Alternative ISIS upgrade investigations (FFAG etc.)

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ISIS MW upgrades meeting, RAL, May 2009

What do we want to do?

- An upgrade should actually be an upgrade
  - The stage including ISIS must be compelling
  - Green field stage 2 <= SNS upgraded
- Can only initially afford 0 or 1 new rings
  - Boosting to 3.2GeV gives 640kW at 200uA
    - 768kW at 240uA, “960kW at 300uA”
  - SNS is already there
  - ESS Lund estimates construction start 2012, first neutrons 2018 (thanks Ciprian)

Go to highest energy possible

- Only way of getting considerable power while building on existing machine
- Although neutron yield *per unit power* decreases, hard to believe this cancels overall power increase at constant uA
  - MARS15 code has just been installed on the correct server so will be able to calculate this given information on what sort of neutrons are considered “useful”

Technology choices

- Using an FFAG
  - Gives full 20ms cycle for accelerating
  - Allows use of superconducting magnets
    - Smaller ring, lower civil engineering cost
    - Tricky MMPS replaced by tricky cryogenics
- Variable frequency RF similar in range to ISIS 2h system (but many more of them)
  - 6.2 – 7.3MHz if maintaining wavelength
  - Slotted for orbit excursion (c.f. cyclotrons)

How high in energy?

- Existing 2RF is 2x11kV in 1.9707m module
  - 11.16kV/m * 20ms * c = 67GeV
- Assume 30% ring RF packing factor
  - 67GeV * 30% = 20GeV
- Assume $\langle \cos \phi \rangle = 0.7$ ($\phi \sim 45°$)
  - 20GeV * 0.7 = 14GeV
- Finally, velocity goes from 0.84c to ~0.99c
  - 14GeV * 0.9 = 12.6GeV

“Ideal ring” parameters

- FFAG of some sort (but with 2-4m drifts)
- Energy: 800MeV – 12GeV
- 30% RF packing factor, 20% magnets
- Ring radius 52m (2x ISIS) could do 2.5x,3x
- Mean dipole field in magnets 0.47 – 4.14T
- Superconducting magnets
- Warm 6.2 – 7.3MHz RF
- Harmonic number 8 (10,12 in larger ring)

Power

- 200uA * 12GeV = 2.4MW
- 240uA * 12GeV = 2.88MW
- And then if H- injection were later possible from an 800MeV linac...
  - Fill all 8 buckets instead of 2 → 9.6MW
  - Note that levels of space charge still not increased significantly from ISIS late cycle
  - Real limit could be ~24MW (2mA mean)
    - 50mA, 0.8ms (4% duty) injector, c.f. FETS

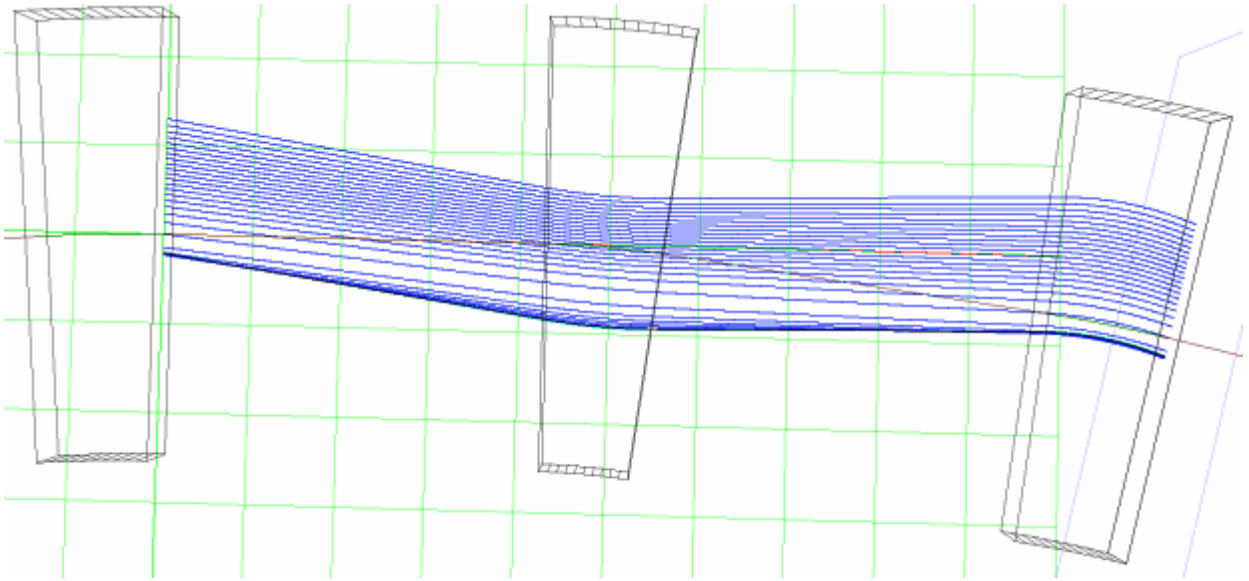
A 20MW spallation source?

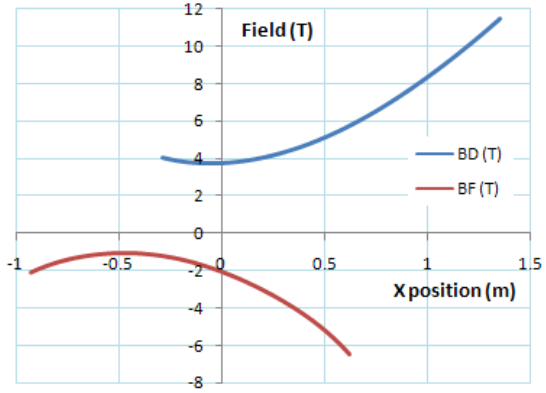
- “That's a stupid idea, no one wants that”
- Actually Thomas Mason's (ORNL) talk at PAC suggested the limit for pulsed spallation sources was around 100MW
  - Above this getting heat out of the target limits useful neutron brilliance
- Thus a post-SNS (or post-ESS) generation is a niche on *our* stage 2 timescale
  - Stage 1 competitive meanwhile at 2MW

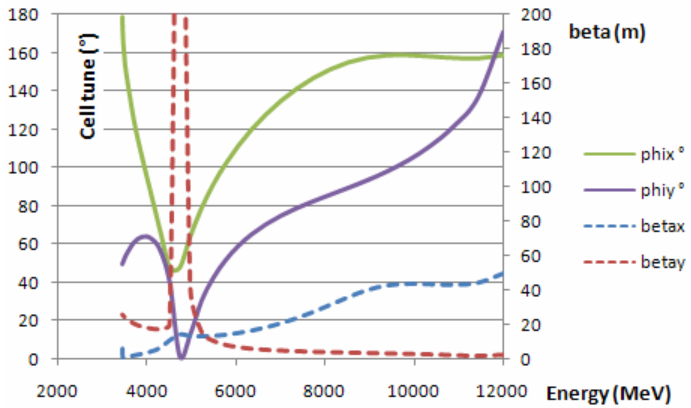
Attempt 1: non-scaling FFAG

- Subject of my PAC'09 paper
- Fix ring radius, allow two magnets with arbitrary spline field profiles
  - Maxwellian field model developed for ends
- Muon1 modified to find closed orbits from 12GeV stepping downwards
- Existing genetic algorithm search for largest energy range with stable optics

FODO lattice (from 3.5GeV)







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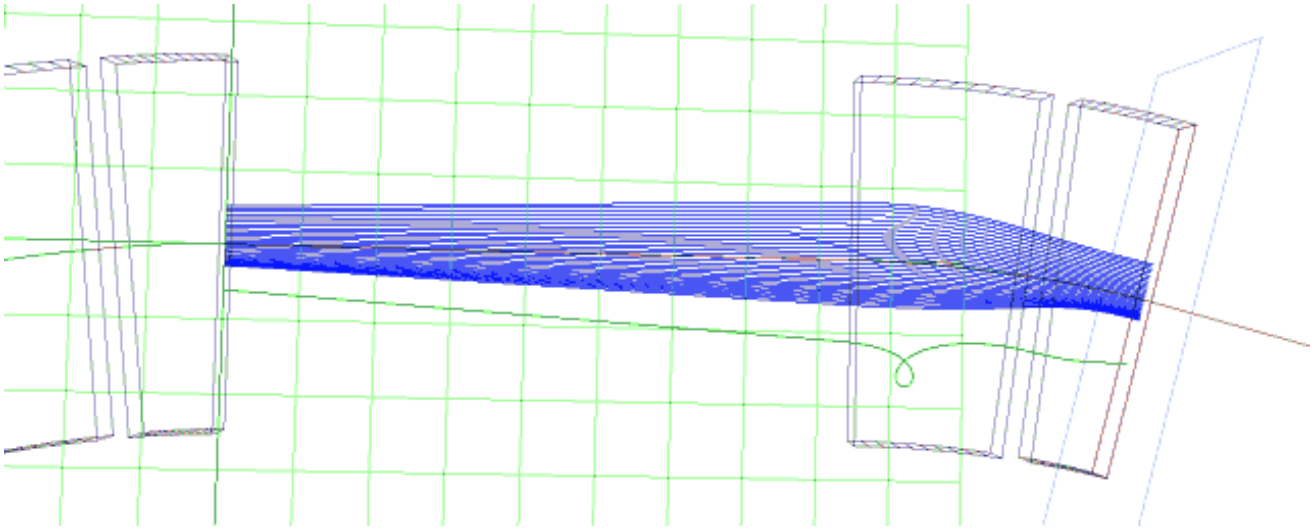
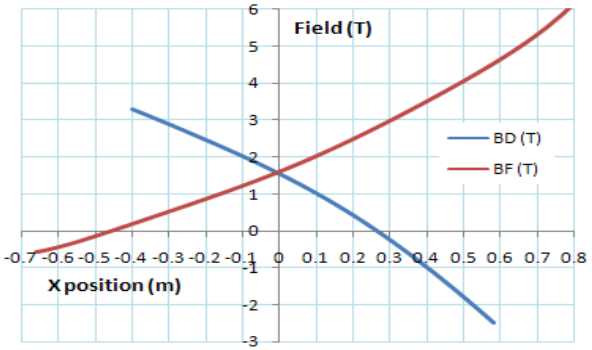
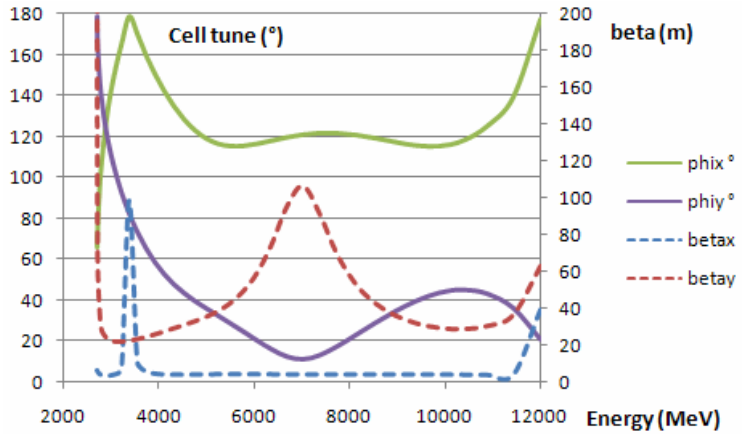
Doublet lattice (from 2.7GeV)







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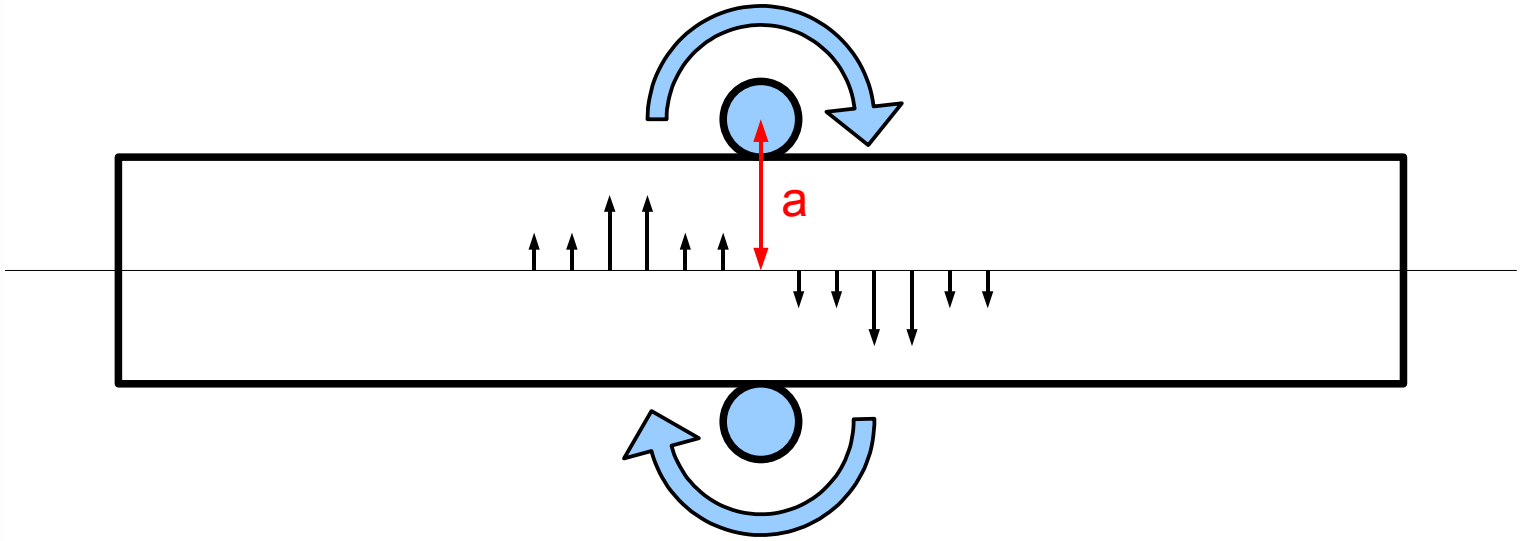
Non-scaling FFAG observations

- Probably need to try again with a more careful figure of merit
- Proton machines (kturns) need tunes *very* stable, may be better to fix them explicitly
- Generally, shrinking the orbit excursion makes quad gradients too high
  - Shorter focussing period lattice?
- Magnets are still very wide ~1m
  - Not so easy to build this way around...

Horizontal magnet problem

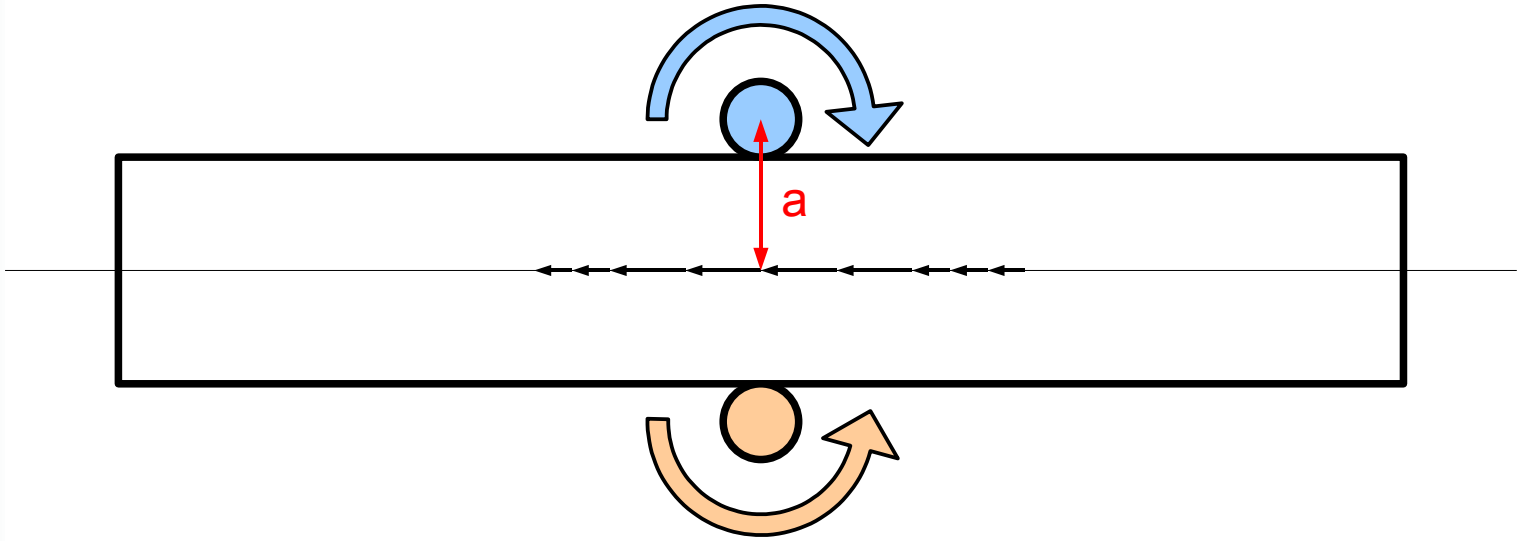
- Getting vertical B field requires same-direction current windings (nearby)



- By proportional to x/(a^2+x^2)

Horizontal magnet variation

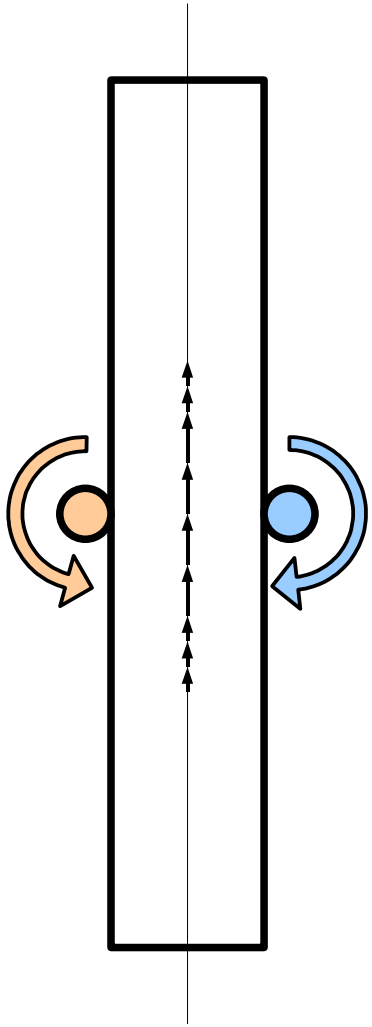
- Getting horizontal B field requires opposite current windings and is easier



- Bx proportional to a/(a^2+x^2)

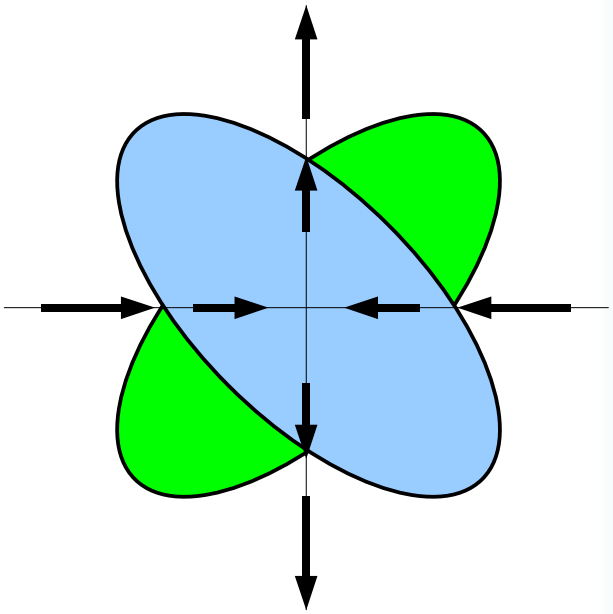
Vertical magnet

- But now the field is in the wrong direction!
- That's OK, rotate the magnet
- The dipole field is there
- But what sort of focussing does this magnet give?



VOX-FFAG magnet

- Dipole field should increase moving up the magnet, so set By=exp(ky) on axis (x=0)
- Subtracting dipole component leaves the field of a skew quad:



• Exponential is good because moving upwards just scales the field and all gradients
• Thus closed orbits at different momenta are exactly the same shape, just translated upwards
• VOX-FFAG = Vertical Orbit eXcursion FFAG

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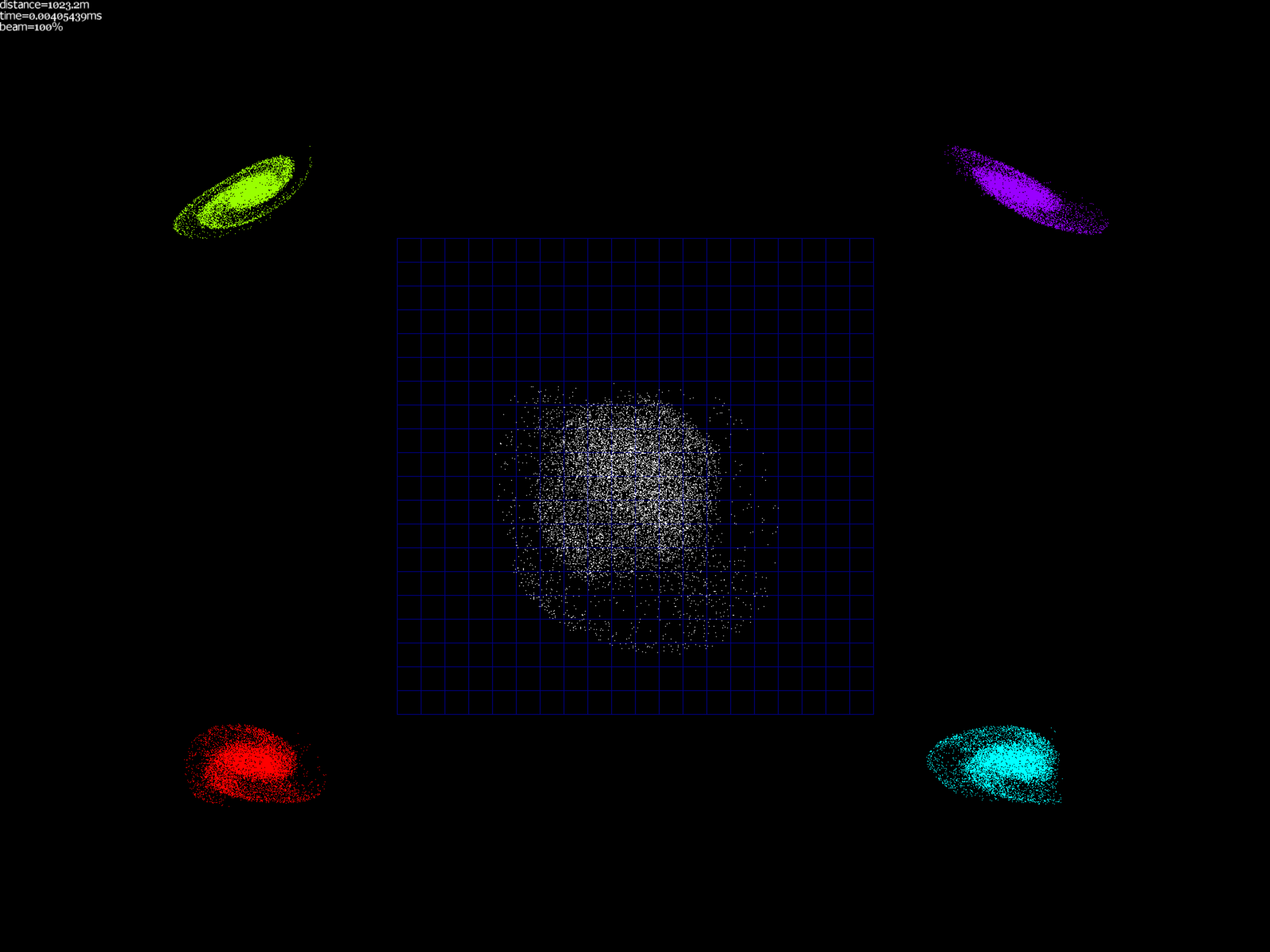
Attempt 2: VOX-FFAG FODO

- Simulation


distance=1023.2m
time=0.00405439ms
beam=100%

Scaling FFAG disease

- This ring has unlimited energy range (until the maximum magnet field is reached)
- Constant tunes
- Space charge is probably a smaller term than intrinsic nonlinearities, need to check
- Unfortunately it is about 10x larger than ISIS instead of the desired 2x
  - Defocussing is locked to reverse bending, as in scaling FFAGs

Search for “lopsided” lattices

- 10000 particles were tracked for 1km
- Survival rate plotted on axes of lengths of “F” and “D” type magnets
- This reveals both the lattice stability region and resonance stop-bands

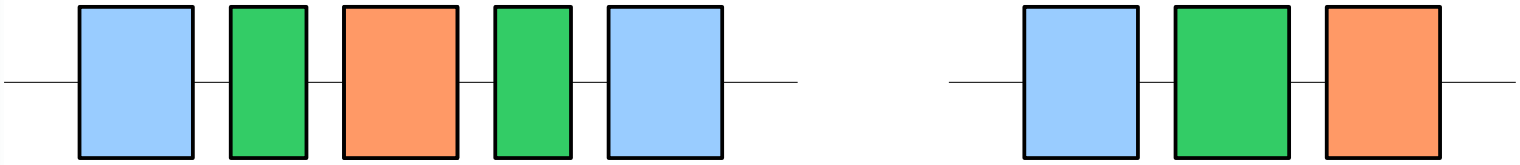

transmission1fodo.csv
54.74%
100%
13.3%
13.31%
100%
100%
67.63%
67.74%
100%
100%
24.37%
100%
100%
100%
91.15%
21.77%
24.58%
100%
100%
100%
100%
82.44%
28.23%
91.46%
100%
100%
100%
99.73%
95.58%
64.3%
22.31%
20.44%
100%
100%
100%
98.43%
96.09%
87.65%
51.89%
11.65%
18.79%
4.52%
81.78%
99.4%
97.85%
89.95%
92.36%
51.12%
66.44%
7.34%
21.77%
27.66%
96.09%
95.96%
94.61%
96.17%
50.51%
59.19%
13.05%
64.38%
88.7%
50.78%
49.5%
43.95%
40.66%
6.11%
22.91%
52.72%
66.25%
60%
42.93%
55.75%
18.47%
22.13%
11.87%
6.75%
4.94%
6.19%
4.85%
5.07%
4.38%

Lattices can't be very lopsided

- Unfortunately in all cases the region of dynamic stability sticks very close to the F=D diagonal line
  - So pure exponential VOX-FFAGs will always be big, with much reverse bending
- Another reason for choosing the non-scaling machine initially was to ensure msot magnets contribute to the bend
  - Thus, non-scaling VOX-FFAG? Interesting!

Fixed tune non-scaling FFAGs

- In principle if you have at least three free magnet gradients, you can simultaneously satify the equations
- Sum of dipole = momentum * constant
- d(X tune)/dp = d(Y tune)/dp = 0
- Thus, Grahame's pumplet lattice
  - 1-2-3 configuration also possible



Conclusions so far

- Theoretically a one-stage upgrade to 2MW does not exceed available technology
  - Stage 2 to 20MW also not ruled out
- Main difficulty is finding an efficient lattice to keep the ring size practical
- New (as far as I know) VOX-FFAG machine suggested, has some advantages
- Design of non-scaling one will be tricky
  - Next step making tune fixing work