External RMP boundary conditions with internal coils

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The problem with internal 3D coils

- Coils are often placed just outside the limiter for maximum plasma response (DIII-D I-coils, SPARC REMC)
- Including the 3D coil in the simulation domain would be difficult at the very least, so the simulation boundary is generally placed at the limiter
- Having a conducting wall (ideal or resistive) at the limiter is not desirable, as it can artifically stabilize the modes being driven by the 3D coil (unless it is very resistive, in which case you have no conducing boundary for your plasma at all).

The situation in NIMROD

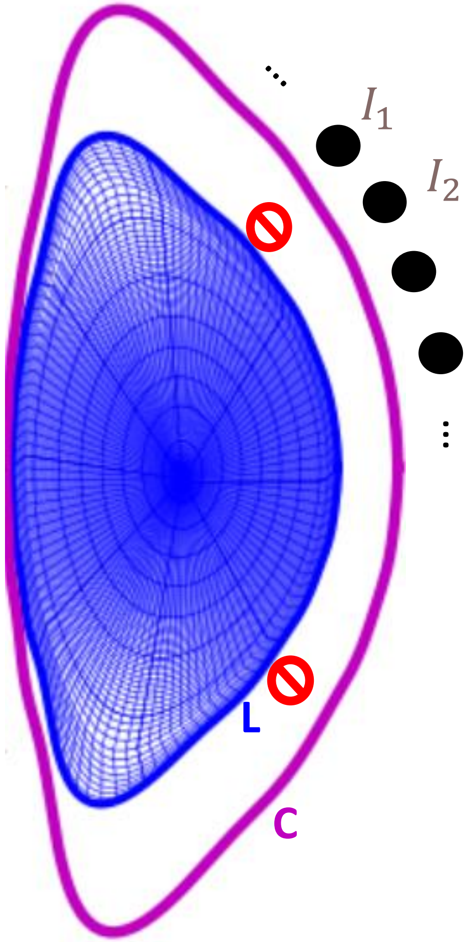
- The NIMBND rw boundary condition has only one wall, so it must be placed inside the coils. Penetration of the coil fields can be solved, but the artificial stabilization issue can not
  - Also, the n=0 component for NIMBND does not work yet
- The multi-region method used in nimuw requires gridding the external vacuum region, and so is not easily compatible with the 3D coil in that region.

What if we just pretend the coils are farther out?

- Concept is to apply and *equivalent* set of fields at the outer conducting wall that give you (nearly) the same field distribution at the limiter (or separatrix) as the coils, but *assuming a vacuum where the coils would be*

How would we find these fields?

For *each Fourier component*, assume (at least) m toroidal current loops arranged around the larger wall, where m is the poloidal grid resolution.



$$\boldsymbol{x} = \begin{bmatrix} I_1 \\ . \\ . \\ . \\ I_m \end{bmatrix}$$

A = fields produced by circular loop at boundary points

$$A_L \boldsymbol{x} = \boldsymbol{b}_n^L$$

Known b_n on each segment of limiter wall

$$A_C \boldsymbol{x} = \boldsymbol{b}_n^C$$

Unknown b_n on each segment of conducting wall

$$A_C A_L^{-1} \boldsymbol{b}_n^L = \boldsymbol{b}_n^C$$

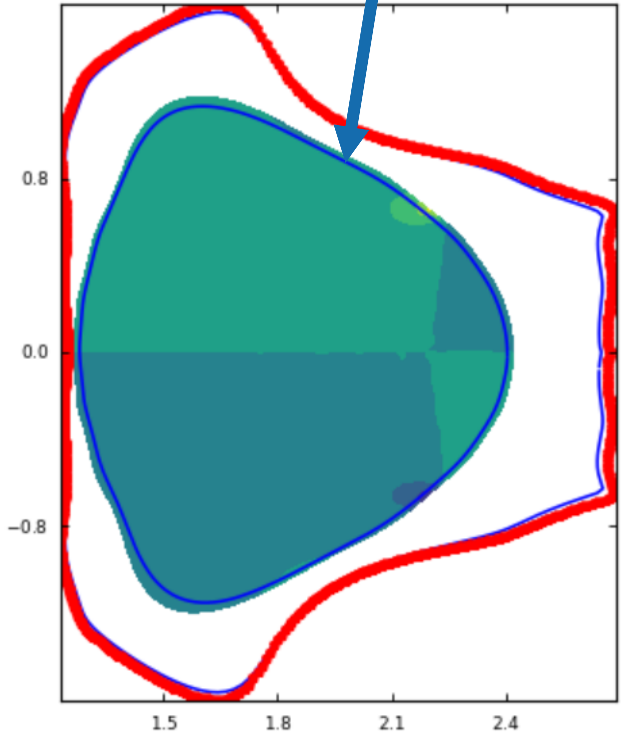
Is there an exact solution if the number of coils and boundary points are the same?

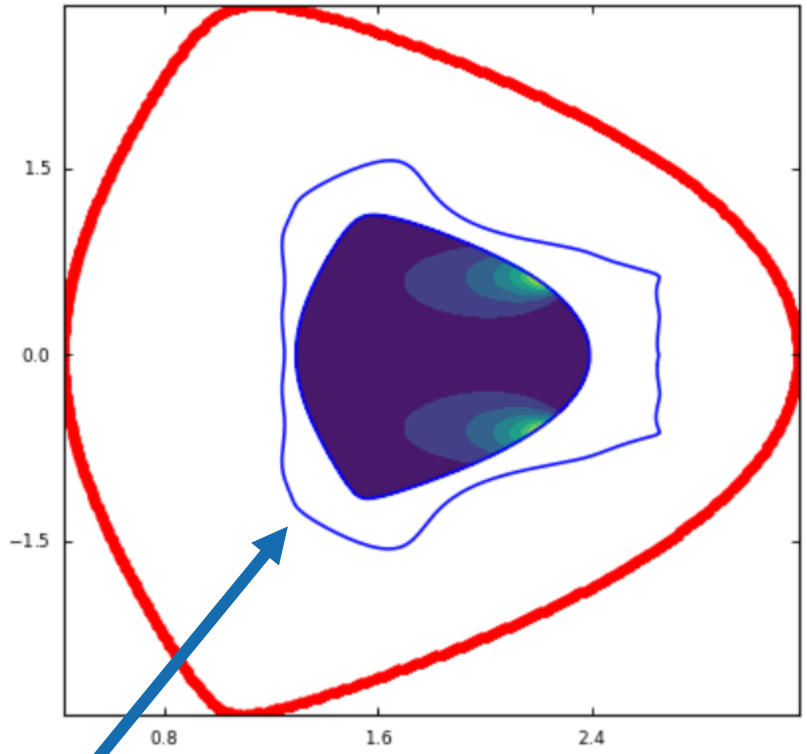
- Yes, but it's really useless
- I think the continuous problem has no solution. The discrete problem can be solved exactly, but the resulting coil currents oscillate wildly between +/-ridiculous for alternating coils
- This crazy arrangement of currents all cancels out to exactly what you need at the original boundary points, but projects to a crazy set of fields anywhere else

But can find least-squares solutions that are constrained to play nice

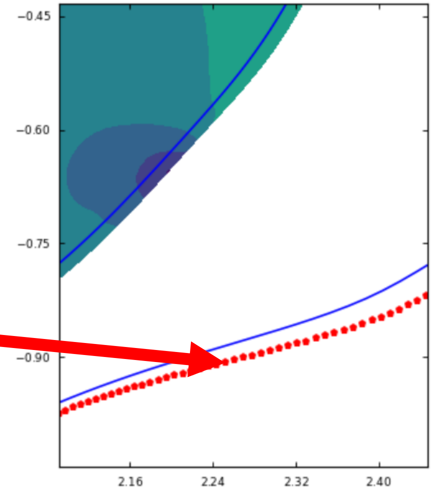
Some trial and error on where to put the coils… both sets of coils seems to be best

Initial boundary with known Bn (roughly the separatrix, just inside limiter)





VV boundary with unknown Bn

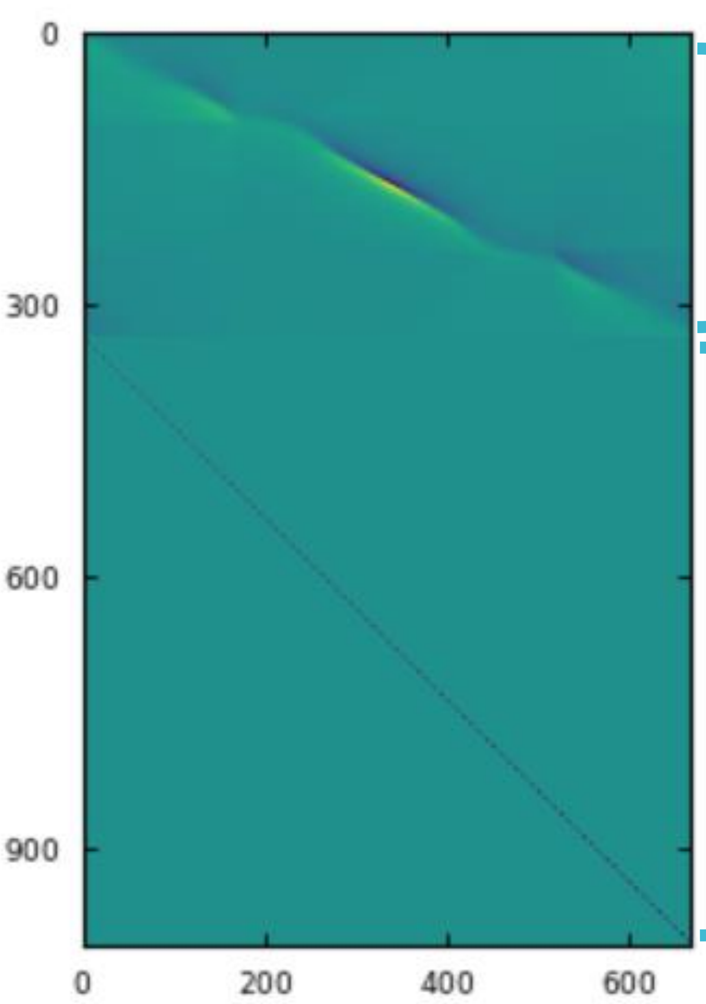


Locations of many virtual coils, whose current are solved for

How to constrain the solution? (1st thought)

A_L (336+670) rows **x** 671 columns
336 is # boundary points, 671 is # coils

$$A_L \boldsymbol{x} = \boldsymbol{b}_n^L$$



Upper part of matrix is coupling of coil currents to boundary fields (only this part is underdetermined)

$$= \begin{matrix} w & -w & 0 \\ 0 & w & -w \\ 0 & 0 & w \\ & & & \ddots \end{matrix}$$

This part wants to force neighboring pairs of coils to have almost equal currents (w is some weight). Prevents wild oscillations. Becomes overdetermined.

$$\boldsymbol{x} = \begin{bmatrix} I_1 \\ . \\ . \\ . \\ I_m \end{bmatrix} \quad m=671$$

$$\boldsymbol{b}_n^L = \begin{bmatrix} b_0 \\ \vdots \\ . \\ b_N \\ 0 \\ . \\ . \\ . \\ . \\ . \\ . \\ 0 \end{bmatrix} \quad \begin{matrix} N=336 \\ \\ 670 \end{matrix}$$

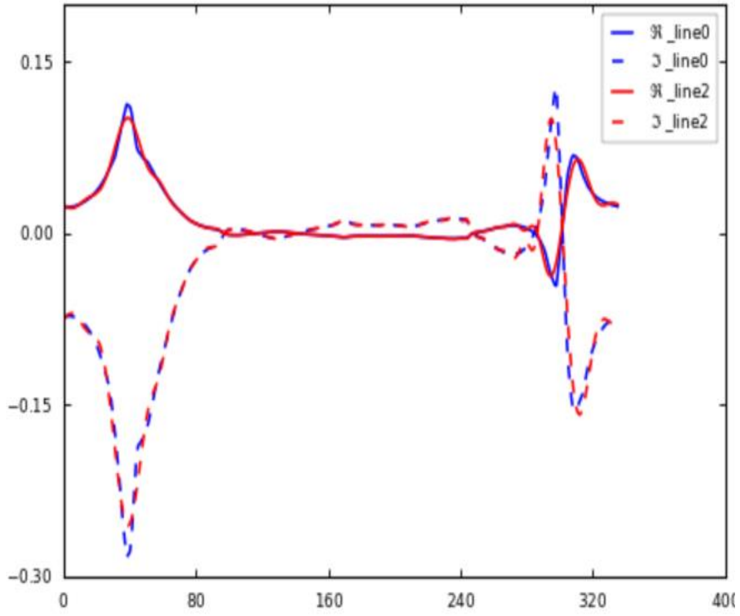
One other thing I tried

- I have the matrix for the coupling of the coils to the larger wall– don't know the RHS, that's what I'm trying to get
- But I considered finite differencing the rows of that matrix rather than the coil currents for the bottom half of the overdetermined matrix… this would constrain the final solution to be smooth rather than the coil currents that I don't ultimately care about
- Seemed like a more promising idea than my first thought… but it wasn't. Anything that doesn't directly prevent huge oscillations in the coil currents goes back to giving those kinds of solutions.

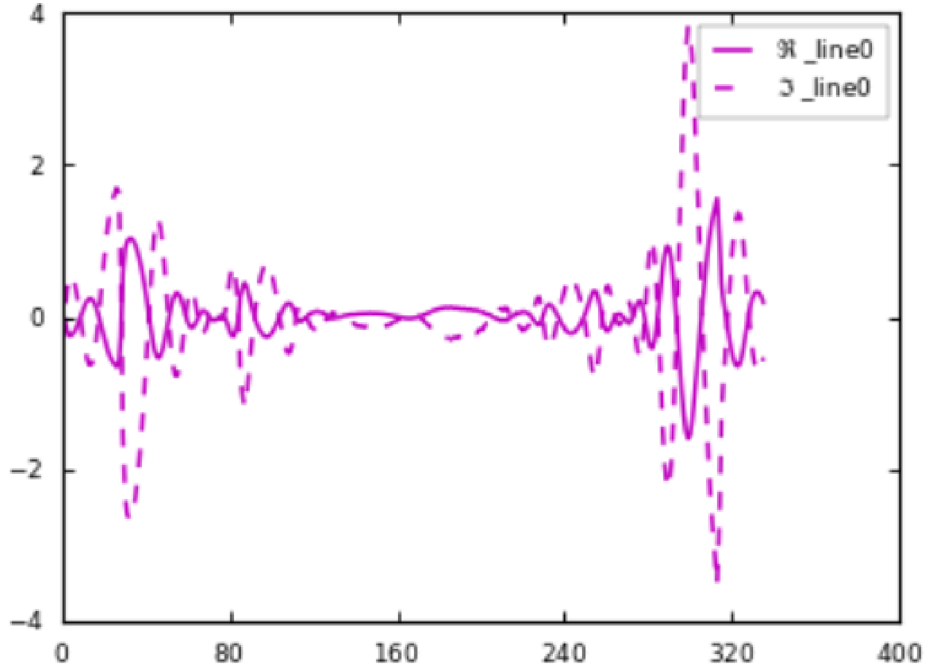
Jumping to the punchline

Known B-fields for 336 boundary points

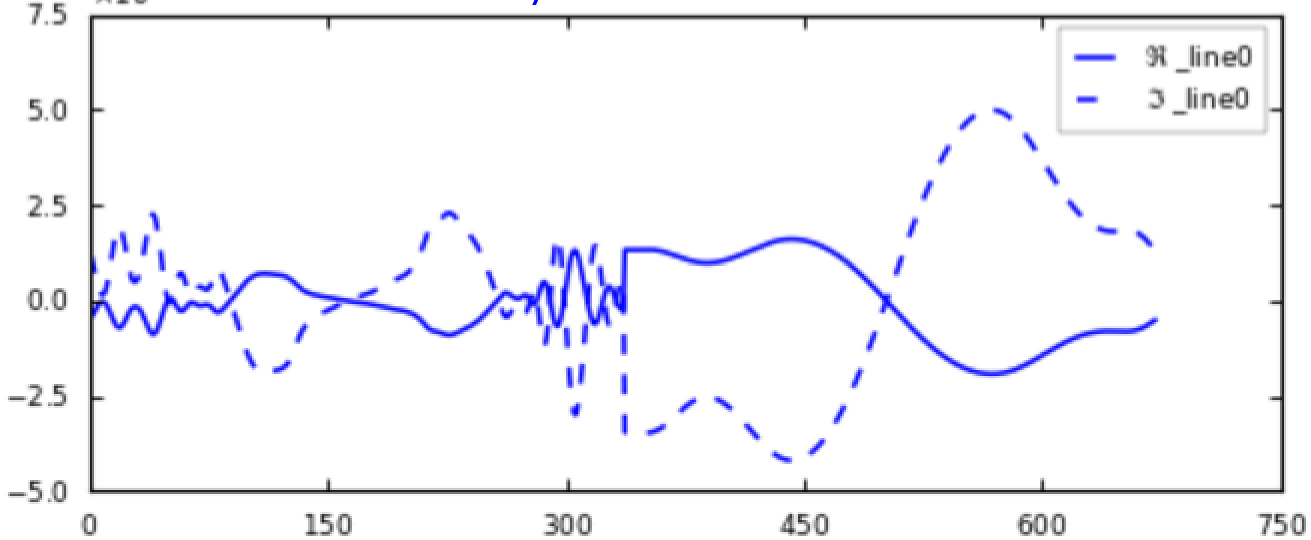
Approximate B-fields of least squares solution



Fields projected to larger VV boundary



Coil currents in 672 virtual coils



Test will be to see if plasma response looks similar to original boundary fields

- In progress
- If this method is successful, a good case could be made for using the multi-region boundary conditions with a true vacuum outside the limiter … especially because the n=0 works … but would need to be incorporated into nimdevel