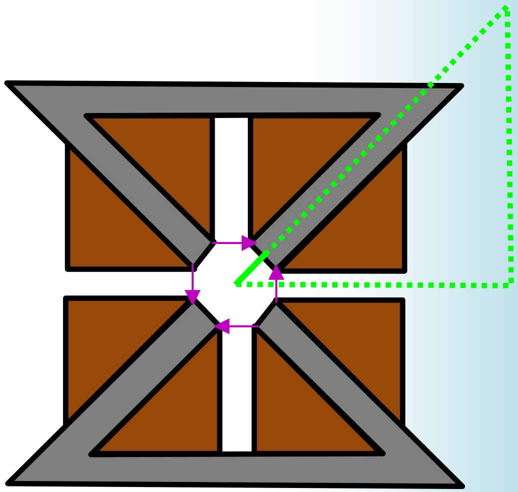
Rough Power Estimates for Fully Electromagnetic Quadrupoles

Amp-Turns Required in Quad Coil



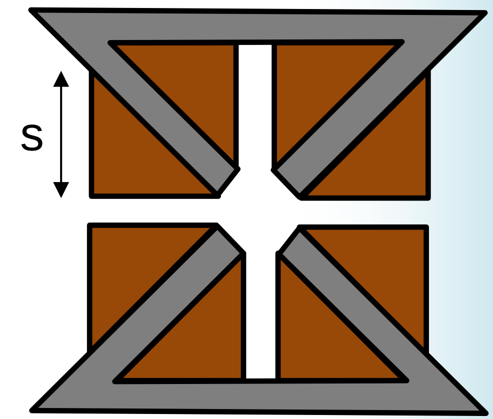
- Ampere's law: $\oint \mathbf{H}.\,\mathrm{d}\mathbf{s} = I$
- $\mathbf{H} = \mathbf{B}/\mu$
  - If $\mu \approx \infty$ in iron then $\mathbf{H} \approx \mathbf{0}$ there
- $\mathbf{B} = \mu_0 \mathbf{H} = \begin{bmatrix} gy \\ gx \end{bmatrix}$ in quad aperture
- $\mu_0 I = \int_0^R \mathbf{B}.\,\mathrm{d}\mathbf{s} = \int_0^R g \frac{1}{\sqrt{2}} \begin{bmatrix} r \\ r \end{bmatrix} \cdot \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix} dr = \int_0^R g r dr = \frac{1}{2} g R^2$

Amp-Turns Required in Quad Coil

Ring	*g* = Gradient (T/m)	*R* = Pole radius (m)	*I* (Amp.Turns)
FFAG2	49.515	0.017	5693.702
FFAG1	9.5 (averaged)	0.044088 (scaled)	7347.216

- Pole radius calculated by
  - FFAG2: measuring from Wuzheng's diagram
  - FFAG1: scaling by orbit r_{max} from magnetic centre
- FFAG1 gradients actually differ by ~10% between F and D magnets but not significant

Power/Resistivity Calculation



- $P = \rho V j^2$
- $P/L = \rho A j^2$
- $j = I/A$
- $P/L = \rho I^2/A$
- Let $A = s^2/2$
- $P/L = 2\rho I^2/s^2$
- As there are 8 coils, $P_{ring} = 16 L_{magnets} \rho I^2/s^2$
  - $L_{magnets}$ = 2985.821m for full eRHIC hexagon

Power/Resistivity Calculation

Ring	*s* = Coil side (m)	Coil material	Resistivity (Ω.m)	P/L (W/m)	Ring Power (MW)
FFAG2	0.10	Copper	1.68×10^{-8}	108.9253	2.602
FFAG1	0.15	Copper	1.68×10^{-8}	80.6125	1.926
Total				**189.5378**	**4.527**
FFAG2	0.10	Aluminium	2.82×10^{-8}	182.8389	4.367
FFAG1	0.15	Aluminium	2.82×10^{-8}	135.3138	3.232
Total				**318.1528**	**7.600**
FFAG2	0.15	Aluminium	2.82×10^{-8}	81.26174	1.941
FFAG1	0.20	Aluminium	2.82×10^{-8}	76.11403	1.818
Total				**157.3758**	**3.759**

- Comparison: at least 12MW is going into the RF for synchrotron radiation loss compensation

Conductor Cost Calculation

Ring	Material	Volume (m^3)	Mass (kg)	Price ($/kg)	Cost (M$)
FFAG2	Copper	119.4328	1070118	6.981	7.470
FFAG1	Copper	268.7239	2407766	6.981	16.809
Total	(s=10,15cm)	**388.1567**	**3477**884		**24.279**
FFAG2	Aluminium	119.4328	322468.6	1.866	0.602
FFAG1	Aluminium	268.7239	725554.5	1.866	1.354
Total	(s=10,15cm)	**388.1567**	**1048**023		**1.956**
FFAG2	Aluminium	268.7239	725554.5	1.866	1.354
FFAG1	Aluminium	477.7313	1289875	1.866	2.407
Total	(s=15,20cm)	**746.4552**	**2015**429		**3.761**

- Aluminium benefits doubly since $\rho_{Al} = 2700\ kg/m^3$ but $\rho_{Cu} = 8960\ kg/m^3$

Conclusions

- Our current design uses 1.812MW just for the correctors (due to small area)
  - And almost as many channels since we would replace 3 correctors by 4 coil trims
    - Could have series bus and low-power trims separately
- The larger Al design doubles this to 3.759MW and materials cost is very small
  - Only possible issue: magnets are now ~50cm across for each ring