APS Upgrade: Cross-Talk Simulation Between Q2 and L-Bend Magnets of APS-U

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OVERVIEW

1) Confirmations of the Q2 and M1 magnets
2) Combined model of Q2 with M1 with the same layout in the storage ring
3) Comparison of the main and multipole fields along the full trajectory before and after their cross-talk with my simulation

INTRODUCTION

Q2 is a quadrupole and L-bend (M1) is a dipole magnet. They were designed by M. Jaski for the 67pm (V6) lattice of the APS-U. However, they will be installed in the storage ring with a yaw angle with respect to each other by a limited distance between them.

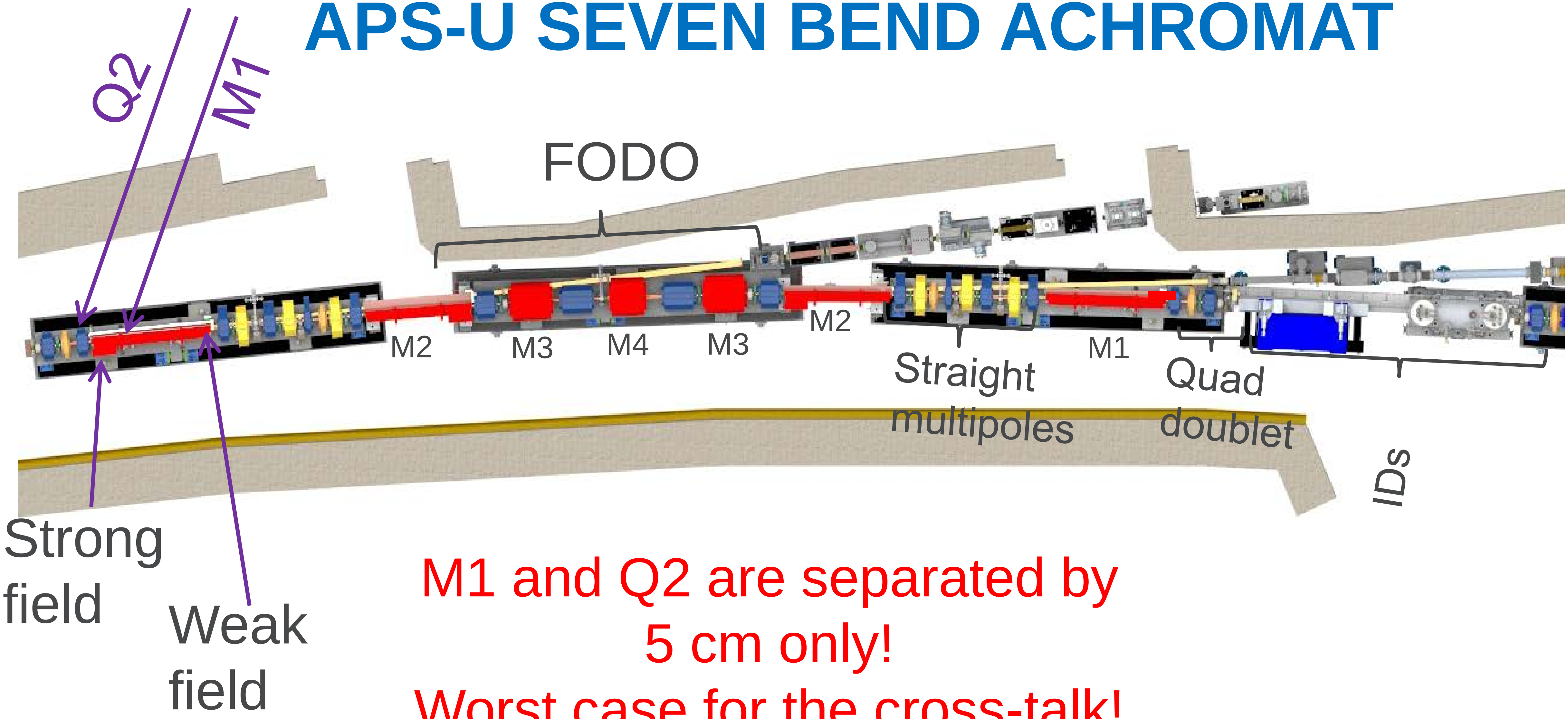
The purpose of the magnetic simulation of Q2 with yawed M1 together is to determine:

1) Whether the designs of the Q2 and M1 magnets are acceptable from the magnetic cross-talk point of view

2) Whether magnetic measurement data of the individual magnets will still be applicable during installation in the storage ring. Impossible to measure the field along the trajectory. Rely on the cross-talk simulation results to decide the measurement data of these individual magnets

3) Whether the full trajectory of the electron beam from upstream of Q2 to downstream of M1 matches with the required lattice trajectory

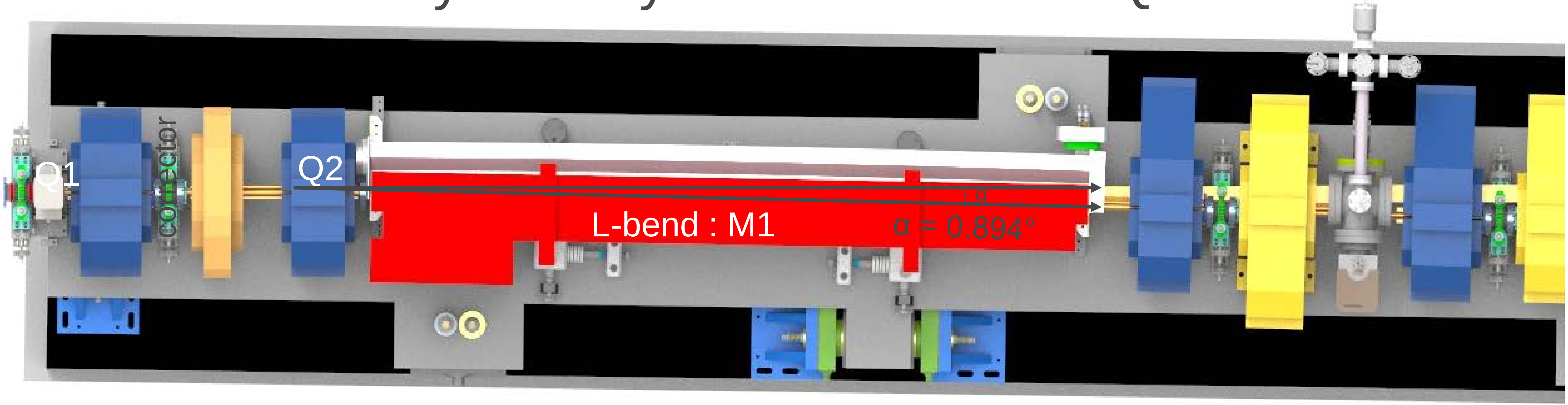
APS-U SEVEN BEND ACHROMAT

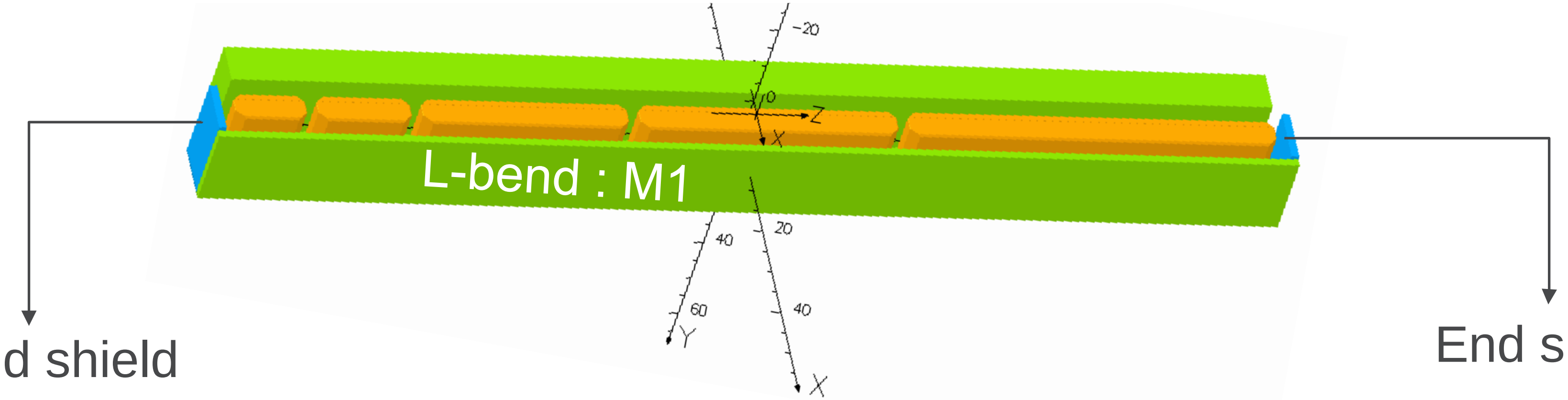


M1 and Q2 are separated by 5 cm only!
Worst case for the cross-talk!

ENLARGED LATTICE AROUND THE Q2 AND M1

M1 is yawed by 0.894° relative to Q2





SIMULATION PROCESS:

1) Simulation of the single straight M1 magnet ---------------- Straight M1 Case 1

2) Simulation of the single Q2 quadrupole magnet ------------------ Q2 Case 2

3) Simulation of a yawed M1 (coordinate transformation)----- Yawed M1 Case 3

4) Simulation of Q2 with yawed M1 together -------------------- Q2 Yawed M1 Case 4

REQUIRED TOLERANCE FOR THE CROSS-TALK:

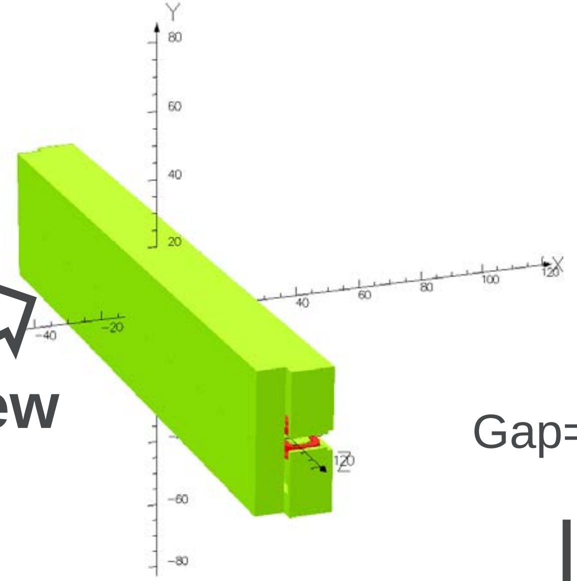
All the integrated harmonics from the cross-talk should be less than 0.1% compared to the main fields

*The simulation differences of the integrated main fields should be less than 0.1%

Case 1

Straight M1

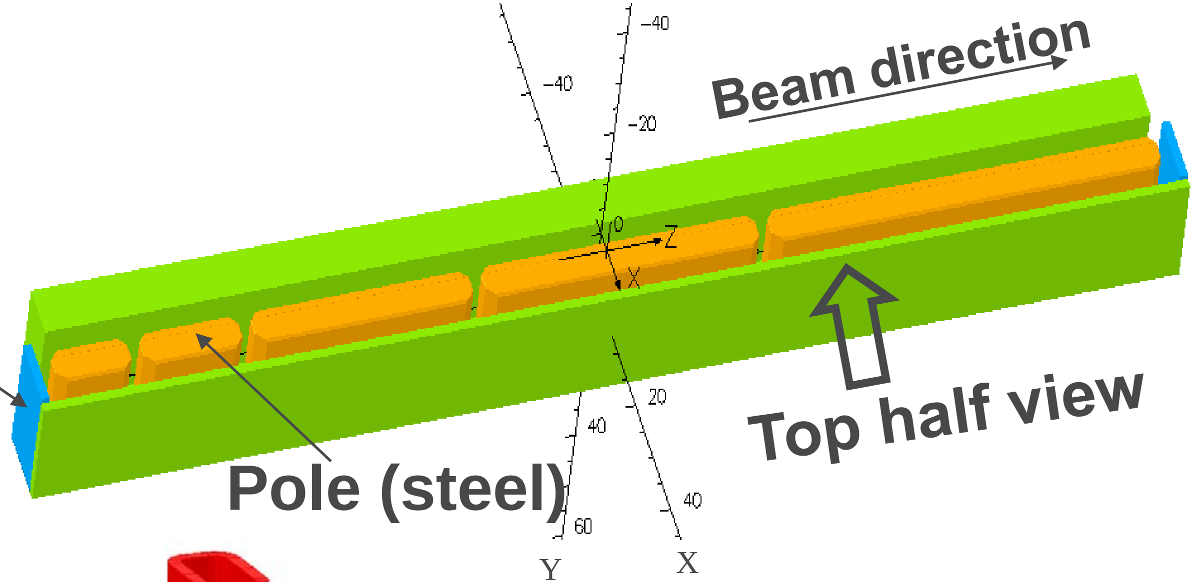
SIMULATION OF THE SINGLE STRAIGHT M1



A 3D view of M1

End shield

Gap= 2.7 cm

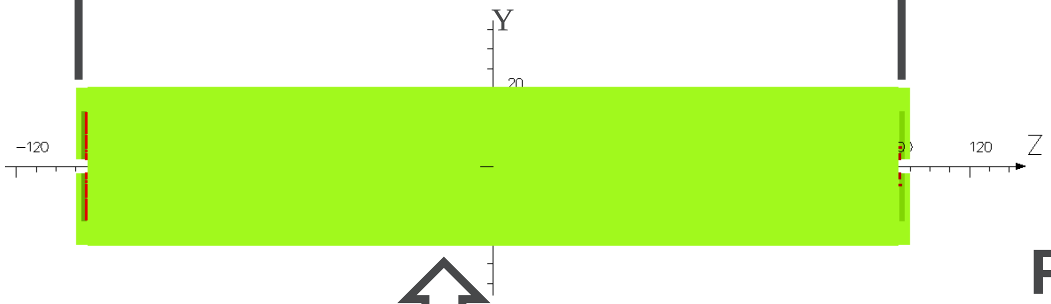


Beam direction

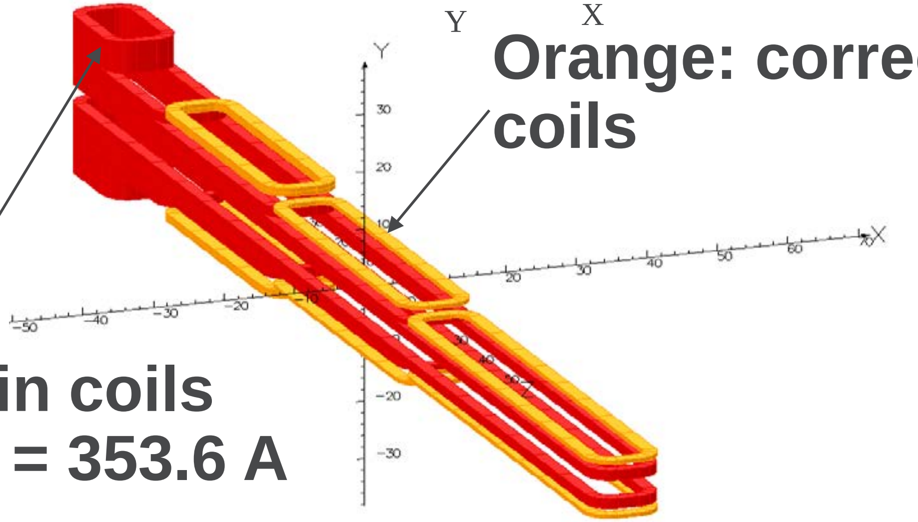
Top half view

Pole (steel)

Length = 209.6 cm



Side view



Orange: corrector coils

Red: Main coils
Current = 353.6 A

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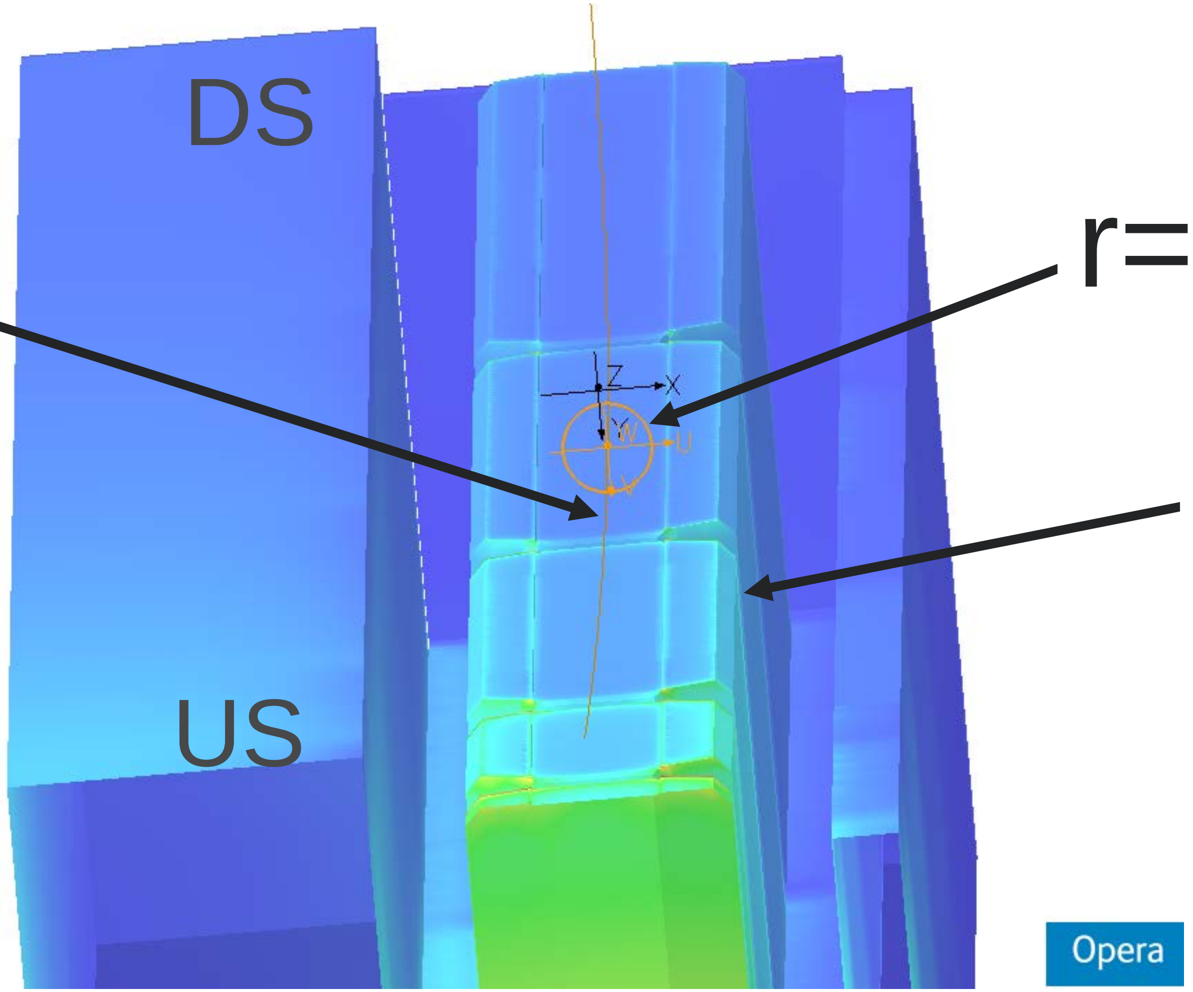
Case 1

Straight M1

A 3D VIEW OF THE SIMULATED ELECTRON BEAM TRAJECTORY IN THE SINGLE STRAIGHT M1

e-beam trajectory



r= 10 mm

Top pole

Note: Opera-3D does not compute the field and its multipoles along the beam trajectory; therefore, I created a separate code for this.

Computed the field and its multipoles within a 10 mm radius circle centered at the beam position and integrated them over the beam trajectory.

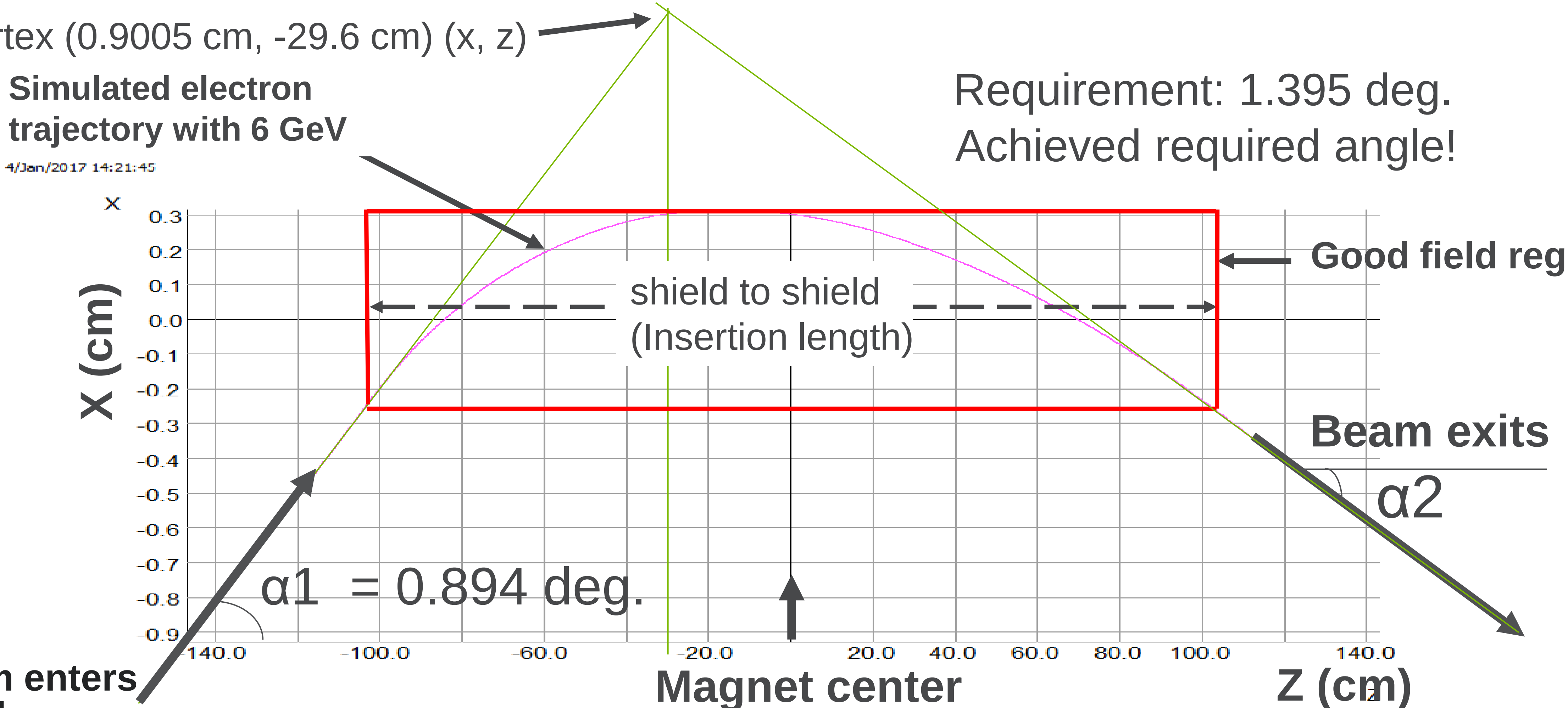
Case 1

Straight M1

SIMULATED 2D-ELECTRON BEAM TRAJECTORY IN THE SINGLE STRAIGHT M1

Vertex (0.9005 cm, -29.6 cm) (x, z)

Requirement: 1.395 deg.
Achieved required angle!



$\alpha = \alpha 2 - \alpha 1 = -0.5013$ deg. $- 0.894$ deg. $= -1.395$ deg.

US beam position:
(X=-0.927 cm, Y=0, Z=146.72 cm)

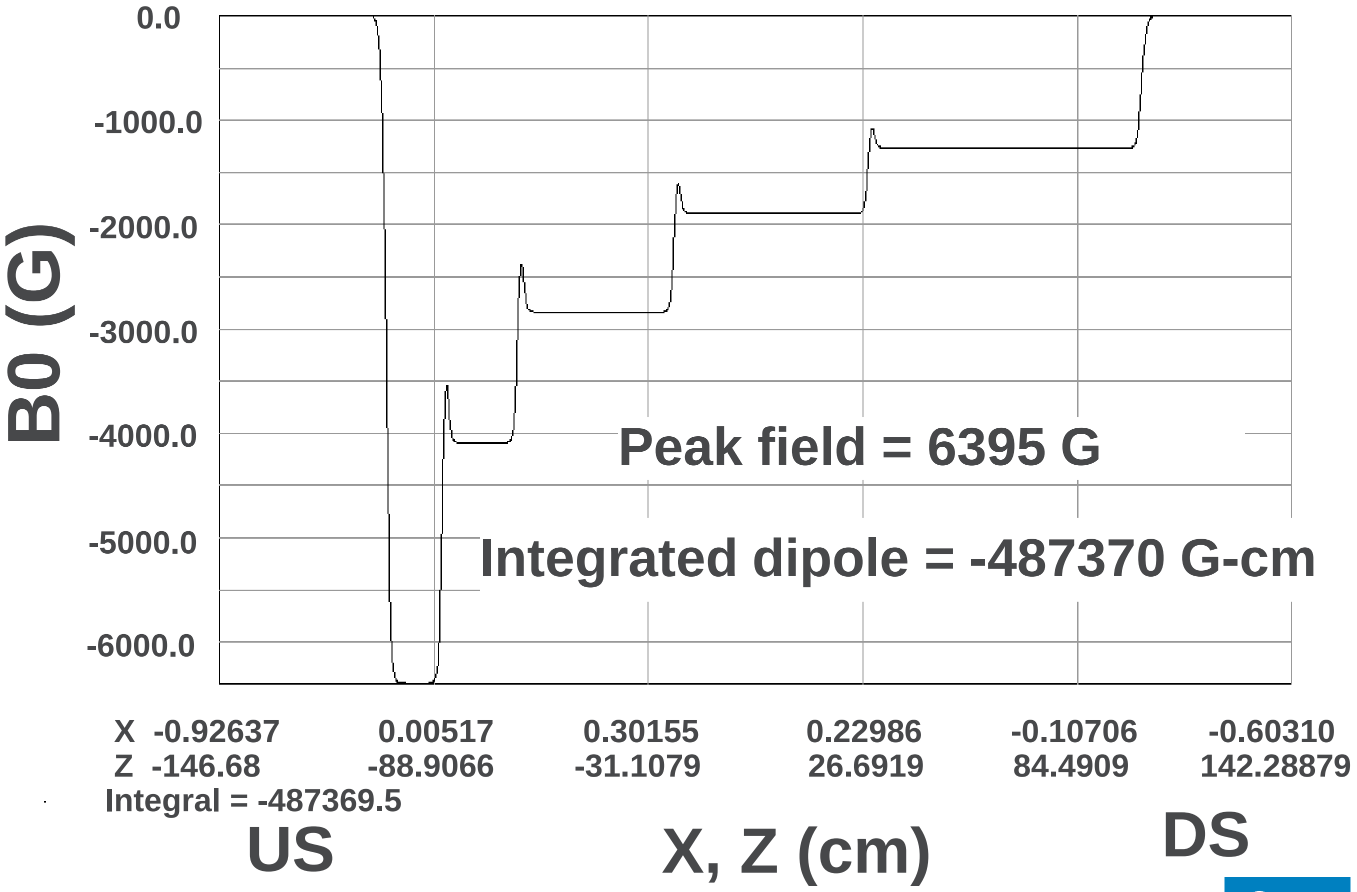
Opera

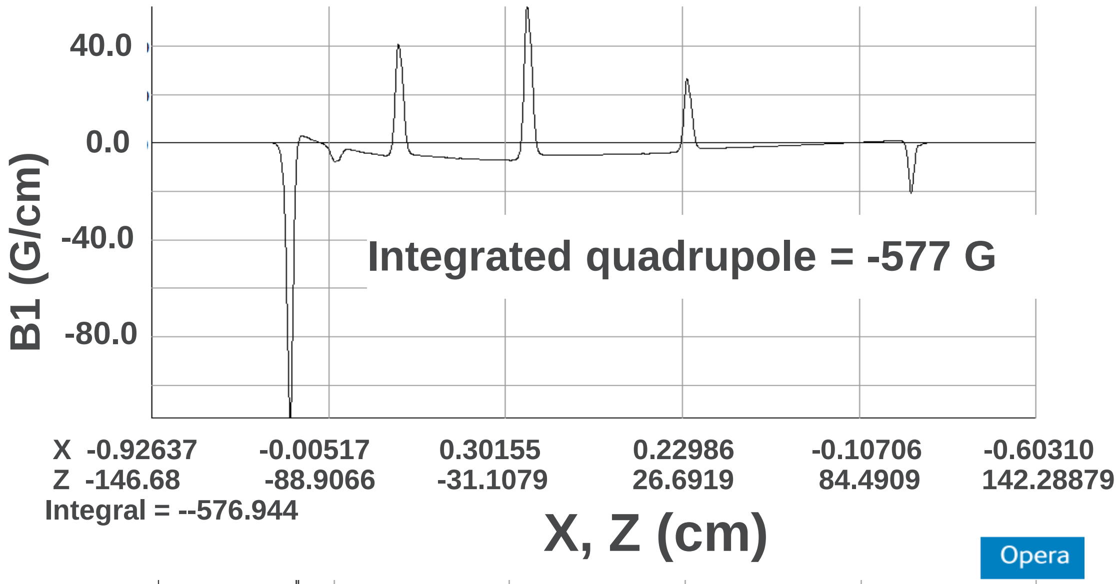
Case 1

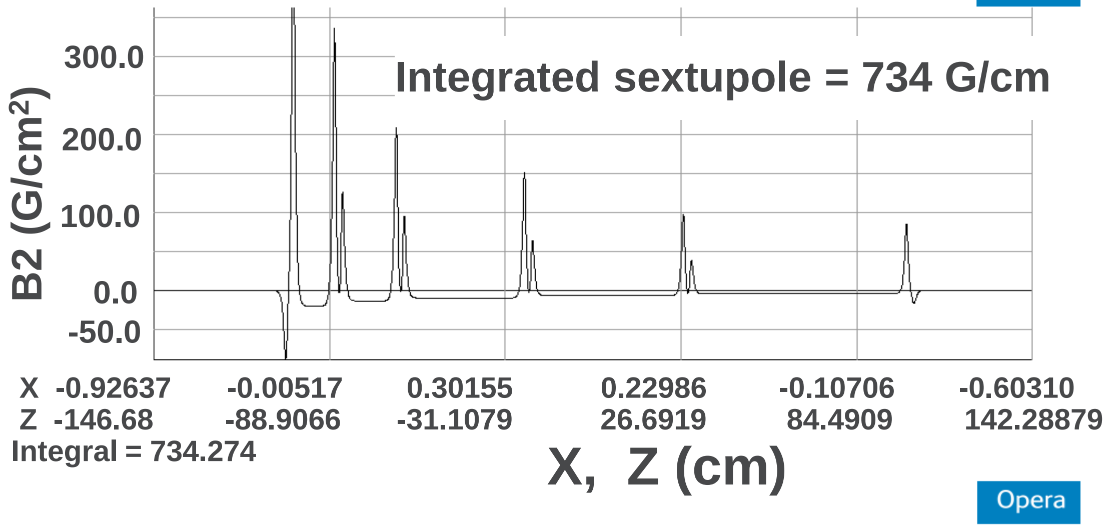
Straight M1

SIMULATION RESULTS OF THE DIPOLE, QUADRUPOLE, AND SEXTUPOLE FIELDS ALONG THE ELECTRON BEAM TRAJECTORY IN THE SINGLE STRAIGHT M1

Main Current = 353.56 A







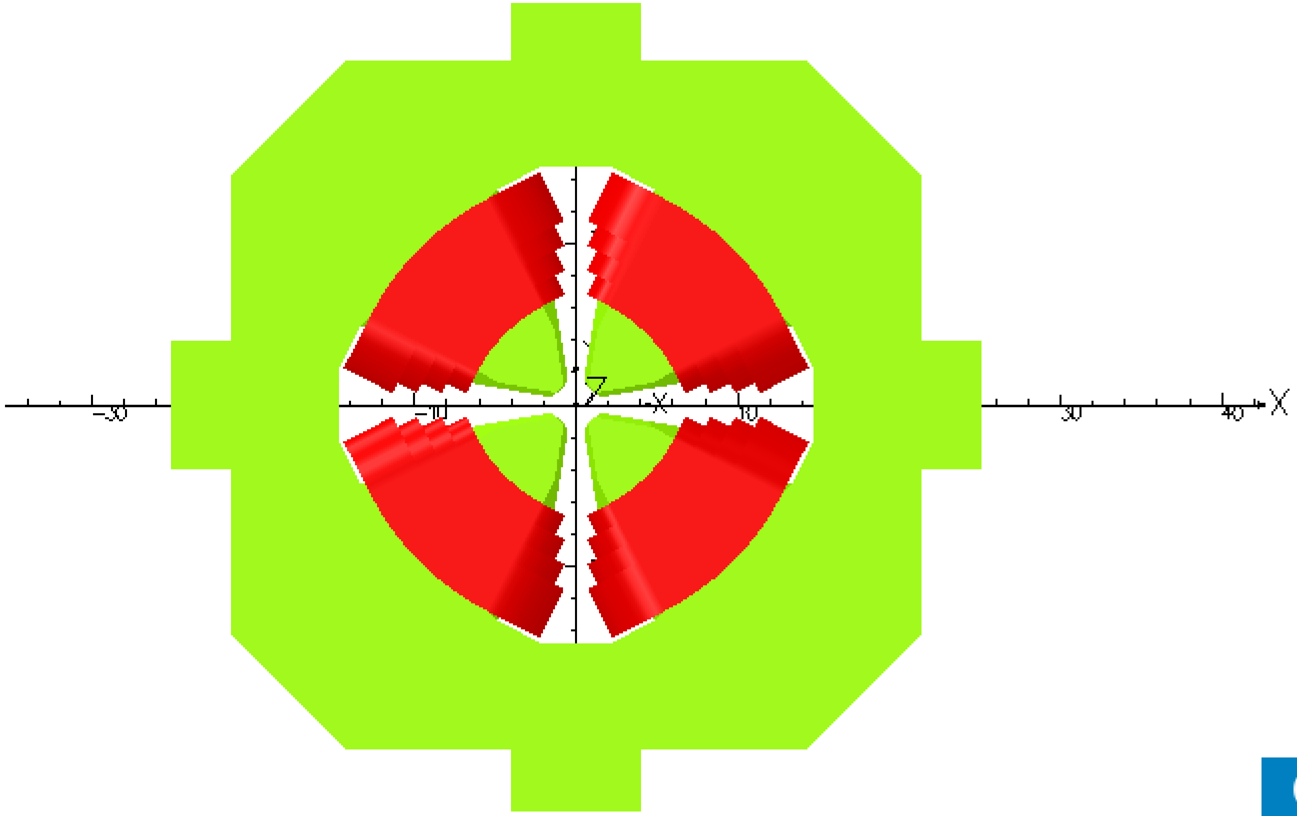
The simulated fields are in the requirement!

Case 2

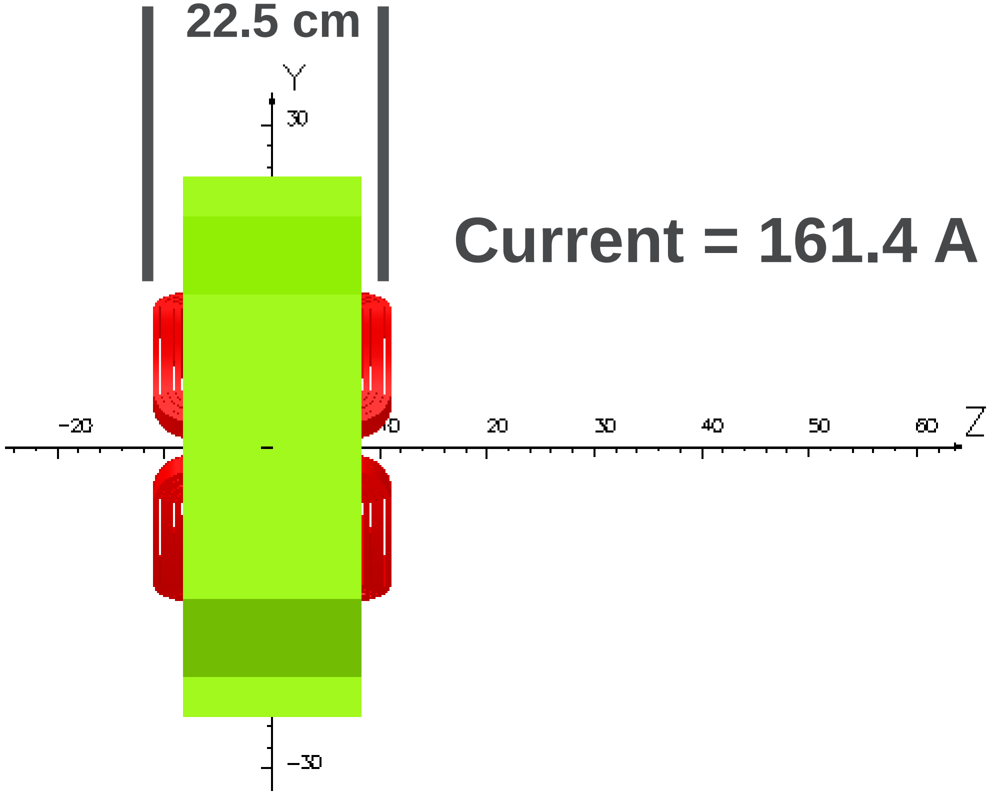
Q2

SIMULATION OF THE SINGLE Q2 MAGNET

A view from the beam direction



Dimension is in cm



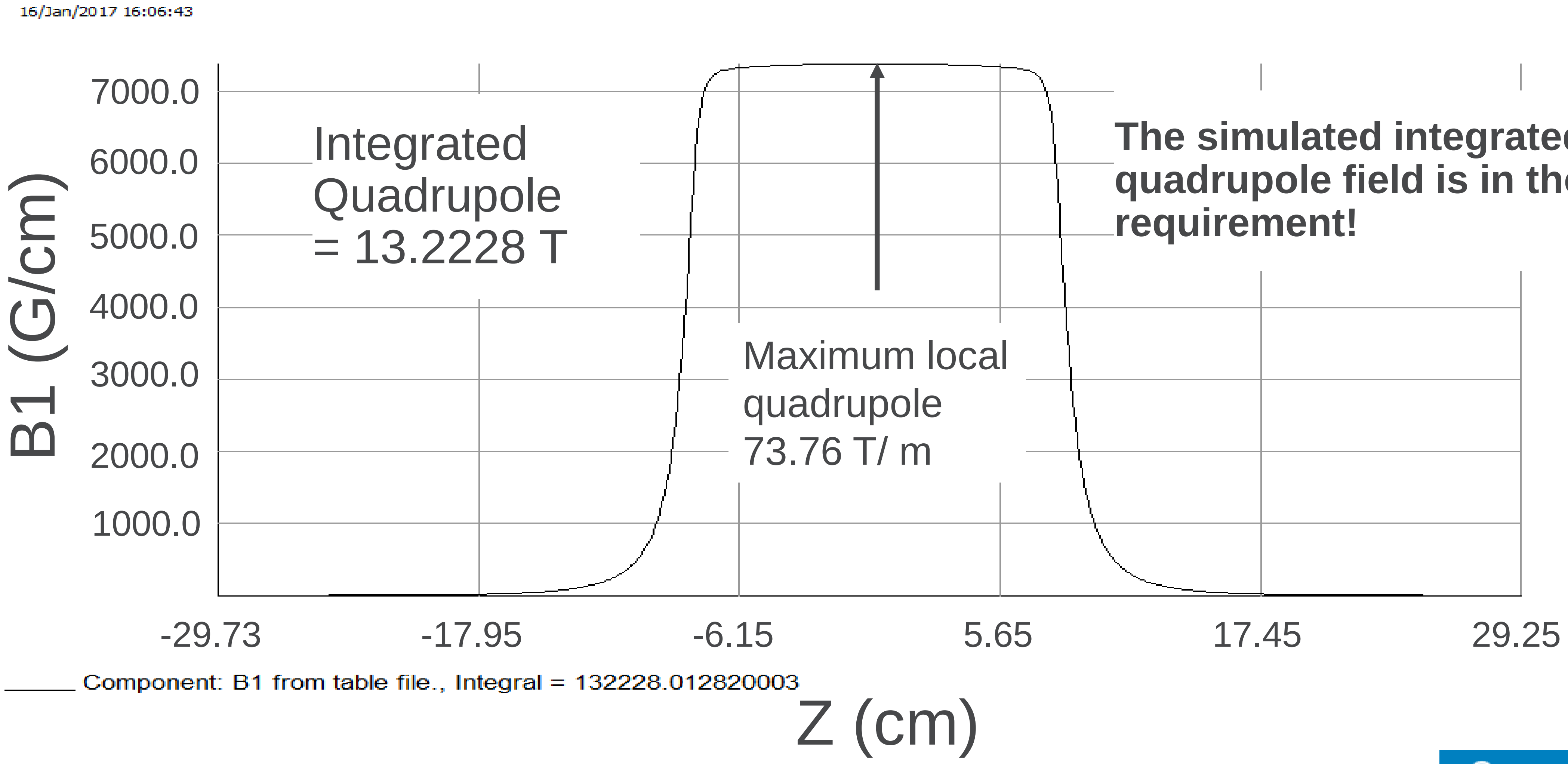
Current = 161.4 A

Side view

Case 2

Q2

SIMULATED QUADRUPOLE FIELD ALONG THE LENGTH OF THE Q2 MAGNET



The simulated integrated quadrupole field is in the requirement!

Opera

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Case 1

Straight M1

SIMULATION RESULTS OF THE MAIN AND HARMONIC INTEGRATED FIELDS OF THE Q2 AND STRAIGHT M1

Main current = 353.56 A

	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	unit
Along the beam trajectory (not measureable)	-487369 -487243	-577 -502	734 832	-35 ---	470 ---	262 ---	315 ---	38 ---	6 ---	-32 ---	cgs
	10000 10000	11.8 10.3	-15.1 -17.1	0.7 0.9	-9.6 -9.8	-5.4 -5.2	-6.5 -6.3	-0.8 -0.8	-0.1 -0.2	0.6 0.5	---

	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	unit
Along a straight line at gap center (measurable)	-487354	-279	676	-119	290	38	273	14	36	-7	cgs
	10000 10000	5.7 5.3	-13.8 -16.2	2.4 2.8	-5.9 -6	-0.8 -0.8	-5.6 -5.1	-0.3 -0.2	-0.7 -0.8	0.1 0.1	---

Case 2

Q2

Current = 161.4 A

Black numbers: from M. Abliz
Red numbers: from M. Jaski

The numbers are in agreement

	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	unit
In 10 mm radius from the gap center (measurable)	0	132228	0	4	0	-78	0	0	0	-54	cgs
	0 0	10000 10000	0 0	0.3 0	0 0	-5.9 -6.3	0 0	0 0	0 0	-4.1 -4.3	---

REQUIRED AND CONFIRMED RESULTS OF THE Q2 AND STRAIGHT M1

Case 1

Straight M1 (dipole)

	Total Length	Total Angle	Peak Field	Integrated By field
Required	209.6 cm	1.395 deg.	-6360 G	487270 G-cm
Modeling Results (M. Abliz) (Main current = 353.56 A)	209.6 cm	1.3953 deg.	-6395 G	487369 G-cm

Case 2

Q2 (quadrupole)

	Total Length	Total Quadrupole field
Required	22.5 cm	132000 G
Modeling Results (M. Abliz) (Current= 161.4A)	22.5 cm	132228 G

CROSS-TALK STARTS FROM HERE….

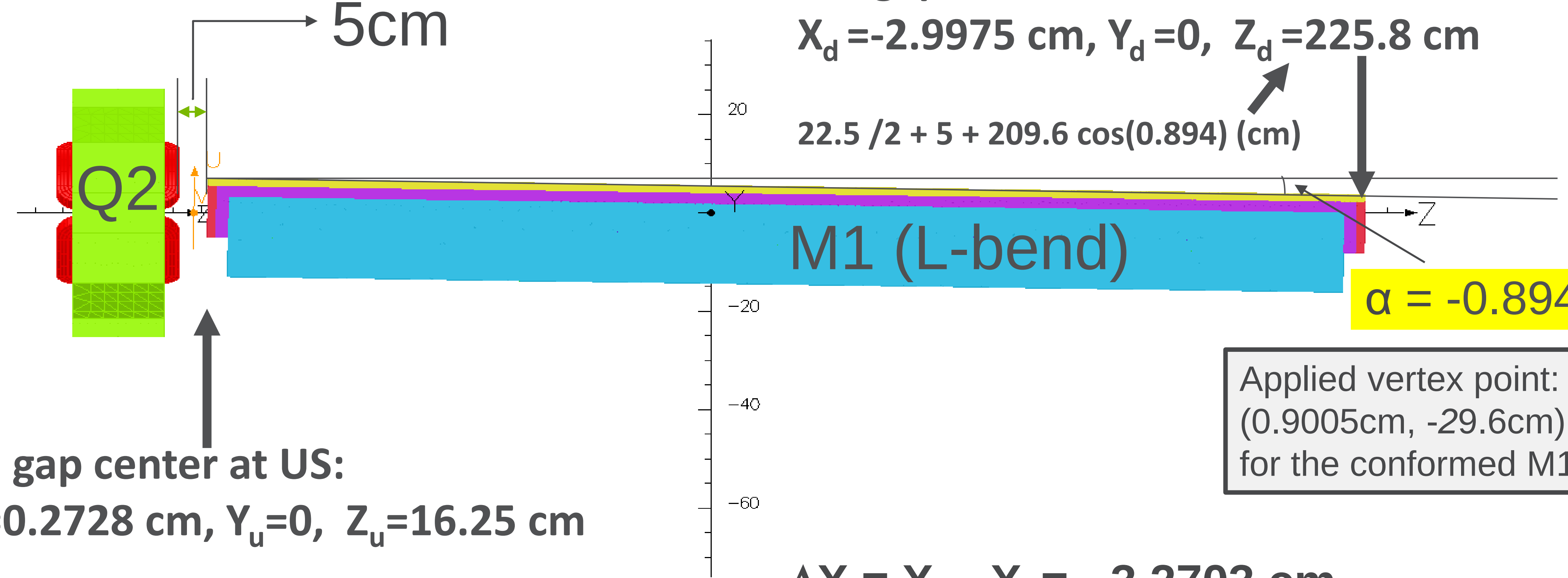
MODELING Q2 AND M1 TOGETHER

LAYOUT OF THE Q2 WITH YAWED M1 TOGETHER

M1 gap center at DS:

X_d =-2.9975 cm, Y_d =0, Z_d =225.8 cm

22.5 /2 + 5 + 209.6 cos(0.894) (cm)



Applied vertex point:
(0.9005cm, -29.6cm) (x, z)
for the conformed M1 layout

M1 gap center at US:

X_u=0.2728 cm, Y_u=0, Z_u=16.25 cm

$\Delta X = X_d - X_u = -3.2703$ cm

$\Delta Z = Z_d - Z_u = 209.6$ cm

Starting point of electron beam trajectory in M1:
Z (cm) = (22.5 /2 + 5/2)(cm) = 13.75 cm

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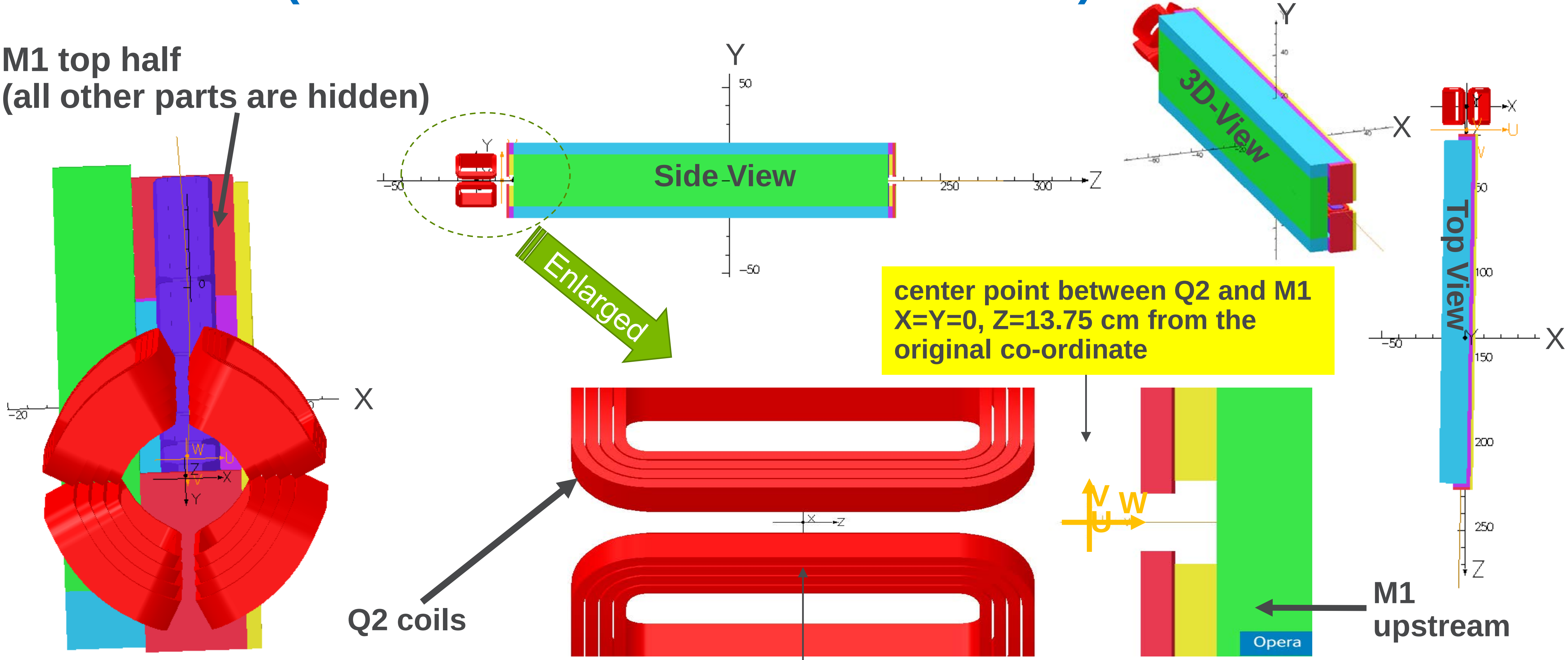
Origin of the coordinate is located at center of the Q2 magnet

Case 3

SIMULATION OF A YAWED M1

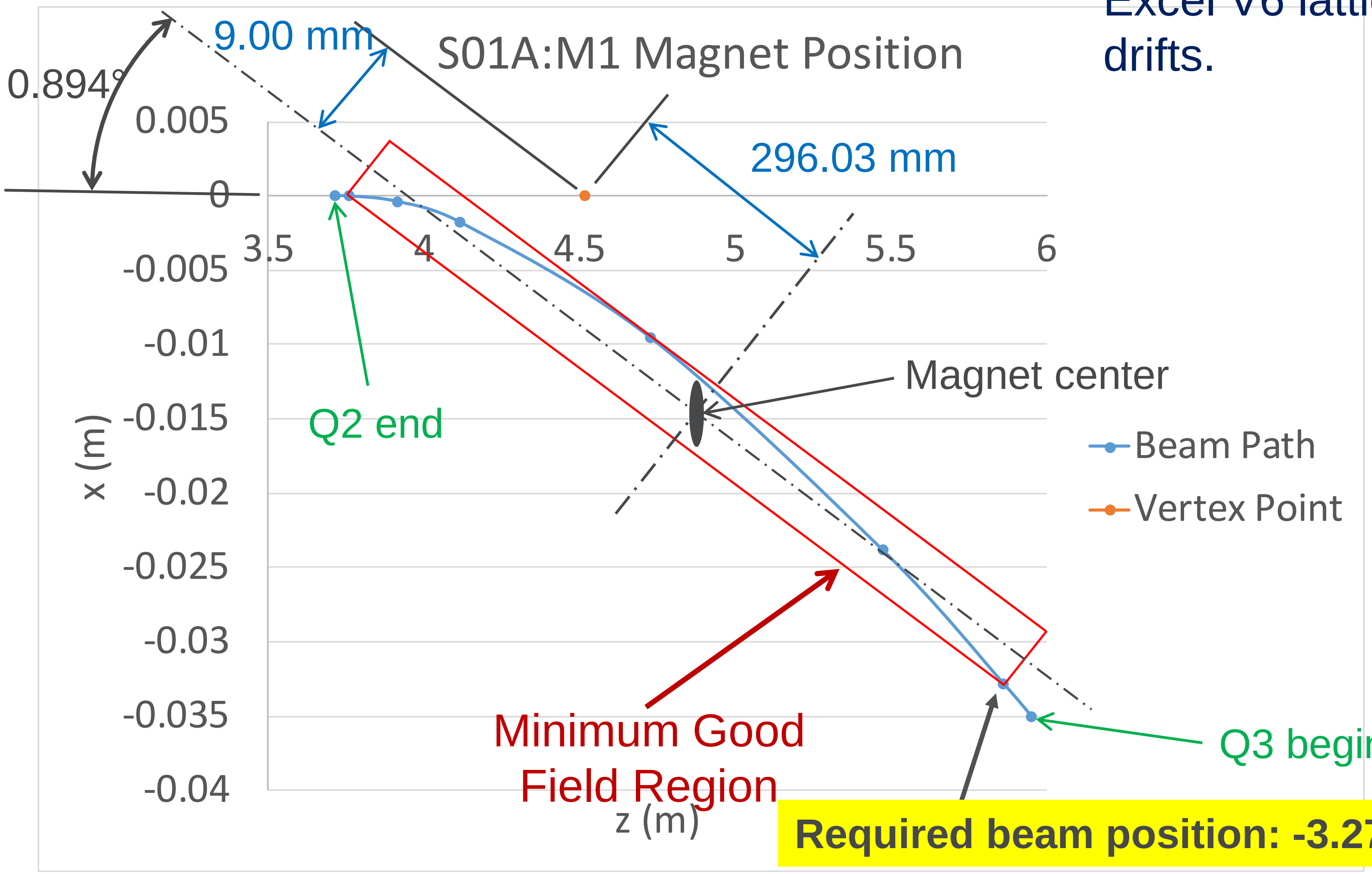
(COORDINATE TRANSFORMATION)



Units are in cm

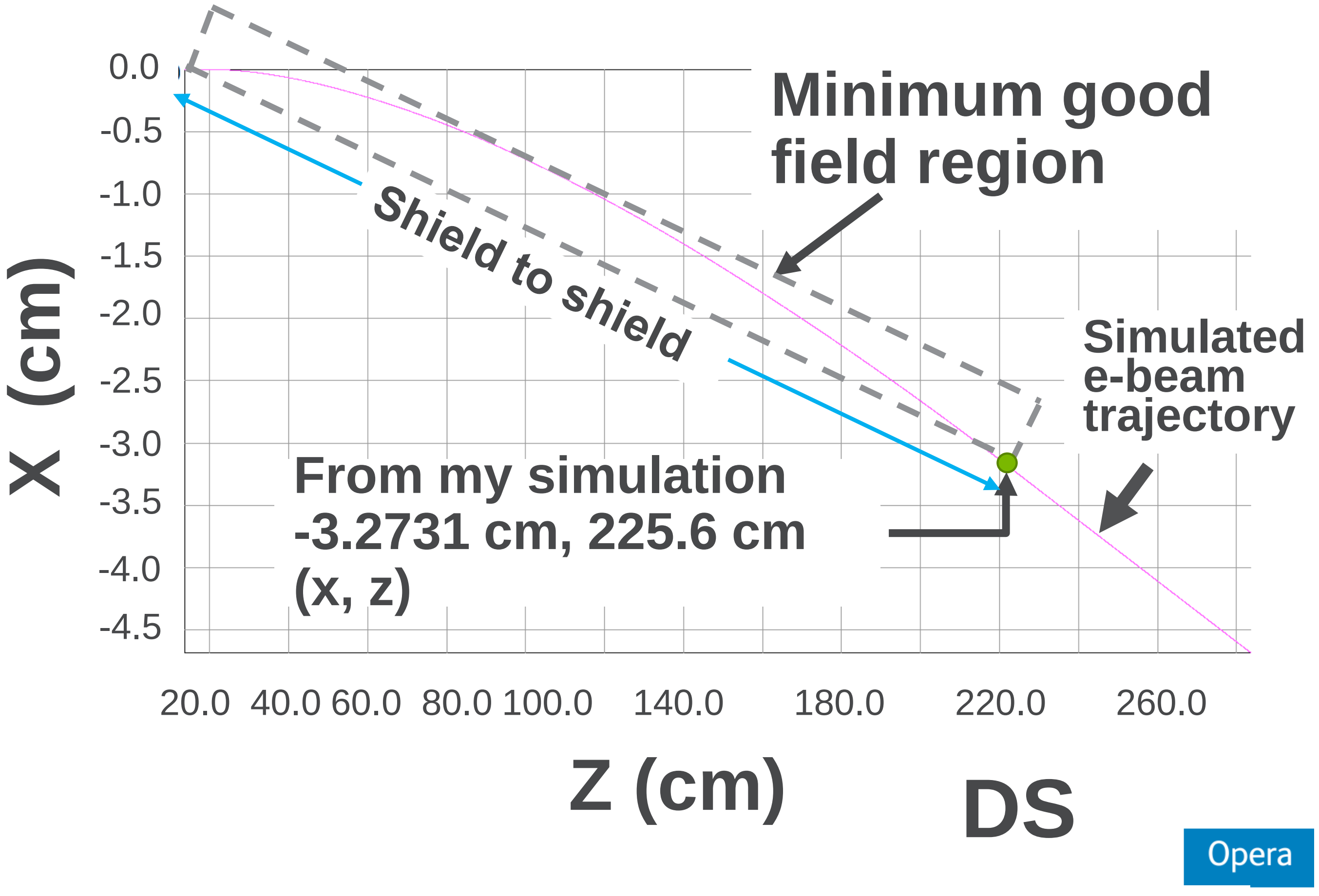
Required position of M1

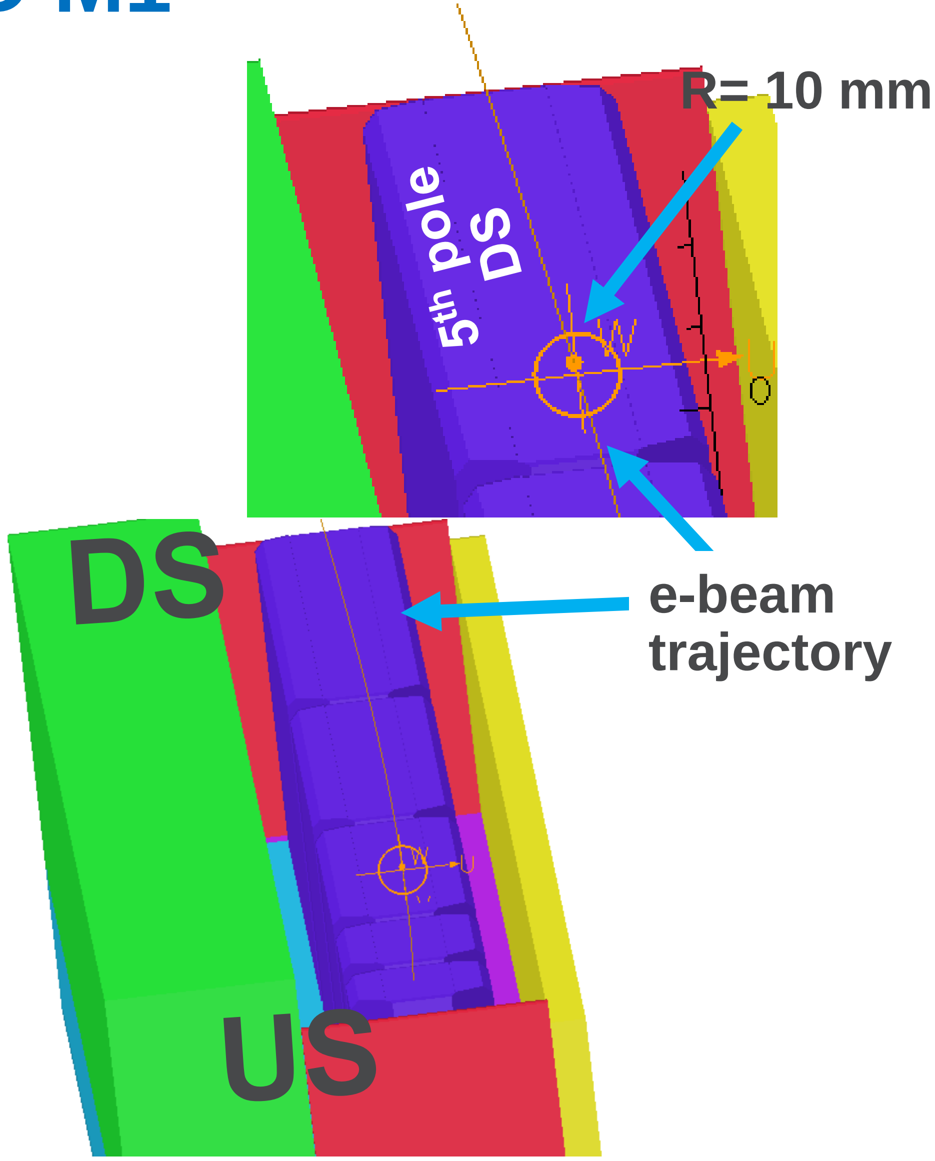
Plotted from M. Borland Excel V6 lattice file with drifts.



Required beam position: -3.278 cm, z= 210 cm (X, Z)

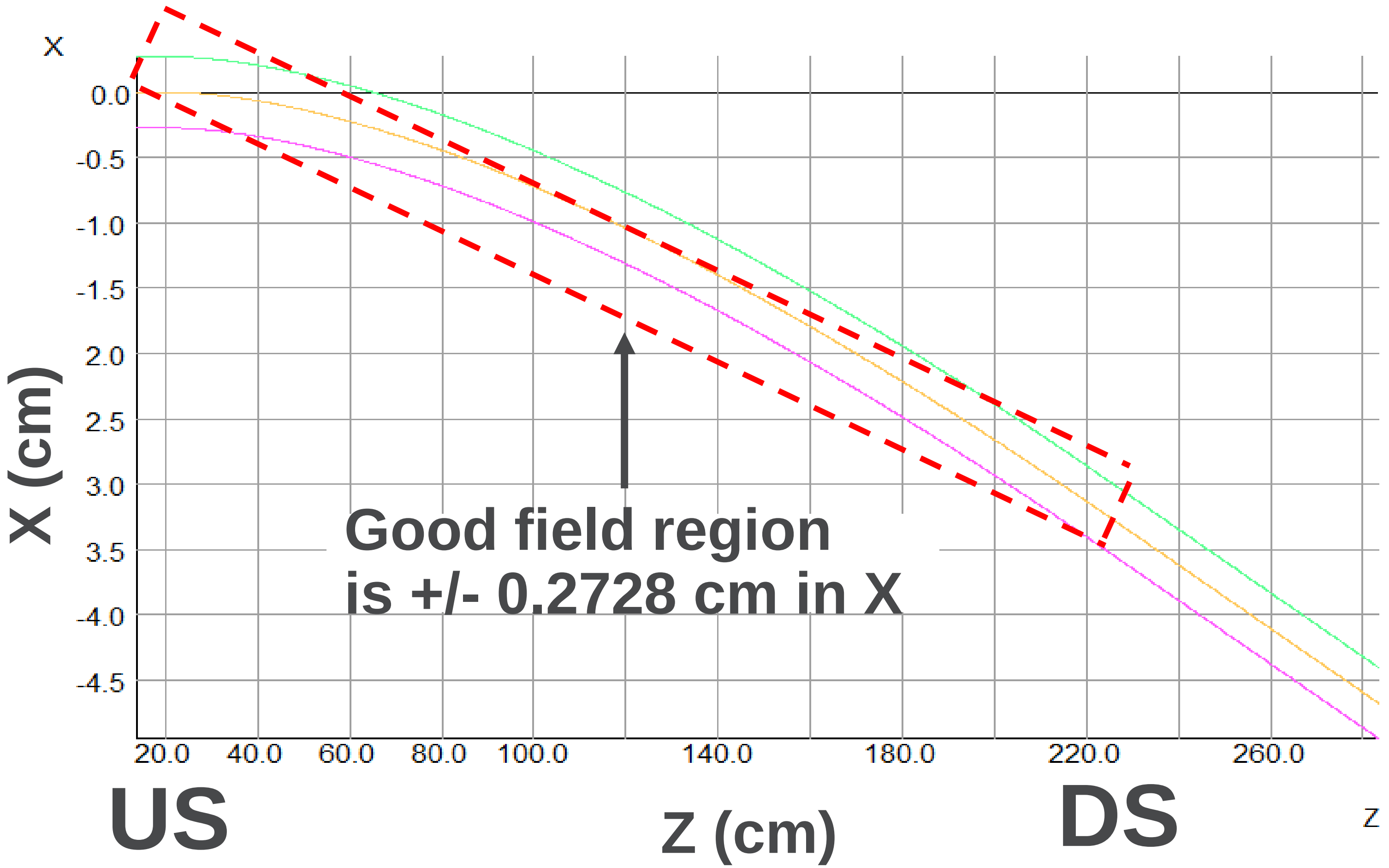
Case 3 TRAJECTORY OF THE ELECTRON BEAM IN THE YAWED M1





Achieved required beam position!

Case 3 ELECTRON TRAJECTORIES IN THE YAWED M1



Starting positions at US:

Center (Orange)
+ 0.2728 cm outboard (Green)
-0.2728 cm inboard (Pink)

Integrated By (dipole) field along the trajectory:
-487482 G-cm (center-Orange)
-487538 G-cm (outboard-Green)
-487298 G-cm (inboard-Pink)

Field uniformity =

Opera $$\frac{\Delta By\ integral}{By\ integral\ (center)} = 5 \times 10^{-4}$$

Achieved required field uniformity

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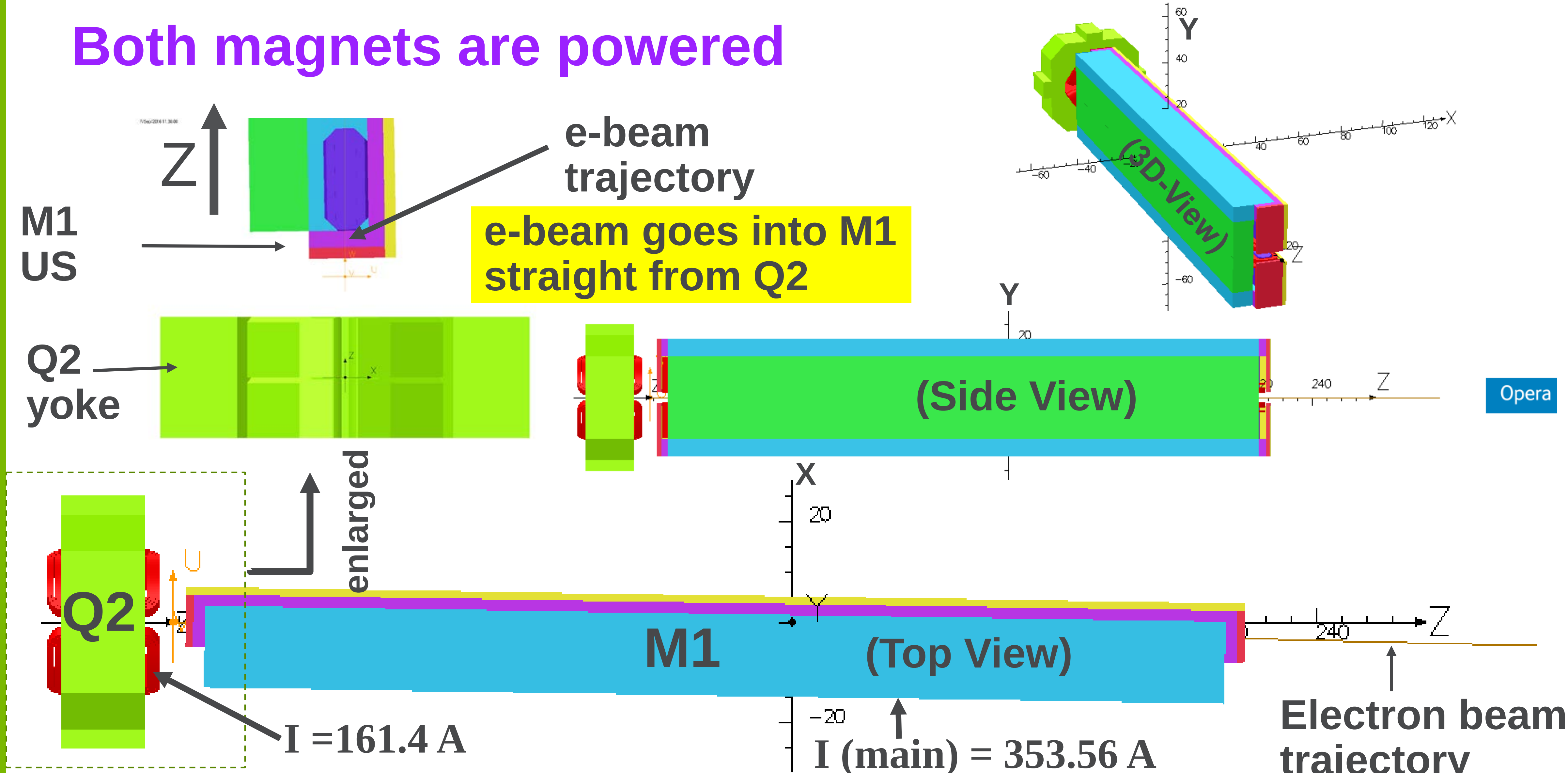
Case 4

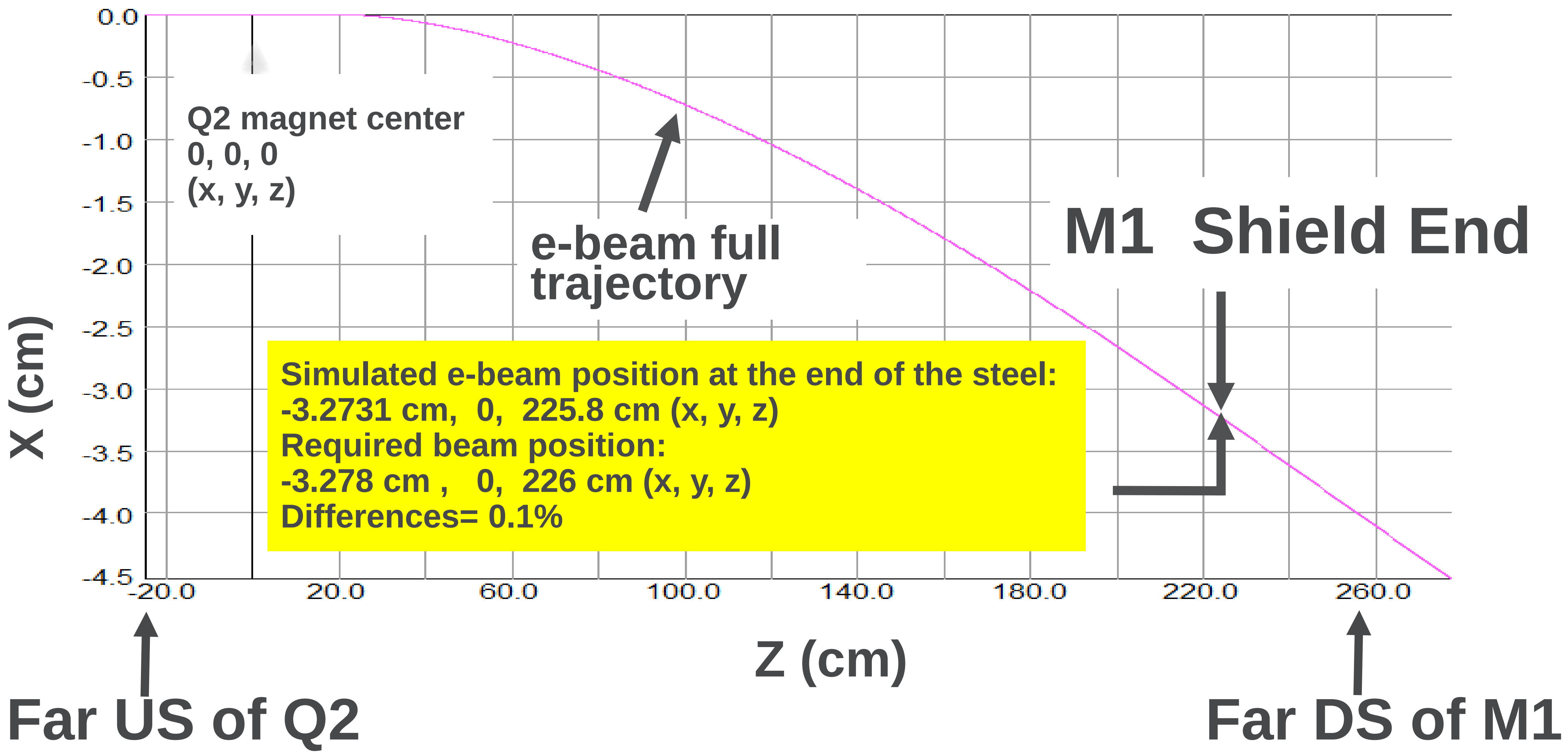
SIMULATION OF Q2 WITH YAWED M1

Both magnets are powered



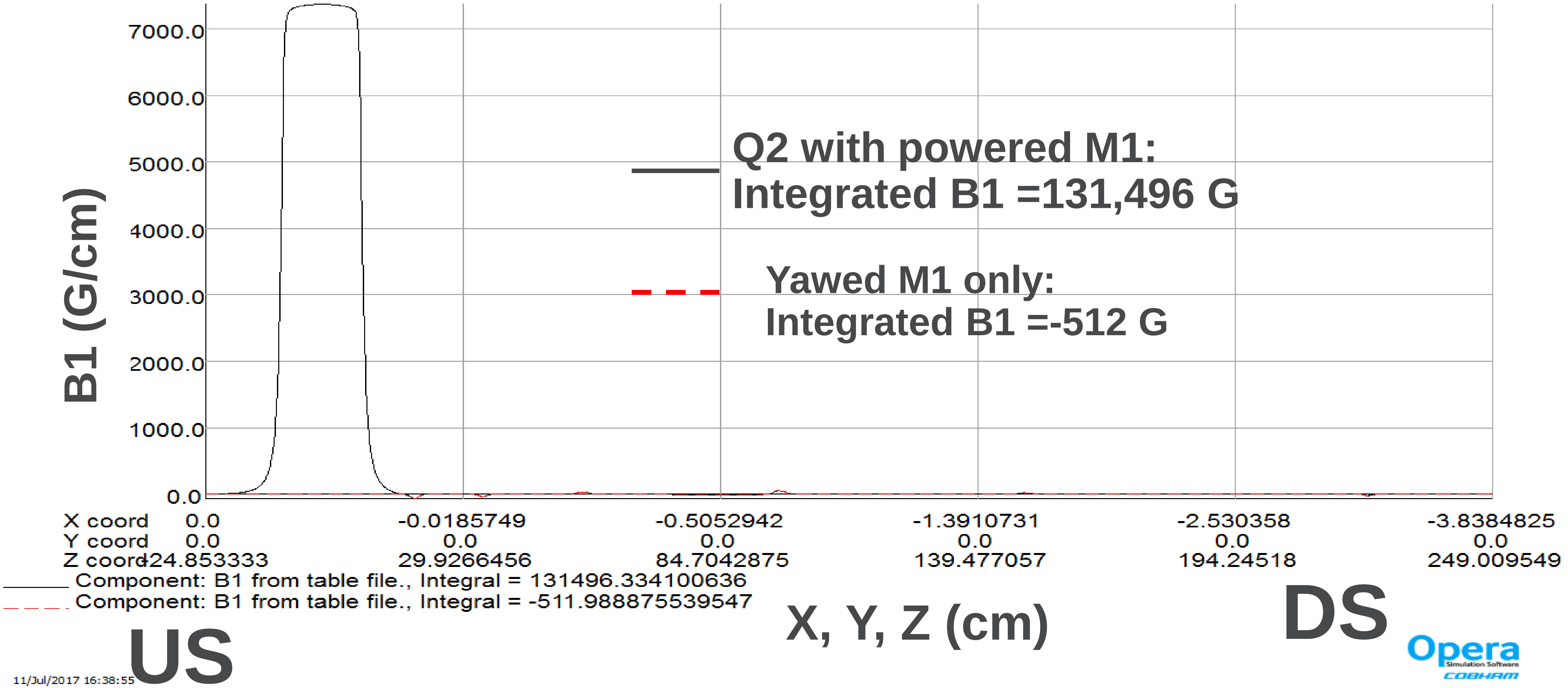
Case 4

ELECTRON BEAM TRAJECTORY WITH POWERED Q2 AND M1



Case 3 & 4

QUADRUPOLE FIELD ALONG THE FULL TRAJECTORY



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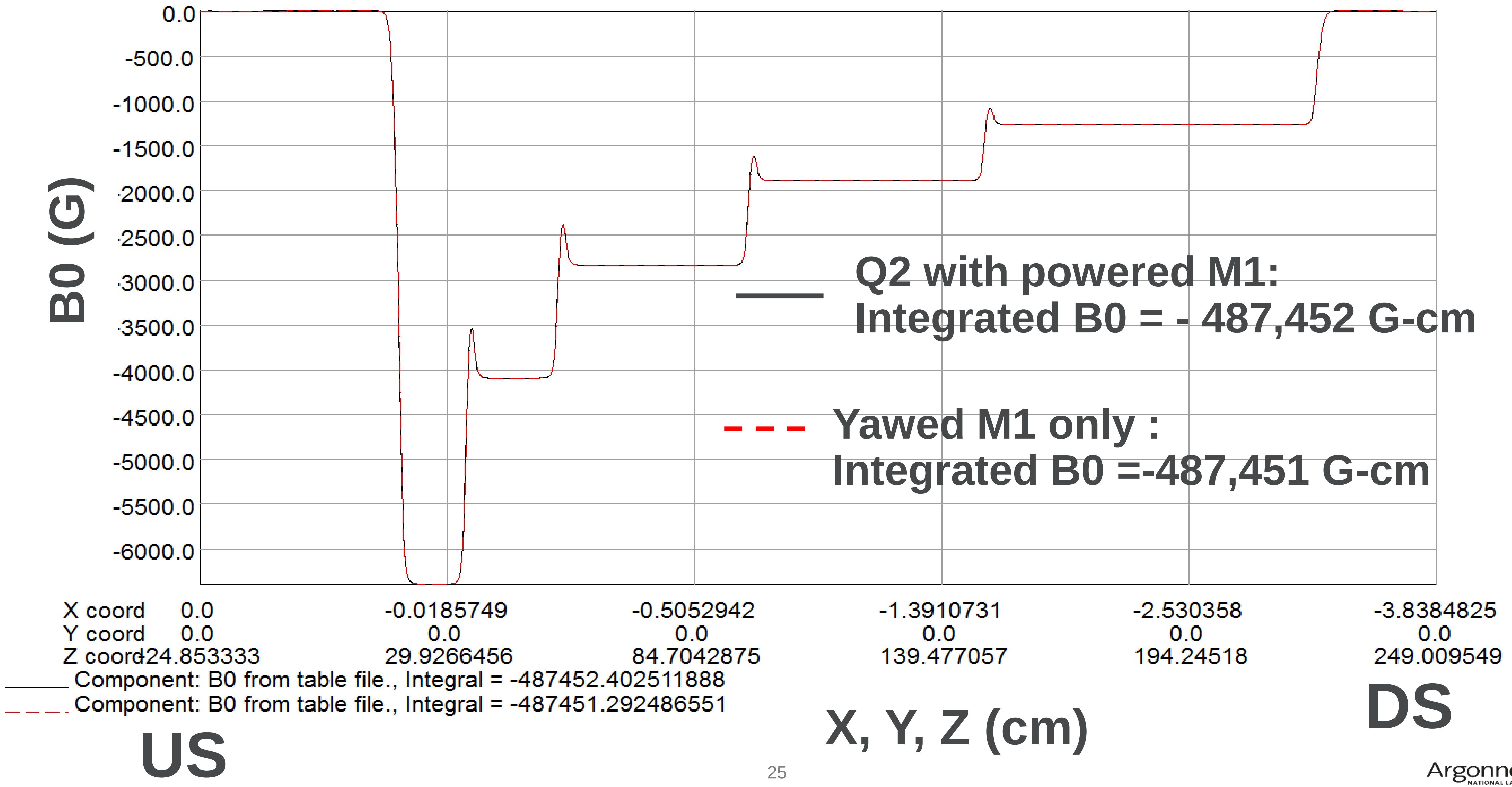
Case 3 & 4

DIPOLE FIELD ALONG THE FULL ELECTRON TRAJECTORY



INTEGRATED MULTIPOLE FIELDS ALONG THE FULL TRAJECTORY

Before cross-talk	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	unit
Case 2 + Case 3	-487451	131716	764	-30	475	169	307	35	6	-78	cgs

After cross-talk	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	unit
Case 4	-487452	131496	751	-28	487	224	307	45	-7	-64	cgs

Differences between Case 4 and Case 2 + Case3

	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	unit
cross-talk	1	-220	-13	-2	12	55	0	10	-13	-14	cgs

CONCLUSIONS

1) The designs of the Q2 and M1 magnets are acceptable from the cross-talk simulation results
2) The full trajectory meets the required lattice trajectory
3) The maximum effect to the multipoles caused by the cross-talk was only 0.045% which is much smaller than the limitation of < 0.1%
4) For all cases of the cross-talk simulation, the multipole fields were computed within a 10 mm radius circle centered at beam trajectory along the length
5) The integrated quadrupole field of the Q2 magnet dropped by 220 G out of 131,716 G (0.1%) from the M1
6) The integrated M1 dipole field only increased by 1 G - cm out of 487451 G-cm (< 0.1%) from the Q2 magnet
7) We'll rely on this cross-talk simulation results to decide the individual measurement data of Q2 and M1 magnets will be applicable during installation in the storage ring

THANK YOU!