Mu2e Calorimeter Mechanics

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NEWS General Meeting,

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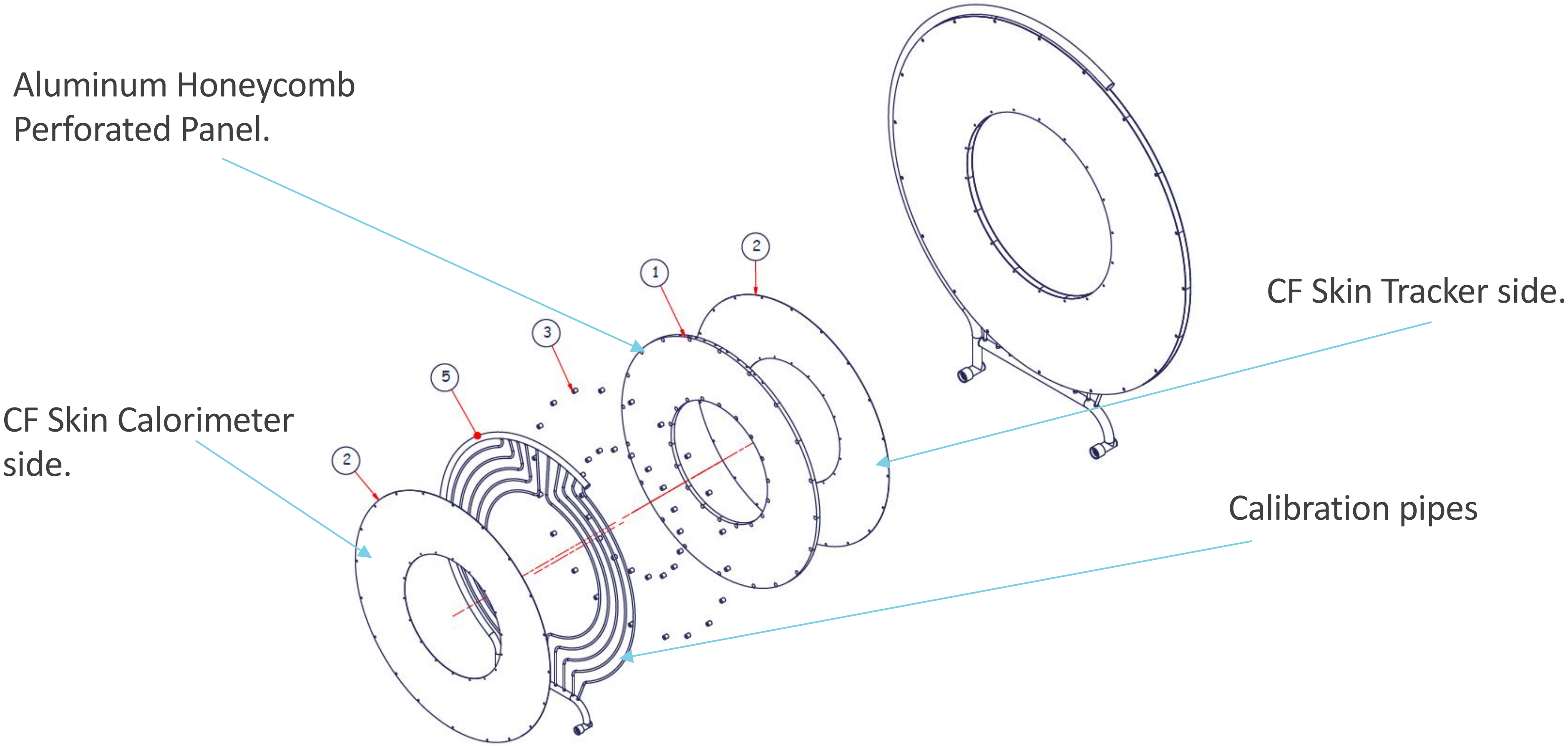
Front panel and Inner CF cylinder Design

- Front pate Design.
- Update on the design of the inner cylinder.
- Status of CF parts.
- Conclusions

Design of front plate.

The front plate is a sandwich panel that incorporates the calibration system.

1) It must be compatible with vacuum, magnetic field and radiation.



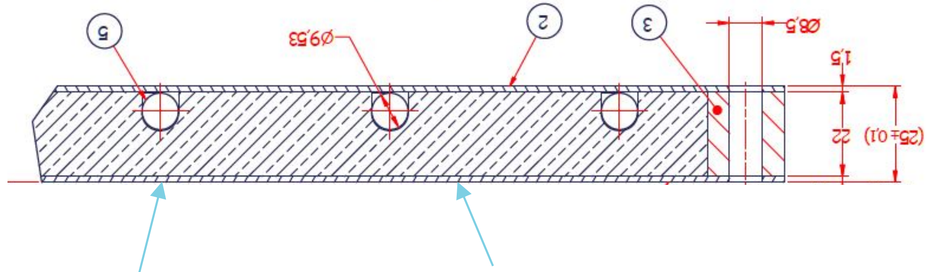
Carbon fiber Front plate QC control:

1. Lamination of the two skins.
2. Survey of the skins. (report thickness and flatness)
3. Preparation of an assembly plate.
4. Trimming and drilling holes including the evacuation holes using the assembly plate.
5. Cleaning and preparation skins for gluing.(honeycomb outgassing in vacuum bag in oven)
6. Position of the Tracker side skin on the assembly plate.
7. Gluing the honeycomb Curing at room temperature.(adhesive 3M 2216)
8. Verification of the curing process 24 h room temperature using a Glue samples. (report)
9. Removing from the assembly plate the skin with the honeycomb.
10. Milling skin bonded with honeycomb to realize the circular shape, the holes and the grooves for the source line.
11. Dry Milling with vacuum sucking the honeycomb and vacuum backing on autoclave.
12. Leak test source lines cleaning and preparation for gluing with sensitivity of 10^{-10} mbar/liters.(report)
13. Dry positioning of the honeycomb and source line on a skin.

Carbon fiber Front plate QC control:

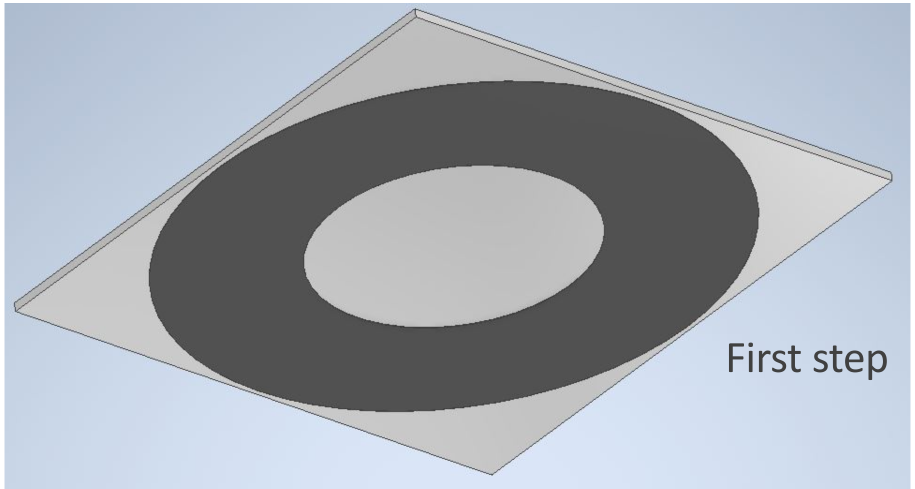
14. Position of the skin and the assembly plate.
15. Manually dispensing glue.
16. Positioning the assembly skin honeycomb and pipes source on the assembly plate.
17, Applies gravity pressure with weights.
18. Verify the glue curing using a glue test sample. (report)
19. Survey the CF front plate.
20. Vacuum tightness test with a HLD, He Leak Detector, (mass-spectrometer) with a measurement sensitivity of 10^{-10} mbar/liters. (report)
21. Evacuation test.
22. Cleaning and packaging.

At the end of the QC control phase all certifications and controls performed will be provided to the Mu2e calorimeter engineering team. The two CF inner cylinder and front plate source are packed in in a sealed back suitable for transportation by air-plane shipping. The basic ideas are: The CF inner cylinder packed can be housed in a wood box with proper foam.
The CF front plates are joint together is that **a fully assembled back plate will be kept in vertical position restrained in a cradle that is going to protect it during travelling.**



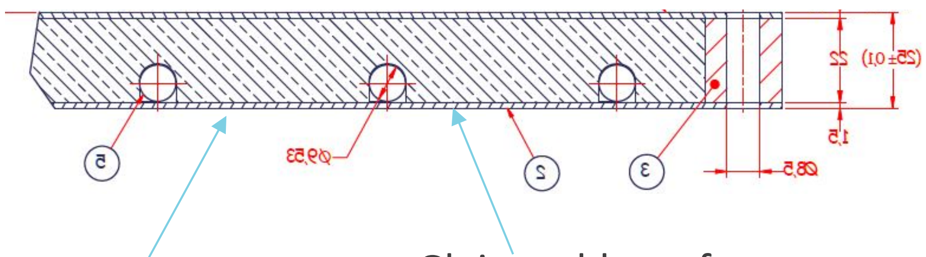
Skin facing tracker

Gluing table surface



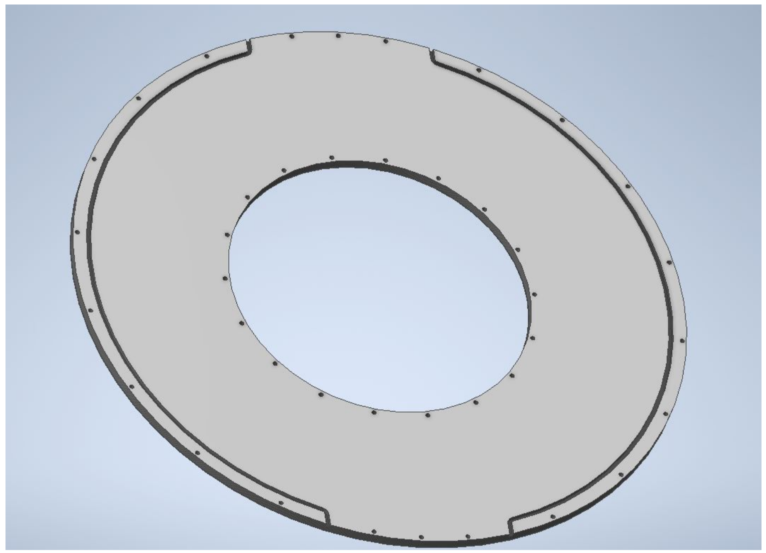
Second step Machining honeycomb

We turn the machined honeycomb with the one skin Glued.



Skin facing calorimeter

Gluing table surface



Material data:

1) Carbon fiber T300 3K plain waves 200 +/-10 gr/m2 resin content 40-43% volume. Resin cyanate ester.
2) Some Glue data 3M 2216.

3M

Scotch-Weld™

Epoxy Adhesive

2216 B/A Gray • 2216 B/A Tan NS • 2216 B/A Translucent

Technical Data March, 2002

Product Features

- Excellent for bonding many metals, woods, plastics, rubbers, and masonry products.
- Base and Accelerator are contrasting colors.
- Good retention of strength after environmental aging.
- Resistant to extreme shock, vibration, and flexing.
- Excellent for cryogenic bonding applications.
- Excellent for potting parts subject to thermal cycling.
- The tan NS Adhesive is non-sag for greater bond-line control.
- The translucent can be injected.
- Meets DOD-A-82720.

		Dose absorbée (MGy)			
		0	0.5	1	3
Type de support	Type d'adhésif	Résistance au cisaillement (Mpa)			
Antico décapé N° 4	XD4447 4448	24.9	22.6	22.4	8.7
idem	AZ 15 HZ 15	20.5	16.9	12.8	5
idem	AW 106 HV 953 U	28.3	27.4	29.4	28.5
idem	Stycast 2850 FT (cat 11)	20.8	20.2	22.5	21.6
idem	Scotchweld 2216	20.6		19	17

Typical Cured Outgassing Properties

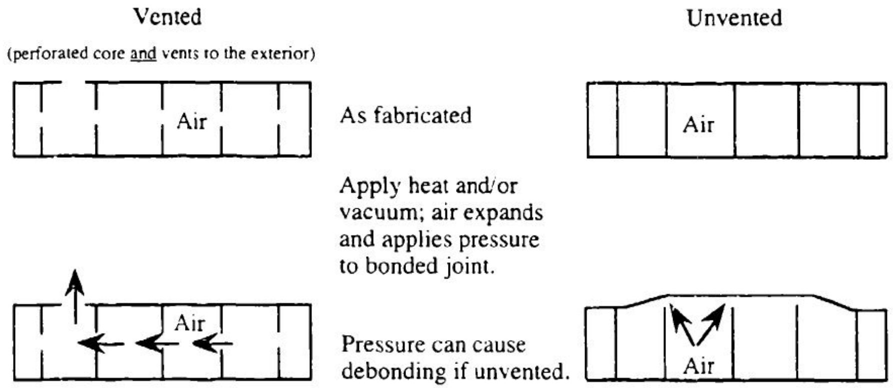
Outgassing Data
NASA 1124 Revision 4

	% TML	% CVCM	% Wtr
3M™ Scotch-Weld™ Epoxy Adhesive EC-2216 B/A Gray	.77	.04	.23

Cured in air for 7 days @ 77°F (25°C).

Material data:

3) Aluminum honeycomb Material aluminum 5056 or 5052 vented



Designation

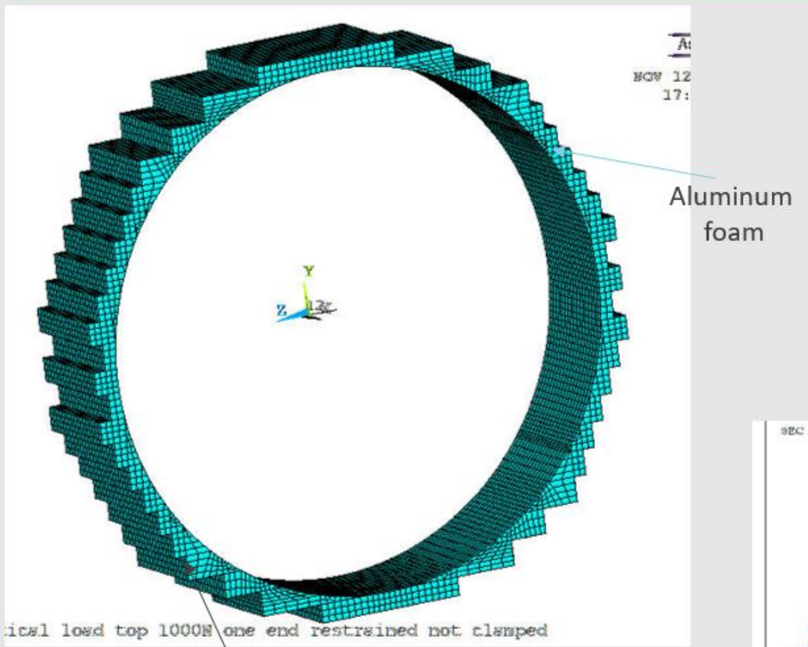
The full description of the honeycomb provides:
Alloy: description of the type of aluminum alloy used (5052 and 5056)
Density: the weight of material expressed in pounds per cubif feet or kg/m3
Cell: distance between two sides of the hexagon (mm or fraction of an inch)
Foil Nom: thickness of the wall that makes up the hexagon (mm or inches) -
P or N : material can be supplied perforated or non perforated
Tolerances + / - 10%

Venting. A very important consideration that must not be overlooked is that the core must allow venting of gases within the core. If this is not done, high pressure inside the core can lead to facesheet debonding or core explosion in the space vacuum environment. The cell walls in aluminum honeycomb are usually perforated for venting requirements.

Update on Design of the inner cylinder.

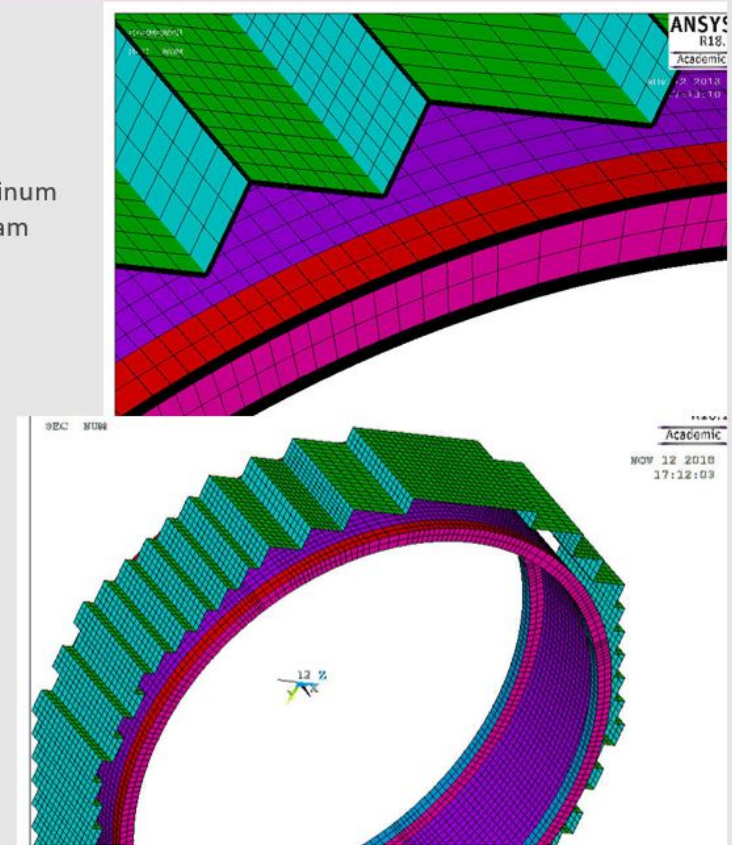
Design requirements:

1. We are proceeding to replace the aluminum foam with a solution all carbon fiber.



EX	1E+008	GXY	1.99E+008
EY	1E+008	GYZ	1.99E+008
EZ	1E+008	GXZ	1.99E+008

Unit SI (Pa)



Aluminum open cell Foam properties

Physical Characteristics of Duocel® Aluminum Foam* (8% Nominal Density 6101-T6)

Compression Strength	367 psi	(2.53 MPa)
Tensile Strength*	180 psi	(1.24 MPa)
Shear Strength*	190 psi	(1.31 MPa)
Modulus of Elasticity (Compression)*	15×10^{3} psi	(103.08 MPa)
Modulus of Elasticity (Tension)*	14.6×10^{3} psi	(101.84 MPa)
Shear Modulus	2.9×10^{4} psi	(199.95 MPa)
Vickers Pyramid Number	35 HV	
Specific Heat	.214 $^{\text{BTU/lb-°F}}$	(.895 $^{\text{J/g-C}}$)
Bulk Thermal Conductivity	3.4 $^{\text{BTU/ft-hr-F}}$	(5.8 $^{\text{W/m-C}}$)
Coefficient of Thermal Expansion (0-100°C)	13.1×10^{-6} $^{\text{in/in--F}}$	(23.58×10^{-6} $^{\text{m/m--C}}$)
Bulk Resistivity	2.84×10^{-5} ohm - in	(7.2×10^{-5} ohm - cm)
Melting Point	1220°F	(660°C)

Aluminum Foam Thermal conductivity

Kfoam=167*0.08*0.33=4.49 W/m C

Ctotal = Csolid ligaments + Cgas + Cgas convection + Cradiant

Where

Csolid ligaments =the conductivity of the three-dimensional array of solid ligaments or struts that form the foam structure. This term is also often referred to as the "bulk thermal conductivity" of the foam. In most applications, particularly for metal foams used as heat exchangers, this is the quantitatively largest and most thermally dominant of the four components and has the following simplified equation form:

Csolid ligaments = Csolid × relative density × .33

Where

Csolid ligaments = direct thermal conductivity or bulk conductivity of the ligament array

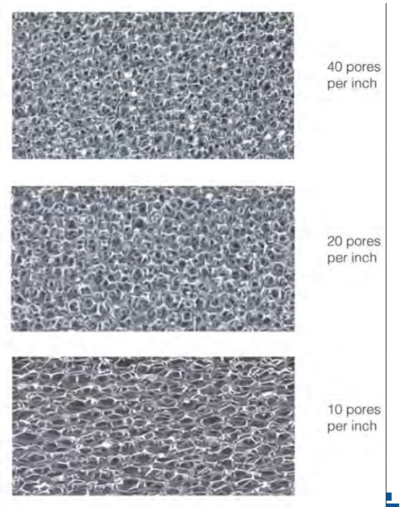
Csolid = conductivity of the solid material of the struts

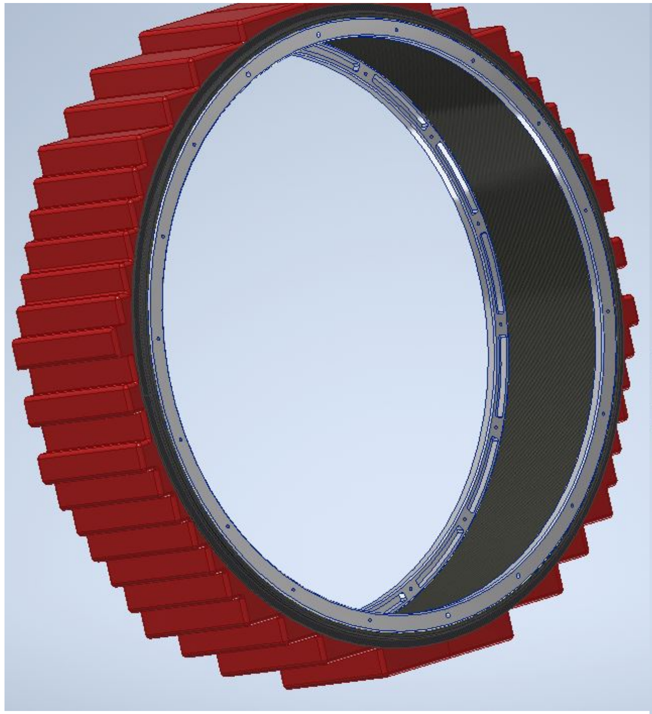
Relative Density = % relative density in decimal form, i.e. 10% = .1

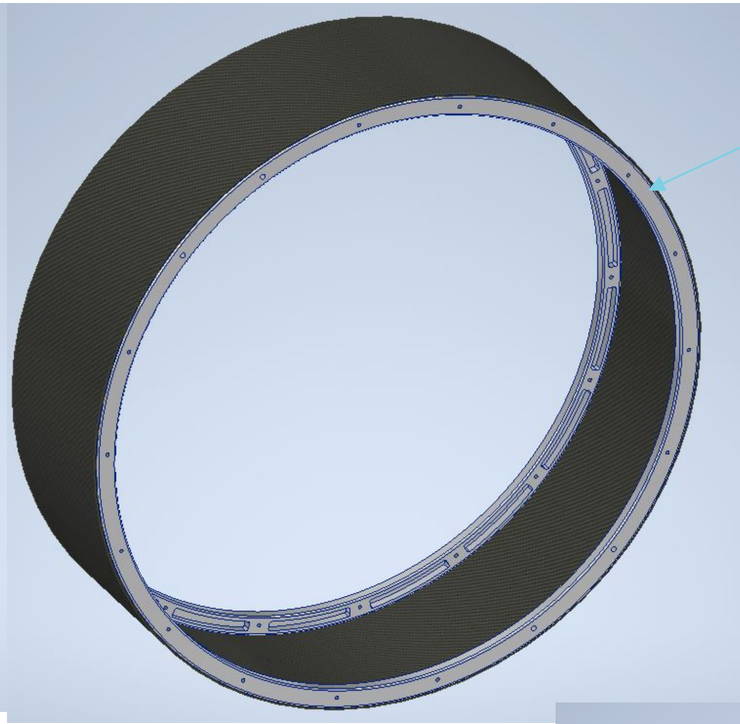
.33 = coefficient representing the foam structure geometric or "tortuosity" factor.

It should be noted that the .33 coefficient is derived both from conductivity tests and conceptual analysis wherein the foam can be analogized to a three-dimensional orthogonal pin fin array. In this case is it obvious that one third of the pins or pin mass are oriented in each of the orthogonal x, y, and z directions.

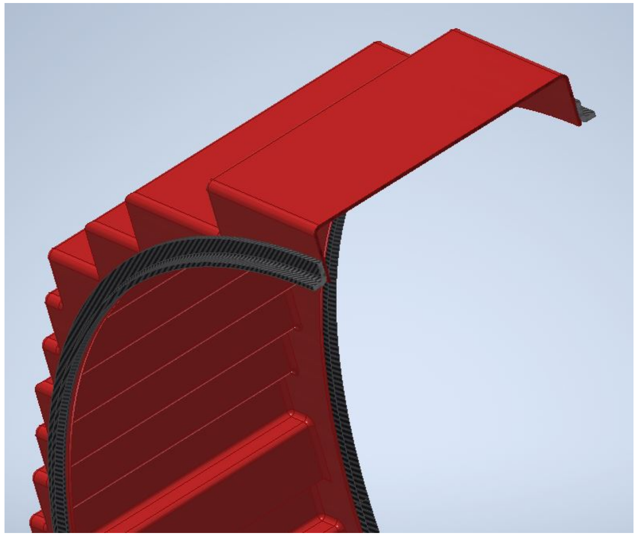
It should also be noted that this equation is somewhat simplified, but is reasonably accurate, slightly conservative, and is more easily understood from a conceptual standpoint than some of the empirical equations that have been developed from various tests.





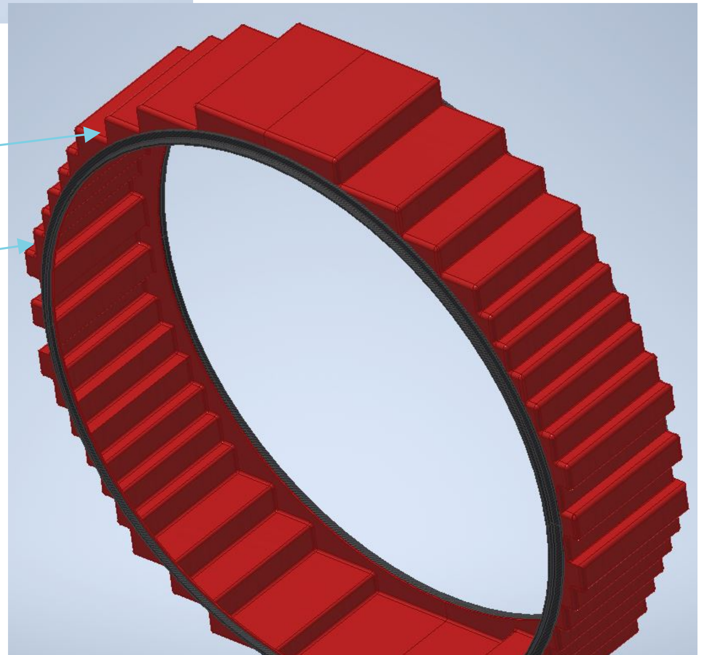


CF inner tube + aluminum rings



CF steps

L connecting profile



Status of CF parts.

The Carbon fiber pre-preg material is at the CETMA company in Brindisi.

1)Some material has been processed to make some test samples.

2)A sandwich of the front panel with the final material has been made. It will vacuum tested at Frascati. Next will be machining test on honeycomb.

3) The manufacturing plan of the inner cylinder is still on discussion. We have the steel mold to produce the inner tube and aluminum rings are on order. We are still working on the steps design.

Conclusions

- We realized that before to produce the final parts we need to qualify the processes and make several parts.

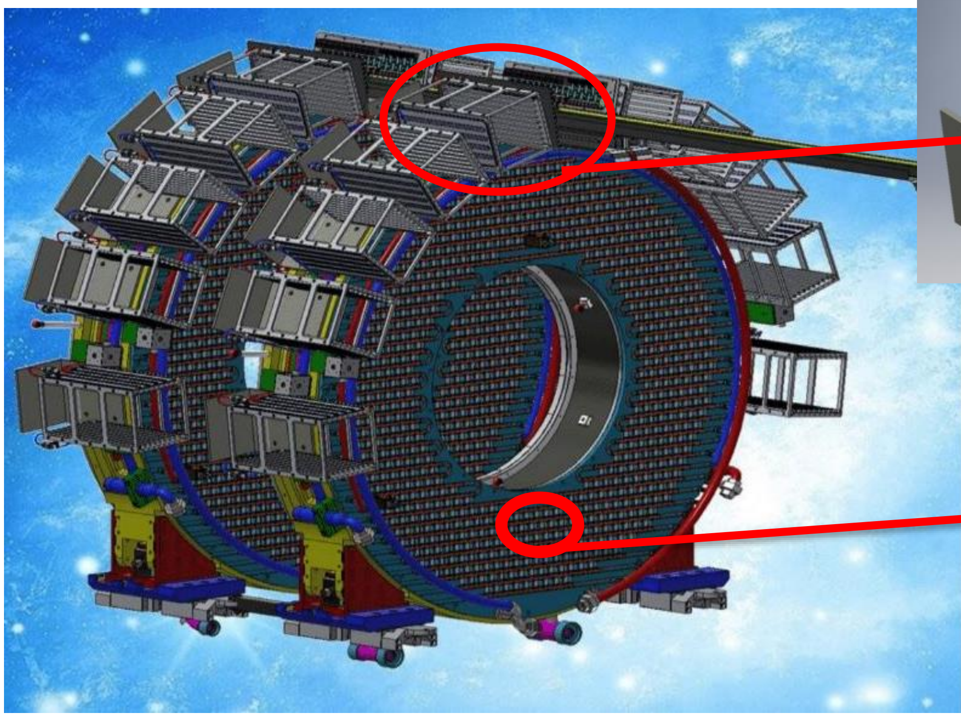
- A validation tests have been discussed and set with supplier.
- Details drawing has been summited to the producer CETMA
- A construction method has been discussed with manufacturing company.

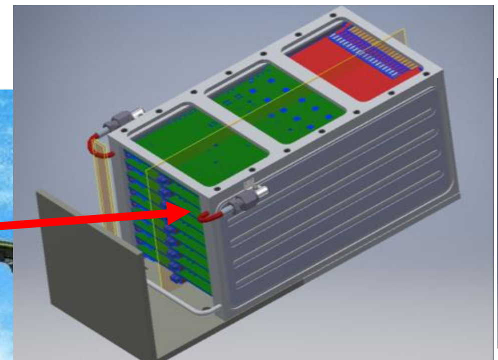
Update calorimeter cooling.

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

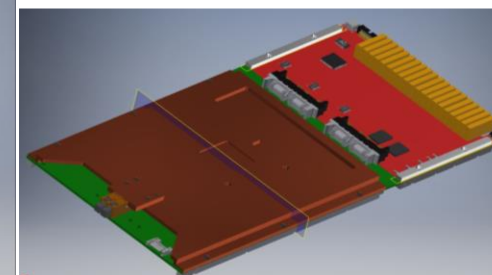
Cooling system overview

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

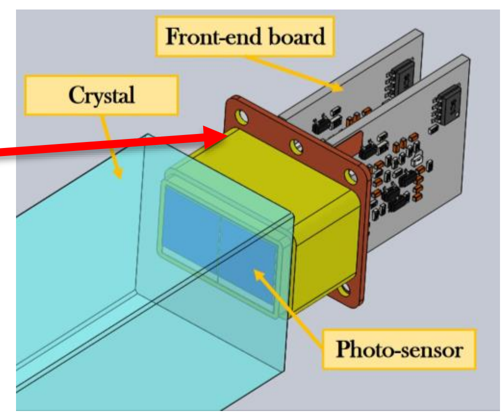




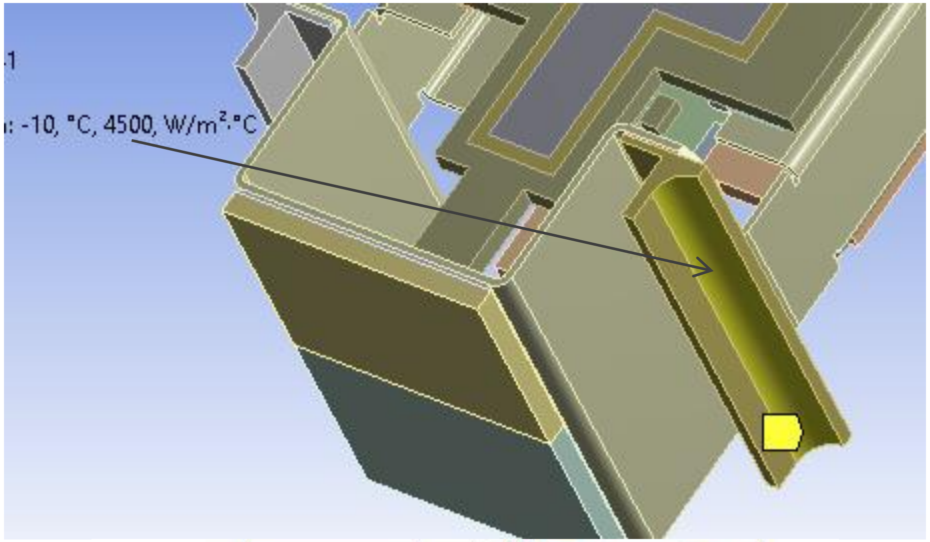
Dirac and mezzanine

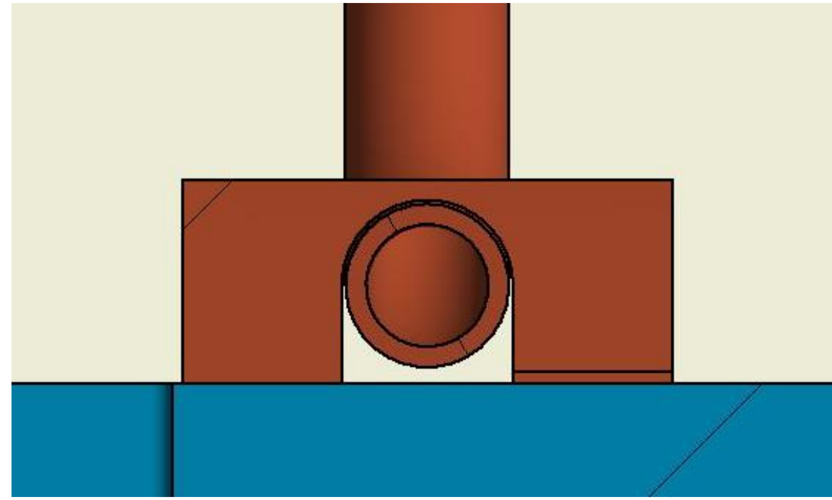


Front-end

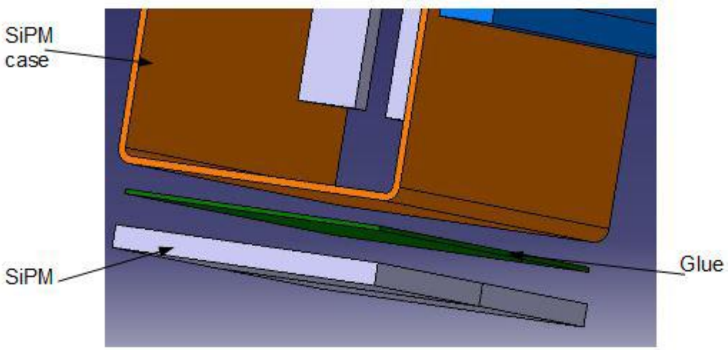


Mu2e SIPM FEM details

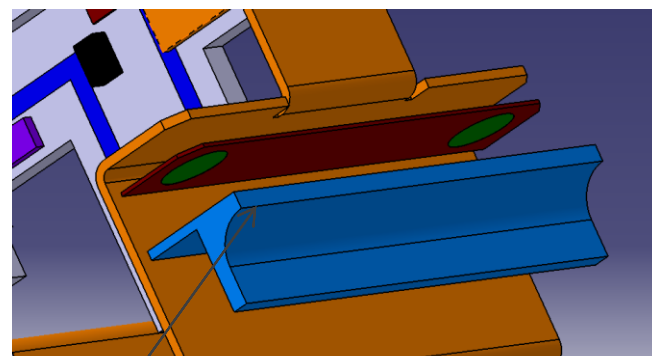




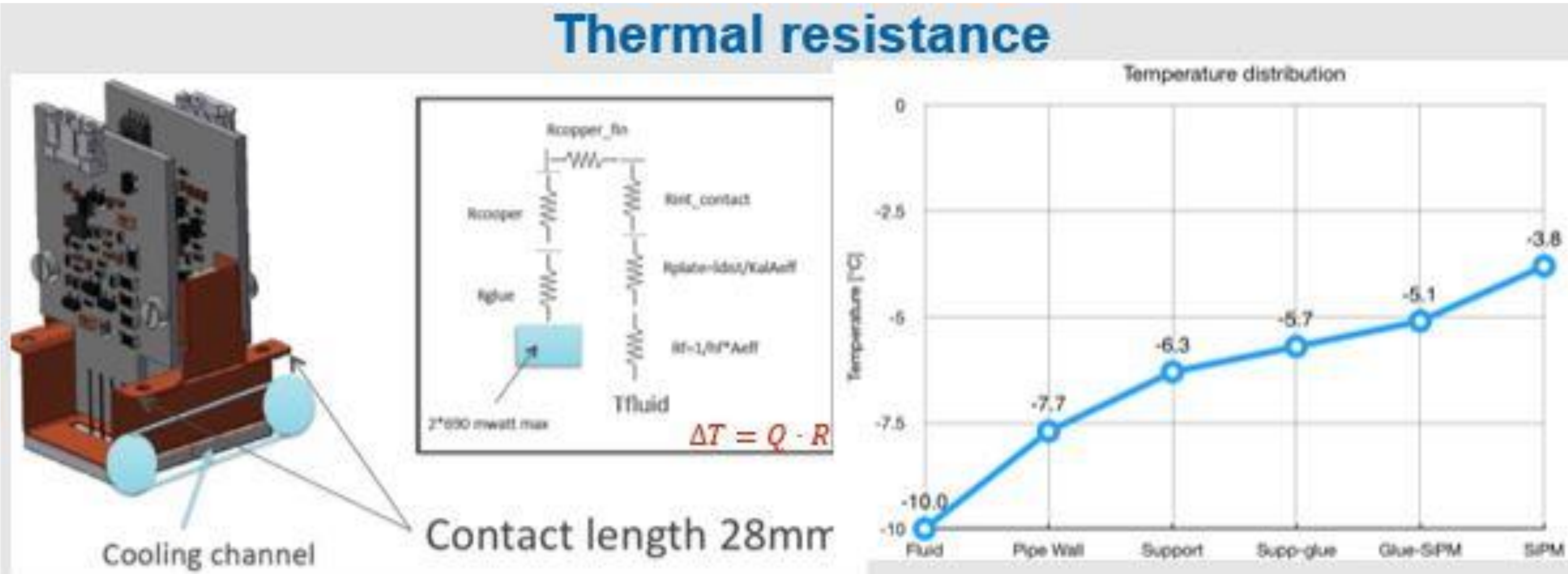
Realist model respected the adopted solution



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

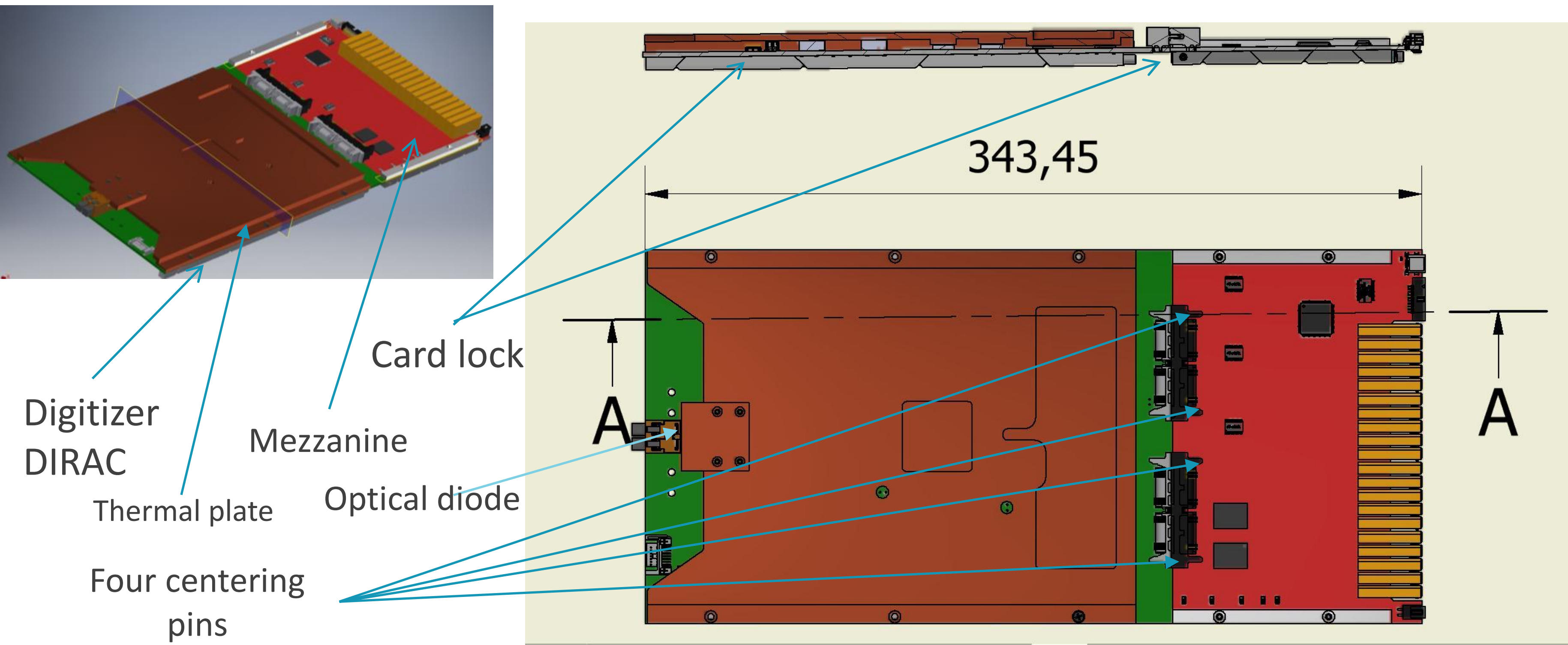


FEM analysis has been qualify by experimental data.

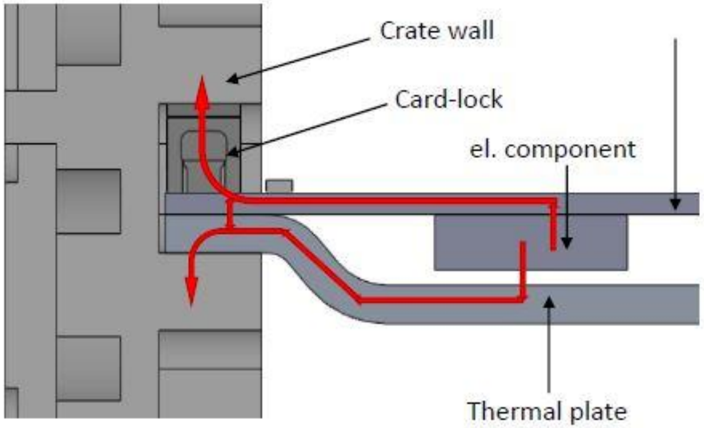
Fluid gradient 3.3 ^{0}C for SIPM at 0 ^{0}C

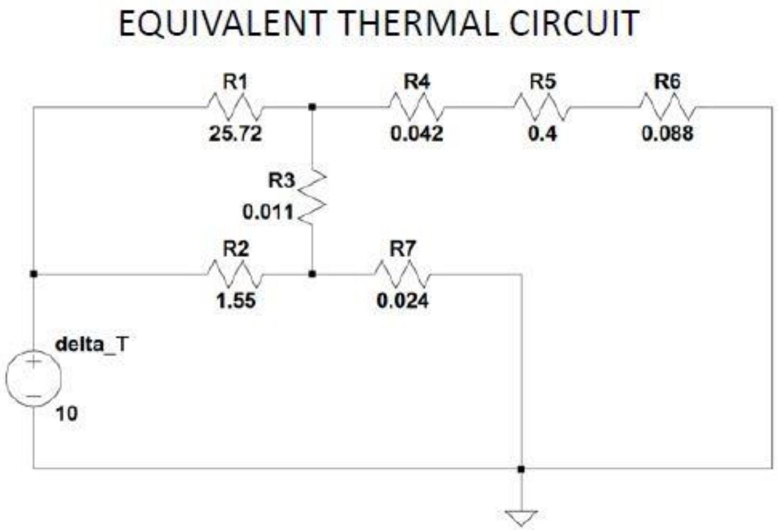
A compact crate with 9 board slots

- 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.



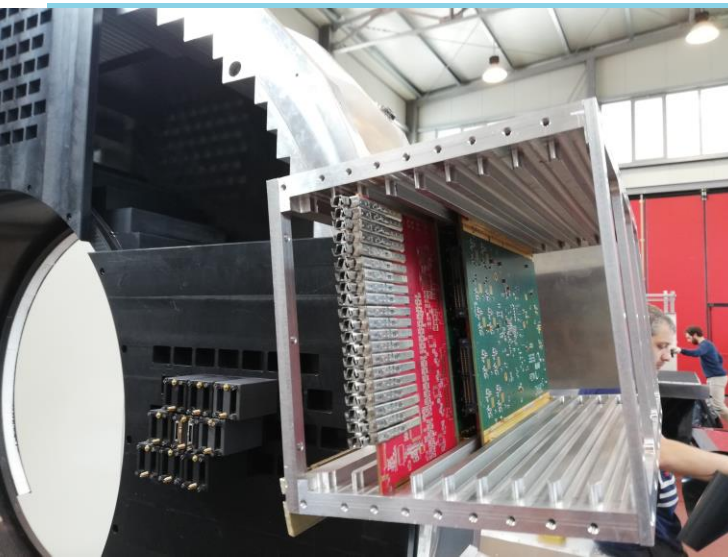
Board cooling

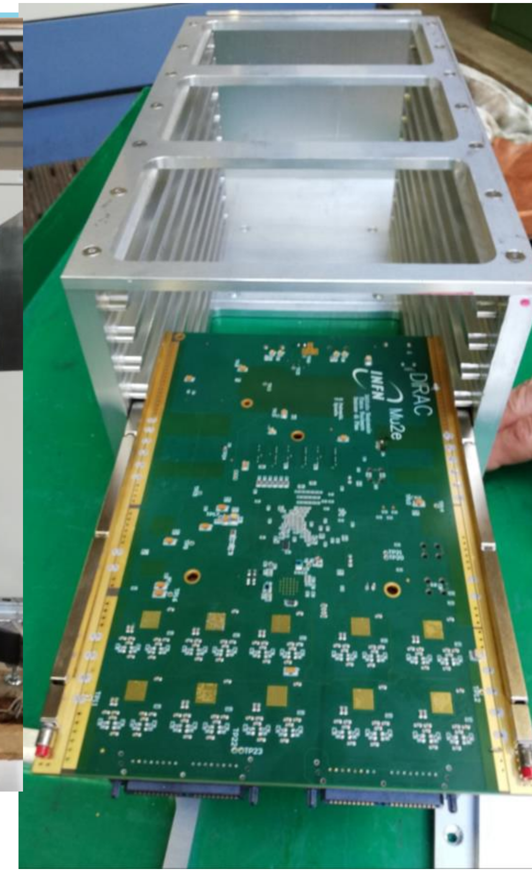


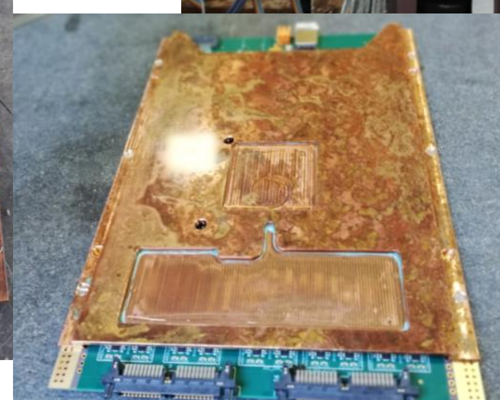


R1: thermal resistance between the junction and the edge of thermal plate
R2: thermal resistance between the junction and the edge of the board
R3: thermal resistance due to the contact (Cu-Cu) between the board and the thermal plate
R4: thermal resistance due to the contact (Cu-Al) between the board 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

Dirac board assembly and test.

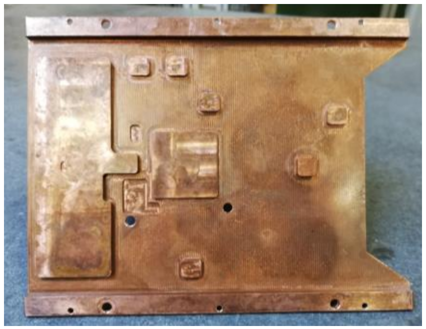




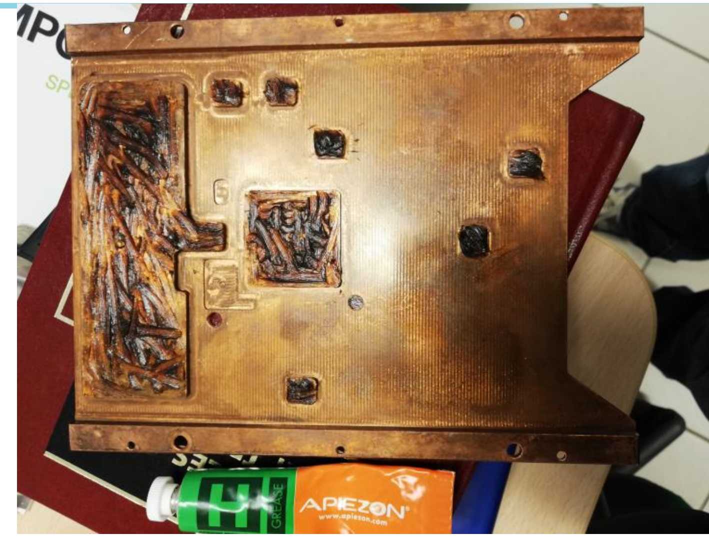


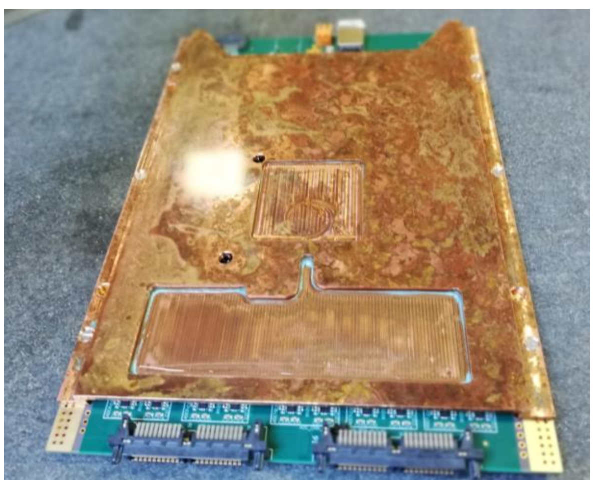
Crate design.

Copper Plate



We prototype three copper plate in our machine shop. We are testing under vacuum with different TIM materials.





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.

25 temperature point has been measured

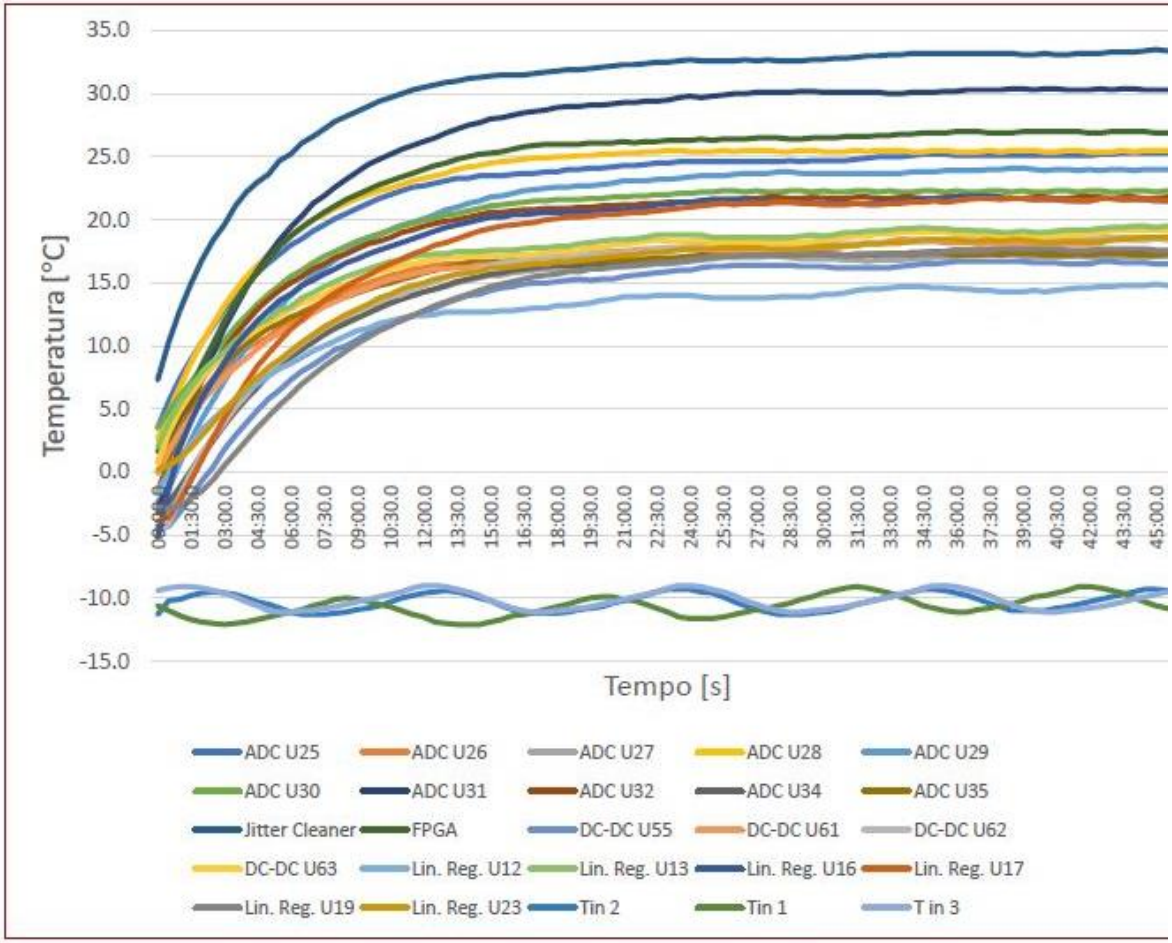
Crate cooling test.

Temperature test

INFN Fermilab Università di Pisa

Results:

- Total measurement time 45 minutes
- State status reached in 20 minutes



Crate cooling.

The first prototype of DIRAC has been available. We were able to do a realist thermal test on it.

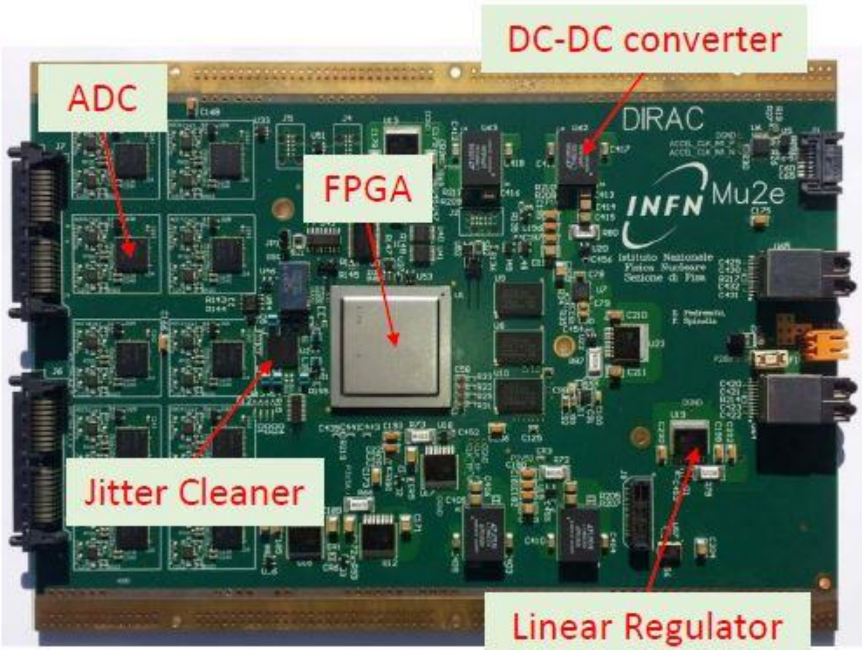
Componenti elettronici	Potenza dissipata [W]
10 ADC	5
1 FPGA	4
1 Jitter cleaner	0.8
4 DC-DC converters	7
6 Linear Regulator	20

The powers reported are the maximum reported on the reported on the components datasheet.

$$P_{diss}^{DIRAC} \approx 37W$$

$$P_{diss}^{INTERF} \approx 10W$$

$$P_{diss}^{Crate} \approx 423\,W$$



Justifying the new 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 first thing to do, is to reconsidered the secondary fluid. The actual fluid is a mixture of water and Monopropylene glycol (35%) volume that has the Freezing temperature -17-degree C. This cannot be used for lowering the SIPM temperature. The primary fluid must have a freezing point at one reasonable temperature in order to have a compact heat exchanger. The possibility to have a low freezing point at the operating temperature of -20/-24 of the fluid degree C implied a freezing point at least bellow -40/-50 C. Alternative possibilities excluding fluid that are corrosive, explosive, toxic etc are:

1. Following the initial choice, a Mixture of water and organic fluid like glycol ethylene, Monopropylene lowering the fluid freezing point. This implies to increasing of percentage of polymer at least up 40%. The degrading properties of the fluid (viscosity, thermal conductivity, heat capacity density) are not justifying their use any more.
2. Since 2002 we study in Pisa several cooling fluids to refrigerate the silicon tracker of CMS that operate at -20-degree C using fluid running at -30 C. Excluding fluid solutions that are not applicable that are more efficient for the cooling. We identify one family that are viscose fluids that have a good thermal conductivity base on hydrocarbons (modified benzene). There are several commercial. We tested SYLTHERM XLT(and the dowtherm J (Mixture of Isomers of an Alkylated Aromatic)
3. The other solution that we tested was the use of HFE7100 and PF5060. Thermally these fluid have a low viscosity but a low thermal conductivity. From a point of view thermal efficiency are not the best.The decision to use the PF5060 was dictated by the fact this fluid respect the other is clean.

Clean means if you have a leak does not cause damage to the experimental apparatus. It is like a solvent; it is an electrical insulator. The other fluids are very messy if drop falls they are able to cover a large area with a monomolecular layer.

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	C6F14 (a -20°C)	Monopropylene glycol 35%, water (a -10°C)
Density [Kg/m^3]	1000	1040
Specific heat [J/(Kg K)]	982	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]	0,057	0,429
Freezing temperature [°C]	-90	-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 C6f14

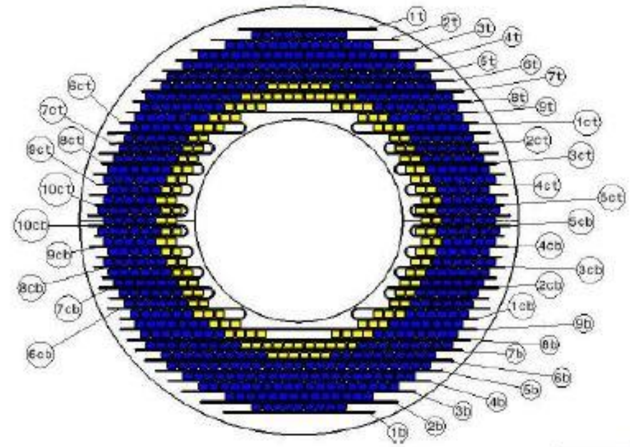
Gradient in cooling fluid 3.3 ^{0}C per mixture 30% organic

Gradient in cooling fluid 6 ^{0}C per C6F14

Summary of cooling.

Heat to remove

Item	Contribute	Number	Total
Internal SiPMs (yellow)	0.69W for each SiPM	284 for each disk	196W for each disk
External SiPMs (blue)	0.23W for each SiPM	1064 for each disk	245W for each disk
FEE boards	0.355W for each board	1348 for each disk	479W for each disk
Digitizer	46.9W for each board	9 for each crate	422W for each crate
TOTAL for both disks			**10300W**

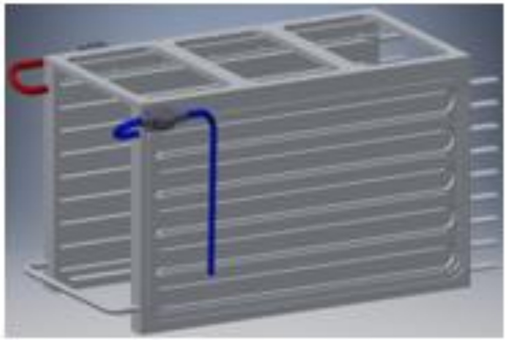


Exp. less

lt
isa)

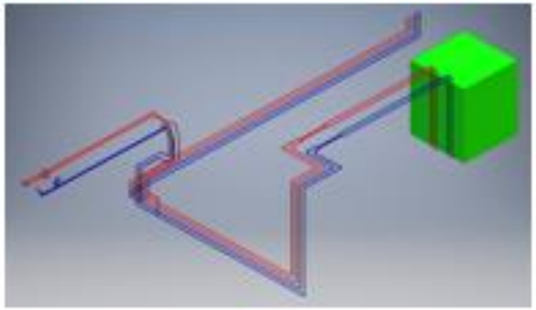
Item	Mass flow
Front end	1.1kg/s for one disk
Digitizer	0.8kg/s for one disk
Total for one disk	1.9kg/s
TOTAL for 2 disks	**3.8kg/s**

Hydraulic volumes



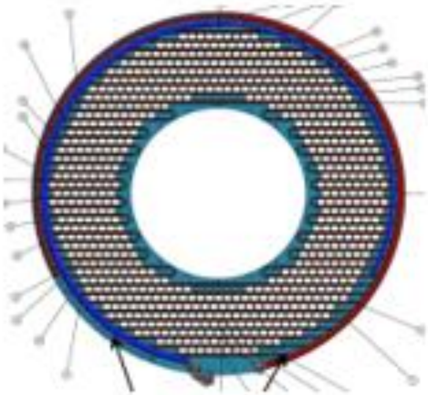
DAQ line:

$8 \cdot 10^{-3}\ m^3$



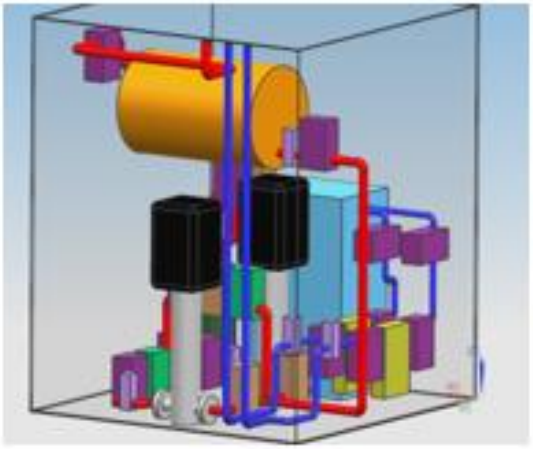
Routing lines:

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



FEE line:

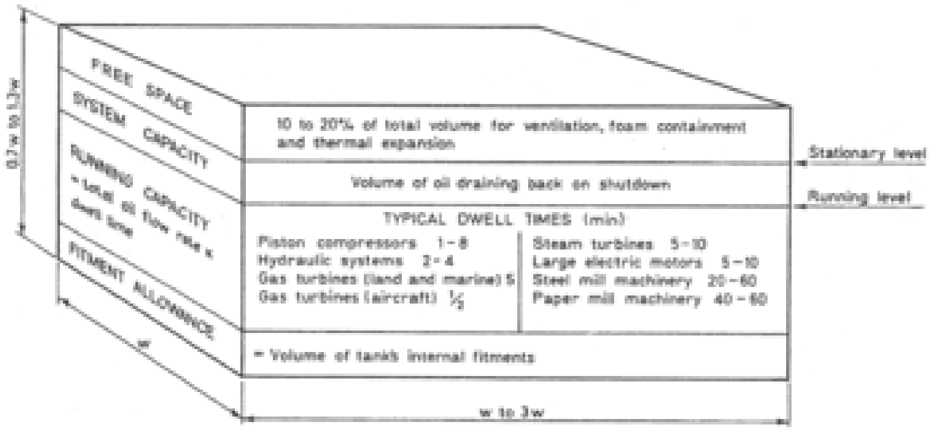
$3.27 \cdot 10^{-3}\ m^3$



Alcove:

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

Tank size

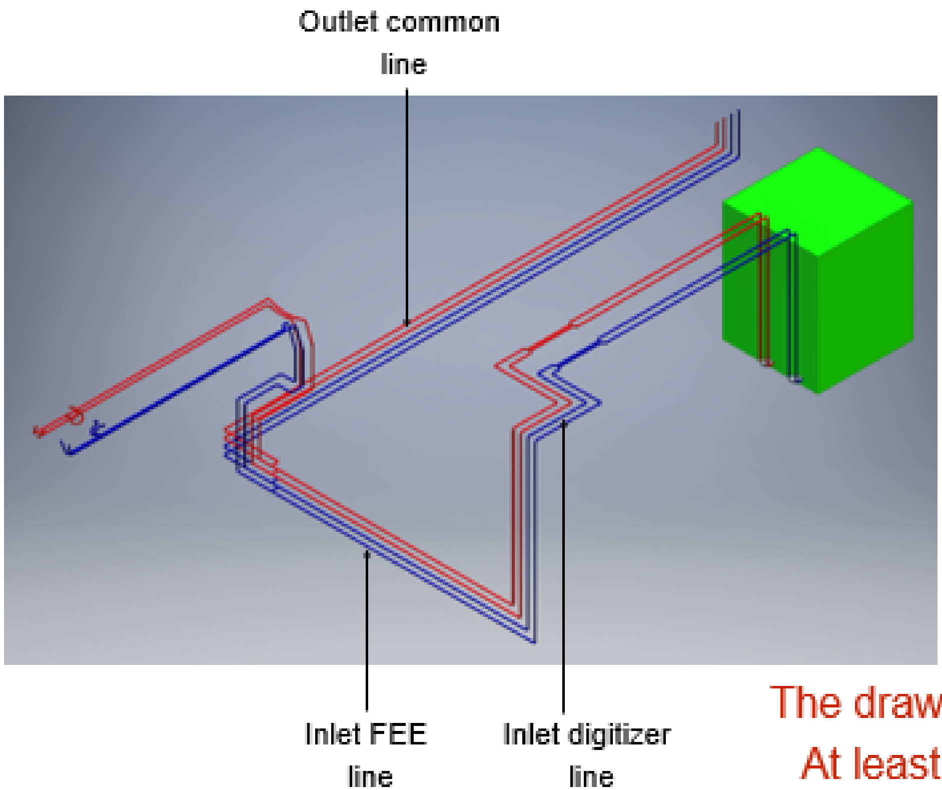


TANK VOLUME AND PROPORTIONS

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$

Aggiornamento sul raffreddamento del calorimetro.

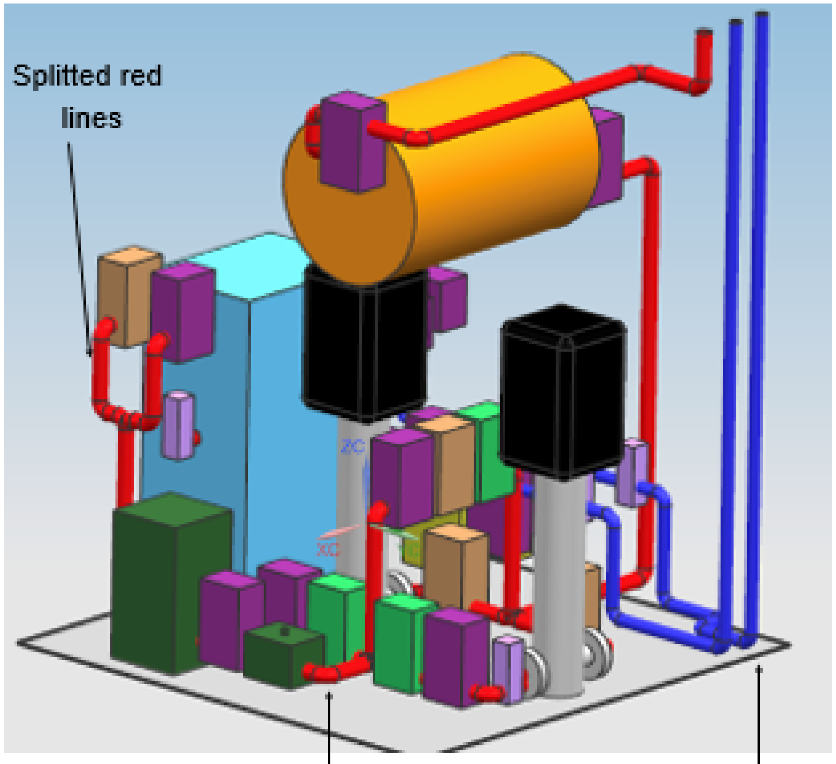
Routing lines pressure losses



	Flow rate	Pressure loss
Inlet FEE line (1")	2.5 kg/s	1.56 bar
Inlet Digitizer line (1")	2 kg/s	0.98 bar
Outlet common line (1 1/2")	4.5 kg/s	0.34 bar
Total pressure loss		**1.9 bar**

The drawing needs to be updated.
At least the outlet common line

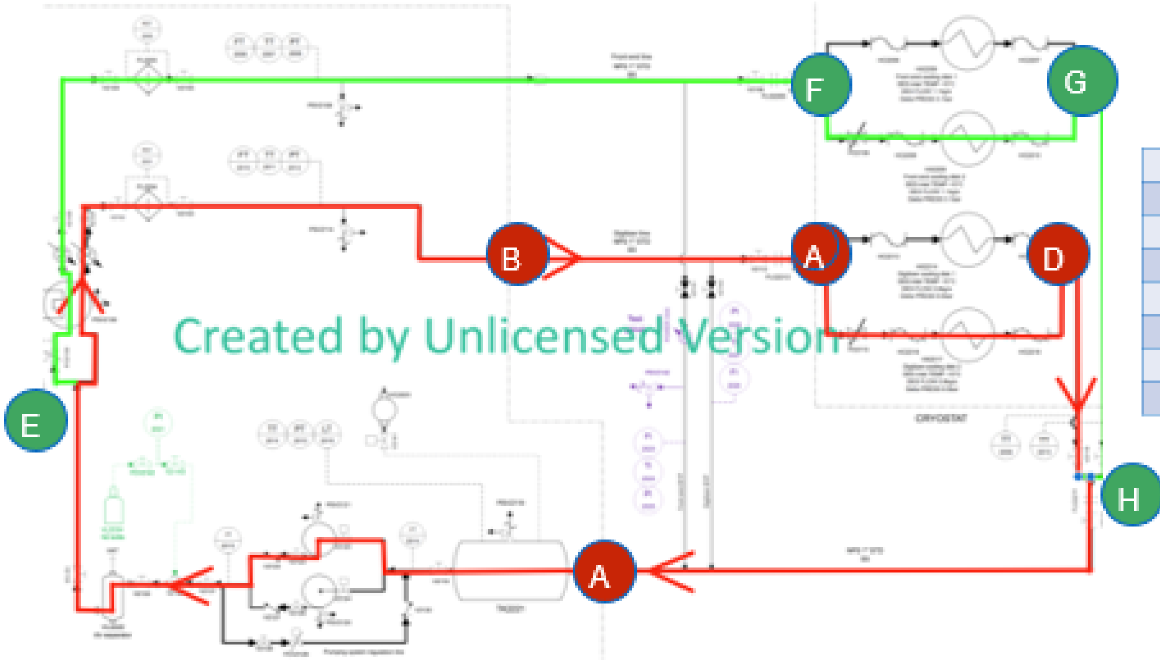
Mechanical alcove pressure losses



	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

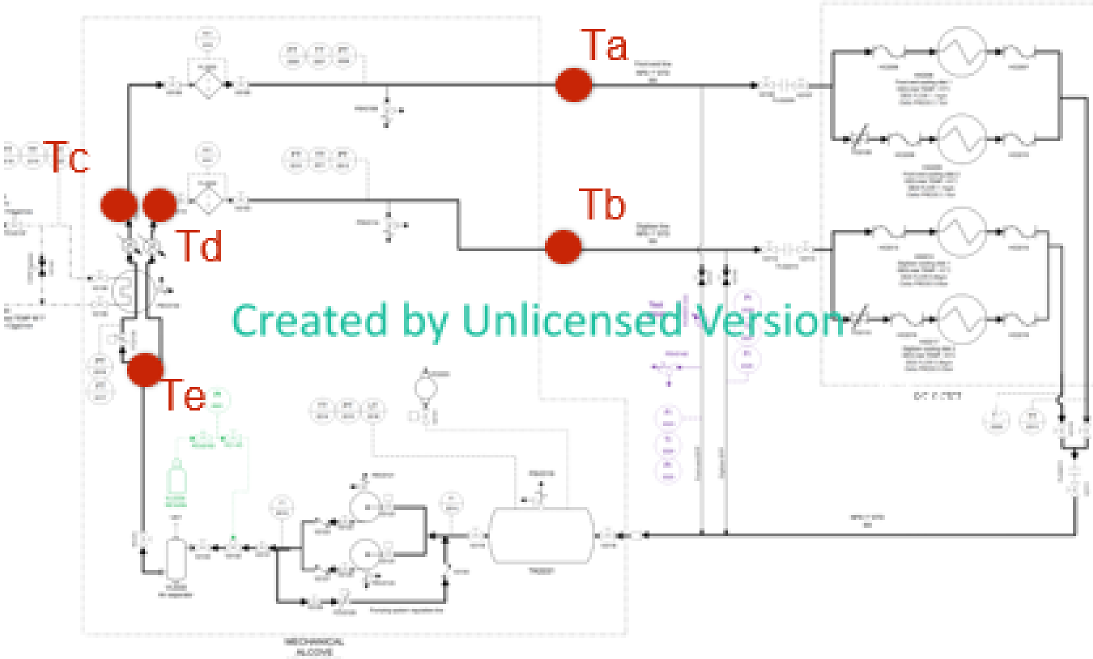
Pressure losses summary



PATH	PRESSURE LOSS
MECHANICAL ALCOVE A-B	0.23 bar
ROUTING DIGITIZER B-C	0.99 bar
CRATES COOLING LINE C-D	4.45 bar (9.1*)
COMMON OUTLET LINE D-A	0.34 bar
VALVES & EQUIPMENT	1.04 bar
MARGIN OF SAFETY	10%
TOTAL	7.5 bar (13.8*)

Balancing pressure E-B-C-D & E-F-G-H: 3.07 bar

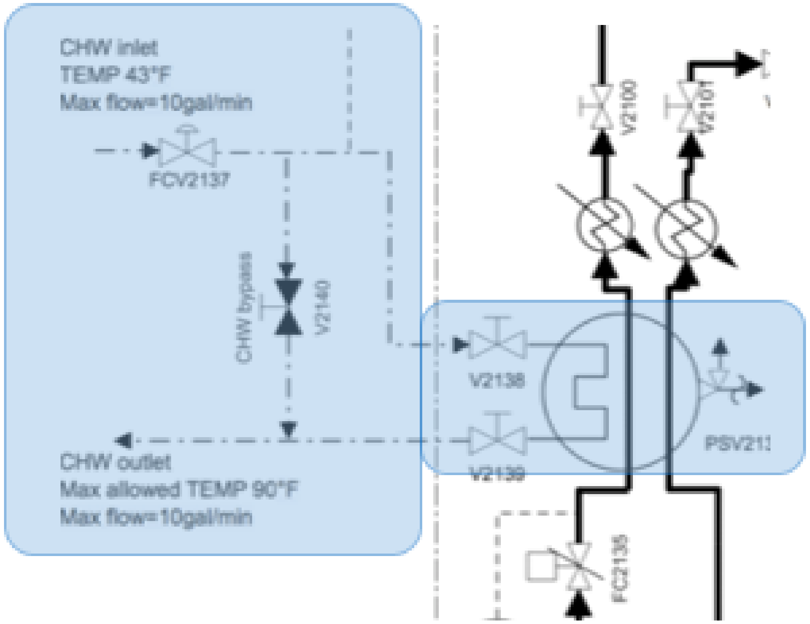
Fluid temperatures



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

Chiller requirements



- Chemically compatible with perfluorohexane
- 2 inlet and 2 outlet ports
- One channel crossed by 2 kg/s, and the other by 2.5 kg/s
- T entrance -21.1 °C, and outlet T -18.5 °C
- Able to absorb 10.8 kW
- Water cooled (preferably)
- Able to withstand a fluid pressure of 9 bar

Aggiornamento sul raffreddamento del calorimetro.

Open problems:

1) Max power available 25 Kwatt. Power needs to remove 10.8 Kwatt. Considering 4 Kwatt for pumping. We have 10 Kwatt that are marginal for the chiller efficiency and for the temperature control.

May be we need to have a very efficient chiller (more expensive)

We need to have to line at different temperature -26 degree C and -10 degree C.

2) Calorimeter temperatures control:

Equilibrium temperatures it is very difficult to estimate with a good level of confidence. All cold part are thermally isolate for the calorimeter structure and from crystals, but small thermal flow are unavoidable. (like the cold SIPM toward the crystal). On the other end cables and outer surface are warm and irradiated toward the calorimeter. In this situation we need to have an active temperature control system.

Revision of cooling operation and power.

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

1) Commission at SIDET.
2) Operation on the experimental area in air.
3)Operation at lower power and eventually high temperature in the first period.
4) Last period of operation at lower temperature and high power.

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

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 power dissipated are necessary. Furthermore we need to verify the compatibility with the current infrastructures.
- For instance Commission at SIDET. We need to be aware for instance If we run the system with different fluid from that one that will be used on cooling station. We need to have a procedure to clean and dry out efficiently the tubes before use the final fluid.(Risk involved)
- All operation phases must be detailed in deep regarding the environmental conditions and the necessary data (power consumption and temperature)

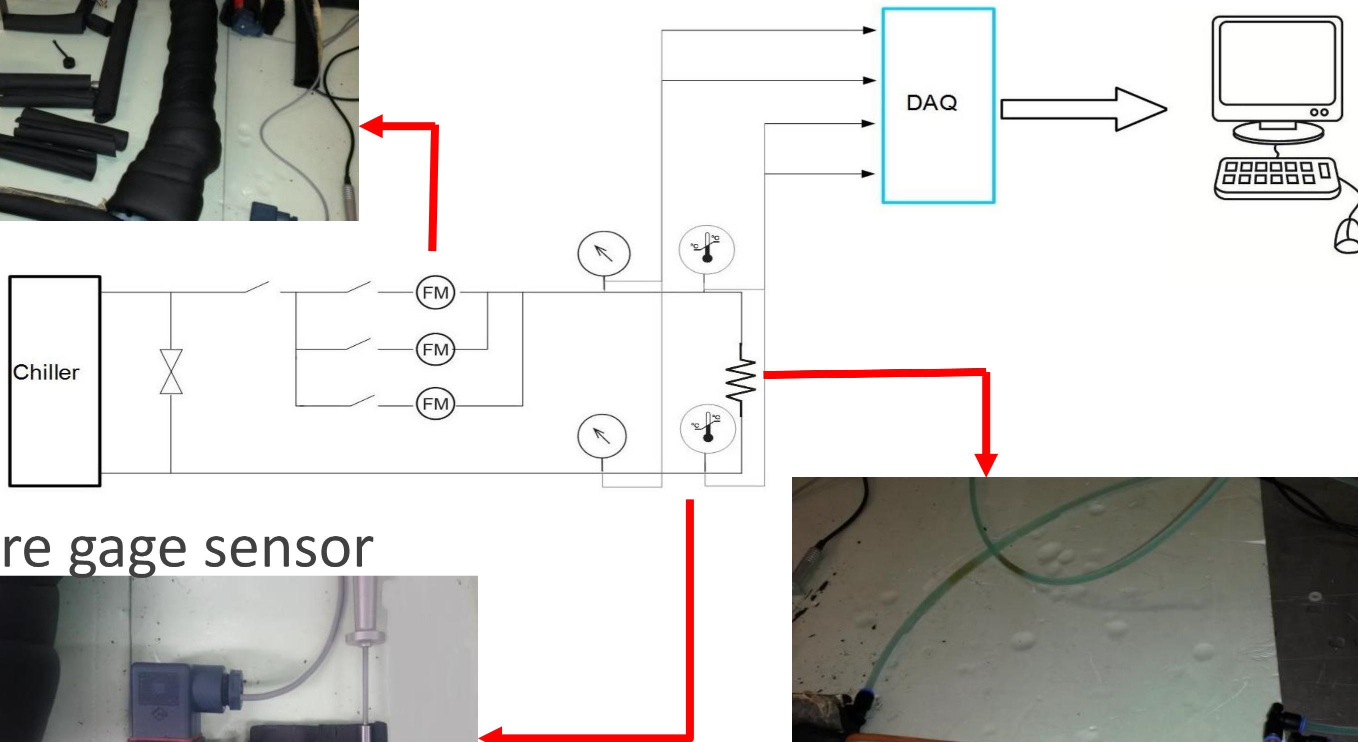
Cooling test at Pisa.

We operating this week a chiller that runs C6F14 that can work up -80 ^{0}C.
The idea is to re do the experimental pressure losses at -20 ^{0}C.
This will be done on the back line and on the creates.

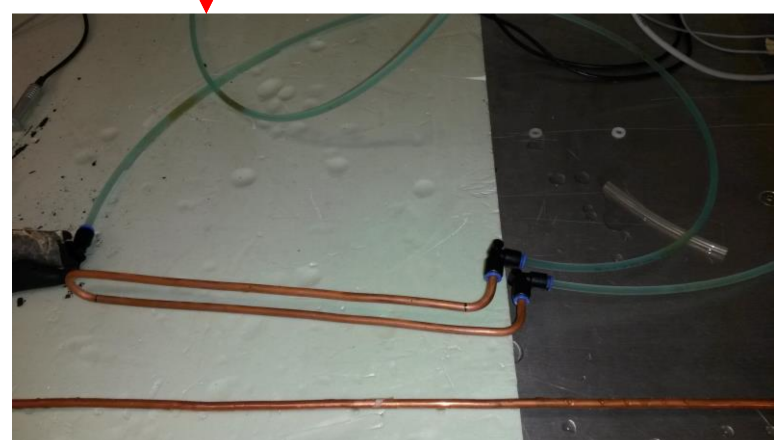
Experimental setup to measure pressure losses

Test fluid temperature at 0º C

Mass Flow meter



Pressure gage sensor



Conclusion

- We will continue to do the thermal test during the production of components. Very important to be able to predicted components behavior in the experiment.
- 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 new cooling specification of the cooling plant are right implemented in the experimental area.
- A process start to be able to write the cooling station specification.