eRHIC Low-Energy (FFAG) Ring

Progress Report 2

Economising a Dual-FFAG Girder

- The low energy ring (LER) has now changed energy to 920, 1828MeV
- Idea: make cell length to a multiple of the high-energy ring cell and use a common girder
  - 2x length means 50% more components
  - 3x length means only 33% more, etc.
    - This applies to correctors, power supplies, cables and diagnostics as well as the magnets
  - Only valid if comparing doublet to doublet lattice

Muon1 FFAG Optimisation

- Attempts to progressively cover the energy range with closed orbits with stable optics
- Optional additional constraints:
  - TuneMin, TuneMax
  - TOFRange, TOFRangeRel (maximum TOF variation)
  - MaxRadius (maximum distance from x,y=0,0)
  - MaxExcursion (maximum distance from first orbit)
    - These last two are at matching plane only
  - Bore limit within a given component

Muon1 FFAG Optimisation

- Secondly, once the energy range is covered successfully, tries to optimise a final figure of merit
- Current options:
  – TuneRange (minimise tune range)
  – TOFrange (minimise TOF variation)
  – SR_eRHIC (minimise eRHIC synchrotron radiation)

Stuff That Would Be Nice to Have

- $|\mathbf{B}|_{max}$ along any orbit
  - Is in the output but not yet a constraint or goal
- x_{max}-x_{min} of all orbits everywhere in curvilinear coordinate system
  - Is in the output but not yet a constraint or goal
- Largest x_{max}-x_{min} of all orbits in the rectangular local coordinate system of a single quadrupole
  - Plus r_{max} relative to magnetic centre

Main FFAG TOF = 35.4ppm

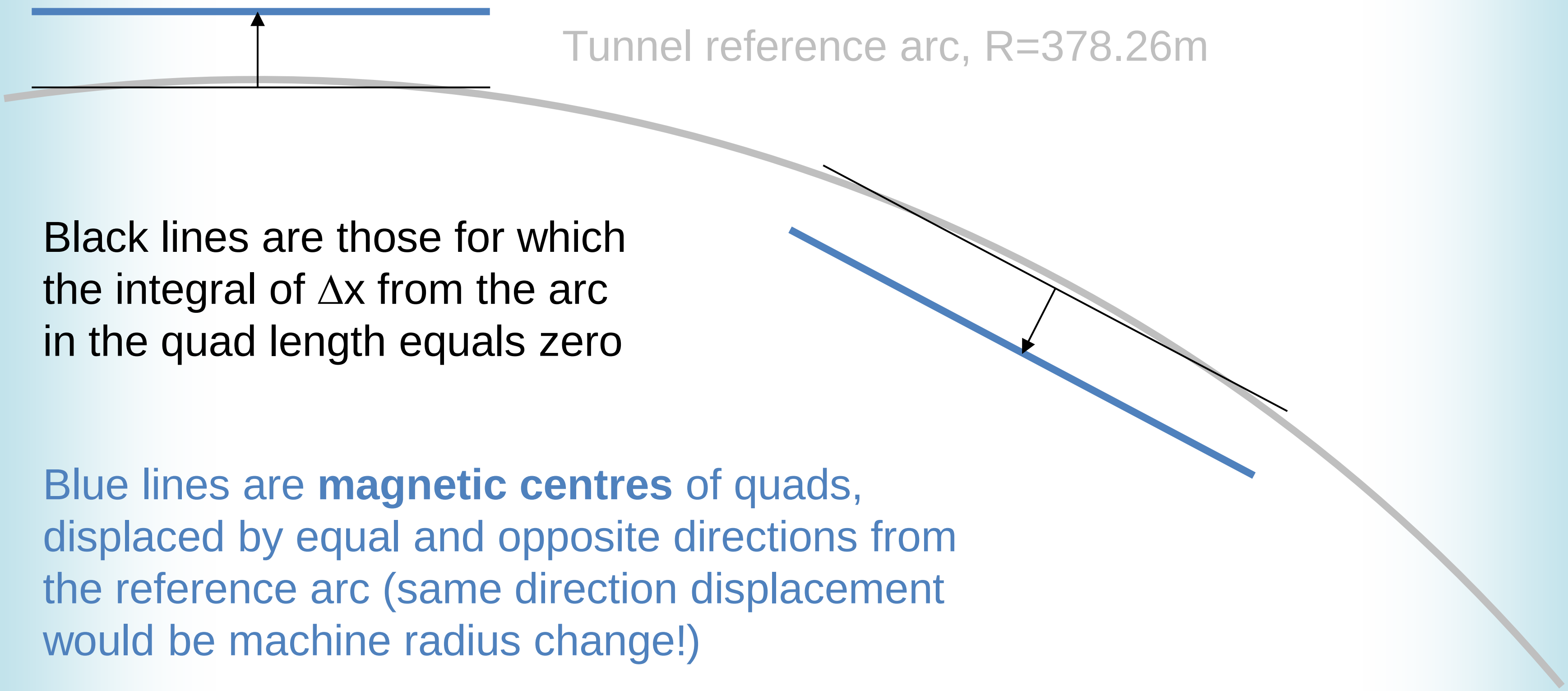
Old energy range

Not offset quads

Girder cells	Optimisation variant	Failure energy (MeV)	Notes / Constrained params	SR power (MW)	Orbit range at matching plane (m)	Orbit range relative to tunnel arc (m)	TOF range (ppm)	Tune min	Tune max	Magnet packing factor	Max gradient (T/m)	Max field on orbit (T)	Quad offsets relative to tunnel arc (m)	
2	-			0.001814	0.019191	0.026997	35.80214	0.14091	0.38398	0.181832	5.435435	0.139772	0.016491	
2	a			0.001659	0.017506	0.02467	32.78023	0.10067	0.39943	0.19356	5.255255	0.118041	0.017568	
2	c			0.001192	0.015632	0.021869	30.8304	0.051563	0.44909	0.270984	4.034034	0.080862	0.017467	
3	dejan/Nov17-2013-TRIPLET			0.007626	0.025728	0.025732	0.747382	0.068689	0.38869	0.193657	7	0.340846	0.04294	
3	-	1122.498												
3	a			0.002765	0.037577	0.053476	63.56596	0.10269	0.39859	0.113467	4.454454	0.186904	0.042793	
3	c			0.002104	0.031775	0.052424	34.97136	0.1331	0.44951	0.170253	2.912913	0.14933	0.041191	
3	d			0.005703	0.032375	0.054508	34.99896	0.15809	0.40036	0.105481	10	0.571136	0.032082	
3	e	1021.039												
3	es			0.002149	0.03495	0.057369	34.89465	0.1634	0.40107	0.178937	2.547548	0.158498	0.039449	
3	e42			0.002276	0.029572	0.048855	34.90536	0.13613	0.41563	0.154602	3.578579	0.159493	0.041552	
3	ers		Changed e	0.001708	0.035038	0.058399	29.59934	0.16294	0.46169	0.178937	2.451009	0.149056	0.039449	
3	er42			0.00189	0.033393	0.056666	24.37148	0.13558	0.47931	0.154602	3.442969	0.152316	0.041552	
3	errs			0.001612	0.042175	0.062921	53.06336	0.15503	0.39861	0.178937	2.343744	0.144711	0.039449	
3	err42			0.001803	0.039704	0.060585	45.62975	0.12832	0.4056	0.154602	3.292292	0.147594	0.041552	
3	erms			0.001648	0.038647	0.060663	41.42492	0.15877	0.42209	0.178937	2.394695	0.146823	0.039449	
3	erm42			0.001835	0.036596	0.058634	35.1425	0.13176	0.43025	0.154602	3.363864	0.149884	0.041552	
3	f	985.4509												
3	fs	986.5593												
3	g		E-mailed t	0.002565	0.038211	0.060695	27.89499	0.15847	0.40022	0.130087	4.289289	0.218266	0.035105	
3	h		Recomme	0.001876	0.037656	0.062187	28.75985	0.1579	0.39875	0.180746	2.447447	0.163298	0.038889	<--
3	i			0.006226	0.02997	0.05486	10.75224	0.11957	0.3994	0.180746	4.60961	0.318238	0.024034	
3	i2			0.006972	0.017054	0.047452	49.03826	0.11929	0.35809	0.180746	3.148148	0.276571	0.037628	
3	dejan/Nov	Old needs	Uses comb	0.003884	0.034578	0.056401	5.743728	0.065059	0.40544	0.129105	3.924983	0.226558	0.117899	
3	dejan/Nov15-2013-Doublet-0.92			0.003845	0.034565	0.056305	4.967229	0.065048	0.40553	0.129105	3.924983	0.225463	0.117257	
3	dejan/Nov17-2013-Doublet_Des			0.003845	0.034565	0.056304	4.96856	0.065048	0.40548	0.129105	3.925013	0.225462	0.117256	
3	j			0.002408	0.033231	0.063376	0.002471	0.12882	0.37476	0.180746	2.357357	0.179018	0.094642	
3	jb	1058.827												
3	jc		R dipole =	0.004827	0.03223	0.056298	0.079929	0.13075	0.39456	0.180746	4.269269	0.289093	0.073909	
3	jd			0.002698	0.030772	0.058928	0.00487	0.057286	0.39056	0.180746	2.577578	0.188094	0.108363	
3	je			0.002369	0.03018	0.059664	0.003245	0.059397	0.39526	0.180746	2.357357	0.171209	0.112011	
4	-	1773.767												
4	a	1251.257												
4	b	1231.042												
4	c	1322.888												

Main FFAG $|\mathbf{B}|_{max} = 0.265442$ T

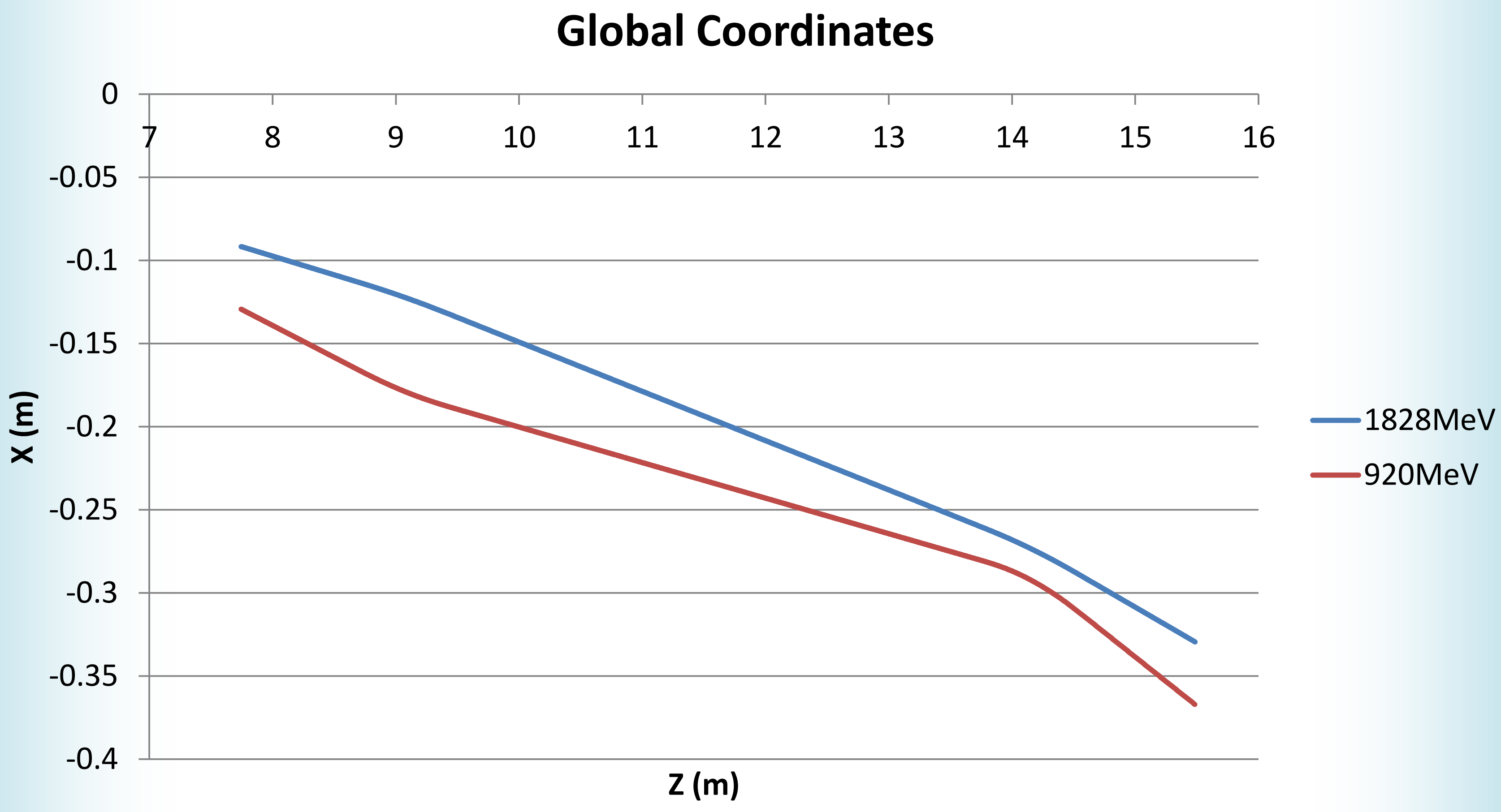
Notes on Muon1 Quad Alignment



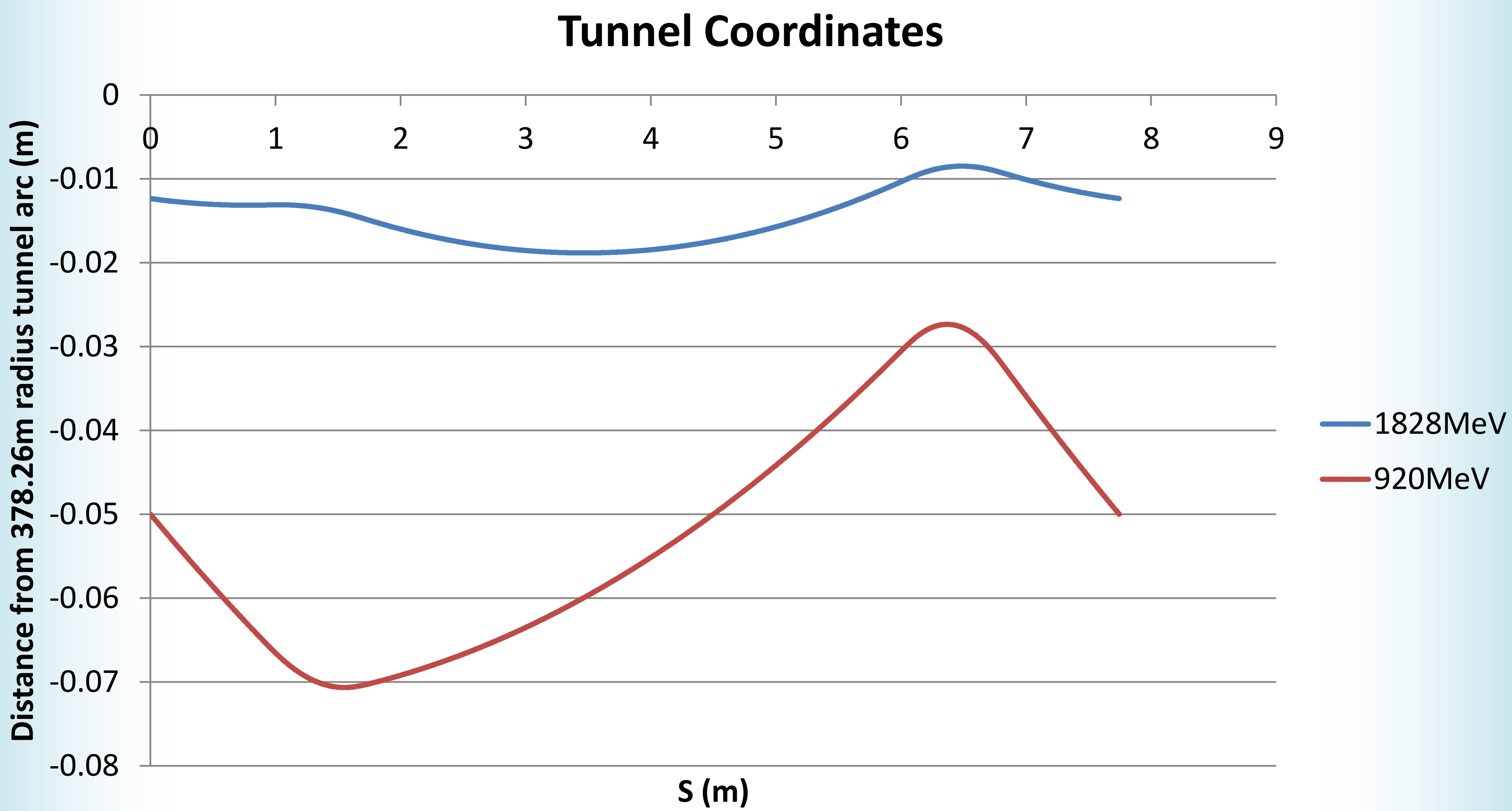
Black lines are those for which the integral of Δx from the arc in the quad length equals zero

Blue lines are **magnetic centres** of quads, displaced by equal and opposite directions from the reference arc (same direction displacement would be machine radius change!)

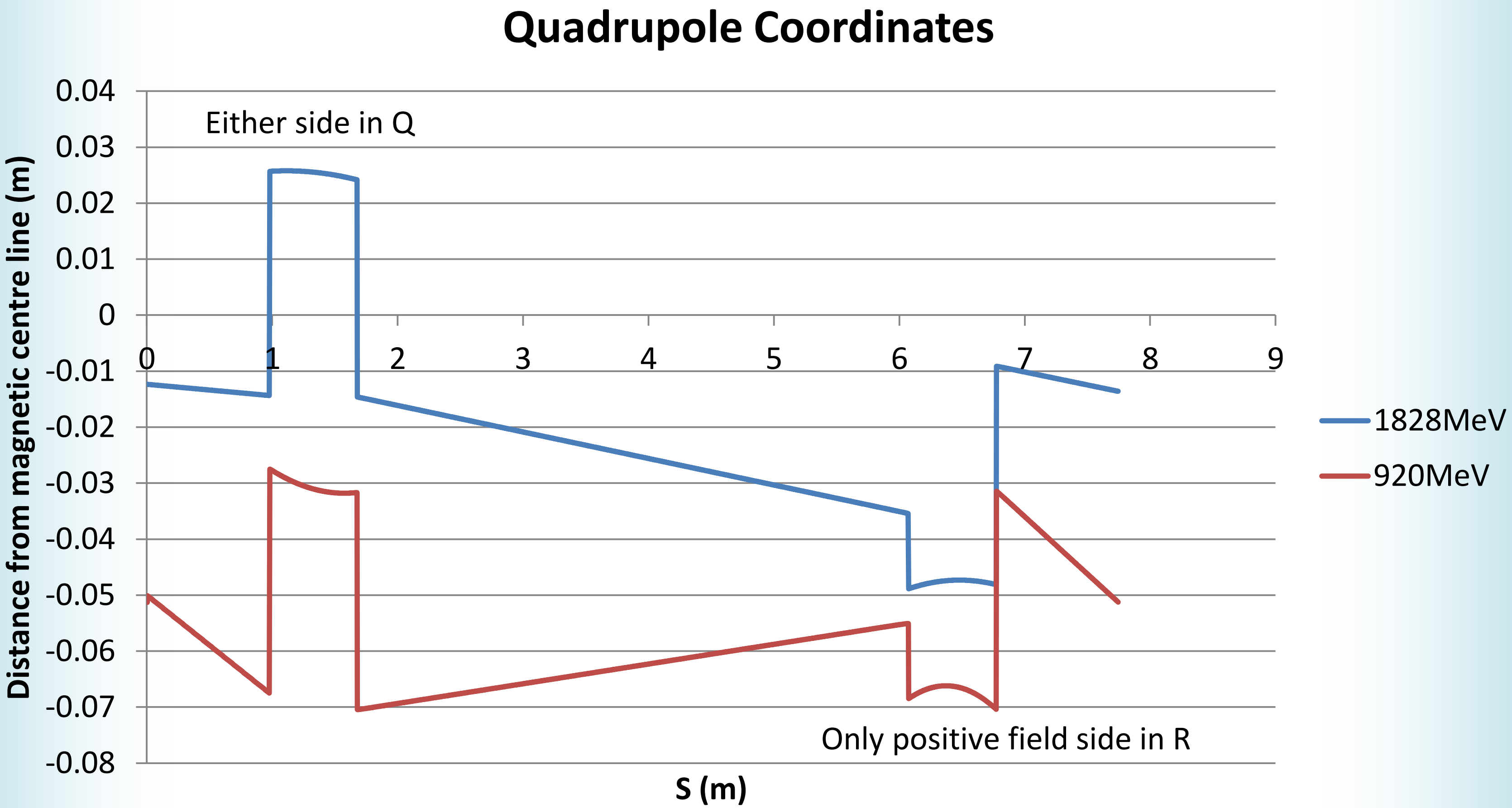
‘h’ Lattice in Global Coordinates



‘h’ Lattice in Tunnel Coordinates



‘h’ Lattice in Magnet Coordinates



Conclusion Depends on Tradeoffs

- Fewer magnets vs. smaller apertures
  - How does the per-unit cost of magnet assembly, testing, corrector coils and cables compare to the cost of a larger bore?
- Lower field vs. magnet length
  - Is there a special field level where we can use a cheap material like ferrite?
- Offset quads vs. combined function
  - Field quality in quads? Matching CF to straight?

What Did the Input Look Like?

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{eRHIC low-energy FFAG ring for 920 and 1828MeV passes
'h' variant is 'g' with magnet lengths fixed at 70cm to avoid short, high-field magnet syndrome}

#QL=0.7;
#RL=0.7;
{Parameter Value}
QX [-7cm,7cm]

#CellLength=2.58188724637682*3;
#Drifts=CellLength-QL-RL;
DL [0,#Drifts#]
#EL=Drifts-DL;

#BendRadius=378.26;

{Drift Length Angle}
D #DL# #DL/BendRadius#
HE #EL/2# #EL/2/BendRadius#

{Multipole Length Angle Quad Xhere Fringe AlignMode}
Q #QL# #QL/BendRadius# [-5,5] #-QX# 7cm Integral
R #RL# #RL/BendRadius# [-5,5] #QX# 7cm Integral

Cell: HE,Q,D,R,HE;

{MatchScan Estart Egoal Estep Species TuneMin TuneMax MaxRadius FOM}
Match 1828MeV 920MeV 908MeV Positron 0.05 0.4 5cm TOFrange

{Match-Aperture}
MatchEnd

Cell,Match,Cell,MatchEnd,Cell;
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