Technological challenges – An overview

Daniel Schoerling

CERN

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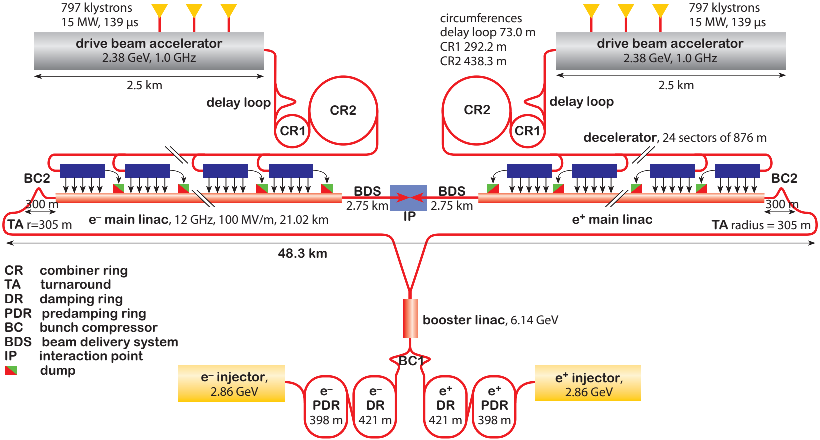
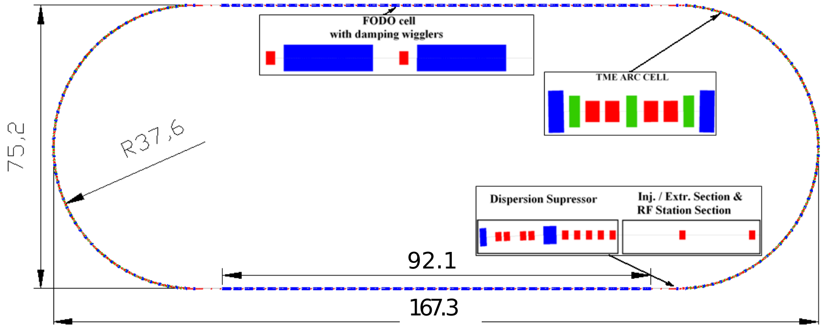
Outline

1. Introduction
2. Conceptual wiggler design
3. Prototyping
4. Vacuum requirements and technology
5. Coatings
6. Cooling concept
7. Power supply and QPS
8. Magnetic measurements
9. Conclusion

Overview of CLIC layout



Introduction: CLIC damping rings



Racetrack shape with (S. Sinyatkin, et al., LER 2010):

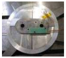
- 96 TME arc cells (4 half cells for dispersion suppression).
- 26 Damping wiggler FODO cells in the long straight sections.
- Space reserved upstream the long straight sections for injection/extraction elements and RF cavities.

Roadmap

Nb_3Sn Technology

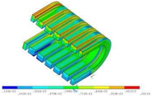
First Tests Short Model

- Conceptual Design for Short Model
- 5 Test Coils for Insulation and Heat Treatment tests
- One Vertical Racetrack Coil ready to be tested
- 2-period wiggler in mirror and full configuration (planned)



Small Prototype

- Modules, Design and Test
- Joint Testing
- Field Quality Measurements at CASPER at ANKA



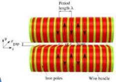
Full-Scale Prototype

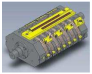
- Full Scale Nb_3Sn Prototype with cryogenics to be tested at ANKA
- Design and manufacturing at CERN but with synergies from Nb-Ti wiggler!

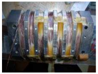
Nb-Ti Technology

First Tests Short Model

- Conceptual Design for Short Model
- 2-Period Short Model, successful tested at CERN in mirror configuration
- Short Model at BINP successful tested







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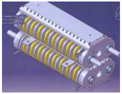
Small Prototype

- Modules, Design and Test
- Joint Testing
- Field Quality Measurements at CASPER at ANKA



Full-Scale Prototype

- Full Scale Nb-Ti Prototype with cryogenics to be tested within the collaboration framework with ANKA, Karlsruhe, Germany
- Design: Collaboration of ANKA, BINP and CERN.
- Manufacturing at BINP

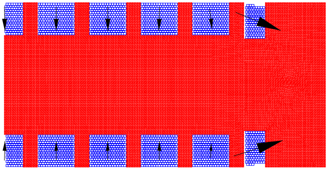
SCU14 in ANKA

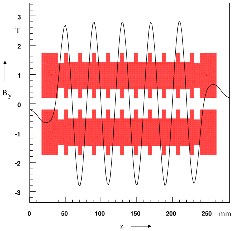
TDR

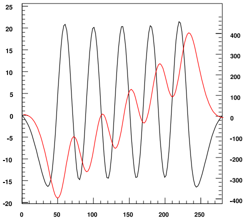
Conceptual wiggler design: Wiggler and ANKA parameters

Vacuum-Gap	13 mm
Magnet-Gap	18 mm
Period	56 mm
Maximal magnetic field	3.6 T
Operating magnetic field	3 T
$I_{\mathrm{op}}/I_{\mathrm{c}}$	83%
Inductance	1.6 H
Stored Energy at 600 A	250 kJ
Energy	2.5 GeV
Current	200 mA
Circumference	110.4 m
Current per bunch	3 mA
Emittance	50 nm rad
horizontal beta @ ID	15 m

Matching coils:



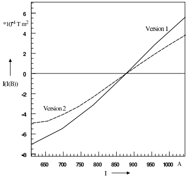




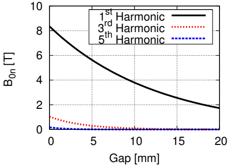
- Matching coils are sufficient for field compensation.
- Only one (main) power supply needed (in CLIC DR 13 wigglers will be powered in series).
- Two steerers in warm will be foreseen for first and second field integral correction.
- Magic fingers (permanent magnets) are foreseen to correct multipole field errors.

Conceptual design: Magnetic design II

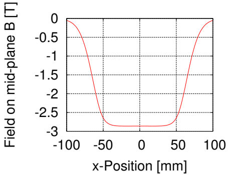
Sensitivity



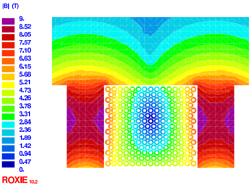
Harmonics



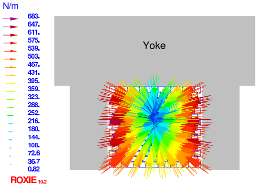
Roll-off



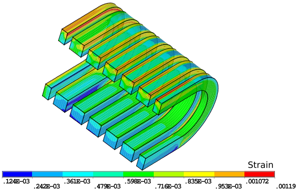
Peak Field



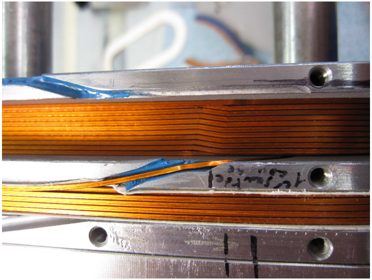
Forces

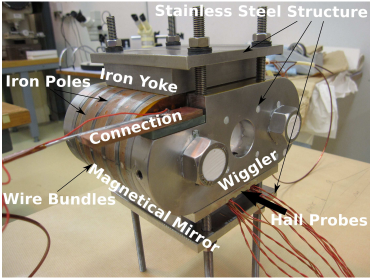


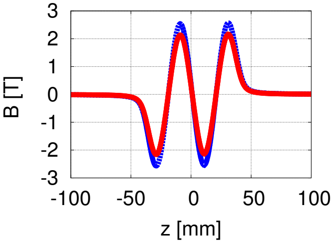
Strain

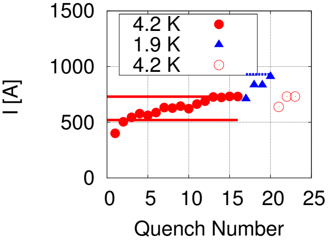


Manufacturing and testing: CERN Nb-Ti racetrack design



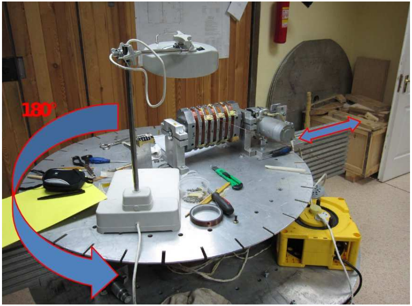


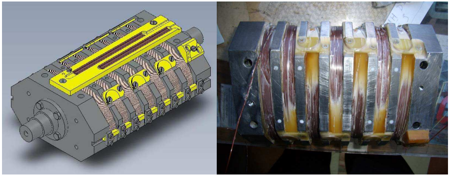




Manufacturing and testing: BINP Nb-Ti racetrack design I

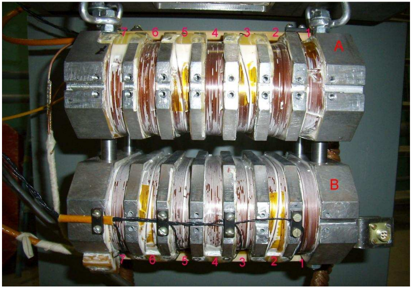
First design failed. New design without G11 spacers was proposed.

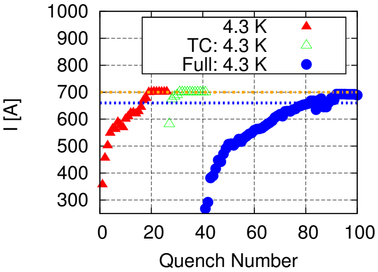


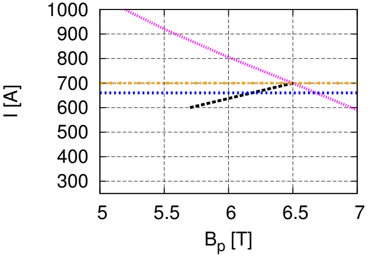


Winding with CERN and BINP staff:

Manufacturing and testing: BINP Nb-Ti racetrack design II







- Short sample current in wiggler half "A" was achieved, 1% degradation in wiggler half "B". 2.5 T could be achieved with $\lambda = 50$ mm and 20 mm gap.
- Due to higher ramp rate the full wiggler had a very long training. Ramp rate should be small.

Vacuum requirements: CLIC damping rings

Source: G. Rumolo et al., MOPP049, EPAC08, pp. 658-660

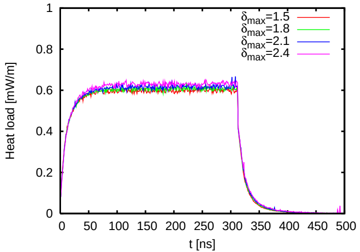
- Vacuum much better as $1.3 \times 10^{-7}\,\mathrm{Pa} \approx 1\,\mathrm{nTorr}$ both in cold (20 K) and warm (320 K) parts.
- Ions like CO^+, N_2^+ or H_2O^+ will be trapped and will accumulate around the electron beam, potentially becoming a source of fast ion instability in the electron rings.
- Further comments by Giovanna Vandoni, Erhard Huttel, and Giovanni Rumulo.

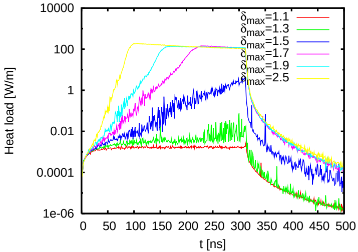
Vacuum requirements: ANKA

- The system shall be equipped with the standard ANKA vacuum components (Penning gauges (Pfeiffer)), ports for roughing, ion pumps (Varian).
- The transition from the cold 13 mm gap to the warm 32 mm gap with the standard ANKA profile shall be smooth and part of the liner. The isolation vacuum must be broken without breaking the e-beam-vacuum.
- All vacuum and pressure vessels shall be designed for a maximum leak rate of 10^{-9} mbar 1 s^{-1} as tested with a helium mass spectrometer leak detector.
- The vacuum pressure shall be better 10^{-10} mbar measured at both ends of the e-beam chamber, and better 10^{-6} mbar for the isolation vacuum.
- In addition the general vacuum specification of ANKA has to be fulfilled.

Coating: E-cloud simulations

- Calculations with ECLOUD by Giovanni Rumulo.
- 99.9% synchrotron radiation was assumed to be absorbed.
- The 1 GHz option has been considered, bunch spacing 1 ns.





- Multipacting does not affect the electron beam in the wigglers.
- No serious e-cloud induced heat load limitations seem to be present in the electron ring.
- Vacuum requirements have to be specified.

- Multipacting appears in the positron ring for $\delta_{\max}$ above 1.3 which is the same level as for SPS, out-gassing and aging (increase of SEY with time) are under study.
- Electron clouds are not tolerable (heat load, beam stability, etc.). Therefore, low SEY coating such as amorphous carbon or NEG is needed.

Coating: Image currents and impedance issues

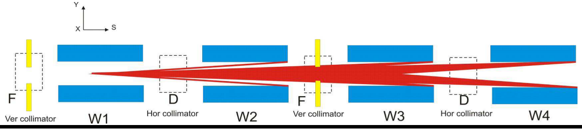
- Image currents in a cold-bore undulator (Podobedov, 2009):

$$\text{Good conducting pipe (Cu):} \quad P/L = \frac{\Gamma(\frac{5}{6}) c Z_0}{4 b \pi^2} B_{\mathrm{Mat}} \frac{I_{av}^2}{\sigma_{\mathrm{z}}^{\frac{5}{3}} \eta f_{\mathrm{RF}}} \approx 1 \, \frac{\mathrm{W}}{\mathrm{m}}$$

$$\text{Poor conducting pipe (Steel):} \quad P/L = \frac{\Gamma(\frac{3}{4}) c \sqrt{Z_0}}{\sqrt{32} b \pi^2} \frac{1}{\sqrt{\sigma_{\mathrm{c}}}} \frac{I_{av}^2}{\sigma_{\mathrm{z}}^{\frac{3}{2}} \eta f_{\mathrm{RF}}} \approx 32 \, \frac{\mathrm{W}}{\mathrm{m}}$$

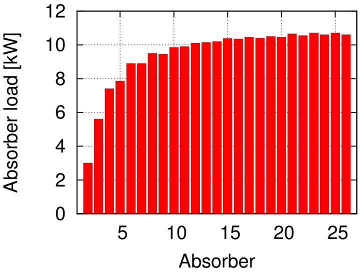
- What is the effect on the coupled bunch instabilities if we use poor conducting coating in some part of the beam pipe to reduce electron cloud effects in the positron ring?
- For the electron ring Cu (coating) seems to be perfect. However, Cu (coating) might not work in the positron ring due to electron clouds. Materials with low SEY are also poor conductors, i.e., the heat load from image currents may be too high in the cold parts of the beam-pipe and coupled bunch instabilities may occur (Discussion?). What is the solution? What approach can be tested in the wiggler prototype which will be tested only in an electron synchrotron?

Collimation scheme: CLIC damping rings



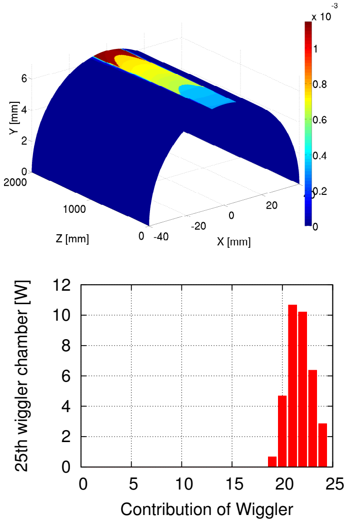
Element	Length [m]	V [mm]	H [mm]	Shape
Horizontal Collimator	0.5	13.5	12.3	Rectangular
Vertical Collimator	0.5	9.5	12.5	Rectangular

- Water cooled copper collimators, power density up to 200 W/cm (PETRA III value) $\Longrightarrow$ at least 55 cm collimator.
- Collimators have to be in warm $\Longrightarrow$ 2 $\times$ 0.4-0.5 m warm-cold transition (Maccaferri, LER 2009).
- Space for quadrupoles, steerers, and instrumentation.

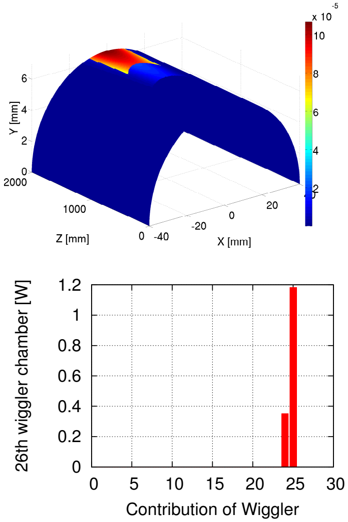


Schoerling and Zolotarev, 2010

Synchrotron radiation: Vacuum chamber



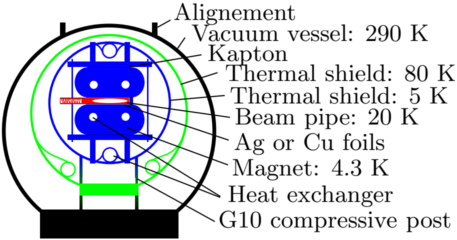
Odd numbered chamber heat load: 20 W/m (can be reduced to 10 W/m with HC: 7.5 mm)

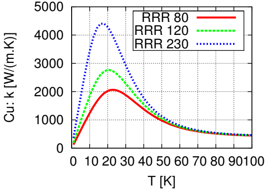


Even numbered chamber heat load: < 1 W/m

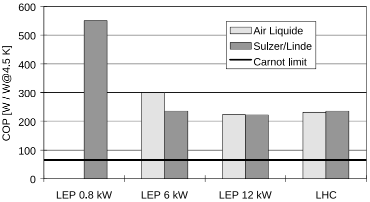
Cooling concept

Source: Bottom: Claudet et al., LHC Project Report 317





Carnot cycle: $W = Q\left(\frac{T_R}{T_O} - 1\right) = Q\left(\frac{320}{4.2} - 1\right) \approx 75Q$



- Beam-pipe can be tested in between 20 K and 80 K.
- BINP can provide major design input from ANL experience.
- Antonio Perin, CERN can consult on the procurement and installation of the cryoplant.

Current leads (Slide provided by Amalia Ballarino)

- Low current (1 kA)
- DC mode operation
- No specific low-losses requirement
- Few units needed

1. Easiest "standard" solution: conventional self-cooled current leads. Heat load at 4.5 K: $\sim$**1.1 W/kA**. If this heat load can be accepted, they are "the" choice.
2. Conduction-cooled leads with thermalization at say 70 K. Heat load of the resistive part at 70 K: $\sim$45 W/kA. Thermalization at the required operating currents is difficult to be achieved.
3. High Temperature Superconducting leads of the type 1) or 2). Advantage: reduced heat load into the helium bath –factor up to 10, depending on other system requirements. Disadvantage: more complicated. They require separate protection of the HTS element.For optimum performance and low losses, separate cooling of the resistive and of the HTS unit are required.

Heat load

Overview of heat loads (all sources)

	80 K shield	5 K shield	SC coils	Beam-pipe
Synchrotron Radiation				50 W
Image Currents				2 W
E-Clouds				$<$ 20 mW
Joints		100 mW		
Radiation	6.3 W	90 mW	0.01 mW	
Convection	0.8 W	146 mW	5.2 mW	
Conduction	0.9 W	102 mW		
TOTAL	8.0 W	438 mW	5.2 mW	52.0 W
Current leads		2×1.1 W		

Power supply and QPS: CLIC damping rings

- Powering of 13 wigglers in series, Power supply class 50 ppm.
- Electronic Detection System.
- IGCT-based switches: 1 kA, 1 kV, $\ll$ 1 ms.
- Protection with cold parallel resistors, and only if needed quench heaters.
- Necessary measurements: $R(t)$ after quench, $L(I)$, C to ground, transfer function of magnet.
- Instrumentation and feed-through.

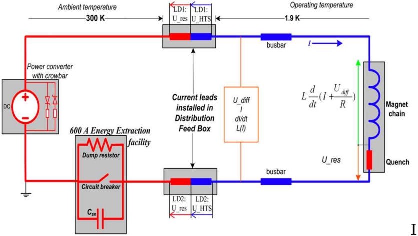
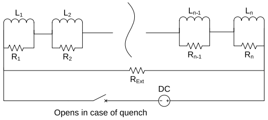


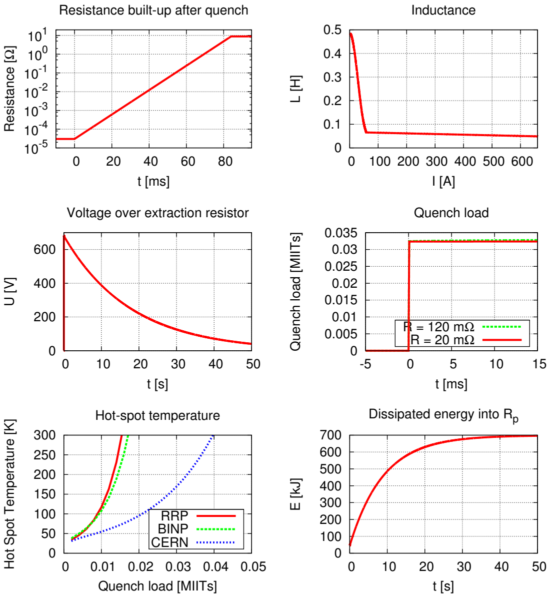
Image: Courtesy of Gert-Jan Coelingh

Power supply and QPS: CLIC damping rings



Simulations with PSpice (Emmanuele Ravaioli):

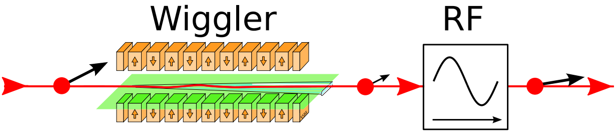
- R quench model needs to be updated for other strands.
- $R_{\text{ext}} = 1.2\,\Omega$.
- $R_{\text{p}} = 20\,\text{m}\Omega$.
- 11 kJ stored energy/module.
- 30 modules/wiggler.
- MIITs around 0.03 MIITs.
- R_{ext} can be optimized to deposit little energy into Helium.



Power supply and QPS: Prototype

- Same power supply as for 13 wigglers can be used for 1 wiggler (will allow faster ramping).
- Main Specifications: PC class 50 ppm, maximal current 1100 A (Nb_3Sn ready).
- Same QPS can be tested in prototype as in final ring.
- Quench simulation/measurements with existing short model have to be undertaken in BINP and CERN collaboration. QPS concept will be presented by Reiner Denz and Knud Dahlerup-Petersen.

Magnetic Measurements: Requirements



Equilibrium Emittance	$\gamma\epsilon_x \approx \gamma\epsilon_{\mathrm{a}} \frac{J_{x\mathrm{a}}}{J_{x\mathrm{a}}+F_{\mathrm{w}}} + \gamma\epsilon_{\mathrm{w}} \frac{F_{\mathrm{w}}}{J_{x\mathrm{a}}+F_{\mathrm{w}}}$
Generated Equilibrium Emittance	$\gamma\epsilon = \frac{C_{\mathrm{q}}\gamma^3}{J_x} \frac{I_5}{I_2}$
Damping via photon emission	$I_2 = \oint \frac{1}{\rho^2}$
Excitation via dispersion	$I_5 = \oint \frac{\mathcal{H}}{\lvert\rho^3\rvert} \mathrm{d}z$
$J_x \approx 1 \qquad F_{\mathrm{w}} = \frac{I_{2\mathrm{w}}}{I_{2\mathrm{a}}}$	$\mathcal{H} = \gamma(z)\eta^2 + 2\alpha(z)\eta\eta' + \beta(z)\eta'^2$
Specified equilibrium emittances	$\gamma\epsilon_x \leq 500\,\mathrm{nm.rad} \qquad \gamma\epsilon_y \leq 5\,\mathrm{nm.rad}$
Specified maximum damping time	$\tau_y \leq 1.91\,\mathrm{ms}$

Mechanical Tolerances for Nb-Ti baseline design

$\sigma(B^*)$	$0.2\,\mathrm{T}$
$\sigma(\lambda^*)$	$1\,\mathrm{mm}$
$\mu(\gamma\epsilon_x), \gamma\epsilon_x$	$312.1\,\mathrm{nm.rad}, 309.7\,\mathrm{nm.rad}$
$\sigma(\gamma\epsilon_x)$	$0.2315\,\mathrm{nm.rad}$

Source: P. Emma and T. Raubenheimer, Phys. Rev. ST AB, Vol 4, 021001 (2001)

Required measurements at around 20 K as specified by ANKA:

	Vert	Hor	
1. field integral	3×10^{-5}	3×10^{-6}	Tm
2. field integral	4×10^{-4}	1×10^{-5}	Tm^2
	Normal	Skew	
Quadrupole component	0.005	0.005	T
Sextupole component	0.1	0.1	T/m
Octupole component	100	100	T/m^2
Roll off at ± 10 mm	0.5		%
Maximum field variation	1		%
Field stability	$\pm 10^{-4}$ in 2 w		

- In the framework of this research project two new wiggler technology options will be developed and tested as close as possible to the actual CLIC damping wiggler requirements.
- This research involves all aspects of superconducting magnet design and operation.