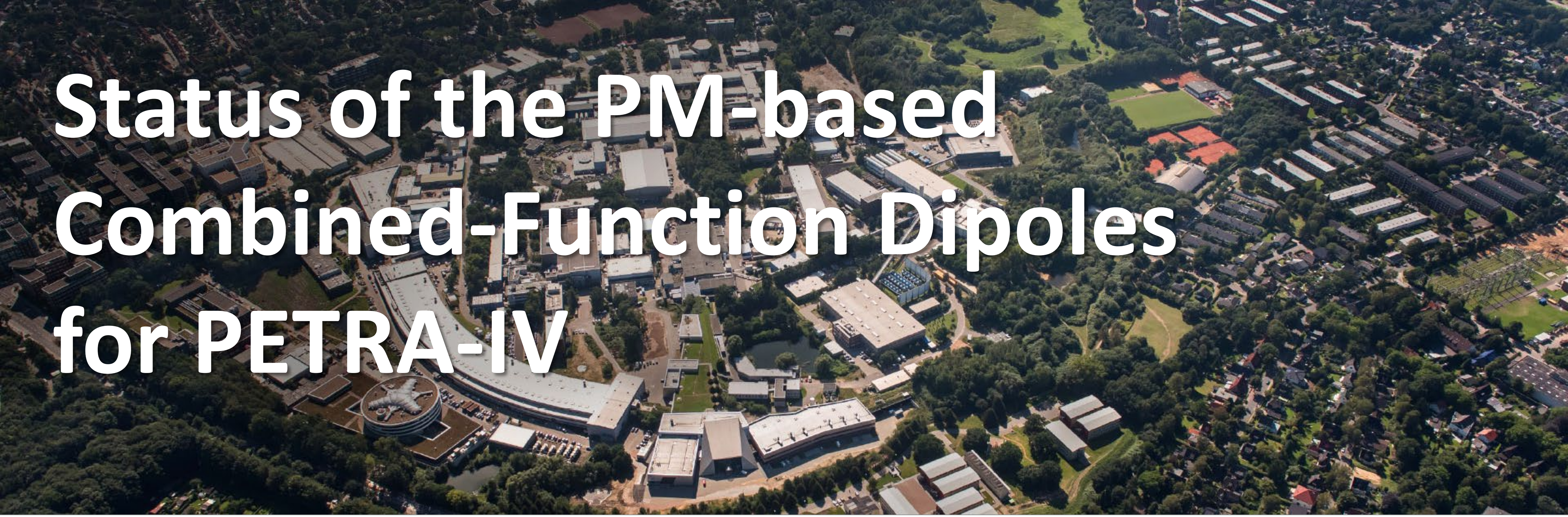


Status of the PM-based Combined-Function Dipoles for PETRA-IV

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

2nd PerMaLIC Workshop, ALBA, 03.-04.11.2022

HELMHOLTZ

DESY.

Outline

Permanent magnet based DLQs

01 Project Overview

- PETRA IV upgrade
- Magnet portfolio

02 Full Model of DLQ1

- Parameters
- Magnetic field analysis
- Trajectory

03 Shimming Strategies

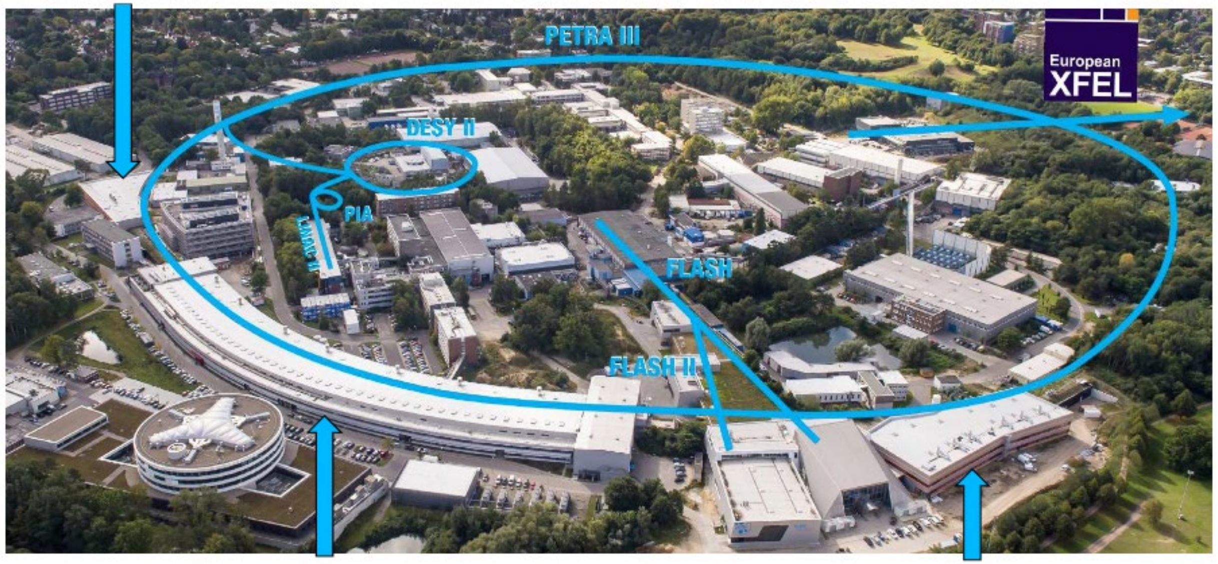
- Single Modules
- Fully assembled DLQs

04 Mechanical Design

- General concept
- Design details

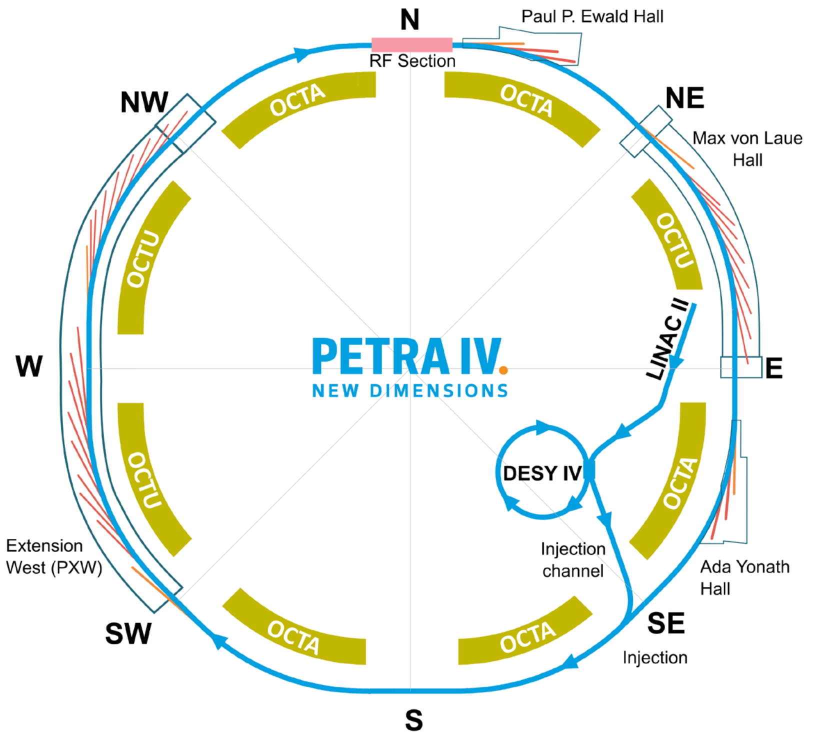
PETRA IV Project

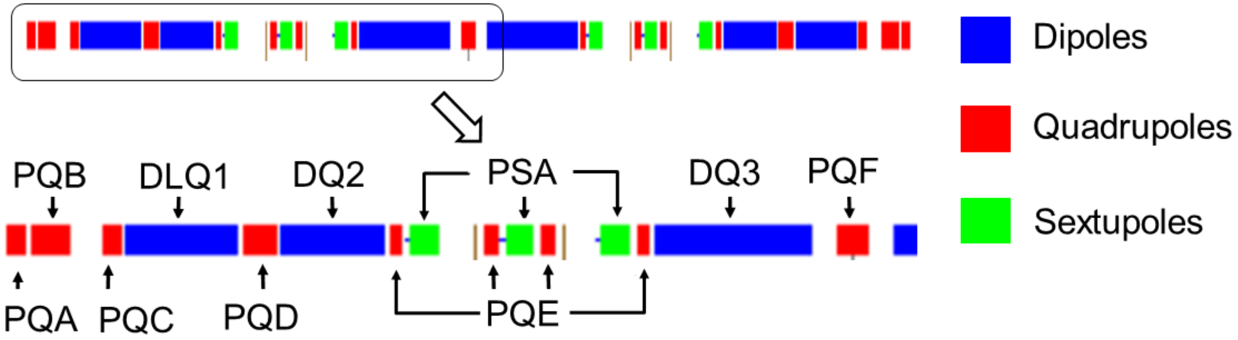
Ada Yonath Hall
Extension Hall East



Max von Laue Hall

Paul P. Ewald Hall
Extension Hall North





	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

DLQs – Overview and Parameters

PETRA IV. NEW DIMENSIONS

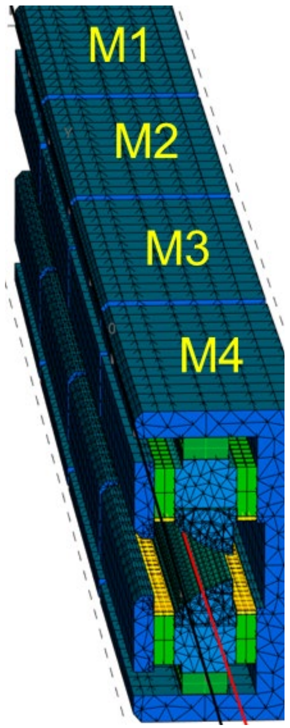
Permanent magnet-based dipoles with transverse and longitudinal gradient

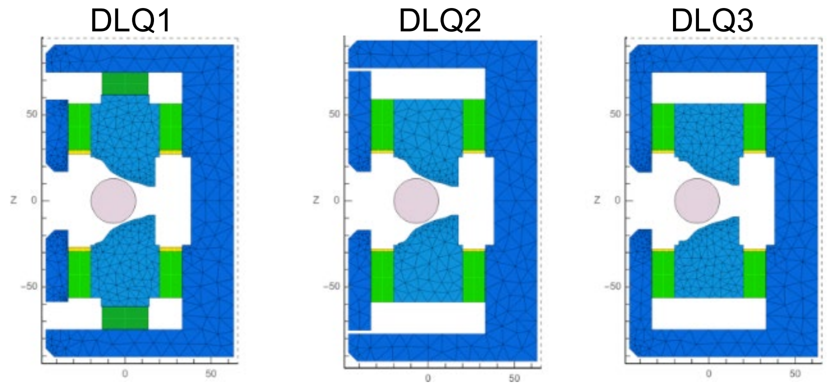
Developed and built in collaboration with ESRF

Design derived from ESRF-EBS DL-magnets

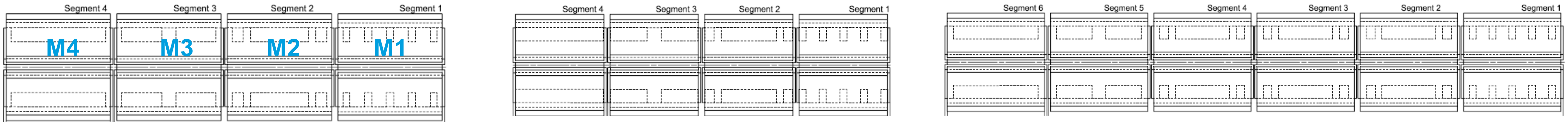
General

- Armco poles and yoke;   SmCo magnets
- Modular concept, unification across the 3 DLQ types as much as possible (yoke, block size, mounting, shimming etc.)
- 144 DLQs of each type to build, i.e. ~2000 modules
- Outer diameter of vacuum chamber: ~25 mm
- Thermal shims for temperature compensation





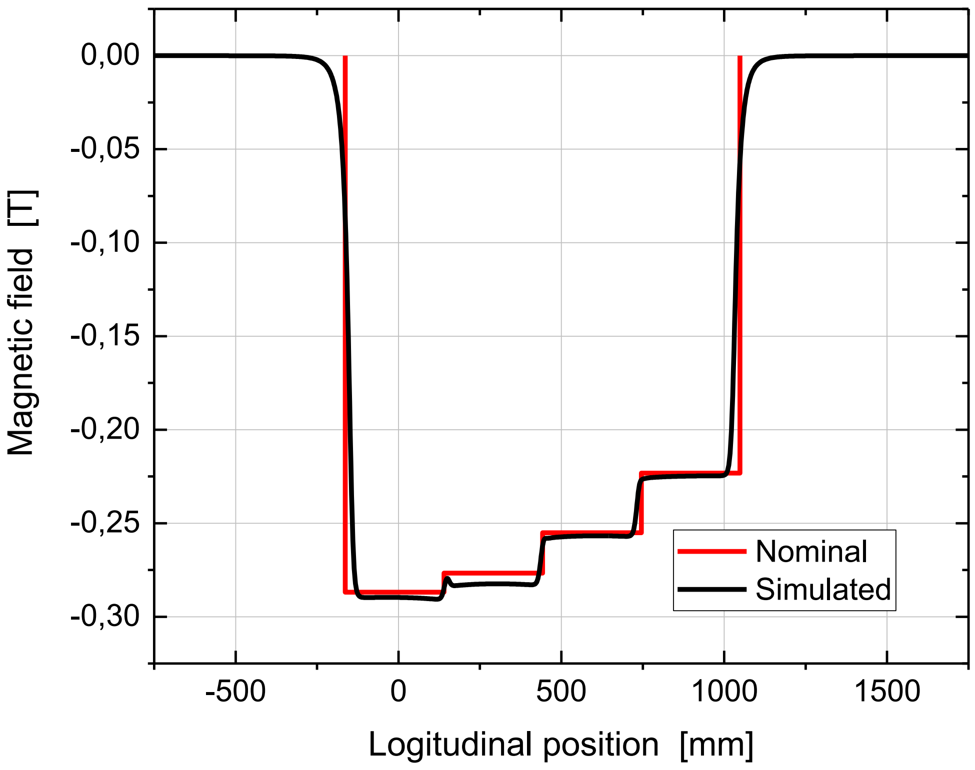
	Magn. Length, m	Field, T	Gradient, T/m
DLQ1	0.303 0.303 0.303 0.303	-0.287 -0.277 -0.255 -0.223	-11.69 -11.27 -10.39 - 9.09
DLQ2	1.084	-0.191	-7.81
DLQ3	1.818	-0.193	-6.63



DLQ1 DLQ2 DLQ3

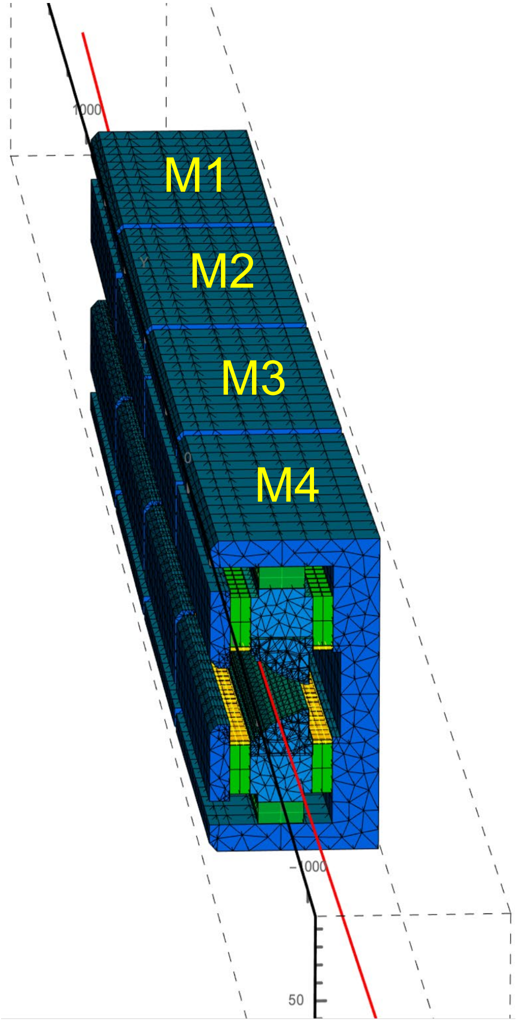
DLQ1 – Full 3D Model

Field profile and parameters



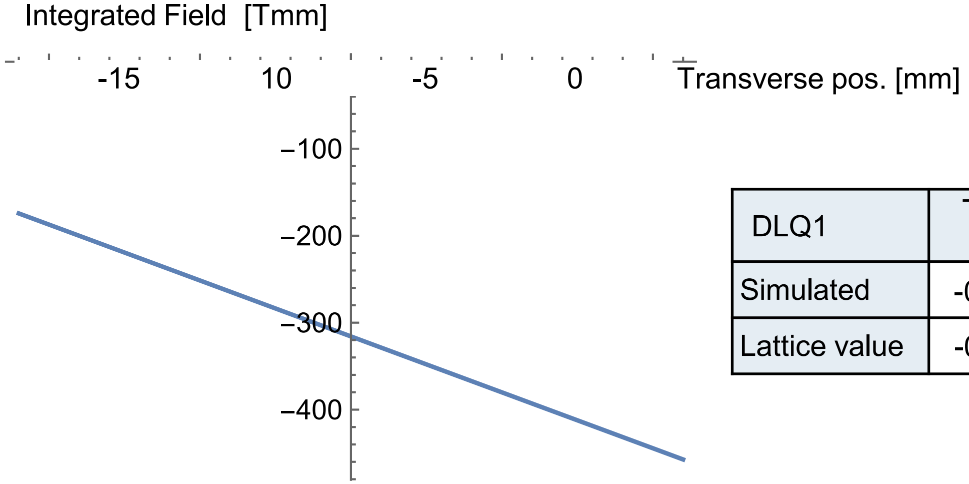
- 4 modules à 303mm length (nom.) L_{tot} = 1212mm
- Longitudinal field gradient with constant B/G ~ 0.025m for transverse gradient
- Nominal magnet filling factors
  - M4…M1: 0.87% ,0.83%, 0.75%, 0.65%

DLQ1	B [T]	G [T/m]
M4	-0.287	-11.69
M3	-0.277	-11.27
M2	-0.255	-10.39
M1	-0.223	-9.09

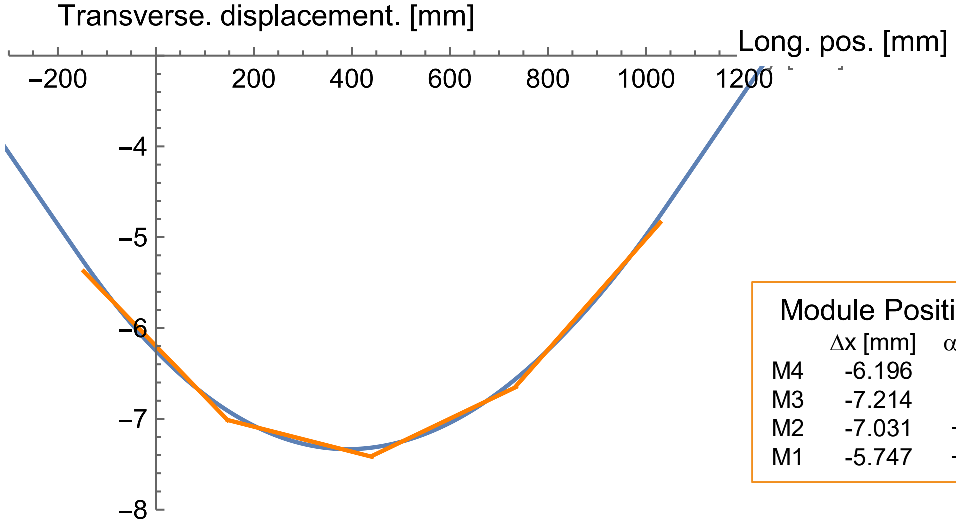


DLQ1 – Full 3D Model

Analysis of magnetic field

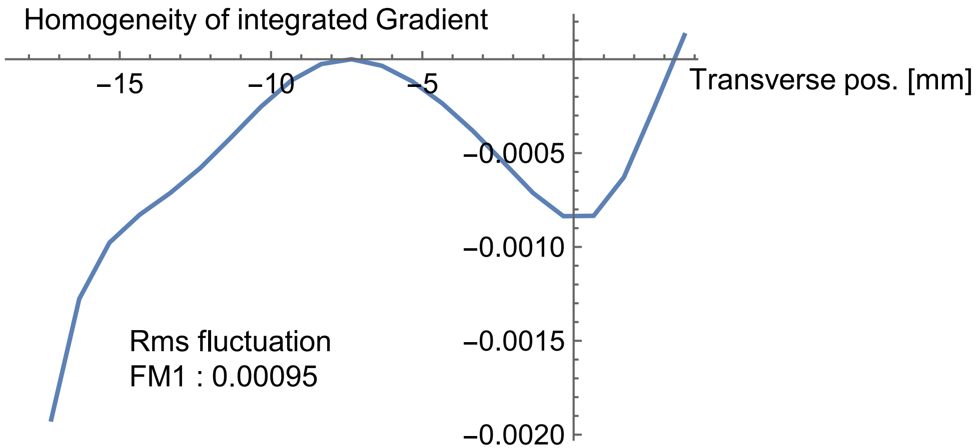


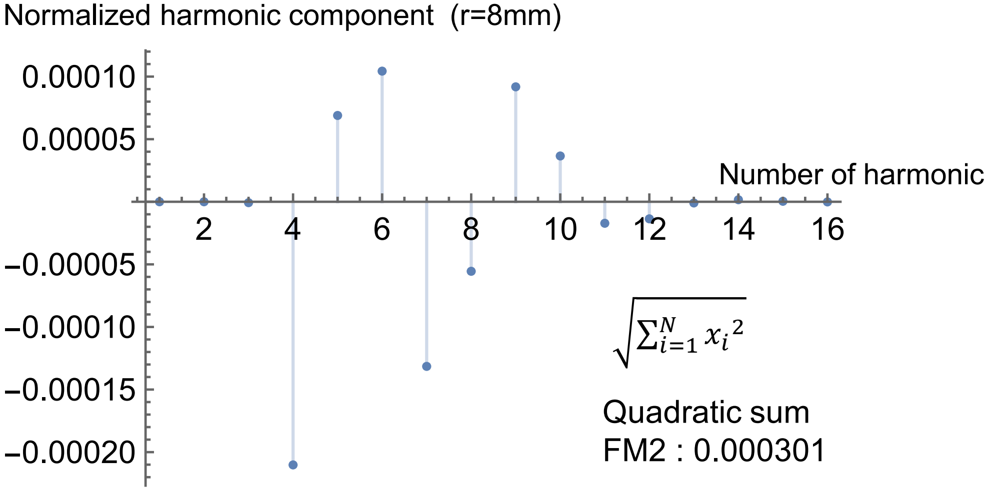
DLQ1	Tot.Int1 [Tm]	Integr.Grad [T]
Simulated	-0.31580	-12.866
Lattice value	-0.31566	-12.862



Module Positioning

	Δx [mm]	α [mrad]
M4	-6.196	-5.578
M3	-7.214	-1.376
M2	-7.031	+2.583
M1	-5.747	+6.118



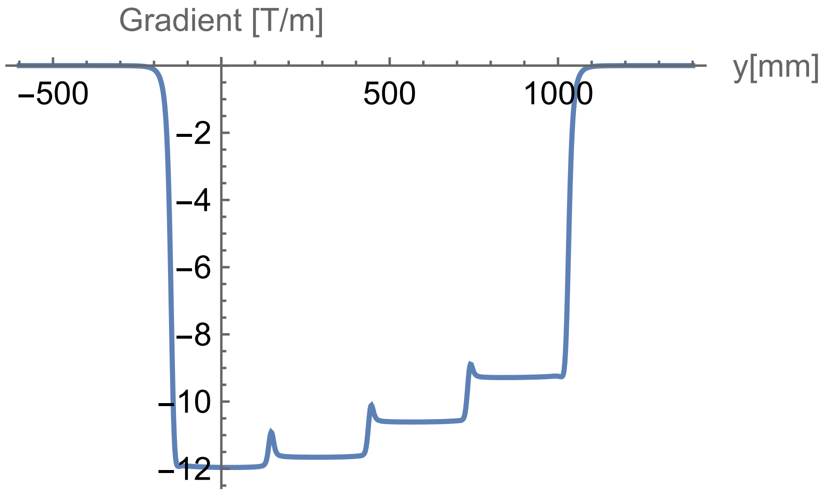


$$\sqrt{\sum_{i=1}^{N} x_i^2}$$

Quadratic sum
FM2 : 0.000301

DLQ1 – Full 3D Model

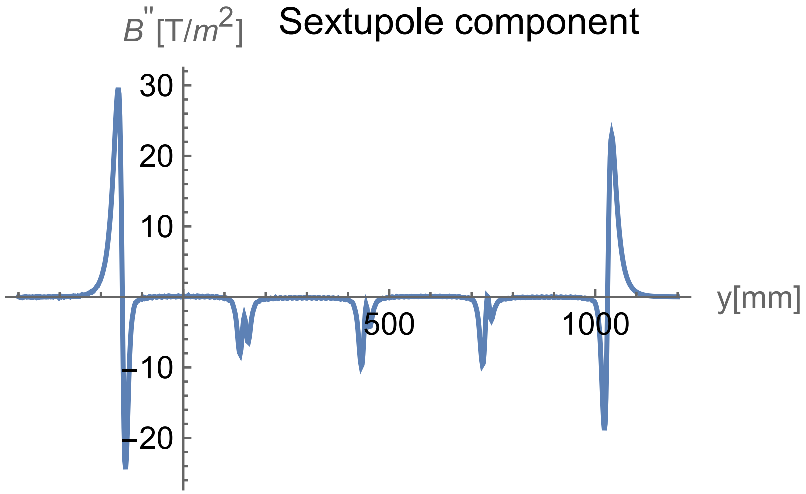
Longitudinal evolution of higher order moments

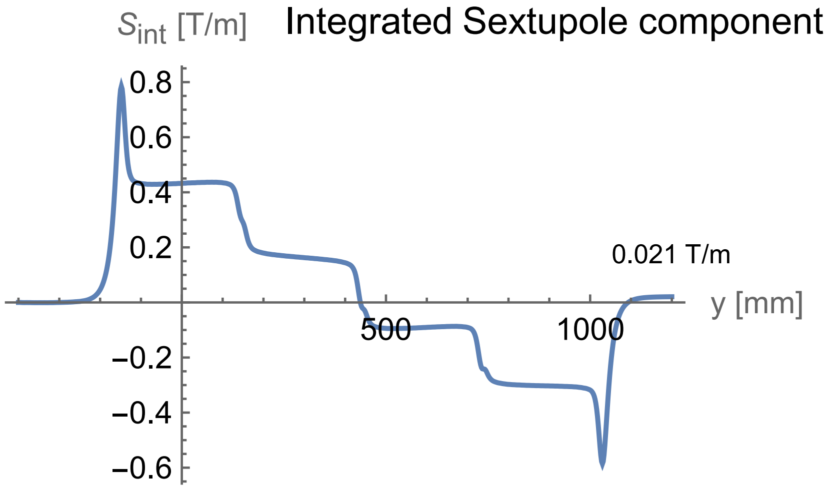


> Quadrupole
  - Intrinsic dips of the gradient due to segmentation to modules
  - Integrated gradient: -12.866 T (lattice value: -12.862 T)

> Sextupole
  - Systematic sextupole contributions at ends and module interfaces
  - Needs to be inspected by beam dynamics group

> Endpole designed to cancel the integrated sextupole

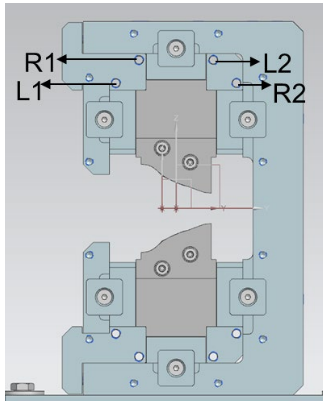


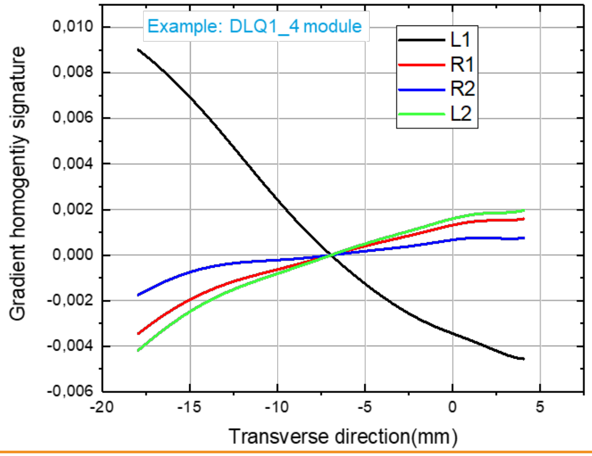


Field Tuning

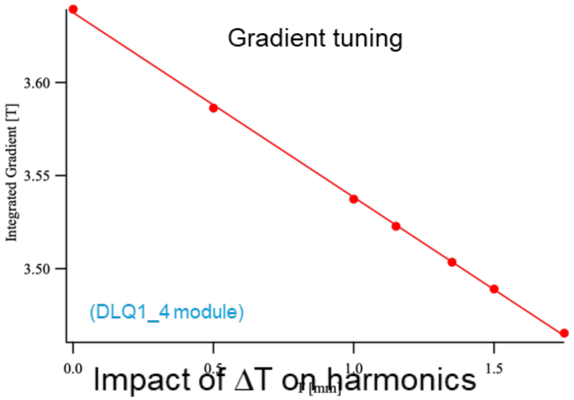
3 Options for shimming of single modules

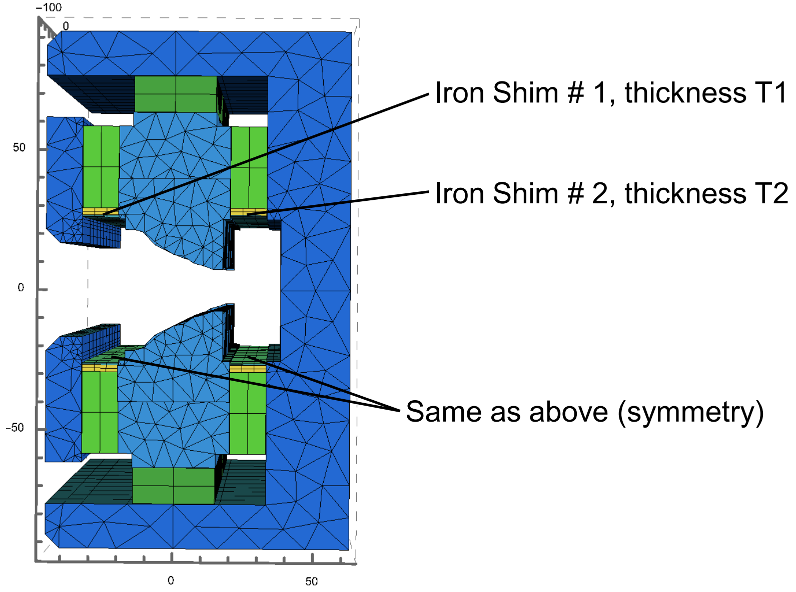
- **Iron shims on side magnets**
- Inequal magnet filling
- Fe-rods inside Aluminium spacer





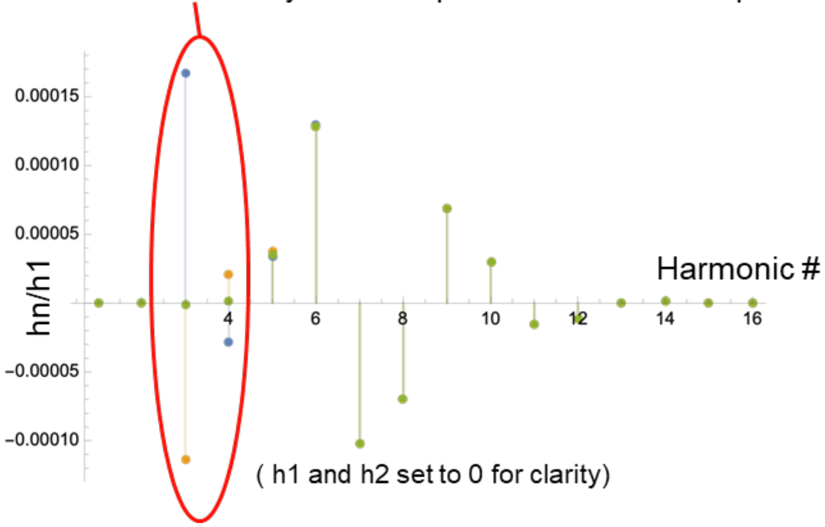
- T=T1+T2 → tuning of gradient
- T1-T2 (T=const) → control of sextupole

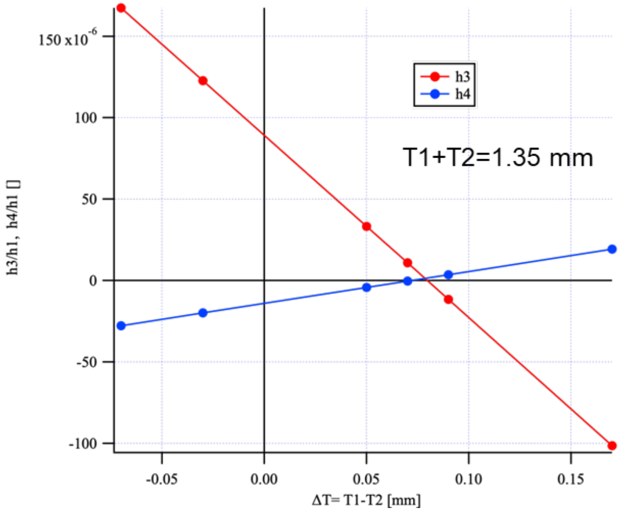




Impact of ΔT on harmonics

- mainly h3: sextupole and and h4:octupole

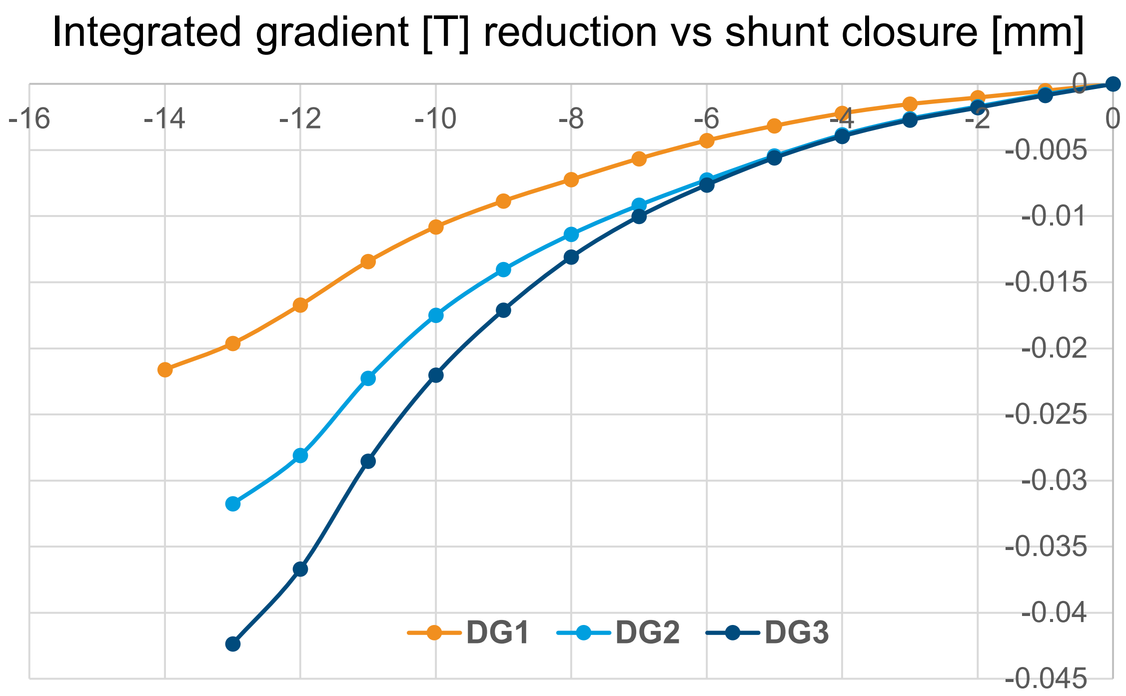




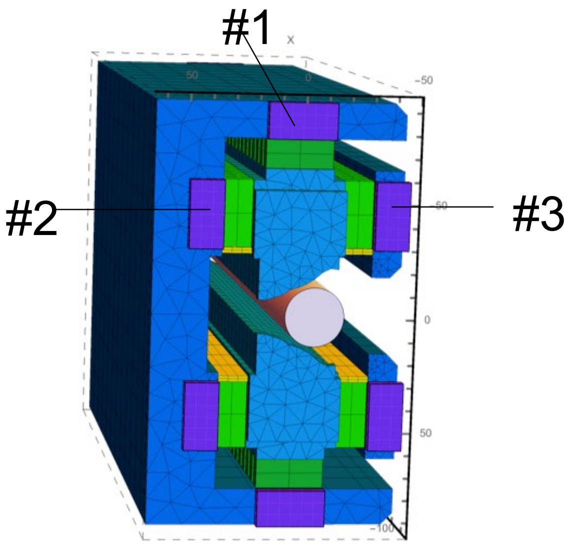
Trim Shunts – Fine corrections for fully assembled DLQs

Example for Low Field Module of DLQ1

Shunts have same height (width) like side magnet blocks (top magnets). Thickness: 5mm, 15-16mm in width (height) to cover the transverse space of the magnet (allows for fully open → fully closed)



Study to be repeated for the high field module.



- Movable shunts #1 , #2, and # 3 have different effects on the gradient
- Shunt at auxiliary pole has the strongest effect

All shunts impact different harmonics

Mainly sextupole & octupole to be quantified more precisely:

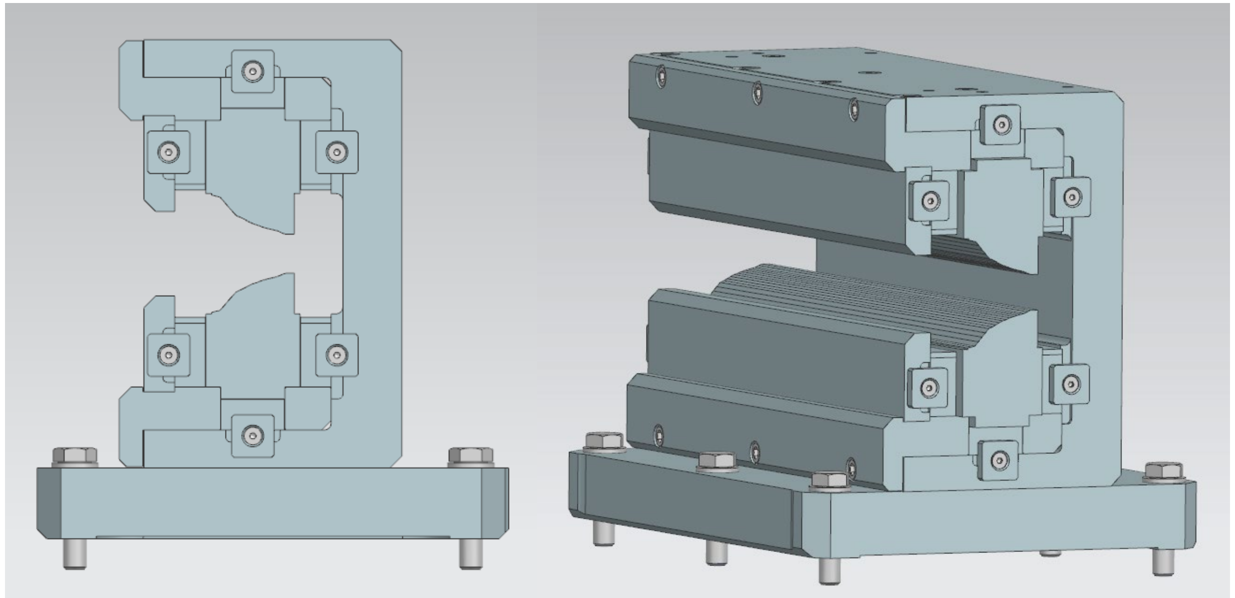
- Sextupole terms of shunts # 2 and 3# are opposite. Both shunts may be used to compensate residual sextupole errors

Mechanical Design

General

Concept (based on DLQ1)

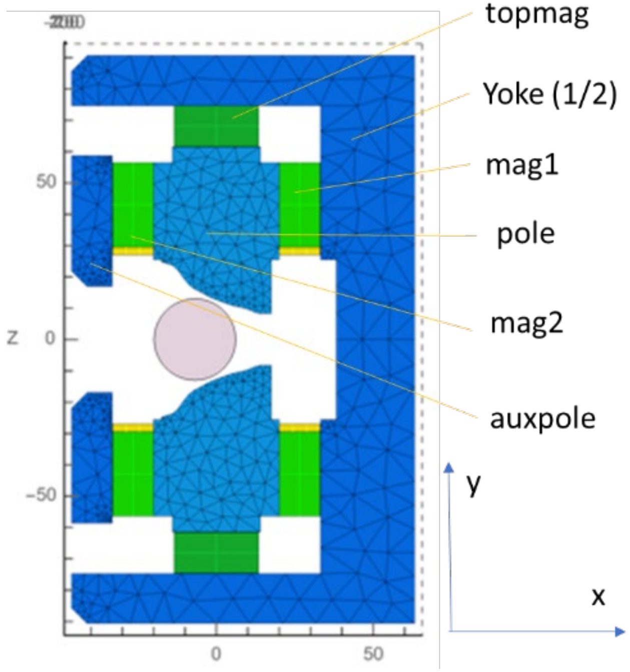
- Goal: generic design for all types and strength of modules, adaptable to later changes
- Iron yoke milled as single piece, Aluminium inserts as precision spacers for pole fixation
- Difficulty: precision of aux. pole position under magn. forces; retaining mech. precision in the assembly process



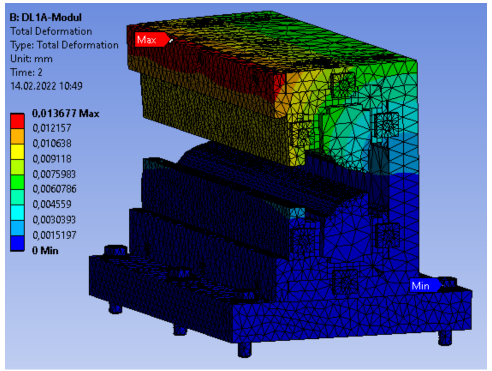
FEM simulations (work in progress!)

- First preliminary results are promising
- Total deformation (~15um) is in the range of machining and mounting accuracy
- Vertical & horizontal deformations of aux. pole below 10um

item	Fx[N]	Fy[N]
pole	221	-305
auxpole	1058	-37
yoke	-1173	-4030
mag1	244	239
mag2	-331	191
topmag	-28	324



DL1A3
L=280 mm



Court. T.Ramm

Mechanical Design

Design Details

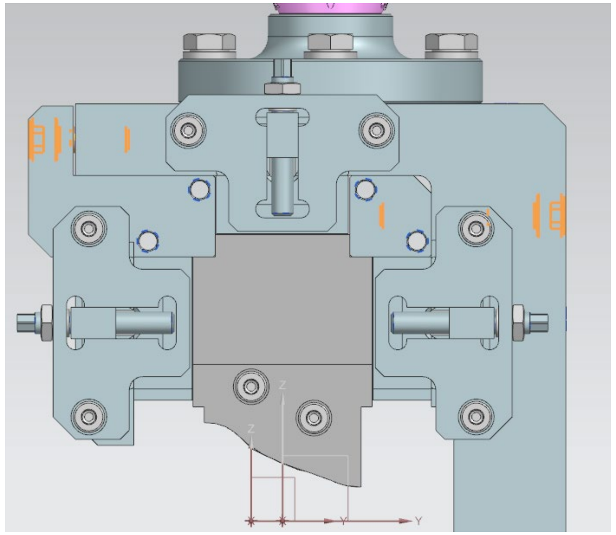
> Magnet Module

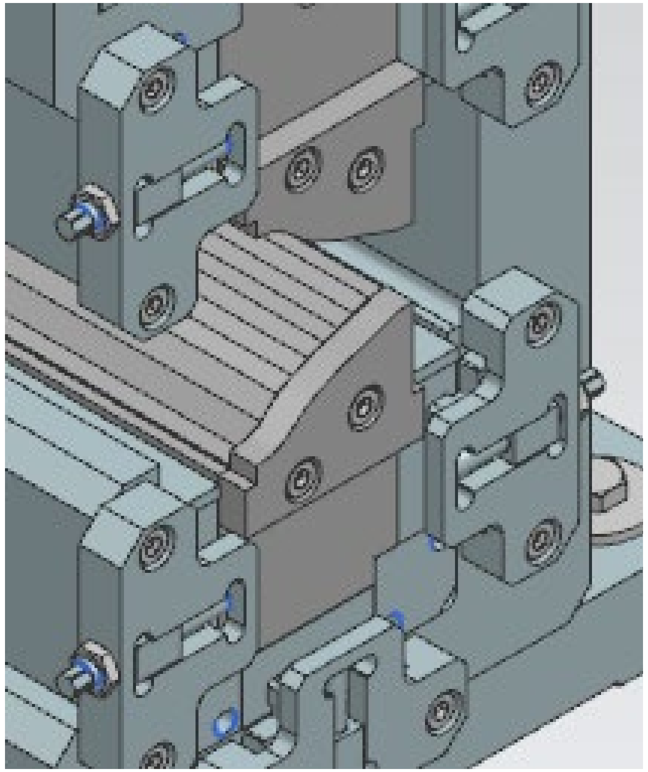
- Integration of endpole pieces
- Attachment of trim shunts
- Integration of long bore holes for shimming

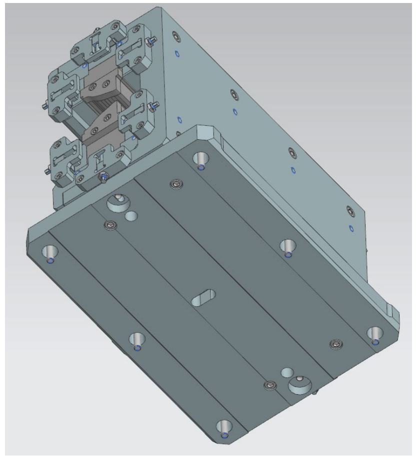
> Magnet mounting tool for modules

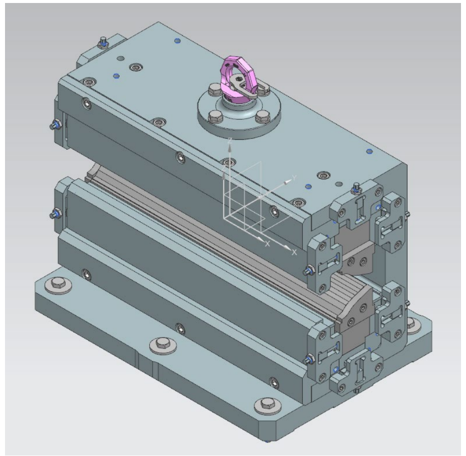
Adapted from DL mounting tool at ESRF

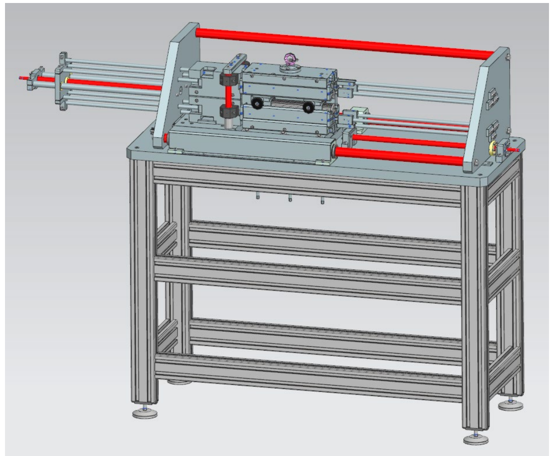
> Transverse mover mechanism for DLQ support

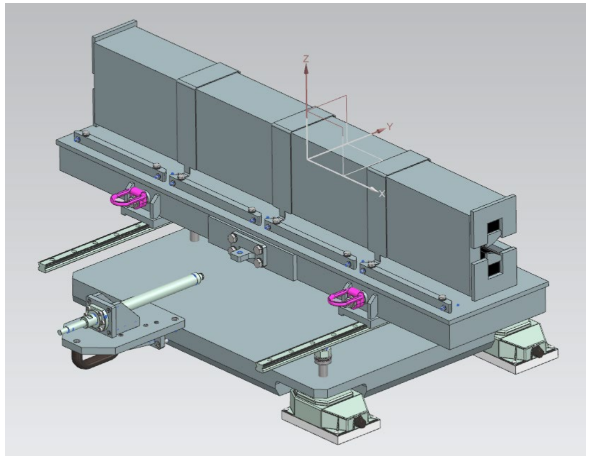












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Thank you

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