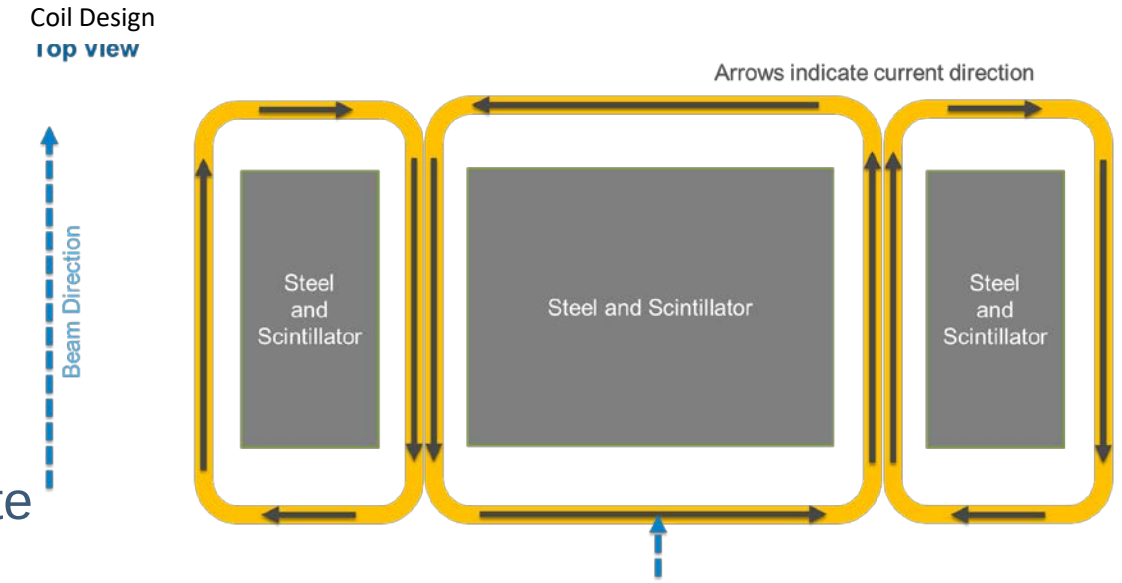
Magnetic Field Update

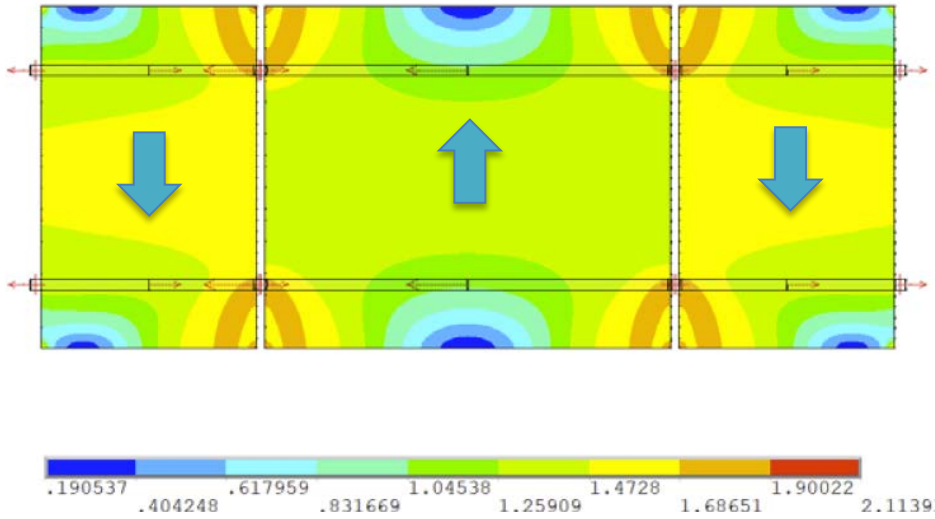
Tom LeCompte, Rick Fischer, Vic Guarino
Argonne National Laboratory

Our Story So Far…

- Magnet
  - Each plate sees a dipole; outside it's a sextupole
    - 1.4-1.5 T inside, < 0.1 T at the edge of LArTPC
  - Plan on 15000 Ampere-turns to slightly oversaturate the plates
  - Can possibly be air-cooled

- Some issues with the model output presentation
  - Field lines weren't continuous
  - Fields at adjacent points were dissimilar
  - Tracked them down: these are all presentational

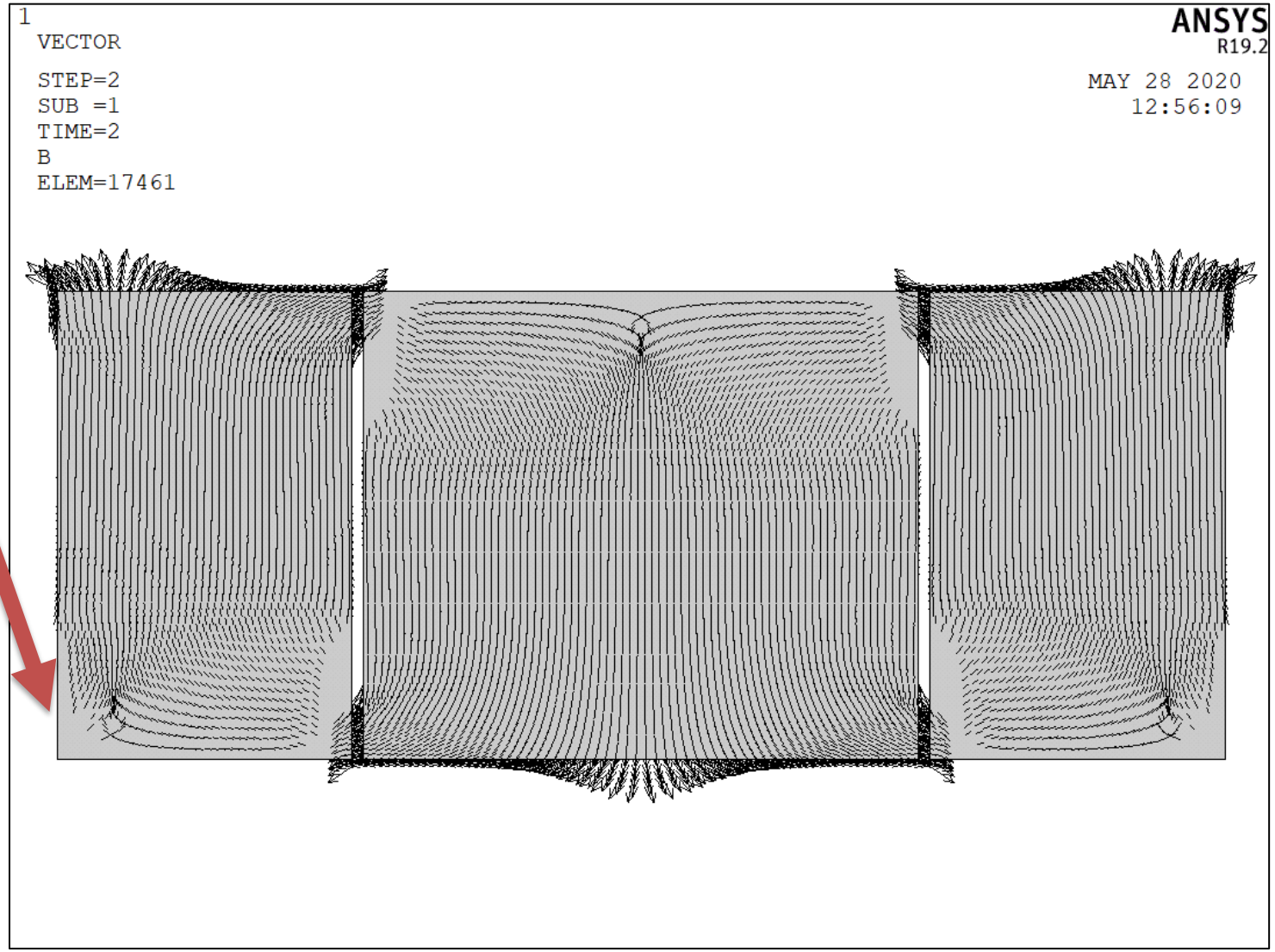




Magnetic Field at First Plate

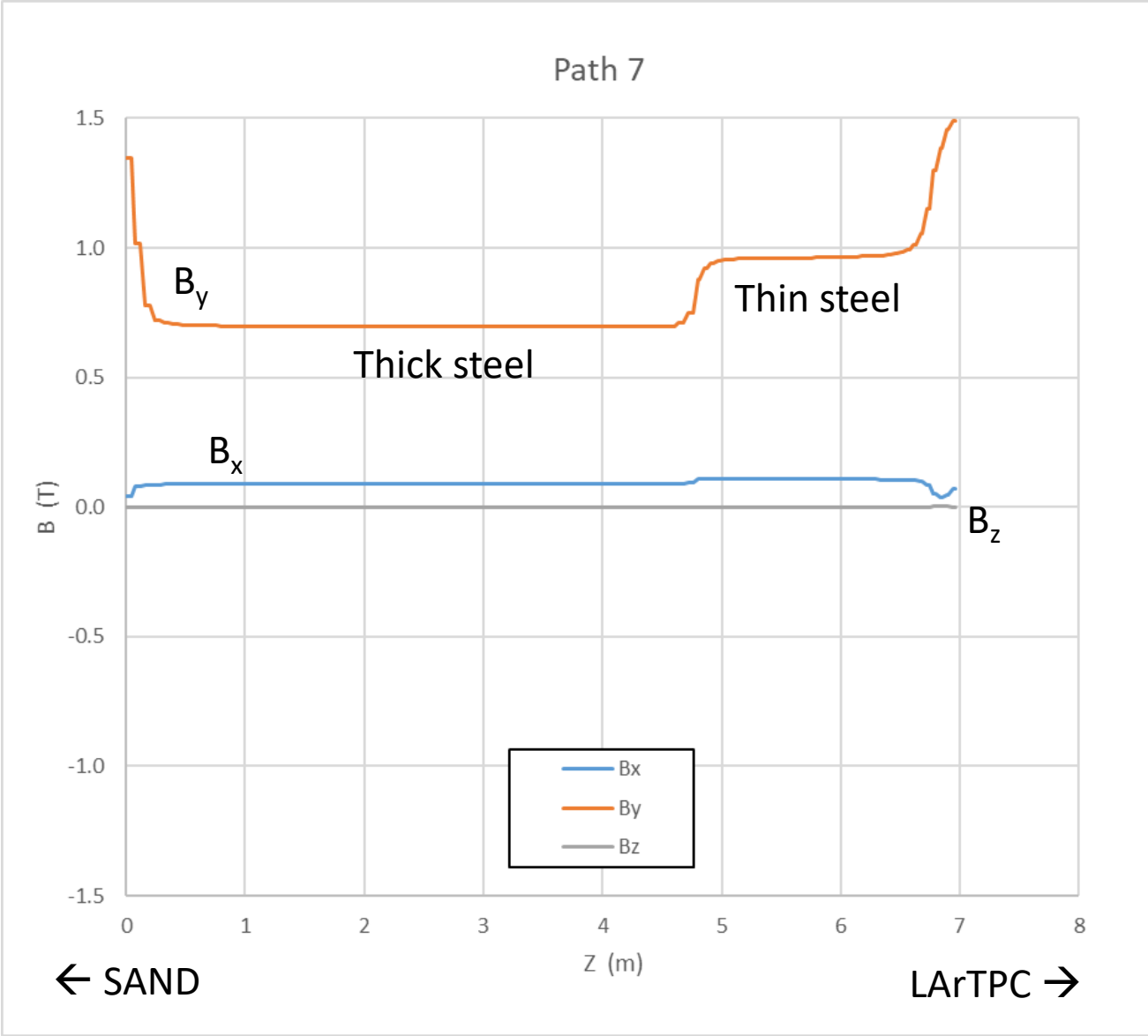
Magnetic Field Display Issues

- The field at the bottom left appears to run parallel to the current.
- The top and bottom are not symmetric
- By looking at tables of B(x,y,z) we are now sure that this is purely a display issue.
  - The tables look reasonable and do not match the lines.



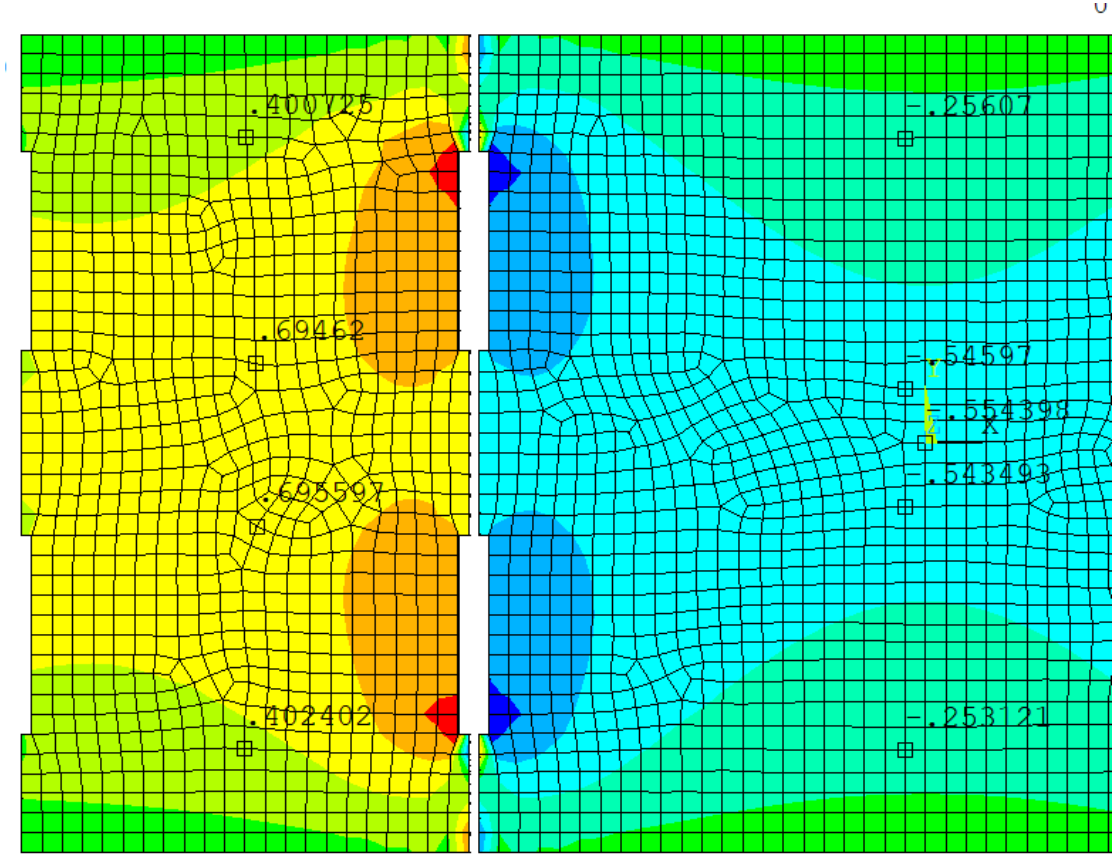
Reading a B-field Plot

- This is not (exactly) B vs. z
- This is B sampled **only in the iron** vs. z.
  - Failure to do this produced artifacts from aliasing
    - (the beat period between air gaps and sampling)
- I will go over the features of the field in a few slides

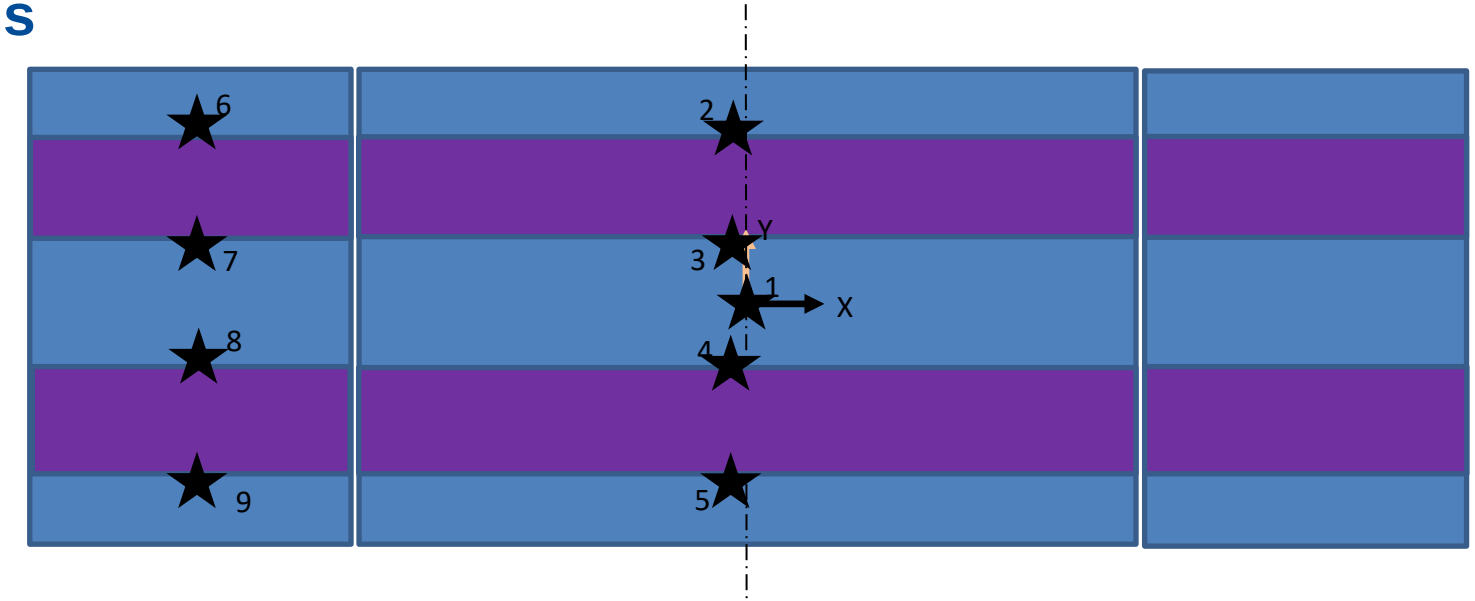


A Word On Symmetries

- The elements simulated do not have the exact symmetry of the magnet as a whole
  - There are technical reasons that this is a good idea
- This means that in regions where we expect the field to be zero by symmetry it may be small but non-zero
  - There are examples of this



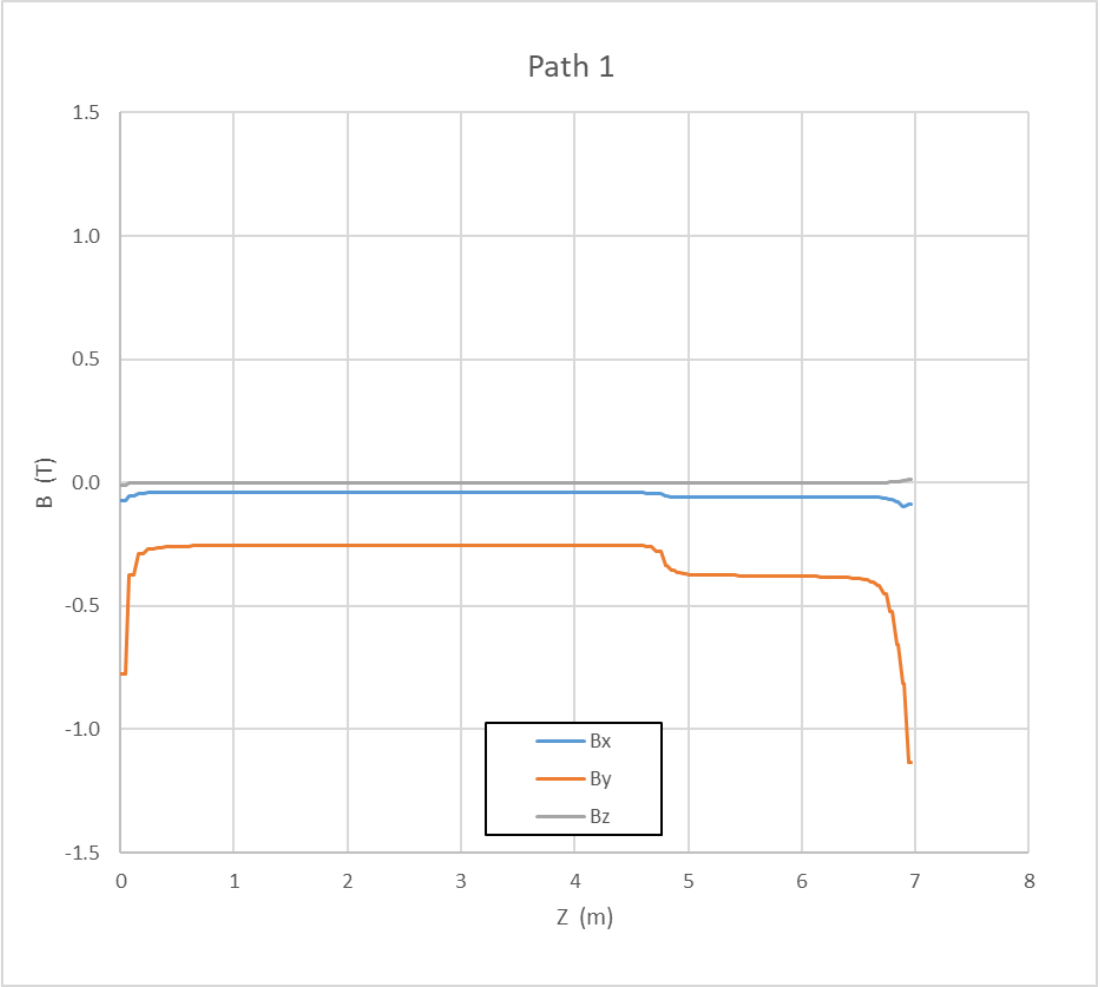
Simulated Paths



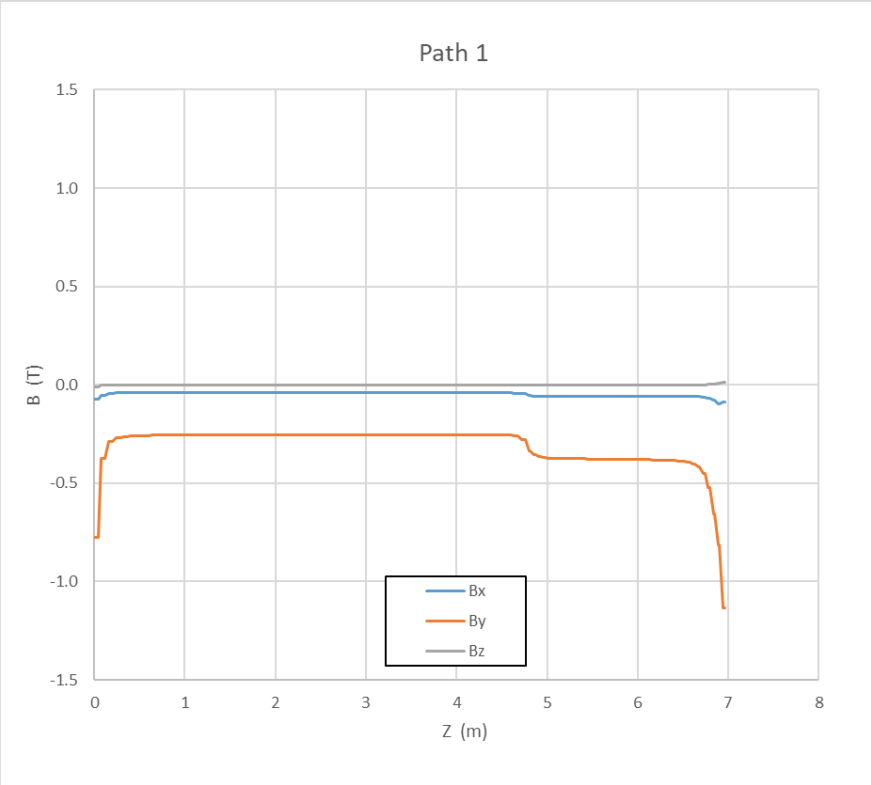
- We have selected nine “paths” – points at constant (x,y) where we plot B vs. z
- Some are intended as checks
  - e.g. 7 and 8 should be similar with Bx flipped
  - Similarly for 6 and 9
- I will not show them all

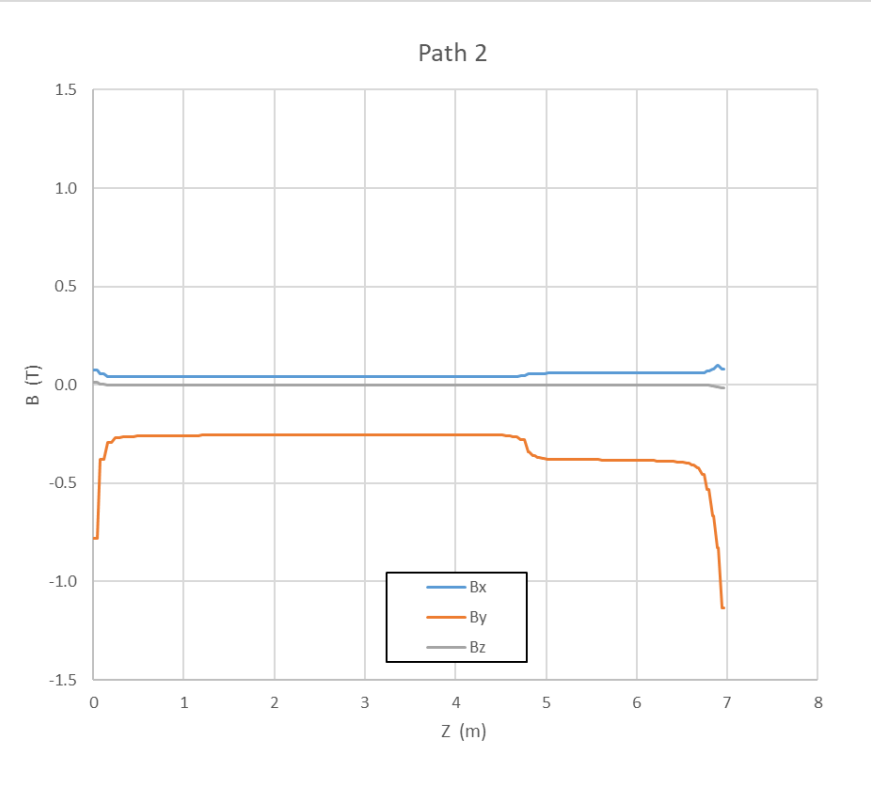
Path #1 – Dead Center

- This had surprisingly little field
  - it showed 1.2T in the color plot…
  - …but once inside the bulk of the steel, the field is much lower
- B_x should be zero by symmetry
  - It is small, but not zero
  - This is an example of what I discussed a moment ago
- The thick steel has less field than the thin steel (!)



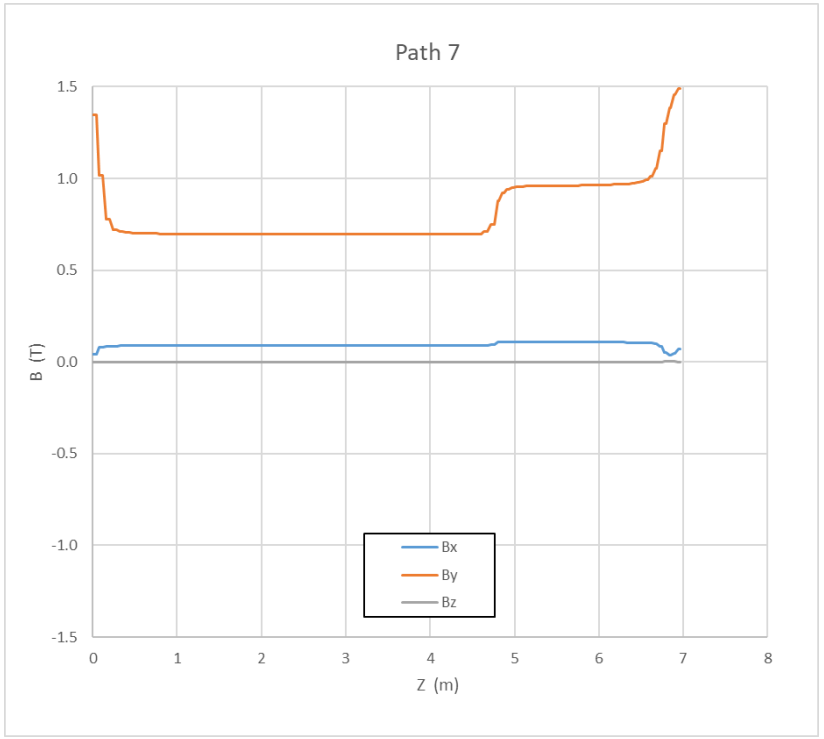
Path #2 – Above the Coil at center

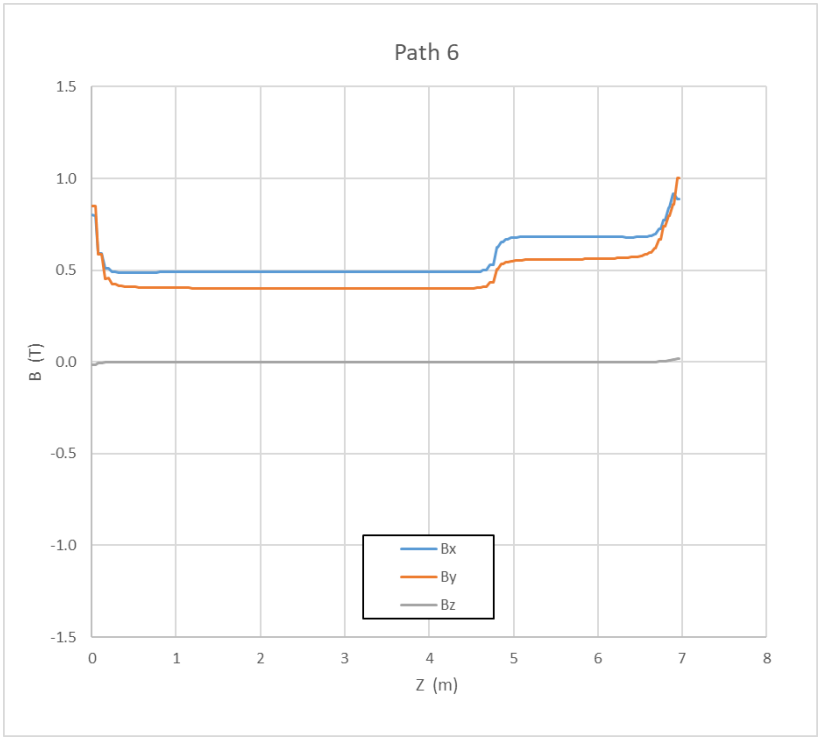




- Paths 1 and 2 look similar, as expected
  - (slightly different rounding errors in x-component)

Path #6 and 7 – Above/Below the Coil on the Left





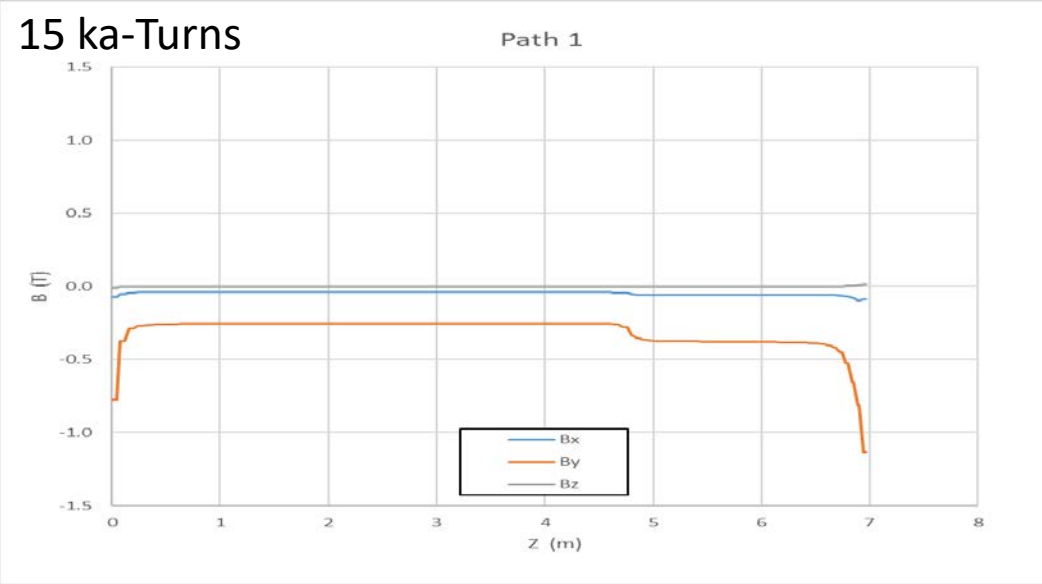
- Here we have more field
- In Path 7 (between the coils) the field is mostly vertical
- In Path 6 (just above the top coil) the field is tipped ~50º towards the inside

Mid-Talk Conclusions

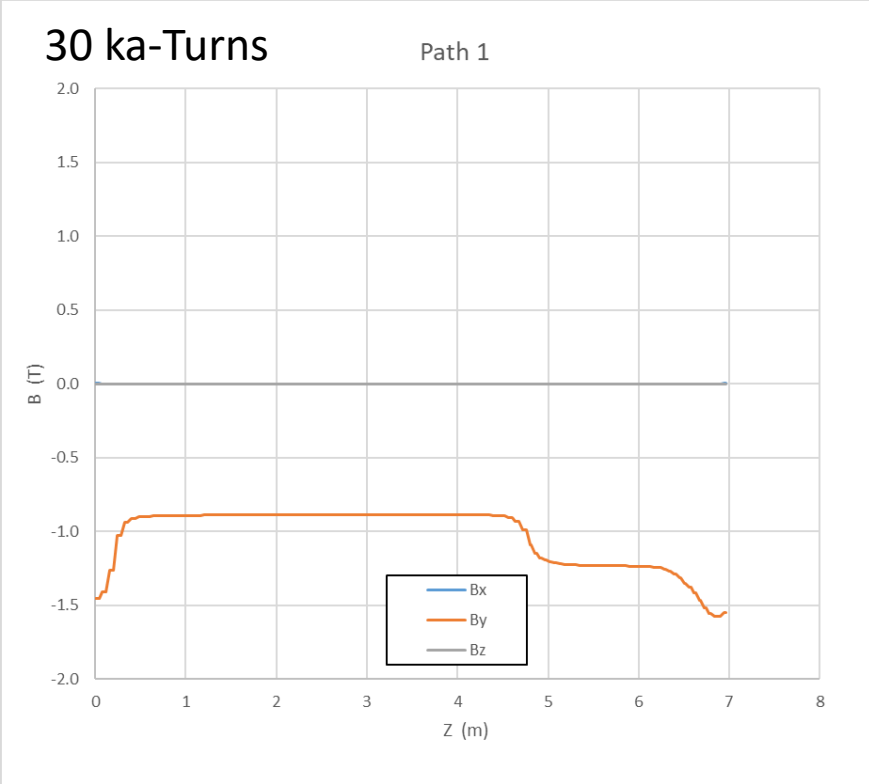
- We appear not to be saturating the steel
  - The field is low, especially deep inside the center plates
  - The field outside the coil is being returned through the steel (the 50^{o} tilt) rather than the air
  - The thick plates have less field than the thin plates
    - Mysterious in general, but definitely not what you expect with saturation

- Test – what does this look like at twice the current?

Path #1 (dead center) – 30 kA turns vs. 15 (nominal)

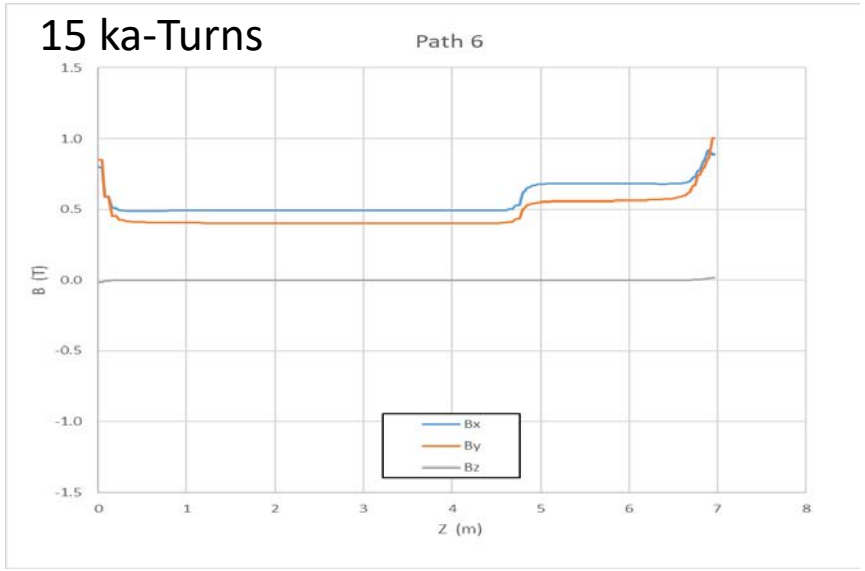


Attempted to set to the same scale.

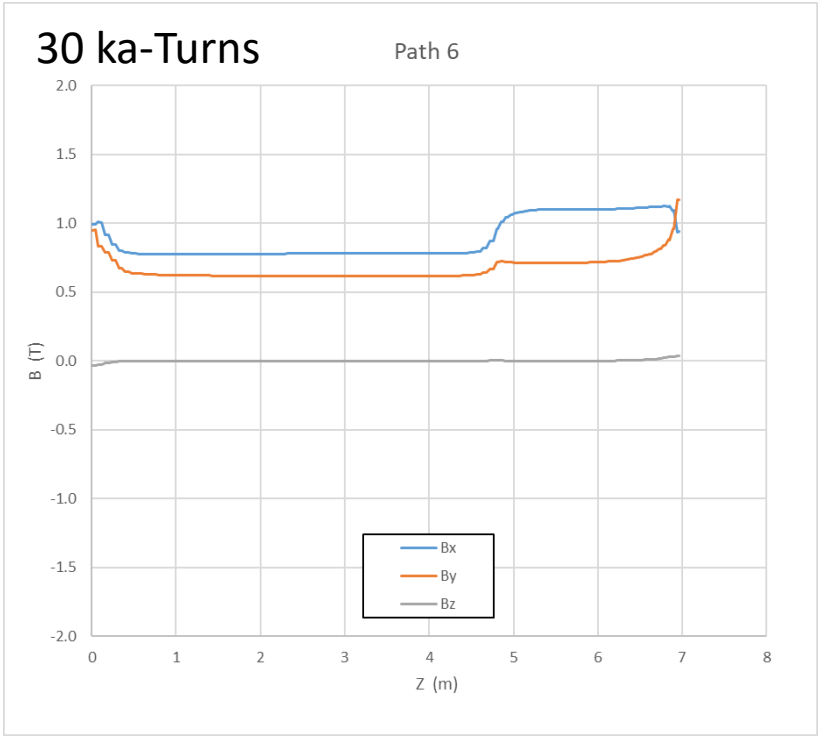


- This looks much more reasonable (but the steel still isn't saturated)
- Twice the current gives 3.5x the field. (!)

Path #6 (left, above the top coil) – 30 kA turns vs. 15 (nominal)



Attempted to set to the same scale.



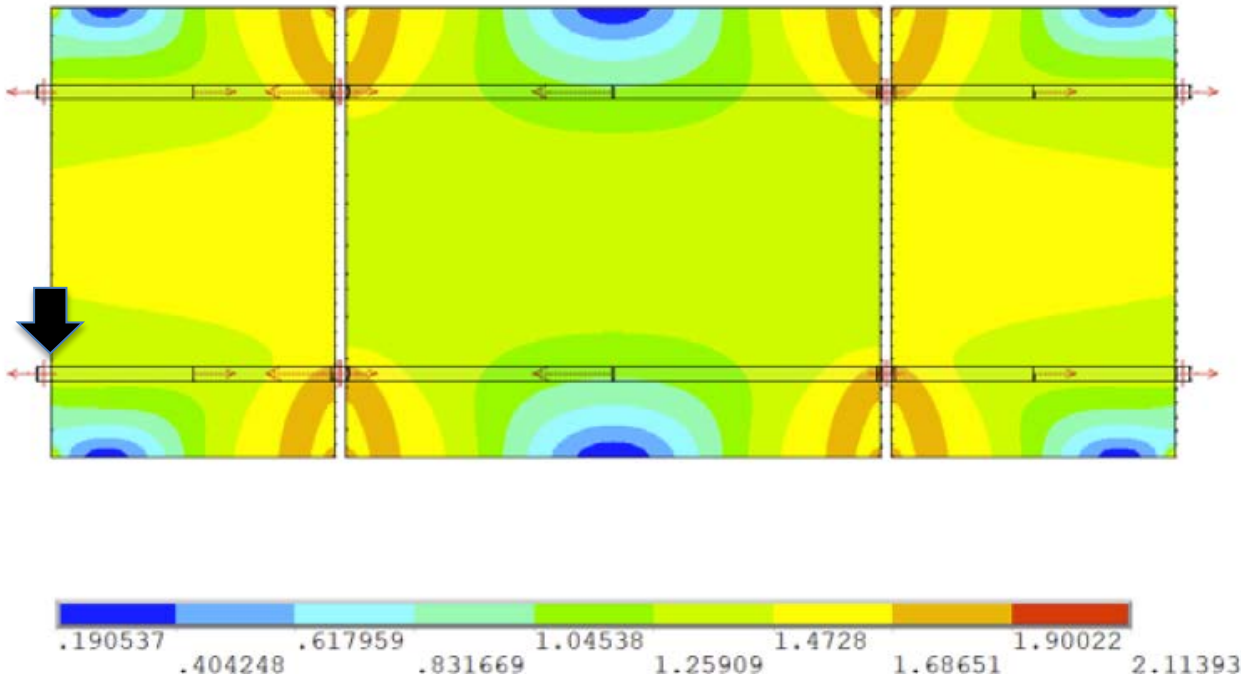
- The steel still isn't saturated – in fact, the tipping is slightly larger at 30 kA-turns than 15 kA-turns for the bulk of the steel

Conclusions from 30 kA study

- We aren't saturating the steel at 15 kA-turns
- We probably aren't even saturating the steel at 30 kA-turns
  - But we're coming closer
- How much field do we need? (I don't think we know for sure)
  - Having more field in the front is what we would like – and what the model says we have
  - It is still less expensive to add field than to add channels
- If we aren't yet saturating the steel, we know that the field in the air gaps is approximately zero

Future Studies

- We want to make the plot on the right for z = 9.1 m (in this coordinate system)
  - This is the closest the LAr fiducial can get to the spectrometer without colliding – closer than the nominal
  - I hope we can plot this for both B_{mag} and B_{xy} (the dangerous direction)
    - B_{mag} is possible;B_{xy} may be trickier



- We need a spec.
- “As low as possible” is not a spec.
  - We know at ~1 kG multiple scattering dominates over magnetic bend

The worst spot will be at the point indicated by the arrow (and symmetric equivalents). This is where the argon is closest to a coil and farthest from the counterbalancing coil.

Future Studies II

- The fringe in the argon may not be driven by the field as designed. It may be driven by imperfections in the physical object.
  - 0.3% steel thickness tolerance
  - Steel composition and grain structure non-uniformities may cause permeability to vary (~1%?)
- We will add 1% to the current of an end coil and see what it does to the field in the argon

Electrical steel grain structure (from Wikipedia)

Future Studies III

- We had planned to consider what happens when the coils are moved to the very top and bottom

- If we need more current, that probably means the coils will need to cover the full face
  - Effectively, the first plane is not steel, but copper (or possibly aluminum, but aluminum coils have their own issues)

- Low momentum is a hard place to do sign selection. This could be improved by making the first plate or two out of high silicon steel (~6x the permeability so 6x the bend). But there are tradeoffs:
  - This puts more fringe in the argon
  - Each layer adds ~3% to the steel cost

Summary

- Early issues have been tracked down to display problems, not problems with the underlying ANSYS models.

- The design of the stack was to slightly oversaturate the steel
  - 15 kA-turns doesn't do it.
  - 30 kA-turns doesn't do it either, but comes much closer.

- There are some additional studies we would like to do, but are relatively small perturbations on the model shown
  - We're nearing the end of this exercise

- There exists more data than I showed. It would be good to collect it on a Wiki page.
  - That would allow consolidation to more useful forms as well, e.g. $\int Bdz$