



Experiences from the connector development  
for the current LHCb-Velo and AMS-Tracker  
with extreme high leak tightness requirements.

*Workshop on pipe joining techniques for the ATLAS  
and CMS Tracker Upgrades*

<https://indico.cern.ch/event/721360/overview>

18 May 2018

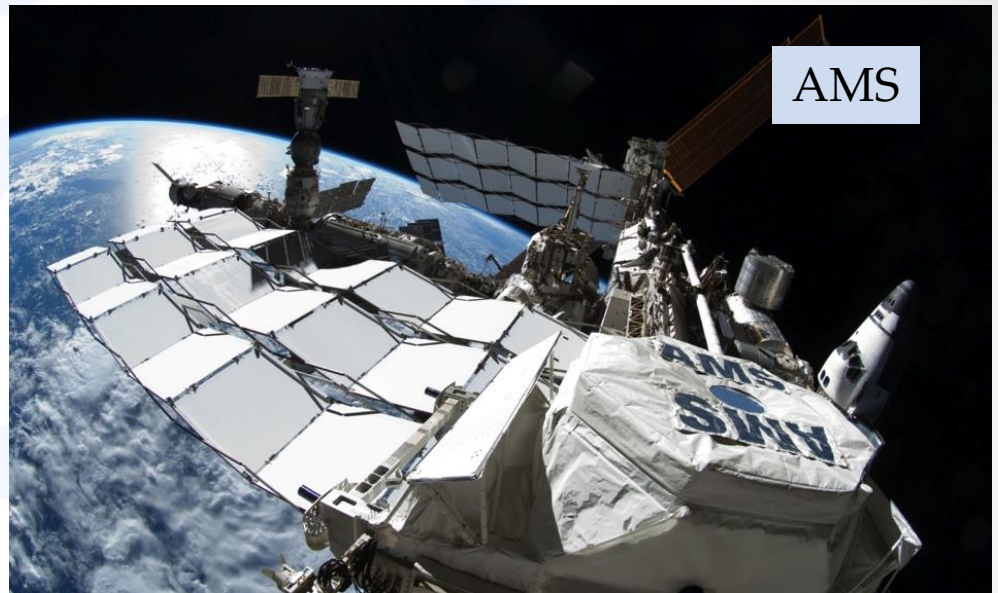
**Bart Verlaat**

# CO<sub>2</sub> cooling developments for AMS and LHCb

LHCb-Velo



AMS



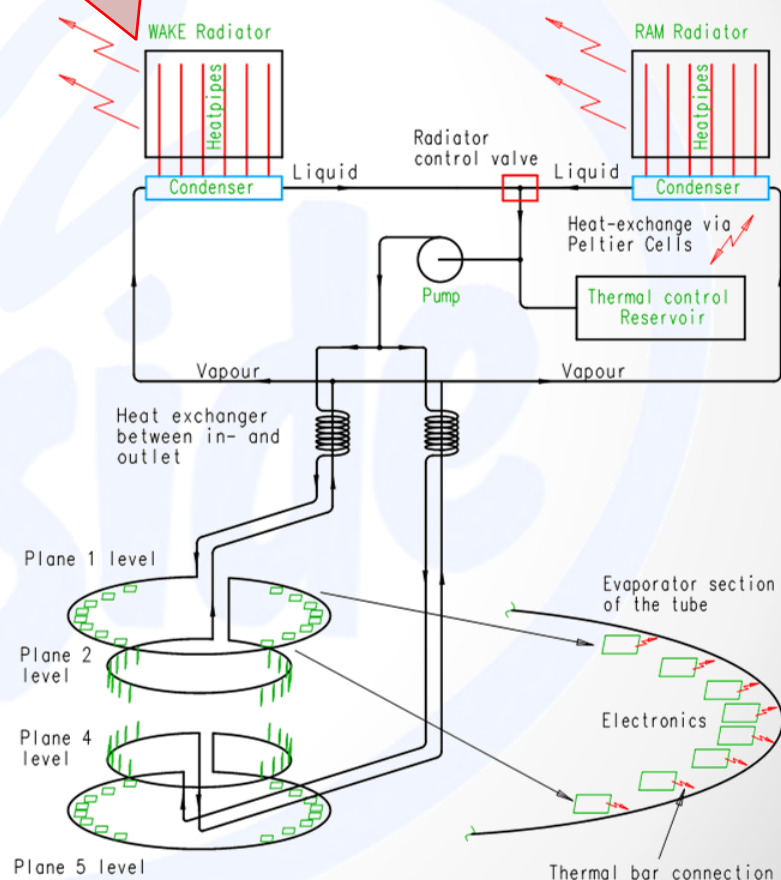
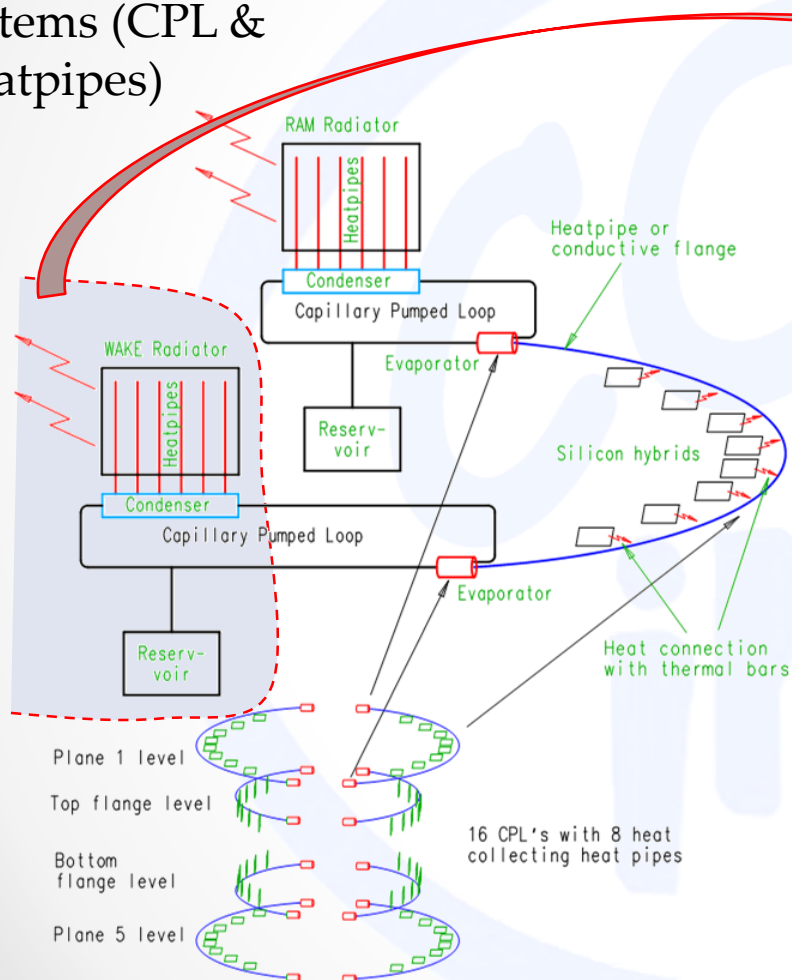
- CO<sub>2</sub> cooling was 1<sup>st</sup> considered in 1998 at Nikhef for the LHCb-Velo cooling to reduce the evaporator tube size.
- CO<sub>2</sub> cooling was adopted by AMS-Tracker in 2000 for the same reason
- For AMS a new circulation concept was developed based on capillary system used in satellite thermal control => 2PACL
- This 2PACL from AMS has become the baseline for all CO<sub>2</sub> systems at CERN so far.

# The birth of the 2PACL cycle for AMS

*Derived from the capillary pumped loop system  
used for satellite cooling*

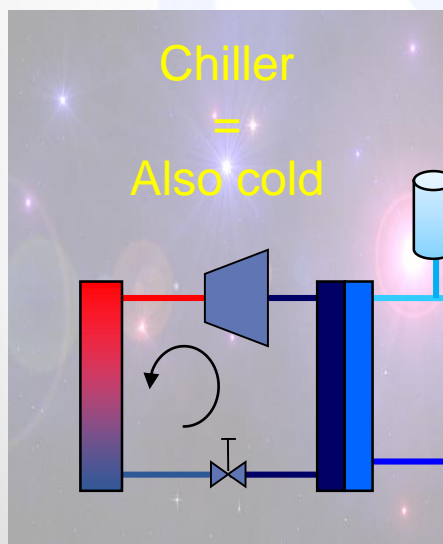
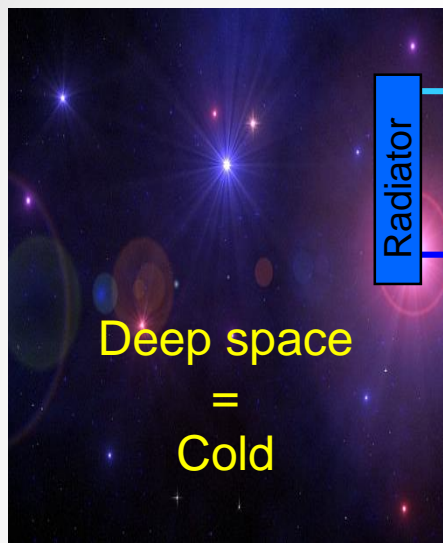
Initial AMS concept a  
cascade of capillary  
systems (CPL &  
Heatpipes)

Capillary pumps replaced by  
a mechanical pump and small  
tubes with CO<sub>2</sub>

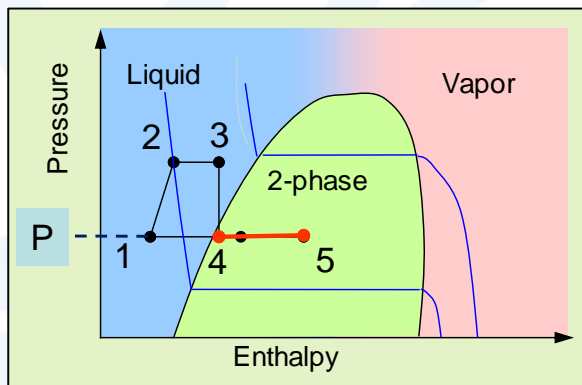
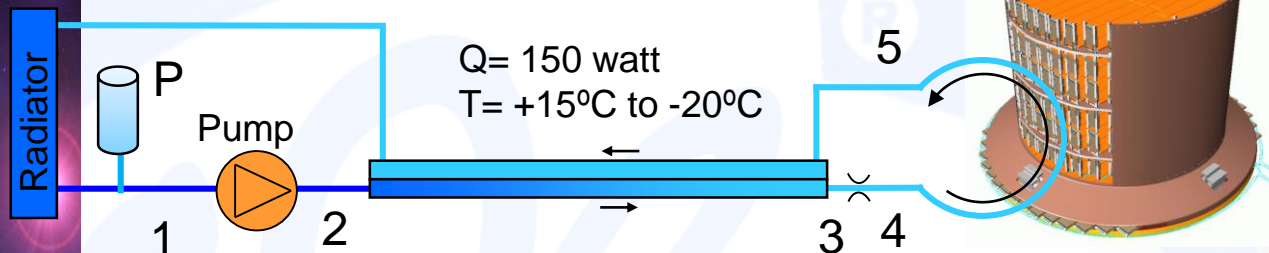


All systems so far at CERN use the 2PACL cycle developed for AMS

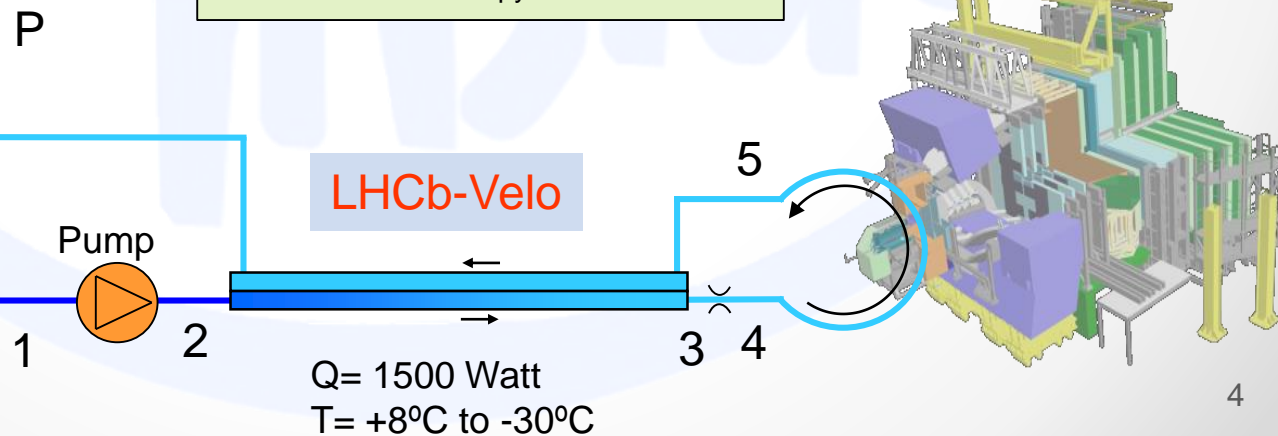
# From AMS to LHCb



## AMS-Tracker



## LHCb-Velo

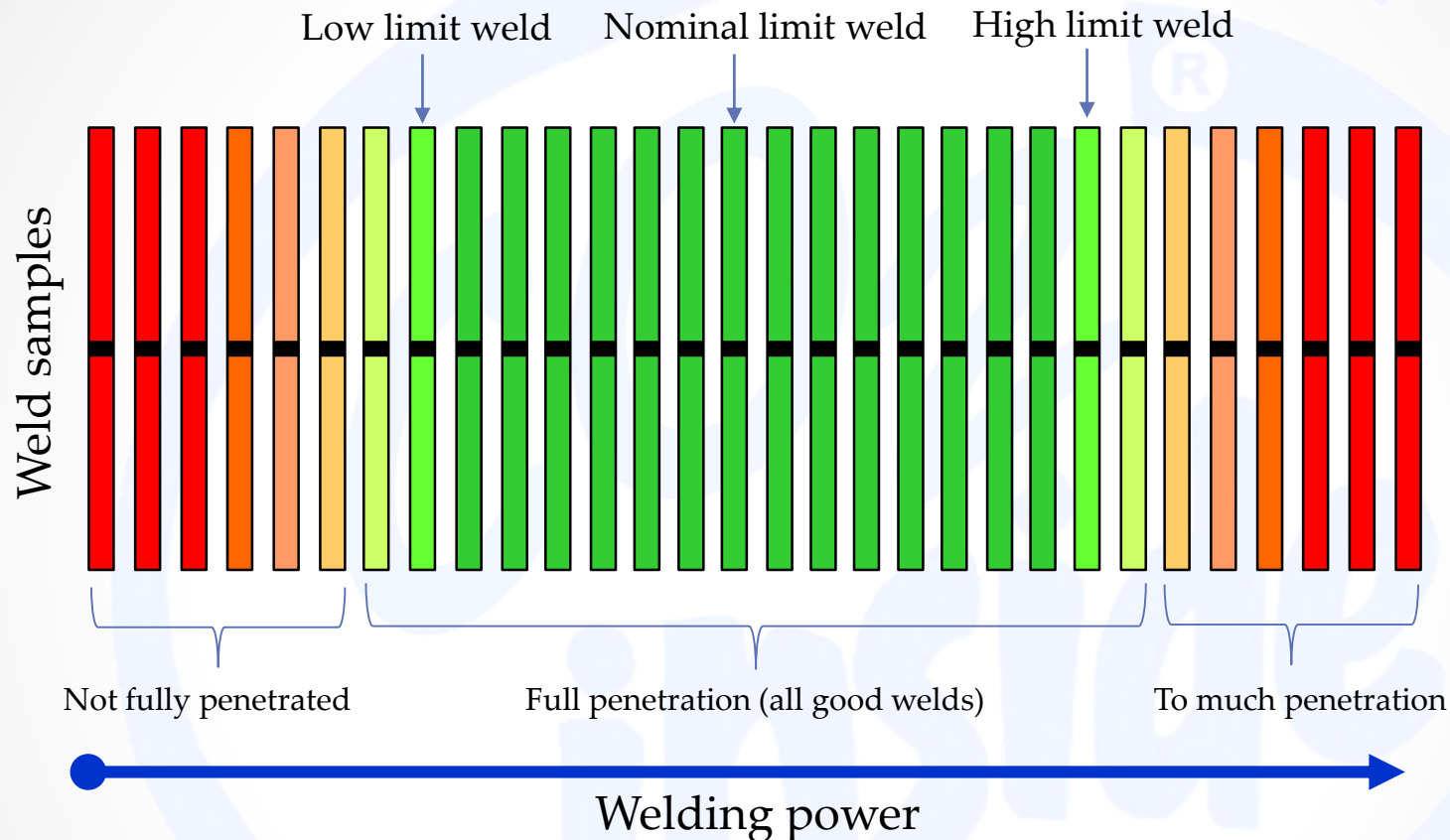


# Requirements for tube and connection design

- Both AMS and LHCb CO<sub>2</sub> piping had to be designed for extreme circumstances:
  - Vacuum environment
  - In accessible
  - Vibration due to launch (AMS)
- Extreme leak tightness requirements
  - AMS is a small volume and no possibility to refill
  - LHCb inside the LHC vacuum system, a small leak would be catastrophic
- Only known and robust joining technologies were chosen
  - Orbital welding of standard 316L tubing
  - Capillary tubing: Vacuum brazing (LHCb) / Laser welding (AMS)
    - Vacuum brazing was not an option for AMS as the process requires more quality control at NASA than welding
  - Connectors: Swagelok VCR (LHCb) / Dynatube (AMS)
- We were obliged to use the NASA welding method and certification.
  - This method was easy and reliable and was also adapted for the construction of the LHCb-Velo cooling

# NASA welding method

*Selecting the right welding parameters for automatic welding*



- The Low-Limit / High limit method is a good method to select the nominal welding parameters and assure that possible fluctuations do not bring the series welds out of spec.

# NASA welding method

## Certification procedure

- Each welding type is pre-qualified with weld samples
  - 5 Low limit welds, 5 nominal welds and 5 high limit welds.
  - From each weld group the following tests are done to qualify the quality
    - All visual inspection (in and outside), all should look similar
    - 1 burst test (>4x design pressure)
    - 1 longitudinal cut and microscopic analyses
    - 3 samples for further research if needed
- Production of a series of welds
  - 3 high, 3 low and 3 nominal pre welds samples.
  - All process welds done at nominal settings
  - 3 high, 3 low and 3 nominal post welds samples.
  - The pre and post weld samples are send to NASA for inspection
    - 1 burst, 1 microscopic and 1 spare for each type
  - All process welds are inspected visually and compared with post and pre weld samples.
  - Dye penetrant tests on process welds
- Due to the automatic welding and the similarity of all welds, no further complex inspection of the welds is needed
- Welding requirements are described in document PRC-0010, Rev A, attached to the indico

PRC-0010, Rev. A

### Process Specification for Automatic and Machine Arc Welding of Steel and Nickel Alloy Flight Hardware

Engineering Directorate

Manufacturing, Materials, and Process Technology Division



July 1999



National Aeronautics and Space Administration

Lyndon B. Johnson Space Center  
Houston, Texas

Verify correct version before use.

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The evaporators were designed for welding

- Thin wall tubes in straight length were laser welded to a thick wall tube weld connector
  - 3mmx0.2 to 4mmx0.7 (both 2.6mm ID)
- After bending and assembly the sections were welded together with orbital welding.
- Tube layout designed for orbital weld head access.

SHELL CHEMICALS, SRTCA

ORBITAL TUBE ARC WELDING PROCEDURE SPECIFICATION (WPS)

WPS Number: ASME/93.1101.1 Revision \_\_\_\_\_ Company / Organization: TIG/BEI  
 Supporting POR no (s): WELD 18 Welding Process(es): Automatic Orbital Tube Gas Tungsten Arc

**BASE and FILLER METAL :**

Material number: 45375853200 Group \_\_\_\_\_ To Material number: 45375853200 Group \_\_\_\_\_  
 Material spec., type, and grade: 14404 DIN17458 D4/T3 To Material spec., type, and grade: 14404 DIN17458 D4/T3  
 Base metal thickness range \_\_\_\_\_  
 Pipe / Tube diameter: 4.00 Wall thickness: 0.7  
 Filler metal F No: X AWS Class & Spec. \_\_\_\_\_  
 Consumable Insert, AWS Class & Spec. \_\_\_\_\_

**WELDING SET-UP :**

Power Supply (Model): SWAGelok M100-2.1.1728  
 Weld Head(s): IGT  
 Joint Position(s): \_\_\_\_\_  
 Turgation type: CWS 040-705 Diameter: \_\_\_\_\_ Arc gap: 0.64  
 Tip diameter: 1MM Tip angle: \_\_\_\_\_  
 Weld direction: ROTATION HORIZ Pulse Mode: \_\_\_\_\_

**WELD SETTINGS :**

Start current (amps): 13.3 Upslope (sec.): \_\_\_\_\_  
 Level Slope Time (sec.): 10-10 Downslope (sec.): .5  
 Start Delay (sec.): 0.3 Override (%): \_\_\_\_\_  
 Finish Current (amp): 8.6 Fixture Speed (RPM): 1201  
 Weld Time (on/off): \_\_\_\_\_ Stop Mode (on/off): \_\_\_\_\_  
 Wire Mode (on/off): \_\_\_\_\_

**NOMINAL HEAT INPUT CONDITIONS :**

Level	Time (sec.)	Weld		Allowable Current (amps) Settings		Pulse Rate (pps)	Pulse Width (mm)
		+5%	-5%	HIGH	LOW		
1	_____	_____	_____	_____	_____	_____	_____
2	_____	_____	_____	_____	_____	_____	_____
3	_____	_____	_____	_____	_____	_____	_____
4	_____	_____	_____	_____	_____	_____	_____

**TECHNIQUE :**

Joint cleaning: ETHANOL  
 Other: \_\_\_\_\_

We certify that this welding procedure and schedule were qualified in accordance with the requirements of NASA / JSC PRC-0010.

Prepared By \_\_\_\_\_ Org. \_\_\_\_\_ Date \_\_\_\_\_  
 Approved \_\_\_\_\_ Org. \_\_\_\_\_ Date \_\_\_\_\_

**GAS :**  
 Torch/Head gas(es): ARGON 4.8  
 % Composition: 4.8 Flow Rate: 6 LPM  
 Prepurge Time: 15 SEC Postpurge Time: 15 SEC  
 Backing gas(es): ARGON 4.8  
 % Composition: 4.8 Flow rate: 1.77 MMWVC  
 Prepurge Time: 15 SEC Postpurge Time: 15 SEC

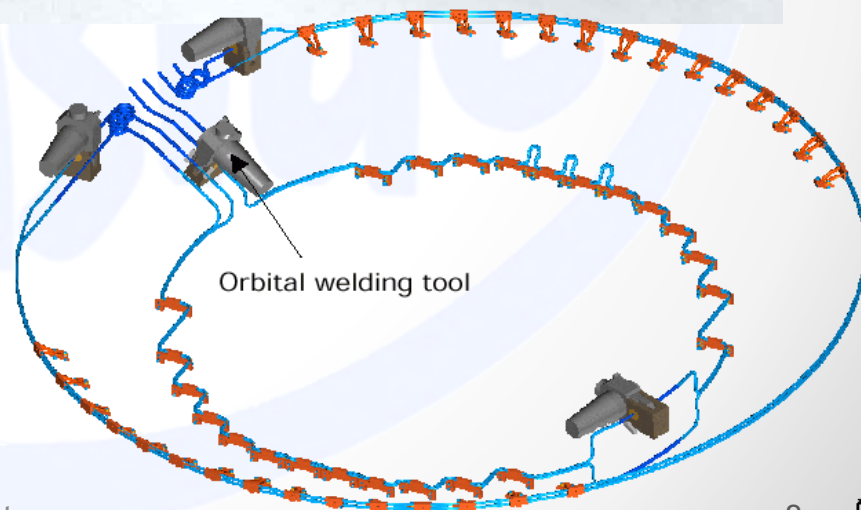
**PRE and POSTWELD HEAT**

Preheat temperature minimum: \_\_\_\_\_  
 Preheat temperature maximum: \_\_\_\_\_  
 Interpass temperature minimum: \_\_\_\_\_  
 Interpass temperature maximum: \_\_\_\_\_  
 Postweld Heat Treatment: \_\_\_\_\_

**JOINT DESIGN**

Joint type: \_\_\_\_\_  
 Groove angle: \_\_\_\_\_ Radius: \_\_\_\_\_ Land: \_\_\_\_\_  
 Root opening: \_\_\_\_\_ Size of fillet: \_\_\_\_\_  
 Socket weld pull-back: \_\_\_\_\_

**SETUP SKETCH -**



# AMS laser weld

Welds were done by the Shell Technology Centre in Amsterdam (Shell-STCA)

Laser welded with a Haas™ Neodinium-YAG pulsed Laser

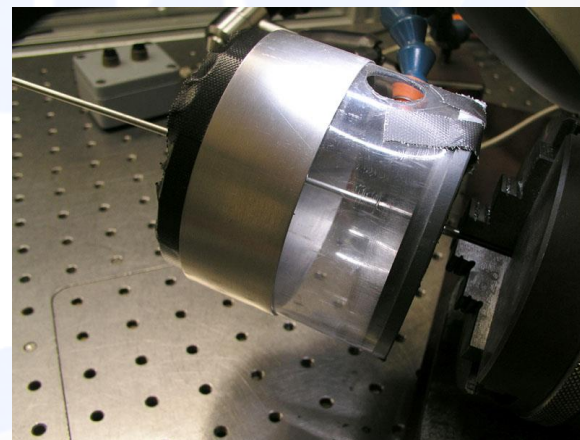
- Laser spot welds
- Argon backing gas
- No material addition



17/03/2010



D. Verlaet



# Laser weld pre-qualification

## Laser Welds for AMS 02 TTCS Evaporator

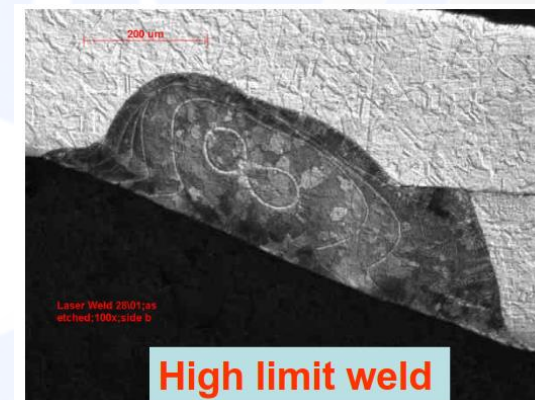
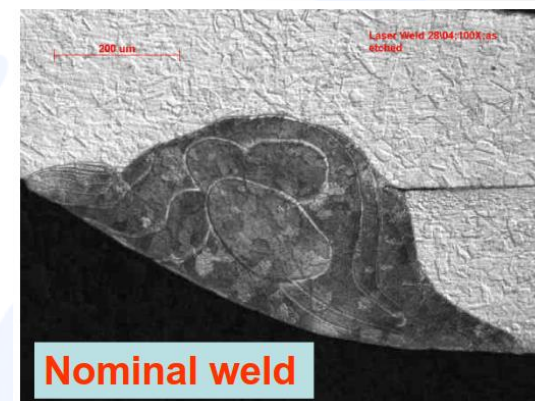
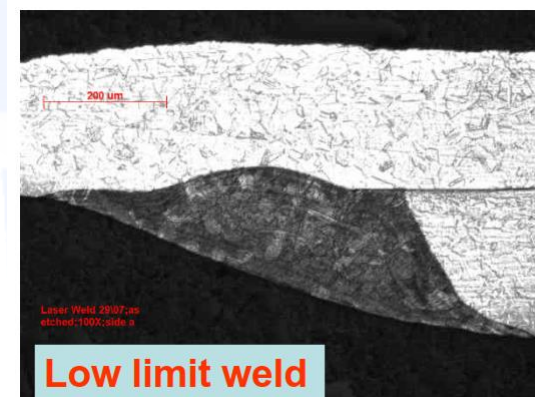
Base material : 316L

Specimen Traceability Numbers: ASM006\04\04\28\7,  
ASM006\04\04\28\4, ASM006\04\04\28\1

Three cross-sections were taken transverse to the laser weld, mounted, ground and polished. Then, the six weld locations on the cross-sections were electrolytically etched with 10% oxalic acid and examined on the metallograph.

The laser welds were judged to be sound and of high quality. No metallurgical anomalies were detected at magnifications up to and including 1000X. There was no notches, no lapped material, no pores, no voids, and no cracks detected. Penetration and fusion were proper for this type of socket weld.

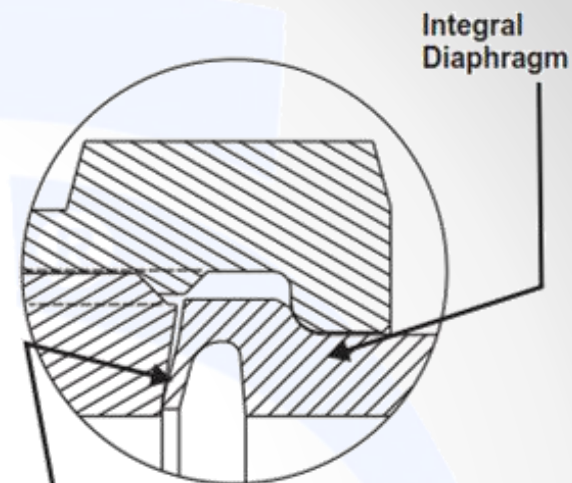
John Figert  
Metallurgical Engineer, P.E.  
Lockheed Martin Space Operations



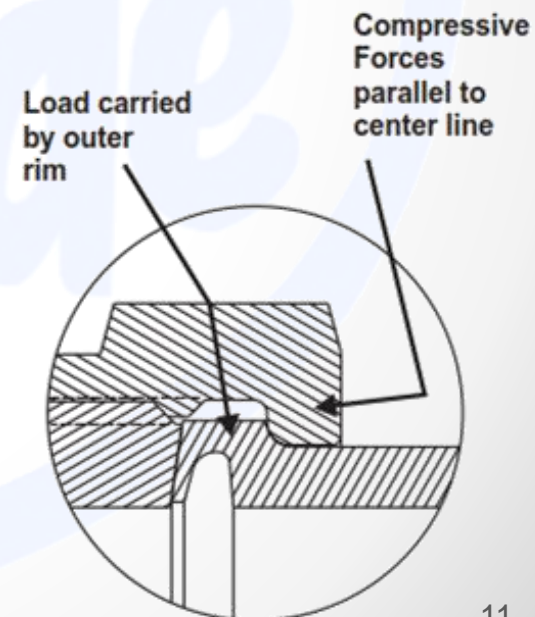
## Dynatube® Fittings



Dyna tube fittings 15-5PH SS with CRES 345 SS intermediate weld piece



Primary Seal at inner edge



Material	Designation	Material Code	Specification	Operating Temp.
Titanium	6AL-4V STA	T	AMS 4965	-65°F to 650°F
Stainless Steel	17-4PH H1075	P	AMS 5643	-110°F to 650°F
Stainless Steel	15-5PH H1075	S	AMS 5659	-110°F to 650°F
Inconel*	Alloy 718	N	AMS 5663	-320°F to 1300°F

\*Trademark

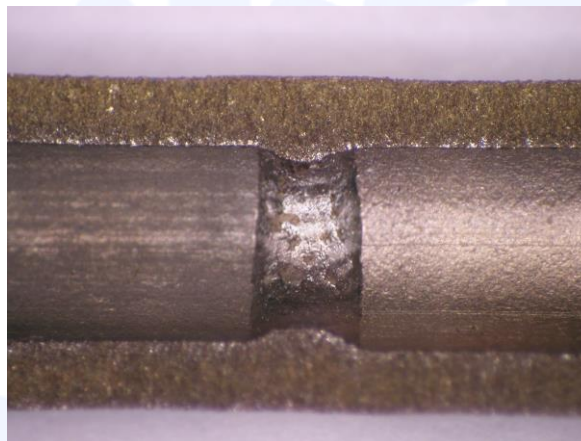
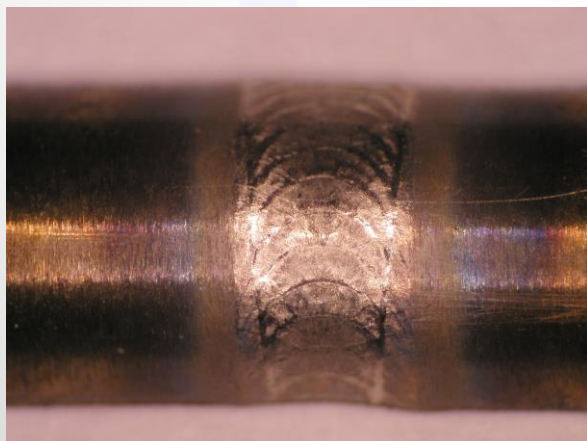
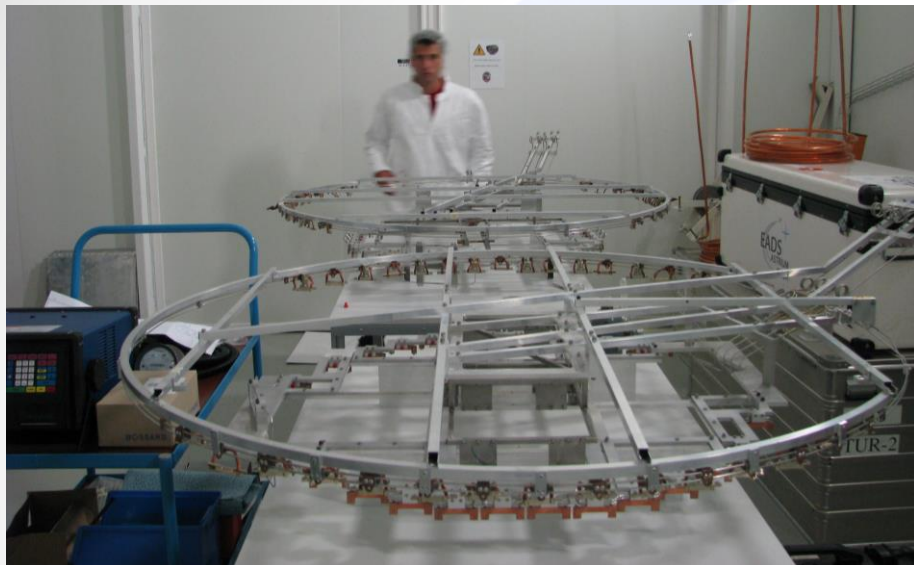


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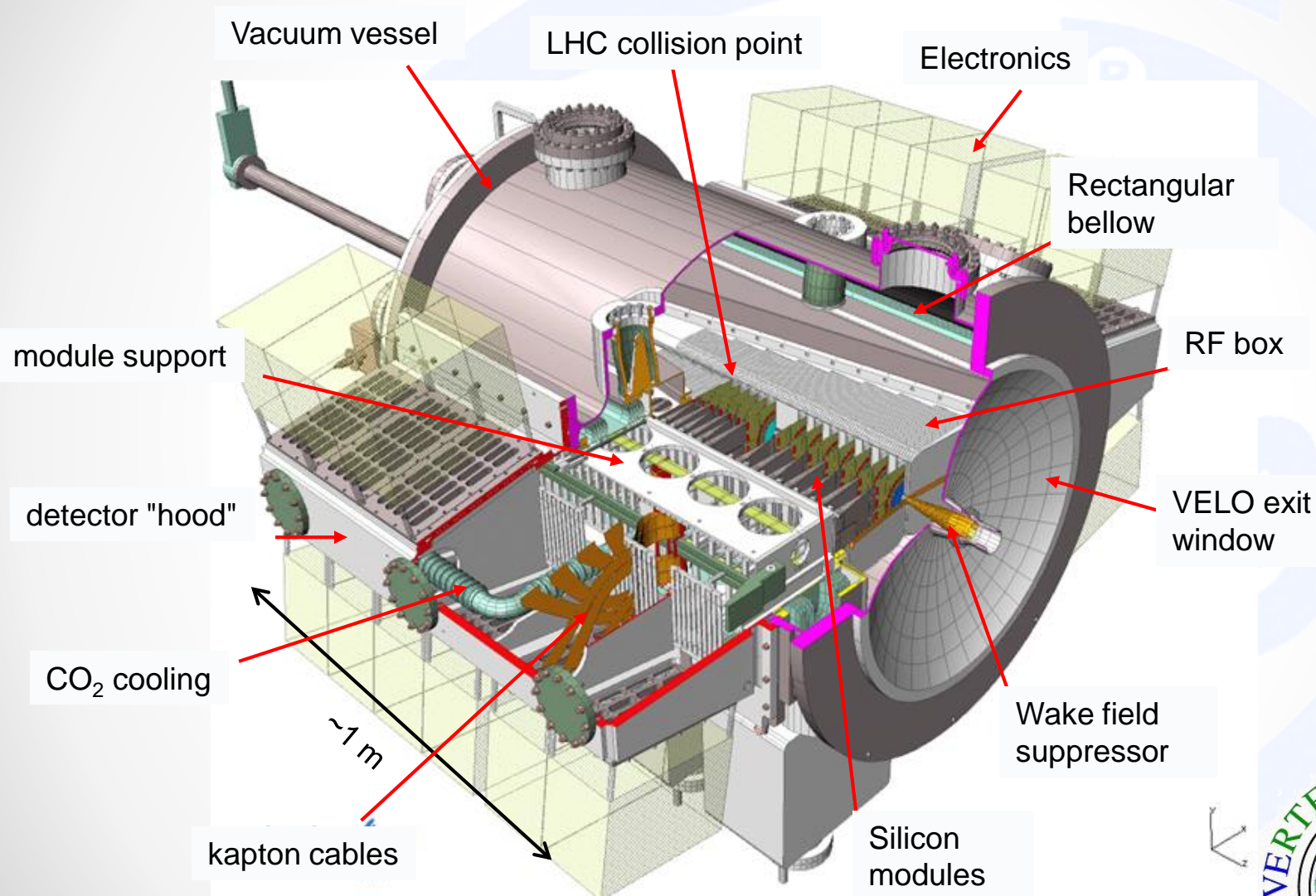
Parker Hannifin Corporation  
Stratoflex Products Division  
Jacksonville, Florida

# AMS Orbital welding

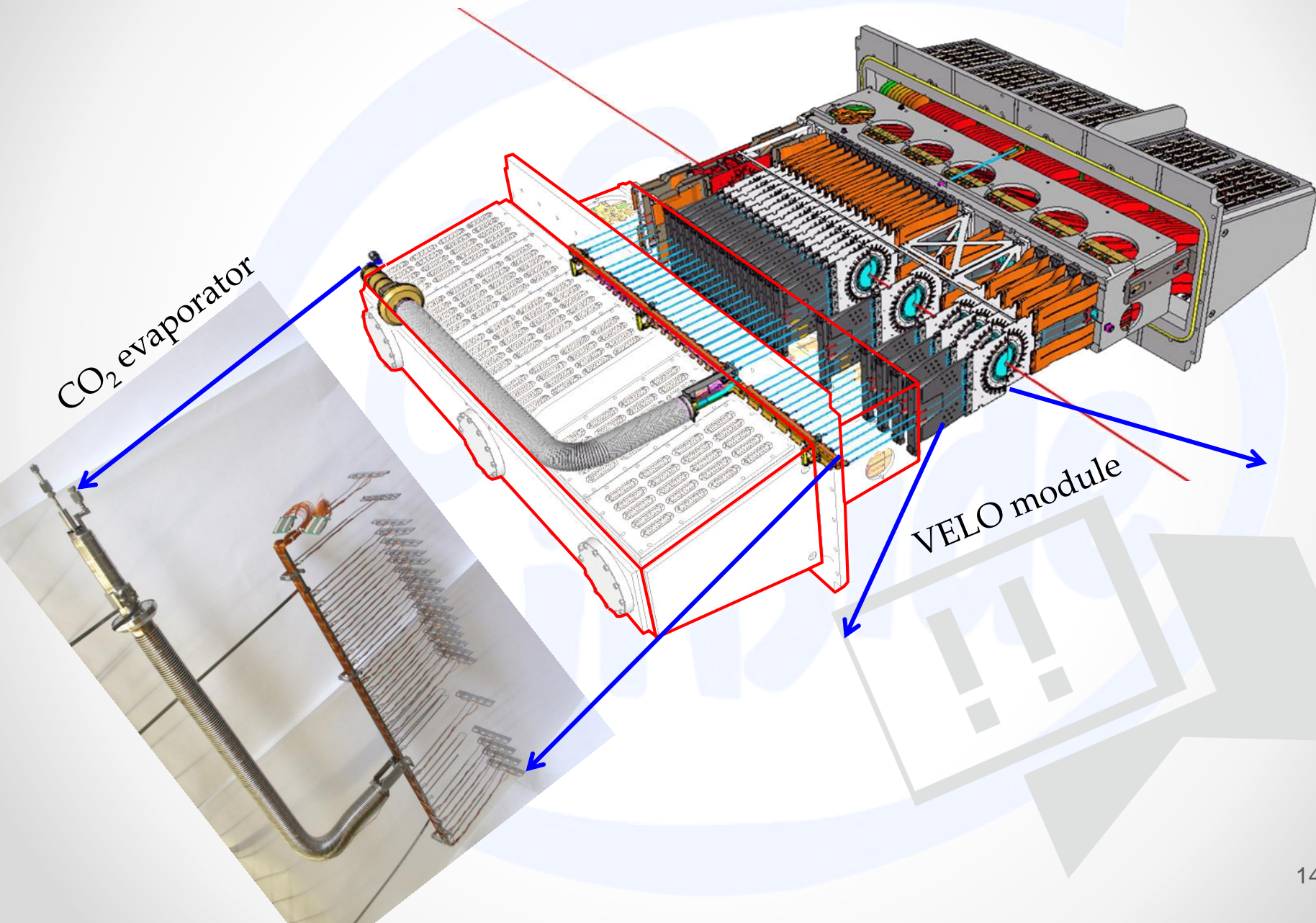
- CRES 316L 4x0.7 mm orbital weld
- Welded with a Swagelok/Cajon™ orbital welding system
- Welding head: Cajon™ CWS-5H-B
- Fixture block: Cajon™ CWS-5TFB
- Collets: Cajon™ CWS-5UCI-04mm



# LHCb Velo overview



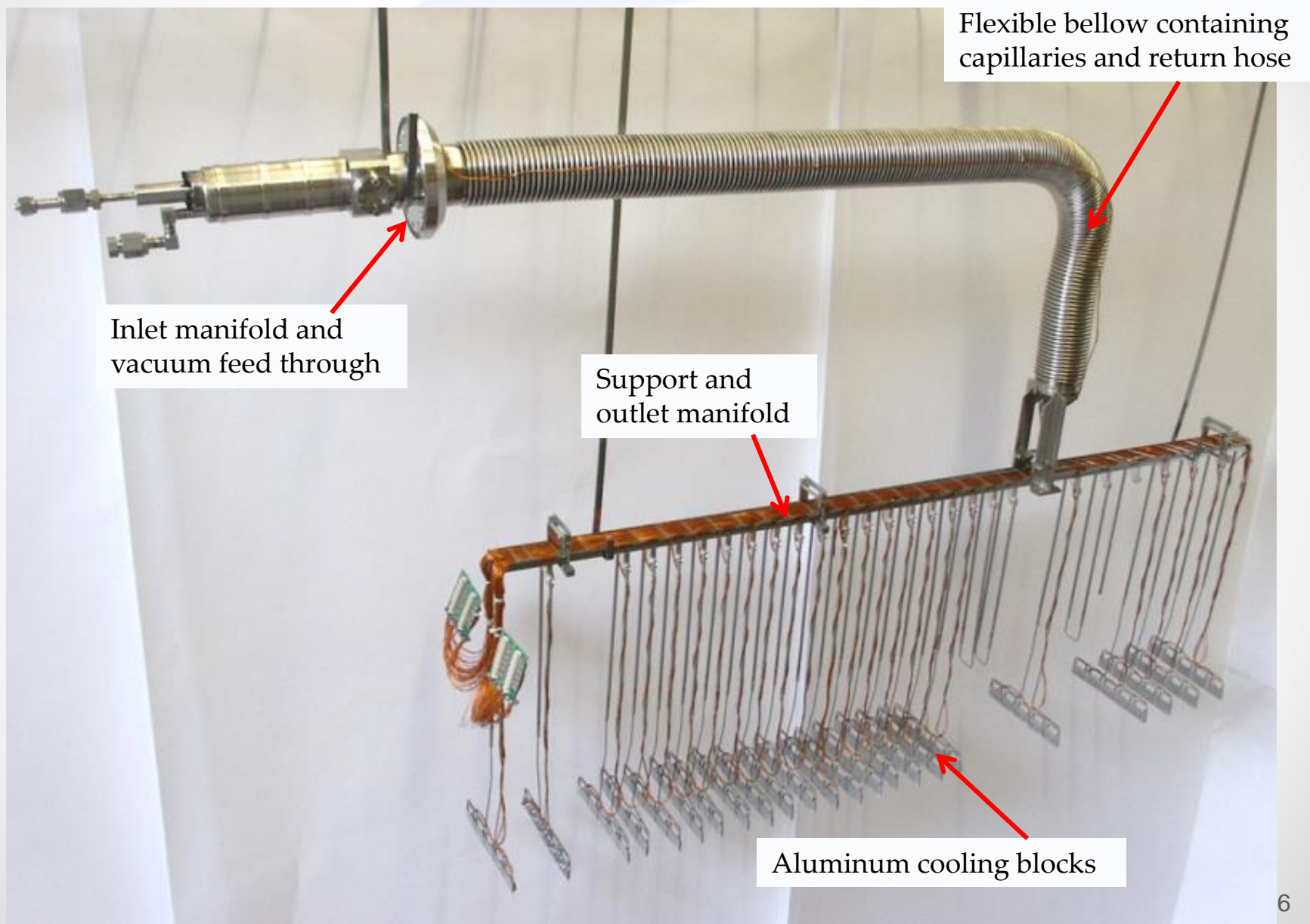
# VTCS Evaporator



# VTCS evaporator

- The VELO evaporator is inside the LHC vacuum system
- Only very reliable joining techniques allowed
- No connectors inside the vacuum system!
- Designed for orbital welding and vacuum brazing only
  - Vacuum brazing Nicrobraz EL-36
  - Swagelok Series 5, 4 and 8 orbital welding tools
  - Welding tool space and access taken into account in 3D model
  - Models of weld heads can be downloaded at:  
<https://www.nikhef.nl/pub/departments/mt/projects/ams/SiTracker/ModelExchange/Orbitaal/>
- Sub elements are brazed first and all orbital welded together
- The rest of the system (plant etc) made with orbital welding and VCR connectors (1/4" VCR and 1/4" HVCR)

# VTCS evaporator



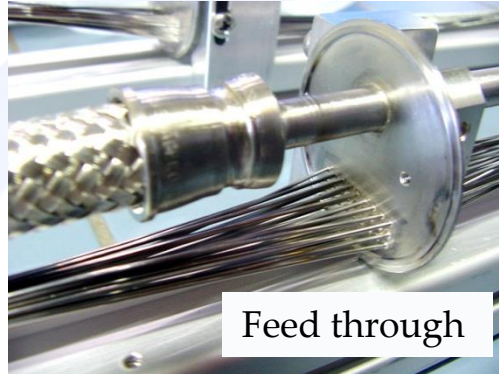
# LHCb Velo evaporator joint overview

		Welding method	Number weldings per unit	Total number weldings	Part number	Material	Fixing weld	Support tool	Remarks
<b>A</b>	<b>Balg assembly</b>								
A1	Ø4*0.7mm orbital weld connectors to Ø1x0.25mm capillaries (ca 2m)	Nicro-Braz EL-36	27	54	16-14	316Ti-321	Y	Y	High frequency oven
A2	3/8"x0.035" return bellow flange	3/8" Orbital weld	2	4	08-10-13	316L-316L-316L	N	N	Orbital head 8 series incl. Fixing block
A3-1	Capillaries (A1) en 3/8"(A2) feedthrough in flange	Nicro-Braz EL-36	1	2	14-13-12	321-316L-316L	Y-12-13	Y	High frequency oven
A3-2	Capillaries (A1) en 3/8"(A2) feedthrough in flange	Nicro-Braz EL-36	1	2	14-08-01	321-316L-316L	Y-01-08	Y	High frequency oven
A4	Outer below to A3-1	TIG-welding	1	2	04-12	316L-316L	N	N	
A5	Base flange to A4	TIG-welding	1	2	03-04	316L-316L	N	N	
A6	Tube on base flange	TIG-welding	1	2	03-?	316L-316L	N	N	
A7	Length determination								
A8	Heatshield to capillary flange	TIG-welding	1	2	01-02	316L-316L	N	N	
A9	Heatshield A8 to A6	TIG-welding	1	2	02-?	316L-316L	N	N	
A10	3/8" cajon connector with weld elbows to return	3/8" Orbital weld	3	6	06-07-08	316L-316L-316L	N	N	Orbital head 8 series incl. Fixing block
	Orbital			10					
	TIG			10					
	Nicro-Braz EL-36			58					
	Laser Fixing weld			56					
	Total number weldings			134					
<b>B</b>	<b>Manifold assembly</b>								
B1	27 Ø4mm pipes in ca 1m manifold with lid	Brazing	1	2					Vacuum oven
<b>C</b>	<b>Cooling block assembly</b>								
C1	2x Ø4*0.7mm orbital weld connections to Ø1.5x0.25mm capillaries	Brazen	27	54					High frequency oven
<b>D</b>	<b>Total assembly</b>								
D1	3/8" Return tube welding to manifold	3/8" Orbital weld	1	2					Retal of serie 8 weldhead with 3/8" fix block
D2	Spot weld of weld connectors (A1) to manifold (B)	TIG fixing	27	54					Hand weld
D3	Orbital weld of coolingblock (C) assemblies to manifold (B)	4mm Orbitaal lassen	81	162					Retal of serie 4 weldhead with 4mm fix block

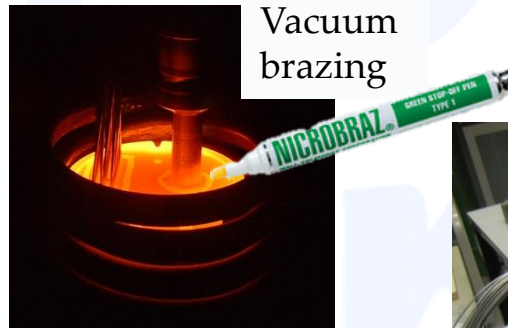
# VTCS assembly

## *Flexible in and outlet below*

Brazed  
capillary  
assembly



Feed through

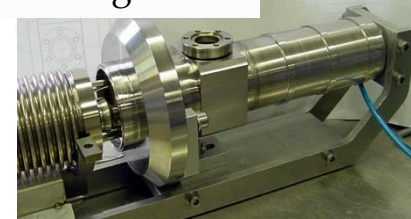


Vacuum  
brazing

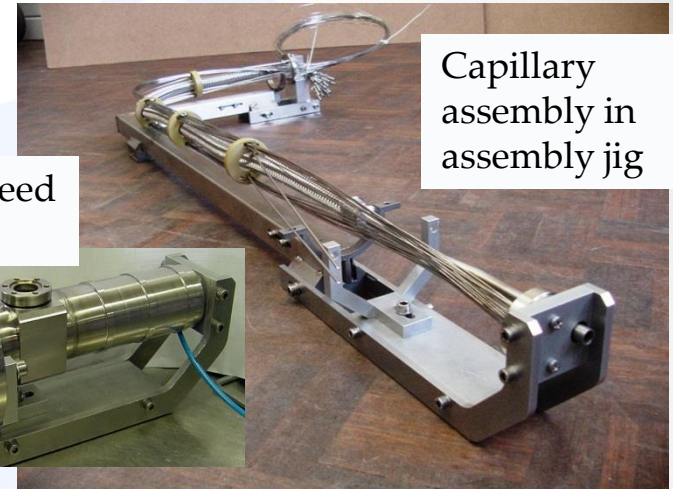


Brazed  
inlet  
manifold

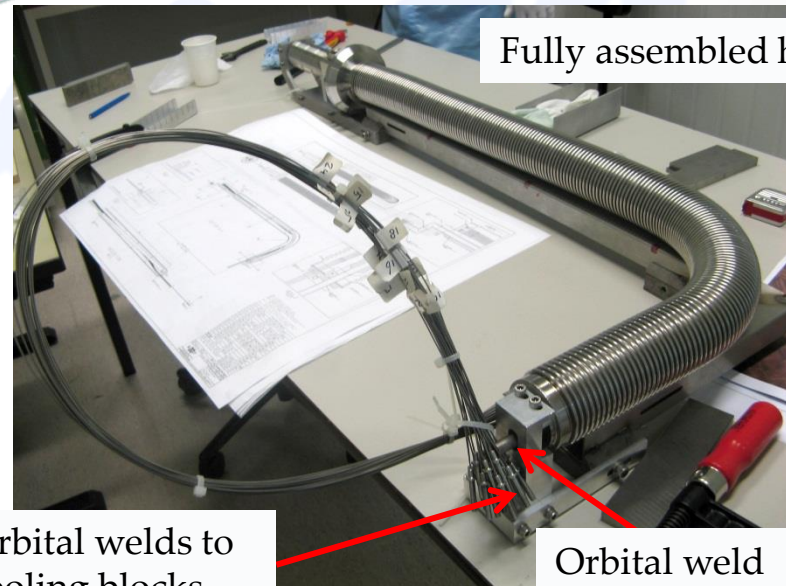
Vacuum feed  
through



Capillary  
assembly in  
assembly jig



Fully assembled hose



Orbital welds to  
cooling blocks

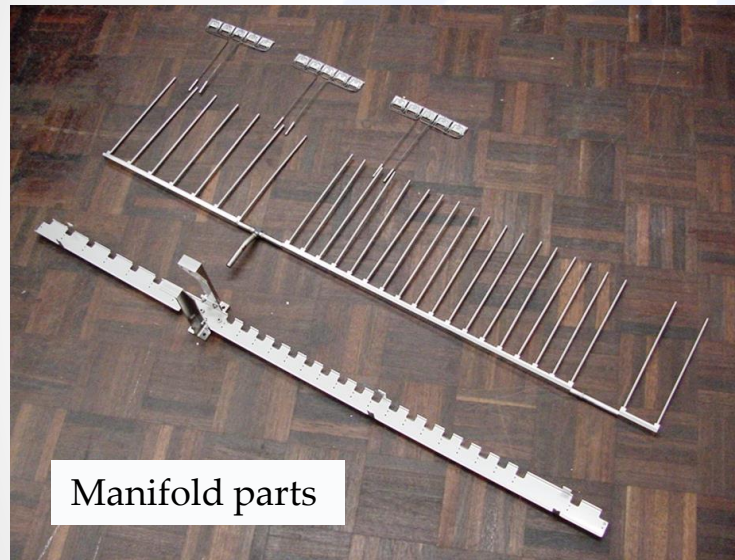
Orbital weld  
to outlet  
manifold

# VTCS assembly

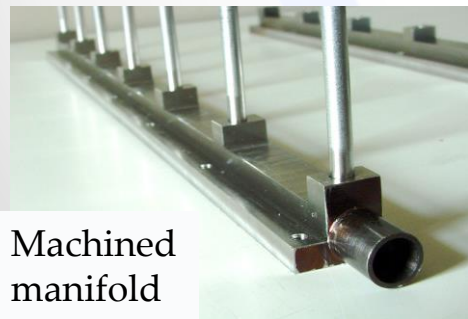
## *Support manifold*



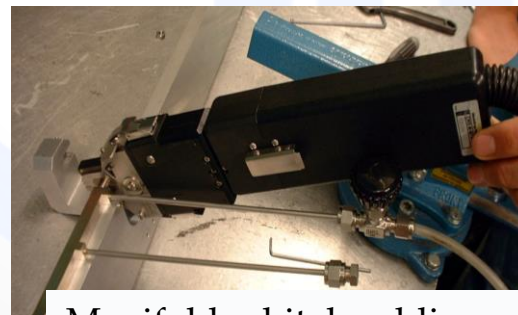
Cable and capillary channel



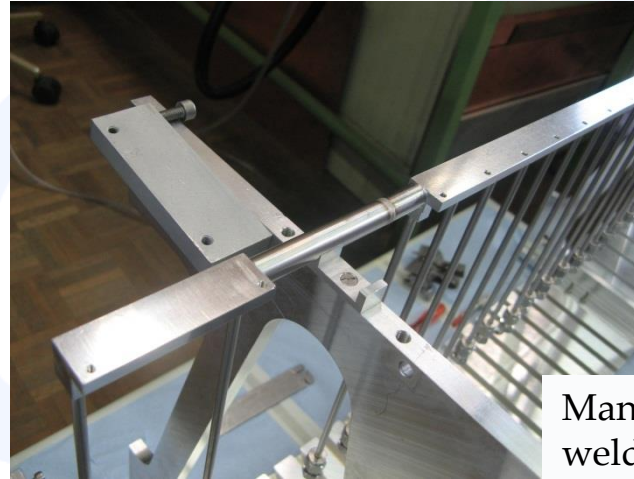
Manifold parts



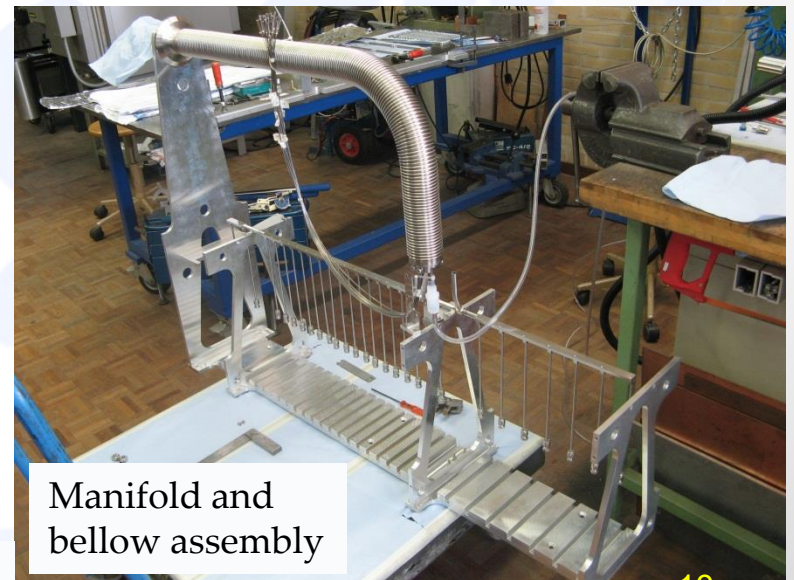
Machined  
manifold  
section



Manifold orbital welding  
(Swagelok series 8)

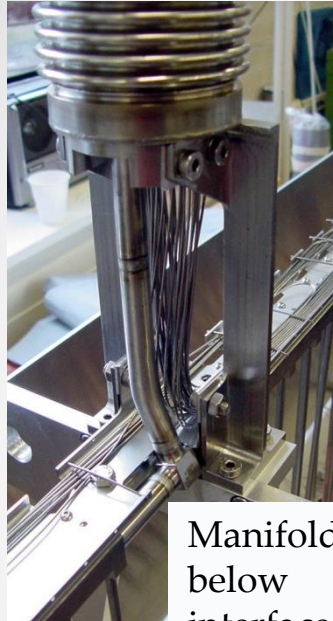


Manifold  
welds



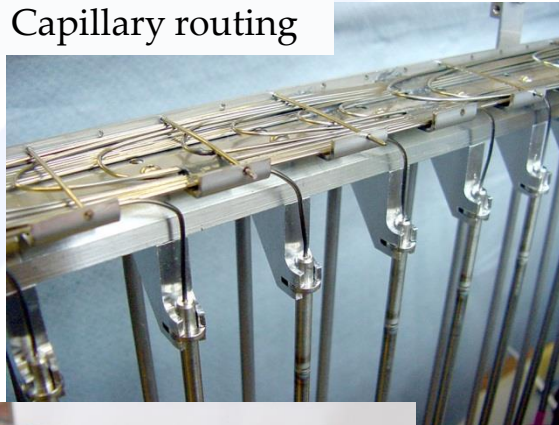
Manifold and  
bellow assembly

# VTCS assembly *Evaporator block assembly*

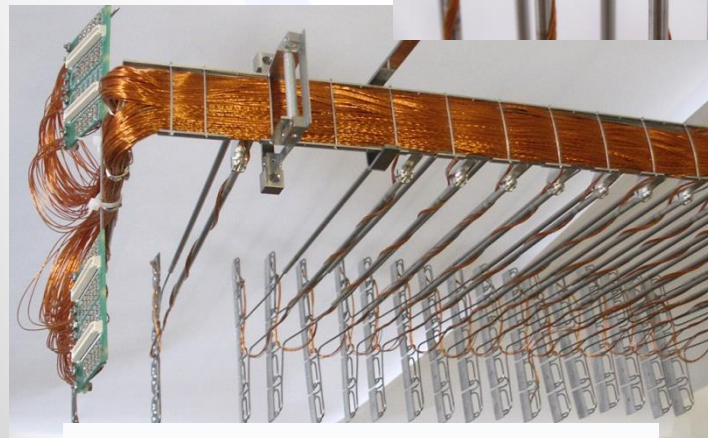


Manifold  
below  
interface

Capillary routing



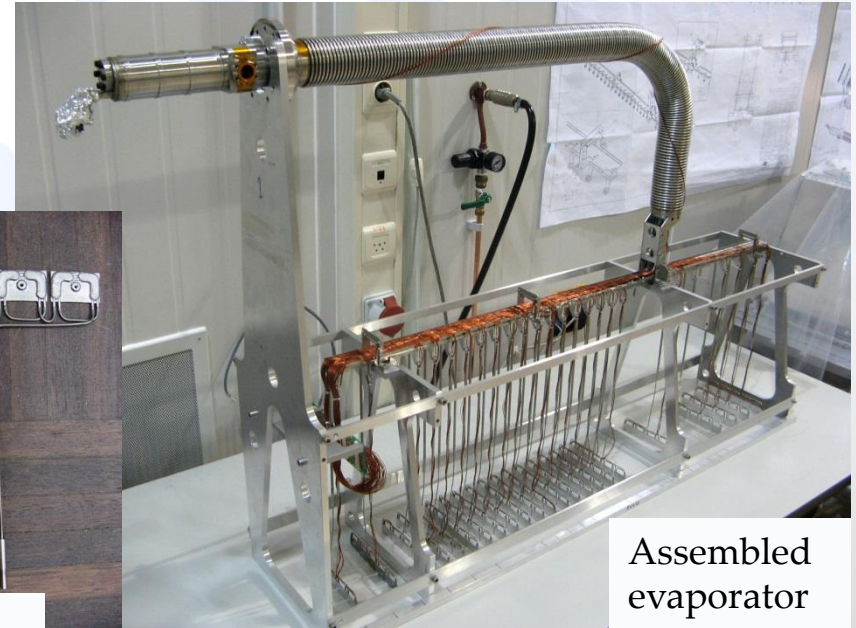
Cooling block orbital welding  
(Swagelok series 4)



Cable channel with sensor cables



Aluminum  
cooling block



Assembled  
evaporator

# Summary & Conclusions

- AMS and LHCB-VELO cooling was designed using professional joining technologies.
- No leaks have ever been observed in detector cooling lines
  - 7 years of development experience and 10 years of underground operation
- The NASA welding method is a helpful method also for non-space hardware
- Philosophy of making weld connectors for orbital welding to thin wall piping before production worked really well
- The LHCb Velo system will be taken out of service in LS2.  
Inspection of joints and pipes with 10 years of operation with CO<sub>2</sub> is foreseen to see the effects of long term exposure