Results from the Double Double Bend Achromat Installation

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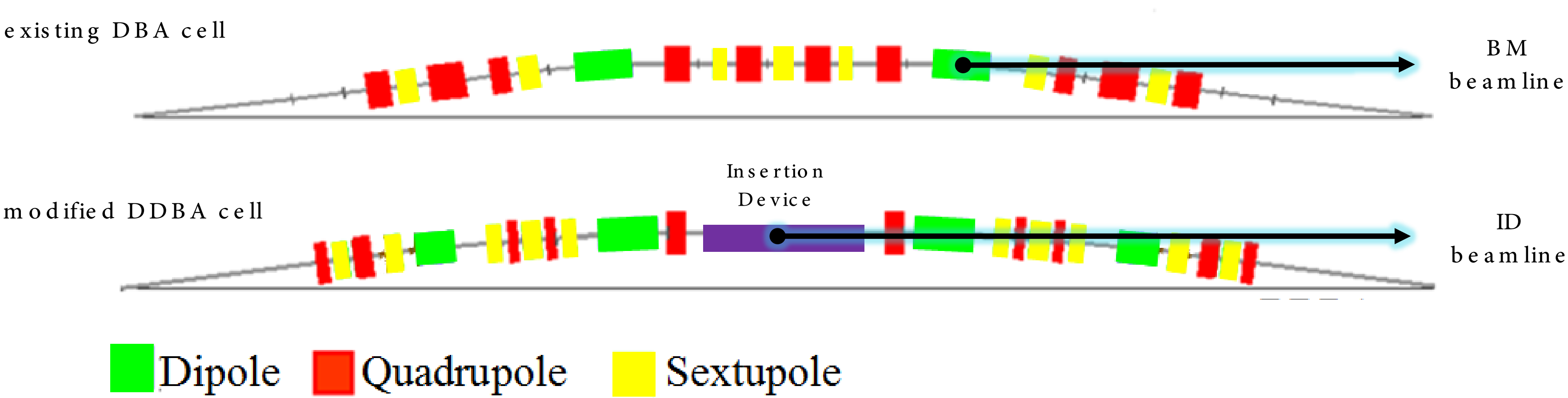
IMMW20, Diamond Light Source Ltd., Didcot, Oxfordshire, UK, 4-9th June, 2017

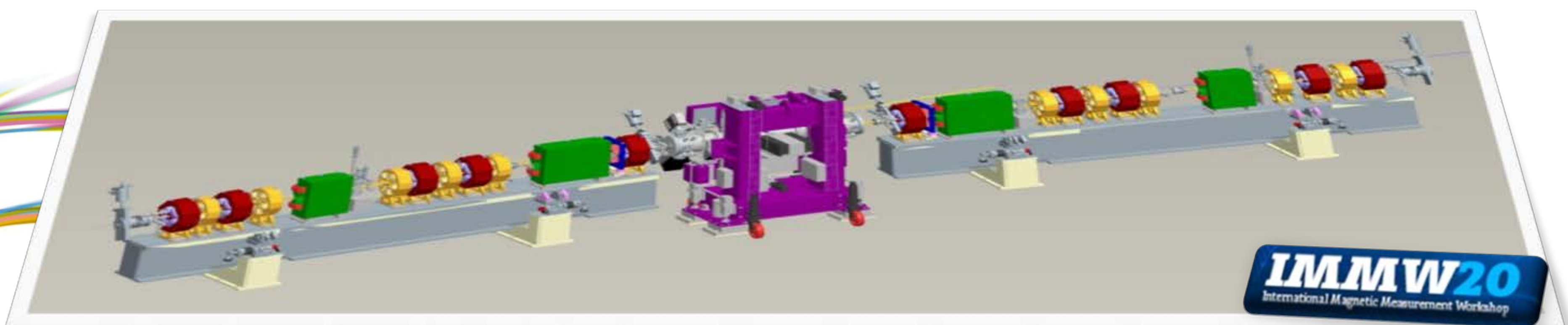
Outline

- The DDBA upgrade of Diamond
- Magnet Measurements and Alignment
- ID measurements

DDBA upgrade in Diamond

One more beamline with no significant gain in emittance



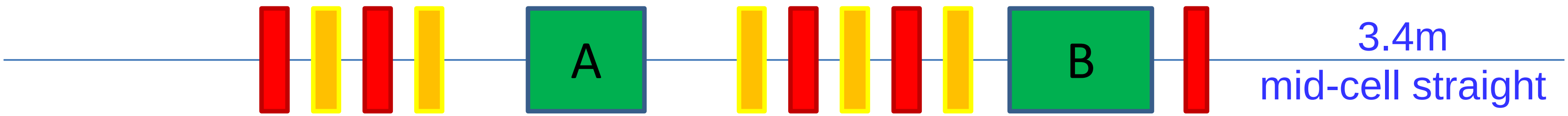


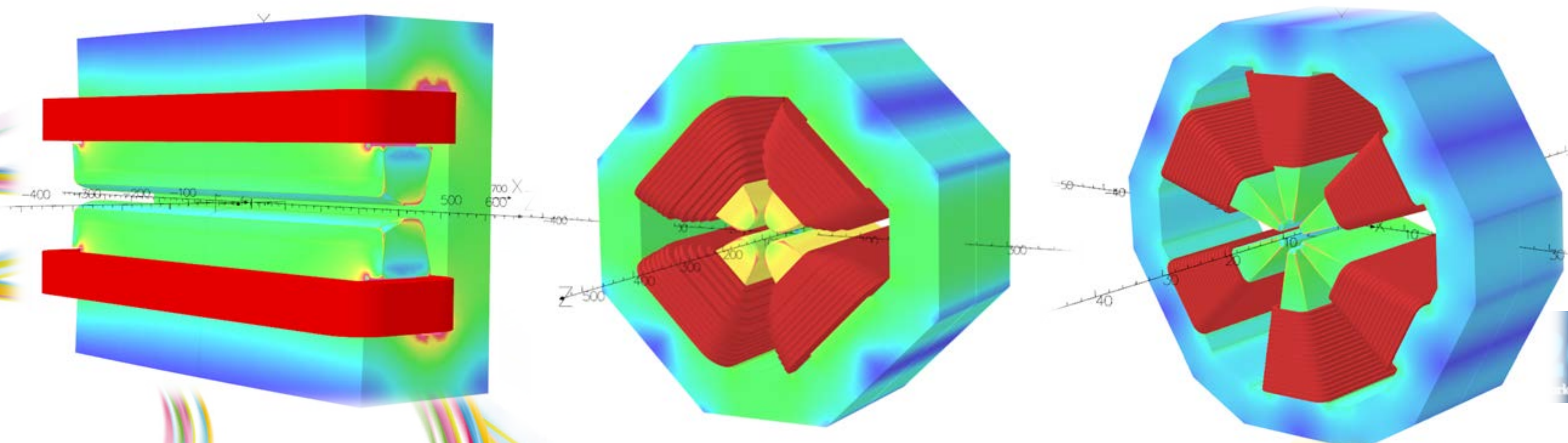
Magnets

Quadrupoles, Gmax=70 T/m L=25 cm

Sextupoles, Smax=2000 T/m^2 L=17.5 cm (with trim coils)

Dipole A: B=0.8 T, G=-14.4 T/m, L=67 cm | Dipole B: B=0.8 T, G=-14.4 T/m, L=97 cm





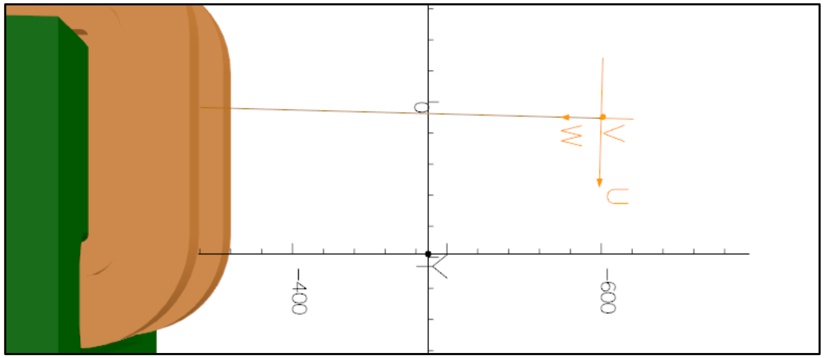
Magnetic Measurements

- All measurements done in the manufacturer premises
- Hall probe measurements for Dipoles
- Single Stretch Wire (SSW) measurements for multipoles
- Just for multipoles, manufacturer results re-measured and cross checked during the alignment

Magnetic Measurements

Dipoles

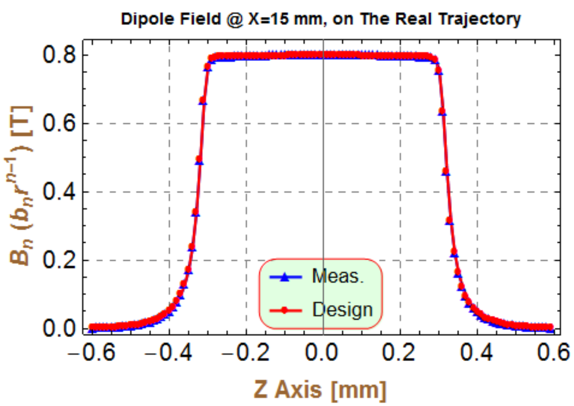
- Magnetic field is measured using Hall probe bench
- Trim coils and lateral movement mechanism are fitted for tuning field components
- Particle trajectory is calculated and field is analysed along this trajectory
- Good agreement between simulations and measurements results

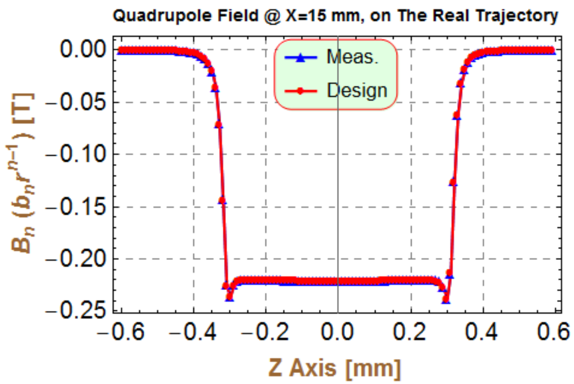


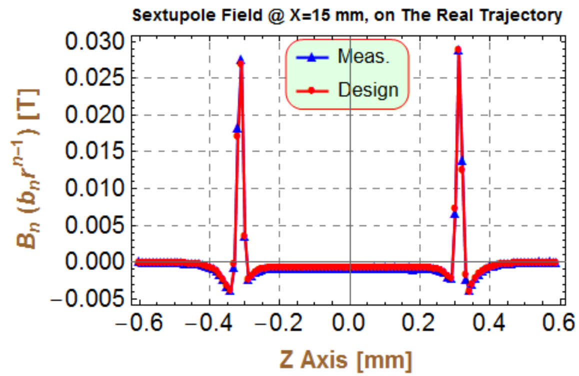
Measurements at Danfysik

Magnetic Measurements

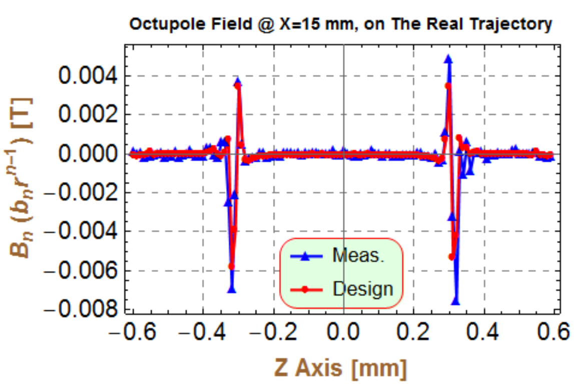
Dipoles

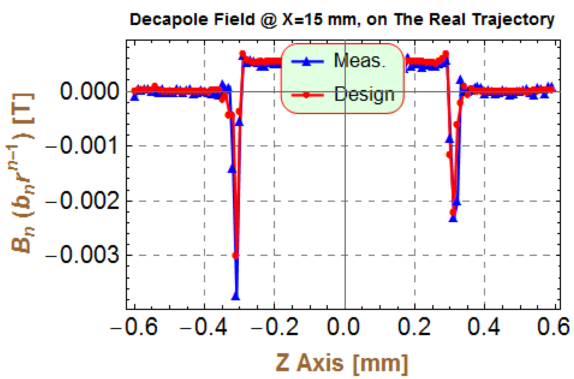


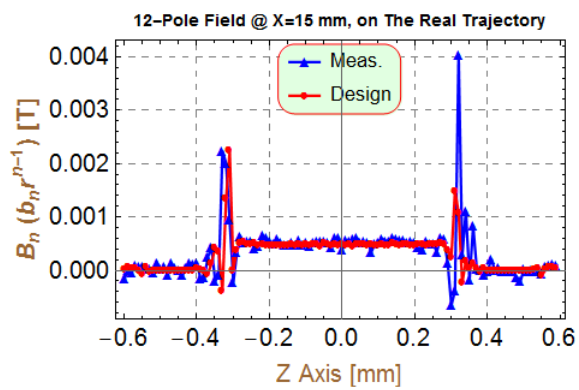




Good agreement between simulation and measurement results







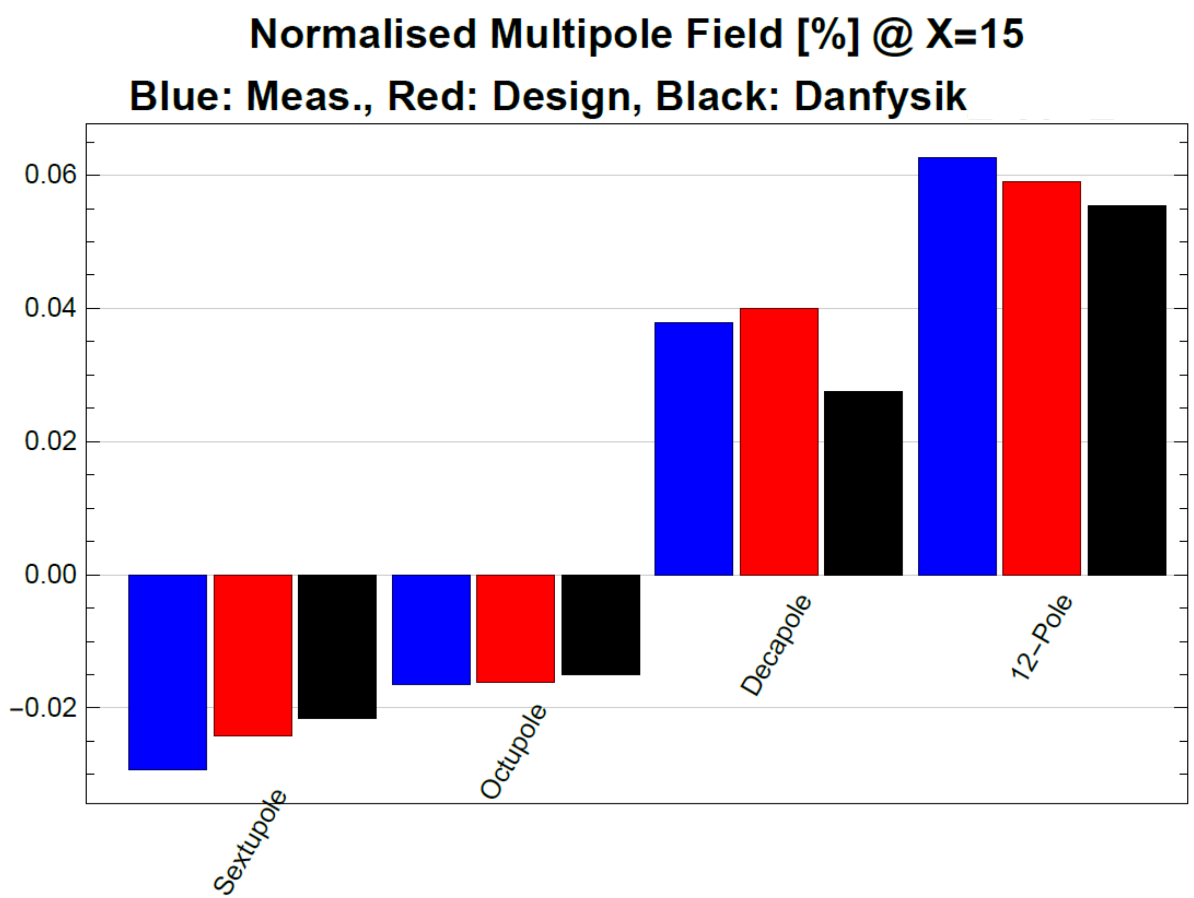
Magnetic Measurements

Dipoles

Black data are based on the integration along parallel arc trajectories. Done at Danfysik

Red: Simulations

Blue: Real Trajectory



Magnetic Measurements

Dipoles

BUT THERE IS A PROBLEM…

The Effective length of B and G components are not the same (Quadrupole's Leff is ~16 mm shorter in both types A and B)

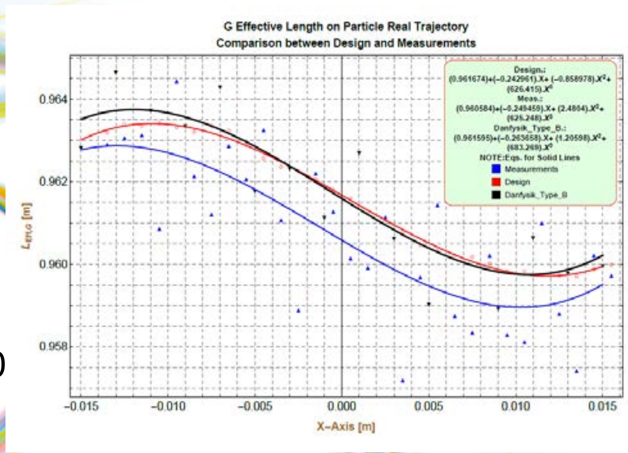
Quadrupole effective length

Design.:

(0.961674)+(–0.242961).X+ (–0.858978).X^2+ (626.415).X^3

Meas.:

(0.960584)+(–0.249459).X+ (2.4804).X^2+ (625.248).X^3



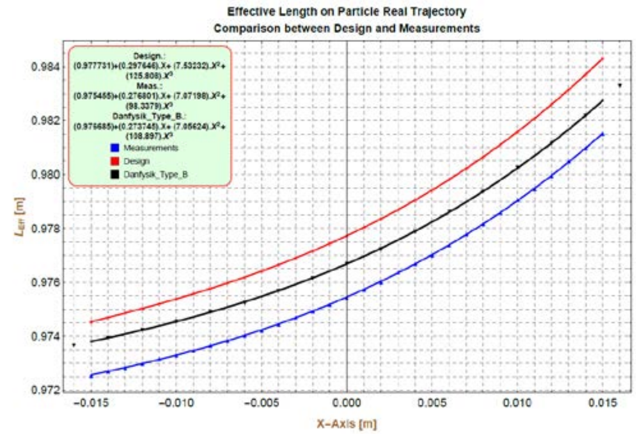
Dipole effective length

Design.:

(0.977731)+(0.297646).X+ (7.53232).X^2+ (125.808).X^3

Meas.:

(0.975455)+(0.276801).X+ (7.07198).X^2+ (98.3379).X^3



Magnetic Alignment

Dipoles

By changing current in trim coils, and applying horizontal shift to the every single magnet one can have is:

both $\int B.dS$ and $\int G.dS$ have right values, (at least in theory)

Parameter	Goal	S/N14206	Error	S/N14207	Error
Nominal central field strength, By (T)	0.8000	0.8008	0.09%	0.8005	0.07%
Magnetic Length (m)	0.6700	0.6698	-0.03%	0.6700	0.00%
Nominal integrated field ∫Byds along the beam axis (Tm)	0.5364	0.5364	0.00%	0.5364	0.00%
Nominal central transverse field gradient dBy/dx (T/m)	14.3952	14.7452	2.37%	14.7418	2.35%
Nominal integrated field gradient ∫(dBy/dx)ds along the beam axis (T) (Reference)	9.6510	9.6506	0.00%	9.6514	0.00%
Trim Coil Current (A) / *Shift(mm)*		*144.261*	*-1.199*	*142.420*	*-1.327*

Parameter	Goal	S/N14208	Error	S/N14209	Error
Nominal central field strength, By (T)	0.8000	0.7930	-0.88%	0.7925	-0.95%
Magnetic Length (m)	0.9670	0.9754	0.87%	0.9761	0.93%
Nominal integrated field ∫Byds along the beam axis (Tm)	0.7730	0.7736	0.00%	0.7736	0.00%
Nominal central transverse field gradient dBy/dx (T/m)	14.3900	14.4951	0.69%	14.4893	0.65%
Nominal integrated field gradient ∫(dBy/dx)ds along the beam axis (T) (Reference)	13.9192	13.9194	0.00%	13.9201	0.01%
Trim Coil Current (A) / *Shift (mm)*		*97.012*	*-0.832*	*98.318*	*-0.916*

Magnetic Alignment

Dipoles

But during commissioning, it turned out the mechanical shifts were not correct!

(As shown by the corrector pattern.)

Therefore to reach a more regular corrector magnet patterns, these H offsets were applied by the following amounts:

Magnet	Applied Shift (Installation)	Correction (Necessary)	Correction (Applied)	Shift (Remaining)
S/N14206	1.199	0.680	0.680	0.519
S/N14207	1.327	0.200	0.000	1.327
S/N14208	0.832	0.480	0.480	0.352
S/N14209	0.916	0.780	0.780	0.136

It is still unclear what is the reason why the calculated shifts were wrong:

wrong path chosen to compute the integrated fields

systematic error in positioning of magnetic grid during measurements

… WIP

Magnetic Alignment

Dipoles

Dipoles:

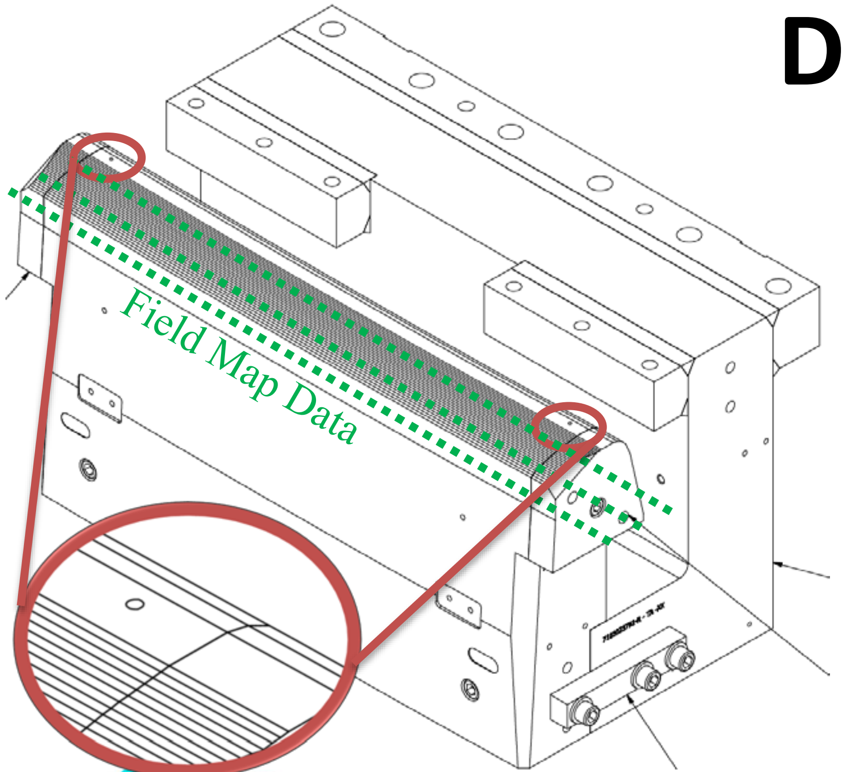
- ***Aligned mechanically using a laser tracker***
- ***Magnet shimming has done in situ***
- ***Alignment target +/-50 um***

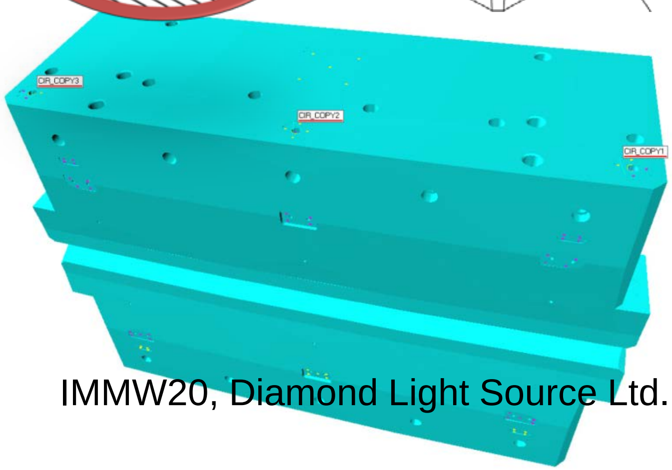
Difficulties:

- Purely mechanical alignment accuracy is restricted to the laser tracker accuracy (±25 um)
- Very time consuming alignment process (many iterations is needed)

Magnetic Alignment

Dipoles





Dipole alignment is done by putting magnetic field mapping data in the right place on the girder by:

1- Relating magnetic field map position to two holes on the bottom pole, using the magnetic cone

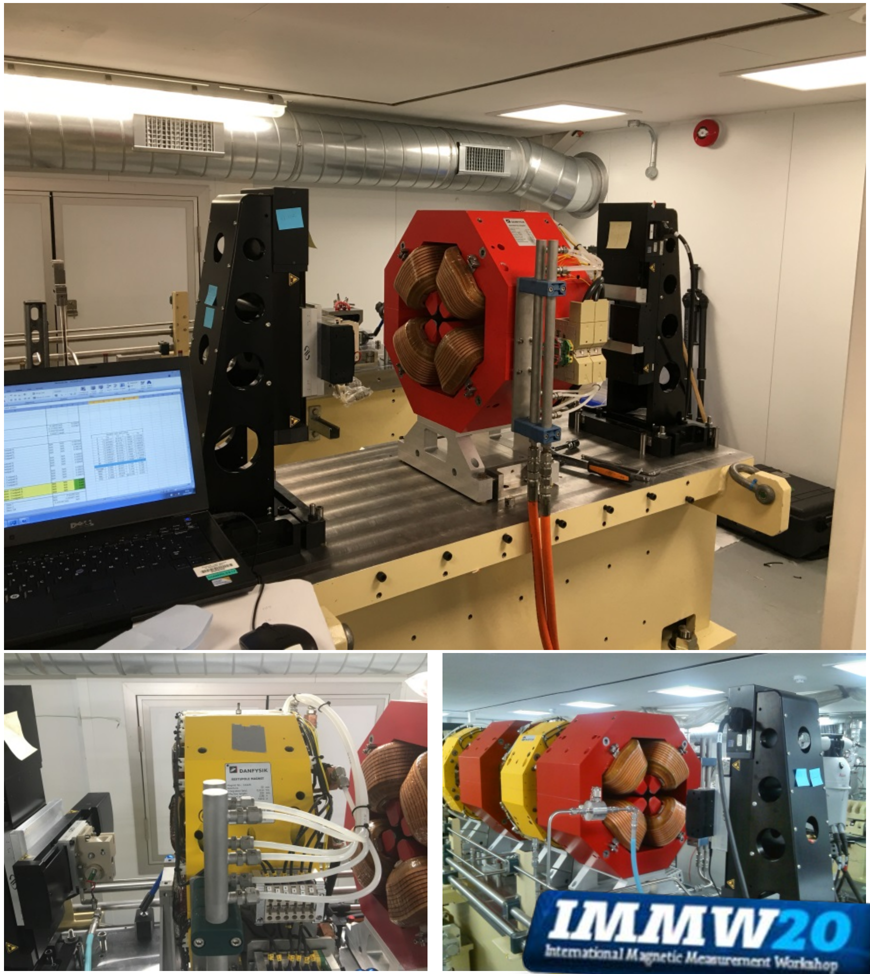
2- Relating two holes positions to three tooling holes on the top of magnet, using CMM report

3- Using laser tracker to place tooling holes in the right place

Magnetic Measurements

Multipoles

- Magnetic field is measured using Single Stretch Wire Bench
- Side shims and magnet feet are adjusted to get its centre in the right place as well as its roll, yaw, and pitch less than 0.1 mrad
- Good agreement between simulations and measurements results



Magnetic Measurements

Uncertainties of Stretched-wire measurements

- Laser tracker measurement +/-25um
- Magnetic measurements:

Error	St Dev [μm]
Mag. Meas. Repeat.	1
Wire Pos. Repeat.	5

By Courtesy of: Gaël LE BEC, Advances in Stretched-wire measurements at the ESRF, IMMW19, Hsinchu, Taiwan, October 2015

Magnetic Measurements

Concept

$$B_r(r,\theta) = \sum_{n=1}^{\infty} C(n)\left(\frac{r}{R_{ref}}\right)^{n-1} \mathrm{Sin}[n\theta - \alpha_n]$$

$$B_\theta(r,\theta) = \sum_{n=1}^{\infty} C(n)\left(\frac{r}{R_{ref}}\right)^{n-1} \mathrm{Cos}[n\theta - \alpha_n]$$

$C(n)$: Amplitude of $2n$ – Pole

Cartesian Coordinates

$$B_x(r,\theta) = B_r\,\mathrm{Cos}[\theta] - B_\theta\,\mathrm{Sin}[\theta] = \sum_{n=1}^{\infty} C(n)\left(\frac{r}{R_{ref}}\right)^{n-1} \mathrm{Sin}[(n-1)\,\theta - \alpha_n]$$

$$B_y(r,\theta) = B_r\,\mathrm{Sin}[\theta] + B_\theta\,\mathrm{Cos}[\theta] = \sum_{n=1}^{\infty} C(n)\left(\frac{r}{R_{ref}}\right)^{n-1} \mathrm{Cos}[(n-1)\,\theta - \alpha_n]$$

Complex Representation

$$B(z) = B_y(x,y) + i.B_x(x,y) = \sum_{n=1}^{\infty}\left[C(n)\,e^{-i\alpha_n}\right]\left(\frac{z}{R_{ref}}\right)^{n-1}$$

14221_100_PerCent_100A_10.dat - Notepad

File Edit Format View Help

```
Measurement_Date:        Fri 4 Sep 2015
Measurement_Time:        08:06:19
File_Index:      10

Magnet_Type:      Sextupole
Magnet_Serial_Number:     14221

Coil_Current:     100
Measurement_Radius:      13

an        bn
21.15    -183.78
49.089   17.056
35.889   48199
1.5701   24.981
24.568   -47.571
4.5951   38.163
-2.9786 -7.6592
-1.703   1.4985
2.5009   -217.4
0.78272 -1.2648
-5.1322 -10.51
-2.4044 7.3017
-0.97202        0.35404
-0.213   -2.4352
-2.7221 -171.62
0        0
```

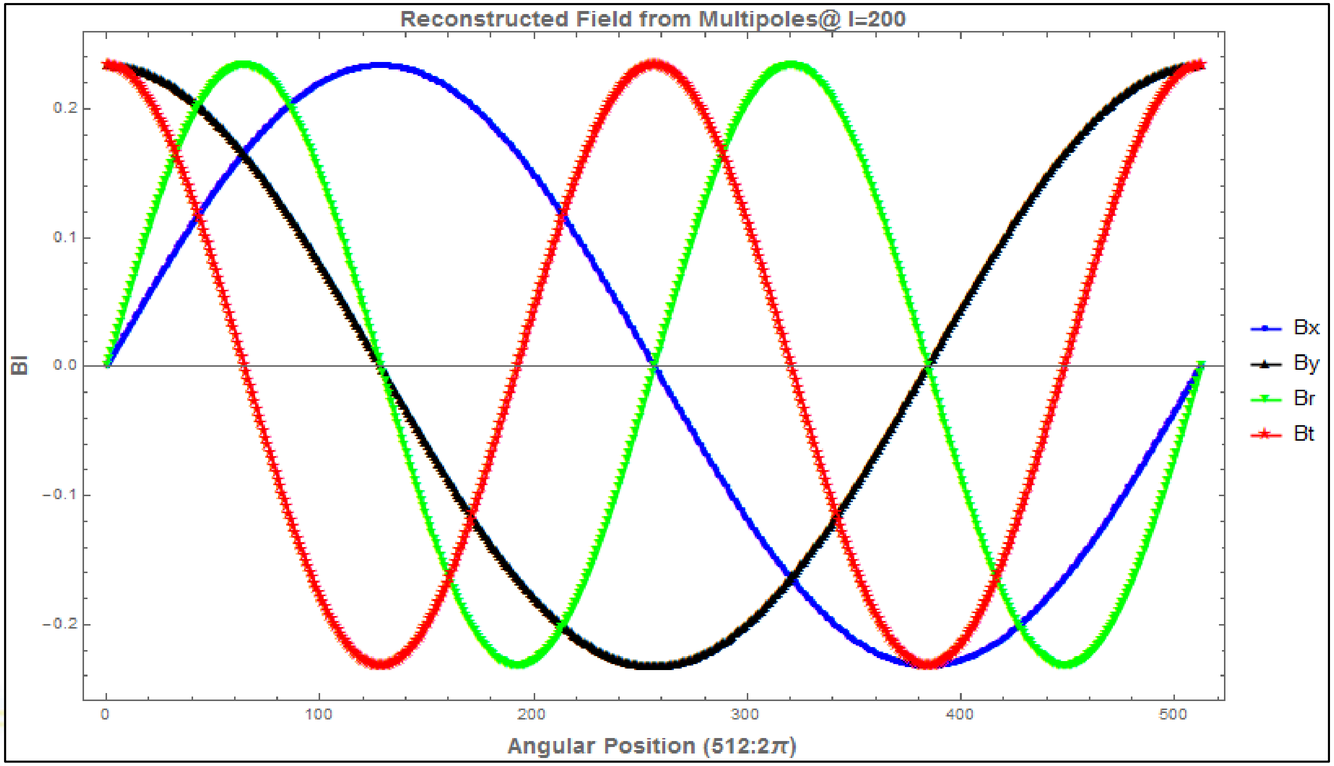
$$Cn = \sqrt{an^2 + bn^2}$$

$$\alpha n = Tan^{-1}\,(an/\,bn)$$

Magnetic Measurements

QM Results, Field from multipoles

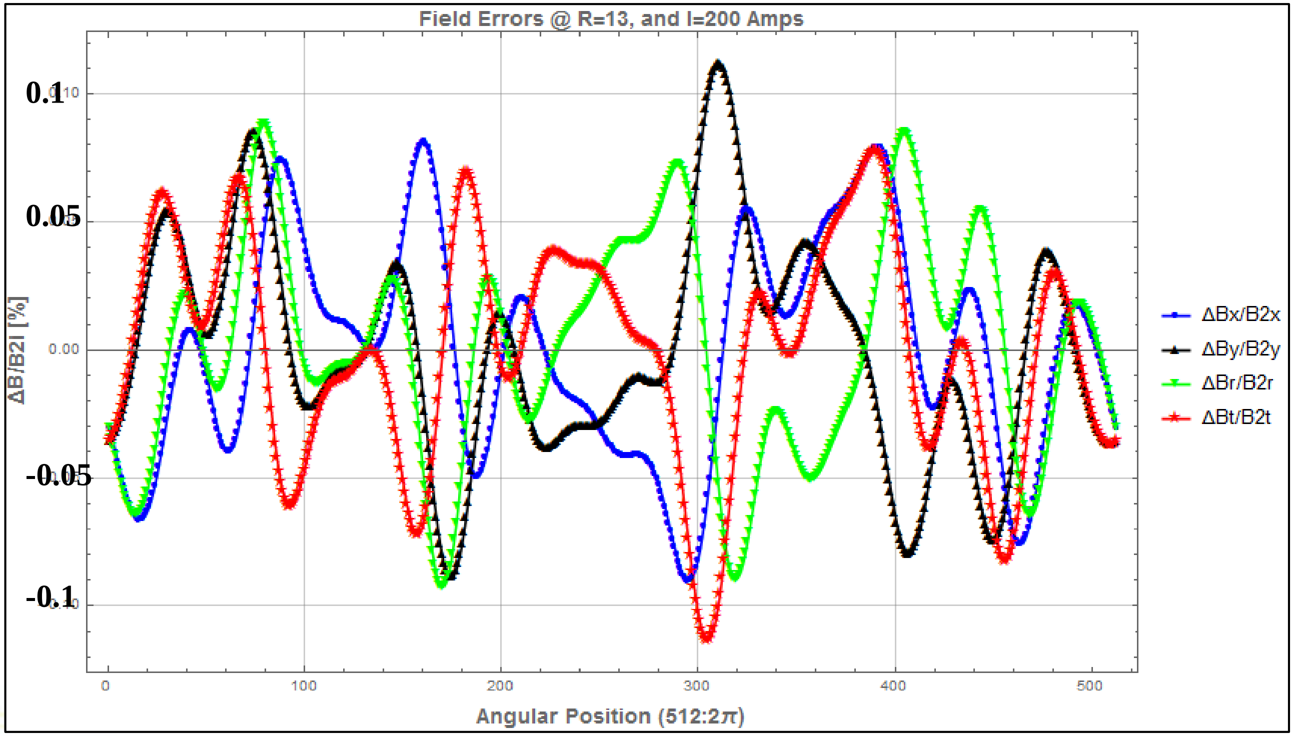
Once the magnets measured, the magnetic field can be reconstructed anywhere inside the circle of measurement



Magnetic Measurements

QM Results, Field errors [%]

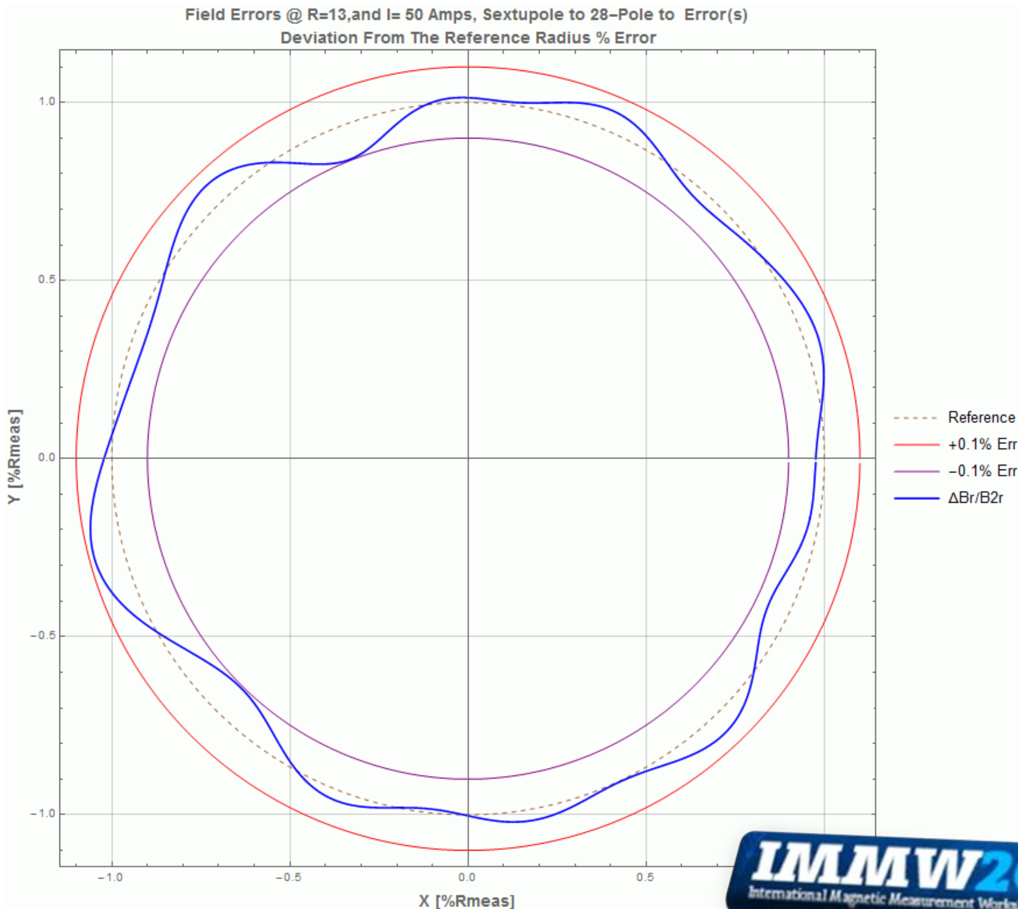
By extracting the main component, the field errors can be given by the reconstructed field equation



Magnetic Measurements

QM Results, By Field errors vs. Current

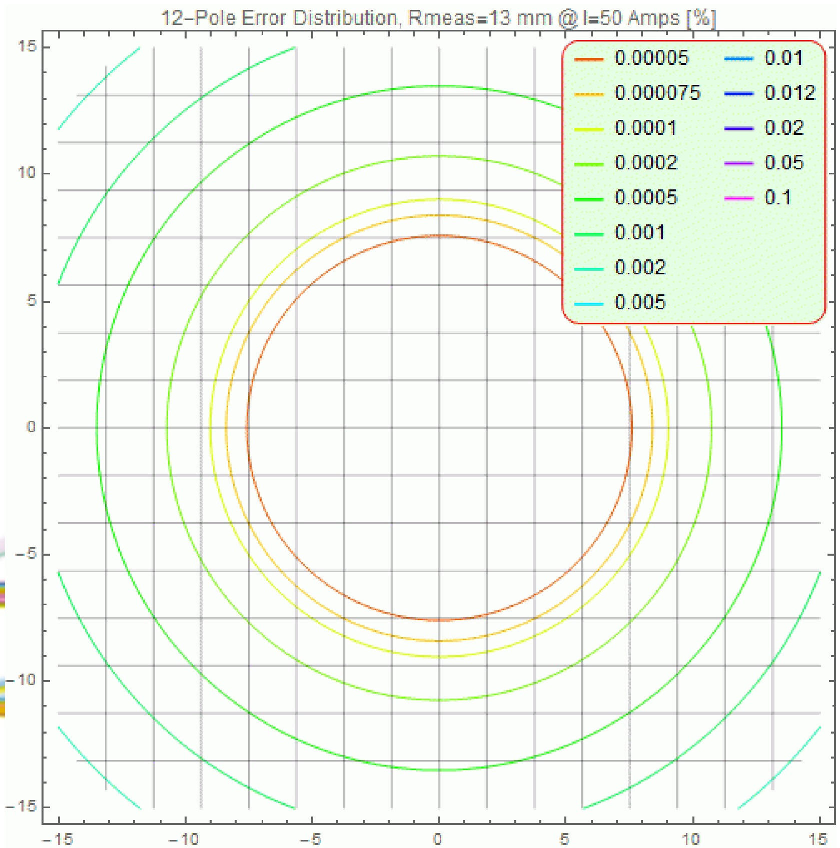
Field errors around the circle of measurement as a function of current can be seen in the polar plot



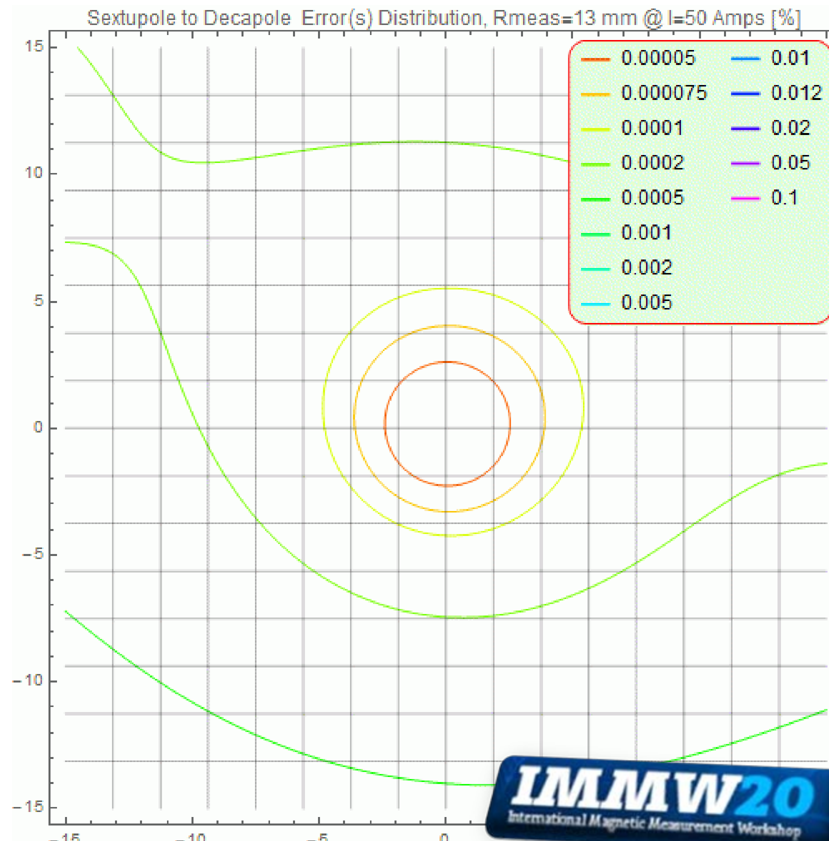
Magnetic Measurements

QM Results, Iso-Error lines

12-Pole error



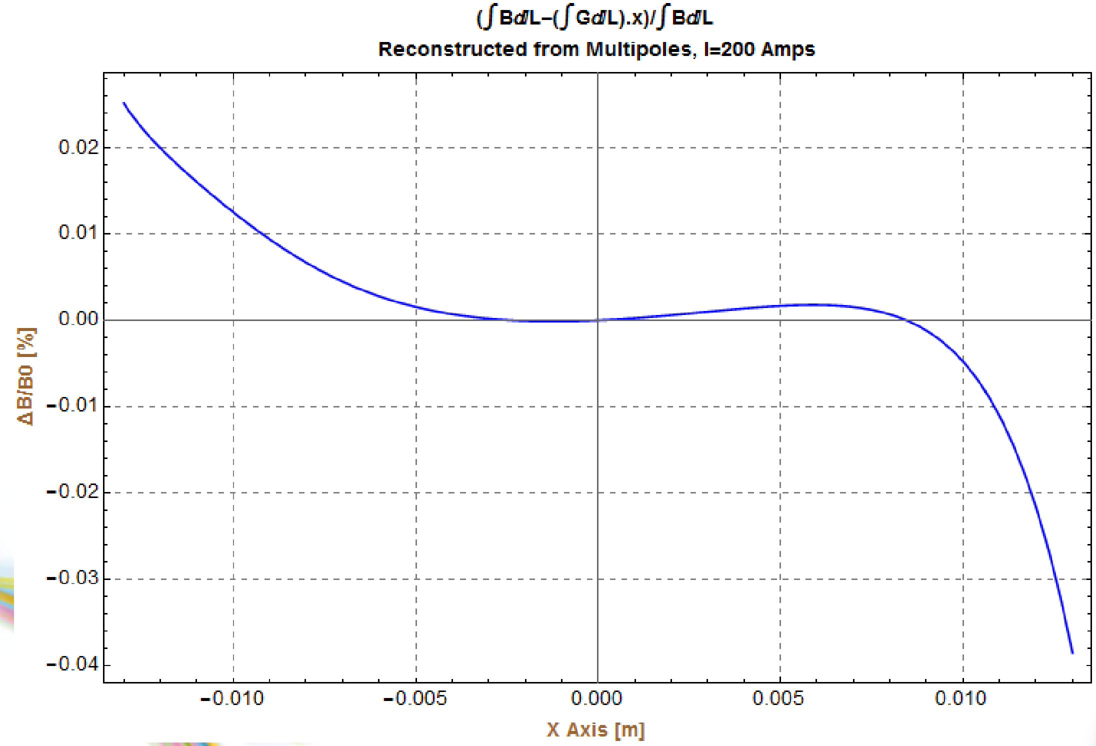
Sum of Sextupole to Decapole



Magnetic Measurements

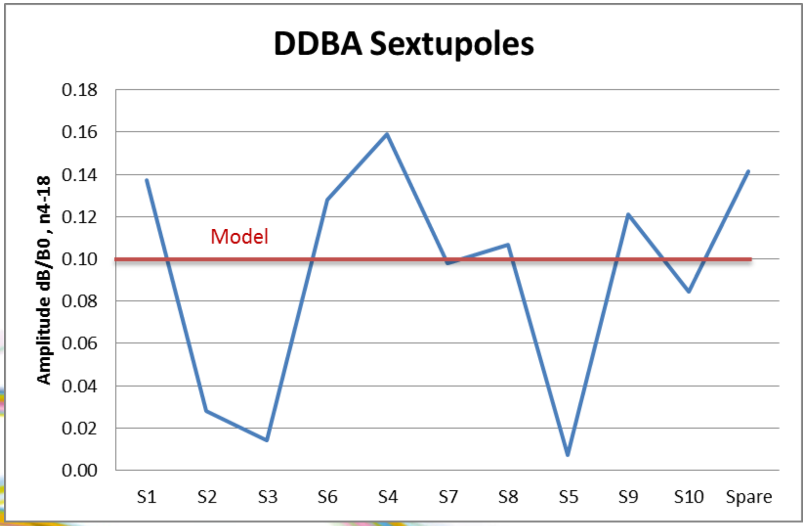
QM Results

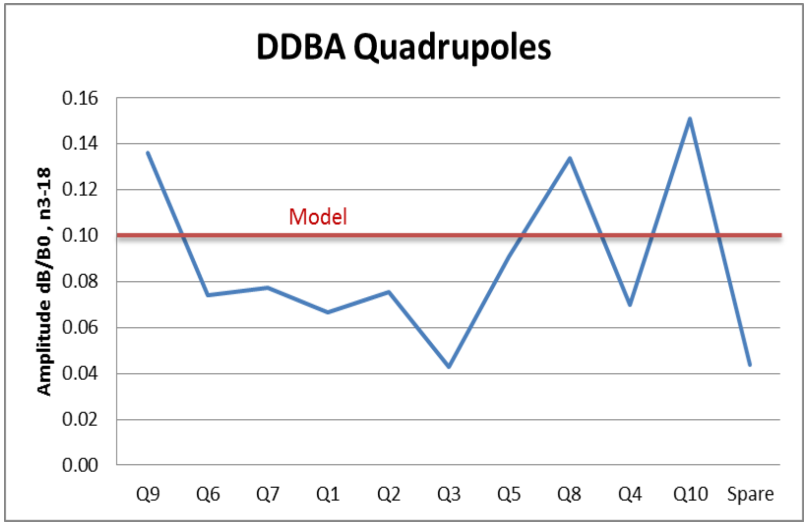
on-axis field quality (< 5·10-4 in ± 10 mm)



Magnetic Measurements
All Multipoles

Statistics over 11 magnets
Sum of all higher harmonics @ 100 Amp and r=10 mm

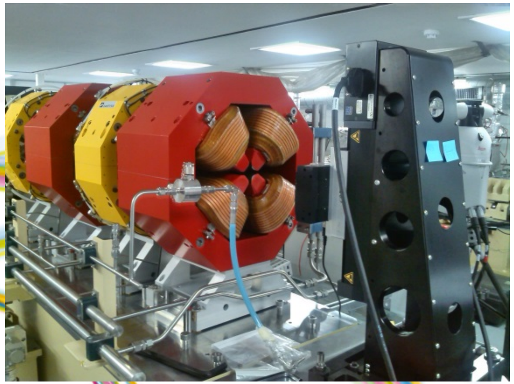




Magnetic Alignments

Multipoles

- Stretch Wire bench has been used for the alignment on the complete girder
- Just magnet centre could be measured on the complete girder
- All magnets top has been split and closed once before alignment and then aligned
- Opening and closing magnets top can change the axis position by 1-5 um

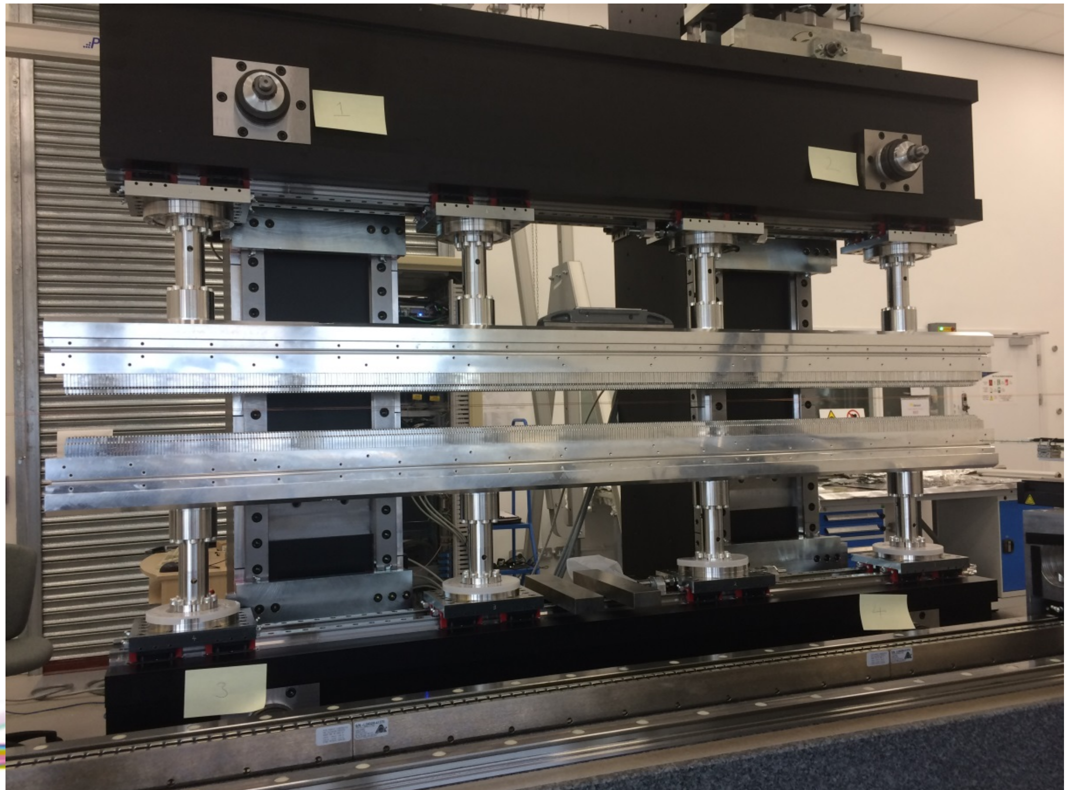


Magnetic Alignments

Difficulties

- Restrictions due to lots of stuffs on girder which affect on accuracy of alignment
- Magnets assembly/disassembly toques were unknown (all magnets have been spilt once and closed with specific torques then aligned, achieving reproducibility of less than 5 um for magnet centre)
- The location of the stretched wire needs re-evaluating every time it is snapped and/or replaced (But we did not!)
- Using Stretch wire for complete girders is limited to magnetic centre measurements, not axis; then Pitch and Yaw could not be measured (required more accurate post-production measurement)
- Quadrupole remnant field while measuring sextupoles may introduce offsets
- No alternative methods available for verifying the alignment process
- Bench alignments and shimming for every magnet batches is time consuming process..

The Insertion Device: J02



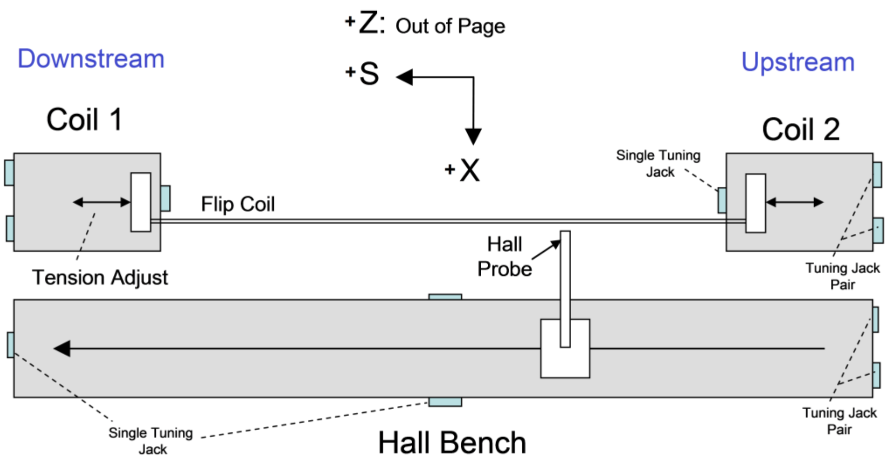
- Sm_2Co_{17} PPM
- 21 mm period
- 95.5 periods
- 2 m magnetic length
- 5 mm min. gap
- 0.8 T peak field

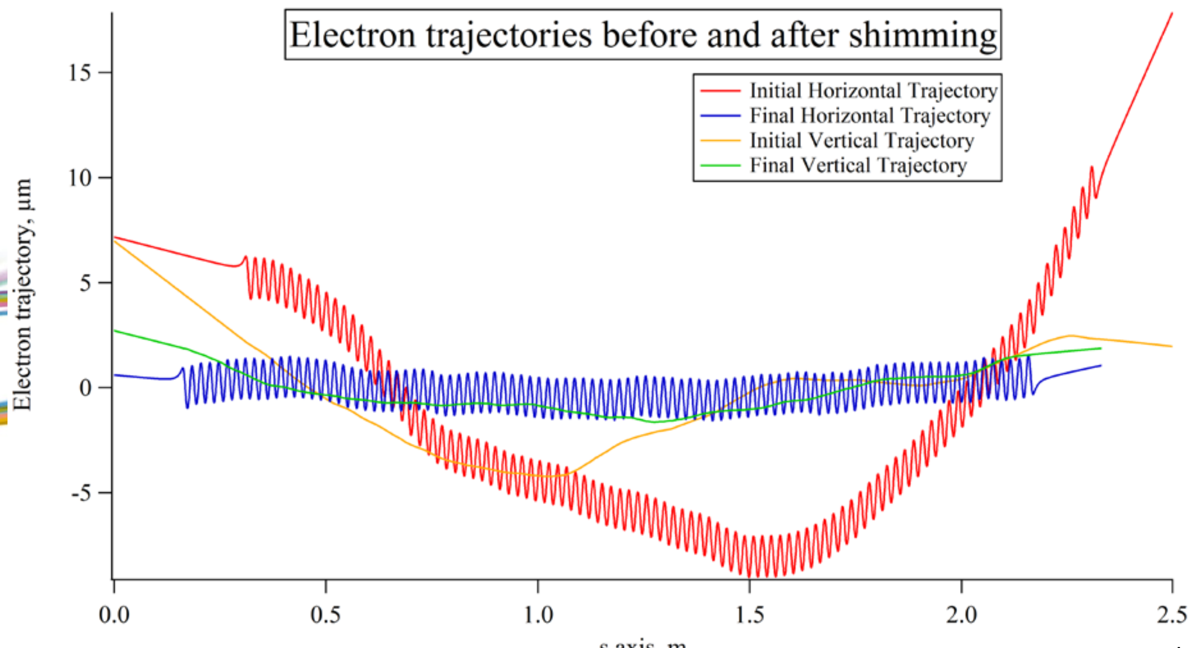
7 – 25 keV (0.57 – 2 Å) photons for the VMXm beamline (Macromolecular Crystallography for atomic structure)

J02 measurements

3 stages of correction:

- Trajectory shimming
- Phase shimming
- Field integral magic fingers



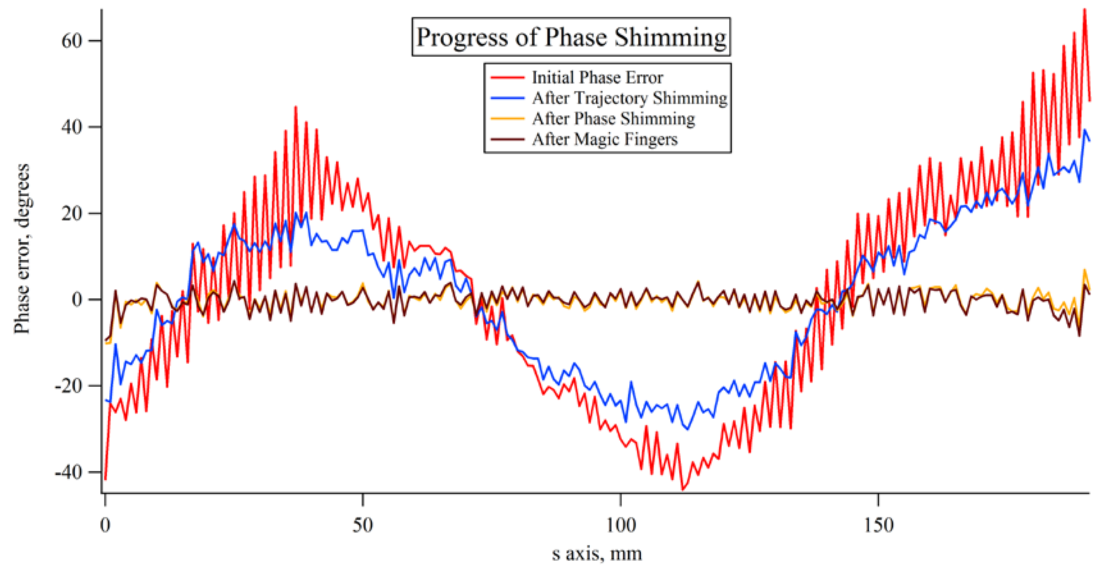


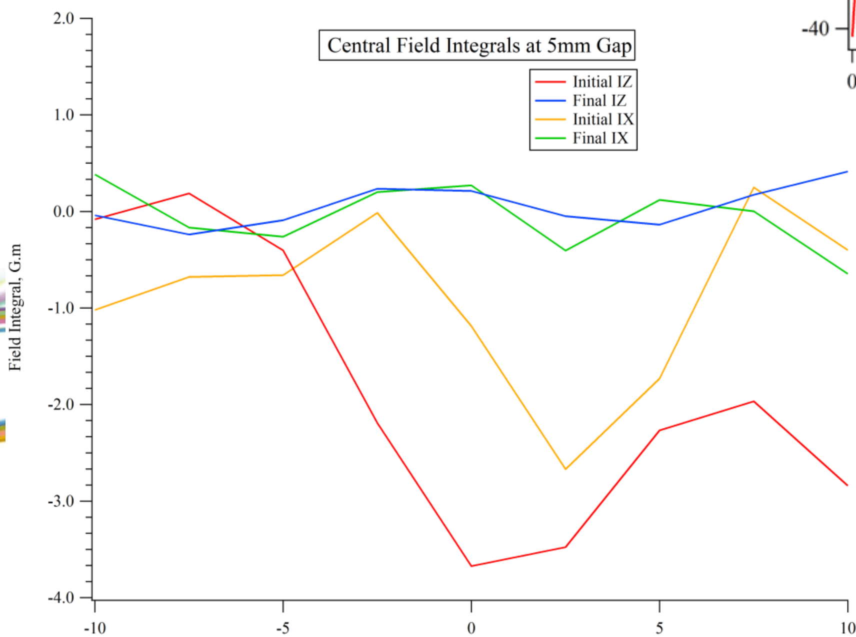
3D Hall probe & flipping coil for ID measurements

e^- trajectory corrected by swapping magnets

J02 measurements

Phase error reduced from 16.3˚ to 2.0˚ by moving magnets into and out of gap

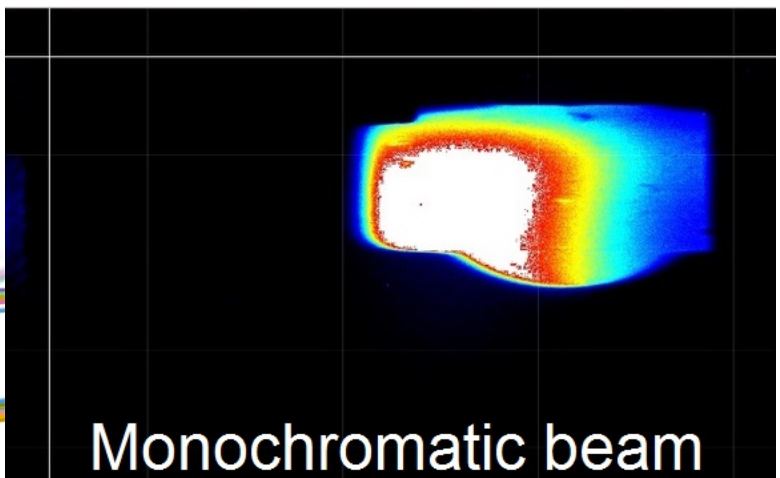


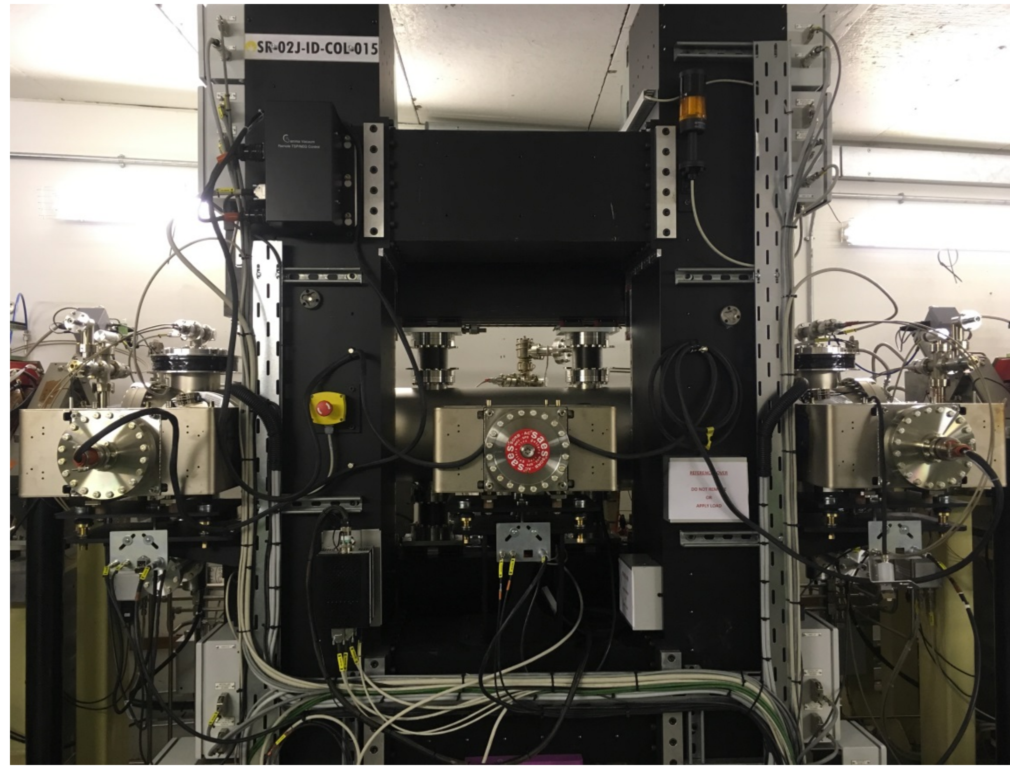


Field integrals reduced across ±10 mm of the device to ± 0.5 Gm using magic fingers

J02 first light

- J02 installed March 2017
- First light seen on the VMXm beamline April 2017





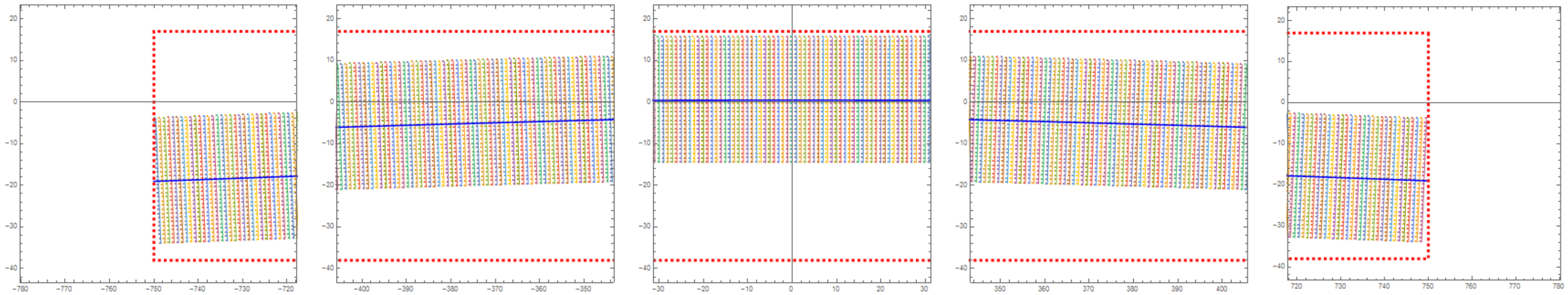
Beam-based alignment still to be performed

Thank You Everyone for Listening

diamond

backup

Real_Shift_0.626_mm Trajectory and Analysis Points



Installation and Alignment Dipoles: Continue…

Alignment Process:

- Magnetic grid position is known wrt pole fiducials
- Pole fiducials position are known wrt yoke fiducials
- Yoke fiducials are known in Girder Coordinates system

Then: