Septum Magnet Design for MBA Lattice

Melike Abliz

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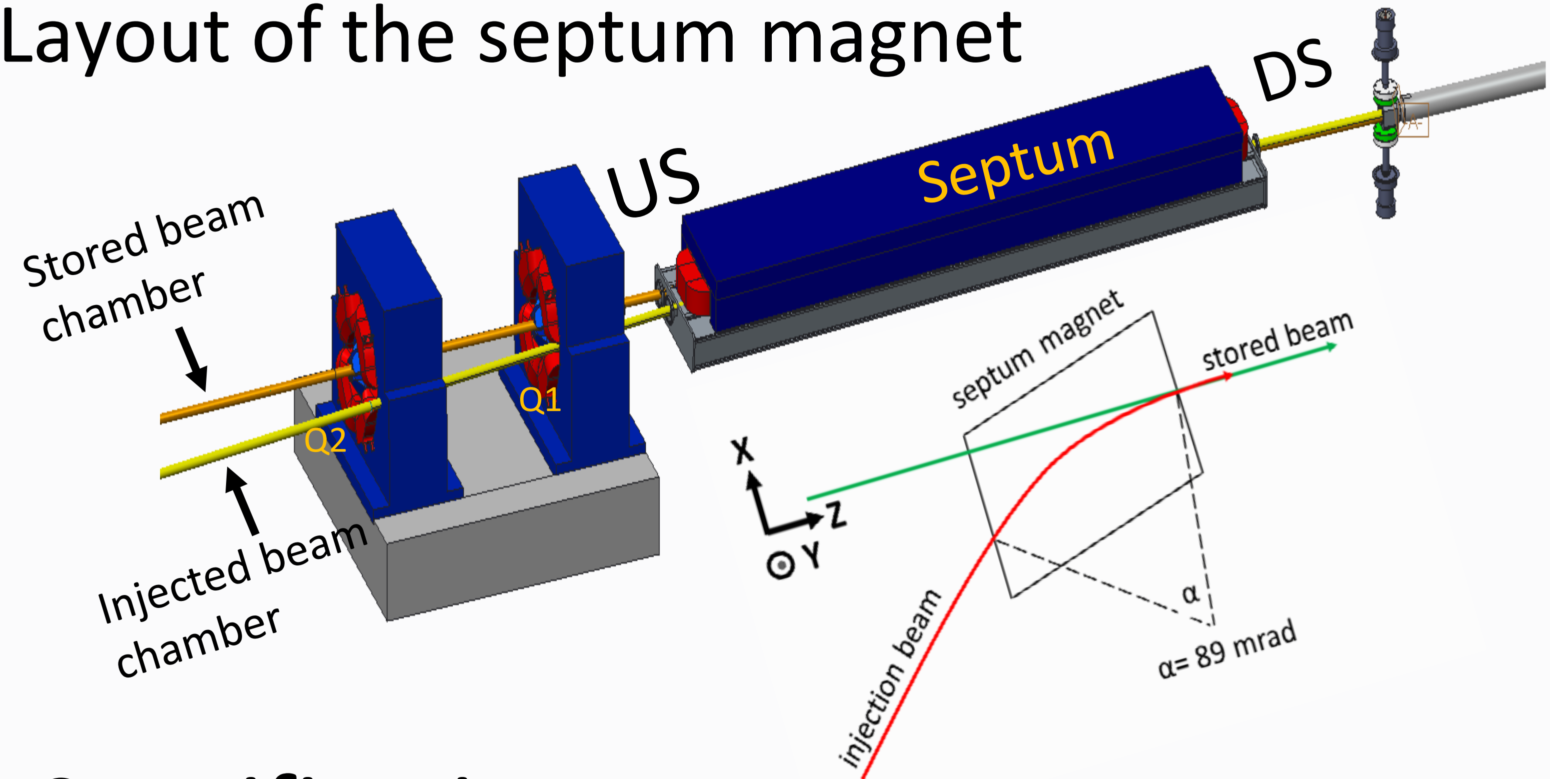
Outline

1) Specifications
2) Magnetic designs
3) Trajectories of the injected and stored beams
4) Bx, By, and Bz fields along the trajectory of the injected beam
5) Field multipoles for the injected beam
6) Field multipoles for the stored beam
7) Angle and position of the injected and stored beams at the DS end

The electron beam needs to be put in the storage ring of the APS-U before circulating it.

The magnet that injects the bunches into the ring is called a: Septum magnet

Layout of the septum magnet

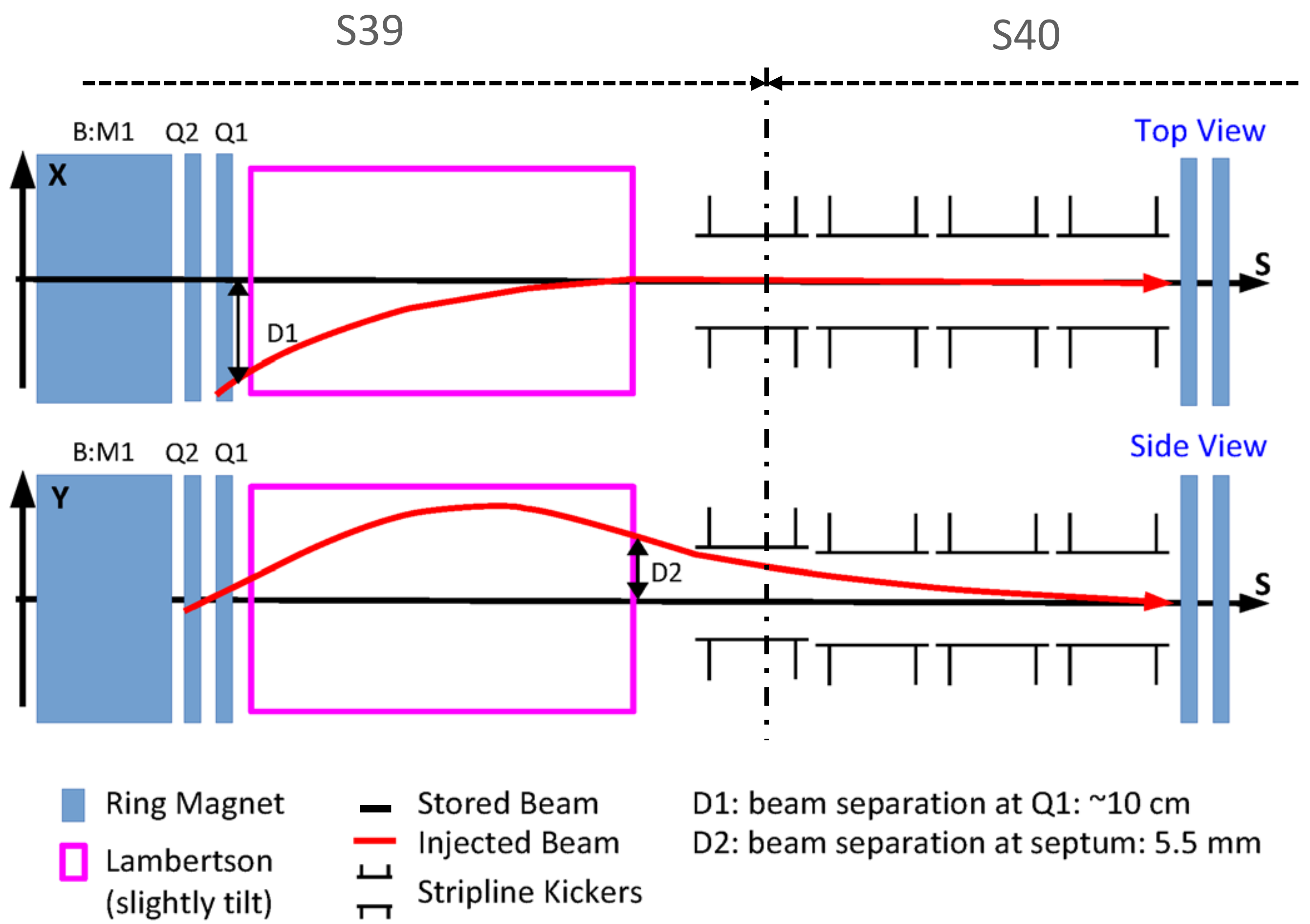


Specifications

Length	Septum Thickness	Field Strength	Bend Angle	Tilt Angle	Half Aperture	Field leakage	Field uniformity
178 cm	2 mm	1 T	89 mrad	93 mrad	3 mm	<100 µrad	$<10^{-3}$

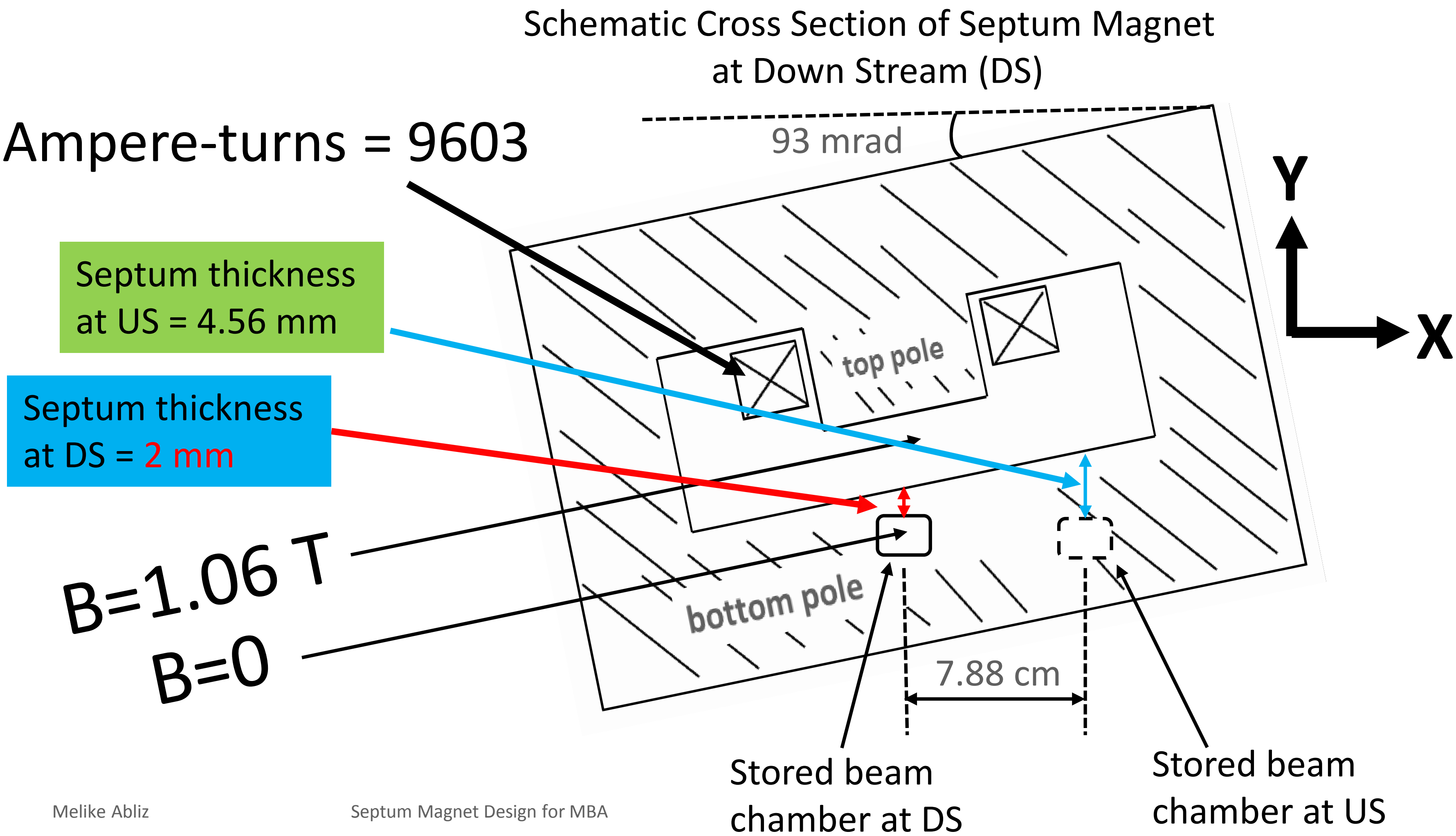
Limitation of the fast corrector is 350 µrad

On-axis injection line configuration



D1: beam separation at Q1: ~10 cm
D2: beam separation at septum: 5.5 mm

The magnet is tilted in yaw, pitch, and roll



Designed Septum Magnets' Parameters

	Field (T)	Length (m)	Septum Thickness (mm)	By Field Leakage (G-cm)	Bx Field Leakage (G-cm)	Maximum End Field, By (G)	Maximum End Field, Bx (G)
SNS	0.68	2.44	10	1231	1012	32	20
APS(pulse)	0.74	0.98	5	700	---	---	---
MAX-IV	0.83	2.5	2	510	---	27	37

Relations of the field leakage to the injection field and septum thickness:
1) A high field for the injected beam causes high field leakage.
2) A thin septum causes high field leakage .

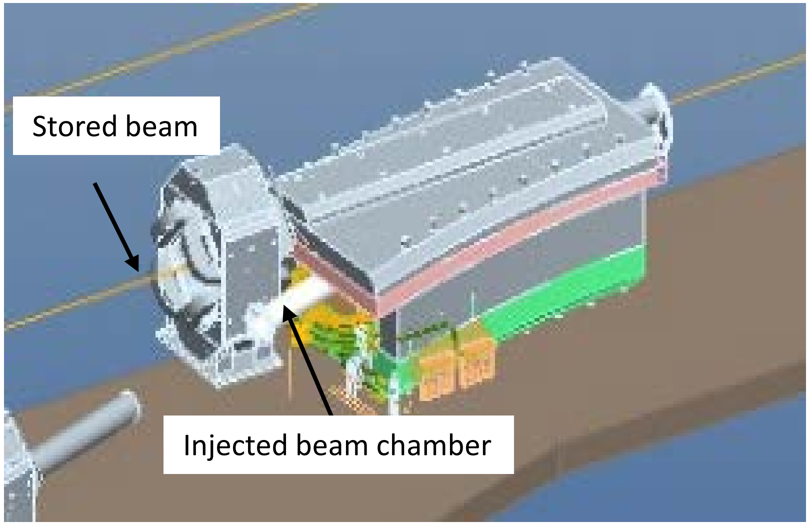
Achieved with the design

MBA	1.06 T	1.78	2	375 or 19μrad	771 or 39 μrad	16	14

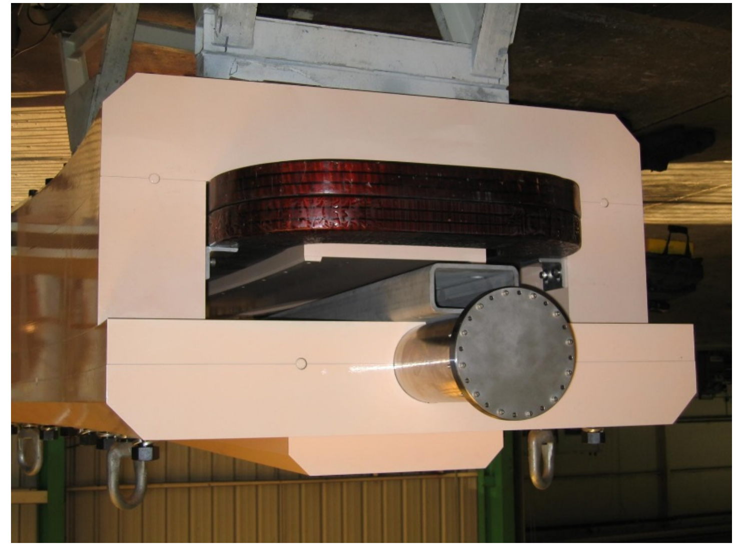
Requirement is <100 μrad

This is the field that deflects the injected beam for the requited angle of 89 mrad.

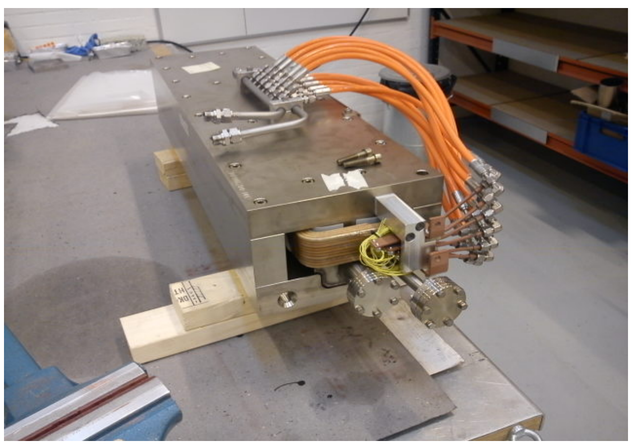
Septum magnet of SNS



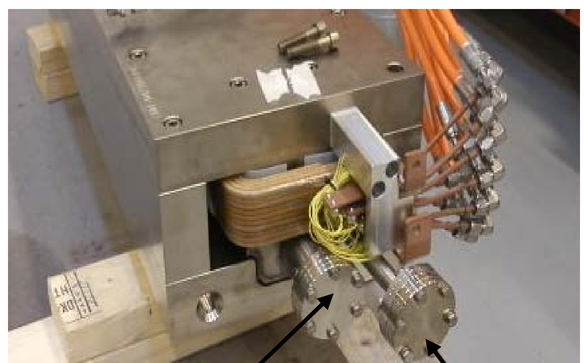
view at downstream end



Septum magnet of MAX-IV



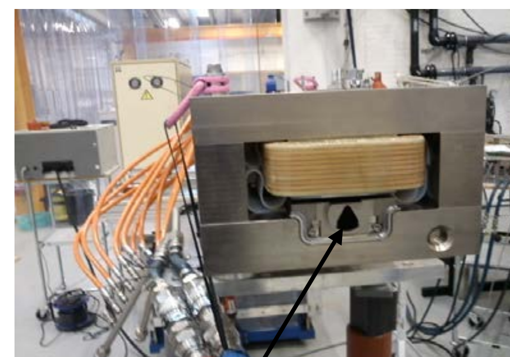
view at upstream end



Injected beam chamber

Stored beam chamber

view at downstream end



Stored beam chamber

a) Problems with the magnetic design of the septum magnet for the APS-U

- High injection field
- Thin septum
- Super ellipsoidal stored beam chamber

→ **CHALLENGING DESIGN** in order to reduce leakage field

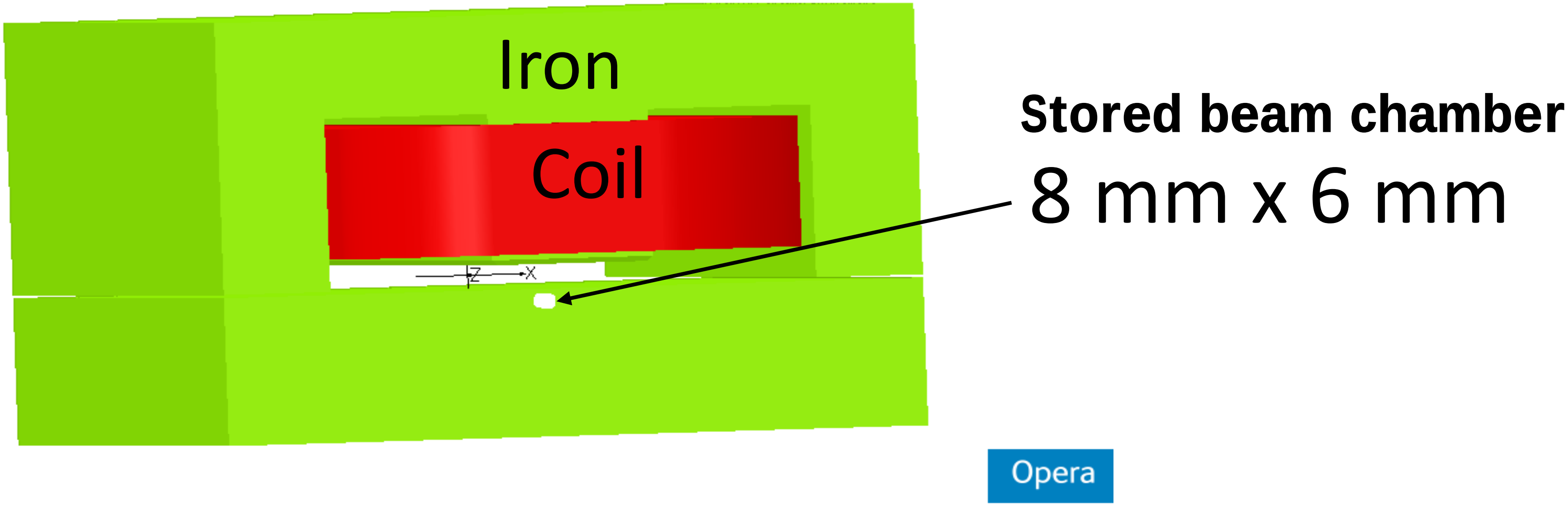
- The tilted magnet in yaw, pitch, and roll

→ **Complicated Design**

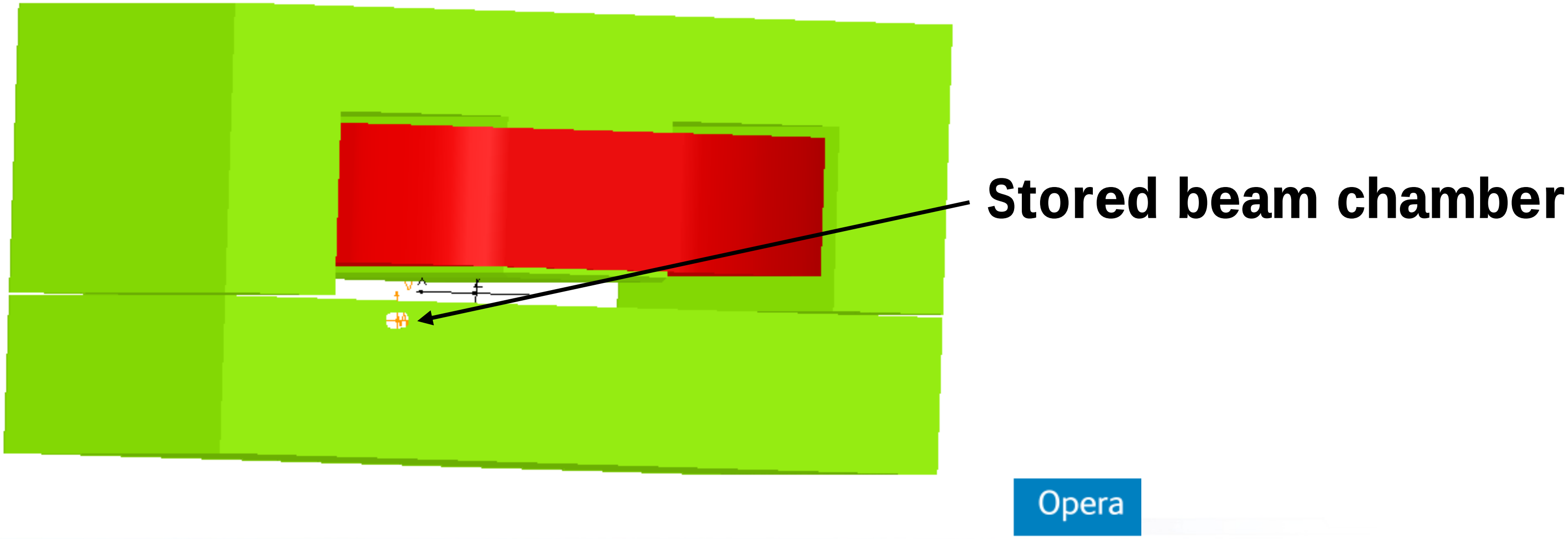
b) Multiple iterations required; I will tell you about a few designs

Original Design

View from the stored beam chamber at DS

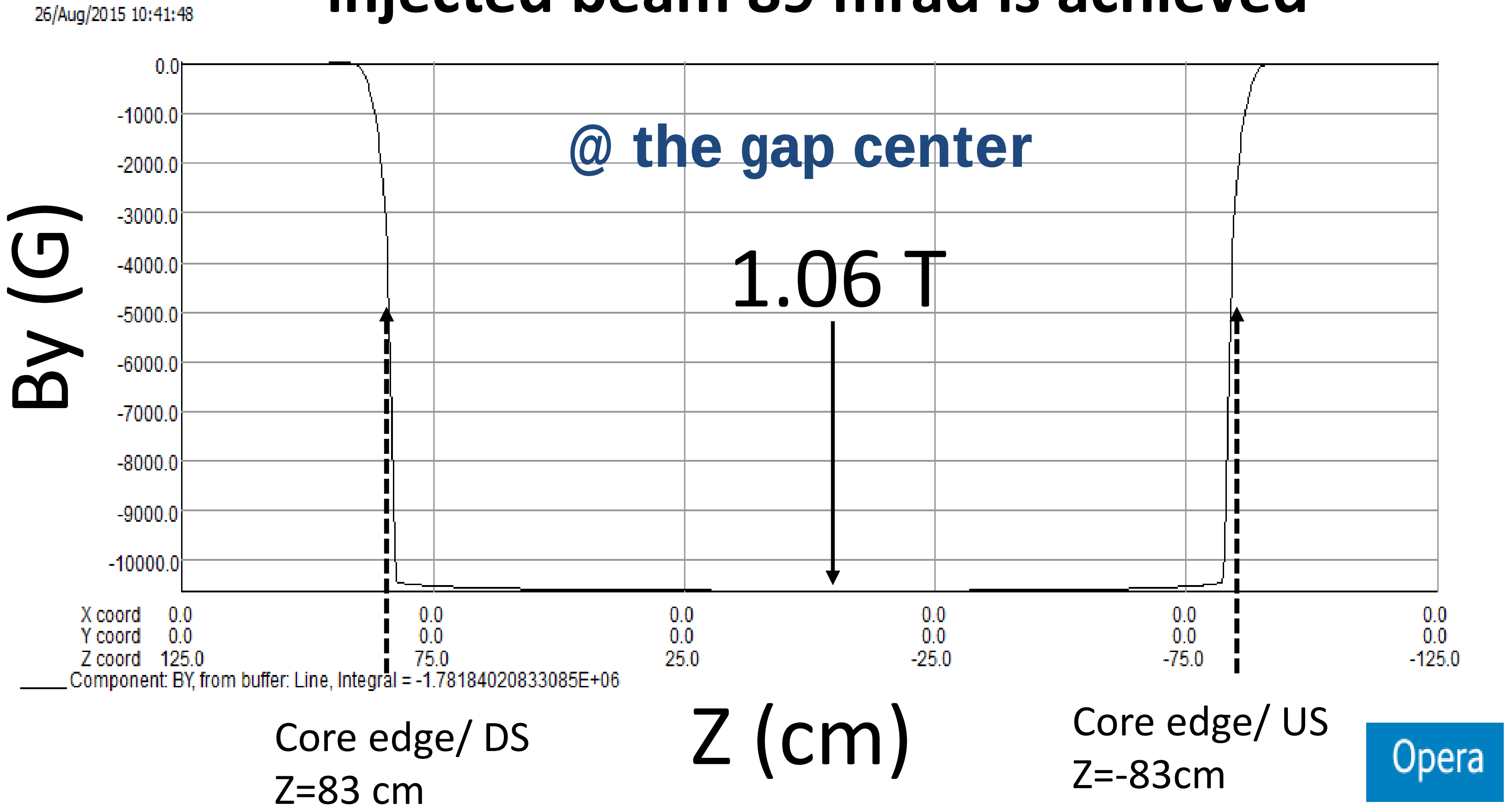


View from the stored beam chamber at US



Original Design

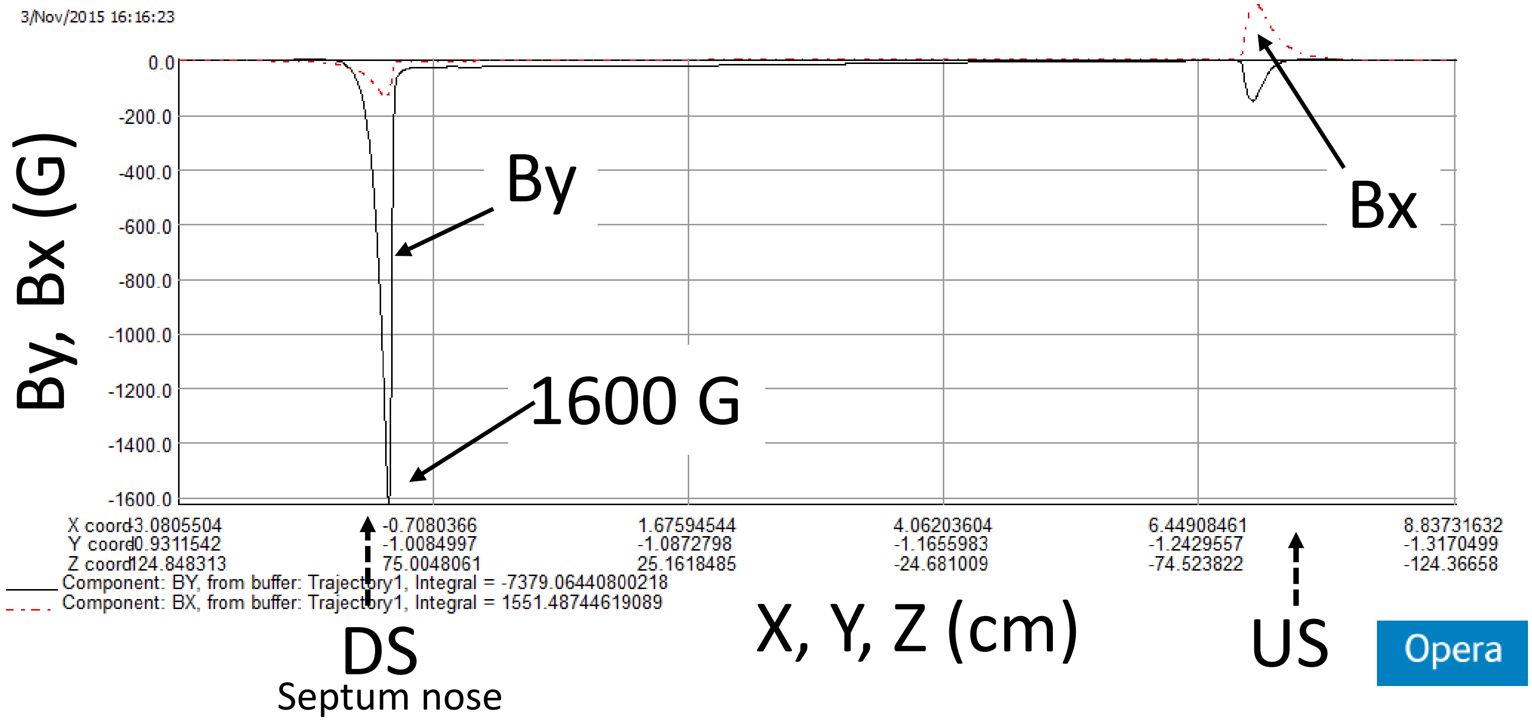
The required total deflecting angle of the injected beam 89 mrad is achieved



The peak field is 1.06 T.

Original Design

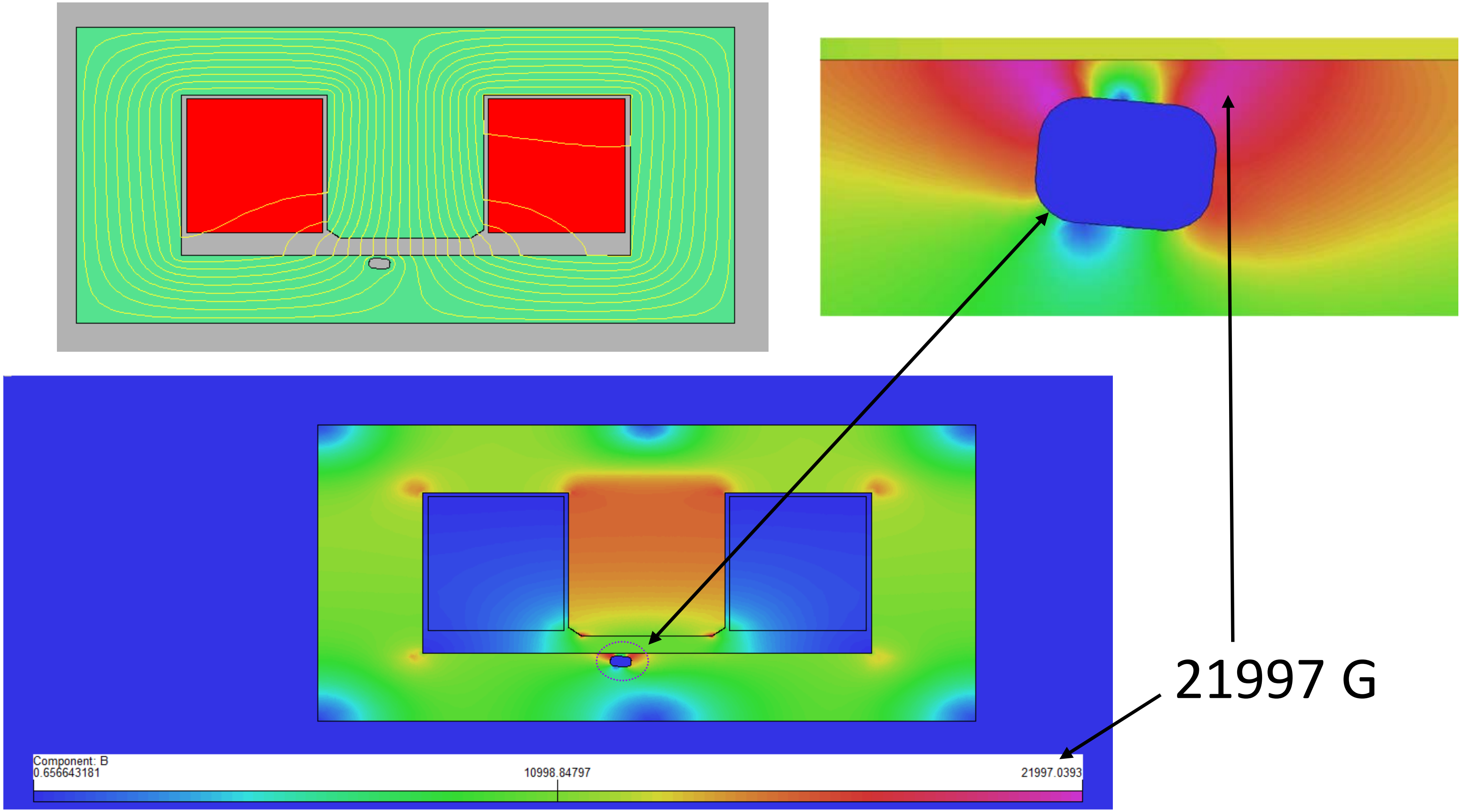
The effect of field leakage on the stored beam was 369 µrad



- **Integrated By field inside the stored beam chamber = 7379 G-cm.**
- **The peak field at the septum nose was 1600 G. UNACCEPTABLE!**

Original Design

Magnetic Flux and Flux Density at DS



Schemes and Skill to the original design

Scheme 1: Cut the top pole at US and DS ends and made it shorter than the bottom pole.

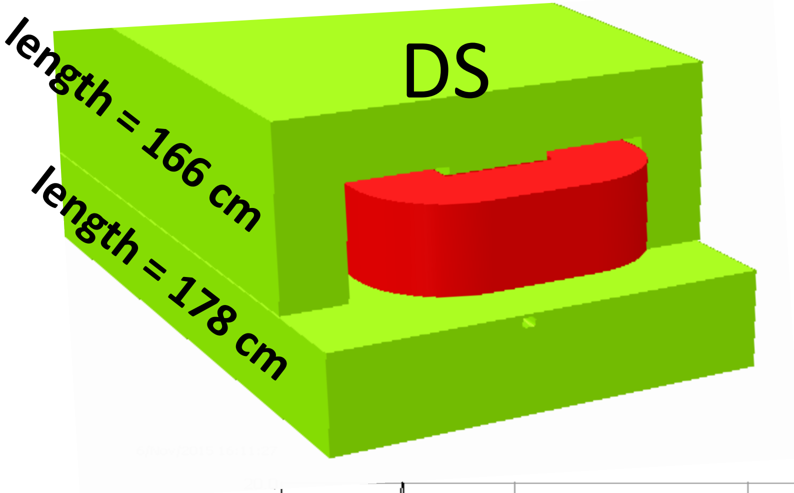
Scheme 2: Changed the material of the stored beam chamber from steel to Vanadium permendur.

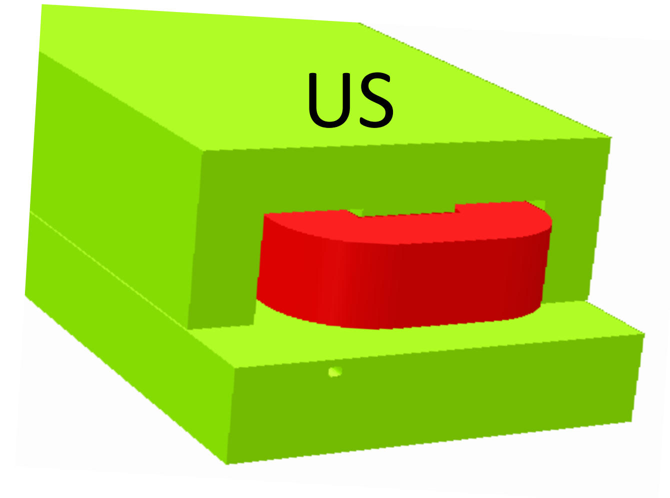
Scheme 3: Introduced a unique shaped air pocket around the stored beam chamber

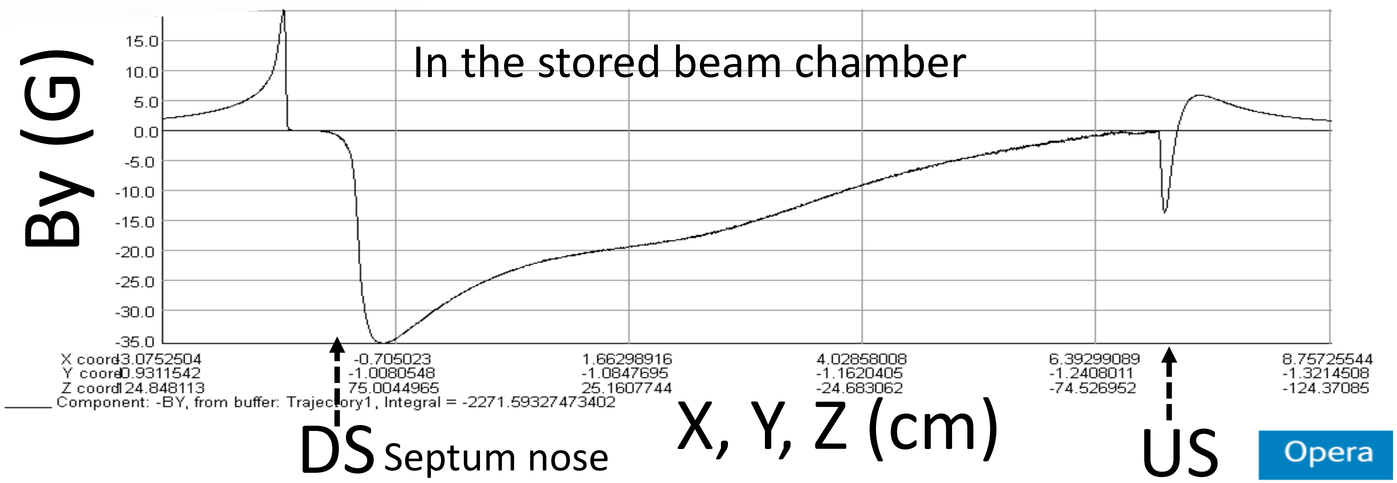
Technical Skill: Created a post processing code that accurately reads computed fields and their integrals along the particle trajectories, and successfully applied it to the field evaluation of the septum magnet.

Scheme 1

The effect of field leakage on the stored beam was decreased to 114 μrad.



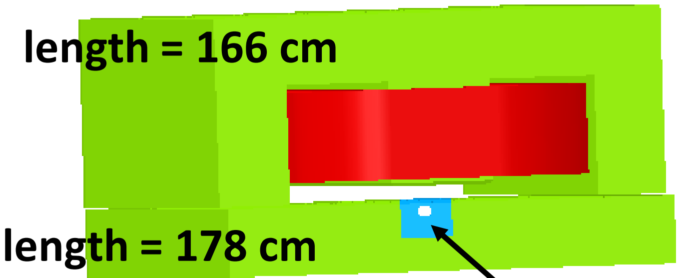


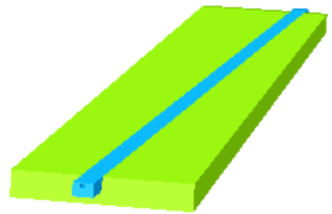


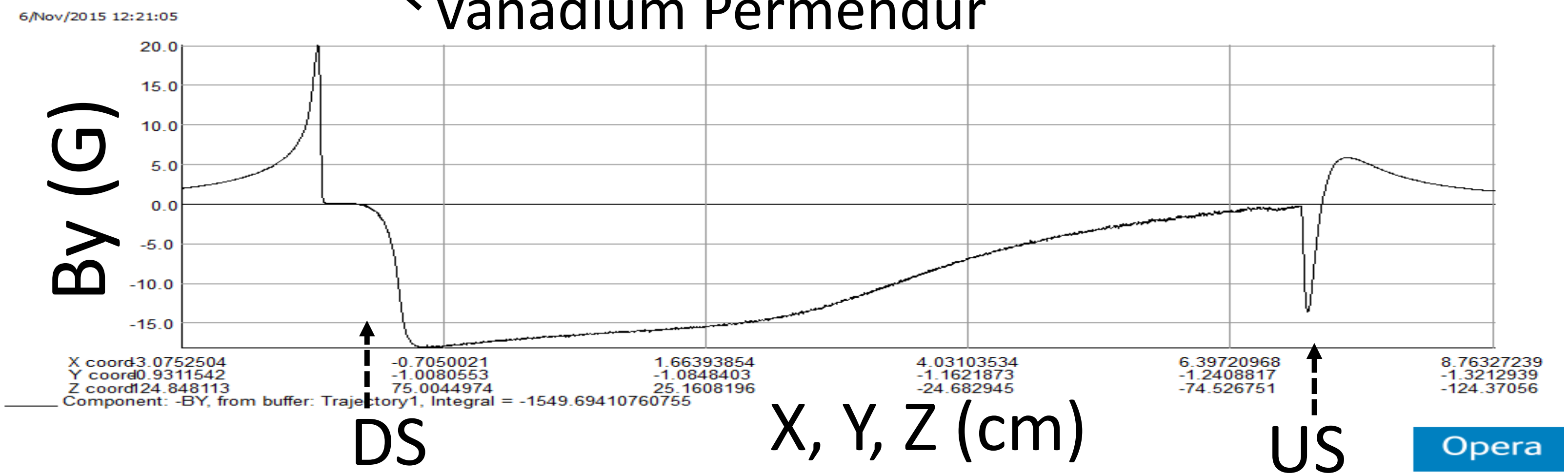
- **Integrated By field inside the stored beam chamber = 2271 G-cm.**
- **The peak field at the septum nose is decreased to 35 G from 1600 G. STILL NOT ACCEPTABLE!**

Scheme 2

The effect of field leakage on the stored beam was decreased to 77 μrad.





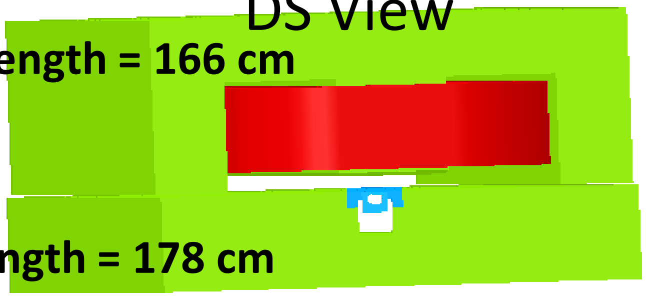


- Integrated By field inside the stored beam chamber = 1549 G-cm.
- The peak field at the septum nose is decreased to 17 G from 1600 G. ACCEPTABLE!

Scheme 3

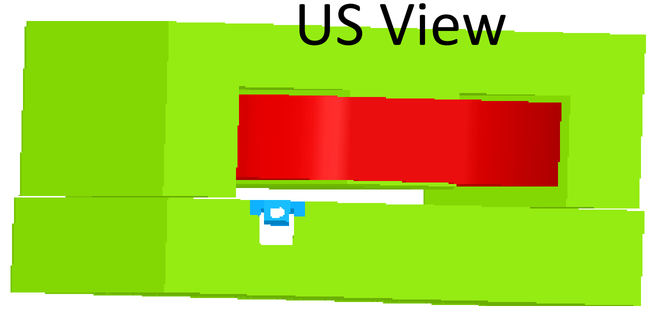
The effect of field leakage on the stored beam was decreased to 19 μrad.

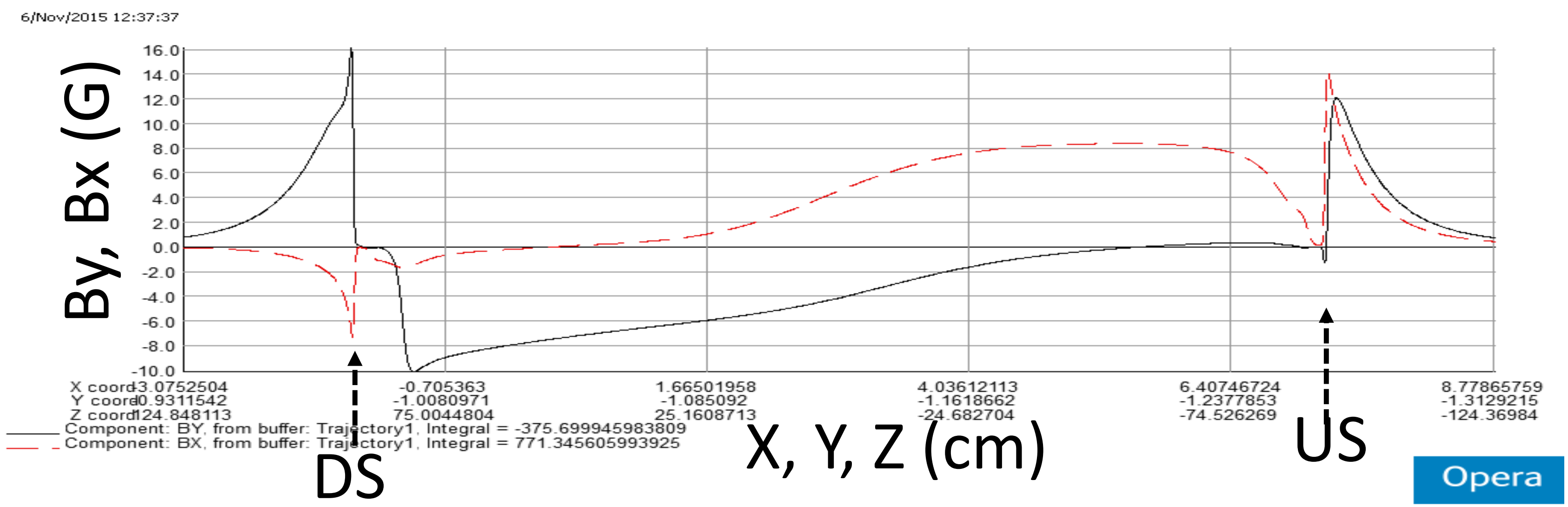
DS View



Enlarged DS View

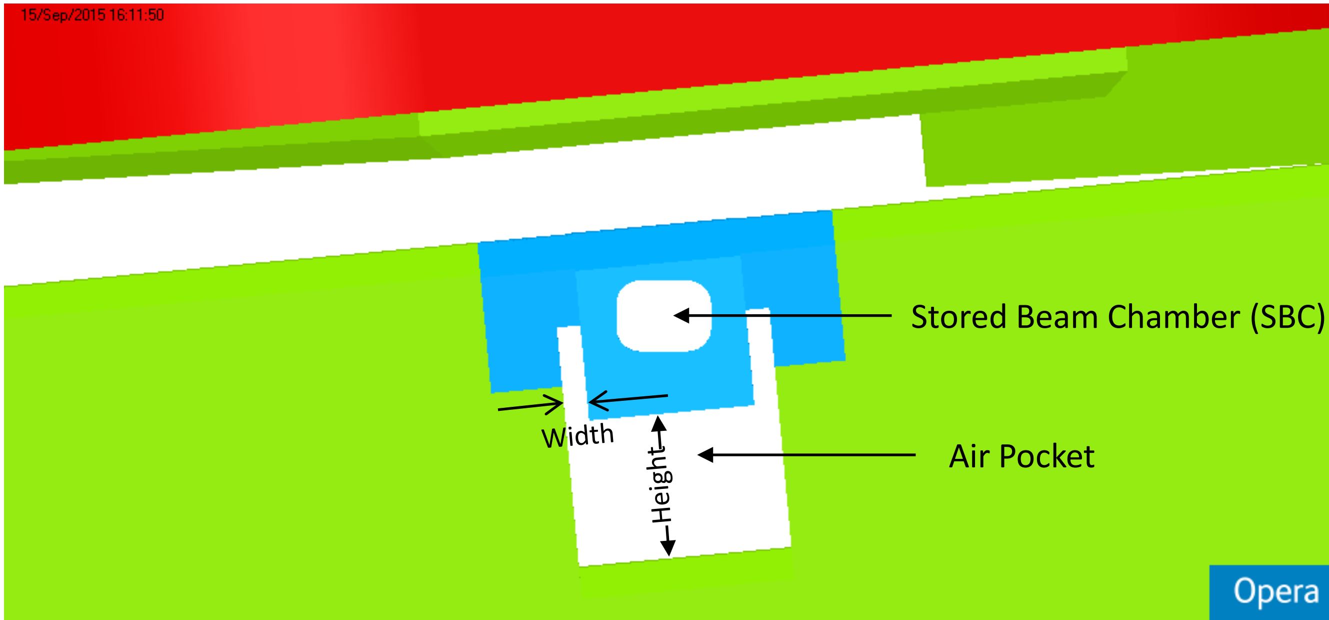
US View



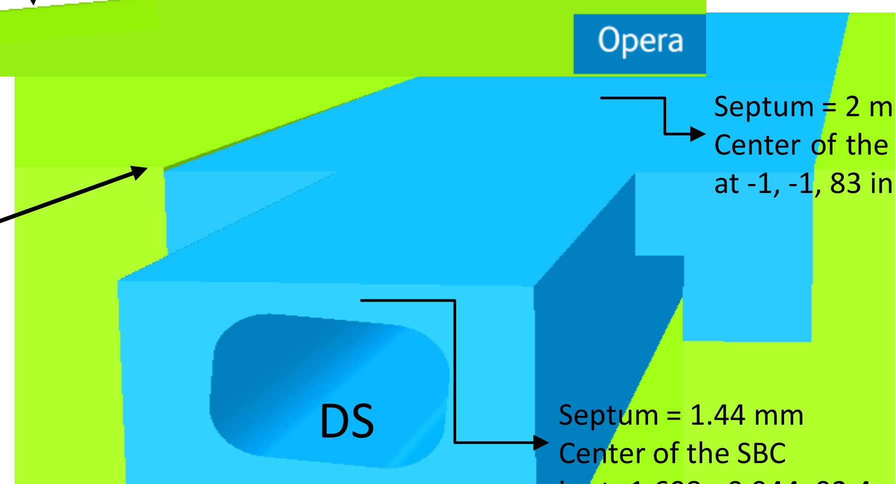


- Integrated By field inside the stored beam chamber = 375 G-cm.
- The peak field at the septum nose is decreased to 10 G from 1600 G. ACCEPTABLE!

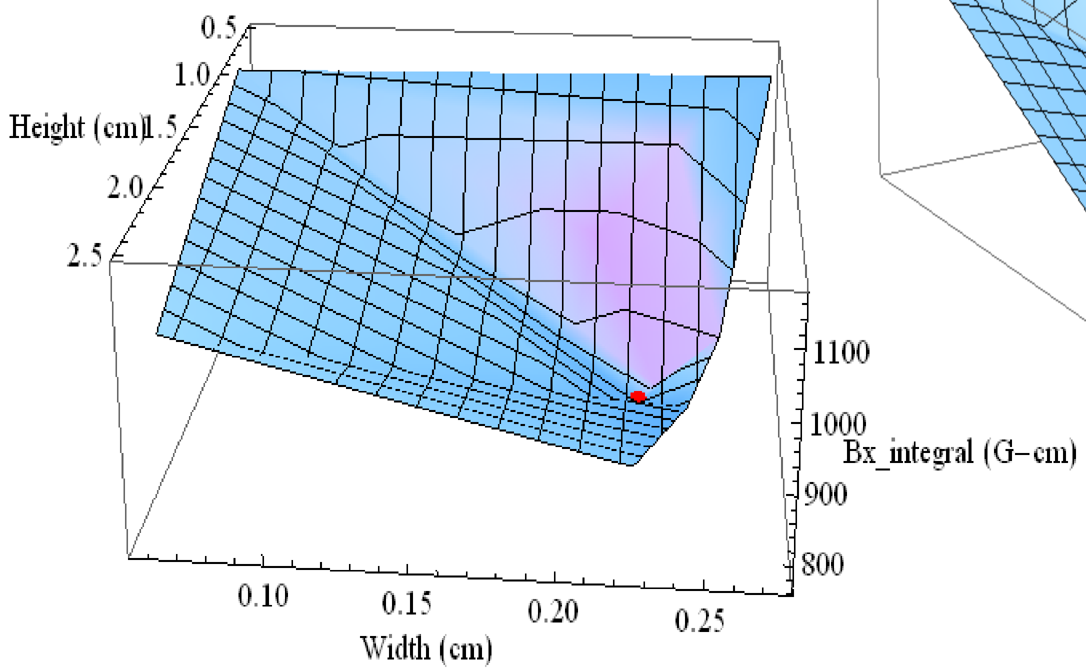
DS view with an optimized width x height of 2.25 mm x 15 mm of the air pocket

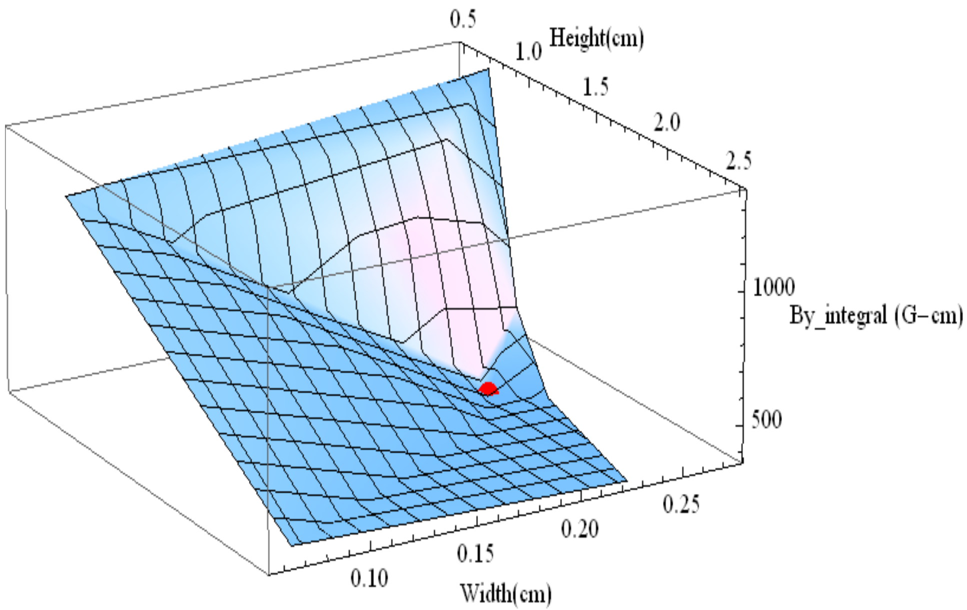


A thin triangular cut of 350 µm at DS to have a septum thickness of 1.44 mm.



Optimization of width and height of the air pocket with Opera-3D

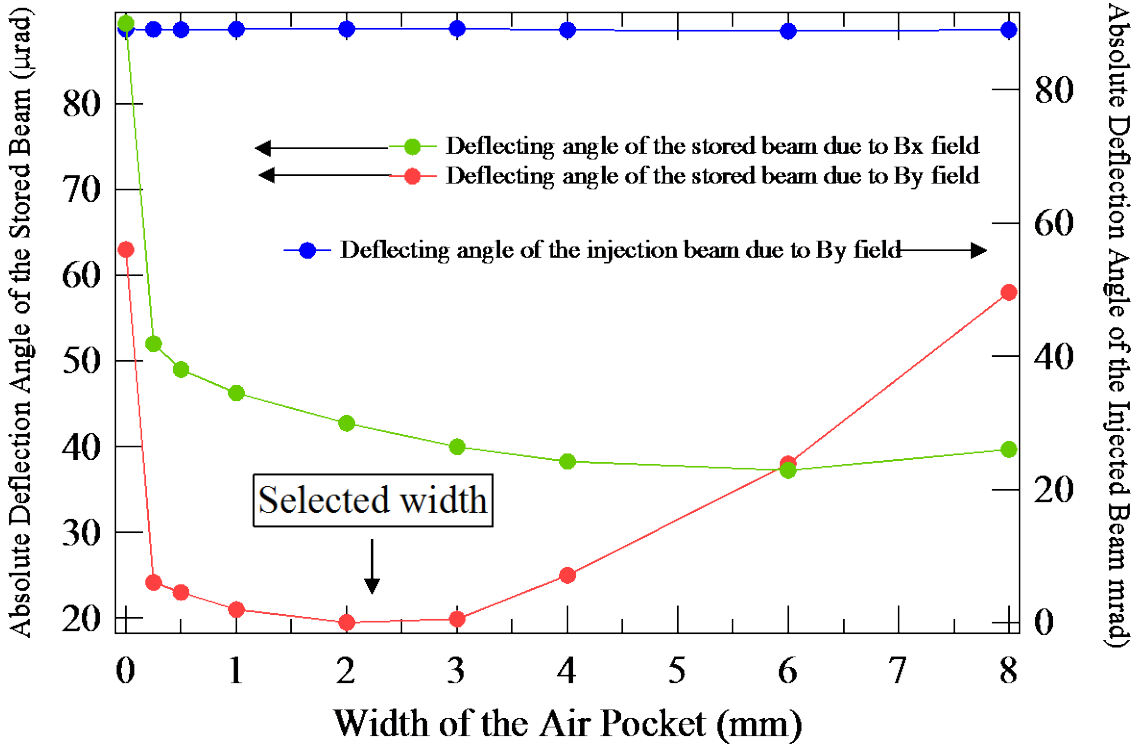




Red point: 2.25 mm /width; 15 mm/ height

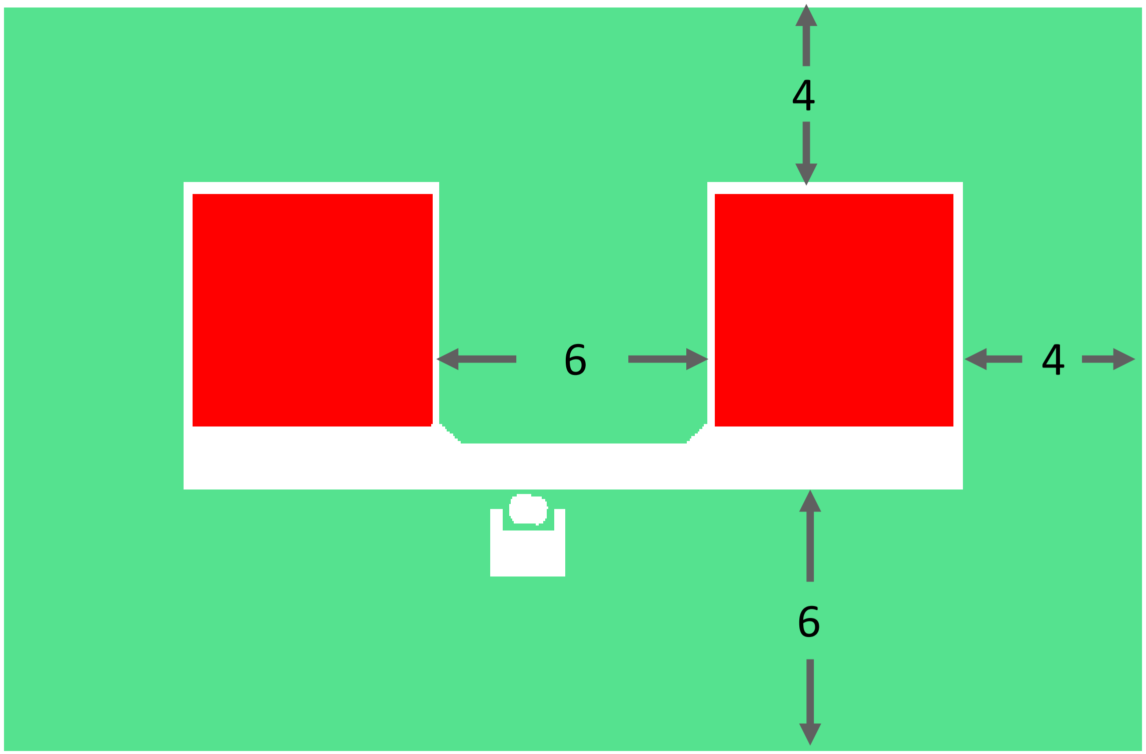
The horizontal and vertical deflecting angles at red point are 19 µrad and 39 µrad.

3D-optimization of the air pocket's width
Height of the air pocket = 15mm

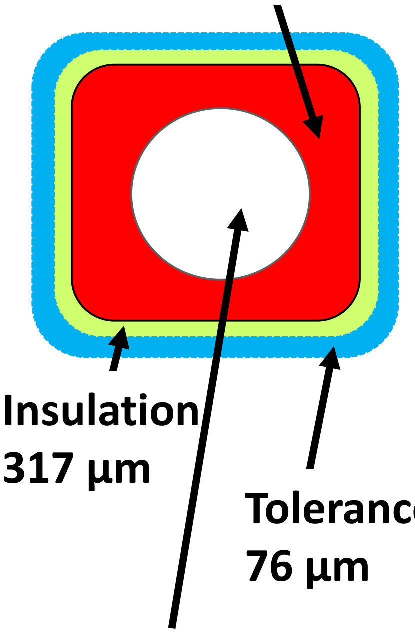


The field leakage (deflecting angle of the stored beam) of By shows minimum around 2 mm width of the air pocket. The deflecting angle of the injected beam is optimized to 89 mrad at each different width of the air pocket.

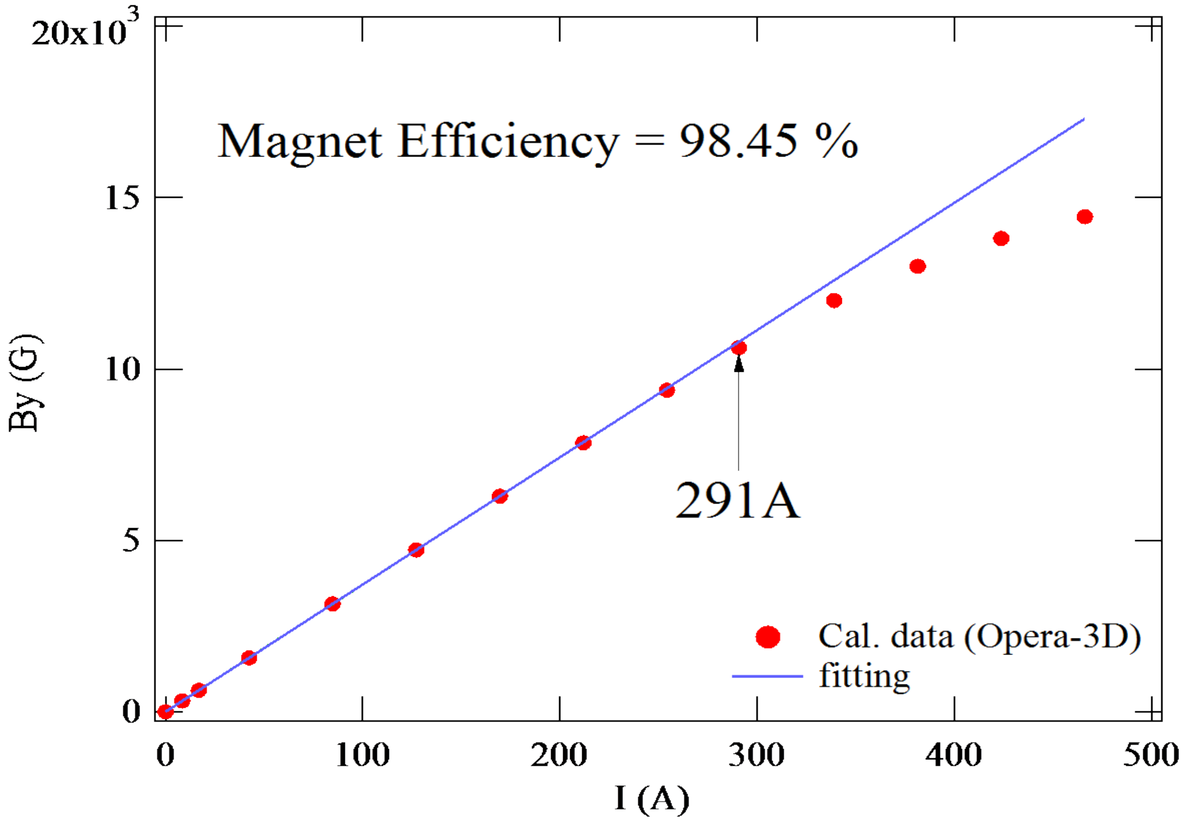
Optimized yoke dimensions; 33 turns coil
Air pocket's width x height = 2.25 mm x 15 mm



G10 :508 µm
3 layers half lap fiberglass : 1.067 mm

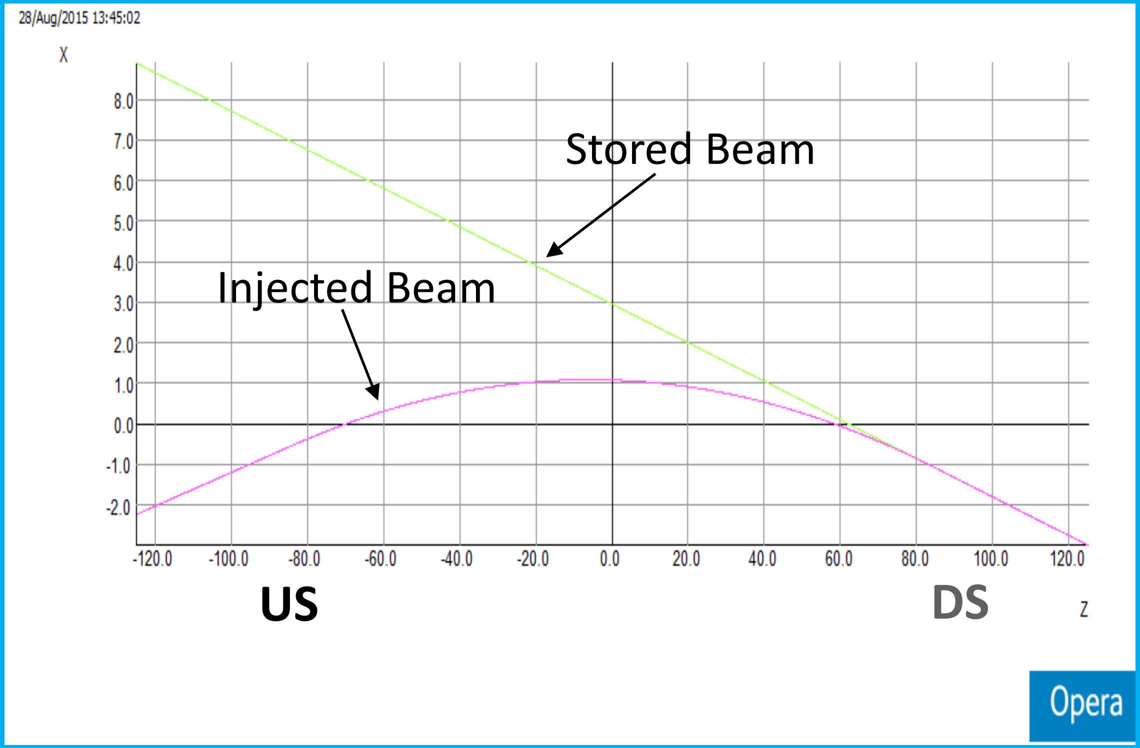


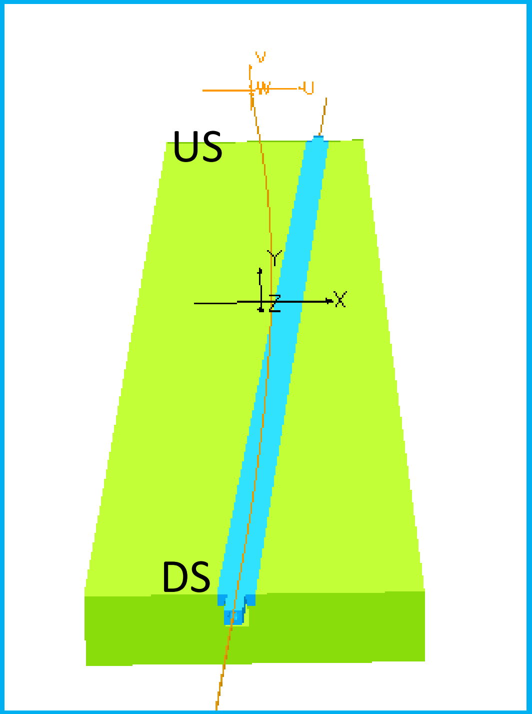
Achieved required magnet efficiency with the design



Number of turns (3 layered pancake coil)	R (mΩ)	I(A)	V (V)	P (kW)	Current density (A/cm^2)	Coil temperature (C°)
33	59	291	17	4.9	876	32

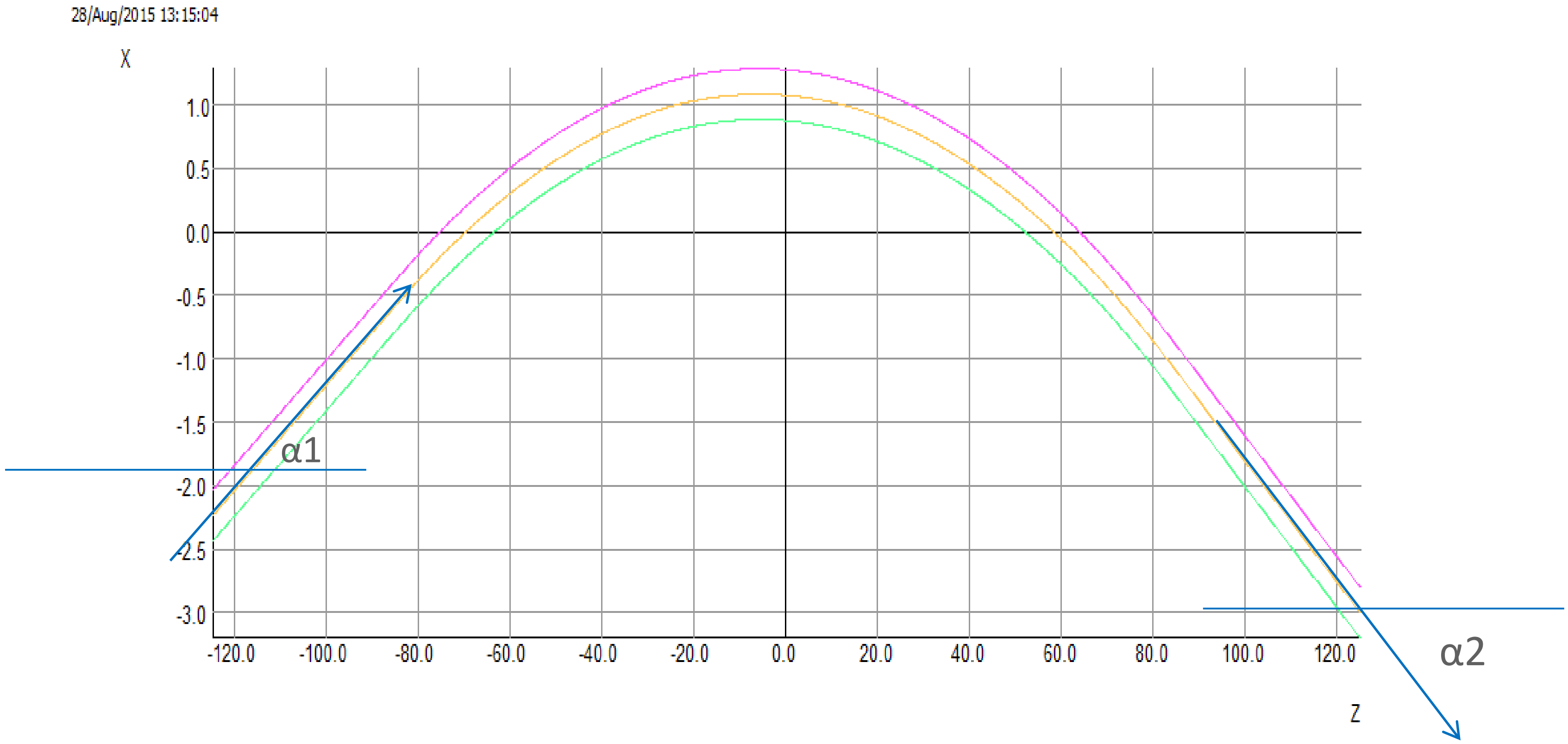
Trajectory of the Injected and Stored Beams





The trajectory of the stored beam is straight along the length of the stored beam chamber. The injected beam trajectory overlaps with the stored beam trajectory at the DS end of the septum magnet.

The required -89 mrad angle achieved from the trajectory of the injected beam

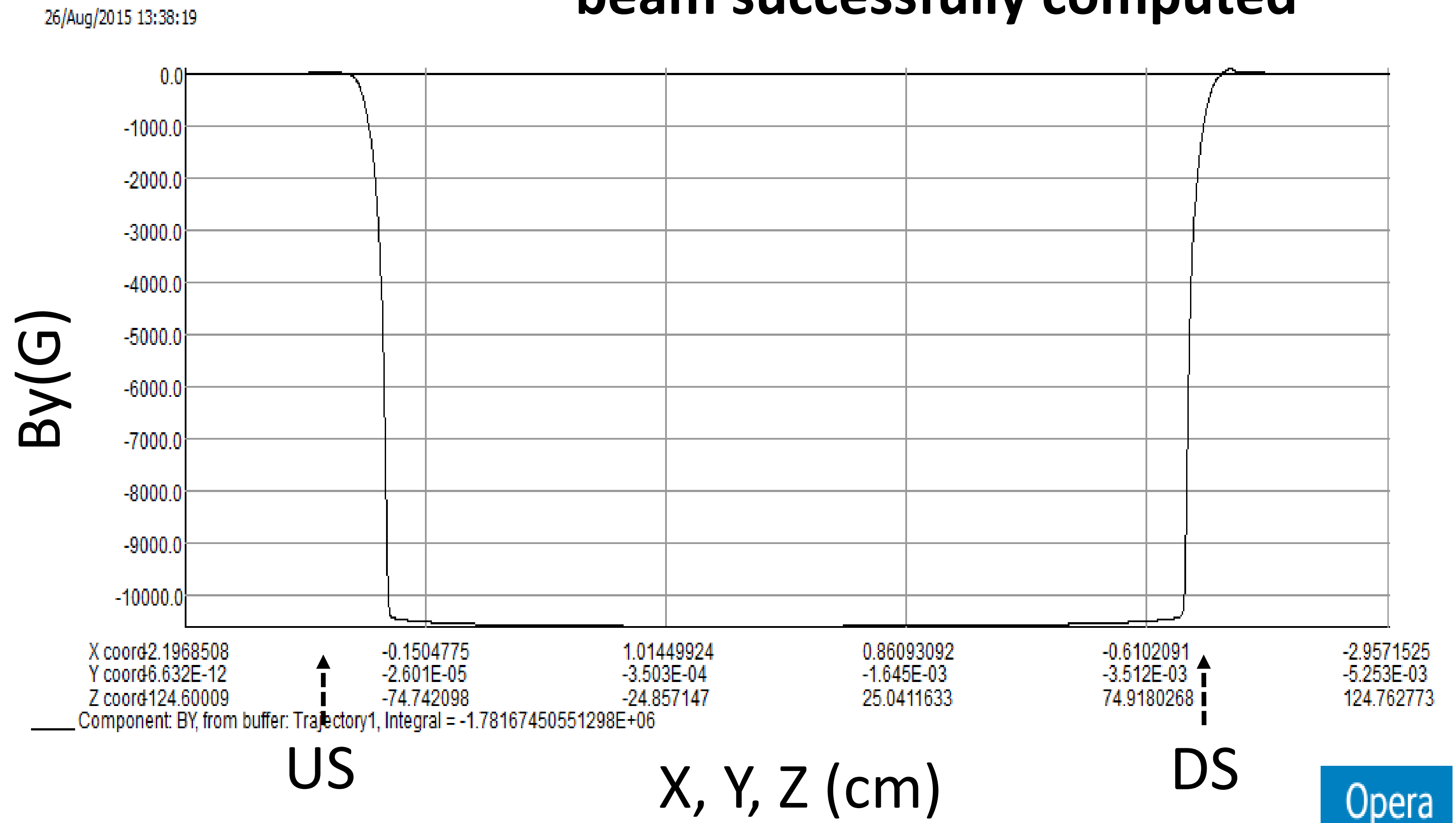


Total deflecting angle is : -α2 – α1 = -89.086 mrad.

Vertex position (2.9497, 0.0125) in (x, z) in cm.

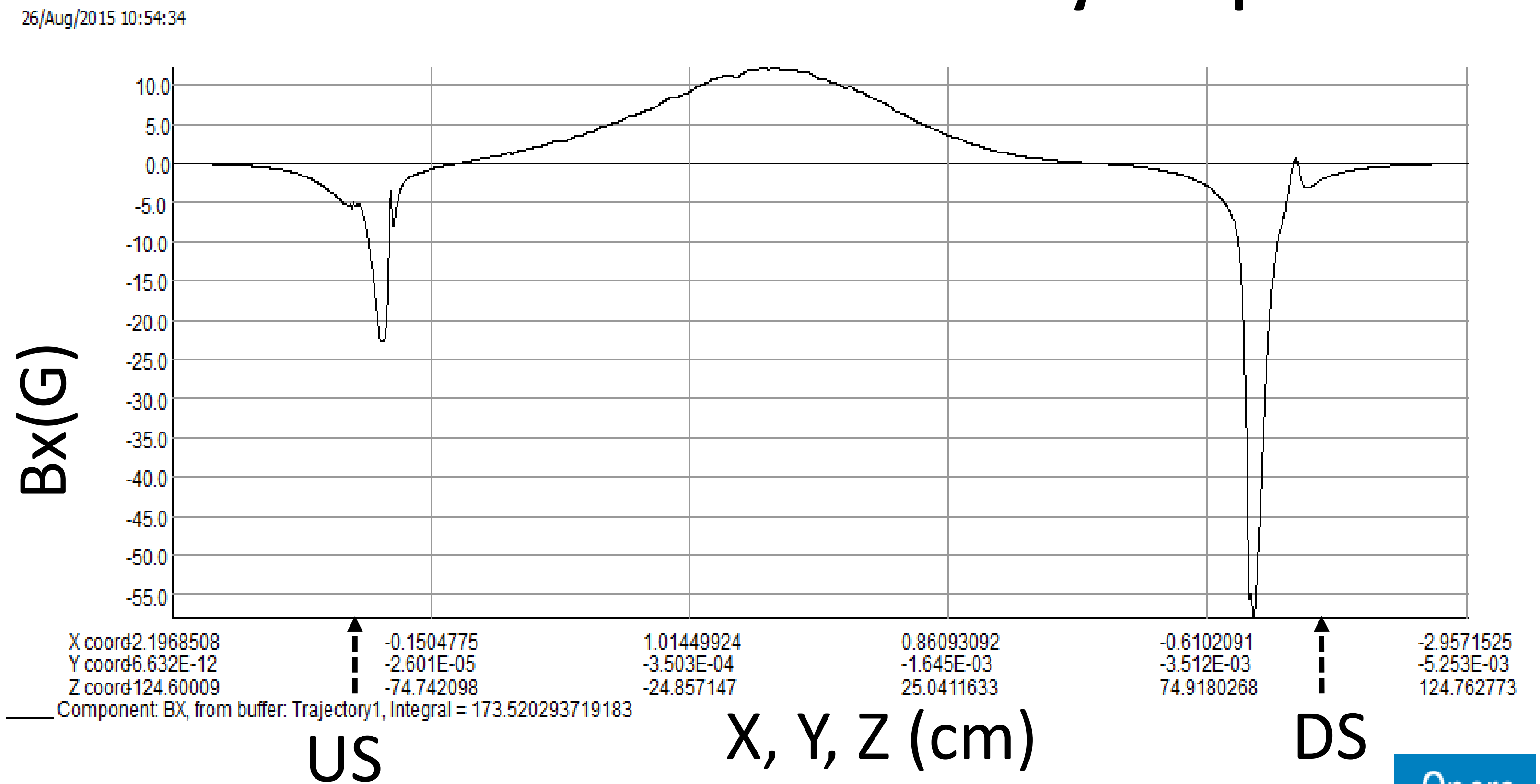
Opera

Technical Skill: **By field along the trajectory of the injected beam successfully computed**



The required total horizontal deflecting angle of the injected beam of 89 mrad is confirmed.

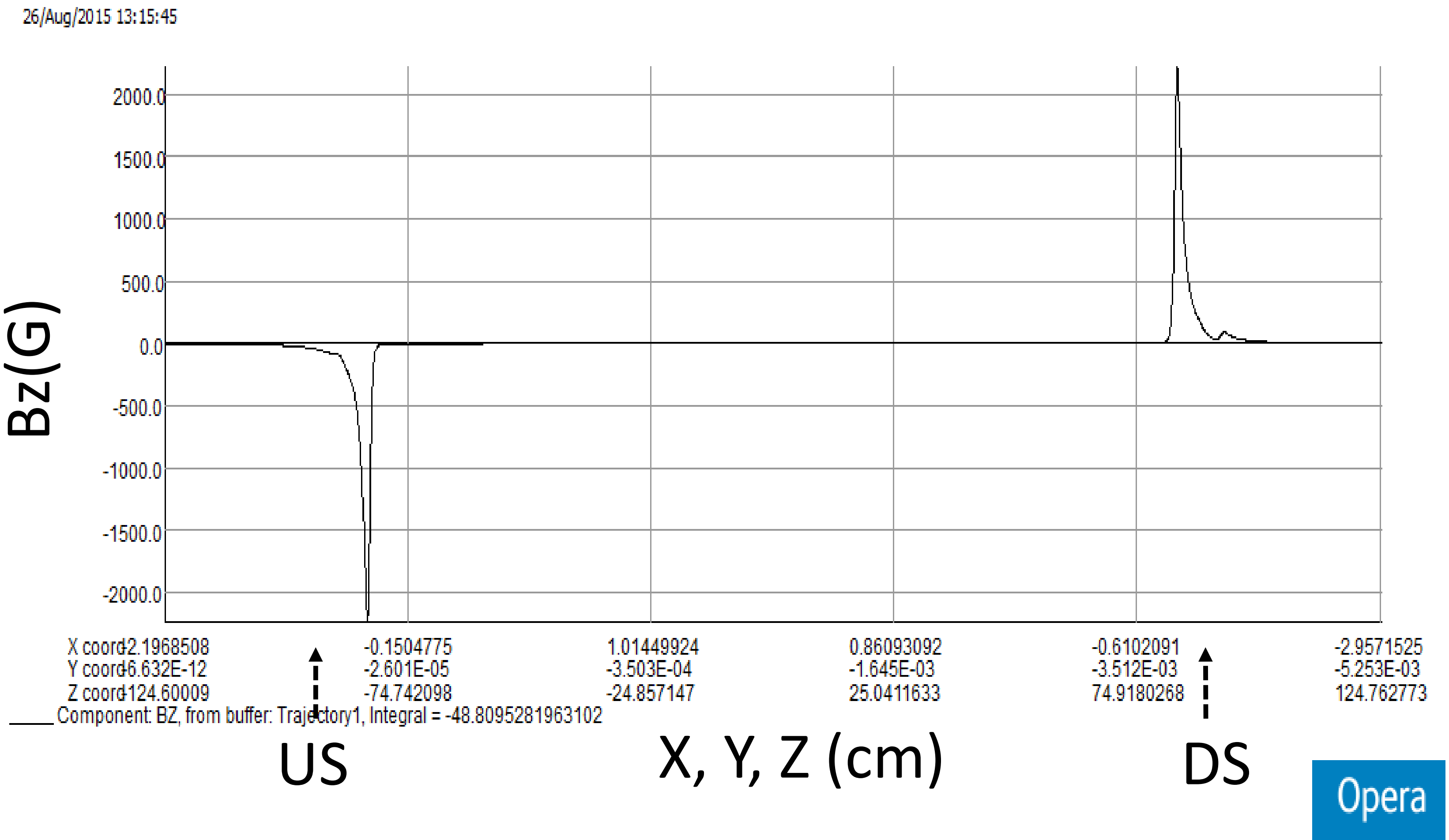
Technical Skill: **Bx field along the trajectory of the injected beam successfully computed**



Total vertical deflecting angle of the injected beam is 8 μrad which is 0.009% of the total horizontal deflecting angle.

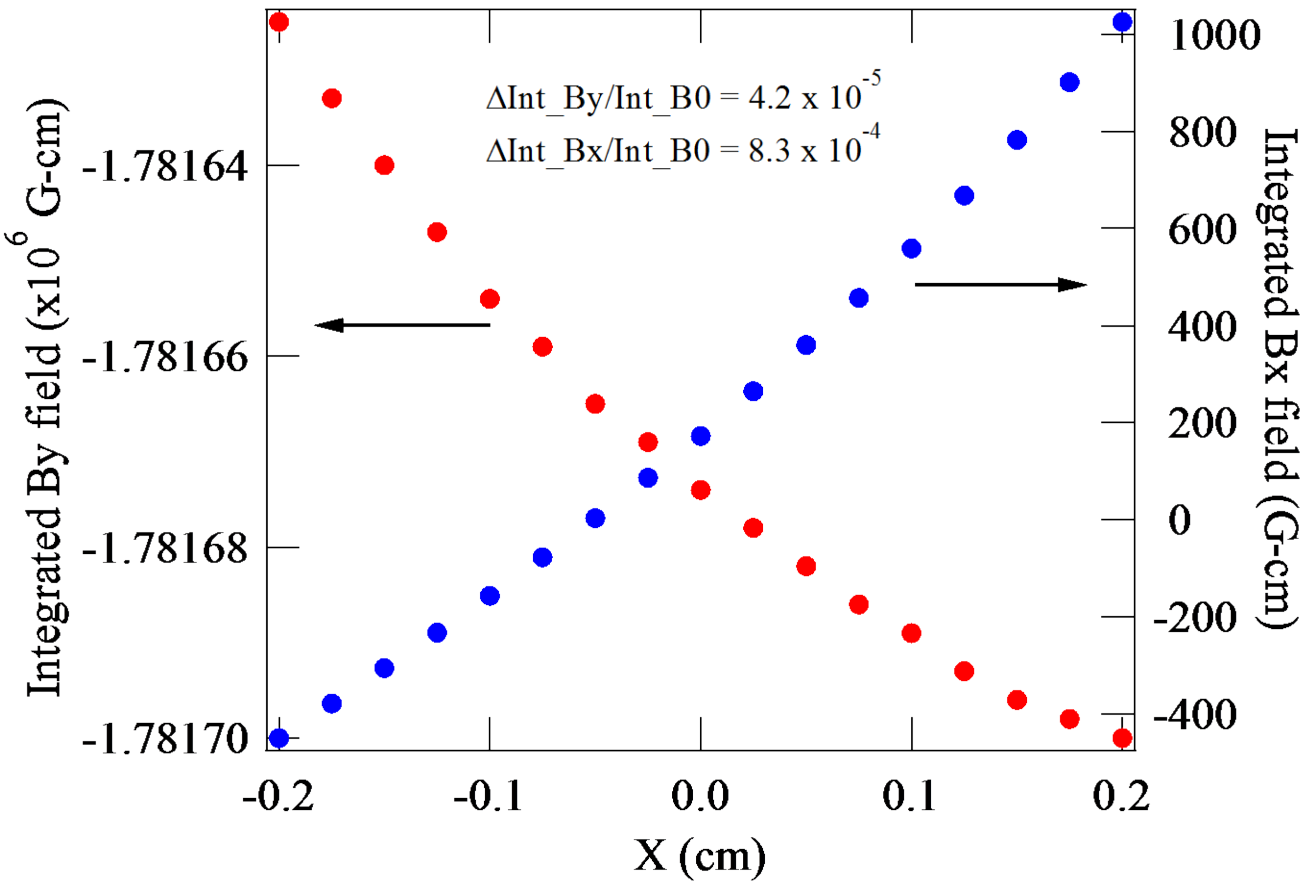
Technical Skill:

Bz field along the trajectory of the injected beam successfully computed



More than 2000 G of Bz field reverses its signs at the core edges due to the flux return.

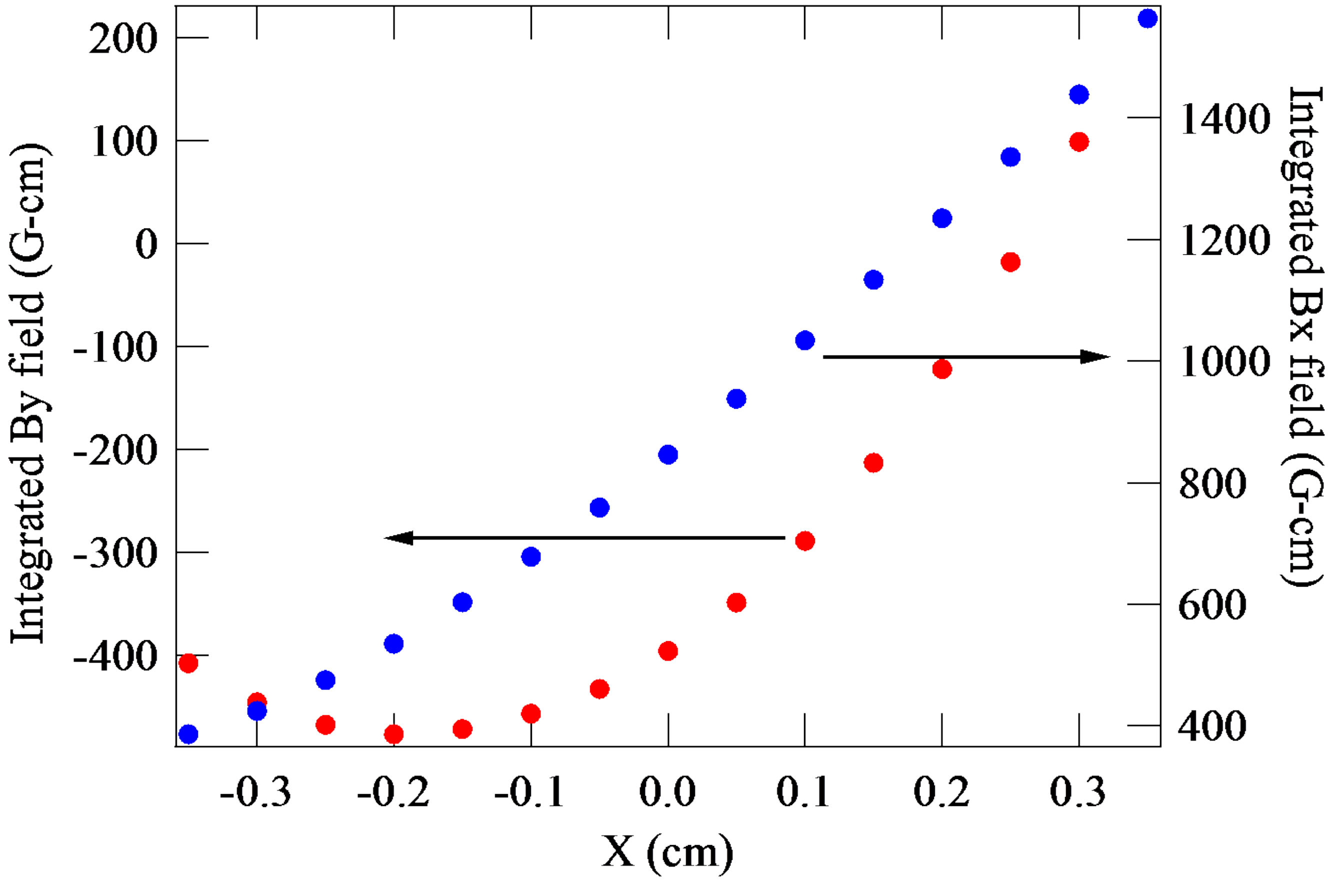
Field uniformities of the integrated Bx and By fields along the length of the magnet within the requirement



Normalized multipoles of the injection field are small enough compared to the dipole fields with the design

By field components	Fitting Coefficients $G*(cm)^{-n+1}$	$10000*(b_n/b_0)*x^n$ where X =0.2 cm
b_0	-1.7817e+6	10000
b_1	-177.81	0.1996
b_2	177.32	-0.0399
b_3	1586.9	-0.0712
b_4	8967.8	-0.0805
b_5	-2.4046e+5	0.4311
b_6	-4.6253e+5	0.1652
b_7	9.2028e+6	-0.6609
b_8	1.2799e+7	0.1839
b_9	-1.0836e+008	0.31139
b_{10}	-1.2982e+008	0.0746

Integrated Bx and By fields in the vicinity of the stored beam trajectory +/- 3.5 mm in X



The integrated field multipoles in the stored beam chamber are small enough compared to the dipole fields

b_n	$T*(mm)^{-n+1}$
b_0	-0.375
b_1	0.081
b_2	0.022
b_3	0.002
b_4	0
b_5	0
b_6	0
b_7	0
b_8	0
b_9	0
b_{10}	0

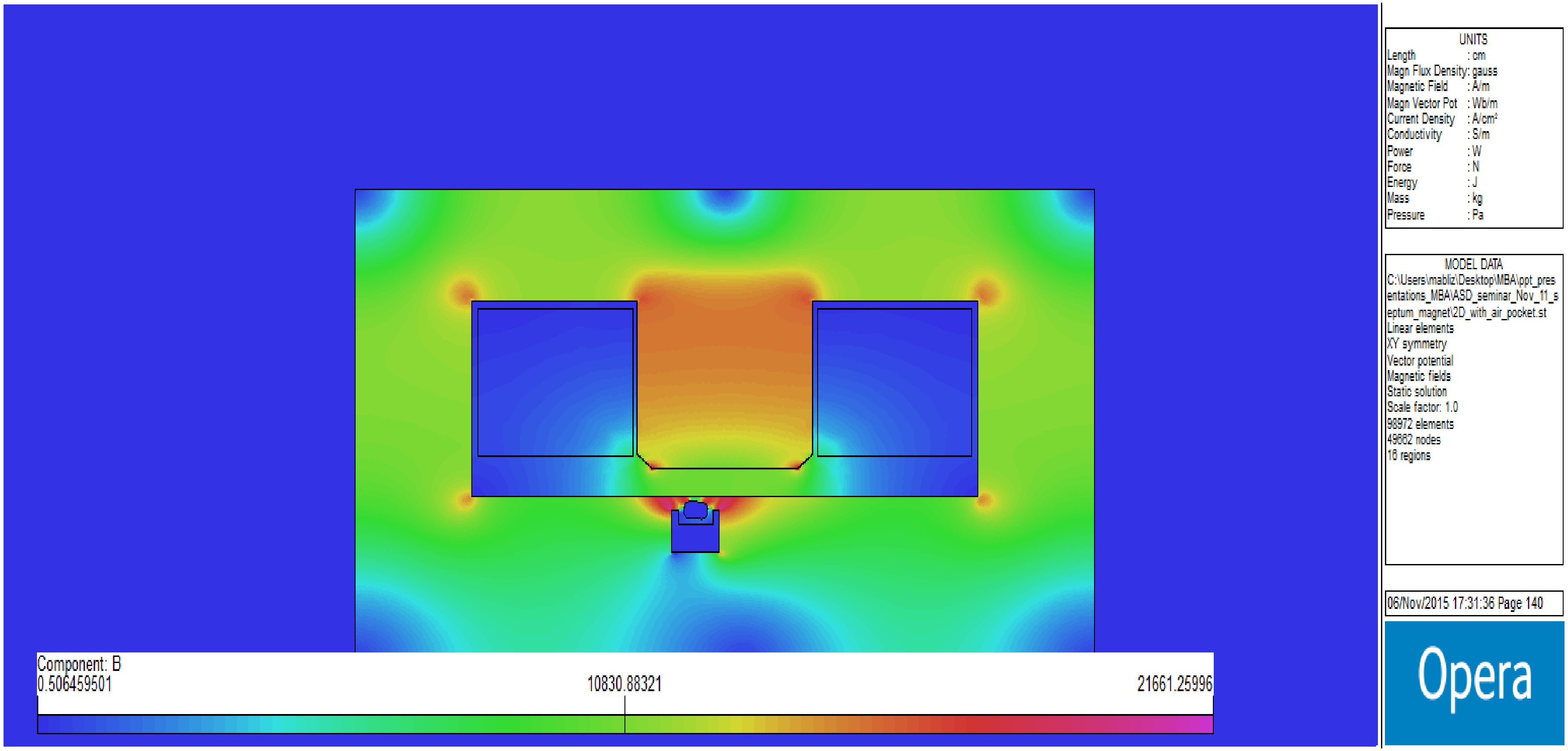
a_n	$T*(mm)^{-n+1}$
a_0	0.771
a_1	-0.162
a_2	0.01
a_3	0
a_4	0
a_5	0
a_6	0
a_7	0
a_8	0
a_9	0
a_{10}	0

Conclusion

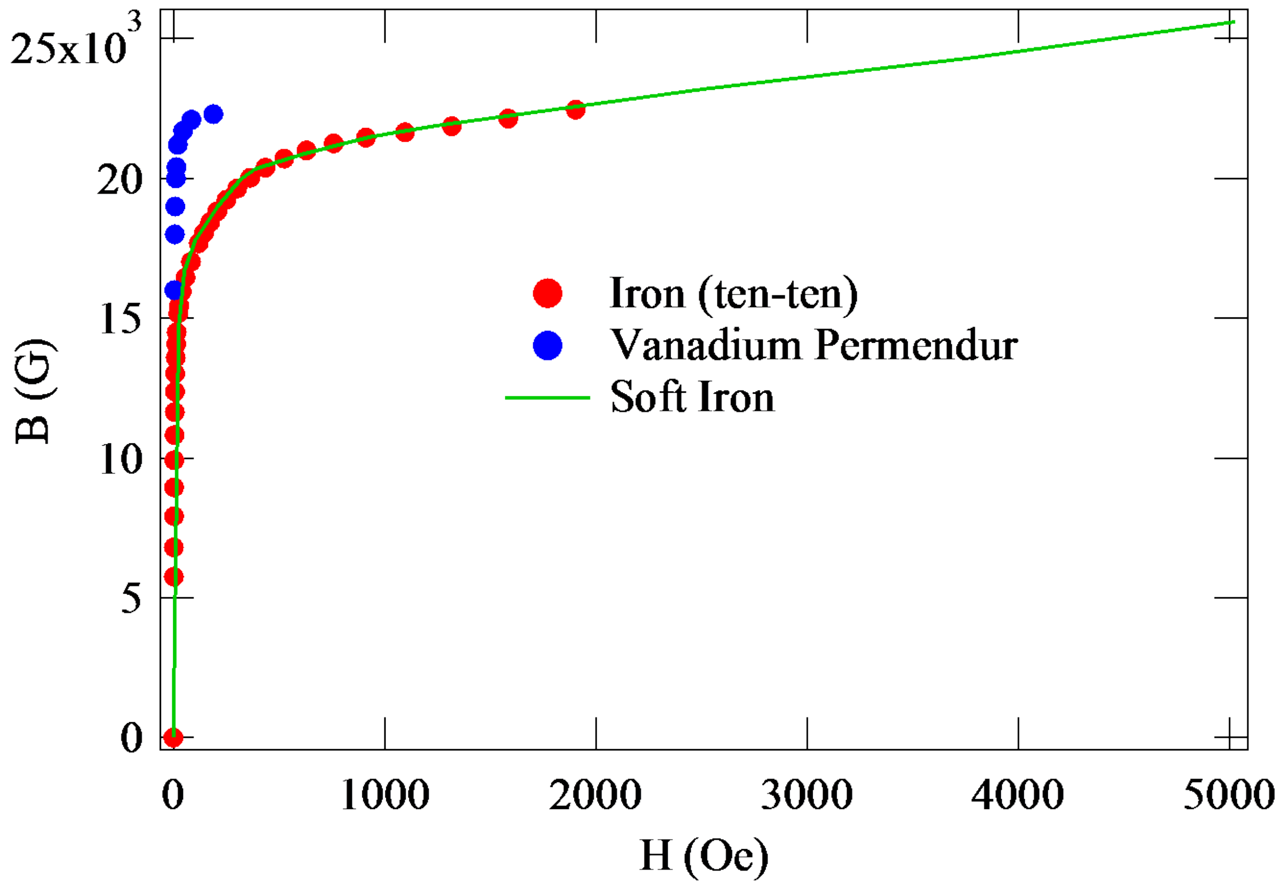
- ✓ A septum magnet was designed for APS-U with the required parameters.
- ✓ Three unique schemes fixed the excessive field leakage inside stored beam chamber.
- ✓ All the dimensions of the design were optimized to get a magnet efficiency more than 98% and lower the field leakage to a minimum level.
- ✓ The program that I created traced the trajectory and read the fields of Bx, By, and Bz along the trajectory successfully.
- ✓ The angle and position in x of the injected beam matched with the stored beam's angle and position in x with a precision of 0 µrad and 2 µm at the DS end.
- ✓ The calculated field multipoles in the stored beam chamber showed about 20% normal and skew quadrupole compared to normal and skew dipole fields. This is due to the rotation of 93 mrad of the magnet in XY-plane. We can do nothing about these quadrupole fields inside the stored beam chamber.
- ✓ Finally, we found the way to decrease the effect of field leakage to 19 µrad from 369 µrad with such a high injection field of 1.06 T and a very thin septum of 2 mm.

Thank You!

Flux Density Around Stored Beam Chamber With the Three Schemes



BH-Curves



25x10^3
20
15
10
5
0
B (G)
0
1000
2000
3000
4000
5000
H (Oe)
Iron (ten-ten)
Vanadium Permendur
Soft Iron

Leakage field inside the stored beam chamber