CERN, 3 December 2015
Engineering Design Review

Istituto Nazionale
di Fisica Nucleare
Sezione di Milano

LHCb CO2 cooling EDR

UT evaporator concept and performance

Review of the suggested evaporator and manifold designs and results of performance measurements

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For the Milano UT Group

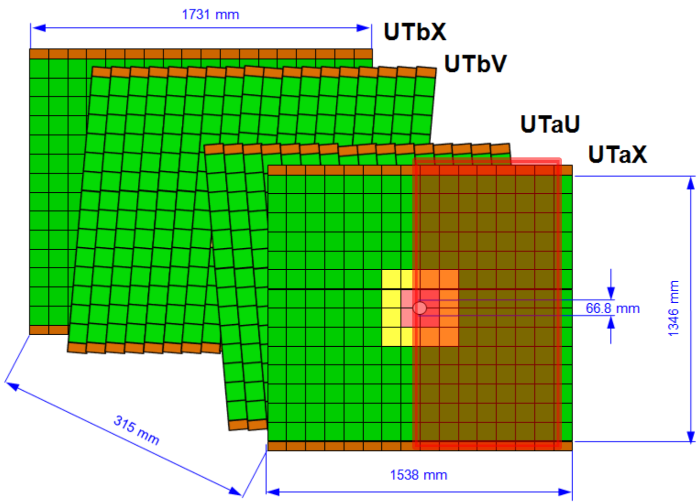
SUMMARY

- UT DETECTOR THERMAL MANAGEMENT
- F.E.A. THERMAL ANALYSIS
- CO_2 DISTRIBUTION DESIGN PROPOSAL
- CO_2 COOLING TEST
- WORK IN PROGRESS

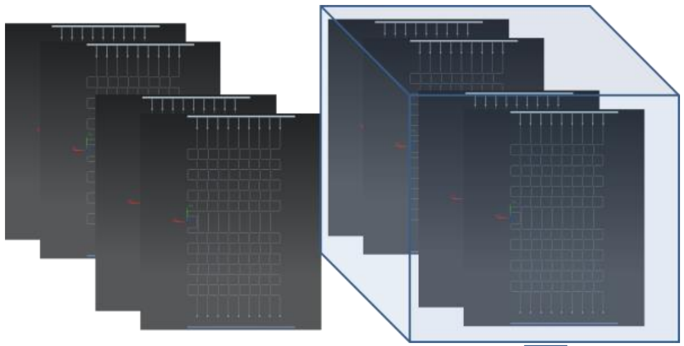
UT DETECTOR THERMAL MANAGEMENT

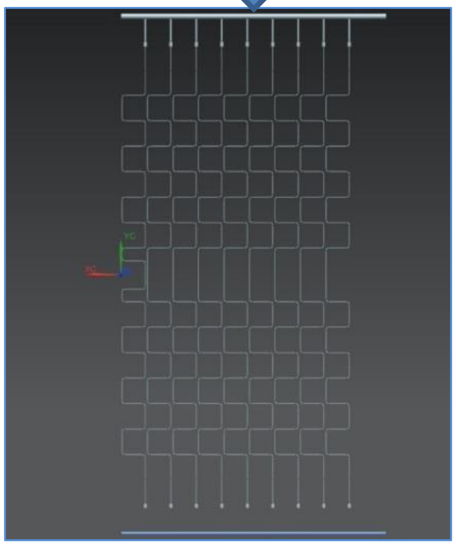
COOLING SYSTEM DESCRIPTION

SCHEMATIC DETECTOR GEOMETRY



- THE DETECTOR CAN BE SPLIT IN TWO HALVES
- Each one is made of 4 "half planes"
- Each "half plane" is made of 8 or 9 parallel staves (8+8-9+9)
- Each "half plane" has its inlet and its outlet coolant connection

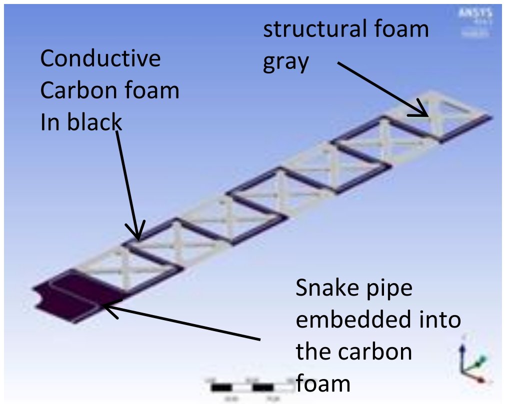




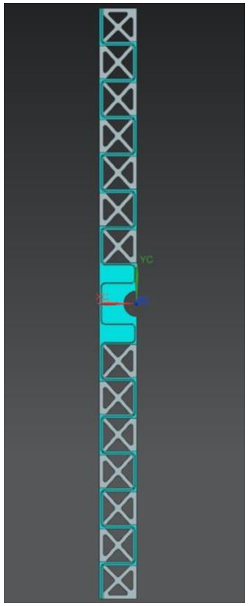
1 of the 8 "Half-planes" showing the cooling pipes integrated into the staves

The pipe routing is designed to remove the heat where it is produced, passing underneath the read-out ASICs power sources and cooling the sensors

STAVE INTERNAL STRUCTURE



This picture is ½ of the central stave "C" type, mounted near the beam pipe



STAVE COOLING PIPE

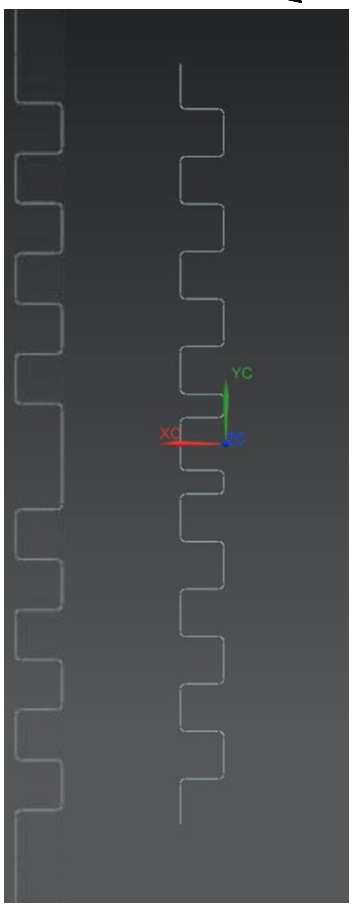
There are 2 cooling pipe geometries:

Number: 60 staves
A,B type

Pipe Length 2,82 m
Heated length = 14 * ~85 mm = 1,19 m

Number: 8 central staves
C type, it is required to have 2 more passages under 2 ASICs rows

Pipe Length 3 m
Heated length = 16 * ~85 mm = 1,36 m

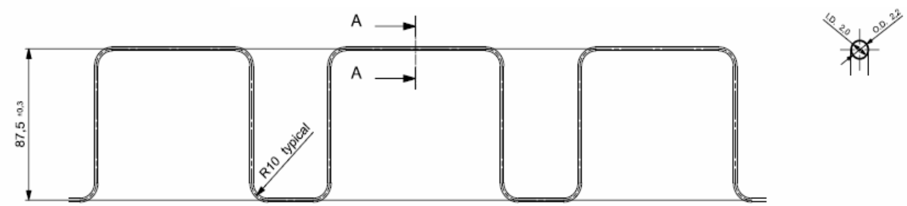


Titanium C.P. 2 from HIGH-TECH U.K. Company
I.D. 2,025 mm
O.D. 2,275 mm

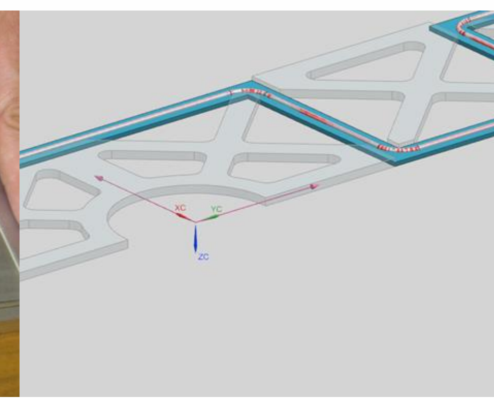
cooling snake pipe produced starting from a 3 .1 m long straight pipe annealed ¼ hard.
Bending radius R= 10 mm

Optimal pipe material as for:

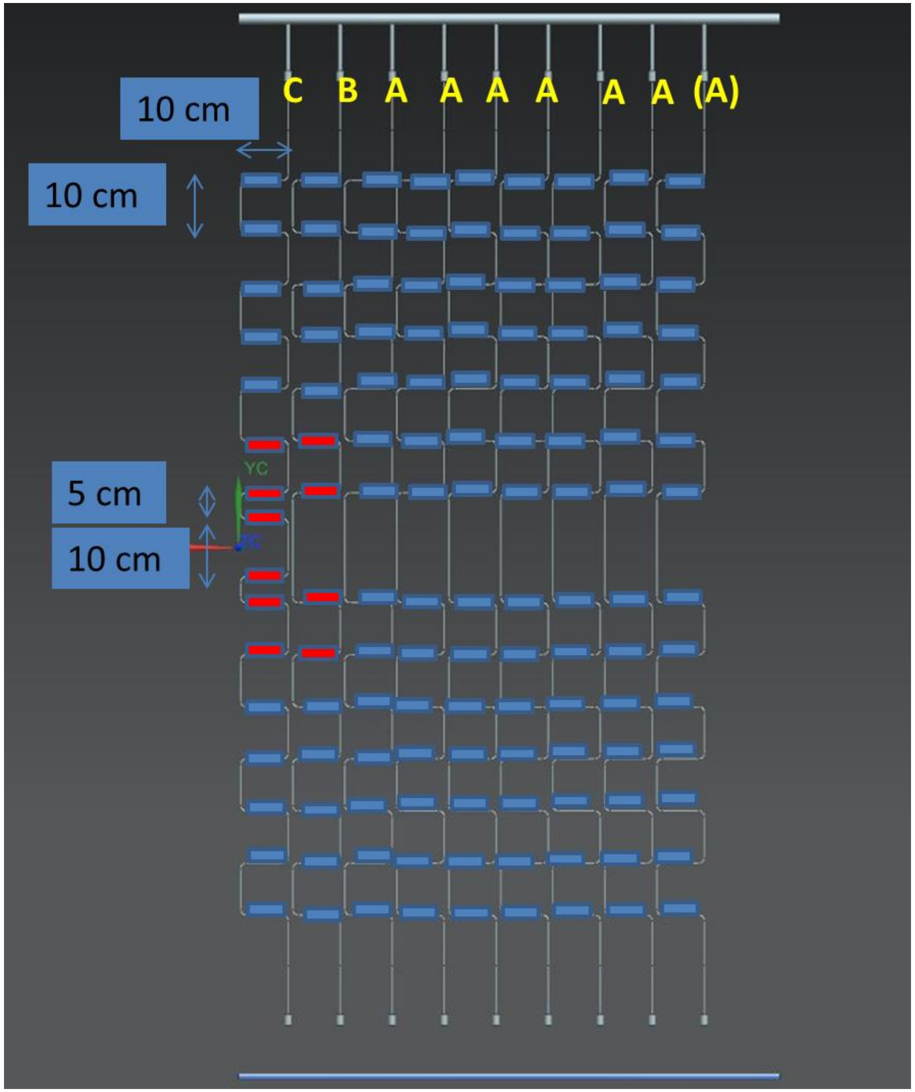
- big radiation length
- low thermal expansion coefficient
- Big strength
- Good thermal conductivity
- Thin pipe availability

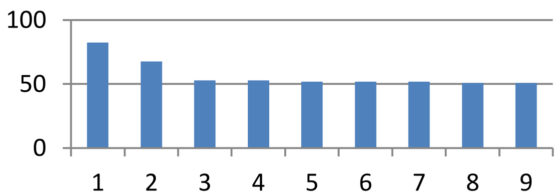


Bended pipes fit very well in the geometry mask after the bending



DETECTOR PLANE POWER DISTRIBUTION





= 4 ASICs

= 8 ASICs

Nominal power
0,768 WATT/ASIC

+ power dissipation in the cables (+10%)

Sensors self-heating is calculated to be almost neglible

PARALLEL EVAPORATING CHANNELS
Differencies:

- GEOMETRY

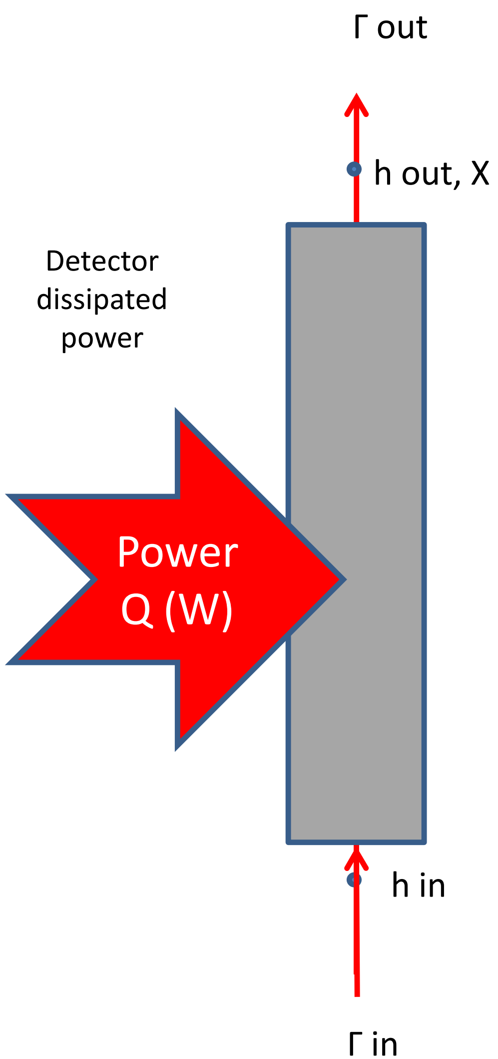
The snake pipe in the “C” central stave

- 4 more 90° bends
- bit longer (+ 6 % length)

- THERMAL LOADS

The “C” central stave has 76 W nominal power, the other staves have less power, down to 50 W in the external ones
(3:2 ratio between max/min powering)

MASS AND ENERGY BALANCE



<u>mass conservation law</u>

Γ = mass flow rate (g/s)

<u>Γ in = Γ out</u>

<u>energy conservation law</u>

H = hentalpy (J/kg)

<u>Q = Γ *(h out – h in)</u>

(W = g/s * J/g)

Mass flow rate

=> Γ = Q / (h out – h in)

- INLET CO2 LIQUID SUBCOOLED NEAR TO SATURATION h in = ~ h liq
- X ~ 0

- OUTLET VAPOUR FRACTION X
- H lv := hentalpy difference liquid to vapour (depending slightly on the evaporation pressure: 280-300 kJ/kg in the range of interest)

- X := outlet vapour fraction
- h out = hl + X * hlv

=> (h out – h in) = X * hlv

- Mass flow rate

⇒ **Γ = Q / X * hlv**

design mass flow-rate needed to extract given power Q, using evaporating fluid the from saturated liquid to a exhaust mixture with a given X fraction of the vapor phase

STAVE ENERGY BALANCE

DESIGN REQUIREMENTS FOR THE COOLING SYSTEM:

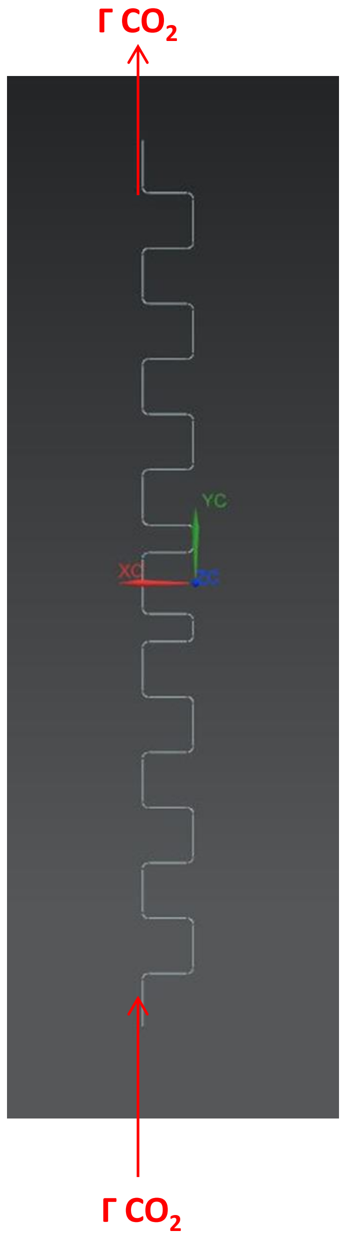
- **INLET CO_2 LIQUID SUBCOOLED, NEAR TO SATURATION**

- **OUTLET VAPOUR FRACTION X OUT NOMINAL DESIGN 0.3, (0.5 MAX)**

  TO AVOID DRY-OUT WITH SOME MARGIN

  TO LET IN THE EXHAUST A FRACTION OF LIQUID CO_2 TO CONDITION THE CO_2 SUPPLY EVAPORATING IN THE ESTERNAL JACKET OF THE COAXIAL CONNECTION PIPE

H lv = hentalpy difference liquid to vapour = 280 kJ/kg
At evaporation temperature of -25 °C



CALCULATION OF THE MASS FLOW-RATE

Γ CO_2 = Q / X * hlv
= POWER /X *DELTA $H_{LIQ\text{-}VAP}$

CENTRAL "C" STAVE

IF X OUT = 50 %
Γ = 75 W / 0,5*280 kJ/kg= ~ 0.5 g/s

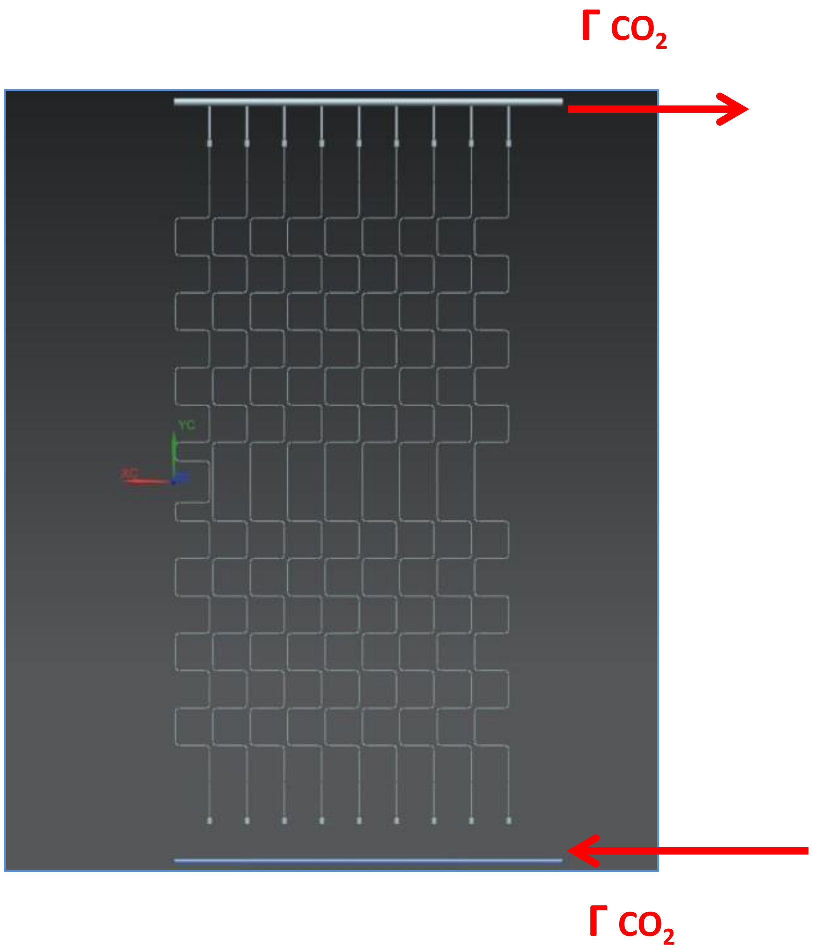
IF X OUT = 30 %
Γ = 75 W / 0,3*280 kJ/kg= ~0.9 g/s

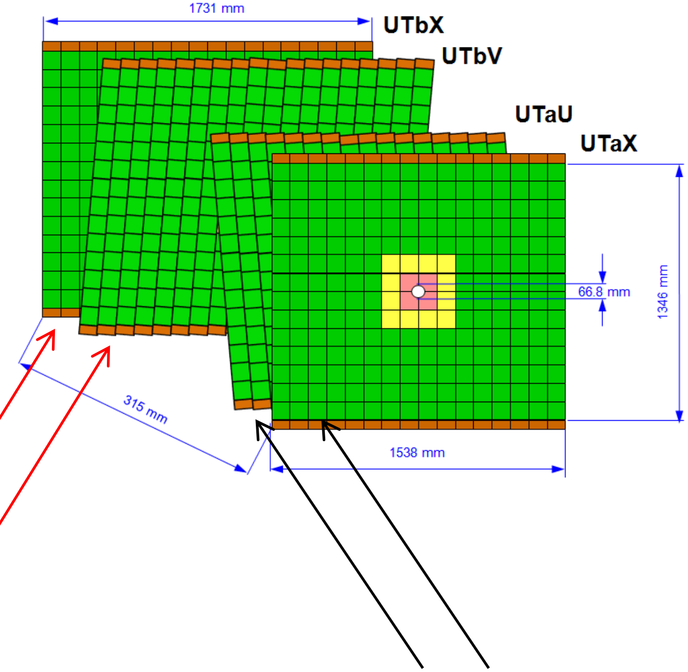
LATERAL "A" STAVE

IF X OUT = 50 %
Γ = 50 W / 0,5*280 kJ/kg= ~ 0.4 g/s

IF X OUT = 30 %
Γ = 50 W / 0,3*280 kJ/kg= ~ 0.6 g/s

HALF PLANES ENERGY BALANCE





Half planes UTbV, UTbX
with 9 staves

Q = ~512 W
X outlet= 30 %
H lv = 280 kJ/kg

Coolant Mass flow rate
Γ = Q / X * hlv
⇒ Γ = ~6 g/s

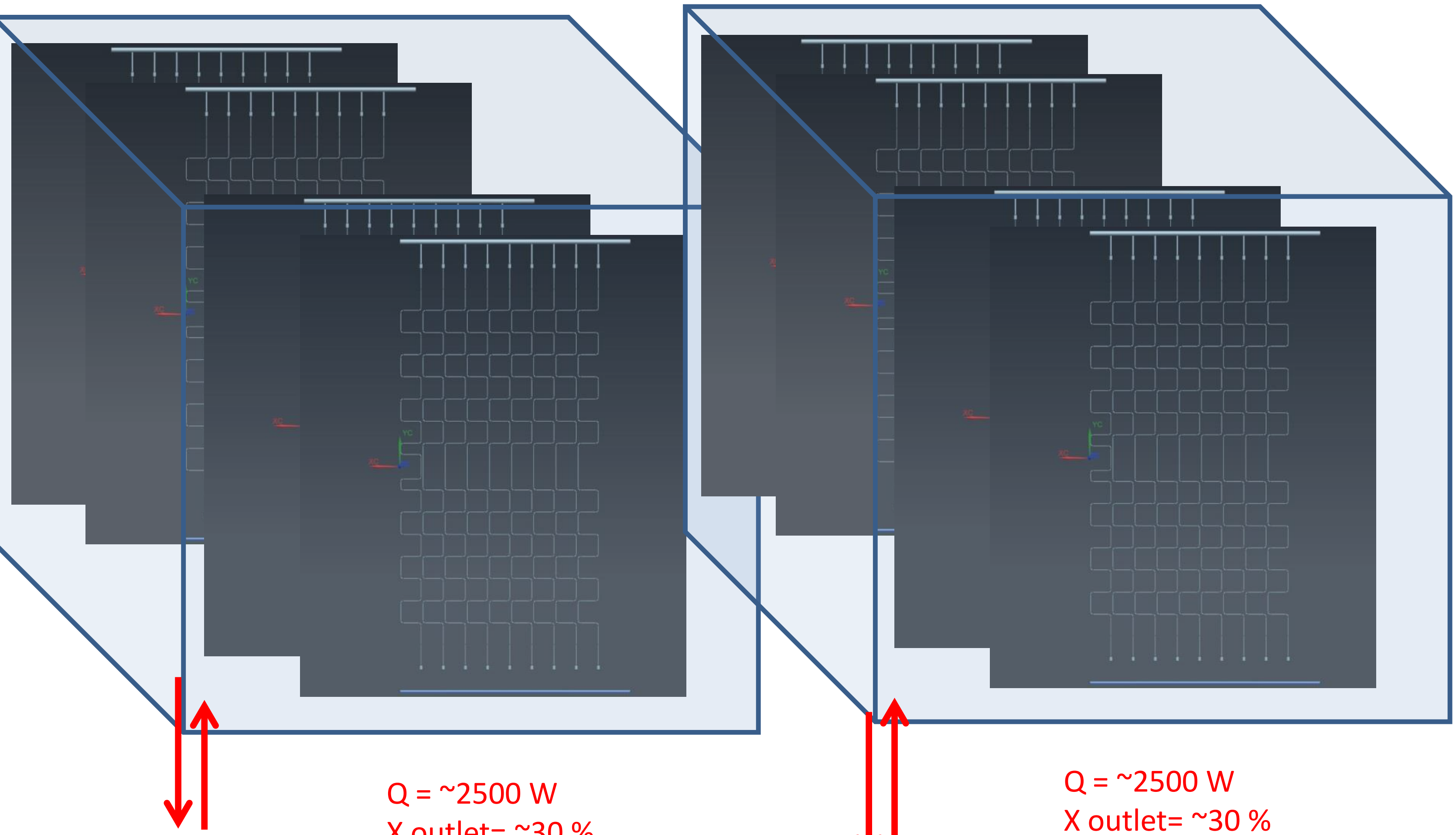
Half planes UTaX, UTaU
with 8 staves

Q = ~460 W
X outlet= 30 %
H lv = 280 kJ/kg

Coolant Mass flow rate
Γ = Q / X * hlv
⇒ Γ = ~5,5 g/s

UT DETECTOR GLOBAL ENERGY BALANCE

Extimate including a 20% margin
used in the cooling requirements document
to account for ambient heat pick-up



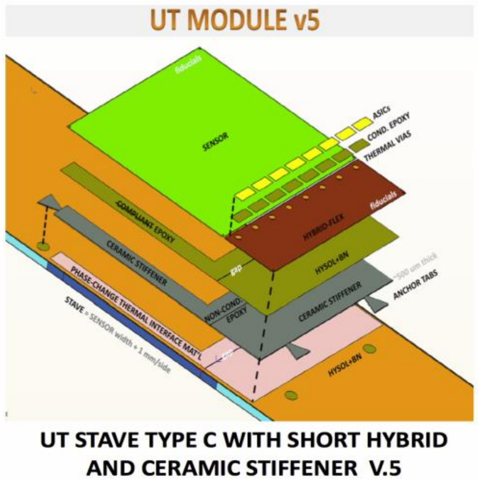
Γ CO_2

Q = ~2500 W
X outlet= ~30 %
H lv = ~280 kJ/kg
Coolant Mass flow rate
Γ = Q / X * hlv
⇒ Γ CO_2 = ~30 g/s

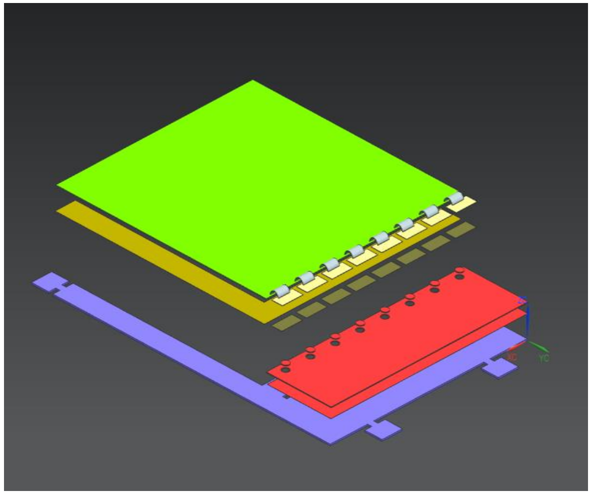
Γ CO_2

Q = ~2500 W
X outlet= ~30 %
H lv = ~280 kJ/kg
Coolant Mass flow rate
Γ = Q / X * hlv
⇒ Γ CO_2 = ~30 g/s

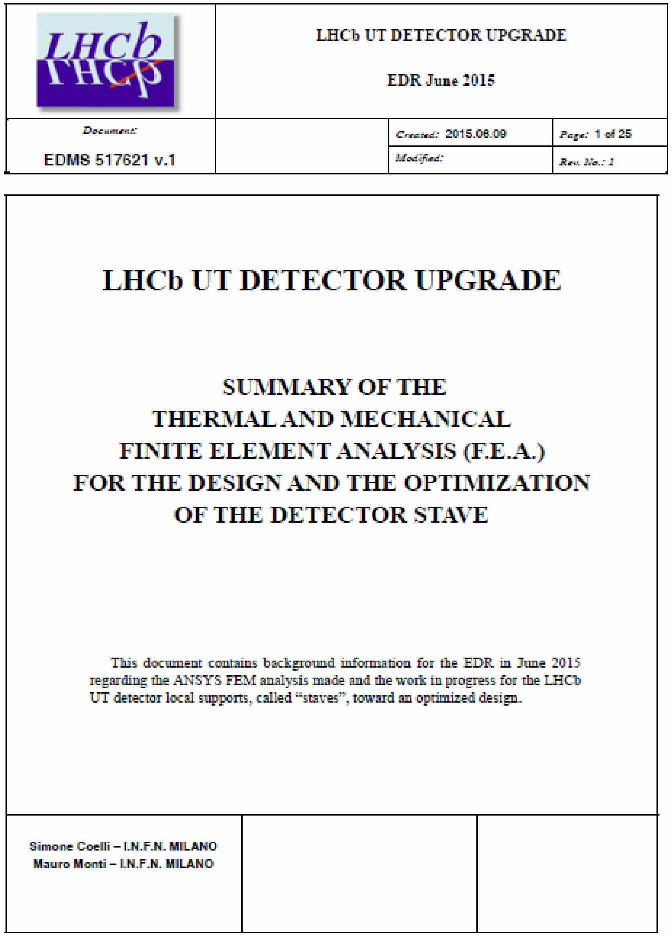
DETECTOR F.E.A. ANALYSIS



Model from Ray Mountain (Siracuse Un.)



ANSYS model
Note copper thermal vias under the ASICs passing through the hybrid (Kapton) in a design hypothesis



	LHCb UT DETECTOR UPGRADE EDR June 2015		
Document: EDMS 517621 v.1		Created: 2015.06.09 Modified:	Page: 1 of 25 Rev. No.: 1

LHCb UT DETECTOR UPGRADE

SUMMARY OF THE THERMAL AND MECHANICAL FINITE ELEMENT ANALYSIS (F.E.A.) FOR THE DESIGN AND THE OPTIMIZATION OF THE DETECTOR STAVE

This document contains background information for the EDR in June 2015 regarding the ANSYS FEM analysis made and the work in progress for the LHCb UT detector local supports, called "staves", toward an optimized design.

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Mauro Monti – I.N.F.N. MILANO

Design version v.5
- SHORT HYBRID
- L-shaped CERAMIC STIFFENER + removable glue

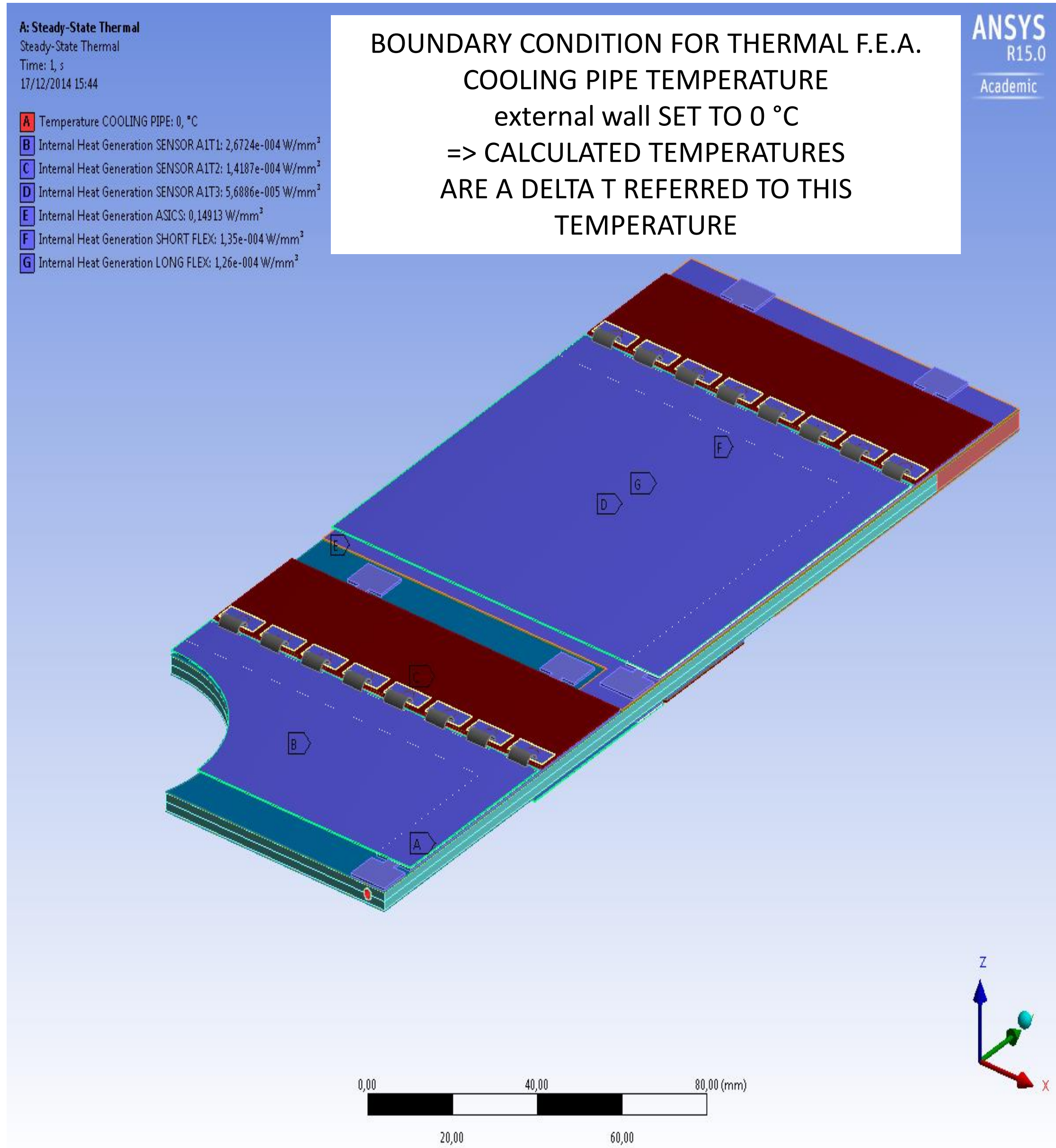
MATERIALS UNDER STUDY:
- PBN (Pyrolytic Boron Nitride) K = 60/60/2; thickness = 0.500 mm
- AlN (Aluminum Nitride) K = 180/180/180; thickness = 0.250 mm

=> EDMS DOCUMENT:
https://edms.cern.ch/document/1517621/1

DETECTOR HEAT LOADS

A: Steady-State Thermal
Steady-State Thermal
Time: 1, s
17/12/2014 15:45

- **A** Temperature COOLING PIPE: 0, °C
- **B** Internal Heat Generation SENSOR A1T1: 2,6724e-004 W/mm³
- **C** Internal Heat Generation SENSOR A1T2: 1,4187e-004 W/mm³
- **D** Internal Heat Generation SENSOR A1T3: 5,6886e-005 W/mm³
- **E** Internal Heat Generation ASICS: 0,14913 W/mm³
- **F** Internal Heat Generation SHORT FLEX: 1,35e-004 W/mm³
- **G** Internal Heat Generation LONG FLEX: 1,26e-004 W/mm³

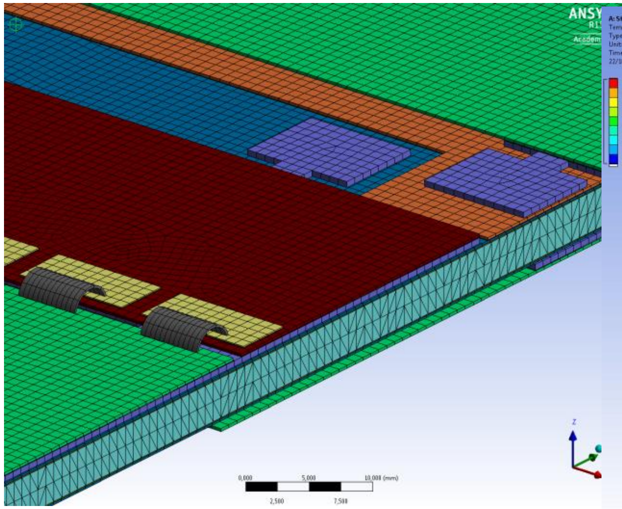


Read-out chip POWER:
+ 0.768 W / ASIC

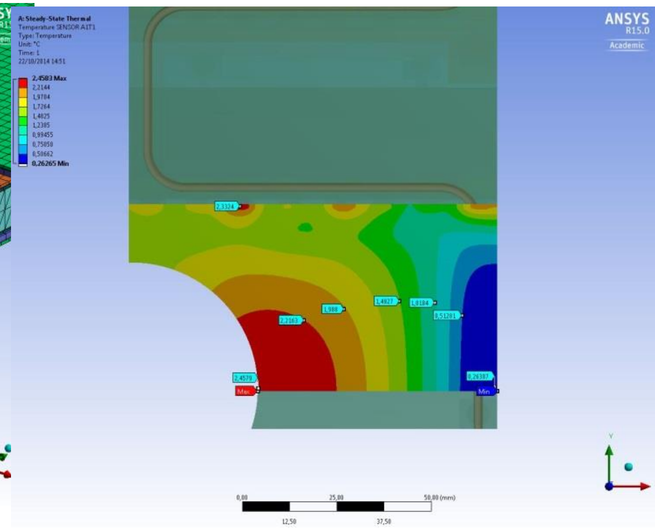
POWER dissipated in the FLEXBUS:
+ 10 % of the transported power
(i.e. 8 * 0,768 = 6,14 W)

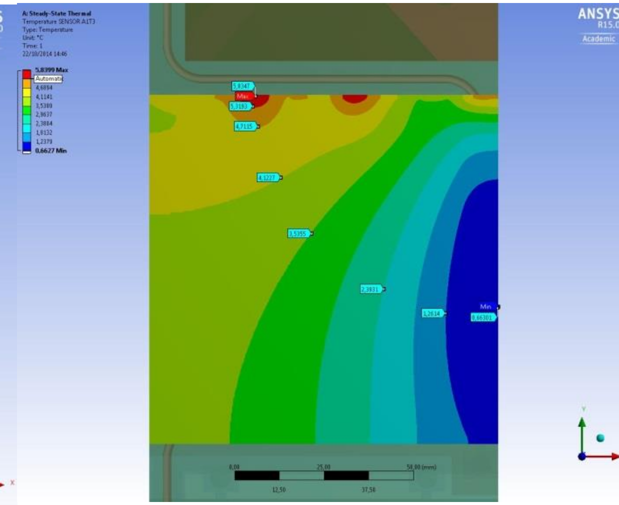
SENSOR SELF HEATING:
T1 = + 0.261 W
T2 = + 0.171 W
T3 = + 0.135 W

F.E.A. ANALYSIS



ANSYS F.E. MODEL





STIFFENER WITH SLITS - Material PBN (Pyrolytic Boron Nitride)
Thermal conductivity k = 60/60/2 - Ceramic thickness = 0.500 mm

SENSOR A1.T1
MAX DELTA T = 2.2 °C

SENSOR A1.T3
MAX DELTA T = 5.1 °C

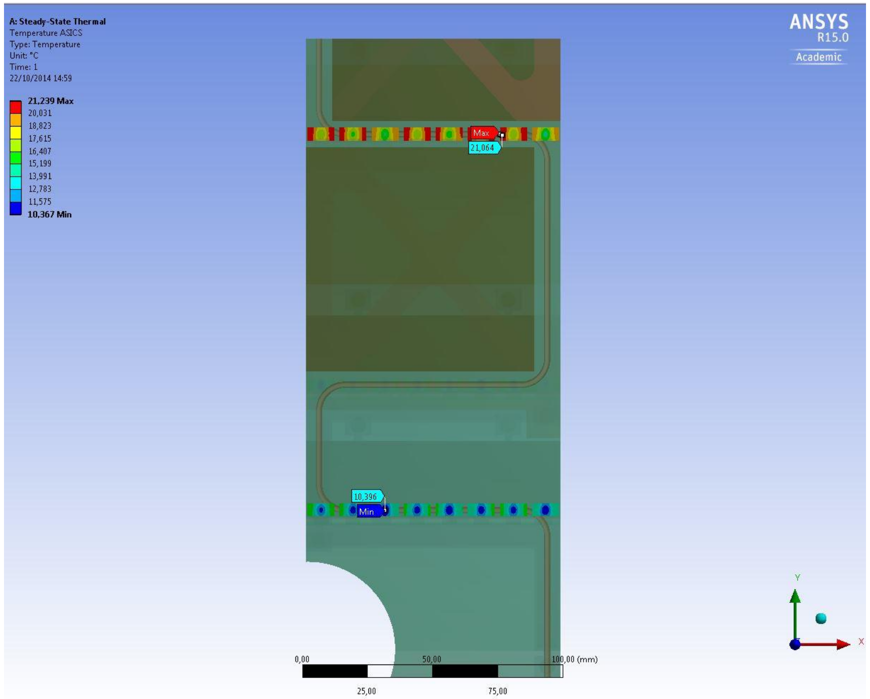
⇒ FOR BOTH CERAMIC MATERIALS (PBN/AlN):

SENSOR T1: MIN TEMP ~ + 0,2 °C, REF TO COOLING PIPE TEMP
SENSOR T2: MIN TEMP ~ + 0,5 °C, REF TO COOLING PIPE TEMP
BOTH SENSOR T1 AND T2: MAX TEMP ESCURSION OVER THE SILICON SENSOR
DELTA T ~ 2- 2.2 °C

SENSOR T3: MIN TEMPERATURE ~ + 0,6-0,8 °C, REF TO COOLING PIPE TEMP
MAX TEMPERATURE ~ + 5,8 °C, REF TO COOLING PIPE TEMP

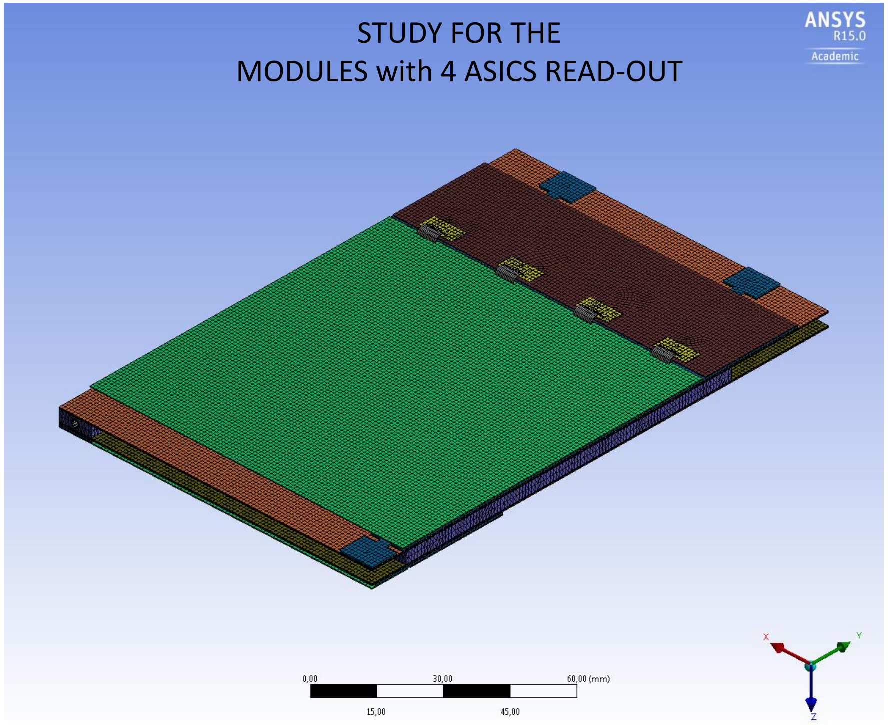
MAXIMUM TEMPERATURE ESCURSION OVER THE SILICON SENSOR
DELTA T ~ 5°C

F.E.A. ANALYSIS



=> FOR BOTH CERAMIC MATERIALS (PBN/AlN):

ASICs TEMPERATURE
IN THE RANGE + 17-21 °C, REFERRED TO COOLING PIPE TEMP



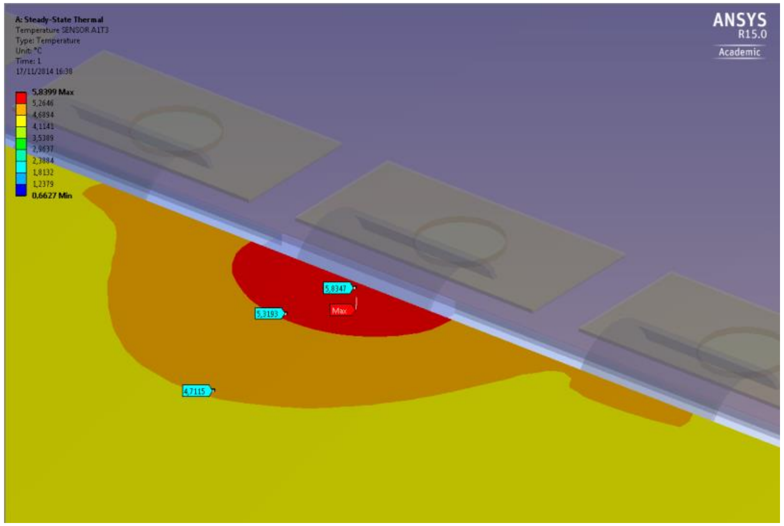
FOR BOTH CERAMIC MATERIALS (PBN/AlN):
SENSOR T3:

MIN TEMP ~ + 0,7 °C, REF TO COOLING PIPE TEMP
MAX TEMPERATURE ~ + 4,3-4,9 °C, REF TO COOLING PIPE TEMP

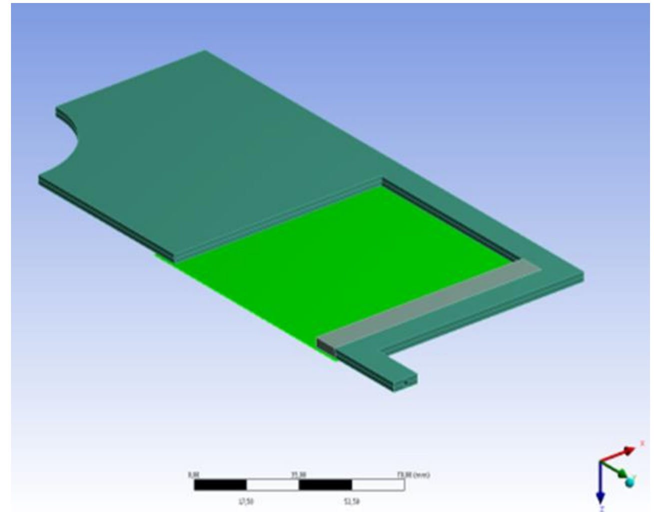
MAXIMUM TEMP ESCURSION OVER THE SILICON SENSOR
DELTA T ~ 3,6-4,2 °C

=> CERAMIC STIFFENER WITHOUT SLITS COULD BE USED FOR THE 4 ASICs SENSORS

F.E.A. ANALYSIS
DESIGN WITH THERMAL OPTIMIZATION



HOT SPOT on the sensor (A1.T3)
⇒ Driving the sensor ΔT
⇒ GOAL: MINIMIZE THIS EFFECT

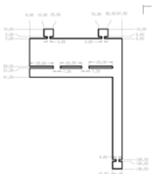


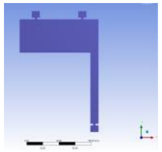
extension of the carbon foam high conductive material (gray) under the T3 sensor

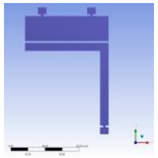
using a snake pipe design the temperature difference across the sensor is mainly due to the hot spot (maximum) temperature in the silicon sensor, located on the side of the sensor not glued on the stave.
The coolest points of the sensor are almost at the same temperature, few degrees above the cooling pipe temperature
⇒ An effective way to reduce delta T over the sensor is to reduce the local hot spots

CALCULATED LOCAL THERMAL PERFORMANCES
for the «C» central stave, sensors T1, T2, T3

SUMMARY TABLE







STIFFENER TYPE	STIFFENER MATERIAL	SENSOR A1.T1 MAX DELTA T [°C]	SENSOR A1.T2 MAX DELTA T [°C]	SENSOR A1.T3 MAX DELTA T [°C]	ASICs MAX DELTA T OVER THE PIPE [°C]
CERAMIC STIFFENER WITH SLITS	PBN - THICKNESS 500 µm	2.2	2.1	5.1	21
	AlN- THICKNESS 250 µm	2.2	2.0	5.0	17
CERAMIC STIFFENER WITHOUT SLITS	PBN - THICKNESS 500 µm	2.8	2.7	6.7	20
	AlN- THICKNESS 250 µm	2.5	2.4	5.9	17
CERAMIC STIFFENER SEPARATED INTO TWO PARTS	PBN - THICKNESS 500 µm	2.0	1.9	3.0	23
	AlN- THICKNESS 250 µm	1.8	1.8	2.2	19

- THE TEMPERATURE DIFFERENCE ACROSS THE SENSORS IS ALWAYS ACCEPTABLE FOR THE INNERMOST SENSORS T1 AND T2 (around 2 °C)
- THE TEMPERATURE DIFFERENCE ACROSS THE SENSOR T3 (in the central stave) ACCEPTABLE FOR BOTH THE CERAMIC MATERIALS IN THE DESIGN GEOMETRY WITH SLITS (around 5 °C)

=> Both PBN and AlN solutions provide efficient heat transfer

- ASICs TEMPERATURE ARE ALWAYS WITHIN SPECIFICATION. Operative temp. cooling pipe will be ~ -15 °C, ASICs ~ +5 °C, with a large margin against the limit of 40 °C.

CO_2 DISTRIBUTION LINES AND MANIFOLDING

Sum-up of the requirements for the staves CO_2 coolant connection lines:

OUTLET CONNECTIONS

- Transport the exhaust CO_2 coolant flow, leaving the staves, to the detector outlet
- Mixture of CO_2 liquid + vapour, evaporated fraction 30%, max 50%, according to the design nominal operational conditions
- Inner diameter I.D. >= I.D. stave titanium cooling pipe = 2 mm, to **minimize pressure drop downstream of the evaporator** (that could be detrimental for thermo-hydraulic stability)
- Design with an even pressure drops on all the parallel lines, using the same geometry for all the outlet connections
- AISI 316L stainless steel
- More flexible as possible to facilitate mounting and demounting the1/8” VCR connection stave interface
- Choice: commercially available AISI 316L, I.D.= 2.00 mm, O.D.= 2.50 mm
- “coil” design + annealing after bending to enhance the pipe flexibility
- Pipes welded to the outlet manifold, to save space
- 8 or 9 pipes non detachable on the manifold side
- Need tools space to tighten the VCR joints only on the stave side

INLET CONNECTIONS

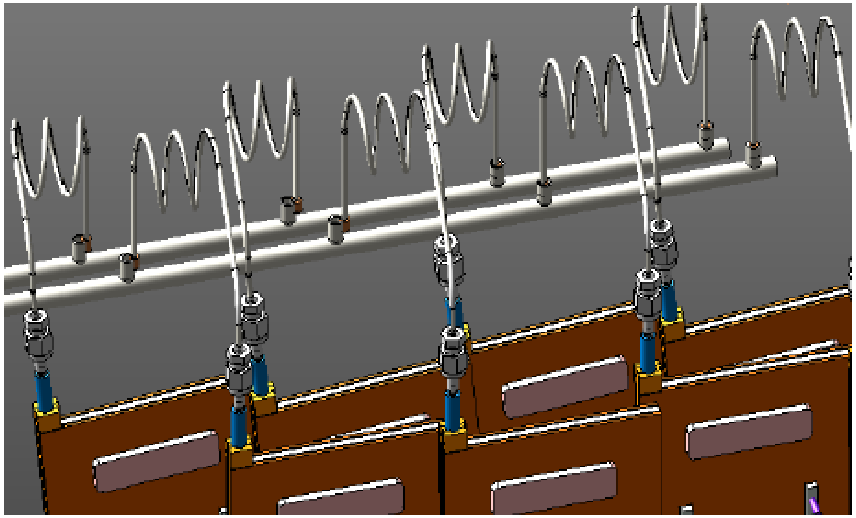
- Distribute the liquid CO_2 coolant flow, arriving from the cooling plant, to the staves inlets
- Slightly subcooled near saturation fluid
- **Supplying parallel evaporating channels, these connection lines must have a pressure drop bigger (> 5 times i.e.) than the evaporation channels pressure drop**
- **thermo-hydraulic stability could be assured using passive elements in the inlet distribution system**.
- Two options are under investigation:
    - **calibrated orifices:** concentrated inlet pressure drops, inserted before the stave inlet. The same piping connection design used on the outlet could be replicated on the inlet. Every detector half-plane has 2 manifolds on each side, 1 on top and 1 on bottom.
    - **capillaries**: distributed inlet pressure drops. Can be coiled and connection to a manifold, or used to route the lines from the staves to the detector outside. Manifold could be placed in any convenient place, inside or outside the detector cold box.

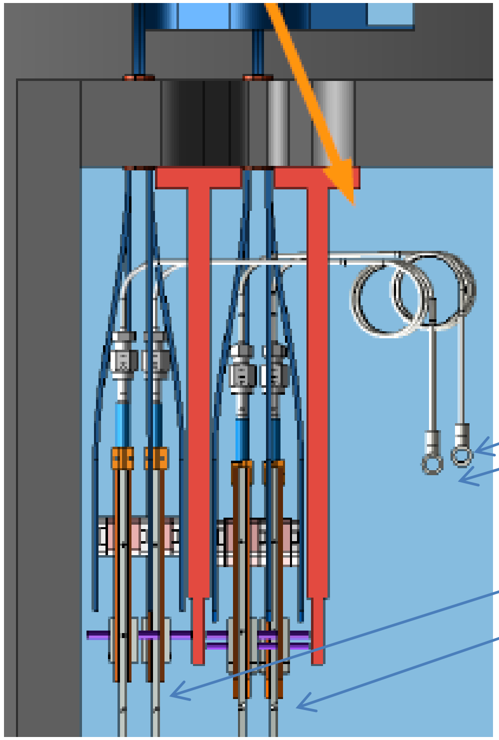
UPSTREAM FLOW

- inlet liquid cooling supplied from the bottom to the staves, 1/8” VCR SWAGELOK FITTING
- exhaust collected from the staves, 1/8” VCR SWAGELOK FITTING, toward a manifold on the top

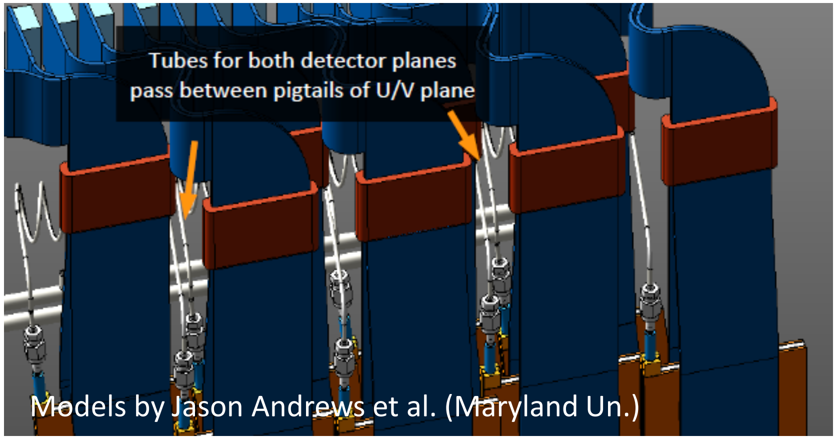
OUTLET CONNECTIONS

DESIGN STUDY WITH 3 COILS TO CHECK INTERFERENCES
NUMBER OF COILS IS UNDER INVESTIGATION: MAY BE 1, 2 OR 3





LATERAL VIEW OF TWO HALF PLANES
THIS MODULE IS REPEATED 4 TIMES IN THE DETECTOR
EACH HALF BOX IMPLEMENTING MODULES ALMOST SPECULAR, HAVING 8/9 STAVES CONNECTED

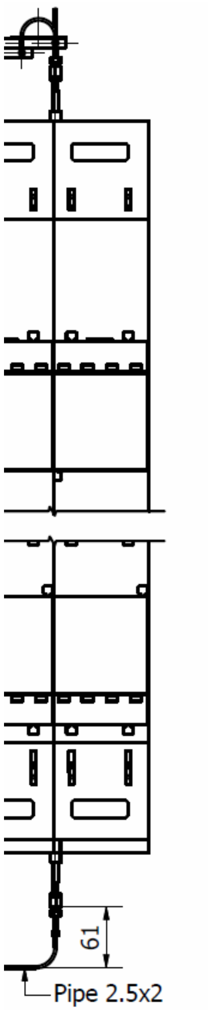


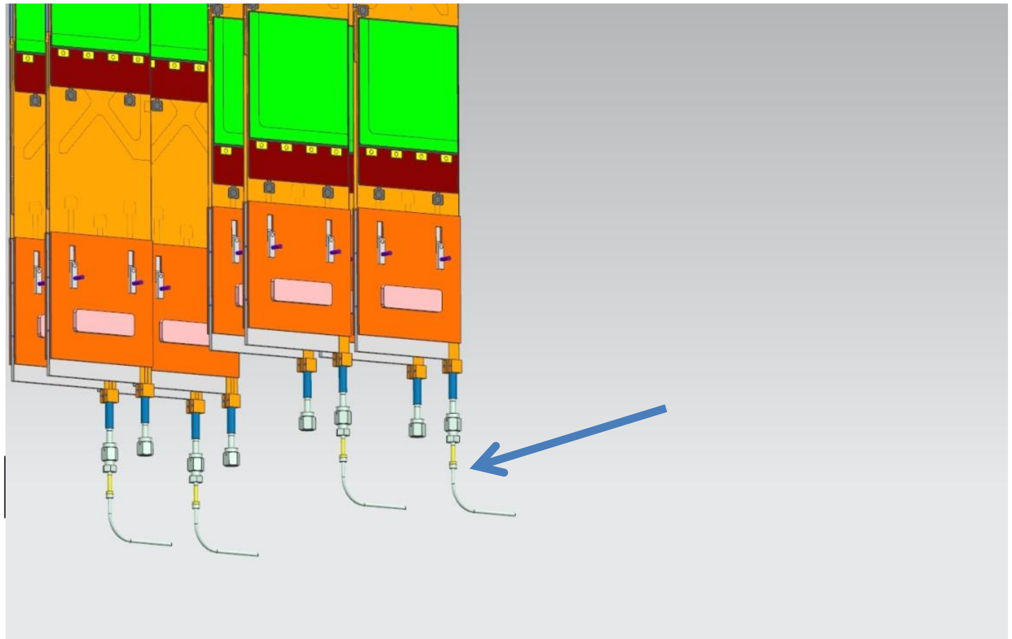
DETECTOR 3D MODEL WITH THE COOLING CONNECTION LINES

ORDER PLACED TO A COMPANY TO PRODUCE THE CONNECTION PIPES SAMPLES FOR QUALIFICATION, AND ELASTIC FORCE ON STAVE FITTING WILL BE MEASURED

INLET CONNECTIONS

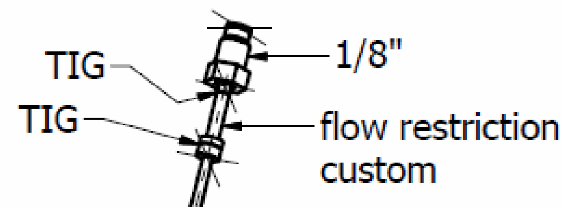
Option **with calibrated orifices**: concentrated inlet pressure drops, inserted before the stave inlet



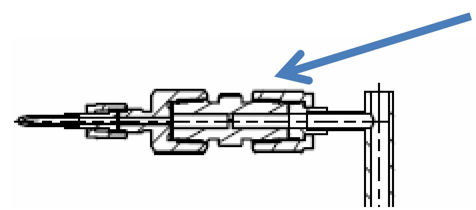


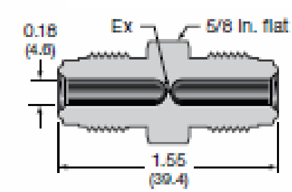
The required stave inlet pressure drop obtained with a **compact design** component incorporated in the inlet connection line, here shown under the stave pipe inlet fitting

Micro-TIG, or laser welded, joint

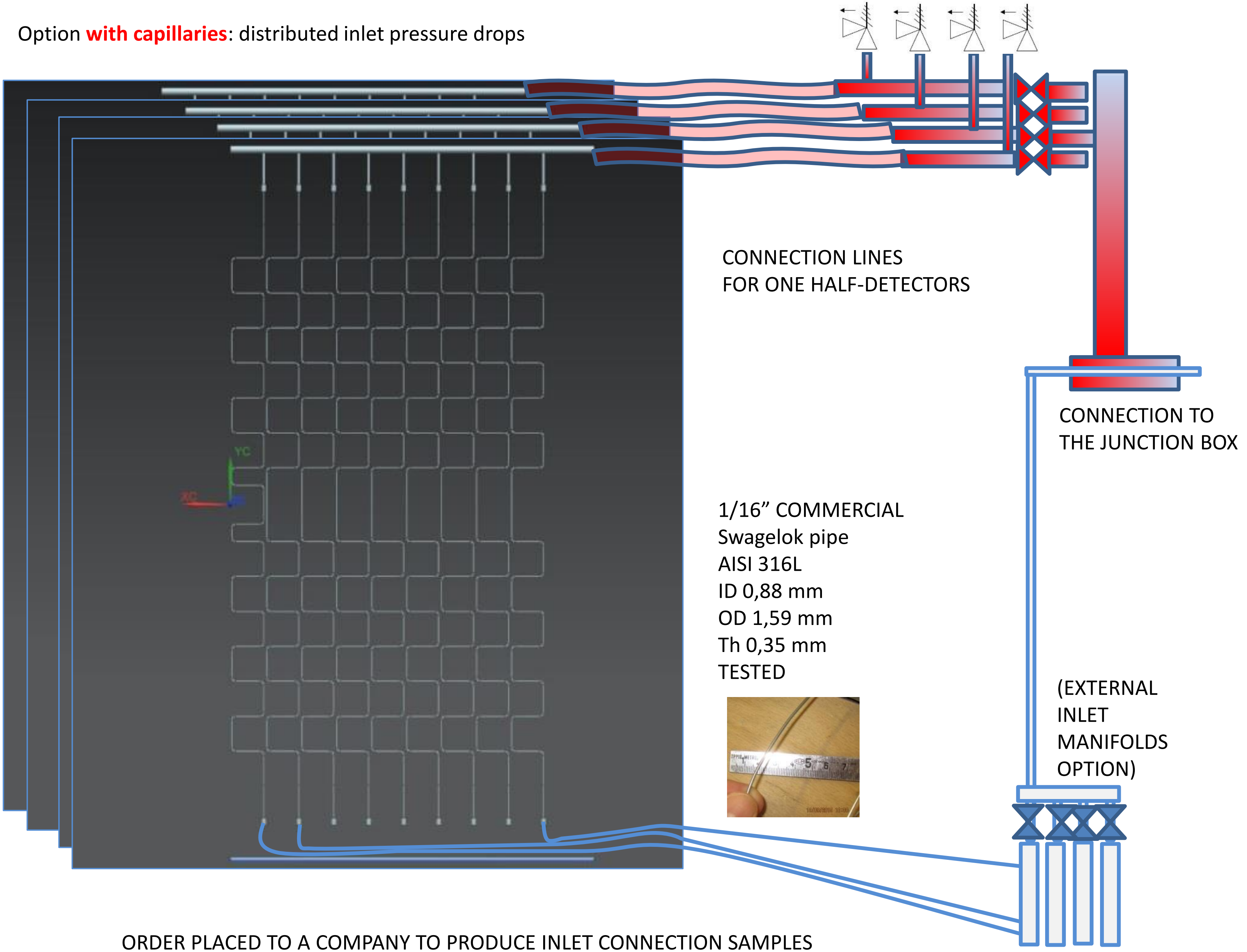


AISI 316L **SWAGELOK FLOW RESTRICTOR**
USED IN THE **TEST SET-UP**
CHARACTERIZATION TEST IN PROGRESS





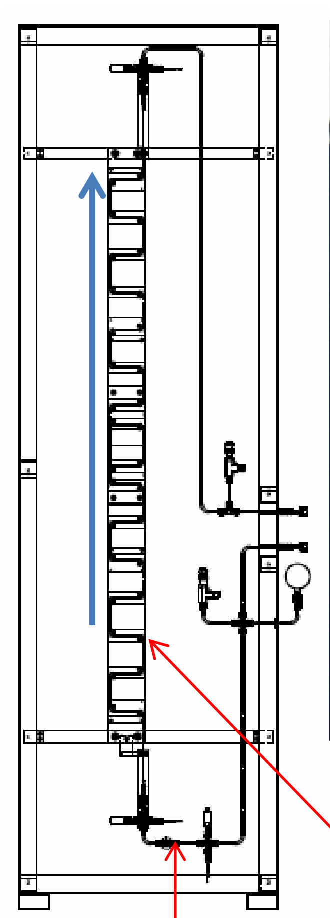
Option **with capillaries**: distributed inlet pressure drops

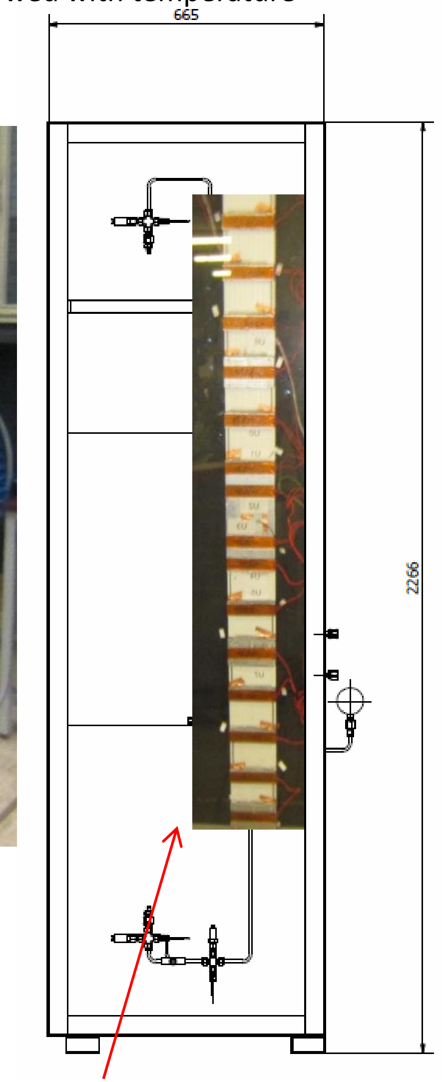


ORDER PLACED TO A COMPANY TO PRODUCE INLET CONNECTION SAMPLES
WITH 1/16’’ PIPE WELDED TO 1/8’’ SWAGELOK FITTINGS

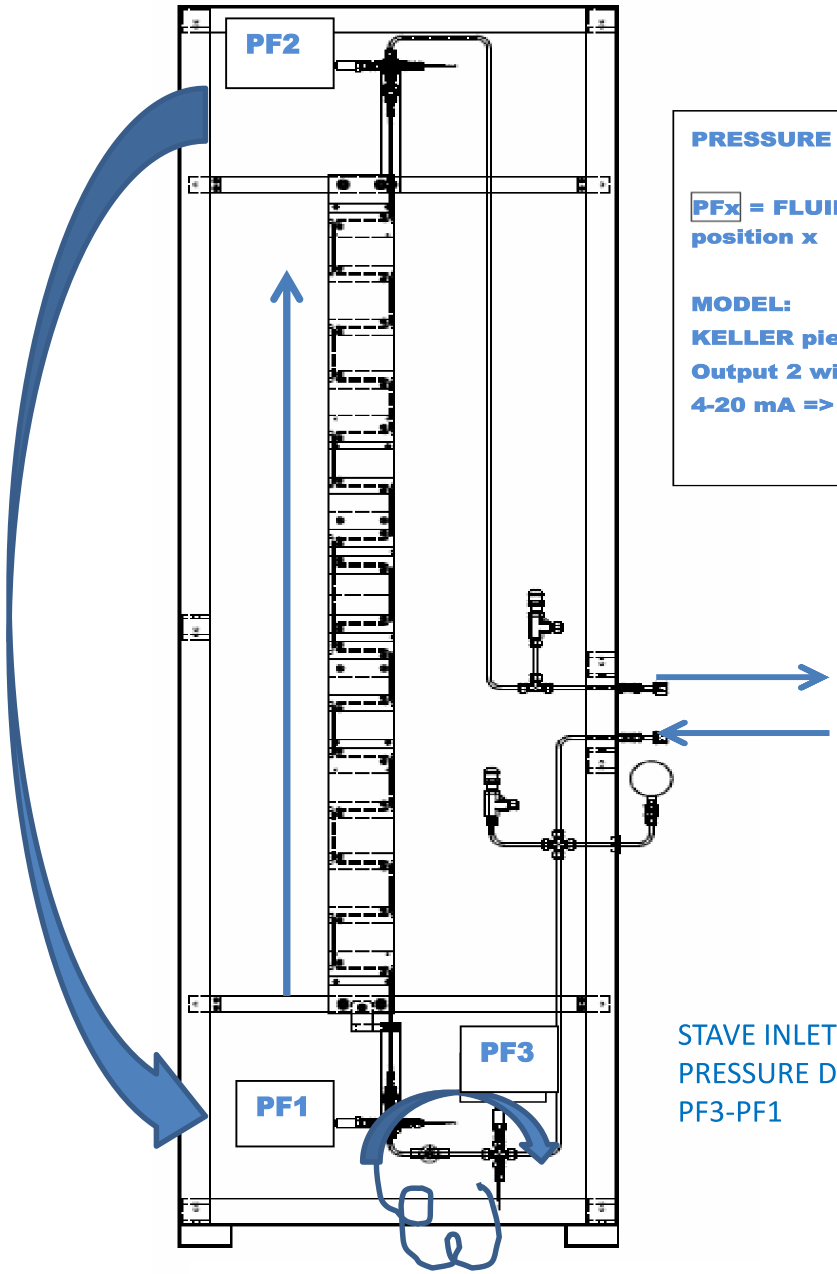
CO_2 COOLING TEST SET-UP DESCRIPTION

The test system is using a 2 P.A.C.L. refrigeration unit TRACI V.1, and a 1:1 test stave prototype, with the real cooling pipe. Power heat load is simulated using heaters. Cooling condition applied with accurate CO_2 mass flow-rate, CO_2 temperature and pressure measured at the stave inlet and outlet. Temperatures of all the circuit are followed with temperature measurements probes attached externally to the pipe.





Experiment instrumentation



LHCb UT STAVE PROTOTYPES CHARACTERIZATION CIRCUIT
WITH "C" CENTRAL SNAKE DUMMY STAVE MOUNTED

DETECTOR STAVE CHANNEL PRESSURE DROP PF1-PF2

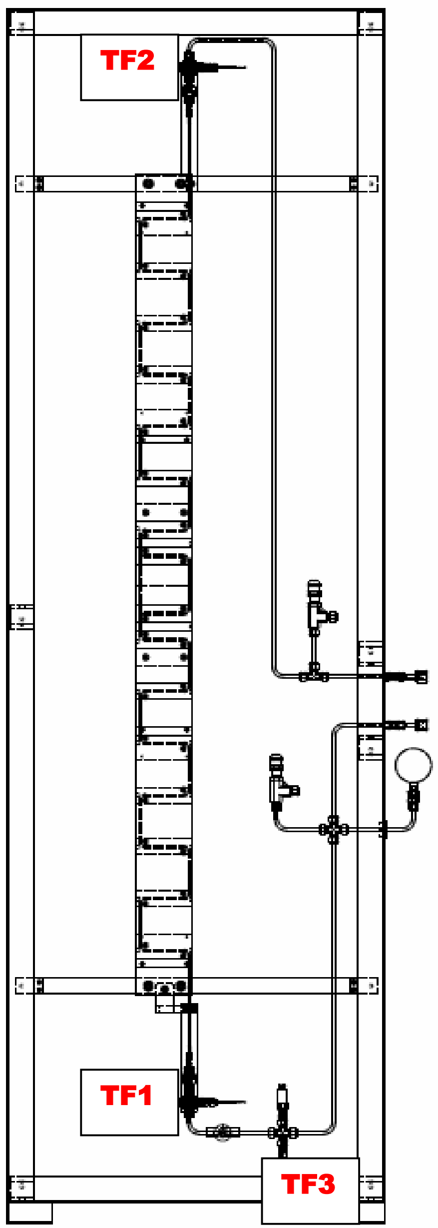
PRESSURE SENSORS INSTALLED

PFx = FLUID Pressure Trasmitter position x

MODEL:
KELLER piezoresistive 21Y
Output 2 wire
4-20 mA => 0-80 bar ABS

CO2 FLOW TO THE STAVE UPWARD FLOW

STAVE INLET PRESSURE DROP PF3-PF1



TEMPERATURE SENSORS INSTALLED

TFx = FLUID TEMPERATURE Trasmitter position x

MODEL:

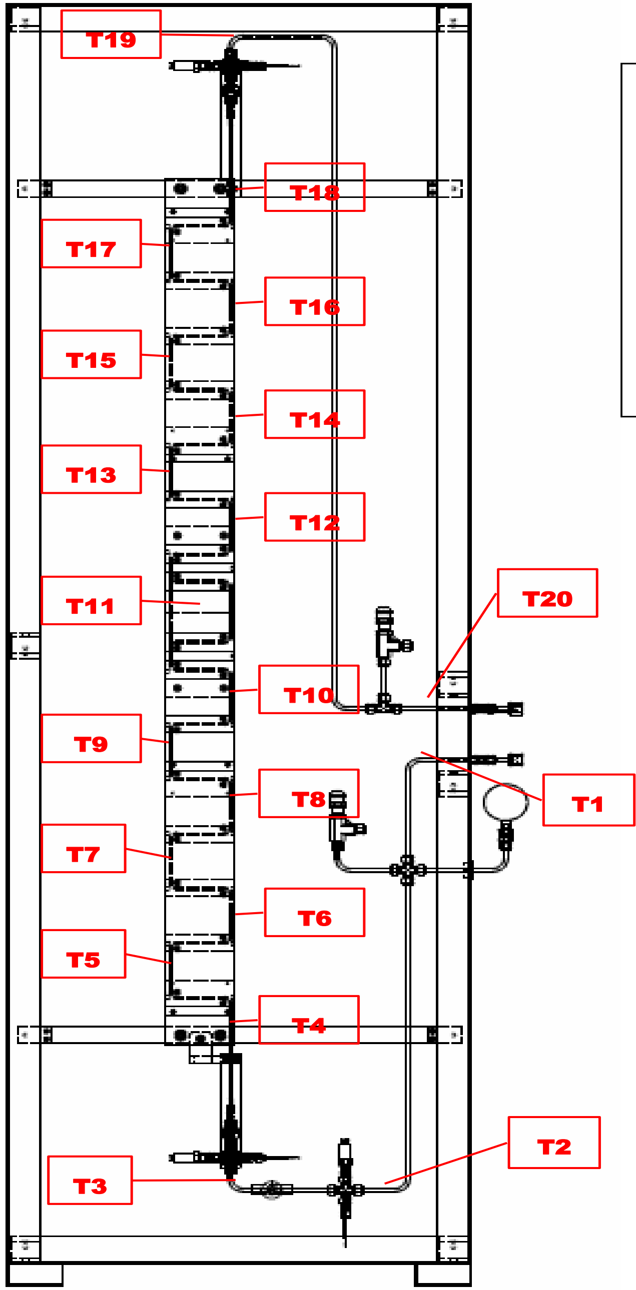
RODAX

PT100

OD 4 mm; length 80 mm

4 wire connection

Experiment instrumentation

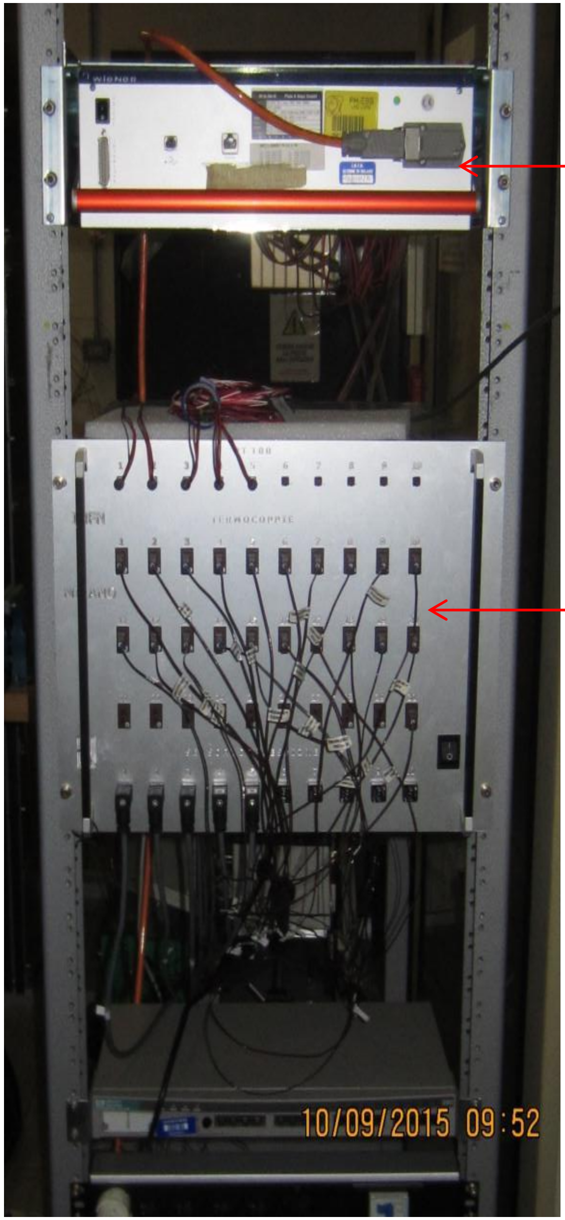


PIPE TEMPERATURE SENSORS INSTALLED

Tx = TEMPERATURE
position x = 1 to 20

MODEL:
Thermocouple “T” type
2 wires

Type	Material		Color Code	Range (°C)	
Thermocouple Grade	Positive Wire	Negative Wire		Minimum	Maximum
J	Iron	Constantan		0	750
K	Chromel	Alumel		-200	1250
T	Copper	Constantan		-200	350
E	Chromel	Constantan		-200	900



Power supply
WIENER-12 channels regulation
With MUSE software to control

- Heaters Voltage and POWER

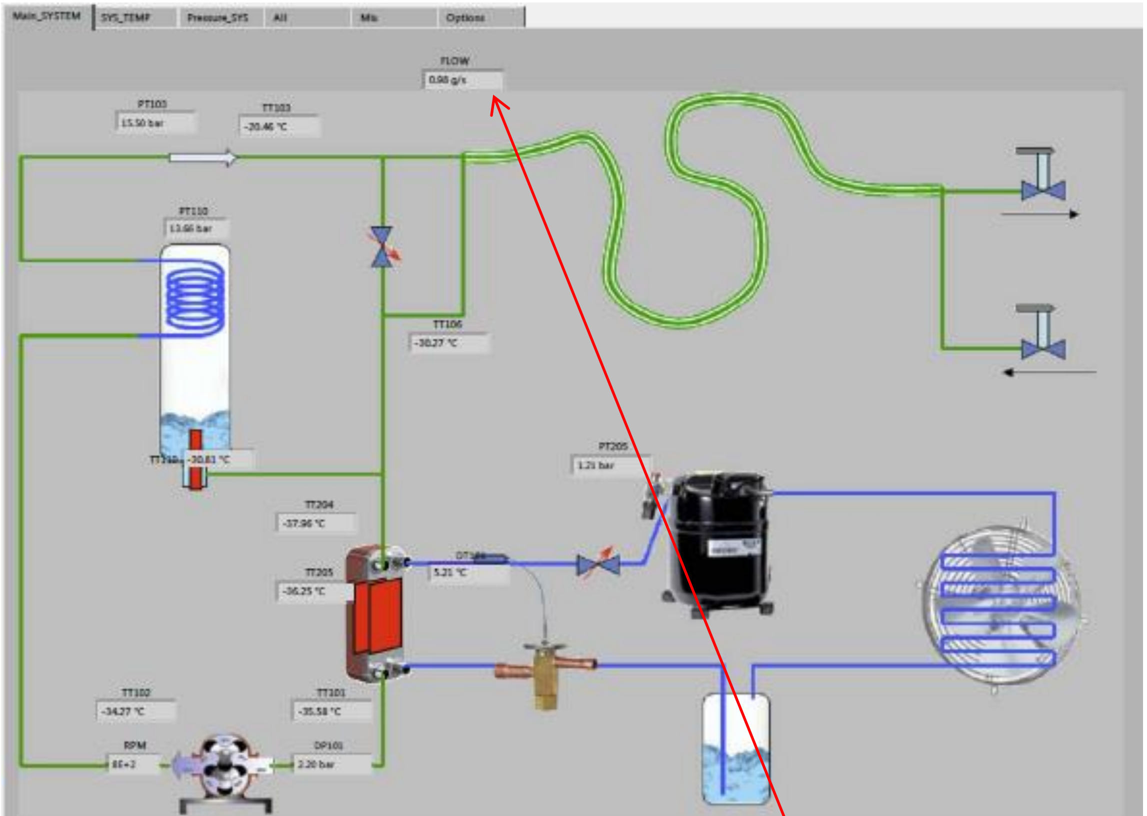
DAQ test measurement:

- CO2 Fluid pressures
- CO2 Fluid temperatures
- Termocouples 'T' attached along the line

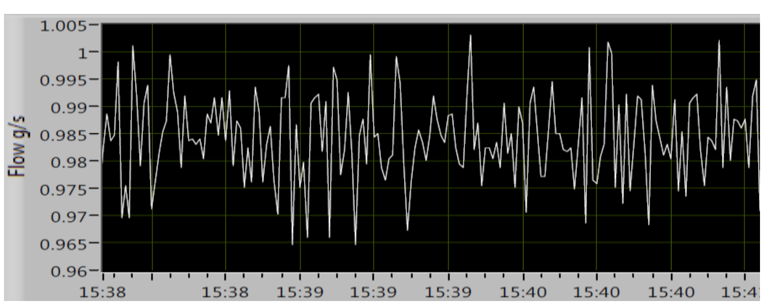
+ TRACI DAQ

- CO_2 mass flow-rate
- TRACI cooling plant Pressures and Temperatures

Experiment instrumentation

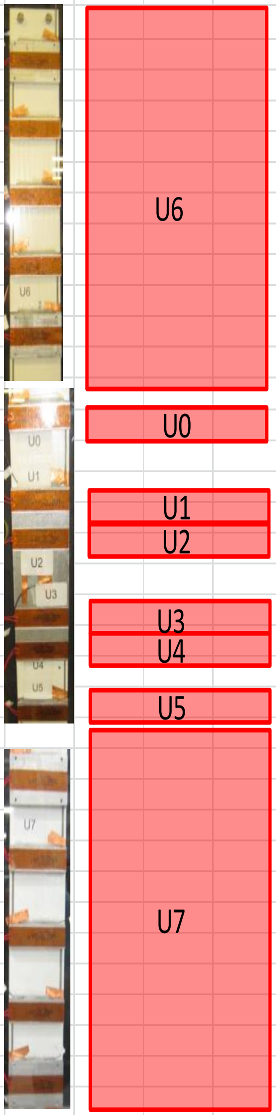


TRACI V1
DAQ
Data acquisition



TRACI Mass flowrate measurement
Coriolis flowmeter

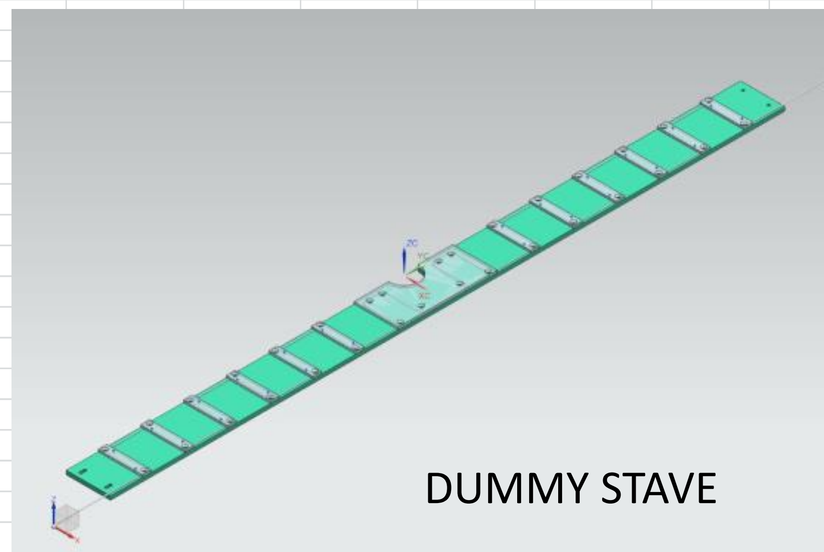
DUMMY STAVE POWERING SCHEME



INPUT

	CENTRAL STAVE										
		ONLY CHIP	CHIP+DISSIP	25%	50%	75%	100%	125%	150%	175%	200%
HEATER NUMBER	HEATER NOMINAL POWER	Watt tot	Watt tot	WATT	WATT	WATT	WATT	WATT	WATT	WATT	WATT
			NOMINAL								
U 6 GROUP	5 rows * 4 ASIC	15	18	4,5	9	13,5	18	22,5	27	31,5	36
U 0	8 ASIC	6,1	6,5	1,625	3,25	4,875	6,5	8,125	9,75	11,375	13
U 1	8 ASIC	6,1	6,5	1,625	3,25	4,875	6,5	8,125	9,75	11,375	13
U 2	8 ASIC	6,1	6,5	1,625	3,25	4,875	6,5	8,125	9,75	11,375	13
U 3	8 ASIC	6,1	6,5	1,625	3,25	4,875	6,5	8,125	9,75	11,375	13
U 4	8 ASIC	6,1	6,5	1,625	3,25	4,875	6,5	8,125	9,75	11,375	13
U 5	8 ASIC	6,1	6,5	1,625	3,25	4,875	6,5	8,125	9,75	11,375	13
U 7 GROUP	5 rows * 4 ASIC	15	18	4,5	9	13,5	18	22,5	27	31,5	36
		66,6	75	18,75	37,5	56,25	75	93,75	112,5	131,25	150
				TOTAL POWER	TOTAL POWER	TOTAL POWER	TOTAL POWER	TOTAL POWER	TOTAL POWER	TOTAL POWER	TOTAL POWER

DUMMY STAVE

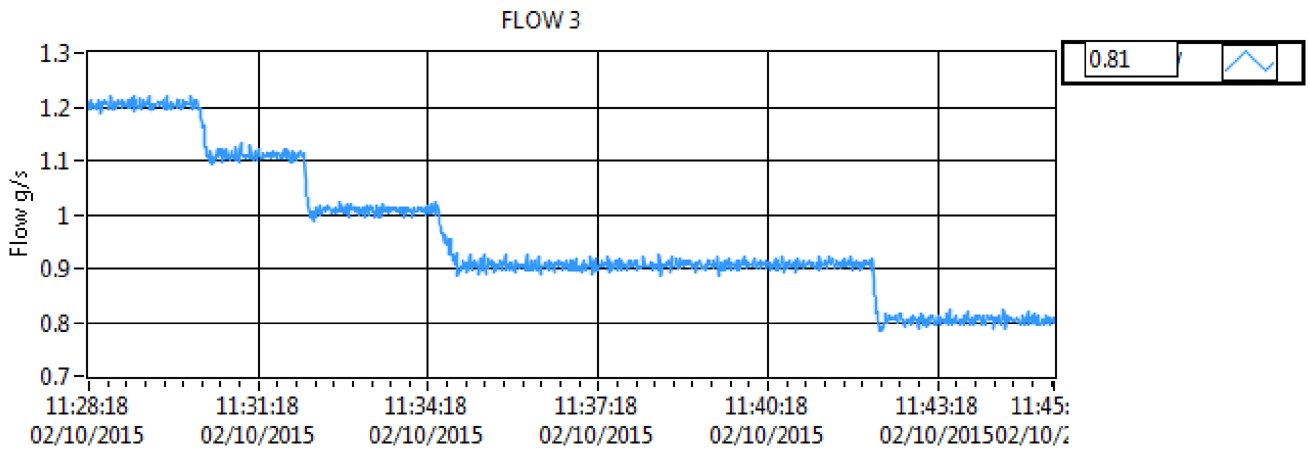


COOLING TEST
THERMO-HYDRAULIC CHARACTERIZATION OF THE BOILING CHANNEL

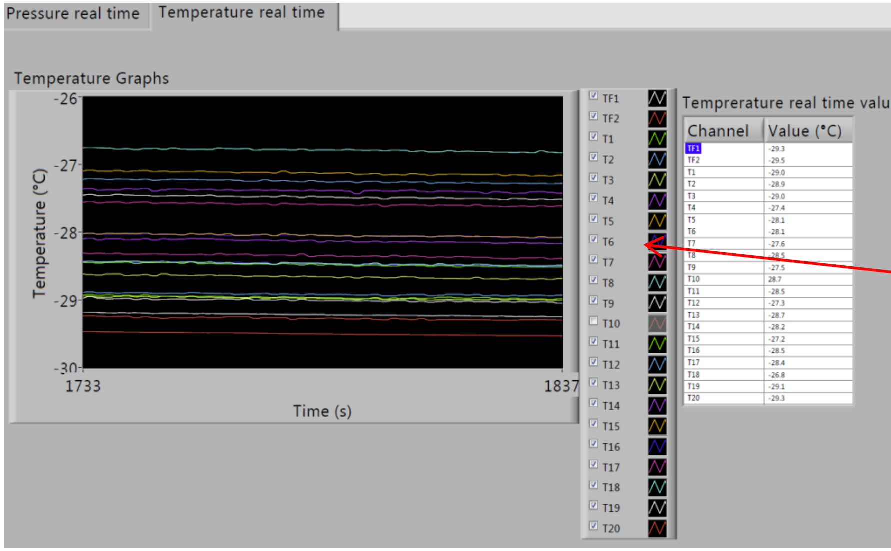
GENERAL EXPERIMEMENTAL CONDITIONS

- CO2 refrigeration UNIT: TRACI v.1
- STAVE under test: TIPE CENTRAL «C» TYPE
- dummy stave with 16 heaters mounted on aluminum plates in contact with the titanium snake pipe, using thermal paste
- FLOW DIRECTION: bottom-up, upward flow
- INSULATION: Cold box closed with 3* 25mm Armaflex layers each side

MASS FLOW-RATE VARIATION IN TIME
DURING A TYPICAL CHARACTERIZATION MEASUMENT



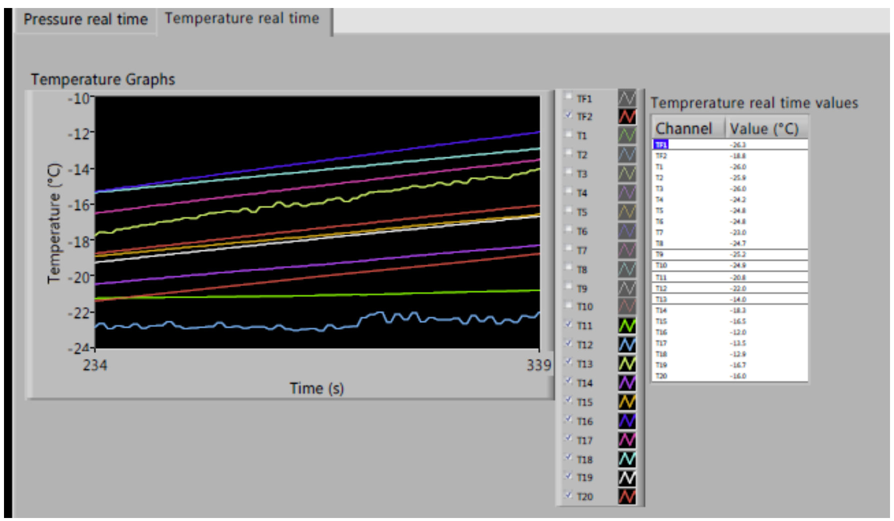
WAITING STEADY-STATE CONDITION BEFORE TO SAVE MEASURED DATA

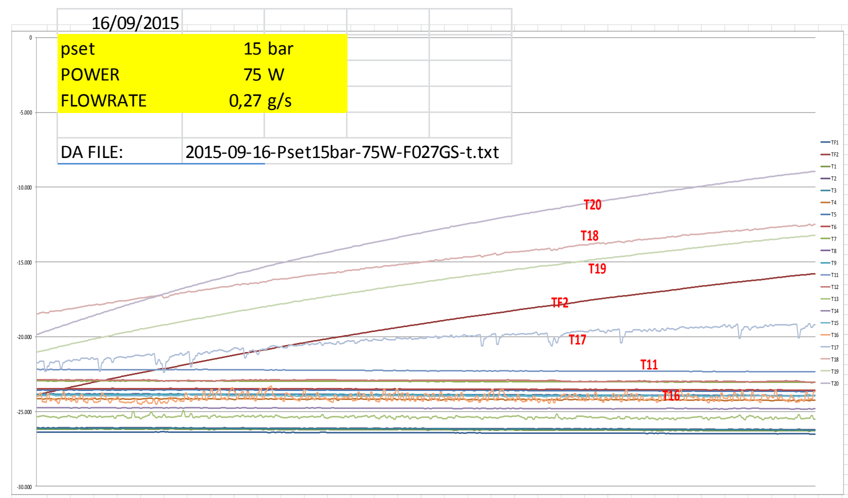


THE CHANNEL IS NEAR ISOTHERMAL CONDITIONS AND THE TEMP. ARE CONSTANT IN TIME, WITH CONSTANT FLOW

THE TEMPERATURES MEASURED ARE AFFECTED BY INSTRUMENTAL ERROR, CALIBRATION NEED TO BE REFINED (PT100 CALIBRATED WILL BE INSTALLED)

MEASURED TEMPERATURES VS TIME IN **COLD NOMINAL OPERATIONAL CONDITIONS**
WHEN EXHAUST VAPOUR FRACTION IS LESS THAN ~ 90 %





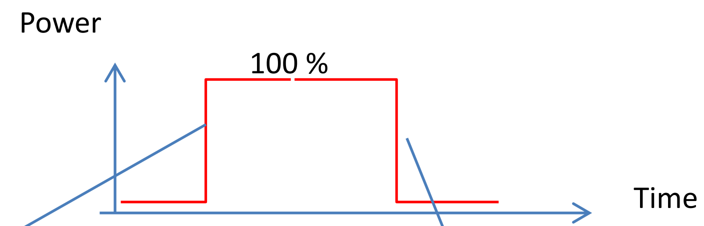
STAVE TEMPERATURES VS TIME WHEN THE MASS FLOW-RATE IS TOO LOW AND THE CHANNEL HAS A **DRY-OUT CONDITION**
OSCILLATING TEMP. ARE OBSERVED AT A CERTAIN POINT IN THE STAVE (PIPE WETTED/DRYED NER DRY-OUT REGION)
FROM THAT POINT CO_2 VAPOUR TEMPERATURE, WITHOUT LIQUID EVAPORATING, INCREASES.
EXPERIMENT IS THEN STOPPED BECAUSE THIS IS NOT A DESIRED OPERATIVE SITUATION, BUT JUST A VERIFICATION.

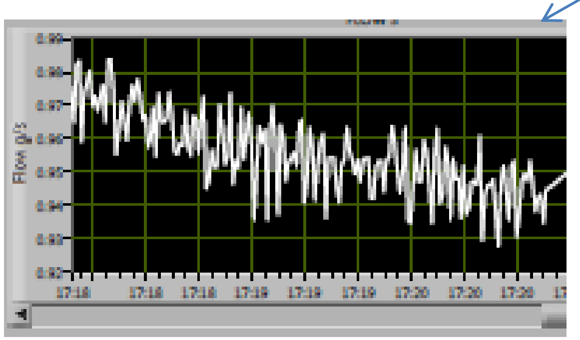
«C» stave TEST transients

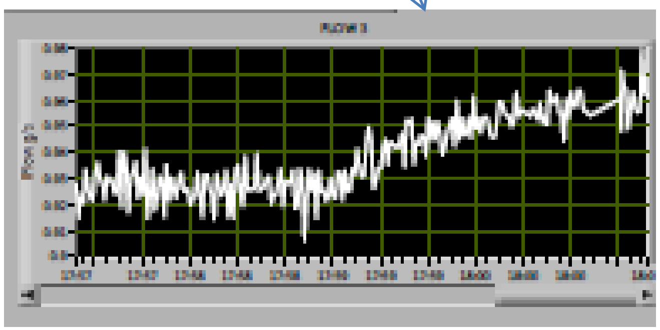
at nominal flowrate: power from 0 to 100% and viceversa

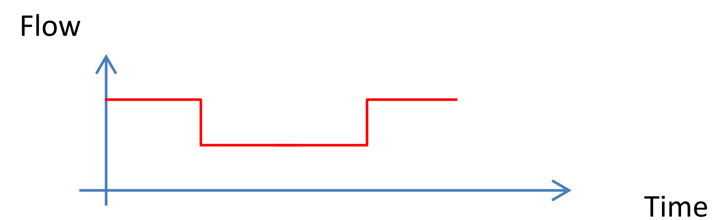
Initial Mass flowrate F fixed = 0,9 g/s

1. OFF Power = 0
2. ON Power = 75 w
3. OFF Power = 0









when power is switched on
Flow-rate decreases from ~0,9 to ~0,8 g/s

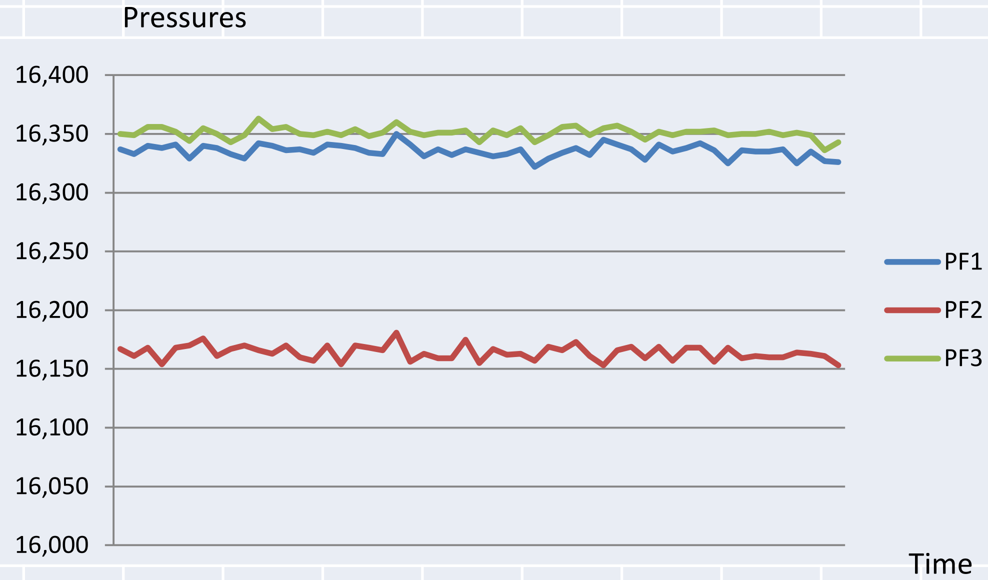
Increase in the channel pressure drop due to evaporation

Viceversa the flow come back to initial value when switched off

Typical data taken in a steady-state cold working point

2015-10-02-16BAR-38W-05GS-P.txt

PF1	PF2	PF3	p1-p2+corr
16.337	16.167	16.350	293
16.333	16.161	16.349	295
16.340	16.168	16.356	295
16.338	16.154	16.356	307
16.341	16.168	16.352	296
16.329	16.170	16.344	282
16.340	16.176	16.355	287
16.338	16.161	16.350	300
16.333	16.167	16.343	289
16.329	16.170	16.349	282
16.342	16.166	16.363	299
16.340	16.163	16.354	300
16.336	16.170	16.356	289
16.337	16.160	16.350	300
16.334	16.157	16.349	300
16.341	16.170	16.352	294
16.340	16.154	16.349	309
16.338	16.170	16.354	291



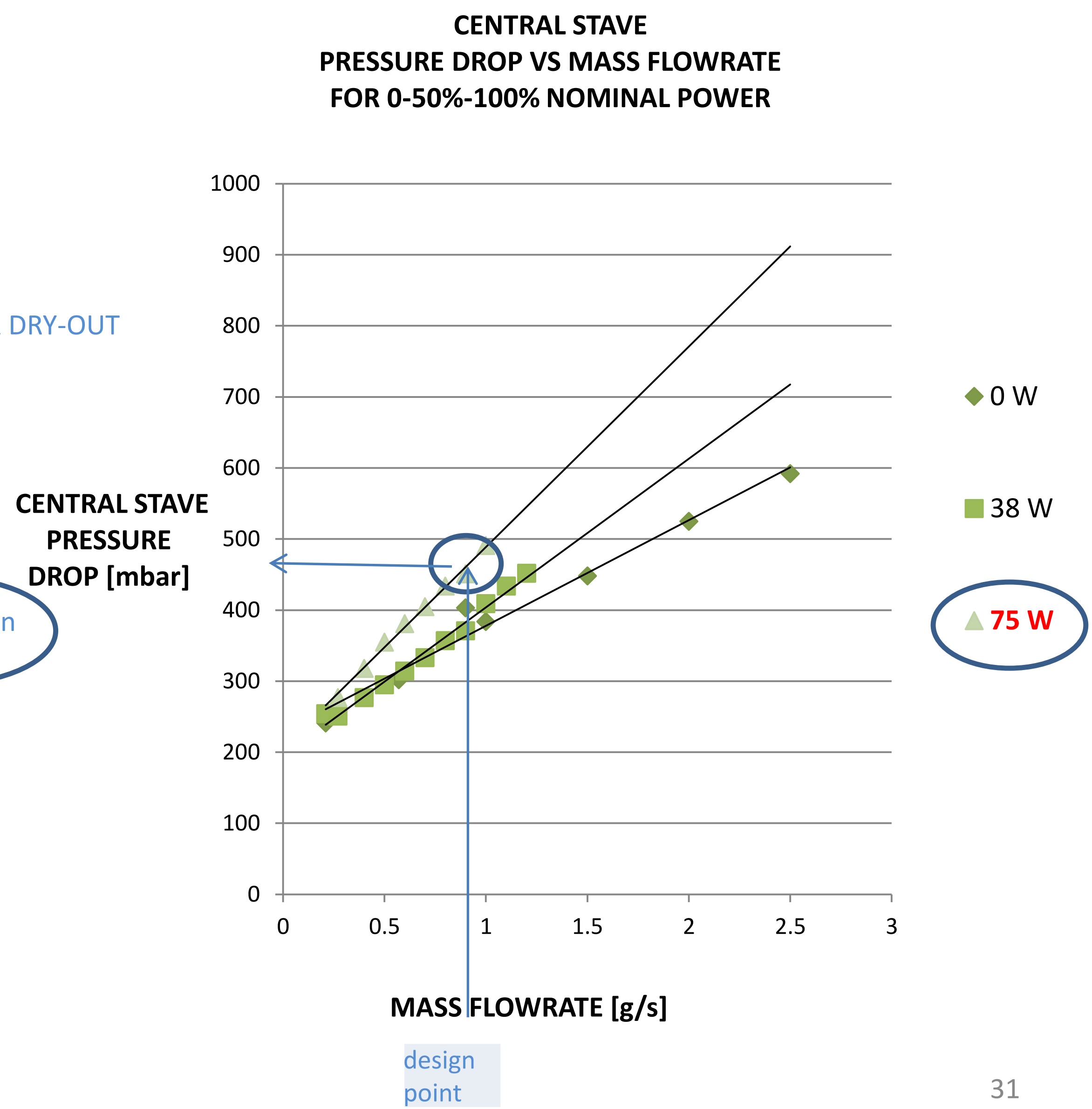
TF1	TF2	T1	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
-26.105	-26.242	-25.810	-24.095	-24.618	-24.882	-22.428	-24.792	-25.268	-25.027	-24.174	-23.832	-25.413	-25.019	-24.021	-25.388	-24.111	-22.940	-25.692	-26.004
-26.108	-26.240	-25.826	-24.073	-24.615	-24.889	-22.442	-24.799	-25.275	-25.025	-24.170	-23.830	-25.427	-25.014	-24.023	-25.397	-24.114	-22.945	-25.707	-26.001
-26.106	-26.240	-25.826	-24.073	-24.615	-24.889	-22.442	-24.799	-25.275	-25.025	-24.170	-23.830	-25.427	-25.014	-24.023	-25.397	-24.114	-22.945	-25.707	-26.001
-26.103	-26.241	-25.818	-24.077	-24.605	-24.891	-22.448	-24.795	-25.269	-25.029	-24.180	-23.835	-25.421	-25.006	-24.019	-25.385	-24.116	-22.952	-25.713	-26.025
-26.104	-26.242	-25.818	-24.077	-24.605	-24.891	-22.448	-24.795	-25.269	-25.029	-24.180	-23.835	-25.421	-25.006	-24.019	-25.385	-24.116	-22.952	-25.713	-26.025
-26.105	-26.242	-25.808	-24.072	-24.620	-24.881	-22.438	-24.796	-25.269	-25.027	-24.177	-23.832	-25.426	-25.005	-24.013	-25.388	-24.110	-22.939	-25.711	-26.031
-26.113	-26.241	-25.808	-24.072	-24.620	-24.881	-22.438	-24.796	-25.269	-25.027	-24.177	-23.832	-25.426	-25.005	-24.013	-25.388	-24.110	-22.939	-25.711	-26.031
-26.109	-26.241	-25.822	-24.110	-24.616	-24.891	-22.442	-24.798	-25.282	-25.034	-24.174	-23.834	-25.430	-25.025	-24.027	-25.400	-24.112	-22.940	-25.703	-26.017
-26.113	-26.240	-25.822	-24.110	-24.616	-24.891	-22.442	-24.798	-25.282	-25.034	-24.174	-23.834	-25.430	-25.025	-24.027	-25.400	-24.112	-22.940	-25.703	-26.017
-26.112	-26.239	-25.817	-24.072	-24.615	-24.873	-22.437	-24.792	-25.275	-25.021	-24.165	-23.830	-25.429	-25.010	-24.013	-25.383	-24.120	-22.932	-25.706	-26.035
-26.107	-26.239	-25.817	-24.072	-24.615	-24.873	-22.437	-24.792	-25.275	-25.021	-24.165	-23.830	-25.429	-25.010	-24.013	-25.383	-24.120	-22.932	-25.706	-26.035
-26.106	-26.238	-25.828	-24.093	-24.609	-24.882	-22.439	-24.793	-25.273	-25.024	-24.173	-23.824	-25.416	-25.005	-24.019	-25.388	-24.116	-22.946	-25.706	-26.027
-26.106	-26.239	-25.828	-24.093	-24.609	-24.882	-22.439	-24.793	-25.273	-25.024	-24.173	-23.824	-25.416	-25.005	-24.019	-25.388	-24.116	-22.946	-25.706	-26.027
-26.105	-26.239	-25.813	-24.070	-24.623	-24.889	-22.440	-24.794	-25.285	-25.040	-24.168	-23.830	-25.418	-25.012	-24.021	-25.376	-24.097	-22.924	-25.684	-26.003
-26.108	-26.238	-25.813	-24.070	-24.623	-24.889	-22.440	-24.794	-25.285	-25.040	-24.168	-23.830	-25.418	-25.012	-24.021	-25.376	-24.097	-22.924	-25.684	-26.003
-26.114	-26.240	-25.819	-24.108	-24.613	-24.896	-22.443	-24.790	-25.285	-25.037	-24.176	-23.839	-25.416	-24.998	-24.034	-25.390	-24.120	-22.943	-25.712	-26.005

«C» stave pressure drop vs flow relation at given powers

Psetpoint=	15 barA			
Mass flowrate	Pressure drop	Pressure drop	Pressure drop	
g/s	mbar	mbar	mbar	
Power heaters	0 W	38 W	75 W	Xout 75 W
0,21	241	254		
0,27		251	277	93%
0,4		277	318	63%
0,5		295	355	50%
0,57	302			
0,6		314	381	42%
0,7		333	405	36%
0,8		357	**434**	**31%**
0,9	403	371	**451**	**28%**
0,95	305	344	392	26%
1	384	409	491	25%
1,1		434		
1,2		452		
1,5	448			
2	525			
2,5	592			

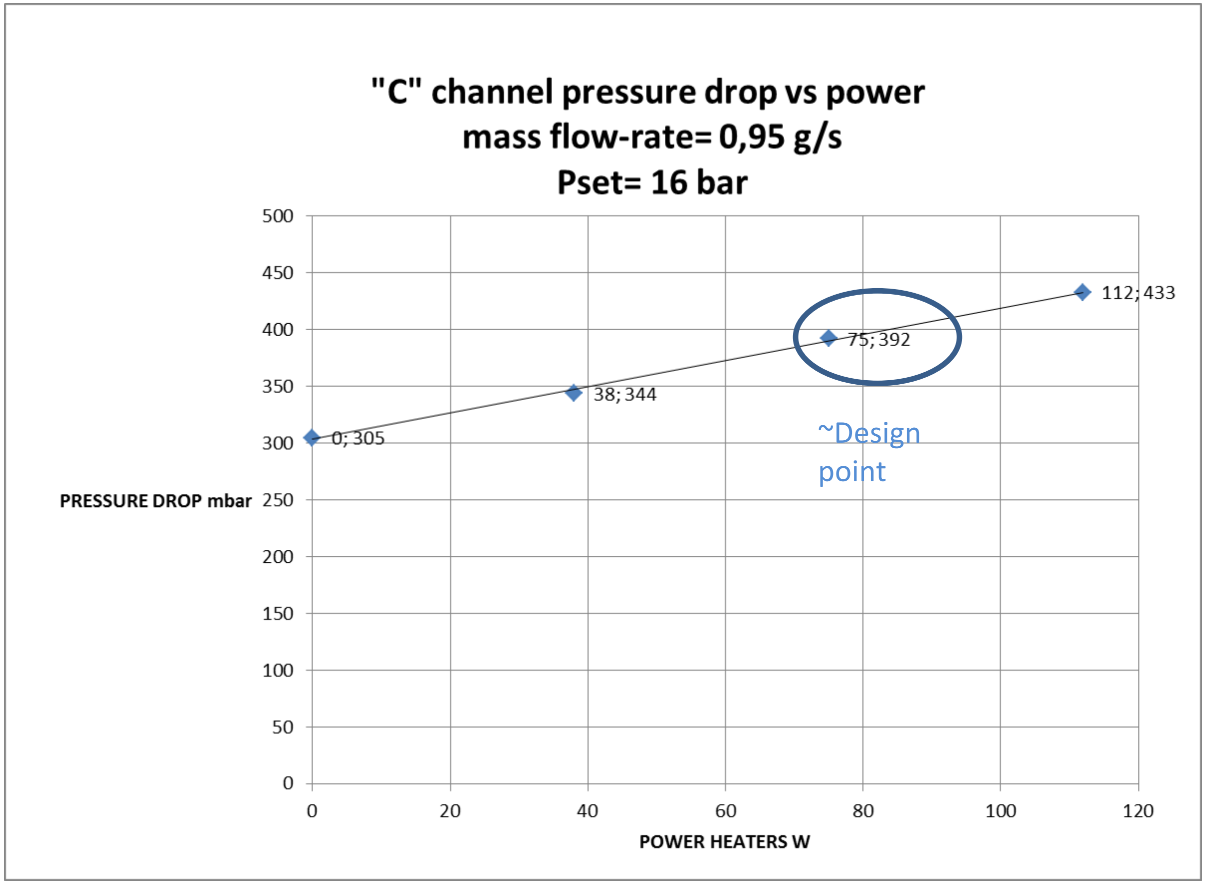
NEAR DRY-OUT

Design point



«C» stave pressure drop vs power relation at given flux

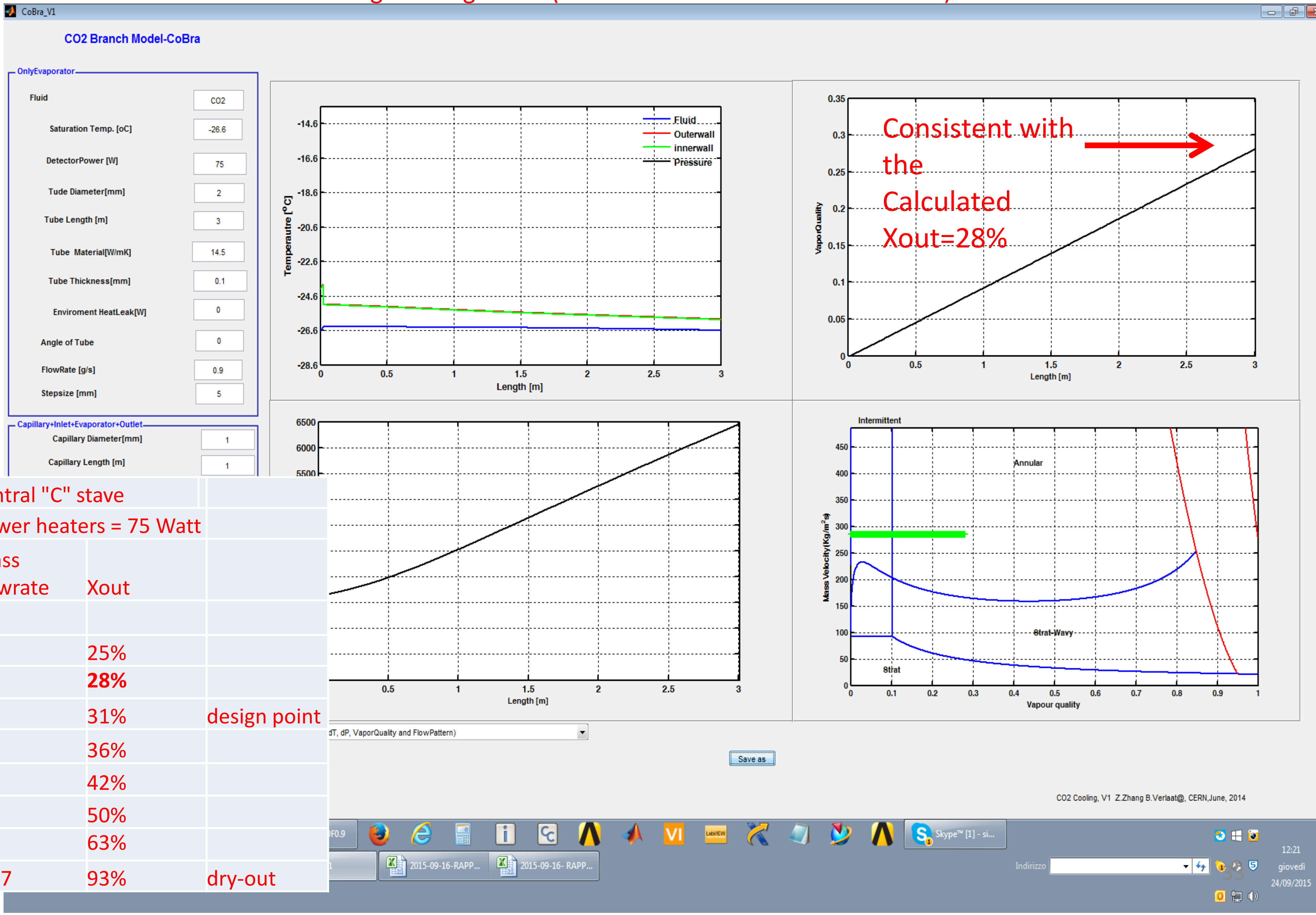
"C" channel pressure drop vs power				
mass flowrate= 0,95 g/s; Pset= 16 bar				
Power heaters W	0	38	75	112
0,95	305	344	392	433



COBRA simulation for 100% power and nominal 0,9 g/s flux

Note: available only model with horyzontal straight pipe

Using full length 3 m (more correct for friction calculation)

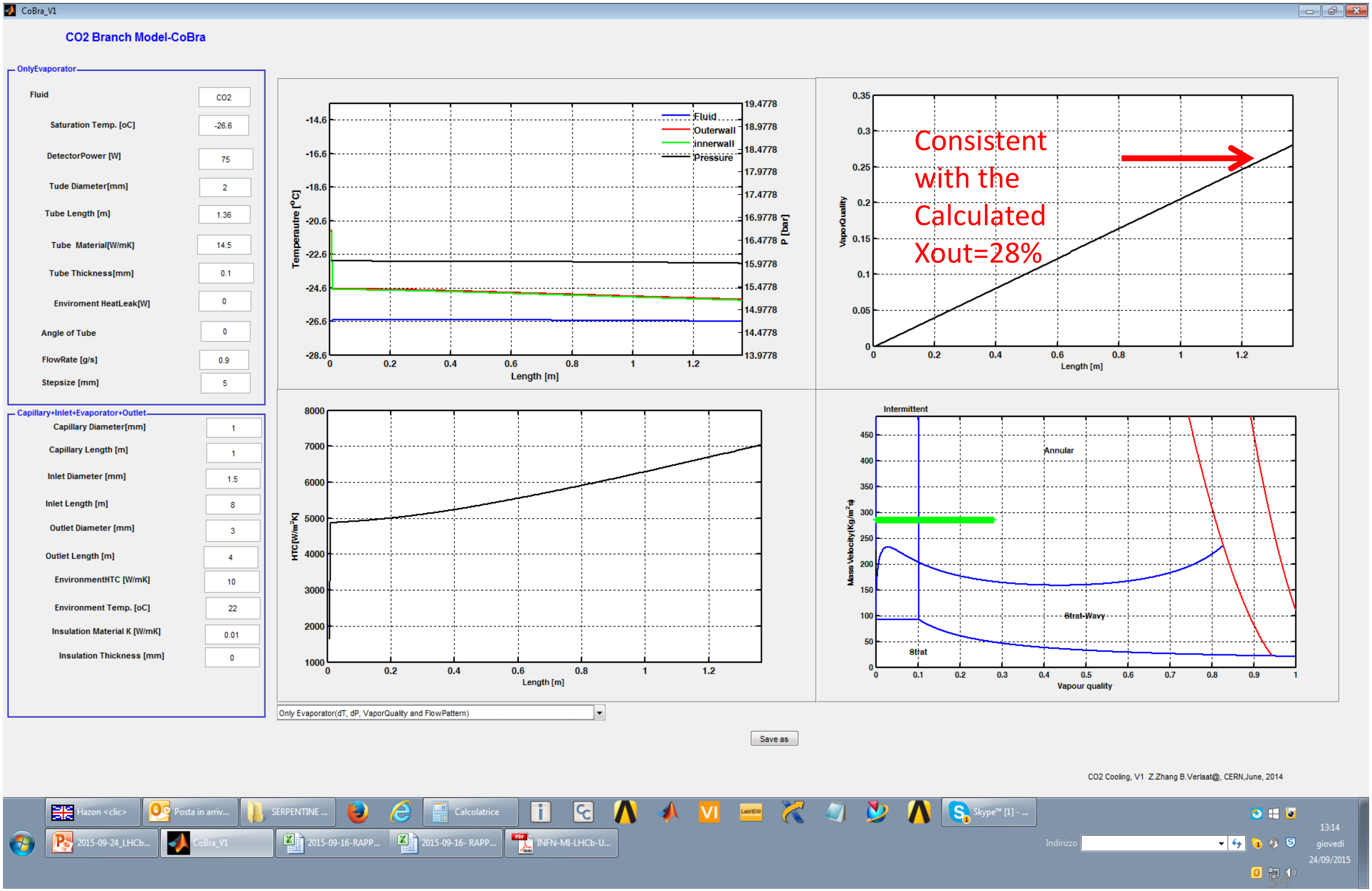


central "C" stave		
Power heaters = 75 Watt		
Mass flowrate	Xout	
g/s		
1	25%	
0,9	**28%**	
0,8	31%	design point
0,7	36%	
0,6	42%	
0,5	50%	
0,4	63%	
0,27	93%	dry-out

COBRA simulation for 100% power and nominal 0,9 g/s flux

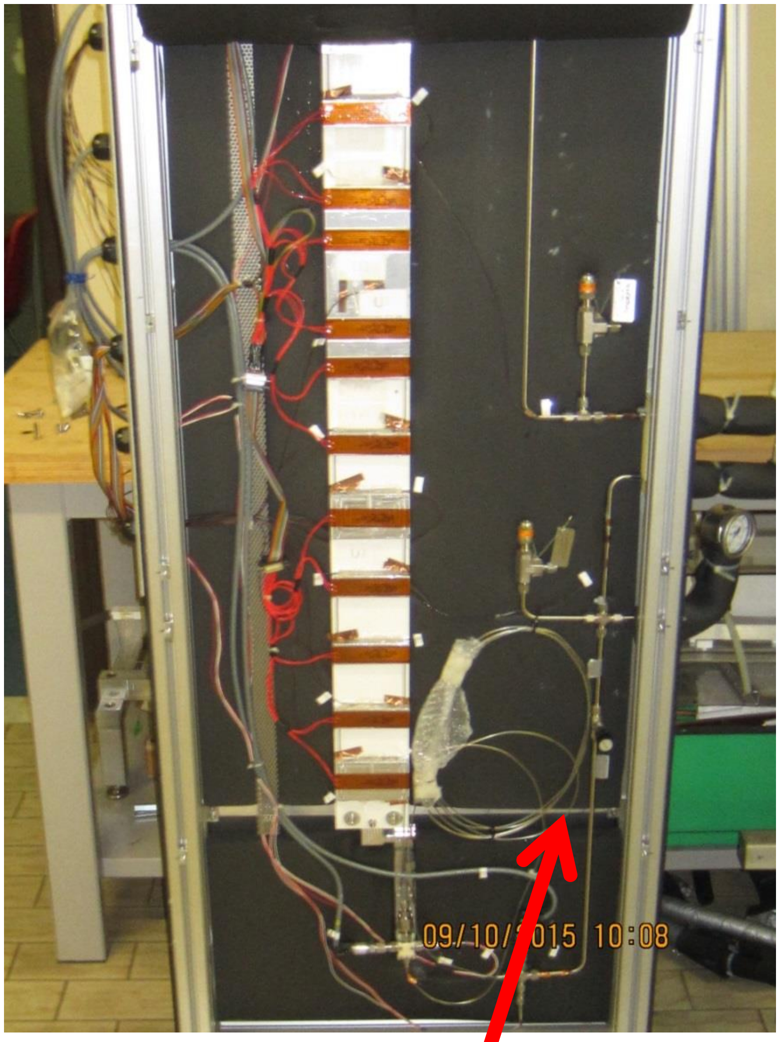
Note: available only model with horyzontal straight pipe

Using heated length 1,36 m, more correct for heat exchange

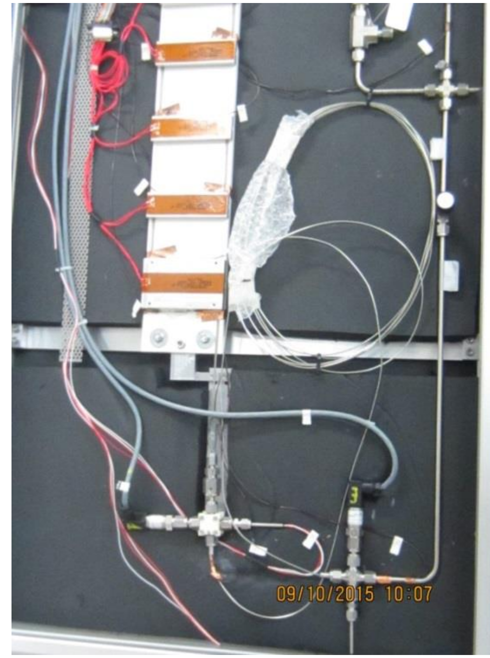


THERMO-HYDRAULIC CHARACTERIZATION OF CIRCUIT COMPONENTS UNDER STUDY

- 1/16 "CAPILLARY INLET PIPE, 0.88 mm ID
- 6 METER AND 1 METER LENGTH
- MEASUREMENTS DONE IN OPERATIVE CONDITION -20 °C AND -30 ° SEVERAL MASS FLOW-RATE POINT TESTED



6 METERS INLET CAPILLARY MOUNTED AND MEASURED



MEASUREMENT

- CO_2 UPWARD FLOW
- FULL POWER (75 W)
- SET P 16 BAR
- EVAP. - 28 °C

6m CAPILLARY
MEASURED PRESSURE
DROP AT 0,45 G/S
~ 3 BAR

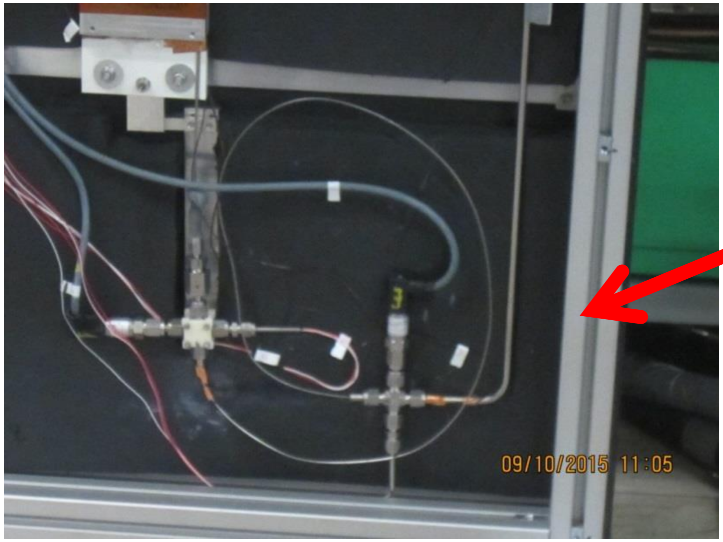
COOLING TEST WITH TRACI

1 METER INLET CAPILLARY MOUNTED

LENGTH CALCULATED WITH Darcy–Weisbach equation
VALID FOR MONOPHASE CO_2 LIQUID FLO
THE LENGTH TO HAVE I.E. «2 BAR INLET PRESSURE DROP»
AT NOMINAL MASS FLOWRATE 0,9 G/S
=> IS ~ 1 METER WITH 1/16 INCH SWAGELOK PIPE

Darcy–Weisbach equation

$$h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$



1 METER INLET CAPILLARY 1/16 INCH
MOUNTED AND MEASURED

CONFIRMATION
With 0.9 g/s measured pressure drop is 2 bar/ on 1 meter

A 3 °C DECREASE IN TEMP INTO THE CAPILLARY MEANS THAT SOME BOILING STARTS AND THIS NEED TO BE INVESTIGATED

BOILING BEFORE THE STAVE INLET IS NOT ACCEPTABLE BECAUSE A SEPARATION OF VAPOUR 8BUBBLES) CAN HAPPEN , EMPTYING SOME EVAPORATOR CHANNEL

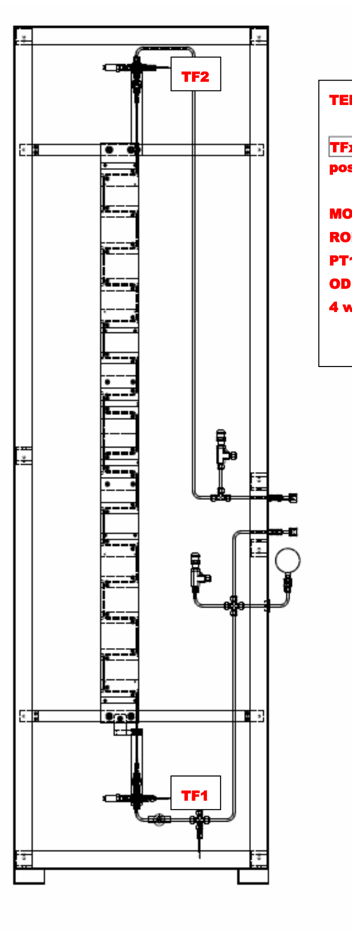
COOLING TEST WITH TRACI

1 METER INLET CAPILLARY MOUNTED AND MEASURED

SET P 15 BAR

T EVAPORATION = -28 °C

POWER 75 W

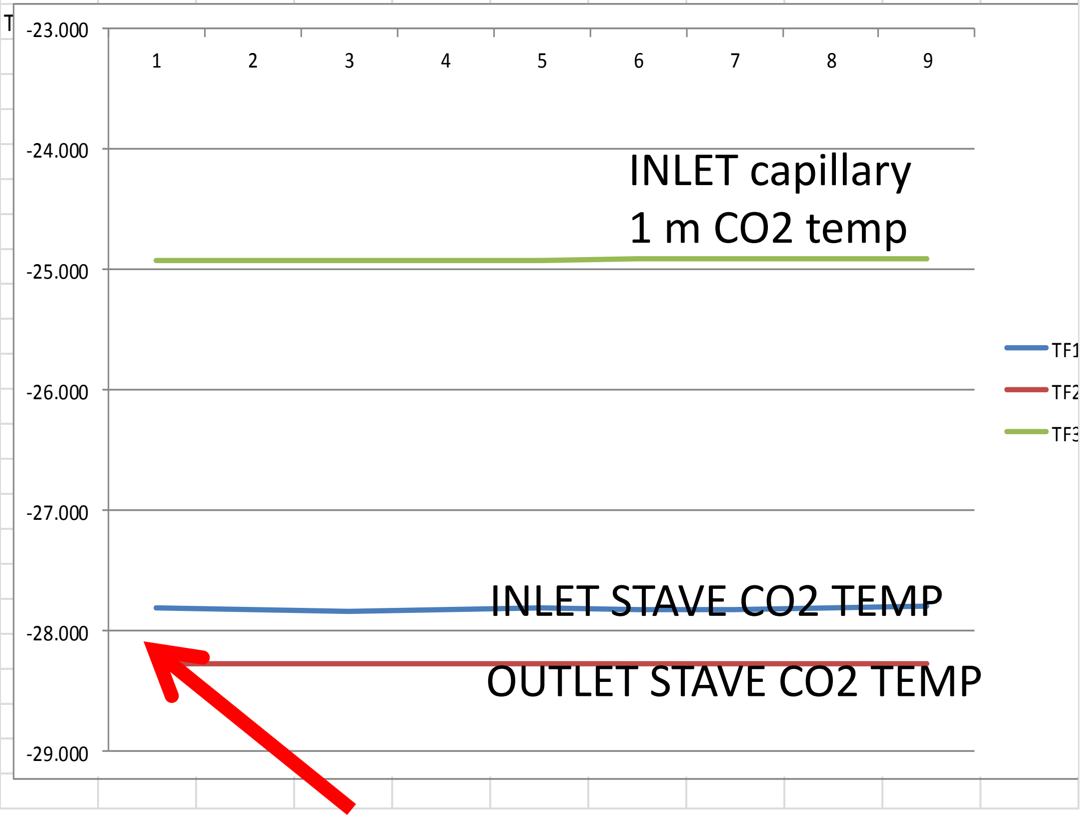


TF1	TF2	TF3	T
-27.814	-28.270	-24.919	
-27.829	-28.270	-24.921	
-27.840	-28.271	-24.921	
-27.826	-28.272	-24.923	
		24.920	
		24.916	
		24.911	
		24.905	
		24.904	

TEMPERATURE SENSORS INSTALLED

TFx = FLUID TEMPERATURE Trasmitter position x

MODEL:
RODAX
PT100
OD 4 mm; length 80 mm
4 wire connection



MEASURED FLUID TEMPERATURES °C

STAVE CHANNEL MEDIUM TEMPERATURE
= - 28 °C

DELTA T CHANNEL IN-OUT
= LESS THAN 0,5 °C

WORK IN PROGRESS

- measurement work is in progress for the Inlet concentrated pressure drop using calibrated orifices (Swagelok components)

- stave measured in the actual cooling test is the “C” central stave, snake pipe type A, B will follow, to measure the differences

- warm test at +15 °C to masure flow and delta pressure

- Changing from Armaflex insulation and using a cold box similar to the UT box, with poly-stirene insulator surrounding a plastic air-tigth box, dry-air controlled volume to have dew-point <- 40 °C

- TO VALIDATE THE PROPOSED TECHNOLOGY PRODUCTION for the INLET and OUTLET piping:

Production in progress with company Real-vacuum
WELDED JUNCTIONS OF THE CHOOSEN PIPE AND THE SWAGELOK «VCR» CHOOSEN FITTINGS

TEST:

- HELIUM LEAK-RATE
- PRESSURIZATION
- HELIUM LEAK-RATE AFTER PRESSURIZATION
- MOUNTING INTO TRACI COOLING TEST

MEASUREMENT AND QUALIFICATION USING THE COOLING SYSTEM OPERATIONAL CONDITIONS (REAL PRESSURES, AMBIENT TO COLD OPERATION)

CONCLUSION

- THE DETECTOR CONCEPT IMPLEMENTING A CO2 BOILING EVAPORATIVE CHANNEL WITH A «SNAKE GEOMETRY » SERPENTINE COOLING PIPE, MOUNTED INTO A VERTICAL STAVE, HAS BEEN DEMOSTRATED TO WORK IN BOILING CONTROLLED CONDITIONS AT EVAPORATION TEMPERATURES OF -30 °C AND - 20 °C

- THE CENTRAL STAVE THERMO-HYDRAULIC CHARACTERIZATION IN OPERATIVE CONDITION HAS BEEN DONE

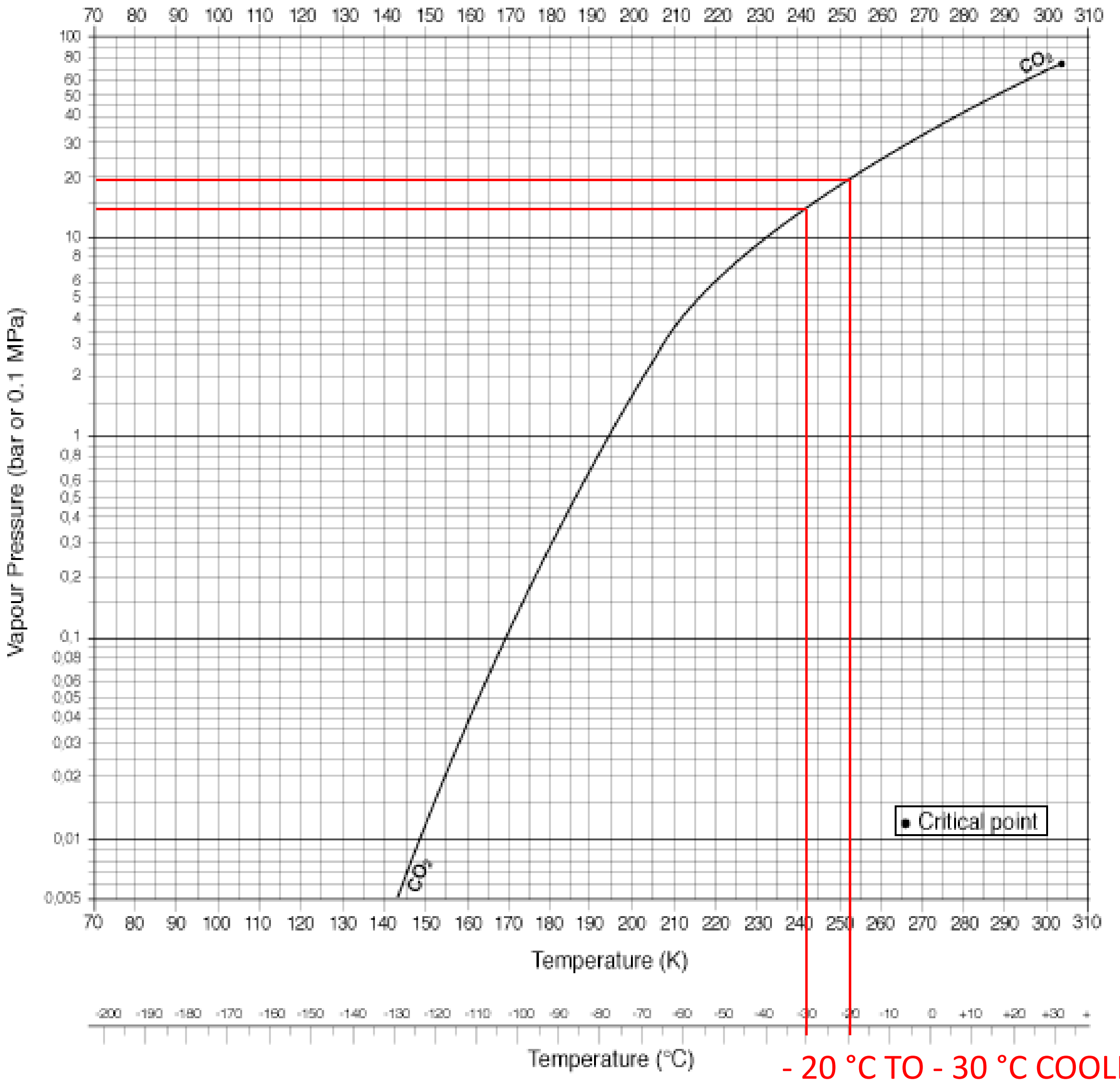
- CONNECTION COMPONENTS PROPOSED FOR THE DESIGN ARE UNDER INVESTIGATION AND MEASURED IN OPERATIVE CONDITIONS

THANKS FOR THE ATTENTION

Back-up slides

PURE **CO2 SATURATION CURVE**
TEMPERATURE AND PRESSURE INSIDE THE EVAPORATION CHANNEL

=> 15 TO 20 bar COOLING FLUID OPER. PRESSURE

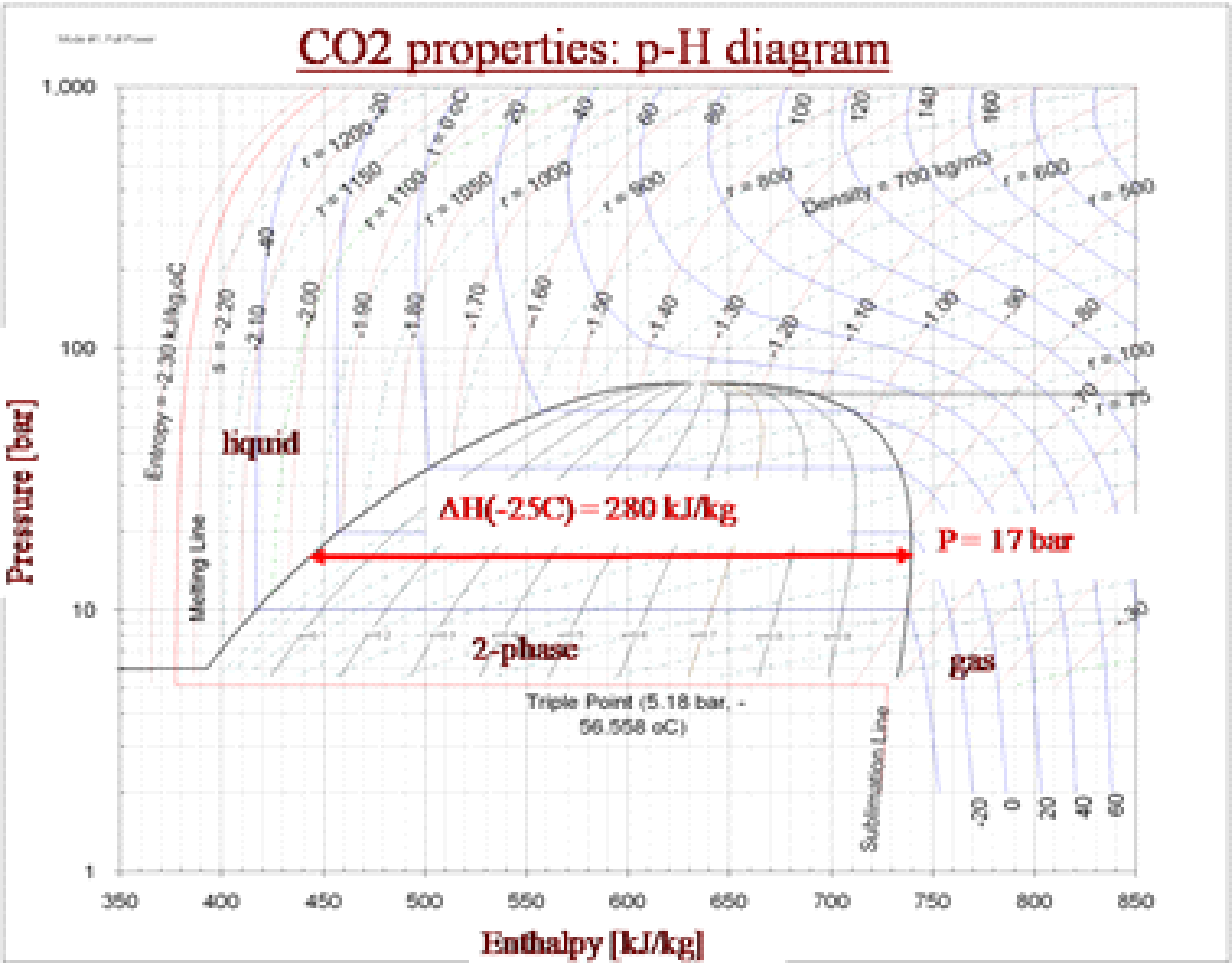


- 20 °C TO - 30 °C COOLING FLUID OPER. TEMP.

THE **LATENT HEAT OF VAPORIZATION FOR CO2** CAN BE KNOWN FROM THE CO2 PRESSURE-HENTALPY DIAGRAM

IN THE RANGE OF INTEREST

DELTA H liq.=> vap. = 280 kJ/kg



CO_2 physical properties

Set point on TRACIv1:
Accumulator pressure P = 15 bar ABS / T saturation= - 28,5 °C

at 15 bar ABS
Hentalpy liquid (X=0)
Hentalpy vapour (X=100%)

1. General Properties | 2. Saturation Properties | 3. CO2 Turbine | 4. Flash Evaporator | 5. P-H Diagram | 6. P-H Diagram (large)

Input Data

Select function: 1. function (p, x)
1. Pressure (absolute): 15 bar
2. Quality: 0 %

Calculate

Register and Create Account

	Property name	Property ID	Results (Liquid)	Results	Results (Vapor)	Units (SI)
	1. Thermodynamic Properties - Main					
1	Pressure (absolute)	p	15.0000000000	15.0000000000	15.0000000000	bar
2	Temperature	t	-28.5199041122	-28.5199041122	-28.5199041122	°C
3	Density	d	1069.3872426404	1069.3872426404	39.0557745757	kg/m³
4	Specific volume	v	0.0009351150	0.0009351150	0.0256044083	m³/kg
5	Specific enthalpy	h	-370.2278554471	-370.2278554471	-70.1517506628	kJ/kg

delta h L-V @15 bar ABS	**300**	**J/g**

calculated exhaust vapour fraction Xout
Xout = (h out-h in)/delta h L-V

(h out-h in)= Power/F
F= mass flowrate g/s
Power= elctrical heaters power W

=> Xout = (Power/F)/ delta h L-V

delta h L-V @15 bar ABS	300	J/g

Xout = 75 / (300 * F) W/(J/g*g/s) =1

Materials Properties Database for F.E.A.

LHCb UT STAVE - MATERIAL PROPERTIES DATABASE

rev. 2 09/06/2014

Orthotropic Material / Type			Thickness [µm]	E_X [GPa]	E_Y [GPa]	E_Z [GPa]	G_{XY} [GPa]	G_{YZ} [GPa]	G_{XZ} [GPa]	PR_{XY}	PR_{YZ} PR_{XZ}	ρ [Kg/m³]	CTE_X [ppm/K]	CTE_Y CTE_Z [ppm/K]	K_x [W/m K]	K_y [W/m K]	K_z [W/m K]	Fiber Vol. Ratio
CFRP STAVE FACEPLATE HYBRID STIFFENER	Fiber K13C / Resin Polycyanate RS3	Prepreg K13C/RS3	65	410	5,6	5,6	4,1	4,1	4,1	0,39	0,39	1731	-0,765	15				60%
	LAMINATE	Lay-up (0/90/0)	175	276	141		4,1			0,0156		1731	0,933	1,21	64	32	0.5	

Isotropic Material / Type		Thickness [µm]	E [GPa]	Poisson Ratio PR	ρ [Kg/m³]	CTE [ppm/K]	K [W/m K]
CARBON FOAM	ALLCOMP CARBON FOAM		0,7	0,25	200	3,5	35
ROHACELL	ROHACELL 51 IG		0,07	0,40	52,1	33 @20°C 24 @-100°C	0,029
COOLING PIPE I.D. 2,0 mm O.D. 2,2 mm	*BASELINE* TITANIUM CP grade 2	100	105	0,34	4510	8,6	16,4
	2[nd] *OPTION* STAINLESS STEEL AISI 316	100	193	0,30	8000	16,0	16,3
SIGNAL/POWER FLEX	KAPTON	230	2.5	0,34	1400	27	0,23
HYBRID FLEX	KAPTON	250	2.5	0,34	1400	27	0,23
SENSOR	SILICON	250	110	0,28	2400	2,5	124
ASIC		100					
GLUE	HYSOL 9396+35%BN	50	2,75	0.33 guess	1140	39,1 @ 20°C 27,1 @-40°C	1,4
	COMPLIANT EPOXY (SENSOR GLUE)	50	0,005	0,49	2360	200	1,34
	LOW CONDUCTIVE COMPLIANT EPOXY (SENSOR GLUE)	50	same	same	same	same	0,60
THERMAL VIAS	COPPER	250	110	0,34	8930	16,4	385
WIREBONDS	ALUMINUM		68	0,36	2700	24,0	210

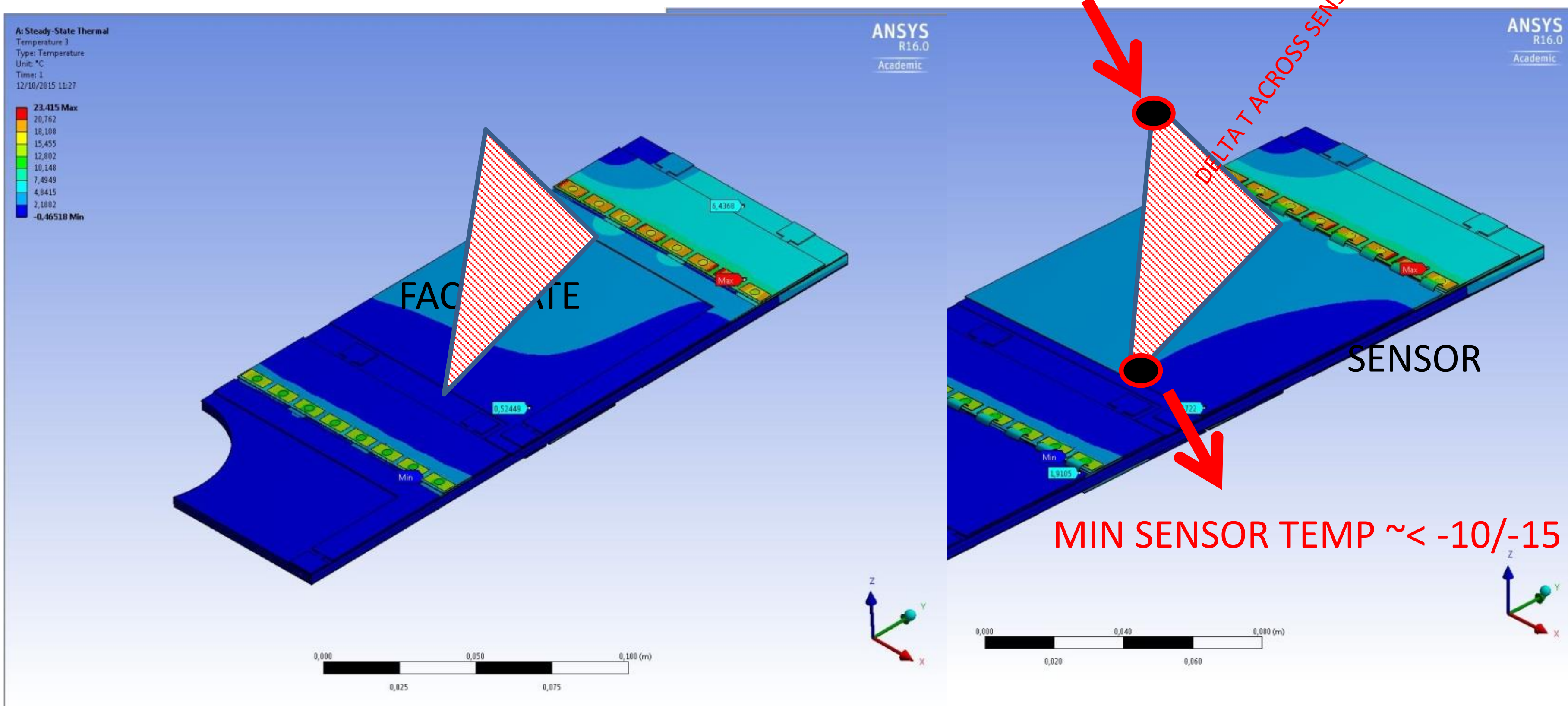
DETECTOR TEMERATURE FIELD
F.E.A. SIMULATION
COOLING PIPE TEMPERATURE SET TO 0 °C
=> TO SEE THE DETECTOR DISTRIBUTION OF TEMPERATURE

- SENSOR 8 ASICS (T3)

- VERSION V.5
- L-SHAPED SENSOR SUPPORT
- CERAMIC MATERIAL PBN /PYROLITIC BORON NITRIDE

REQUIREMENT MAX

SENSOR TEMP < -5 °C



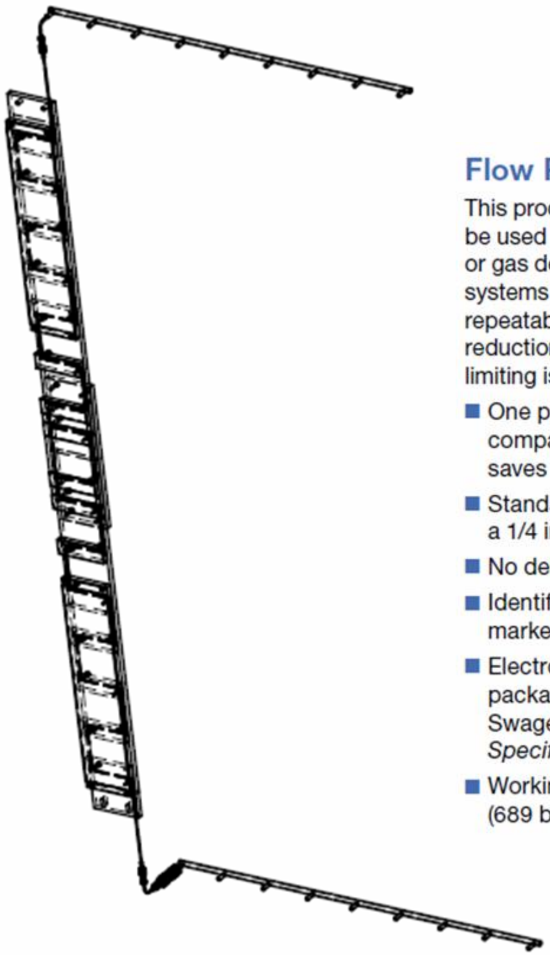
⇒ DETECTOR FACEPLATE AND STRUCTURE IS ALWAYS 1-6 °C OVER THE COOLING PIPE TEMPERATURE

⇒ SENSOR TEMPERATURE IS 1-7 °C OVER THE COOLING PIPE TEMPERATURE

TO RESPECT REQUIREMENT WITH MARGINS AND TAKING IN ACCOUNT CO_2 INTERNAL PIPE H.T.C. => COOLING PIPE < -20 °C

STAVE INLET CO2 CONNECTION

Calibrated orifices option

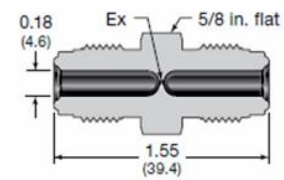


Flow Restrictors

This product can be used in liquid or gas delivery systems where repeatable flow reduction or limiting is required.

- One piece, compact design saves space
- Standard orifice sizes drilled through a 1/4 in. male VCR union
- No dead volume for clean operation
- Identification of orifice and heat code marked clearly on the body
- Electropolished, cleaned, and packaged in accordance with Swagelok *Ultrahigh-Purity Process Specification (SC-01)*, MS-06-61
- Working pressure 10 000 psig (689 bar)

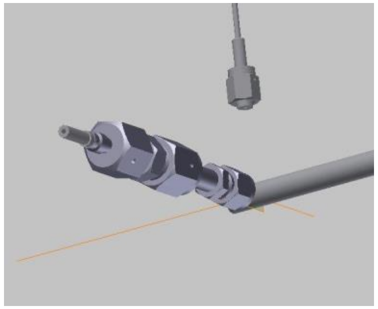
Ordering Information and Dimensions



VCR components with fixed threads must remain stationary during normal installation. These fitting connections should be assembled only to glands with rotating female nuts.

Ex, in. (mm)	Ordering Number
0.010 (0.254)	6LV-4-VCR-6-DM-010P
0.012 (0.305)	6LV-4-VCR-6-DM-012P
0.015 (0.381)	6LV-4-VCR-6-DM-015P
0.017 (0.432)	6LV-4-VCR-6-DM-017P
0.020 (0.508)	6LV-4-VCR-6-DM-020P
0.023 (0.584)	6LV-4-VCR-6-DM-023P
0.025 (0.635)	6LV-4-VCR-6-DM-025P
0.026 (0.660)	6LV-4-VCR-6-DM-026P
0.027 (0.686)	6LV-4-VCR-6-DM-027P
0.030 (0.762)	6LV-4-VCR-6-DM-030P
0.035 (0.889)	6LV-4-VCR-6-DM-035P
0.040 (1.016)	6LV-4-VCR-6-DM-040P
0.045 (1.143)	6LV-4-VCR-6-DM-045P

Ex, in. (mm)	Ordering Number
0.050 (1.270)	6LV-4-VCR-6-DM-050P
0.055 (1.397)	6LV-4-VCR-6-DM-055P
0.060 (1.529)	6LV-4-VCR-6-DM-060P
0.065 (1.651)	6LV-4-VCR-6-DM-065P
0.070 (1.778)	6LV-4-VCR-6-DM-070P
0.075 (1.905)	6LV-4-VCR-6-DM-075P
0.080 (2.032)	6LV-4-VCR-6-DM-080P
0.085 (2.159)	6LV-4-VCR-6-DM-085P
0.090 (2.286)	6LV-4-VCR-6-DM-090P
0.093 (2.362)	6LV-4-VCR-6-DM-093P
0.095 (2.413)	6LV-4-VCR-6-DM-095P
0.100 (2.540)	6LV-4-VCR-6-DM-100P



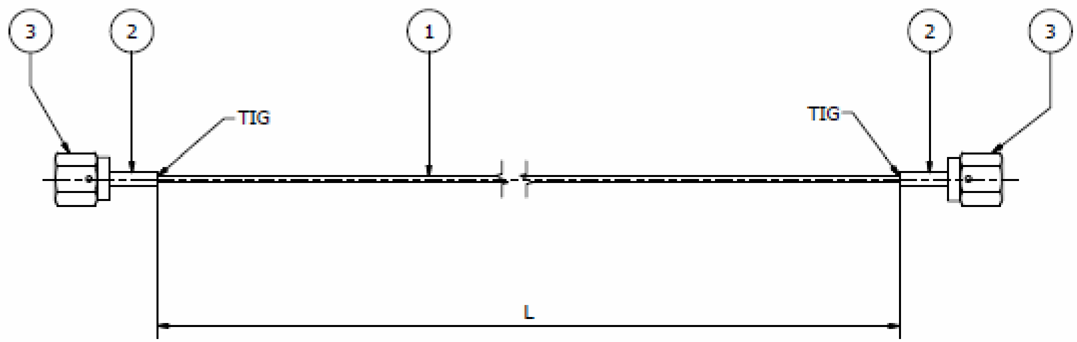
ONE INLET
FLOW RESTRICTION
FOR EACH STAVE

INLET CONNECTION
COMPONENT PRODUCTION QUALIFICATION: 2 SAMPLES

1/16”
COMMERCIAL
Swagelok pipe

ID 0,88 mm
OD 1,59 mm
Th 0,35 mm

AISI 316 L
MICROTIG/LASER
WELDING



NOTE:
L1= 500 mm
L2= 2500 mm

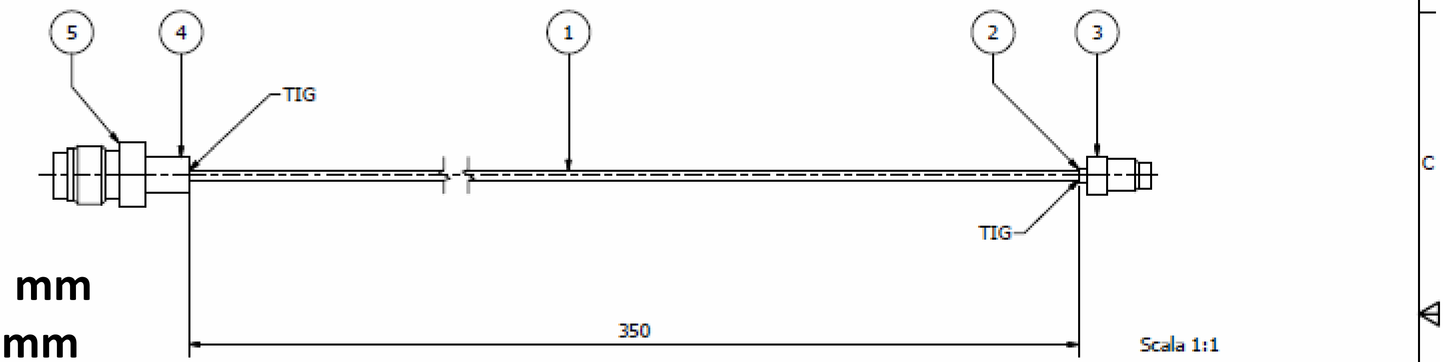
Scala 1:1

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Pipe_1-16 in._0.014 in. Wall	Swagelok SS-T1-014-6ME
2	2	SS-1-VCR-3	
3	2	SS-2-VCR-1	

Designed by	Checked by	Approved by	Date	Date	
Gesmundo Carlo				05/10/2015	

Prototipo tubazione saldata Linea inlet raffreddamento	TRACI - INFN Milano		
	STAVE 00.01.12	Edition	Sheet 1 / 1

OUTLET CONNECTION
COMPONENT PRODUCTION QUALIFICATION: 2 SAMPLES



ID 2,0 mm
OD 2.5 mm
Th 0.25 mm

NOTA: Le due flange di estremita' dovranno avere un foro passante corrispondente al Ø interno del tubo principale (Ø 2 mm)

AISI 316 L
MICROTIG/LASER
WELDING

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Pipe_2x2.5x160	AISI 316L/304
2	1	SS-1-VCR-3	Swagelok
3	1	SS-2-VCR-4	Swagelok
4	1	SS-4-VCR-3_BL	Swagelok
5	1	SS-4-VCR-4	Swagelok

Designed by	Checked by	Approved by	Date	Date
Carlo Gesmundo				05/10/2015

Prototipo tubazione saldata
Linea outlet raffreddamento

TRACI - INFN Milano

	Edition	Sheet
STAVE 00.01.11		1 / 1

ORDER PLACED TO A COMPANY
TO PRODUCE INLET AND OTLET CONNECTION SAMPLES

THE GOAL IS

- TO PRODUCE THE INLET AND OUTLET PIPING SAMPLES
- REAL PIPE /REAL FITTING WELDED JOINTS

TESTING

- LEAK-RATE AFTER PRESSURIZATION
- TRACI TEST IN REAL CONDITIONS (MOUNT-DEMOUNT VCR FITTINGS, COLD OPERATION)
- MEASURE THE RIGIDITY OF THE 2/2,5mm OUTLET PIPE, AFTER COILING AND POST-ANNEALING

<u>IF POSITIVELY</u> QUALIFIED,
THE COMPANY COULD BE A CANDIDATE FOR THE PRODUCTION OF THE MANIFOLDS, PIPING CONNECTIONS ETC FOR THE UT DETECTOR.

Rodofil® tecnologie di elettroerosione
edm filo e tuffo - microforatura - fresatura e tornitura cnc - elettrodi grafite - rettifica - saldatura laser

From: **Marco Canetti**
RIAL VACUUM RESEARCH
Via Tito ed Ettore Manzini 7/a
43126 Parma ITALIA
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e-mail: marco.canetti@rialvacuum.com

To: **Carlo Gesmundo**
I.N.F.N. Sez. Milano
Via Giovanni Celoria, 16
20133 Milano
tel: 02 50317681
e-mail: carlo.gesmundo@mi.infn.it

OFFERTA

N. 15/420b　　Pag: 1/1　　Data: 15.10.2015

Gent.mo Carlo,

a seguito della vostra gradita richiesta, Vi inviamo l'offerta per la realizzazione delle linee di raffreddamento.
Tubi in AISI 316L.
Dimensioni dei tubi e i raccordi di estremità come da vostri disegni.
Nella presente quotazione viene considerato di unire i raccordi ai tubi mediante tecniche di saldatura TIG e LASER.
Controllo visivo, controllo dimensionale e test di tenuta con cercafughe He inclusi.

Pos.	*Disegno*	*Descrizione*	*Q.tà*	*Prezzo tot*
1	STAVE 00.01.11	LINEA OUTLET RAFFREDDAMENTO	2	1.160,00 €
2	STAVE 00.01.12	LINEA INTLET RAFFREDDAMENTO L=500	1	580,00 €
3	STAVE 00.01.12	LINEA INLET RAFFREDDAMENTO L=2500	1	610,00 €
4	-	Trasporto	1	60,00 €

Imballaggio incluso
Tempo di esecuzione: 3 settimane da ricevimento ordine

Restiamo a disposizione per ogni richiesta di chiarimento.
Cordiali saluti,

RIAL VACUUM RESEARCH
Marco Canetti
Marco Canetti

RIAL VACUUM RESEARCH

RODOFIL s.n.c. di Alessandro Zanichelli & C. - Strada di Chiozzola 29 - 43058 Chiozzola di Sorbolo - Parma - tel. +39.0521.604366-7 - fax +39.0521.604368
e-mail: info@rodofil.com - www.rodofil.com - C.F. e P. IVA 01702180348 - Iscr. trib. di Parma N.20315 - R.E.A. N.172730

SENSORS FOR THE TEST

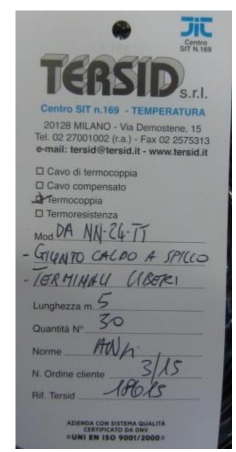
5 CO2 pressure sensors

Piezoresistive
Pressure Transmitters
KELLER Series 21 Y
Type PAA-21Y / 80bar / 81555.33
4-20 mA
0-80 bar abs.

5 CO2 temperature sensors

Resistance temperature detectors PT100
RODAX
OD 4 mm; length 80 mm;
4 wire connection

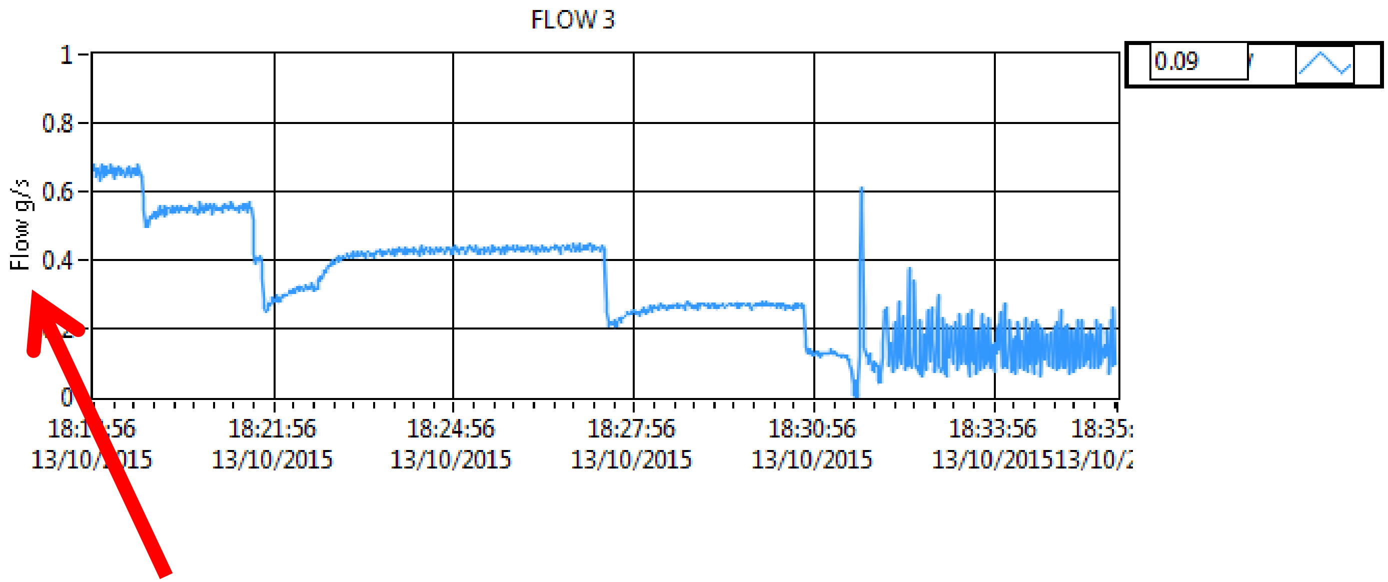
30 external temperature Termocouples T type



COOLING TEST WITH TRACI

Many data have been collected

But output need to be elaborated and made presentable



POWER:

- 0 W
- 50% = 38 W
- 100% = 75 W
- 150% = 113 W

MASS FLOW-RATE:

- NOMINAL =TO HAVE 30 % CO2 EXHAUST FRACTION
- DECREASING UNTIL DRY-OUT
- INCREASING TO MAX POSSIBLE
- 0,1 - 2 g/s RANGE

PRESSURE SET POINT:

- 20 BAR (T EVA ~ -20 °C)
- 15 BAR (T EVA ~ -28 °C)

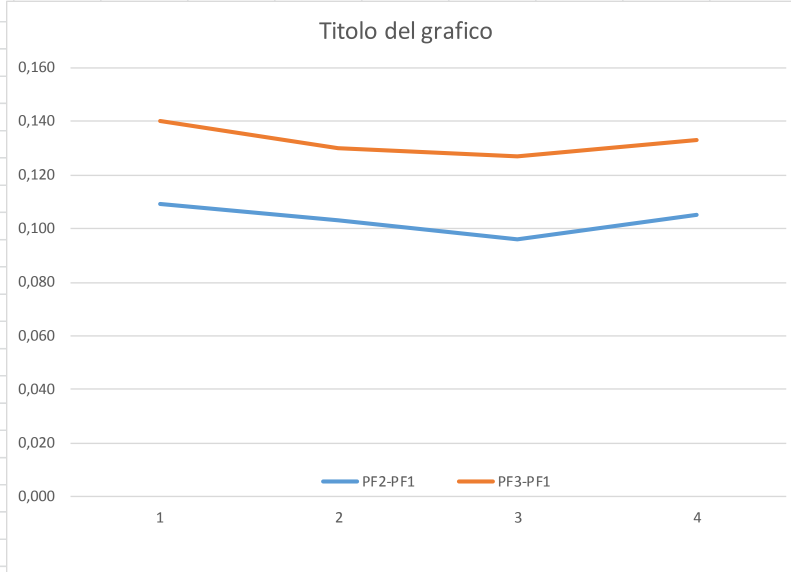
STUDY OF TRANSIENTS AND FINAL STEADY -STATES

- SETTING FLOWRATE AT NOMINAL POWER
- POWER FROM 0 - 100% - 0
- 0-50-100-150-100-0

PRESSURE SENSOR SETTING

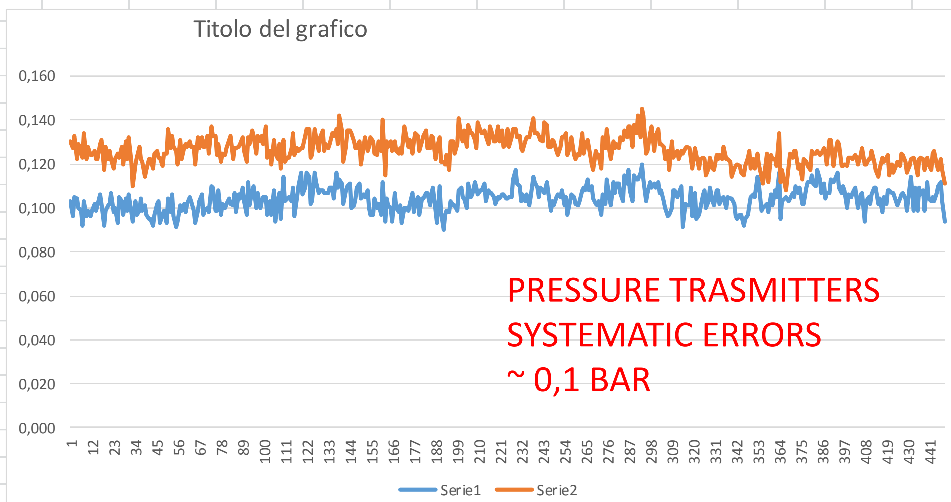
2015-10-13 TARATURA PF

PF1	PF2	PF3
22,72	22,84	22,869
22,712	22,826	22,856
22,713	22,824	22,852
22,709	22,823	22,851



FLOW = 0

PF1	PF2	PF3	PF2-PF1	PF3-PF1
20,612	20,721	20,752	0,109	0,140
20,618	20,721	20,748	0,103	0,130
20,6	20,696	20,727	0,096	0,127
20,593	20,698	20,726	0,105	0,133
20,604	20,708	20,726	0,104	0,122
20,59	20,69	20,719	0,100	0,129
20,576	20,675	20,701	0,099	0,125
20,583	20,675	20,706	0,092	0,123
20,562	20,665	20,696	0,103	0,134
20,569	20,665	20,691	0,096	0,122
20,556	20,655	20,684	0,099	0,128
20,558	20,654	20,682	0,096	0,124
20,552	20,651	20,676	0,099	0,124
20,529	20,631	20,655	0,102	0,126
20,539	20,638	20,661	0,099	0,122
20,526	20,627	20,648	0,101	0,122
20,514	20,62	20,643	0,106	0,129
20,517	20,619	20,648	0,102	0,131
20,512	20,604	20,629	0,092	0,117
20,5	20,599	20,628	0,099	0,128

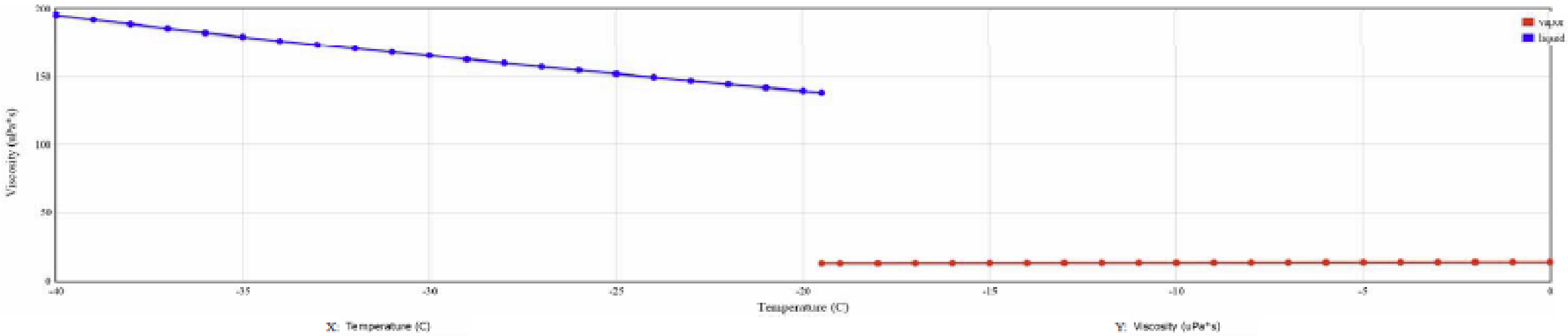


PRESSURE TRASMITTERS
SYSTEMATIC ERRORS
~ 0,1 BAR

Fluid Data

Isobaric Data for P = 20.000 bar

Plot | Help | Software credits



Auxiliary Data

Reference States

Fluid Data

Isobaric Data for P = 20.000 bar

Plot | Help | Software credits