The DESY Experience

Bernward Krause

Compact and Low Consumption Magnet Design
The DESY Experience

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HELMHOLTZ
ASSOCIATION

DESY

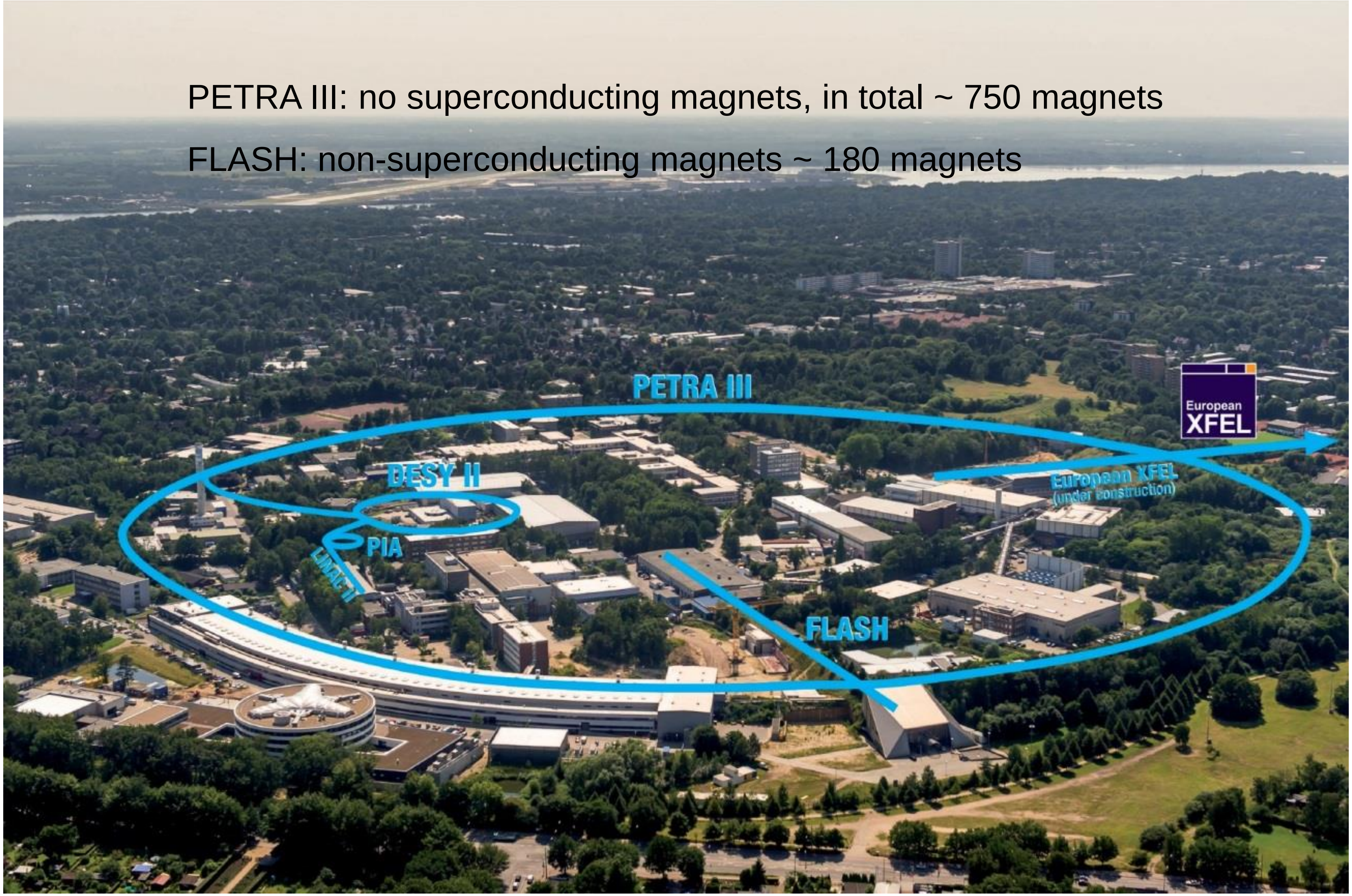
Outlook

- DESY and it‘s accelerators FLASH, PETRA III; accelerator XFEL
- Influences on electro-magnet design
- „Combined function“ magnets
- Example of reducing electricity costs
- Permanent magnet

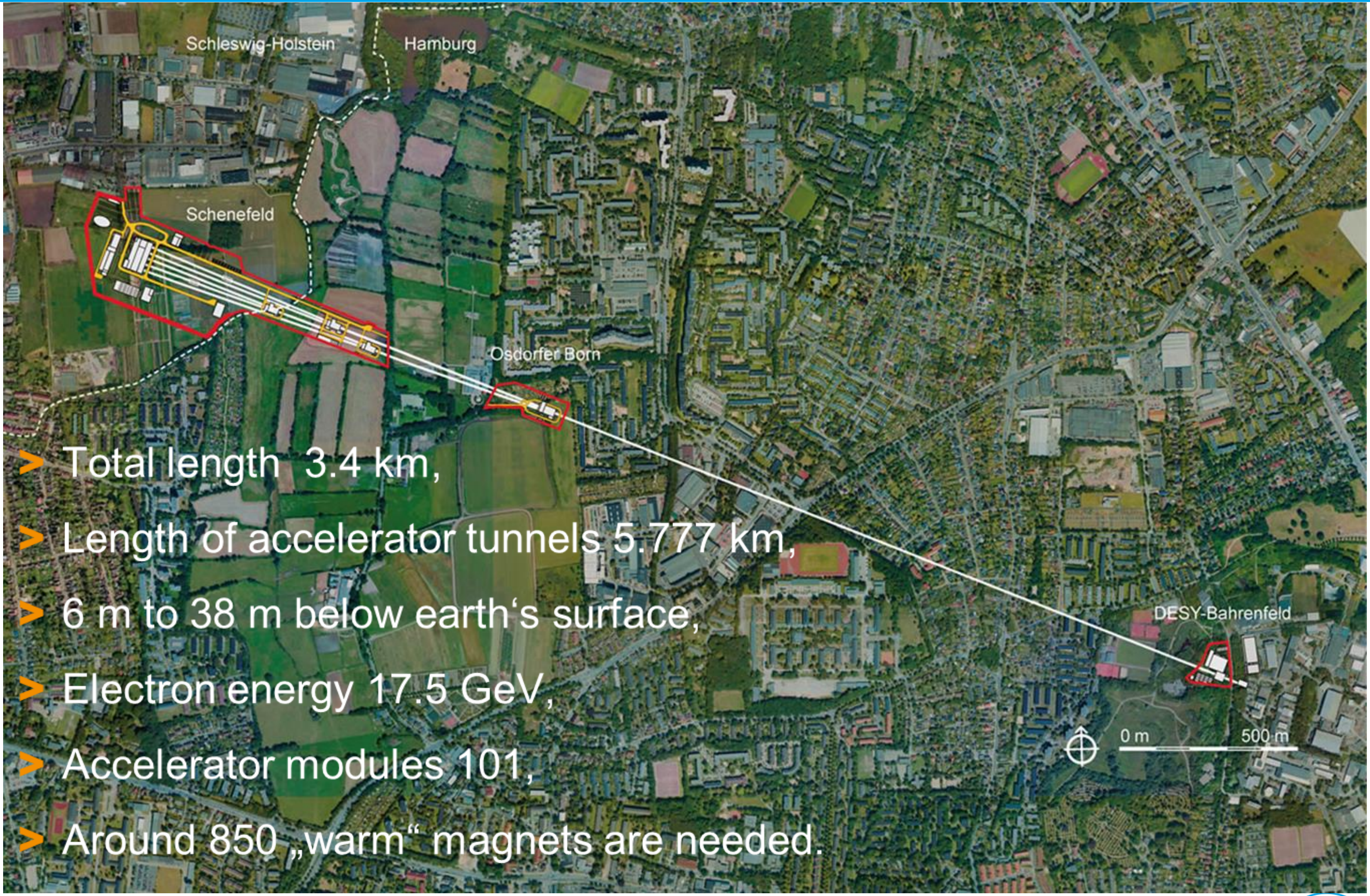
DESY's accelerators

PETRA III: no superconducting magnets, in total ~ 750 magnets

FLASH: non-superconducting magnets ~ 180 magnets



The European XFEL Accelerator



- Total length 3.4 km,
- Length of accelerator tunnels 5.777 km,
- 6 m to 38 m below earth‘s surface,
- Electron energy 17.5 GeV,
- Accelerator modules 101,
- Around 850 „warm“ magnets are needed.

Information needed for a magnet design

- Lattice design of the accelerator defines
  - **Magnet types and quantity, iron length, magnetic field quality and magnetic strength**
- Vaccum system defines
  - **Magnet aperture (quadrupole and multipole magnets),**
  - **Gap height and gap width (dipole magnet)**
- Utilities like power supply devices, cooling water and pressure, temperature stabilization defines
  - **Magnet coil design**

Information needed for a magnet design

- Beam diagnostics could end up in
  - **Special magnet design**
- Tunnel layout and installation defines
  - **Magnet weight and geometry**
- Survey and alignment
  - **Special equipment added to the magnet (fiducial marks)**

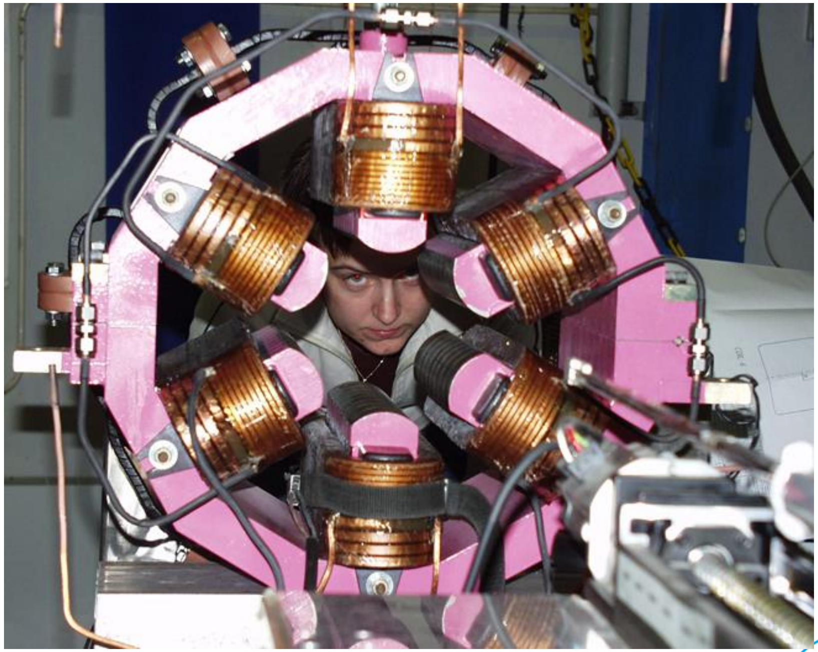
All these mentioned items have an impact on the magnet design and energy consumption!

„Combined function“ magnets @ DESY

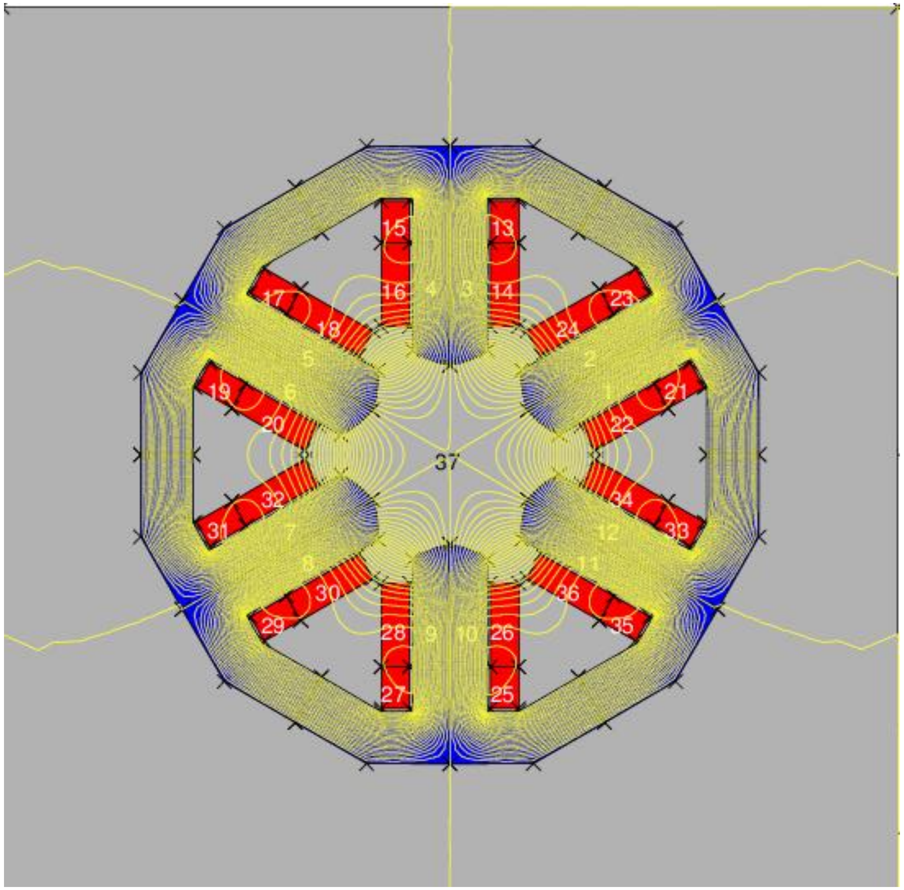
- The accelerator FLASH and XFEL have no combined function magnets
- Lack of space in PETRA III for an additional steerer magnet leads to a „combined function“ sextupole magnet.

PETRA III sextupole magnet

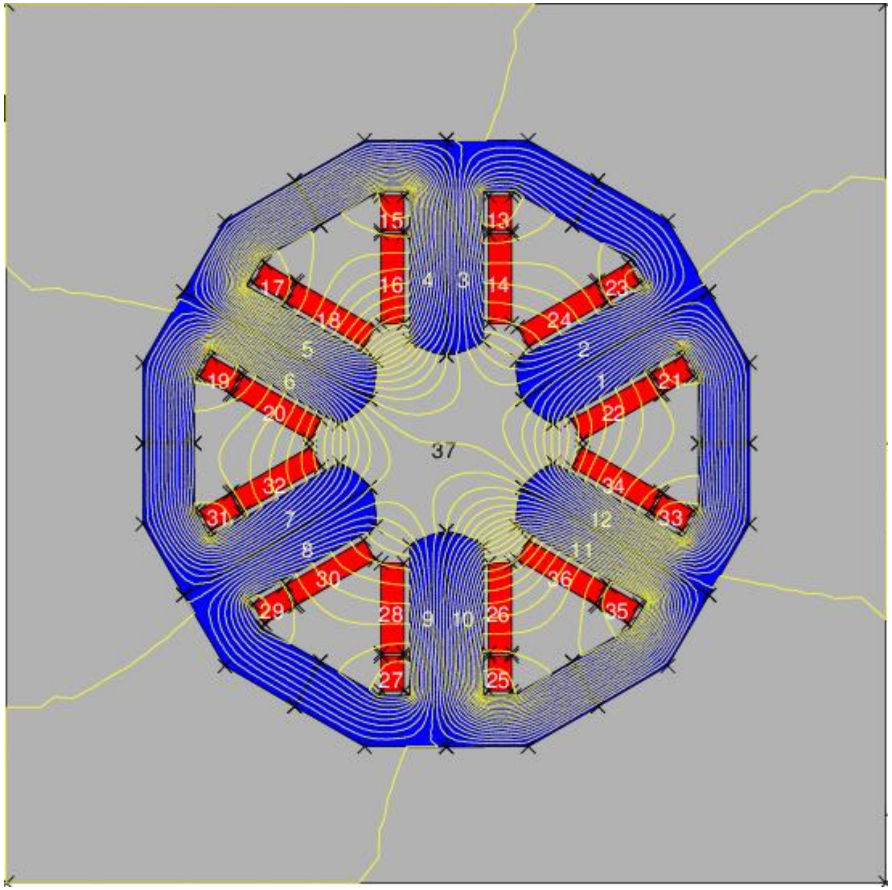
- Replacement of the sextupole aluminium coils with copper coils gives enough space for adding an additional coil on each pole.



Simulation with program Opera2d



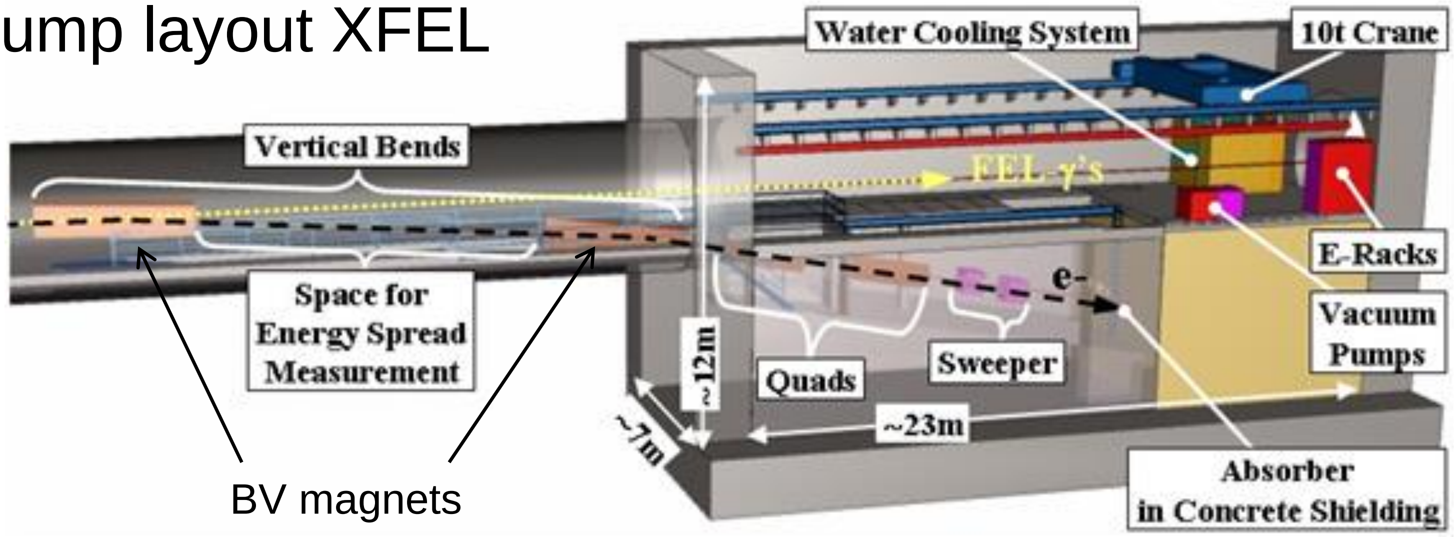
Only sextupole coils on



Sextupole and correction coils on

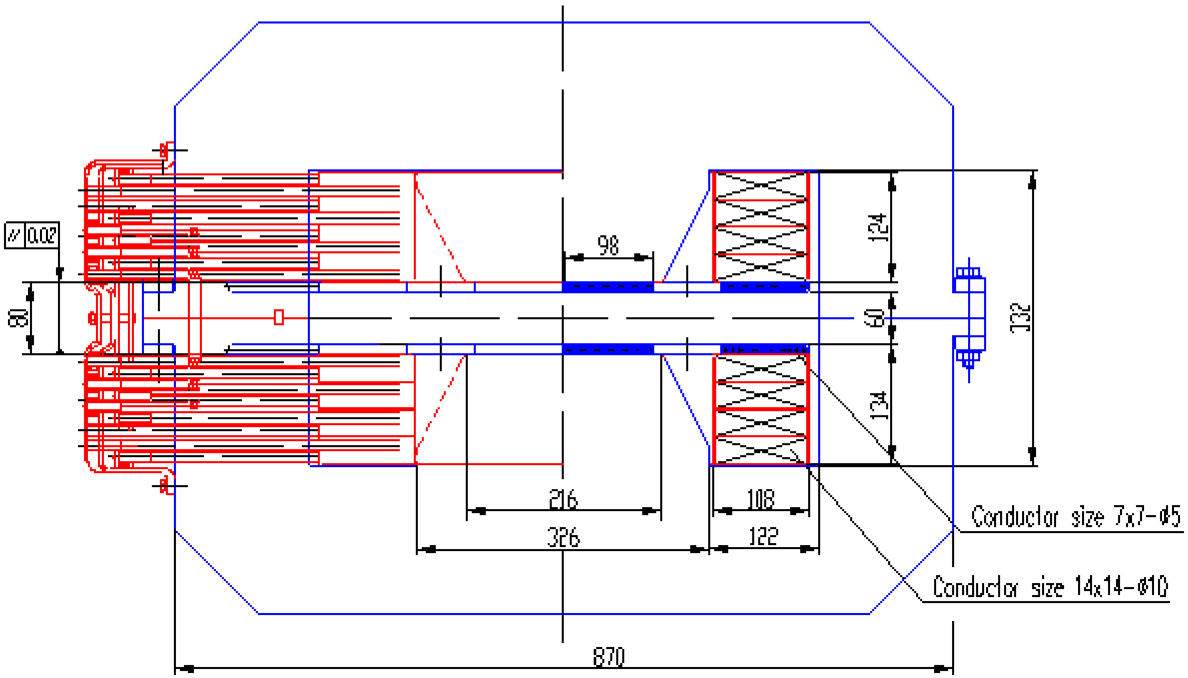
„Combined function“ magnet XBV (for XFEL)

Dump layout XFEL

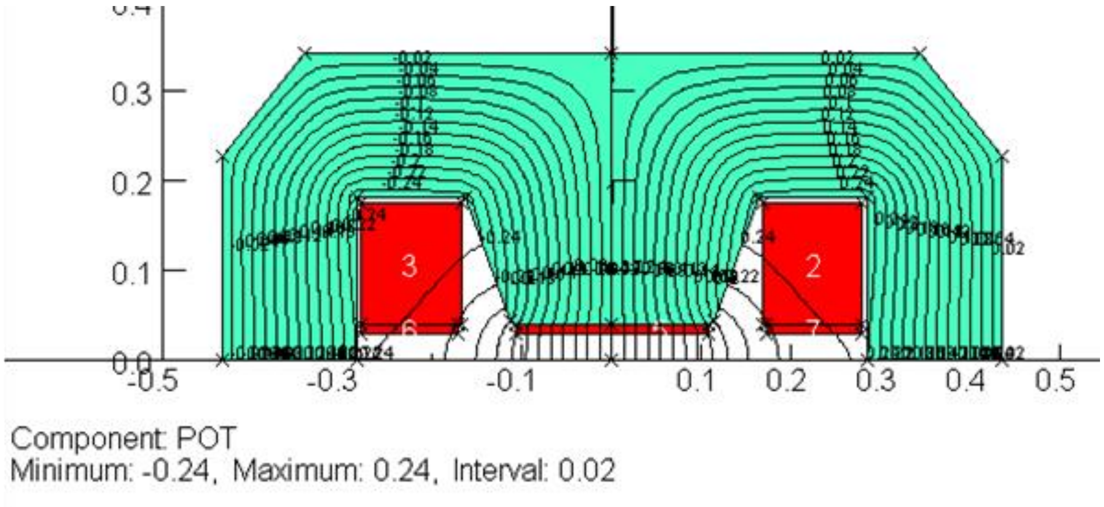


The BV magnets bend the beam into the dump and two strong quadrupoles (Quads) magnify the beam to allow dump window operation at full beam current. The two quadrupoles are operated at their maximum strength. To obtain reasonable matching of optical functions the BV magnets have to have a slight gradient (machine physicist statement).

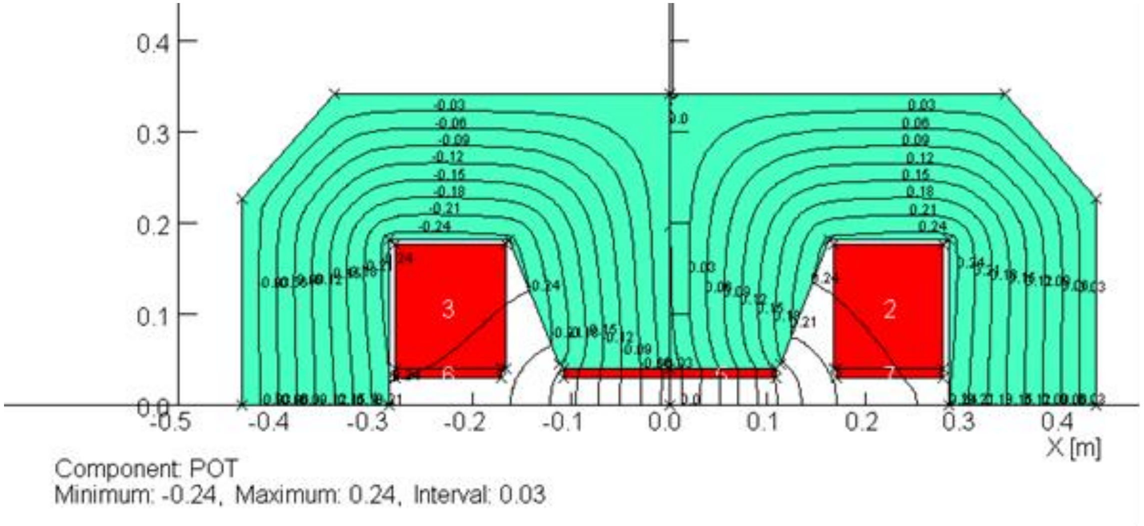
„Combined function“ magnet XBV (for XFEL)



„Combined function“ magnet XBV

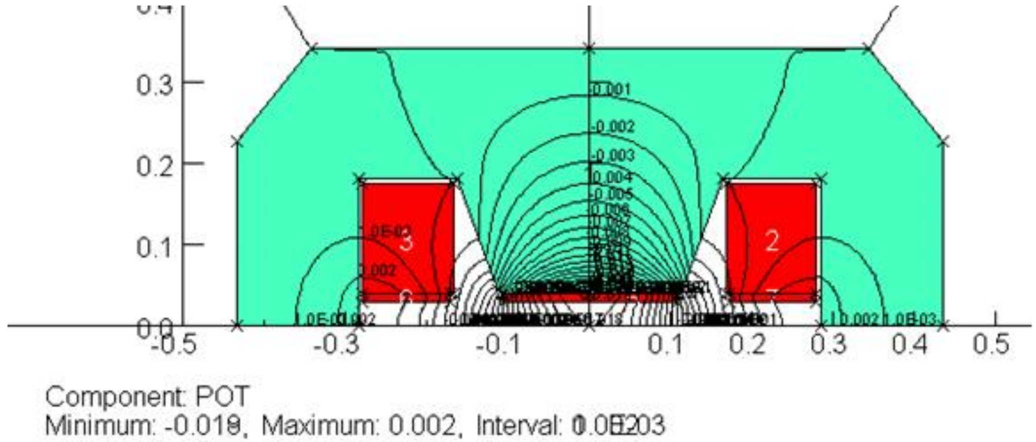


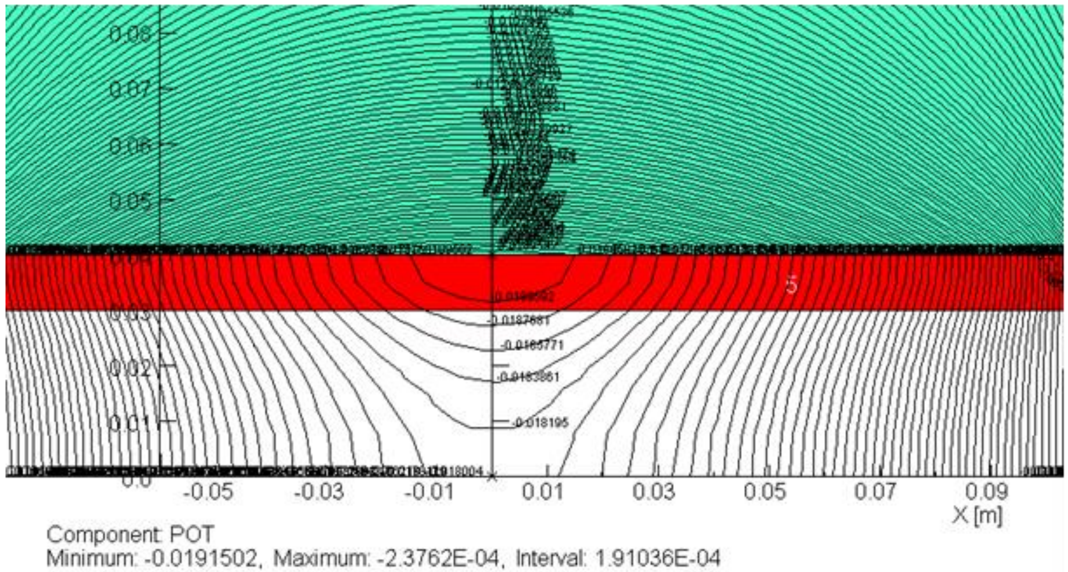
Dipole coils on: B=1.478T



Dipole and „quadrupole“ coils on: B=1.478T; G=1.61T/m

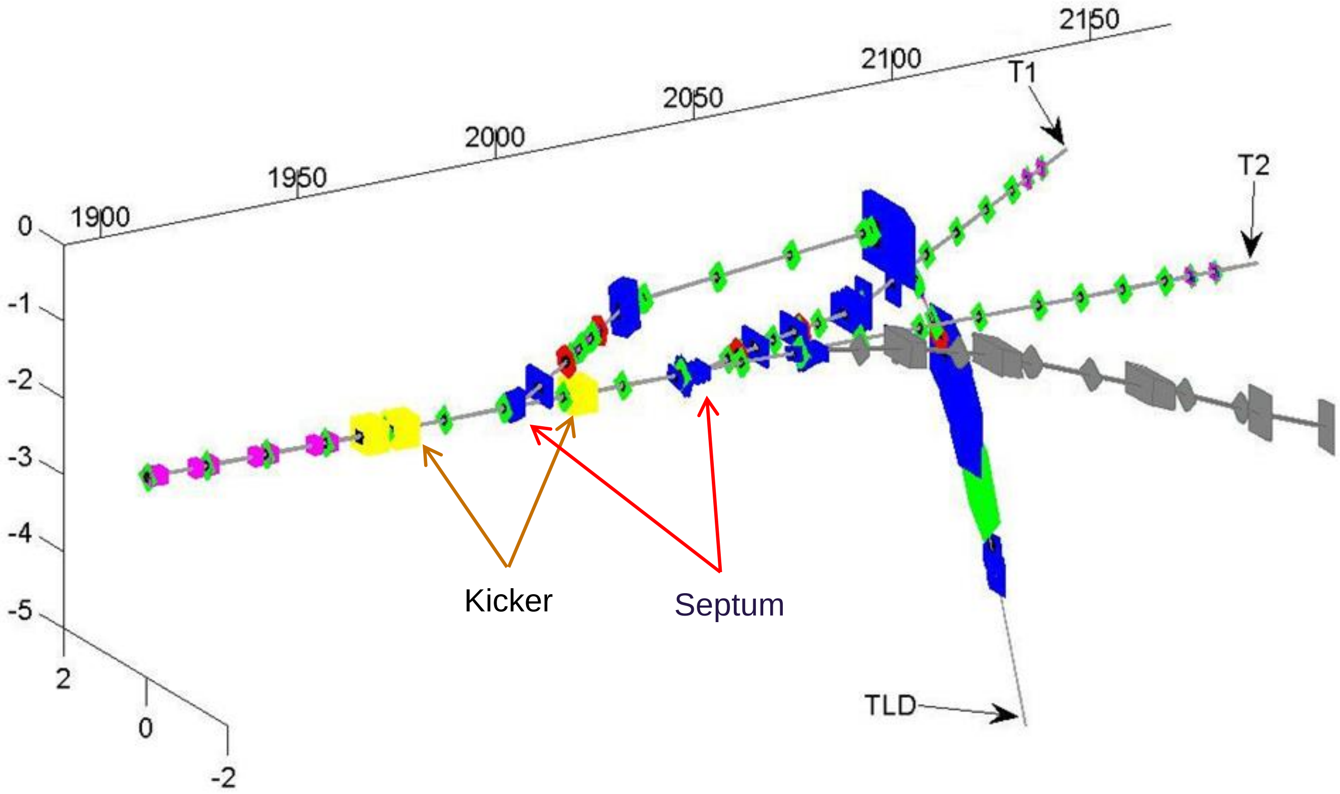
„Combined function“ magnet XBV



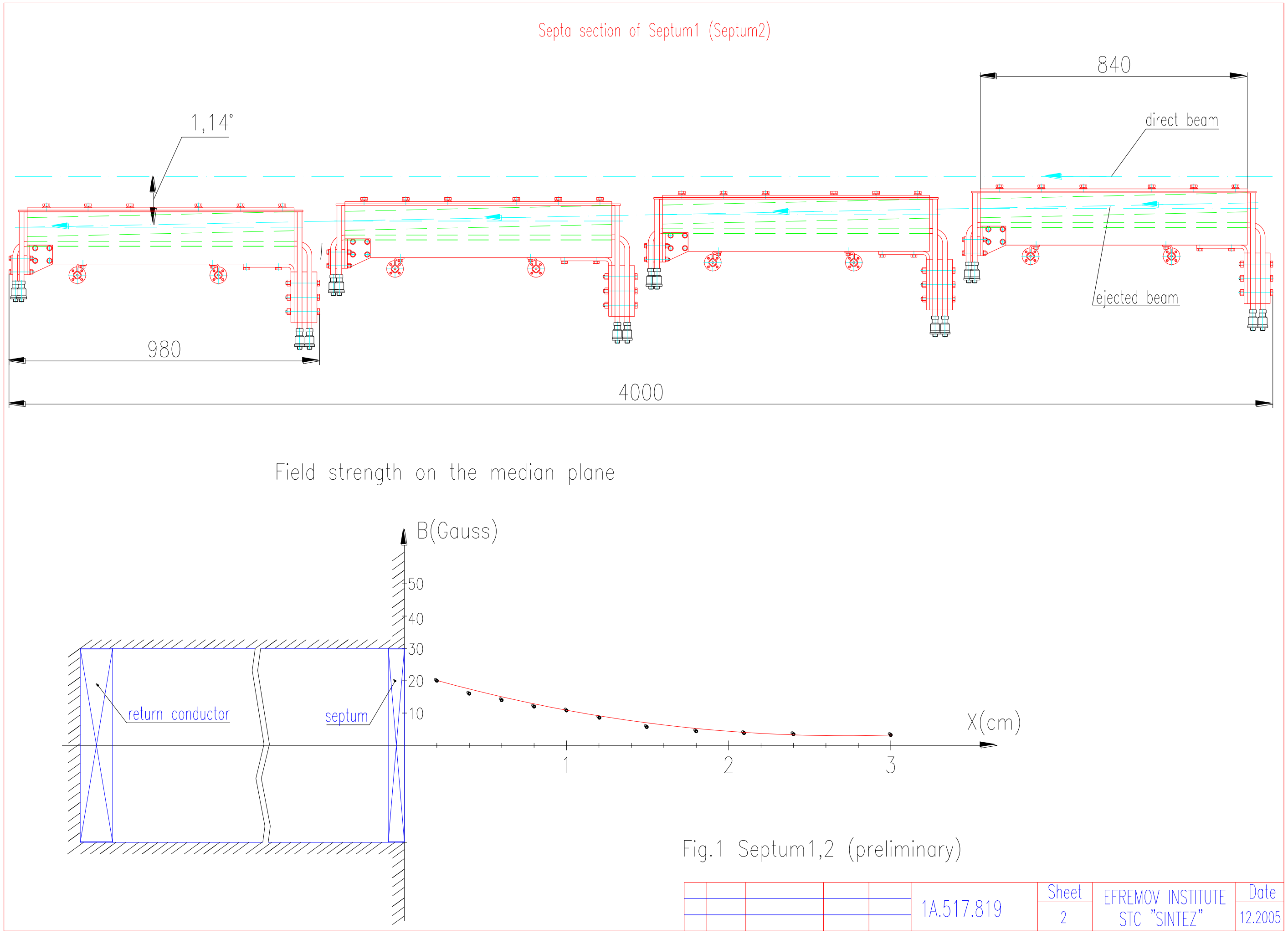


only „quadrupole“ coils on
G=1.61T/m

Reducing Electricity Cost:
XFEL Beam Switch yard and the septum magnet



XFEL Septum first ideas in 2007

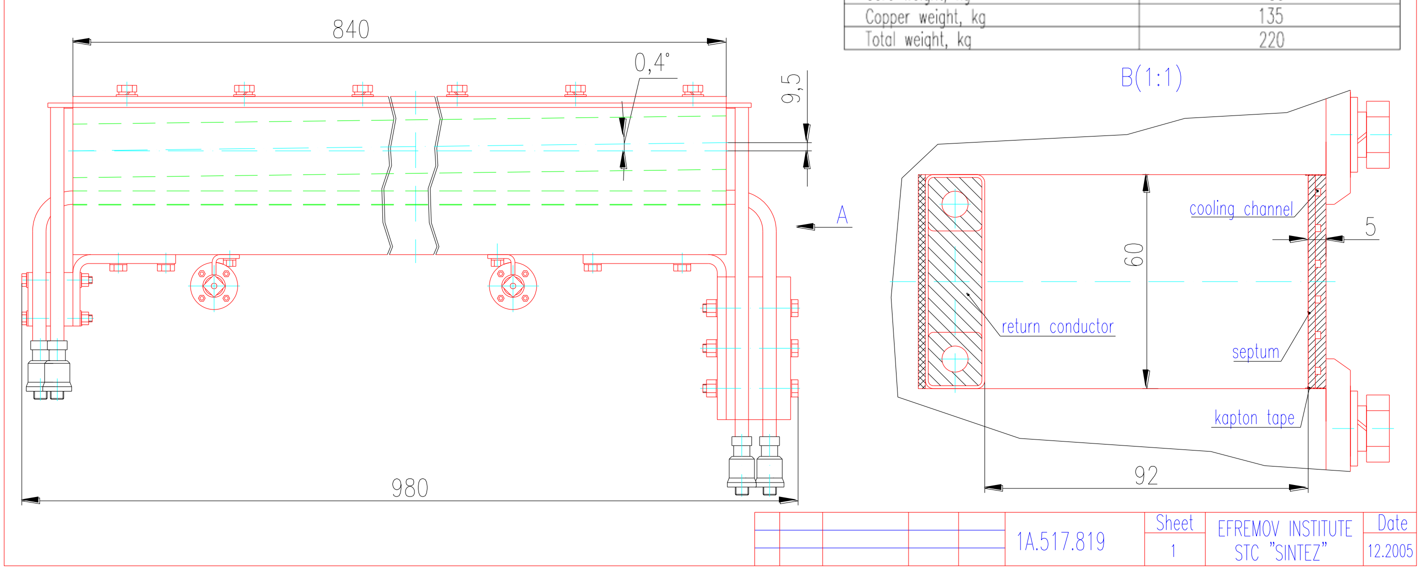


Efremov Institute, Design Study for XFEL

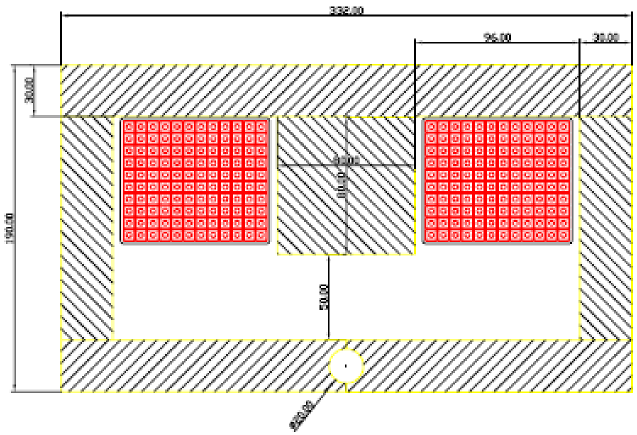
XFEL Septum first ideas in 2007

- High current density in septum blade
- High power consuption
- Active parts in beam path

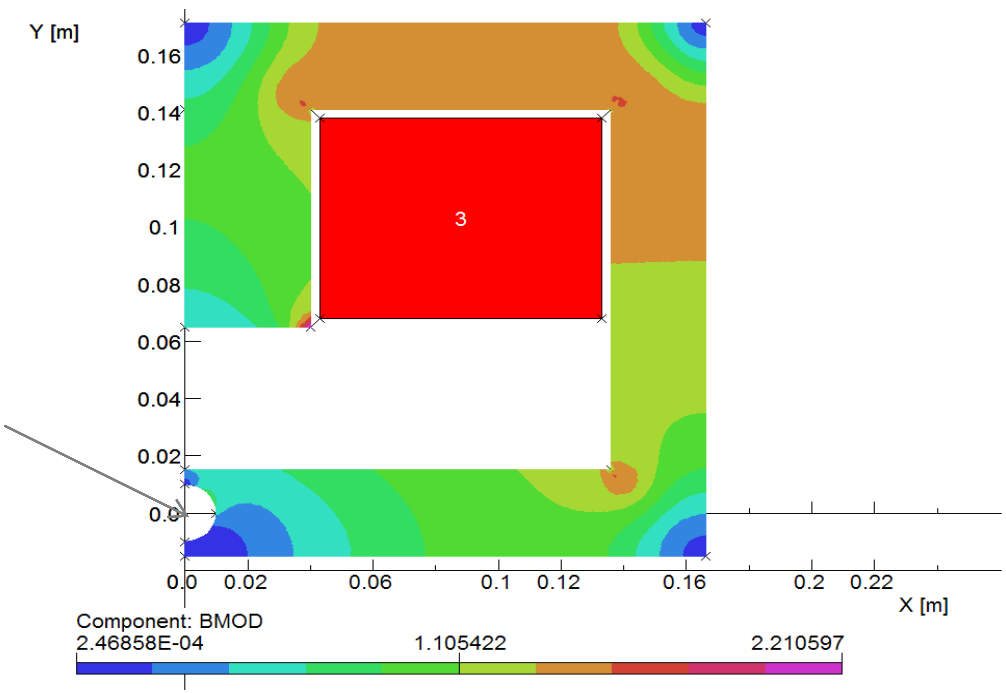
Parameters	Value	
	septum	return conductor
Gap heigth, mm	60	
Gap width, mm	90	
Magnetic field Bo, T	0,45	
Number of magnets	4	
Core length, mm	840	
Number of winding turns	1	
Nominal current, kA	21,6	
Septum copper thickness, mm	5	15
Septum current density, A/mm^2	74,5	27,4
Septum resistance, Ohm	5,36x10^{-5}	1,96x10^{-5}
Water cooling		
Pressure drop, Atm	5	
Cooling water flow, l/min	6,72	68
Water overheating, (degrees)	50	2
Voltage drop, V	1,13	0,41
Power loss, kW	24,13	8,82
Core weight, kg	85	
Copper weight, kg	135	
Total weight, kg	220	



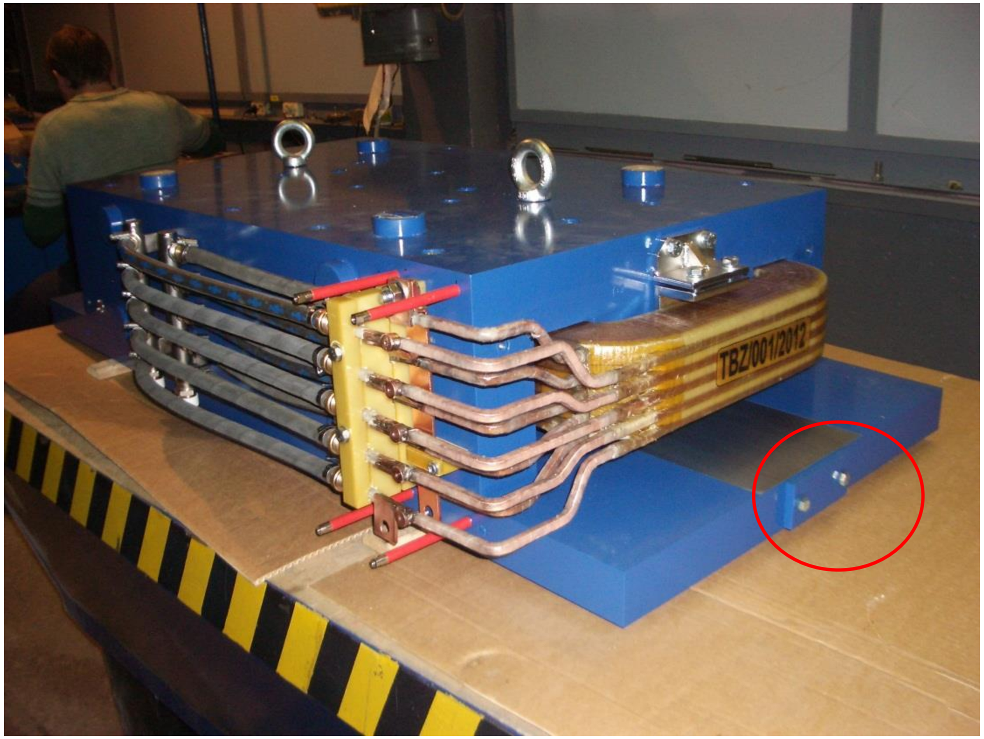
Better option for Septum: Lambertson DC Septum

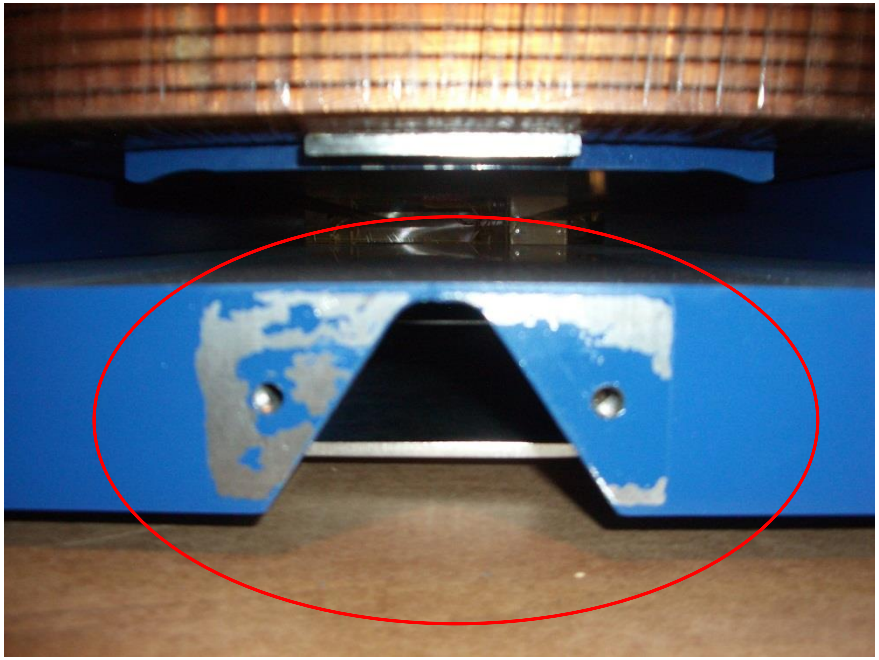


- B-field inside hole ~2.5 Gauss
- beam deflection horizontally
- Nominal current 170 A
- Current density 3.85 A/mm²
- Power loss 2.7 kW

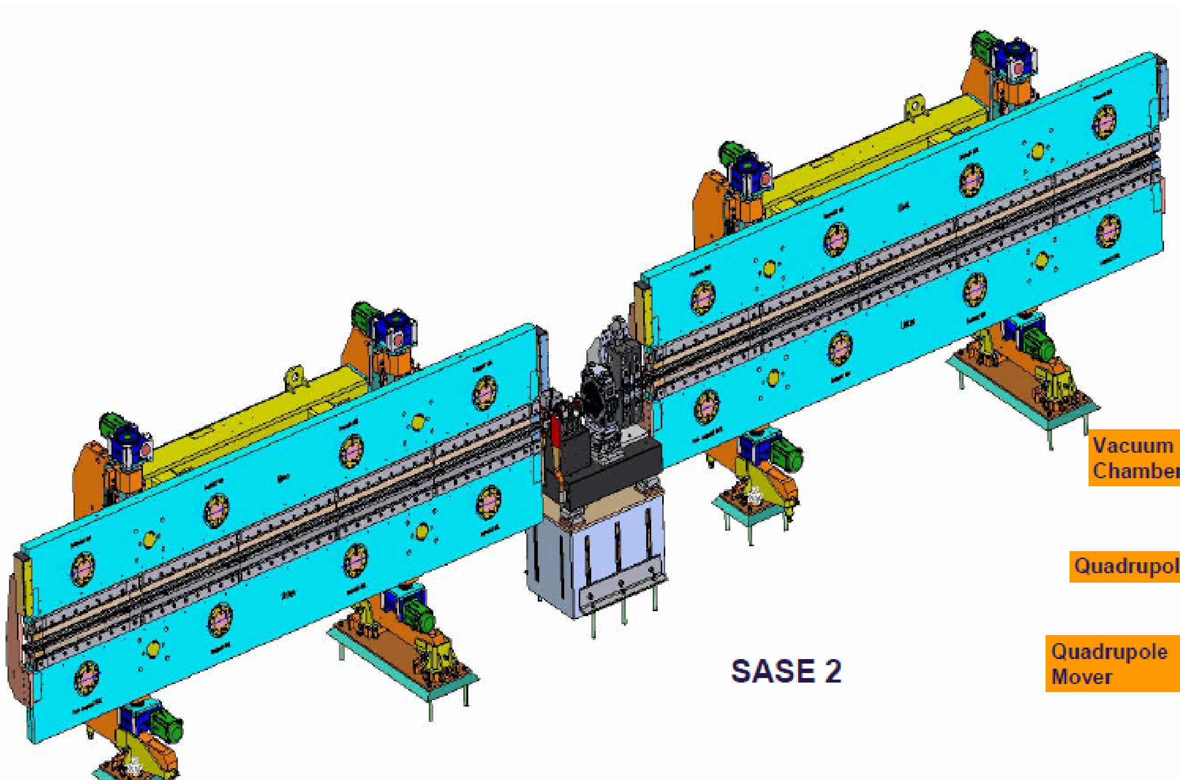


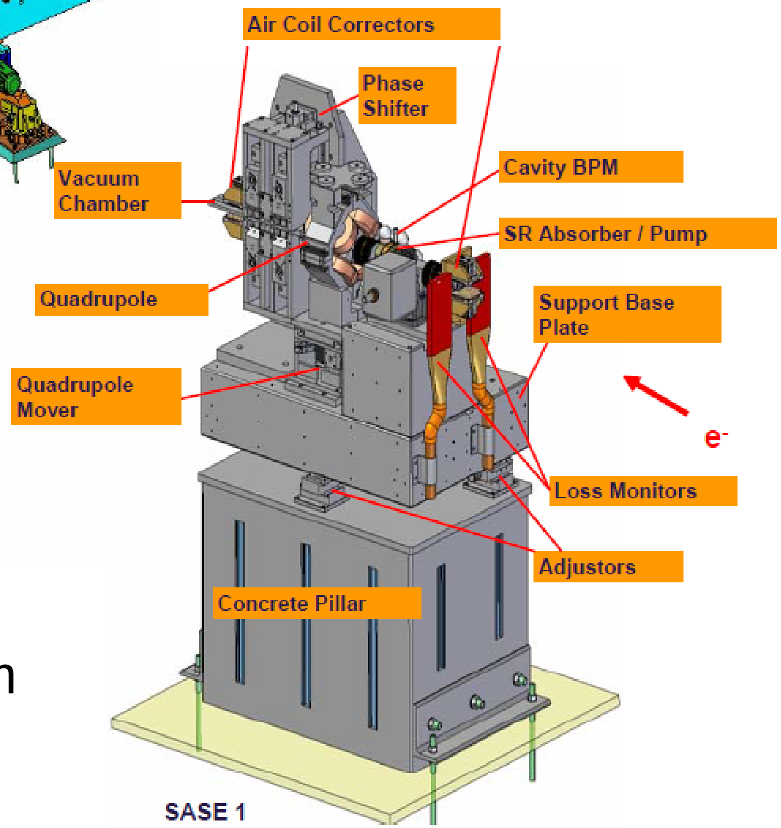
Lambertson Septum





A Hybrid Quadrupole for the XFEL undulator intersection

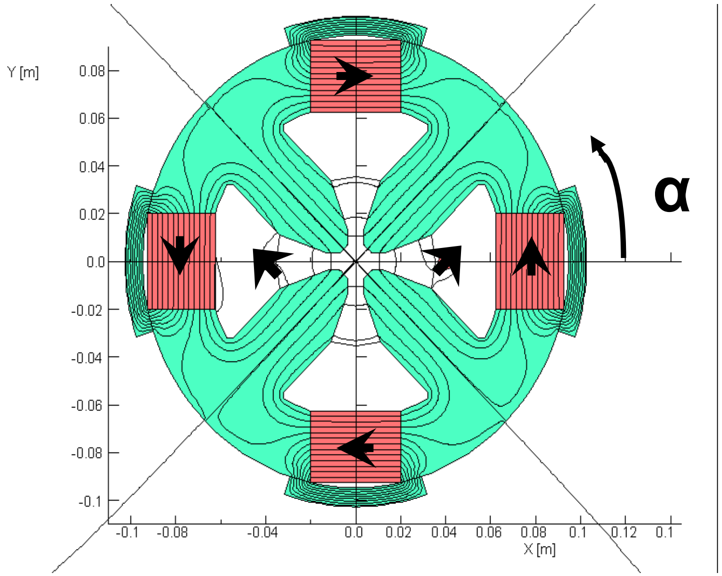




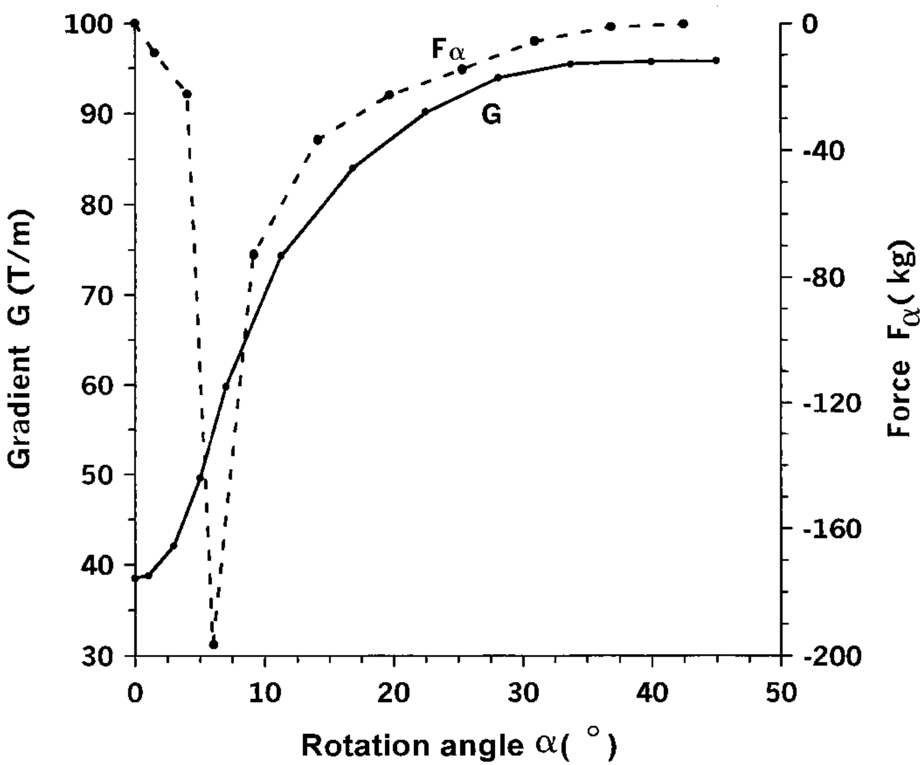
Requirements Quadrupole:

- Gradient between 30 to 100 T/m
- Length <150 mm; bore hole 15 mm
- Magnetic axis stability < ± 5 µm

Hybrid Quadrupole with External Adjustment rings*

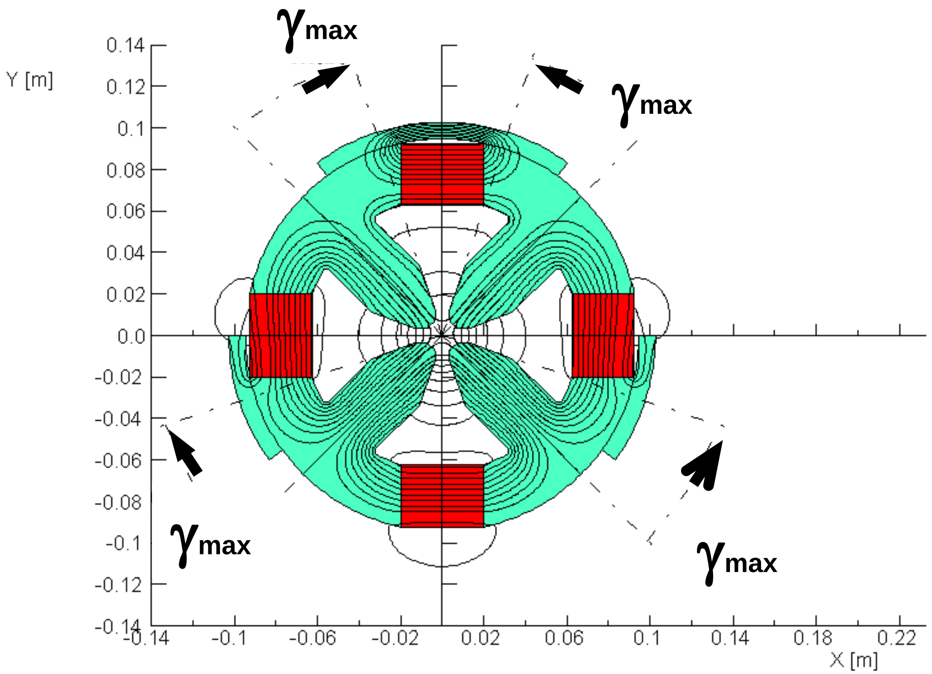


Quadrupole with shunts and adjusting HMM rods. Rectangular bars from SmCo-alloy are used as PM.
Shown maximum flux shunting (α=0).

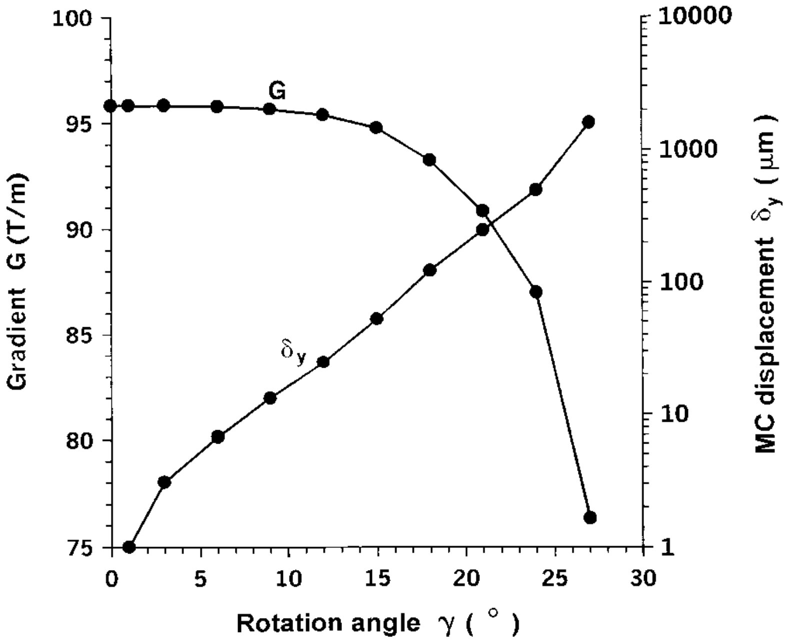


*E. Bondarchuk et al. „Hybrid Quadrupole With Variable Gradient and Precise Regulation of the Magnetic Center“, IEEE Transactions on Applied Superconductivity, Vol. 16, No.2, June 2006

Hybrid Quadrupole with External Adjustment Ring



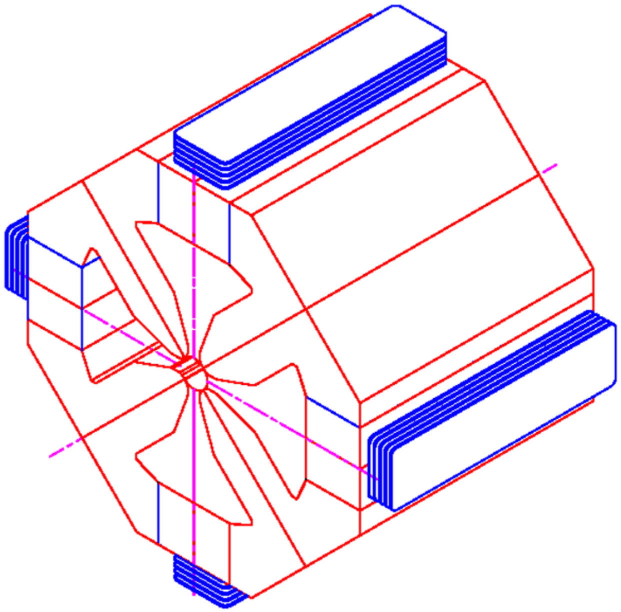
Scheme for regulation of the quadrupole magnetic center at Gmax.
γ - shunt displacement direction at δy>0, δx=0.



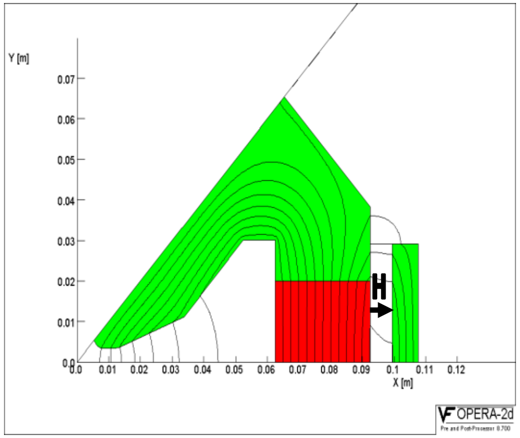
Functions G(γ) and δ(γ)

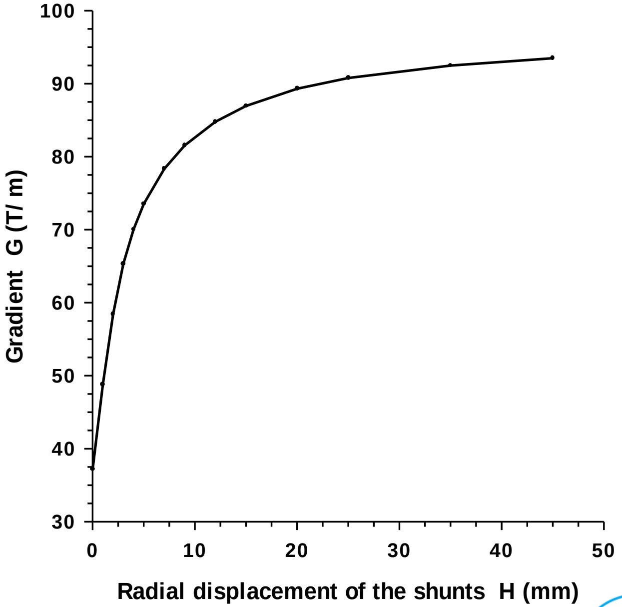
<u>Fine regulation of δy(γ) is possible only at small γ with the gradient remaining practically unchanged.</u>

Hybrid Quadrupole with Radially Displaced Shunts



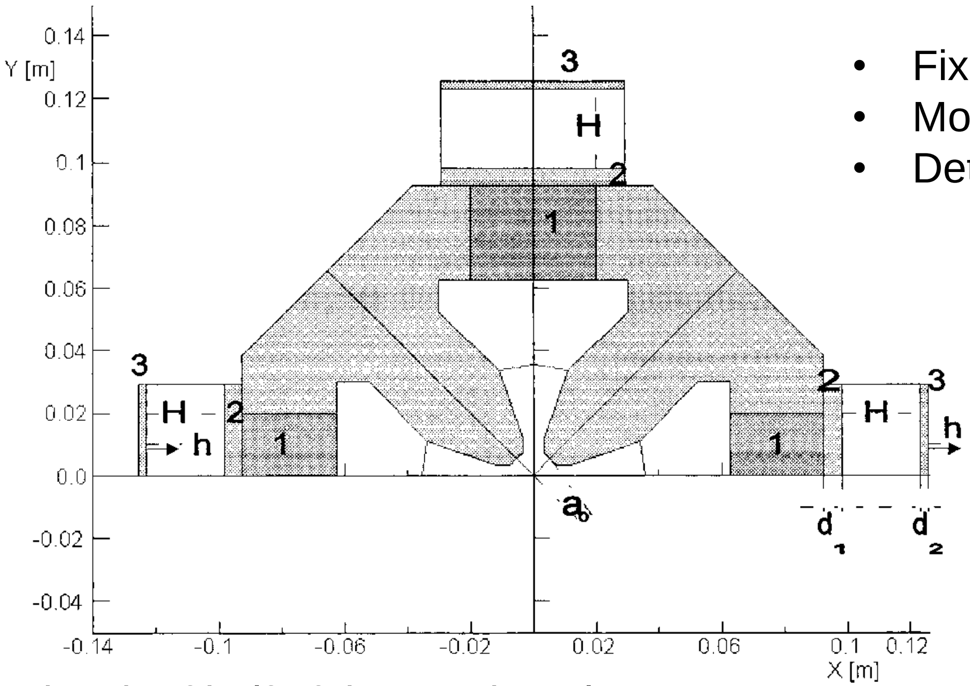
Hybrid quadrupole with radially displaced shunts





Hybrid Quadrupole with Radially Displaced Shunts

- The aim is to vary the gradient in wide ranges and simultanous to regulate the magnetic center.
- Solution: the shunt must be sectionalized.

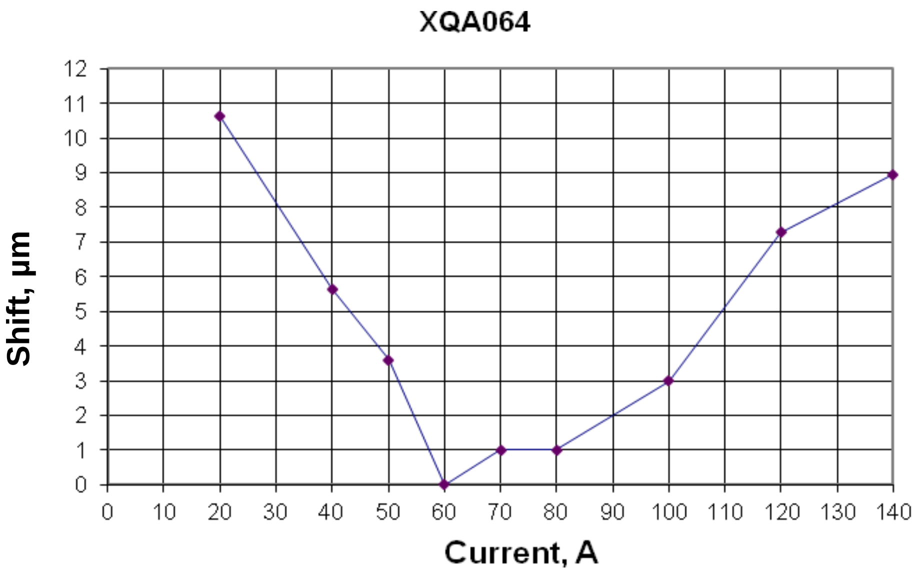


Sketch of half of the quadrupole magnet:
a_0 7.5mm, 1-permanent magnets, 2-fixed part of the shunt (d1), 3-displaceable part of the shunt (d2); H=25mm, h=2mm

- Fixed part d1 define the required gradient.
- Movable part d2 shifts the magnetic center.
- Detachment force of the whole shunt is ~120 kg

Disadvantages:
- Radiation damage of PM material,
- Complicated moving devices,
- Radiation damage of these devices (electronics).

The magnet built for the undulator intersection



Magnetic requirements for the intersection quadrupole magnet:

- Gradient 100 T/m (at 140 A)
- Field quality ΔB/B at radius 3 mm better than 10E-03 (bore 16 mm diameter).
- Magnetic axis stability at 50% of excitation current for a 10% gradient variation should be less than ± 5 µm.

Summary

- Up to now no combined function magnets at DESY.
- Hybrid magnets studied at DESY but not yet manufactured.
- Magnet design is predominately optimized to reduce manufacturing and running costs.
- The experiments made demands on the beam quality and saving prospects may play an underpart!

Thank you for your attention