

The BPIX Phase 1 Cooling System

Lessons learned and the experience made

Thursday 15 June 2018

Peter Robmann

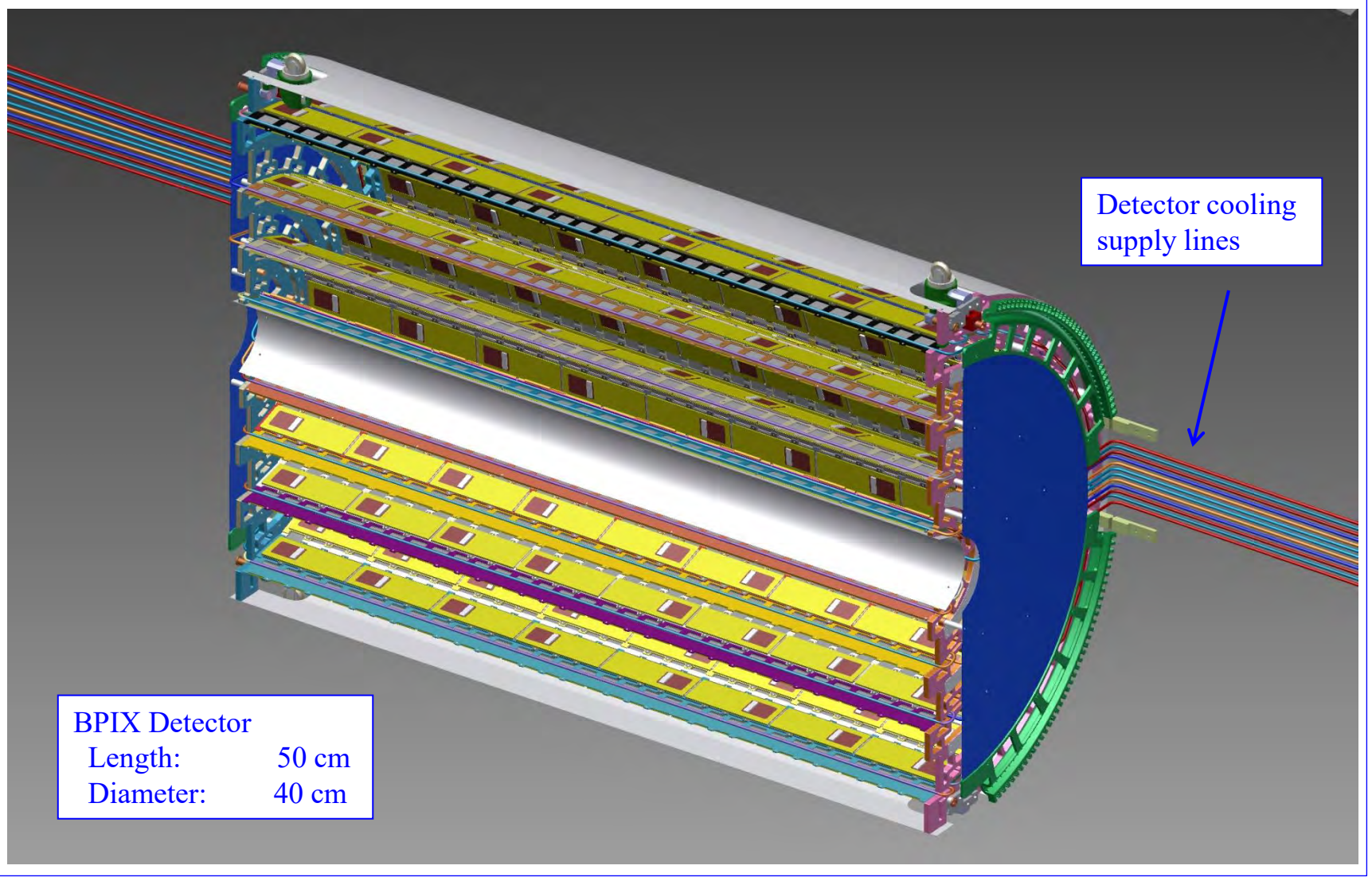
Universität Zürich



The CMS BPIX Phase 1 cooling system – Table of contents

- Overview
- Laser welded test loops
- The final cooling system
- VCR Fittings and Mini Fittings
- Quality Control
- Production of the cooling system
- Integration of the cooling system

The CMS BPIX Phase 1 Detector – An overview



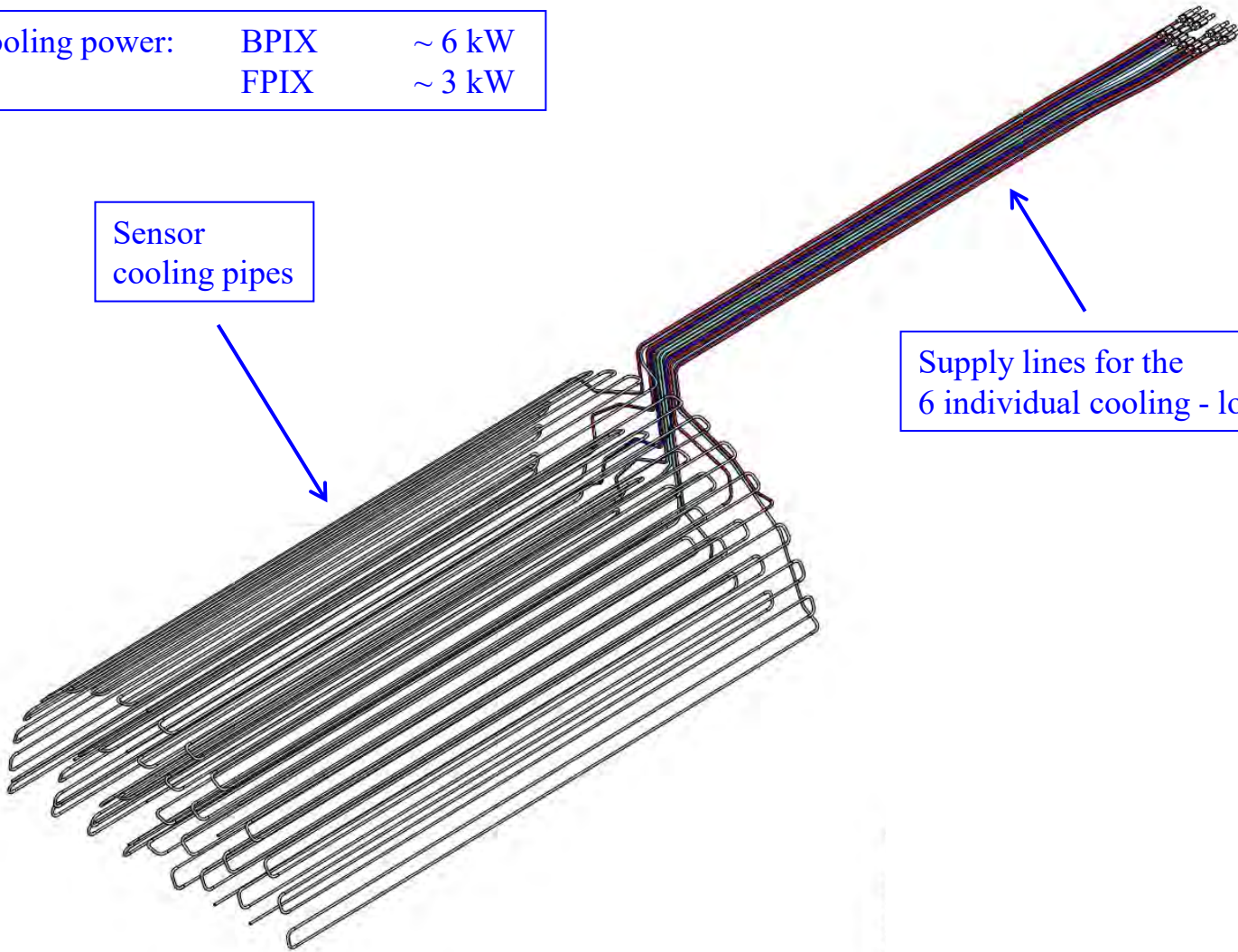
The CMS BPIX CO₂ cooling system

Detector cooling pipes (halfshell)

Total cooling power:	BPIX	~ 6 kW
	FPIX	~ 3 kW

Sensor
cooling pipes

Supply lines for the
6 individual cooling - loops



The CMS BPIX CO₂ cooling system

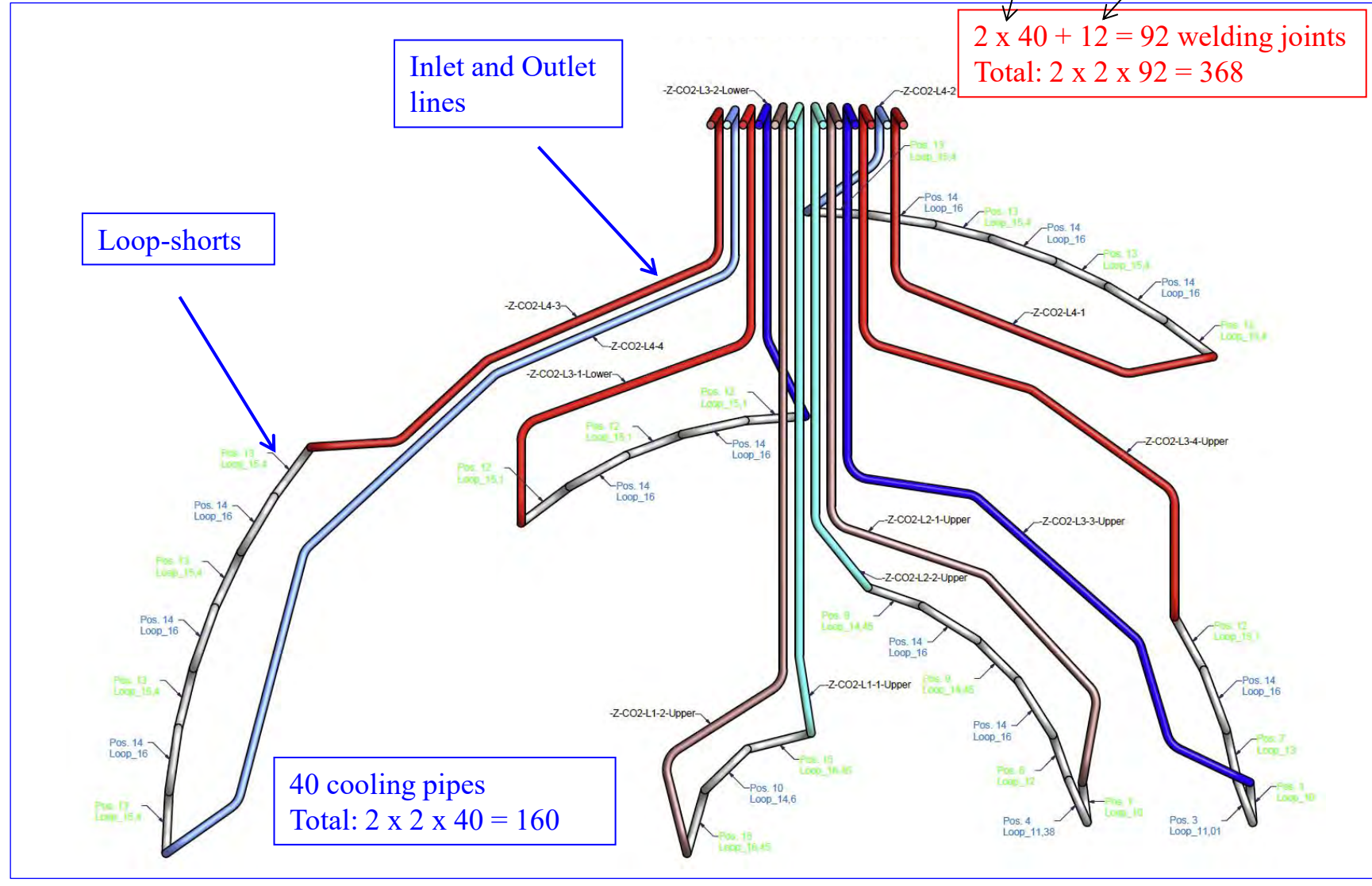
Cooling tubes Mini-Fitting
 Detector cooling pipes (halfshell)

2 x 40 + 12 = 92 welding joints
 Total: 2 x 2 x 92 = 368

Loop-shorts

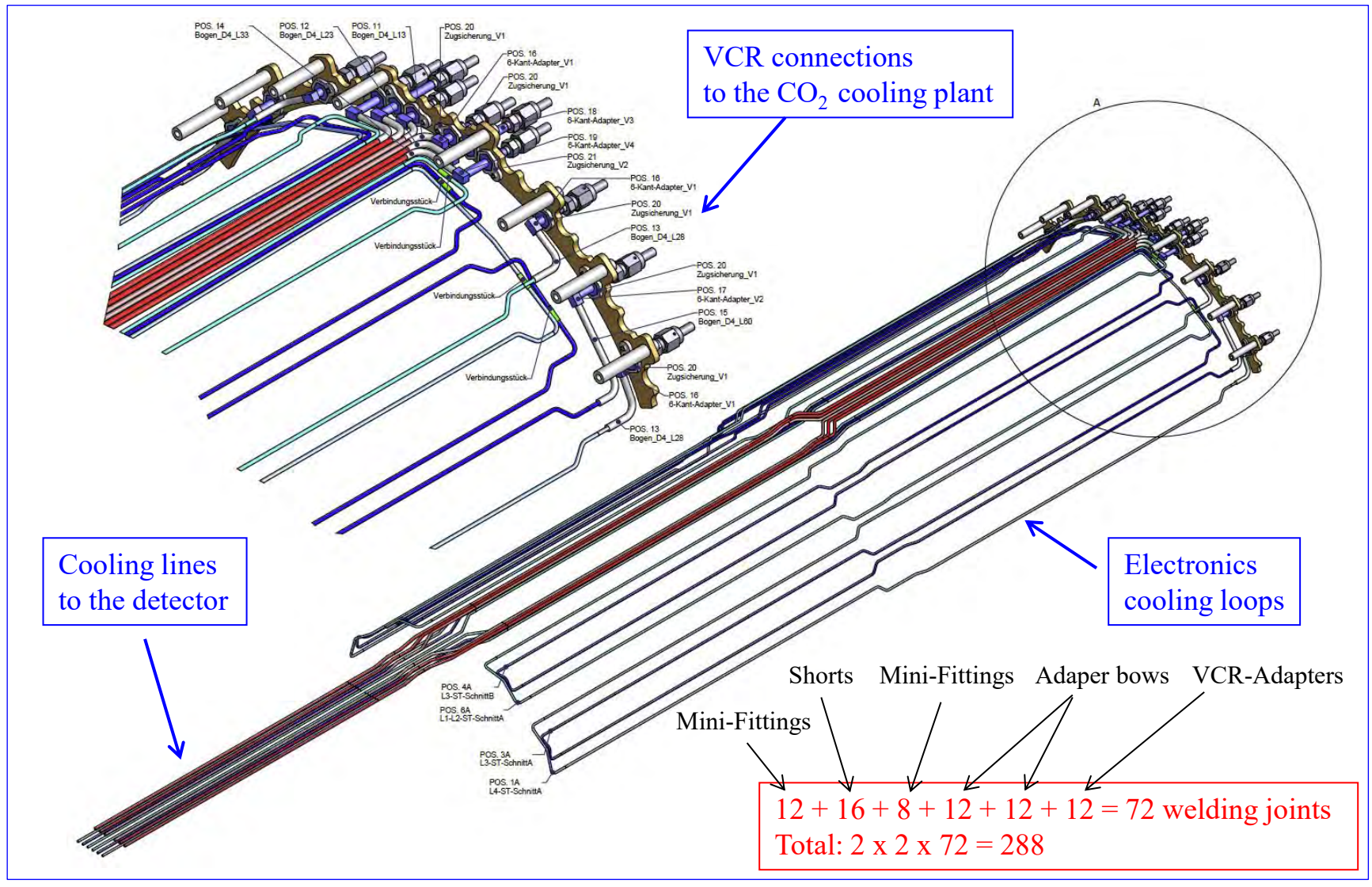
Inlet and Outlet lines

40 cooling pipes
 Total: 2 x 2 x 40 = 160



The CMS BPIX CO₂ cooling system

Supply tube cooling pipes (halfshell)



The CMS BPIX CO₂ cooling system

Length of the individual loops

	Bogen (in)	Part 1	Part 2	Part 3
Rohr-Durchmesser	4.0 x 2.2	2.2 x 1.8	2.2 x 1.8	2.2 x 1.8
	Länge [mm]	Länge [mm]	Länge [mm]	Länge [mm]
	Volumen	Volumen	Volumen	Volumen
	2,2	1,8	1,8	
My loop Nr.				
1	51,00 Pos. 13	2314,12 CMS-26-7-12-01	5888,72	1781,01 CMS-26-7-12-10
2	77,00 Pos. 15	2270,26 CMS-26-7-12-03	5777,11	2316,10 CMS-26-7-12-04
3	51,00 Pos. 13	2307,52 CMS-26-7-12-06	5871,92	1718,13 CMS-26-7-12-07
4	51,00 Pos. 13	2307,52 CMS-26-7-12-06	5871,92	1718,13 CMS-26-7-12-07
5	77,00 Pos. 15	2270,26 CMS-26-7-12-03	5777,11	2316,10 CMS-26-7-12-04
6	51,00 Pos. 13	2314,12 CMS-26-7-12-01	5888,72	1781,01 CMS-26-7-12-10

men	Totale Länge [mm]	Totales Volumen [mm ³]	Totales Volumen [l]	Totales Volumen [ml]
3				
325,15	11780,22	33638,13	0,0336	33,64
254,47	12726,40	36355,34	0,0364	36,36
183,78	9465,63	28303,26	0,0283	28,30
183,78	11629,87	33208,02	0,0332	33,21
254,47	12906,33	36813,21	0,0368	36,81
325,15	11533,15	33009,41	0,0330	33,01
Total	70041,60	201327,37	0,2013	201,33

Total length: 2 x 2 x 70 m = 280 m

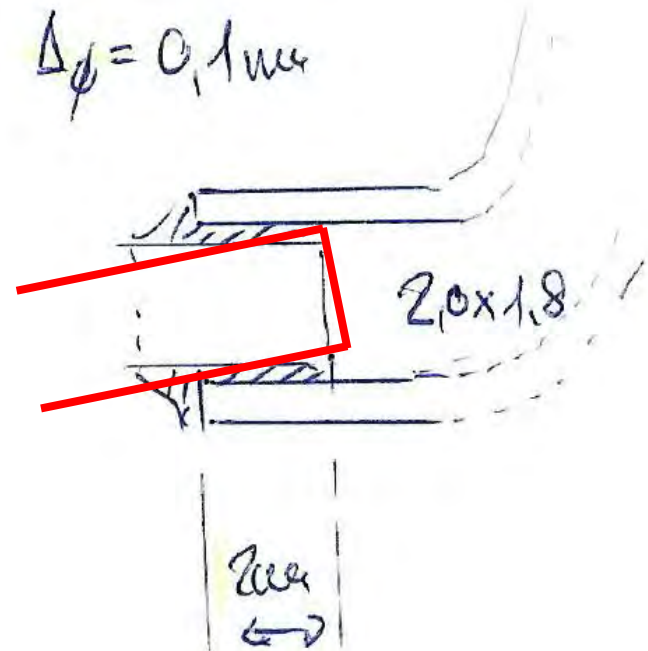
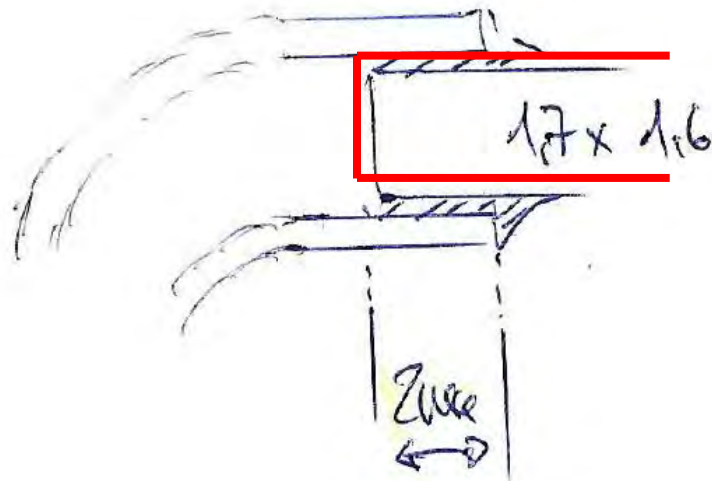
Laser welding

- No brazing gap needed
 - tight tolerances – allowing high precision
- No filler alloy
 - Welding without adding other metals
- No flux
 - Helps to keep system clean
- Only local heating
 - Heat deposit is very small
- No cleaning needed
 -(Juhui!)
- Computer controled process
 - perfectly repeatable

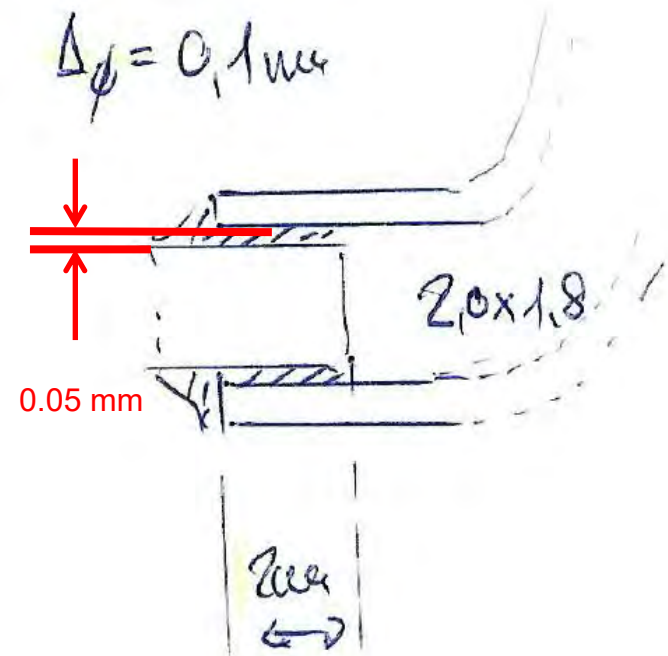
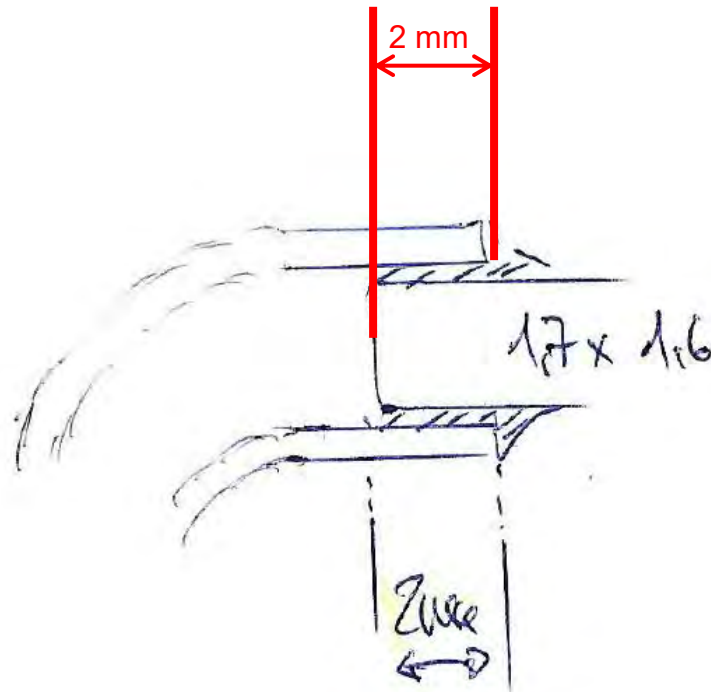
Brazing

- Brazing gap needed
 - Difficult to achieve high precision
- Brazing alloy
 - We add other metals
- Flux
 - Contaminates the parts
- High temperatures
 - Heat deposit is large
- Cleaning needed
 - At the inside and outside
- Manual flame brazing
 - Process not easily repeatable

- What has to be considered
 - Mechanical tolerances
 - Alignment



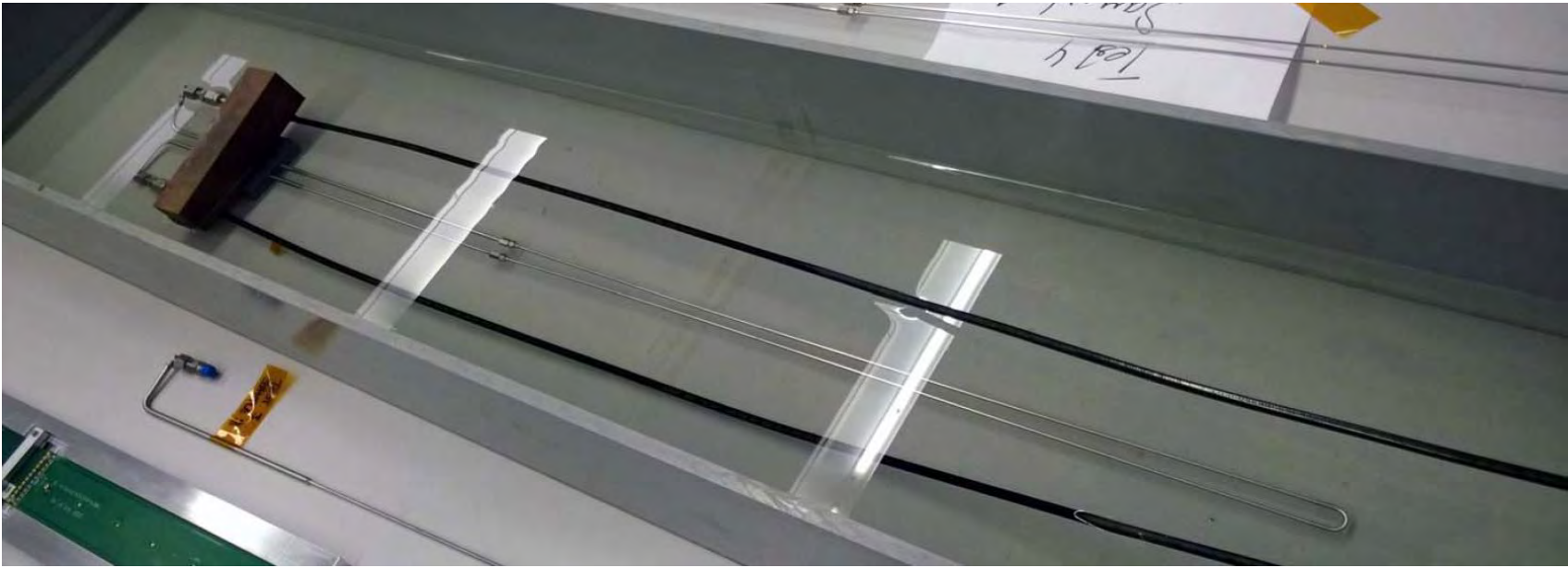
- What has to be considered
 - Mechanical tolerances
 - Alignment



Testloops – Experience made with laser welded testloops



Picture of running test - loop under pressure (200 bar)



Testloops – Experiences made with laser welded testloops

- A test loop includes all the components of a complete BPIX cooling loop
 - Swagelok VCR Fittings
 - Custom made Mini-Fittings
 - All tube sizes (Supplytube and Detector)

Experiences made with testloops

- Reliability of the individual components
 - Swagelok VCR fittings - no problems found
 - Custom made Mini-Fittings - no problems found
 - All tube sizes (Supplytube and Detector) – no leaks found since we do laser welding

Testloops – Experiences made with laser welded testloops

- A test loop includes all the components of a complete BPIX cooling loop
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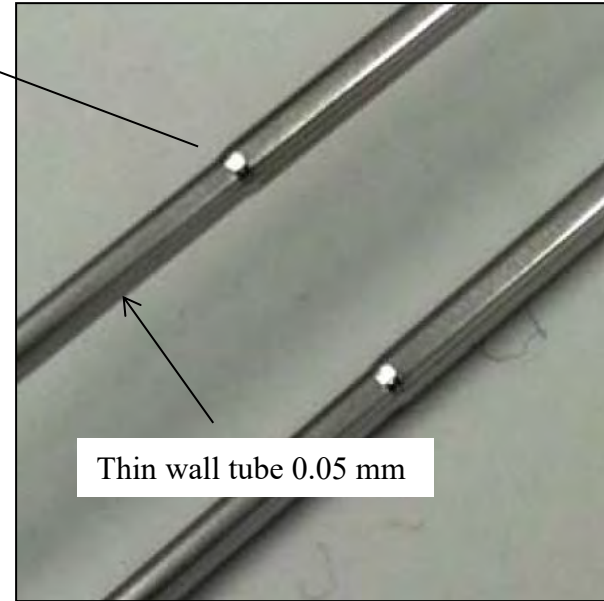
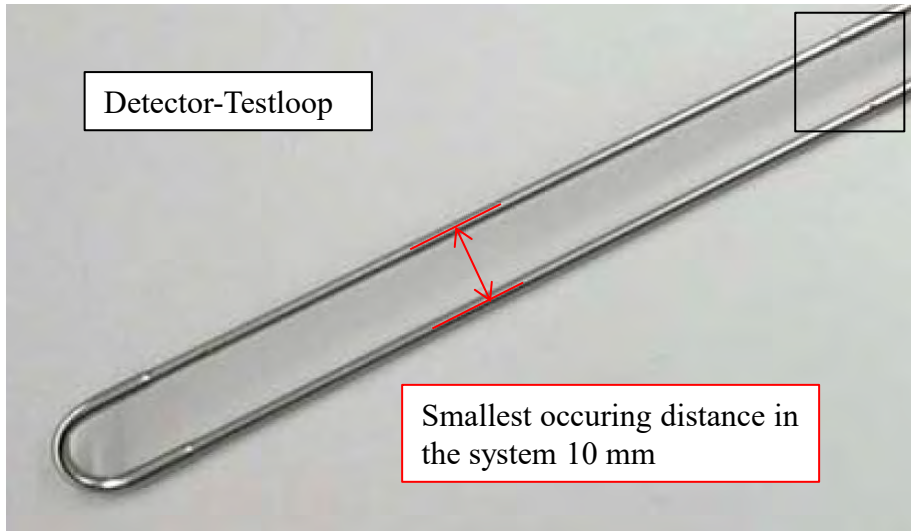
Experiences made with testloops

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These facts formed the basis for the system which was finally built

Testloops – Experiences made with laser welded testloops

Testloop components



The final BPIX cooling system - Material used

Material used for the different components

- We use the same stainless steel quality for all components
 - Swagelok VCR fittings - Stainless steel 316L
 - Swagelok fitting adapter - Stainless steel DIN 1.4441 (compatible to 1.4435)
 - Custom made Mini-Fittings - Stainless steel DIN 1.4441 (compatible to 1.4435)
 - Cooling tubes - Stainless steel DIN 1.4441 (compatible to 1.4435)
 - We use the same stainless steel quality for all components

- Chemical composition

DIN 1.4441

AØ 1.800 / IØ 1.700 / Wa 0.0500 / L 570.000 mm

Los-Nr. Rohmaterial : 39849

Produktions-Nr. : 140758

900 PCS

Schmelznr. : 871063

Chemische Zusammensetzung :

C	Cr	Cu	Mn	Mo	N	Ni	P	S	Si
0.018	17.40	0.06	1.78	2.72	0.078	14.15	0.018	0.001	0.53

The final BPIX cooling system - Material used

Cooling tubes made by MEDELC



Belagdatum 09.02.2016

Debitorenr. 32663
Auftragsnummer VC-115592
Referenz NR. 12774

Abnahmeprüfzeugnis für das Vormaterial nach EN 10204/3.1 für Lieferschein VBL-121495

Beschreibung		Menge							
DIN 1.4441 Aø 2.20 / Iø 1.80 / Wa 0.20 mm Los-Nr. Rohmaterial : 39849 Produktions-Nr. : 141257		501 ME							
Schmelznr. : 871063									
Chemische Zusammensetzung :									
C	Cr	Cu	Mn	Mo	N	Ni	P	S	Si
0.018	17.40	0.06	1.78	2.72	0.078	14.15	0.018	0.001	0.53

Note the Tolerances:

Außen ø: +0.000 / -0.020
Innen ø: +0.020 / -0.020
Edelstahl, rundes Rohr, nahtlos, gegläht,
gerade gerichtet in Längen von 2000.0mm +/-20.0
Zugfestigkeit: Rm < /=850 N/mm²
DIN 1.4441 kompatibel mit 1.4435

Cooling Loop Engineering Model improvements

NUMBER OF WELDING JOINTS

Detector			Supply Tube						
			Mini Connectors	Return Lines	Loops				
Layer 1	4	4			8 4 Hülsen/Dünn	16 8 Hülsen dünn	8 4 Hülsen dünn	3 dünn "dick"	
Layer 2	8	8	12 6 dick, 6 dünn	12 6 Hülsen dick		12 6 Hülsen dünn		6 dick "dick"	
Layer 3	12	12 (2 x 6)			8 4 Hülsen Dünn	16 8 Hülsen dünn	8 4 Hülsen dünn	3 dünn "dick"	
Layer 4	16	16 (2 x 8)							
Number of solder joints	40	40	12	12	12	16	56	16	12
Total number of solder joints									216
Number of connecting loops	20	14	Number of connecting pieces		6	8	28	8	
Total number of connecting loops		34	Total number of connecting pieces						64

NOTICE: WE CAN OMIT THE MOST PROBLEMATIC PART AND REDUCE THE NUMBER OF WELDING JOINTS BY A FACTOR OF TWO....

The final BPIX cooling system - Optimal bending radii

Bending tests to find the best pipe diameters and pipe wall thickness to guarantee perfect bendings

Biege-Radien

UniBiegetest mit Zusammenfassung Huber&Suhner Biegetests

Rohrtyp	Durchmesser		Biege-Radius neutrale Faser	Durchmesser	Biege-Werkzeuge	
	aussen	innen			Durchmesser Innen-Werkzeug	Radius Innen-Werkzeug
2,0 x 1,8	2,00	1,80	9,00	18,00	16,00	8,00
2,2 x 1,8	2,20	1,80	5,00	10,00	7,80	3,90 Det-Loops *
	2,20	1,80	6,00	12,00	9,80	4,90
2,4 x 2,2	2,60	2,20				
2,6 x 2,2	2,60	2,20	7,00	14,00	11,40	5,70 U-Rohre **
3,0 x 2,6	3,00	2,60	10,50	21,00	18,00	9,00
4,0 x 2,2 *	4,00	2,20	6,00	12,00	8,00	4,00
4,0 x 3,0 *	4,00	3,00	9,00	18,00	14,00	7,00

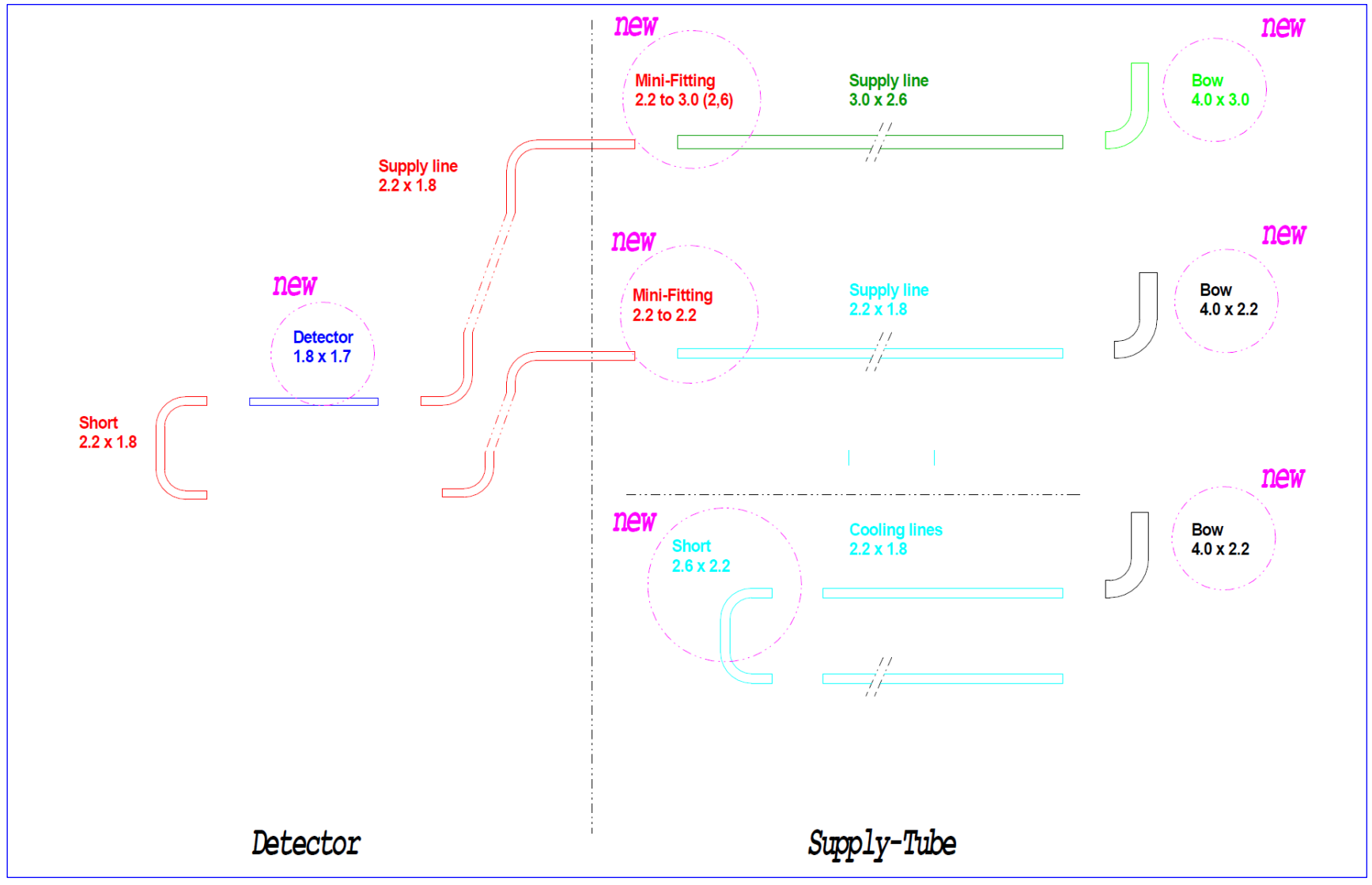
* neue Durchmesser

* kommt nicht in H&S Testtabelle vor
Loops wurden aber gebogen (Rohrdurchmesser 2,2 x 1,8)

** U-Rohre, eigene Tests

Biege-Radien auf Zeichnungen		
Biege-Radius neutrale Faser	Durchmesser	Kleinster Biegeradius (neutrale Faser) <small>unsere Biegetests 2015 mit Medelec Rohren</small>
5,00	10,00	9,00
5,00	10,00	5,00
6,00	12,00	
		10,00
7,00	14,00	6,00
8,00	16,00	8,00
8,00	16,00	8,00
8,00	16,00	8,00

The final BPIX cooling system - Diameters of the cooling pipes



The final BPIX cooling system - The Swagelok VCR Fittings

Swagelok 2/28/2013 3:06:57 AM
www.swagelok.com

VCR® Metal Gasket Nuts, Caps, and Plugs



Part No.
SS-2-VCR-1

Part Description:
316 SS VCR Face Seal Fitting, 1/8 in. Female Nut

Product Specifications

General

Body Material	316 Stainless Steel
---------------	---------------------

Swagelok 2/28/2013 3:15:41 AM
www.swagelok.com

VCR® Metal Gasket, Glands



Part No.
SS-2-VCR-3

Part Description:
316 SS VCR Face Seal Fitting, Socket Weld Gland, 1/8 in. VCR x 1/8 in. Tube Socket


Product Specifications

General

Body Material	Stainless Steel
---------------	-----------------

Swagelok 2/28/2013 3:17:57 AM
www.swagelok.com

VCR® Metal Gasket Nuts, Caps, and Plugs



Part No.
SS-2-VCR-4

Part Description:
316 SS VCR Face Seal Fitting, 1/8 in. Male Nut

Product Specifications

General

Body Material	316 Stainless Steel
---------------	---------------------

Swagelok 2/28/2013 3:19:48 AM
www.swagelok.com

VCR® Metal Gasket, Gaskets



Part No.
SS-2-VCR-2-VS

Part Description:
316 SS VCR Face Seal Fitting, 1/8 in. Unplated Gasket, Non-Retained Style

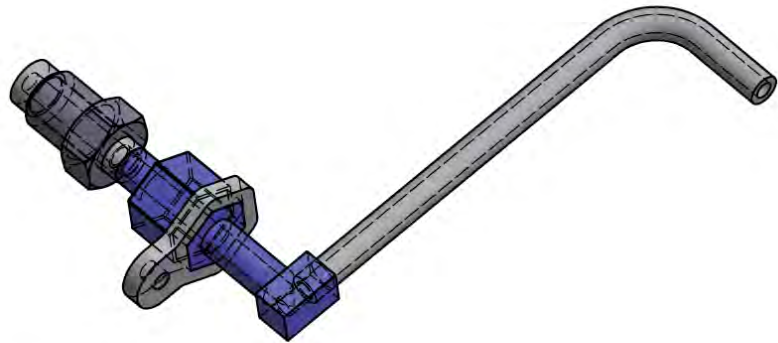
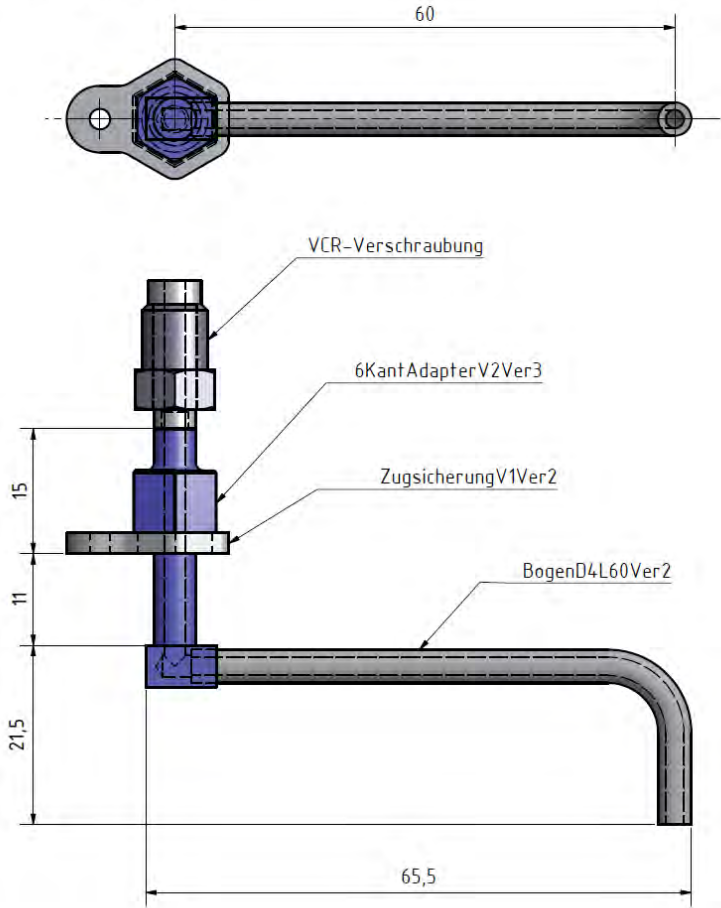
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Body Material	316 Stainless Steel
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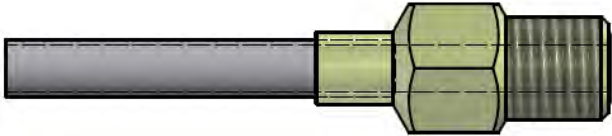
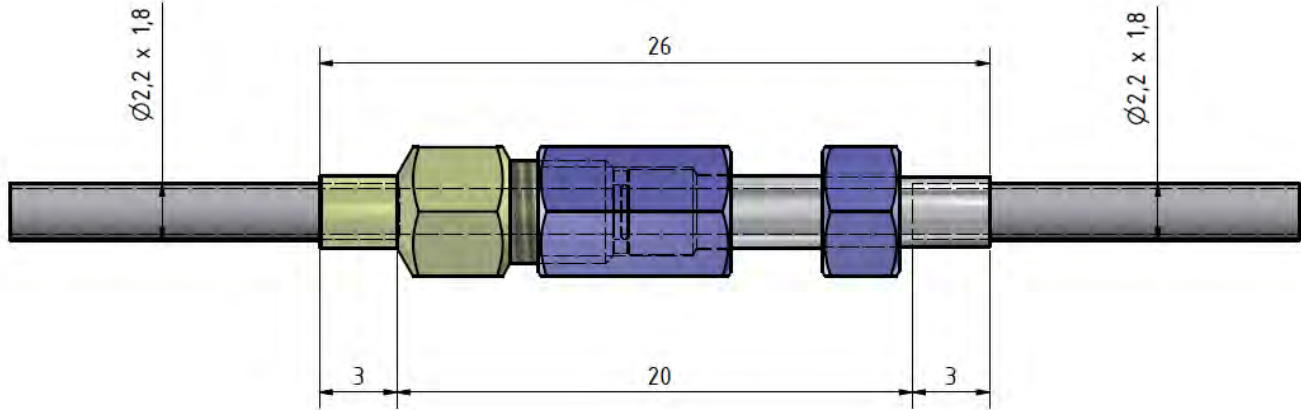
The final BPIX cooling system - The adapter parts

6-Kant Adapter 60 mit Bogen und VCR-Verschraubung
 2 Stück / Supply Tube Halbschale
 Anzahl: 16 Stück



Benennung/Merkmale	Material	Anzahl	Masstab
6-Kant Adapter 60 Bogen und VCR-Verschraubung	DIN 1.4441	s. oben	2
	Datum	Name	
	Gezeichnet: 02.10.2015	peu	
	Kontrolliert:		
	Norm		
CMS Barrel Pixel Supplytube 2015			

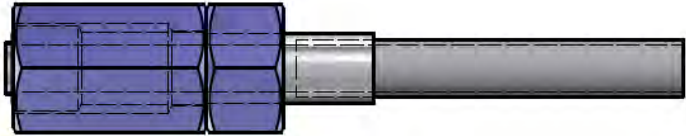
The final BPIX cooling system - The custom made Mini-Fittings



Mini-Fitting screw

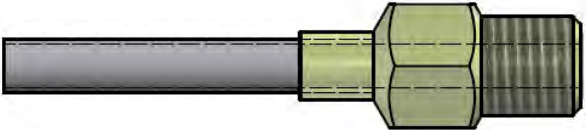
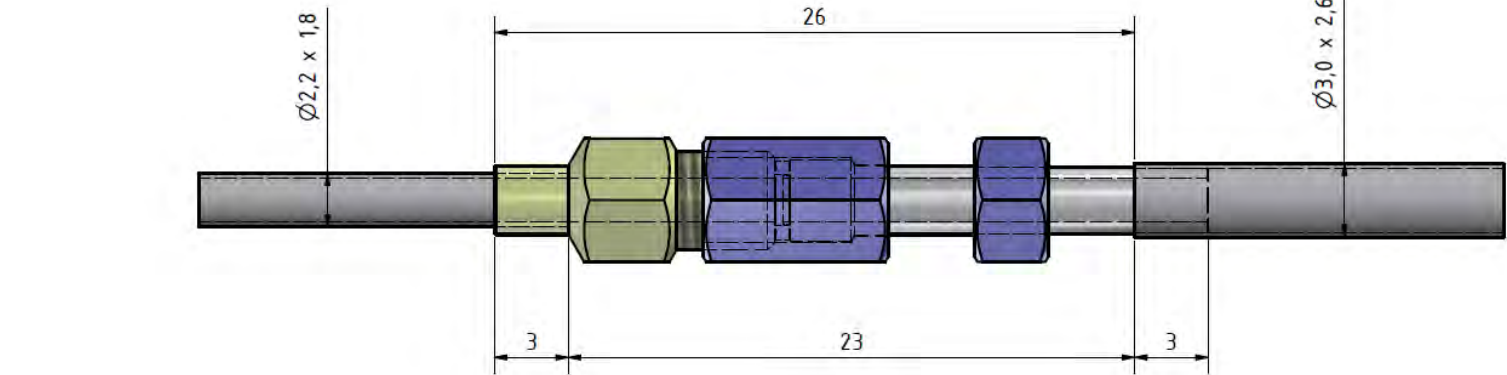


Sealing ring
(copper)



Mini-Fitting counter part

The final BPIX cooling system - The custom made Mini-Fittings



Mini-Fitting screw



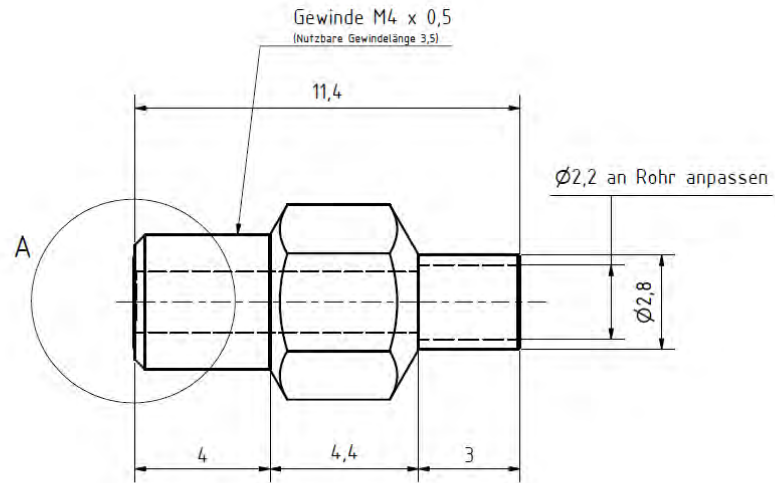
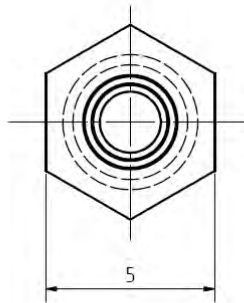
Sealing ring (copper)



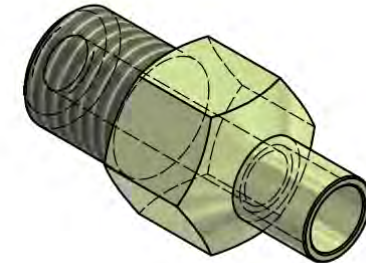
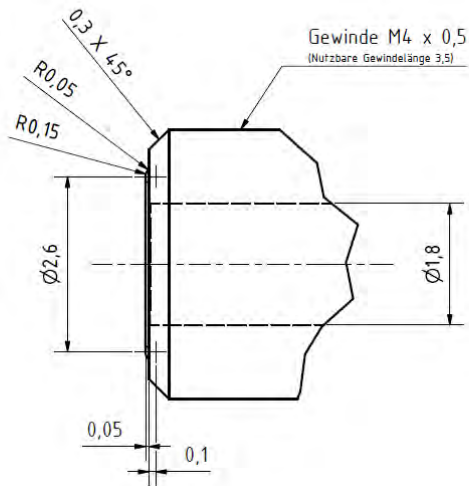
Mini-Fitting counter part

The final BPIX cooling system - The custom made Mini-Fittings

Fitting Schraube Supply Tube \varnothing Rohr 2,2 mm
 8+12 Stück / Supply Tube Halbschale
 Anzahl: 160 Stück



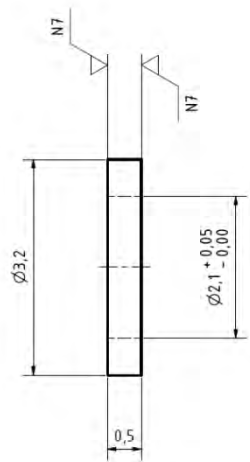
Detail A



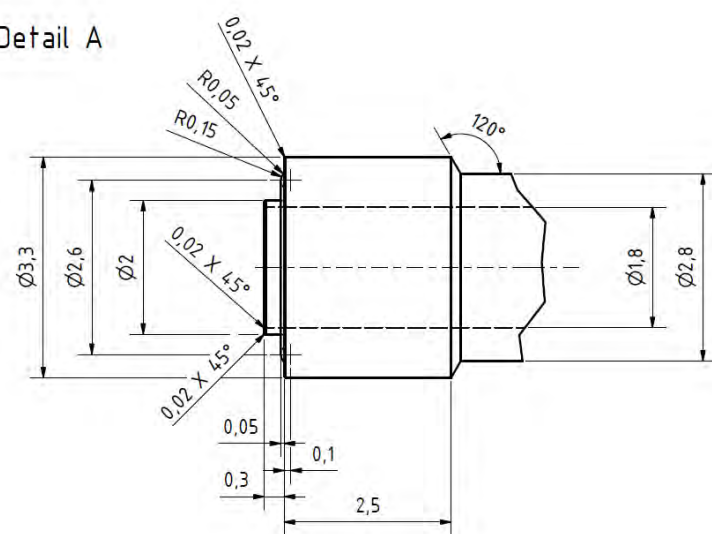
Benennung/Merkmale		Material		Anzahl		Messstab	
Fitting Schraube 2,2 mm Supply Tube		SS 316L DIN 1.4441		s. oben			
		Datum	Name	CMS Barrel Pixel Supplytube 20			
		Gebeschied 12.10.2016	Pfz				
		Kontrolliert					
		Norm					

The final BPIX cooling system - The custom made Mini-Fittings

Sealing ring
(copper)

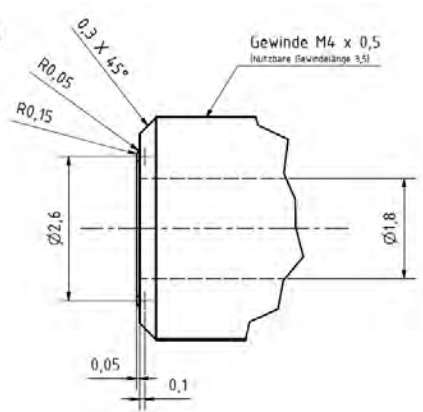


Detail A



Mini-Fitting counter part

Detail A



Mini-Fitting screw

The final BPIX cooling system - Laser welding quality control

Quality control of the laser welding

- Visual inspection after welding
 - Check geometry of completed component
 - Check the contour of the welding seam
- Pressure tests at 200 bar of all individual components immediately after the laser welding

The final BPIX cooling system - Testing of the BPIX cooling system

BPIX cooling system tests

- Pressure tests at 200 bar of all individual components immediately after the laser welding
 - Test adapter parts with Swagelok VCR fittings (before welding to the longer thinner tubes)
 - Test individual completed cooling loop parts of the Supplytube
 - Test individual completed detector cooling loops
- Long time pressure tests at 200 bar of complete cooling loop components – whenever possible
- Pressure tests at 200 bar of complete cooling system
- Pressure tests at 200 bar after integration of the cooling system (Supplytube and Detector)

Production of the cooling system Bending of the pipes at Huber & Suhner

CNC Bending machine at Huber & Suhner



Production of the cooling system Bending of the pipes at Huber & Suhner

Completed set of detector supply lines



Production of the cooling system EDM cutting of the pipes at Hanhart



Production of the cooling system EDM cutting of the pipes at Hanhart

Completed set of detector supply lines



Production of the cooling system Laser welding at Createch

Laser welding of a layer 1 loop



Welding tool for a layer 1 loop

Production of the cooling system Laser welding at Createch

Detector cooling loops of
layer 1 during the pressure
test a Createch

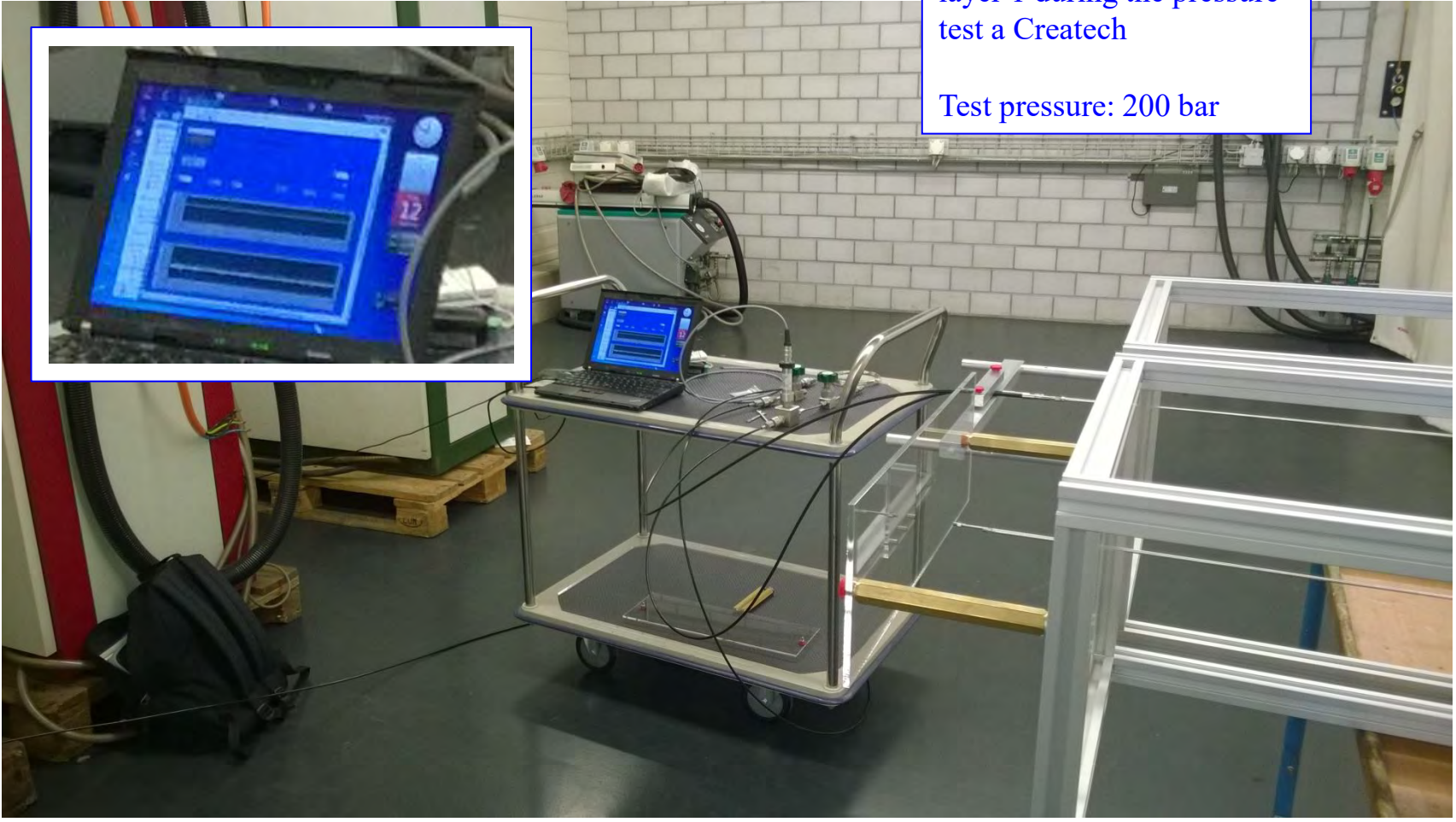
Test pressure: 200 bar



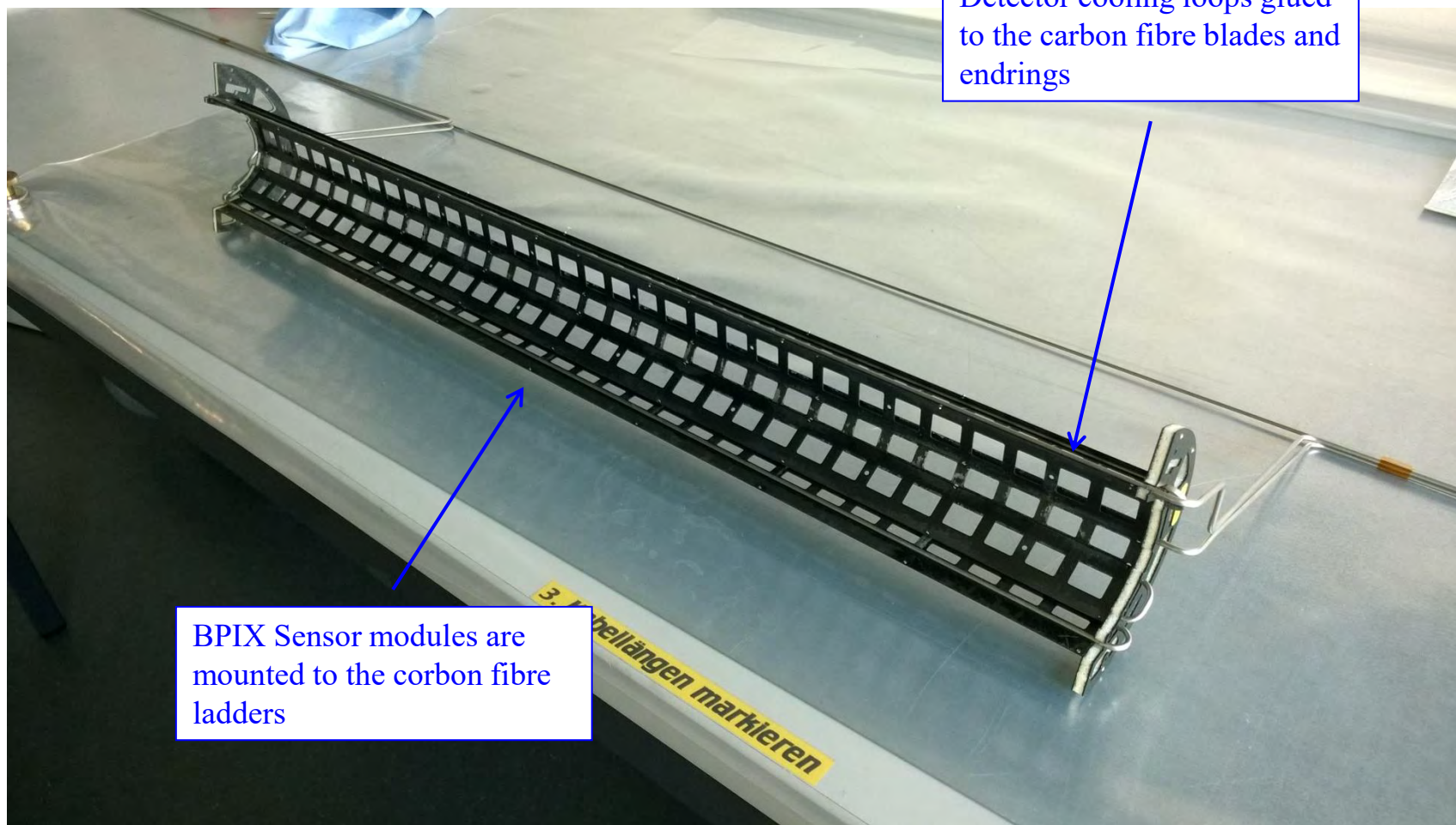
Production of the cooling system Laser welding at Createch

Detector cooling loops of layer 1 during the pressure test a Createch

Test pressure: 200 bar

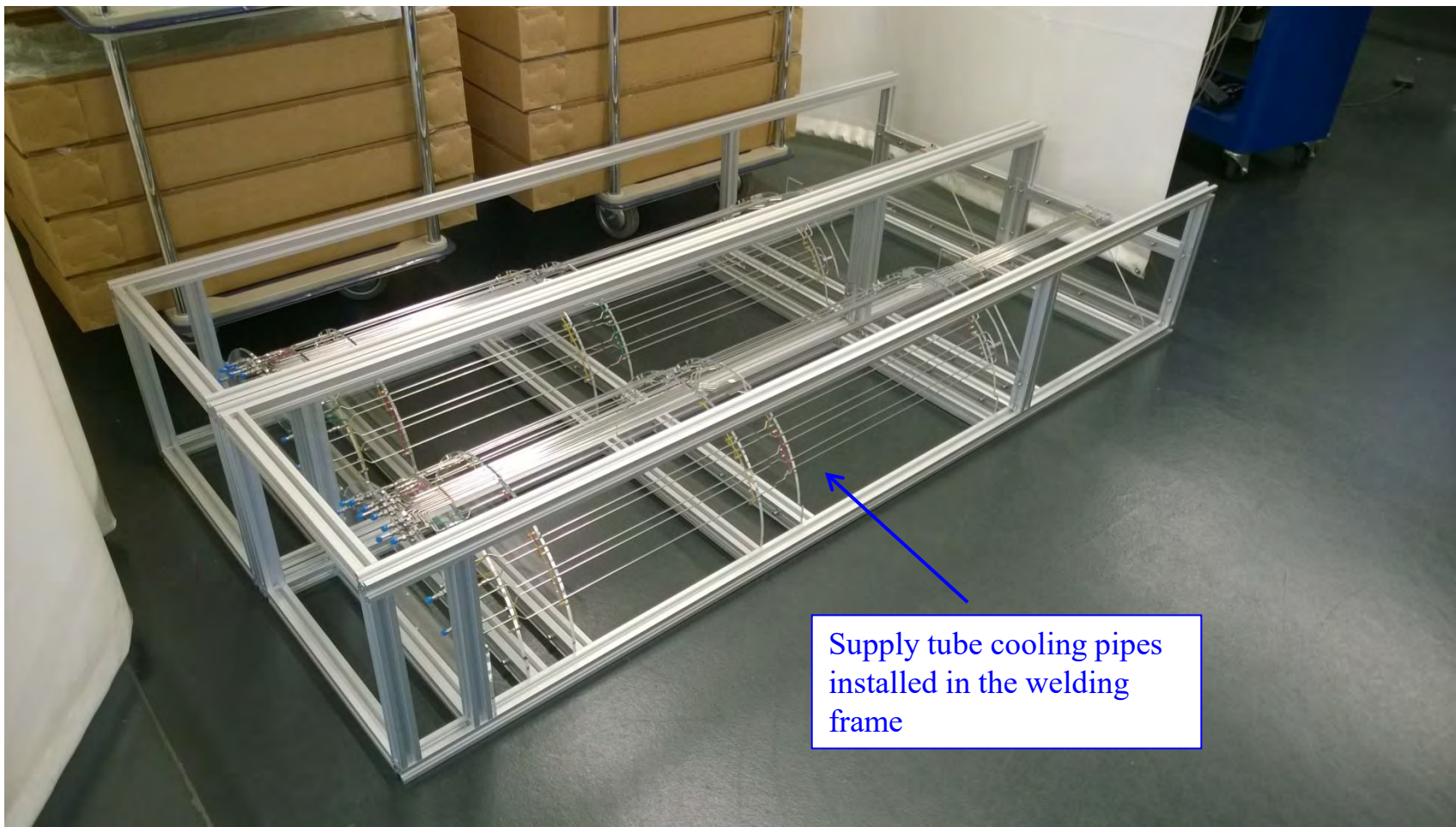


Production of the cooling system Completed detector supportstructure (Layer 1)



Production of the cooling system Laser welding at Createch

Laser welding of the Supply tube cooling loops



Supply tube cooling pipes
installed in the welding
frame

Production of the cooling system Laser welding at Createch

Laser welding of the Supply tube cooling loops

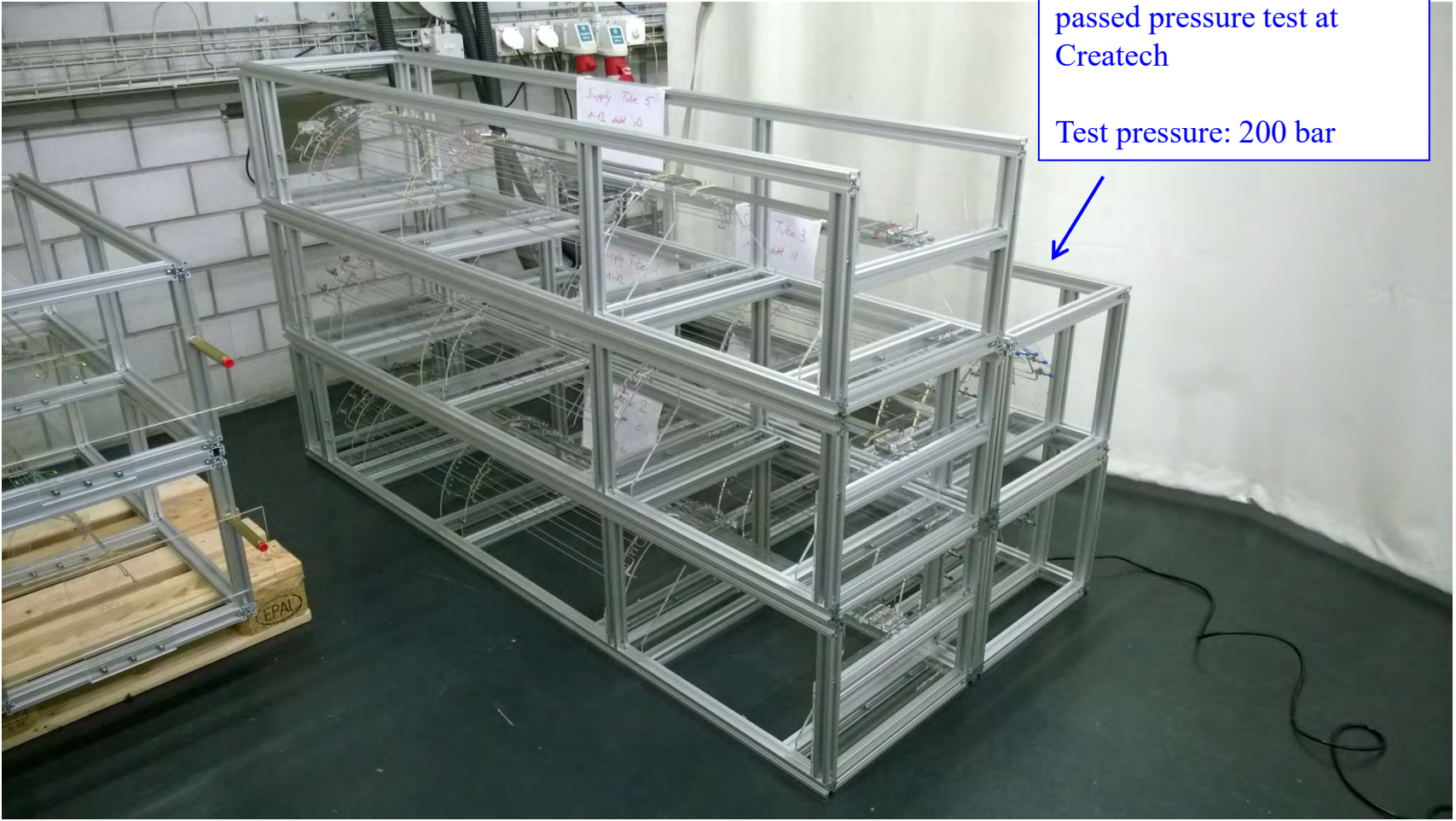


Welding frame installed on the laser welding machine

Production of the cooling system Laser welding at Createch

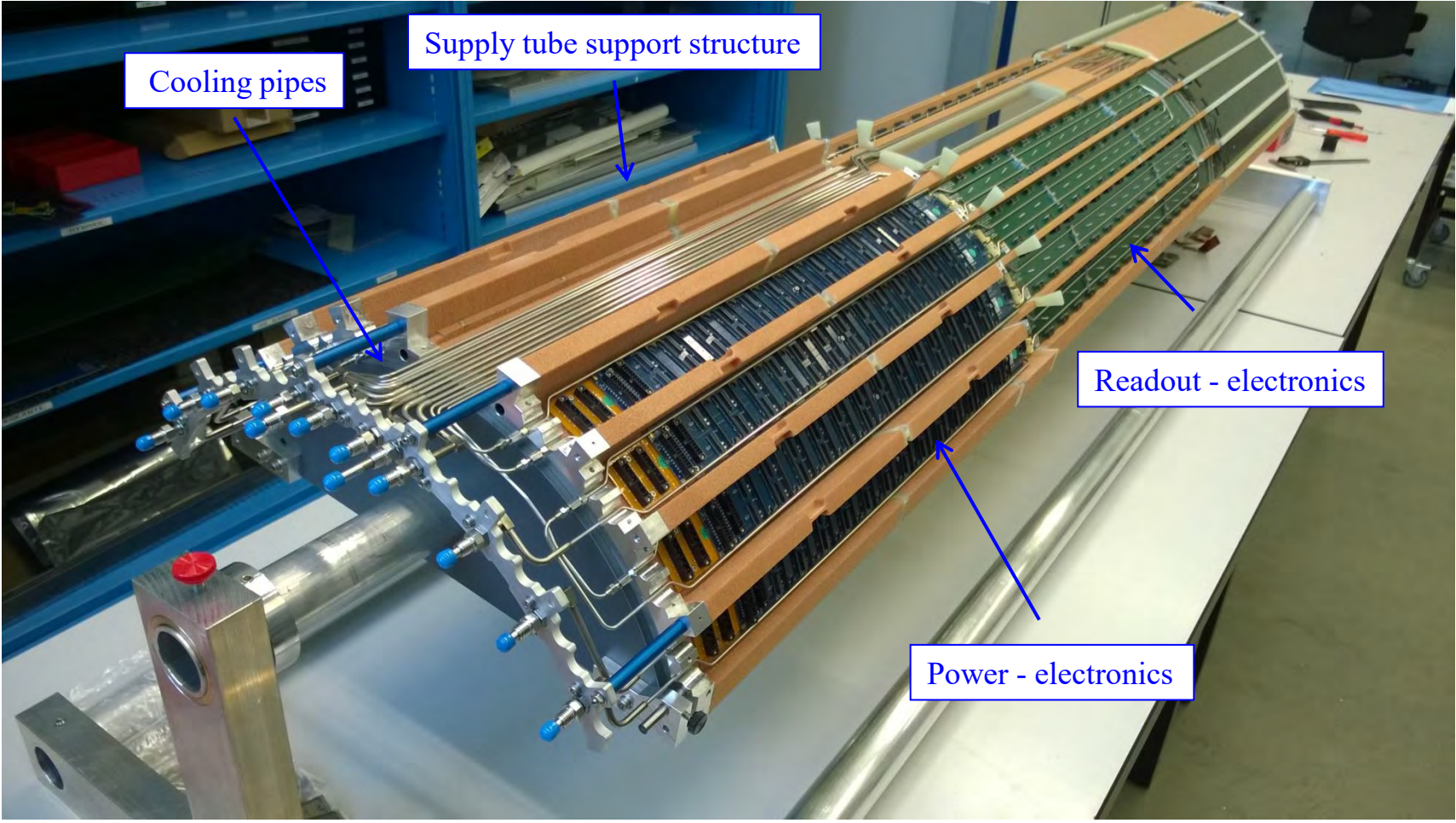
Laser welding of the Supply tube cooling loops

Completed Supply tube cooling systems after the passed pressure test at Createch
Test pressure: 200 bar



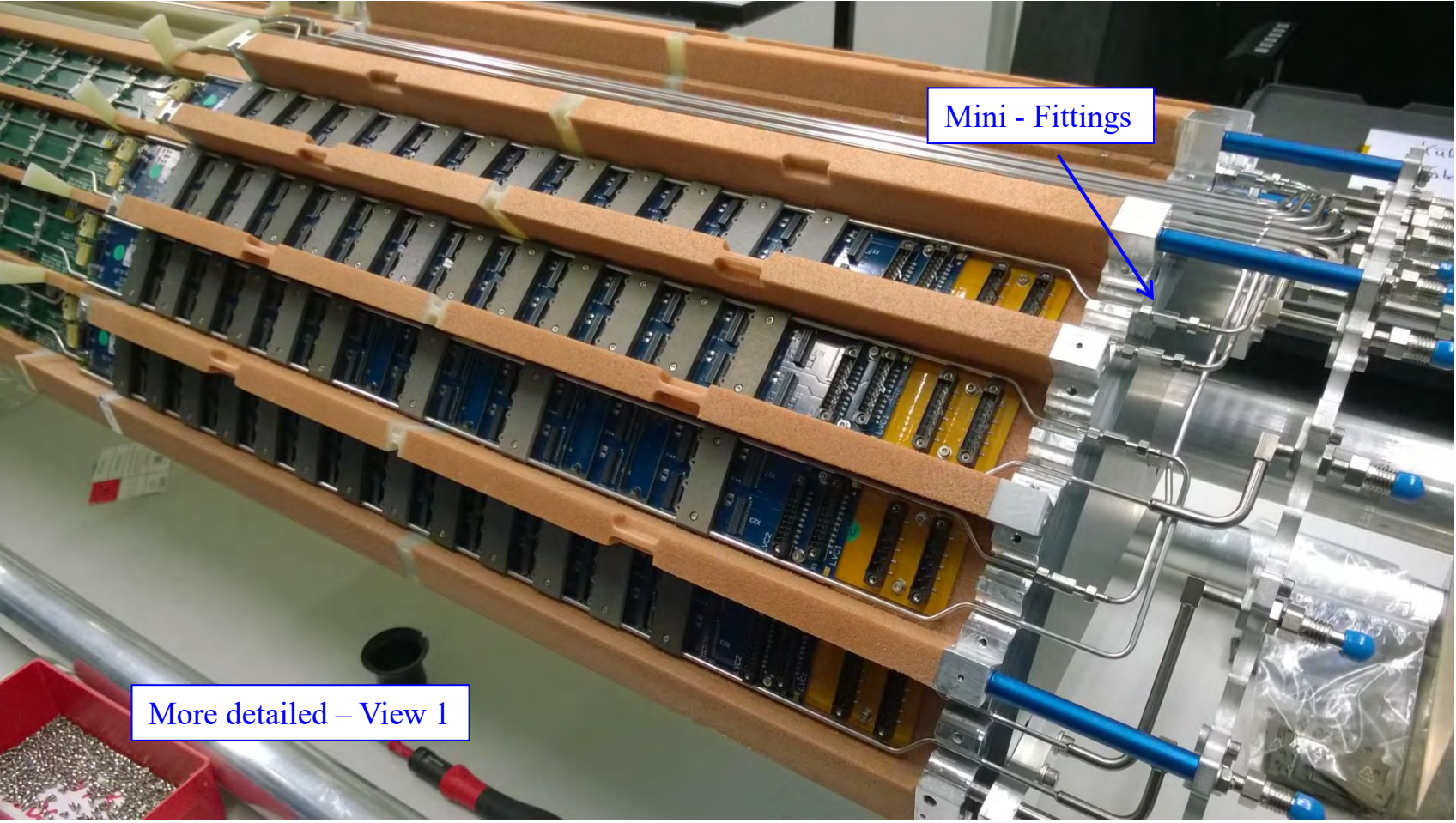
Production of the cooling system Intergration of cooling system

Integration of the Supply tube cooling loops on the Supply tube support structure



Production of the cooling system Intergration of cooling system

Integration of the Supply tube cooling loops on the Supply tube support structure



Production of the cooling system Intergration of cooling system

Integration of the Supply tube cooling loops on the Supply tube support structure



More detailed – View 2

Production of the cooling system Intergration of cooling system

Integration of the Supply tube cooling loops on the Supply tube support structure

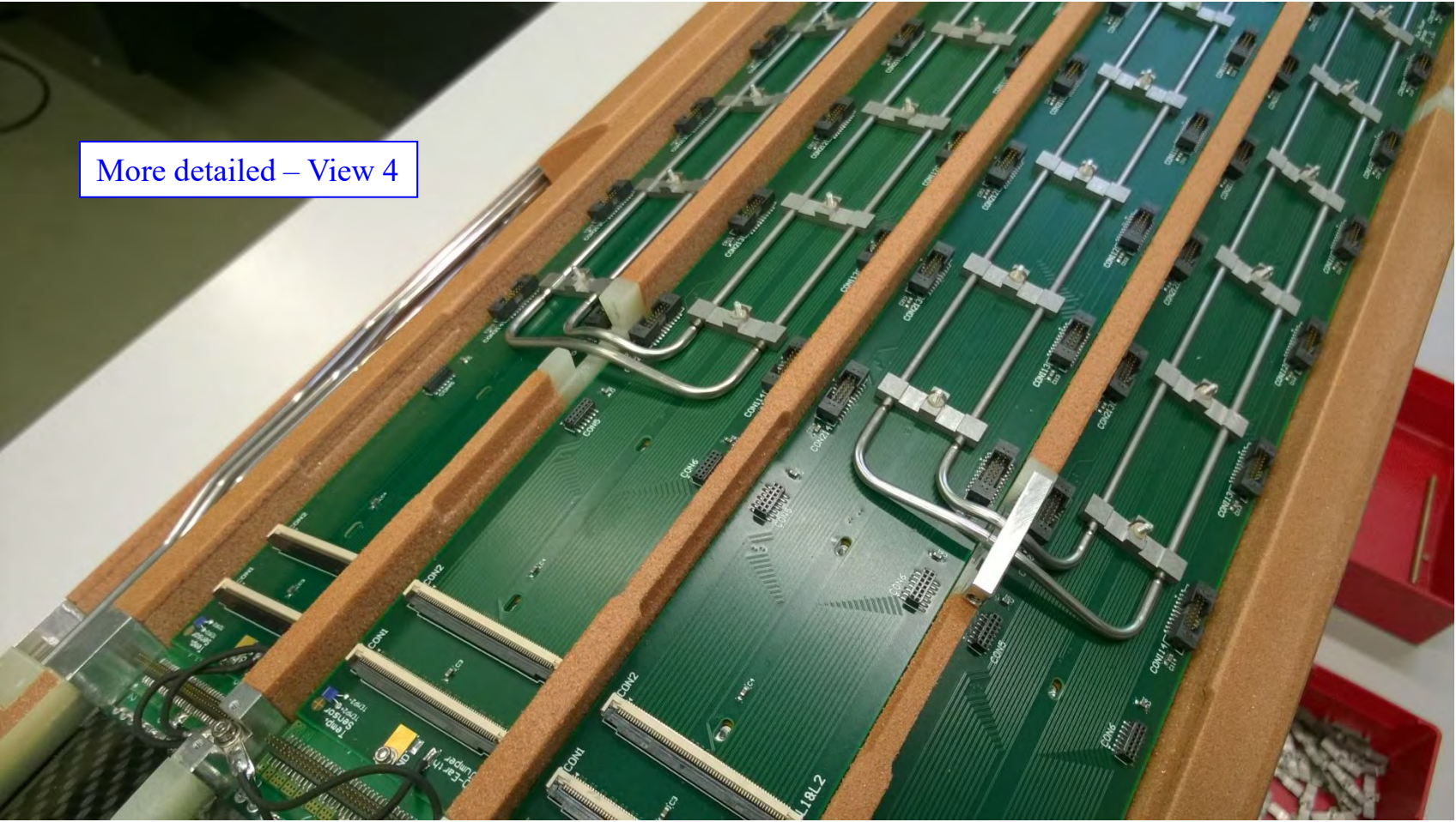


More detailed – View 3

Production of the cooling system Intergration of cooling system

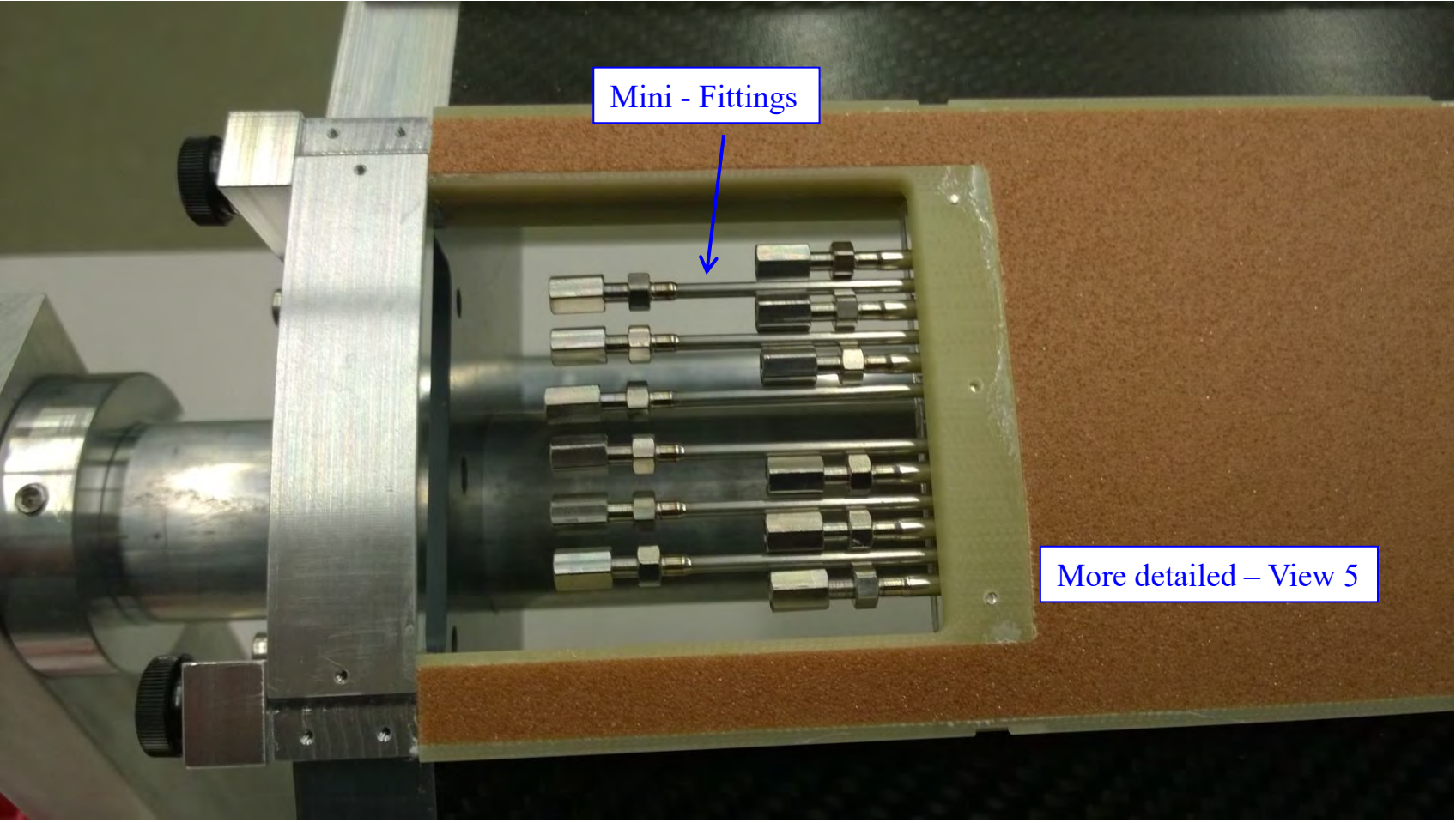
Integration of the Supply tube cooling loops on the Supply tube support structure

More detailed – View 4



Production of the cooling system Intergration of cooling system

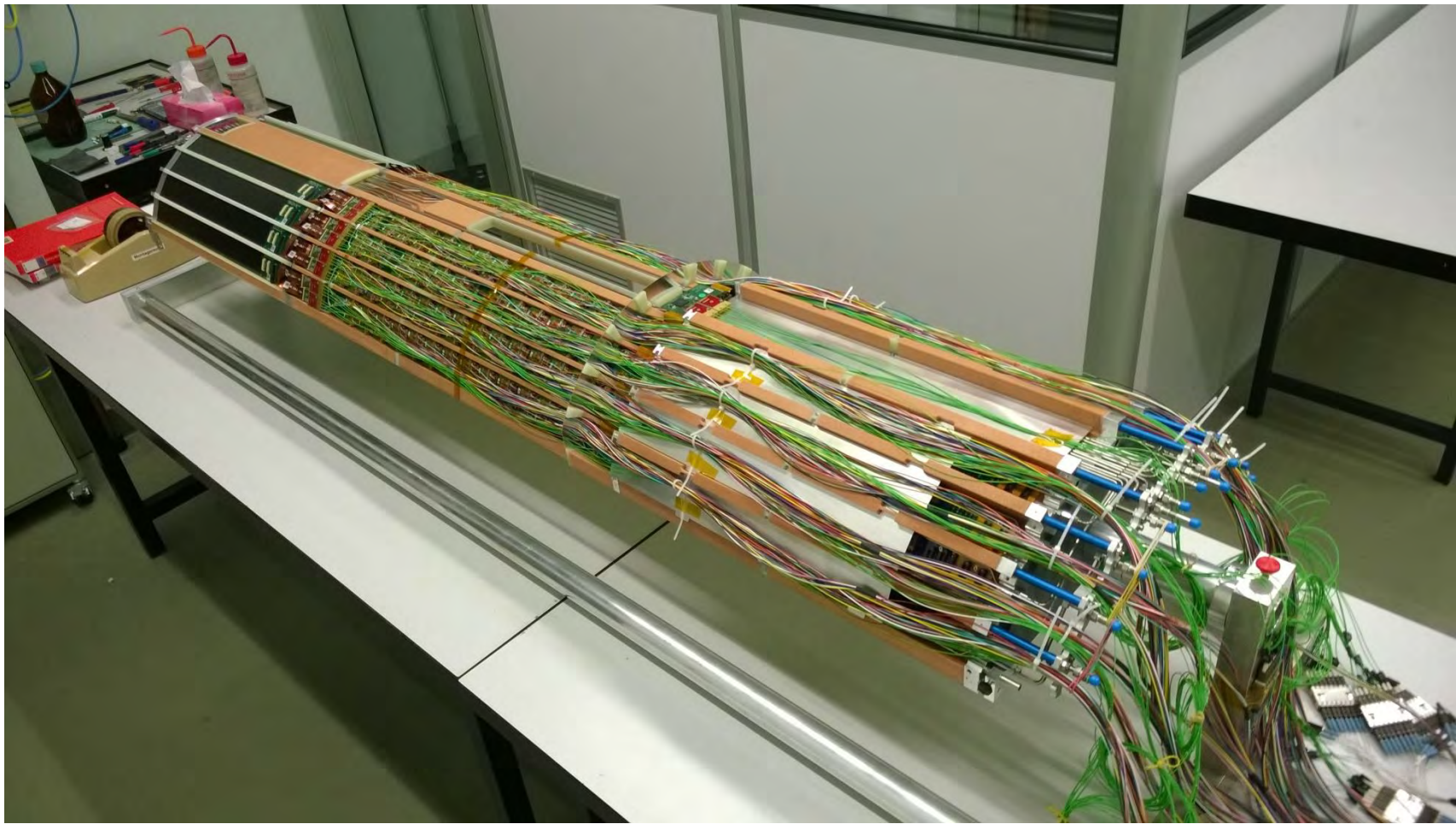
Integration of the Supply tube cooling loops on the Supply tube support structure



More detailed – View 5

Production of the cooling system Intergration of cooling system

Completed Supply tube structure

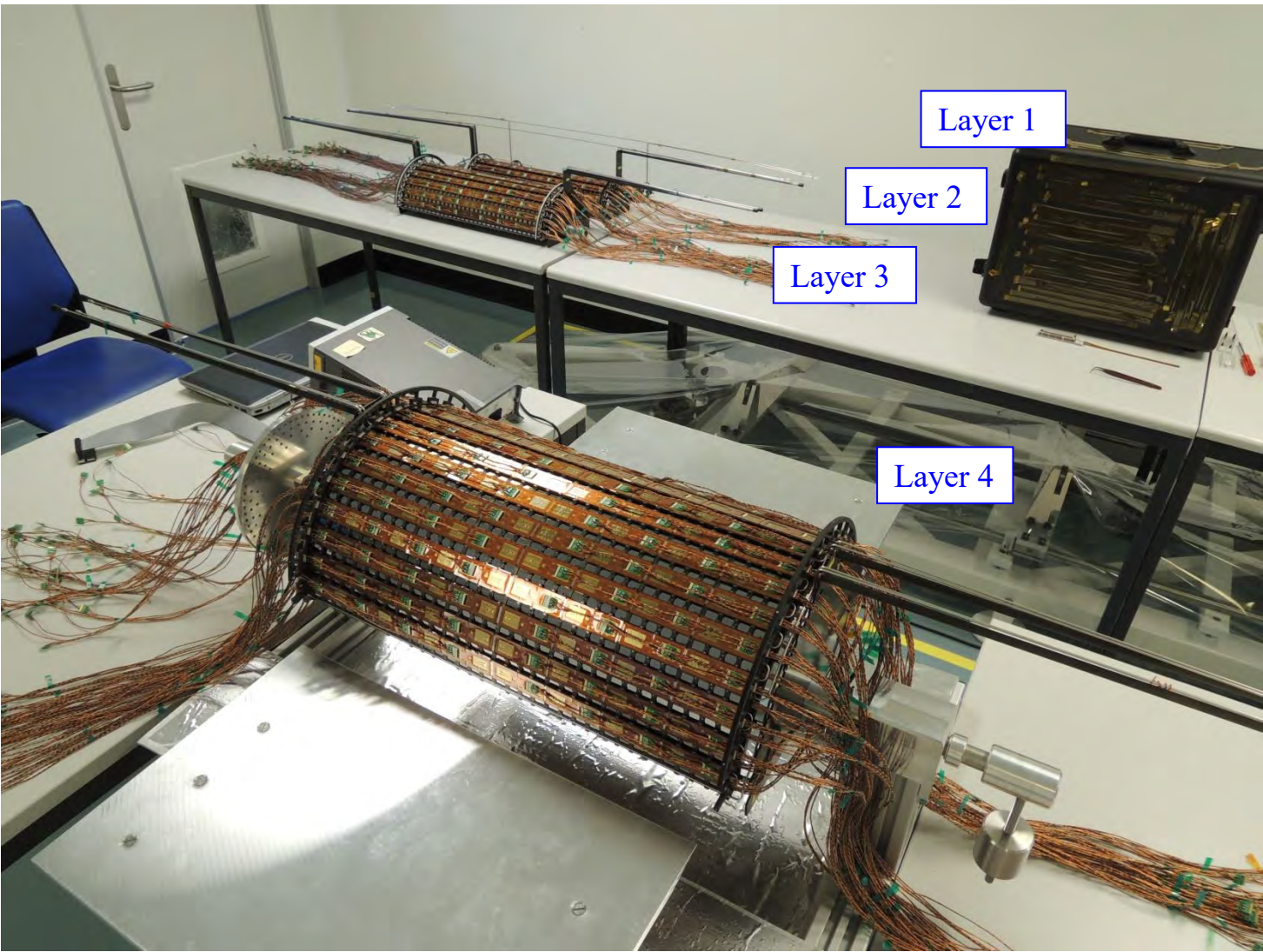


Production of the cooling system Intergration of cooling system

Completed Supply tube structure



Production of the cooling system Intergration of cooling system

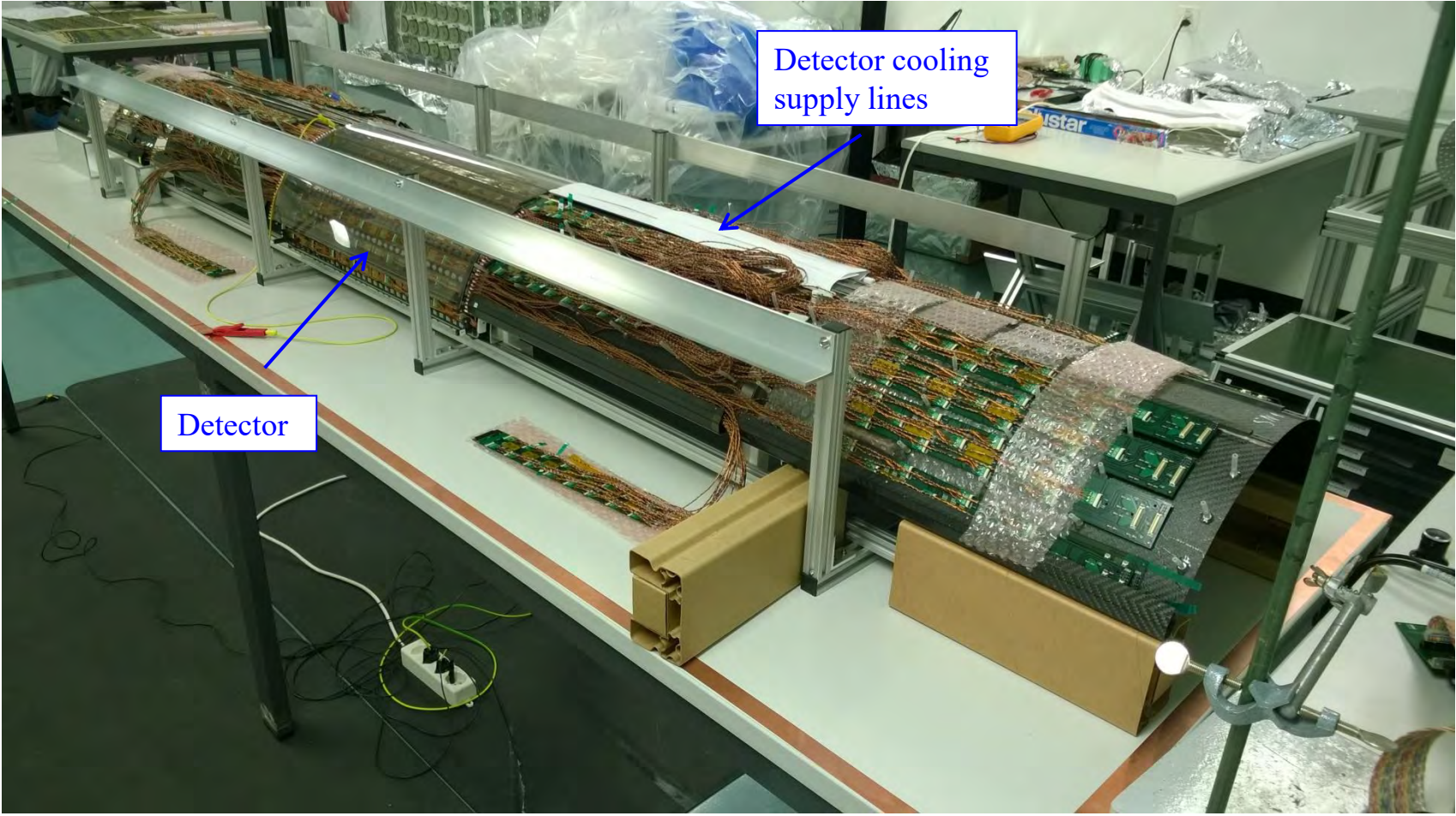


Production of the cooling system Intergration of cooling system

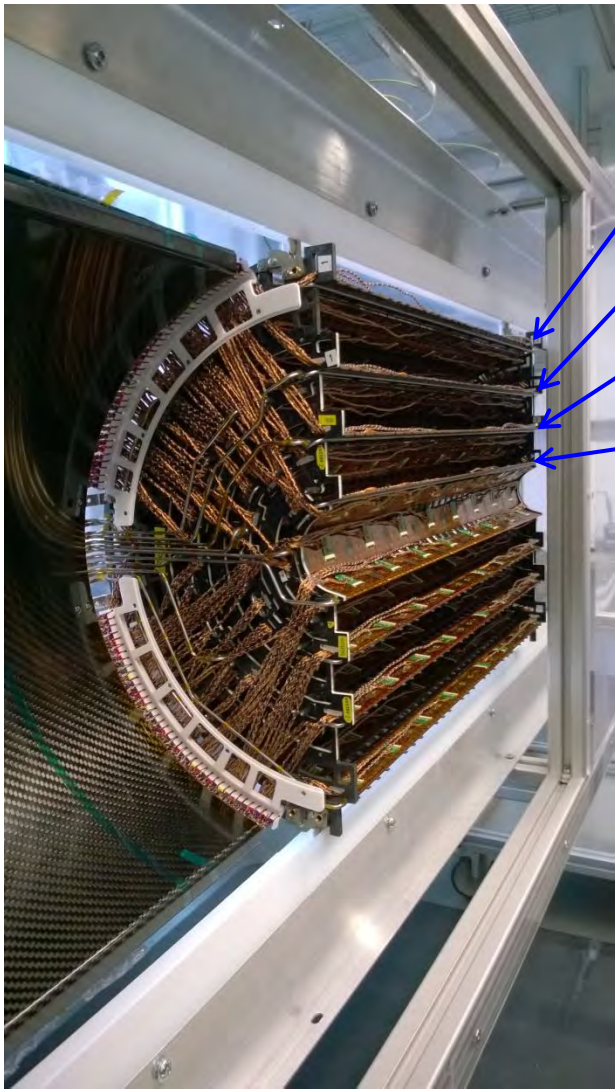
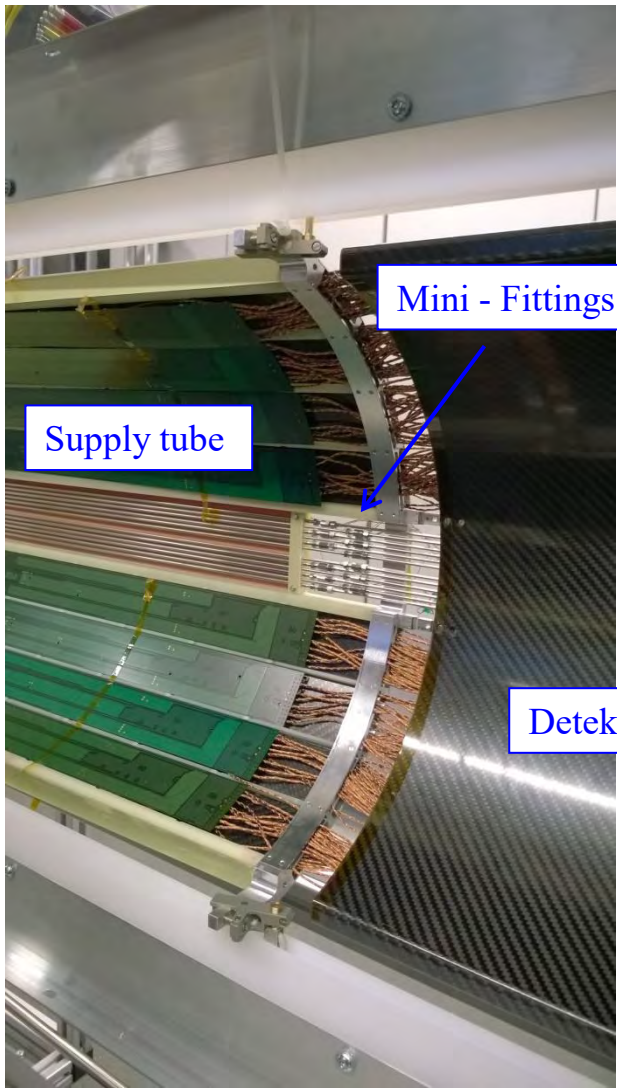
Completed detector halfshell

Detector cooling supply lines

Detector

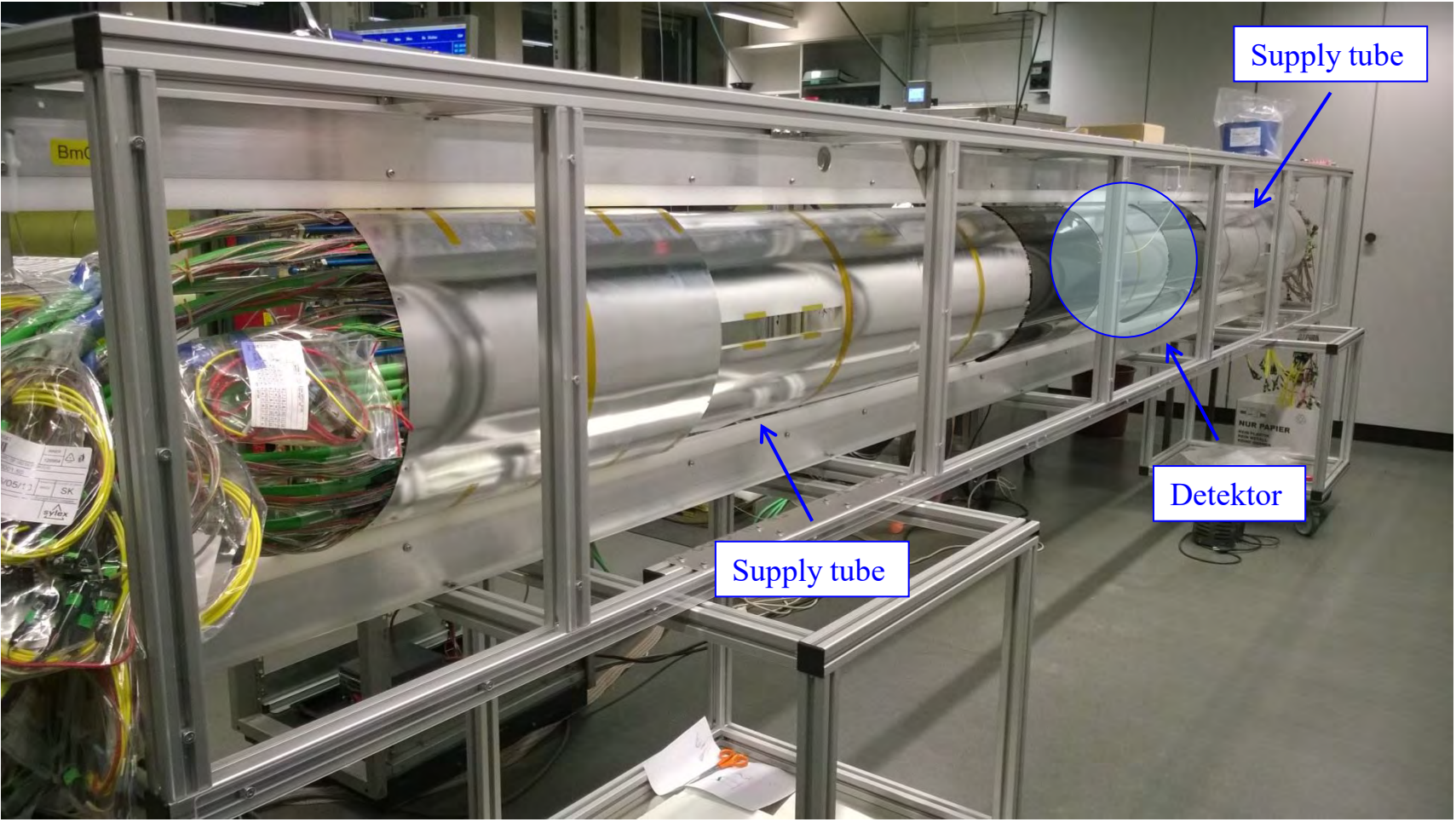


Production of the cooling system Intergration of cooling system



Production of the cooling system Intergration of cooling system

Completed BPIX detector halfshell



Production of the cooling system Intergration of cooling system

Completed BPIX detector halfshell



Production of the cooling system A historical moment... Friday, February 3rd 2017

The completed BPIX detector halfshells ready for the shipping to CERN

