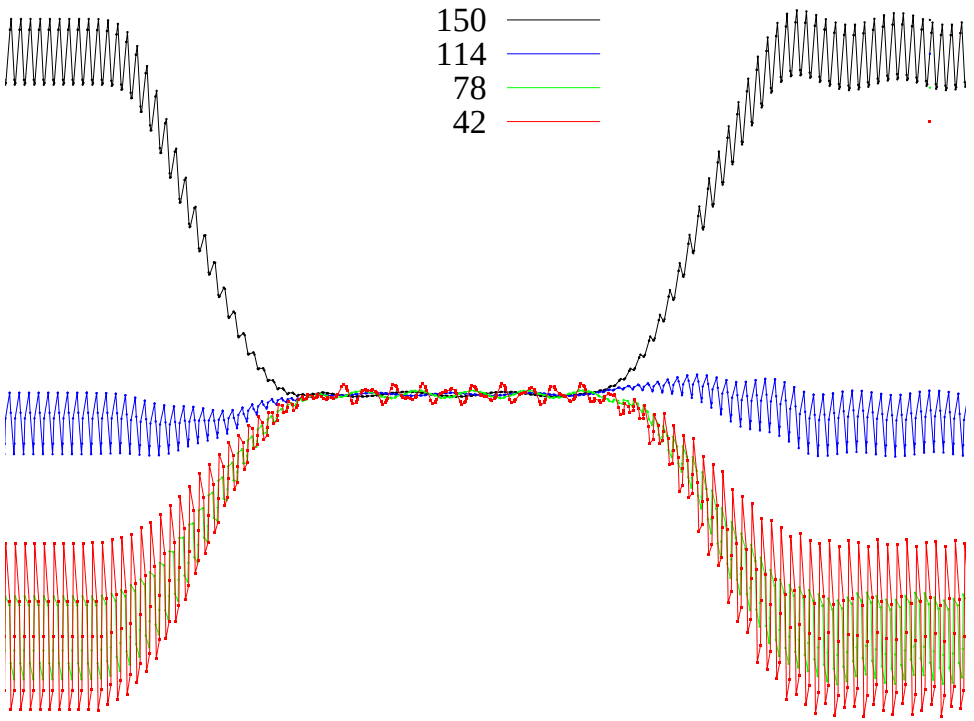
# SIMULATION METHODS TOWARDS 100% TRANSMISSION

**F. Méot**
**BNL C-AD**

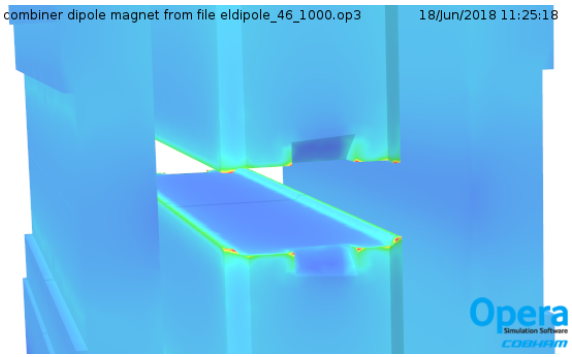


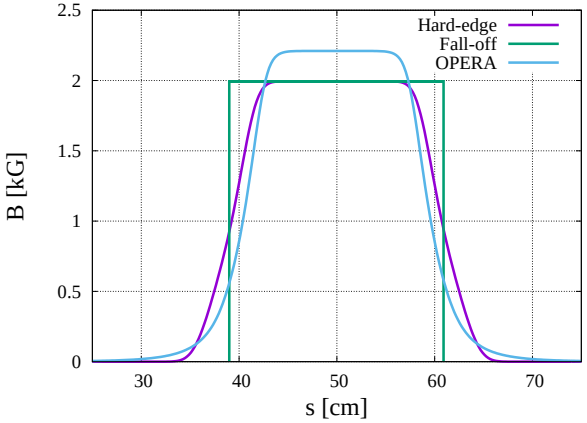
# FINDING #1: MODELING OF S AND R LINE DIPOLES IS NOT AS SIMPLE AS THIS:

$$M_{\text{DIPOLE}} = \begin{pmatrix} 1 & 0 & 0 \\ \frac{1}{\rho}\tan\delta & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\phi & \rho\sin\phi & \rho(1-\cos\phi) \\ -\frac{1}{\rho}\sin\phi & \cos\phi & \sin\phi \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ \frac{1}{\rho}\tan\delta & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- **Splitter line magnets have large gap/width, gap/length, chamfers, shims ("to equalize $\int \mathrm{B}\,\mathrm{ds}$ along arcs".)**

**Ex.: H1 series:**




## Ex.1: MR1DIP02_3350

### (i) From matrix model above:

```
 1          0.21700    0          0          -3.44E-2
 0          1          0          0          -0.31666
 0          0          0.9503     0.220605    0
 0          0         -0.4396     0.950276    0
-0.31666   -0.0343     0          0           3.61E-3
```

**Focal distances** $\begin{cases} \mathrm{f_x} = \infty \\ \mathrm{f_y} = -2.3\,\mathrm{m} \end{cases}$

### (ii) from OPERA field map:

```
 0.9834    0.215709    0          0          -3.415E-2
-0.1520    0.983583    0          0          -0.31409
 0          0          0.9696     0.2188      0
 0          0         -0.2736     0.9696      0
-0.3141   -0.0341572   0          0           3.6048E-3
```

**Focal distances** $\begin{cases} \mathrm{f_x} = -6.6\,\mathrm{m} \\ \mathrm{f_y} = -3.65\,\mathrm{m} \end{cases}$

# Ex.2: MR1DIP04_3350

## (i) From matrix model:

| | | | | | |
|---|---|---|---|---|---|
| 1.00000 | 0.215917 | 0.00000 | 0.00000 | 0.00000 | -4.059583E-02 |
| 0.00000 | 1.00000 | 0.00000 | 0.00000 | 0.00000 | -0.376032 |
| 0.00000 | 0.00000 | 0.930116 | 0.220970 | 0.00000 | -0.00000 |
| 0.00000 | 0.00000 | -0.610421 | 0.930116 | 0.00000 | 0.00000 |
| -0.376032 | -4.059583E-02 | 0.00000 | 0.00000 | 1.00000 | 5.053004E-03 |

**Focal distances** $\begin{cases} \mathbf{f_x = \infty} \\ \mathbf{f_y = -1.6\,m} \end{cases}$

## (ii) from OPERA field map:

| | | | | | |
|---|---|---|---|---|---|
| 0.975362 | 0.215335 | 0.00000 | 0.00000 | 0.00000 | -4.436723E-02 |
| -0.226111 | 0.975323 | 0.00000 | 0.00000 | 0.00000 | -0.406992 |
| 0.00000 | 0.00000 | 0.945560 | 0.220350 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | -0.480863 | 0.945516 | 0.00000 | 0.00000 |
| -0.406993 | -4.436527E-02 | 0.00000 | 0.00000 | 1.00000 | 6.030060E-03 |

**Focal distances** $\begin{cases} \mathbf{f_x = -4.4\,m} \\ \mathbf{f_y = -2.1\,m} \end{cases}$

# FINDING #2: RECOVERING MATRIX OPTICS, USING FIELD MAPS, IS DIFFICULT

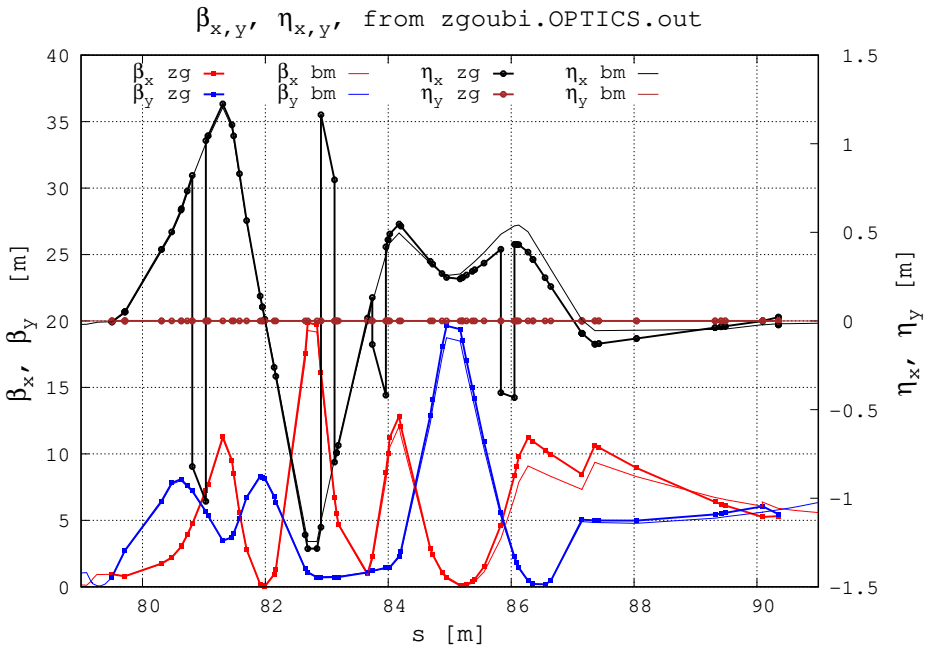



Figure 1: Hard-edge. Optical functions from field-maps and BMAD.

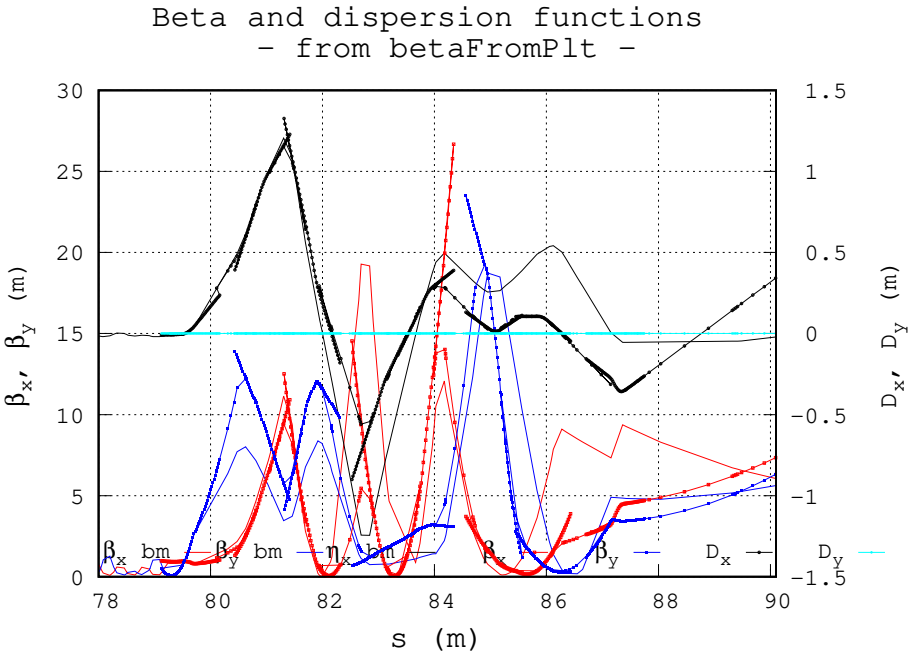



Figure 2: Field maps. Optical functions from field-maps (compared w/ BMAD). Using all 8 quads: I can't get final betas and Dx tuned concurrently.

- Beam matrix at RETURN1.TIME_PATCH (from R1_OPTICS_TOSCA.INC_allMult.res or as well R1_OPTICS_MULT.res):

```
Reference, before change of frame (part #     1)  :
      x             x'                                          s           t
-6.738569E-06 -1.692496E-05 -0.000000E+00 -0.000000E+00  9.0349361E+03  3.01395E-01

                 BEAM  MATRIX (beta/alpha/alpha/gamma, D,D'),              FINAL
5.42043         0.612627        0.00000         0.00000         -2.540056E-02
0.612627        0.253727        0.00000         0.00000         -0.212696
0.00000         0.00000         5.15726         0.977542        0
0.00000         0.00000         0.977542        0.379191        0
```

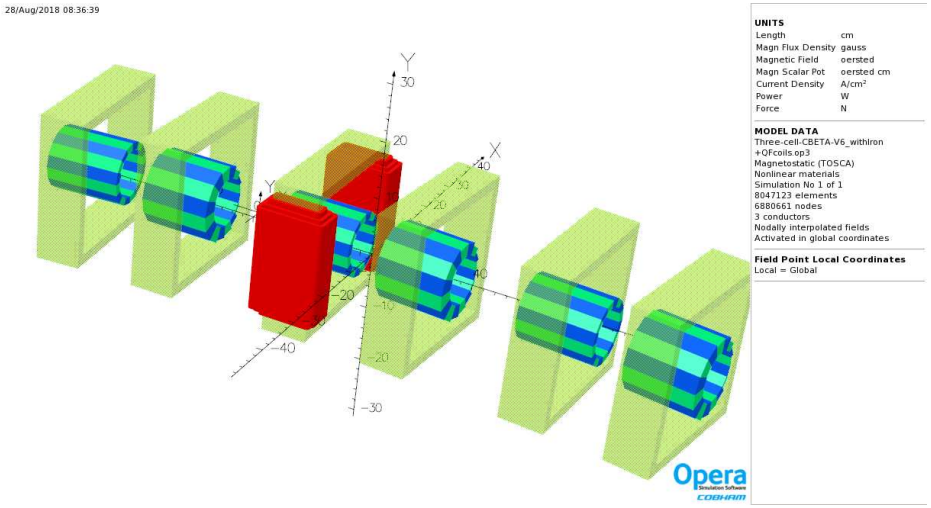
- Final beam matrix (R1_OPTICS_TOSCA.INC.res):

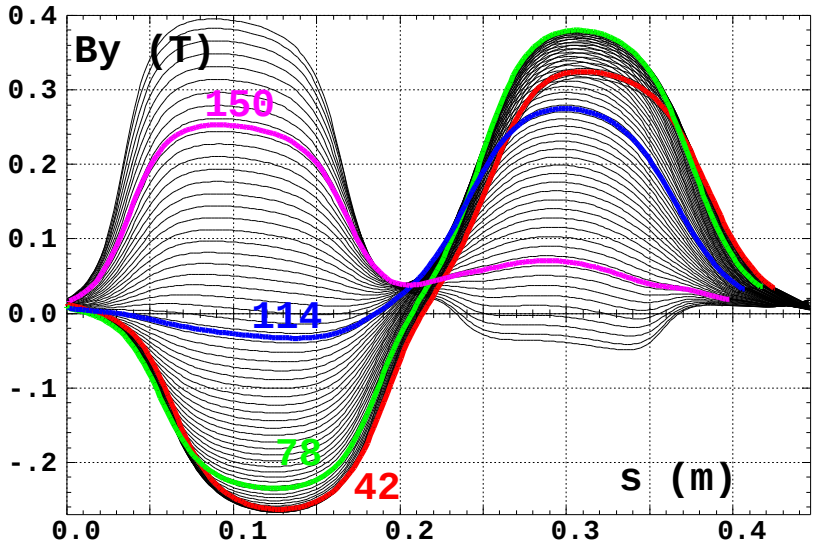
```
Reference, before change of frame (part      1)  :
      x             x'                                          s           t
 3.27543192E-05   7.17094151E-05   0.000000  -0.000000   9.03486555E+03   3.01392983E-01

                 BEAM  MATRIX (beta/alpha/alpha/gamma, D,D'),              FINAL
   8.35898       -0.825777         0.00000         0.00000         0.633710
  -0.825777        0.198838        0.00000         0.00000         4.091696E-02
   0.00000         0.00000         6.07972         0.691029        0
   0.00000         0.00000         0.691029        0.243025        0
```

# FINDING #3: THE FFAG LOOP WAS DESIGNED, AND HALBACH TECHNOLOGY VALIDATED IN CBETA APPLICATION, USING OPERA FIELD MAPS [1]. AND THE FFAG LOOP WORKS

- Probably hard to find worse in the matter of field inhomogeneity:




[1] F. Méot, N. Tsoupas, et al.,
Beam dynamics validation of the Halbach Technology FFAG Cell for Cornell-BNL ERL
Nuclear Inst. and Methods in Physics Research, A 896 (2018) 6067

# COMMENT #1

- **Obviously, field maps will give a different optics of S/R lines**

# COMMENT #2

- **We need to commission CBETA with more than a single simulation tool**

# COMMENT #3

- **CBETA commissioning and operation is an opportunity for BNL to confront the beam dynamics tools they develop - for the benefit amongst other of the EIC**

# COMMENT #4

- We do have a double-engine, on-line, at the AGS [1]

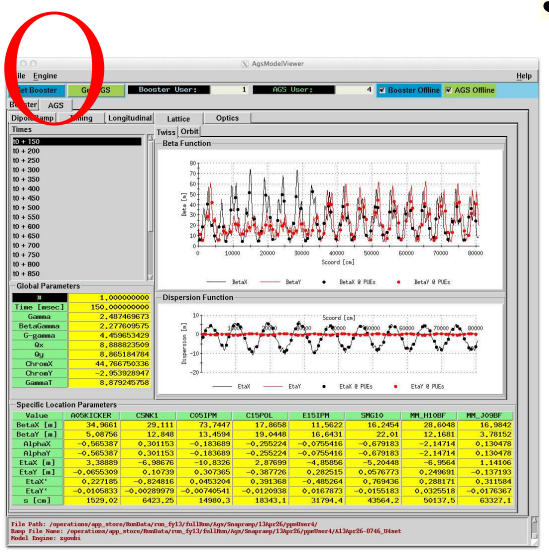
  The tracking engine interface

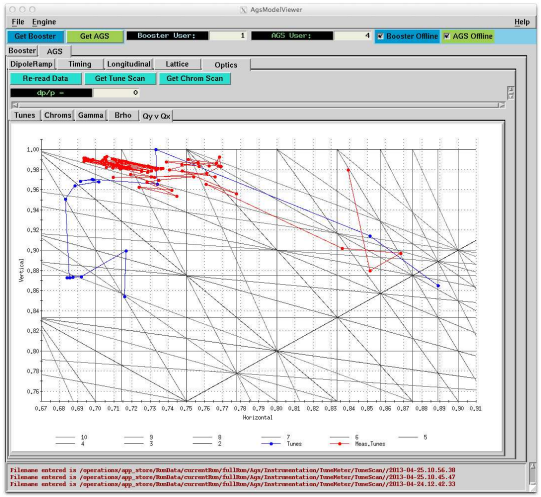
  "AGSModelViewer"

has been designed with "multiple-engine" capability.

This is easy, if difficulties, C-AD can help installing such capability at CBETA

## just 1 clic





[1] V. Schoefer et als., RHIC injector complex online model, FR5REP003, http://accelconf.web.cern.ch/AccelConf/PAC2009/papers/fr5rep003.pdf
[2] F. Méot et als., http://accelconf.web.cern.ch/AccelConf/IPAC2013/papers/wepea082.pdf

# SELF-RECOMMENDATION #1: USE MODERN BEAM DYNAMICS TOOLS

- Plan to give up archaic, 1950s style matrix products (for a while)
- and instead, use modern tools:
  - accurate, field map models, from magnet codes,
  - today's computer power,
- to solve $\vec{F} = m\vec{a}$ numerically, which means accurately

# SELF-RECOMMENDATION #2: PUT BEAM DYNAMICS SOFTWARE TOOLS TO WORK

- During the shut down, plan further commissioning of CBETA based on an on-line model using field maps