CLIC Damping Rings Meeting, 3 December 2010

Cryogenics for the superconducting wigglers of the CLIC damping rings

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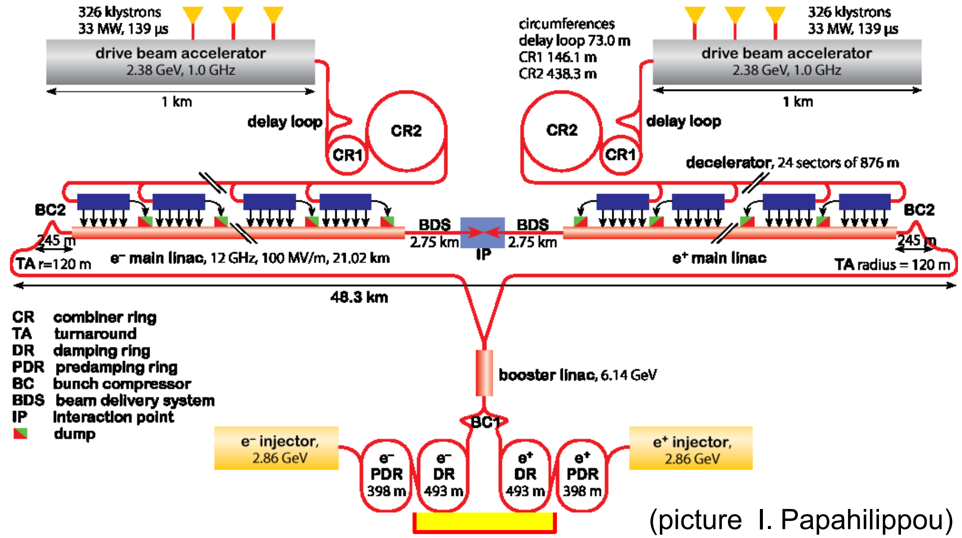
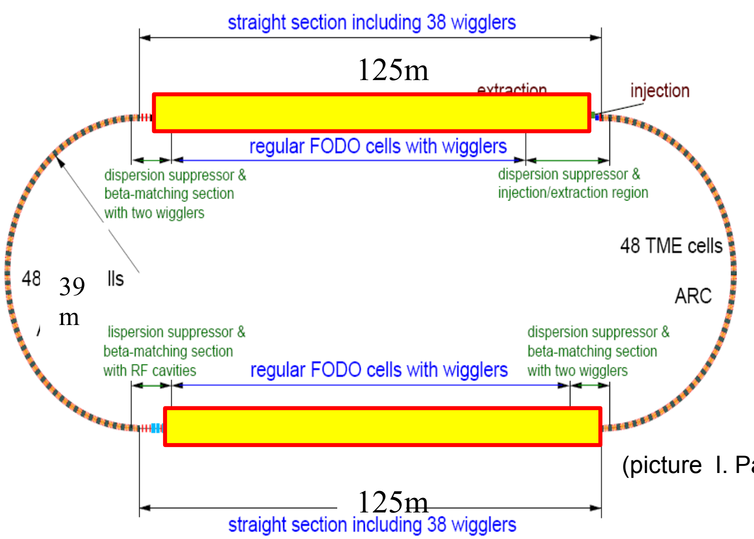
CLIC Damping Rings Cryogenics

CLIC damping rings requires superconducting wigglers to achieve the required emittance
(h: 500 nm, v: 5 nm, long. 5960 eVm)

Damping performed by emission of X-ray synchrotron radiation in SC wigglers (alternating field magnets)



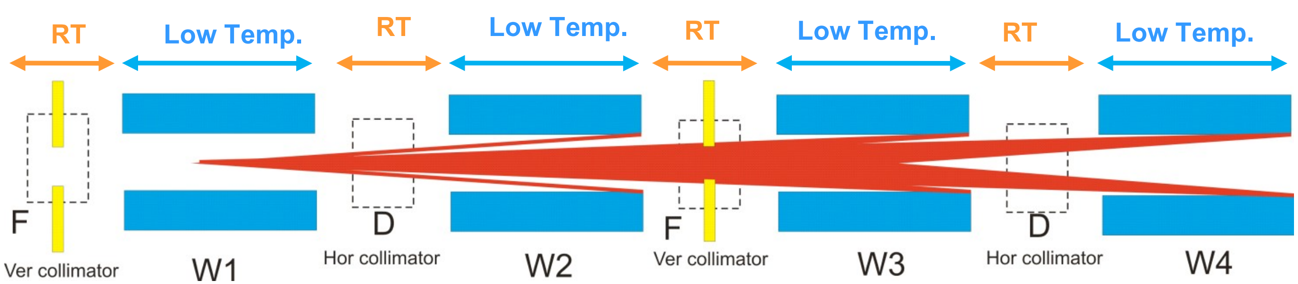
(picture I. Papahilippou)



(picture I. Papahilippou)

Characteristics

- succession of cells made of wiggler-collimator
- essentially synchrotron radiation heat load:
  - up to 10 kW dissipated into each collimator
  - peak 22 W/m – 26 W/m in the beam pipe walls

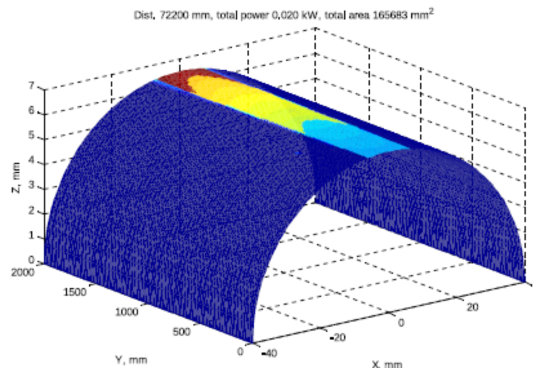


(picture I. Papahilippou)

Cooling the CLIC Damping Rings SC wigglers

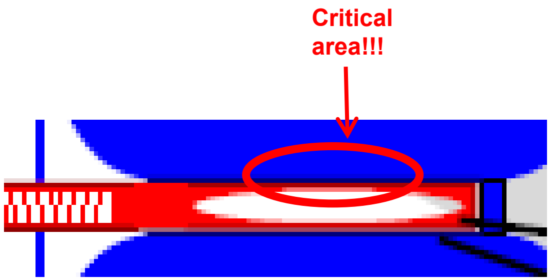
Temperature levels, heat extraction and cooling scheme

- the SC coils of the wigglers must be cold (<5 K)
- very low power on the coils, most power is on the beam pipes
- temperature limit driven by choice of SC material:
    - 4 K for NbTi
    - 5 K for Nb_3Sn
- Dynamic heat loads: 22 W/m – 26 W/m
- Total heat loads: 1’300 W / 1’500 W @ Temperature to be defined



Power deposition on beam pipes (picture D. Schoerling)

Main problem: extract localized heat load <u>in very close proximity of the coils</u> with very limited space available



Conceptual design of a wiggler cryostat (picture D. Schoerling)

System characteristics

- localized, small distance, few hundred meters
- horizontal, not deep underground
- low static heat load, essentially dynamic (beam induced) heat loads
- small power: < 2 kW @ 4.5 equivalent, cost < 8 MCHF, elec. power < 1 MW
- even 1.9 K superfluid helium would mean less than 2 MW , cost < 10 MCH
- choice of one cryoplant (no cryocoolers because of reliability), simple config.

The cryogenic system (cryoplants + fluids) is not a design driver !

(And probably also not a cost driver)

Heat extraction at low temperature with immersed magnets

	NbTi	Nb3Sn		1.9 K
SC Max temperature	4 K	5 K		2
He max. temperature	3.5 K	4.5 K		1.9
Max heat load on beam pipe	22 W/m	26 W/m		22 W/m
Total heat load on beam pipe / ring	1.3 kW	1.5 kW		1.3 kW
Tin / Tout / mf for ff cooling	3 K / 3.5 K / 1 kg/s	4.2 K / 4.5 K / 1 kg/s		-
Equiv. Power @4.5 K	1.9 kW	1.6 kW		6 kW
Est. Electrical power	500 kW	400 kW		1’500 kW
Est.cryoplant cost.	4 MCHF	3.5 MCHF		8 – 10 MCHF

Immersed magnets

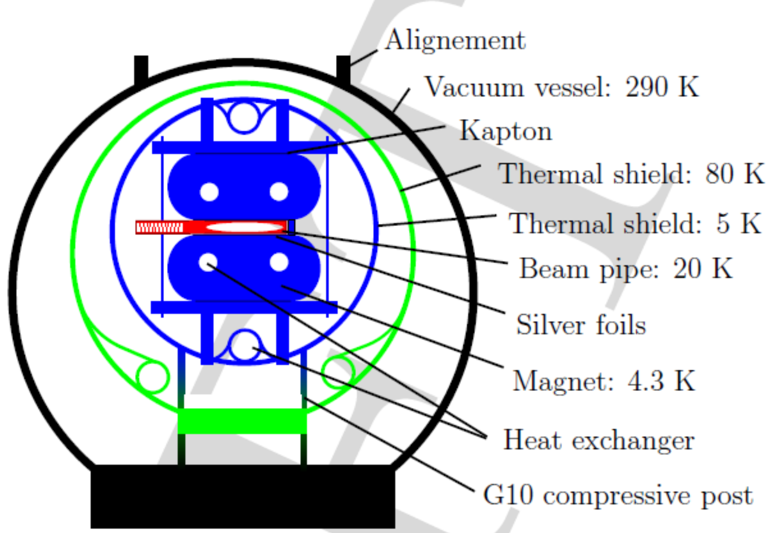
- design pressure of cold masses 10 bar
- cooling of 26 wigglers in series
- two variants (both like ATLAS / :
    - For NbTi: 3.5 K max outlet temperature. Forced flow cooling loop with subcooler and circulation pump.
    - For Nb3Sn: 4.5 K max outlet temperature. Forced flow cooling loop with subcooler and circulation pump

Heat extraction at intermediate temperatures

Thermally decouple the coils from heat source (beam pipe)

- introduce a vacuum gap between the beam pipe and the coils
- very reduced cryostat heat loads on the magnets
- no externat pressure on the beam pipe
- Nb3Sn wigglers
- Temperature levels
  - SC coil: 5 K
  - beam tube: 15 – 20 K (higher temperatures possible, possible with shielding…)

- several technological issues:
  - cooling, temperature gradients
  - interfaces, powering
  - SC splices, etc.

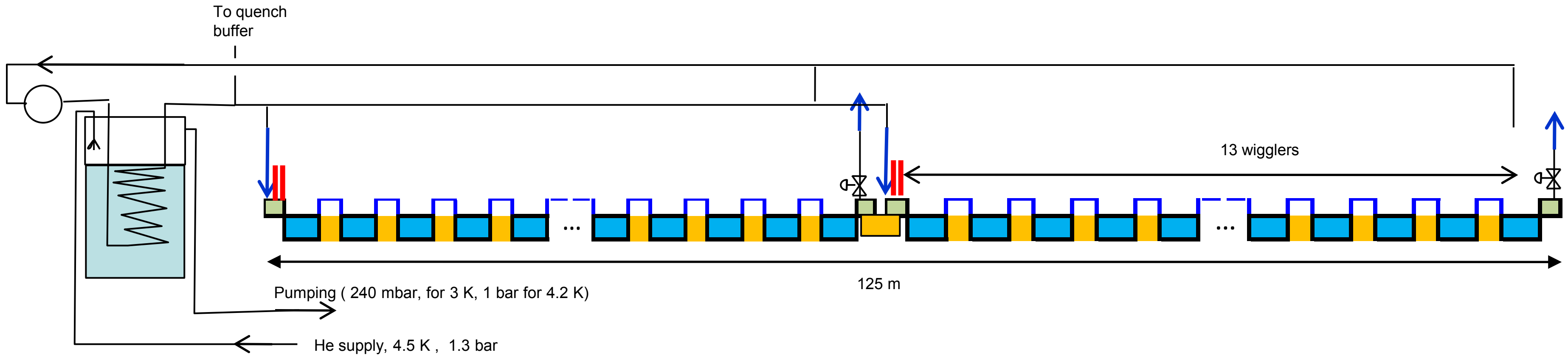


Conceptual design of a wiggler cryostat
(picture D. Schoerling)

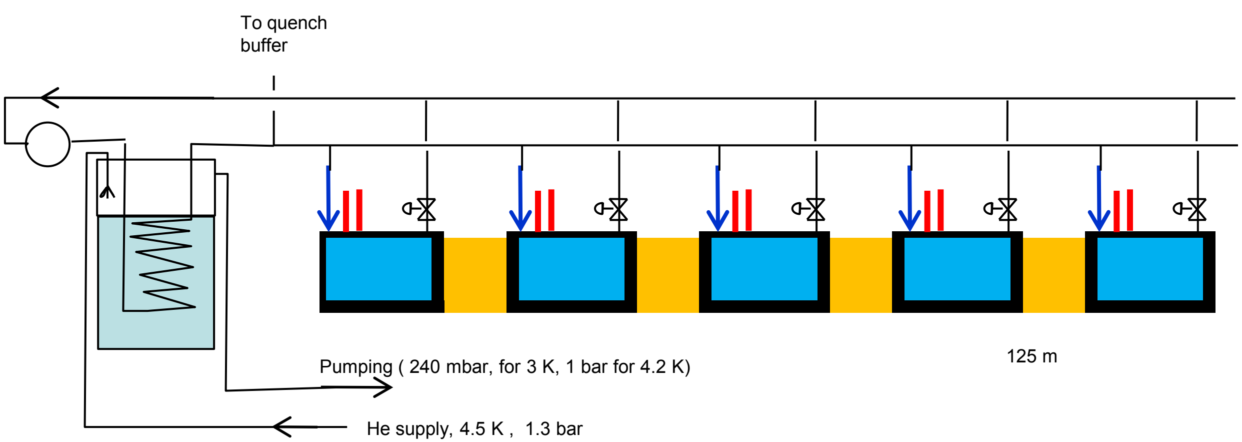
	« dry magnets »	
SC Max temperature	5 K	
Total heat load on beam pipe / ring @ 15 - 20 K	1.5 kW	
Mass flow for beam pipe cooling - equiv power	50 g/s - 0.4 kW	
Power @4.5 K	0.2 kW	
Tin / Tout / mf for magnet cooling	4 K / 4.5 K / 0.13 kg/s	
Total equiv. Power @ 4.5 K	0.6 kW	
Est. Electrical power	150 kW	
Est.cryoplant cost.	2 MCHF	

Cooling the wigglers with forced flow SC helium

Series cooling / powering (no beam screen, not optimized, no current leads, no geometry represented)
- forced flow cooling, subcooled liquid helium
- no beam screen



Smaller granularity



Cryogenic / electrical layout comparison

	Advantages	Disadvantages
Series cooling / powering	- simpler from cryogenic point of view - reduced number of valves - lower heat loads - only one/two feedboxes - reduced number of current leads - limited number of powering and protection equipment	- temperature gradient - more difficult debugging - more difficult leak detection - higher mass flow / pressure drop - collective commissioning - higher voltages, - longer repair times in case of problems - commissioning only at end - need of cryo/electrical jumper
Group cooling / powering	- same as series , but possible to mitigate with group of magnets - more modular than full series	- same as series - added complexity of sectorization
Individual cooling /powering	-Installation as complete unit - lower voltages - lower pressure drop - can be fully tested and commissioned individually - « easy » repair / replacement - no need of cryo/electrical jumper - pool boiling easier	- Many current leads - large number of powering and protection equipment - large number of cryo jumpers to cryo distribution. Large number of valves. -

Cryo-related technical issues to be investigated (with prototype ?)

	Forced flow cooling Immersed magnets	Conduction cooled magnets
Layout / configuration	- distribution of fluids (N) - pressure drop (**Y**) - cool down studies (Y) - feedboxes (Y)	- distribution of fluids (N) - pressure drop (**Y**) - cool down studies (Y) - feedboxes (Y)
Heat extraction	- Design of the beam pipe and cooling piping	-Design of the cooling channels
Cryostat design	- Design of cryo / electrical jumpers (Y)	- Design of cryo / electrical jumpers (Y) - current leads (Y) - busbar connections (Y)
Quench behaviour	- Pressure increase, recooling (Y)	- pressure increase, recooling (Y) - behaviour of busbars (Y)
Etc.	Etc.	Etc.

(Y) Significant knowledge to be gained with possible from ANKA / Prototype

(N) Little knowledge from prototype / ANKA

What cooling system for ANKA / prototype?

	Pool boiling 4.5 K	Forced flow immersed	Conduction cooled
Equiv. Power @4.5 K	100 W -200 W	100 W – 200 W	100 W
Est. Electrical power	30 kW – 60 kW	30 kW – 60 kW	30 kW
Est.cryoplant cost.	1 MCHF	1 MCHF	1 MCHF
Comments	-Simplest from cryogenic point of view - no flexibility - little investigation possible - probably not representative of CLIC DR	- may require circulating pump - representative of CLIC DR	- more complex system -representative of CLIC DR - Use cryocooler?

Configuration recommendations

- cryostat: shall be representative of as many elements as practically possible:
    - current leads feedboxes
    - cryo and electrical jumpers
    - electrical connections
    - supports, cold-warm transitions, etc.
    - etc.

Conclusions

The global cryogenic powers to be extracted are in well known range. No particular problem for the cryoplants is foreseen for all envisaged configurations

Main problem: extract localized heat load in very close proximity of the coils with very limited space available

The beam pipe cooling configuration shall be chosen to optimize the CLIC performance (magnet, vacuum, etc.) . Cryogenics complexity appears to be manageable for all envisaged configurations.

The overall layout is be chosen taking into account cost/complexity/testing/commissioning.

The cooling configuration for the ANKA/prototype shall be defined in order to go to a more detailed definition of the cryogenics.

For the ANKA / prototype the cryogenic cryostat configuration shall ideally be as representative as possible to a possible CLIC configuration.