Performance of the Low Charge State Laser Ion Source in BNL

Masahiro Okamura, James Alessi, Edward Beebe, Michael Costanzo,
Leonard DeSanto, Shunsuke Ikeda, James Jamilkowski, Takeshi Kanesue, Robert Lambiase, Daniel Lehn, Chong-Jer Liaw, Daniel McCafferty,
John Morris, Robert H. Olsen, Alexander I. Pikin, Robert Schoepfer,
Andrew N. Steszyn
BNL, Upton, Long Island, New York

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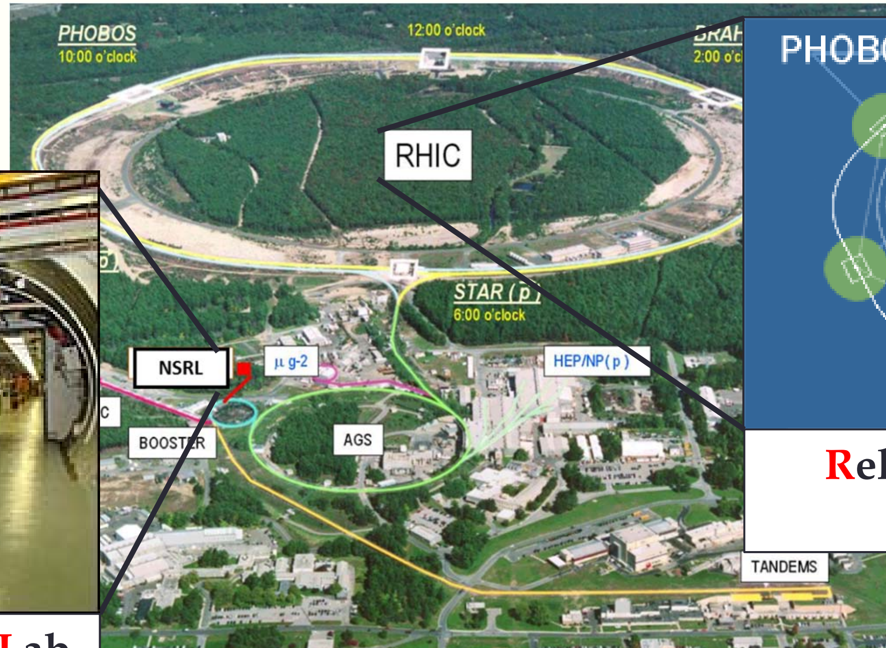
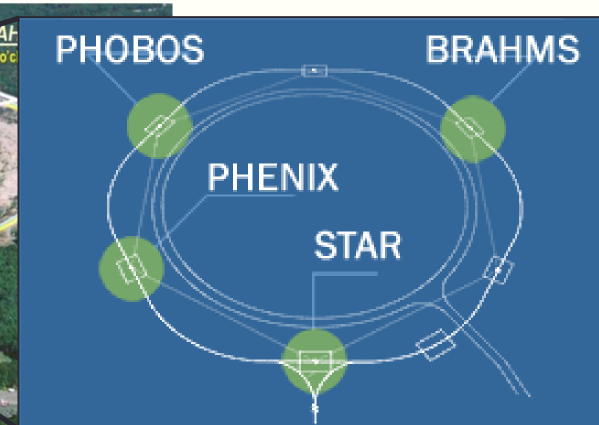
Chicago

Since 2014, the laser ion source is providing beams to

NASA Space Radiation Lab



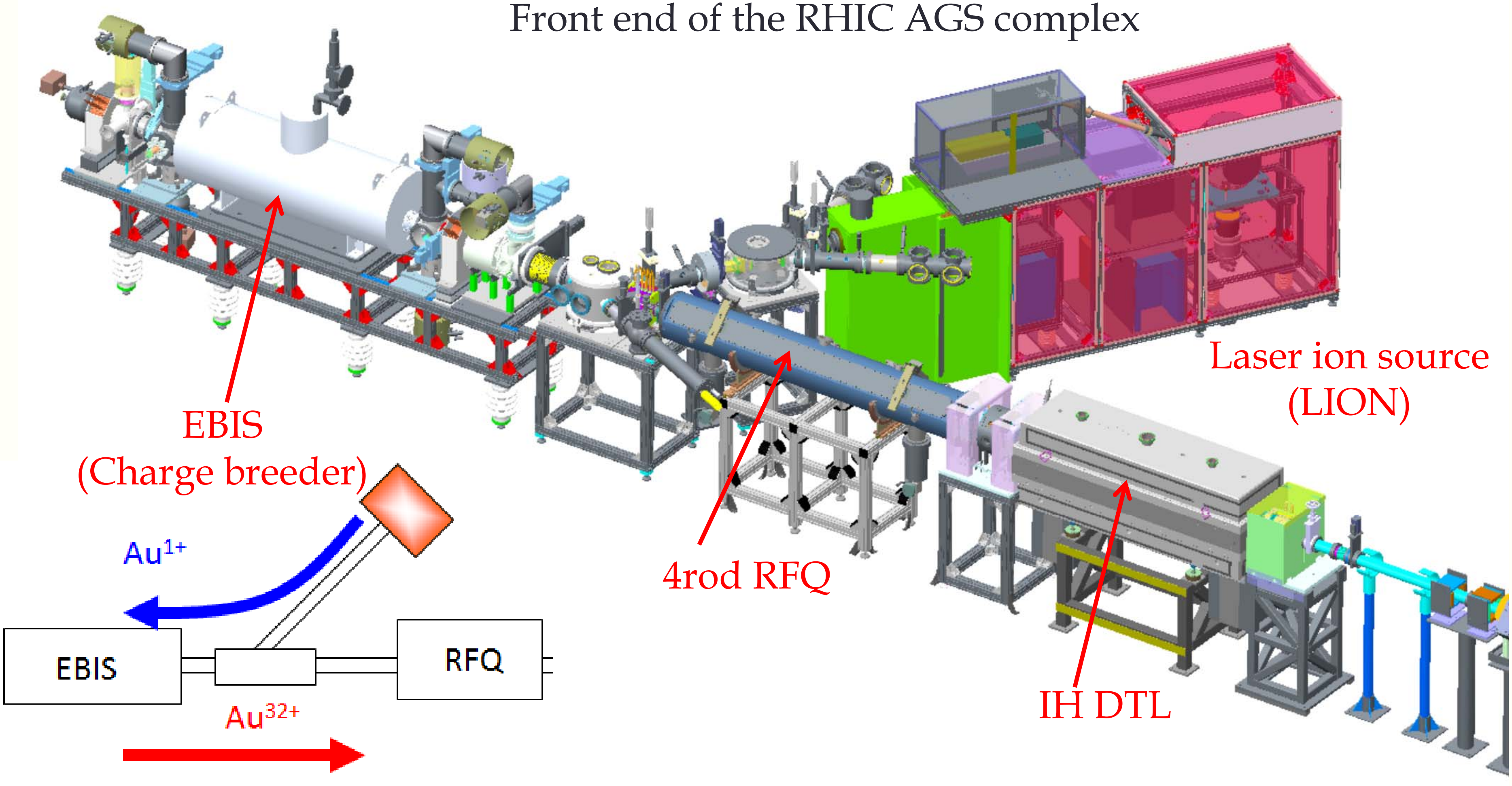


Relativistic Heavy Ion Collider

	NSRL	RHIC
For what?	Simulate galactic cosmic rays	Create quark gluon plasma
Species	Li, B, C, O, Ca, Ti, Fe, Ta, Au	Au (Al)
Energy	~1GeV/n	100GeV/n

RHIC: 24H/day, 7days/week, for continuous 6 months
NSRL: 8H/day, 5days/week, for total 4 months

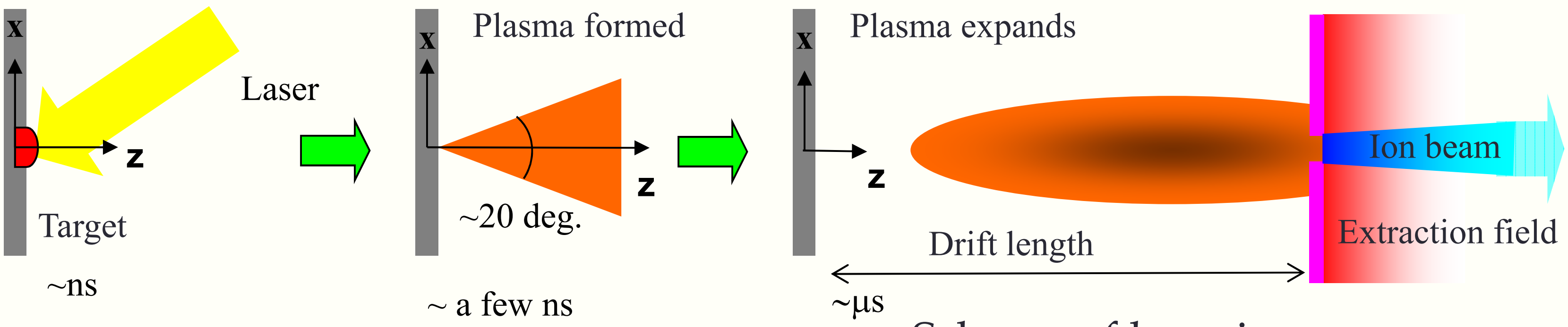
Front end of the RHIC AGS complex



Typical timing sequence:
The entire accelerator complex is triggered at a signal of every 6 seconds.

Within a period of 6 seconds:
RHIC accepts 12 laser pulses at 200 ms interval. (standby mode needs 1 pulse.)
NSRL needs 1 laser pulse.

Advantages of laser ion source (LIS)



Scheme of laser ion source

Many species can be delivered from a LIS.
Species switching can be very fast.

Stability of an ion source

Stability of an ion source

⬍

Stability of an ion source

⇕

Stability of plasma heating process

Stability of an ion source

⇕

Stability of plasma heating process

Micro wave

Stability of an ion source

⇕

Stability of plasma heating process

Gas pressure

Micro wave

Stability of an ion source

⇕

Stability of plasma heating process

Gas pressure

Micro wave

Magnetic field

Stability of an ion source

Stability of plasma heating process

Gas pressure

Micro wave

Electron stream

Magnetic field

Stability of an ion source

⇕

Stability of plasma heating process

Material of chamber

Gas pressure

Micro wave

Electron stream

Magnetic field

Stability of an ion source

⇕

Stability of plasma heating process

Material of chamber

Magnet stability

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⇕

Stability of plasma heating process

Material of chamber

Gas pressure

Micro wave

Magnet stability

Oven temperature

Electron stream

Magnetic field

Stability of an ion source

⇕

Stability of plasma heating process

Seeding gas

Material of chamber

Magnet stability

Gas pressure

Oven temperature

Electron stream

Micro wave

Magnetic field

Stability of an ion source

Stability of plasma heating process

Seeding gas

Material of chamber

Magnet stability

Gas pressure

Oven temperature

Electron stream

Micro wave

Magnetic field

Drift tube voltage

Stability of an ion source

⇕

Stability of plasma heating process

Seeding gas

Material of chamber

Magnet stability

Gas pressure

Oven temperature

Electron stream

Micro wave

Discharge

Magnetic field

Drift tube voltage

Stability of an ion source

⇕

Stability of plasma heating process

Seeding gas

Material of chamber

Magnet stability

Gas pressure

Oven temperature

Electron stream

Micro wave

Discharge

Magnetic field

Drift tube voltage

Laser

Stability of an ion source

⇕

Stability of plasma heating process

Seeding gas

Material of chamber

Magnet stability

Gas pressure

Oven temperature

Target

Electron stream

Micro wave

Discharge

Magnetic field

Drift tube voltage

Laser

Stability of an ion source

⇕

Stability of plasma heating process

Seeding gas

Material of chamber

Magnet stability

Gas pressure

Oven temperature

Target

Electron stream

Micro wave

Discharge

Magnetic field

Drift tube voltage

Laser

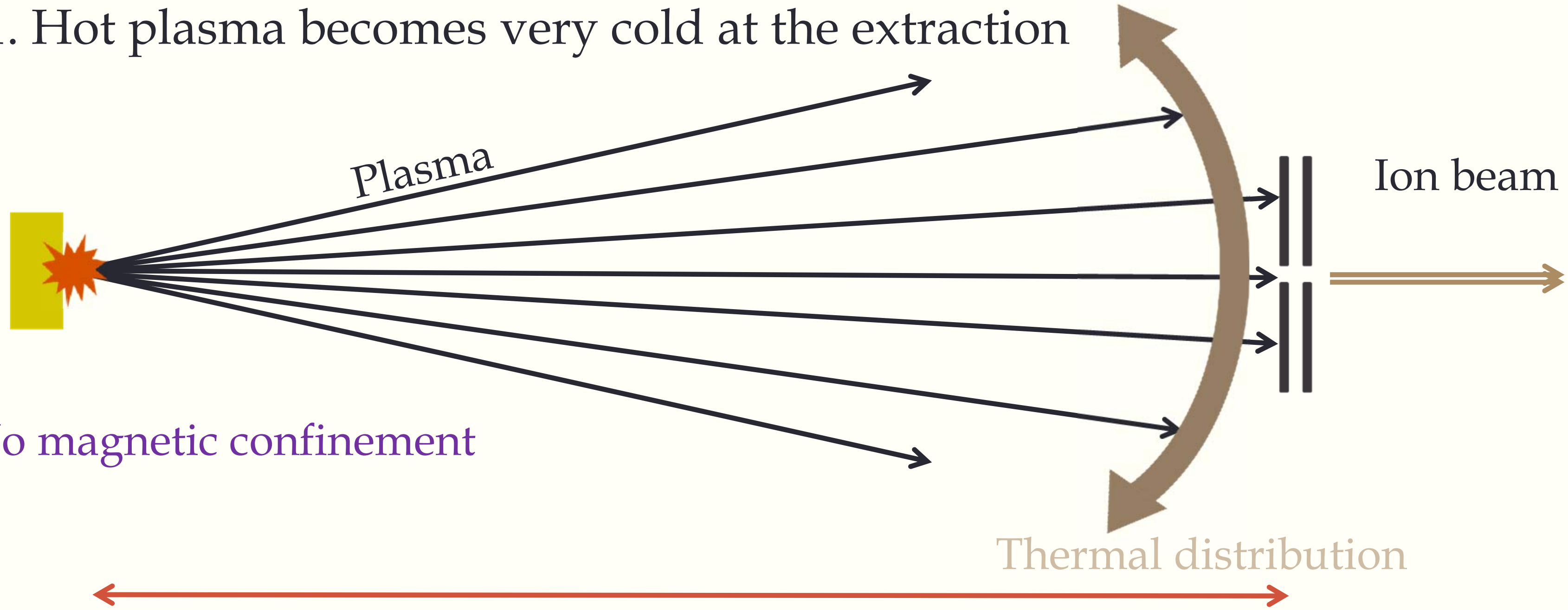
We need to stabilize only two components.

Laser & target

To achieve high brightness

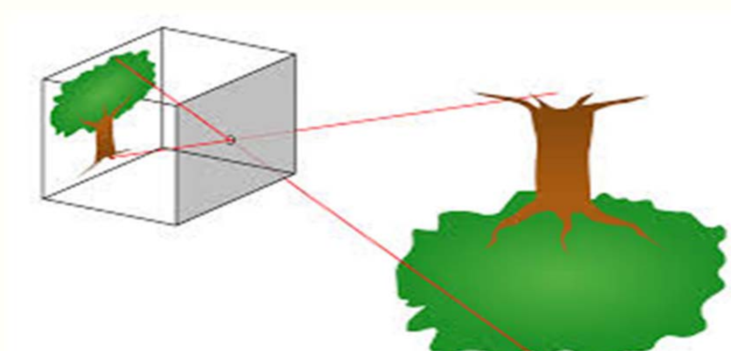
- Low plasma temperature
- Less magnetic field at extraction
- Good uniformity of plasma at sheath

1. Hot plasma becomes very cold at the extraction



2. No magnetic confinement

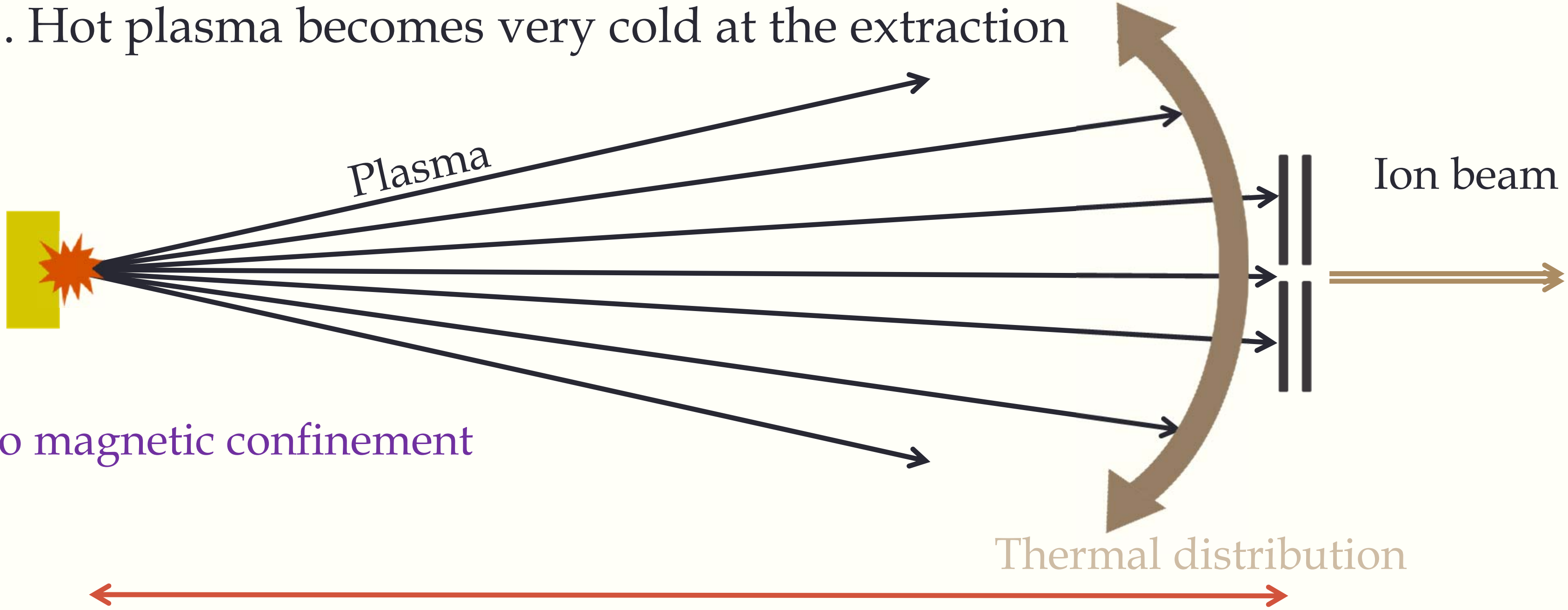
7.5 mm / 3300 mm → 0.13 degree



3. Pin point ionization
-uniform plasma density-

Beam is always affected by shape of plasma.

1. Hot plasma becomes very cold at the extraction



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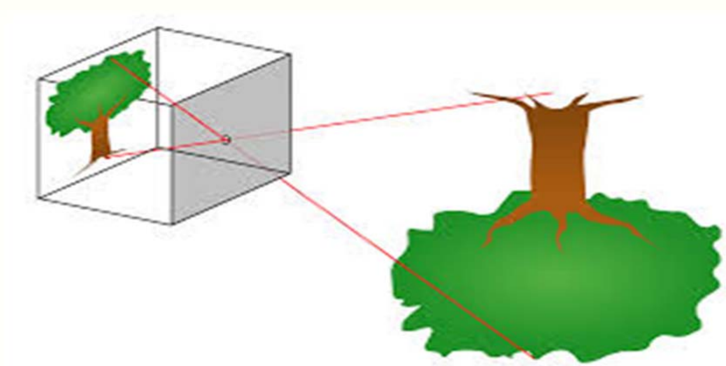


3. Pin point ionization
-uniform plasma density-

Beam is always affected by shape of plasma.

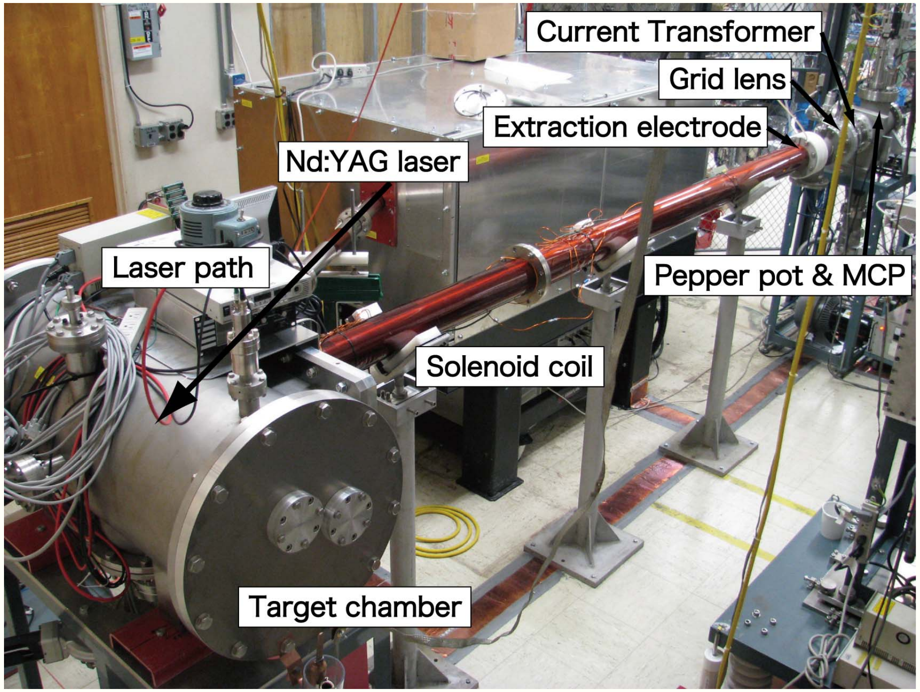
High brightness beam can be delivered from laser ion source

Laser ion source provides stable high brightness heavy ion beams.

Time line of the project named as LION

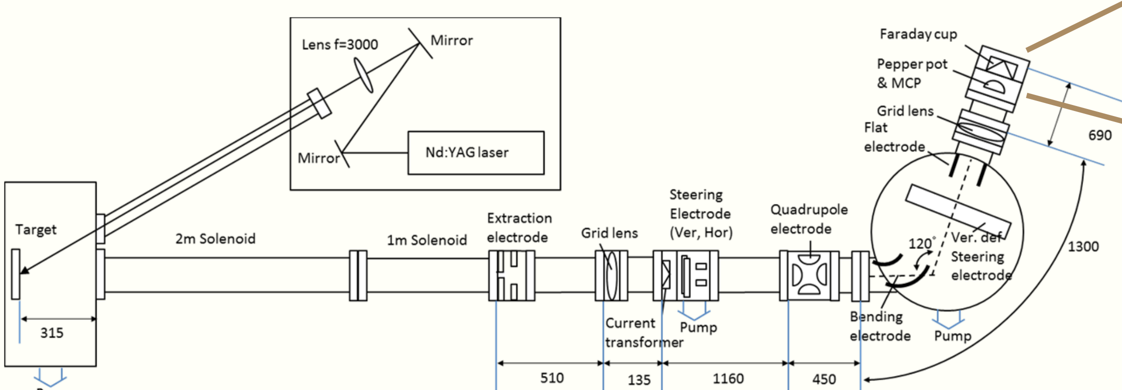
2007 Stable production of Low charge state beam was established.
2009 The project was approved by NASA. Solenoid guiding filed was tested.
2010 Funded. RHIC-EBIS pre-injector system was completed.
2014 The first beam was delivered to EBIS.
2015 Upgraded to provide beams to NSRL and RHIC simultaneously.
2016 Fast solenoid was added.

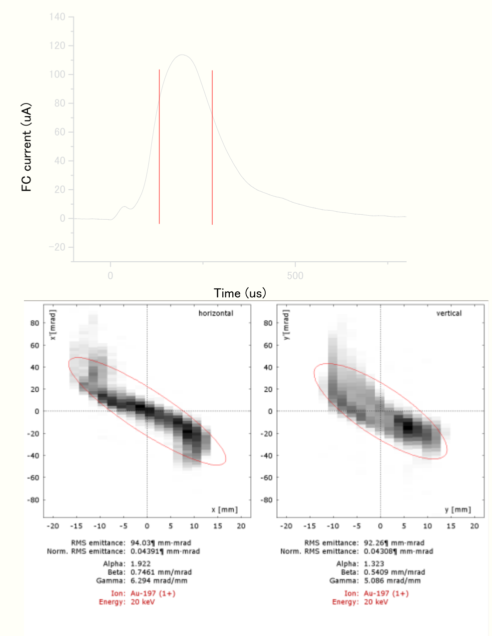
Test laser ion source in 2012

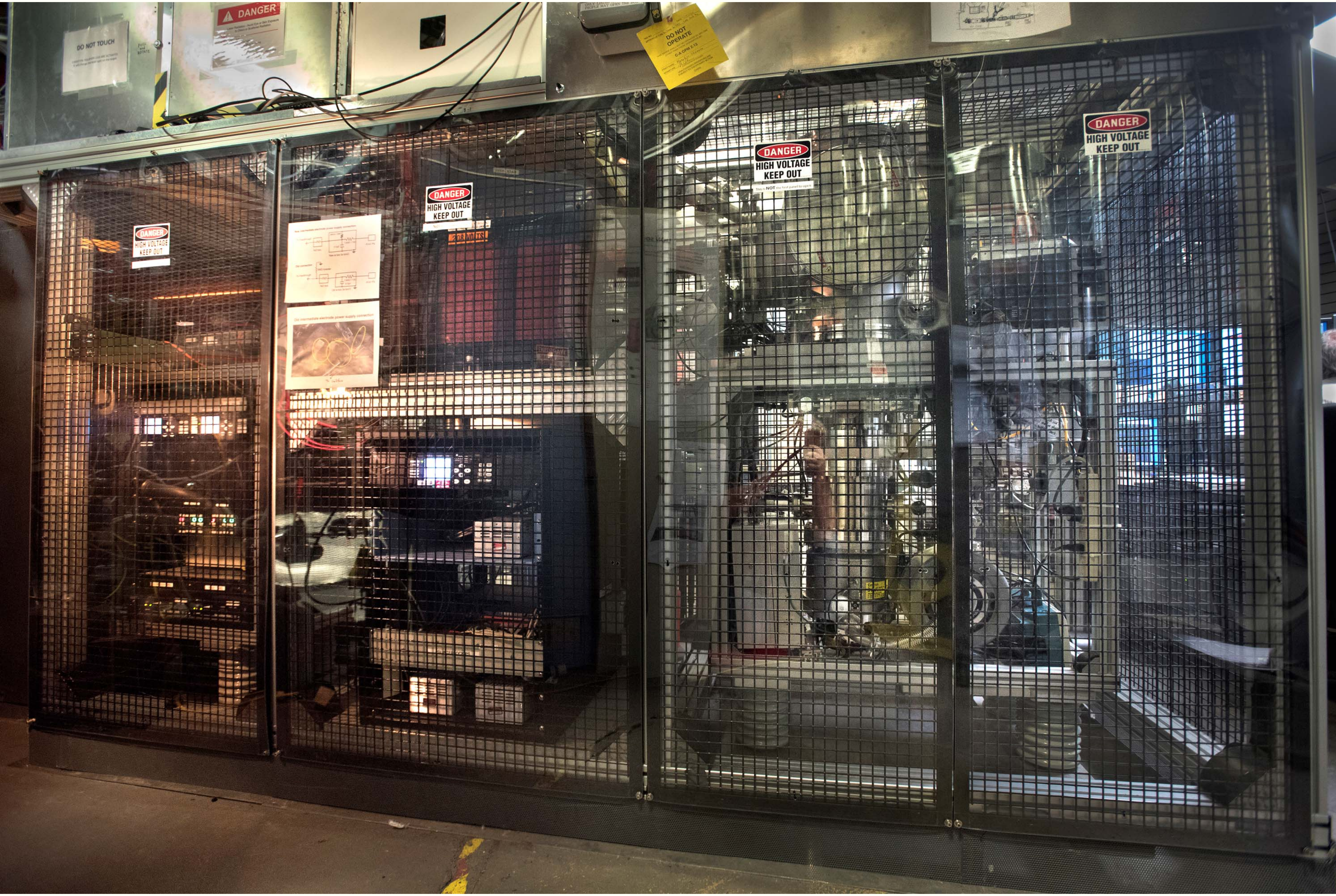


Required value		
Mass of injected ion	AMU	197
charge state of interest	+	32
q/A		0.16
overall efficiency	%	50
injection time	μs	145
avg inj 1+ current	μA	38.1
total ion charge in species of interest	Coulomb	5.5E-09

Experimental results		
Experimental result of injection time	μs	145
Experimental result of peak current	μA	113
Experimental result of total ion charge	Coulomb	1.46E-08
Nor RMS emittance X	πmmmrad	0.043
Nor RMS emittance Y	πmmmrad	0.043
solenoid	gauss	0
twin pulse	yes/No	N






DO NOT TOUCH
DANGER
DO NOT OPERATE
DANGER
HIGH VOLTAGE
KEEP OUT
DANGER
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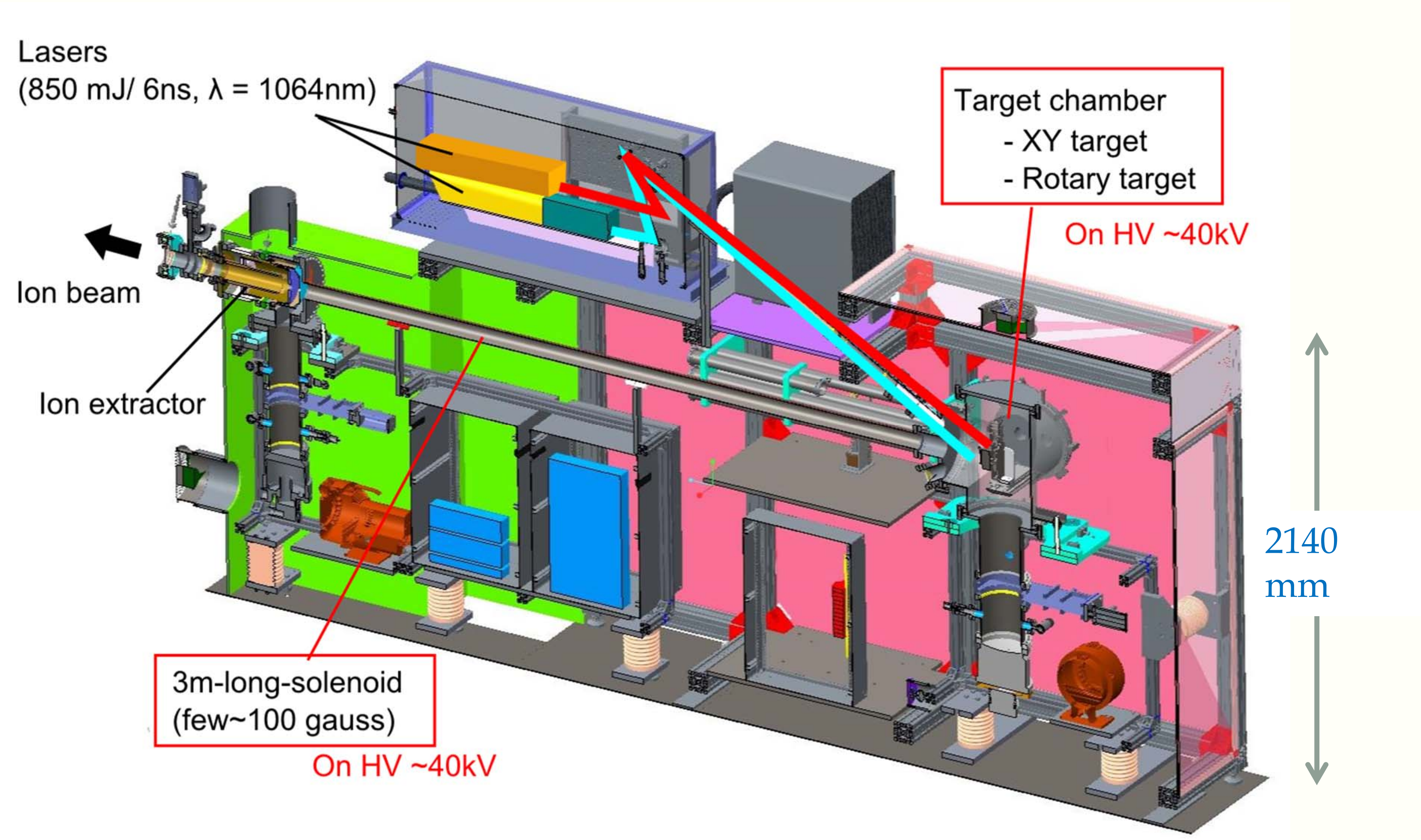
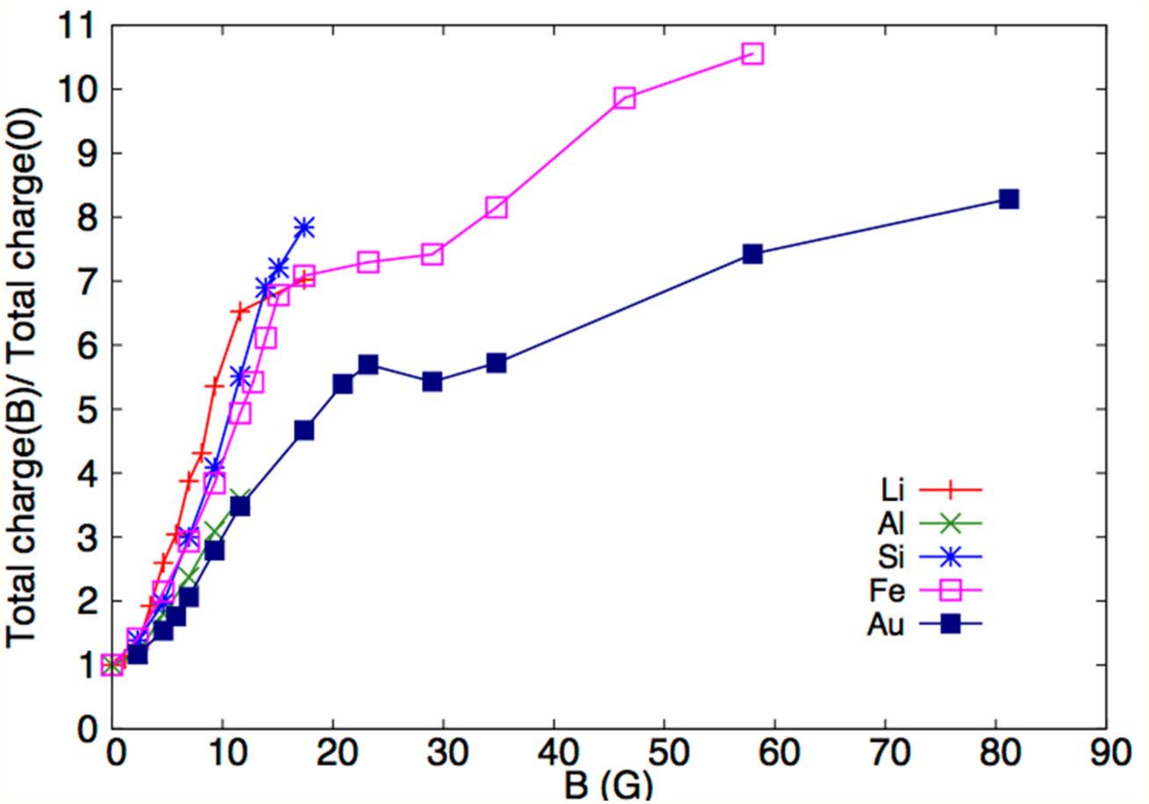
KEEP OUT



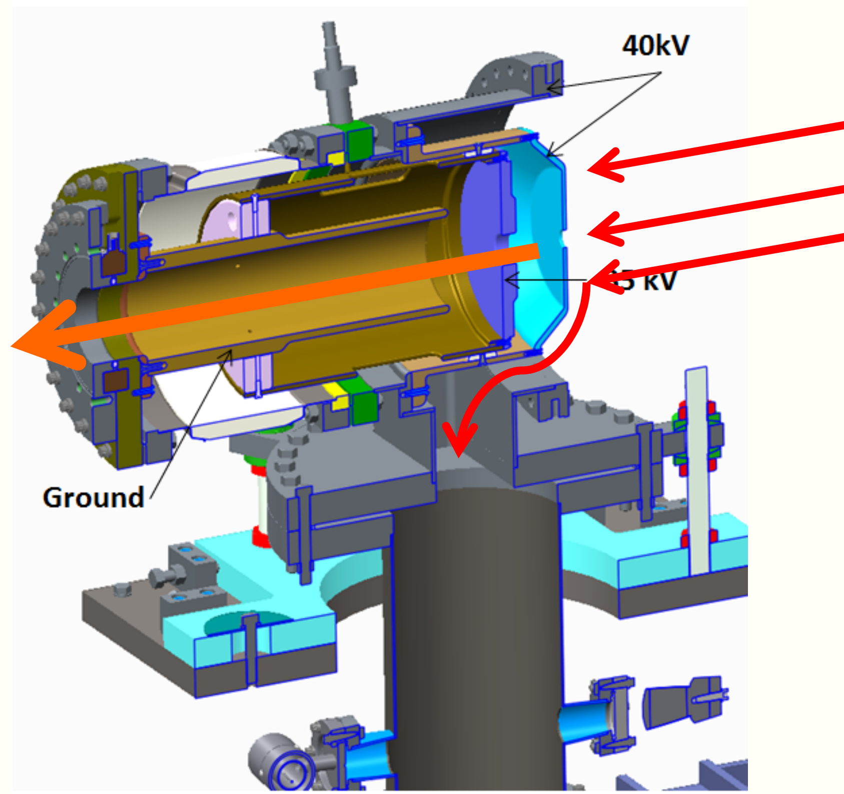
Lasers
(850 mJ/ 6ns, λ = 1064nm)
Ion beam
Ion extractor
Target chamber
- XY target
- Rotary target
On HV ~40kV
2140
mm
3m-long-solenoid
(few~100 gauss)
On HV ~40kV

Effect of the 3 m DC solenoid on total extracted charge

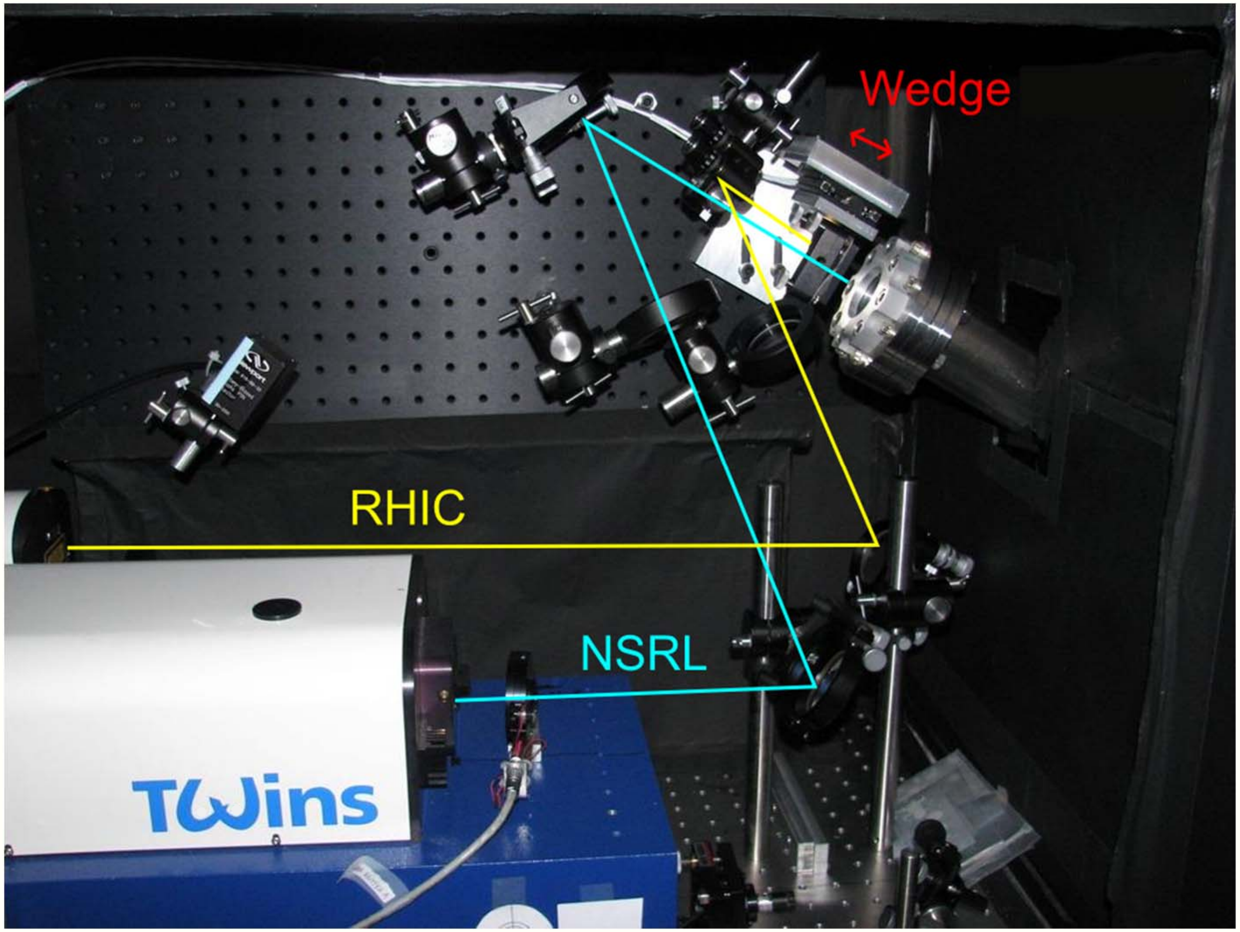


DC solenoid can adjust the beam currents as desired.

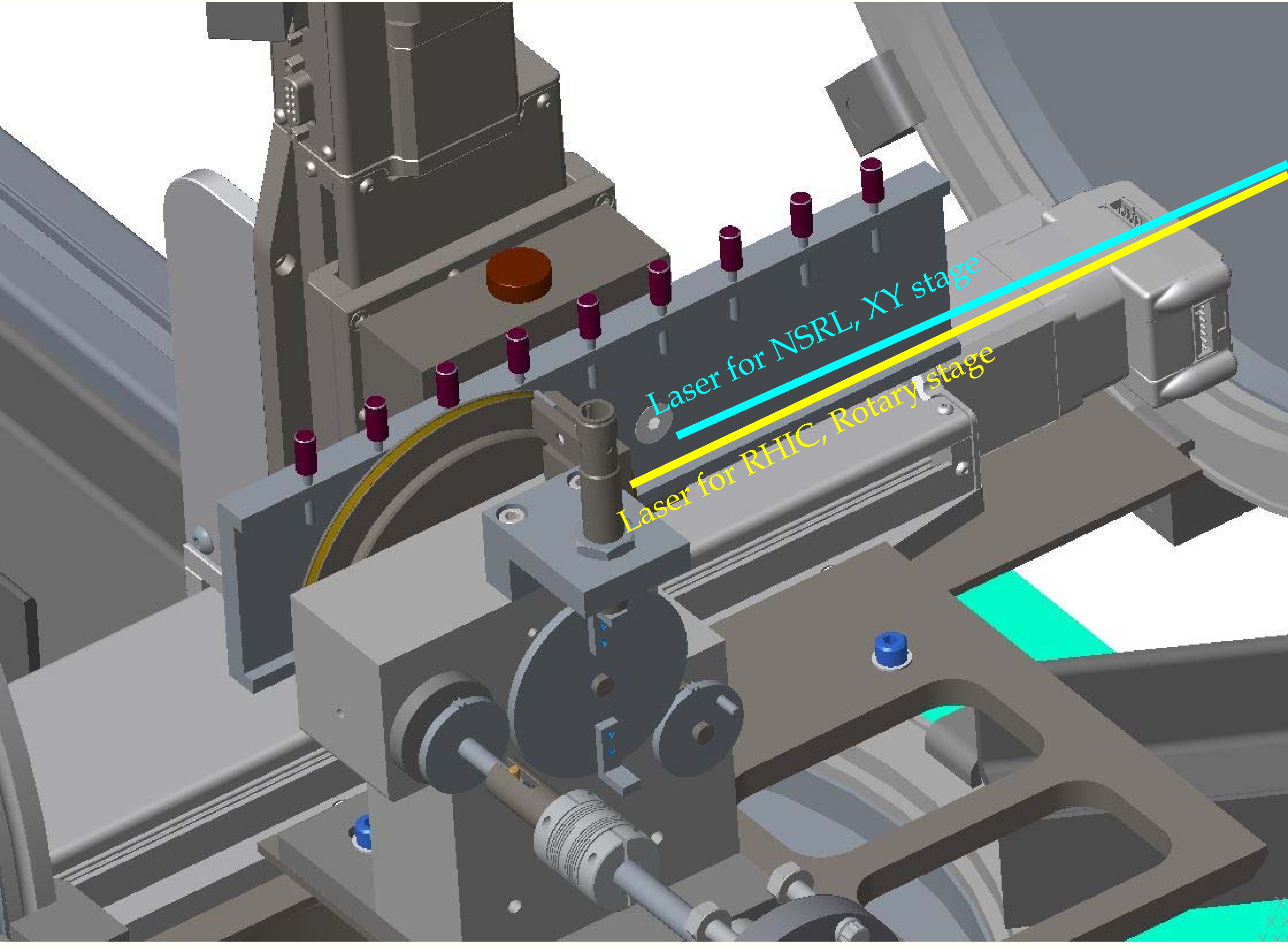
The Extraction Electrode

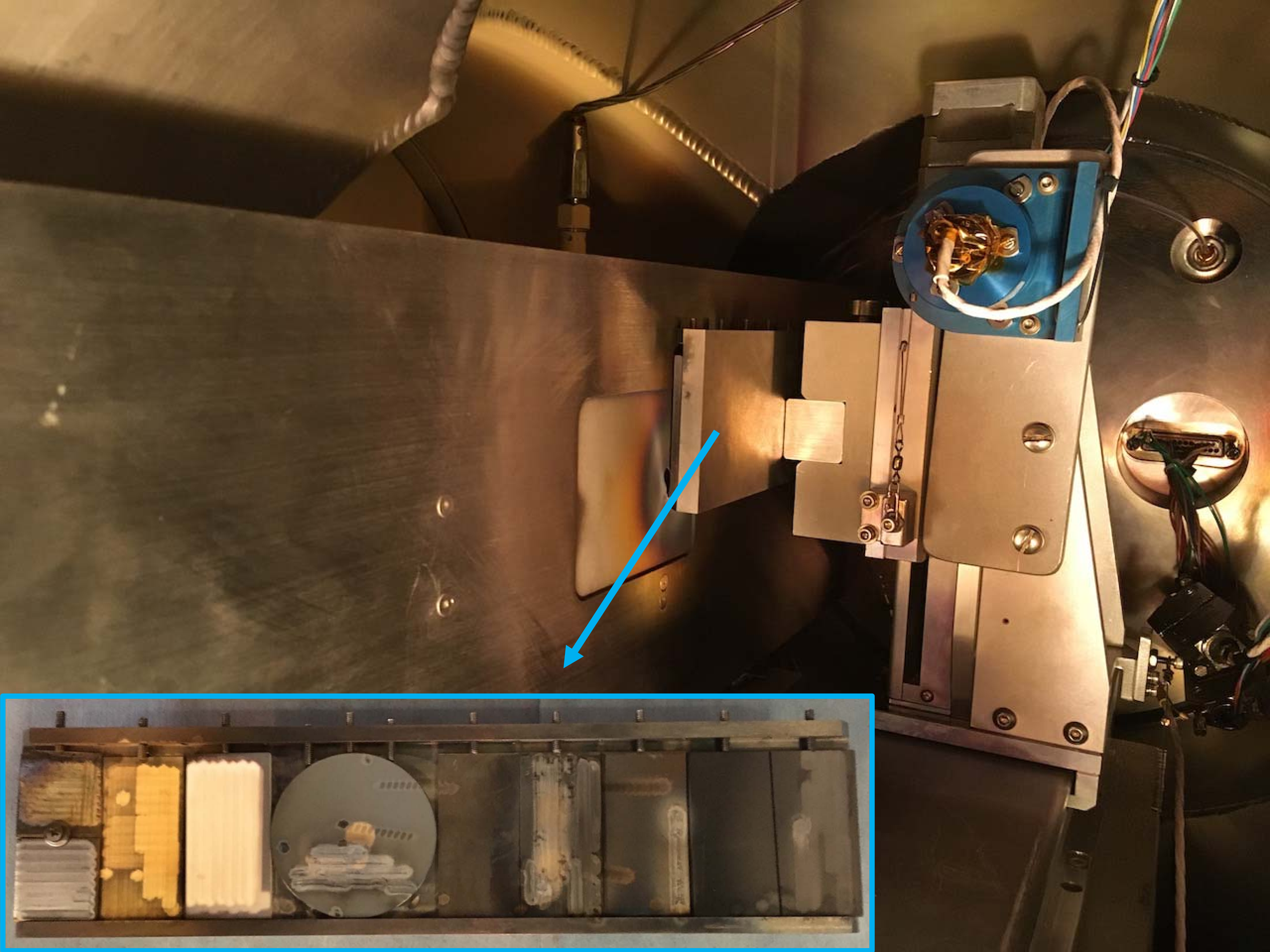


Un-extracted plasma and neutral gas are evacuated to avoid recombination in the successive plasma.

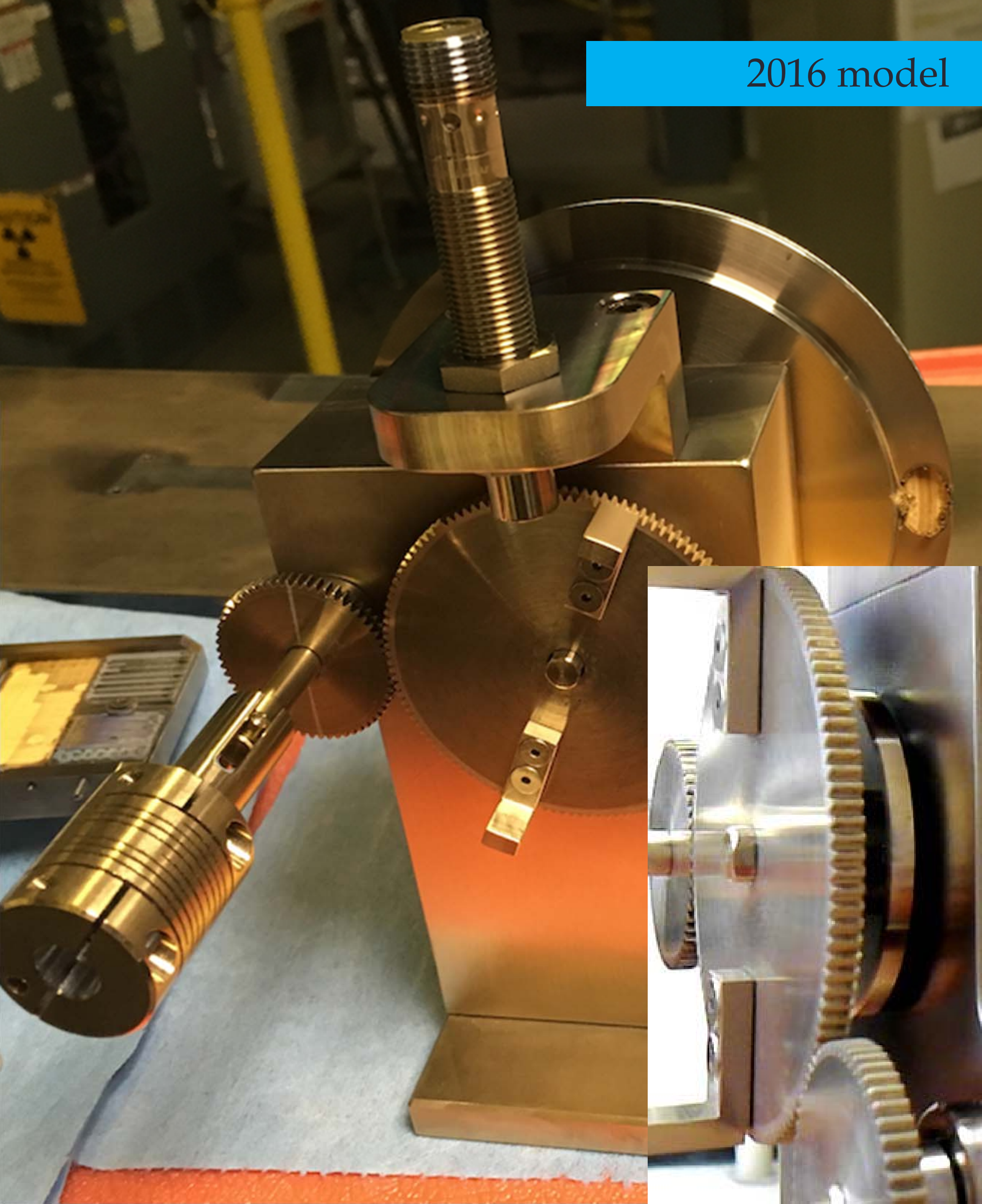


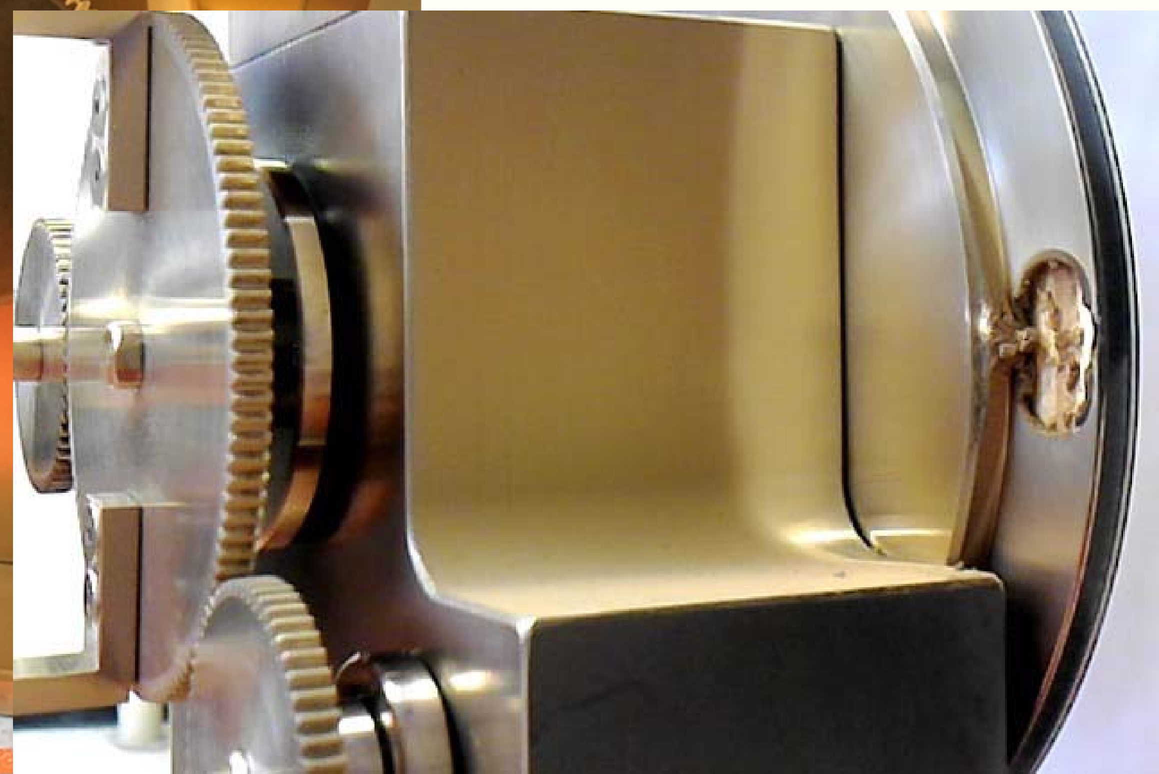
Model	Quantel laser Brilliant B
Laser type	Nd:YAG 1 laser for RHIC 2 laser + combiner for NSRL
Wave length	1064 nm
Laser energy on target	400 ~ 700 mJ
Pulse width	6 ns
Rep. rate	5 Hz
Laser Spot size on target	ϕ 3 ~4 mm


Laser for NSRL, XY stage
Laser for RHIC, Rotary stage

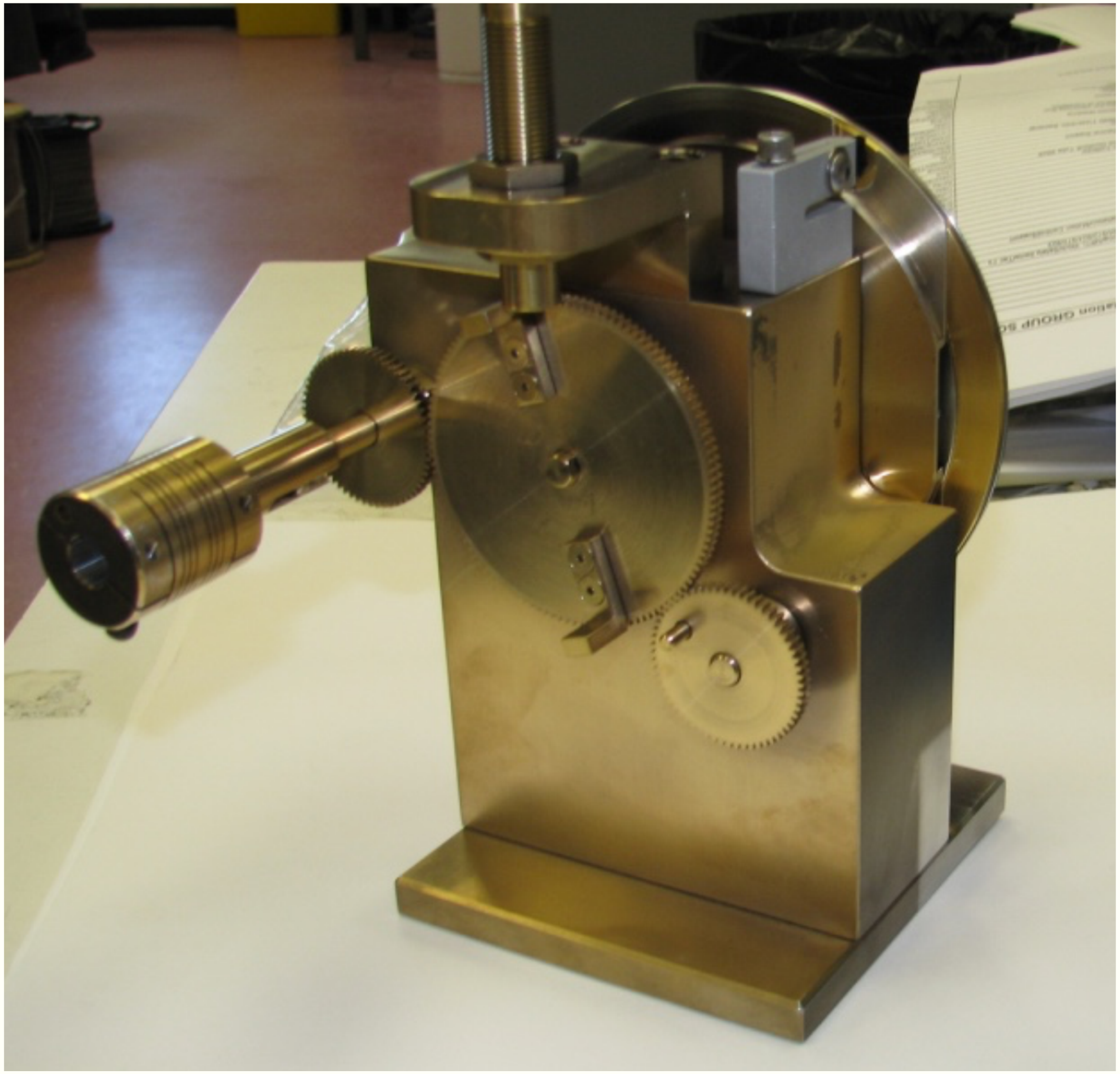


2016 model

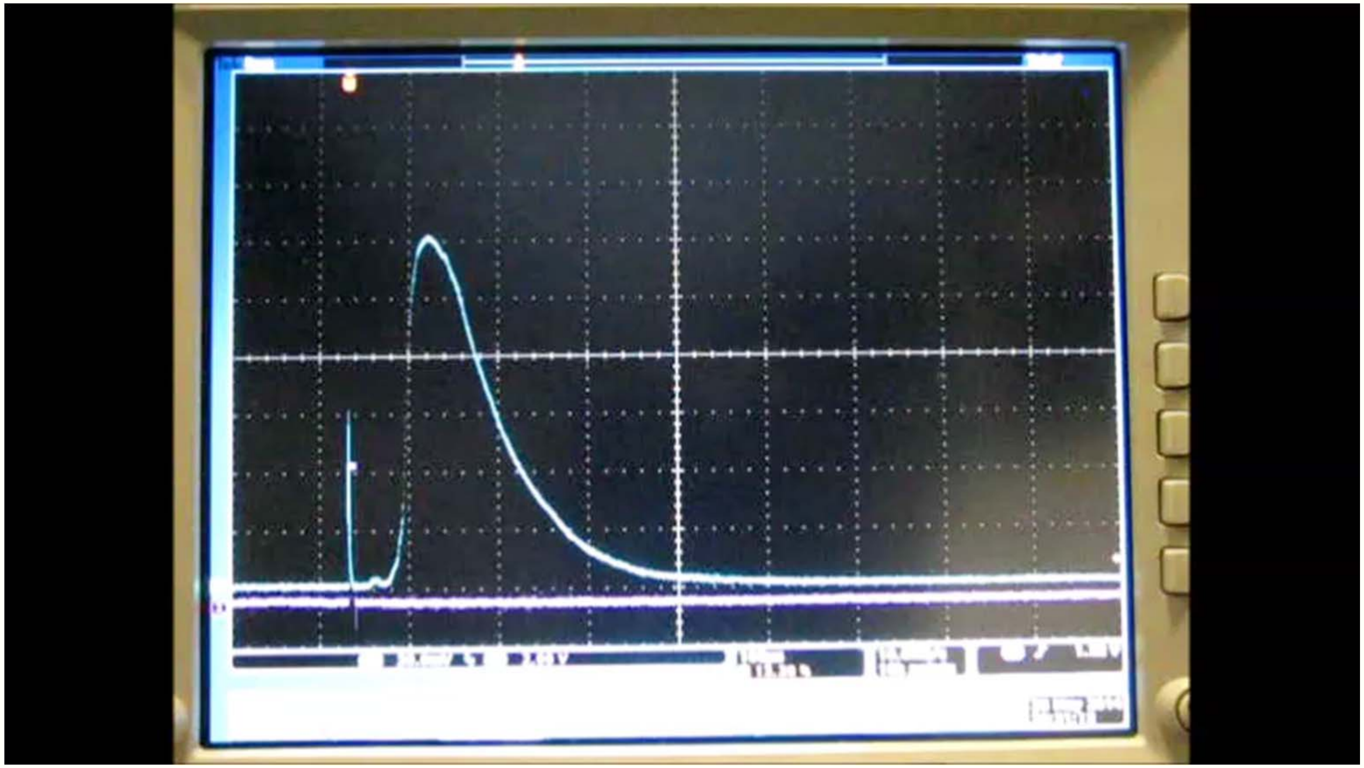





2017 model



Fast switching of ion species



- Repetition rate 1 Hz
- Switching between Au (lower current) and Ti (higher current)
- The current profile is due to the thermal distribution of ions.

The LIS has been used for long term operation. Almost NO down time.

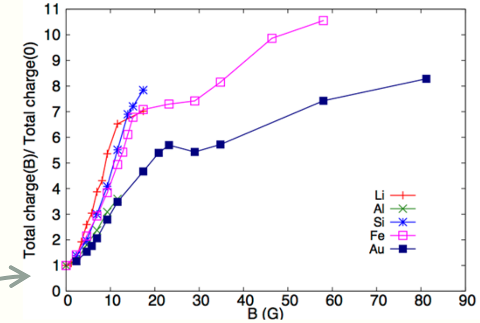
Beam time at the facilities

		Li	B	C	O	Al	Ca	Si	Ti	Fe	Ta	Au
Run14 (since March 25, 2014)	NSRL (days)			2				11	1	18	1	3
	RHIC (days)											33
Run15	NSRL (days)	1		2			1	18	4	30		6
	RHIC (days)					14						42
Run16	NSRL (days)		1	5	9			13	5	33	4	1
	RHIC (days)											198

NSRL: 8h/day, 5 days/week, 4 months
RHIC: 24h/day, 7days/week, 6 months

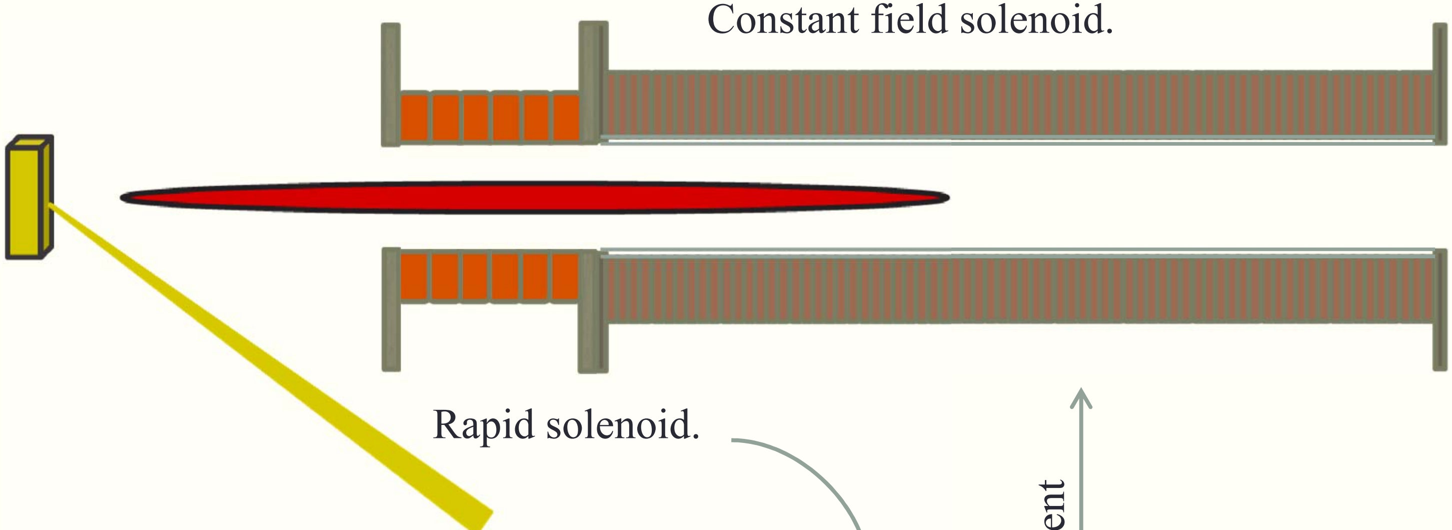
BROOKHAVEN NATIONAL LABORATORY

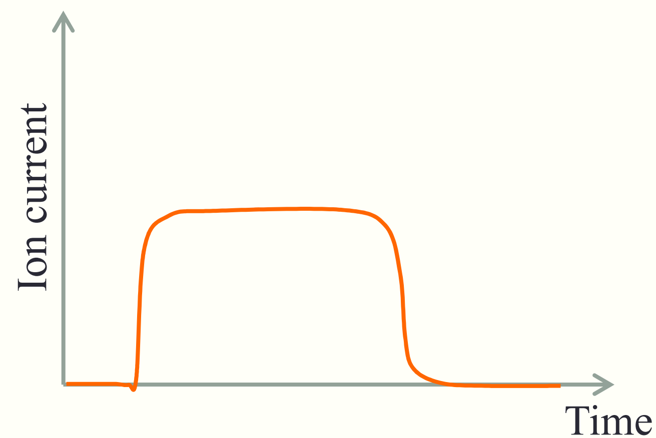
Recent upgrade for RUN 17



Static solenoid enhance entire current profile.

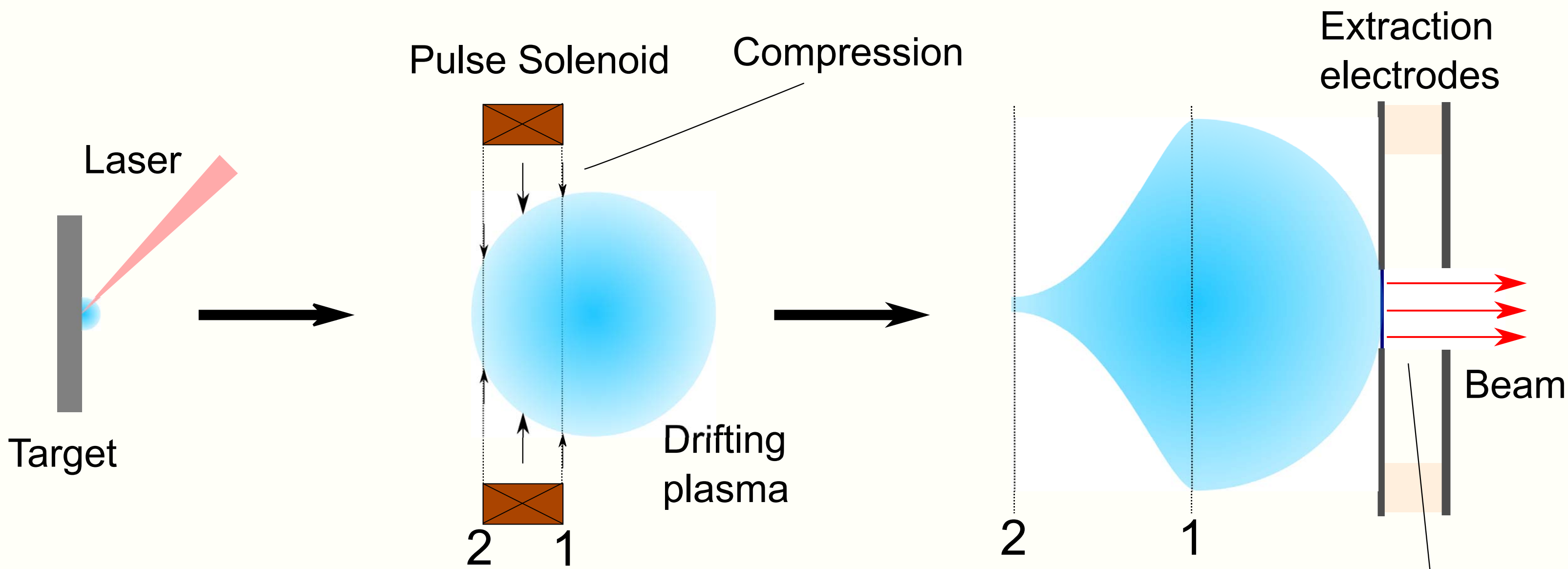
Rapid solenoid may control the ion density.



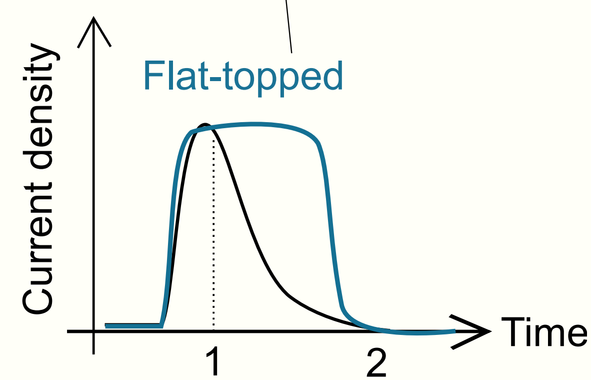


Rapid solenoid manipulates current profile.

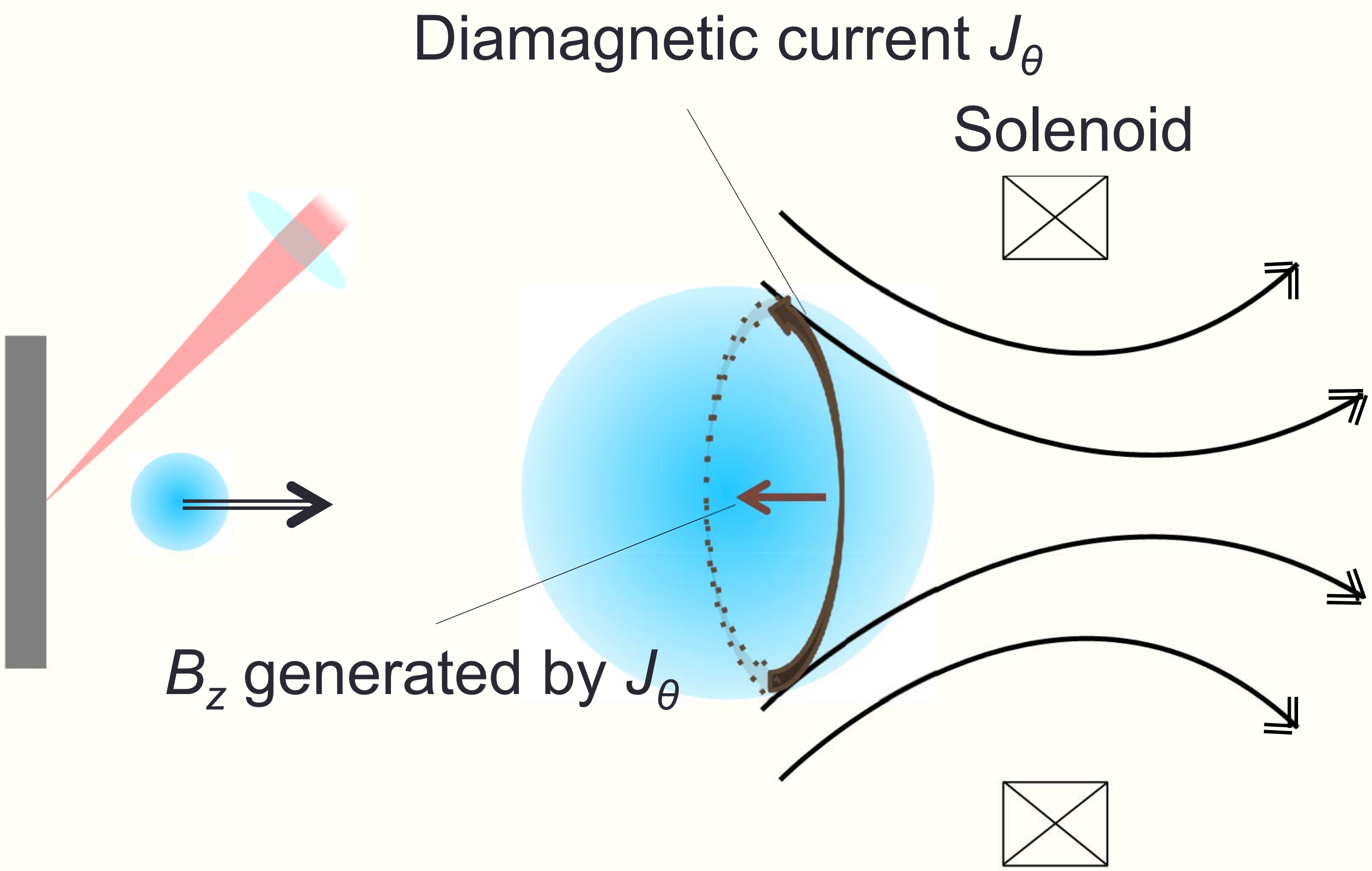
How to tailor the current profile ??



- Fast rising magnetic field may selectively compress the plasma at the beam tail.
- By applying the pulsed field, we are trying to control the current profile.

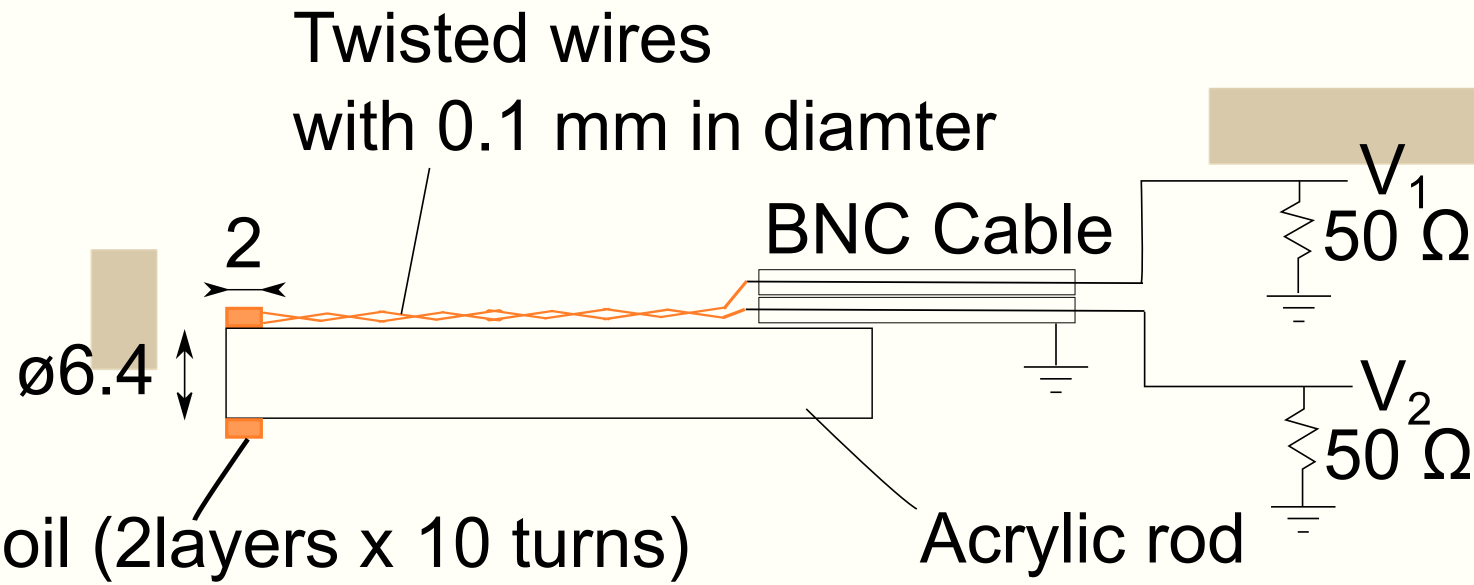


Measurement of ΔB unveiled eddy current distribution in the plasma.



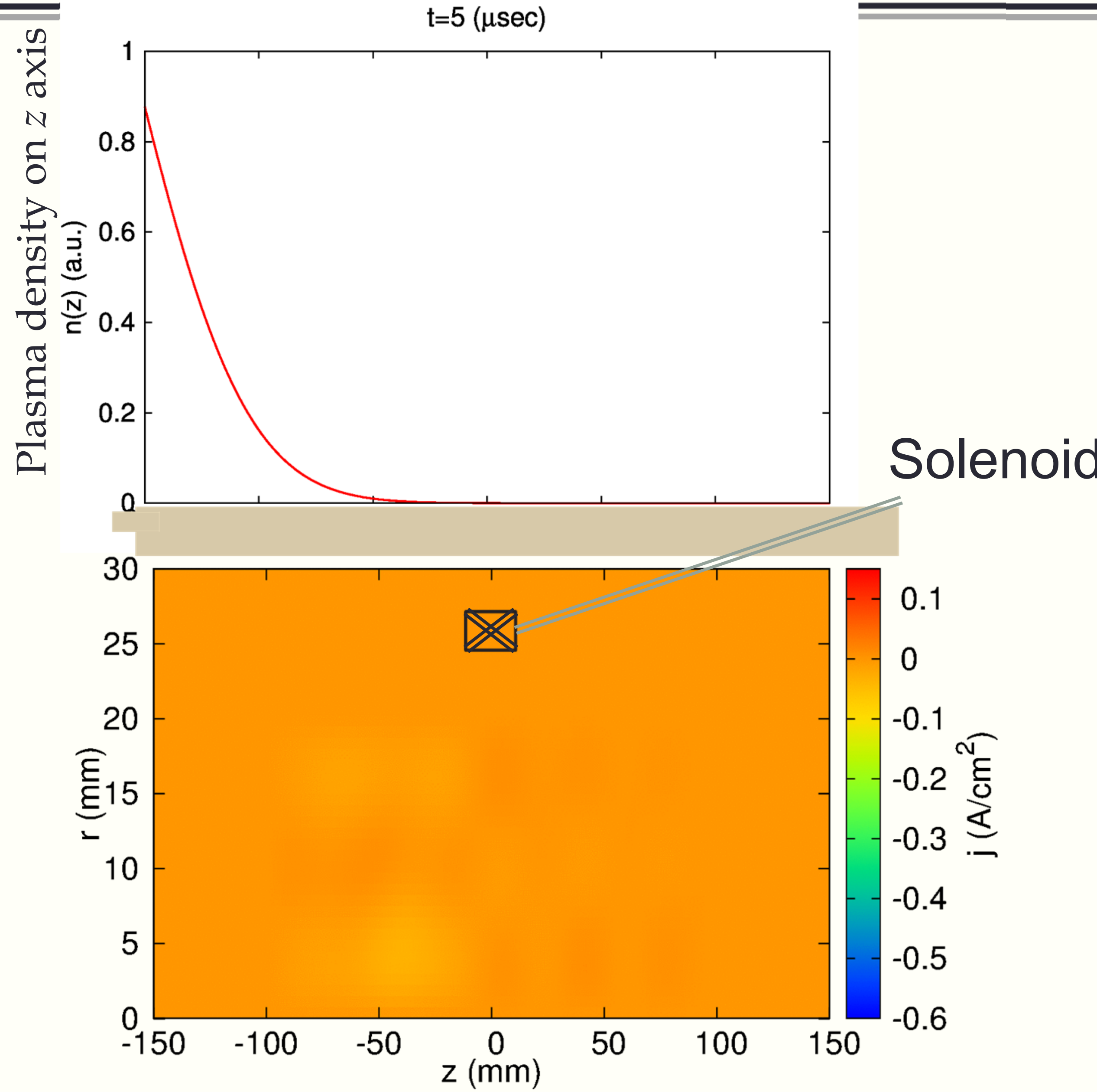
J_θ distribution was estimated from the measured ΔB_z.

Magnetic probe

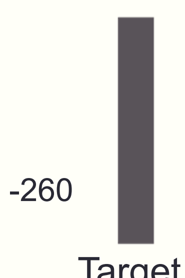


- Temporal change of magnetic flux through a pick-up coil generates voltage signals.
- To remove a common mode noise, we measured the differential signals of V_1, and V_2.

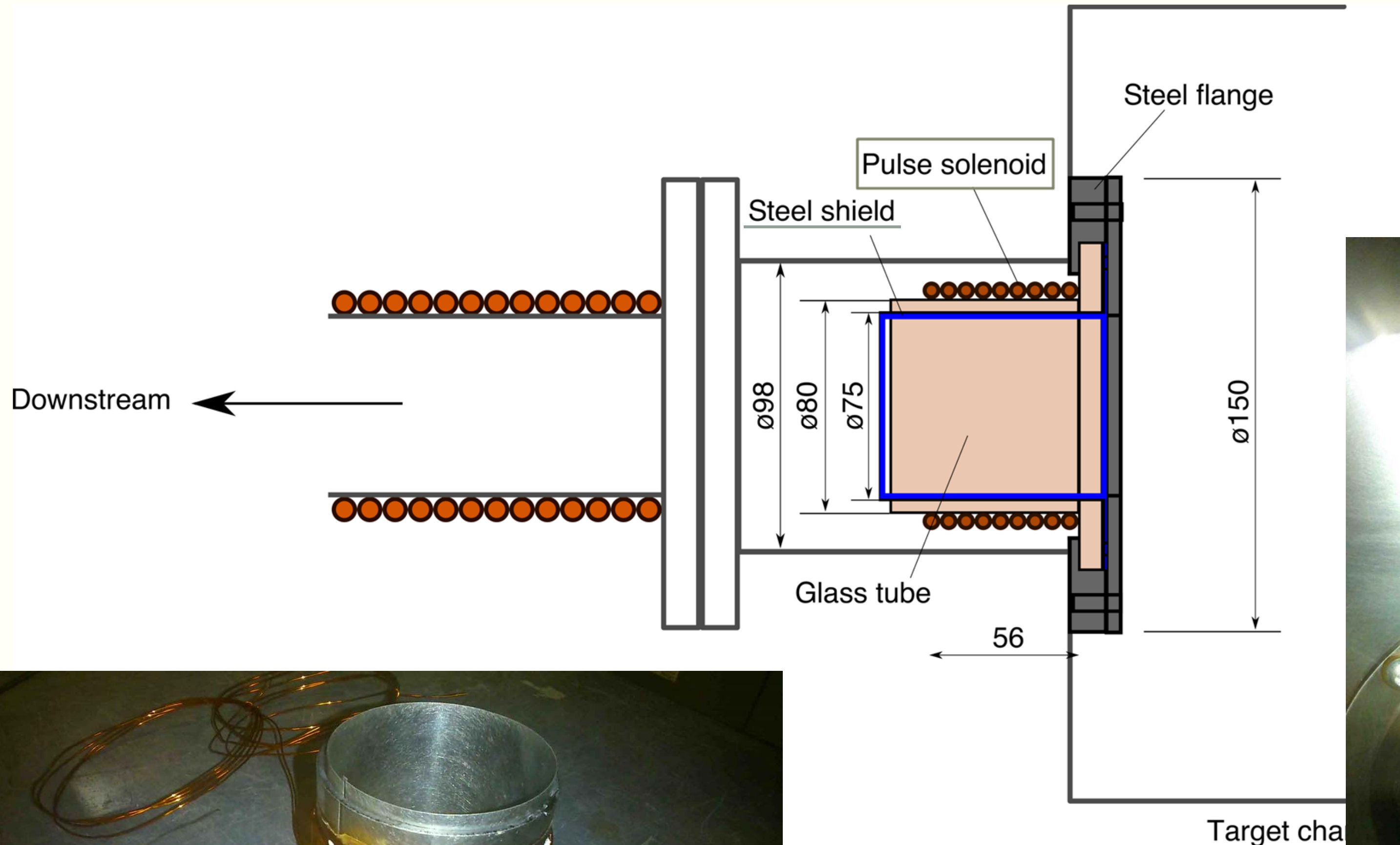
Reconstructed J_θ (r,z,t) map

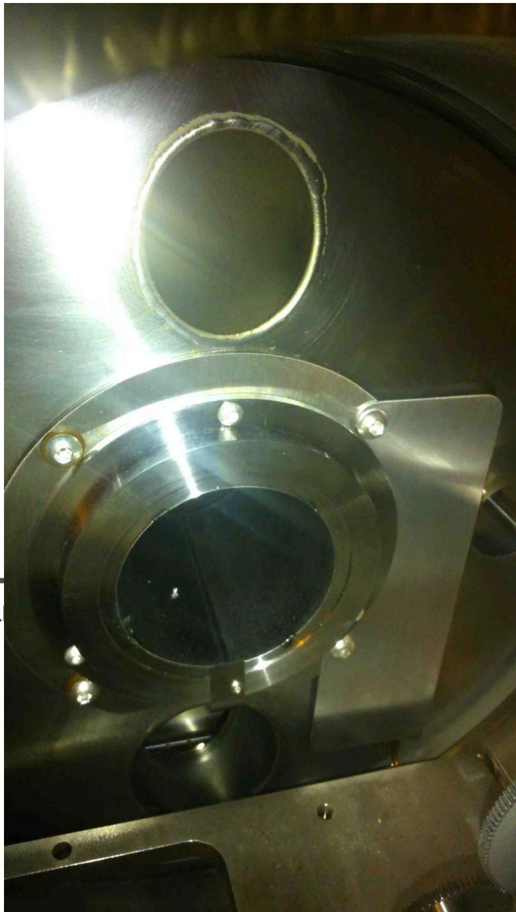


J_θ was induced in accordance with plasma motion.

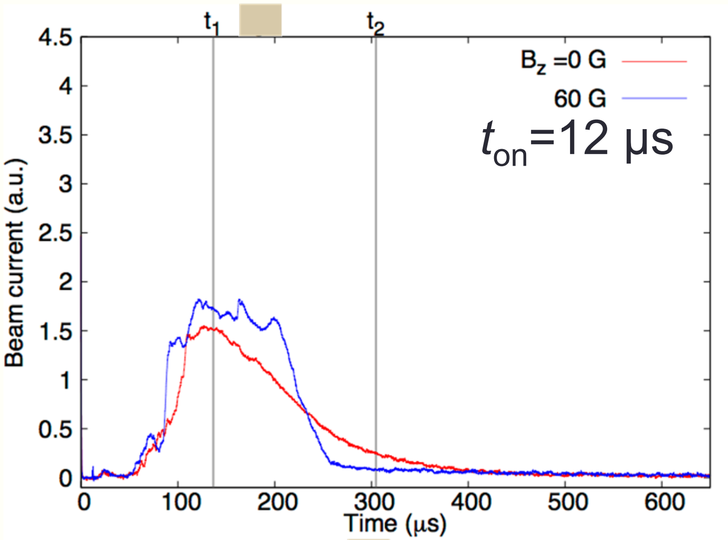


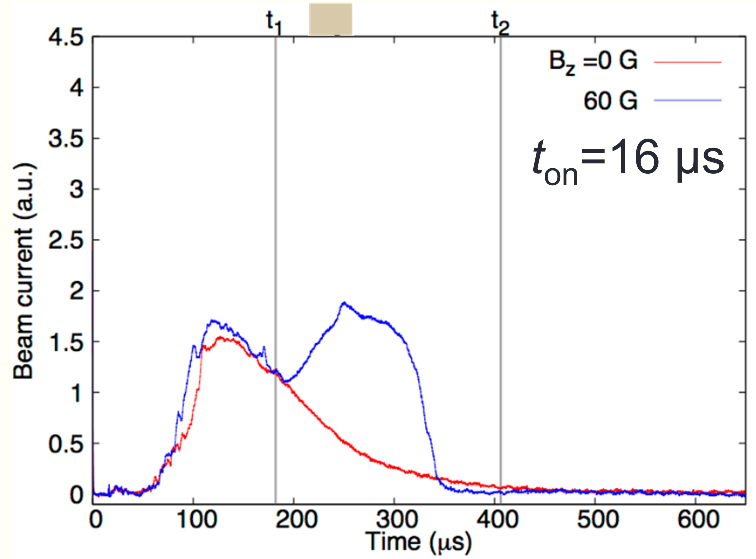
Pulsed solenoid

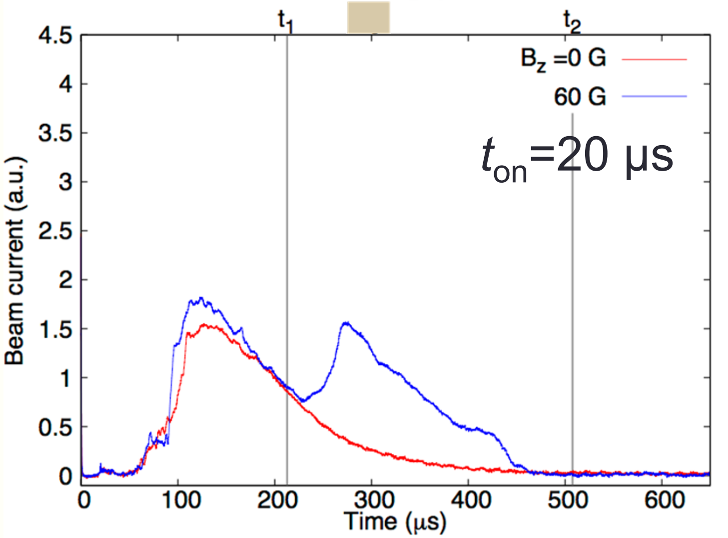




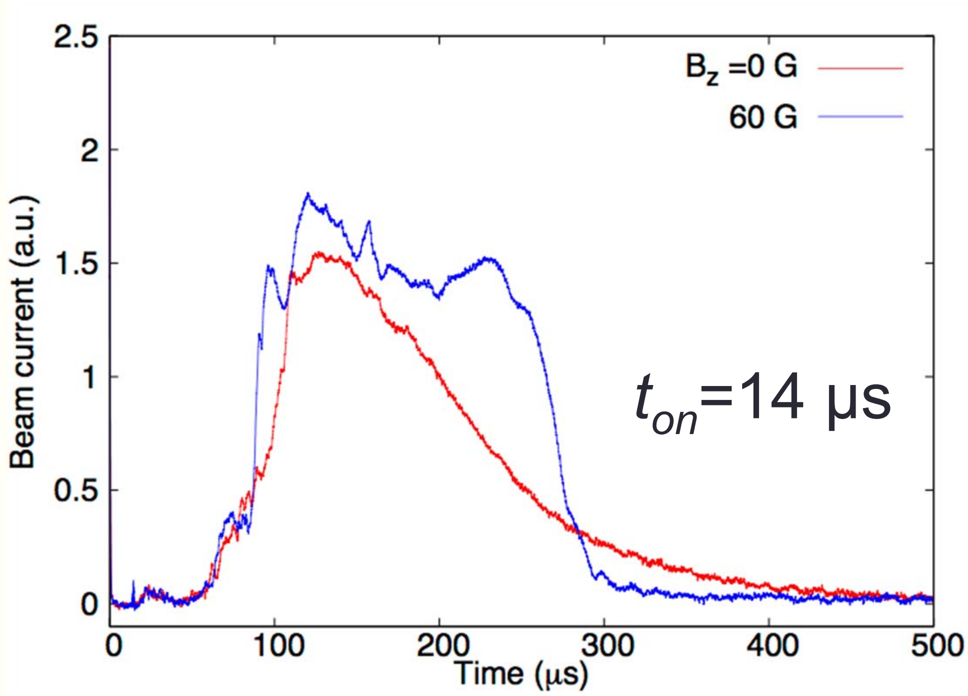
Selective enhancement by pulsed solenoid







- Enhancement occurred when t_{on} is between t_1 and t_2.
- These show that the compression occurred by the pulsed field.



Pulsed solenoid tailors current shape.

- Long static solenoid gives large enhancement.
- Combination of pulsed and static solenoid gives more flexibility of laser ion source.

Summary

- The Laser Ion Source has been used for a real long term operation for RHIC and NSRL.
- The laser Ion Source can provide many species with fast switching.
- The Long solenoid can enhance beam current up to 10 times.
- Beam current profile of the laser ion source can be controlled by the pulsed solenoid.
- We have provided the beams with almost NO down time.

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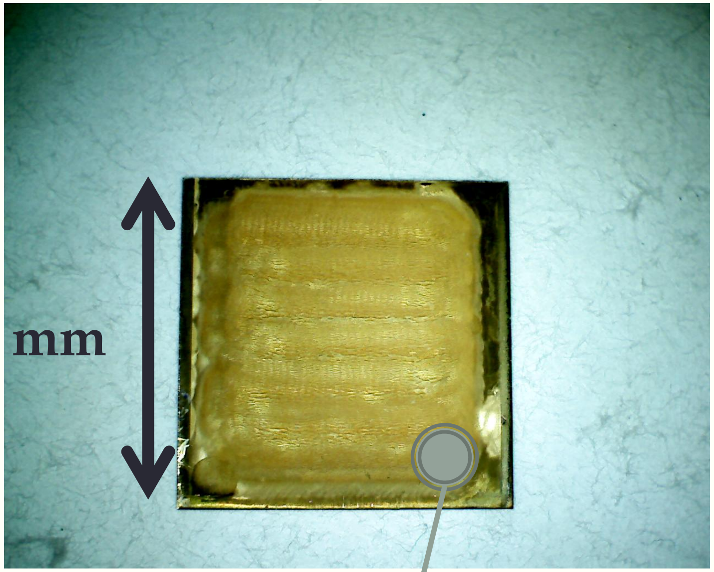
- We have provided the beams with almost NO down time.

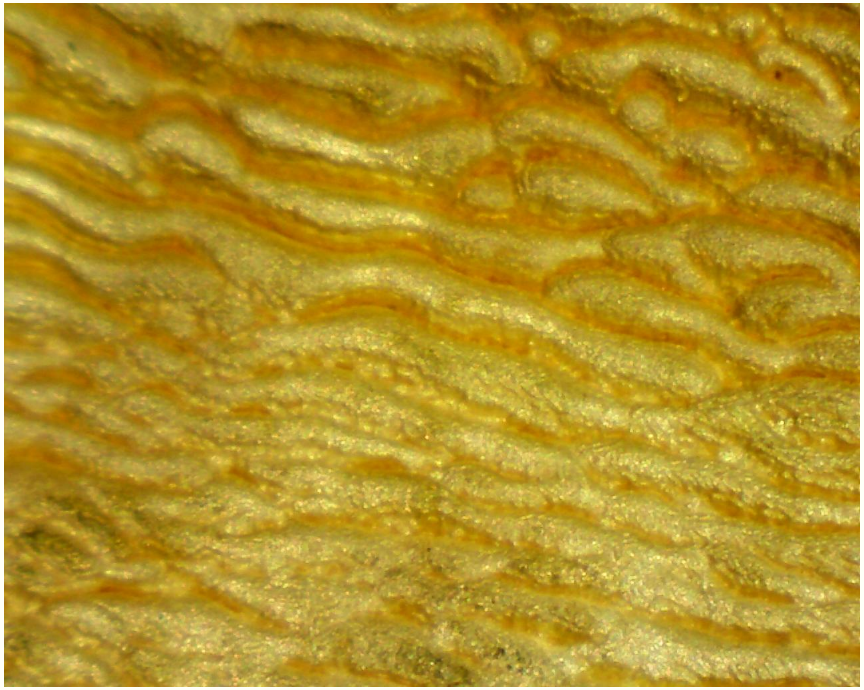
Thank you for your attention.

Gold target after Run 14



Laser spot size ~ ϕ 4.5mm

Top



Bottom

- Beam current was decreasing because of surface condition
- Solenoid was used to compensate beam current (~10 gauss)