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"ION" B-DOT AND FARADAY CUP RESULTS LOCATED INSIDE THE CATHODE KNOB OF THE SELF MAGNETIC PINCH (SMP) DIODE (A NEW DIAGNOSTIC FOR DIODE BEHAVIOR?)

Michael G. Mazarakis, Mark L. Kiefer, Joshua J. Leckbee, Dan S. Nielsen, and Derek Ziska
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

This paper describes our effort to measure the back-streaming ions emitted from the target x-ray convertor and thus estimate the ion contribution to the A-K gap bipolar current flow.
Knowing the ion contribution is quite important in order to calculate the expected x-ray dose and compare it with the actual measurements. Our plans were first to measure the total ion current using B-dot monitors, Rogowski coils, and Faraday cups and then to utilize filtered Faraday cups and time of flight techniques to identify and measure the various ionic species. The kinetic energy (velocities) of the ions should help evaluate the actual voltage applied at the anode-cathode (A-K) gap. LSP simulations found that the most prominent ions are protons and carbon single plus (**C^+**). For an 8-MV A-K voltage, the estimated proton current back-streaming through an 1 cm in diameter hollow cathode tip was on the average 3 kA and the carbon current 0.7 kA. Since only a small fraction of the ions will make it through the cylindrical aperture, the corresponding total currents were calculated to be respectively 25kA for proton and 7 kA for carbon ions, a quite substantial contribution to the total bipolar beam current. Hence, approximately only 10% of the total back-streaming ionic currents could make it through the hollow cathode tip aperture. Unfortunately the diagnostic cables connecting the Faraday cup and the B-dot monitors to the screen room scopes experienced a large amount of charge pick-up that obliterated our effort to directly measure those relatively small currents. However, we succeeded in measuring those currents indirectly with activation techniques [Contribution of the back-streaming ions to the self-magnetic pinch (SMP) diode Current., M. G. Mazarakis, M. G. Mazarakis, M. E. Cuneo, S. D. Fournier, M. D. Johnston, M. L. Kiefer, J. J. Leckbee, D. S. Nielsen, B.V.Oliver, M. E. Sceiford, S. C. Simpson, T. J. Renk, C. L. Ruiz, T. J. Webb, and D. Ziska. Subitted for publication.]. In the following sections we present some typical cable pick-up results and also our efforts to verify that the observed "current" scope traces were indeed not ion currents but instead cable charge pic-up. Interestingly enough we also discovered that the appearance of those "currents" are in synchronism with the A-K gap impedance variation (decrease) and the MITL sheath current re-trapping. Hence those B-dots or Faraday cups could be utilized as diode behavior diagnostics.

Introduction

For the present experiments the electron diode utilized was a high energy, high current Self Magnetic Pinch (SMP) diode. It was mounted on the front surface of an almost spherical cell called "knob" which was secured at the front high voltage (~8MV) end of the RITS accelerator cathode stalk. RITS [1] is a Self-Magnetically Insulated Transmission Line (MITL) voltage adder that adds the voltage pulse of six 1.3 MV inductively insulated cavities. Figure 1 presents pictorially the entire accelerator and diode assembly, and Fig. 2 is the actual knob and diode design. One of the possible locations where B-dots, Faraday cup, and Rogowski coils could be placed is indicated in red. Fig. 3 shows the two B-dots, the Rogowski coil and the copper ion beam stop mounted at the backside of the knob front plate. Special fixtures were built to install the Faraday cup behind the backside of the cathode tip (backside of the front plate) (Fig. 4a) or on the back inner surface of the knob (Fig. 4b). The knob has relatively thin walls and oblong shape; its axial length is 44.9 cm, and its interior as well as the entire accelerator and diode are under the same vacuum, which is of as low pressure as 2.3 10^{-5} torr.

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The A-K gap can be adjusted and is usually of the order of 1-2 cm. The cathode tip is a hollow cylinder 8cm long with an 1cm diameter inner bore. The cathode tip and sometimes the front plate are damaged following each shot. The first station B-dots are located at ~11.5 cm axial distance from the anode target and the Rogowski at 10 cm.

Experimental results (the ion B-dot current puzzle)

The Faraday cup (Fig. 4b), Rogowski coil, or B-dots positioned at the back end of the knob (Fig. 2) could distinguish the arrival times of proton and $\mathbf{C^+}$ ions since their "time of flights" from the anode target along the knob axis would be respectively 11.4 ns for protons and 39.6ns for $\mathbf{C^+}$. Of course the arrival of protons at the first measuring station at the back of the anode plate should be almost prompt with the turning-on of the diode, namely 3-ns for the protons and 10-ns for the C^+ ions. Therefore, measuring the time of flight from the first measuring station to the second one appeared quite feasible.
Figure 5 presents the first results obtained with the B-dots at the first measuring station. The B-dot current traces are superimposed with the SMP beam current traces. The beam current (IBEAM) is measured with 4 B-dots azimuthally located at 0^0, 90^0 , 180^0 and 270^0 around the cathode tip at the front surface of the knob facing the A-K gap (Fig. 6). The two ion B-dots are named # 45 and # 270. This notation is arbitrary and does not refer to any azimuthal angle location around the cathode hole. It merely corresponds to pre-existing cable and diagnostic channel numbering since the B-dots were 180^0 apart (Fig.3, 6). We were surprised to observe such huge currents, tens of kA instead of the expected 2-3 kA predicted by the LSP [2] simulations (Fig. 7). In Fig. 5 one of the B-dots (#45) received so much current that the scope clipped it. This is because we did not anticipate so much current and the scope sensitivity was high. Also another puzzle was the timing of those large peaks: too late relative to the start of the beam current. Being 65 ns late instead of 3ns for proton arrival was inexplicable. This phenomenon continued for all the shots. The ion B-dot current amplitude varied from shot to shot.

Experimental tests to identify the origin of the ion B-dot signals

Below we present a number of experiments that were carried out in order to establish the origin of those signals:,

a) First we covered one of the B-dots (Shot 1766, Fig. 8) with an aluminum foil. If really it was measuring incoming current, then the observed current peak should have disappeared. To our surprise both B-dots, the aluminum covered as well as the uncovered, showed the same amplitude of "current" (Fig. 9).
b) The signal persisted even when we used a solid cathode tip without bore-hole (Fig. 10).
c) Then we rotated one of the B-dots by 180^0 (B-dot #45). The "current" should have changed polarity. To no avail both B-dot signals appeared with the same polarity and same intensity (Fig. 11).
d) In the following test we disconnected the diagnostic cables from the ion B-dots. The cable of the # 45 B-dot was left open while the #225 cable was shorted. As we predicted, the shorted cable gave a signal similar to that obtained when it was connected to B-dot while the open cable registered a very strong step function pulse (12).
e) In the following tests we disconnected the cables from the B-dots and left them open (not shorted). The integrated signals appeared at the scope as step functions because the cables did not have a path to discharge to ground. (Fig.13)

By now we were convinced that what we were seeing was not real current but charge pick-up by the diagnostic cables.

In the next tests we were aiming to find where the cables were picking up that charge:

f) Suspecting a charge pick up inside the knob, we lengthened one of the cables inside the knob with a 15-m long (50') cable loop. The signal went skyrocketing high. The amplitude was so large that even with very low scope sensitivity the trace was clipped. Also interesting enough the trace was wider by almost 75 ns. Obviously the capacitance of the longer cable was much higher and the discharge pulse length was much longer. (Fig. 14)
g) Then we shielded the section of the cables located inside the knob with a 0.5mm Al and 0.5mm stainless steel thick tubes. This did not reduce or eliminate the observed signals (Fig. 15).

All those null tests convinced us beyond doubt that the observed signals were due to cable charging by a large influx of electrons. The diagnostic cables travel all along the entire length of the MITL cathode stalk (~12m) before exiting the vacuum region of the accelerator and being connected to the scopes of the screen room. At the time of those tests we could not afford the time or the effort to take apart the entire cathode stalk and shield the cables with heavy metals to verify if the pick-up was due to energetic electrons traversing the relatively thin walls of the stalk. But that would have make the stalk very heavy to candeliver

Ion B-dots as diagnostics of the SMP diode impedance behavior

If we reexamine Fig. 5 we see that the onset of the ion B-dot traces coincide with the change of the electron beam current (IBEAM) slope and peak when the beam current also peaks. The change of the current slope and the sharp increase reflects a decrease of the diode impedance. The beam current peaks at 200 kA. If at that particular point in time the A-K gap voltage was still between 7.5 and 8MV, then the observed maximum current should not exceed the 156 kA since the matched MITL load impedance is 51.3 Ohms. However, by that time the diode voltage is almost zero (Fig.16), it is therefore apparent that some portion of the "beam current" registered in Fig. 5 is not due to real beam but to a parasitic current contribution possibly from the front end of the knob. When the diode voltage goes to zero, currents larger than the 200 kA may flow between the knob and the front dust bin wall (anode) (Fig.2) not recorded by the electron beam B-dots (IBEAM) located in a 8cm radius around the A-K cathode stalk.

According to the MITL parapotential propagation theory [3], part of the propagating current flows at the surface of the cathode stalk, and approximately one third of the current flows inside the vacuum volume enclosed between the MITL cathode and anode electrodes. This is when the load at the front end is matched to the MITL impedance. This current is called "sheath" or flow current. However, when the MITL is undermatched, depending on the load impedance, the cathode or bound current is larger, and the sheath current decreases to become almost zero in the case of the load being a short. The phenomenon of the bound current increase is call "retrapping" of the sheath current. The retrapping was predicted by the parapotential theory and at first verified in special experiments performed with HERMES III accelerator [4,5]. Therefore, when the SMP diode impedance decreases, a retrapping front of the sheath current starts to propagate upstream along the cathode stalk of the MITL. The B-dots located at point F on the cathode stalk (Fig.17) that measure the part of the total current flowing on the cathode stalk surface can clearly detect the re-trapping front. Indeed, shortly after the onset of the ion B-dot signal, the currents at locations E, F, and G increase substantially and abruptly (Fig. 17), indicating the passage of the re-trapping wave front. In addition, the ion B-dot signal timing coincides with the diode voltage decrease or collapse (Fig. 16) and the sharp beam current increase. During the small A-K shots, where we observed a much more pronounced and earlier diode impedance collapse, the re-trapping wave was very large in amplitude. In those shots the B-dot signals were very strong and as high as 10-kA. Hence, it is obvious that the diode and MITL behavior can clearly be amplified and easily detected just by the ion B-dot traces. Although their original function was to measure the back-streaming ion current, they ended up of being diode impedance detection monitors

Summary

It was established following a quite exhaustive null investigation that the signals registered by the two ion B-dots were not ion currents but diagnostic cable charge pick–ups. It is speculated that those signals might be due to energetic electrons entering the MITL cathode stalk and striking the cables during the retrapping of the sheath current following the diode impedance collapse. Those signals could be used as diagnostic means to monitor the diode impedance behavior.

References

[1] “Status of the 10 MV, 120 kA RITS-6 Inductive Voltage Adder” D. Johnson, V. Bailey, R. Altes, P. Corcoran, I. Smith, S. Cordovaa, K. Hahna, J. Maenchena, I. Molinaa, S. Portilloa, E. Puetza, M. Sceiforda, D. Van De Valdeb, D. Rosec, B. Oliverc, D. Welch, D. Droemer, in Proceedings of the 15th IEEE International Pulsed Power Conference, edited byJohn Maenchen and Edl Schamiloglu (IEEE, Piscataway, NJ, 2005) p. 314-317

[2] LSP is a software product of Mission Research Corp.: http://www.mrcabq.com

[3] “Relativistic Brillouin flow in the high n/g diode” J.M.Creedon,J.Appl.Phys.46,2946(1975).

[4] M. G. Mazarakis, K. Mikkelson, J. W. Poukey, R. L. Westfall, D. J. Erven, D. A. Muirhead, P. Pankuch, and Hermes-III operation team. “Successful Hermes-III Power Transport in a 10-m long extention MITL Directorate 1200 weekly News Notes, February 16 1995.

[5] M. G. Mazarakis, K. Mikkelson, J W. Poukey. “Retrapping experiments in the HERMES III with the 10-m extended MITL and very low impedance loads”. March 1995. Unpublished.

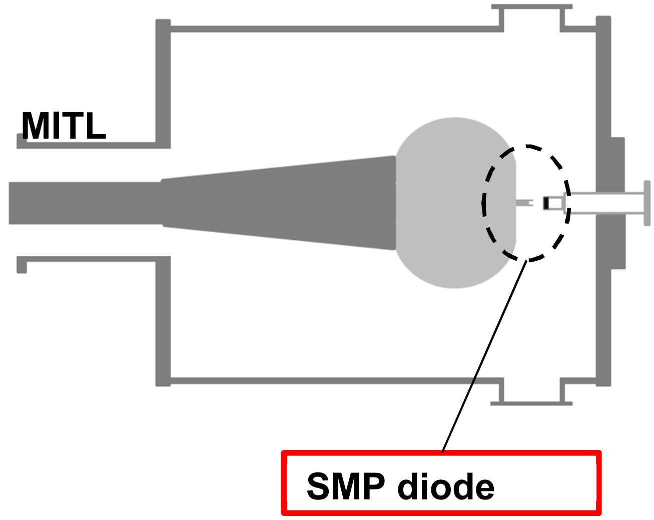


Figure 1. A schematic diagram of the RITS vacuum chamber (dustbin) and SMP diode. The relative dimensions are approximate.

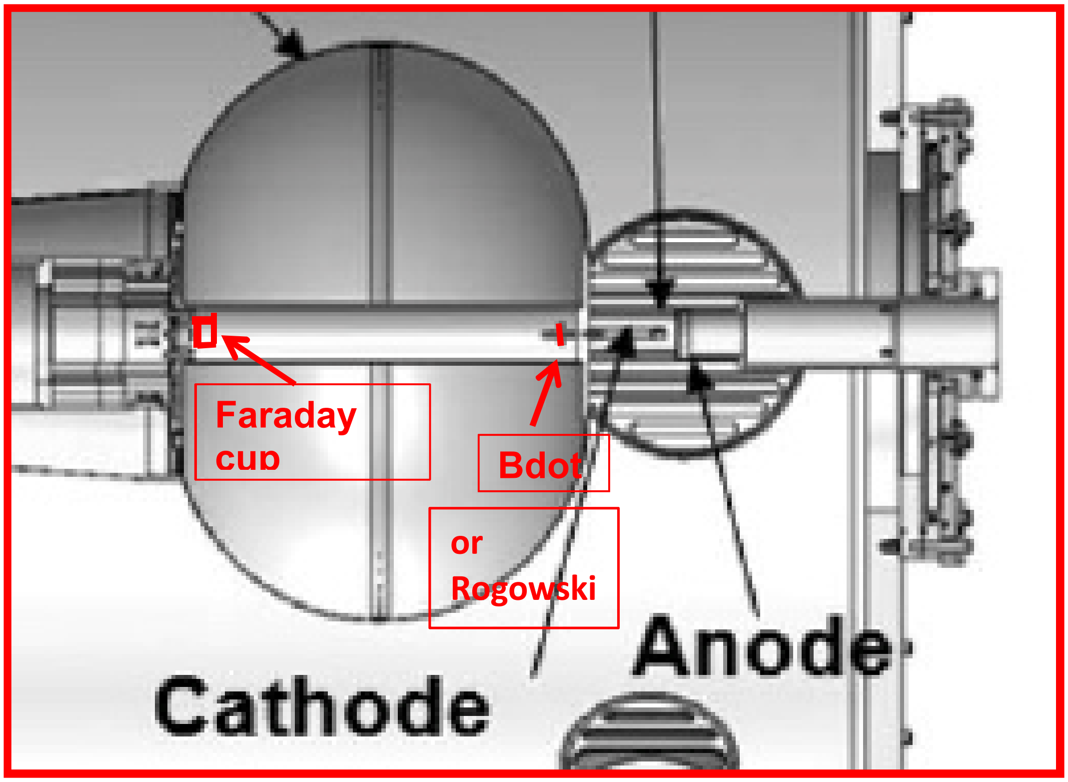


Figure 2. The engineering design of the dustbin indicating also the possible locations of Bdots and Faraday cup.

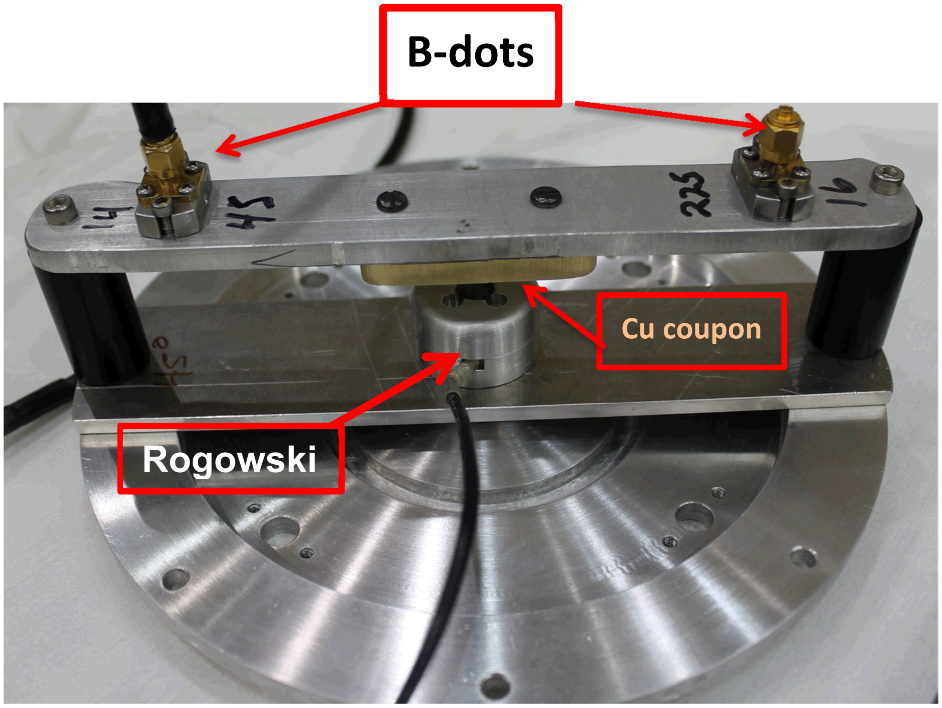


Figure 3. Bdot ,Rogowski coil and copper coupon arrangement mounted at the back of the knob front flat plate (first measuring station).

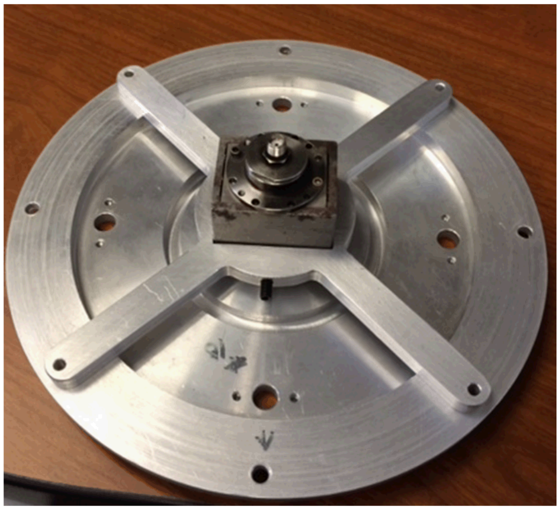


Fig. 4a

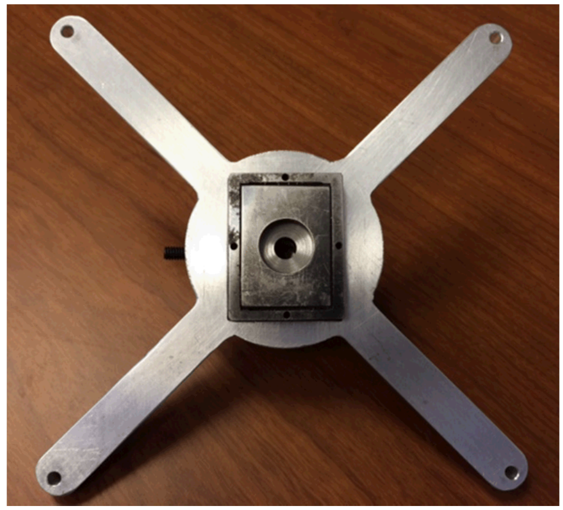


Fig. 4b

Fig. 4 The Faraday cup could be mounted at the back end of knob (Fig. 3a) or at the first station at the backside of the front plate (Fig. 3b)

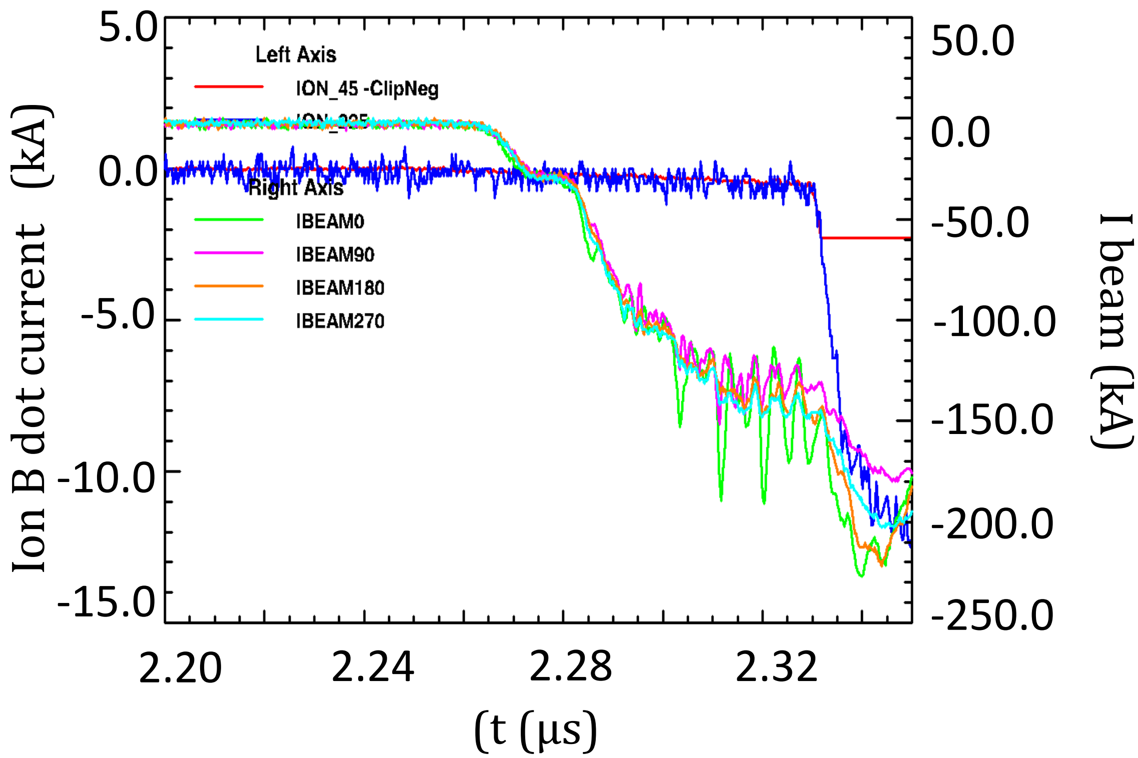


Figure 5. Shamble of the first results obtained with the B-dots at the first measuring station just on the back surface of the front plate. The ion B-dot #45 because of the large signal was clipped by the scope.

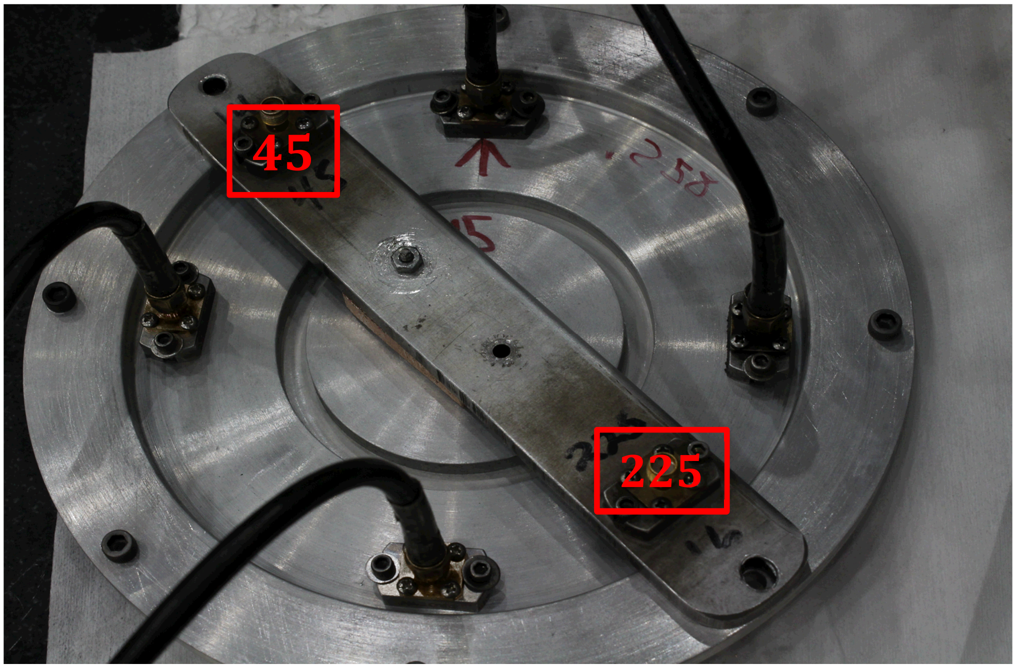
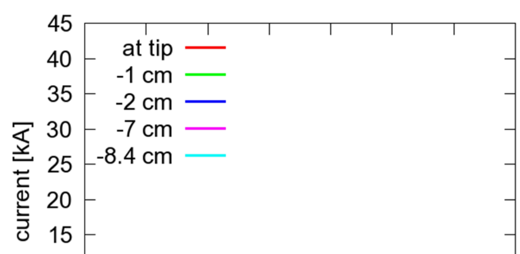
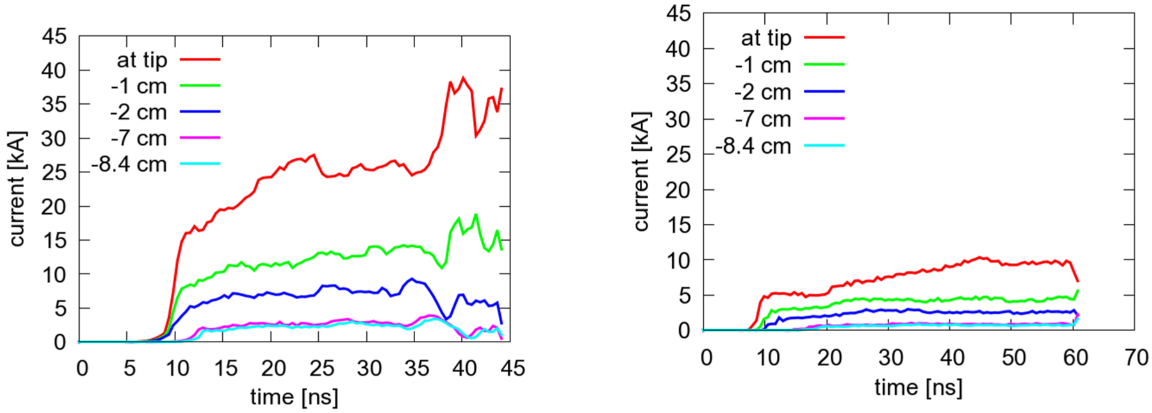


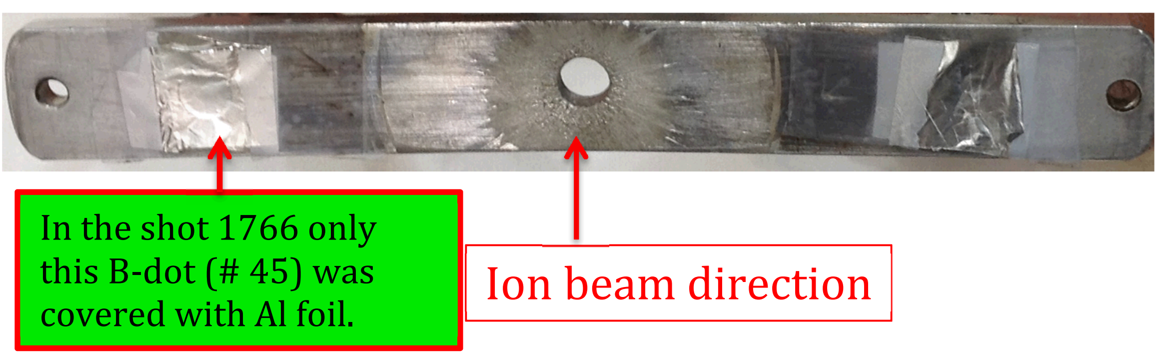
Figure 6. Back surface of the bin front plate. In this photo the four B-dots measuring the beam current (IBEAM) are connected with the diagnostic cables, the Ion B-dots are not connected. The numbers indicate the ion B-dot location. The beam four B-dots are located at the front surface of the plate and measure the current emmitted from the cathode tip while the two ion B-dots should measure the back-streaming ion current striking the aluminum bar.





proton ions **C^+ ions**

Fig. 7. LSP simulations of the back-streaming proton and carbon ions. In these simulations the cathode stalk length (needle), 8.4 cm, and the inner diameter, 1 cm.



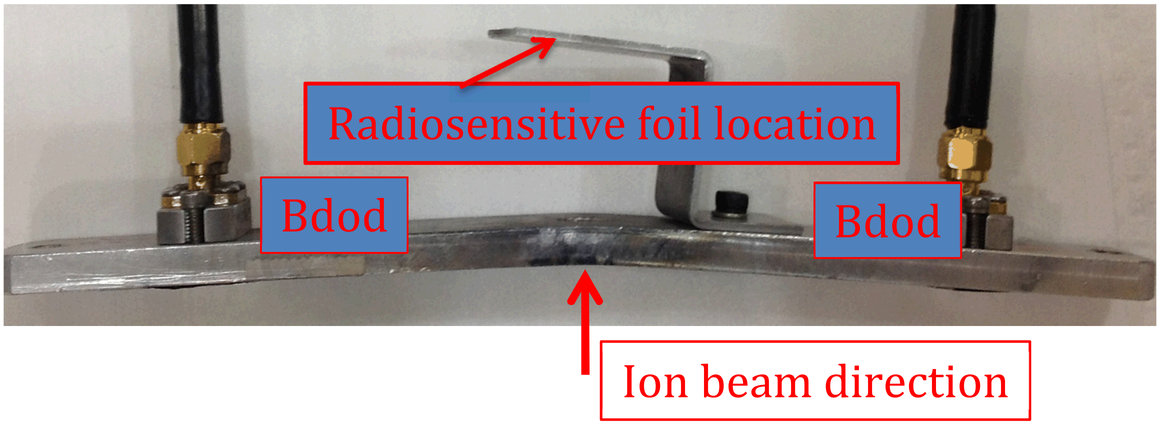


Fig. 8. Ion B-dot holder with both covered with aluminum foil

SHOT 1766

12.5 mm CATHODE. TOW B-dots THE ION_45 COVERED WITH Al FOIL

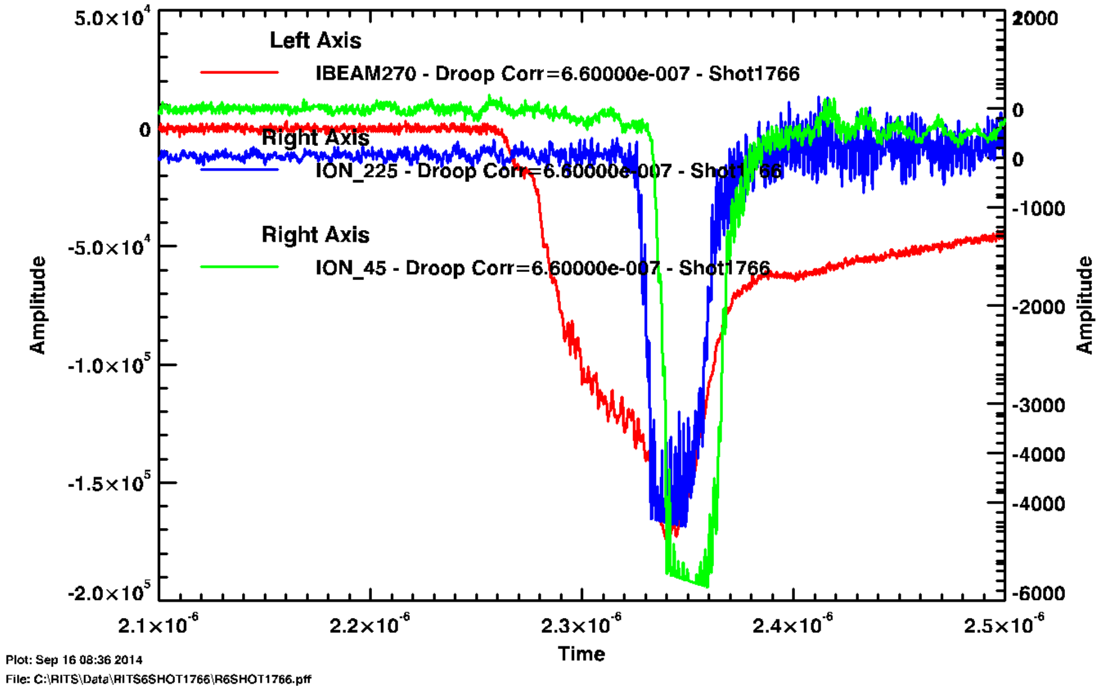


Fig. 9. Shot 1766. Both B-dots, the aluminum covered as well as the uncovered, showed the same polarity signal. Actually the covered B-dot (#45) registered even higher amplitude of "current".

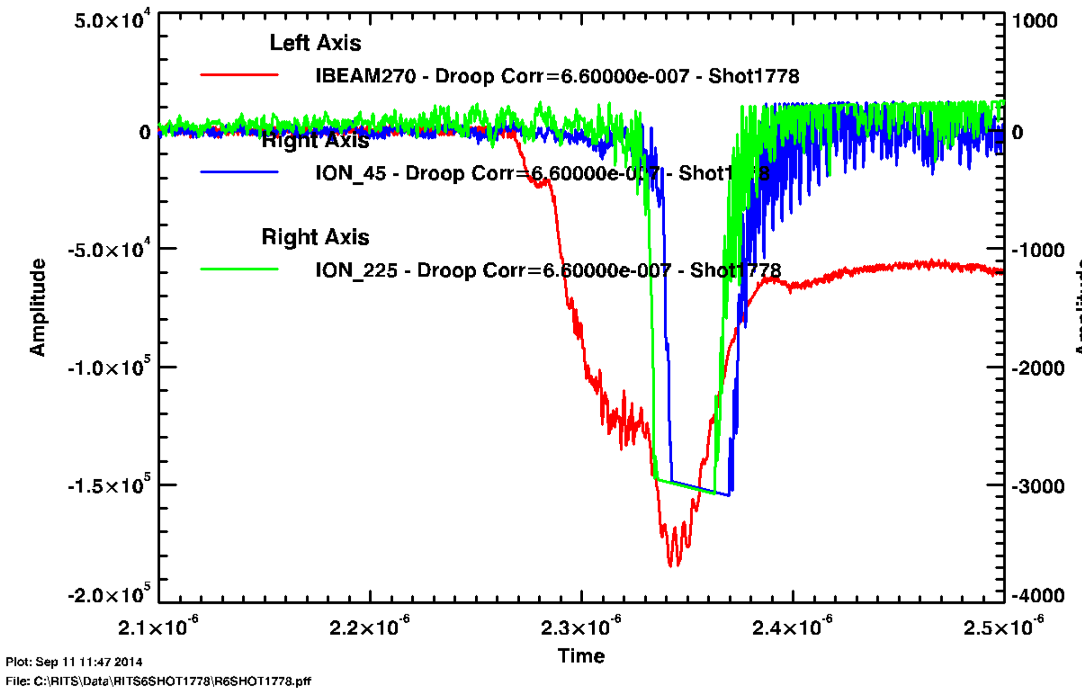


Fig. 10. The signal persisted even when we used a solid cathode tip without bore-hole.

SHOT 1772 8.5mm cathode
ION_225 **rotated by 180. It should change polarity but did not**

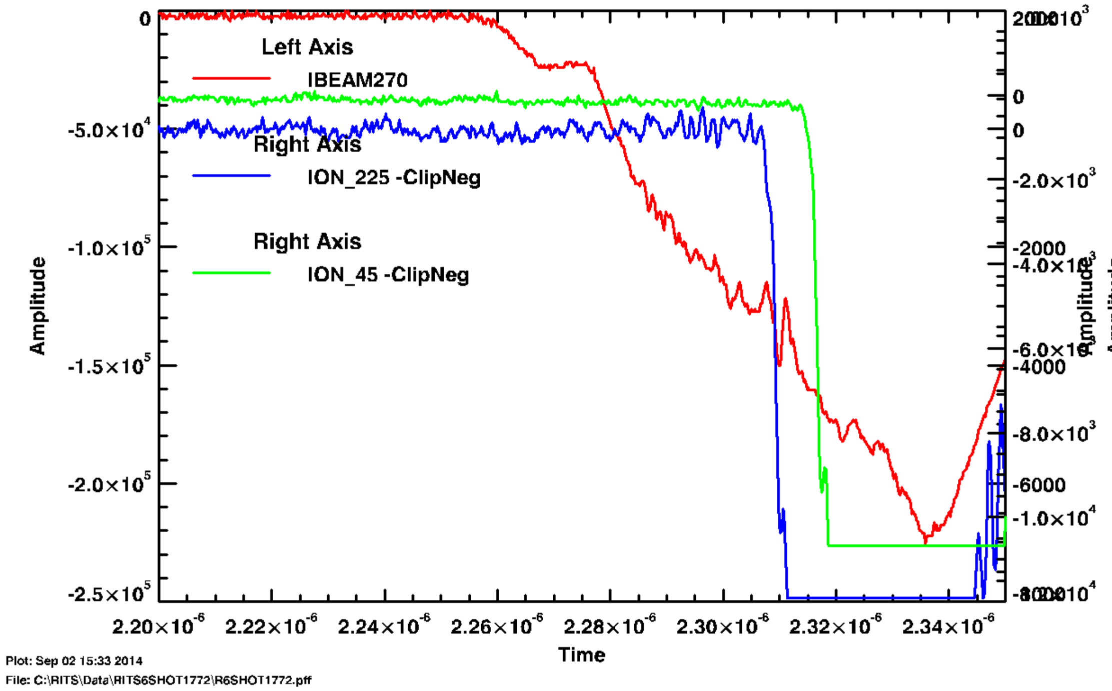


Fig. 11. One of the B-dots (#45) was rotated 180^0. The "current" should have changed polarity. To no avail, as shown both B-dot signals appeared with the same polarity and same intensity

Shot 1775

One cable shorted (ION-225). Cable of ION_45 open.

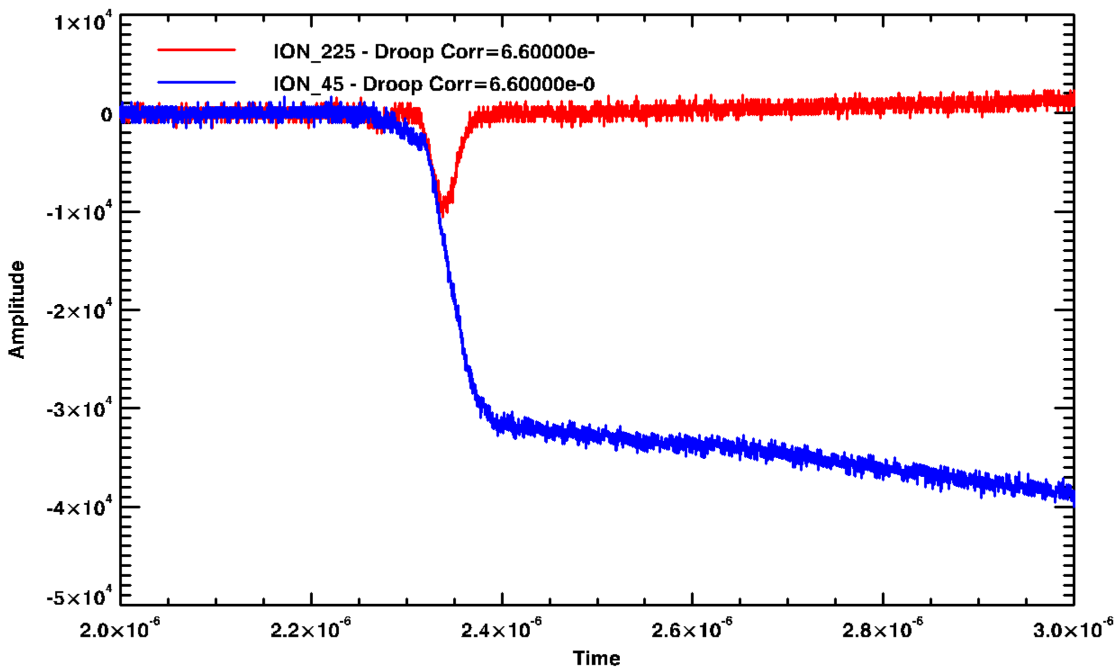


Fig. 12. We disconnected the diagnostic cables from the B-dots and shorted the end of one of them (# 225). The signal of #225 cable appeared similar to a B-dot while cable #45 gave a strong negative step function. Both signals started at the same time in synchronism with the diode collapse.

Shot 1774
Cables attached to the Al bar but not connected to B-dots

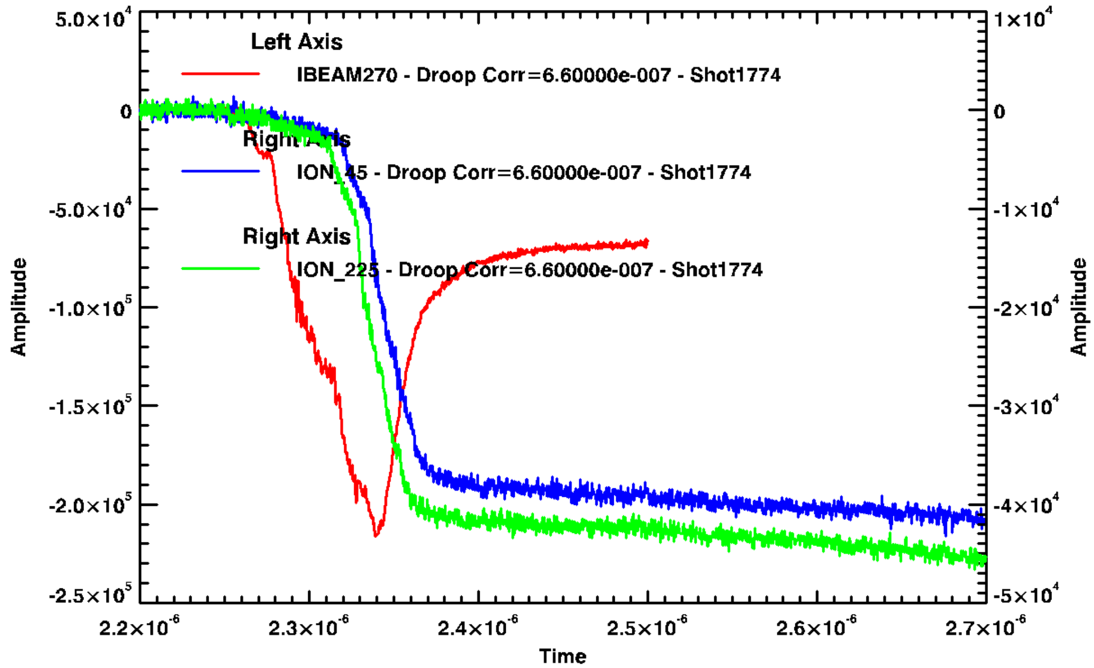
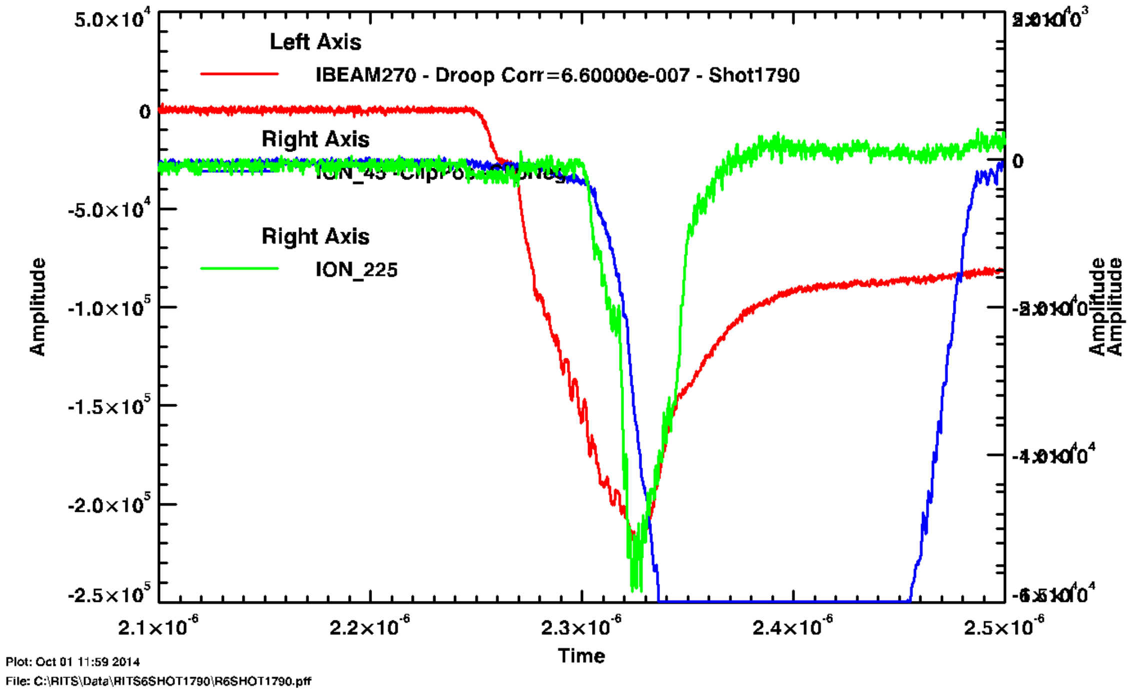


Fig. 13. Here we disconnected the cables from the B-dots and left them open (not shorted). The integrated signals appeared at the scope as step functions because the cables did not have a path to discharge to ground.

SHOT 1790

ION_45 had in series INSIDE the knob 50’ additional cable. Scope at 100mV/div



The signal is enormous and starts at the same time as when there was not the 50’ cable. So the cable loop picks-up a lot of charge inside the knob. Also the pulse duration is much longer.

Fig. 14. Suspecting a charge pick up inside the knob, we lengthened one of the cables (of ion B-dot #45) inside the knob with a 15 -m long cable loop. The signal went skyrocketing high. The amplitude was so large that even with very law scope sensitivity the trace was clipped. Also interesting enough the trace was wider by almost 75 ns. Obviously the capacitance of the longer cable was much higher and the discharge pulse length was much longer.

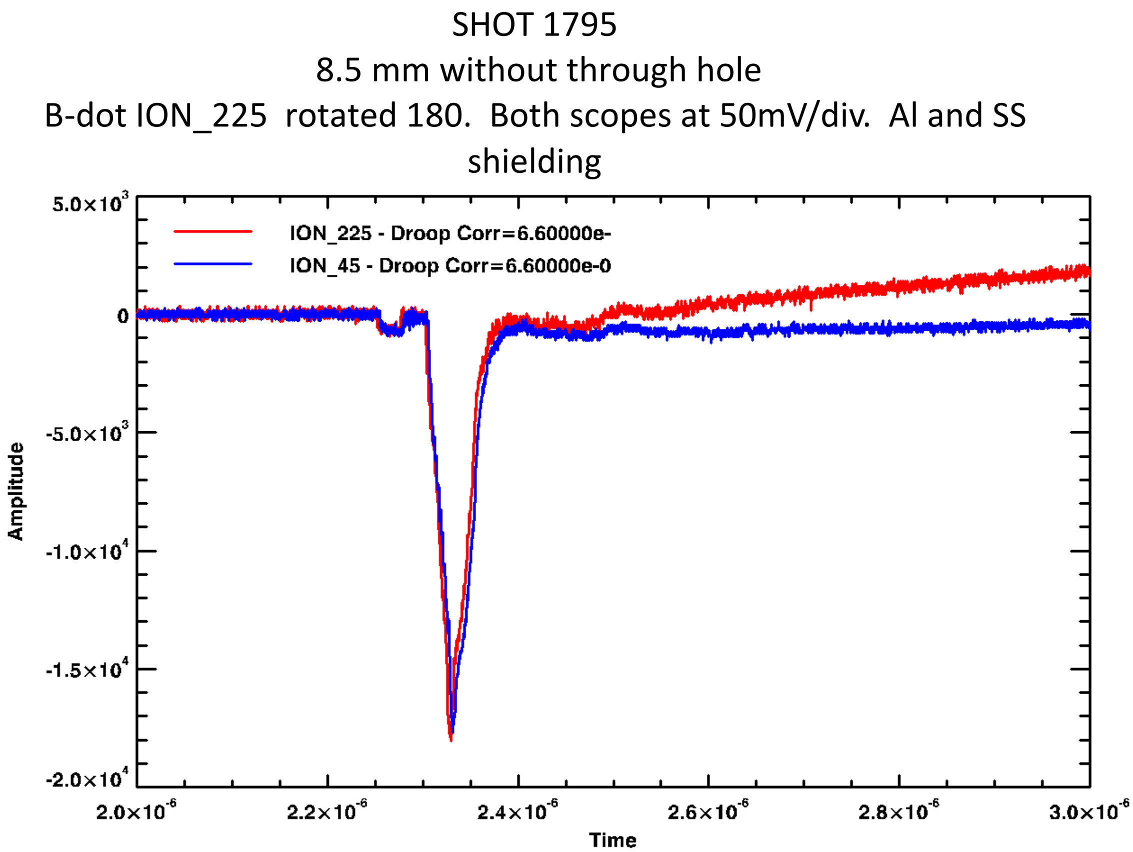


Fig. 15. In this shot we shielded the section of the cables located inside the knob with a 0.5 mm thick aluminum and stainless steel pipes. This did not reduce or eliminate the observed signals.

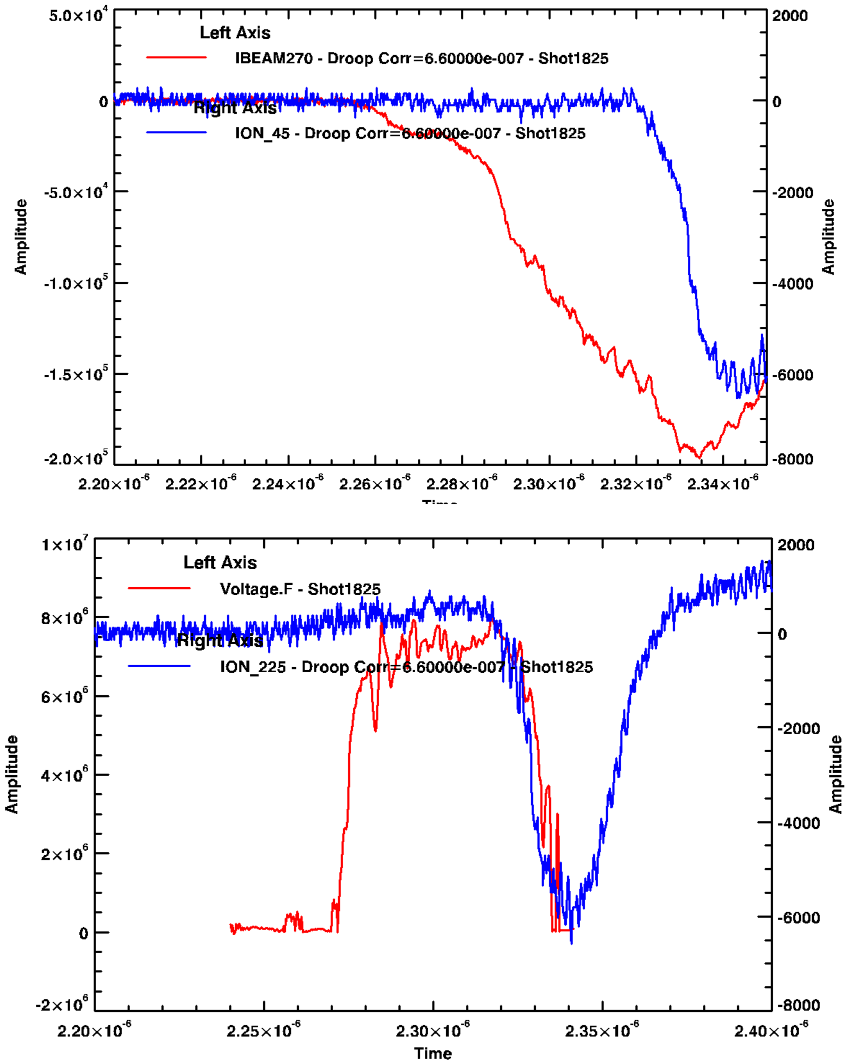


Fig. 16. The beam (IBEAM) current peak (200kA), the ion B-dot trace maximum and the A-K voltage collapse happens at the same time at approximately 2.34 μs. The start of the voltage trace estimated at location F is corrected for the travel time of the retrapping wave from the diode to the F location.

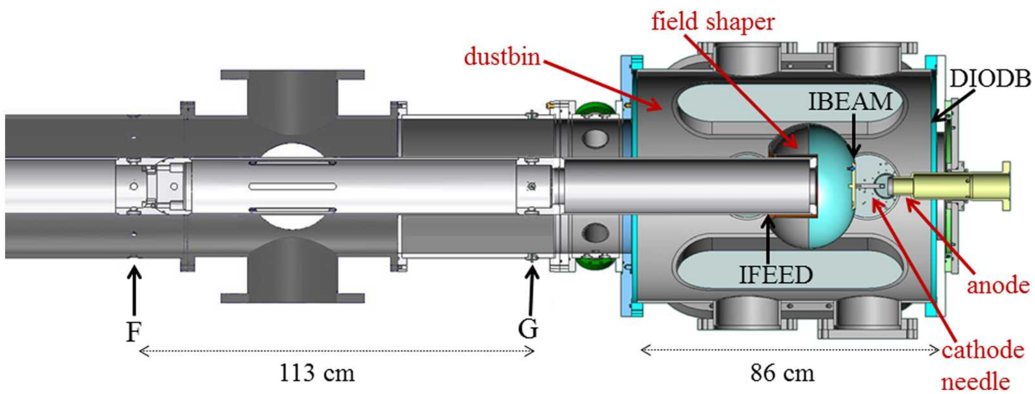


Fig. 17. Drawing of the Cathode stalk MITL indicating the location of B-dots measuring the current flowing along the cathode at different locations(F , G, IFEAD) upstream of the A-K gap.

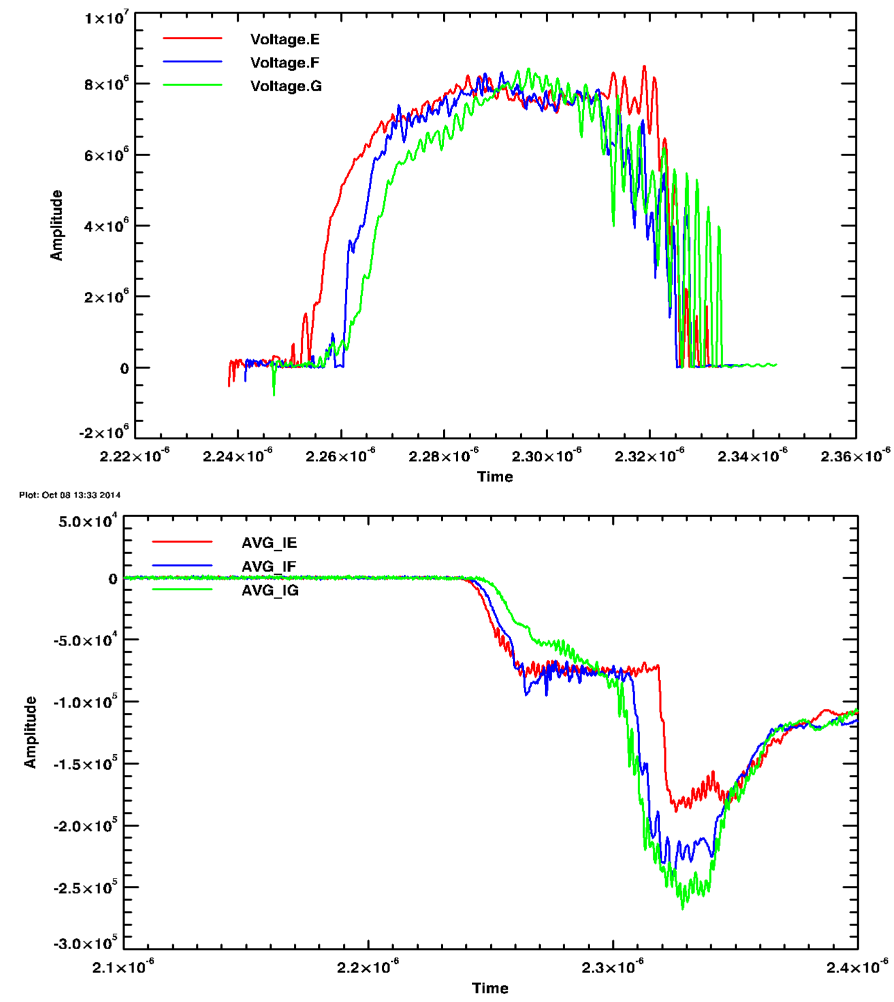


Fig. 17. The bound currents at location F (IF), G (IG) and E (IE) showing the retrapping wave propagating upstream follow the diode voltage collapse. The different voltage traces are calculated utilizing the parapotential formulas at

cathode MITL locations E, F, and G. The current and the estimated voltages traces correspond to the average currents measured with the four B-dots located symmetrically around the surface of the cathode stalk in each station. (Shot 1795). The observed small time differences of the start of the three traces correspond to the time it takes the retrapping front to reach of the stations E, G, and F.

Fig. 19. When the ion B-dot s peak the x-ray radiation quenches.