Towards higher polarization by matching DX prime at two snakes

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APEX workshop 2012

Motivation

The spin tune shift due to horizontal dispersion angles in the Snakes and rotators:

$$\delta Q_{sp} = \frac{1+G\gamma}{2\pi}\left(2\Delta D'_{sn} + \Delta D'_{rt_ip6} + \Delta D'_{rt_ip8}\right)\left(\frac{\Delta p}{p}\right)_{ave}$$

$$\Delta D'_{sn} = D'_{sn9} - D'_{sn3}$$

$$\Delta D'_{rt_ip} = D'_{co_rt_left} - D'_{co_rt_right}$$

On the ramp only the Snake locations contribute.

	Design ΔD', mrad	δQ_{sp}, 10^{-3}
Snakes	**53.6**	**4.2**
Rotator	**5.3**	**0.2**

The table is for dp/p = $5 \cdot 10^{-4}$ which corresponds to the orbit radial shift ~0.8mm
The radial orbit excursion of the ramp is less than that

DX prime difference at rotators need to be checked when reducing DX prime difference at snakes.

Courtesy by V. Ptitsyn

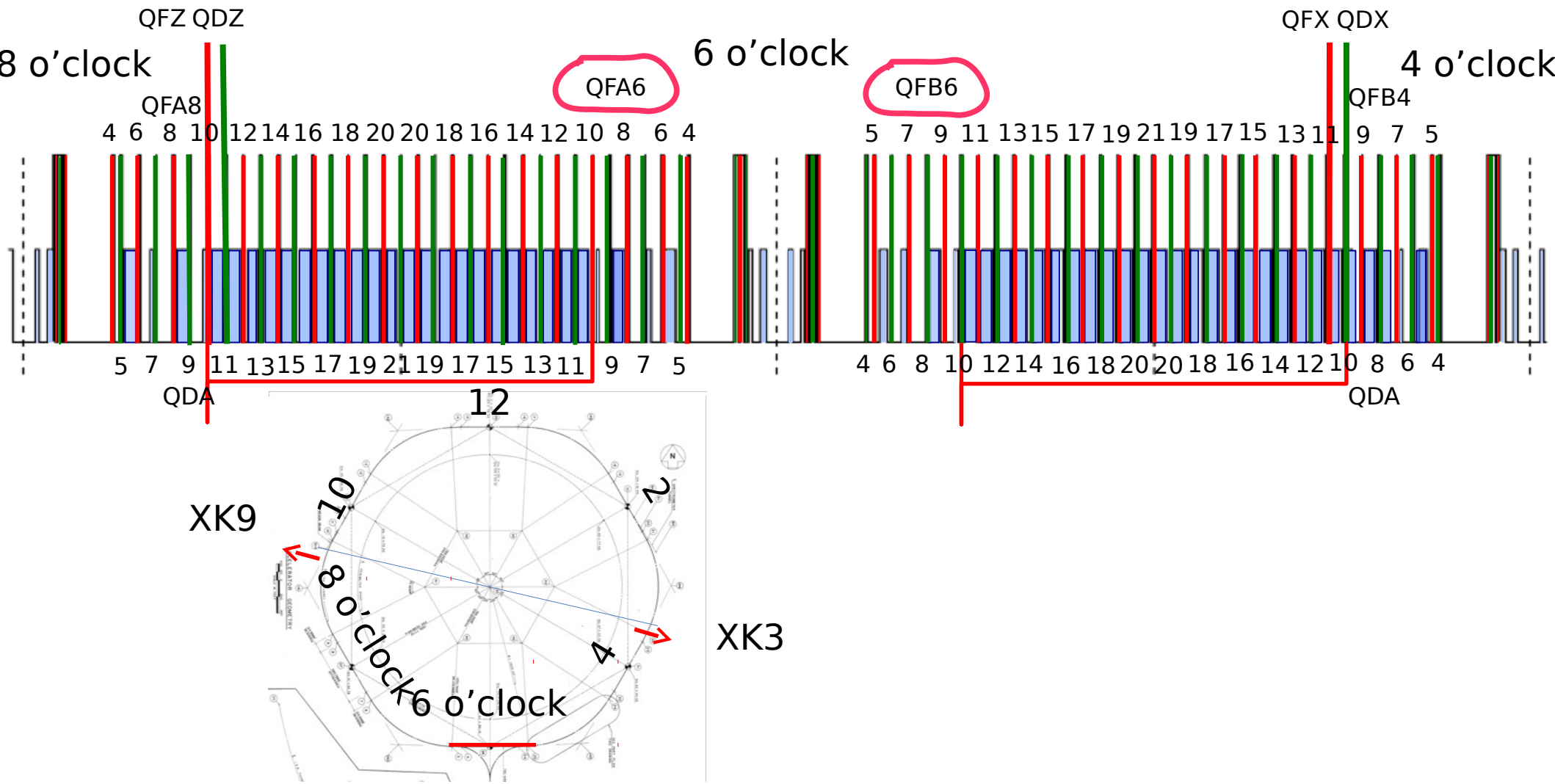
[1] V. Ptitsyn, M. Bai, and T. Roser, “Spin tune dependence on closed orbit in RHIC,” in Proceedings of International Particle Accelerator Conference, 2010.

[2] http://www.cadops.bnl.gov/AP/ap_notes/ap_note_334.pdf

[3] V. Ranjbar, M. Bai, A. U. Luccio, W. W. MacKay, T. Roser, and S. Y. Lee, “Snake Calibration in RHIC,” 2002.

qf8&qf9 matching solution for pp12b-v2::t250

qf8&qf9 solution



Variables & constraints

```
xxx = -0.03;
match, sequence=BLUE;

vary, name=xxx, step = 0.0000001, LOWER=-0.2, UPPER=0.2;


vary, name=QFA6->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;   !qf8
vary, name=QFA8->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFA10->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFA12->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFA2->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFA4->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;


vary, name=QFB6->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;   !qf9
vary, name=QFB8->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFB10->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFB12->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFB2->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;
vary, name=QFB4->K1, step = 0.000001, LOWER=0.0, UPPER=0.1;

WEIGHT, DPX=400;


constraint,range=snake2,dpx=xxx;
constraint,range=snake1,dpx=xxx;                                  ! matching dpx
constraint,sequence=BLUE,range=CLOCK6, dx > -0.01, dx < 0.01;
constraint,sequence=BLUE,range=CLOCK8, dx > -0.01, dx < 0.01;   ! control dx at 6 & 8

constraint,sequence=blue,range=clock6,betx=table(twiss,clock6,betx);
constraint,sequence=blue,range=clock8,betx=table(twiss,clock8,betx);
constraint,sequence=blue,range=clock6,bety=table(twiss,clock6,bety);
constraint,sequence=blue,range=clock8,bety=table(twiss,clock8,bety);   ! maintain beta stars at 6 & 8

constraint,sequence=blue,range=MEND,mux=table(twiss,MEND,mux);
constraint,sequence=blue,range=MEND,muy=table(twiss,MEND,muy);  ! maintain tunes

constraint,sequence=blue,range=QF[6],betx < table(twiss,QF[6],betx)*1.2,betx > table(twiss,QF[6],betx)*0.8;
constraint,sequence=blue,range=QF[18],betx < table(twiss,QF[18],betx)*1.2,betx > table(twiss,QF[18],betx)*0.8;
constraint,sequence=blue,range=QF[30],betx < table(twiss,QF[30],betx)*1.2,betx > table(twiss,QF[30],betx)*0.8;
constraint,sequence=blue,range=QF[42],betx < table(twiss,QF[42],betx)*1.2,betx > table(twiss,QF[42],betx)*0.8;
constraint,sequence=blue,range=QF[54],betx < table(twiss,QF[54],betx)*1.2,betx > table(twiss,QF[54],betx)*0.8;
constraint,sequence=blue,range=QF[67],betx < table(twiss,QF[67],betx)*1.2,betx > table(twiss,QF[67],betx)*0.8;    ! control global beta beat

lmdif,calls=1500,tolerance=1.e-18;

endmatch;
```

Matching results

MATCH SUMMARY

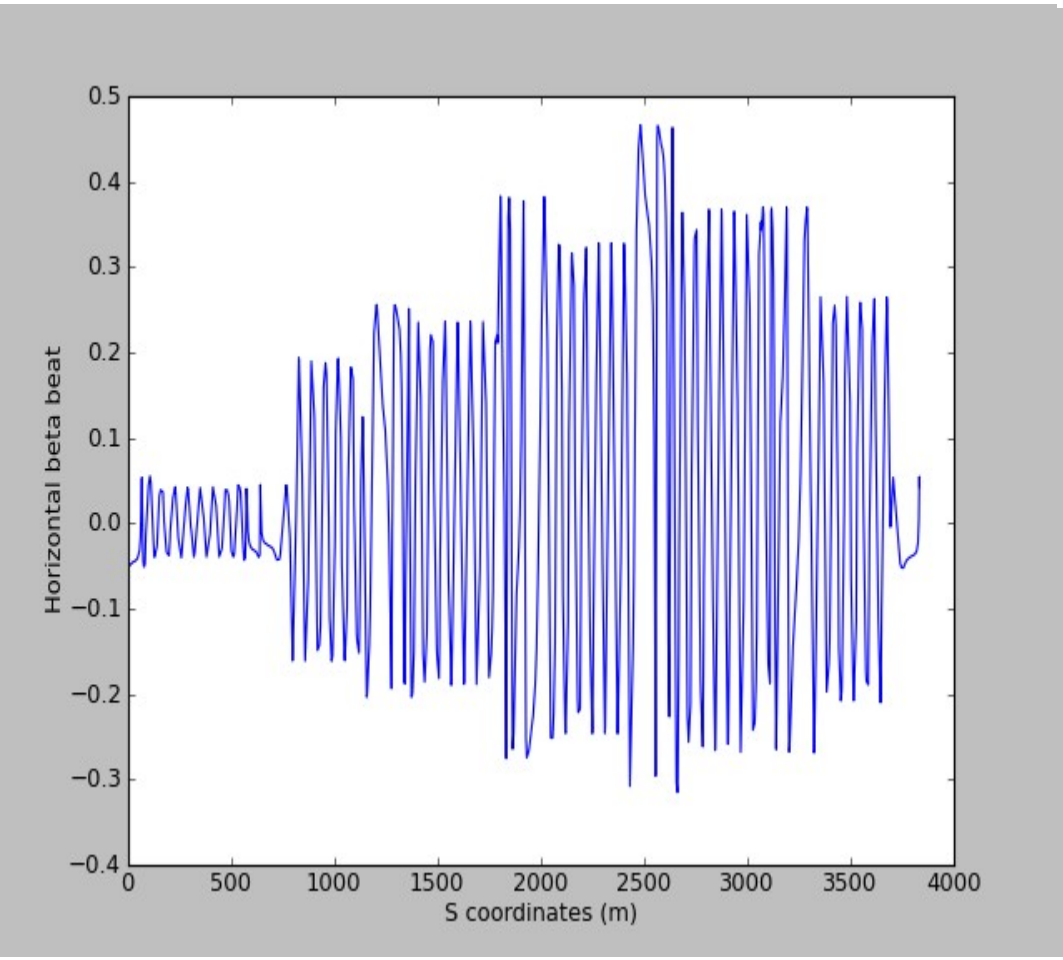
Node_Name	Constraint	Type	Target Value	Final Value	Penalty
clock6:1	dx	3	-1.00000000E-02	1.00000000E-02	-1.89076601E-03	0.00000000E+00
clock6:1	betx	4	1.60445226E+00	1.68287982E+00	6.15088233E-03	
clock6:1	bety	4	1.63345908E+00	1.61995650E+00	1.82319537E-04	
qf:6	betx	3	3.91950468E+01	5.87925702E+01	4.88407134E+01	0.00000000E+00
clock8:1	dx	3	-1.00000000E-02	1.00000000E-02	-1.56684276E-02	3.21310715E-03
clock8:1	betx	4	1.60344893E+00	1.64509826E+00	1.73466629E-03	
clock8:1	bety	4	1.64159946E+00	1.70801201E+00	4.41062715E-03	
qf:18	betx	3	3.78543111E+01	5.67814666E+01	5.59174735E+01	0.00000000E+00
snake1:1	dpx	4	-3.00000000E-02	-2.99818340E-02	5.28003719E-05	
qf:30	betx	3	3.90815361E+01	5.86223041E+01	4.88814523E+01	0.00000000E+00
qf:42	betx	3	4.00101025E+01	6.00151538E+01	5.77230633E+01	0.00000000E+00
qf:54	betx	3	3.88434648E+01	5.82651973E+01	4.86423662E+01	0.00000000E+00
snake2:1	dpx	4	-3.00000000E-02	-3.00007663E-02	9.39663203E-08	
qf:67	betx	3	3.99270802E+01	5.98906203E+01	5.98975364E+01	4.78323993E-05
mend:1	mux	4	2.86850000E+01	2.86901740E+01	2.67705240E-03	
mend:1	muy	4	2.96750000E+01	2.96757642E+01	5.83971746E-05	

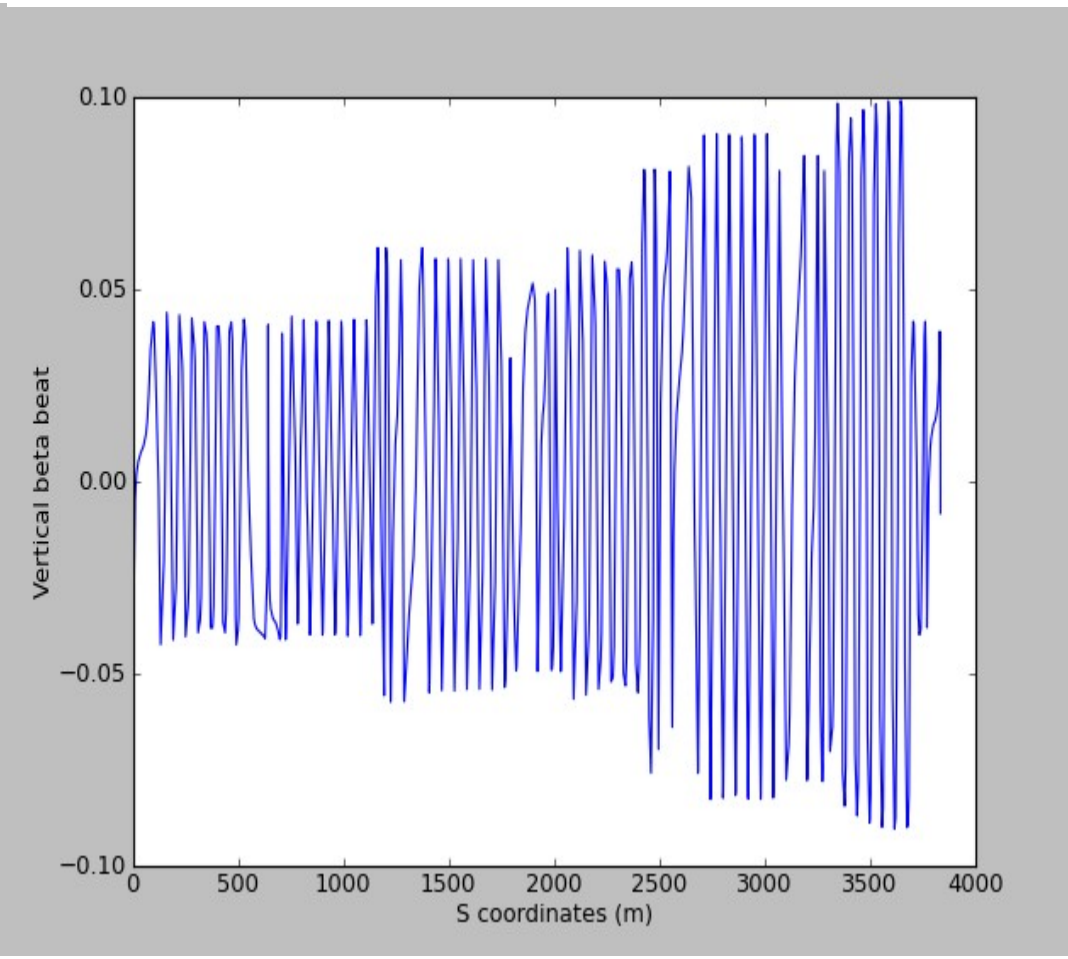
Final Penalty Function = 1.85277788e-02

Variable	Final Value	Initial Value	Lower Limit	Upper Limit
xxx	-3.00000e-02	-3.00000e-02	-2.00000e-01	2.00000e-01
qfa6->k1	7.97930e-02	8.51501e-02	0.00000e+00	1.00000e-01
qfa8->k1	8.75657e-02	8.51501e-02	0.00000e+00	1.00000e-01
qfa10->k1	8.62944e-02	8.07370e-02	0.00000e+00	1.00000e-01
qfa12->k1	8.26227e-02	8.07370e-02	0.00000e+00	1.00000e-01
qfa2->k1	8.43956e-02	8.23113e-02	0.00000e+00	1.00000e-01
qfa4->k1	8.23227e-02	8.07370e-02	0.00000e+00	1.00000e-01
qfb6->k1	8.40926e-02	8.45783e-02	0.00000e+00	1.00000e-01
qfb8->k1	8.44324e-02	8.45783e-02	0.00000e+00	1.00000e-01
qfb10->k1	8.05808e-02	7.95547e-02	0.00000e+00	1.00000e-01
qfb12->k1	7.34157e-02	7.95547e-02	0.00000e+00	1.00000e-01
qfb2->k1	8.39466e-02	8.12185e-02	0.00000e+00	1.00000e-01
qfb4->k1	7.58067e-02	7.95547e-02	0.00000e+00	1.00000e-01

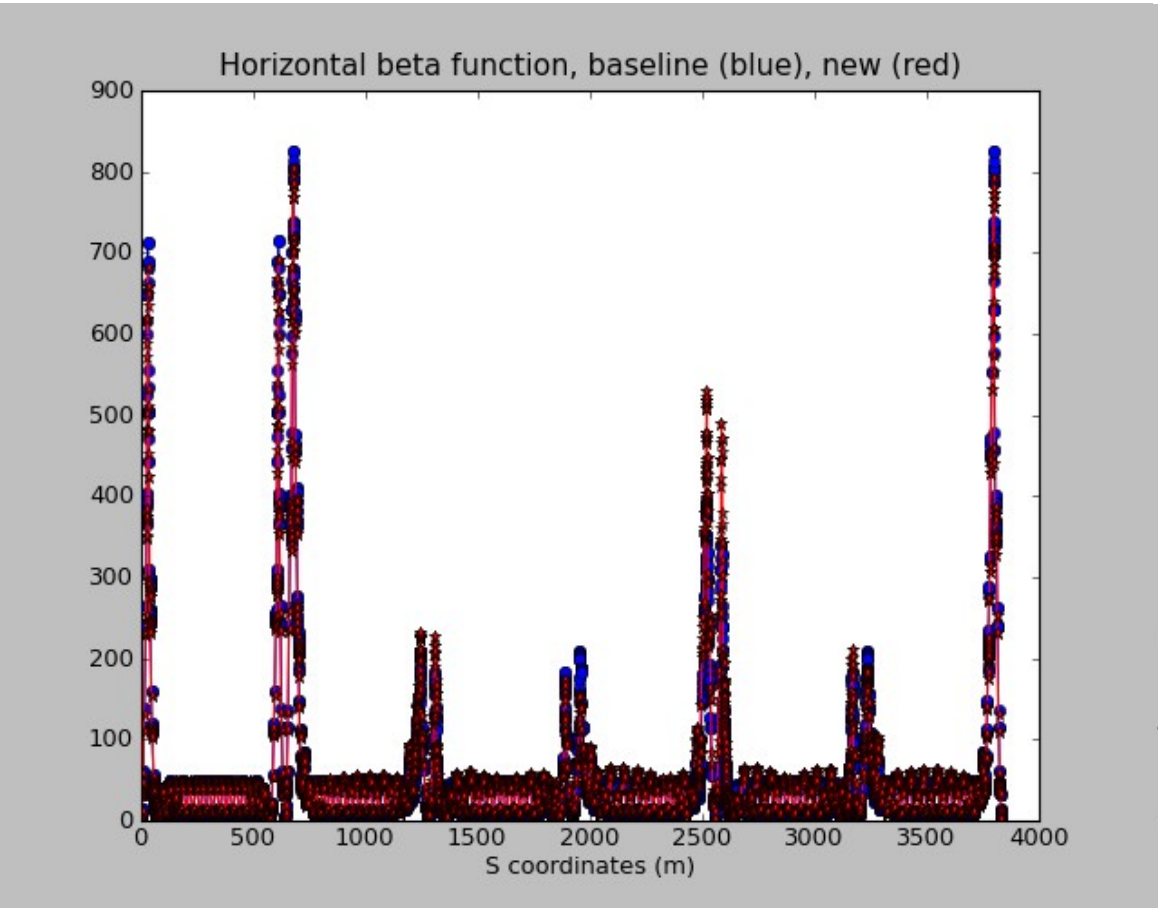
END MATCH SUMMARY

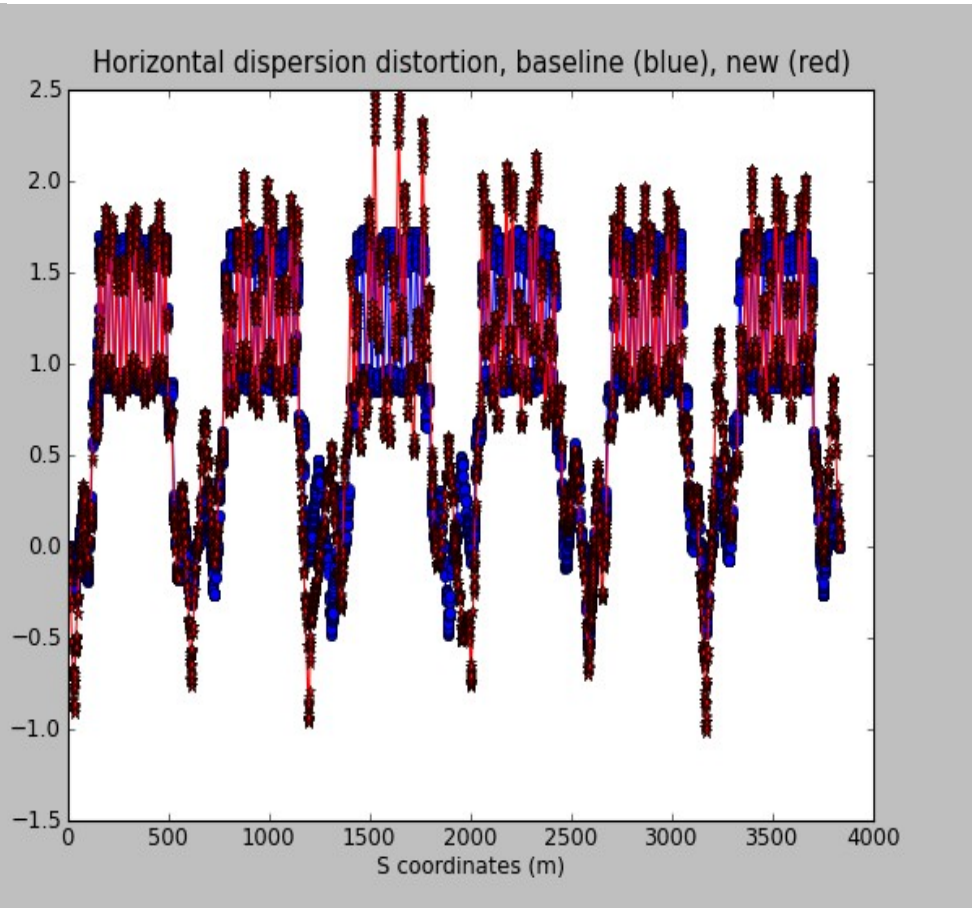
Beta beat


Horizontal beta beat
S coordinates (m)
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
0
500
1000
1500
2000
2500
3000
3500
4000


Vertical beta beat
S coordinates (m)
0.10
0.05
0.00
−0.05
−0.10
0
500
1000
1500
2000
2500
3000
3500
4000

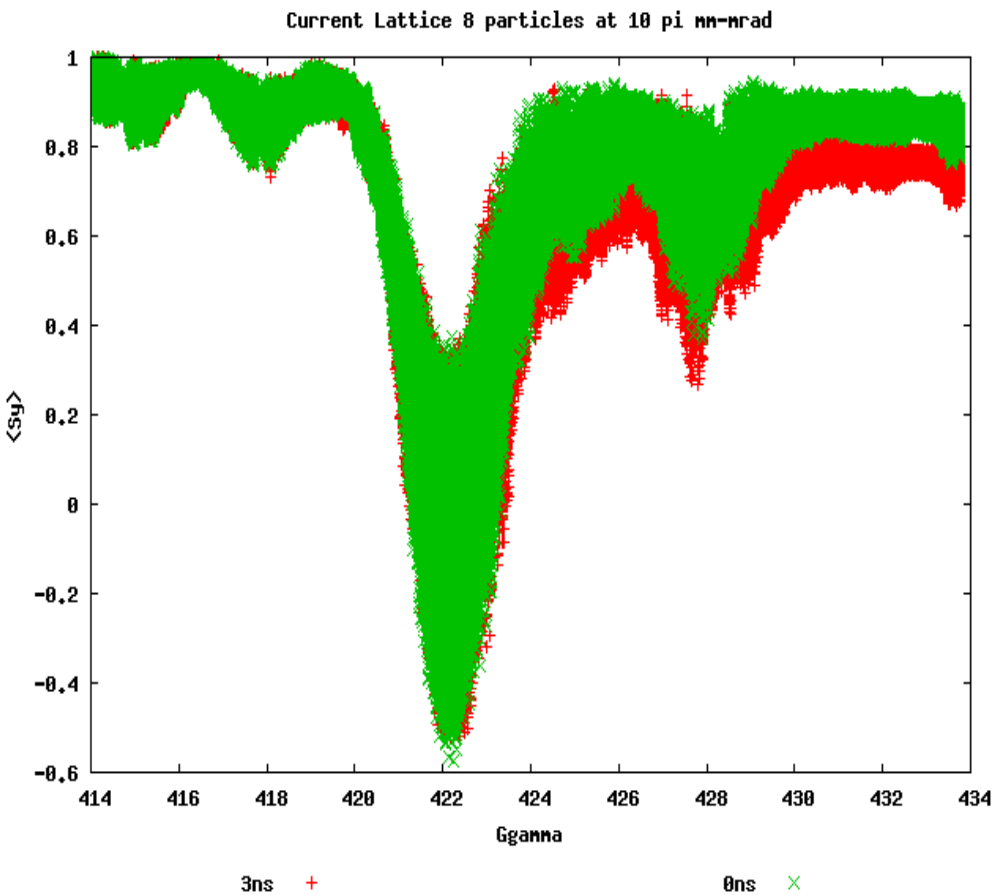
Beta & Dispersion



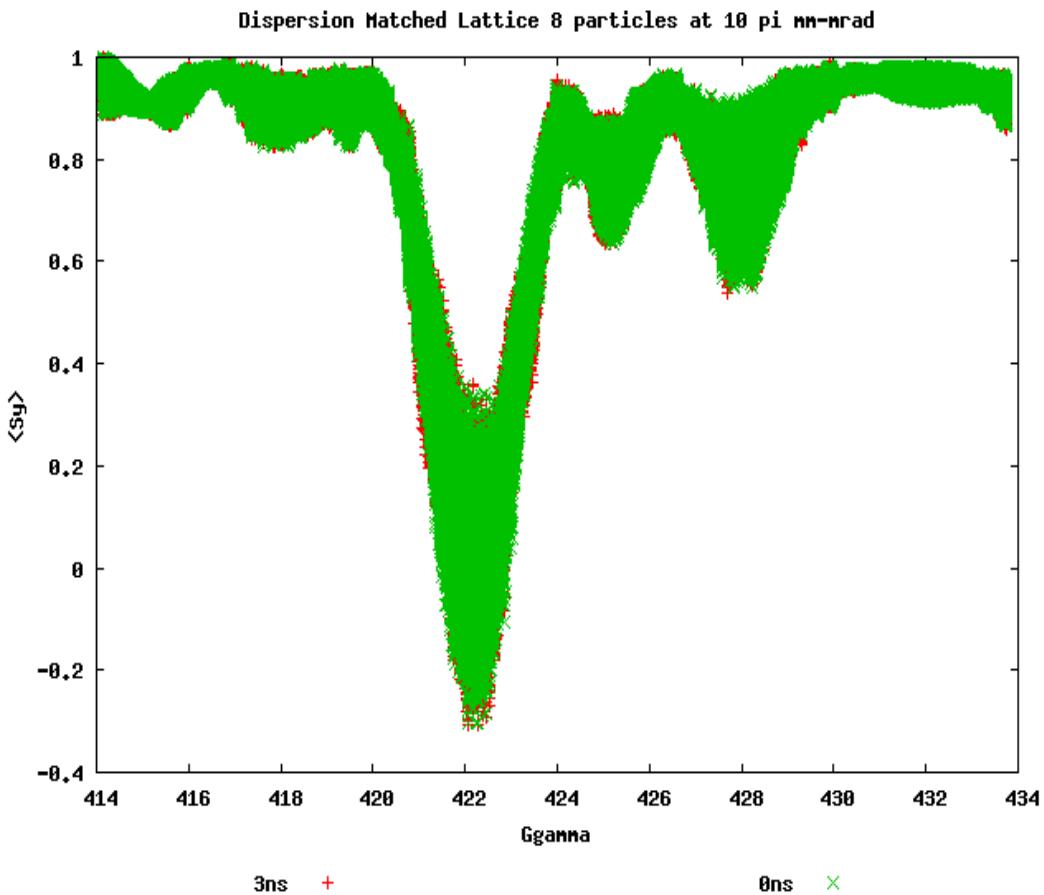


Spin tracking results

Before DX prime matched:



After DX prime matched using qf8&qf9 solution:



Courtesy by Vahid

Relative changes vs. limit

	Final value	Initial value	Change (%)
qfa6->k1	7.97930e-02	8.51501e-02	-6.2913607852
qfa8->k1	8.75657e-02	8.51501e-02	2.8368727694
qfa10->k1	8.62944e-02	8.07370e-02	6.8833372555
qfa12->k1	8.26227e-02	8.07370e-02	2.3356082094
qfa2->k1	8.43956e-02	8.23113e-02	2.5322161113
qfa4->k1	8.23227e-02	8.07370e-02	1.9640313611
qfb6->k1	8.40926e-02	8.45783e-02	-0.5742607737
qfb8->k1	8.44324e-02	8.45783e-02	-0.172502876
qfb10->k1	8.05808e-02	7.95547e-02	1.2898043736
qfb12->k1	7.34157e-02	7.95547e-02	-7.7167030986
qfb2->k1	8.39466e-02	8.12185e-02	3.3589637829
qfb4->k1	7.58067e-02	7.95547e-02	-4.7112238498

Reachable range: -3% --0%

Response matrix method for controlling required strength change

How does RM work?

1. check if the response of parameters of interest to variables (for our case, dpx/tunes to quad strength) are linear, the answer is positive
2. establish the response matrix for parameters of interest to variables
3. invert the response matrix using SVD
4. calculate the required changes of quad strength, and the resulting parameters of interest
5. put relative changes in Madx file, simulate the parameters of interest, compare with calculation

SVD manipulation

$$R^{-1} = \left(U \cdot S \cdot V^T\right)^{-1} = V \cdot S^{-1} \cdot U^T$$

$$\begin{bmatrix} 1/s_{11} & 0 & 0 \\ 0 & 1/s_{22} & 0 \\ 0 & 0 & 1/s_{33} \end{bmatrix}$$

Two ways to manipulate the SVD to control the required changes:

1. cut eigenvalue
2. Tikhonov regulation

Required changes

Required changes:

```
[ -3.94345623e+00   1.70518844e+00   4.29812218e+00   6.62632591e-01
   2.52846565e-01  -1.51941697e+00  -7.66769703e-01  -1.38460108e+00
   4.27231663e-01   3.85762096e-01  -3.88326558e-02   3.66833141e-02
  -1.02636185e+00   6.86201392e-01   8.36646400e-01   3.16303414e-01
   2.10609691e-01  -6.22883888e-01  -8.59729020e-02   9.84288537e-01
   1.66572361e-03   1.02780456e-01   8.05557857e-02   2.49187469e-01
  -1.37716485e+00   2.97115589e-01]
```

Calculation vs. Madx simulation

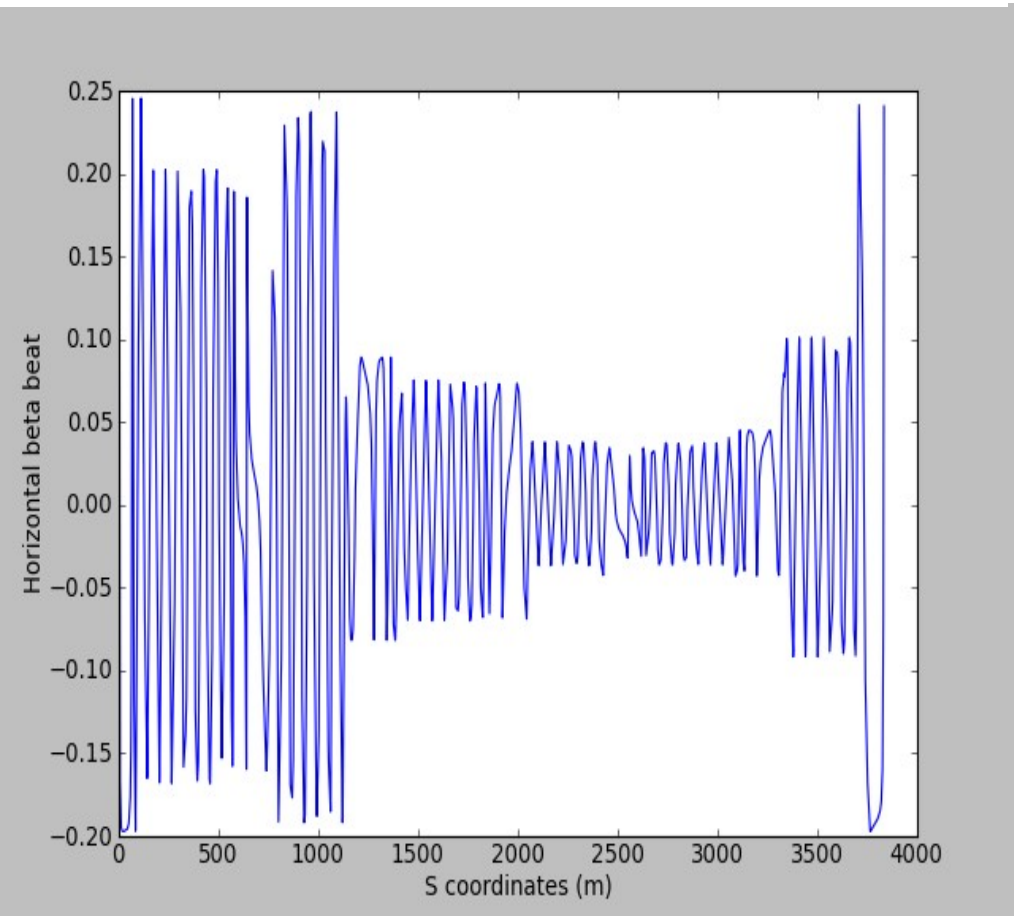
Expected final values for parameters:

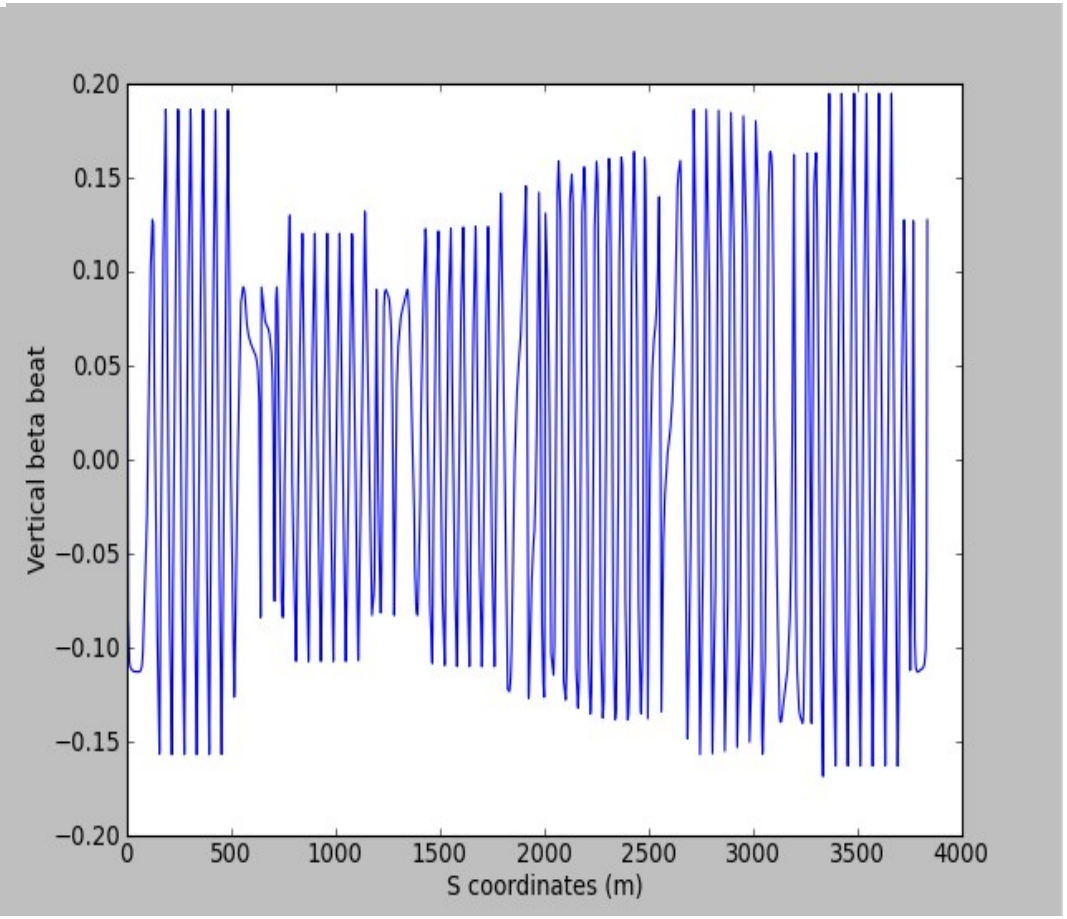
[-1.82600000e-02 -1.82600000e-02 2.86850000e+01 2.96750000e+01]

Results from Madx:

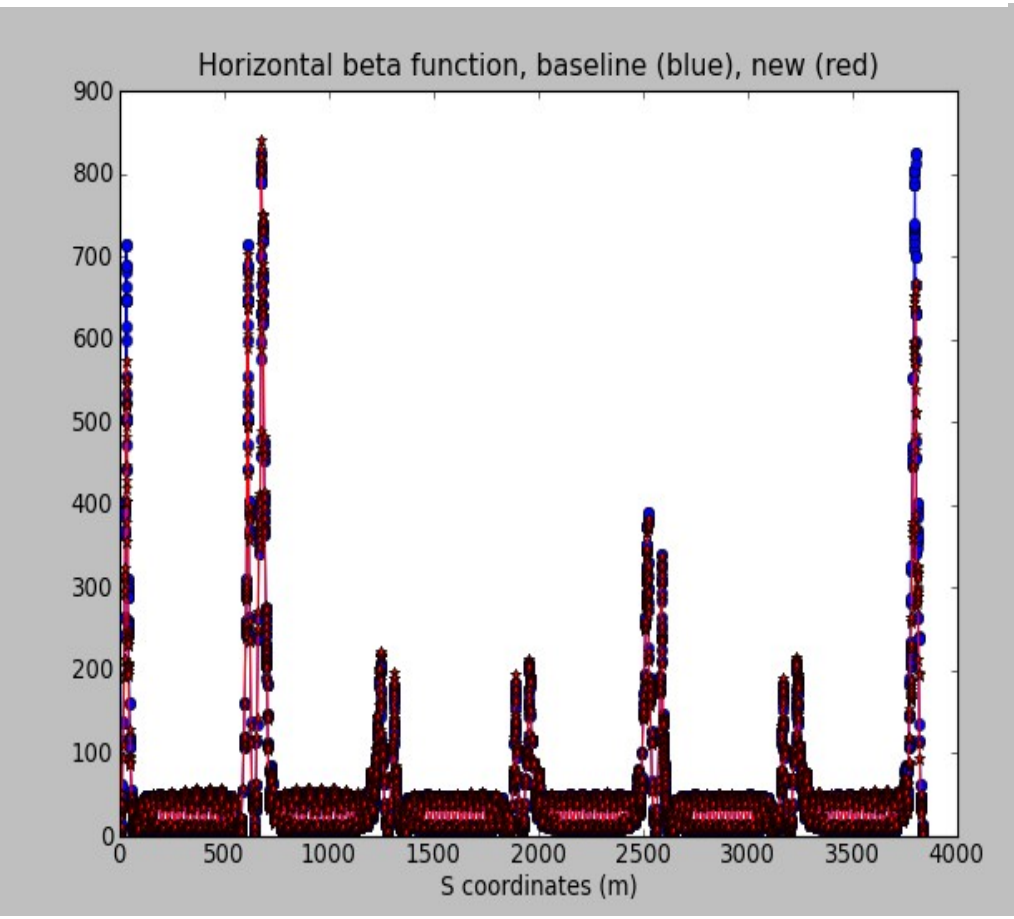
* NAME	S	MUX	MUY	DPX
$ %s	%le	%le	%le	%le
"SNAKEONED"	1155.594172	8.993352138	8.681395058	-0.0181778759
"SNAKETWOD"	3073.16014	23.36800307	23.59754464	-0.01888173921
"MEND"	3833.845181	28.68714417	29.67341806	-0.03397854378

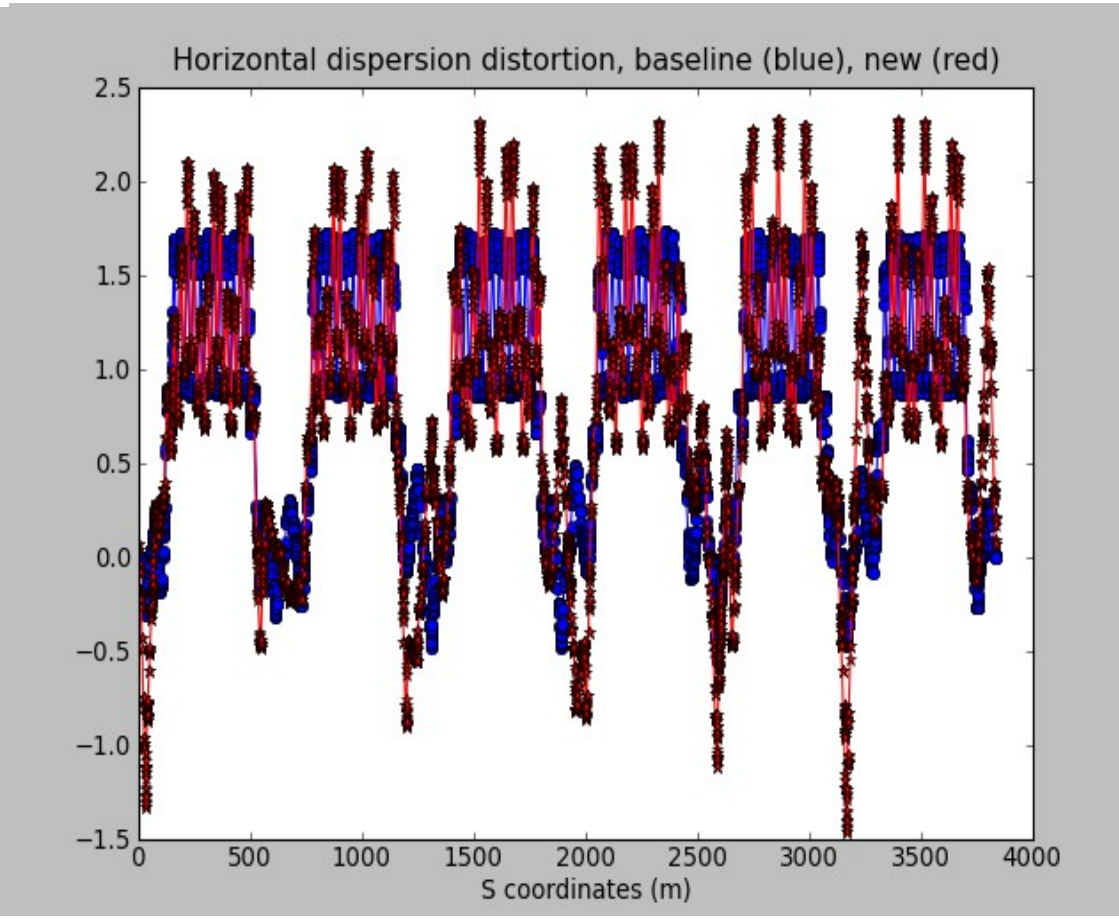
Beta beat


Horizontal beta beat
S coordinates (m)
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
500
1000
1500
2000
2500
3000
3500
4000


Vertical beta beat
S coordinates (m)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
500
1000
1500
2000
2500
3000
3500
4000

Beta & dispersion





Cut one eigenvalue?

Required changes:

```
[-3.92577244  1.10830802  4.04391385  0.82972112  1.12207157 -1.13839989
 -1.08810458 -1.63892916  0.23371155  0.02105209  0.17644676  0.37484607
 -1.00103194  0.52496496  0.57831233  0.48512074  0.49549206 -0.5439681
 -0.05635381  0.89647046 -0.37442831  0.11828038  0.42072288  0.21205929
 -1.43607327  0.28877017]
```

Final parameters:

```
[ -2.24036214e-02  -2.47855276e-02   2.86843274e+01   2.96749381e+01]
```

Cut two eigenvalue?

Required changes:

[-0.01491495 -0.01417618 -0.01457441 -0.01509674 -0.01567722 -0.0153576
-0.01484281 -0.01492009 -0.01428341 -0.0141108 -0.01477877 -0.014824
-0.0034529 -0.00323226 -0.00394476 -0.00438066 -0.0041796 -0.00431135
-0.011051 -0.01090265 -0.01222054 -0.00210074 -0.01089159 -0.01050271
-0.01256229 -0.00207504]

Final parameters:

[7.02578184e-03 -4.34395533e-02 2.86839748e+01 2.96752643e+01]

With Tikhonov regulation_best case

Required changes:

[-2.03029476 0.86661322 2.1992134 0.33486177 0.12776527 -0.78430977
-0.40123994 -0.7180947 0.21254078 0.1904701 -0.0248707 0.01448668
-0.52860978 0.34967687 0.42615097 0.16098888 0.1073842 -0.32155253
-0.04827141 0.50061095 -0.00598813 0.05178235 0.03881921 0.12366366
-0.71235376 0.15143465]

Final parameters:

[-5.97810493e-03 -3.05526784e-02 2.86845772e+01 2.96751336e+01]

Power supplies all within limits, dpx difference reduced from ~0.05 to ~0.025.

For e-lens lattice at $T_{psudo} = 80$

Required changes

Required changes of gradients:

```
[ 1.40044006 -0.72944903 -0.41186897  5.84329303 -3.56338641 -0.59231935
  0.65180094  0.25153357  0.29237029  1.85698643 -3.1098964  -2.12864729
  0.26675165 -0.46230299 -0.28925753  1.85771063 -1.33967989 -0.07235193]
```

Expected final DPX:

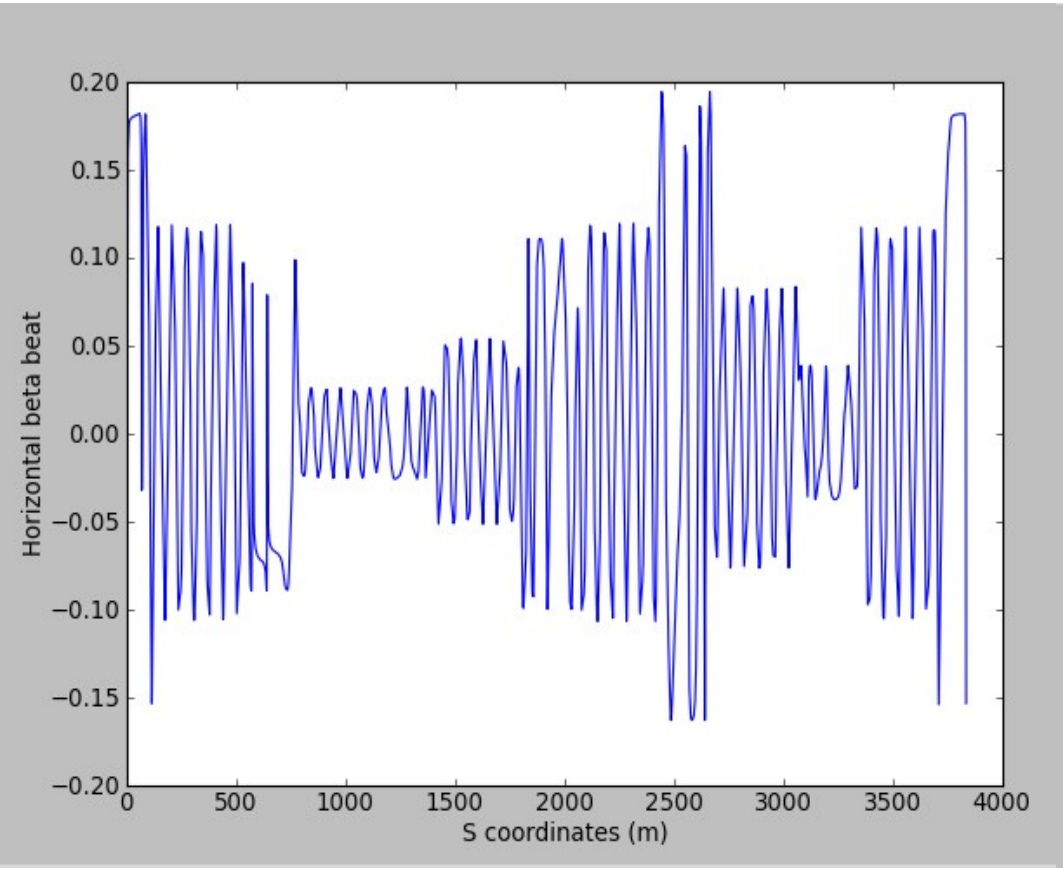
```
[ -2.00000000e-02  -2.00000000e-02   2.76900000e+01   2.96800000e+01]
```

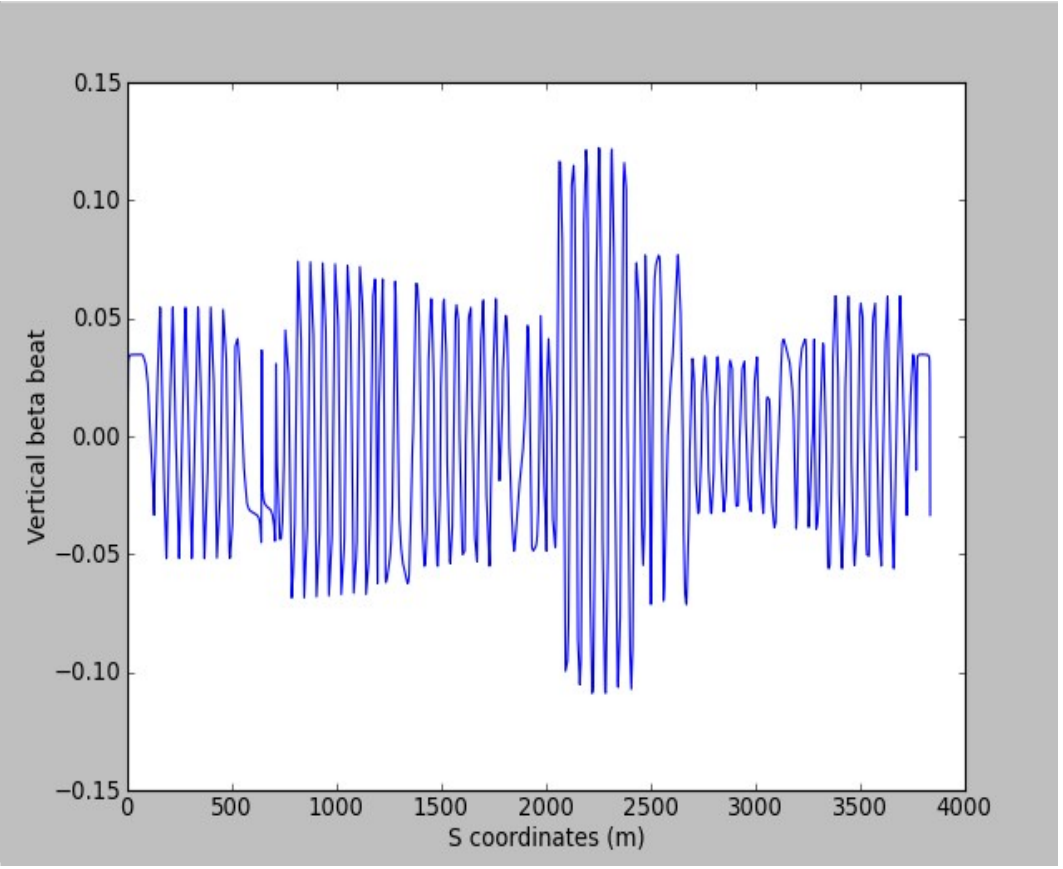
The best w/o power supply work

Required changes of gradients:
[1.40044006 -0.72944903 -0.41186897 2.33731721 -2.49437049 -0.59231935
  0.65180094 0.25153357 0.29237029 1.85698643 -2.17692748 -2.12864729
  0.26675165 -0.46230299 -0.28925753 1.85771063 -1.33967989 -0.07235193]
Expected final DPX:
[-8.93357306e-03 -3.07179930e-02   2.76832265e+01   2.96810533e+01]

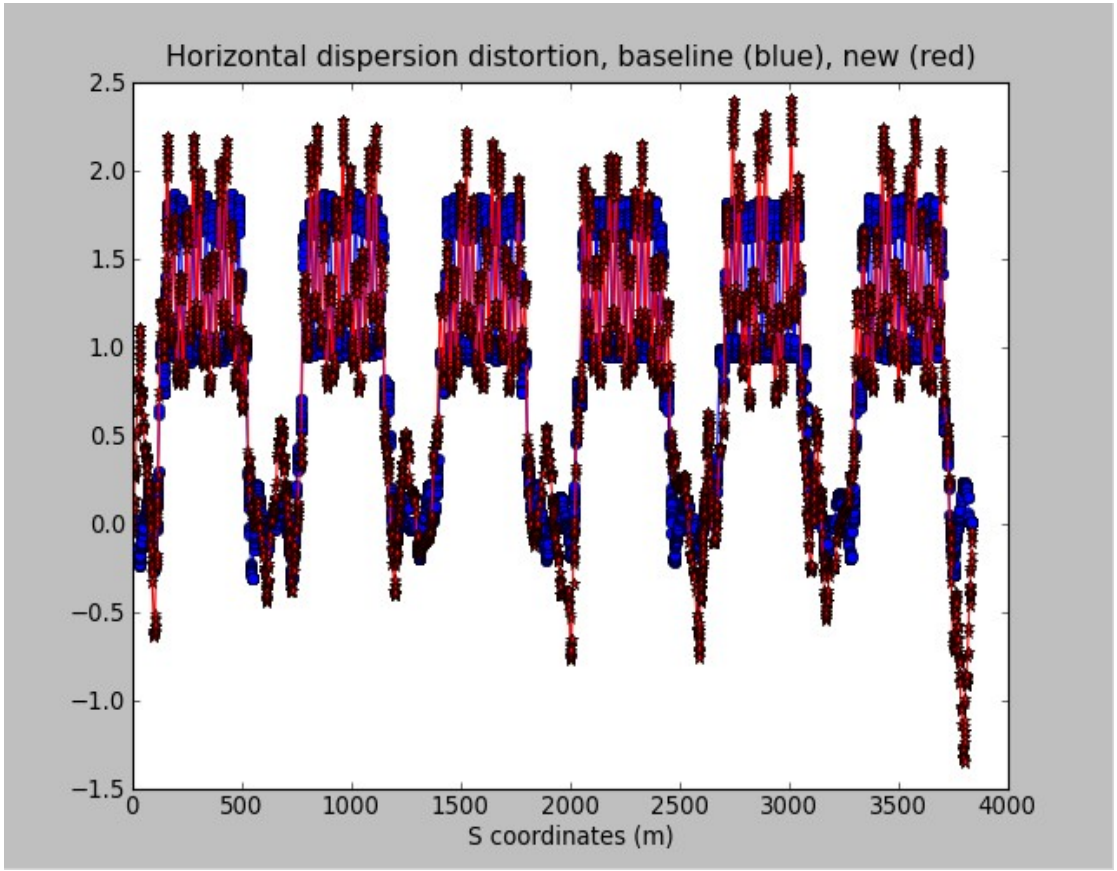
DPX reduced by factor of 3

Beta beat


Horizontal beta beat
S coordinates (m)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
500
1000
1500
2000
2500
3000
3500
4000


Vertical beta beat
S coordinates (m)
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
500
1000
1500
2000
2500
3000
3500
4000

Dispersion


Horizontal dispersion distortion, baseline (blue), new (red)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
500
1000
1500
2000
2500
3000
3500
4000
S coordinates (m)

Proposals

Demonstration at injection

1. At injection, take dispersion measurement
2. Implement changes on shunt supplies, take dispersion measurement again to confirm
3. 1 hrs at injection
4. tune feedback in place to be safe

Verify the benefit

1. detune snake, then sweep AC dipole frequency across new spin tune location. Do this for the new lattice and the old lattice see difference in amount of spin flipping.

2. Do same as 1) only blow up bunch with RF into hollow bunch..this should amplify the effect

3. Also go with high Chroms this should also amplify the effect

4. Just try and measure the DX values directly?

5. Apply the new lattice and see if it effects Pol lifetime

6. (most expensive one..probably not the best either) ramp with the new lattice compare with old.

Summary

1. DX prime matching and response matrix method demonstrated and showed consistency
2. Benefit shown by spin tracking
3. Applying partial DX prime matching on the ramp seems promising
4. DPX can be reduced by factor of 3 w/o power supply upgrade
5. Flip polarities are needed
6. DX prime matching at injection will be demonstrated first
7. DX prime matching at store needs more effort