LIEBE project review: Offline commissioning

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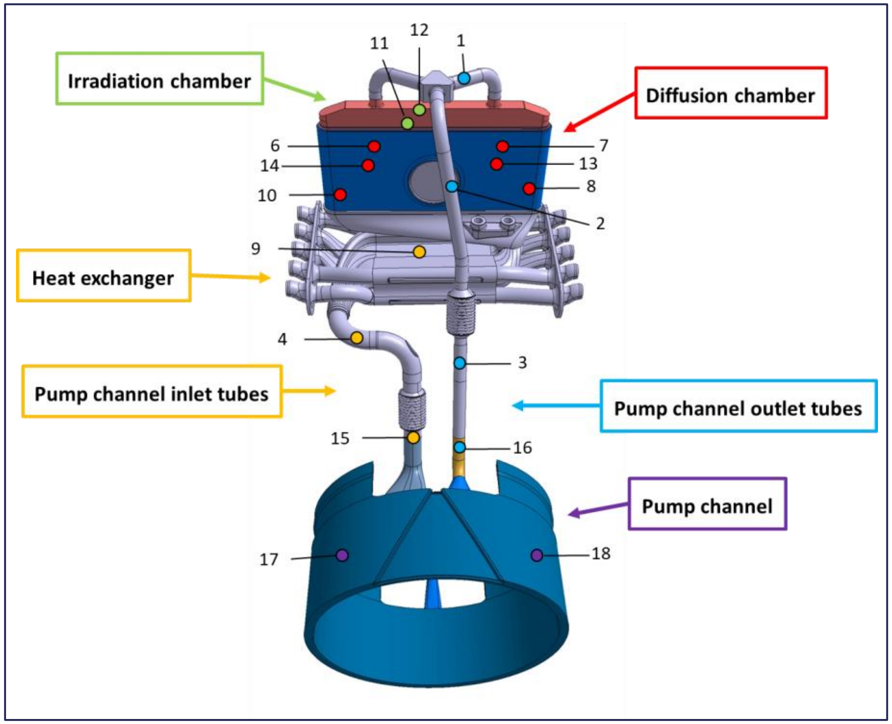
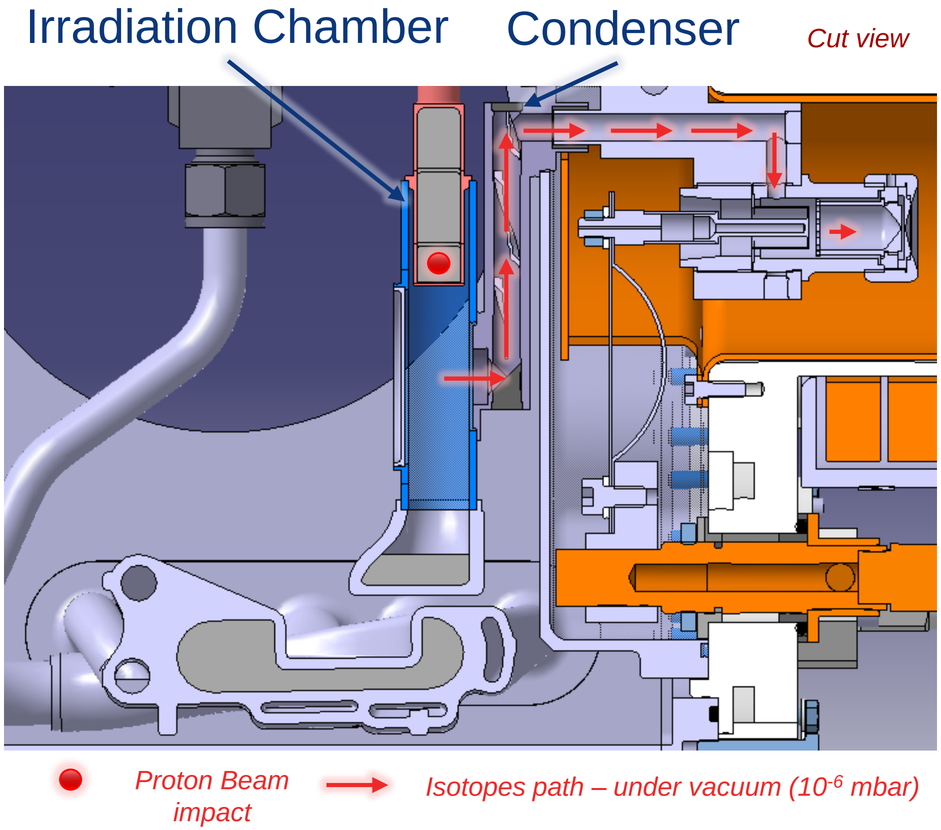
Outline

- Assembly
  - LIEBE target design
- Offline commissioning
  - Interventions in the ISOLDE target area
  - Hydrodynamic characteristics of the loop
  - Alignment-vibration
  - 1st offline tests
  - 2nd offline tests
- Options for the future
  - Present design
  - Lanthanum option, beams in the 100Sn vicinity
  - LIEBE2? Re-usable elements and expectable costs

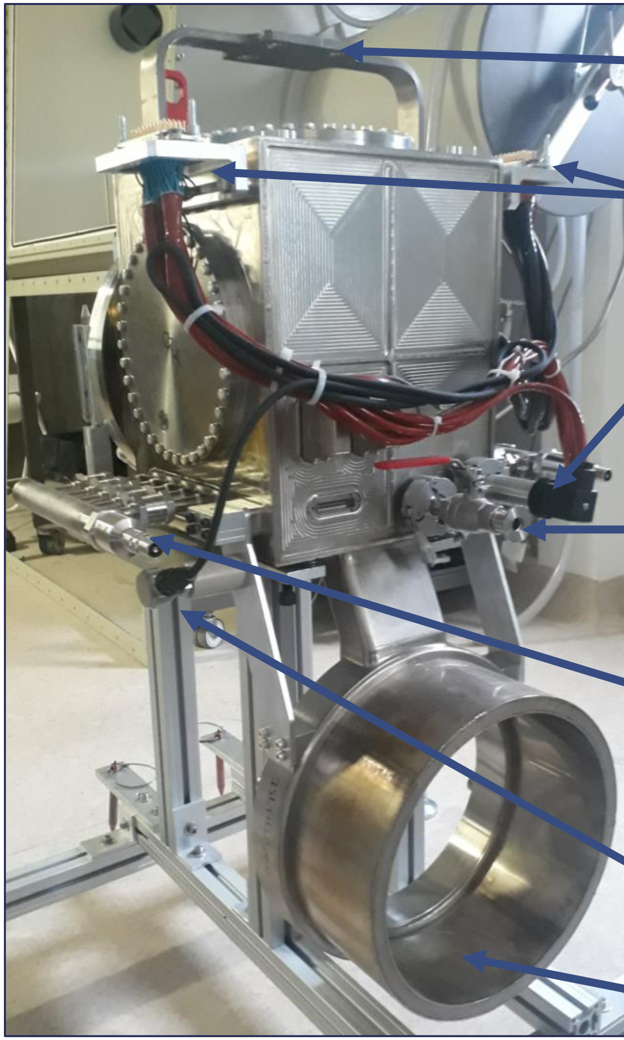
LIEBE target design: The loop

- Design approved in Project Review October 2015. EDMS nº 1554616





LIEBE target design: The second envelope



Robot handle

Hypertacks

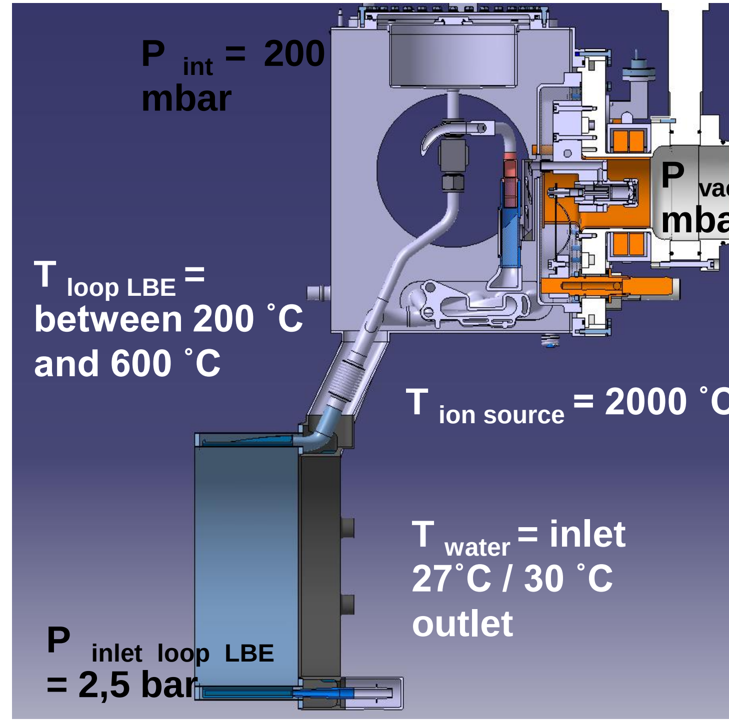
Pressure sensor

Gas valve

Water connection

Accelerometer

Pump channel



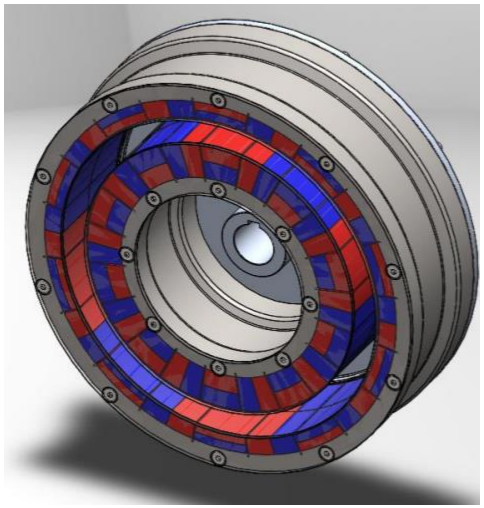
Chiller:

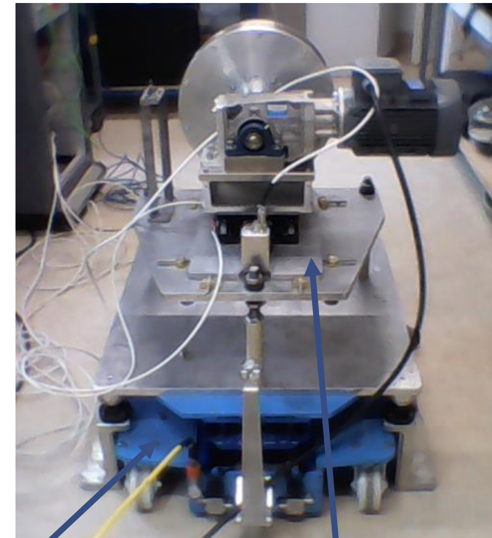
- Resins to demineralize water
- Qth=0.22L/s

LIEBE target design: The electromagnetic pump

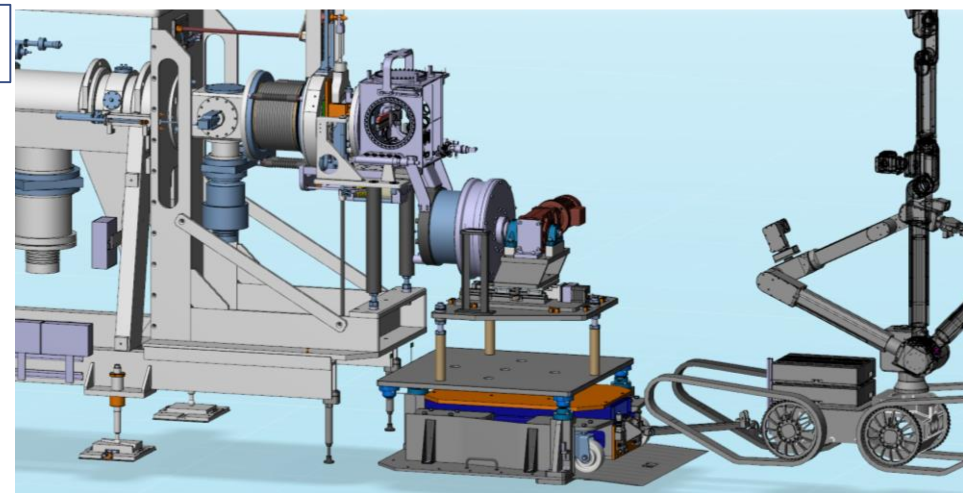
University of Latvia
Institute of Physics

Magnetic wheel





EN-STI-TCD



The EM pump:
- Double Hallbach array axisymmetric
- P=2,2kW , B=1,1T

The coupling:
- Pneumatic lift trolley manipulated by TELEMAX.

Offline commissioning

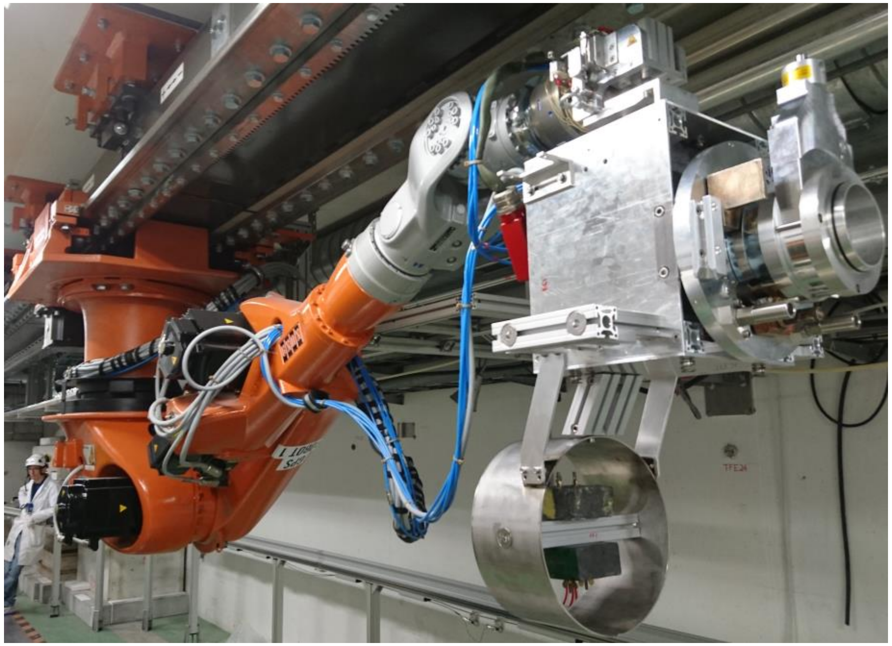
- Interventions in the ISOLDE target area
- Hydrodynamic characteristics of the loop
- Alignment-vibration
- 1st offline tests
- 2nd offline tests

ALARA committee 2016

- Modifications on GPS:
  - Pump support
  - GPS reinforcement
  - Electrical connections
  - Shelf for storage

1.6 man.mSv approved

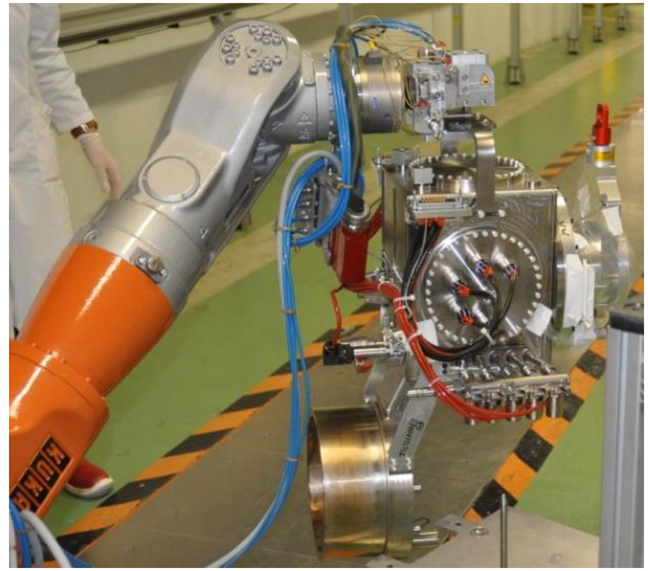
- Fake target tests:
  - KUKA and TELEMAX handling

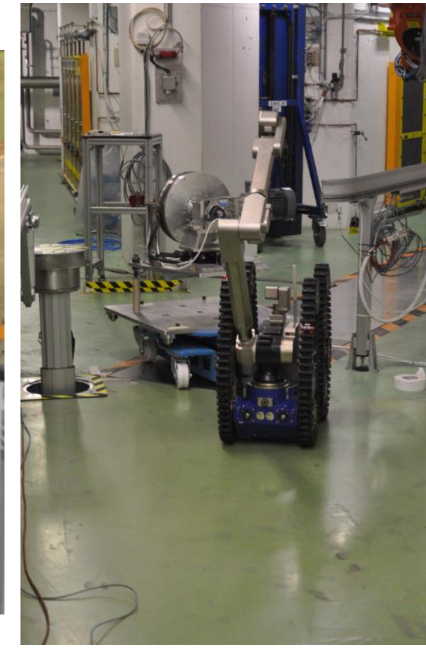


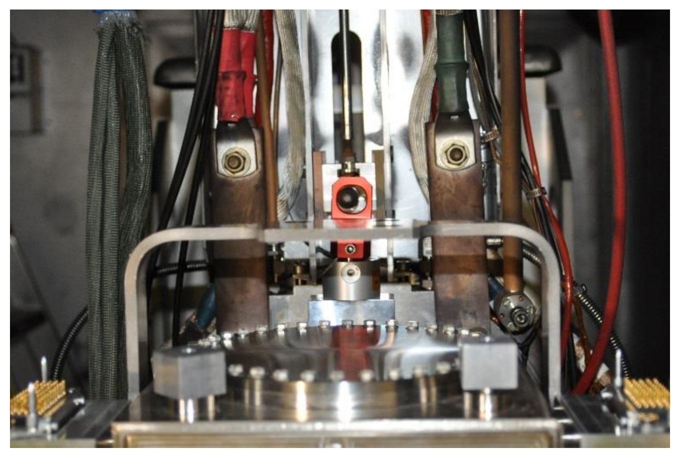
Intervention LIEBE 2018

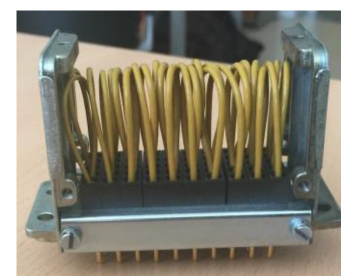
Intervention feedback in EDMS nº 1570850

- Handling of the real elements by the robots:
  - Visual inspection of good alignment with the front end
  - Shelf modification
  - Feedback on TELEMAX manipulation of the pneumatic system
  - Geometrical measurements of the EM pump positioning
- Chiller installation
- Necessary installation of new cables through the Boris tube
- Re-cabling and testing of the Hypertack connections



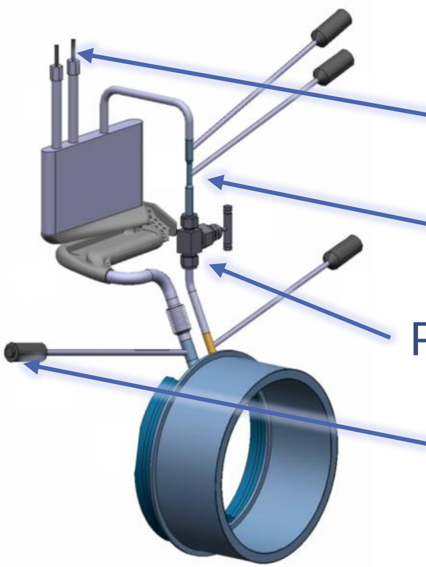






Hydrodynamic characteristics of the loop

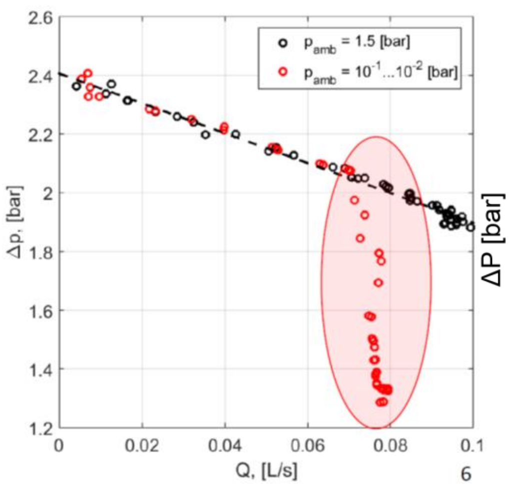
- Tests performed at IPUL in September 2017
  - Operate in the absence of cavitation
  - Reach the desired flow for release optimization
    - LBE Velocity preferred: **2 m/s** ⟶ **Q=0.13 l/s**
    - **Ø0.4 mm** droplets ⟶ factor **5** more release

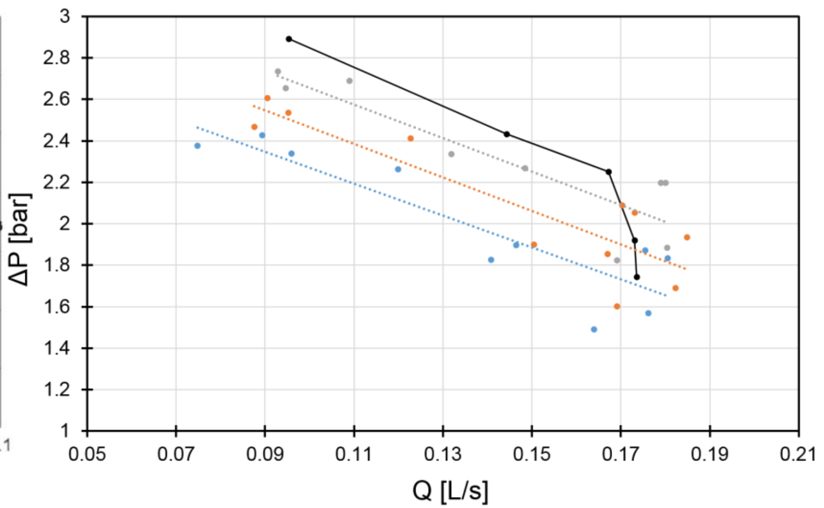


Ref: Melanie Delonca, Development of new target concepts for proton beams at cern/Isolde, CERN Ph.D thesis

$$E_{potential} - E_{losses} = E_{kinetic}$$

$$p_0 + \rho g z - p_{losses} = \frac{\rho Q_{max}^2}{2S^2}$$





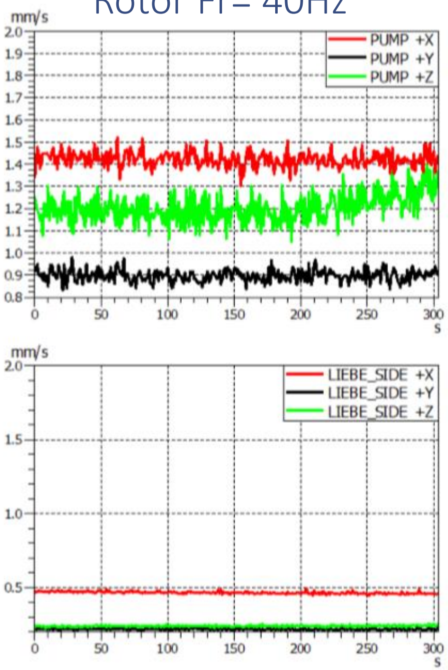
Alignment-vibration

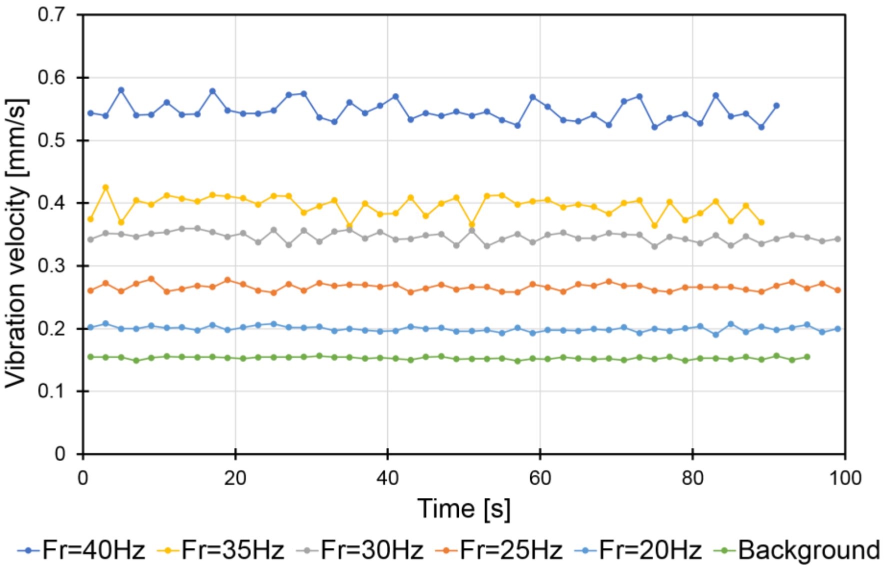
Fidualization and alignment EDMS nº 1894710,1894735,1894729.
Vibration EDMS nº1868573, nº 2043157.

- Target and EM pump fidualization and alignment evaluation in offline 1
- Good/satisfactory levels for operational frequencies
- Accelerometer to monitor the vibration throughout operation with LBE

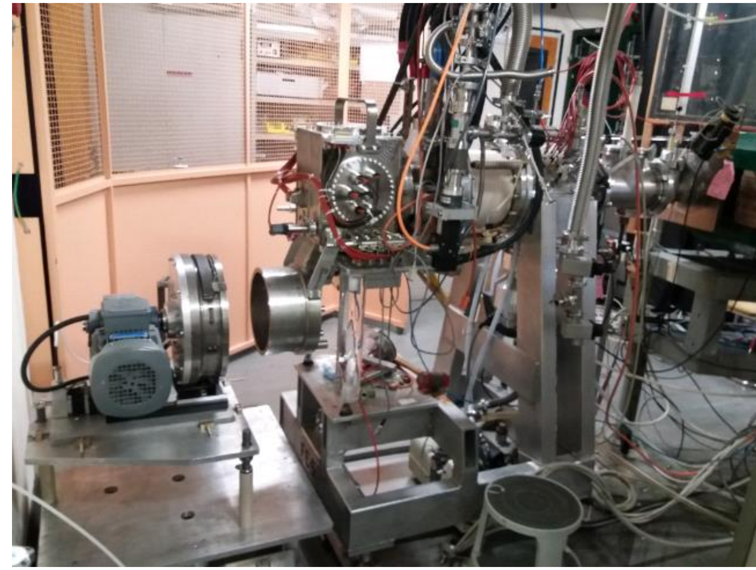
	PUMP			LIEBE_SIDE (Uncoupled)			LIEBE_SIDE (Coupled)		
	+X	+Y	+Z	+X	+Y	+Z	+X	+Y	+Z
Baseline	0.20	0.19	0.19	0.06	0.05	0.04	0.05	0.05	0.04
10Hz	0.83	0.54	0.47	0.05	0.05	0.04	0.52	0.17	0.22
20Hz	0.54	0.39	0.64	0.06	0.05	0.04	0.24	0.85	1.27
30Hz	0.88	0.79	1.13	0.06	0.05	0.04	0.45	0.39	0.19
40Hz	1.44	0.92	1.19	0.07	0.05	0.04	0.48	0.22	0.25
50Hz	4.28	1.76	1.41	0.05	0.05	0.05	0.73	0.27	0.25

Rotor Fr= 40Hz

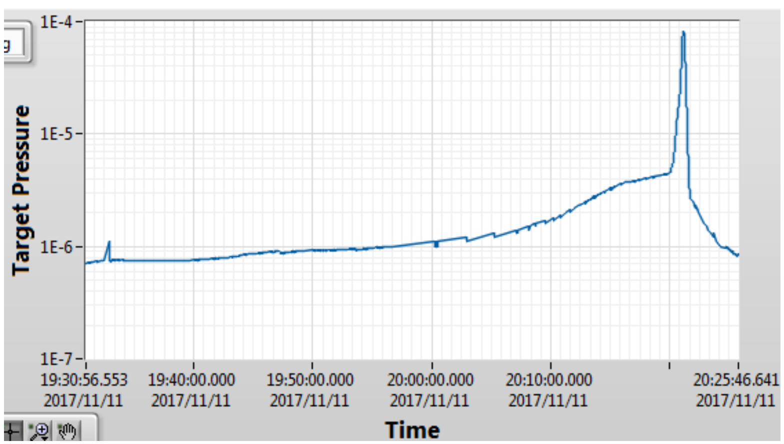


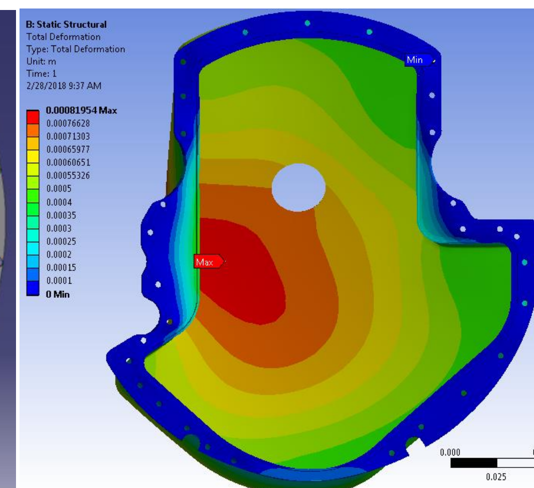


1st offline tests



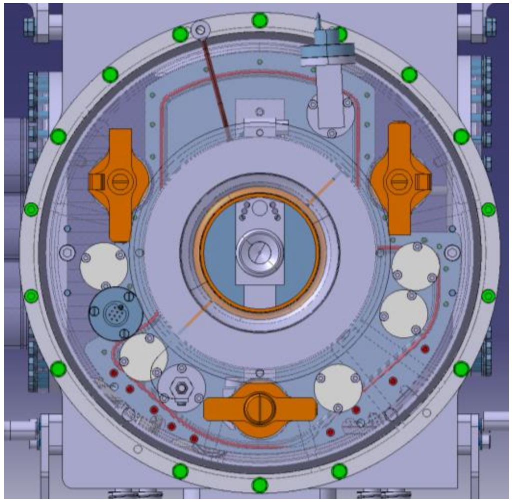
- **NO melting of LBE:**
  - Leaking ion source vacuum vessel:
    - Leak appearing when heating up the ion source to 1700 ºC
  - Parasitic currents generated by the pump power cables

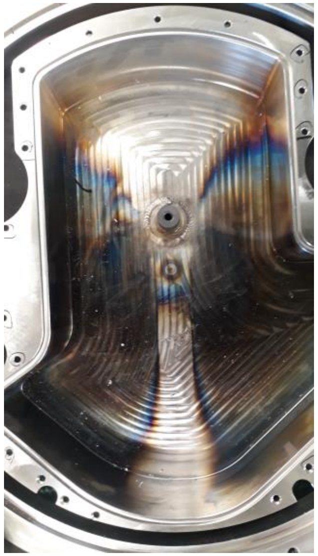


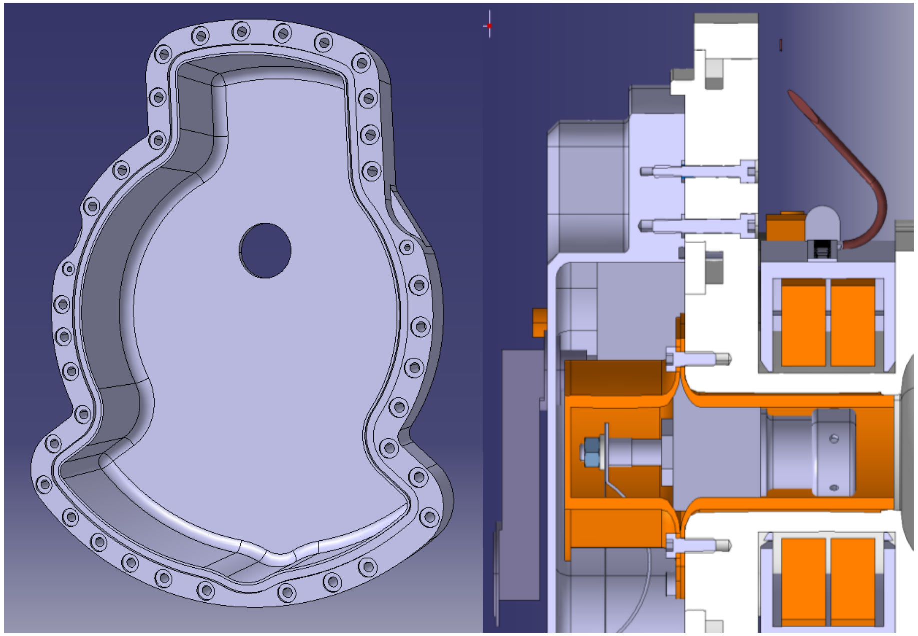


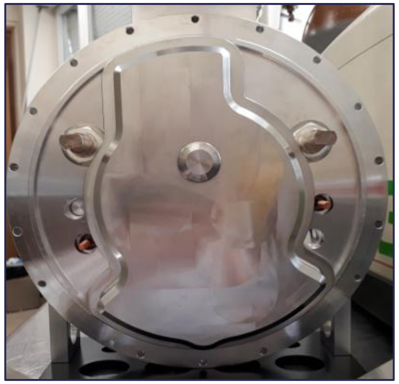
Base replacement

- New ion source Vessel:
  - Double isolation
  - Easier removal
  - Overall higher mechanical resistance
  - Incorporated heat screen





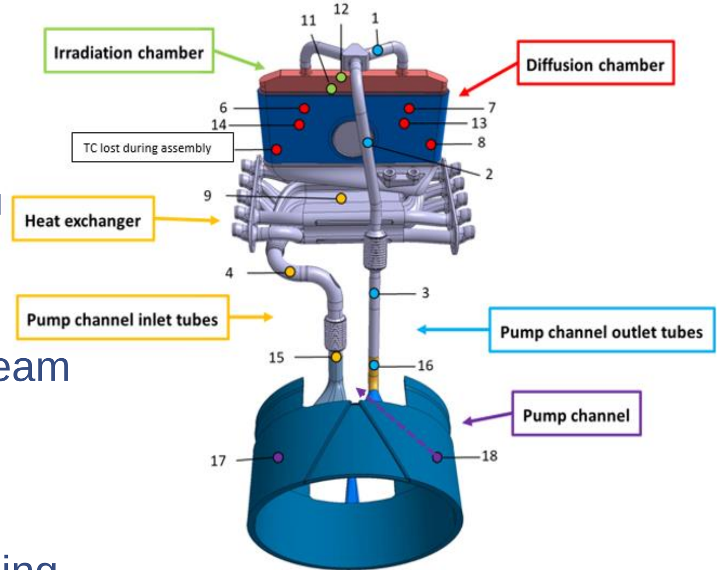


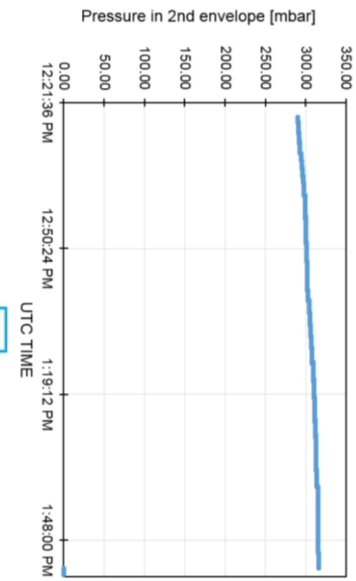


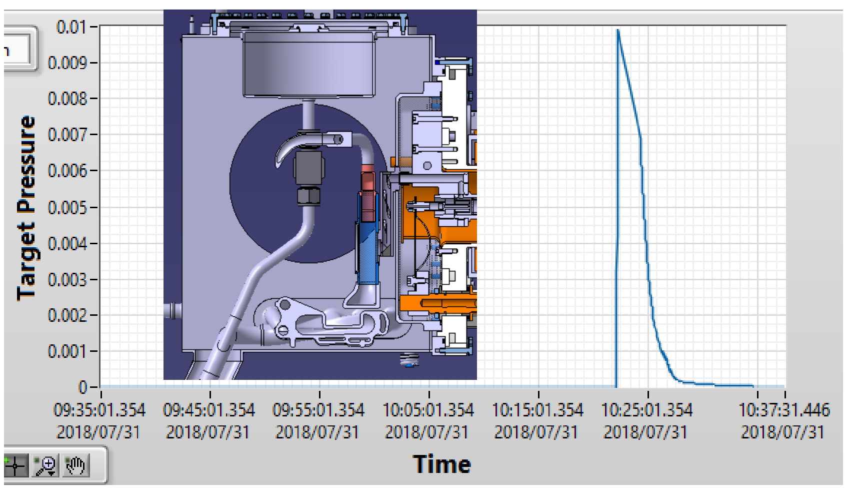
From November 2017 to July 2018

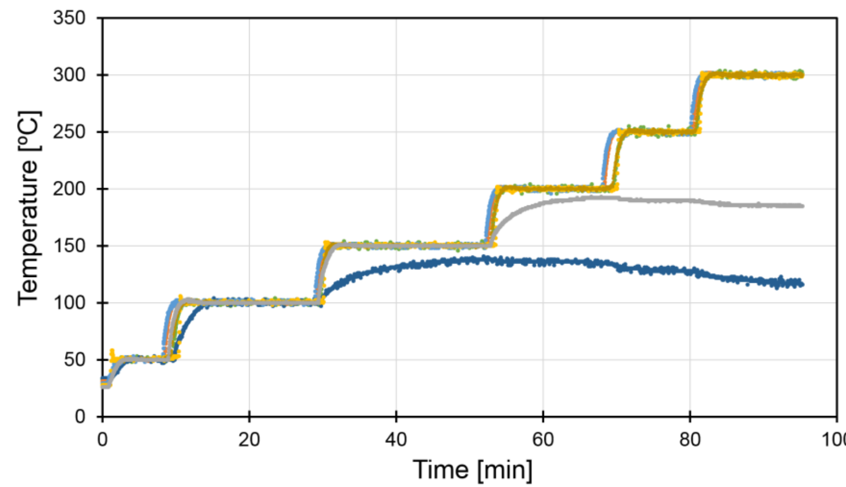
2nd offline tests

- Successful coupling and alignment, systems check
  - Good pressure read outs from 2nd envelope
  - Issues with level sensors
- No heat contribution from the proton beam
  - 1.2KW proton beam
  - 2.7KW heating elements
  - 1.4KW EM pump (calculated)
- Expected pressure peak due to remaining argon on top of the LBE container



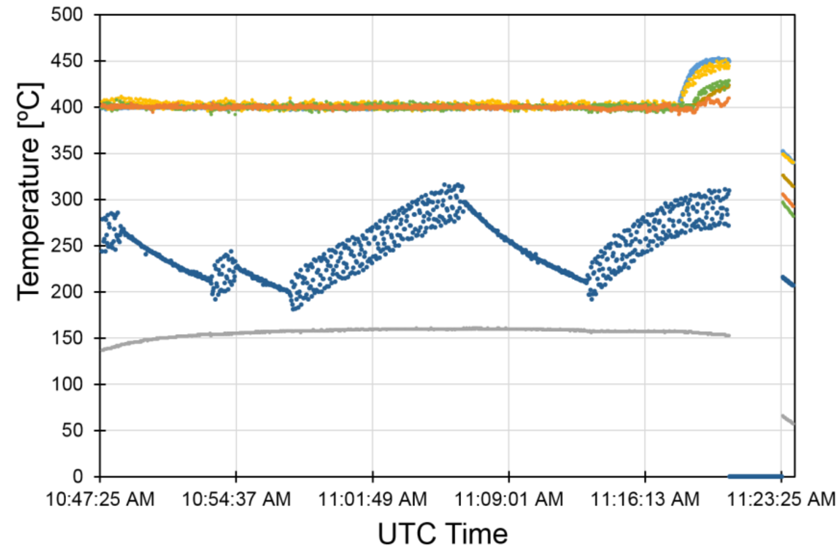






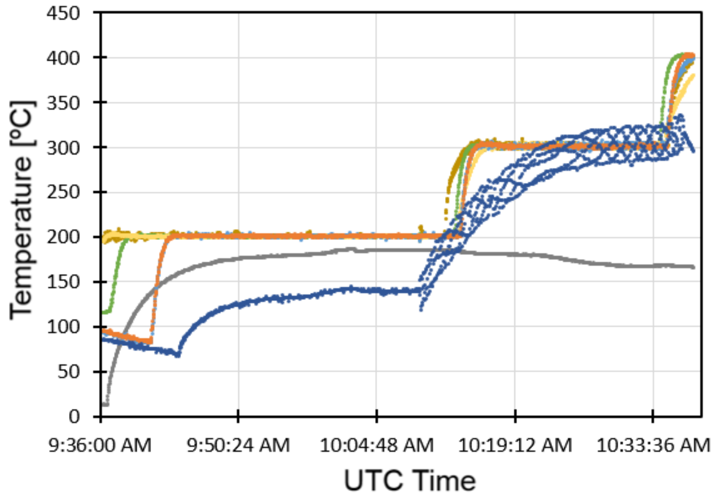
2nd offline tests

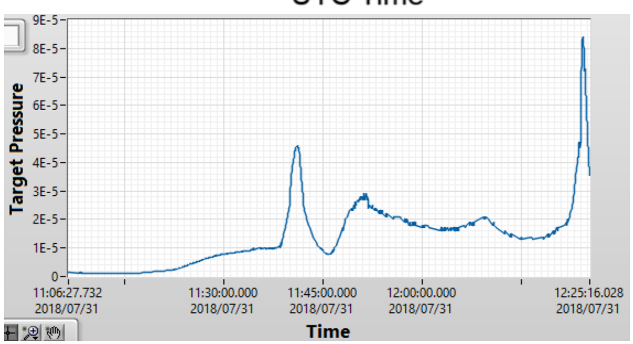
- Channel inlet
- Irr.chamber
- Channel
- Diff.chamber
- Channel outlet
- HEX
- Inlet Irr.chamber

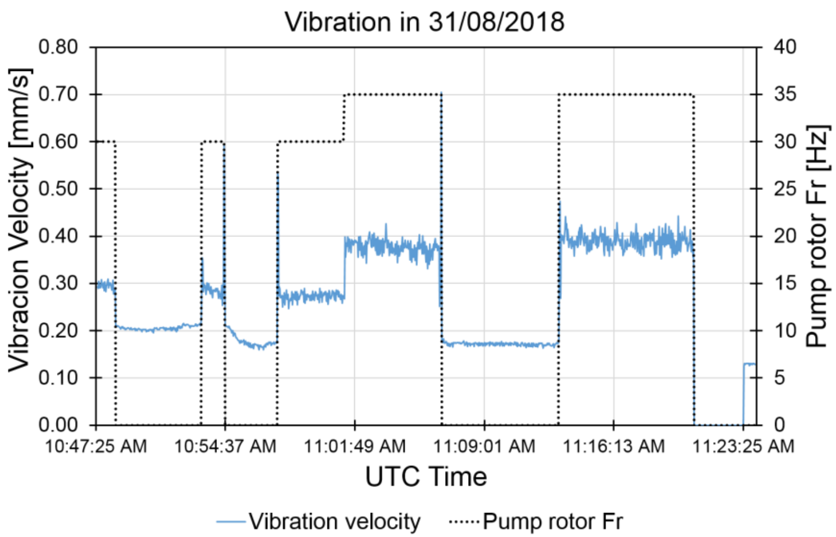


Early operation with LBE 30/07/2018:

- Signs of outgassing
- Similar vibration as in vacuum
- Pump uncontrolled stops
- HEX slightly colder



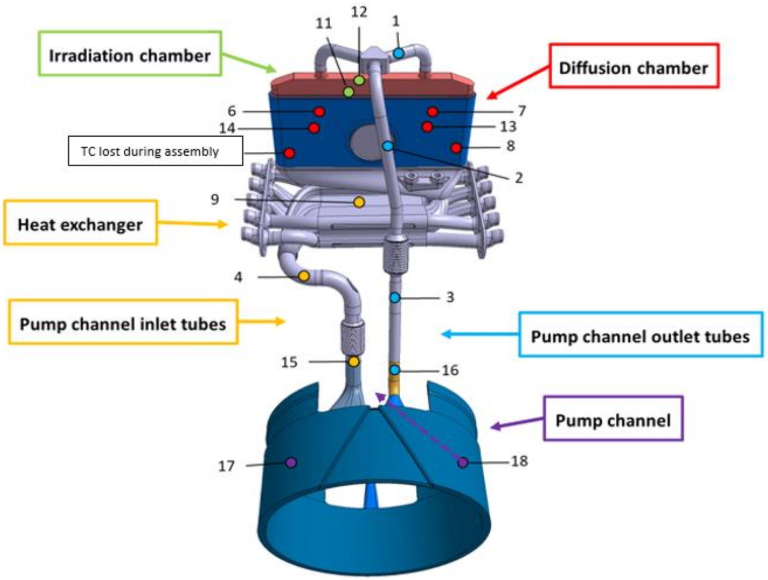




2nd offline tests

Tests interruptions:

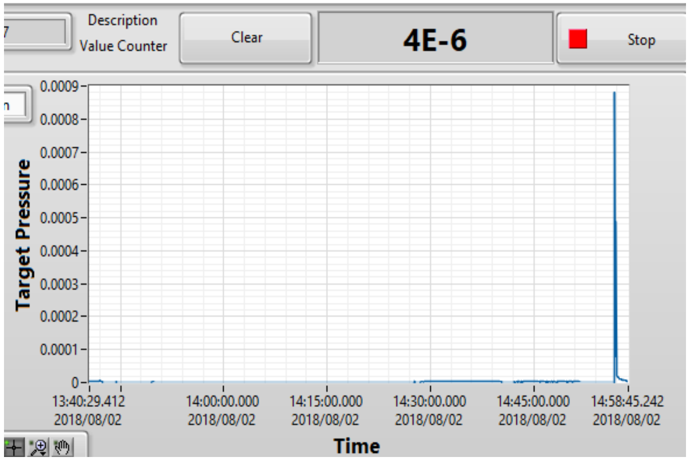
- Broken HE
  - Lost control of the heating element
  - 21A sent to heat nearby parts of the loop
  - Lost heating in power in particular sections



LBE solidification in the loop
Not considered in the design phase

Vacuum leaks:

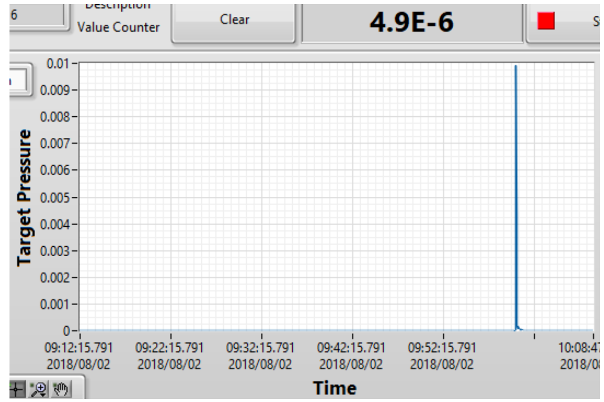
- Considered to be caused by remaining argon bubbles

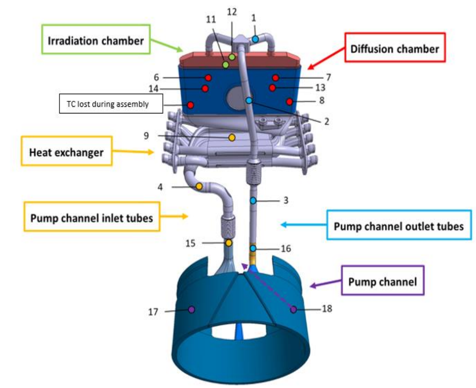


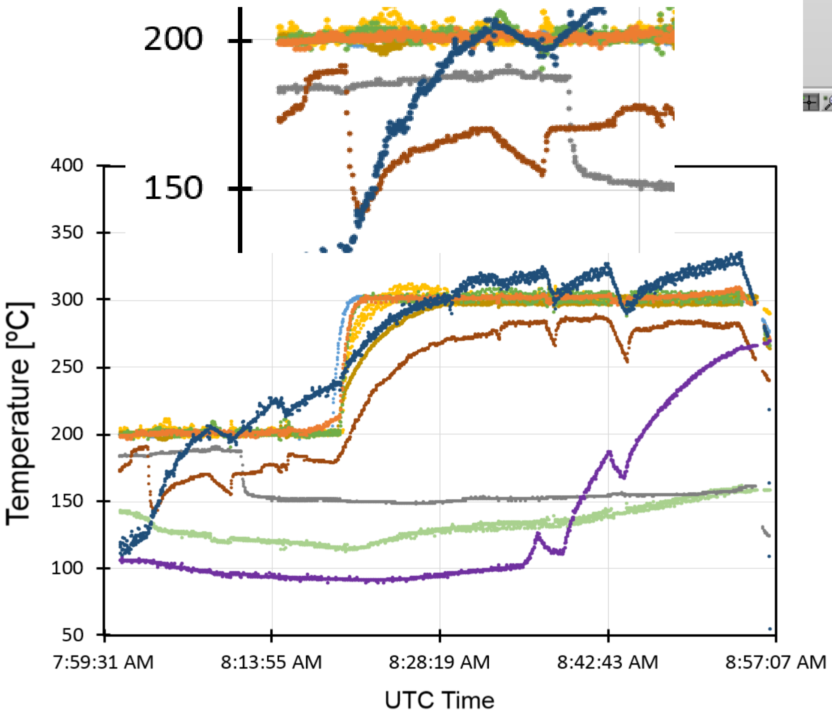
2nd offline tests

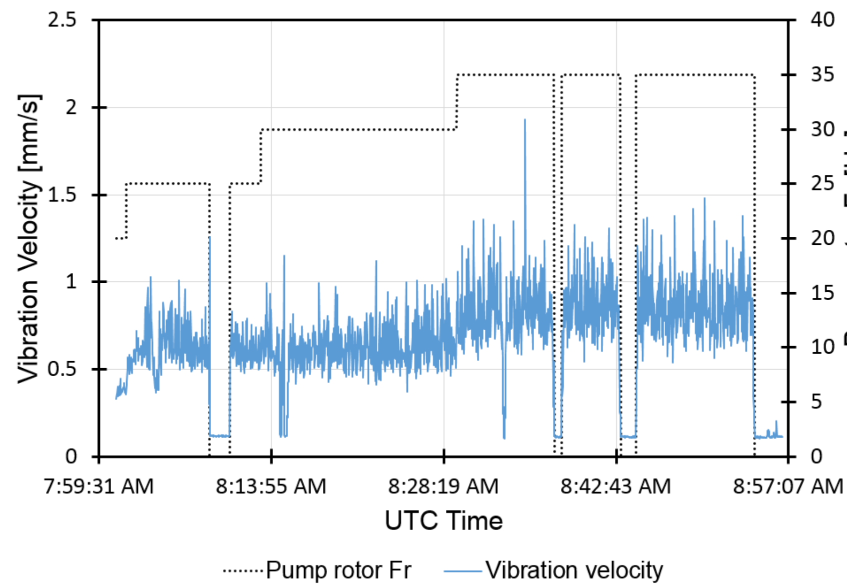
- Channel inlet
- Irr.chamber
- Channel
- Diff.chamber
- Channel outlet
- HEX
- Inlet Irr.chamber

- Drastic temperature drops
- Higher vibration levels





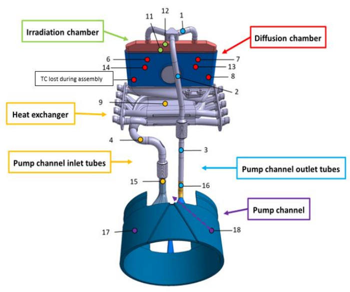


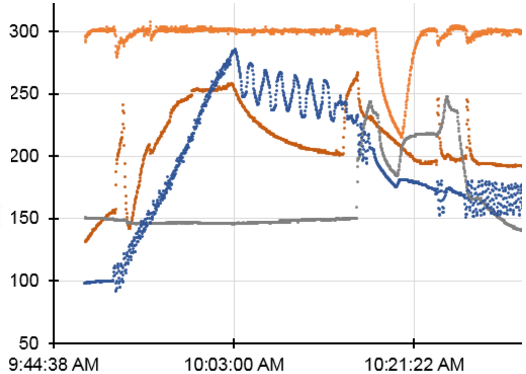


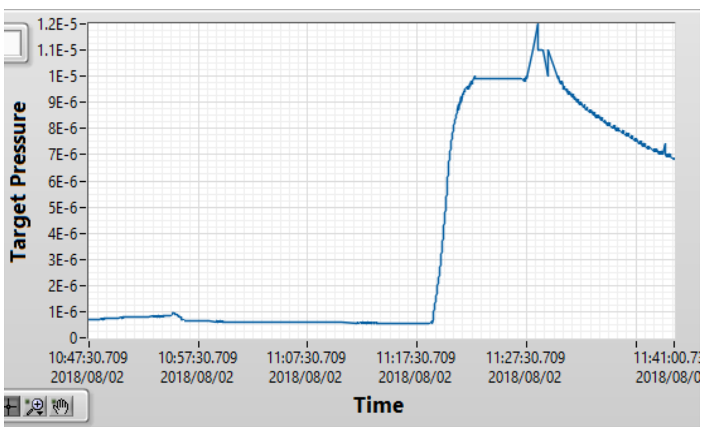
- Outlet tube without HE
- Channel averaged
- Tube to tank
- HEX exit

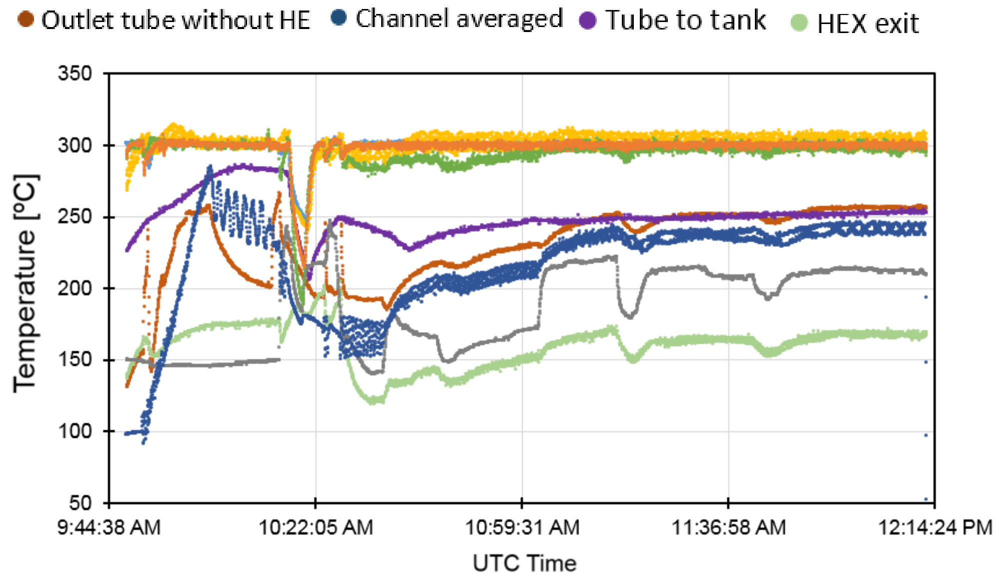
2nd offline tests

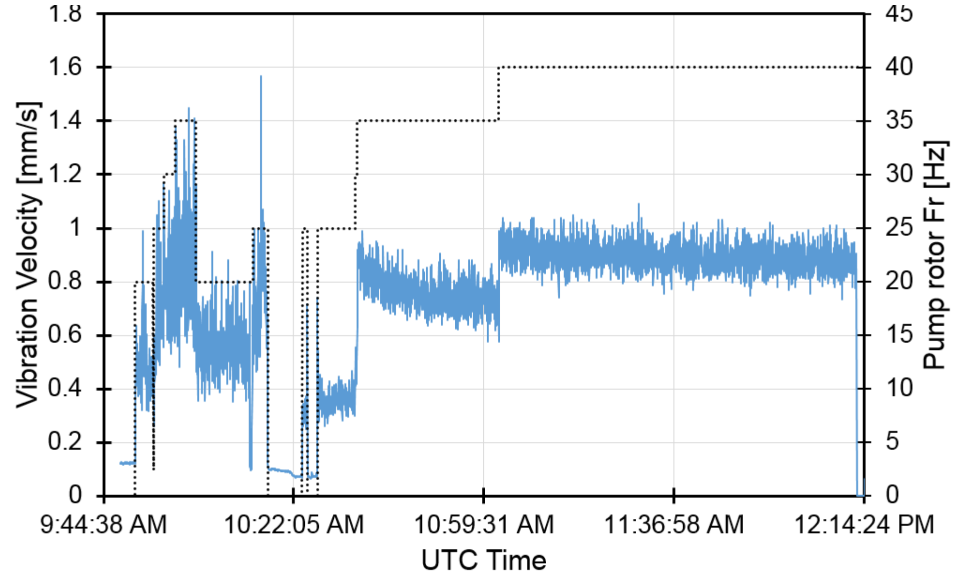
- Cavitation
- Temperature drops
- Loose of vacuum





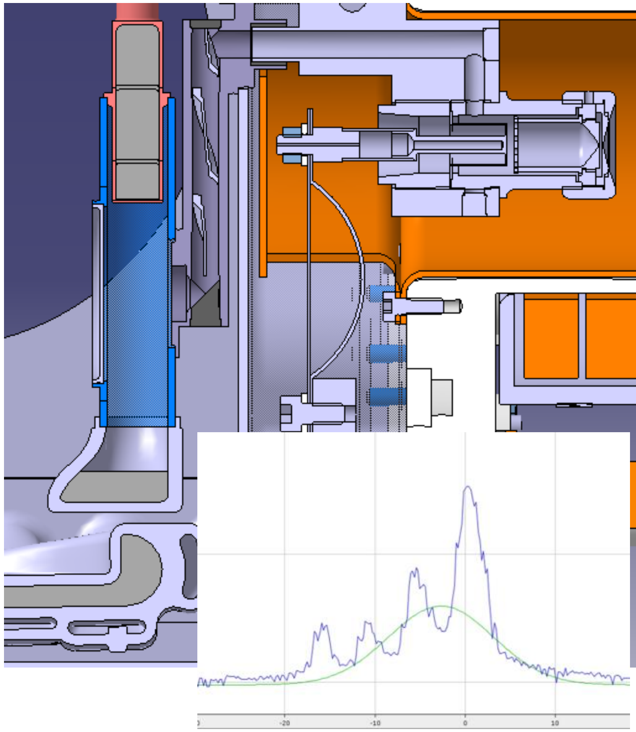


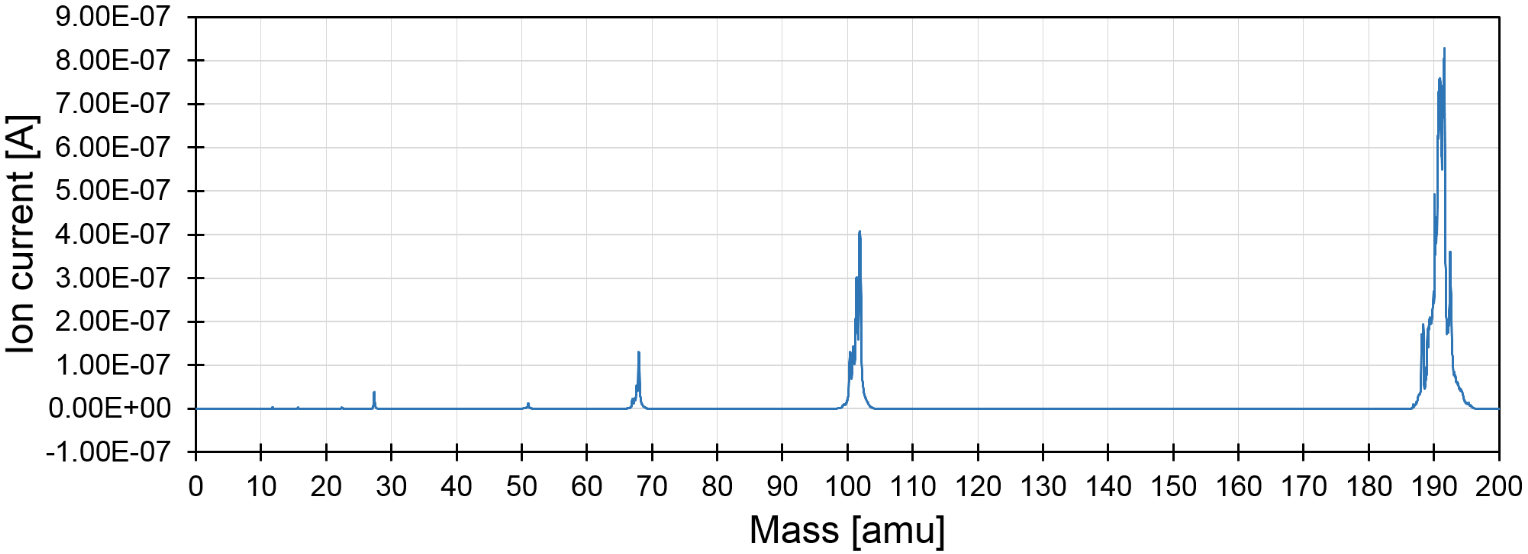




2nd offline tests: Mass scans

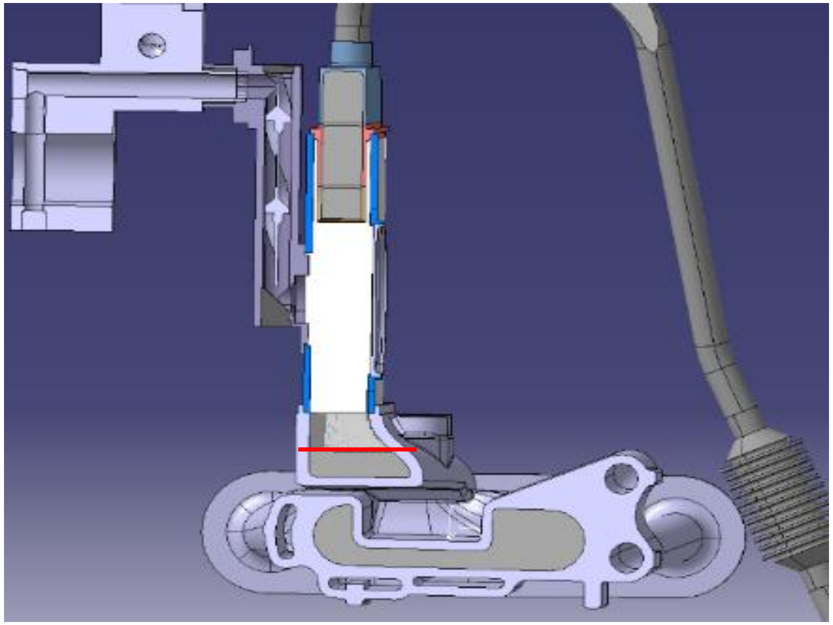
- Short-circuits detected in the VADIS.
- High contamination levels of Pb and Bi ions from LBE up to 0.8µA
- No perturbation of the beam by the EM pump magnets or vibration



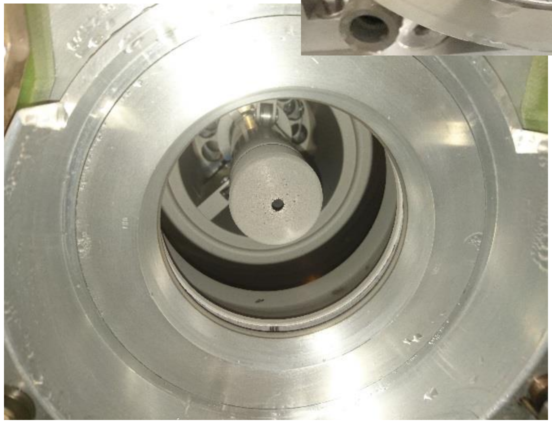


2nd offline tests

- LBE solidification
- Insufficient heating system
- Unknown hydrodynamic conditions



Volume to fill the diffusion chamber in the worst case scenario (not taking into account the “chimney” small volume) = 0.3L



Post tests inspection:

- LBE coated all surfaces near the ion source and extraction electrode
- Bigger quantities following a stream path towards and underneath the ion source

Offline commissioning conclusions

Commissioning with positive feedback:

- Installation in the ISOLDE target area
- Hydrodynamics of the droplet formation
- Mechanical stability of the coupling target/EM pump
- Beam production
- Safety requirements:
  - 2nd envelope
  - Vibration control
  - Durability of the sensors in the target area?

Non compliant commissioning:

- Thermal system
  - Insufficient to guarantee molten LBE by itself
- Hydrodynamics in case of a plug
  - EM pump developed pressures
- Control system
  - Security measures against short-circuits
  - User interface

Related issues:

- Design rigidity
- Short operation tests time

Options for the future

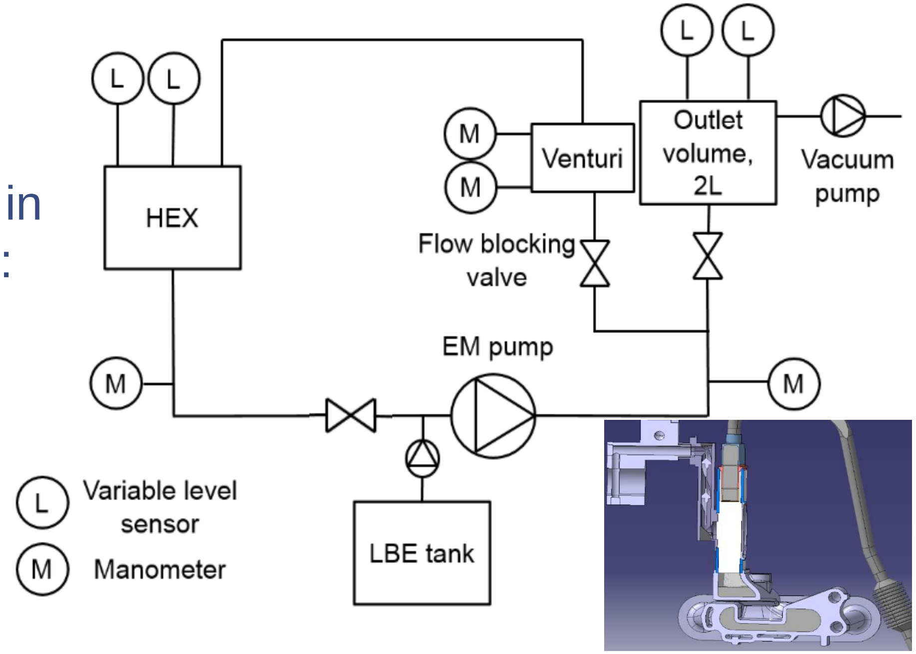
- Present design
- Lanthanum option, beams in the 100Sn vicinity
- LIEBE2? Re-usable elements and expectable costs

Present design

- Experimental study of the hydrodynamics in case of a plug (in collaboration with IPUL):
  - Liquid metal developed columns
  - Total LM volume in the loop
  - Heating elements test

↓

Safe operation mode



- Dedicated loop test stand:
  - Gain operating experience
  - Refine control and data acquisition systems (EN-SMM-MRO)

↓

Operating procedure → **Offline tests**

Expectable costs	Cost (CHF)
Dedicated stand	10000
Heating elements + thermocouples	15000
Dedicated worker	50000 /year

LIEBE 2?

Advantages:

- Changes of design from lessons learned:
  - Simplified HEX ↔ chiller water flow control
  - Design flexibility
- Estimated costs from CERN EDH (Electronic Document handling system)

Re-usable elements/studies	Cost* (CHF)
EM pump	33000
Skid (chiller)	23000
EM pump coupling system	40000
Control system	40000
Mechanical design (Bureau d'etudes)	54000

Expectable similar costs	Cost (CHF)
Assembly	100000
Heating elements + thermocouples	15000
Mechanical design + control system	35000
Dedicated worker	50000/year

Re-usable 190000CHF

*Costs take into account human work power

The Lanthanum option

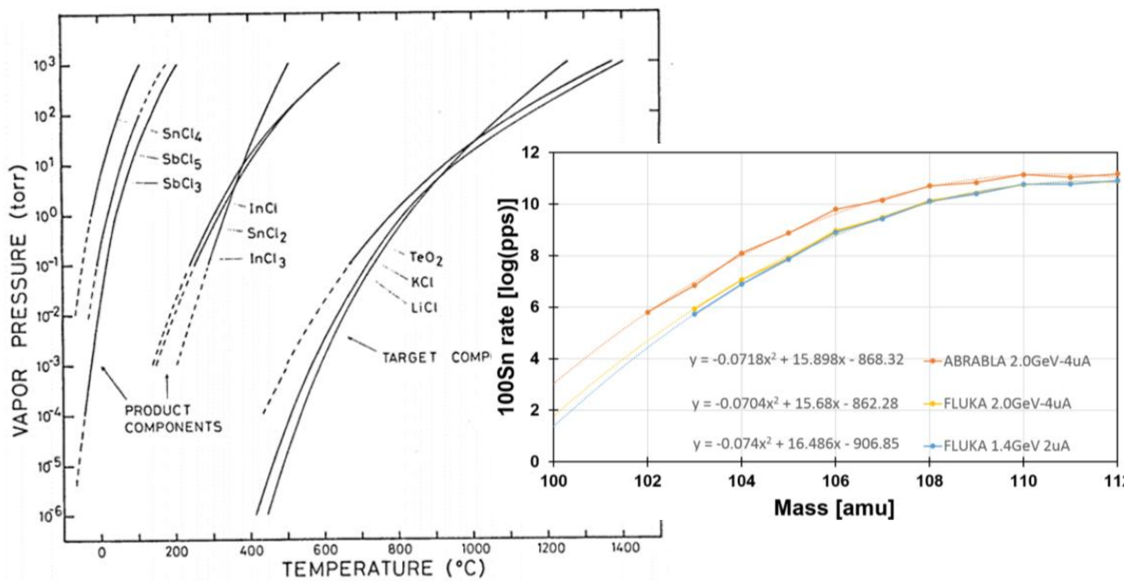
EMIS2018 proceedings: The LIEBE high-power target: Offline commissioning results and prospects for the production of 100Sn ISOL beams at HIE-ISOLDE

Molten targets operated online		
Material	Operation temp.[°C]	Beams
Ge	1100	Zn
Sn	1100	Cd
Pb	700	Hg
Bi		
Pb-Bi	600	Kr/Xe/I/Cd/Hg/At
NaF-LiF	700	CO/Ne
$TeCl_4$	420	SbCl/SnCl
Sc-La	1300	Ca/K/Ar
Y-La	1300	Sr/Rb/Kr
La	1400	Ba/Cs/Xe
Th-La	1400	Ra/Fr/Rn
Gd-La	1400	Eu/Sm
Lu-La	1400	Yb/Tm
Prospective eutectics for beams in the ^{100}Sn region		
Ag-La	518 *	Cd/MCl_x(M=In,Sn,Sb)
Au-La	561 *	Cd/MCl_x
Ni-La	532 *	Cd/MCl_x

- **Changes in the LIEBE design:**
  - Heating elements
  - Design of a diffusion chamber with gas line

Lanthanum based liquid loop req.	
Lanthanum eutectic characterization	· Melting Point · Vapor pressure · EM pump induction · Viscosity
Material compatibility	· Corrosion
Hydro-dynamic properties	· Droplet formation · Cavitation
MCl_x compounds	· Formation temperature · Effusion transport · Ionization
Monitoring systems and full loop operation	

Table 1: Requirements to be fulfilled to validate a lanthanum ba
liquid loop target.



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EN-SMM : Thierry Feniet, Antje Behrens, Alexandre Beynel

EN-HE : Jean Louis Grenard

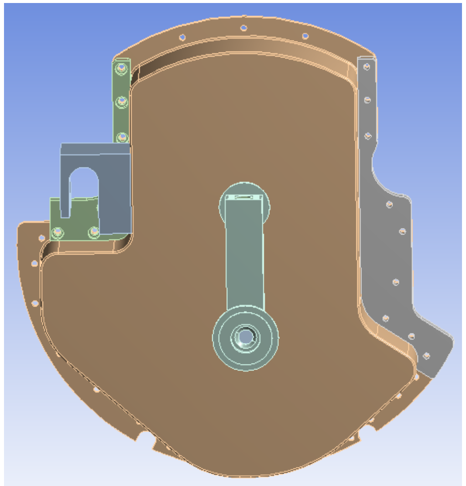
BE-OP : Pascal Fernier

SINP, IPUL, SCK.CEN : Susanta Lahiri, Kalvis Kravalis, Donald Houngbo,

Thank you for your attention

1st offline tests

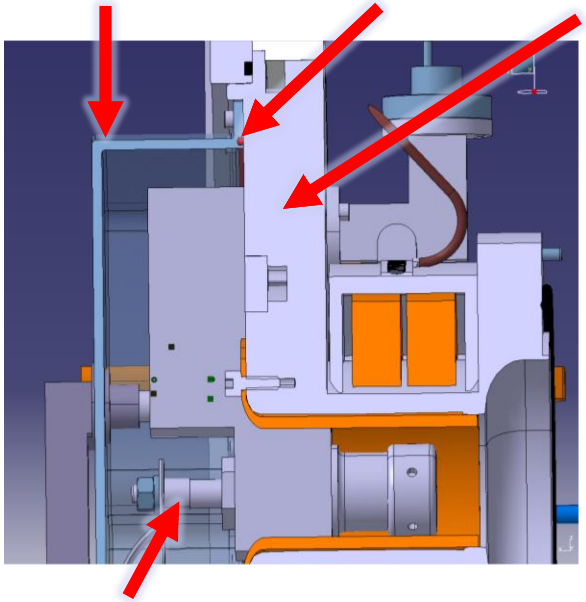
- Analysis and first solutions attempted



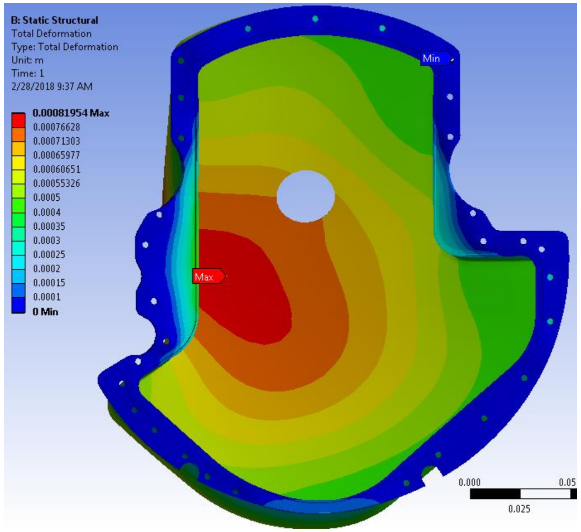
Stainless steel vessel

EPDM joint

Water cooled aluminum base

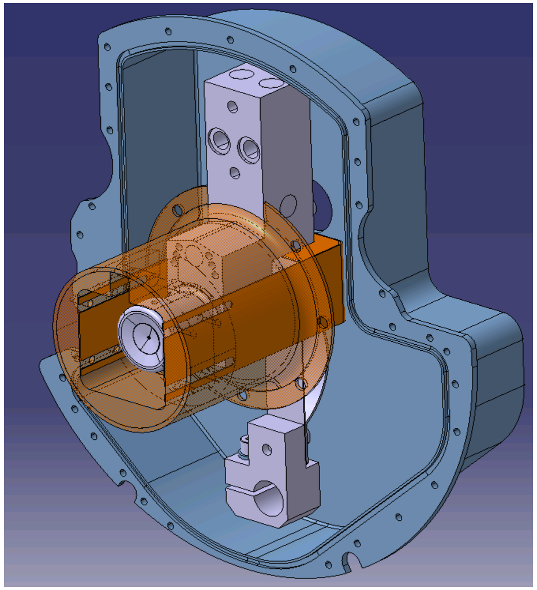


Cathode (up to 2000 °C)



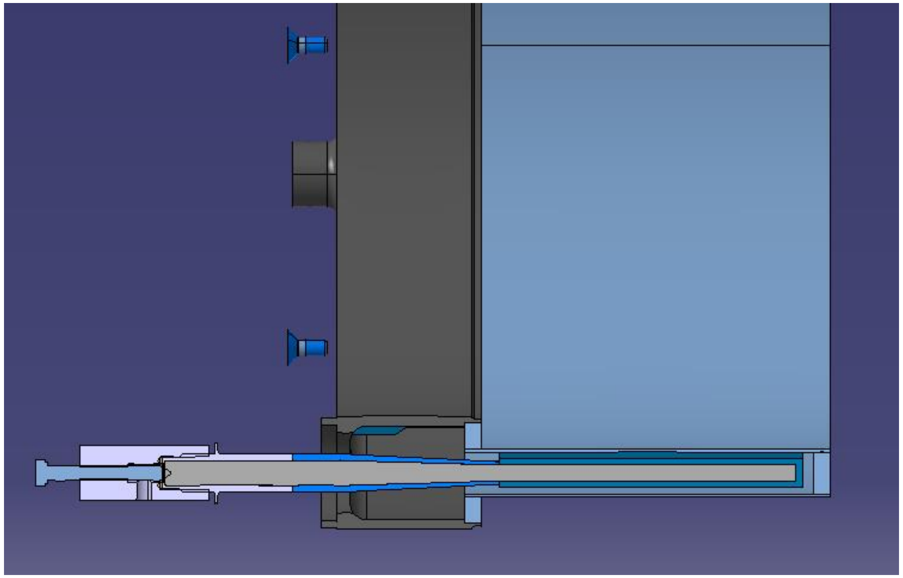
Near solving solution, stable vacuum at 1900degC, leak at 2000degC

Ineffective mechanical rigidness and contact cooling from electrical feedthroughs



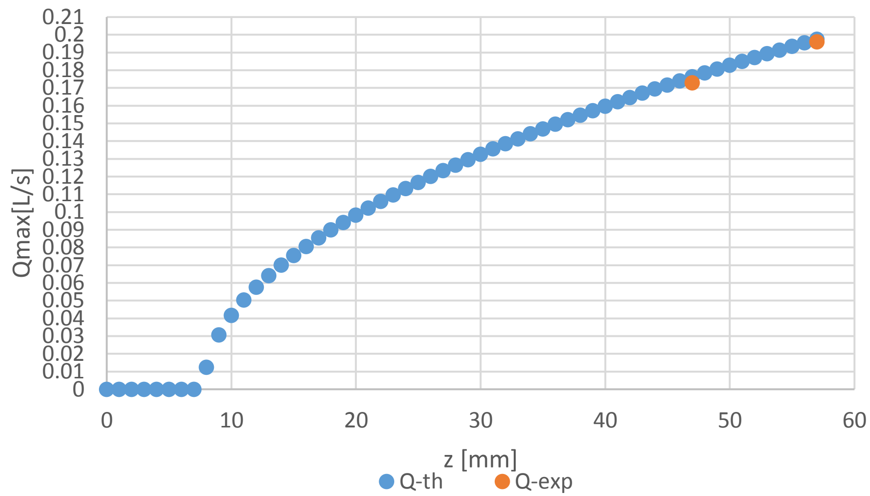
Emptying system

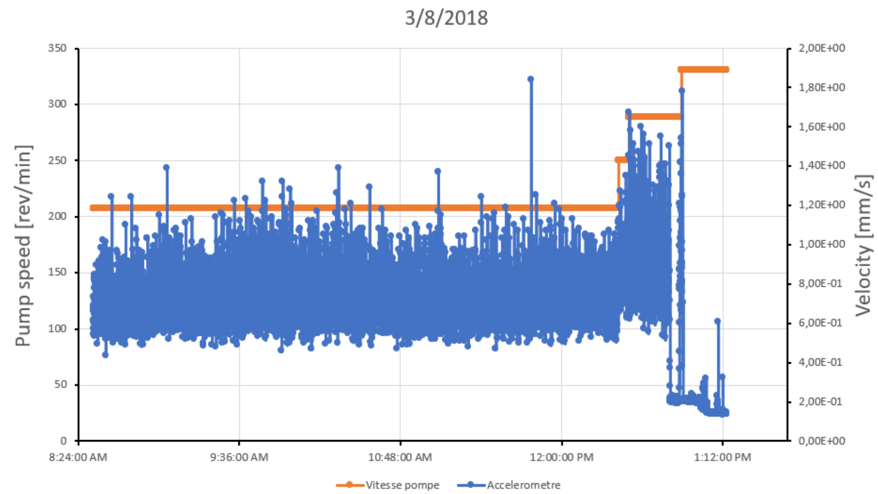
- Piercing of a thin wall at the bottom of the target
- Tank with gas connector to pump possible vapors.
- Leak tight Swagelok connection between the tank and LIEBE

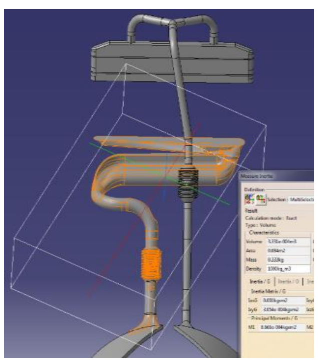


LIEBE mock-up extended tests

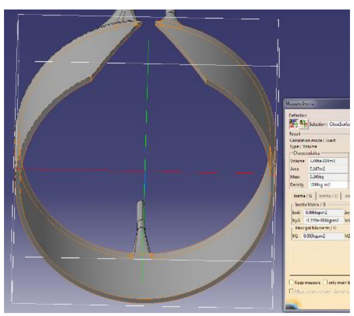
- Possibility to slightly reduce the level of LBE
  - Gain of 0.1L to fill the diff.chamber at Qmax=0.15L/s
  - Only 2/3 of the channel volume filled
- No sign of pressure problems for 4h at a low pump Fr (25Hz).



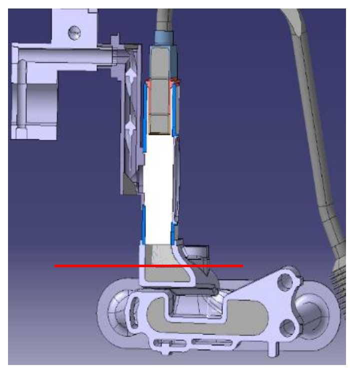




Volume in the inlet side of the channel = 0.3L



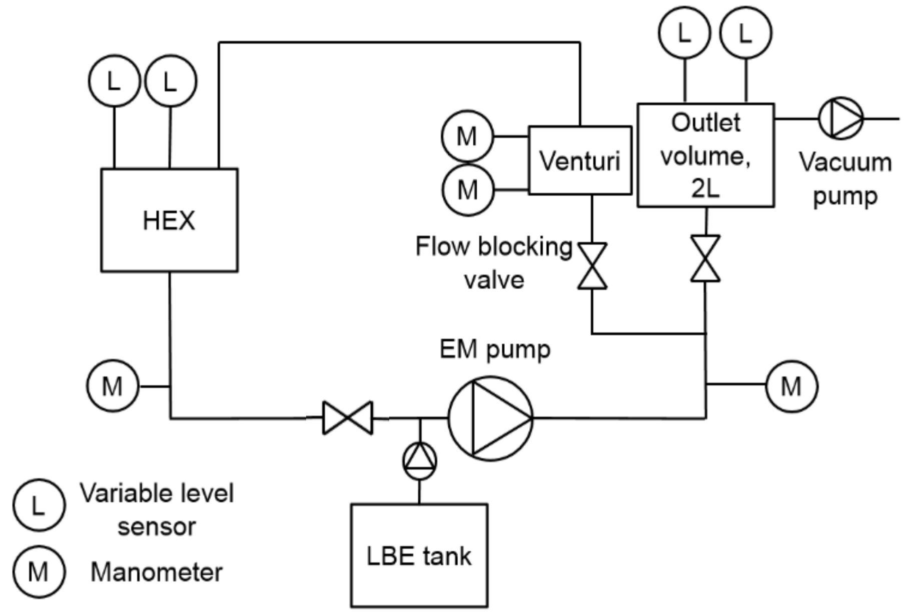
Channel volume = 0.3L

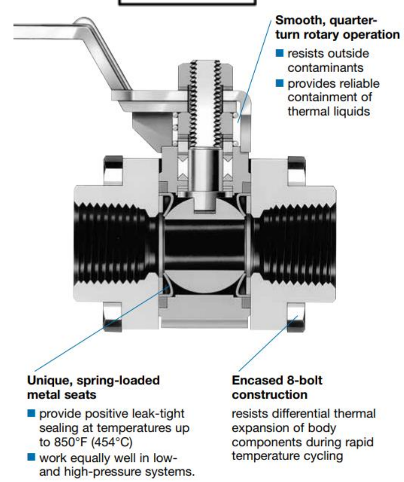


Volume to fill the diffusion chamber in the worst case scenario = 0.3L

LIEBE mock-up extended tests

- Outlet LM level depending on:
  - Total LM volume in the loop
  - Pump Fr
- Level detection:
  - Pressure
  - Electric contact
  - Inductance sensors (sensor developed in IPUL)
- Qmax experimental confirmation at lower "z"
  - Similar setup to previous tests

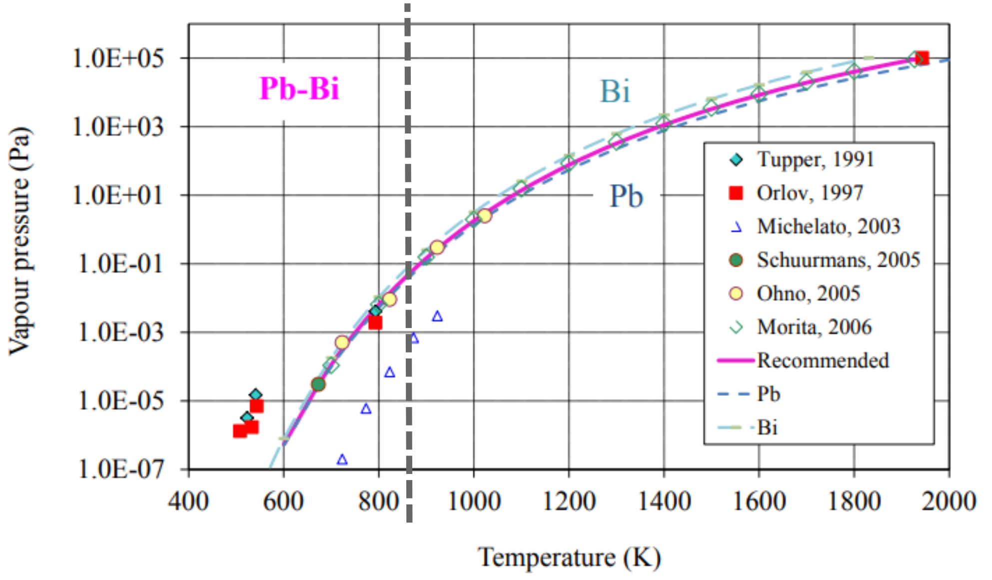




High flow and temperature valve

Saturated vapour pressure

Figure 2.8.3(a): Saturated vapour pressures of liquid LBE versus temperature



$$p_{s(\mathrm{LBE})}[\mathrm{Pa}] = 1.22 \times 10^{10} \cdot \exp(-22552/T)\mathrm{K}$$

- Recommended correlation:
  - T=673K(400degC) – Ps= 3.4e-7mbar
  - T=773K(500degC) – Ps= 2.6e-5mbar
  - T=873K (600degC) – Ps= 7.3e-4mbar
  - T=923K (650degC) – Ps= 3e-3mbar