Cryogenic and safety design of the future High Field Cable Test Facility at Fermilab

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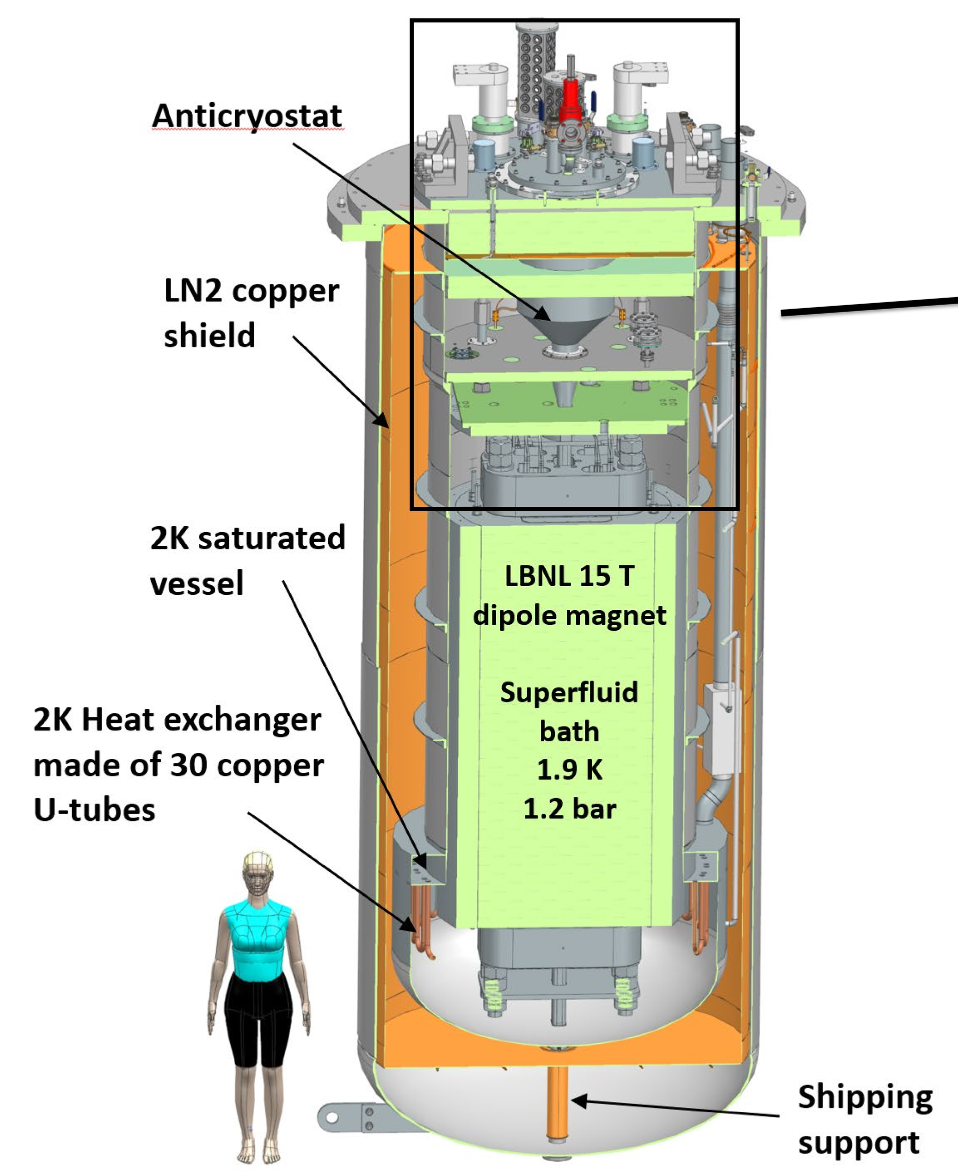
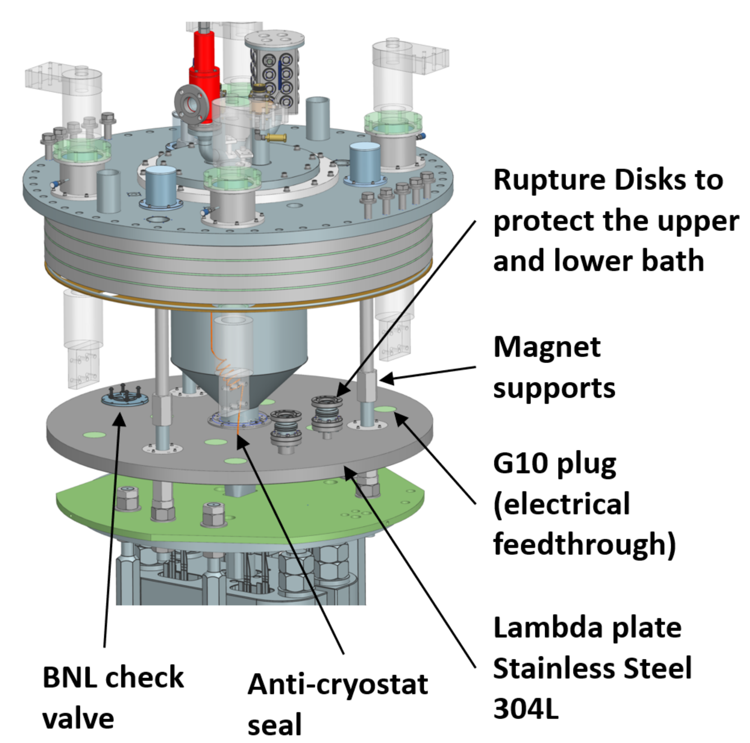
C1Po2D-05
FERMILAB-POSTER-23-143-TD

Overview of the test facility

High Field Vertical Magnet Test Facility (HFVMTF) is a new test stand installed at Fermilab to characterize future superconducting magnet and HTS cables for fusion. The HFVMTF cryostat is a large double-bath vessel with a lambda plate that separates the 4.5 K normal liquid helium on the upper section from the pressurized superfluid helium at 1.9 K and 1.2 bar. The maximum design pressure of this vessel is 6.9 bar. The pressurized superfluid bath will host a 25 tons magnet with a maximum diameter of 1.4 m and a maximum length of 3 m.



Overview of the HFVMTF test facility



Top and Lambda plate assembly

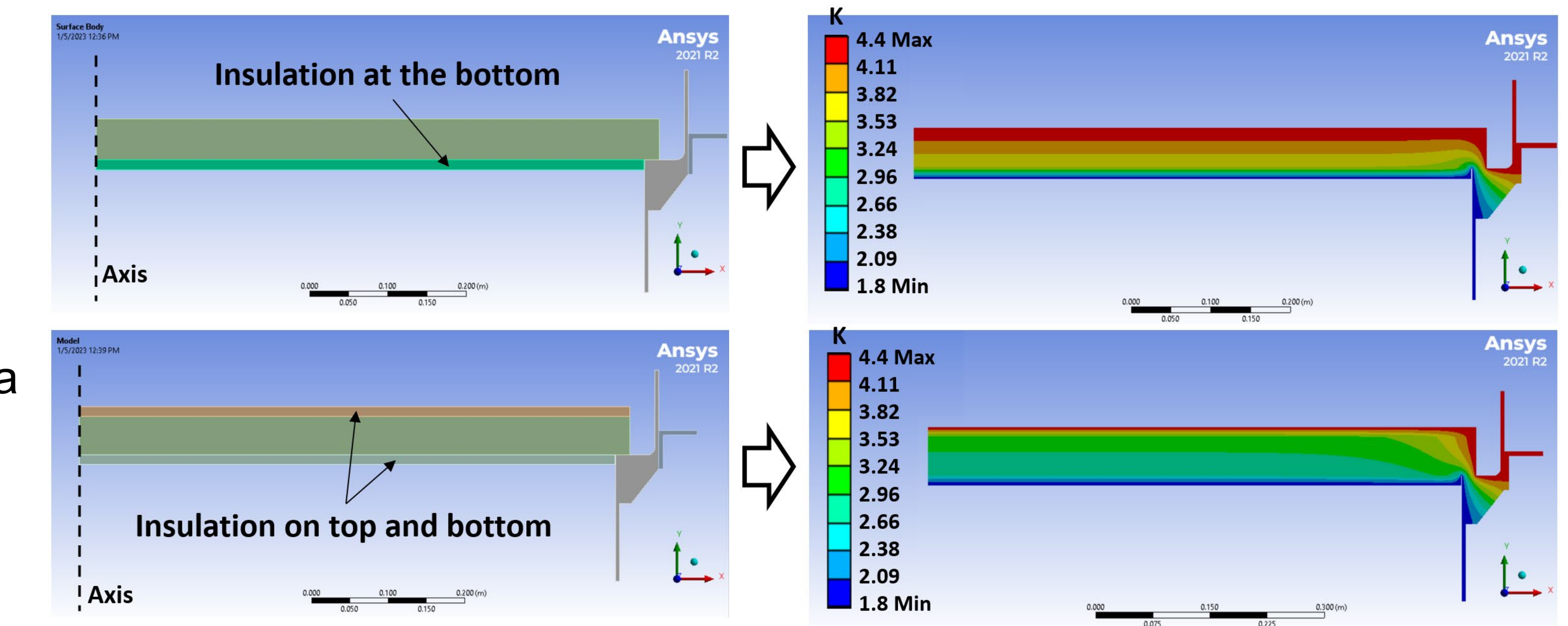
Lambda plate characteristics:

- 304L stainless steel 50 mm thick plate
- 1.4 m diameter energized seal (minimum 8 tons to seal the plate)
- 1 Check valve and 2 rupture disks to protect the helium vessel

Thermal analysis of the lambda plate

Lambda plate insulation:

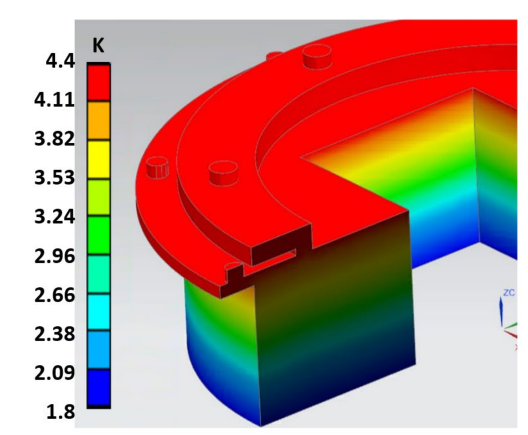
- **G10** or **PEEK GF30** considered - low thermal conductivity and similar thermo-contraction to stainless steel
- Thermal FEA performed to test multiple insulation configurations (on top of the lambda plate, on the bottom,…)
- Best configuration with the insulation on top and bottom of the lambda plate: **3.6 W** using G10 against **20 W** without insulation



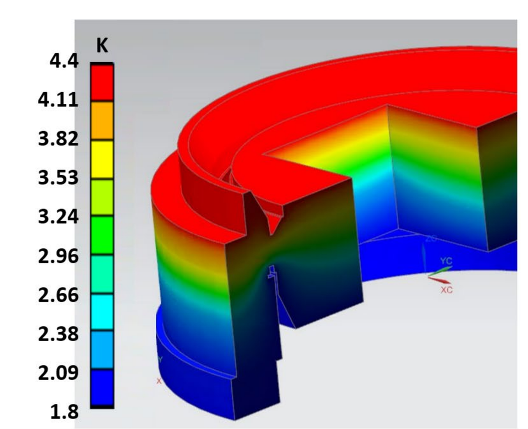
Thermal FEA of the Lambda plate

Anticryostat sealing:

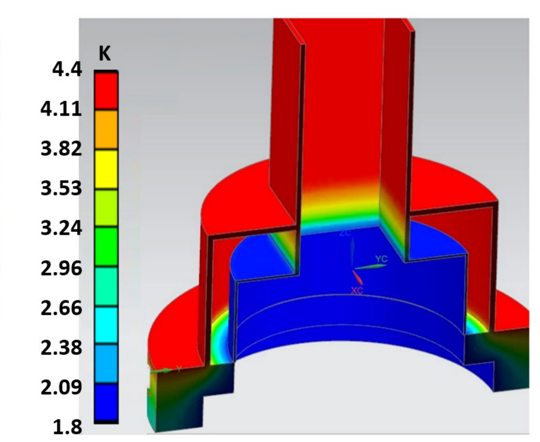
- Thermal FEA performed to test multiple sealing solutions for the anticryostat
- Best configuration using the **PTFE (Teflon®) plug** solution: **0.2 W**, against 0.33 W for the Energized seal and 0.66 for the CF flange



PTFE Plug



Spring Energized Seal



CF Flange Seal

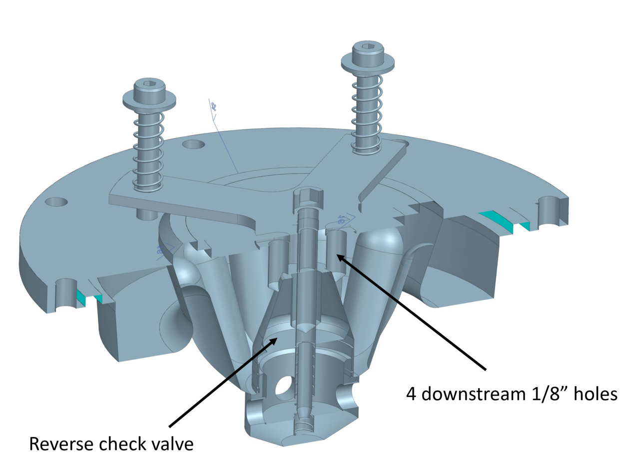
Summary of the 2K Total heat loads:

	Heat load on 2K bath (W)	Cooling capacity at 2K (%)
Lambda plate insulation	3.6	5
BNL check valve	0.51	0.71
1" Rupture Disk	0.78	1.08
2" Rupture Disk	2.22	3.08
3 magnet supports	0.048	0.07
4 Regular feedthrough	0.04	0.06
4 Feedthrough with current leads	5.2	7.22
Anti-cryostat seal	0.195	0.27
Total	**12.59**	**17.49**

Safety analysis of the lambda plate

Brookhaven National Laboratory (BNL) check valve:

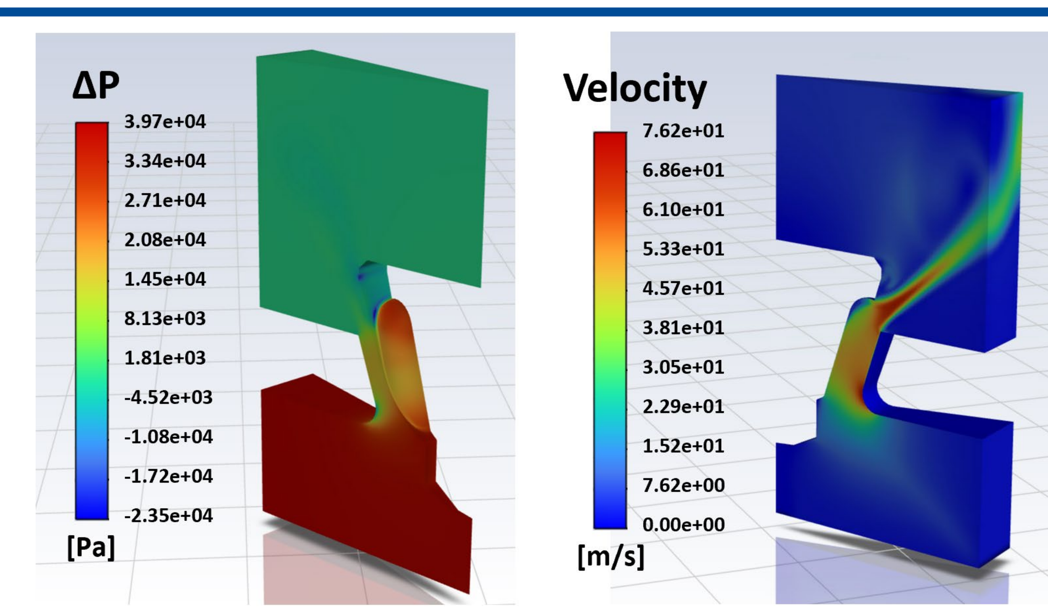
- Composed of **two check valves**
- The larger valve is made of Teflon and protects the superfluid bath from over-pressure during the quench of the magnet
- CFD analysis performed to calculated the maximum pressure drop through the valve during the quench (and vacuum break)
- Maximum pressure difference of **0.41 bar**



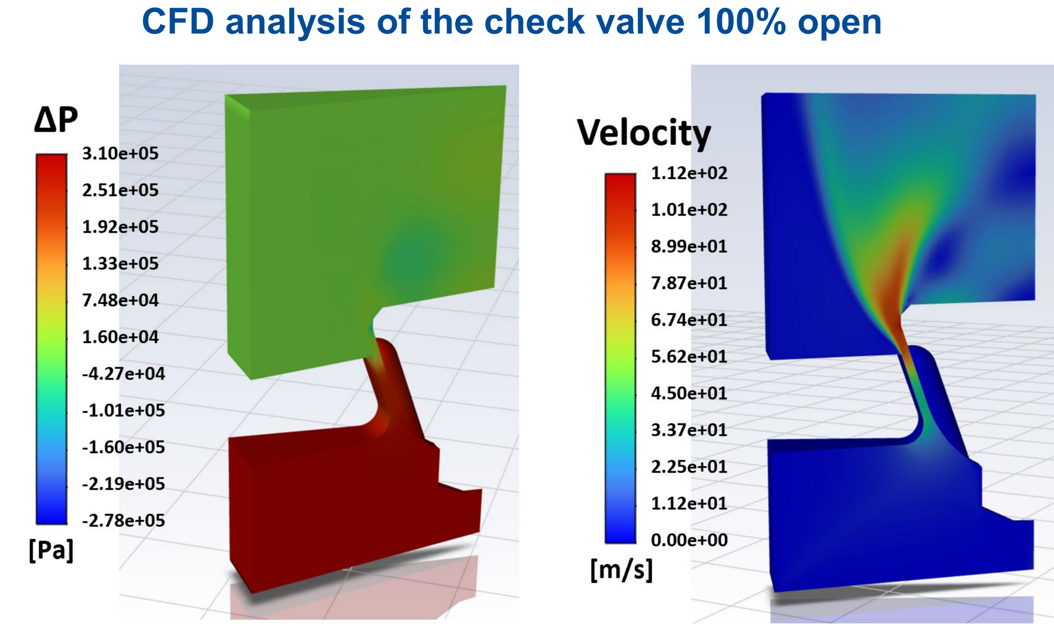
BNL Double check valve

Results of the CFD analysis of the check valve

			100% Open		50% Open	
	Mass flow (kg/s)	Downstream conditions	Upward force (N)	DeltaP (bar)	Upward force (N)	DeltaP (bar)
Quench of the magnet	2.09	4.21 K & 1 bar	144	0.391	**1528**	**3.07**
	3.47	5.3 K & 2.3 bars	151.99	0.412	**1610**	**3.23**
	1.79	7.55 K & 6 bars	28.24	0.077	**305**	**0.61**
Vacuum break	4.21	8 K & 7.3 bars	149.42	0.392	**1521**	**3.05**
Cool down	0.03	300 K & 1 bar	3.11	0.009	**35.07**	**0.07**



CFD analysis of the check valve 100% open



CFD analysis of the check valve 50% open

Reverse check valve:

- Smaller and locate inside the other valve
- Accommodates the pressure between the two baths during the cool down be-tween 4.5 K and 1.9 K
- Minimum mass flow of **76 g/s** through the reverse check valve (10 g/s maximum supply)

Maximum mass flow through the reverse check valve during the cooldown

Tin (K)	Pin (bar)	Pout (bar)	Max flow (g/s)
4.4	1.2	1.1	**76.5**
4.4	1.2	1	**105.8**
4.4	1.2	0.9	**126.4**

1” and 2” Rupture disk:

- Burst pressure of **1 bar**
- Maximum mass flow of 4.3 kg/s in case of a vacuum break (induce the quench of the magnet)
- 2” rupture disk required to protect the lower (superfluid) bath during worst case scenario (vacuum break)
- 1” rupture disk required to protect the upper helium bath considering 70 g/s of helium at 80 K (maximum mass flow through the helium supply valve)

Required diameters for the two rupture disk

Rupture Disk	Protect the Lower Bath	Protect the Upper Bath	
Maximum mass flow (g/s)	**4250 (Vacuum break event)**	**70**	
Burst pressure (bar)	1	1	
Backpressure (bar)	6.89	1	
Relief temperature (K)	8.3	5.1 (gas)	80
Required Diameter (mm)	**50**	**7.45**	**20.7**

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.