The rf in magnet problem in ionization cooling and an idea for an open cavity experiment

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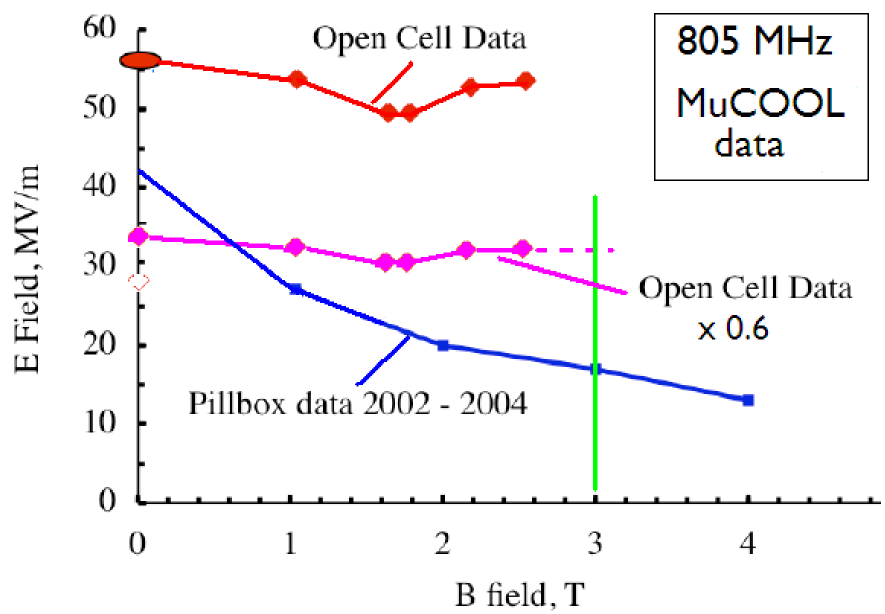
- Open Cavities
  - Introduction including simulations
  - 201 MHz RFOFO
  - Needed Experiments
  - Conclusions

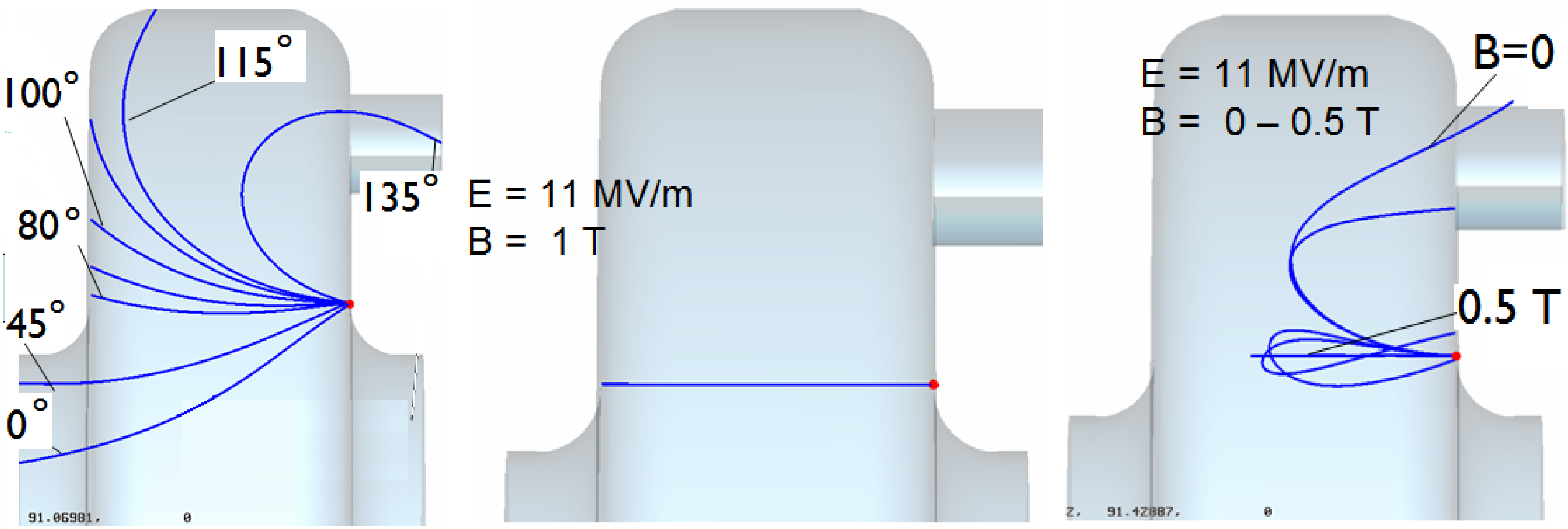
- Bucked field
  - 10 T RFOFO
  - 25 T Super Fernow
  - Conclusions

Introduction

- An 805 MHz 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 200 MHz, will preclude operation of 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
- Even though an open cavity yields less ($\approx 60\%$) acceleration per surface field, it is still prefered for magnetic fields above ≈ 1 T



Romanov simulations

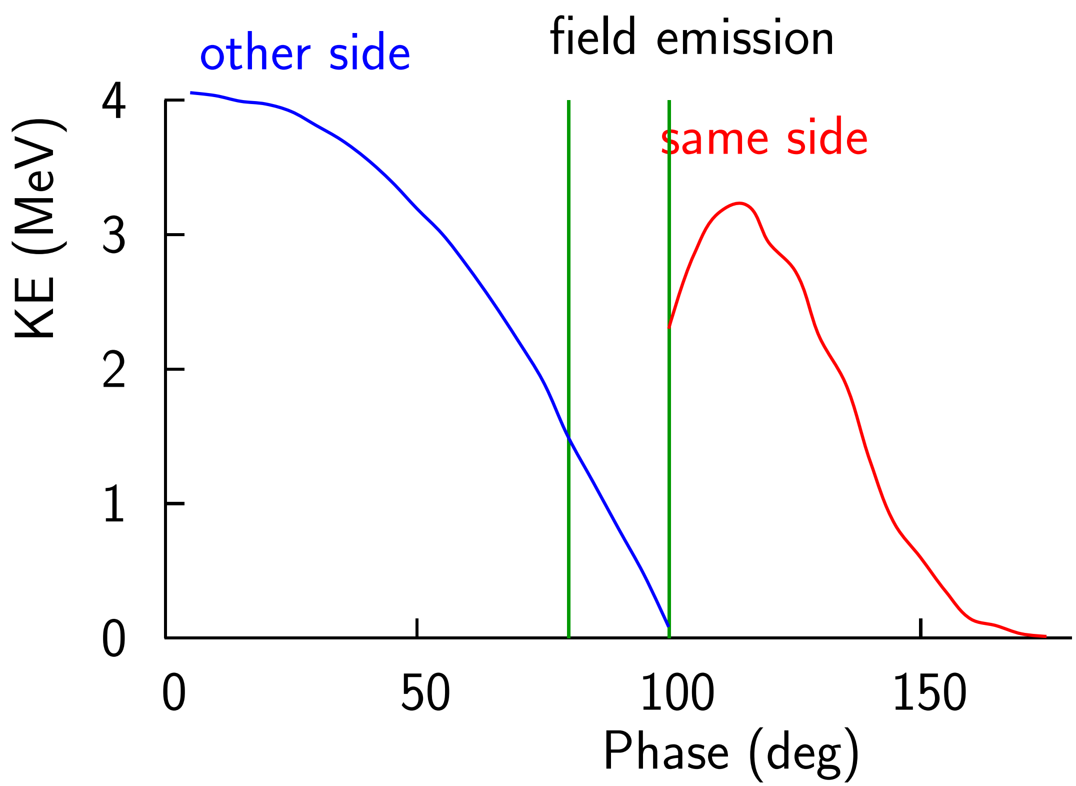


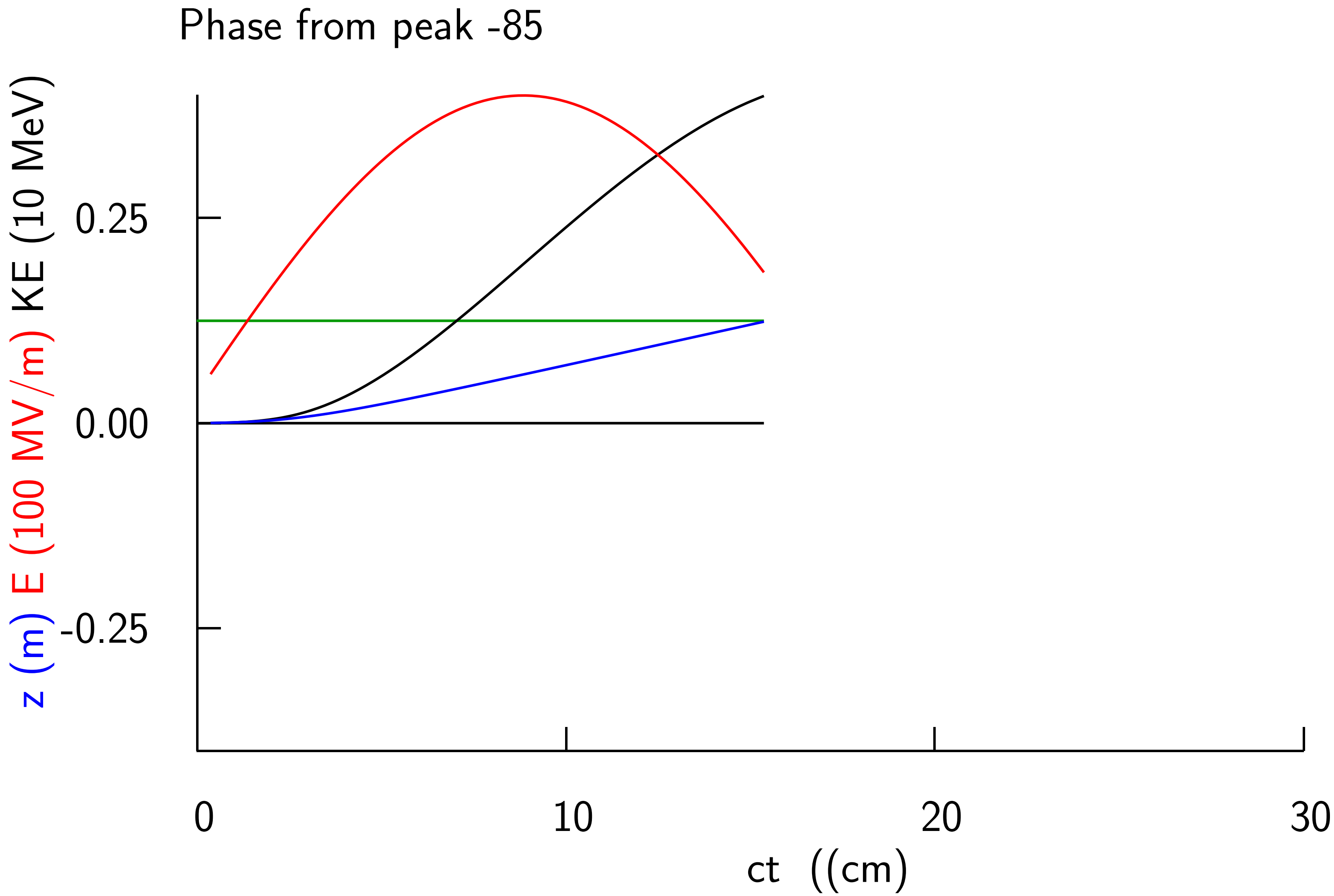
B=0 B=1 $\phi < 110^o$ B=1 $\phi > 110^o$

- With no field, elections emitted end up widely distributed
- With axial field and low phases, they are focused to opposite high field region
- With axial field and high phases, they are focused back to same high field region

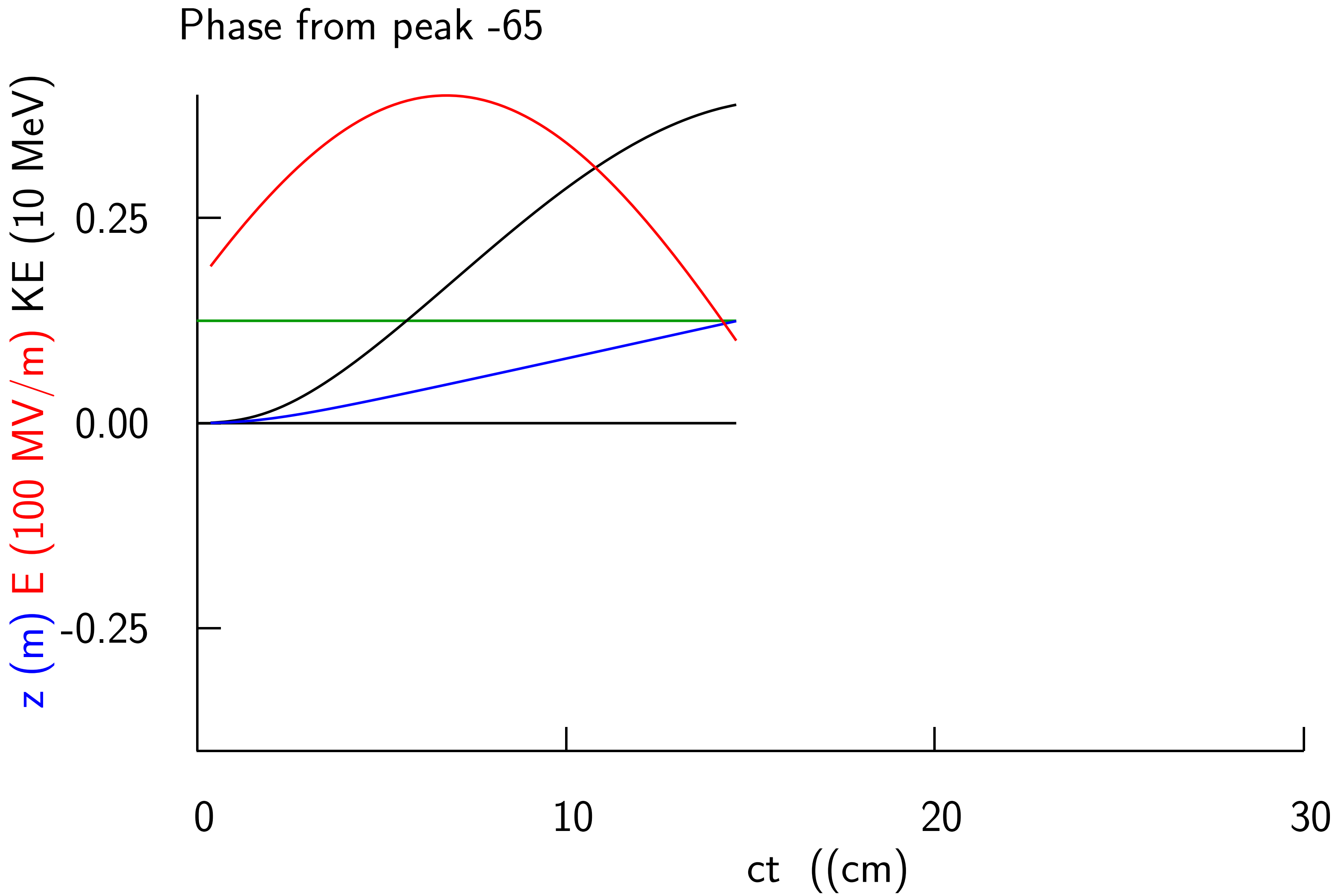
Simulations Fernow (Prog: CAVEL), Gallardo, Palmer (1D)

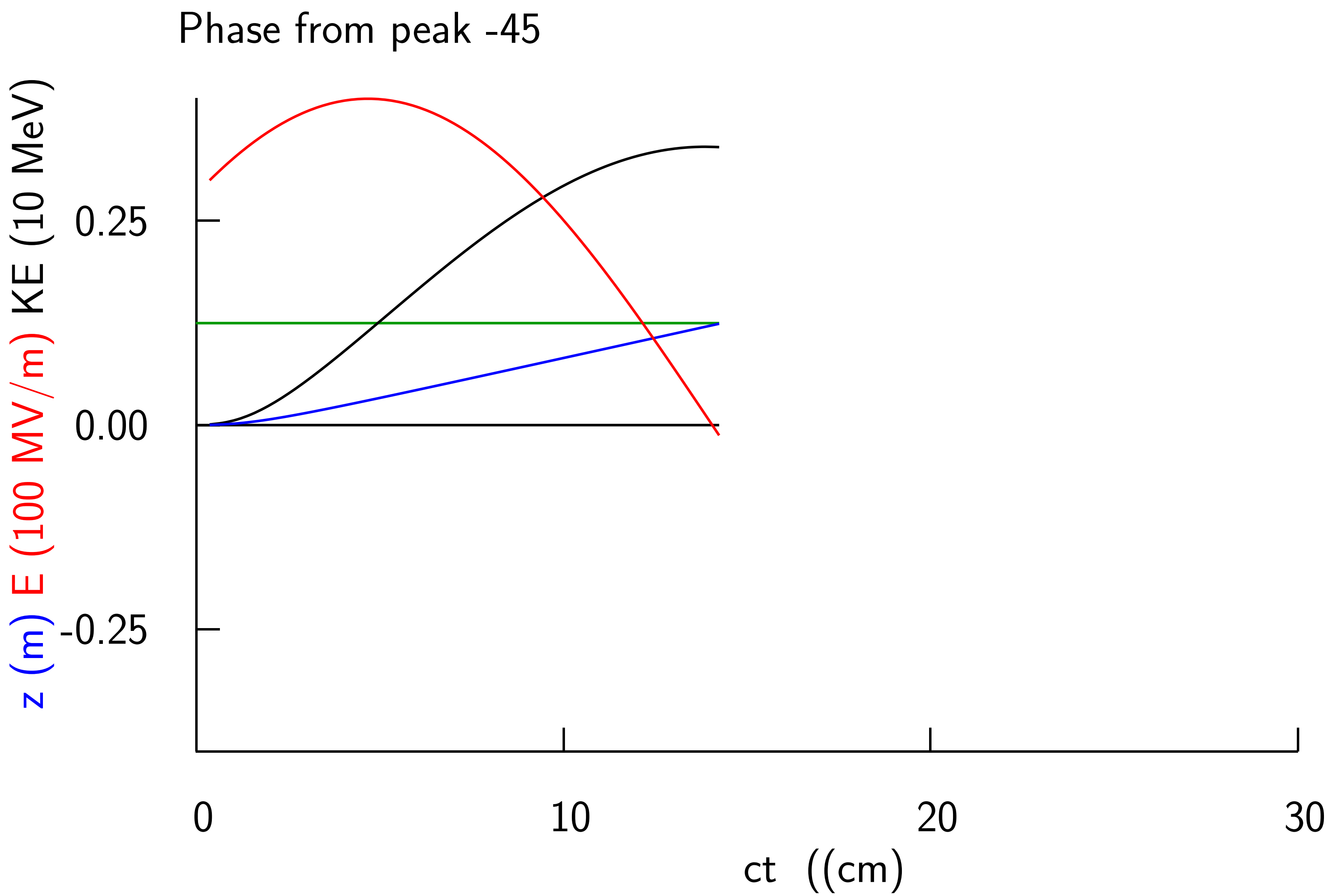
- On axis with, or without axial field, one gets qualitatively the same results as with open cavity and axial fields
- The electron energies when they hit are a few MeV
- With B>1 T perpendicular to the emitting surface
  - All electrons are returned to near their origen
  - With energies of a few keV or less (instead of a few MeV)

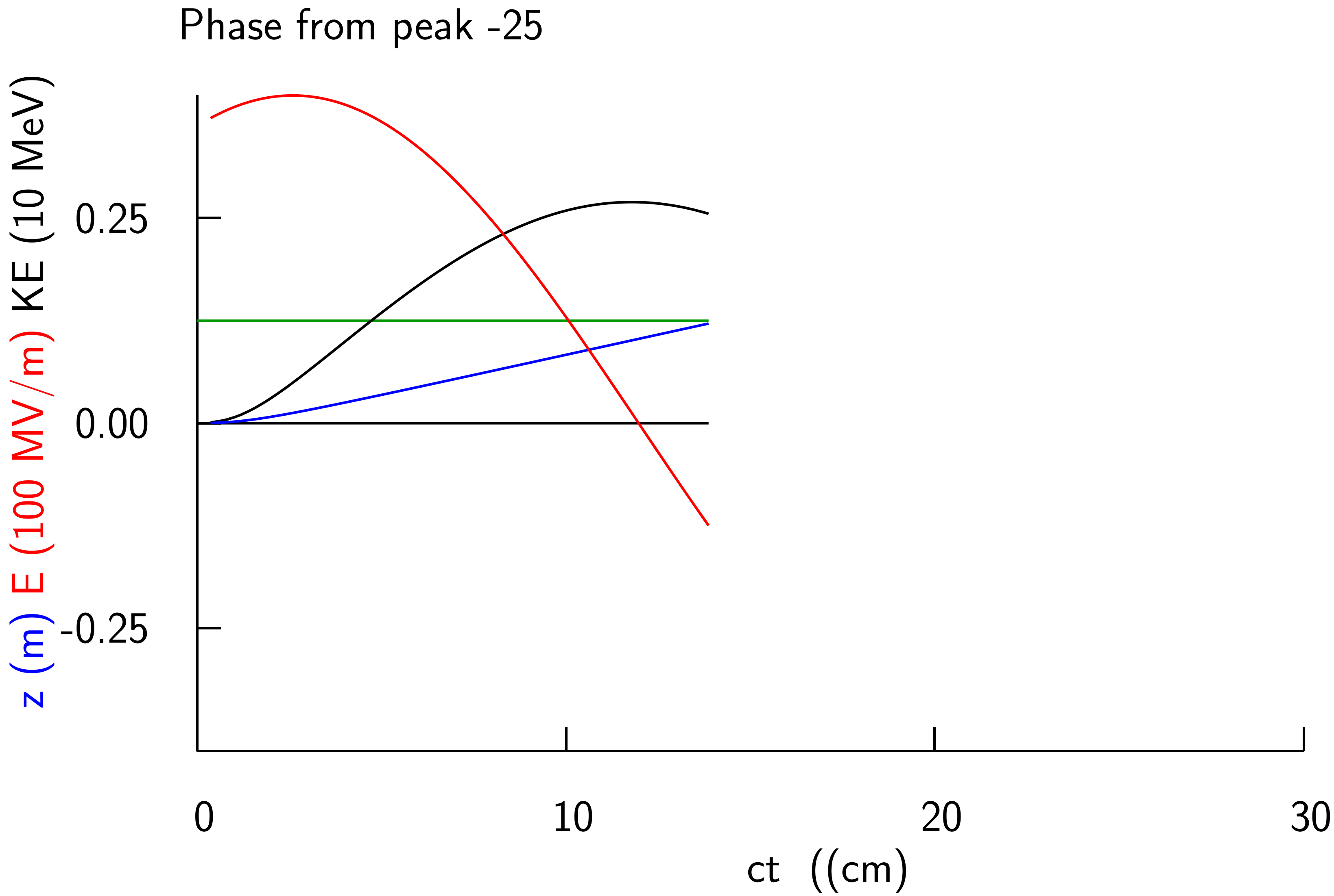




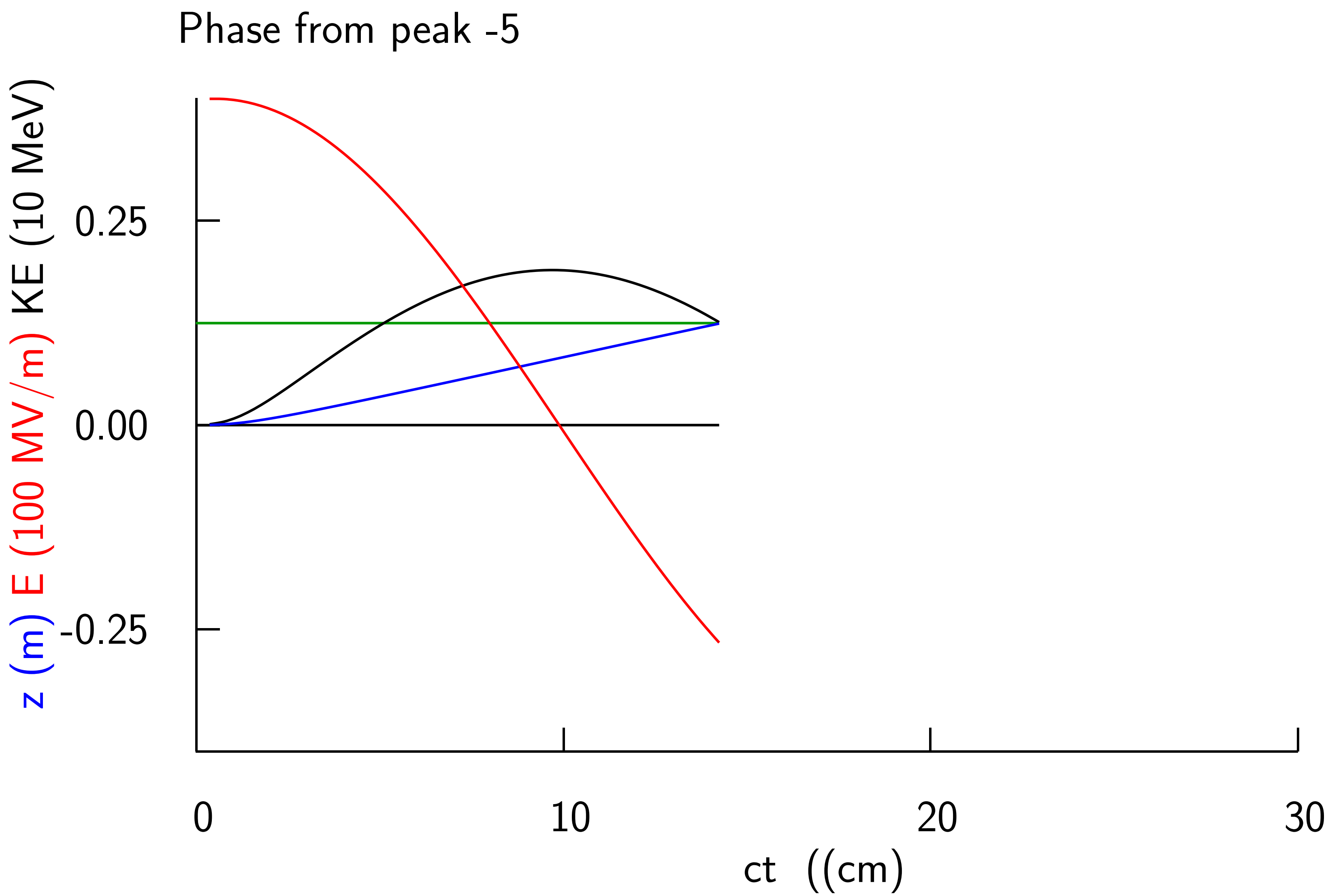
Phase from peak -85
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)


Phase from peak -65
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)

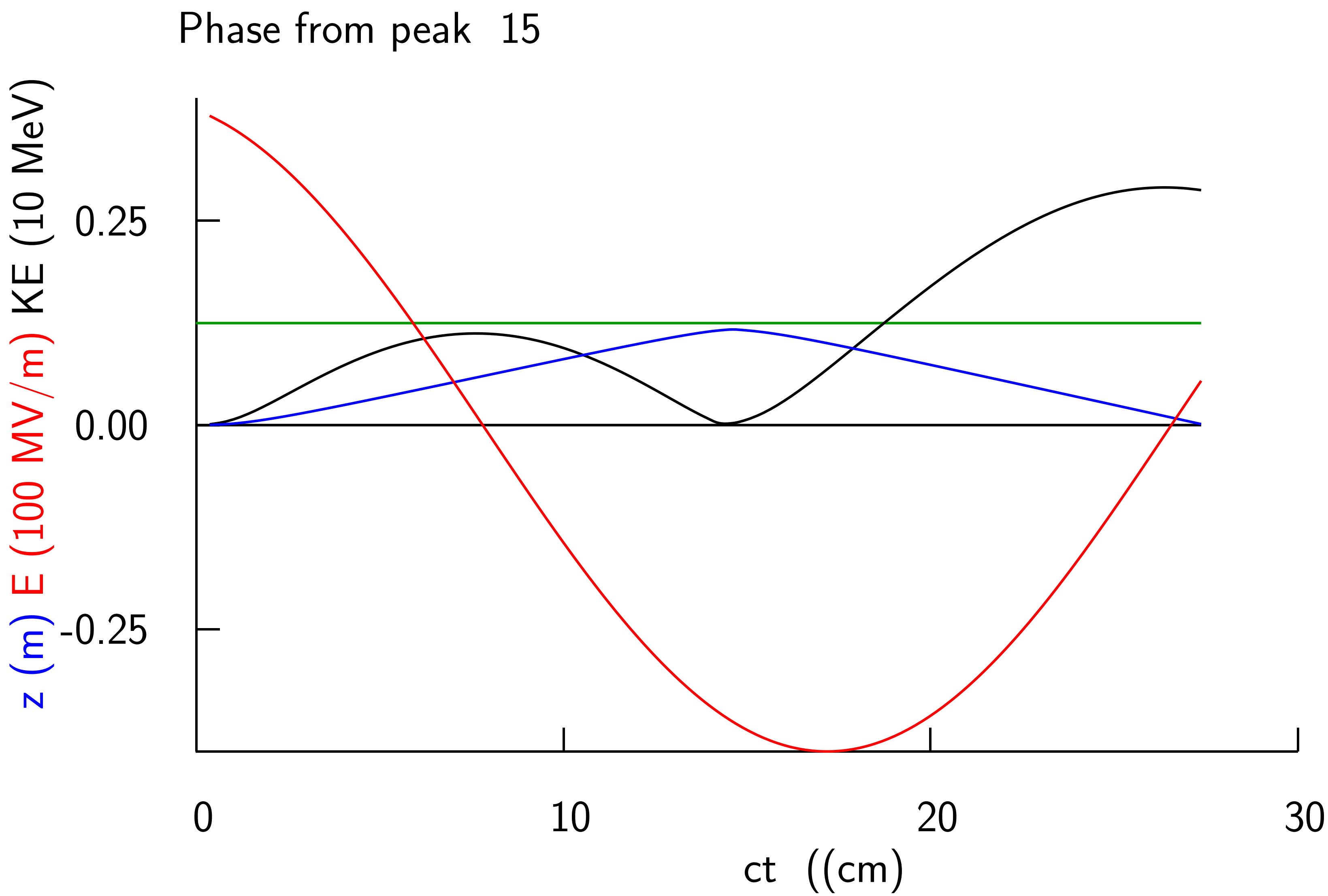

Phase from peak -45
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)



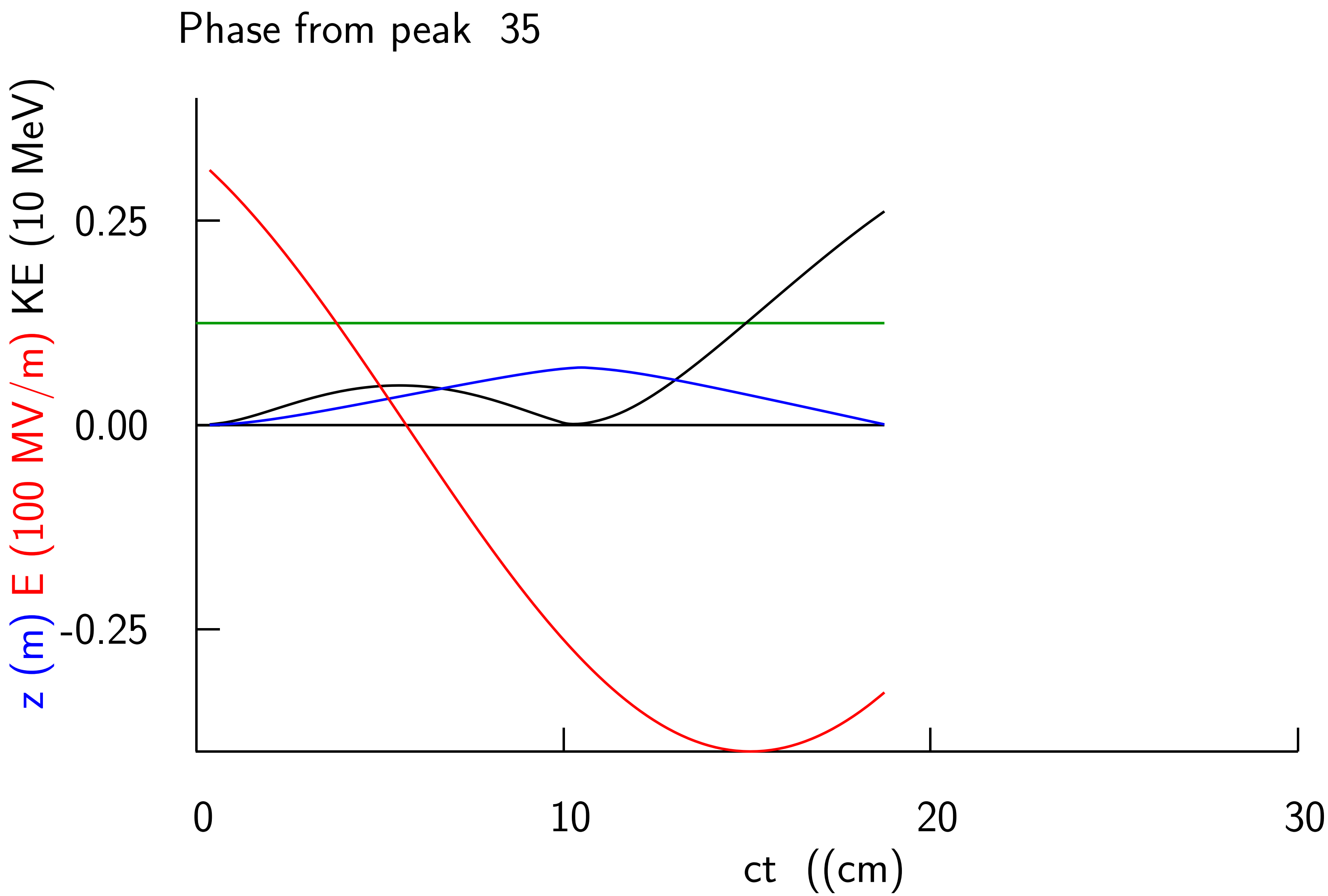
Phase from peak -25
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)



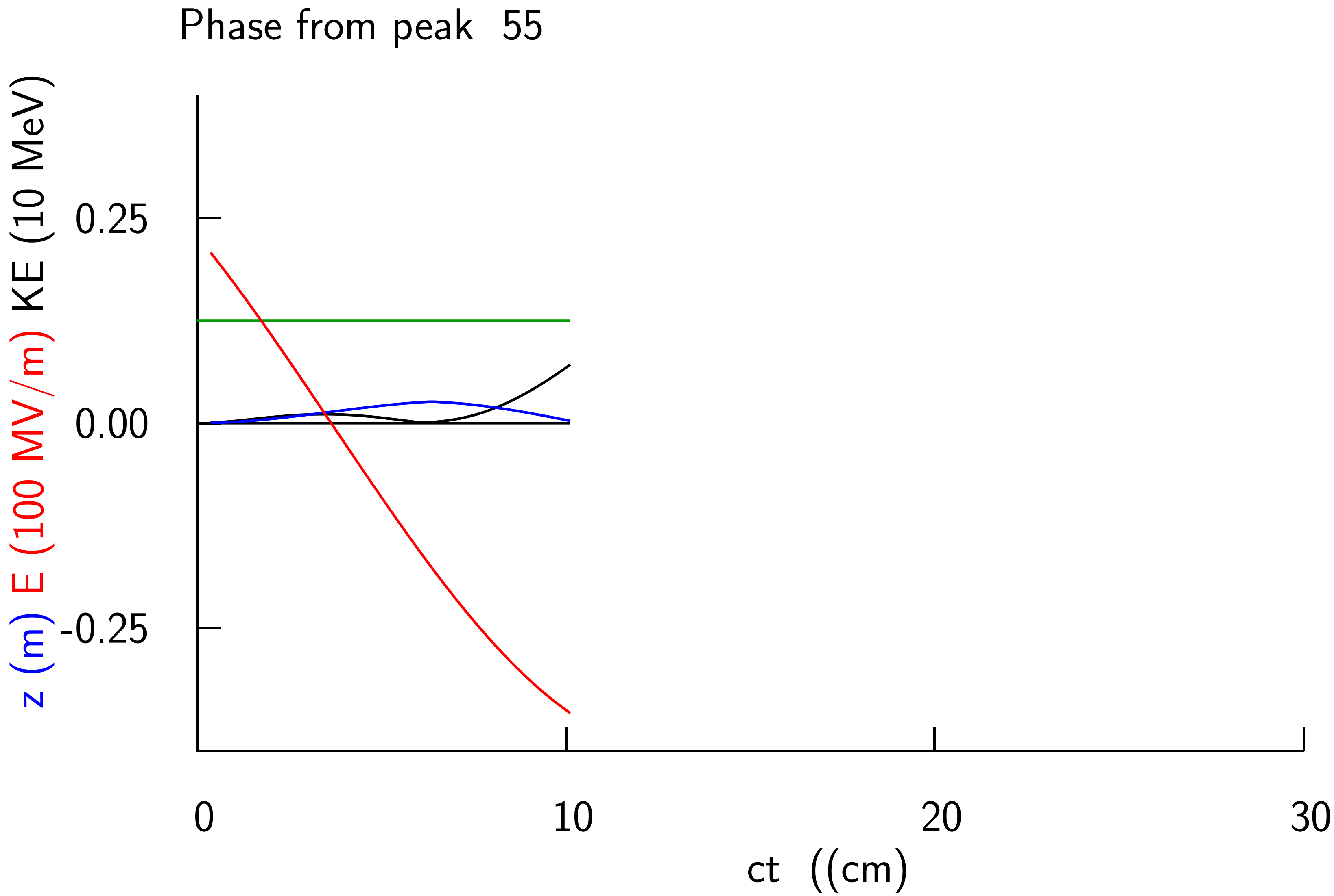
Phase from peak -5
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)

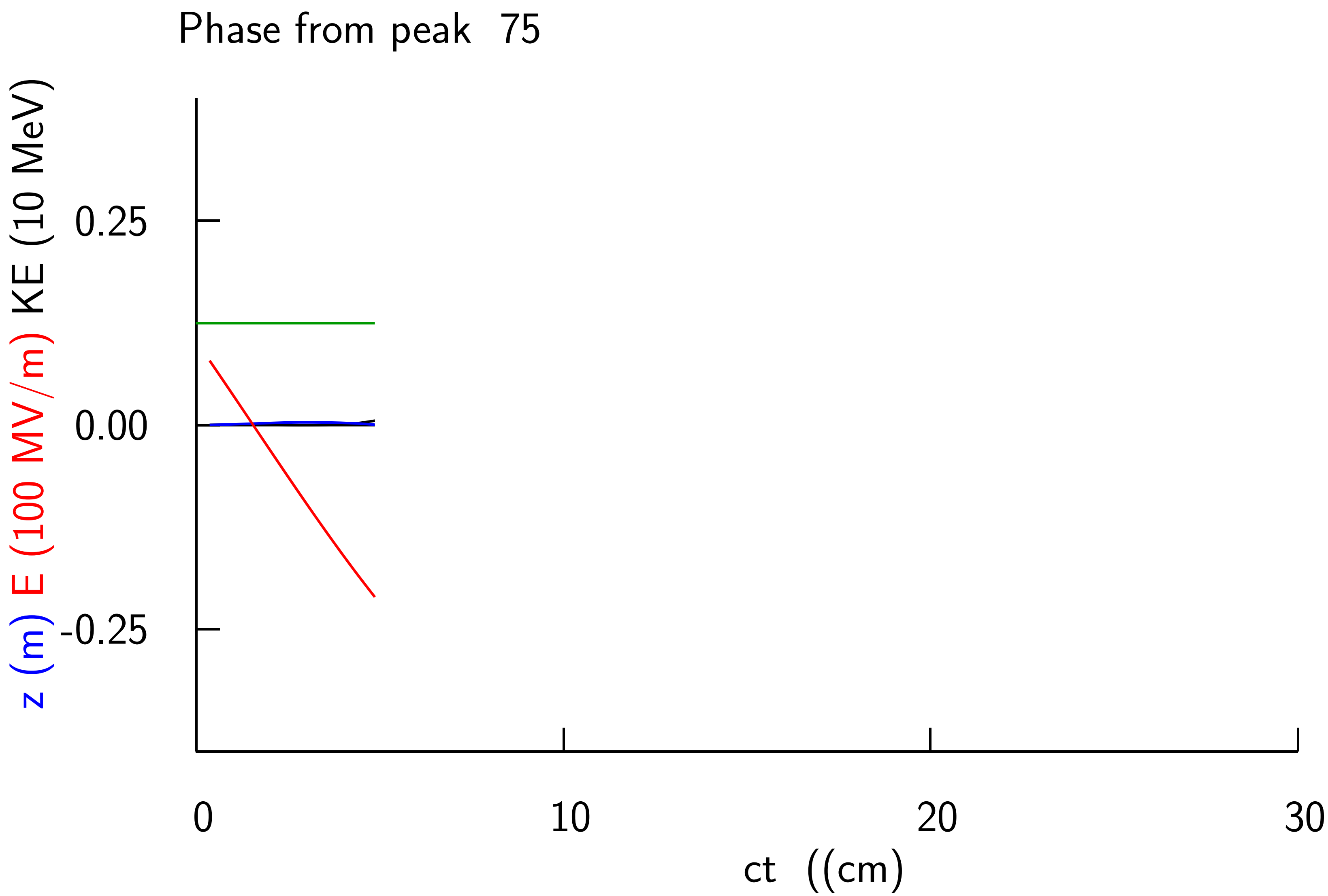


Phase from peak 15
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)



Phase from peak 35
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)


Phase from peak 55
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)


Phase from peak 75
z (m) E (100 MV/m) KE (10 MeV)
0.25
0.00
-0.25
0
10
20
30
ct ((cm)

Magnetic Insulation

- The name "Magnetic Insulation" was coined by F Winterberg[1] for insulating very high voltages (1 GV) in a pulsed transformer to rival Van-de-Graaff's as a high energy accelerator
- The proposal was soon rejected by E H Hirsch[2] and others because space charge and instabilities would still give breakdown (as in a Magnetron)
- But the basic idea was accepted and crossed magnetic and electric fields should breakdown at higher gradients than without a magnetic field

1. F Winterberg, Rev Sci Instrum 41,1756 (1970) 2. E H Hirsch, Rv Sci Instrum, 41, 1371 (1971)

What do we know?

- A magnetic field has strong effects on breakdown (muCool)
- High pressure gas removes the effect of the field (Muons Inc)
- These imply that gross election motion is somehow involved in breakdown
- Since emitted electrons can hit the same, or other, side of a cavity with significant energy, the impact of such electrons may be the cause

How could such electrons cause breakdown?

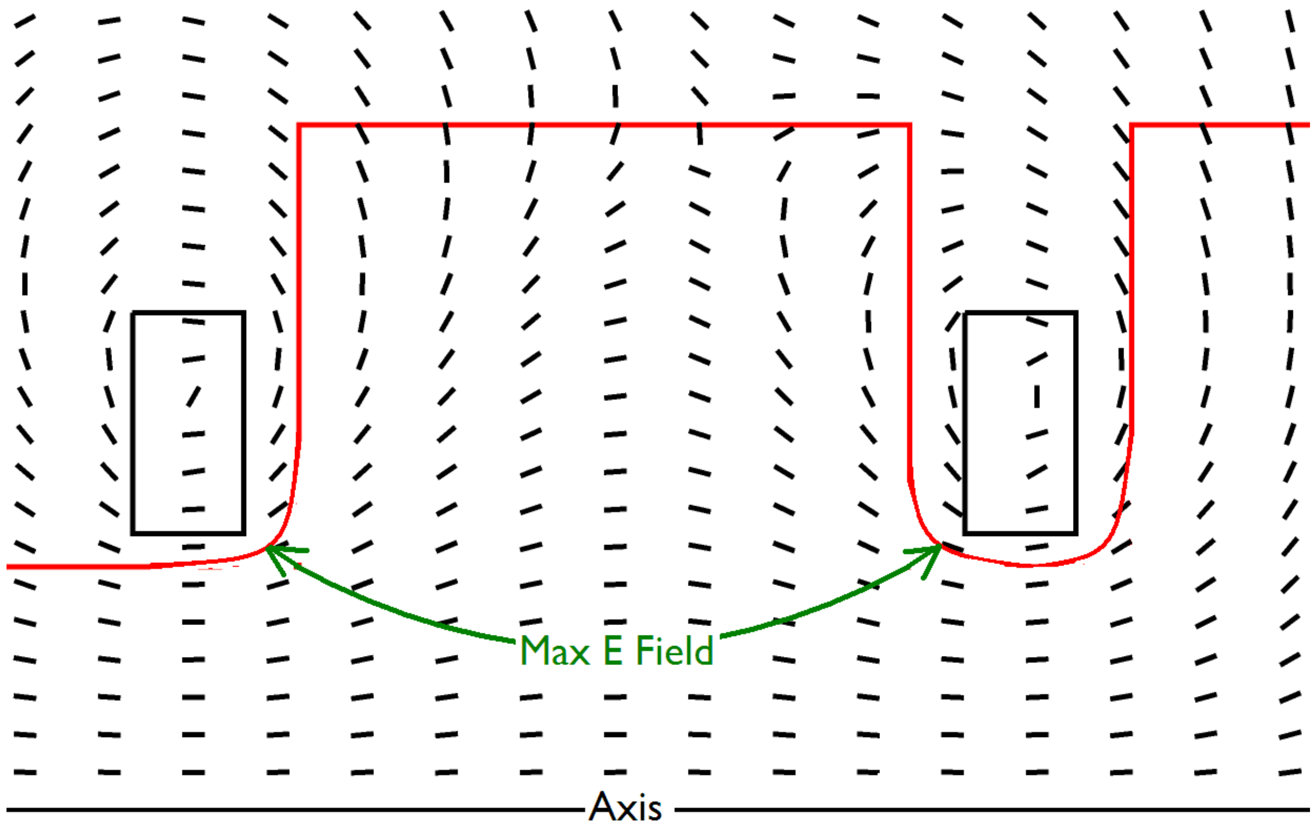
1. The electrons, emitted from field emission (at phases near zero) or from a "plasma spot"* (at phases from 0 to 180) go across the cavity, hit and heat a spot on the other side. This secondary hot spot then emits electrons that come back to the first source, heat it and make things progressively worse
2. Alternatively, a "plasma spot"* emits electrons at later phases, that come back, hit the same spot and heat it more (Wilson).

- But whichever process causes the breakdown, suppressing the emission will suppress the breakdown,
- And having magnetic fields perpendicular to the surface in regions where the electric fields are high, should suppress the electrons, and thus the breakdown

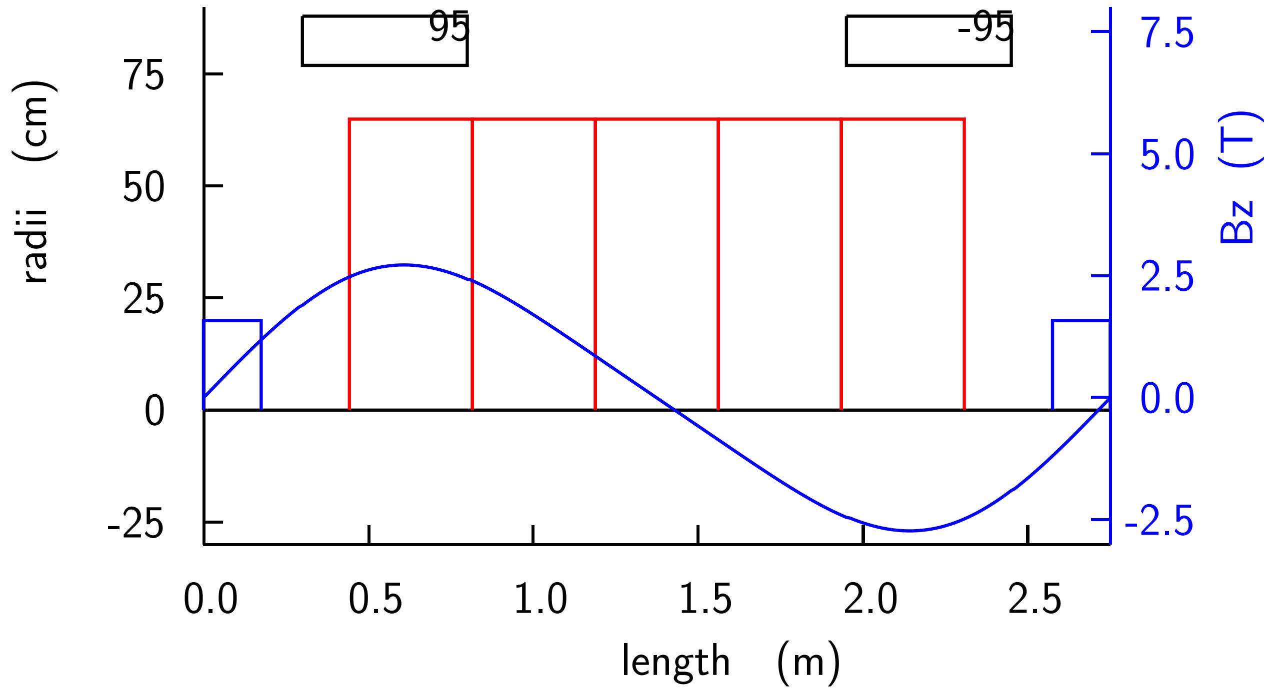
* "plasma spots" are bright spots that are seen on surfaces in high fields: both DC and rf. They do not automatically produce breakdown and usually self-extinguish. They may represent high temperature spots that are not actually plasmas, but in any case, they will emit copious electrons.

How do we arrange that magnetic fields are perpendicular to the electric fields?

Use open cell rf with coils in irises

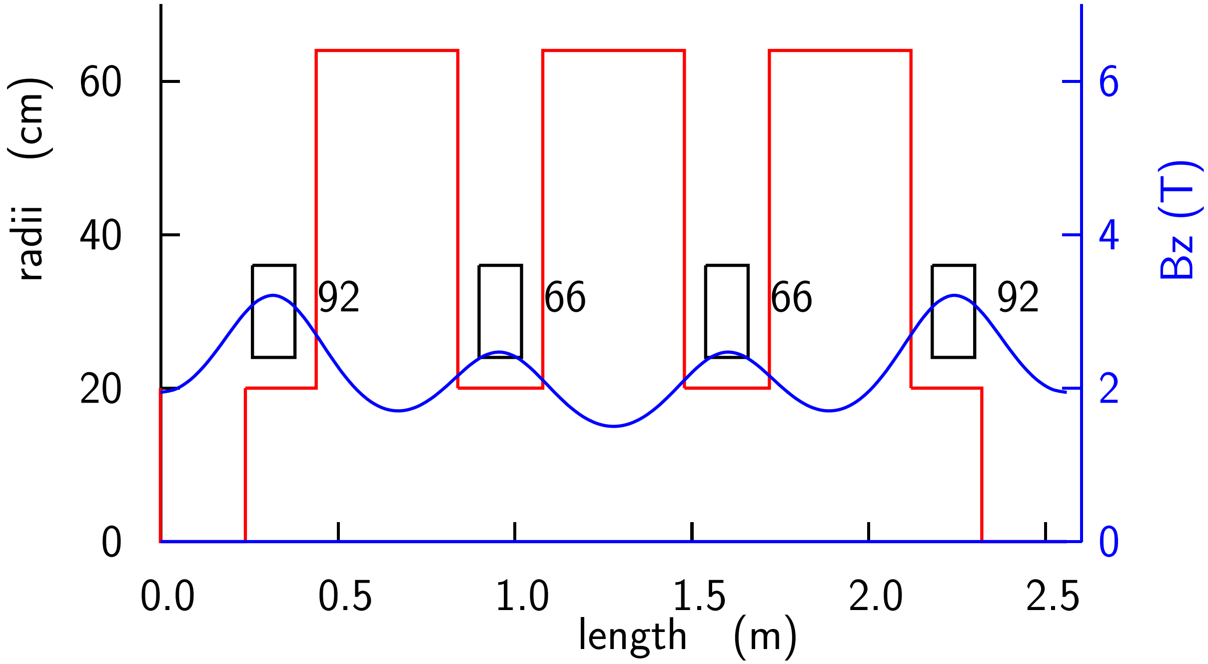


Example of lattice at start of RFOFO 6D cooling

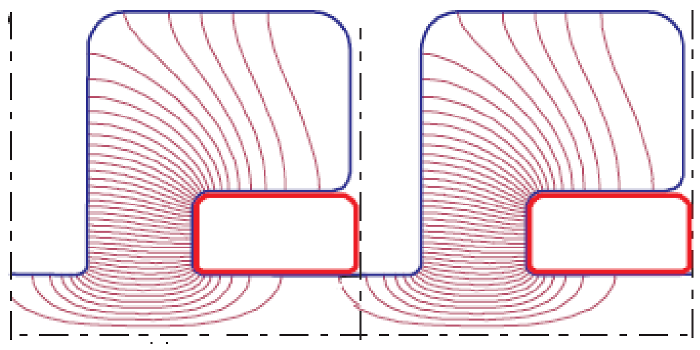


- Local fields in First RFOFO: 3 T in 201 MHz at 12 MV/m
  If breakdown $\mathcal{E} \propto \sqrt{\mathrm{f}}$ then max $\approx$ 6 MV/m

Alternative open cell lattice

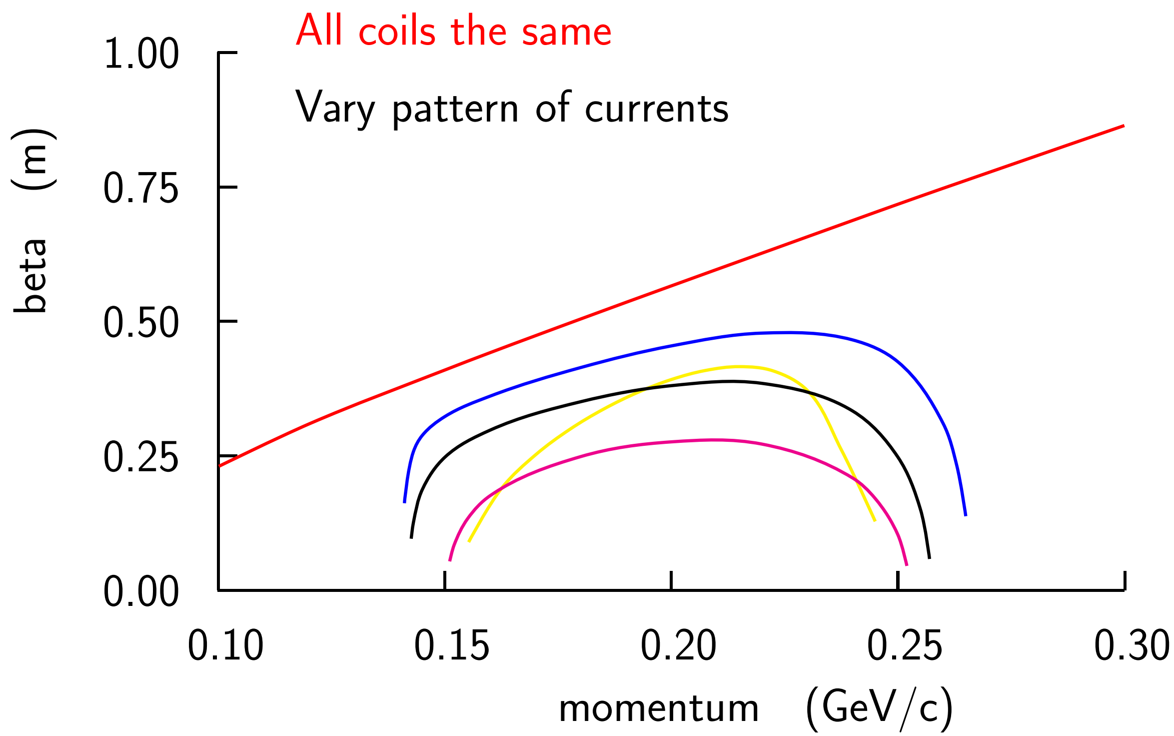


CERN 88 MHz rf proposal was another such solution



Beta adjustment by coil currents

Allows lattice to be tapered   lowering $\beta_\perp$ as $\epsilon_\perp$ falls



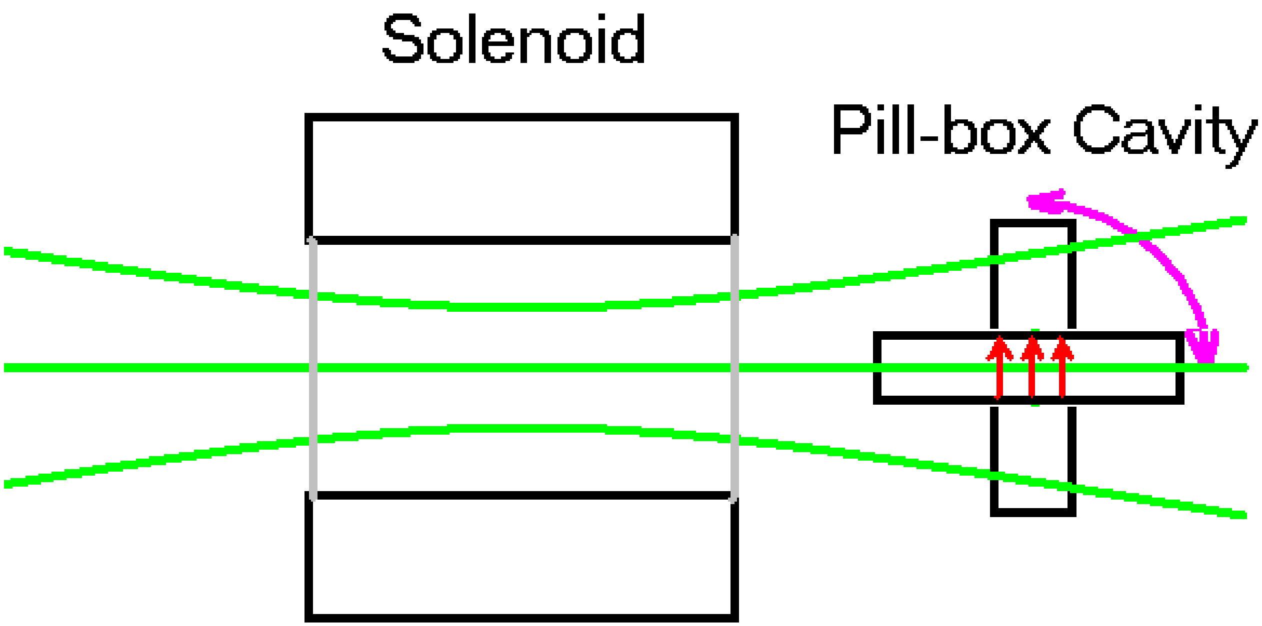
- Note trade-off between beta and momentum acceptance

Needed Experiments

805 MHz, rather than the 201 MHz to keep cost down

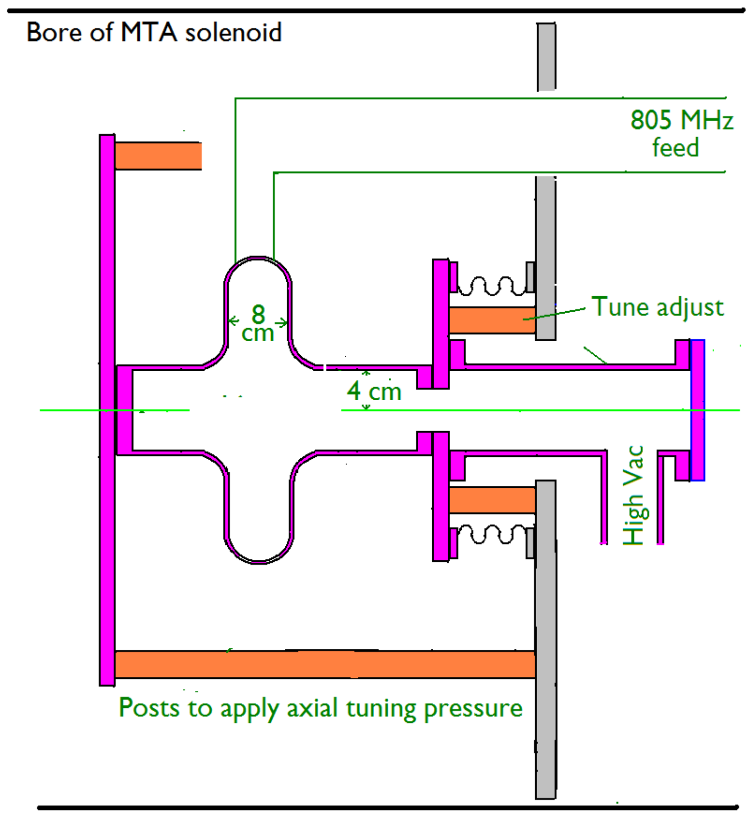
Experiment 1

Already planned



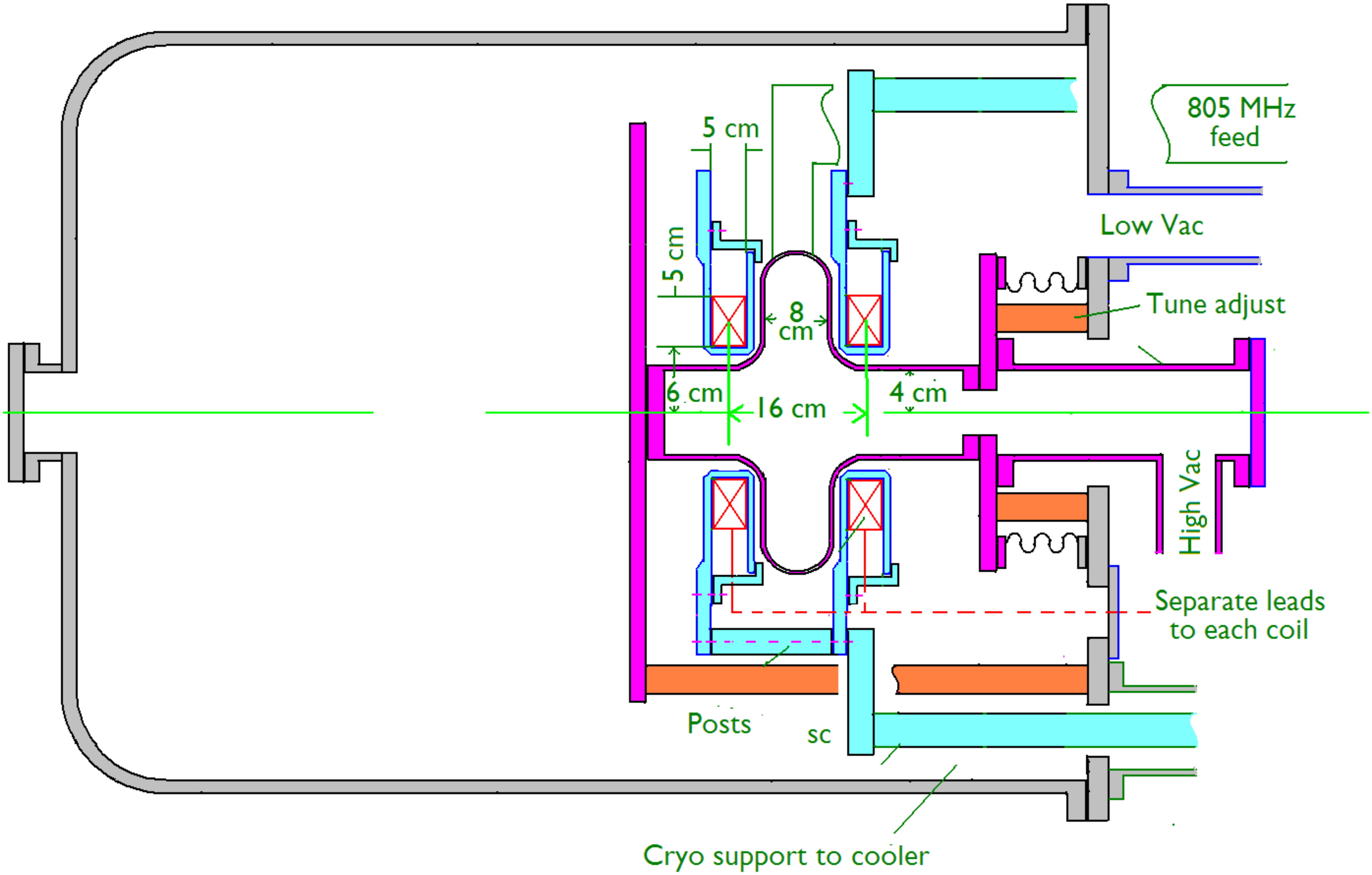
Is expected to show strong reduction of breakdown in horizontal position

Experiment 2



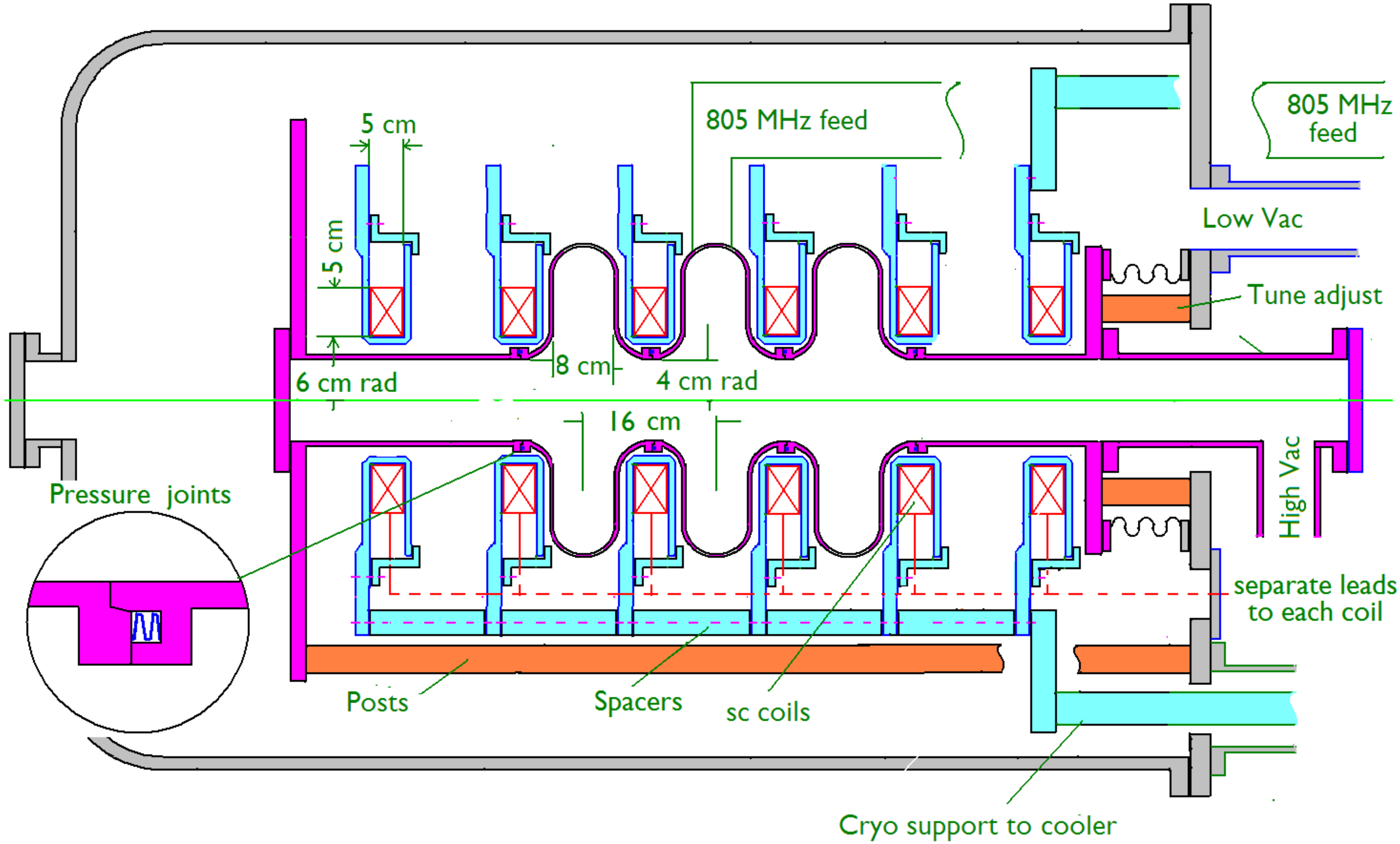
- Single cavity without joints
- Install in existing 5 T solenoid
- Establish baseline to compare coils in iris geometries

Experiment 3



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

Experiment 4



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

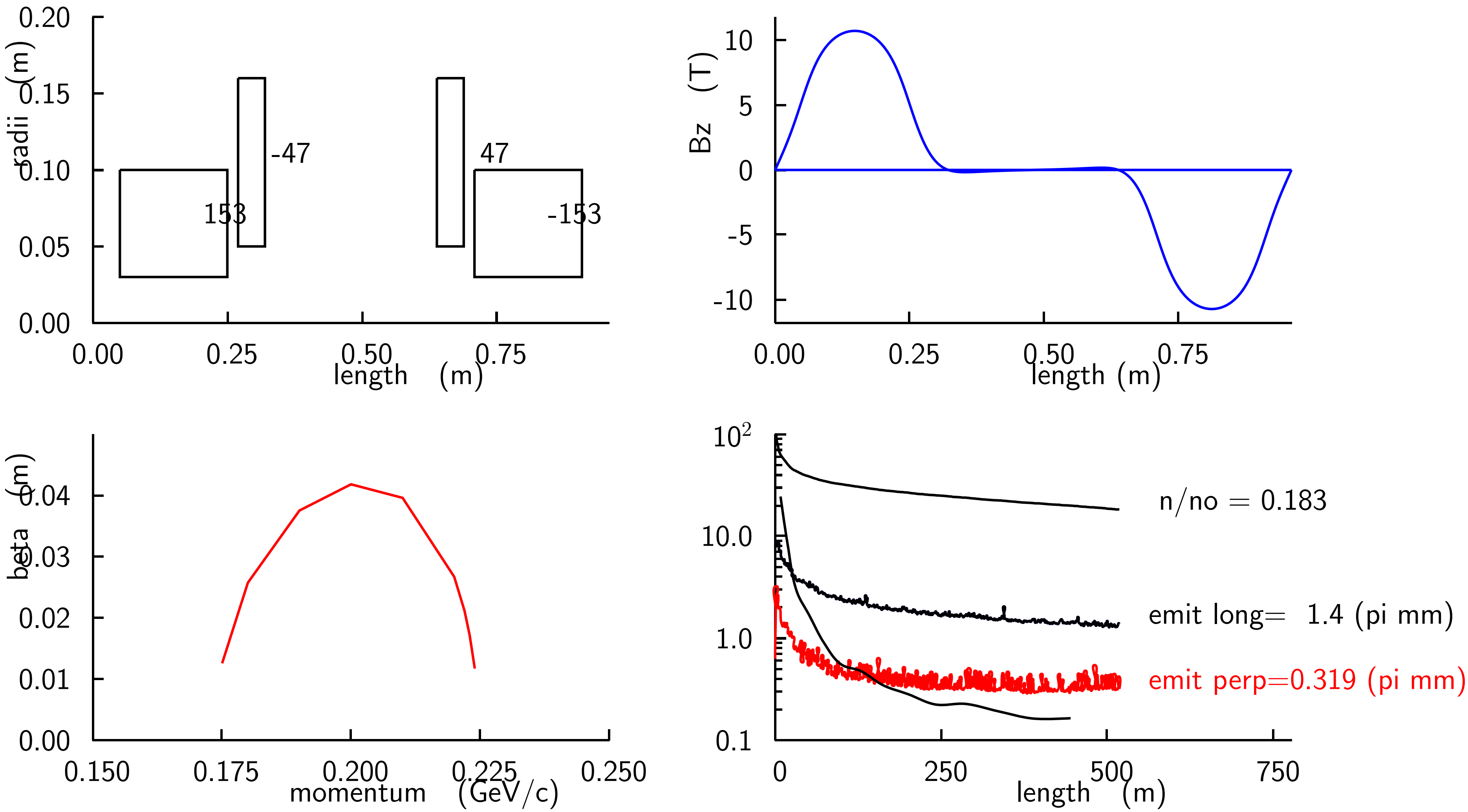
Conclusion on Open Cavities

- We expect that we have a breakdown problem with collider cooling, and probably also with the ISS neutrino factory design
- Simulations show that electrons emitted can strike the same or opposite sides with significant energy
- But with fields perpendicular to a surface, the electrons do not go far and gain little energy
- An open cell geometry with coils in the irises seems would have such a geometry at the high gradient regions

- But these ideas need Experiments
  1. Test a pill-box cavity with axis perpendicular to a magnetic field
  2. Using 805 MHz, study breakdown with an open cavity with coils on either side
  3. Using 805 MHz, study breakdown with short open linac with coils in the irises

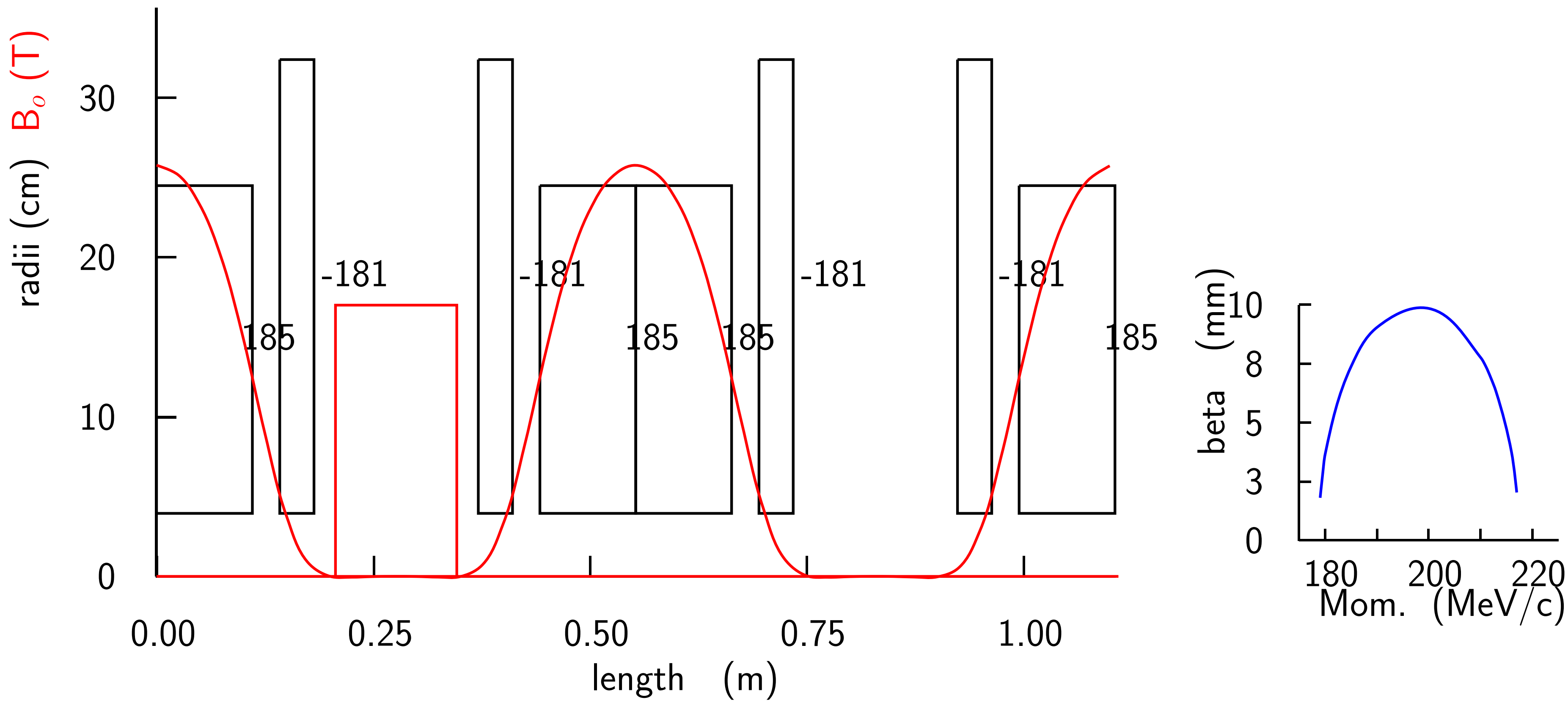
Use of bucking coils to remove all field at rf

Example 1: 10 T 805 MHz RFOFO



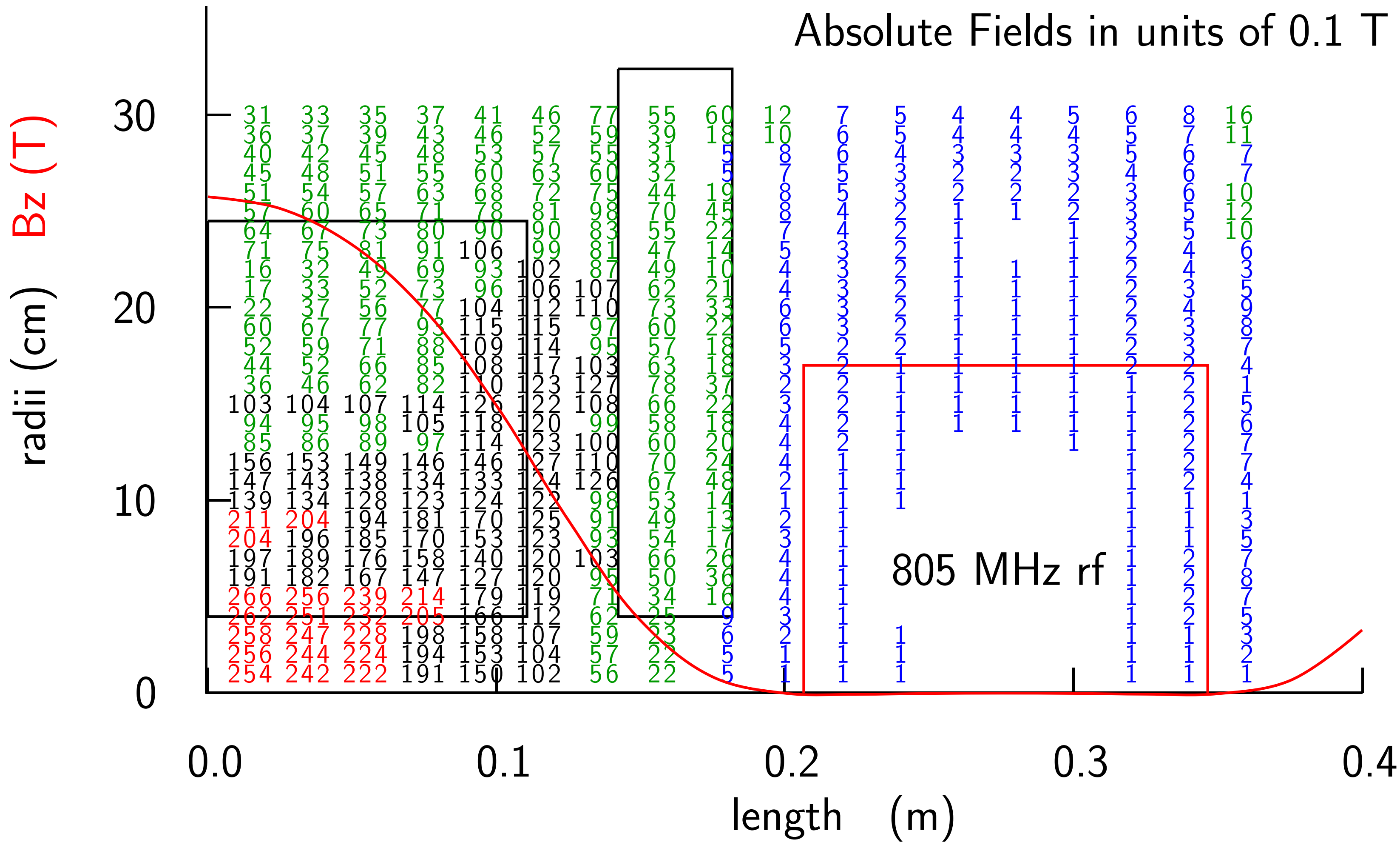
- This is for last 6D cooling in baseline scenario
- Has higher losses than non-bucked lattice

Example 2: 25 T 805 MHz RFOFO



- This was the "Super Fernow" lattice refered to in 50 T talk
- Uses plausible current densities (< 200 A/mm^2)

Fields at RF



- Field at the rf are less than 0.2 T
- If improved to < 0.1 T, Superconducting cavity could be used

Conclusion for bucked coil lattices

- Bucking coils can remove all fields at rf
- But fraction of length with rf is than small
- And higher harmonics lead to greater losses
  But these losses are a function of the order used in the simulation
  So this could be an artifact of ICOOL
- It is probably the only solution for late lattices with high fields
- Needs more study