IMMW21

International Magnetic Measurement Workshop

24th – 28th June 2019

Magnetic Alignment of magnets for CHESS-U upgrade

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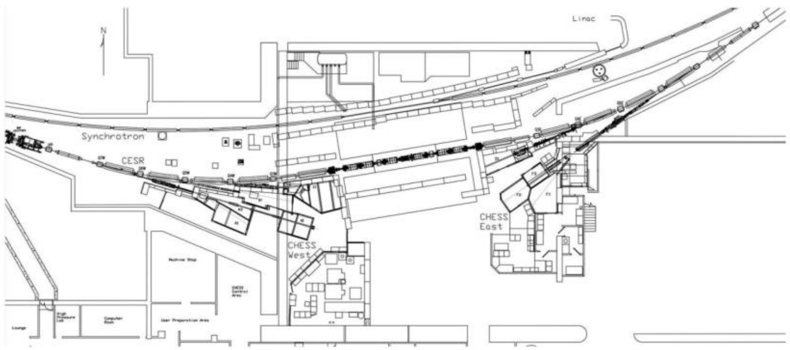
Outline

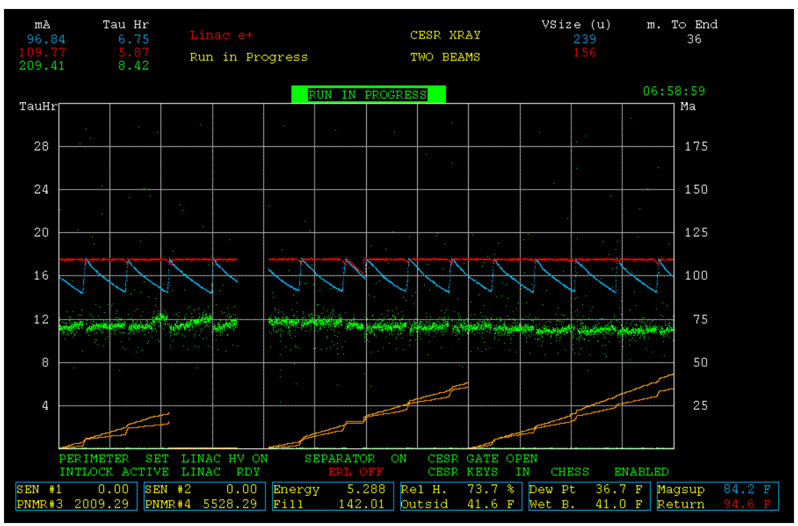
- Introduction:
  - CHESS-U upgrade project general information
  - New Magnets
- Instrumentation
  - Vibrating Wire setup
  - Hall Probe setup
- Magnetic alignment procedure
  - Coordinate System establishing
    - Vibrating Wire position in respect to girder fiducials
    - Hall probe position in respect to Vibrating Wire
  - Quadrupole Magnets ***magnetic*** survey and alignment
  - Dipole-Quadrupole (DQ) ***magnetic*** survey and alignment
- Conclusion and Acknowledge

CHESS-U upgrade: general information

Before:
E=5.3 GeV; two (e+/e-) beams; ex = 140 nm-rad

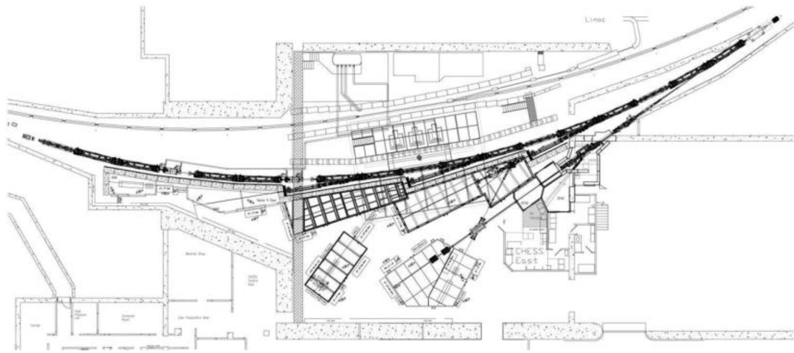


X-ray beam lines in two directions

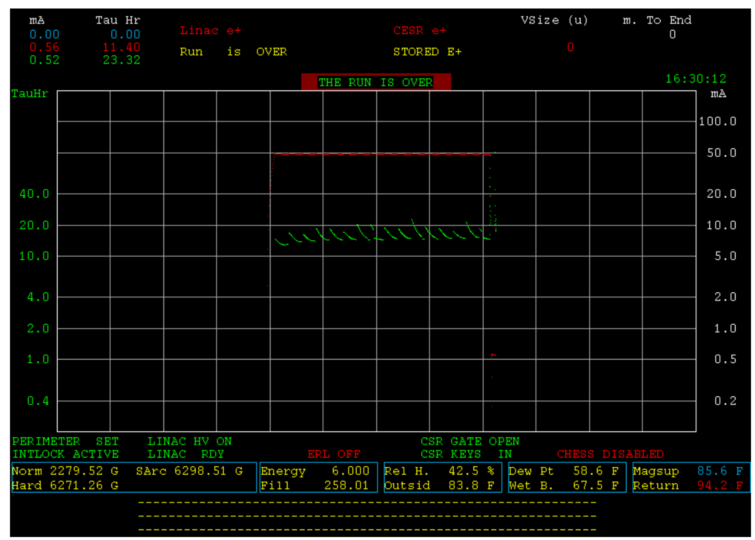


May 29 2018, Single beam operation

After:
E=6 GeV; One (e+) beam; ex = 29 nm-rad



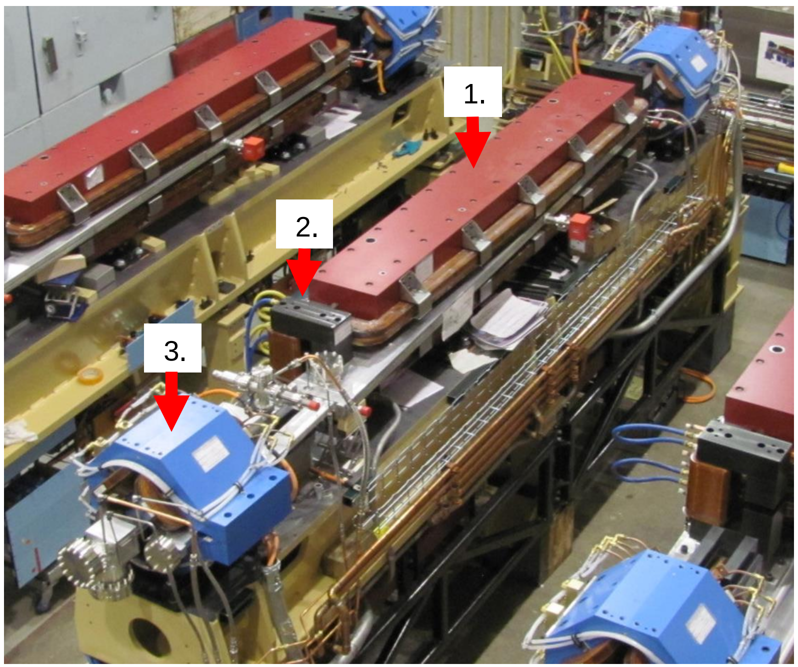
All x-ray beam lines in one directions



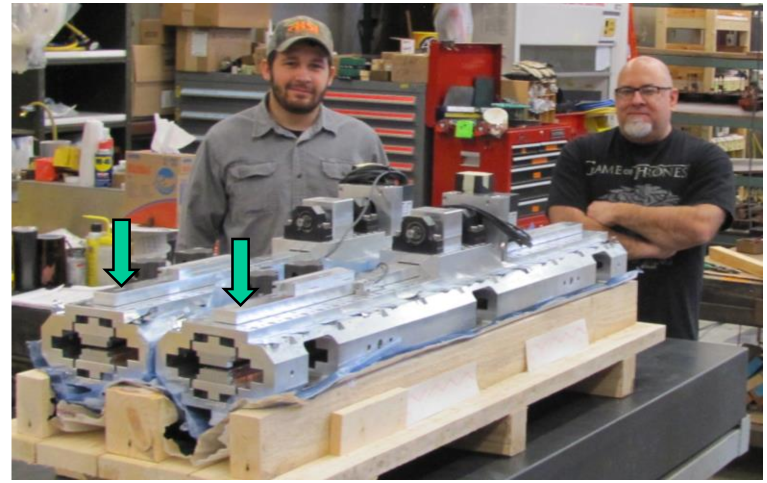
June 9 2019, Single beam operation

CHESS-U upgrade: new magnets

1. Dipole-Quadrulole (DQ) (12)
2. DQ dipole trims (24)
3. Quadrupole Magnets (24)
4. Vertical Steering (12)
5. Skew Quads (Panofsky style) (12)
6. CHESS Compact Undulators (CCU) (8)

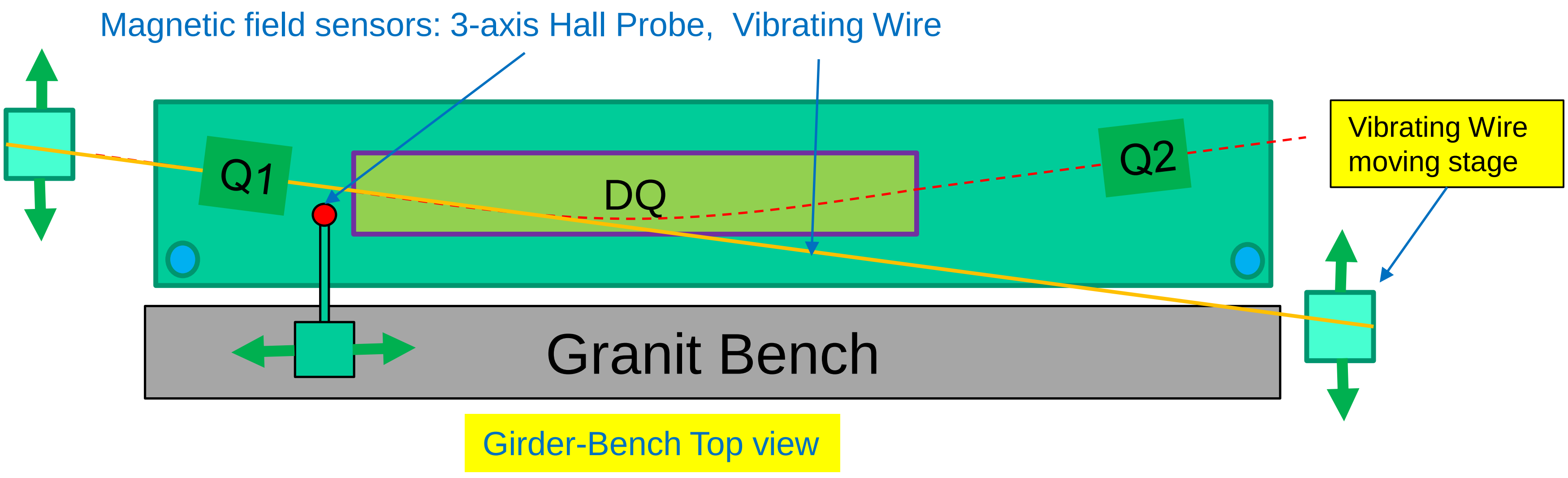


CHESS-U girders, Sept 2018



Cornell Compact Undulators (by KYMA)

Instrumentation



Vibrating Wire setup:

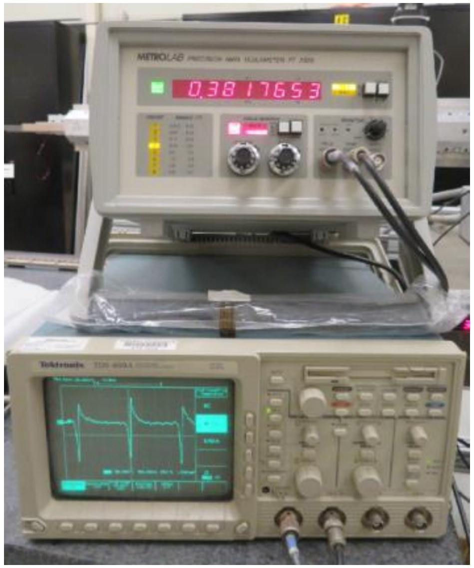
- 0.1mm Copper Beryllium wire, length ~ 5.5m,
- f1 ~ 21 Hz, Sag ~ 0.695mm
- Wire position sensor assemblies on both wire ends. Assemblies are mounted on platform moving with stages

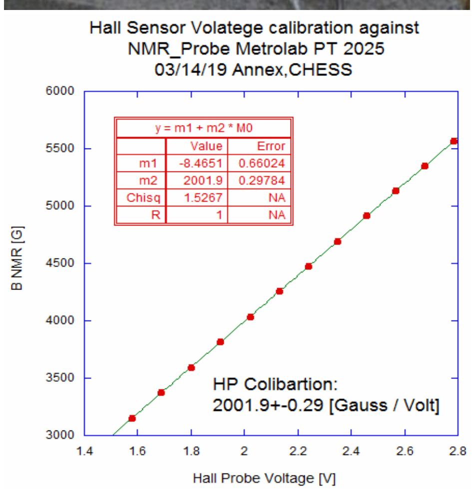
Hall Probe Setup (SENIS F3A Magnetic Field Transducer):

- High spatial resolution (By: 0.03 x 0.005 x 0.03mm^3; Bx and Bz: 0.15 x 0.01 x 0.15 mm^3)
- High angular accuracy (orthogonality error less than 0.1°)
- HP was Mount on Newport stages providing 3D positioning with ~0.001mm accuracy.
- Was calibrated against PT2025 NMR Tesla-meter.

Instrumentation: Hall Probe Characterization

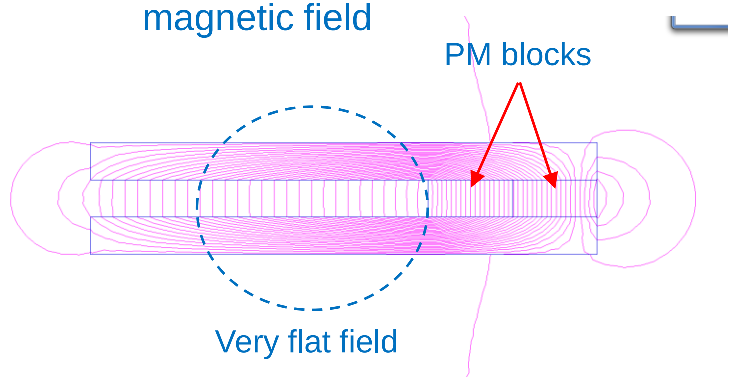
Transducer Calibration with NMR Tesla meter



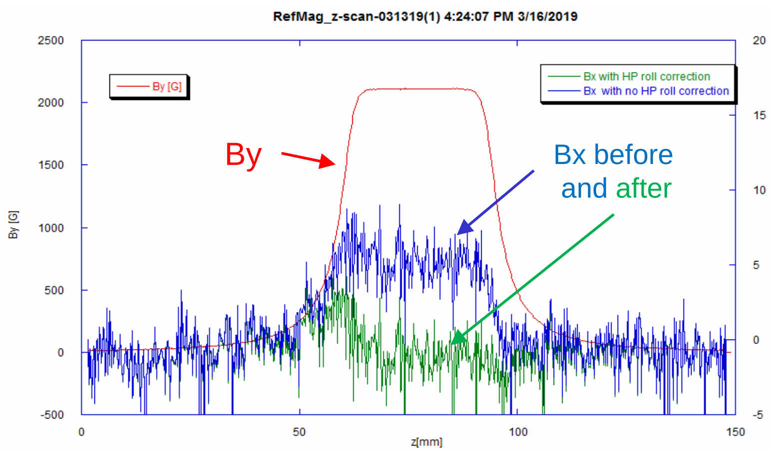


Field Components de-coupling correction

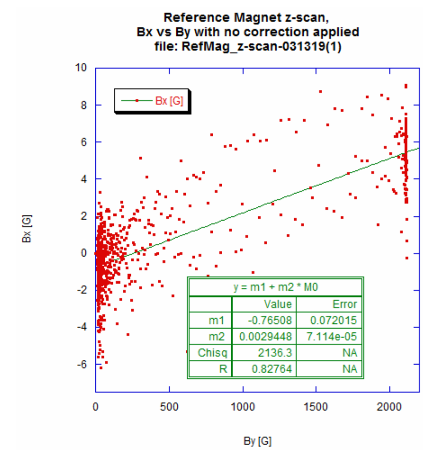
Magnet with flat geometry and flat magnetic field



0.042 mrad (0.0024deg)/div

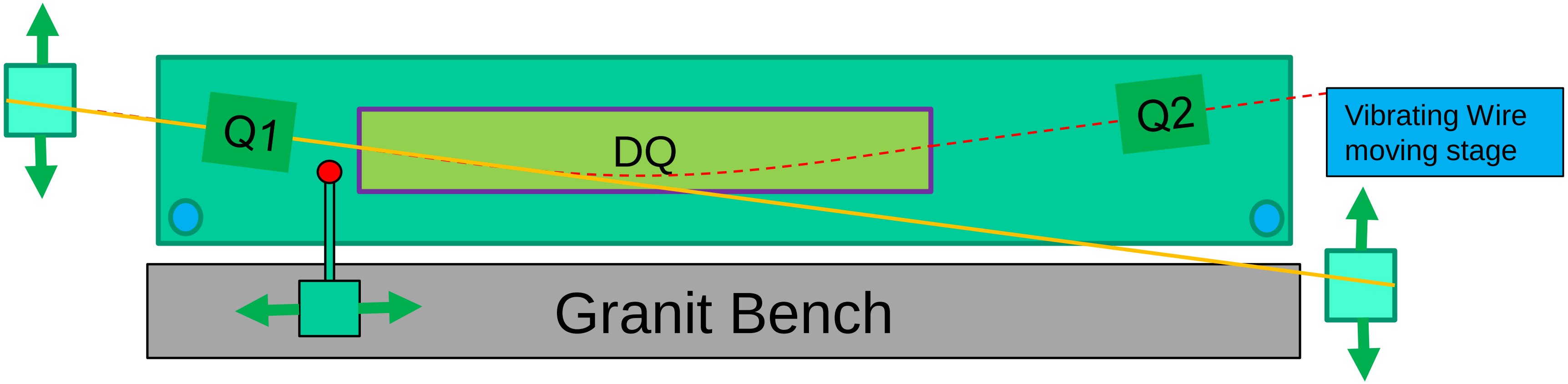


Bx before and after introducing de-coupling correction.



$dBx/dBy = 0.00294 \pm 0.00007$
Presidion ~ 0.07 mrad (0.004 deg)

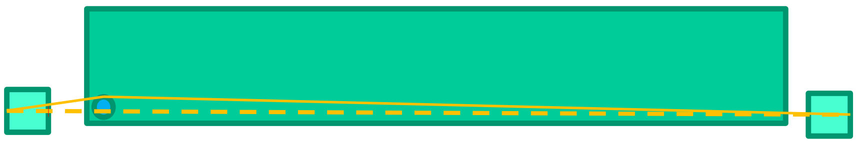
Magnetic Alignment procedure: sequence



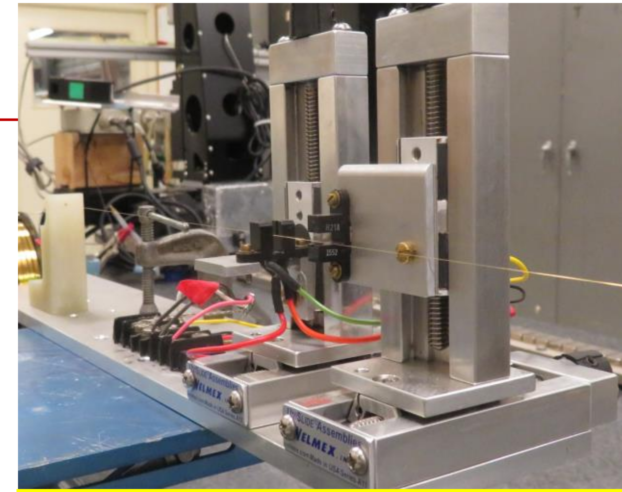
1. Align girder (fiducials) parallel to Hall Probe Path
2. Establish Vibrating Wire position in respect to girder fiducials
3. Establish Hall Probe position in respect to wire
4. Place wire on beam axis on Q1/Q2 side and align Q1/Q2 magnetic axis to the wire
5. Energize DQ and minimize yaw, pitch, vertical offset and roll.
6. Take DQ 2D field map, simulate beam trajectory, find field gradient integral along trajectory (2-3 iterations) and determine nominal current.
7. At nominal current take 2D field map (all 3 components), simulate beam trajectory and adjust DQ position to place this trajectory on desired location.
8. Survey and record position of the magnets on the girder with optical instruments.

Establish Vibrating Wire position in respect to girder fiducials

Wire is free

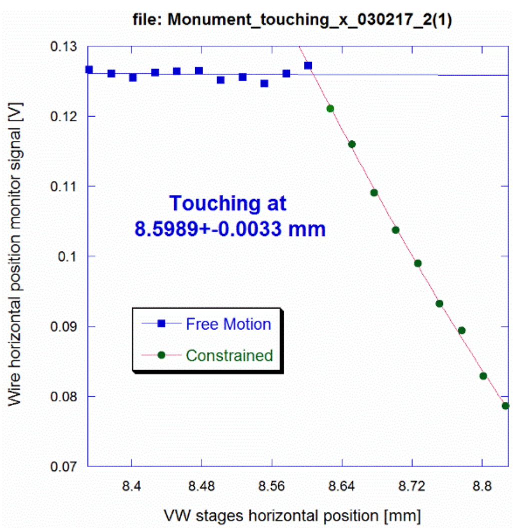


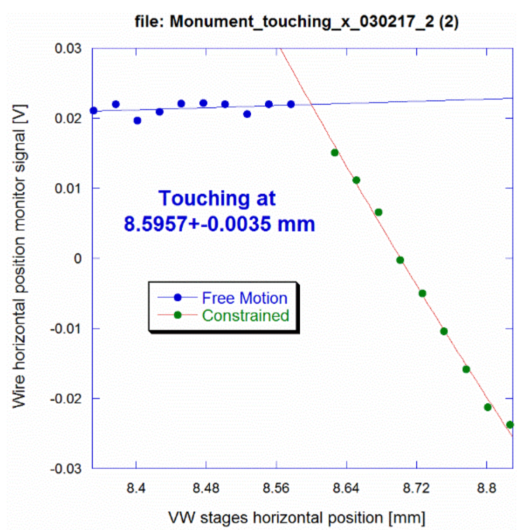
Wire is in contact with fiducial (dowel pin)



Vibrating Wire position sensors mounted on platform

Two consecutive measurements

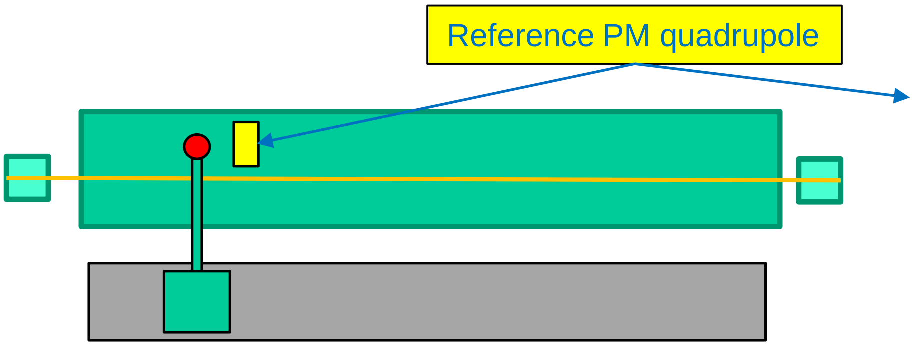


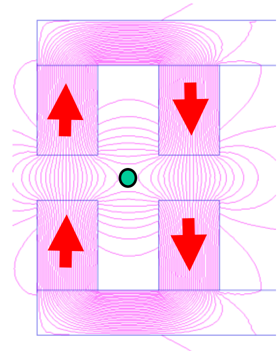


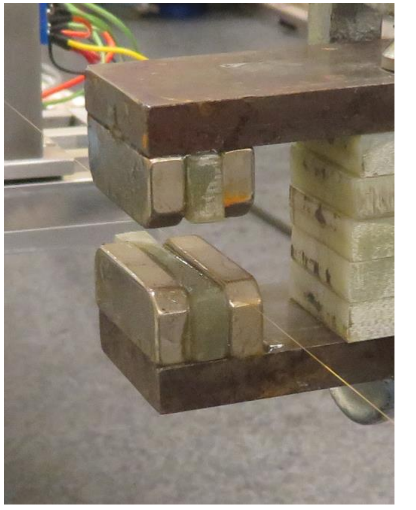
	Pin touching coordinate [mm]		
Measurement #	Try #1	Try #2	Try #3
1	-80.985	-80.981	-80.987
2	-80.985	-80.982	-80.987
3	-80.986	-80.982	-80.986
4	-80.984	-80.981	-80.986
5	-80.985	-80.981	-80.986
<x>	-80.985	-80.9814	-80.9864
std(x) [mm]	0.00071	0.00055	0.00055
std (try-to-try) [mm]	0.0026		

Between each try, fiducial pin was removed and reinstalled.

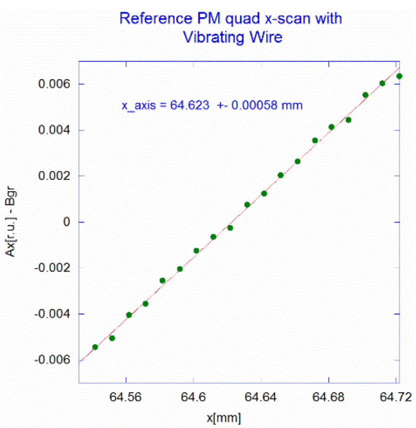
Establish
Hall probe position in respect to Vibrating Wire

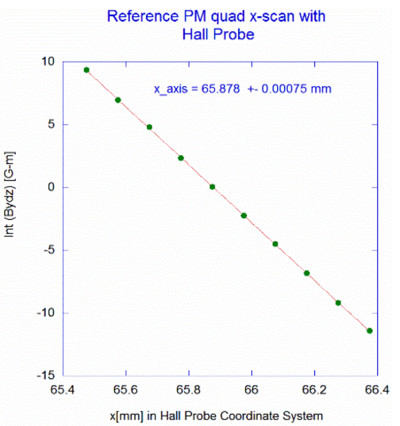




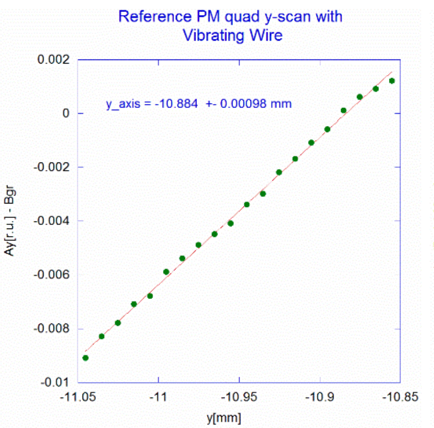


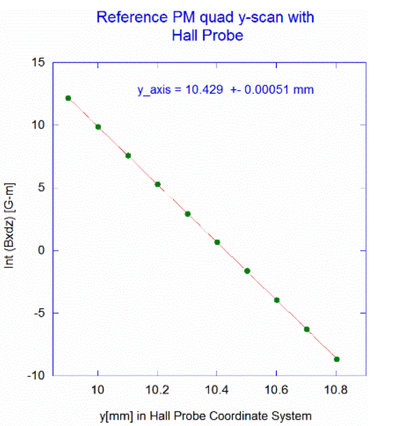
Horizontal Scan





Vertical Scan



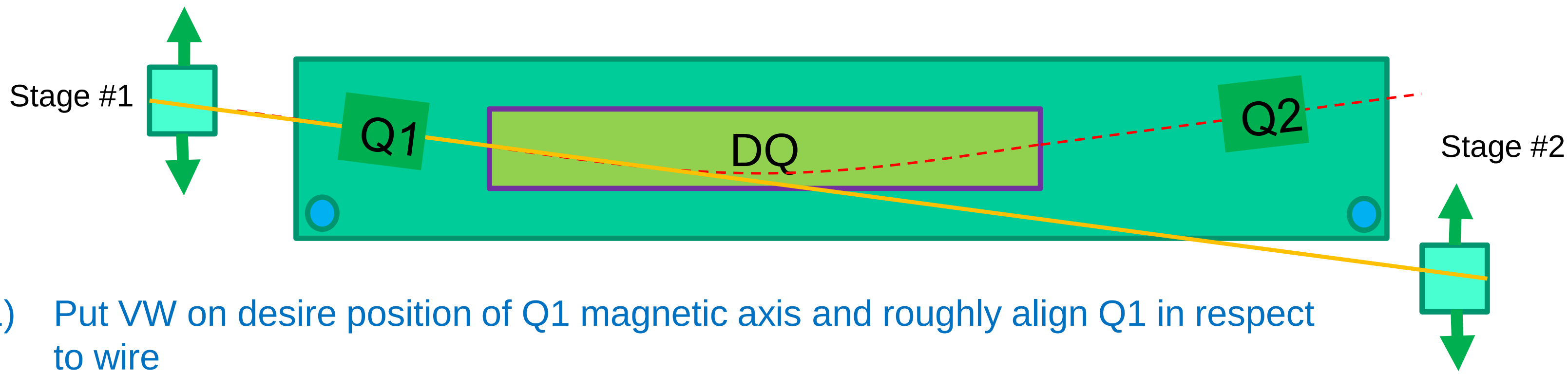


	xc [mm]	xc error [mm]
Vibrating Wire CS	64.623	+-0.00058
Hall Probe CS	65.878	+-0.00075

	yc* [mm]	yc error [mm]
Vibrating Wire CS	-10.884	+-0.00098
Hall Probe CS	10.429	+-0.00051

*Wire sag should be taking into account

Magnetic Alignment: Quadrupole magnets alignment

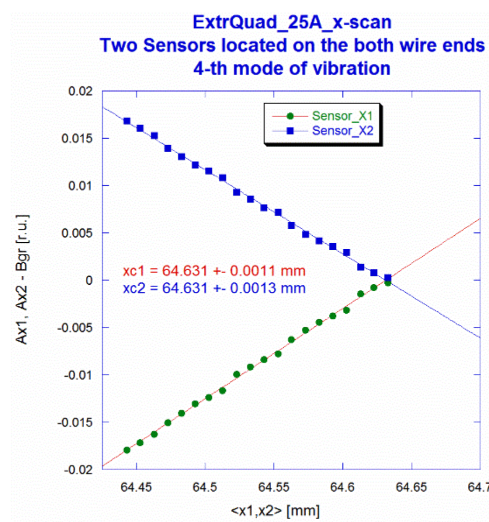


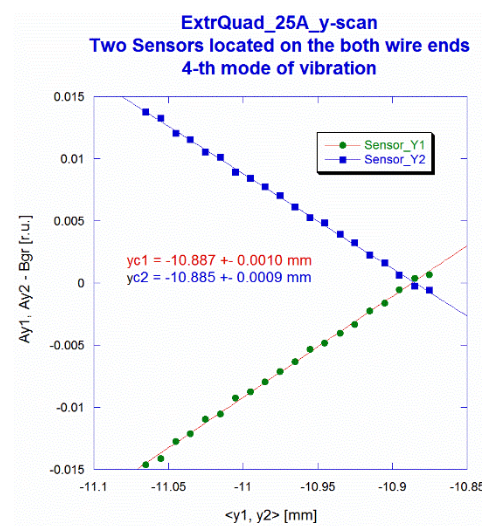
1) Put VW on desire position of Q1 magnetic axis and roughly align Q1 in respect to wire
2) With “zero” field in Q1, take VW background measurement
3) With 25A (~20% of nominal) current make horizontal and vertical scans with VW to find location of magnetic axis, see plots below.
4) Move quad to put magnetic axis on desire position and check result.

Example

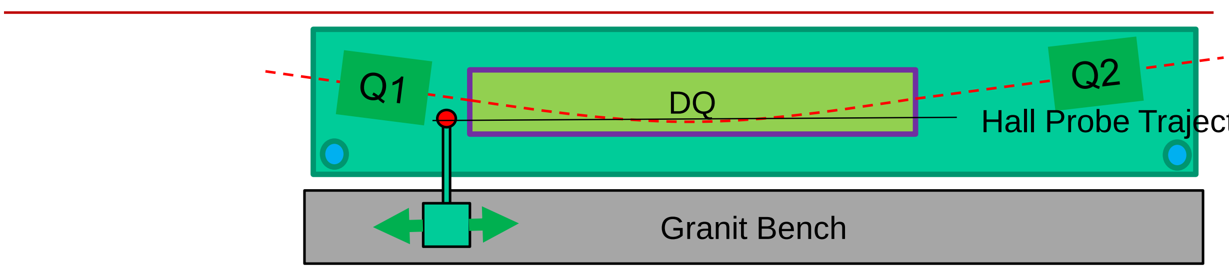
	After rough alignment [mm]	Desired position	distance to move
xc	64.631+-0.001	64.210	-0.421
yc*	-10.886+-0.001	-10.330	0.556

yc* is the wire ends position.
Wire sag should be taking into account when it is translating to quad location





Magnetic Alignment: DQ "yaw" correction



1. Energize DQ with nominal (approximately) current ~690A
2. Measure field along straight line along magnet (z-scan)
3. Find difference between center of gravity of the field distribution (z_COG) and location of maximum (z_peak).
4. Calculate "yaw", move magnet and repeat 2.

$$B_y(z,\theta_{yaw}) = B_0 + G\left[\frac{z^2}{2R} + \theta_{yaw} \times z\right];$$

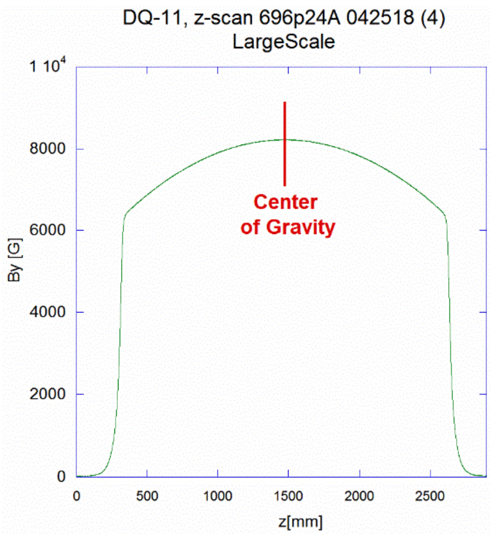
$z_{peak} - field\ maximum\ location;$
$z_{CoG} - Centre\ Of\ Gravity\ location$

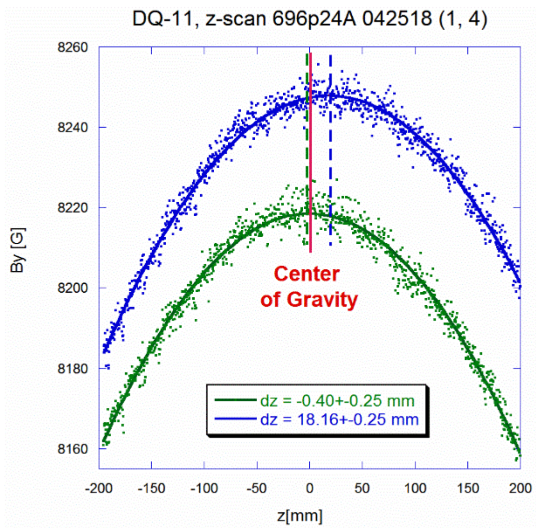
$z_{peak} = \theta_{yaw} R;\ R{=}31.42m$

$$z_{CoG} = \theta_{yaw}\frac{Gl_m^3}{12I};\ I = B_0 l_m - \frac{Gl_m^3}{24R}$$

$$dz = z_{peak} - z_{CoG} = \theta_{yaw}\left(R - \frac{Gl_m^3}{12I}\right)$$

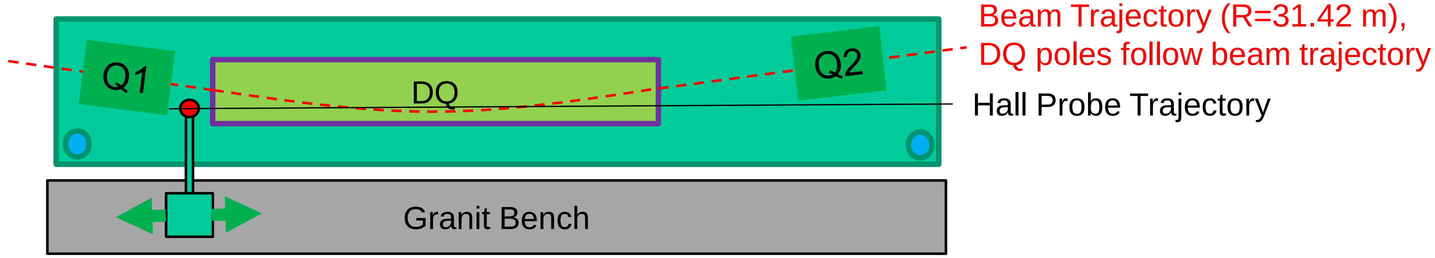
$$\theta_{yaw} = \frac{dz}{\left(R - \frac{Gl_m^3}{12I}\right)}$$



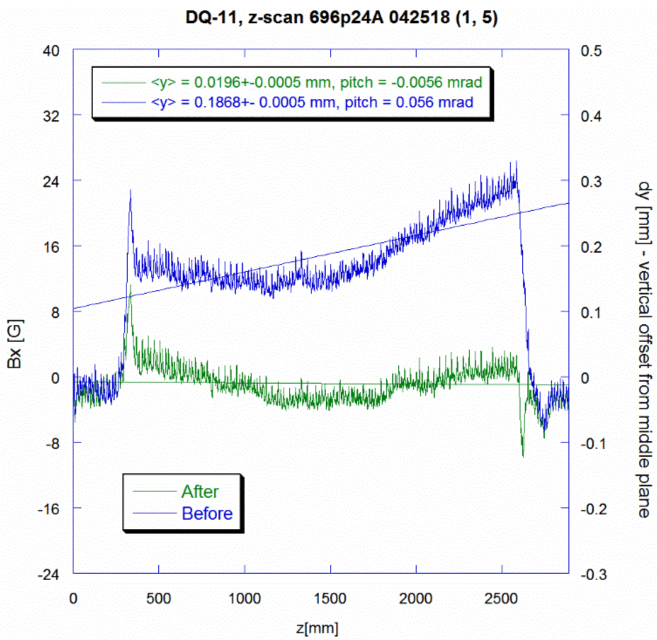


1) $dz = 18.16 \pm 0.25\ mm; \theta_{yaw} = 0.736 \pm 0.010\ mrad$
2) $dz = -0.40 \pm 0.25\ mm;\ \theta_{yaw} = -0.016 \pm 0.010\ mrad$

Magnetic Alignment:
DQ vertical offset and pitch correction



1. Nominal (~693A) current
2. Z- scan => analyze horizontal field component (Bx)
3. Move magnet, repeat step 2.



$$B_x(z,\theta_{pitch}) = G\left[y_{off} + \theta_{pitch} \times (z - \tilde{z})\right];$$

$G = 8\,T/m$; y_{off} - vertical offset from axis

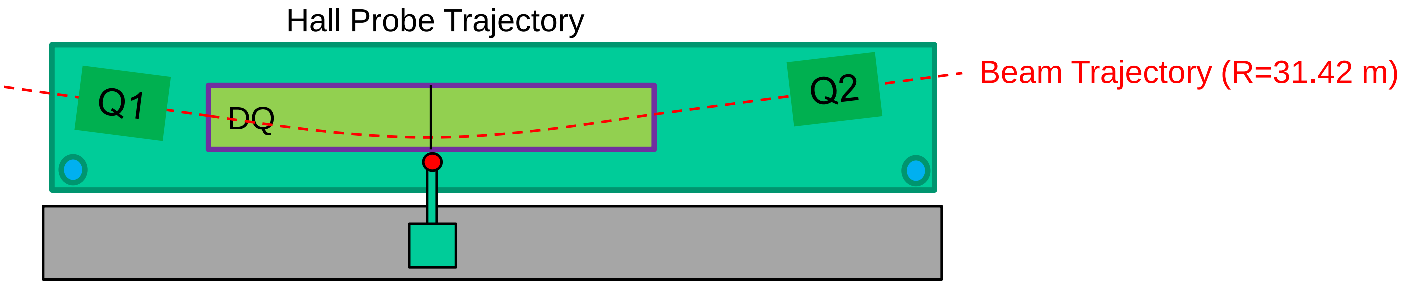
Before alignment:

$$y_{off} = 0.1868 \pm 0.0005\, mm; \theta_{pitch} = 0.0558 \pm 0.0008\, mrad$$

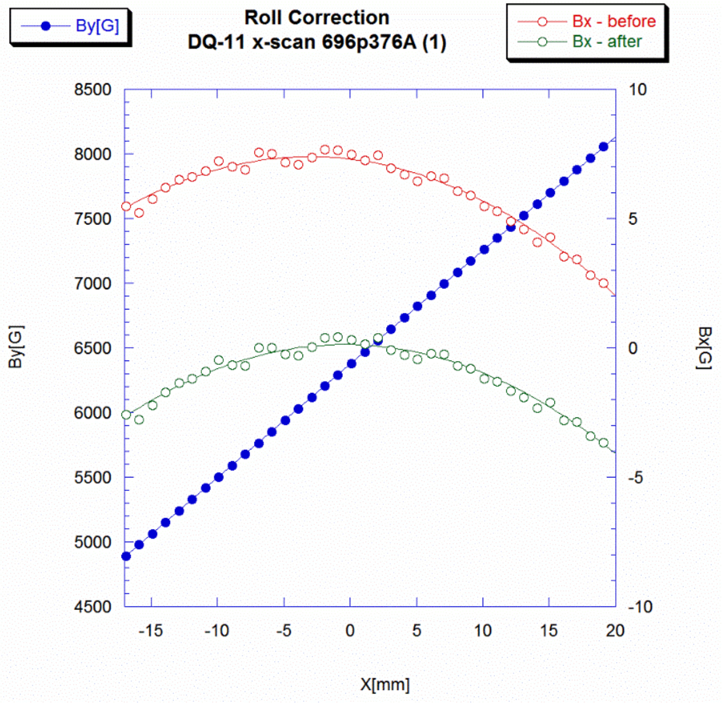
After:

$$y_{off} = 0.0196 \pm 0.0004\, mm; \theta_{pitch} = -0.0057 \pm 0.0007\, mrad$$

Magnetic Alignment: DQ “roll” correction

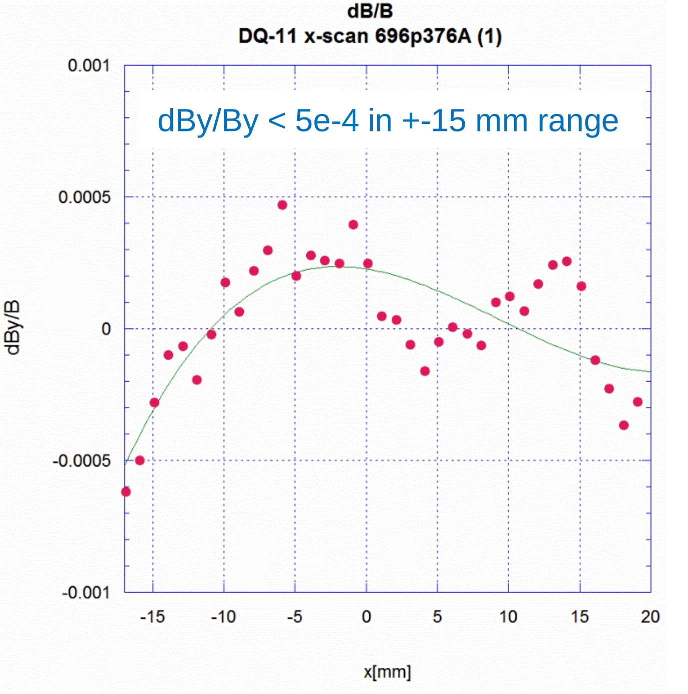


1. Nominal (~693A) current
2. X - scan => analyze horizontal field component (Bx)
3. Move magnet, repeat step 2.

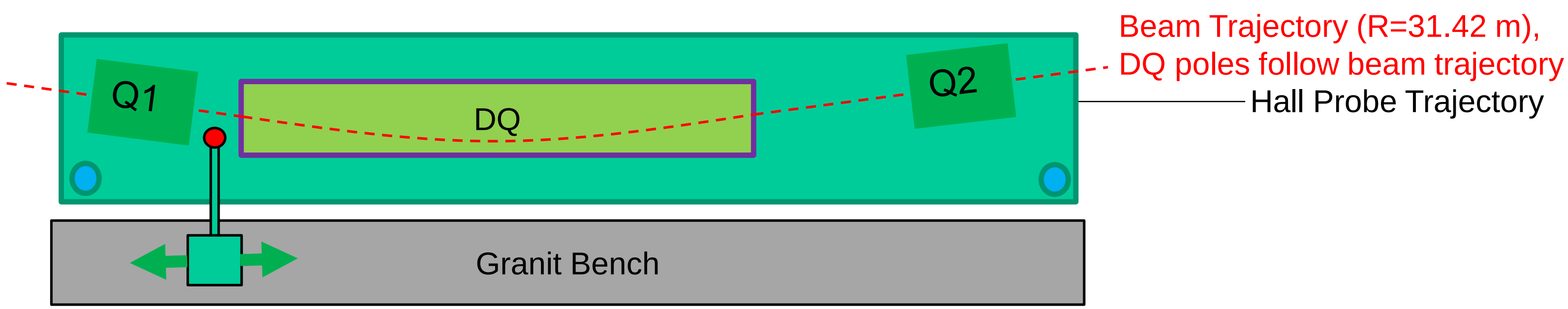


Before:
Roll = -0.691 mrad
Offset = 0.083 mm

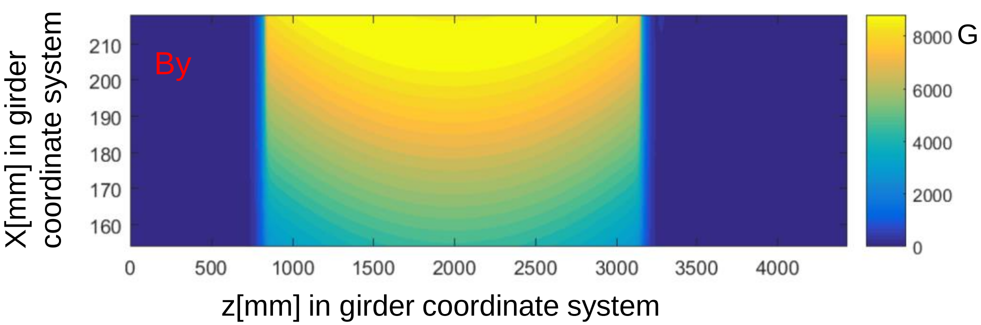
After
Roll = -0.091 mrad
Offset = 0.010 mm

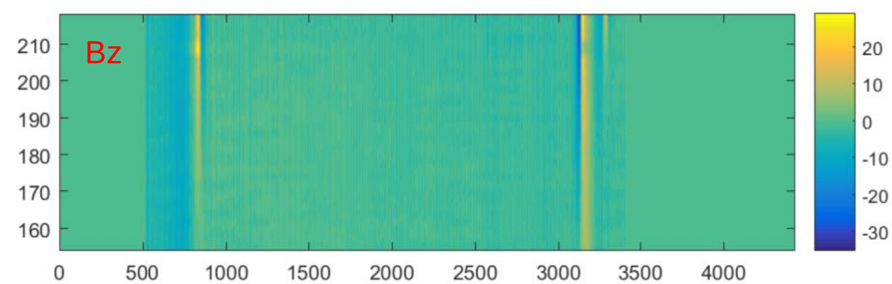


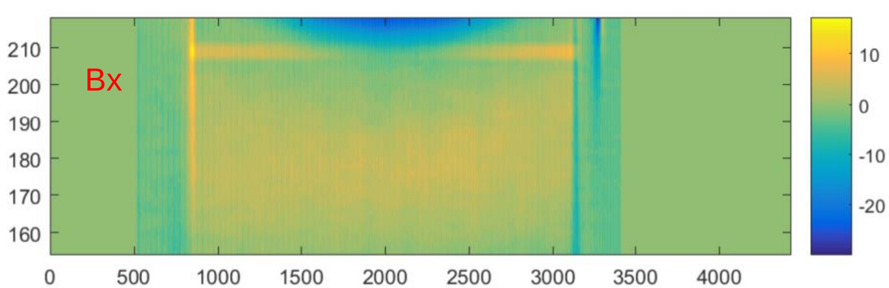
Magnetic Alignment: DQ horizontal positioning



DQ-11 2D Field Map, I_mag = 696.34A

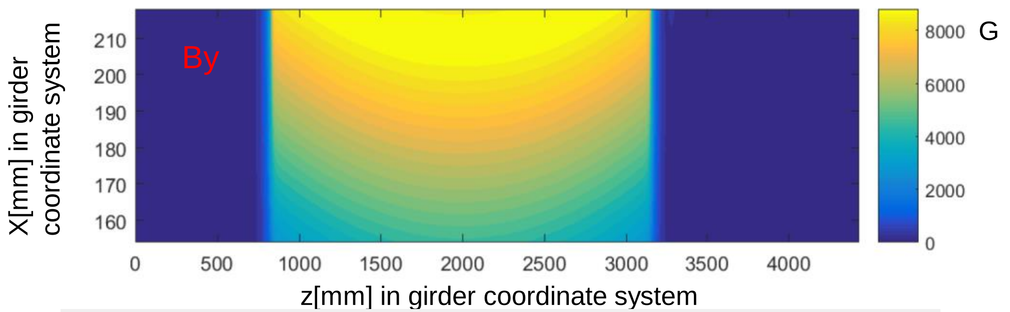


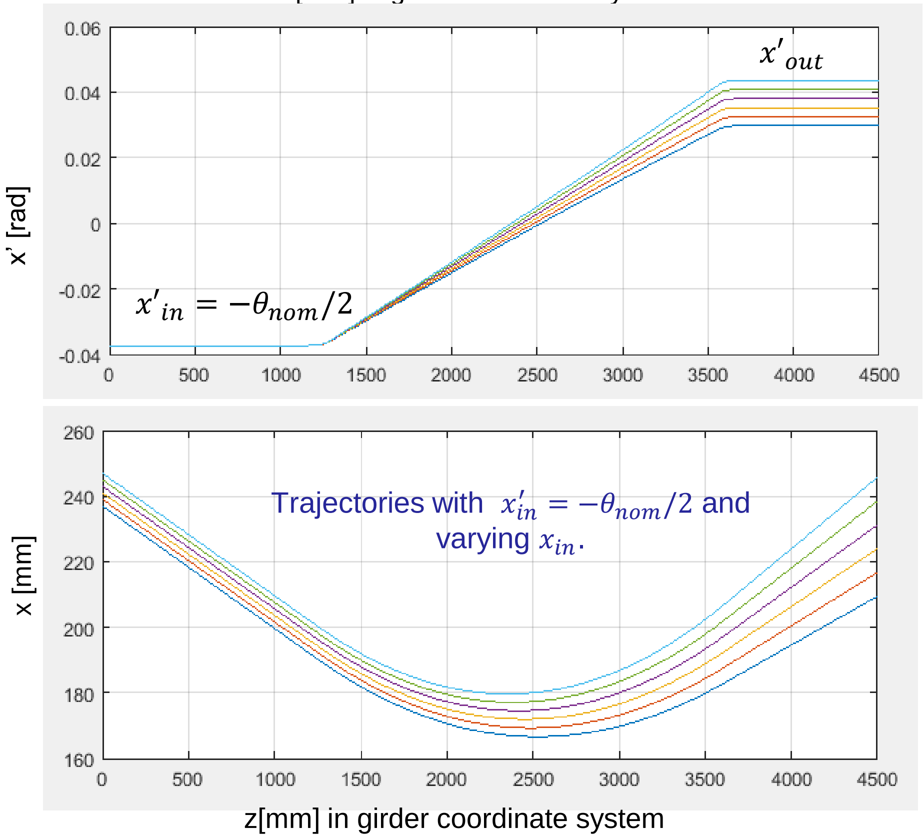




1. Take 2D field map
2. Find beam trajectory for nominal bending angle ($\theta_{nom} = 74.799\ mrad$)
3. Calculate gradient integral along this trajectory.
4. If integral close enough to nominal (20.57 T-m/m) proceed with alignment, if not correct current and repeat steps 1,2,3.

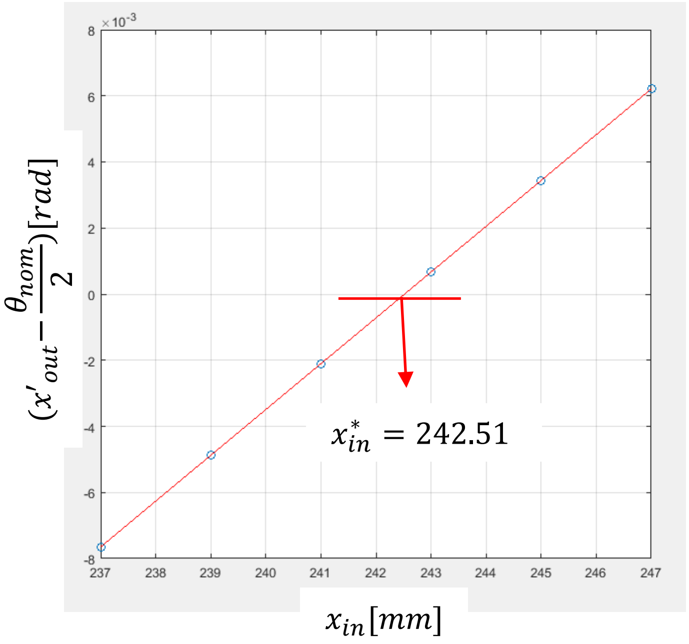
Magnetic Alignment: DQ horizontal positioning





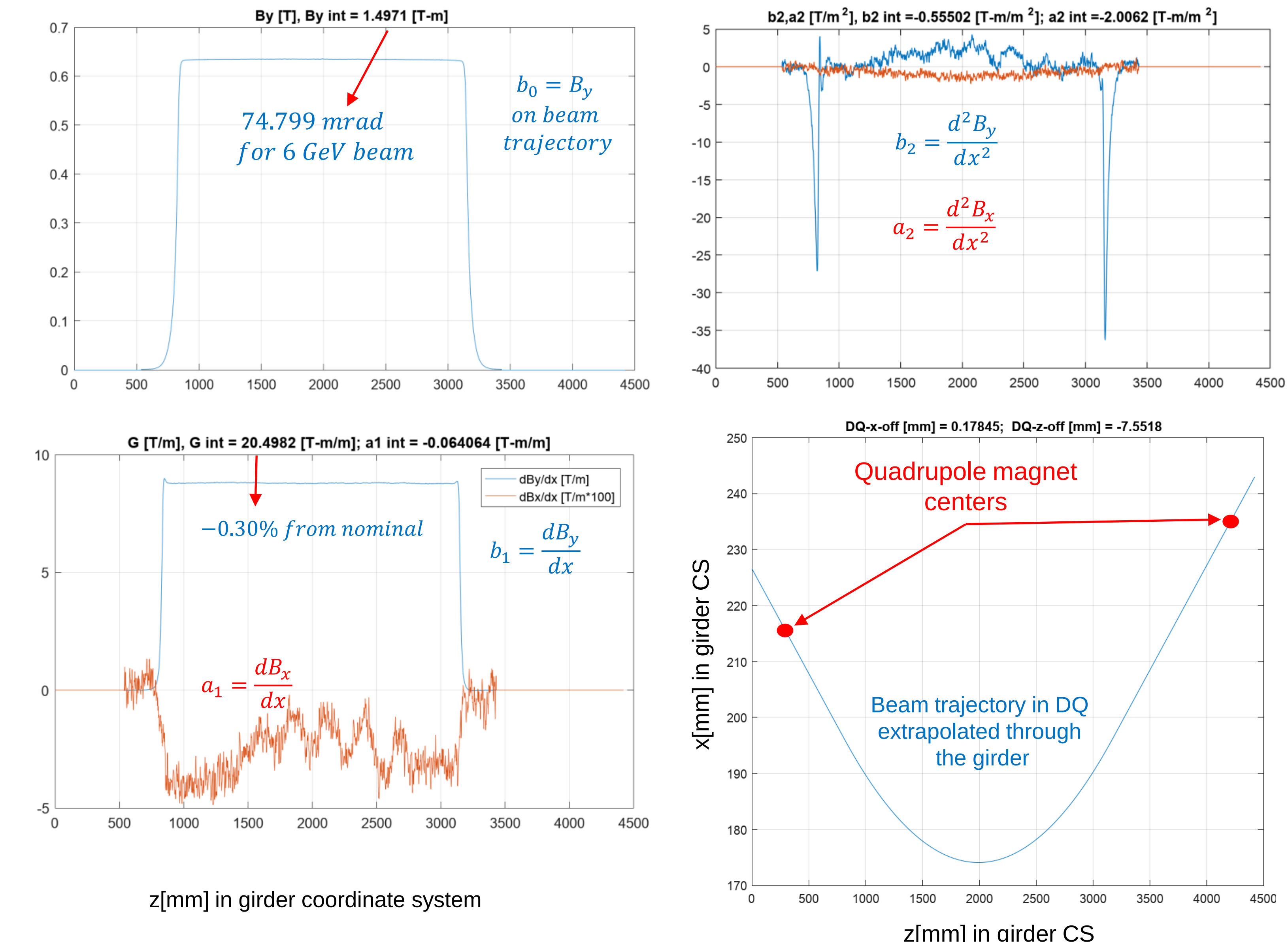
Two constrains:

1) $\theta_{nom} = 74.799\ mrad$ – bending angle
2) $\int Gdl = 20.57\ T - m/m$ - field gradient integral along beam trajectory



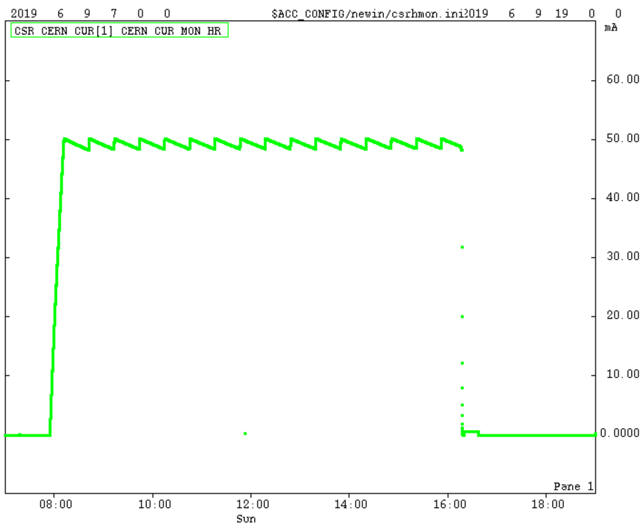
After we found trajectory with nominal bending angle, we can find field gradient integral along this trajectory and more, see next slide.

Magnetic Alignment: DQ horizontal positioning

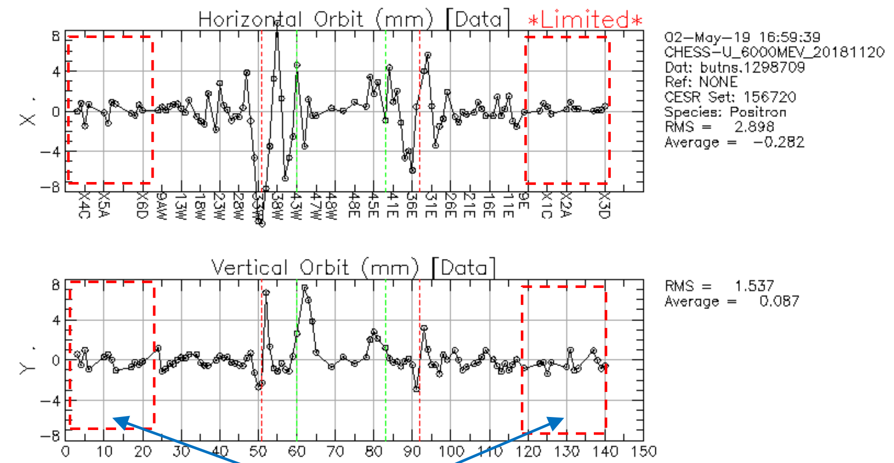


Beam commission confirmed magnets alignment

Top-off operation at 50mA, 6Gev



Closed Orbit

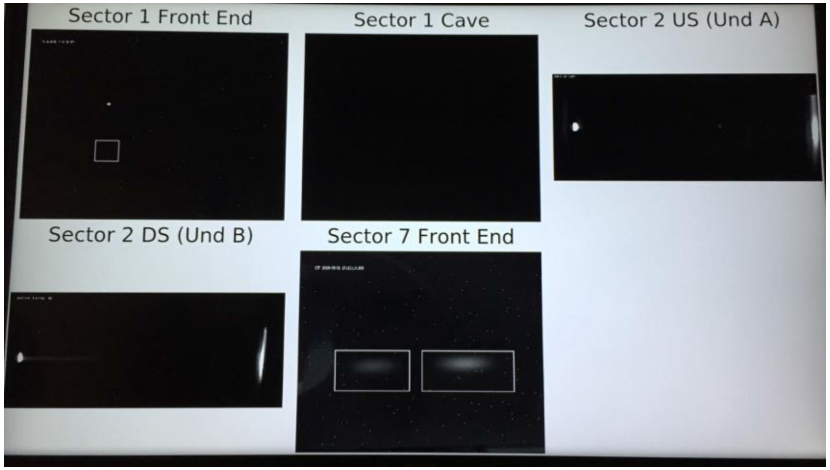


Areas with new magnet structure

In addition:

8 CHESS Compact Undulators have been installed and put into operation

First light from the undulators



Conclusion and Acknowledge

- To speed up the process of the magnet alignment on girders, we used Vibrating Wire and Hall Probe magnetic field measurement techniques and aligned magnetic axis of the mounted magnets. This approach appeared to be quite practical and efficient.

- The precision of the alignment was confirmed with beam measurement.

- The work has been supported by NSF award DMR-1332208