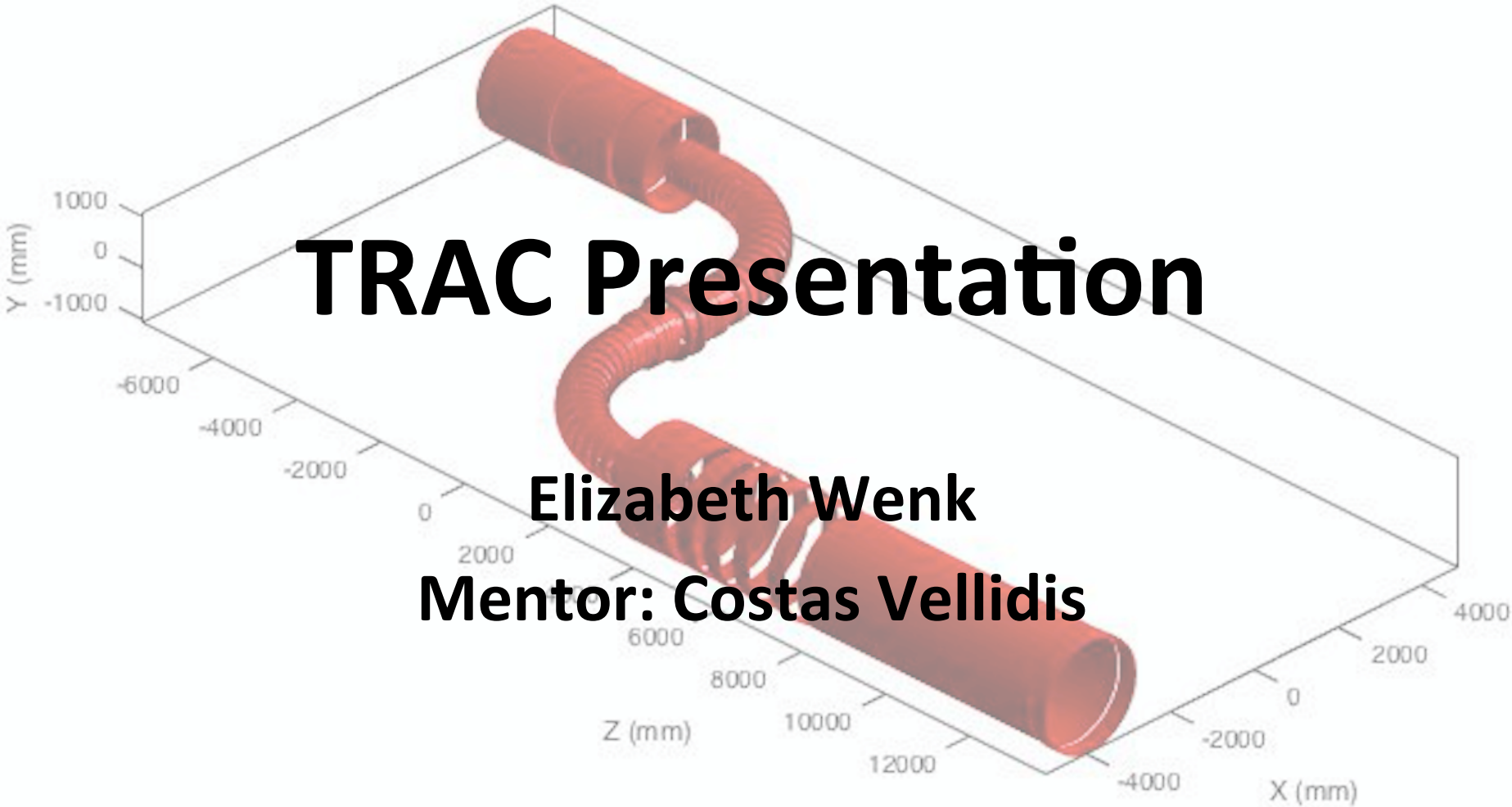
TRAC Presentation

Elizabeth Wenk

Mentor: Costas Vellidis



July 30, 2015

Calculating the Magnetic Field of Mu2e for Given Geometric Variations in the Transport Solenoid

Fermilab

Mu2e

The reason for Mu2e in 60 Seconds

By Bob Bernstein

http://mu2e.fnal.gov/research_goals.shtml

Charged leptons are a breed of elementary particle that comes in three masses: the lightweight electron, responsible for the electricity in our homes; the middleweight muon; and the heavy tau. Two other types of elementary particles, quarks and neutrinos, come in three masses as well.

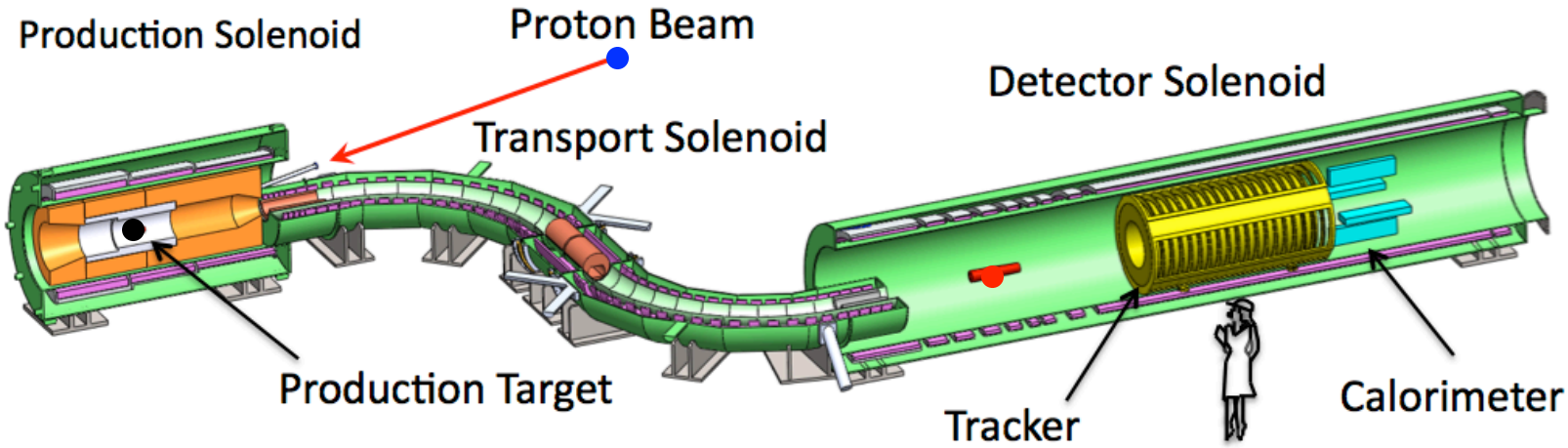
You might not think about dogs while you wonder about particle physics, but there are similarities. Poodles, for example, also come in three sizes — toy, miniature and standard — but they're all the same breed, and genetically similar. Learning how poodles and other breeds are related helps us understand the rules of dog genetics.

We want the same type of understanding of how elementary particles relate to one another. Quarks can change from one type to another; so can neutrinos. If you want to have any sensible "laws of genetics" for particle physics, that last breed, the charged leptons, had better be able to change types as well. That's called charged lepton flavor violation. Surprisingly, physicists have never seen it happen.

Previous experiments have looked at about ten trillion muons; Fermilab's Mu2e experiment will observe 10,000 times more data, looking for a change from a muon to an electron. Discovering this change would point us toward a single theory explaining the genetics of the particles born in the big bang. If we don't discover this change, there will be a lot of head-scratching (as opposed to fur-scratching) as we try to understand the rules of the universe.

http://mu2e.fnal.gov/research_goals.shtml

Muon Beam Line and Mu2e Detector



- Production Target
  - Proton beam strikes target, producing mostly pions
- Production Solenoid
  - Contains backwards pions/muons and reflects slow forward pions/muons
- Transport Solenoid
  - Selects low momentum, negative muons
- Capture Target, Detector, and Detector Solenoid
  - Capture muons on Aluminum target and wait for them to decay
  - Detector blind to ordinary (Michel) decays, with $E \leq \frac{1}{2} m_\mu c^2$
  - Optimized for $E \sim m_\mu c^2$

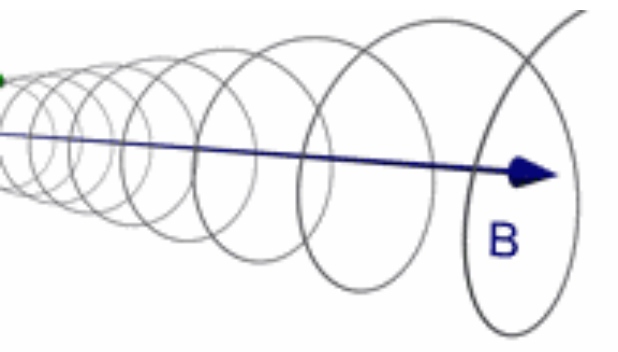
http://home.fnal.gov/~prebys/

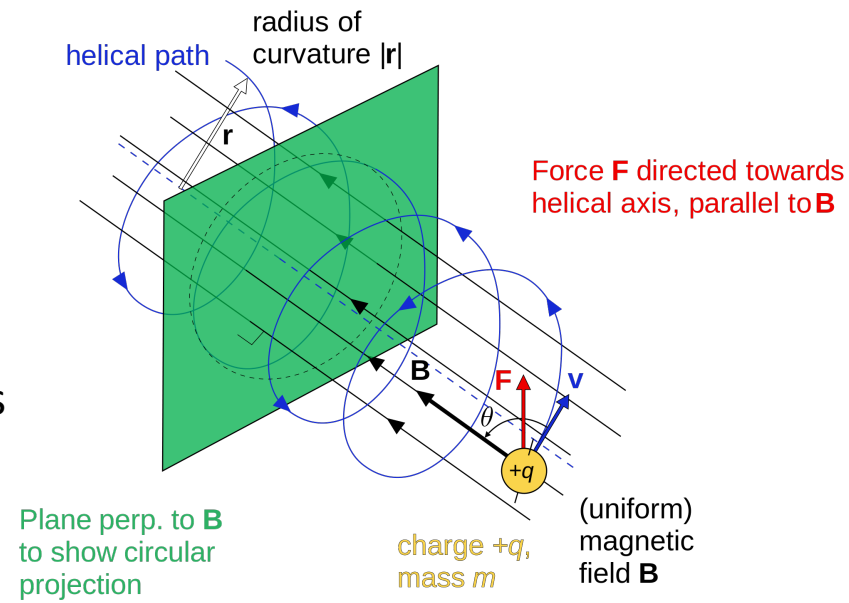
Particle Motion in a Solenoidal Field

Generally, particles move in a helical trajectory

$$\rho = \frac{p}{qB}; \rho[m] = \frac{p[MeV/c]/299}{B[T]}$$

For high momentum particles, the curvature is used to measure the momentum





$$\mathbf{F} = -m\frac{(\mathbf{v}\cdot\mathbf{v})}{|\mathbf{r}|}\hat{\mathbf{r}} = q\,(\mathbf{v}\times\mathbf{B})$$

Low momentum particles are effectively "trapped" along the field lines

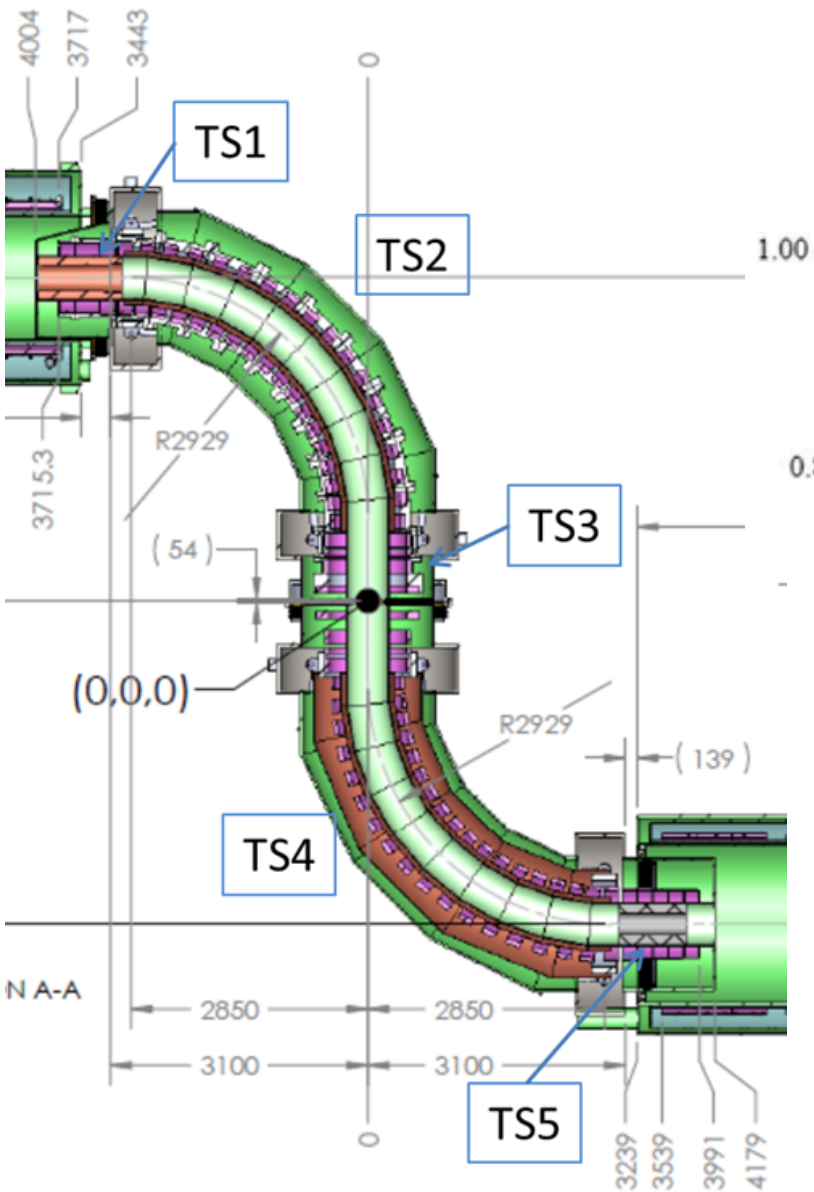
A particle trapped along a *curved* solenoidal field will drift out of the plane of curvature with a velocity

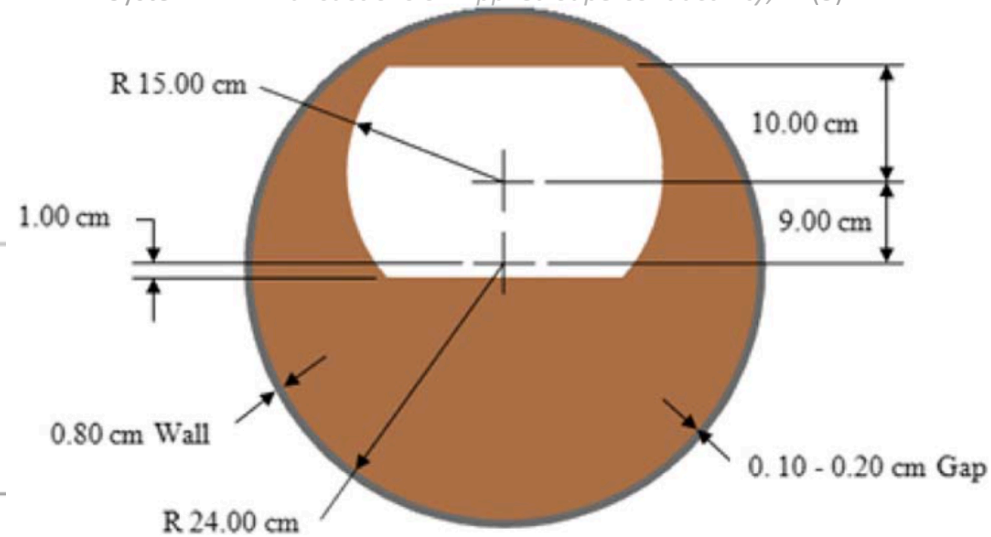
$$v_{drift} = \frac{\gamma m}{q}\frac{\hat{R}\times\hat{B}}{RB}\left(v_{\parallel}^2 + .5v_{\perp}^2\right)$$

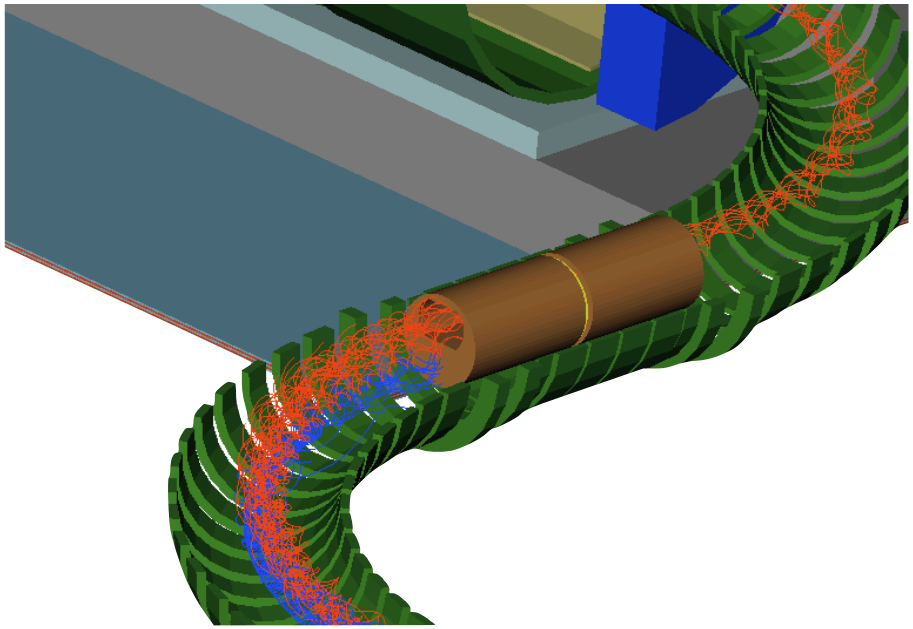
Can be used to resolve charge and momentum!

Transport Solenoid

Lopes, M. et al (2014). Studies on the Magnetic Center of the Mu2e Solenoid System. *IEEE Transactions on Applied Superconductivity, 24*(3).







http://home.fnal.gov/~prebys/

Alignment of the Transport Solenoid Magnetic Center Due to Coils Displacements (Magnetic Design Version 7), M. Lopes G. Moretti

- Systematic errors, due to thermal or mechanical stress; they usually affect all the coils of only one of the sections of the TS (TS1, TS2 etc.)
- Random errors, due to building tolerances; they affect each single coil, that moves from its original position.
- CONCLUSION
  - The results show that the most critical configurations, in terms of random errors, are those obtained giving random pitch or random yaw rotation angles to each of the coils.
  - Regarding systematic errors, some of the configurations considered introduce an offset in terms of displacement from the nominal trajectory.
  - Particularly, the worst cases are those having TS3u and TS3d bent in opposite directions toward one of the axis.

The purpose of my study was to investigate the effects of geometric misalignments of the Transport Solenoid on the magnetic field and the induced effects on muon and background rates.

- Use MATLAB package SolCalc from TD with Mau9 input for the solenoids
- Input data consist of a 66×10 table
  - ✧ inner and outer radii
  - ✧ lengths
  - ✧ center locations (in Mu2e coordinates, origin at TS3 center)
  - ✧ rotation angles
  - ✧ Currents

  for the 66 Mu2e coils:

  - ✓ 3 PS coils
  - ✓ 52 TS coils
  - ✓ 11 DS coils
- SolCalc computes the B field at a given point in space using the input data
- MATLAB provides the possibility of visualizing the solenoid geometry in detail

MATLAB R2015a

HOME | PLOTS | APPS | EDITOR | PUBLISH | VIEW

Search Documentation

New | Open | Save | Find Files | Compare | Print | Go To | Find | Insert | Comment | Indent | Breakpoints | Run | Run and Advance | Run Section | Advance | Run and Time

FILE | NAVIGATE | EDIT | BREAKPOINTS | RUN

/ ▸ Users ▸ elizabethwenk ▸ Desktop ▸ Working Folder ▸

Current Folder

Name

FieldCoil.m

Editor - /Users/elizabethwenk/Desktop/Working Folder/PSFieldMap.m

FldSolSysCOILS.m | PSFieldMap.m

Workspace

Name	Value
ans	0

MATLAB R2015a

HOME | PLOTS | APPS | EDITOR | PUBLISH | VIEW

Search Documenta

New | Open | Save | Find Files | Compare | Print | Go To | Find | Insert | Comment | Indent | Breakpoints | Run | Run and Advance | Run Section | Advance | Run and Time

FILE | NAVIGATE | EDIT | BREAKPOINTS | RUN

/ ▸ Users ▸ elizabethwenk ▸ Desktop ▸ Working Folder ▸

Curren...

Editor - /Users/elizabethwenk/Desktop/Working Folder/FieldSolenoidSystem.m

RotationEffectsTSuTSd1.m | RotationEffectsTSuTSd.m | untitled2 | FieldSolenoidSystem.m

```
ain Calculation
ointNum=length(Xp);

eros(MaxPointNum,1);
eros(MaxPointNum,1);
eros(MaxPointNum,1);


aralelo==1
parfor i=1:MaxPointNum
    for nc=1:size(Coils,1)
        rr=sqrt((Xp(i)-origin(nc,1))^2+(Yp(i)-origin(nc,2))^2+(Zp(i)-origin(nc,3))^2);%#ok<PFBNS>
        Ra=(Ri(nc)+Ro(nc))/2;%#ok<PFBNS>
        if (rr/Ra)<IGN
            [Bxc,Byc,Bzc] = FieldSolenoid_mex(Xp(i),Yp(i),Zp(i),Ri(nc),Ro(nc),L(nc),I(nc),origin(nc,:),rotation(nc,:),1e-1);%#ok<PFBNS>
        else
            Bxc=0;
            Byc=0;
            Bzc=0;
        end
        Bx(i,1)=Bx(i,1)+Bxc;
        By(i,1)=By(i,1)+Byc;
        Bz(i,1)=Bz(i,1)+Bzc;
    end
end

for i=1:MaxPointNum
    for nc=1:size(Coils,1)
```

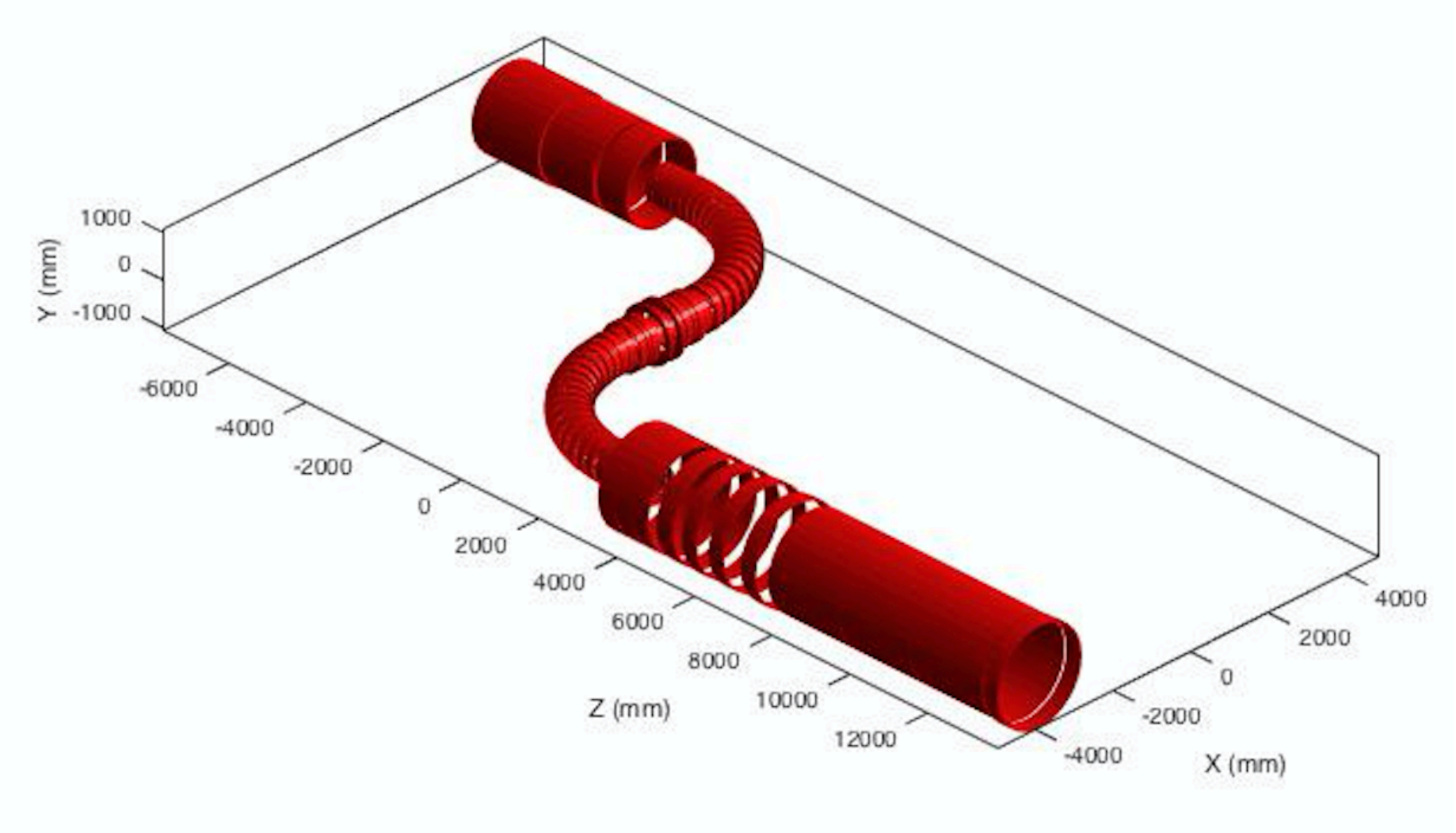
Command Window

Parallel pool using the 'local' profile is shutting down.

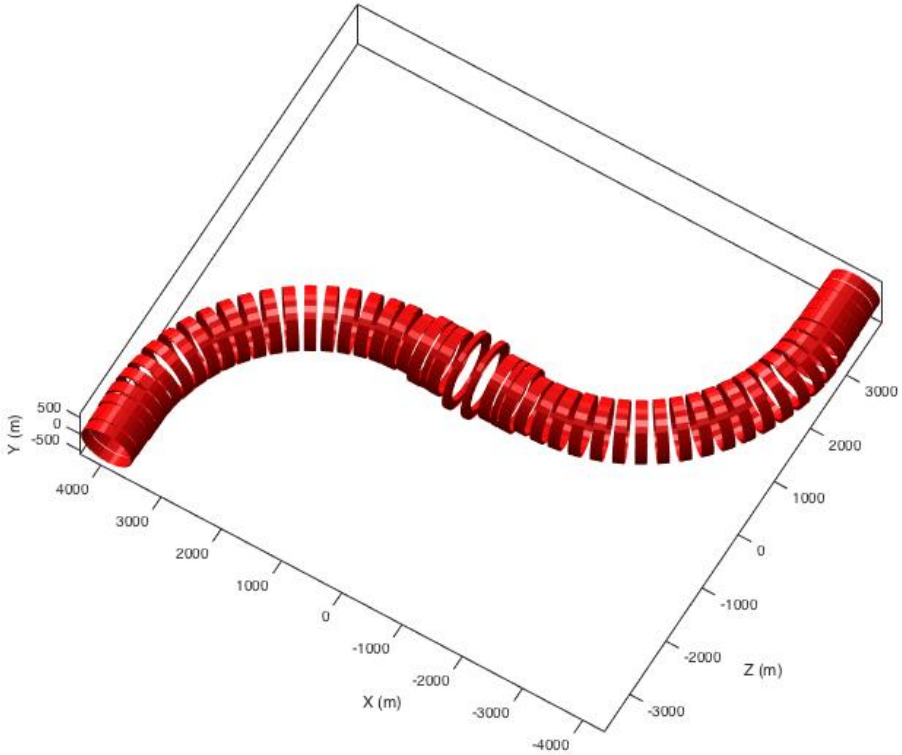
>>

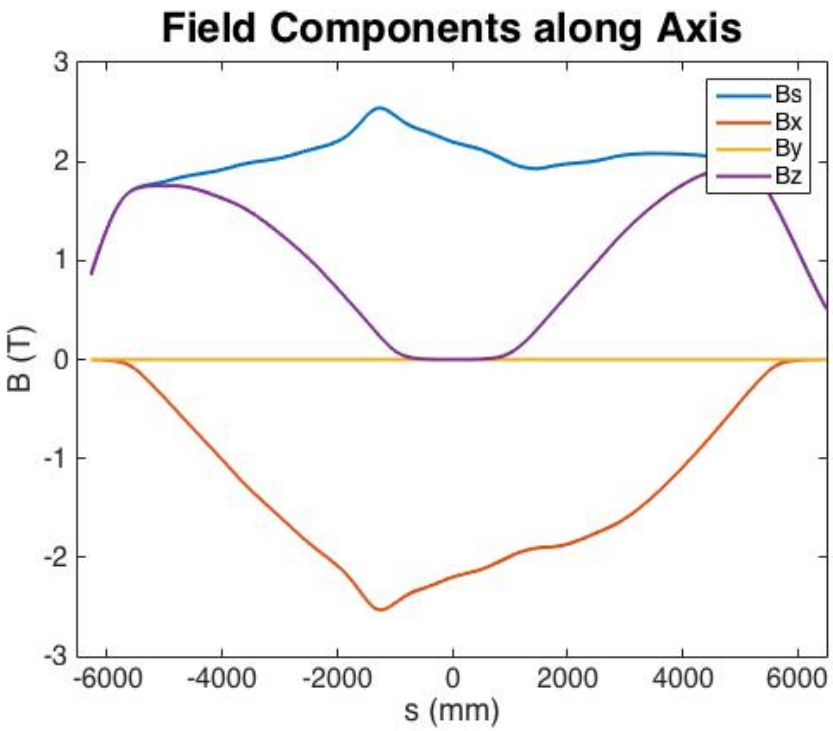
Ln 1

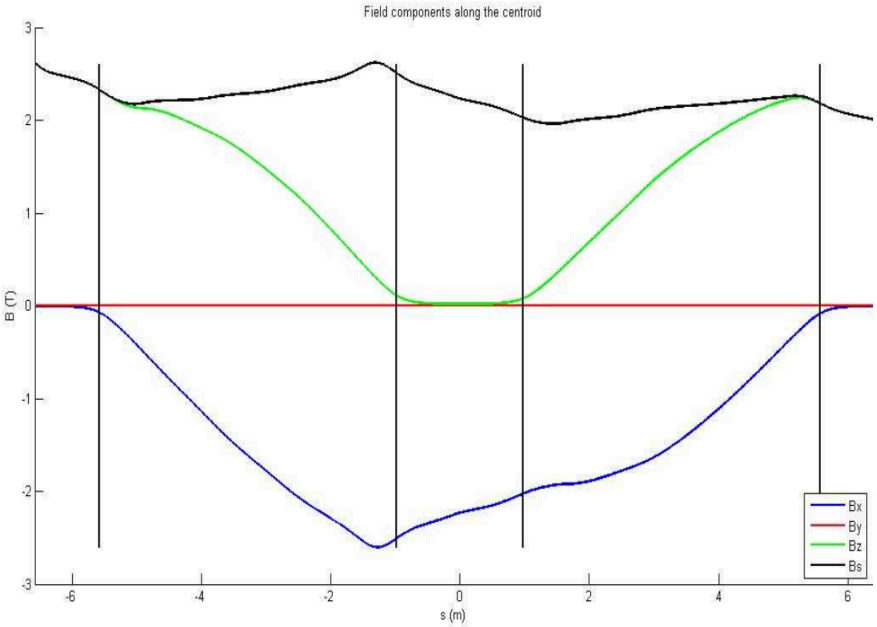
Mu2e: Coil by Coil



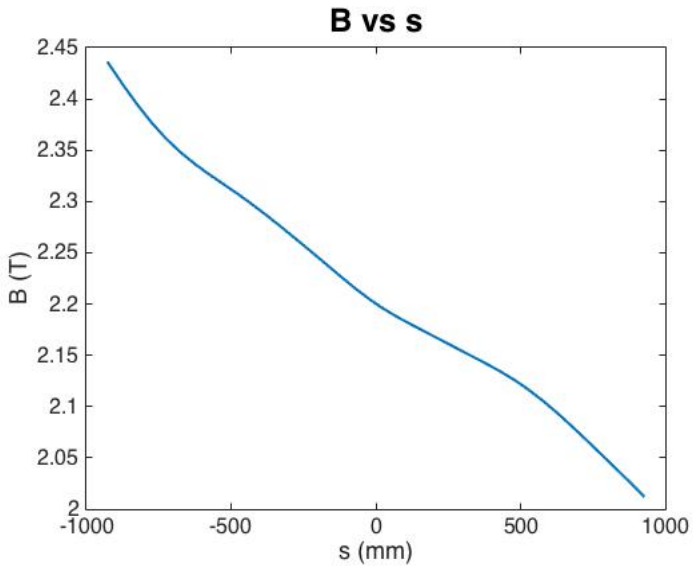
The preliminary study focused solely on the Transport Solenoid

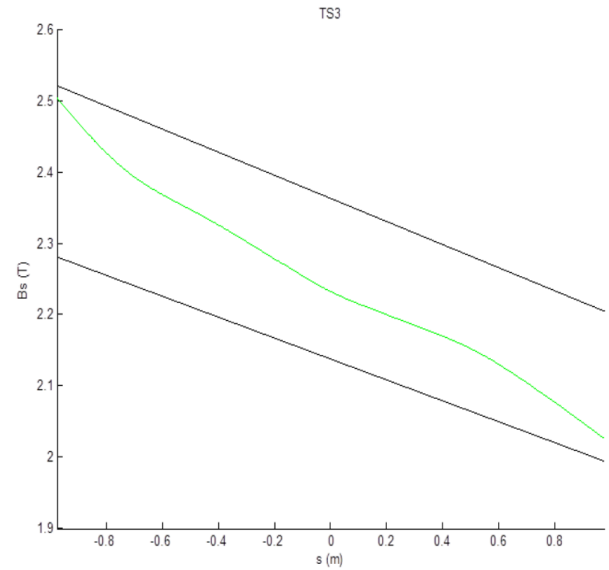




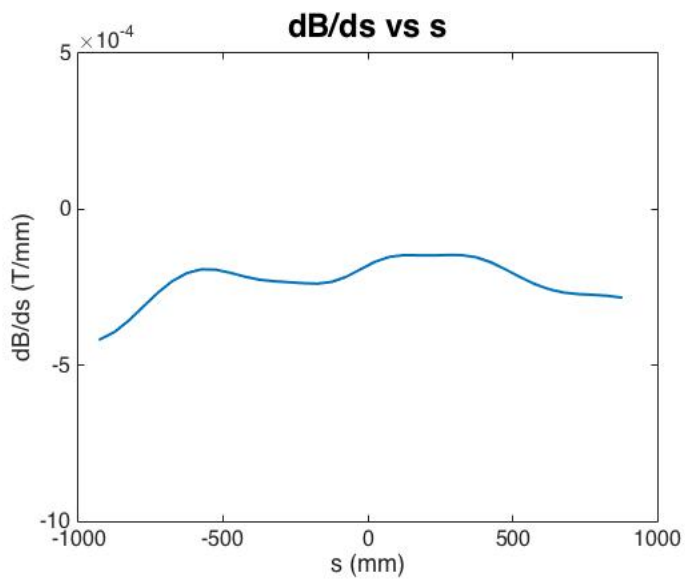


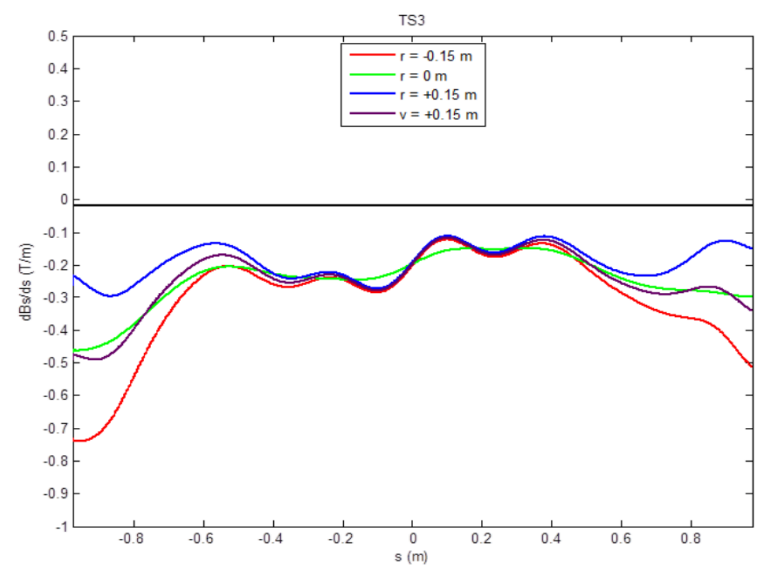
Magnetic field components along the axis of TS. The vertical black lines represent the geometric interfaces between the straight and curved sections. [Figure 1: Mu2e-doc-2156-V3]



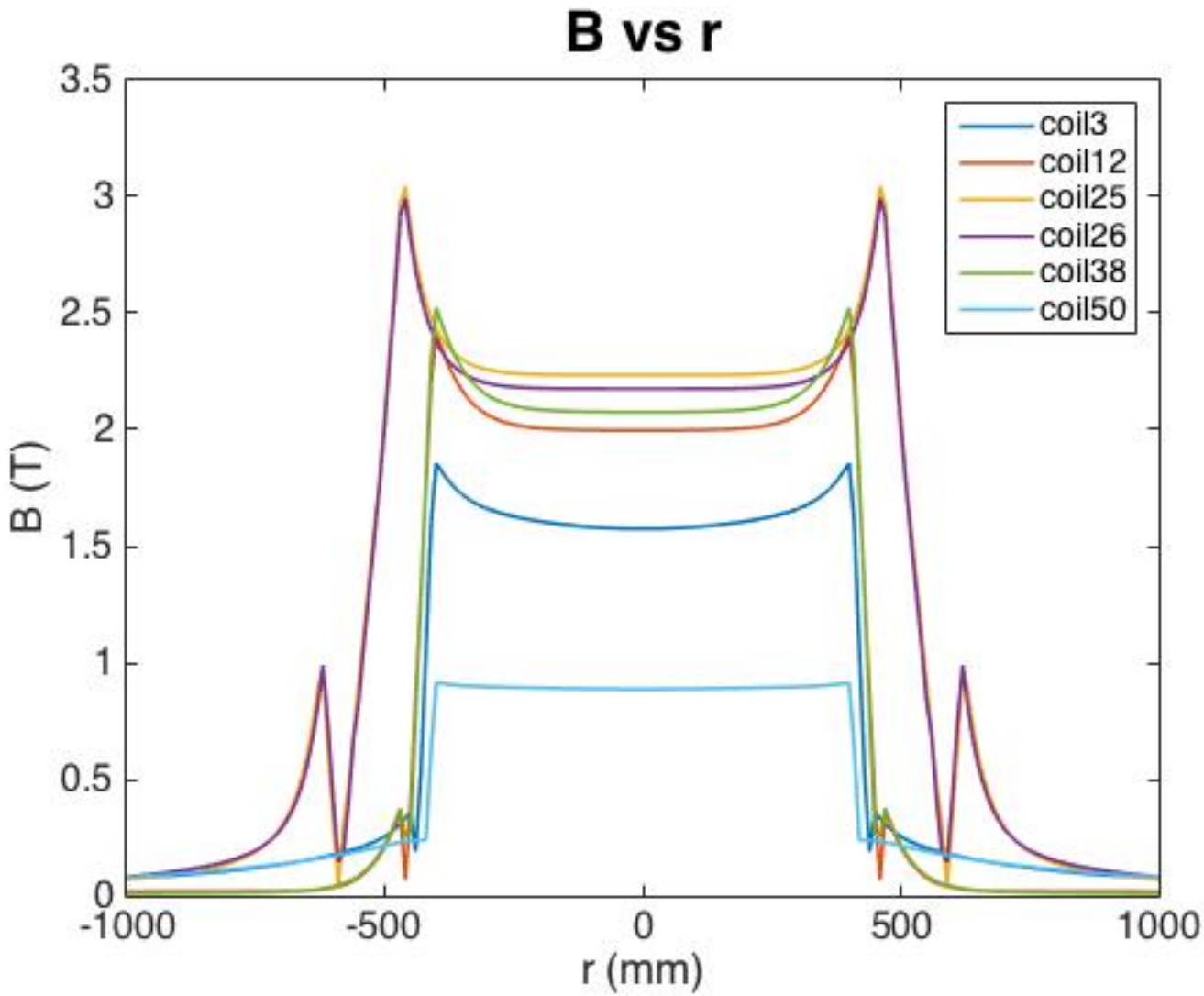


Axial field distribution at the center of TS3 [Figure 6.48: TDR]





Axial gradient along TS3 [Figure 6.48: TDR] *Note that the green line is the comparison


B vs r
3.5
3
2.5
2
1.5
1
0.5
0
B (T)
-1000
-500
0
500
1000
r (mm)
coil3
coil12
coil25
coil26
coil38
coil50

~~TS1: $\begin{cases} x = R + L_3/2 \\ y = 0 \\ z = \end{cases}$~~

In plane

$$TS1: \begin{cases} x = R + L_3/2 \\ y = 0 \\ -(R+L_1) < z < -R \end{cases} \quad \Bigg| \quad \begin{aligned} \delta x &= \varepsilon = \text{const} \\ \delta y &= 0 \\ \delta z &= 0 \end{aligned}$$

$$TS2: \begin{cases} x = R\sin\theta + L_3/2 \\ y = 0 \\ z = R(\cos\theta - 1) \end{cases} \quad \frac{\pi}{2} > \theta > 0 \quad \Bigg| \quad \begin{aligned} \delta x &= \varepsilon \sin\theta \\ \delta y &= 0 \\ \delta z &= \varepsilon \cos\theta \end{aligned}$$

$$TS3: \begin{cases} L_3/2 > x > -L_3/2 \\ y = 0 \\ z = 0 \end{cases} \quad \Bigg| \quad \begin{aligned} \delta x &= 0 \\ \delta y &= 0 \\ \delta z &= \varepsilon \end{aligned}$$

$$TS4: \begin{cases} x = -(R\sin\theta + L_3/2) \\ y = 0 \\ z = R(1 - \cos\theta) \end{cases} \quad 0 < \theta < \frac{\pi}{2} \quad \Bigg| \quad \begin{aligned} \delta x &= \varepsilon \sin\theta \\ \delta y &= 0 \\ \delta z &= \varepsilon \cos\theta \end{aligned}$$

$$TS5: \begin{cases} x = -(R + L_3/2) \\ y = 0 \\ R < z < R + L_5 \end{cases} \quad \Bigg| \quad \begin{aligned} \delta x &= \varepsilon \\ \delta y &= 0 \\ \delta z &= 0 \end{aligned}$$

$R = 2929$ mm $\quad L_1 = 700$ mm

$L_3 = 1950$ mm

$L_5 = 974.3$ mm

On axis: $\begin{cases} TS2: (x - L_3/2)^2 + (z+R)^2 = R^2 \\ TS4: (x + L_3/2)^2 + (z-R)^2 = R^2 \end{cases}$

Off axis: $\begin{cases} TS2: (x - L_3/2)^2 + (z+R)^2 = (R+\varepsilon)^2 \\ TS4: (x + L_3/2)^2 + (z-R)^2 = (R-\varepsilon)^2 \end{cases}$

Out of plane

$\delta y = \eta \qquad \sqrt{\varepsilon^2 + \eta^2} < \min\{R_{in}^{coil}\}$

$R_{in}^{TS1} = R_{in}^{TS2} = R_{in}^{TS4} = R_{in}^{TS5} = 405$ mm $\qquad R_{in}^{TS3} = 465$ mm

$$\sqrt{\varepsilon^2 + \eta^2} < 405$$

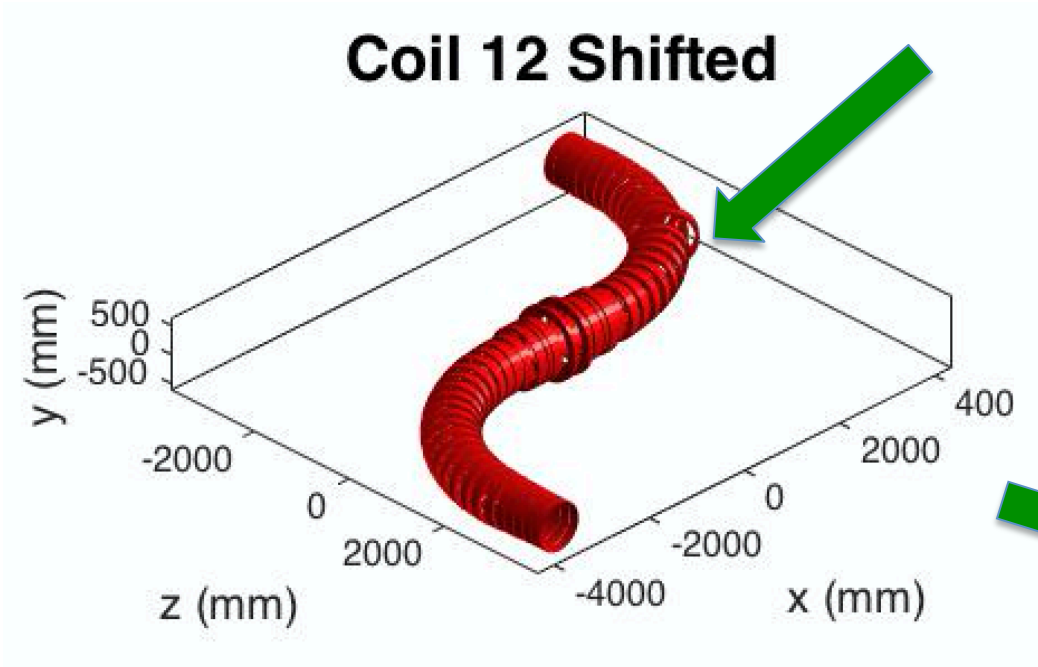
$\varepsilon = -405, -390, \ldots, 0, \ldots, 390, 405$ $\quad$ 55 points

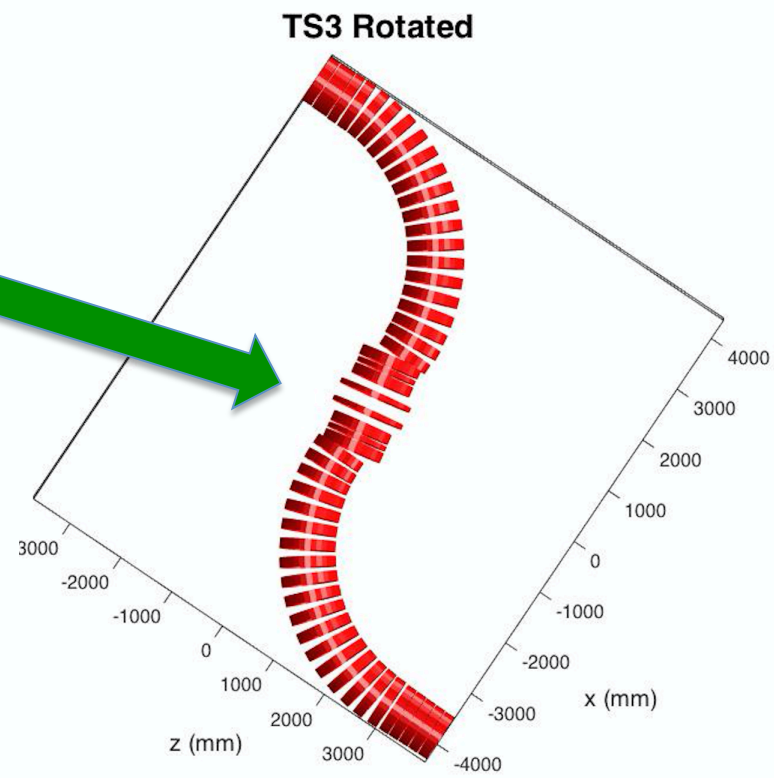
$\eta = -405, -390, \ldots, 0, \ldots, 390, 405$ $\quad$ 55 points

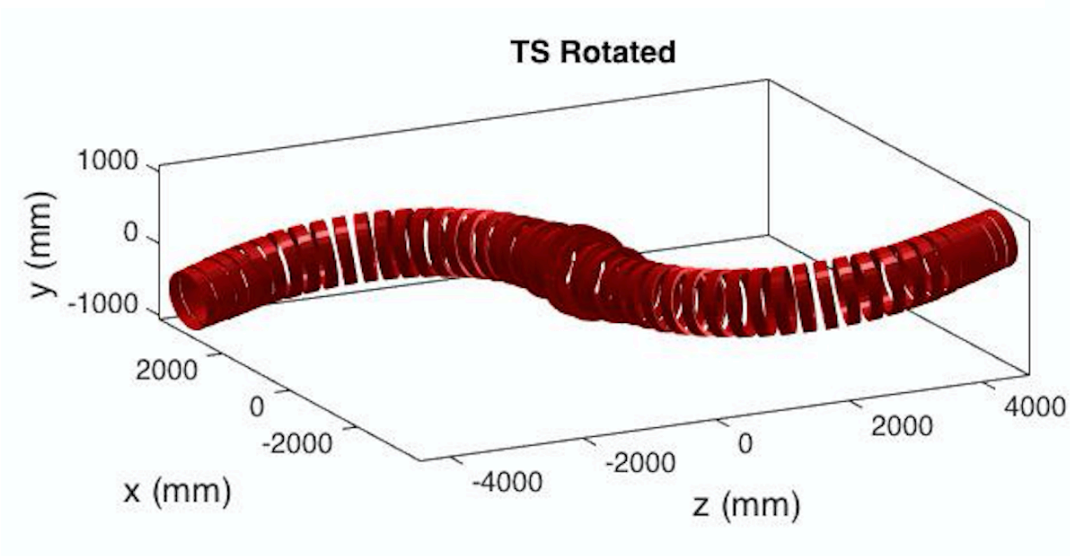
$3025 = 55 \times 55$ matrix

For every point (ε, η) in matrix, check if $\sqrt{\varepsilon^2 + \eta^2} < 405$

2376 points with $\sqrt{\varepsilon^2 + \eta^2} < 405$


Coil 12 Shifted
y (mm)
500
0
-500
-2000
0
2000
z (mm)
-4000
-2000
0
2000
400
x (mm)


TS3 Rotated
3000
-2000
-1000
0
1000
2000
3000
z (mm)
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
x (mm)


TS Rotated
y (mm)
1000
0
-1000
2000
0
-2000
x (mm)
-4000
-2000
0
2000
4000
z (mm)

The Plan

- Generate field maps for variations of the default geometry, which simulate possible misalignments of the TS coils within "reasonable" tolerances

- Although variations of only the TS geometry will be considered, the field maps will be generated for the whole PS+Tsu+TSd+DS geometry to maintain continuity of the field calculation

PSFieldMap1.txt

2804.00000000	0.00000000	-9929.00000000	0.0600398898225	-7.51000332865E-18	0.117623298674
2804.00000000	0.00000000	-9904.00000000	0.0616675569487	-7.71042612573E-18	0.119703731812
2804.00000000	0.00000000	-9879.00000000	0.063349293893	-7.91748069476E-18	0.121830108995
2804.00000000	0.00000000	-9854.00000000	0.0650872046313	-8.13142481976E-18	0.124003538722
2804.00000000	0.00000000	-9829.00000000	0.0668834860665	-8.35252766676E-18	0.126225152826
2804.00000000	0.00000000	-9804.00000000	0.0687404325944	-8.58107034311E-18	0.128496106432
2804.00000000	0.00000000	-9779.00000000	0.0706604409186	-8.81734648711E-18	0.130817577849
2804.00000000	0.00000000	-9754.00000000	0.0726460151274	-9.06166288978E-18	0.133190768389
2804.00000000	0.00000000	-9729.00000000	0.0746997720494	-9.31434015083E-18	0.135616902103
2804.00000000	0.00000000	-9704.00000000	0.0768244469054	-9.57571337076E-18	0.138097225417
2804.00000000	0.00000000	-9679.00000000	0.0790228992736	-9.84613288148E-18	0.140633006669
2804.00000000	0.00000000	-9654.00000000	0.0812981193889	-1.01259650178E-17	0.143225535526
2804.00000000	0.00000000	-9629.00000000	0.0836532347969	-1.04155929322E-17	0.145876122271
2804.00000000	0.00000000	-9604.00000000	0.0860915173842	-1.07154174563E-17	0.148586096942
2804.00000000	0.00000000	-9579.00000000	0.0886163908115	-1.10258580103E-17	0.151356808316
2804.00000000	0.00000000	-9554.00000000	0.0912314383721	-1.13473535665E-17	0.154189622709
2804.00000000	0.00000000	-9529.00000000	0.0939404113074	-1.16803636668E-17	0.157085922572
2804.00000000	0.00000000	-9504.00000000	0.0967472376065	-1.20253695008E-17	0.16004710488
2804.00000000	0.00000000	-9479.00000000	0.099656031324	-1.2382875047E-17	0.163074579254
2804.00000000	0.00000000	-9454.00000000	0.102671102451	-1.27534082814E-17	0.16616976583
2804.00000000	0.00000000	-9429.00000000	0.105796967374	-1.31375224588E-17	0.169334092812
2804.00000000	0.00000000	-9404.00000000	0.109038359971	-1.35357974712E-17	0.172568993687
2804.00000000	0.00000000	-9379.00000000	0.112400243375	-1.39488412888E-17	0.175875904076
2804.00000000	0.00000000	-9354.00000000	0.115887822468	-1.43772914903E-17	0.179256258157
2804.00000000	0.00000000	-9329.00000000	0.119506557145	-1.48218168868E-17	0.182711484631
2804.00000000	0.00000000	-9304.00000000	0.123262176414	-1.5283119249E-17	0.186243002172
2804.00000000	0.00000000	-9279.00000000	0.127160693385	-1.57619351428E-17	0.189852214302
2804.00000000	0.00000000	-9254.00000000	0.13120842122	-1.62590378824E-17	0.19354050363
2804.00000000	0.00000000	-9229.00000000	0.135411990113	-1.67752396104E-17	0.197309225378
2804.00000000	0.00000000	-9204.00000000	0.139778365386	-1.73113935134E-17	0.20115970011
2804.00000000	0.00000000	-9179.00000000	0.144314866775	-1.78683961839E-17	0.205093205584
2804.00000000	0.00000000	-9154.00000000	0.149029189013	-1.84471901417E-17	0.2091109676
2804.00000000	0.00000000	-9129.00000000	0.153929423805	-1.90487665241E-17	0.21321414975
2804.00000000	0.00000000	-9104.00000000	0.159024083309	-1.96741679628E-17	0.217403841918
2804.00000000	0.00000000	-9079.00000000	0.16432212189	-2.03244912467E-17	0.221681047393
2804.00000000	0.00000000	-9054.00000000	0.169832976279	-2.10008922412E-17	0.22604666841
2804.00000000	0.00000000	-9029.00000000	0.175566574693	-2.17045870043E-17	0.230501489936
2804.00000000	0.00000000	-9004.00000000	0.181533380667	-2.24368571553E-17	0.235046161464
2804.00000000	0.00000000	-8979.00000000	0.187744422985	-2.31990535395E-17	0.239681176577
2804.00000000	0.00000000	-8954.00000000	0.194211331269	-2.39926005871E-17	0.244406849968
2804.00000000	0.00000000	-8929.00000000	0.200946374235	-2.48190009988E-17	0.249223291605
2804.00000000	0.00000000	-8904.00000000	0.207962500866	-2.56798407868E-17	0.254130377629
2804.00000000	0.00000000	-8879.00000000	0.215273384752	-2.65767947065E-17	0.259127717562
2804.00000000	0.00000000	-8854.00000000	0.222893471895	-2.75116321096E-17	0.264214617292
2804.00000000	0.00000000	-8829.00000000	0.230838032286	-2.84862232614E-17	0.269390037246
2804.00000000	0.00000000	-8804.00000000	0.239123215606	-2.95025461624E-17	0.274652545057
2804.00000000	0.00000000	-8779.00000000	0.24776611143	-3.05626939203E-17	0.280000261905
2804.00000000	0.00000000	-8754.00000000	0.256784814341	-3.16688827253E-17	0.285430801596
2804.00000000	0.00000000	-8729.00000000	0.266198500788	-3.28234612618E-17	0.290941201263
2804.00000000	0.00000000	-8704.00000000	0.276027480159	-3.40289169635E-17	0.296527842392
2804.00000000	0.00000000	-8679.00000000	0.286293314974	-3.52878907331E-17	0.302186360623
2804.00000000	0.00000000	-8654.00000000	0.297018885767	-3.66031848873E-17	0.30791154253
2804.00000000	0.00000000	-8629.00000000	0.30822849434	-3.79777758029E-17	0.313697207212
2804.00000000	0.00000000	-8604.00000000	0.319947969016	-3.9414826806E-17	0.319536069289
2804.00000000	0.00000000	-8579.00000000	0.332204778615	-4.09177021304E-17	0.325419585275
2804.00000000	0.00000000	-8554.00000000	0.345028155756	-4.24899820176E-17	0.33133776739
2804.00000000	0.00000000	-8529.00000000	0.358449230027	-4.41354790258E-17	0.337278976501
2804.00000000	0.00000000	-8504.00000000	0.372501171474	-4.5858255602E-17	0.343229677111
2804.00000000	0.00000000	-8479.00000000	0.387219344679	-4.76626429515E-17	0.349174152684
2804.00000000	0.00000000	-8454.00000000	0.402641473433	-4.95532612049E-17	0.355094172864
2804.00000000	0.00000000	-8429.00000000	0.418807815585	-5.15350480243E-17	0.360968603248

PSFieldMap3.txt

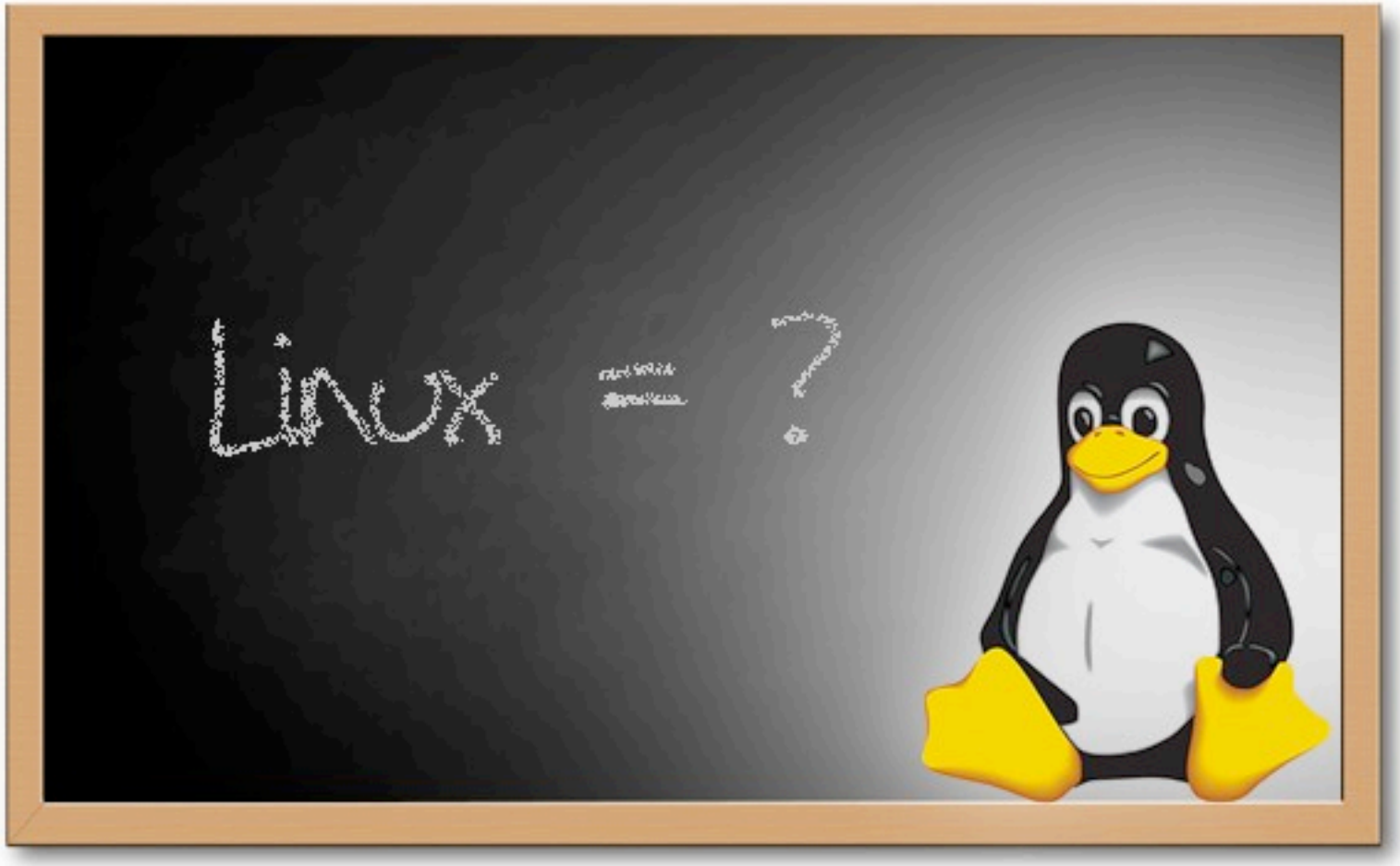
4604.00000000	750.00000000	-4879.00000000	0.227176898567	0.244814925938	-0.199353941075
4604.00000000	750.00000000	-4854.00000000	0.236177711164	0.254471040428	-0.197623270305
4604.00000000	750.00000000	-4829.00000000	0.245457184495	0.264425949975	-0.194190107472
4604.00000000	750.00000000	-4804.00000000	0.255270152896	0.274952698839	-0.188662226671
4604.00000000	750.00000000	-4779.00000000	0.265612525897	0.286046912153	-0.180500578403
4604.00000000	750.00000000	-4754.00000000	0.276167134563	0.297368774165	-0.168885846298
4604.00000000	750.00000000	-4729.00000000	0.2864129269	0.308360023324	-0.15299307597
4604.00000000	750.00000000	-4704.00000000	0.295556455211	0.31817054589	-0.131933500634
4604.00000000	750.00000000	-4679.00000000	0.302301027973	0.32541103868	-0.104821496495
4604.00000000	750.00000000	-4654.00000000	0.304631370272	0.327922288109	-0.0701024291617
4604.00000000	750.00000000	-4629.00000000	0.299995127783	0.322969638764	-0.0329024999728
4604.00000000	750.00000000	-4604.00000000	0.285809841631	0.307786180767	0.00734608984218
4604.00000000	750.00000000	-4579.00000000	0.260598778516	0.280789710638	0.0432658493435
4604.00000000	750.00000000	-4554.00000000	0.225374745388	0.243065389886	0.0673525913764
4604.00000000	750.00000000	-4529.00000000	0.184184680092	0.19894923501	0.0733334241668
4604.00000000	750.00000000	-4504.00000000	0.142830967224	0.154658098779	0.0585708166196
4604.00000000	750.00000000	-4479.00000000	0.107368597148	0.116679483477	0.0250000855887
4604.00000000	750.00000000	-4454.00000000	0.0821963745846	0.0897264072727	-0.0214552057774
4604.00000000	750.00000000	-4429.00000000	0.068833815683	0.0754269367951	-0.0736033450757
4604.00000000	750.00000000	-4404.00000000	0.0661320687011	0.072550173595	-0.124655100503
4604.00000000	750.00000000	-4379.00000000	0.071626627353	0.0784555898816	-0.170862654122
4604.00000000	750.00000000	-4354.00000000	0.0826742616393	0.0903111687055	-0.210797970017
4604.00000000	750.00000000	-4329.00000000	0.0972507535554	0.105948120794	-0.244136730539
4604.00000000	750.00000000	-4304.00000000	0.113968039964	0.123879251915	-0.272772642116
4604.00000000	750.00000000	-4279.00000000	0.131956422502	0.143172759207	-0.296448517488
4604.00000000	750.00000000	-4254.00000000	0.15075504281	0.163334883207	-0.316428330483
4604.00000000	750.00000000	-4229.00000000	0.170138280077	0.184123905202	-0.333335556227
4604.00000000	750.00000000	-4204.00000000	0.189933664968	0.205355055002	-0.347709579841
4604.00000000	750.00000000	-4179.00000000	0.210161236456	0.227049821803	-0.359847571549

PSFieldMap2.txt

3704.00000000	375.00000000	-7404.00000000	0.27600589687	-0.518977793546	3.64229253054
3704.00000000	375.00000000	-7379.00000000	0.266169046855	-0.500542131492	3.71318974887
3704.00000000	375.00000000	-7354.00000000	0.256098724748	-0.481668776418	3.78064626216
3704.00000000	375.00000000	-7329.00000000	0.245880118939	-0.462517457448	3.84541675425
3704.00000000	375.00000000	-7304.00000000	0.23558832773	-0.44322898481	3.90679041251
3704.00000000	375.00000000	-7279.00000000	0.225288234446	-0.423925015666	3.96507055372
3704.00000000	375.00000000	-7254.00000000	0.215035171737	-0.404709299691	4.02032719702
3704.00000000	375.00000000	-7229.00000000	0.20487503482	-0.385667891385	4.07264133301
3704.00000000	375.00000000	-7204.00000000	0.194845326304	-0.366871109137	4.12210114421
3704.00000000	375.00000000	-7179.00000000	0.184975914144	-0.348374956384	4.16879987745
3704.00000000	375.00000000	-7154.00000000	0.17530009795	-0.330241870934	4.21283248836
3704.00000000	375.00000000	-7129.00000000	0.165804240441	-0.31244628395	4.25429443683
3704.00000000	375.00000000	-7104.00000000	0.156530824753	-0.295067852406	4.29327928213
3704.00000000	375.00000000	-7079.00000000	0.147476590035	-0.27810046332	4.329880109
3704.00000000	375.00000000	-7054.00000000	0.138645319674	-0.261551211691	4.36418506789
3704.00000000	375.00000000	-7029.00000000	0.130036814591	-0.245419725412	4.39627870456
3704.00000000	375.00000000	-7004.00000000	0.121648045169	-0.229700325157	4.42624101707
3704.00000000	375.00000000	-6979.00000000	0.113474255032	-0.214384093944	4.45414721162
3704.00000000	375.00000000	-6954.00000000	0.105508765837	-0.199458511141	4.47996317181
3704.00000000	375.00000000	-6929.00000000	0.0977435072081	-0.184908446085	4.50402047753
3704.00000000	375.00000000	-6904.00000000	0.0901665612448	-0.170711554037	4.52620807424
3704.00000000	375.00000000	-6879.00000000	0.0827710516381	-0.156854943272	4.54654445837
3704.00000000	375.00000000	-6854.00000000	0.0755512891656	-0.143327947889	4.56512775338
3704.00000000	375.00000000	-6829.00000000	0.0684981524825	-0.130113466796	4.58200402375
3704.00000000	375.00000000	-6804.00000000	0.0615849242495	-0.117161406443	4.59721456589
3704.00000000	375.00000000	-6779.00000000	0.0548085765938	-0.104466091072	4.6107959991
3704.00000000	375.00000000	-6754.00000000	0.0481635916255	-0.092017176182	4.62278038373
3704.00000000	375.00000000	-6729.00000000	0.0416283768353	-0.0797741774	4.63319536486
3704.00000000	375.00000000	-6704.00000000	0.0351921636155	-0.0677169052122	4.64201815003
3704.00000000	375.00000000	-6679.00000000	0.0288536516657	-0.0558429232244	4.64930441416

SFieldMap1.txt

0.0600398898225	-7.51000332865E-18	0.117623298674
0.0616675569487	-7.71042612573E-18	0.119703731812
0.063349293893	-7.91748069476E-18	0.121830108995
0.0650872046313	-8.13142481976E-18	0.124003538722
0.0668834860665	-8.35252766676E-18	0.126225152826
0.0687404325944	-8.58107034311E-18	0.128496106432
0.0706604409186	-8.81734648711E-18	0.130817577849
0.0726460151274	-9.06166288978E-18	0.133190768389
0.0746997720494	-9.31434015083E-18	0.135616902103
0.0768244469054	-9.57571337076E-18	0.138097225417
0.0790228992736	-9.84613288148E-18	0.140633006669
0.0812981193889	-1.01259650178E-17	0.143225535526
0.0836532347969	-1.04155929322E-17	0.145876122271
0.0860915173842	-1.07154174563E-17	0.148586096942
0.0886163908115	-1.10258580103E-17	0.151356808316
0.0912314383721	-1.13473535665E-17	0.154189622709
0.0939404113074	-1.16803636668E-17	0.157085922572
0.0967472376065	-1.20253695008E-17	0.16004710488
0.099656031324	-1.2382875047E-17	0.163074579254
0.102671102451	-1.27534082814E-17	0.16616976583
0.105796967374	-1.31375224588E-17	0.169334092812
0.109038359971	-1.35357974712E-17	0.172568993687
0.112400243375	-1.39488412888E-17	0.175875904076
0.115887822468	-1.43772914903E-17	0.179256258157
0.119506557145	-1.48218168868E-17	0.182711484631
0.123262176414	-1.5283119249E-17	0.186243002172
0.127160693385	-1.57619351428E-17	0.189852214302
0.13120842122	-1.62590378824E-17	0.19354050363
0.135411990113	-1.67752396104E-17	0.197309225378
0.139778365386	-1.73113935134E-17	0.20115970011
0.144314866775	-1.78683961839E-17	0.205093205584
0.149029189013	-1.84471901417E-17	0.2091109676
0.153929423805	-1.90487665241E-17	0.21321414975
0.159024083309	-1.96741679628E-17	0.217403841918
0.16432212189	-2.03244912467E-17	0.221681047393
0.169832976279	-2.10008922412E-17	0.22604666841
0.175566574693	-2.17045870043E-17	0.230501489936
0.181533380667	-2.24368571553E-17	0.235046161464
0.187744422985	-2.31990535395E-17	0.239681176577
0.194211331269	-2.39926005871E-17	0.244406849968
0.200946374235	-2.48190009988E-17	0.249223291605
0.207962500866	-2.56798407868E-17	0.254130377629
0.215273384752	-2.65767947065E-17	0.259127717562
0.222893471895	-2.75116321096E-17	0.264214617292
0.230838032286	-2.84862232614E-17	0.269390037246
0.239123215606	-2.95025461624E-17	0.274652545057
0.24776611143	-3.05626939203E-17	0.280000261905
0.256784814341	-3.16688827253E-17	0.285430801596
0.266198500788	-3.28234612618E-17	0.290941201263
0.276027480159	-3.40289169635E-17	0.296527842392
0.286293314974	-3.52878907331E-17	0.302186360623
0.297018885767	-3.66031848873E-17	0.30791154253
0.30822849434	-3.79777758029E-17	0.313697207212
0.319947969016	-3.9414826806E-17	0.319536069289
0.332204778615	-4.09177021304E-17	0.325419585275
0.345028155756	-4.24899820176E-17	0.33133776739
0.358449230027	-4.41354790258E-17	0.337278976501
0.372501171474	-4.5858255602E-17	0.343229677111
0.387219344679	-4.76626429515E-17	0.349174152684
0.402641473433	-4.95532612049E-17	0.355094172864

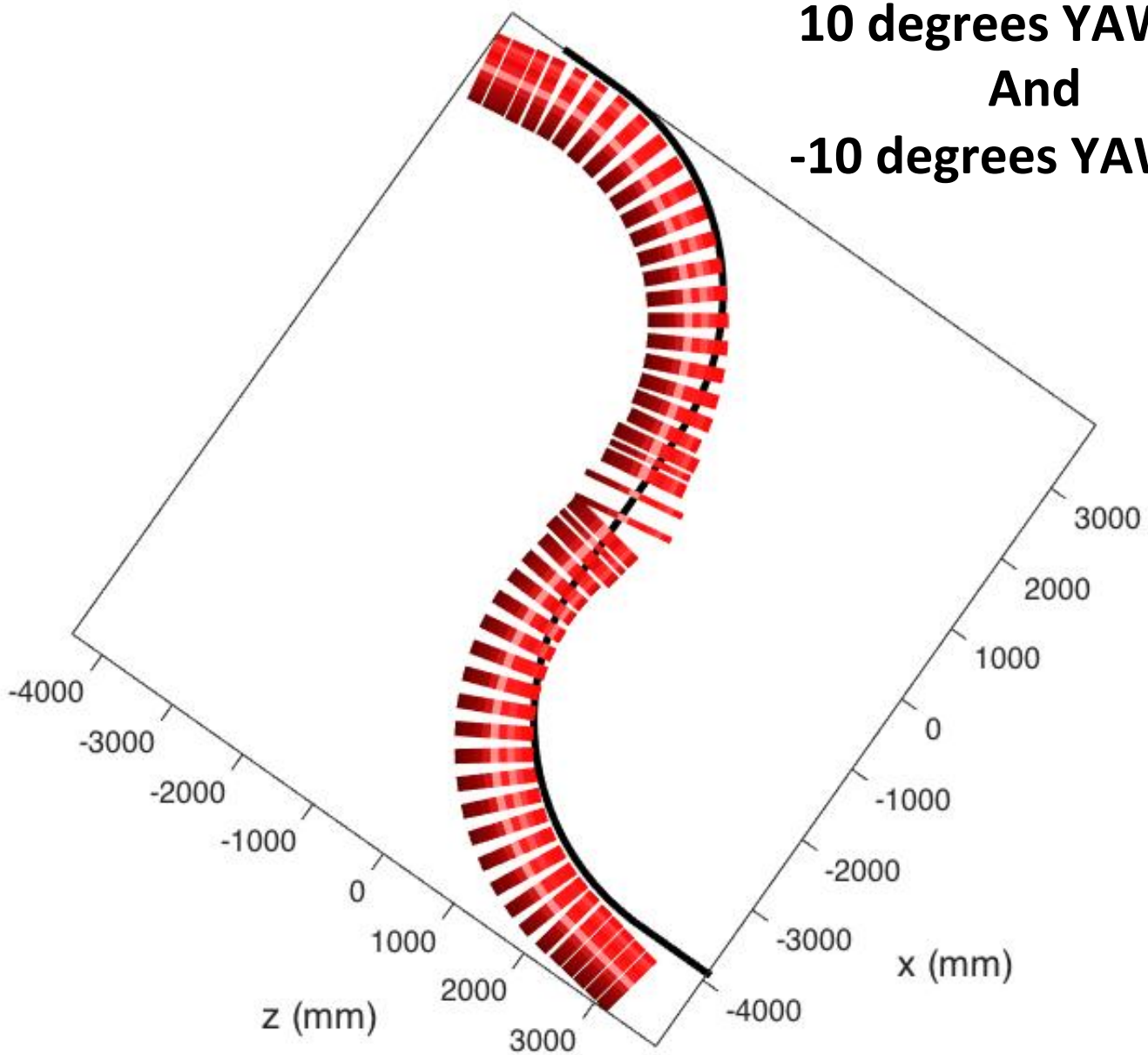

Linux = ?

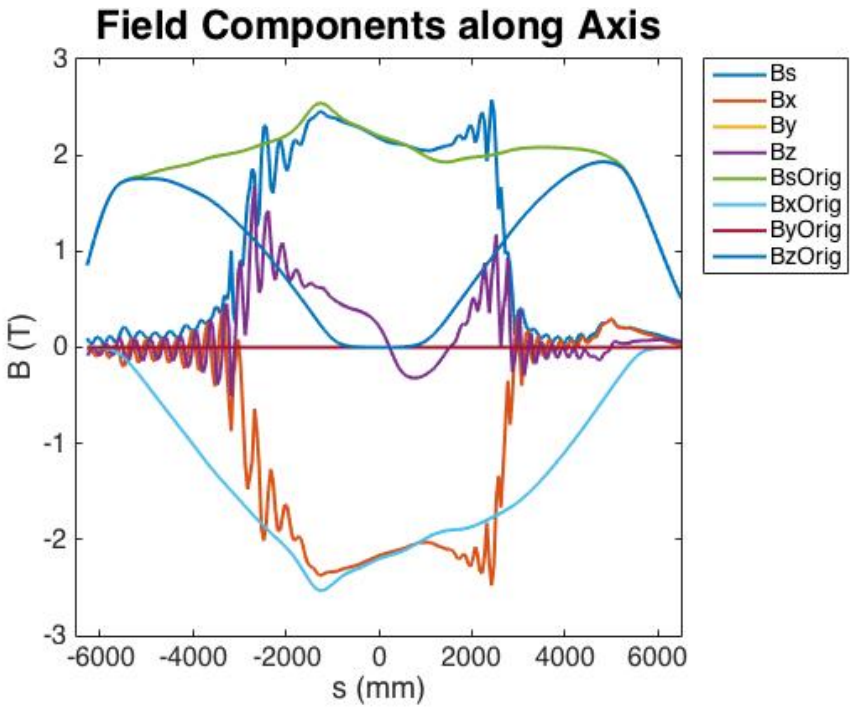
```
-rw-r--r--  1 elizabethwenk  staff   333B Jul 29 09:42
-rw-r--r--  1 elizabethwenk  staff   434B Jul 29 09:49
-rw-r--r--  1 elizabethwenk  staff   448B Jul 29 09:50
elizabeths-mbp:GAmaps elizabethwenk$ rm fprint.txt
elizabeths-mbp:GAmaps elizabethwenk$ ls -ltrh *.txt
-rw-r--r--  1 elizabethwenk  staff   9.6K Jul 29 09:28
-rw-r--r--  1 elizabethwenk  staff   9.6K Jul 29 09:28
-rw-r--r--  1 elizabethwenk  staff   434B Jul 29 09:49
-rw-r--r--  1 elizabethwenk  staff   448B Jul 29 09:50
elizabeths-mbp:GAmaps elizabethwenk$ cat fprintf_mau9.
  for(int i=0; i<nX; i++)
    {
      for(int j=0; j<49; j++)
        {
          for(int k=0; k<nZ; k++)
            {
              //fprintf(diff,"%15.3f %15.3f %15.3f %15
[i][j][k],Ze[i][j][k],Zm[i][j][k],(ewenkBx[i][j][k]-ma
ewenkBz[i][j][k]-mau9Bz[i][j][k])/mau9Bz[i][j][k]);
            }
        }
    }
elizabeths-mbp:GAmaps elizabethwenk$ cat fprintf.txt
  for(int i=0; i<nX; i++)
    {
      for(int j=0; j<49; j++)
        {
          for(int k=0; k<nZ; k++)
            {
              fprintf(diff,"%15.3f %15.3f %15.3f %15.3
2[i][48-j][k],Z1[i][j][k],Z2[i][48-j][k],(GA1Bx[i][j][
][48-j][k],(GA1Bz[i][j][k]-GA2Bz[i][48-j][k])/GA2Bz[i]
            }
        }
    }
elizabeths-mbp:GAmaps elizabethwenk$ vi fprintf_mau9.t
elizabeths-mbp:GAmaps elizabethwenk$ vi fprintf.txt
elizabeths-mbp:GAmaps elizabethwenk$ cat fprintf_mau9.
  for(int i=0; i<nX; i++)   //X coordinate
    {
      for(int j=0; j<49; j++)   //Y coordinate
        {
          for(int k=0; k<nZ; k++)   //Z coordinate
            {
              //fprintf(diff,"%15.3f %15.3f %15.3f %15
[i][j][k],Ze[i][j][k],Zm[i][j][k],(ewenkBx[i][j][k]-ma
```

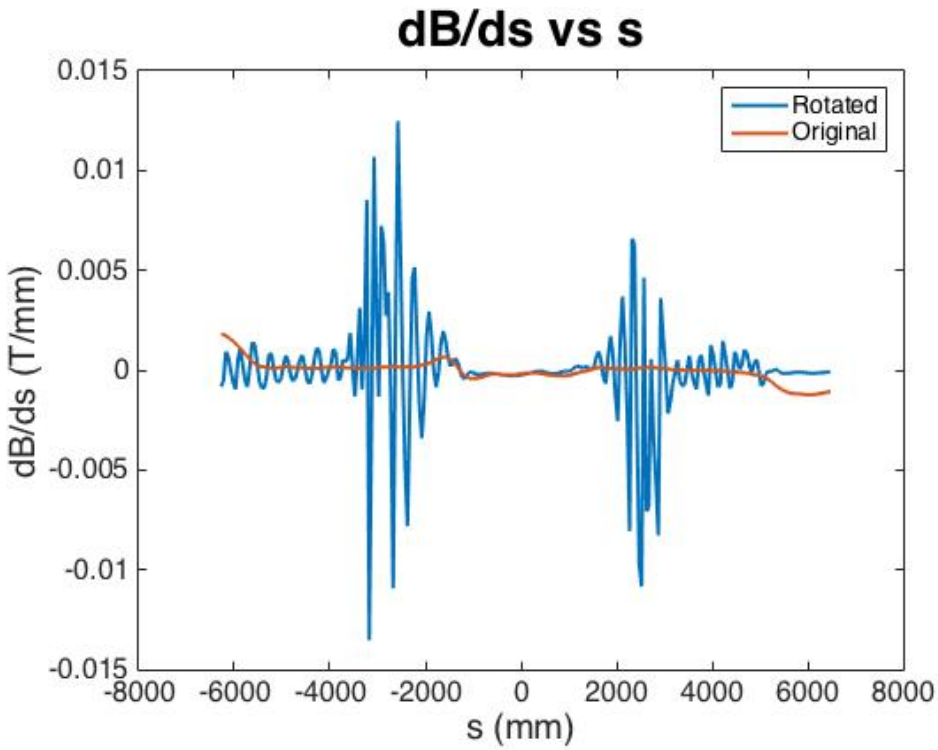
Working Folder — ssh — 89×53

```
 151  ssh ewenk@mu2egpvm01
      cd /mu2e/data/users/ewenk/field_maps        (on mu2egpvm01)
elizabeths-mbp:~ elizabethwenk$  cd Desktop/Working\ Folder/
elizabeths-mbp:Working Folder elizabethwenk$ ls -ltrh *FieldMap*.txt
-rw-r--r--  1 elizabethwenk  staff    62M Jul 22 15:05 PSFieldMap1.txt
-rw-r--r--  1 elizabethwenk  staff    62M Jul 22 15:05 PSFieldMap2.txt
-rw-r--r--  1 elizabethwenk  staff    28M Jul 22 15:06 PSFieldMap3.txt
elizabeths-mbp:Working Folder elizabethwenk$ scp PSFieldMap1.txt ewenk@mu2egpvm01:/mu2e/d
ata/users/ewenk/field_maps
PSFieldMap1.txt
                    100%   62MB  30.8MB/s   00:02
scp: /mu2e/data/users/ewenk/field_maps/PSFieldMap1.txt: Disk quota exceeded
elizabeths-mbp:Working Folder elizabethwenk$ scp PSFieldMap2.txt ewenk@mu2egpvm01:/mu2e/d
ata/users/ewenk/field_maps
PSFieldMap2.txt
                    100%   62MB  20.5MB/s   00:03
scp: /mu2e/data/users/ewenk/field_maps/PSFieldMap2.txt: Disk quota exceeded
elizabeths-mbp:Working Folder elizabethwenk$ scp PSFieldMap3.txt ewenk@mu2egpvm01:/mu2e/d
ata/users/ewenk/field_maps
PSFieldMap3.txt
                    100%   28MB  27.7MB/s   00:01
scp: /mu2e/data/users/ewenk/field_maps/PSFieldMap3.txt: Disk quota exceeded
elizabeths-mbp:Working Folder elizabethwenk$ ssh ewenk@mu2egpvm01
Last login: Wed Jul 22 09:16:11 2015 from 131.225.95.88
                              NOTICE TO USERS

      This  is a Federal computer (and/or it is directly connected to a
      Fermilab local network system) that is the property of the United
      States Government.  It is for authorized use only.  Users (autho-
      rized or unauthorized) have no explicit or  implicit  expectation
      of privacy.

      Any  or  all uses of this system and all files on this system may
      be intercepted, monitored, recorded,  copied, audited, inspected,
      and  disclosed  to authorized site, Department of Energy  and law
      enforcement personnel, as  well as authorized officials of  other
      agencies,  both  domestic and foreign.  By using this system, the
      user consents to such interception, monitoring, recording,  copy-
      ing,  auditing,  inspection,  and disclosure at the discretion of
      authorized site or Department of Energy personnel.

      Unauthorized or improper use of this system may result in  admin-
      istrative  disciplinary  action and civil and criminal penalties.
      By continuing to use this system you indicate your  awareness  of
      and  consent to these terms and conditions of use.  LOG OFF IMME-
      DIATELY if you do not agree to  the  conditions  stated  in  this
      warning.

      Fermilab  policy  and  rules for computing, including appropriate
      use, may be found at http://www.fnal.gov/cd/main/cpolicy.html
<mu2egpvm01.fnal.gov> cd /mu2e/data/users/ewenk/field_maps
<mu2egpvm01.fnal.gov> cat history
  34  cat TSUFieldMap1.txt TSUFieldMap2.txt TSUFieldMap3.txt TSUFieldMap4.txt TSUFieldMa
```

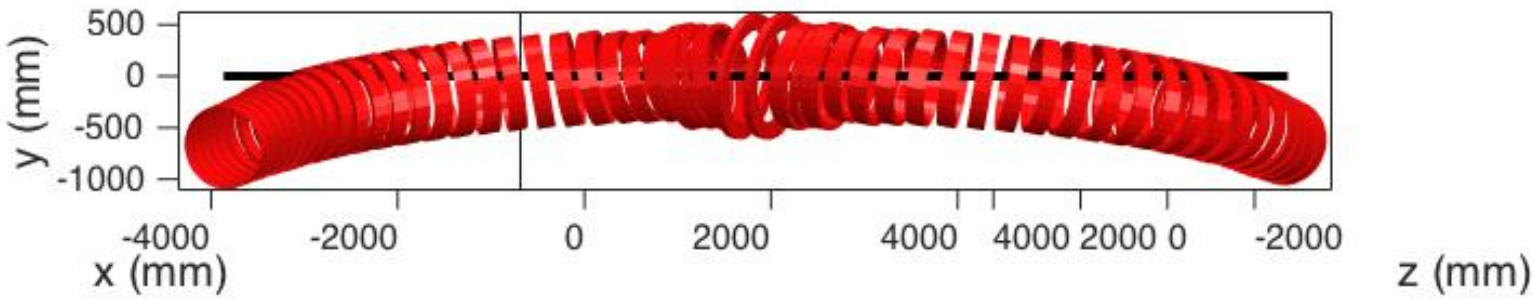
10 degrees YAW TSu
And
-10 degrees YAW TSd

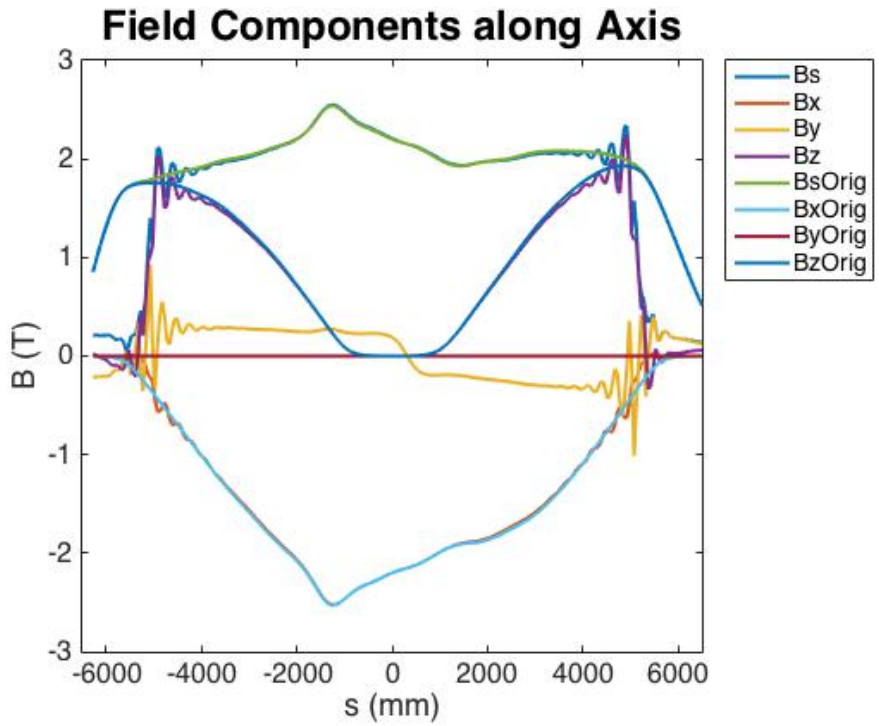


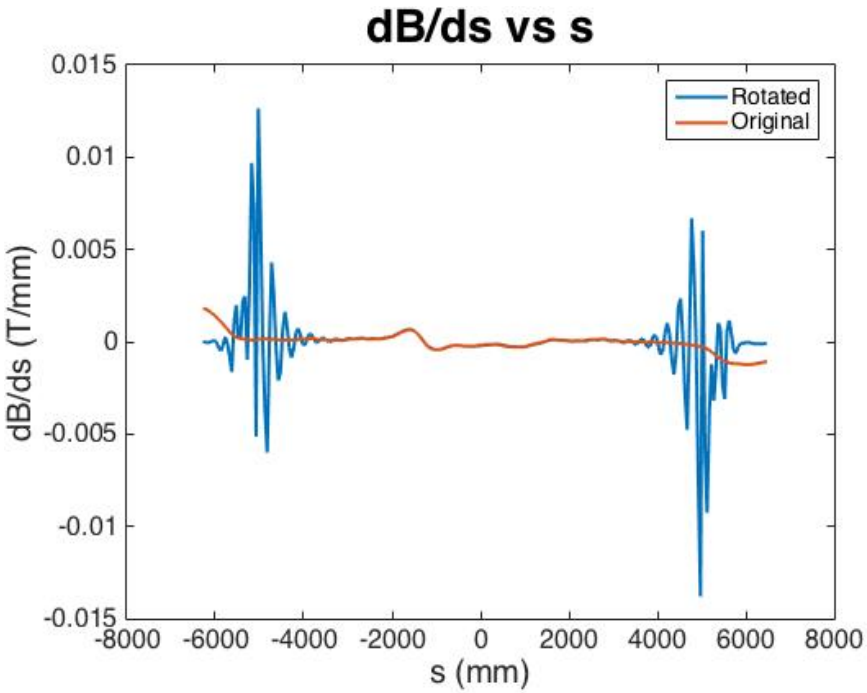

Field Components along Axis
B (T)
s (mm)
Bs
Bx
By
Bz
BsOrig
BxOrig
ByOrig
BzOrig


dB/ds vs s
dB/ds (T/mm)
s (mm)
Rotated
Original

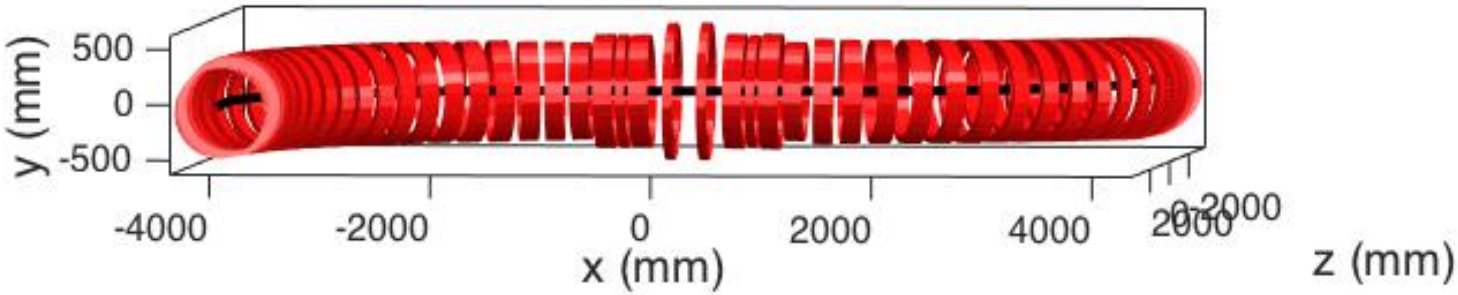
+10 degrees PITCH TSu
And
-10 degrees PITCH TSd

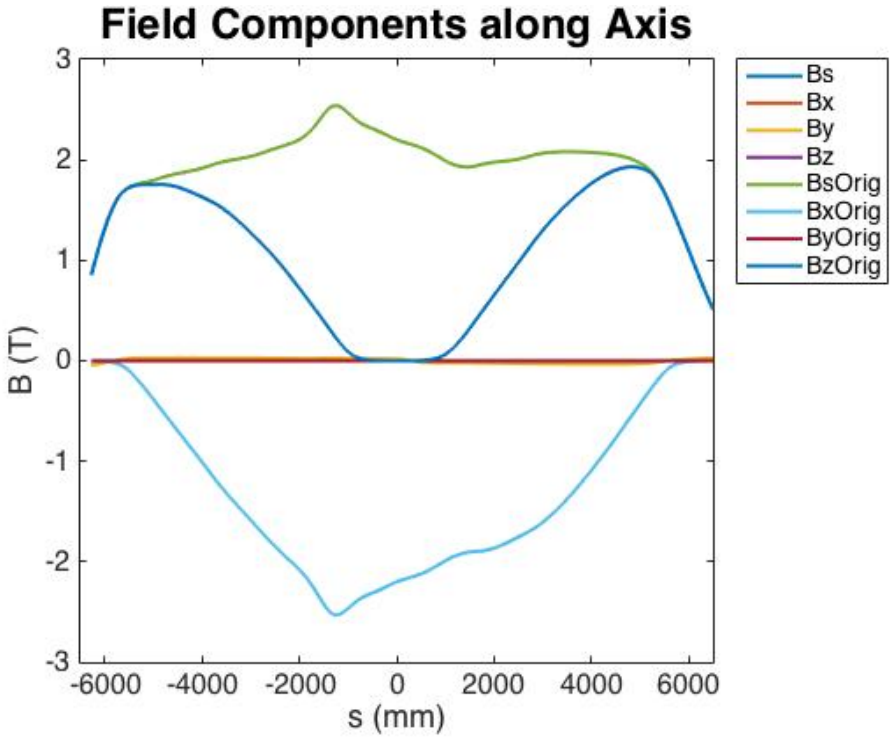


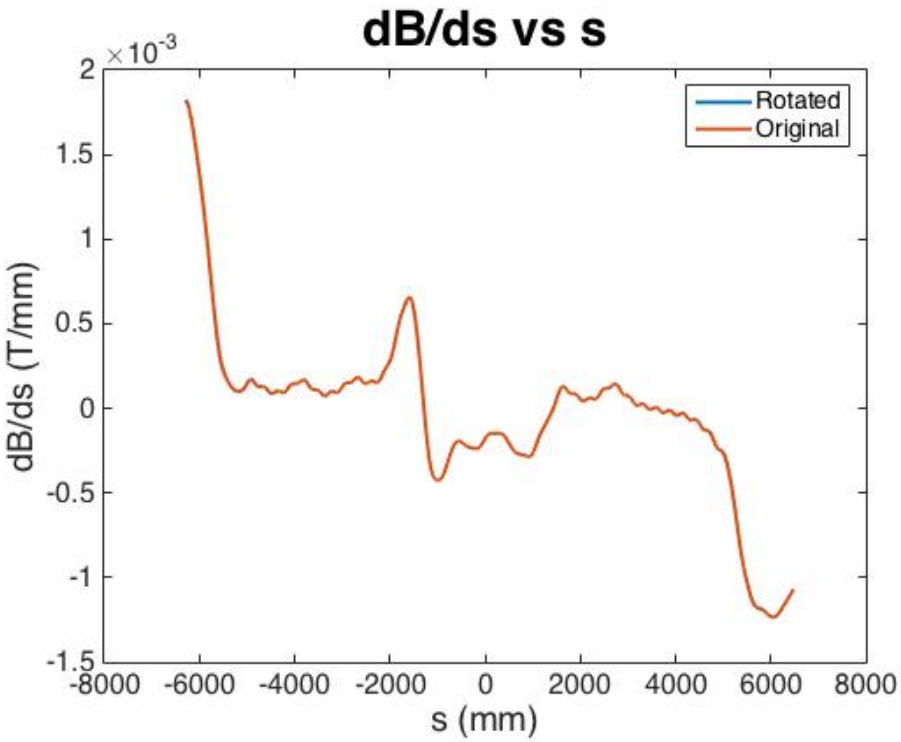

Field Components along Axis
B (T)
s (mm)
Bs
Bx
By
Bz
BsOrig
BxOrig
ByOrig
BzOrig

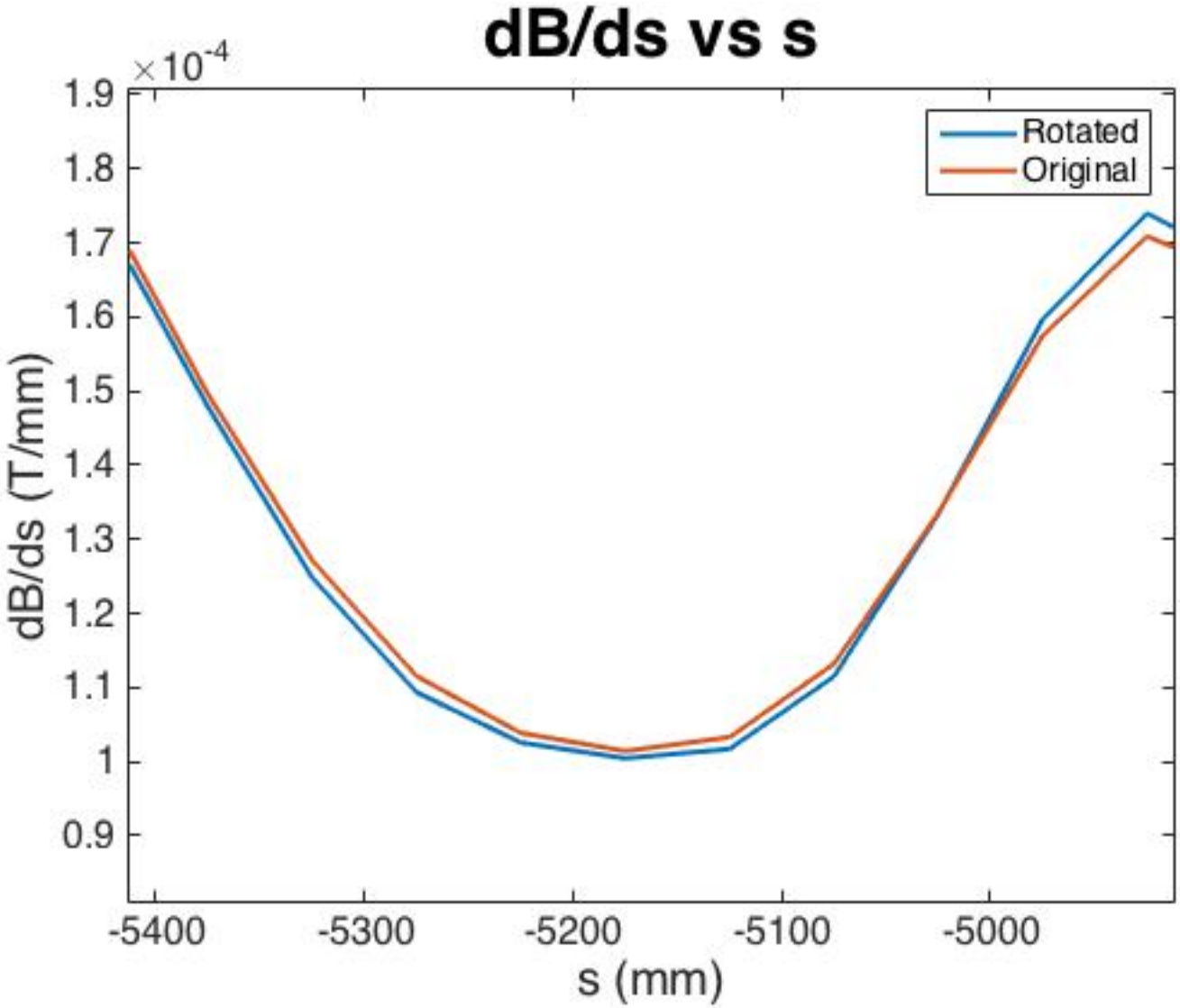

dB/ds vs s
dB/ds (T/mm)
s (mm)
Rotated
Original

1 degree PITCH TSu
And
-1 degree PITCH TSd




Field Components along Axis
B (T)
s (mm)
Bs
Bx
By
Bz
BsOrig
BxOrig
ByOrig
BzOrig


dB/ds vs s
×10^-3
dB/ds (T/mm)
s (mm)
Rotated
Original


dB/ds vs s
×10^-4
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
dB/ds (T/mm)
-5400
-5300
-5200
-5100
-5000
s (mm)
Rotated
Original

```
{
  TStyle *RootStyle = new TStyle("Root-Style","The Perfect Style for Plots");

#ifdef __CINT__
  TStyle *GloStyle;
  GloStyle = gStyle;                          // save the global style reference
```

```
RootStyle->SetStatW          (0.25);
RootStyle->SetStatH          (0.20);

// Labels, Ticks, and Titles

RootStyle->SetTickLength ( 0.015,"X");
```

FldSol

```
Bz= vertcat(BzA,BzB,BzC,BzD,BzE

% Calculate Field
Bmod=sqrt(Bx.^2+By.^2+Bz.^2);

%%%
```

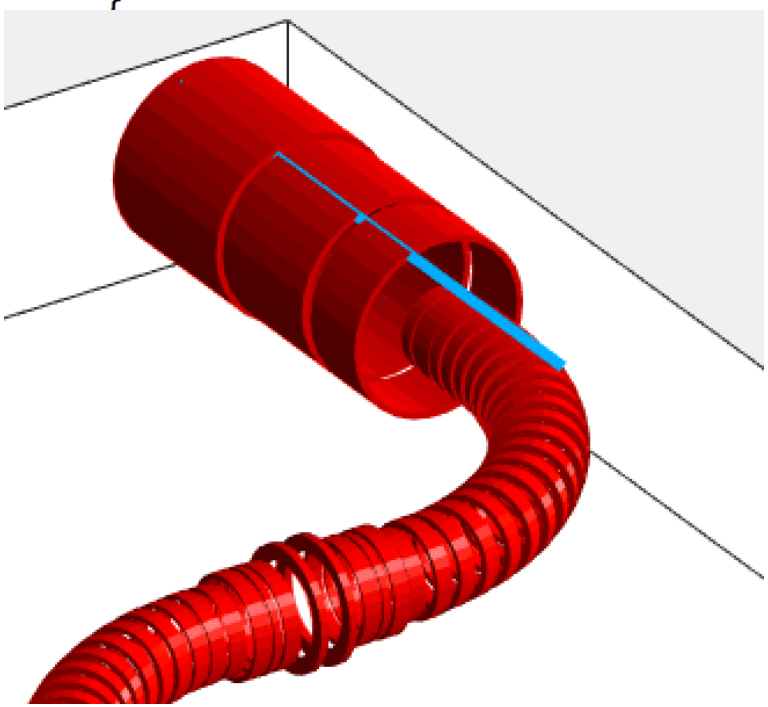
We checked the fractional differences between Mau9 and Solcalc maps in the form (Solcalc – Mau9) / Mau9

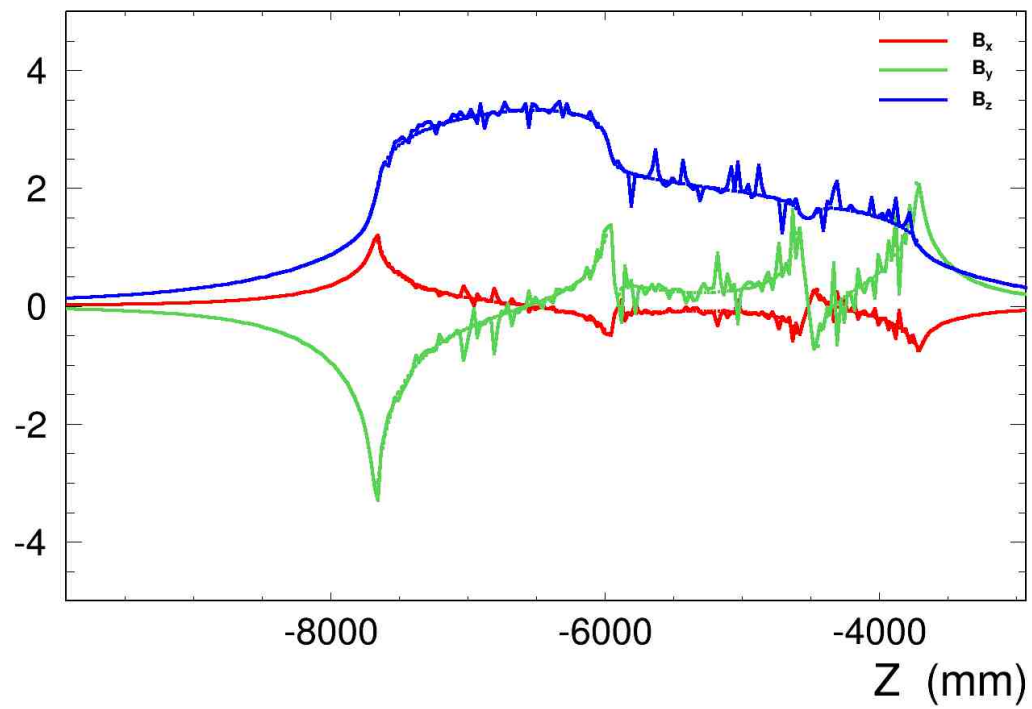
```
for(int i=0; i<nX; i++)   //X coordinate
  {
    for(int j=0; j<49; j++)   //Y coordinate
      {
        for(int k=0; k<nZ; k++)   //Z coordinate
          {
            //fprintf(diff,"%15.3f %15.3f %15.3f %15.3f %15.3f %15.3f %20.12e %20.12e %20.12e\n"
,Xe[i][j][k],Xm[i][j][k],Ye[i][j][k],Ym[i][j][k],Ze[i][j][k],Zm[i][j][k],(ewenkBx[i][j][k]-mau9Bx[
i][j][k])/mau9Bx[i][j][k],(ewenkBy[i][j][k]-mau9By[i][j][k])/mau9By[i][j][k],(ewenkBz[i][j][k]-mau
9Bz[i][j][k])/mau9Bz[i][j][k]);
          }
      }
  }
```

X = 3604 mm

Y = 825 mm

Production Solenoid

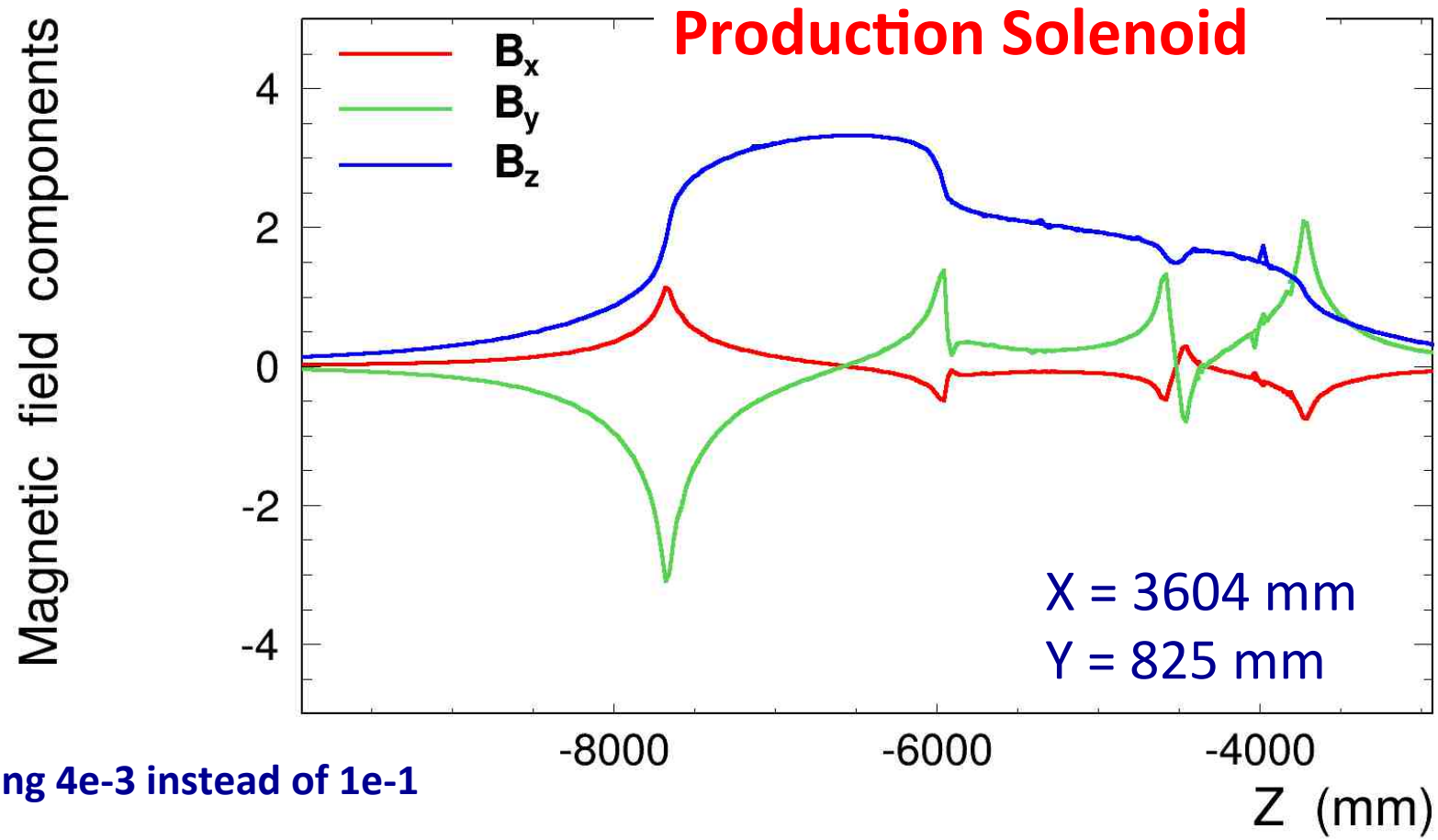




Editor – /Users/elizabethwenk/Desktop/Working Folder/BENCHMARKFieldMapWPlots.m

DispSolSyst.m | CoilsWithLine.m | FldSolSysBenchmarkEQNSoffAxis.m | BENCHMARKFieldMapWPlots.m

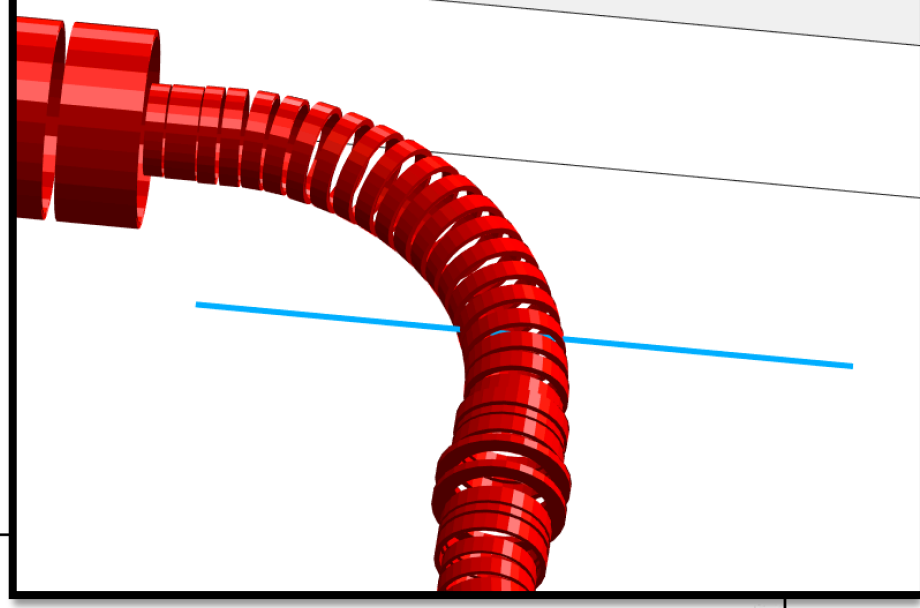
```
zf=zeros(MaxPointNum,1);

tic
        parfor i=1:MaxPointNumX
            for j=1:MaxPointNumY
                for k=1:MaxPointNumZ
                    X1=0.001*Xp(i,j,k);
                    Y1=0.001*Yp(i,j,k);
                    Z1=0.001*Zp(i,j,k);
                    for nc=1:size(Coils,1)
                            [Bxc,Byc,Bzc] = FieldSolenoid_mex(X1,Y1,Z1,Ri(nc),Ro(nc),L(nc),I(nc),origin(nc,:),rotation(nc,:),1e-1);
                        Bx(i,j,k)=Bx(i,j,k)+Bxc;
                        By(i,j,k)=By(i,j,k)+Byc;
```

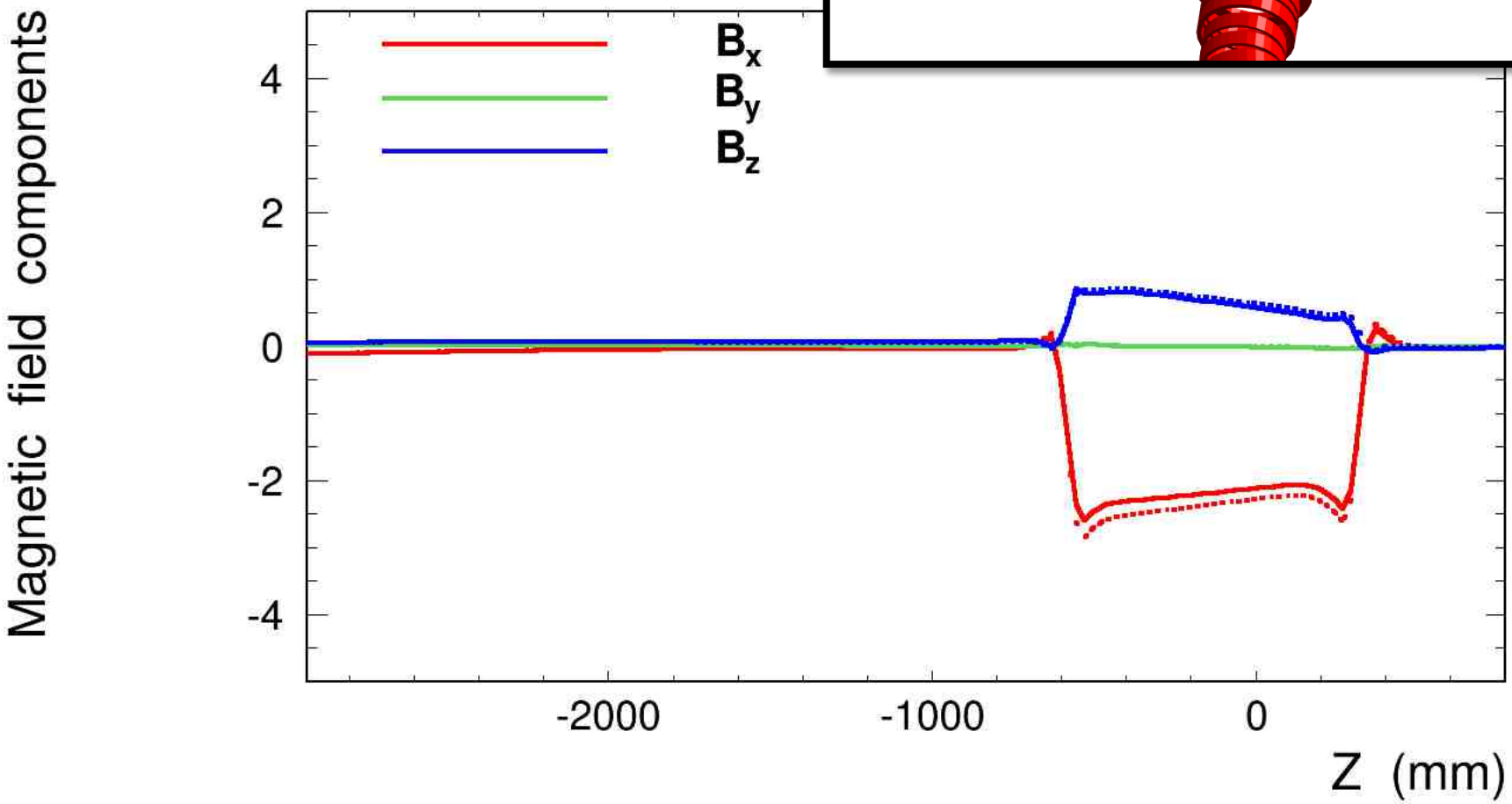


Using 4e-3 instead of 1e-1

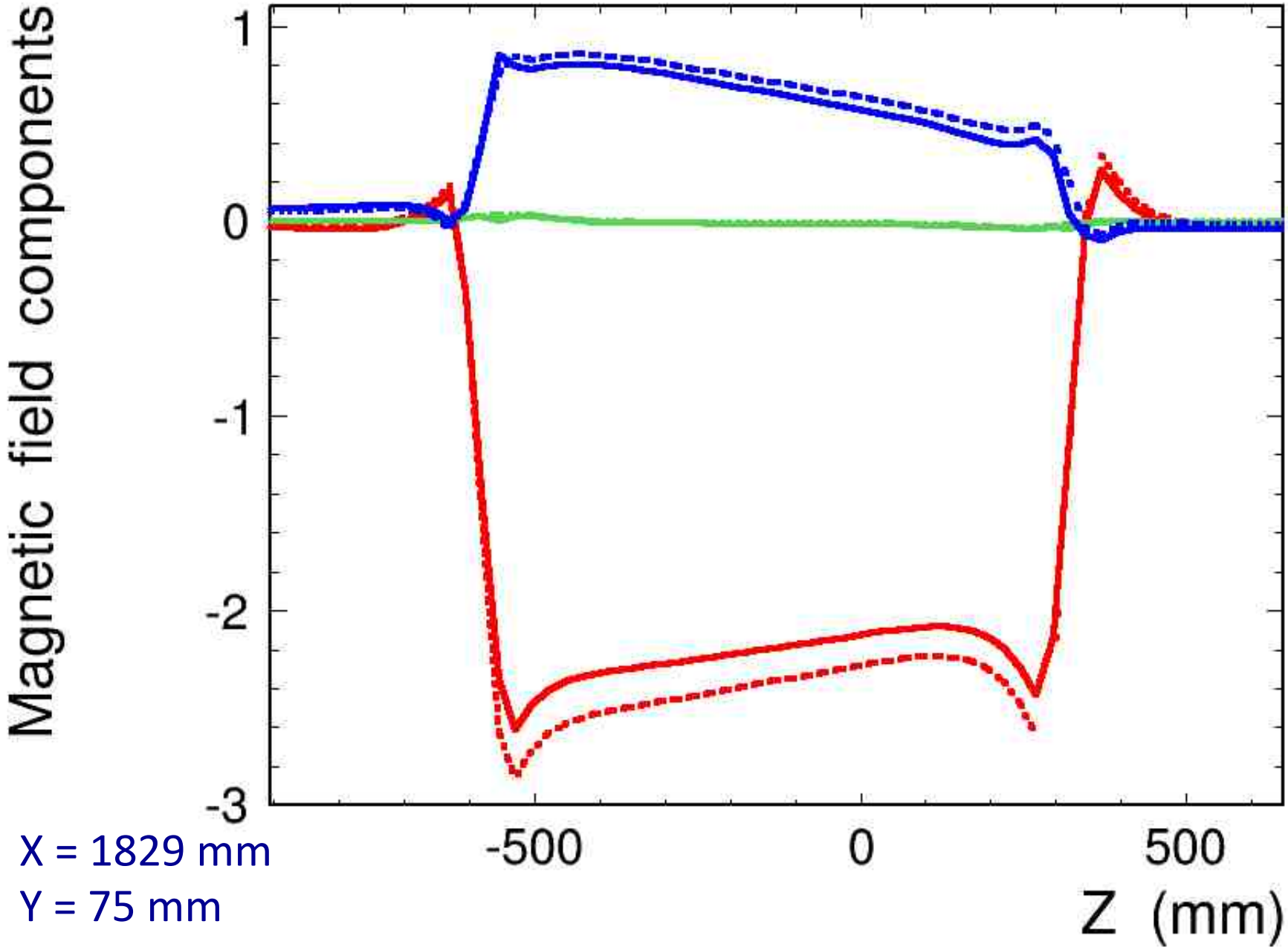
TSu

X = 1829 mm
Y = 75 mm





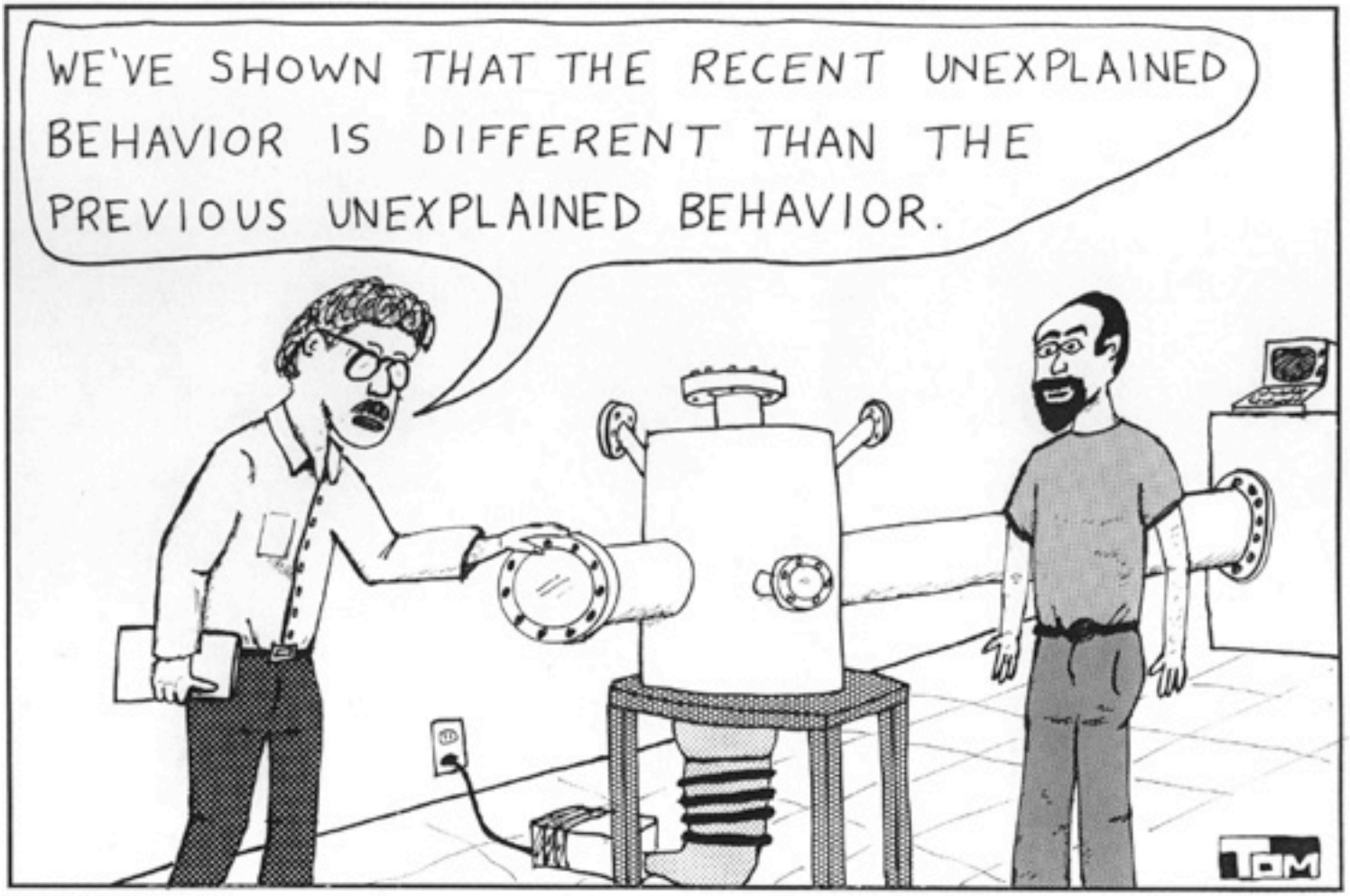
TSu



X = 1829 mm

Y = 75 mm

opera
simulation software



©1994 Tom Swanson

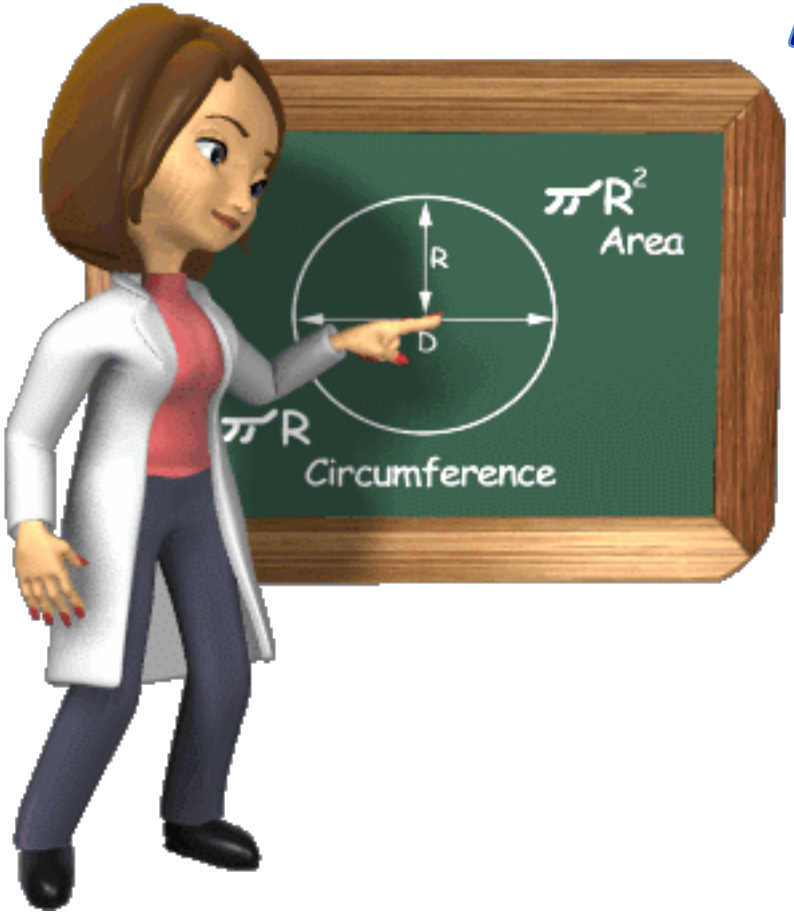
http://home.netcom.com/~swansontom/

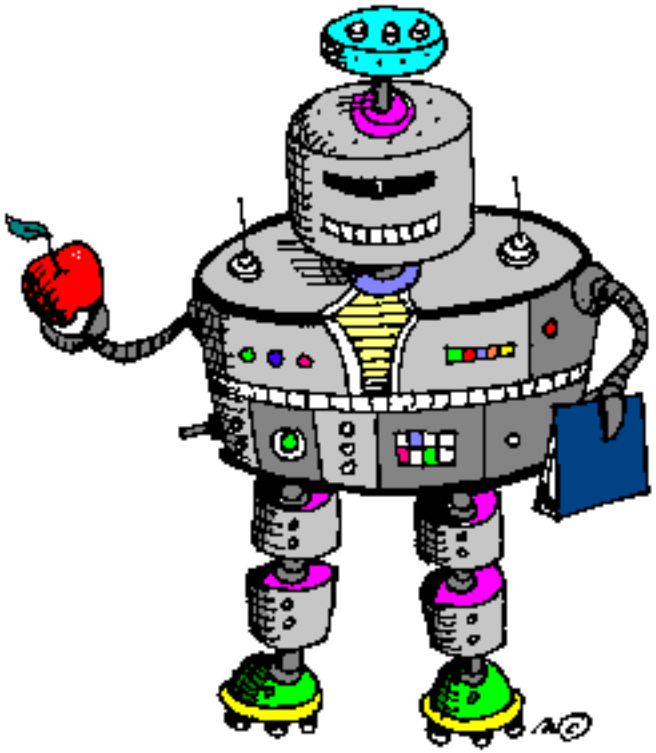
After I leave…

- Geometric changes made in SolCalc will be the input data for OPERA to calculate the field.

- Altered field maps will be used in an art-based Geant simulation to study the effect of those misalignments on the muon and background rates at the detector target

Classroom Applications





A: $x = 3904$ $\quad -3629 < z < -2929$ $\quad (\Delta z = 700)$

B: $x = 2929 \sin\theta + 975$ $\quad z = 2929(\cos\theta - 1)$ $\quad \theta: 0 \to \frac{\pi}{2}$

C: $-975 < x < 975$ $\quad z = 0$ $\quad (\Delta x = 1950)$

D: $x = -(2929 \sin\theta + 975)$ $\quad z = 2929(1 - \cos\theta)$ $\quad \theta: 0 \to \frac{\pi}{2}$

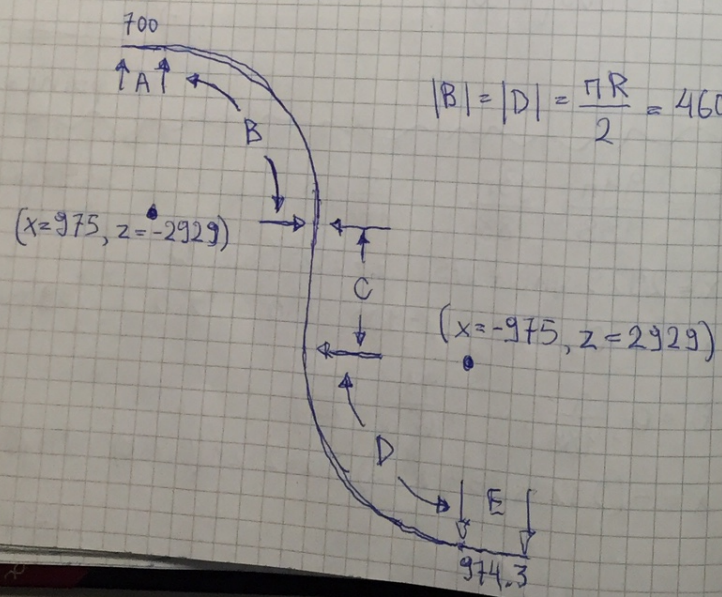
E: $x = -3904$ $\quad 2929 < z < 3904.7$ $\quad (\Delta z = 974.3)$

B: $(x - 975)^2 + (z + 2929)^2 = 2929^2$

$O(x = 975, z = -2929)$ $\quad R = 2929$

D: $(x + 975)^2 + (z - 2929)^2 = 2929^2$

$O(x = -975, z = 2929)$ $\quad R = 2929$



$$|B| = |D| = \frac{\pi R}{2} = 4600.86$$

A: $x = 3904$

$z = -3629, -3579, \ldots, -2979, \cancel{-2929}$ $\quad$ 14 points

B: $\theta = \frac{\pi}{2}, \frac{455}{460} \times \frac{\pi}{2}, \ldots, \frac{1}{460} \times \frac{\pi}{2}, 0$ $\quad$ 93 points

$x = 2929 \sin\theta + 975$ $\quad z = 2929(\cos\theta - 1)$

C: $x = 925, 875, \ldots, 25, -25, \ldots, -875, -925$

$z = 0$ $\quad$ 38 points

D: $\theta = 0, \frac{1}{460} \times \frac{\pi}{2}, \ldots, \frac{455}{460} \times \frac{\pi}{2}, \frac{\pi}{2}$ $\quad$ 93 points

$x = -(2929 \sin\theta + 975)$ $\quad z = 2929(1 - \cos\theta)$

E: $x = -3904$

$z = \cancel{2929}, 2979, \ldots, 3829, 3879$ $\quad$ 19 points

(+)

257 points

Scientists use LOG Books to keep track of their research… or they use digital versions (LabLog)

Classroom Applications

- Science research requires team work and good communication skills
- Creativity is a necessity for problem solving
- The reality is, scientists often end up using trial and error
- Measure twice, cut once – silly mistakes can cost a lot of time and money
- Organization is essential in order for others to understand your research

THANK YOU

Costas Vellidis
Harry Cheung
Pratima Jindel
Mau Lopes
Other TRAC teachers

References:

Lopes, M. et al (2014). Studies on the Magnetic Center of the Mu2e Solenoid System. *IEEE Transactions on Applied Superconductivity, 24*(3).

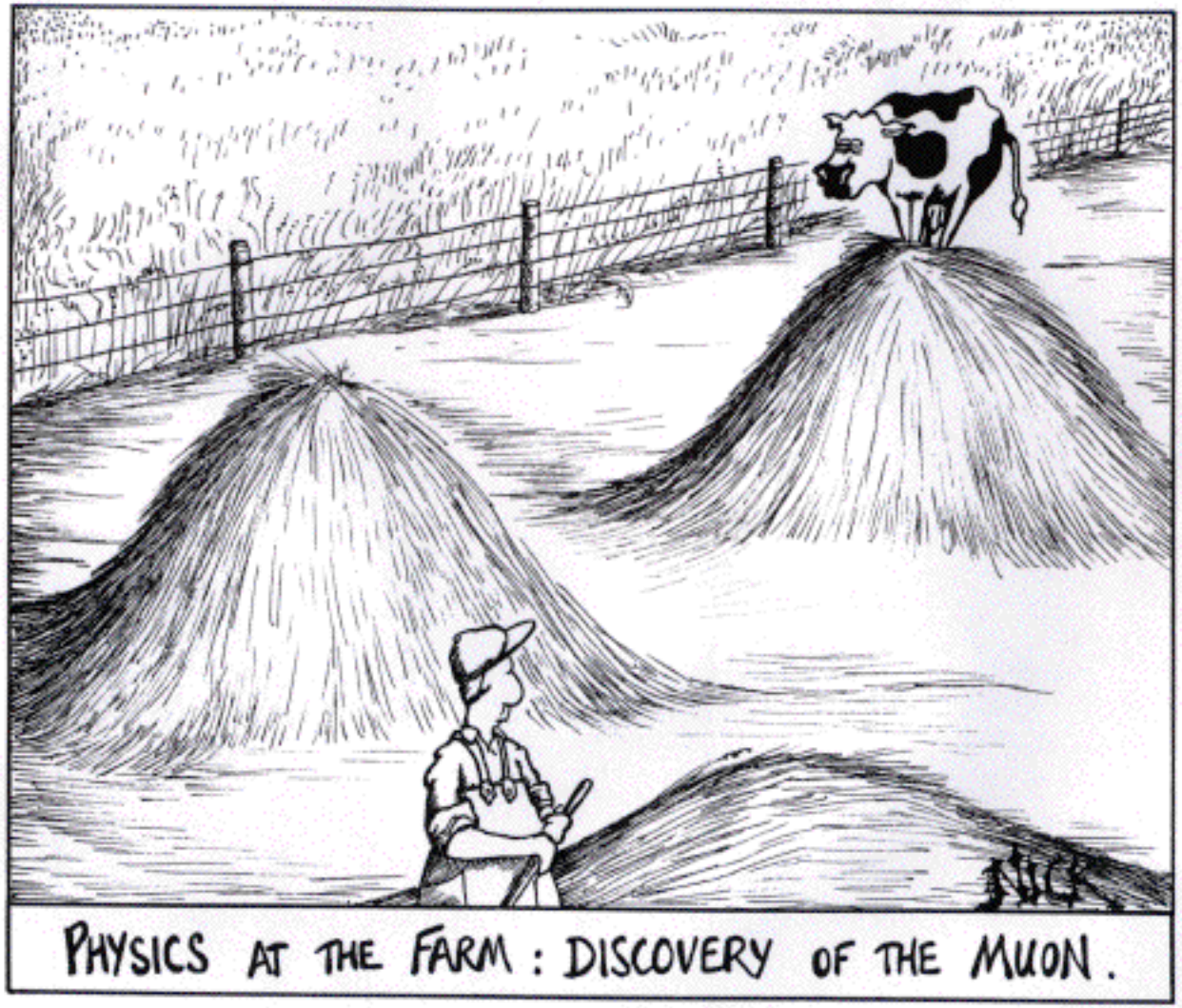
Lopes, M. et al (2012). Alignment of the Transport Solenoid Magnetic Center Due to Coils Displacements (Magnetic Design Version 7). Mu2e-doc-2403-V2

Mu2e. (n.d.). Retrieved July 14, 2015, from http://mu2e.fnal.gov/research_goals.shtml

Mustain, A. (2010). The Muon Guys: On the Hunt For New Physics. *Symmetry, 7*(6), 10-17.

Prebys, E. (2013, February 8). "The Mu2e Experiment at Fermilab", Colloquium given at Virginia Tech. Retrieved July 18, 2015, from http://home.fnal.gov/~prebys/

Backup Slides



http://www.quantumdiaries.org/tag/muon/

Comparing GA Maps:

We checked the fractional differences between 1 – and 2 – sided maps in the form (map1 – map2) / map2

```
for(int i=0; i<nX; i++)   //X coordinate
  {
    for(int j=0; j<49; j++)   //Y coordinate
      {
        for(int k=0; k<nZ; k++)   //Z coordinate
          {
            fprintf(diff,"%15.3f %15.3f %15.3f %15.3f %15.3f %15.3f %20.12e %20.12e %20.12e\n",X
1[i][j][k],X2[i][48-j][k],Y1[i][j][k],Y2[i][48-j][k],Z1[i][j][k],Z2[i][48-j][k],(GA1Bx[i][j][k]-GA
2Bx[i][48-j][k])/GA2Bx[i][48-j][k],-(GA1By[i][j][k]+GA2By[i][48-j][k])/GA2By[i][48-j][k],(GA1Bz[i]
[j][k]-GA2Bz[i][48-j][k])/GA2Bz[i][48-j][k]);
          }
      }
  }
```

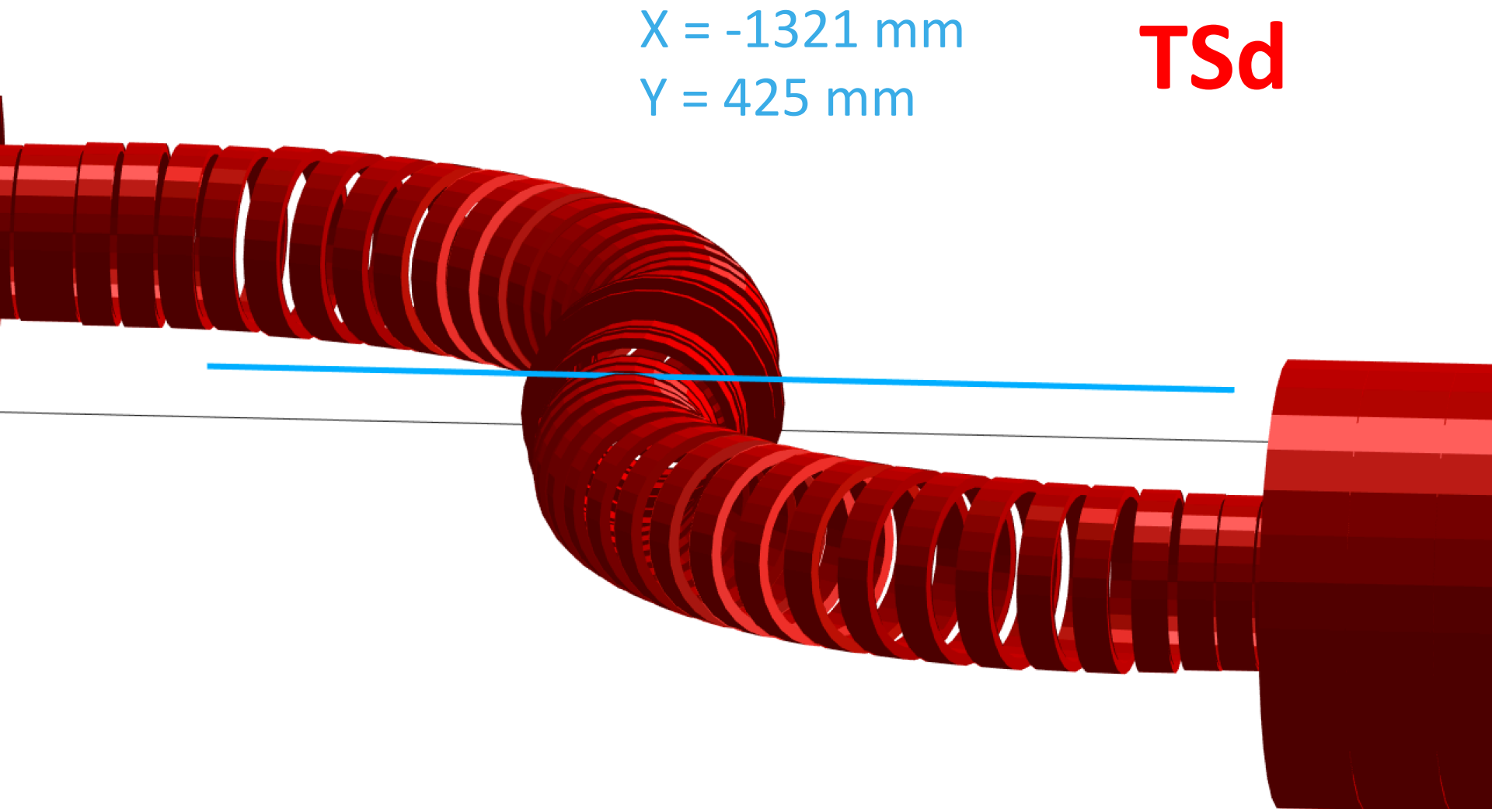
Zero differences detected between 1- and 2-sided GA TSd maps

-2.846	-2.846	1.200	-1.200	0.971	0.971	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	0.996	0.996	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.021	1.021	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.046	1.046	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.071	1.071	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.096	1.096	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.121	1.121	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.146	1.146	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.171	1.171	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.196	1.196	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.221	1.221	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.246	1.246	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.271	1.271	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.296	1.296	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.321	1.321	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.346	1.346	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.371	1.371	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.396	1.396	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.421	1.421	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.446	1.446	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.471	1.471	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.496	1.496	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.521	1.521	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.546	1.546	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.571	1.571	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.596	1.596	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.621	1.621	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.646	1.646	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.671	1.671	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.696	1.696	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.721	1.721	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.746	1.746	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.771	1.771	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.796	1.796	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.821	1.821	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.846	1.846	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.871	1.871	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.896	1.896	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.921	1.921	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.946	1.946	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.971	1.971	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	1.996	1.996	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.021	2.021	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.046	2.046	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.071	2.071	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.096	2.096	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.121	2.121	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.146	2.146	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.171	2.171	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.196	2.196	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.221	2.221	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.246	2.246	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00
-2.846	-2.846	1.200	-1.200	2.271	2.271	-0.000000000000e+00	-0.000000000000e+00	0.000000000000e+00

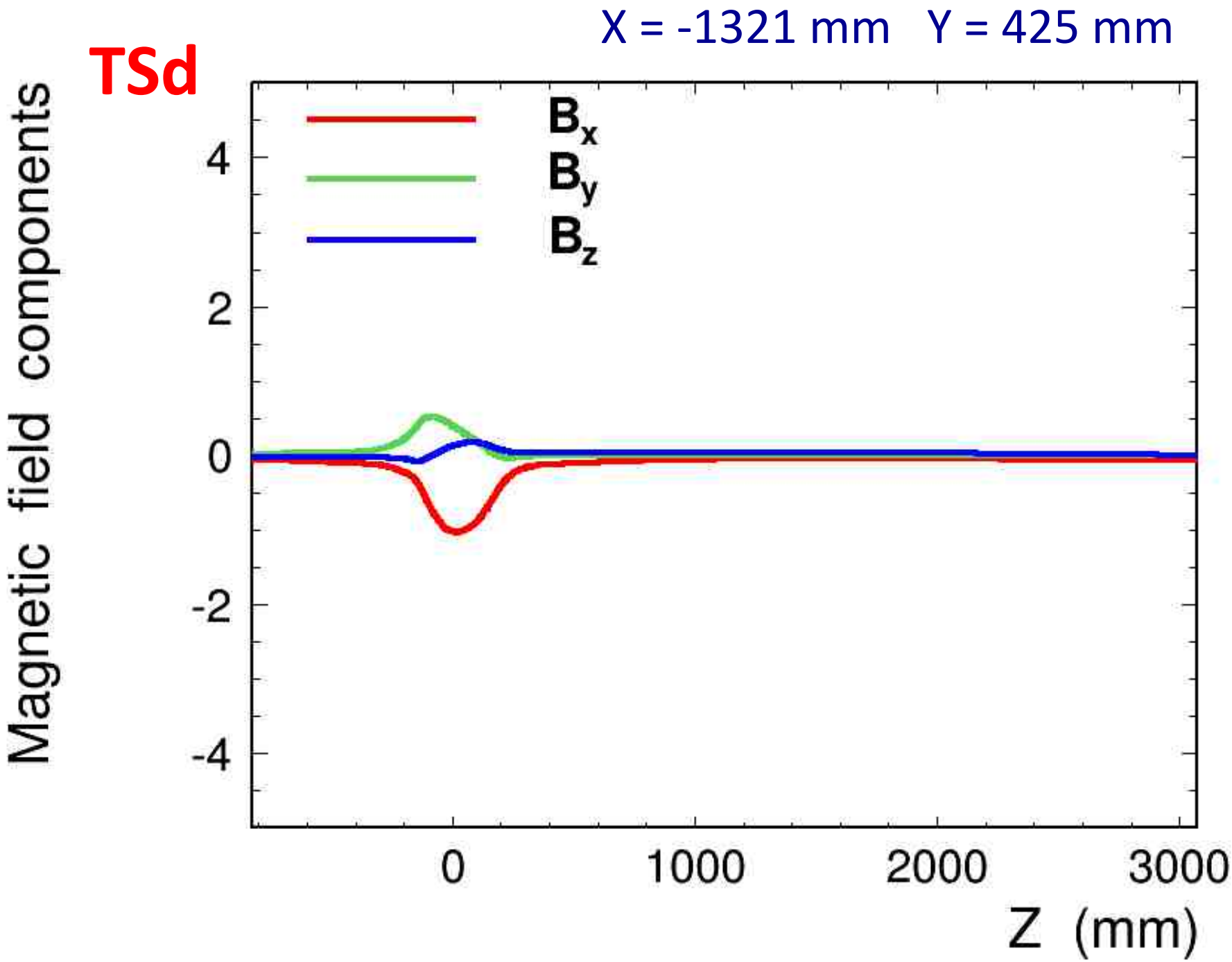
Zero differences detected between 1- and 2-sided GA DS maps

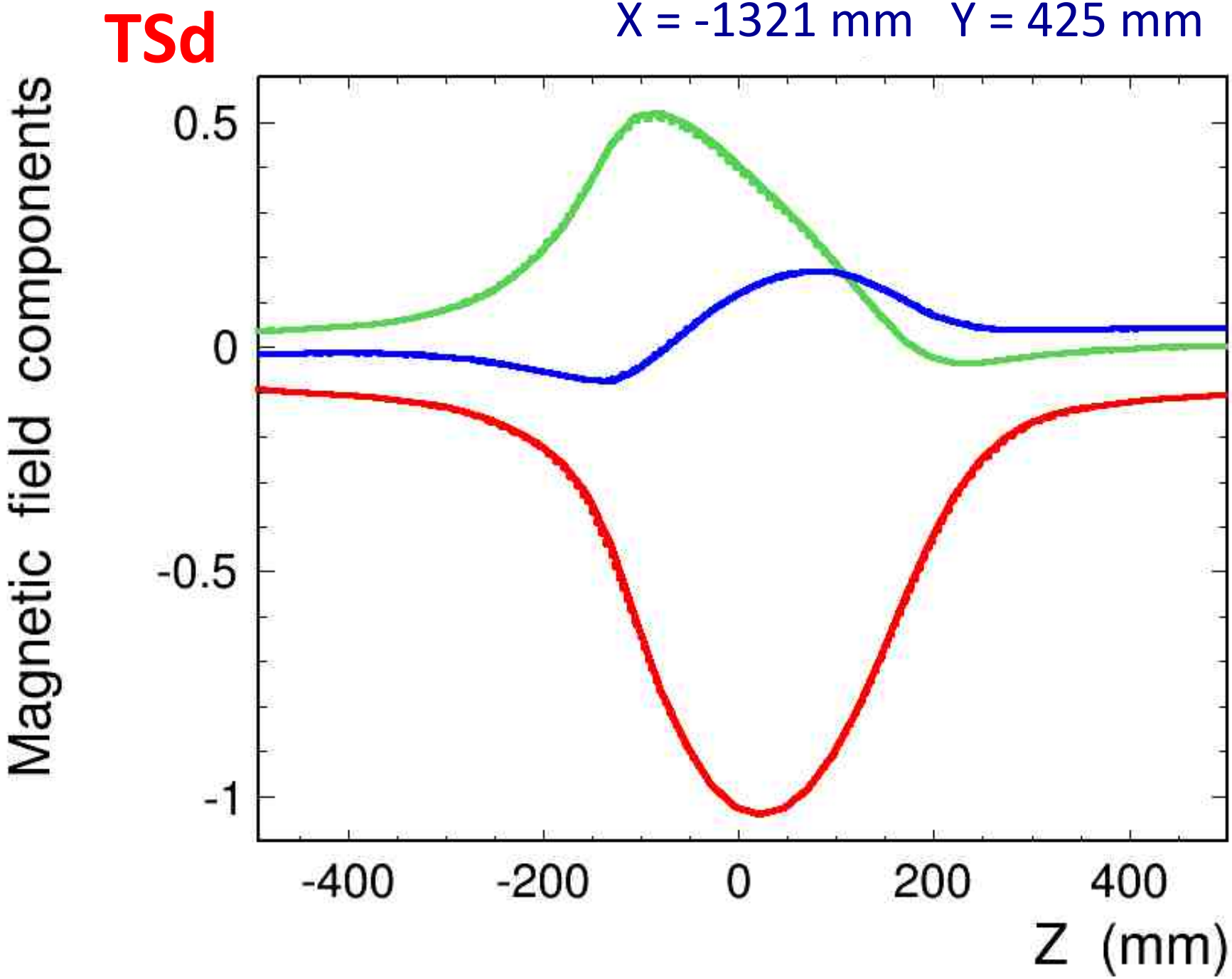
-4.121	-4.121	0.200	-0.200	7.546	7.546	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.571	7.571	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.596	7.596	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.621	7.621	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.646	7.646	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.671	7.671	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.696	7.696	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.721	7.721	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.746	7.746	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.771	7.771	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.796	7.796	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.821	7.821	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.846	7.846	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.871	7.871	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.896	7.896	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.921	7.921	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.946	7.946	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.971	7.971	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	7.996	7.996	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.021	8.021	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.046	8.046	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.071	8.071	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.096	8.096	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.121	8.121	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.146	8.146	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.171	8.171	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.196	8.196	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.221	8.221	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.246	8.246	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.271	8.271	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.296	8.296	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.321	8.321	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.346	8.346	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.371	8.371	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.396	8.396	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.421	8.421	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.446	8.446	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.471	8.471	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	[illegible]	[illegible]	[illegible]	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	[illegible]	[illegible]	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.546	8.546	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.571	8.571	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.596	[illegible]	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.621	8.621	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	[illegible]	-0.200	8.646	[illegible]	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.671	8.671	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.696	8.696	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	[illegible]	-0.200	[illegible]	8.721	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	[illegible]	[illegible]	[illegible]	8.746	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	[illegible]	[illegible]	[illegible]	8.771	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.796	8.796	-0.000000000000e+00	[illegible]	[illegible]
-4.121	-4.121	0.200	-0.200	8.821	8.821	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00
-4.121	-4.121	0.200	-0.200	8.846	8.846	-0.000000000000e+00	0.000000000000e+00	0.000000000000e+00

Y– Symmetry is confirmed for GA TSd and DS!!

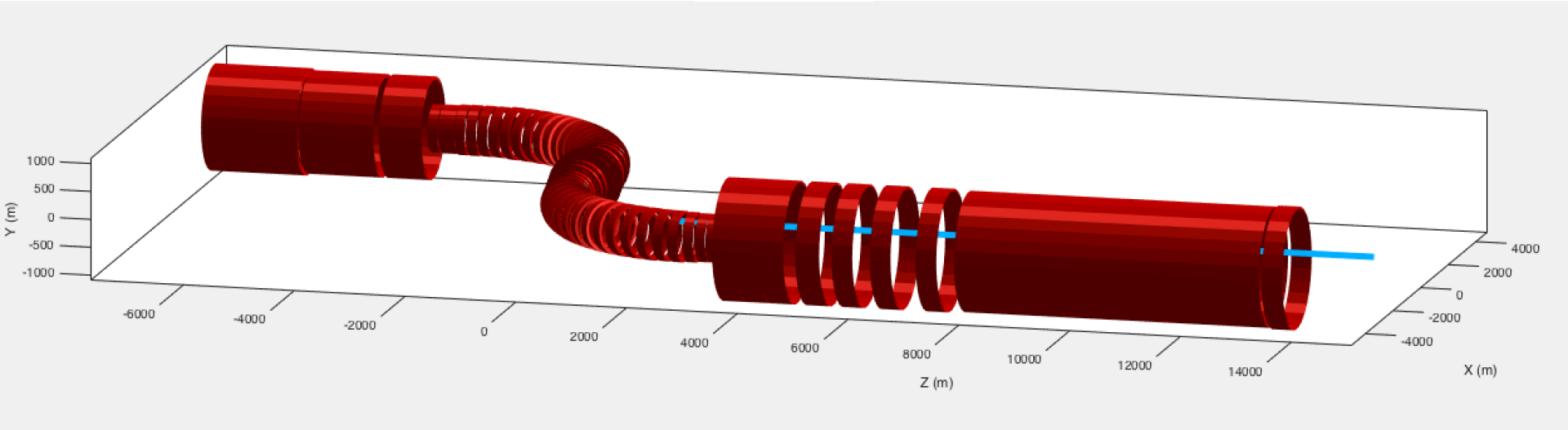


Mau9 Maps compared to GA Maps

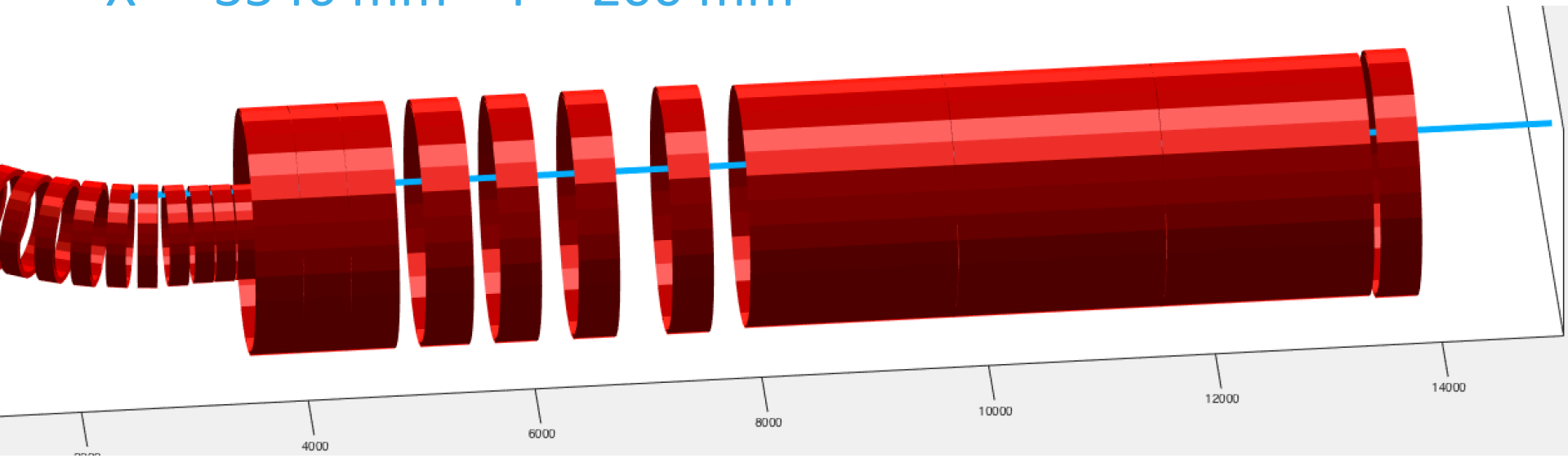

X = -1321 mm Y = 425 mm
TSd
Magnetic field components
Bx
By
Bz
4
2
0
-2
-4
0
1000
2000
3000
Z (mm)


TSd
X = -1321 mm Y = 425 mm
Magnetic field components
0.5
0
-0.5
-1
-400
-200
0
200
400
Z (mm)

DS

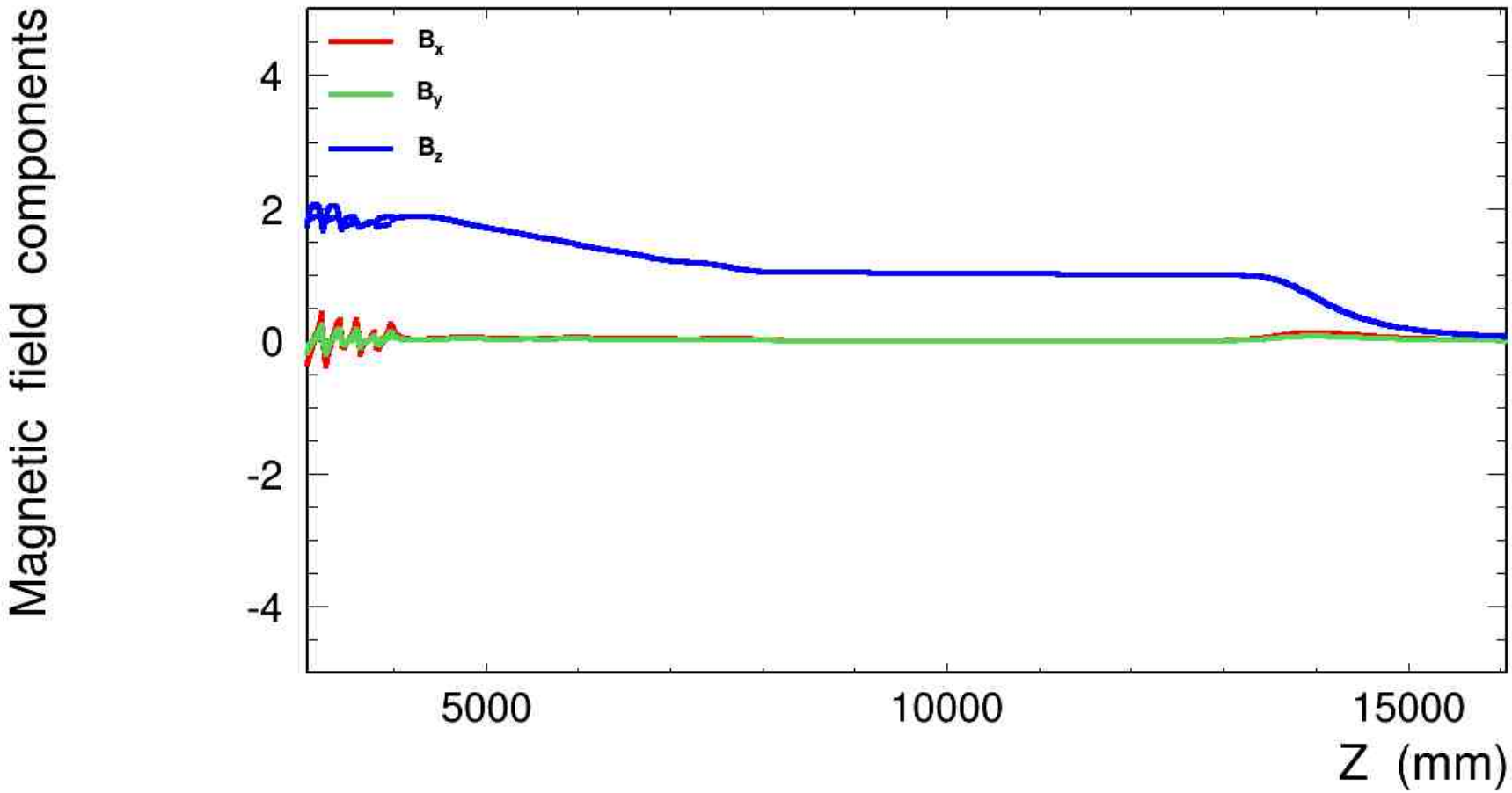


X = -3546 mm Y = 200 mm



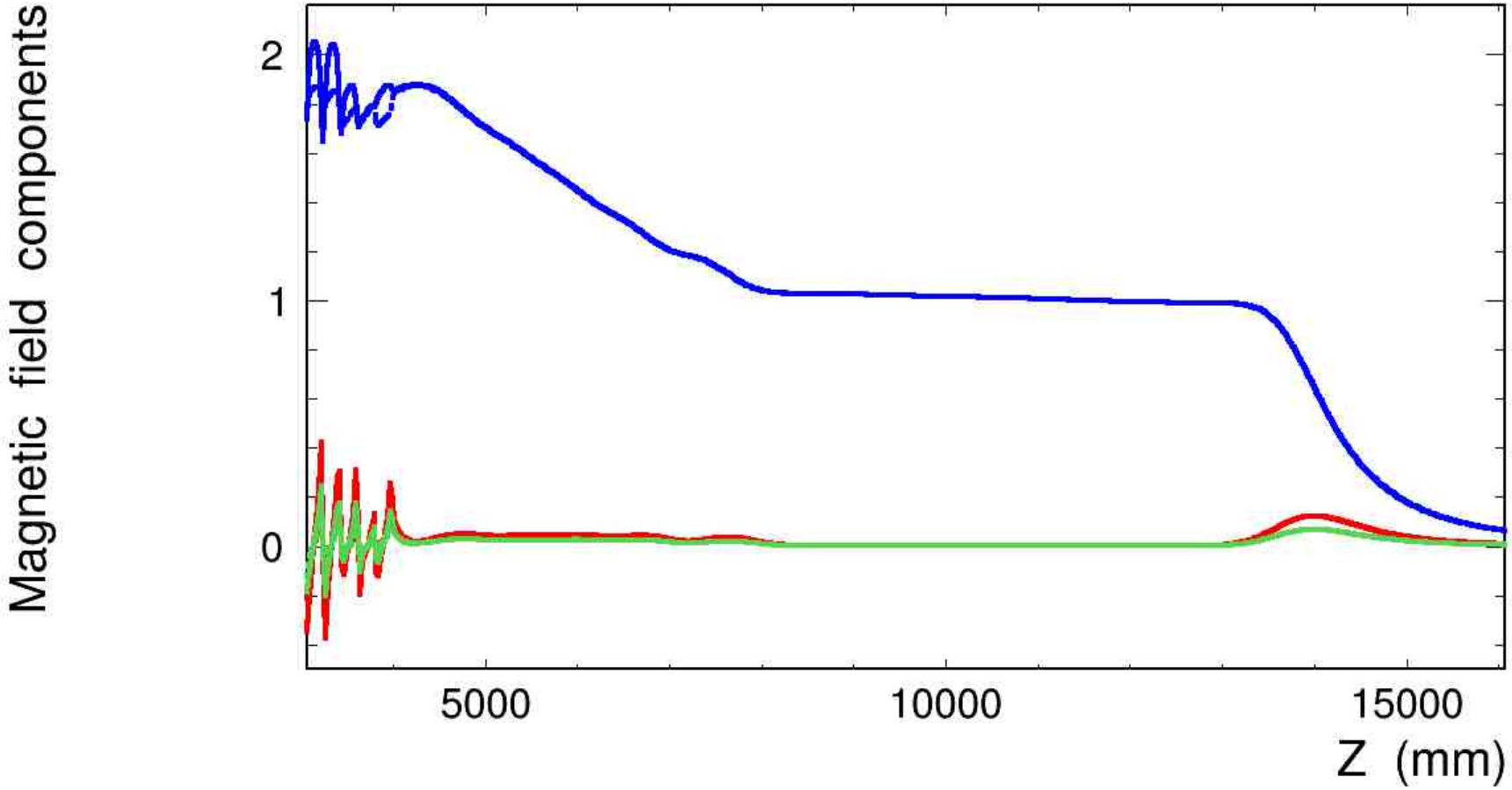
DS

X = -3546 mm Y = 200 mm



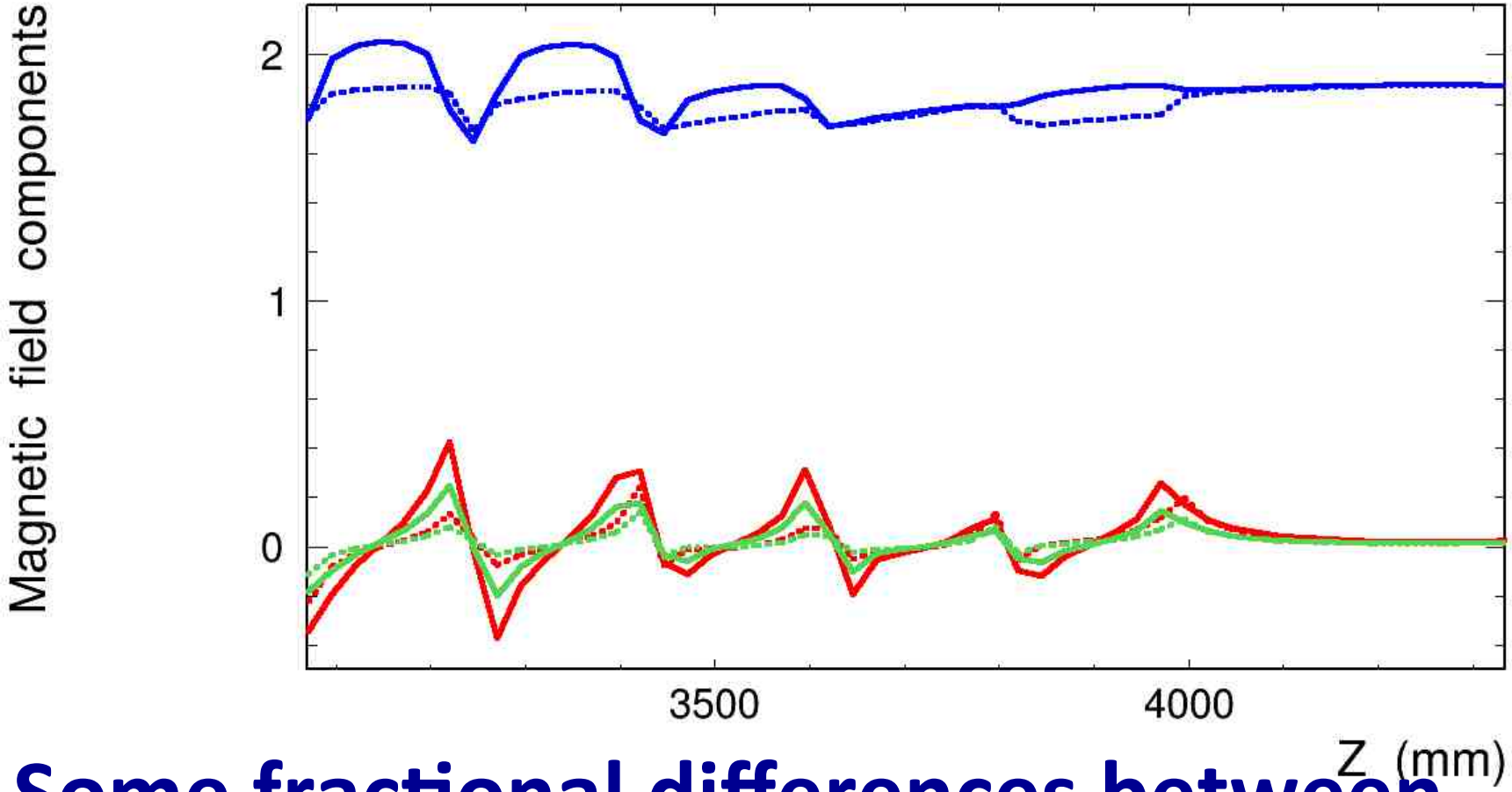
DS

X = -3546 mm Y = 200 mm



DS

X = -3546 mm Y = 200 mm



Some fractional differences between Mau9 and GA for TSd and DS detected