The rf in magnet problem in ionization cooling and ideas for solutions and experiments

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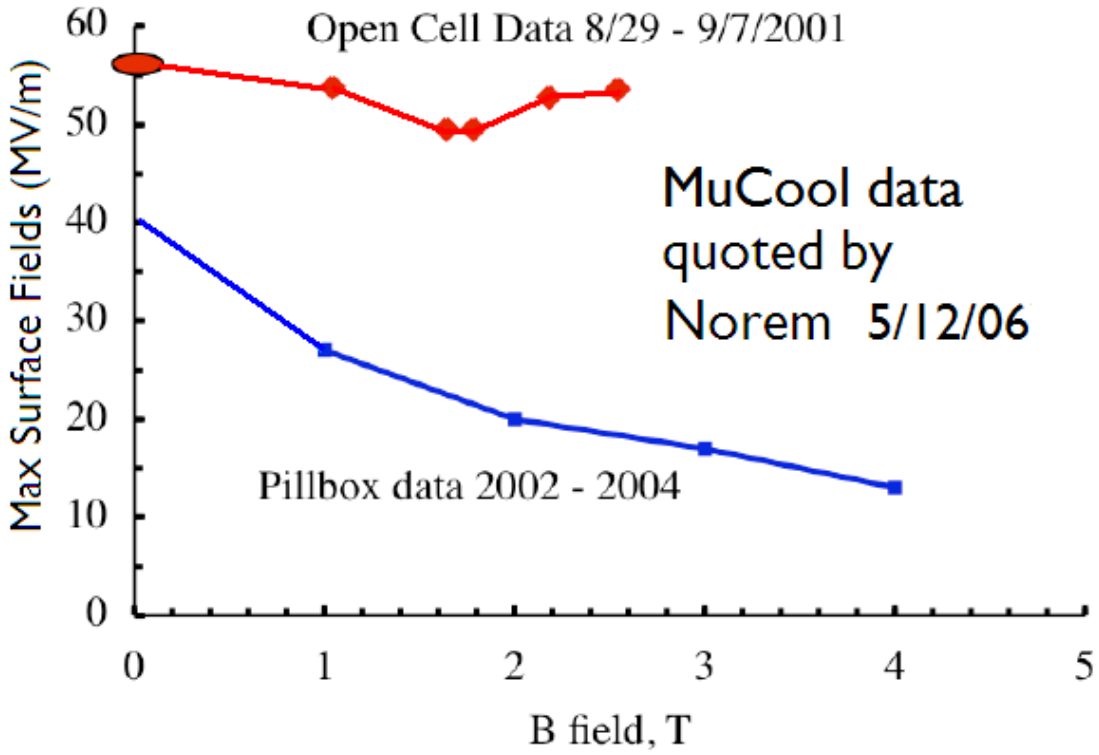
1. Introduction to possible/probable problem
2. Possible solutions
3. Experimental tests of 805 MHz open cavities
4. Experimental tests of 805 MHz bucked high field lattice
5. Low emittance cooling demonstration with the above assembly
6. Conclusion

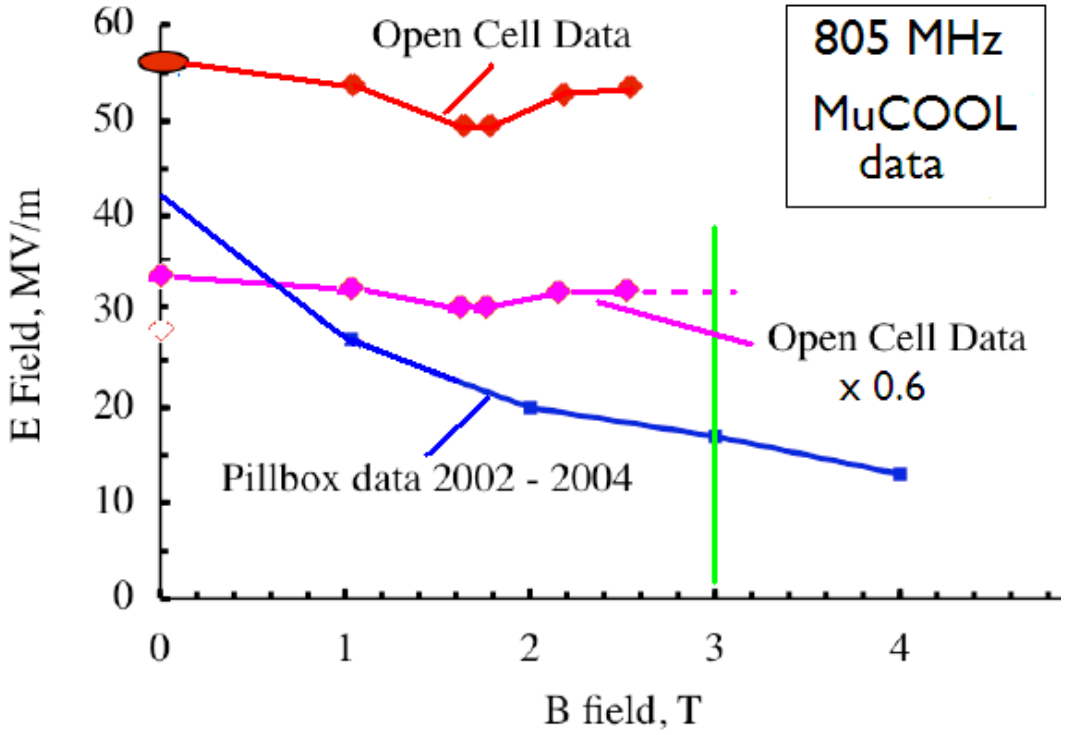
These are meant as illustrations of a program not a fixed program

1) INTRODUCTION



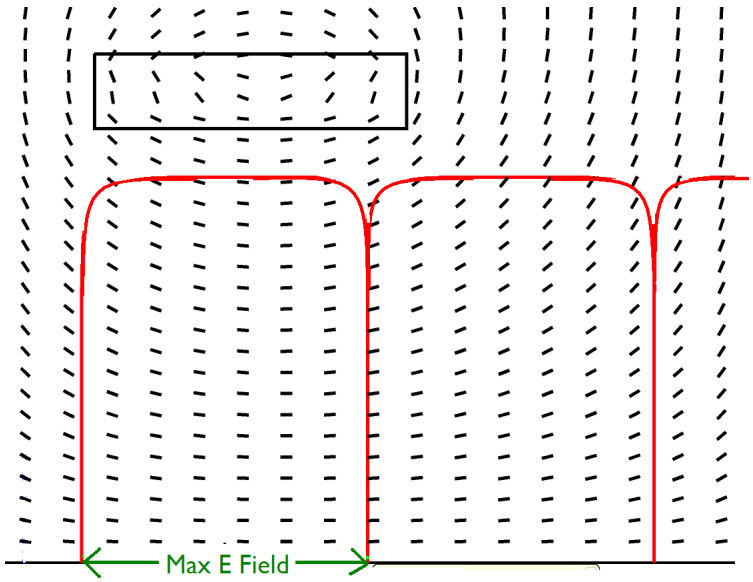
- A pill-box cavity has been shown (Lab G and MTA) to have rapidly falling maximum gradient as the magnetic field is increased
- This relative drop, if present at 201 MHz, will preclude specified operation of current ISS Neutrino Factory and Guggenheim RFOFO Muon Collider cooling schemes
- But Lab G did not see such a fall off with a multi-cell open cavity design

Loss of acceleration/surface fields in open cavities

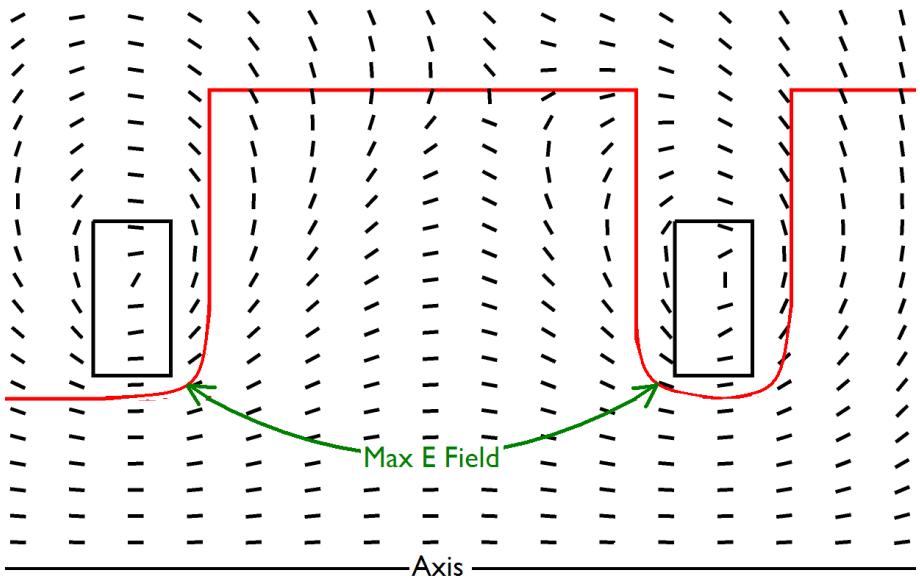


- even though an open cavity yields less ($\approx 60\%$) acceleration per surface field, it is still prefered for magnetic fields above ≈ 1 T

Open cell rf with coils in irises



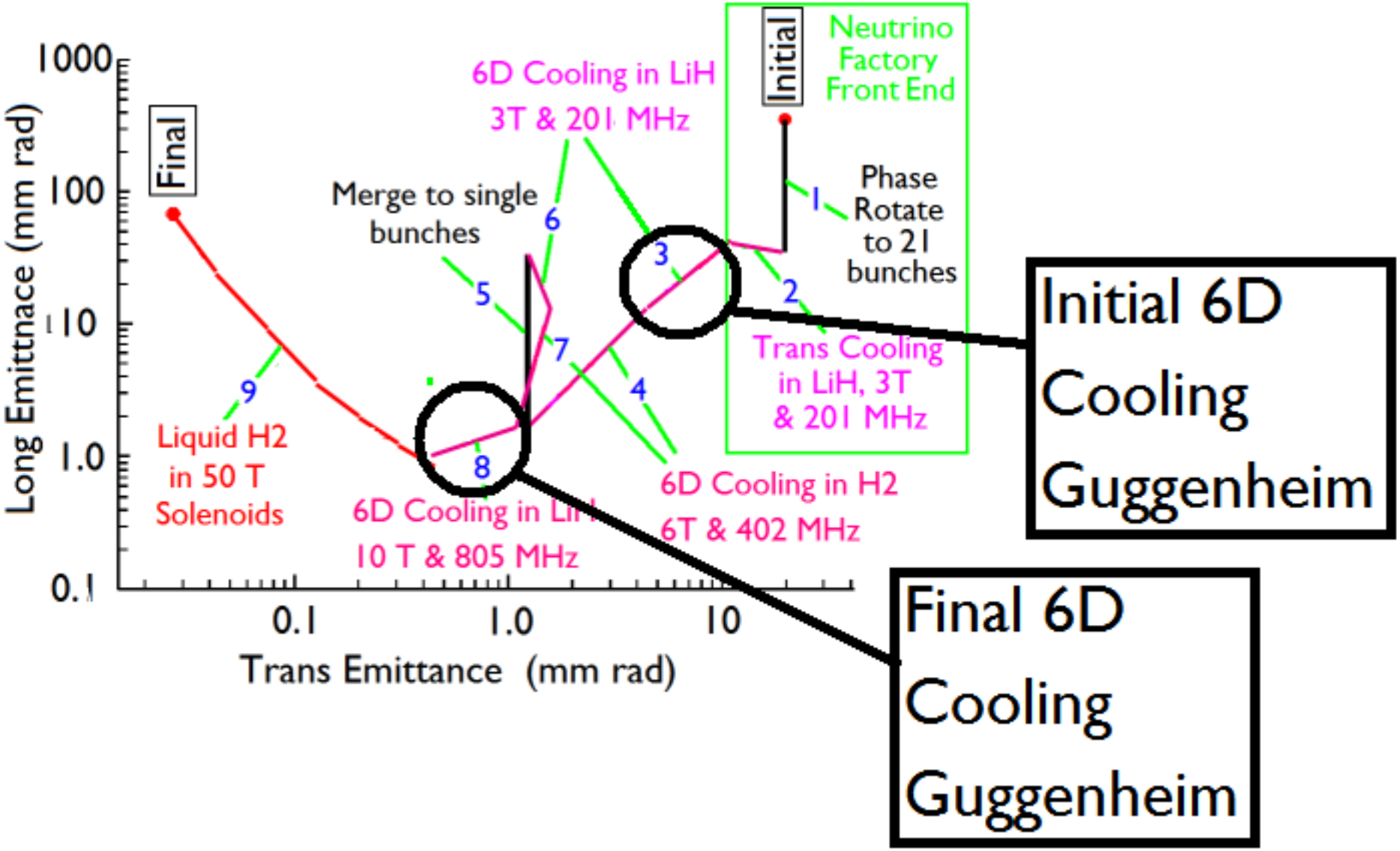
201 MHz RFOFO Lattice



Alternative 201 MHz Open Cavity

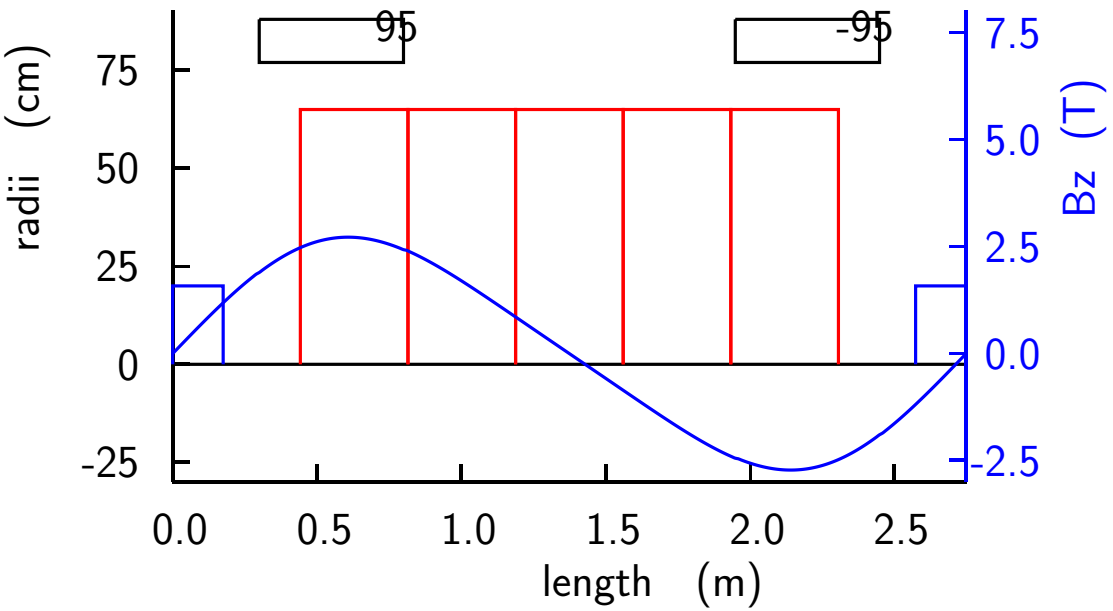
- An even better geometry may be to have the coils in the irises. The maximum electric fields are then almost perpendicular to the magnetic fields, providing "magnetic insulation".
- Note that the effect is present even when the polarity of the coils is the same (as in the above example)

Study 1st & last 6D cooling in Collider Scheme (v1)

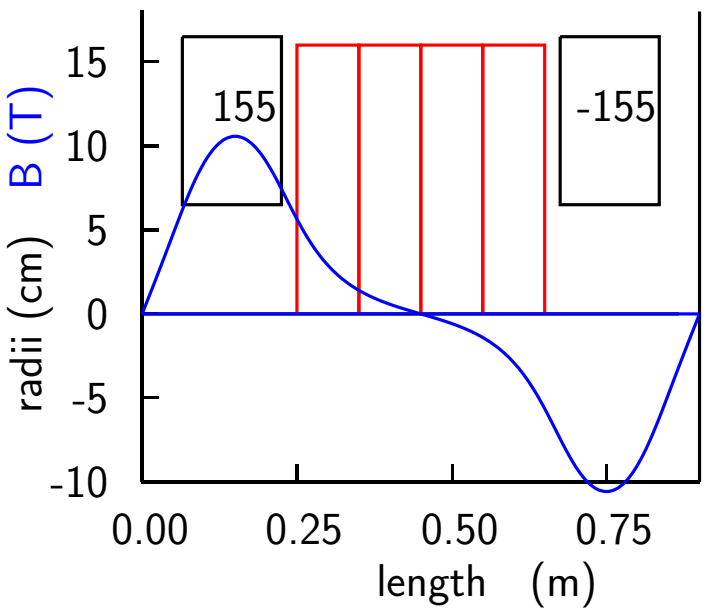


Note these lattices are used with slightly tilted coils to generate uniform bending (Guggenheim), or alternating bends (Alexahin)

RFOFOs used in above scheme (v1)



First RFOFO Lattice (#3 & #6)

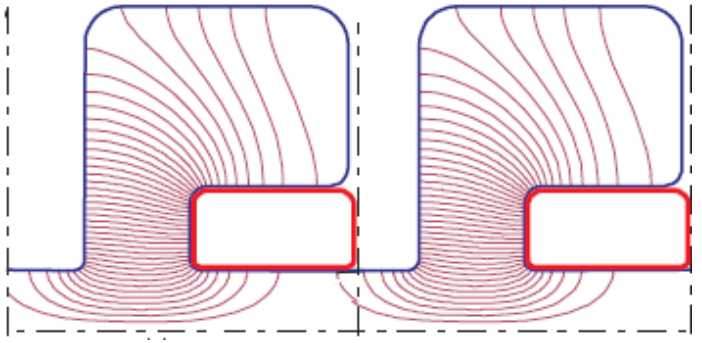


Last RFOFO Lattice (#8)

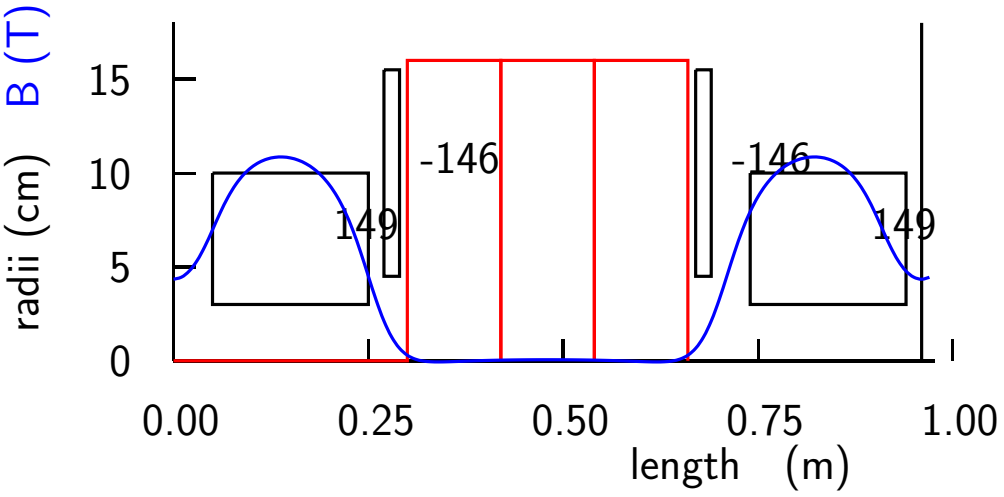
- Local fields in First RFOFO: 3 T in 201 MHz at 12 MV/m
  If breakdown $\mathcal{E} \propto \sqrt{\mathrm{f}}$ then max $\approx$ 6 MV/m
- Local fields in Last RFOFO: 5 T in 805 MHz rf at 20 MV/m
  Extrapolated limit at $\approx$ 10 MV/m

2) POSSIBLE SOLUTIONS

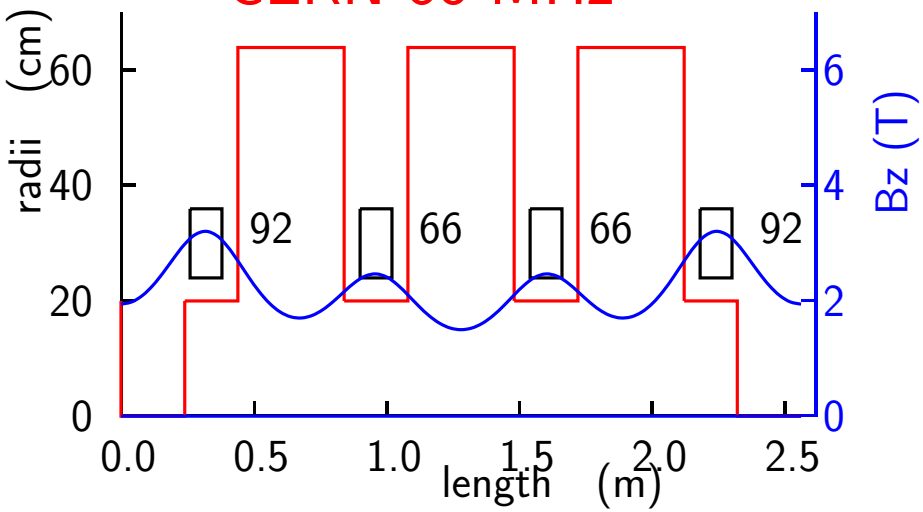
1. Use high pressure gas
   - Gas may breakdown in beam
   - It is anyway unsuitable in final stage because we must use a local focus to get $\beta_\perp$ low enough
2. Buck the fields at the RF (super Fernow Lattice)
3. Use open cavity with coils in the irises
   as suggested above and in early CERN study



CERN 88 MHz



Bucked field coil



Open Cavities

Conclusion from study of lattice performances

- Open cavities good for ISS and early 6D cooling,
  giving large Δp/p ($\pm$ 30%) acceptance and $\epsilon_\perp \rightarrow 4\ (\pi\ \mathrm{mm})$
- Bucked field cavities good for late 6D cooling
  Smaller Δp/p, ($\pm$ 12%) but $\epsilon_\perp \rightarrow 0.4\ (\pi\ \mathrm{mm})$

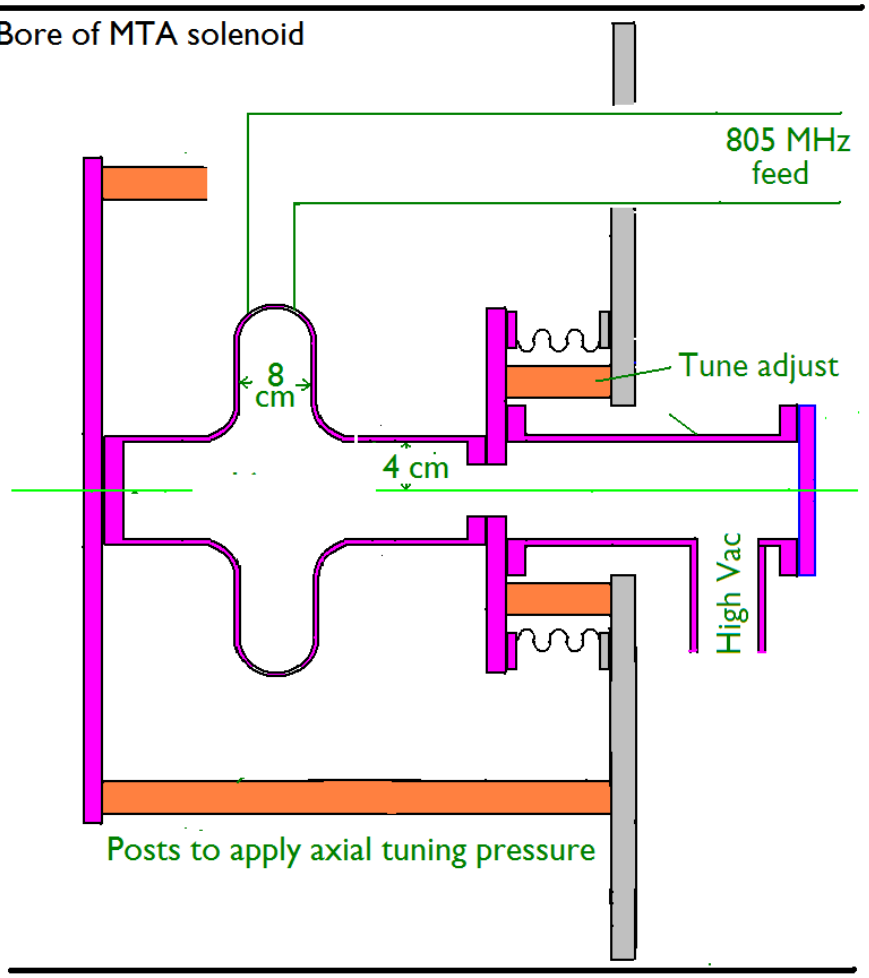
- Both need experiments

3) EXPERIMENTS ON OPEN CAVITIES

The experiment would study rf breakdown in an open cell standing wave linac with solenoid coils in the irises. The experiment would have 4 or more phases, including:

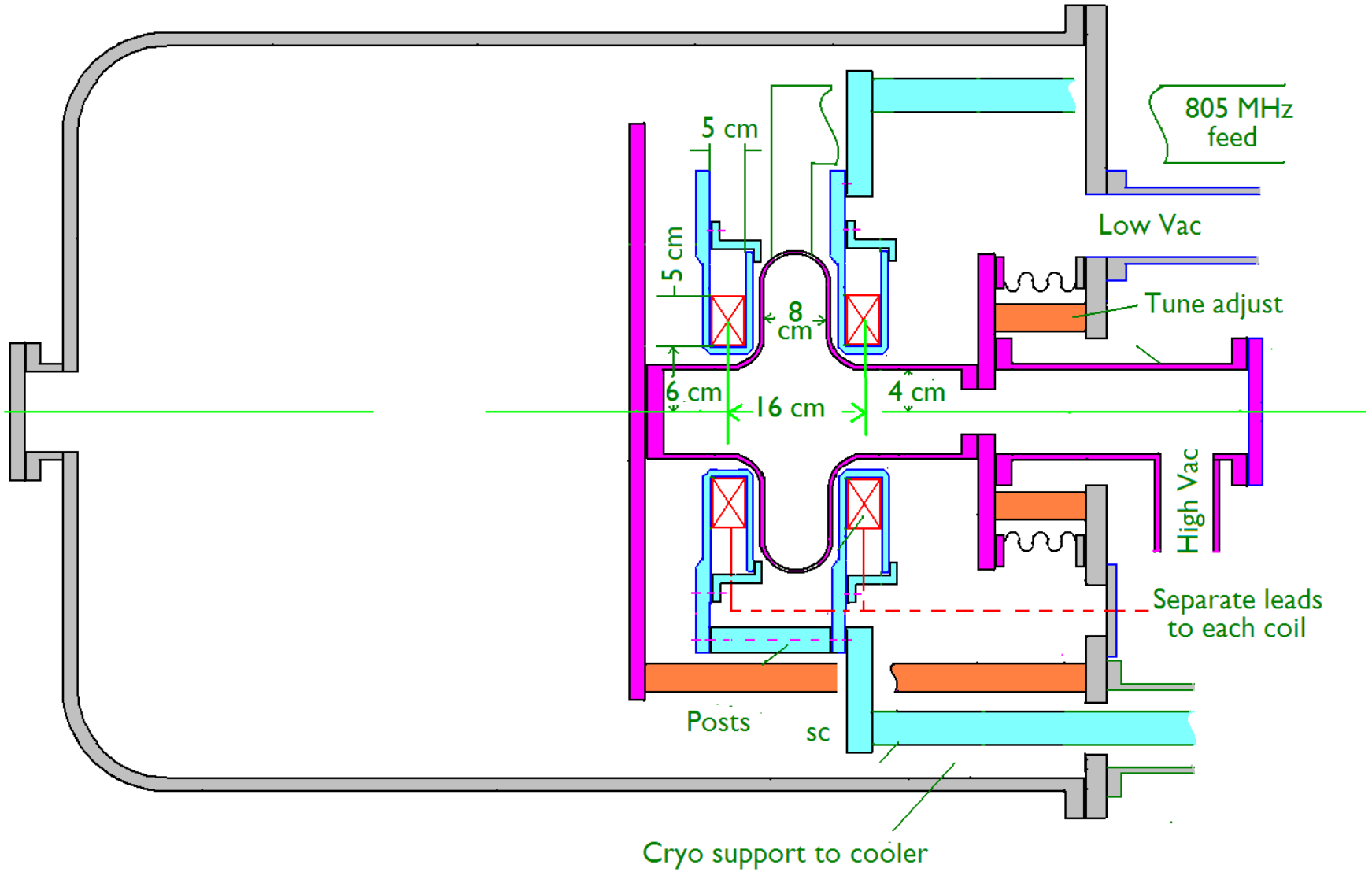
1. Test a single 805 MHz open bore cavity in existing MTA solenoid
2. Test a single 805 MHz open bore cavity with two solenoid coils, one on either side of the cavity
3. Test a single 805 MHz open bore cavity with two wider solenoid coils, one on either side of the cavity
4. Test an 805 MHz model of a full cell of a 201 MHz Muon Collider 6D cooling lattice

Sketch of phase 1 of open cavity experiment



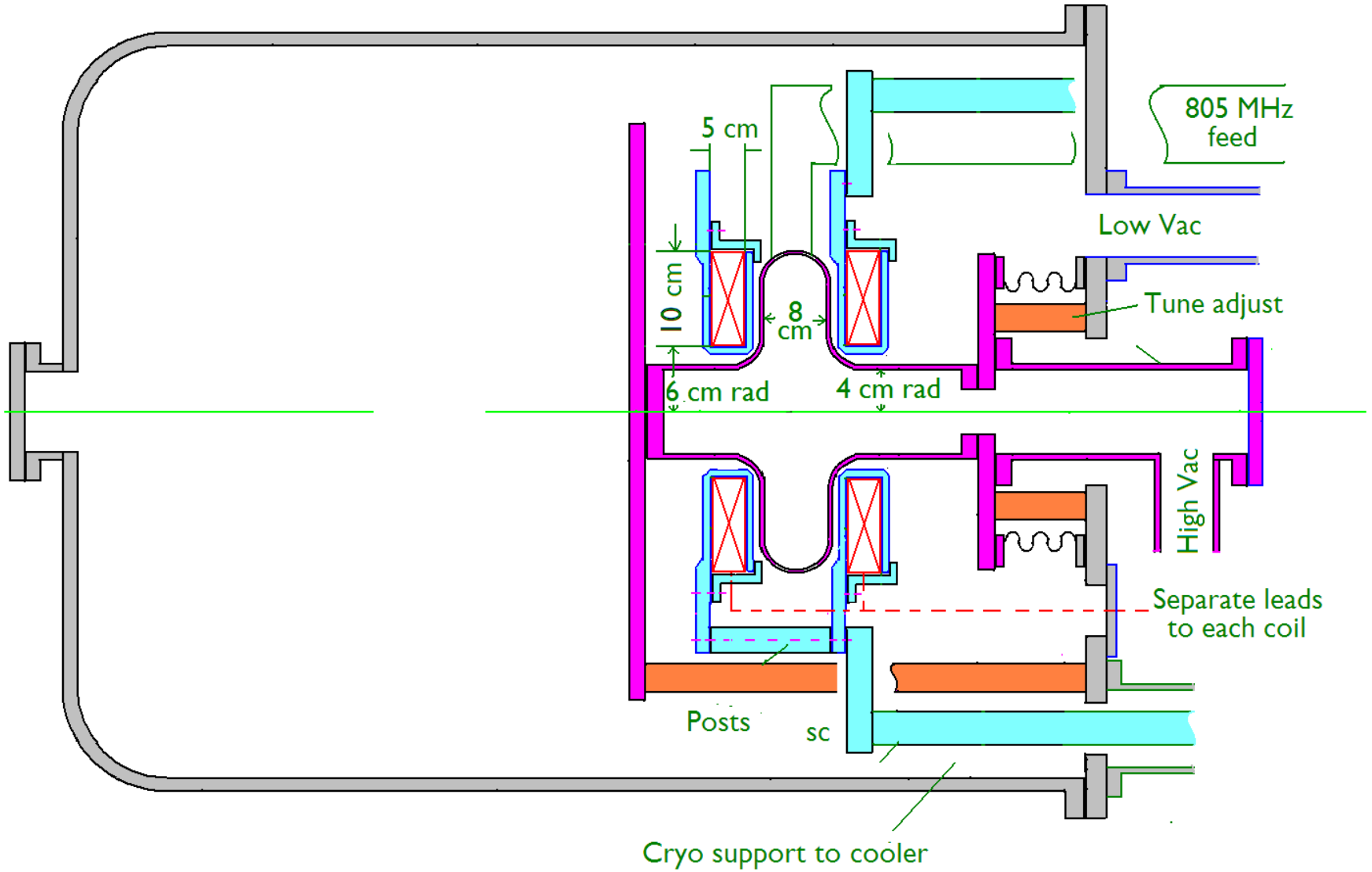
- Single cavity without joints
- Install in existing 5 T solenoid
- Establish baseline to compare coils in iris geometries

Sketch of phase 2 of open cavity experiment



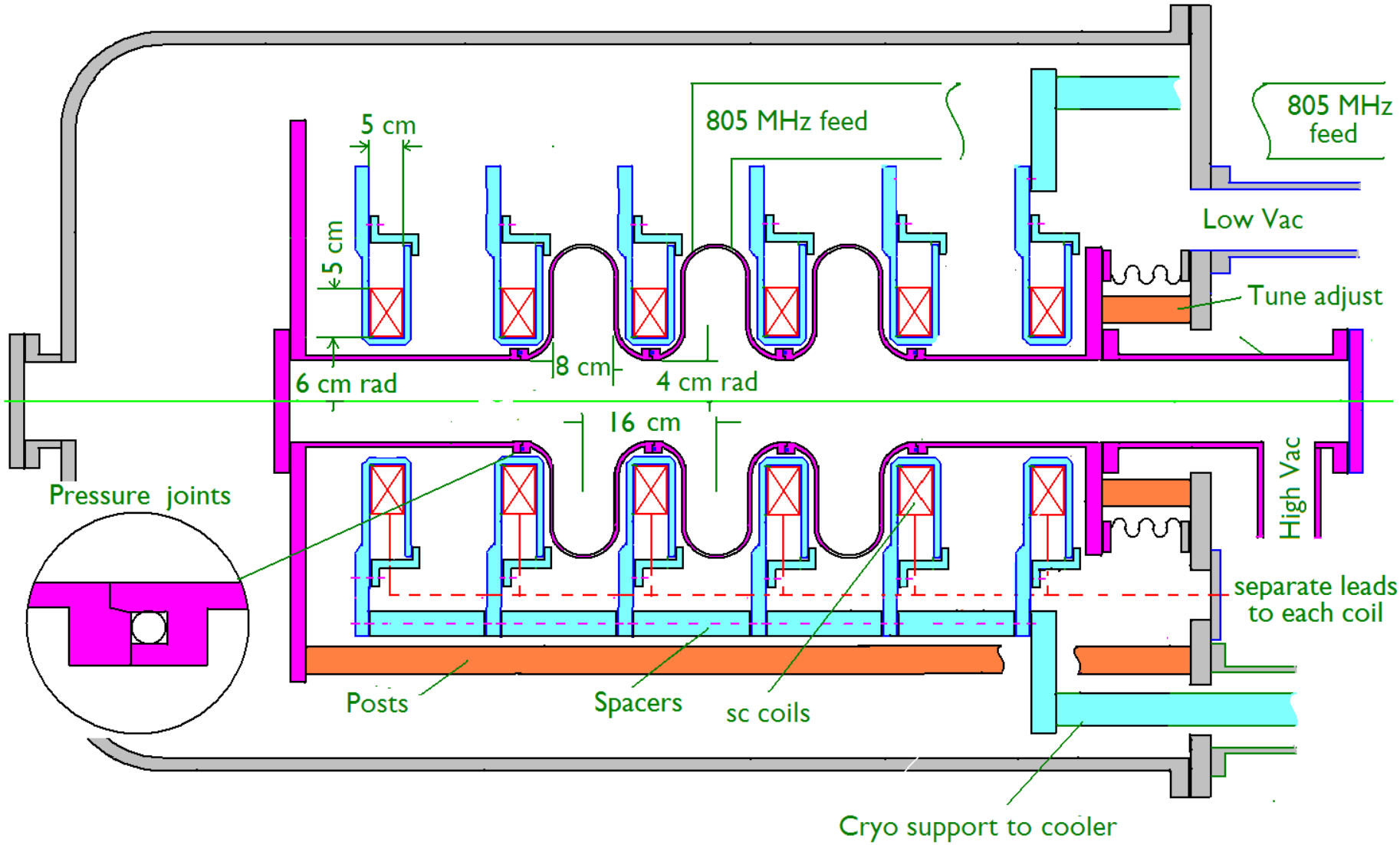
- Single cavity without joints
- Two coils
- Qualitative results, but not real fields: rf or magnetic

Sketch of phase 3 of open cavity experiment



- Using the same cavity without joints
- Wider coils give slightly better field for cooling
- But have fields less perpendicular to breakdown

Sketch of phase 4 of open cavity experiment



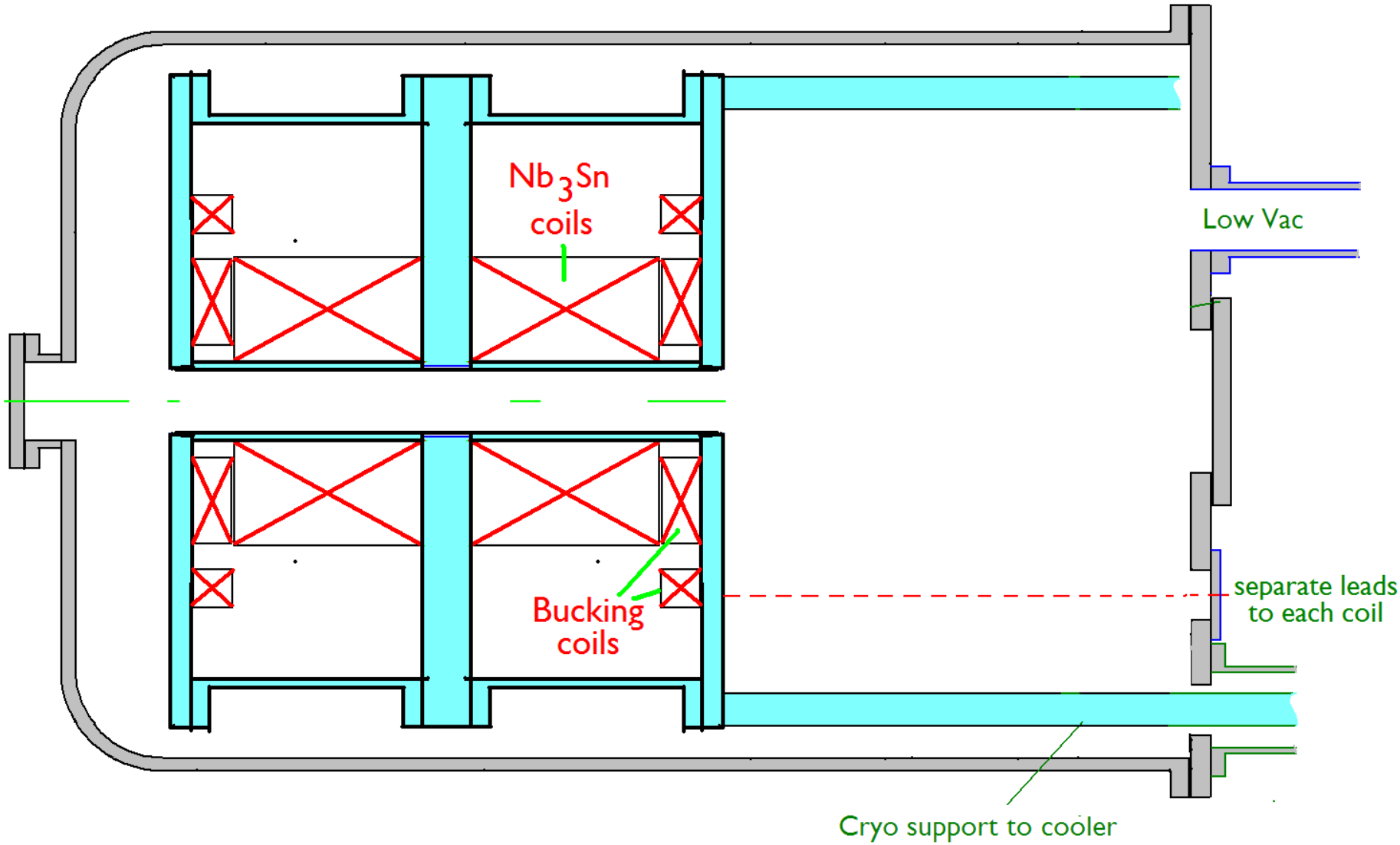
- 805 MHz Model of one full 201 MHz cell
- Including space where absorbers belong
- End coils allow good approximation to end fields

4) EXPERIMENTS ON BUCKED COIL LATTICE

These experiment are far less thought out, and would be much later than the open cell experiments. It would be hoped to use the same basic enclosures, cooling, vacuum and electrical systems as in the open cell experiments. Again there would be a sequence of stages.

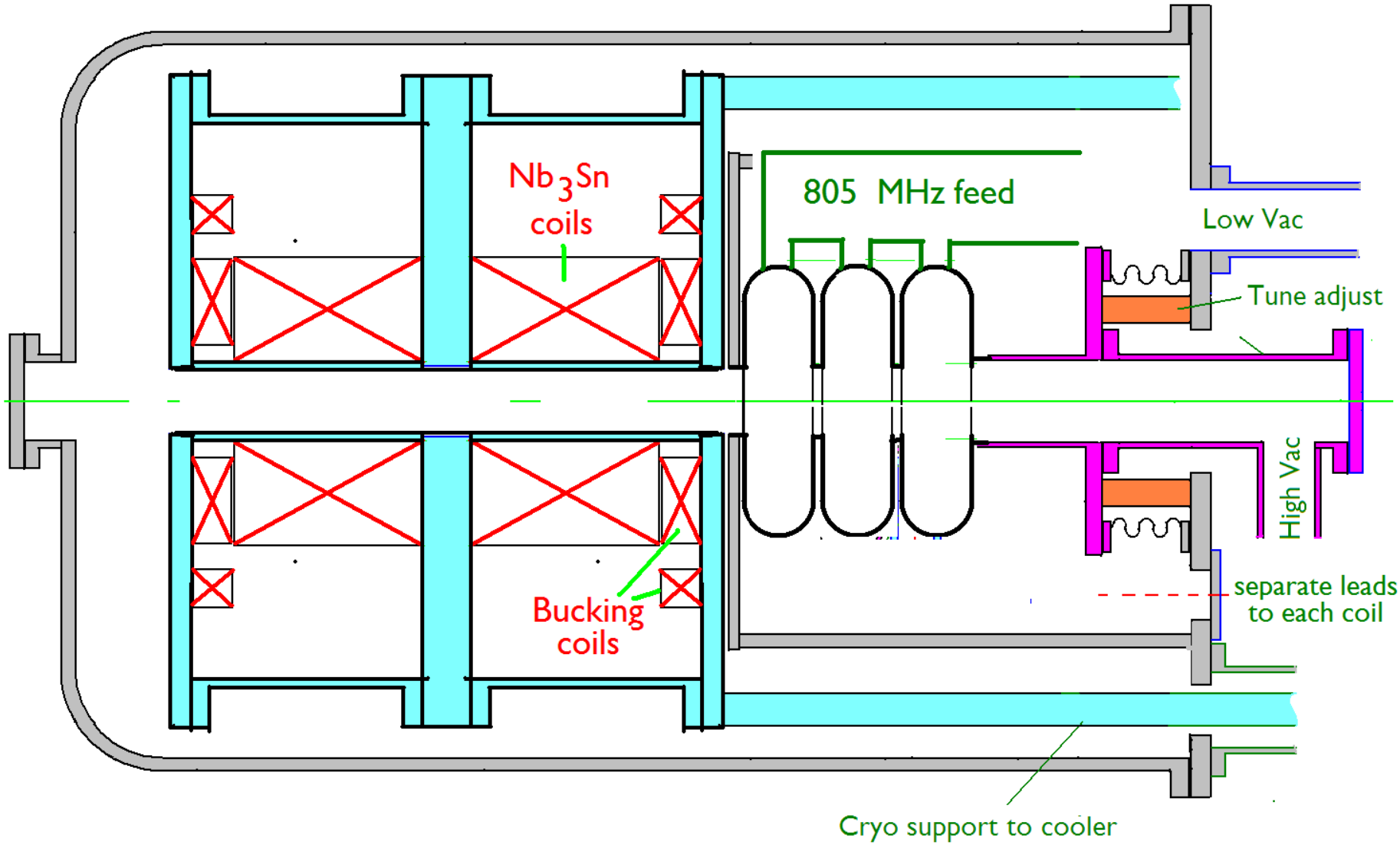
1. Tests of single coils of higher field and higher current density coils (using Nb_3Sn), leading to a test of a pair of focus solenoids with their bucking coils.
2. Introduce a new pillbox cavity designed to allow its close proximity to the focus coil assembly
3. Add a LiH (or other material) wedge absorber, with appropriate cooling. It probably needs to run at a higher temperature than the superconducting magnet.

Sketch of Phase 1 of Bucked Coil Experiments



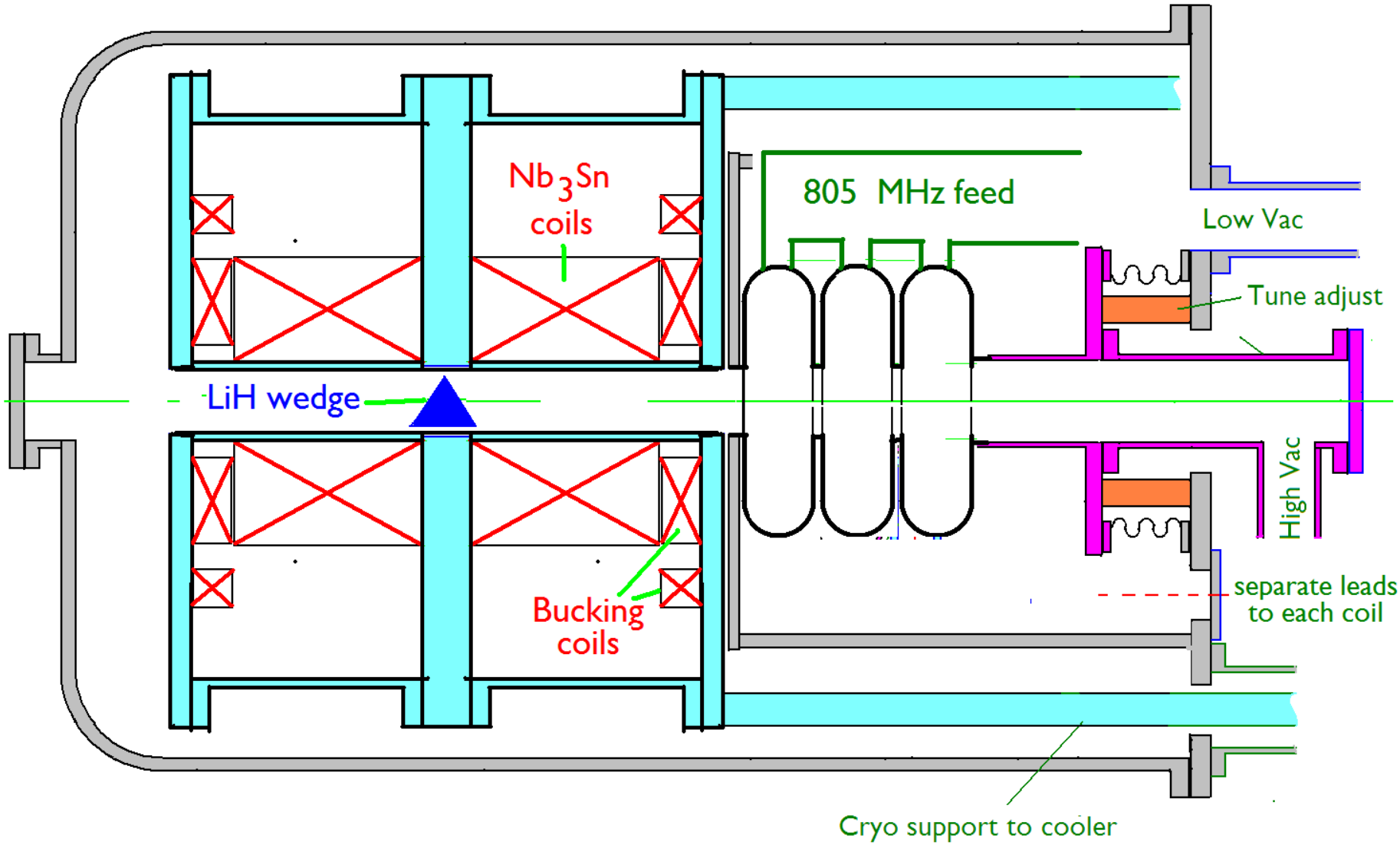
- Tests of 10 T Nb_3Sn coil with bucking coils
- Not to scale

Sketch of Phase 2 of Bucked Coil Experiments



- Add 805 MHz pill box cavities and feed
- Again: not to scale

Sketch of Phase 3 of Bucked Coil Experiments



- Add LiH wedge, with cooling and safety considerations
- This will need a lot of engineering
- But we will have to face it to know if we are realistic

5) LOW EMITTANCE COOLING EXPERIMENT WITH BUCKED COIL LATTICE

If the above low beta lattice using bucked coils is successful, it should form the basis for a low emittance cooling experiment. With its beta of approximately 4 cm it should be able to cool to approximately 0.4 pi mm rad

Questions:

- Can the MICE detectors measure an emittance of $400 \ \ (\pi \ \mathrm{mm \ mrad})$?
- What modifications might be needed ?
- Can it measure the momentum of such a beam ?
  probably need to enter solenoids off axis to get significant helix radius
- What would the detector look like if we start from scratch at FNAL ?

6) CONCLUSION

- We may well have a breakdown problem with current collider and ISS cooling designs
- An open cell geometry with coils in the irises seems like a good solution for early collider or NF cooling
  But works poorly for final collider cooling
- Canceling the field at the rf, using bucking coils, works well for the final collider 6D cooling with small dp/p
  But works poorly for NF or the early stages where large dp/p acceptance is essential

- Both these concepts need Experiments
  1. Using 805 MHz, study breakdown with open cavities and various coil in iris geometries
  2. At 805 MHz, test high field solenoids with bucking coils to cancel fields at the cavities
  3. This would naturally lead towards a low emittance 6D cooling demonstration experiment