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CO_2 superheating and boiling onset measurements in the ATLAS CO_2 cooling system

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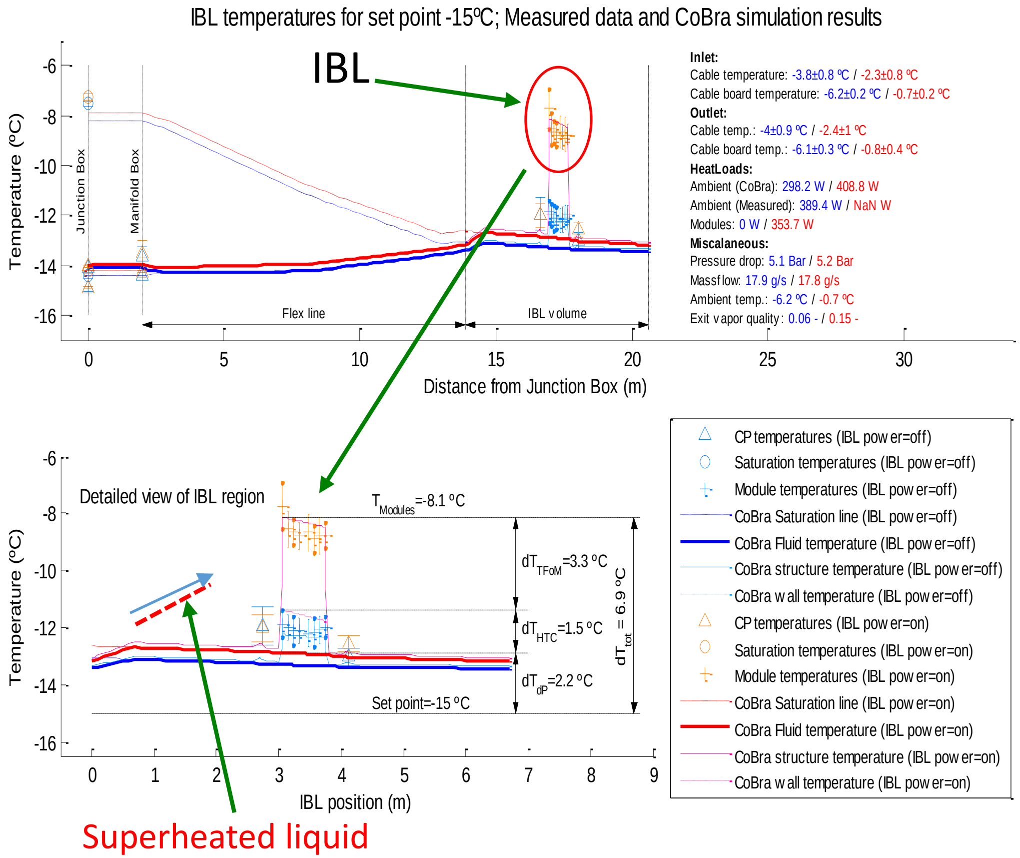
Bart Verlaat, Lukasz Zwalinski, Nicola Suzzi

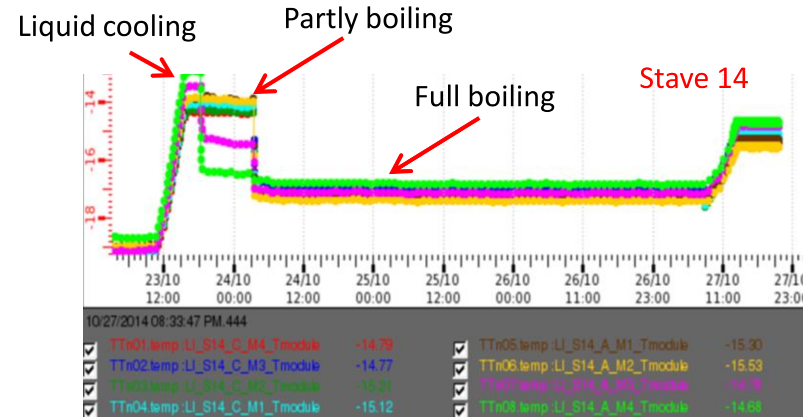
5th July 2017
Forum on tracking detector mechanics

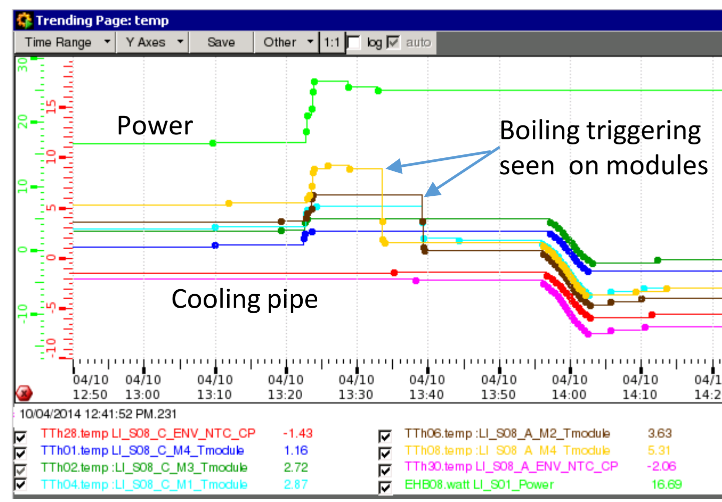
Boiling onset problems in IBL

The temperature of the inlet of the staves is irregular causing problems for the alignment



Boiling onset seen during bake-out





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Boiling onset seen during normal operation

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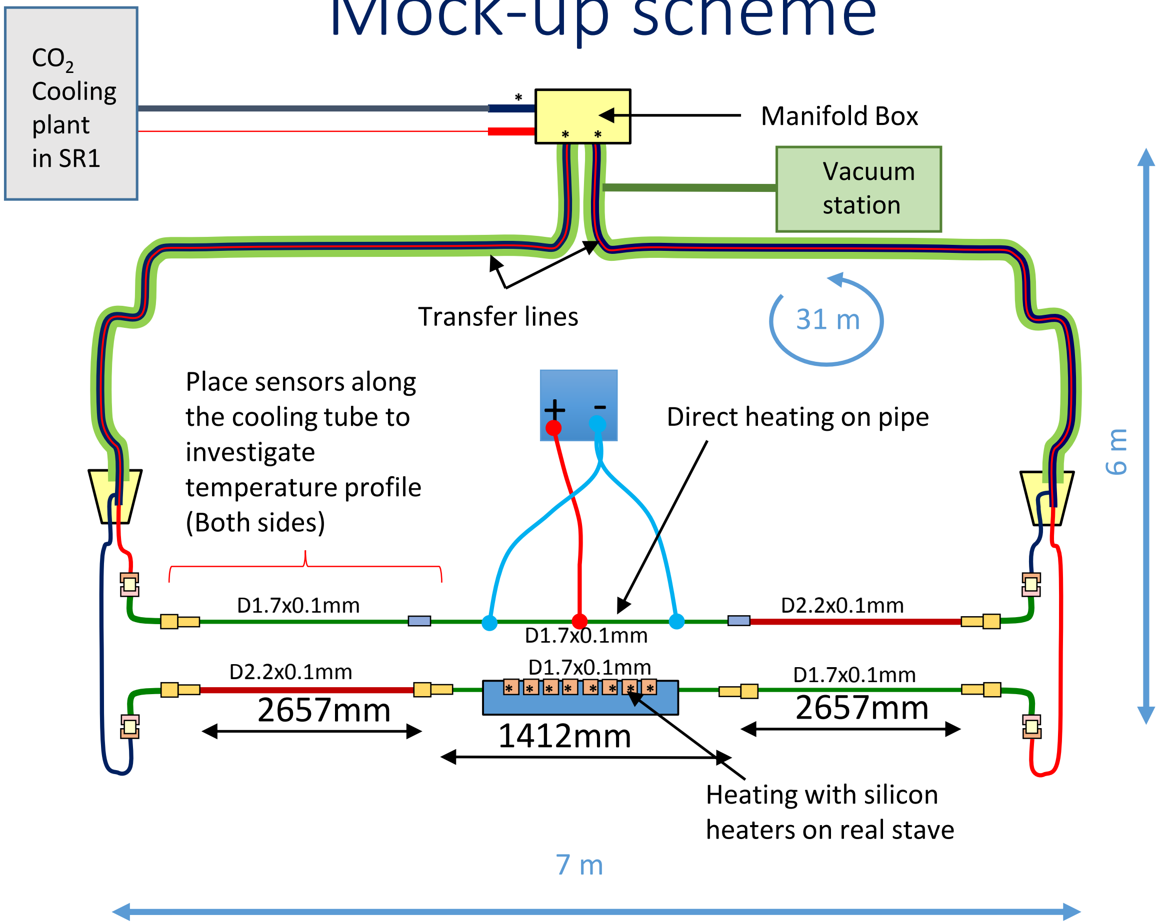
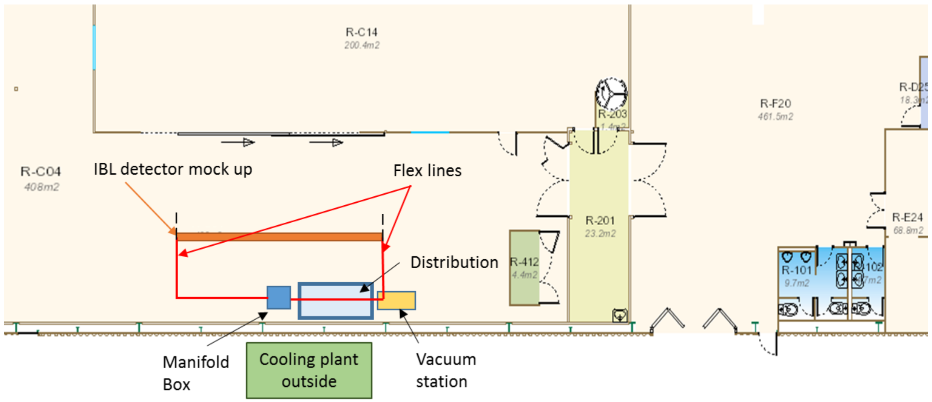
IBL boiling Onset investigation

Mock-up scheme

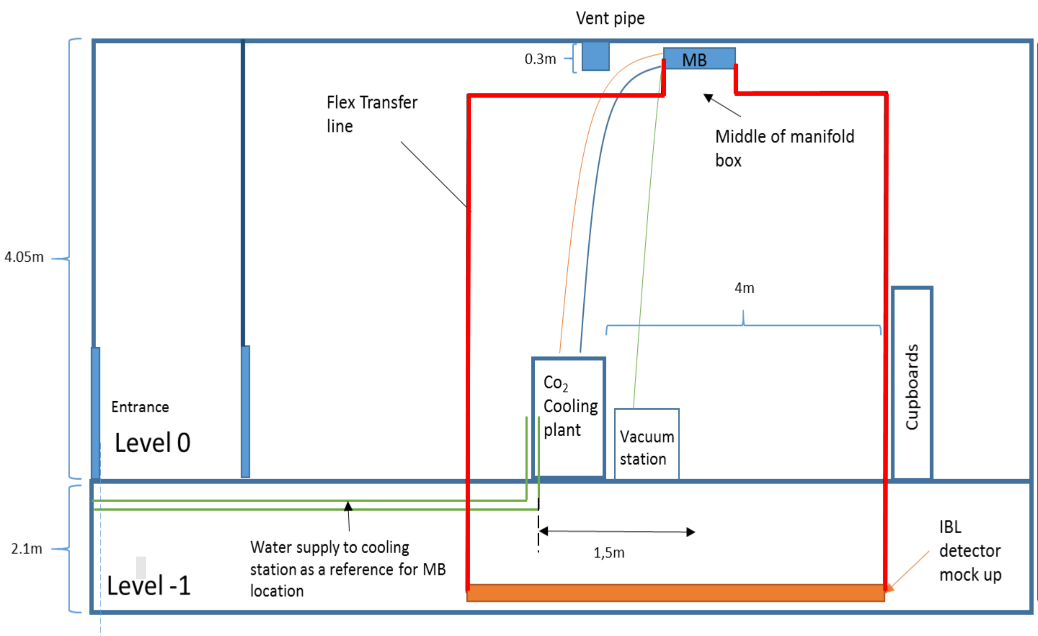
- We build a real size cooling mock-up of the ATLAS IBL stave pair to investigate boiling front movement phenomena
- Reproduce current situation as seen in ATLAS to understand what is ongoing
- Finding the best solutions to improve current situation in IBL
  - Optimize flow
  - Optimize manifold

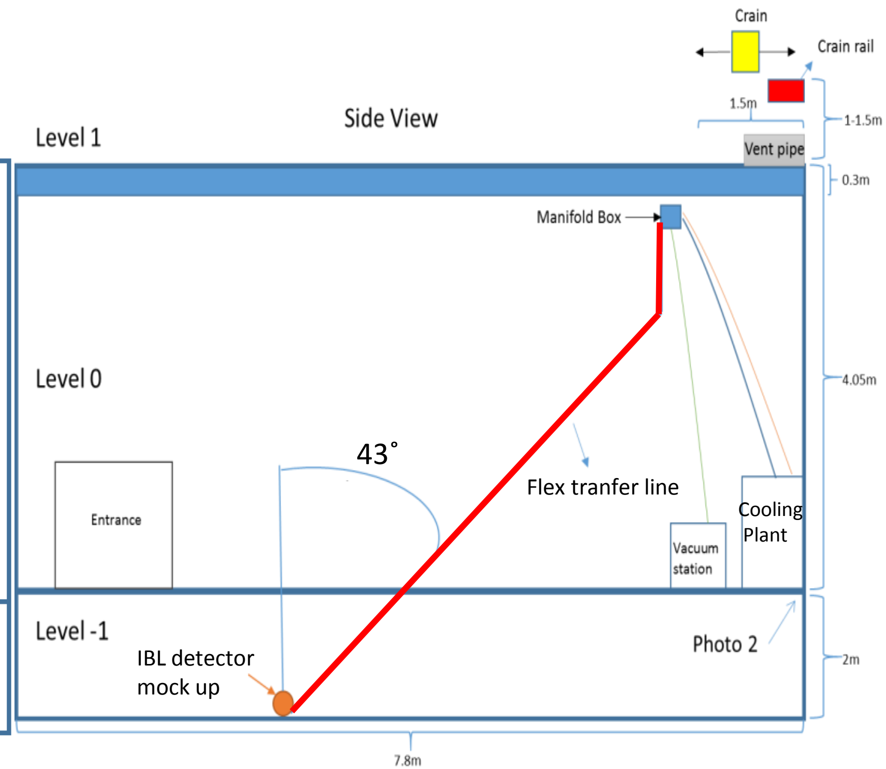


Mock-up location in SR1



Static height is an important issue!
Due to that, we need to place the IBL dummy staves in the basement of SR1

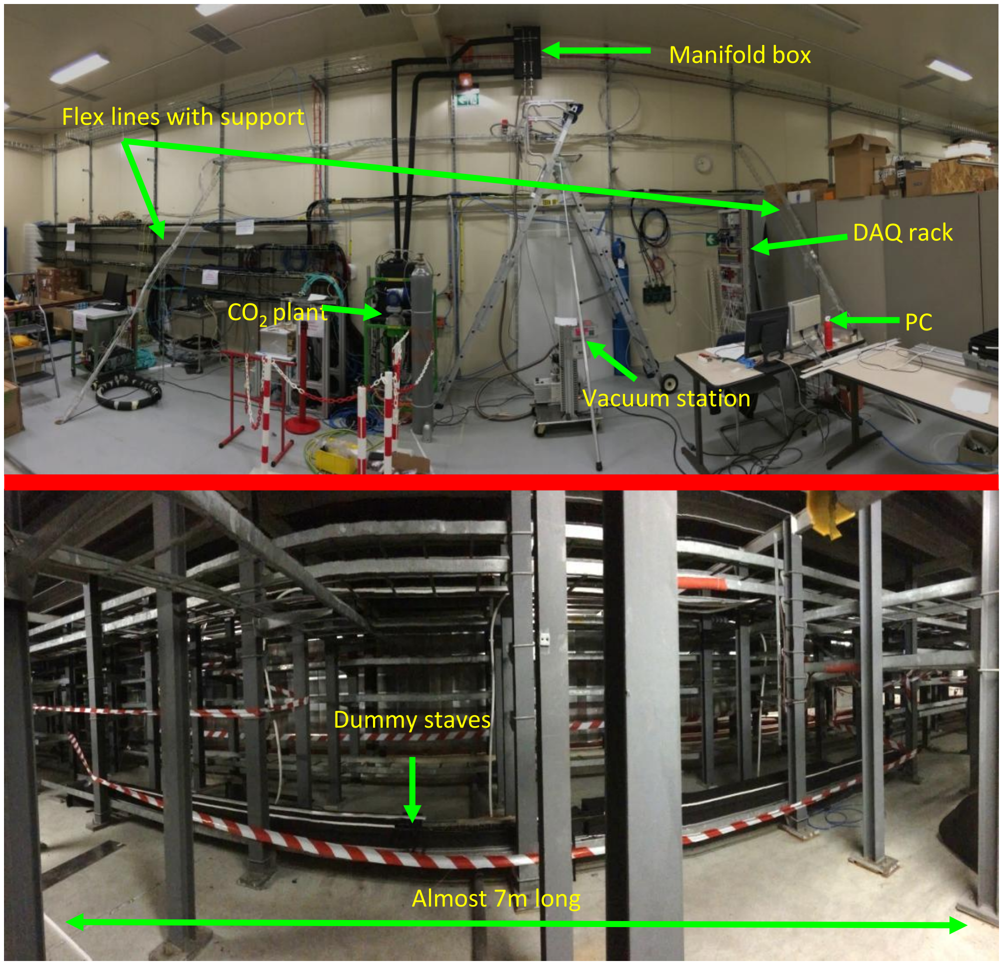




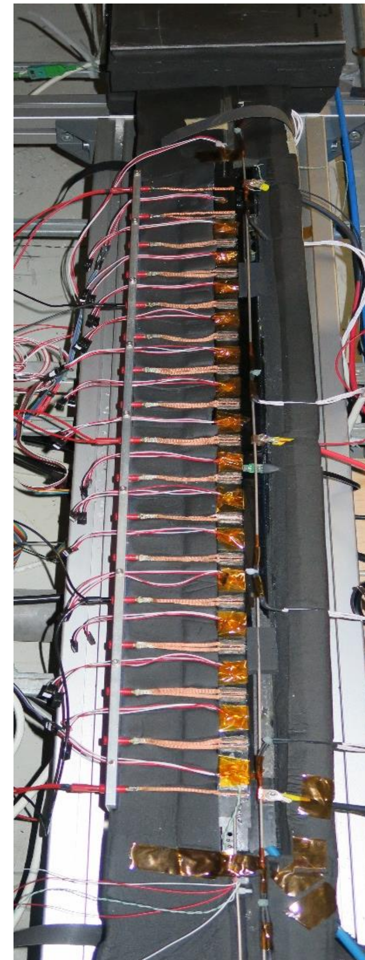
Setup overview

SR1 clean room

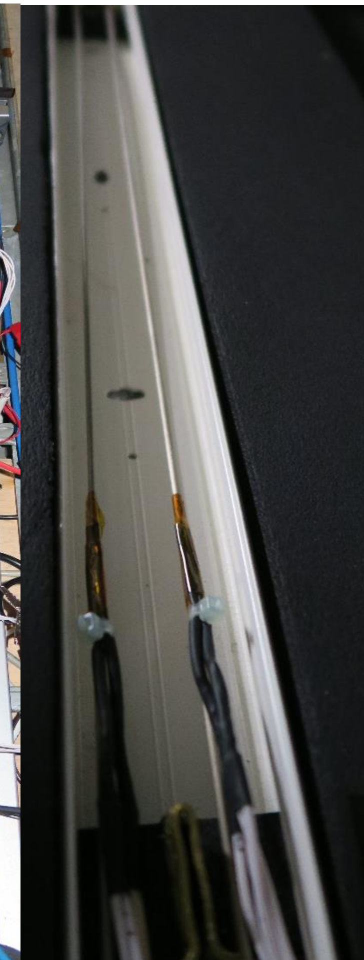
SR1 Level -1



Representative height difference

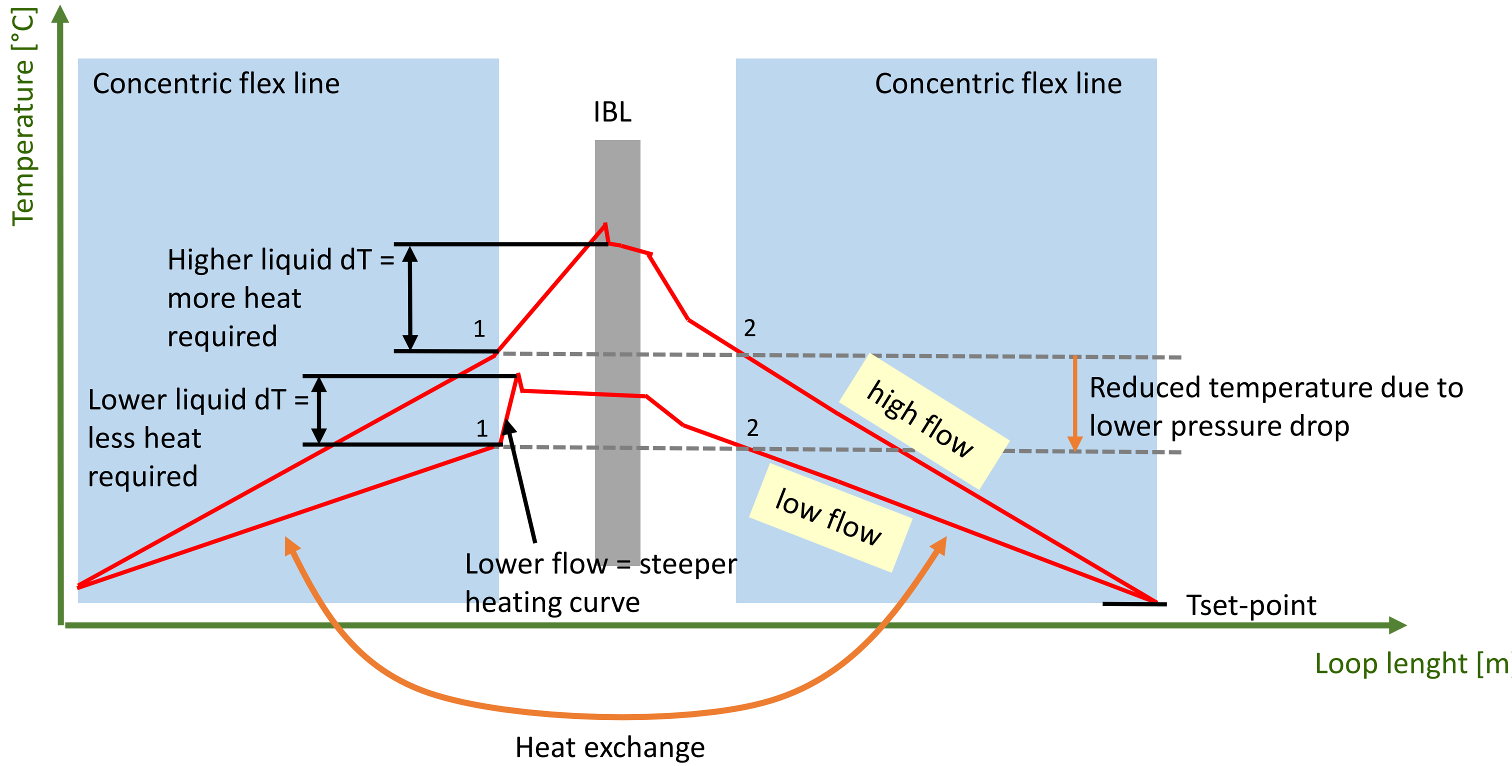


Dummy stave



Cooling lines

The expected effect of flow reduction



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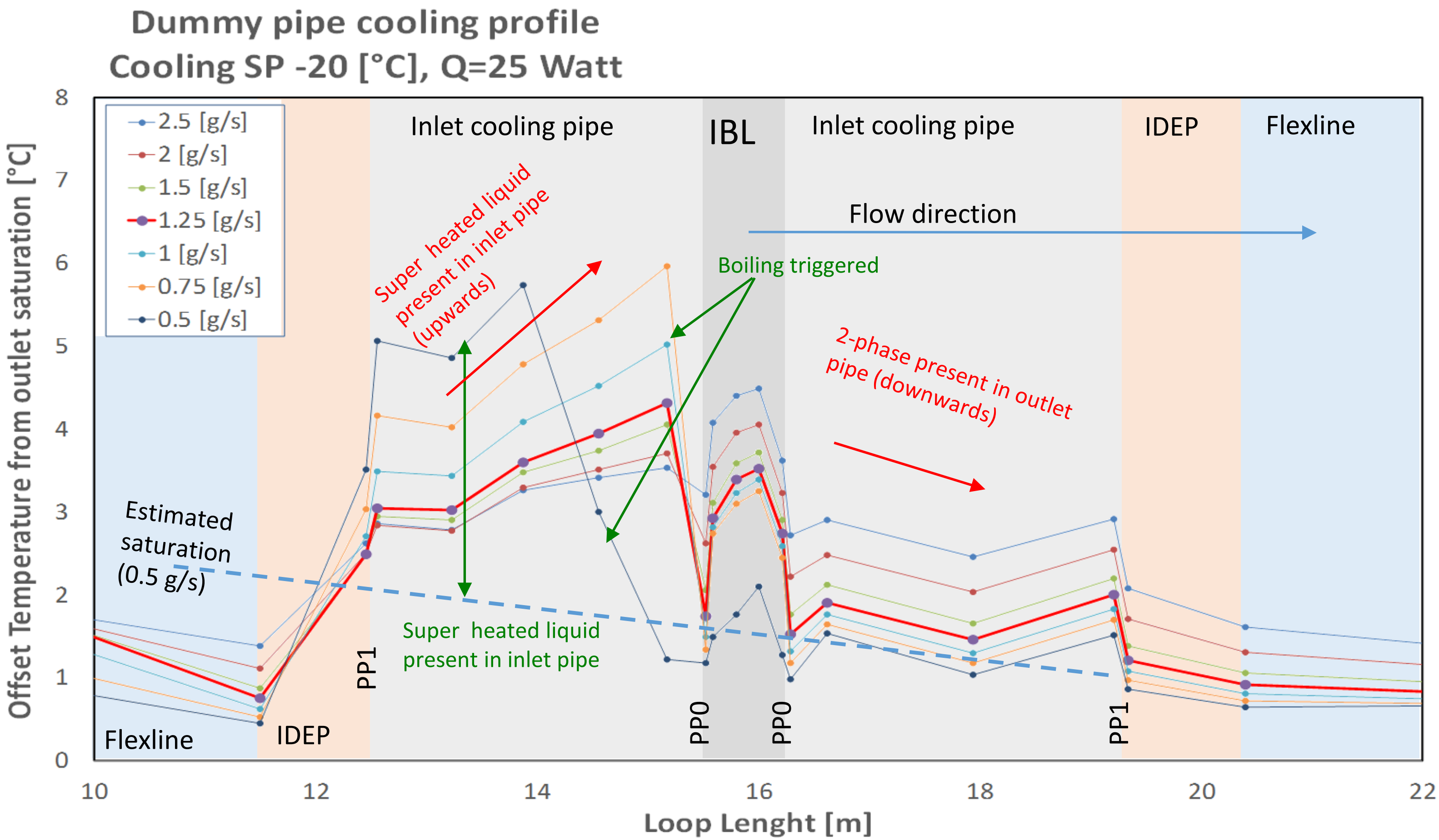
Flow reduction should give less pressure drop and hence less sub cooling at the pipe inlet.
Less sub cooling means less liquid heating is needed.
Less flow means heating goes faster
=> Boiling should be easier to get started

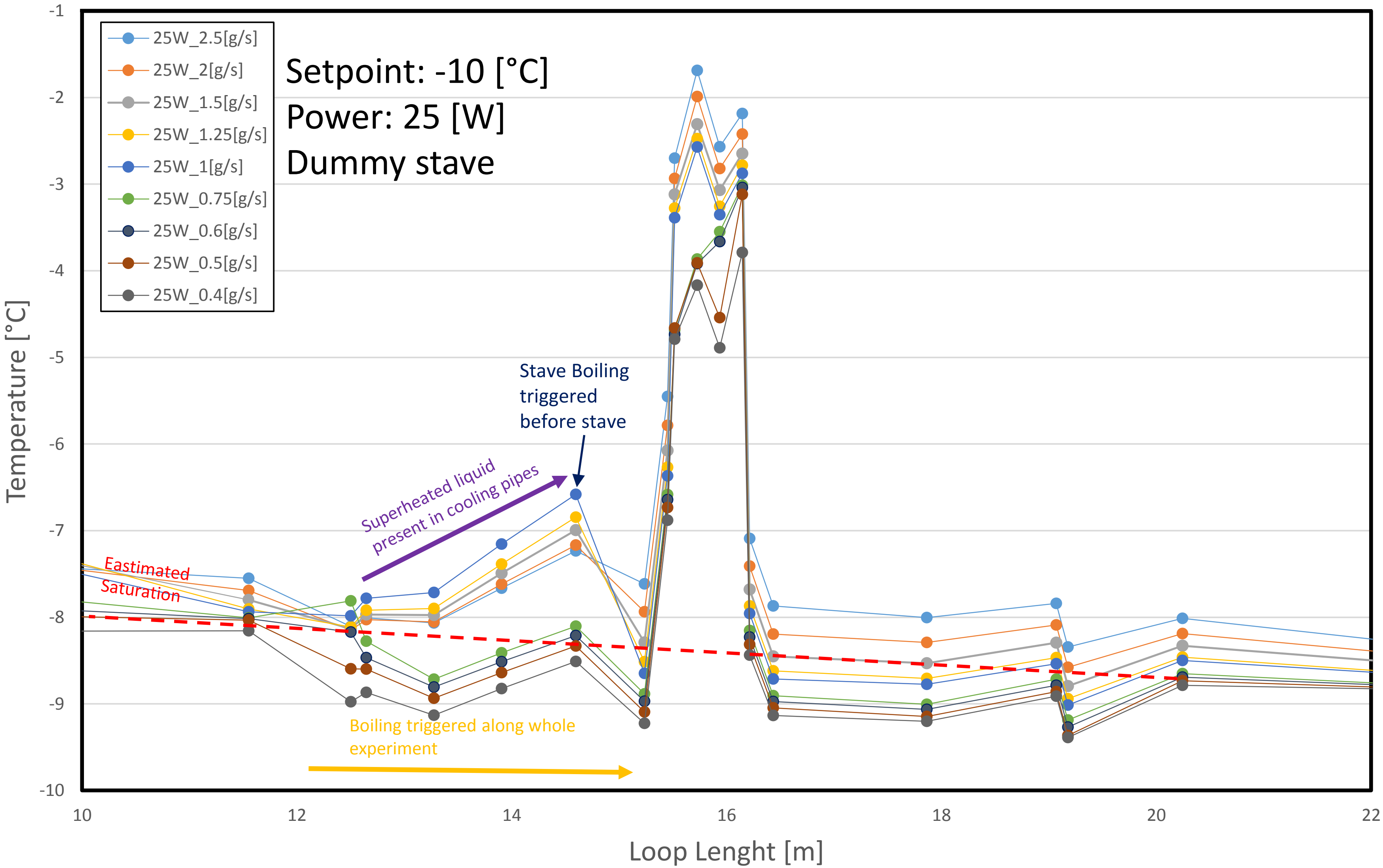
1st results from SR1 test



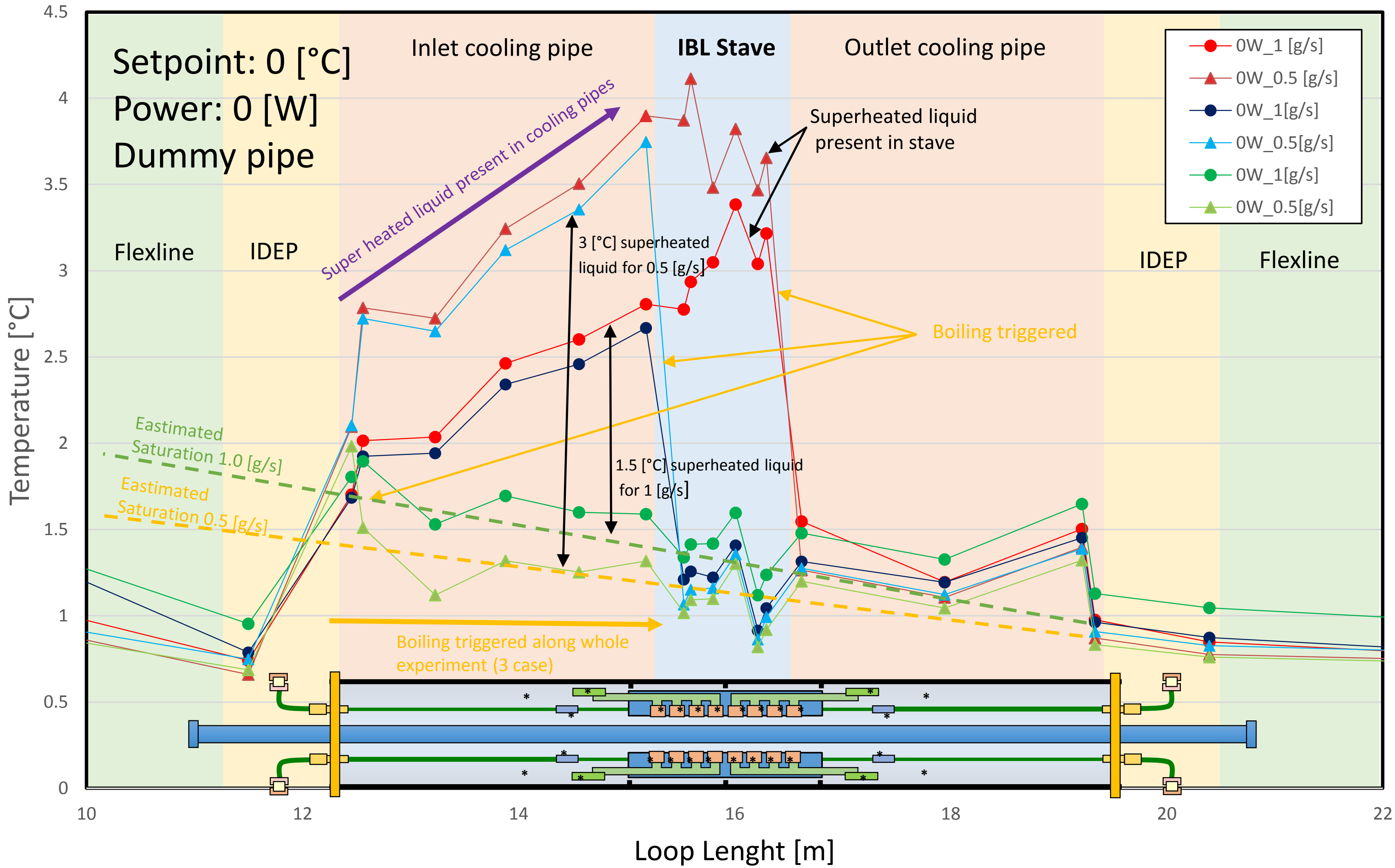
1st results from SR1 show the superheated liquid in the inlet tube

Flow reduction looks promising

Flow reduction results



Results from SR1 test



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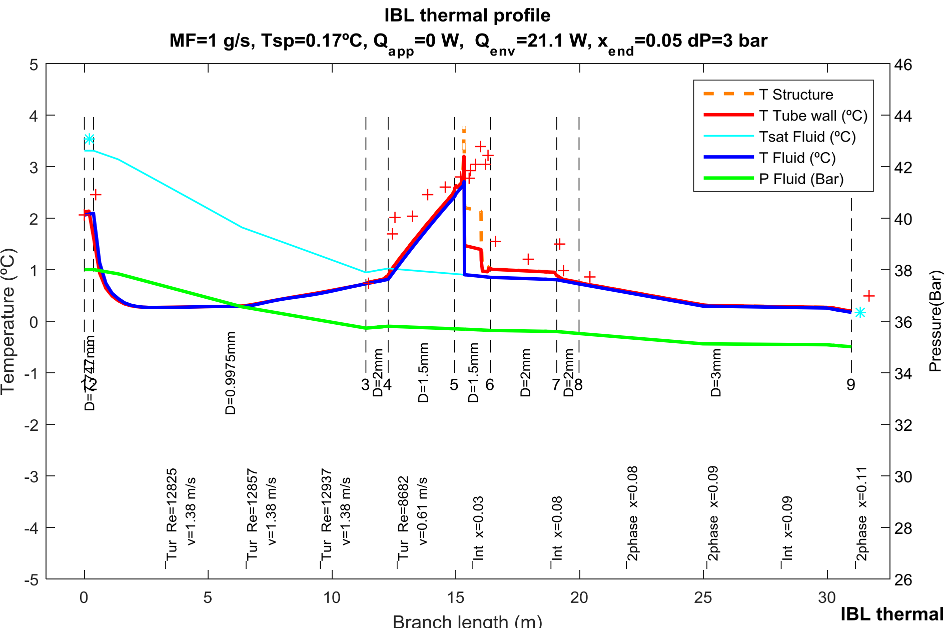
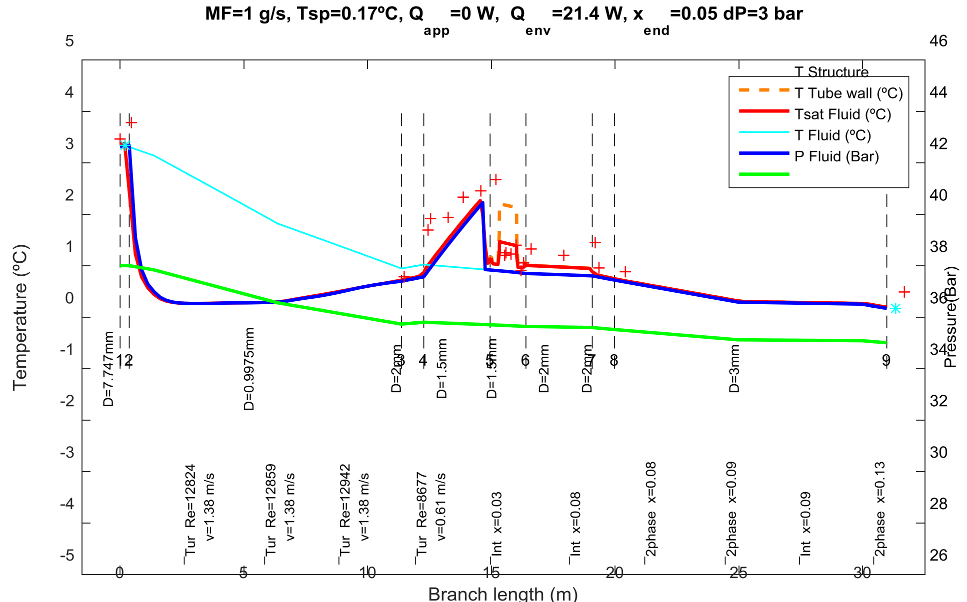
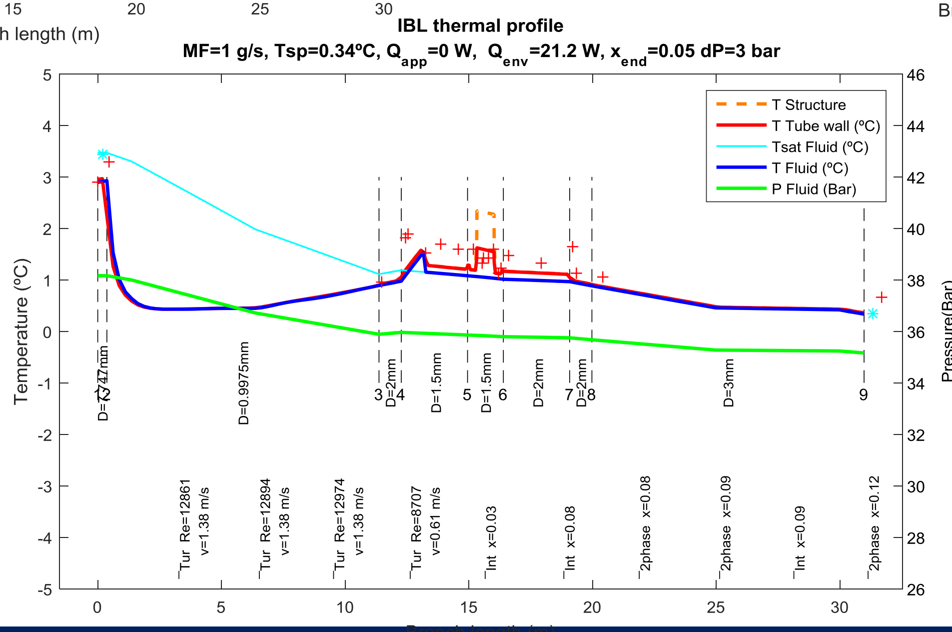
CoBra simulations





Super heated liquid propegated into stave

Super heated liquid presented but boiling trigered before stave



Boiling triggered along whole experiment

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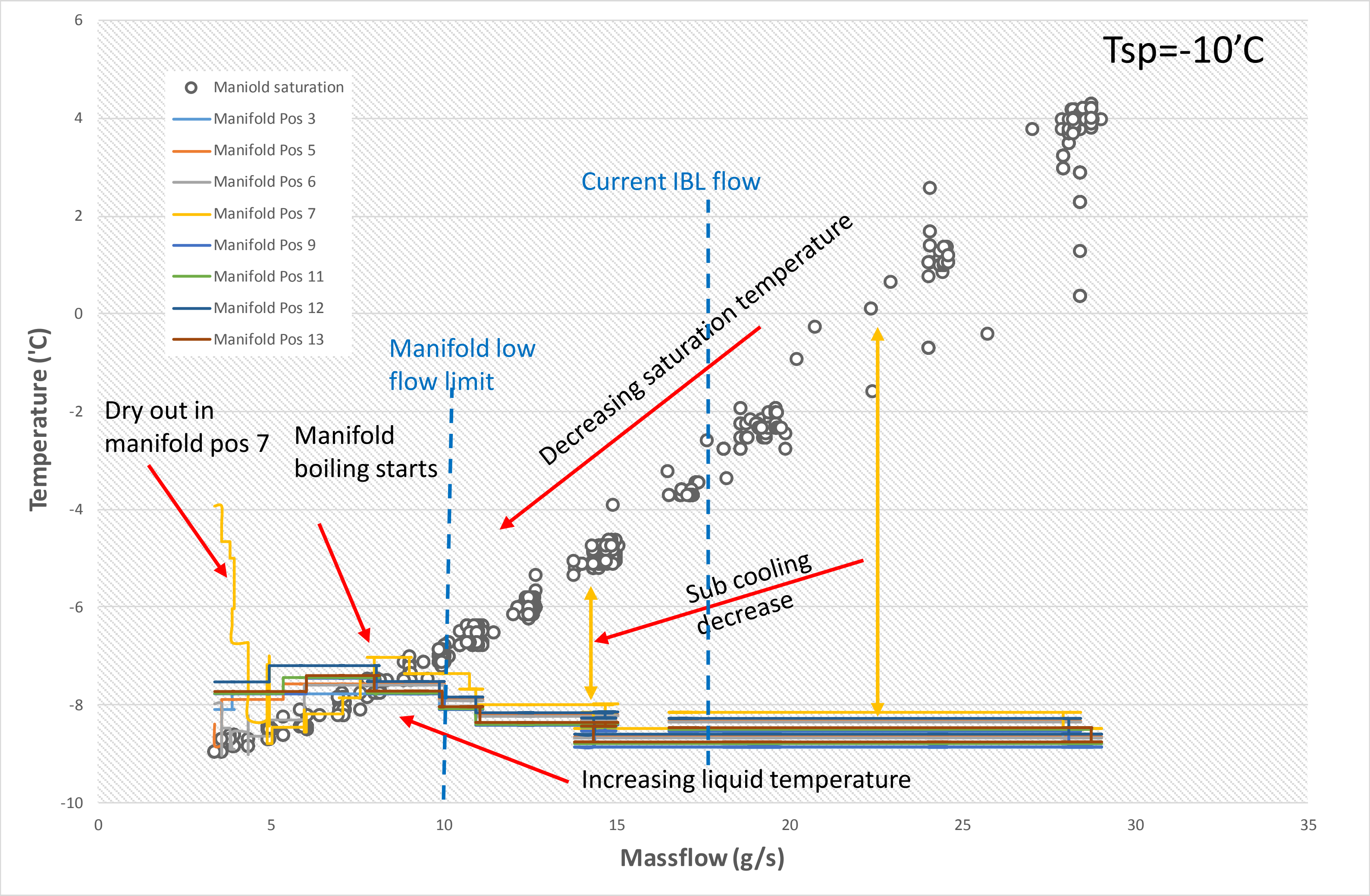
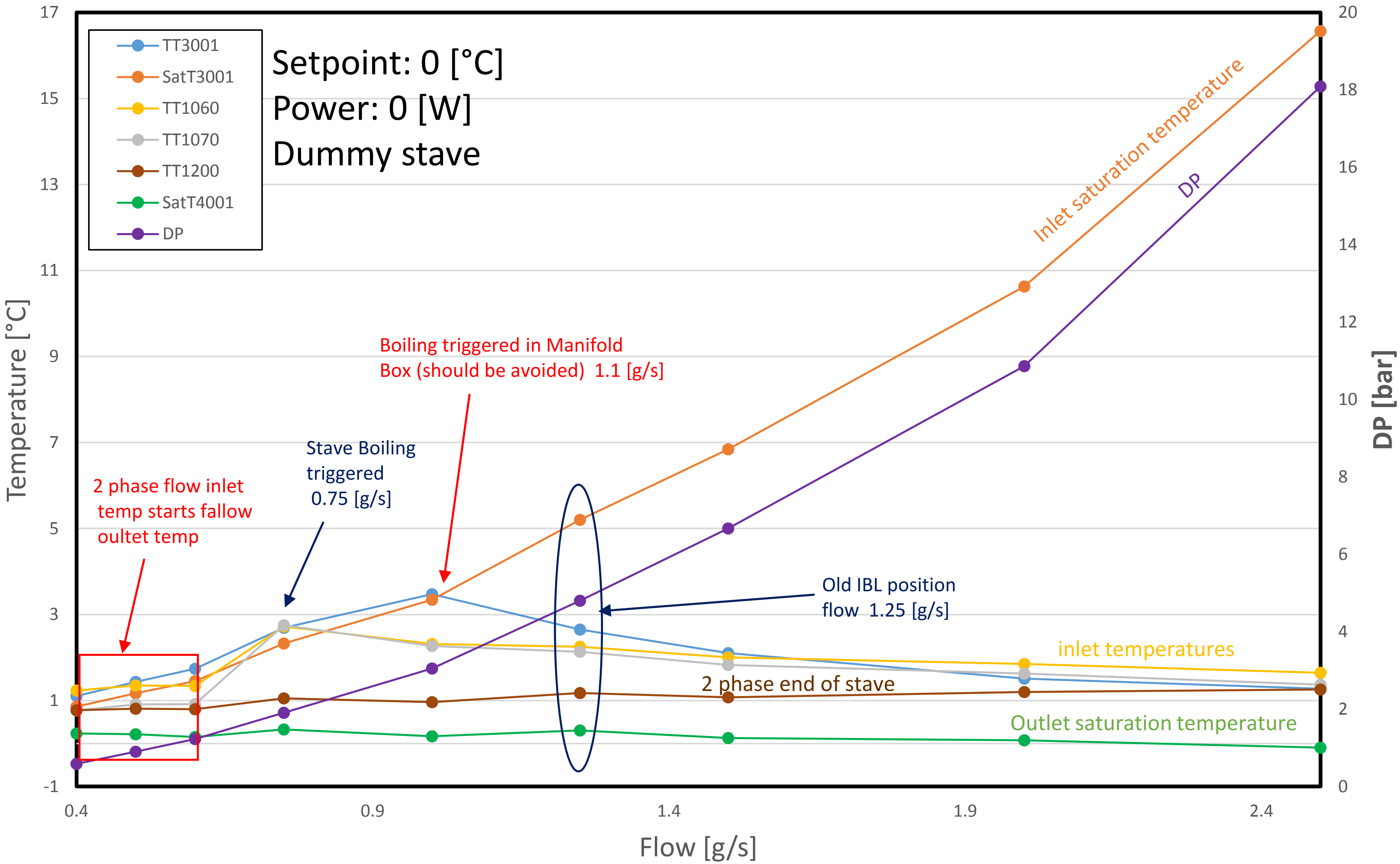
Test of flow reduction in IBL (Nov 15)

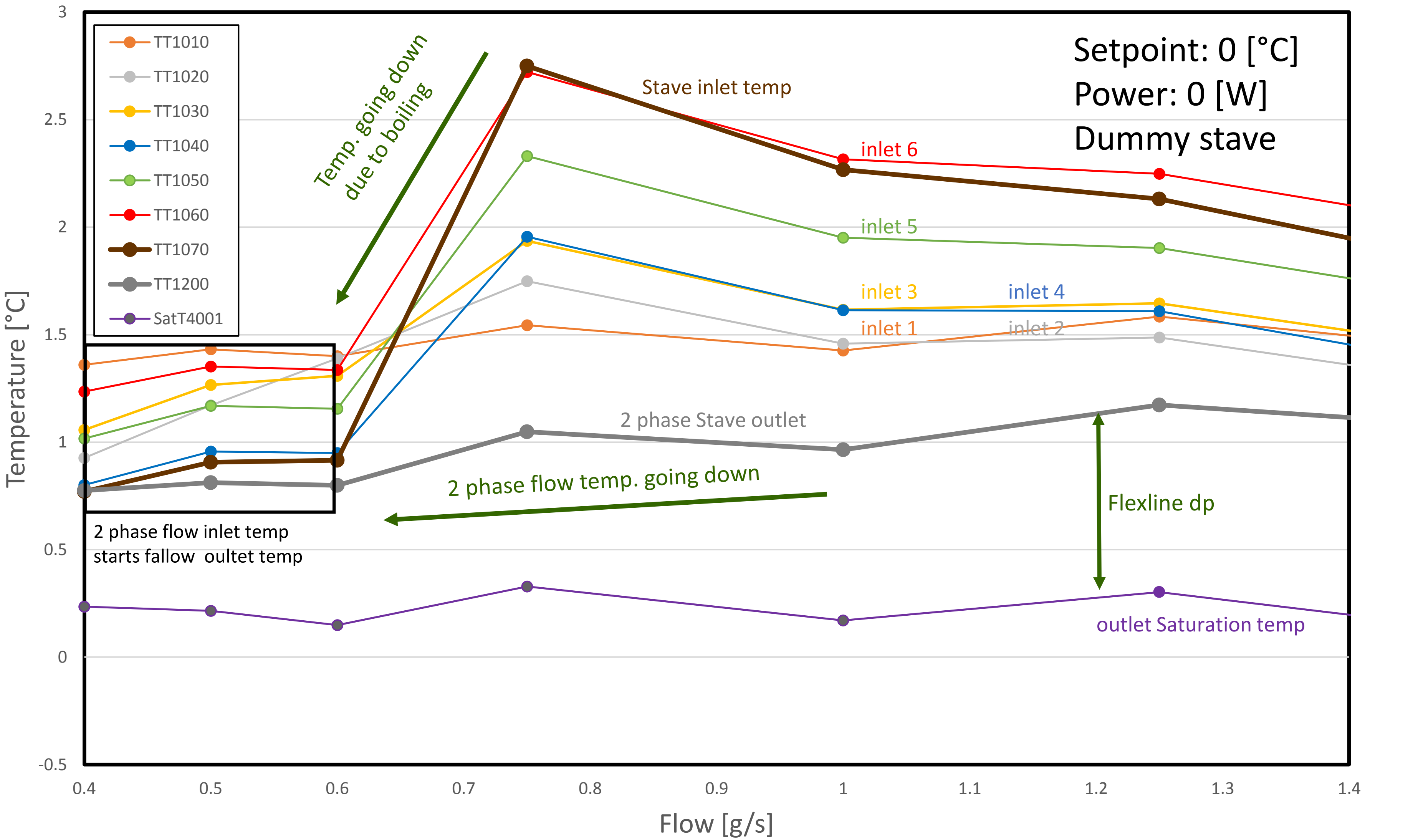
By Bart Verlaat



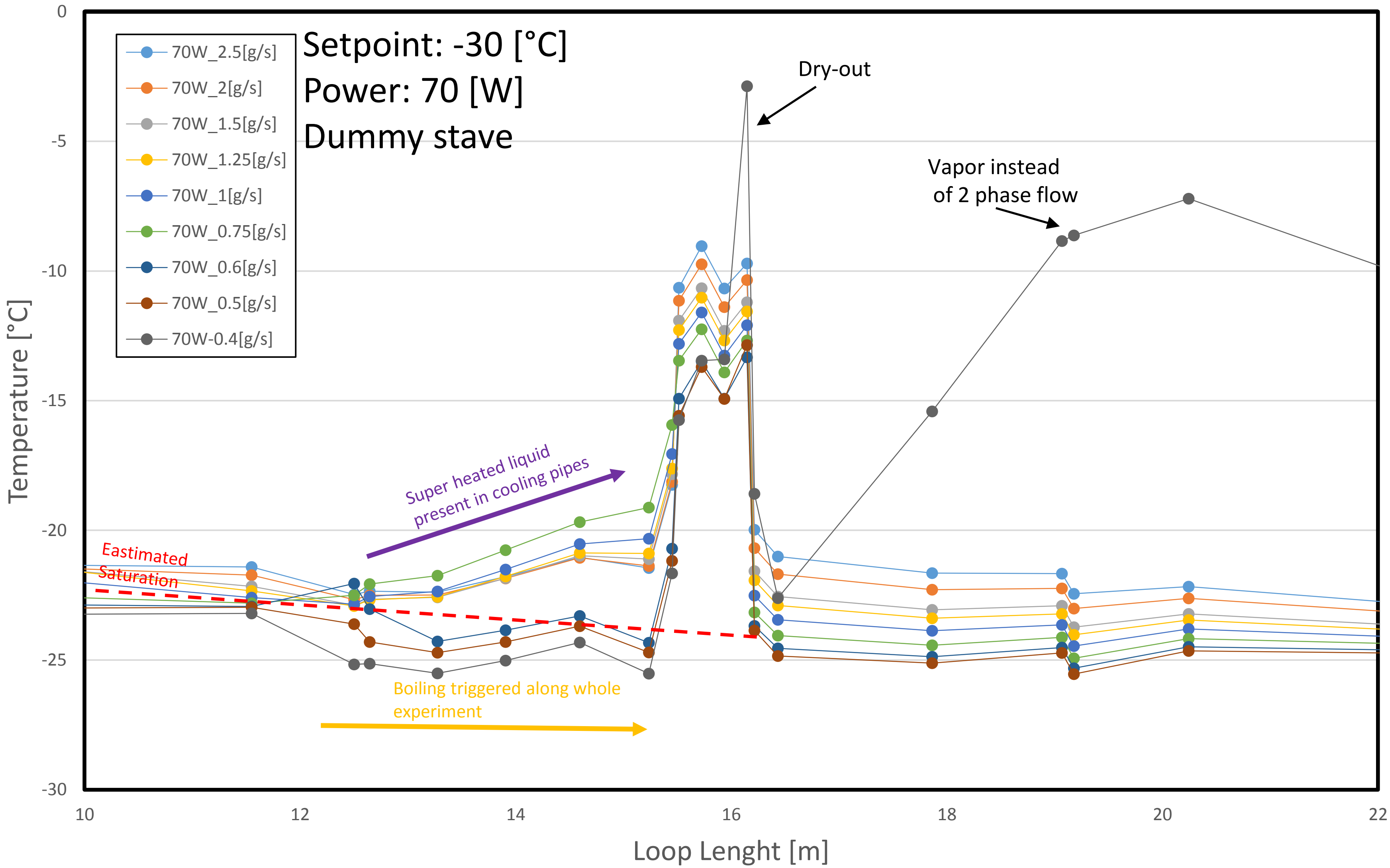
Flow reduction results



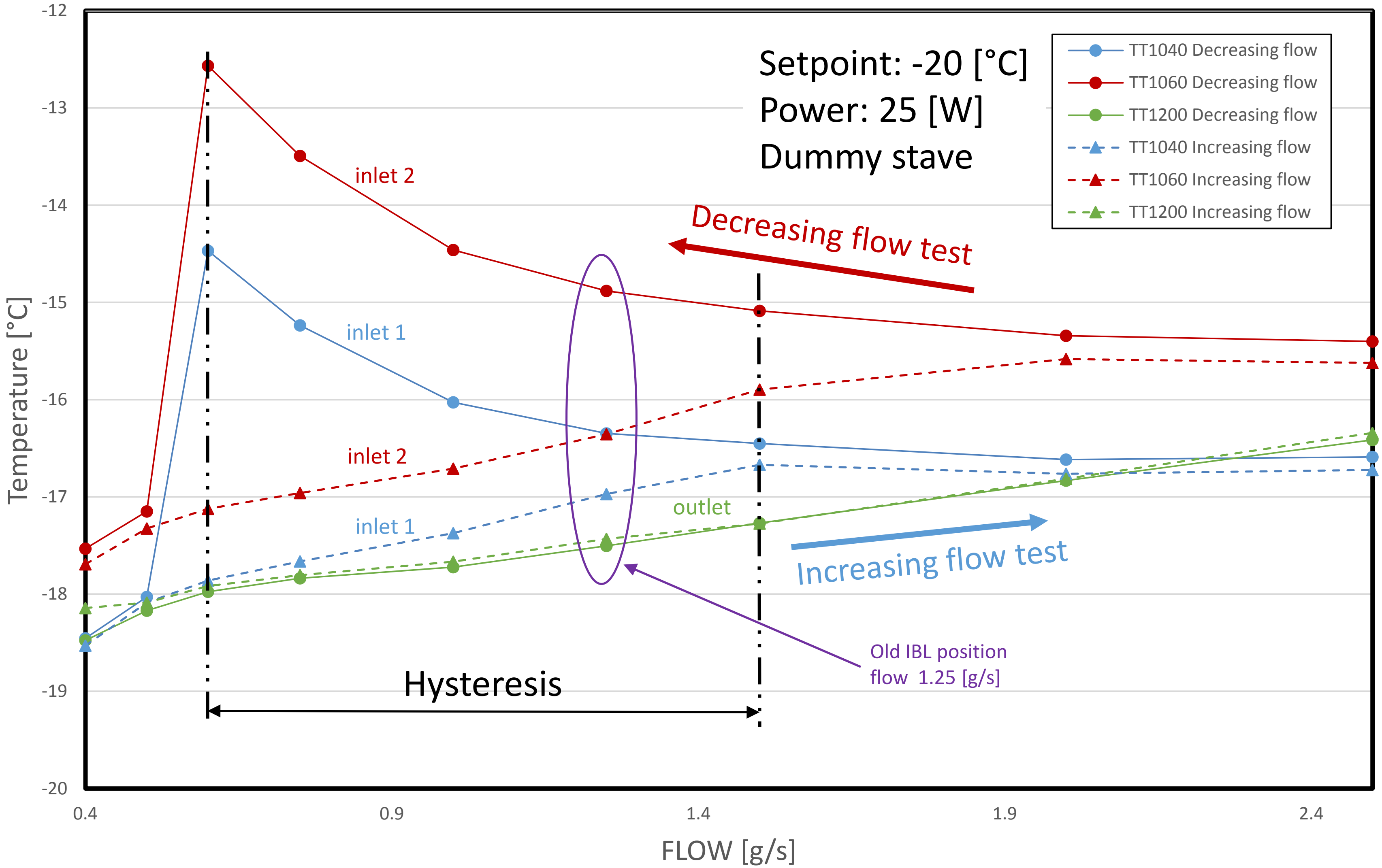
Flow reduction results



Flow reduction results



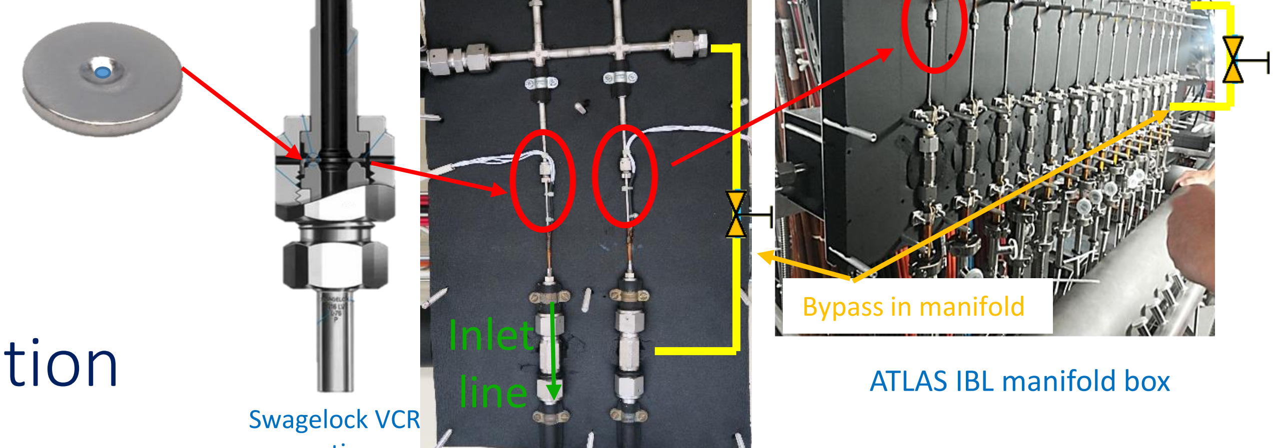
Boiling hysteresis



VCR gasket with calibrated orifice as solution for non boiling

Lenox LASER
The Leader in Small Hole Technology

VCR gasket with calibrated orifiece

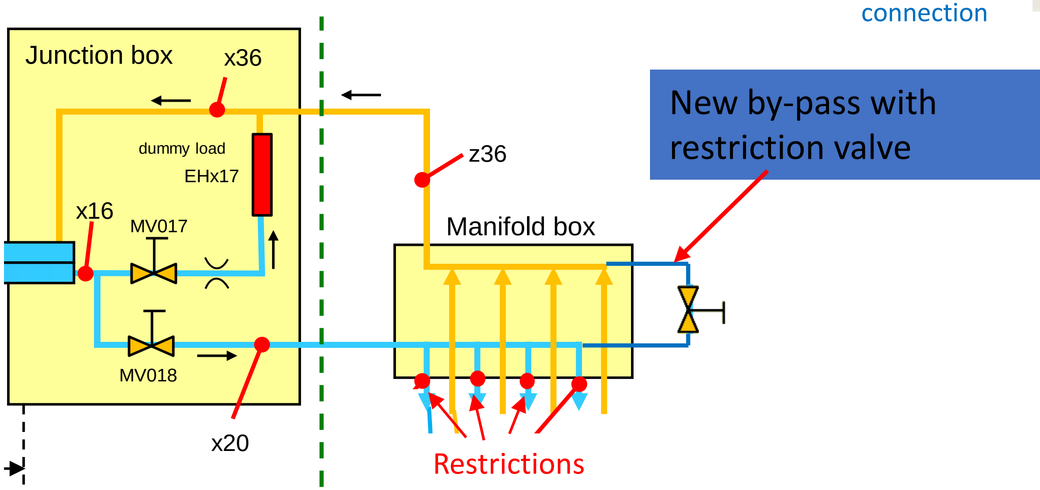


Swagelock VCR connection

SR1 mock-up manifold box

ATLAS IBL manifold box

Manifold modification

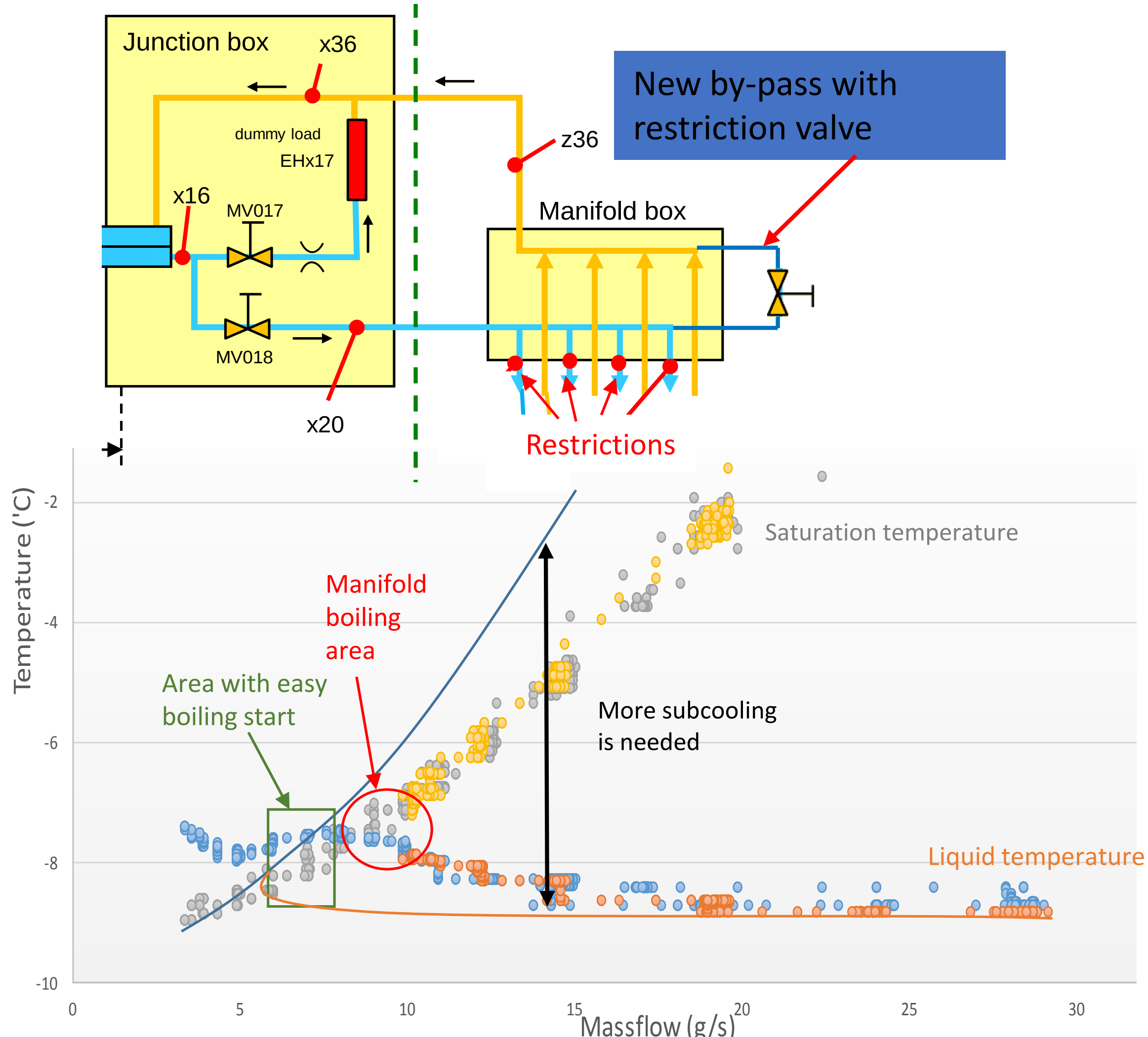


VCR gasket with calibrated orifice allows to reduce flow in the experiment

- Is beneficial for boiling control
  - Boiling should be easier to get started
  - Low temperature in stave
- Easy and quick to install during EYETS
  - Stop of cooling needed

Manifold modification as one of non boiling solution

- Manifold by-pass allows a higher manifold sub cooling
  - Is also beneficial for plant sub cooling
    - Better low temperature operation
    - Does not change the IBL conditions
  - Easy to install
    - Stop of cooling needed
- Restrictions will help for better flow distribution and increased manifold sub cooling



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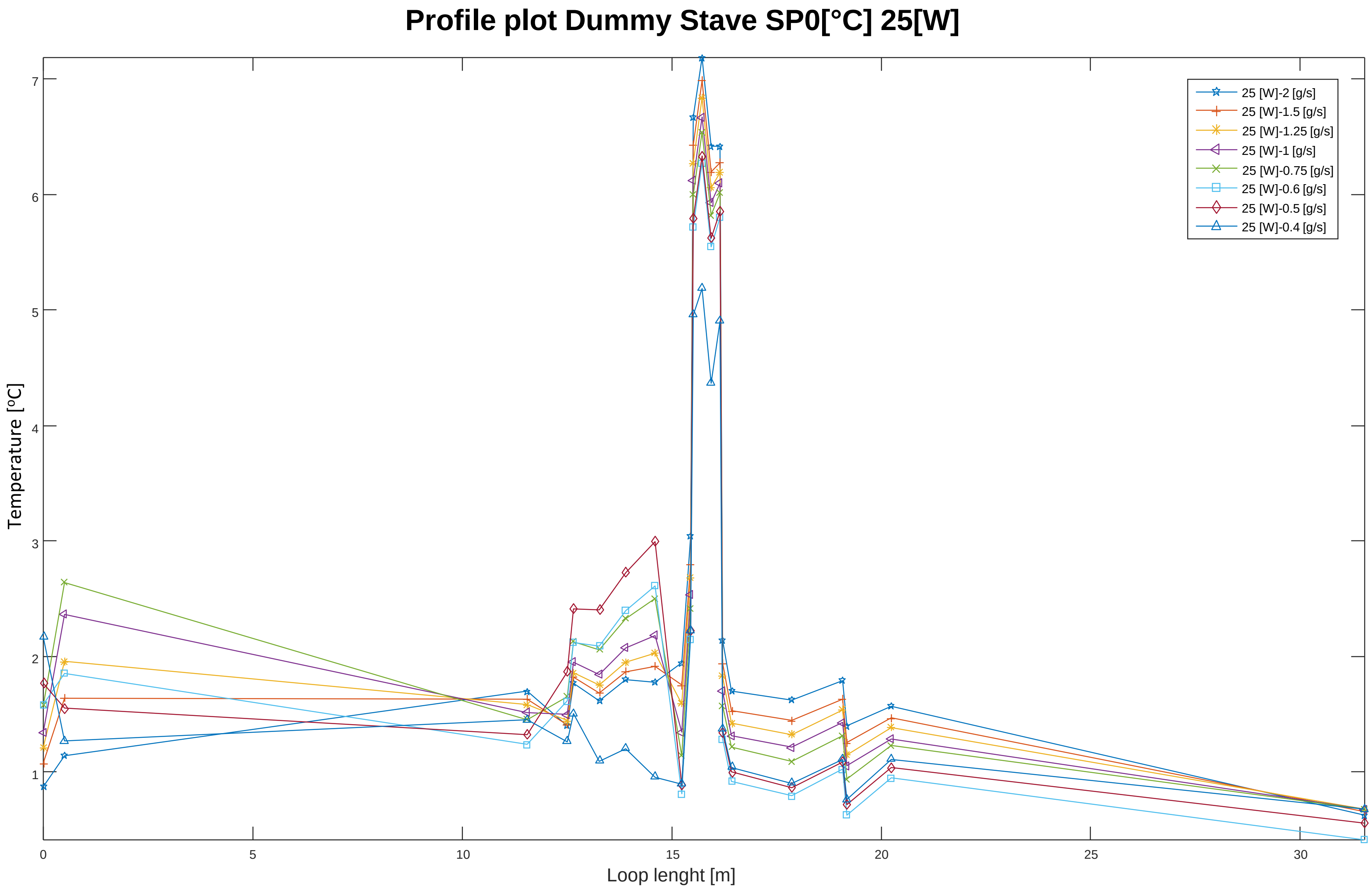
Requirements for gaskets with calibrated orifice

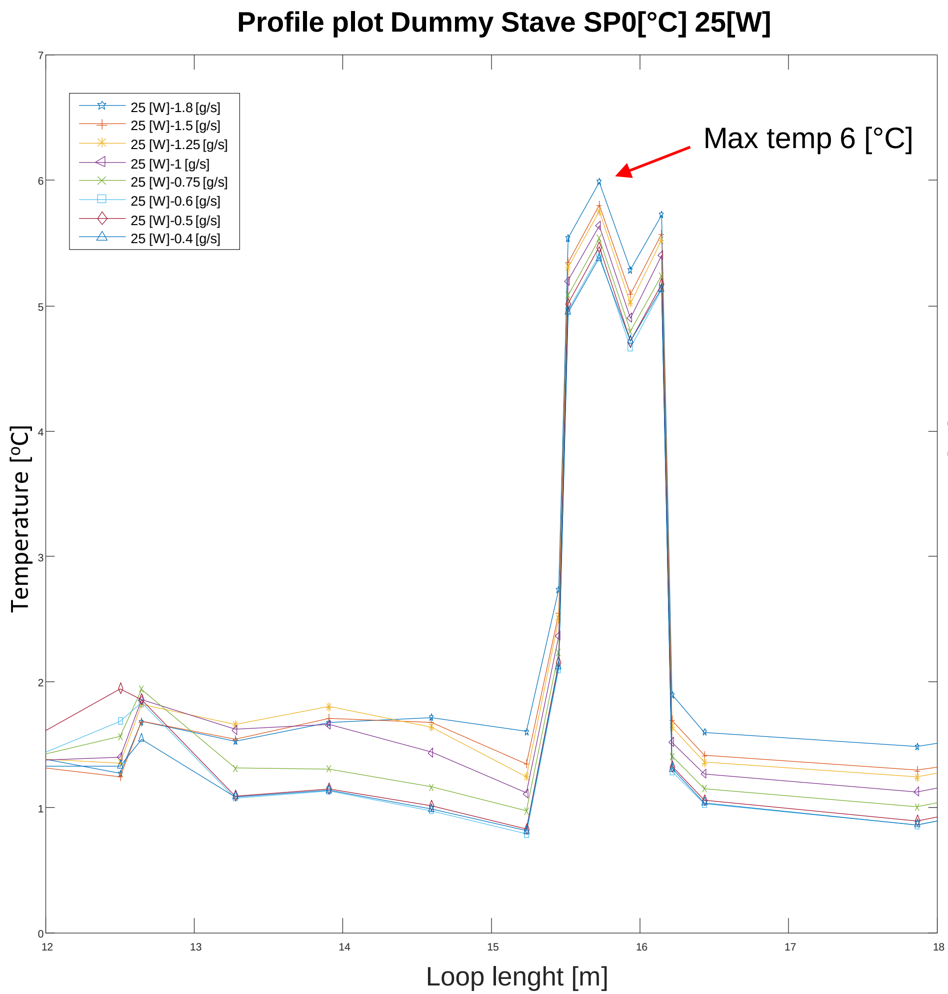
- 5 [bar] of pressure drop after gaskets with calibrated orifice for diffrent Setpoints and flows:
  - SetPoint range 57-15 [bar]
  - Flow range 1.2-0.6 [g/s]
- Size of gaskets which were ordered from LENOX LASER:
  - 275 Micron
  - 250 Micron
  - 225 Micron
  - 200 Micron

250 Micron orifice results

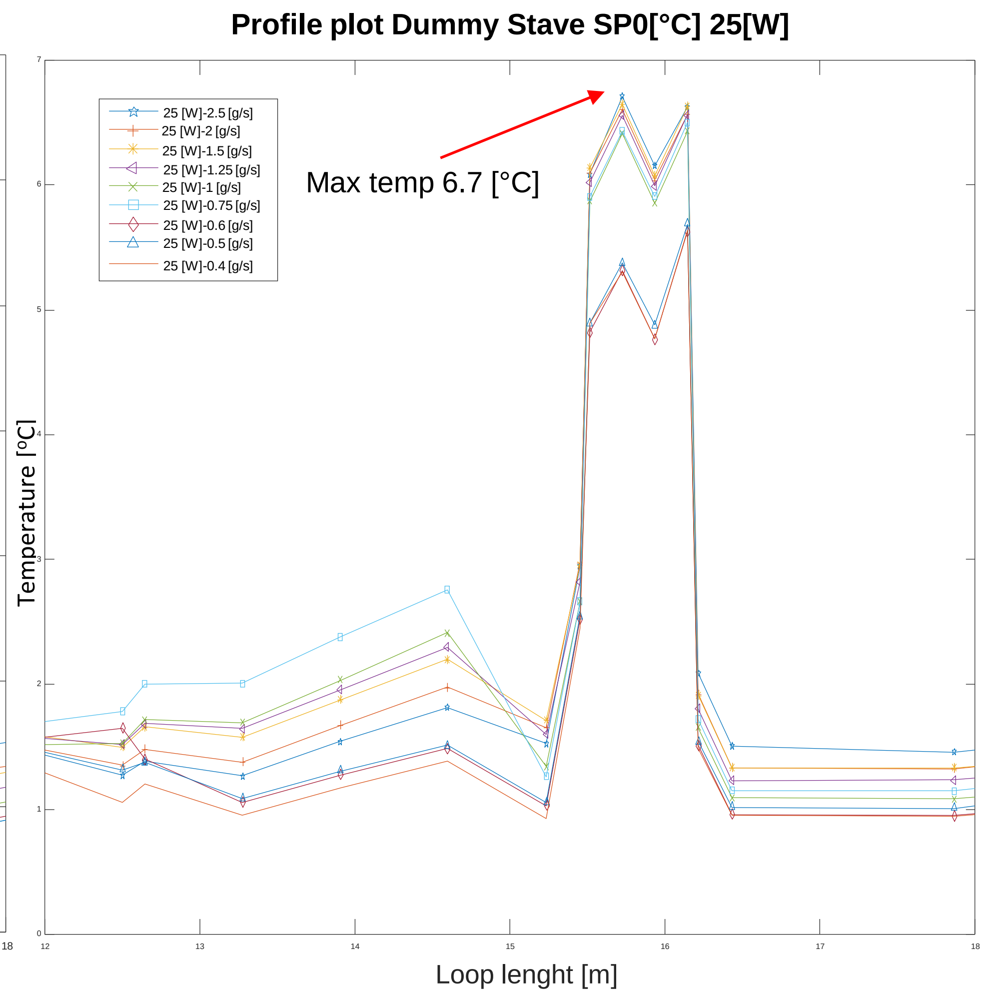


225 Micron orifice results

With 225 micron orifice

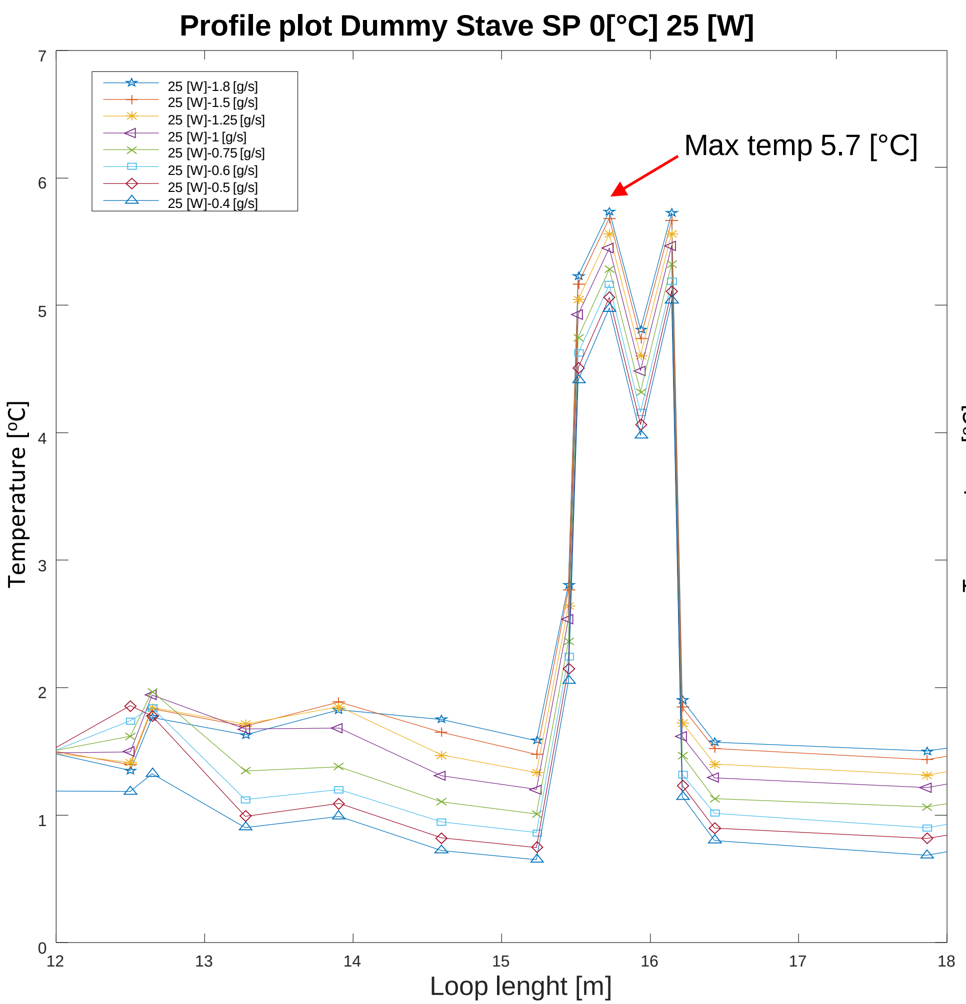


Without gasket

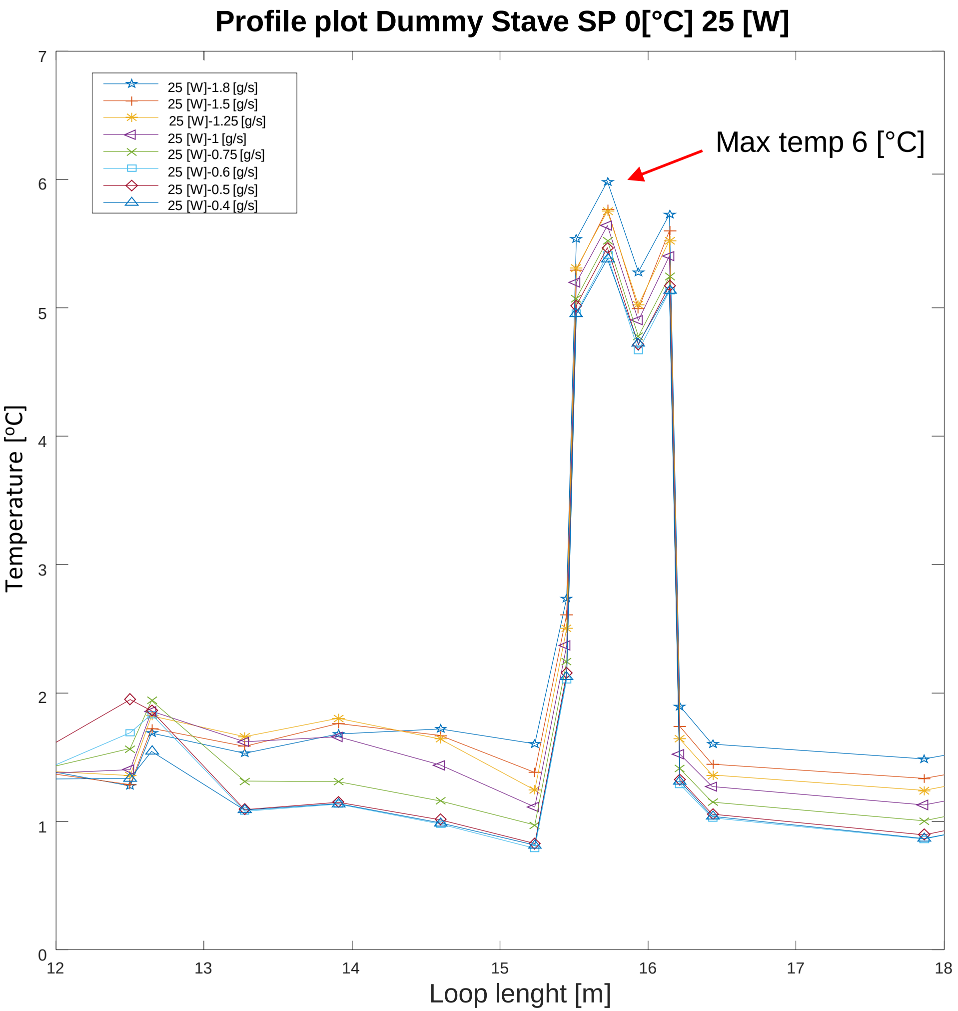


200 Micron orifice results

With 200 micron orifice



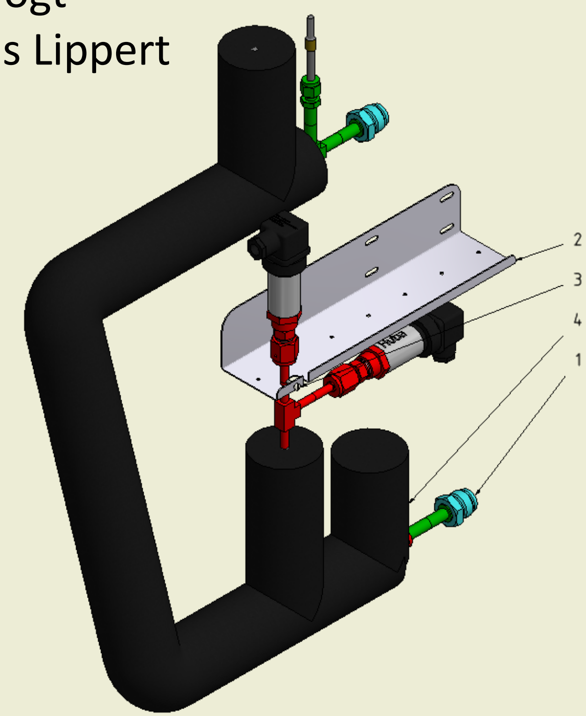
With 225 micron orifice

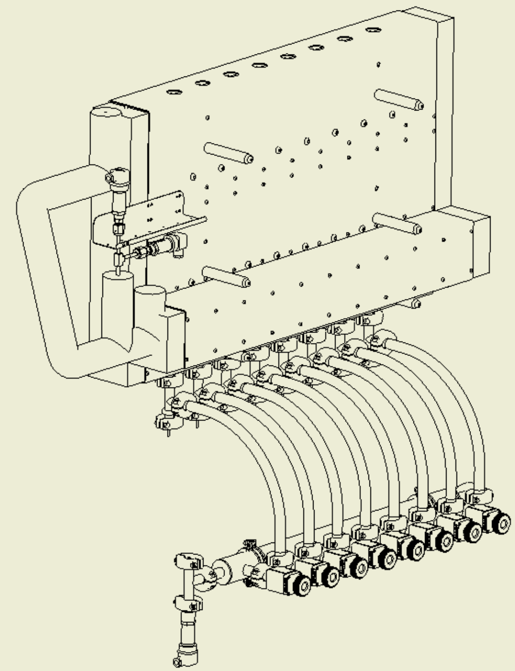


New IBL Manifold Bypass

Design in Max-Planck-Institut für Physik:

- Sven Vogt
- Markus Lippert





2	1	holder	112-050401.ipt	Alu-Leg			
1	1	CO2 Manifold Bypass Piping	112-051000.iam				
3	1	Zyl.-Schr. m. Schlitz	-	PA 66	M3x10	ISO 1207	(ähnl. DIN 84)
4	1	insulation CO2 Manifold Bypass	112-050600.ipt	AF-Armaflex			
Teil	St.	Benennung	Zeichn. Nr. / EDV Nr.	Werkstoff	Abmessungen / Art. Nr.	Norm	Bemerkung

Stückliste

-0,1 +0,1

Hauptprojektion

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut) München

Gewicht......: 4,778 kg
Dimensionen : mm
Maße ohne Toleranzangabe nach DIN ISO 2768 m K

	Tag	Name
gezeichnet	10.01.2017	
geprueft		
geplottet	30.11.2016	
Entwurf	23.01.2017	

Projekt
CO2-ATLAS-BELLE
CO2 Manifold Bypass
CO2 Manifold Bypass

Werkstoff

Maßstab 1:2 (1:5)

CO2 Manifold Bypass

Tel:

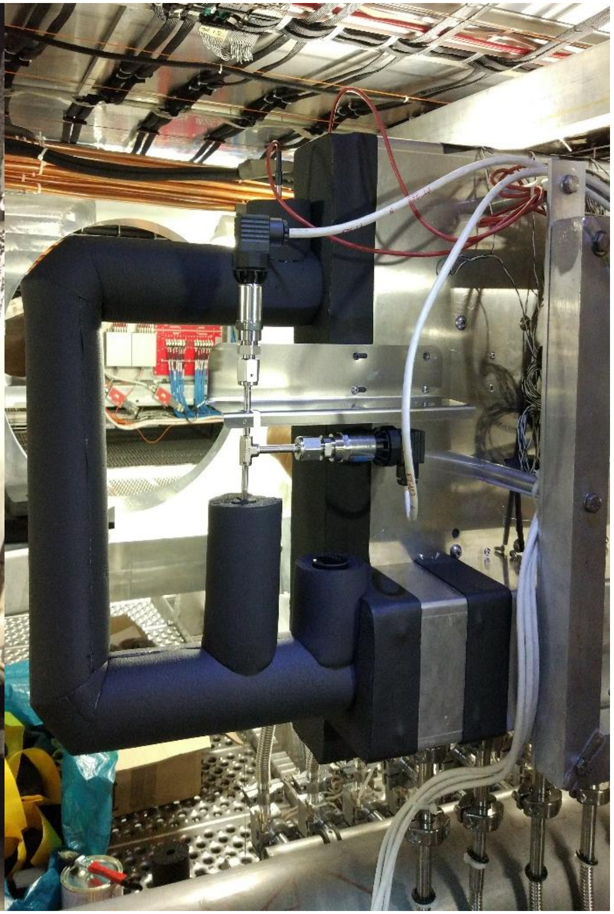
Zeichnungsnummer / EDV Nr.: 112-050000.idw

Software....: Inventor 2016
Blatt: 1 Gesamtzahl: 1 V16c
DIN EN 20 216 - A2 (420 x 594)

Modification of IBL Manifold Box

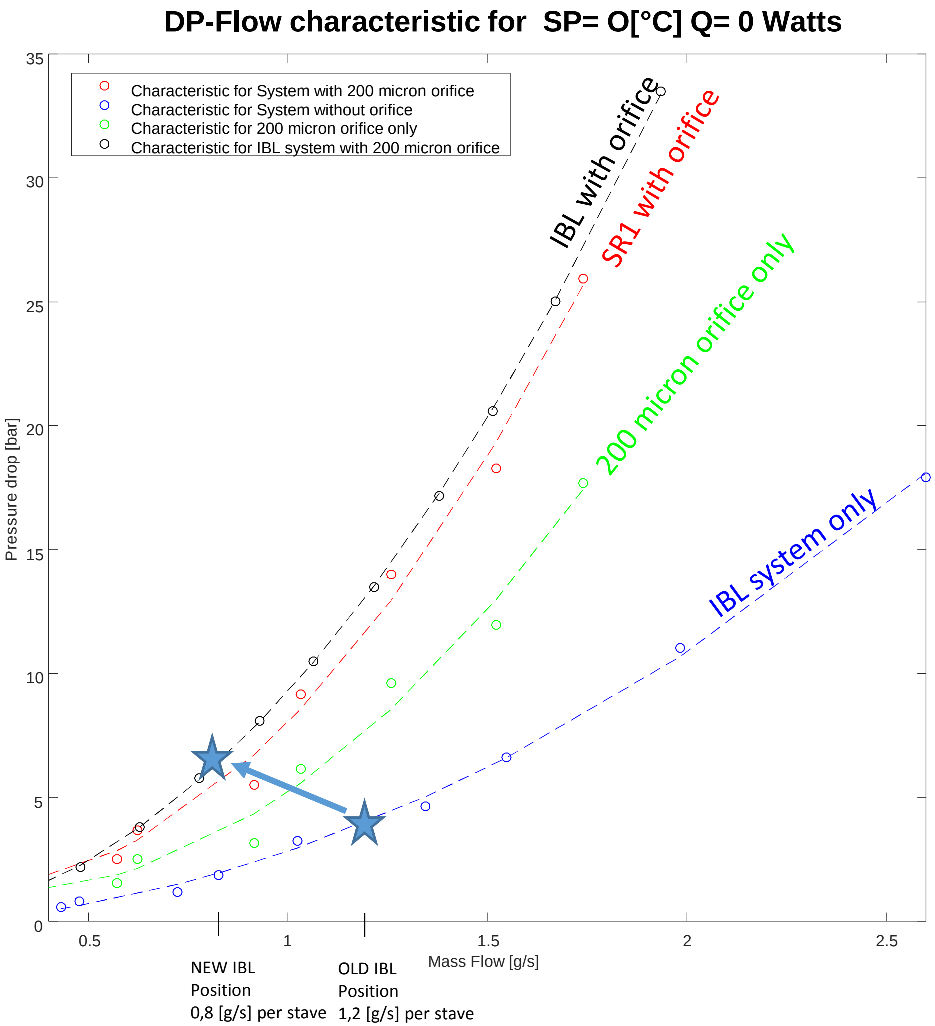
Gaskets with orifice installation

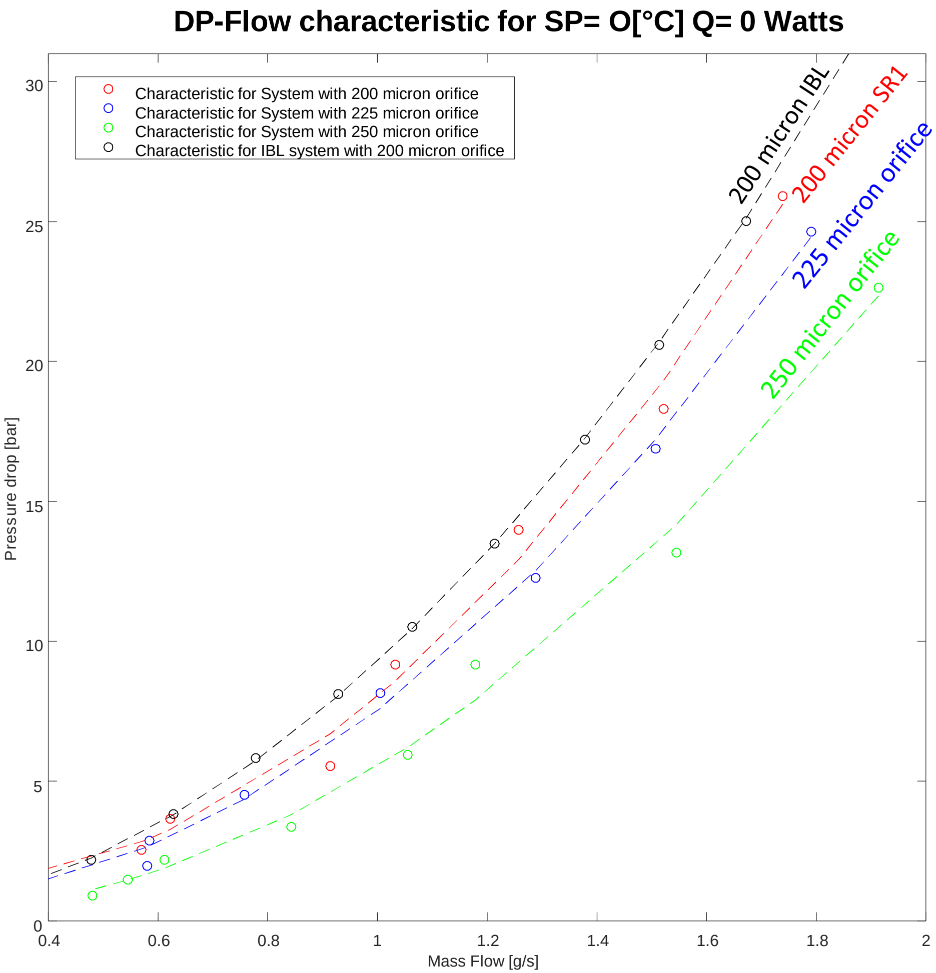
New 40um filter before IBL Manifold box



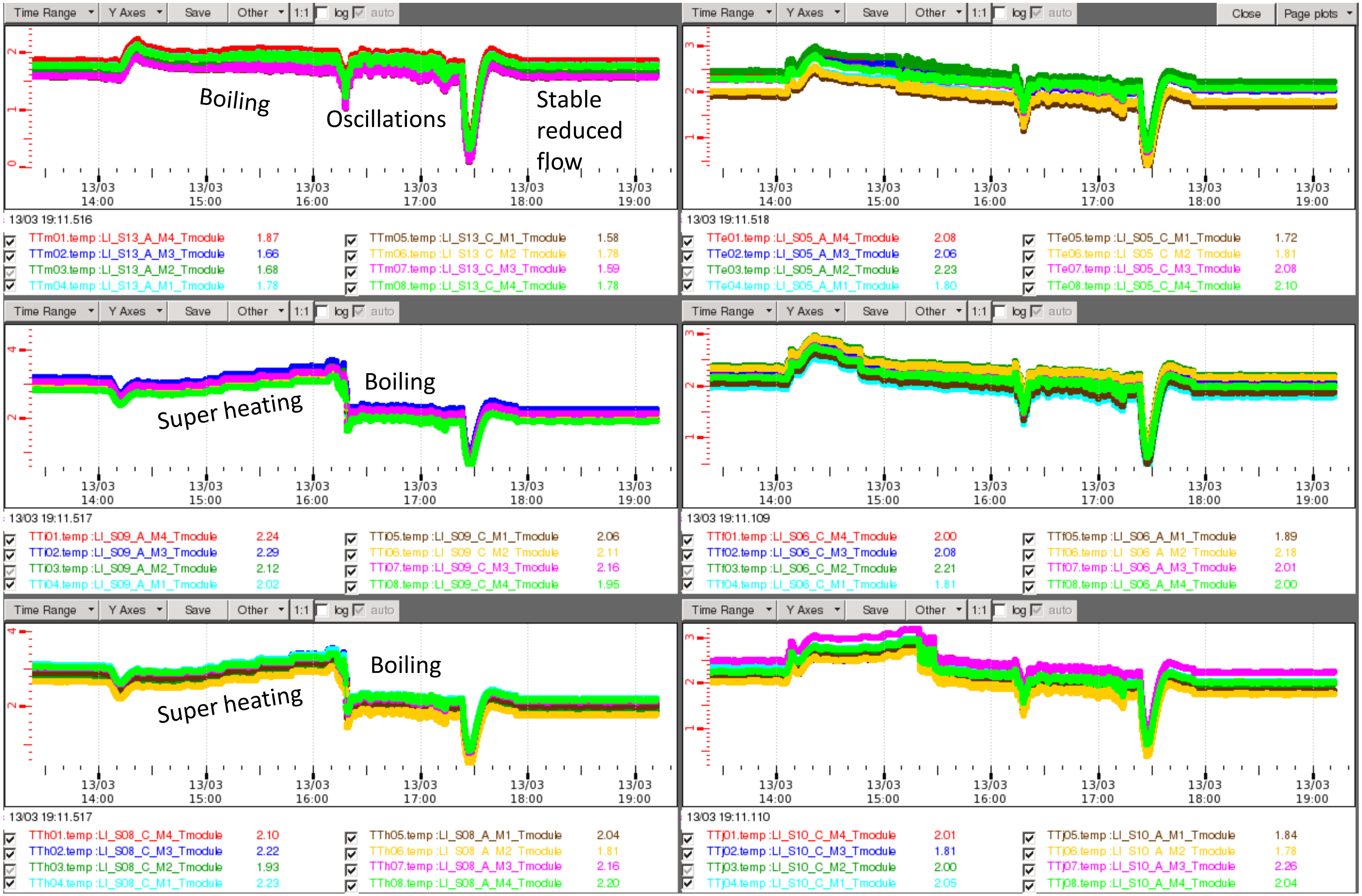
New By-pass in Manifold box

IBL with orifice DP-Flow characteristic





Flow reduction tests of IBL cooling system with detector connected



Modules temperatures with unpowered and powered detector

Unpowered detector

IBL_TEMPS: IBL Temps

LI_S01	5.8 C	4.1 C	1.1 C	2.1 C	1.9 C	1.7 C	1.9 C	1.9 C	1.9 C	1.9 C	1.9 C	1.2 C	4.1 C	6.6 C
LI_S02		3.8 C	1.3 C	2.0 C	1.9 C	1.8 C	1.9 C	2.1 C	1.9 C	2.2 C	2.1 C	1.1 C	4.2 C	6.0 C
LI_S03	6.6 C	4.0 C	1.4 C	2.1 C	1.8 C	1.8 C	2.0 C	2.1 C	2.2 C	2.1 C	2.2 C	1.0 C	4.2 C	7.4 C
LI_S04	5.0 C	4.3 C	1.4 C	2.2 C	1.9 C	2.3 C	2.2 C	2.0 C	2.1 C	2.1 C	2.0 C	1.3 C	4.0 C	5.2 C
LI_S05		4.1 C	1.1 C	2.2 C	2.1 C	1.9 C	1.8 C	1.9 C	2.3 C	2.1 C	2.1 C	1.6 C	4.2 C	
LI_S06	5.0 C	4.0 C	1.3 C	2.0 C	2.1 C	2.3 C	1.8 C	1.9 C	2.3 C	2.1 C	2.1 C	1.3 C	4.2 C	5.7 C
LI_S07	6.7 C	4.2 C	1.2 C	2.1 C	1.9 C	1.9 C	1.9 C	1.8 C	1.9 C	2.0 C	2.2 C	1.4 C	4.1 C	6.6 C
LI_S08	4.8 C	4.1 C	1.2 C	2.2 C	2.3 C	2.0 C	2.2 C	2.1 C	1.9 C	2.2 C	2.2 C	1.2 C	4.3 C	5.7 C
LI_S09		3.9 C	1.0 C	2.0 C	2.2 C	2.2 C	2.1 C	2.1 C	2.2 C	2.3 C	2.3 C	1.5 C	4.3 C	
LI_S10	4.9 C	3.9 C	1.4 C	2.1 C	1.8 C	2.1 C	2.1 C	1.9 C	1.8 C	2.3 C	2.1 C	1.3 C	3.9 C	5.1 C
LI_S11	5.3 C	3.7 C	0.9 C	2.2 C	2.1 C	1.9 C	1.9 C	1.9 C	1.9 C	1.8 C	2.0 C	1.1 C	4.0 C	6.6 C
LI_S12		4.4 C	1.1 C	2.3 C	2.2 C	1.9 C	2.2 C	1.8 C	2.1 C	1.9 C	2.0 C	1.2 C	4.0 C	
LI_S13	6.4 C	3.8 C	1.0 C	1.8 C	1.6 C	1.8 C	1.6 C	1.8 C	1.7 C	1.7 C	1.9 C	1.1 C	4.0 C	6.5 C
LI_S14	5.1 C	3.9 C	1.4 C	1.9 C	2.2 C	2.1 C	2.0 C	2.1 C	2.1 C	1.8 C	2.3 C	1.4 C	4.3 C	4.8 C

Temperatures inside staves are more homoginues in both cases !!!

Powered detector

IBL_TEMPS: IBL Temps

LI_S01	6.6 C	7.2 C	1.2 C	5.4 C	6.3 C	5.4 C	5.4 C	5.3 C	5.1 C	5.3 C	5.2 C	1.3 C	7.2 C	7.6 C
LI_S02		7.2 C	1.5 C	5.5 C	4.8 C	5.1 C	5.1 C	5.4 C	5.1 C	5.4 C	5.2 C	1.1 C	7.5 C	7.2 C
LI_S03	7.6 C	7.2 C	1.5 C	5.9 C	5.1 C	5.4 C	5.1 C	5.2 C	5.8 C	5.4 C	5.6 C	1.2 C	7.6 C	8.6 C
LI_S04	6.3 C	7.9 C	1.6 C	7.9 C	5.6 C	6.0 C	6.0 C	6.8 C	5.5 C	5.4 C	5.0 C	1.4 C	7.4 C	6.3 C
LI_S05		7.5 C	1.1 C	5.6 C	5.3 C	5.2 C	6.2 C	5.1 C	5.5 C	5.7 C	5.7 C	1.8 C	7.7 C	
LI_S06	6.2 C	7.5 C	1.5 C	5.5 C	5.4 C	5.7 C	5.2 C	5.6 C	5.4 C	5.3 C	5.4 C	1.4 C	7.6 C	6.8 C
LI_S07	7.9 C	7.8 C	1.4 C	5.6 C	5.3 C	5.8 C	5.1 C	5.0 C	5.3 C	5.6 C	8.5 C	1.7 C	7.7 C	7.8 C
LI_S08	5.9 C	7.5 C	1.3 C	5.6 C	5.8 C	5.5 C	5.8 C	5.9 C	5.1 C	5.5 C	6.2 C	1.3 C	7.8 C	6.9 C
LI_S09		7.2 C	1.0 C	5.4 C	5.5 C	5.5 C	5.5 C	6.0 C	5.5 C	5.8 C	5.9 C	1.7 C	7.6 C	
LI_S10	5.9 C	7.1 C	1.5 C	6.5 C	6.9 C	6.1 C	5.8 C	6.4 C	6.0 C	6.3 C	5.7 C	1.5 C	7.1 C	6.1 C
LI_S11	5.9 C	6.7 C	1.0 C	5.5 C	6.0 C	5.6 C	5.3 C	5.1 C	5.4 C	5.1 C	5.4 C	1.2 C	7.1 C	7.5 C
LI_S12		7.4 C	1.2 C	6.2 C	[illegible]	[illegible]	5.2 C	4.9 C	5.2 C	[illegible]	5.1 C	1.3 C	6.9 C	
LI_S13	7.2 C	6.6 C	1.0 C	4.2 C	4.0 C	4.2 C	4.1 C	4.4 C	4.2 C	4.2 C	4.5 C	1.2 C	6.8 C	7.0 C
LI_S14	5.7 C	6.4 C	1.5 C	5.0 C	[illegible]	5.4 C	5.4 C	5.6 C	5.1 C	[illegible]	5.4 C	1.5 C	7.0 C	5.4 C

The lower temperatures due to lower pressure reduction.
This cooling line had to be checked

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ATLAS EXPERIMENT

Modules temperatures after intervention in April

After the change of the orrifice the modules temperature looks ok

IBL_TEMPS: IBL Temps

LI_S01	-6.9 C	-3.8 C	-17.6 C	-13.2 C	-11.9 C	-13.0 C	-13.2 C	-13.5 C	-13.6 C	-13.3 C	-13.1 C	-17.2 C	-3.8 C	-6.1 C
LI_S02		-3.8 C	-16.9 C	-12.3 C	-13.1 C	-12.8 C	-12.8 C	-12.7 C	-12.7 C	-12.4 C	-12.5 C	-17.8 C	-3.5 C	-5.3 C
LI_S03	-4.8 C	-4.1 C	-17.1 C	-12.7 C	-13.5 C	-13.4 C	-13.6 C	-13.4 C	-12.8 C	-13.0 C	-12.9 C	-17.6 C	-3.5 C	-4.5 C
LI_S04	-6.8 C	-2.8 C	-17.0 C	-10.1 C	-12.9 C	-12.2 C	-12.5 C	-11.4 C	-13.2 C	-13.4 C	-13.5 C	-17.3 C	-3.8 C	-7.1 C
LI_S05		-3.5 C	-17.7 C	-13.2 C	-13.6 C	-13.5 C	-11.8 C	-13.6 C	-12.9 C	-13.5 C	-13.2 C	-16.7 C	-3.6 C	
LI_S06	-7.0 C	-3.7 C	-17.0 C	-12.5 C	-12.5 C	-12.1 C	-12.5 C	-12.1 C	-12.5 C	-12.5 C	-12.1 C	-17.6 C	-3.5 C	-6.3 C
LI_S07	-4.7 C	-3.7 C	-17.2 C	-13.1 C	-13.6 C	-13.4 C	-13.8 C	-13.9 C	-13.7 C	-13.3 C	-10.4 C	-16.3 C	-3.3 C	-5.6 C
LI_S08	-7.8 C	-3.3 C	-17.6 C	-13.2 C	-13.0 C	-13.2 C	-12.9 C	-13.3 C	-13.6 C	-13.3 C	-12.6 C	-17.6 C	-3.5 C	-6.3 C
LI_S09		-3.5 C	-17.9 C	-13.3 C	-13.0 C	-12.8 C	-12.8 C	-12.2 C	-13.0 C	-12.9 C	-12.8 C	-16.6 C	-3.3 C	
LI_S10	-7.8 C	-3.9 C	-17.1 C	-12.3 C	-11.4 C	-12.6 C	-13.0 C	-11.9 C	-12.5 C	-12.1 C	-12.9 C	-16.8 C	-4.0 C	-7.5 C
LI_S11	-8.3 C	-4.1 C	-18.0 C	-12.3 C	-11.5 C	-12.0 C	-12.4 C	-12.7 C	-12.3 C	-12.8 C	-12.5 C	-17.5 C	-3.7 C	-6.1 C
LI_S12		-3.3 C	-17.6 C	-12.0 C	-12.4 C	-12.9 C	-13.3 C	-13.8 C	-13.5 C	-13.7 C	-13.3 C	-17.5 C	-3.8 C	
LI_S13	-5.0 C	-3.9 C	-17.7 C	-12.9 C	-13.0 C	-12.8 C	-12.8 C	-12.5 C	-12.8 C	-12.7 C	-12.6 C	-17.2 C	-3.8 C	-6.1 C
LI_S14	-7.0 C	-3.5 C	-16.9 C	-12.7 C	-11.7 C	-12.4 C	-12.4 C	-12.1 C	-12.7 C	-12.7 C	-12.2 C	-17.2 C	-2.5 C	-8.3 C

Conclusions

- Overall temperature in stave went down
- Better CO_2 flow distibution for each stave
- Temperature of modules inside stave looks like more homogeneous
- Less superheated liquid inside cooling pipes
- Thanks to new by-pass more sub cooling inside the manifold
- Upgrades did not change the IBL condition

Need of CO_2 boiling research

- Under some circumstances which might be material related there are deviations in the boiling onset and hence heat transfer which can cause larger and irregular temperature gradients than expected.

- Differences observed between stainless steel prototypes and final titanium cooling pipes.

- ITk cooling is providing preheating with a heat exchanger to enhance boiling (Warm nose heat exchanger)

- Results from SR1 and ATLAS shown that this proces requires better understanding. We encourage detector designers to seriously investigate the boiling onset behaviour of their cooling pipes.

Thank you for your attention!

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Backup slides

HW & SW issues and solutions

Design:

- Feb-Mar

Building:

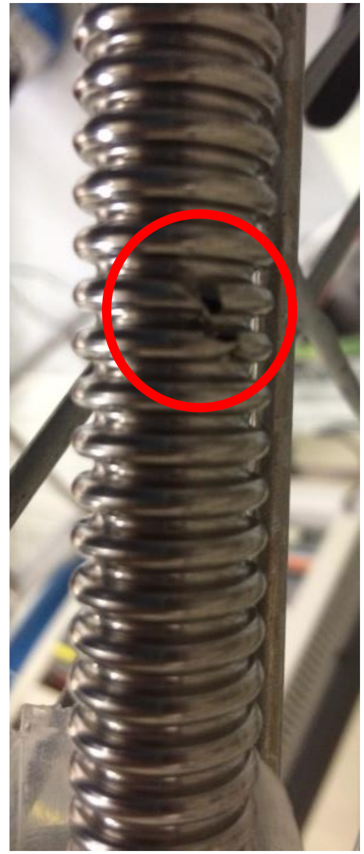
- Apr-Jun

Plant tuning

- Jul-Aug

We experienced many problems and solved them:

- Manifold box adjustment 4 m above floor
- Temperature sensors installation
- Exchanging mismatching Lapp connectors
- Cleaning low vacuum gauge sensor
- Repairing leaking titanium cooling pipes
- Debuging LabVIEW software
- Fixing broken spare flex line*
- Repairing misbehaving CO_2 plant



Fixing broken spare flex line

Repair by gluing

*The repair method works very well and can be applied in ATLAS in case a flex line gets damaged

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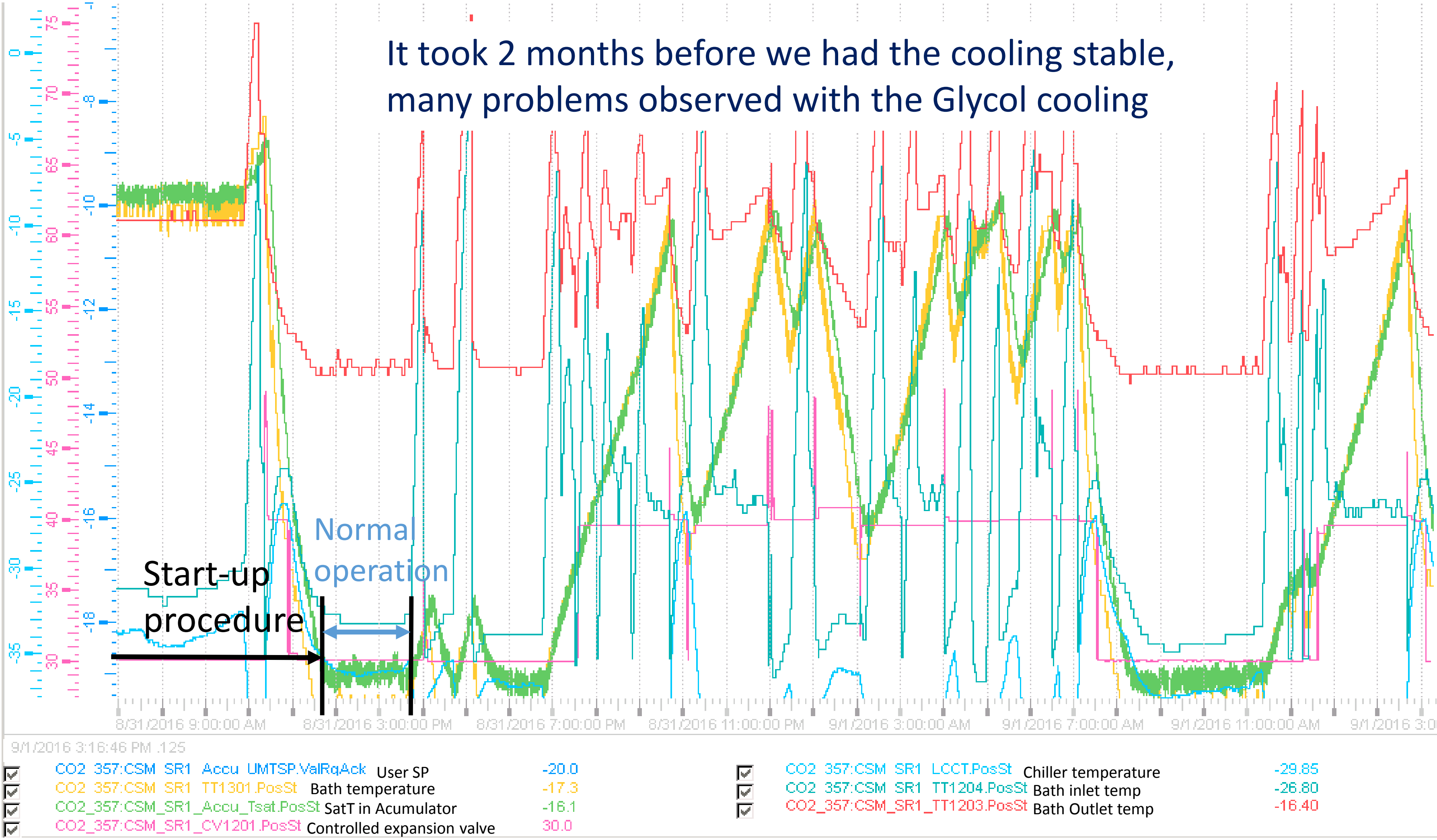
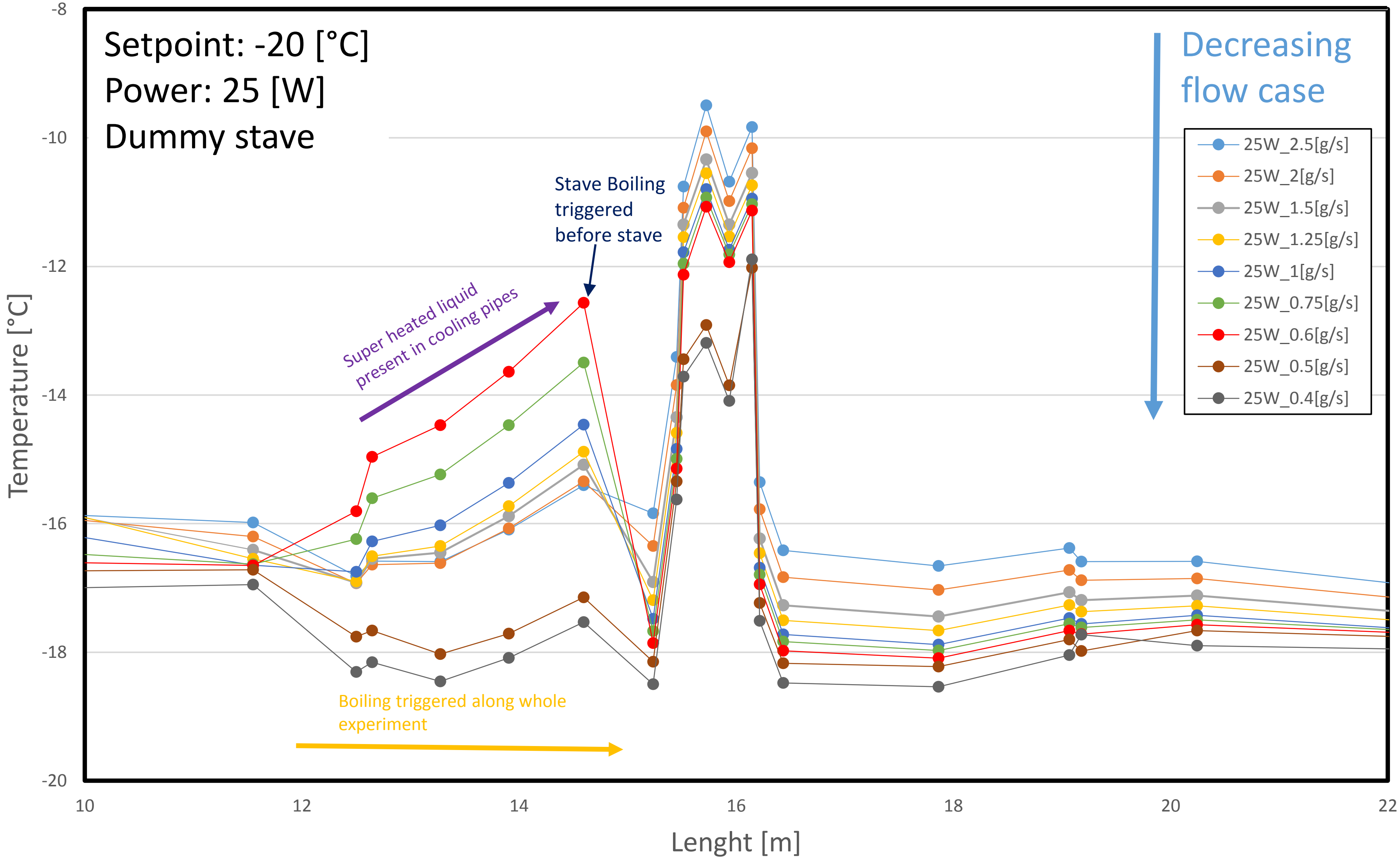
ATLAS EXPERIMENT

SR1 C0$_2$ plant issues



CO_2 plant behavior

Flow reduction results



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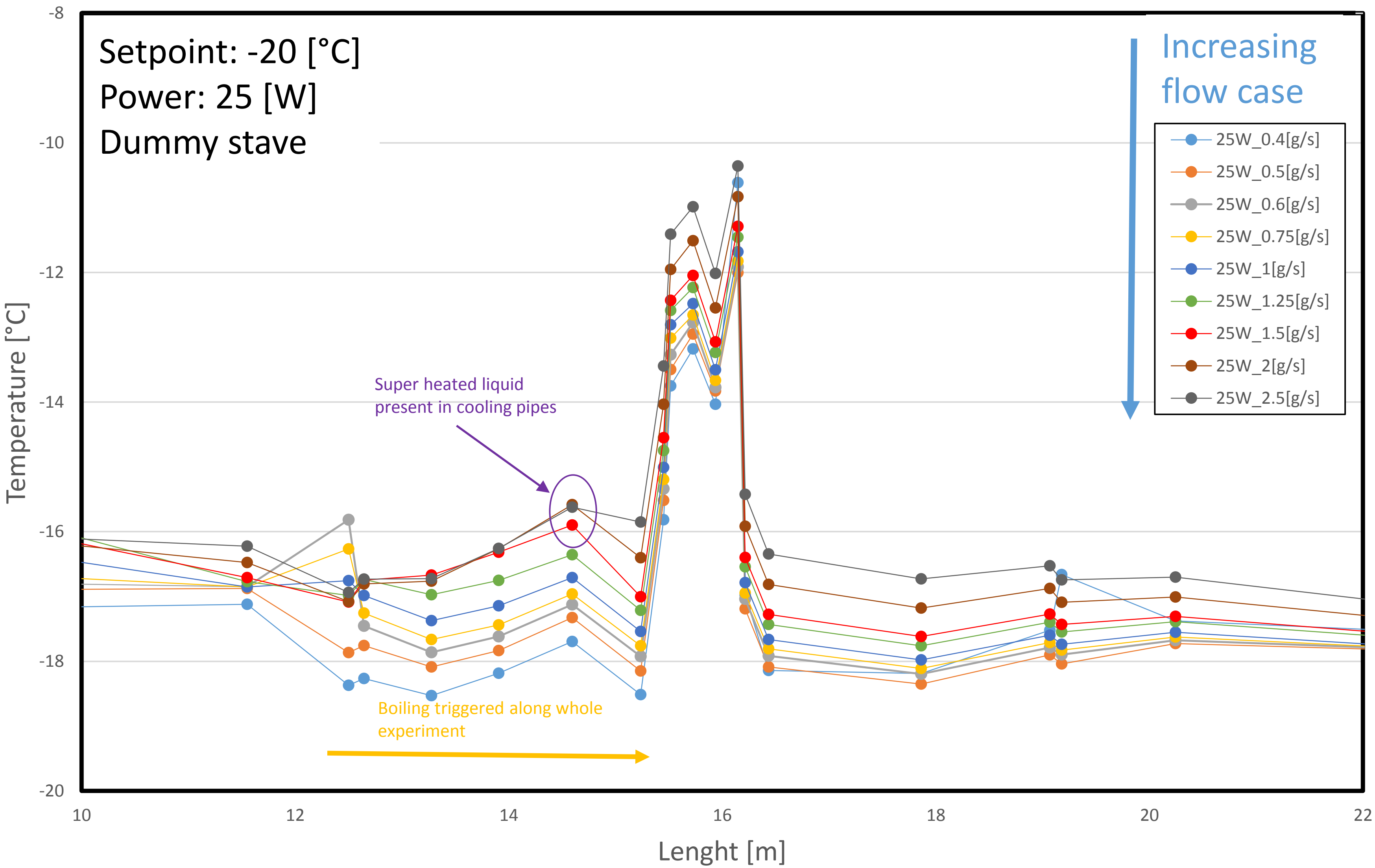
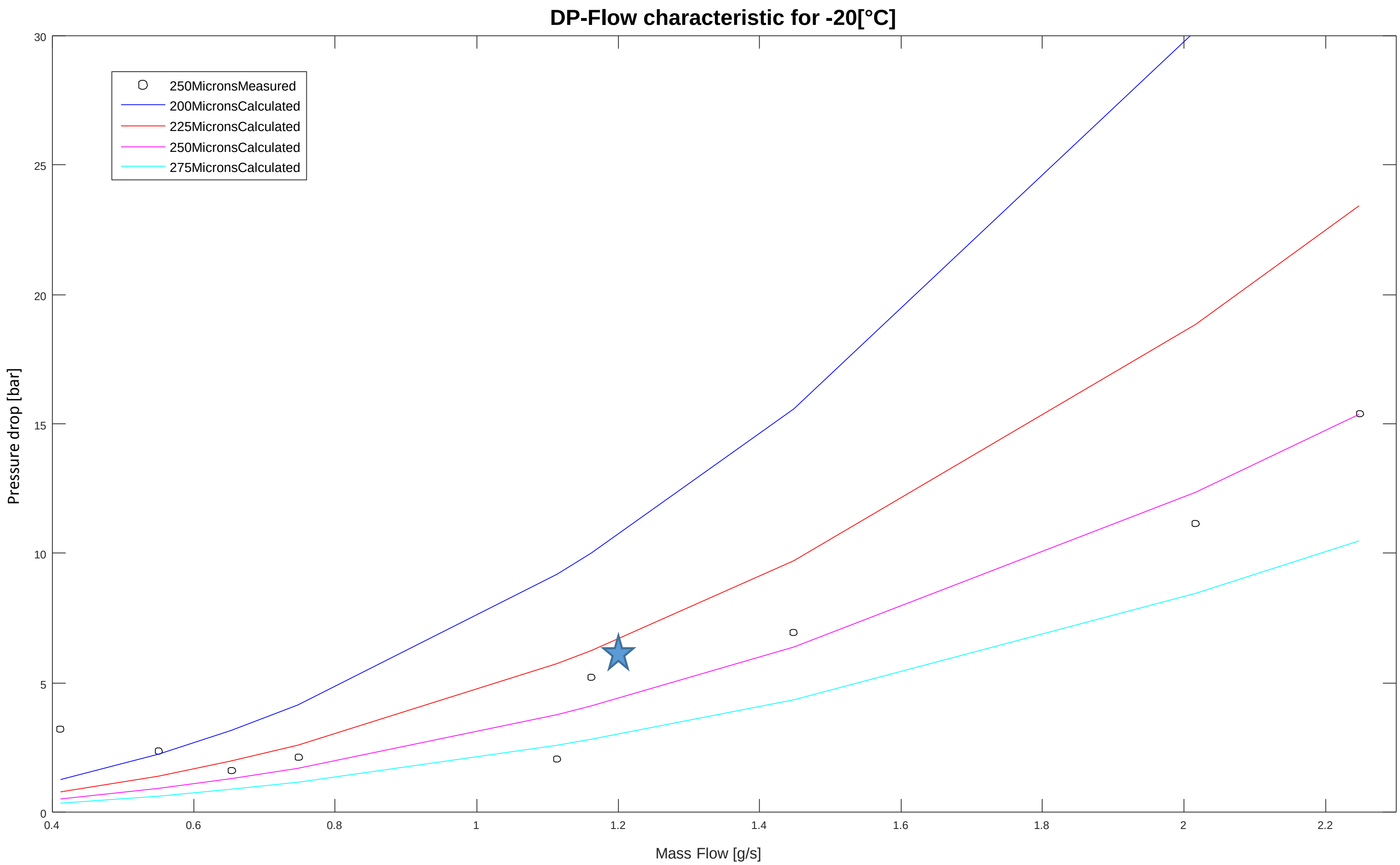
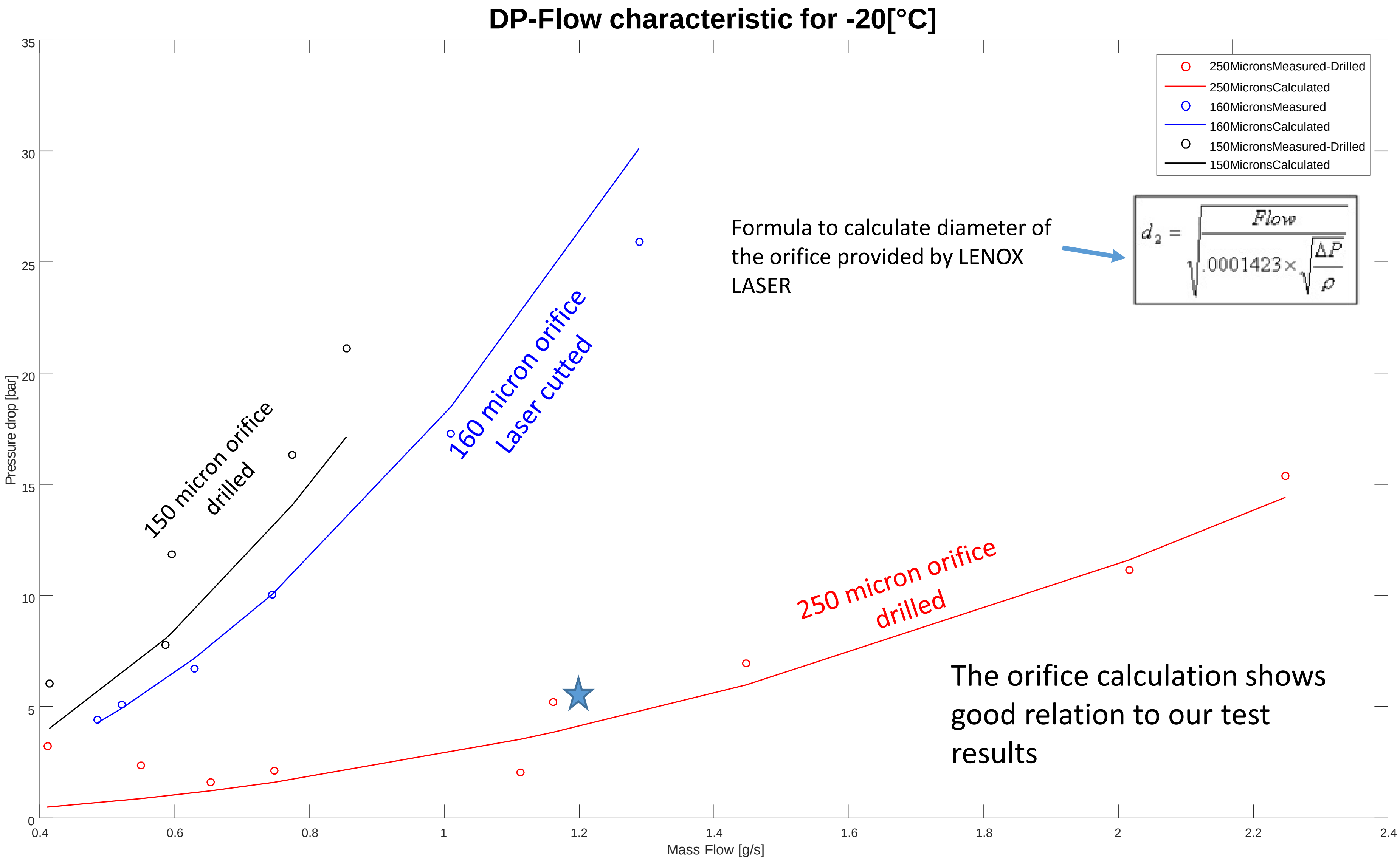
Flow increase results



Calculated orifice sizes according to our requirements



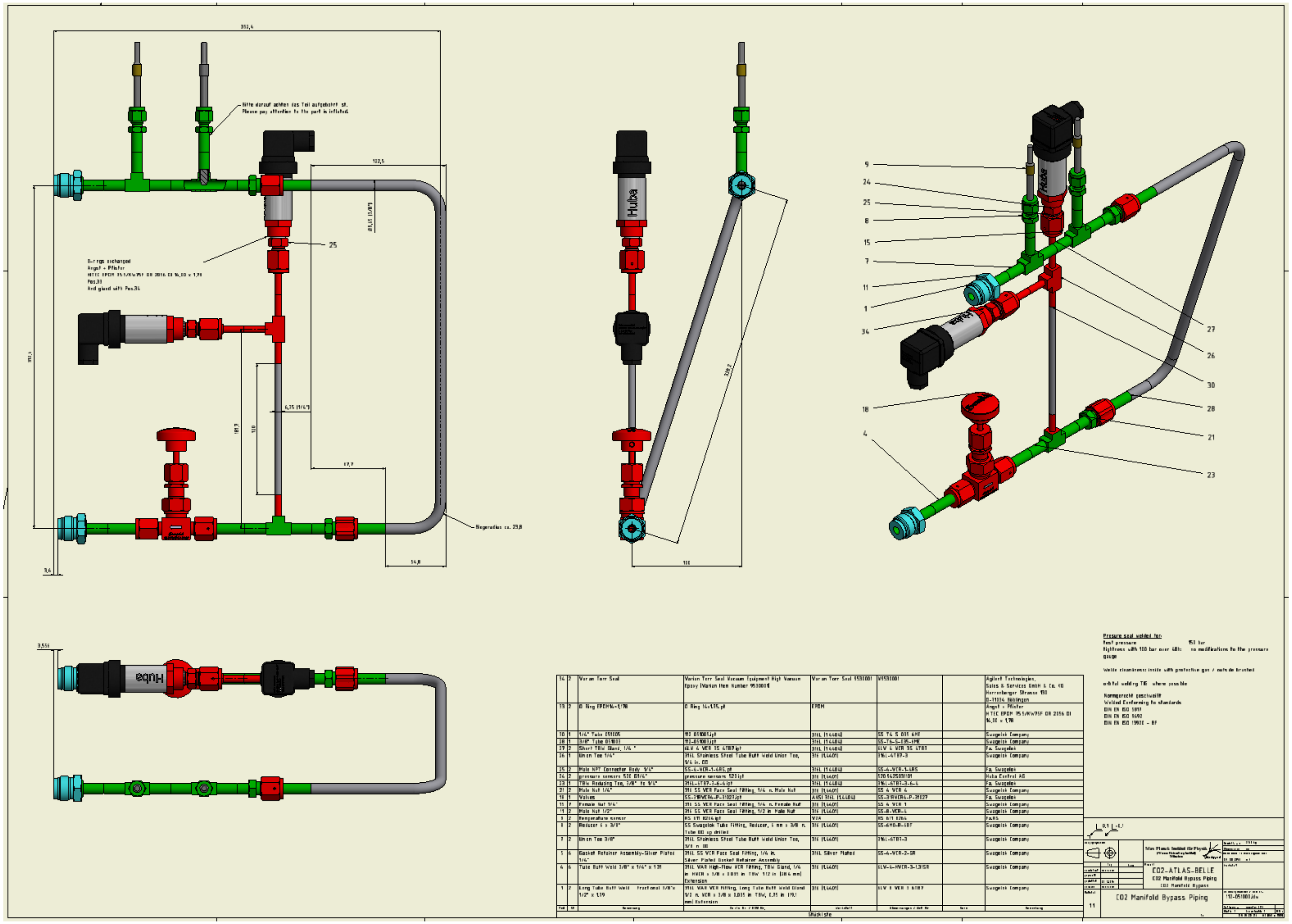
Orifice characteristic



$$d_2 = \sqrt{\frac{Flow}{.0001423 \times \sqrt{\frac{\Delta P}{\rho}}}}$$

The orifice calculation shows good relation to our test results

New IBL Manifold Bypass



Flow reduction tests of IBL cooling system with detector connected

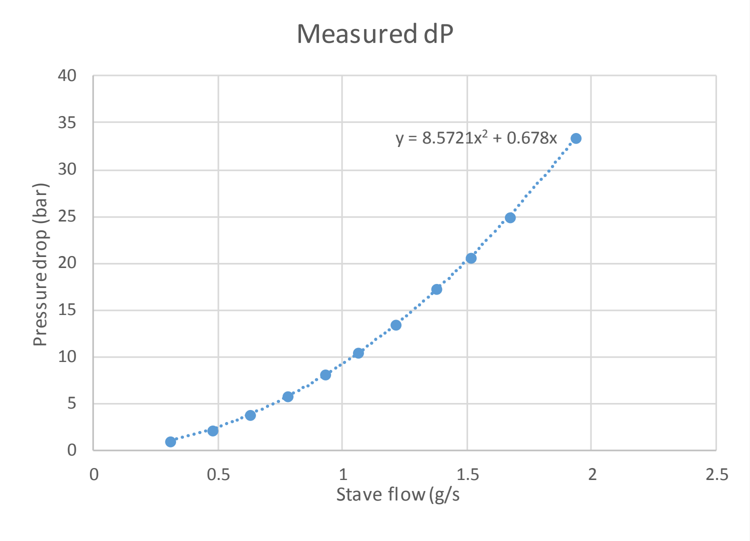
Stroke (mm)	Total Flow (g/s)	Flow per stave (g/s)	dP (bar)
7.5	27.1	1.935714	33.5
6.5	23.4	1.671429	25
6	21.2	1.514286	20.6
5.5	19.3	1.378571	17.2
5	17	1.214286	13.5
4.5	14.9	1.064286	10.5
4	13	0.928571	8.1
3.5	10.9	0.778571	5.8
3	8.8	0.628571	3.8
2.5	6.7	0.478571	2.2
2	4.3	0.307143	0.9

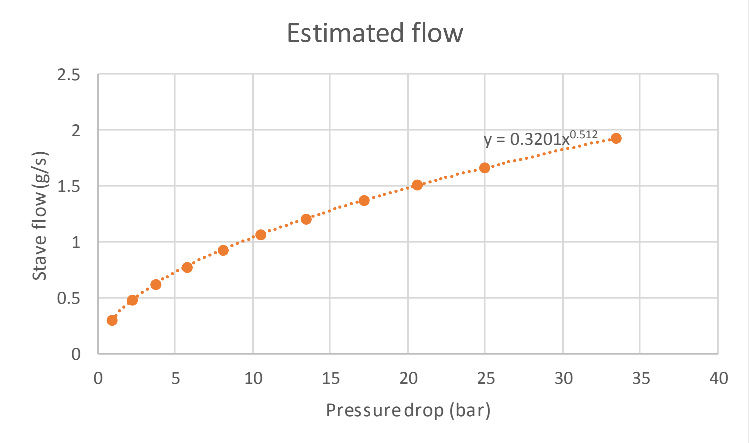
Old IBL setting (current pump setting)

Set dP	Estimated flow (g/s)
6.4	0.828037148

Current setting with by-pass

(1.064-0.83)*14=3.2 g/s over by-pass, 11.6 through detector





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What is next?

With 200 micron orifice | With 225 micron orifice