Cryostat 5 K Thermal Shield -- CERN and DESY Experience

T. Peterson

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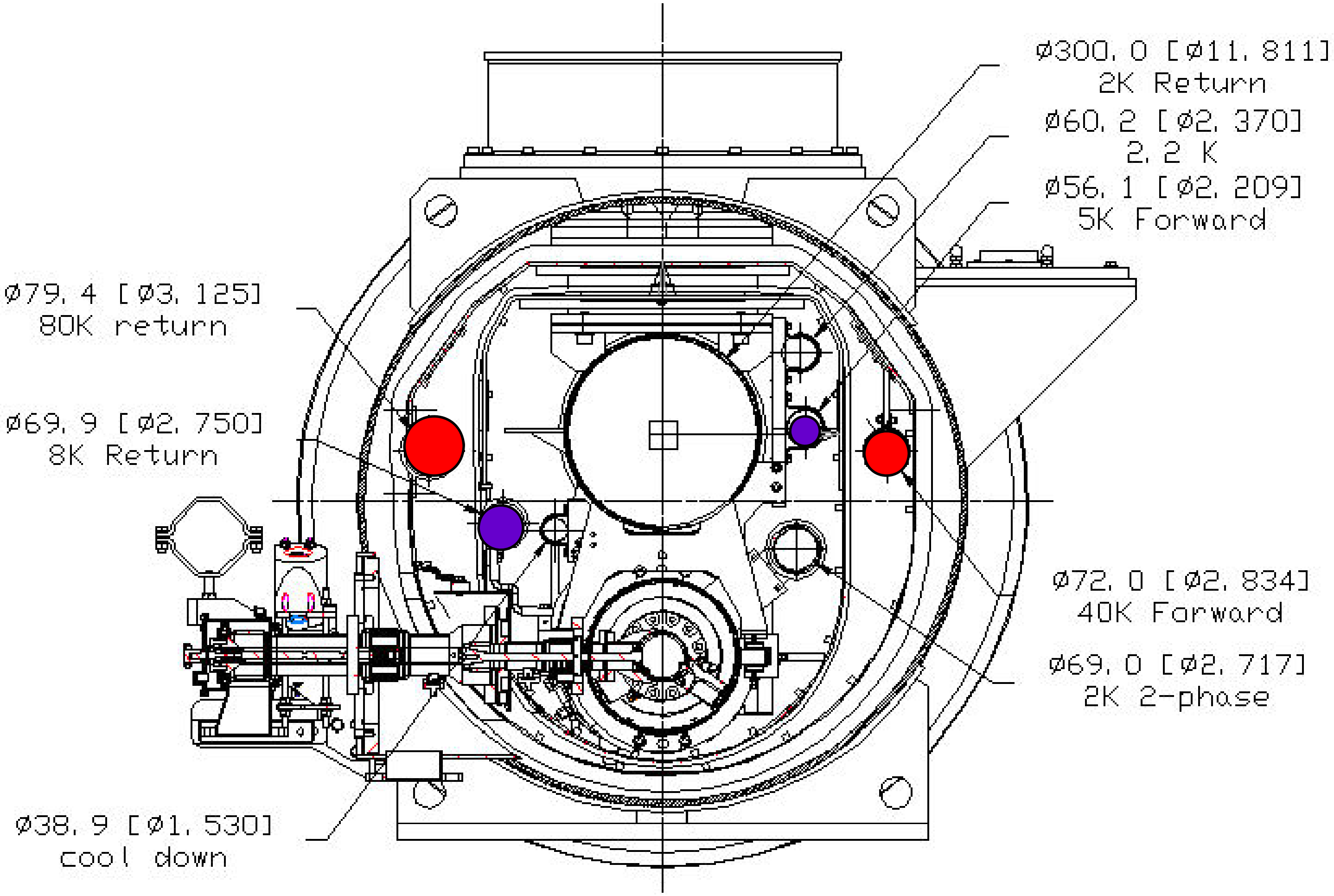
Introduction

- LHC: we heard from Laurent Tavian and Alain Poncet of CERN at a Webex meeting on 7 Feb 2008
  - **CERN did a cost-benefit analysis in 1998-1999 and decided not to include an active 5 K thermal shield in the LHC dipole magnets**
- DESY TTF cryomodules include a 5 K thermal shield
  - **We heard from Paolo Pierini and Norihito Ohuchi about analyses of 5 K thermal shield trade-offs. I will just provide a few comments from Paolo's 7 Feb talk.**
- Talks and related documents for cryomodule thermal optimization have been placed at http://tdserver1.fnal.gov/peterson/tom/Thermal-Cost-Optimization/CryomoduleOptimization.html

Type 4 cryomodule



2 K ILC heat load estimate

Heat load per cryomodule

Temperature Level	TESLA 2K		ILC 2K		
RF load		4.95		7.46	Dynamic load scaled by the number of cavities and Gfac
Supports	0.60		0.60	-	Assume independent of nuimber of cavities
Input coupler	0.76	0.14	0.55	0.16	Static load scaled by number of cavities, dynamic by Pfac also
HOM coupler (cables)	0.01	0.27	0.01	0.18	Static and dynamic load scaled by number of cavities, dynamic by Cfac also
HOM absorber	0.14	0.02	0.14	0.01	Dynamic load scaled by Bfac
Beam tube bellows		0.24		0.36	Dynamic load scaled by the number of cavities and Gfac
Current leads	0.04		0.28	0.28	Weigh by a factor of 1/3 since only 1 in 3 modules have quads**
HOM to structure		1.68		1.20	Static load scaled by the number of cavities, dynamic by Bfac also
Coax cable (4)	0.05		0.05		Assume indepent of nuimber of cavities
Instrumentation taps	0.07		0.07		Assume indepent of nuimber of cavities
Scales as Gfac		**5.19**		**7.83**	
Scales as Pfac		**0.14**		**0.16**	
Independent of G,Tf	**1.67**	**1.97**	**1.70**	**1.68**	
Static, dynamic sum	**1.67**	**7.30**	**1.70**	**9.66**	Total for 9-8-9 RF unit below
2K Sum [W]	**9.0**		**11.4**		34.08

Total for one cavity

1.00 1.3107

5 K, 40 K ILC heat load estimates

Heat load per cryomodule

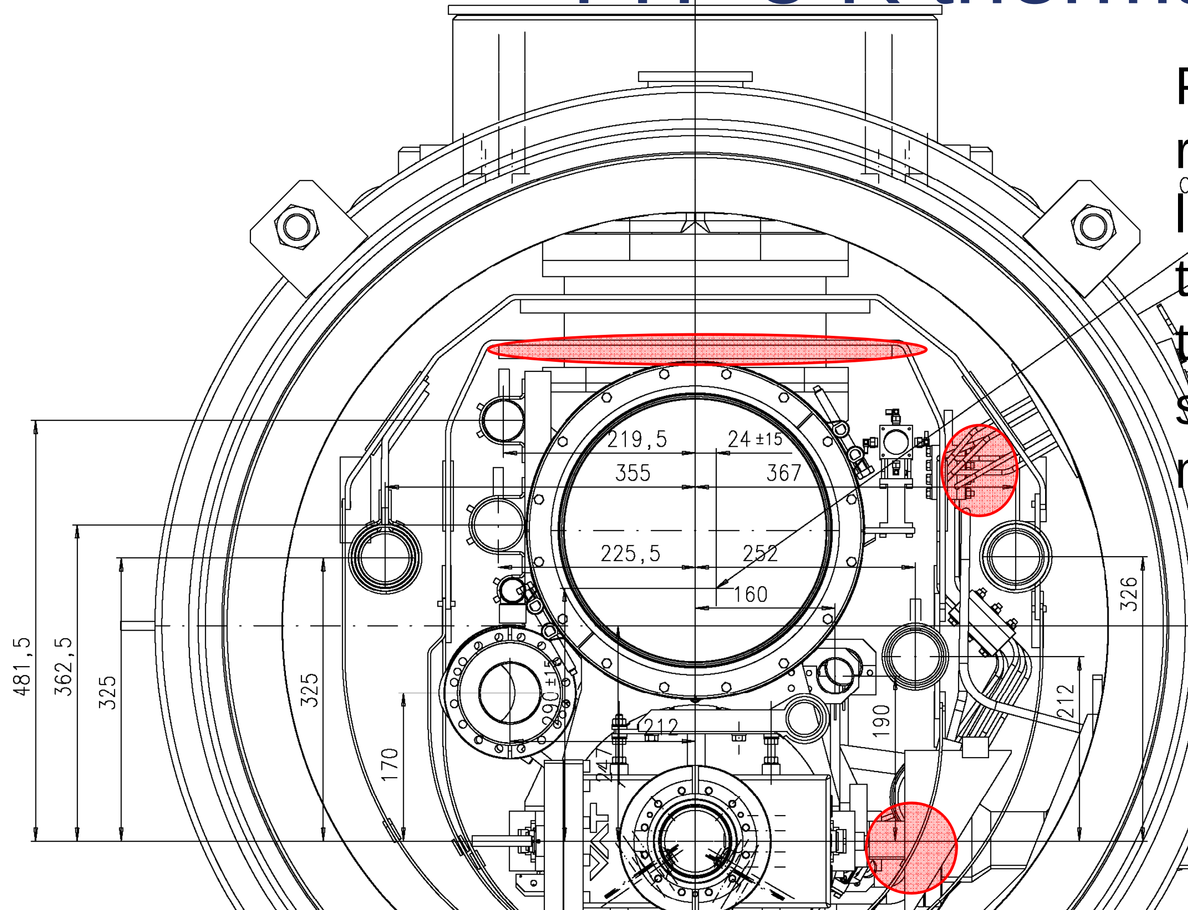
	TESLA		ILC		
	5K		5K		
Radiation	1.95		1.83		1.83 from KEK analysis
Supports	2.40		2.40		Assume indepent of nuimber of cavities
Input coupler	2.05	1.19	1.48	1.32	Static load scaled by number of cavities, dynamic by Pfac also
HOM coupler (cables)	0.40	2.66	0.29	1.82	Static and dynamic load scaled by number of cavities, dynamic by Cfac alsc
HOM absorber	3.13	0.77	3.13	0.76	Dynamic load scaled by Bfac
Current leads			0.47	0.47	Weigh by a factor of 1/3 since only 1 in 3 modules have quads**
Diagnostic cable	1.39	-	1.39	-	Assume independent of nuimber of cavities
Scales as Pfac		**1.19**		**1.32**	
Independent of G,Tf	**11.32**	**3.43**	**10.99**	**3.04**	
Static, dynamic sum	**11.32**	**4.62**	**10.99**	**4.37**	Total for 9-8-9 RF unit below
5K Sum [W]	**15.9**		**15.4**		46.06
	40K		40K		
Radiation	44.99		32.49		Static load scaled by number of cavities
Supports	6.00		6.00		Assume indepent of nuimber of cavities
Input coupler	21.48	59.40	15.51	66.08	Static load scaled by number of cavities, dynamic by Pfac also
HOM coupler (cables)	2.55	13.22	1.84	9.04	Static and dynamic load scaled by number of cavities, dynamic by Cfac alsc
HOM absorber	(3.27)	15.27	(3.27)	15.04	Dynamic load scaled by Bfac
Current leads			4.13	4.13	Weigh by a factor of 1/3 since only 1 in 3 modules have quads**
Diagnostic cable	2.48		2.48		Assume indepent of nuimber of cavities
Scales as Pfac		**59.40**		**66.08**	
Independent of G,Tf	**74.23**	**28.49**	**59.19**	**28.22**	
Static, dynamic sum	**74.23**	**87.89**	**59.19**	**94.30**	Total for 9-8-9 RF unit below
40K Sum [W]	**162.1**		**153.5**		460.46

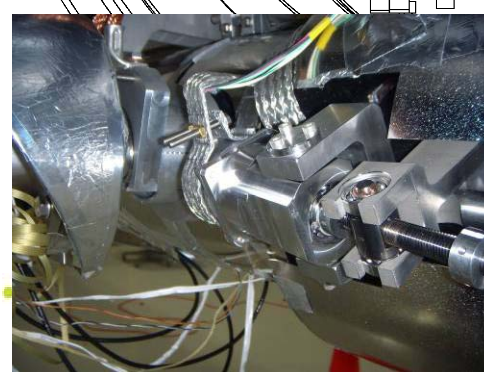
CERN/LHC summary

- An active 5 Kelvin thermal shield reduces refrigeration capital costs by about 240 CHF/meter of magnet string length.
  - **Would translate to about 2880 CHF refrigerator savings per cryomodule**
- Operating cost savings over ten years are about 250 CHF/m of magnets.
  - **3000 CHF operating cost savings over 10 years per cryomodule**
- The study in 1998-9 concluded that “the 5 K shield . . . can be expected to pay for itself in 8 to 10 years of LHC operation.”
- Overall conclusion: “In order to limit the investment, and for reasons of simplicity it was proposed to retain the Yellow Book reference design without an actively cooled 5 K shield.”

TTF 5 K thermal anchors

Paolo Pierini of INFN reminded us of the locations of the various thermal intercepts and the value of the thermal shield as a conductive manifold.





5 K shield

INFN comments

- With removal of 5 K shield, for radiative load to 2 K consider factor of 2 increase due to the following issues:
  - **Taking out 5 K shield how many layers of MLI?**
  - **What shielding efficiency?**
- If only radiation flow is taken into 2 K (including factor 2 increase for worse MLI protection) and all conduction intercepted
  - **Plug power increased by 15%**
  - **5K thermalizaton for 3 posts, 8-9 couplers, HOM, leads, cables**

Conclusions 1

- CERN's decision not to include the active 5 K thermal shield was decided not by the economics, which were moderately in favor of the 5 K shield, but by the status of the project at the time of the decision (1998-1999).
- CERN had a design without an active screen, and the space into which to add the screen was very tight. There was a desire to keep the cryostat simpler, other things being equal.

Conclusions 2

- An amplification of the cost savings from removing the 5 K thermal shield could come from reduction of the vacuum vessel diameter. Norihito Ohuchi is exploring this option.
- Two issues were raised, however.
  - **One is the stiffness of the vacuum vessel, which is important for cavity and magnet alignment and stability.**
  - **The other is space at the interconnects which is needed not only for the larger outer diameter of bellows but also for automatic welding and cutting of pipes.**
- Studies at INFN and KEK continue with some help and input from Fermilab