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Optics Measurement at MEBT 1.1

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On the behalf of PIP-II Injector Test Team

PIP-II Technical Meeting

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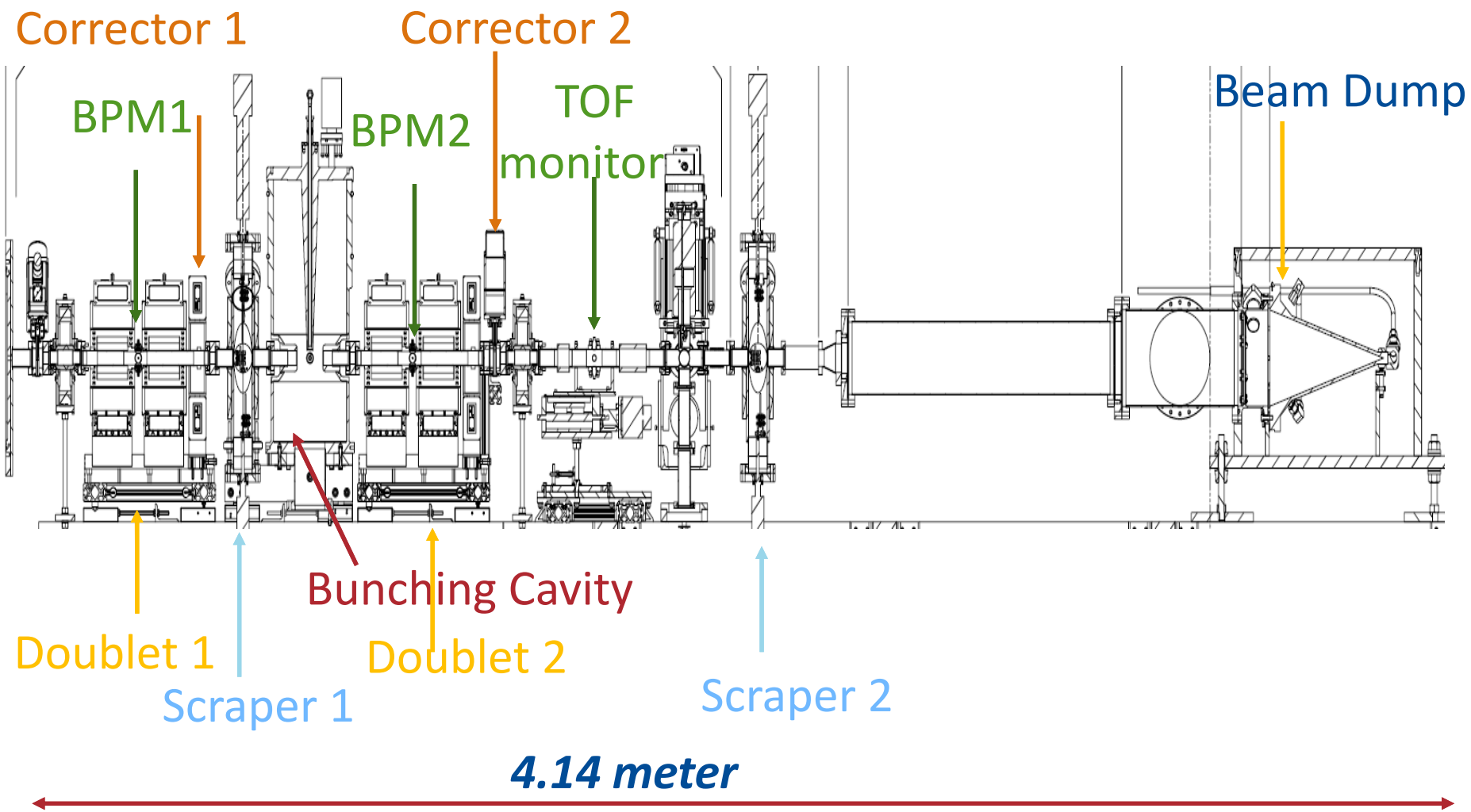
Introduction

- Optics Measurement goal is to model
  - Beam transverse sizes along the beamline
  - Beam trajectory along the beamline
- Differential Trajectory method will be used to determine beam trajectory.
  - Measured shift in beam position with variation in corrector currents.
- However, before achieving those goals we need to
  - Validating the type of quadrupole magnets
  - Verifying calibration of steering correctors, BPMs
  - Establishing the reference coordinate system

Outline

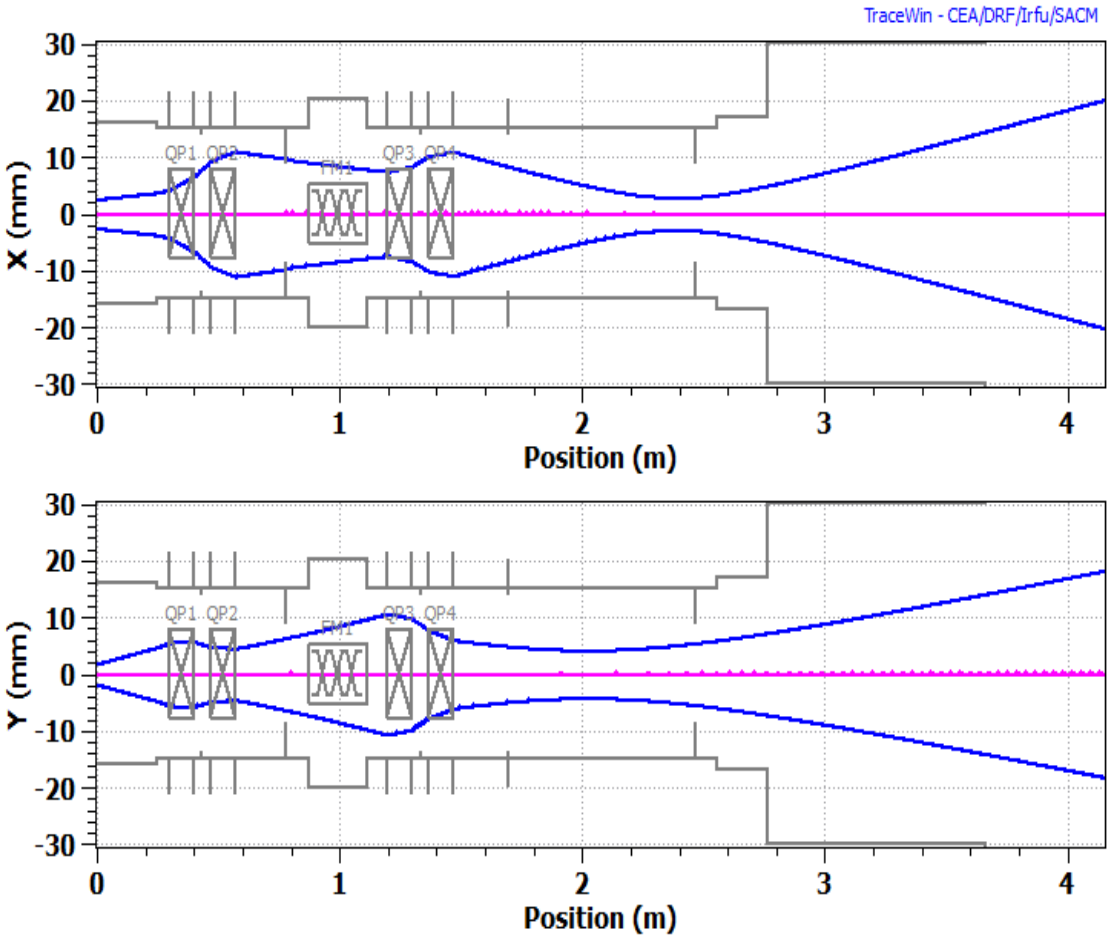
- MEBT-1.1 Layout
- Measurements
  - Understanding of Beamline Elements
  - Establishing sign convention/coordinate system
  - Modeling of transverse optics using steering correctors via
    - Beam Scrapers
    - BPMs
  - Summary

MEBT 1.1 Layout



Beam Envelope

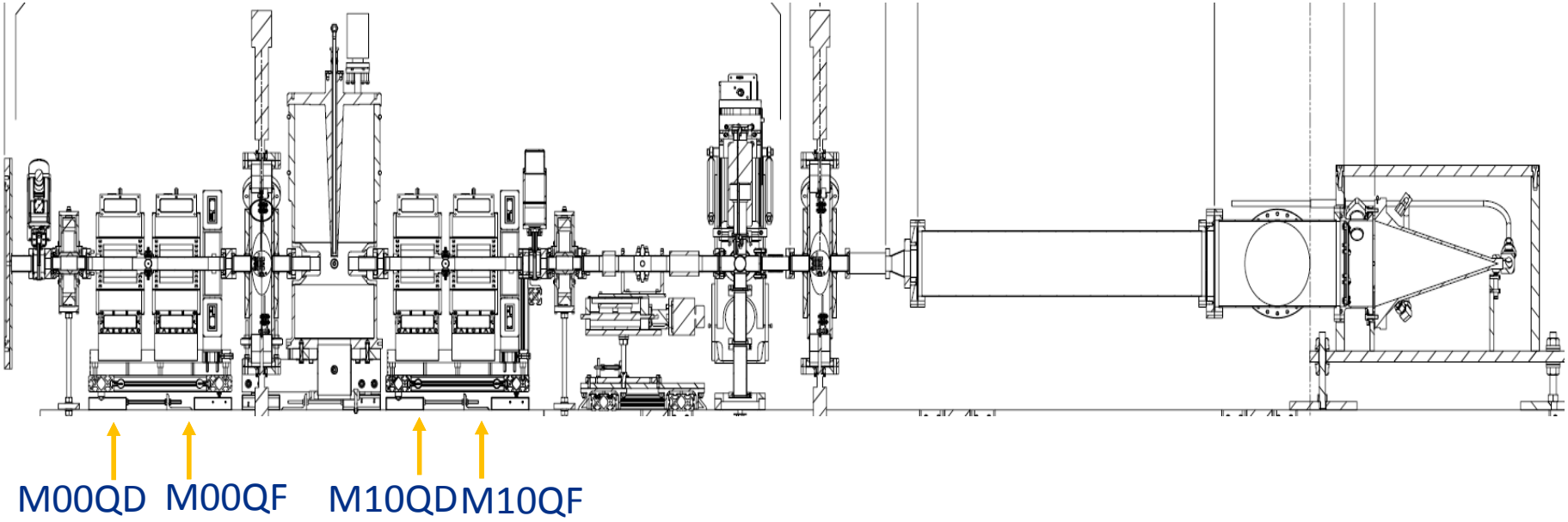
3 RMS Beam Envelope



Initial Settings

- Beam Energy is 2.1 MeV
  - Measurement shows errors within +/- 1%
- Quads settings:
  - M00QD = 11.07 T/m
  - M00QF = 9.14 T/m
  - M10QD = 7.91 T/m
  - M00QF = 7.12 T/m
- Quadrupole length: 0.1 m
- Doublet length: 0.27 m

Identification of Beam Line Elements : Quadrupole Type



Convention:

- QF is focusing Quadrupole in horizontal plane.
- QD is focusing quadrupole in vertical plane

Understanding Quadrupoles Nature (1)

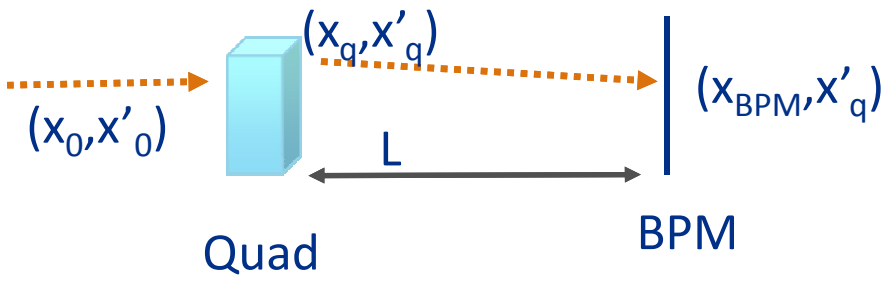
- Transfer matrix of the focusing quadrupole is :

$$\begin{bmatrix} \cos\sqrt{K}l & \frac{1}{\sqrt{K}}\sin\sqrt{K}l \\ -\sqrt{K}\sin\sqrt{K}l & \cos\sqrt{K}l \end{bmatrix}$$

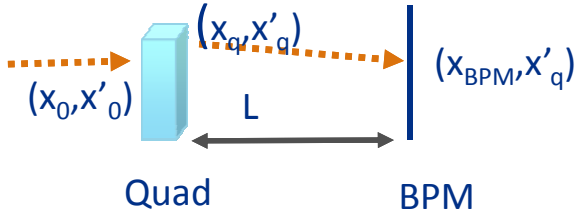
  - For a thin lens approximation, transfer matrix is simplified to:

$$\begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix} \qquad where\ \frac{1}{f} = Kl;\ K = \frac{qG}{P}$$

  - A off-centered beam received deflection from quadrupole:



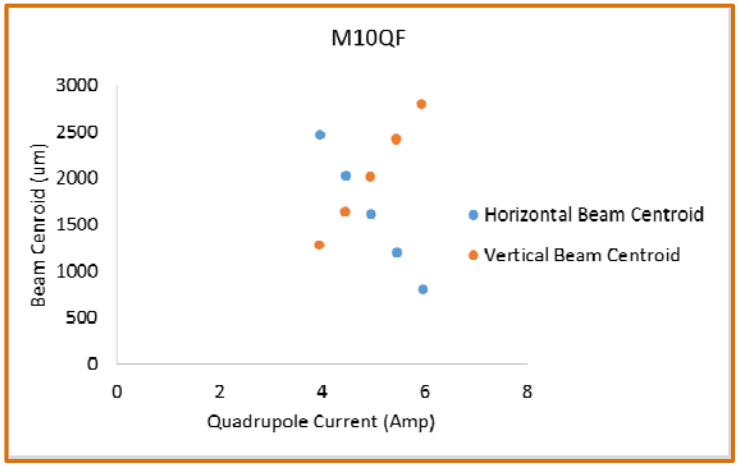
Understanding Quadrupoles Nature(2)



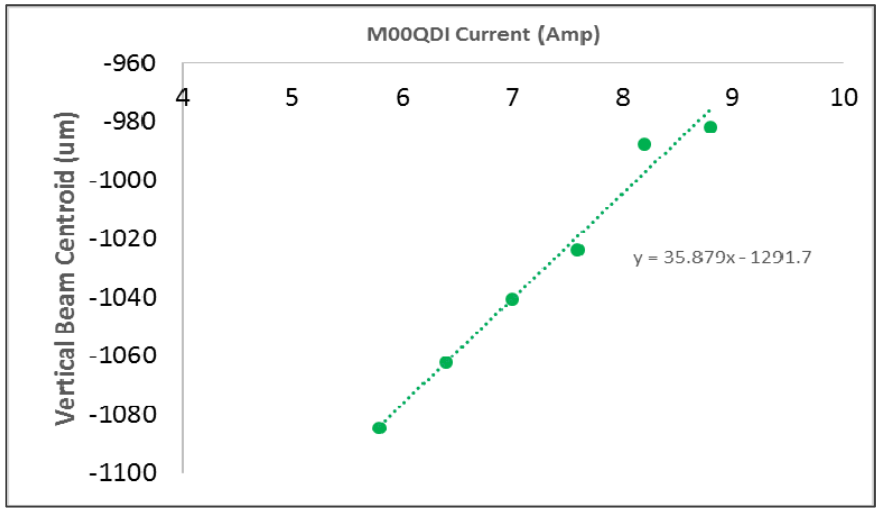
- Deviation of beam centroid from a F-quadrupole is: $x'_q = \left(\frac{-1}{f} x_0 + x'_0 \right)$
- Centroid position at BPM is: $x_{BPM} = \left(\frac{-1}{f} x_0 + x'_0 \right) L + x_0$
- Change in quadrupole current will result in change in quadrupole strength, slope of beam shift at BPM with quadrupole current is:

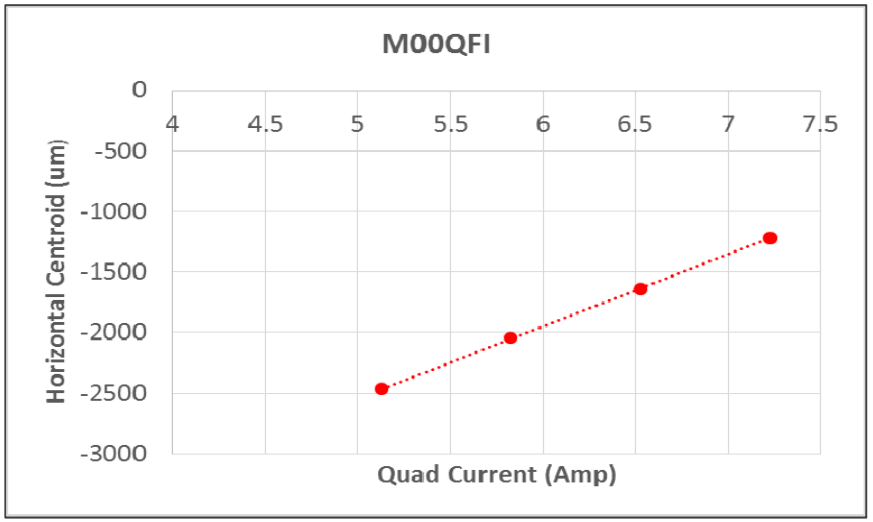
$$\frac{dx_{BPM}}{dI} = \left(-\frac{dK}{dI} x_0 \right) L$$

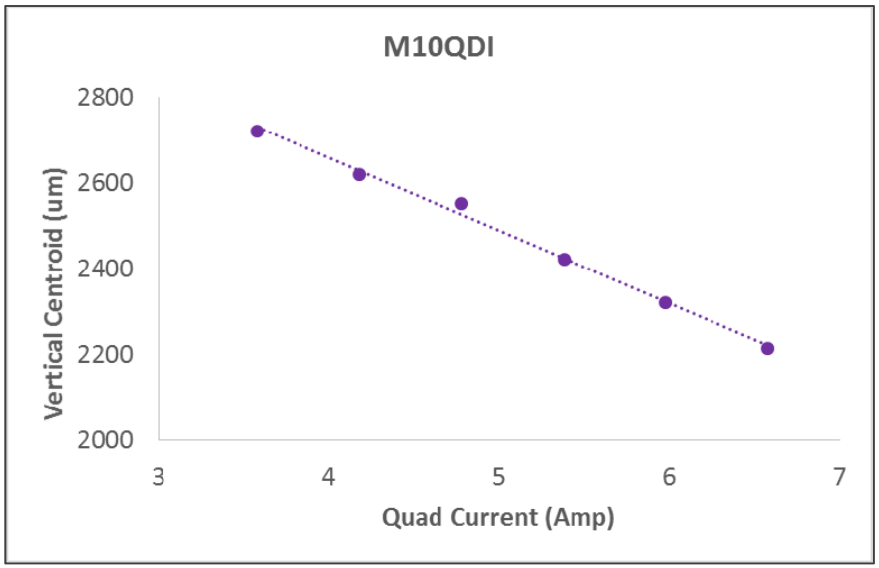
- If x_0 is positive, -ve slope of beam centroid shift with quad current indicates focusing quad.
- Measurement is performed for all quads in MEBT.

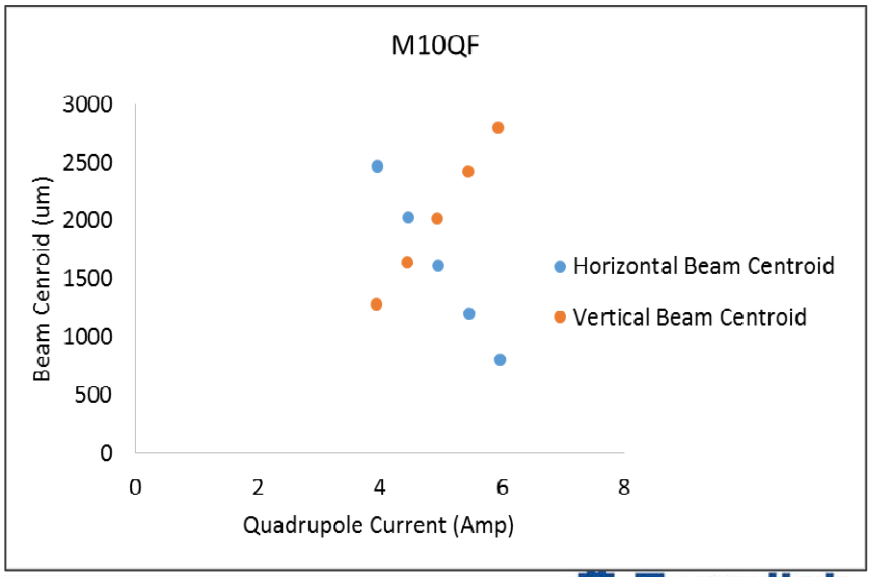


Ouadrupoles in MEBT 1.1A







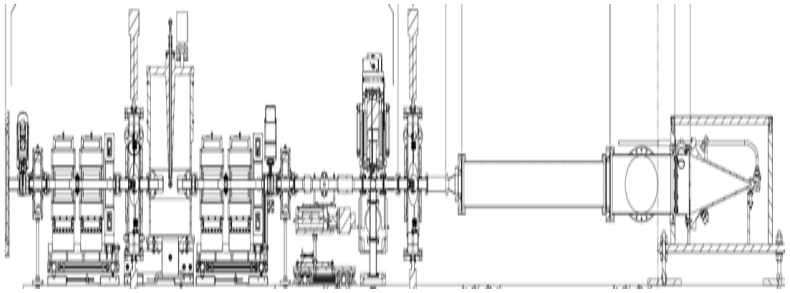


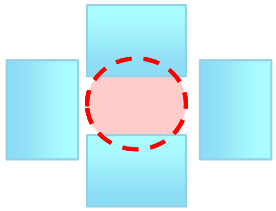
Establishing the coordinate system:

- Convention
  - Positive *x* = H^- Beam is moving toward left when looking downstream to the beam dump.
  - Negative *x*= H^- Beam is moving toward right.
  - Positive *y* = H^- Beam is moving upward.
  - Negative *y* = H^- Beam is moving downward.
- Positive current in *x*-corrector will steer the beam in left direction.
- Positive current in y-corrector will steer the beam in upward direction.

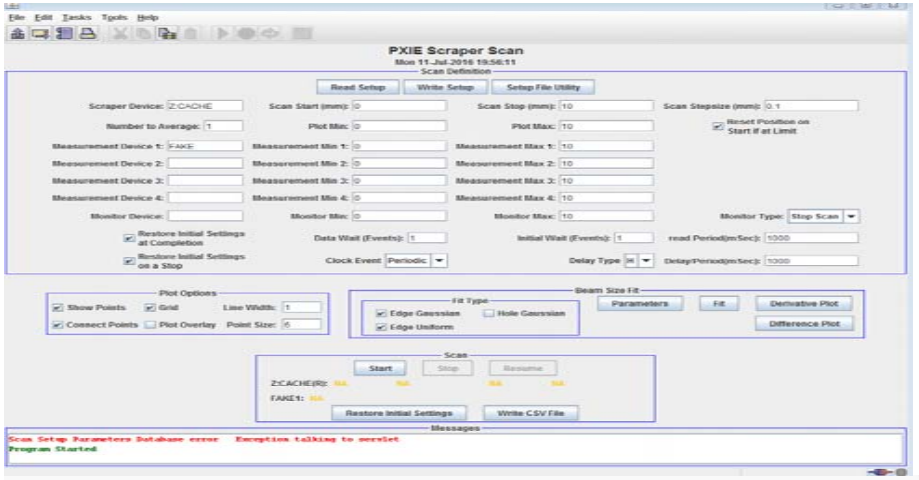
Java Program: B. Marsh

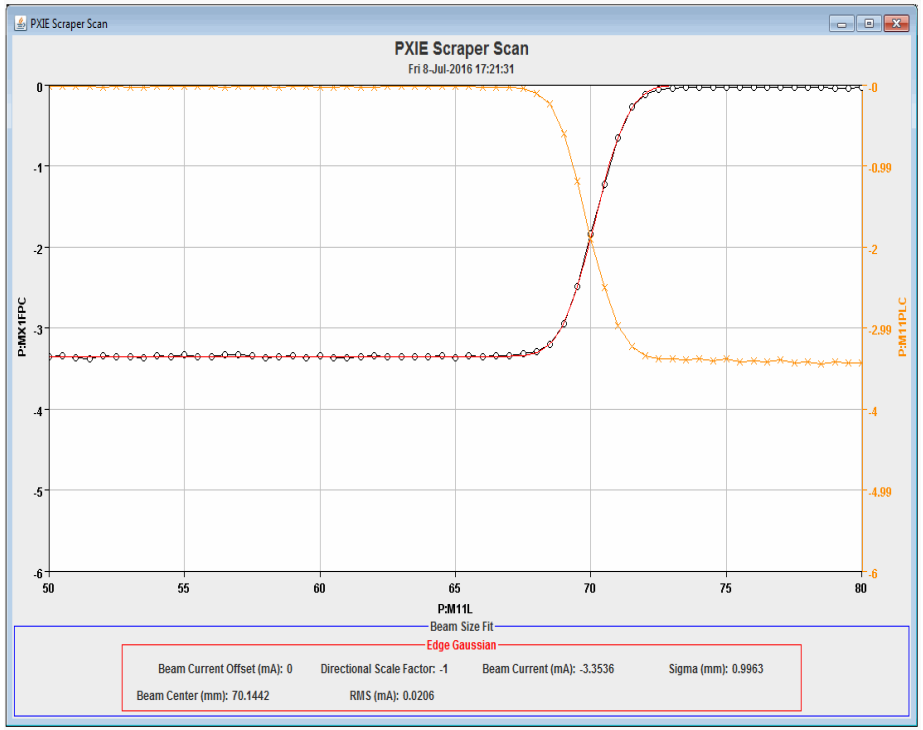
Scraper Scan





Pictorial presentation of a scraper set. 4 moveable, radiation – cooled blades.

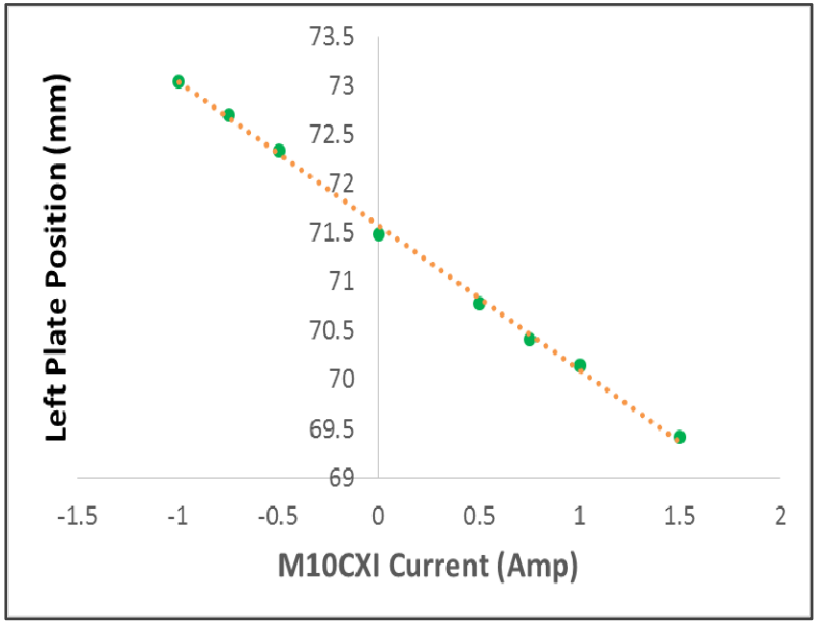




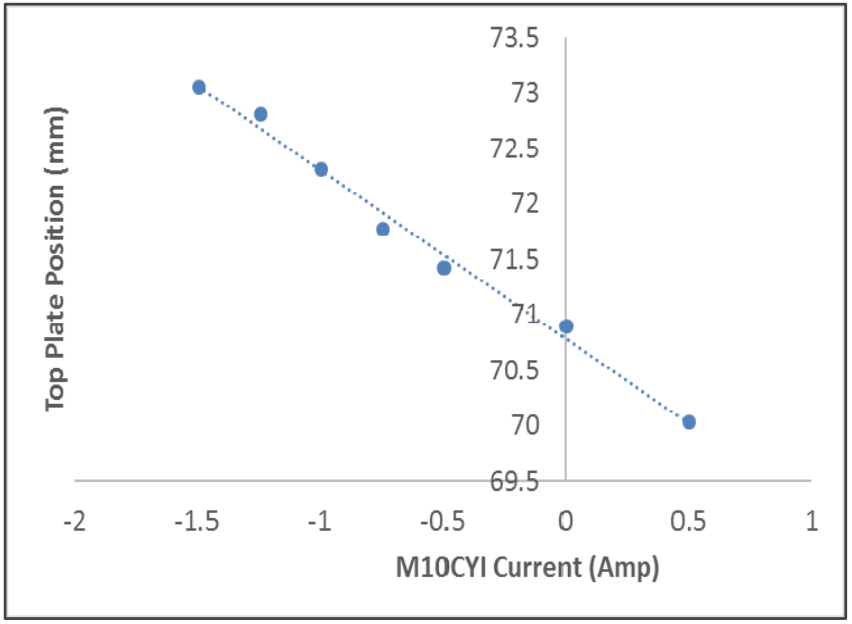
- Scraper are utilized to verify calibration of correctors.
- Scraper scan is performed by intercepting the beam using one of blades.
- Beam current is measured at scraper blade and at dump.
- This information is used to determine beam centroid position on the scraper.

Understanding Steering Corrector Polarity :

Left Plate at Scraper 2

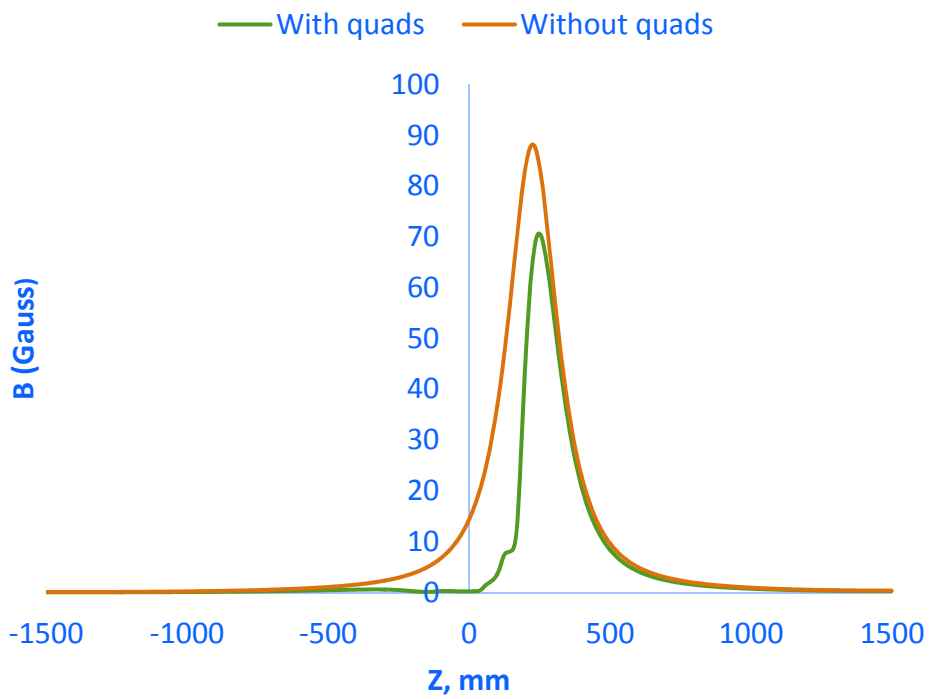


Top Plate at Scraper 2



- Corrector current is varied and scraper scan is performed and beam centroid position on scraper is measured.
- Positive current in horizontal corrector results in reduced in-ward movement of left plate indicating beam is moving toward left.
- Negative current in vertical corrector shows large inward movement of top plate indicating beam is steered downward.
- Typical error range involved in scraper scan measurement is 2-4 %

Influence of Quadrupole on corrector fields



- Simulation suggests that quadrupole presence will affect strength of steering corrector and result in:
  - Shift in center of gravity by 88 mm.
  - Integral field is reduced to about 44 %.
- Magnetic integral field of corrector is measured standalone without quadrupoles.

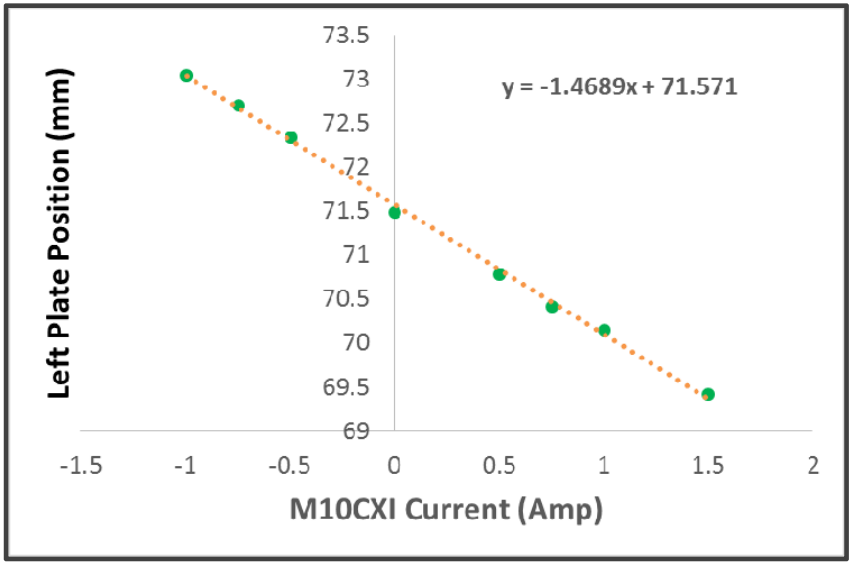
- Corrector Calibration coefficient that implies integral field per unit corrector current is changed.
  - Need to determine new calibration coefficient for correctors.

Estimation of Calibration Coefficient of steering correctors

- Calibration Coefficient of correctors are estimated using scraper scan.
- It is given as:

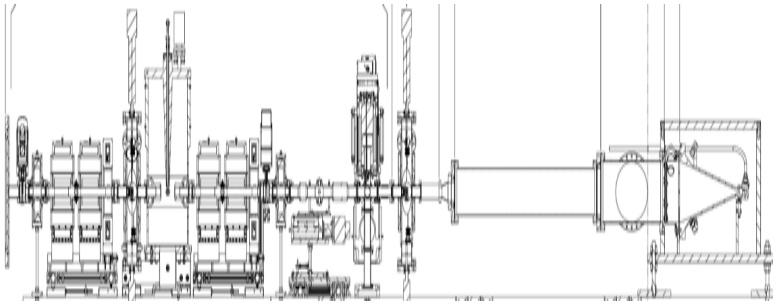
$$C_{M10CX} = \left(\frac{dx}{dI}\right) * \frac{\gamma\beta mc^2}{Lc}$$

where $\left(\frac{dx}{dI}\right)$ is slope of line representing shift of scraper plate with corrector current, L is distance between center of corrector to the scraper plate.

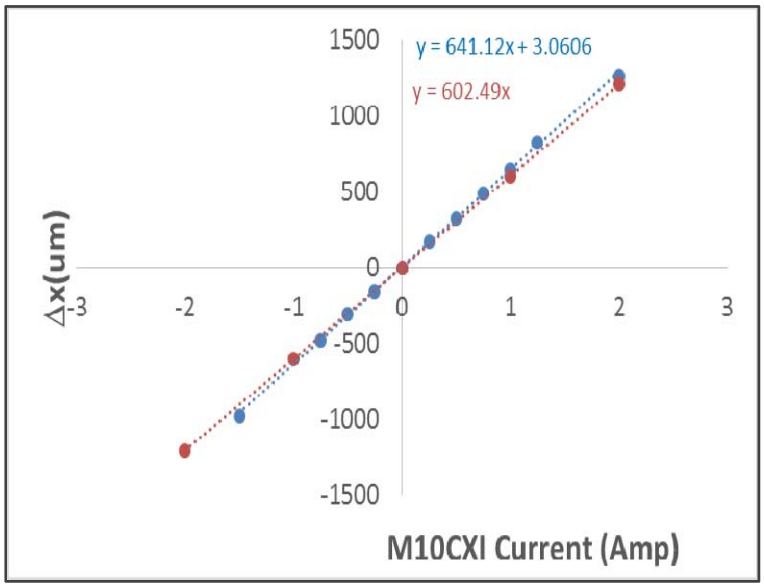


Element	Calibration Coefficient
M00CXI	0.7015 mT-m/Amp
M00CYI	0.8765 mT-m/Amp
M10CXI	0.3589 mT-m/Amp
M10CYI	0.3798 mT-m/Amp

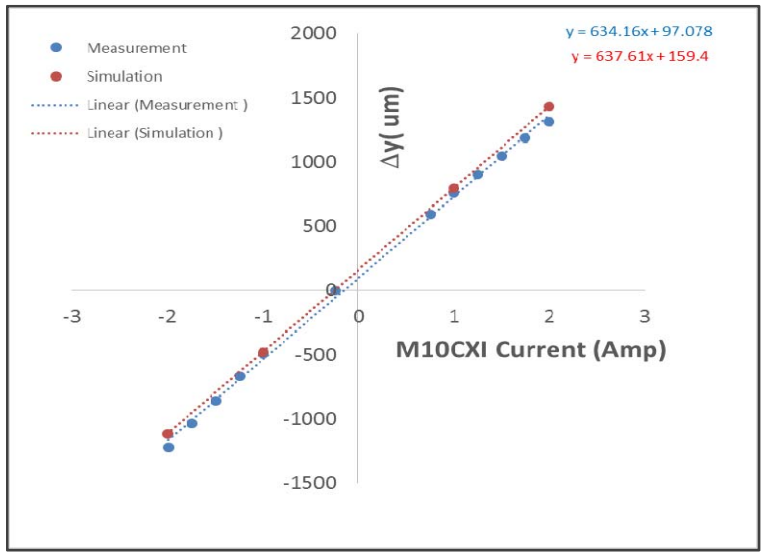
Corrector Scan:



Horizontal Steering Corrector2

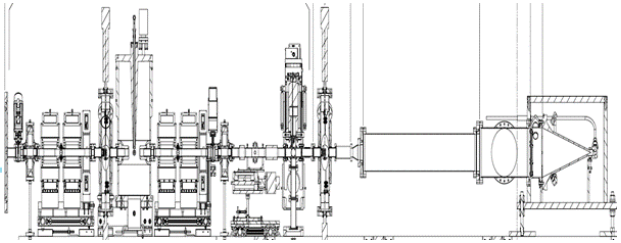


Vertical Steering Corrector2

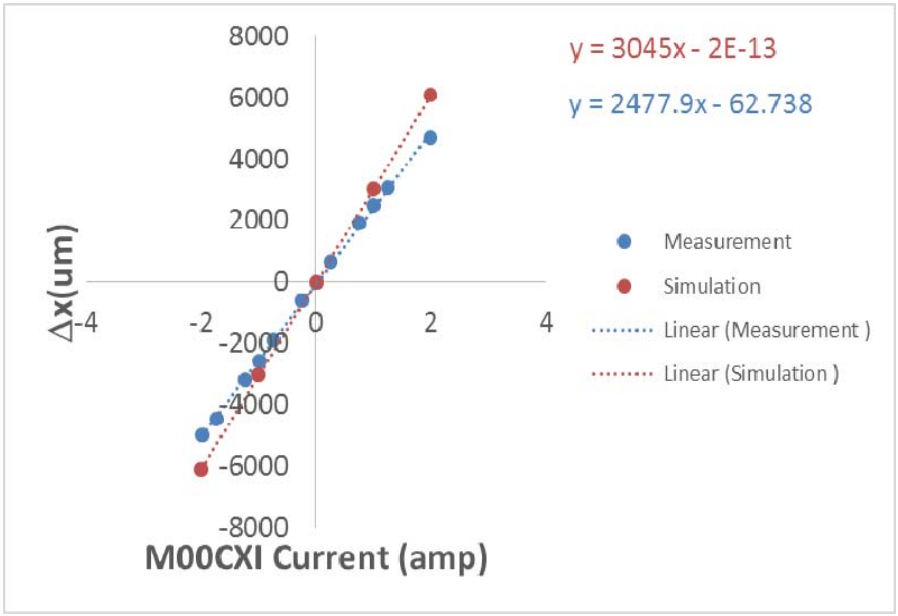


- Second horizontal and vertical corrector scan is performed. Beam centroid shift is measured in TOF monitor .
- Reasonable agreement with simulation 6% and 1 % for horizontal and vertical scan respectively.
- Measurement RMS error is around 6 % and 1. % in horizontal and vertical scan.

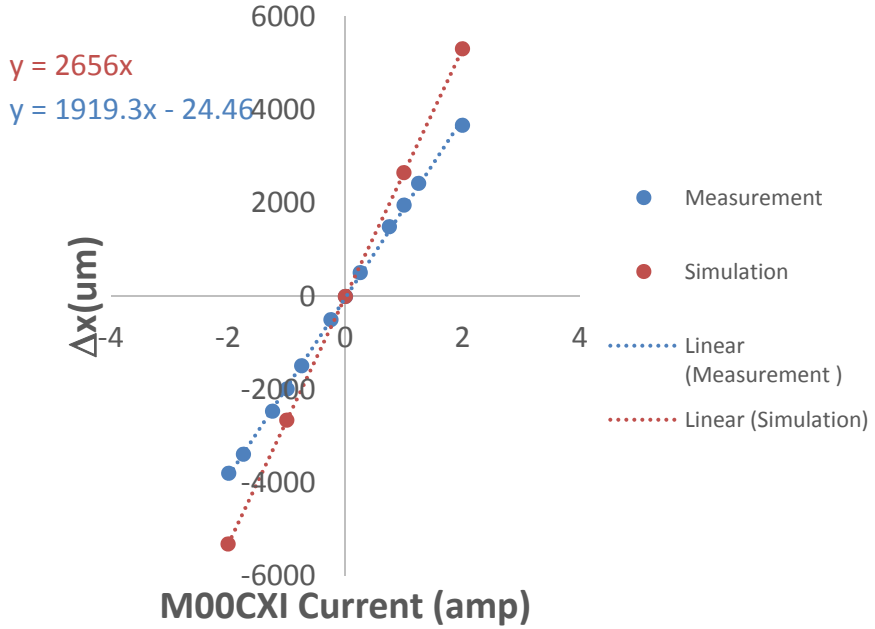
Horizontal Corrector Scan:



Measurement at M10BPM



Measurement at TOF monitor



- First corrector scan is performed and beam centroid position is measured at M10BPM and TOF monitor.
- A large discrepancy between measurement and simulation results.
- Similar behavior for vertical corrector

Corrector Scan Summary:

Element	Calibration Coefficient
M00CXI	0.7015 mT-m/Amp
M00CYI	0.8765 mT-m/Amp
M10CXI	0.3589 mT-m/Amp
M10CYI	0.3798 mT-m/Amp

Scan		Scraper 1 um/Amp	M10BPM um/Amp	TOF Monitor um/Amp	Scraper 2 um/Amp
M00CXI	Measurement	226.2	2477.9	1919.3	
	Simulation	226.4	3045	2656	
M00CYI	Measurement	212.4	1231.50	1073.3	
	Simulation	212.5	1912.3	2703	
M10CXI	Measurement			641.9	1468.9
	Simulation			604.5	1469.7
M10CYI	Measurement			634.1	1524.
	Simulation			637.6	1524.9

- Corrector integral strength is calibrated using scrapers.
- Measurement performed using first corrector scan shows large discrepancy with respect to simulation prediction.

Summary and Outlook

- Conventions are established about beamline elements and reference coordinate system.
- Validates beamline elements.
- Optics modelling is performed using corrector scan.
  - Integrated strength of correctors are estimated using scrapers.
  - There is significant discrepancy between measurement and predicted results for first corrector scan.
  - Discrepancy between measurement and simulation is reduced to within 10 % for second corrector scan.
- Next step is to resolve discrepancy and obtain a good optics model to predict:
  - Beam rms sizes
  - Beam centroid position along beam line.