

APS-U Storage Ring Magnets

Mark Jaski

APS-U Magnet Group Leader
Argonne National Laboratory

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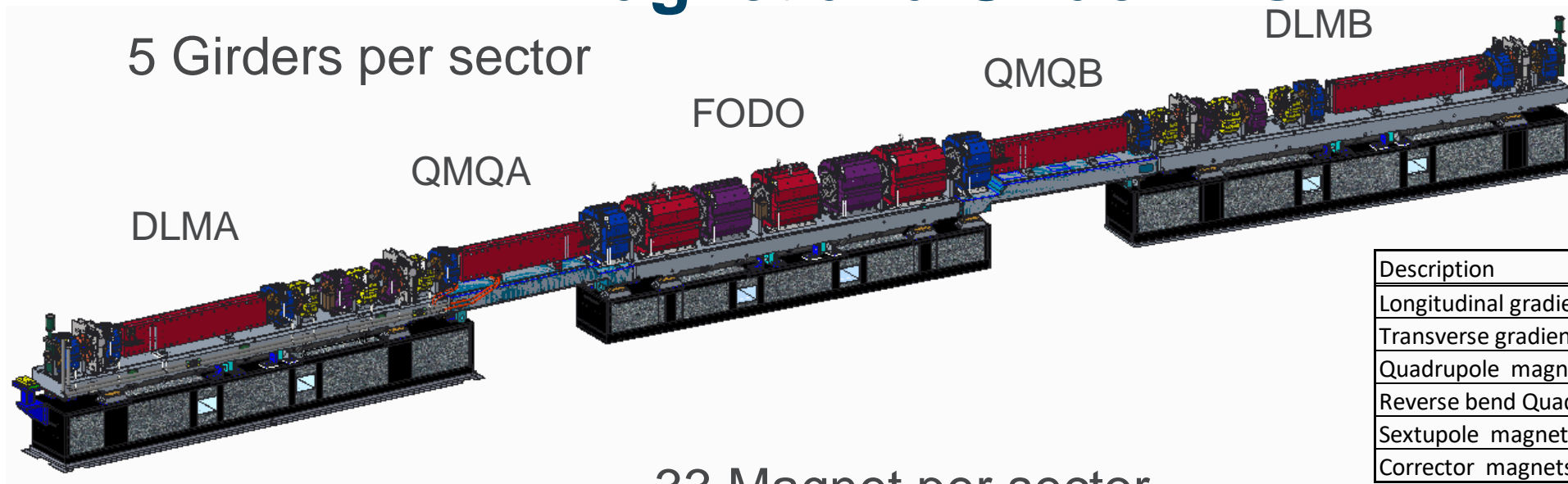


Assembly of first APS-U FODO module vacuum string.

Outline

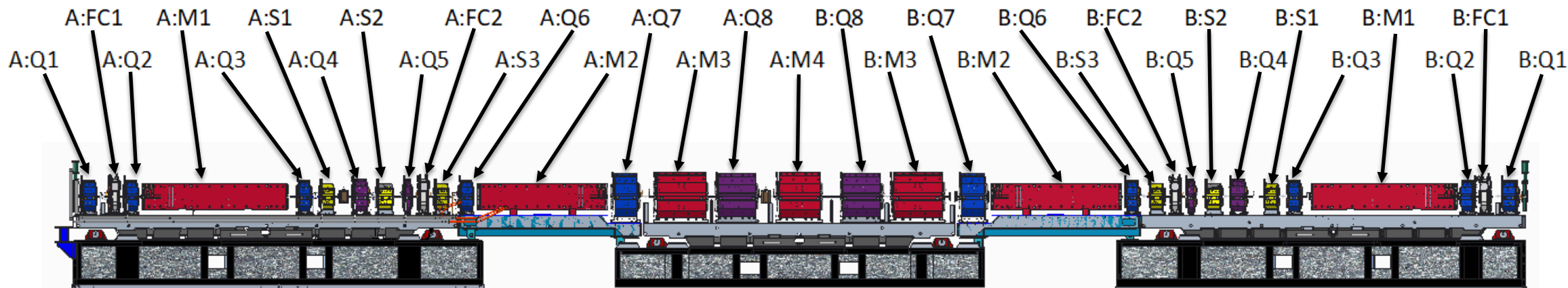
- Sector Layout
 - Magnet and Girder IDs
- APSU Accelerator Magnets Part Numbers
- APSU Accelerator Magnets
 - Quadrupole Magnets
 - Longitudinal Gradient Dipole Magnets
 - Transverse Gradient Dipole Magnets
 - Reverse Bend Quadrupole Magnets
 - Sextupole Magnets
 - Corrector Magnet

Sector Layout Magnet and Girder IDs



Description	Color
Longitudinal gradient Dipole magnets	Red
Transverse gradient Dipole magnets	Red
Quadrupole magnets	Blue
Reverse bend Quadrupole magnets	Purple
Sextupole magnets	Yellow
Corrector magnets	Orange

33 Magnet per sector



APSU Accelerator Magnets Part Numbers

Item	ID	Description	Part Number	Vendor code	Quantity ordered
1	M1	Longitudinal gradient dipole	A174-100000	D	82
2	M2	Longitudinal gradient dipole	A174-200000	D	82
3	M3	Transverse-Gradient dipole	A175-300000	T	82
4	M4	Transverse-Gradient dipole	A175-400000	T	42
5	Q1	Quadrupole	U2330101-100000	D	82
6	Q2	Quadrupole	U2330101-200000	S	81
7	Q3	Quadrupole	U2330101-300000	S	83
8	Q4	Reverse bend Quadrupole	U2330101-400000	D	82
9	Q5	Reverse bend Quadrupole	U2330101-500000	D	82
10	Q6	Quadrupole	A166-600000	S	82
11	Q7	Quadrupole	A170-700000	D	82
12	Q8	Reverse bend Quadrupole	A171-800000	E	82
13	S1 and S3	Sextupole	A172-100000	D	164
14	S2	Sextupole	A173-200000	E	82
15	FC1 and FC2	Fast Corrector	APS-MG-CRR-3000	M	165
					1355

Vendor codes	
Dial	A
Danfysik	D
Buckley	B
SigmaPhi	S
Milhous	M
Everson Tesla	E
Tesla	T



Q1 Production Magnet

APS-U Quadrupole Magnets



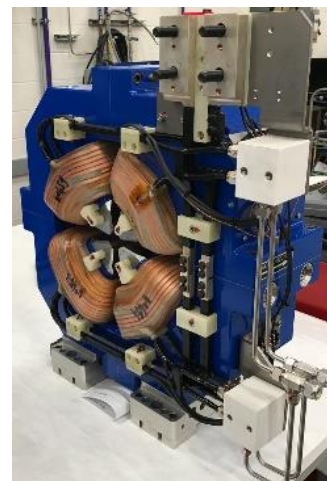
Q1



Q2



Q3



Q6



Q7

Selected Features

1. Solid Steel Cores
2. Q1 and Q7 have vanadium permendur pole tips
3. All quadrupole magnets are eight-piece design
4. Q7 has vertical and horizontal correction coils.
5. Q7 can exceed 100 T/m

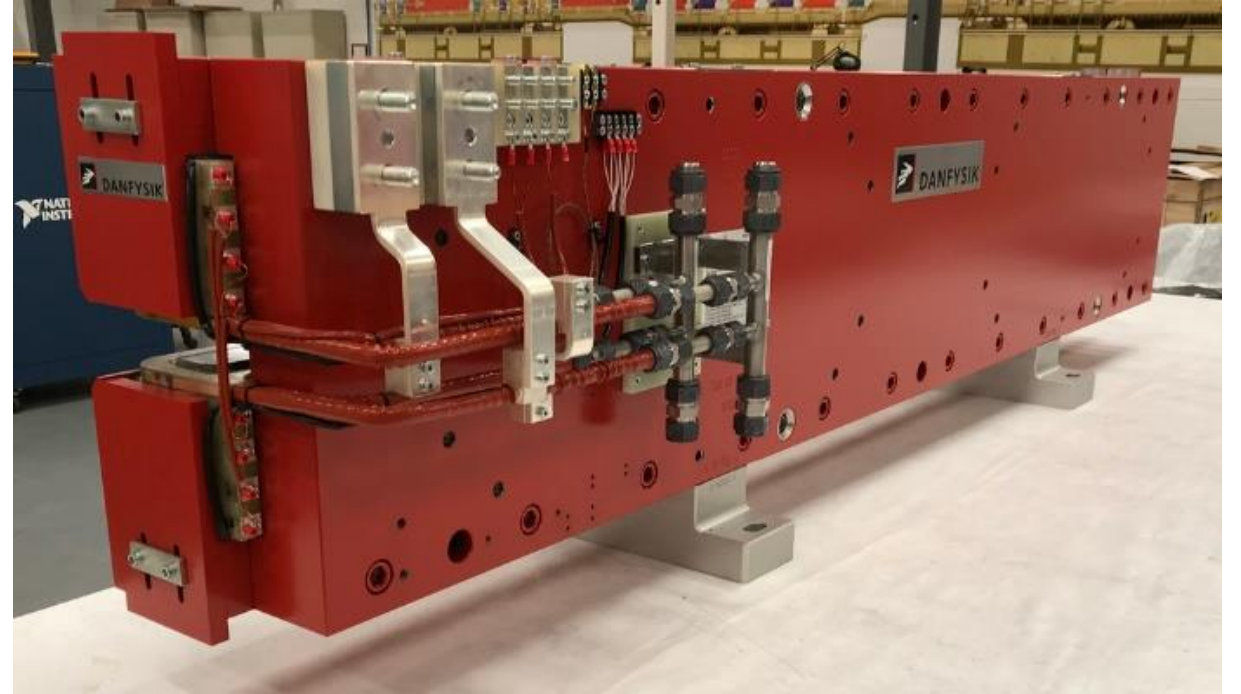
Table 2.6: Summary of straight quadrupole magnet parameters.

Magnetic Requirements		Q1	Q2	Q3	Q6	Q7
Insertion length	m	0.250	0.225	0.225	0.225	0.424
$B'L$ (nom.)	T	16.6	12.6	10.7	10.6	30.7
$B'L$ (max.)	T	18.3	13.9	11.8	11.7	33.8
Operating range (wrt nom.)	%	75-110	75-110	75-110	75-110	95-105
Vertical and horizontal BL (max.)	T-m	–	–	–	–	0.006
Quantity		80	80	81	80	80
Mechanical Requirements						
Bore radius	mm	13	13	13	13	13
Minimum vertical gap	mm	10	10	10	10	10
Pole tip Material		VP	ST	ST	ST	VP
Color		ANSI safety blue				

Longitudinal Gradient Dipole Magnets



M1



M2

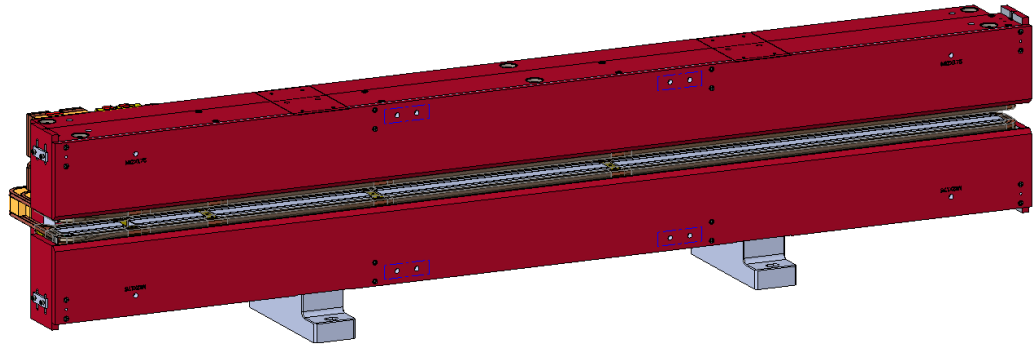
Selected Features

1. Solid Steel Cores
2. Five Poles
3. 1st and 2nd integral steering
4. Adjustable end plates to fine tune the integrated field
5. Added shielding to reduce leakage field

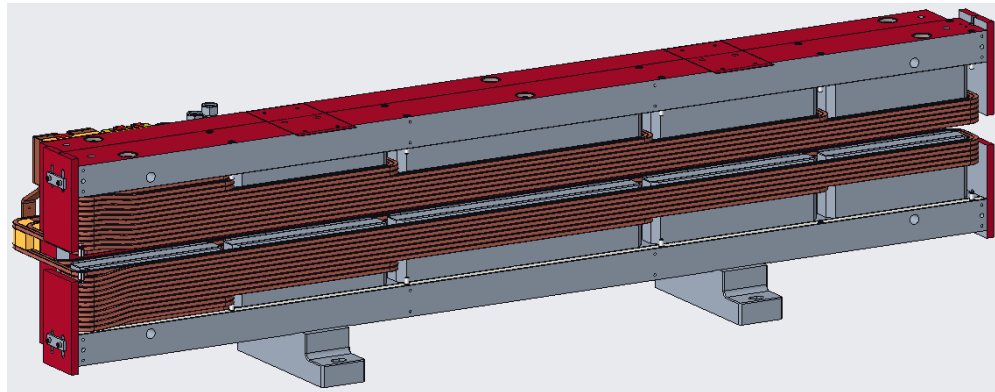
Table 2.4: M1 and M2 Bending magnet parameters

Magnetic Design Requirements											
		M1.1	M1.2	M1.3	M1.4	M1.5	M2.1	M2.2	M2.3	M2.4	M2.5
Length	mm	192	233	493	671	636	292	359	487	308	540
Bend angle	°	0.357	0.267	0.381	0.375	0.257	0.135	0.187	0.297	0.222	0.495
B_0	T	0.650	0.400	0.270	0.195	0.141	0.161	0.182	0.213	0.252	0.320
Quantity		80					80				
Mechanical Design Requirements											
Pole length	m	2.225					1.986				
Min. gap	mm	27					27				
Pole tip material		ST					ST				
Color		ANSI safety red					ANSI safety red				

Longitudinal Gradient Dipole Magnets

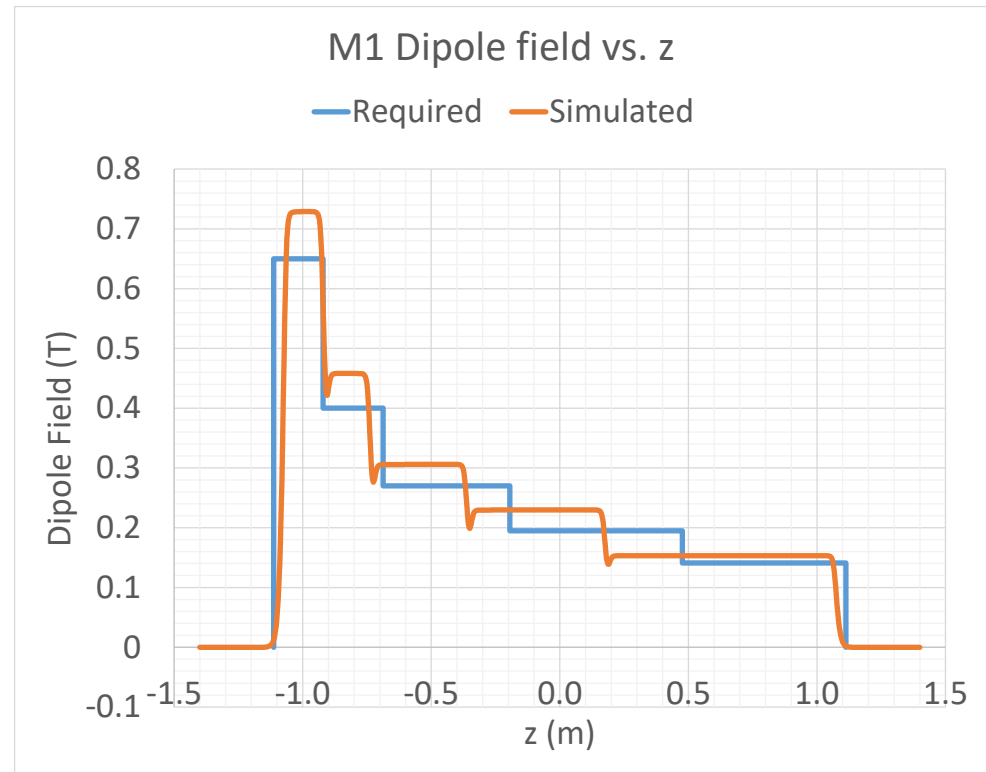


M1 dipole



M1 dipole with side plates (shielding) removed

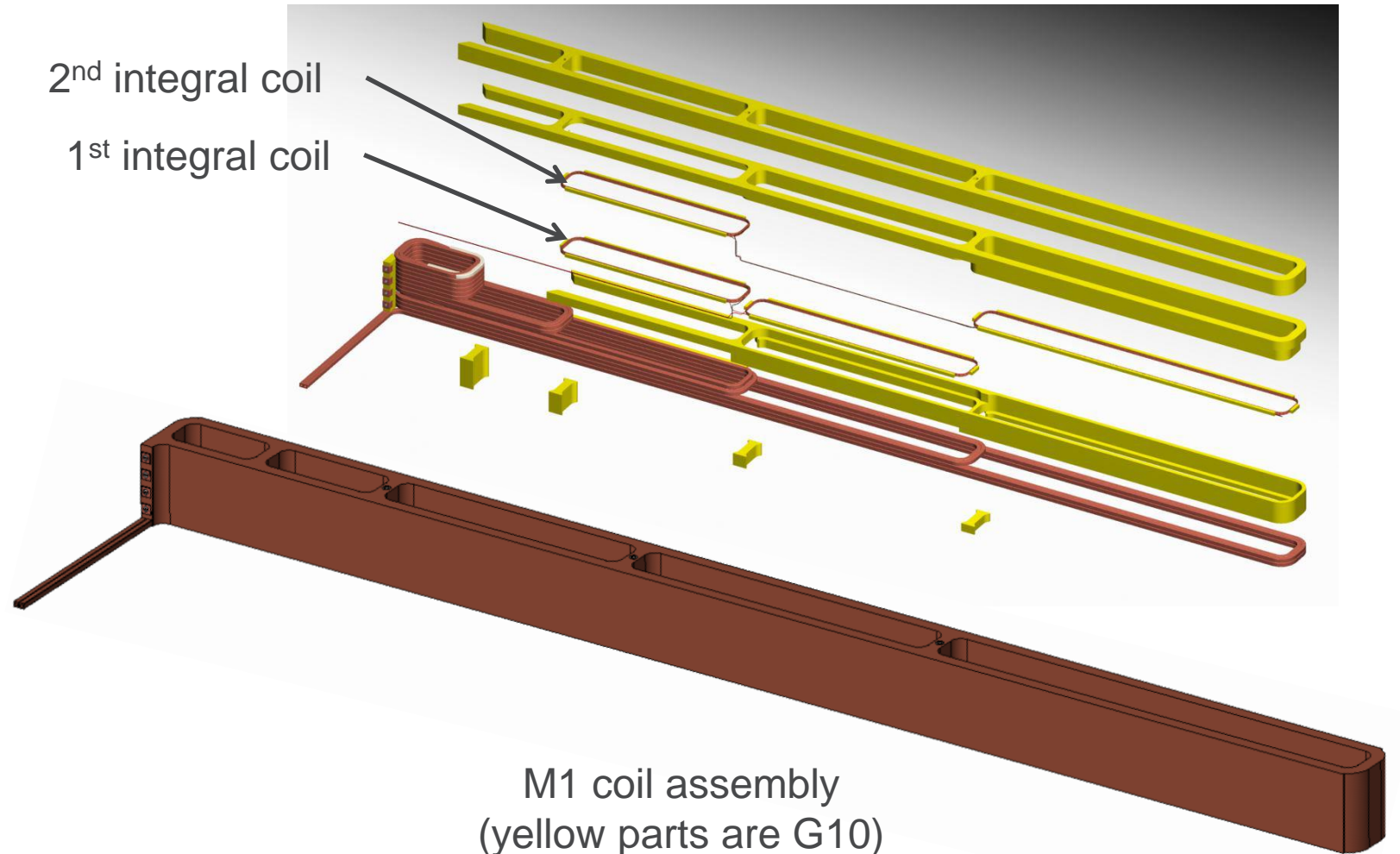
- M1 L-bend field does not match the required field.
- The simulated field does preserve the fundamental quantities (the 1st integral and vertex point)



Longitudinal Gradient Dipole Magnets

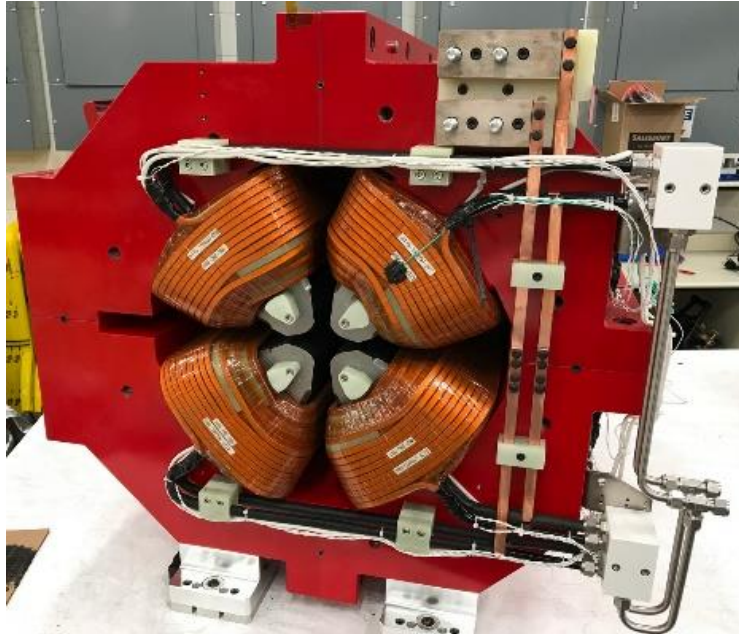


Epoxy impregnated M1 coil



M1 coil assembly
(yellow parts are G10)

Transverse Gradient Dipole Magnets



M3



M4

Selected Features

1. Solid Steel Cores
2. Curved pole tips
3. Vanadium permendur pole tips
4. Eight-piece design
5. Horizontal correction coils to allow the gradient to be changed $\pm 5\%$ while the dipole remain constant.

Table 2.5: Summary of transverse-gradient bending magnet parameters.

Magnetic Requirements		M3	M4
Insertion length	m	0.820	0.700
$B'L$ (nom.)	T	31.90	31.1
$B'L$ (max.)	T	33.5	32.7
Operating range (wrt nom.)	%	95-105	95-105
Vertical BL	Tm	0.5012	0.3924
Bending Angle	°	1.436	1.124
Quantity		80	40
Mechanical Requirements			
Bore radius	mm	21.7	20.8
Minimum vertical gap	mm	10	10
Pole tip Material		VP	VP
Radius of curvature	m	32.7	35.7
Horizontal offset	mm	-14.467	-11.798
Color		ANSI safety red	

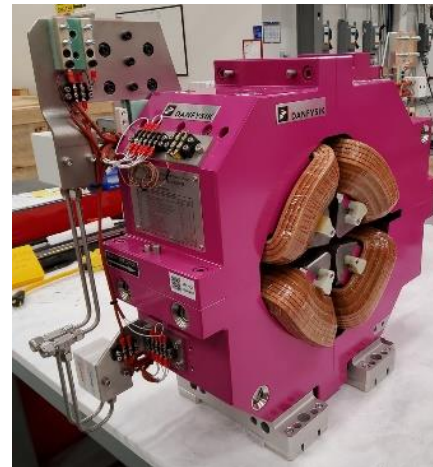
Reverse Bend Quadrupole Magnets

Selected Features

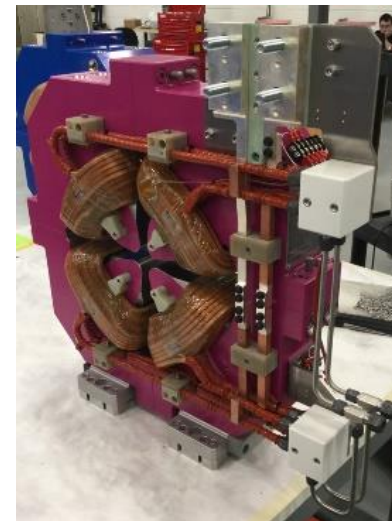
1. Solid Steel Cores
2. Q8 has curved pole tips, Q4 and Q5 have straight pole tips
3. Q4 and Q8 have vanadium permendur pole tips
4. Q4 and Q8 are eight-piece design, Q5 is four-piece design
5. All have horizontal correction coils to allow the gradient to be changed +/-5% while the dipole remain constant.
6. Q8 has a vertical dipole corrector



Q8



Q4



Q5

APSU Storage Ring Magnets

Table 2.7: Summary of reverse-bending quadrupole magnet parameters.

Magnetic Requirements		Q4	Q5	Q8
Insertion length	m	0.260	0.150	0.646
$B'L$ (nom.)	T	16.8	4.49	46.1
$B'L$ (max.)	T	17.6	4.72	48.4
Operating range (wrt nom.)	%	95-105	95-105	95-105
Vertical BL (max.)	T-m	0.0342	0.0232	0.1072
Horizontal BL (max.)	T-m	-	-	0.006
Bending angle	°	0.098	0.066	0.307
Quantity		80	80	80
Mechanical Requirements				
Bore radius	mm	14.35	16	14.5
Minimum vertical gap	mm	10	10	10
Pole tip Material		VP	ST	VP
Radius of curvature	m	∞ (straight)	∞ (straight)	120.56
Color		ANSI safety purple		

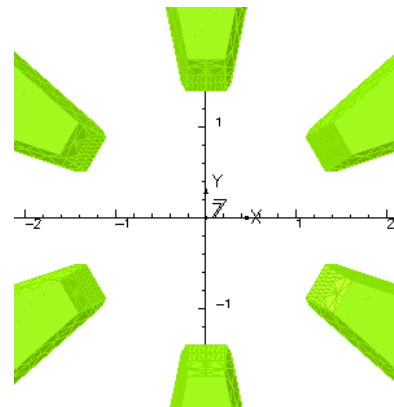
Sextupole Magnets



S1/S3



S2



Pole tip Profile

Selected Features

1. Solid Steel Cores
2. S2 has vanadium permendur pole tips
3. S1 and S3 have steel pole tips
4. All have horizontal and vertical correctors
5. The 18-pole error is more than 300 units in magnitude (approved by lattice designers).

Table 2.8: Summary of sextupole magnet parameters.

Magnetic Requirements		S1/S3	S2
Insertion length	m	0.230	0.260
$B''L$ (nom.)	T/m	727.1	1315.2
$B''L$ (max.)	T/m	872.5	1578.2
Operating range (wrt nom.)	%	50-120	50-120
Quantity		160	80
Mechanical Requirements			
Bore radius	mm	14	14
Minimum vertical gap	mm	10	10
Pole tip Material		ST	VP
Color		ANSI safety yellow	

Corrector Magnet



FC

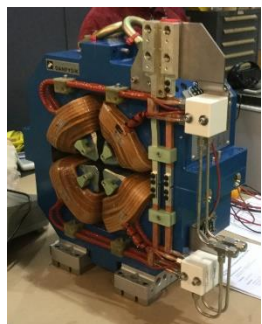
Selected Features

1. Designed by Brookhaven National Laboratory.
2. Laminated core
3. Horizontal, vertical, and skew quadrupole correctors
4. Capable of rewiring to an octupole corrector

Table 2.9: Fast Corrector Design Parameters

Magnetic Requirements		
DC Steering	μrad	300
Dipole horizontal field integral	Tm	0.006
Dipole vertical field integral	Tm	0.006
Skew Quad. Field integral	T	0.25
Steering at 1kHz	μrad	> 3
Field lag (max.) at 1kHz	μs	70
Mechanical Requirements		
Insertion Length	mm	160
Bore radius	mm	15.5
Minimum pole gap	mm	10
Count	Total	161 ⁽¹⁾

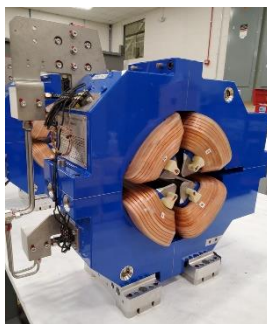
All APS Upgrade Accelerator Magnets on One Slide



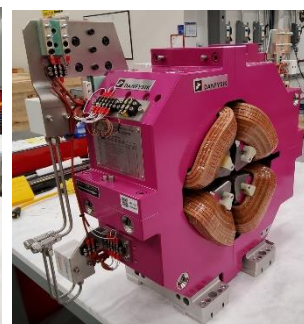
Q1



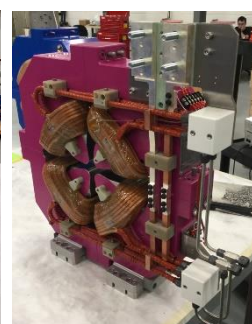
Q2



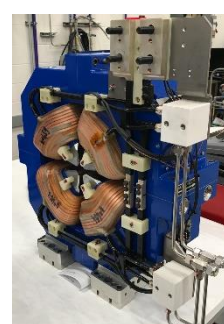
Q3



Q4



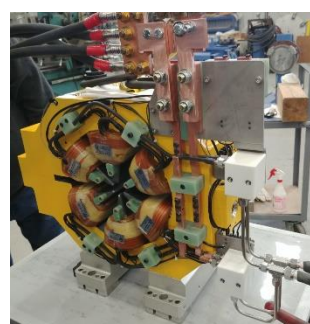
Q5



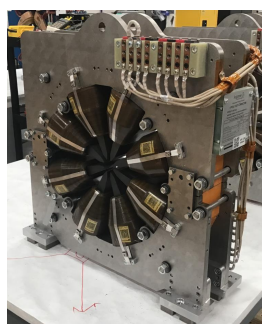
Q6



S1/S3



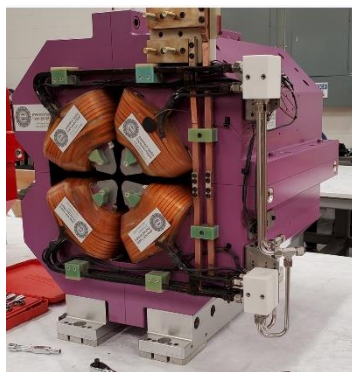
S2



FC



Q7



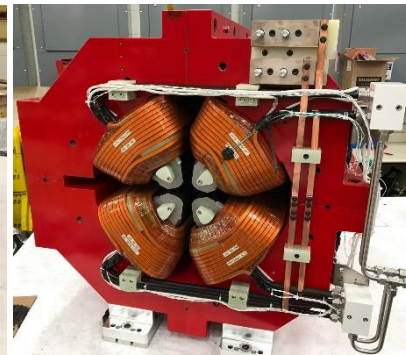
Q8



M1



M2



M3



M4

Accelerator Magnets in the Tunnel

