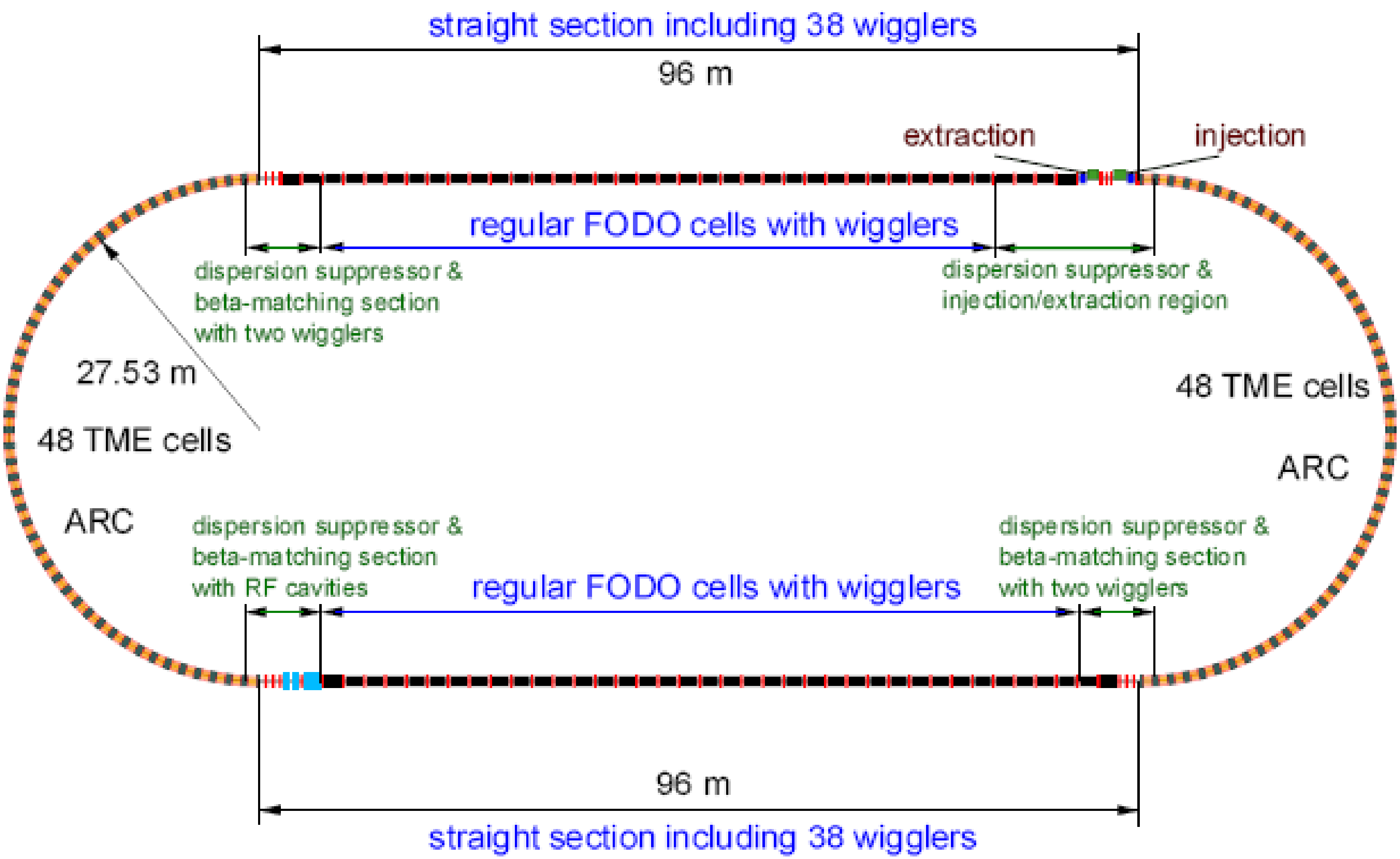
The Wiggler for the SR Damping ring

R. Maccaferri

CERN: AT/MCS

The CLIC SR Damping ring



SC Undulators & Wigglers at CERN

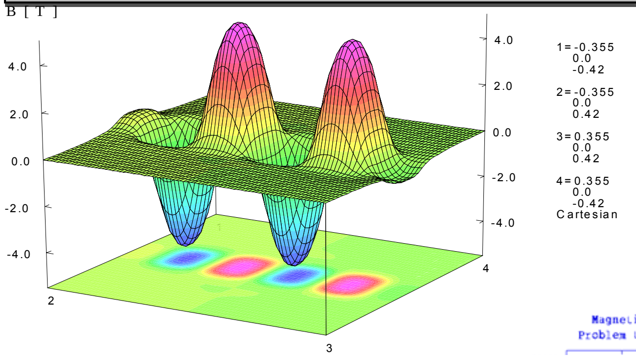
☑History

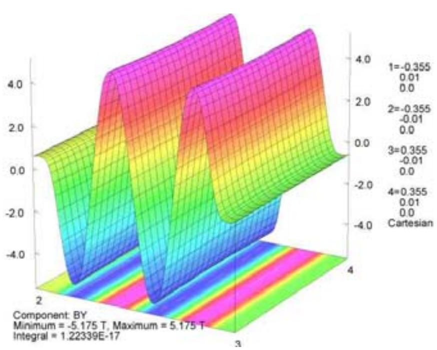
- NbTi Undulator for the LHC beam monitor

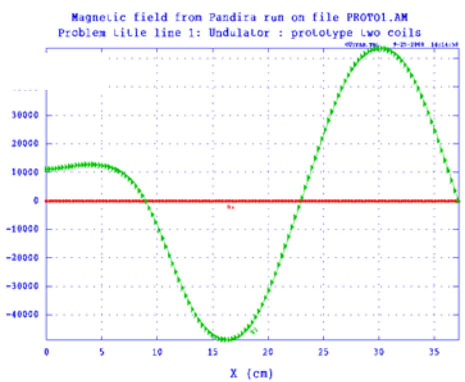
Period: 280 mm Gap: 60 mm

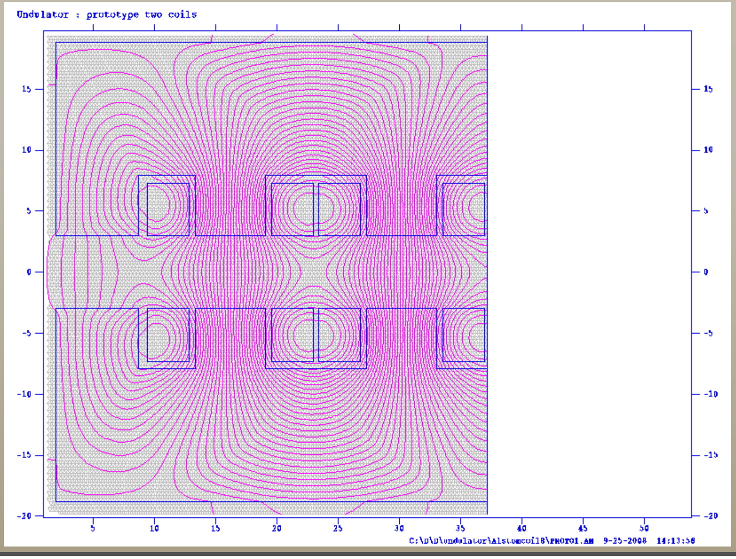
Field in the gap: 5 T Field on coils: 6.2 T

Operating current: 450 A >>> 350 A /mm²





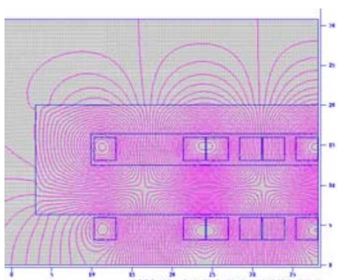


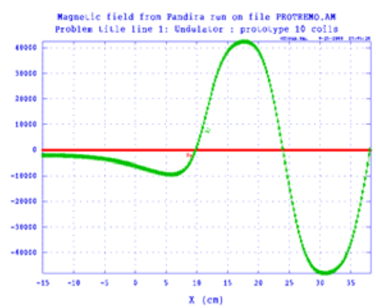


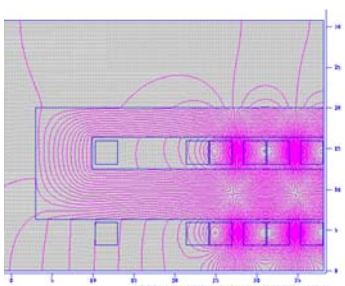
LHC Undulator upgrade for lead ions

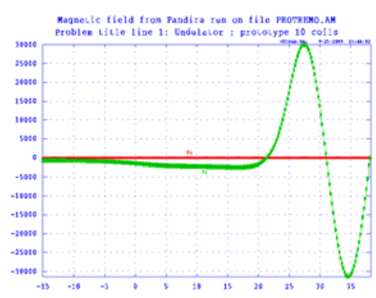
- LHC upgrade with lead ions, requires modification
  - Flexible operation: undulator period 280 mm/140 mm with 60 mm gap

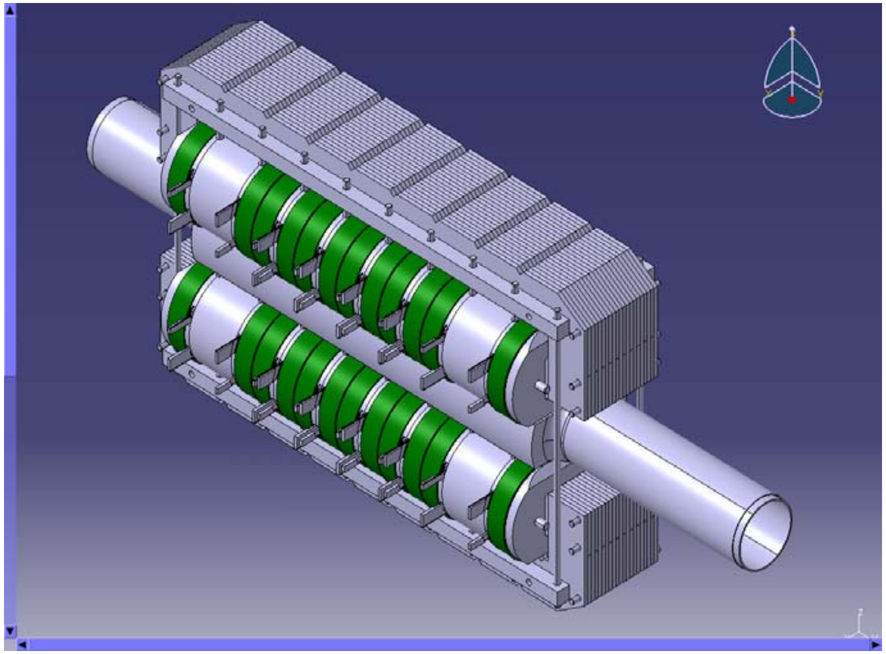
    B_{GAP} = 5 T for 280 mm period which mean B_{COIL}: 8 T(590 A/mm^2)
    B_{GAP} =>3 T for 140 mm period which mean B_{COIL}= 9T (550 A/mm^2)



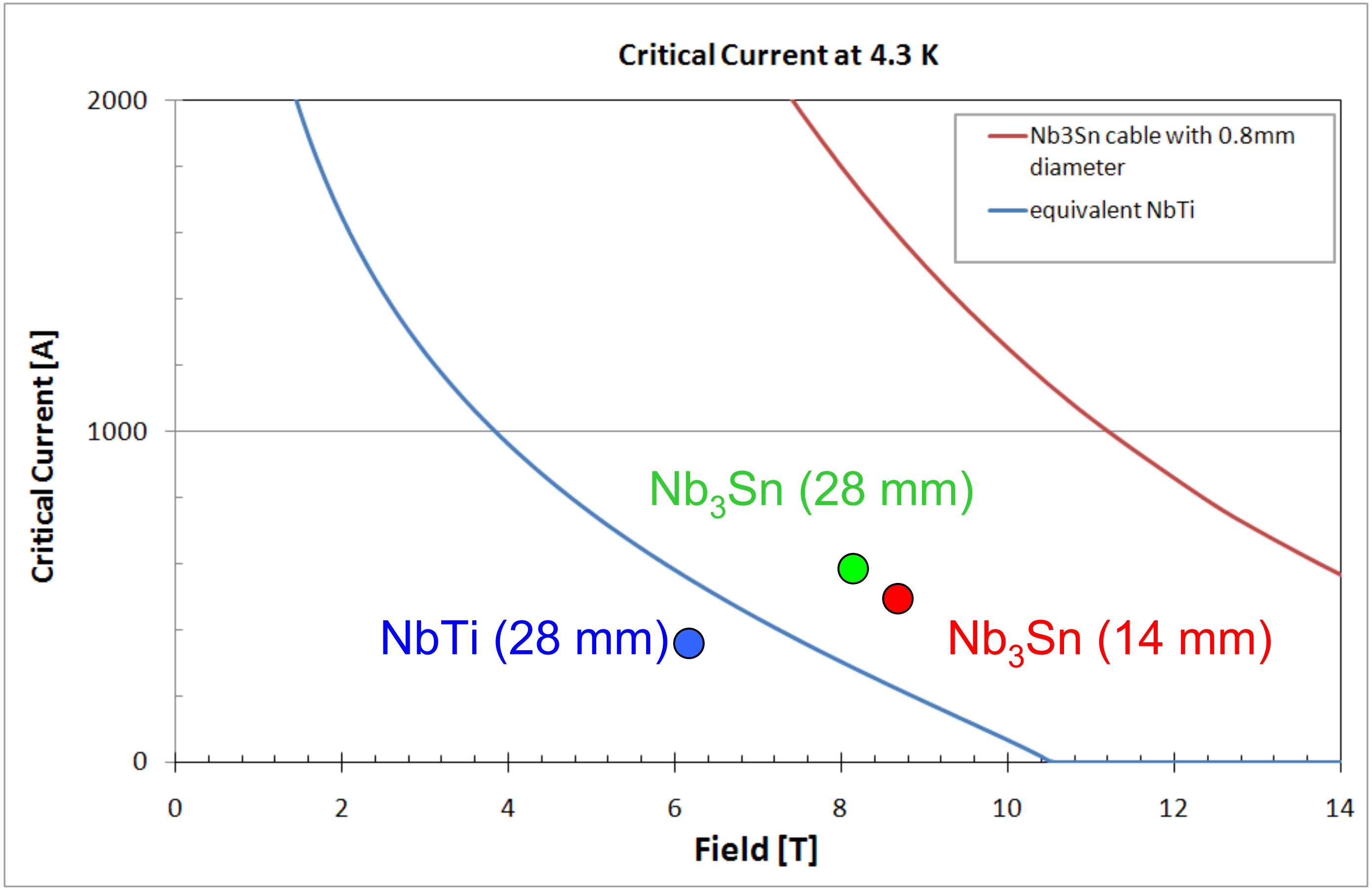








Comparison NbTi vs Nb_3Sn



Superconductor choice

- NbTi is not suitable for the Lead Ions undulator
- Nb_3Sn seem to be the right choice but…
  - *Needs a long reaction treatment up to 700 C*
  - *Becomes brittle after treatment*
  - *The insulation between turns and layers must resist high temperatures.*
  - *Shows instabilities at low field (flux jumps)*

- Nevertheless, it is the only superconductor available to build this undulator and eventually the CLIC wiggler!

NB3Sn Strand

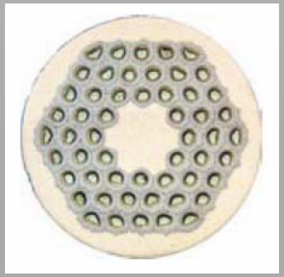
☑ Properties

- **Produced by Oxford Instruments Superconducting Technology (OST) using restacked rod process(RRP)**

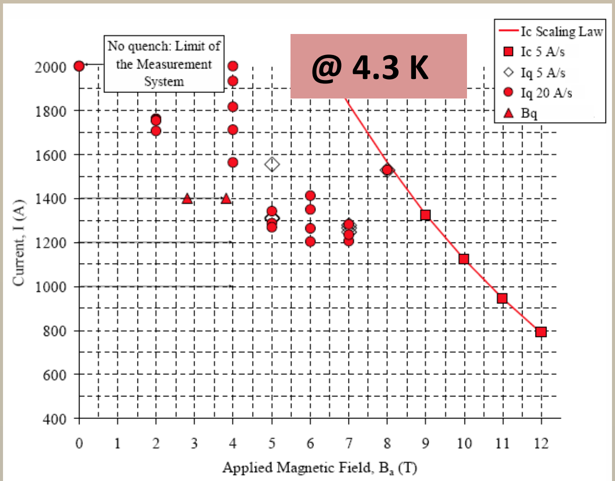
http://www.oxinst.com/wps/wcm/resources/file/ebcab80df0182aa/RRP_NbSn.pdf

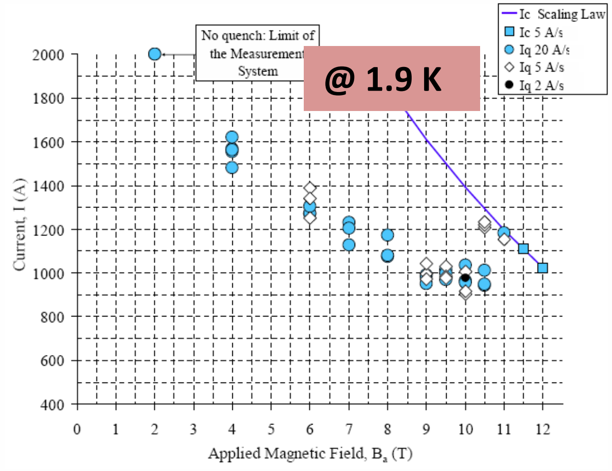
- **Bare diameter = 0.8 mm + S2-glass insulation**
- **Price: ~8chf/m**

Stabilizer	Copper
Non copper volume	53% +/- 3%
RRR of Cu	>40
Twist pitch , dia. < 1mm	12 ± 4 mm
Twist pitch , dia. ≥ 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**
  - Increase T to 205 ºC (25 ºC /h), hold for 72 h
  - Increase T to 400 ºC (50 ºC /h), hold for 48 h
  - Increase T to 695 ºC (50 ºC /h), hold for 17 h
    - Improved RRR and magneto-stability, B.Bordini
- **Measurements:**
  - RRR > 300 (short sample and coil), B. Bordini





"Test Report of the Ceramic-Insulated Nb^{3}Sn Small Split Solenoid"; B. Bordini, R. Maccaferri, L. Rossi, D. Tommasini EDMS: 907758

How to handle

3 Methods:

- React, Wind then impregnate
  - *This method apply only if a large bending radius(>200 mm) can be done. The reacted wire is very brittle, rigid and breaks if bent.*
- Wind, react and then impregnate
  - *Need fiber glass de-sizing by additional thermal cycle in flowing air followed by a special residual cleaning.*
  - *Reaction cycle in vacuum or Ar gas*
  - *Vacuum impregnation with epoxies*
- Wet-wind and react
  - *Ceramics wet-winding*
  - *Reaction cycle in vacuum or Ar gas*

We intend to choose the last method !

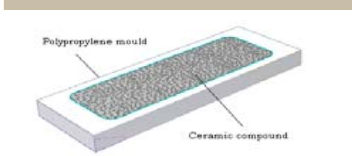
Suitable Insulations process

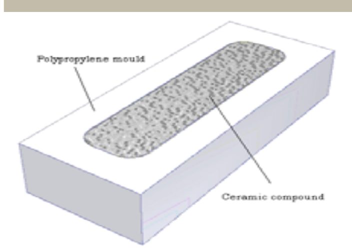
☑ **Ceramics adhesive 989 F, produced by Cotronics corp. N.Y.(USA)**

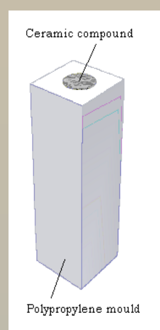
- 989 F, very fine granulometry
- Alumina based
- Used for wire impregnation
- Cures at room temperature
- Working temperature >1600 °C
- Dielectric Strength > 8 kV/mm

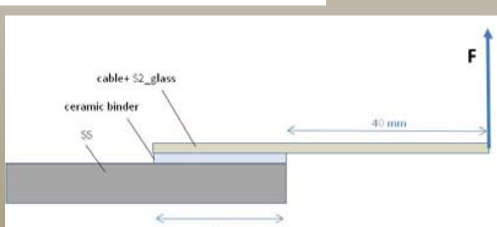
Ceramics validation tests

- **Curing tests**
  - Changing $r=A_{cure}/V_{sample}$
    - Total cure
    - Retraction
    - Fissures
- **Band test**
  - Adherence to fiber glass
- **Peeling test**
  - Adherence properties

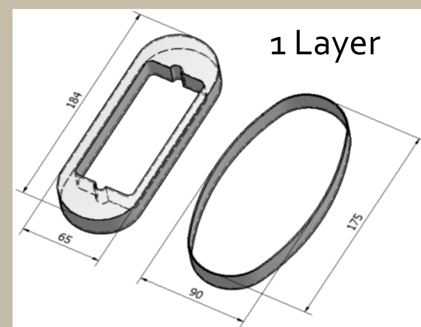


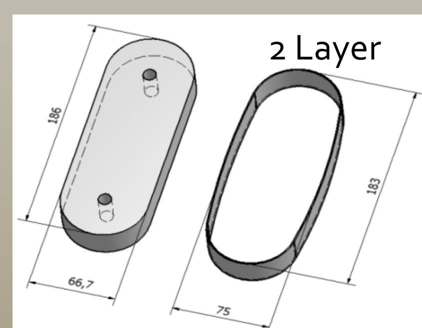




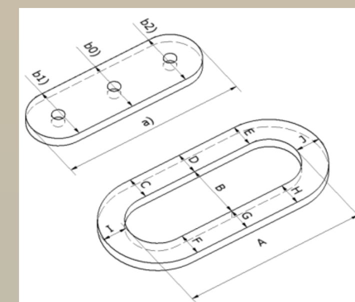


- **Basic winding test**
  - Inter layer/turn adherence
  - Rigidity





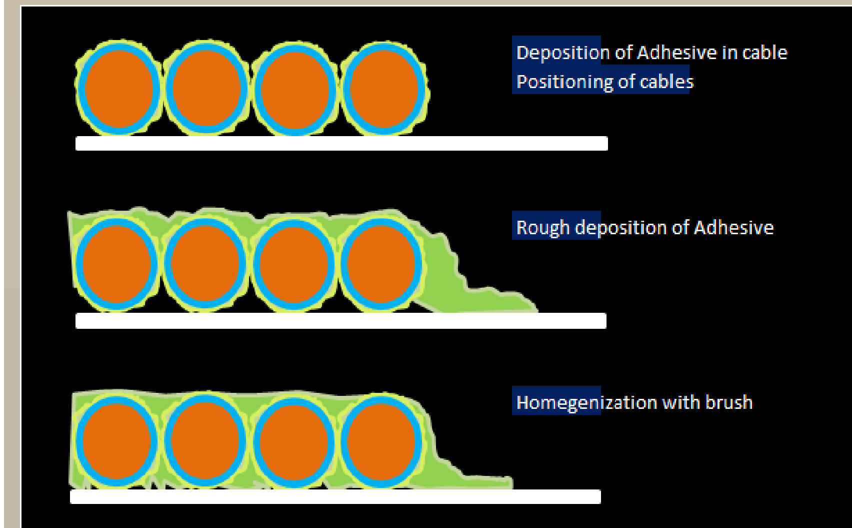
- **Advanced winding test**
  - Interlayer adherence/ voids
  - Pre-cure + air blowers
  - Hardener



Coil Winding

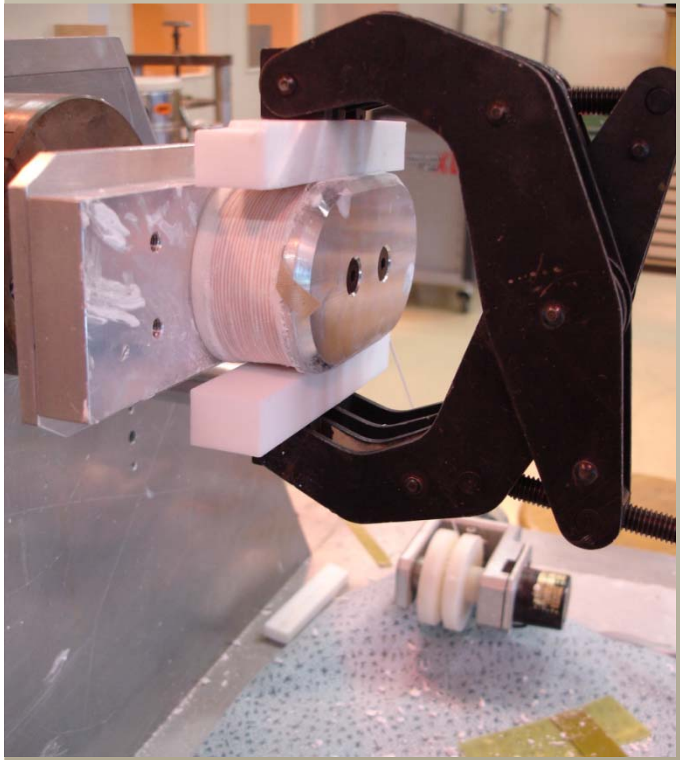
☑ **Dedicated machine + 2 persons**

- 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**
  - **Too much adhesive = low current density**
  - **Not enough = bad insulation and mechanical stability**
- **Pre-curing by layers (10 mins) + confinement + hot air circulation**
  - **Compensate wire elasticity**

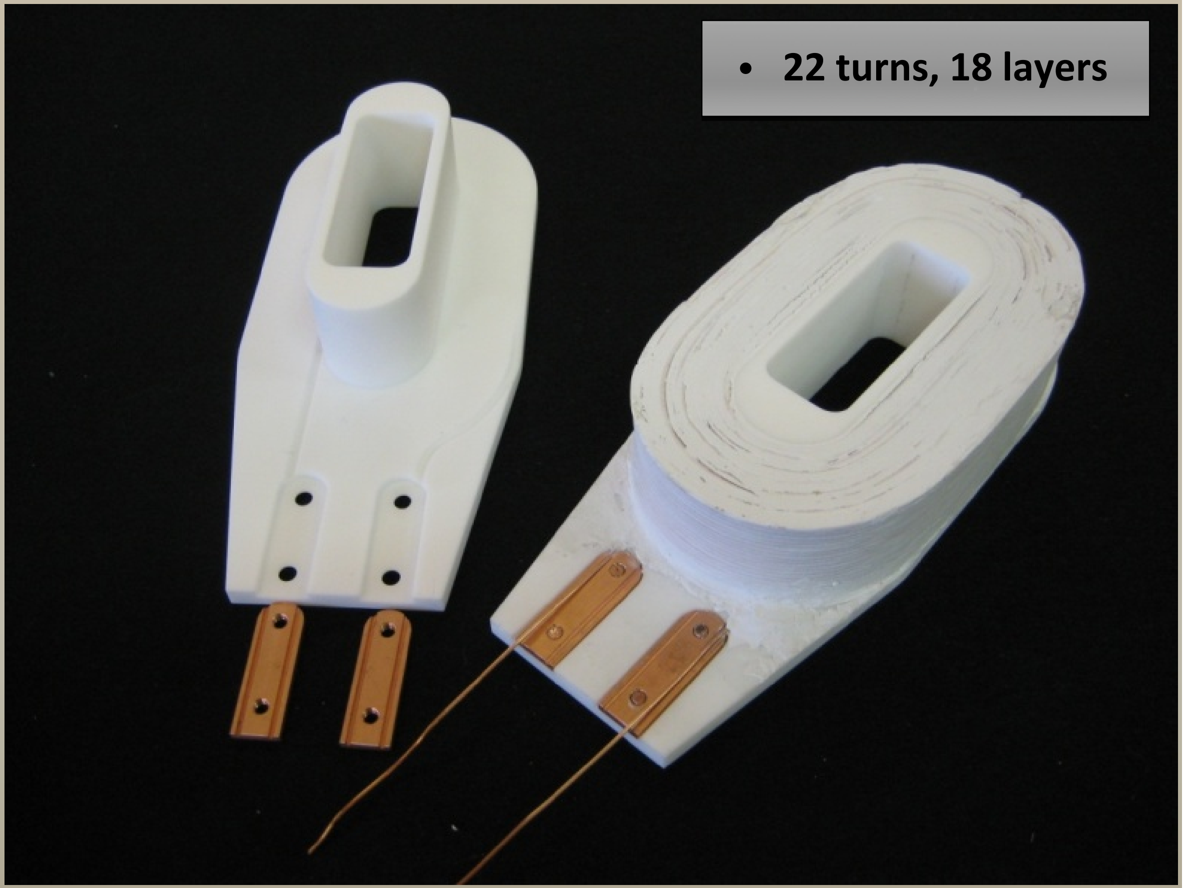


Coil Winding

- + 24 hour curing in winding machine (wire tensioned)
- Wire terminals soldered to Cu supports
- Drying in oven at 65 ºC



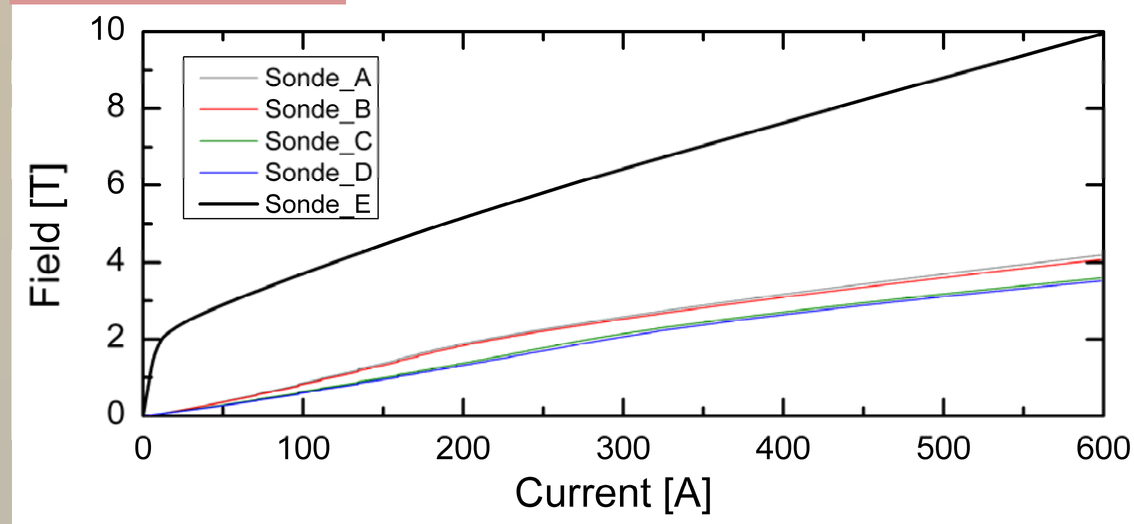
- 22 turns, 18 layers

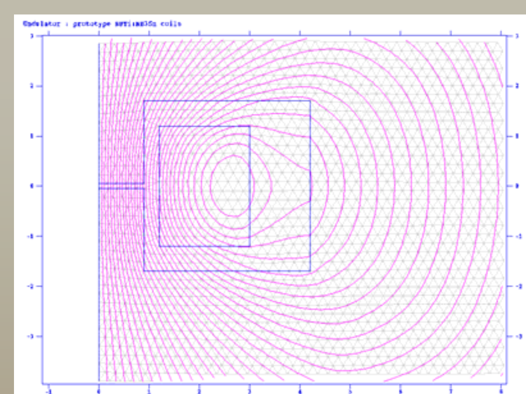


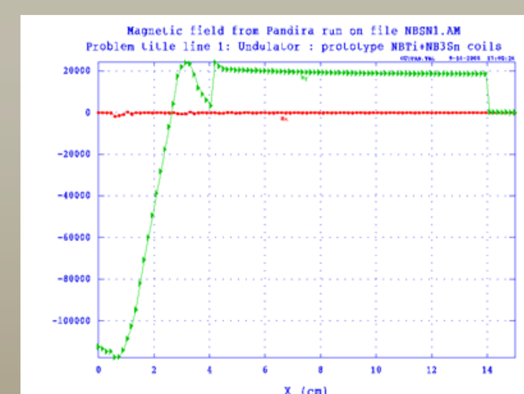
Measurements

- ☑ **Good agreement between model and measurements.**
- ☑ **I_{max}= 599 A; B= 10 T**
- ☑ **T= 4.3 K**

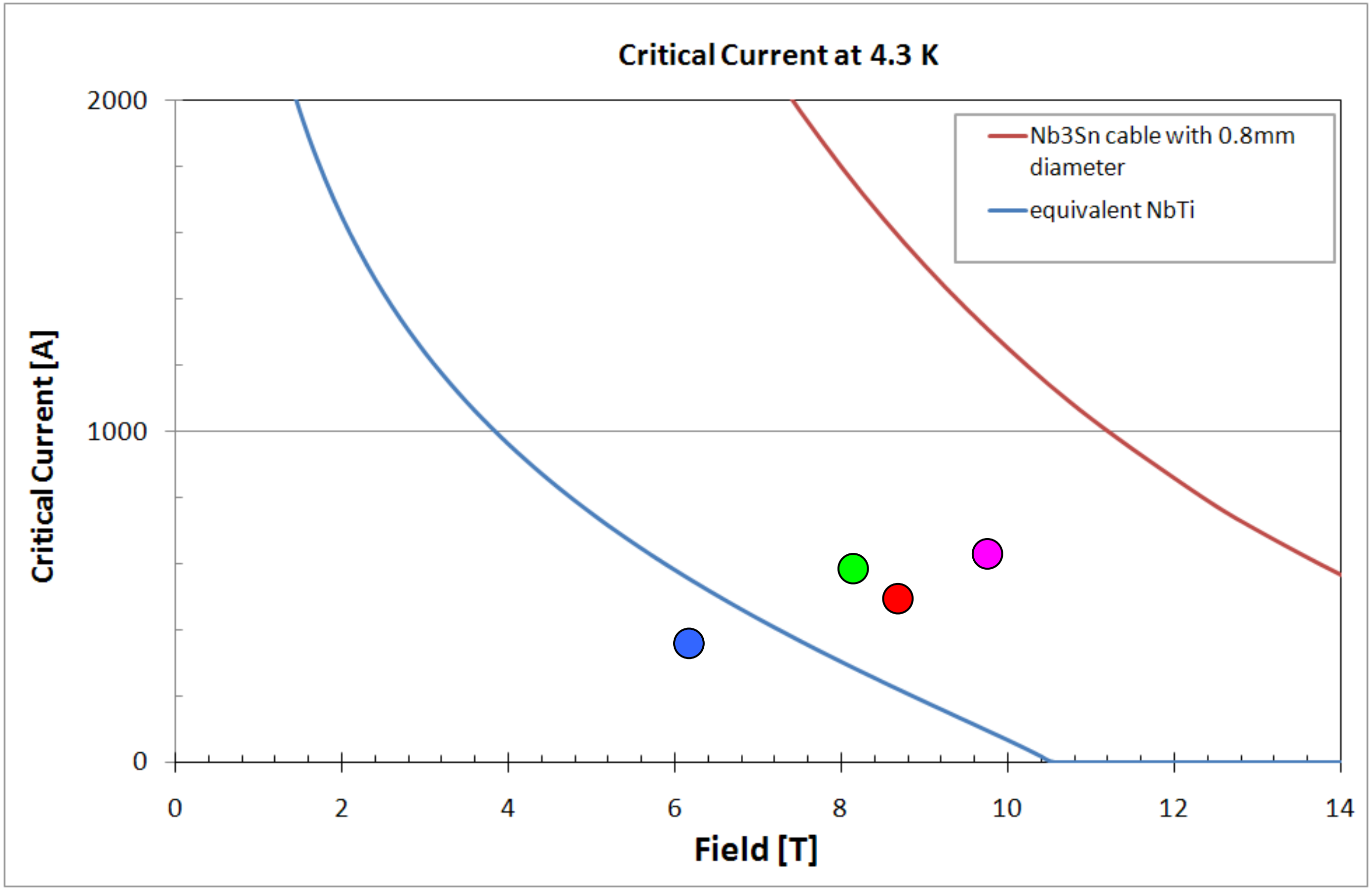
Load line @ 4.3 K





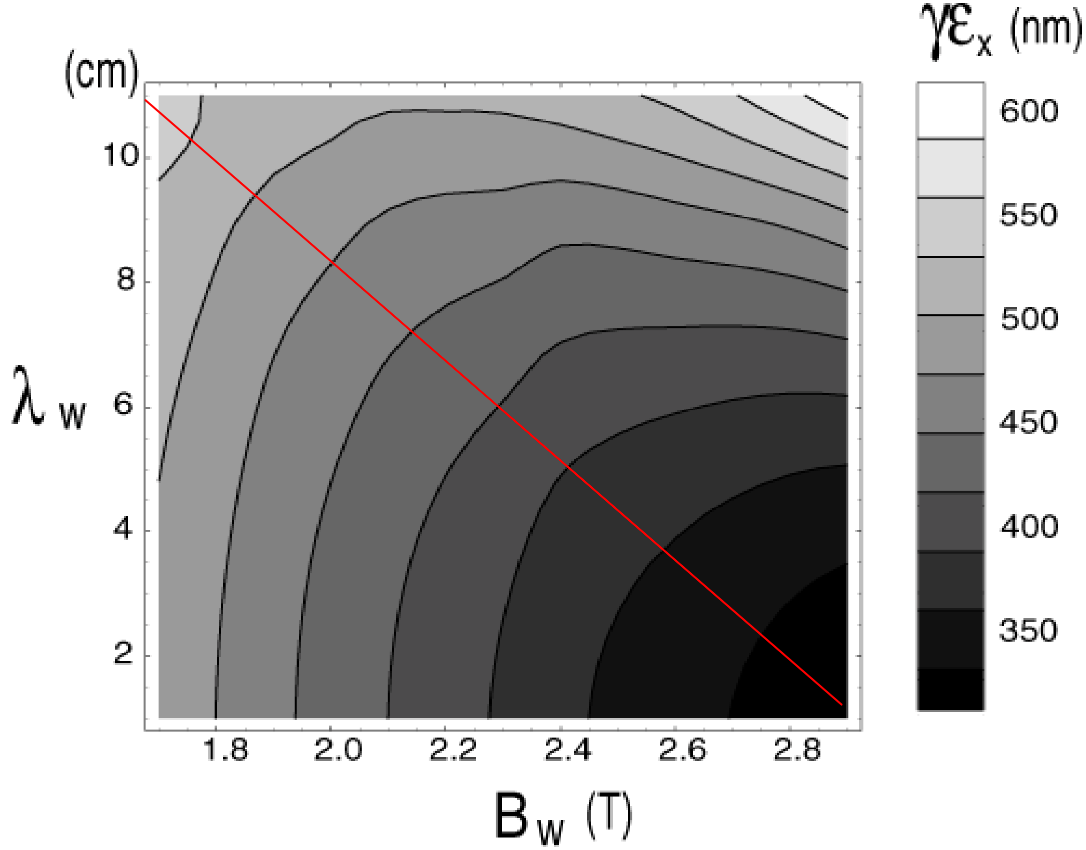


Undulators working points



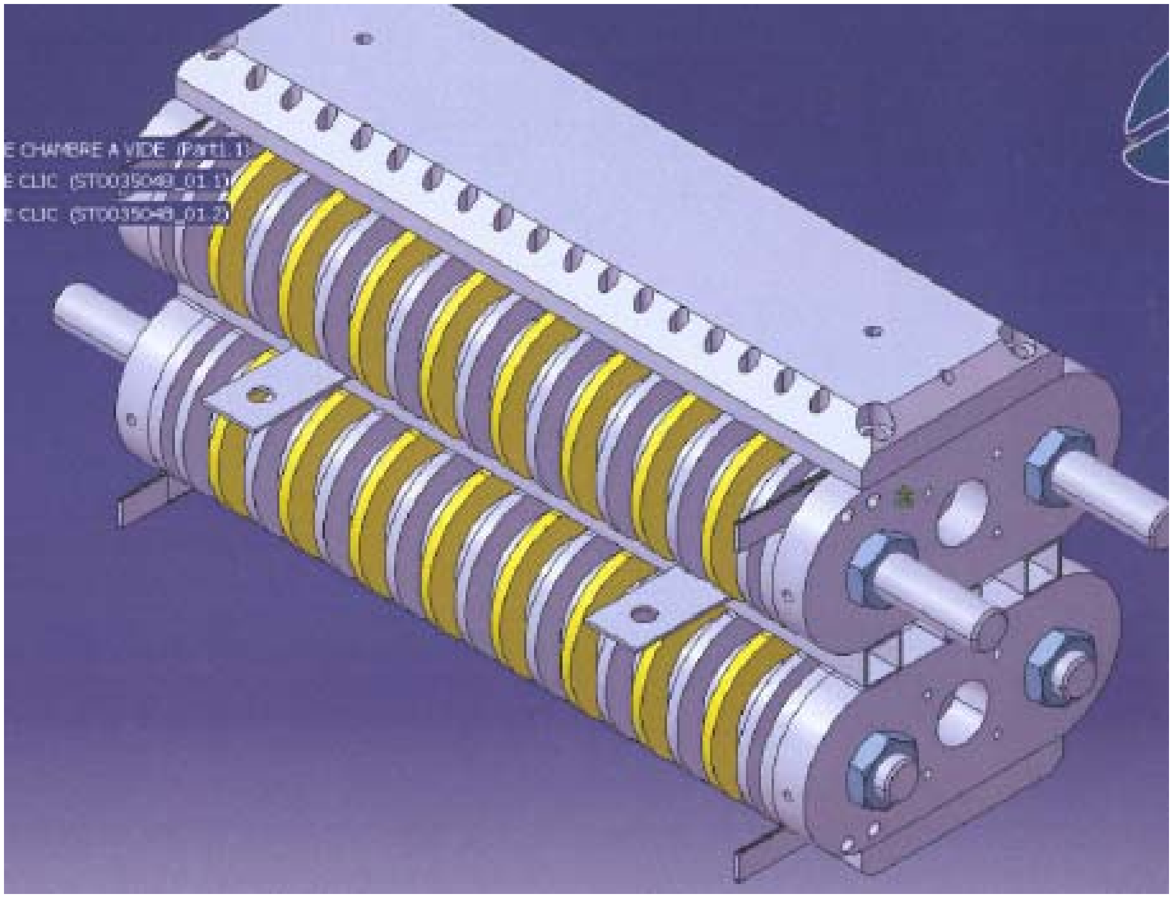
● NbTi 28mm ● Nb3Sn 28mm ● Nb3Sn 14 mm ● Nb3Sn proto-coil

Wigglers optimum efficiency



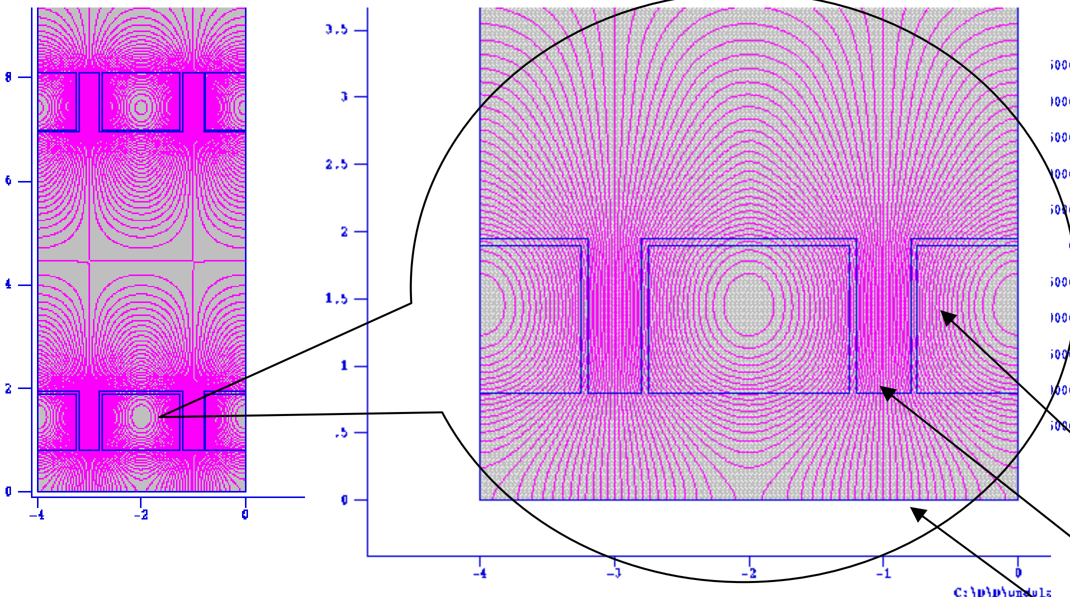
Contour plot of horizontal emittance with IBS as function of wiggler parameters

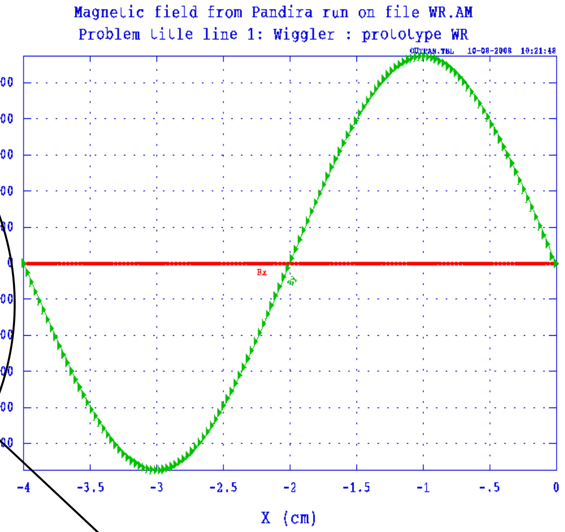
Wiggler Models discussion



Type: Vertical racetracks coils (WR)

WR magnetic Model 2D

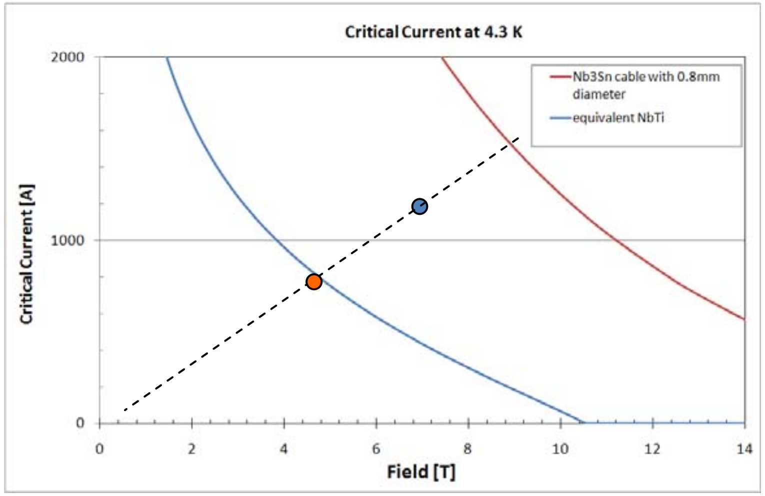




7 T on the coil &

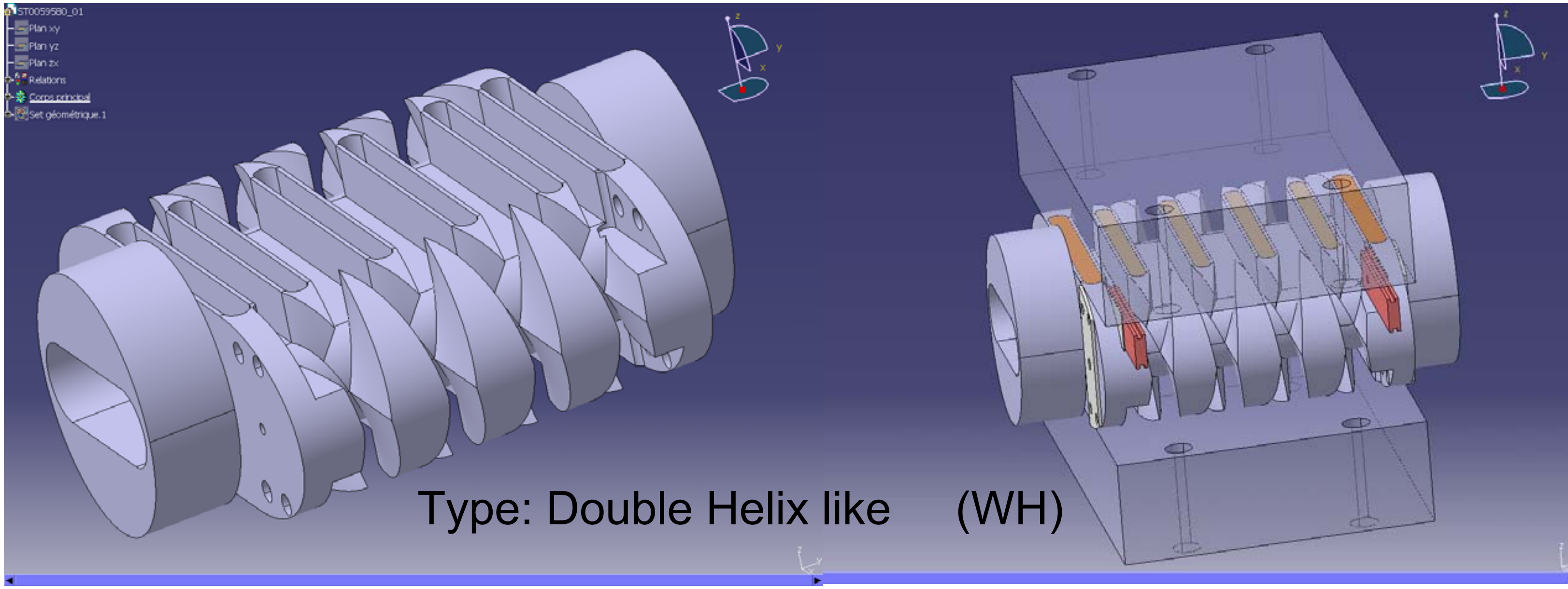
8.8 T in the iron pole

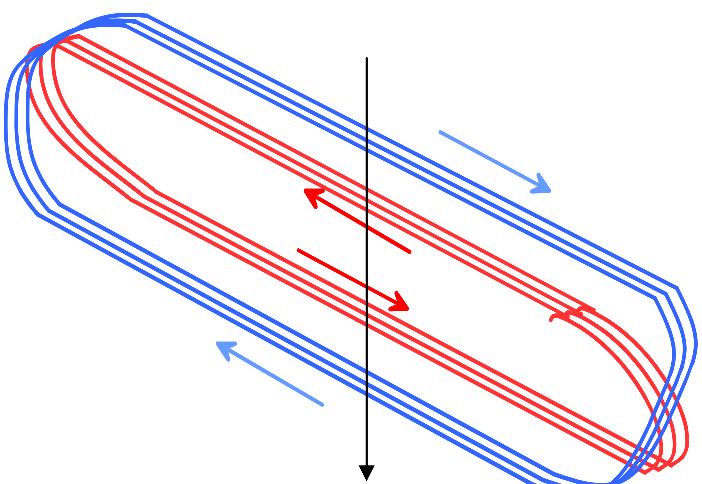
2.8 T Beam axis

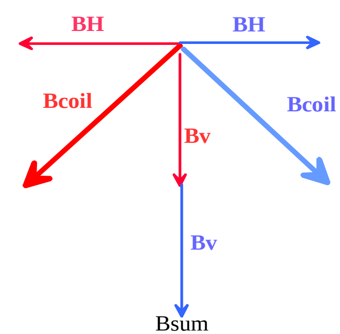


With this geometry(40mm period,16 mm Gap) if we use NbTi superconductor we can reach only 2 T on the Beam axis.

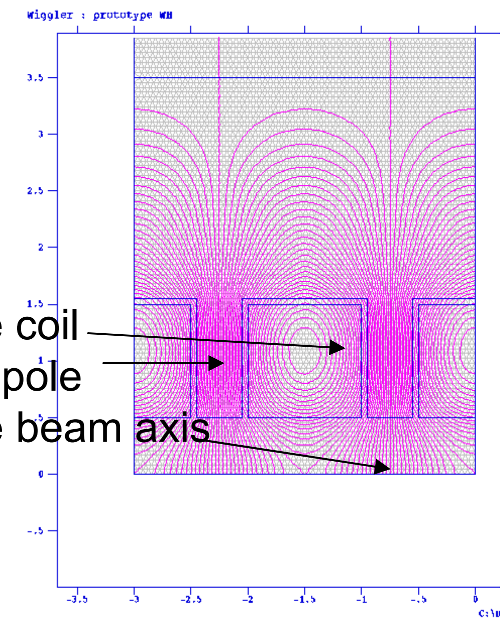
Wiggler Models discussion(cont.)



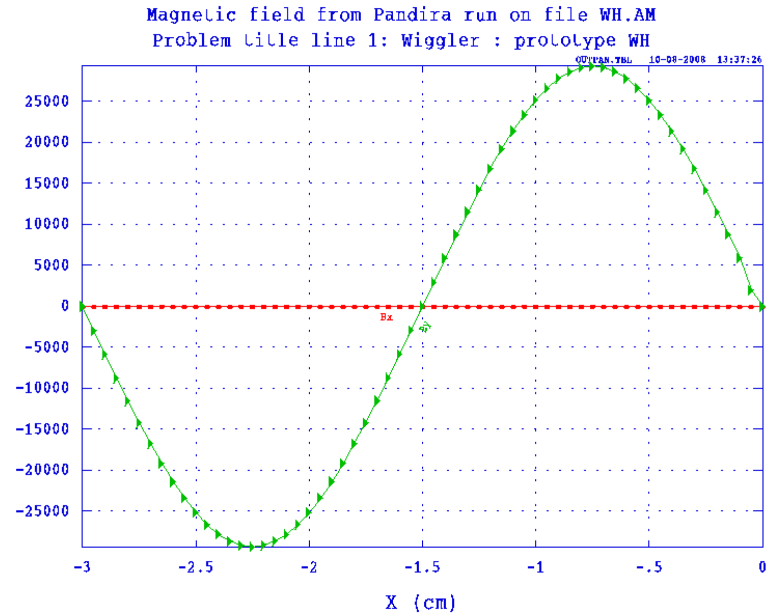


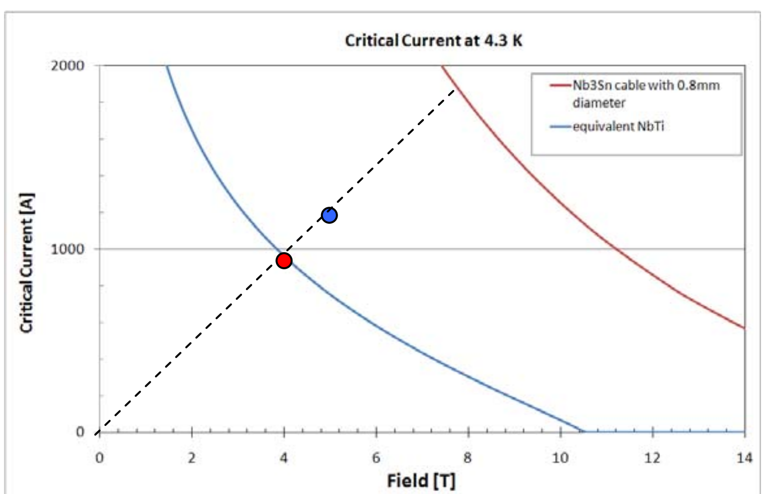


WH magnetic Model 2D



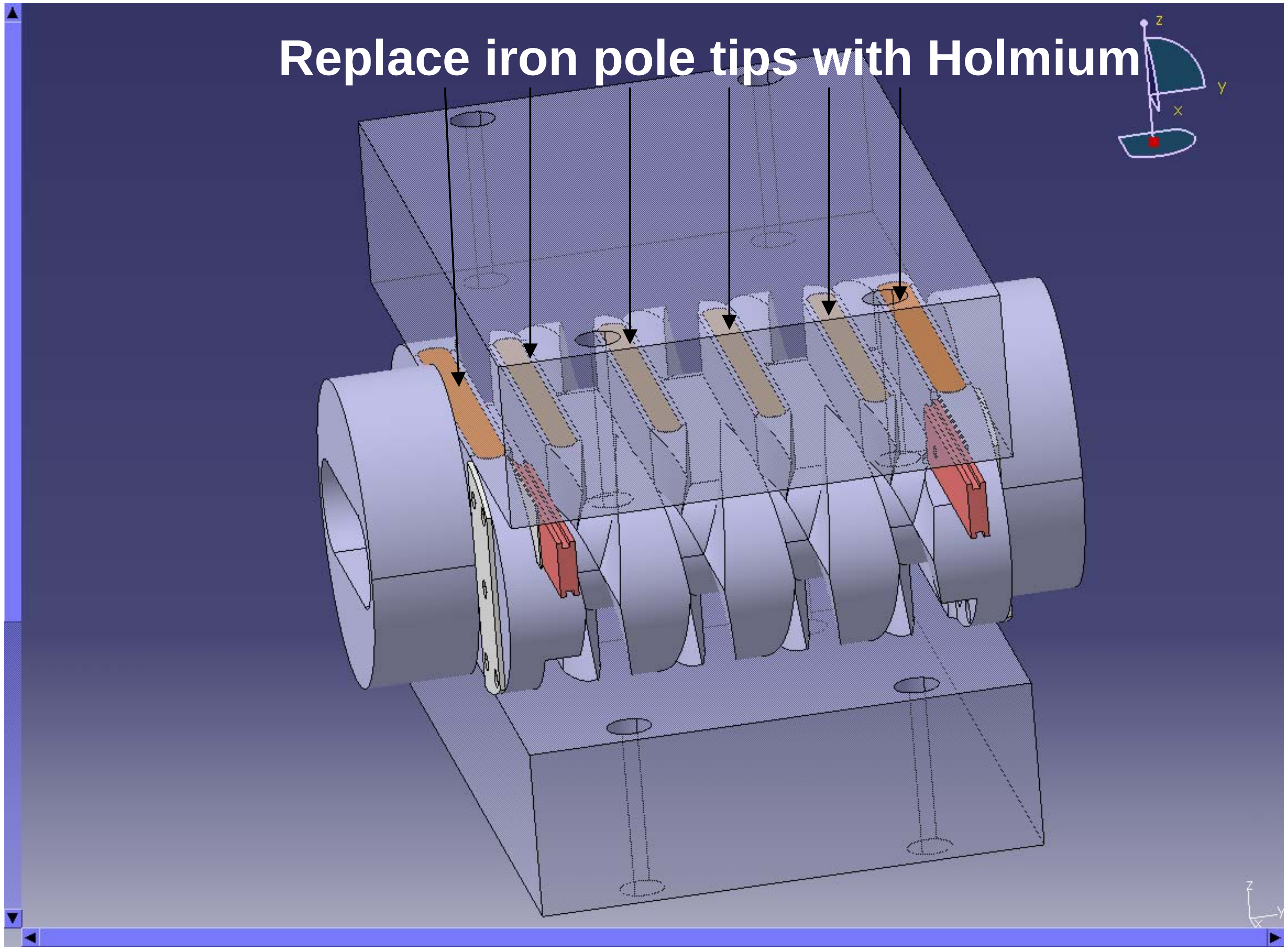
5.3 T on the coil
7.2 T in the pole
2.8 T at the beam axis





With this geometry(30mm period,10 mm Gap) if we use NbTi superconductor we can reach 2.2 T on the Beam axis.

Enhanced WH wiggler



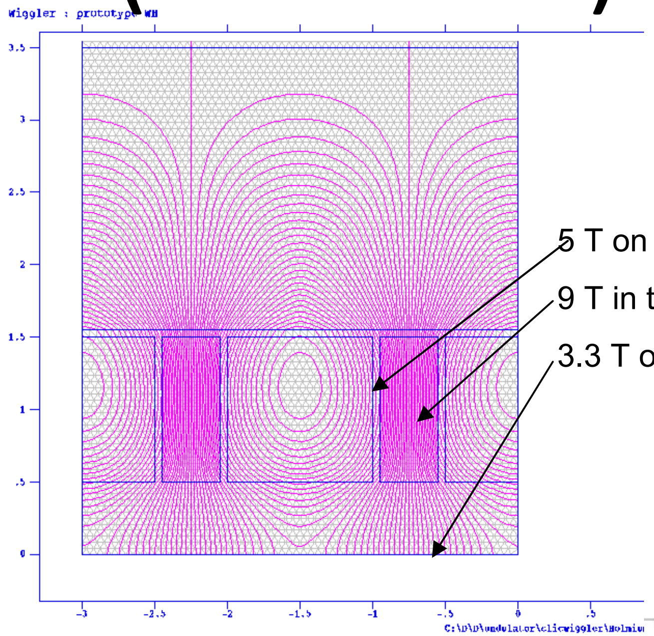
Holmium properties

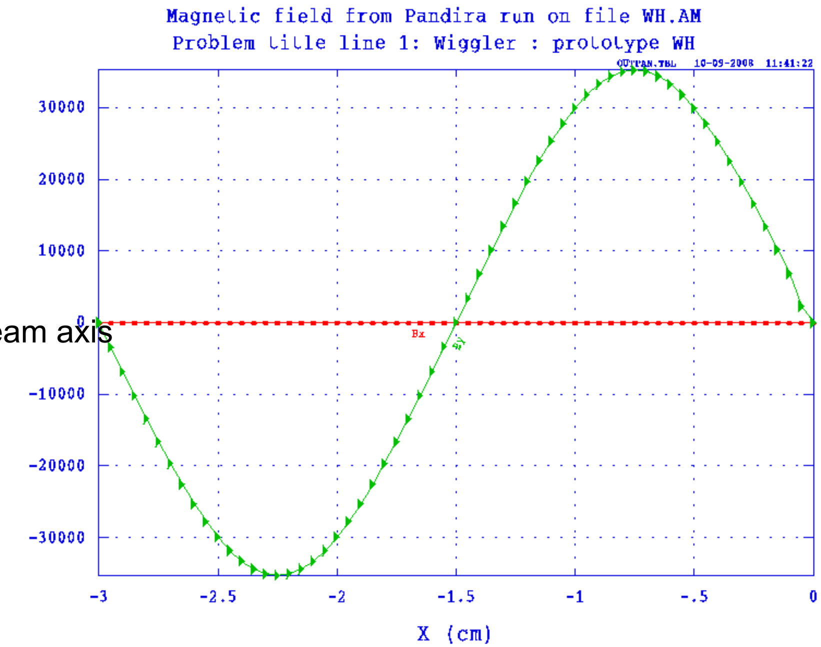
HolmiumAtomic Number:	67
Atomic Weight:	164.93032
Melting Point:	1747 K (1474°C)
Boiling Point:	2973 K (2700°C)
Density:	8.80 g/cm^3
Phase at Room Temperature:	Solid
Element Classification:	Metal
Bsat (Below 20 K see footnote):	3.2 T
Cost, pure:	740 $/100g

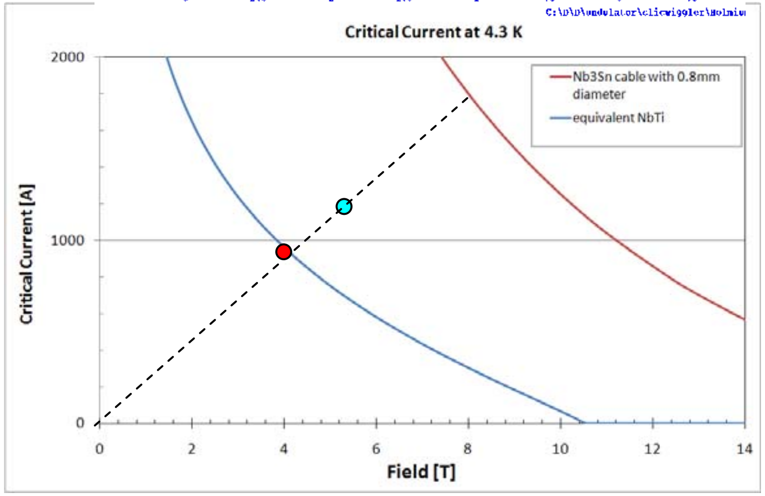
Magnetic Properties of Holmium and Thulium Metals*

B. L. Rhodes, S. Legvold, and F. H. Spedding
Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa
(Received August 12, 1957)

WR(Holmium) magnetic Model 2D

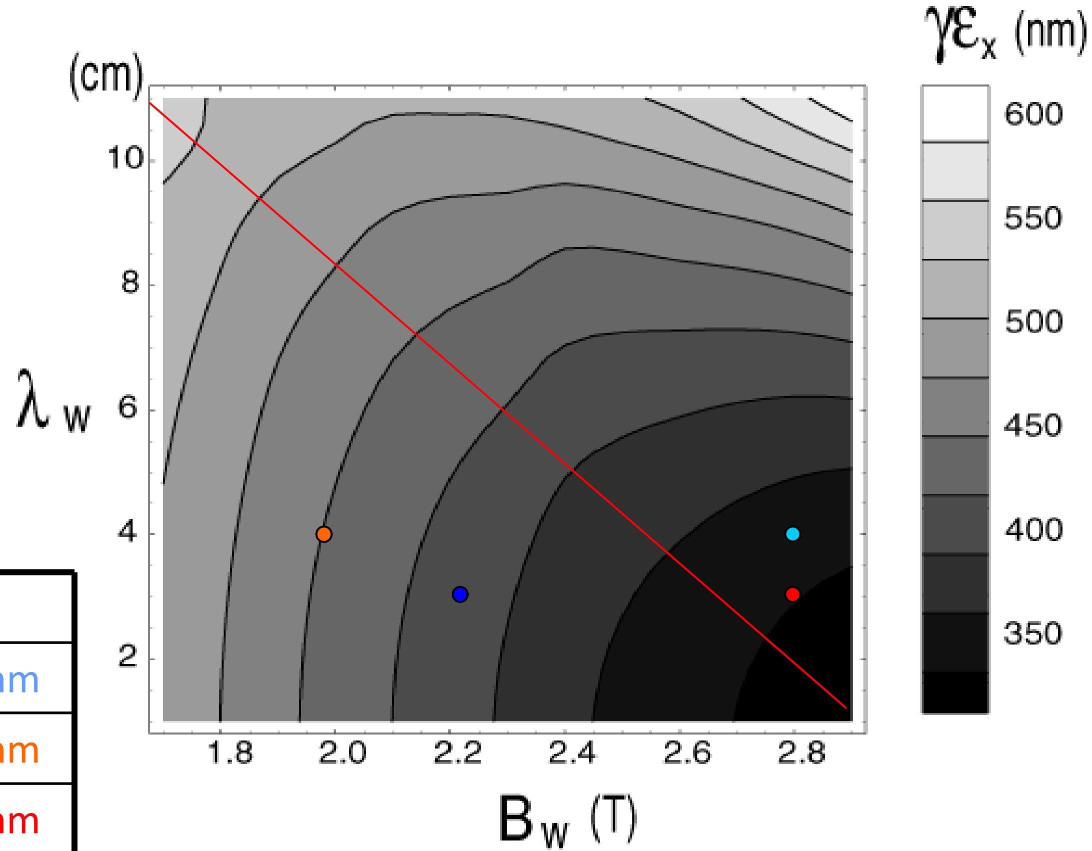






With this geometry(30mm period,10 mm Gap) if we use NbTi superconductor we can reach 2.7 T on the Beam axis.

Wigglers working points



Type	Bmax	Period	Gap
Nb_3Sn	2.8 T	40 mm	16 mm
NbTi	2.0 T	40 mm	16 mm
Nb_3Sn	2.8 T	30 mm	10 mm
NbTi	2.2 T	30 mm	10 mm

Discussion: advantages/drawbacks

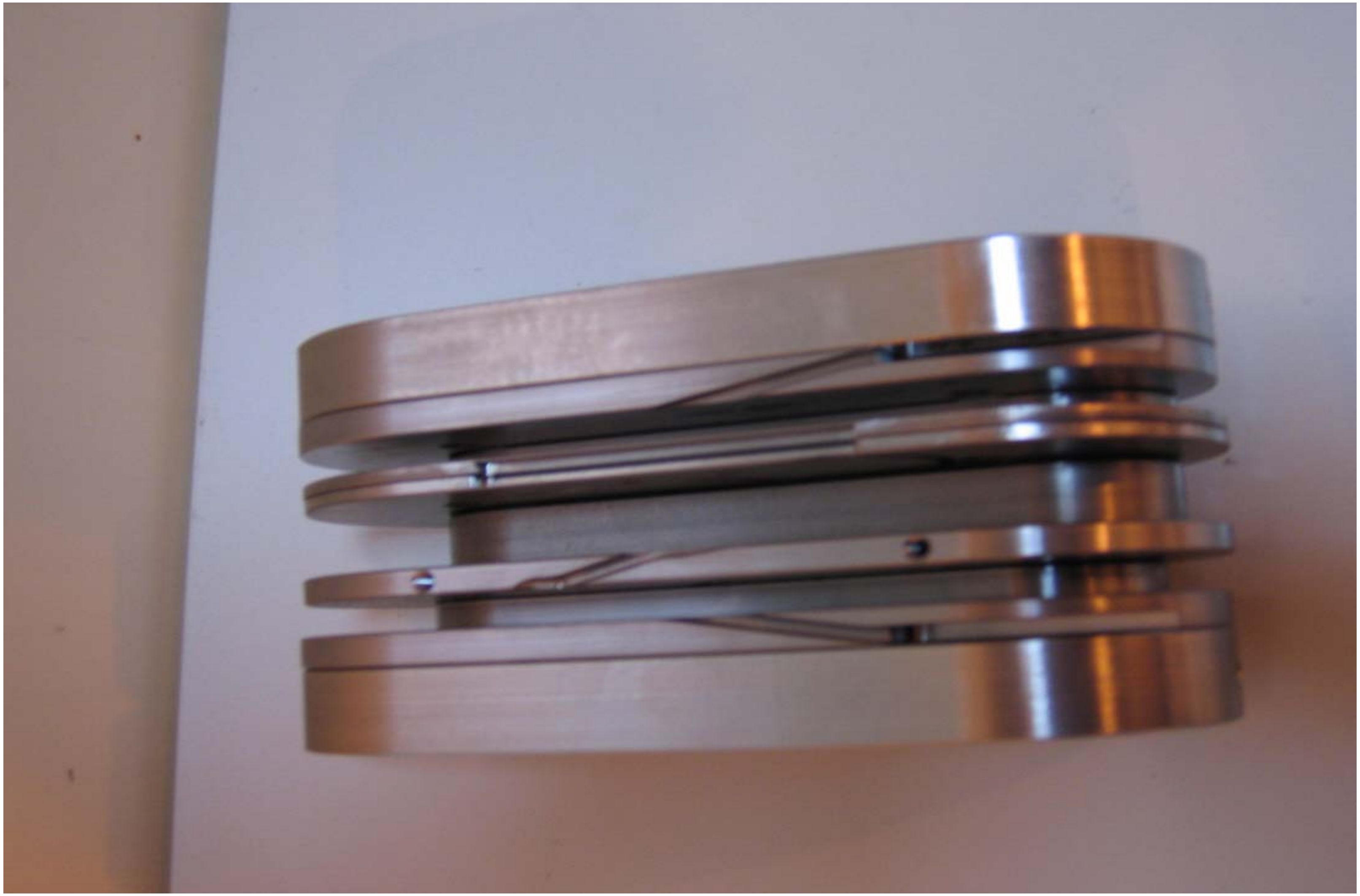
NbTi		Nb_3Sn	
+	-	+	-
Robust and ready to use			Brittle, need thermal treatment
	Limited Field <6 T	No practical field limit >15T	
	1W/m heat depostion (note 1)	10 W /m heat deposition (note 1)	
Stable			Unstable under certain conditions
Standard EU and US Production			Only US commercial production

NOTE 1: Comparative study of heat transfer from Nb-Ti and Nb3Sn coils to He II Marco La China and Davide Tommasini Phys. Rev. ST Accel. Beams 11, 082401 (2008)

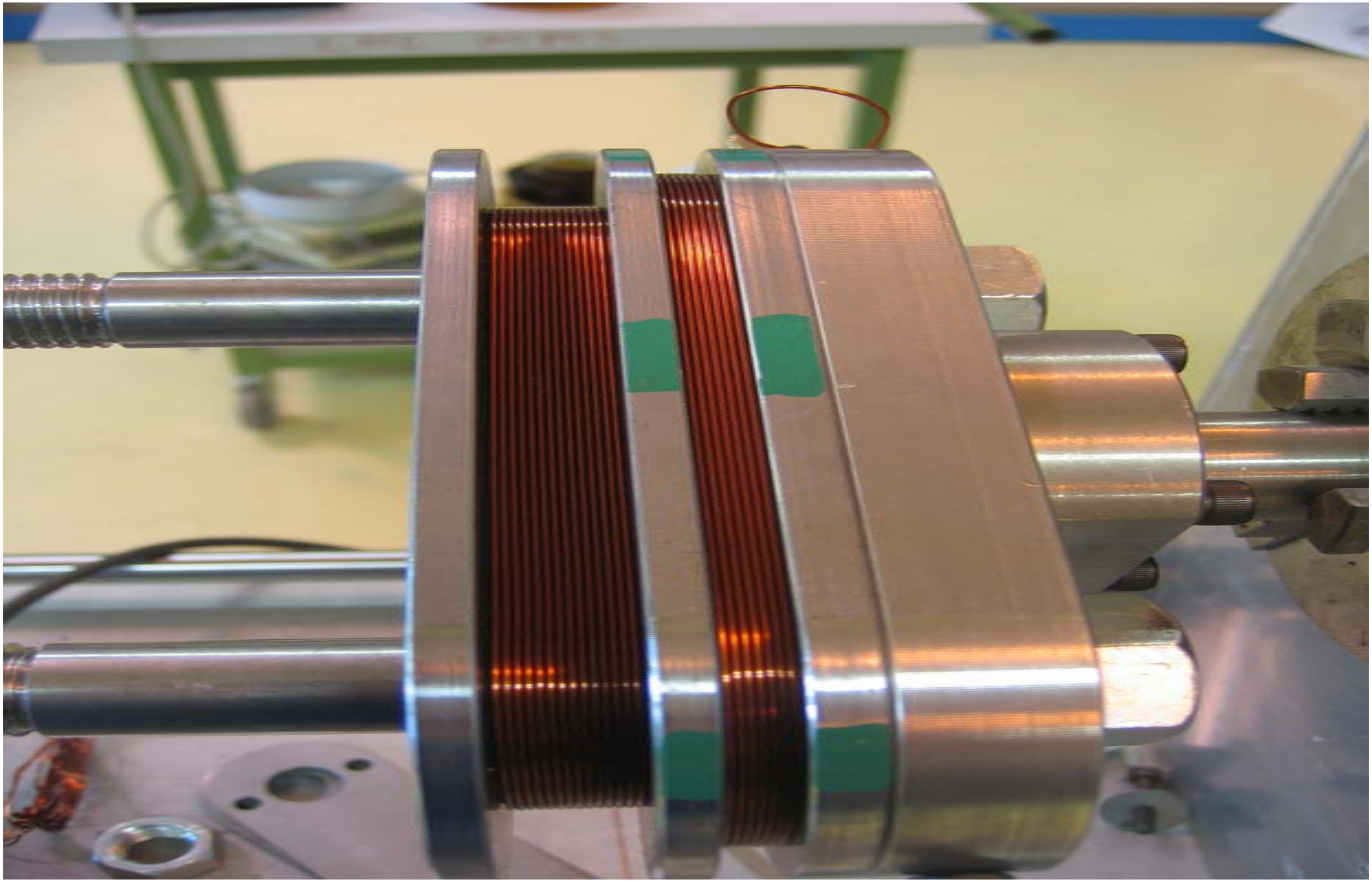
WR prototype (actual status)

WR prototype (actual status)

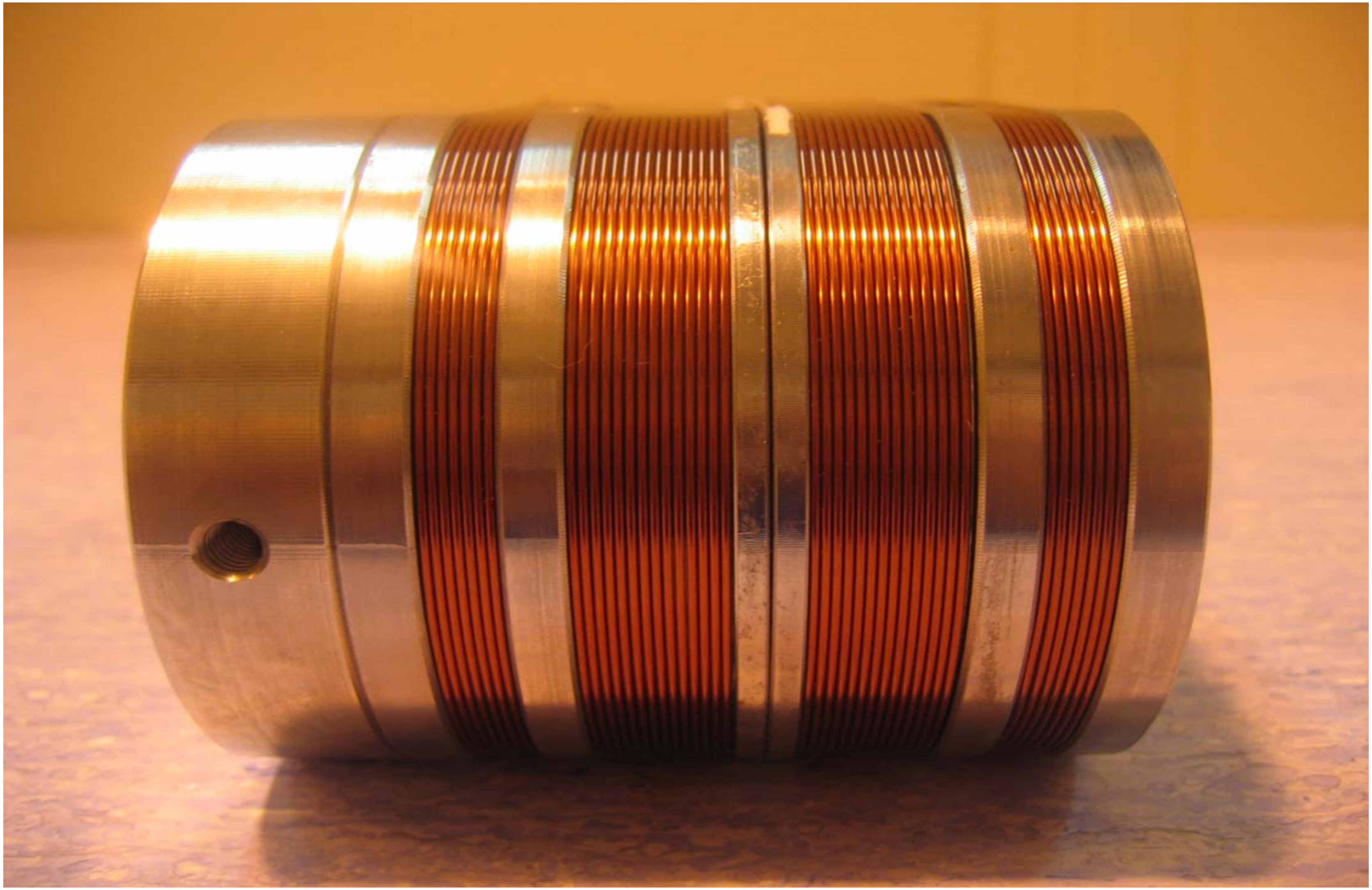
WR prototype (actual status)



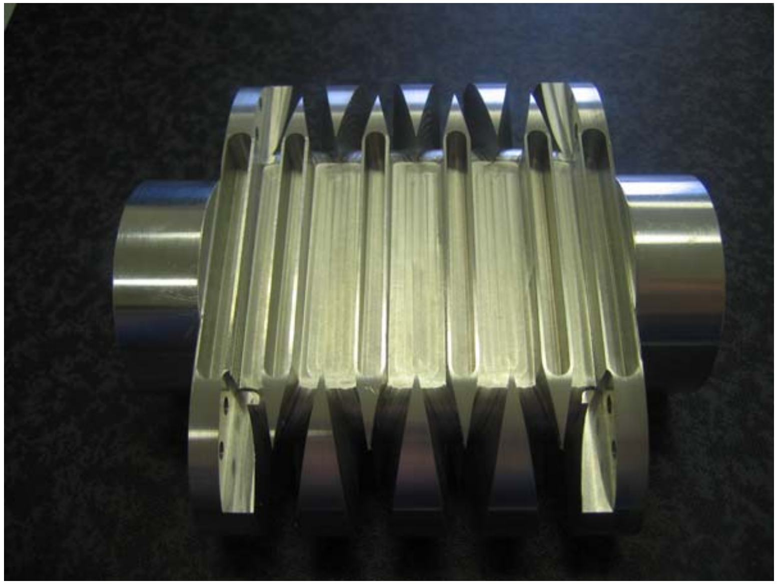
WR prototype (actual status)



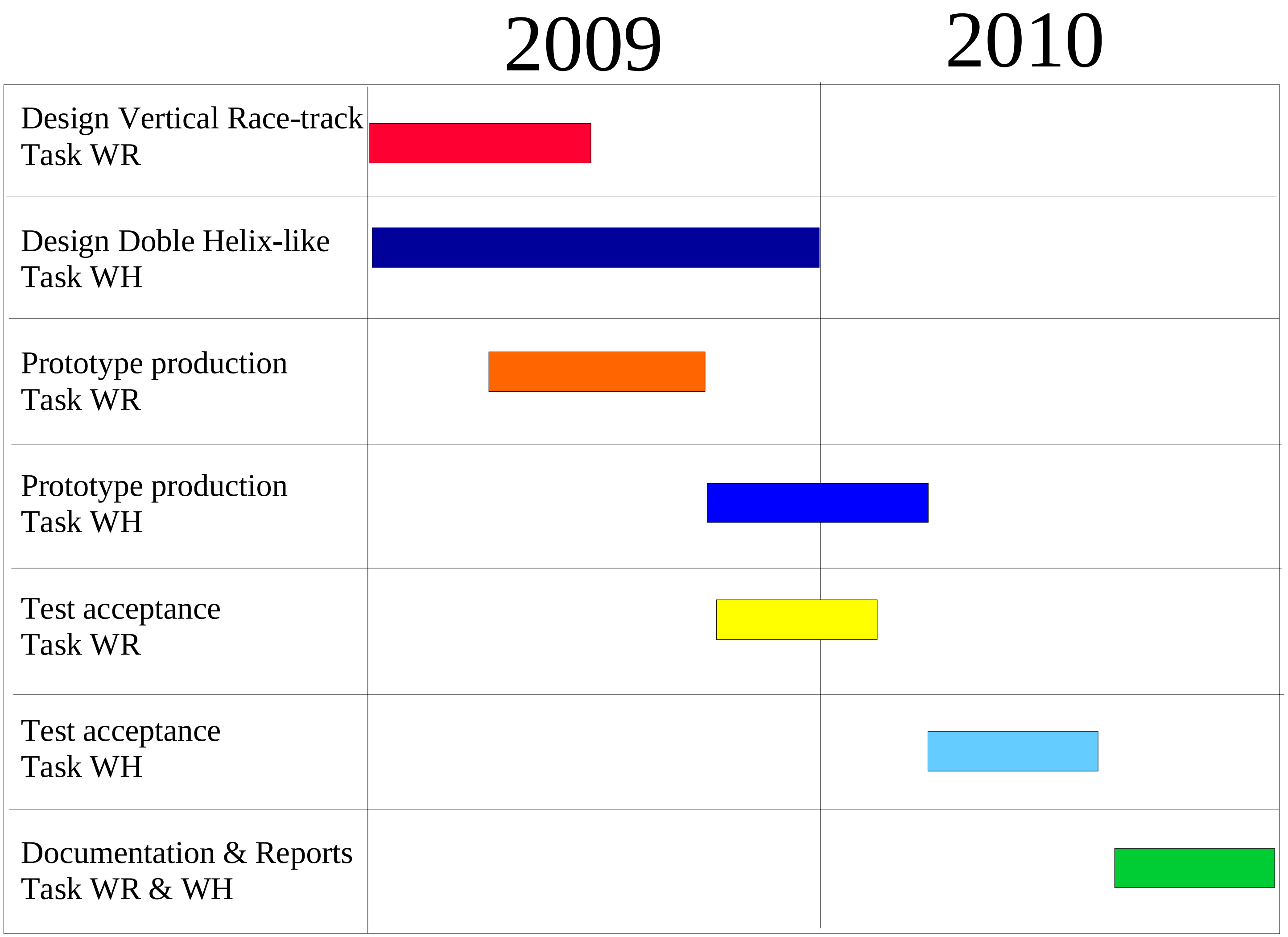
WR prototype (actual status)



WH prototype (actual status)



Planning


2009
2010
Design Vertical Race-track
Task WR
Design Doble Helix-like
Task WH
Prototype production
Task WR
Prototype production
Task WH
Test acceptance
Task WR
Test acceptance
Task WH
Documentation & Reports
Task WR & WH

Milestones

- End June 2009: Verticl race-track prototype (WR)design completed
- End October 2009 WR prototype production completed
- December 2009 Double Helix-like prototype (WH) design completed
- February 2009 WR test acceptance completed
- End April 2010 WH prototype production completed
- End June 2010 WH test acceptance completed
- End 2010 Documentation & final reports completed

Conclusions

- This project is a challenge as we try to push the SC performances to its limits.
- We are still trying to improve the assembly & winding techniques in particular for the WH wiggler type
- The use of Holmium should be implemented at least in the prototype phase despite its cost.

Thank You