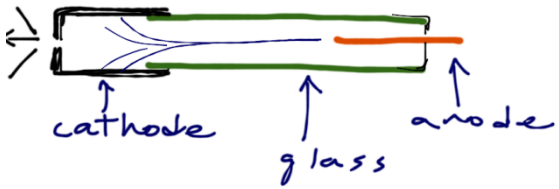
Counted 196 switches!



Hollow Cathode Ion Source

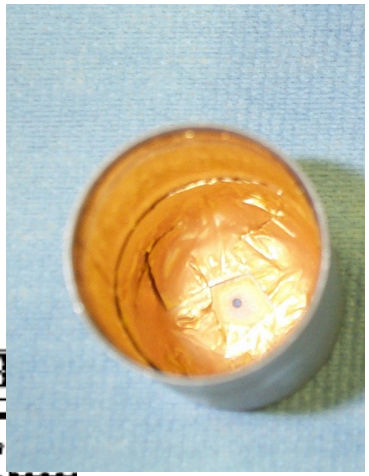
External 1+ ion production to feed the EBIS trap

Hollow cathode ion source



Hollow Cathode Ion Source

Discharge of buffer gas sputters/ionizes solid cathode material



EBIS is a "charge breeder" of the injected 1+ ions

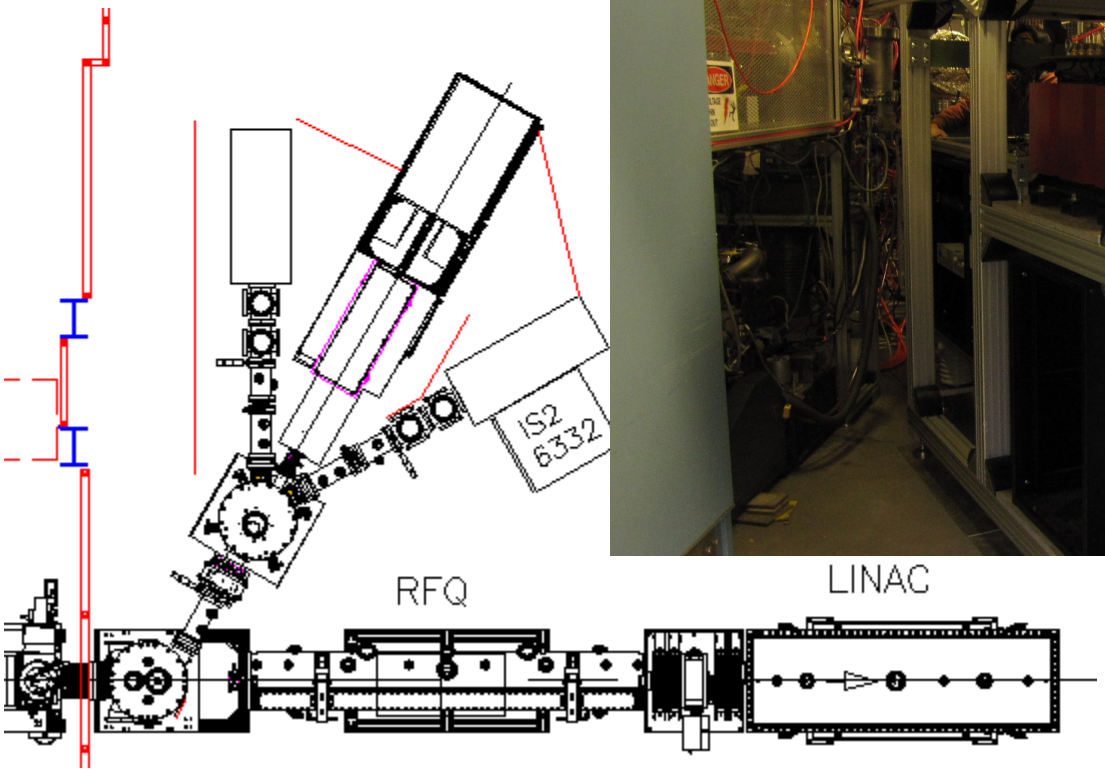
RFQ

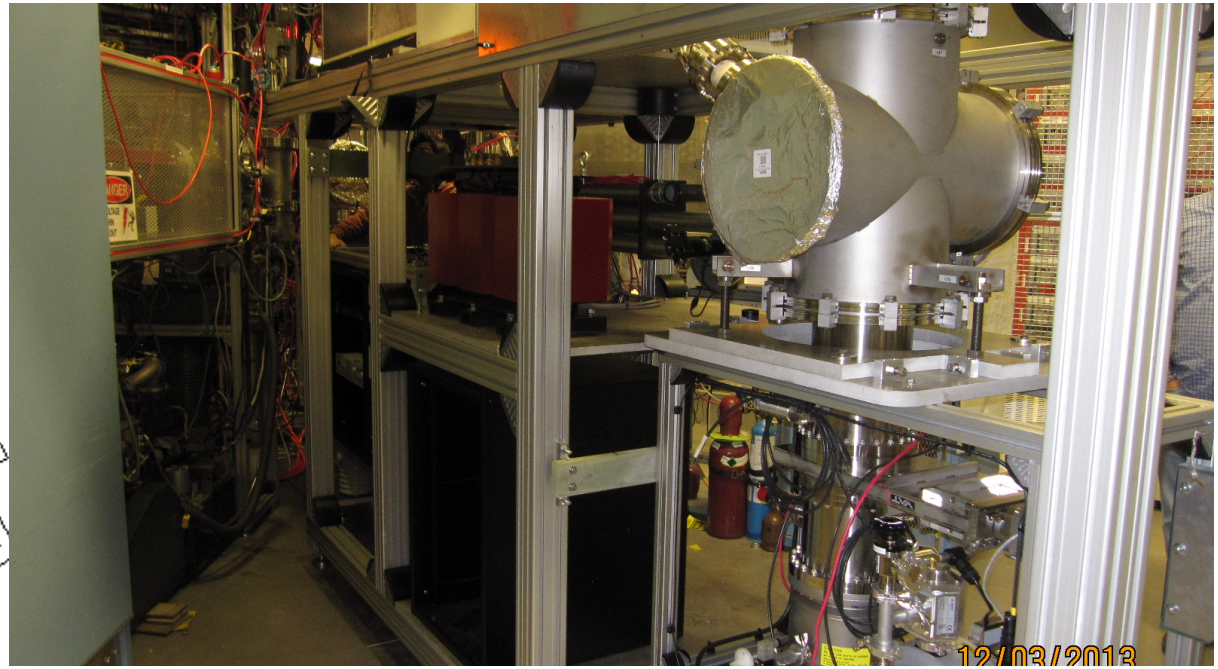
1+ Ions into EBIS

32+ Ions out of EBIS

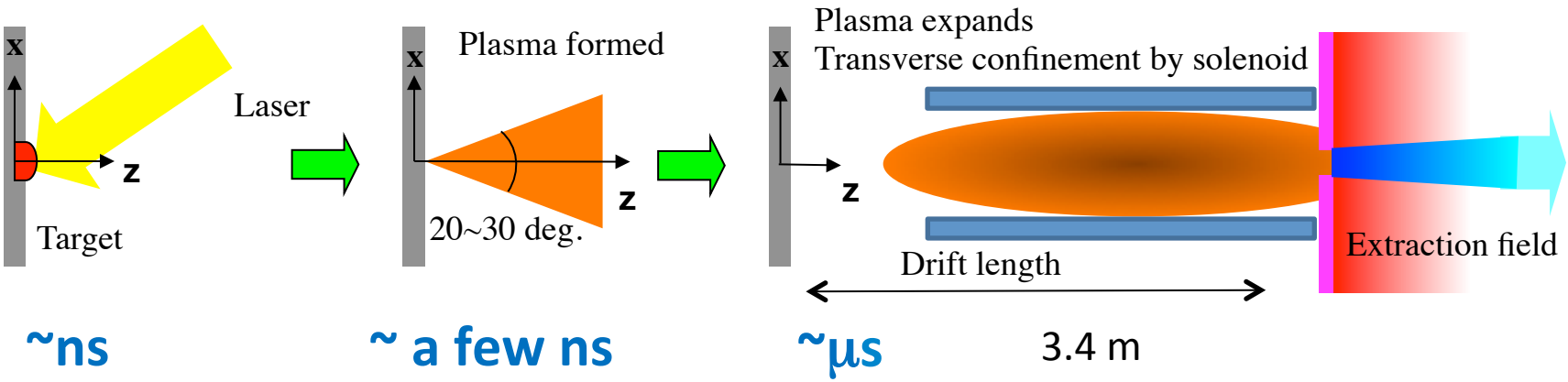
The new Laser Ion Source (LION) was commissioned during this run. New way of providing 1+ ions for injection into the EBIS trap.

Motivation was faster switching between more species, for NSRL "GCR simulator".





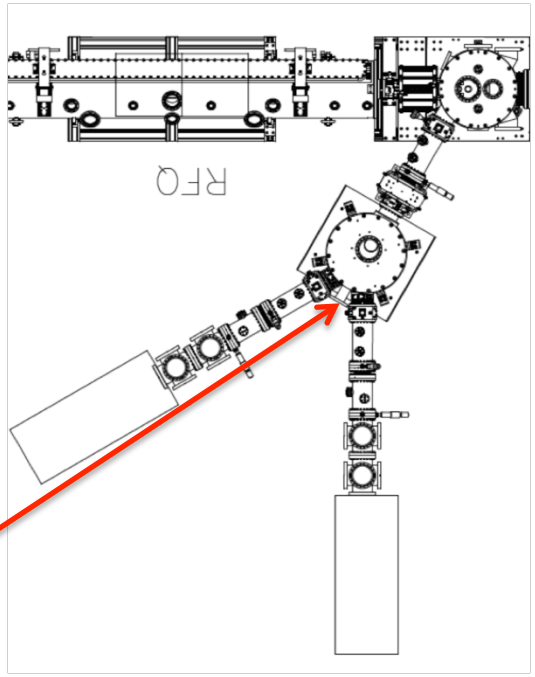
Laser Ion Source

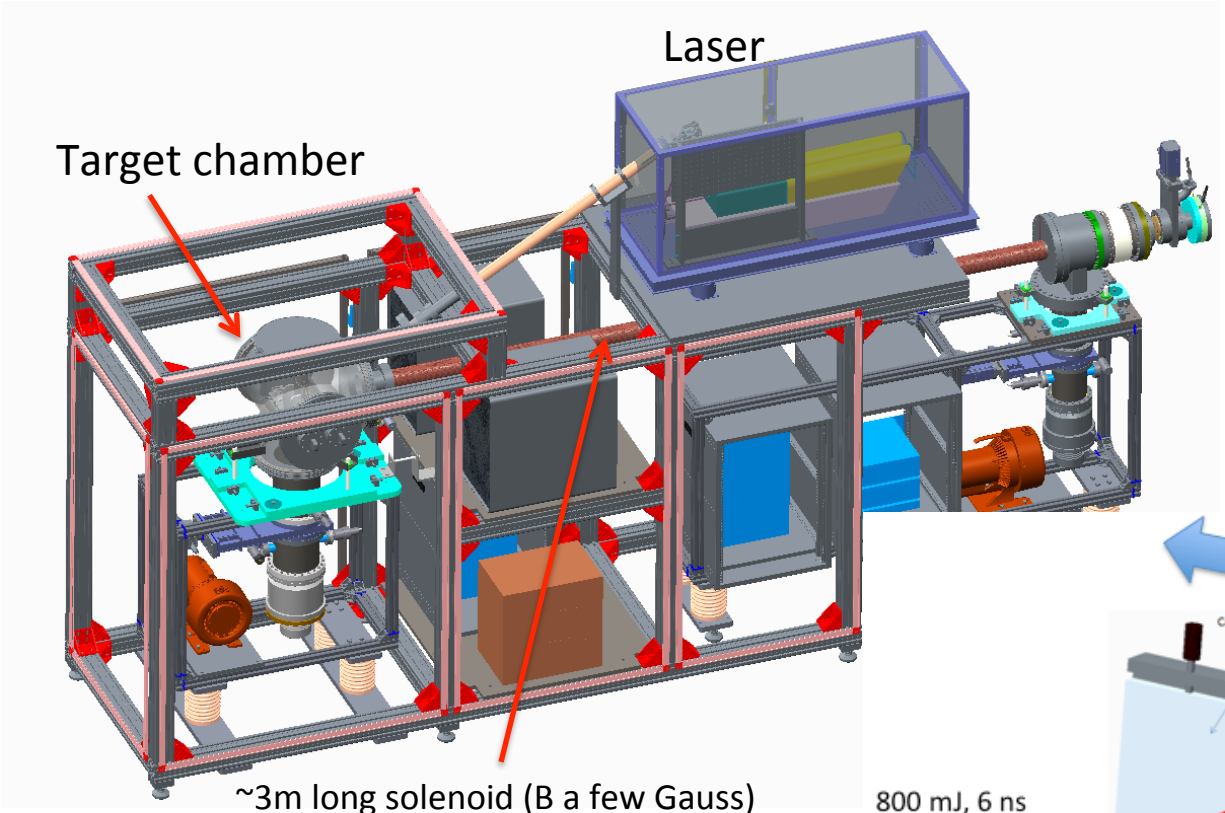


~ns **~ a few ns** **~μs** 3.4 m

- **High current (200 μA - 1 mA), short injection time (a few hundreds μs). "Fast injection"**
- Good vacuum condition (solid target, no gas load into EBIS)
- Target material can be changed in a second by moving target holder or changing mirror angle

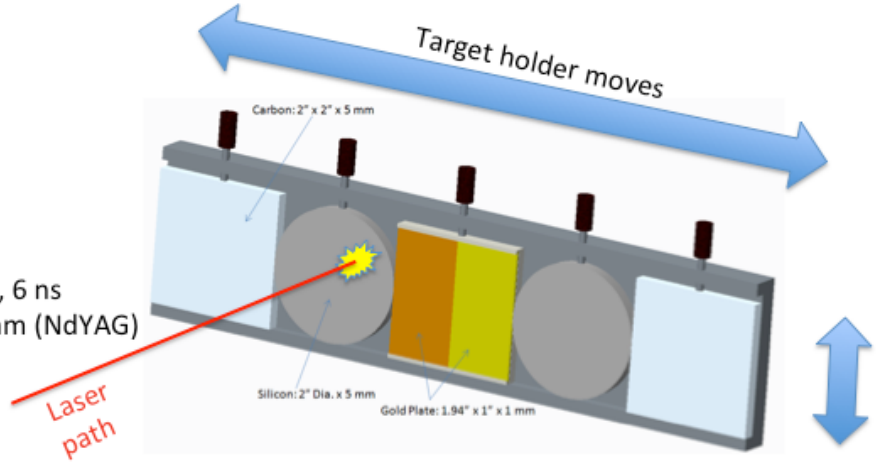
3rd injection line - Laser Ion Source:



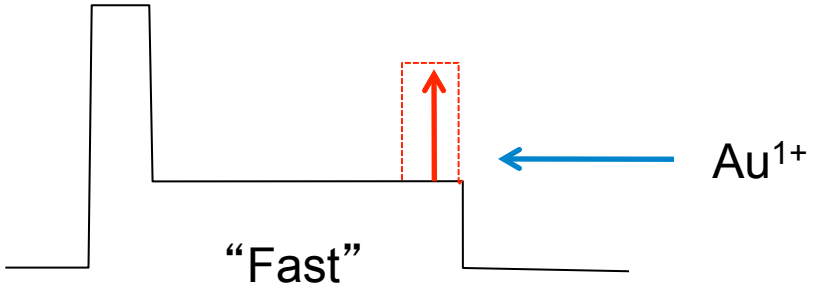


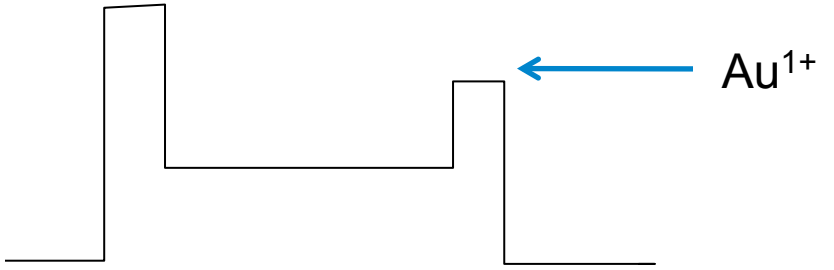
~3m long solenoid (B a few Gauss)
- plasma transport to stretch pulse

800 mJ, 6 ns
1.064 nm (NdYAG)



INJECTION

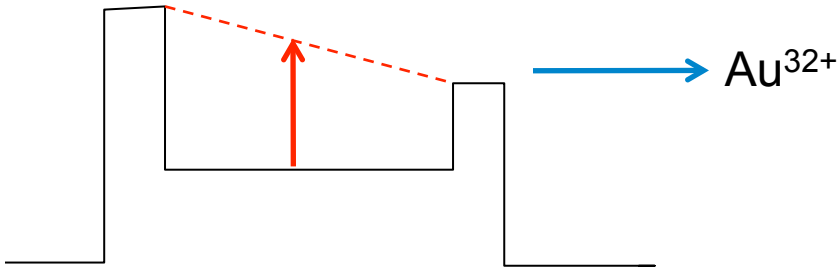




Fast injection – close the exit barrier to efficiently trap one "round-trip" worth of 1+ ions (~100-300 µs)

Slow injection – if an ion goes from 1+ to 2+ before exiting, it will remain trapped.
Lower efficiency, but can inject for 10's of ms.

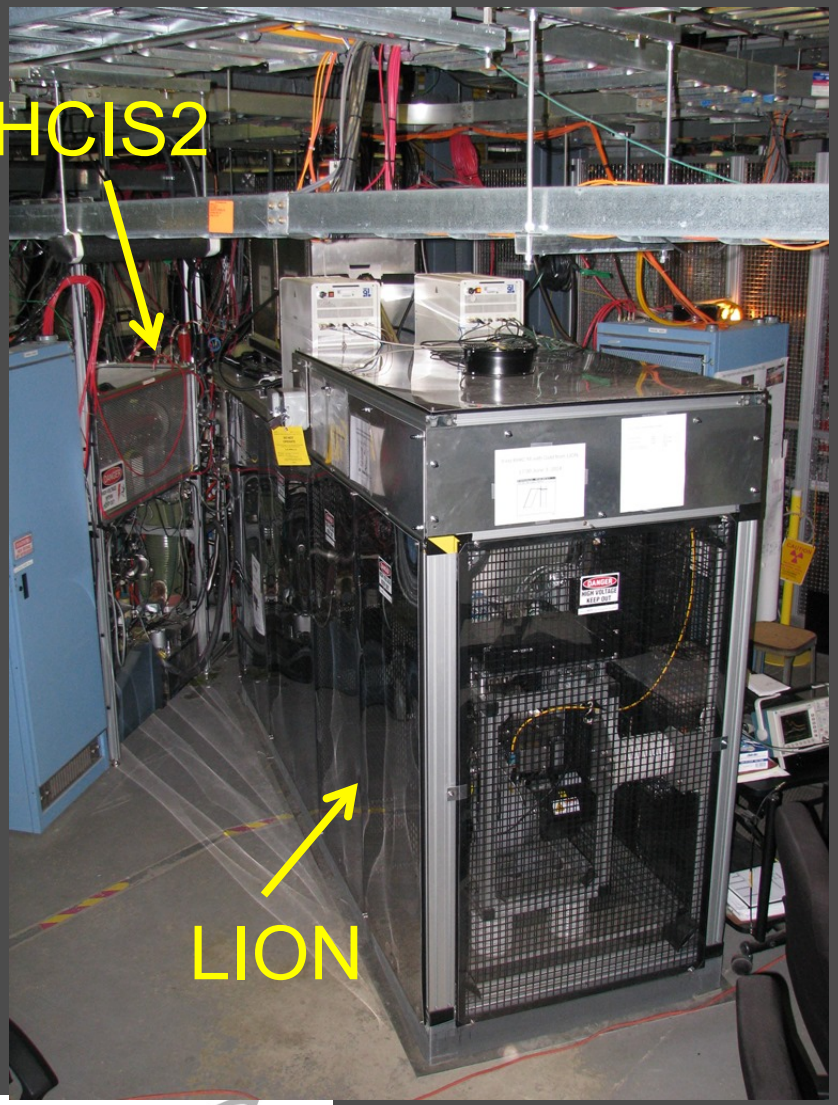
EXTRACTION



Fast – ~30 µA of Au^{1+}, ~100 µs
>500 µA of C^{1+}, ~300 µs

Slow - ~10 µA of either, but
~20 ms Au^{1+} to ~60 ms C^{1+}

Construction and commissioning



- Dec 3, 2013 Moved from Bldg 919 to EBIS
- March 7: Fe beam @LION
- Mar 14: Au with EBIS start
- Mar 16: Au extracted from EBIS
- Mar 26: Beam @NSRL target room

- Mar 27: Ta for NSRL user
- June 3: First RHIC fill with Au
- June 4: Started 24/7 for RHIC

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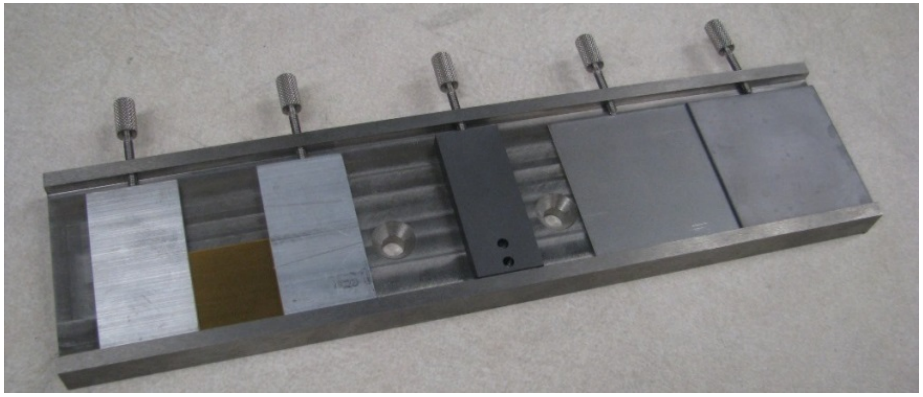
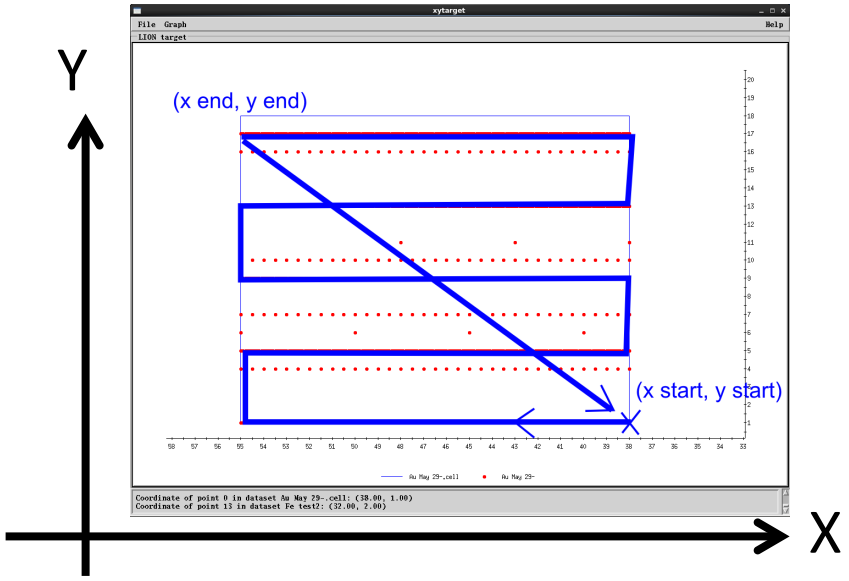
Beams for NSRL in Run14

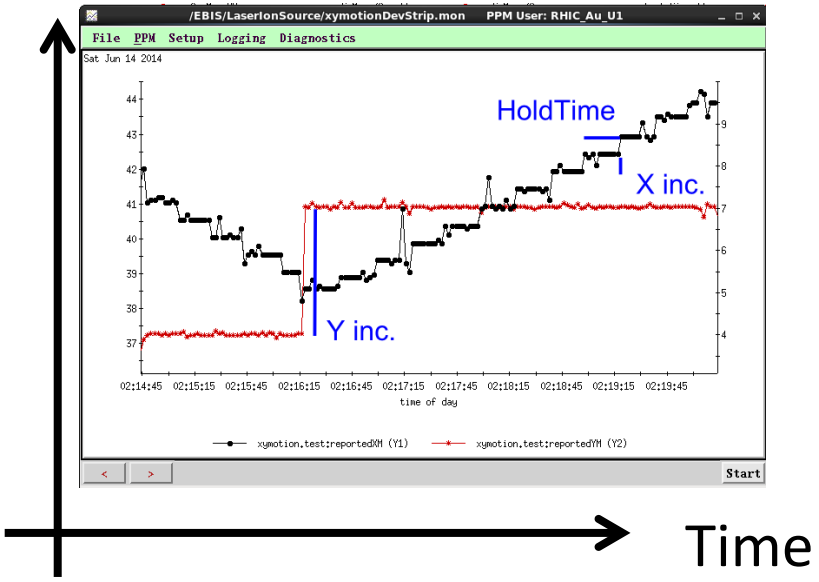
Species	Days	Total hours
C	2	43.5
Si	11	97
Ti	1	10.5
Fe	18	214.5
Ta	1	8
Au	3	49.5



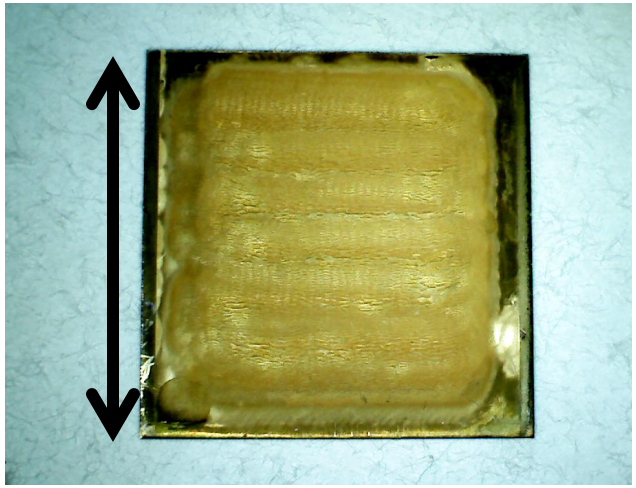
- Target holder: 50 x 254 mm
- Motion controller velocity: 10 mm/sec



X or Y

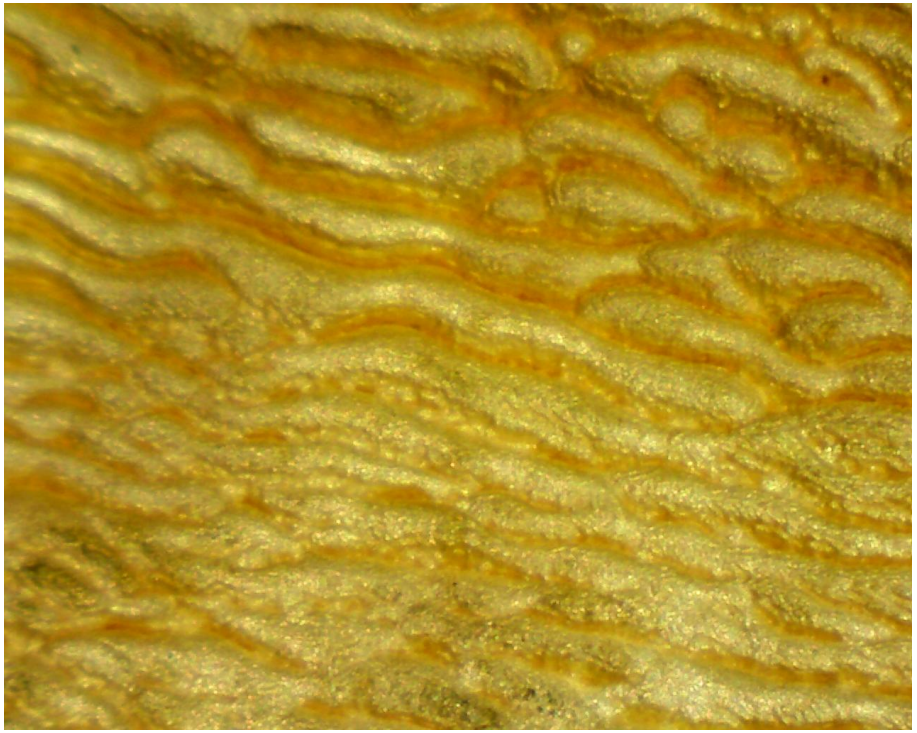


Au target after Run14 (used for NSRL and RHIC)



Gold target
25 mm by 25 mm
Thickness = 1 mm
Eroded ~0.5 mm during run

Top



Bottom

Au target consumption
12.3023 - 9.5217 = 2.7806 g
1,534,600 pulses → 1.8 x 10^{-6} g/pulse

C, Si, Ti, Fe also measured. Consumption was 1.4 - 8.4 x 10^{-7} g/pulse

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- Operation with LION was easy. Long term stability seems good (target scanning works).
  - occasionally adjust laser power, timing of laser pulse
- What failed on LION:
  - Laser ps
  - target motion – motor and controller
  - HV feedthrough; HV capacitor
- Also, HV arcs closed EBIS valves, tripped HV, RFQ, reset LLRF, etc.

These were normal things for a new system, and are being resolved. Reliability looks like it will be very good.

Comparison of LION to HCIS

- More flexibility of ion species
  - Multiple ion species, fast switching
  - Less gas load to EBIS
    - Bigger trap capacity for ions of interest
    - Less frequent cryo-pump regeneration
- So far, comparable performance for gold beam
  - but further tuning could lead to an improved charge state distribution
- Advantage for light ions
  - Higher injection voltage allows injection of higher current
  - Injection time is fast → more particles in lower charge states (if lower Q, such as Al^{5+}, is desired)
- Probably less maintenance will be required

Sixteen EBIS beams have been used to date

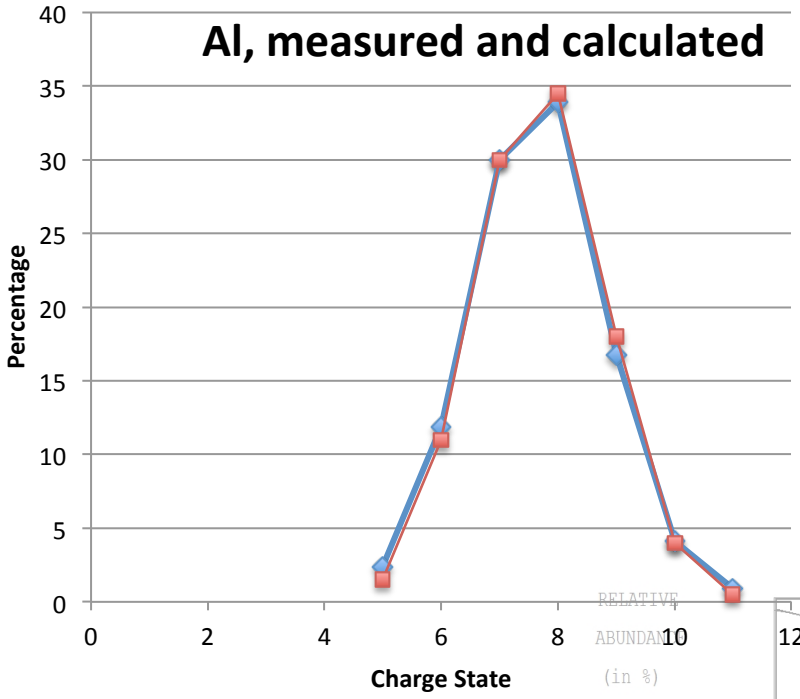
- **He-3 2+ RHIC & NSRL**
- **He-4 1+, 2+ NSRL**
- **C 5+ NSRL**
- **O 6+ NSRL**
- **Ne 5+ NSRL**
- **Si 11+ NSRL**
- **Ar 11+ NRSL**
- **Ti 18+ NSRL**
- **Fe 20+ NSRL**
- **Cu 11+ RHIC**
- **Kr 18+ NSRL**
- **Xe 27+ NSRL**
- **Ta 38+ NSRL**
- **Au 32+ RHIC & NSRL**
- **Pb 34+ AGS**
- **U 39+ RHIC**

Gas fed into the trap.
All other ions were via injection of 1+ ions from **HCIS** (and some LION)

Considerations for 1+ Beams

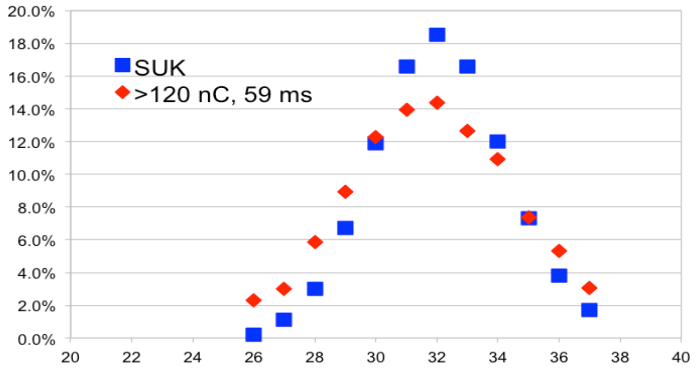
ex. for RHIC, recent questions about Pb, O, Al, Si, Ca, S; NSRL: B

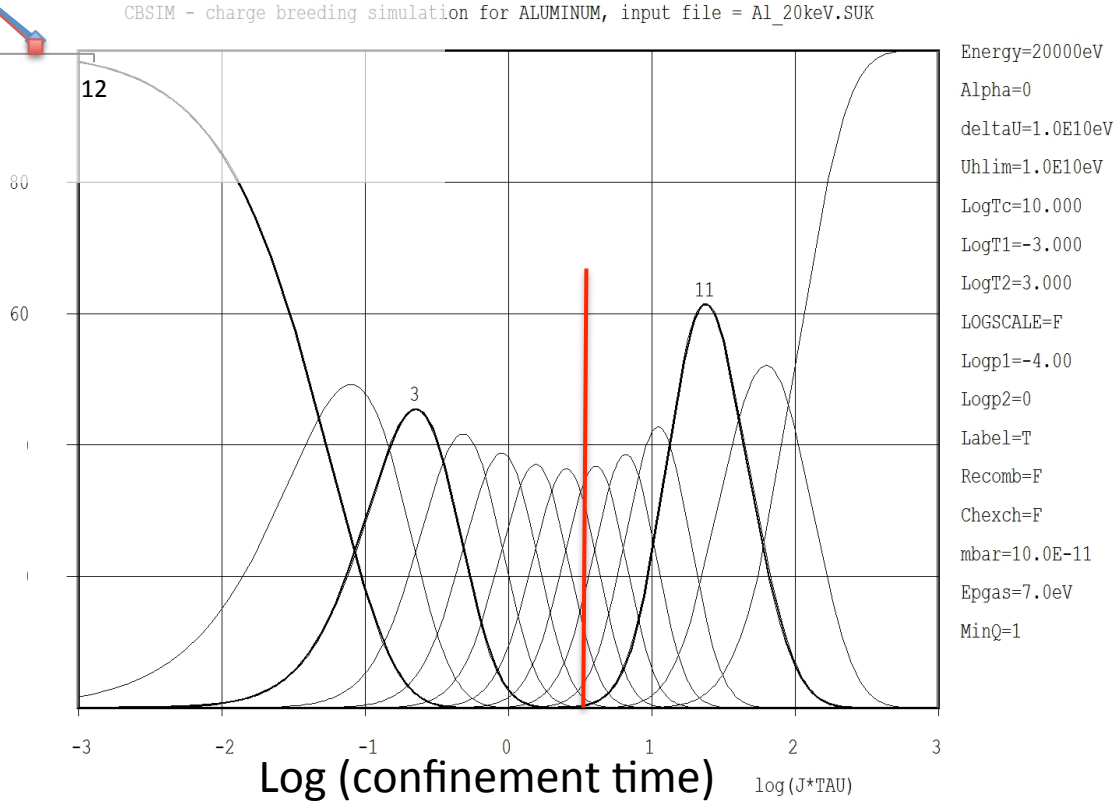
- **Considerations for LION targets/HCIS cathodes - contamination, coating, melting, conductivity, isotopic purity, etc. …**
- **Au, Al, Ti, Ta, W, Fe, Cu, … ~easy (isotopically enriched Cu)**
- **Pb, U – contamination**
  - **bigger concern for LION.**
- **Si, Ca, B - …..**
  - **Si – tried 5 different materials for HCIS (conductivity); with LION – pure Si worked easily**
  - **Ca, B not yet tried**
- **Gases**
  - **not with LION (but someday - condense gases on cold surface?)**
  - **Noble gases - simple for HCIS. (others - can be tricky)**
- **Other than the issues in making 1+, for EBIS, new beams are very straightforward**
  - **This year - Pb into AGS - total running, ever, of ~ 1 hour before we gave beam to Booster/ AGS**
- **2015 run**
  - ***Au^{32+} - will be from LION, with HCIS as backup***
  - ***Al^{5+} - easier than Si since conducting; prefer 5+ since more ions/pulse; but will need to use LION/fast injection for such a low charge state***



Fast injection and short confinement – good agreement with calculation

Slow injection and long confinement – charge state distribution broadens



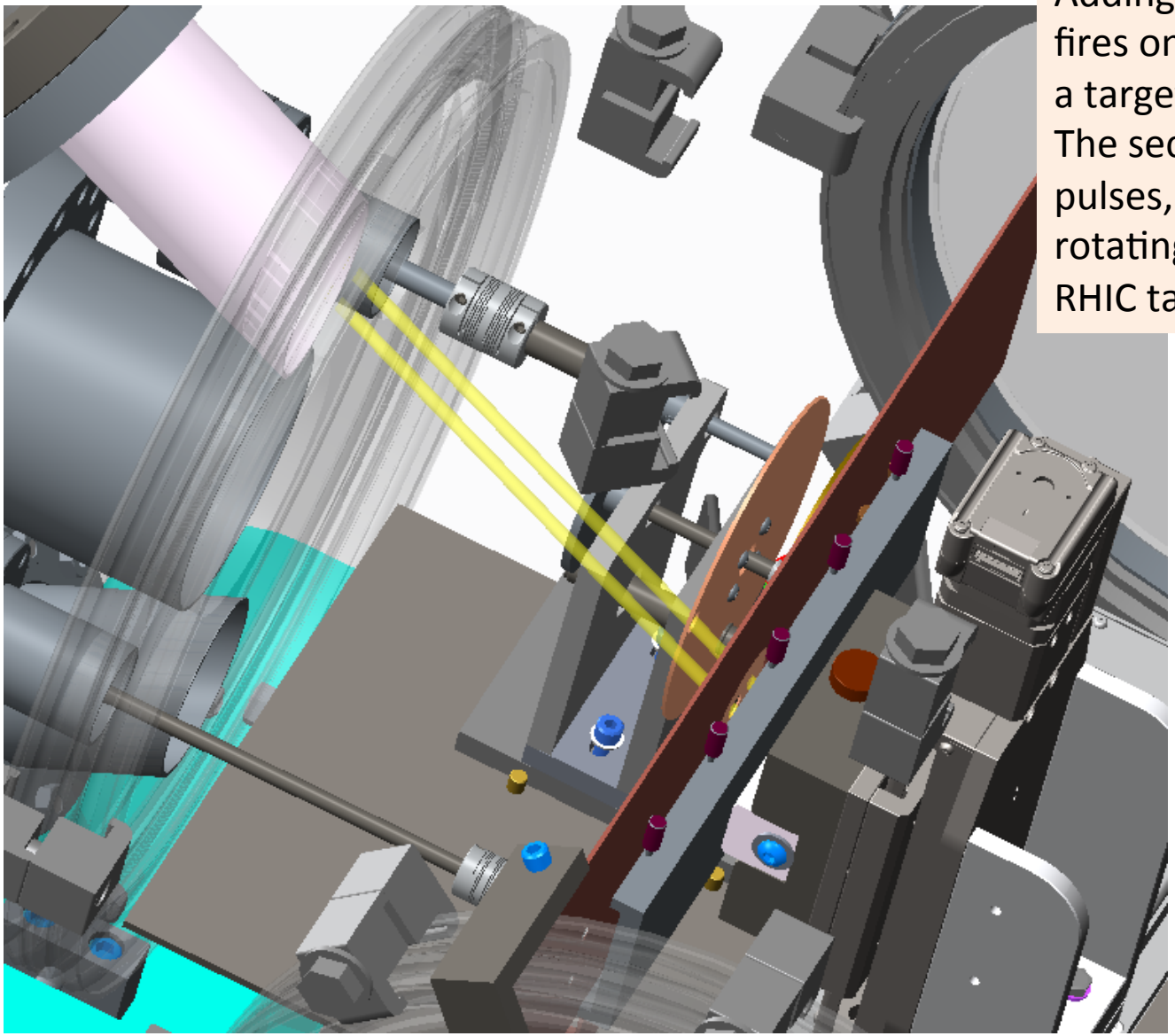


Log (confinement time)

Before next run

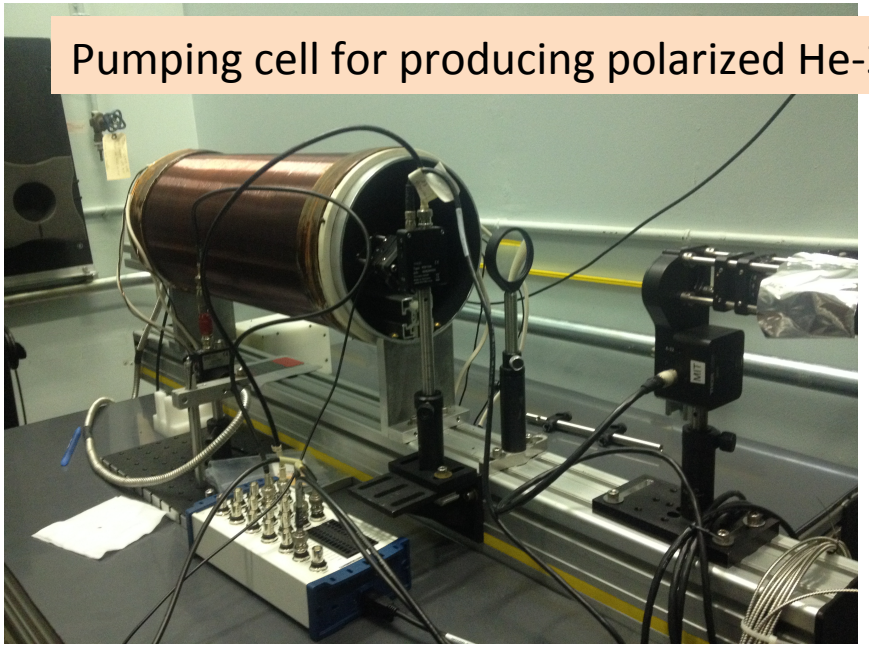
- LION work this summer:
  - Second laser & second target, so **PPM** between RHIC and NSRL beams
  - Preparation for operation at higher extraction voltage
- EBIS work this summer:
  - electron gun modifications - better pressures in gun region by reducing chance of discharges
  - Replace cathode (maintenance)
  - Bake
  - Add new LEBT diagnostic - measurement of ion energy out of EBIS to better match into RFQ
- RFQ trips – repair ps

LION Upgrade

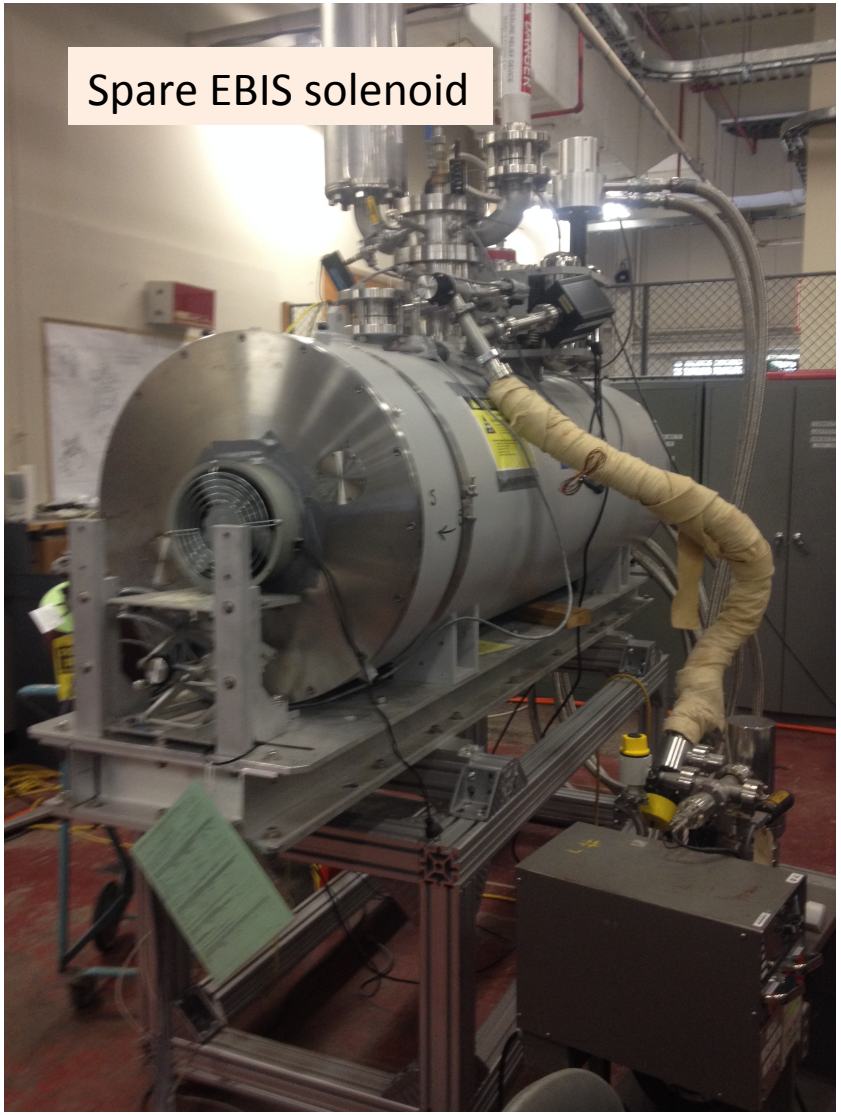


Adding another laser. One fires on NSRL pulses, hitting a target on the x-y stage. The second fires on RHIC pulses, hitting a new rotating wheel with the RHIC target material.

- Future - use EBIS for polarized He-3
- Ongoing R&D - BNL/MIT collaboration



Tests beginning on polarization of gas in weak & strong field, and transport of polarized atoms into the EBIS solenoid without depolarization.



Summary

- EBIS ran continuously for ~5½ months
  - Reliable, unattended operation
- In parallel, EBIS delivered 9 different species to NSRL
- Au-^{3}He running was a demonstration of the versatility of EBIS
- The Laser Ion Source (LION) was installed during Run14, and then used routinely for much of the run. This gave us much more flexibility.
  - LION was used for NSRL from March 27; for RHIC from June 3
  - 1+ beams of C, Si, Ti, Fe, Ta, Au were provided from LION
- EBIS + LION is really an ideal marriage, adding operational flexibility to the accelerator complex with rapid switching between *many* species