An eRHIC FFAG Design for 21GeV

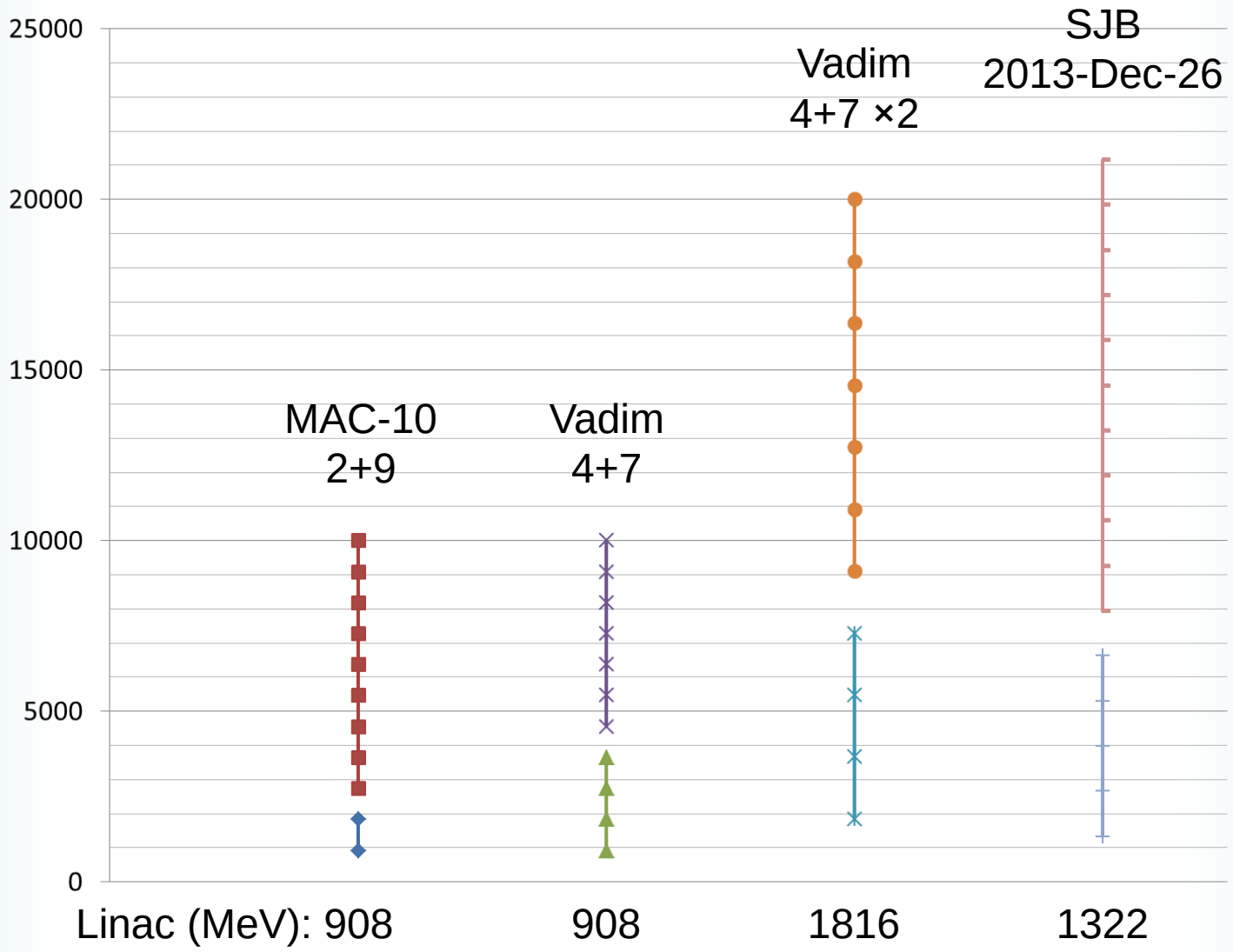
I. Lattices & Muon1 Results
II. Comparison with Other Options
III. To-do List & Design Report

I. Lattice & Muon1 Results

Method

- Using VL's recommended 1.322GeV linac
- Inheritied Vadim's SR-optimal cell geometry
- Reoptimised quadrupole gradients and offset
- Low-energy ring constrained by TOF variation
  - Tried 6 turns initially, had to reduce to 5
- High-energy ring by synchrotron power
  - (SR power is a good proxy for magnetic field)
- 16 passes: could use h=48, 450MHz RF

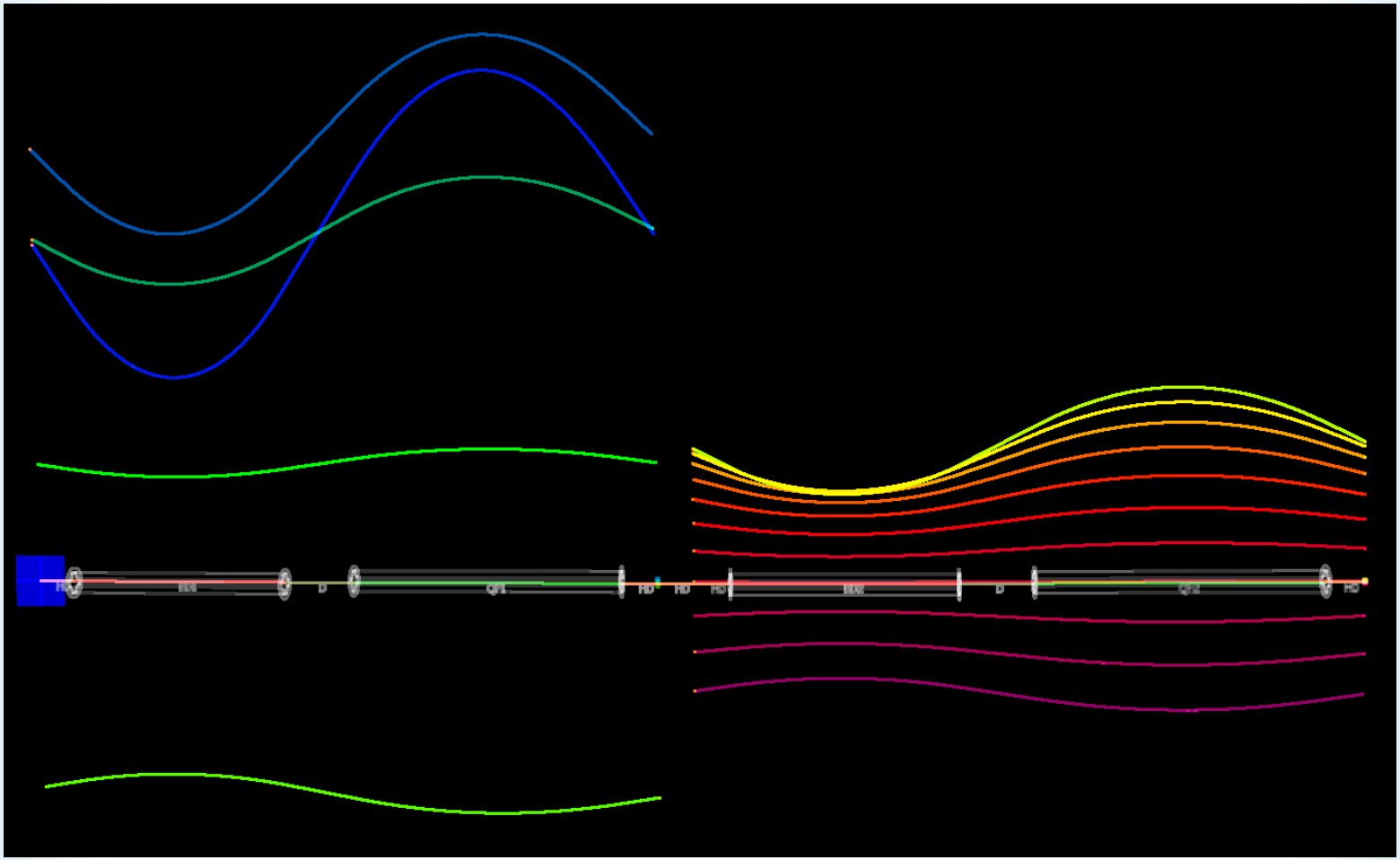
Energy Ranges



15/21GeV eRHIC (SJB 2013-Dec-26)

Parameter	Low-Energy FFAG	High-Energy FFAG
Energy range	1.334 – 6.622 GeV	7.944 – 21.164 GeV
Energy ratio	4.96×	2.66×
Turns (1.322GeV linac)	5	11
Synchrotron power	0.26MW @ 50mA	9.8MW @ 21.1GeV, 18mA 10.3MW @ 15.8GeV, 50mA 3.2MW @ 10.5GeV, 50mA
TOF range	54.7ppm (12cm)	22.3ppm (5cm)
Drift space	29.1cm	29.1cm
Tune range	0.036 – 0.424	0.036 – 0.370
Orbit range (quads)	31.3mm (r_{max} = 23.5mm)	12.5mm (r_{max} = 9.1mm)
Max $\|\mathbf{B}\|$ on orbit	0.228 T	0.448 T
Max quad strength	10.1 T/m	50 T/m

Orbits Exaggerated 100x

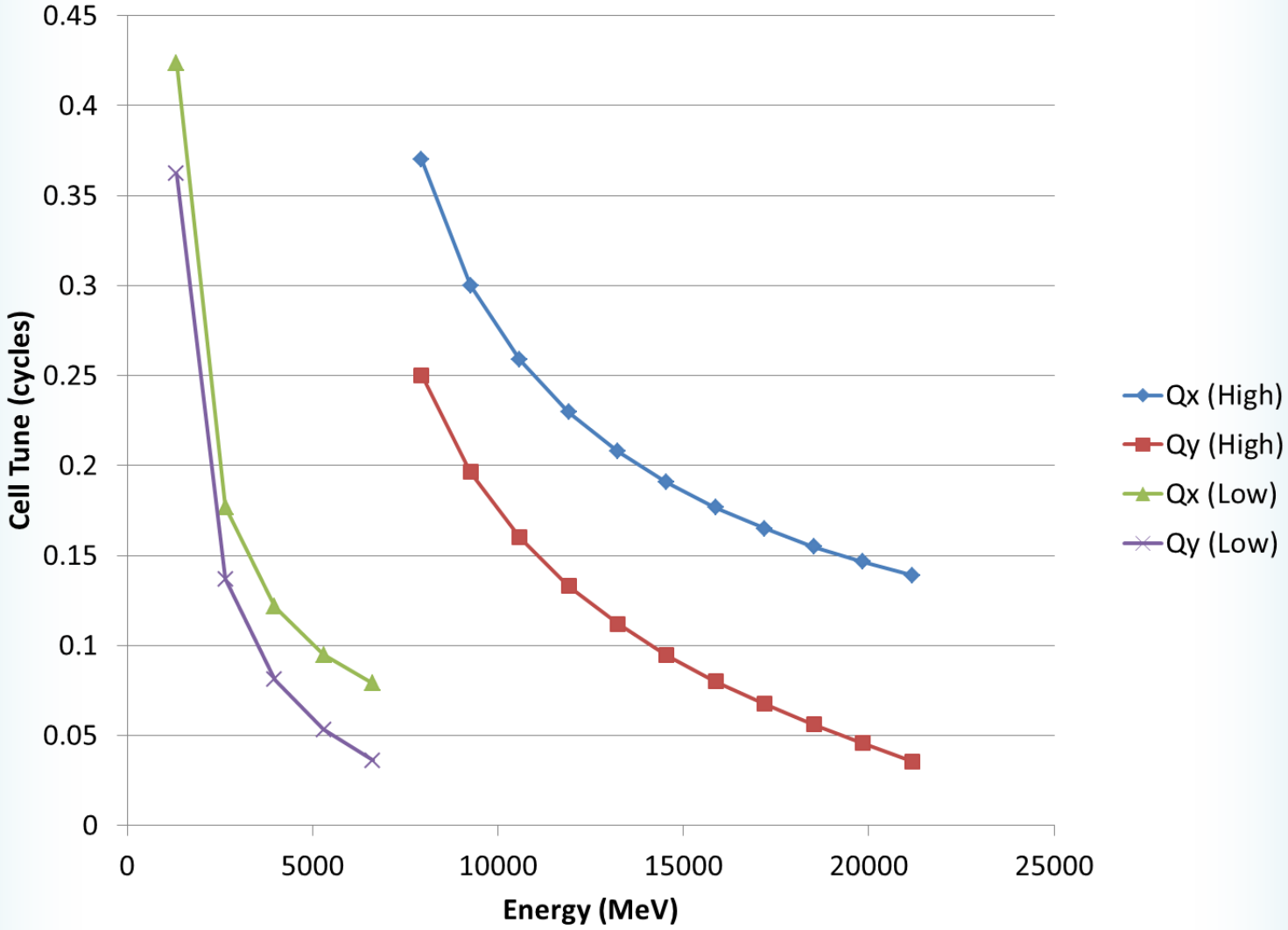


Lattice Description

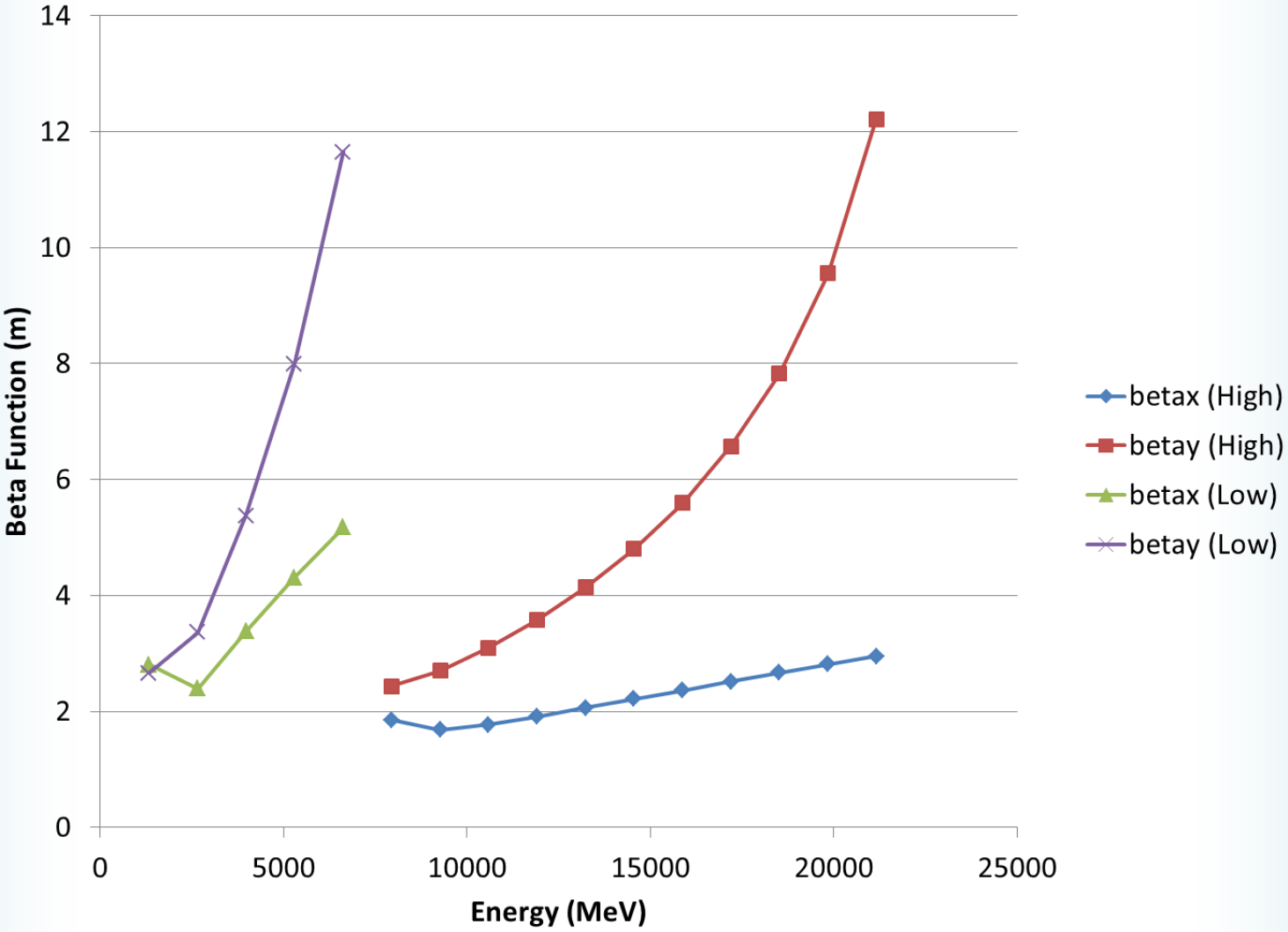
Element	Length (m)	Angle (mrad)	Gradient (T/m)	Offset (mm)
All Drifts	0.2909436	0		
BD (Low)	0.9	3.014379	10.07508	-6.946947
QF (Low)	1.1	3.742197	-8.993994	6.946947
BD (High)	0.9 (as above)	3.014379	50	-3.913914
QF (High)	1.1	3.742197	-49.49950	3.913914

- Cell: ½D,BD,D,QF,½D
- Cells stack exactly, allowing common girder
- First 2 columns fixed, last 2 optimised
  - 50 T/m value was at upper limit of allowed range

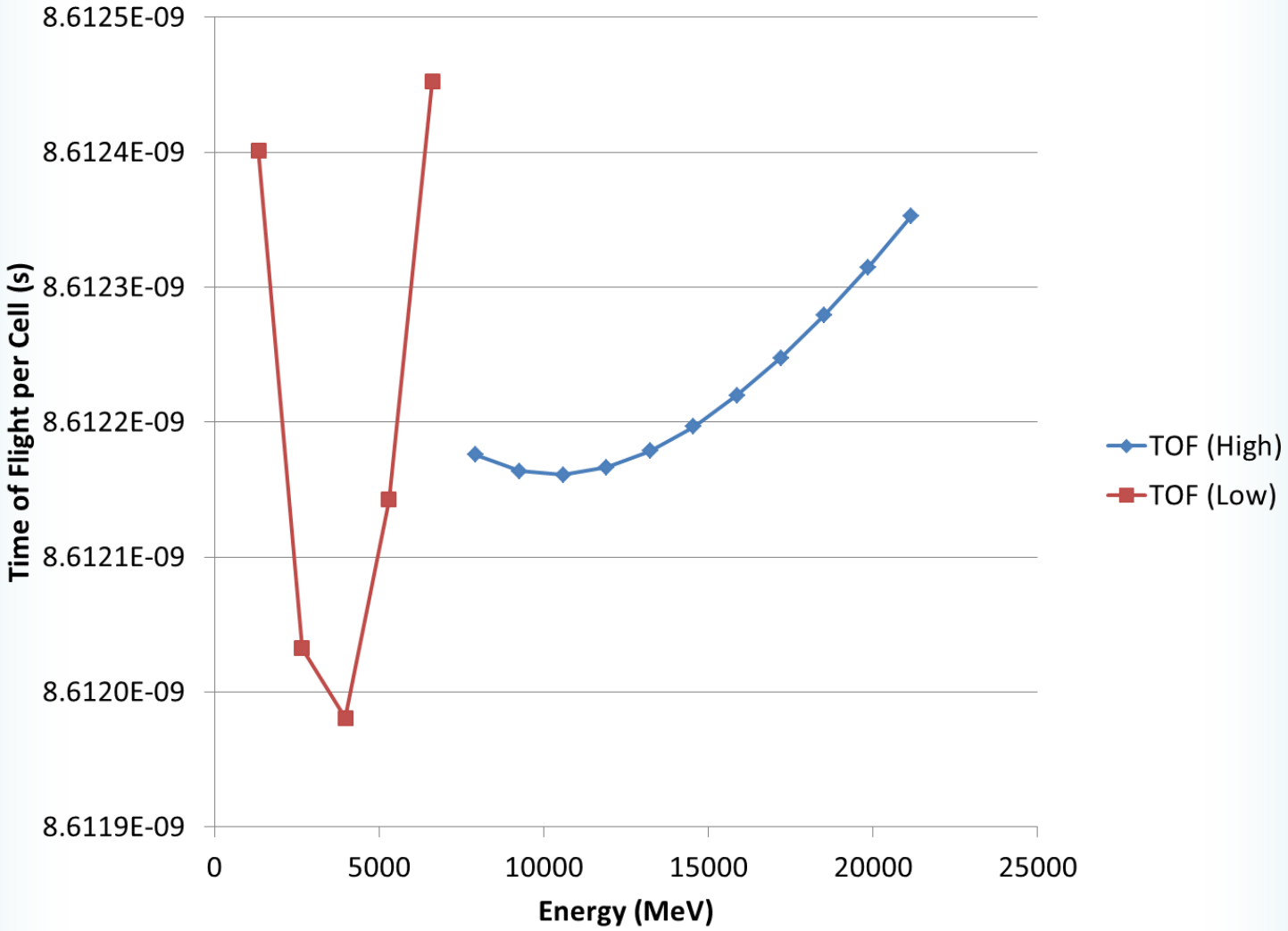
Tunes


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Cell Tune (cycles)
0
5000
10000
15000
20000
25000
Energy (MeV)
Qx (High)
Qy (High)
Qx (Low)
Qy (Low)

Betas at Matching Plane



Time of Flight Variation



II. Comparison with Other Options

Vadim's 4+7 Design ×2 in Energy

Parameter	Low-Energy FFAG	High-Energy FFAG
Energy range	1.840 – 7.288 GeV	9.104 – 20.000 GeV
Energy ratio	3.96×	2.20×
Turns (1.816GeV linac)	4	7
Synchrotron power	0.28MW @ 50mA	12.6MW @ 20.0GeV, **50mA** 5.3MW @ 16.3GeV, 50mA 1.4MW @ 10.9GeV, 50mA
TOF range	43.4ppm (9cm)	14.5ppm (3cm)
Drift space	29.1cm	29.1cm
Tune range	0.036 – 0.395	0.036 – 0.395
Orbit range (quads)	23.6mm (r_{max} = 15.1mm)	8.1mm (r_{max} = 6.6mm)
Max |**B**| on orbit	0.181 T	0.387 T
Max quad strength	13.0 T/m	58.6 T/m

Low Energy Ring vs. Vadim's 4+7 ×2

Parameter	SJB 2013-Dec-26	Vadim 4+7 ×2
Energy range	1.334 – 6.622 GeV	1.840 – 7.288 GeV
Energy ratio	4.96×	3.96×
Linac energy	1.322 GeV	1.816 GeV
Turns	5	4
Synchrotron power	0.26MW @ 50mA	0.28MW @ 50mA
TOF range	54.7ppm (12cm)	43.4ppm (9cm)
Drift space	29.1cm	29.1cm
Tune range	0.036 – 0.424	0.036 – 0.395
Orbit range (quads)	31.3mm (r_{max} = 23.5mm)	23.6mm (r_{max} = 15.1mm)
Max $\|\mathbf{B}\|$ on orbit	0.228 T	0.181 T
Max quad strength	10.1 T/m	13.0 T/m

High Energy Ring vs. Vadim's ×2

Parameter	SJB 2013-Dec-26	Vadim 4+7 ×2
Energy range	7.944 – 21.164 GeV	9.104 – 20.000 GeV
Energy ratio	2.66×	2.20×
Linac energy	1.322 GeV	1.816 GeV
Turns	11	7
Synchrotron power	9.8MW @ 21.1GeV, 18mA 10.3MW @ 15.8GeV, 50mA 3.2MW @ 10.5GeV, 50mA	12.6MW @ 20.0GeV, **50mA** 5.3MW @ 16.3GeV, 50mA 1.4MW @ 10.9GeV, 50mA
TOF range	22.3ppm (5cm)	14.5ppm (3cm)
Drift space	29.1cm	29.1cm
Tune range	0.036 – 0.370	0.036 – 0.395
Orbit range (quads)	12.5mm (r_{max} = 9.1mm)	8.1mm (r_{max} = 6.6mm)
Max $\|\mathbf{B}\|$ on orbit	0.448 T	0.387 T
Max quad strength	50 T/m	58.6 T/m

1.322GeV linac vs. 1.816GeV

- Larger energy range for high energy ring…
  - Because lower ring couldn't do it on its own
    - 6× range would require 20-25cm path length difference
- …means higher SR in high energy ring
  - Plus the effect from more turns, so a bit over 2×
- …means lower current at ~20GeV for 10MW
  - 18mA not 38mA
- Watch out for costs from 16 splitter lines

Dejan's Dec20-2013 Design

Parameter	Low-Energy FFAG	High-Energy FFAG
Energy range	1.375 – 6.825 GeV	8.1875 – 20.450 GeV
Energy ratio	4.96×	2.50×
Turns (1.3625GeV linac)	5	10
Synchrotron power	0.77MW @ 50mA	9.8MW @ 20.4GeV, 15mA 17.7MW @ 15.0GeV, 50mA 6.2MW @ 10.9GeV, 50mA
TOF range	61.4ppm (13cm)	11.6ppm (2½cm)
Drift space	48.6cm	12.3cm
Tune range	0.042 – 0.377	0.035 – 0.387
Orbit range (quads)	30.0mm (r_{max} = 19.7mm)	9.0mm (r_{max} = 10.6mm)
Max $\|\mathbf{B}\|$ on orbit	0.527 T	0.502 T
Max quad strength	24.9 T/m	49.5 T/m

Low Energy Ring vs. Dejan's Dec20

Parameter	SJB 2013-Dec-26	Dejan Dec20-2013
Energy range	1.334 – 6.622 GeV	1.375 – 6.825 GeV
Energy ratio	4.96×	4.96×
Linac energy	1.322 GeV	1.3625 GeV
Turns (1.322GeV linac)	5	5
Synchrotron power	0.26MW @ 50mA	0.77MW @ 50mA
TOF range	54.7ppm (12cm)	61.4ppm (13cm)
Drift space	29.1cm	48.6cm
Tune range	0.036 – 0.424	0.042 – 0.377
Orbit range (quads)	31.3mm (r_{max} = 23.5mm)	30.0mm (r_{max} = 19.7mm)
Max |**B**| on orbit	0.228 T	0.527 T
Max quad strength	10.1 T/m	24.9 T/m

High Energy Ring vs. Dejan's Dec20

Parameter	SJB 2013-Dec-26	Dejan Dec20-2013
Energy range	7.944 – 21.164 GeV	8.1875 – 20.450 GeV
Energy ratio	2.66×	2.50×
Linac energy	1.322 GeV	1.3625 GeV
Turns	11	10
Synchrotron power	9.8MW @ 21.1GeV, 18mA 10.3MW @ 15.8GeV, 50mA 3.2MW @ 10.5GeV, 50mA	9.8MW @ 20.4GeV, 15mA 17.7MW @ 15.0GeV, 50mA 6.2MW @ 10.9GeV, 50mA
TOF range	22.3ppm (5cm)	11.6ppm (2½cm)
Drift space	29.1cm	12.3cm
Tune range	0.036 – 0.370	0.035 – 0.387
Orbit range (quads)	12.5mm (r_{max} = 9.1mm)	9.0mm (r_{max} = 10.6mm)
Max $\|\mathbf{B}\|$ on orbit	0.448 T	0.502 T
Max quad strength	50 T/m	49.5 T/m

Conclusion

- The Vadim-based design is a very tempting option if we can afford a 1.816 GeV linac
- Otherwise, the SJB 2013-Dec-26 design is an ambitious attempt to use a 1.322 GeV linac
  - This approach with the high number of turns may come with some hidden costs
- The energy-doubled MAC-10 design is worse than the above in terms of radiation power

III. To-do List & Design Report

To-do List (stars = difficulty)

- Find vertical gap size required for synchrotron radiation ★★
  - Feeds into magnet LDRD parameters
- Arc-to-straight matching sections ★★
- Splitter/combiner at both ends of linac ★★★
- 10/15/21GeV septum ★★★★
  - With possible optical bumping etc.

Scope of February Design Report

- Still seems mostly undecided
- We could go with something like this lattice
  - Pending possible improvements from Vadim et al.
  - ~20GeV one stage, runs ~15GeV at full 50mA
  - Permanent magnets, two FFAGs
- Looks like we don't even have time to do parametric costing now
- Discuss…