First Look at CBETA-V Optimization Analysis of Orbit Response Matrix Data from the Fractional Arc Test

Post-presentation update: add info on measurement procedure and some minor corrections

11 magnet excitation scans on May 17 & 18

(Complementary to the more comprehensive ORM data from AC and CG)

9 dipoles: D1DIP01, S1DIP02-7, S1DPB01/8 (BNL sector magnets)
4 vertical correctors: CRV01-4
8 quadrupoles: S1QUA01-8
10 BPMs: S1BPM01-6, FABPM01-4

21 scans of 11 pts each per data set
9 minutes per data set

Dipoles:11 settings +/-5% of nominal
Fine scans: 11 settings +/-10% of nominal (correctors, quads)
Coarse scans: 11 settings: quads 0 to 11 A, correctors -4 to 4 A

Scans at 6 MeV, 42 MeV (seven, two with quads off), 38, 47, 53 MeV

CBETA tech note 32
The CBETA Fractional Arc Test
Gulliford et al

CBETA

Jim Crittenden

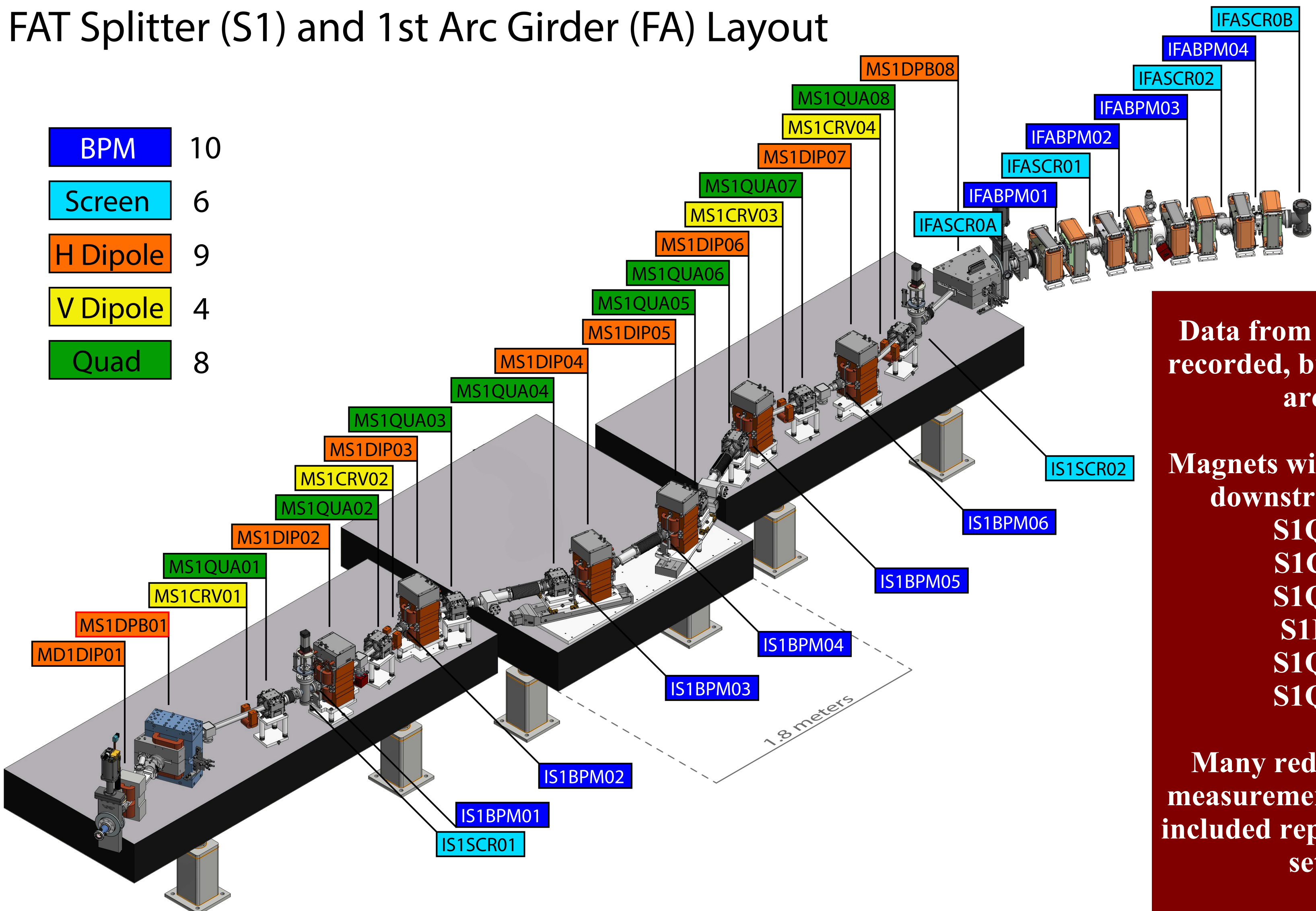
11 October 2018

CBETA tech note 26
First Tests of Electron Beam Transport in the CBETA S1 Splitter Line
Biddulph-West summer 2018 REU project

FAT Layout

FAT Splitter (S1) and 1st Arc Girder (FA) Layout

BPM	10
Screen	6
H Dipole	9
V Dipole	4
Quad	8



Data from D1BPC01 not recorded, but known from archiver

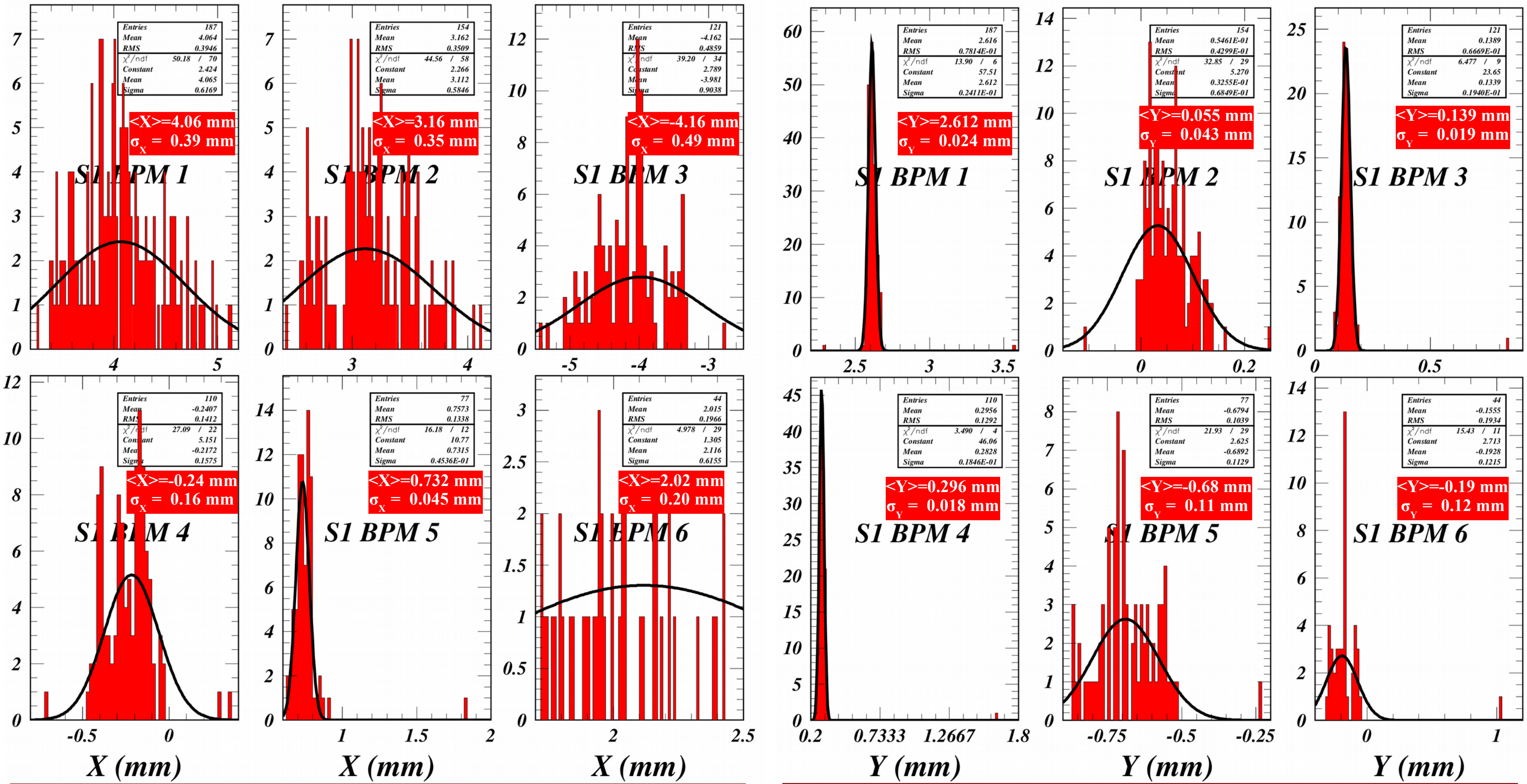
Magnets with neighboring downstream BPMs:
S1QUA01
S1CRV01
S1QUA03
S1DIP04
S1QUA05
S1QUA07

Many redundant BPM measurements, since scans included repeated nominal settings

BPM measurement reproducibility

(Average 10 readback values. Measurement delay 0.2 seconds)
full_corrector_range_42mev.pdf

42 MeV data set (May 18, 5:02 PM): Use only BPM measurements where a downstream magnet was scanned.



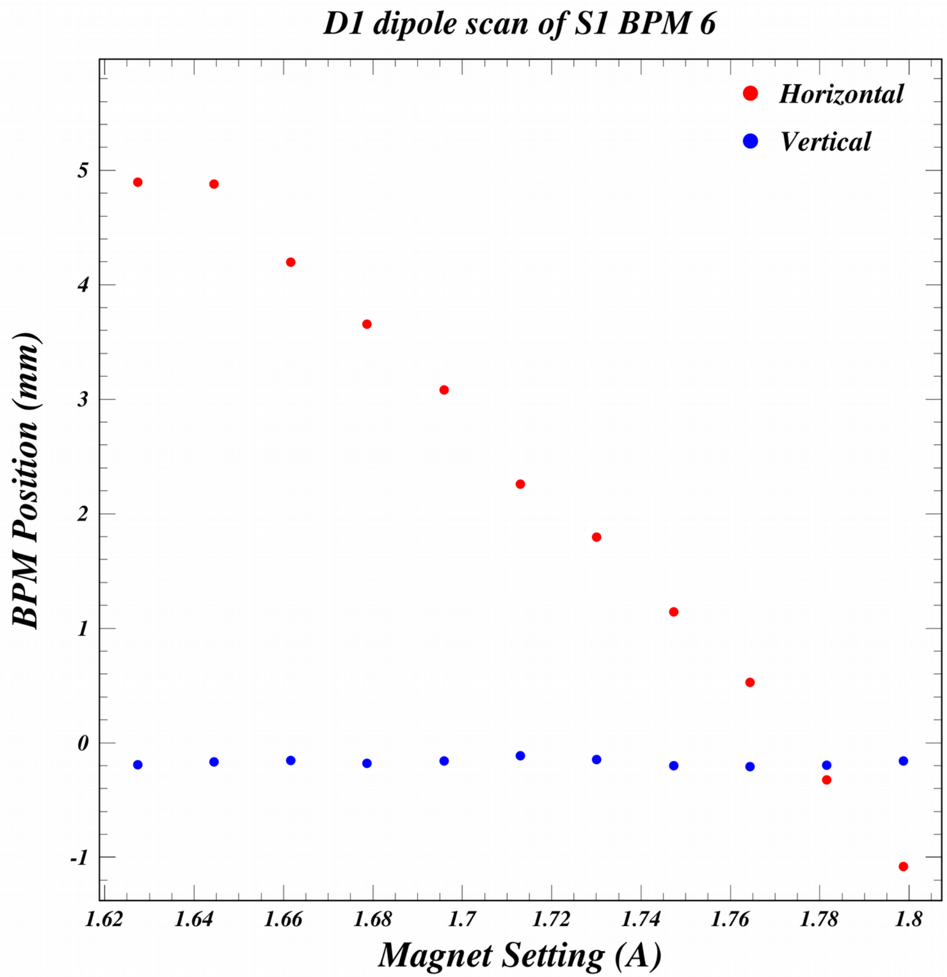
Example S1 BPM 1

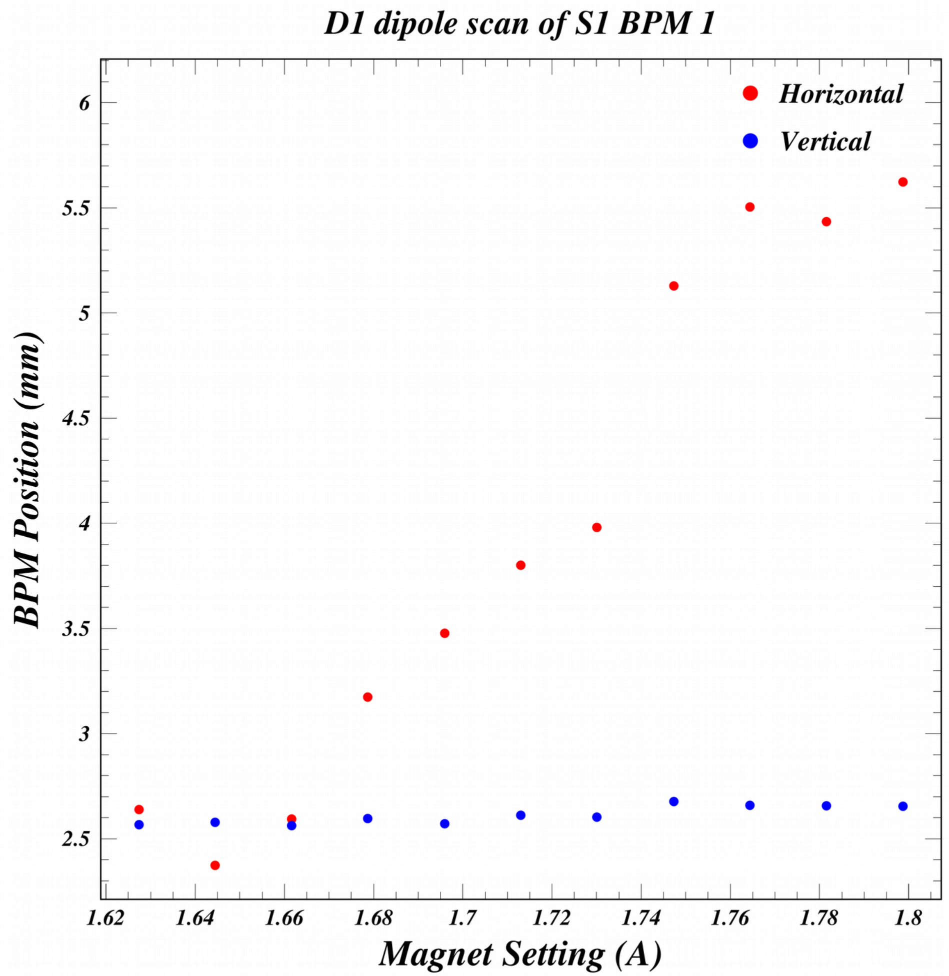
σ_X = 0.39 mm, η_X = 0.67 m corresponds to σ_E/E = 5.8e-4

Vertical BPM resolution typically 0.02 mm.

Examples of magnet setting scans

BPM measurements include offline correction for the S1 racetrack vacuum chamber shape





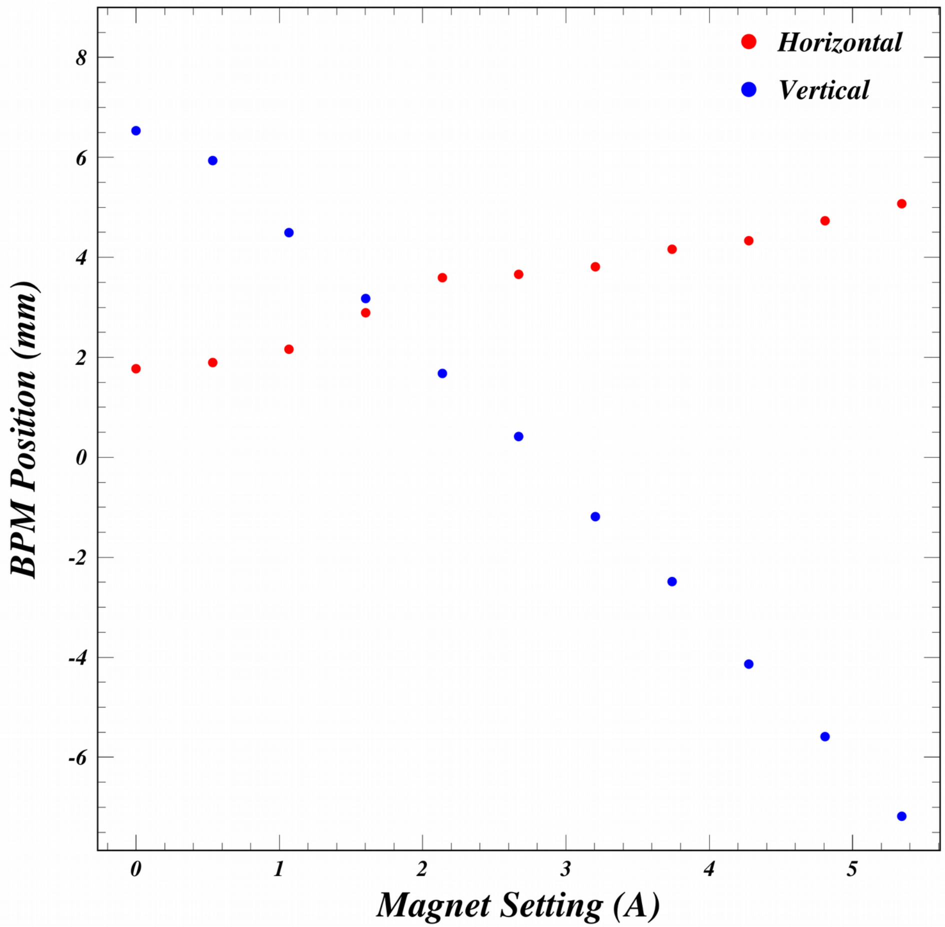
Precise determination of the slope (mm/A)
Very little coupling in evidence.
Point at lowest setting nearly always wrong.
Have an untested hypothesis for it.

Occasionally some funny business as shown here in the horizontal dependence.
Question: does this measurement put a limit on the "second order vertical focusing" in S1DPB01 and S1DIP02?

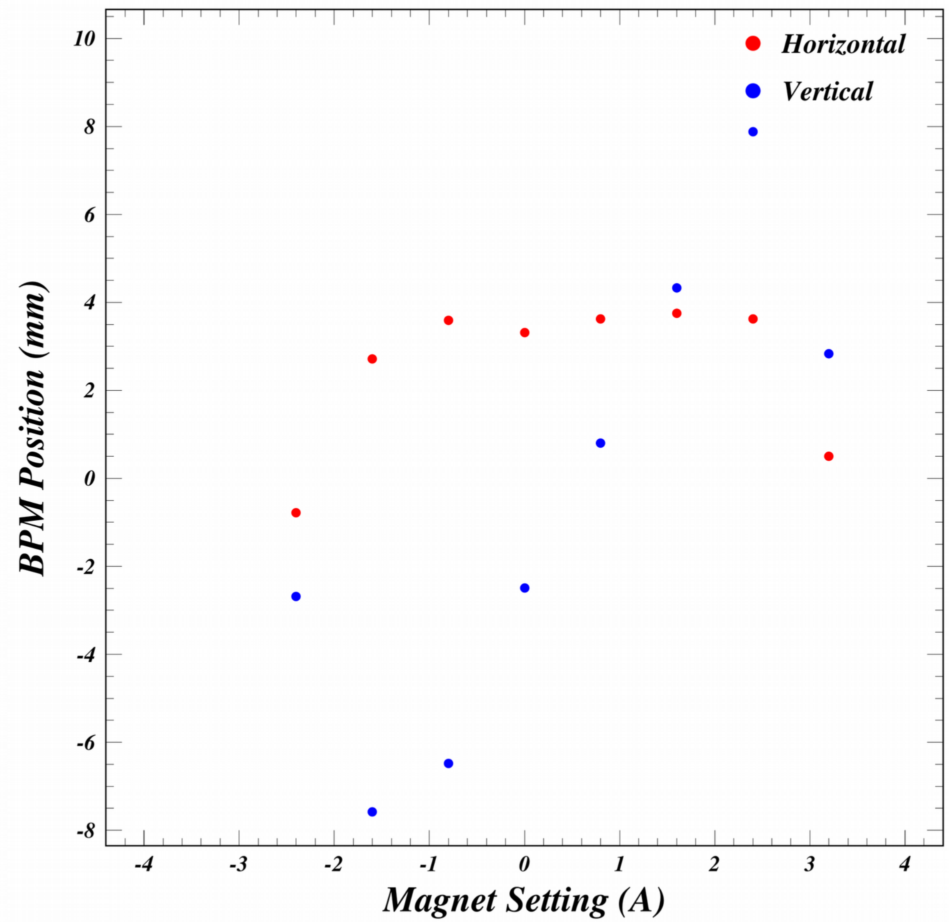
Examples of magnet setting scans

Quads and vertical correctors

S1 quadrupole QUA01 scan of S1 BPM 2



CRV01 scan of S1 BPM 2

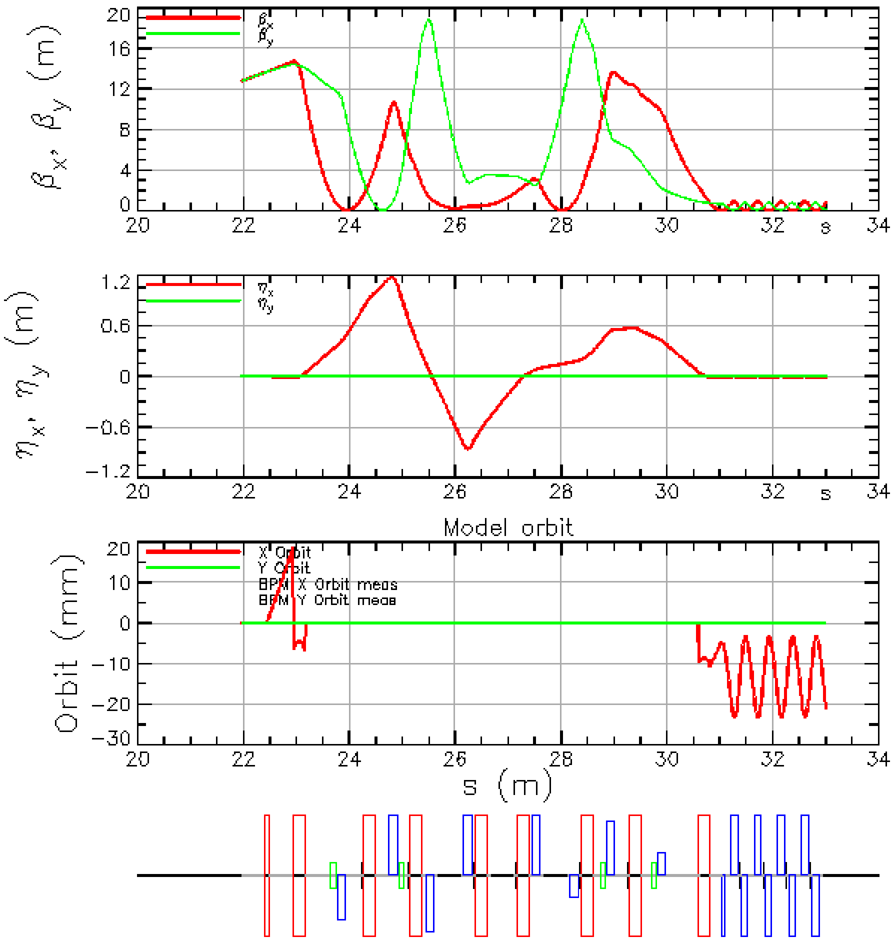


S1QUA01 is steering strongly because the beam is 2-7 mm high, deflecting it toward the nominal beam axis.

This 5-cm vertical corrector had enough range to put the beam on axis at BPM 2. In fact, it moves the beam +-5 mm at BPM 1, 48 cm away. These correctors are also used for the 76 MeV beam. Here it runs out of vertical physical aperture.

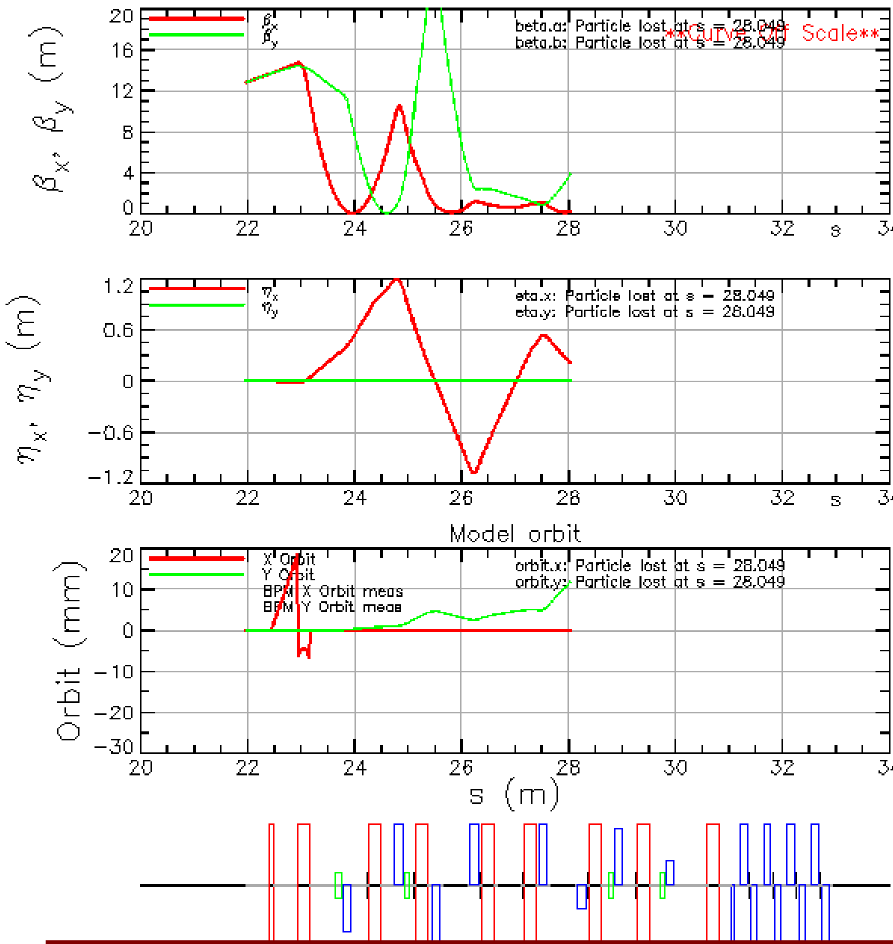
Initial CBETA-V optimizations

Design Lattice



Ignore orbit between S1DPB01 patch elements

Load quad and corrector settings

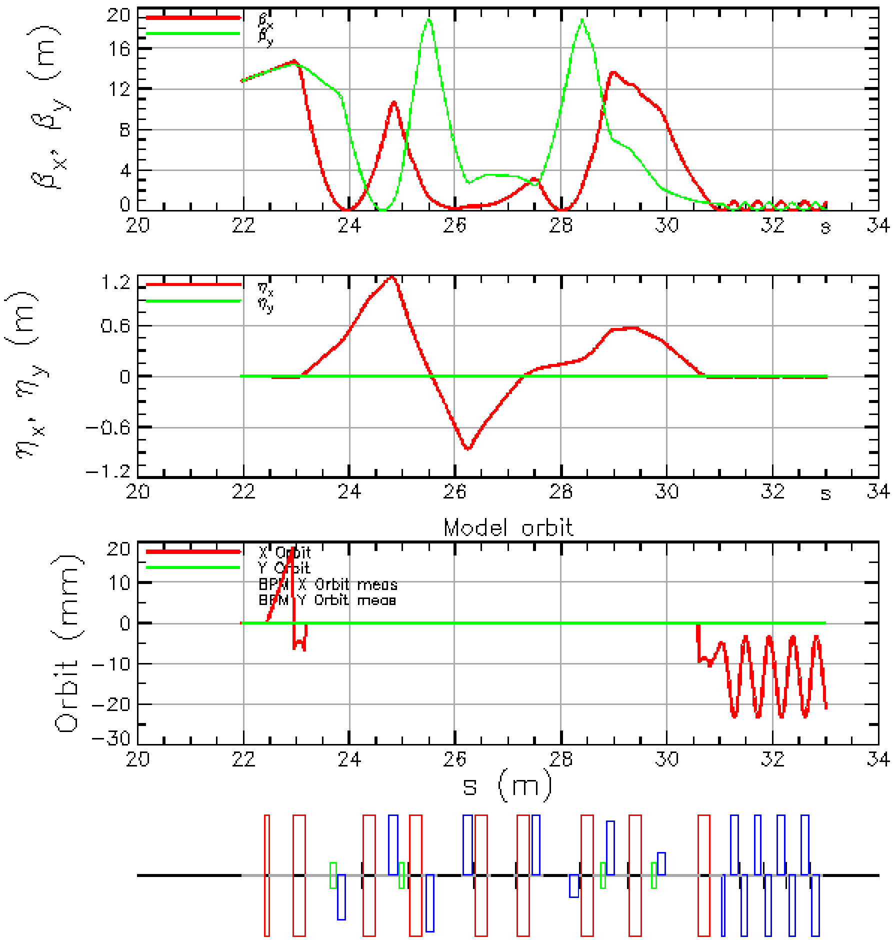


Load machine state 122.
CRV01 & 02 turned on (same polarity!)
Quad gradients increased 4-5%.
Need to correct entrance beam position !

Initial CBETA-V optimizations

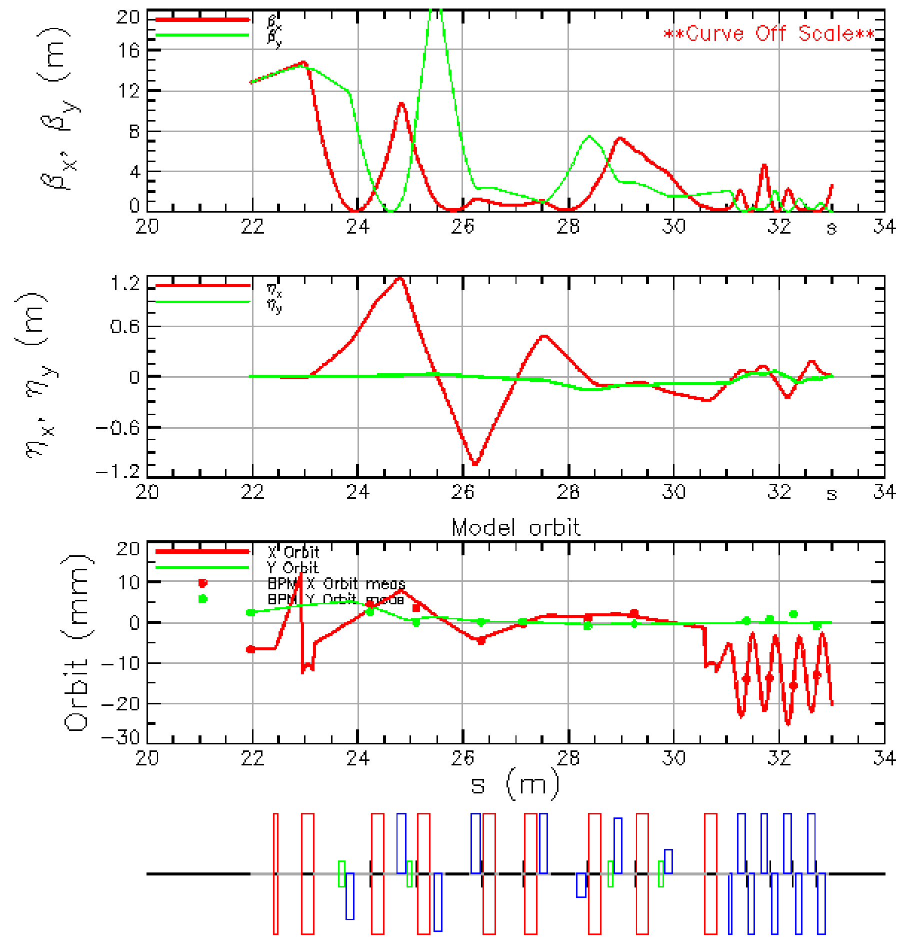
--Use BPMs to find entrance beam positions and angles --

Design Lattice



Ignore orbit between S1DPB01 patch elements

After setting beam entrance coordinates



10 BPM measurements to give beam X, PX, Y, PY.
Merit function very good, i.e. orbit is a good match.
BUT, magnet & BPM offsets not yet estimated.

Initial CBETA-V optimizations

--With a decent model, ask a million questions --

Example question

If we include the 8 quad gradients together with the beam coordinates in the optimization do we get a better match to the measured trajectory data? 20 constraints, 12 unknowns.

Answer: No. The merit function changes by a negligible amount.
There is no systematic change in the quad strengths.

		Set values	Optimized values	Original design values
Index	Controlled Attributes(s)	Meas	Model	Design
1	[1:2]@MS1QUA01_FIELD[VALUE]	1.0660E+00	1.0668E+00	1.0129E+00
2	[1:2]@MS1QUA02_FIELD[VALUE]	-2.2094E+00	-2.2092E+00	-2.1151E+00
3	[1:2]@MS1QUA03_FIELD[VALUE]	1.3373E+00	1.3426E+00	1.2860E+00
4	[1:2]@MS1QUA04_FIELD[VALUE]	-2.8995E+00	-2.8762E+00	-2.7742E+00
5	[1:2]@MS1QUA05_FIELD[VALUE]	-2.8954E+00	-2.8848E+00	-2.7764E+00
6	[1:2]@MS1QUA06_FIELD[VALUE]	5.2255E-01	6.1679E-01	5.0715E-01
7	[1:2]@MS1QUA07_FIELD[VALUE]	-1.3039E+00	-1.3007E+00	-1.2500E+00
8	[1:2]@MS1QUA08_FIELD[VALUE]	-5.4973E-01	-1.5083E+00	-5.1991E-01

Optimized values show changes of less than 1%, except for the relatively weak quads 6 and 8 which appear to be correlated. Also, they are not well constrained, because the beam is nearly on axis there and they affect the trajectory at fewer BPMs.

Quad 1, which is steering strongly, changes by 0.08%.

How to use CBETA-V and these measurements?
--Consultations with Rubin, Sagan, Shanks ongoing --

Some questions and observations

*** The use of difference orbits removes sensitivity to BPM offsets.

*** Quad offsets can be obtained from matching difference orbits from quad strength changes using the quad offsets as variables. We can consider varying the beam entrance coordinates and quad offsets in both planes simulataneously in 16 “universes,” where each universe has two quad settings in a given quad. 160 constraints with 20 unknowns.

*** We already have accurate determinations of the FA BPM offsets relative to the FA quad axis. Should the FA girder positions and angles be included in the optimization?

*** Similar question for the S1 table relative to the MLC.

*** Once we have an accurate estimate of the beam entrance coordinates and quad offsets, We may be able to just “read off” the BPM offsets from the measured trajectory, since the dipole and corrector deflections have little sensitivity to beam position.

*** Once we have a robust procedure, it should be incorporated into the commissioning plan. How best to do that?

Fun Homework

Have a look through the 215 plots in each of the six uploaded graphics files and think about whether they appear as you expect them to. Notify me of suspicious findings. Suggest possible reasons and how to verify or exclude them. I can send an answer, or provide a CBETA-Vscript for you to play with.