Scaling VFFAG eRHIC Design

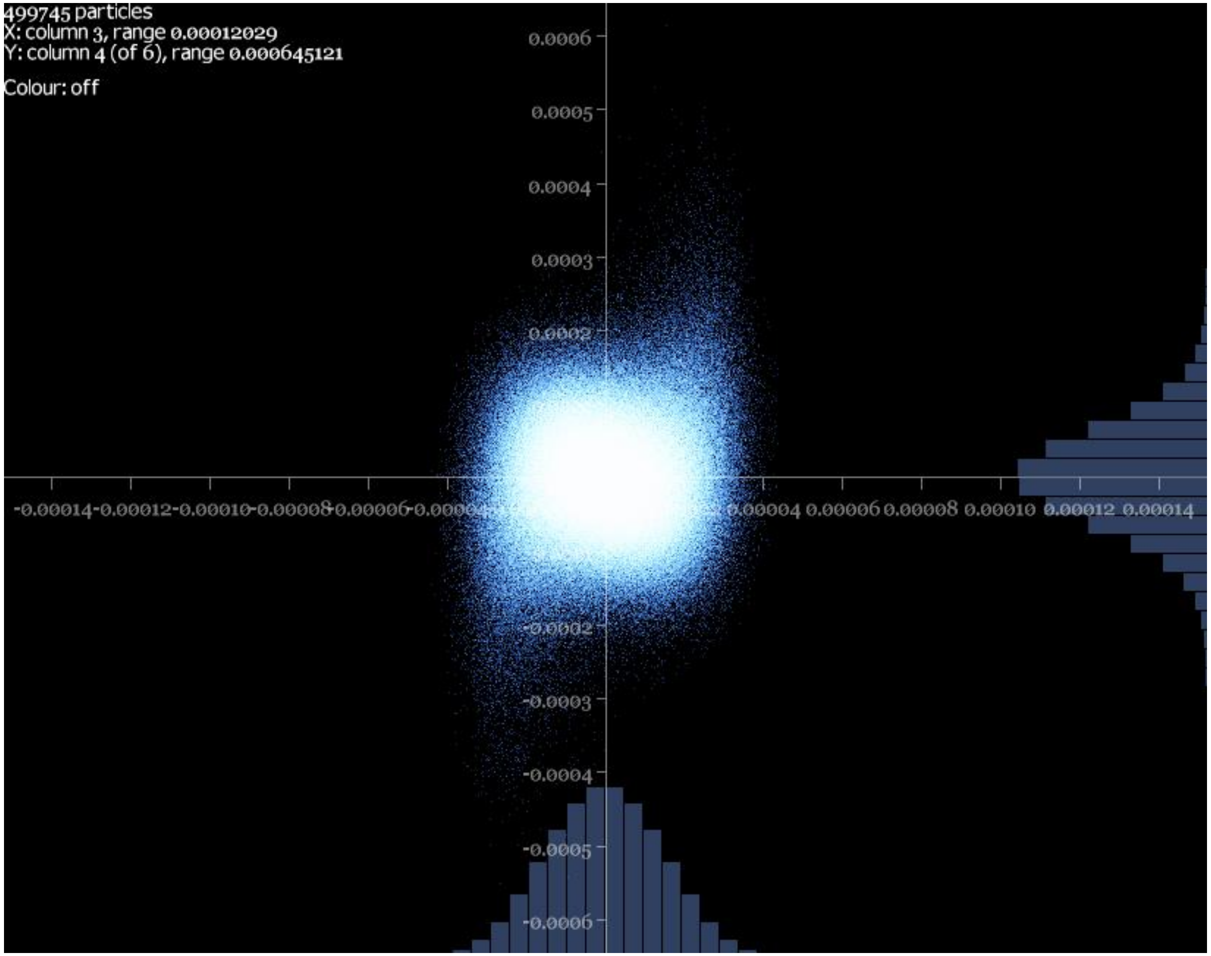
Progress Report

I. Beam Distribution Model

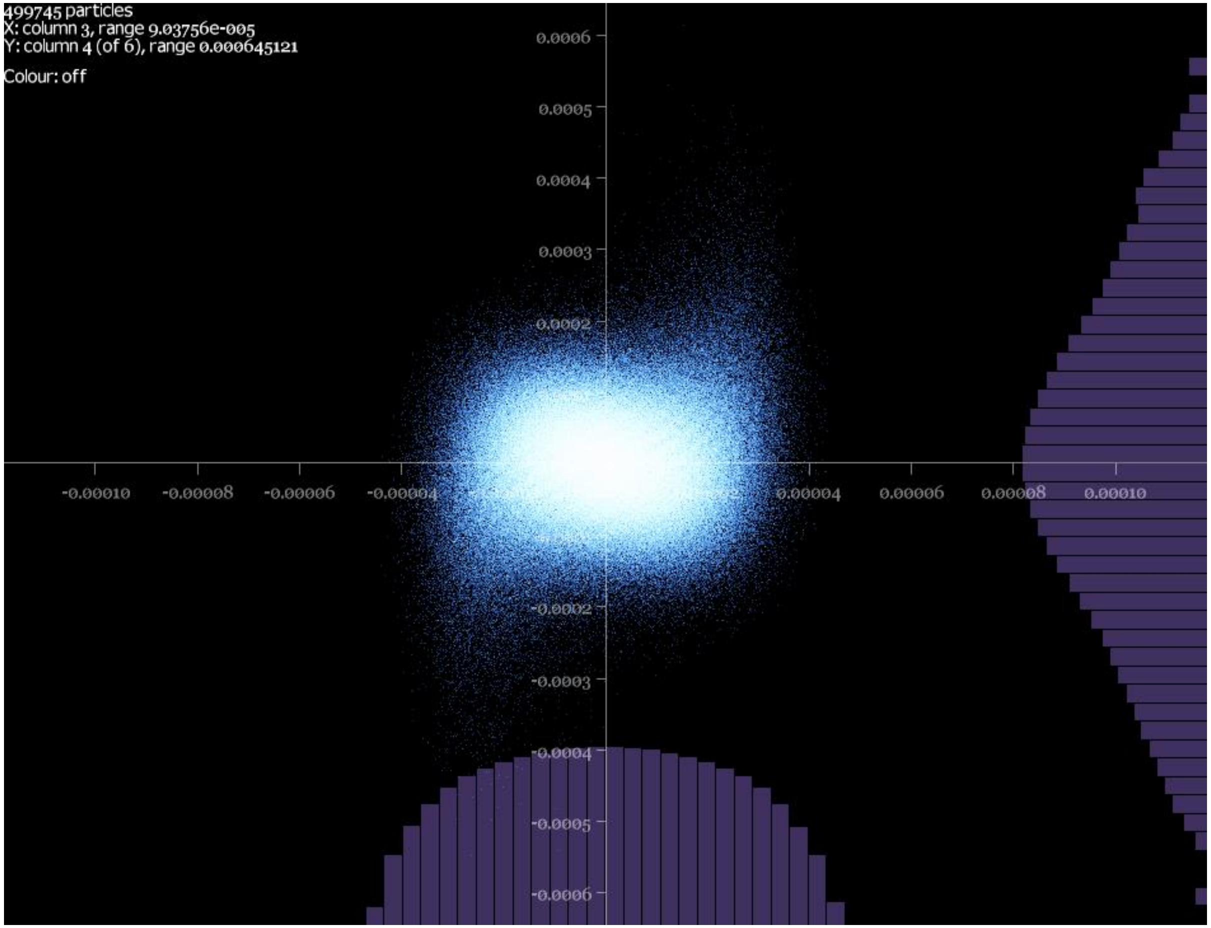
Input from Beam-Beam Simulation

- To check dynamic aperture, want a "worst case" beam with tails
- Received a distribution from Yue Hao
  - Electrons immediately after interaction at 10GeV
- Loss required <1e-6 so long tails are important
  - Define model distribution not discrete particles
    - Fit model to Yue's beam distribution

y-y’ with Linear Histograms



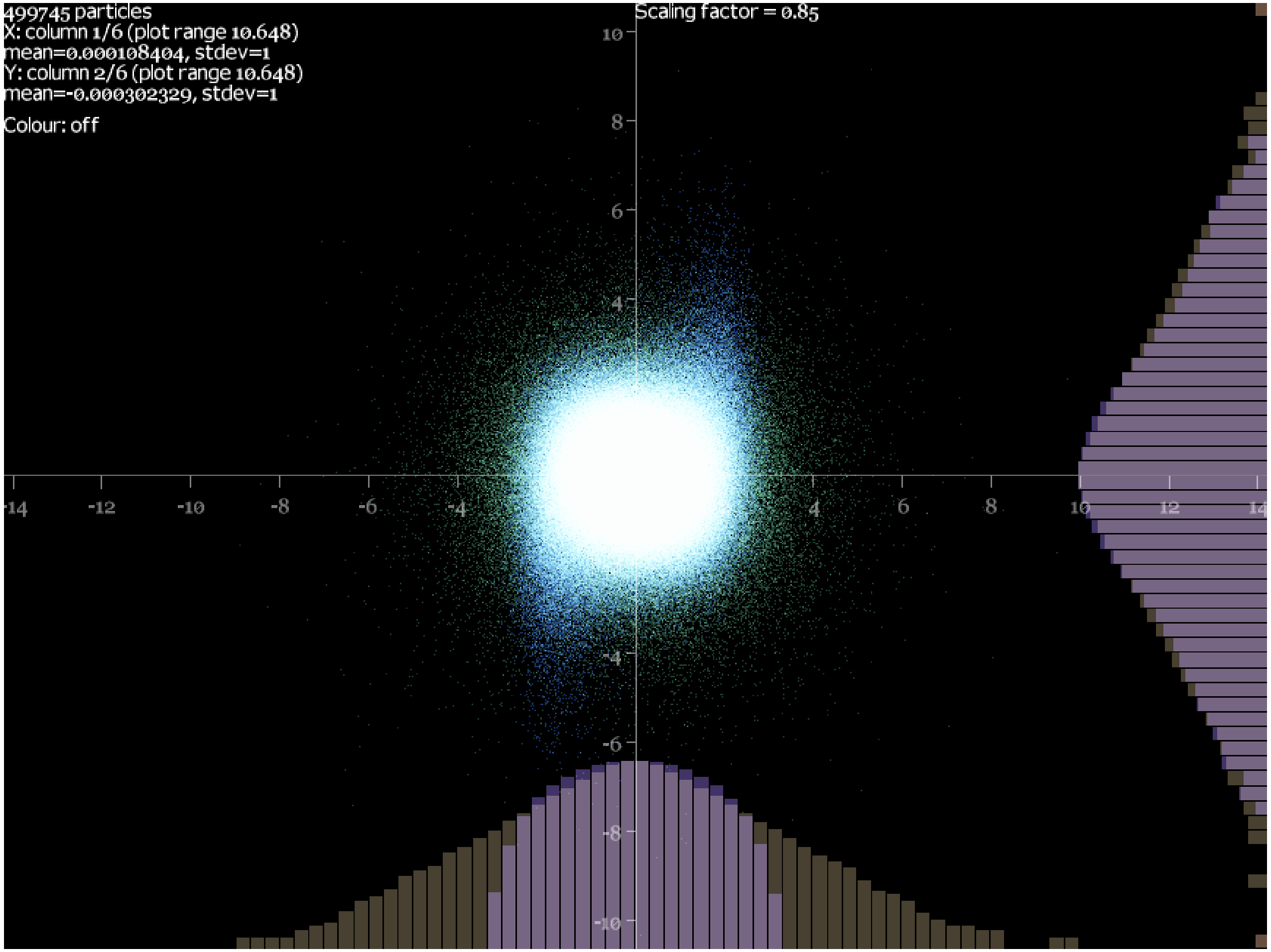
y-y' with Log Histograms



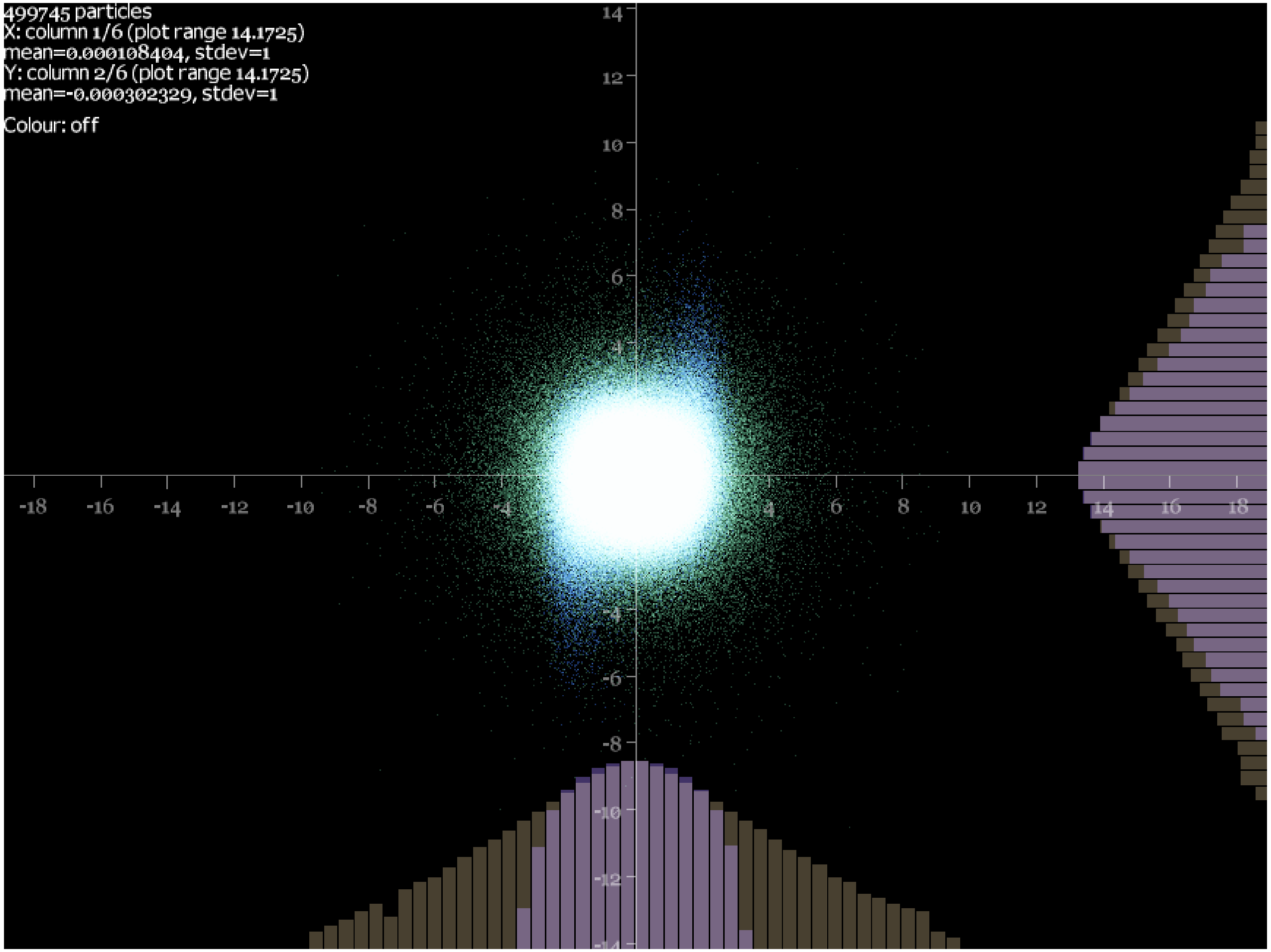
Distribution Model

- y’ (and x’) tails on log plots look like e^-x
- Turns out in a 4D (x,x’,y,y’) distribution that’s not a very natural tail to have
- Cumulative F(Z) = (1-e^-Z)^4 mostly works
  - Z is normalised amplitude (expressed in sigmas)
  - Needed to scale to 0.85Z to get good fit in tails
- Idea is phase-independent distribution that is “at least as bad” as real one in all projections

Distribution Model Comparison



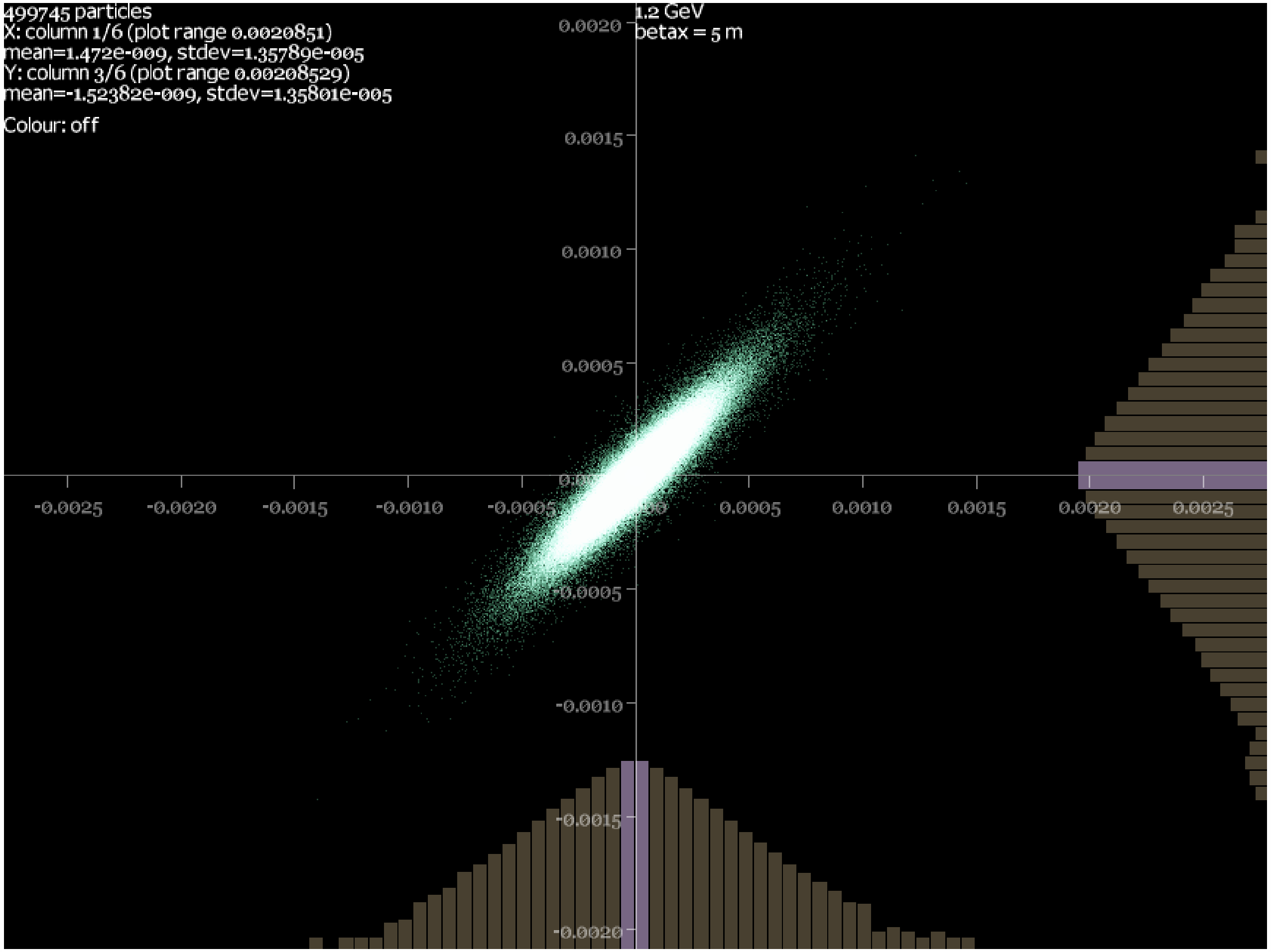
Comparison Without 0.85 Scaling



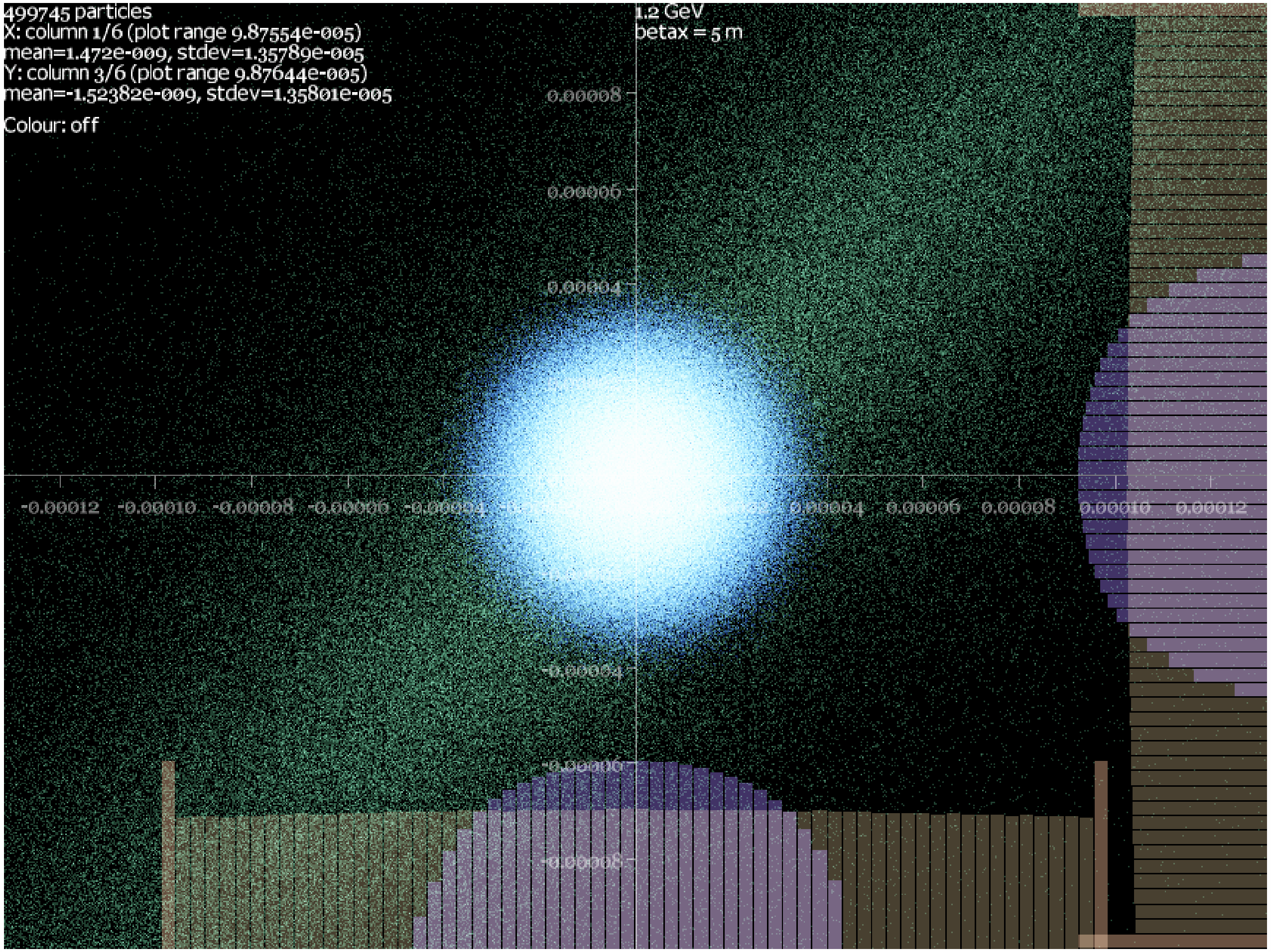
Beam Size in Real Phase Space

- sigma_x = 13.6um, sigma_x’ = 72.9mrad
  - At IR! So beta_RMS = 18.6cm
- em_geom_RMS = 0.99 nm.rad (at 10GeV)
  - em_norm_RMS = 19.4 um.rad
- Scaling to beta = 5m and 1.2GeV gives
  - sigma_x = 203um
  - Tails were approaching 10 sigma
    - So [dynamic] aperture needs to be +/- 2mm: large!

x-y Example VFFAG Beam @1.2GeV



Zoom 20x to see Beam at IR

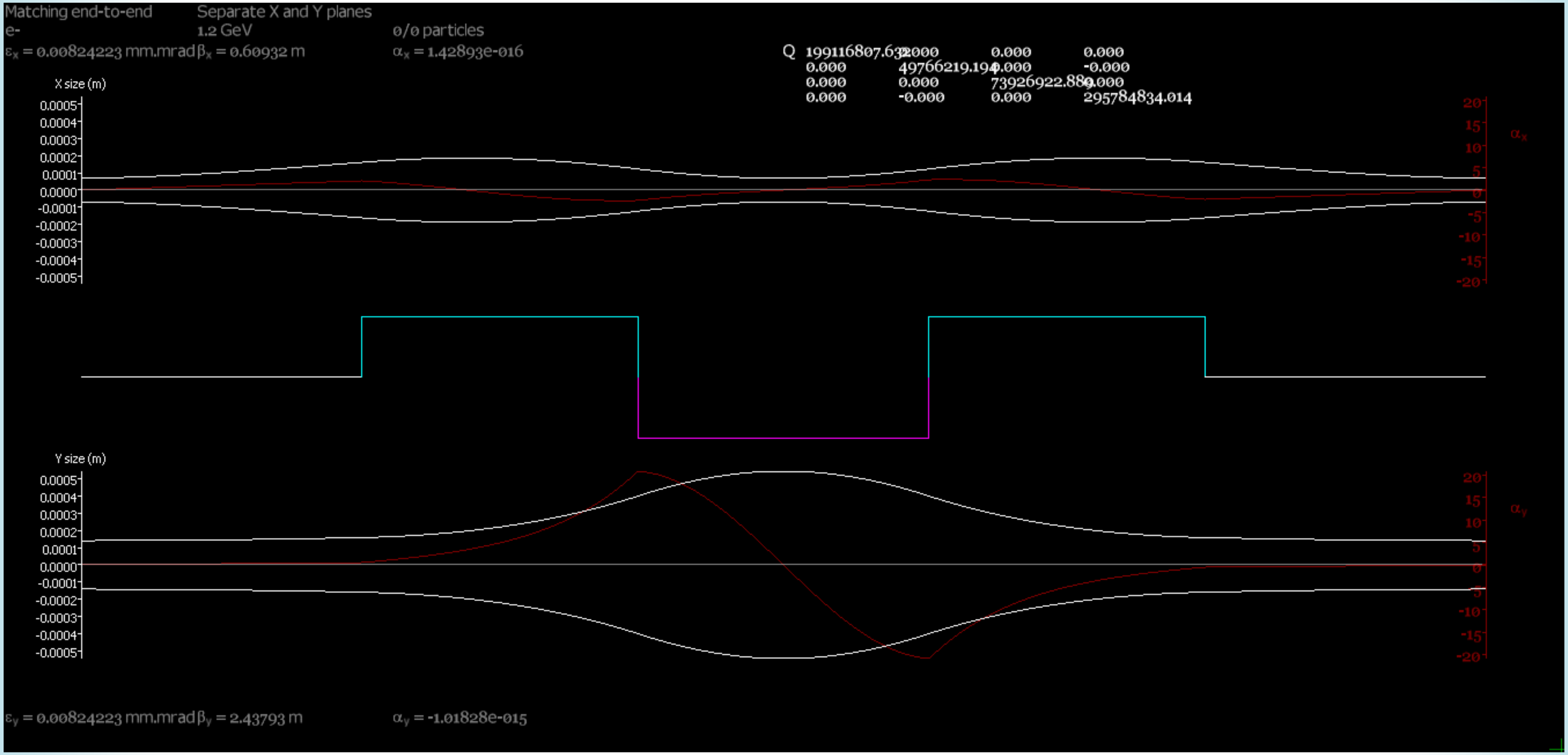


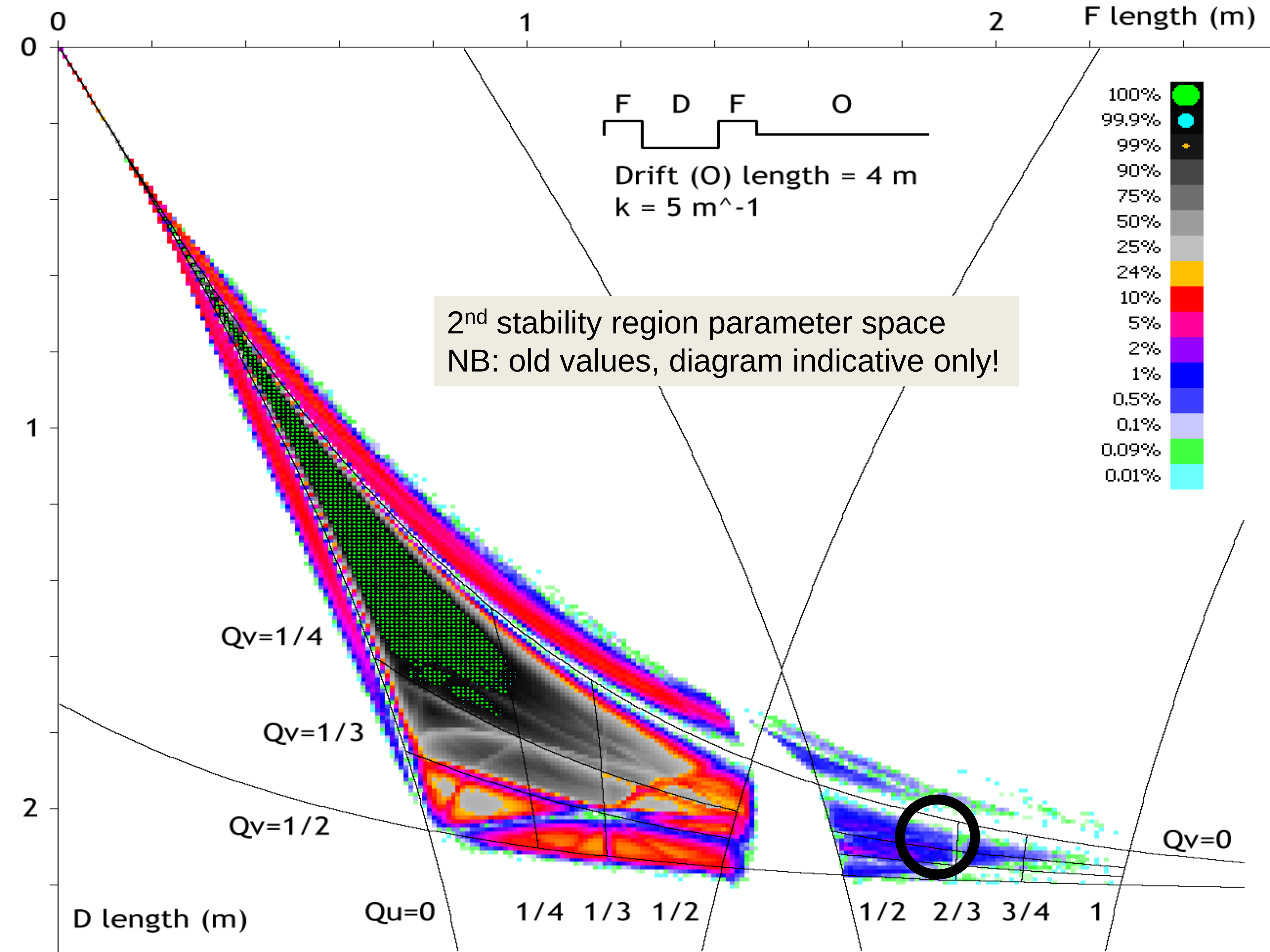
II. Dynamic Aperture k Scaling

Scaling VFFAG Design from April

- k=100m^-1 (reminder: B_y = B_0 e^ky)
  - 21.2mm orbit offset, B_0=0.0529T, B_{10GeV}=0.441T
- Used triplet "2nd stability region" lattice
- Tracking indicated dynamic aperture too small
- F=1.23m, D=1.3m (2cm fringe), O=2.507m
  - FDFO lattice cell = 6.267m
  - 60% packing factor
  - Circumference factor = 3.241

2nd Stability Region Optics





0
1
2
F length (m)
F D F O
Drift (O) length = 4 m
k = 5 m^-1
100%
99.9%
99%
90%
75%
50%
25%
24%
10%
5%
2%
1%
0.5%
0.1%
0.09%
0.01%
2nd stability region parameter space
NB: old values, diagram indicative only!
Qv=1/4
Qv=1/3
Qv=1/2
Qv=0
D length (m)
Qu=0
1/4
1/3
1/2
1/2
2/3
3/4
1

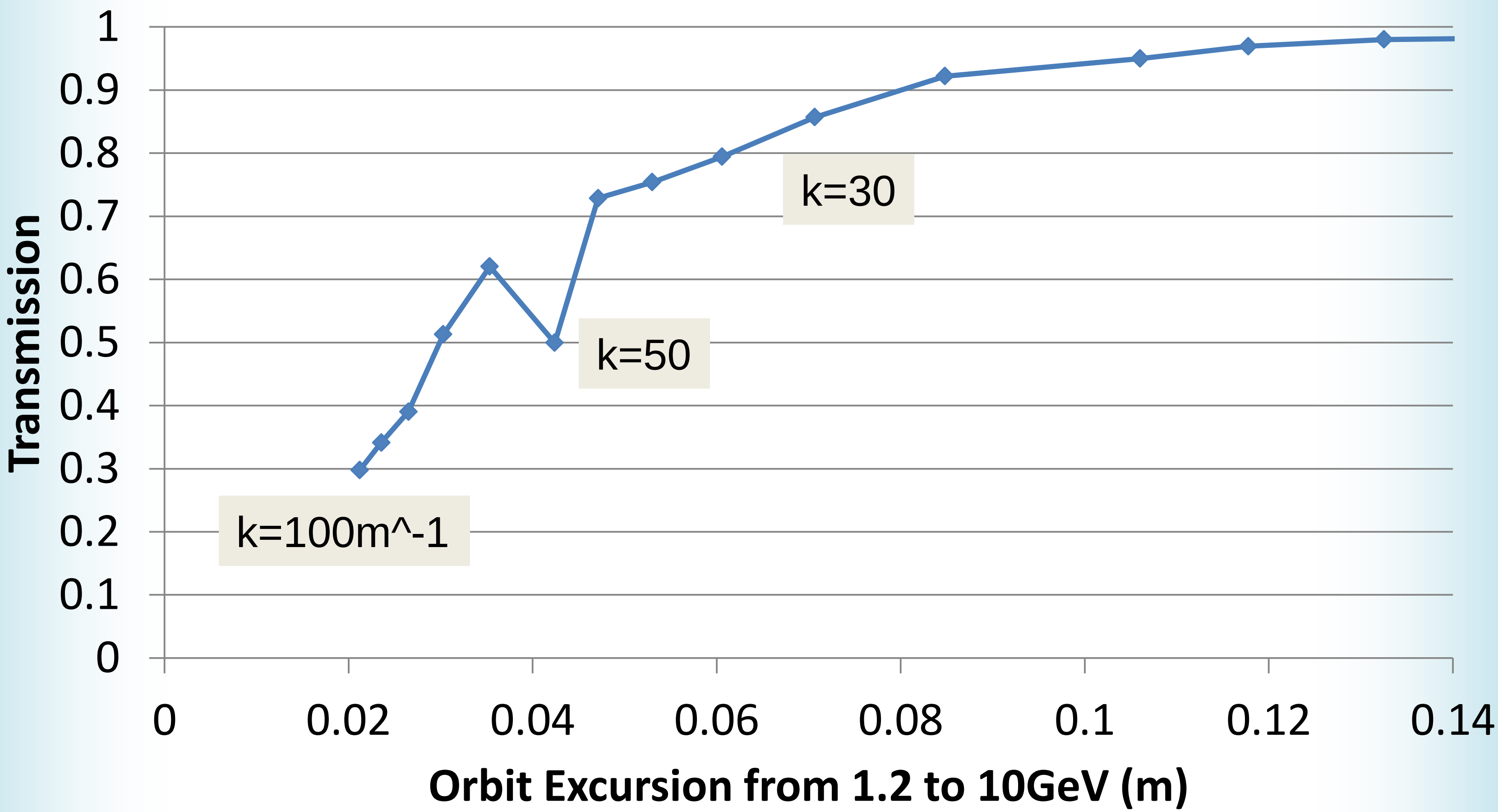
How to Scale k?

- Orbit spacing scales with 1/k
- Magnet/drift lengths with 1/sqrt(k)
  - 2k with same magnet L gives focal L/2
  - But 2k with magnet L/sqrt(2) gives focal L/sqrt(2)
- Beta is focal length so also 1/sqrt(k)
- Fringe field length with 1/k
  - Because magnet height scales with 1/k
- Dipole fields remain the same

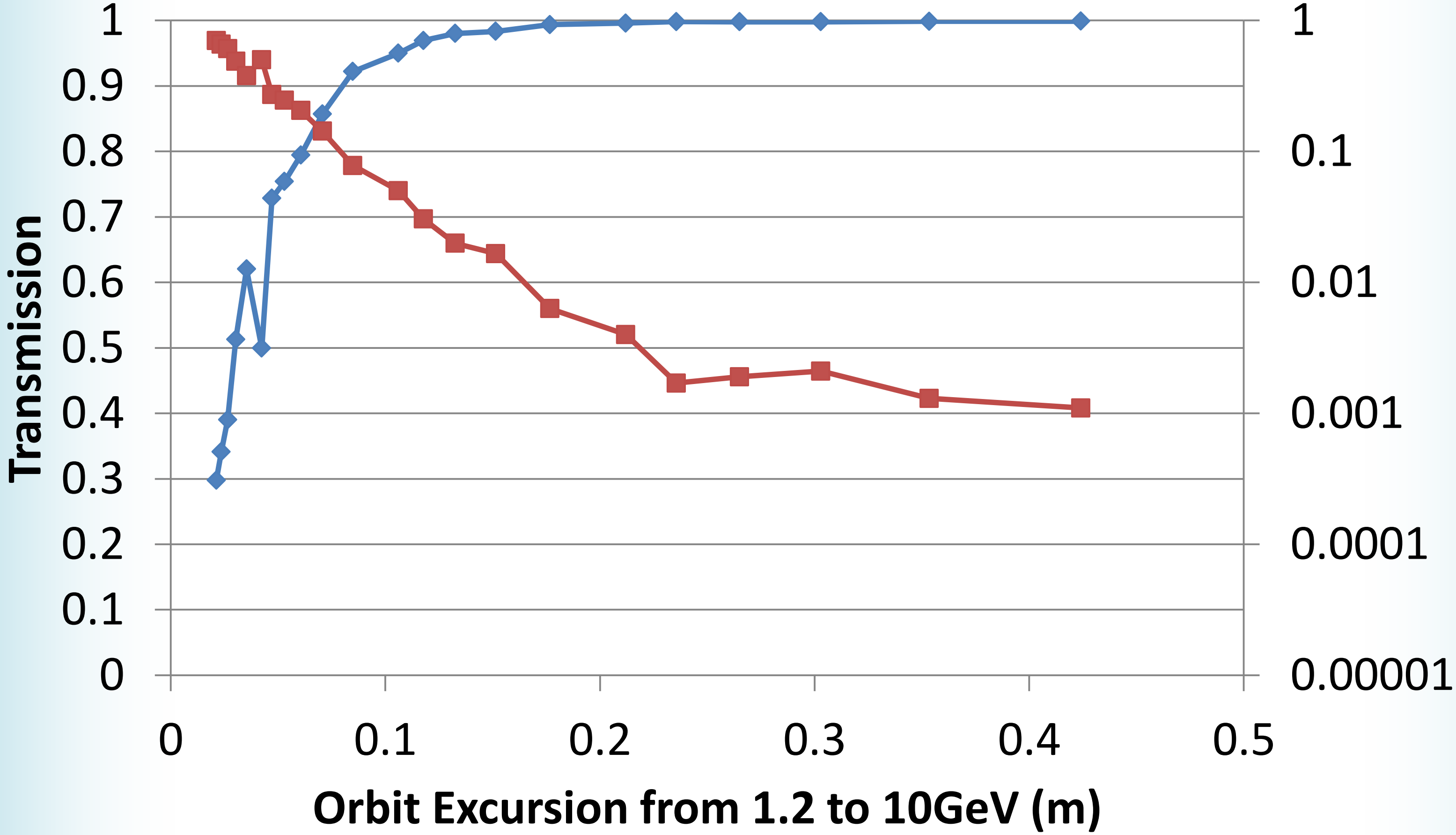
Dynamic Aperture Simulation

- Most difficult turn is 1.2GeV: largest beam
  - Higher order poles smaller for smaller beams
- Disrupted beam is harder than original
- Do 2 turns of disrupted beam at 1.2GeV as proxy for whole 1.2->10->1.2 cycle
  - C_eRHIC = 3843.16m, 2 turns ~ 7.7km
  - 10000 particles for now
- 1.2-10GeV orbit excursion = 2.12/k

Transmission as k is Decreased

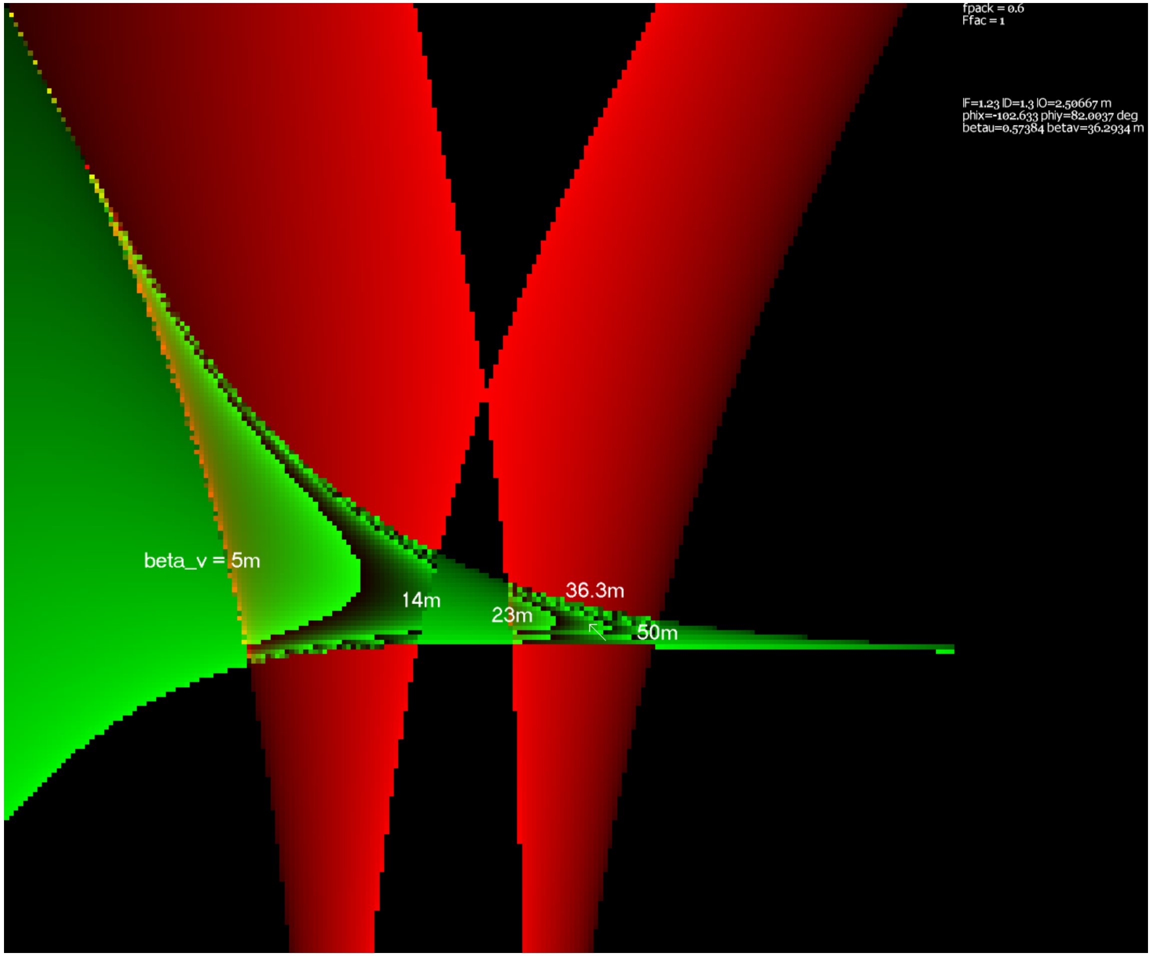


Better but Not Good Enough!



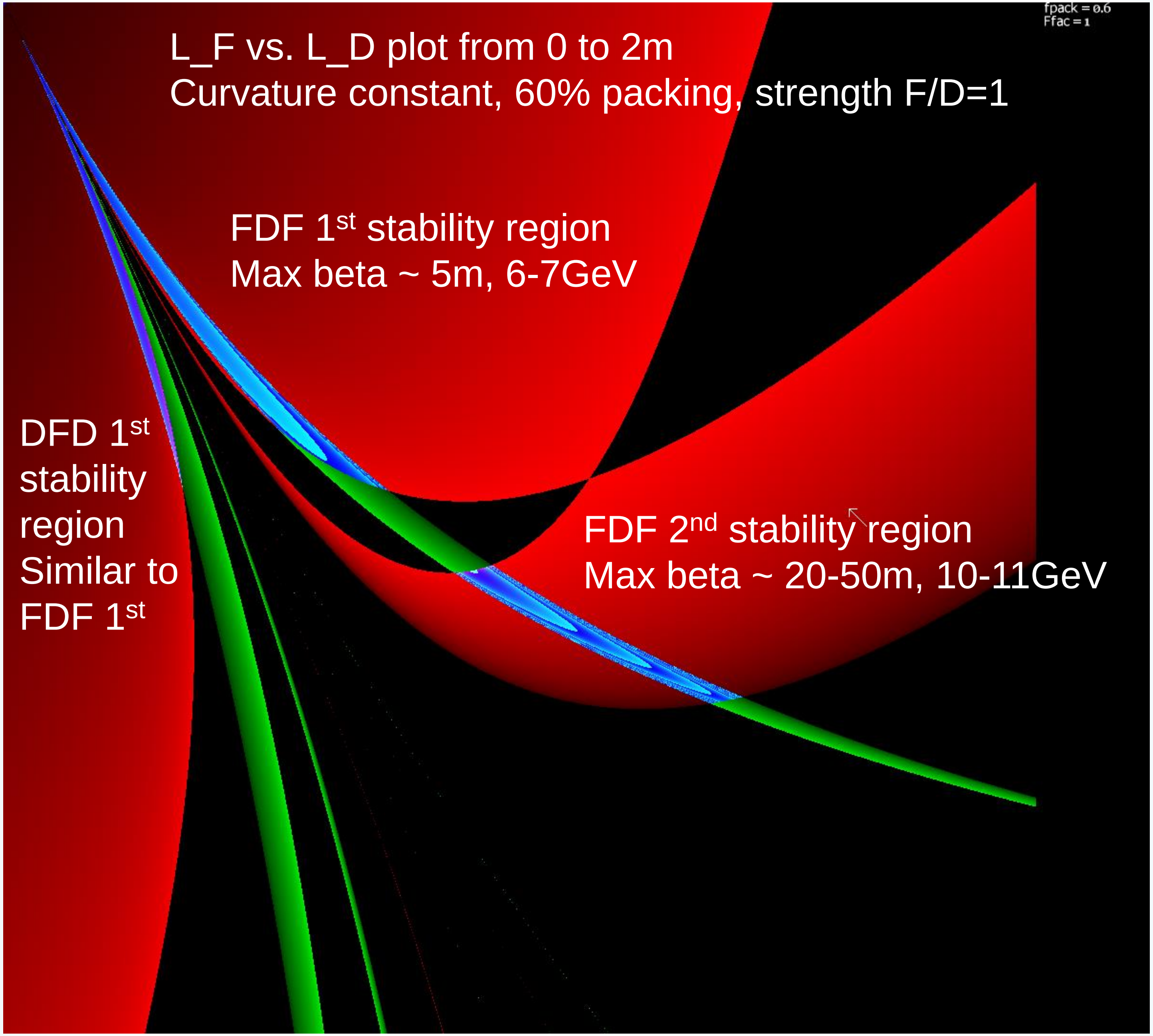
III. Stability Diagrams

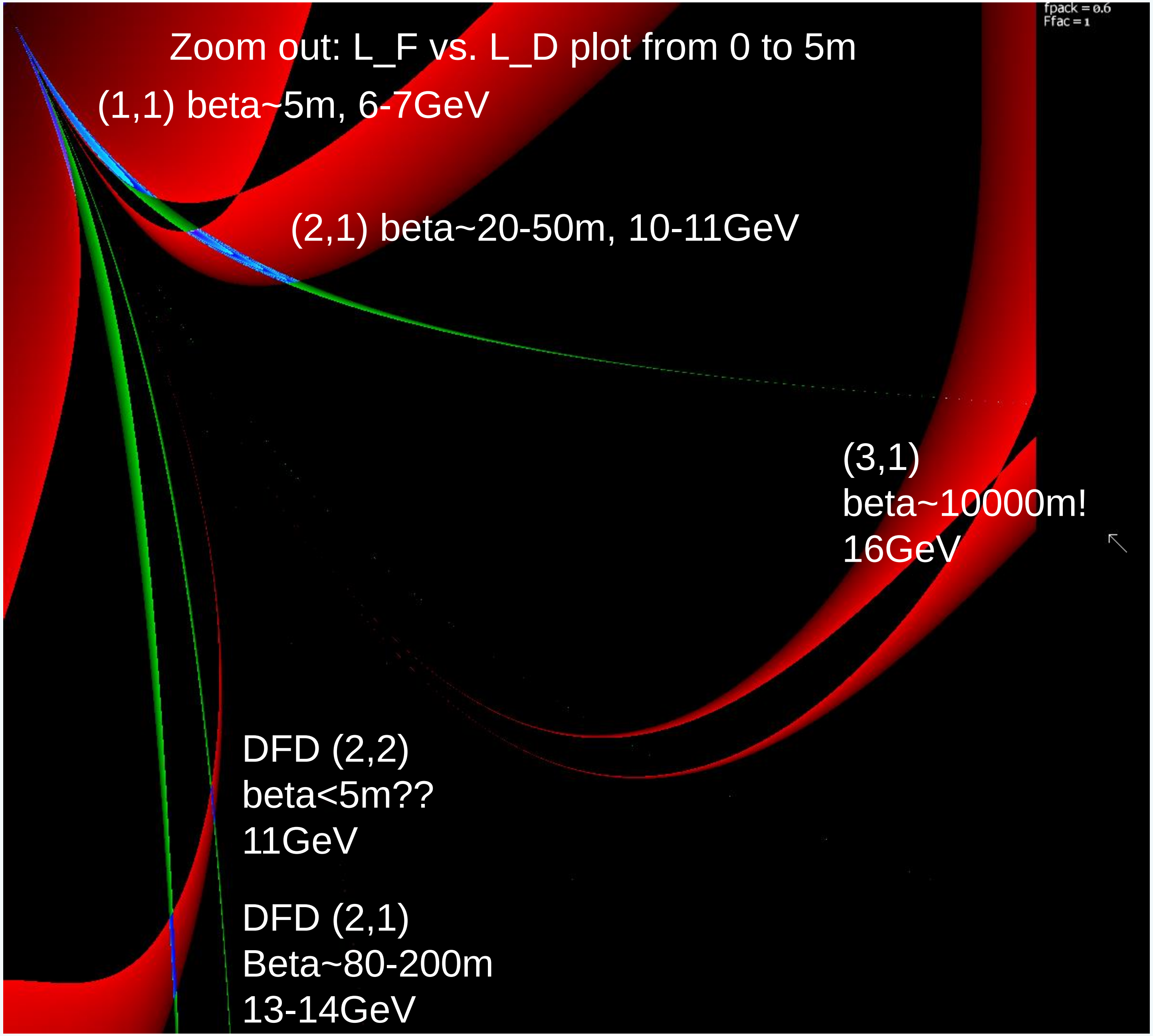
Necktie FDF Triplet Stability Plot



Lattice Variables & Constraints

- FDFO triplet has 3 lengths and 2 magnet strengths (the B_0 for F and D; k is fixed)
- Packing factor 60% fixes Length_O
- Tunnel bending radius 378.26m fixes overall field magnitude
  - The previous "necktie" plots didn't enforce this!
- Leaves 5-2=3 free parameters: L_F, L_D and F/D strength ratio


fpack = 0.6
Ffac = 1
L_F vs. L_D plot from 0 to 2m
Curvature constant, 60% packing, strength F/D=1
FDF 1st stability region
Max beta ~ 5m, 6-7GeV
DFD 1st stability region
Similar to FDF 1st
FDF 2nd stability region
Max beta ~ 20-50m, 10-11GeV


Zoom out: L_F vs. L_D plot from 0 to 5m
fpack = 0.6
Ffac = 1
(1,1) beta~5m, 6-7GeV
(2,1) beta~20-50m, 10-11GeV
(3,1)
beta~10000m!
16GeV
DFD (2,2)
beta<5m??
11GeV
DFD (2,1)
Beta~80-200m
13-14GeV

IV. eRHIC Energy Limit Formula

“Maximum GeV” for a Lattice

- Reference case: 60% packing factor, 0.43*2/3 = 0.2867T, Eref=20GeV
- Synchrotron power P proportional to E^2B^2
- <P> = E^2<B^2>
- So Emax^2<((Emax/E)B)^2> = Eref^2<Bref^2>
- (Emax^4/E^2)<B^2> = Eref^2<Bref^2>
- Emax = sqrt(E Eref Brmsref/Brms)
  - = Eref sqrt(E/Brms)/sqrt(Eref/Brmsref)

Maximum GeV Examples

- The non-FFAG eRHIC with separate beamlines (no reverse bend) has Emax=20GeV and C=1
- Having a circumference factor multiplies up the required fields (Brms) by C for a given energy, so E/Brms is divided by C
- Square root means Emax is divided by sqrt(C)
- Existing C=3.241 case gets to 11.1GeV

V. Future Work

Where to go next

- Try to find scaling VFFAG at lower energy (~5GeV) but with enough dynamic aperture
  - Perhaps alignment error studies too
  - Acts as a back-stop
- A few places remain to optimise the scaling VFFAG but since the tunes do not matter a non-scaling machine has more freedom