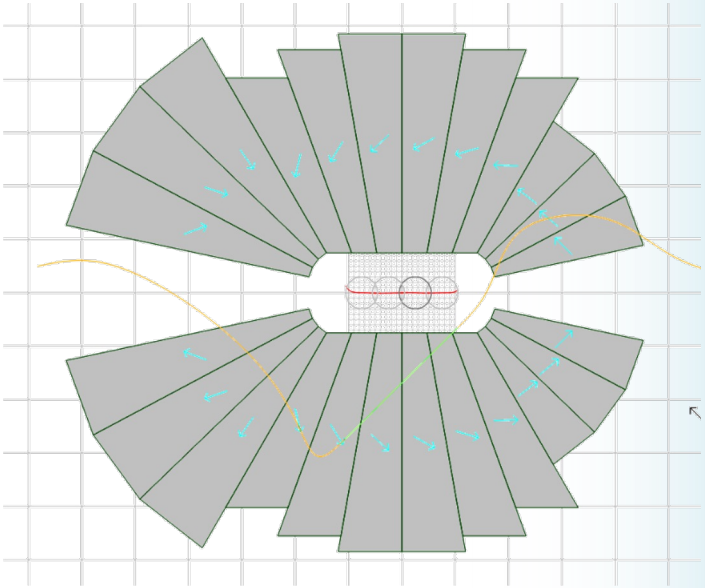
High-Field Combined Function Permanent Magnet

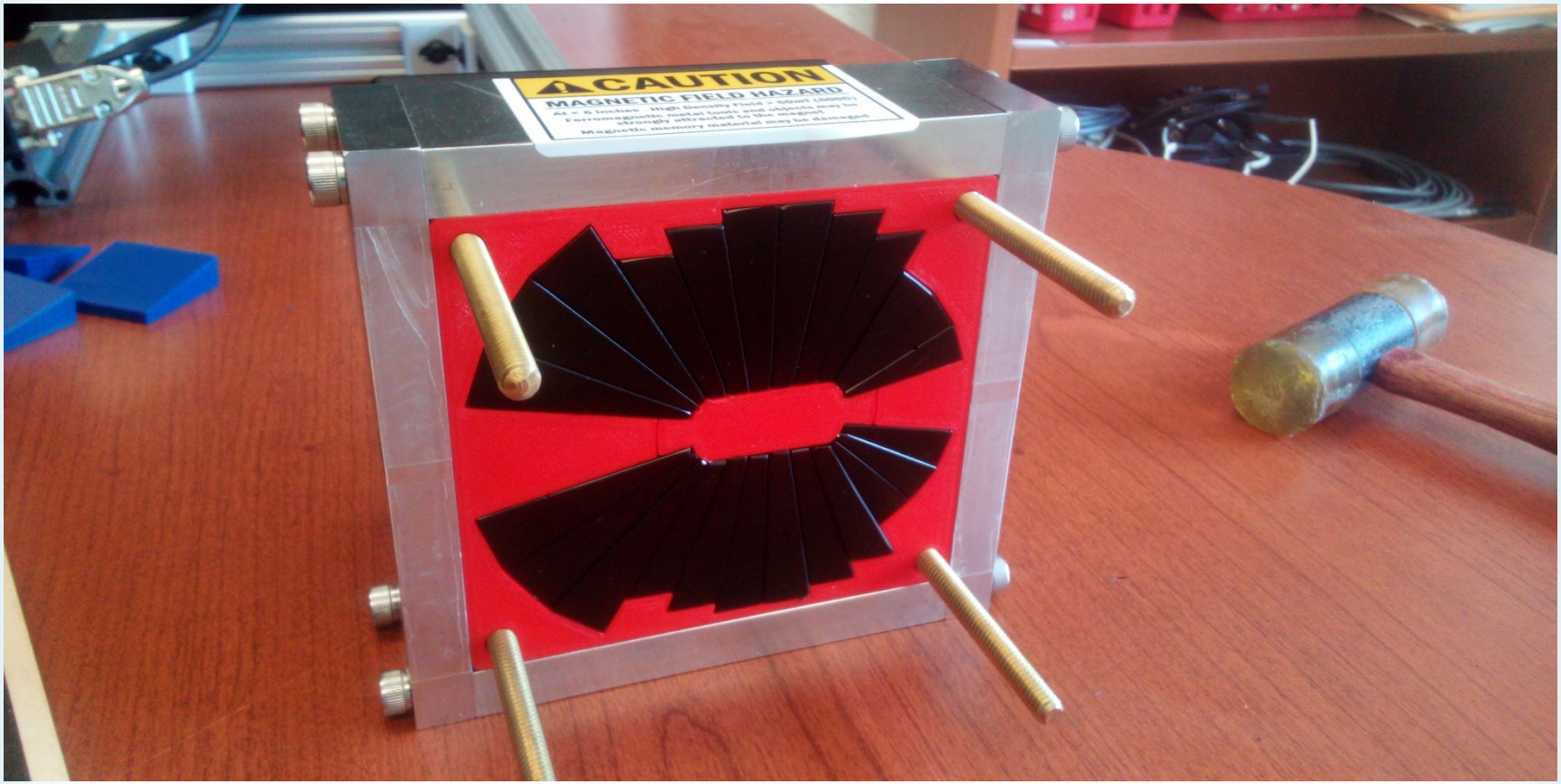
Open midplane design with >1.5T in good field region, 10^{-3} field accuracy, relevant for CEBAF upgrade

Magnet Design

- Bought 24 permanent magnet wedges from AllStar Magnets
  - Material grade N42EH, B_r=1.30T
  - 45mm length
- B(0) = -0.9512T, 55.54T/m
- ±10.5mm good field region
  - $B_{max,gfr}$ = -1.536T
- ±7.5mm vertical aperture
- 6mm total minimum gap

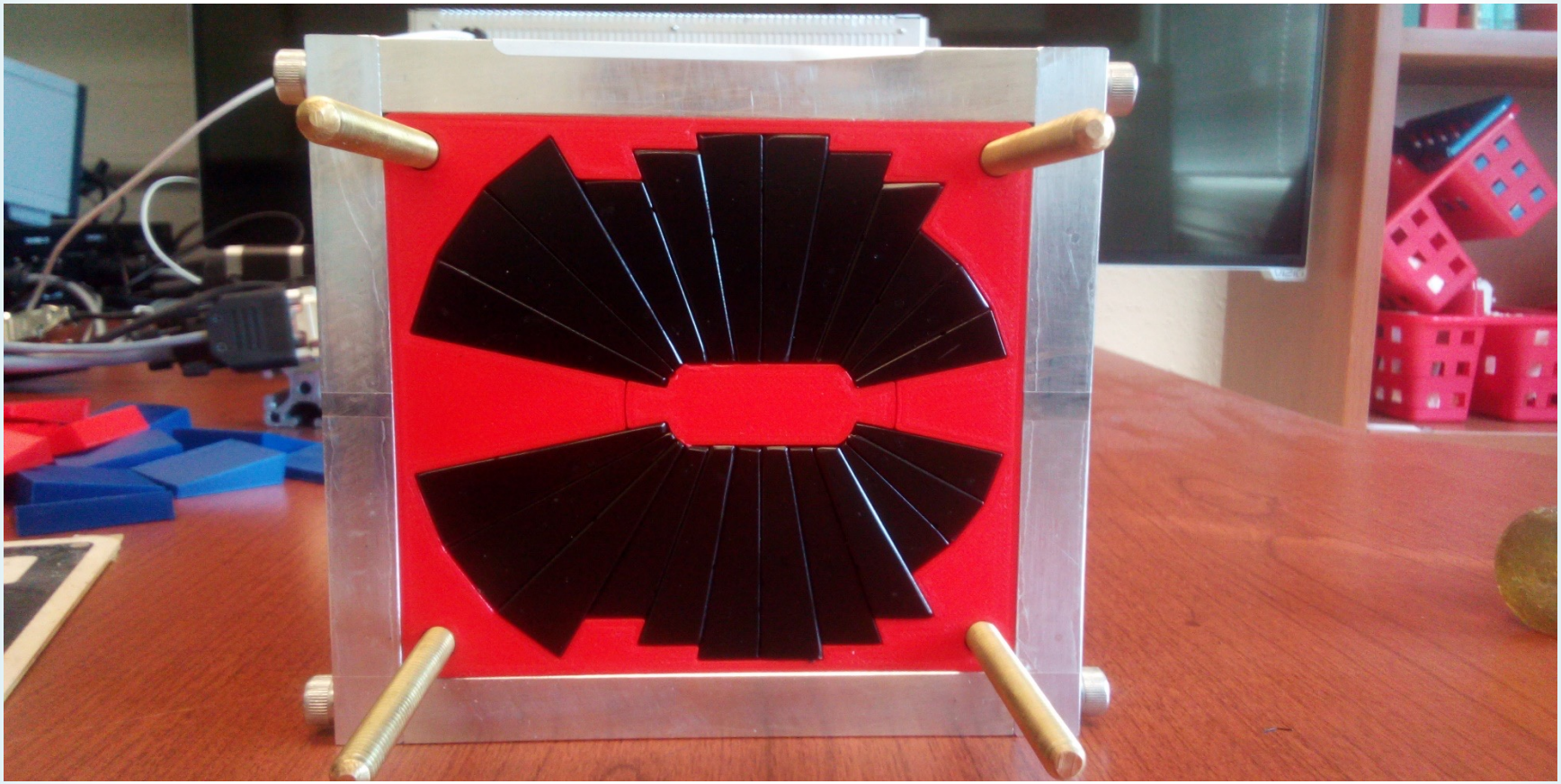


Assembled Magnet



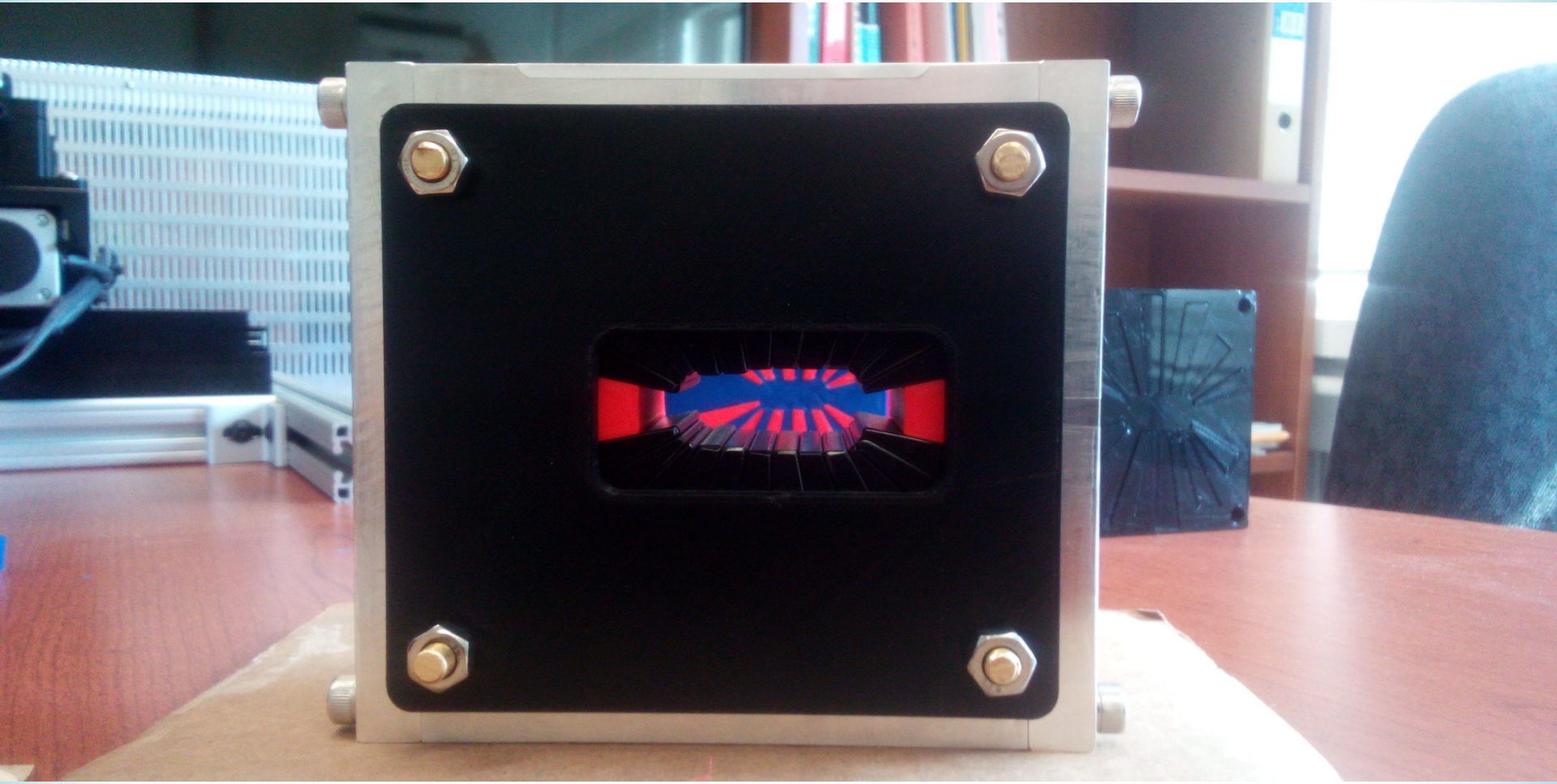
Outer ½” thick aluminium frame for strength

Assembled Magnet



Outer ½” thick aluminium frame for strength

Endcaps for Safety (no shims here)

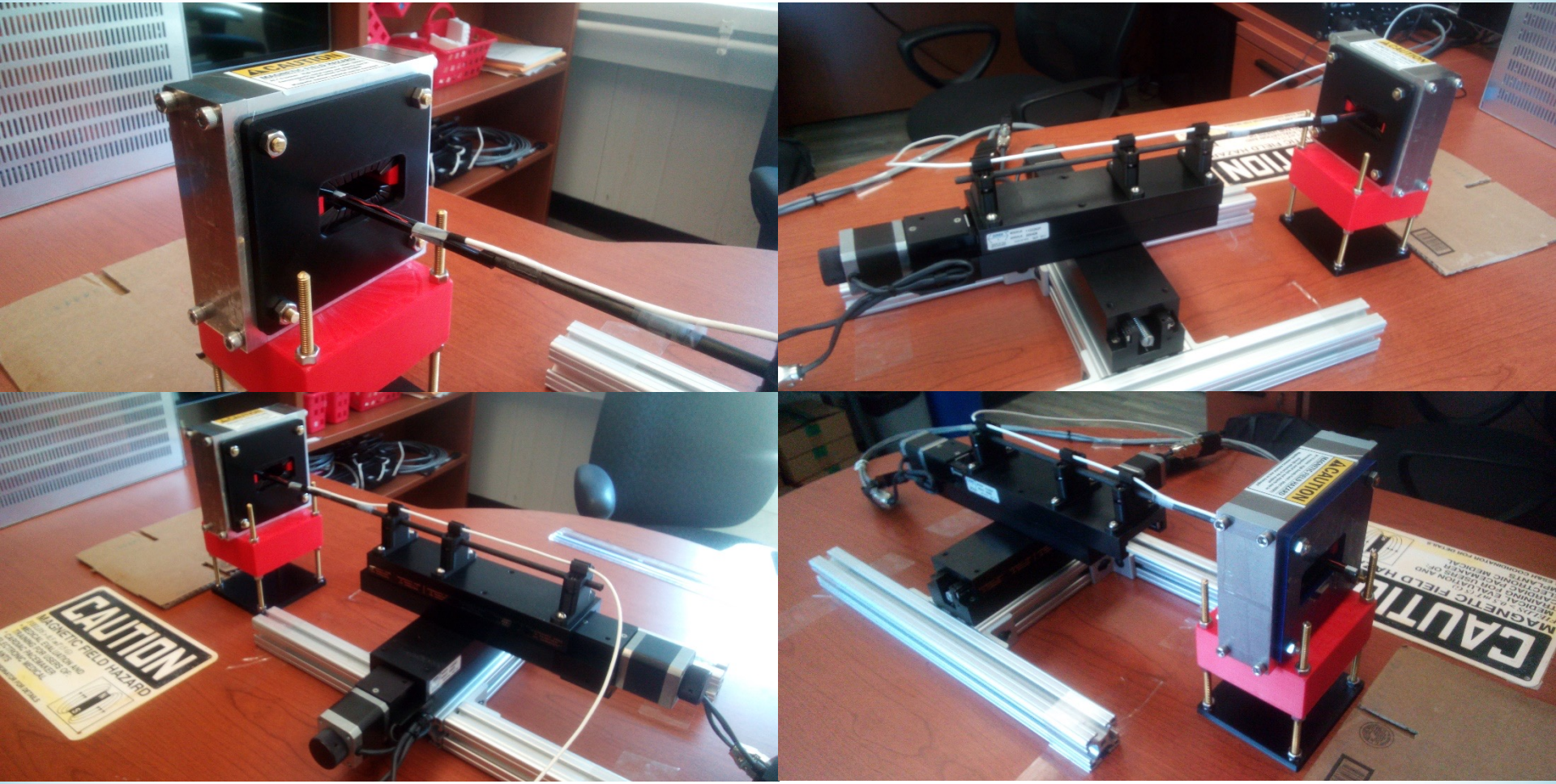


High fields exist in aperture

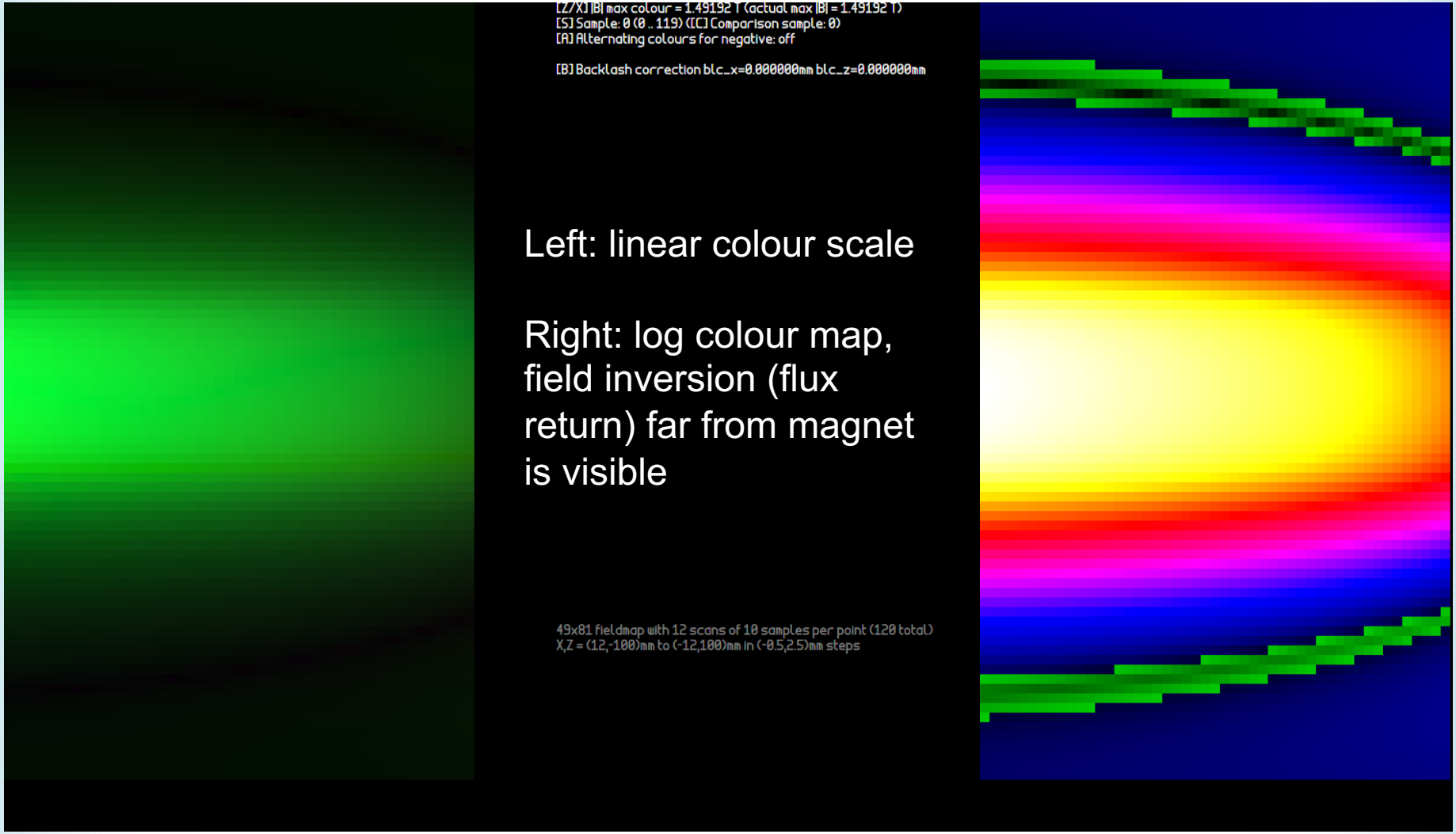
Fieldmap Measurement

- Used Senis 3MH6 teslameter with 3-axis Hall probe
  - Accurate to ±0.01%
- Two (horizontal X,Z) linear movement stages
  - Few microns
- ±10.5mm × 200mm
  - 0.5mm, 2.5mm steps
- 8 repeated scans

Fieldmap Measurement



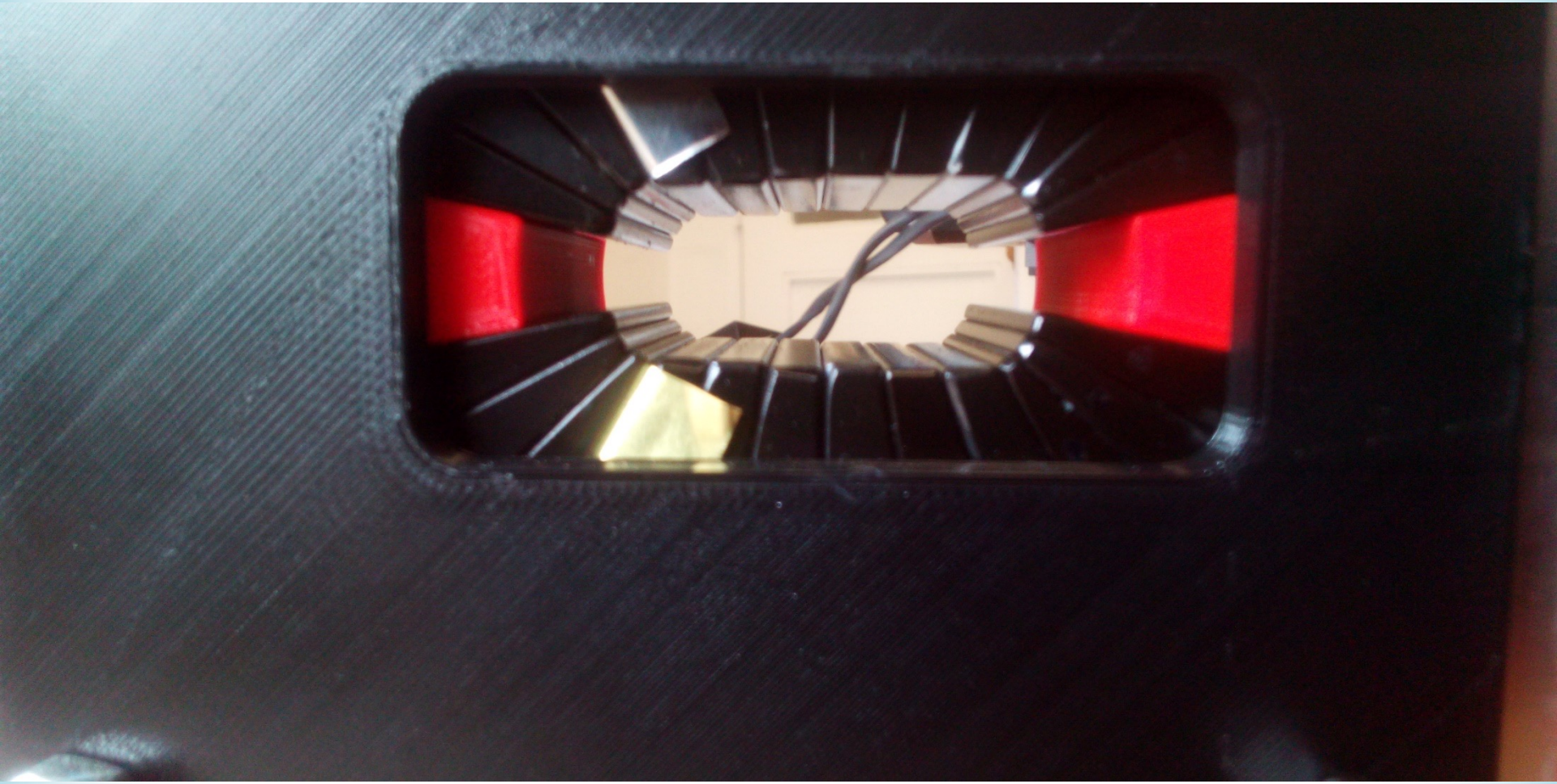
Graphical Fieldmap Plot



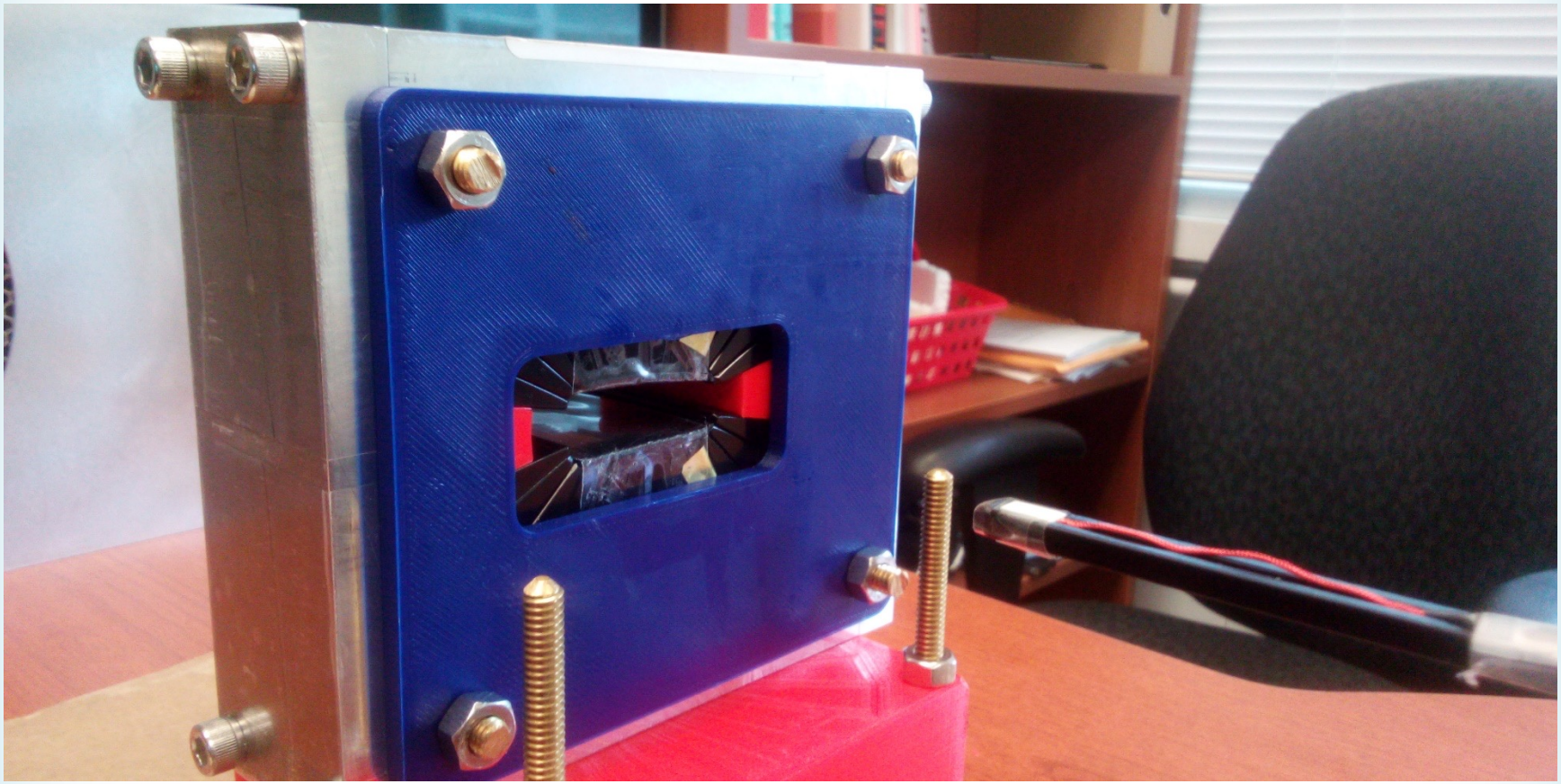
Run Sequence

- Run 1: bare magnet but bad wedge alignment
- Run 2: added brass shims between wedges (better alignment)
- Run 3: added 26× 35mil Ø iron tuning rods but got X-axis direction definition wrong!
- Run 4: tried first tuning iteration again with corrected X axis
- Run 5: verify first tuning iteration with different rod holder but field changed
- Run 6: investigate bare magnet without tuning rods again, field had changed, wedge alignment worse perhaps
- Run 7: tuning rods first iteration based on run 6
- Run 8: 2nd tuning iteration from run 6
- Run 9: 3rd tuning iteration from run 6

Aperture after Brass Shims (Run 2)

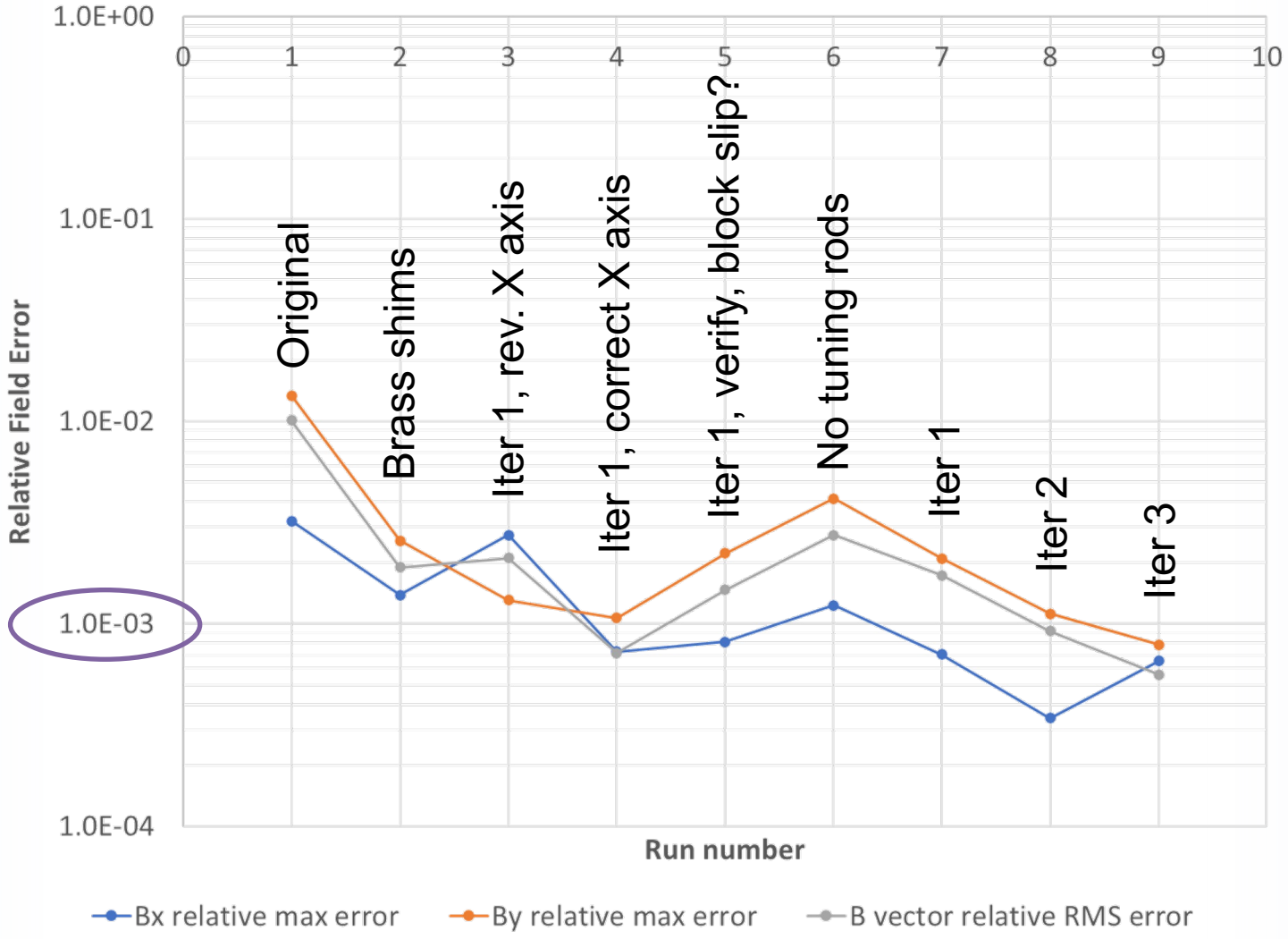


Magnet with Iron Tuning Rods

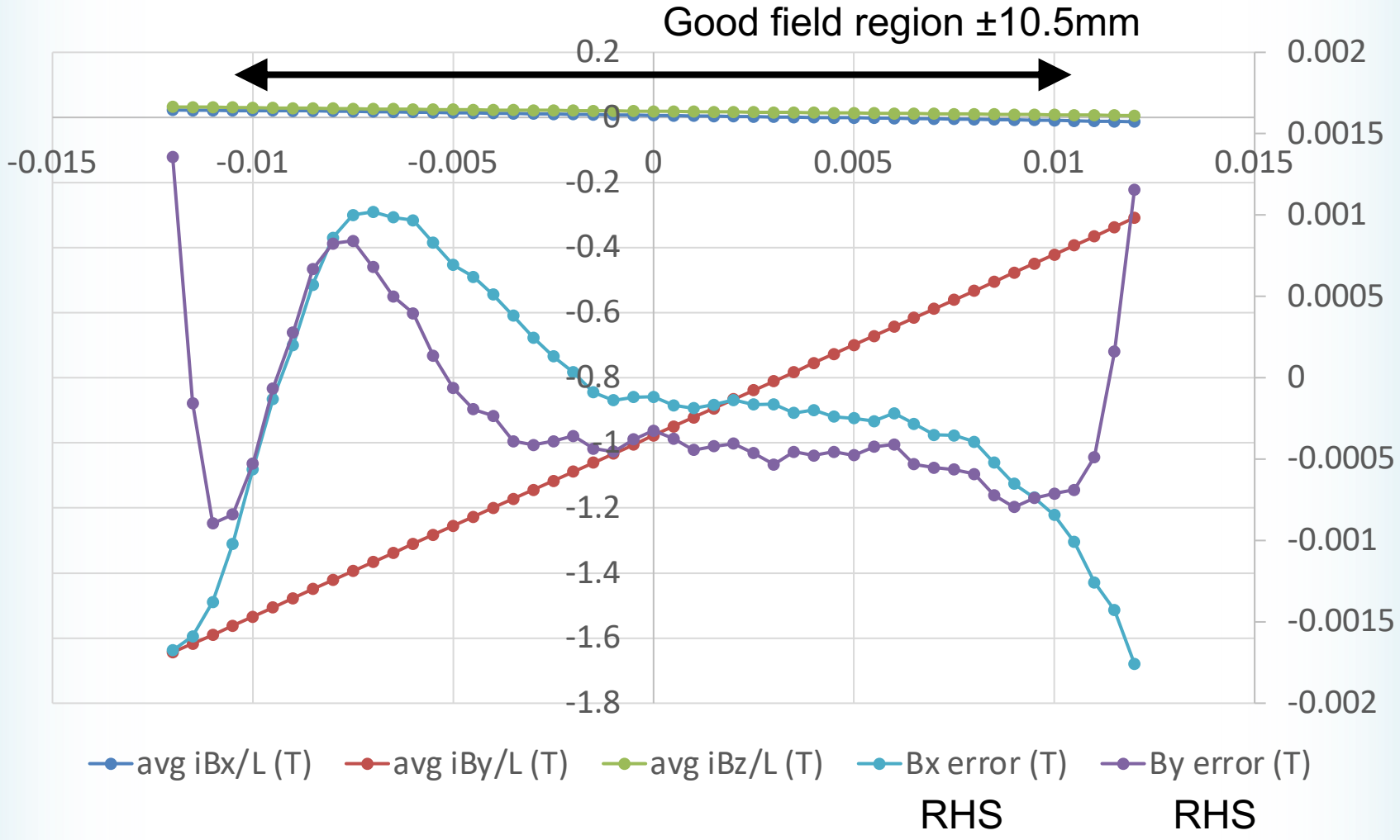


Magnet with Iron Tuning Rods

Maximum Field Error History

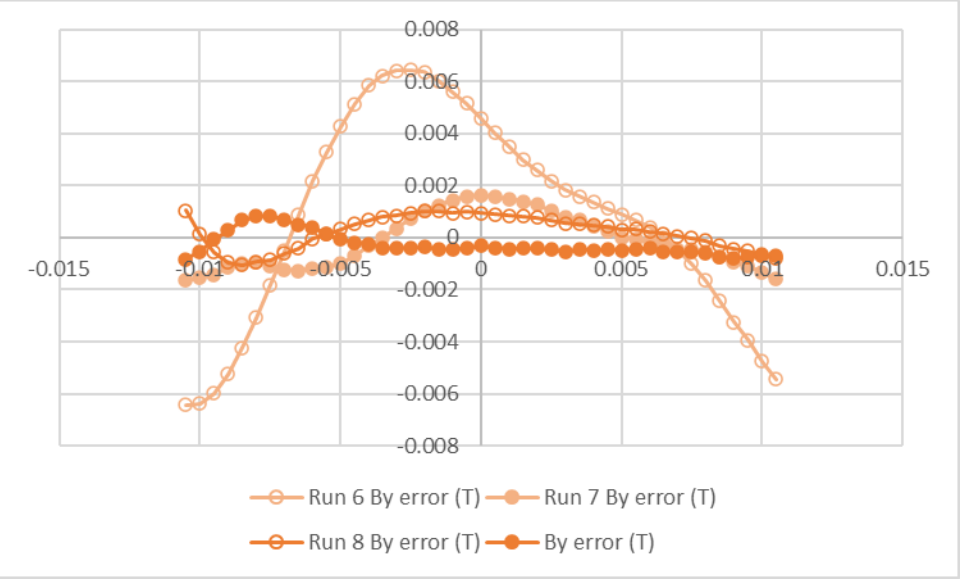


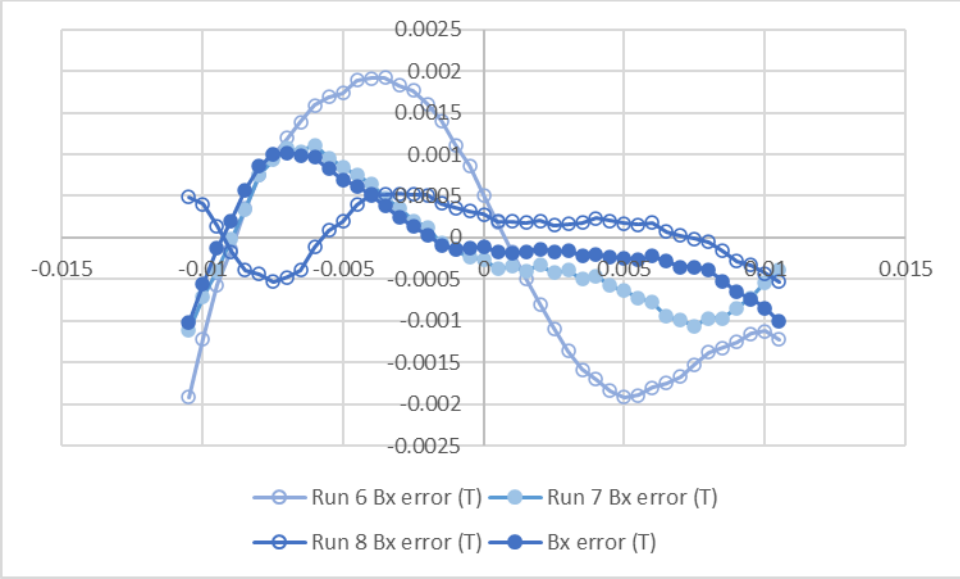
Integrated Fields (Run 9)



Integrated Field Error History

- Gradual improvement over runs 6-9
- Short magnets often require more iterations because of end field effects





Conclusion and Future Work

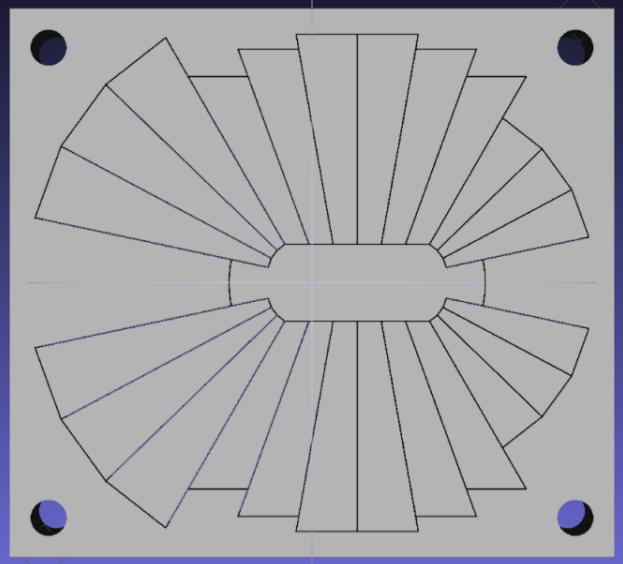
- A short section of magnet similar to CEBAF upgrade FFA has been tuned to <1e-3 accuracy
  - No glue/epoxy was used (might reuse wedges), so some issues with blocks staying in place
- Temperature variation and material thermal coefficient appears to be the main source of measurement error now
  - Working on temperature-controlled enclosure

Tooling for Assembling a Permanent Magnet

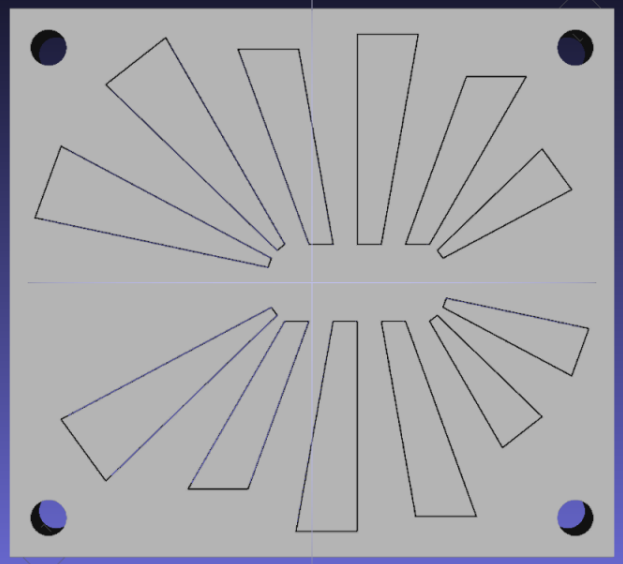
Combined function, high gradient, open midplane with >1.5T in good field region – for CEBAF upgrade

Tooling Design

Full mould
all pieces and central plug, printed
double wall thickness for strength

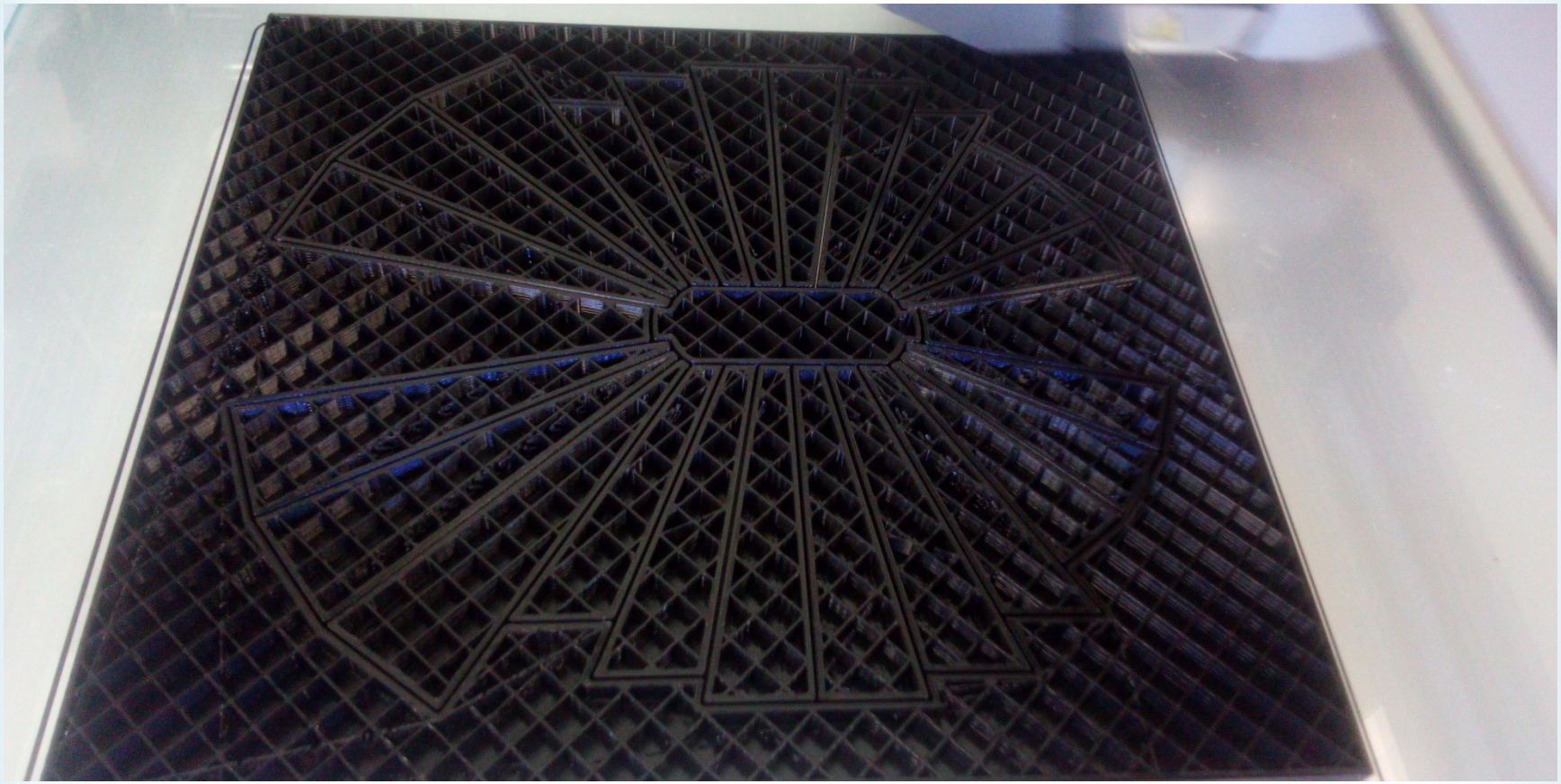


"Spider"
Channels for half the pieces
Can be flipped over to get other half



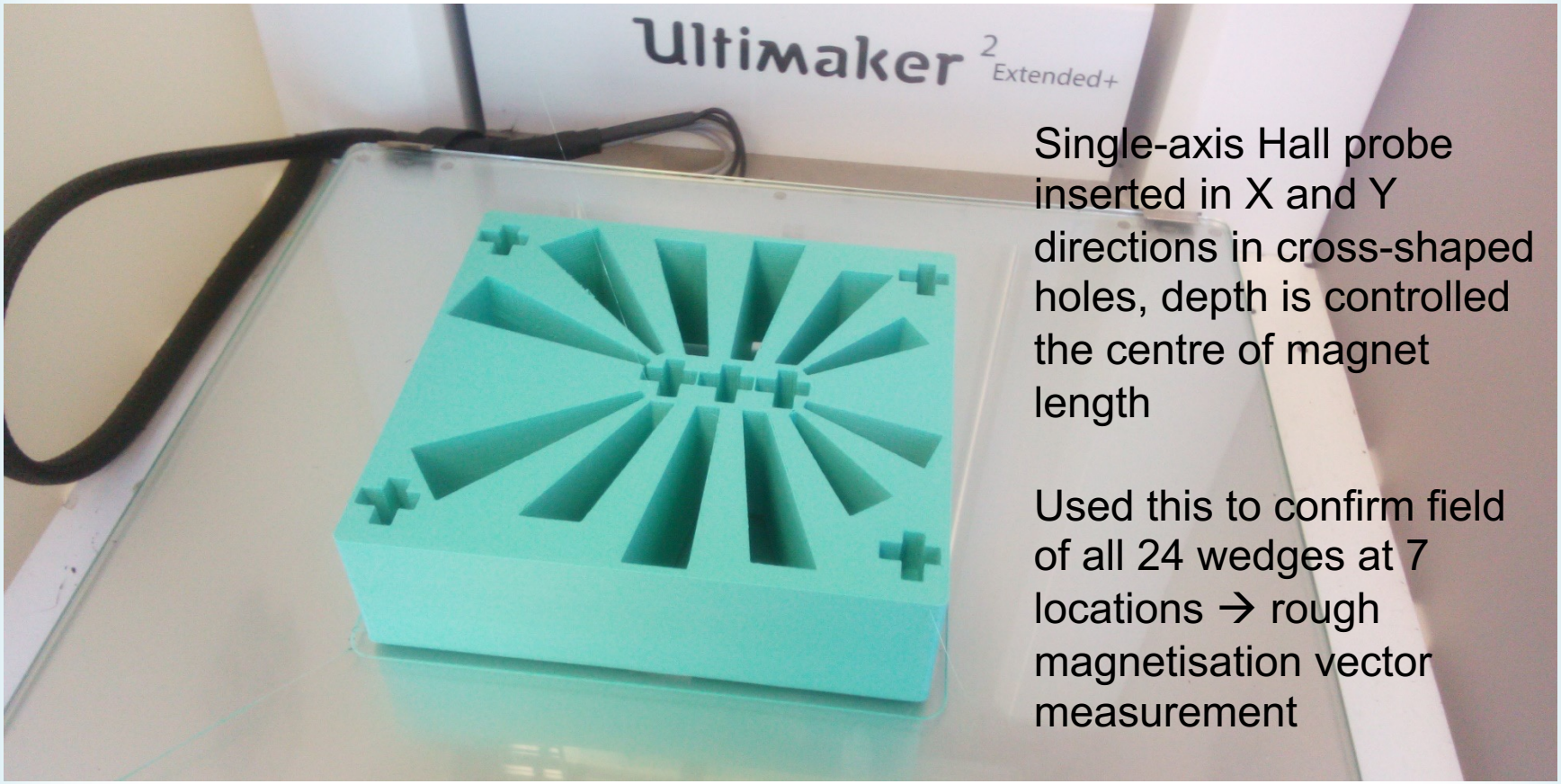
Corner holes for ¼"-20 threaded rods throughout, provide loose alignment, constraint

Can 3D print all parts in place



0.3mm spacing between pieces minimum possible with our printers

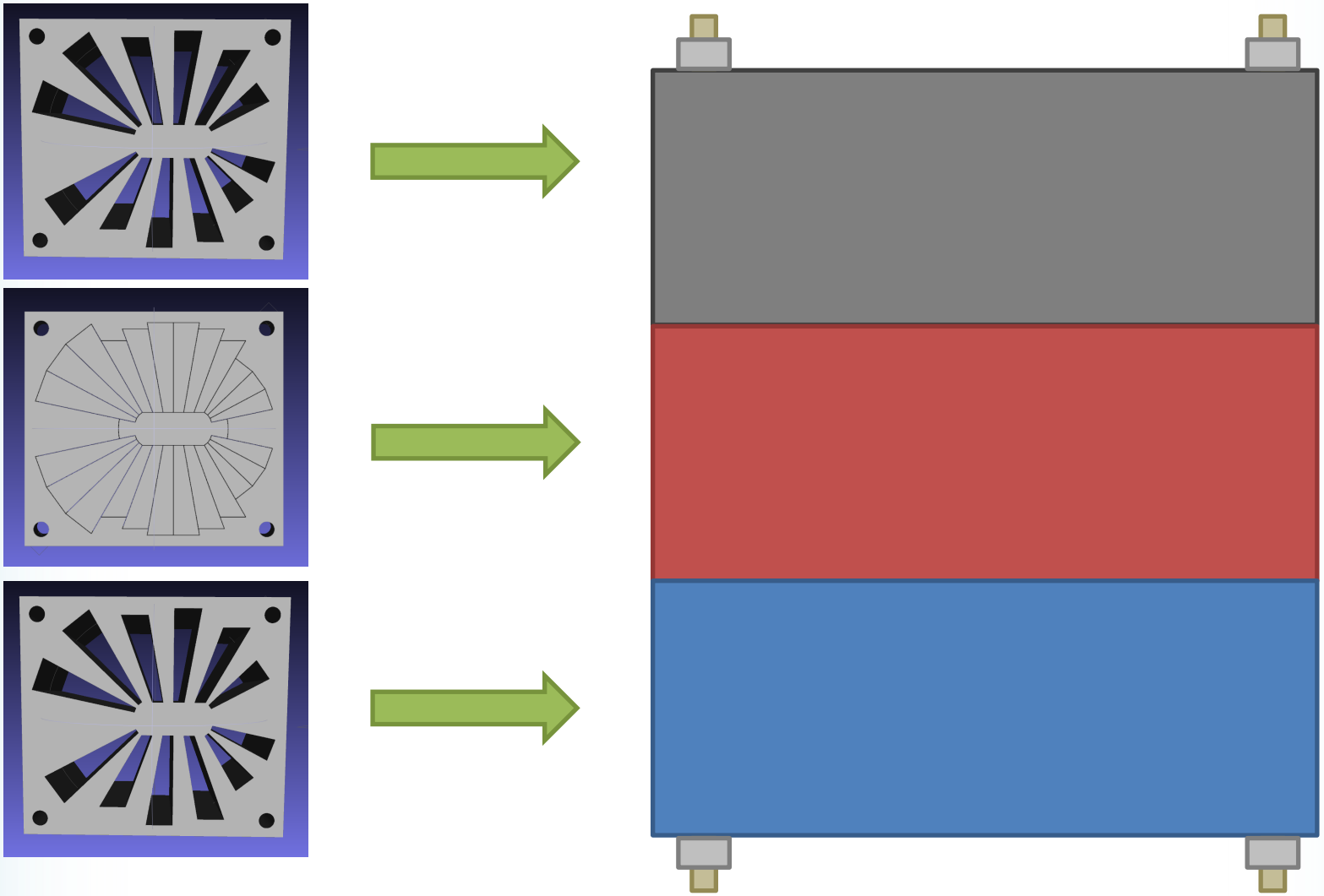
Point field measurement tool for Hall probe, also a “spider”



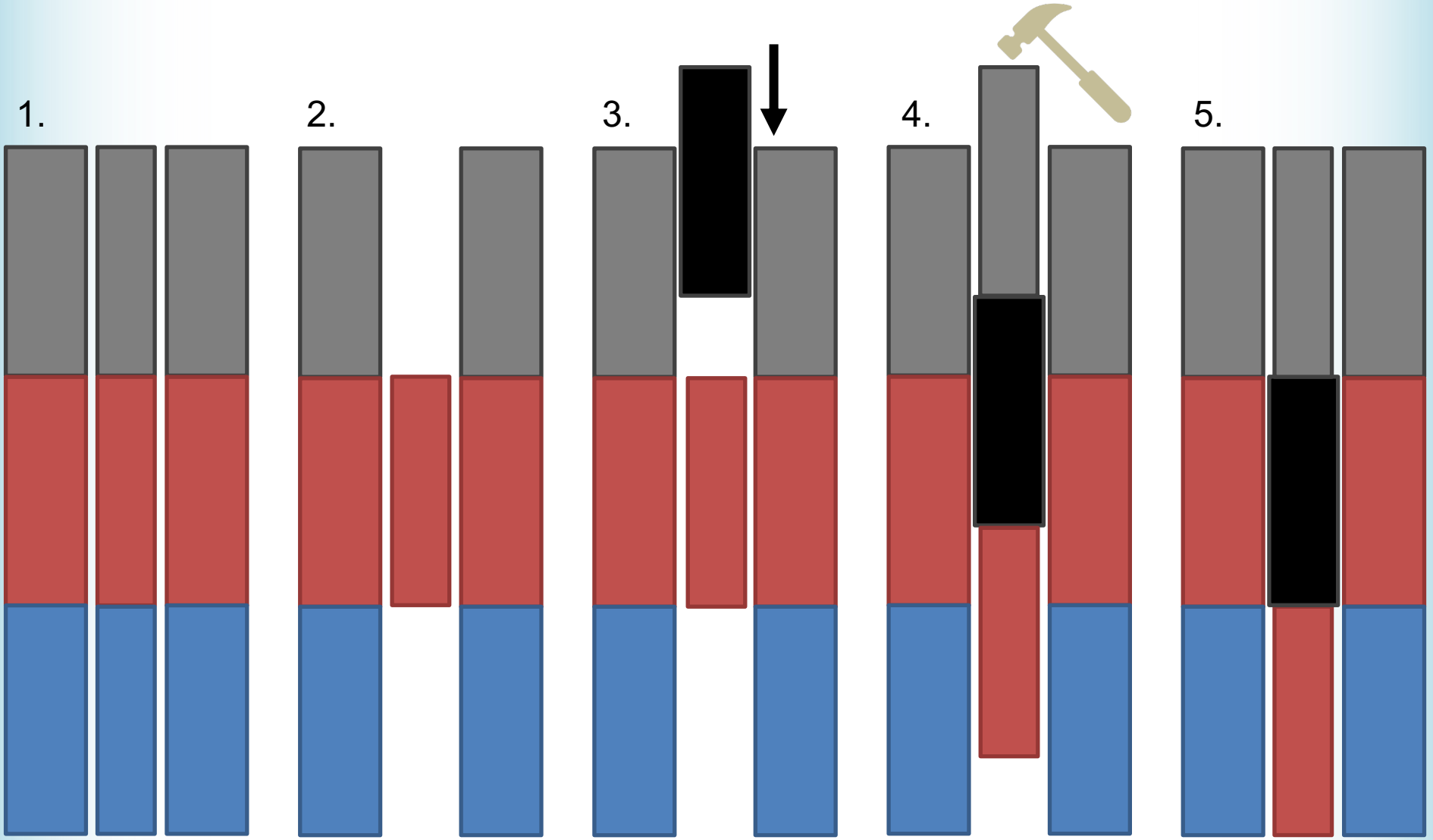
Single-axis Hall probe inserted in X and Y directions in cross-shaped holes, depth is controlled the centre of magnet length

Used this to confirm field of all 24 wedges at 7 locations → rough magnetisation vector measurement

Assembly Sandwich



Assembly Process



Assembly Process Notes

- Insert one half of the blocks and then flip the spiders over and insert the other half
- Make sure each block is pushed all the way in because they can repel longitudinally
  - Actually a mixture of attraction and repulsion
- The later blocks will be tighter fit but it was OK with the 0.3mm gaps (0.15mm larger mould)
  - Small gaps between some magnets were visible after central plug removed (0.1-0.2mm), inserted brass shims