Synthesis and optimization of electromagnetic fields for the elements of particle accelerators using MERMAID-3D code

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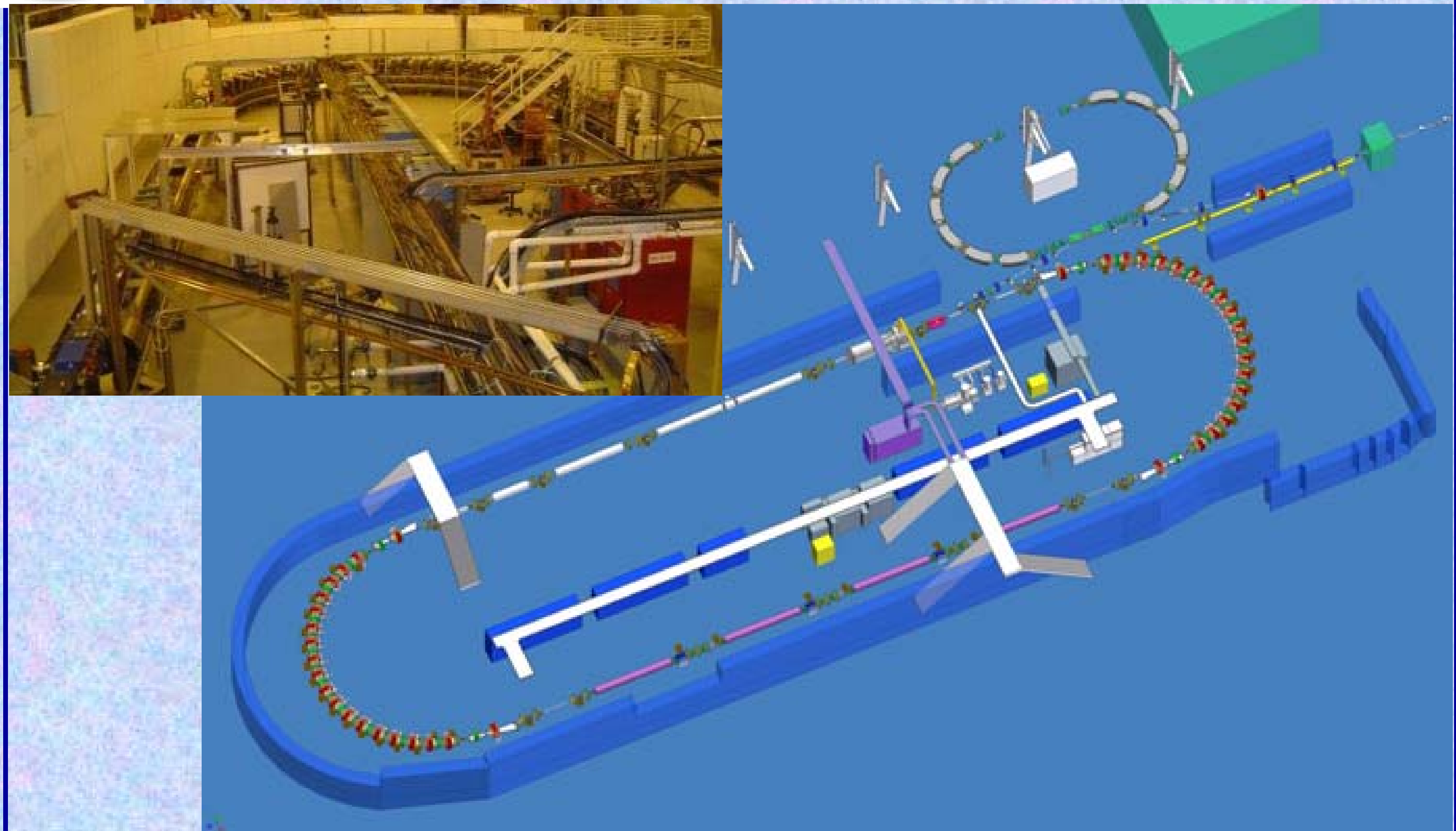
Duke 1.2 GeV storage ring and booster



Parameters of the Duke FEL ring

Maximum beam energy E_{max} [GeV]	1.2
Injection energy E_{inj} [GeV]	0.24 - 1.2 GeV
Stored beam current [mA]	
- in single bunch/in multibunch	> 50/400
Circumference [m]	107.46
Bending radius [m]	2.1
RF frequency [MHz]	178.55
Harmonic number	64
@ E_{max} = 1.0 GeV:	
Beam emittance ε_x	18
Betatron tunes Q_x/ Q_y	9.11 / 4.18
Momentum compaction factor	0.0086
Natural chromaticities C_x/ C_y	-10.0 / -9.8
Damping times $\tau_{x,y}$/ τ_s [ms]	18.3 / 17.0
Energy spread	$5.8 \cdot 10^{-4}$
Energy of Compton γ-rays by HIγS	1.5 – 60 MeV
Energy spread of γ-rays (collimated)	0.5 - 3.5%
γ-ray flux on target (collimated)	$10^4 – 10^9$ γ /sec

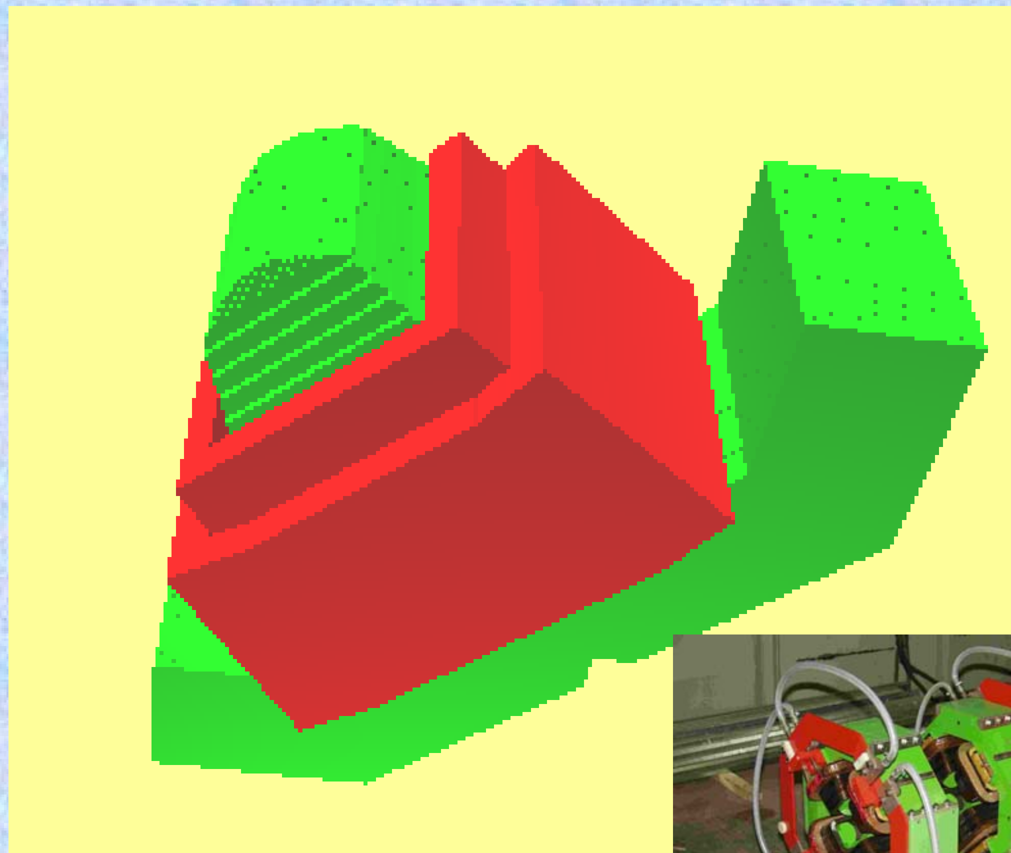
Duke 1.2 GeV booster

Commissioned in 2006

Parameters of the booster

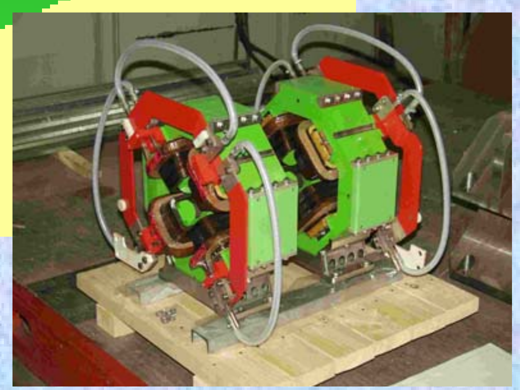
	Single bunch	Two bunch
Maximum beam energy E_{max} [GeV]	1.2	
Injection energy E_{inj} [GeV]	0.24-0.24	
Stored beam current [mA]	1.5 - 2	2-4
Circumference [m]	31.902	
Bending radius [m]	2.273	
RF frequency [MHz]	178.55	
Harmonic number	19	
Operation cycle [sec]	1.4-1.6	2.3-2.5
Energy rise rate [sec]	0.60	
@ E_{max} = 1.2 GeV:		
Beam emittance ε_x, ε_y	440 / 6	
Betatron tunes Q_x/ Q_y	2.375 / 0.425	
Momentum compaction factor	0.158	
Maximum β_x/ β_y/ η_x [m]	9.9 / 27.2 / 1.65	
Natural chromaticities C_x/ C_y	-1.7 / -3.7	
Damping times $\tau_{x,y}$/ τ_s [ms]	3.16 / 1.60	
Energy loss per turn [KeV]	80.7	
Energy spread	$6.8 \cdot 10^{-4}$	

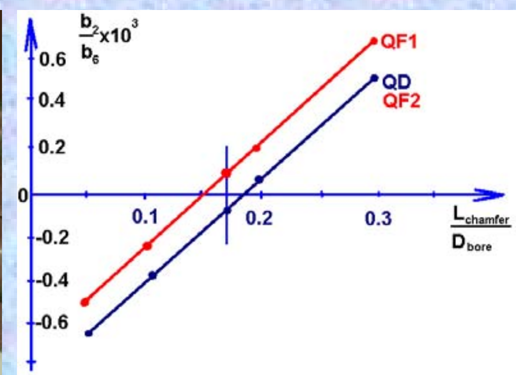
3D magnetic simulations of the booster quadrupole magnets



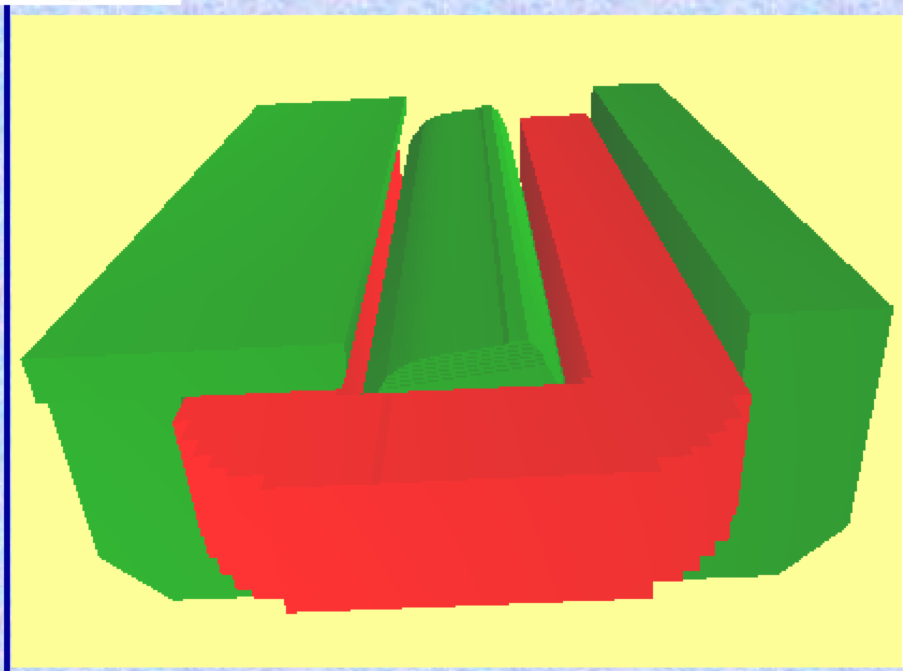
- One quadrant
- 3 types of quadrupole: QF1, QF2 and QD
- 151×201×201 mesh size
- Stacking factor = 0.98
- E=0.27-1.2GeV,12 points

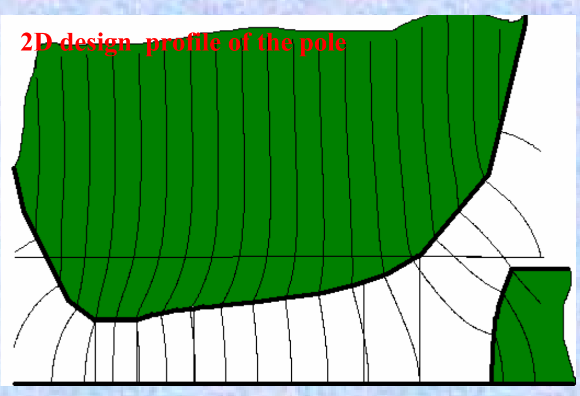
Magnetic simulations by MERMAID 3D

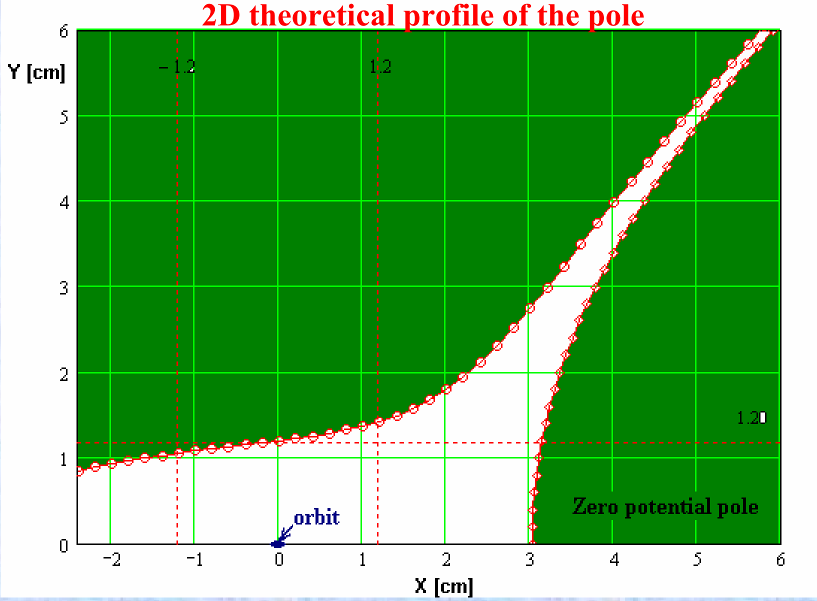




Dipo-Quadro-Sextu-Octupole magnet (DQSO) for low emmitance Duke lattice







- One half
- 161×199×199 mesh size

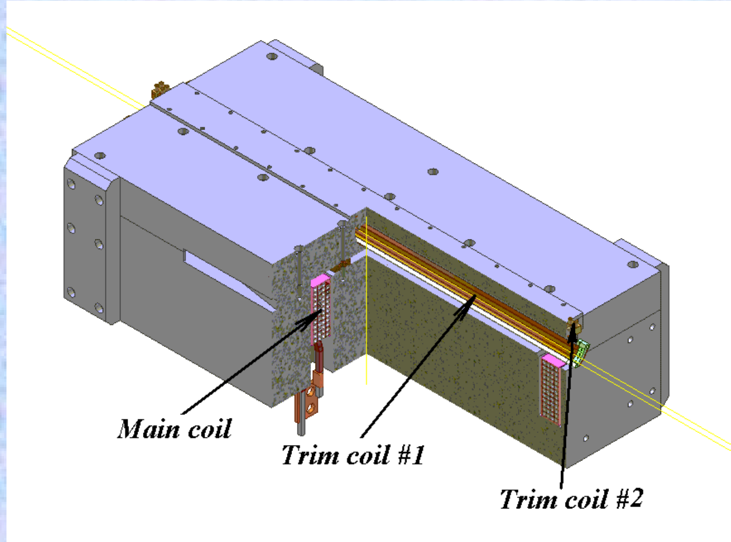
Magnetic simulations by MERMAID 3D

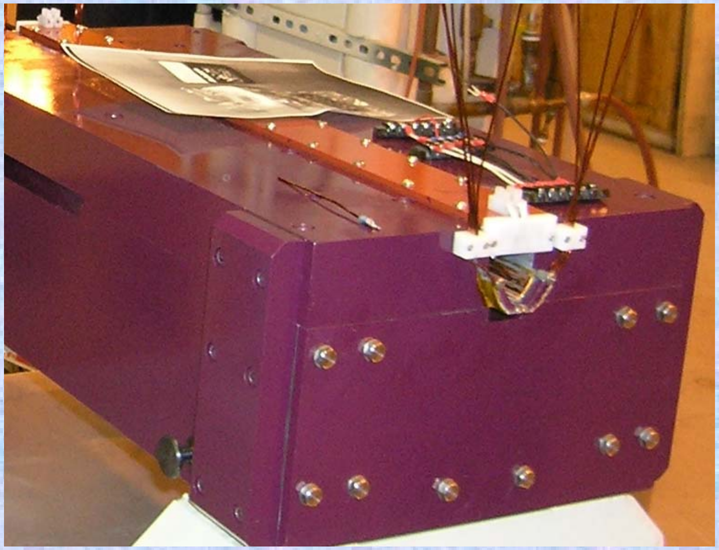
Dipo-Quadro-Sextu-Octupole magnet (DQSO) for low emmitance Duke lattice

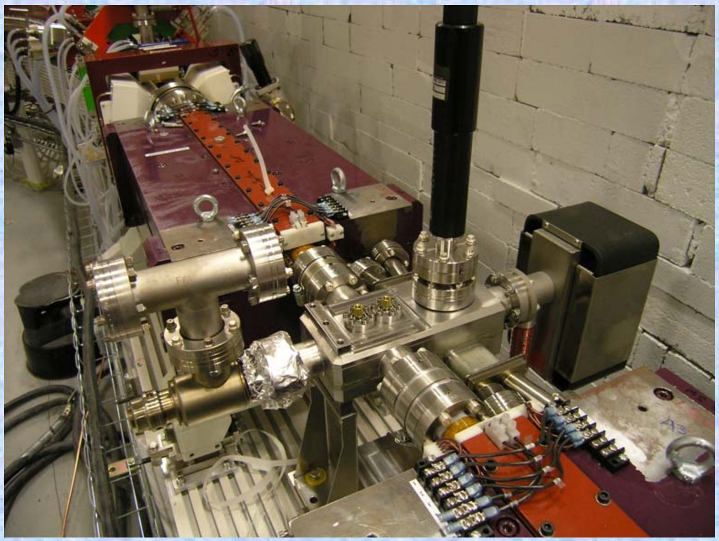
Required harmonics contents of DQSO magnet at nominal energy E=1.0 GeV:

n	Field term	for L_{eff}=68.0 cm		$K_{n-1}L=\int K_{n-1}dz$	$\int \partial^{n-1}B/\partial x^{n-1}dz$
		K_{n-1}	$\partial^{n-1}B/\partial x^{n-1}(0,0)$		
		$1/m^n$	kG/cm^{n-1}	$1/m^{n-1}$	kG/cm^{n-2}
1	Dipole	$\pi/(14\cdot L_{eff})$	11.008	$\pi/14$	748.52
2	Quadrupole	-4.2448	-1.416	-2.8865	-96.3
3	Sextupole	-105.88	-0.353	-72.0	-24.0
4	Octupole	-33250	-1.109	-22610	-75.4

Booster Lamberson septum

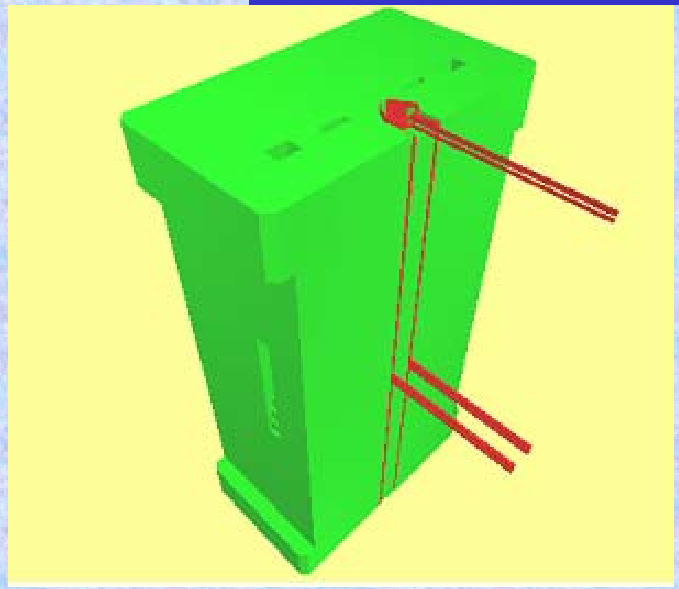


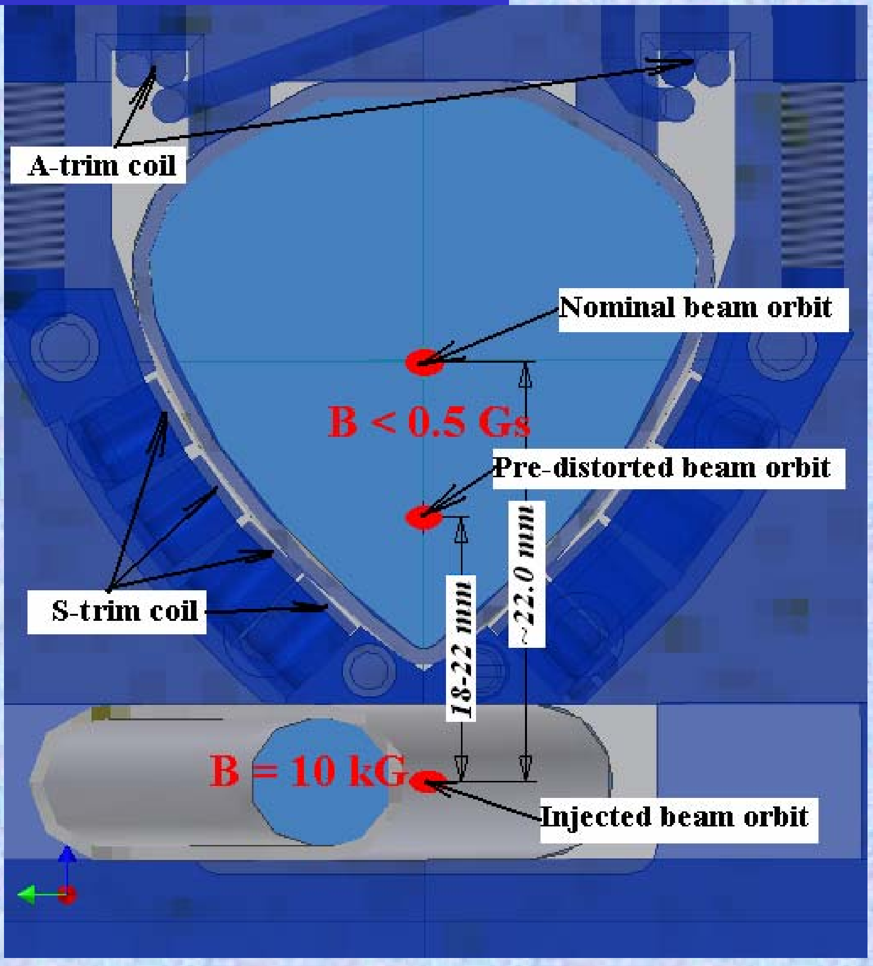


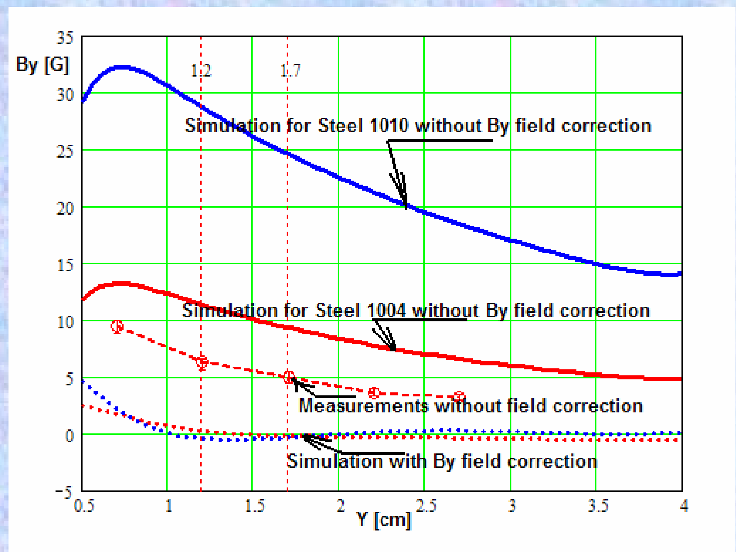


• Maximum bending field	1.00 T
• Maximum current	175 A
• Number of turns	48
• Gap	1.0 cm
• Bending angle	9.0°
• Effective magnetic length	0.642 m
• Width of "knife"	2 mm
• Corrected field integral in zero chamber	<50 G*cm
• Corrected gradient integral in zero chamber	<40 G

Booster Lamberson septum

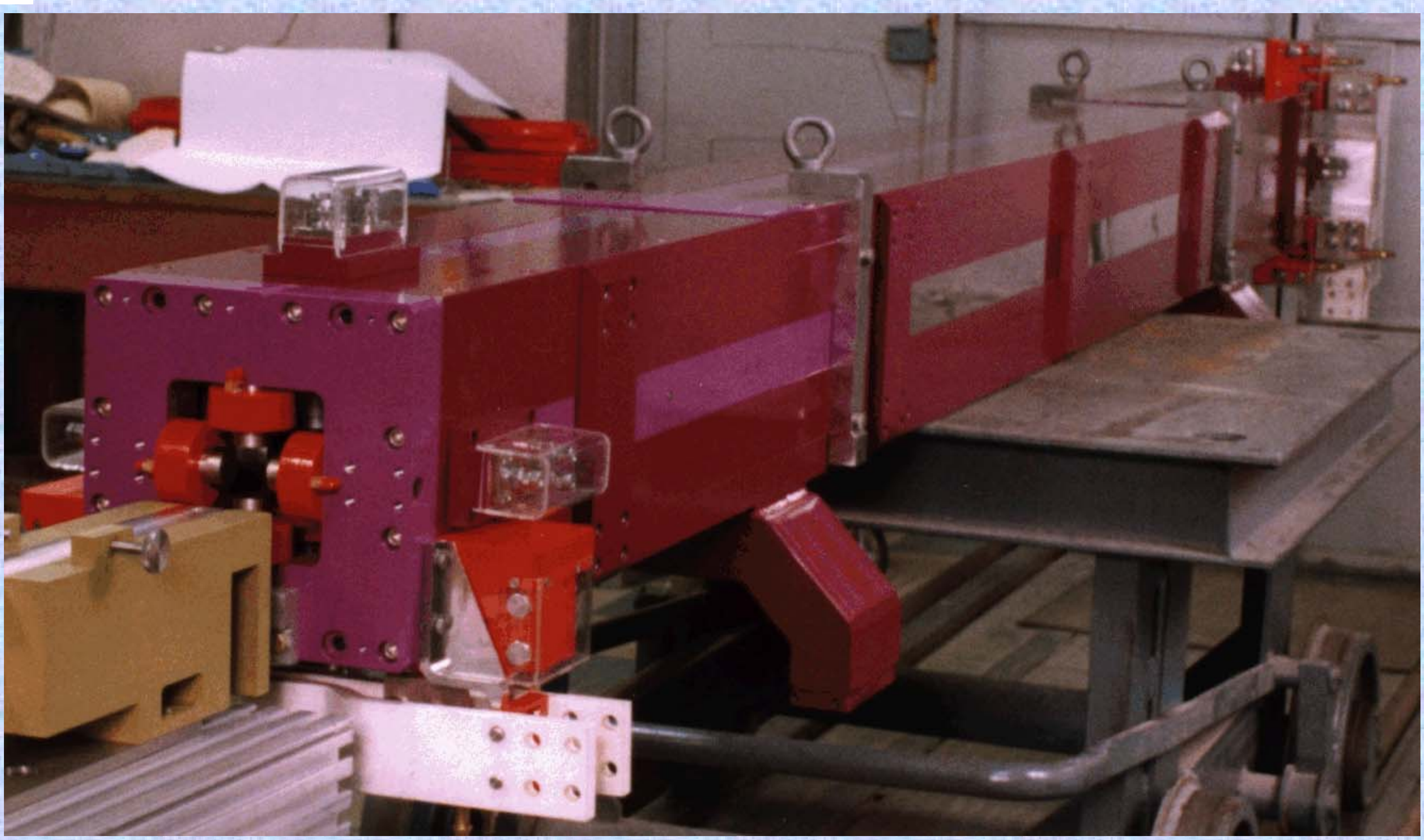






Magnetic simulations by MERMAID 3D vs. magnetic measurements

OK-5 FEL wigglers



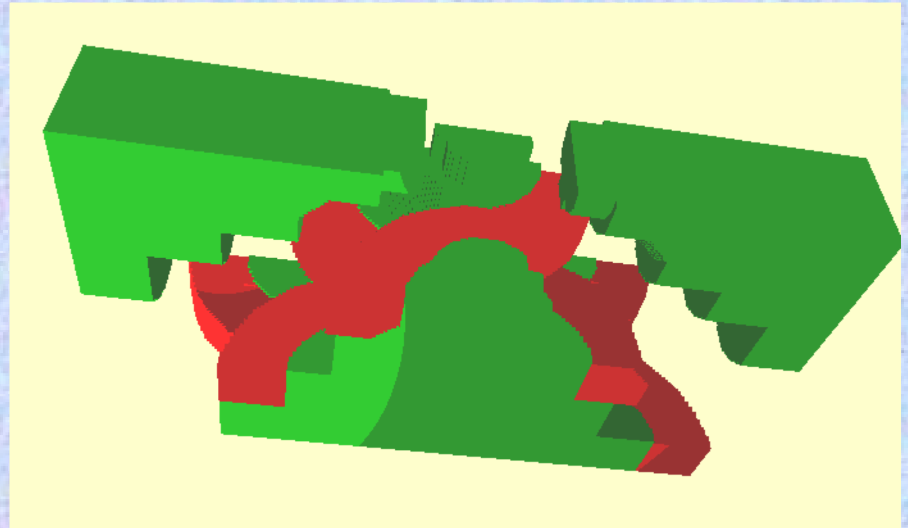
Stepan Mikhailov
June 27, 2007

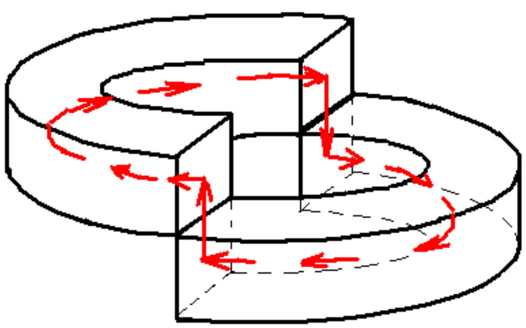
Magnet design workshop at PAC 2007

OK-5 FEL wigglers

Wiggler period λw, cm	12.0
Wiggler gap (vertical and horizontal), cm	4 × 4
Number of periods (vertical and horizontal)	32
Maximum current [kA]	2 × 3
Maximum field, kG	2.86
Amplitude of fundamental harmonic @ I=2 kA, kG	2.07
Relative value of the 3^{rd} harmonic, %	0.6
Power consumprion [kW]	2×57
Overoll dimensions: -Horizontal (width) [m] -Vertical (height) [m] -longitudinal (length) [m]	0.274 0.324 4.04

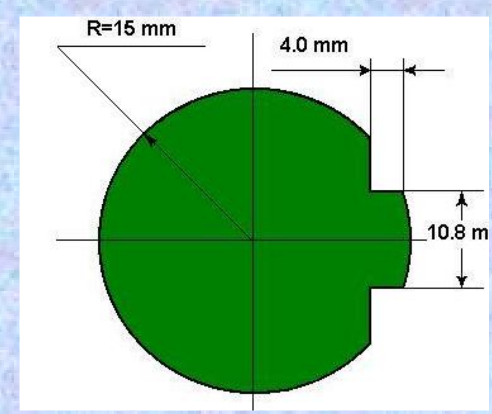
OK-5 FEL wigglers





Effective current loop around the pole for the serpentine coil

Pole cut compensating intergal gradient and octuppole



Magnetic simulations by MERMAID 3D

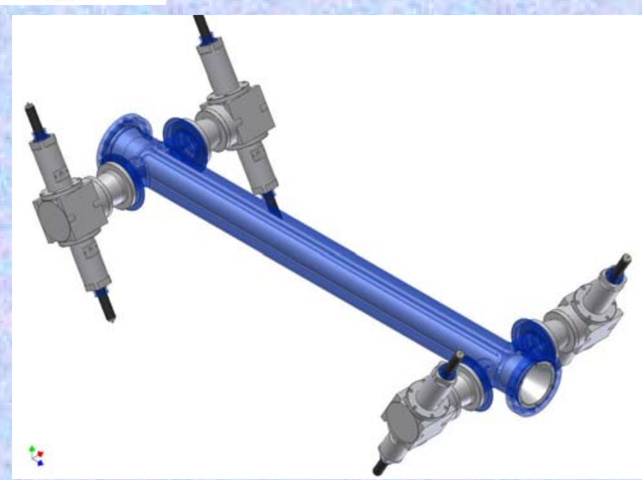
OK-5 FEL wigglers

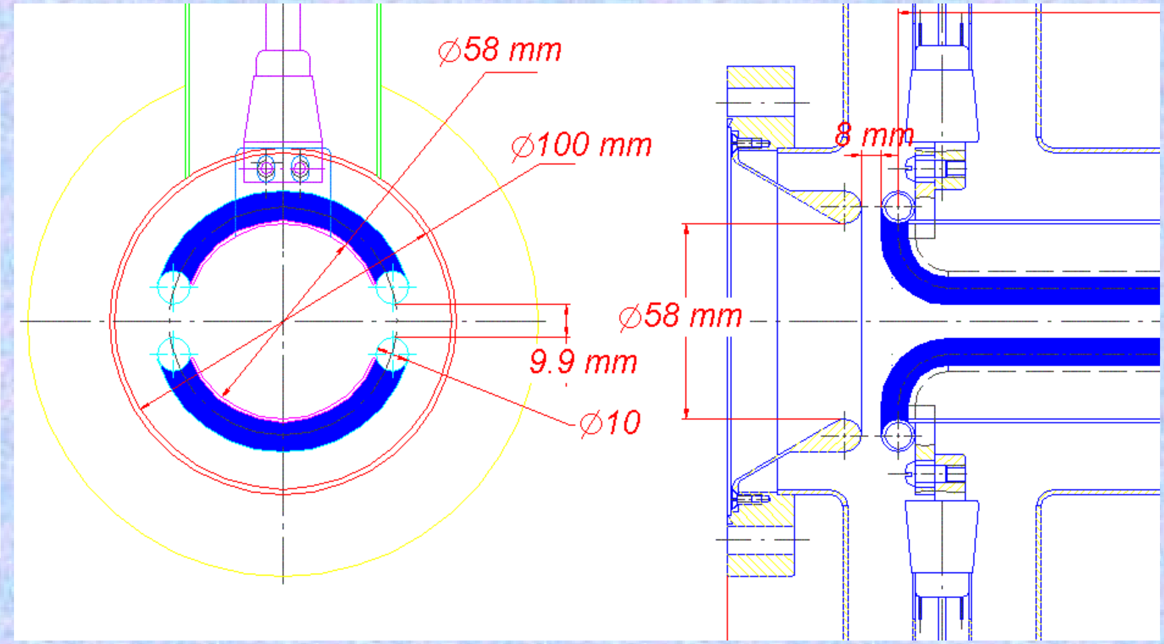
Compensation of asymmetry of the coils

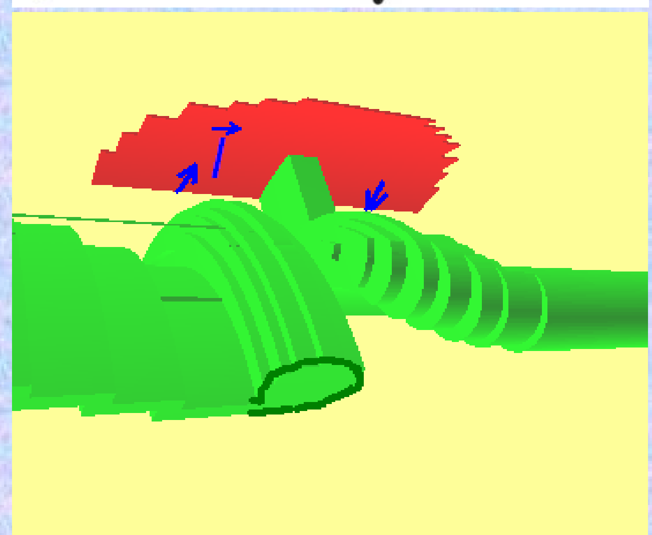
	I=2kA				I=3kA	
	Not cut		With cut		No cut	With cut
	3D calc.	Mag. meas.	3D calc.	Mag. meas.	3D calculations.	
GradientGs/cm	5.64	6.60	-0.21	1.57	8.64	0.22
Octupole G/cm^3	-2.76	-2.70	0.00	-0.32	-4.38	0.03

Magnetic simulations by MERMAID 3D

Kickers for Duke FEL ring







Maximum electrical field	< 70 kV/cm
3D edge field over-stress	~1.12
Impedance	25 Ω
Inscribed diameter	58 mm
Minimum gap	9.9 ± 0.3 mm
Maximum kick angle @ 1.2 GeV	2.8 mRad
Effective electric length	117.5 cm

Magnetic simulations by MERMAID 3D

MERMAID 3D features:

- MERMAID 3D is a powerful tool for magnetic design ;
- Mesh up to 20×10^6 elements with RAM drive of 2 Gb;
- Fast calculation (~1-6 hours with 20×10^6 elements;
- Well developed library of nonlinear materials (includes St.1004, 1006, 1010, permendur, permalloy, etc., etc. ,etc.)
- Has helical symmetry as an option (makes it 2D case);
- Perfect for FFAG magnets, undulators, helical undulators, etc.;
- Not great for superconducting magnets unless super ferric;
- Easy to learn, to master, and to use.