Magnets for a new low emitance storage ring at ESRF

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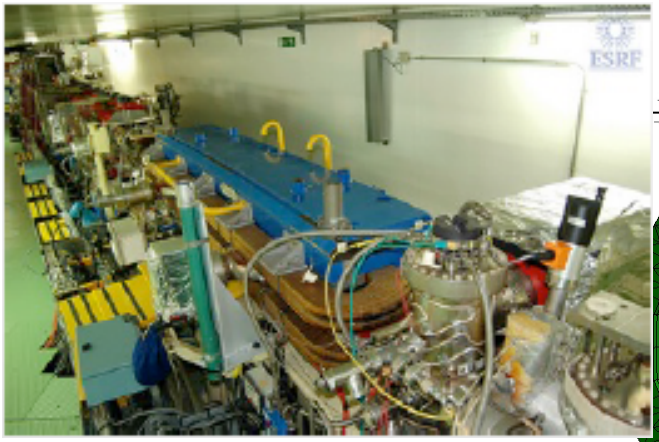
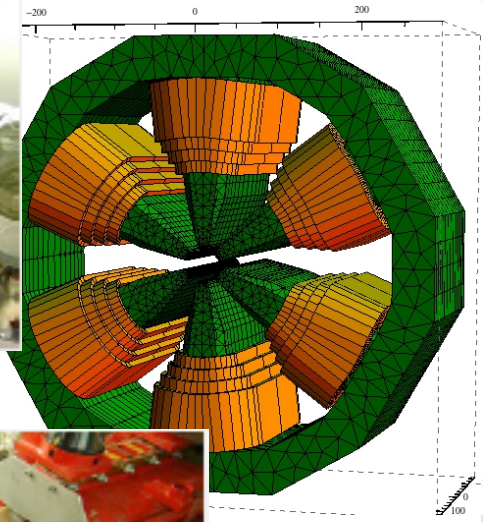
Outline

New magnet lattice

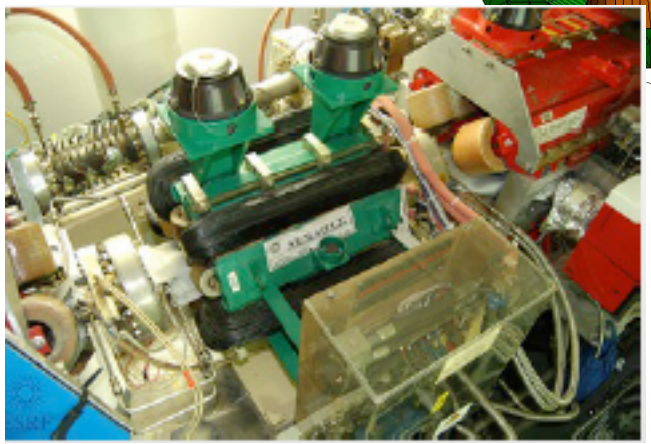
- Why?
- Magnet requirement





Magnet design

- Specifications
- Constraints



Magnetic measurements

- Integral
- local

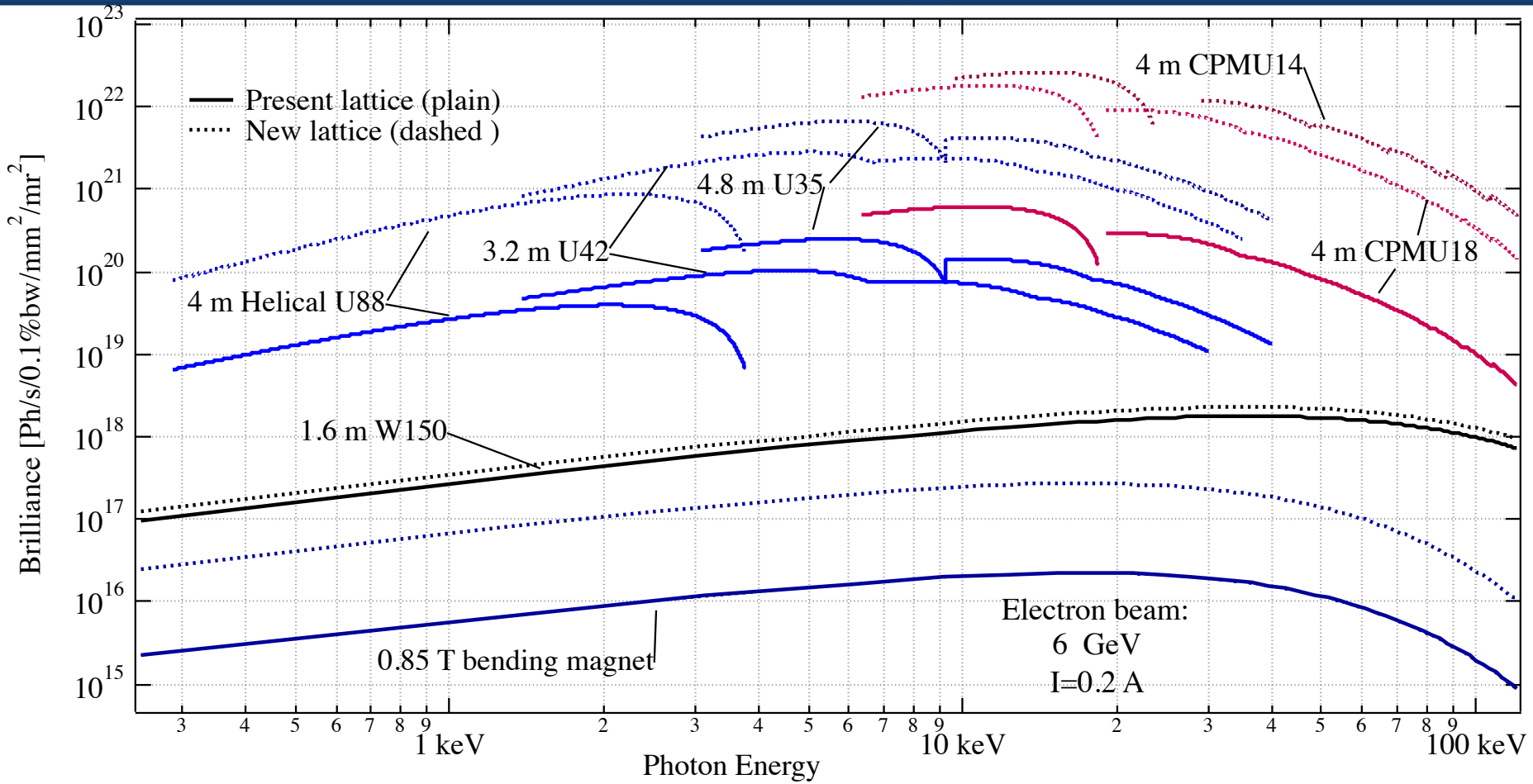
Summary

Electron Beam Parameters

Reduction of horizontal emittance by a factor of 25

Parameter	Existing lattice	New lattice
Energy [Gev]	6.03	6.03
Circumference [m]	844	844
Beam Current [mA]	200	200
Horizontal emittance [nm]	4	**0.16**
Vertical emittance [pm]	5	3
Energy Spread [%]	0.1	0.1
Beta at ID center , H x V [m]	37.6 x 3 (high Beta) 0.37 x 3 (low Beta)	3.35 x 2.79
Beam Size at ID center H x V [µm]	400 x 3.9 50 x 3.9	23.5 x 3.7
Beam Divergence at ID H x V [µrad]	10 x 1.3 107 x 1.3	6.9 x 1.3

Higher brilliance



	H emittance	V emittance	Energy spread [%]
Present	4 nm	5 pm	0.1
New lattice	0.16 nm	3 pm	0.1

Emittance reduction

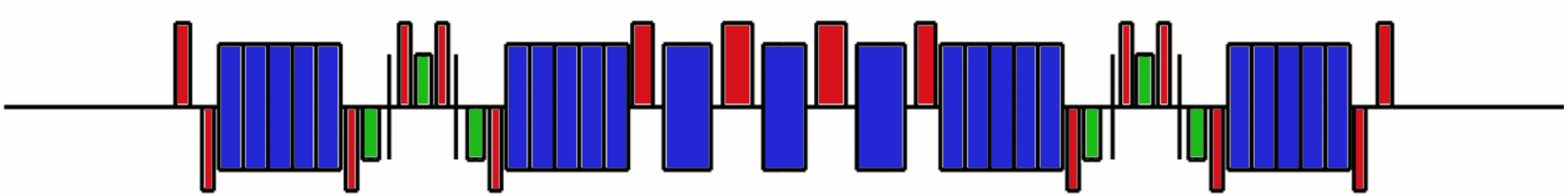
Electron energy

$$\varepsilon_x \sim E^2 / N^3$$

Number of identical dipoles

ESRF magnet lattice today: DBA (2BA)

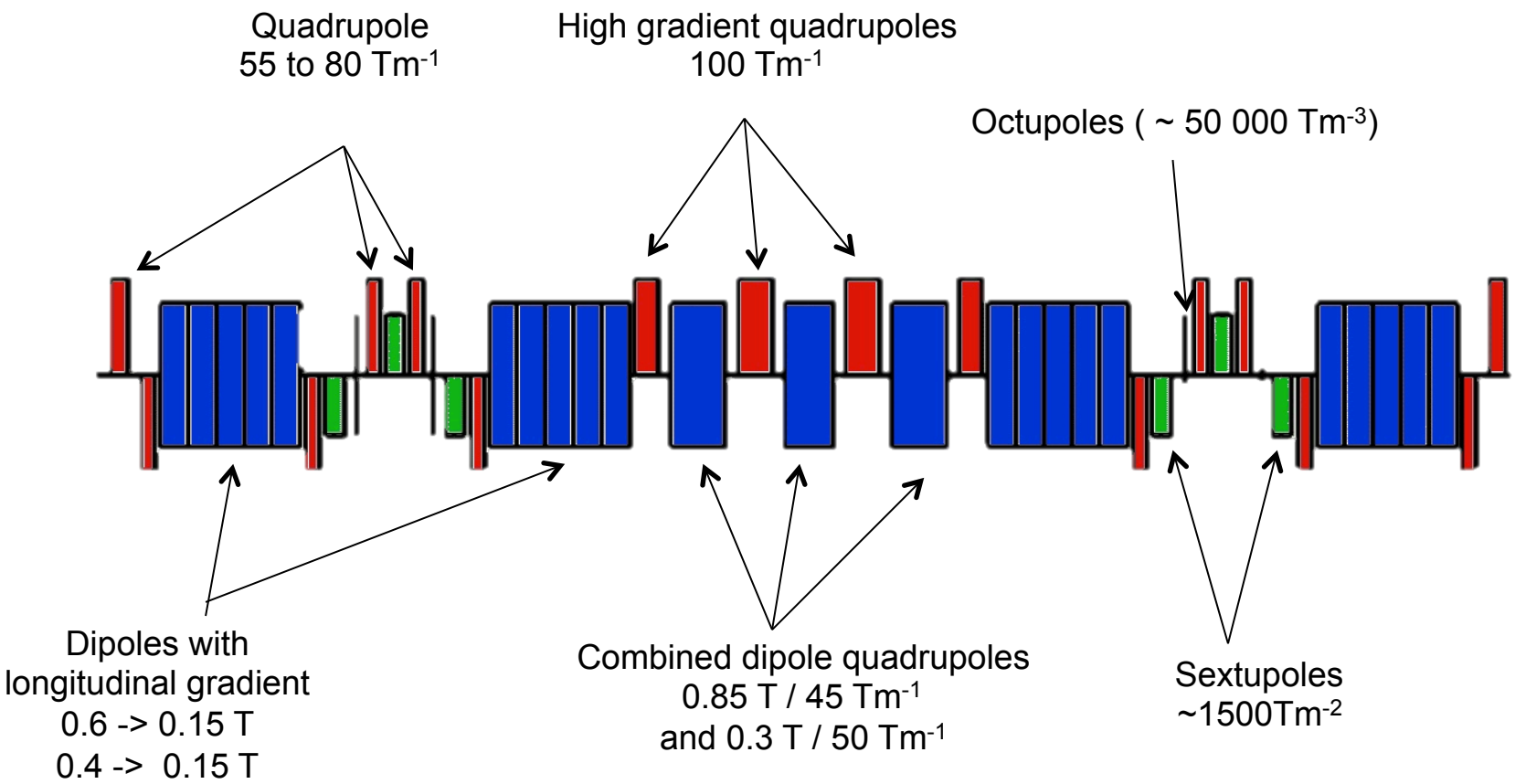
New Lattice 7BA



Constraint:

- same energy
- fit new magnet lattice in existing ring (844 m)
- Keep existing BM sources

ESRF S10 Lattice



Compact magnet lattice

ESRF Accelerator upgrade: 1056 magnets to build

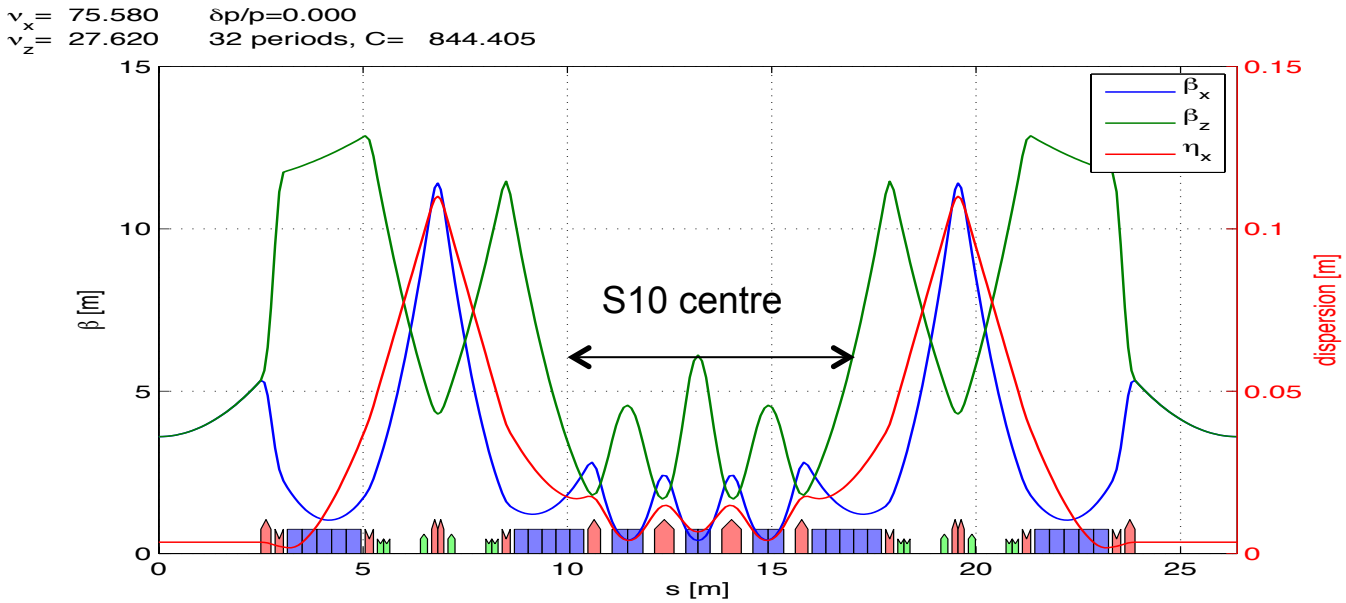
Magnet type	Quantity	Total magnetic length[m]	share
Dipole	7	11.38	65%
Quadrupole	16	4.17	24%
Sextupole	6	1.68	10%
Octupole	4	0.4	2%
All magnets	33	17.6	100%

Total length of a cell: 26.376 m
Length of ID straight section: 5.8 m

~ 3 m of drift space distributed between magnets
~ 8 m presently

Limited longitudinal space is a specificity of the new ESRF lattice

Aperture and good field region



Initial parameters for preliminary study

S10 All	Horizontal [mm]	Vertical [mm]
Vacuum chamber aperture (radius)	15.1	10.1
Good field region (radius)	8.3	5.5

S10 Centre (high gradient)	Horizontal [mm]	Vertical [mm]
Vacuum chamber aperture (radius)	8.3	5.5
Good Field Region (radius)	7	5

Road map

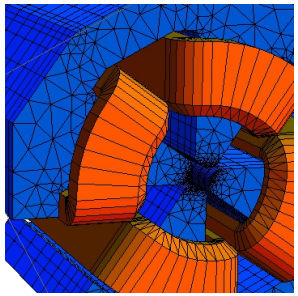
- Project not yet funded (decision early 2015)
- Go ahead with prototype development and magnetic measurements
- 2013-2015
  - Magnetic design
  - Mechanical design
  - First prototypes
  - Improvement/development of magnetic measurement systems
    - stretched wire/vibrating wire benches
    - Local field mapping
    - Other …
- …… 2019 all magnet installed

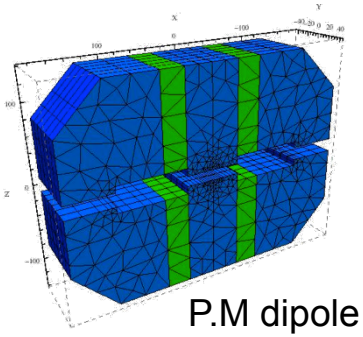
Magnet design approach

- Achievable Magnet performance/ field quality in defined aperture
- Impact on vacuum chamber technology
- Impedance issue,….., etc
- Energy efficiency

- 3D magnetic modeling using RADIA

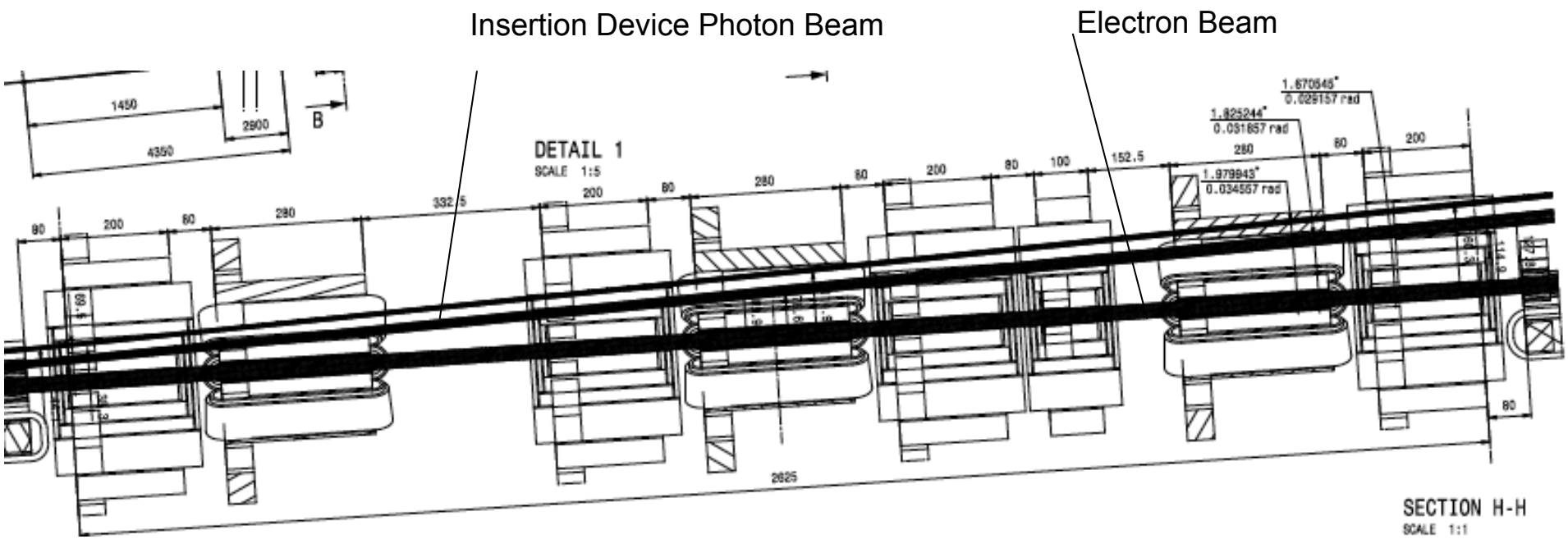
Native field integral calculation
Electron beam tracking in magnet
Efficient parameterization for various optimization
  - Pole shape
  - Geometrical errors budget
  - Electrical power
  - ….





P.M dipole

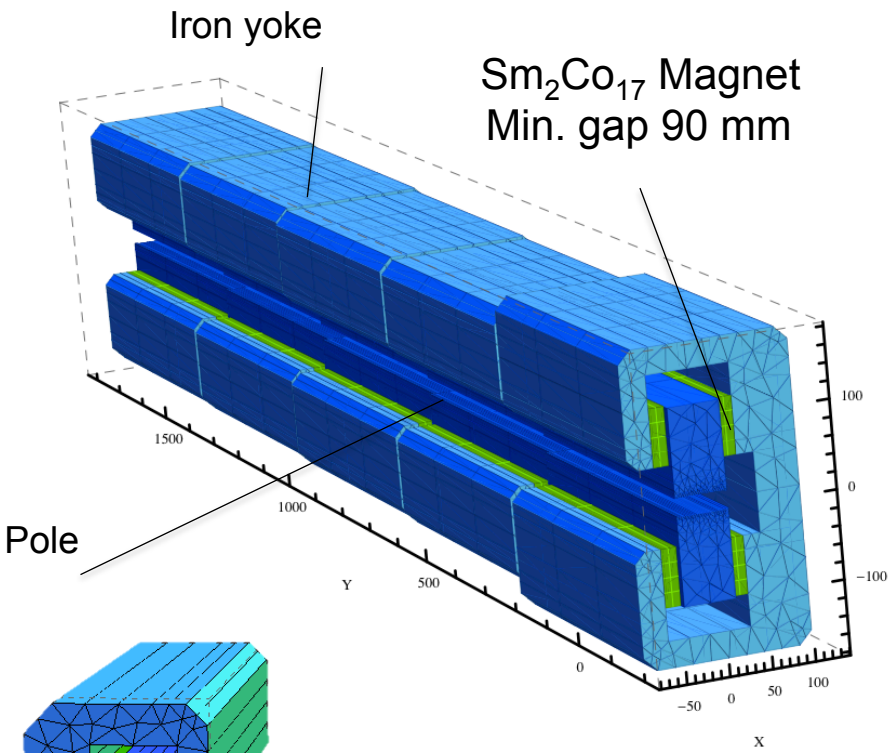
Geometrical design constraints

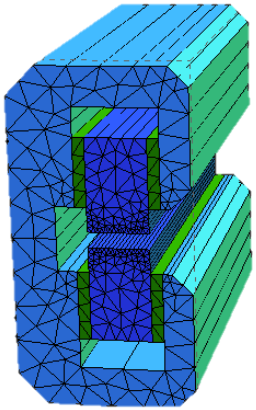


- Small bore radius = tight mechanical tolerances
- Mechanical length (limited space) → short coils
- Photon beam path specific to SR sources (open magnets)
- … etc

Dipole with longitudinal gradient

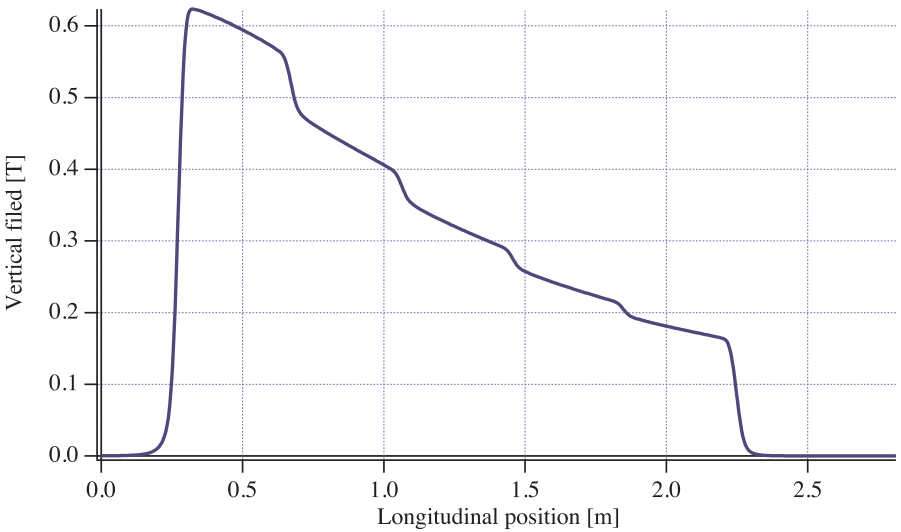
ESRF has a long experience with Permanent magnet systems (Insertion Devices)





Building Block

PM weight ~ 25kg
Total weight 400 ~500 kg
Magnetic length: 2.07 m



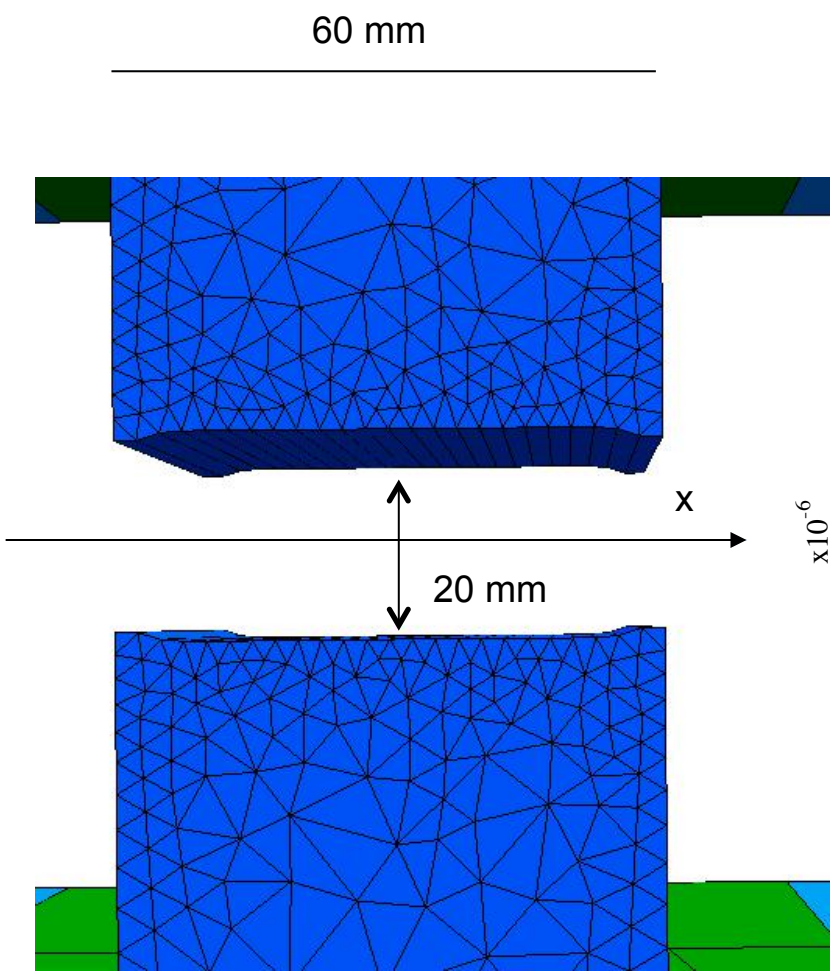
Vertical field along beam path
(3D simulations)

Field tuning

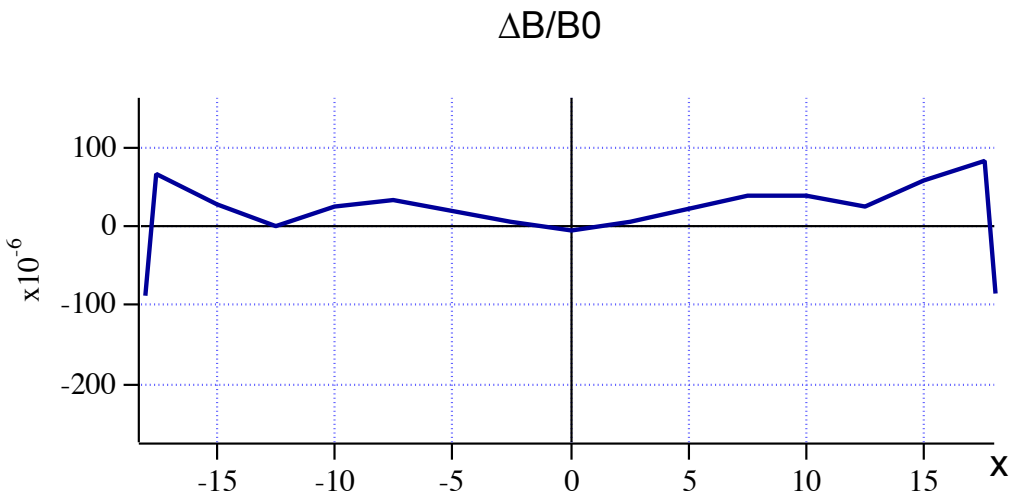
Dedicated movable shims : ± 3 %

Coil: ± 100 A.turns ± 1.5 % of total Deflection angle

Pole shape optimization

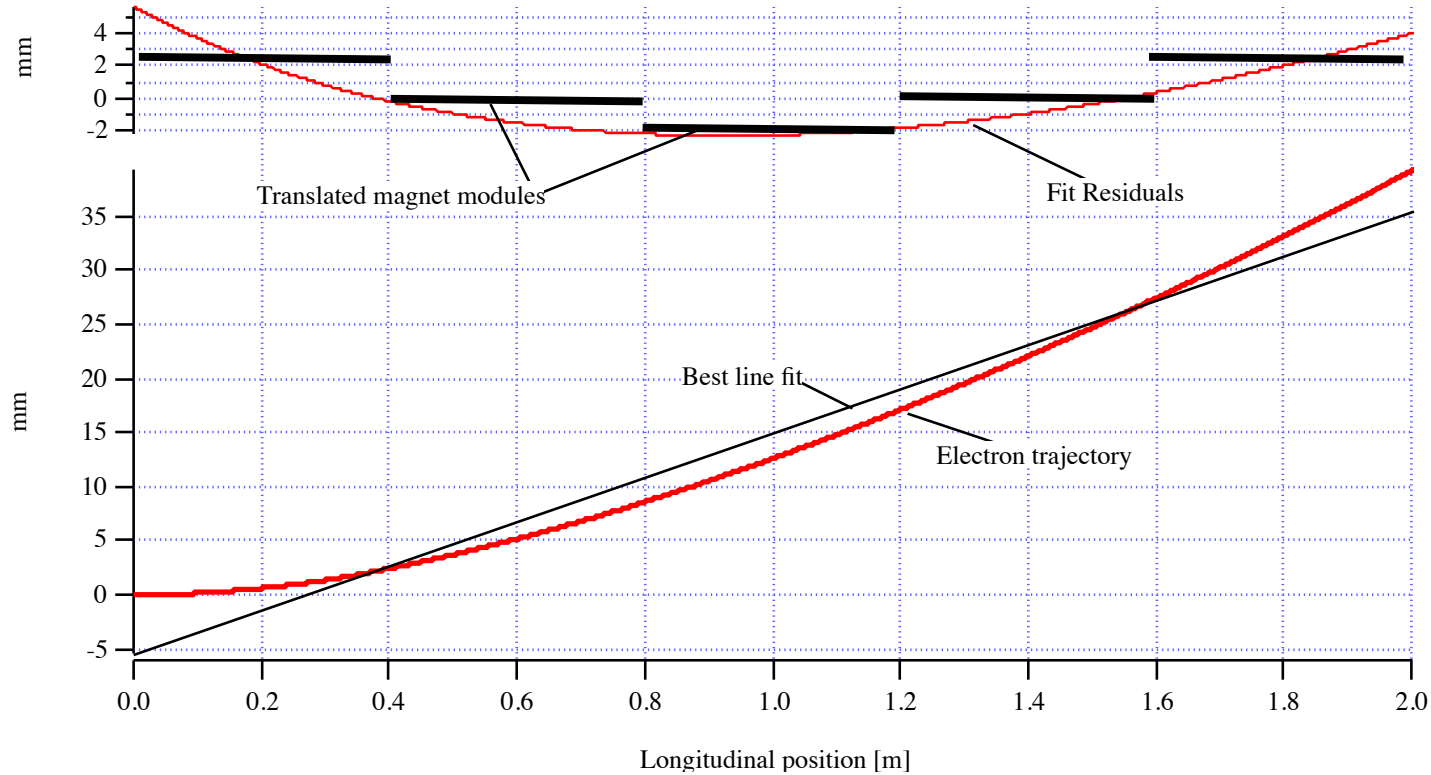


Max field 0.6 T



$\Delta B/B, < 10^{-4}$ (-15 mm <x<15 mm)

Magnet modules arrangement



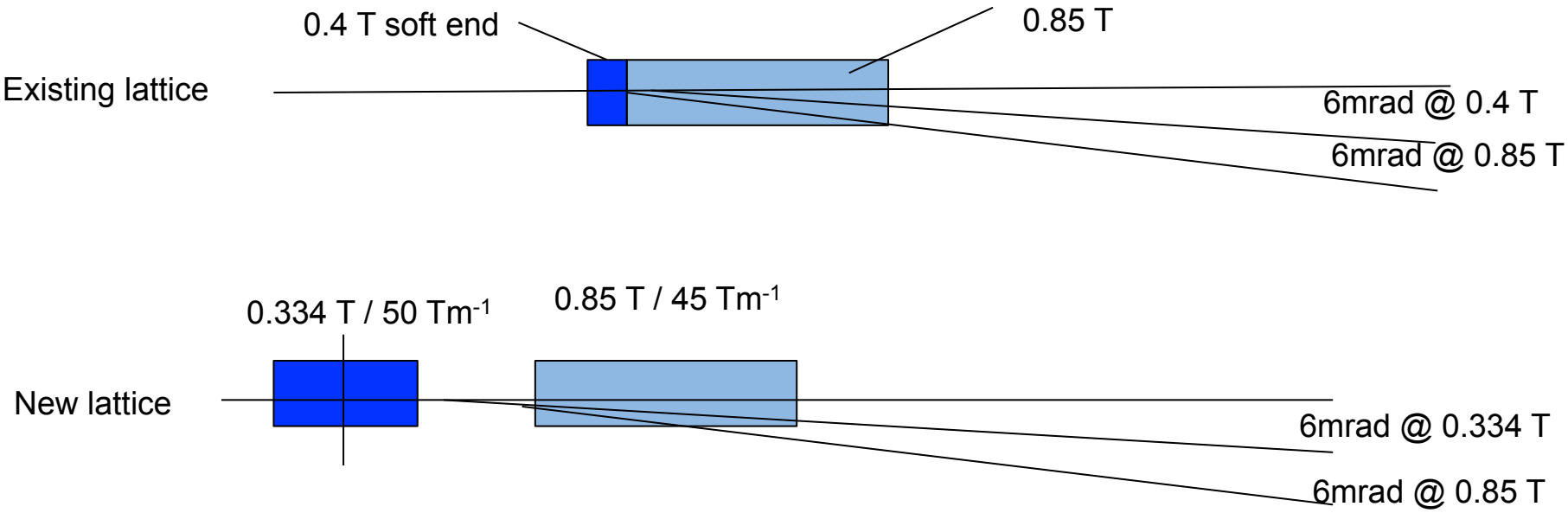
Whole magnet oriented along mean beam path
Modules translated horizontally by few millimeters
Residual offsets vs local magnetic axis ±2.5 mm

All magnets with longitudinal gradient= 640 modules with similar shape and different amount of magnet blocks

~ 3.2 tons (380 dm^3) of Sm_2Co_{17} permanent magnets needed for all 128 magnets

Combined dipole/quadrupoles

Purpose : restore exiting BM source points for the new lattice



Magnetic design under study

Possibly based on Permanent Magnets as other dipoles

Field tunability …..

High gradient quadrupoles

No laminations

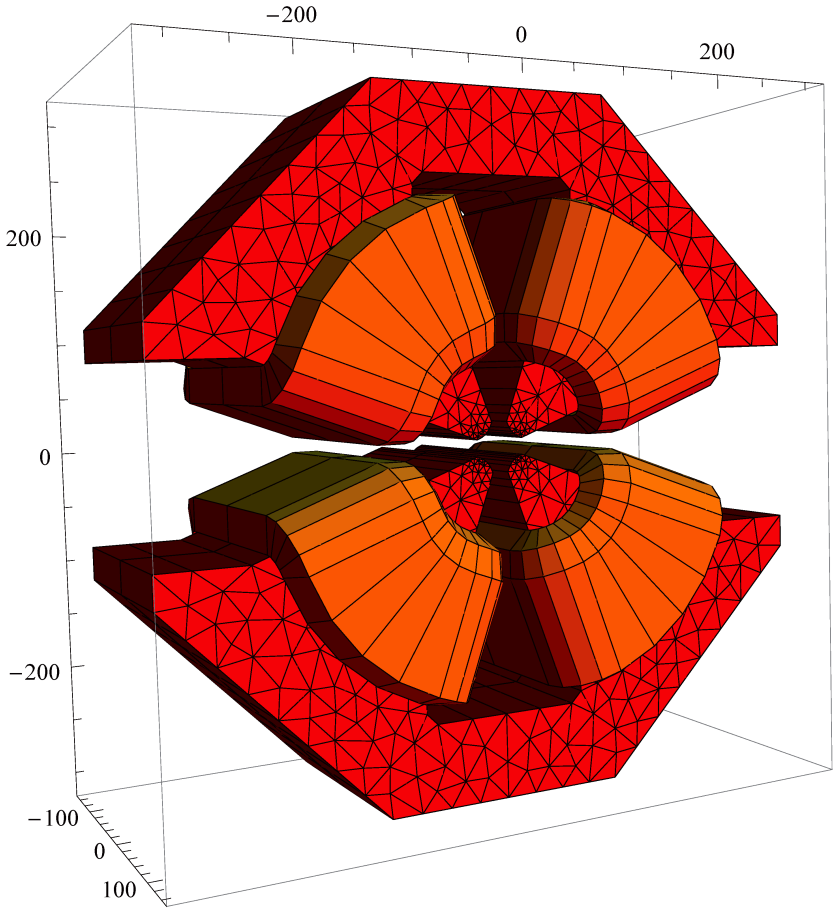
- Storage ring→ Constant field
- Stringent mechanical tolerances
- Demanding alignment

Field quality

- Asymmetric GFR ($\Delta G/G<10^{-3}$)
- Optimization of the pole profile

Optimization criteria

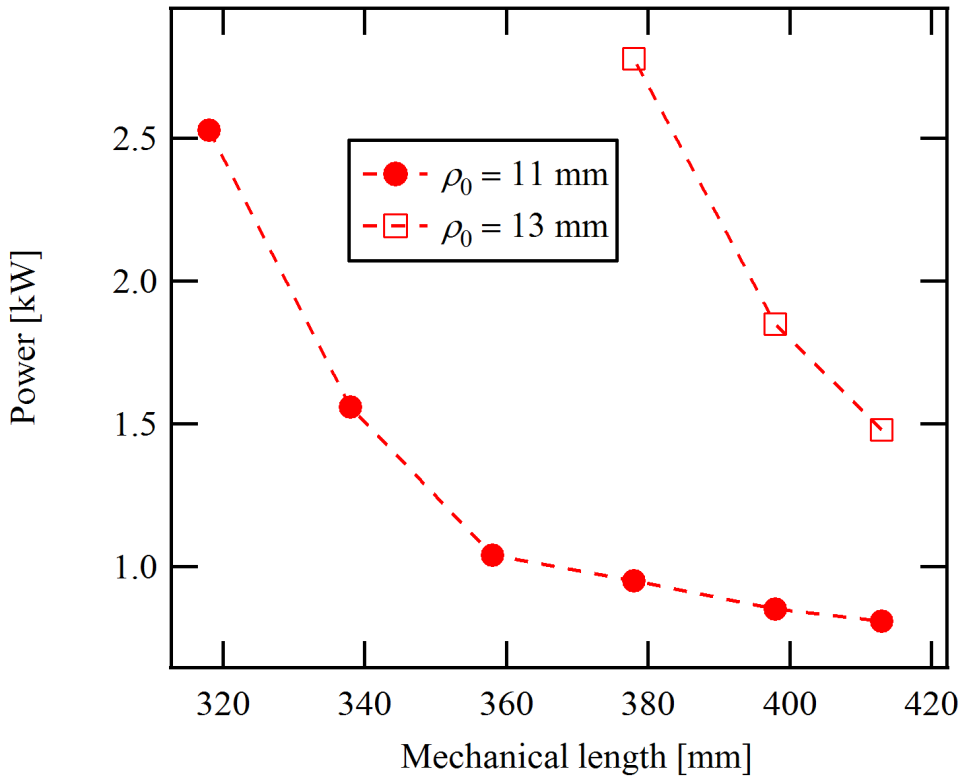
- Field quality in GFR
- Power consumption
- Compactness



High gradient quadrupole design

Design parameters

- Spec: 100 T/m x 335 mm
- Bore radius: 11 mm

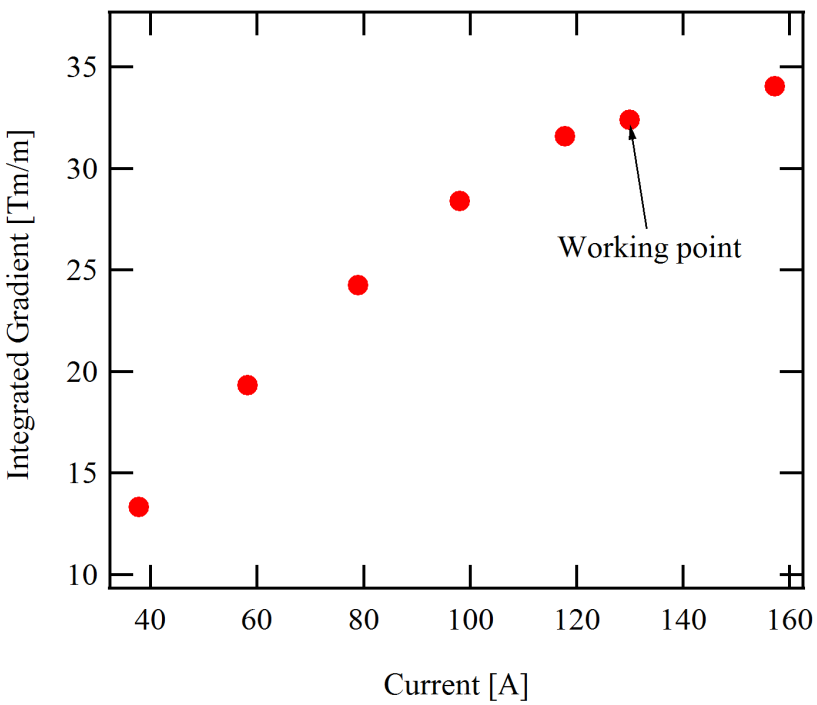


Magnet length

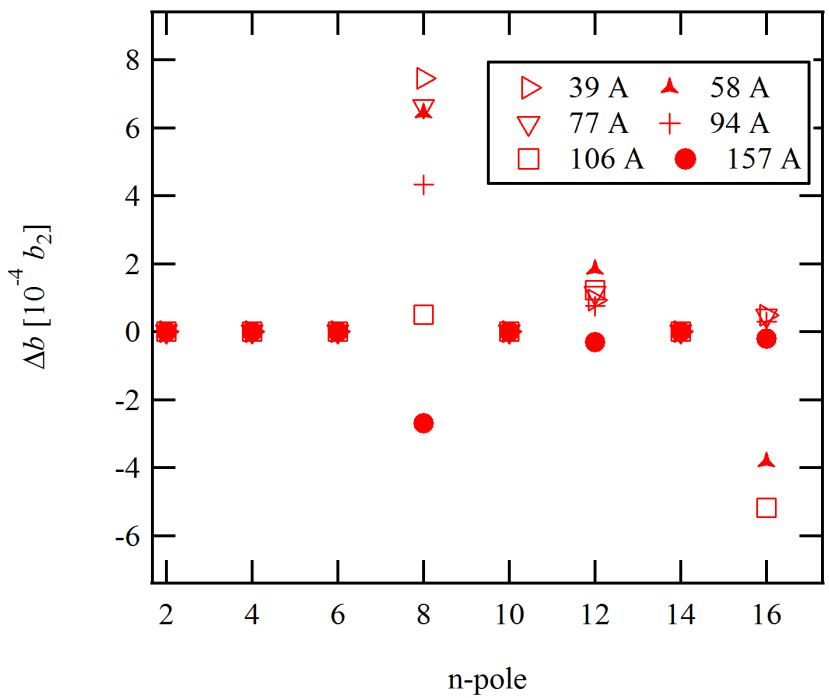
- Mechanical length: 360 mm (iron +coils)
- 1 kW

High gradient quadrupole design

Magnet close to saturation



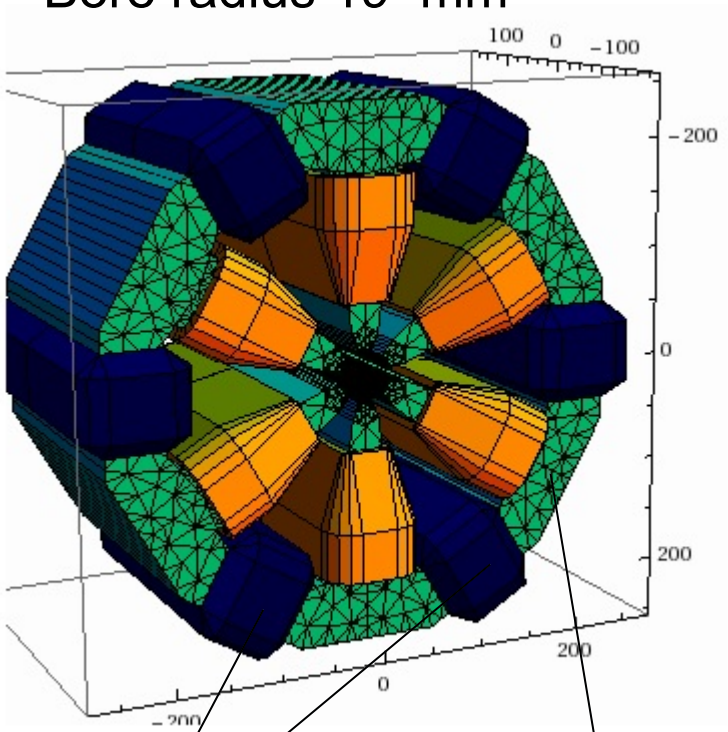
Gradient vs. current



Variation of multipole content (reference: 130 A)

Sextupole magnet

Bore radius 19 mm



Laminate yoke

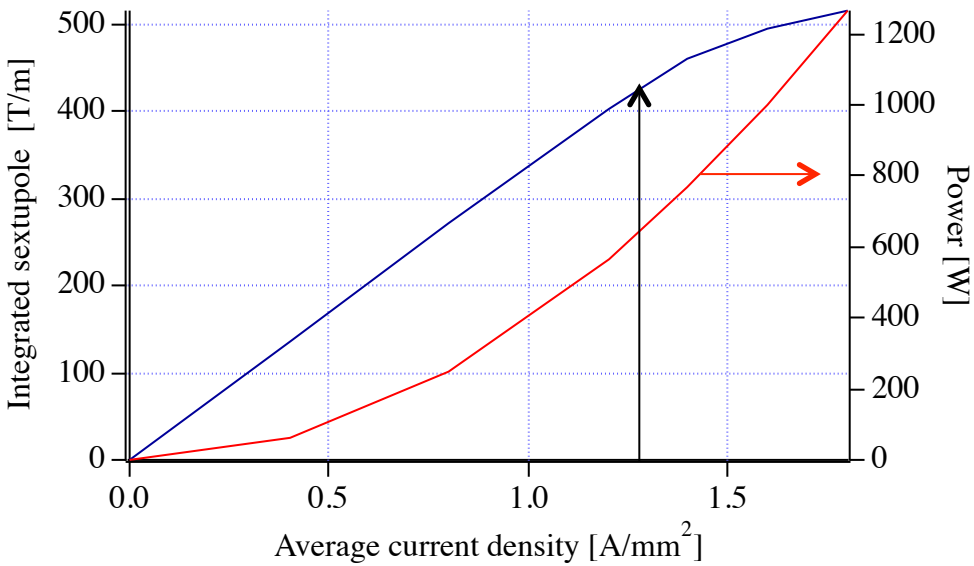
correctors

Mechanical length < 300 mm

Sextupole homogeneity < 1% in GFR

Integrated sextupole : 420 T/m nominal

2D sextupole: 1500 T/m^2

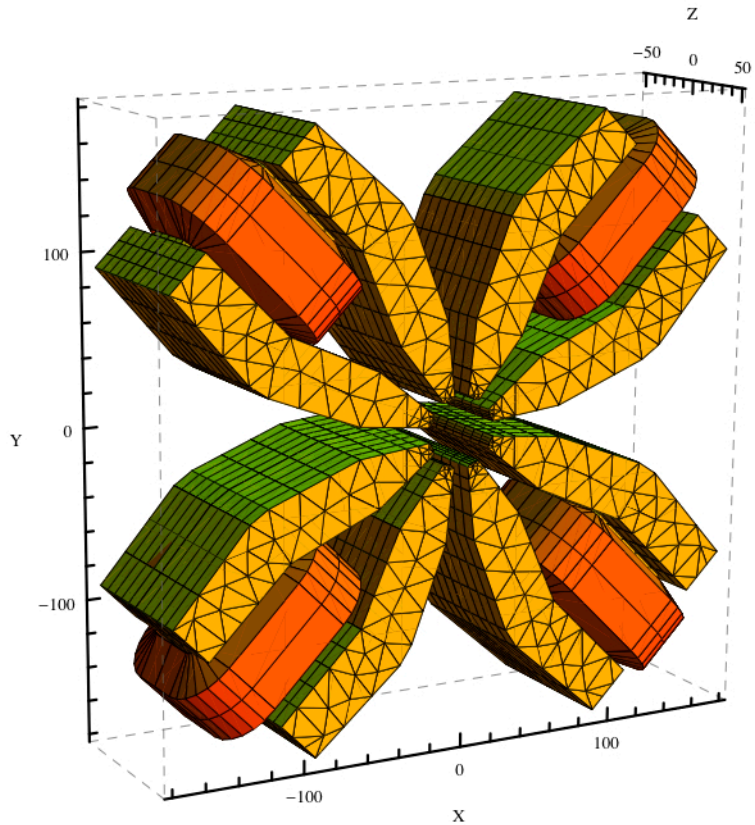


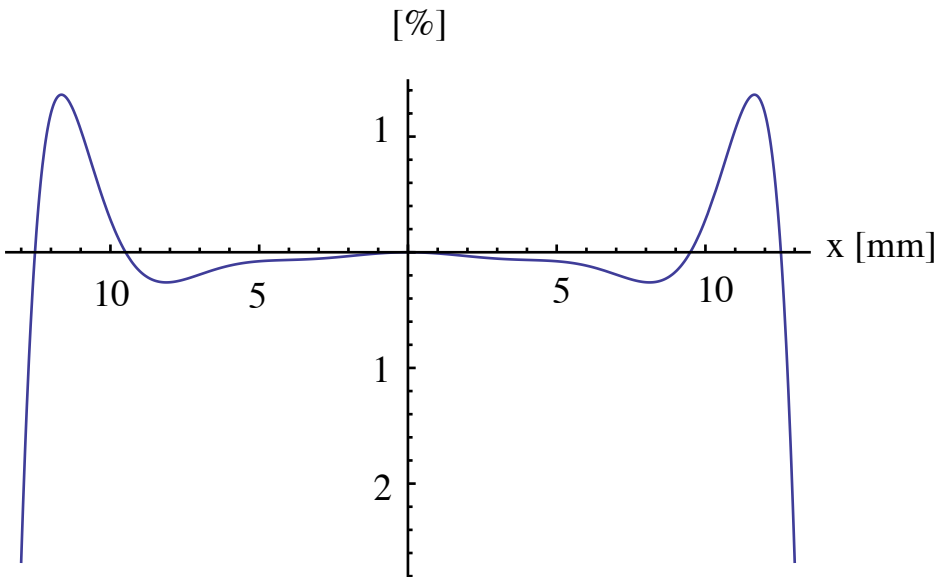
Octupoles

Needed for this lattice

Mechanical length ≤ 100 mm

Integrated octupole> 5000 T/m^2





Horizontal homogeneity of integrated octupole < 10 % in GFR

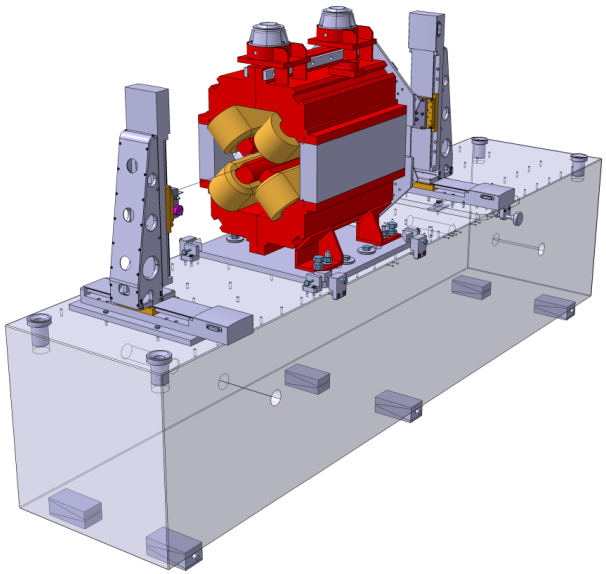
Integral measurements

Stretched wire:

- Integrated multipoles analysis
- magnetic center
- Other variants (vibrating wire)

Adequate for

- Quadrupoles
- Sextupoles
- Octupoles
- Dipole modules



ESRF stretched wire bench

- Curved magnets will need dedicated curved coils

Local field measurements

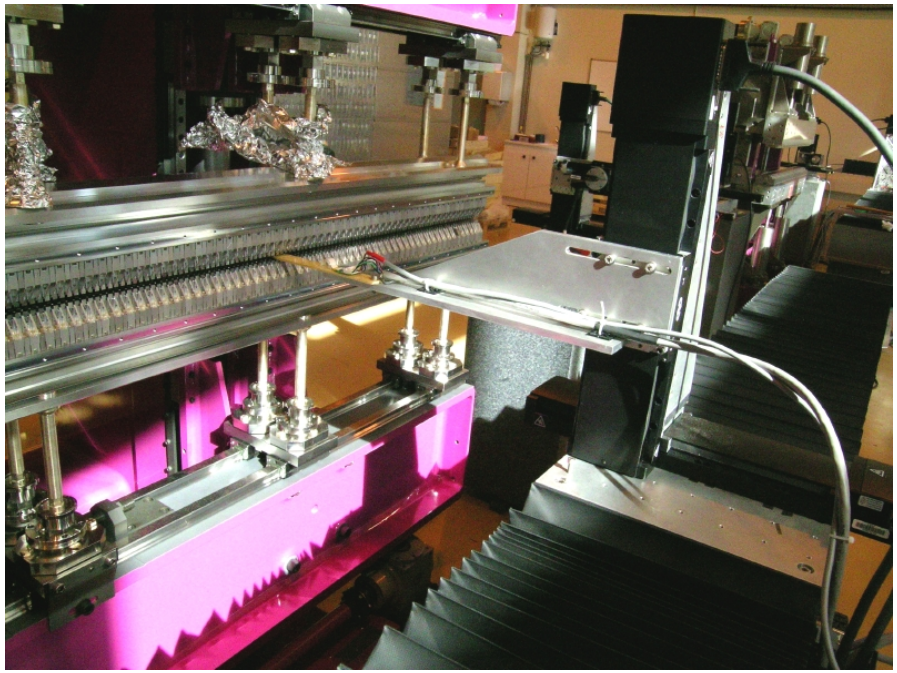
Rely on existing experience with Insertion Device Hall Mapping

Several units in operation

- Modern mutli-axis control
- High positioning accuracy
- Appropriate for open magnets
- Search coil vs hall sensors

Used for

- Curved magnets (dipole)
- Combined dipole/quadrupole



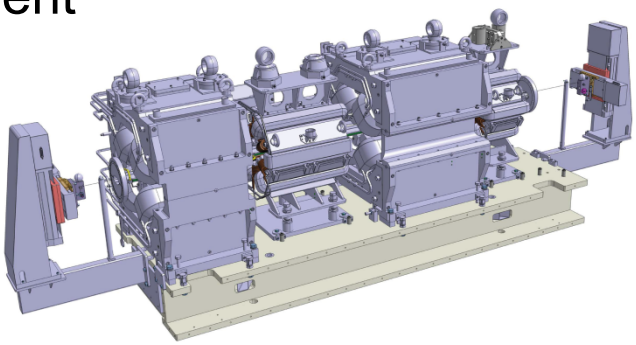
To be probably adapted for dipoles & combined function magnets

Magnet alignment

Difficult and essential part

Usual alignment based on fiducialisation not sufficient

In situ alignment on girder with
stretched wire/ vibrating wire seems better option



RMS alignment error of 20 µm looks feasible (wire length ~ 3m)

(see Stretched wire measurements of magnet girders, G. Le Bec on Wednesday)

Appropriate for straight magnet assembly (eg. quadrupoles sextupoles, etc)

Magnet girder with combined dipole/quadrupole need other approach

Summary

Very challenging magnets in focus @ ESRF

- Field performance close to magnetic saturation for quadrupoles, sextupoles
- High stability permanent magnet materials must enter in the process
- Preliminary magnetic design to be completed (combined function magnets)

- Magnetic measurements
  - Stretched/vibrating wire is a good option
  - Local field mapping to be refined

More to come at next IMMWs …..