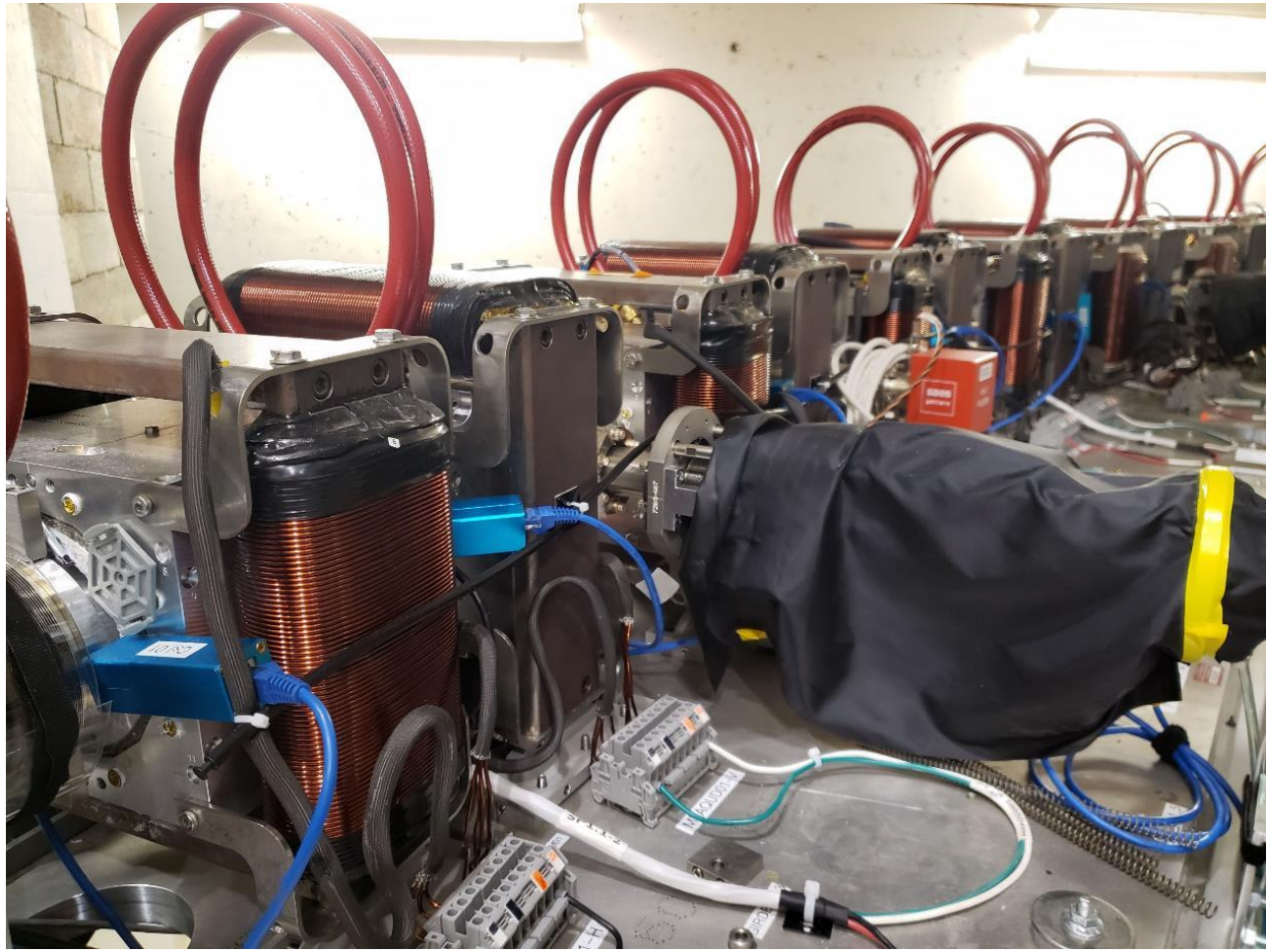
Modeling FFAs in

Bmad



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Outline

- Introduction to *Bmad*
- Modeling FFAs in *Bmad*
- Exercise 1: One energy
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- Conclusion

Introduction to *Bmad*

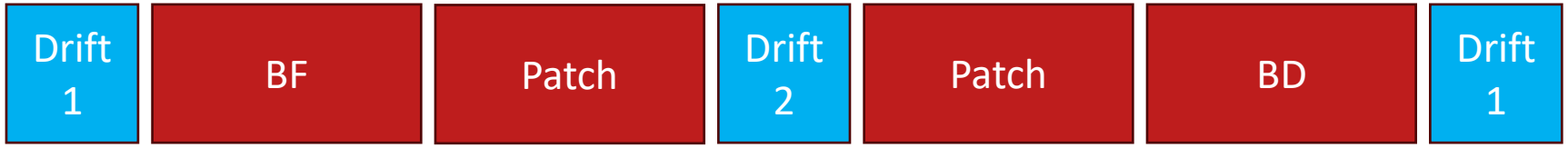
- *Bmad* is an open-source software library (toolkit) for simulating charged particles and x-rays; it is used by programs for doing calculations

- *Tao* is a general purpose simulation program based on *Bmad*; it can be used to view lattices, do Twiss and orbit calculations, nonlinear optimizations on lattices, etc., etc.
  - Other *Bmad*-based programs exist, many specialized for certain computations – information is available on the *Bmad* website, but it's beyond the scope of this tutorial.

- Much thanks to Scott Berg (BNL), who provided the files that eventually became the exercises of this course

Modeling FFAs in *Bmad*

- Because of *Bmad*'s flexibility, there are multiple ways, this is just my preferred approach



- Dipoles are modeled using db_field, which is energy independent and keeps the magnets rectangular

- This approach does not change the design trajectory, so patches are used to do so
  - This sometimes causes the orbit plot to have discontinuities, but they aren't physical
  - Longer cells may be better modeled with patches on either side of both magnets

Modeling FFAs in *Bmad*

- To run, type `tao` into the command line – this will automatically call tao.init
  - To specify a different file, `tao -init tao_specific.init`

- tao.init will specify a plotting file (tao_plot.init) and a start up file (tao.startup)
  - In these examples, the start up file is only helping out the plot settings, but it can also be used to set alias commands, optimization settings, etc.

- tao.init will also specify the number of universes and point to a lattice file for each
  - In these examples, lattices files are named like cell.lat.bmad, which defines the species, energy, lattice geometry (closed or open), and calls cell.bmad – this file is where the FFA cell is defined

Exercise 1: One Energy

- Change into the Exercise 1 directory and examine the files – do things make sense? What's the energy of the beam?

- Run `tao`

- Type `sho val lat::tune.a[end]/(2*pi)` and `sho val lat::tune.b[end]/(2*pi)` to examine the tunes

- Examine the energy by typing `sho ele 0` to look at the beginning of the lattice
  - Under the attributes (at the top), you see E_tot is 42 MeV → this corresponds to the reference energy of the lattice at this element
  - Under the orbit section (at the bottom), you see the z momentum is 0 (this is the default when pz is not specified) and E_tot is 42 MeV → this corresponds to the energy of the beam at this element

Exercise 1: One Energy

- Change the beam energy by typing `set particle_start pz = 0.4`
  - Take another look at the beginning of the lattice (`sho ele 0`); notice how the reference energy hasn't changed. What's the new energy of the beam?
  - Check the tune values – do they match the plot? (`sho val lat::tune.a[end]/(2*pi)`)

- Try a few different energies by selecting different values for pz
  - If the beta plot disappears, you've set an energy that BMAD can't find a closed solution for – try a different value for pz
  - As you change energies, what happens to the orbit?

Exercise 2: Two Energies

- Change into the Exercise 2 directory and look at the lattice files
  - What are the energies of the two universes?

- Variables and datum have been added to tao.init – what do they refer to?
  - unstable.orbit = 0 and unstable.lattice = 0 means that BMAD can find a closed solution
  - `sho val 1@lat::tune.a[end]` will return the horizontal tune of universe 1

- Run `tao`, and type `sho var` to list all variables. Type `sho var b1` and see that the b1_gradient of both magnets is being changed – with the change occurring in both universes simultaneously

- Type `sho dat` to see all the datum. See how each datum listed in tao.init is given for both universes – what are the consequences of this?

Exercise 2: Two Energies

- Look at the new files: fit-orbit.tao and fit-tune.tao which optimize on the orbit and tunes, respectively
  - For each optimization, which datum and variables are being used? Do the combinations make sense?
  - Why does fit-tune.tao set the desired tunes the way it does?

- Back in tao, call the optimization files using `call fit-tune.tao` and `call fit-orbit.tao`
  - Do the optimizations seem to achieve the goal?
  - What happens to the tune curves when you `call fit-orbit.tao`? Even after you re-run the tune optimization, do the curves revert?

- Plotting tip: `scale r24 -0.03 0.03` and `scale r34 -0.03 0.03`

Exercise 3: Four Energies

- Change into the Exercise 3 folder – what are the energies?

- Call `tao` and run the optimization files – they're the same as in exercise 2, but what happens to the orbit of the intermediate energies?

- Going into tao.init, you'll see additional datum in fit.center, many turned off by the good_user flag. Change which ones are turned on, save the file, type `reinit tao` for the changes to take effect, and re-run the optimizations – how does your selection change things?
  - Alternatively, turn all datum on, reinit, and select datum with `use dat 1@fit.orbit[1:7]` (or some selection) then run the optimization with `run lmdif`

Conclusion

- *Bmad* is an extremely powerful and flexible tool for modeling FFAs – and many other types of accelerators

- Ongoing support from the developer David Sagan (Cornell) and assistance from a thriving user community through the slack channel
  - If you want to add some capability to *Bmad*, that can be done – no need to write an entirely separate code; your addition can be added into the main distribution for widespread use when it's complete and verified

- Due to frequent (~weekly) updates, if you switch to *Bmad*, make sure the updating process is smooth for you – I strongly recommend a package manager

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Questions?

Thanks for your attention!