Cavel Tracking in Open Cavities

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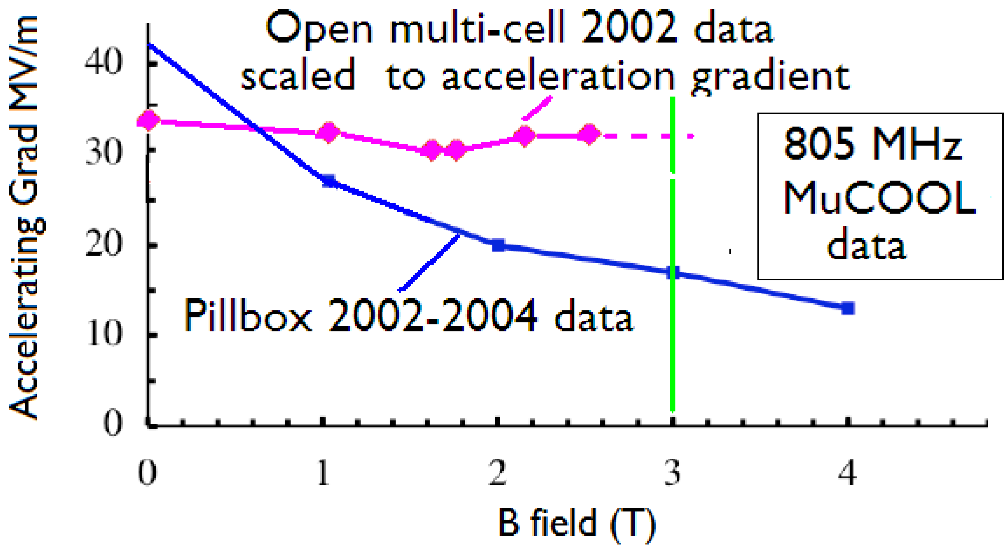
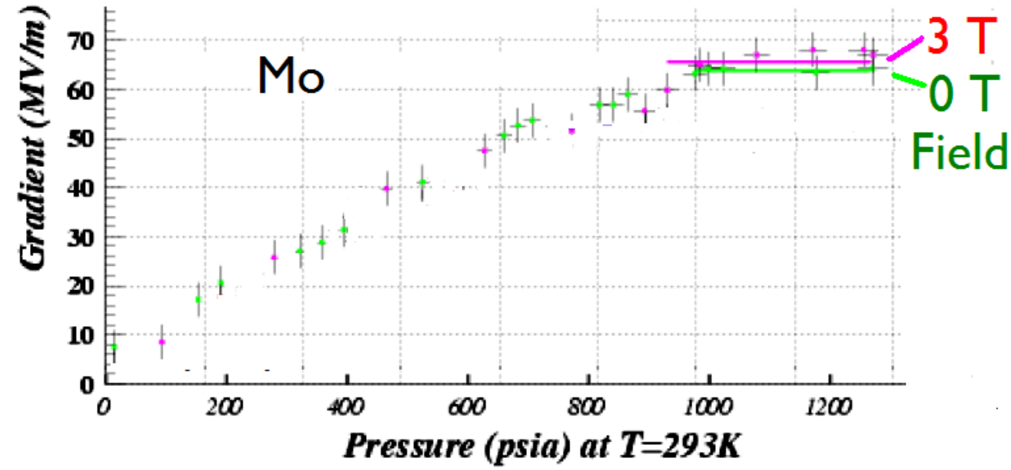
Introduction





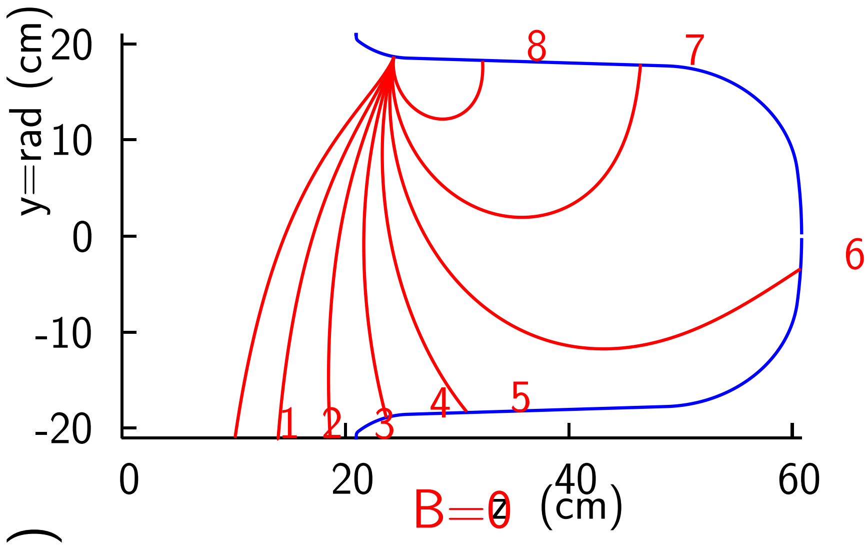
- Vacuum breakdown is sensitive to magnetic fields
- Vacuum breakdown is sensitive to cavity shape
- High pressure gas removes magnetic field sensitivity
- These facts strongly suggest that electron motion in the cavity plays a significant role in breakdown

Assumptions

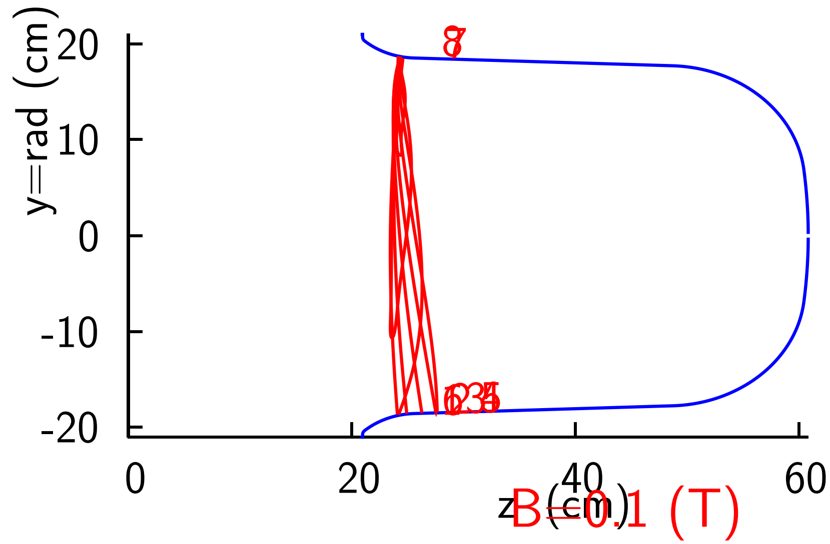
- Using Fernow's CAVEL version 1.06
- Start electrons on a maximum gradient point
- Vary phase when emitted

Tracks at different phases

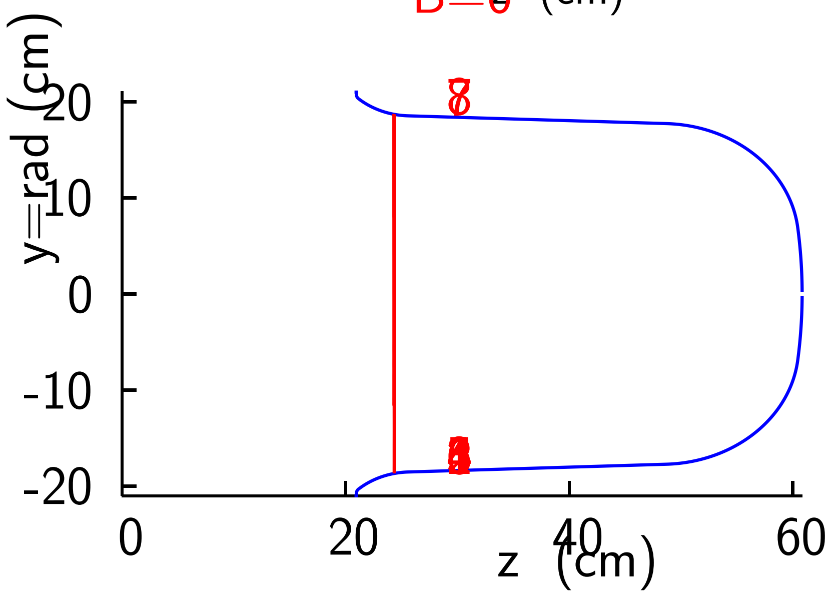
For FNAL 201 MHz cavity and uniform Bz Grad =17 MV/m



B=0



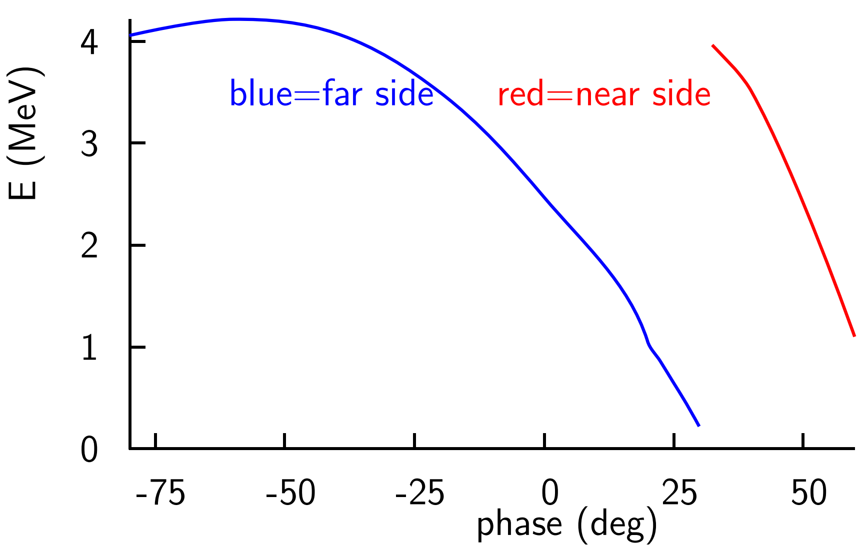
B=0.1 (T)



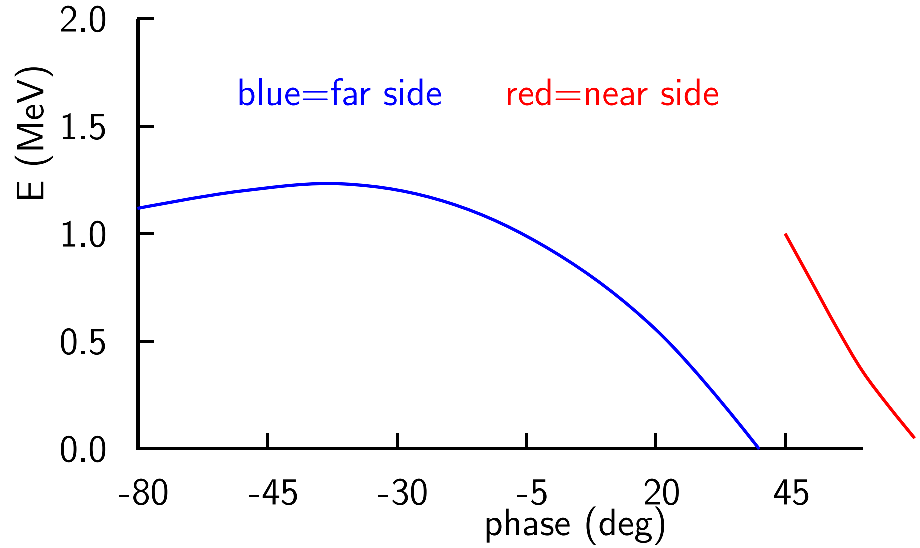
B=1 (T)

- The higher the Bz the more tightly focused
- Some of the electrons come back to the source

Electron Energy vs Phase



201 MHz (17 MV/m)



805 MHz (17 MV/m)

- These energies are higher for 201 MHz than for an 805 MHz cavity
- So is it worse at 201 MHz?
- Higher electrons penetrate deeper in the copper surfaces and could do less damage
- The worst case will be when the electron's penetration is comparable with the thermal diffusion distance for the appropriate fill times

What is the worst electron energy ?

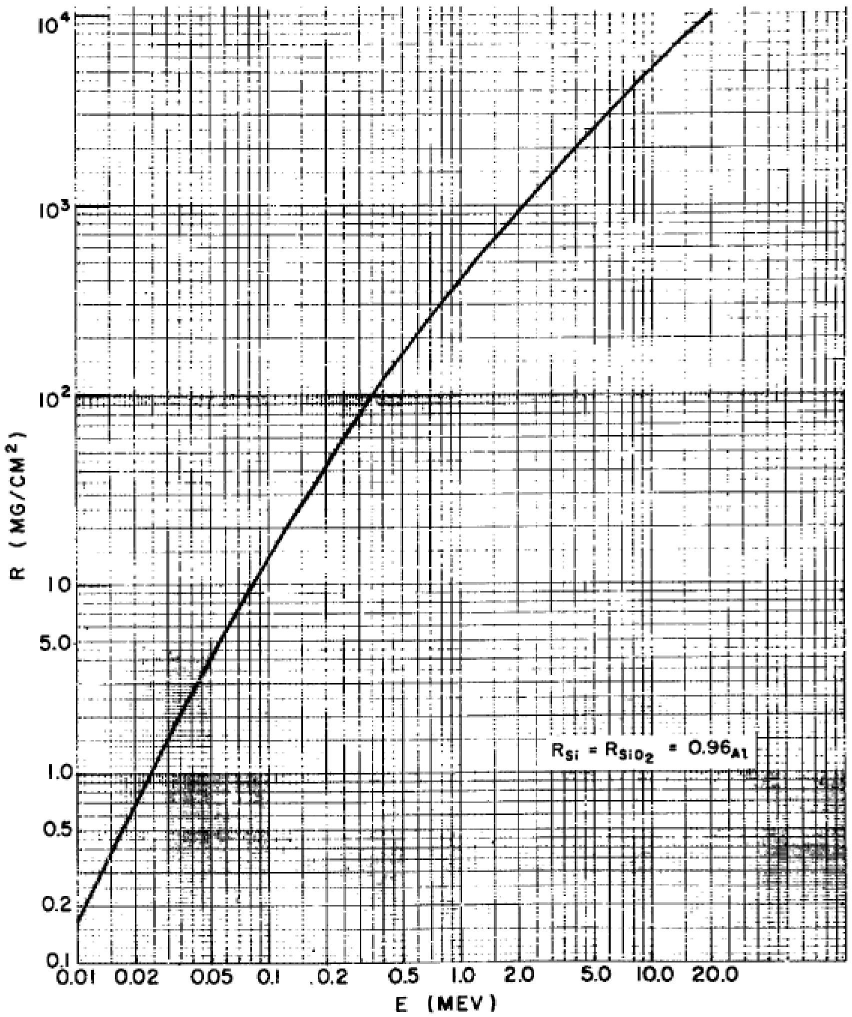


Fig. 5 - Range-energy relationship for electrons in aluminum (from Ref. 9)

Energy MeV	Cu range mm	Be range mm
.13	.02	.07
0.25	0.05	.2
.5	0.19	.76
1	0.44	1.76
4	2.2	8.8

Thermal diffusion depth

$\tau_{201} = 200\mu\ sec \qquad \tau_{805} = 25\ \mu\ sec$

$$\delta = \sqrt{\frac{2k\tau}{C_v}} = \sqrt{\frac{2\ 4.01\ \tau}{3.45}}$$

$= \ 0.2 \ \ (mm)$ for 201 MHz

$= \ 0.07 \ \ (mm)$ for 805 MHz

So ≈ .5 (.2) MeV bad at 201 MHz for Cu (Be)

So ≈ .3 (.13) MeV bad at 805 MHz for Cu (Be)

Be is better than Cu because the electrons go deep & dE/dx is less

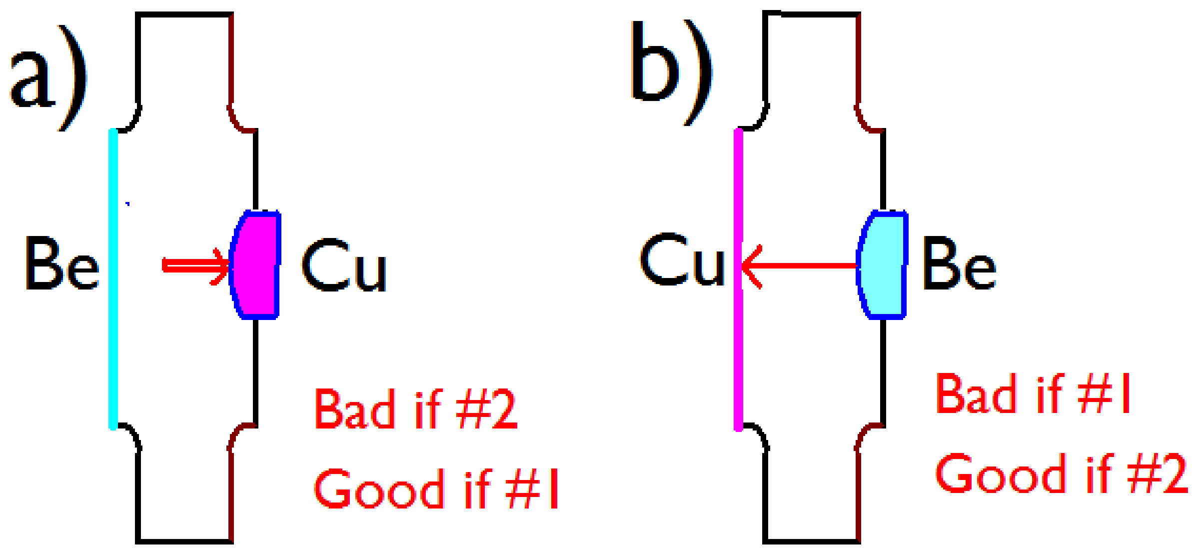
This needs a real simulation, the above is only a qualitative argument

What causes the breakdown with magnetic field

1. Electrons focused to a spot on the opposite side, causing breakdown from there
2. Electrons coming back to the originating trouble spot, causing breakdown there

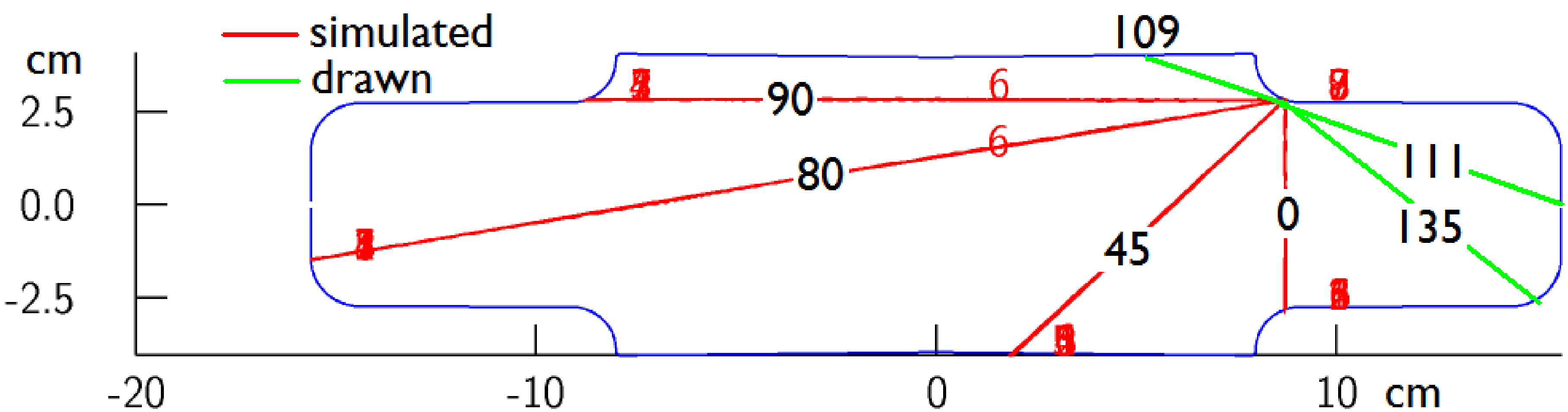
We can easily find out which by testing the button cavity in two configurations

- Since electron bombardment is far less serious on Be than Copper
- Then if #1 true, then b) is bad and a) is better; if #2 true, then a) is bad and b) is better



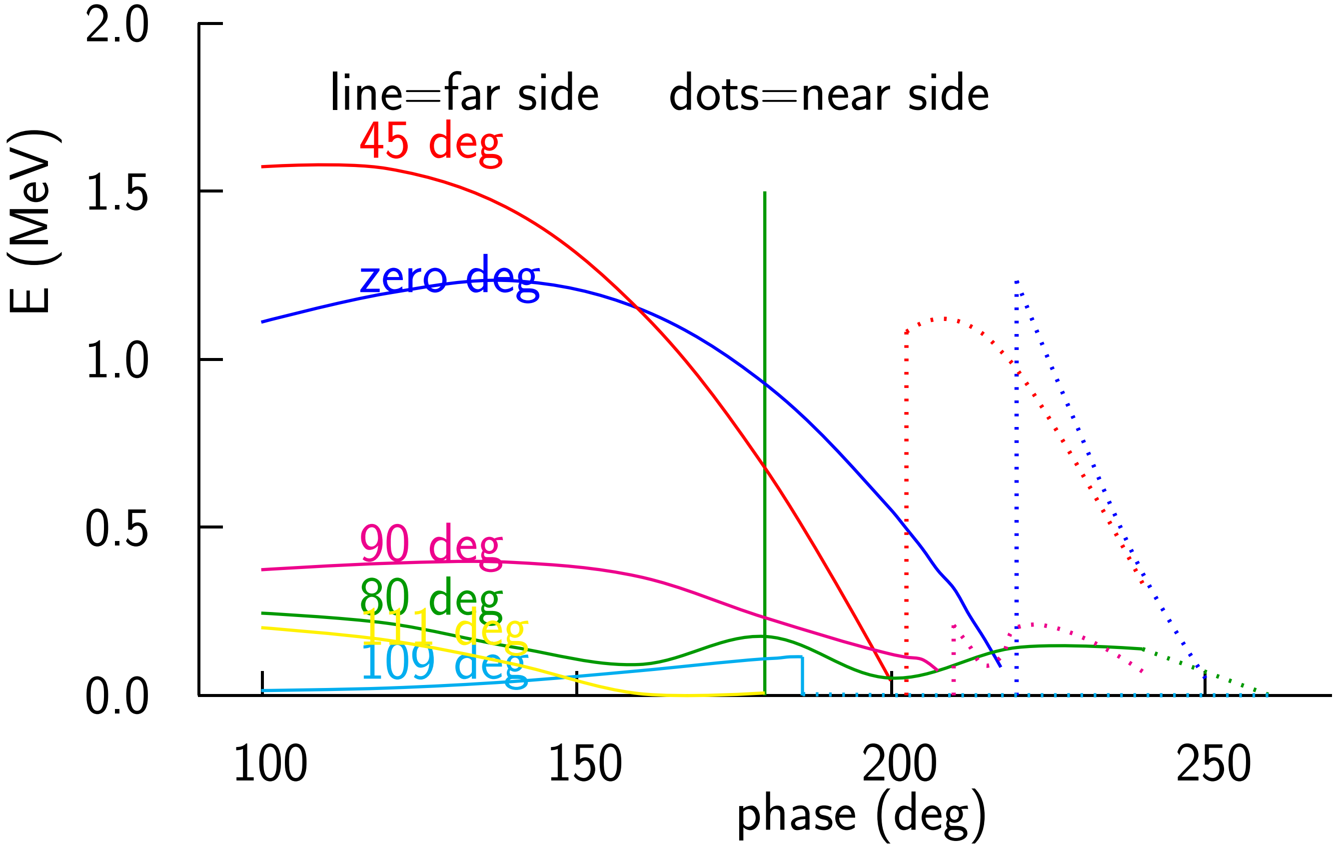
Tracks of electrons for different B directions

- Axial Gradient=30 MV/m
- Current MTA 805 MHz Cavity
- Differing phases
- Only electrons from highest field point



- In essentially all angles the electrons go somewhere
- 0,45,90 and 109 to other high gradient locations BAD ?
- 80 and 111 to very low gradient locations GOOD ?

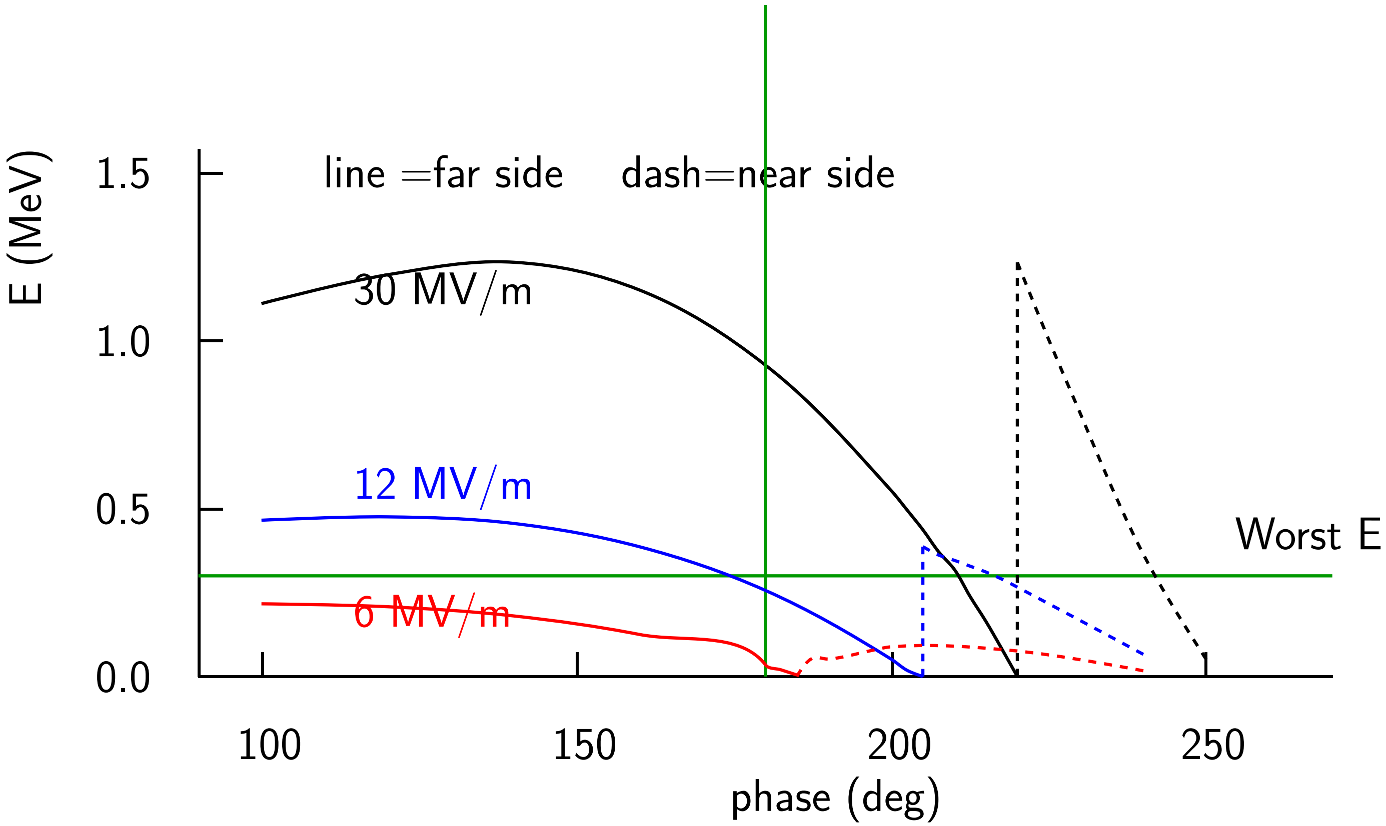
Energy of arriving electrons



- 90 and 80 give lower energy
- But that is not necessarily good
- At larger phases the electrons come back
- Field emission will not generate these
- But a plasma spot would

Axial Gradient=30 MV/m

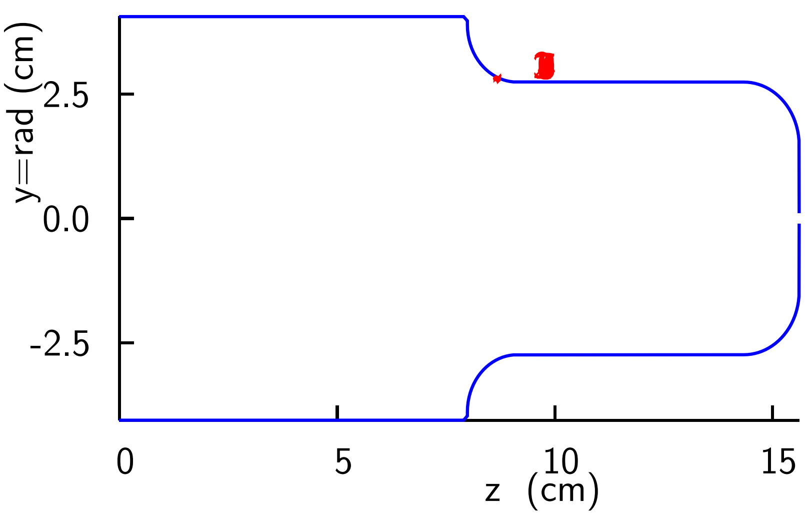
vs. Gradient

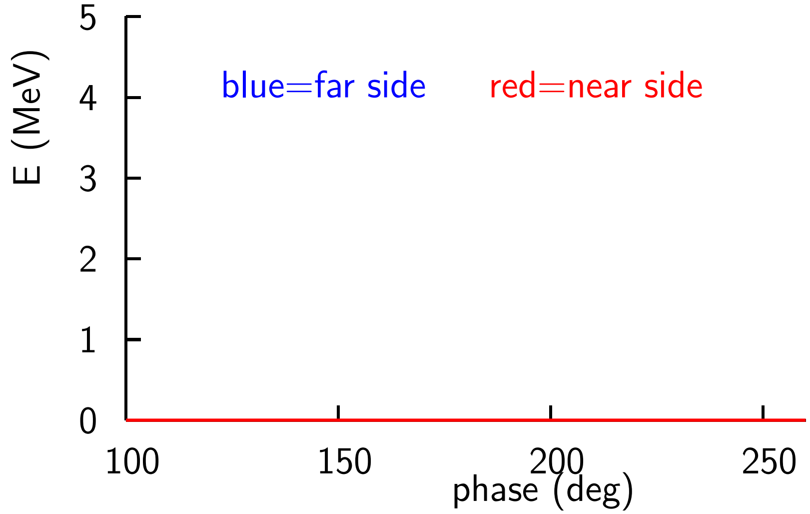


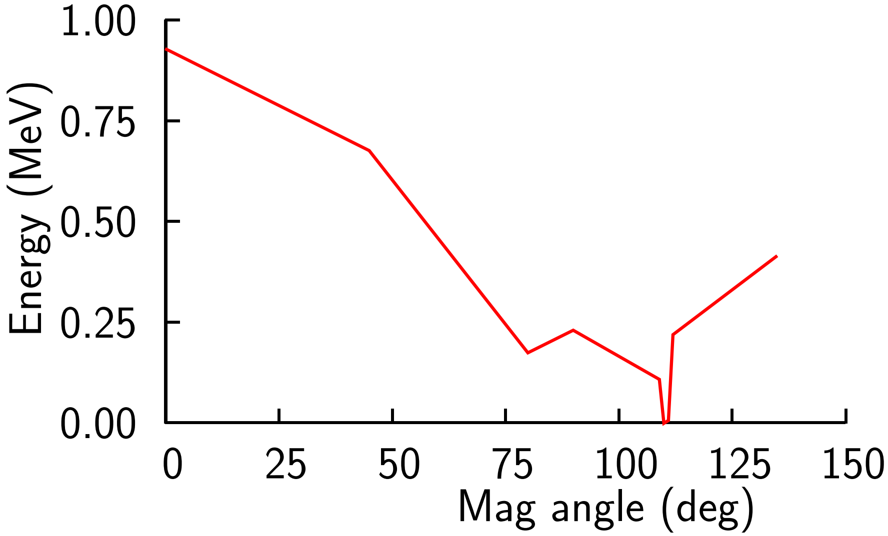
- at lower gradients the energies are nearer the worst
- and the electrons that come back can now come from field emission

Ideal Field angle

When field angle=110.1 degrees all particles remain near surface



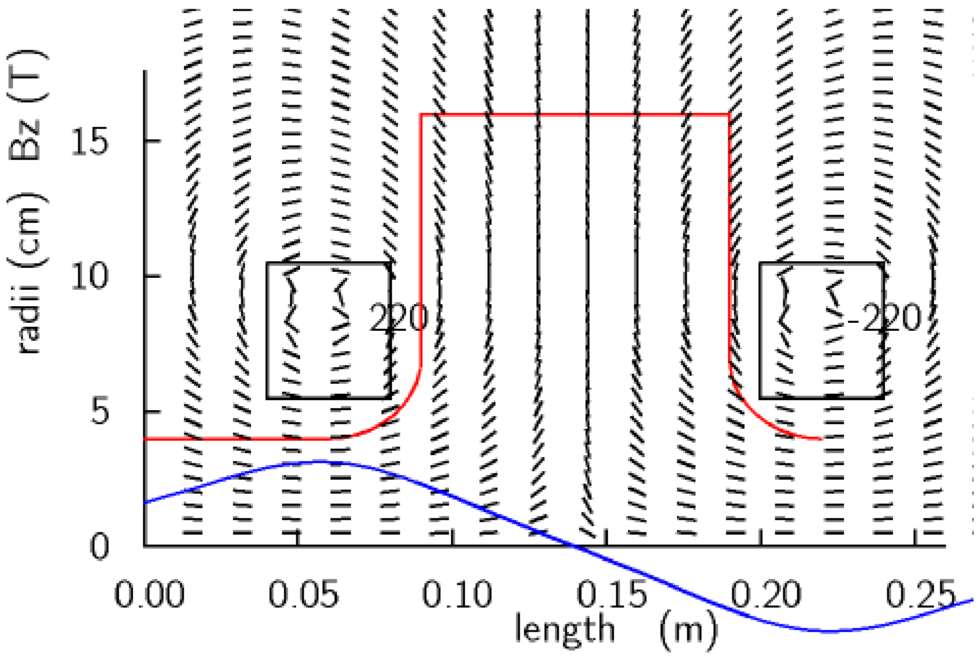


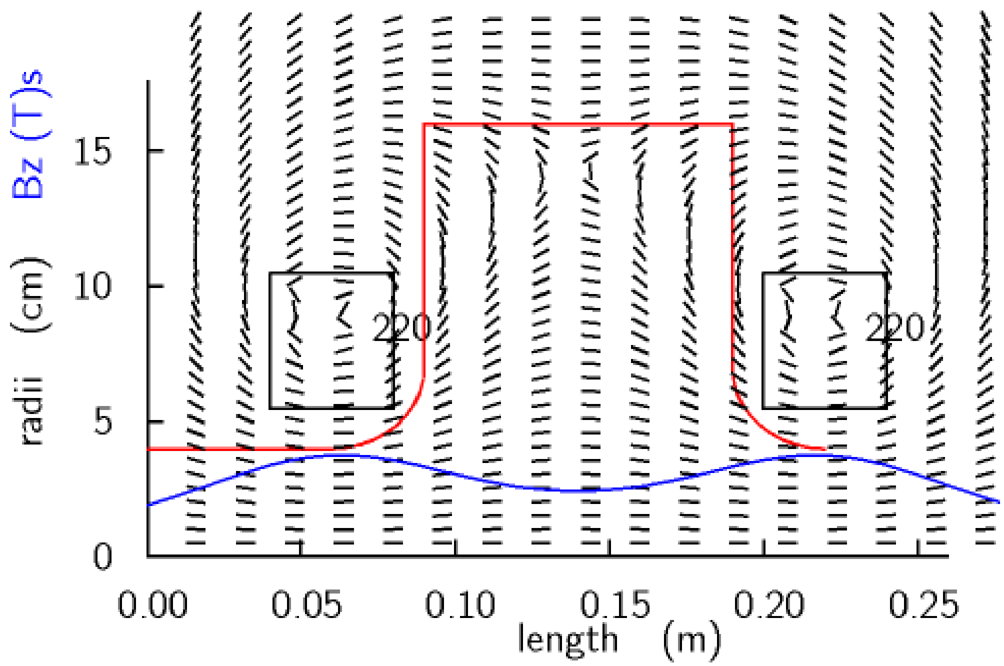


- This is "magnetic insulation"
- But this works over a quite small angular range ($\approx \pm 0.5$ deg)

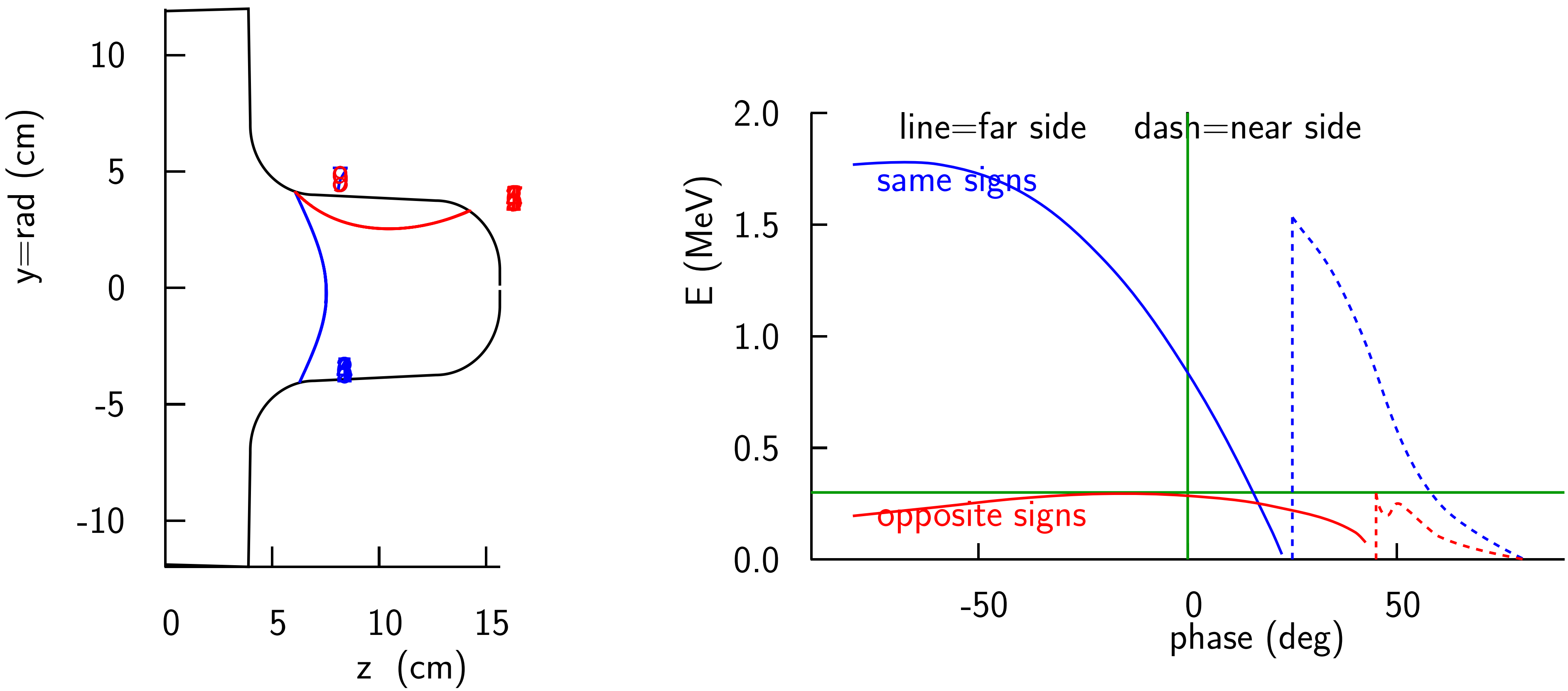
Coils in Irises

- The above runs were for unrealistic constant fields
- But we can get similar results with coils in irises of an open cavity
- We will consider 2 cases: aligned and opposed coil currents





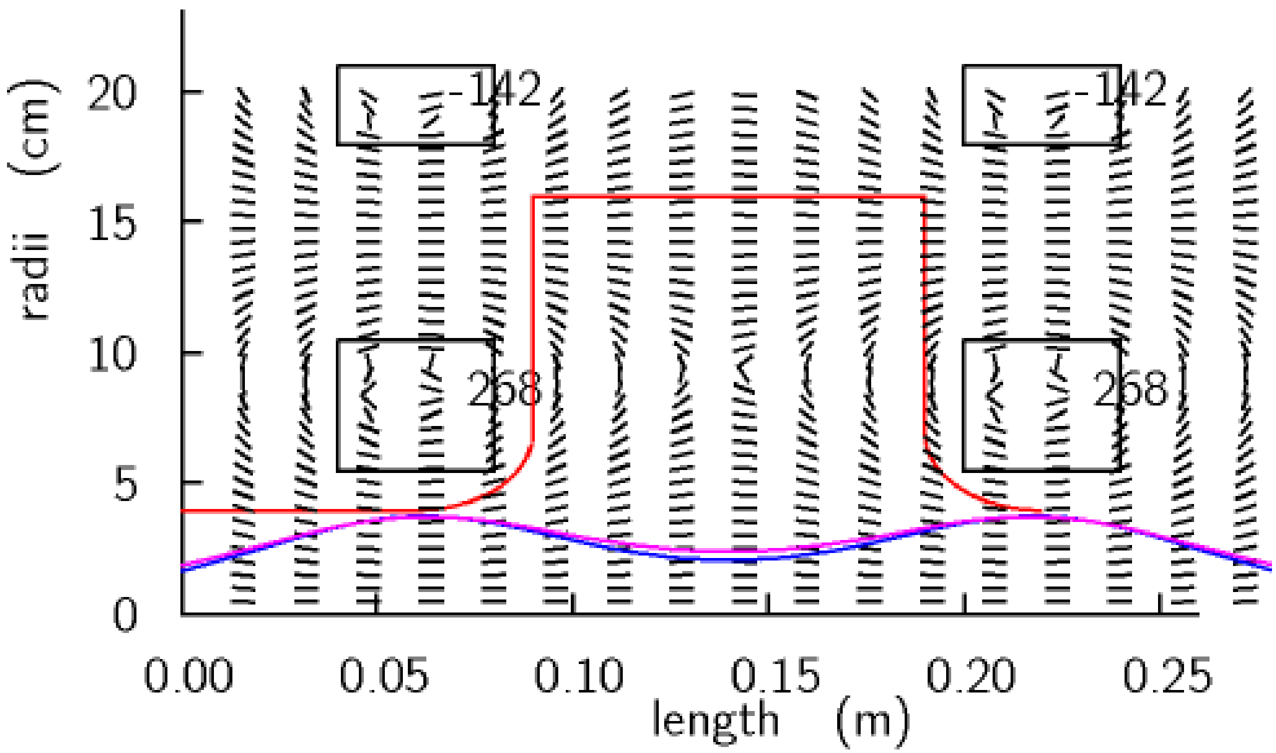
tracks



- With opposed currents
  - Energies are less - no help
  - But tracks end in low gradient region - GOOD
- With aligned currents - no improvement over uniform fields

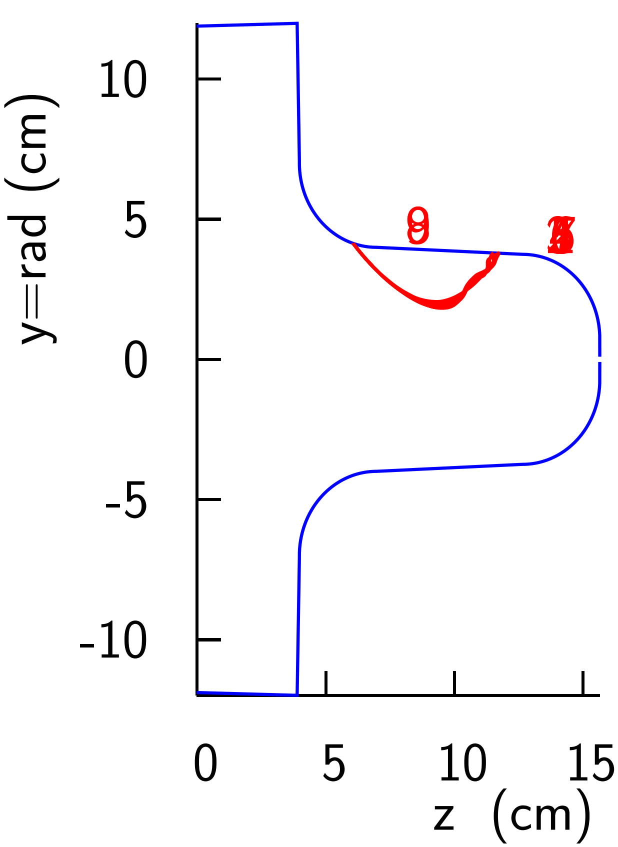
Solution for same signs

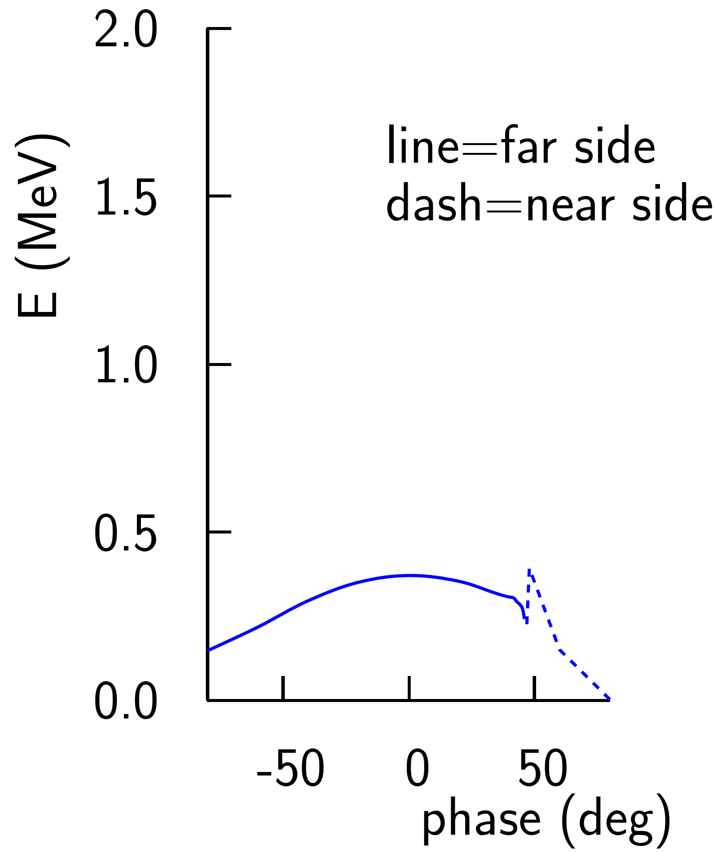
- Add outer coils with opposite currents
- Increase, somewhat main coils to regain field



- Fields on axis are not much different

Tracks and Energy

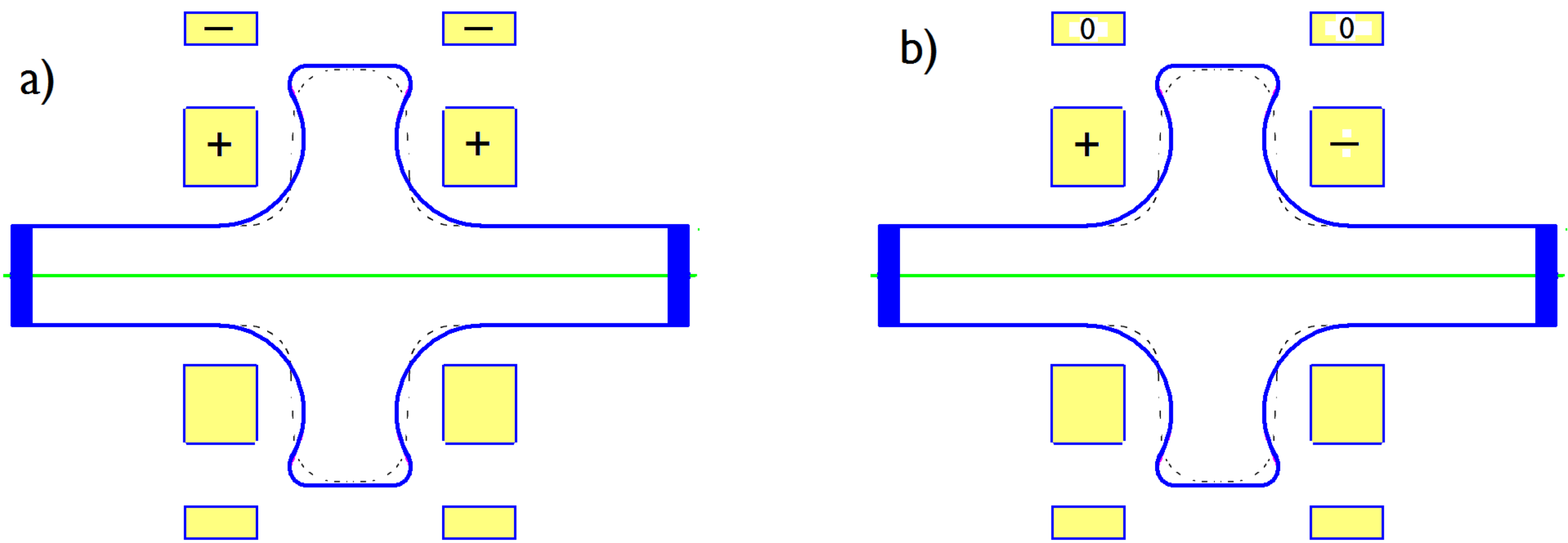




- Now it performs much like the opposed current case
  - Energies reduces - no help
  - But tracks end in low gradient area- GOOD

For True Magnetic Insulation

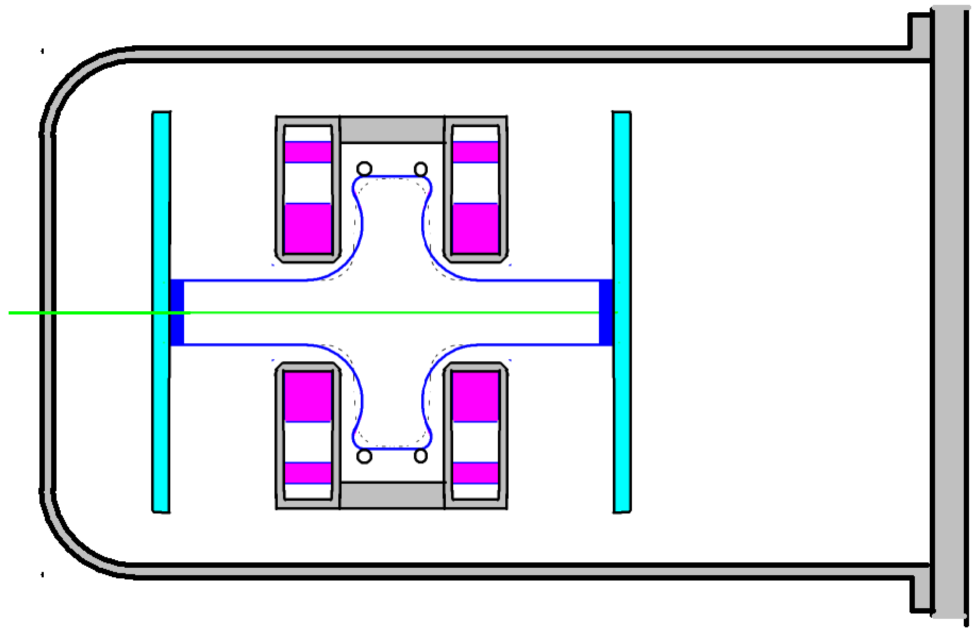
- The above may help, but is not magnetic insulation
- For that, the cavity surfaces must follow magnetic field lines
- This is possible for either
  a) aligned + reverse outer coils, &
  b) opposed coils & no outer
- Magnetic insulation is not perfect and will need a nitride coating to stop the cavity becoming a magnetron



Conclusion

- Experiments suggest electron motion causes breakdown in magnetic fields
- Could come from focused bombardment of opposite surfaces,
  or back bombardment of electron source
- Simple experiments would determine which or both of these dominates
- Conventional open cavity geometries with coils in irises
  could direct electrons to low gradient regions
  but cannot stop some back bombardment
- Special geometries could trap all emitted electrons near their source and provide "magnetic insulation"
- With this geometry, magnetic fields should INCREASE the breakdown gradients

Proposed Open Cavity Experiment



- Coils powered separately allow multiple field geometries
- Cavity is at 77 degrees to ease insulation in narrow spaces
- Experiment could be designed to fit in Lab G magnet, but this would greatly complicate the design and is superfluous since the field geometries can be changed sufficiently by the internal coils
- The cavity could also be designed to hold high pressure, but again this greatly complicates the design
- However, everything should be mounted and supplied from a single flange, thus allowing easy access, modifications and other experiments