Benchmarking and Simulating the CBETA FFAG Arc Cell

Muon1 Simulations — Stephen Brooks
Lattice Design — Scott Berg

CBETA FFAG Arc Cell Lattice

Table 2.6.1: Hard edge arc cell design parameters.

Injection Total Energy (MeV)	6	
Maximum Total Energy (MeV)	150	
Linac Passes	4	
Reference Radius (m)	5.099439	
L_{DF} (mm)	120	
L_{FD} (mm)	70	
α	F	D
$L_{Q\alpha}$ (mm)	133	122
x_{α} (mm)	−7.182	+20.132
Gradient (T/m)	+10.621	−10.017

Table 2.6.2: Horizontal displacements for the real magnets, determined using field maps.

x_F (mm)	−4.089
x_D (mm)	+17.313

Code Comparison

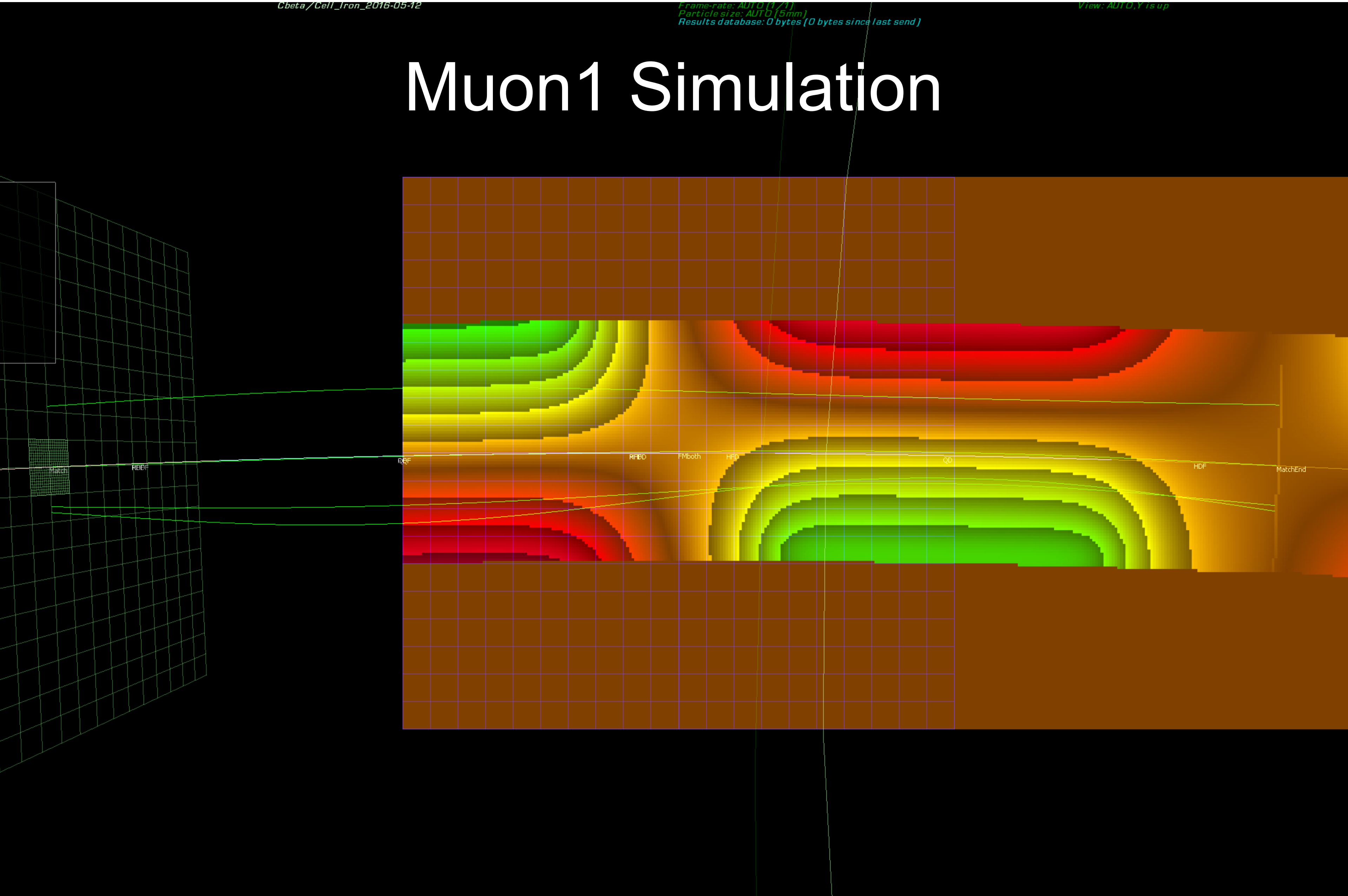
Muon1 (by Stephen Brooks)

- Uses Cartesian global-frame coordinates
- Tracks in t
- Runge-Kutta 4th order
- Based on F=q(E+v×B) (no Hamiltonians)
- Fixed timestep of 10ps (I sometimes lower this to 5ps for CBETA, very little difference)
- Fieldmaps are interpolated trilinearly (occasionally leads to rough edges when finding tunes)

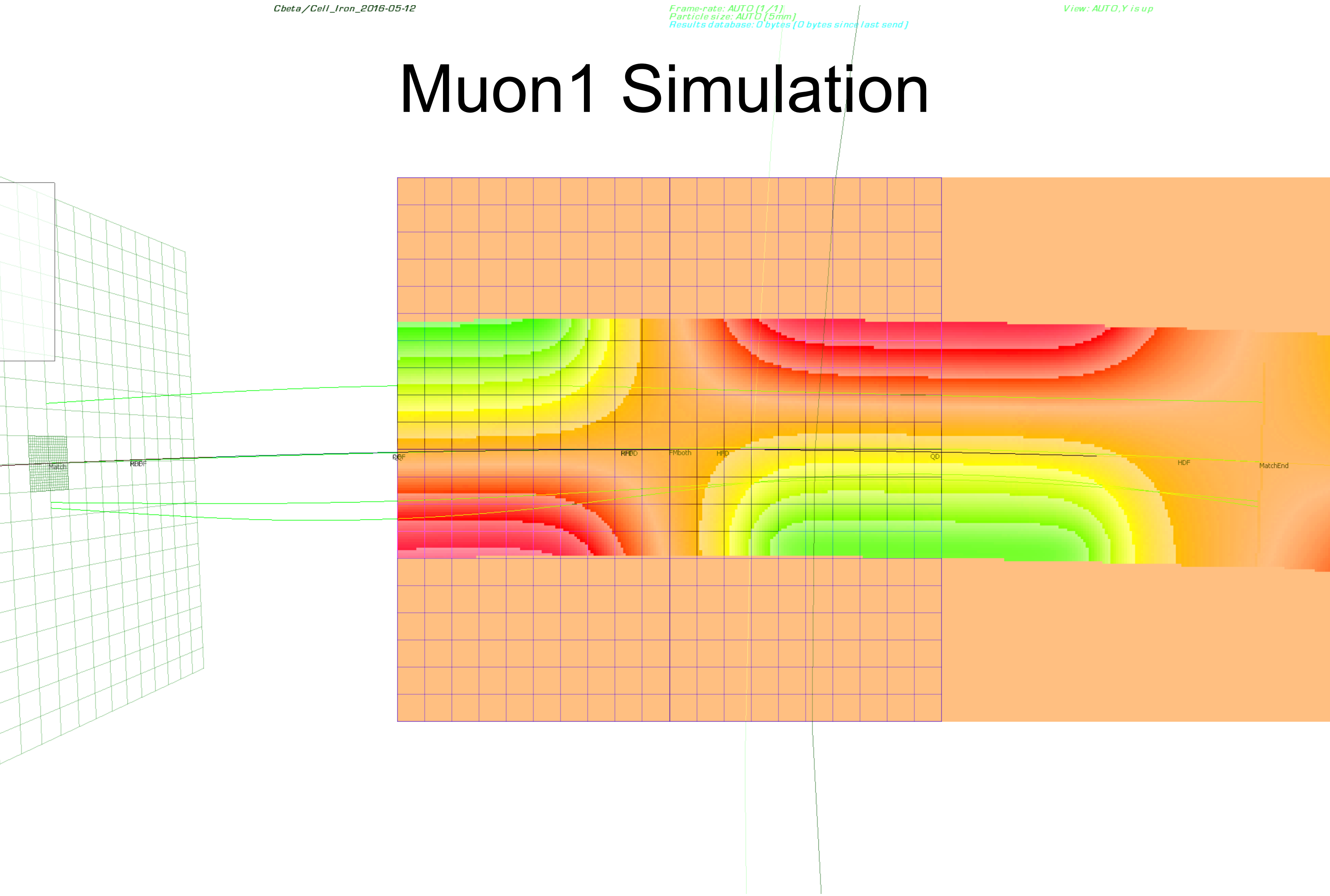
"Scott's Code" (developed recently for CBETA)

- Uses cylindrical polar coordinates (r,theta,y)
- Tracks in theta
- [Not sure what integrator]
- Based on Hamiltonians
- Fieldmaps are smoothed and particles are tracked through a highly-differentiable spline fit

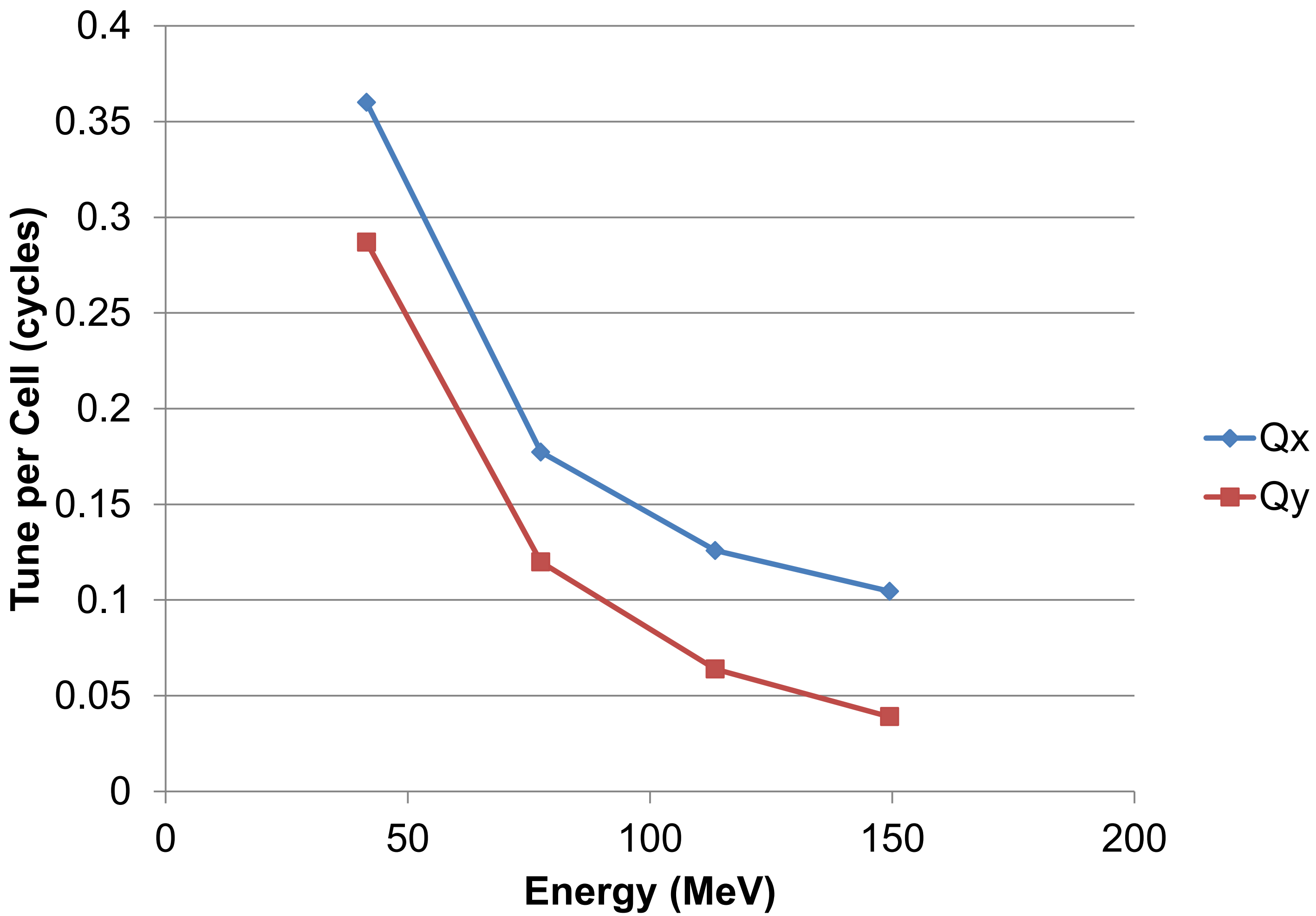
Muon1 Simulation



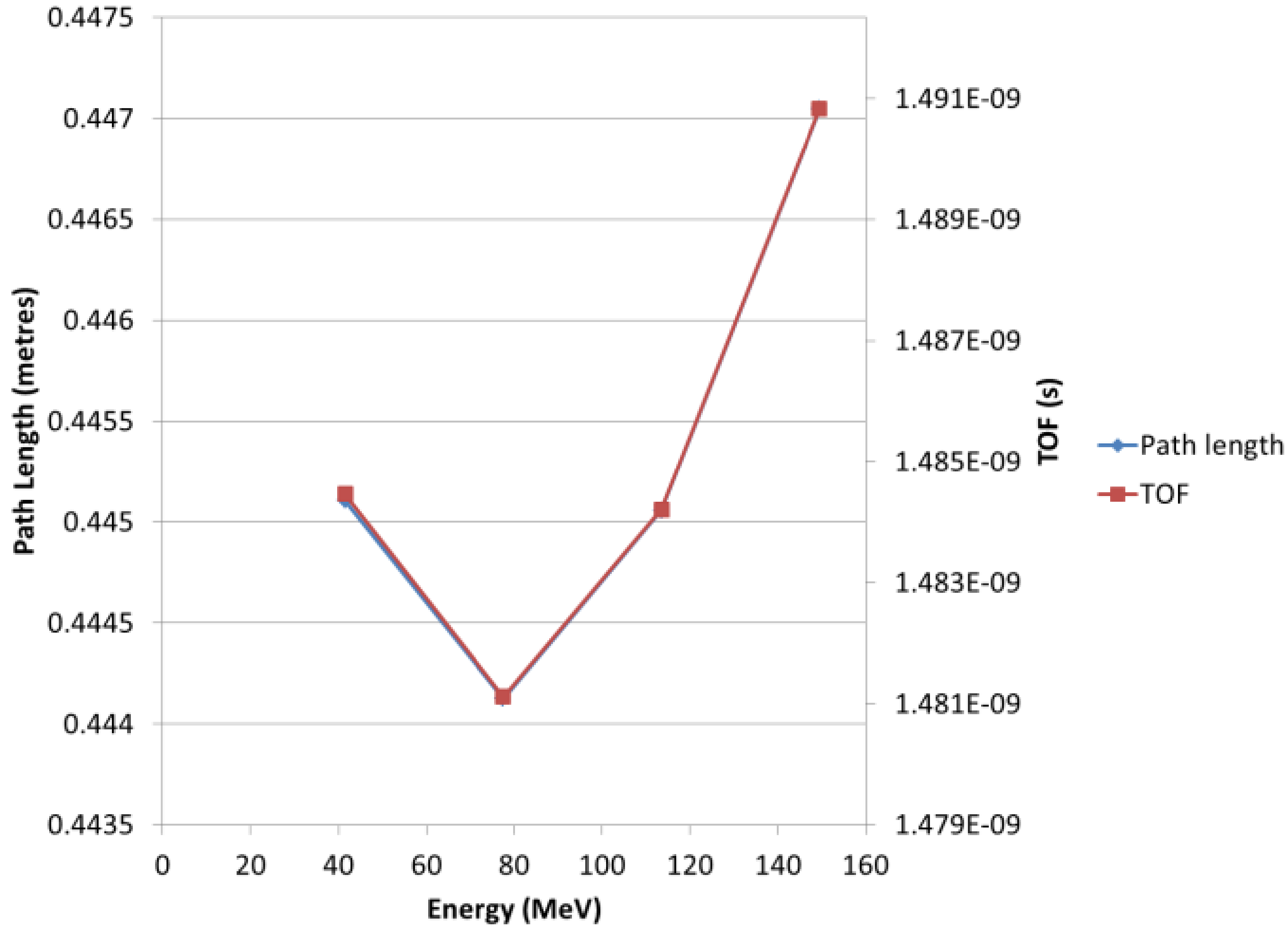
Muon1 Simulation



Cell Tunes from Muon1



Cell Path Length and TOF



Cell Tunes from Both Codes

Total Energy (MeV)	Muon1 Cell Tune X	Muon1 Cell Tune Y	Scott Cell Tune X	Scott Cell Tune Y
42	0.360041	0.286975		
78	0.177298	0.119886		
114	0.125858	0.0638703		
150	0.104551	0.0390379		

Only the first turn (42MeV) is in the region susceptible to strong resonances. The rest of the turns are in the pseudo-continuous phase advance regime.

The low tune is always the Y tune at the highest energy. Going higher makes it difficult to find a lattice with practical field strengths. Going lower makes optics sensitive to focussing errors and not enough phase advance for “adiabatic” transition from FFAG arc to straight.

Scott Berg's CBETA FFAG Arc Cell (and Holger's Fieldmaps) Imported Into Muon1

File "Cbeta/Cell_Iron_2016-05-12"

```
{Scott's 150MeV lattice from "160507-JSBerg" folder, using Holger's
fieldmaps from "160512-FieldMap" subfolder}

#h    = +1.9610000439244032e-01;
#R=1.0/h;
```

Scott's parameters
h is inverse radius

```
#lqf  = +1.3300000000000001e-01;
#lqd  = +1.2200000000000000e-01;
#lfd  = +7.0000000000000007e-02;
#ldf  = +1.2000000000000000e-01;

#thqf=2*asin(0.5*lqf/R);
#thqd=2*asin(0.5*lqd/R);
#thfd=2*asin(0.5*lfd/R);
#thdf=2*asin(0.5*ldf/R);
```

Convert chord lengths to arc lengths

```
{Drift Length Angle}
DF #R*thdf# #thdf*-1#
QF #R*thqf# #thqf*-1#
FD #R*thfd# #thfd*-1#
QD #R*thqd# #thqd*-1#
HDF #DF.Length/2# #DF.Angle/2#
HFD #FD.Length/2# #FD.Angle/2#
```

Define empty circular arc elements (radius R) for layout reference

Half-elements

```
#scalboth = 1; dispboth = 0;
#scalF = 1; scalD = 1;
#dispF = 0; dispD = 0;
```

No scaling or displacement for final fieldmap version

```
{TrilinearFieldMap File Strength Xrel MirrorY=1}
FMboth Cbeta\Iron_2016-05-12\160308a-38-
48_5deg150MeVCombQdOnQfOn_polar.txt #scalboth*-1# #dispboth-
R#
FMF Cbeta\Iron_2016-05-12\160308a-38-
48_5deg150MeVSepQfOn_polar.txt #scalF*-1# #dispF-R#
FMD Cbeta\Iron_2016-05-12\160308a-38-
48_5deg150MeVSepQdOn_polar.txt #scalD*-1# #dispD-R#

CellFM: HDF,QF,HFD,FMboth,HFD,QD,HDF;
CellFMsep: HDF,QF,HFD,FMF,FMD,HFD,QD,HDF;
```

Cell definitions

```
#Emin = +4.2000000000000000e+07;
#Emax = +1.5000000000000000e+08;
#n    = 4;
```

Scott's energy range
Number of passes
Units, total E. -> k.e.

```
#EmasseV=510998.928;
{MatchScan Estart Egoal Estep Species=Electron AllowUnstable=1}
Match #Emax-EmasseV#eV #Emin-EmasseV#eV #(Emax-Emin)/(n-
1)#eV
MatchFine #Match.Estart# #Match.Egoal# 1MeV

{Match-Aperture}
MatchEnd

CellFM,Match,CellFM,MatchEnd,CellFM;
```

Place 3 cells to allow fringe field overlaps

Focus: Aligning the Fieldmaps

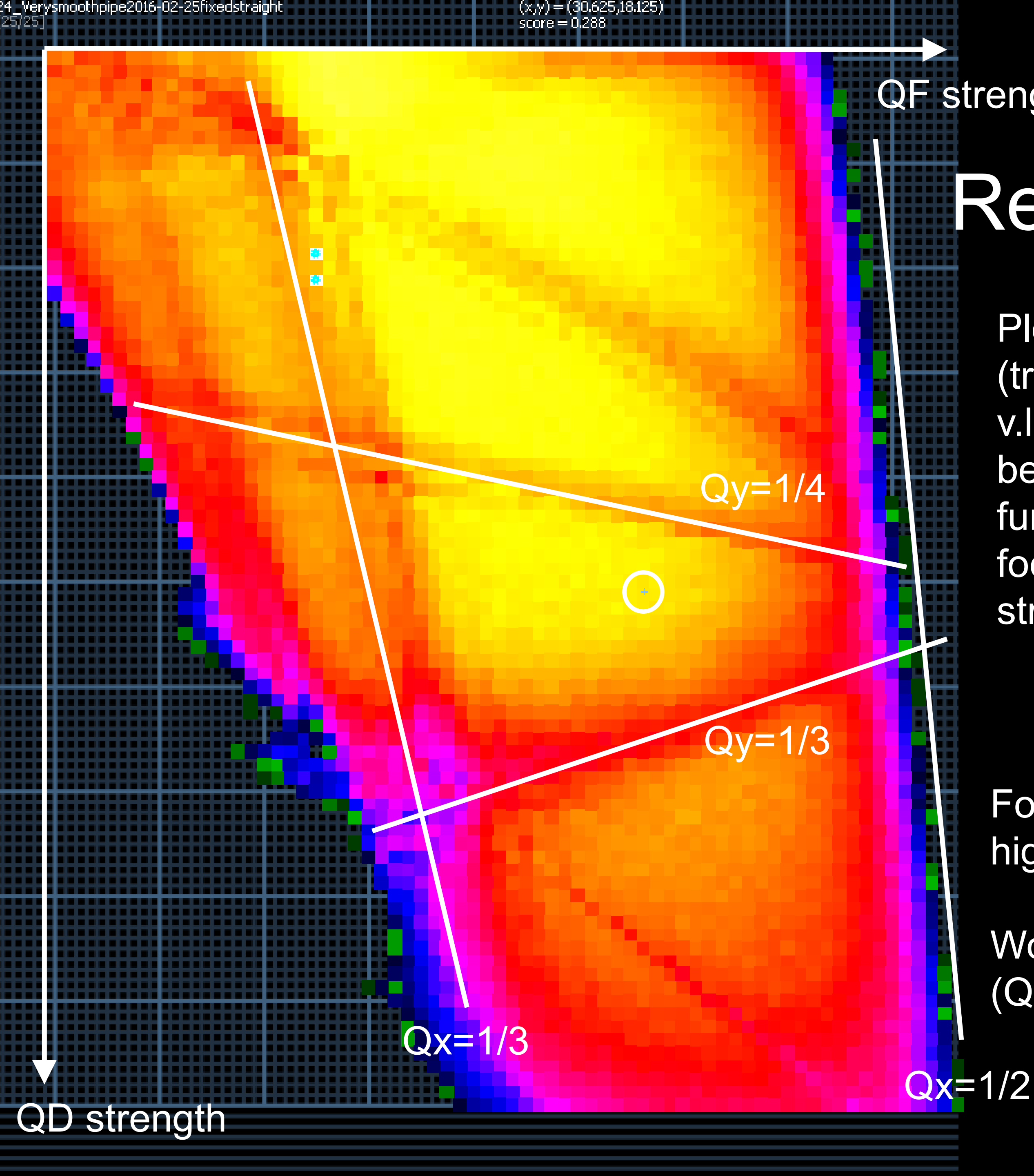
{TrilinearFieldMap File Strength Xrel MirrorY=1}
FMboth Cbeta\Iron_2016-05-12\160308a-38-48_5deg150MeVCombQdOnQfOn_polar.txt #scalboth*-1# #dispboth-R#
FMF Cbeta\Iron_2016-05-12\160308a-38-48_5deg150MeVSepQfOn_polar.txt #scalF*-1# #dispF-R#
FMD Cbeta\Iron_2016-05-12\160308a-38-48_5deg150MeVSepQdOn_polar.txt #scalD*-1# #dispD-R#

3 fieldmaps with long file names
Field magnitude is inverted due to difference in curvature direction (Scott vs. reality)
Relative position in local X is “-R”, i.e. origin is centre of radius R circle
Mirrored in Y to give both positive and negative Y

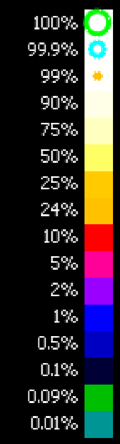
CellFM: HDF,QF,HFD,FMboth,HFD,QD,HDF;
CellFMsep: HDF,QF,HFD,FMF,FMD,HFD,QD,HDF;

For each version of the cell (combined or separate fieldmaps), the maps are placed at the centre of the F-to-D (short) drift
The cell entrance/exit is the centre of the D-to-F (long) drift

Resonance Plot



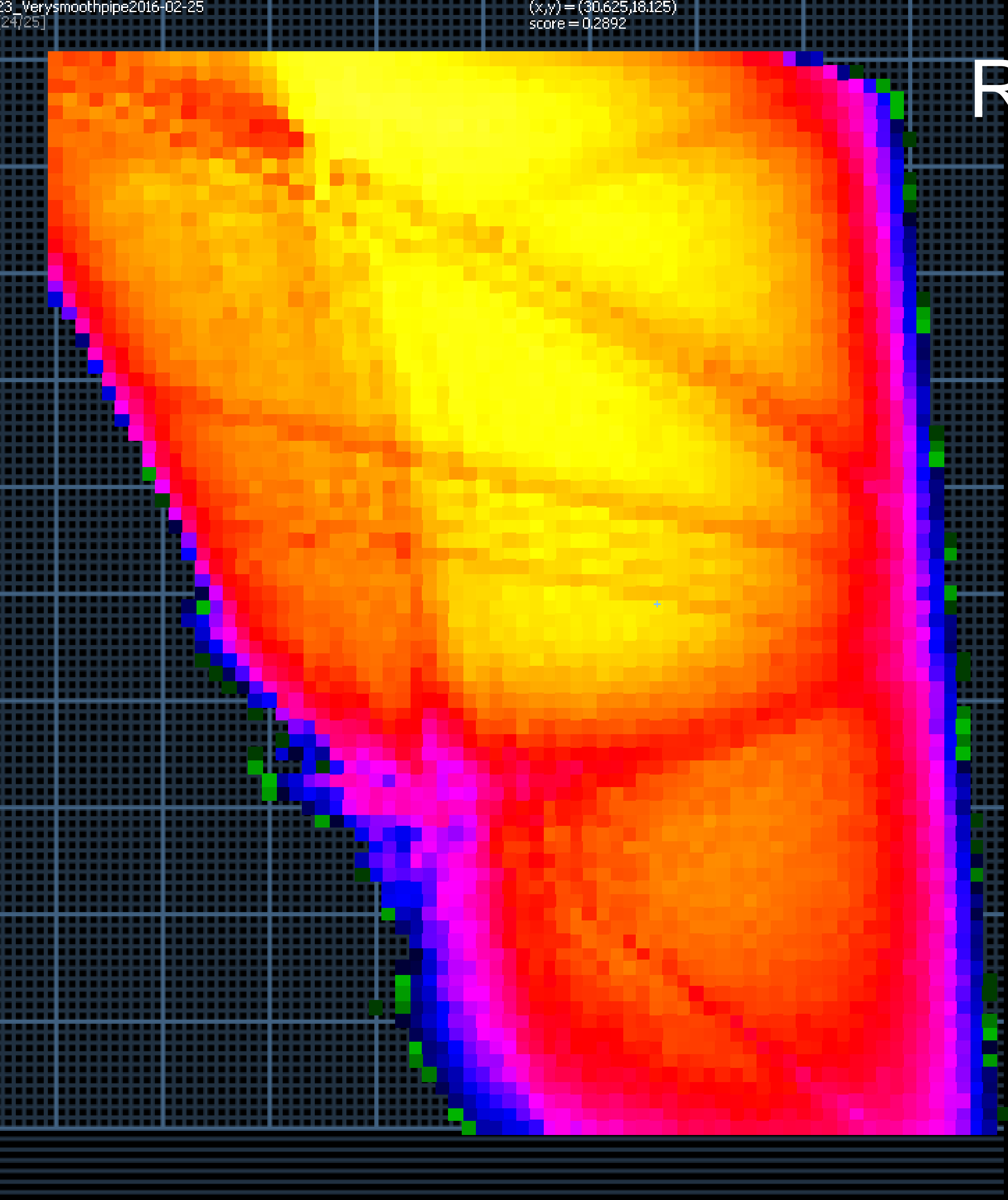
Plot of aperture (transmission of v.large 1cm-radius beam) as a function of two focussing strengths



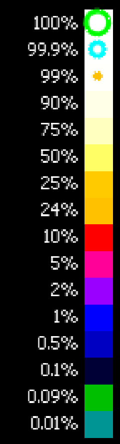
For lowest-energy pass, highest tunes.

Working point circled: (Qx,Qy) = (0.360,0.287)

Resonance Plot



before adjustment to straight drift lengths



Resonance band features broadened because straight section has different tunes to arcs. Can fix by adjusting straight section drift lengths.

Conclusions

- The CBETA FFAG has been simulated in Scott's code, Muon1 and BMAD
- These codes have very different internal operation yet we get consistent results
- Arc-to-straight match has been optimised for an old lattice, currently being optimised for the newest version