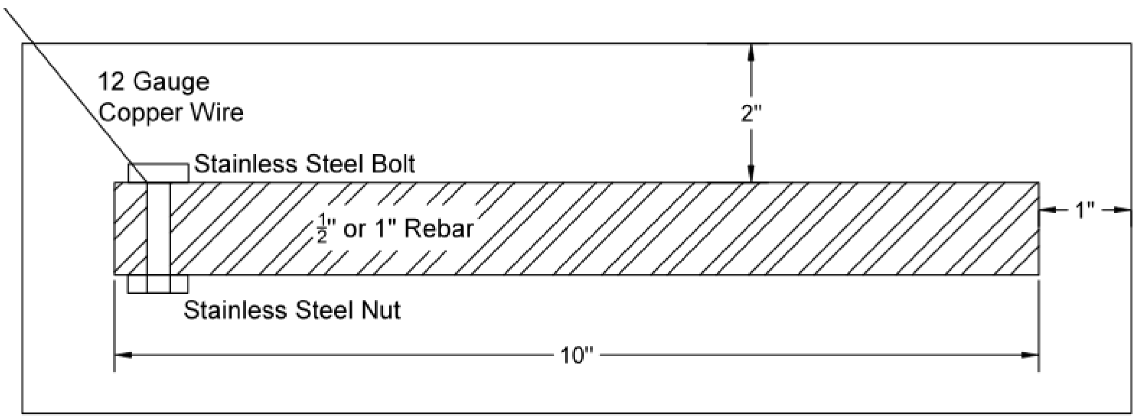
Fall 2013 Procedure for Muon Tomography of Reinforced Concrete for the Detection of Rebar Corrosion

In spring 2013, I meet with Dr. Swain and discussed the acceleration of corrosion by running an electric current through rebar. Dr. Swain's suggestion for this was to make standardized concrete blocks with a single piece of rebar running down the center. To accelerate the corrosion of embedded rebar, the concrete needs to be able to conduct a current. By pouring the concrete myself it would be possible to know the history of the concrete and, by adding salt to the concrete during pouring, it would take less time for the concrete to become saturated with dissolved chloride to conduct a current.

Dr. Swain's suggestion was to make a 12" long concrete block with 10" of rebar running through the center. He recommended a minimum of ~2" of concrete on each side of the rebar, with a minimum of 6 lbs of chloride per yard of concrete. Although I have been told concrete does not like chloride, using a basic concrete mix purchased at Home Depot, I was able to mix and cure samples with a concentration of salt equal to ~18 lbs of chloride per cubic yard of concrete.

Four test blocks were produced, two with ¾" rebar and two with ½" rebar, as well as two samples of ¾" rebar not in concrete. Later three upright cylindrical samples, two with 1" rebar, one solid concrete without rebar, were also produced. A ¼" hole was drilled in the end of each rebar sample, and a ¼" stainless steel bolt was inserted through the hole. 12 gauge copper wire was secured under the bolts head, and the entire connection was covered in marine epoxy to act as insulation. This was to ensure the applied electrical current would pass to the rebar and not pass straight from the stainless steel bolt to the concrete.



The blocks for the ½” rebar are 4”x4”x12” in size, while the ¾” rebar blocks are 4¼”x4¼”x12”. The upright cylinders are 3” diameter and 6” tall. One block of each size was set aside for testing of non-corroded concrete; The other blocks were placed in sea water to soak two days after being poured.

To apply an external current to accelerate the rebar corrosion and to the monitor potential differential a three electrode cell was set up. Seawater was used as the electrolyte and zinc was chosen as a reference electrode based upon Dr. Swain’s recommendation. Initially stainless steel plate was used as the cathode, with the connection to the copper wire being insulated again with marine epoxy.

Two 12” block samples (one 1” rebar, one ½” rebar), one upright cylinder sample, and one plain rebar sample (no concrete) were set up in a shared seawater bath. Each sample was given its own cathode and constant current power supply. Only a single reference electrode was used; it was connected to each circuit separately to measure the potential difference of the rebar. The objective was to achieve the highest possible current through the rebar while keeping the potential differential of the rebar low enough to avoid electrolysis and hydrogen gas production inside of the concrete samples. Too high of a current would also produce unrealistic corrosion, although it was found that 2" of concrete provides enough resistance that the current was not the limiting factor.

The zinc reference electrode and steel rebar had a potential of 200 mv without any current flowing. Dr. Swain's recommendation was to keep the potential differential to less than -400mv after the current was applied. Although each sample had a separate electric circuit, the applied current to one sample had some affect on the potential of the other samples; current applied to the raw rebar had the greatest affect on the other samples.

The operating currents and potentials were very small, barely registering on the power supplies' displays, making it impossible to obtain very accurate readings. After much fine tuning I found a happy balance with ~14 mA of current flowing to the samples and a potential difference between the zinc and the rebar of -600 to -700 mV depending upon the sample. After a week the recently poured upright cylinder was added to the solution and the applied potential was re-adjusted. All of the rebar samples now had a potential difference with the zinc of -700 mV. The measured current passing through each of the samples was:

¾" Raw Rebar	~60 mAmps
¾" Rebar Block	~20 mAmps
½" Rebar Block	~14.5 mAmps
¾" Upright	~40 mAmps

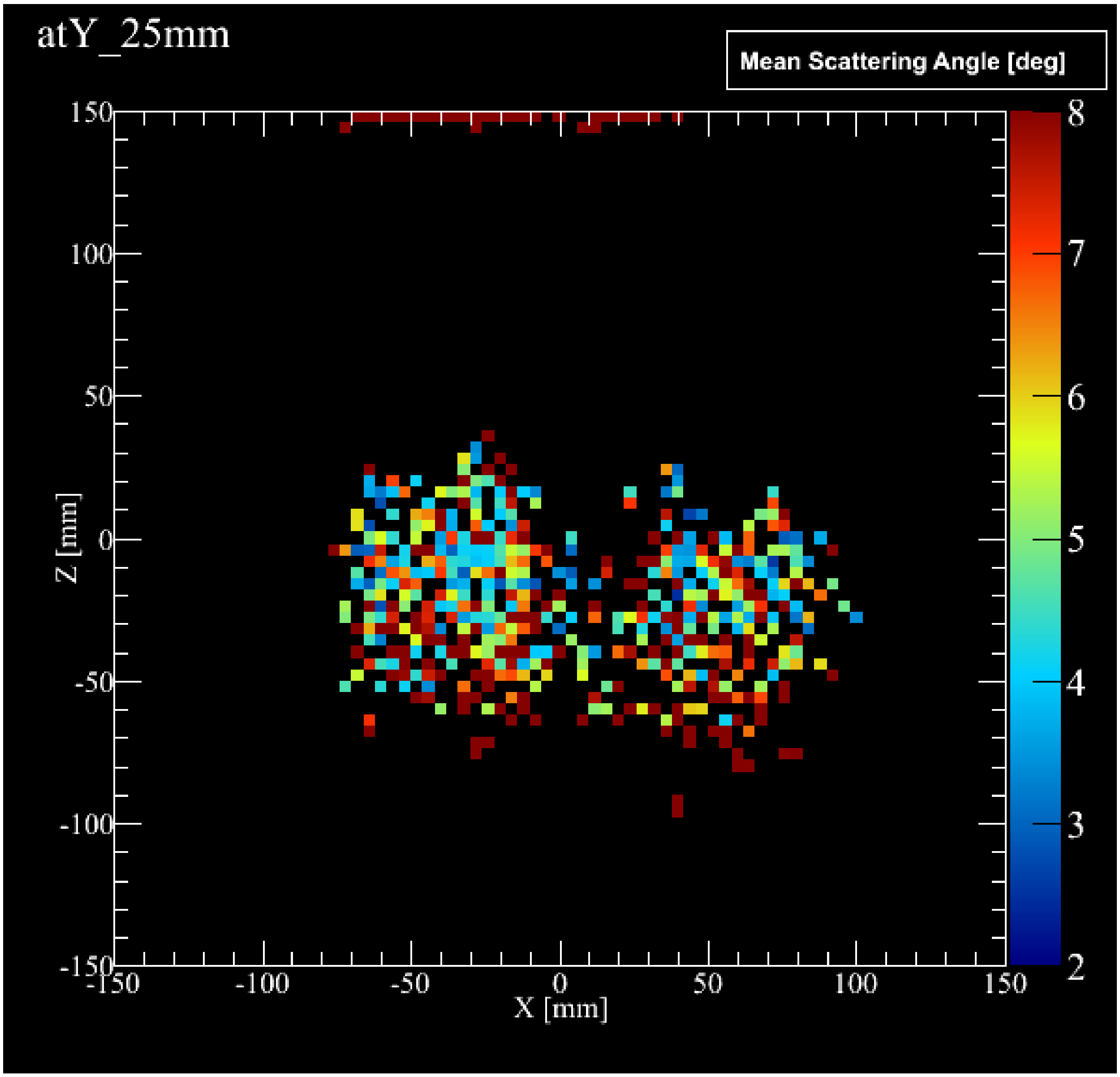
Here I found that the stainless steel cathodes were disintegrating. Multiple holes had appeared in the stainless steel plate and in two cases had even managed to erode all the way around the point of connection to the copper wire. I reconnected those plates that had become separated from the wires but did not take the time to insulate the connections with marine epoxy and permit it to dry. However the connections and cathodes continued to disintegrate at a rapid rate. Believing it possible that the connection points may be the weak points I replaced the stainless steel plate with stainless steel wire. The wire was a considerable improvement over the plates; it raised the connection to the copper wire above the water and it lay along the entire length of the block, hopefully permitting a more even corrosion of the rebar.

The wire continued to disintegrate, although at a slower rate than the copper connections had previously. After about a week the 1/16" steel wire had been reduced to little more than black sludge. Speaking with the chemistry department, I eventually reached the following conclusion. Although I had managed to avoid a reaction producing hydrogen within the concrete, I was producing hydrogen gas and hydroxide at the cathode. It was in very small quantities, the hydrogen produced would not be noticeable, but around the cathodes a very thin layer of a basic solution was formed and the hydroxide was eroding the stainless steel. The entire solution remained neutral however as the hydroxide eventually bonded with iron ions that had dissolved into solution from the raw rebar sample; the iron hydroxide then precipitated out of solution.

The solution to this was to agitate the water to inhibit the formation of a concentrated basic layer around the cathodes. To accomplish this I obtained an aquarium pump to mix the water. So far this seems to have been very helpful.

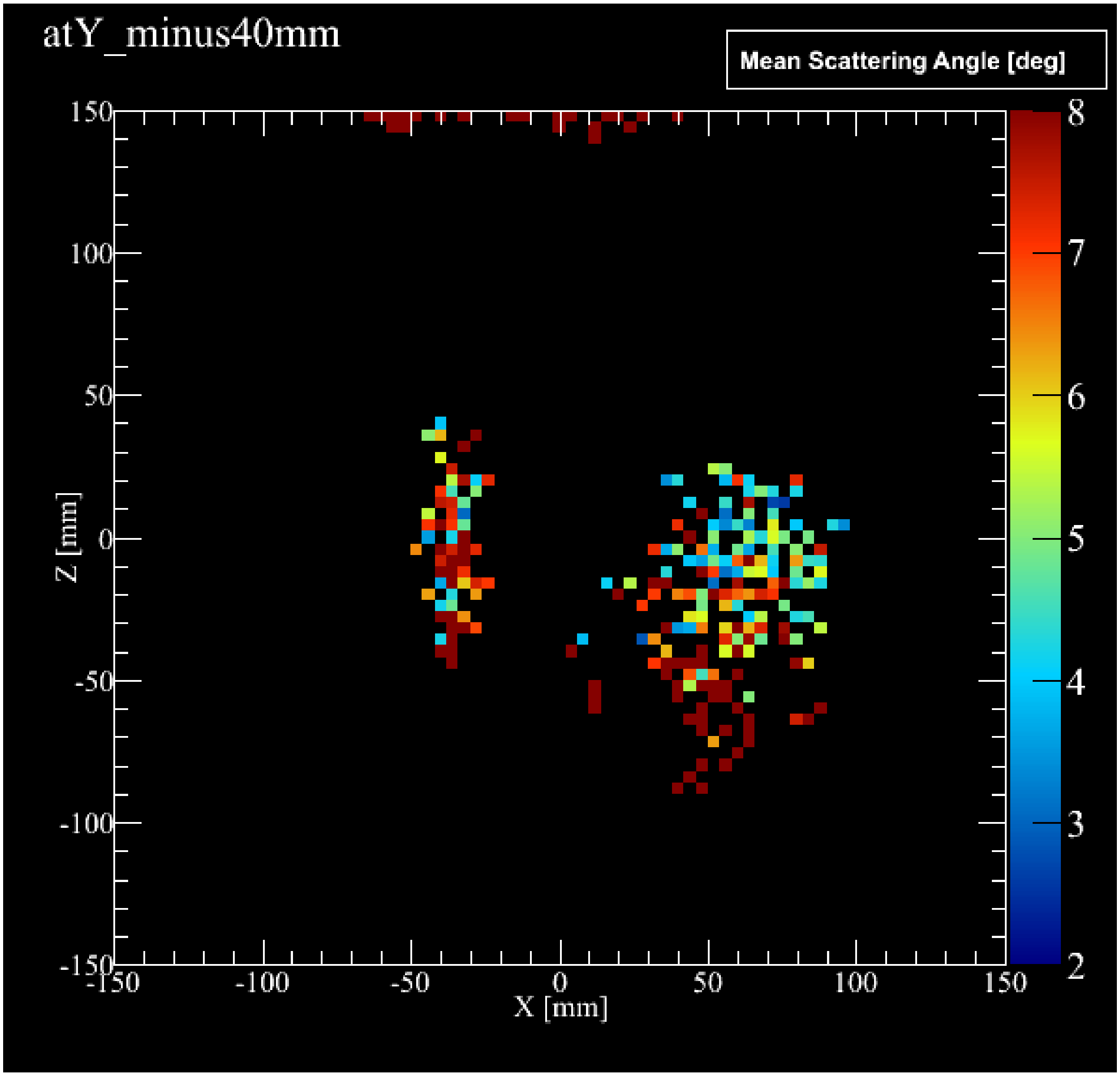
Because of the high iron content in the water it needs to be disposed of as hazardous waste. I am currently working on arranging this with Greg Pebbles.

This semester several upright cylinders were combined into a single scenario for the MTS. They included ¾” rebar in concrete, raw ¾” rebar, solid concrete without rebar, and a lightweight concrete mix without rebar. 10 million events were taken; the final data set included 1,071,889 reconstructed events. I would like to next develop a quantitative analysis of the scattering of the concrete and rebar and compare this to the concrete block with rebar from the scenario last semester.



Poca: 40 mm XZ slice @ Y = 25 mm; Muon Cut 14, NMC 0

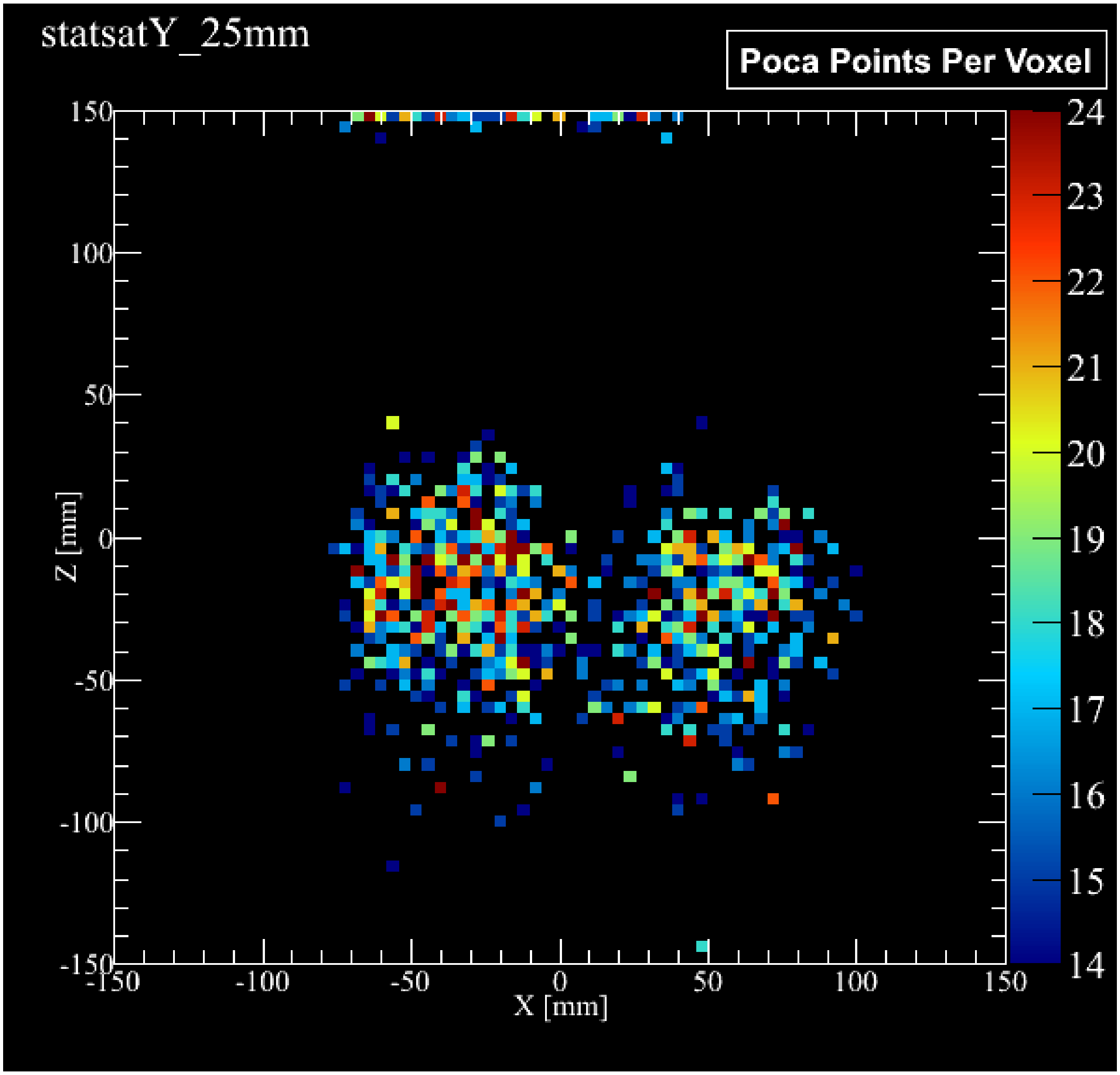
Left = Plain Concrete, Right = Lightweight Concrete



Poca: 40 mm XZ slice @ Y = -40 mm; Muon Cut 14, NMC 0

Left = Plain ¾" Rebar, Right = Concrete with ¾" Rebar

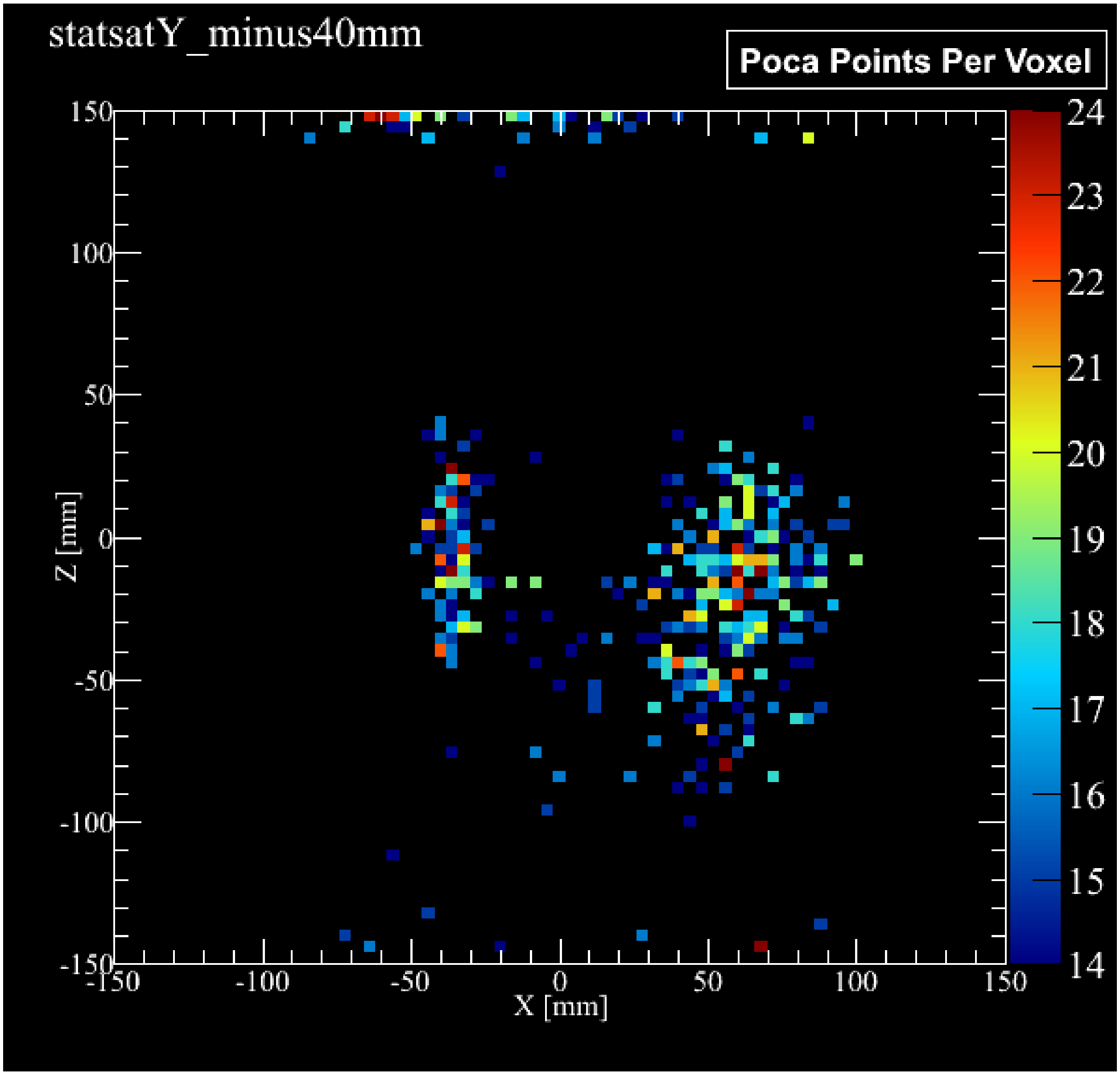
The lightweight concrete shows up a little sparser than the plain concrete however they are not terribly distinguishable from these plots. The plain rebar is clearly identifiable, however the rebar in the concrete next to it is not identifiable. However, the rebar within the concrete has a noticeable high deflection "tail" not seen in either the pain rebar or plain concrete. I would like to compare this with previous scenarios and see if there are any situations where anything similar has appeared.



Stats: 40 mm XZ slice @ Y = 25 mm; Muon Cut 14, NMC 0

Left = Plain Concrete, Right = Lightweight Concrete

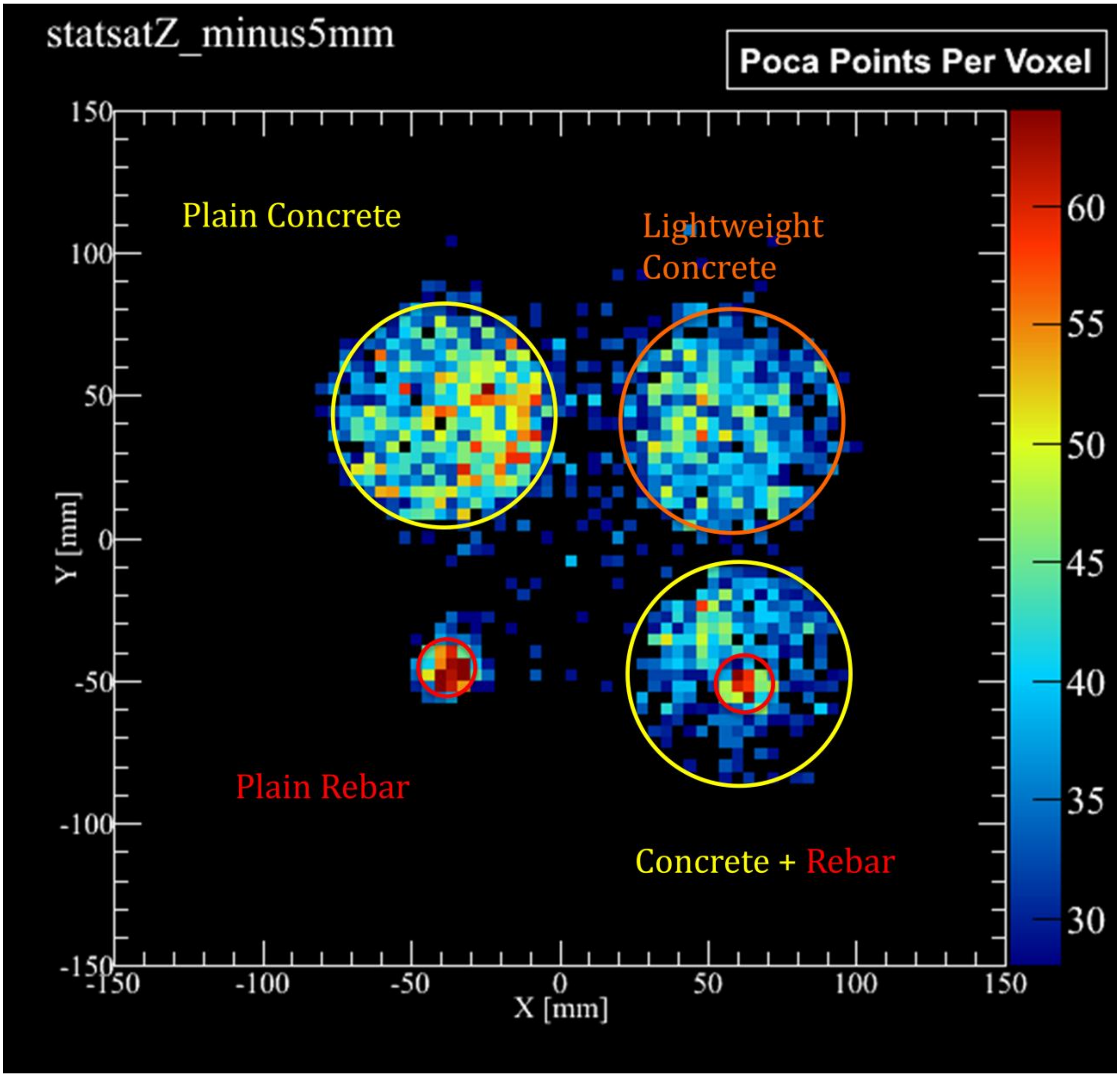
These plots are identical to the above, but are the stats plots instead of poca. Here there is a noticeable difference in the scattering density between the regular concrete and the lightweight concrete.



Stats: 40 mm XZ slice @ Y = -40 mm; Muon Cut 14, NMC 0

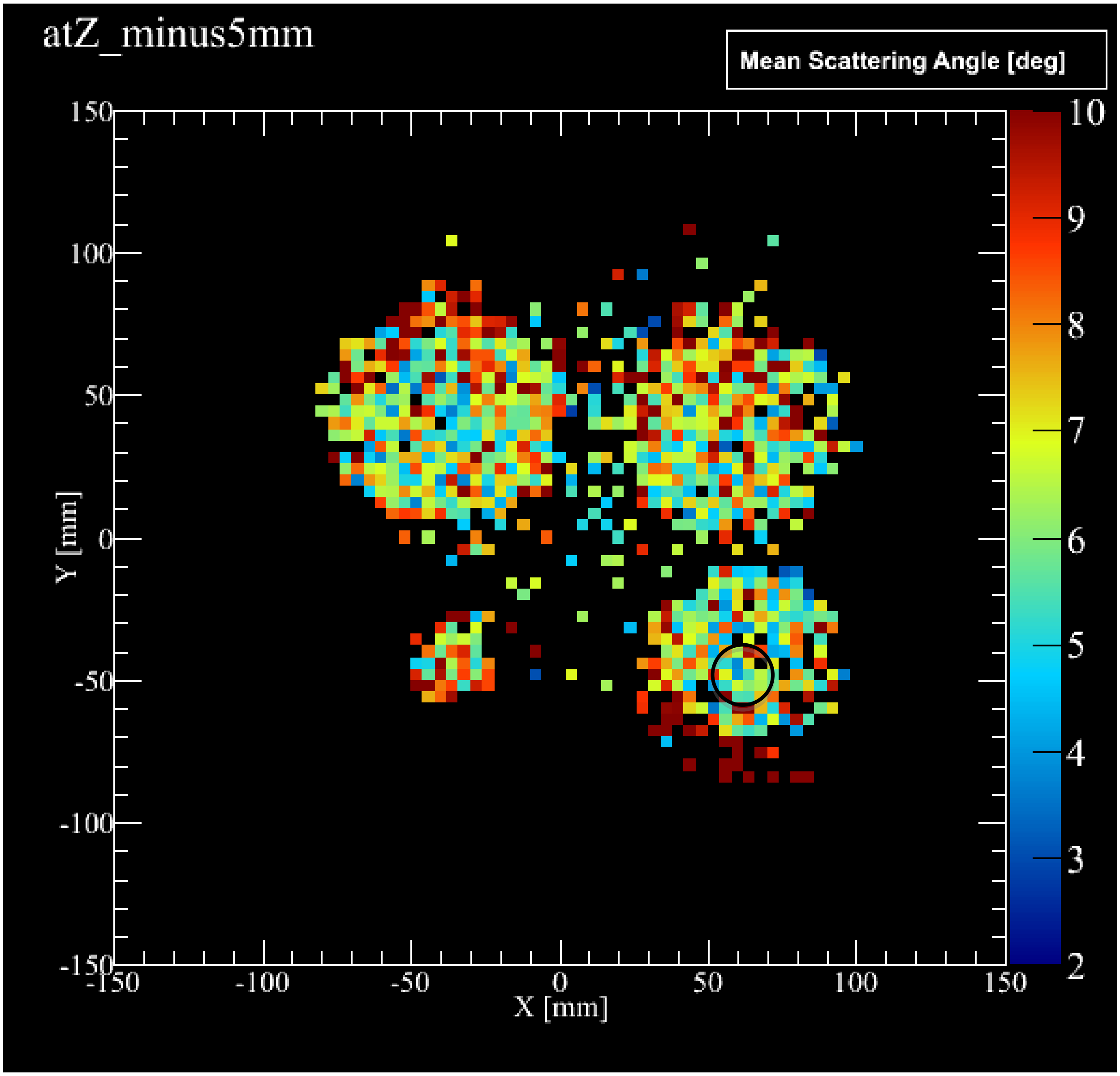
Left = Plain ¾" Rebar, Right = Concrete with ¾" Rebar

As before this is a stat plot identical to the earlier poca plot. This time the rebar in the concrete is discernable with a higher scattering density. The ghosting "tail" is still noticeable although it has a much lower scattering density than the rebar itself.



Stats: 120 mm XY slice @ Z = -5 mm; Muon Cut 28, NMC 0

This XY view is a 120 mm slice, the full height of the rebar. The Concrete + Rebar and the Plain Concrete use the same mix, however they show up with very different scattering densities. While we are aware that the MTS currently does have a bias, the difference between these samples seems greater than what was seen in the 1 cm lead scenarios. The rebar in the concrete is clearly visible here, however it appears smaller than the rebar outside the concrete (The circles represent actual measured sizes of the rebar and cylinders). This affect of the concrete may be exaggerated by the bias of the detector.



Poca: 120 mm XY slice @ Z = -5 mm; Muon Cut 28, NMC 0

This poca plot matches the above stats plot. The plain rebar has a higher deflection angle with very little blue, compared to the concrete samples. All three concrete samples appear very similar and there is no discernable higher scattering angle at the location of the rebar in the concrete sample (the black circle is the location of the rebar, based upon the stat plot).