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A Study of the Gain of Microchannel Plates in the Ionization Profile Monitors at Fermilab*

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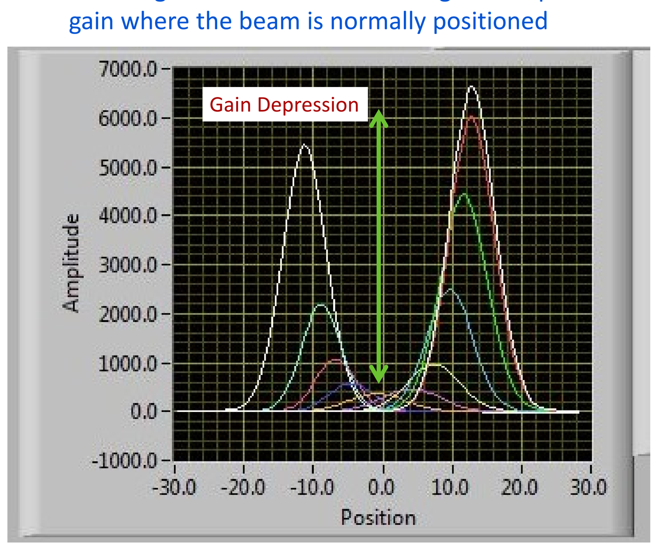
Abstract
One of the on-going issues with the use of microchannel plates (MCP) in the ionization profile monitors (IPM) at Fermilab is the significant decrease in gain over time. There are several possible issues that can cause this. Historically, the assumption has been that this is aging, where the secondary emission yield (SEY) of the pore surface changes after some amount of extracted charge. Recent literature searches have brought to light the possibility that this is an initial 'scrubbing' effect whereby adsorbed gasses are removed from the MCP pores by the removal of charge from the MCP. This paper discusses the results of studies conducted on the IPMs in the Main Injector at Fermilab.

Introduction

Ionization profile monitors (IPM) are used in many accelerator laboratories around the world [1-7]. They have been used in nearly all the synchrotrons built at Fermilab, and presently are used in the Main Injector (MI), Recycler Ring (RR), and Booster synchrotron [8], with another one being planned for the Integral Optics Test Accelerator (IOTA). All Fermilab IPMs, as well as many of those at other laboratories, utilize one or more microchannel plates (MCP) for signal amplification. Historically we have found that the gain of the MCP decreases over time and have attributed it to the well-known fact that they age with current extracted from them [9]. Thus, we have periodically replaced them.

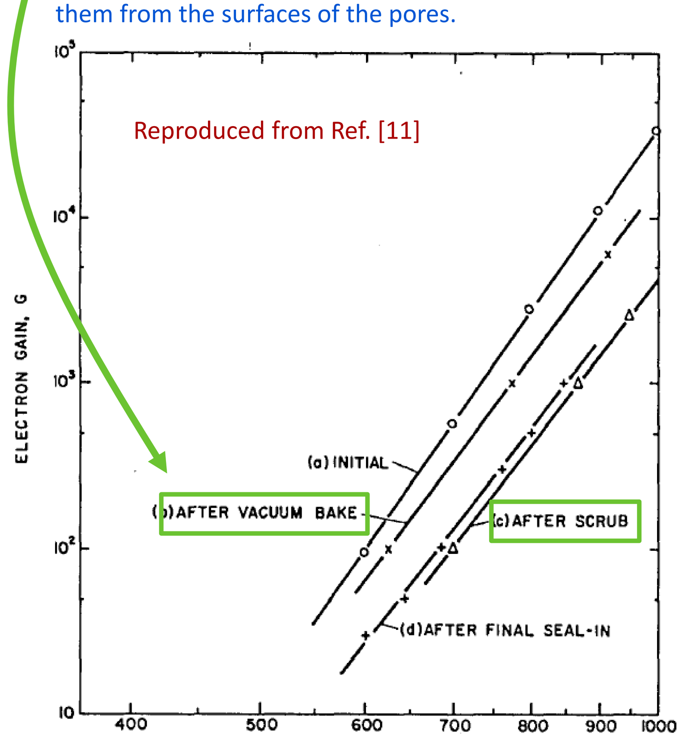
Recently, more in-depth investigations have revealed that the decrease in the gain is much more consistent with conditioning, or 'scrubbing', of the MCPs, and not aging. Literature searches have rediscovered the fact that a decrease in gain with conditioning is a known property of MCPs [10,11]. Our own historical IPM data and a recent dedicated test show results which are much more consistent with what one expects from conditioning.

Scan of gain over the MCP showing the drop in gain where the beam is normally positioned



Previous MCP Literature

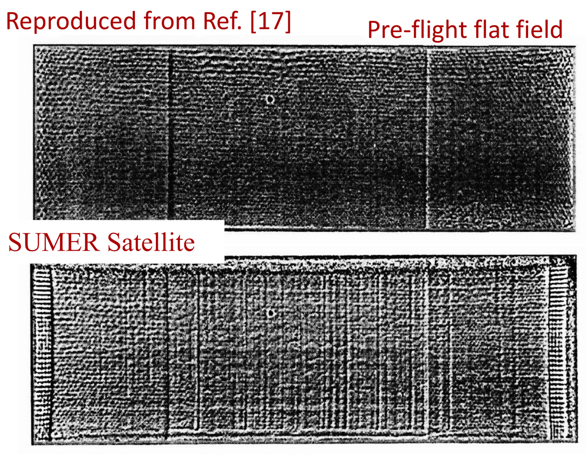
Measured gain of an MCP (taken from [11]) at various stages in the preparation: initial, after vacuum bake, after scrub, and after final seal-in. The gain decrease from after vacuum bake to after scrub is a factor of 3. Scrubbing refers to the initial phase of operation of the MCP, where the electrons act to ionize adsorbed gases and remove them from the surfaces of the pores.



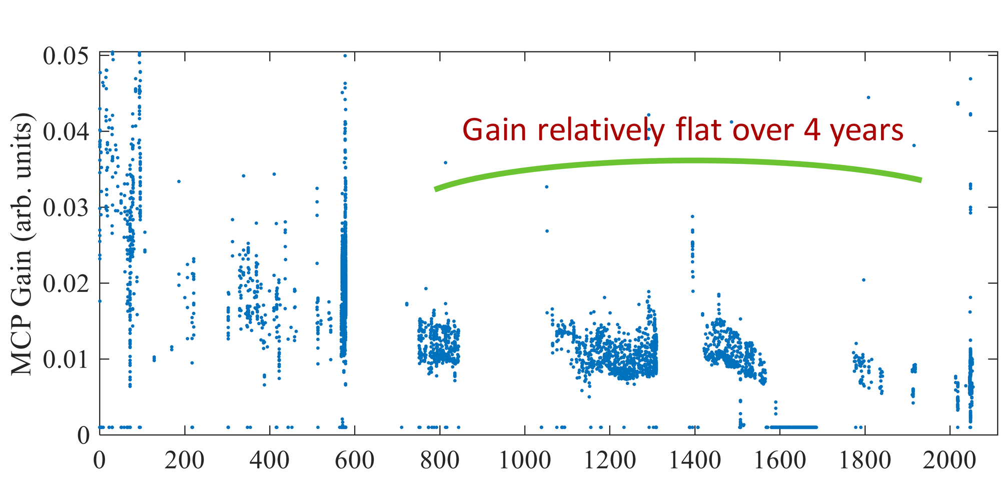
MCPs can be conditioned by illumination with ultraviolet radiation until the gain stabilizes [10]. Whether or not the MCP can be exposed to atmosphere after conditioning without losing the benefits of the conditioning is not yet entirely clear to us [15,16].

The lifetime of a MCP is generally > 1 C/cm². Conditioning of the MCP happens much faster than that, typically less than 0.1 C/cm² [9,19,21].

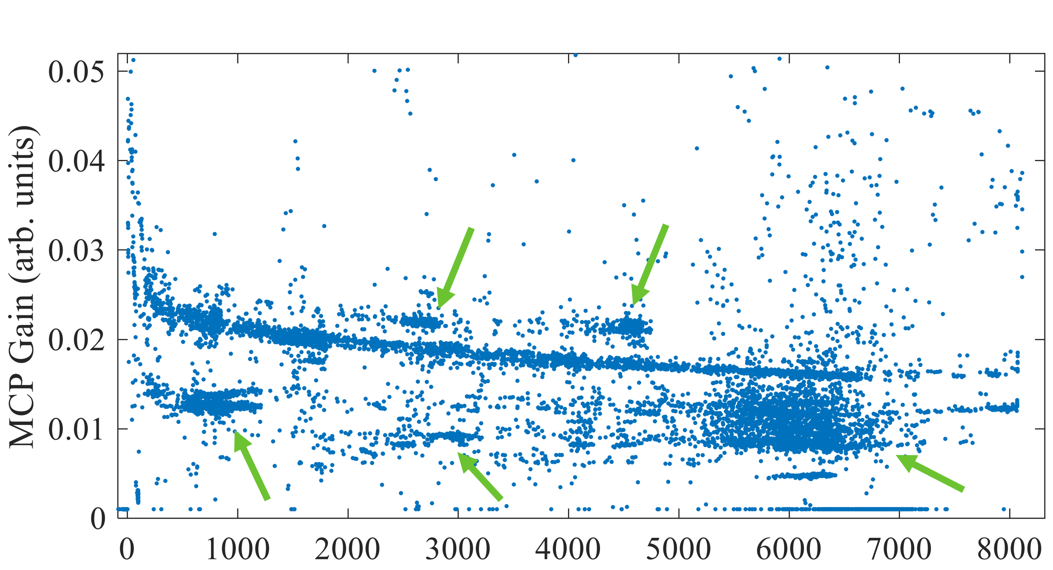
Reproduced from Ref. [17]



The use of MCPs in satellites encounters similar gain issues as we do with the IPMs [17-19]. When used in a spectrometer, spectral lines are placed at defined positions on the MCP. As it is apparently impractical [16] to keep a satellite MCP under vacuum, the initial operation of it in space causes the brighter lines to scrub faster resulting in a non-uniform gain, just as the beam in an accelerator is always located at the same location and produces a dip in the gain.

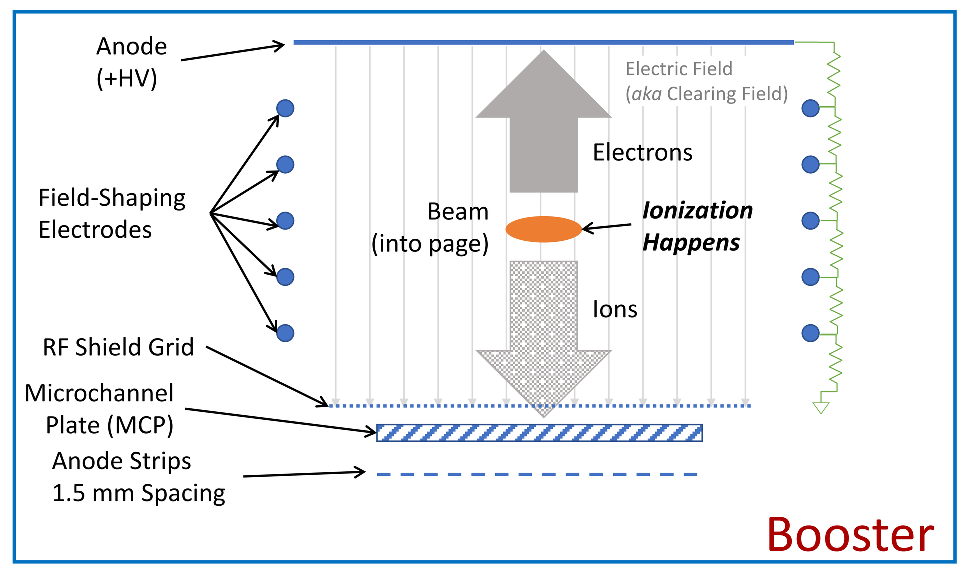


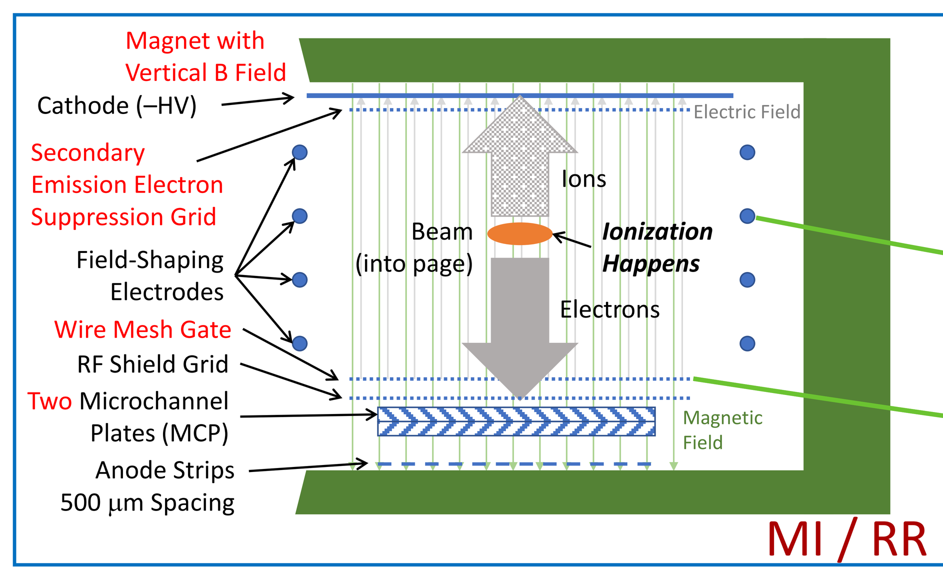
Historical MCP gain resulting from the scaling by beam intensities and the voltage gain curve. It would appear that the MCP gain decreased after initial installation but has been relatively flat after that. This is a behavior consistent with initial conditioning, and not aging.

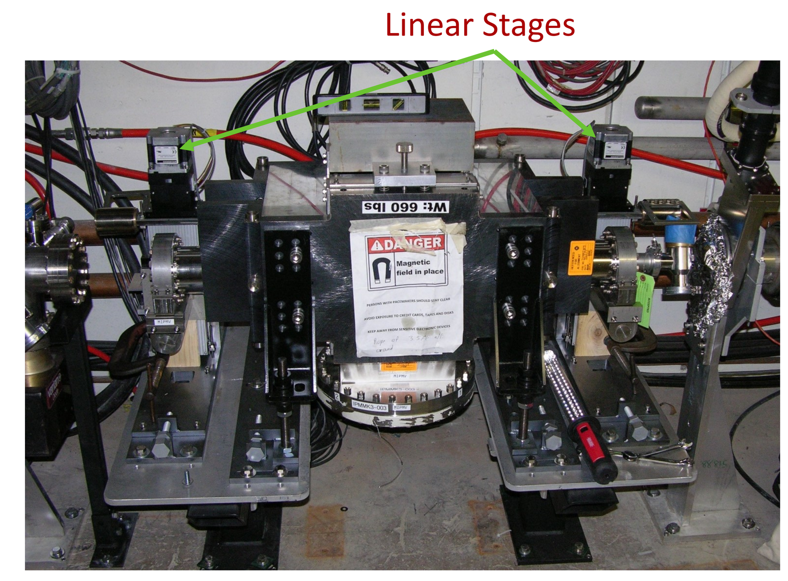


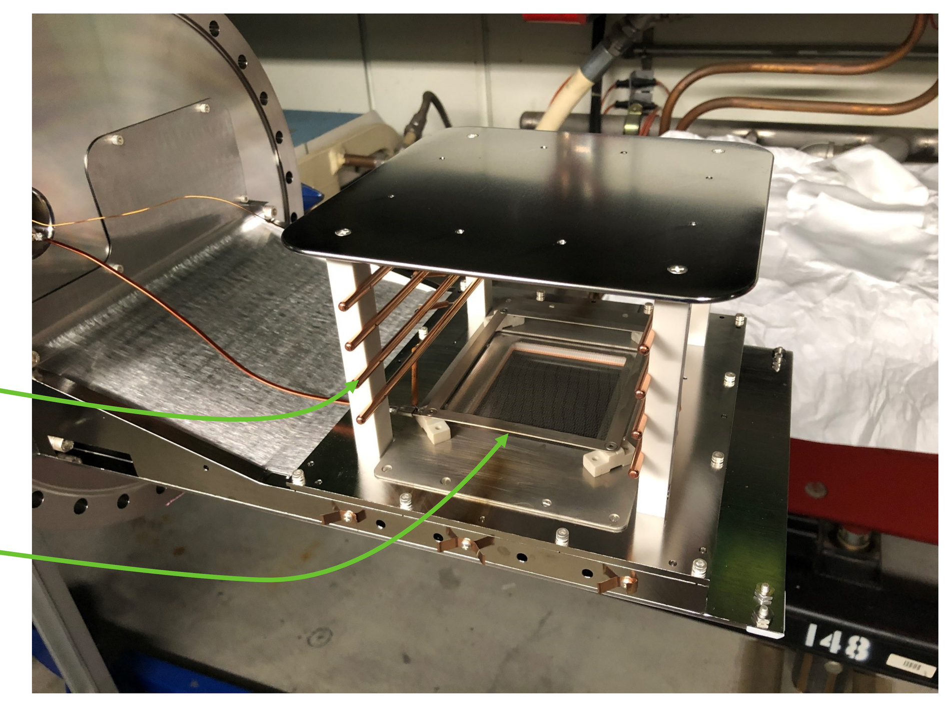
MCP gain vs. beam intensity after scaling for beam intensity. It is not flat and there are various isolated regions (some indicated by green arrows) that need to be understood.

Experimental Devices



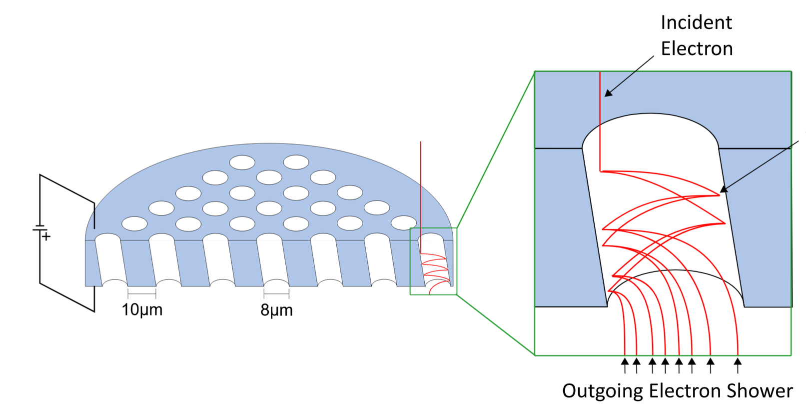


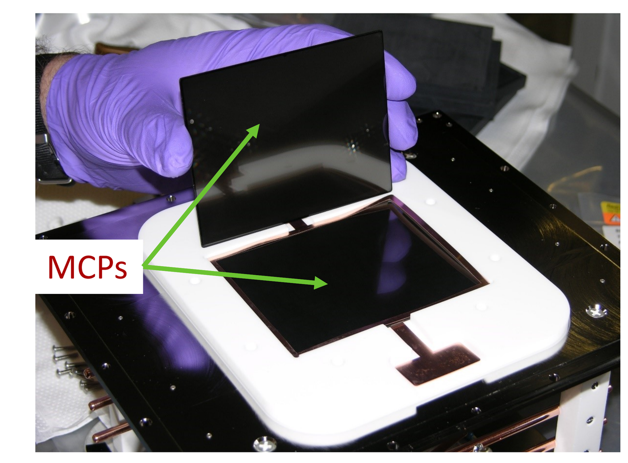




MCP

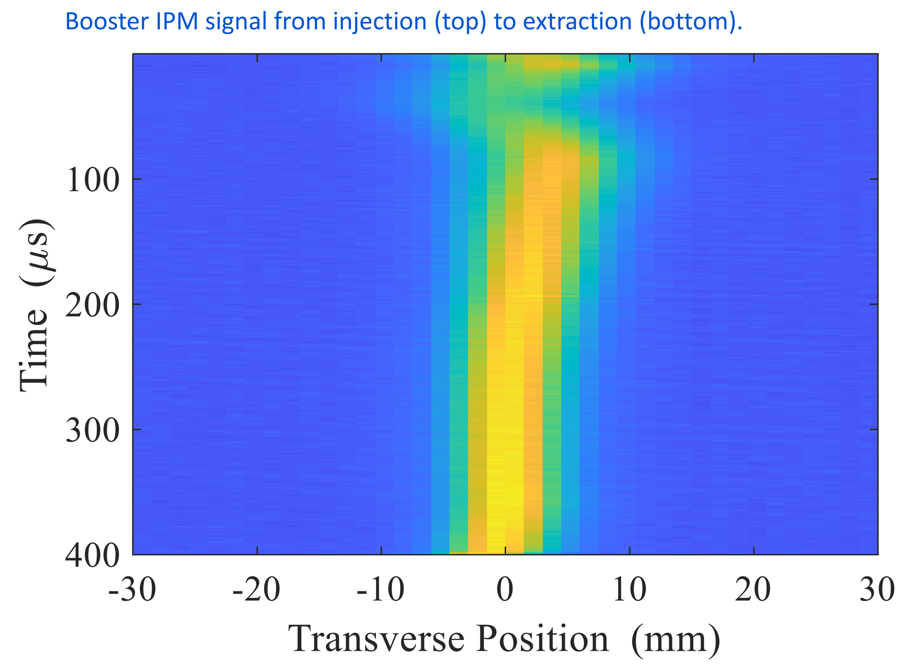
Schematic of MCP functional behavior showing amplification by electron avalanche.



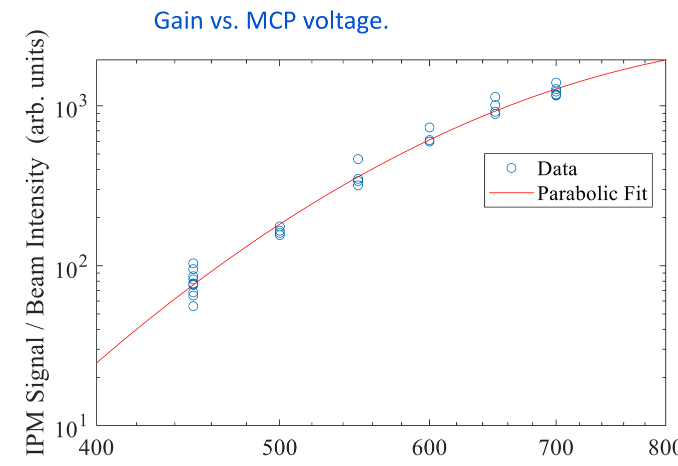


Historical Booster Data

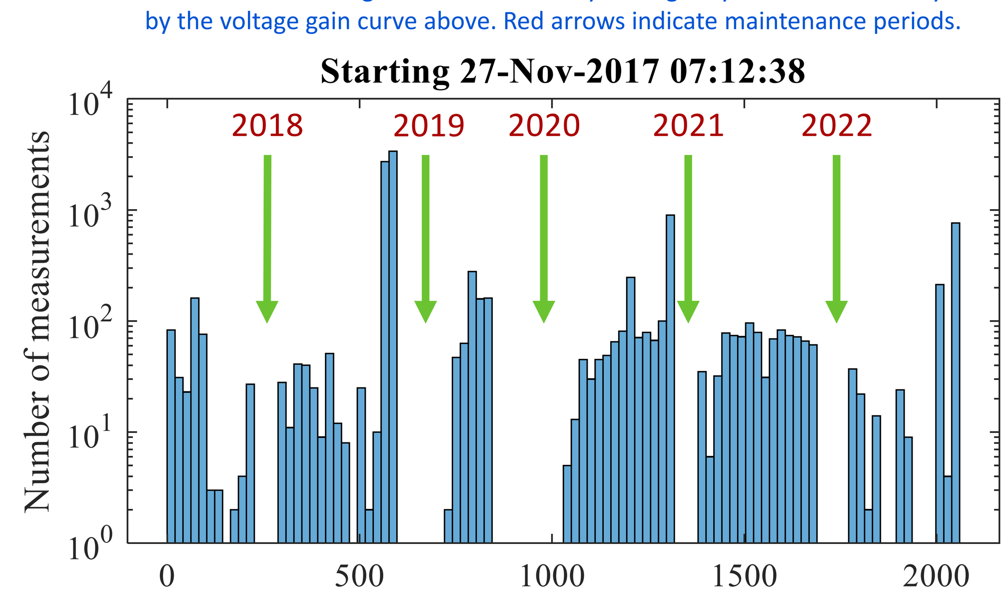
Booster IPM signal from injection (top) to extraction (bottom).



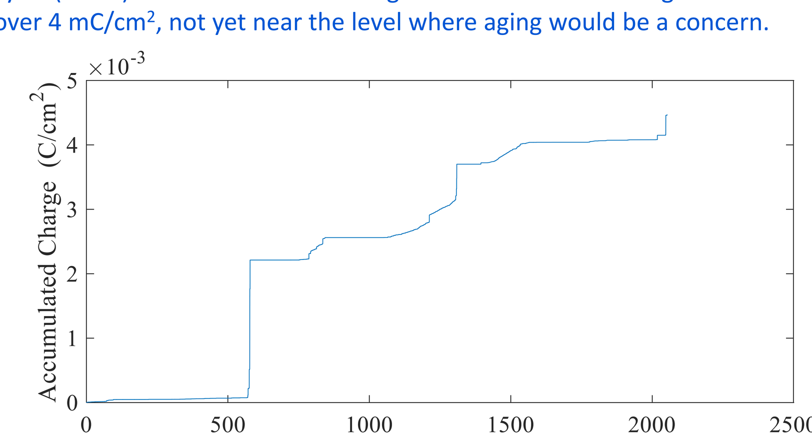
Gain vs. MCP voltage.



The distribution of Booster IPM acquisitions as a function of time. We calculated the MCP gain from this data by scaling it by the beam intensity and by the voltage gain curve above. Red arrows indicate maintenance periods.

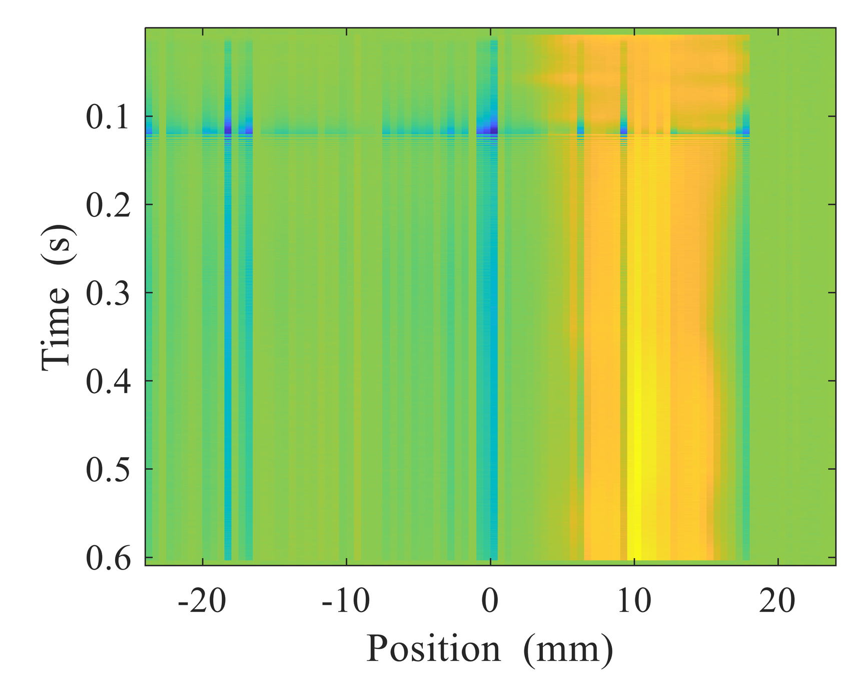


Since the MCP should age with extracted charge, we calculate the extracted charge for an acquisition as $Q = ITD$, where I is the average current from the MCP during the acquisition, T is the time the high voltage is on (~3 seconds), and D is the Booster duty cycle (~50%). Shown here is the integral of the extracted charge vs. time which is a little over 4 mC/cm², not yet near the level where aging would be a concern.

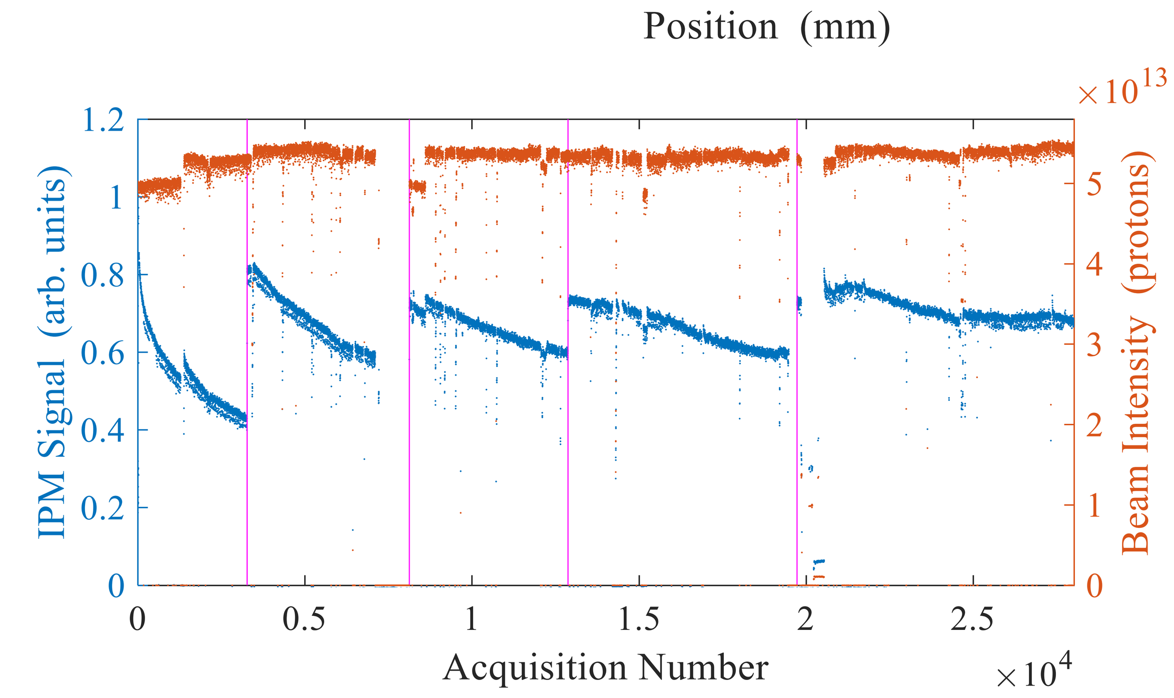


Main Injector Study

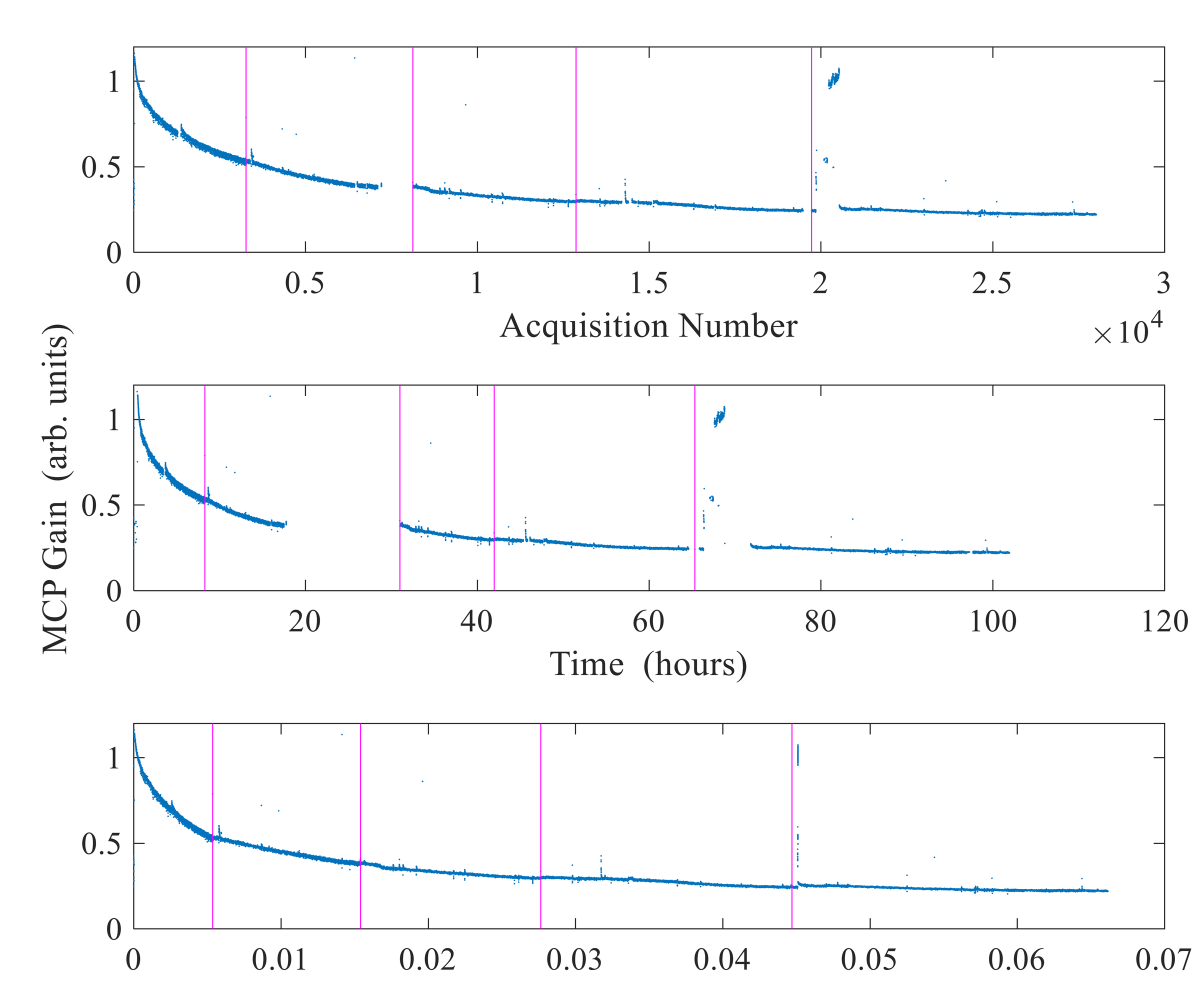
The MCP was moved to a new region of the plate, and then run repeatedly for a period of ~5 days. MI IPM signal from injection (top) to extraction (bottom).



The raw IPM integrated signals and the beam intensities. During the 5 days, the voltage was periodically adjusted to keep the signals at similar levels. This is indicated by the vertical magenta lines. The processing corrected for the beam intensity and accounted for the changes in voltage by scaling the data in each voltage region to match at the boundaries.



Processing of the data corrected for the beam intensity and accounted for the changes in voltage by scaling the data in each voltage region to match at the boundaries. shows this gain as a function of acquisition number, time, and integrated charge out of the MCP. Here as well, the change in gain is consistent with scrubbing, not with aging. One additional thing to note is that since the MI/RR IPMs have a pair of MCPs, the scrubbing is mostly affecting the second MCP which has much higher current draw.



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