Laser Ablation of Solids into an Electron Cyclotron Resonance Ion Sources for Accelerator Mass Spectroscopy

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MANTRA

- Measurements of Actinides Neutrons Transmission Rates with Accelerator mass spectroscopy.
- Joint project INL and ANL.
- Determine energy-averaged actinide neutron capture cross-sections.

a. Preparation and Irradiation of pure actinide samples. ^{232}Th, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{244}Pu, ^{241}Am, ^{243}Am, ^{244}Cm and ^{248}Cm.

b. Use accelerator mass spectroscopy to measure the nuclide densities of actinides produced in irradiation through sequential n-capture processes.

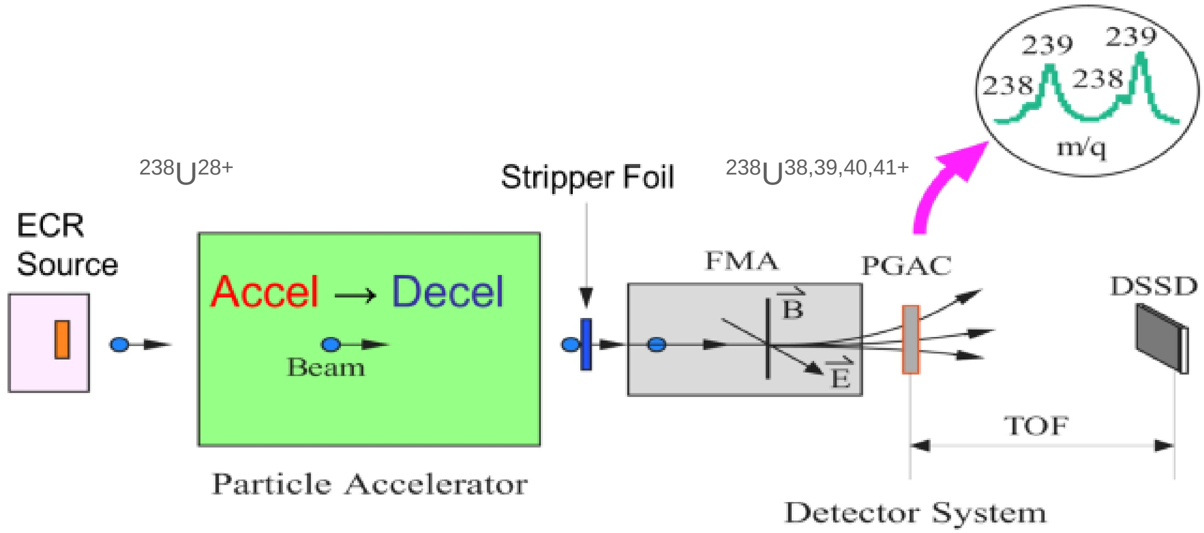
c. Infer capture cross-sections from these ratios.

MANTRA

AMS Challenges:

- Small sample size (few mg total, actinide component <1mg)
- large number of samples desired to reduce errors
- Minimize cross-talk between samples
- Stable, repeatable transmission between source and ion detector
- Limited “Z” element resolution in detectors

ATLAS Actinide AMS Configuration



MANTRA

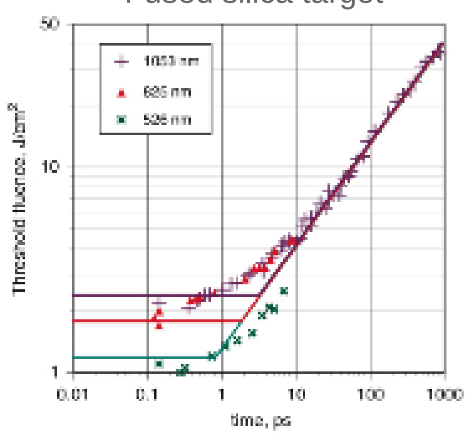
- We will use laser ablation at relatively low power levels to efficiently introduce solid materials into plasma. Benefits of laser ablation expected are:
  - Efficient use of solids for AMS and enriched isotopes.
  - Less sensitive to material chemical composition.
  - Cleaner source operation (yet to be proven).
  - Decouples source operation from material insertion.

Laser ablation

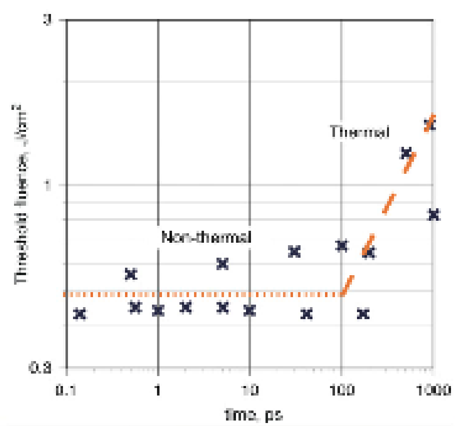
- Laser Ablation- Removal of material by laser action. Distinguished from evaporation in equilibrium conditions
- To remove atom from solid $\varepsilon_{kin} = \varepsilon_{tot} - \varepsilon_b > 0$
  - Material parameters: Typical time for thermal equilibrium.
  - Laser parameters: Wavelength, Pulse duration, Energy.
- Two regimes of Laser Ablation
  - Thermal ablation - Heat conduction and hydrodynamic. Large heat affected zones and throw out of a molten material.
  - Non equilibrium - Electrostatic ablation

Threshold laser fluence for ablation of versus laser pulse duration

Fused silica target



Gold target



Source: The experimental points are from Stuart et al. (1996). Theory (dotted line) is from Gamaly et al. (2002).

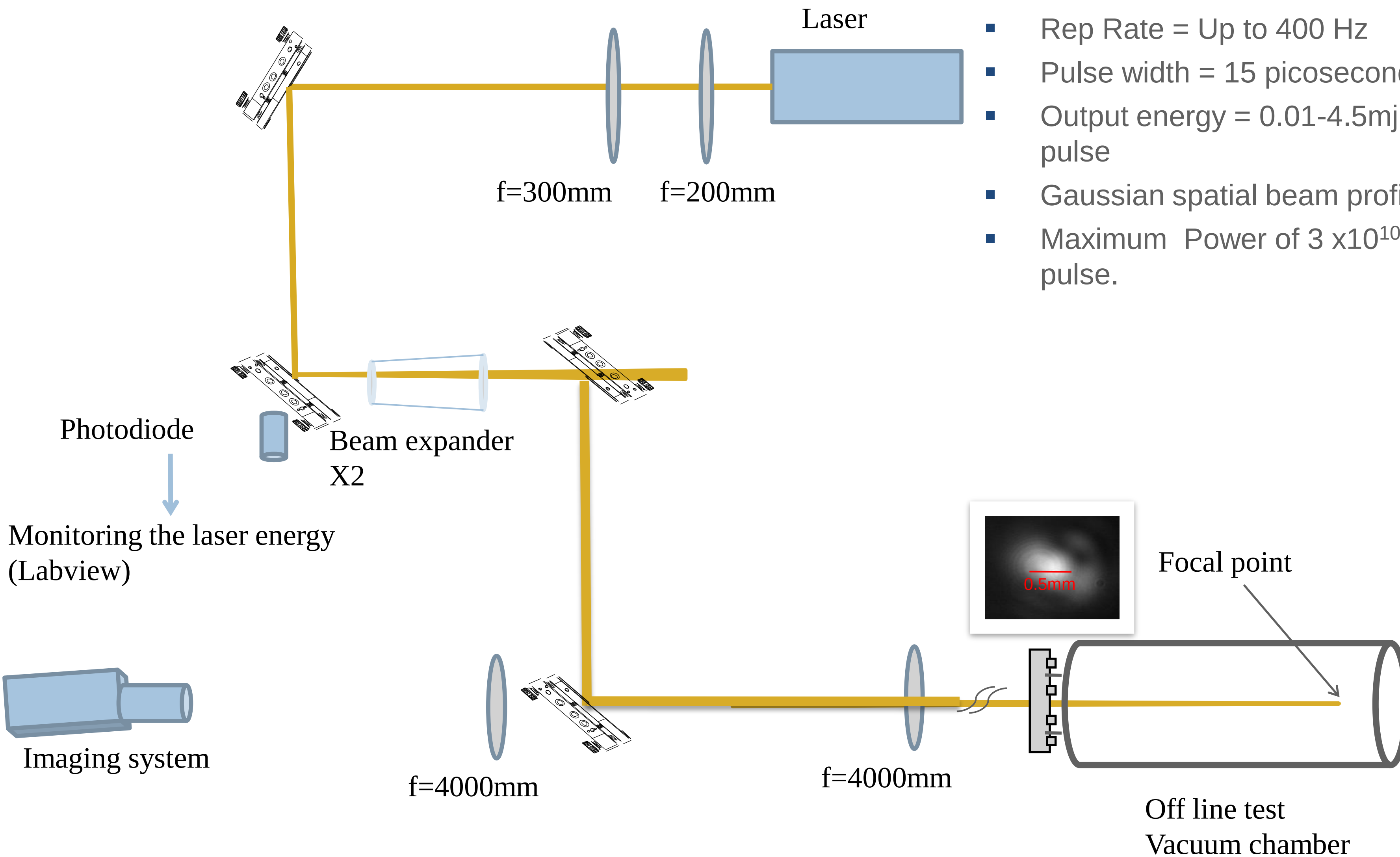
Laser ablation

- The ablation induces plasma expansion. Plume
- Plasma expansion speed of the order $1X10^6$ cm/sec.
- laser plumes contain ions atoms, macroscopic particles and liquid droplets
    - Spatial intensity across the focal spot of the laser
    - condensation of vapor during the plume expansion

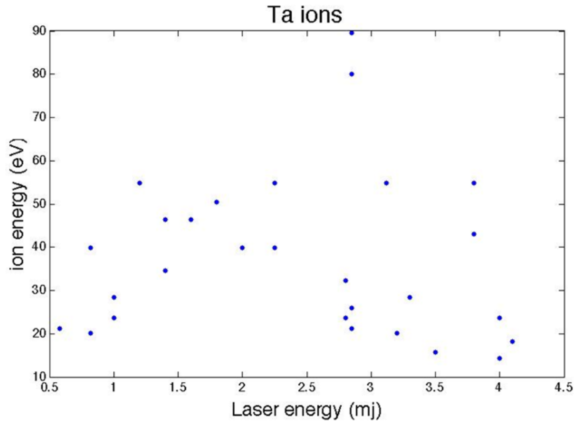
- The number of ejected atoms for picosecond laser 10^{13} atoms/pulse. The ion flux is about 1%.

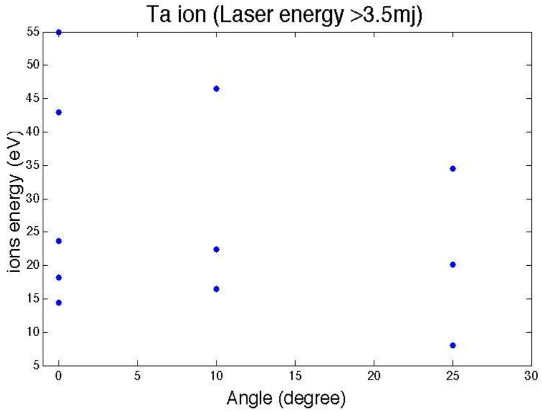
Off line experimental set up

- λ= 1064 nm
- Rep Rate = Up to 400 Hz
- Pulse width = 15 picosecond
- Output energy = 0.01-4.5mj per pulse
- Gaussian spatial beam profile
- Maximum Power of 3 x10^{10}W per pulse.

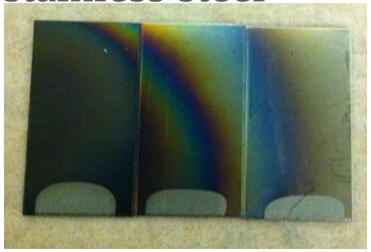


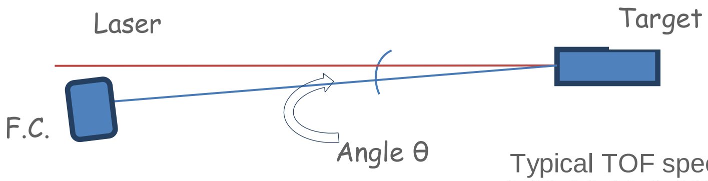
Off line Test





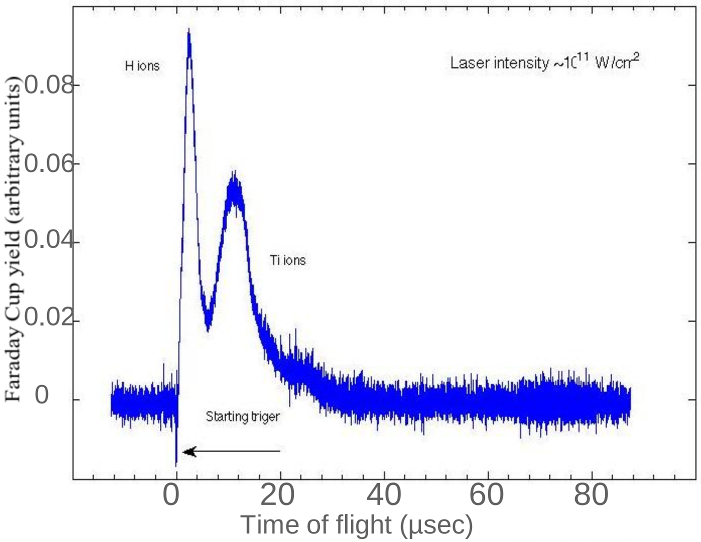
Ti deposition on stainless steel

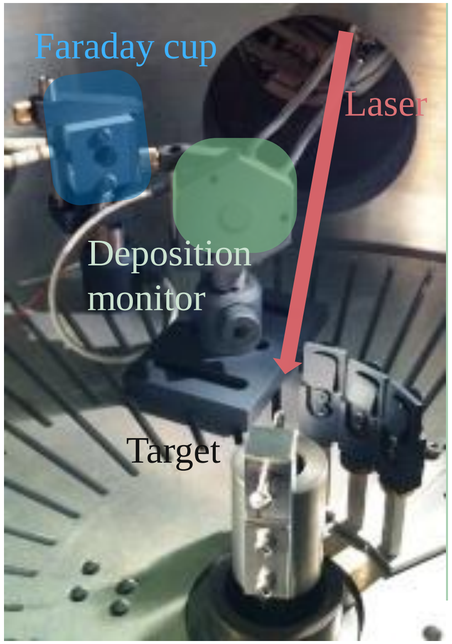




The ions energy was extracted from time of flight measurements using a Faraday cup. The cup was at a distance of 6.875 inch from a solid Ta target.

Typical TOF spectrum to Faraday Cup for Ti ions





Ablating Rates for different materials

Ablating Rates

Samples from INL

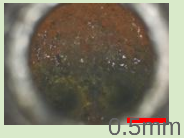
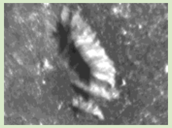
Laser Energy : 1.5-1.6mJ

400Hz repletion rate

Focal spot diameter: 0.5mm

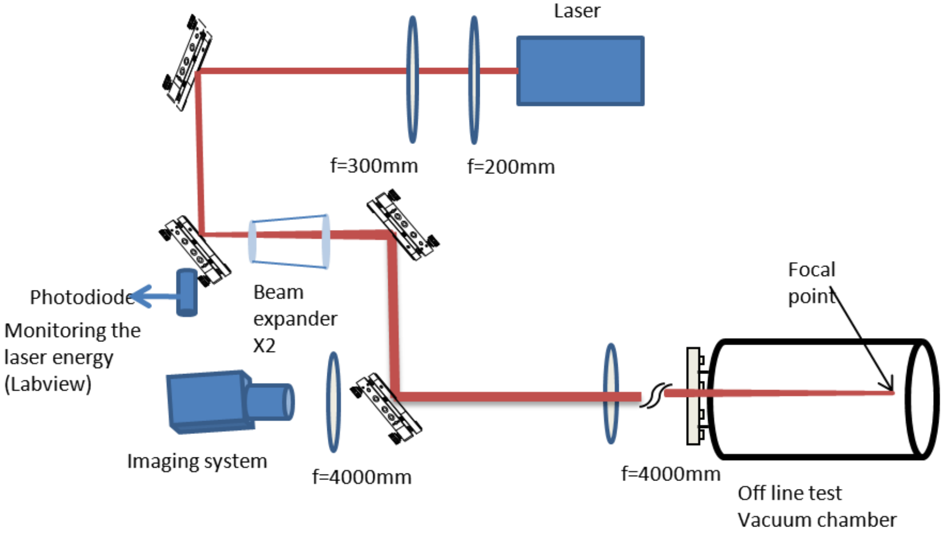
Peak flounce : 0.7 J/cm^2

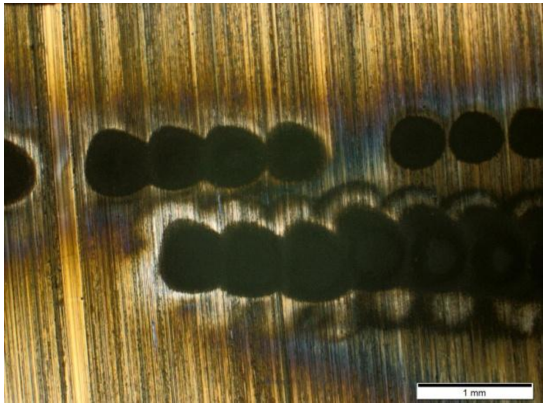
Pulse duration : 15ps

	Consumption rate	Hole depth	Image
Fe solid (1 location shooting for 39 min)	1.3mg/39min 0.033mg/min	1.2mm (for 39 min)	
Fe solid (3 locations 13 minutes on each location)	1.4mg/39min 0.035mg/min 3.7*10^17 atoms/min	1.19mm (for 13 min) 0.09mm/min	
Fe oxide powder-MANTRA target (3 locations 13 minutes on each location)	1.3mg/39min 0.033mg/min 1.24*10^17 atoms/min	1.07mm (for 13 min) 0.08mm/min	
Al oxide powder-MANTRA target (3 locations 10 minutes each)	0.1mg/30min 0.003mg/min 1.77*10^16 atoms/min	0.8mm (for 10 min) 0.08mm/min	
Tb oxide powder MANTRA target (2 locations 10 minutes each)	0.1mg/20min 0.005mg/min 8.2*10^15 atoms/min	0.57mm (for 10 min) 0.057mm/min	
U metal (3 locations 10 minutes each)	4mg/30min 0.13mg/min 3.289*10^{17} atoms/min		
U oxide (3 locations 10 minutes each)	0.5mg/30min 0.016mg/min 3.56*10^{16} atoms/min		

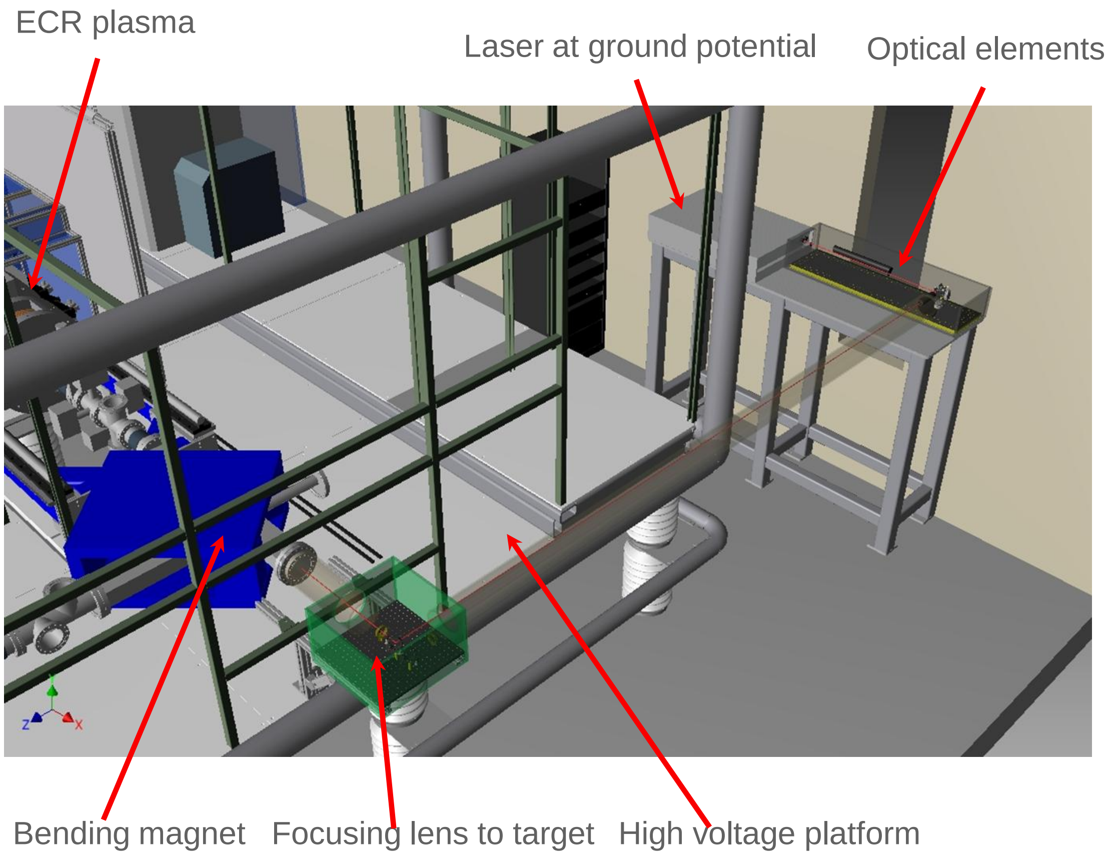
The Beam Manipulator

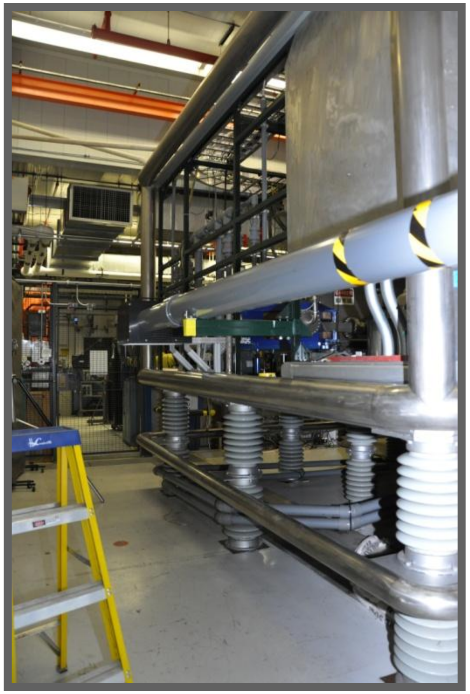
- Controlled motors that placed on the aligning knobs of the last mirror.
- Can wobble the laser beam on the target sample.





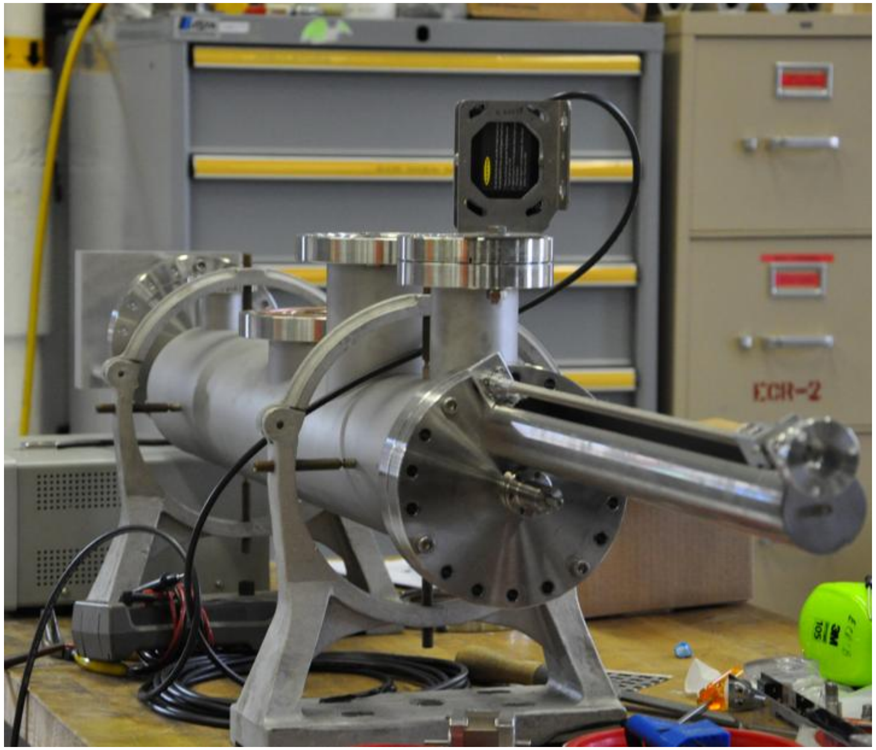
Installation at the source (ECRII)

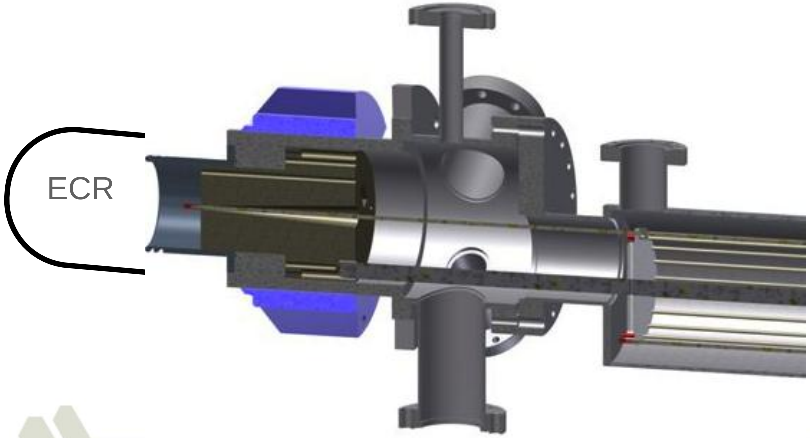




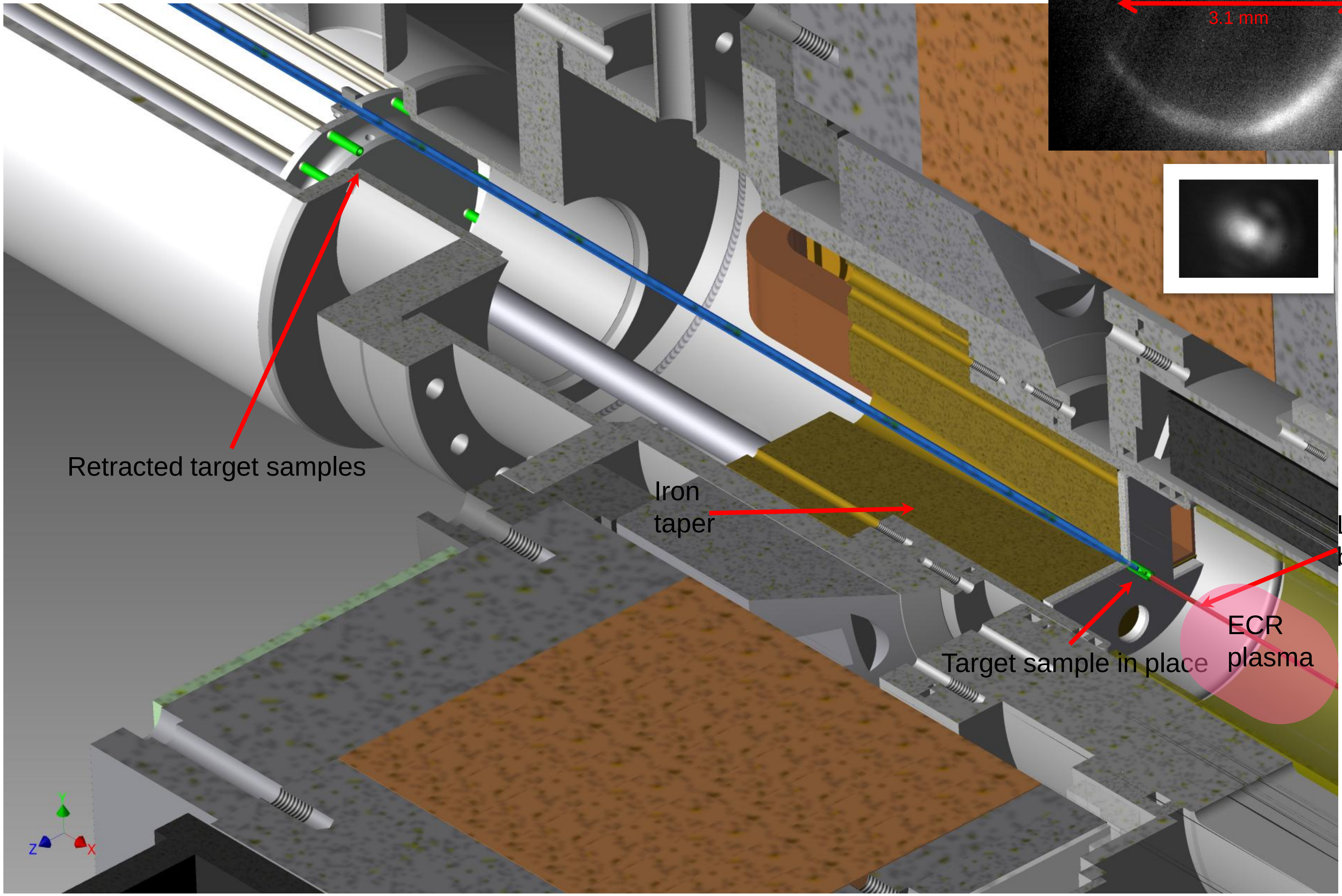
Multisample changer for the source

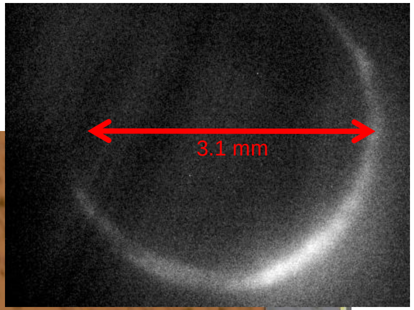
holds 20 samplescan change between samples in <1 minuteabsolute encoder so position information is preservedsize keeps operating mechanism out of high B fieldlaser sensor to ensure sample is retracted before rotatingoperation can be controlled by accelerator crew or experimental program (batch program)





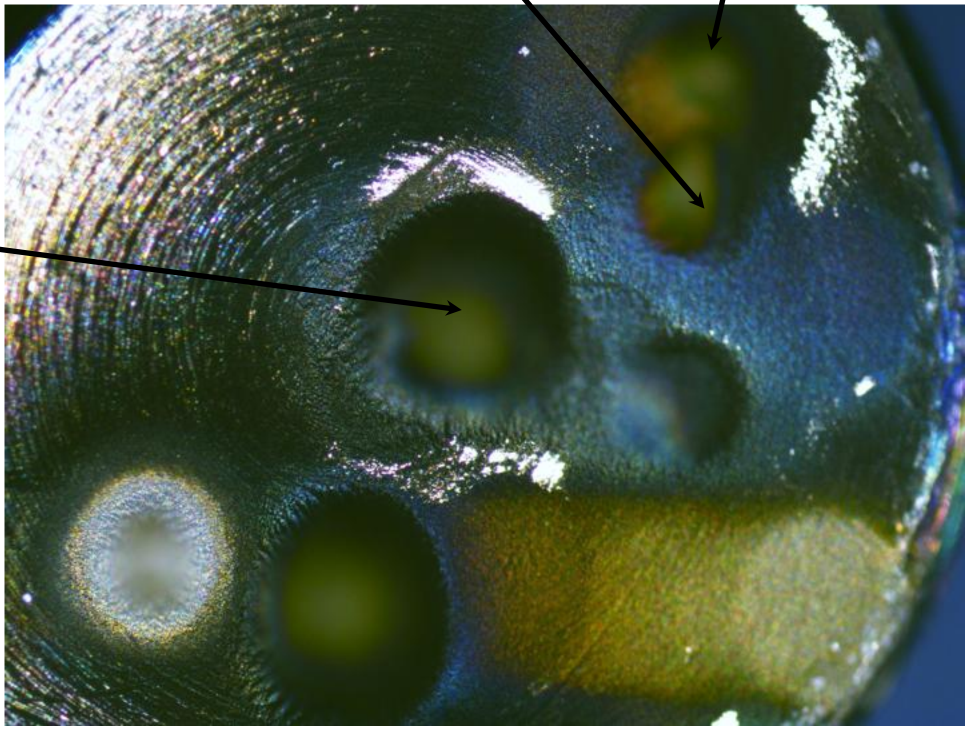
Back light


Retracted target samples
Iron
taper
Laser
beam
ECR
plasma
Target sample in place


3.1 mm

Ti sample at the ECR source

- Consumption rate 0.3 mg/hour
- Laser parameters:
  - Repetition rate 25Hz
  - Energy 0.5-1.5 mJ
  - Peak intensity of $5X10^{10}$ W/cm^2



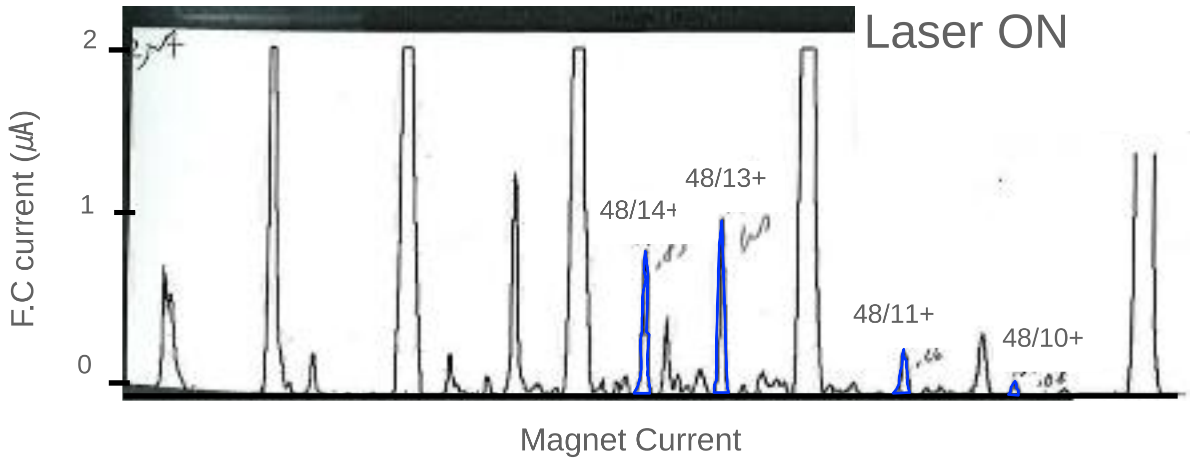
Depth 200μm
Diameter 0.18mm

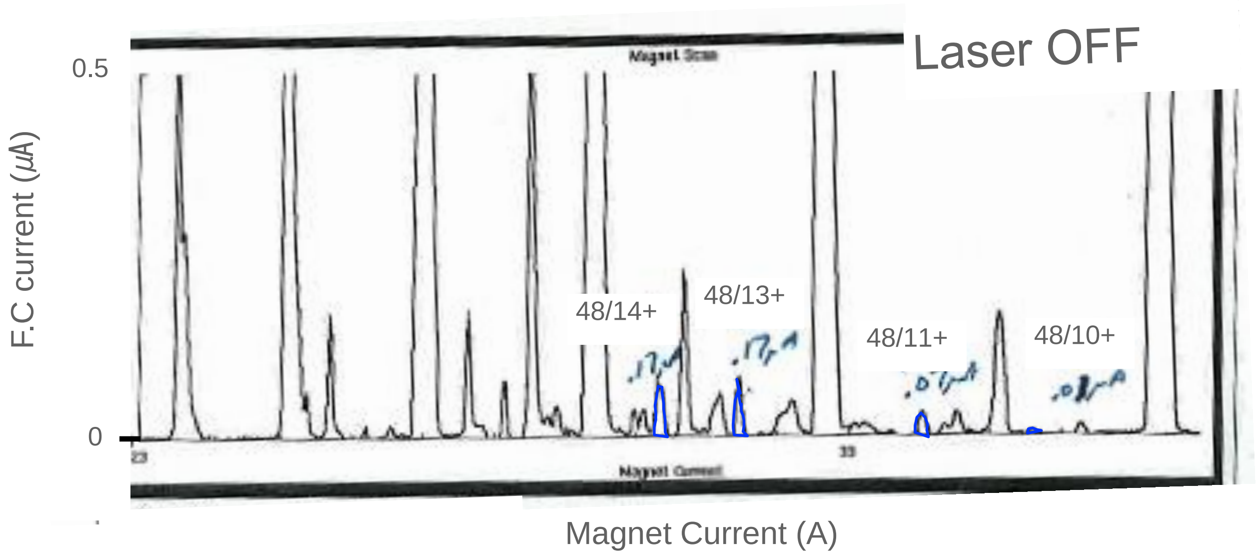
Depth 350μm
Diameter 0.24mm

Depth 930μm
Diameter 0.42mm

Beam from titanium sample ablated into ECRIS

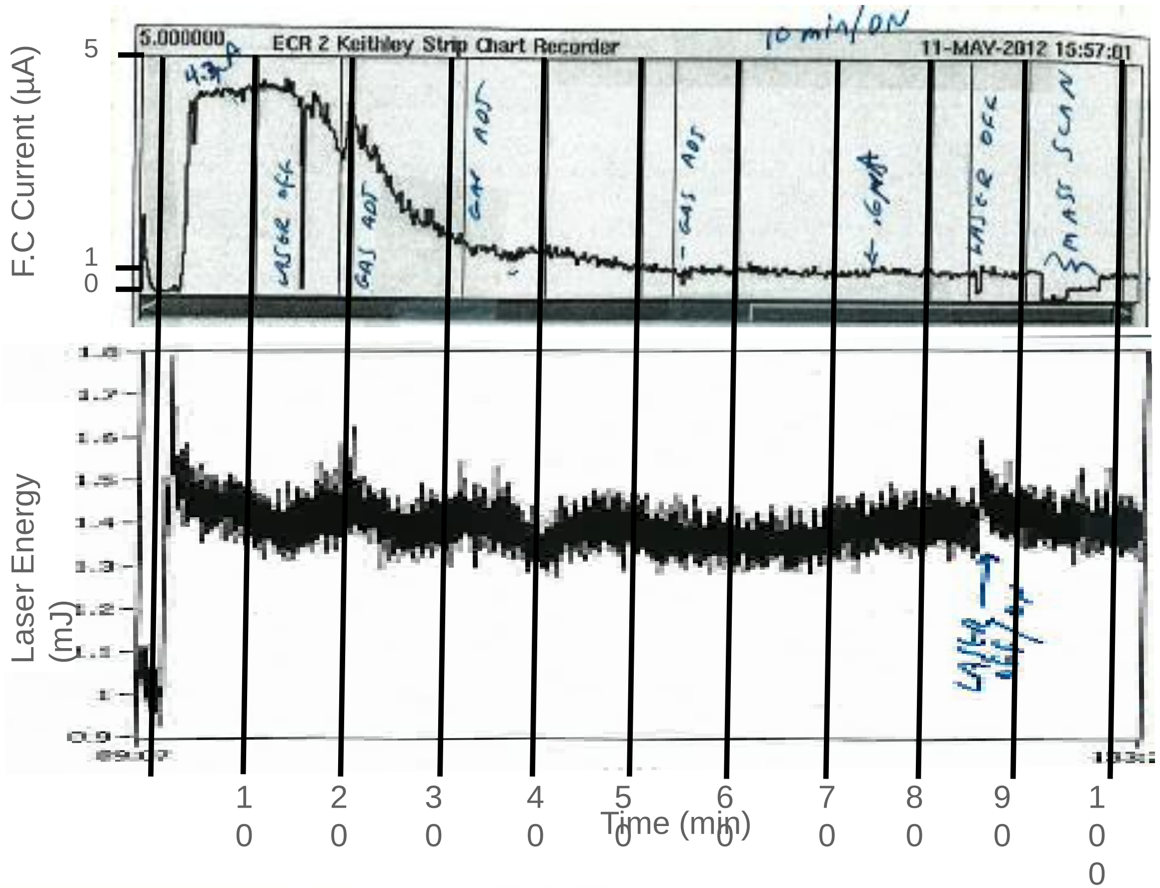
- Charge State Distribution





Long-term beam output from ablated Ti sample

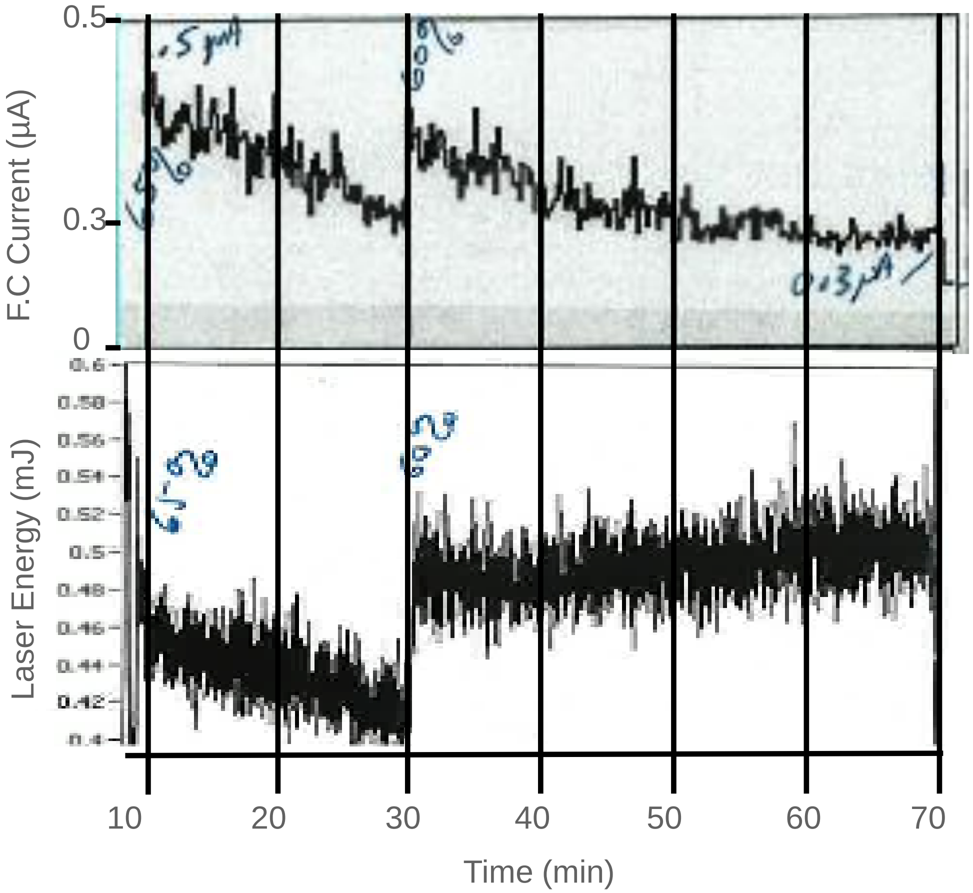
- Laser repetition rate 25 Hz
- Laser Energy ~ 1.5mJ
- Charge state 48/13+
  - stable for the first 10 min
  - drops 80% in the next 20 min
  - stay stable for 65min



Long-term beam output from ablated Ti sample

- Laser repetition rate 25 Hz
- Laser Energy ~ 0.5mJ
- Charge state $48/13^{+}$

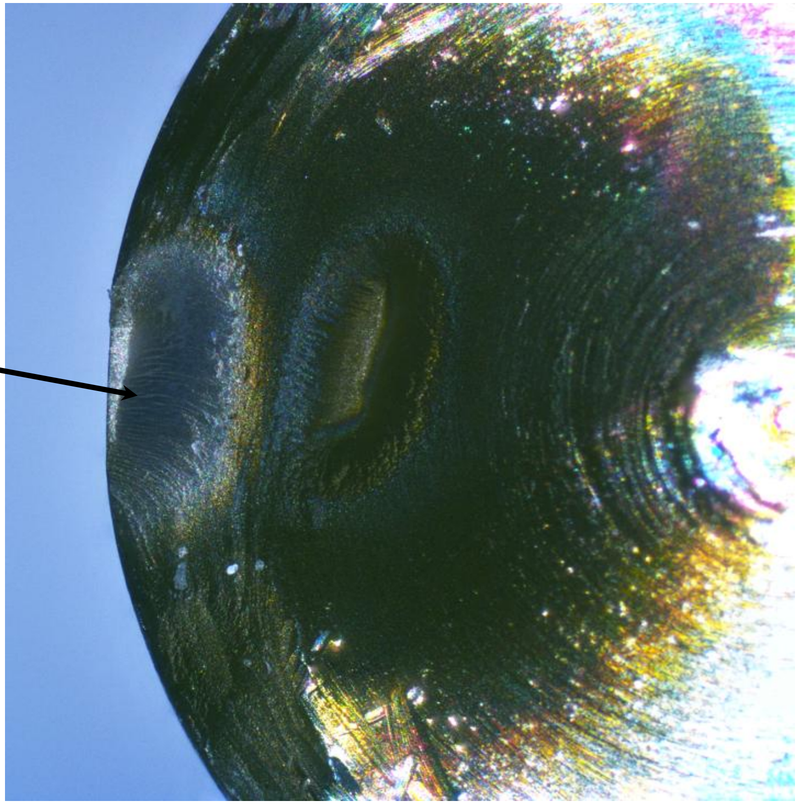
  - drops 36% for the first 20 min
  - drops 15% for the next 20 min
  - stay stable for 20 min



Ti sample at the ECR source

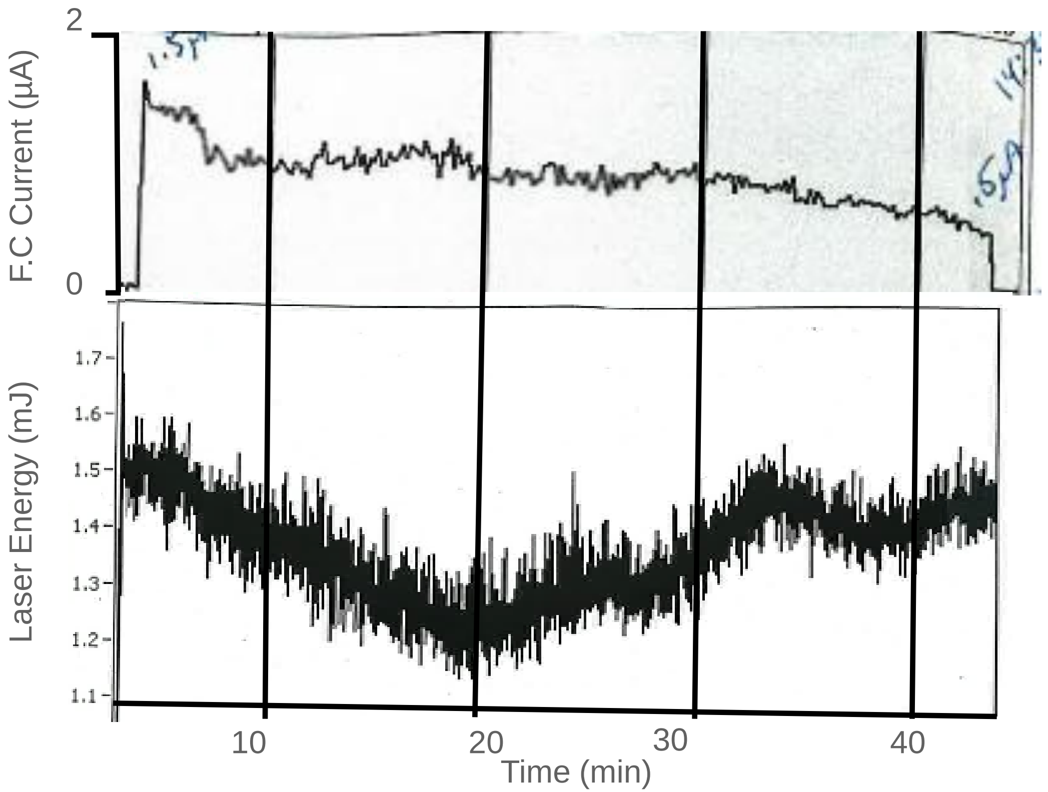
- New target
- Changed the focal spot to be bigger
- Consumption rate 0.35 mg/hour

Depth 450μm
Diameter 0.2mm



Long-term beam output from ablated Ti sample

- Laser repetition rate 25 Hz
- Laser Energy ~ 1.5mJ
- Charge state 48/13^{+}
  - drops 37% in the first 2 min
  - stay stable for the next 20 min
  - drops 43% for 15 min



Conclusion

- Demonstrated beam production at moderate intensities.
- Most of the beam loss is due to the drilling.
- Only part of the beam loss is due to laser instabilities .

What next

- Improving the stability of the beam
  - Adjusting the focal spot of the laser
    - bigger focal spot.
    - change the spatial profile of the laser beam to a hat top.
  - Moving the laser beam on the sample in a constant rate using the beam manipulator.
- Next test July 12.