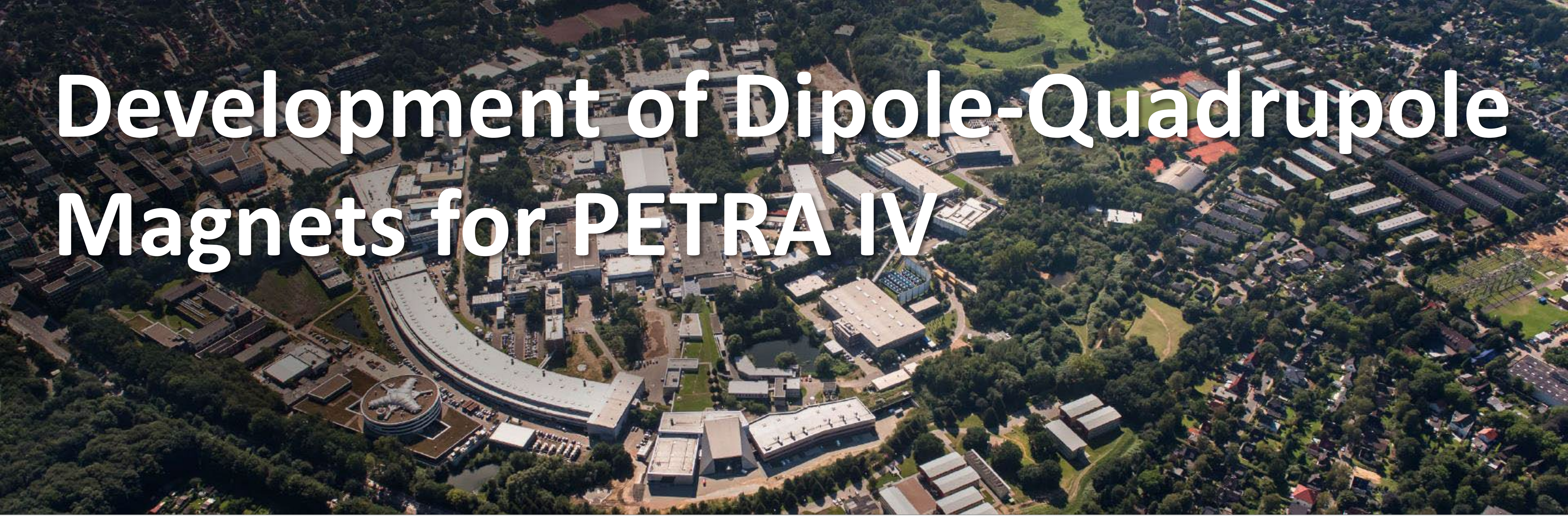


Development of Dipole-Quadrupole Magnets for PETRA IV

Markus Tischer, Mona Gehlot, Joel Chavanne (ESRF) , Torsten Ramm

3rd PerMaLIC & iFAST Workshop, Trieste, 14-15.11.2023

HELMHOLTZ

DESY.

Outline

Permanent magnet based DLQs

01 Project Overview

02 Magnet Design DLQ1
- Parameters
- Magnetic field analysis

03 Field Tuning

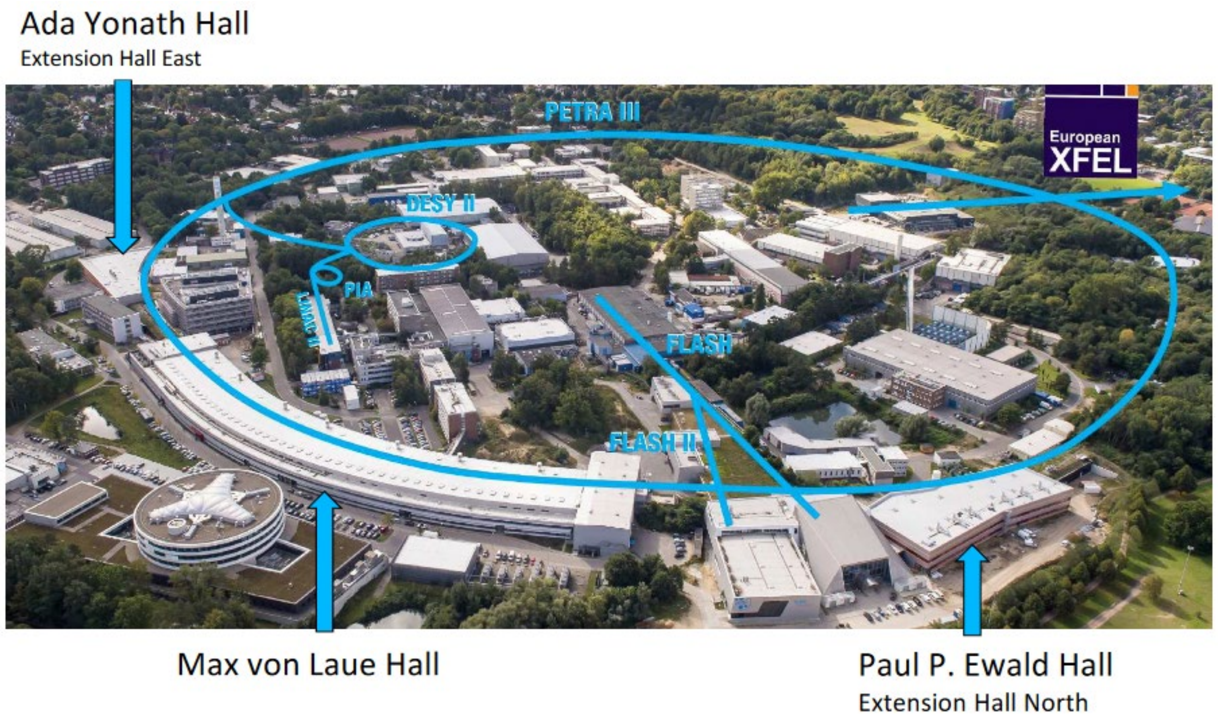
04 Cross-Talk Studies
- General interaction
- Current dependence

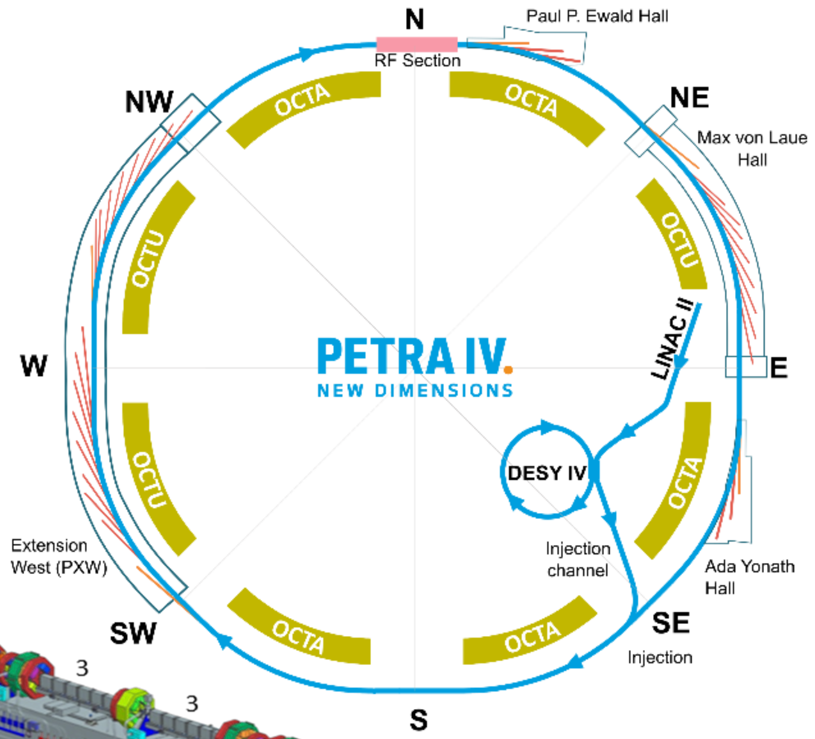
05 Curved Trajectory Analysis

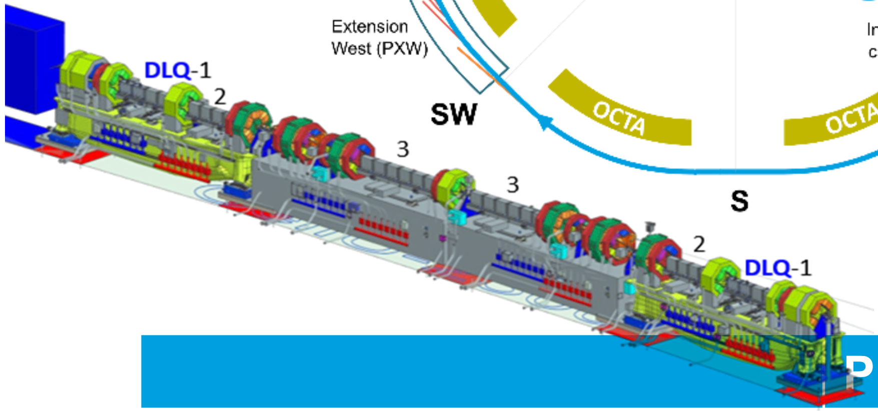
06 Mechanical Design

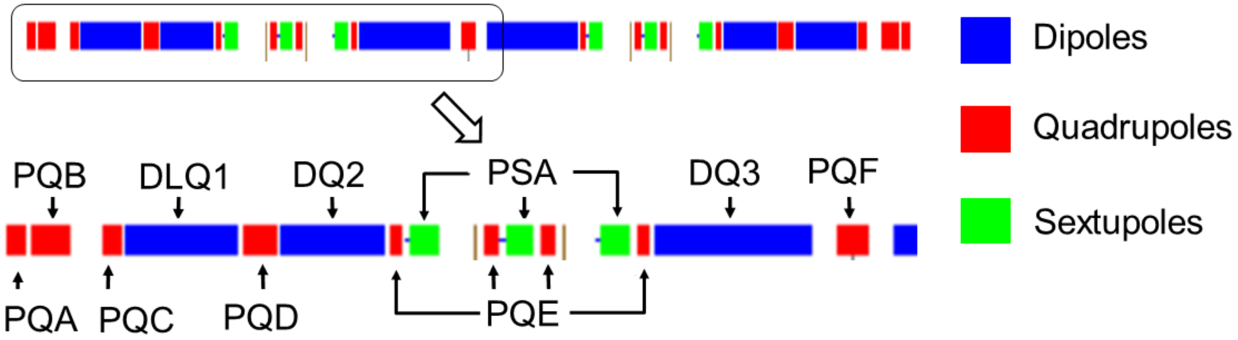
07 Prototype Status

PETRA IV Project









	PETRA IV
Lattice	H6BA
Energy (GeV)	6
Horizontal emittance (pm rad)	<20
Circumference (m)	2304

Magnets for the PETRA IV Project

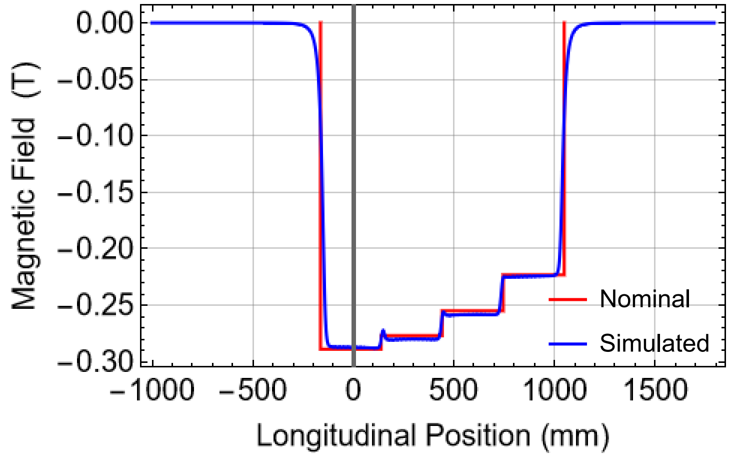
Accelerator	Name	Type	Magnetic length, m	Aperture diameter, mm	Maximum gradient (lattice)	Harmonics	Reference radius, mm	Quantatie
PETRA IV	PDLQA	PM DQL	1.112	25			7.9	144
	PDQB	PM DQ	1.084					144
	PDQC		1.818					144
	PQA	Quadrupoles	0.169	22	115.2 T/m	$\sqrt{\sum_{n=3}^{14} b_n^2}$ < $5\cdot10^{-4}$ $\sqrt{\sum_{n=3}^{14} a_n^2}$	6.5	144
	PQB		0.345		111.8 T/m			144
	PQC		0.161	25	85.9 T/m		7.9	144
	PQD		0.28		97 T/m			144
	PQE		0.11		90.8 T/m			576
	PQF		0.25		82.9 T/m			72
	PQG		0.2	40	46 T/m			162
	PQH		0.3	25	86 T/m			14
	PQK		0.2	80	19 T/m			1
	PSA	Sextupole	0.25	25	2248 T/m^2			432
	POA	Octupole	0.09		100000 T/m^3			288
	PCA	Corrector	100	25				576
DESY IV	DQs							72
	Quadrupoles							78
	Sextupoles							66
	Correctors							72
Transfer line	Dipoles							15
	Quadrupoles							35

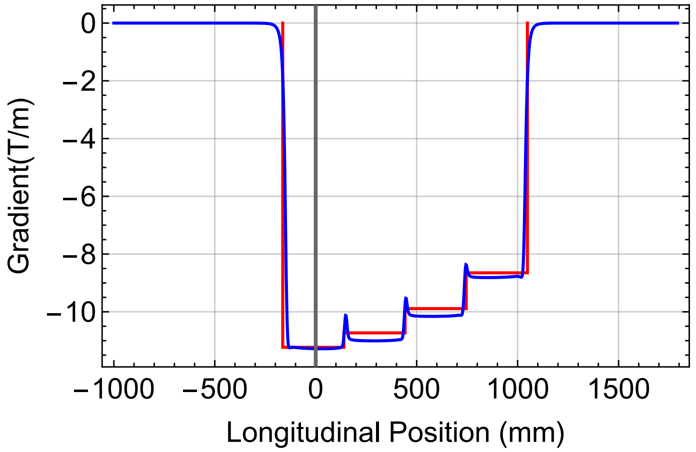
DLQ Parameters

Small change of lattices parameters was implemented together with more elaborated endpoles

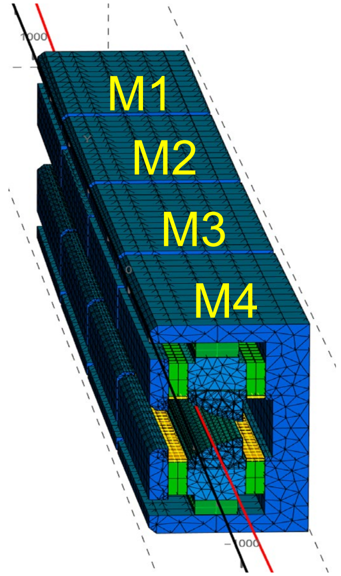
Required DLQ1 Parameters

	Magn. Length, m	Field, T	Gradient, T/m	Integrated field, T.m	Integrated gradient, T	B/G, mm
DLQ1	0.303 0.303 0.303 0.303	-0.289 -0.277 -0.255 -0.223	-11.23 -10.73 - 9.89 - 8.65	-0.0878 -0.0838 -0.0773 -0.0676	-3.40 -3.25 -3.00 -2.62	25.8 25.8 25.8 25.8
				∑ = -0.317	∑ = -12.27	





- ❖ Gradient reduced by 4.5% while field remains constant (slightly increased B/G ratio)
- ✓ New pole profile is created to obtain required B/G ratio
- ✓ Reduced gap between auxiliary pole and yoke from 15mm to 13mm helps to improve homogeneity of gradient



✓ Different (inner and outer) endpoles integrated in the magnetic design for better cancellation of sextupole also inside each module

DLQ1 Re-Optimisation

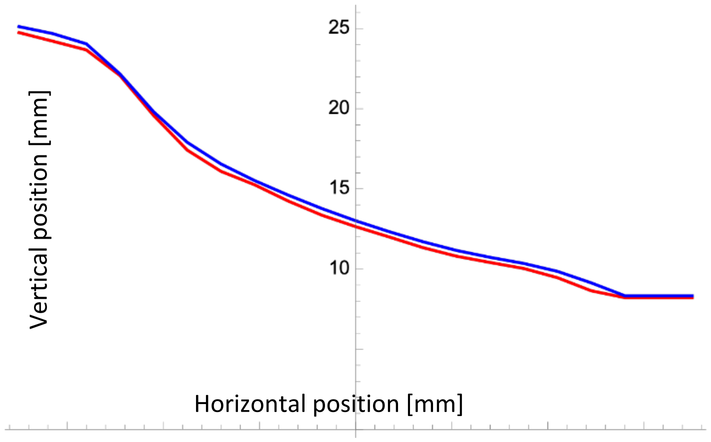
Improved field quality for all DLQ1 modules

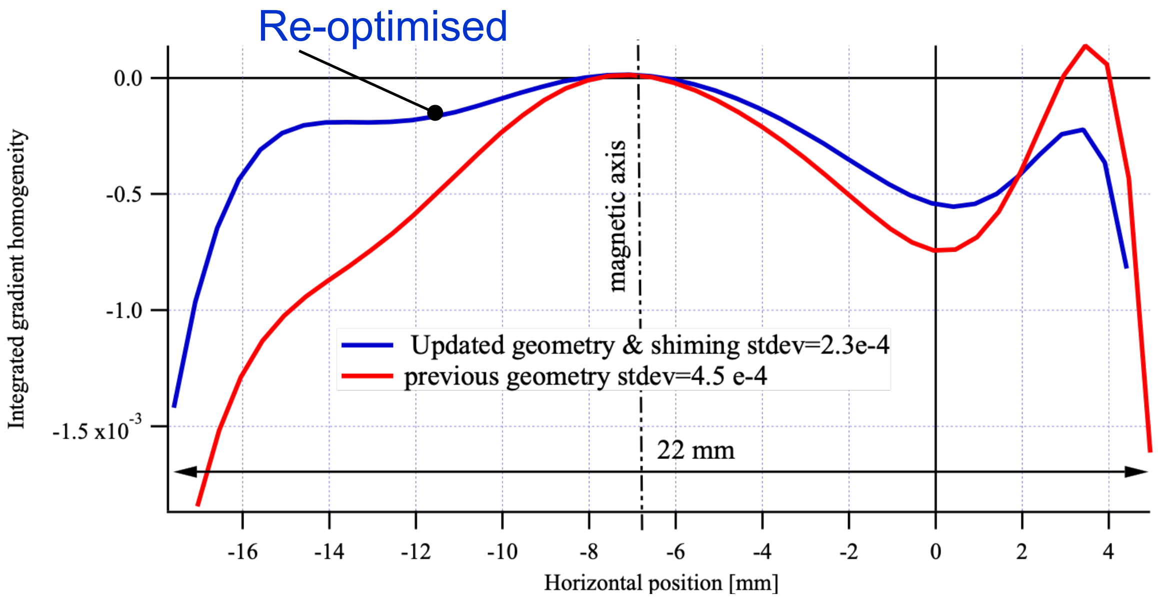
Simulation on a straight 3D DLQ1

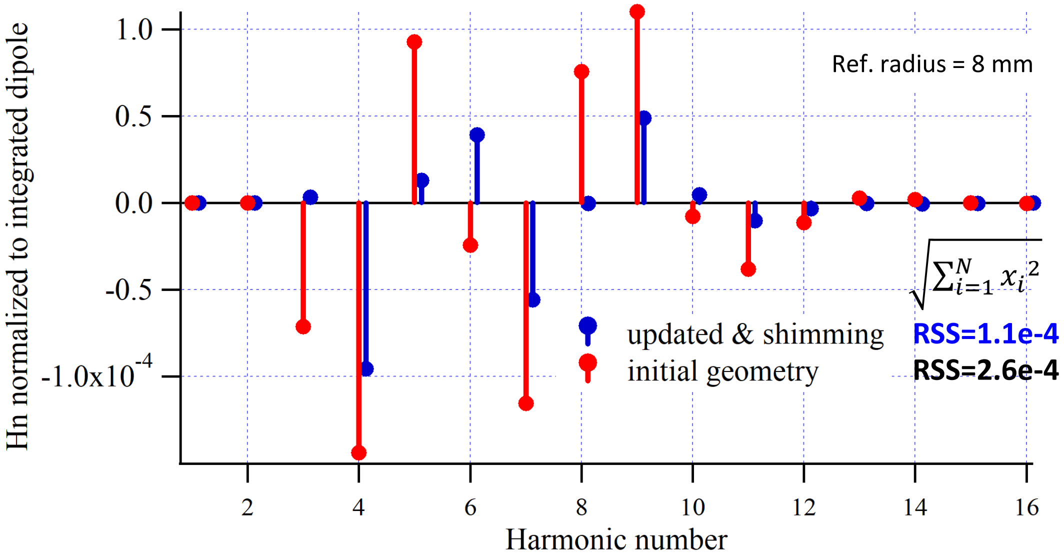
- Individual modules corrected using thin iron shims:
  → nominal gradient & correction of sextupole term
- Movable shunts used on full assembly for final tuning of integrated gradient & sextupole

Slight change of pole profile

- Gap increased by ~0.5 mm (at pole axis)
- Pole geometry remains, only pole profile updated

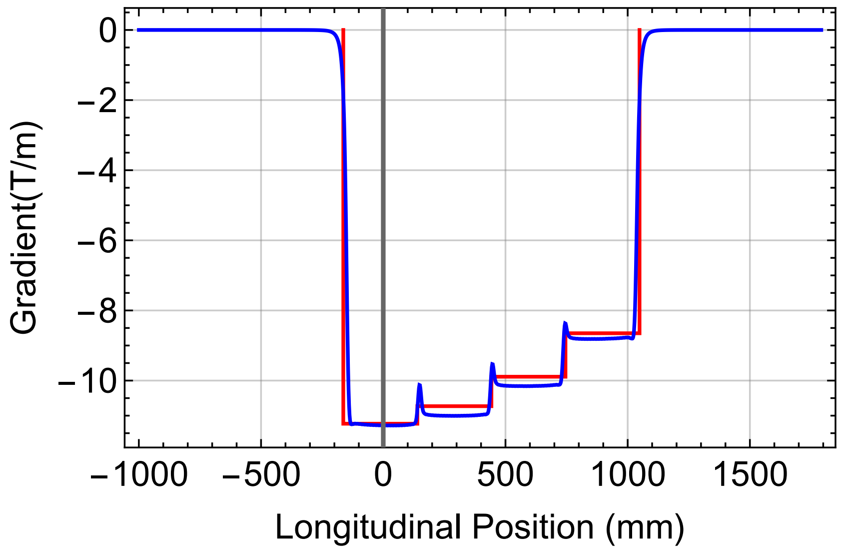


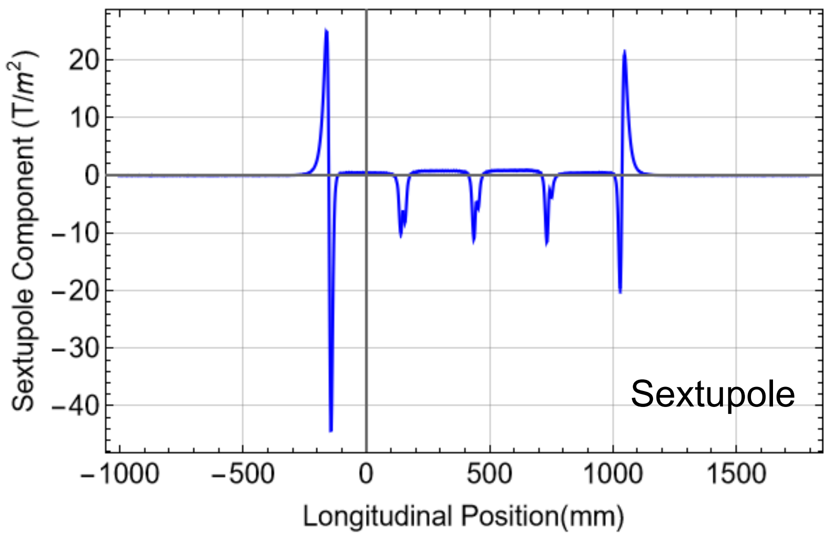




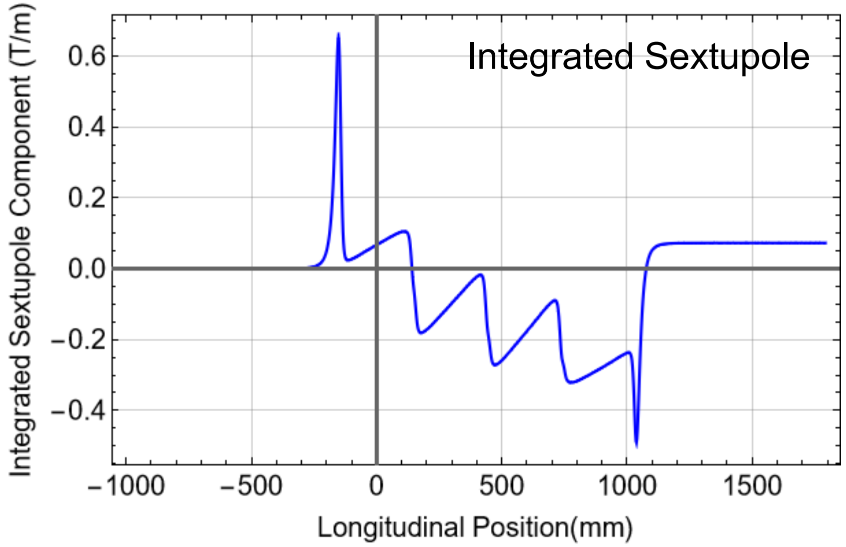
DLQ1 – Full 3D Model

Longitudinal evolution of higher order moments





- **>** Quadrupole
  - Intrinsic dips of the gradient due to module segmentation
- **>** Sextupole
  - Small systematic sextupole contributions at ends and module interfaces
  - Significantly improved by reshaping the inner enpole
  - Outer endpoles designed to cancel the integrated sextupole



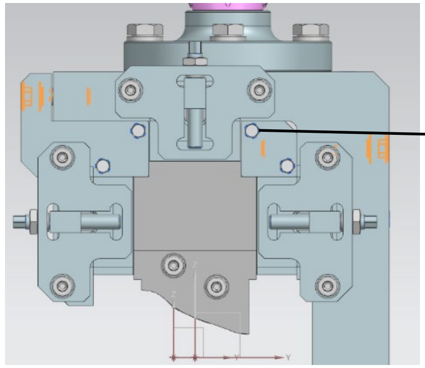
Field Tuning

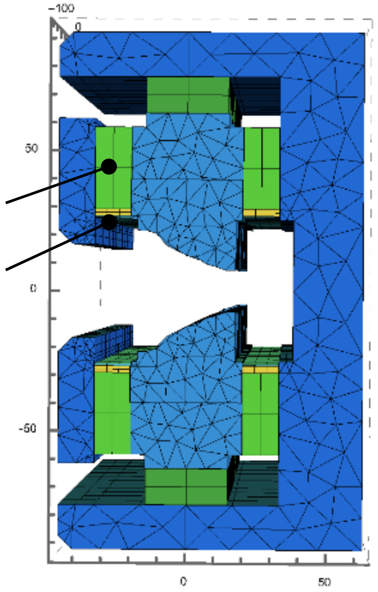
Different shimming options of single modules

(→ 2nd PerMaLIC Workshop, ALBA, Nov.22)

Tuning the gradient and control of sextupole errors by

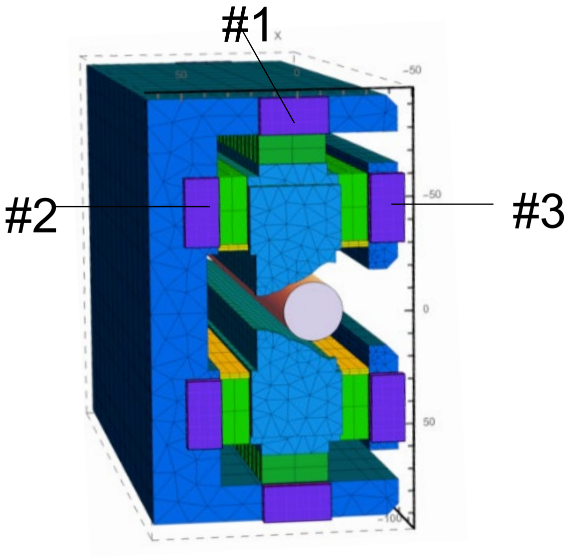
- Iron shims on side magnets
- Inequal magnet filling
- Fe-rods inside aluminium spacer

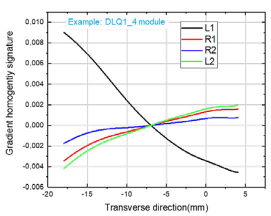


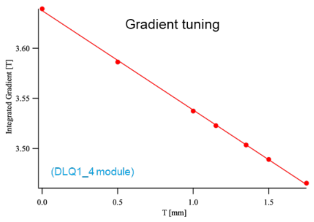


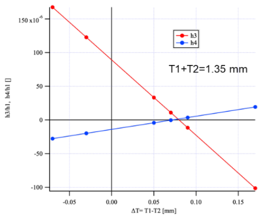
Fine corrections of fully assembled DLQs

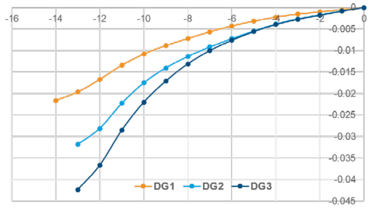
- Movable shunts at outer ends
- Different signatures depending on location
- Final corrections for integrated gradient
- Tuning of 1st vs 2nd field integral





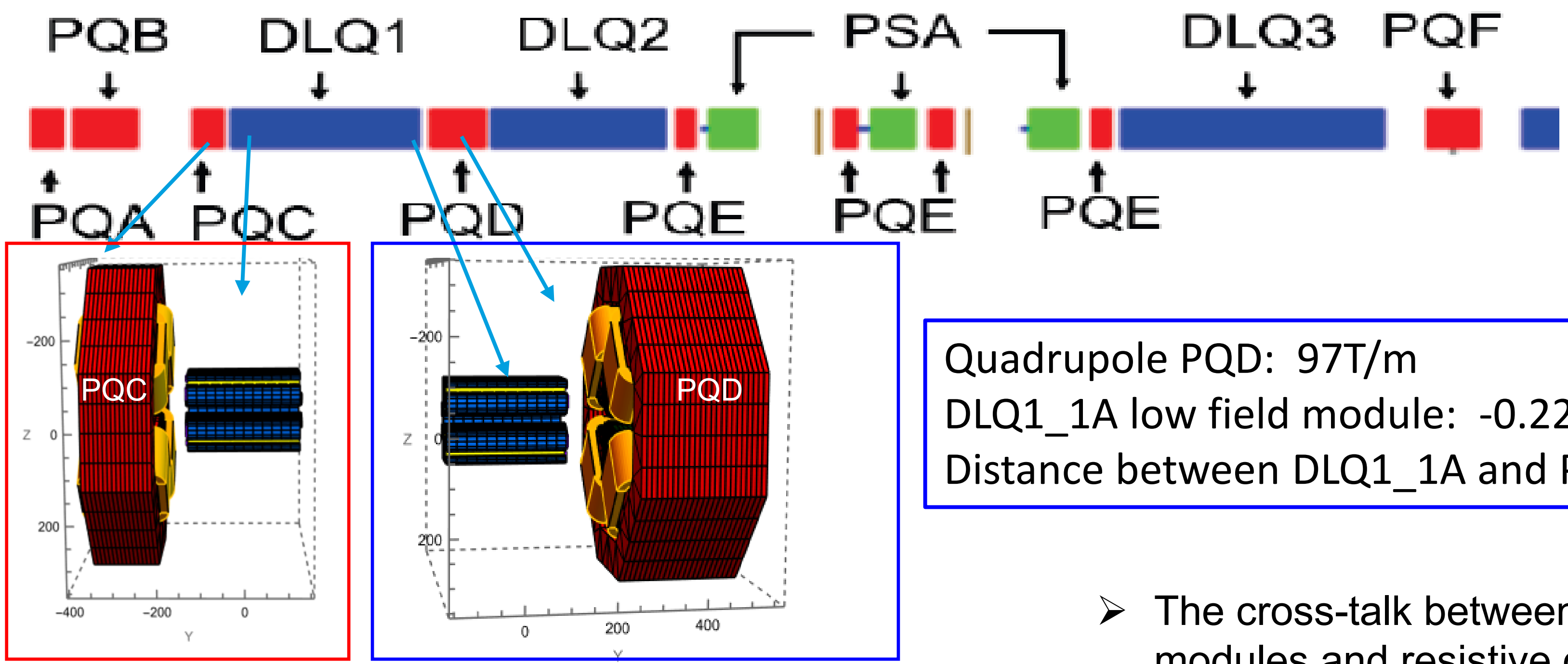


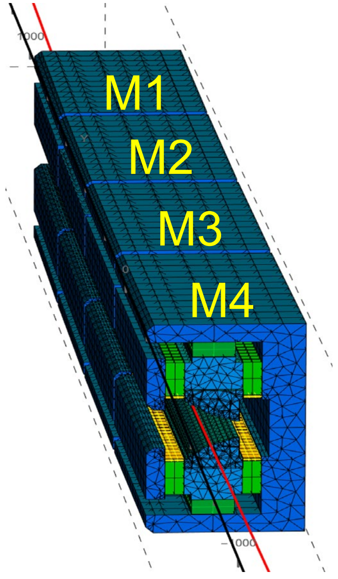




Cross-Talk Studies with Quadrupole

Slightly enhanced filling of high-field module has been necessary





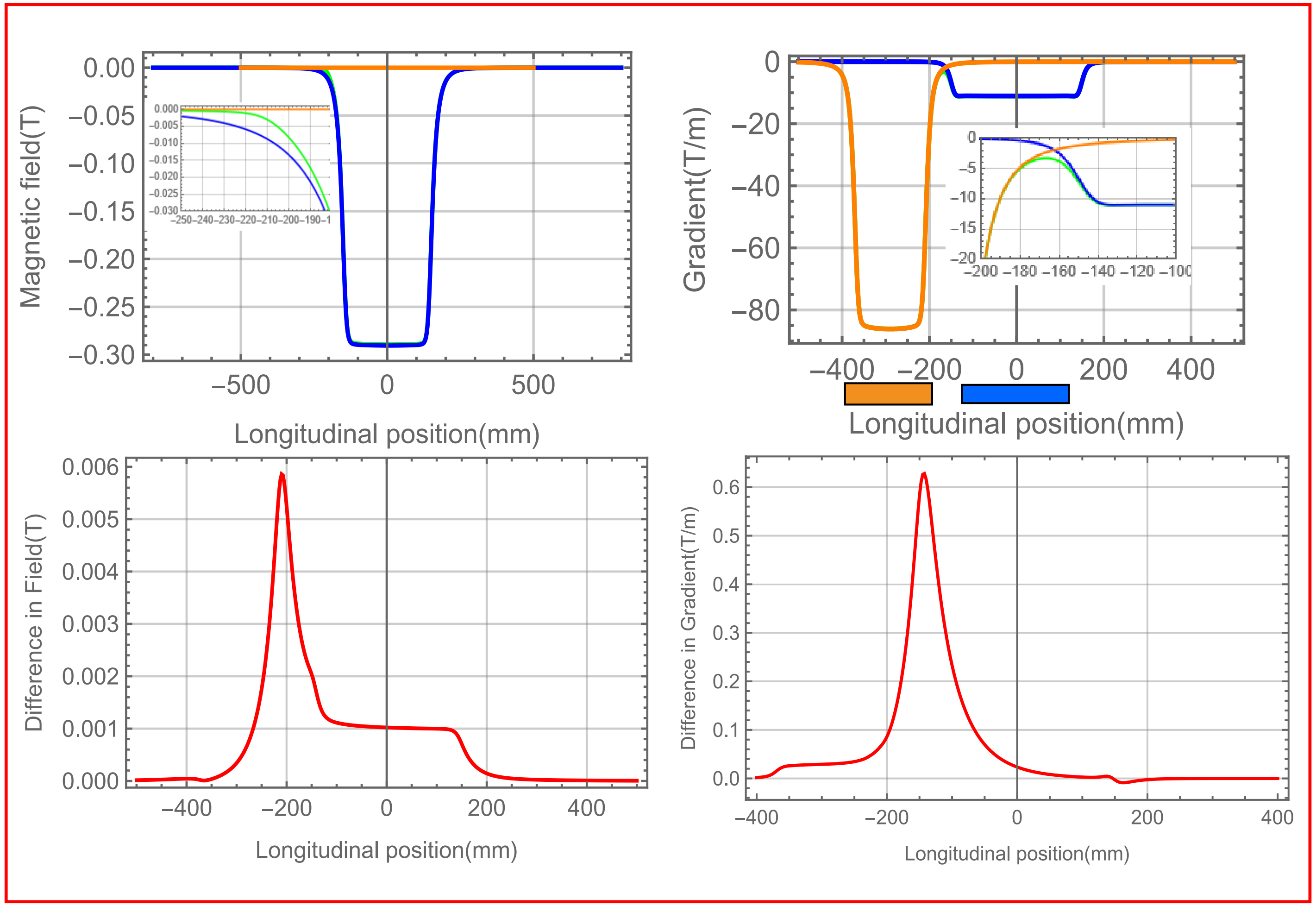
Quadrupole PQD: 97T/m
DLQ1_1A low field module: -0.223T, -8.65T/m
Distance between DLQ1_1A and PQD = 105mm

Quadrupole PQC: -86T/m
DLQ1_4A high field module: -0.289T, -11.23T/m
Distance between DLQ1_4A and PQC = 63mm

- The cross-talk between PM magnet dipole modules and resistive quadrupoles has been simulated in Radia.
- The iron of the neighboring quadrupole acts as a shunt path for the fringe field of the dipole and changes the local field and gradient of the DLQ modules.

Cross-Talk Studies with Quadrupole (DLQ1_4A+PQC)

Overall reduction in integrated strength and gradient is within tuning range of shims



- DLQ and QUAD
- DLQ alone
- Quad alone
- Total Difference = (Q+D) -(Q) -(D)

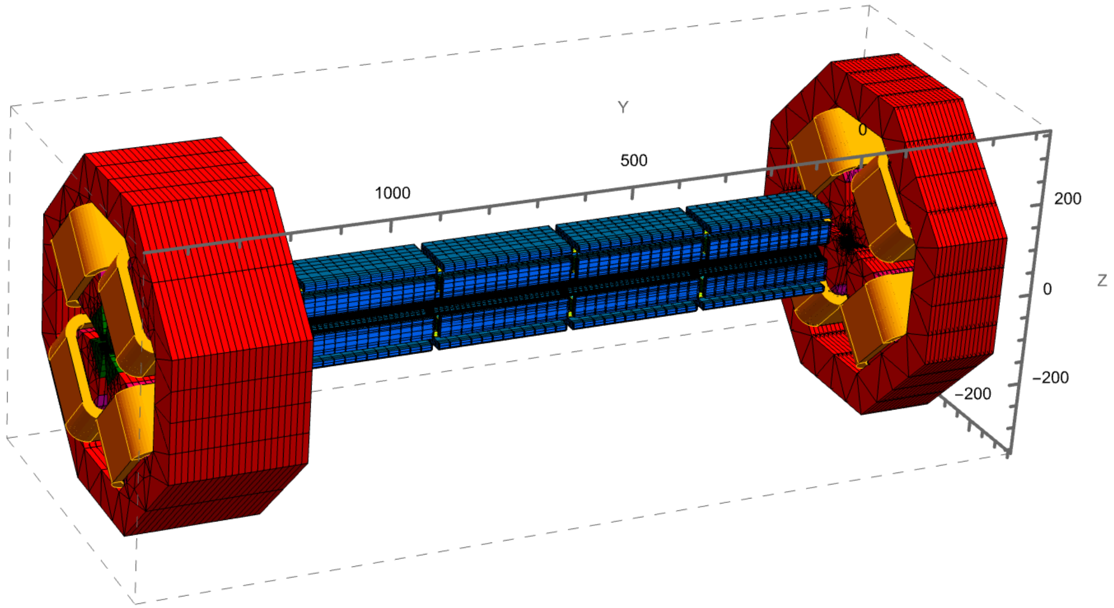
Similar results for the cross talk DLQ1_1A+PQD

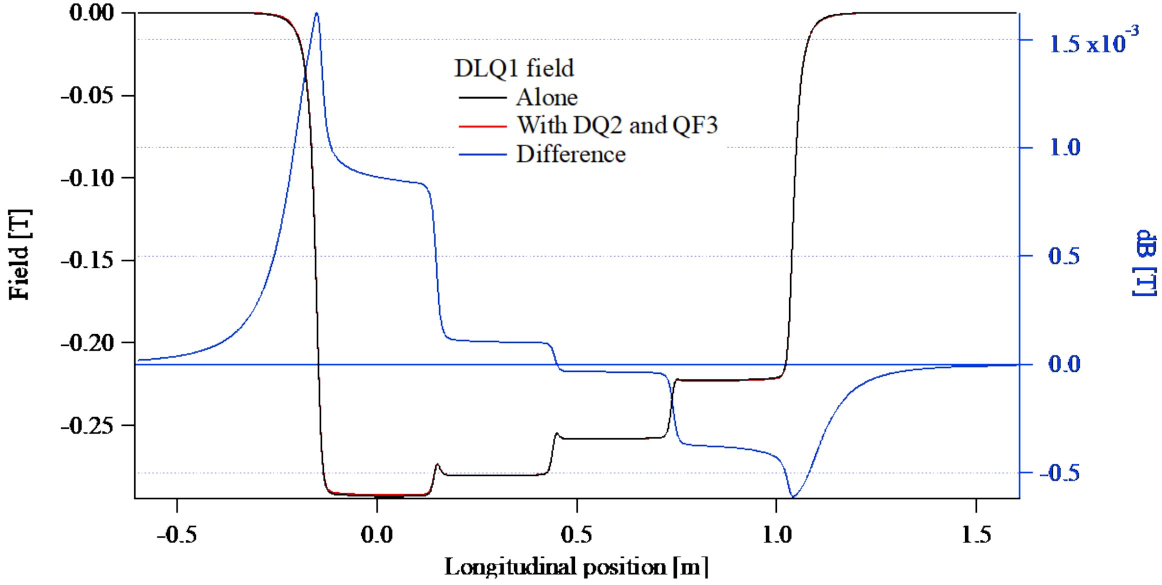
		Quad Effect Q=(Q+D)-(Q)	DLQ Effect D=(Q+D)-(D)	Total Effect (Q+D)
DLQ1_4A and PQC	Int. field [Tm]	0.00029	0.00046 (-0.50%)	0.00076 (-0.82%)
	Int. gradient [T]	0.0023 (-0.015%)	0.049 (-1.44%)	0.05 (-1.48%)

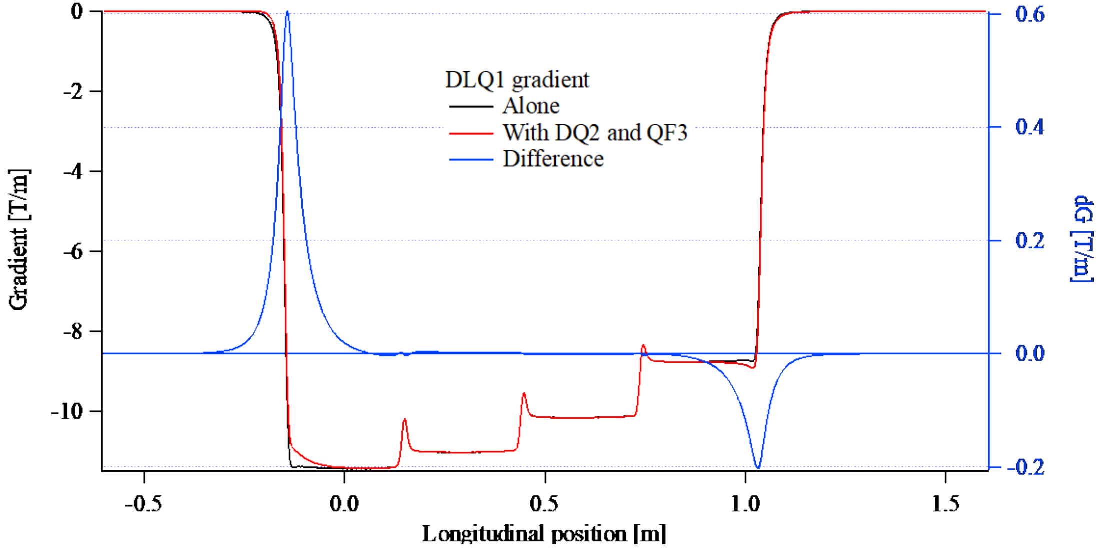
Reduction of DLQ integrated field (gradient) normalized to the integrated nominal value

Cross-Talk of Full DLQ1 with PQC and PQD

Overall cross-talk mainly impacts on DLQ1







Integrated field:

- DLQ1 alone : 0.31693 Tmm
- DLQ1 with Quads : 0.31667 Tmm (-0.085 %)

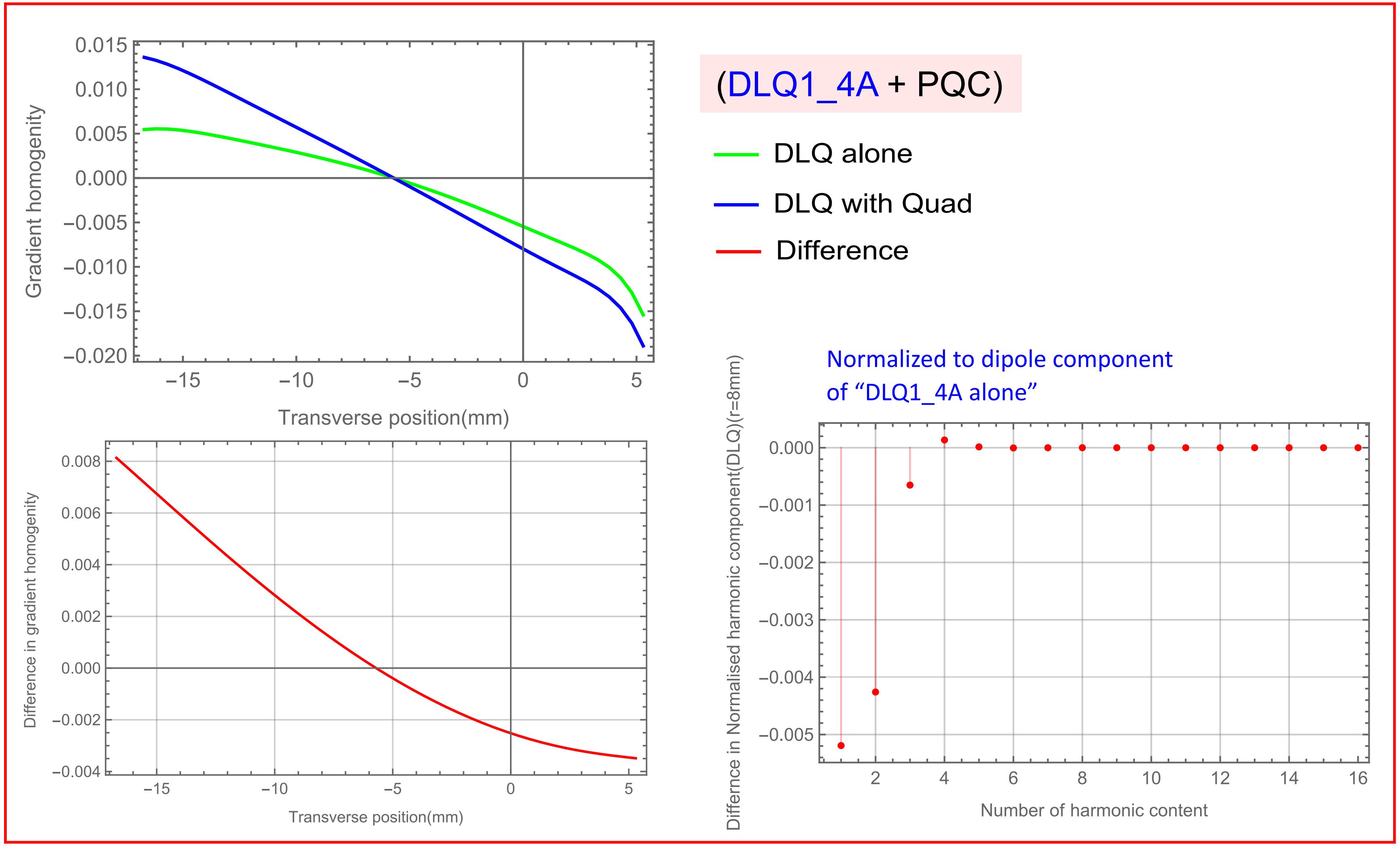
Integrated gradient:

- DLQ1 alone : 12.3002 T
- DLQ1 with Quads : 12.2710 T (-0.24 %)

→ Anticipated and corrected in module filling & shimming

Analysis of Transverse Cross-Talk Effects

Spurious higher harmonic components are created by the asymmetry of the DLQ



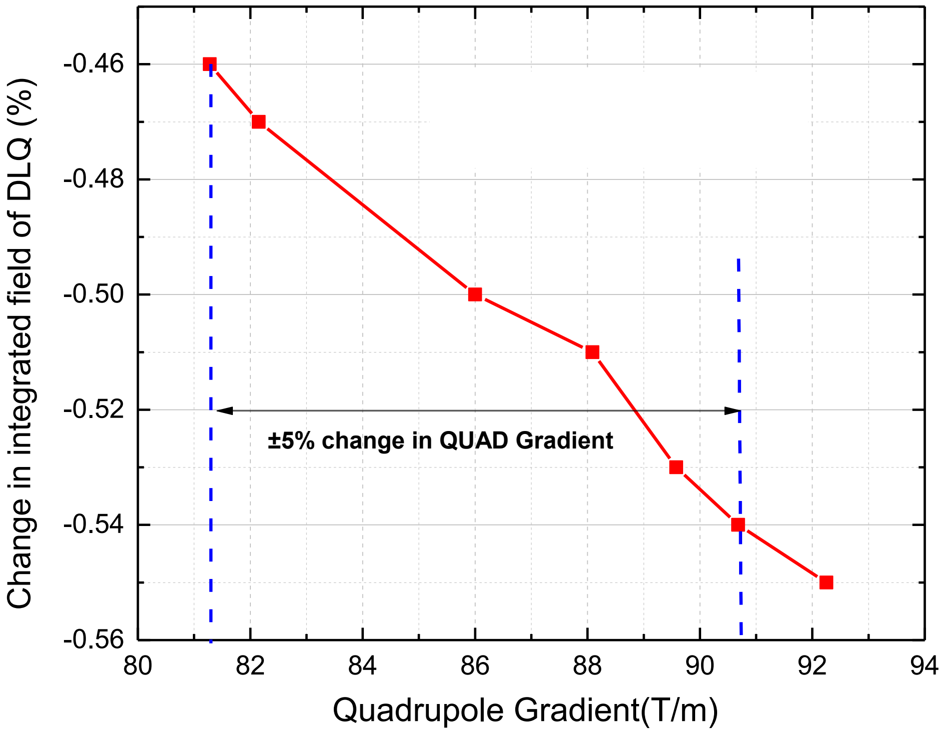
- Fringe fields of the PQC quad change the magnetization of DLQ iron which results in some extra harmonic components

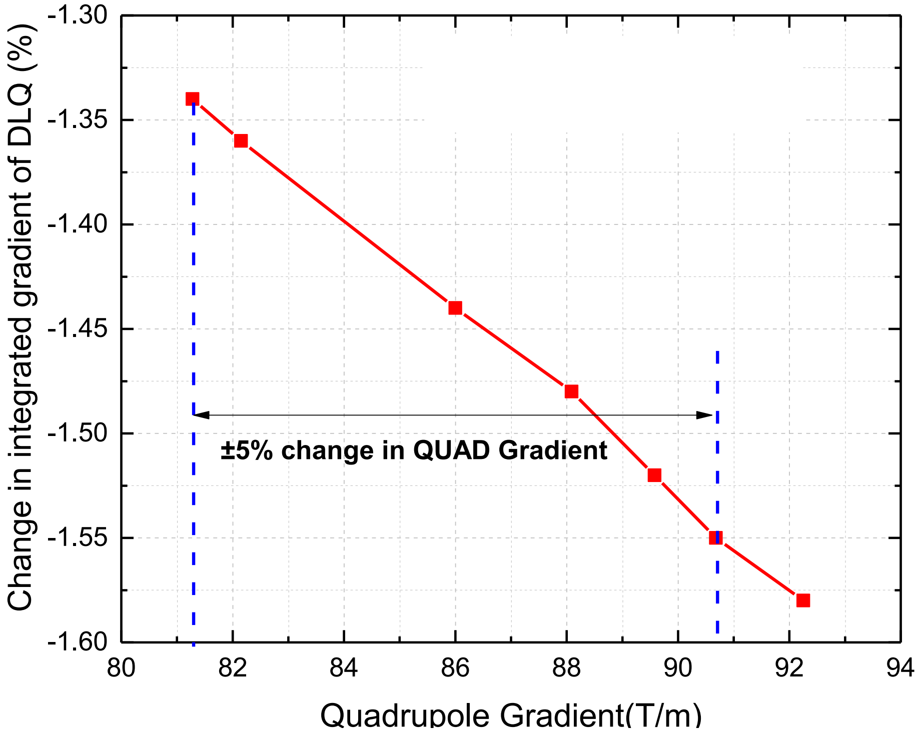
For the low-field module case (DLQ1_1A+PQD), the contribution of higher harmonics has opposite sign and is ~2x smaller

- These cross-talk effects correspond to the nominal quadrupole gradient. Additional effects occurring by gradient changes (<5%) must be taken into account during operation…

Variations in DLQ1 Module due to Changing Quad Gradient

Expected changes of DLQ are small but need to be considered by beam dynamics



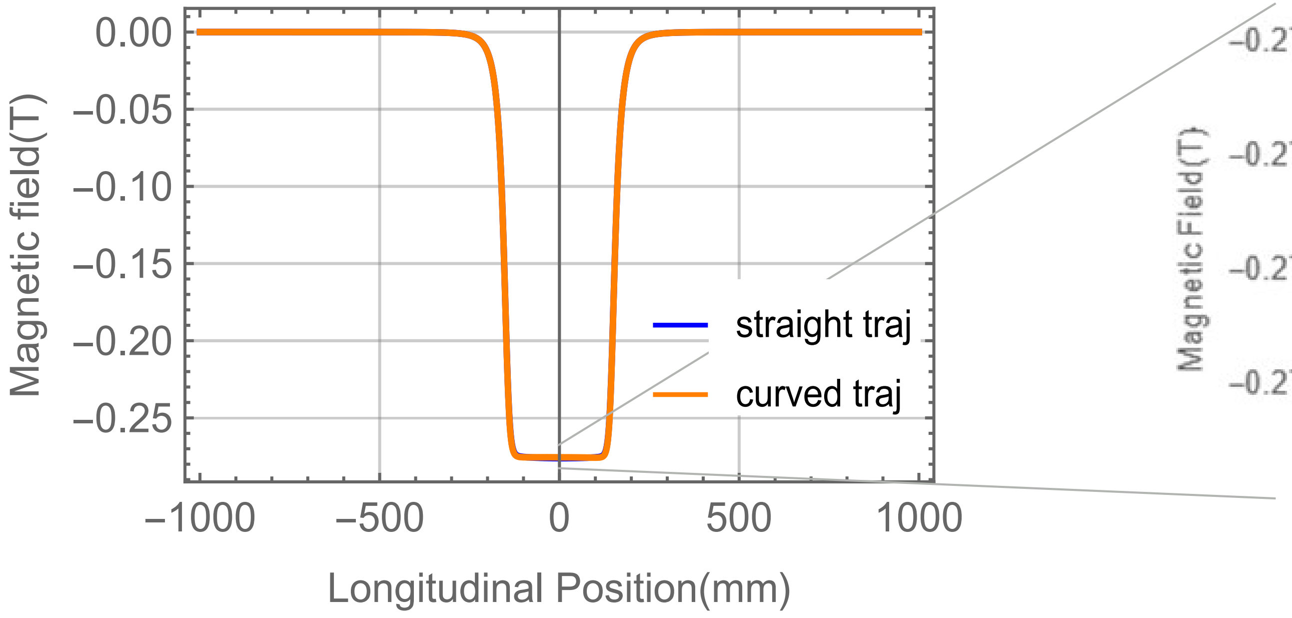


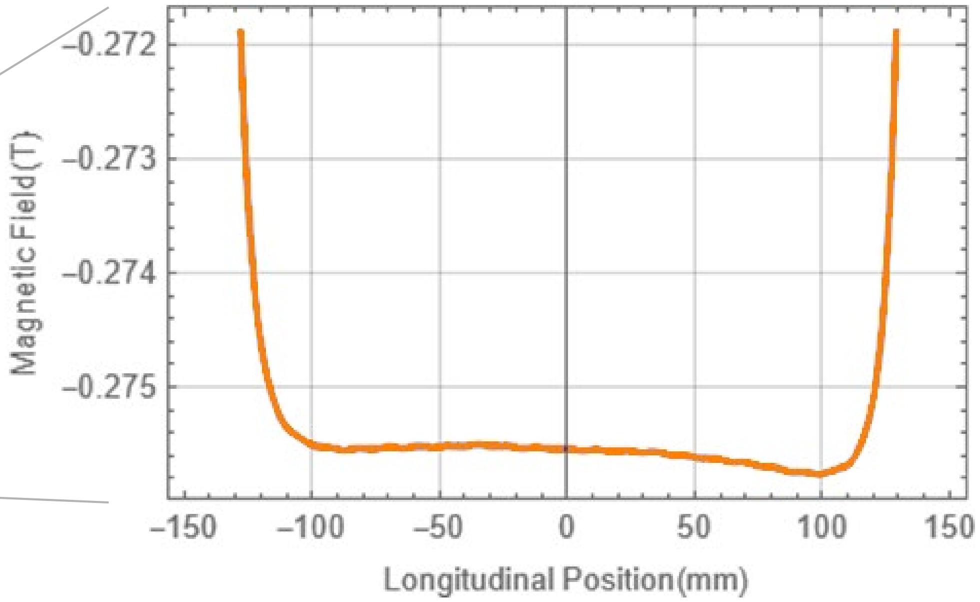
- Linear effect on DLQ strength for changing quadrupole gradient:
  -8.2×10^{-5} /1(T/m) in integrated DLQ field and -2.2×10^{-4} /1(T/m) in integrated DLQ gradient,
  which needs to be anticipated in beam dynamics by dipole correctors all along the ring

- Placement of some shield between DLQ and quadrupole does not improve the cross-talk issue

Comparison of Straight vs Curved Trajectory (1)

Small systematic differences to be considered during magnetic measurements

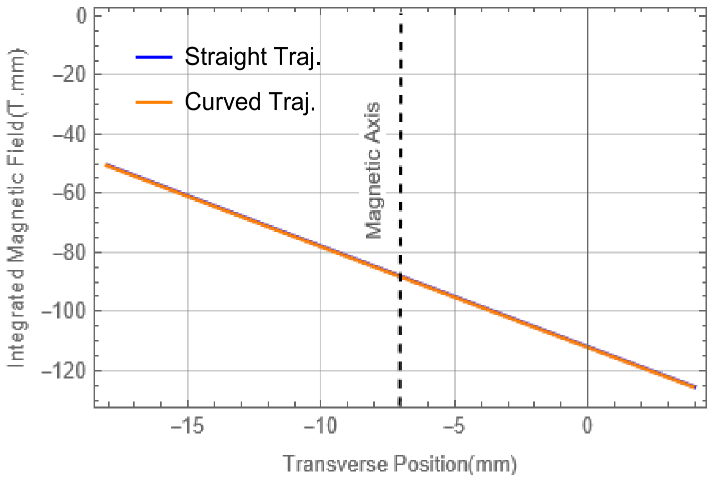


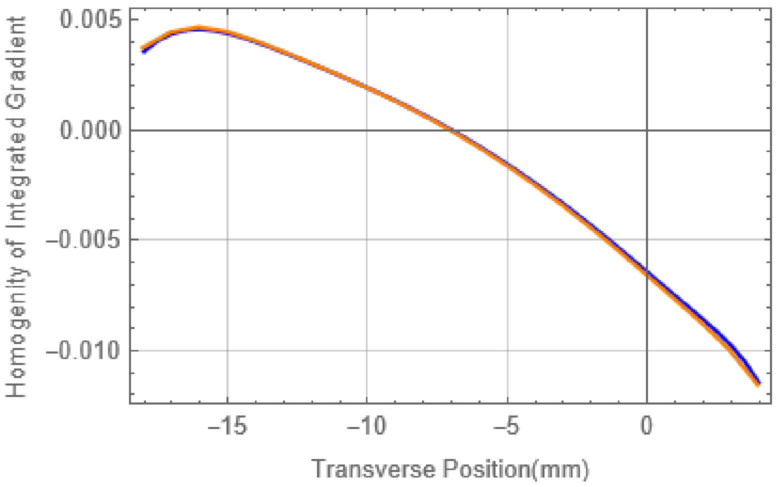


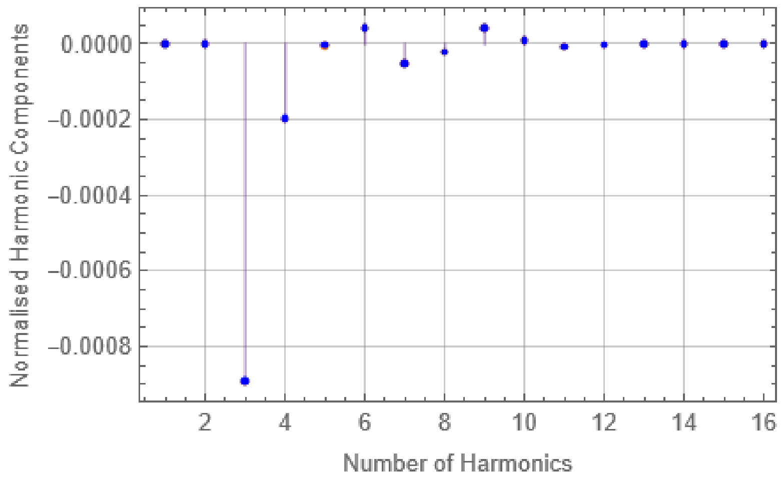
Curved trajectory provides a curved field inside the module

Comparison of Straight vs Curved Trajectory (2)

Small systematic differences to be considered during magnetic measurements



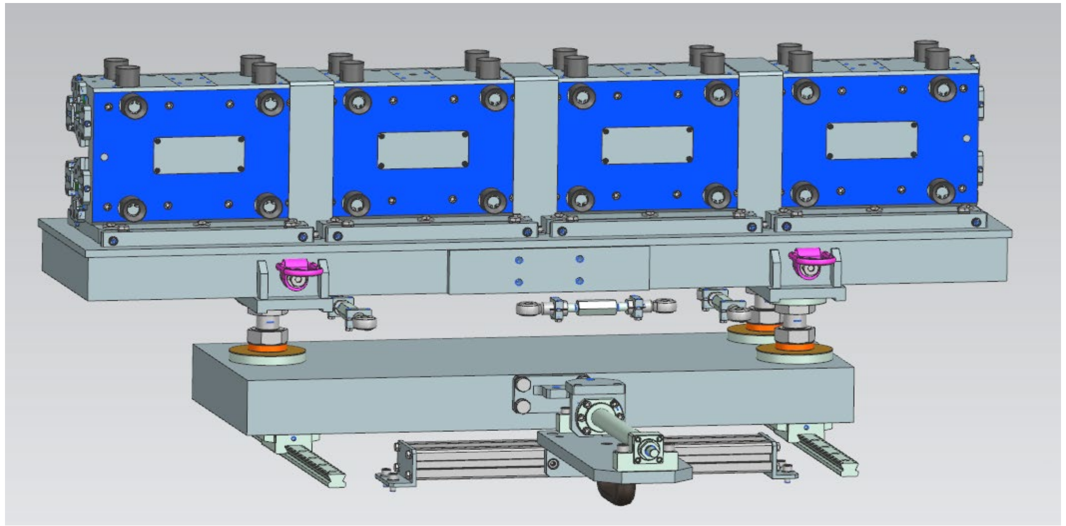




	Straight Trajectory	Curved Trajectory	Difference (S-C)
Integr. Field	-0.08820 Tm	-0.08822 Tm	0.000018 Tm (-2×10-4)
Integr. Gradient	-3.4110 T	-3.4117 T	0.00069 T (-2×10-4)
Integr. Sextupole	0.0761 T/m	0.0788 T/m	-0.0027 T/m
B/G ratio	25.85 mm	25.86 mm	0.009 mm

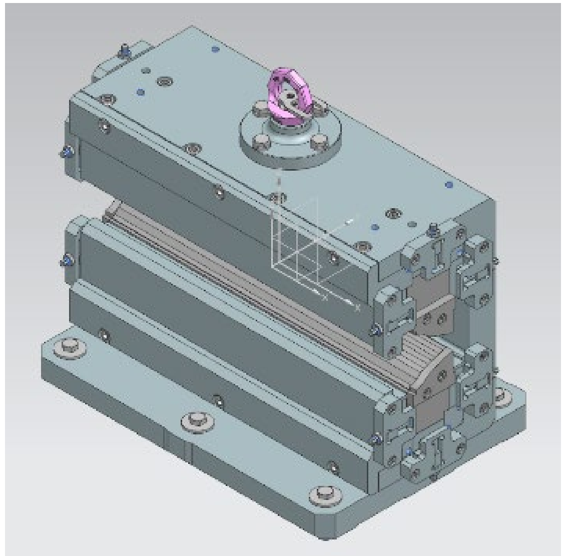
Mechanical Design

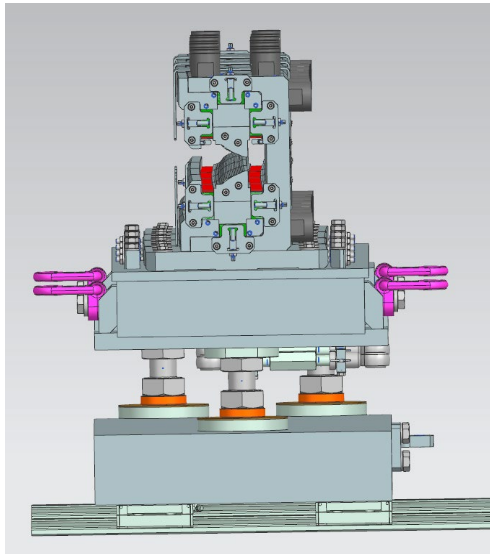
Design completed for DLQ1 (T.Ramm, ZM1)



Concept

- Goal: generic design for all types and strength of modules
  adaptable to later changes
- Iron yoke milled as a single piece,
  Aluminium inserts as precision spacers for pole fixation



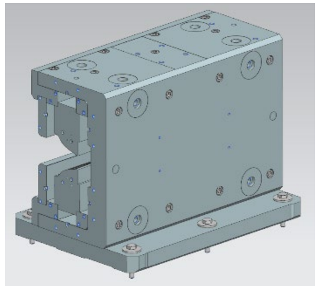


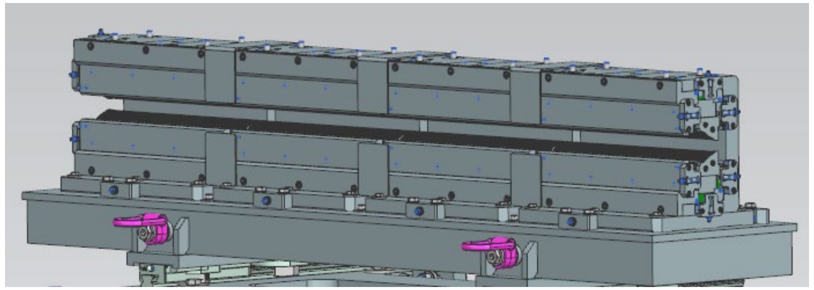
Status

- Design of DLQ1 magnet completed
- Work on mover support and alignment units
  for prototype is nearly completed

DLQ1 Prototype

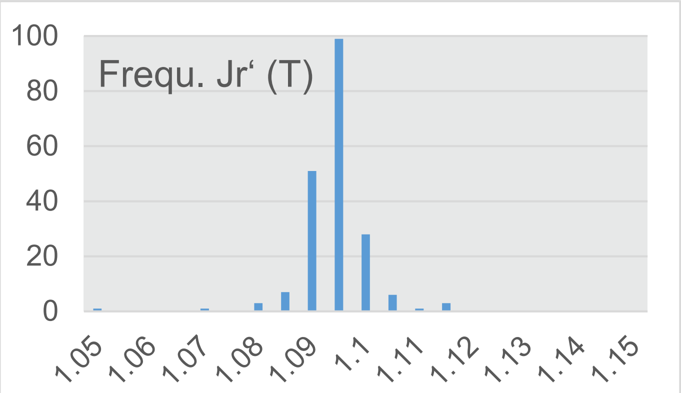
Manufacturing of all parts and tools in progress

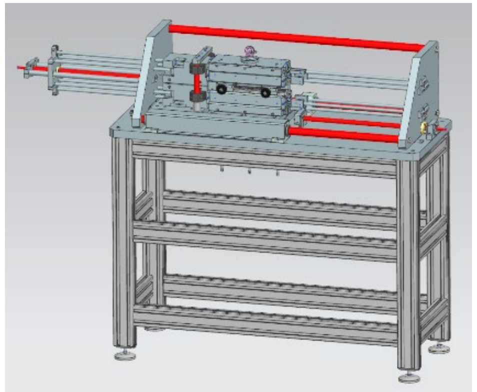


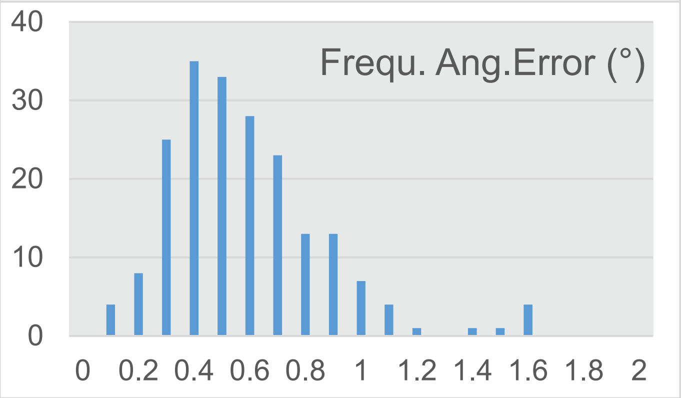


Manufacturing status

- Strategy: fabricate modules at different vendors to qualify them for serial production
- All necessary parts have been contracted
- Sub-supply soft iron material to manufacturers; iron material has only been partly delivered (long lead time)
- Firstly, 1 full DLQ1 (4 modules) shall be built
- 3 further basis-modules are produced for
  - dedicated single-module magnetic studies
  - further assembling tests
  - (Re)-construction of modules to a DLQ2 and DLQ3 prototype
- PMs for the prototypes have been delivered
- Mounting tool for PMs into module is in production







Thank you

Contact

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