Magnets and magnetic measurements for the new light source PETRA IV

IMMW 22

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Agenda

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- Magnet portfolio

02 PM-based bending magnets

- Overview & design example

03 Resistive magnets

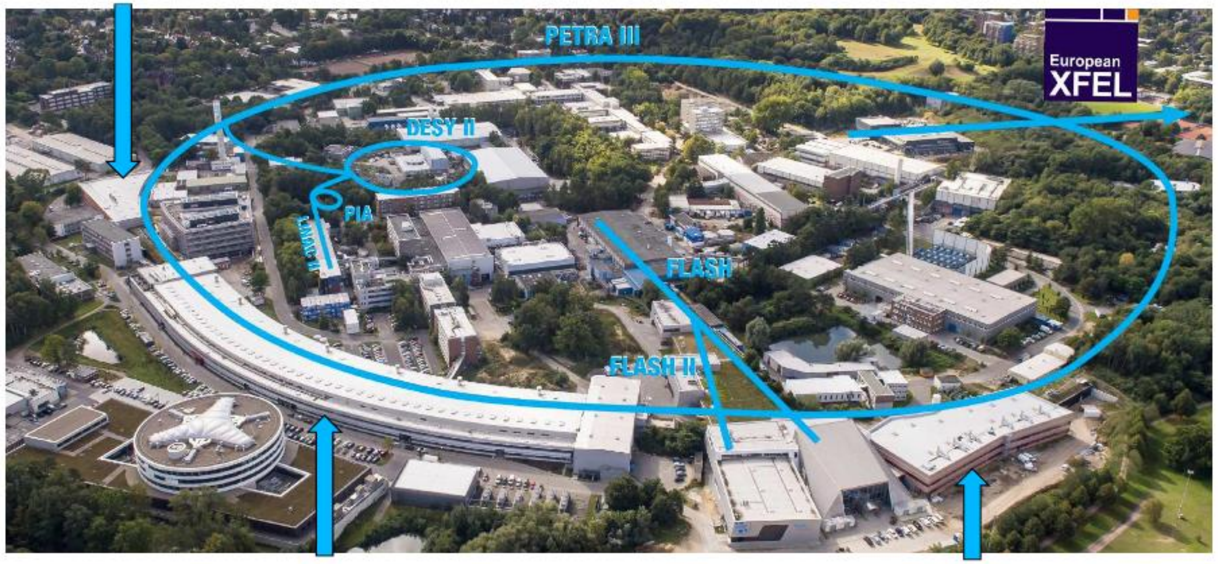
- Design example
- Procurement strategy

04 Magnetic Measurements

- Measurement strategy
- Instrumental developments

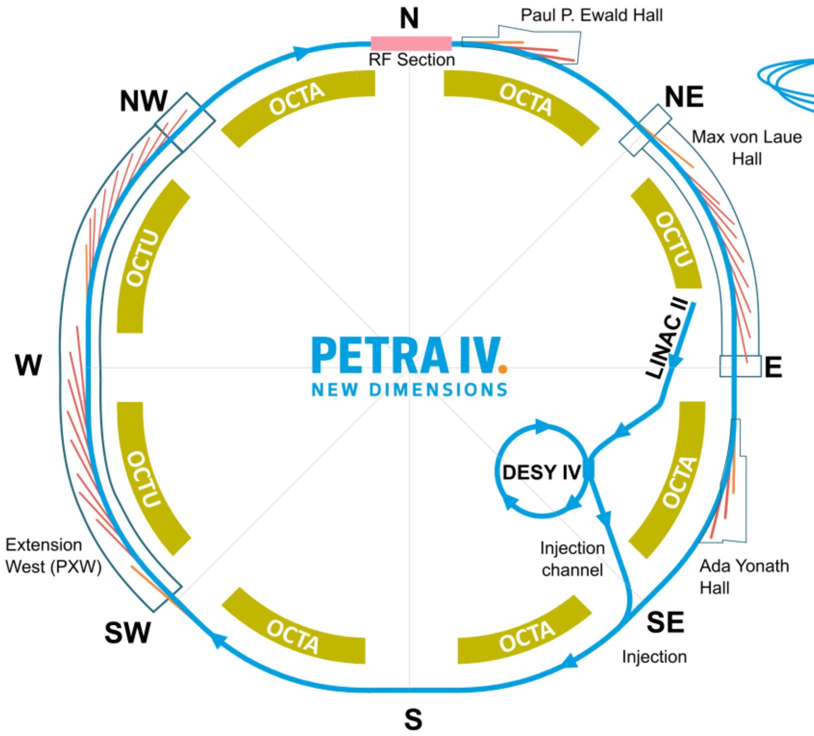
PETRA IV project

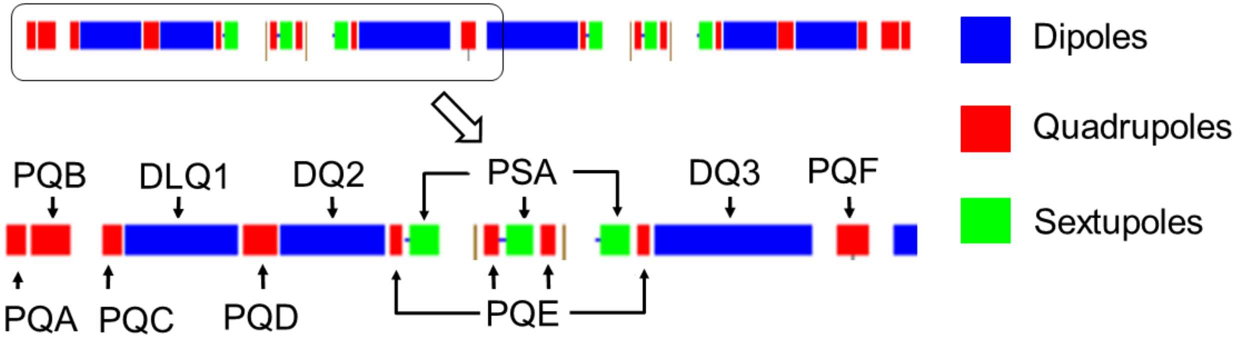
Ada Yonath Hall
Extension Hall East



Max von Laue Hall

Paul P. Ewald Hall
Extension Hall North





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

Magnets for the PETRA IV project

PETRA IV. NEW DIMENSIONS

Accelerator	Name	Type	Magnetic length, m	Aperture diameter, mm	Maximum gradient (lattice)	Harmonics	Reference radius, mm	Quantatie
PETRA IV	PDLQ1	PM DQL	1.112	25		$\sqrt{\sum_{n=3}^{14} b_n^2}$ < 5·10^{-4} $\sqrt{\sum_{n=3}^{14} a_n^2}$	7.9	144
	PDQ2	PM DQ	1.084					144
	PDQ3		1.818					144
	PQA	Quadrupoles	0.169	22	115.2 T/m		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

~3467 magnets

DLQs – Overview and Parameters

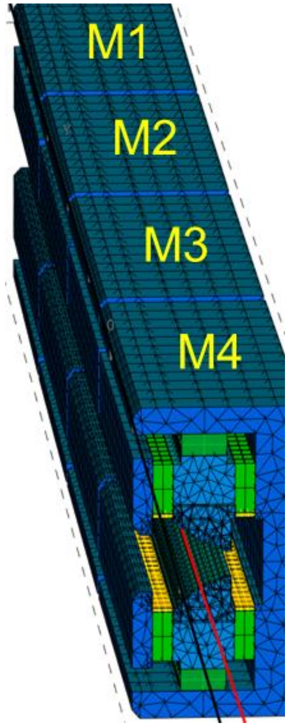
Permanent magnet-based dipoles with transverse and longitudinal gradient

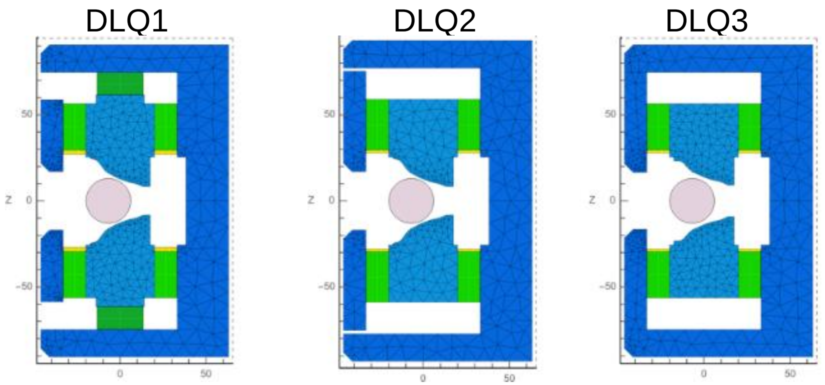
Developed and built in collaboration with ESRF

Design derived from ESRF-EBS DL-magnets

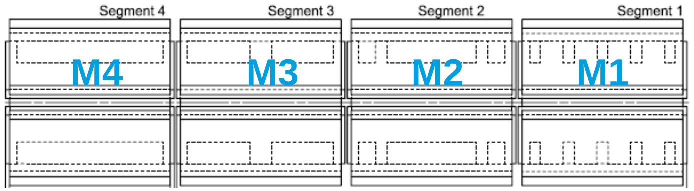
General

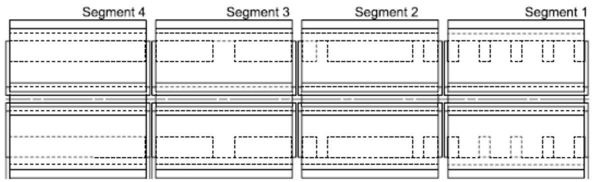
- Armco poles and yoke;   SmCo magnets
- Modular concept, unification across the 3 DLQ types as much as possible (yoke, block size, mounting, shimming etc.)
- 144 DLQs of each type to build, i.e. ~2000 modules
- Outer diameter of vacuum chamber: ~25 mm
- Thermal shims for temperature compensation

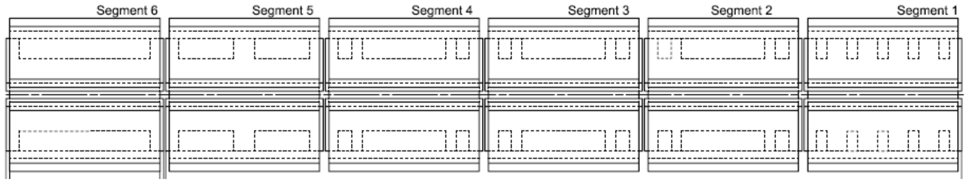




	Magn. Length, m	Field, T	Gradient, T/m
DLQ1	0.303 0.303 0.303 0.303	-0.287 -0.277 -0.255 -0.223	-11.69 -11.27 -10.39 - 9.09
DLQ2	1.084	-0.191	-7.81
DLQ3	1.818	-0.193	-6.63

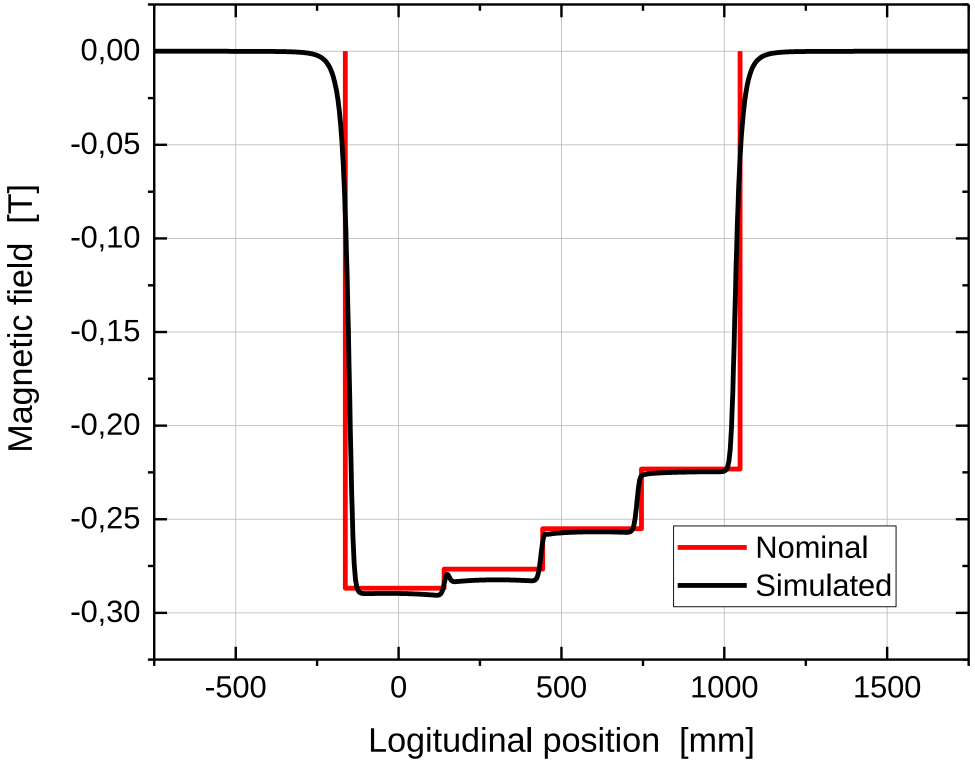






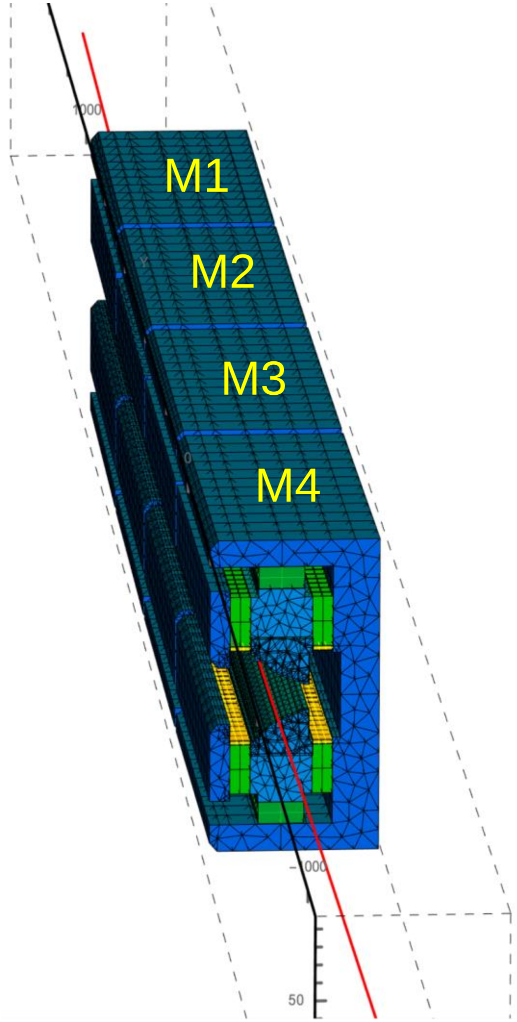
DLQ1 – Full 3D Model

Field profile and parameters



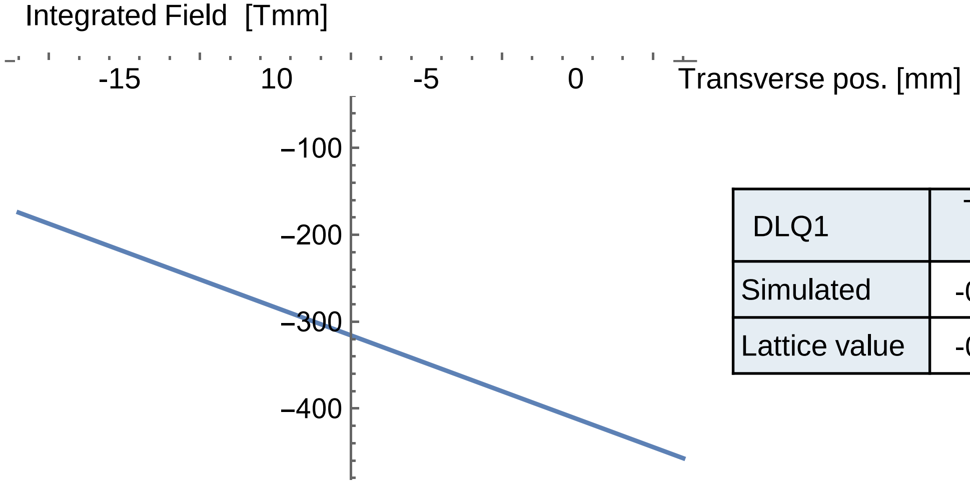
- 4 modules à 303mm length (nom.) L_{tot} = 1212mm
- Longitudinal field gradient with constant B/G ~ 0.025m for transverse gradient
- Nominal magnet filling factors
  - M4…M1: 0.87% ,0.83%, 0.75%, 0.65%

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

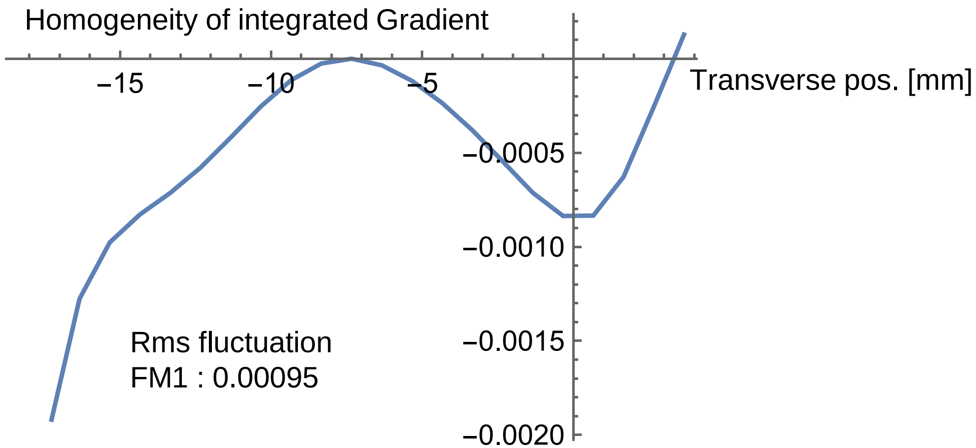


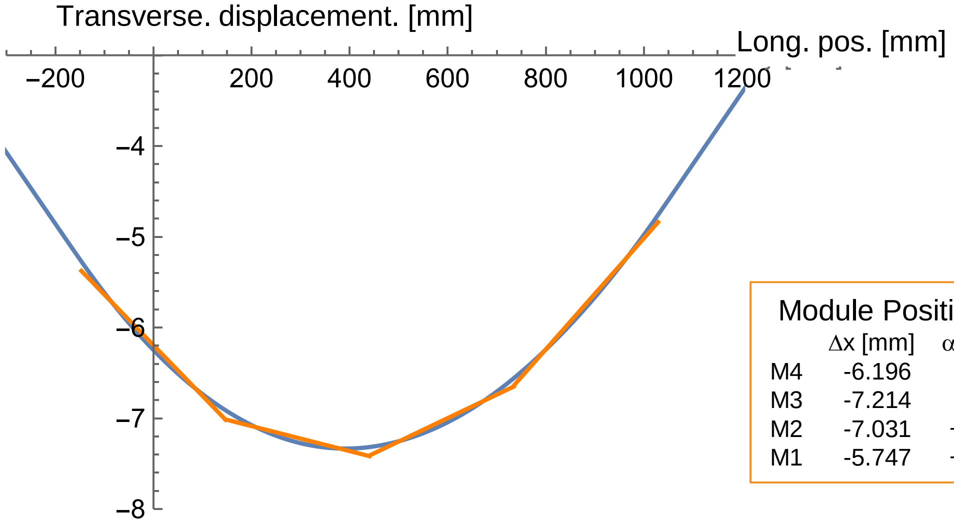
DLQ1 – Full 3D Model

Analysis of magnetic field



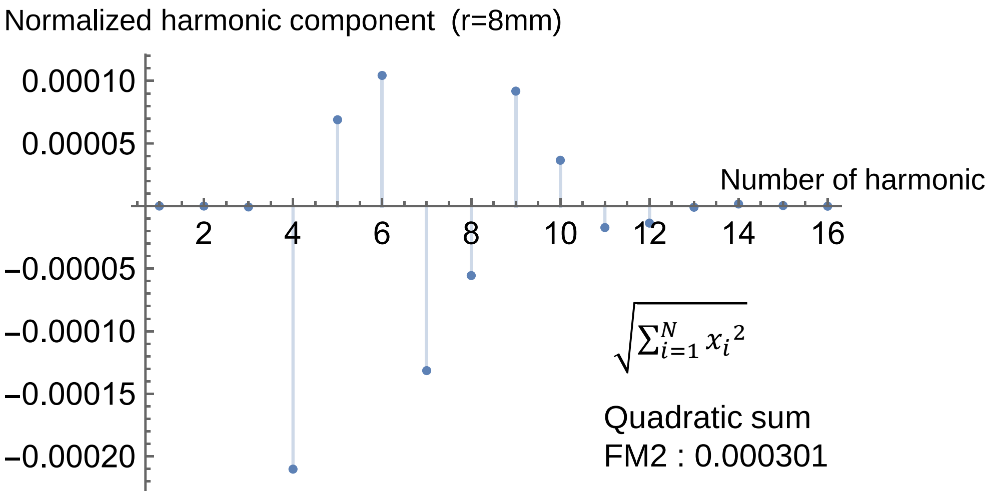
DLQ1	Tot.Int1 [Tm]	Integr.Grad [T]
Simulated	-0.31580	-12.866
Lattice value	-0.31566	-12.862





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

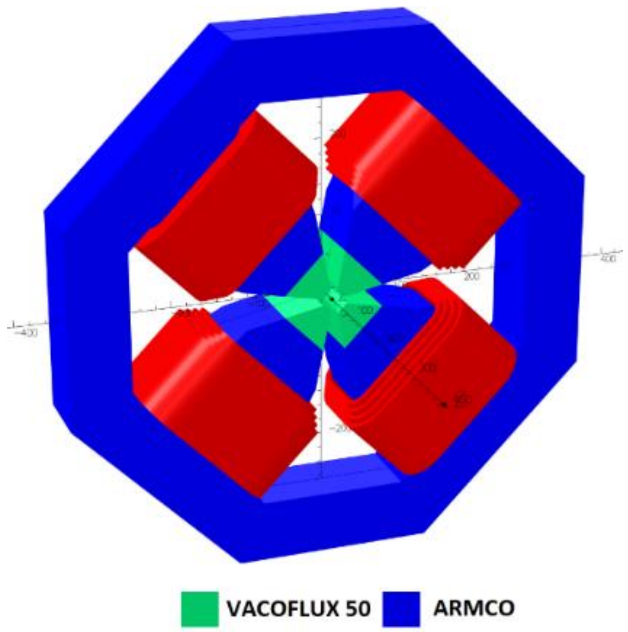


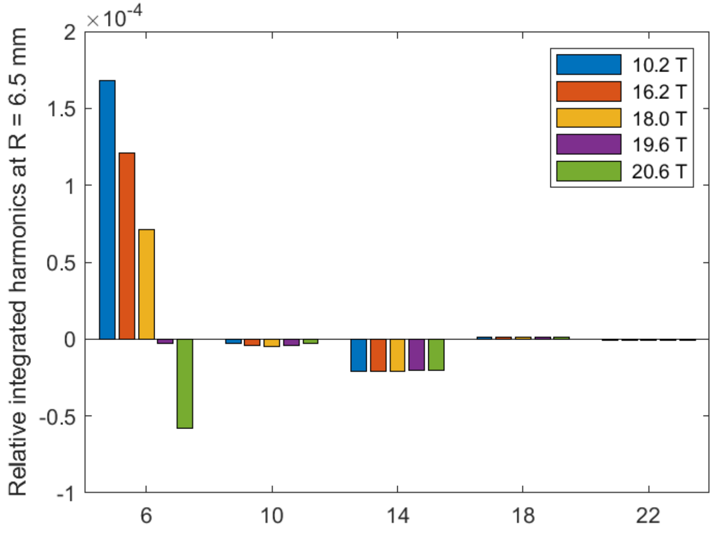
$$\sqrt{\sum_{i=1}^{N} x_i^2}$$

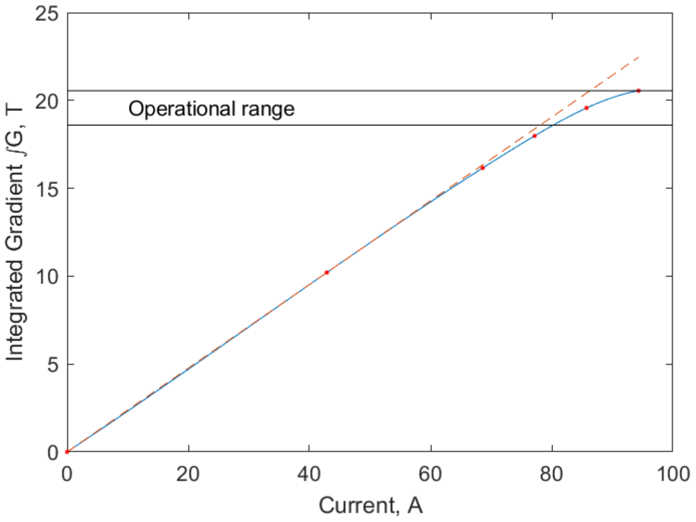
Quadratic sum
FM2 : 0.000301

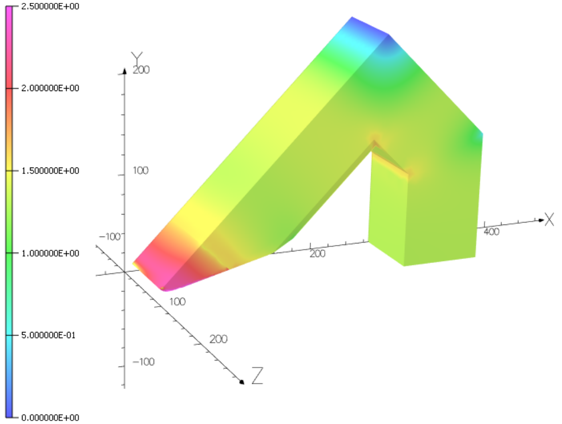
PQA high gradient quadrupole

Gradient, T/m	Mag. length, mm	Int. gradient, T	Aperture radius, mm	Ref. radius, mm	Harmonics	Int. gradient uniformity
115.2	169	19.5	11	6.5	$< 5\cdot10^{-4}$	$< 10\cdot10^{-4}$









- Vacoflux poles to reach the required gradients

PQA call for tender

PETRA IV. NEW DIMENSIONS

Procurement - 3 stage process

Stage 1

- Selection of 6 companies based on their experience, knowledge, production capacity

Stage 2

- Presentation of their magnet proposal inkl. Price indication based on specifications with some flexibility
- Our magnet design is added as an attachment to the specifications
- Magnet supplies are responsible to meet the field quality

Stage 3

- Final specifications are submitted to participants
- Presentation of the final magnet design and price

• nominal gradient	115 T/m
• operational gradient range	109 to 120 T/m
• bore radius	11.0 mm
• magnetic length of magnet	169 mm
• maximal geometric available space in x,y,z x (width), y (height) and z (length in beam direction)	950, ***, 229 mm
• square root of sum of squares of systematic and radom relative integrated normal harmonics b_n $\sqrt{\sum_{n=3}^{14} b_n^2}$ at reference radius 6.5 mm at the operational range should not exceed (*)	5×10^{-4}
• square root of sum of squares of systematic and radom relative integrated skew harmonics a_n $\sqrt{\sum_{n=3}^{14} a_n^2}$ at reference radius 6.5 mm at the operational range should not exceed (*)	5×10^{-4}
• yoke and pole material	**
• max. current	100 A
• power loss should not exceed	1.4 kW
• operational cooling water pressure	6 bar
• cooling water pressure drop	4 bar
• water temperature increase should not exceed	15 °C

Magnetic Measurements and Infrastructure for DLQs

PETRA IV. NEW DIMENSIONS

Setup of Assembly & Measurement Lab

Lab space and Logistics

- About 800m2 have been assigned for all DLQ work
- Not a particularly quiet place (DESY II)
  - booster operation in direct vicinity (early phase) : 12.5Hz and multiples EM noise → to be filtered out in DAQ
  - civil construction work (later project phase) → vibrations

Magnetic measurement Equipment

- Stretched Wire stand
  - selection of components presently under investigation
  - existing SW stand available for prototype measurements
- Hall probe bench available for possibly special issues of the DLQ prototype characterisation

Fabrication & Magnetic Measurements

Modules

- Magnetic tuning of single modules under anticipation of later position within a full DLQ
- Transfer measurement of each module

Fully assembled DLQ magnet

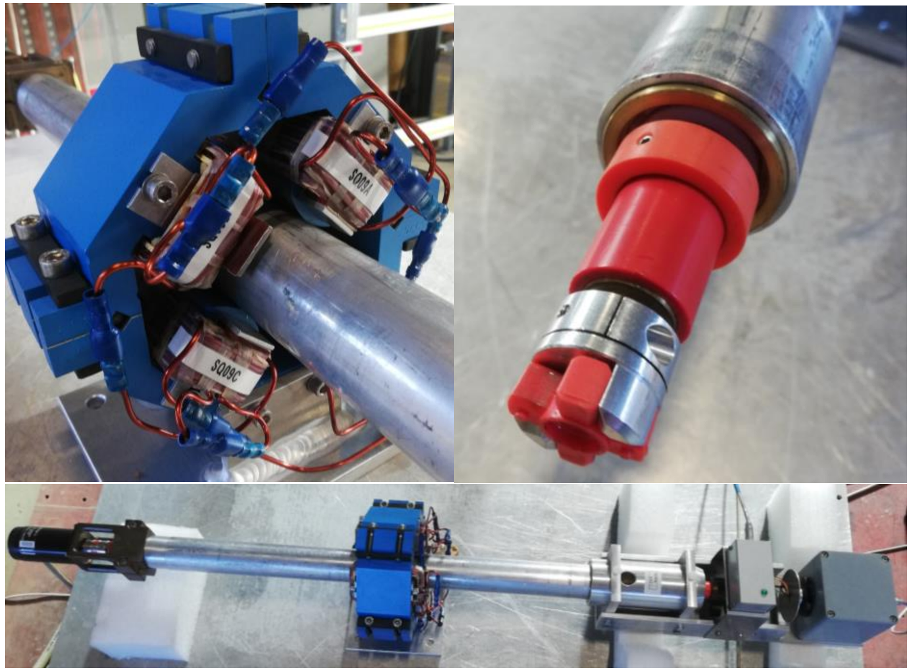
- Tilted/offset placement of single modules along trajectory according to transfer data
- Fine-Tuning of integrated gradient, integrated field, and 2^{nd} field integral

The complete measurement and tuning strategy is not yet developed; fortunately, there is already solid experience and advanced developments at various labs (ESRF-EBS, APS-U, SLS-2)

Present planning based on ESRF experience with DLs, both for measurements infrastructure and measurement/tuning concepts

Magnetic measurement strategy

1. **Manufacturers responsible for the field quality**
   - Precise and standardized field measurement needed inhouse and at the suppliers [1,2]
2. **Manufacturers responsible for measurement benches or DESY provides a self centering rotating coil setup**
3. **SAT includes a field quality measurement with rotating coil at DESY**
4. **Precise fidulization with vibrating wire**
   - Option: rotating coil for fiducialisation like PETRA III [3]
     - However precision unclear tests will be done
     - Easier and faster to operate



[1] S. Sharma, Lessons Learned NSLS-II Magnet Production, DOI: 10.2172/1505208
[2] National Synchrotron Light Source II Project Lessons Learned https://www.energy.gov/sites/prod/files/2016/02/f29/NSLSII_Lessons_Learned_2015-08_0.pdf
[3] Y. Holler, et. al. , Precise Transfer Measurement of the Magnetic Axis to Outside Monuments, DOI: 10.1109/TASC.2008.921278

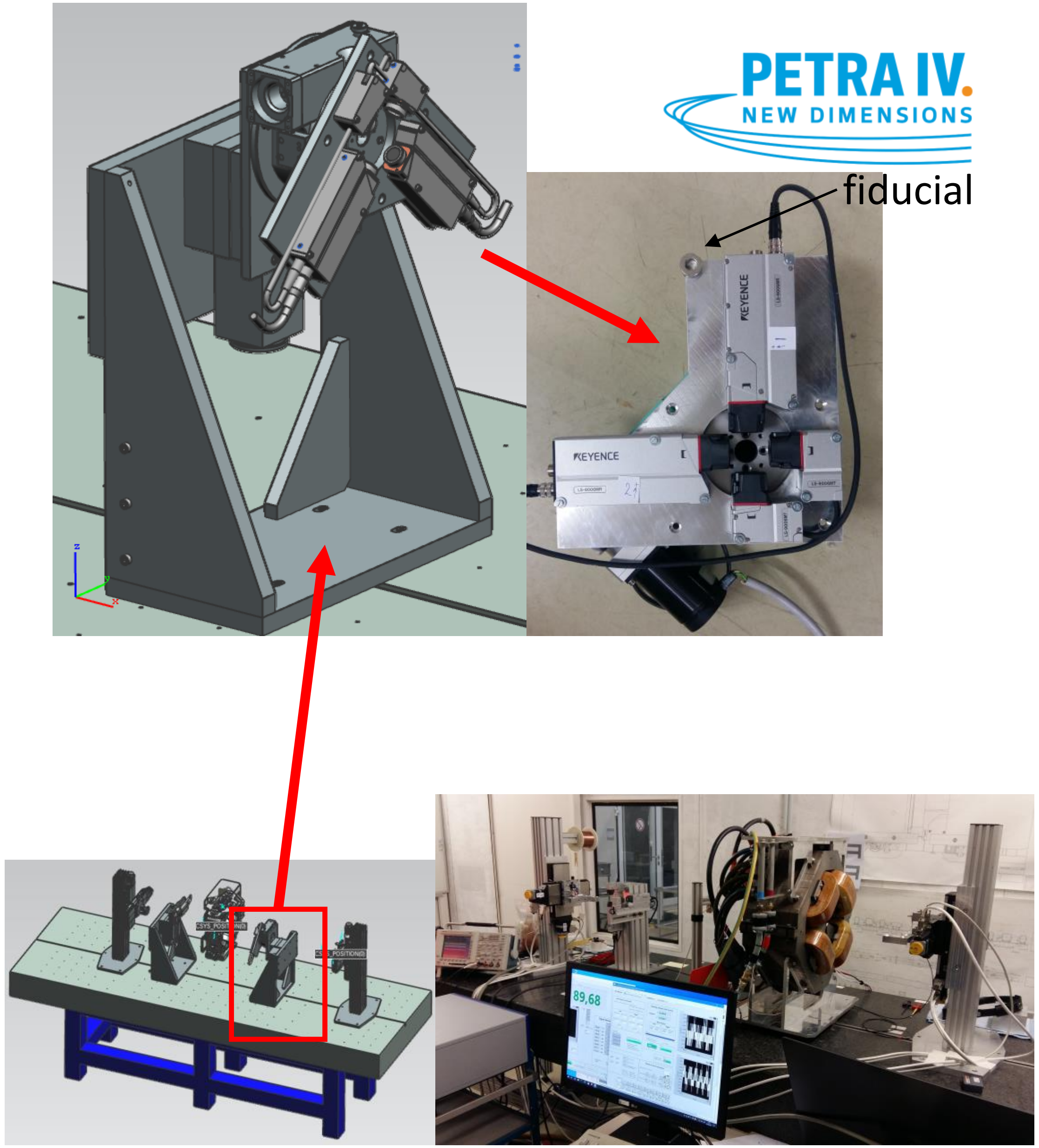
Vibrating wire

Magnetic measurements

PETRA IV.
NEW DIMENSIONS

Vibrating wire bench

- Standard:
  - PI linear stages to move the wire
  - Frequency generator to excite the wire
  - Keyence laser mikrometers to detect vibration amplitude
- NEW:
  - New function in Keyence software allows measurement on the fly
  - Fiducials of the wire position by rotation of the laser mikrometers around the wire → Fiducials glued on the mikrometers measured with laser trackers and the wire measured with laser micrometer have the same rotation center
- Status:
  - Test bench in operation
  - New equipment needed to replaced borrowed components and to avoid resonance due to the translation stages



Rotating coil bench

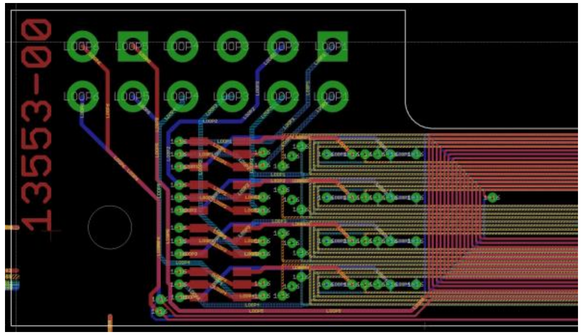
Magnetic measurements

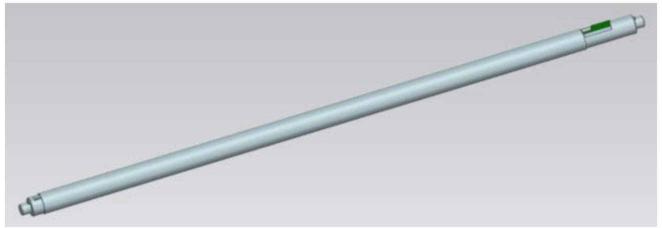
Rotating coil bench

- Re-use of the existing bench for TDR
  - New PCB coil (for prototypes)
  - New PXI data acquisition system
  - Test of the alignment rotating coil vs. vibrating wire

- Installation of new rotating benches for the project phase
  - Upgrade of the rotation stages and bearings
  - Operation mode for non expert users

- Status:
  - PCB boards ordered for Quads
  - Mechanical design of the coil shaft in progress
  - PXI System available, replacement of an old in house designed amplifier card soon





Thank you

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