Cryogenics experience from SPS test

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on behalf of HL-LHC WP9 working team

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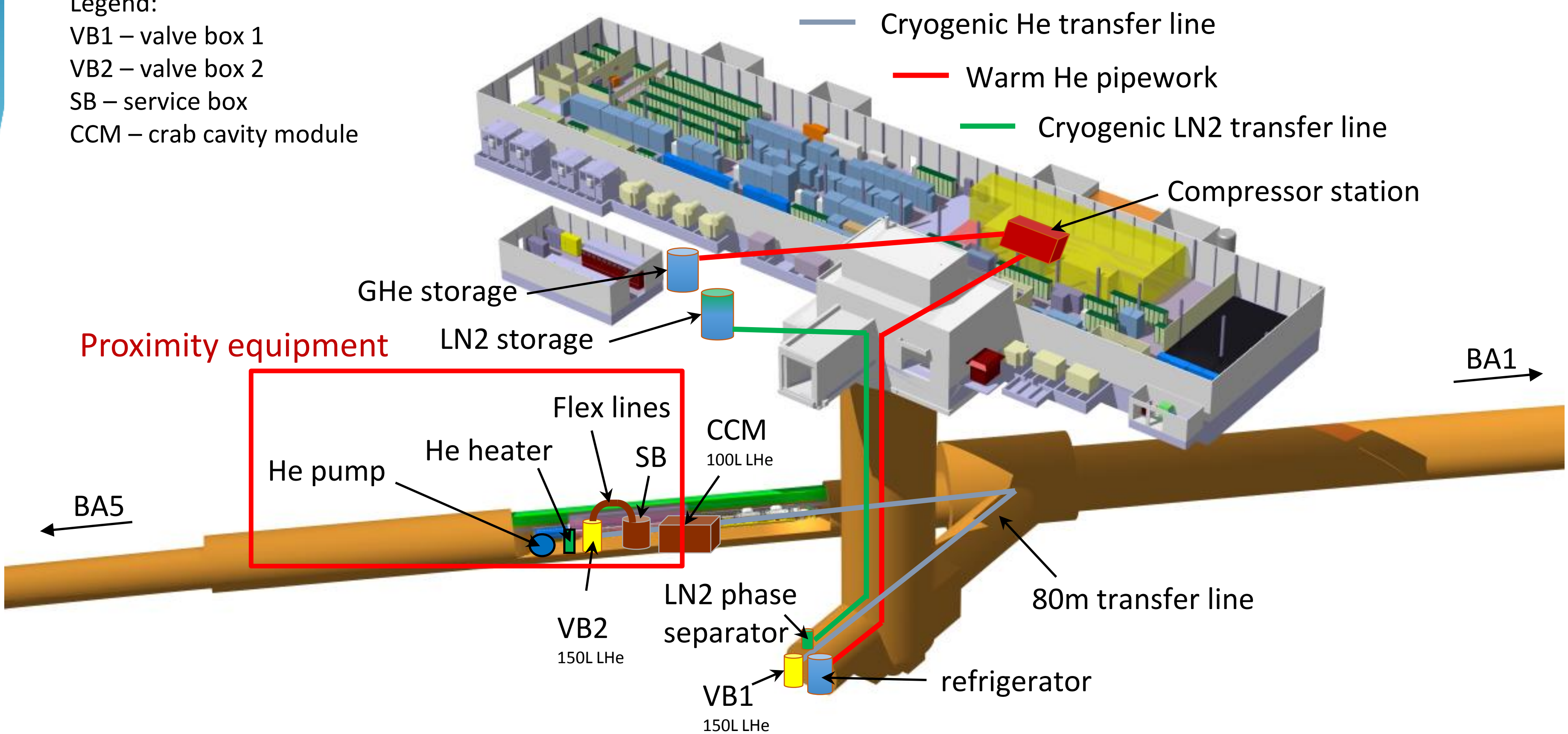
Outlook

- BA6 infrastructure layout and flow scheme
- Operation overview
- Instrumentation failures
- Review of design and proposed improvements
- LHC cryomodule – flow scheme and requirements
- RFD prototype design
- Heat load analysis
  - Static
  - Dynamic
  - BA6 heat load extraction limitation
- Perspectives
- Conclusions

General layout

Legend:
VB1 – valve box 1
VB2 – valve box 2
SB – service box
CCM – crab cavity module



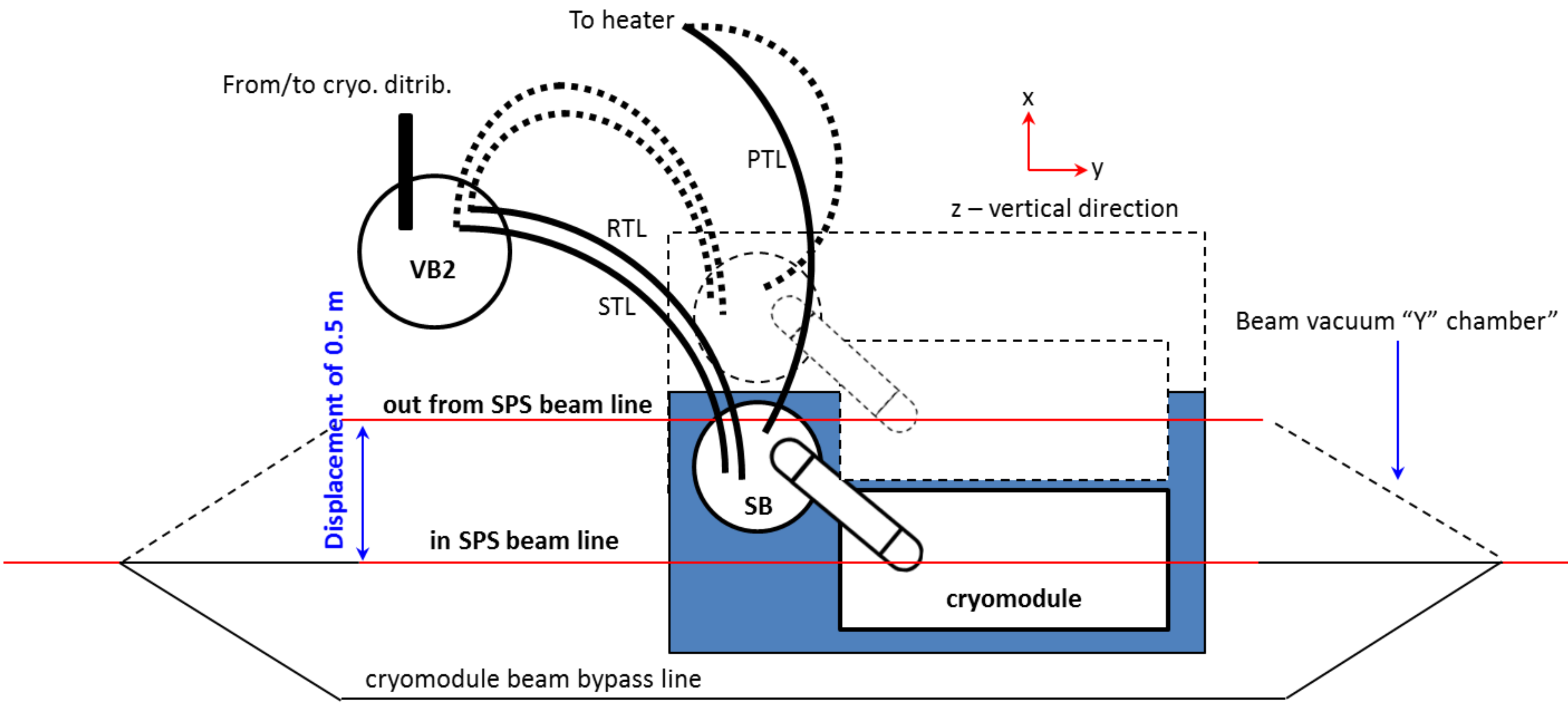
Cold Box:
- Supply 4.5 K helium into distribution system

Distribution system (VB1, 80 m transfer line, VB2):
- Distribution of helium at required thermodynamic parameters between the CB and PE

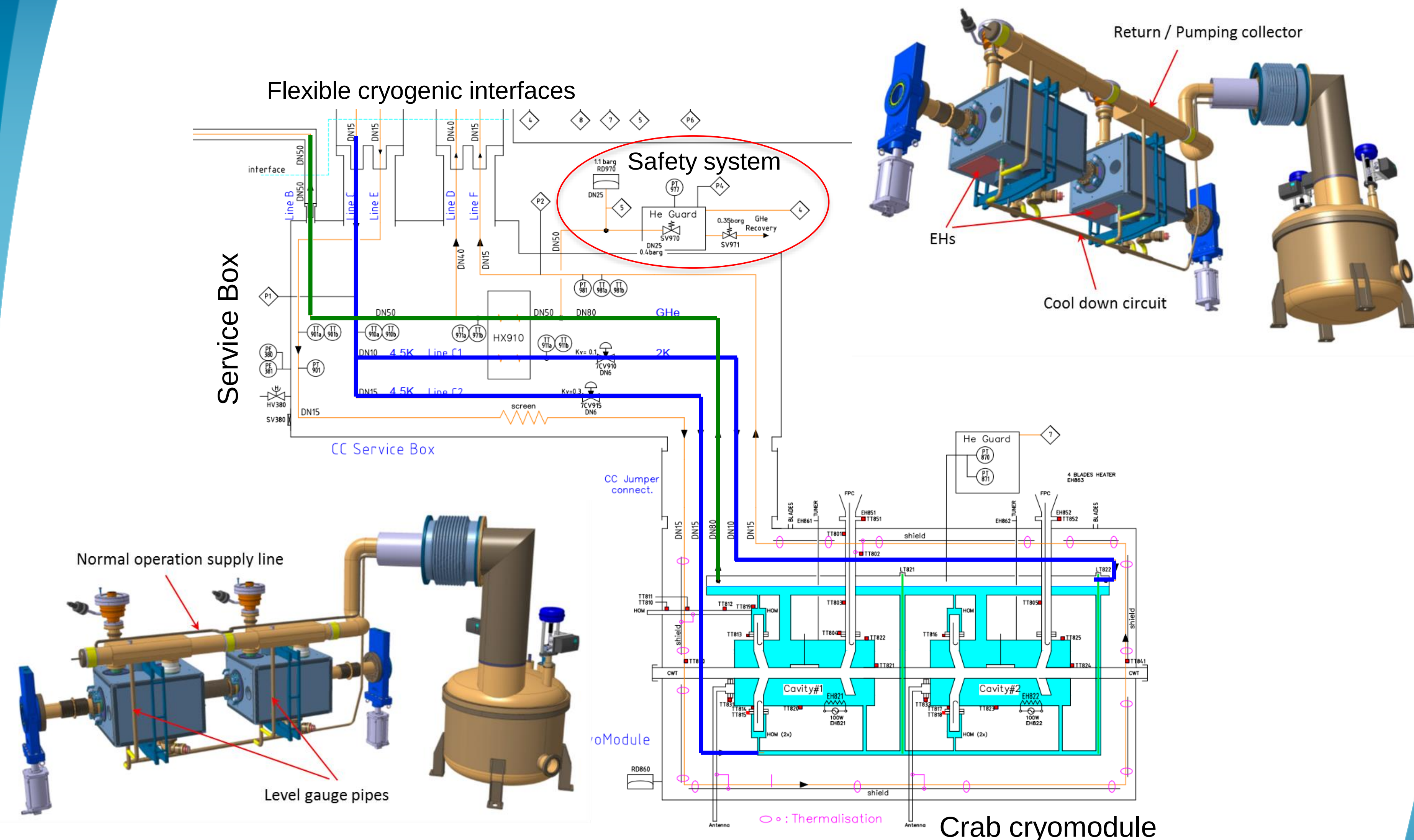
Proximity equipment:
- makes direct refrigeration interface to the crab cavity module
- allows for operation of the cavities with superfluid helium at 2 K

Scheme and principles of displacement

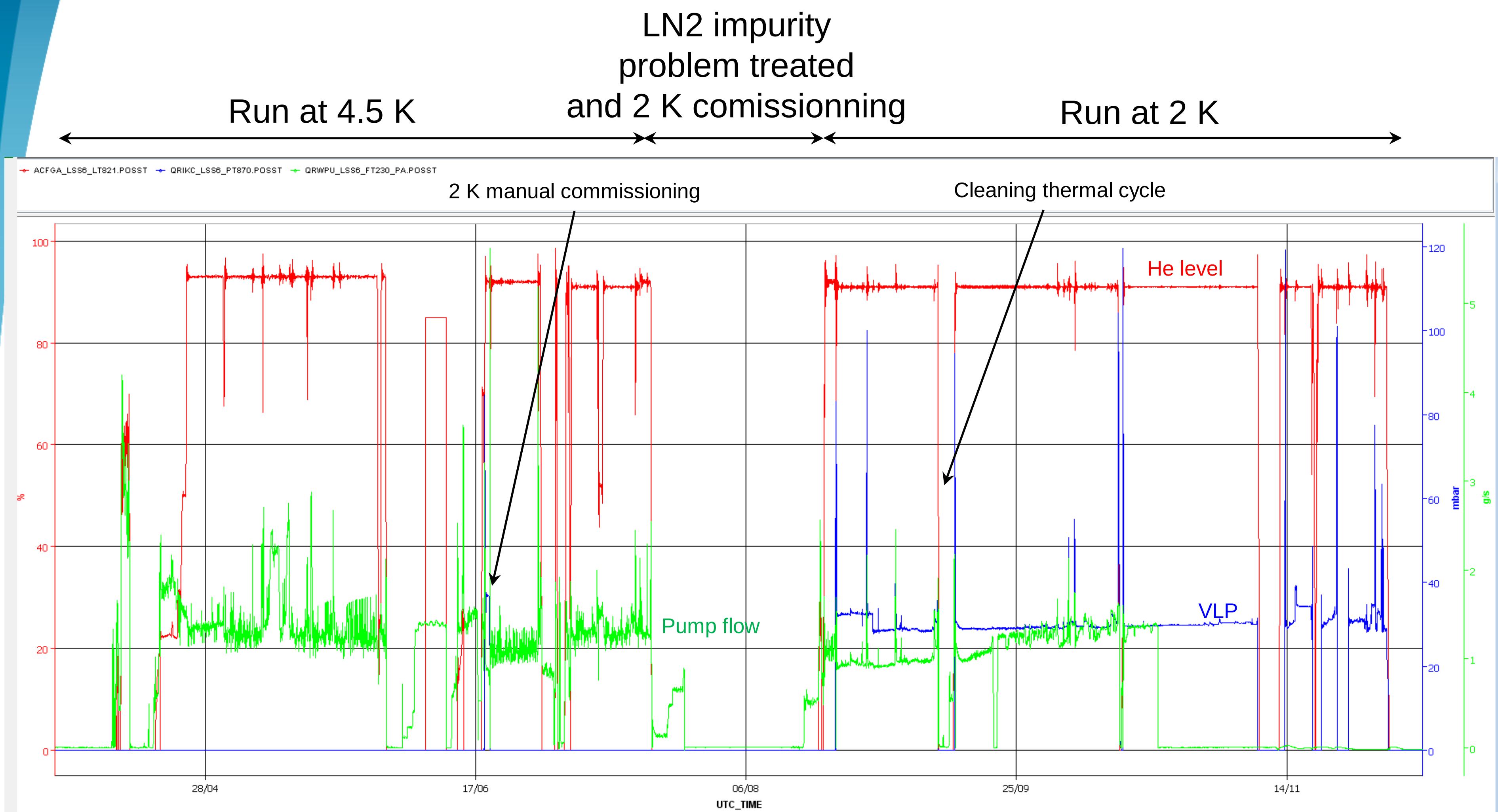
Connection transfer lines between Service Box and cryogenic infrastructure were built as flexible solution to compensate platform displacement of 0.5 m



Scheme and flow diagram

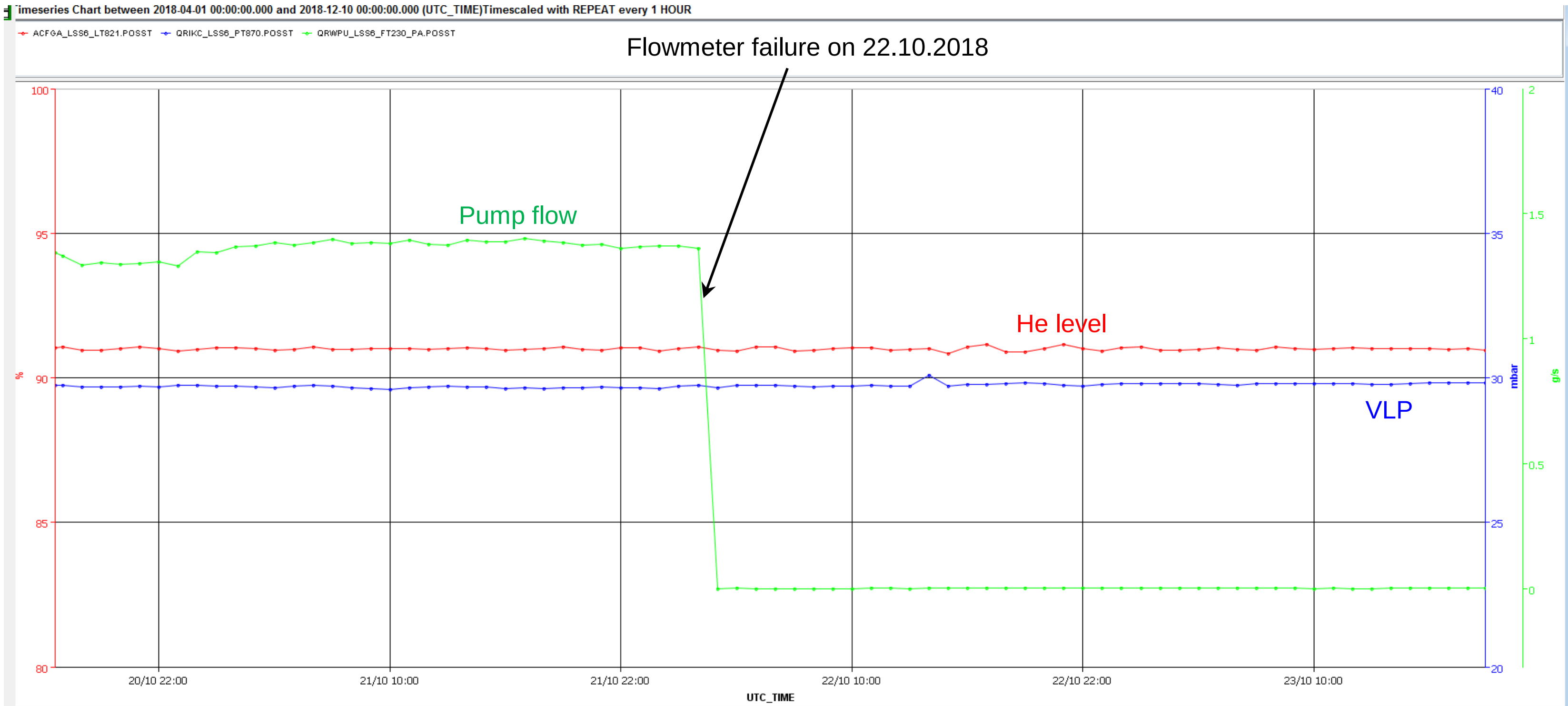


2018 run of BA6 cryogenics – overview



- 3 months of operation at 4.5 K
- 3 months of operation at 2 K
- Very good availability (after LN2 problems treatment and 2 K commissioning)
- Very good stability of the system (within ~1 mbar at 2 K)

Instrumentation failures 1/2



In addition, a few glued diagnostic thermometers were decoupled from measured surface. Action: installation of these sensors is to be improved (remark: all key measurement points, wherever possible, were equipped with screwed sensors – no failure was noticed).

Instrumentation failures 2/2

the tuner heads. Afte
ut any special correctiv
ers.

However, after tuners disassembly some rust was found i.e. some water condensation was present during operation. Inspection on 17.06.2019 confirmed failure in heating element, investigation with mechanical tests and x-rays is underway. Action: re-design of heating system, replacement possibilities/redundancy are to be studied for series production.

Changes and improvements for series production

Lessons learnt – main improvements to the next cryomodule design:

- The level gauge close to LHe supply was perturbed by droplets coming from LHe supply (it was disabled for operation) – protection baffle from helium droplets is to be installed,
- 2 K CERNOX thermometers had too high thermal resistance for correct temperature reading (~300 mK) – at least 2 K TTs to be installed in the liquid helium (e.g. on the bottom of the LTs)

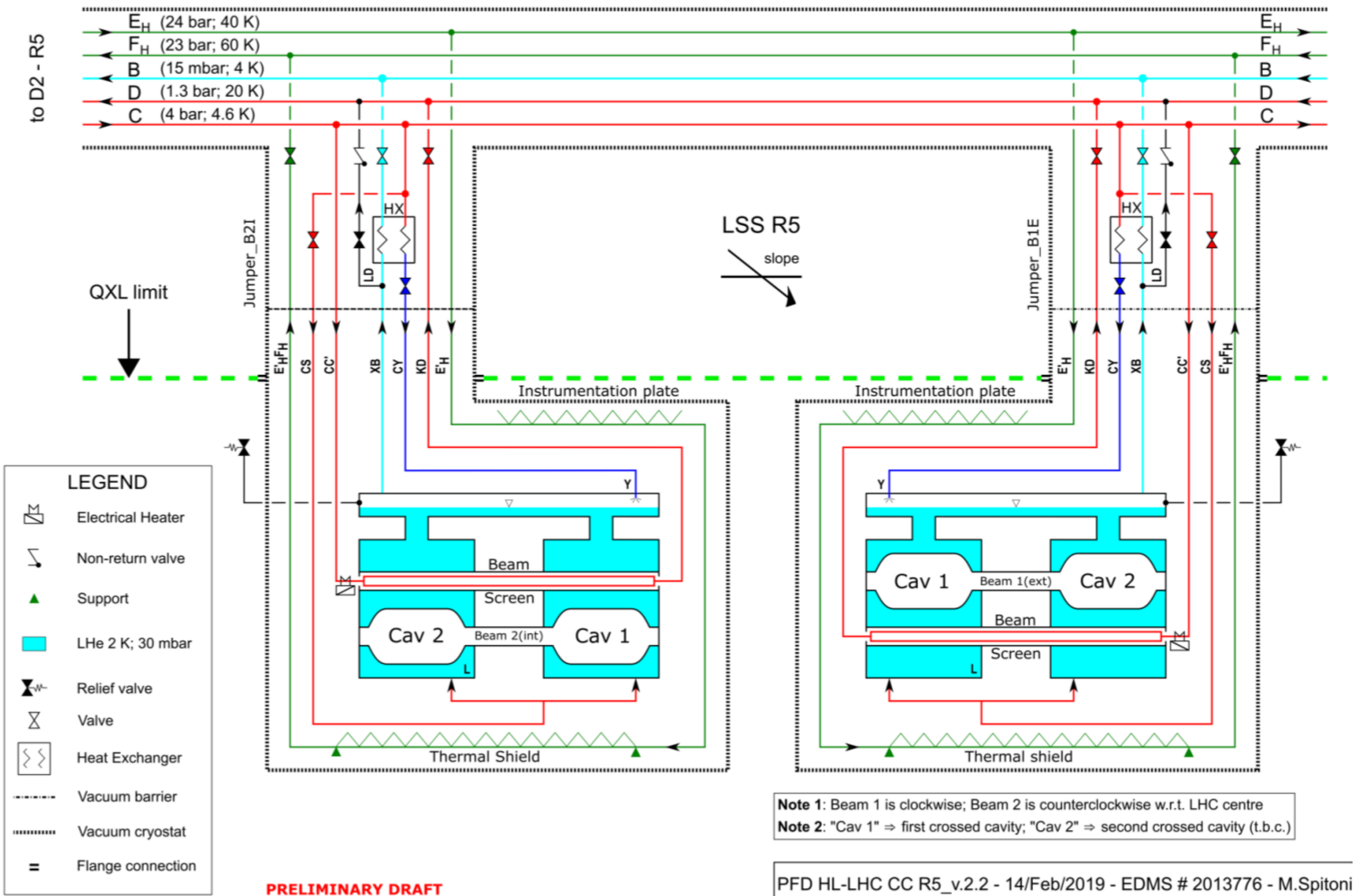
Differences in design for next cryomodule:

- RFD and series cryomodule will have one circuit more than DQW prototype – beam screen for “second” beam pipe (operation at 4.5 – 20 K).

- Assumed approach: with lessons learnt on first DQW, we will adapt maximum solutions from first DQW for design of the module compatible for LHC. The main differences will concern the following aspects:
  - Jumper interface to be done with standard LHC size,
  - BS circuit to be integrated in the module,
  - Safety devices to be integrated on the cryomodule,
  - LTs exchange possible from outside of the cryomodule.

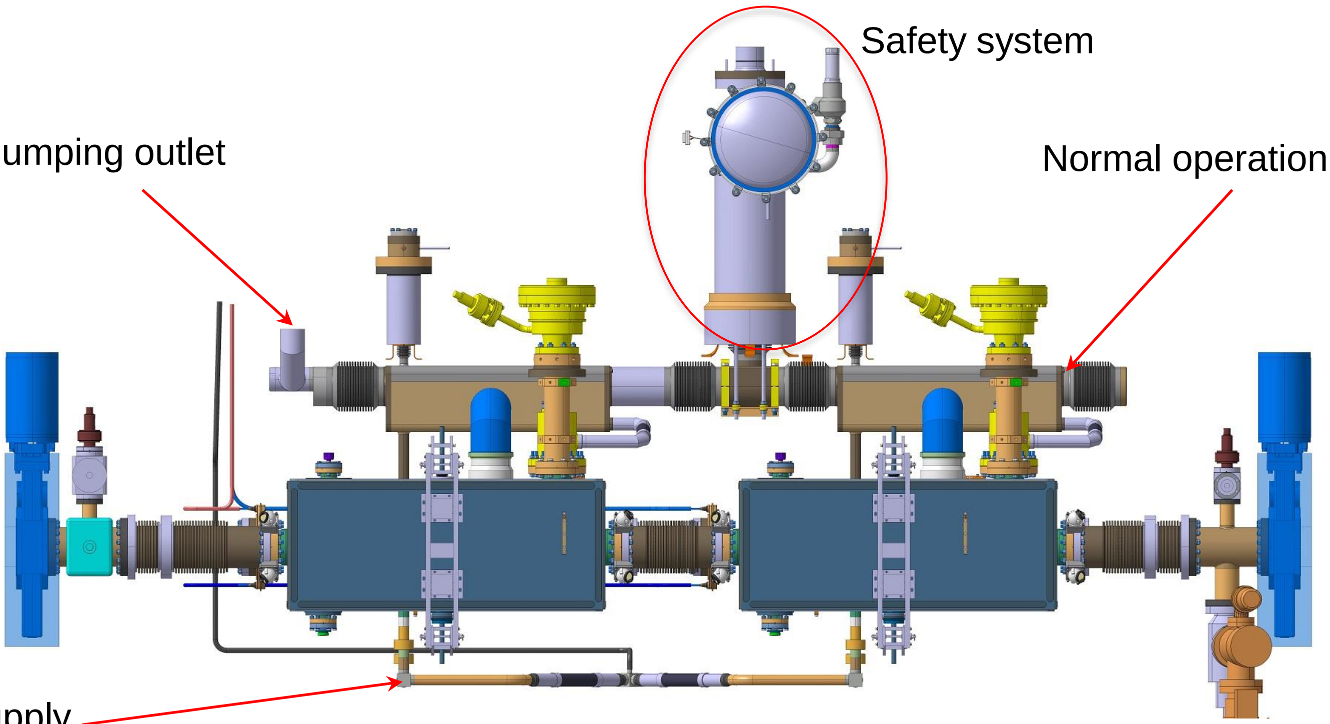
LHC cryogenic flow scheme IP5R

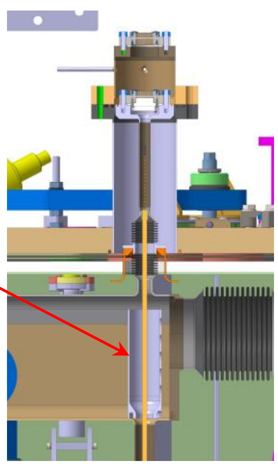
RFD prototype will be built according to below flow scheme – as LHC compatible.

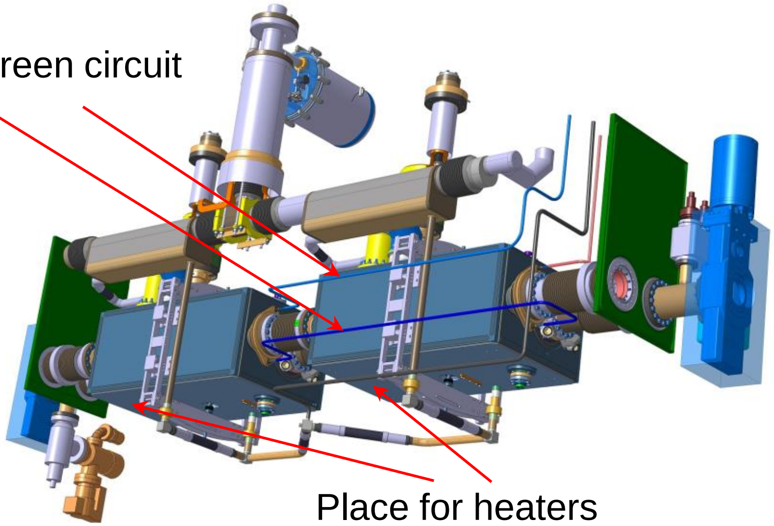


Independent warm up system for each cryomodule (regeneration reasons) is being studied – not represented on above flow scheme.

RFD – draft snaps



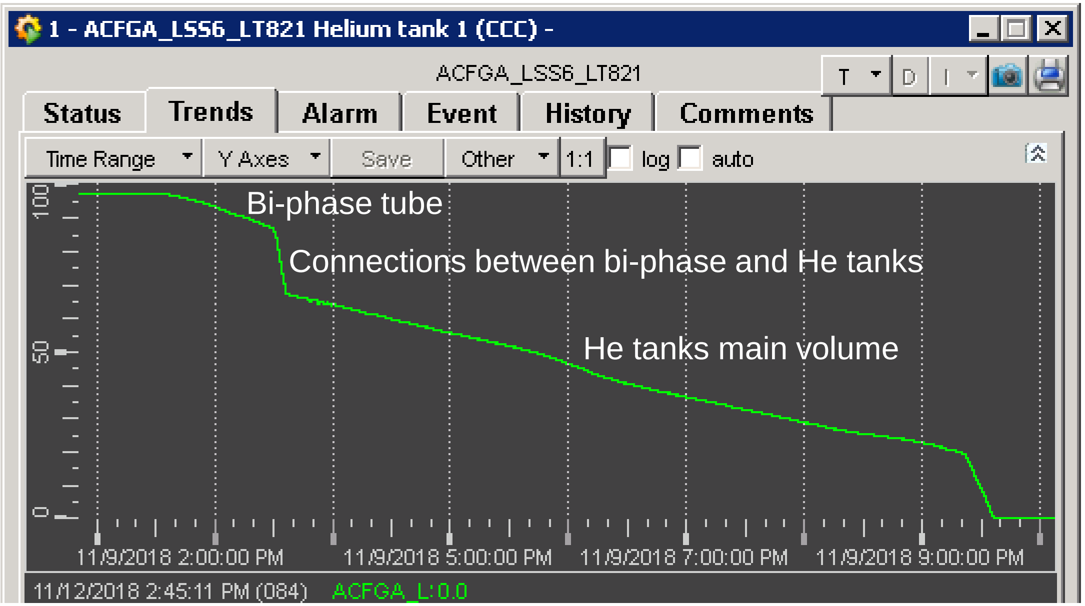




Static heat load – DQW in SPS test

The static heat load to the cryomodule only was checked by means of boil off method. The theoretical value calculated during design was 20.1 W, measured value 18 W.

The cryomodule empting curve



The static heat load measured during operation with VLP flowmeter was **22.1 W**. But this load includes local distribution (Service Box + jumper). The distribution heat load can be recalculated as 22.1–18 = 3.9 W.

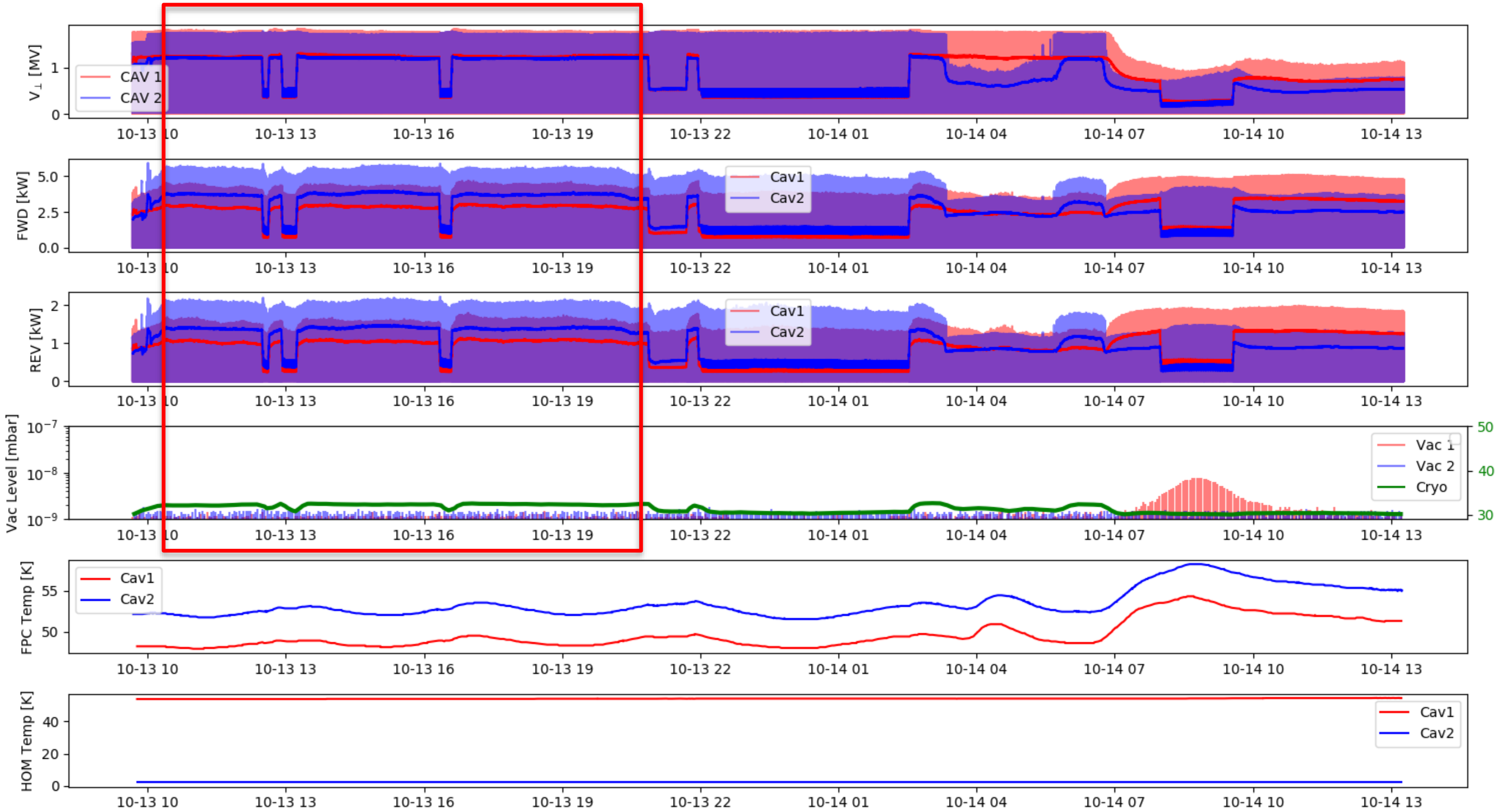
Dynamic heat load 06.10.2018

Cav1 at ~0.6 MV and Cav2 at ~0.8 MV. Dynamic heat load recalculated as **9.9 W** *(calculated design value for cryomodule at 3.4 MV is 21.4 W)*

Coupling between FPC temperature and cryo loss is visible in some cases (not for all of them) – to be better understood.

Dynamic heat load 13.10.2018

Cav1 and Cav2 at ~1.2 MV. Dynamic heat load recalculated as **13.3 W**

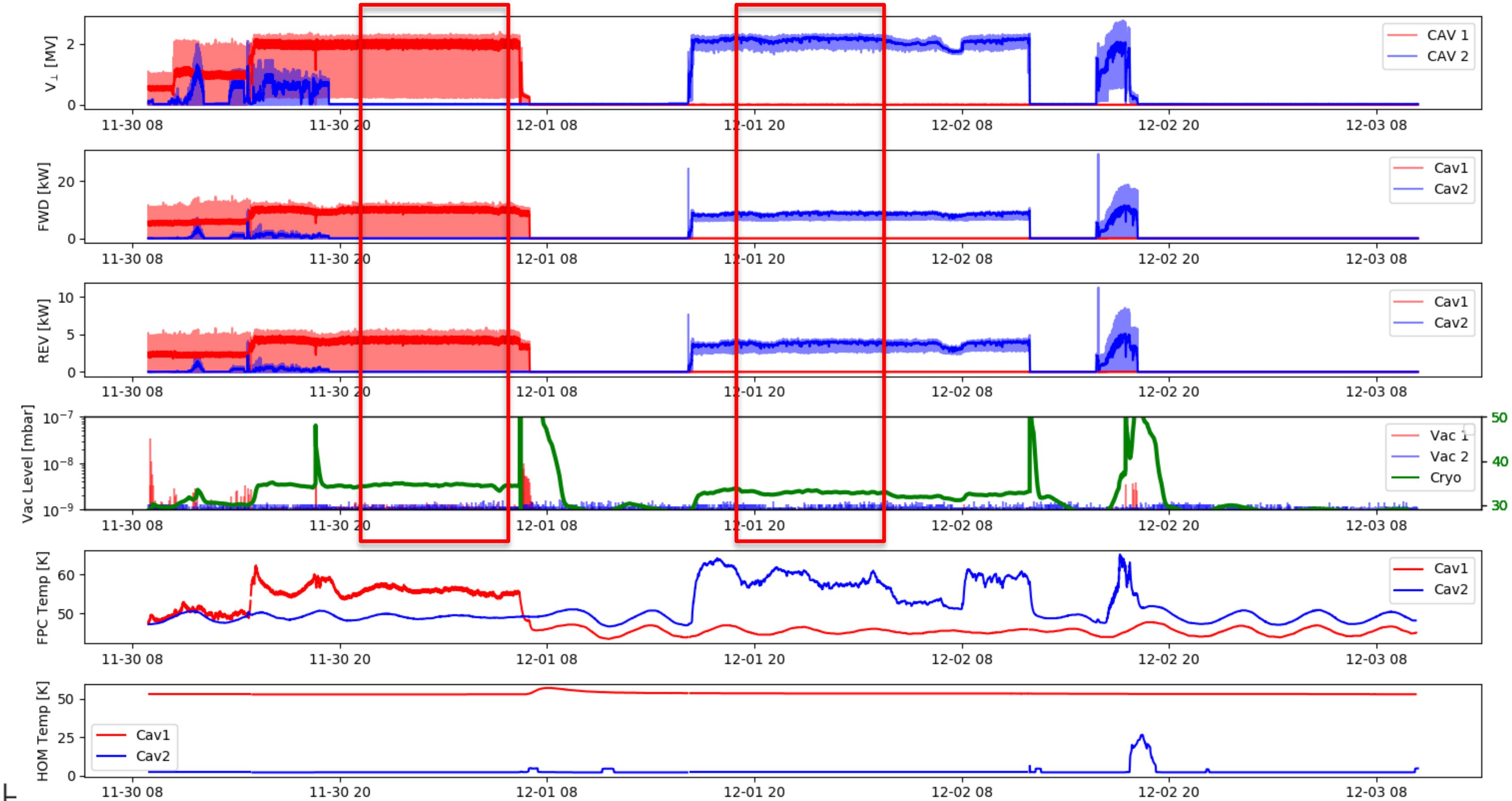


Dynamic heat load 30.11 – 02.12.2018

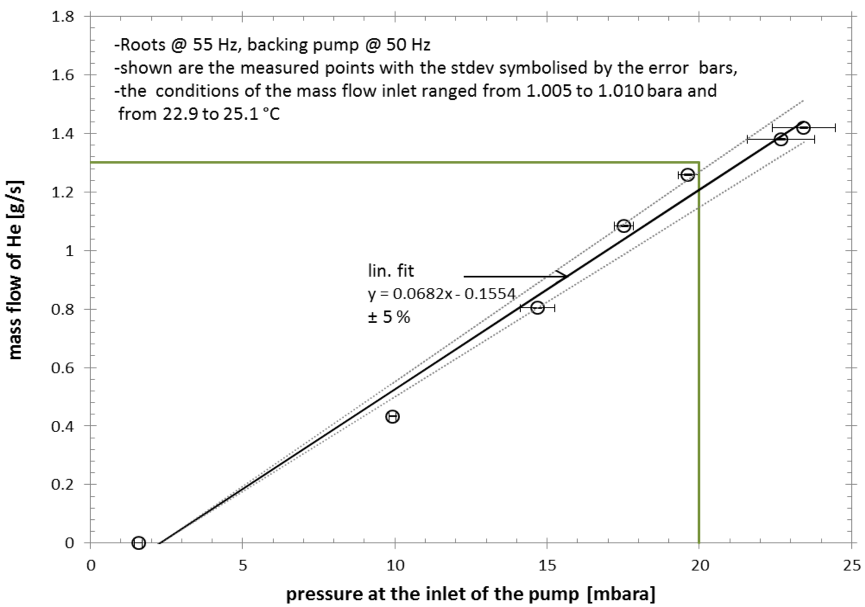
Cav1 at ~2.1 MV. Dynamic heat load recalculated as **~15 W (rough estimate)**

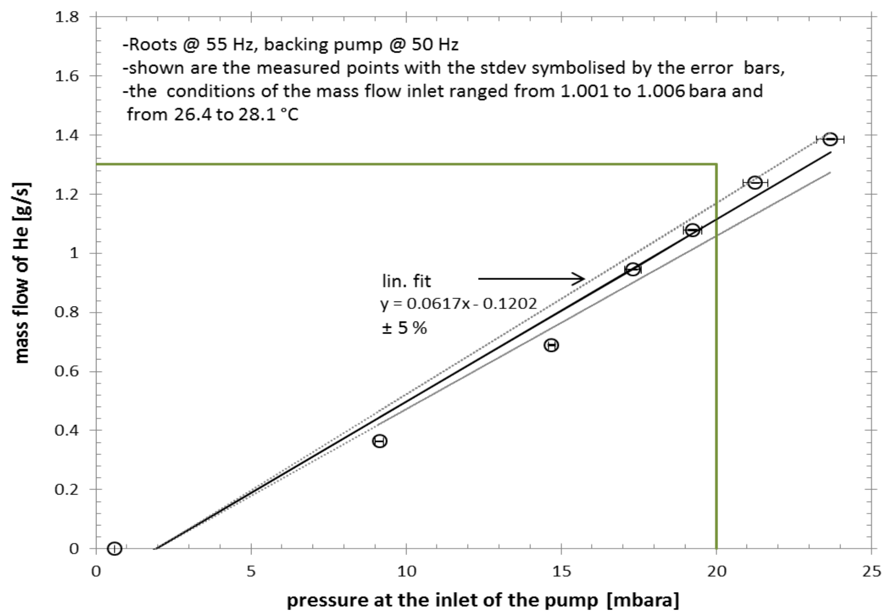
Cav2 at ~2.1 MV. Dynamic heat load recalculated as **~8 W (rough estimate)**

As the FT230 flowmeter was failed, both above estimates were recalculated considering frequency revolution value of the pumps and their capacity curves applying defined scaling. More precise values will be available after restart of the installation and repetition of measurements.



BA6 heat load extraction limitation





The pumps real capacity was measured in cryolab – see curves above.
From operational experience deltaP on VLP between the pumps suction and helium bath is equal to ~10 mbar for flow ~1.5 g/s of flow i.e. total pumping capacity to guarantee 30 mbar in the He bath is 2.1 g/s, what corresponds to 48 W of total heat extraction (26 W of dynamic heat load).

Perspectives regarding BA6

LS2 activities:

- Correction of circuit arrangement in VB2 to allow cool down and 4.5 K operation in refrigeration mode (contract with Criotec, Italia),
- Re-positioning of VB2 (optimization for flexible lines stress),
- Repairs of helium leak in the thermal screen circuit (flex line between refrigerator and VB1),
- Replacement of the liquefaction line flowmeter FT230

Next operation period:

- Capacity measurement of the refrigerator to be done prior production period

Remarks:
BA6 operation requires ~120 kCHF/year for operation, maintenance activities and helium delivery. This amount of money shall be reserved in appropriate budget.

Conclusions

- First period of BA6 cryogenics operation was successful – reliable 4.5 K refrigerator operation, good performance of the distribution, remarkable stability and flexibility for transients of 2 K pumping system.
- Improvements to be considered:
  - Tuner heating system is to be re-designed (redundancy/replacement possibility)
  - Temperature sensors installation: two sensors to be installed in the He bath, gluing of the sensors to be avoided
- RFD prototype cryomodule to be built as “compatible for LHC” – BS circuit and safety devices integrated on the module – design work started,
- Thermal losses: static heat load is in perfect agreement w.r.to the design calculations (18 W for cryomodule), dynamic load to be investigated in more details (in expected range for now).
- Testing infrastructure in SM18 and SPS to be adapted to RFD when required.

Thanks to all members of the crab team for close and successful collaboration !

Thank you for your attention!
Questions?

Great thanks to all people involved in HiLumi adventure!

Back up – heat load calculations DQW

	Static loads	
	2 K	**80 K**
Radiation	3.3	8
CWT	0.1	28
Supports	2.1	21
RF/FPC	5.3	72
Instrumentation	2.4	8
HOM/Pickup	5.5	15
Tuner	1.4	15
Total static	**20.1**	**167**

	Dynamic loads	
	2 K	**80 K**
Cavities	11	0
Beam	0.5	0
RF / FPC	4.9	10
HOM/Pickup	4	10
Total dynamic	**21.4**	**20**

by Federico Carra