Study of Misalignment in the H4-VLE Beamline of the CERN North Area

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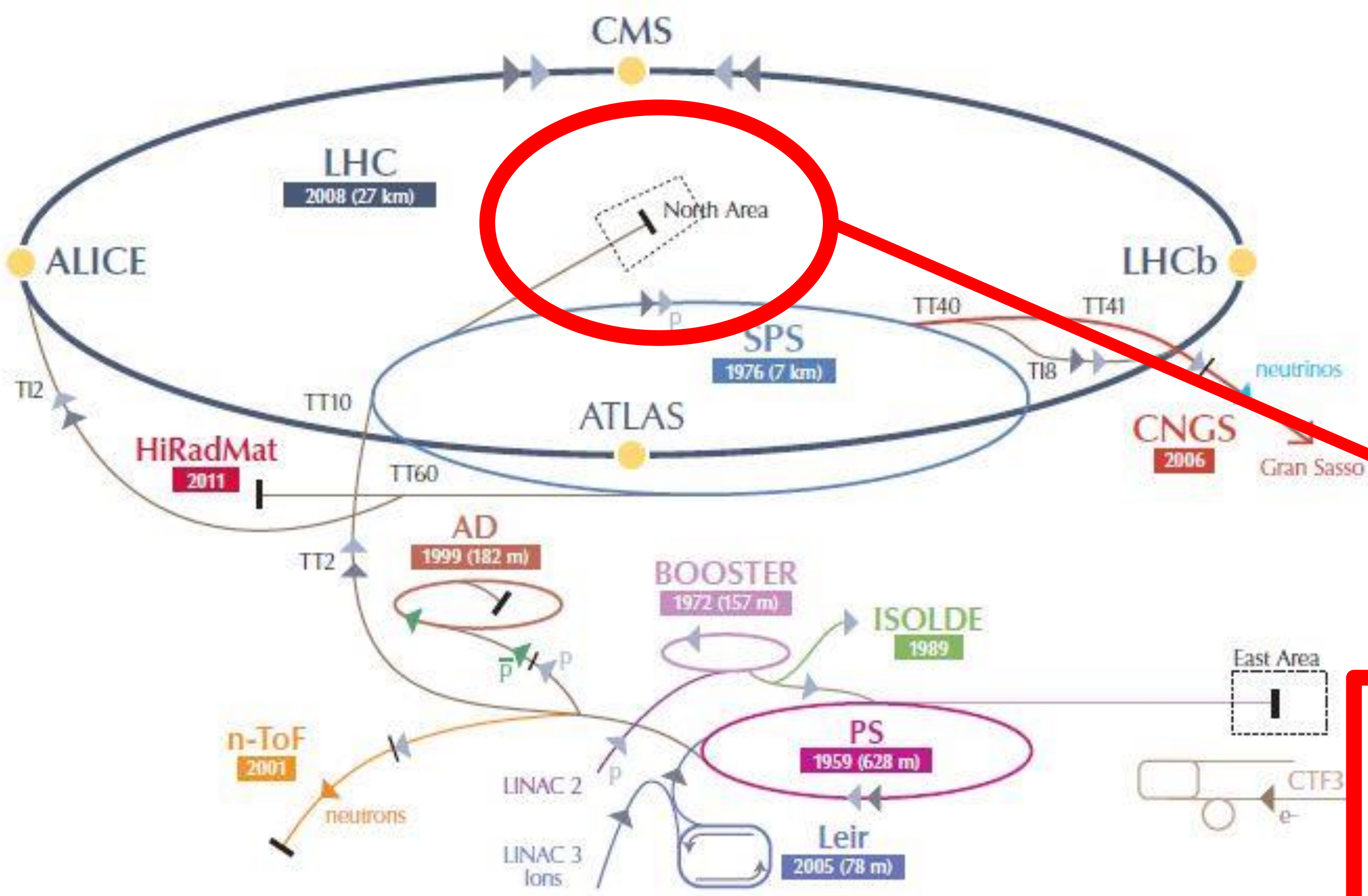
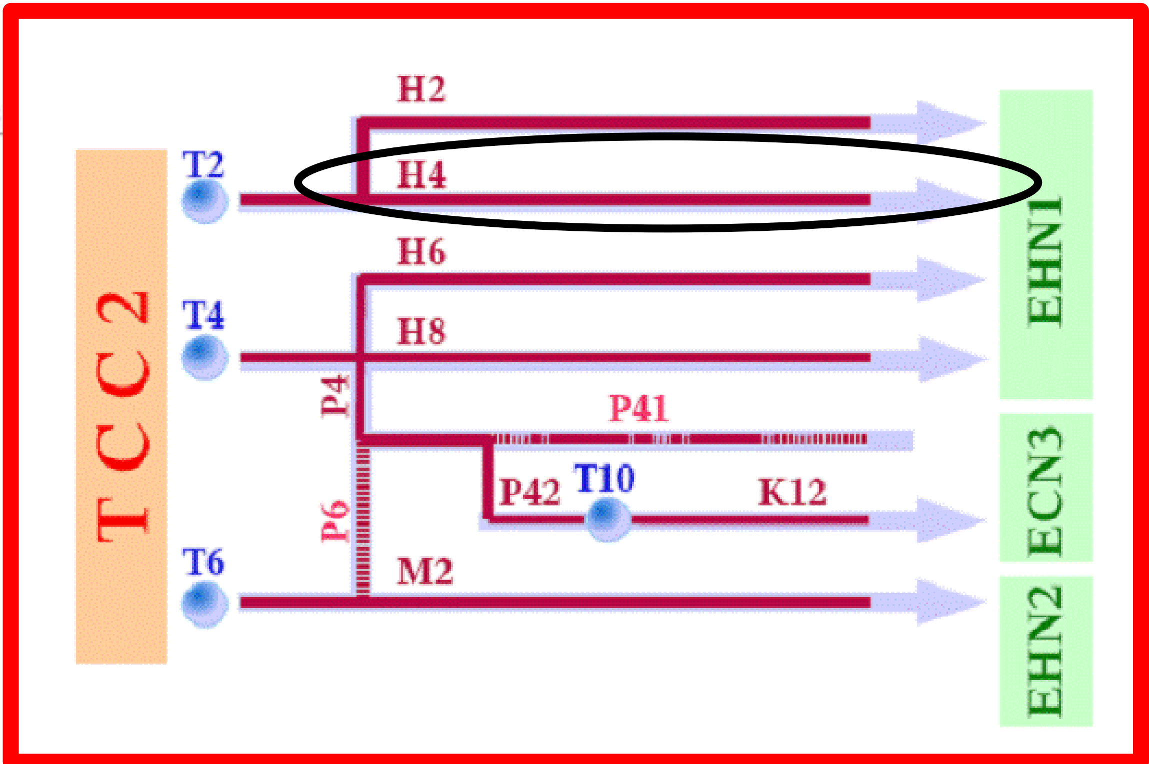
Schematic of Beamlines at CERN and in the North Area

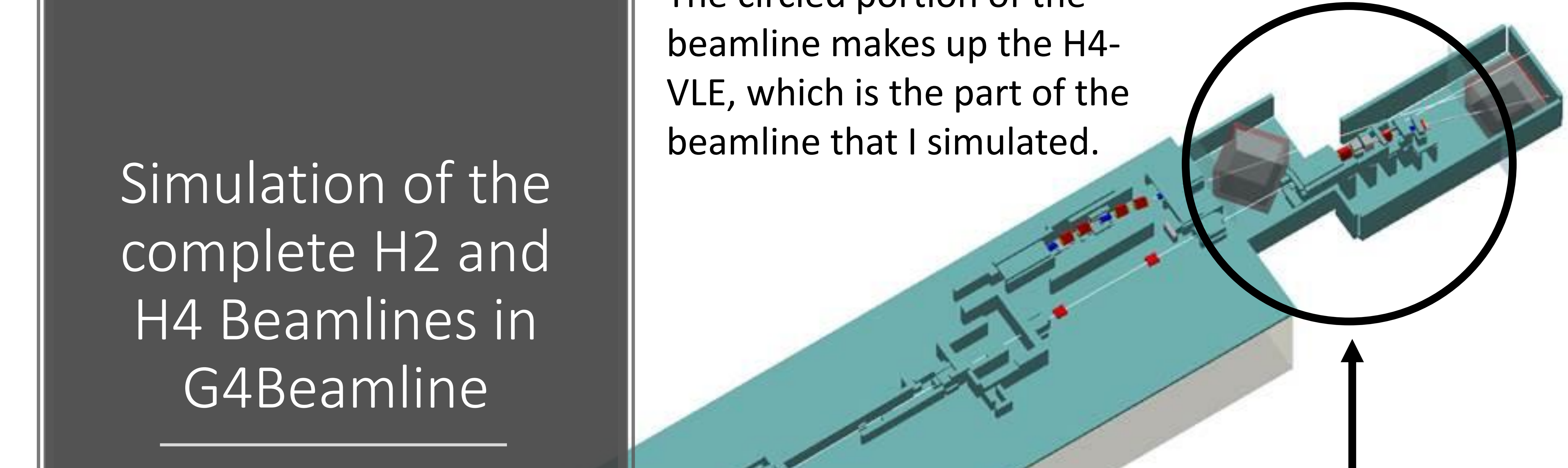
Within the CERN North Area, I am working specifically with a part of the H4 beamline known as the H4-VLE. This beamline will be used to study a prototype neutrino detector designed for DUNE.





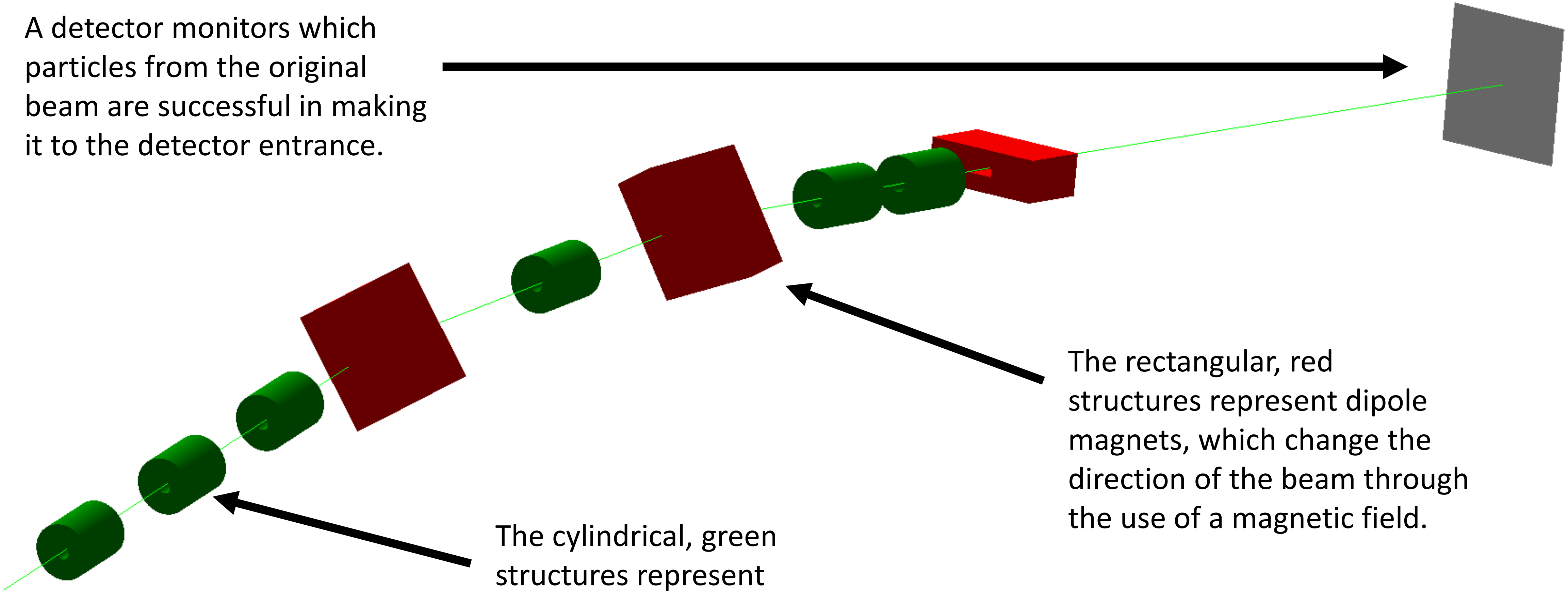
Simulation of the complete H2 and H4 Beamlines in G4Beamline

The circled portion of the beamline makes up the H4-VLE, which is the part of the beamline that I simulated.



My simulation of the H4-VLE beamline in G4Beamline

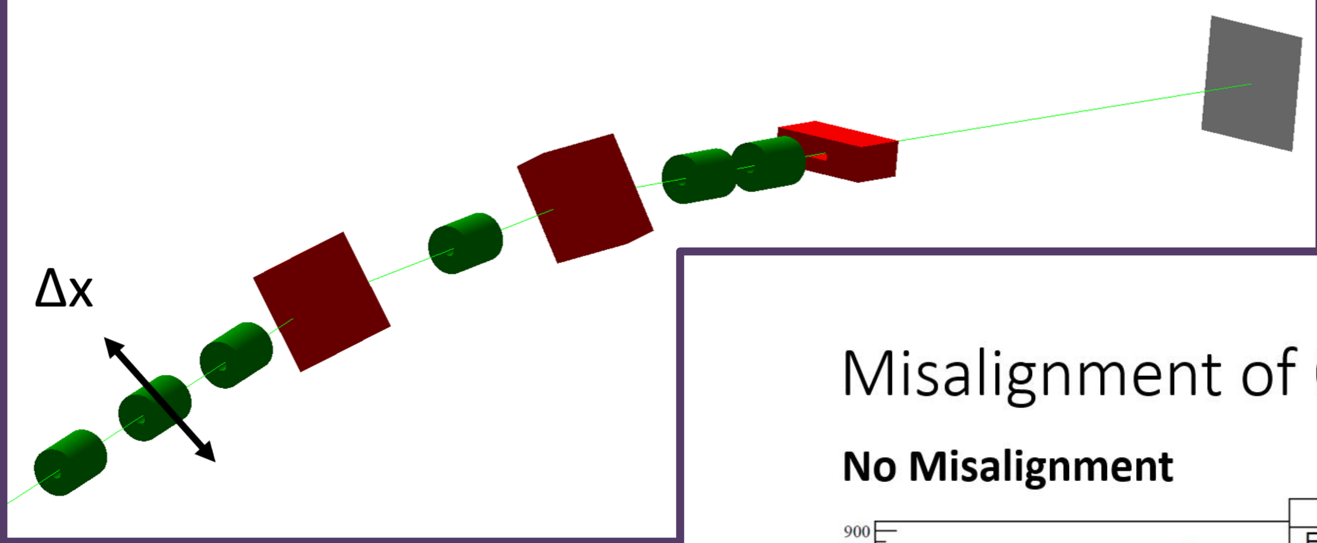
A detector monitors which particles from the original beam are successful in making it to the detector entrance.



The rectangular, red structures represent dipole magnets, which change the direction of the beam through the use of a magnetic field.

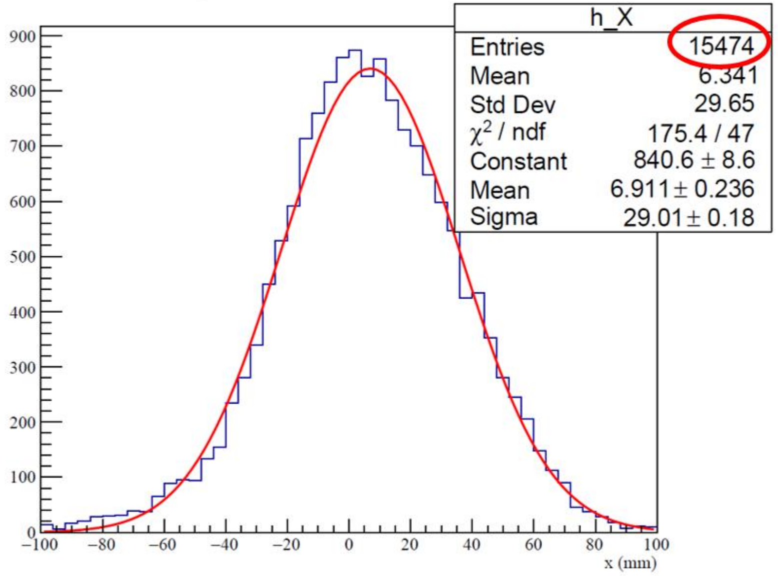
The cylindrical, green structures represent quadrupole magnets, which are used for focusing the beam.

Quadrupole Displacement

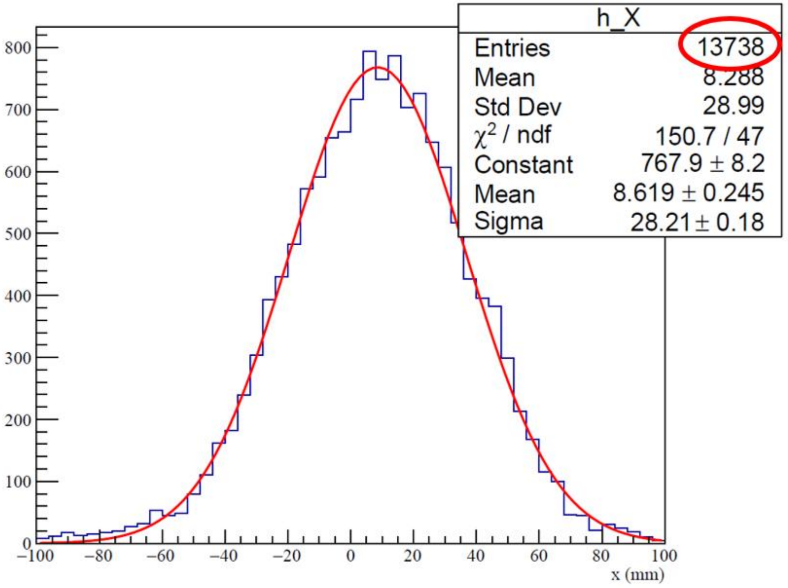


Misalignment of Quadrupole 18 by 2mm in x-direction

No Misalignment



No Correction



Conclusion: Misalignment of the quadrupole leads to significant particle loss at the detector.

Correcting for Misalignments in Beam Elements

x-direction:

$$x(\Delta x, \Delta y, b18, b19, b20,) = 2.27\Delta x - 3.04\Delta y + 120b18 + 53.3b19 - 306b20$$

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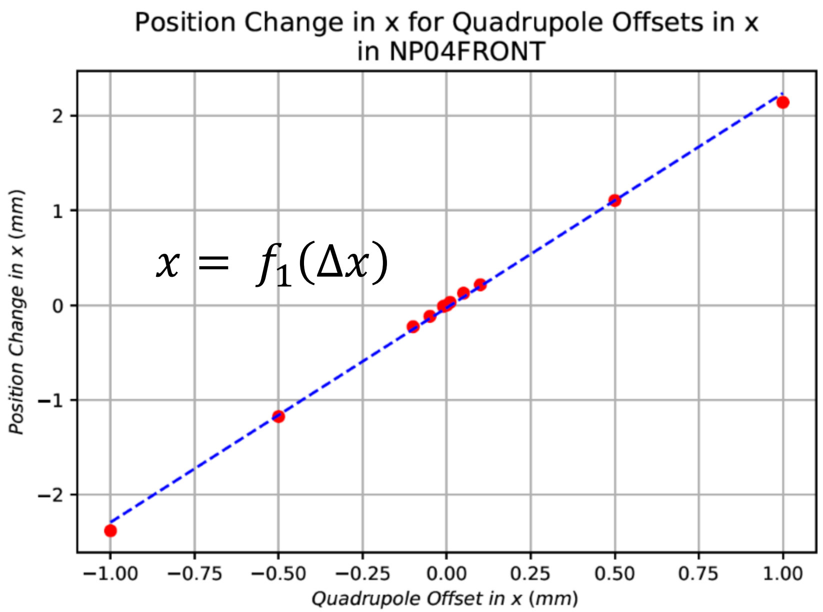
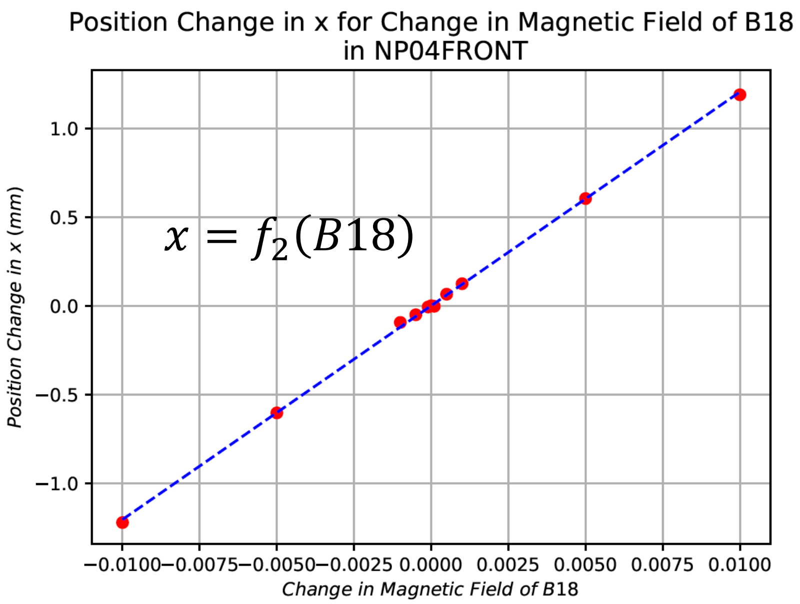
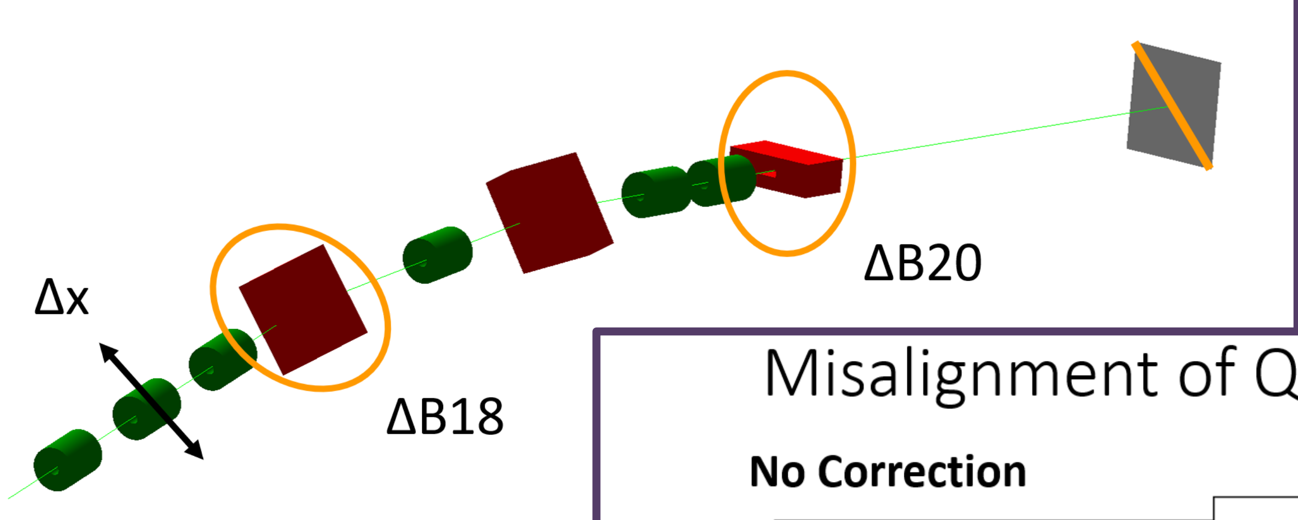
y-direction:

$$\mathrm{y}(\Delta x, \Delta y, b18, b19, b20,) = 3.45\Delta x + 1.97\Delta y + 179b18 + 80.7b19 - 14.4b20$$



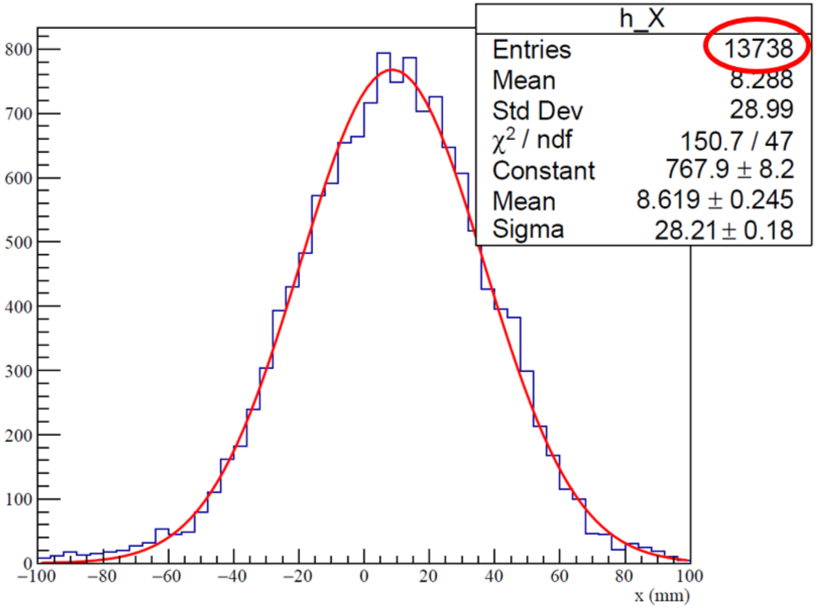


Correction Scheme 1

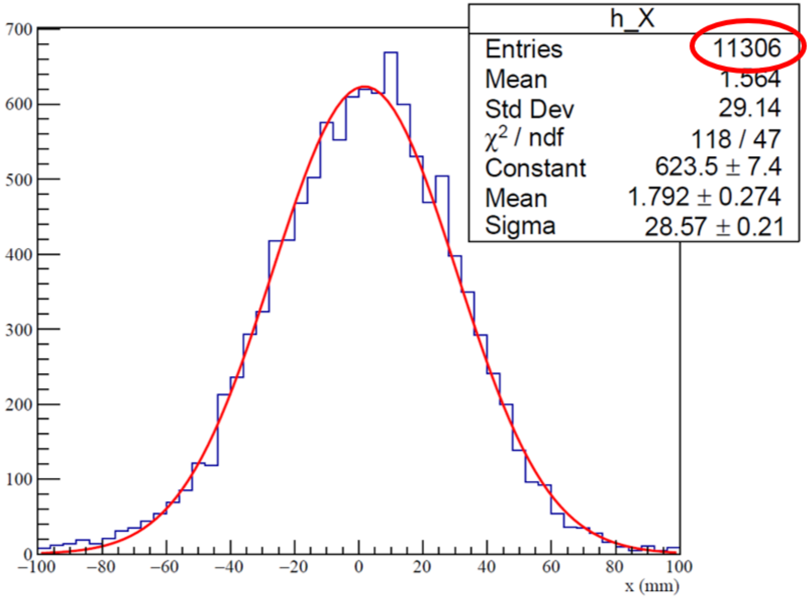


Misalignment of Quadrupole 18 by 2mm in x-direction

No Correction

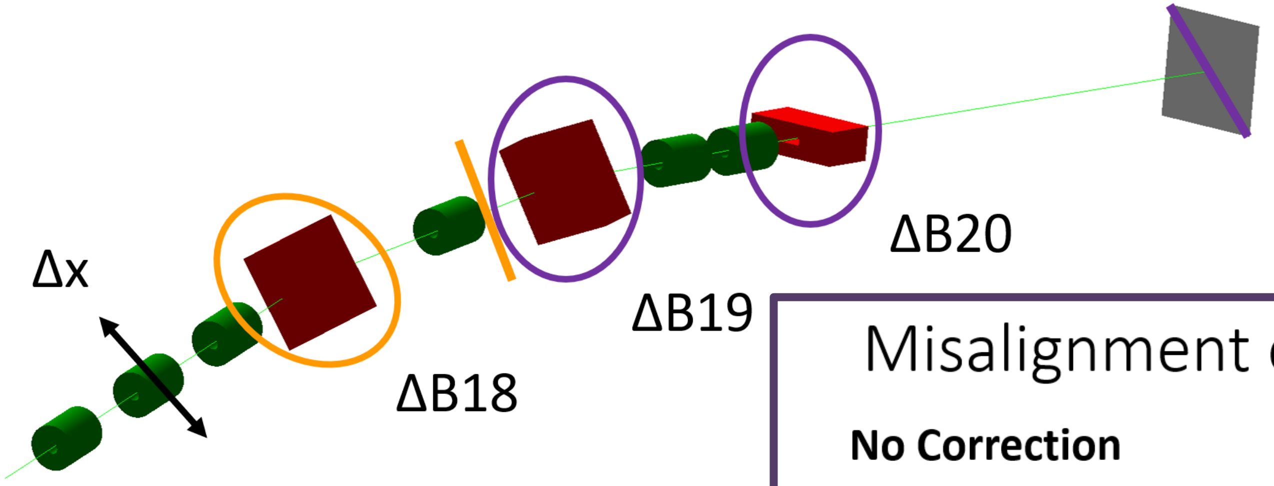


Correction Scheme 1



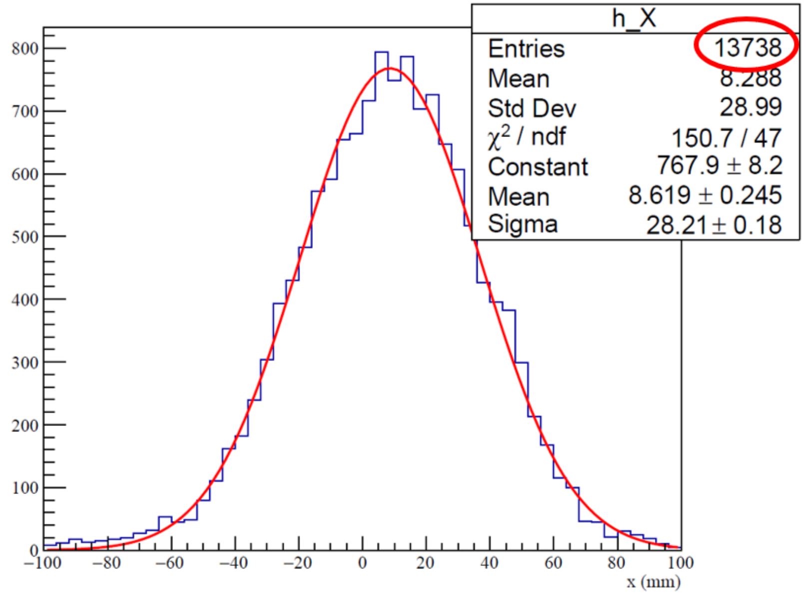
Conclusion: Correcting for the misalignment using CS1 resulted in more particle loss than leaving misalignment uncorrected.

Correction Scheme 2

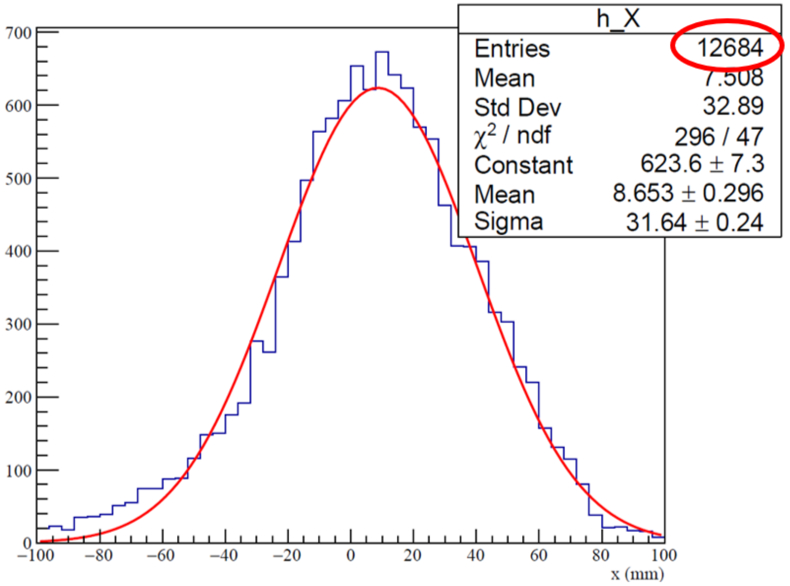


Misalignment of Quadrupole 18 by 2mm in x-direction

No Correction

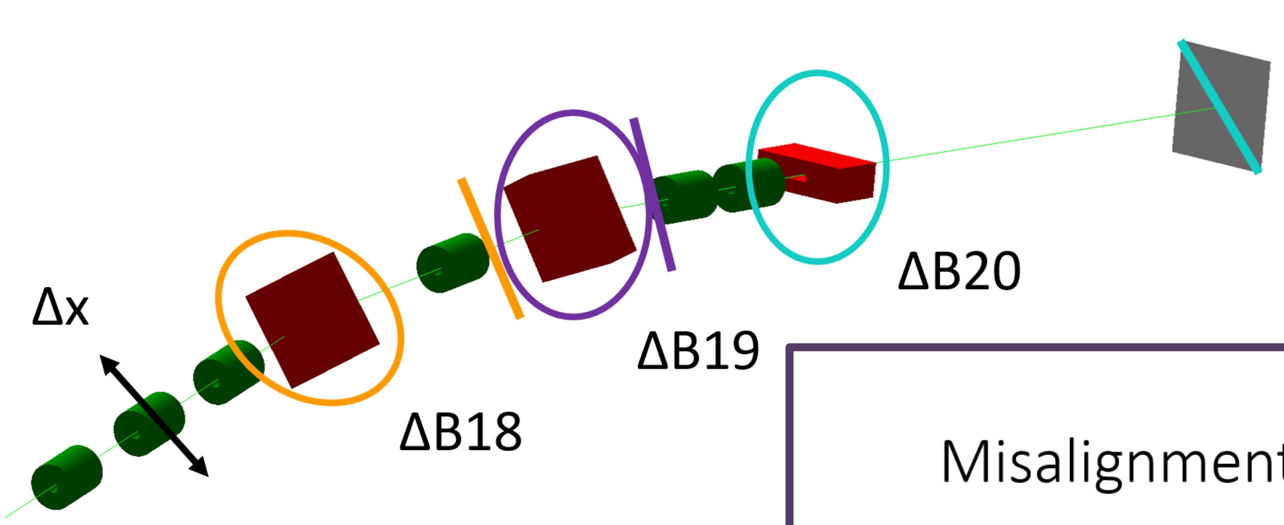


Correction Scheme 2



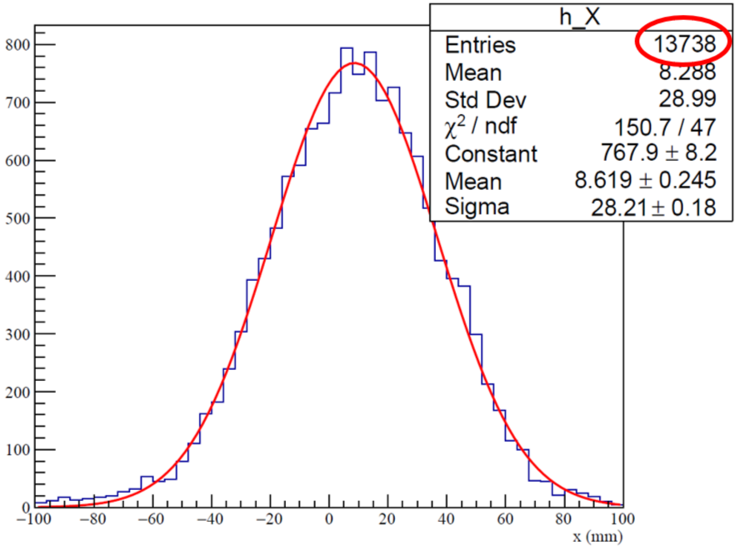
Conclusion: Correcting for the misalignment using CS2 resulted in more particle loss than leaving misalignment uncorrected, but less particle loss than CS1.

Correction Scheme 3

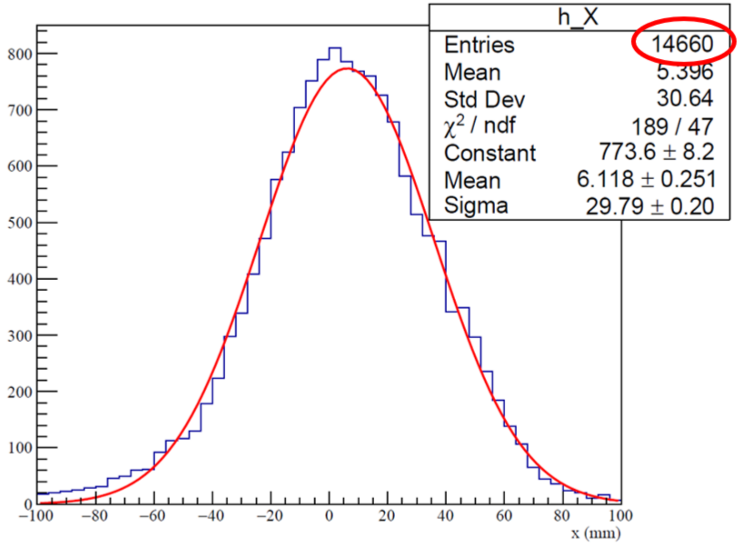


Misalignment of Quadrupole 18 by 2mm in x-direction

No Correction



Correction Scheme 3



Conclusion: Correcting for the misalignment using CS3 resulted in more particle detections compared with no correction.

Conclusion

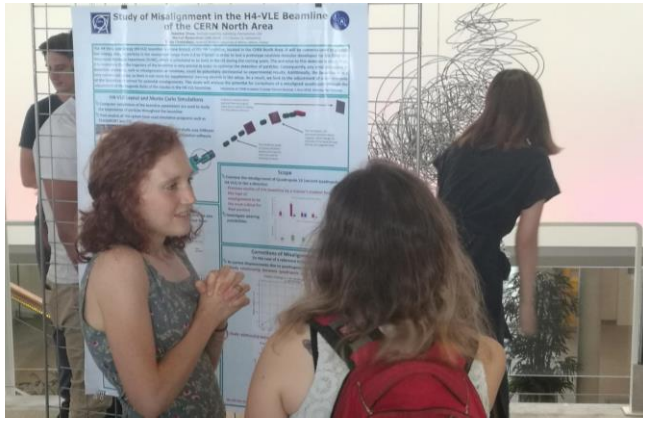
Achievements

- Creation and benchmarking of the simplified G4Beamline model
- Exploring the options for misalignment correction

Future Work

- Investigate further misalignments in a similar fashion
  - Already know change of position based on changing magnetic fields in dipoles

Special thanks to Marcel Rosenthal, Yiota Chatzidaki, and Nikolaos Charitonidis for all their help and mentorship. Also thanks to the National Science Foundation and University of Michigan for funding. And, finally, thank you to the audience for listening!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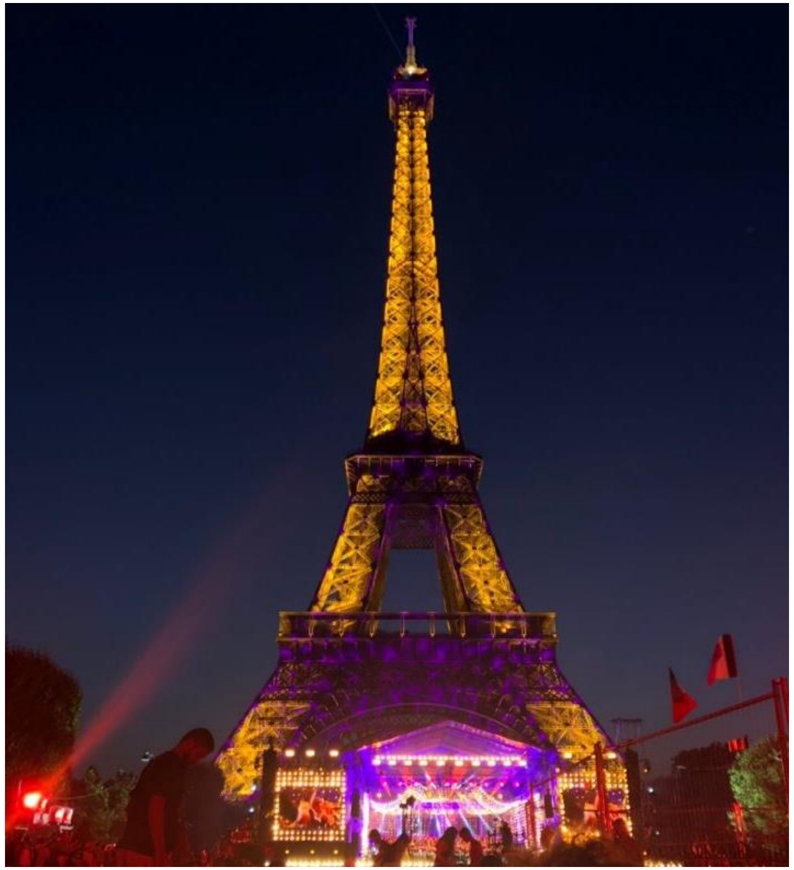
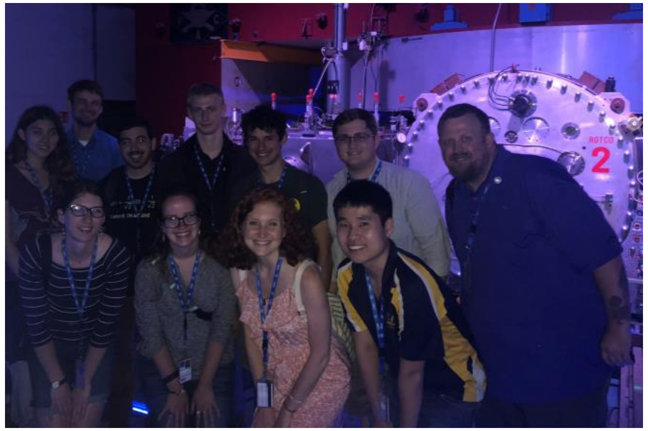
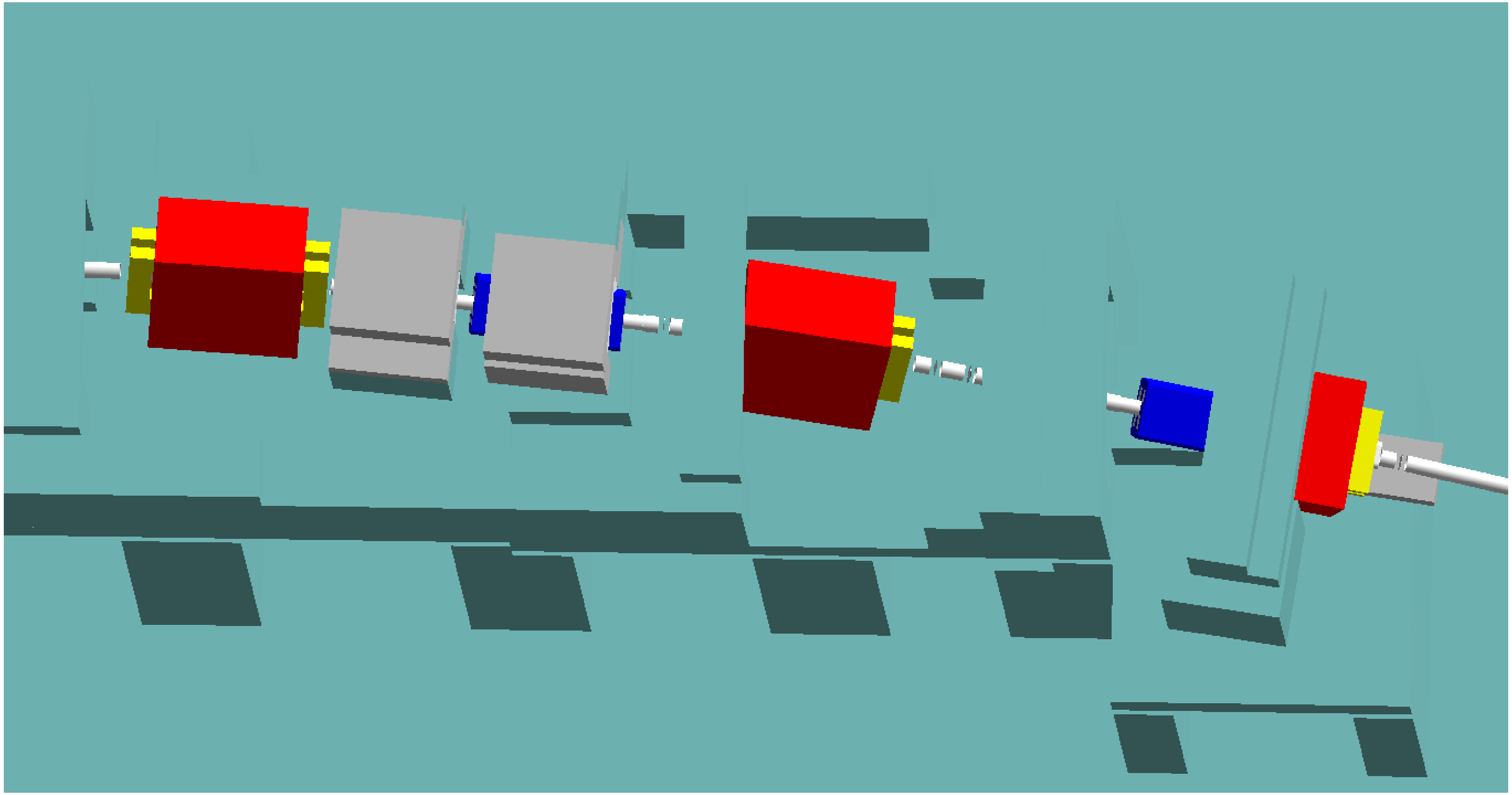




Full H4-VLE Simulation



Matrix Formalization

Focusing quadrupole, K >0:

$$\boxed{M_{foc} = \begin{pmatrix} \cos(\sqrt{K}s) & \frac{1}{\sqrt{K}}\sin(\sqrt{K}s) \\ -\sqrt{K}\sin(\sqrt{K}s) & \cos(\sqrt{K}s) \end{pmatrix}}$$

Defocusing quadrupole, K< 0:

$$\boxed{M_{defoc} = \begin{pmatrix} \cosh(\sqrt{|K|}s) & \frac{1}{\sqrt{|K|}}\sinh(\sqrt{|K|}s) \\ \sqrt{|K|}\sin(\sqrt{|K|}s) & \cos(\sqrt{|K|}s) \end{pmatrix}}$$

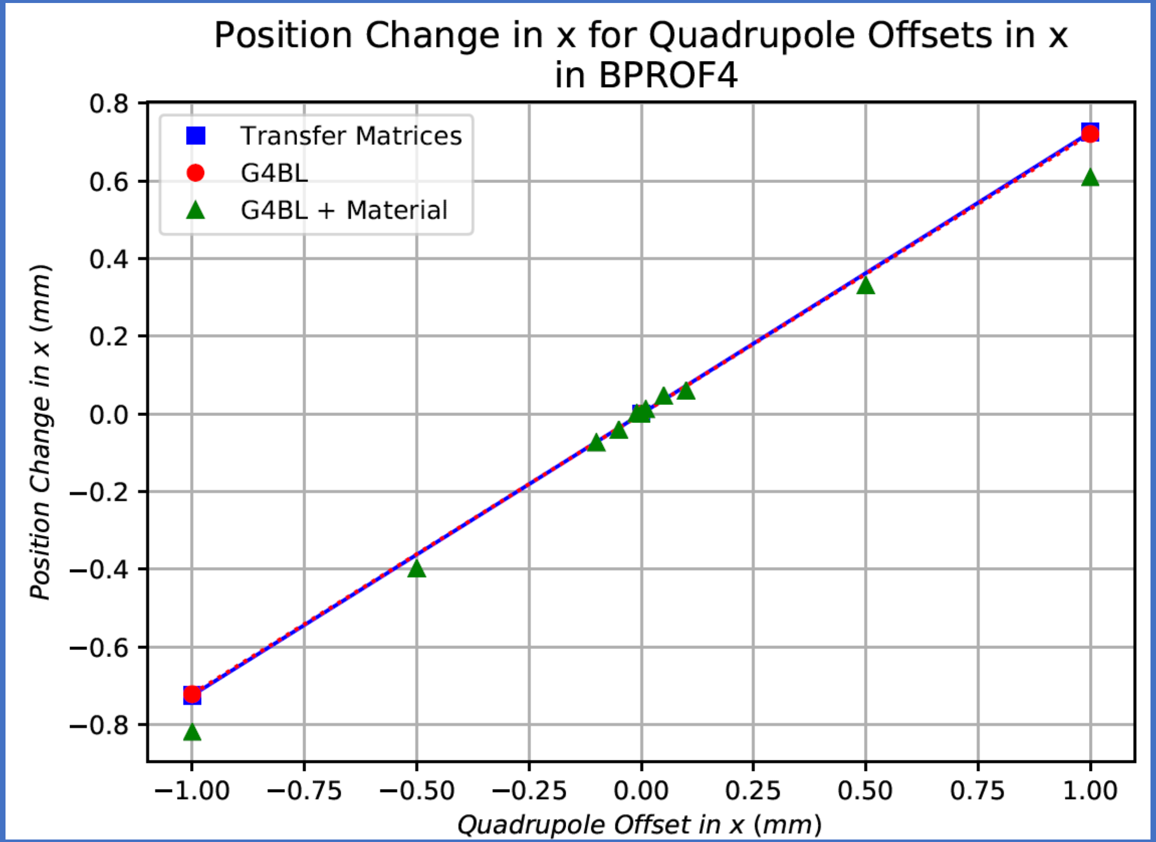
Drift space: length of drift space L

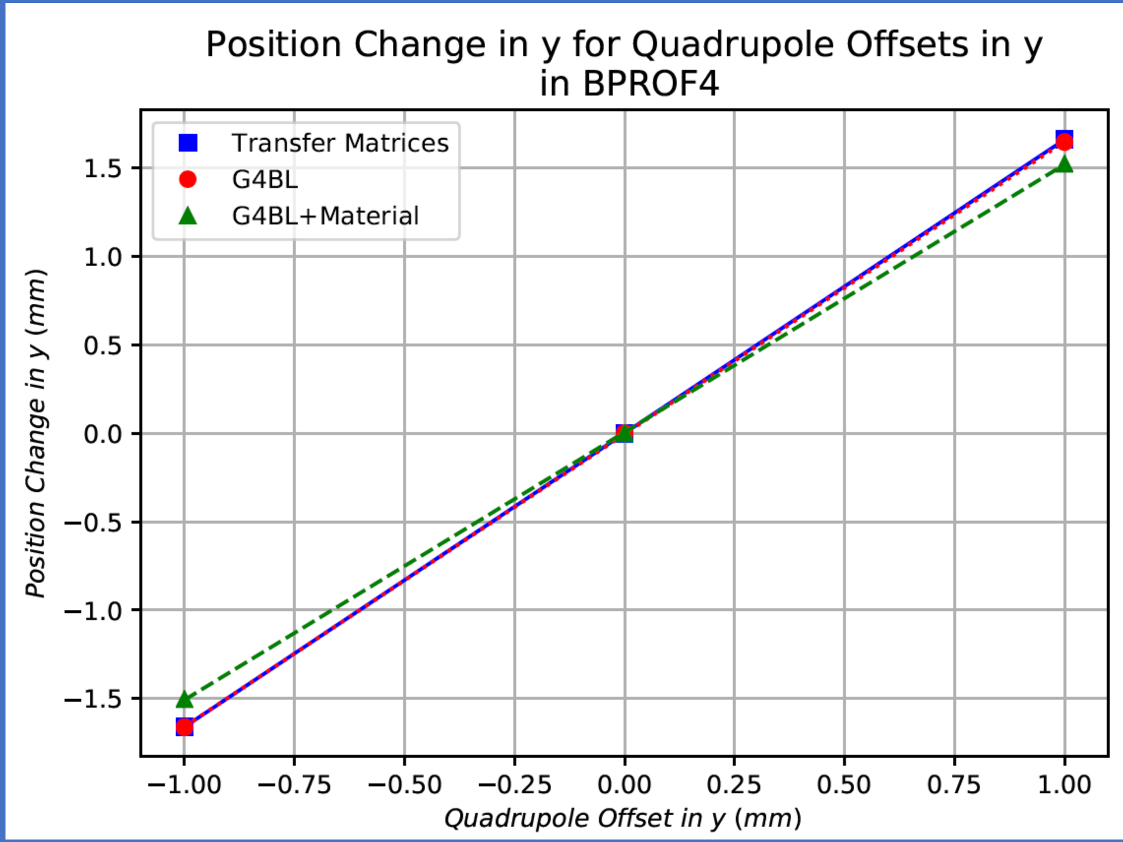
$$\boxed{M_{drift} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}}$$

$$\binom{x}{x'} = M_{drift} \cdot M_{edge} \cdot M_{dipole} \cdot M_{edge} \cdot M_{drift} \cdot M_{foc} \cdot M_{drift} \cdot M_{defoc} \cdot M_{drift} \cdot M_{foc} \cdot \binom{x_0}{x'_0}$$

Matrix formalism

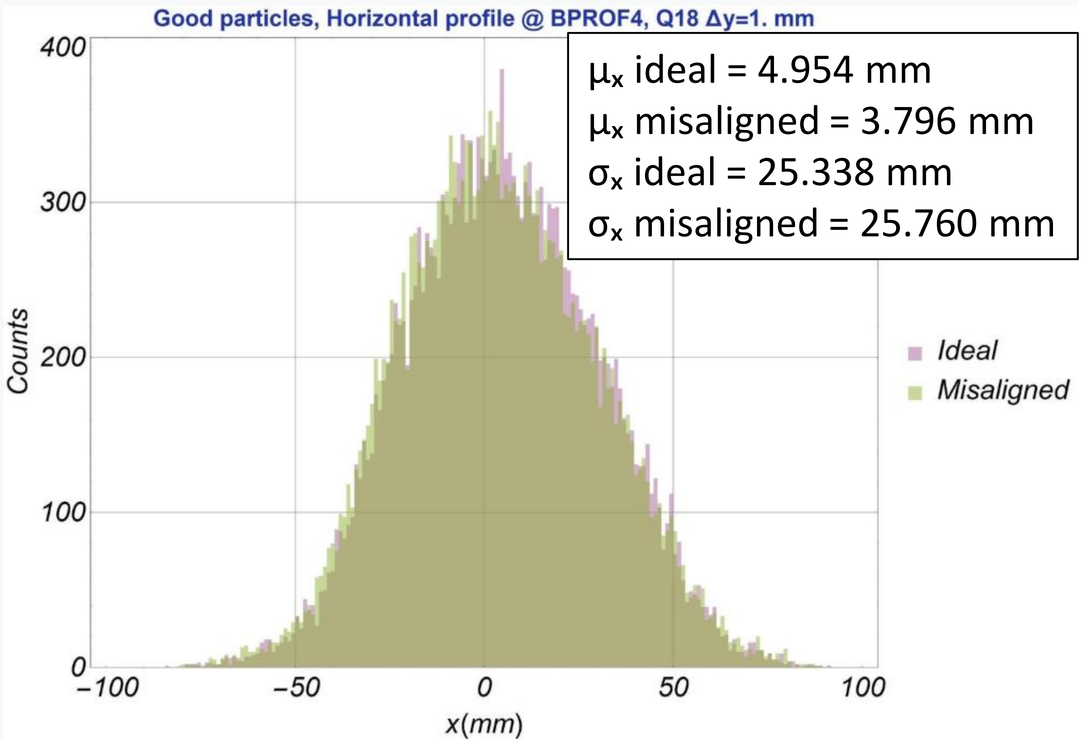
Developed a Mathematica routine for beam optics calculations using transfer matrices to compared with G4Beamline Monte Carlo simulation





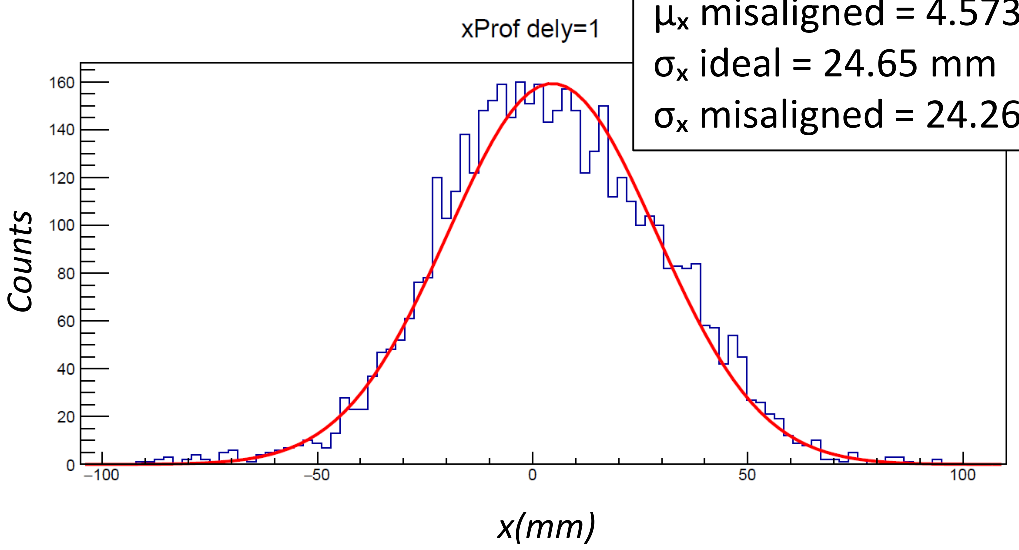
Final x-position for 1mm Misalignment of Quadrupole 18 in y-direction

PTC

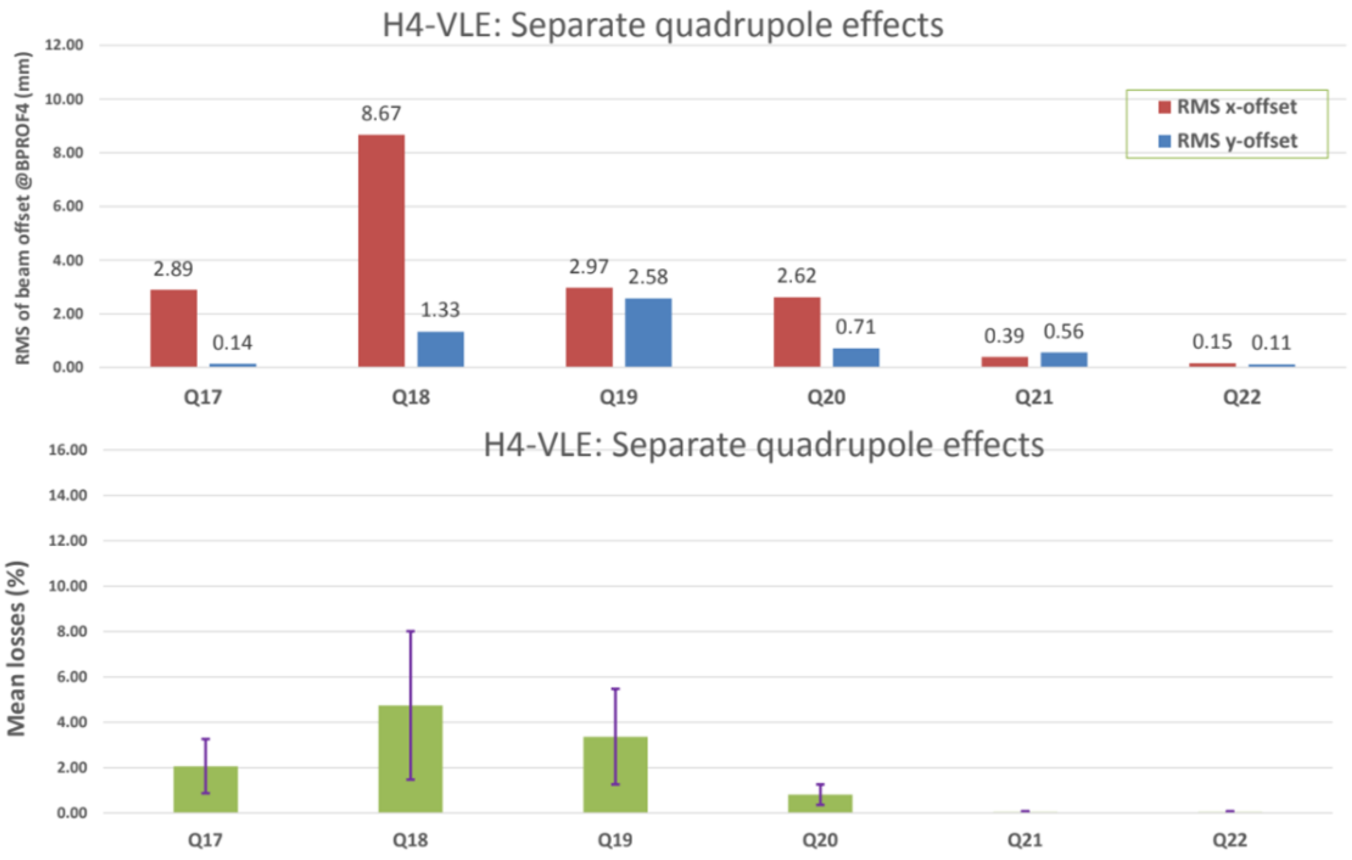


μ_x ideal = 4.954 mm
μ_x misaligned = 3.796 mm
σ_x ideal = 25.338 mm
σ_x misaligned = 25.760 mm

G4Beamline



μ_x ideal = 6.27 mm
μ_x misaligned = 4.573 mm
σ_x ideal = 24.65 mm
σ_x misaligned = 24.26 mm



P. Chatzidaki-Section Meeting 18.01.2018

Previous studies of this beamline by a master's student found this type of misalignment to be the most critical for final position

Misalignment of Quadrupole 18 in the x-direction

Correcting for Misalignments in Beam Elements

Correction Scheme 1:

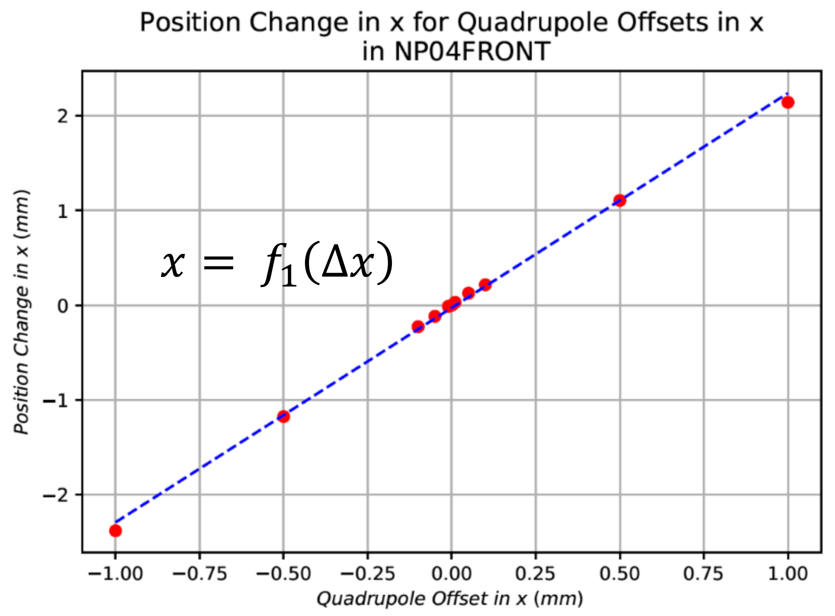
$$B18_1(\Delta x, \Delta y) = -0.0192\Delta x - 0.0122\Delta y$$
$$B20_1(\Delta x, \Delta y) = -0.000187\Delta x - 0.0148\Delta y$$

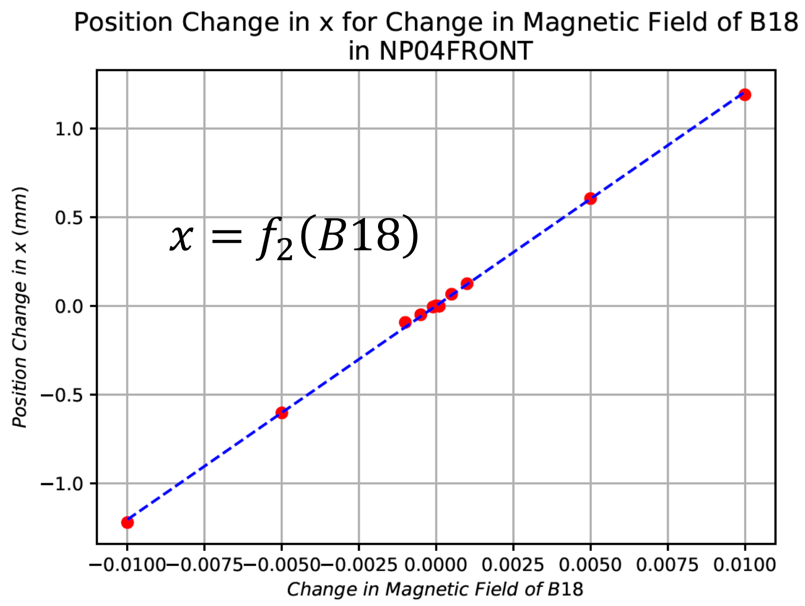
Correction Scheme 2:

$$B18_2(\Delta x) = 0.0133\Delta x$$
$$B19_2(\Delta x, \Delta y, b_{18}) = -2.22b_{18} - 0.0427\Delta x - 0.0271\Delta y$$
$$B20_2(\Delta x, \Delta y, b_{18}) = 0.00797b_{18} - 0.0000335\Delta x - 0.0147\Delta y$$

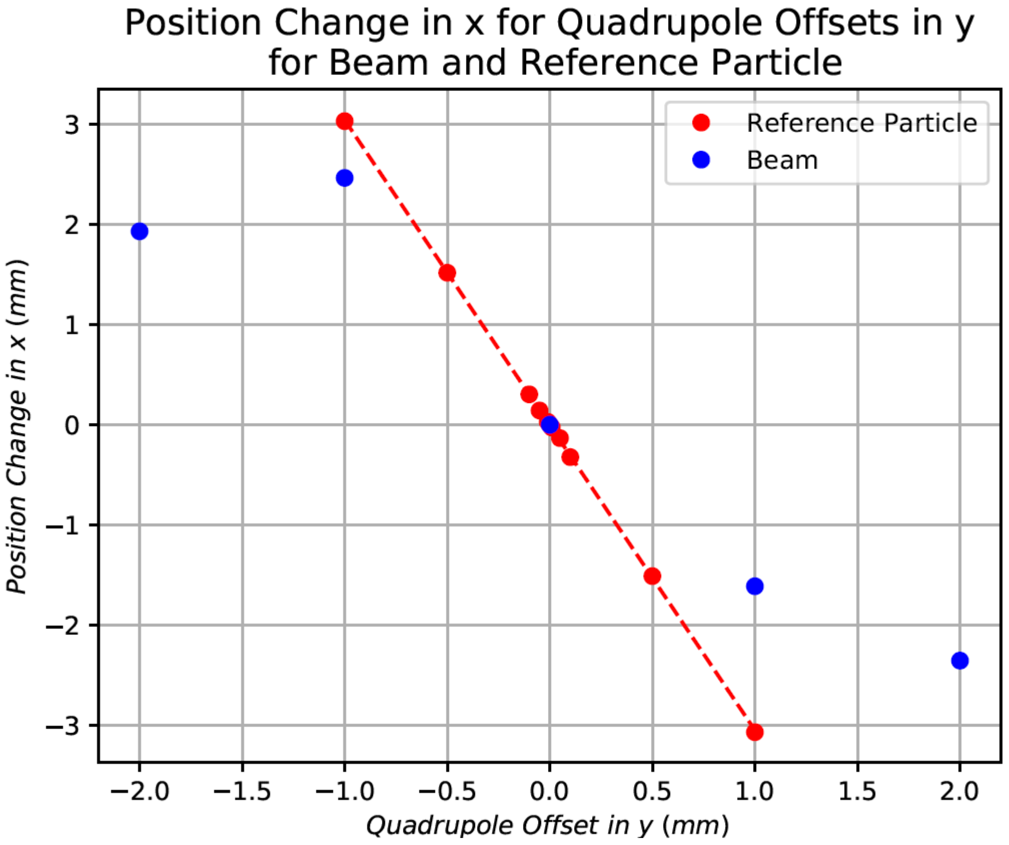
Correction Scheme 3:

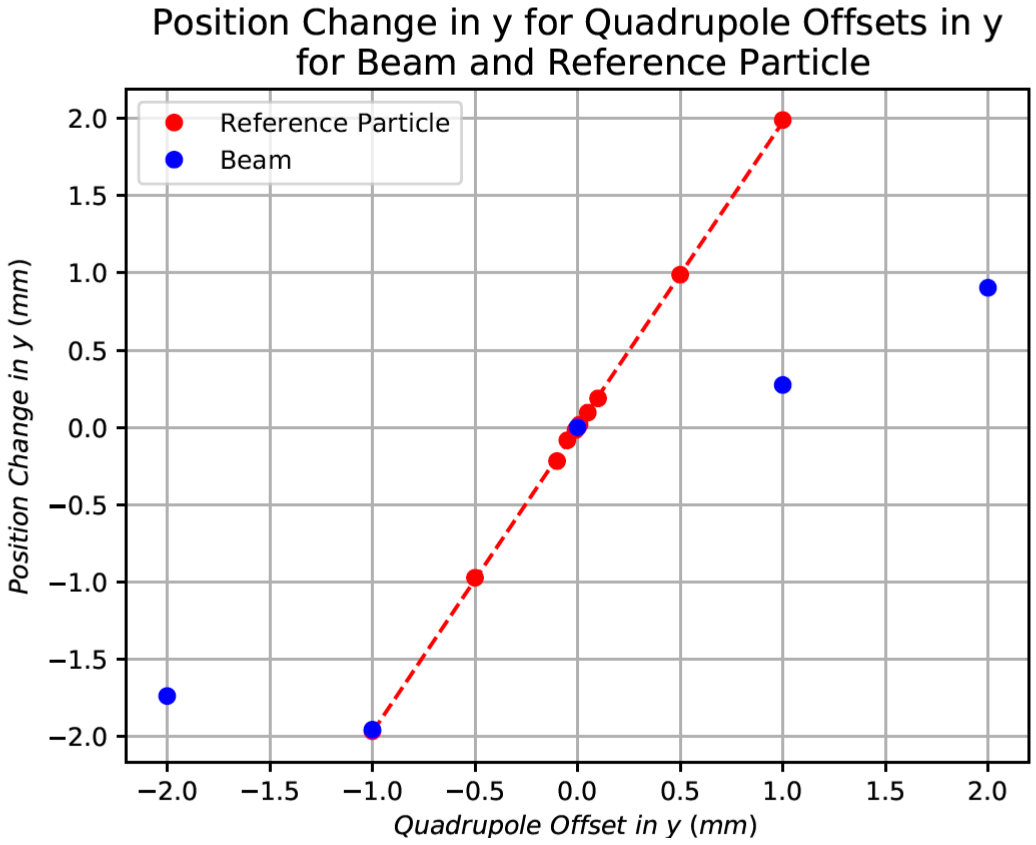
$$B18_3(\Delta x) = 0.0133\Delta x$$
$$B19_3(\Delta x, b_{18}) = 0.109b_{18} - 0.0289\Delta x$$
$$B20_3(\Delta x, \Delta y, b_{18}) = 0.394b_{18} + 0.174b_{19} - 0.00741\Delta x - 0.00995\Delta y$$





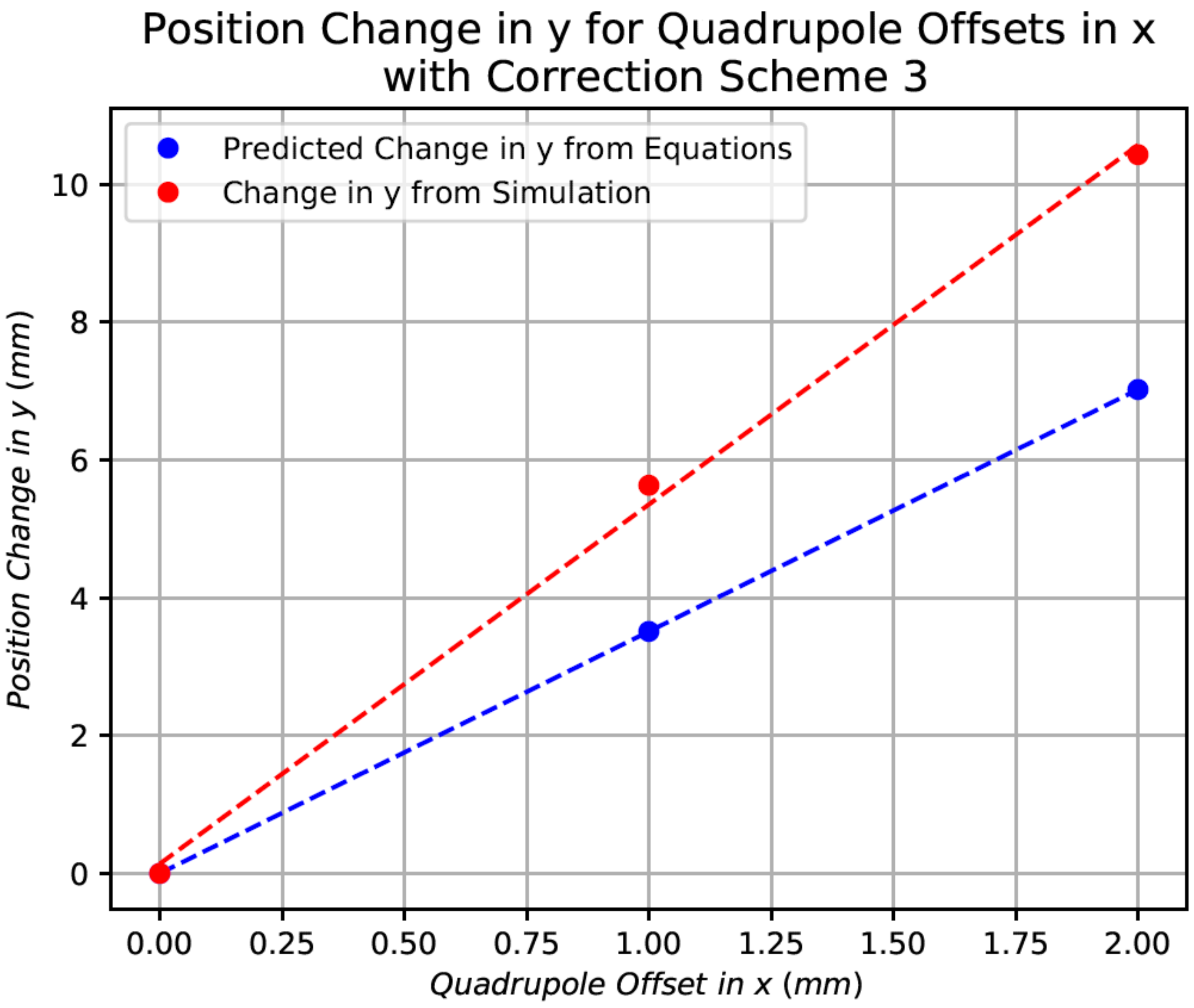
Beam Compared with Reference Particle



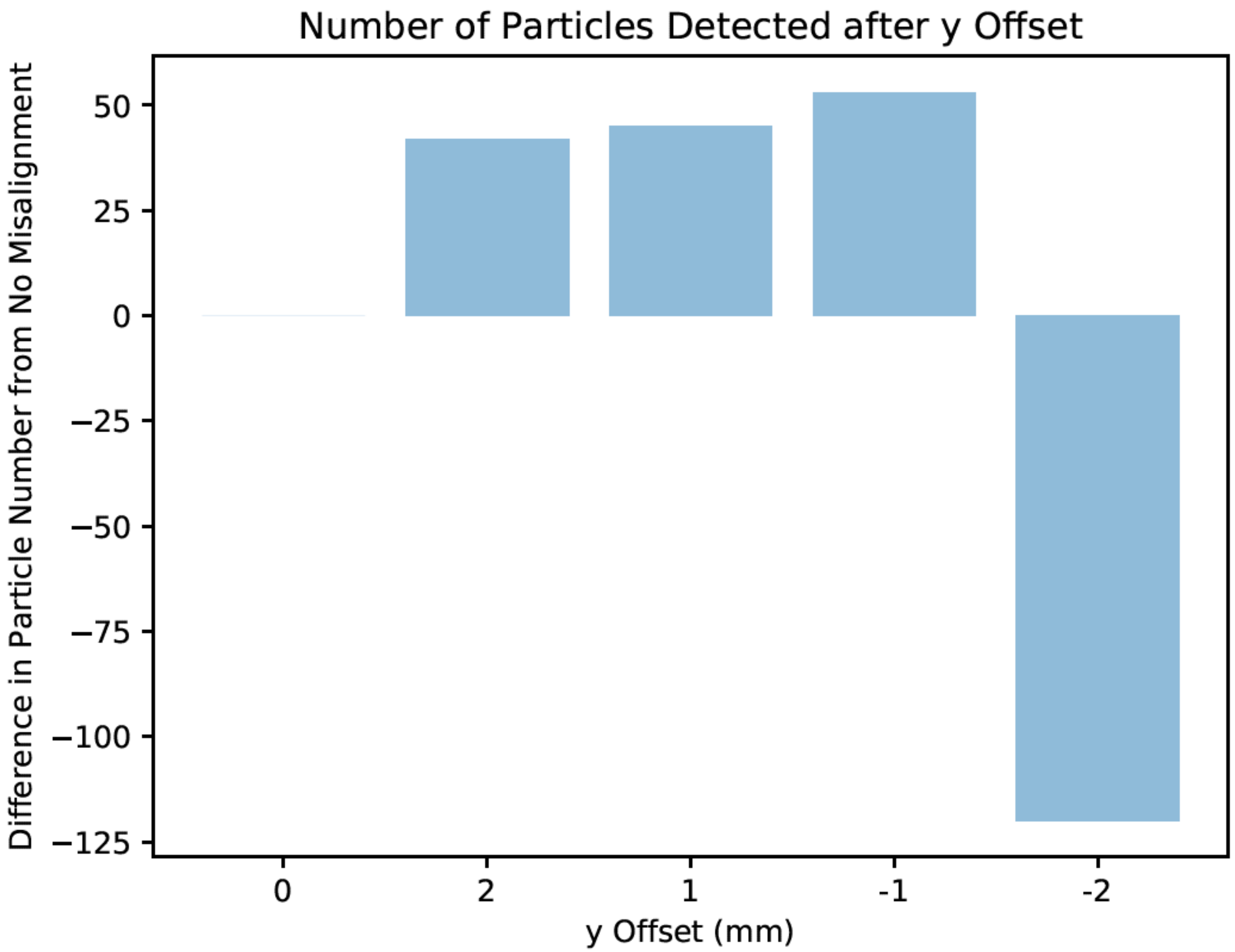


Final displacements in y based on correcting for quadrupole offsets in x using Correction Scheme 3

Examined from simulation data and calculations from equations



Difference in the number of particles that are detected with no misalignment as compared with the number of particles detected after a displacement in the y direction



Loss of Particles at BPROF1

- Collimator in the beamline after first dipole; particles hit collimator and do not continue trajectory
- Loss of particles on one side when quadrupole is misaligned
- Non-symmetric beam