Mu2e Calorimeter: cooling

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L3 Mechanics

INFN Pisa

09 September 2020

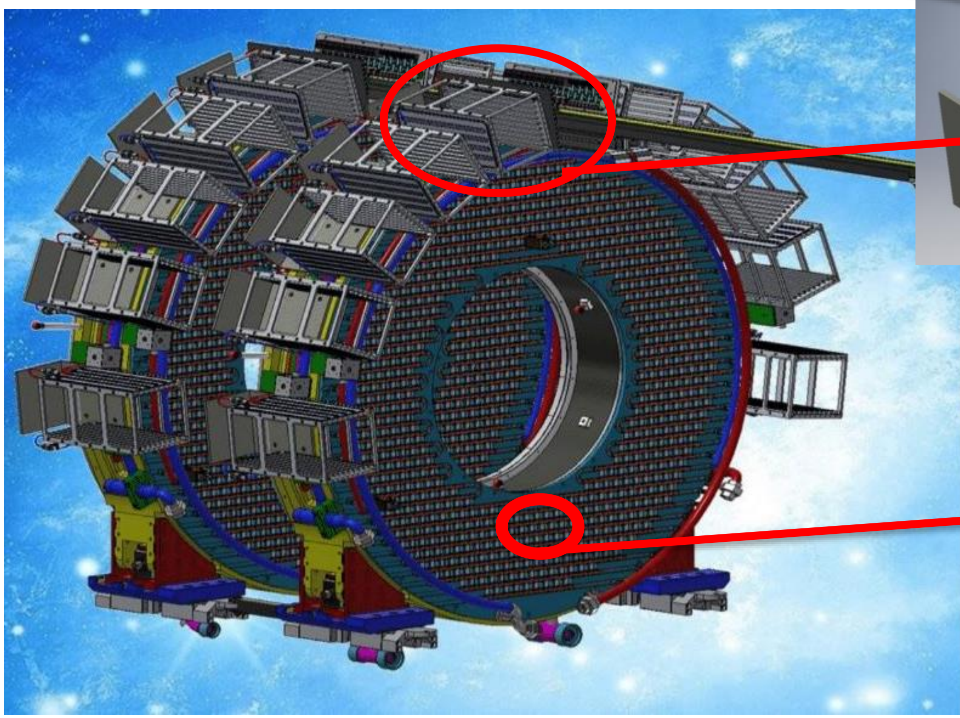
Update calorimeter cooling.

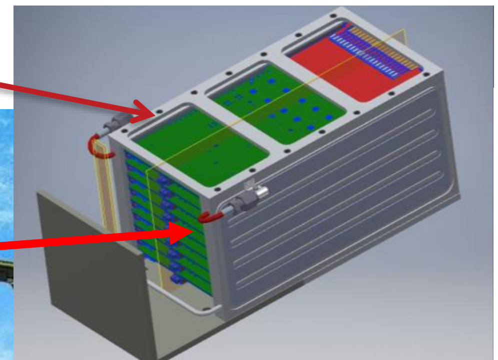
- Overview of calorimeter cooling.
- New SIPM temperature requirement.
- A preparation of the specification of the cooling plant.
- Cooling test at Pisa.
- Conclusions

Cooling system overview

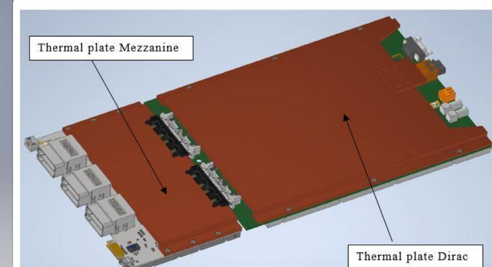
- The power dissipated in the calorimeter are in two main areas:
- On the Back plate (SIPMs and pre-amplifiers)
- On the outside perimeter of the calorimeter ring (10 DAQ crates).

Integrate cooling channel in the lateral wall

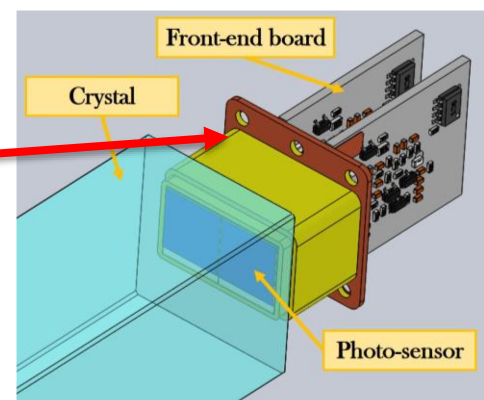




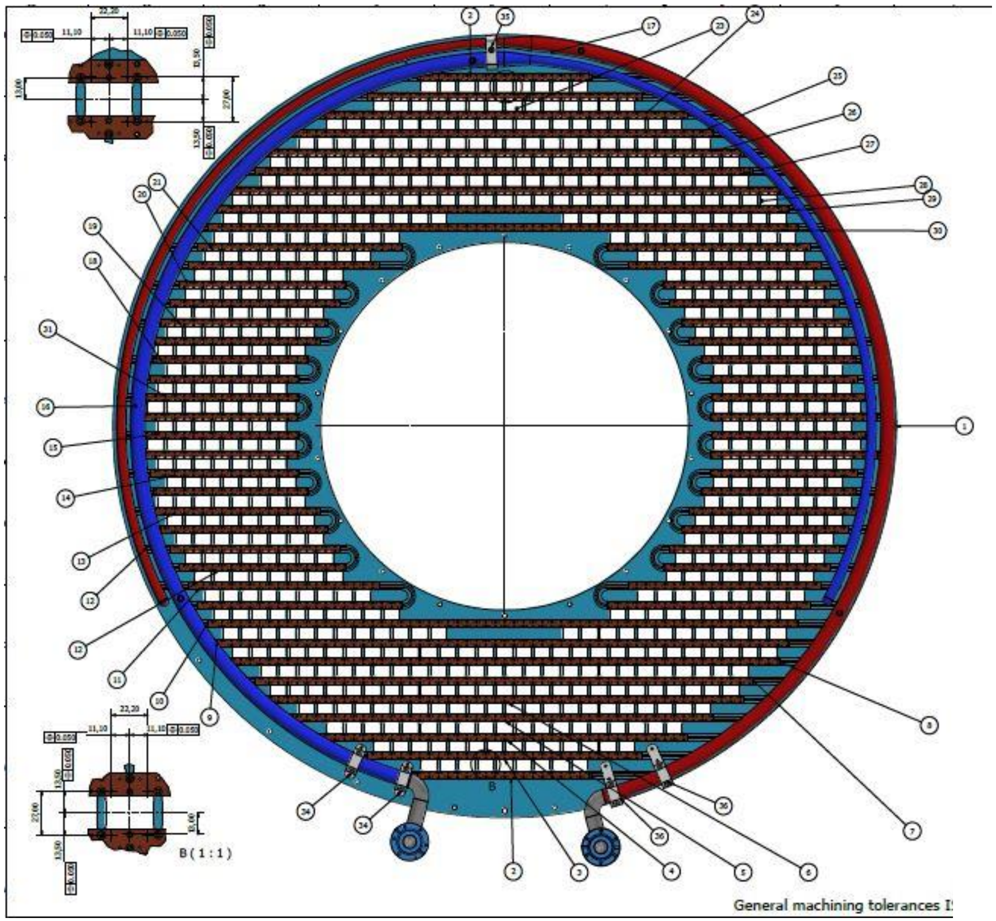
Dirac and mezzanine

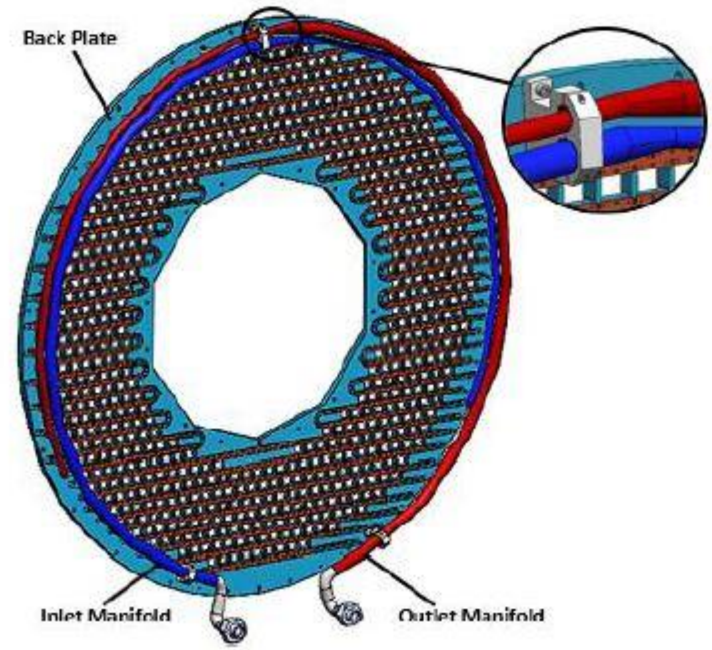


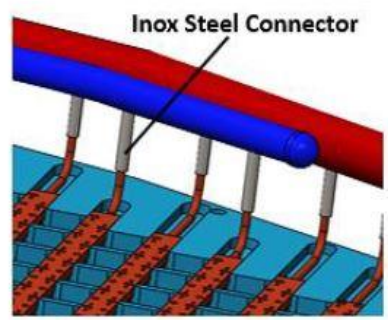
Front-end

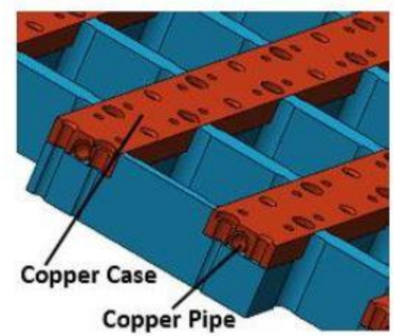


Cooling system overview



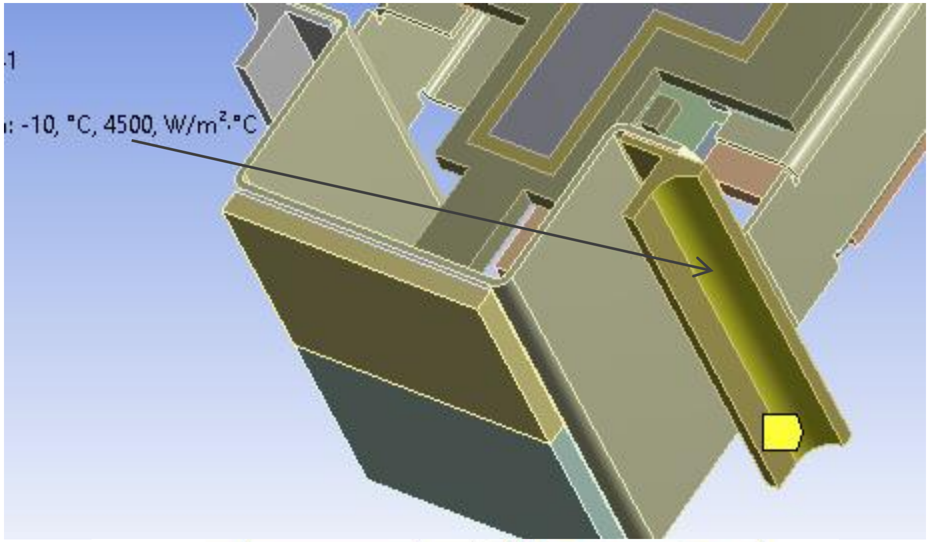


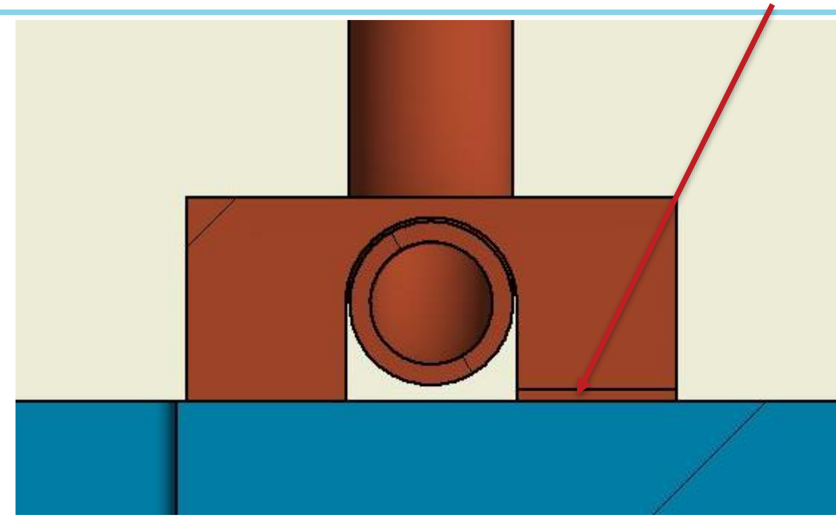


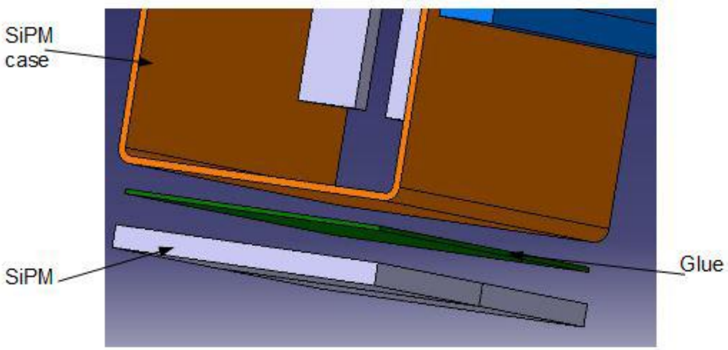


Mu2e SIPM FEM details

Reduce contact with the plate



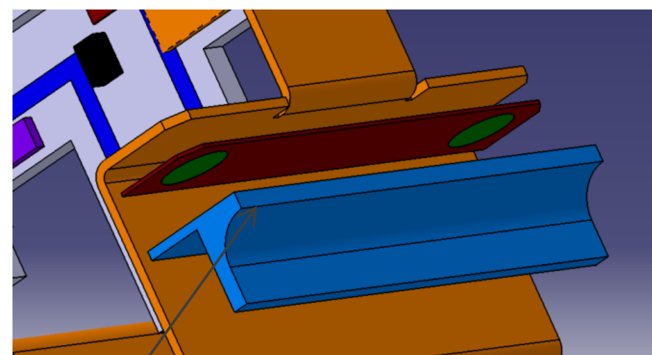




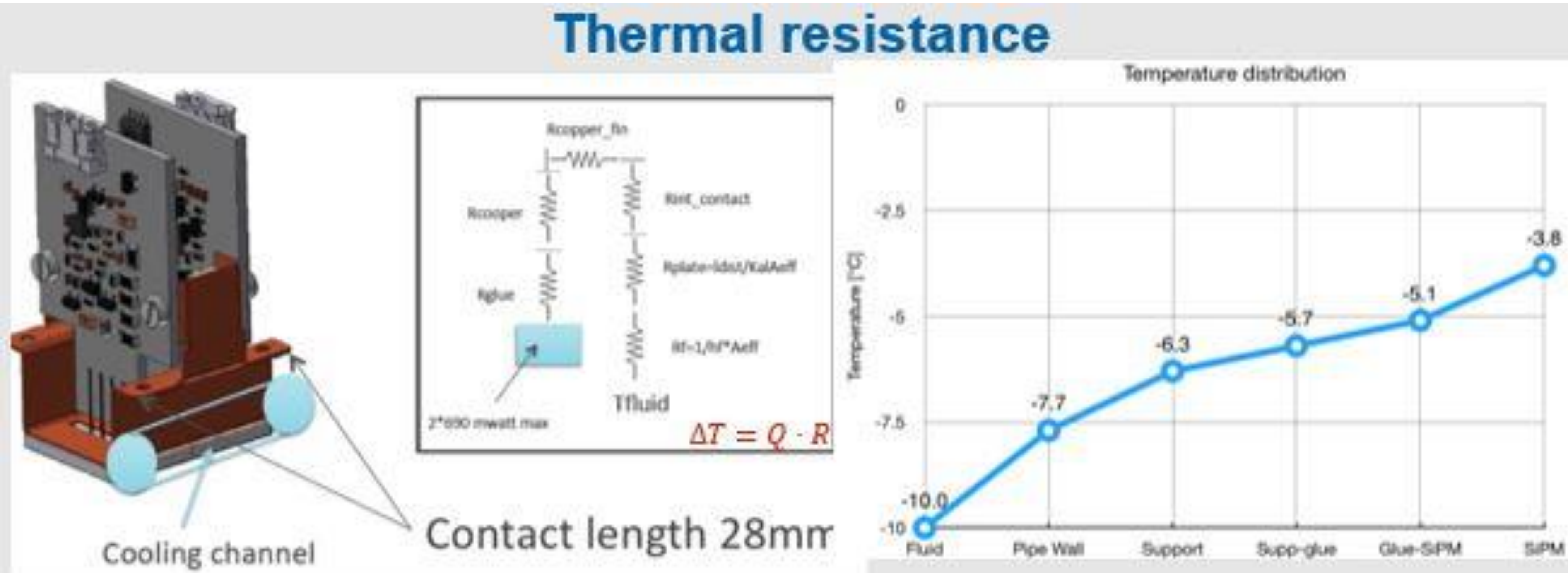
Realist model respected the adopted solution

The pressure is assure by M2.5 property class 70 that can be preload at 250 Newton considering that the thread is on cooper. So an average pressure di 25 Mpa

Rint=0.01 m^2 k/kwatt



Gasket to simulate the thermal contact

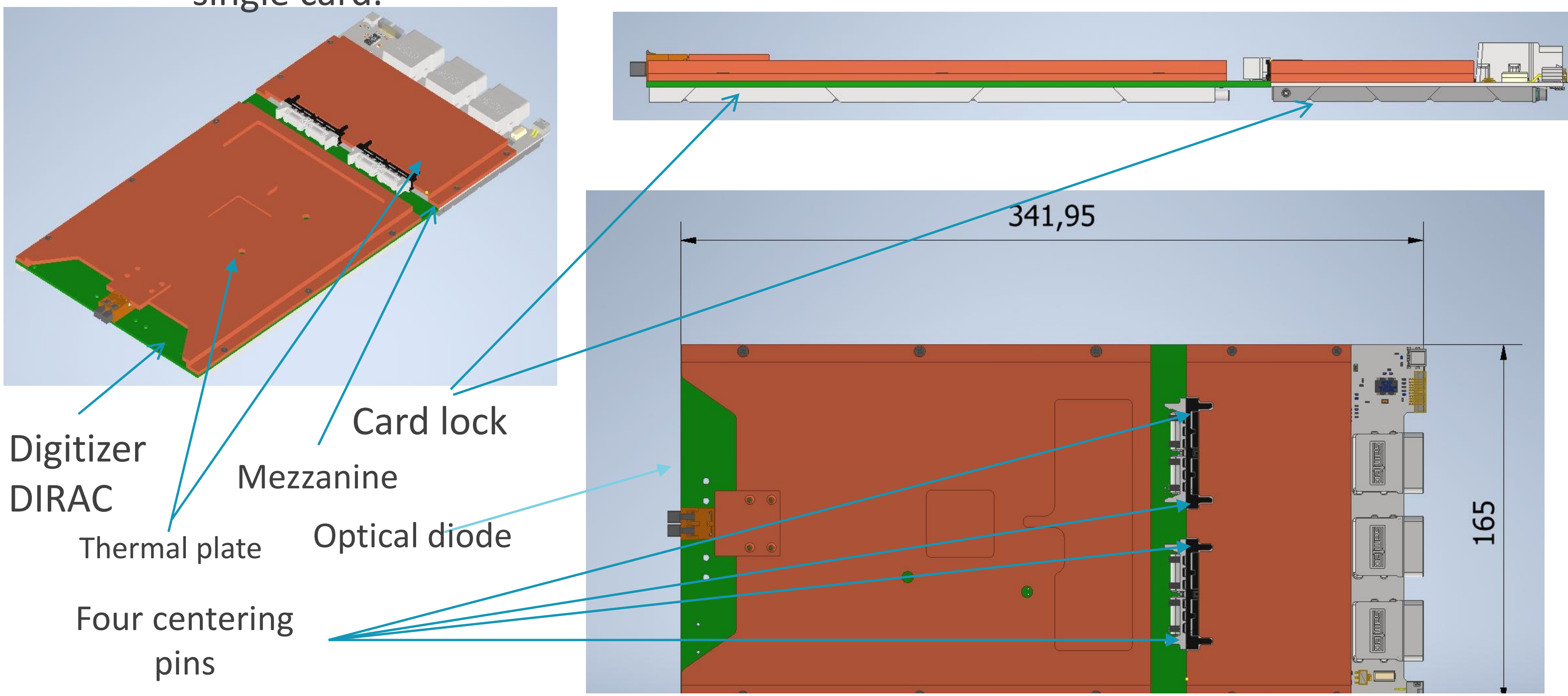


FEM analysis has been qualify by experimental data. SIPM max allowed temperature 0 ^{0}C

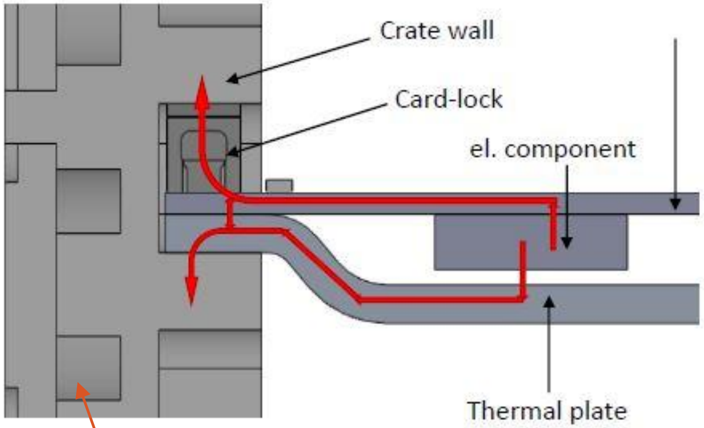
Fluid gradient 3.3 ^{0}C for SIPM at 0 ^{0}C with Monopropylene glycol 35%, water (a -10° C)

A compact crate with 9 board slots

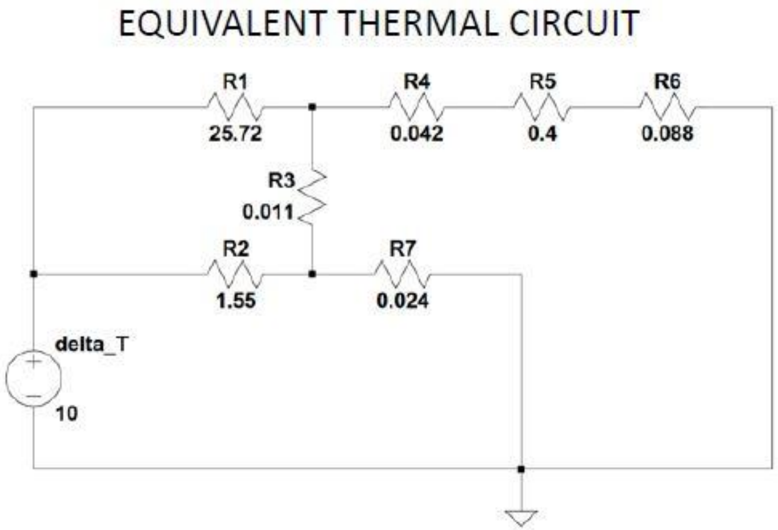
- The crates house the electronic boards and provide their cooling.
- Mechanical issues:
  - The available space is quite limited.
  - The space for the insertion and extraction of the cards does not allow to have a single card.



Board cooling



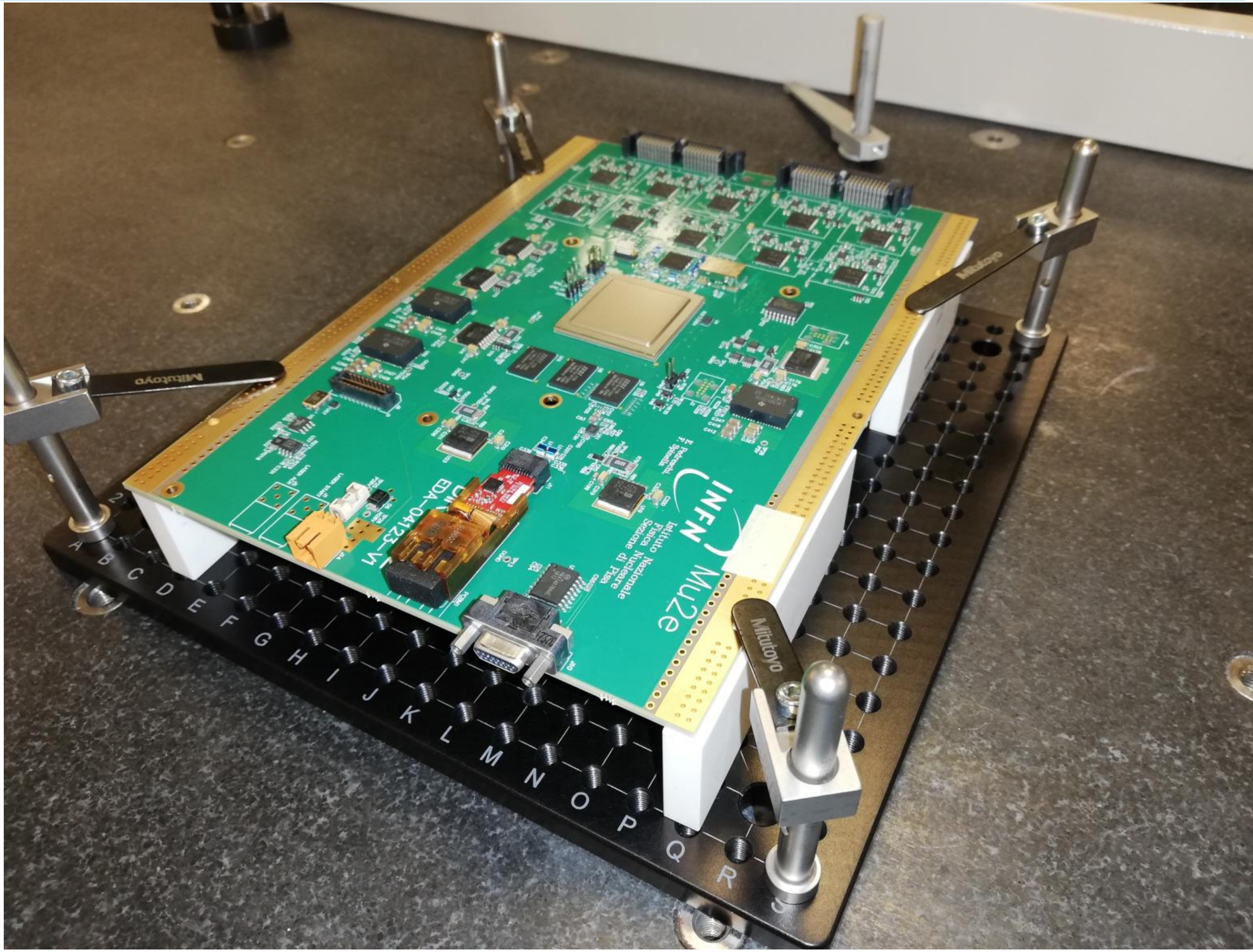
Colling channel integrate in the crate.



R1: thermal resistance between the junction and the edge of thermal plate
R2: thermal resistance between the junction and the edge of the board
R3: thermal resistance due to the contact (Cu-Cu) between the board and the thermal plate
R4: thermal resistance due to the contact (Cu-Al) between the board and the card-lock
R5: Internal thermal resistance of the card-lock
R6: thermal resistance due to the contact (Al-Al) between the card-lock and the crate wall
R7: thermal resistance due to the contact (Cu-Al) between the thermal plate and the crate wall

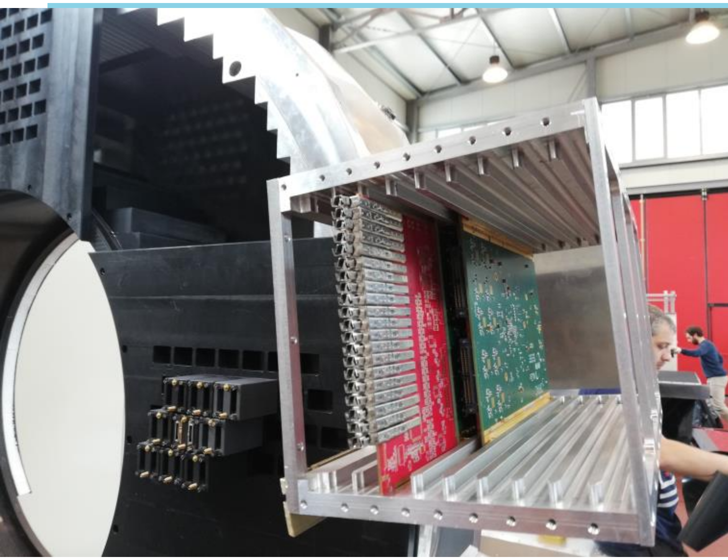
Crate cooling.

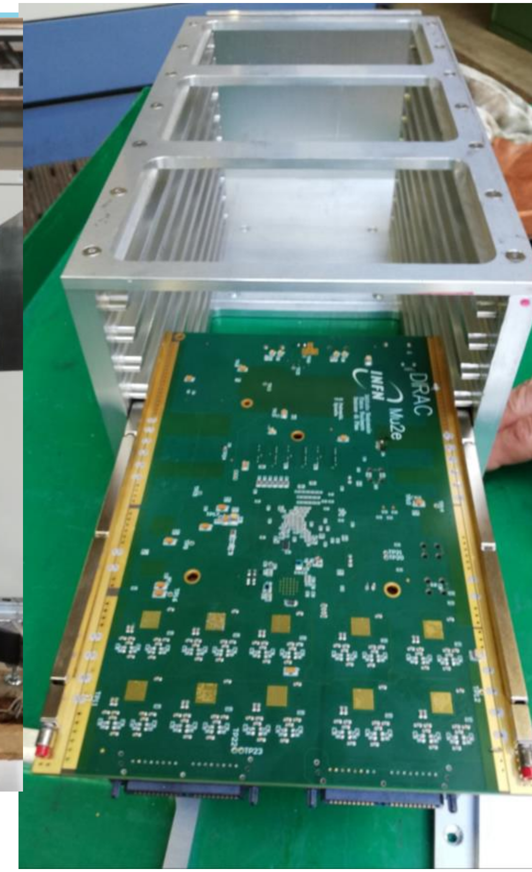
New DIRAC prototype

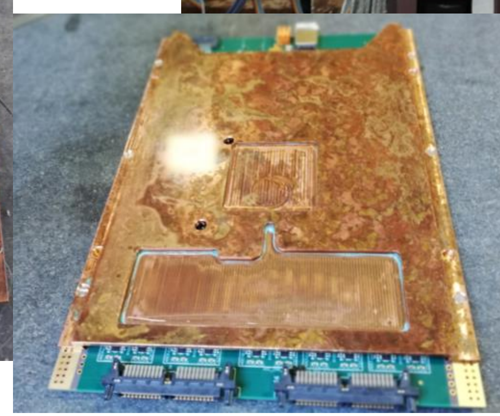


We measure the high of components. Total power dissipated 17 Watt.

Dirac board assembly and test.

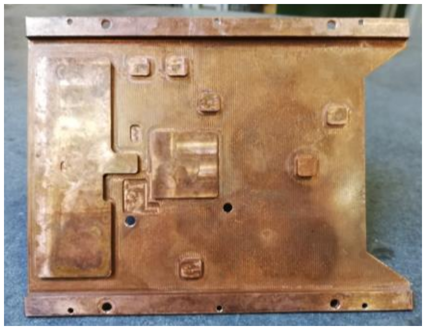




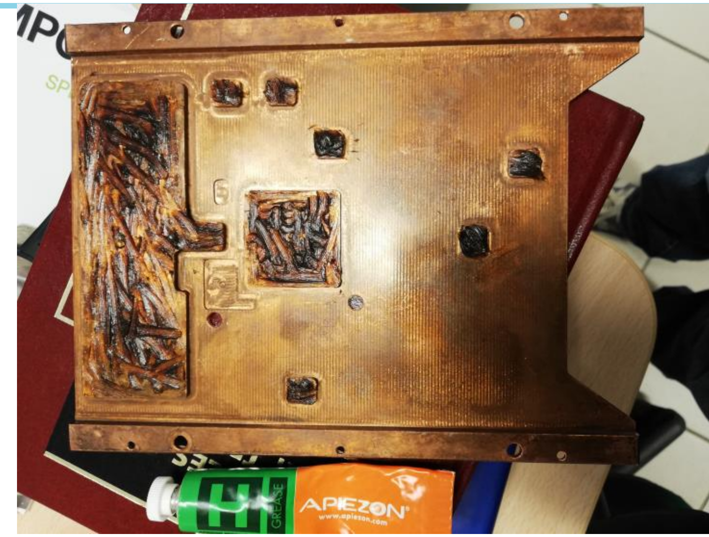


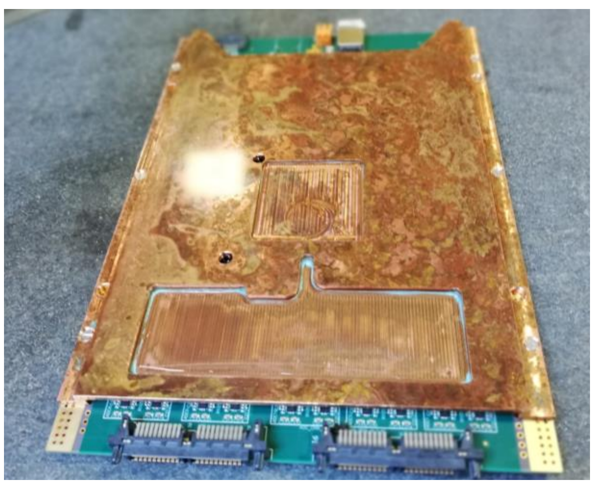
Crate design.

Copper Plate



We prototype three copper plate in our machine shop. We are tested under vacuum with different thermal interface materials (TIM)





Crate cooling test.

Temperatures test

INFN Fermilab Università di Pi

Test sequence.

- Vacuum vessel sealed.
- Vacuum level Ok.
- Chiller start flowing.
- Equilibrium reached.
- Data are taken.

The max desired temperature is 60 ^{0}C

25 temperature points were measured.

After the mechanical review in May 2019

Justifying the new requirement of the SIPM temperature.

The mu2e calorimeter group has proposed to improve the calorimeter SIPM reliability in the final period of operation, reducing the SIPM max operating temperature.

•The max allowed temperature has been set to 0-degree C for a long period of time. Now knowing better the SIPM behavior under radiation and considering the uncertainties on the effective dose absorbed, we consider prudent to have the possibility to operate the SIPM at -10 degree C.

•The implications of lowering the temperature has been preliminary analyzed thermally and mechanically. The first thing to do, is to reconsidered the secondary fluid.

The experience of 15 year of running in CERN experiments is well tested and documented. I attach some documentation about that. Personally I have parts irradiated and filled dipped in C6F14 since 2003. This proposed solution is based on our experience. We are awarded about the problems of fluid containment and for that we adopted special solution. We hope to be able to discuss solution for lowering the operating SIPM temperature. I attach some

REF. documents:

Comparison of liquid coolants suitable for single-phase detector cooling.

P. Gorbounov, M. Battistin, E. Thomas

Version 1.7 April 2016

Technical Specification for the

Perfluorohexane (C_6F_{14}) for ATLAS, CMS and LHCb Cooling Systems.

IT-3397/TS

Project: 3M Novec 649 as a replacement of C_6F_{14} in liquid cooling systems.

P. Gorbounov

Version 1.51 07.04.2015

Property	Novec 649 (a -20°C)	Monopropylene glycol 35%, water (a -10°C)
Density [Kg/m^3]	1700	1040
Specific heat [J/(Kg K)]	1103	3759
Kinematic viscosity [m^2/s]	$3.8\ 10^{-7}$	$4{,}16 \times 10^{-6}$
Absolute viscosity [Kg /m s]	$6.4\ 10^{-4}$	$4{,}33 \times 10^{-3}$
Thermal conductivity [W/mK]	0,067	0,429
Freezing temperature [°C]	-108	-17

Hf=4500-5000 W/m2 K at -10 ^{0}C with mixture water 30% organic

Hf=2000-2500 W/m2 K at -20 ^{0}C with Novec 649 a -20 ^{0}C.

ρCp (kg/m s^2 K) NOVEC 640 14 1.875 10^6 /////MC35% 3.909 10^6

Gradient in the cooling fluid 3.3 ^{0}C per mixture 30% organic at -10 ^{0}C, kinematic viscosity 10 times of Novec.

Gradient in the cooling fluid 6 ^{0}C per Novec 649 at -20 ^{0}C. Mass flow about 2 times the Glycol 35%

Update calorimeter power.

The max power dissipated in the calorimeter has been update.

- The actual number without safety factor is 5.2 Kwatt.
- This number assumes the max power dissipated by SIPM at the end of their life.
- The previous number considered was 10 Kwatt this includes a safety factor.
- With the actual number using a safety factor 1.25 the power raise to 6.4 Kwatt.
- This does not include the power losses of the cooling circuit due to the pump efficiency, pressure losses and lines thermal input.
- The cooling specification can report the max heat removal at -20 C non including the pump efficiency that it not know until the commercial pump has been chosen.

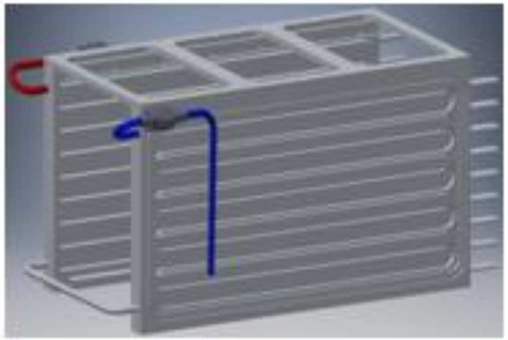
Total power consumption.

New estimate number 6.5 KW with already a safety margin.

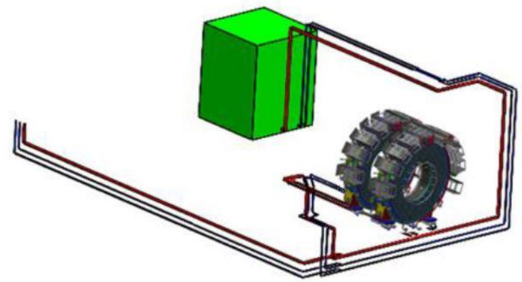
Estimate of Power dissipation											
S.Miscetti V2.0 -05/07/2020	Aaggionato 31/06/2020										
	dati Wmezz+Wdirac 28VX0.8Amp=22.4 Watt										
Measurement of dissipation on SiPM and FEE in different ISIPM conditions											
G.Corradi/S.Ceravolo (Jul 2019)											
	Wpre (mW)	VIN (V)	Vused(V)	Vdrop(V)	Iload(uA)	Isipm (uA)	Itot (uA)	W(Hvreg) FEE mW	Wtot (pre-reg)	Wtot (pre+Sipm)	
Caso 1) FEE only (ISIPM=340 uA)	272	200	160	40	210.00	340	550.00	22	294		
Caso 1) FEE+ SIPM(Isipm=340 uA)			160			340		54.4		348.4	
Caso 2) FEE only (Isipm=2100 uA)	272	200	160	40	210.00	2130	2340.00	93.6	365.6		
Caso 2) FEE + SIPM (Isipm=2100 uA)			160			2130		340.8		706.4	
Ndisks	2										
Ncrystals/disk	674										
Nsipms/disk	1348										
Ntotal SiPMs	2696										
Wtot(FEE+SIPM) (Caso 1) (W)	939.2864			Conclusions--> the Total dissipation on FEE/SiPMs will be ranging from 1 to 2 kW							
Wtot(FEE+SIPM) (Caso 2) (W)	1904.4544										
N mezzanine/whole calo (+TRAD)	140										
W mezzanina (W)	3	TO BE CHECKED									
Wtotal (W)	420										
Wtot(FEE+SIPM+MB) (Caso 1) (W)	1359.2864										
Wtot(FEE+SIPM+MB) (Caso 2 (W)	2324.4544										
W DIRAC	20	TO BE CHECKED									
Wtot (DIRAC)	2800										
Wtot(FEE+SIPM+MB+DIRAC) (Caso 1) (W)	4159.2864										
Wtot(FEE+SIPM+MB +DIRAC) (Caso 2 (W)	5124.4544										
				Totale	5124.4544						
22.4 Watt ripartito 3 Watt mezzanina +20 Watt Dirac				1.25							
				Totale+safety	6405.568						

Cooling station

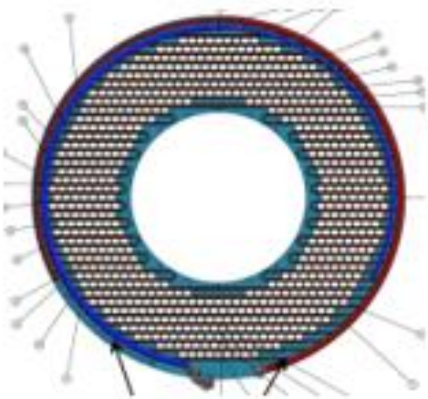
Hydraulic volumes



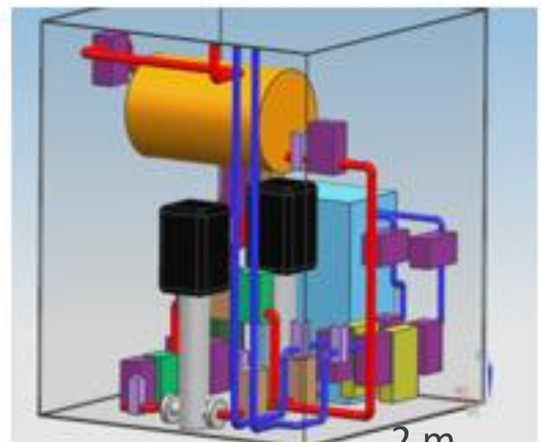
DAQ line:
$8 \cdot 10^{-3}\ m^3$



Routing lines:
$3.6 \cdot 10^{-2}\ m^3$



FEE line:
$3.27 \cdot 10^{-3}\ m^3$



Electrical panel must be included

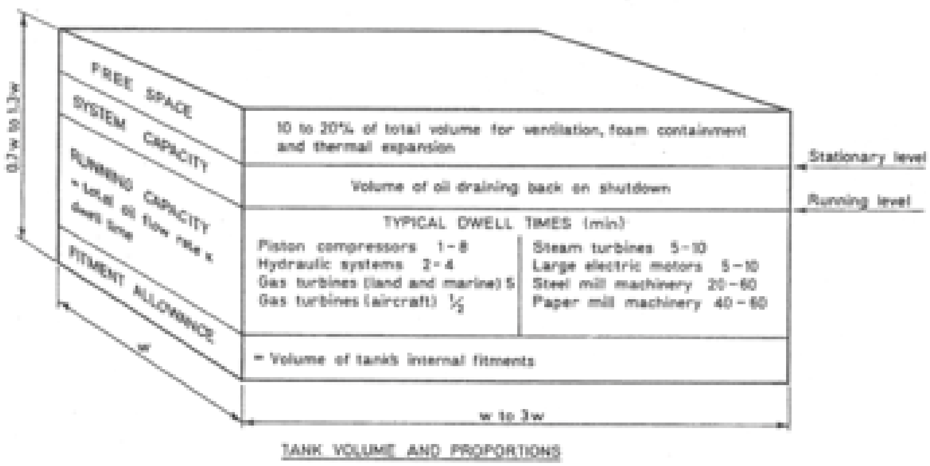
2.5 m

Alcove:
$1.22 \cdot 10^{-1}\ m^3$

2 m

2 m

Tank size



DWELL TIME	30 sec
FLOW RATE	4.5 kg/s
RUNNING CAPACITY	0.075 m^3
SYSTEM CAPACITY	0.3 m^3
TANK VOLUME	0.413 m^3
MASS OF THE FLUID	740 kg
INITIAL FLUID COST	48.9 k$

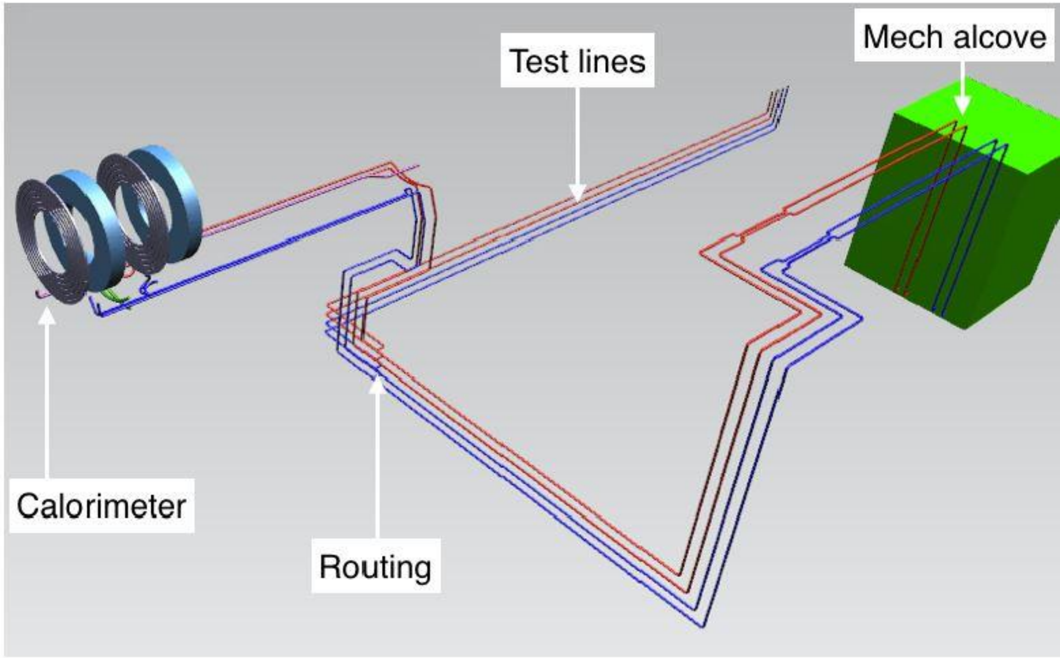
Routing system: layout

Connection between mechanical alcove and calorimeter

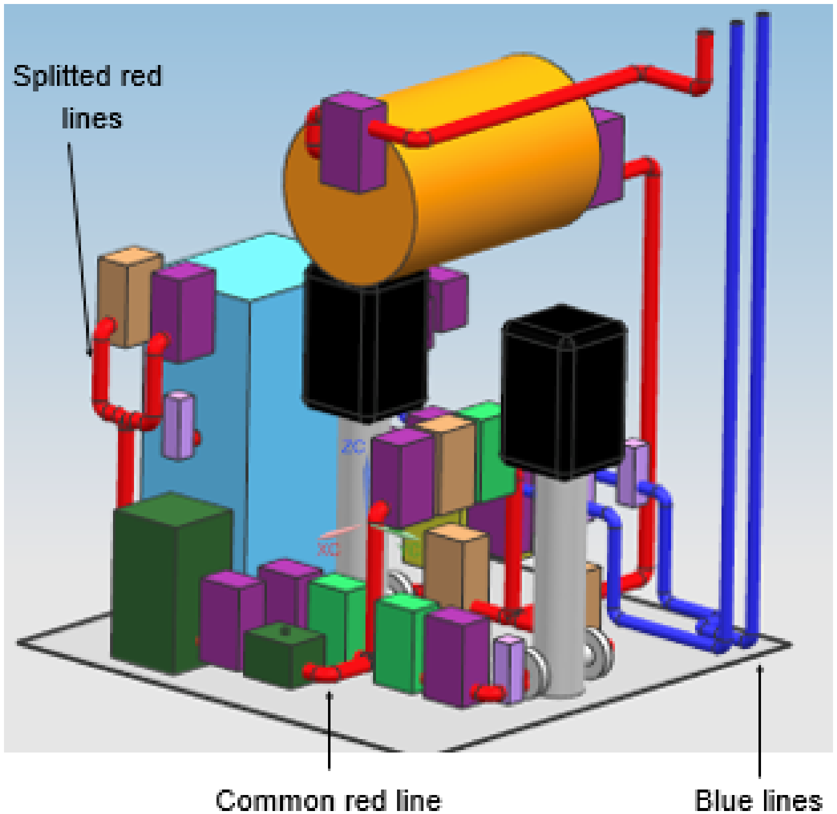
COMPONENTS:

- 2 inlet lines (blue)
- 2 outlet lines (red)
- 4 test lines (endless lines)
- Valves & equipment

1”



Mechanical alcove pressure losses

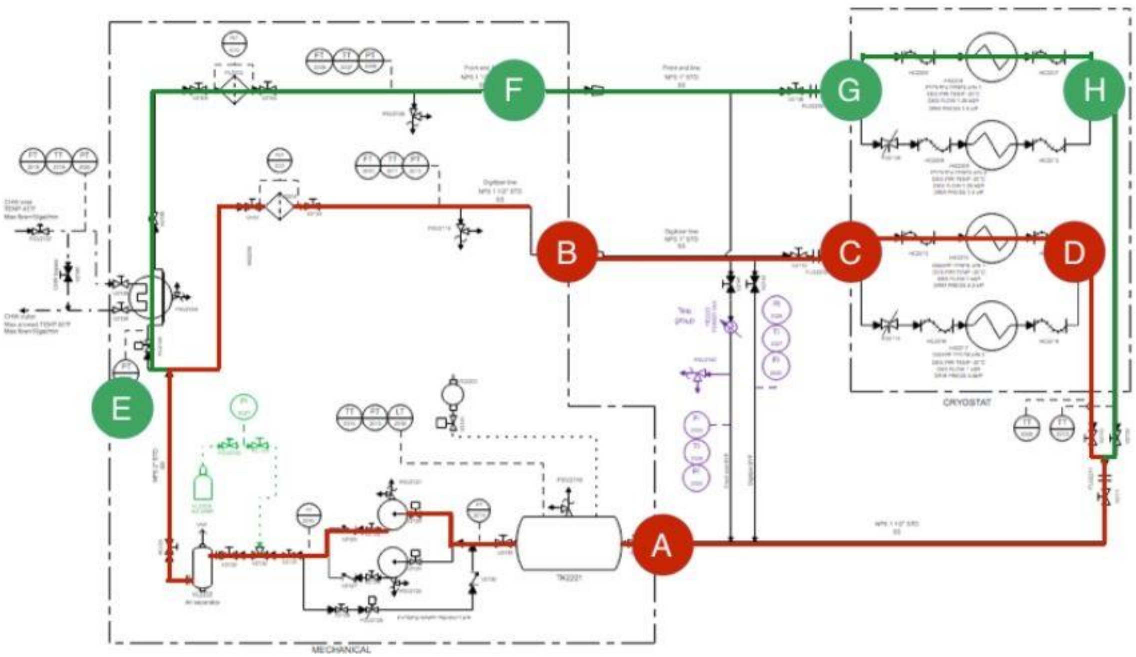


	Flow rate	Pressure loss
COMMON RED LINE (2”)	4.5 kg/s	0.18 bar
SPLITTED RED LINES (1 1/2”)	2 and 2.5 kg/s	0.01 bar
BLUE LINES (1 1/2”)	2 and 2.5 kg/s	0.04 bar
Total pressure loss		0.23 bar

As soon as the lines get out of the chiller envelope, they match the routing pipes dimensions

Pressure losses were assessed for Novec649 at -20 ^{0}C.

Head loss

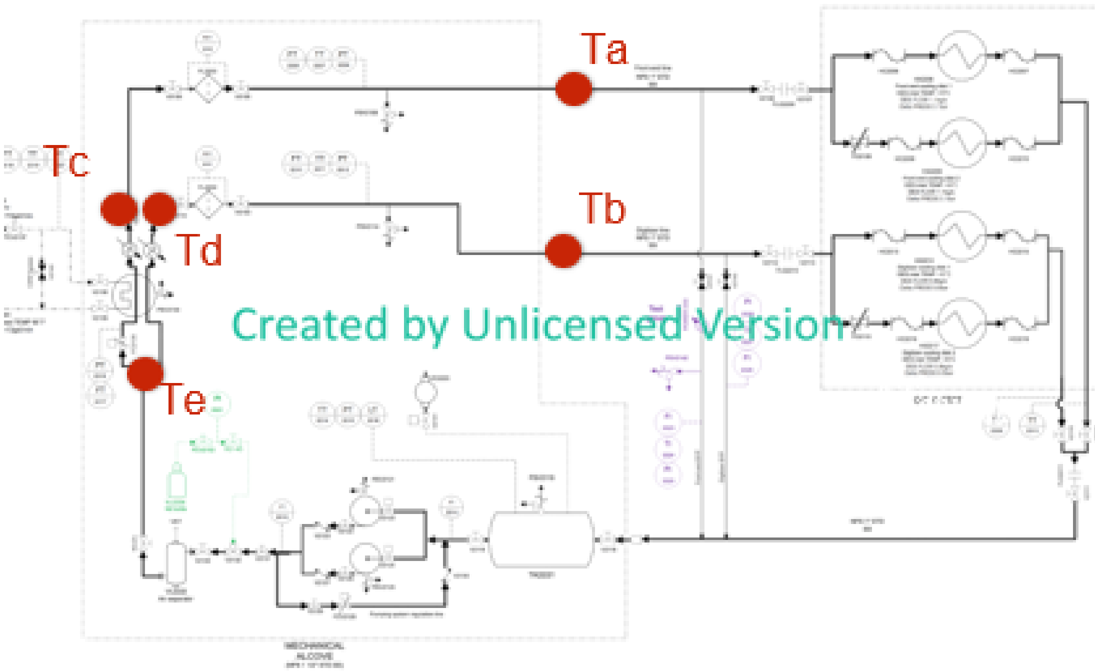


FEE PATH	HEAD LOSS [bar]
Mechanical alcove **A-E-F**	0.23
Routing FEE line **F-G**	1.56
FEE cooling line **G-H**	1.43
Common outlet line **H-A**	0.34
Valves & equipment	1.04
Margin of safety	10%
TOTAL	**5.1 bar**

DAQ PATH	HEAD LOSS [bar]
Mechanical alcove **A-B**	0.23
Routing DAQ line **B-C**	0.99
Crates cooling line **C-D**	4.45 (9*)
Common outlet line **D-A**	0.34
Valves & equipment	1.04
Margin of safety	10%
TOTAL	**8 bar (12.5*)**

Pressure losses were assessed for Novec649 at -20 ^{0}C.

Fluid temperatures



LOCATION	TEMPERATURE
Ta	-20.9 °C
Tb	-21.1 °C
Tc	-21 °C
Td	-21.2 °C
Averaged Tc/Td	-21.1 °C
Te	-18.5 °C
DeltaT chiller:	2.6 °C

The chiller must provide fluid at -21.1 °C of 4.5 kg/s perfluorohexane

Pressure losses were assessed for C6f14 at -20 ^{0}C.

Open problems.

1) Max power available 25 Kwatt. Power needs to remove 6.5 Kwatt.

- Electric power budget summary of the mechanical alcove (source: Mu2e experiment data center).

Component	Percentage of total power budget	Electric power budget [kW]
Chiller	50%	12.5
Pumping group	20%	5
Control cabinet	10%	2.5
Miscellaneous	5%	1.25
Margin	15%	3.75
Total	100%	25

2) Space available in the alcove is sufficient for the cooling station ?

Revision of cooling operation and power.

- We have to consider 4 phases on which cooling is required.

1) Commission at SIDET with Novec 649.(different chiller of the cooling station)
2) Operation on the experimental area in air.
3)Operation at lower power and eventually high temperature (-10 ^{0}C) in the first period of operation.
4) Last period of operation the SIPM temperature must be lowered and power is higher (from -10 ^{0}C to -20 ^{0}C)

- The detail description of the point 2,3,4 are necessary to write the cooling station specifications

Revision of cooling operation and power.

Component	Total number per disk	Total number Calorimeter	Min. unit power [W]	Max. unit power [W]	Min. total power [W]	Max. total power [W]
SiPM	1348	2696	$54.4 \cdot 10^{-3}$	$340.8 \cdot 10^{-3}$	146.7	918.8
FEE boards	1348	2696	$294 \cdot 10^{-3}$	$365.6 \cdot 10^{-3}$	792.6	985.7
DIRAC + Mezzanine	70	140	23	23	3220	3220
Total					**4159**	**5125**

Revision of cooling operation and power.

- All these phases need to be analyzed in detail internally at the calorimeter group. Verification and update on the powers dissipated has been necessary. Furthermore the solutions adopted need to verify with the current infrastructures.
- All operation phases must be described in detail regarding the environmental conditions and the necessary data (power consumption and temperature).
- We are analyzed with fermilab group the operation of filling the and the dry out of the cooling lines and the pressure control system.

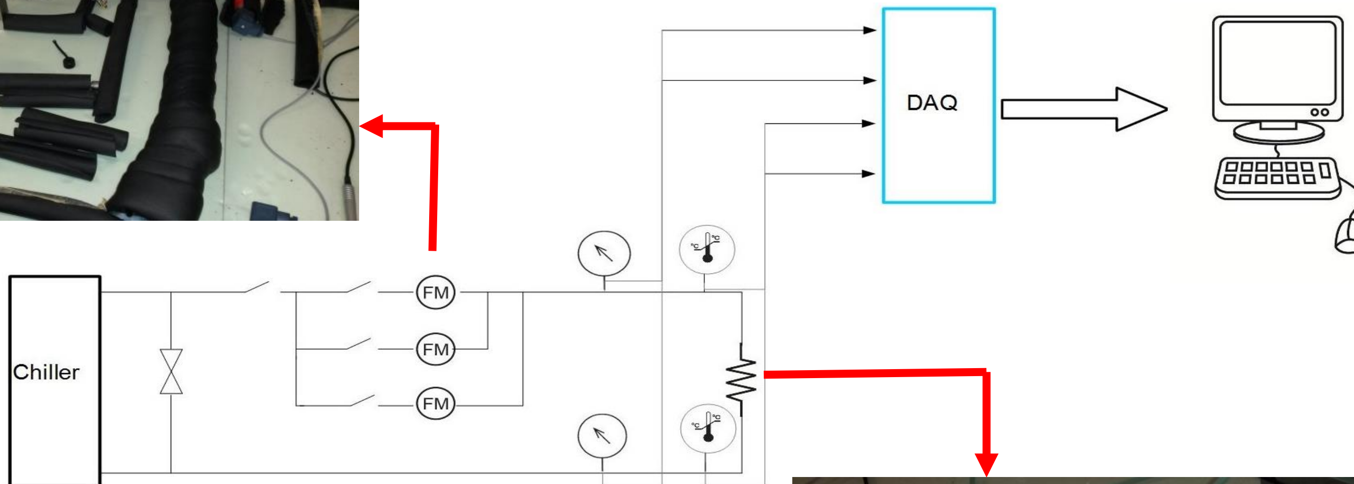
Cooling test at Pisa.

We have a chiller that can run novec 649 or HFE7100 up -80 ^{0}C.
Experimental pressure losses end temperature test at -10/-20 ^{0}C for the crate and for the SIPM lines.

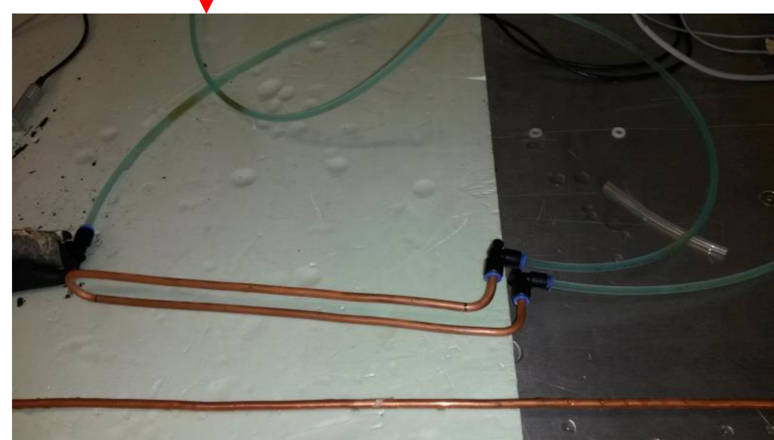
Experimental setup to measure pressure losses

Test fluid temperature at 0º C

Mass Flow meter



Pressure gage sensor



Experimental setup to measure pressure losses

Test fluid temperature at -10º C and -20 C

Mass Flow meter up 500 g/min. The flow meter required is up 5000 g/min.

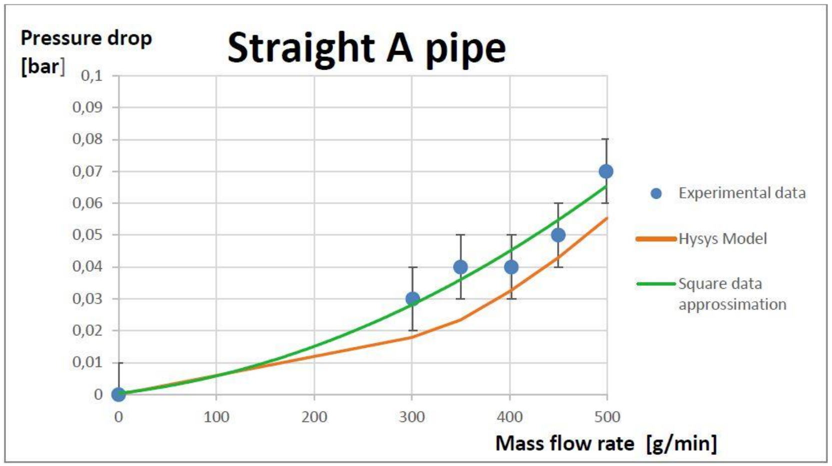


Figure 5.8 – Experimental results for the pipe "Straight A" compared to their square approximation and to the results of the Aspen HYSYS calculation model.

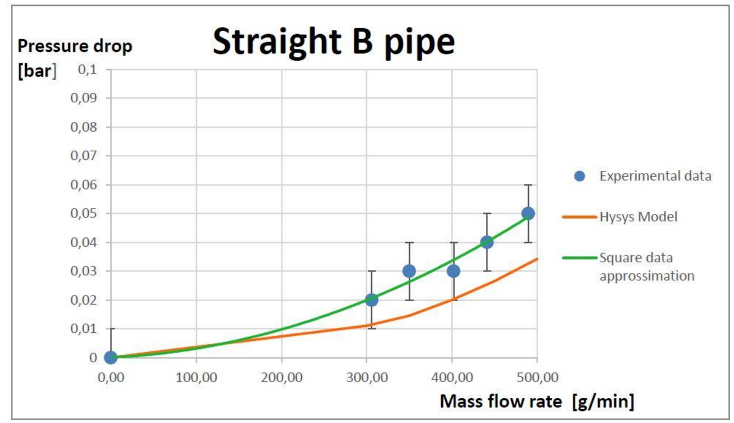


Figure 5.9 - Experimental results for the pipe "Straight B" compared to their square approximation and to the results of the Aspen HYSYS calculation model.

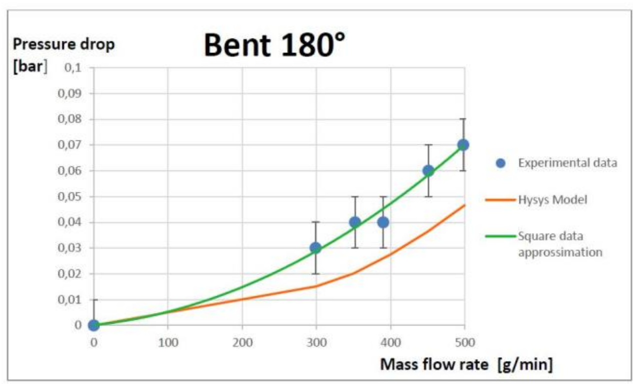


Figure 5.10 - Experimental results for the pipe "Bent 180° " compared to their square approximation and to the results of the Aspen HYSYS calculation model.

Conclusions

- We will continue to do the thermal test during the production of components (SIPM and Crate). It is very important to predicted components behavior in a test bench.
- We need to qualify components during the production to verify their cooling performances.
- We need to have some iterations with the integration Fermilab group to verify that the final cooling specification of the cooling plant are compatible with mu2e.
- The process of reviewing dissipated powers has been completed.
- We start writing the cooling station specification. We expect do have been done at the end of year 2020.
- Chiediamo lo sblocco di 5 Keuro per I trasporti back plane e crates.