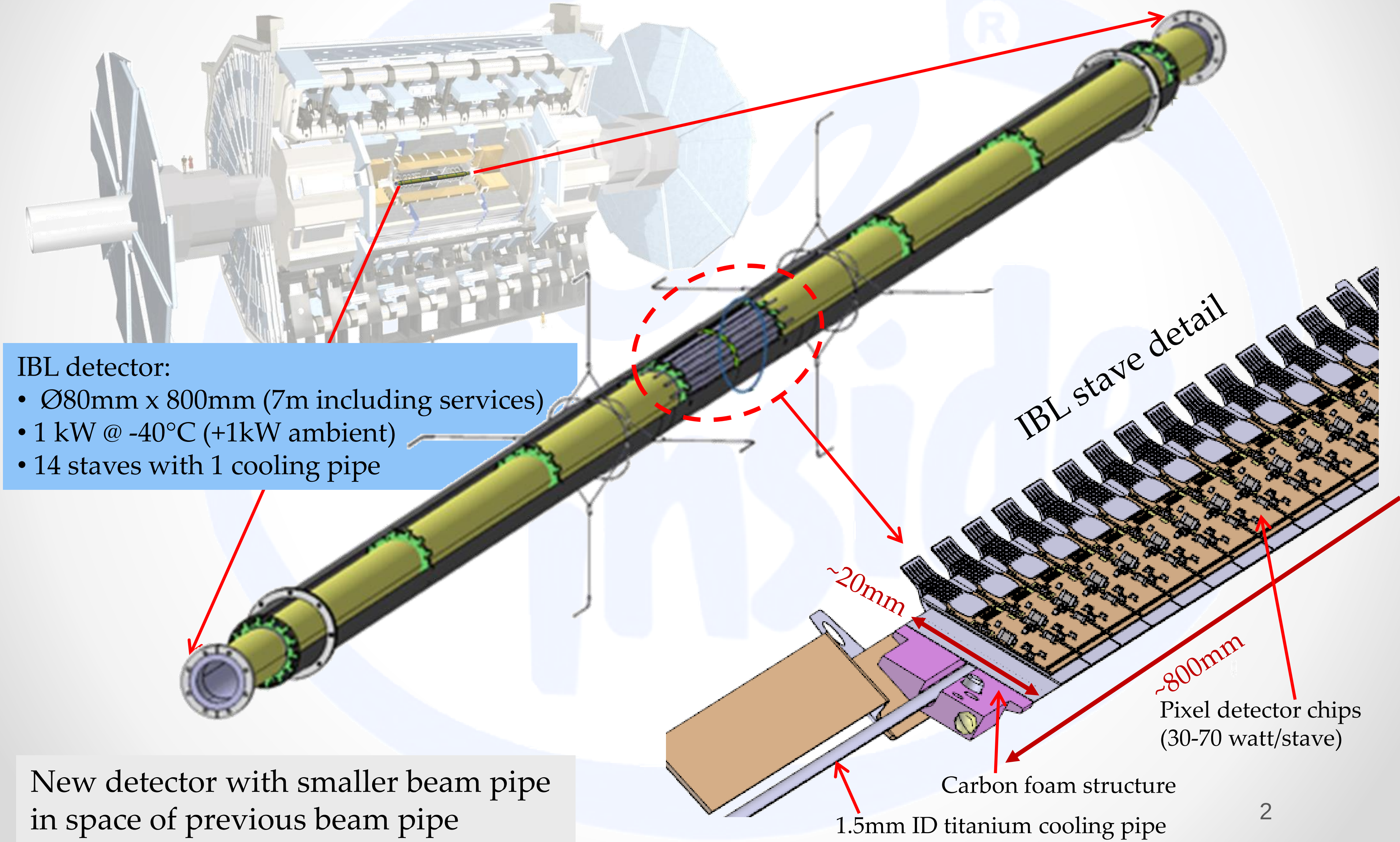
Commissioning of the ATLAS IBL CO_2 Cooling system

Forum on Tracking Detector Mechanics 2016

(Bonn, 23-25 May 2016)

VERLAAT, Bart (CERN), OSTREGA, Maciej (CERN), ZWALINSKI, Lukasz (CERN), BORTOLIN, Claudio (CERN), VOGT, Sven (MPI-Münich (DE)), DELUCA, Carolina (NIKHEF (NL)), DZIURDZIA, Piotr (Cracow University of Technology (PL)), GODLEWSKI, Jan (Polish Academy of Sciences (PL)), CRESPO-LOPEZ, Olivier (CERN), LANTZSCH, Kerstin (Universität Bonn)

Atlas Inner B-Layer (IBL)



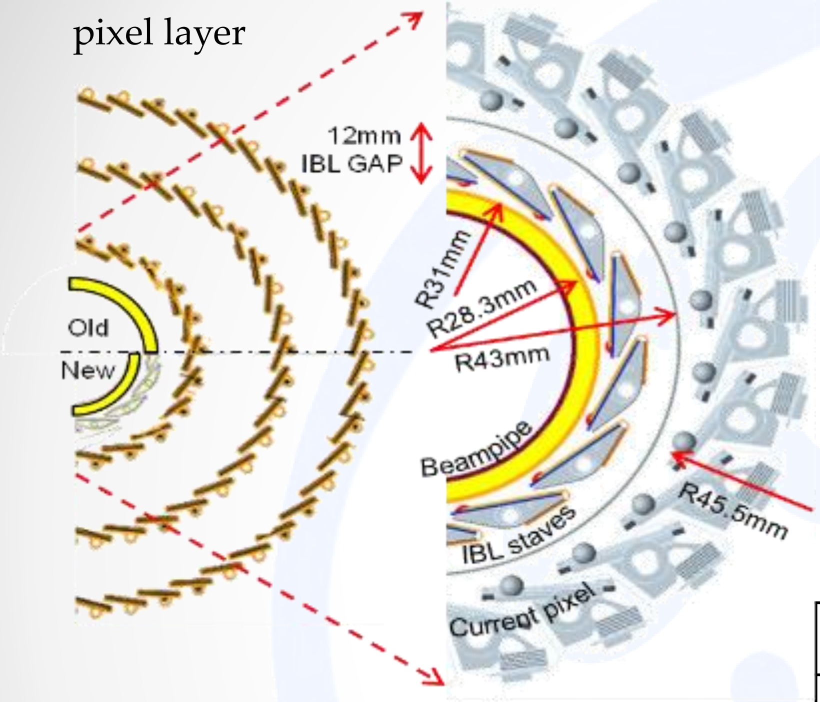
IBL detector:

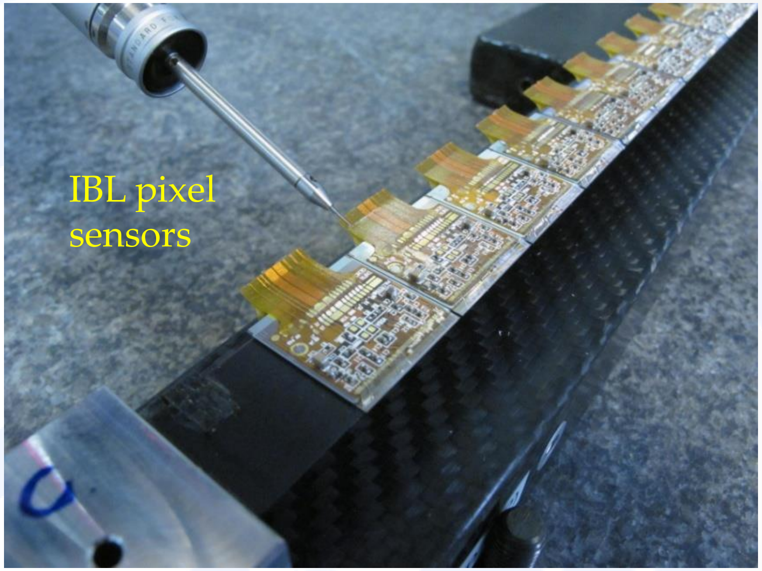
- Ø80mm x 800mm (7m including services)
- 1 kW @ -40°C (+1kW ambient)
- 14 staves with 1 cooling pipe

New detector with smaller beam pipe in space of previous beam pipe

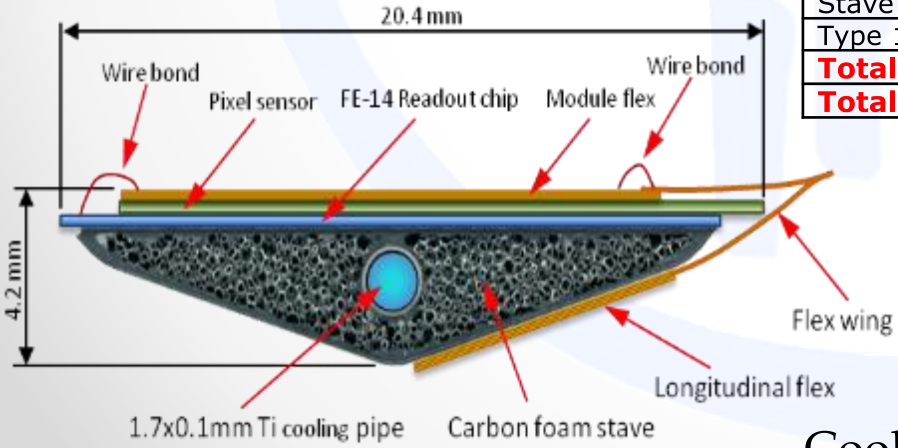
Atlas IBL: A new 1st layer around a reduced beam pipe

IBL an extra pixel layer

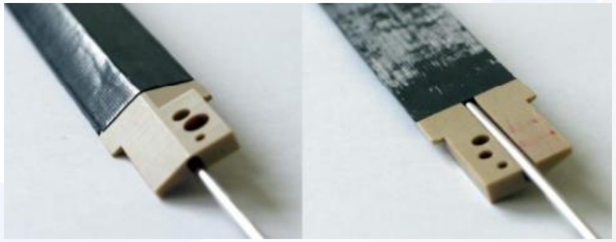




Component (32 per stave)	**Power (W/unit)**	**Power (W/stave)**
FEI4 chip	1.12	35.84
Pixel sensor (after irradiation)	0.68	21.61
Stave flex	0.17	5.38
Type 1 cables	0.17	5.38
Total per stave		**68.21**
Total for 14 staves		**954.94**



IBL Carbon stave with cooling pipe



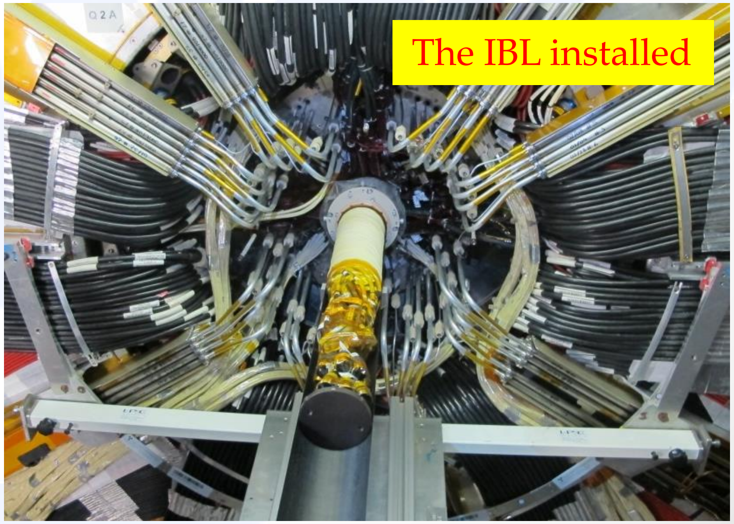
Cooling temperature required: <-35°C

IBL Stave

Installation of the IBL in ATLAS (June 2014)

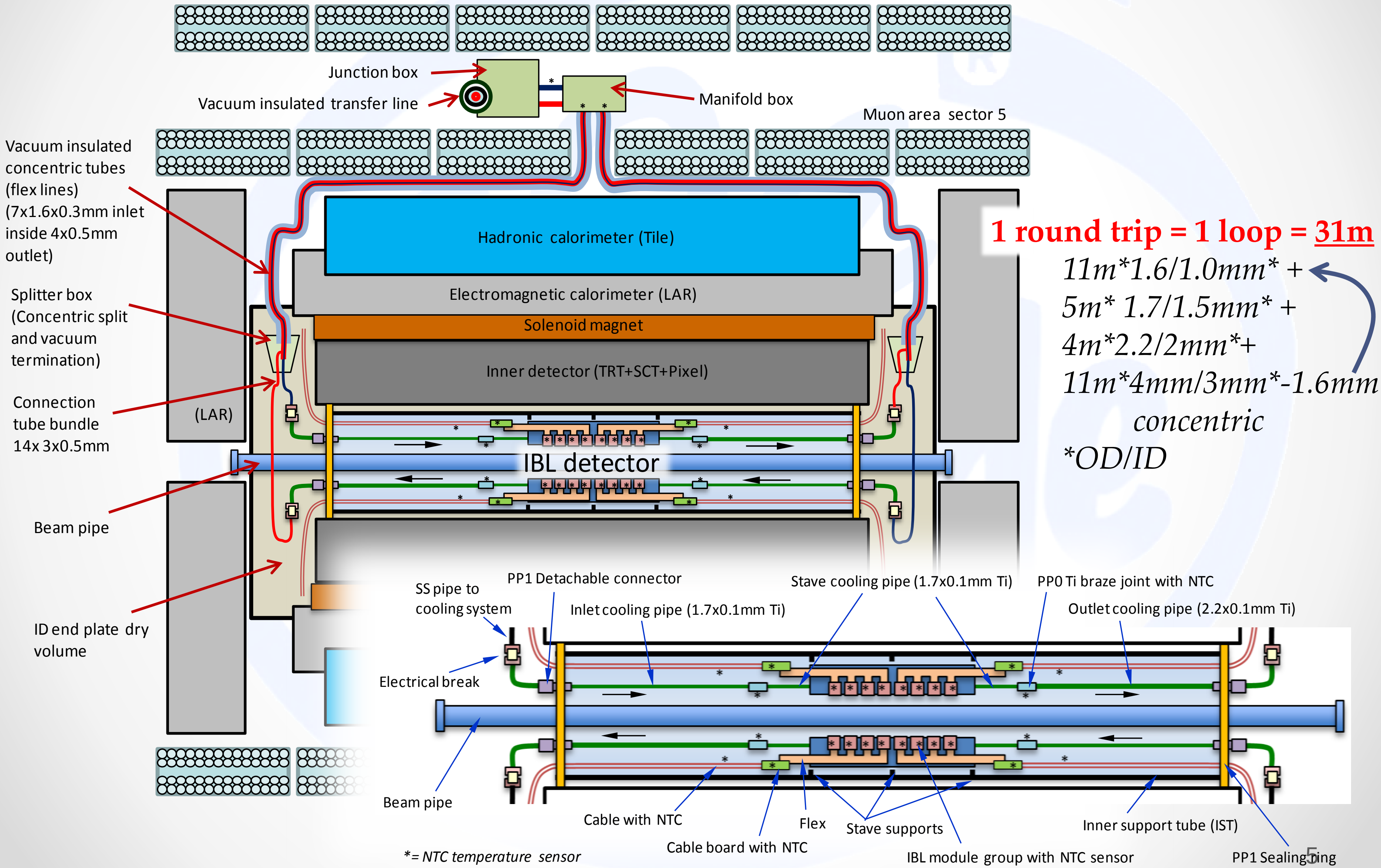
The IBL installation

The IBL central stave section



The IBL installed

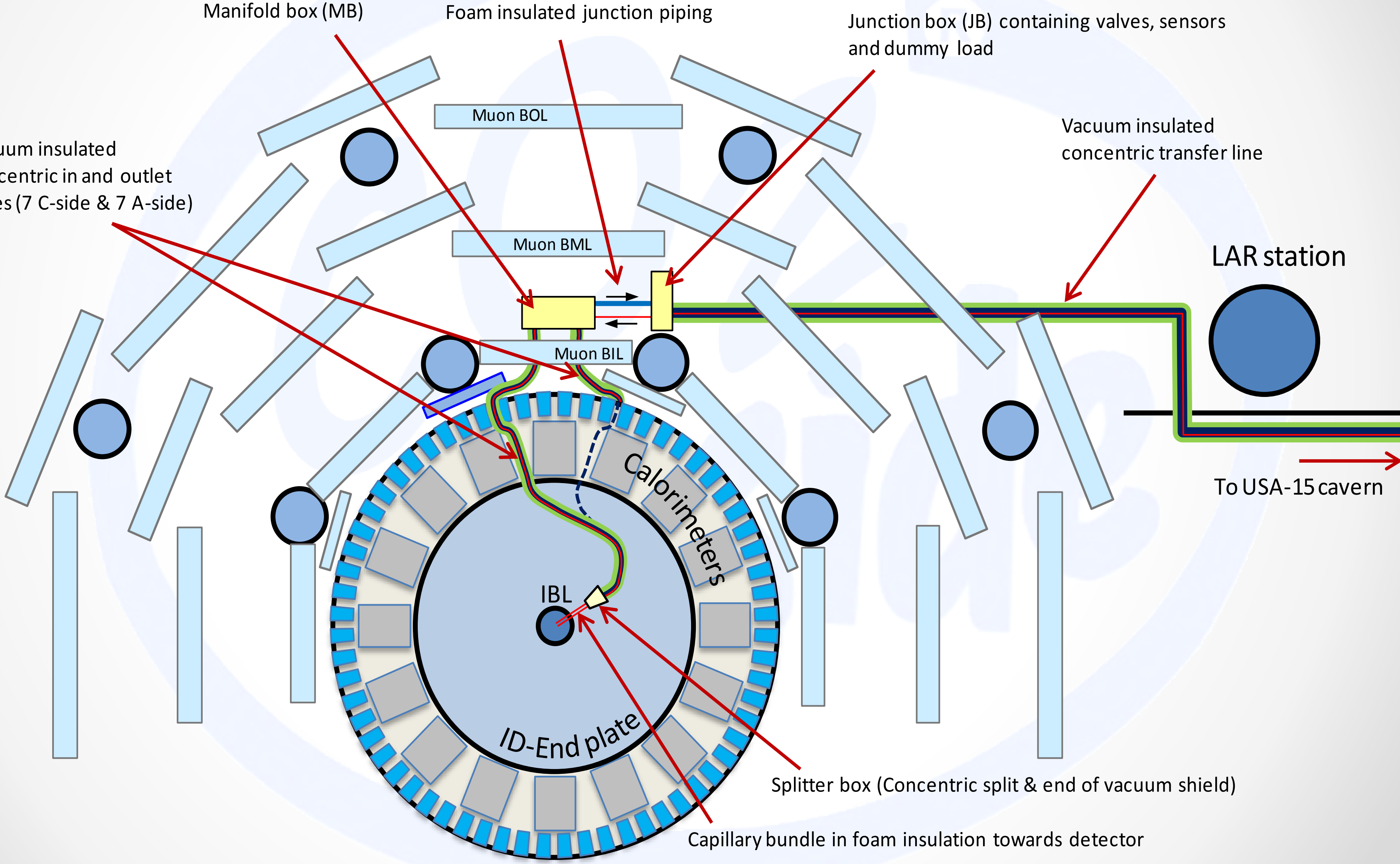
The IBL cooling loop layout (1)



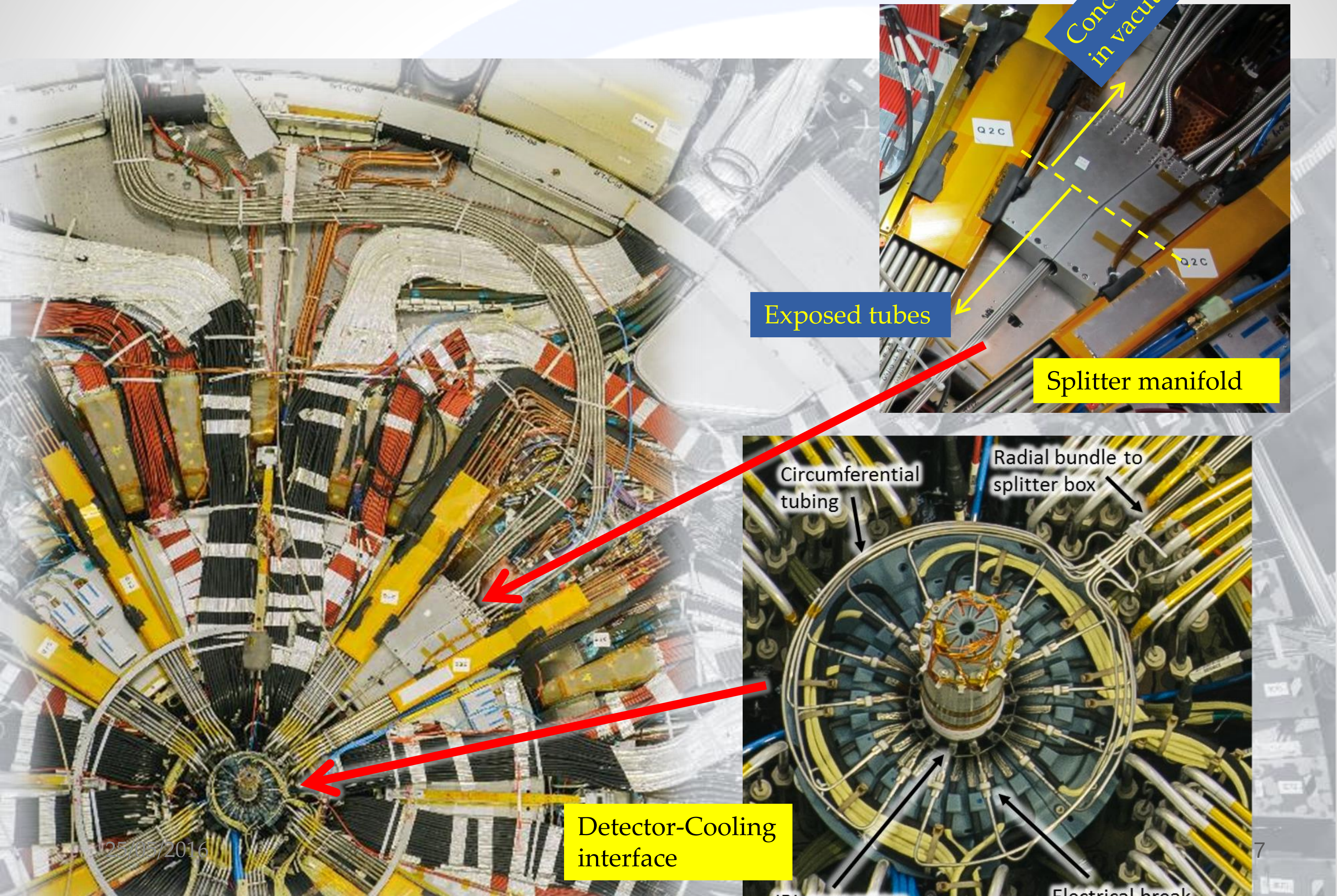
1 round trip = 1 loop = 31m

11m*1.6/1.0mm* +
5m* 1.7/1.5mm* +
4m*2.2/2mm*+
11m*4mm/3mm*-1.6mm
concentric
*OD/ID

The IBL cooling loop layout (2)
(C-side view)



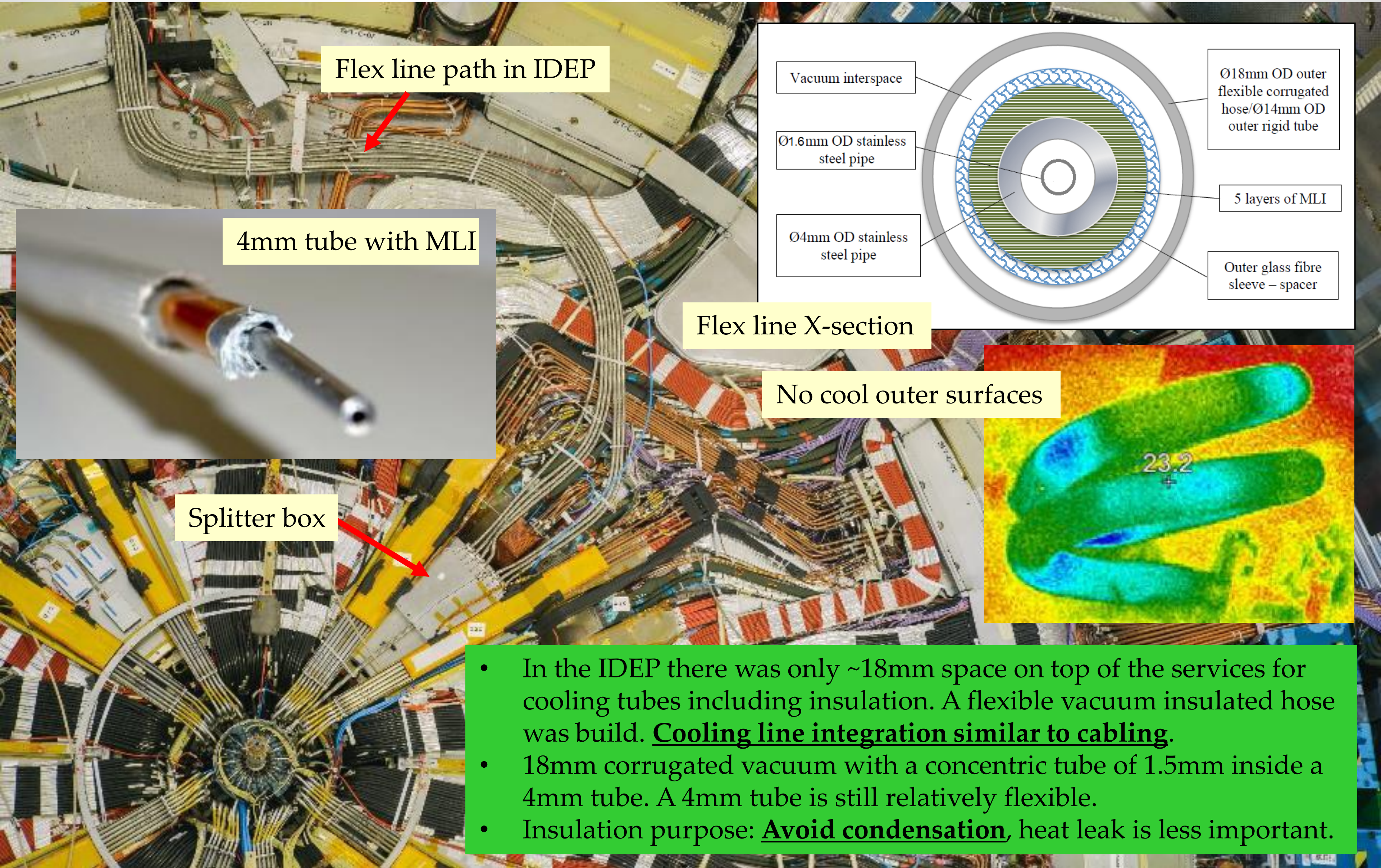
Cooling Connection in PP1



Detector-Cooling
interface

The IBL distribution flex lines

See details in Claudio’s talk at FTDM-2015, https://indico.cern.ch/event/363327/contributions/860744/attachments/722740/991990/ForumNikhef2015.pdf


Flex line path in IDEP

4mm tube with MLI

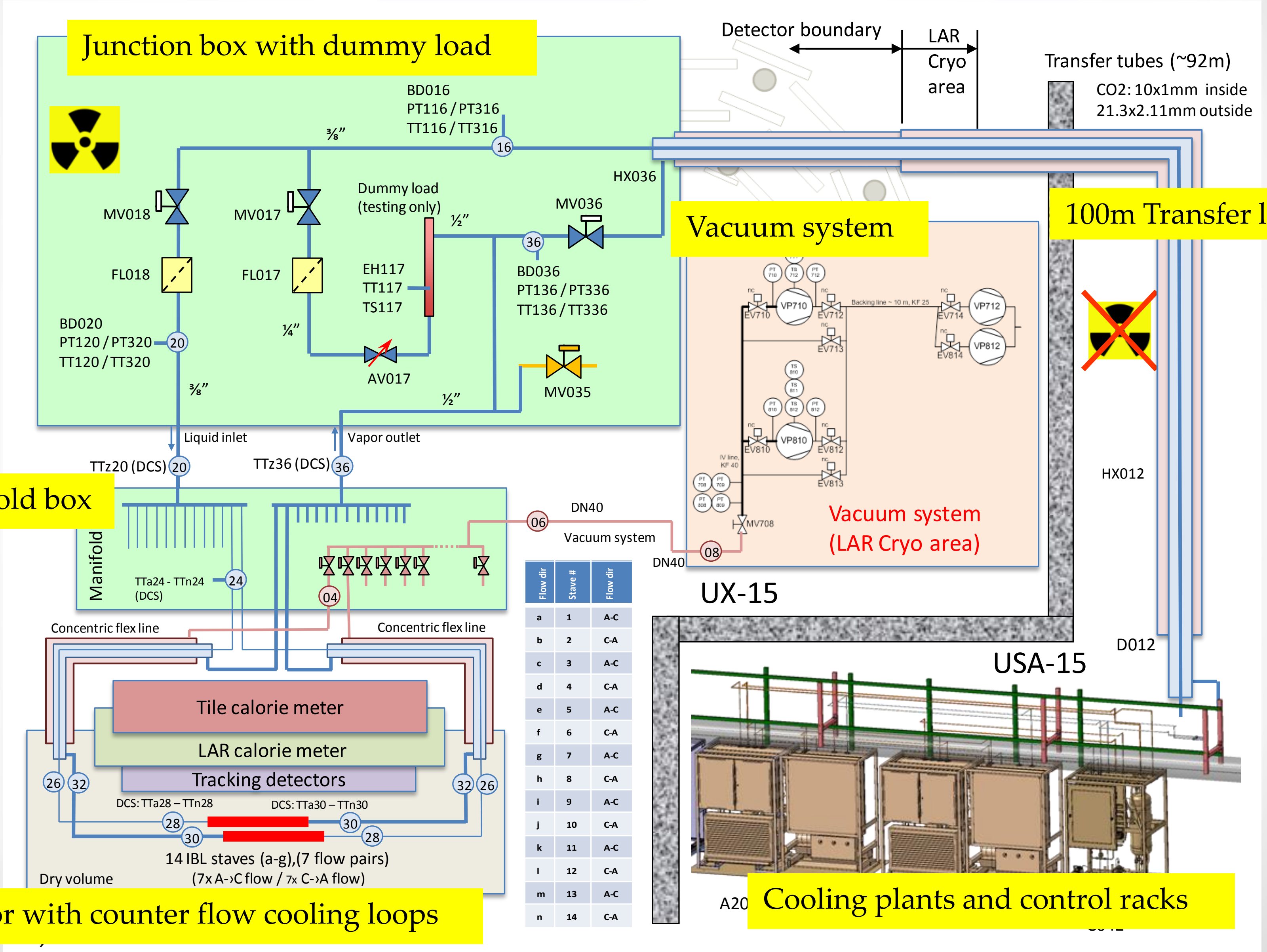
Flex line X-section

No cool outer surfaces

Splitter box

- In the IDEP there was only ~18mm space on top of the services for cooling tubes including insulation. A flexible vacuum insulated hose was build. **Cooling line integration similar to cabling**.
- 18mm corrugated vacuum with a concentric tube of 1.5mm inside a 4mm tube. A 4mm tube is still relatively flexible.
- Insulation purpose: **Avoid condensation**, heat leak is less important.

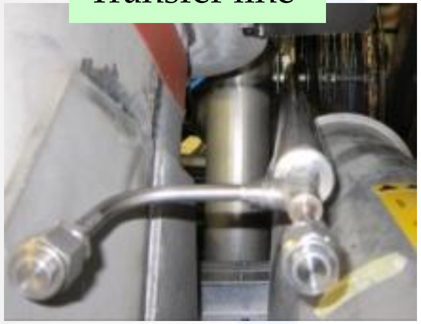
IBL cooling system layout

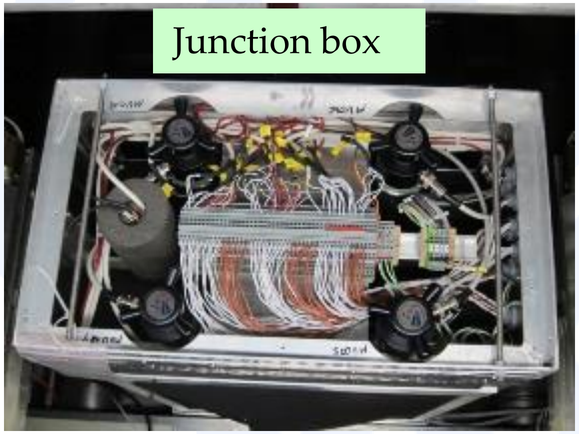


Flow dir	Stave #	Flow dir
a	1	A-C
b	2	C-A
c	3	A-C
d	4	C-A
e	5	A-C
f	6	C-A
g	7	A-C
h	8	C-A
i	9	A-C
j	10	C-A
k	11	A-C
l	12	C-A
m	13	A-C
n	14	C-A

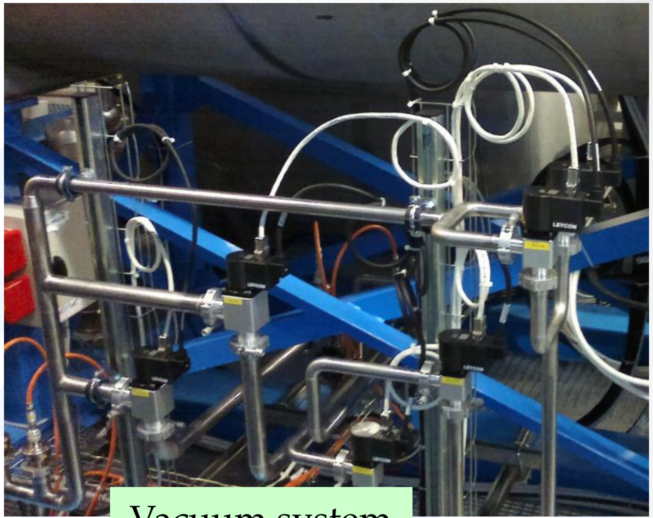
CO_2 cooling hardware in UX

Transfer line





Junction box



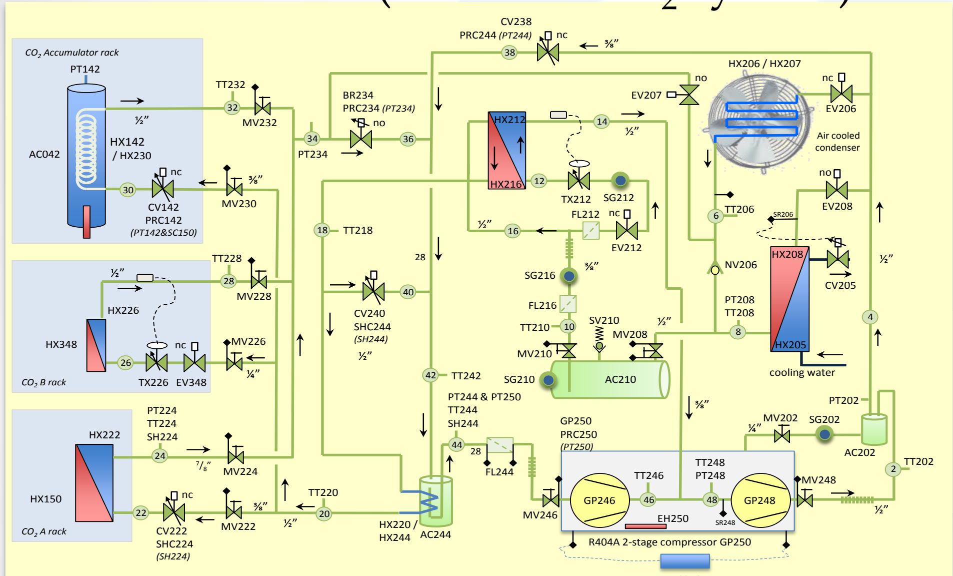
Vacuum system

Flex lines

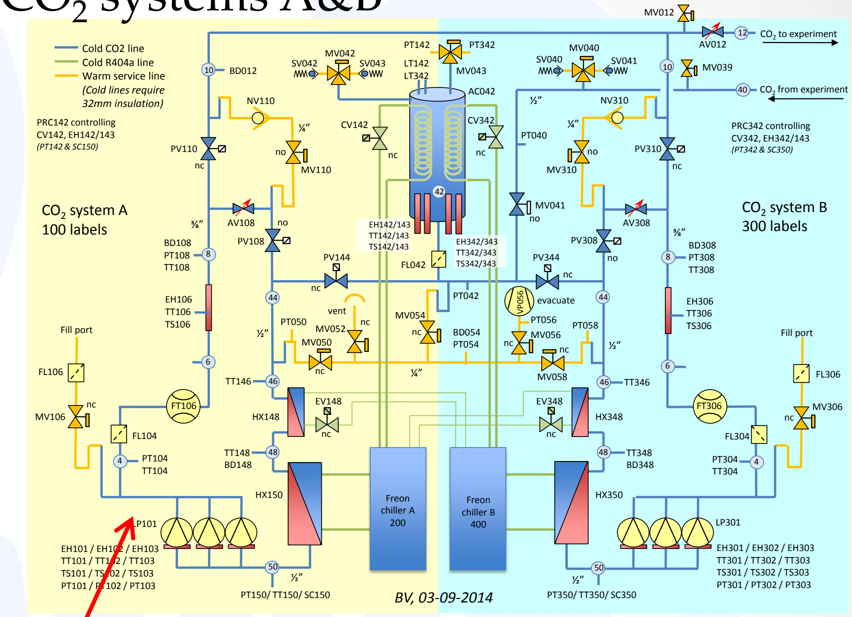
Manifold box

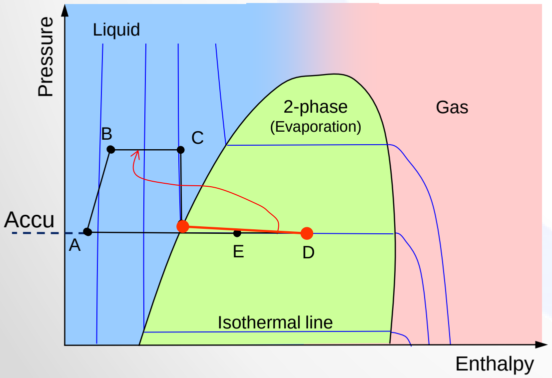
CO_2 and R404a system P&ID

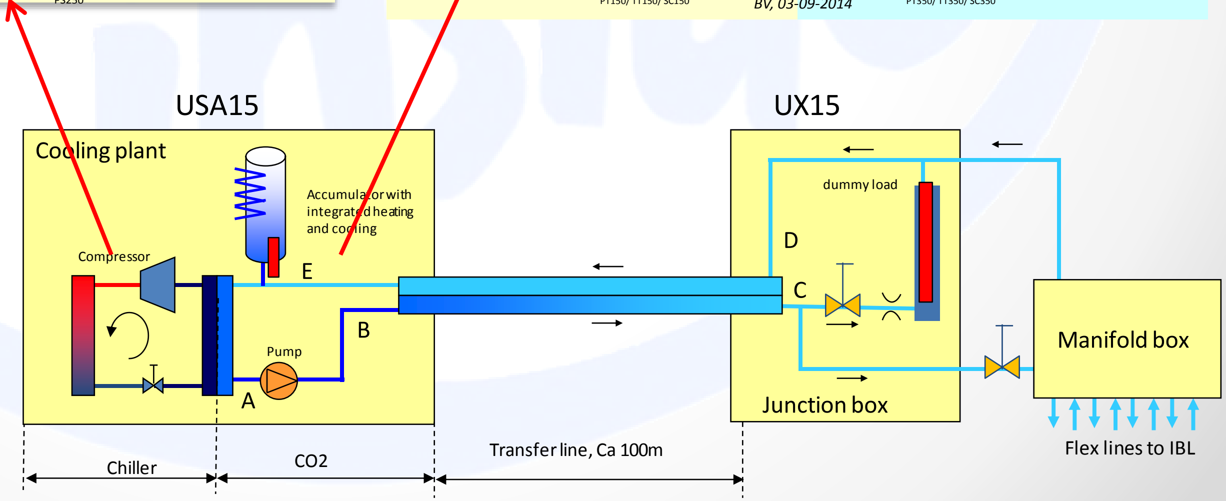
R404a chiller (one each CO_2 system)



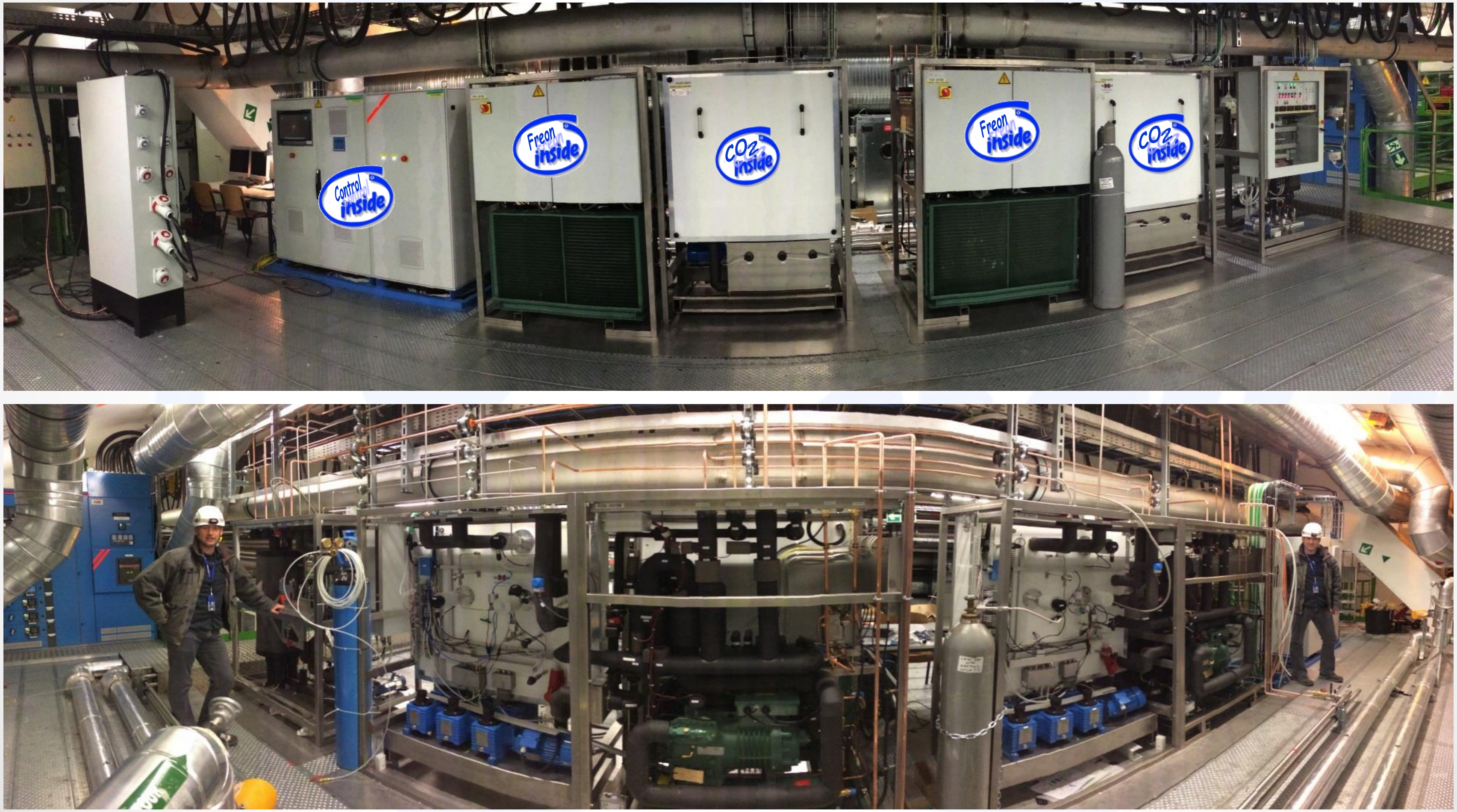
CO_2 systems A&B



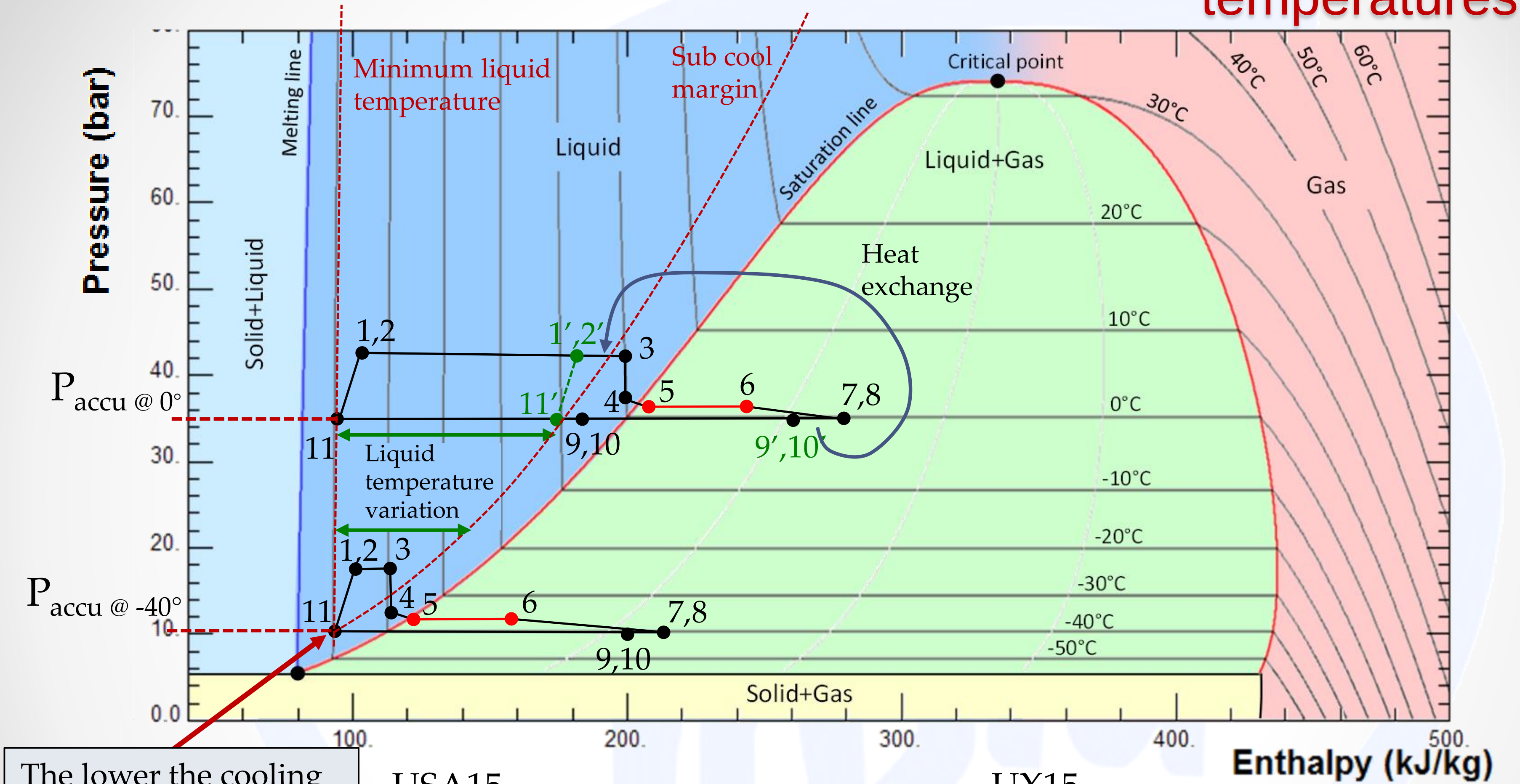




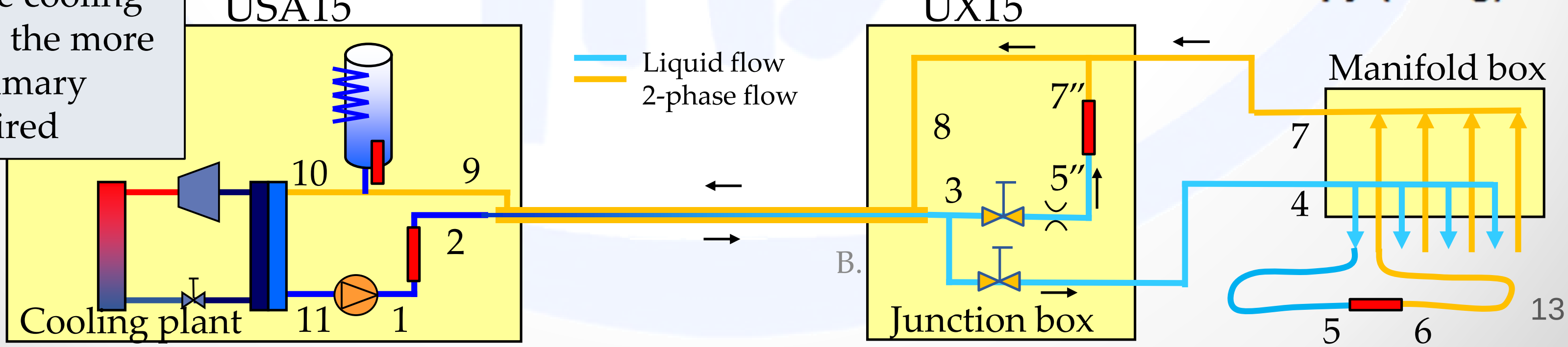
Cooling plants in USA-15



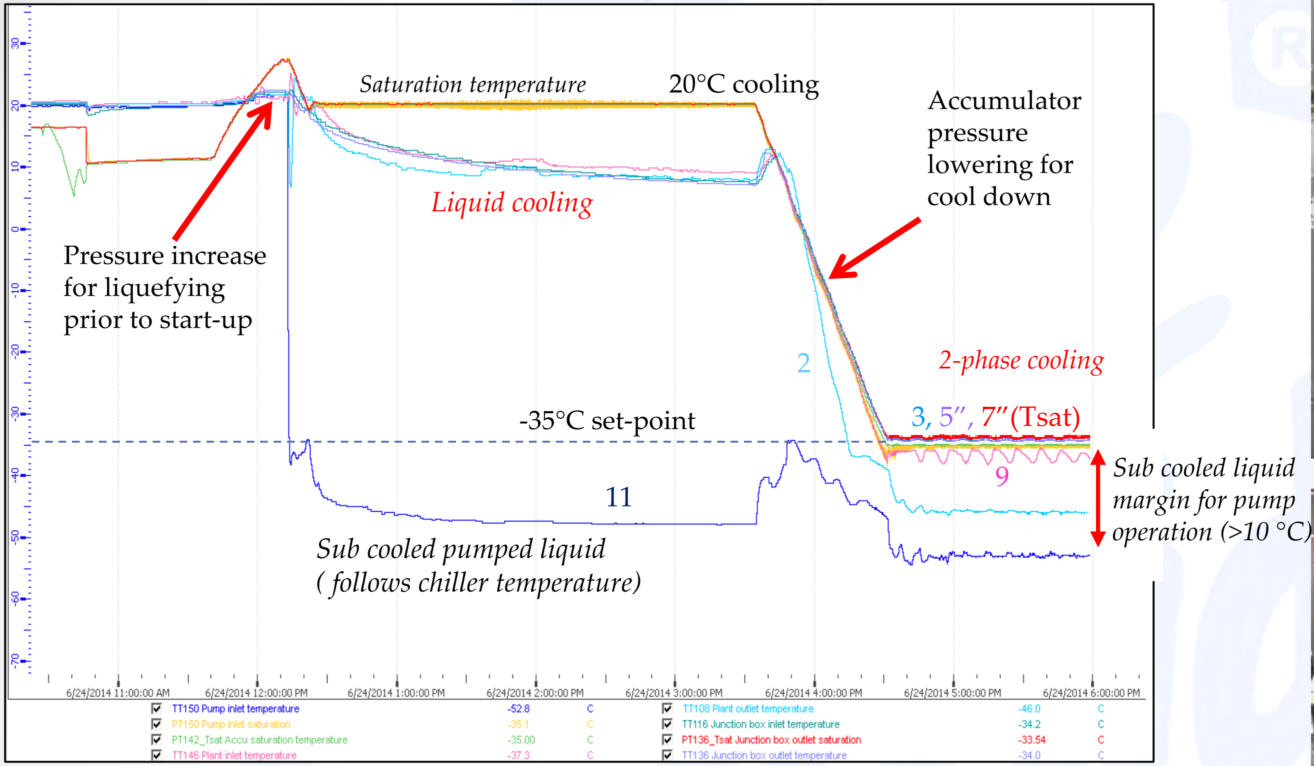
IBL CO_2 operation cycle, challenges at cold temperatures



The lower the cooling temperature, the more stable the primary cooling required



CO_2 plant operation *(over junction box)*



Saturation temperature

20°C cooling

Accumulator pressure lowering for cool down

Liquid cooling

Pressure increase for liquefying prior to start-up

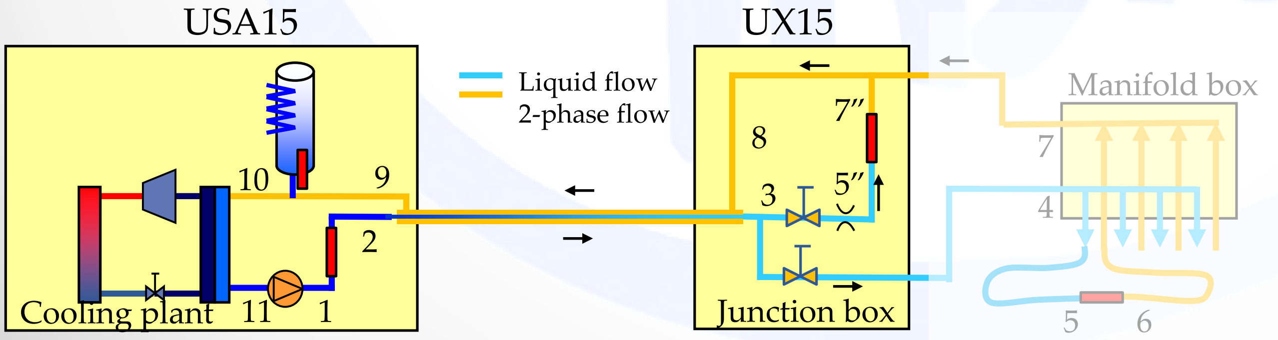
2-phase cooling

-35°C set-point

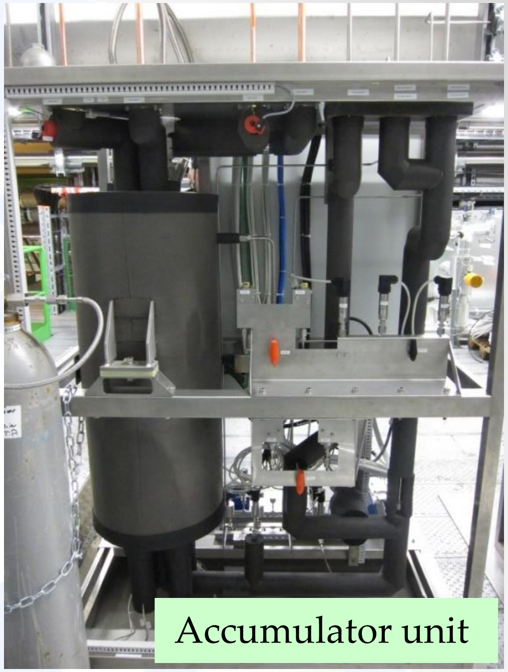
Sub cooled liquid margin for pump operation (>10 °C)

Sub cooled pumped liquid (follows chiller temperature)

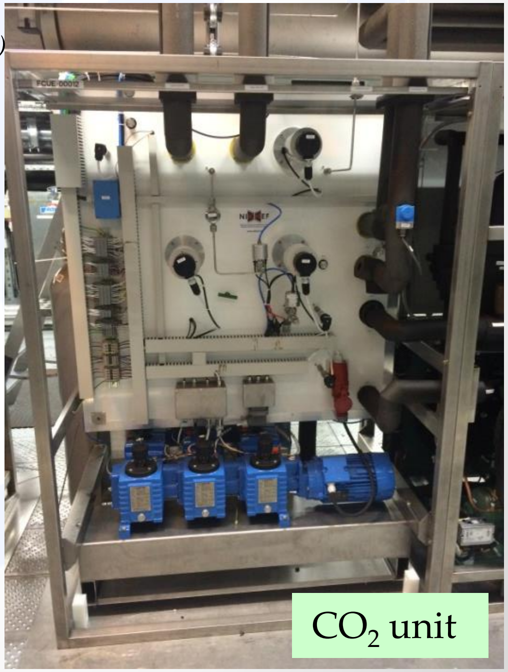
☑	TT150 Pump inlet temperature	-52.8	C	☑	TT108 Plant outlet temperature	-46.0	C
☑	PT150 Pump inlet saturation	-35.1	C	☑	TT116 Junction box inlet temperature	-34.2	C
☑	PT142_Tsat Accu saturation temperature	-35.00	C	☑	PT136_Tsat Junction box outlet saturation	-33.54	C
☑	TT146 Plant inlet temperature	-37.3	C	☑	TT136 Junction box outlet temperature	-34.0	C



Liquid flow
2-phase flow



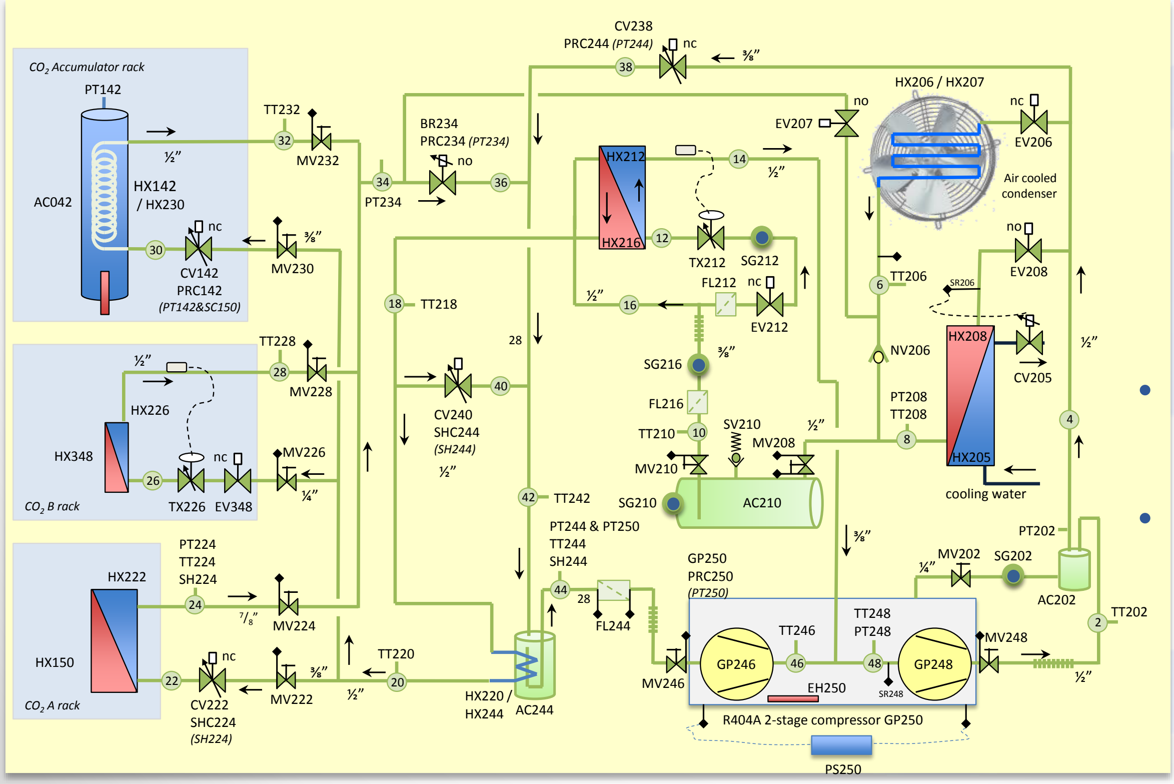
Accumulator unit



CO_2 unit

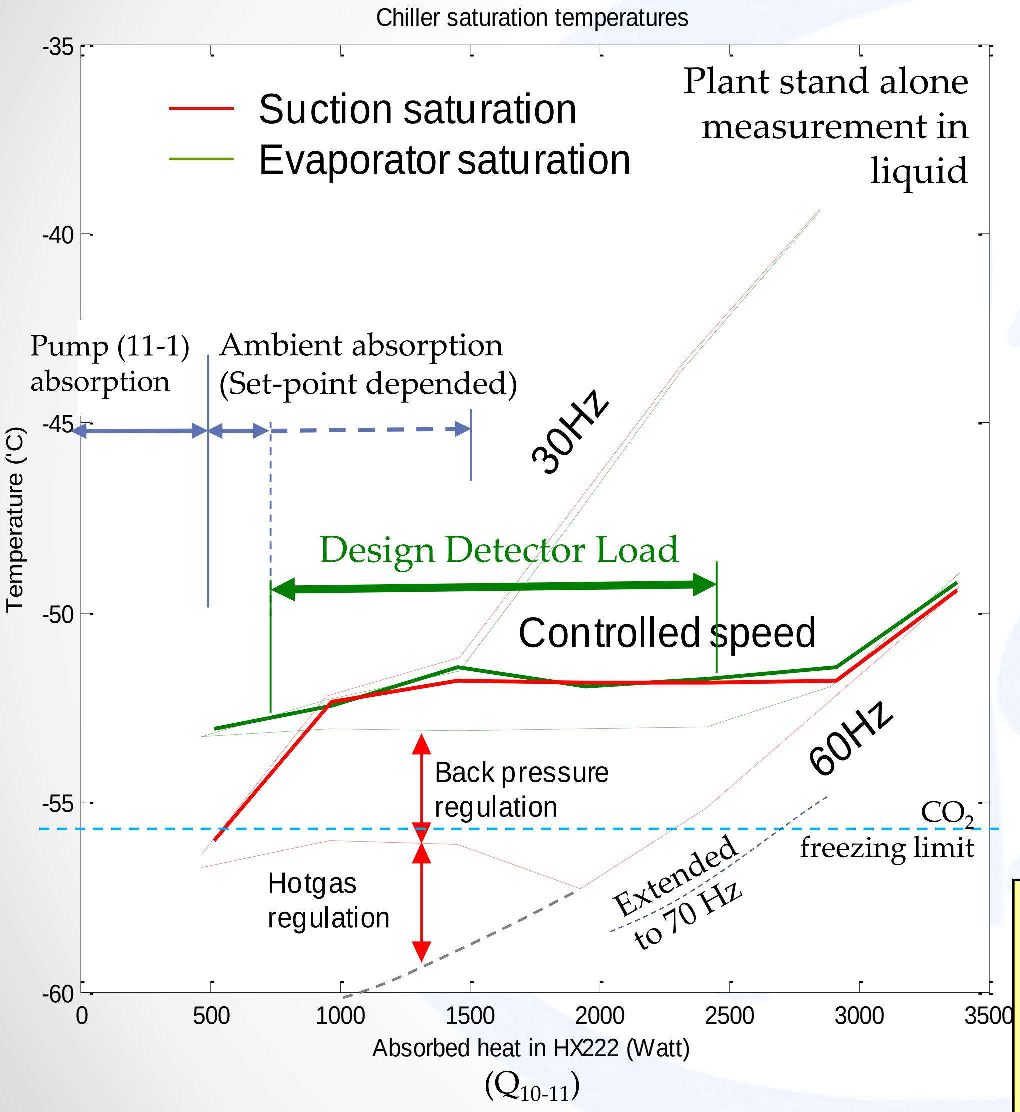
The 2-Stage Chiller
Cold and stable operation

2-stage compressor for low temperature operation



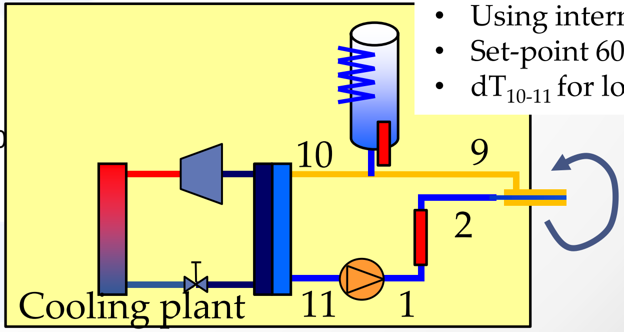
- The chiller is 2-stage to reach lower temperatures
  - CO$_2$ liquid: <-50^{0}C
  - Challenging: CO$_2$ freezes at -56^{0}C
- Chiller need to be very stable
  - Different tricks to stabilize under load changes:
    - Hot gas by-pass with liquid injection
    - Back-pressure regulation
    - Compressor speed control (30-70Hz).
  - Advanced super heating control due to low gas temperature from main evaporator
    - Hot gas injection during fast changes to avoid liquid in the compressor
    - Suction line accumulator
- 2 primary cooling sources:
  - Water cooling
  - Air cooling (Back-up)
- All commercial refrigeration technologies
  - Bitzer, Danfoss, Carel, Swep, Alfa-Laval

Chiller capacity and temperature control



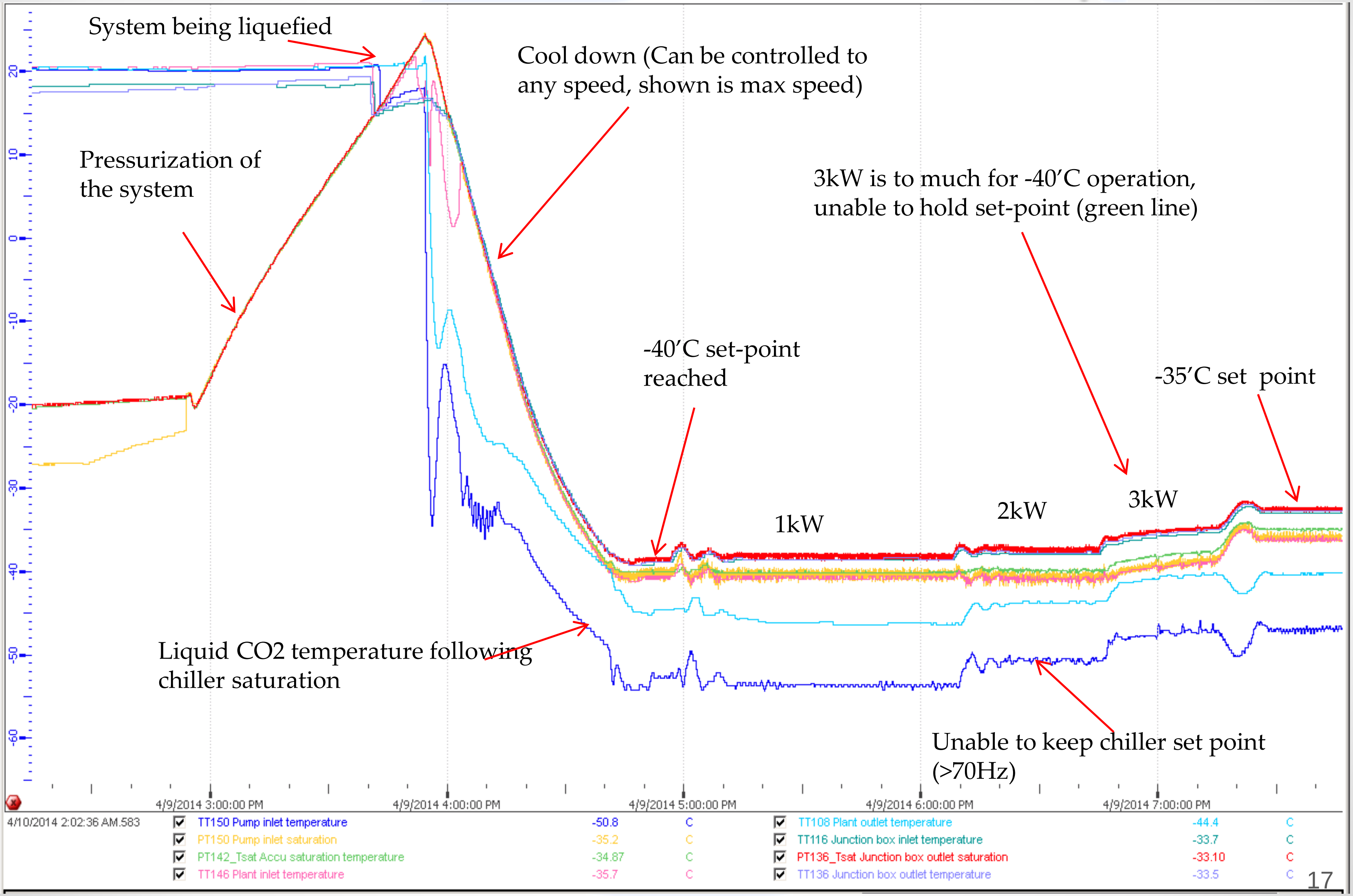
- Suction pressure control:
  - Suction pressure must stay above -70°C saturation
  - Compressor speed: 30-70 Hz
  - Hot-gas-bypass with liquid injection below 30 Hz
- Evaporator control:
  - Saturation must stay above -55°C to avoid CO_2 freezing
  - Back Pressure Regulator (BPR)
- Experience and adjustments
  - The BPR control was too difficult to follow the dynamics as the operation pressure is very low (0.3 – 0.7 bar)
  - The hot-gas-bypass set-point was increased above -55°C
    - Advantage: more stable evaporator temperature
    - Drawback: Efficiency loss
  - The BPR is still active as a protection shield against low suction pressures

USA15



- Flow via internal by-pass
- Using internal heater for load
- Set-point 60 bar => all liquid
- dT_{10-11} for load measurement

Cooling system warm start-up and cold operation



System being liquefied

Cool down (Can be controlled to any speed, shown is max speed)

Pressurization of the system

3kW is to much for -40’C operation, unable to hold set-point (green line)

-40’C set-point reached

-35’C set point

1kW

2kW

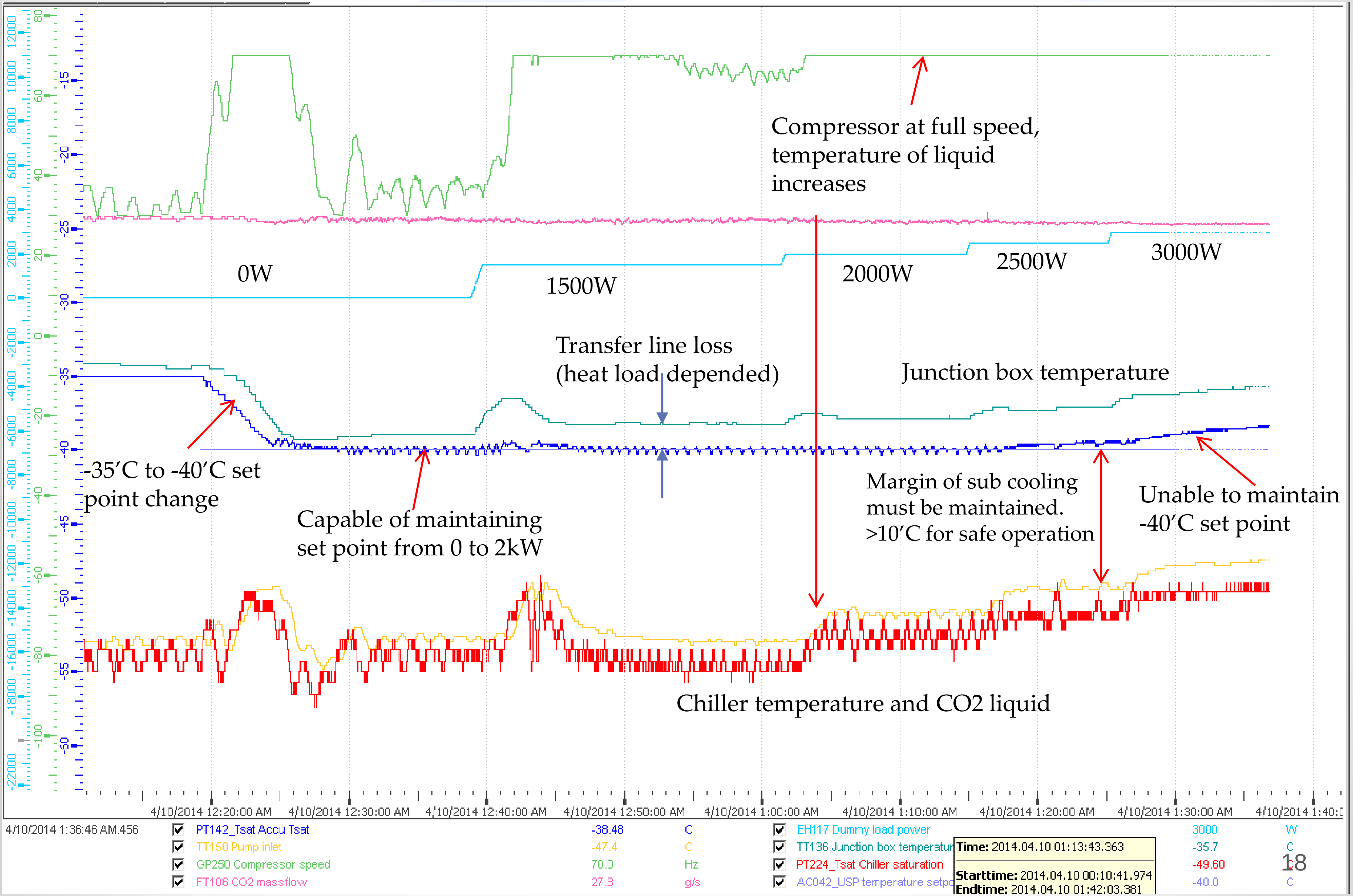
3kW

Liquid CO2 temperature following chiller saturation

Unable to keep chiller set point (>70Hz)

4/10/2014 2:02:36 AM.583	☑	TT150 Pump inlet temperature	-50.8	C	☑	TT108 Plant outlet temperature	-44.4	C
	☑	PT150 Pump inlet saturation	-35.2	C	☑	TT116 Junction box inlet temperature	-33.7	C
	☑	PT142_Tsat Accu saturation temperature	-34.87	C	☑	PT136_Tsat Junction box outlet saturation	-33.10	C
	☑	TT146 Plant inlet temperature	-35.7	C	☑	TT136 Junction box outlet temperature	-33.5	C

IBL Cooling system operation at -40°C set-point



Compressor at full speed, temperature of liquid increases

Transfer line loss (heat load depended)

Junction box temperature

-35’C to -40’C set point change

Capable of maintaining set point from 0 to 2kW

Margin of sub cooling must be maintained. >10’C for safe operation

Unable to maintain -40’C set point

Chiller temperature and CO2 liquid

4/10/2014 1:36:46 AM.456

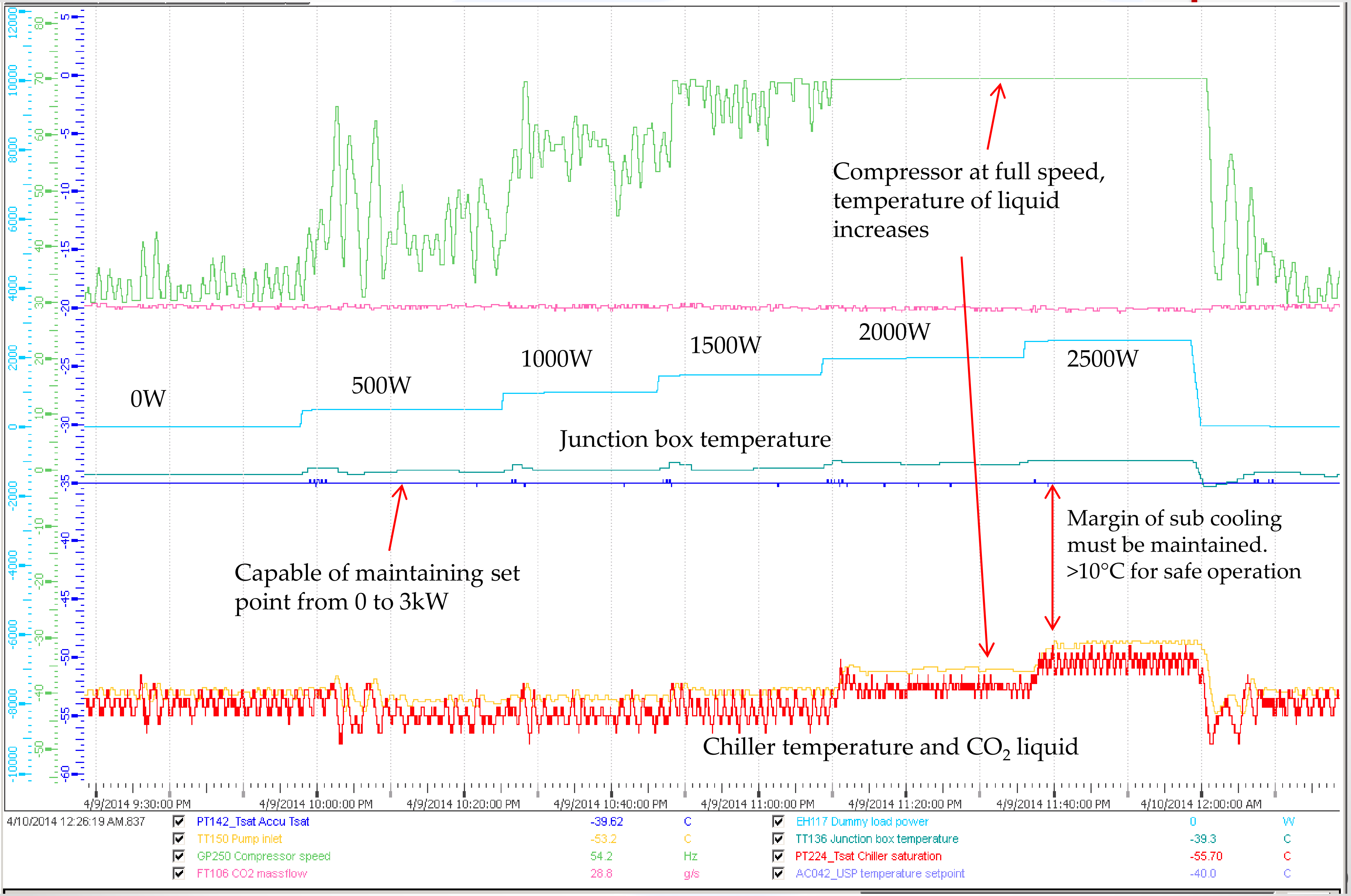
☑ PT142_Tsat Accu Tsat -38.48 C
☑ TT150 Pump inlet -47.4 C
☑ GP250 Compressor speed 70.0 Hz
☑ FT106 CO2 massflow 27.8 g/s

☑ EH117 Dummy load power 3000 W
☑ TT136 Junction box temperatur -35.7 C
☑ PT224_Tsat Chiller saturation -49.60 C
☑ AC042_USP temperature setpo -40.0 C

Time: 2014.04.10 01:13:43.363

Starttime: 2014.04.10 00:10:41.974
Endtime: 2014.04.10 01:42:03.381

IBL Cooling system operation at -35°C set-point



0W

500W

1000W

1500W

2000W

2500W

Compressor at full speed, temperature of liquid increases

Junction box temperature

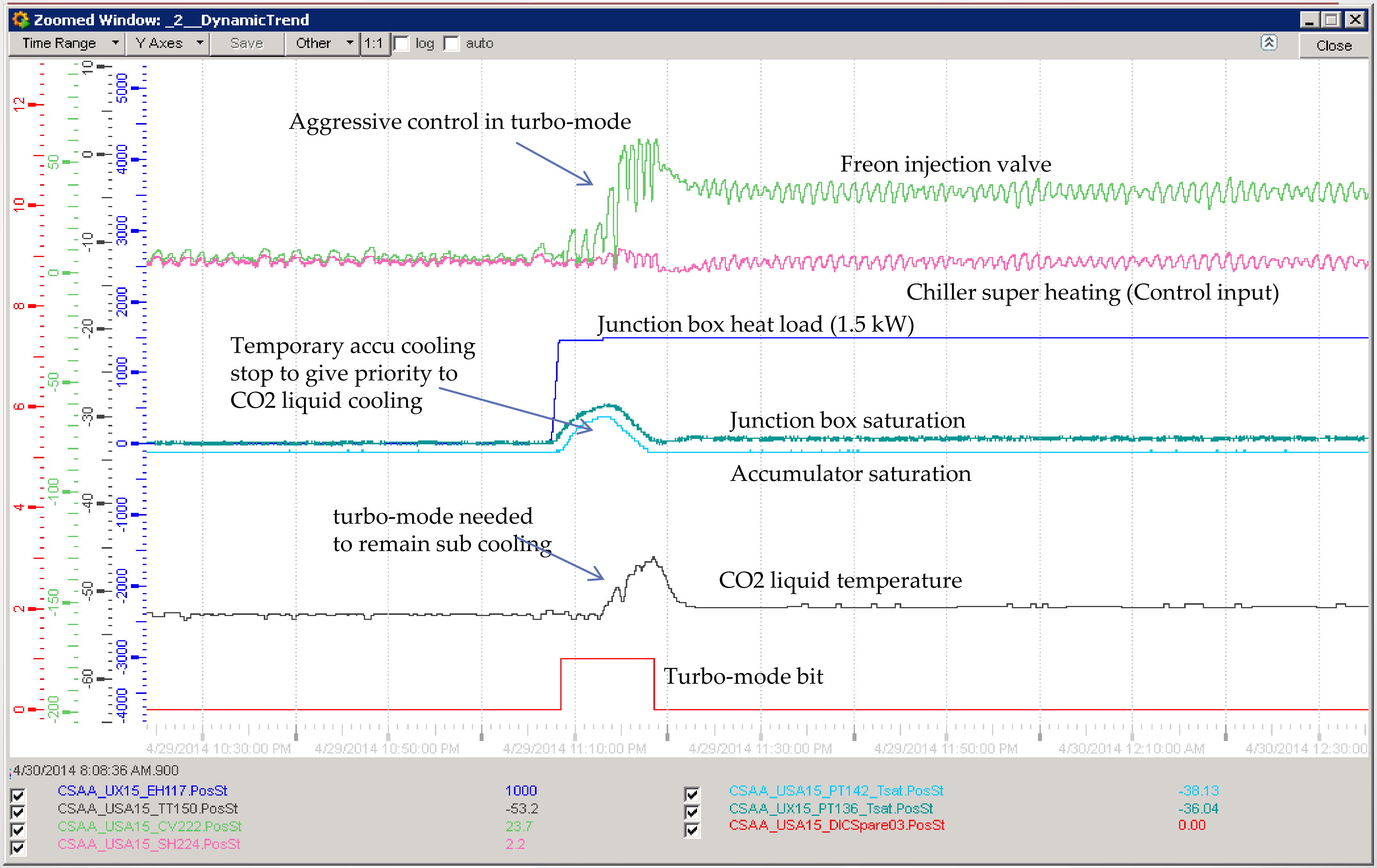
Capable of maintaining set point from 0 to 3kW

Margin of sub cooling must be maintained. >10°C for safe operation

Chiller temperature and CO_2 liquid

4/10/2014 12:26:19 AM.837	☑	PT142_Tsat Accu Tsat	-39.62	C	☑	EH117 Dummy load power	0	W
	☑	TT150 Pump inlet	-53.2	C	☑	TT136 Junction box temperature	-39.3	C
	☑	GP250 Compressor speed	54.2	Hz	☑	PT224_Tsat Chiller saturation	-55.70	C
	☑	FT106 CO2 massflow	28.8	g/s	☑	AC042_USP temperature setpoint	-40.0	C

Cooling system reaction on load changes



Aggressive control in turbo-mode

Freon injection valve

Chiller super heating (Control input)

Junction box heat load (1.5 kW)

Temporary accu cooling stop to give priority to CO2 liquid cooling

Junction box saturation

Accumulator saturation

turbo-mode needed to remain sub cooling

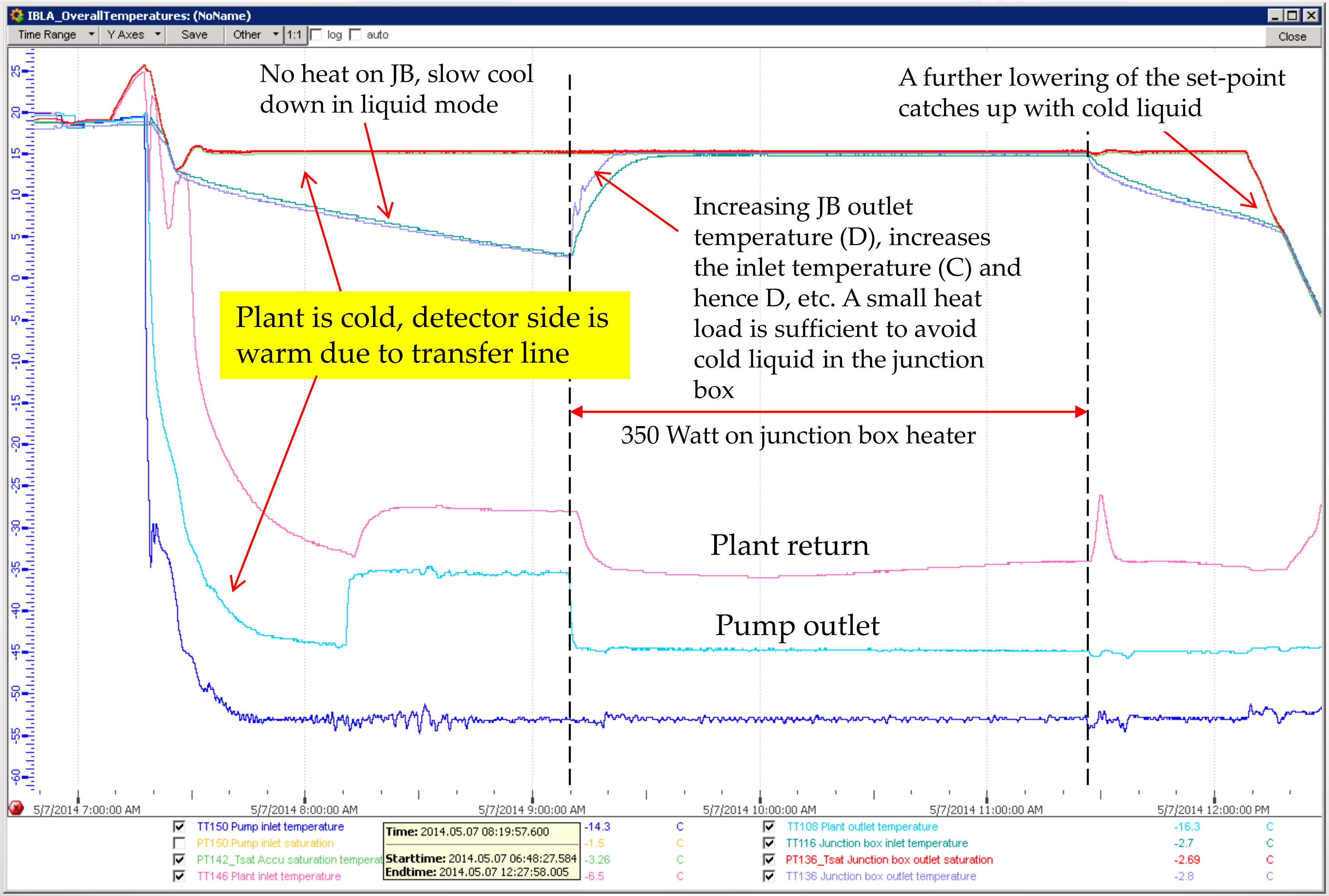
CO2 liquid temperature

Turbo-mode bit

4/30/2014 8:08:36 AM.900

☑	CSAA_UX15_EH117.PosSt	1000	☑	CSAA_USA15_PT142_Tsat.PosSt	-38.13
☑	CSAA_USA15_TT150.PosSt	-53.2	☑	CSAA_UX15_PT136_Tsat.PosSt	-36.04
☑	CSAA_USA15_CV222.PosSt	23.7	☑	CSAA_USA15_DICSpare03.PosSt	0.00
☑	CSAA_USA15_SH224.PosSt	2.2			

IBL Cooling system operation at +15°C set-point



No heat on JB, slow cool down in liquid mode

A further lowering of the set-point catches up with cold liquid

Increasing JB outlet temperature (D), increases the inlet temperature (C) and hence D, etc. A small heat load is sufficient to avoid cold liquid in the junction box

Plant is cold, detector side is warm due to transfer line

350 Watt on junction box heater

Plant return

Pump outlet

Time: 2014.05.07 08:19:57.600

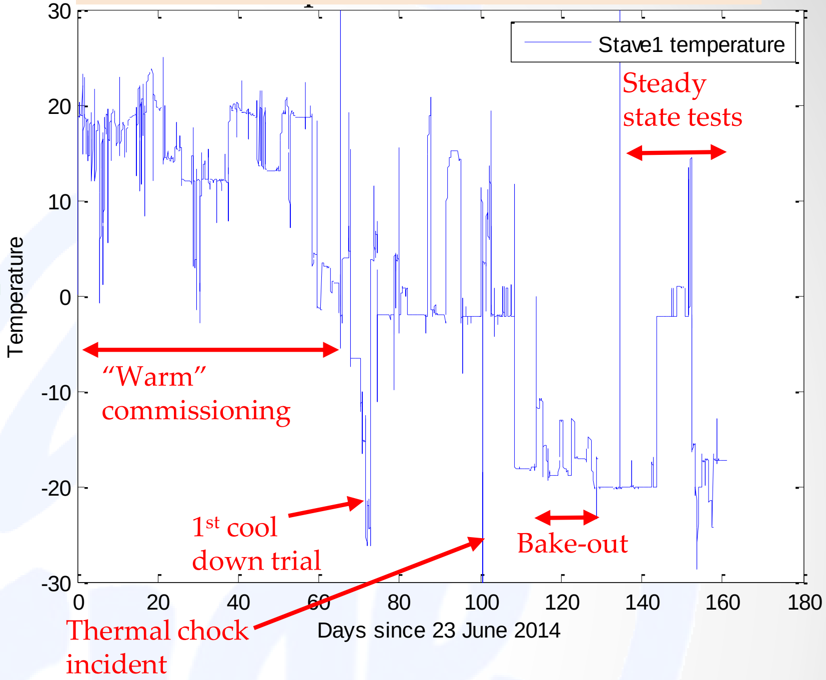
Starttime: 2014.05.07 06:48:27.584
Endtime: 2014.05.07 12:27:58.005

☑ TT150 Pump inlet temperature -14.3 C
☐ PT150 Pump inlet saturation -1.5 C
☑ PT142_Tsat Accu saturation temperat -3.26 C
☑ TT146 Plant inlet temperature -6.5 C
☑ TT108 Plant outlet temperature -16.3 C
☑ TT116 Junction box inlet temperature -2.7 C
☑ PT136_Tsat Junction box outlet saturation -2.69 C
☑ TT136 Junction box outlet temperature -2.8 C

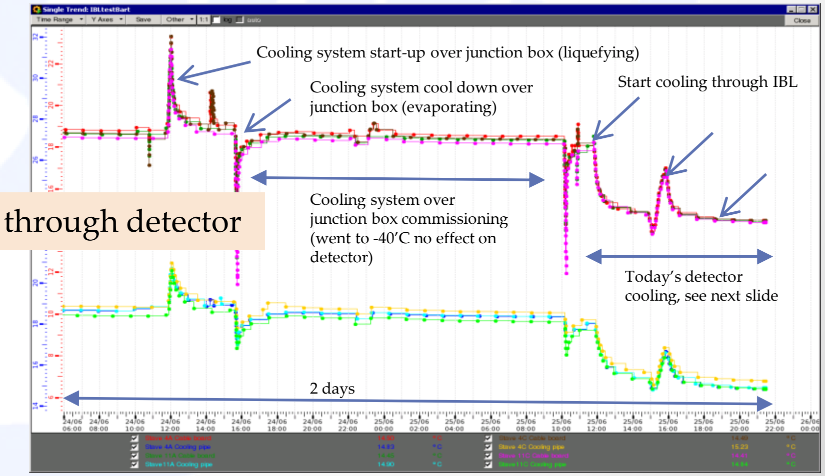
Commissioning Period

- The total commissioning period was about 1 year
- System commissioning:
  - January-April 2014: Plant stand alone commissioning
    - I/O checks
    - Alarm settings
    - System tuning
    - Capacity measurements
  - April-June 2014: System commissioning over junction box with dummy load
    - Full system checks
    - Full system fine tuning
- 25 June 2014: first cooling flow through detector.
- System commissioning with detector
  - June-August 2014
    - Explore detector behaviour with warm cooling (No IDEP closure)
    - Detector commissioning
    - Fine tune system to detector behaviour
  - 29 August 2014
    - First cold cooling (-25°)
  - September 2014
    - Blow off system commissioning for bake-out
    - Prepare cooling system for bake-out
  - 15-29 October 2014
    - Bake-Out period
  - November-December 2014
    - Steady state cooling tests
  - January-May 2015
    - Long term testing
  - June 2015
    - LHC restart

Detector temperature during commissioning

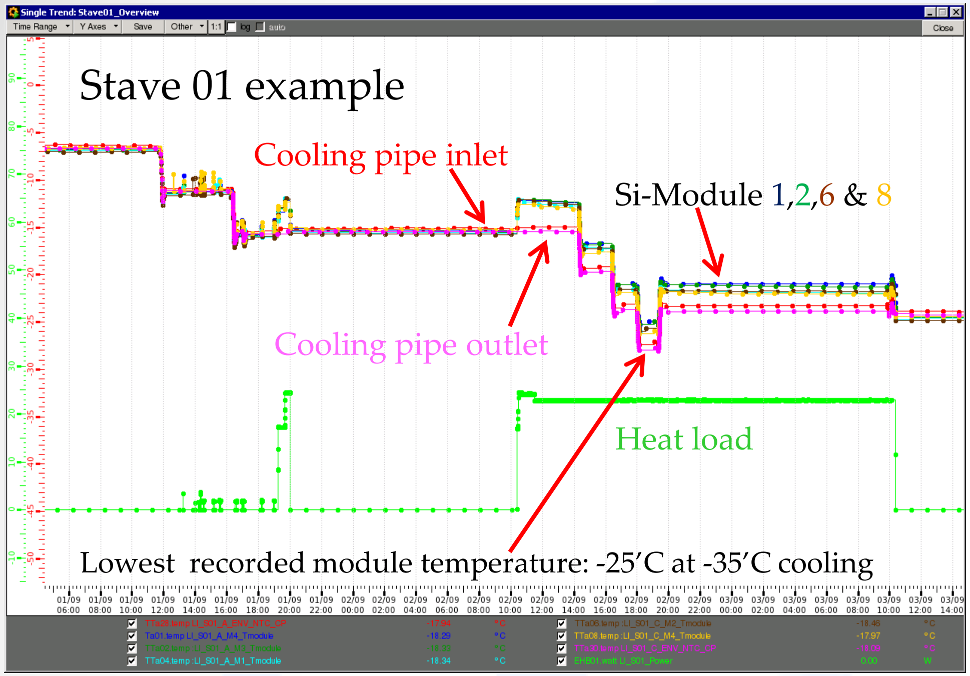


First flow through detector



Detector check-out

Cooling down tests, experiencing temperature stabilities and gradients



Stave 01 example

Cooling pipe inlet

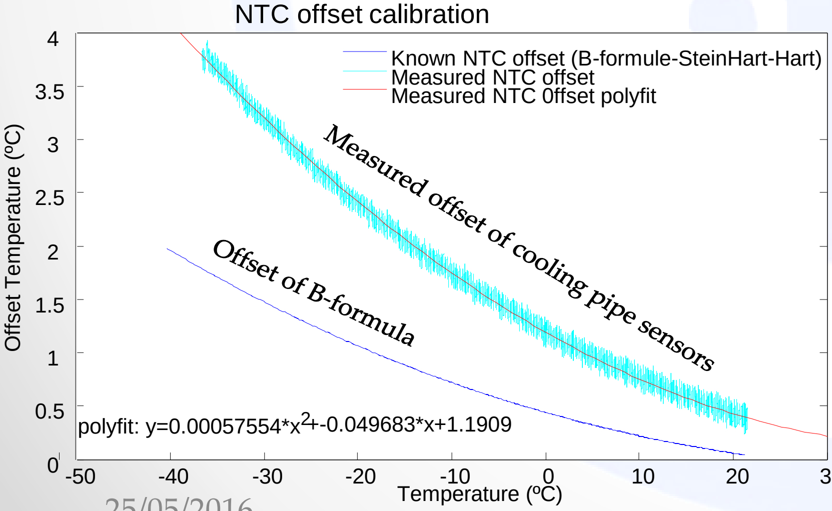
Si-Module 1,2,6 & 8

Cooling pipe outlet

Heat load

Lowest recorded module temperature: -25’C at -35’C cooling

☑	TTa28.temp LI_S01_A_ENV_NTC_CP	-17.94	°C	☑	TTa06.temp :LI_S01_C_M2_Tmodule	-18.46	°C
☑	Ta01.temp LI_S01_A_M4_Tmodule	-18.29	°C	☑	TTa08.temp :LI_S01_C_M4_Tmodule	-17.97	°C
☑	TTa02.temp :LI_S01_A_M3_Tmodule	-18.33	°C	☑	TTa30.temp LI_S01_C_ENV_NTC_CP	-18.09	°C
☑	TTa04.temp :LI_S01_A_M1_Tmodule	-18.34	°C	☑	EHB01.watt LI_S01_Power	0.00	W

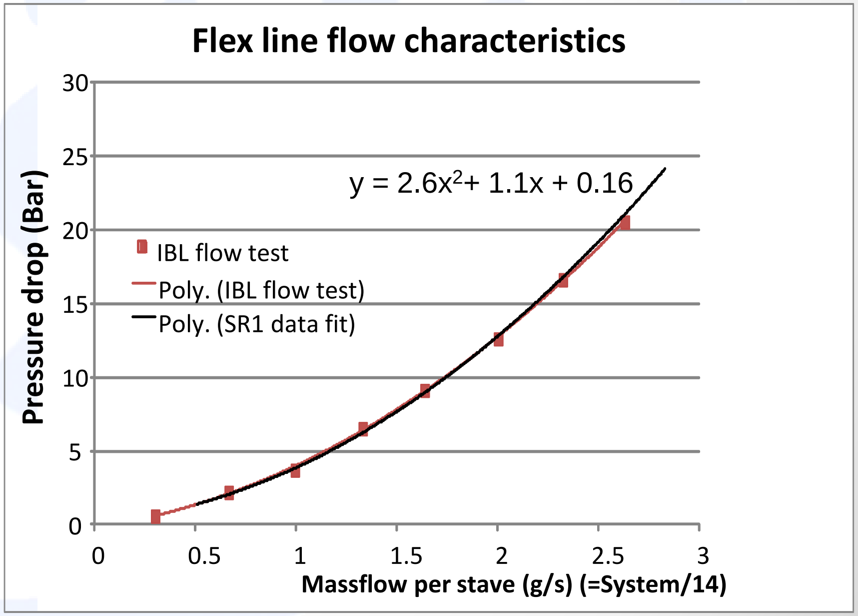


Measured offset of cooling pipe sensors

Offset of B-formula

polyfit: $y=0.00057554*x^2+-0.049683*x+1.1909$

- The cooling system showed a stable behaviour of the detector temperature, both under powered and unpowered condition
- Detector temperature offset with respect to cooling set-point was observed to be around 6-9°C
  - 4°C due to stave conduction, rest by pressure drop gradients
  - It was discovered that the temperature sensors show a large offset
  - Sensors have been recalibrated in situ.
- Good flow impendence similarity wrt SR1 tests

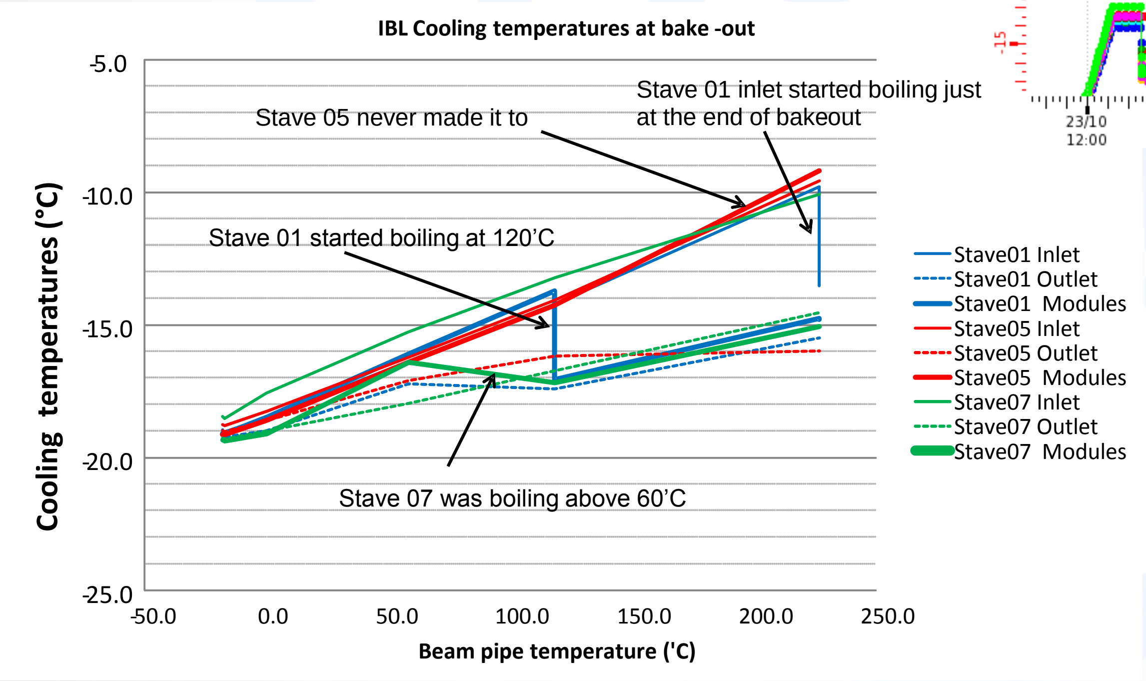


$y = 2.6x^2 + 1.1x + 0.16$

The total flow impedance has been checked with respect to the flex line tests in SR1

Bake-out (1)

- The beam pipe bake-out was a crucial event for the IBL cooling
  - The beam-pipe was heated in steps to 230^{0}C, the cooling system must prevent the IBL to over heat
  - A special operation of the cooling was established
    - 2 systems operated in parallel
    - System back-up by a bottle battery blow system
- Results and observations
  - Maximum recorded sensor temperature was -8^{0}C @ 230^{0}C beam pipe
  - Despite the high ambient load, the staves were hard to boil. (Single phase worked well for BO)
  - Due to twice the flow (2 systems in parallel) => ca. 4x pressure drop, most staves stayed single phase for long time.
  - What was interesting to see is that the boiling front stayed at the same location for a long time despite load increase
    - This indicates that something linked to the geometry is triggering the boiling. => Too smooth pipes?
- No issues during bake-out, system run without problems

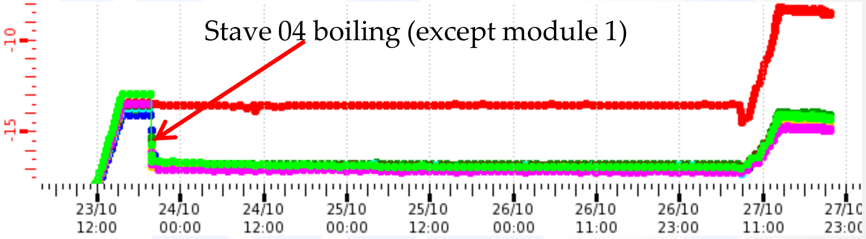


Stave 05 never made it to

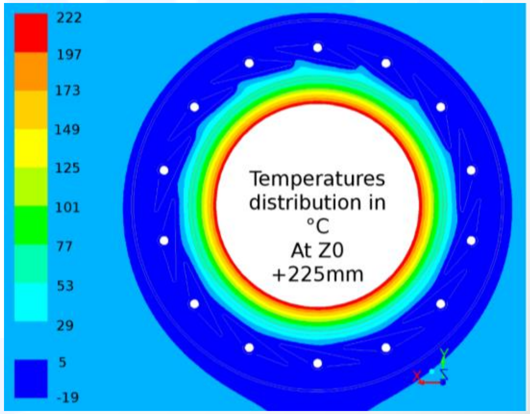
Stave 01 inlet started boiling just at the end of bakeout

Stave 01 started boiling at 120'C

Stave 07 was boiling above 60'C



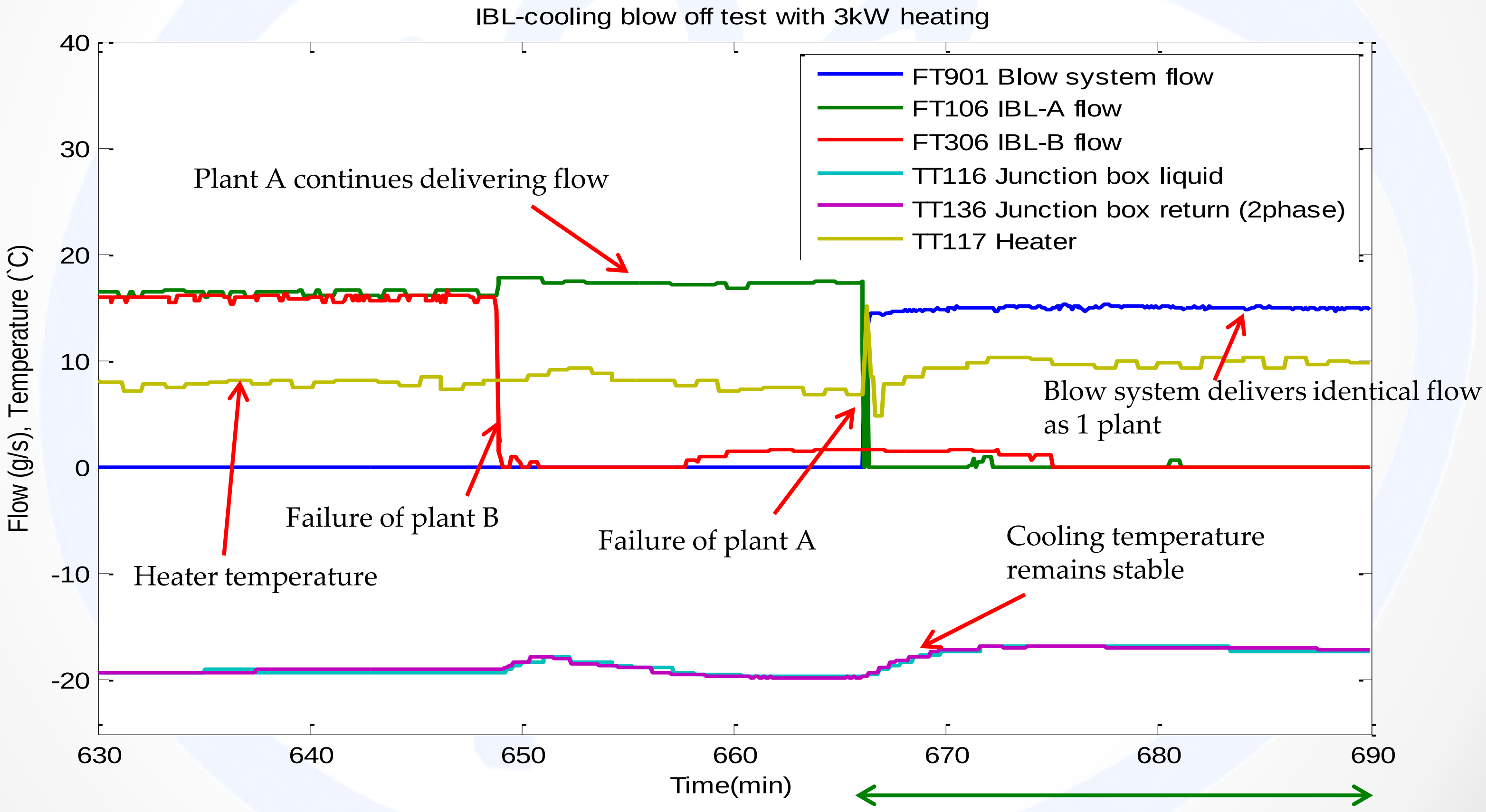
Stave 04 boiling (except module 1)



Temperatures distribution in °C At Z0 +225mm

IBL plant failure test with 3kW heat load

The graph show a failure of plant B and A followed by the blow system activation. A 3kW heat load was on all at time. Shown are the flows and heater temperature.



Plant A continues delivering flow

Failure of plant B

Heater temperature

Failure of plant A

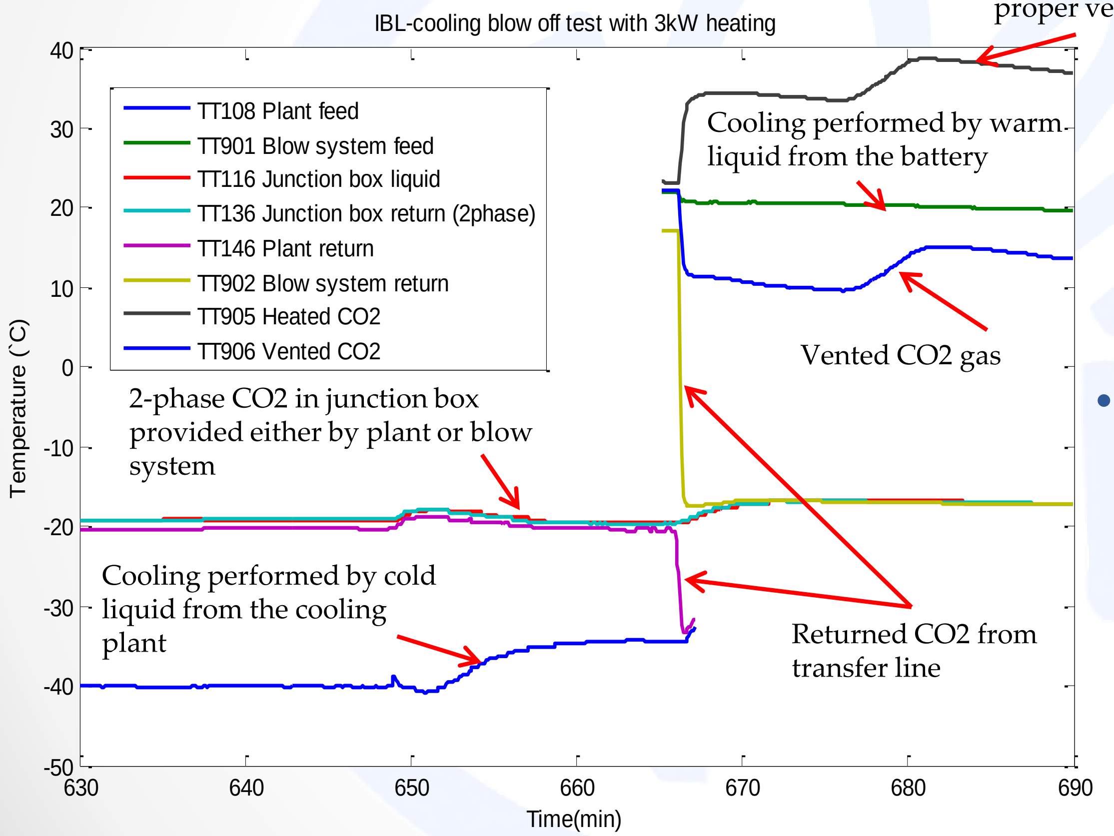
Blow system delivers identical flow as 1 plant

Cooling temperature remains stable

25 minutes of stable 3kW cooling using blow system (3kW Test was stopped to save CO2)

IBL plant failure test with 3kW heat load

The graph show the same test as the previous graph and displays the temperatures in the cooling plants and in the blow system



Heated CO2 gas for proper venting

Cooling performed by warm liquid from the battery

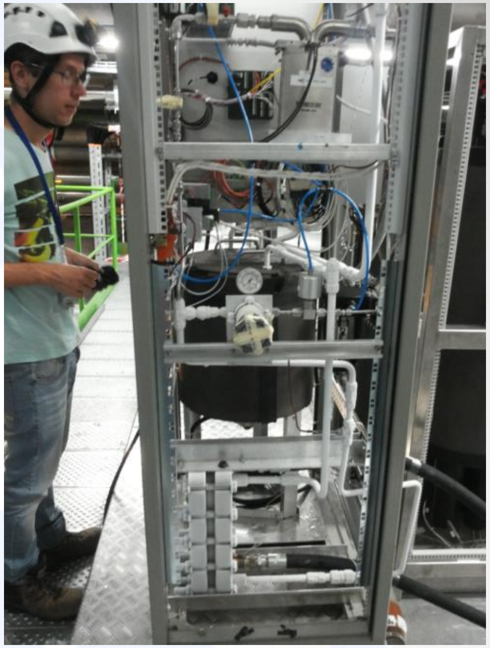
Vented CO2 gas

2-phase CO2 in junction box provided either by plant or blow system

Cooling performed by cold liquid from the cooling plant

Returned CO2 from transfer line

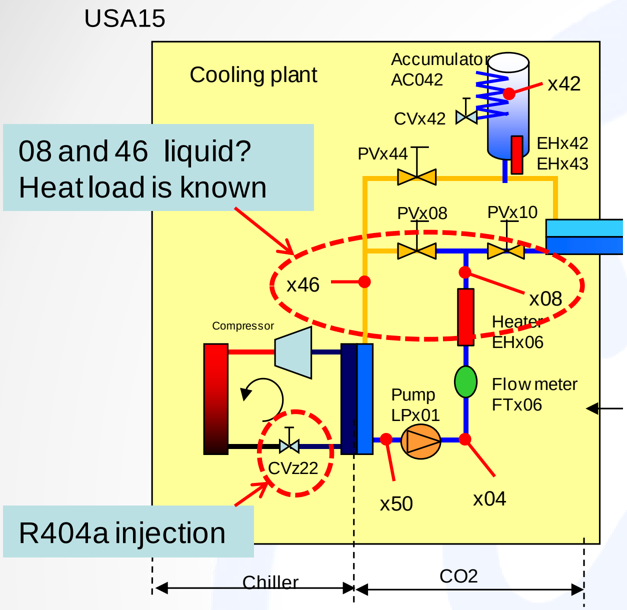
Temperatures during inactivity are deleted



- Activation of the blow system was successful
  - In case of blow activation beam pipe bake-out would be interlocked.
  - The 400 liter of CO_2 battery is good for 3hours additionally cooling, more than sufficient for a beam pipe cooldown

The IBL cooling heat loads

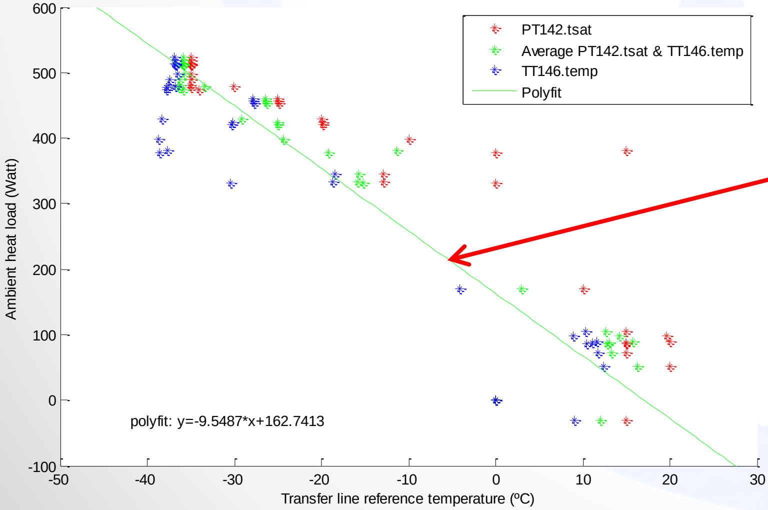
- The cooling system has to coop with several heat loads:
    - Detector electronics power
    - Ambient heat leak in the detector
    - Ambient heat leak of the system
- The total heat load can be measured under certain circumstances
    - The return in the plant can still be liquid despite of having 2-phase in the detector
    - The dT of the liquid feed and return is a function of heat load
- The IBL heat leak can be calculated, by subtracting the heat leak observed during Junction Box tests
- The ambient heat leak in the detector, the system and the detector power is at the same order around -15°C



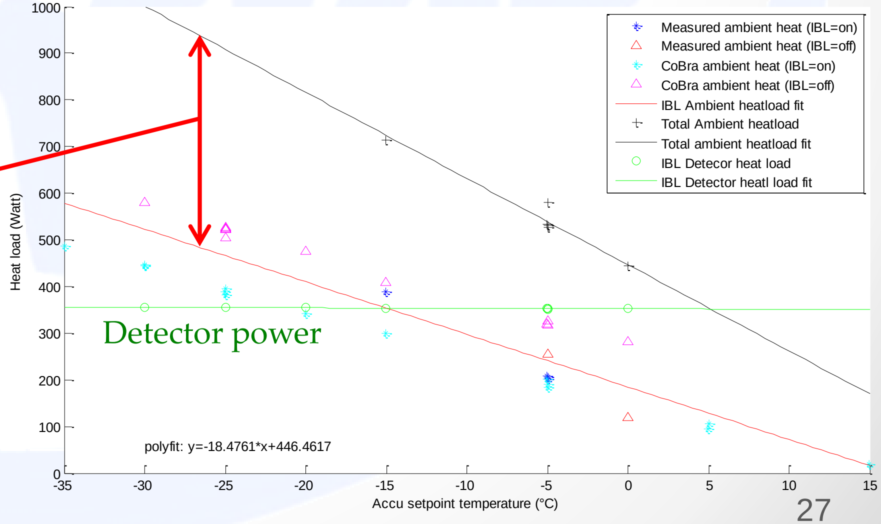
08 and 46 liquid?
Heat load is known

R404a injection

Transfer line ambient heat leak

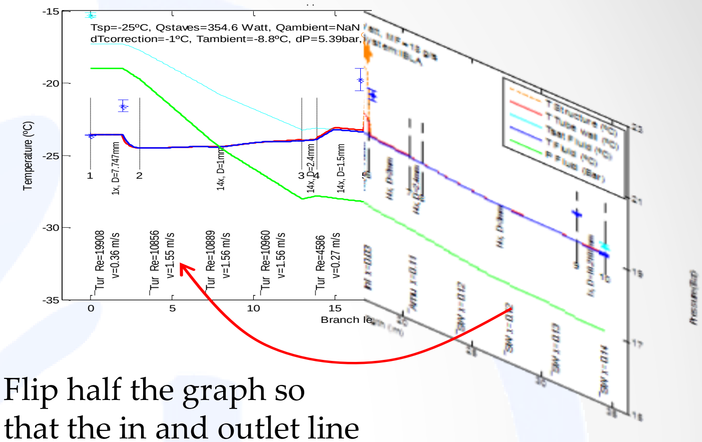


Total ambient heat leak

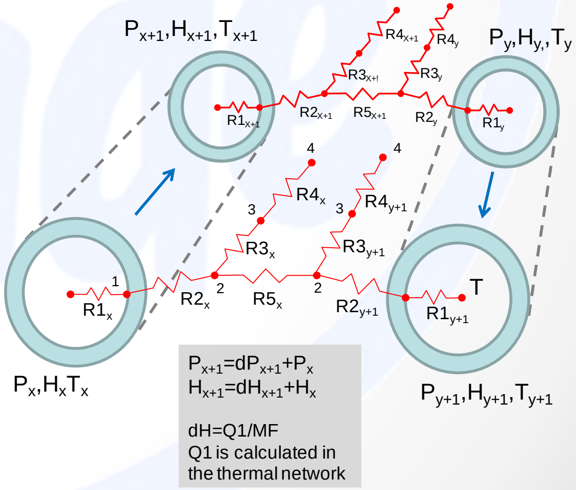


IBL steady state temperature analyses results and CoBra comparison

- The next slides give an overview of the measured (and corrected) IBL temperatures with respect to the CoBra simulation results.
- Each plot contains the data for a powered an not powered IBL detector per temperature set point.
  - Blue data is related to the unpowered situation, red data with respect to the powered situation
- The outlet flex line temperature profile in the graph is mirrored to match in the input to the output
  - Heat exchange behavior becomes visible
- Measured Inputs to the CoBra model:
  - Plant mass flow
  - Cooling loop outlet pressure
  - Cooling loop inlet temperature
  - Average cable board temperature as ambient temperature indications.
  - A 35 W/m^{2}K heat transfer to the pipes and the structure. This value is matched to the measured ambient heat leak explained in the previous slide.
  - Ambient temperature taken from the cable temperature under no-load condition.



Flip half the graph so that the in and outlet line location is at the same place



$P_{x+1}=dP_{x+1}+P_x$
$H_{x+1}=dH_{x+1}+H_x$

dH=Q1/MF
Q1 is calculated in the thermal network

The thermal node network calculates the heat influx in the cooling pipe based on:

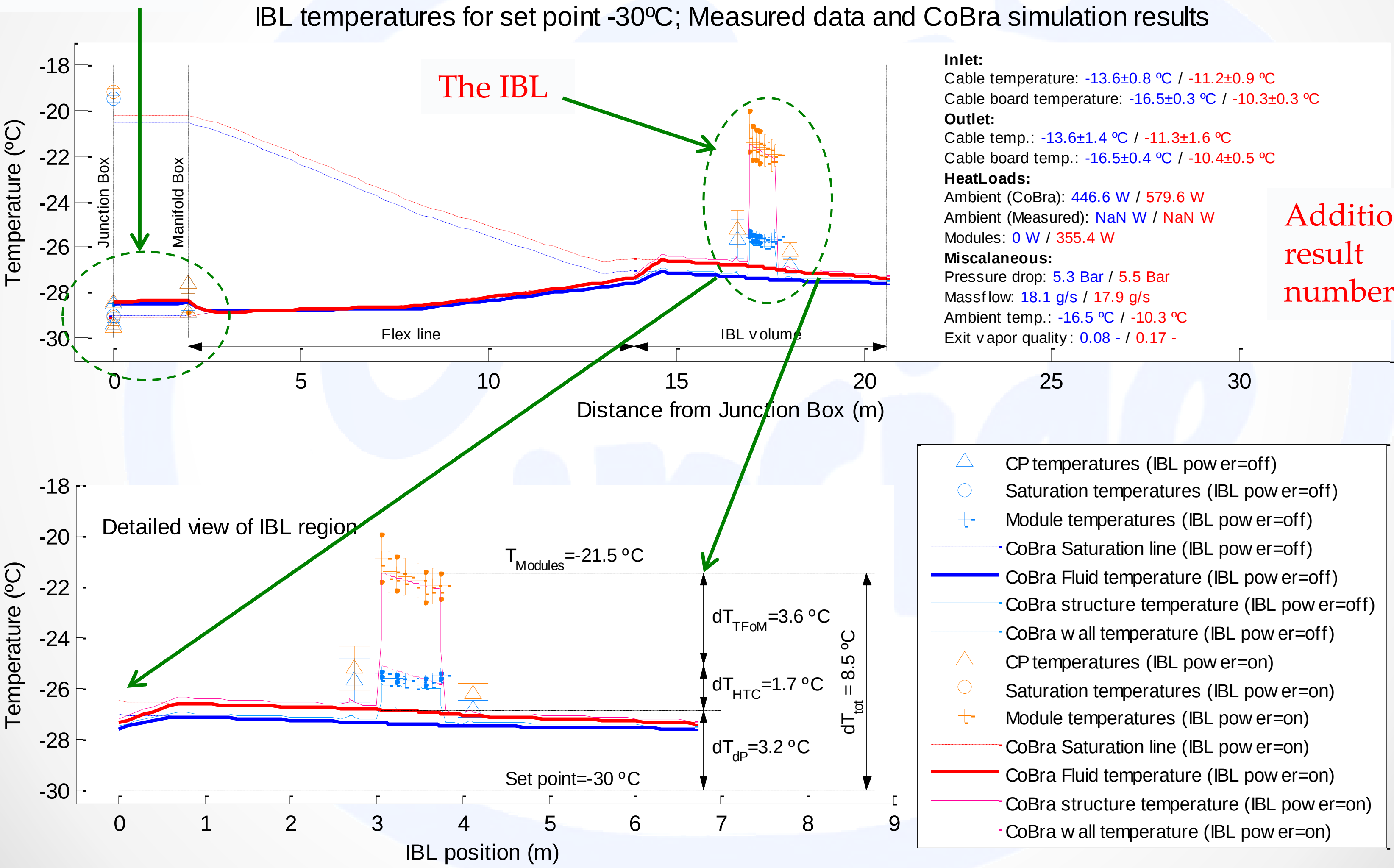
- Applied power Q3 on node 3
- Environmental heating from fixed temperature T4 on node 4
- Heat exchange with another pipe section via R5 between nodes 2 and 2 of the connected sections

Set point = -30°C

Manifold and junction box

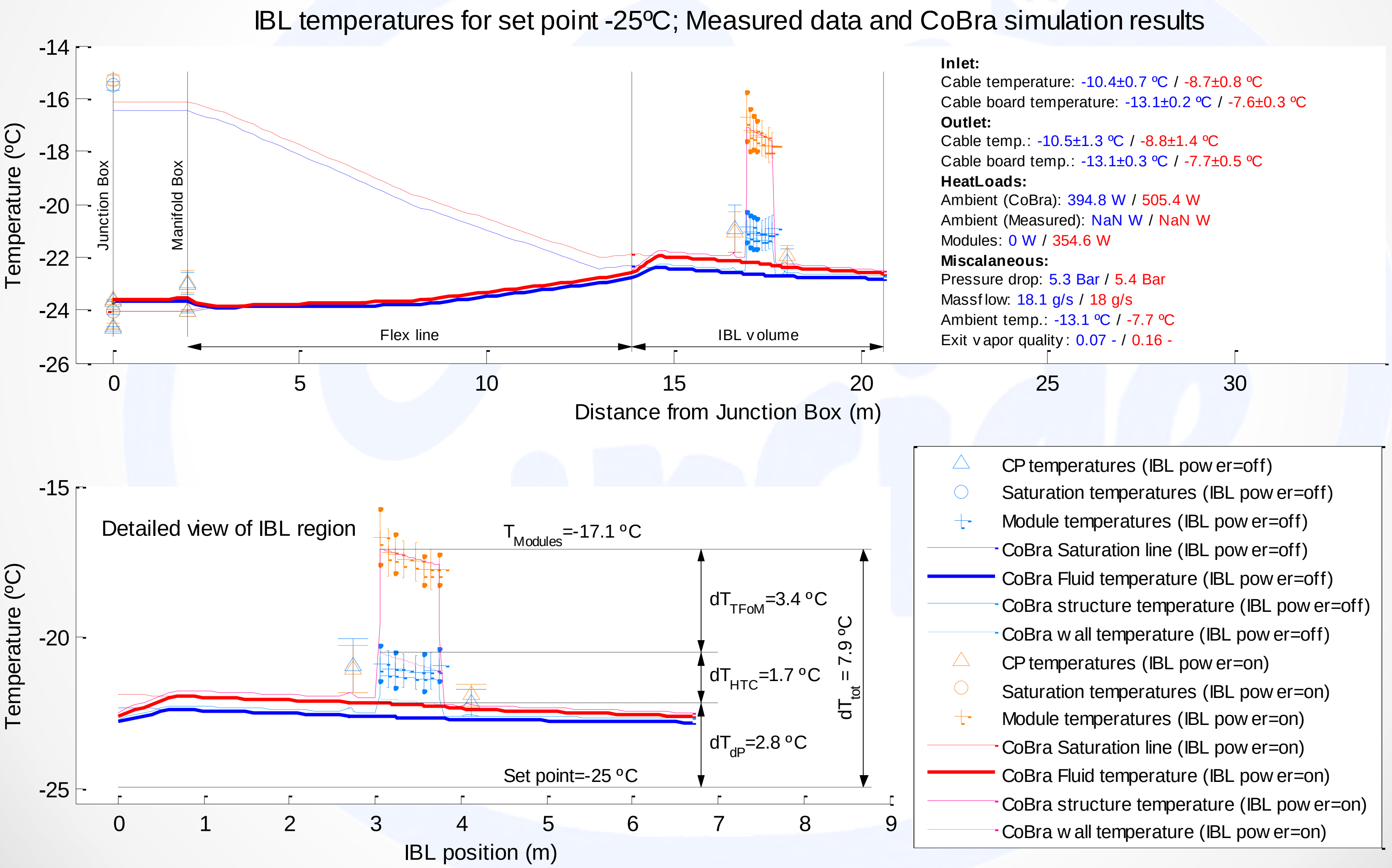
The IBL

Additional result numbers



Inlet:
Cable temperature: -13.6±0.8 ºC / -11.2±0.9 ºC
Cable board temperature: -16.5±0.3 ºC / -10.3±0.3 ºC
Outlet:
Cable temp.: -13.6±1.4 ºC / -11.3±1.6 ºC
Cable board temp.: -16.5±0.4 ºC / -10.4±0.5 ºC
HeatLoads:
Ambient (CoBra): 446.6 W / 579.6 W
Ambient (Measured): NaN W / NaN W
Modules: 0 W / 355.4 W
Miscalaneous:
Pressure drop: 5.3 Bar / 5.5 Bar
Massflow: 18.1 g/s / 17.9 g/s
Ambient temp.: -16.5 ºC / -10.3 ºC
Exit vapor quality: 0.08 - / 0.17 -

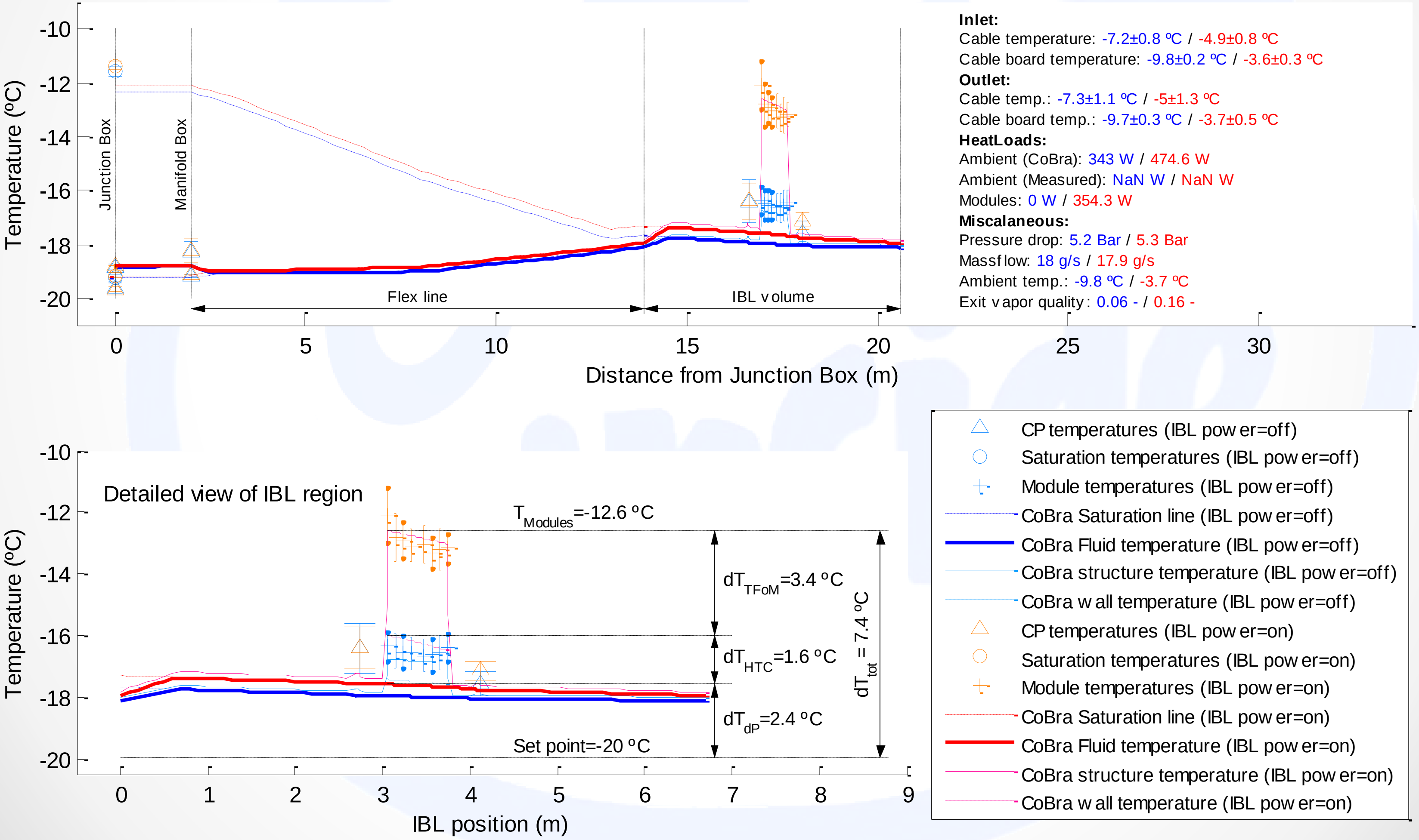
Set point = -25°C



IBL temperatures for set point -25ºC; Measured data and CoBra simulation results

Inlet:
Cable temperature: -10.4±0.7 ºC / -8.7±0.8 ºC
Cable board temperature: -13.1±0.2 ºC / -7.6±0.3 ºC
Outlet:
Cable temp.: -10.5±1.3 ºC / -8.8±1.4 ºC
Cable board temp.: -13.1±0.3 ºC / -7.7±0.5 ºC
HeatLoads:
Ambient (CoBra): 394.8 W / 505.4 W
Ambient (Measured): NaN W / NaN W
Modules: 0 W / 354.6 W
Miscalaneous:
Pressure drop: 5.3 Bar / 5.4 Bar
Massflow: 18.1 g/s / 18 g/s
Ambient temp.: -13.1 ºC / -7.7 ºC
Exit vapor quality: 0.07 - / 0.16 -

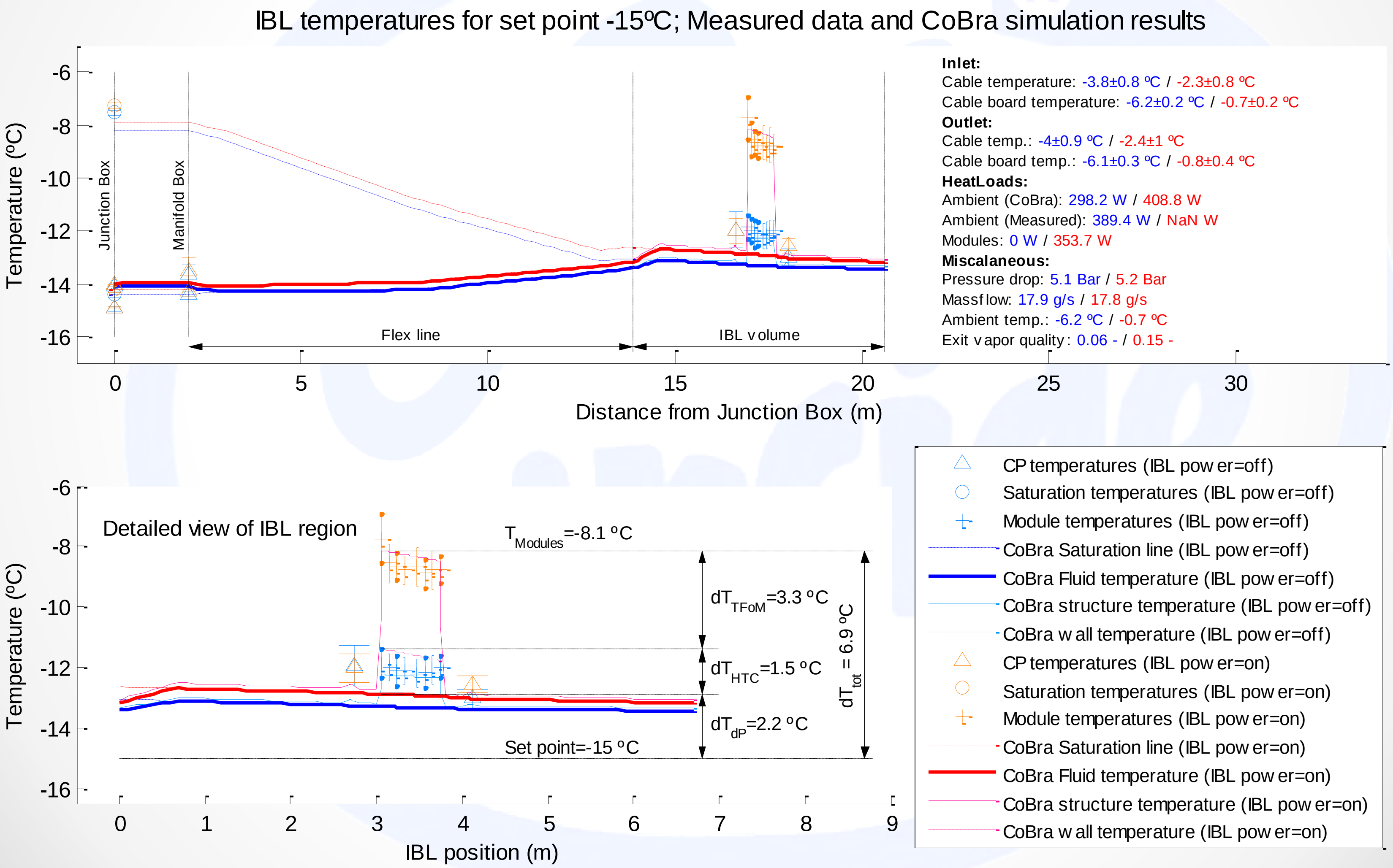
Set point = -20°C



IBL temperatures for set point -20ºC; Measured data and CoBra simulation results

Inlet:
Cable temperature: -7.2±0.8 ºC / -4.9±0.8 ºC
Cable board temperature: -9.8±0.2 ºC / -3.6±0.3 ºC
Outlet:
Cable temp.: -7.3±1.1 ºC / -5±1.3 ºC
Cable board temp.: -9.7±0.3 ºC / -3.7±0.5 ºC
HeatLoads:
Ambient (CoBra): 343 W / 474.6 W
Ambient (Measured): NaN W / NaN W
Modules: 0 W / 354.3 W
Miscalaneous:
Pressure drop: 5.2 Bar / 5.3 Bar
Massflow: 18 g/s / 17.9 g/s
Ambient temp.: -9.8 ºC / -3.7 ºC
Exit vapor quality: 0.06 - / 0.16 -

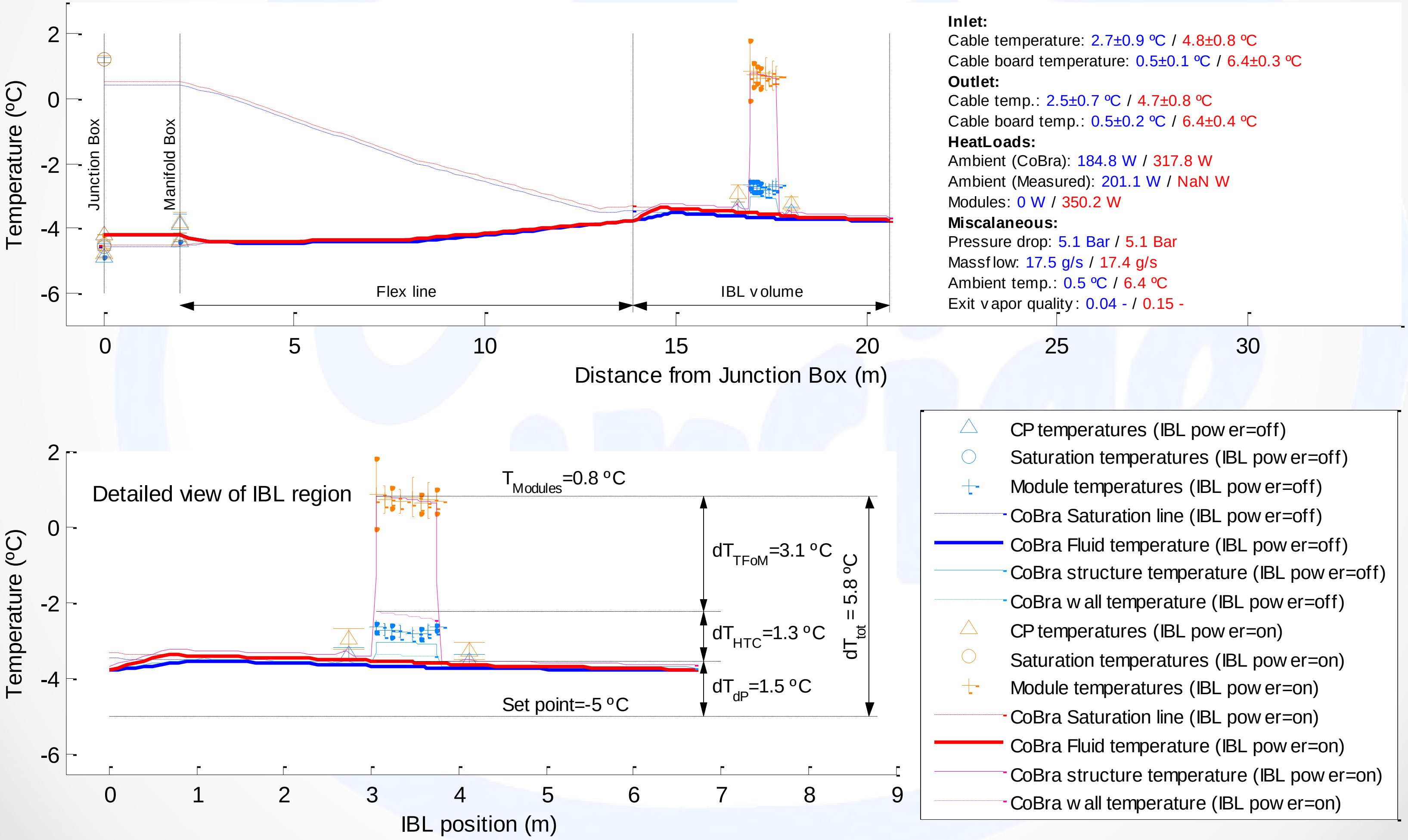
Set point = -15°C



Inlet:
Cable temperature: -3.8±0.8 ºC / -2.3±0.8 ºC
Cable board temperature: -6.2±0.2 ºC / -0.7±0.2 ºC
Outlet:
Cable temp.: -4±0.9 ºC / -2.4±1 ºC
Cable board temp.: -6.1±0.3 ºC / -0.8±0.4 ºC
HeatLoads:
Ambient (CoBra): 298.2 W / 408.8 W
Ambient (Measured): 389.4 W / NaN W
Modules: 0 W / 353.7 W
Miscalaneous:
Pressure drop: 5.1 Bar / 5.2 Bar
Massflow: 17.9 g/s / 17.8 g/s
Ambient temp.: -6.2 ºC / -0.7 ºC
Exit vapor quality: 0.06 - / 0.15 -

Set point = -5°C

IBL temperatures for set point -5ºC; Measured data and CoBra simulation results



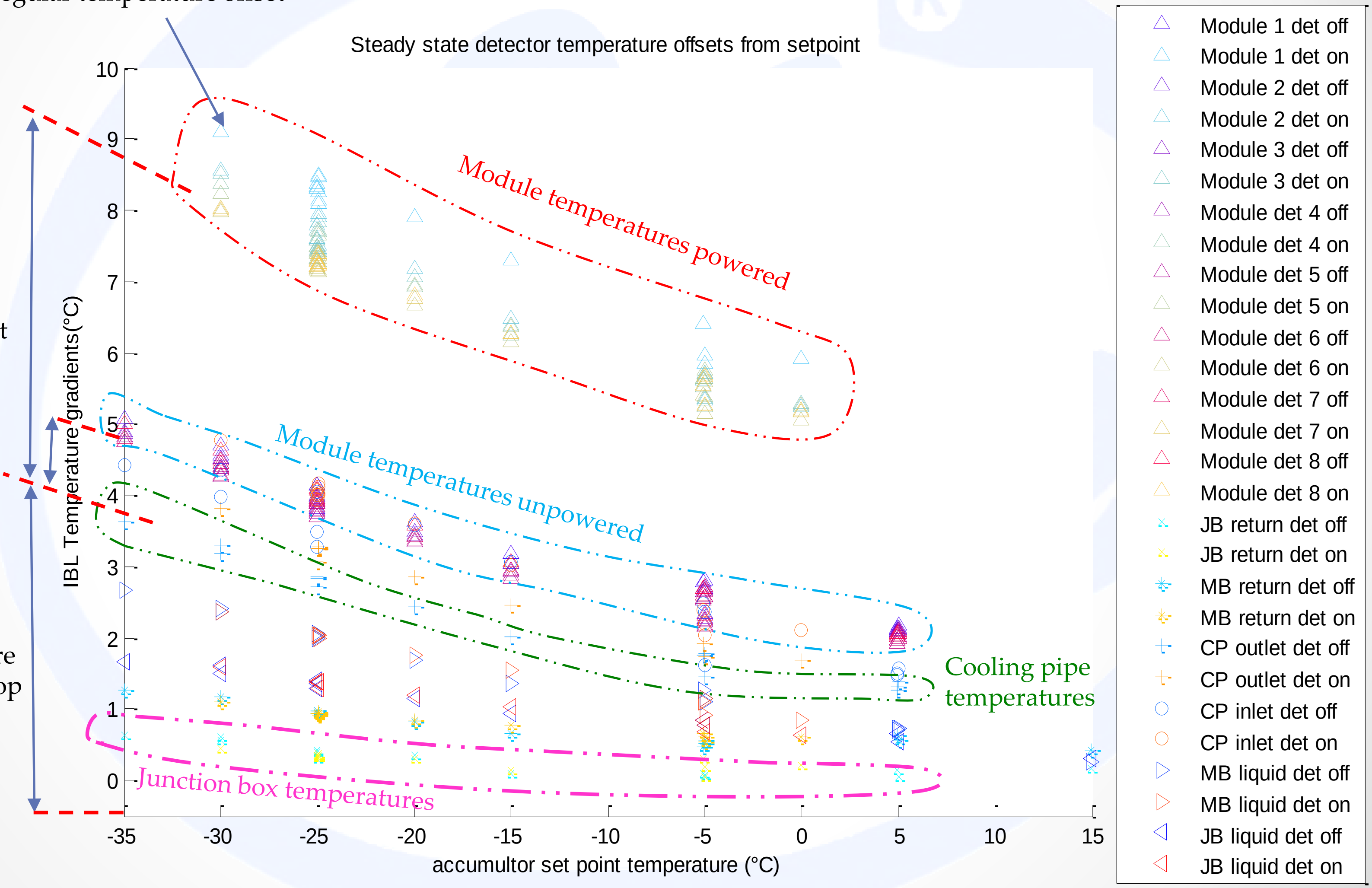
Inlet:
Cable temperature: 2.7±0.9 ºC / 4.8±0.8 ºC
Cable board temperature: 0.5±0.1 ºC / 6.4±0.3 ºC
Outlet:
Cable temp.: 2.5±0.7 ºC / 4.7±0.8 ºC
Cable board temp.: 0.5±0.2 ºC / 6.4±0.4 ºC
HeatLoads:
Ambient (CoBra): 184.8 W / 317.8 W
Ambient (Measured): 201.1 W / NaN W
Modules: 0 W / 350.2 W
Miscalaneous:
Pressure drop: 5.1 Bar / 5.1 Bar
Massflow: 17.5 g/s / 17.4 g/s
Ambient temp.: 0.5 ºC / 6.4 ºC
Exit vapor quality: 0.04 - / 0.15 -

Detector temperature offsets wrt set point

First modules show a larger and more irregular temperature offset

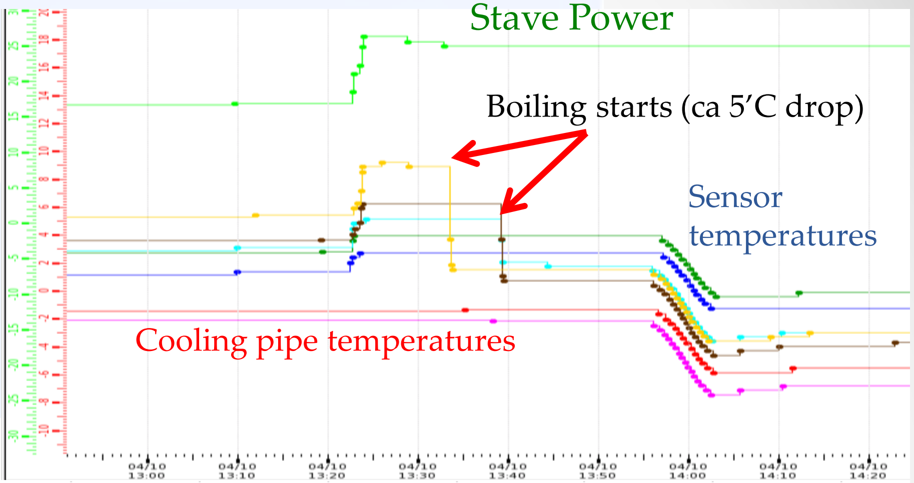
Gradients due to stave conduction relatively constant

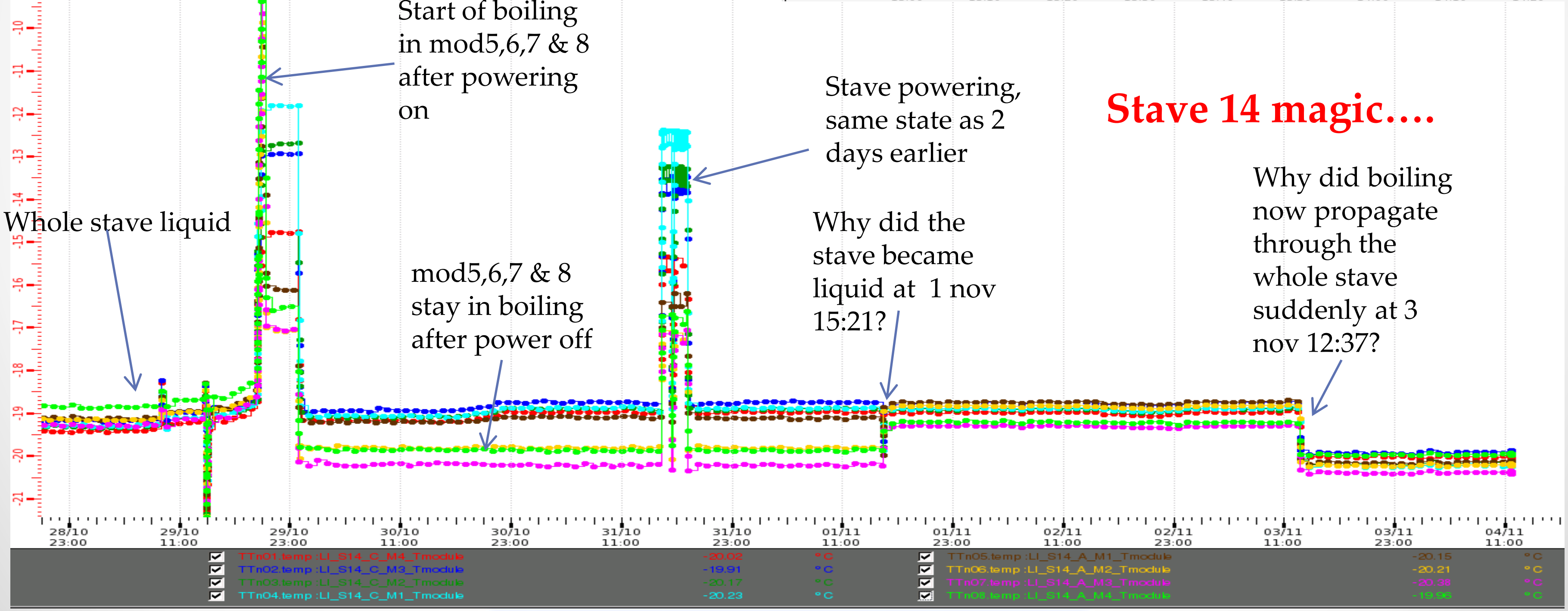
Gradients increase as a function of cooling temperature due to pressure drop (Mainly flex lines)



Super heating problem

- Boiling is not always fully developed
  - This gives irregular temperature behaviour in the order of a degree
- This behaviour is not appreciated by the alignment people ☹
- A study is ongoing to understand the issue.
- Mainly a problem after a detector power cycle, boiling is developed better in time





Start of boiling in mod5,6,7 & 8 after powering on

Whole stave liquid

mod5,6,7 & 8 stay in boiling after power off

Stave powering, same state as 2 days earlier

Why did the stave became liquid at 1 nov 15:21?

Stave 14 magic….

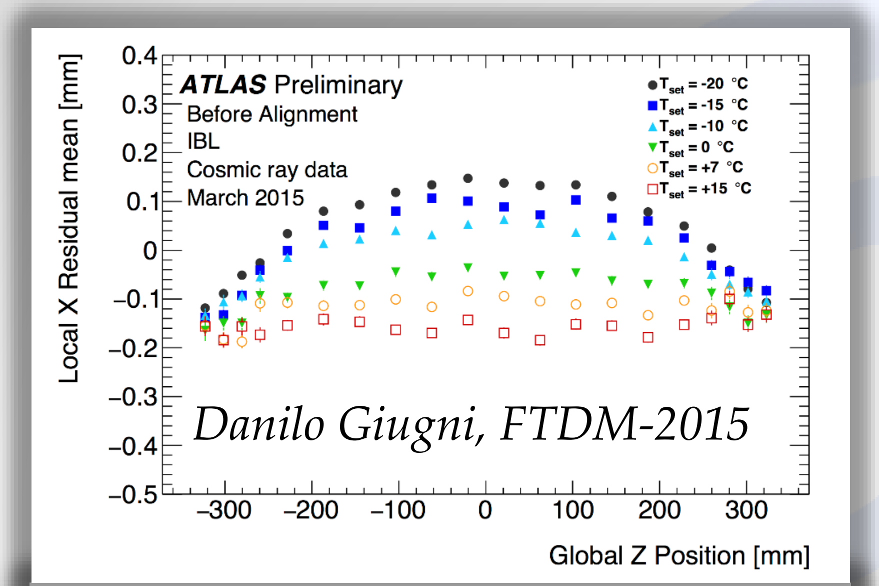
Why did boiling now propagate through the whole stave suddenly at 3 nov 12:37?

Why cooling stability is so important in the IBL

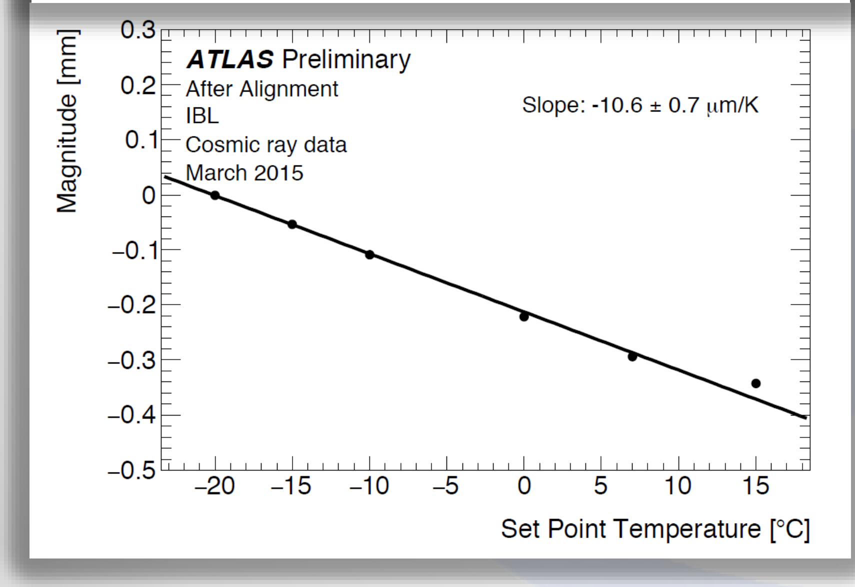
- The IBL has a thermal deformation issue.
- The deformation amplitude depends upon the evaporation set point.
- The dependency is linear and the value is

d=10.6 ± 0.7 mm/ºC

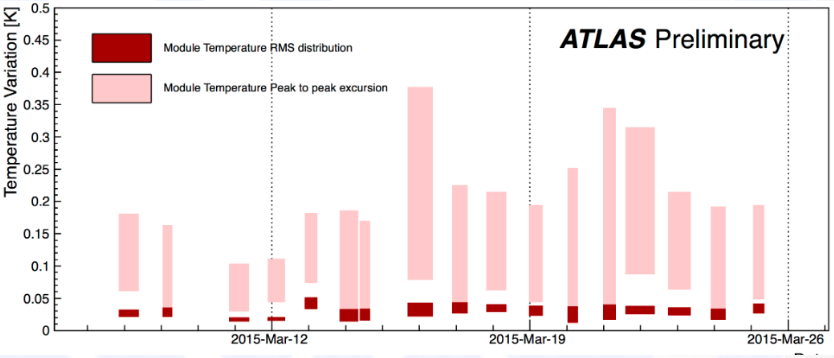
- The cooling is very stable in time (<0.05 ºC RMS)

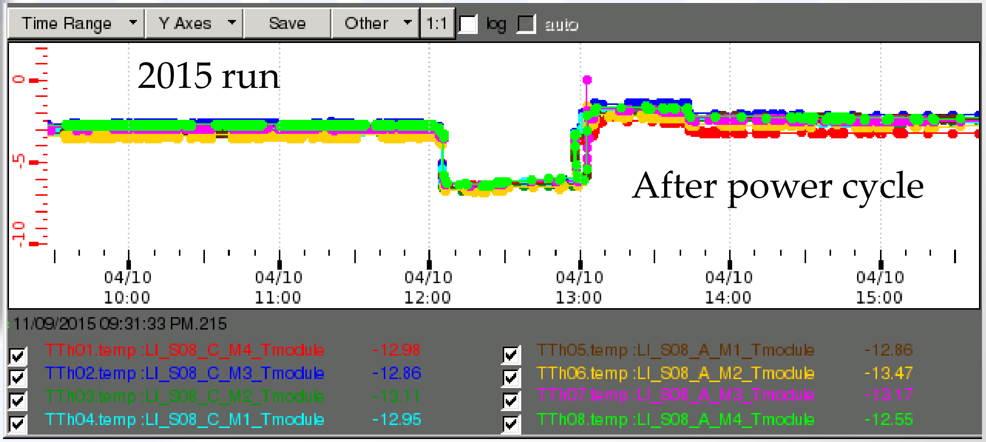


Danilo Giugni, FTDM-2015



https://indico.cern.ch/event/363327/contributions/860749/attachments/722745/991997/2015-06-17_Understanding_the_deformation_issue_of_the_ATLAS_IBL_detector.pptx





2015 run

After power cycle

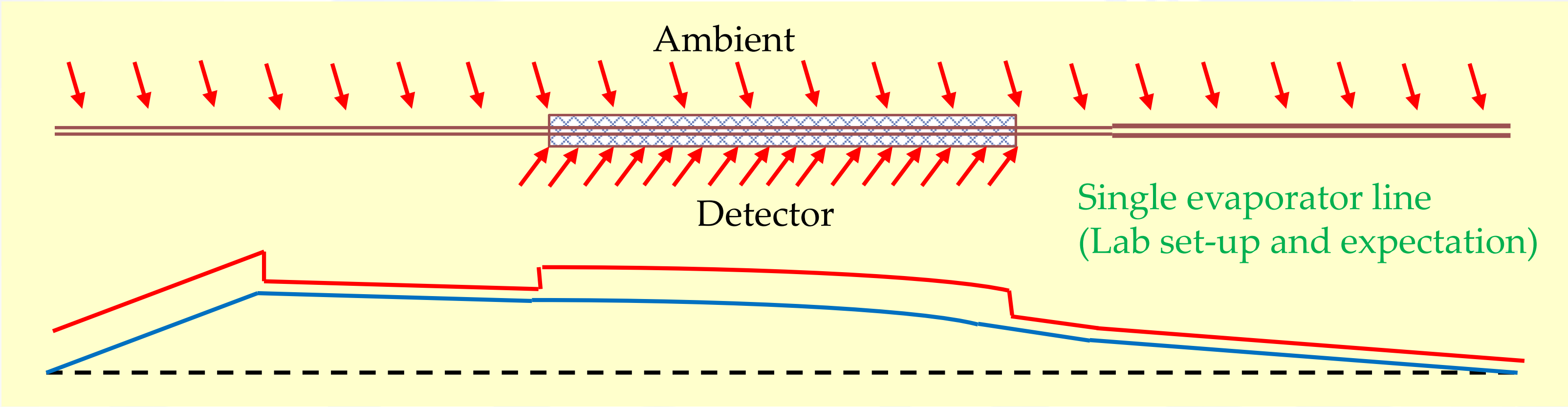
11/09/2015 09:31:33 PM.215

☑ TTh01.temp :LI_S08_C_M4_Tmodule -12.98
☑ TTh02.temp :LI_S08_C_M3_Tmodule -12.86
☑ TTh03.temp :LI_S08_C_M2_Tmodule -13.11
☑ TTh04.temp :LI_S08_C_M1_Tmodule -12.95
☑ TTh05.temp :LI_S08_A_M1_Tmodule -12.86
☑ TTh06.temp :LI_S08_A_M2_Tmodule -13.47
☑ TTh07.temp :LI_S08_A_M3_Tmodule -13.17
☑ TTh08.temp :LI_S08_A_M4_Tmodule -12.55

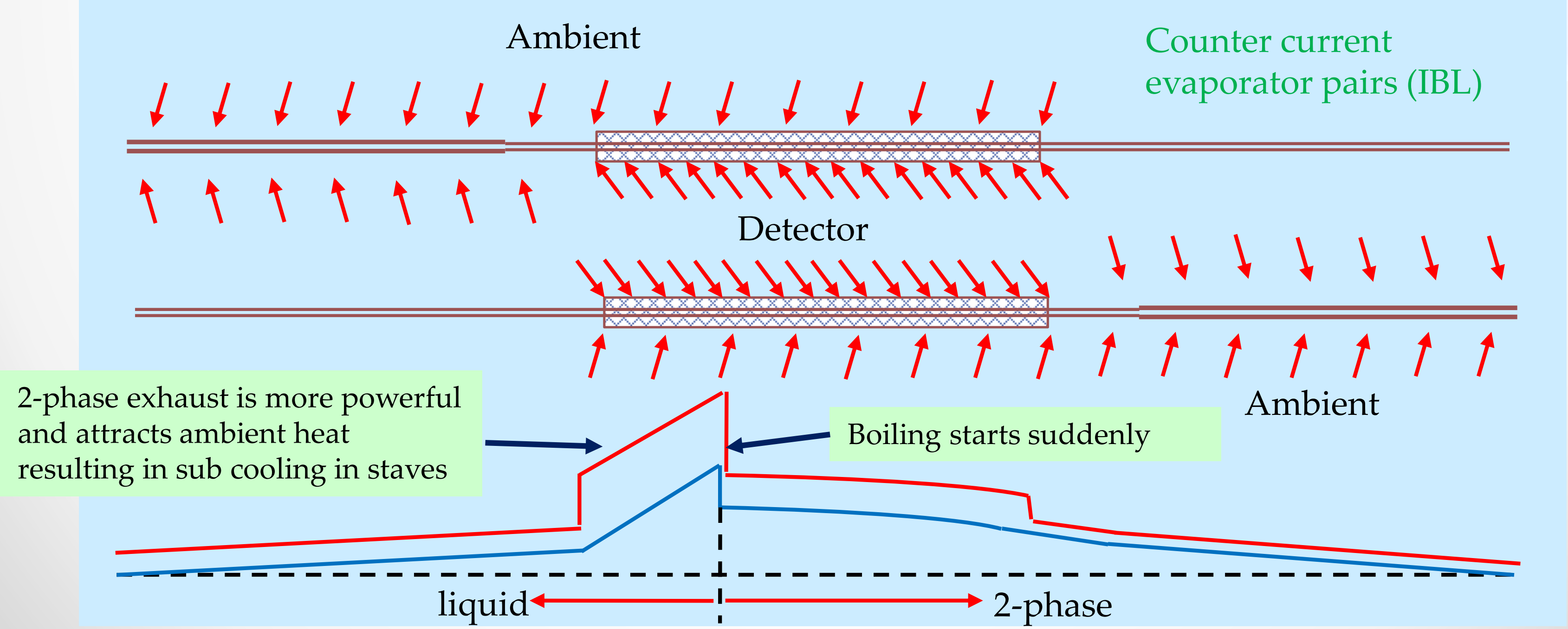
Hypothesis:

Cross flow problem?

(2nd stave outlet absorbs heat of neighbor stave inlet)



Single evaporator line
(Lab set-up and expectation)



Counter current
evaporator pairs (IBL)

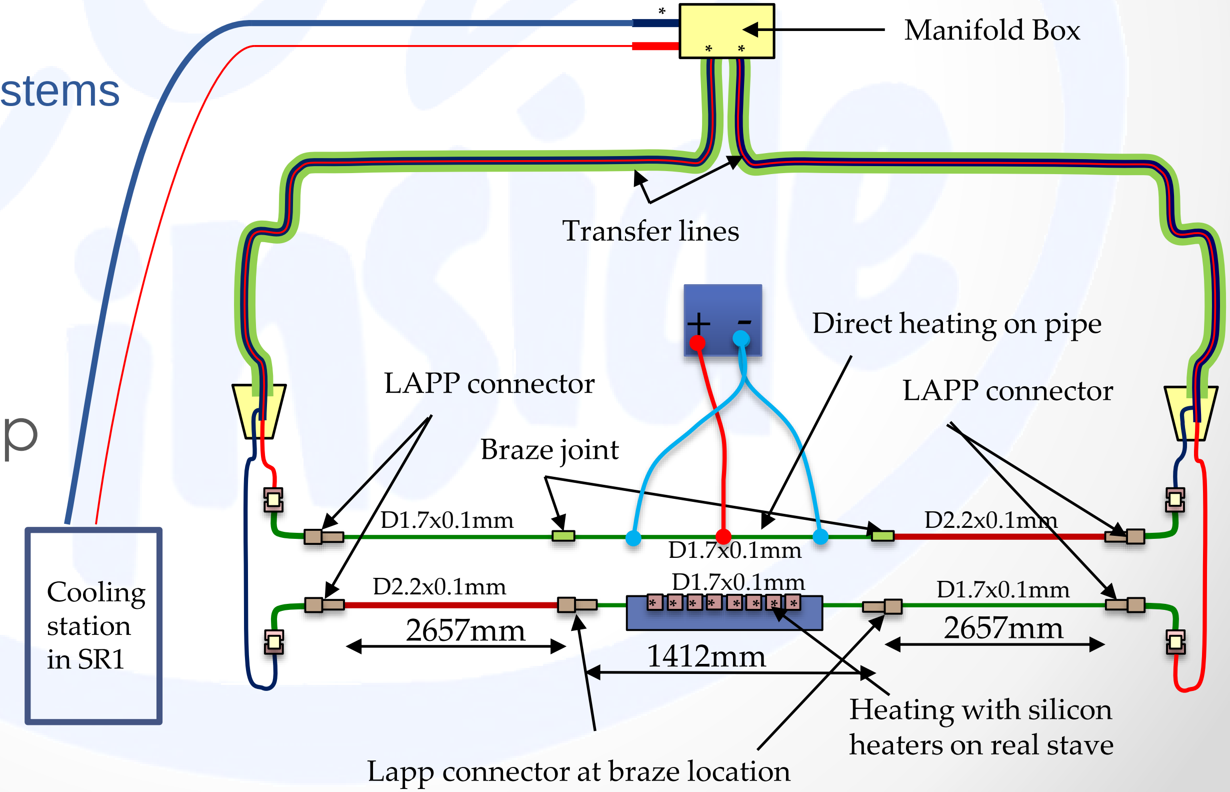
2-phase exhaust is more powerful and attracts ambient heat resulting in sub cooling in staves

Boiling starts suddenly

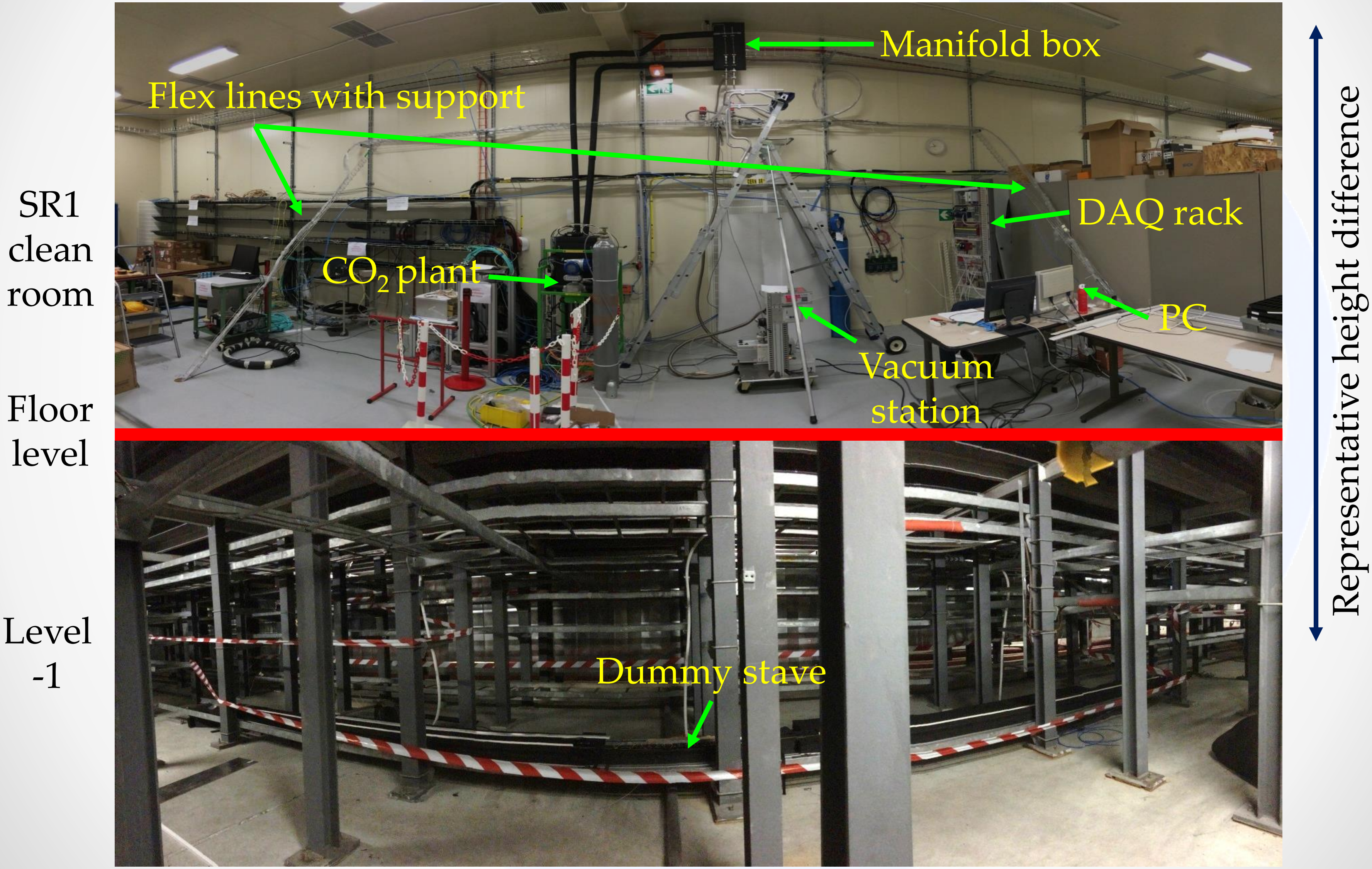
Full scale IBL branch pair set-up in SR1

- Build up a real size cooling mock-up of the ATLAS IBL stave pair to measure boiling front movement phenomena
    - Including real size IBL cooling hardware at real orientations and heights
    - Spare IBL flex lines
    - IBL test dummy stave
- Reproduce current situation as seen in ATLAS to understand current behaviour
- Test solutions to improve current situation in IBL
    - Optimize flow
    - Optimize manifold
- Important to understand phenomena for future systems

IBL Cooling loop mock-up



SR1 Setup overview



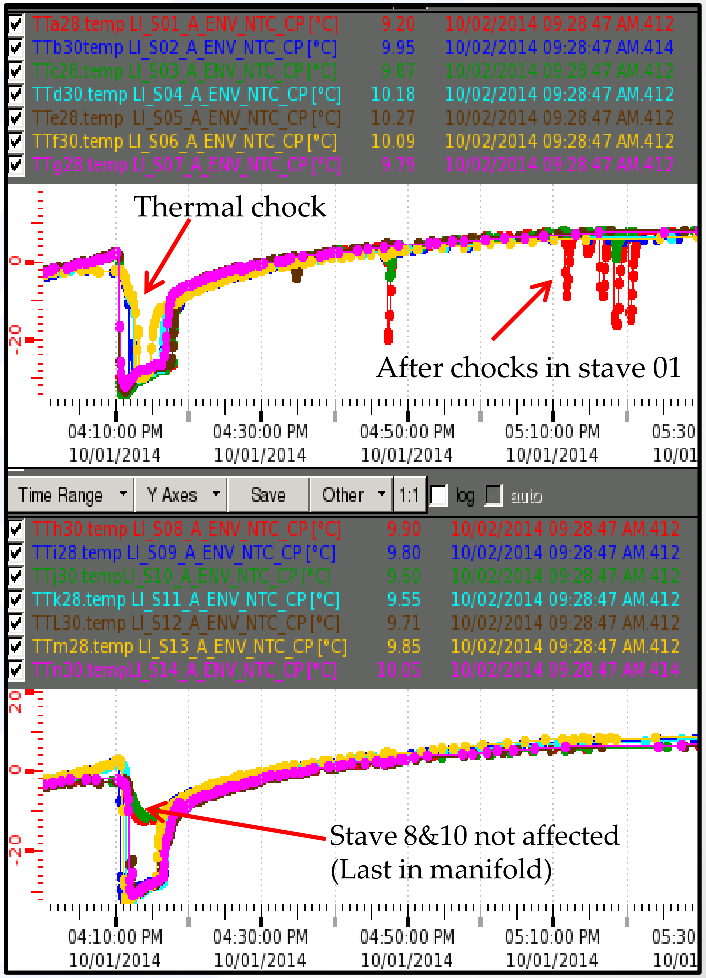
Conclusions

- The IBL cooling was successfully installed and commissioned in 2014.
- The beam-pipe bake out was successful and the IBL temperature stayed below -8'C at all time
- It has been running constantly without unplanned interruptions during all ATLAS data taking in 2015.
- The system temperature is stable in time (<1C°) but has a bi-stable start-up feature (Liquid super heating)
- The liquid super heating phenomena is studied in a 1:1 Scale IBL cooling line pair, both to study solutions for IBL and to understand the phenomena for future systems
- There is still some work to be done to make it reliably operate at cold temperatures.

Back-up slides

1st October: Thermal shock incident

- During the final blow test through the detector, suddenly after the test was over and system was emptying a slug of liquid entered the warming up detector.
  - A thermal shock happened from 0 to -35’C within a minute.
- There was a fear that the IBL was damaged, but tests showed that IBL is in a good shape
- It was discovered that expanding liquid from the plant causes a constant liquid push after a stop.
  - This was seen in small during any stop, but not understood where it came from
- With the IBL at the lowest point the liquid ends up where you don’t like to have it.
  - Despite having the manifolds high up
- An important lesson was learned not to have the detector at the lowest point
  - Introduction of siphons might be a better choice
- In IBL it will be solve with an additional safety by-pass short-cutting in and outlet during stop
  - No pressure build up over the detector causing an uncontrolled flow



☑	TTa28.temp LI_S01_A_ENV_NTC_CP [°C]	9.20	10/02/2014 09:28:47 AM.412
☑	TTb30temp LI_S02_A_ENV_NTC_CP [°C]	9.95	10/02/2014 09:28:47 AM.414
☑	TTc28.temp LI_S03_A_ENV_NTC_CP [°C]	9.87	10/02/2014 09:28:47 AM.412
☑	TTd30.temp LI_S04_A_ENV_NTC_CP [°C]	10.18	10/02/2014 09:28:47 AM.412
☑	TTe28.temp LI_S05_A_ENV_NTC_CP [°C]	10.27	10/02/2014 09:28:47 AM.412
☑	TTf30.temp LI_S06_A_ENV_NTC_CP [°C]	10.09	10/02/2014 09:28:47 AM.412
☑	TTg28.temp LI_S07_A_ENV_NTC_CP [°C]	9.79	10/02/2014 09:28:47 AM.412

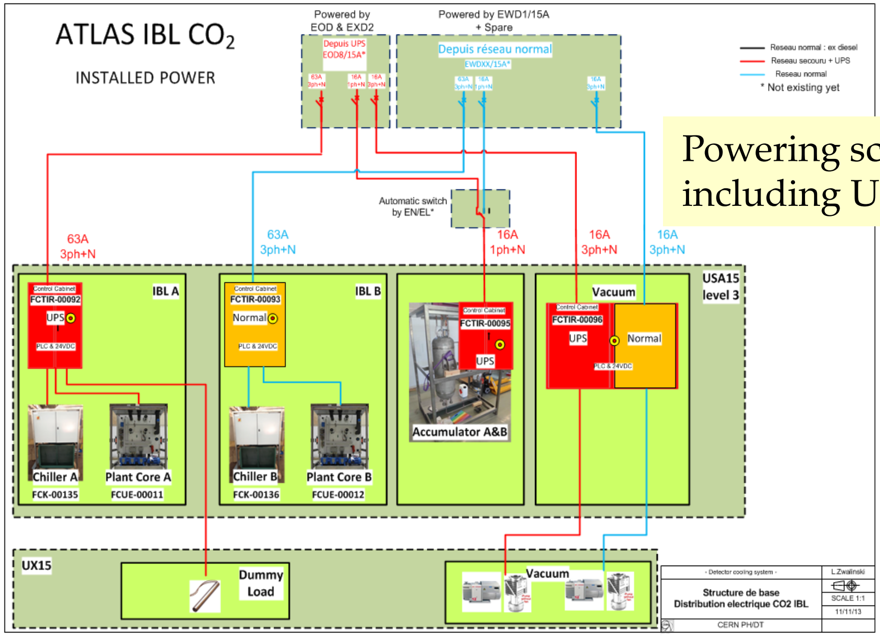
Thermal chock

After chocks in stave 01

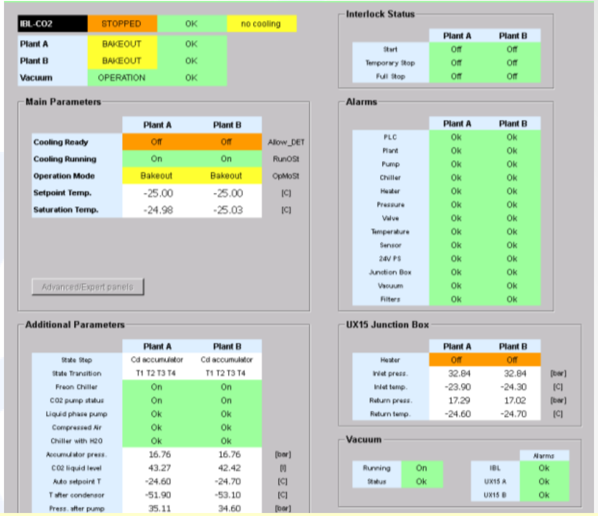
☑	TTh30.temp LI_S08_A_ENV_NTC_CP [°C]	9.90	10/02/2014 09:28:47 AM.412
☑	TTi28.temp LI_S09_A_ENV_NTC_CP [°C]	9.80	10/02/2014 09:28:47 AM.412
☑	TTj30.tempLI_S10_A_ENV_NTC_CP [°C]	9.60	10/02/2014 09:28:47 AM.412
☑	TTk28.temp LI_S11_A_ENV_NTC_CP [°C]	9.55	10/02/2014 09:28:47 AM.412
☑	TTL30.temp LI_S12_A_ENV_NTC_CP [°C]	9.71	10/02/2014 09:28:47 AM.412
☑	TTm28.temp LI_S13_A_ENV_NTC_CP [°C]	9.85	10/02/2014 09:28:47 AM.412
☑	TTn30.tempLI_S14_A_ENV_NTC_CP [°C]	10.05	10/02/2014 09:28:47 AM.414

Stave 8&10 not affected
(Last in manifold)

Control system



Powering scheme including UPS



IBL-CO2	STOPPED	OK	no cooling
Plant A	BAKEOUT	OK	
Plant B	BAKEOUT	OK	
Vacuum	OPERATION	OK	

Main Parameters

	Plant A	Plant B	
Cooling Ready	Off	Off	Allow_DET
Cooling Running	On	On	RunOSt
Operation Mode	Bakeout	Bakeout	OpMoSt
Setpoint Temp.	-25.00	-25.00	[C]
Saturation Temp.	-24.98	-25.03	[C]

Additional Parameters

	Plant A	Plant B	
State Step	Cd accumulator	Cd accumulator	
State Transition	T1 T2 T3 T4	T1 T2 T3 T4	
Freon Chiller	On	On	
C02 pump status	On	On	
Liquid phase pump	Ok	Ok	
Compressed Air	Ok	Ok	
Chiller with H20	Ok	Ok	
Accumulator press.	16.76	16.76	[bar]
C02 liquid level	43.27	42.42	[l]
Auto setpoint T	-24.60	-24.70	[C]
T after condensor	-51.90	-53.10	[C]
Press. after pump	35.11	34.60	[bar]

Interlock Status

	Plant A	Plant B
Start	Off	Off
Temporary Stop	Off	Off
Full Stop	Off	Off

Alarms

	Plant A	Plant B
PLC	Ok	Ok
Plant	Ok	Ok
Pump	Ok	Ok
Chiller	Ok	Ok
Heater	Ok	Ok
Pressure	Ok	Ok
Valve	Ok	Ok
Temperature	Ok	Ok
Sensor	Ok	Ok
24V PS	Ok	Ok
Junction Box	Ok	Ok
Vacuum	Ok	Ok
Filters	Ok	Ok

UX15 Junction Box

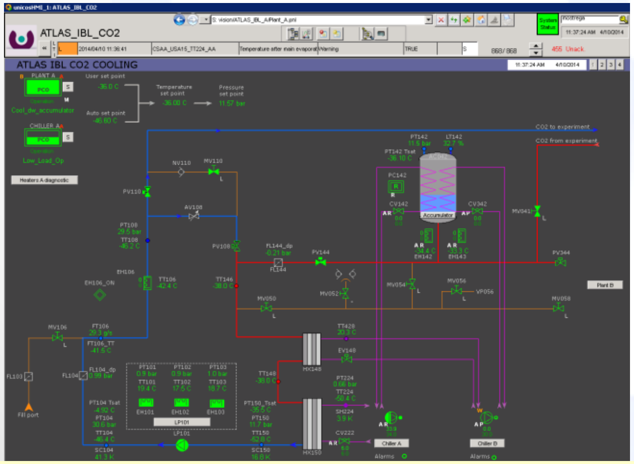
	Plant A	Plant B	
Heater	Off	Off	
Inlet press.	32.84	32.84	[bar]
Inlet temp.	-23.90	-24.30	[C]
Return press.	17.29	17.02	[bar]
Return temp.	-24.60	-24.70	[C]

Vacuum

Running	On
Status	Ok

	Alarms
IBL	Ok
UX15 A	Ok
UX15 B	Ok

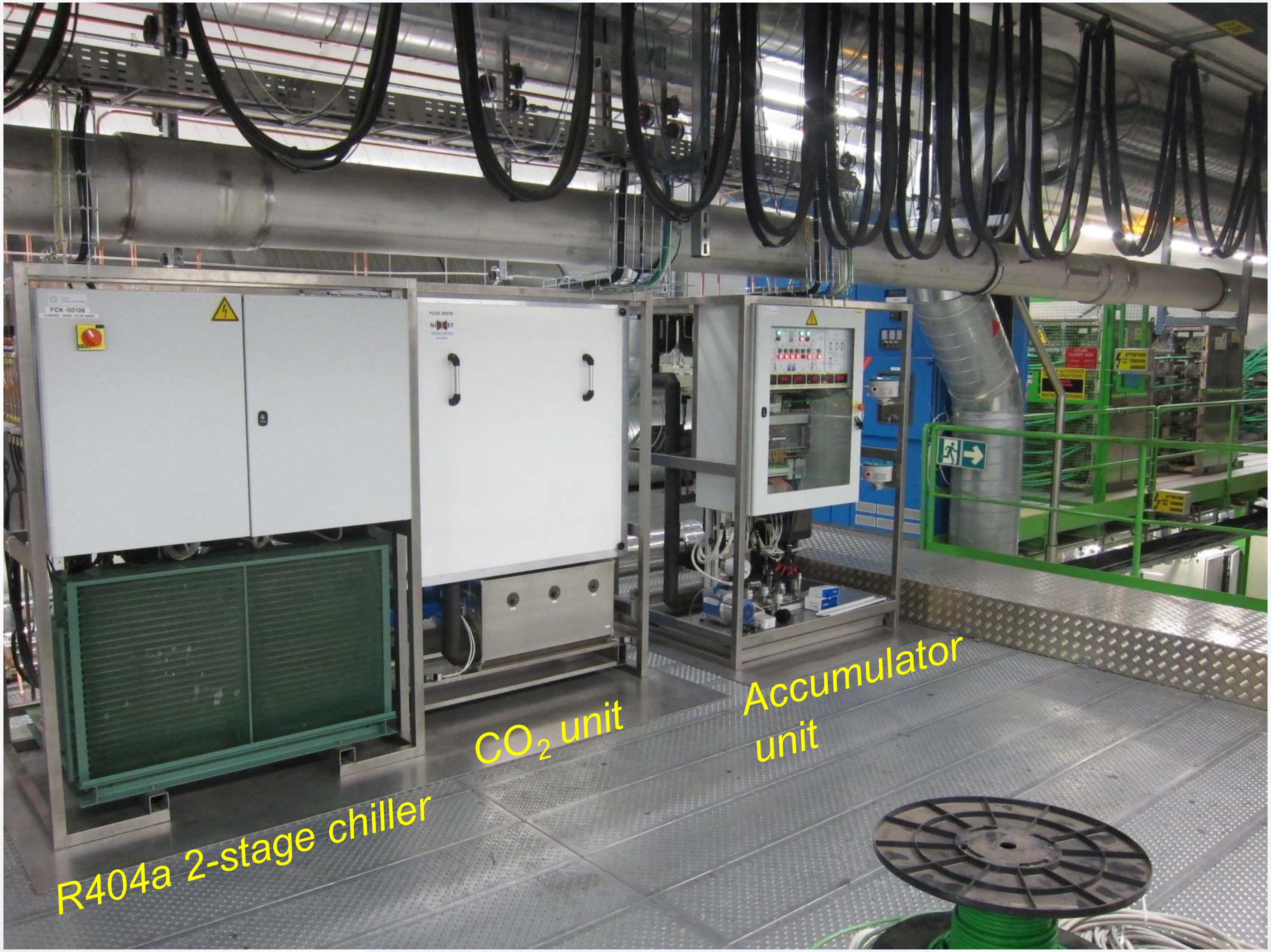
PVSS DCS for control room via DIP protocol (Only important information for user)



PVSS UNICOS Scada for plant control

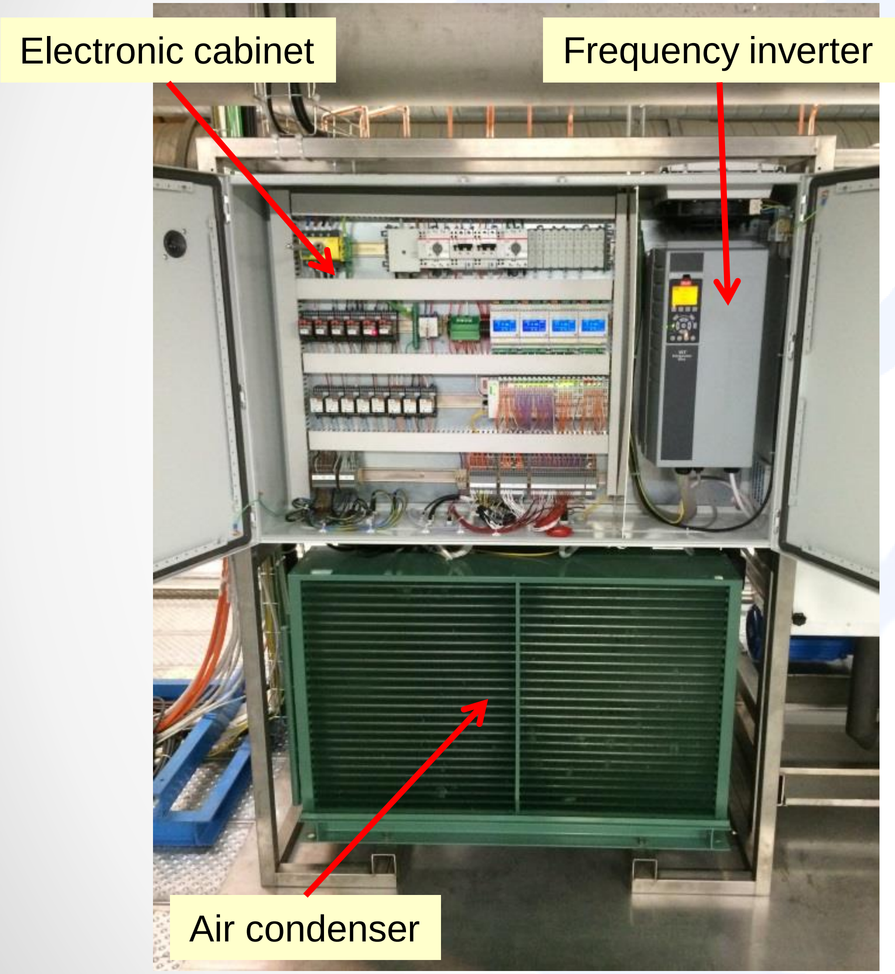
PLC control cabinets in USA15

Plant B and accu rack



IBL R404a 2-stage chiller unit

Front side with control cabinet and air condenser

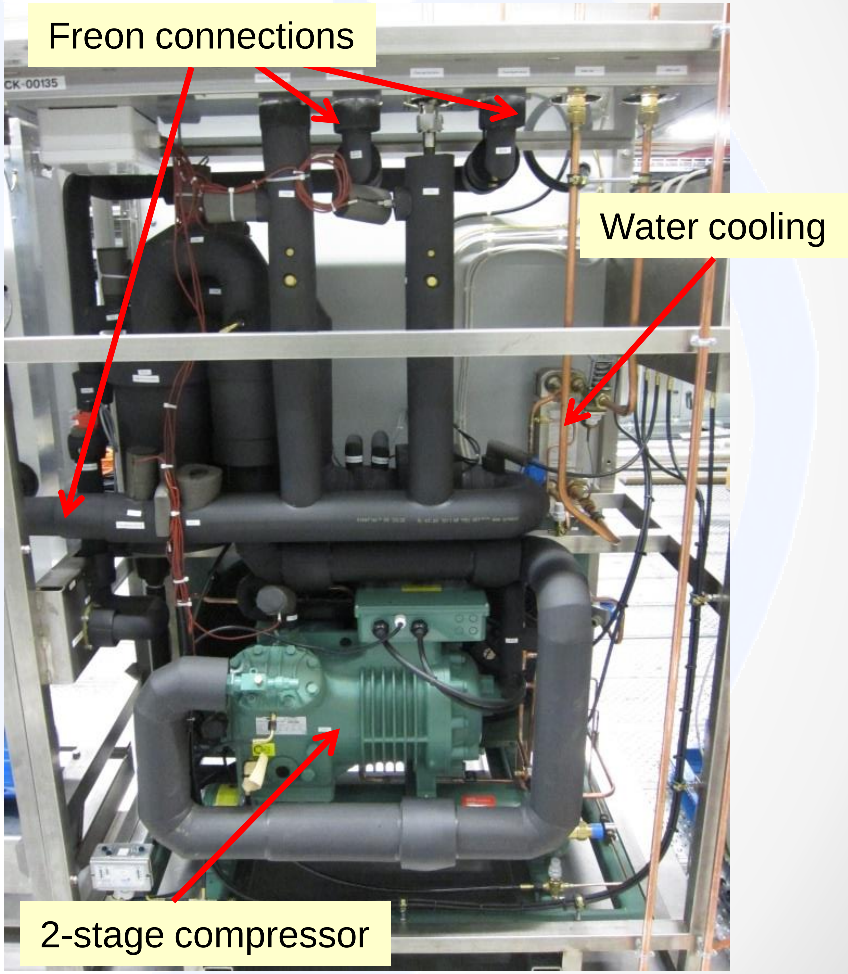


Electronic cabinet

Frequency inverter

Air condenser

Back side with piping



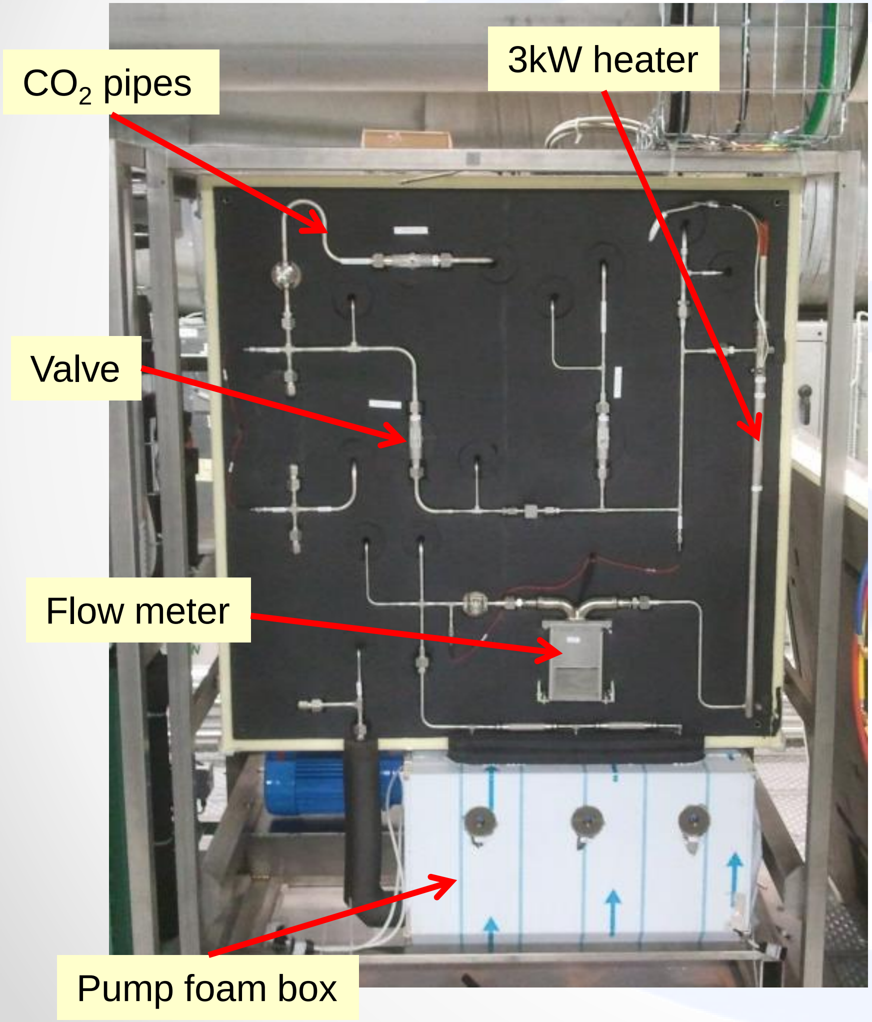
Freon connections

Water cooling

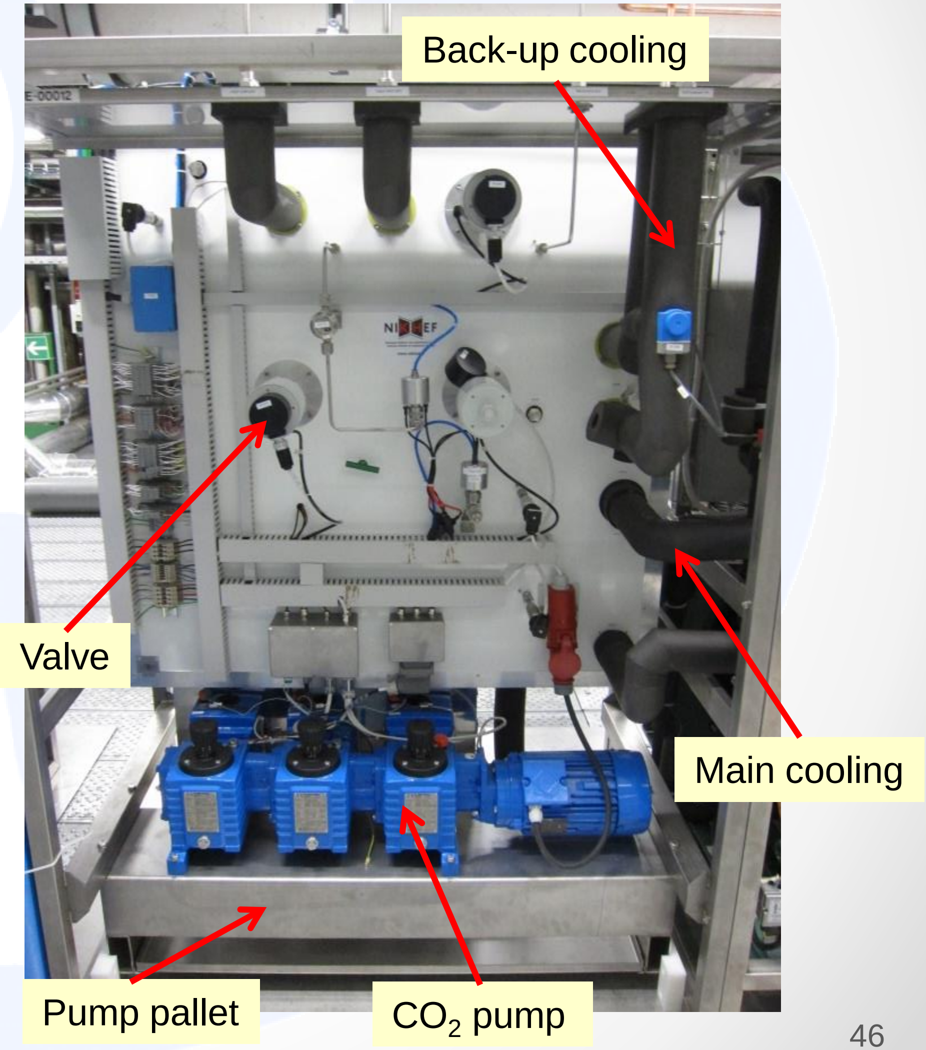
2-stage compressor

CO_2 unit

Front side with foam box

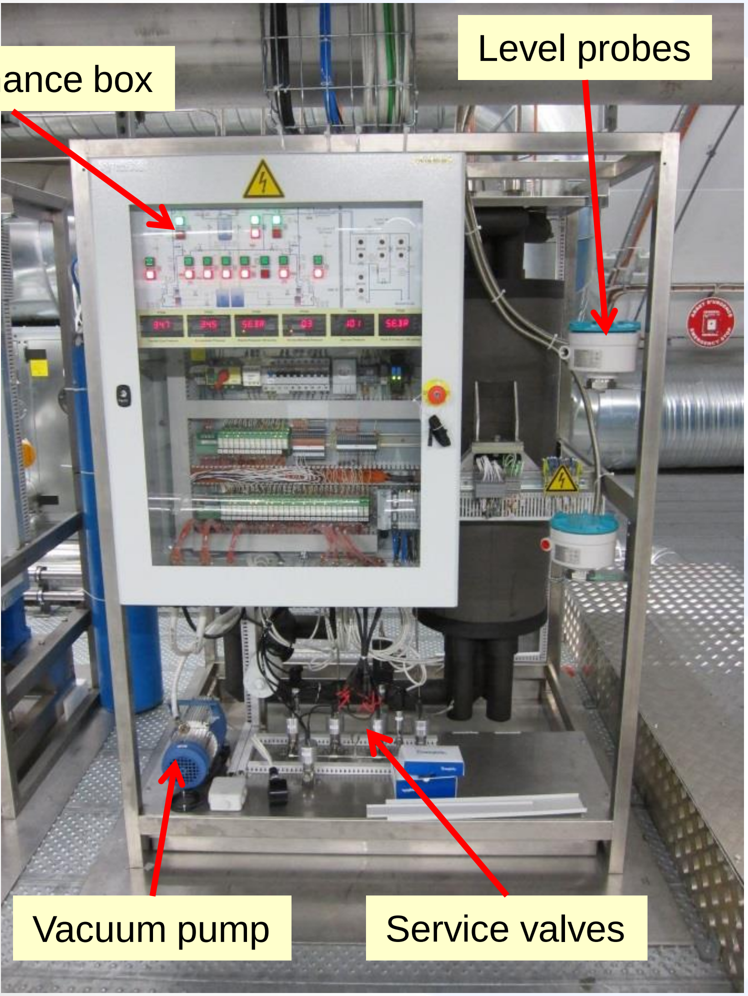


Back side components

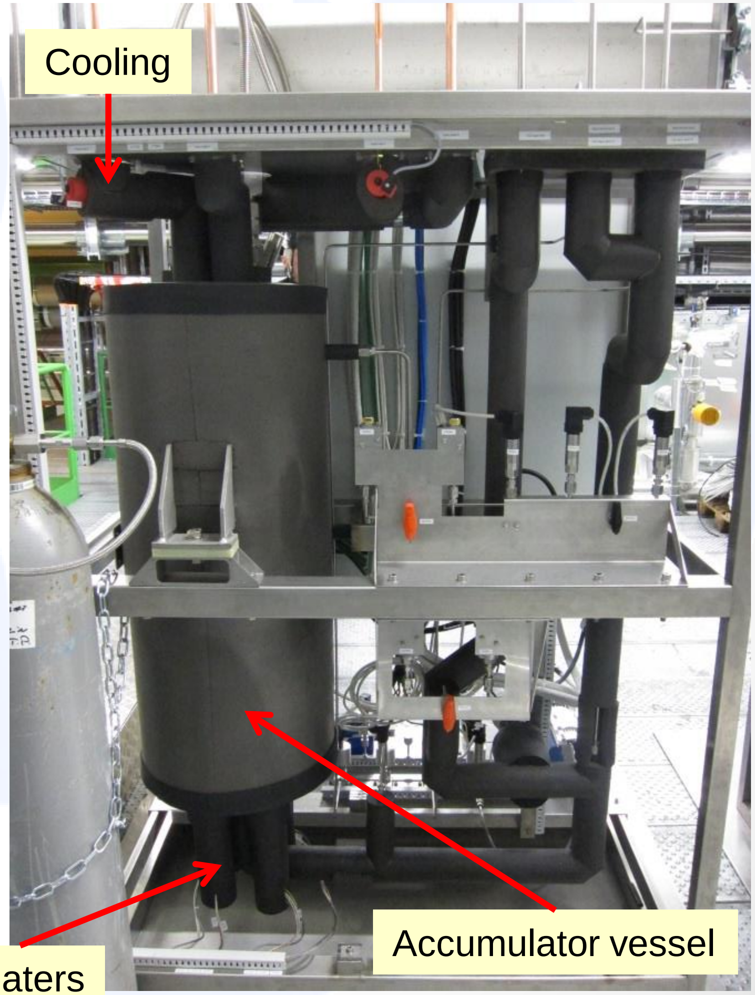


Accumulator unit

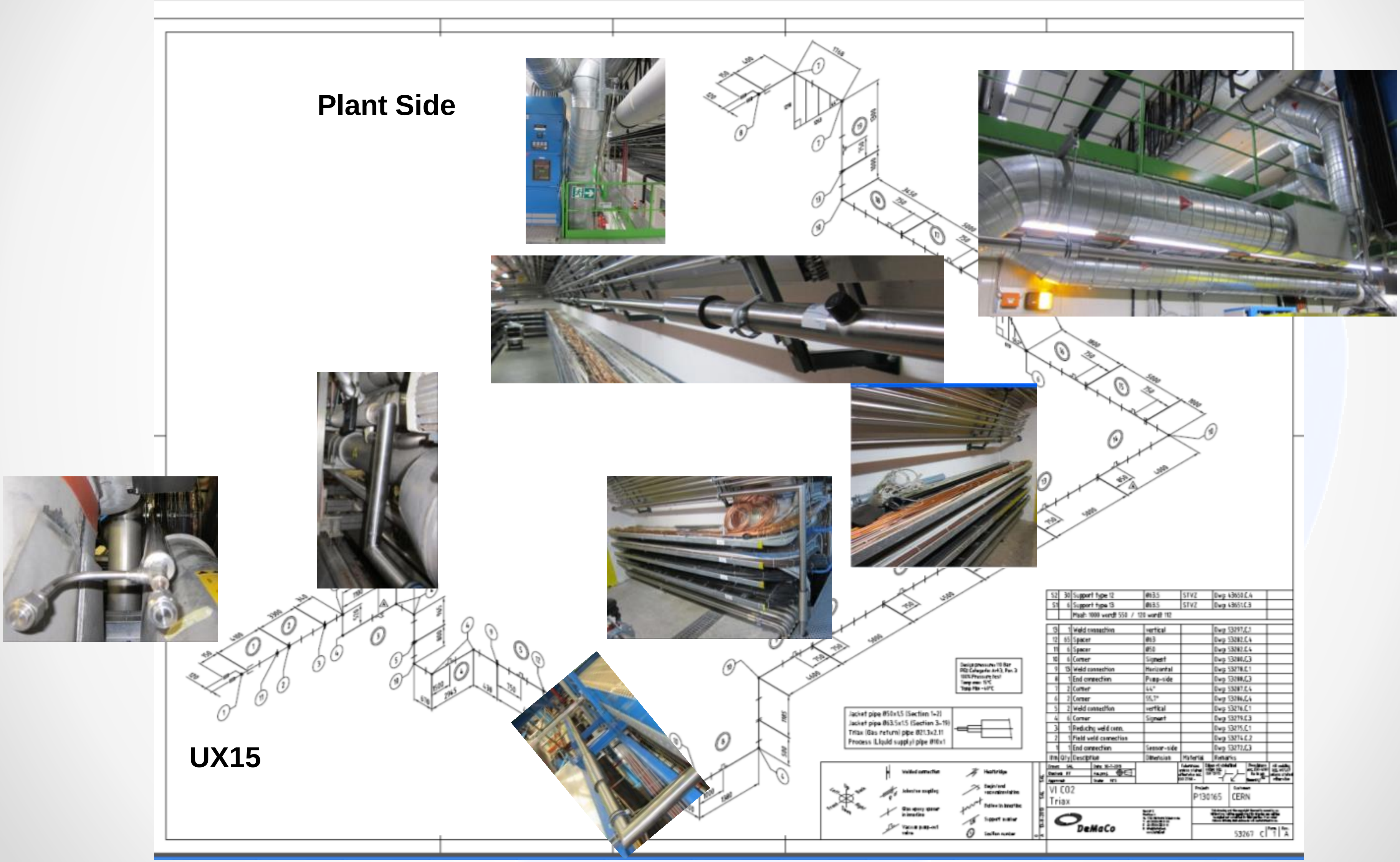
Front side maintenance control box



Back side with accumulator and piping



Vacuum transfer line status



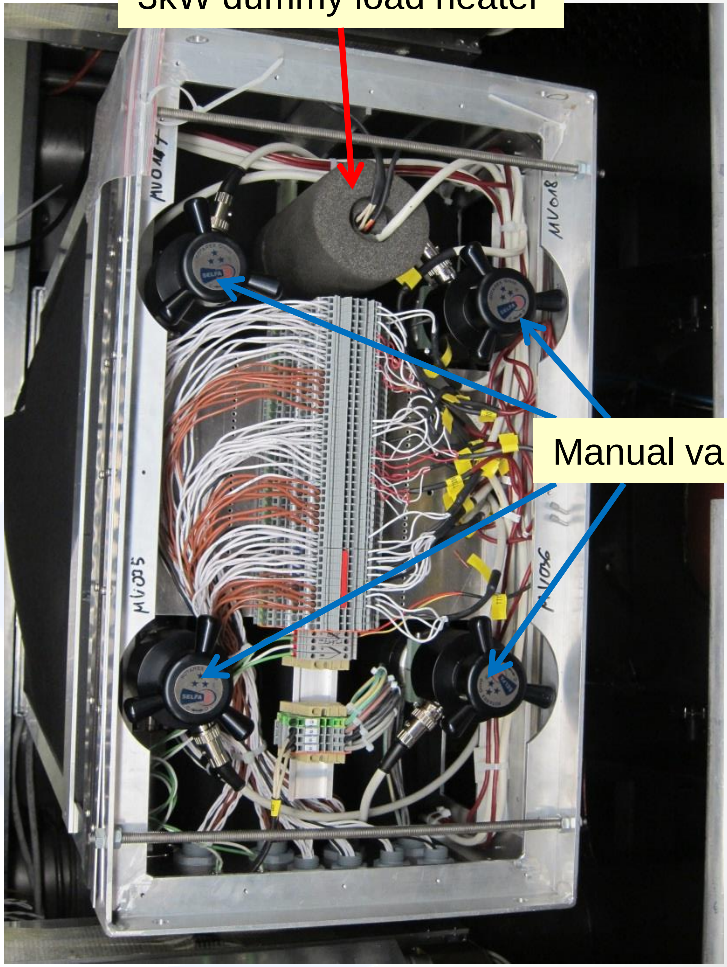
Plant Side

UX15

Item	Qty	Description	Dimension	Material	Remarks
52	30	Support type 12	Ø63.5	STVZ	Dwg 43650.C.4
51	6	Support type 13	Ø63.5	STVZ	Dwg 43651.C.3
		Maat: 1000 wordt 550 / 120 wordt 112			
13	1	Weld connection	vertical		Dwg 53297.C.1
12	65	Spacer	Ø63		Dwg 53282.C.4
11	6	Spacer	Ø50		Dwg 53282.C.4
10	6	Corner	Segment		Dwg 53280.C.3
9	15	Weld connection	Horizontal		Dwg 53278.C.1
8	1	End connection	Pump-side		Dwg 53288.C.3
7	2	Corner	44°		Dwg 53287.C.4
6	2	Corner	55.7°		Dwg 53286.C.4
5	2	Weld connection	vertical		Dwg 53276.C.1
4	6	Corner	Segment		Dwg 53279.C.3
3	1	Reducing weld conn.			Dwg 53275.C.1
2	1	Field weld connection			Dwg 53274.C.2
1	1	End connection	Sensor-side		Dwg 53272.C.3

Jacket pipe Ø50x1.5 (Section 1-2)
Jacket pipe Ø63.5x1.5 (Section 3-19)
Triax (Gas return) pipe Ø21.3x2.11
Process (Liquid supply) pipe Ø10x1

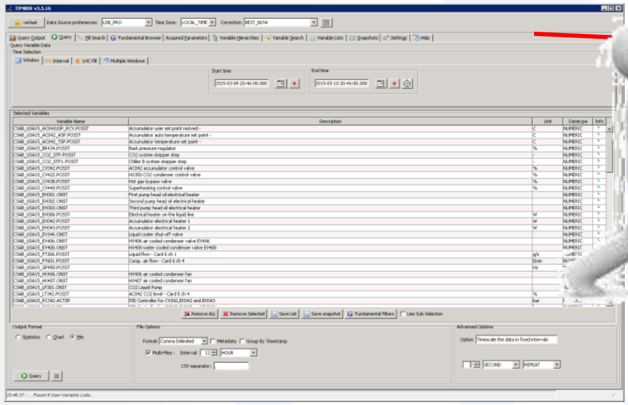
Junction installation



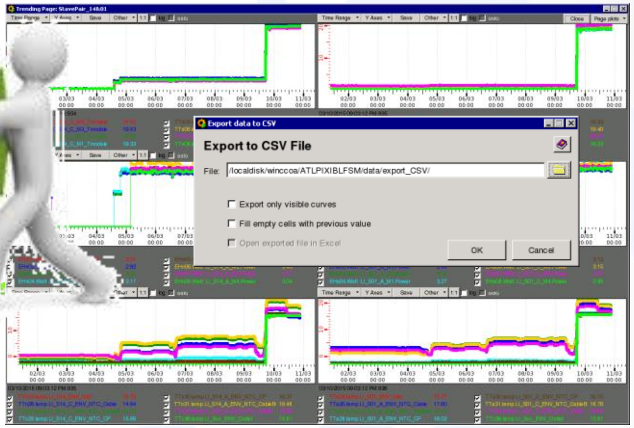
3kW dummy load heater

Manual valves

Importing data into Matlab



Timber



Export data to CSV

Export to CSV File

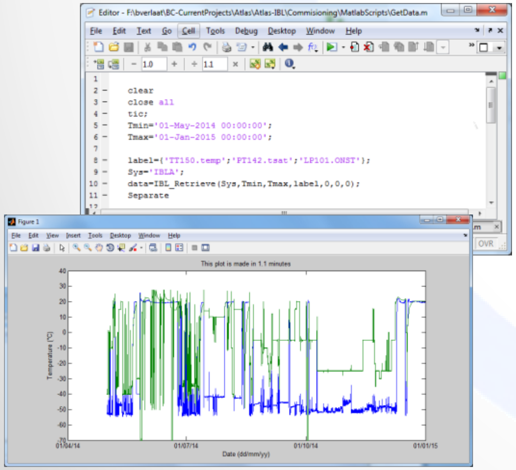
File: /localdisk/winccoa/ATLPIXIBLFSM/data/export_CSV/

☐ Export only visible curves

☐ Fill empty cells with previous value

☐ Open exported file in Excel

PVSS



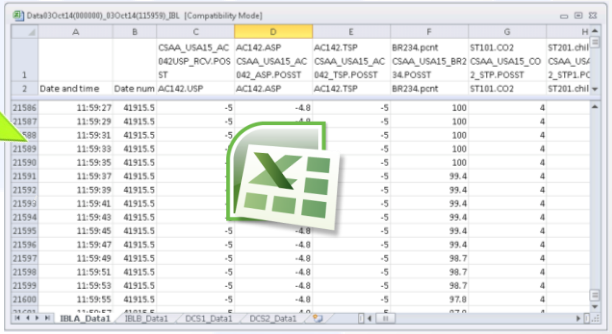
Editor - F:\bverlaat\BC-CurrentProjects\Atlas\Atlas-IBL\Commisioning\MatlabScripts\GetData.m

```
clear
close all
tic;
Tmin='01-May-2014 00:00:00';
Tmax='01-Jan-2015 00:00:00';

label={'TT150.temp';'PT142.tsat';'LP101.ONST'};
Sys='IBLA';
data=IBL_Retrieve(Sys,Tmin,Tmax,label,0,0,0);
Separate
```

This plot is made in 1.1 minutes

Matlab post processing from Matlab database



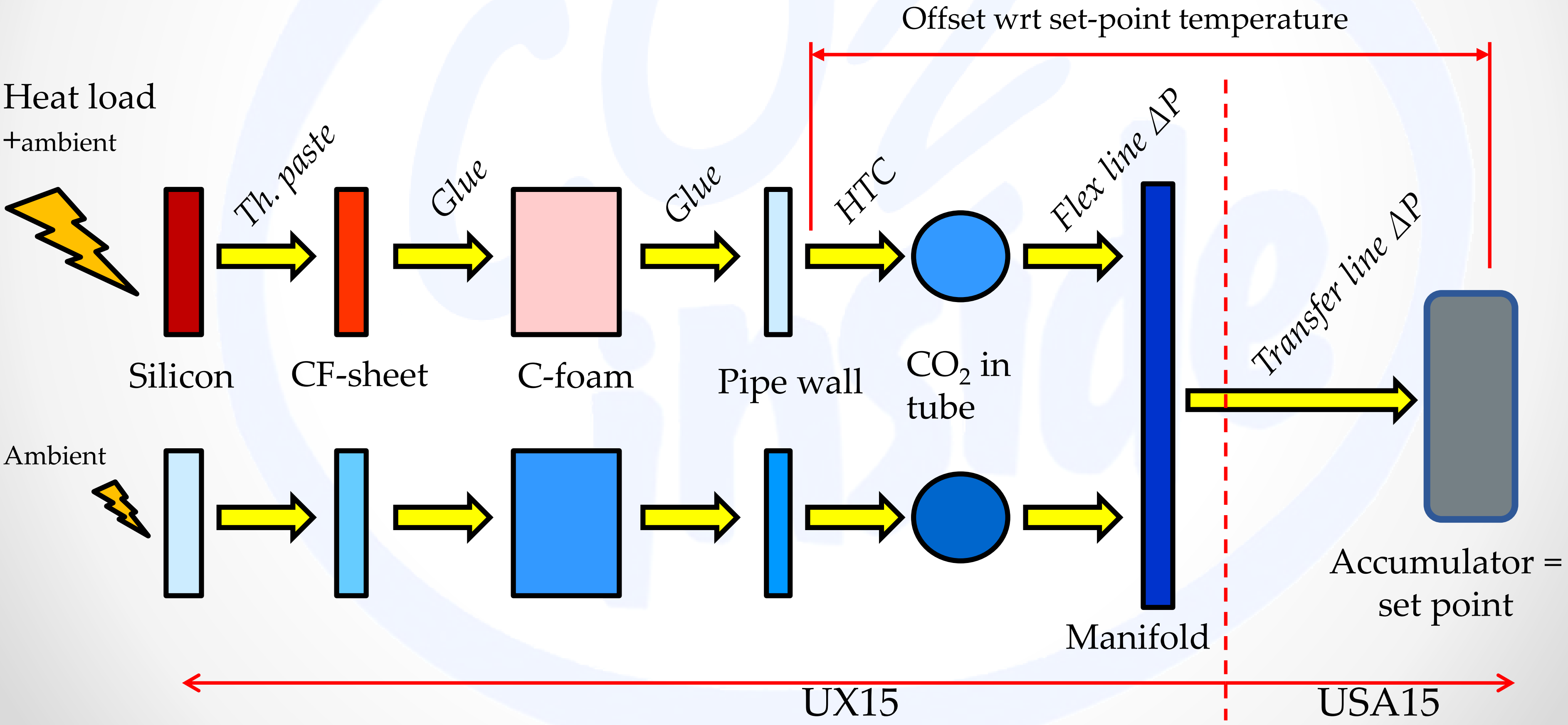
Data03Oct14(000000)_03Oct14(115959)_IBL [Compatibility Mode]

	A	B	C	D	E	F	G	H
1			CSAA_USA15_AC 042USP_RCV.POS ST	AC142.ASP CSAA_USA15_AC 042_ASP.POSST	AC142.TSP CSAA_USA15_AC 042_TSP.POSST	BR234.pcnt CSAA_USA15_BR2 34.POSST	ST101.CO2 CSAA_USA15_CO 2_STP.POSST	ST201.chil CSAA_USA 2_STP1.PC
2	Date and time	Date num	AC142.USP	AC142.ASP	AC142.TSP	BR234.pcnt	ST101.CO2	ST201.chil
21586	11:59:27	41915.5	-5	-4.8	-5	100	4	
21587	11:59:29	41915.5	-5	[illegible]	-5	100	4	
21588	11:59:31	41915.5	-5	[illegible]	-5	100	4	
21589	11:59:33	41915.5	[illegible]	[illegible]	-5	100	4	
21590	11:59:35	41915.5	[illegible]	[illegible]	-5	100	4	
21591	11:59:37	41915.5	[illegible]	[illegible]	-5	99.4	4	
21592	11:59:39	41915.5	[illegible]	[illegible]	-5	99.4	4	
21593	11:59:41	41915.5	[illegible]	[illegible]	-5	99.4	4	
21594	11:59:43	41915.5	[illegible]	[illegible]	-5	99.4	4	
21595	11:59:45	41915.5	-5	-4.8	-5	99.4	4	
21596	11:59:47	41915.5	-5	-4.8	-5	99.4	4	
21597	11:59:49	41915.5	-5	-4.8	-5	98.7	4	
21598	11:59:51	41915.5	-5	-4.8	-5	98.7	4	
21599	11:59:53	41915.5	-5	-4.8	-5	98.7	4	
21600	11:59:55	41915.5	-5	-4.8	-5	97.8	4	

Excel post processing from
Matlab generated excel files
(For public use)

Thermal chain from detector to cooling system

- The pressure drop causes a temperature drop which depends on the received heat load.
  - Therefore the cooling pipe CO_2 temperature is **not constant** and has a heat load depended offset wrt the cooling set point



Offset wrt set-point temperature

Heat load
+ambient

Th. paste
Glue
Glue
HTC
Flex line ΔP
Transfer line ΔP

Silicon
CF-sheet
C-foam
Pipe wall
CO_2 in tube
Manifold
Accumulator = set point

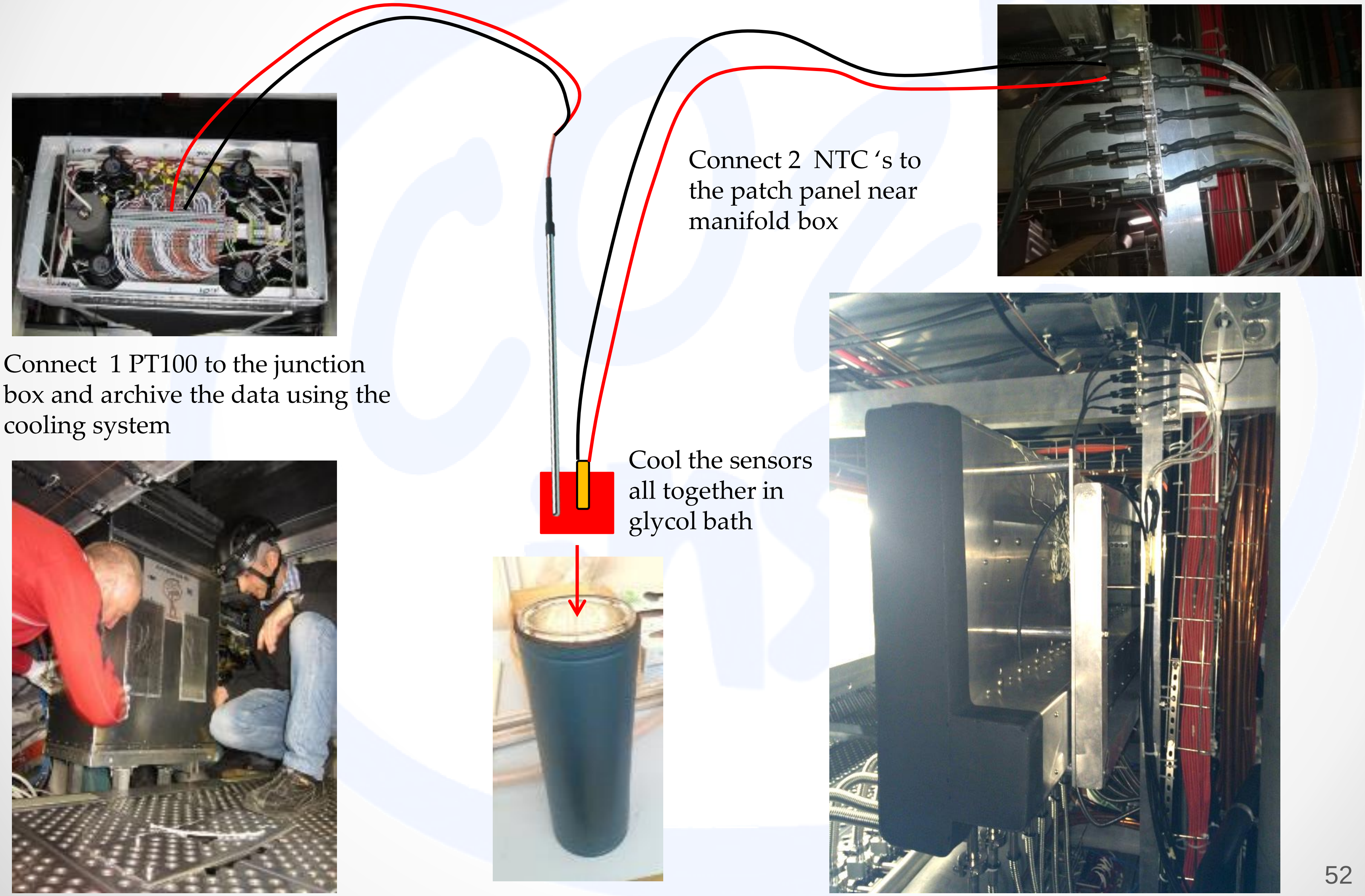
Ambient

UX15
USA15

For the 14 staves the return manifold is the common temperature boundary

Calibration of cooling pipe NTC's in sector 5

(connect DCS and cooling system sensors together to a cold reference)



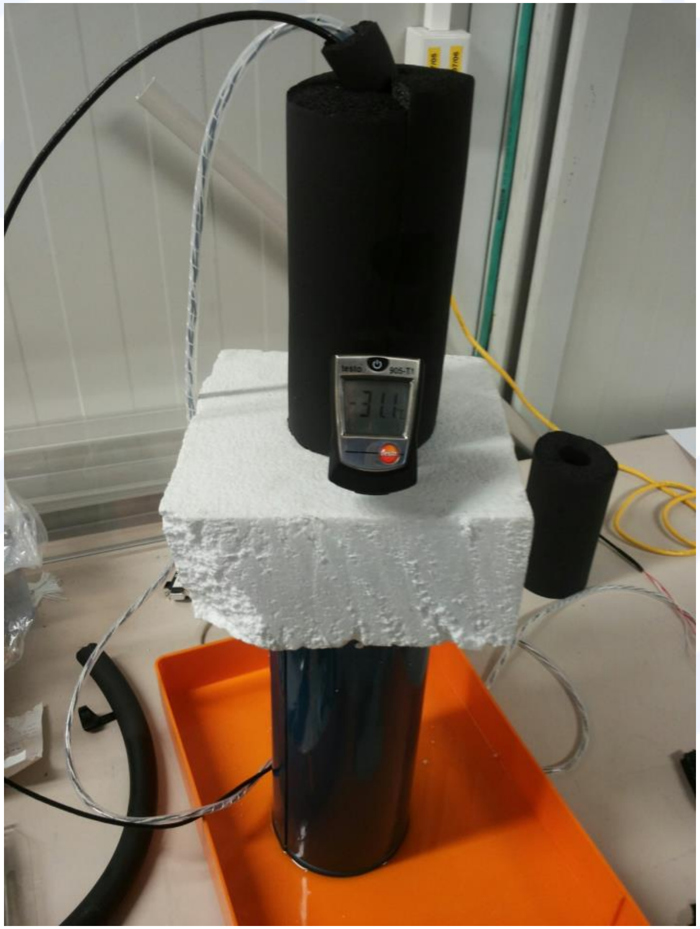
Connect 2 NTC 's to the patch panel near manifold box

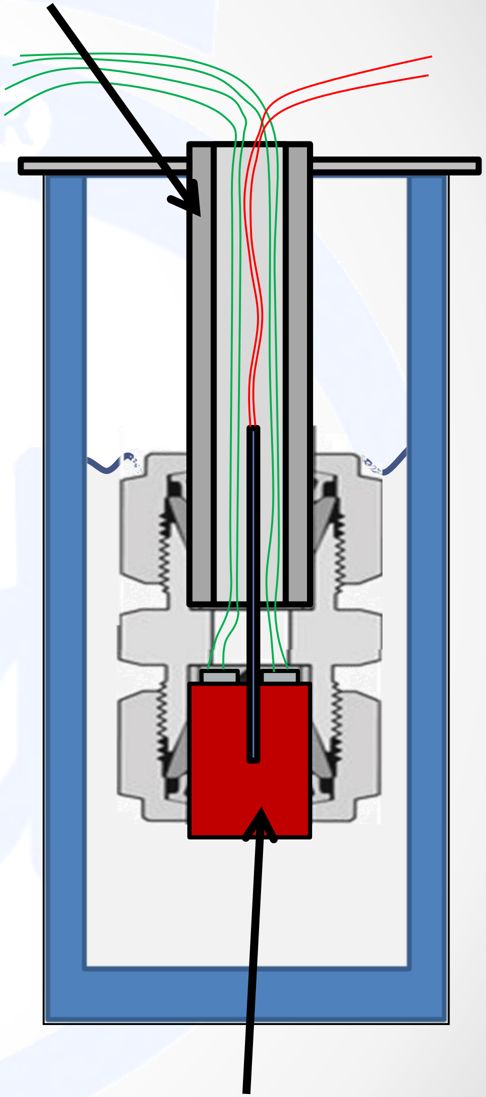
Connect 1 PT100 to the junction box and archive the data using the cooling system

Cool the sensors all together in glycol bath

Calibration setup

Dewar



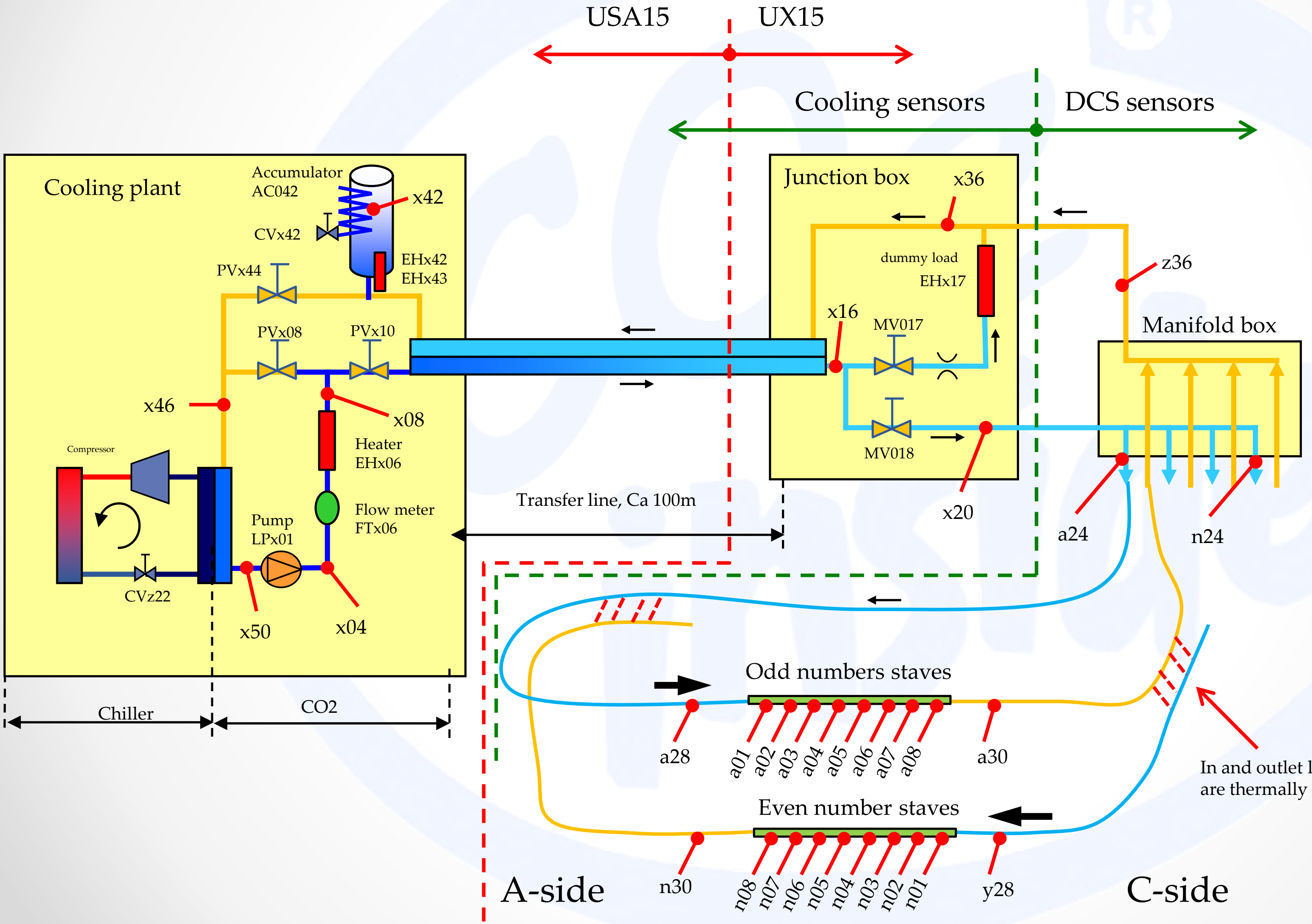


Tube to give a dry passage for wires.

Copper block with a PT100 and 2 NTC sensors dipped in cold glycol stored in a Dewar.

The glycol was cooled to -40°C and warmed up slowly over time to calibrate over the full range

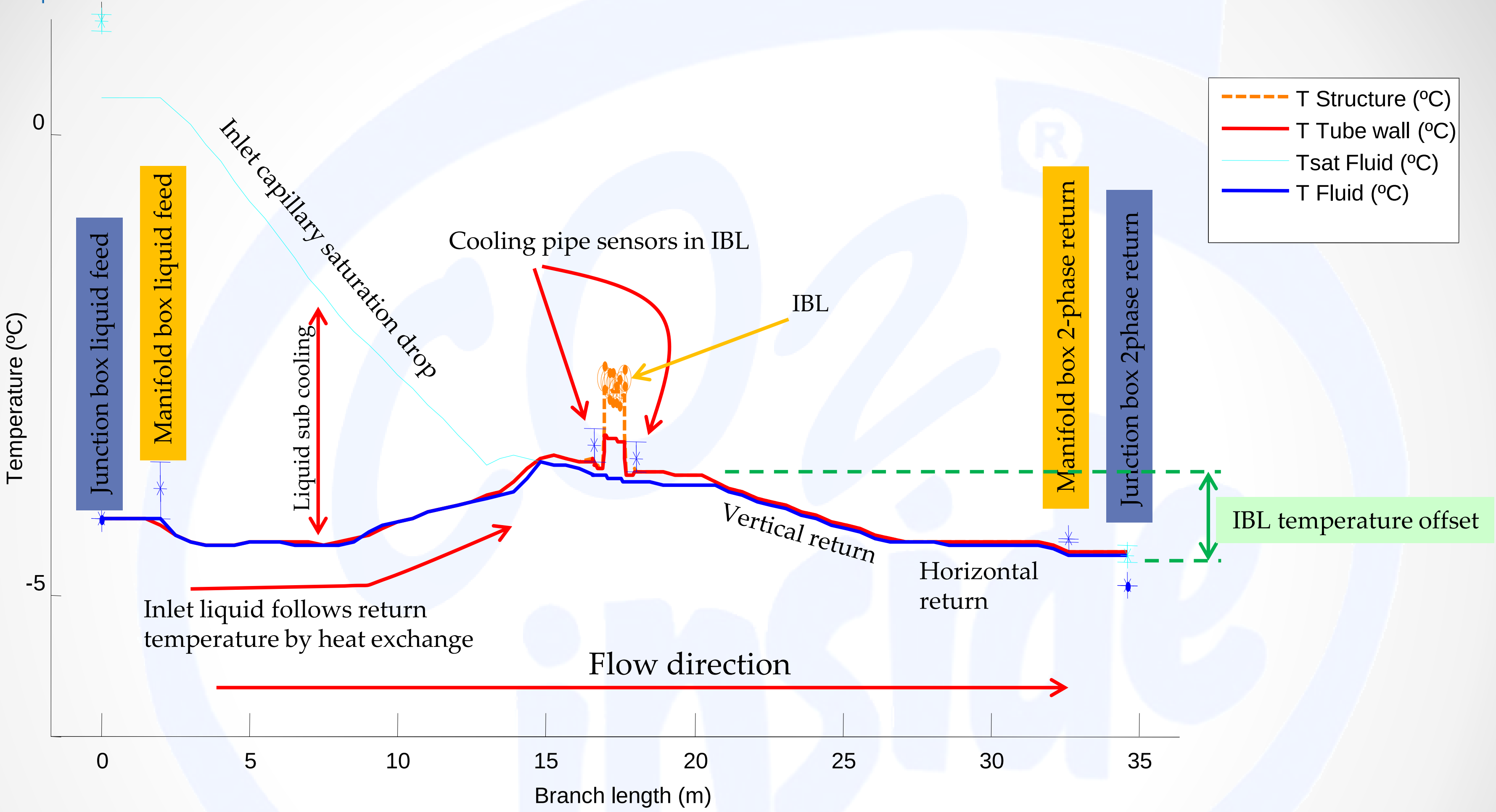
The IBL CO_2 cooling system
Simplified P&ID with temperature sensors



In and outlet lines of different staves are thermally connected

Sensor label	Stave #	Flow dir	Connected to stave
a	1	A-C	14
b	2	C-A	3
c	3	A-C	2
d	4	C-A	5
e	5	A-C	4
f	6	C-A	7
g	7	A-C	6
h	8	C-A	9
i	9	A-C	8
j	10	C-A	11
k	11	A-C	10
l	12	C-A	13
m	13	A-C	12
n	14	C-A	1
x	Cooling system		
y	Average of all		
z	Common		

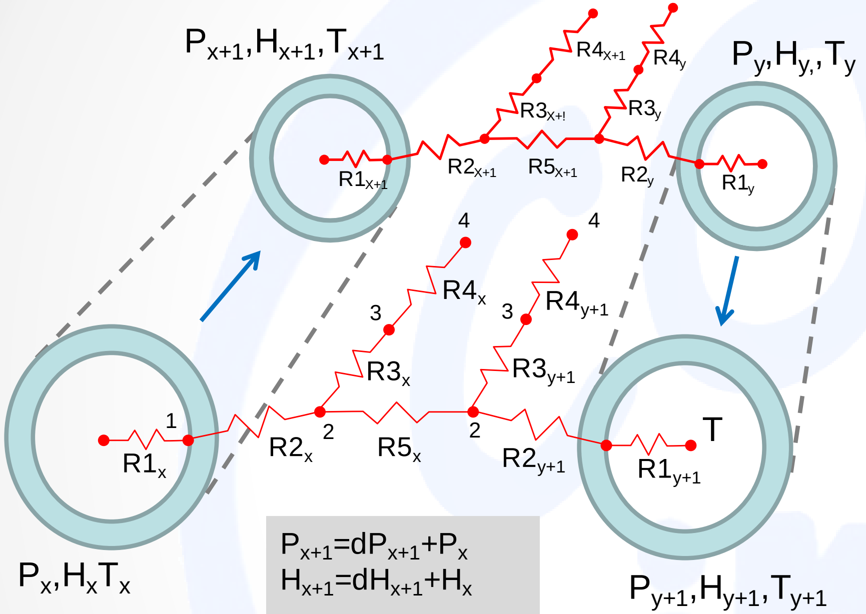
Typical IBL temperature profile



- The only way to check the NTC's is with respect to the CoBra model
  - The CoBra model predicts the temperature profile of cooling lines
  - Pressure drop and heat transfer are analyzed
- As the gradients are heat load depended, a good estimate of the ambient heating is required.

CoBra model

CO_2 *BRAnch model*



$P_{x+1}=dP_{x+1}+P_x$
$H_{x+1}=dH_{x+1}+H_x$

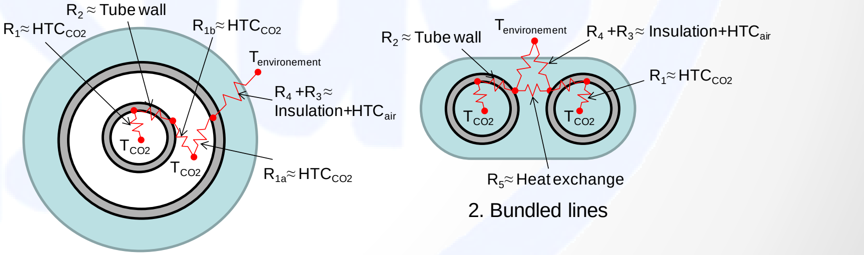
dH=Q1/MF
Q1 is calculated in the thermal network

The thermal node network calculates the heat influx in the cooling pipe based on:

- Applied power Q3 on node 3
- Environmental heating from fixed temperature T4 on node 4
- Heat exchange with another pipe section via R5 between nodes 2 and 2 of the connected sections

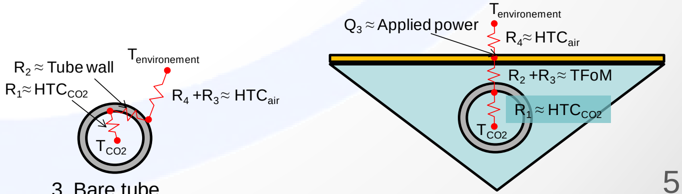
- The CoBra model chops the cooling line in small sections and calculates the heat fluxes, pressure drops and heat transfers according the local properties.
- CoBra works in single and 2-phase
- A simple thermal node network is present per pipe section to include the thermal conductance of the structure. (TFoM)

The different pipe section modeled in the thermal node network



1. Concentric line

2. Bundled lines



3. Bare tube

4. Stave