CLIC Damping Wiggler

Daniel Schoerling

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Outline

1. **Introduction**
   - CLIC Damping Ring
   - Collaborations
   - Superconducting Wires
   - Magnetic field errors
2. **Mock-up – Racetrack Design #1**
   - Simulation
   - Optimal geometry
   - Actual status
3. **Mock-up – Racetrack Design #2**
4. **Mock-up – Double Helix**
5. **Future work**
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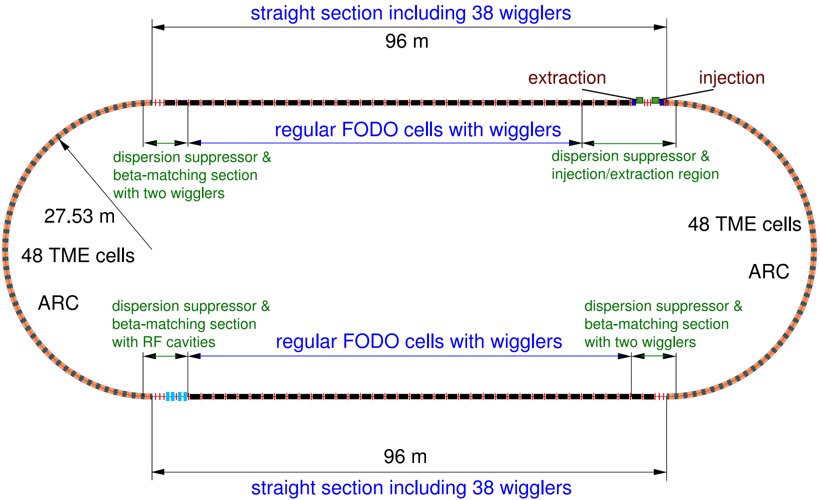
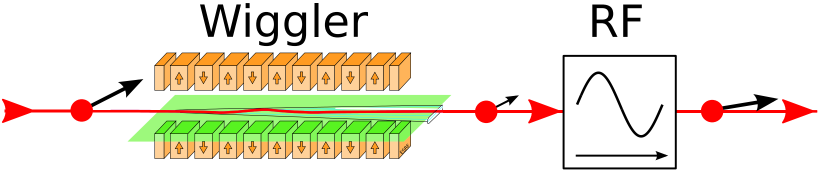
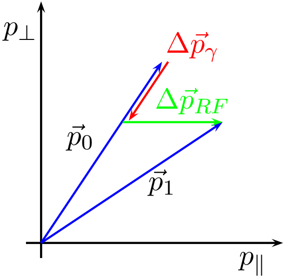
Introduction – CLIC Damping Ring



M. Korostelev: *Optics Design and Performance of an Ultar-Low Emittance Damping Ring for the Compact Linear Collider*



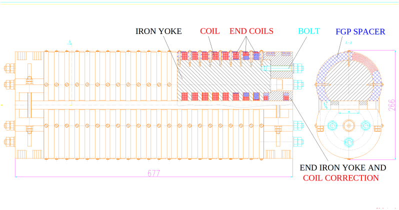


Target equilibrium emittances

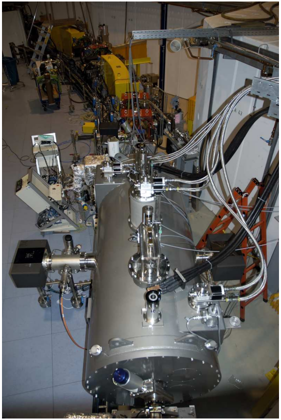
$\gamma\epsilon_x$	$\gamma\epsilon_y$	ϵ_t
<450 nm	<3 nm	<5000 eVm

Introduction – Collaborations

- Technische Universität Bergakademie Freiberg, Germany
- Karlsruhe Institute of Technology, LAS, Germany
- Budker Institute of Nuclear Physics, Russia

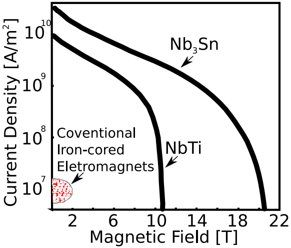


Mock-up of Budker Institute ($\lambda_W = 50\,\mathrm{mm}$)



SCU14, first ever installed superconducting undulator at ANKA

Introduction – NbTi and Nb_3Sn



M. Wilson: *Superconducting Magnets*

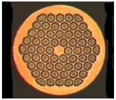
NbTi	Nb_3Sn
Robust and ready to use	Brittle, needs thermal treatment
Stable	Unstable under certain circumstances
Standard EU and US Production	Only US Production
Limited Field	No practical field limit
1W/m heat deposition[1]	10W/m heat deposition[1]

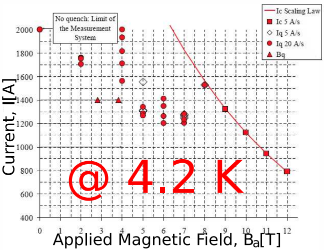
[1] L. China, D. Tommasini (2008): *Comp. study of heat transfer from NbTi and* Nb_3Sn *coils to He*

Introduction – Nb_3Sn Strand

Properties

Bare diameter	0.8 mm
Cross section	$0.5\,mm^2$
Stabilizer	Cu
Non-Cu Volume	53% ± 3%
Twist Pitch $\varnothing < 1$ mm	12 ± 4 mm
Twist Pitch $\varnothing \geq 1$ mm	40 ± 10 mm
Bare size tolerance	±5 μm
Insulation	S-Glass braid
Insulation build	130 μm (nominal)
Ins. size tolerance	±15 μm





Heat Treatment

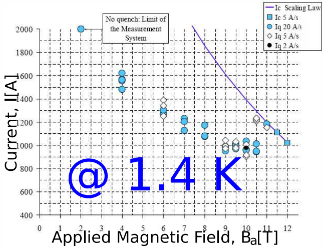
Cycle with improved RRR and magneto-stability, B.Bordini

#1 Increase T to 205°C (25°C/h), hold for 72 h

#2 Increase T to 400°C (50°C/h), hold for 48 h

#3 Increase T to 695°C (50°C/h), hold for 17 h

Measurements RRR > 300, B.Bordini



B.Bordini, R.Maccaferri, L.Rossi, D.Tommasini, *Test Report of the Ceramic-Insulated Nb_3Sn Small Split Solenoid*, EDMS:907758

Handling

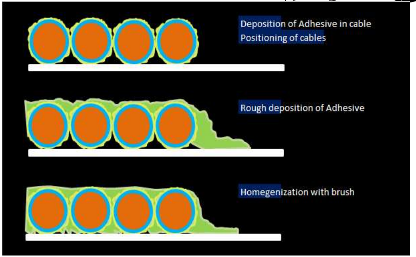
Method	Remarks
React, Wind, Impregnate	Large bending radius (> 200 mm), reacted wire is brittle and rigid
Wind, React, Impregnate	Fiber glass desizing, residual cleaning, reaction in vaccuum or Ar gas
Wet-Wind, React	Ceramics wet-winding, reaction in vaccuum or Ar gas

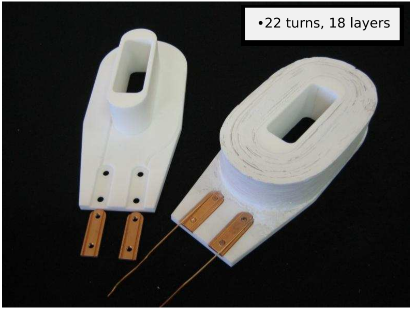
Introduction – Nb_3Sn Coils

Dedicated machine (2 persons)

- Coil size: 24 x 19 mm (WxH)
- Winding tension 50 N
- S2-glass pre-impregnation with ceramic adhesive
- Winding of few turns adjusting wire position
- Ceramics adhesive coverage
- Brushing helps homogeneity and removal of extra material (trade off between mechanical stability, insulation, and current density)
- Pre-curing by layers (10 mins) + confinement + hot air circulation to compensate for wire elasticity
- Measurement results;

  $I_{\max} = 599\,\mathrm{A}$, $B = 10\,\mathrm{T}$, $T = 4.3\,\mathrm{K}$





Courtesy of R. Maccaferri and N. Elias

Reasons for field errors:

- Quality of pole material
- Persitent currents
- Mechanical tolerances

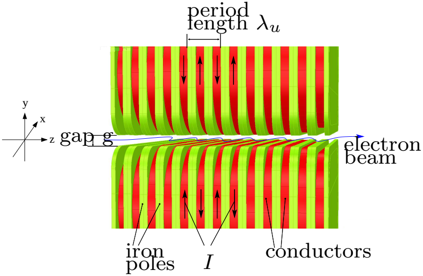
These errors yield to a new trajectory

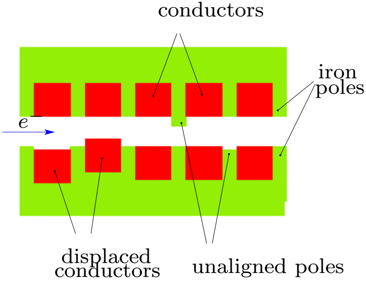
- Deflection angle

$$I_1(z) = \int_{z_0}^{z} B_y(z')dz'$$

- Displacement

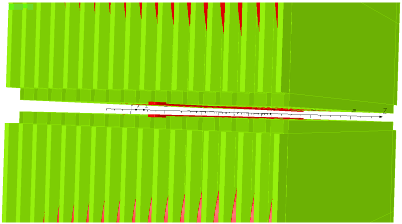
$$I_2(z) = \int_{z_0}^{z} \int B_y(z')dz'^2$$

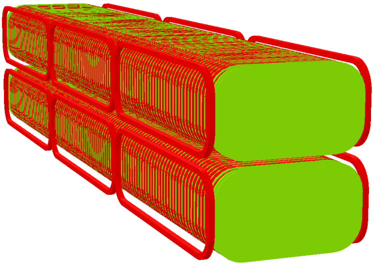




Courtesy of Daniel Wollmann

Magnetic field errors – Shimming



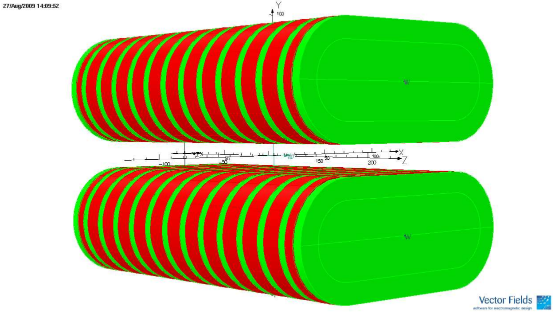


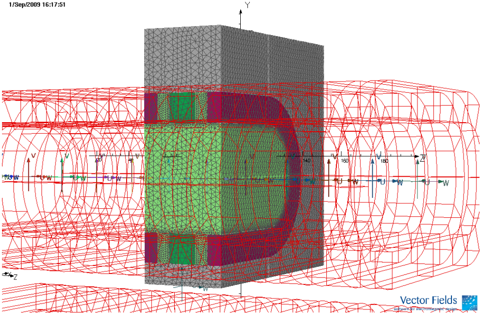
Courtesy of Daniel Wollmann

Possible Solutions:

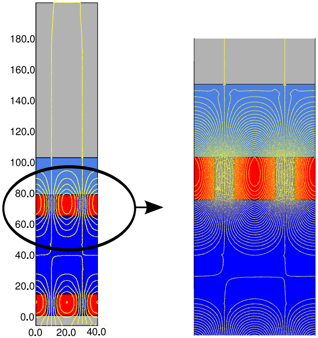
- Mechanical shimming
- Shimming with integral correctors
- Active shimming with local correction coils
- Induction shimming

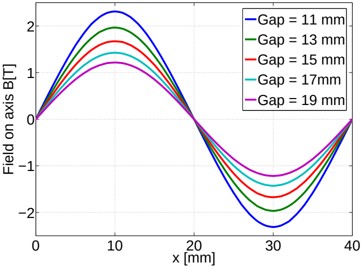
Racetrack Design #1 – 3D model

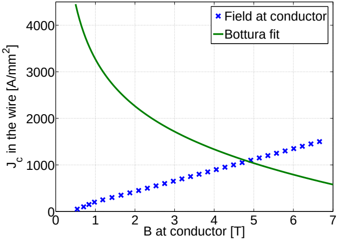


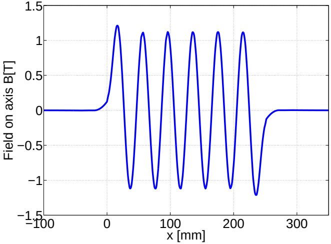


Racetrack Design #1 – 2D Model Overview

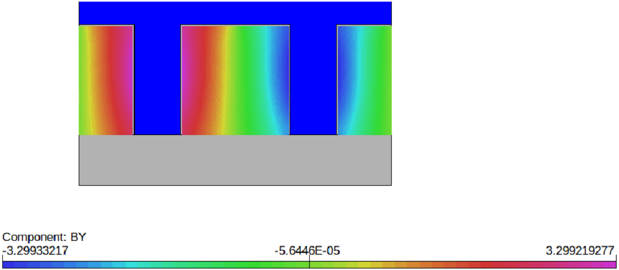


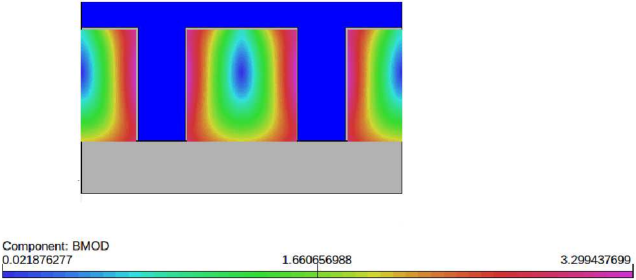




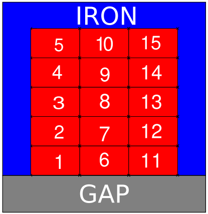


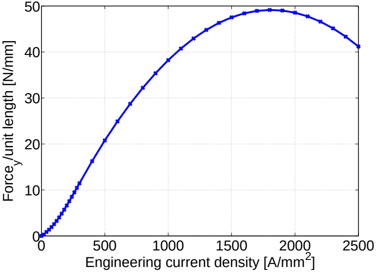
Racetrack Design #1 – Field on Conductor

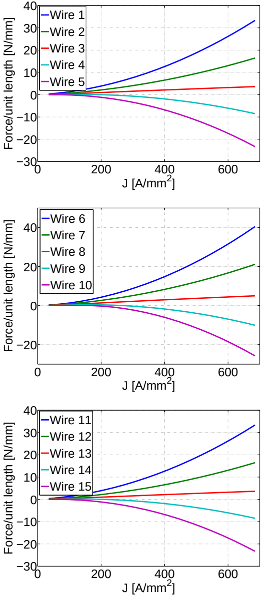




Racetrack Design #1 – Forces



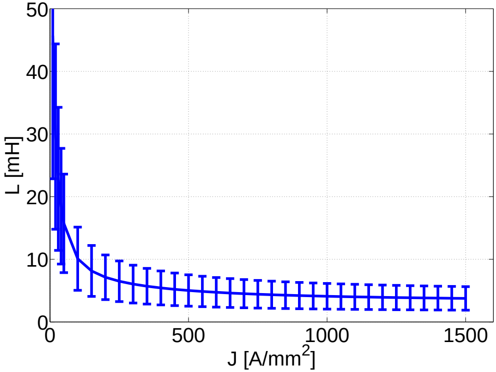




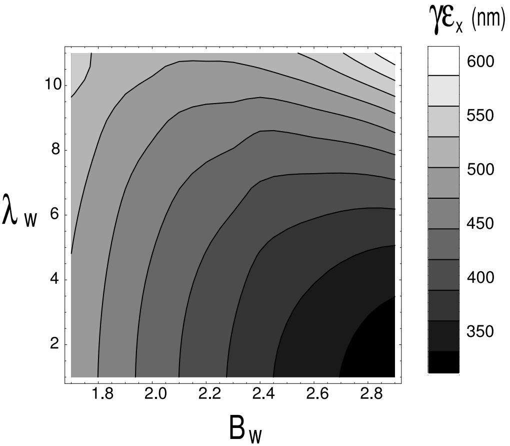
Racetrack Design #1 – Inductance

$$L_{\text{Wiggler}} = 2p\frac{E_{\text{period}}}{\left(\frac{I}{n}\right)^2}$$

p	# periods	E_{period}	stored energy/period
I	current in groove	n	# wires in groove



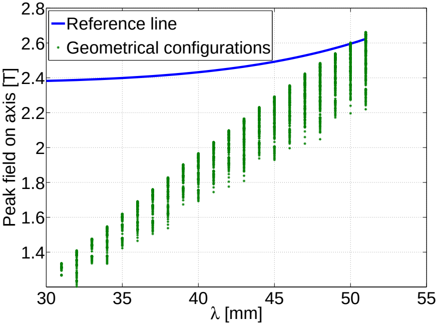
CLIC Wiggler's optimum efficiency

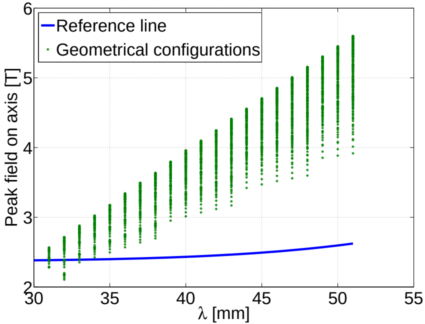


Transverse equilibrium emittance $\gamma\epsilon_x$ at fixed wiggler length $L_w = 152\,\mathrm{m}$

M. Korostelev: *Optics Design and Performance of an Ultar-Low Emittance Damping Ring for the Compact Linear Collider*

Optimal geometry– NbTi and Nb_3Sn





LHC NbTi corrector wire #3, 1.25 x 0.73 mm^2 including insulation, 1.13 x 0.61 mm^2, Cu:Sc 1.71; 70% of maximal current density

0.8 mm RRP Nb_3Sn Strand; 70% of maximal current density

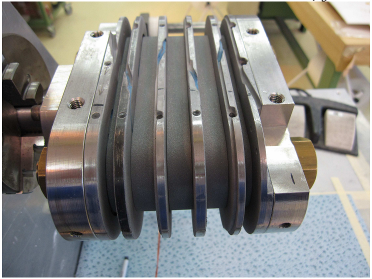
Optimal geometry – NbTi LHC wire #3

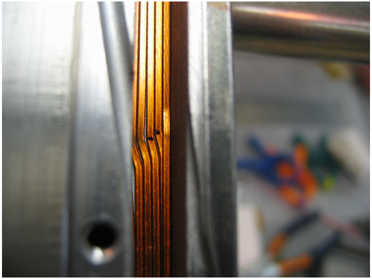
λ_w [mm]	B [T]	$J_{c,70\%}$ [$\frac{A}{mm^2}$]	g_x [mm]	g_y [mm]	p_x [mm]	$\gamma\epsilon_x$ [nm]
35.00	1.62	900	10.88	10.36	6.62	>500
36.00	1.69	891	10.88	11.10	7.12	>500
37.00	1.76	882	10.88	11.84	7.62	>500
38.00	1.83	850	12.24	11.10	6.76	>500
39.00	1.90	841	12.24	11.84	7.26	475
40.00	1.97	845	12.24	11.84	7.76	450
41.00	2.03	837	12.24	12.58	8.26	450
42.00	2.10	797	13.60	12.58	7.40	450
43.00	2.17	801	13.60	12.58	7.90	400
44.00	2.23	794	13.60	13.32	8.40	400
45.00	2.29	787	13.60	14.06	8.90	400
46.00	2.36	762	14.96	13.32	8.04	400
47.00	2.42	755	14.96	14.06	8.54	375
48.00	2.48	749	14.96	14.80	9.04	375
49.00	2.54	726	16.32	14.06	8.18	375
50.00	2.60	720	16.32	14.80	8.68	375
51.00	2.66	723	16.32	14.80	9.18	375

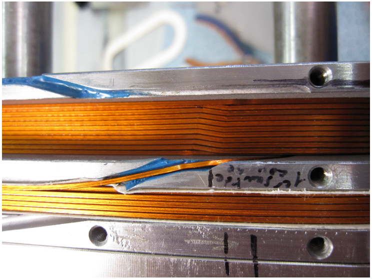
Preliminary optimal geometry – Nb_3Sn wire

λ_w [mm]	B [T]	$J_{c,70\%}$ [$\frac{A}{mm^2}$]	g_x [mm]	g_y [mm]	p_x [mm]	$\gamma\epsilon_x$ [nm]
31.00	2.56	1860	10.88	12.58	4.62	375
32.00	2.71	1767	12.24	13.32	3.76	350
33.00	2.88	1776	12.24	13.32	4.26	350
34.00	3.02	1769	12.24	14.06	4.76	<350
35.00	3.17	1762	12.24	14.80	5.26	<350
36.00	3.34	1696	13.60	14.80	4.40	350
37.00	3.49	1690	13.60	15.54	4.90	350
38.00	3.64	1685	13.60	16.28	5.40	350
39.00	3.80	1627	14.96	16.28	4.54	350
40.00	3.96	1622	14.96	17.02	5.04	350
...	...	...	...	...	...	...
47.00	5.01	1504	17.68	20.72	5.82	350
48.00	5.16	1508	17.68	20.72	6.32	350
49.00	5.30	1505	17.68	21.46	6.82	350
50.00	5.45	1456	19.04	22.20	5.96	350
51.00	5.60	1460	19.04	22.20	6.46	375

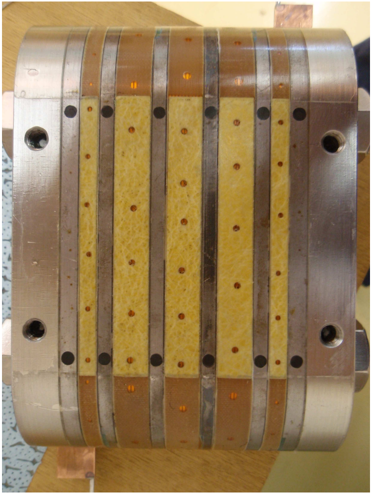
Racetrack design #1 – Actual status

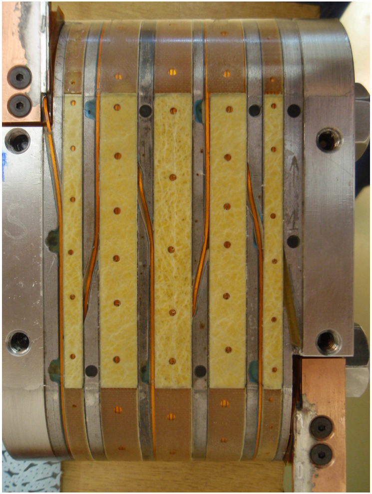




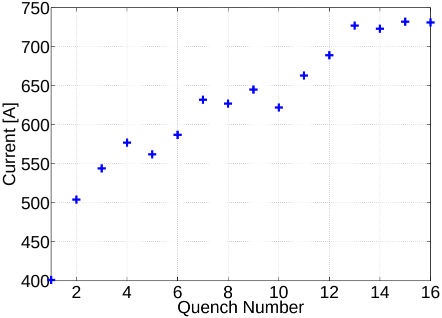


Racetrack design #1 – Actual status

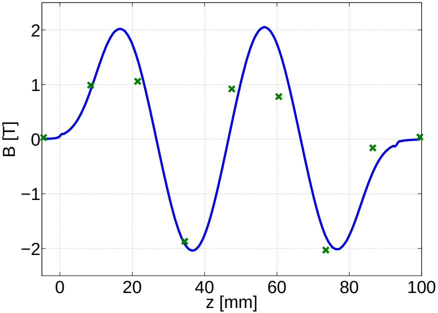




Racetrack design #1 – Measurement results

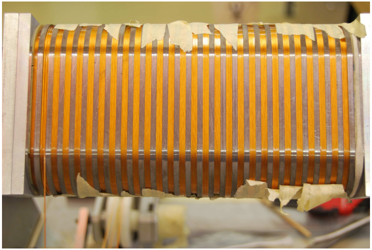


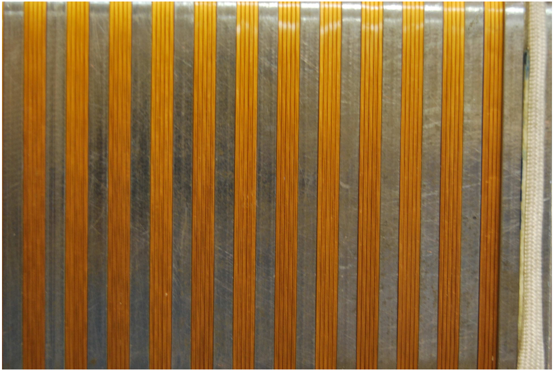
Training



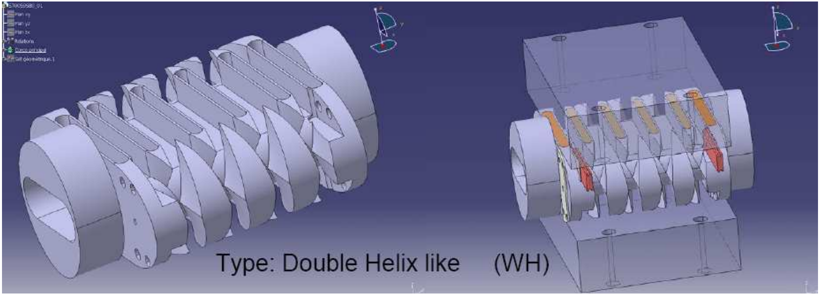
Comparison of calculated and measured field

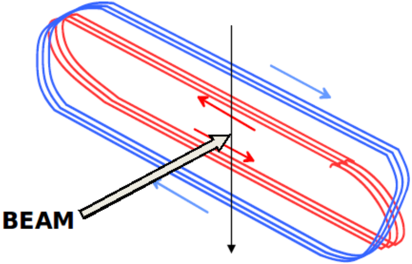
Racetrack design #2 – Actual status





Double helix (R. Maccaferri and S. Bettoni)

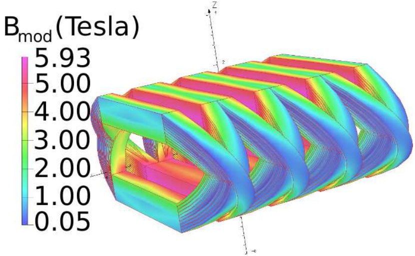


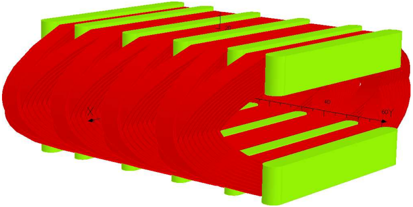


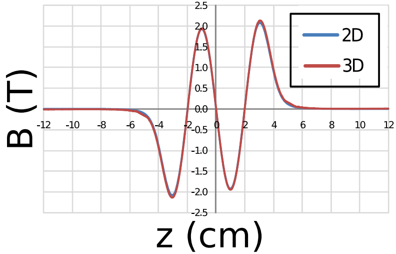
Advantages:

- Half quantity of wire is needed.
- Short period.
- Iron poles can be easily replaced by holmium poles.

Double helix – Simulations

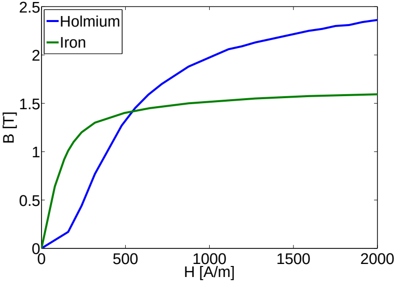






- $P_{max} \approx 32\,\mathrm{MPa}$ on the straight part without considering thermal stress.
- Manufacturing is complicated and an on-going research field.

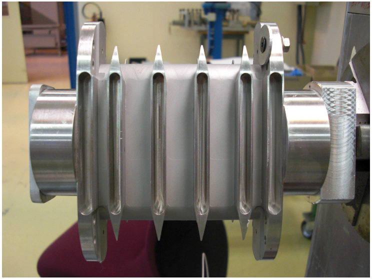
Double helix – Holmium

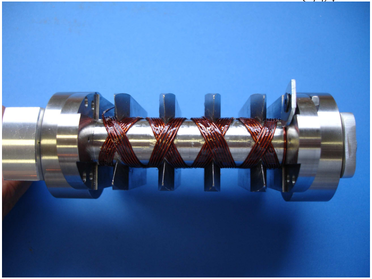


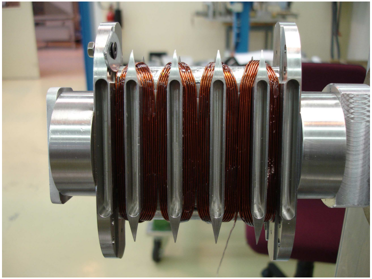
Holmium Atomic Number	67
Melting Point	1474°C
Boiling Point	2700°C
Density	8.80 g/cm^3
Mechanical Properties	Relatively soft and malleable
Chemical Properties	Stable in dry air at room temperature
Cost, 99+%	10 CHF/g

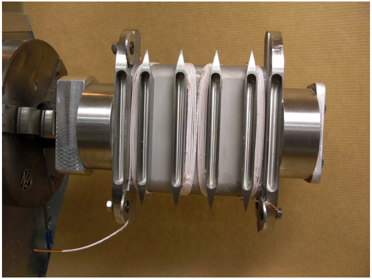
Los Alamos National Laboratory's Chemistry Division

Double helix – Actual status









- **End 2009** Electromagnetic and mechanical design and realisation of a NbTi mock-up.
- **Mid 2010** Electromagnetic and mechanical design and realisation of a Nb_3Sn mock-up.
- **Mid 2011** Design of a full scale prototype.
- **Mid 2012** Manufacturing & test of a full scale prototype.

Summary

- Optimization of CLIC damping wiggler geometrical configuration.
- Simulation of mock-ups.
- Manufacturing, testing, and optimizing of several mock-ups.
- Using Nb_3Sn
- Using Holmium for the double helix design.

Thanks!