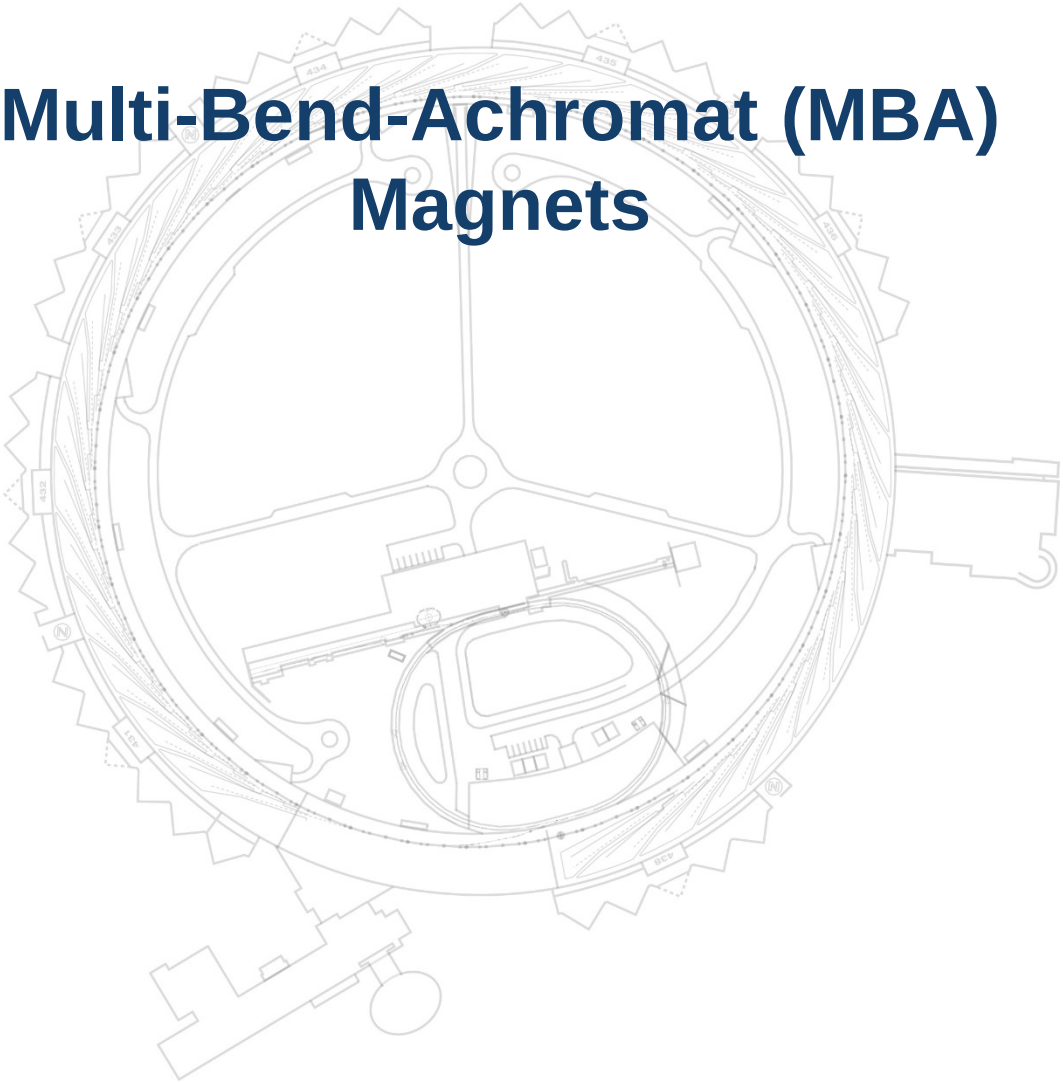
Multi-Bend-Achromat (MBA) Magnets

Mark Jaski



Outline

- Multi-Bend-Achromat (MBA)
- Functional Requirements Document
  - Sector Layout
  - Types of Magnets
  - Magnet requirements
- Magnet Designs
- Modular design
- Coil Designs
- Alternative design (MAX-IV style)
- Assembly concept

The APS Upgrade: The world's leading high-brightness hard x-ray storage ring

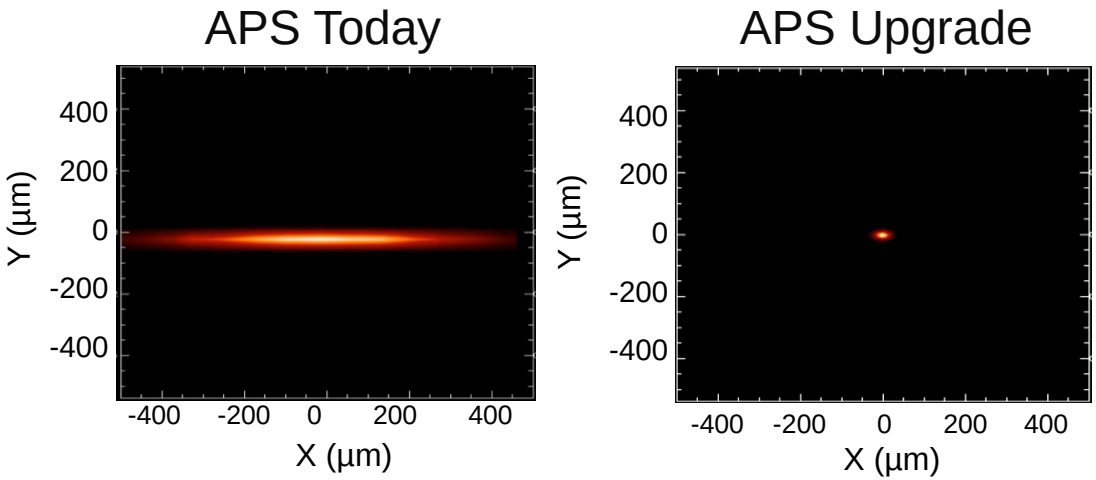
The APS Upgrade will produce the world's leading high-brightness hard x-ray storage ring

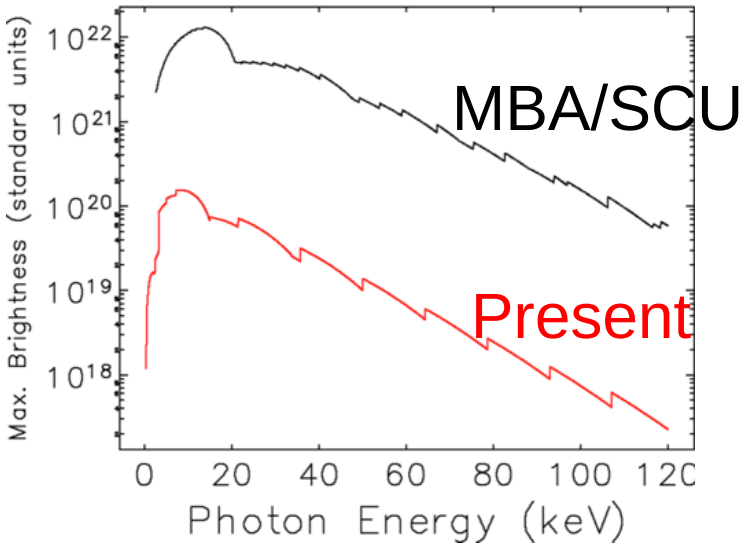
2-3 order-of-magnitude increase in:

- Brightness
- Coherent flux
- Nano-focused flux

Operation with round beams

APS-U ushers in a generational leap in storage ring performance





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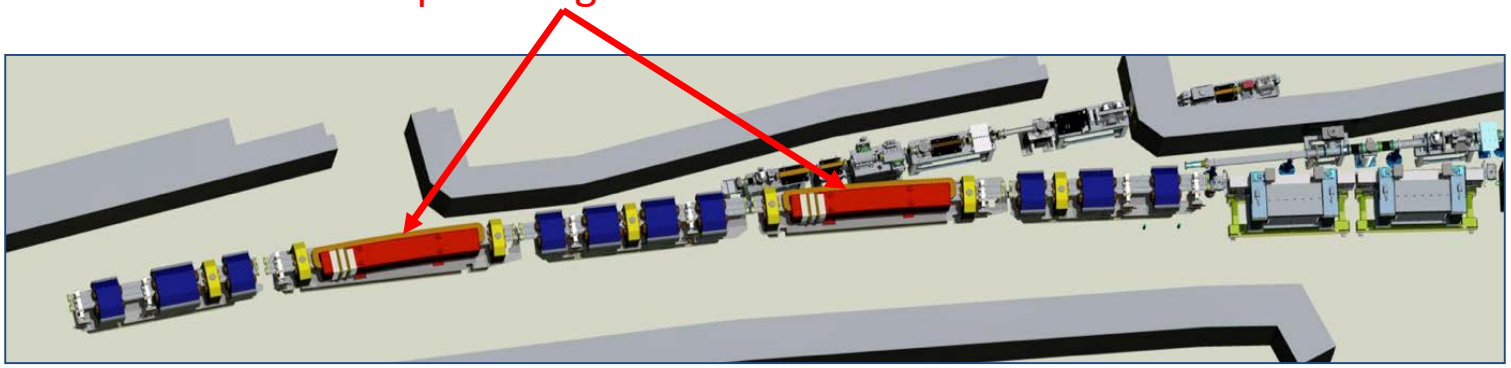
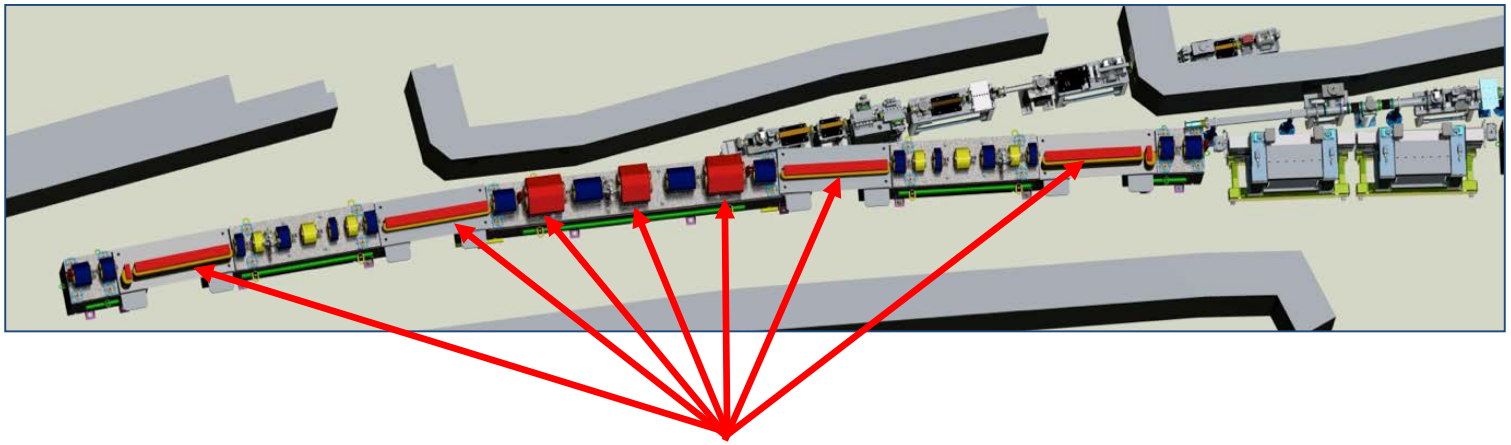
Multi-Bend-Achromat (MBA)

two dipole magnets – double-bend-achromat





Seven dipole magnets – multi-bend-achromat (MBA)

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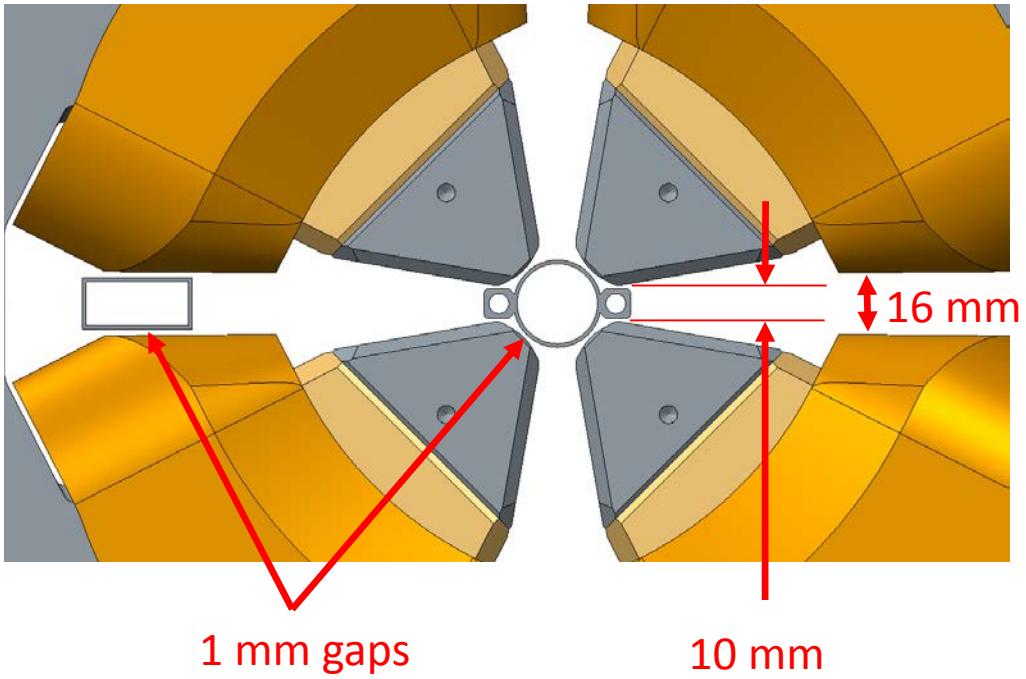
Multi-Bend-Achromat (MBA)

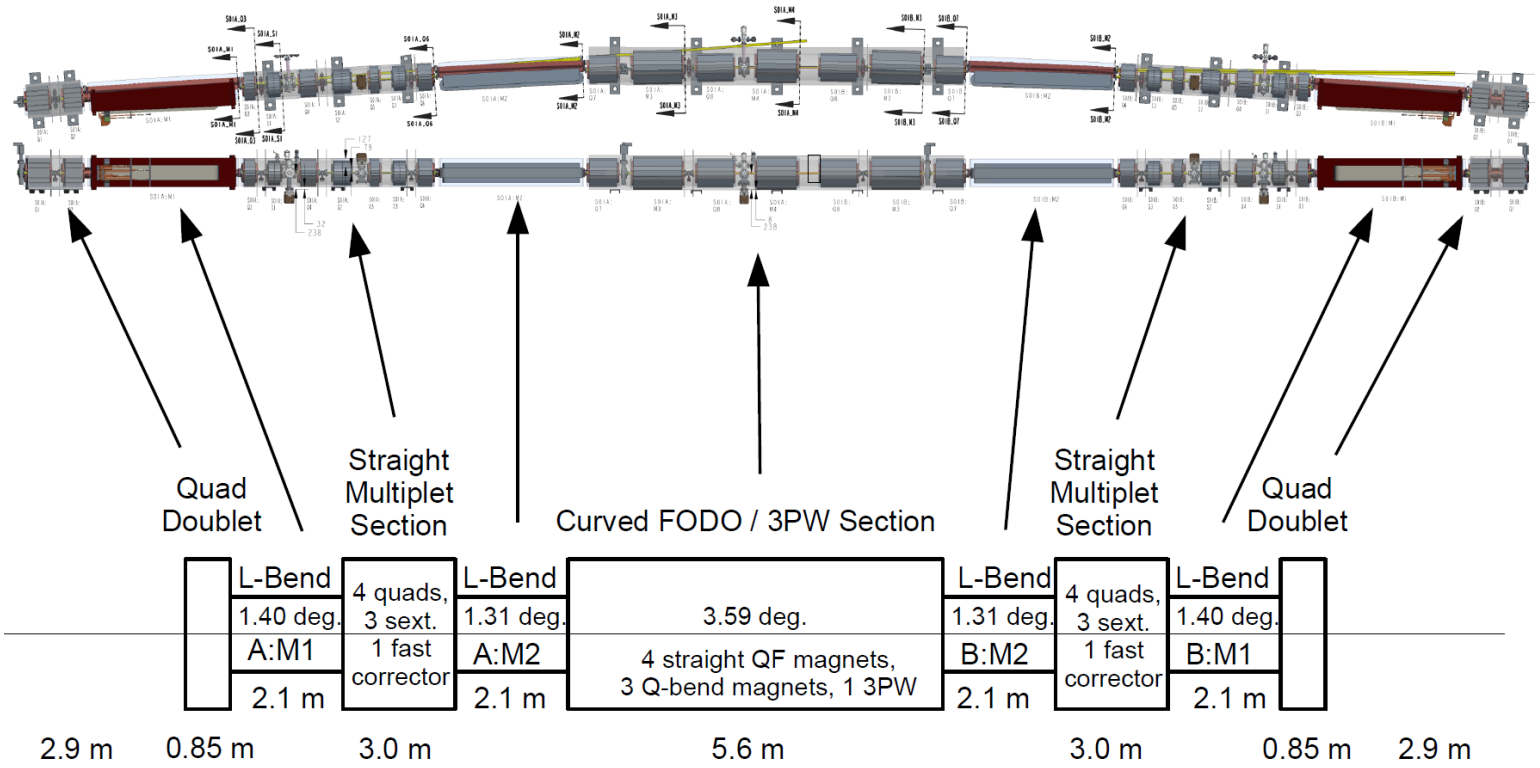
- To go to lower emmitance.
- Requires stronger magnets
- Smaller magnet gaps.
- Tighter tolerances.
- Small gaps between vacuum chamber and magnet poles and magnet coils.



		APS	MBA
		mm	
Dipole	gap	57.20	26.00
Quadrupole	pole tip radius	39.96	13.00
Sextupole	pole tip radius	49.00	14.00

Functional Requirements Document
Sector Layout

with block diagram showing major components



Functional Requirements Document
9 Magnet Types
1320 Total Storage Ring Magnets

Table 1.1: Types of magnets

	Magnet type	Quantity	Core type
L-Bend magnets	M1 Longitudinal dipoles	80	Solid
	M2 Longitudinal dipoles	80	Solid
Q-Bend magnets	M3 Transverse-Gradient dipoles	80	Solid
	M4 Transverse-Gradient dipoles	40	Solid
	Quadrupole 0.592 m	80	Solid
	Quadrupole 0.438 m	80	Solid
	Quadrupole 0.238 m	480	Solid
	Sextupole 0.256 m	240	Solid
Not Presented Here →	Fast Corrector	160	Laminated

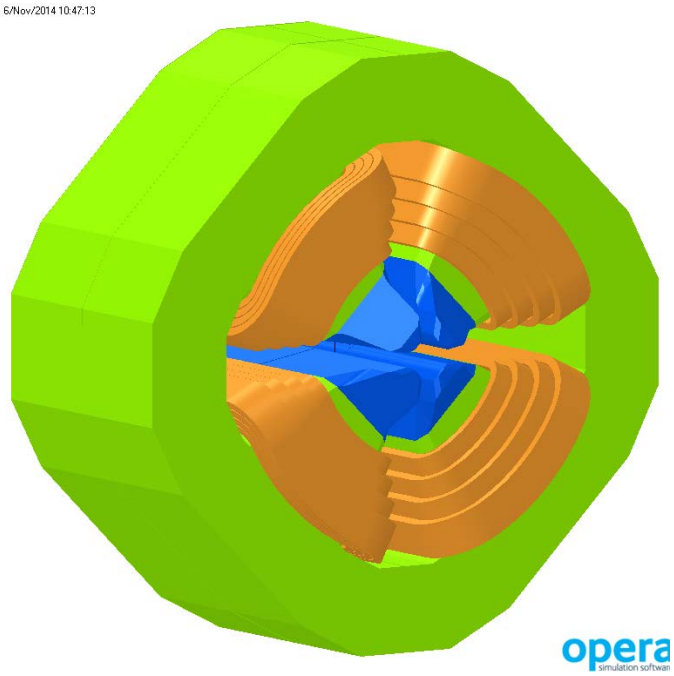
Functional Requirements Document
Quadrupole magnet requirements

Element Name	Length* m	K_1 $1/m^2$	B' T/m	B'L T	Count
Q1	0.238	3.601	-72.1	-17.16	80
Q2	0.238	-2.787	55.8	13.28	80
Q3	0.238	-2.256	45.1	10.75	80
Q4	0.238	3.203	-64.1	-15.26	80
Q5	0.238	1.693	-33.9	-8.07	80
Q6	0.238	-2.444	48.9	11.64	80
Q7	0.438	3.562	-71.3	-31.22	80
Q8	0.592	4.086	-81.8	-48.41	80

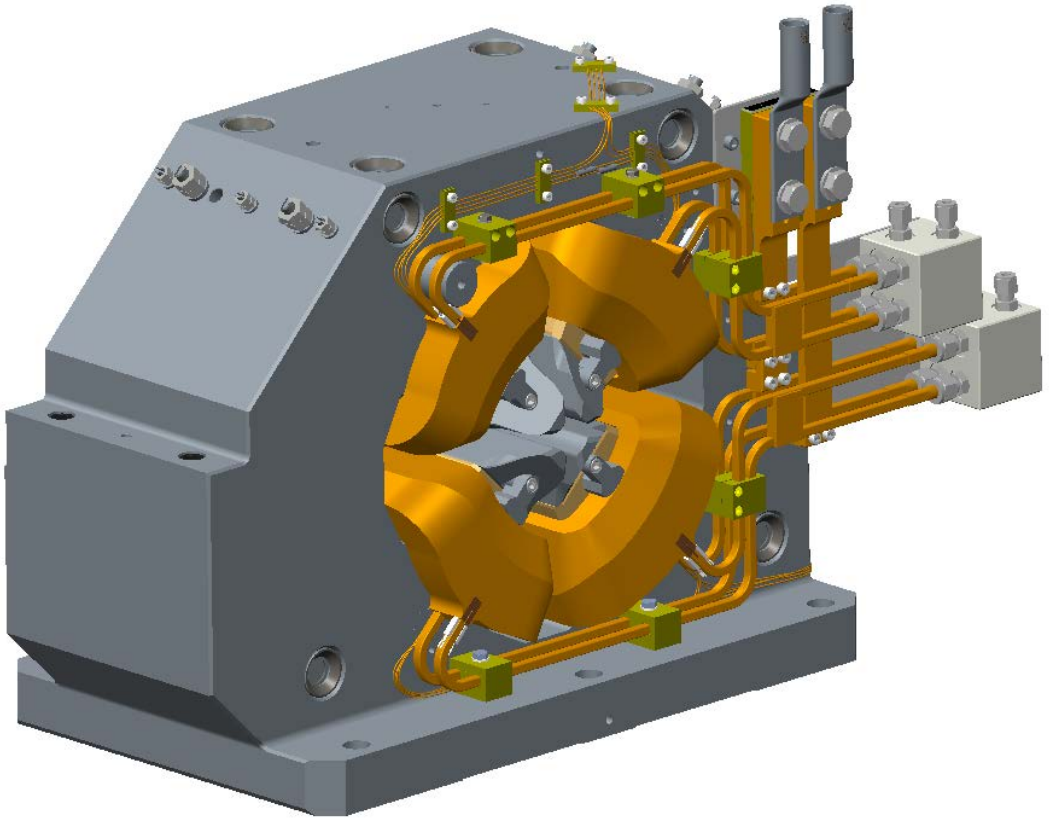
Similar tables are given for sextupole, L-bend, and Q-bend magnets

Provided by M. Borland

MBA Quadrupole Magnets
0.238 m long



DMM Quadrupole Magnet OPERA Model



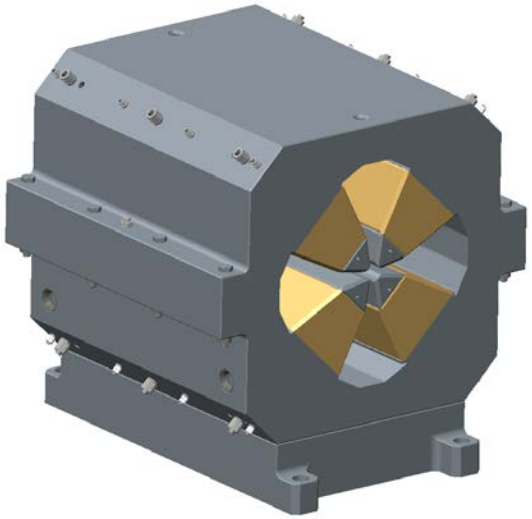
DMM Quadrupole Magnet
Under construction

Q1 Quadrupole Magnet
Vanadium permendur pole tips

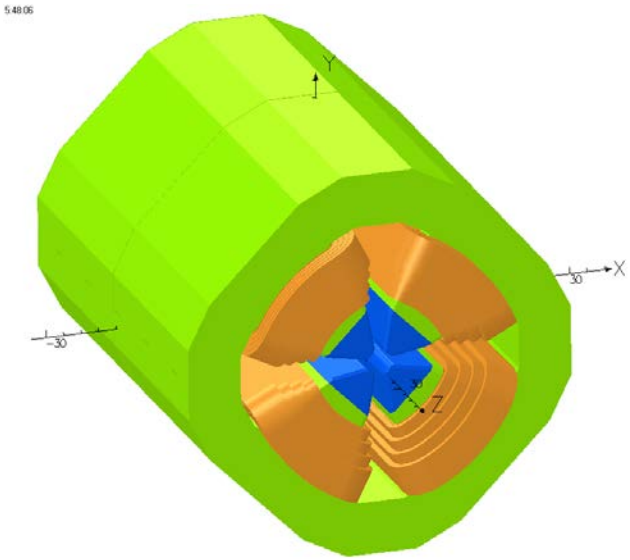
Q2 through Q6 Quadrupole Magnets
Steel pole tips

MBA V6 Quadrupole Magnets 0.592 m long (Q8)

- Q7 and Q8 quadrupole magnets.
- Use vanadium permendur pole tips because of high field (**98.9 T/m**)
- Do not use long pole tips.
- This is because it is a combined function magnet producing both a vertical and horizontal dipole field as well as a quadrupole field.
- Magnet efficiency must be kept to a maximum.
- The shorter pole tip produces a larger field at high efficiency than a long pole tip at the same efficiency.



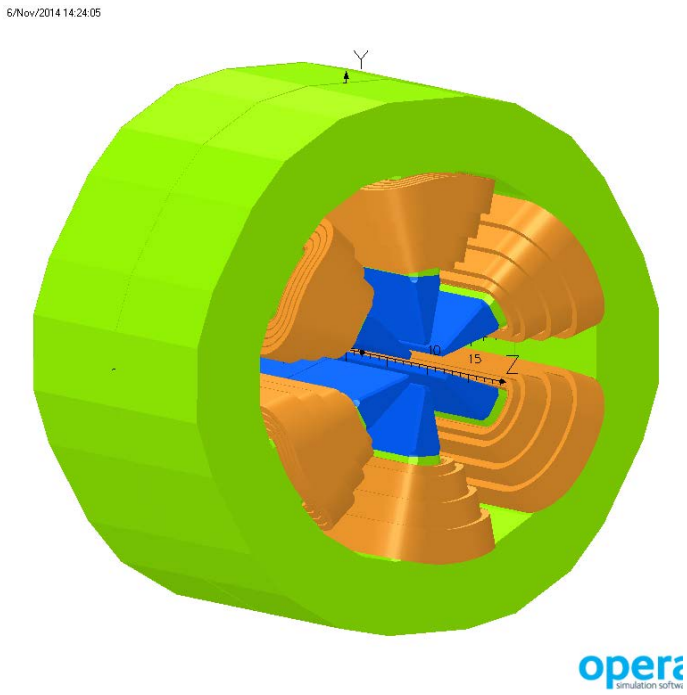
Engineering Development



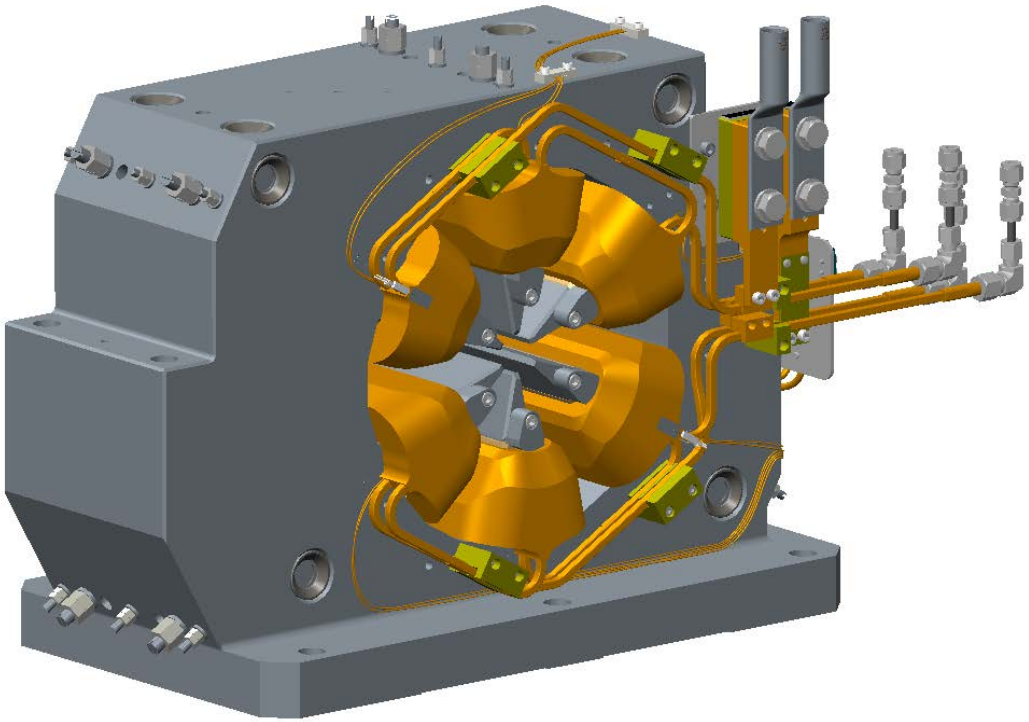
Q8 Quadrupole Magnet
OPERA model

MBA Sextupole Magnets 0.256 m long

Has both vertical and horizontal corrector coils



DMM Sextupole Magnet OPERA Model



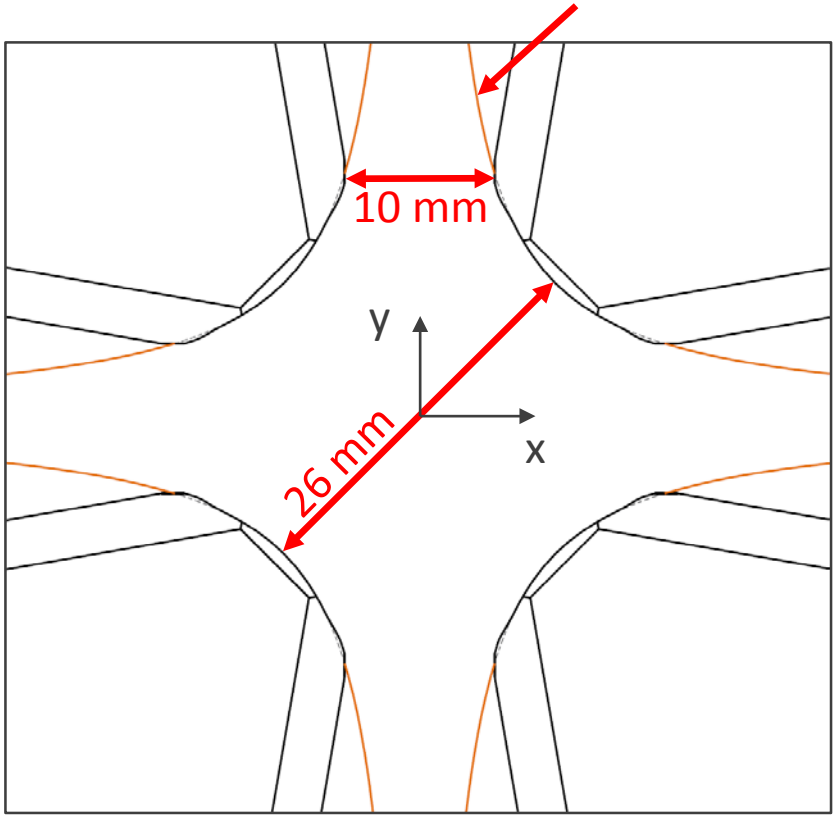
DMM Sextupole Magnet
Under construction

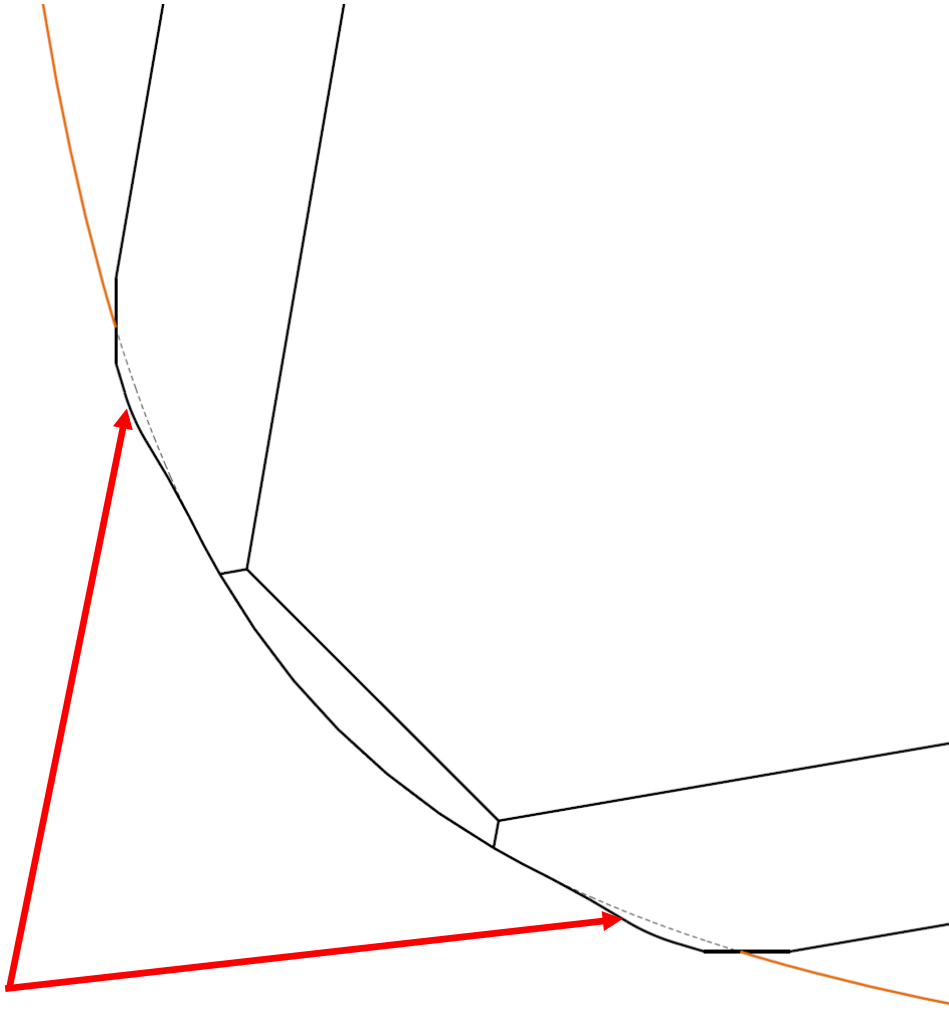
S2 Sextupole Magnet
Vanadium permendur pole tips

S1, S3 Sextupole Magnet
Steel pole tips

Field Quality in a Quadrupole Magnet

Hyperbolic curve $y=r^2/(2x)$ for an ideal quadrupole magnet

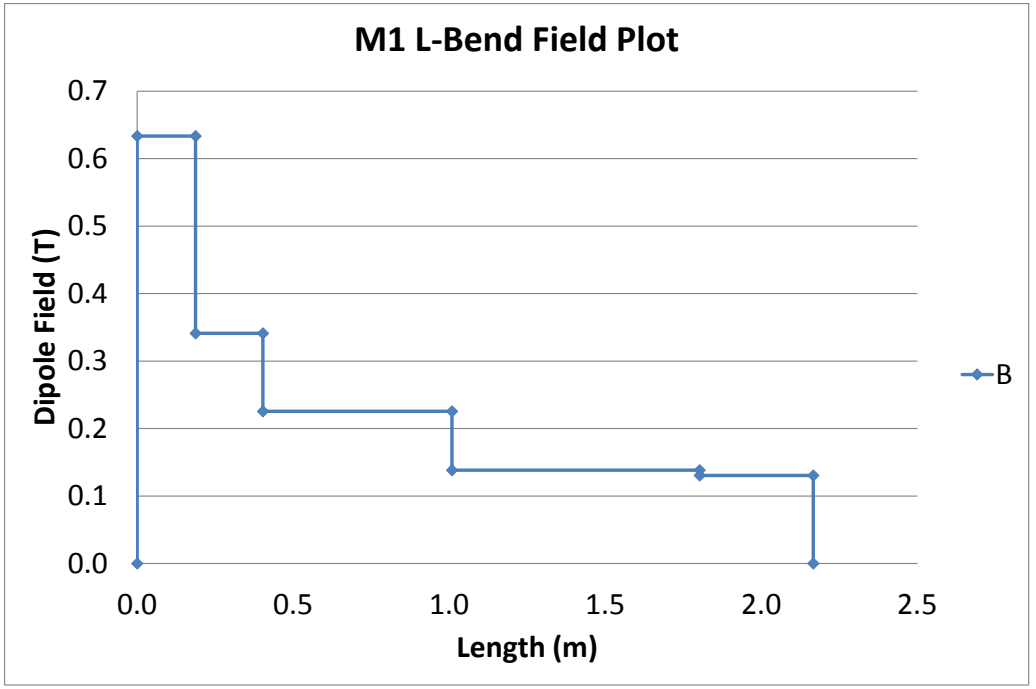




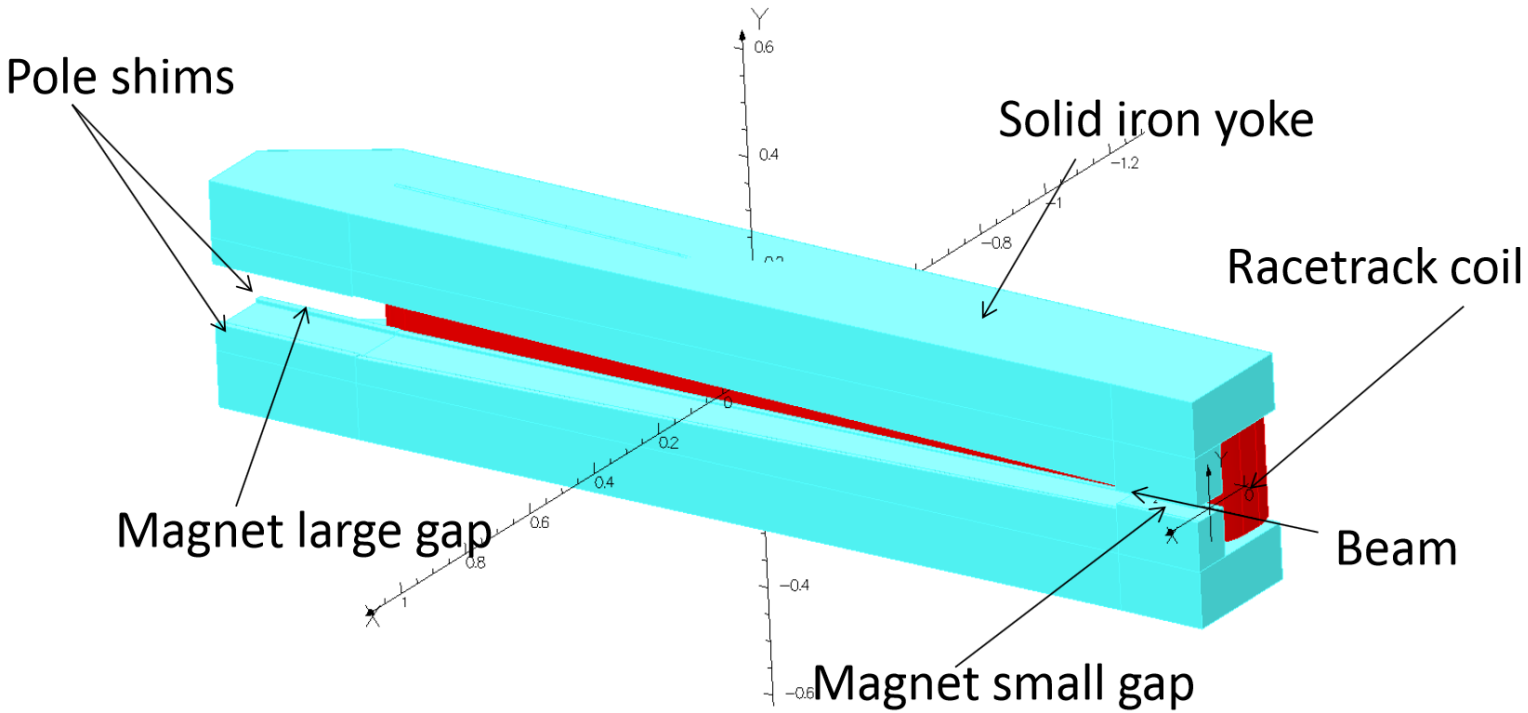
Magnet shims for quadrupole magnet to improve field quality

L-Bend Magnets

- Longitudinal gradient dipole magnets.
- Called L-bend dipole magnets.
- Field varies along the length
- M1 is 2.10 m long

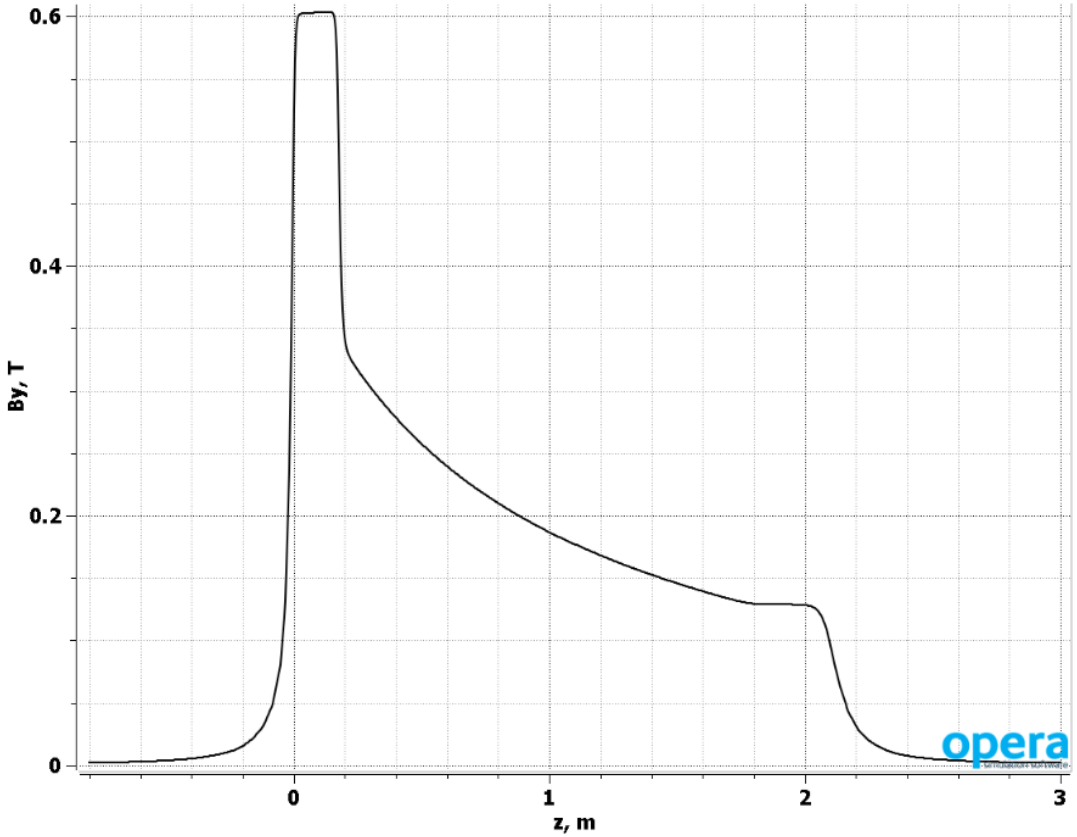


L-Bend Magnets
Tapered Pole Gap - Magnet Model



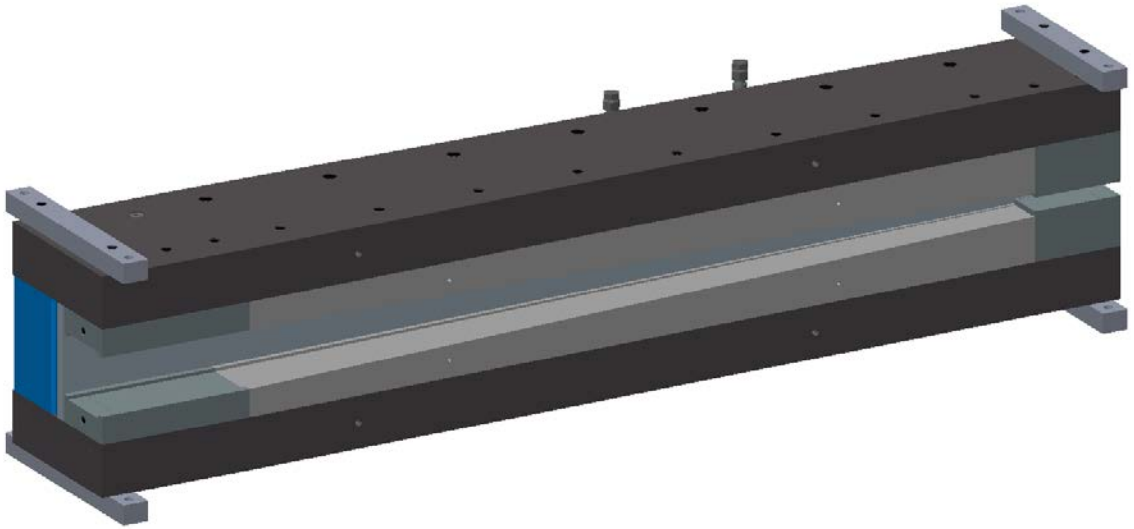
Courtesy of Vladimir Kashikhin of Fermilab

L-Bend Magnets
Tapered Pole Gap - Field Plot

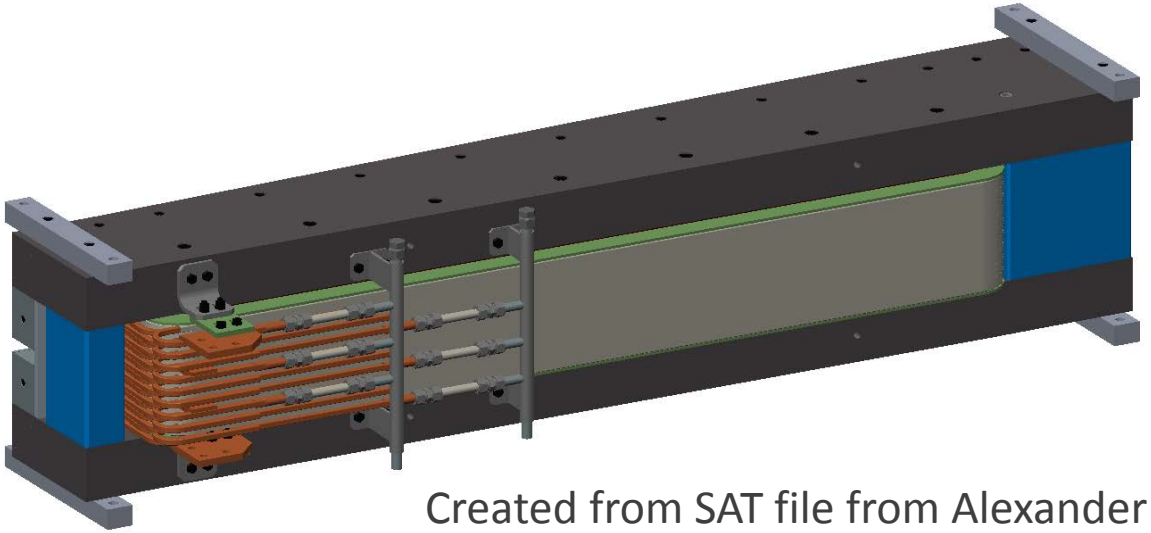


Courtesy of Vladimir Kashikhin of Fermilab

L-Bend Magnets
Tapered Pole Gap - 3D Model



A prototype of this magnet has been built by Fermilab

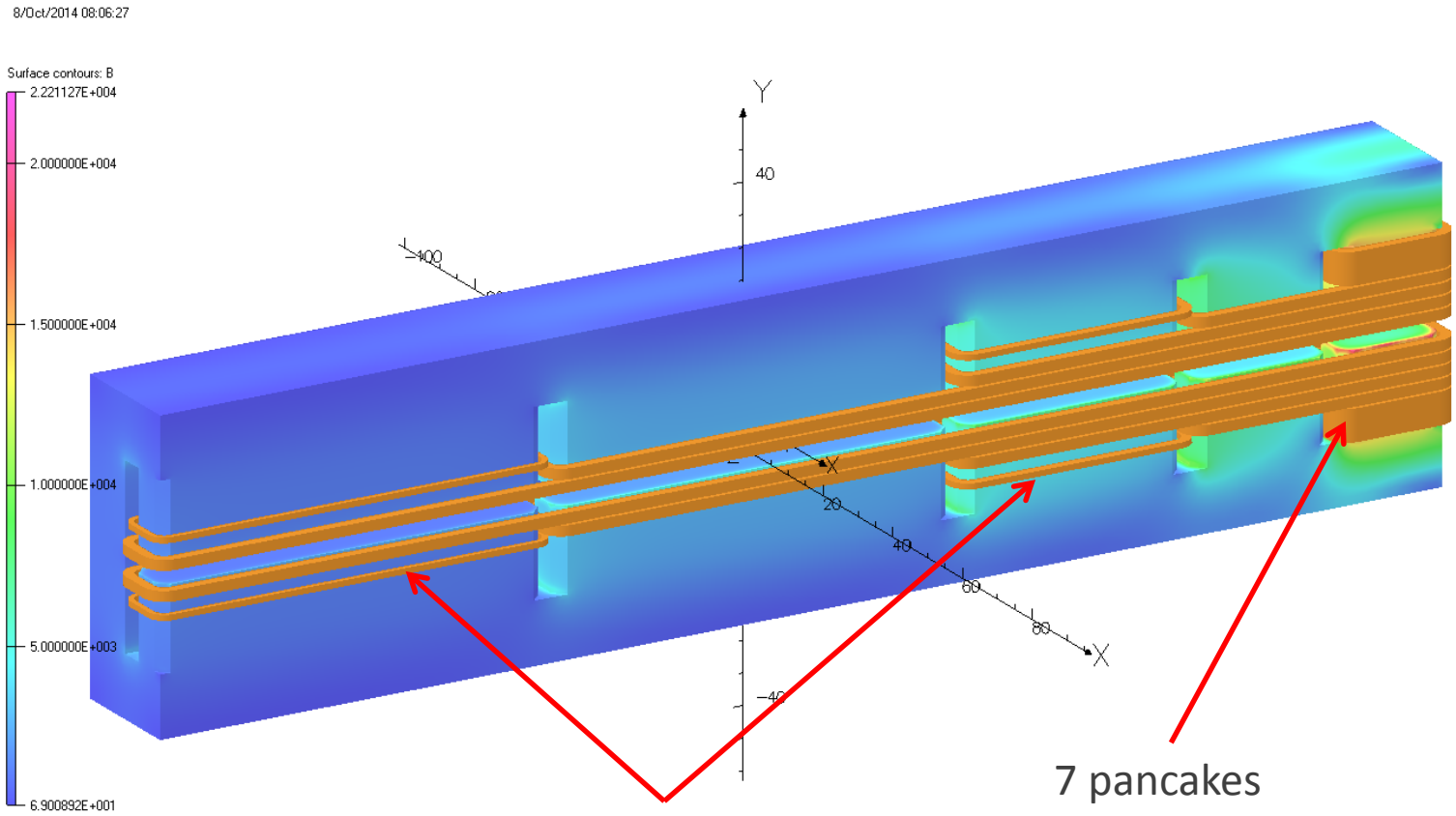


Created from SAT file from Alexander Makarov of Fermilab

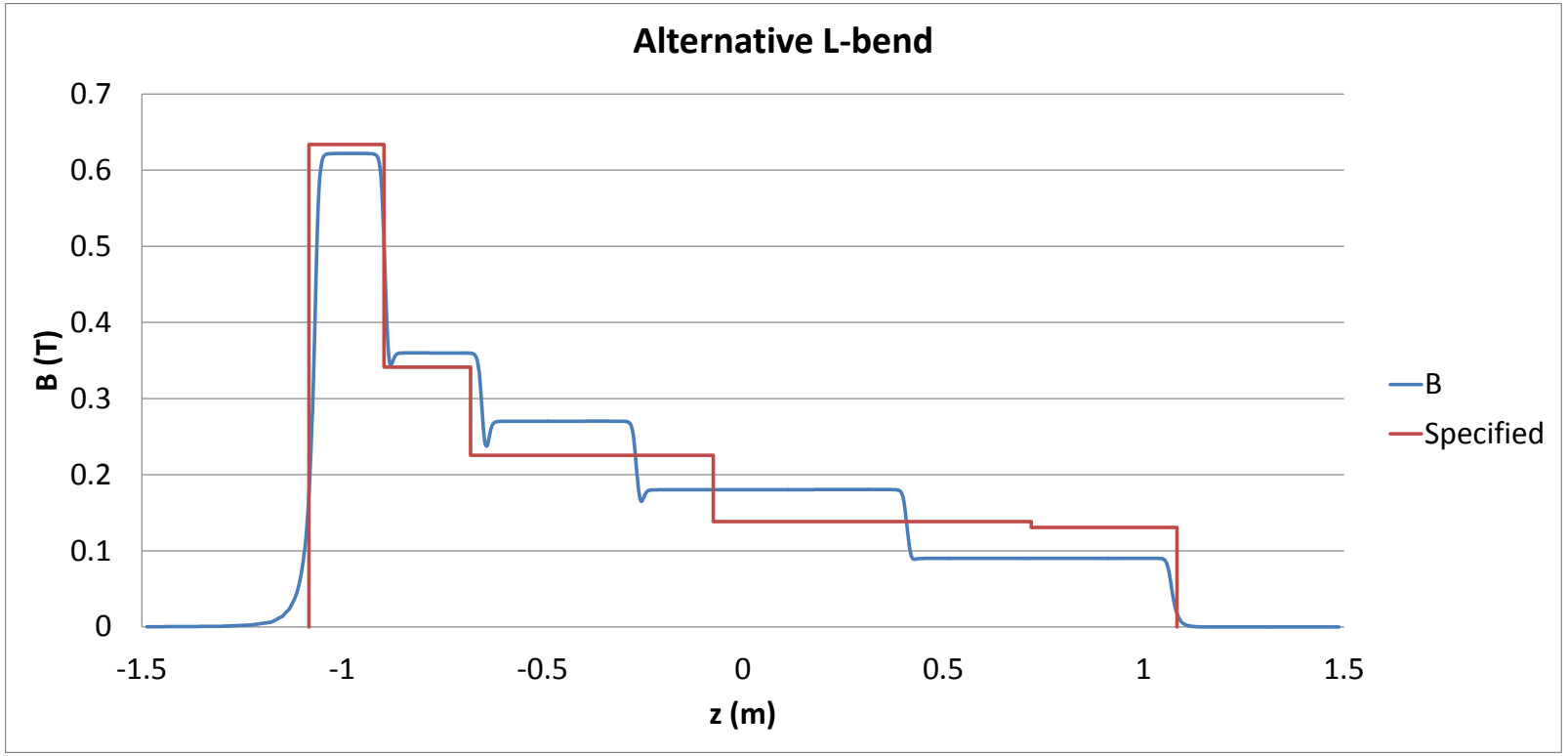
M1 preliminary prototype designed and built by Fermilab.

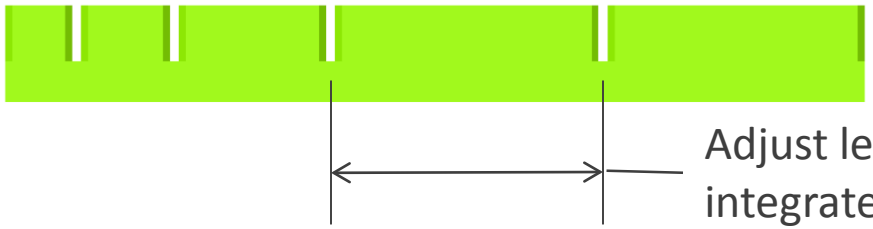
Magnet measurements were done in MM1

Alternative L-Bend M1



Alternative L-Bend Field Plot





Adjust lengths to control the integrated field in each section

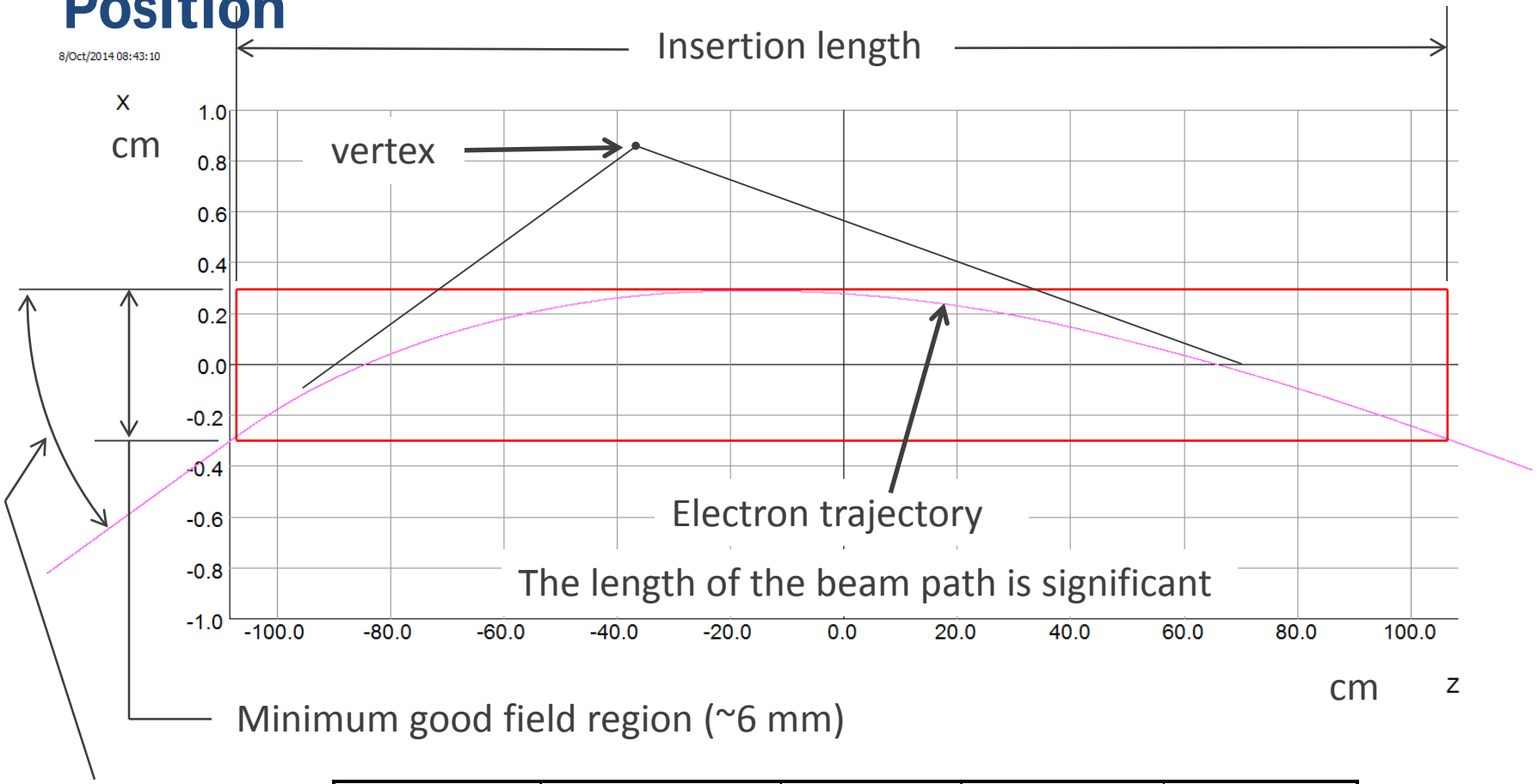
Alternative L-Bend Selected Parameters and field quality

Optimizing the pole tip will reduce the sextupole component

D_current	-236.60	A
B0_int	-486319	Gauss-cm
D_power	1200	W
Conductor square	8.0	mm
Conductor hole	5.0	mm
Flow rate (@ 90 psi)	0.036 (0.58)	l/s (gpm)
Temp. rise	8.0	°C

B0_int	10000	Units
B1_int	9	
B2_int	-13	
B3_int	3	
B4_int	-3	
B5_int	1	
B6_int	0	
B7_int	0	
B8_int	0	
B9_int	0	
B10_int	0	
B11_int	0	
B12_int	0	
B13_int	0	
B14_int	0	
B15_int	0	
B16_int	0	
B17_int	0	

Alternative L-Bend Position

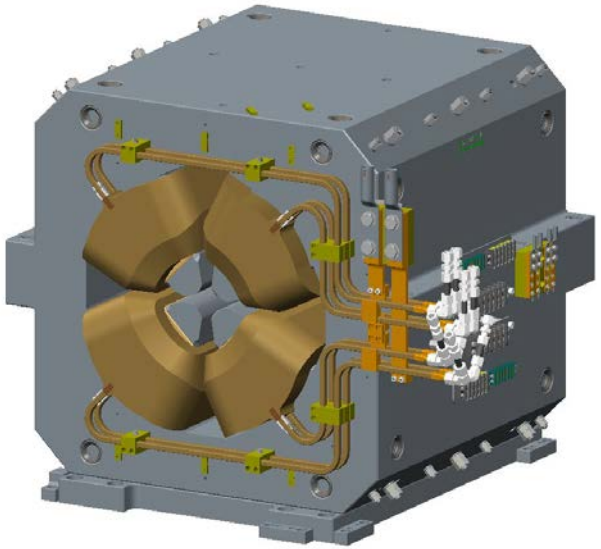


D_current	bend_angle	vertex_x	vertex_z	US_angle
A	°	mm	mm	°
-236.6	1.392	8.68	-359.36	0.925

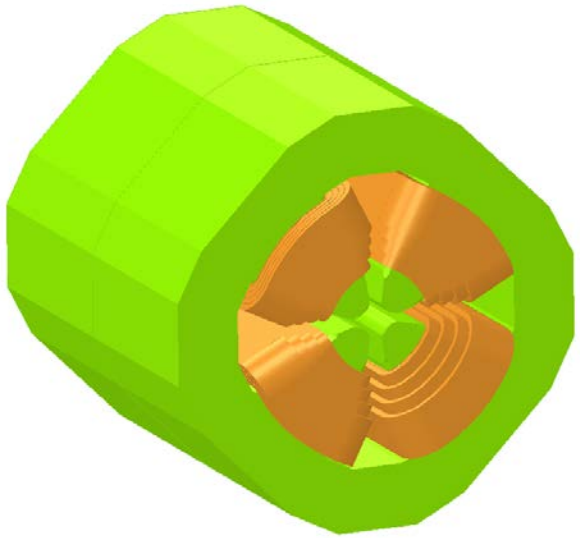
opera simulation software

Q-Bend
0.650 m long M4

- It is a dipole magnet that looks like a quadrupole magnet.
- Produces both dipole and quadrupole fields.
- The beam is offset from center.
- It has curved pole tips.
- Pole tips are made of vanadium permendur.

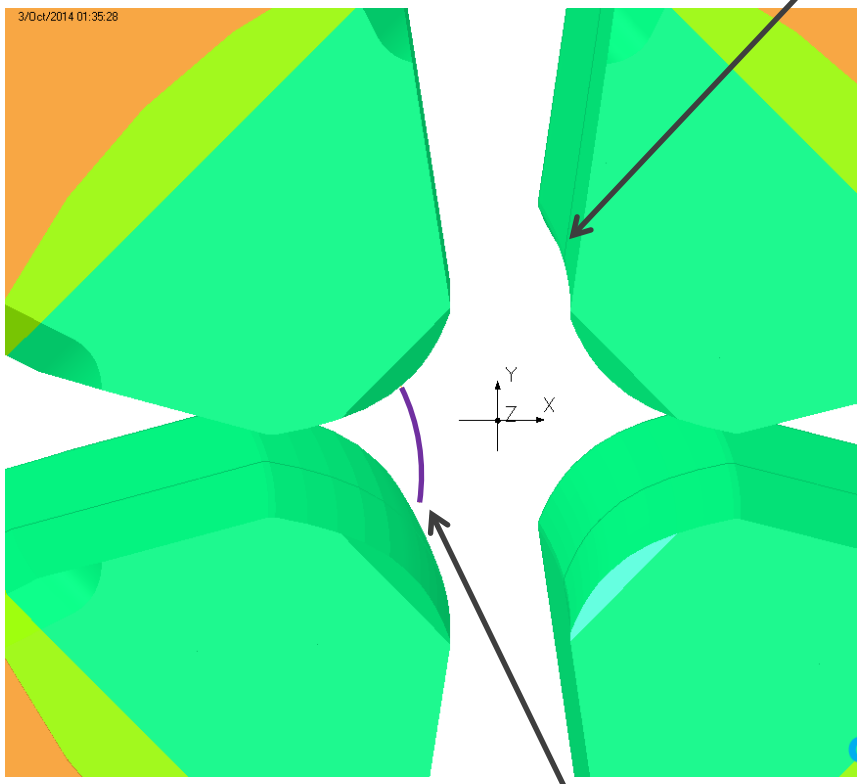


M4 Magnet Engineering Development



M4 Magnet OPERA model

Q-Bend
M4



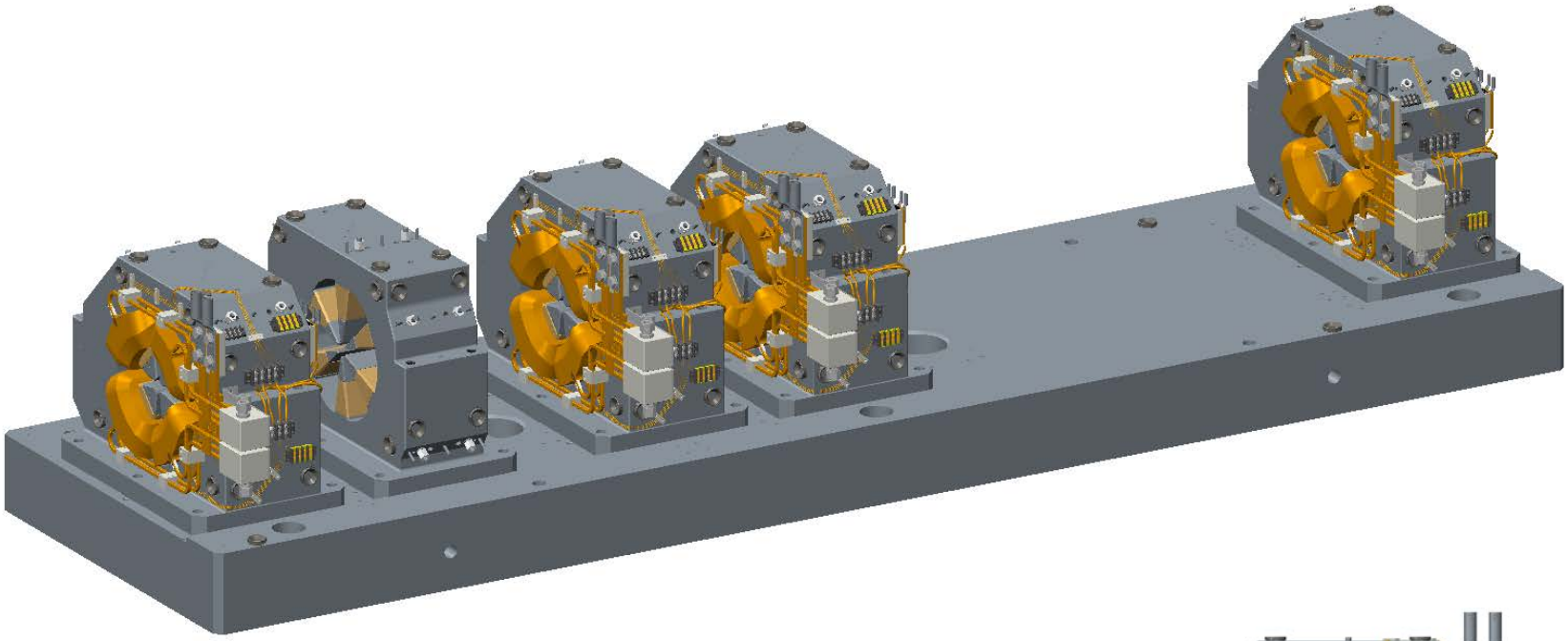
Curved tips

Electron Trajectory

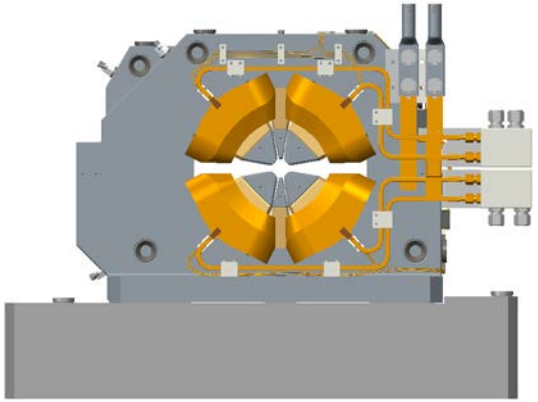
current_Q	236.48	A
current_VD	-18.80	A
B1_central	56.16	T/m
B0_central	-0.6708	T
Q_power	7884	W
#VD_power	660	W
x_offset	-12.53	mm
sagitta	1.412	mm
bend_angle	1.126	degrees
vertex	-1.037	mm

Vanadium Permendur
Pole tips
90.6 % magnet efficiency

Demo-Modular-Multiplet (DMM)



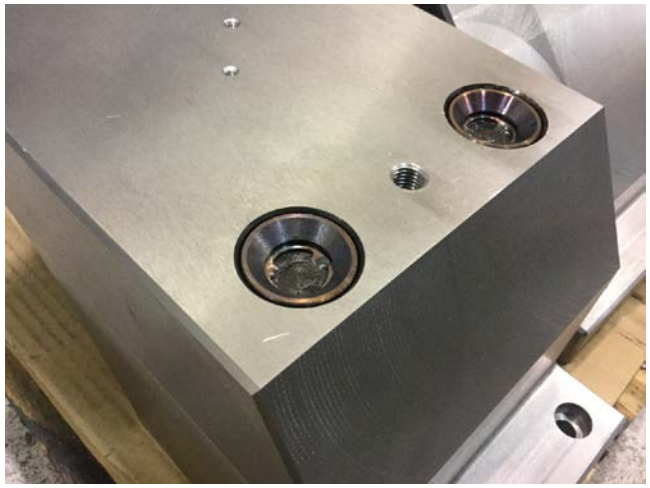
- Solid core magnets.
- Magnet cores and support plate are being built at Dial Machine.
- Coils are being wound here at APS.



DMM at Dial

Support Plate

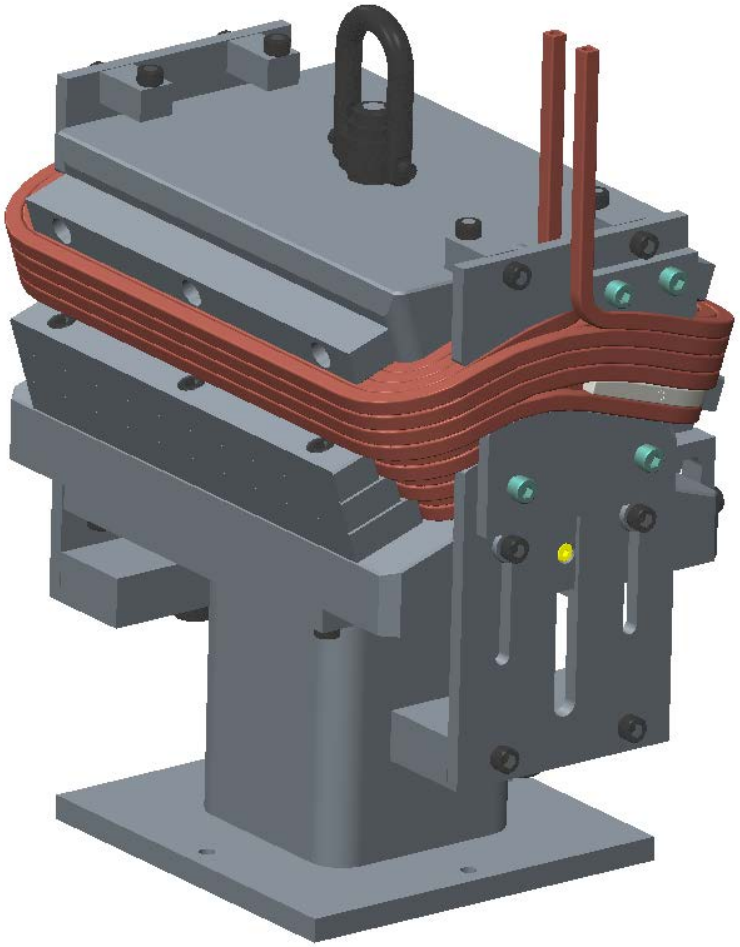
Sextupole core



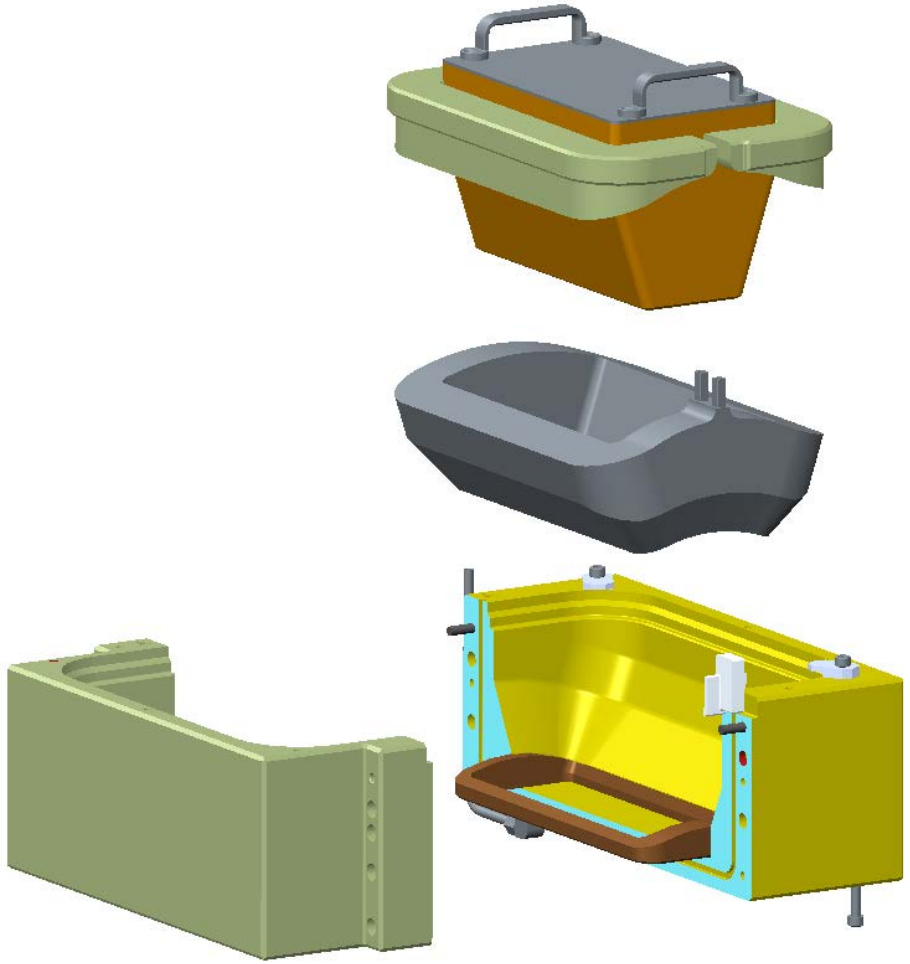
Fiducials

Pole and pole base material

Quadrupole Coil
Models of winding and potting tooling



Winding Tooling



Potting Tooling

DMM Sextupole Coils Fabrication

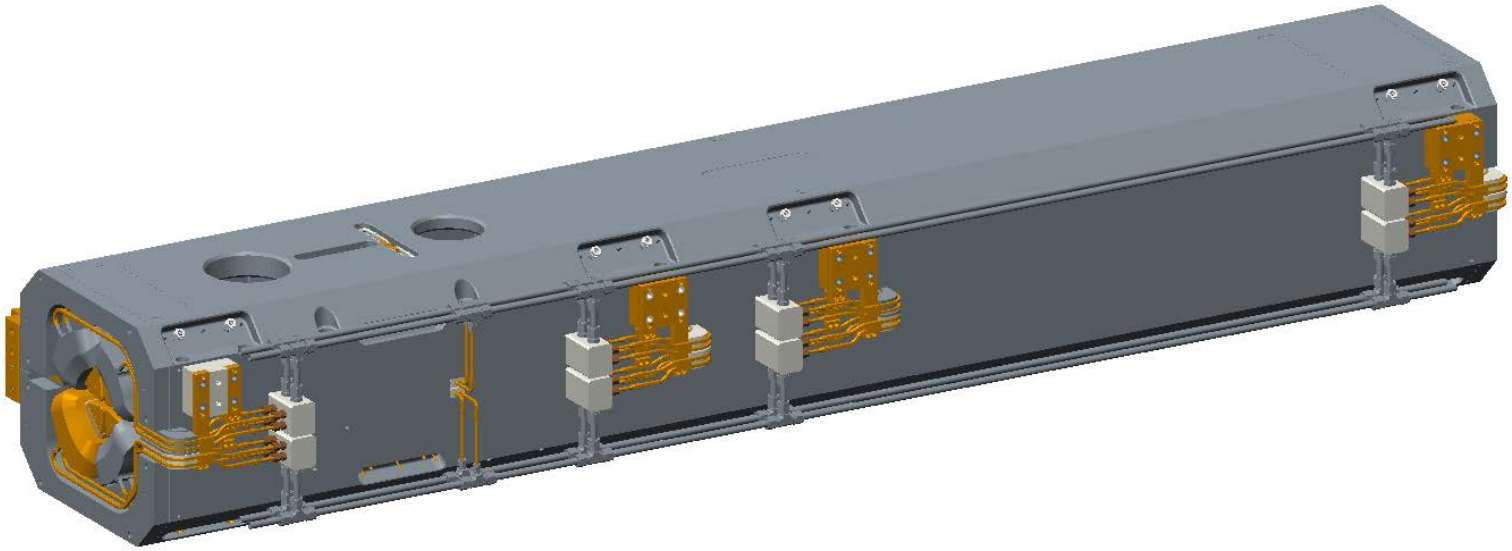
Winding

Inspection and Testing

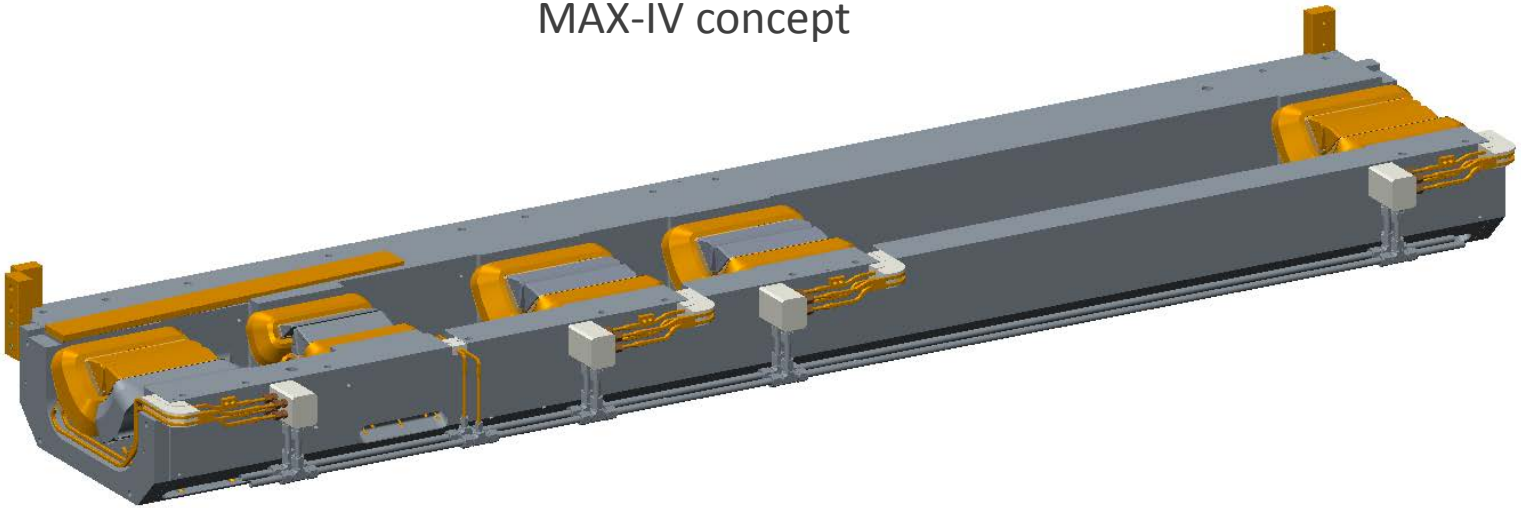
Wrapping

Potting

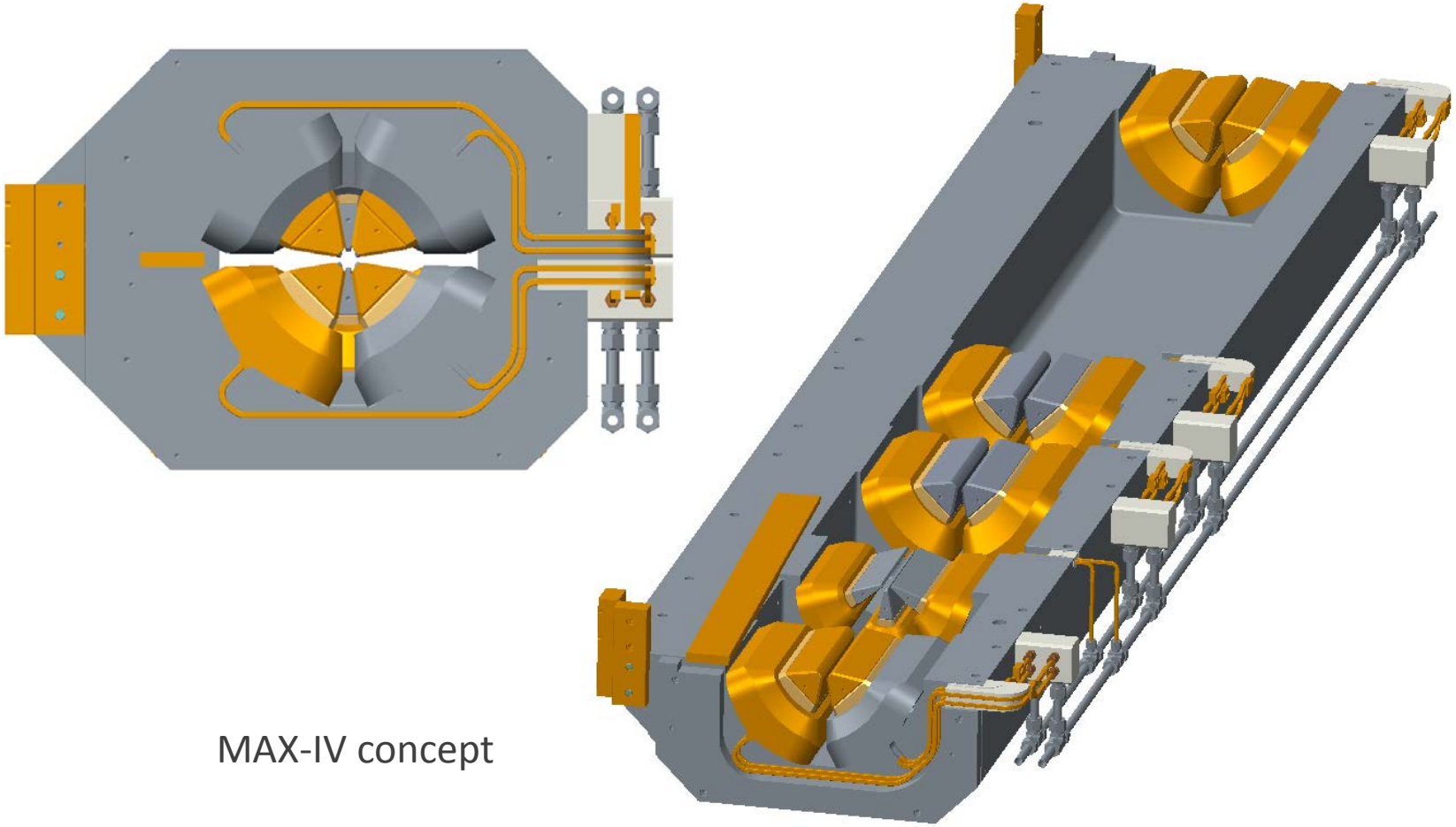
Quadrupole Sextupole Quadrupole (QSQ)



MAX-IV concept

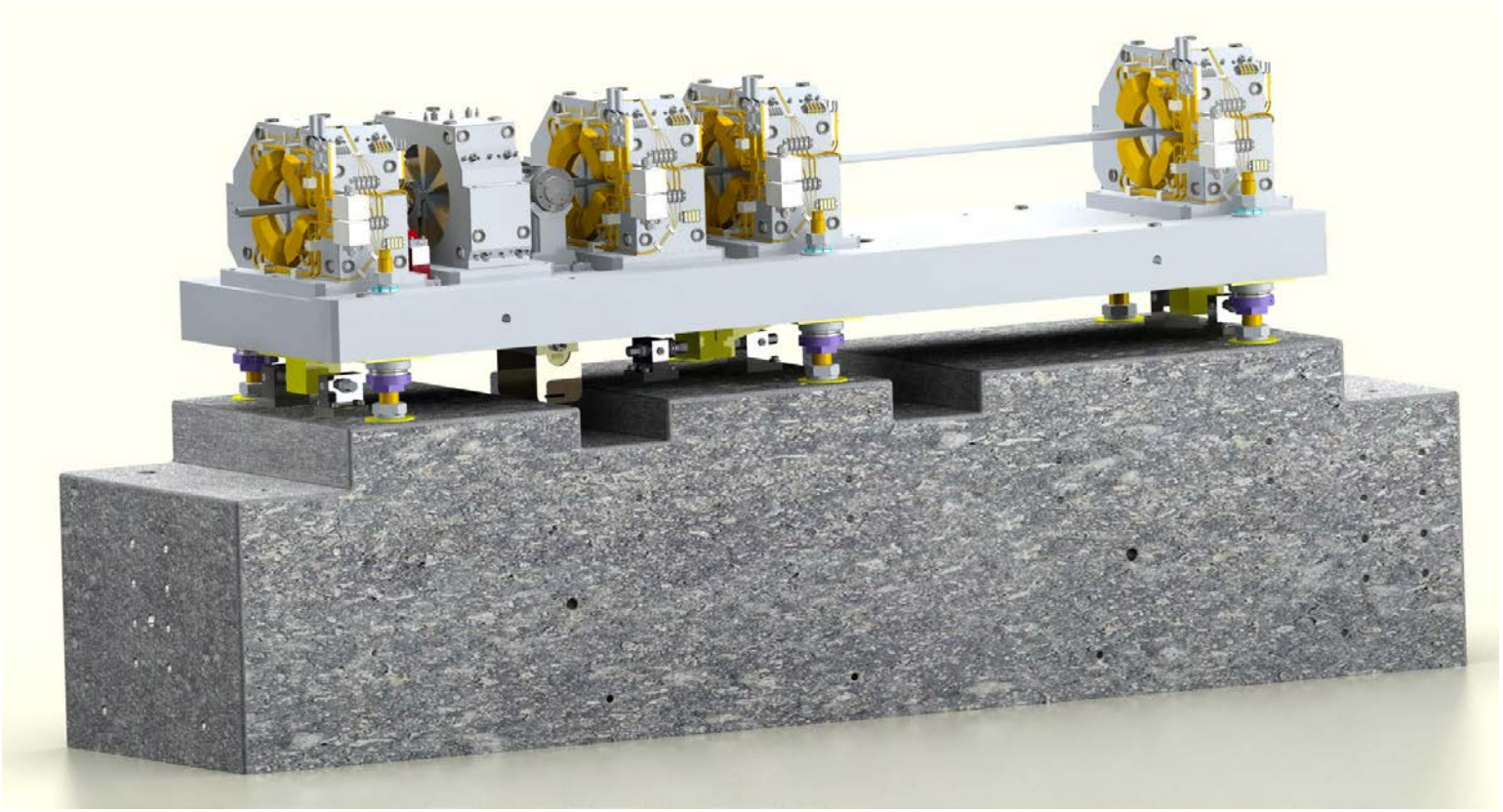


Quadrupole Sextupole Quadrupole (QSQ)



MAX-IV concept

DMM mounted on a granite plinth



Rendering by Bill Turner