UCN Detector and Simultaneous Spin Analysis Update

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TUCAN Collaboration Meeting
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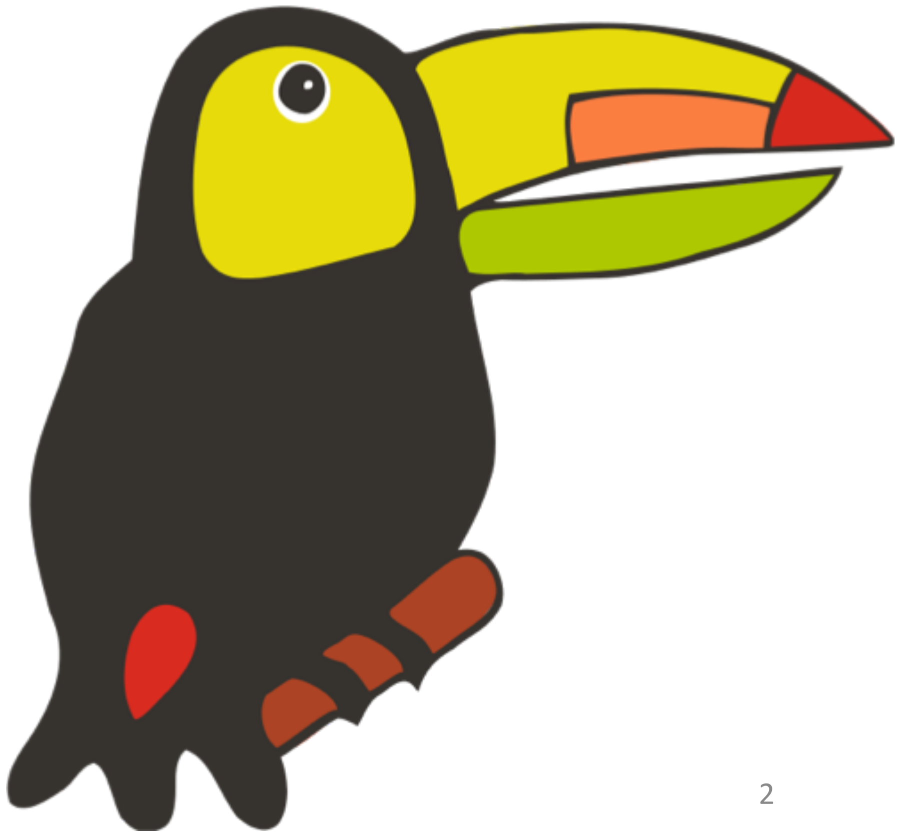
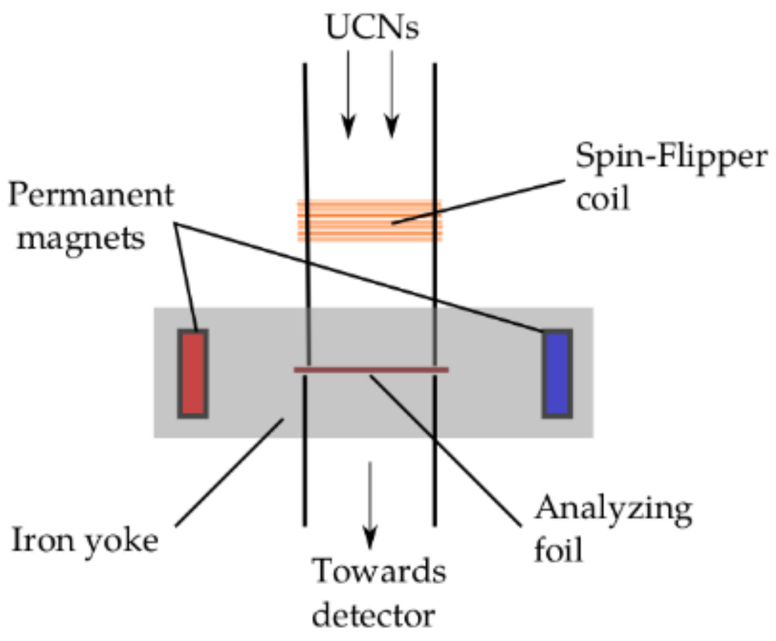
Outline

- Review why use simultaneous spin analysis (SSA) method:
  - Slides stolen from T. Lefort
- Requirements for the SSA
- Current design
- Detector updates for the fall



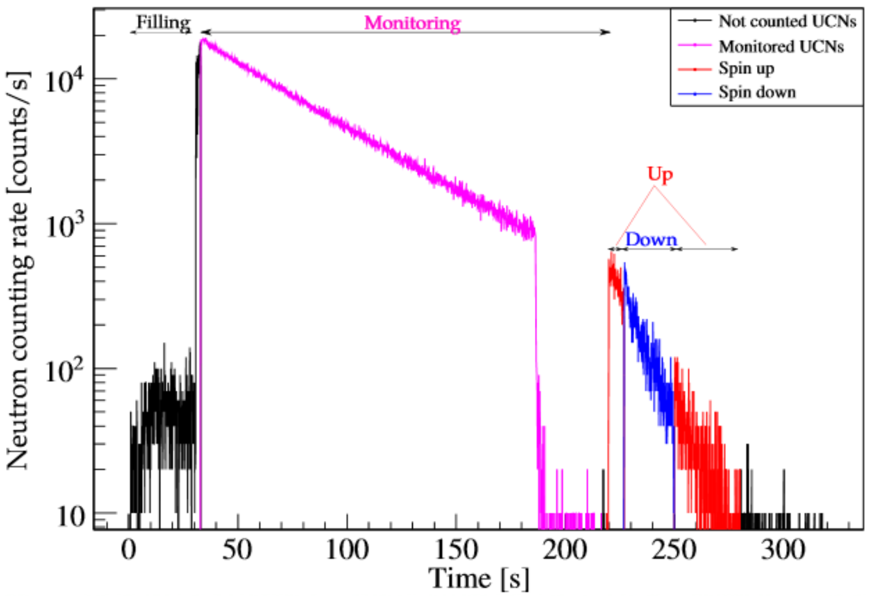


Spin analysis performed by transmission:

- Magnetised iron layer: $V = V_F(Fe) \pm \mu.B_{foil}$
- spin down component able to cross, spin up reflected

ASF use to flip the spin up component

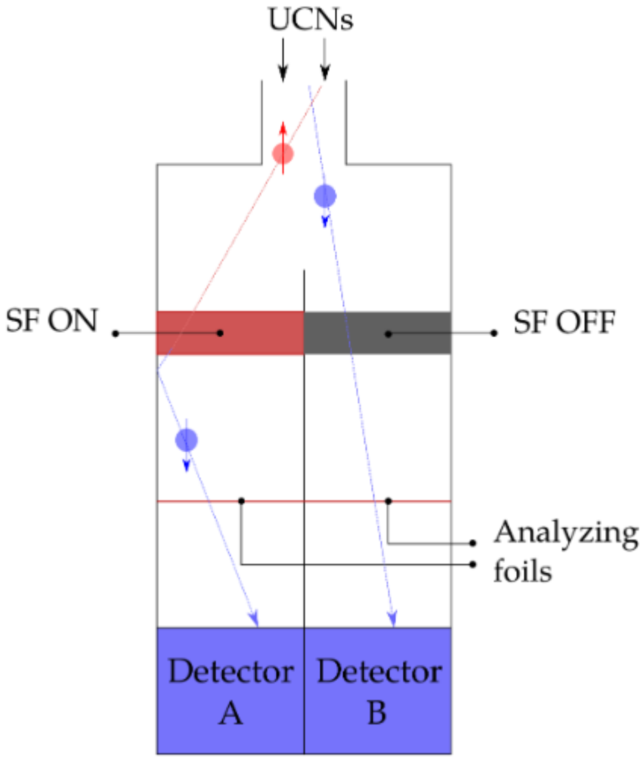
Spin analysis is sequential: one spin is counted while the other one is stored above the foil



Main drawbacks

UCN losses and depolarisations during storage above the foil

The simultaneous spin analyser: principle*



SCOPE

Analyse both spin states at the same time in order to reduce the **UCN losses and depolarisations**

MEANS

Double the sequential analyser system $\longrightarrow$ two arms
Each arm analyse one spin component

RESULTS

Storage time is reduced: N and α are increased

$$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$

Room for improvements:
- UCN reflections on the magnetised foil
- slits in the switch

[* I.S. Altarev et al, PLB 102 (1981) p 13]

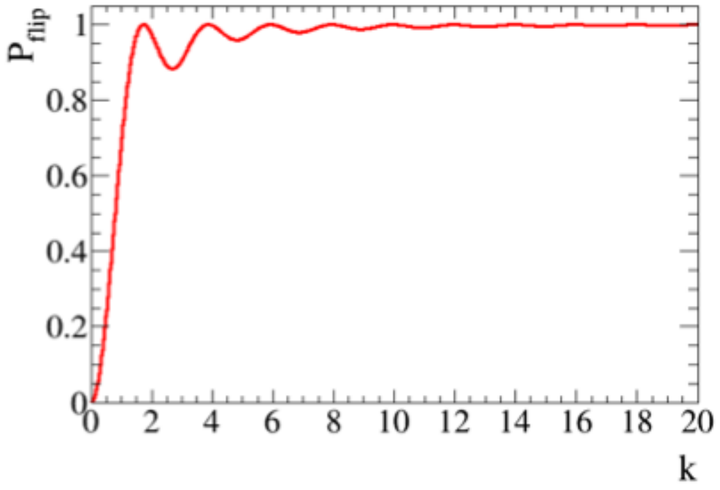
Simultaneous Spin Analyzer Requirements

Based on CAEN system's achieved values…. What really are the requirements? Needs to be studies with simulation.

- Goal is to simultaneously measure both spin states of the neutrons
  - If neutron of wrong spin state goes into one arm, it can bounce back to the other arm and still get detected
- Want to detect as many UCN as possible
  - Transmission >80%
  - Want small asymmetry between arms <0.5%
- Need stable detection efficiency
  - Needs study, worst case is relative stability at 0.05% level over an hour (based on 10^8 n/hour)
- Want to count each spin state correctly
  - Adiabatic spin flipping efficiency >95%
  - Analyzer efficiency >90%
- High fringe visibility and detected UCN
  - Should be >18% better on sensitivity in $\sigma(d_n)$ than sequential measurement
- UCN guide side needs vacuum few x 10^{-6} Torr

Test spin flipper, and analyzer foils this fall?

Adiabaticity condition



- Adiabaticity parameter, k:

$$k = \frac{\gamma_n B_1^2}{v_n \, dB_0/dz} \gg 1$$

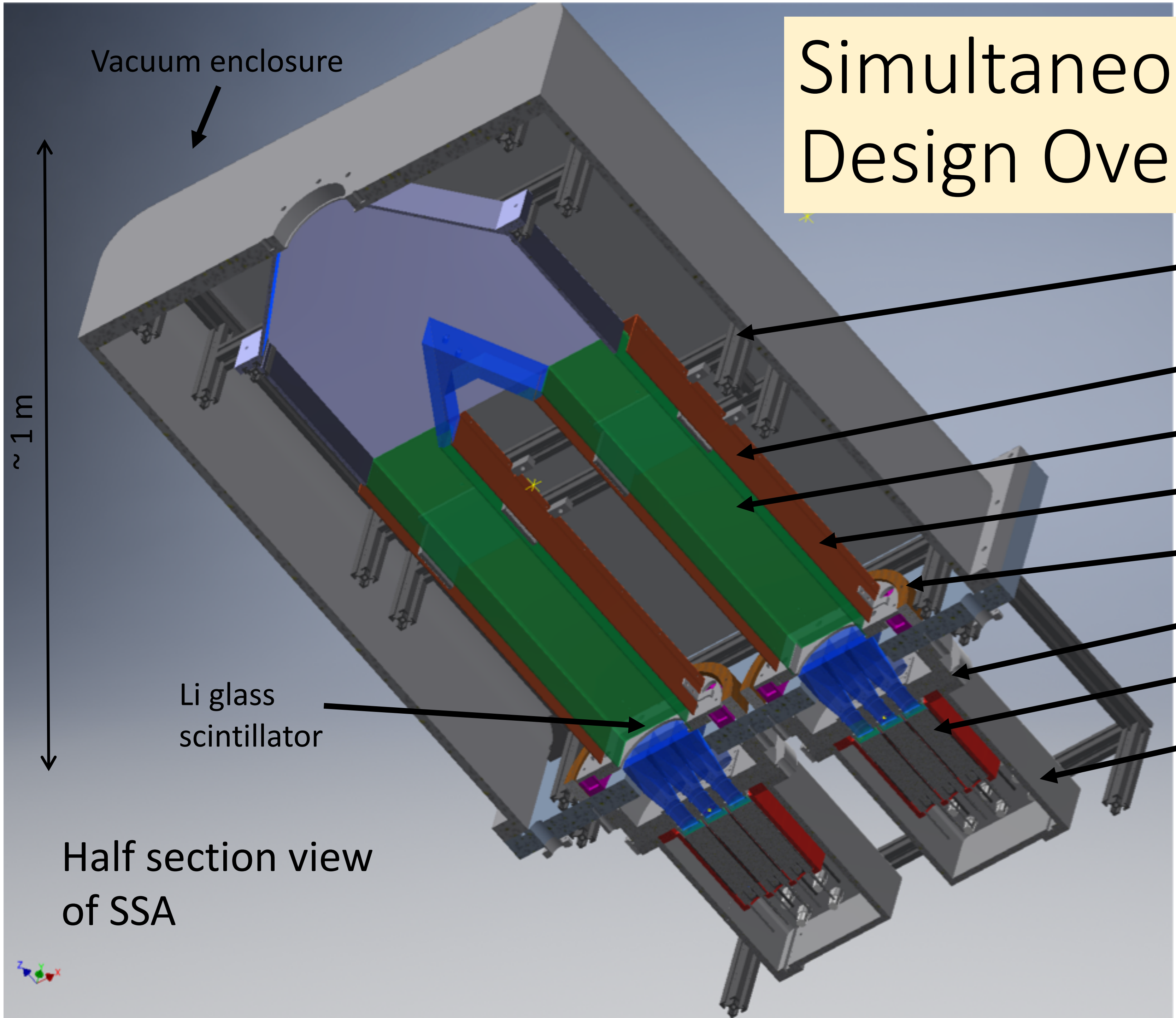
- For RF field following ~ sine function get an spin flip probability:

$$P_{flip} = 1 - \frac{\sin^2\left(\pi\sqrt{1+k^2}/2\right)}{1+k^2}$$

NIM Phys. Res. A 384(23) (1997) 451.

- eg. RCNP ASF
  - B_0 = 2 mT (in z direction), dB_0/dz = 0.01 T/m, B_1 = 0.1 mT (in x direction)
  - k = 1.83x10^8 rad/(s.T) x (10^{-4} T)^2 / (10 m/s x 0.01 T/m) = 18.3

Simultaneous Spin Analyzer Design Overview



Misumi frame

RF Spin flipping coil

Coated square glass tube for guide

Copper RF magnetic shield

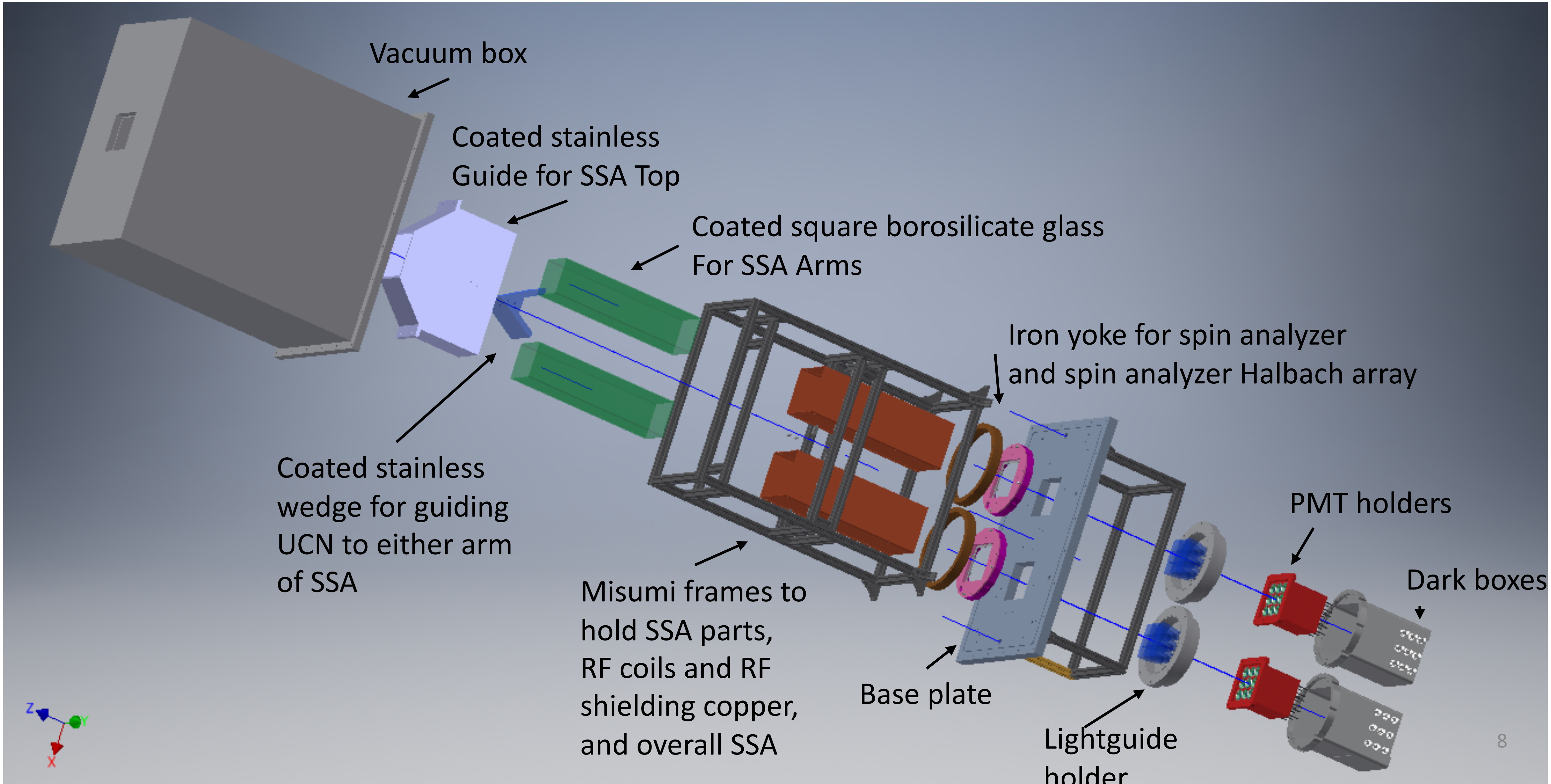
Halbach array and iron spin analyzer foil

Light guide holder

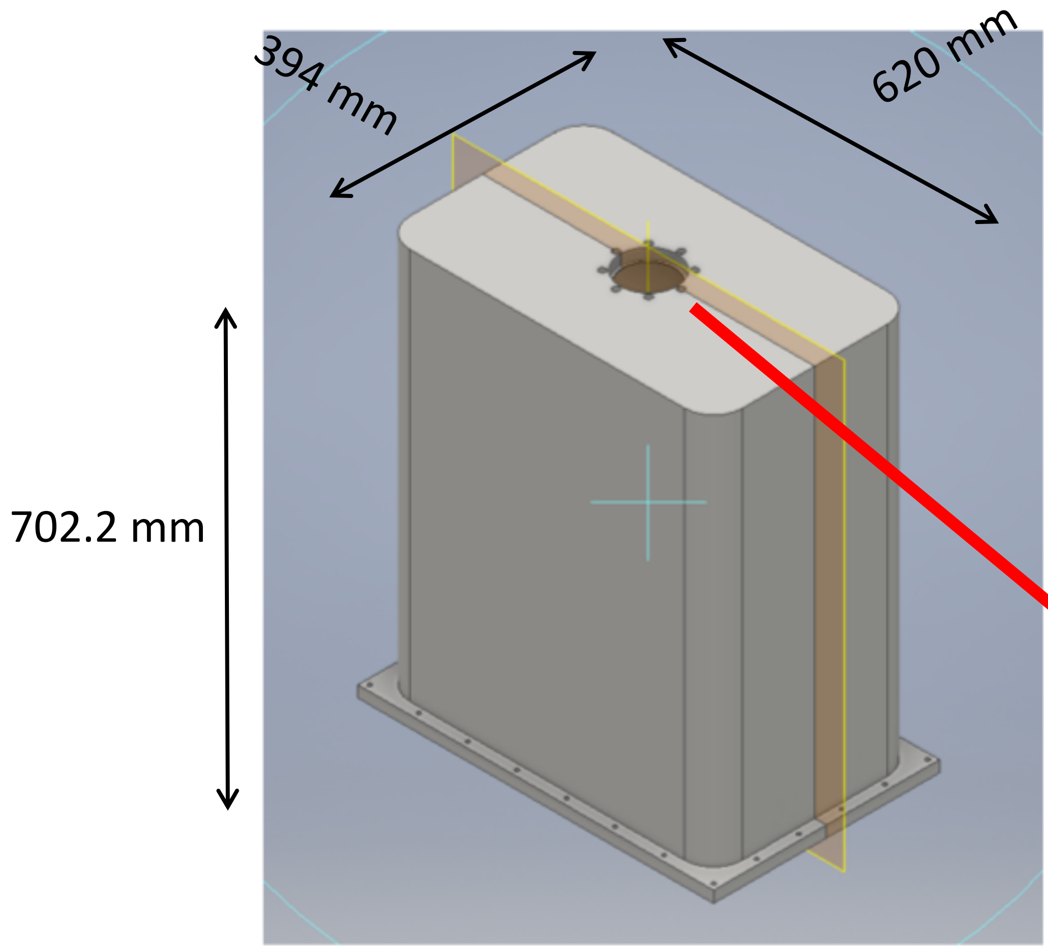
PMTs, gels, and support structure

PMT Dark box

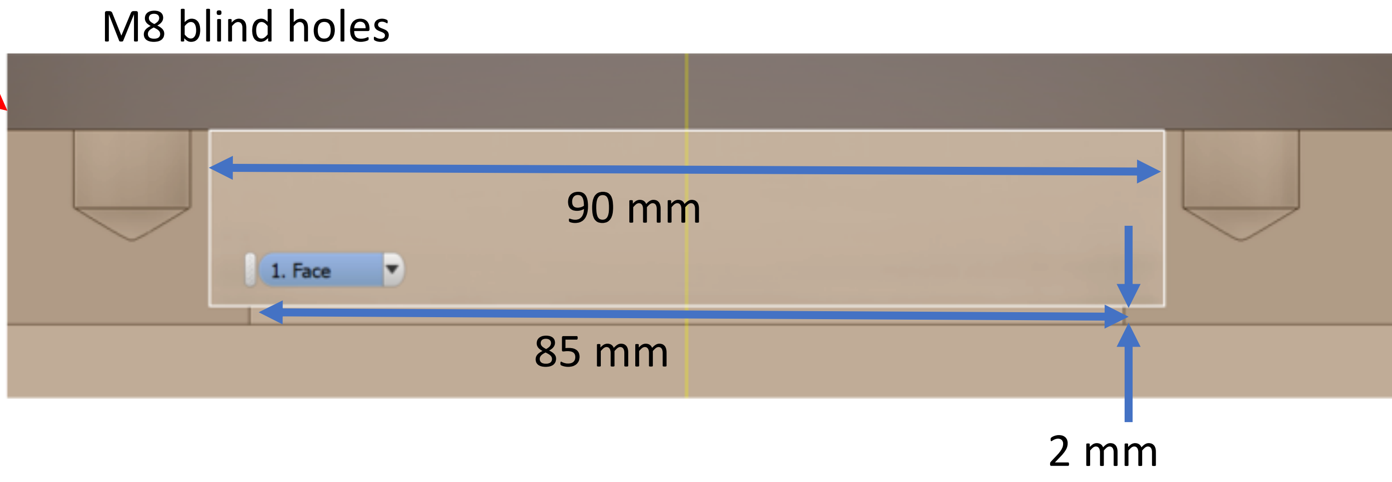
Exploded view of updated overall assembly



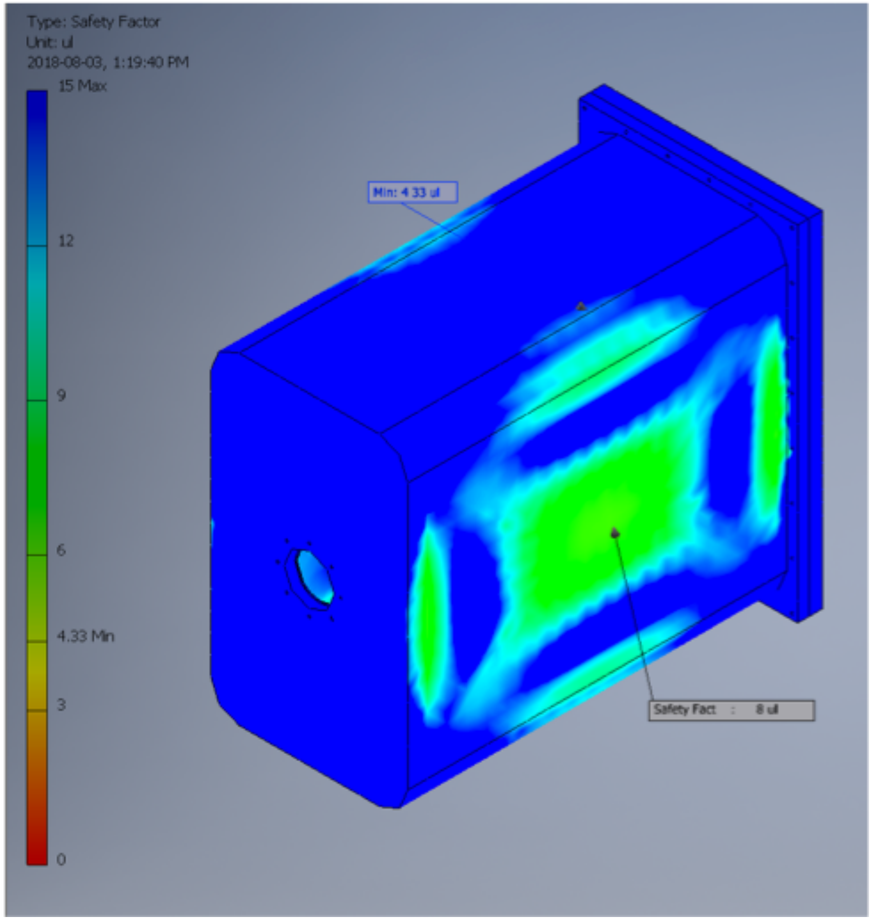
Vacuum box… is fairly large

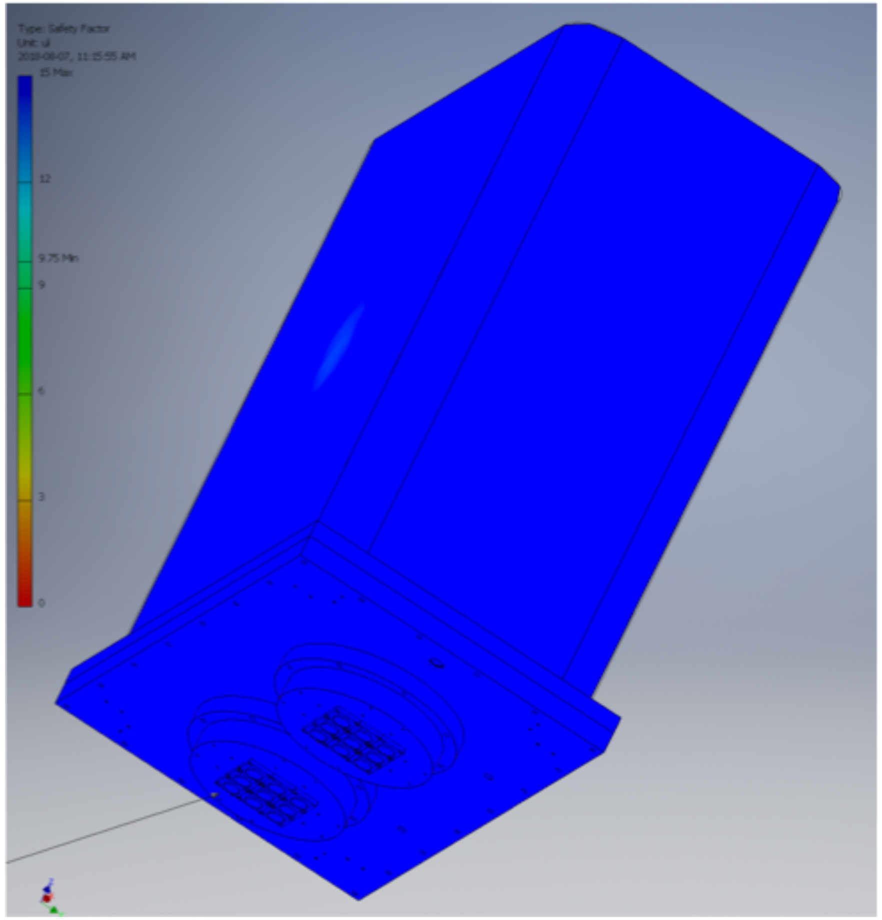


- Assume it is built of two pieces welded together aluminium 6061 – fairly thick wall
- Currently drawn with 90 mm guide connection, with insert of 85 mm wide



Tuned thickness of walls using stress analysis

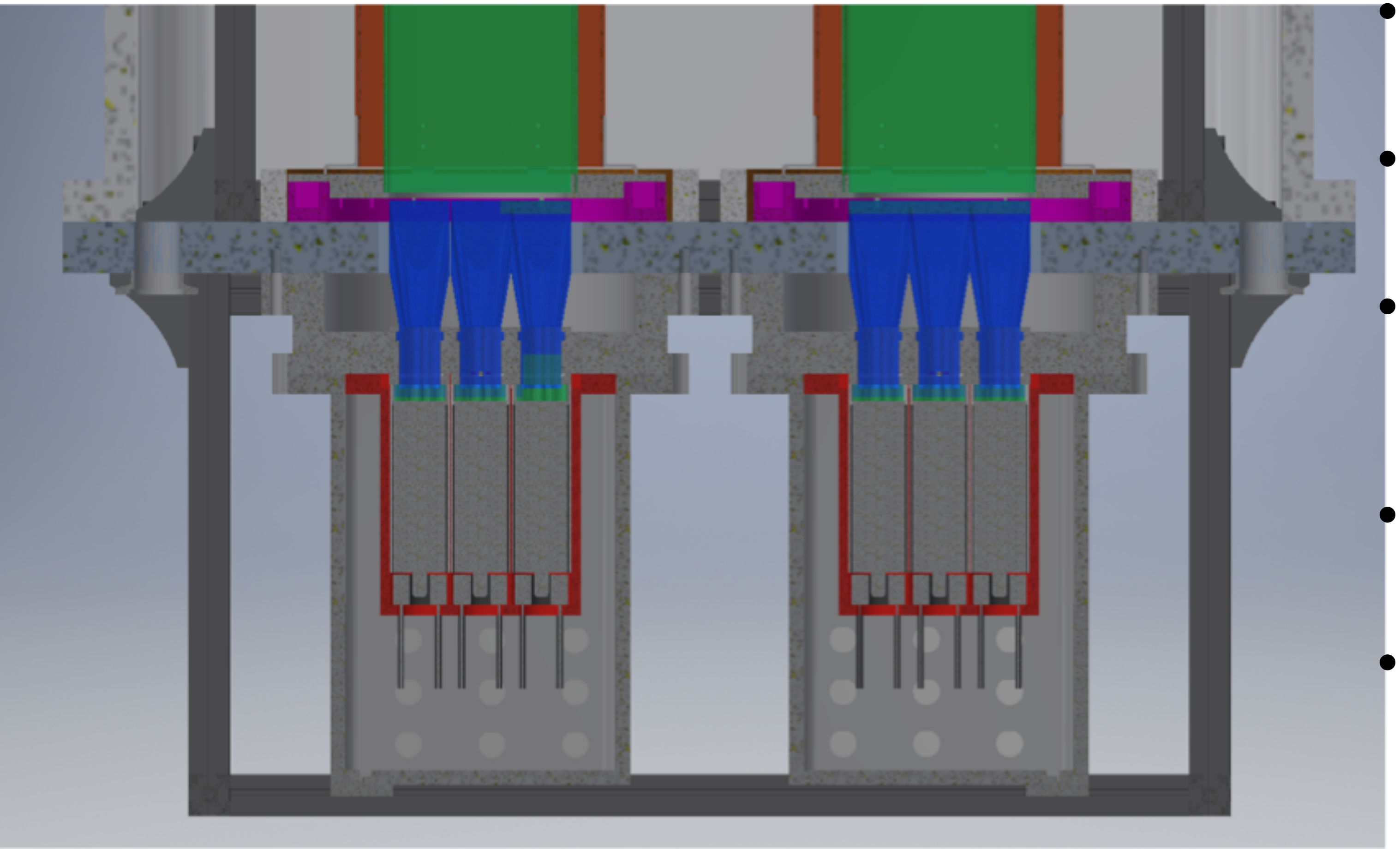




Before thickening walls (~8 mm), min. safety Factor was 4.33 x

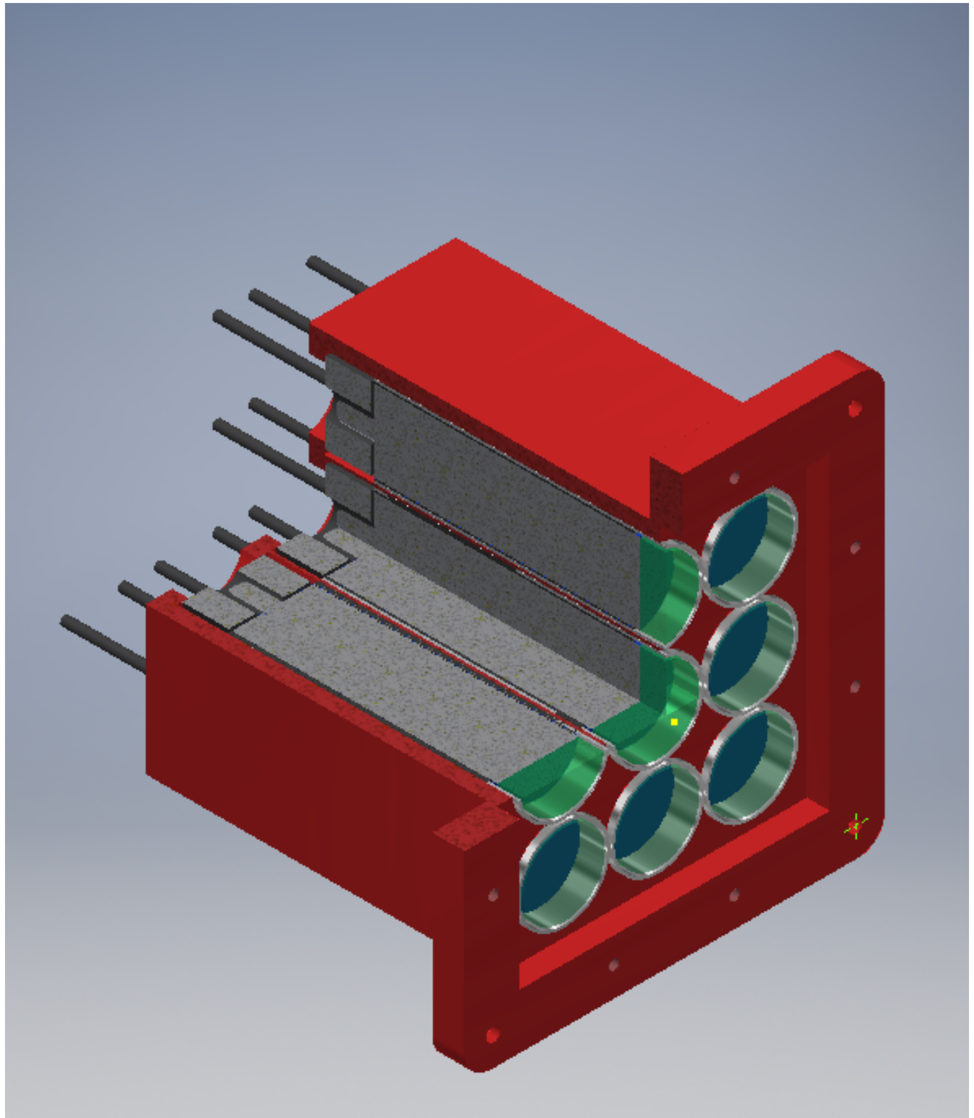
After thickening walls to 15 mm, min. safety Factor is ~ 10 x. Fairly heavy: weighs 63 kg.

Frame for bottom of SSA



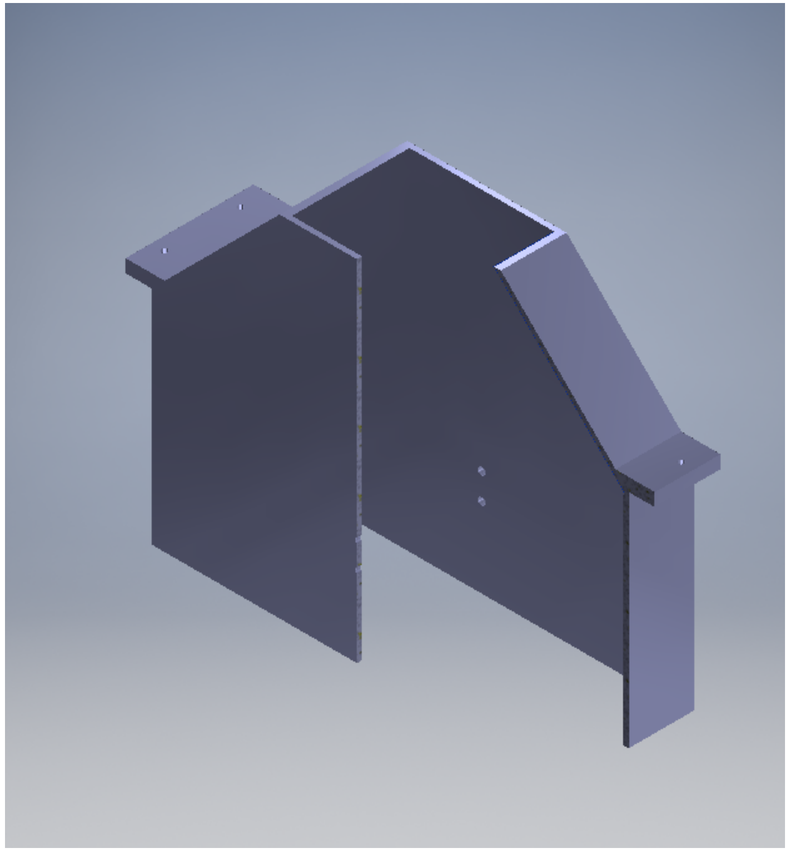
- Frame at bottom of SSA allows it to sit on ground
- Could add second frame around this one to allow adjusting height
- Added two pumping port holes in base plate (or one pump on gauge), to have KF25 flange welded
- Two additional holes in baseplate for RF coil current feedthroughs
- Plan to add feedthroughs for field compensation coils

UCN Detector PMT Support Structure Detail



- PMT is HZC XP3102
  - About 1/3 cost of Hamamatsu square one
  - 25 mm diameter
  - 90 uA/lm at 400 nm
  - +1100 V gives ~10^6 gain
- Iron box + mu metal cylinder to bring magnetic field below earth field value
- 3D printed part inside for holding array
- Wacker silicon gel for PMT to light-guide coupling
  - Less messy than optical grease

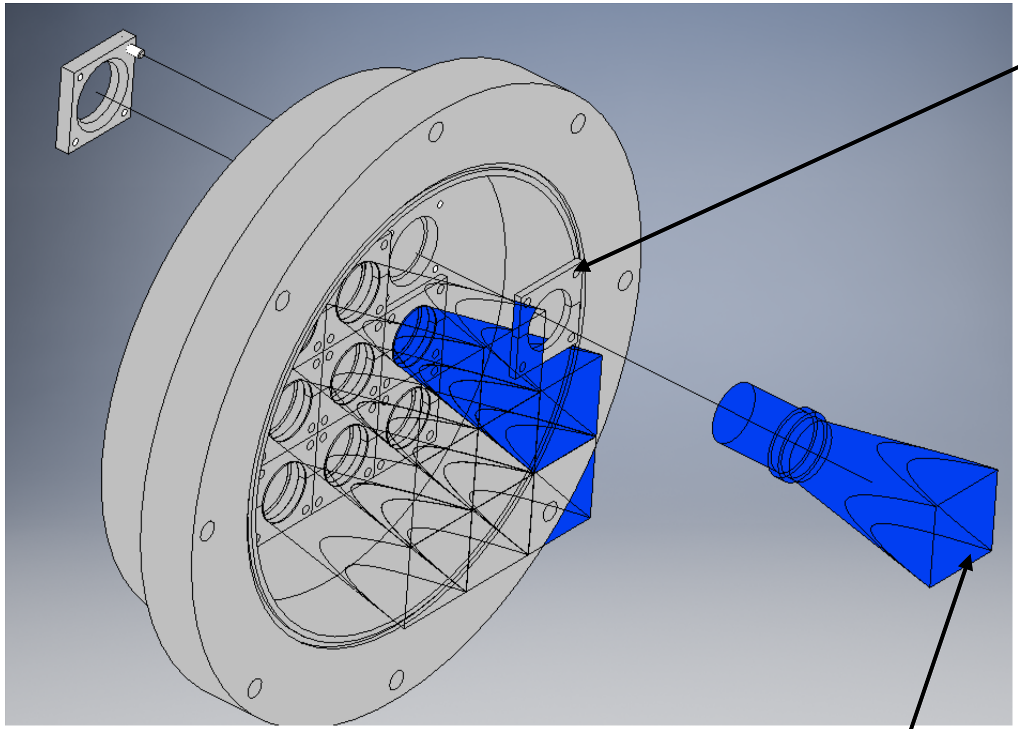
SSA Roof



¾ section view

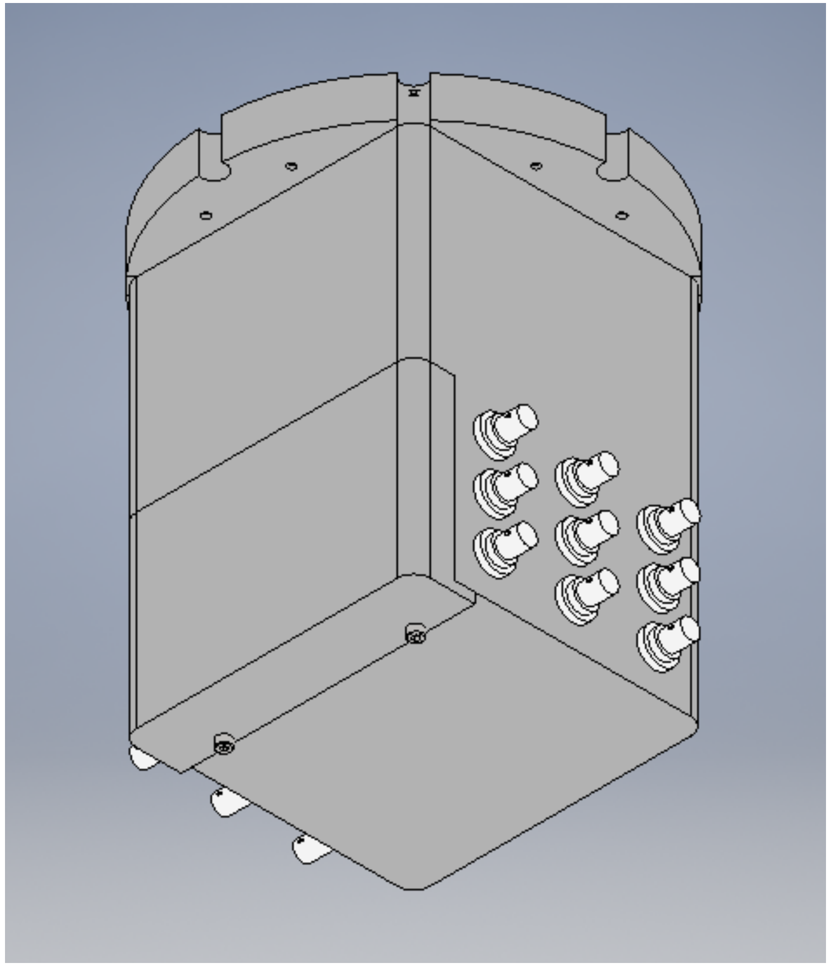
- Angle of roof and wedge still to be optimized by simulation studies
- Build out of aluminium and have inside coated
- Outermost dimensions are 268 x 354 x 98 mm
- Maybe possible to have made from single piece?

Lightguide holder /couple to vacuum



- Provides vacuum to air interface
- Lightguide has ridge on vacuum side to position it and fix it in place with screw on brackets
- Brackets on outside press down o-ring onto lightguide and holder

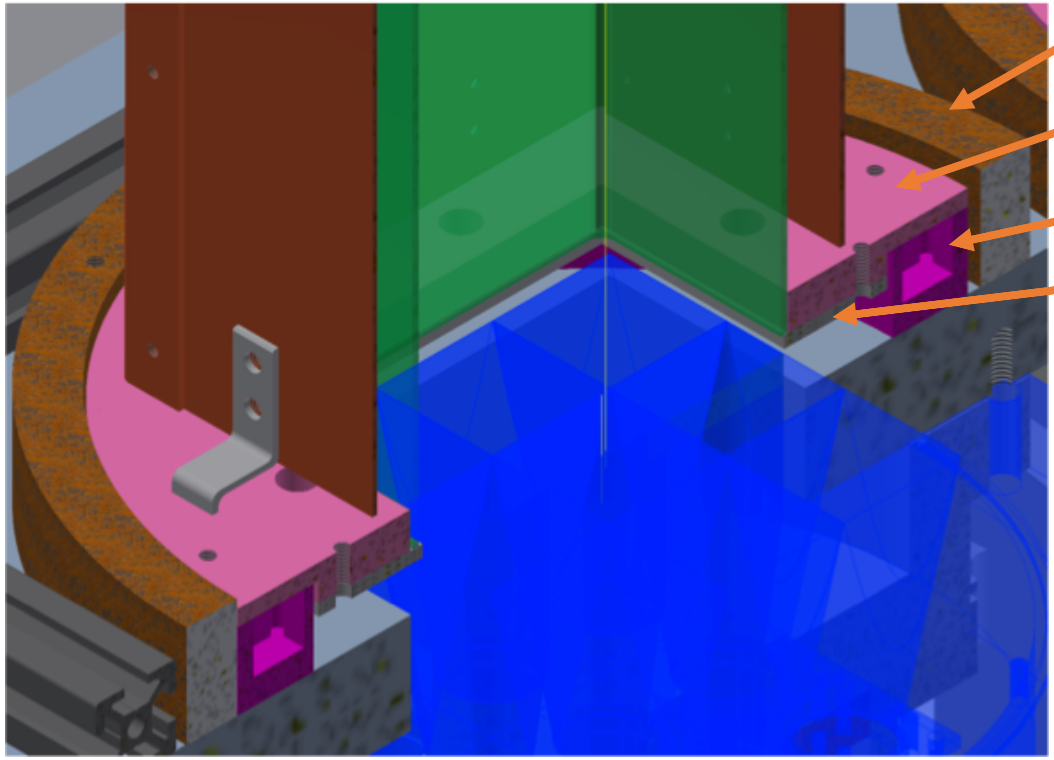
Dark box cover



- BNC and SHV feedthroughs
- Cover for access to connect PMTs to feedthroughs
- Some complex details due to tight space constraints
- Looking into 3D printing these components

Halbach array for analyzer foil magnetization

Half section view

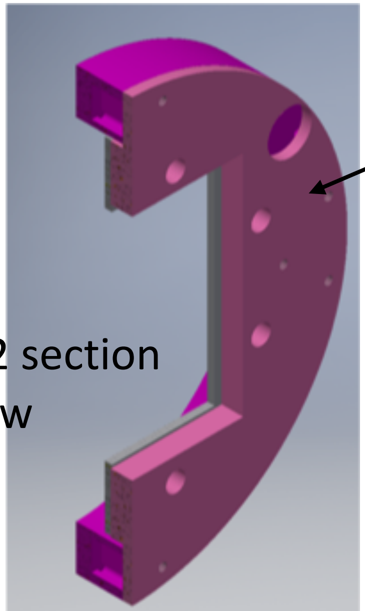


Iron yoke for magnetic field return and isolation between two foils

Halbach array magnet holder lid (Aluminum)

Holder for ½” cube Nd magnets (Aluminum)

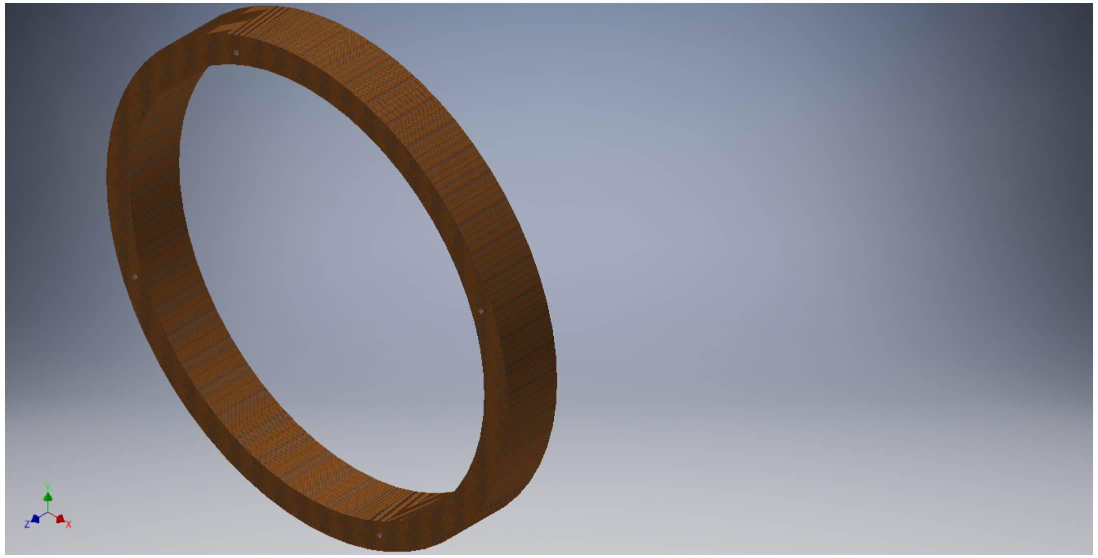
Iron foil holder (Aluminum)

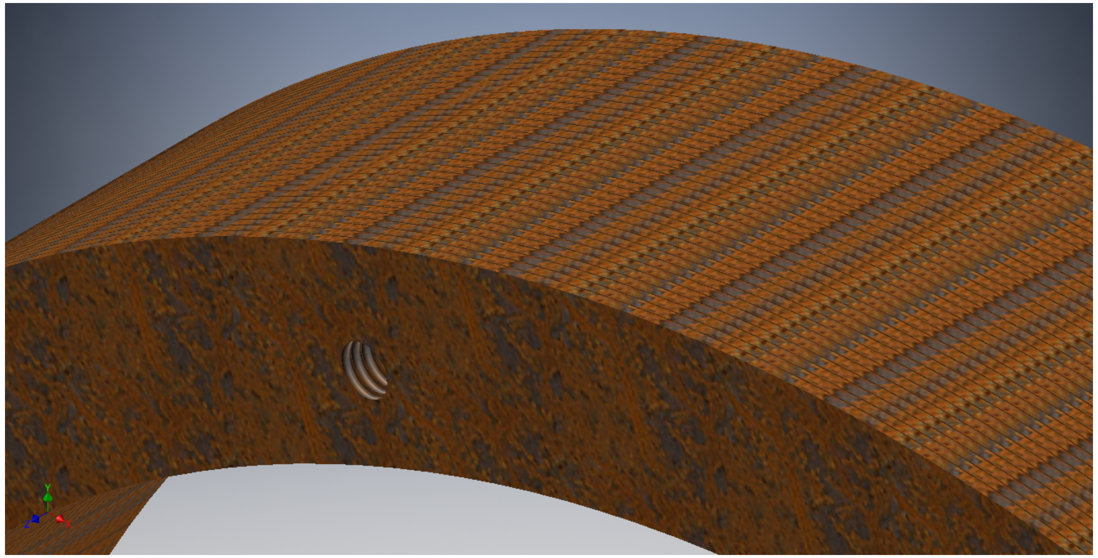


1/2 section view

Hole in cover for Inserting magnets during magnet array assembly

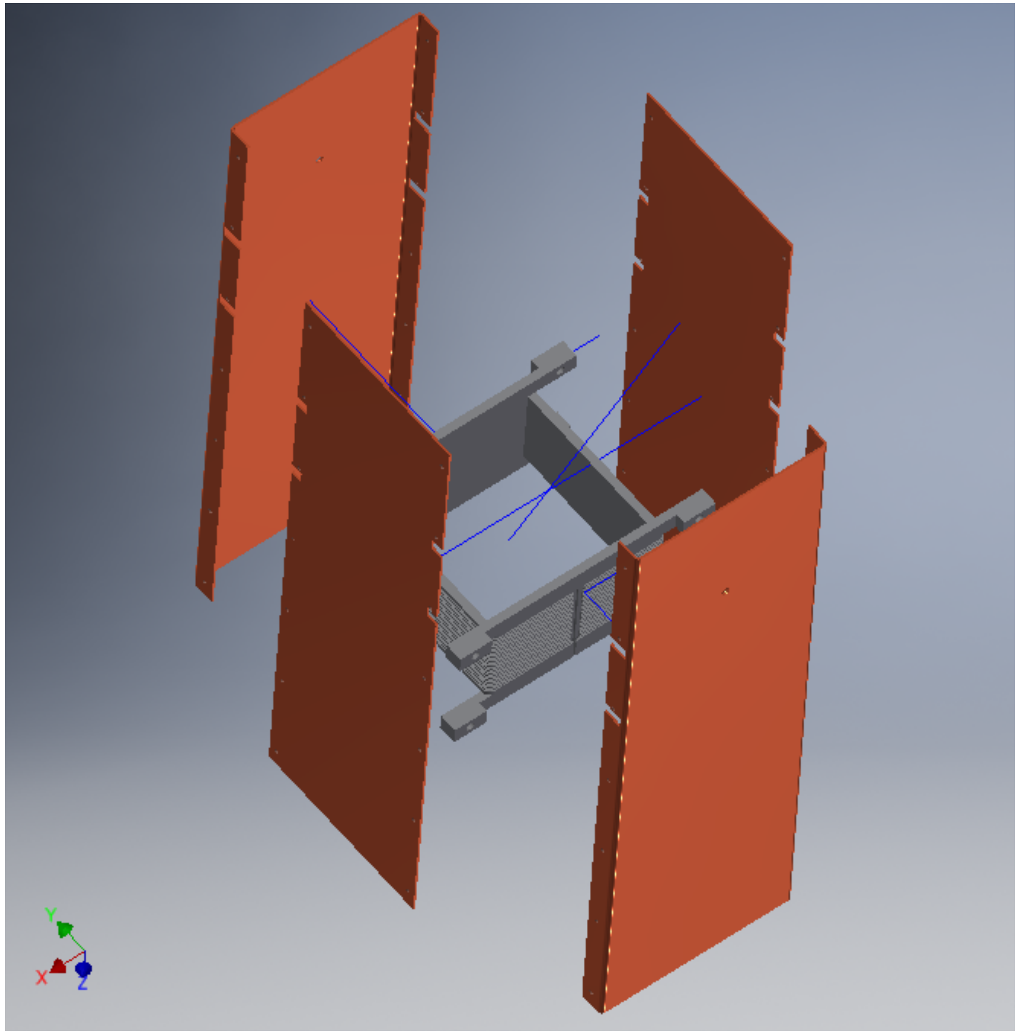
Analyzer foil field return yoke

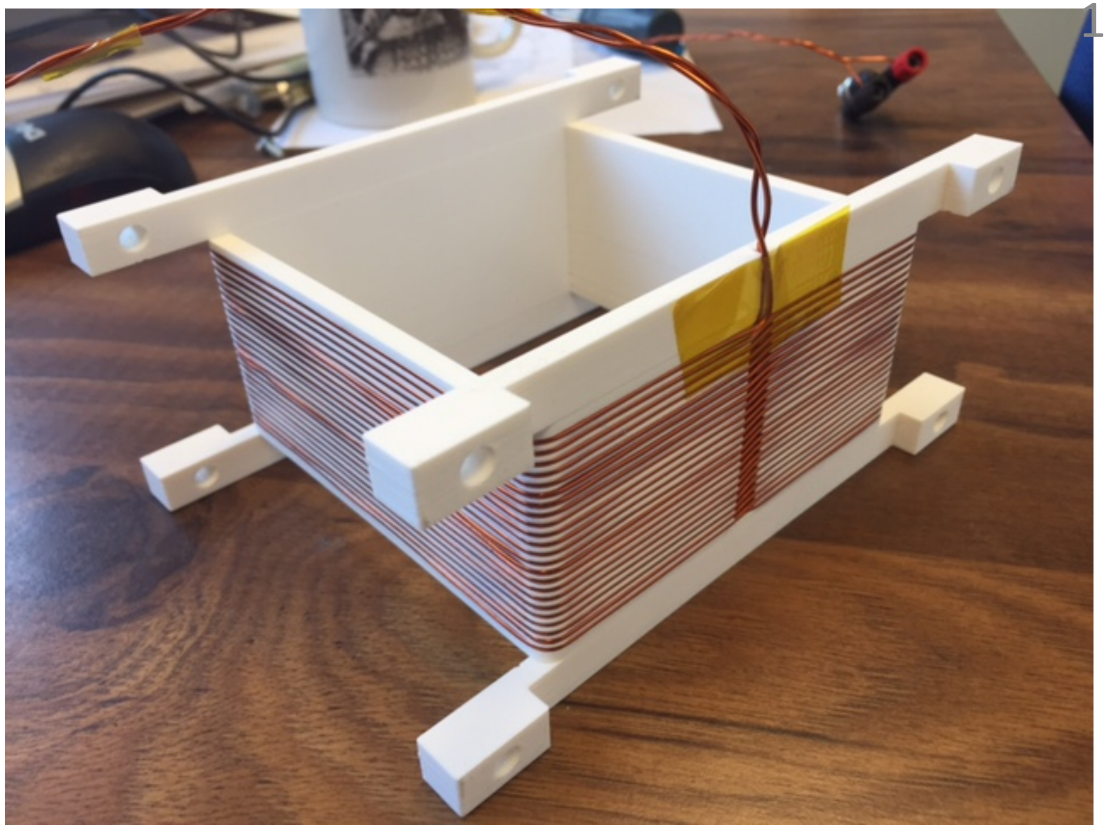




- Make from well characterized iron – eg. Electrical steel used for transformer yokes
- Comes in 24 gauge sheets
- To construct put together 36 layers to make up about one inch (with some gaps for tolerances)
- Ordered 80 pieces of 20” by 10” by 0.025+-0.003” DI-MAX M-19 with C-0 coating
- Will laser cut pieces

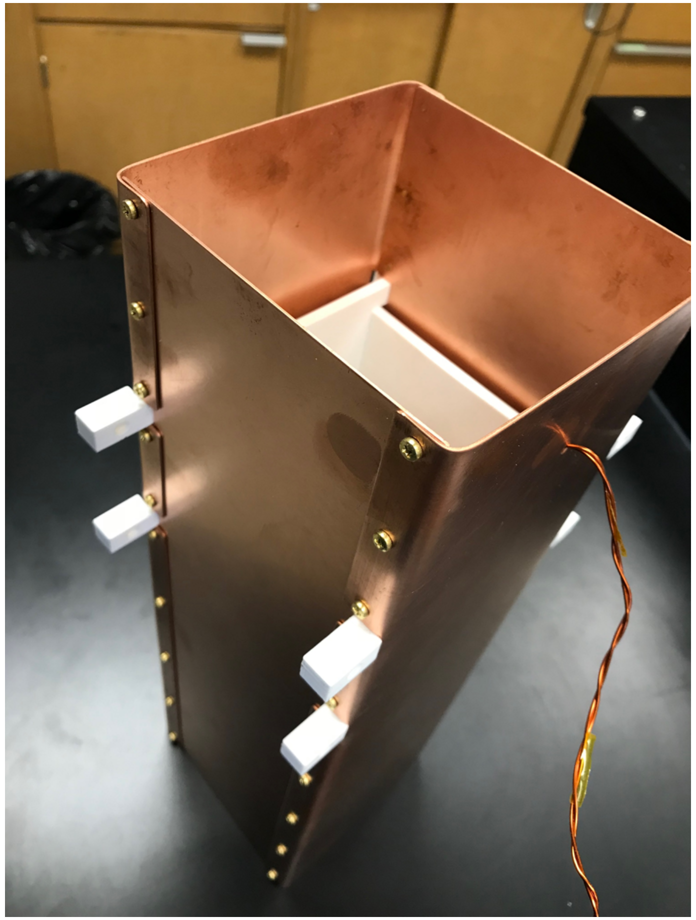
RF Coil and shielding

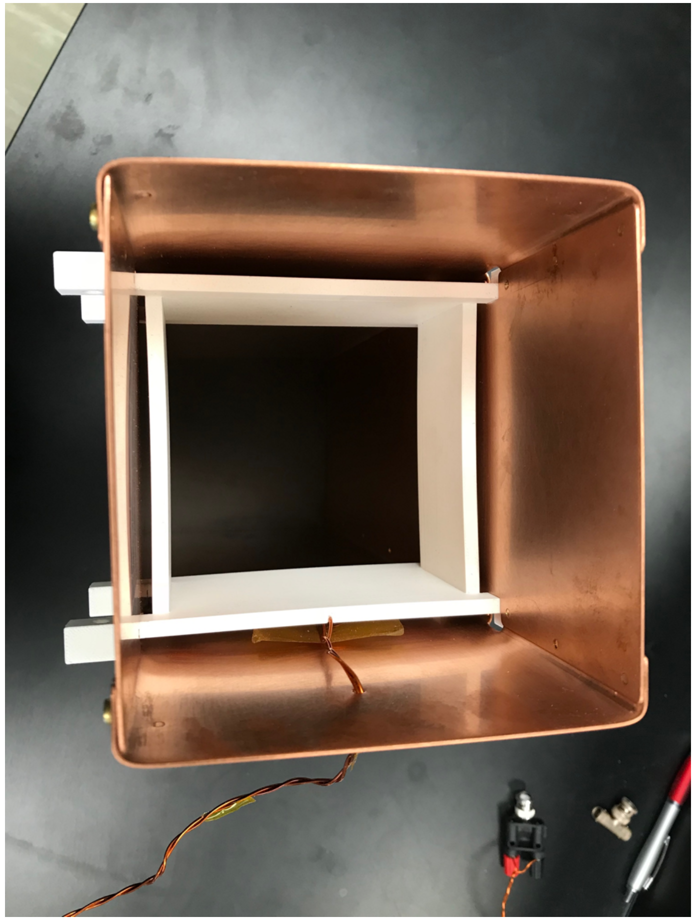




- Built prototype of RF coil and shield

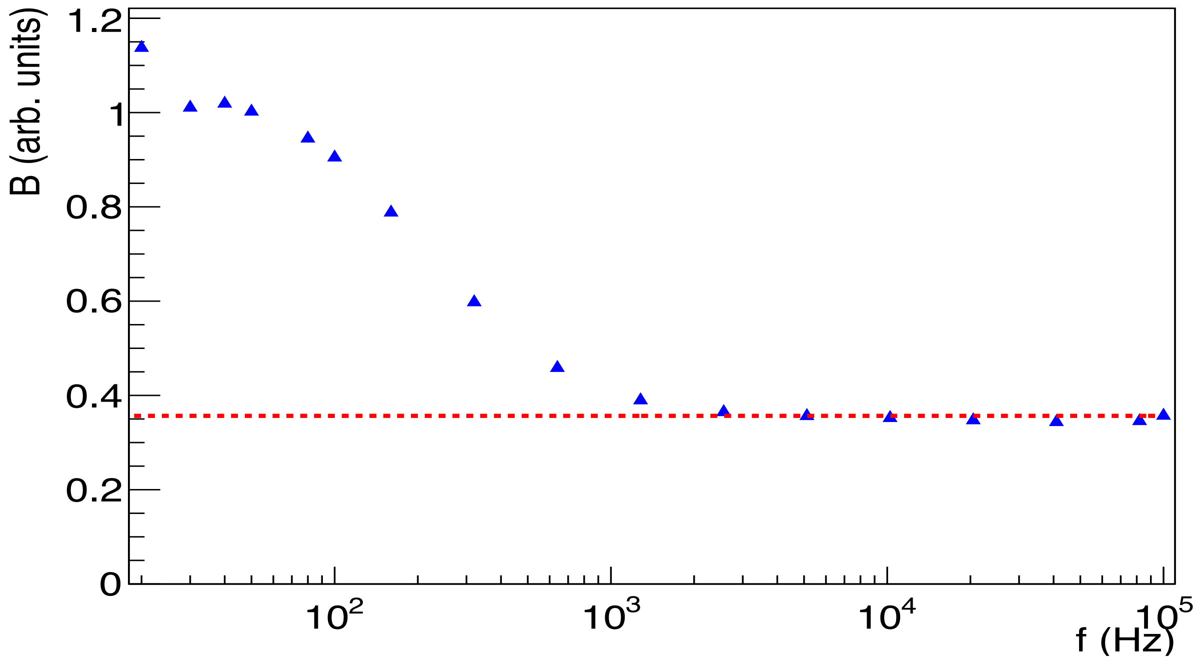
Photos of prototype RF coil and shielding

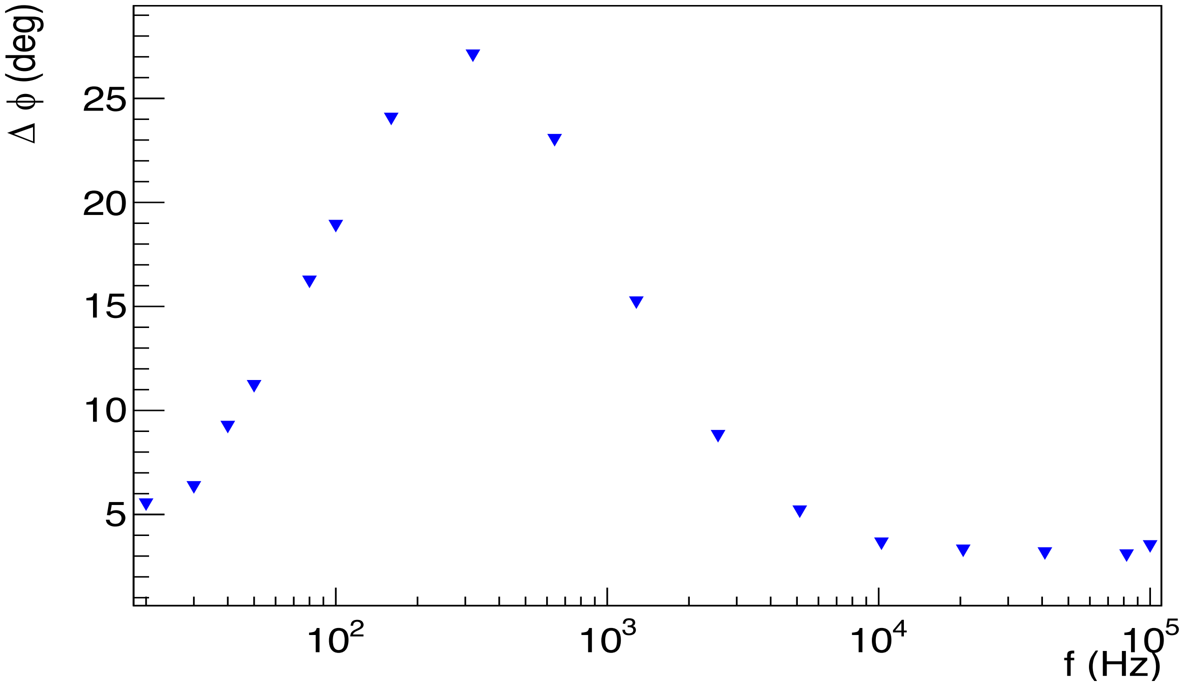




RF Coil Shielding

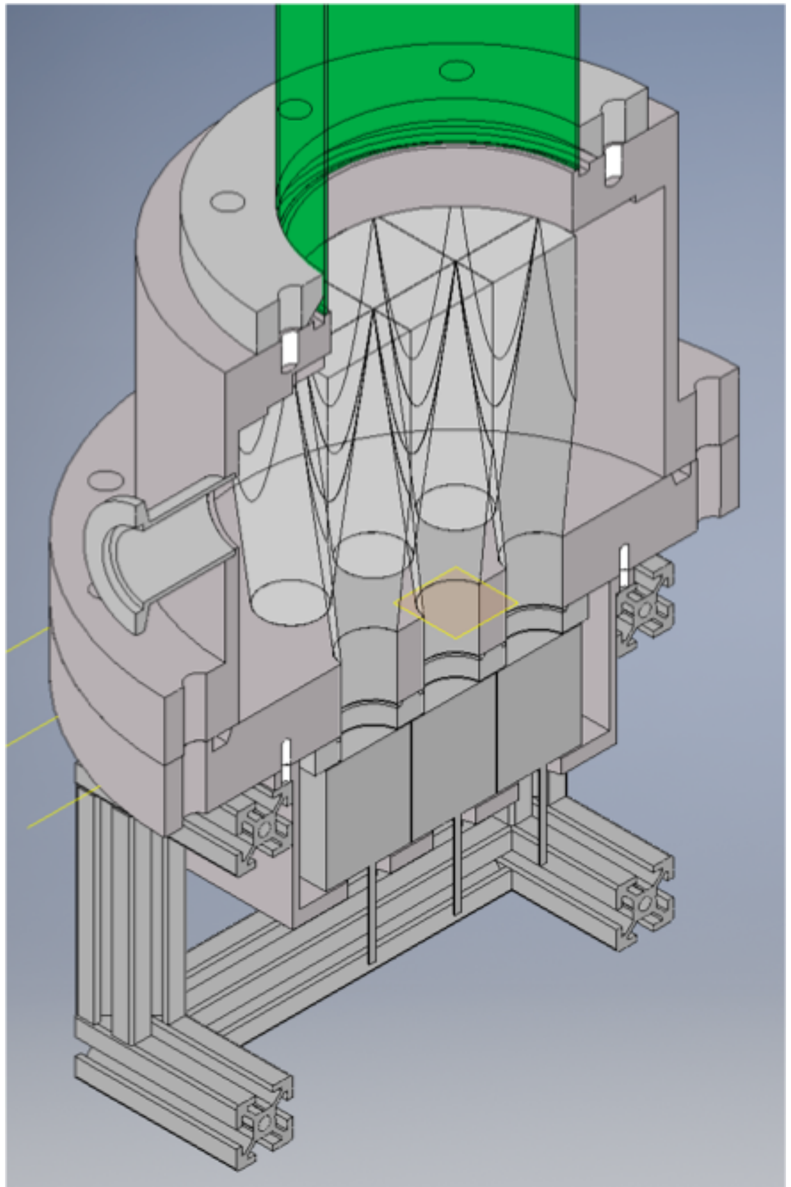
- Measure magnetic field in pickup coil placed in center of RF coil as function of frequency
- Expect RF shielding to turn on at a certain frequency related to the radius (b) at which the shielding is, and the thickness of the shielding layer (t)
- Find shielding is fairly complete above 1kHz
- Also see factor of about 0.35 in magnetic field that is consistent with the inductance measurement



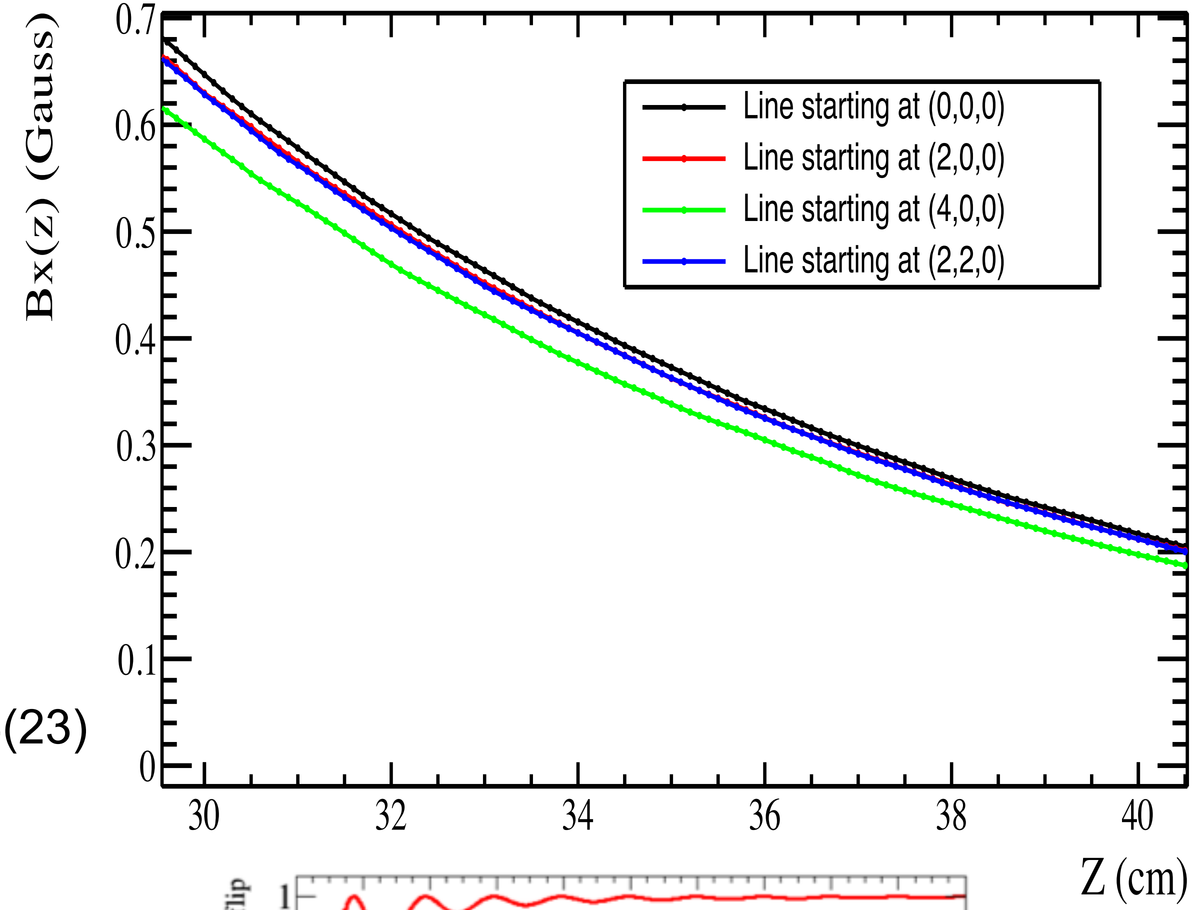


Updates to old detector housing for fall 2018

- Add KF25 pumping port to the housing
- Build a support structure
- Replace 90 mm o-rings on lightguides
- Plug NPT port with blank-off and seal with torr-seal



Spin Flipper Parameters

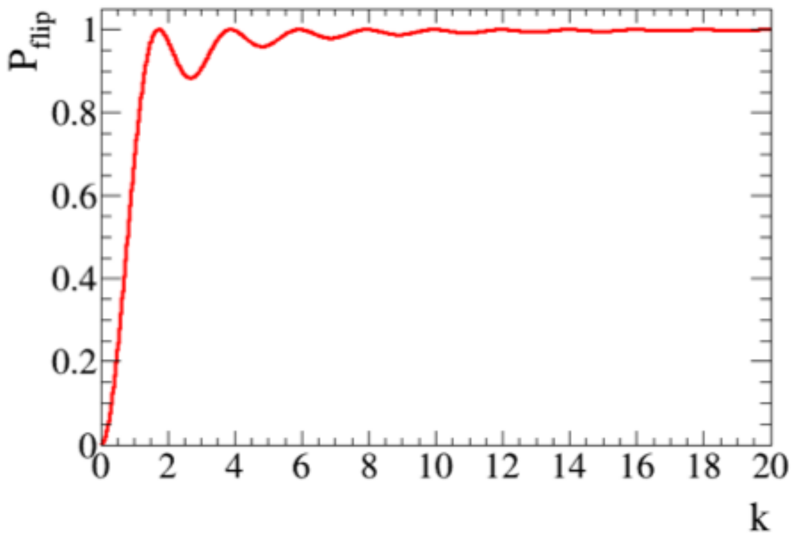


- Uses fringe field of Halbach array
- At 35 cm from foil:
  - Bx(z) = 0.4 gauss -> ~1 kHz RF, 0.1 mT
  - dBx/dz = 0.04 gauss/cm = 0.0004 T/m
- Want large adiabaticity parameter k

$$P_{flip} = 1 - \frac{\sin^2(\pi\sqrt{1+k^2}/2)}{1+k^2}$$

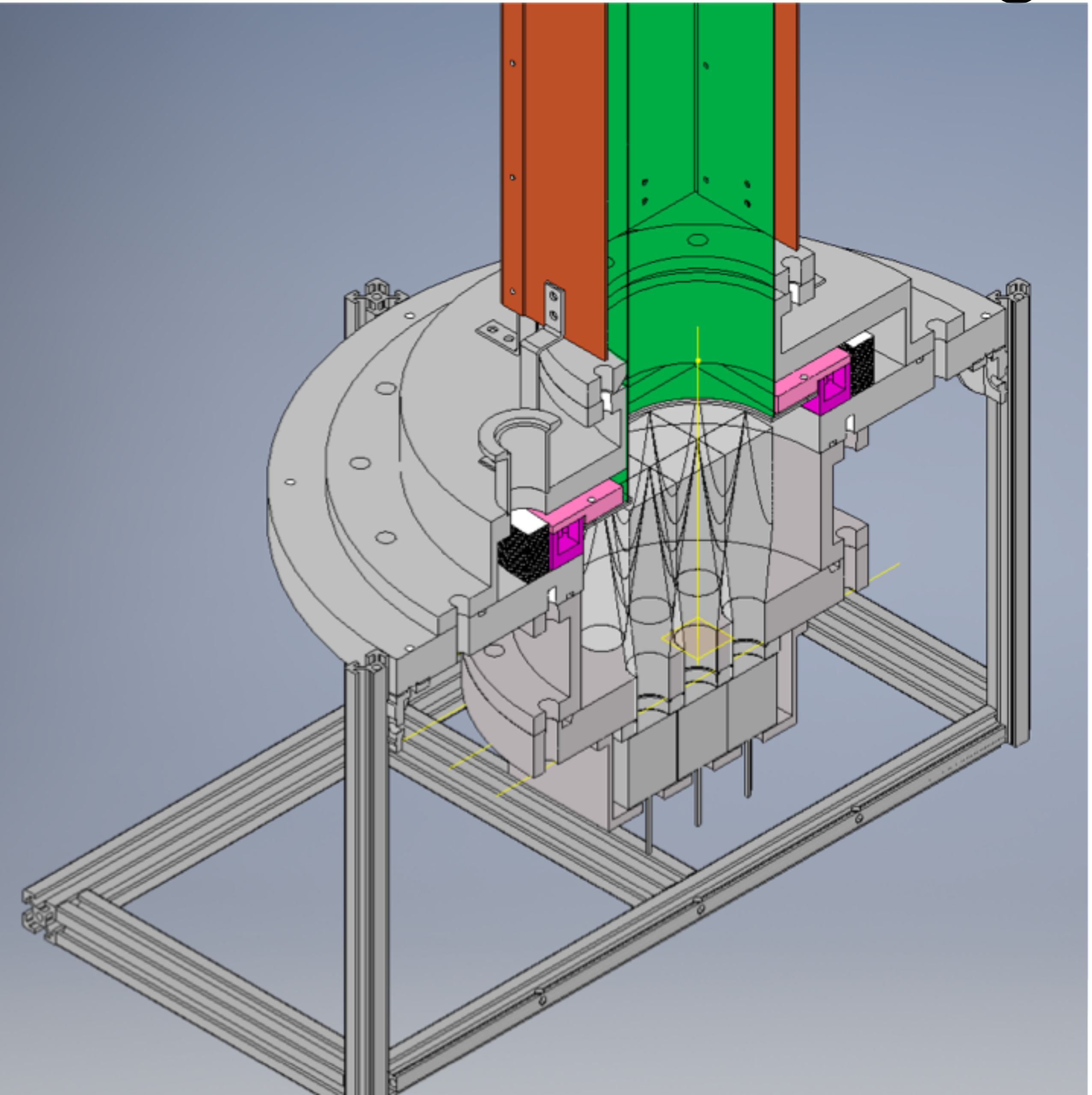
NIM Phys. Res. A 384(23) (1997) 451.

- k = 1.83×10^8 rad/(s.T) x (10^{-4} T)^2 / (10 m/s x 0.0004 T/m) = 457

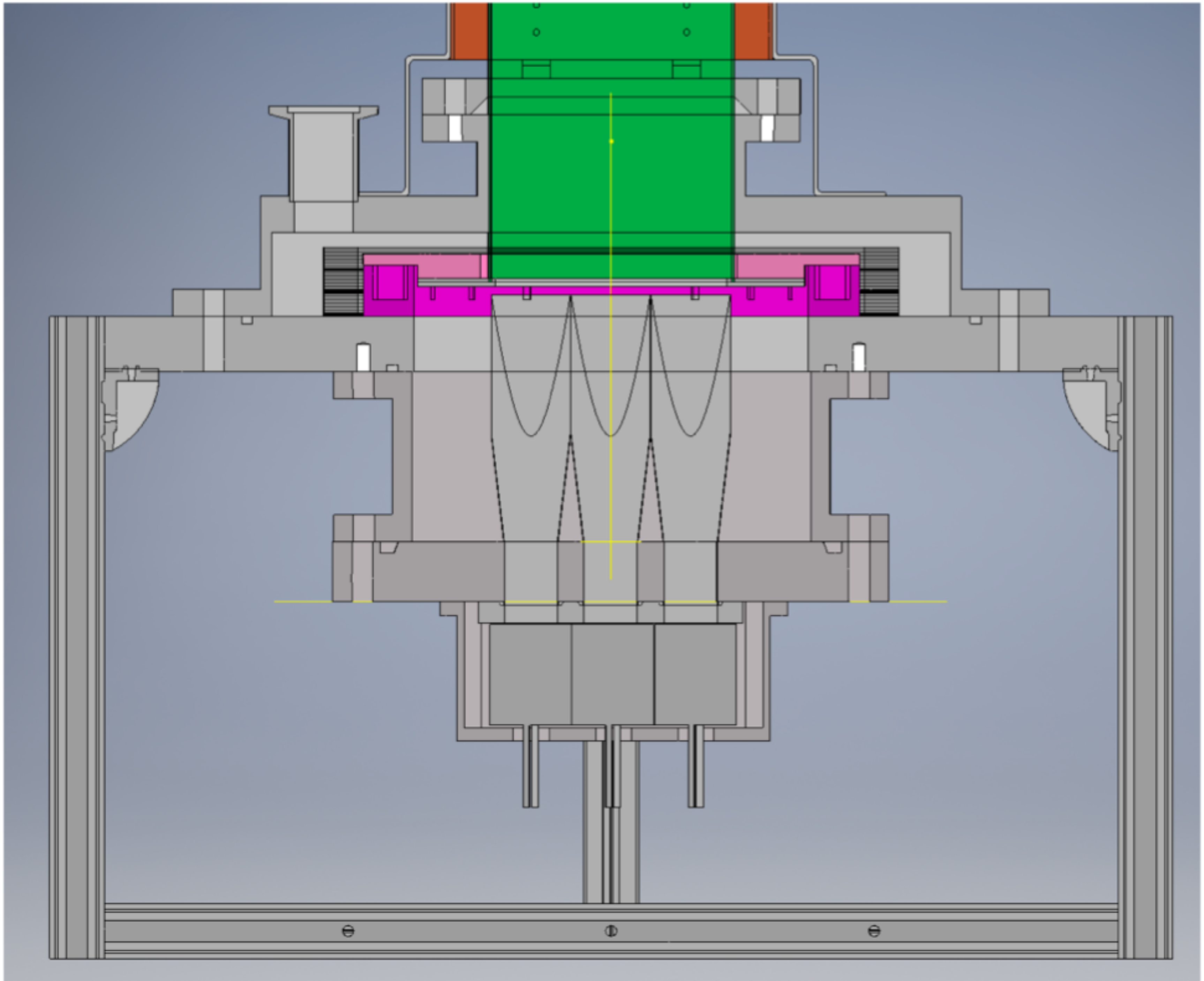


- Problems:
  - May need to buck TRIUMF field
  - May need to buck TRIUMF gradient?
  - 1 kHz RF is a bit close to where shielding works optimally, may want a larger Bx(z) to allow higher freq RF

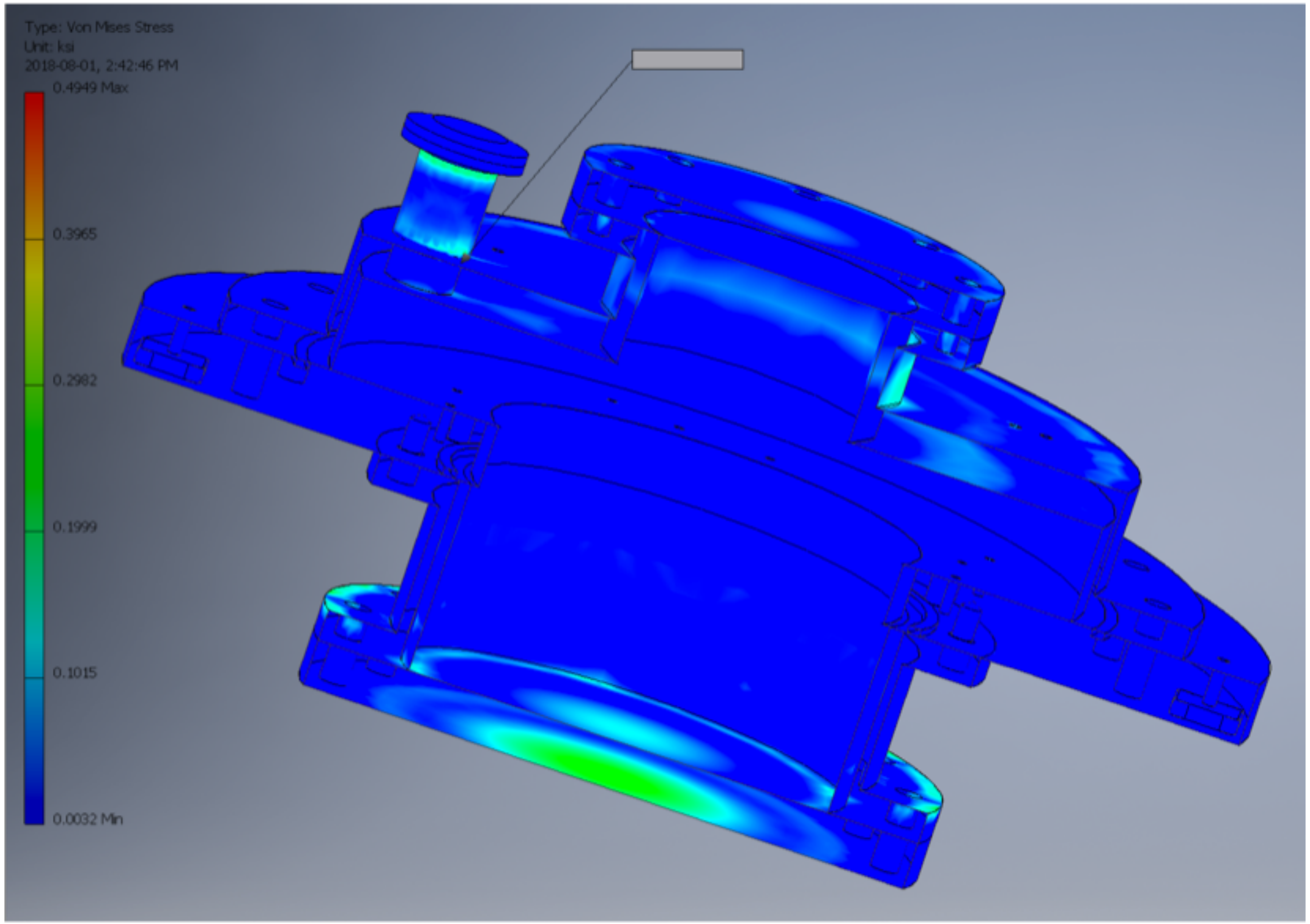
New detector housing with spin-analyzer



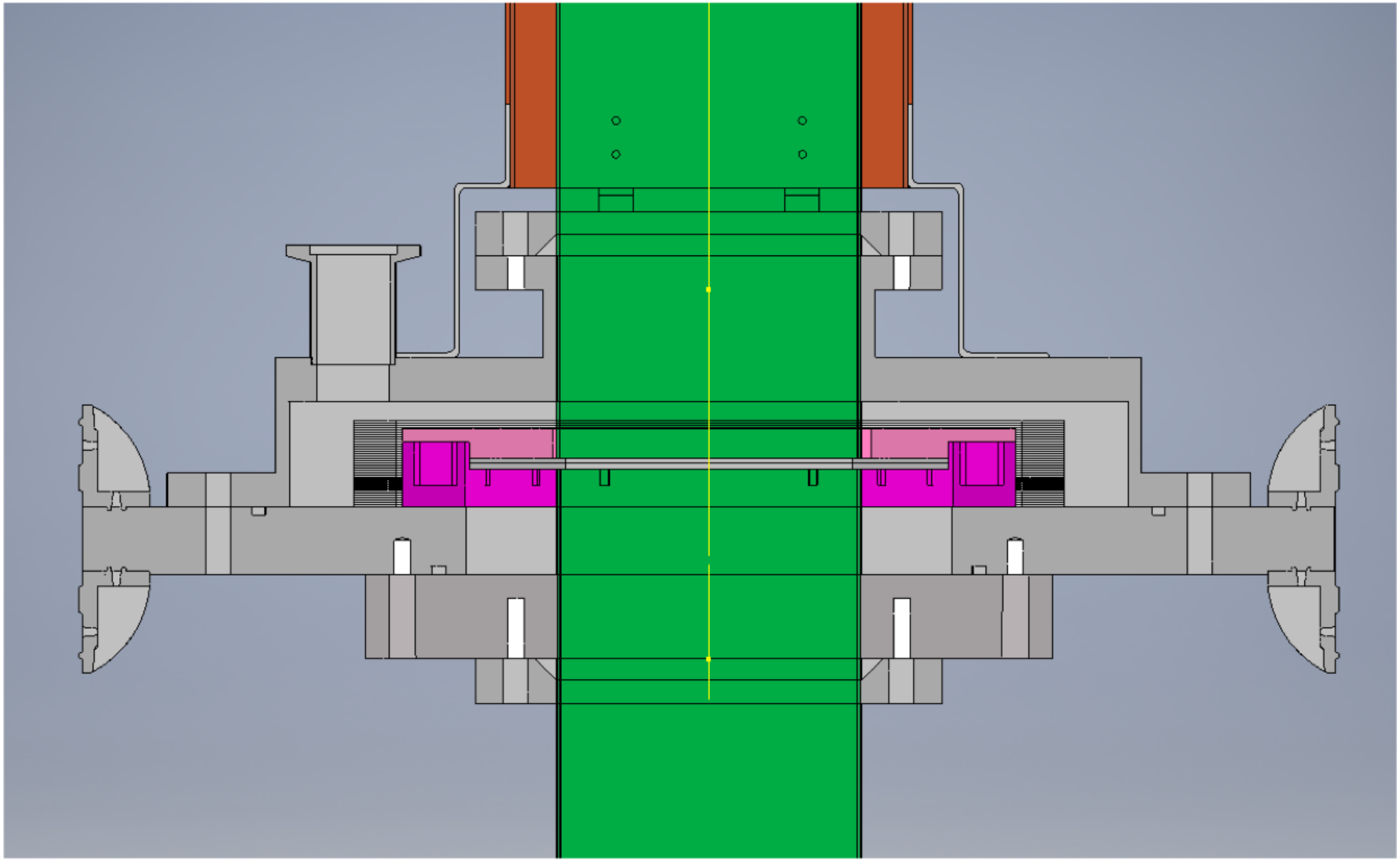
- Top vacuum cover:
  - couples to 85 mm ID, 90 mm OD glass guide via Wilison flange
  - Has KF25 pumping port
  - Holes to attach RF shield/RF coil
- Connection Plate:
  - holds Halbach array+foil, iron yoke
  - Connects to new detector flange
  - Has holes to connect to Misumi 20 mm frame



Stress analysis of new housing

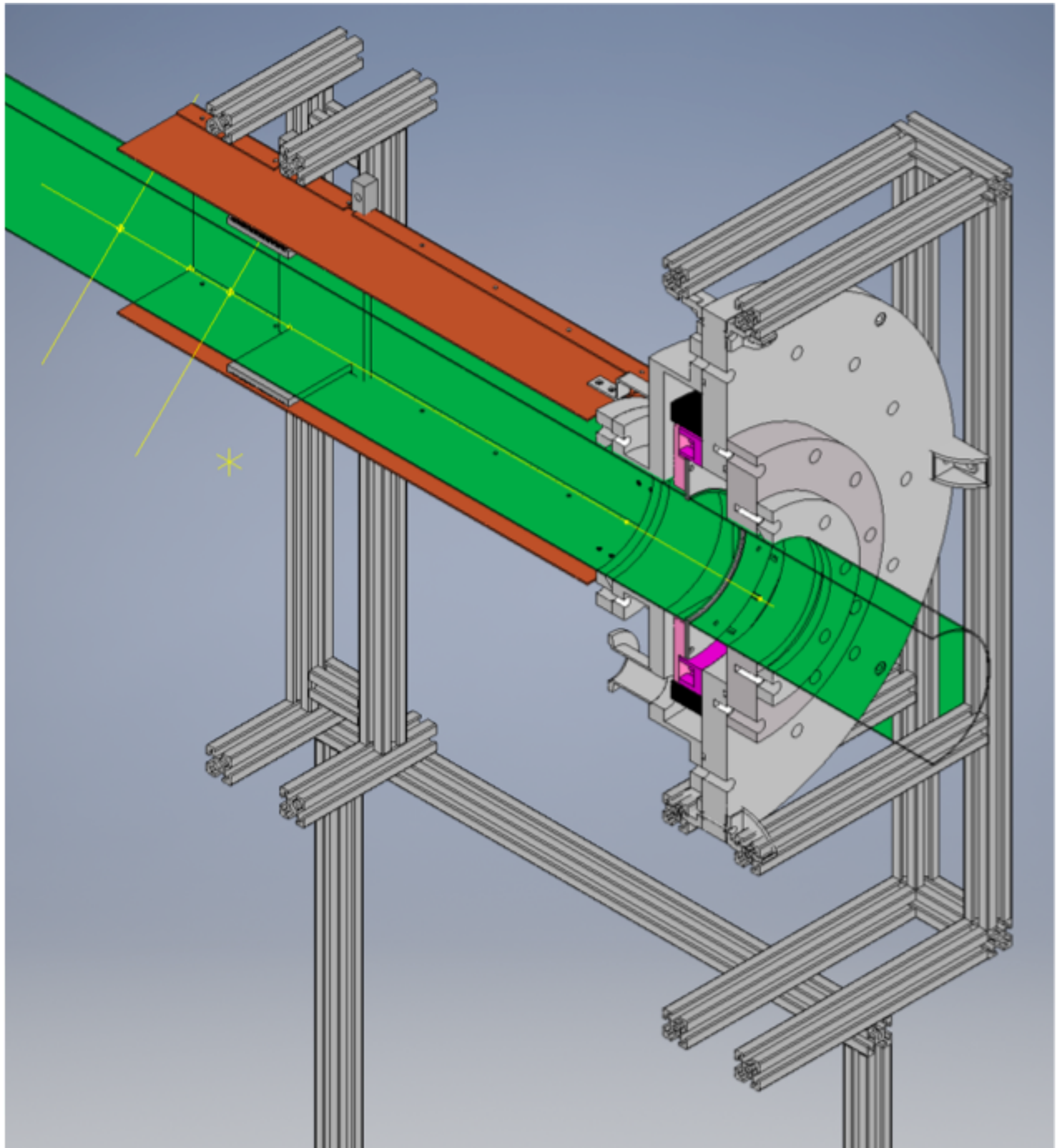


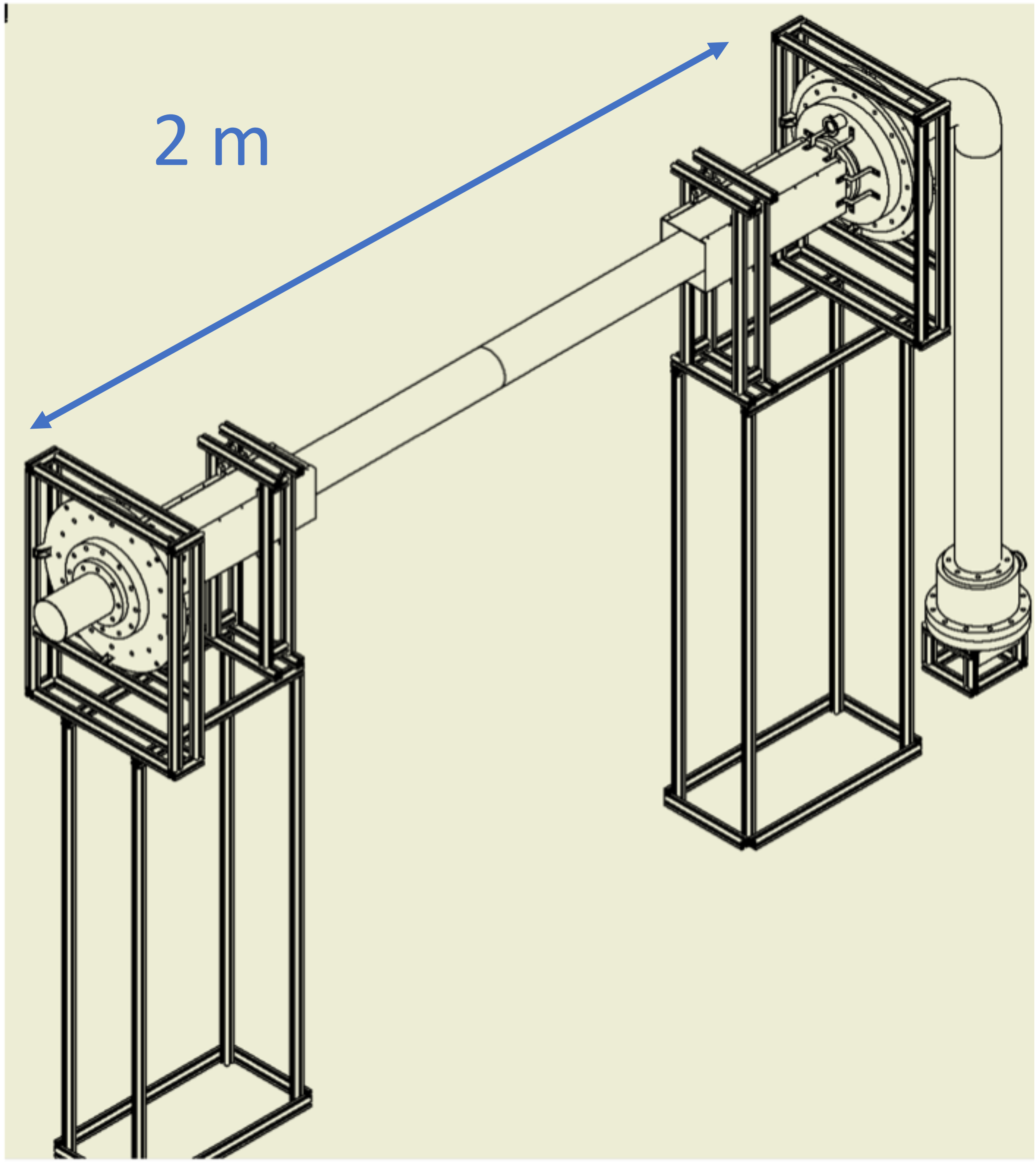
- Maximum stress of 0.5 ksi (more than 20x safety factor)
- Located at KF25 flange
- Seems fine



Spin analyzer foil connection to two guides

- Same as housing that connects to new detector, but
  - Has extra adapter flange on detector side to go to 90 mm glass guide via Wilison flange
- Just yesterday made an initial drawing of support for horizontal orientation



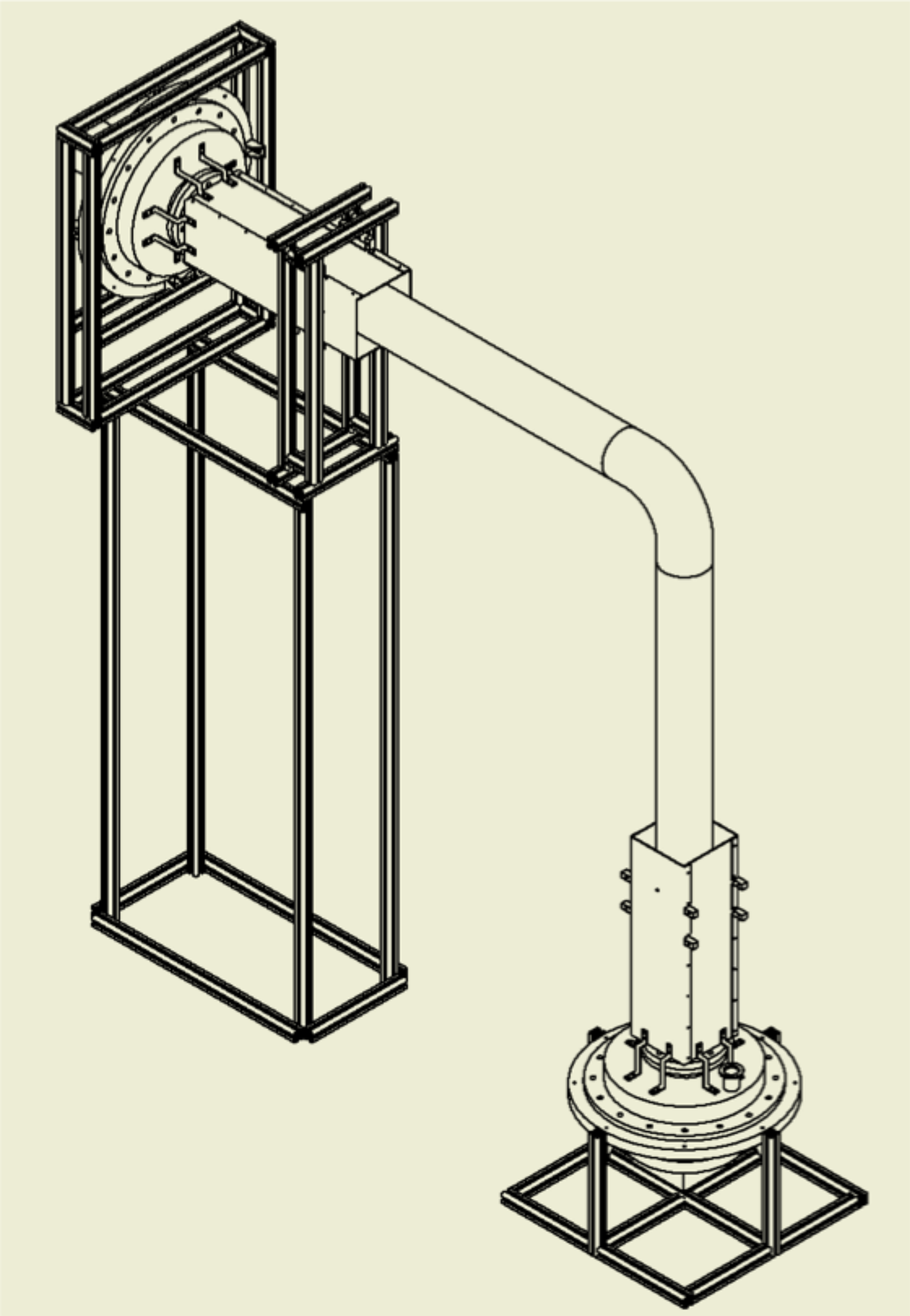


Fall run tests Horizontal orientation

- Has advantage that both spin flippers and anlyzers use same UCN spectrum
- Needs to be after 1 m drop so that UCN spectrum > 90 neV due to saturated iron foils
- Uses old detector housing, since both connections to new housing are used for the spin analyzer foil holders
- (Could update drawing at left to orient detector horizontally or with smaller drop).

Bend orientation for fall run

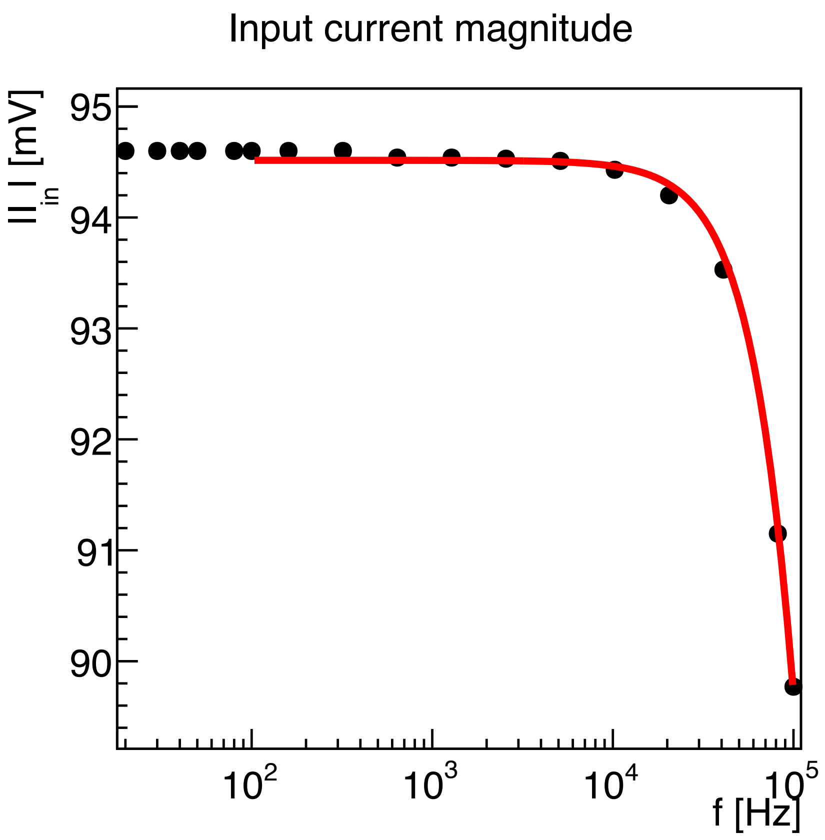
- Advantage is that we use new detector housing
- Disadvantage is that UCN spectrum in each spin analyzer / flipper is different
- Again, this would start at 1 m drop to get UCN spectrum above 90 neV of saturated iron foils

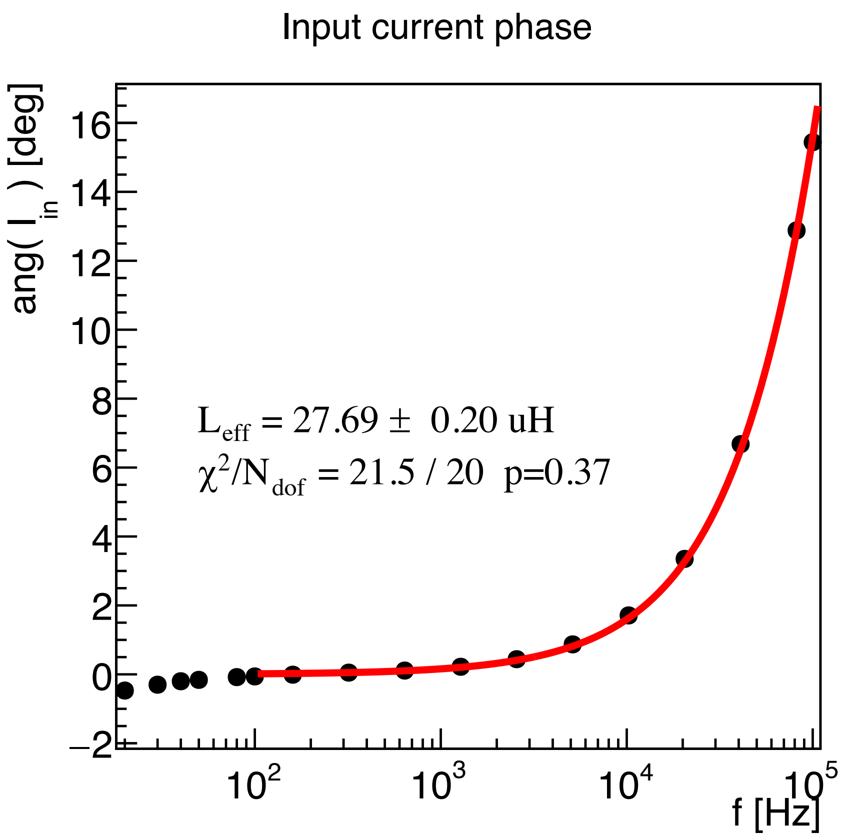


Conclusion

- Have a design for the simultaneous spin analyzer
  - Depends on finishing Geant4 simulations to optimize some dimensions
- Have a plan for testing the components of the SSA
  - Would like to simulate each of the setups as well
  - Expect Sean to work on this from now until we run them
    - May move to penTrack to allow reading in the geometry from the designs shown here
- Parts shown here are being built in Winnipeg
  - Vacuum enclosures being built by local machinist ($7500 shown in Russ' table)
    - Will include blank off flanges to allow vacuum tests at U Winnipeg
  - Spin analyzer foils already ordered
  - Halbach arrays, RF coils, and shielding buing built a U Winnipeg by technician
- Included KF25 Vacuum ports on new detector housing, but have not an extra turbo pump to send… is there budget to have another turbo pump, or is there one we can borrow again?

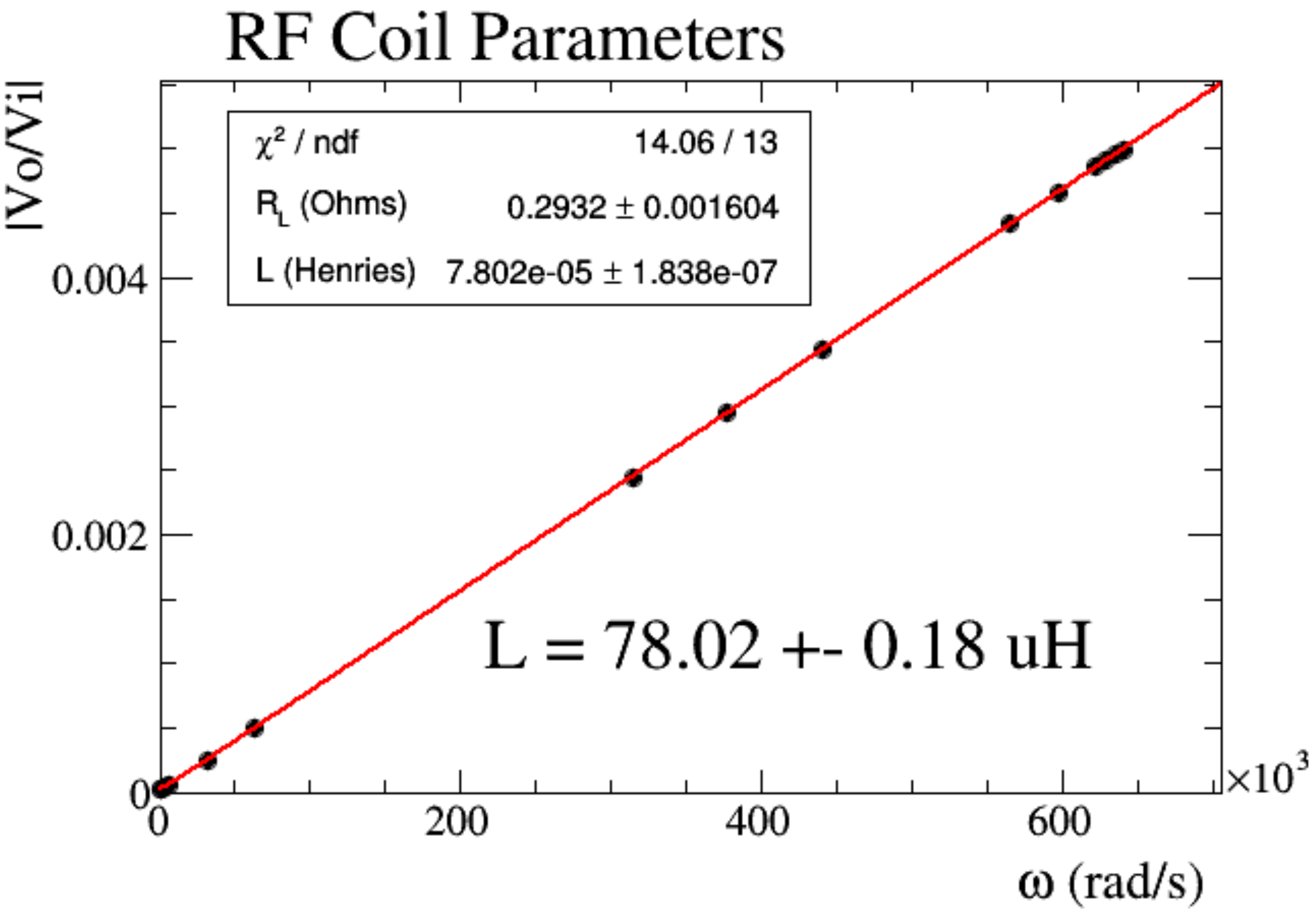
Measurement of effective inductance





- Inductance reduced due to RF shielding
- Without RF shielding found:
- L=78 μH
- Therefore field is 0.346 of free space field due to eddy currents

Coil electrical properties and next tests



- Coil produces ~220 µT/A at center without RF shielding
- Hand calculation expected

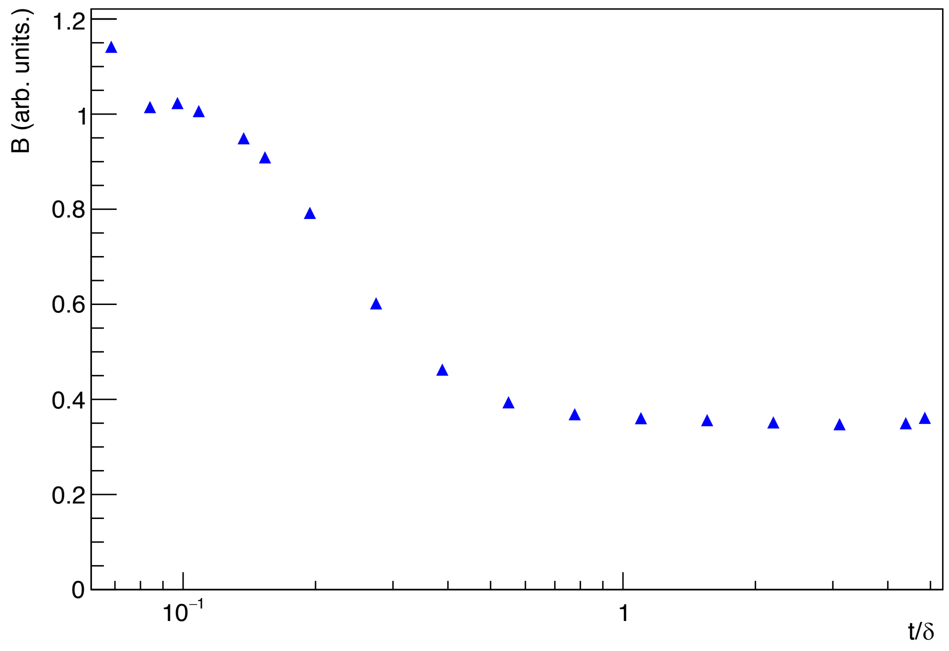
R_L = 0.226 Ohms

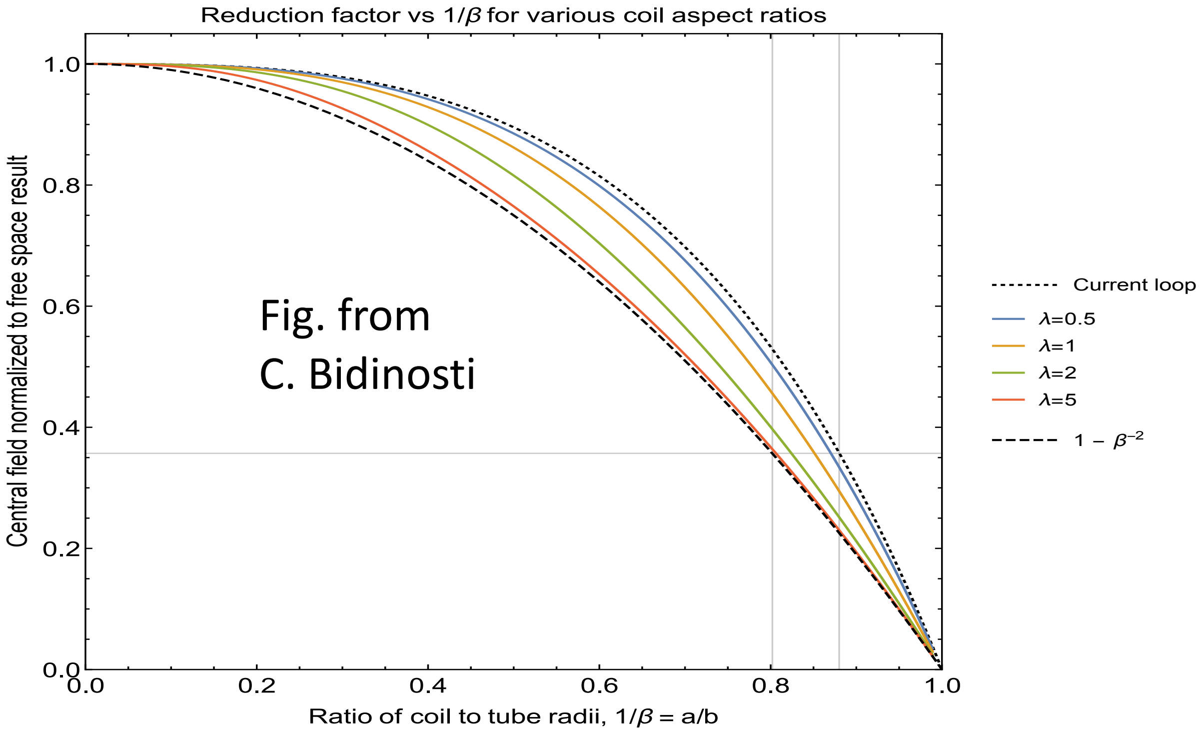
L = 83.1 µH

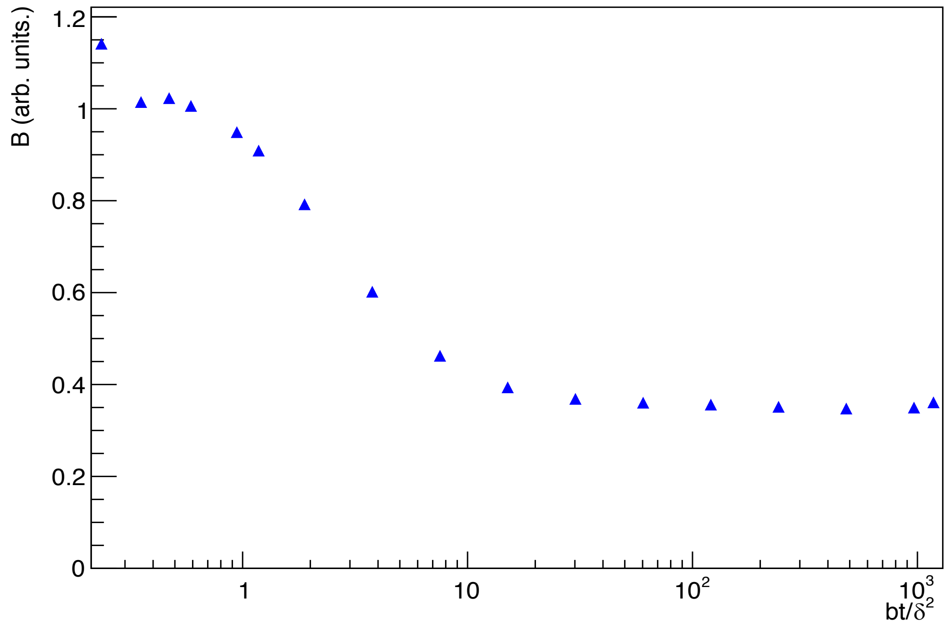
- Not too bad agreement

Same plots as previous page but replaced x-axis with t/δ or bt/δ^2

- See that turn on is somewhere closer to $bt/\delta^2 = 1$, where δ is skin-depth
- See C.Bidinosti paper for details why this happens (coils at 100mm, shield 115mm gives a/b=0.87)







Implications for running the RF coil

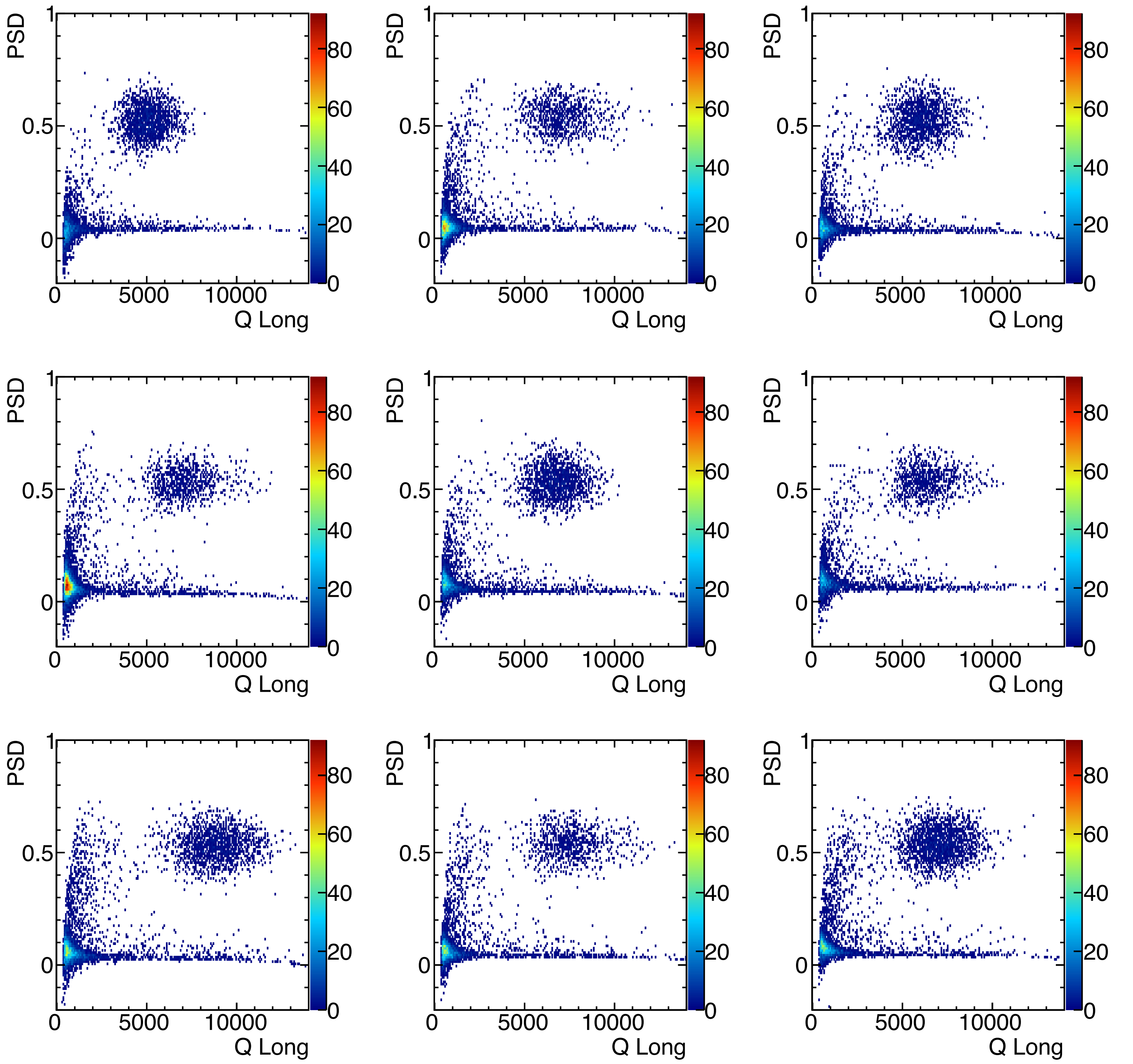
- To run 100 μT RF field in free space required current of 0.45 A
- In RF shielding to get same RF field, need higher current:

  $0.45/0.35 = 1.4$ A
- Power supply $V=IR=(1.4\ A)(0.3\ \Omega) = 0.42\ V$
- At this current, coil and RF shield have power deposit:

  $P = I^2R = (1.4\ A)^2\,(0.3\ \Omega) = 0.588\ W$

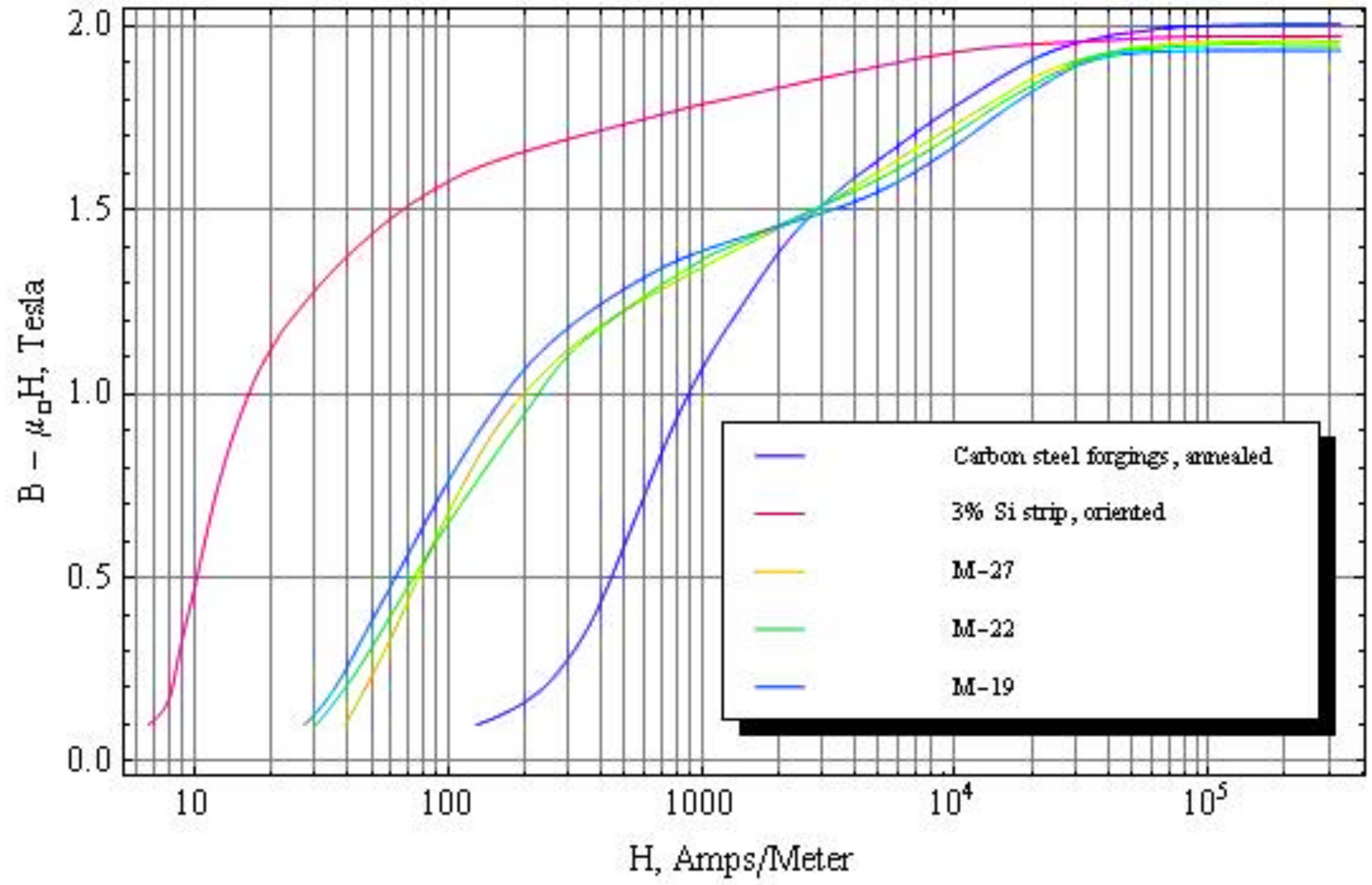
A look at fall 2017 data

- Started with Charge calibration
- On right is PSD vs QL from one of first runs (Run 524)
- To do charge calibration, cut on PSD>0.2 and project onto Q_L axis



About the electrical steel

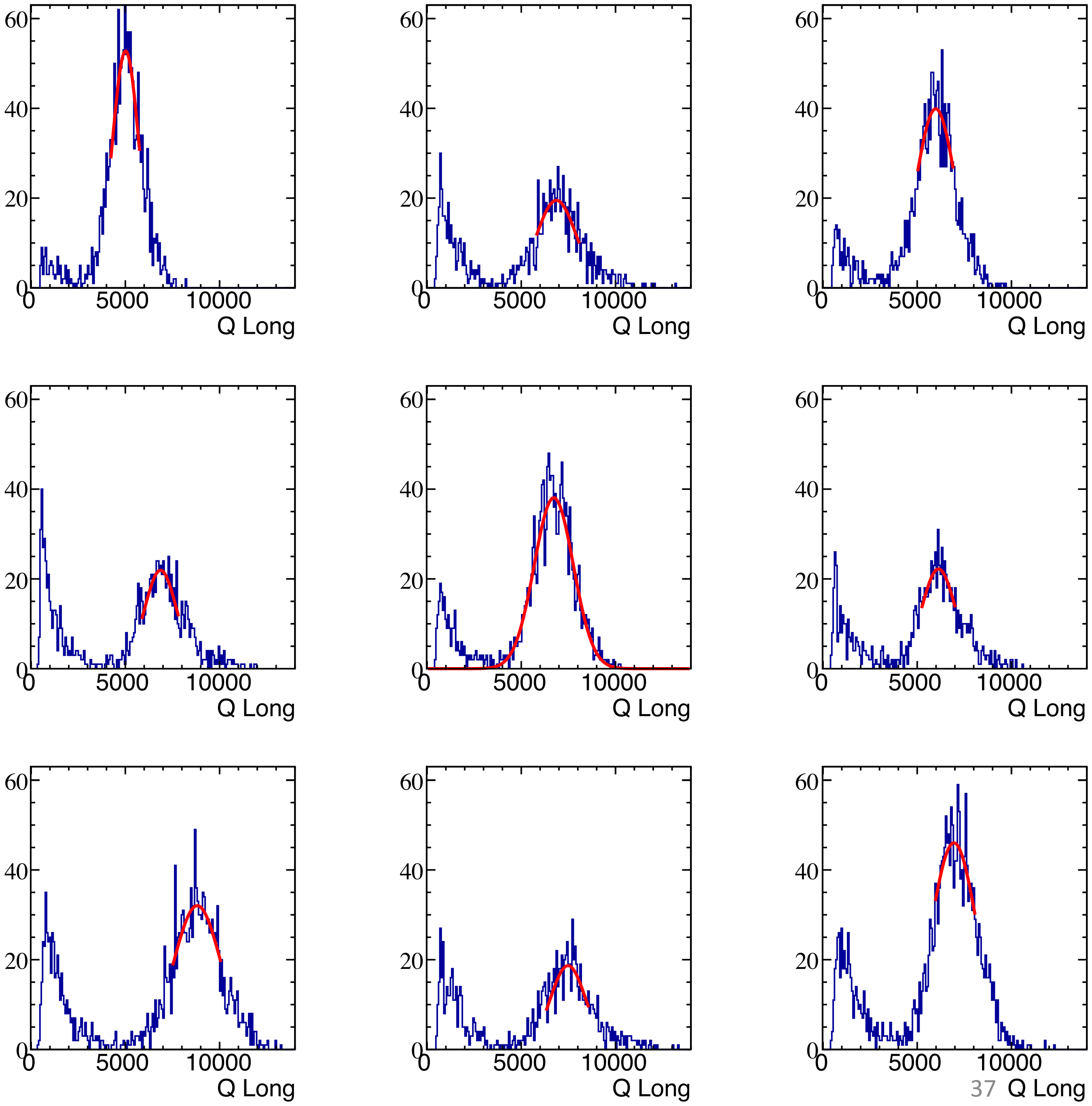
- M-19 BH curve is in FEMM:



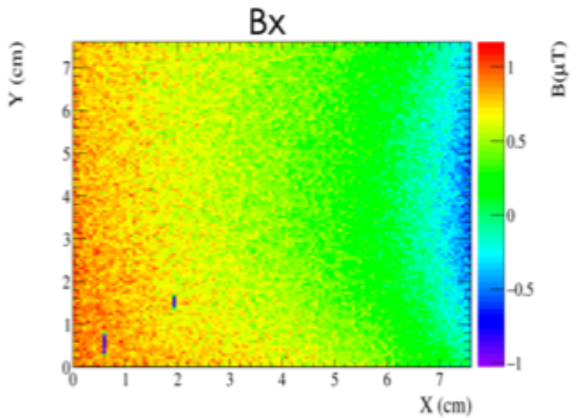
- C-0 coating: An insulation consisting of the natural oxide film formed in processing annealing. The insulation resistance is low, but usually is adequate for small cores. It will withstand stress-relief anneals in neutral or slightly reducing atmospheres.
- Should test it is okay for out-gassing in vacuum

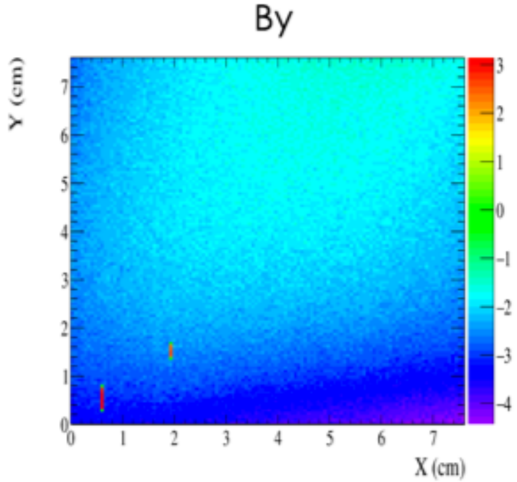
Charge distribution
Run 524 before calib

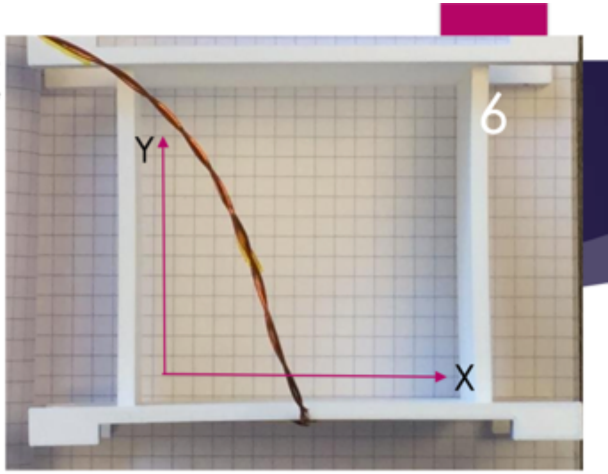
- Fit each peak to a Gaussian
- Collected fit results from all runs and plotted versus run number



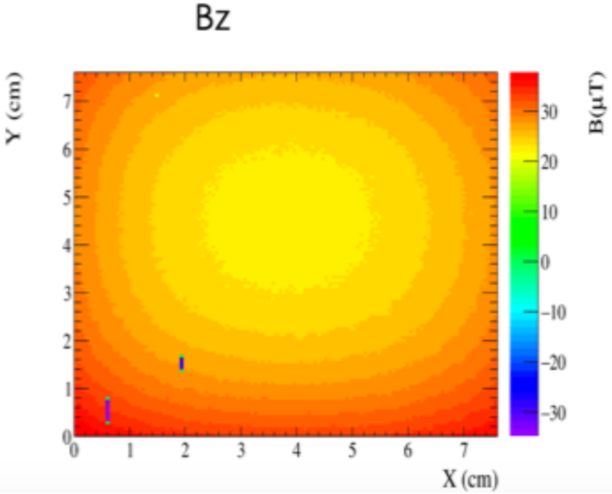
RF coil B-Field measured summer 2017

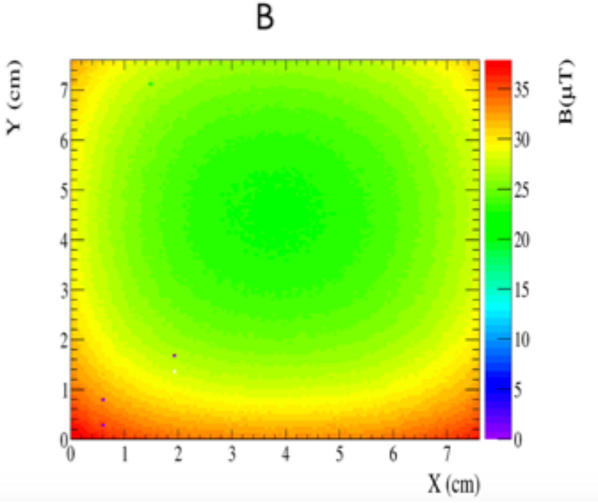






Measurements taken at the same location with the the current +0.1 Amps and -0.1 Amps to eliminate background

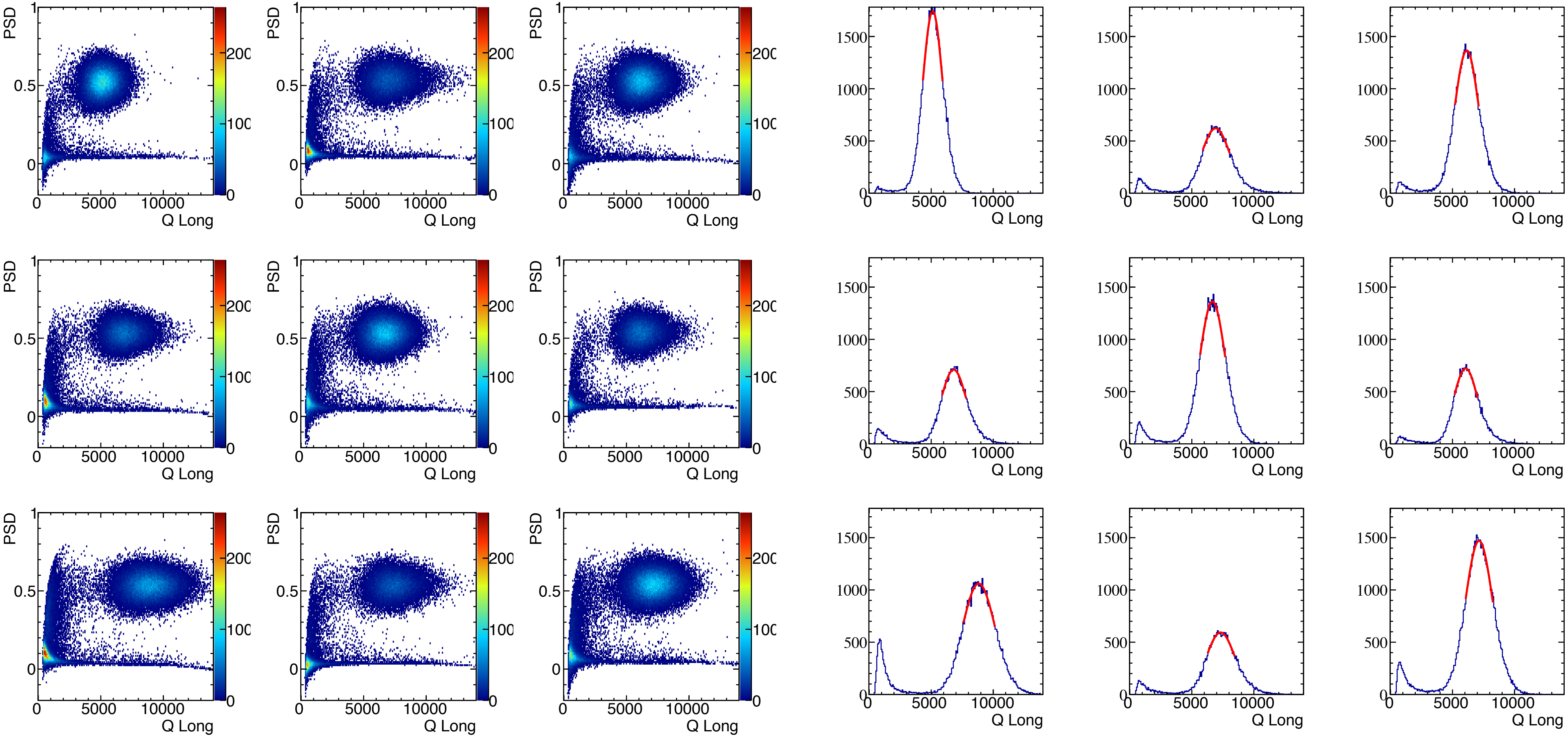




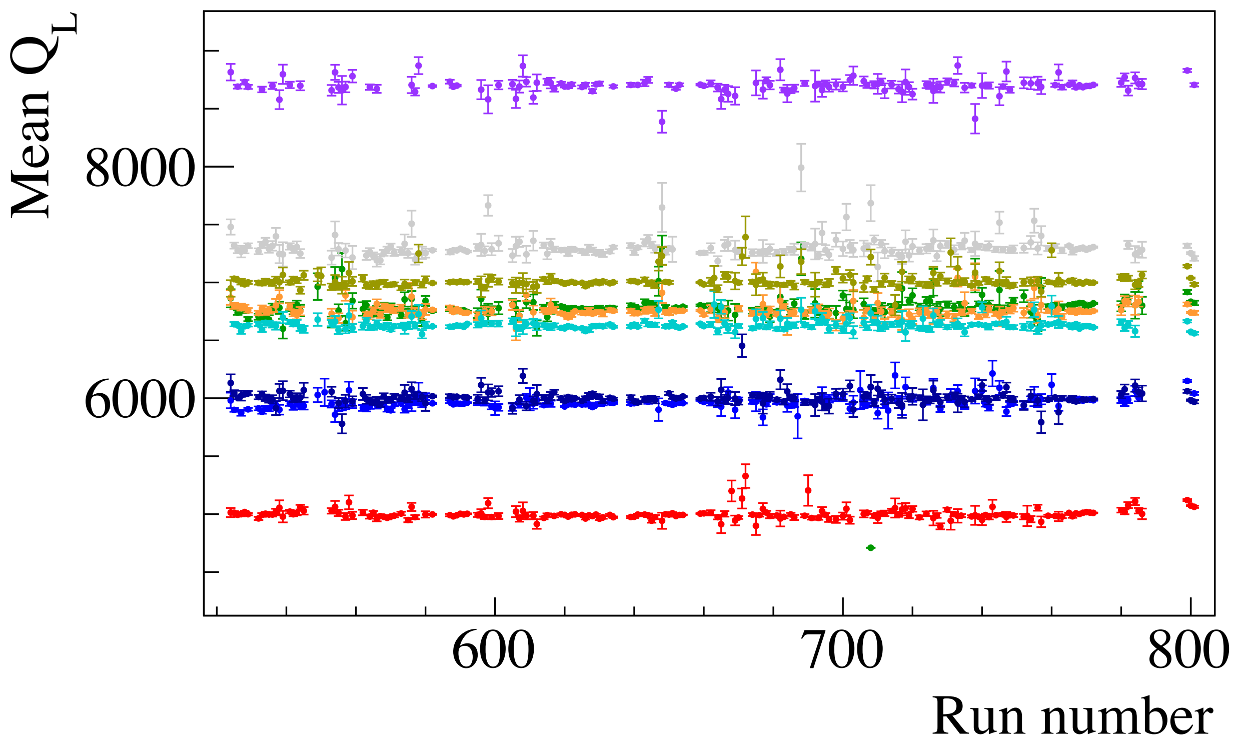
3 axis field mapper that has 3 axis field sensor on arm

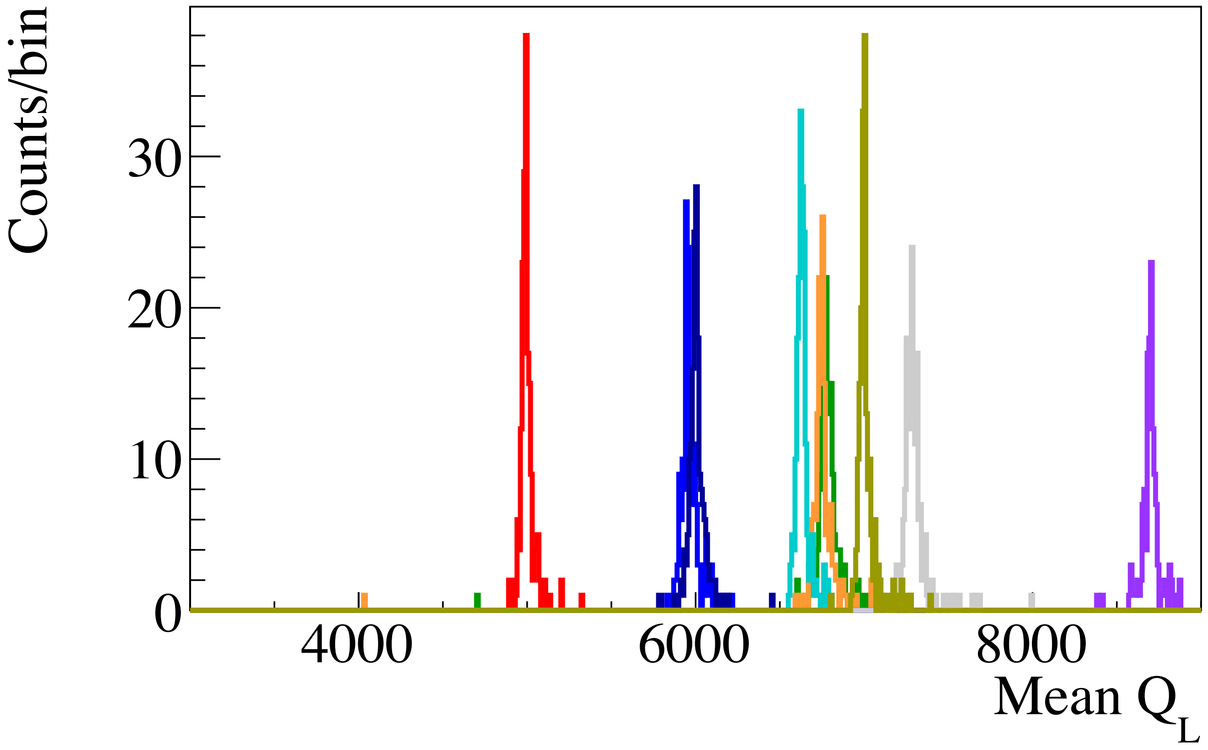
Produces field of ~220 μT/A at center, consistent with Biot-Savart calc. of 220 μT/A

A second example, with higher stats: Run 799



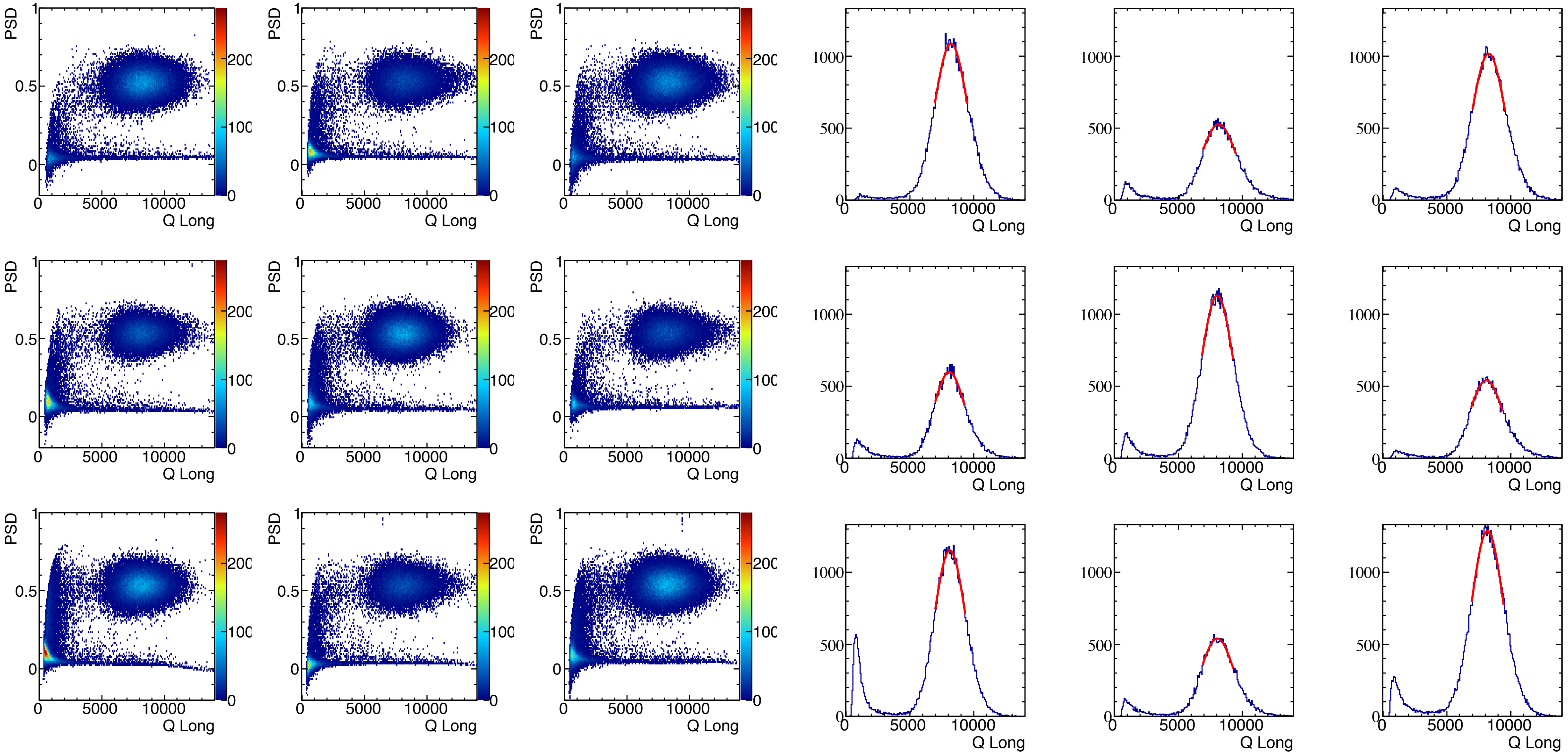
Average charge versus run number





- Charge was fairly constant over all of the run period for all of the channels

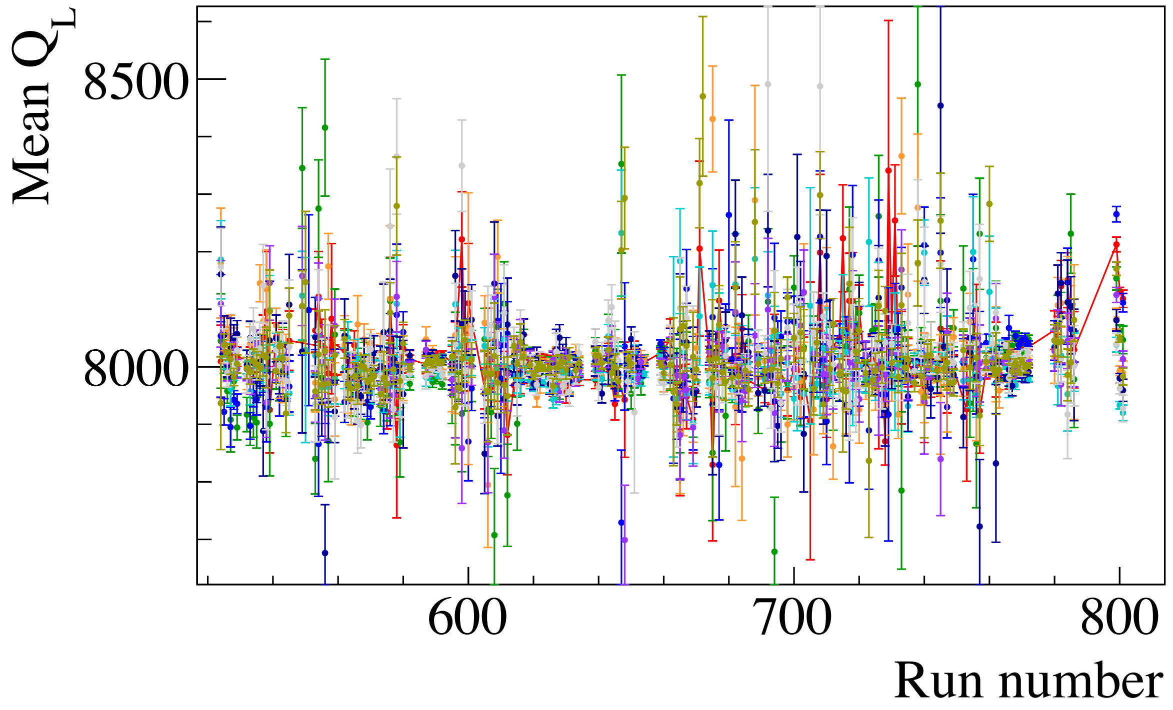
Run 799: After charge calibration



Check of average charge versus run

- Code added to midas2root program to apply charge calibration per channel
- Reads in file calib_li6_gains.txt (Digitizer, Channel, Mean Q_{L})

0 0 4989.12
0 1 6779.14
0 2 5952.67
0 3 6745.55
0 4 6630.66
0 5 6000.06
0 6 8697.78
1 0 7282.14
1 1 6996.85



- Each Q_L reading in calibrated file gets normalized to a Mean charge of 8000
- Re-analyzed files are in /data/ucn/root_files_qcali/