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Dependence of the Back-streaming Ion Current on the Self-magnetic pinch (SMP) Electron Diode Parameters

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Albuquerque NM

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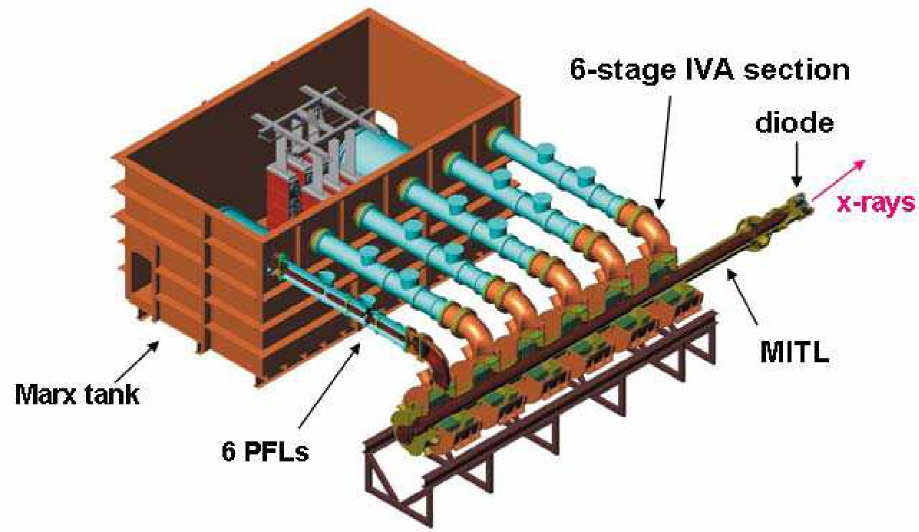
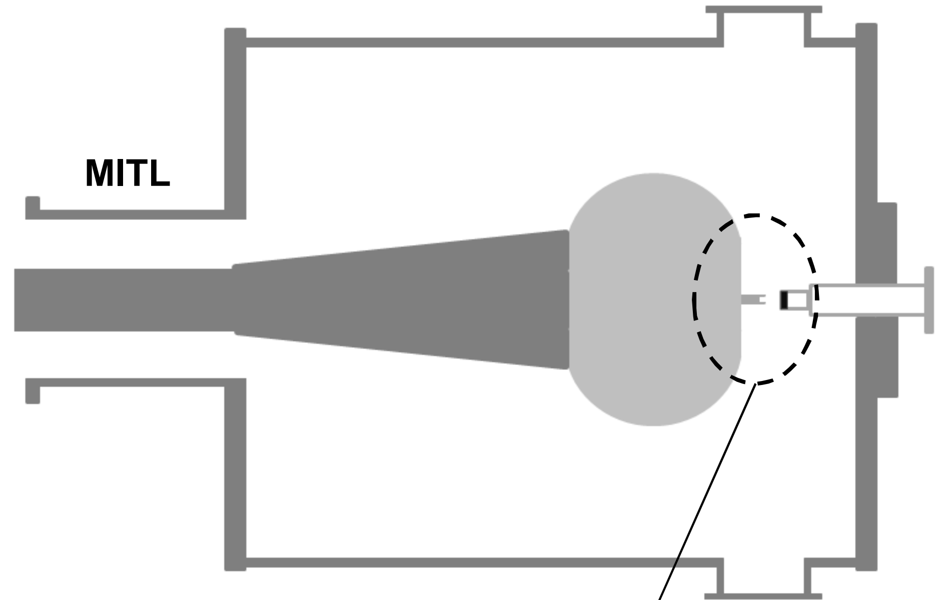
Radiographic Integrated Test Stand: RITS-6





RITS-6 is a 5-11 MV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of flash x-ray radiography diode configurations

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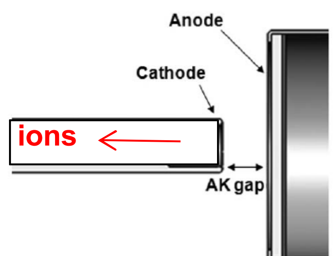
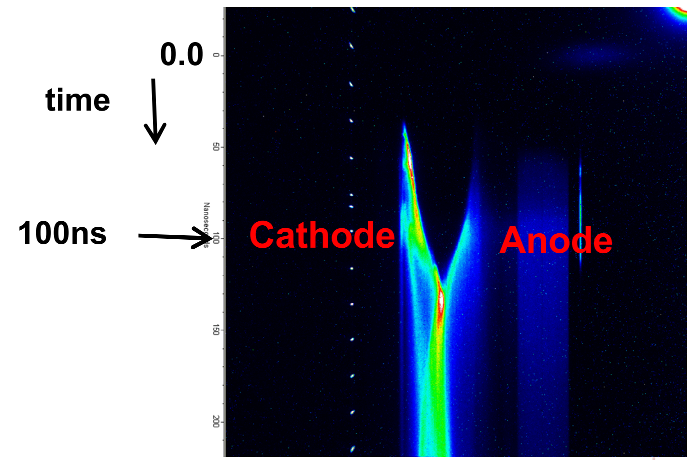
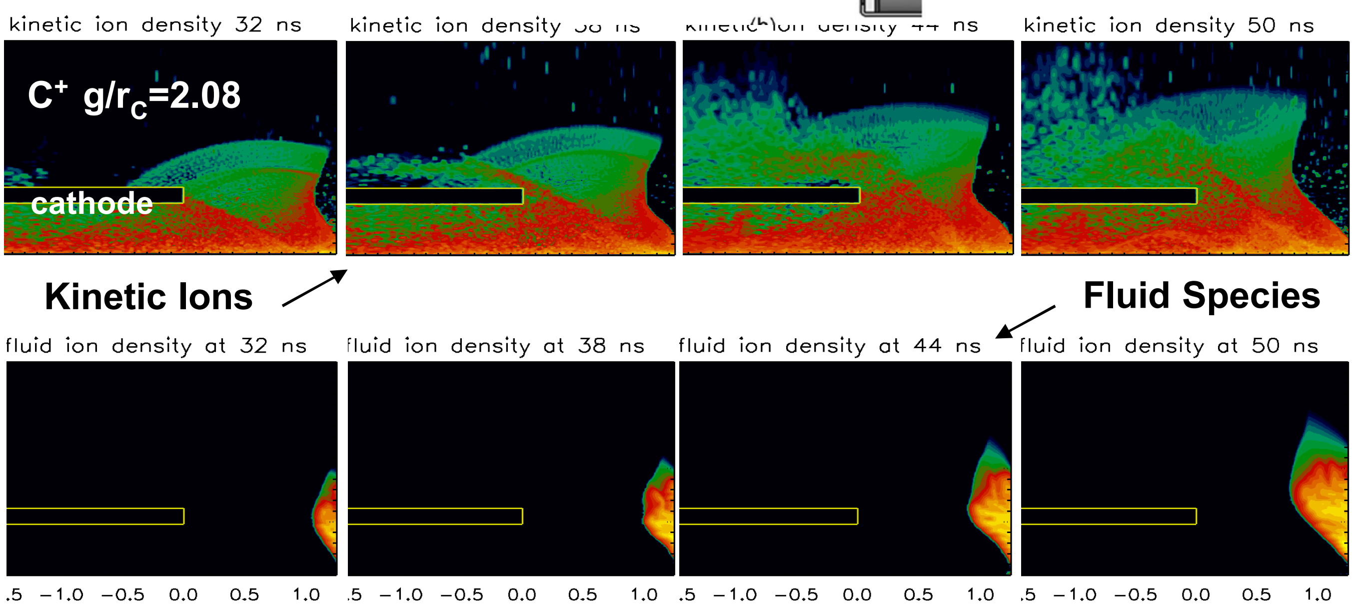
We are measuring the current and the energy of the ions that pass through the cathode hole.

The fast back streaming kinetic ions that traverse the A-K gap (bipolar current) before the merging of the anode and cathode plasmas are substantial contributors to the diode current. The densities of those ions are relative low and cannot be evaluated by optical techniques.

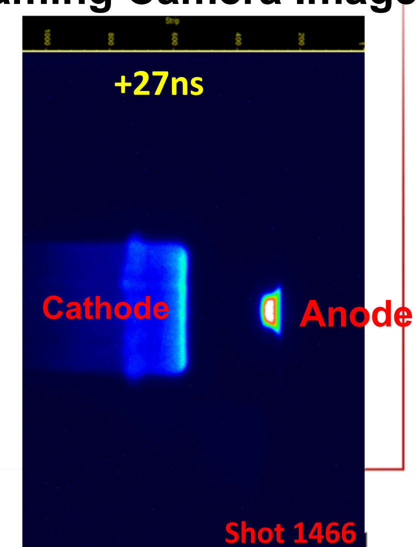


Streak Camera

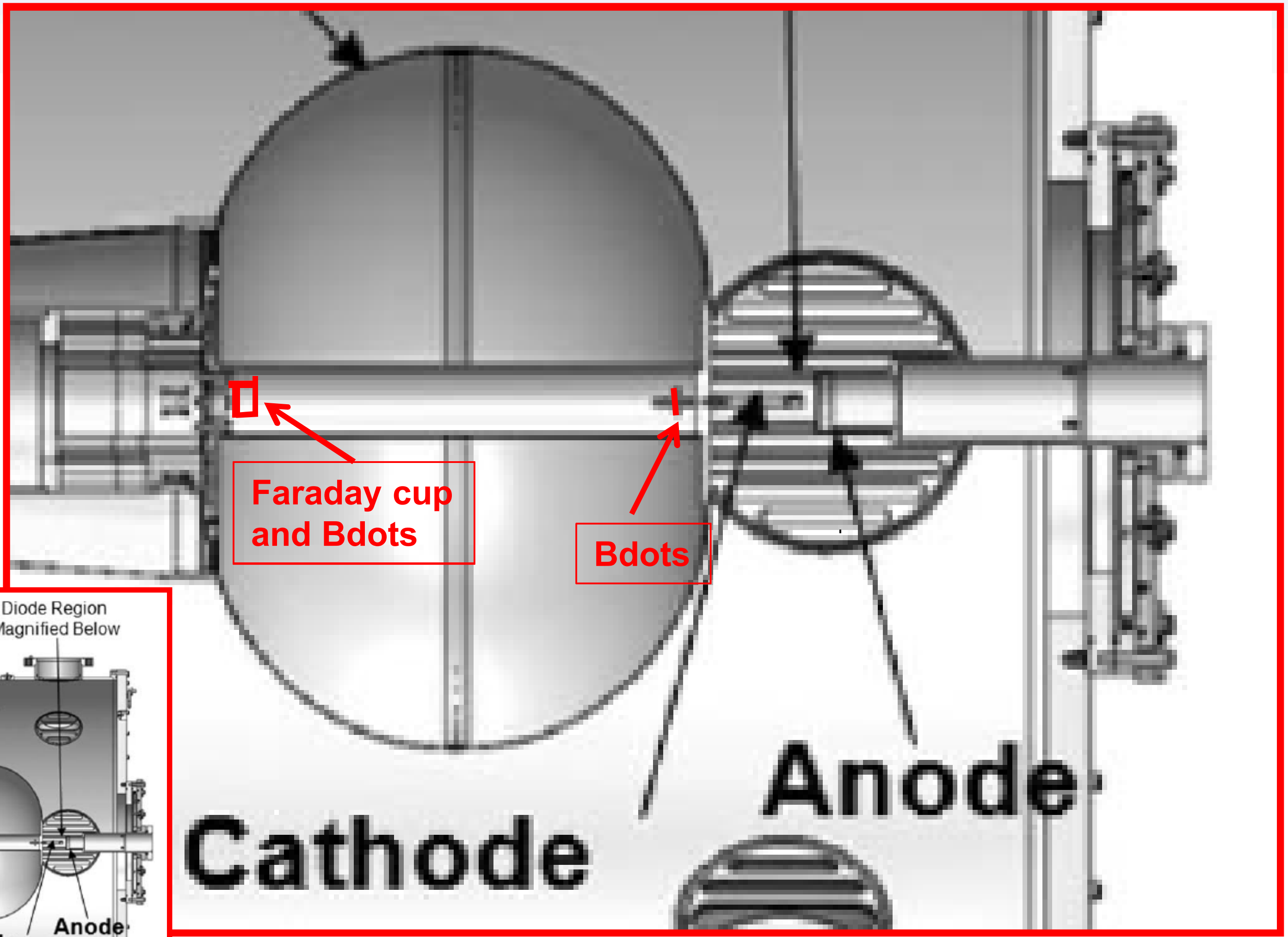


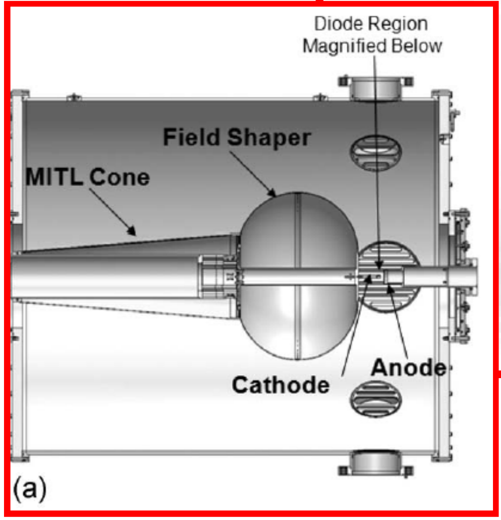


Framing Camera Image



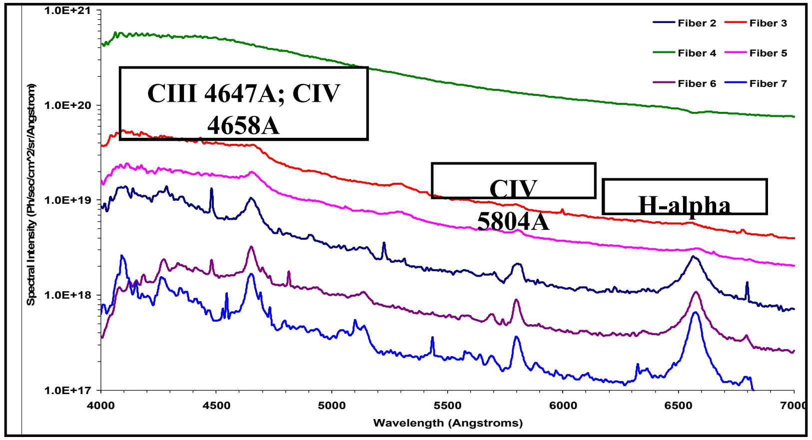
The idea was originally to use filtered Faraday cups and /or time of flight techniques along the bin axis to measure the ion currents and energy.





Times of flight for the ion species observed with spectroscopy

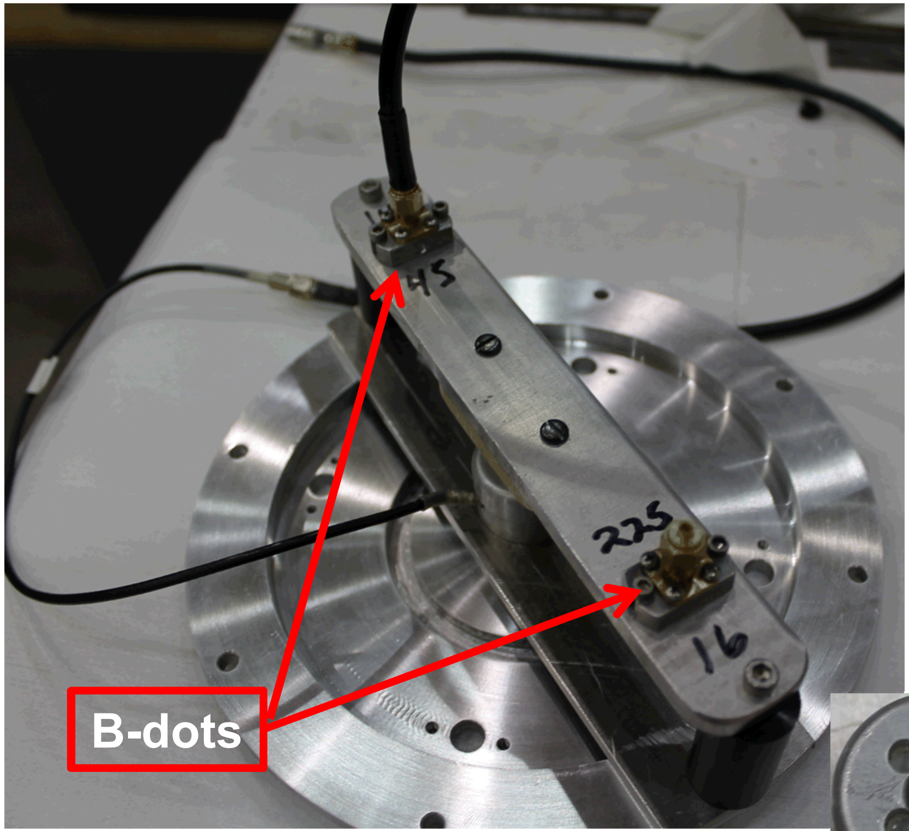
- The plasma formed at the anode electrode during the radiation pulse due to electron beam energy deposition is mainly composed of hydrogen neutrals, protons and carbon ions.
- The times of flight through the bin axis (~44.86 cm length) of the different ionic species for 8 MV diode voltage are as follows:
- t-proton = 11.4 ns
- t- C^{+} (CII) = 39.6 ns
- t- C^{2+} (CIII) = 28 ns
- t- C^{3+} (CIV) =22.9 ns
- It appears that the second group to arrive at the detectors will be the C^{3+} followed by the C^{2+}.

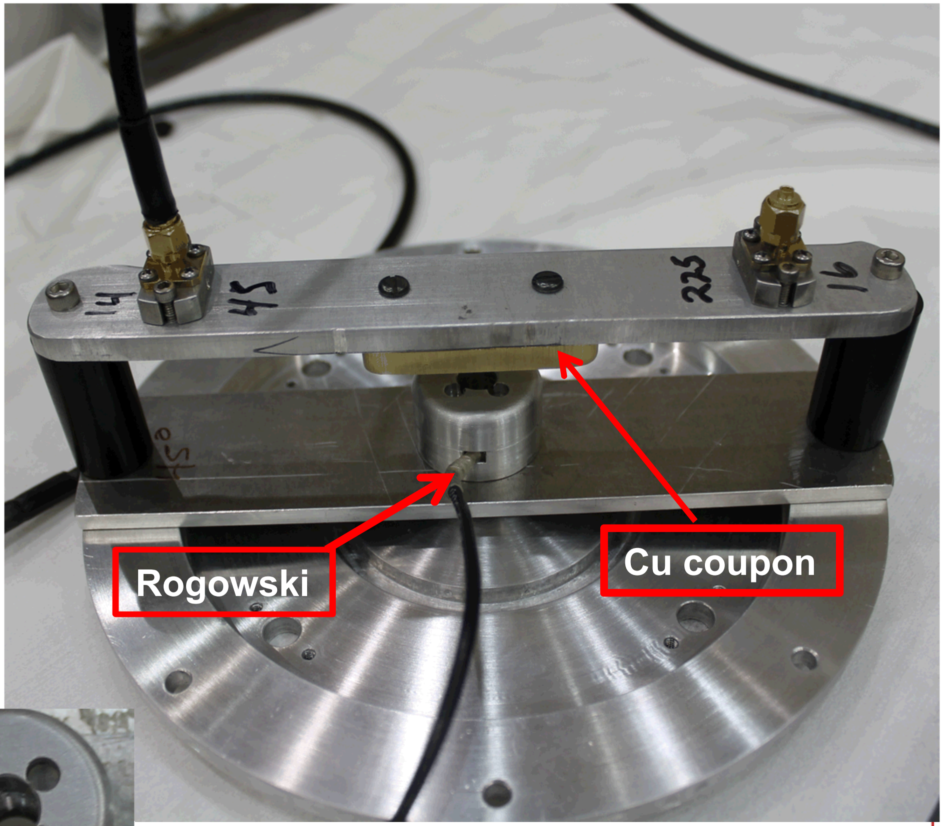


From Mark Johnston at al. IEEE Pulsed Power Conference 2013.

In principle we could evaluate the diode voltage by ion time of flight measurements.

Then in addition to the two B-dots we added a Rogowski and brass witness plate to visualize the ion beam impact.





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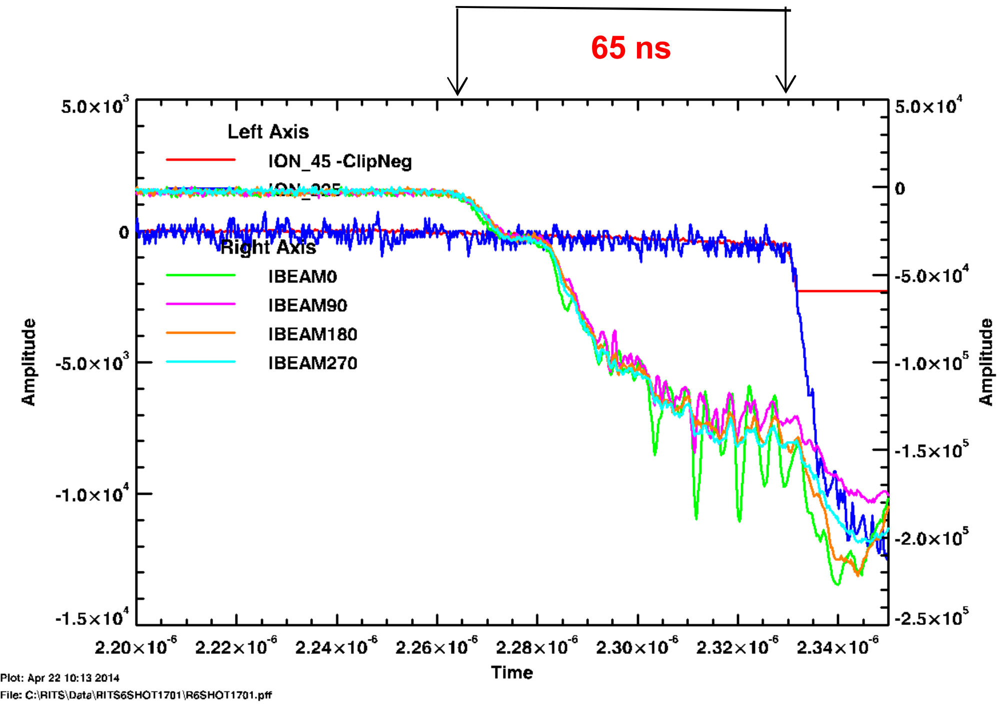
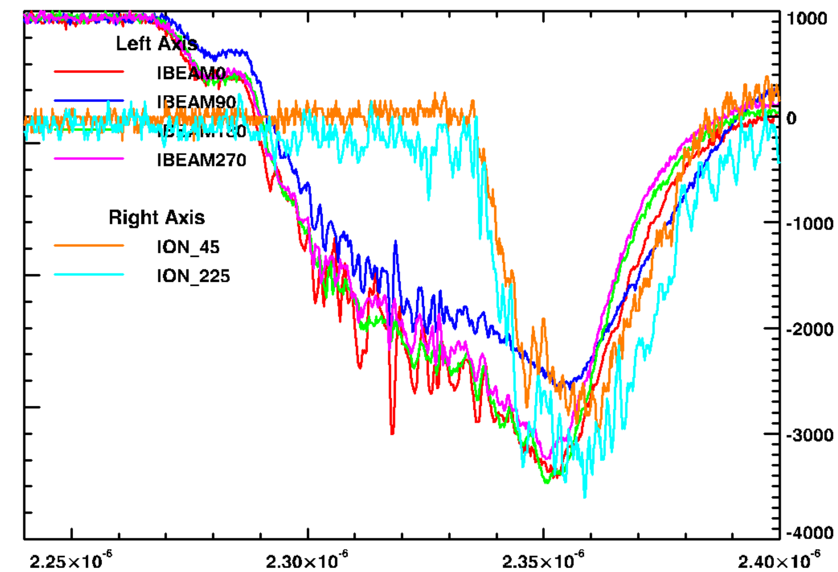
Samples of the B-dot “Currents”





Unfortunately large 10ths of kA cable pick-up currents foiled our ion current and time of flight measurement plans.

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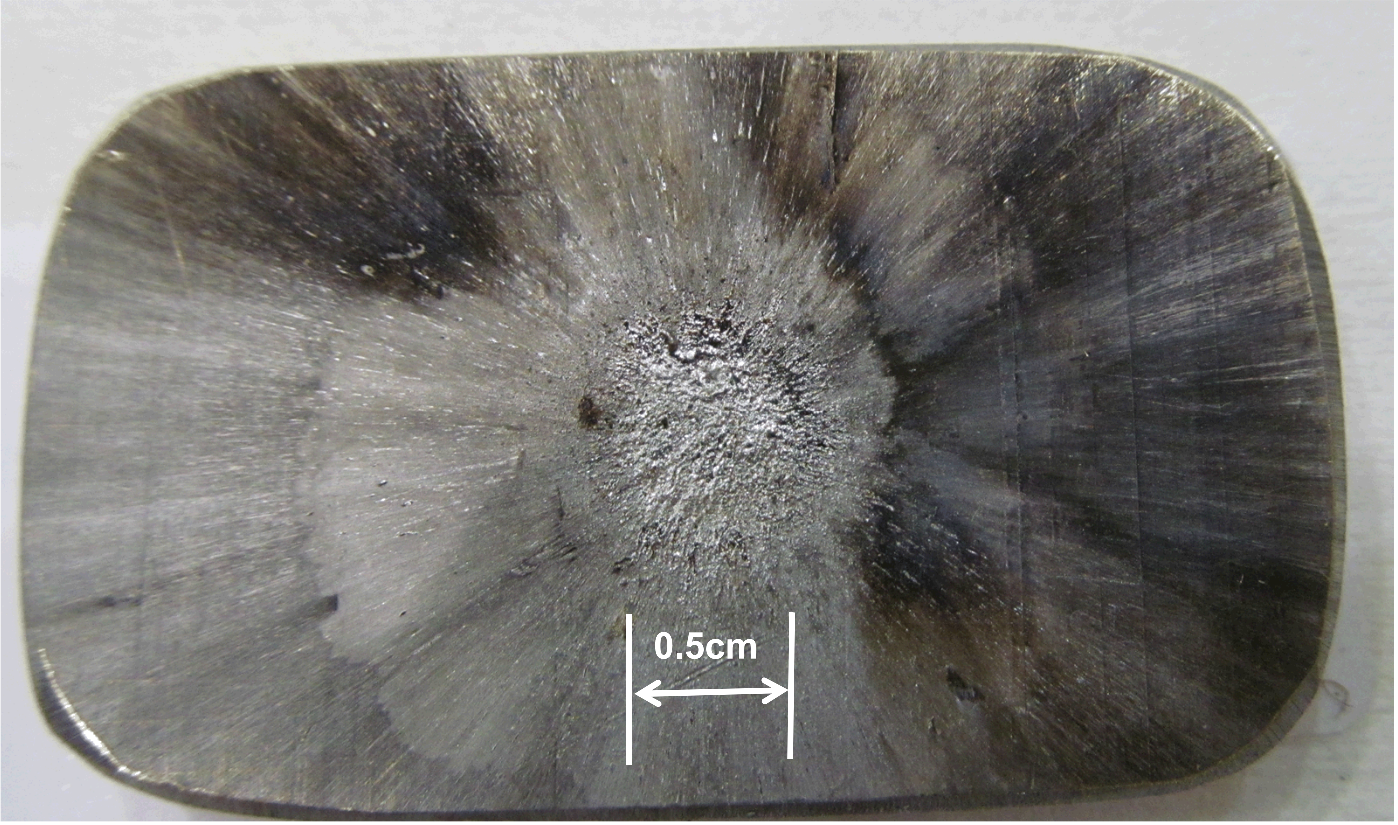
The ion beam imprint as well as possible anode ejected material have the same diameter as the cathode through hole.



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Indirect measurements of the back-streaming proton ions using nuclear activation techniques

- **Because of the large charge pickup by the diagnostic cables, it was impossible to measure the relatively lower ion currents with B-dots, Rogowski coils and Faraday cups.**

- **However, we succeeded in measuring the most prominent proton ion current using proton-copper activation measurements.**

- **The following section presents the measuring technique and portion of the up-to-date results.**

- **The experimental results are in reasonable agreement with LSP simulation predictions.**

We use proton-copper activation reaction.

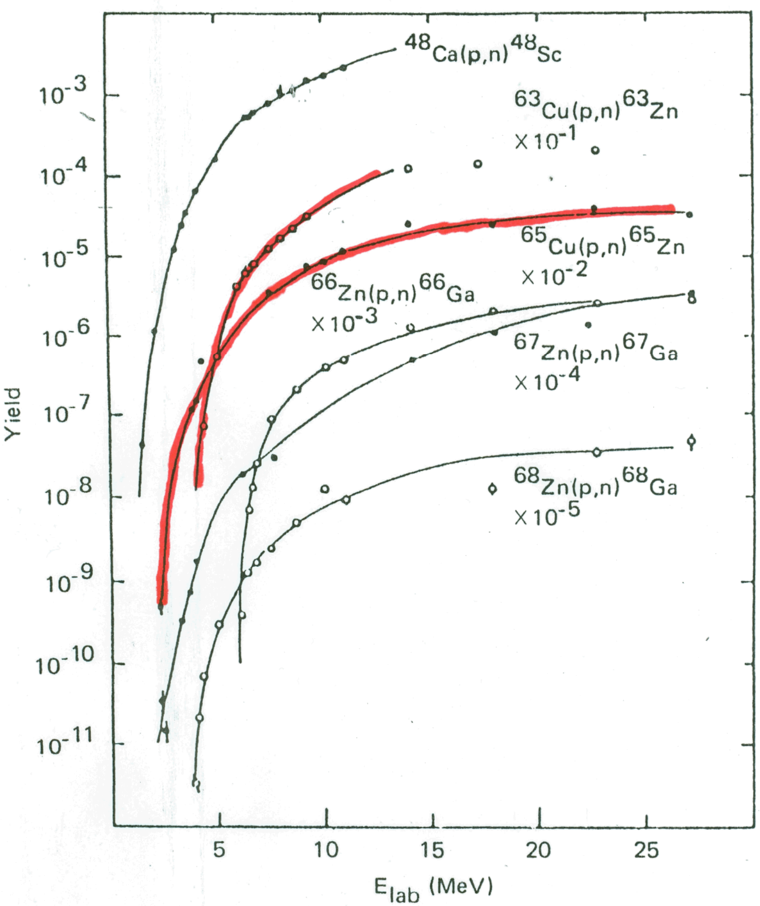
$Cu^{65} + p = Zn^{65} + n$. The Zn^{65} has a 244 day halflife and decay by emitting γ of 1.115MeV.

$Cu^{63} + p = Zn^{63} + n$ The Zn^{63} has a 39.5 minutes halflife. The Z^{63} is in an excited state and decays as follows:

$Zn^{63} = Cu^{63} + \beta^{+} + \Upsilon$.

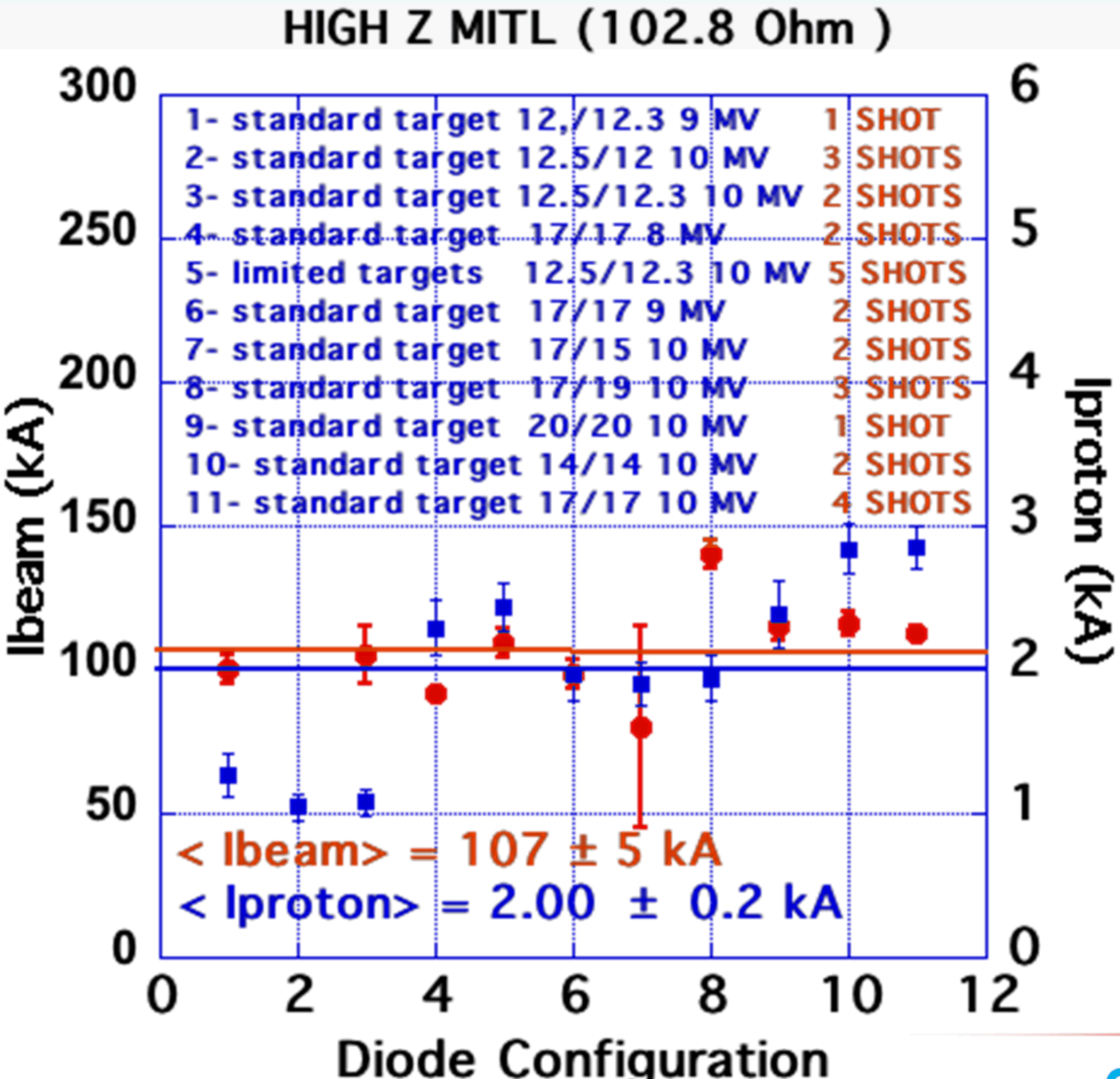
Following eatch RITS shot, because of the high level vacuum chamber (dust been) activation we could not retrieve and ϒ spec. the copper coupons before the next morning.

Hence only the Zn^{65} remained radioactive at ϒ spec. times. However, because of the low yield of the reaction at 8-10MeV, we have to count the Cu coupons for 60,000 seconds, and still the statistics of the measurements remained low.



High Z MITL Bipolar Beam and Proton Current measured through the cathode tip

- Standard targets are of 1mm thick solid Ta with a 10 µm Al foil located 0.6-0.8 mm in front of Ta.
- Limited targets have a small Ta converter of the order of 1mm in diameter.



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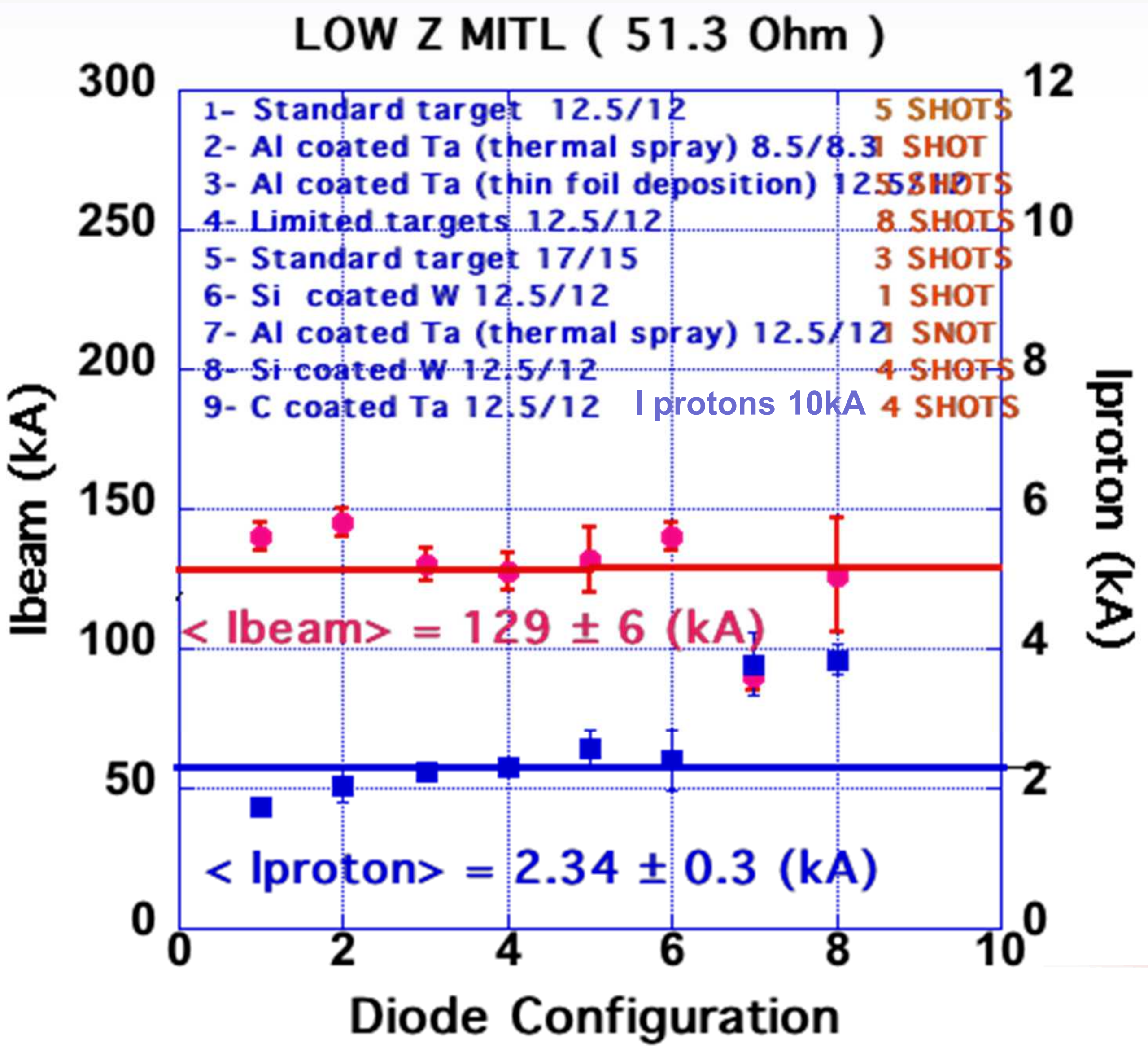
LOW Z MITL Bipolar Beam and Proton Current measured through the cathode tip.



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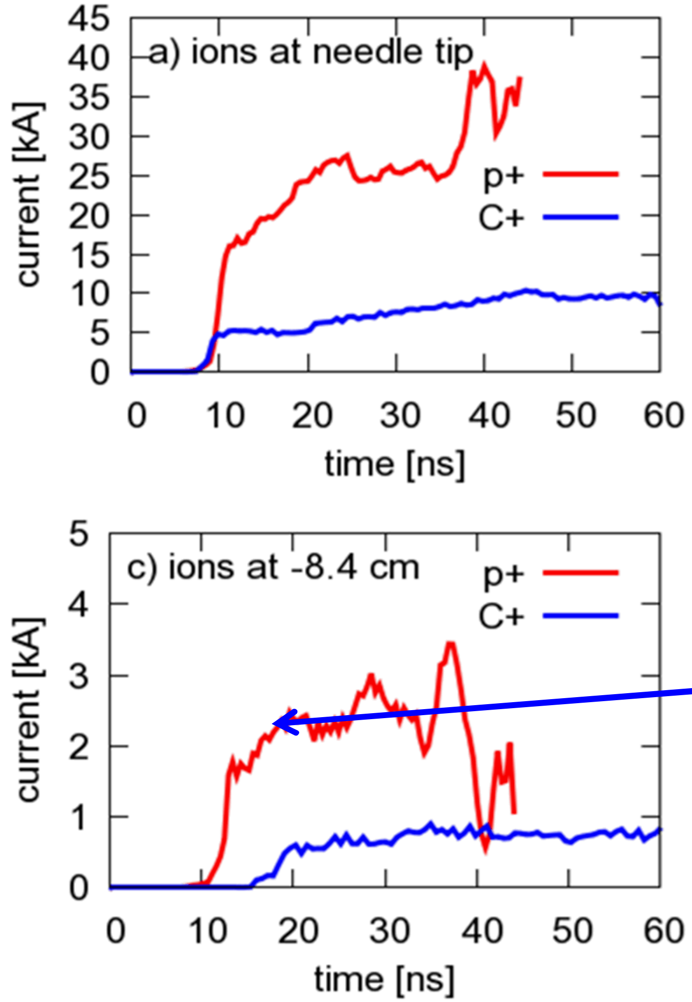
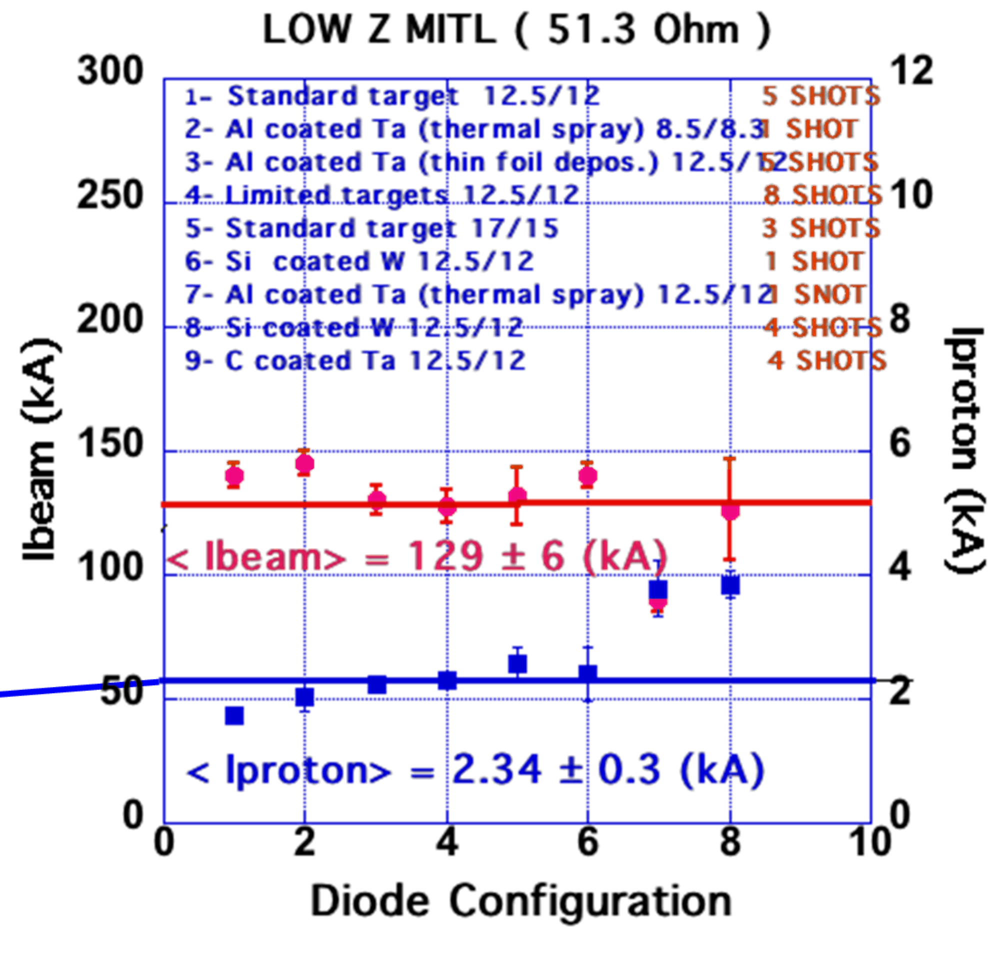
The measured average proton current is in good agreement with LSP simulation.



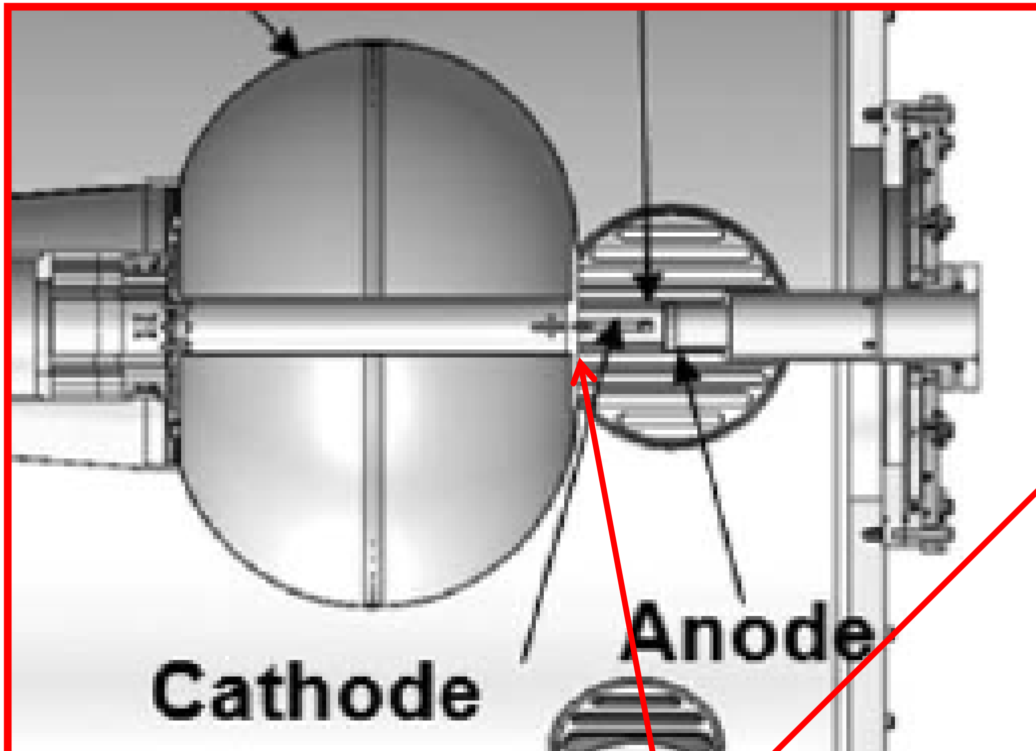


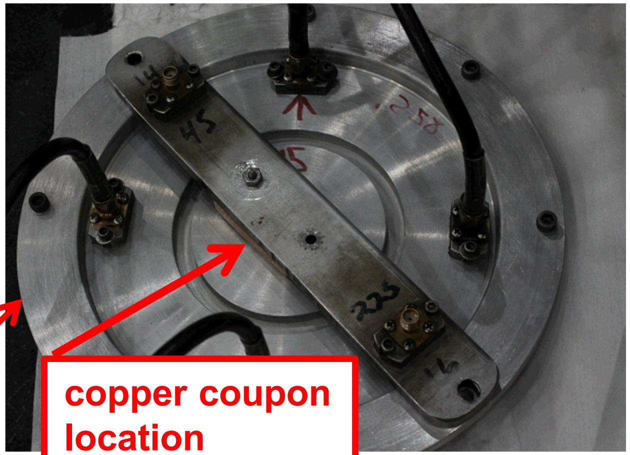
Summary of the Activation Technique Back-streaming Proton Ion Measurements

- The proton currents estimated from the activation results vary considerably from shot to shot.
- The experimental results on the average are in good agreement with Nichelle Bennett's LSP simulations.
- Comparing the measurements with LSP simulations we find that the total proton current striking the front of the cathode tip could be as high as 25 kA and equal to 24% of the net electron beam current.
- The C^+ ions estimate based on the simulations again should not be more than 7.5 kA: about 7% of the net electron beam current.
- Hence the total bipolar beam current could be composed of as much as 31 % of ionic current (Low impedance MITL).
- When we heated the anode target to 900^0 C no proton activation was detected.

- **Back slides**

Simplified setup for copper activation (knob front plate)

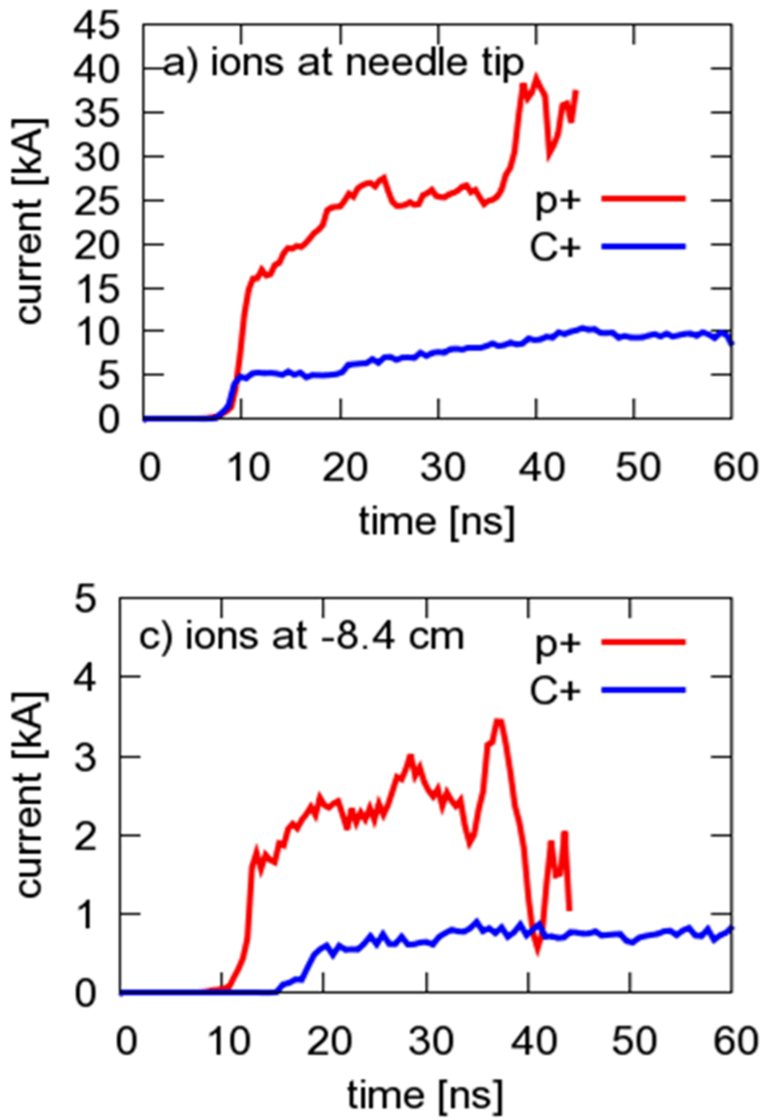




copper coupon location

Knob front plate supporting the A-K cathode stalk

Ion propagation simulation results



LSP simulations by Nichelle (Nicki) Bennett

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Nuclear reaction yield per incident proton

- The copper coupons are many times proton range thick (1/4”), so all protons are stopped in the target.
- The abundance percentage of Cu^{65} is 30.6% as compared with the Cu^{63} which is 69.1% . This is taken into account in the data analysis.
- In order to estimate the proton current for every diode approximate voltage we use the following table obtained from the available literature:

Diode Voltage (MV)	Yield (reaction/proton	I proton/DPM (A/DPM)
10	8.10^{-8}	66.1
9	6.10^{-8}	88.9
8	4.10^{-8}	132.28
7	$2.9.10^{-8}$	182.46
6	$1.8.10^{-8}$	293.97

- For lower energies the yield drops rapidly down to zero since the reaction threshold is 2.12MeV.

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Estimation of the A-K voltage utilizing Al foil filters in front of the Cu coupons

- **The range of the 8 MeV proton beam in Al is 400 μ.**
- **However, because of the 2.12 MeV activation reaction threshold smaller thickness of Al foil will completely cut off any activation of the Cu coupons.**
- **Utilizing the stopping power in Al we find that a 200μ Al foil will cut down the 8 MeV proton energy to ~ 6MeV for which the yield is quite low ($1.8e^{-8}$). From 400 μm and down to 200 μm we did not observe any activation because of the low yields**
- **In a number of low impedance MITL shots where the nominal voltage is estimated (with para-potential flow techniques) to be 8 MV, we used 100 μm Al foils in front of the Cu coupons. Utilizing the 100 μm foil where the net proton energy striking the Cu was ~ 6.9 MeV, we observed recordable activation.**

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