



# Impact of Magnet Performance on the Physics Program of MICE



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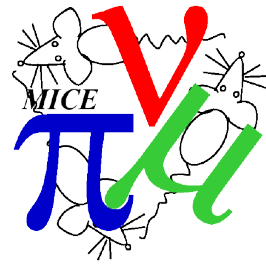


# Overview



- Focus Coil 1 has not reached specified currents
  - Non-flip mode → specified currents reached
  - Flip mode → stuck at around 200 MeV/c required current
    - Even here, need an operating overhead of order 10%
- If FC can't be fixed; how does this limit the performance of Step IV?
- What about Step VI?
- Caveat:
  - All of this is linear optics
  - Great for getting an idea of the parameter space
  - Not sufficient for redefining MICE baseline

# Step IV

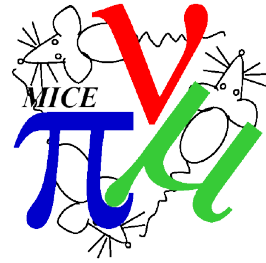


- Step IV has just FC, no coupling coil and no lattice
  - What beta function can be achieved with reduced FC current?
- Coils
  - End coils and Centre coil is fixed for 4 T field on tracker
  - Optimise for matching using Match 2 and Match 1
  - Vary focus coil and look at response

Coil Name	Centre z [mm]	Inner radius [mm]	Radial thickness [mm]	Length [mm]	Current Density [A/mm <sup>2</sup> ]
End 2	3201	258	68.2	110	135.18 fixed
Centre	2451	258	22	1294	152.44 fixed
End 1	1701	258	60.9	110.6	127.37 fixed
Match 2	1301	258	30.9	199.5	148.09 maximum
Match 1	861	258	46.2	201.3	145.94 maximum
Focus	205	263	84	210	113.95 nominal

Tab. 1: Coil pack used for simulation of MICE Step IV. The field has odd symmetry about  $z=0$ ; upstream magnets have opposite polarity. Field values and parameters for the Spectrometer Solenoid were sourced from [2].

# Beta function matching

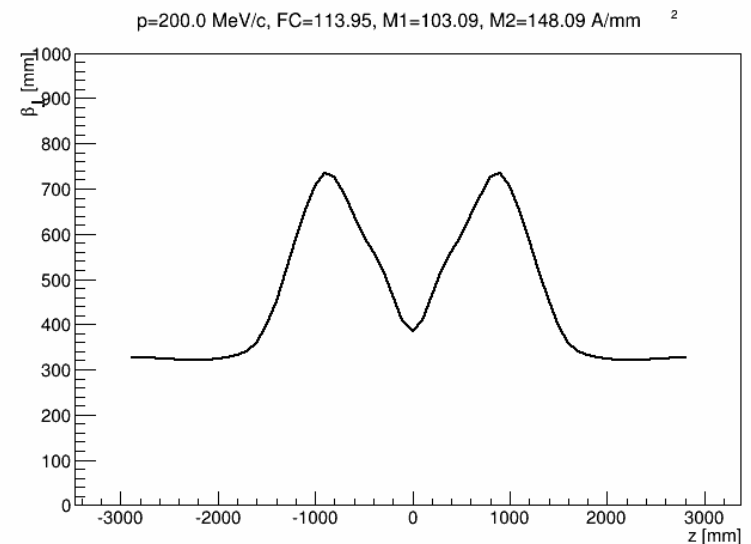
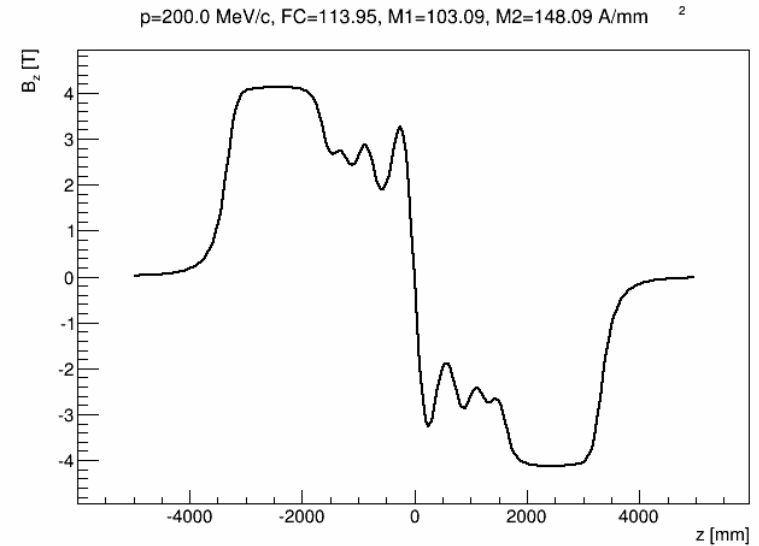


- Standard setting at Step IV is that beta should be symmetric about absorber ( $z=0$ )

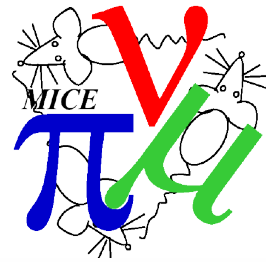
- Require  $d\beta/dz = 0$  at the absorber centre
- Choose  $d\beta/dz = 0$  in the constant solenoid field (analytic solution here)

- Example for 200 MeV/c

- E2, Centre, E1 set for 4 T
- M2 set to max current 148.09 A/mm<sup>2</sup>
- M1 varied for matching
- FC current at nominal 113.95 A/mm<sup>2</sup>

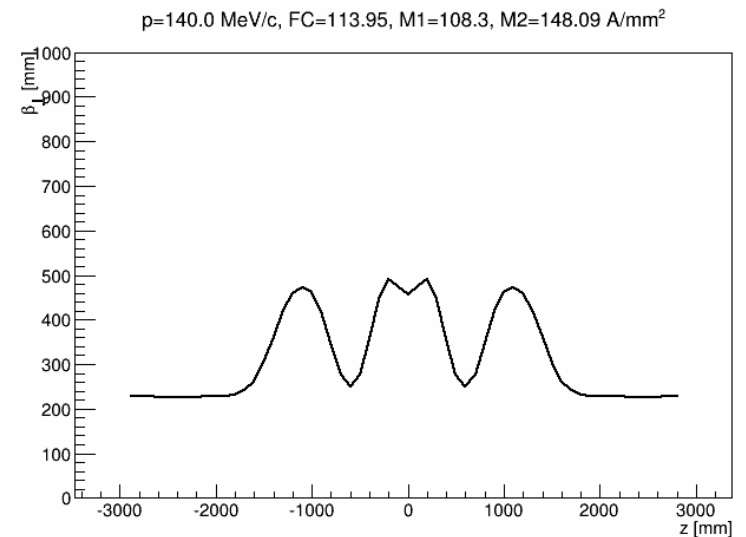
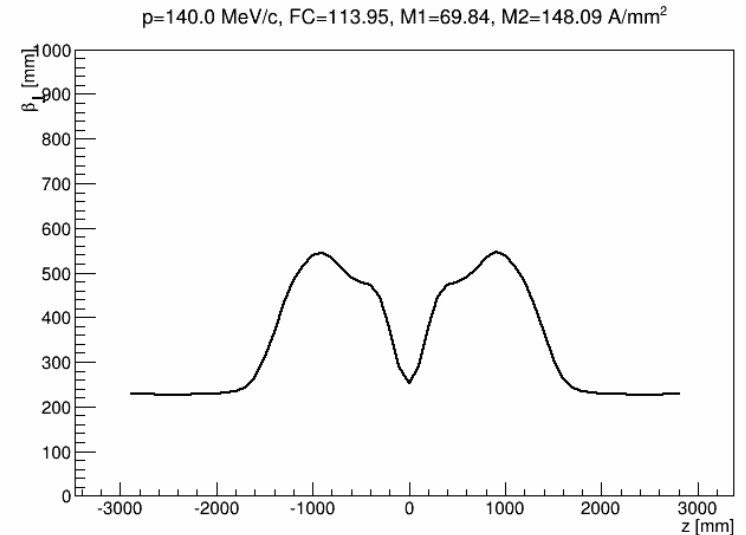


# Solutions to Match Condition

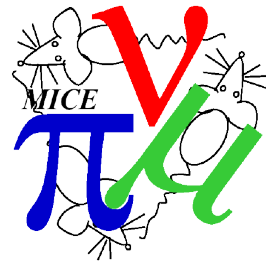


In some cases, there is more than one solution to the match condition for a given M2 current

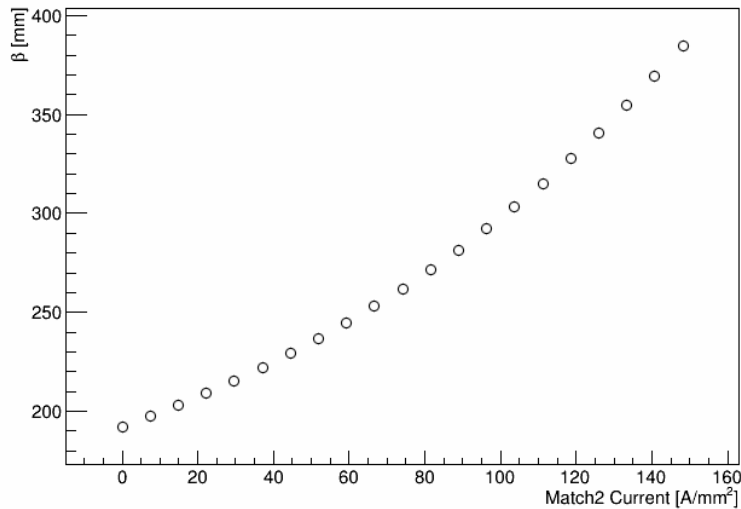
- e.g. at 140 MeV/c case to right
- Means we need to be careful about applying optimisation routines
- Want to find all the possible match conditions...



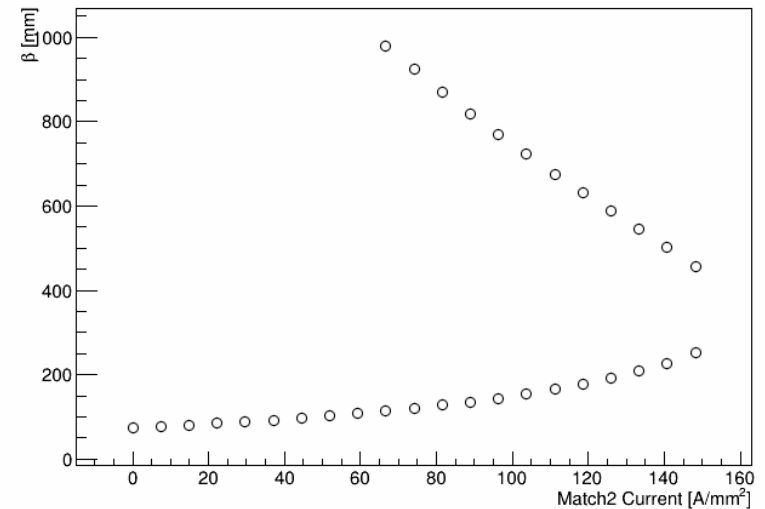
# Scaling M2



Focus Coil=113.95 A/mm<sup>2</sup> Momentum=200.0 MeV/c

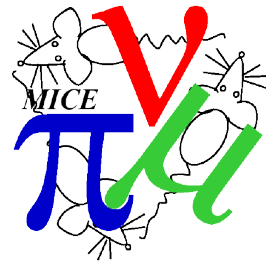


Focus Coil=113.95 A/mm<sup>2</sup> Momentum=140.0 MeV/c

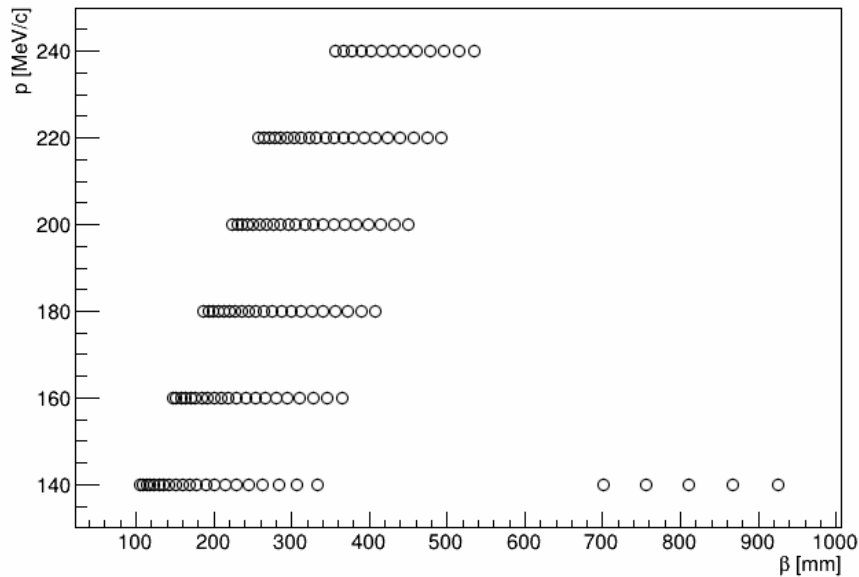


- Fix M2 and let M1 vary freely to find a match
  - As before, scan to find all possible solutions
  - Then optimise to get the best match
- See two families of solutions for  $p = 140$  MeV/c

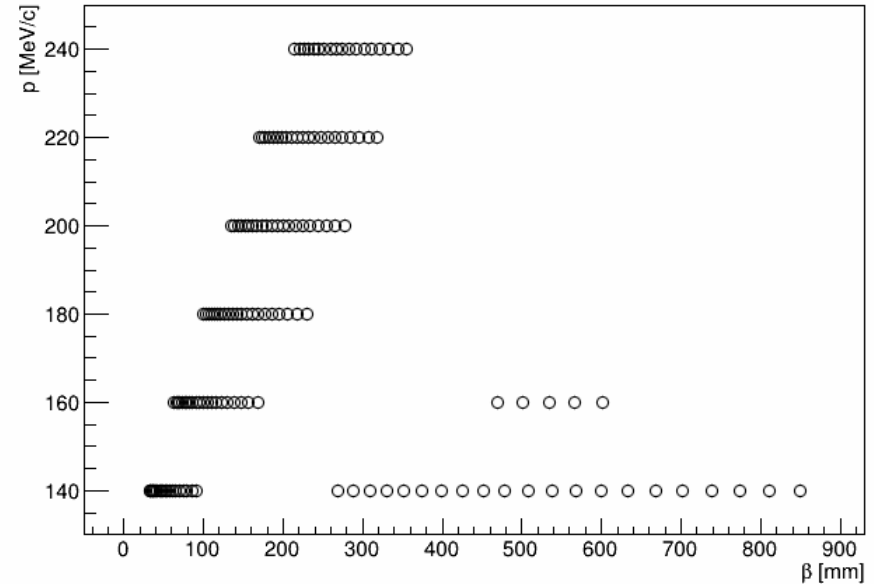
# Matching vs Momentum



FocusCoil 102.555 A/mm<sup>2</sup>

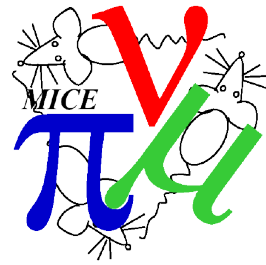


FocusCoil 136.74 A/mm<sup>2</sup>



- Range of available optics for a given focus coil strength
  - Nominal + 20% (“Best”)
  - Nominal - 10% (“Actual”)

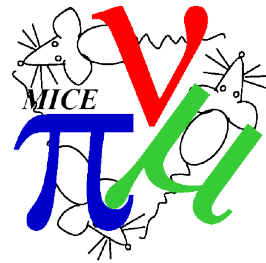
# Step IV - Conclusions



- Reduced FC current limits accessible range of beta functions
  - Assume FC performance as FC 1
    - e.g.  $J < 102 \text{ A/mm}^2$  with 10 % operating margin
  - Minimum beta function 32 mm  $\rightarrow$  104 mm at 140 MeV/c
  - Minimum beta function 136 mm  $\rightarrow$  224 mm at 200 MeV/c
  - Minimum beta function 215 mm  $\rightarrow$  356 mm at 240 MeV/c
  - Can still achieve “nominal” beta function (420 mm)
  - Some exotic options are ruled out in flip mode
  - Maximum beta function is unaffected
    - Prefer low FC current for large beta functions



# Step VI

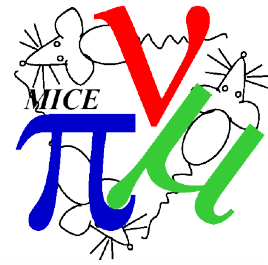


- Consider now Step VI SFoFo lattice only
  - Assume we can match (but see discussion above)
  - Look at how optics scales with Coupling Coil and Focus Coil currents
- Repeat over 5500 mm cell length in flip mode

Coil Name	Centre z [mm]	Inner radius [mm]	Radial thickness [mm]	Length [mm]	Current Density [A/mm <sup>2</sup> ]
Focus	205	263	84	210	113.95 nominal
Coupling	1375	725	116	250	96.21 nominal
Focus	2545	263	84	210	113.95 nominal

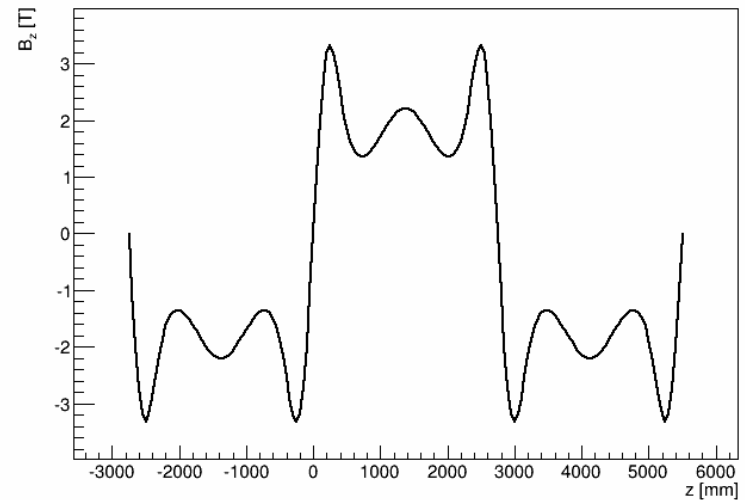
Tab. 3: SFoFo lattice used for simulation of MICE Step VI. The lattice was repeated with a cell period of 5500 mm and adjacent half cells having opposite polarity (i.e. flip mode). 3 half cells were placed on either side of the test cell to ensure correct application of fringe fields.

# Nominal magnets, 200 MeV/c

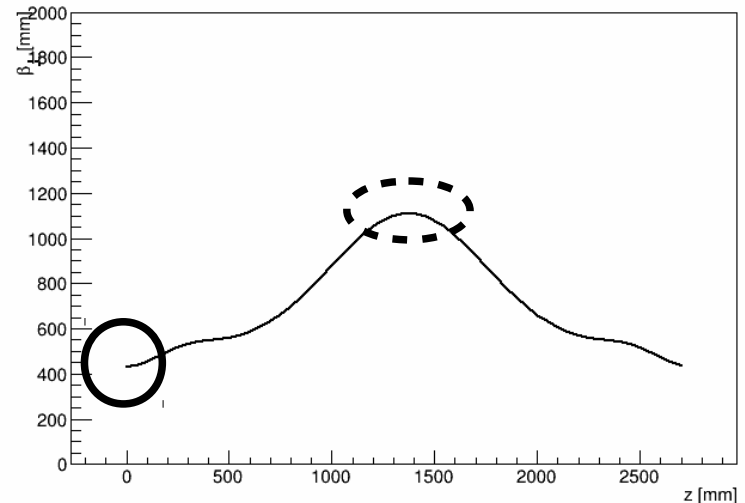


- By way of example
  - $B_z$  as a function of  $z$
  - Beta function for a half cell
- What is momentum dependence of beta function?
  - At focus (absorber)
  - At anti-focus (scraping aperture)

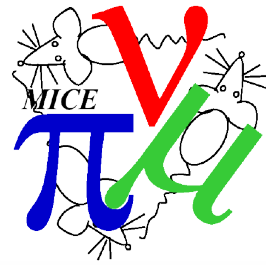
Focus Coil: 113.95 Coupling Coil: 96.21



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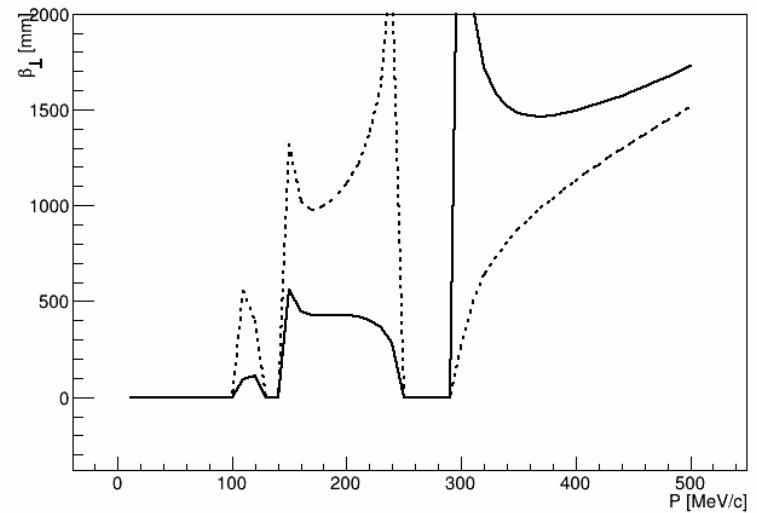


# Response to FC – 200 MeV/c

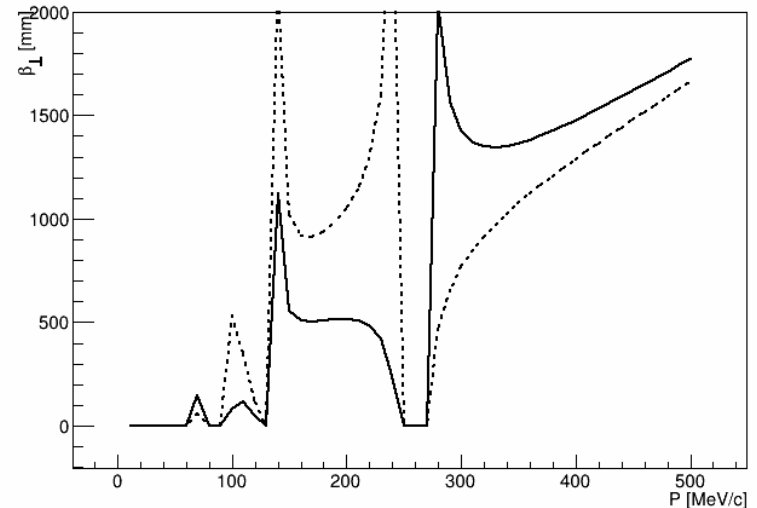


- MICE operates in 2 pi → 4 pi phase advance region
  - Fills the momentum acceptance
  - Interested in beta and stop bands
- Assume FC performance as FC 1
  - e.g.  $J < 102 \text{ A/mm}^2$  with 10 % operating margin
  - Stop bands unmoved
  - Beta function 420 → 500 mm
  - Equilibrium emittance increases by ~ 20% (proportional to beta)

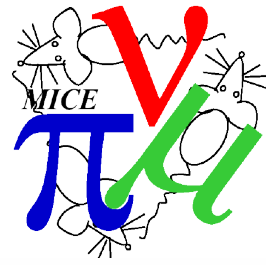
Focus Coil: 113.95 Coupling Coil: 96.21



Focus Coil: 102.555 Coupling Coil: 96.21

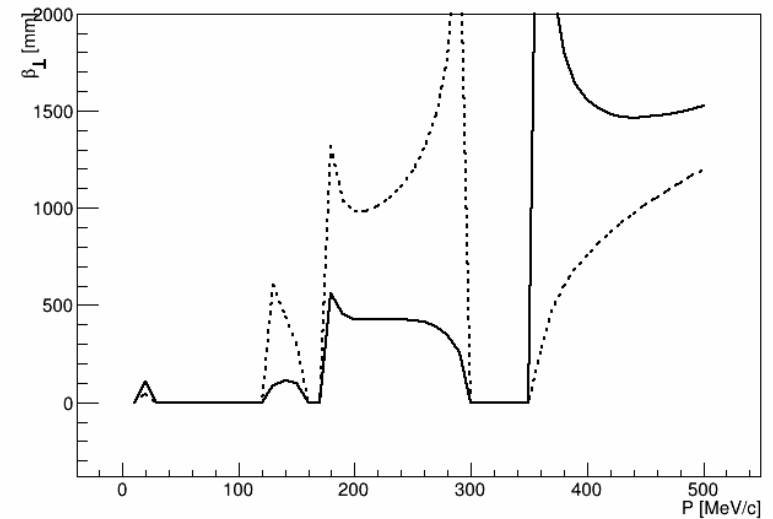


# Response to FC – 240 MeV/c

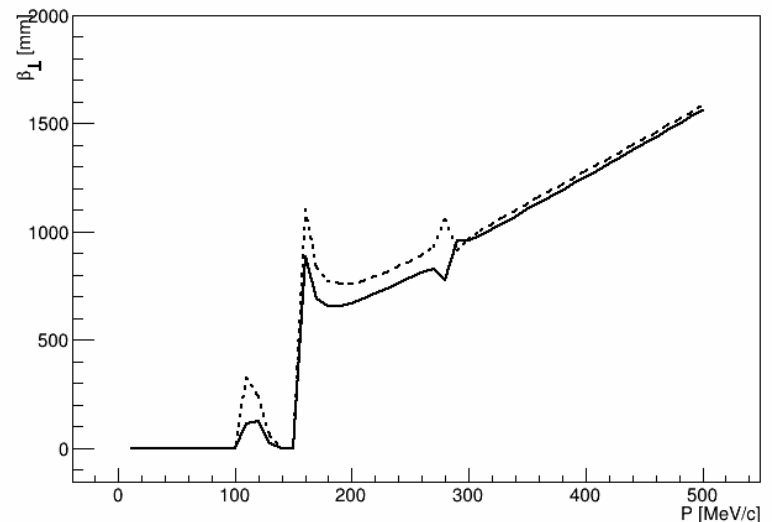


- Scale lattice by increasing currents by 20 %
- Assume FC performance as FC 1
  - Beta function  $\sim$  50-100% higher
  - Equilibrium emittance  $\sim$  50-100 % higher
  - Bigger chromatic aberrations
  - Weaker ( $2\pi$ ) resonance
  - Possibly slightly better acceptance
    - Beta at midpoint is lower
- How do these optics scale with CC current?

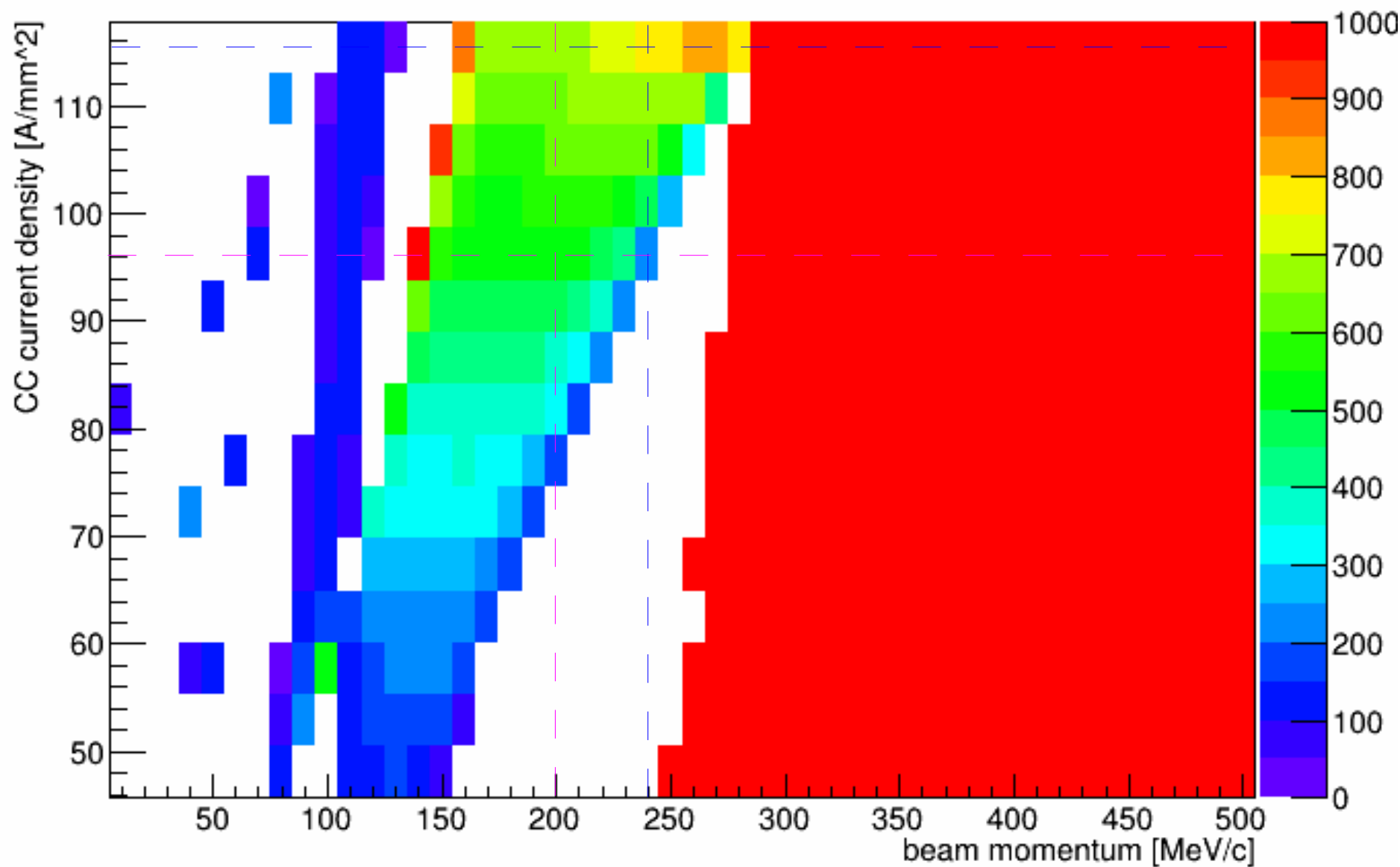
Focus Coil: 136.74 Coupling Coil: 115.452



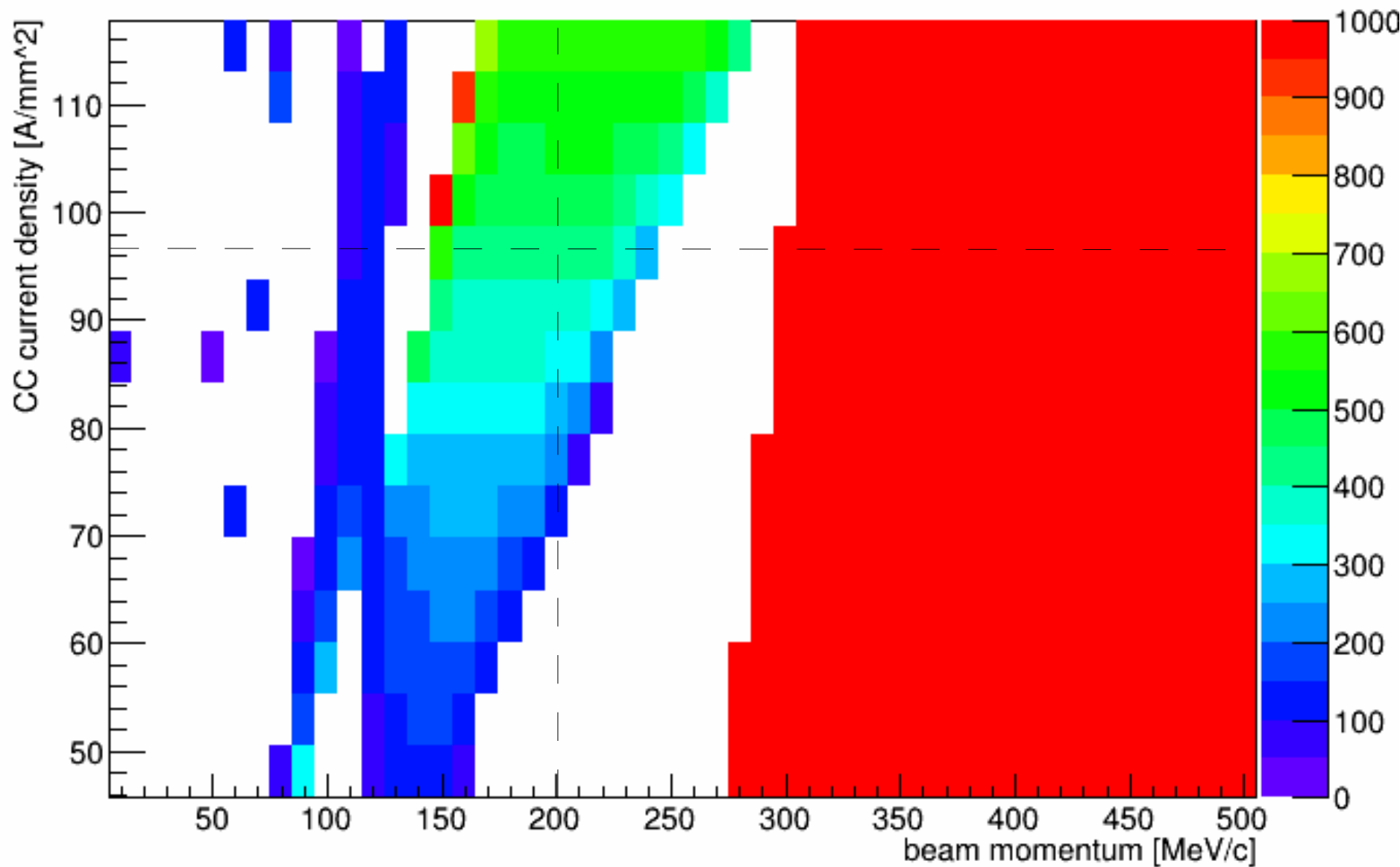
Focus Coil: 102.555 Coupling Coil: 115.452



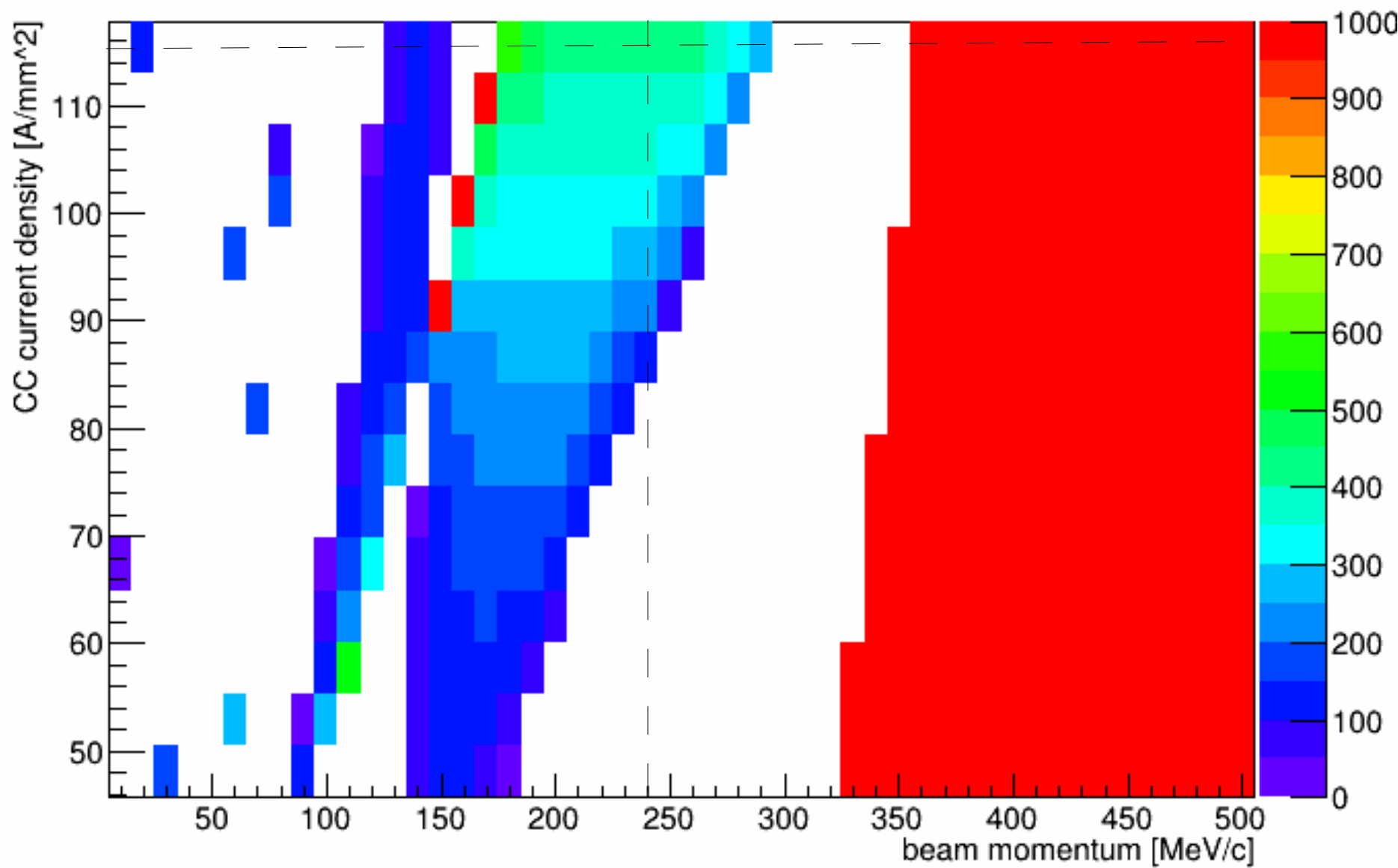
# Focus Coil 102.56



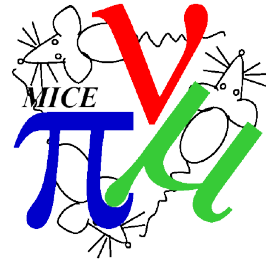
# Focus Coil 113.95



# Focus Coil 136.74



# Conclusions



- MICE is still operable with reduced FC
  - Quite robust to poor performing magnets
- But physics performance is slightly reduced
  - Lose low beta function options at Step IV
  - Poor 240 MeV/c performance at Step VI
- Caveat:
  - All of this is linear optics
  - Great for getting an idea of the parameter space
  - Not sufficient for redefining MICE baseline
- Further details in MICE Note 434
- <http://mice.iit.edu/micenotes/public/pdf/MICE0434/MICE0434.pdf>