Resolution and response of an SSBD exposed to high particle rates: Preparation

Independent Study Fall 2014
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1 Objective

Strange data was observed for several shots during data collection at the Mega Ampere Spherical Tokamak (MAST) throughout Summer 2013 (Figure 1). It is believed that these anomalies might be due to a saturation of particle rates exposed to the silicon surface barrier detectors used. In order to test this hypothesis, it is necessary to replicate the same experimental environment the detectors experienced and analyze their behavior. This is achieved by utilizing the tandem Van de Graaff accelerator located at Florida State University. There, the detectors will be exposed to hydrogen and helium isotope beams, of varying intensities, and the resulting energy spectra will be analyzed and compared to those observed at MAST.

The tasks for this independent study are broken into 2 semesters. Fall 2014 was dedicated towards preparing for data collection at FSU to be conducted January 6-9, 2015. Spring 2015 is dedicated towards analyzing the resulting energy spectra.

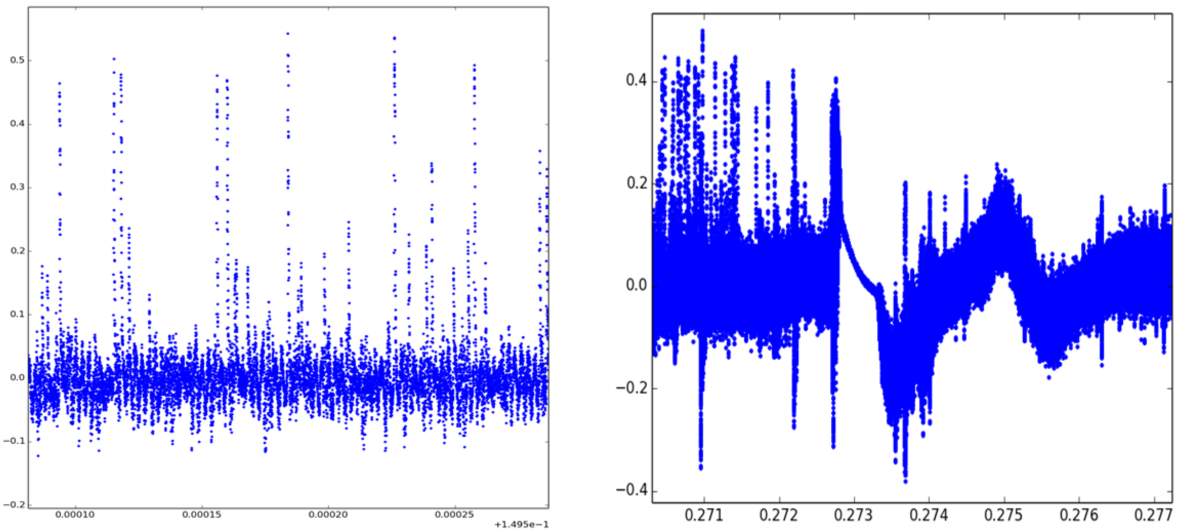
The following tasks were necessary to prepare for data collection in January, 2015:

- Create a code that incorporates Rutherford Scattering to determine the particle rates as a function of the target thickness and type of incoming particle beam
- Visit the accelerator facility to determine what mechanical, electrical, and software preparation is necessary for successful data collection
- Develop software in LabVIEW using pulse-height discrimination to histogram real-time spectra of signal amplitudes

2 Kinematics of the Experiment

While conducting the experiment, it will be necessary to vary the particle rate of the incoming beam; this is achieved by scattering the the beam off of a target. Since it is assumed that the energy and momentum of the of the incoming particles are conserved, it is acceptable to conduct a classical Rutherford Experiment. The Rutherford experiment makes the following assumptions:

- The nucleus of the target is treated as a point particle
- The nucleus is massive compared to the mass of the incident particle and therefore nuclear recoil is neglected



(a) Useful Data

(b) Strange Data

Figure 1: Comparison of useful and strange data collected at MAST Summer 2013

- Classical and electromagnetic forces are applied, no other forces are present
- elastic collisions occur

The experimental setup at FSU allows for a variety of parameters

- Beam intensity
- Type of beam
- Energy of incoming beam
- Target material
- Target thickness
- Area of collimator entrance
- Distance from target to detector

2.1 Equations Used

In order to calculate the particle rate the detectors will experience, it is necessary to find the initial particle rate, the number of target nuclei per unit area of the target, the cross section of the beam-target interaction, and the solid angle of the detector [1].

The solid angle of a small detector is defined as:

$$\Delta\Omega = \frac{A_{det}}{R^2} \tag{1}$$

- A_{det} → active area of the detector
- R → distance between the target and the detector

The incident particle rate of the beam ($\dot{N}_{incident}$) in units of s^{-1} is:

$$\dot{N}_{incident} = \frac{I}{e} \tag{2}$$

- I → incident beam current
- e → charge of an electron

The number of target nuclei per unit area (N_t) is found by the following:

$$N_t = \frac{\rho x \cdot N_A}{M_{Mol}} \tag{3}$$

- ρ → is the density of the target
- x → thickness of the target
- M_{mol} → the Atomic Mass of the target

Throughout this experiment, it is useful to refer to the Areal Density, units of mas per unit area (ρx), as the "thickness" of the target.

The cross section, σ, of the beam-target interaction is:

$$\sigma = \frac{(kzZe^2)^2}{4E_{inc}^2} \cdot \frac{1}{sin^2(\frac{\theta}{2})} \tag{4}$$

- k → Coulomb constant
- z → atomic number of beam
- Z → atomic number of target
- E_{inc} → incoming energy of particle beam
- θ → scattering angle

Finally, the particle rate observed ($\dot{N}_{obs}$) by the detectors is just the product of the terms found above.

$$\dot{N}_{obs} = \dot{N}_{incident} \times N_t \times \sigma \times \Delta\Omega \tag{5}$$

2.2 Values and Graphs

Our initial parameters are given in table 1.

A_det	4 mm^2
R	10 cm
I	0.5-1.5 μA
px	100 μ g/cm^2
Beam	Proton
Target	Carbon
Beam Energy	3 MeV

Table 1: Values of parameters used in initial calculations

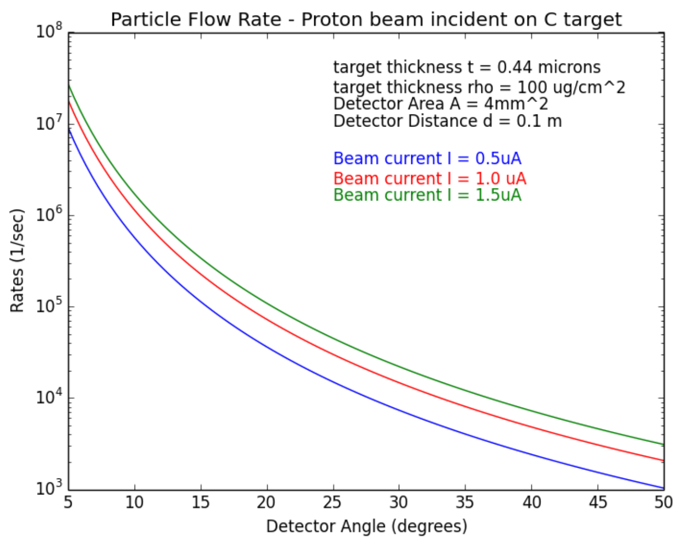


Figure 2: Particle flow rate of a Proton beam incident on a Carbon target

However, after the visit to the FSU facility in October, it was noted that several of the initial parameters were beyond the capabilities of the accelerator. Table 2 indicates the new range capabilities for each parameter. Alex Netepenko was tasked with determining the best values to be used for data collection in January. Figure 3 is an example of what the rates will look like using values within the recommended range.

A_det	4 mm^2
R	10 cm
I	10-100 nA
px	100 μ g/cm^2
Beam	Proton
Target	Gold
Beam Energy	4+ MeV

Table 2: Values of recommended parameters used in updated calculations

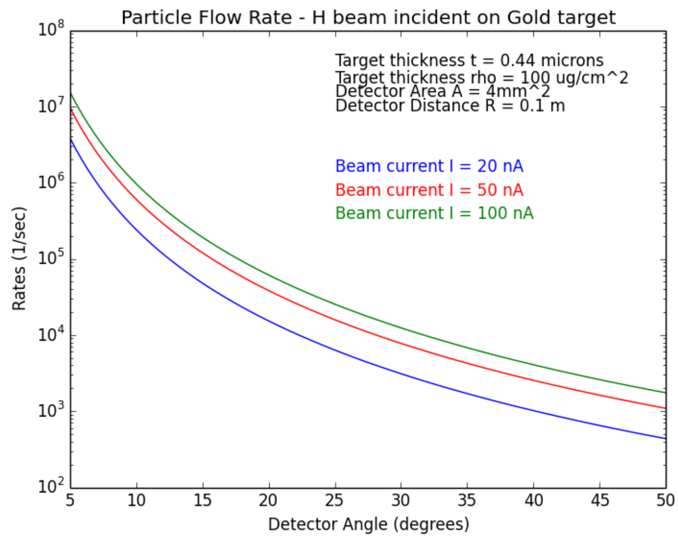


Figure 3: Particle flow rate of a Proton beam incident on a Gold target

3 Visiting the FSU facility

A trip to FSU was taken from October 12-15, 2014 to meet Dr. Ingo Wiedenhoever and determine what preparations were necessary for successful data collection and what ranges were possible for the parameters. As a result, several initial parameters were changed.

It was recommended and preferred that a 4-5 MeV proton and alpha beam is used instead of a 3 MeV proton beam. The beam intensity range is from 10 nA - 100 nA. A Gold target, instead of Carbon, at a thickness around $\frac{\mu}{cm^2}$ is recommended.

It should take one day to set-up for the experiment, two days to actually conduct the experiment and one day to dismantle the set-up. The dates of the experiment are set for **Januray 5-10,2015**.

FSU stated that they would provide any hardware needed. This includes a holder for the detector, the holder for the scattering target, and the scattering target itself. FSU could provide the electronics and cables as well, but in order to preserve as much of the original experiment, the cables and computer used at MAST will be used at FSU. For more details about the visit to FSU, see Appendix B.

The values left for FIU (Alex Netepenko) to determine were:

- Beam intensity
- Type of beam
- Energy of incoming beam
- Target material
- Target thickness
- Area of collimator entrance (detector active area)
- Distance from target to detector

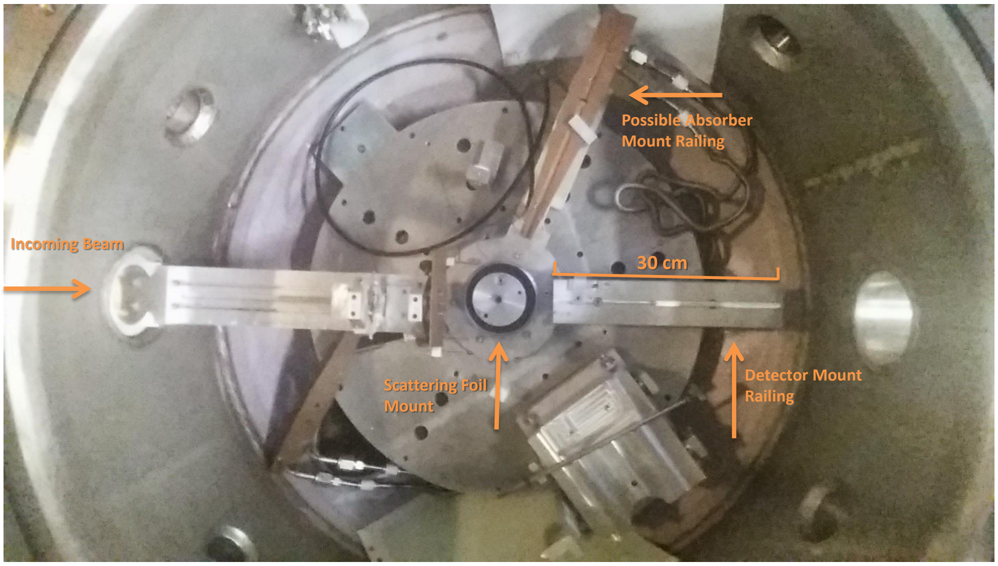


Figure 4: Diagram and image of the scattering chamber

4 LabVIEW Software - FIU Peak Detection Program

A peak detection program was developed using LabVIEW. The FIU Peak Detection Program enables users to view the waveform from the detector (the raw signal) and a histogram that bins the amplitudes of the peaks. Two .txt files are created from each run: the total incoming signal and the peak heights. A python code can be utilized to plot the total signal and histogram the peak heights.

Waveform from Scope The live, raw signal observed by the detector

Waveform Peak A live histogram of each signal peak from the total signal.

Peak Height per Loop Indicates the peak height of each signal live

Number of Loops Indicates the number loops the code has undergone

Total Samples per Loop Indicates the number of samples per loop (Indicator of Samples per Loop input)

Peak Width Input the number of samples per peak. This is determined by observing a single peak and counting the number of samples. The number of samples remains constant despite incoming function generator frequency. See Figure 5

Peak Threshold Determines the minimum voltage value to begin counting the Peak Width

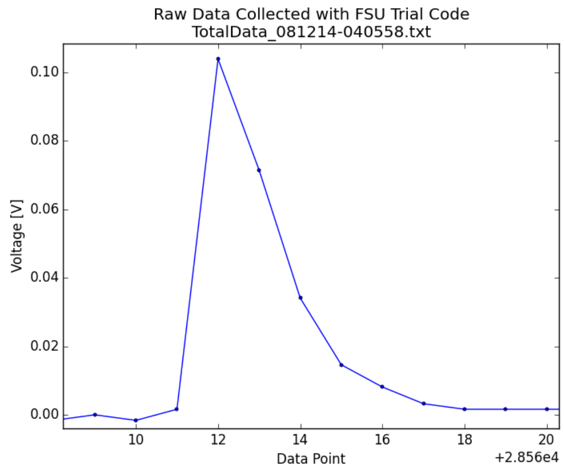


Figure 5: Image of a single peak detected with trial code showing the number of samples (3-4) found within the peak.

Timing

- Min. Sample Rate → Digitizer sampling rate
- Samples per Loop → The number of samples to observe per loop

Vertical and Channel

- Channel → The channel of the incoming signal
- Vertical Range → The maximum voltage height

Trigger

- Trigger Level → The voltage amplitude that starts the trigger
- Trigger Coupling → options of AC, DC
- Trigger Slope → Trigger is triggered by a positive or negative slope

File Destination

- Source/Destination File- Total → Destination of the .txt file created for the total signal
- Filename Total Data → Title of the total signal .txt file
- Source/Destination File -Wave Peaks → Destination of the .txt file created for the peak heights
- Filename Waveform Peak Function → Title of the peak height .txt file

The initial LabVIEW program successfully determined the peak heights of the incoming signal- incidentally, it only binned one maximum peak value per loop. The Waveform Peak Detection VI, however, successfully detects and bins peak heights from the total signal. Figure 7 shows a comparison of the histogram from the previous code to the current code. The software was fed a 10 kHz (top row) and 1 MHz (bottom row) generated square wave function. The leftmost column is a plot of the raw signal, the middle column is the previous code, and the rightmost column is the current code.

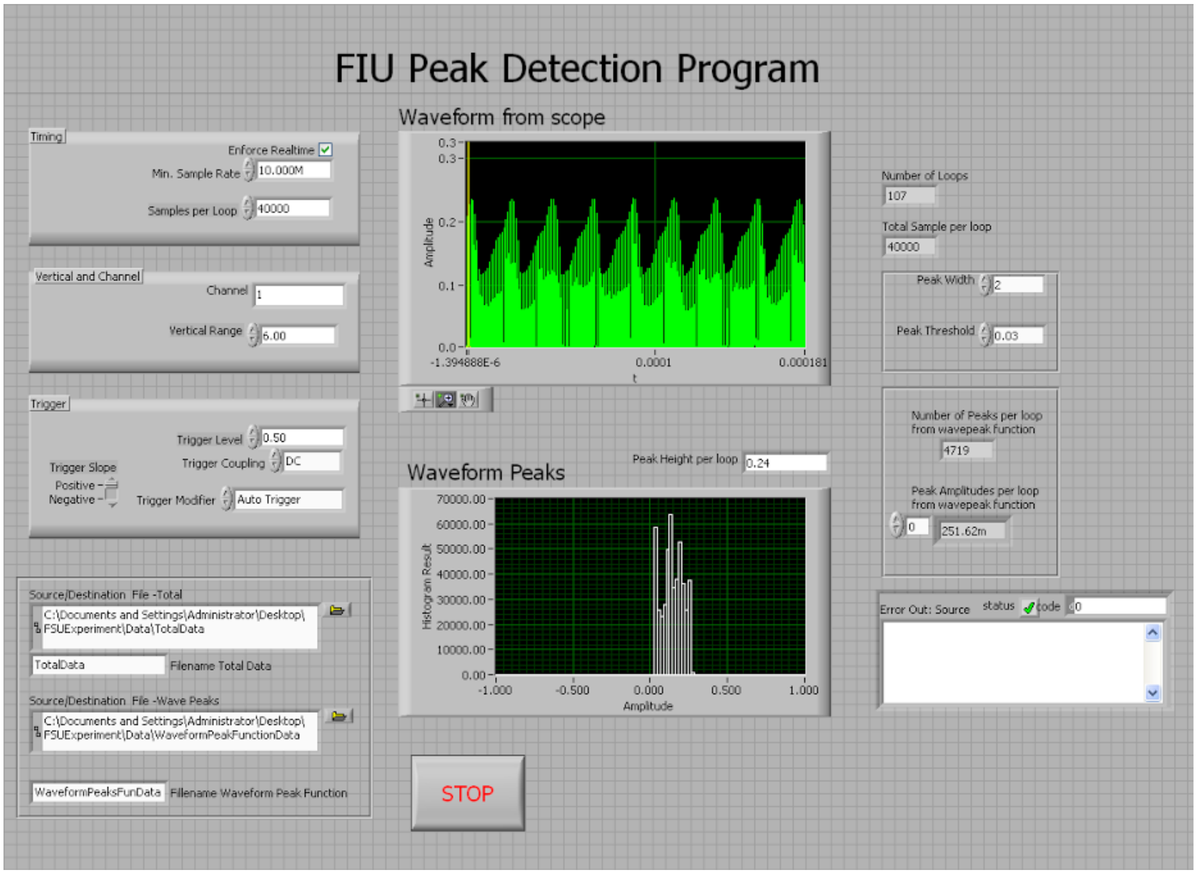


Figure 6: Image of the FIU Peak Detection Program Front Panel

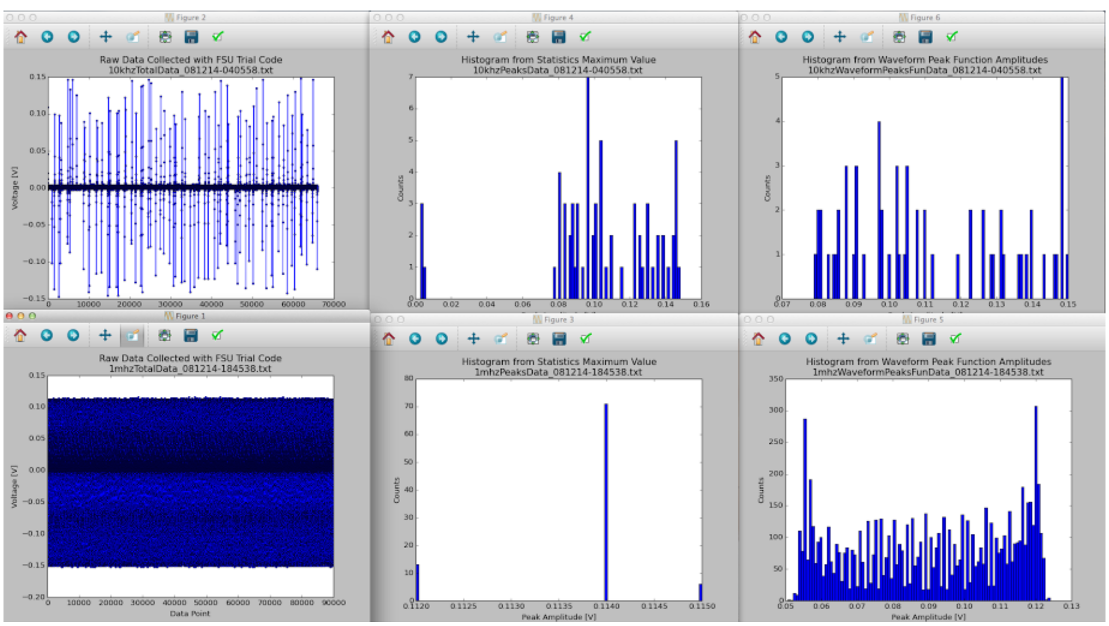


Figure 7: Histogram comparison of previous peak-detection code with current peak-detection code. Top Row collected at 10kHz, Bottom Row collected at 1 MHz.

References

[1] Boeglin,W. Modern Physics I Laboratory Rutherford Scattering
wanda.fiu.edu/teaching/courses/Modern_lab_manual/Rutherford.html

[2] Gilfoyle, G. An Introduction to Cross Sections.
https://facultystaff.richmond.edu/~ggilfoyl/research/CrossSectionIntro.pdf

A Appendix A: Kinematics Code

```
import numpy as np
import LT.box as B
import matplotlib.pyplot as plt

#constants and conversions
pi = np.pi
uA = 1.e-6                      #micro-amps
uG = 1.e-6                      #micro-grams
m2 = 1.e-6
cm2um = 1.e4                    #convert cm to micrometers
dtr = pi/180.                   #degrees to radians
m2tocm2 = 1e4                   #meters squared to cm squared
MeV = 1.6e-13                   #joules
Mmol = 12.                      #Atomic mass of target (Carbon 12) g
Z = 6.                          #Atomic Number of target (Carbon 12)
z = 2.                          #Atomic number of beam (proton particle)
Na = 6.02 * 10**(23)            #Avogadro's number
e = 1.602 * 10**(-19)           #charge of electron
epso = 8.8e-12                  #permittivity of free space
k = 1/(4*pi*epso)               #Coulomb's constant (j*m/C^2)
#k = 8.988*10**9                #Coulomb's constant (J*m/C^2)
#kMeV = k * 6.2415 * 10**12     #convert k from (J*m/C^2) to (MeV*m/C^2)
p = 2.267                       #g/cm^3 C12 density


 #### Para
I =  1.5 * uA                   #current (microAmps)
Einc = 3. * MeV                 #Incoming energy of particle beam
px = 100 * uG                   #target thickness in grams/cm^2
Adet = 4 * m2                   #Area of collimator entrance (m^2)
R = .1                          #distance from target to detector
t =(px/p) * cm2um               #target thickness in microns
print t, 'microns'

#array of scattering angles converted from degrees to radians
angles = np.linspace(5.,50.,100) * dtr

#Calculates SolidAngle of the detector
SolidAngle = Adet /R**2
Ni = I/e                           #Calculates initial particle rate
Nt = px/Mmol * Na                  #Initial particle beam area (molecule/cm^2)


############ use the following inputs for the functions below ###########
# Einc = Kinetic energy of the particle from the beam (MeV)
```

```
# theta = angle of scattered particle (degrees)
# Adet = Area of the detector (in mm )
# R = distance between the target and the detector
# px = Areal density of target (in micrograms/cm^2)




ratearray =[]
sigarray = []

#function dcs calculates the cross section (in m^2)
def dcs(Einc,theta):
    sig = ((k*z*Z*e**2)**2)/((4*Einc)**2 * pow(np.sin(theta/2.),4))
    return sig

diffsig = dcs(Einc, angles) * m2tocm2     #inputs calculate cross section in cm^2


Rate = Ni * Nt * diffsig * SolidAngle      #calculates event rate of scattered
  particles into detector
```

B Appendix B: Summary of FSU Visit

B.1 Mechanical Design (Detector Holder)

- The dimensions of the scattering chamber
  - The distance from the
- What kind of vacuum does the chamber use? How long does it take for the chamber to reach the appropriate vacuum pressure? **"Quickly". They did not specify an exact time.**
- Is there a restriction on materials we can use for the detector holder to be mounted in the chamber(because of outgassing concerns)?
  They will provide a holder for our detector. A follow up email regarding an updated status on the holder needs to be sent
- Do we need to bake the assembled instrument/ detector? If so, at what temperature and for how long? What are the dimensions of the oven?
  Nope
- How are detectors typically mounted inside of the vacuum chamber?
  A holder is inserted into a hole that is on a rotatable railing.
- Will we need to design a cooling mechanism for our detectors? Have other experiments done so?

- Are there remote capabilities inside of the vacuum chamber that would allow us to move the detector? If so, what kind of mechanism is it? In what direction does it move the detector?
  Yes, there are remote capabilities to move the detector. The detector can rotate in both the positive and negative from the vertical(see diagram) The location is given through a digital output that is "very precise"
- Does the facility need to approve our detector holder design?
  It's their detector holder.

B.2 Scattering Foil Questions

- What thickness of Carbon-12 foil are available for use inside of the scattering chamber?
  It was recommended that we use Gold for our scattering foil. They have 10-1000 $\frac{\mu g}{cm^2}$. Around 100 $\frac{\mu g}{cm^2}$ is a good range
- Where are the foils and their backings (if they have them) mounted inside of the chamber?
  See Figure 1. for location. They will provide the foil and mount
- What are the dimensions of the foil/ backing?
  The collimator opening is can be 1-2 mm wide.
- What are the dimensions for the distance from the foil/ backing to the edge of the chamber? In relation to where the detectors are mounted?
  See Figure 1.
- How are the foils installed? Who installs them?
  It is mounted to a collimator, then Iagy Baby installs it
- How is the foil angle changed? How can it be checked for accuracy?
- Is there a remote capability for changing the foil angle? (other questions regarding specifics for remotely capability if it exists)
  No remote capabilities for foil angle change

B.3 Electrical Design Questions

- What electrical feed throughs will be existing at the time of data collection, if we cannot use them do they have new feed throughs we can install?
  BNC-BNC
- Can we ground our signal cable outside of the vacuum chamber at the preamplifier electronics?
  Yes
- Do they need us to bring the NIM-BIN, or do they have CAMAC crates?
  They have CAMAC crates but it is recommended that we bring our own
- Do we bring our own cabling (power cables, signal cables, bias cables, etc.)?
  They have cabling, but it is recommended that we bring our own
- Are there power outlets near the scattering chamber for our electronics? (We need one for: com- puter, ADNACO box, and NIM-BIN bin)
  Plenty of power outlets

- Is there space near the scattering chamber to store our electronics? Would we put it on a table or on a computer rack?
  There is space and they have a rack
- If there is no space, where is there space? What is distance of that space from the scattering chamber? Would we need longer signal cables and power cables?
  There is space. The distance from the chamber to the control room (through a hole in the wall) is approx 10 m
- How close can we get the preamplier to the scattering chamber? What is the length of the cable we would need from the scattering chamber output to the preamplier input?
  The pre-amplifier can be placed within or 5 ft or as far as wanted from the scattering chamber.

B.4 Beam Questions

- How does the beam operate? Who operates the beam?
  Iagy Baby operates the beam. We tell them the intensity and type of beam we want and they prepare the rest. There are 2 chambers of sources that they can get the beam from. It takes about an hour to switch from the source
- How long does it take to create a 3MeV proton beam?
  3 MeV proton beam is smaller than they prefer. They recommended and preferred that we do a 4-5 MeV proton and alpha beam. Boeglin was okay with that change. It takes about 2 hours to prep the beam and 1 hour to switch. The beam intensity range is from 1 μA to 1 nA
- Is the beam pulsed? How long does each pulse last? What is the range for the pulse length?
  The beam can be pulsed but it is more practical to have a continuous beam. They can have the beam on for any time we'd like, from 1/4 sec to days
- What is the frequency range we can use for the beam pulse?
  We decided on using a continuous beam
- How practical is it to change the beam current? the pulse frequency? the pulse length?
  It is comparatively impractical to change the beam current, pulse frequency and pulse length. It more practical that we use a continuous beam

B.5 Logistic Questions

- Which target room will we be using for the experiment?
  Target room 1.
- Are we allowed in the target room during the experiment?
  We can go in the room between shots, but not during. During the shot will be in the control room right next to the target room
- If we are not allowed in the target room during the experiment:
  - Will we have remote access to our computer (wi or ethernet/ network cable)?
    We can get remote access to the computer but it is not practical

  - If we will not have remote access to our computer will we we able to move our computer to a room where we do have access and connect the computer to the ADNACO box in the target room using a bre optic cable? If so, what is the length of bre optic cable we would need?
    the computer room can and should be in the control room. Therefore, they said a 10 meter BNC cable should be sufficient. I would overshoot that to be safe

- Does any type of training need to be completed (online or in person) before the experiment? If so, who specifically needs to take what training?
  No

- Are there any formal or informal mechanical or electrical design reviews to prepare, or machine drawings or cable schedule diagrams that need to be submitted for approval? If so, what are the time frames? Who is on the review committees?
  No

- Is there paperwork we need to ll out, or data access agreements that need to be signed regarding collecting and using any data resulting from the facility experiments? If so, does a formal written collaboration agreement need to be in place? Who needs to sign these agreements?
  No

- With whom do we schedule our dates for data collection?
  Wiedenhover