Crab cavities
– cryogenics for SPS and LHC

LHC-CC13, 6th LHC Crab Cavity Workshop
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K. Brodzinski
on behalf of cryogenic team at CERN

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- Cryogenics for SPS
  - Cryogenic circuits
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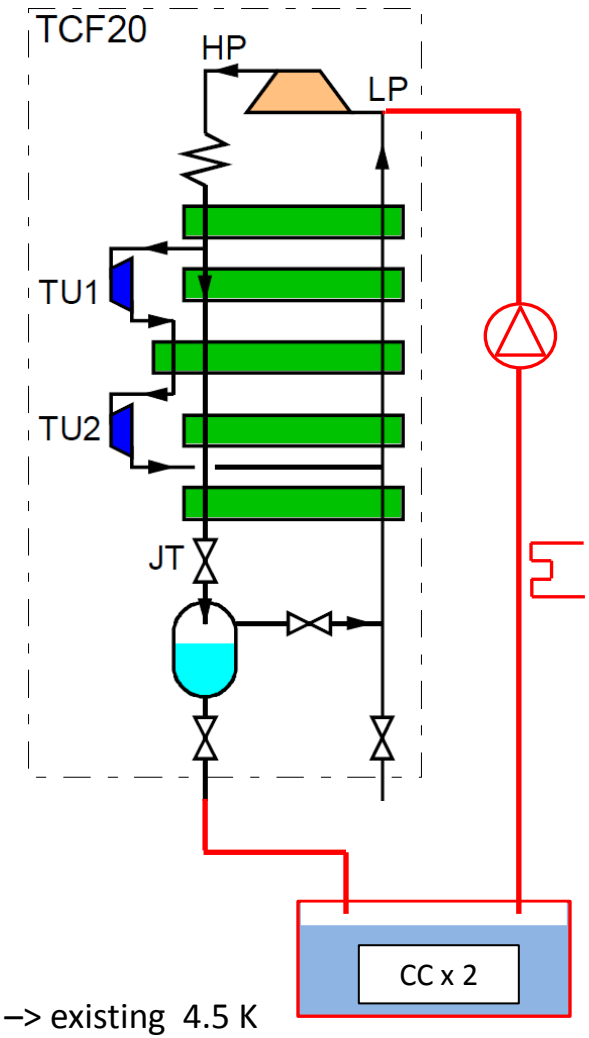
  - SPS cryogenic capacity discussion (feedback from liquefaction test)
  - Brief on integration
- Cryostat design – analytical approach
  - Cryostat circuits and instrumentation
  - Pressures, protection and safety, operation aspects
- Cryogenics for LHC - concept for LHC P1 and P5
- Conclusions

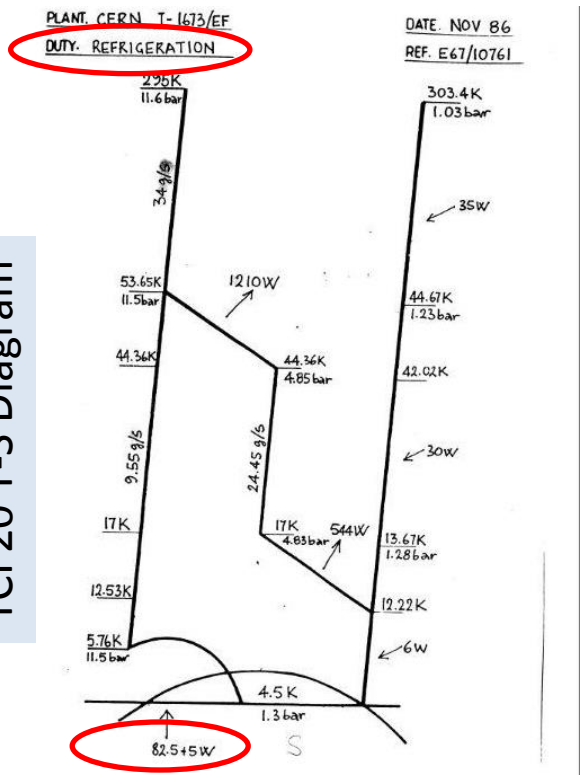
Cryogenic infrastructure in SPS BA4



black –> existing 4.5 K
red –> to be constructed 2 K

Crab cavity cooling at 2 K ➔ TCF20 cryoplant used in pure liquefaction
TCF20 means 20 l/h = 0.7 g/s of LHe

TCF20 T-S Diagram

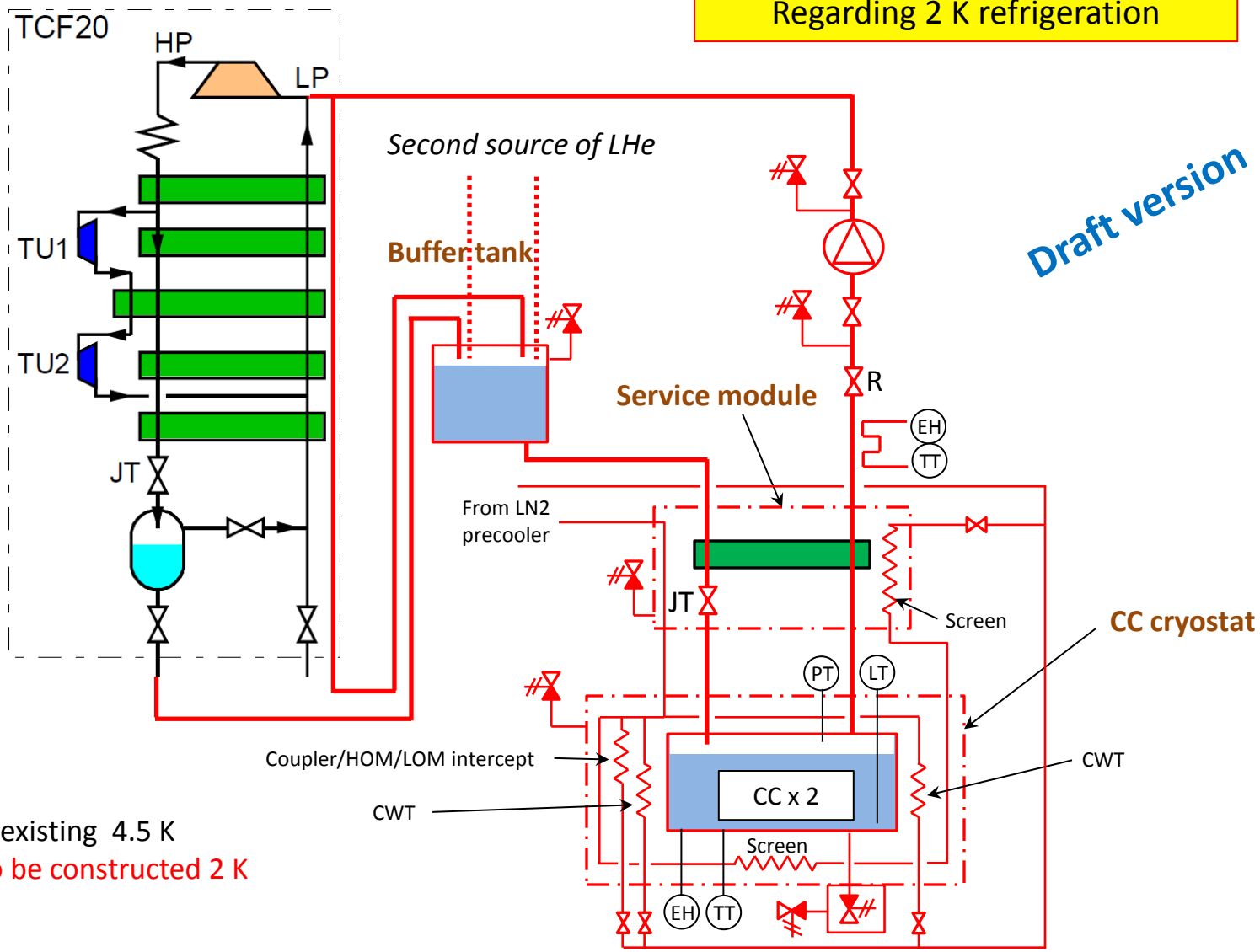


Guaranteed capacity in refrigeration mode: 87.5 W @ 4.5 K
(i.e. isentropic equivalent to ~0.85 g/s of liquefaction)

Operation in liquefaction mode is required

Cryogenic circuits

Regarding 2 K refrigeration



Draft version

black –> existing 4.5 K

red –> to be constructed 2 K

Heat load

Equipment	Heat load	Source of capacity
Service module	~2.5 W @ 4.5/2K ~30 W @ 80 K	Cold box -> 0.13 g/s LN2
Buffer tank	~1.5 W @ 4.5 K	Cold box -> 0.08 g/s
Transfer lines	~4 W @ 4.5 K	Cold box -> 0.21 g/s
Cryo module static	~14 W @ 2 K 223 W @ 80 K	Cold box -> 0.68 g/s LN2
Cryo module dynamic	~11 W @ 2K	Buffer -> 0.5 g/s
Total static:	~22 W	Cold box -> ~1.1 g/s

R. Bonomi, O. Capatina, F. Carra, V. Parma, K. Brodzinski

Summary (assuming cold box capacity of 1.5 g/s):

Total Static: 1.1 g/s -> calculated margin on the cold box is 0.4 g/s

Total Static + Dynamic = 1.6 > 1.5 g/s -> <u>run without thee buffer is not possible</u>

Dynamic (assuming 150 L buffer):
11 W -> 0.5 g/s -> 10.5 h of operation*

Filling of 150 L buffer with 0.4 g/s will take ~13 h

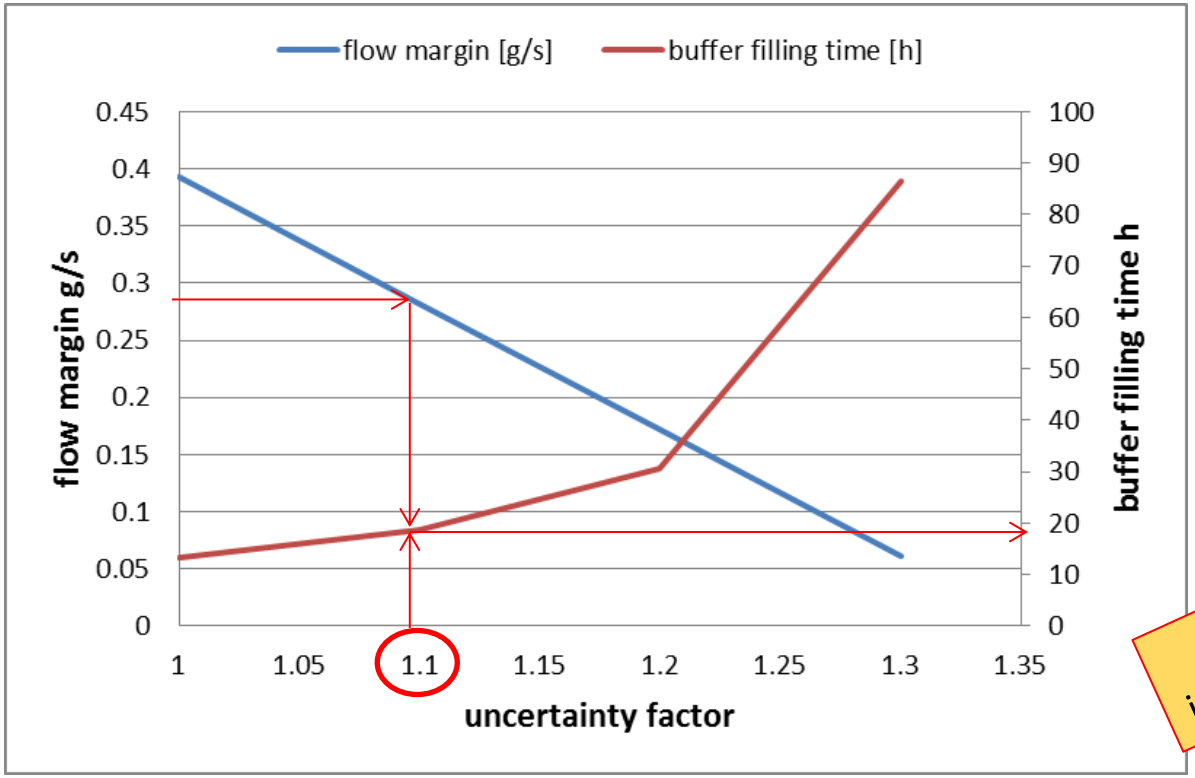
There is no contingency factor added.
Are we ready to respect the above numbers ?

*assuming exclusively buffer capacity

Heat load uncertainty 1

Assumptions:

- Cold box capacity – 1.5 g/s, buffer tank volume - 150 L
- Dynamic heat load – 11 W -> 0.5 g/s -> 10.5 h of operation*



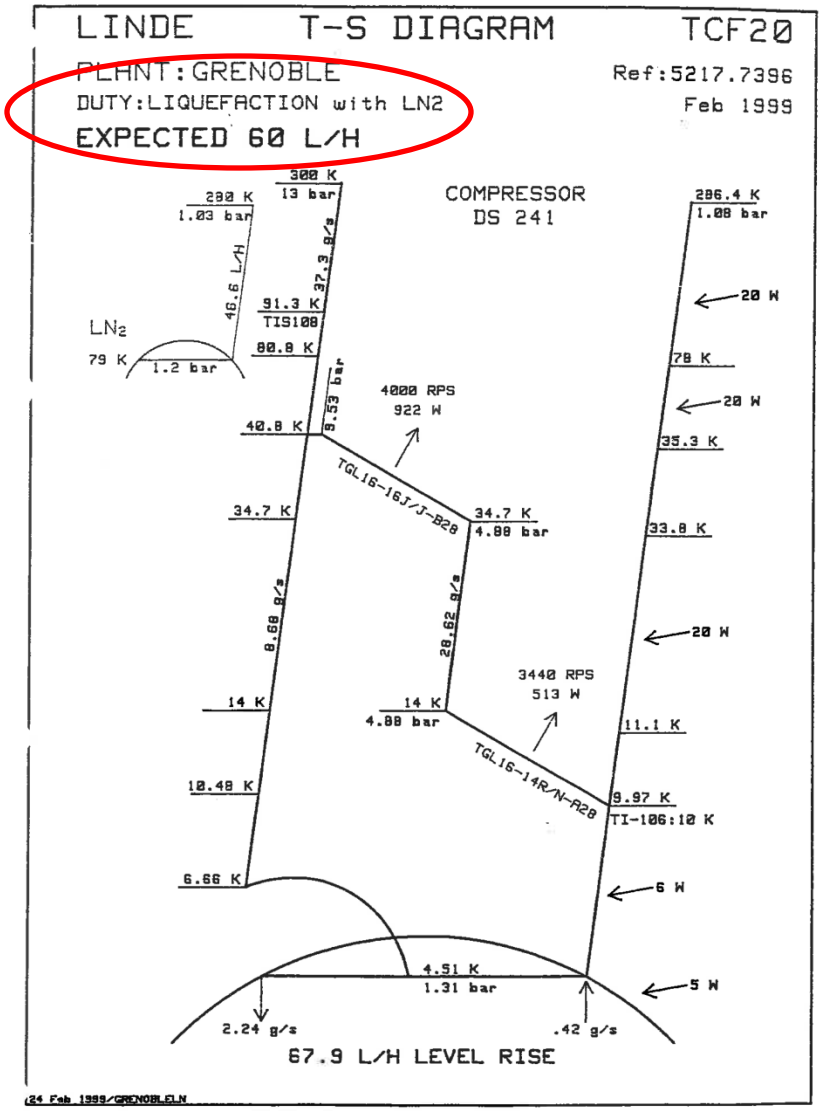
factor	flow margin	bufer filling time
	g/s	h
1	0.39	13.4
1.1	0.28	18.7
1.2	0.17	30.7
1.3	0.06	86.4

Minimization of static heat load is very important to get flow margin

What is the maximum acceptable uncertainty factor we are ready to accept for test run ?
What are the options if the heat load goes above factor of 1.3 ?

*assuming exclusively buffer capacity

“New” TCF20 liquefier



60 L/h -> 2.1 g/s of LHe

- Available at CERN
- Should be commissioned on the surface
- Integrated in BA4
- LN2 boost circuit to be built in BA4

Issues:

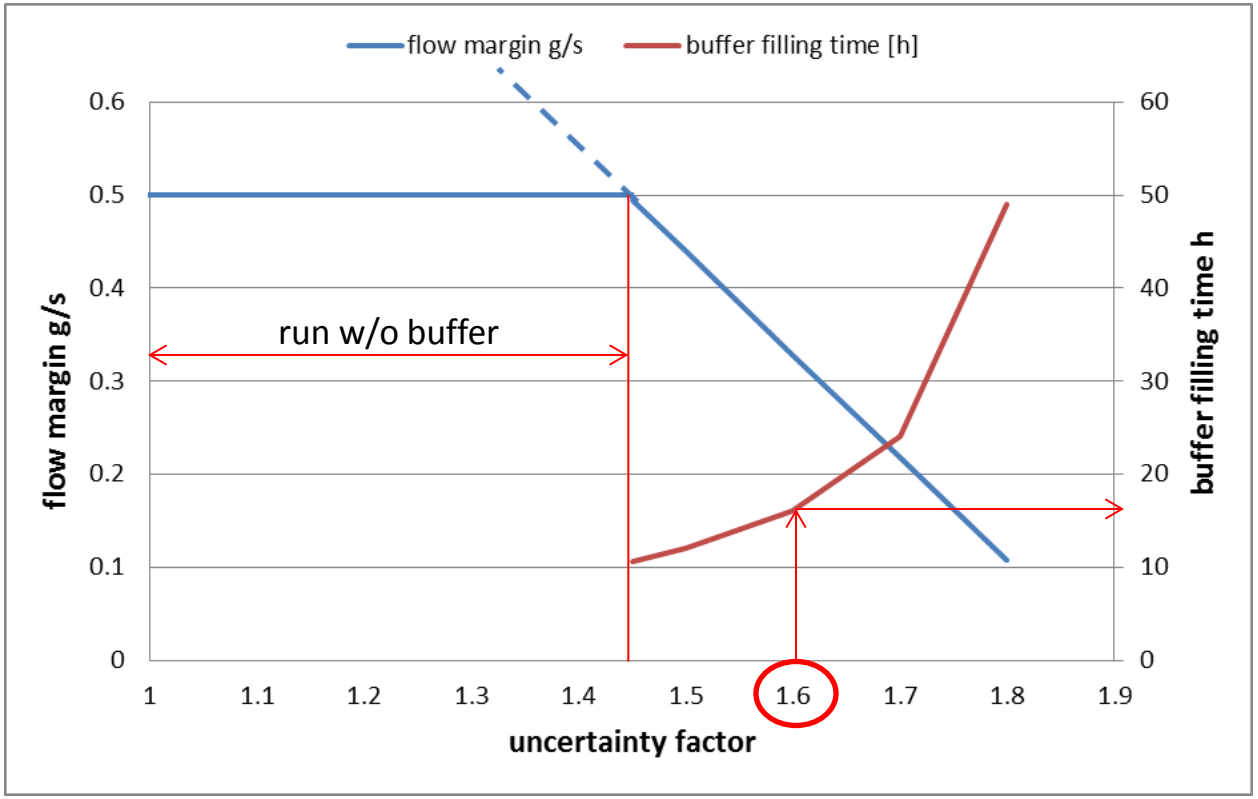
- Not foreseen initially to be installed in SPS
- Additional resources and time needed
- Very, very tight planning in case of LS1 …

We should all make an effort to provide a good design of the cryogenic system minimizing the heat load as much as possible !

Heat load uncertainty 2

Assumptions:

- Cold box capacity – 2.1 g/s, buffer tank volume - 150 L
- Dynamic heat load – 11 W -> 0.5 g/s -> 10.5 h of operation*



factor	flow margin	buffer filling
	g/s	h
1.45	0.50	10.7
1.5	0.44	12.0
1.6	0.33	16.0
1.7	0.22	24.2
1.8	0.11	49.0

Looks nice … but requires additional manpower and much more work in very tight planning.

*assuming exclusively buffer capacity

“Old” Sulzer-Linde TCF20 in BA4

At SPS BA4 there is a 4.5 K cryogenic infrastructure used last time in 2004 for COLDEX experiment.
All 4.5 K equipment was revised and tested with cold run in autumn 2013.

Renovated compressor + elec. motor – run test done

Revised, labeled and qualified pressure control system / oil removal system

New power supply panel for compressor station

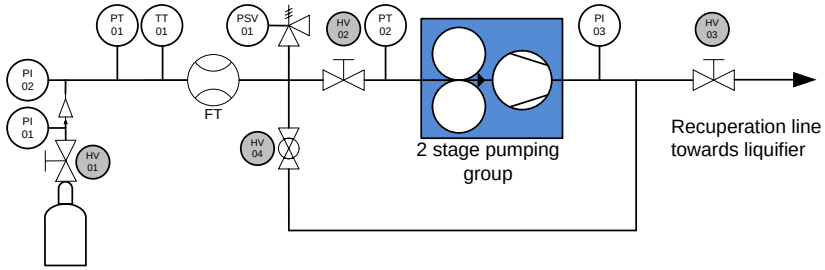
TCF20 Cold box

2 K pumping groups recovered from AMS

Surface equipment

Underground equipment

2 K helium pumps



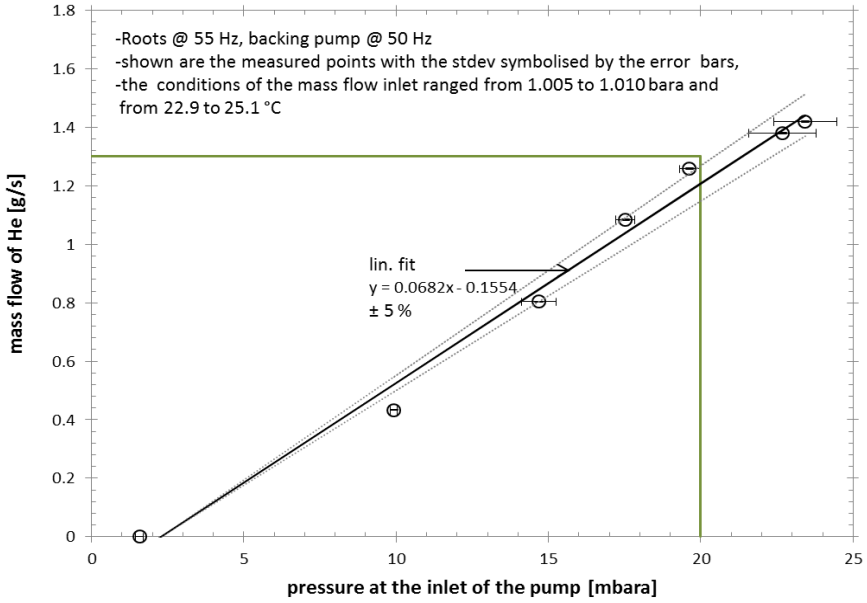
2 batteries of He gas bottles
<200 bar

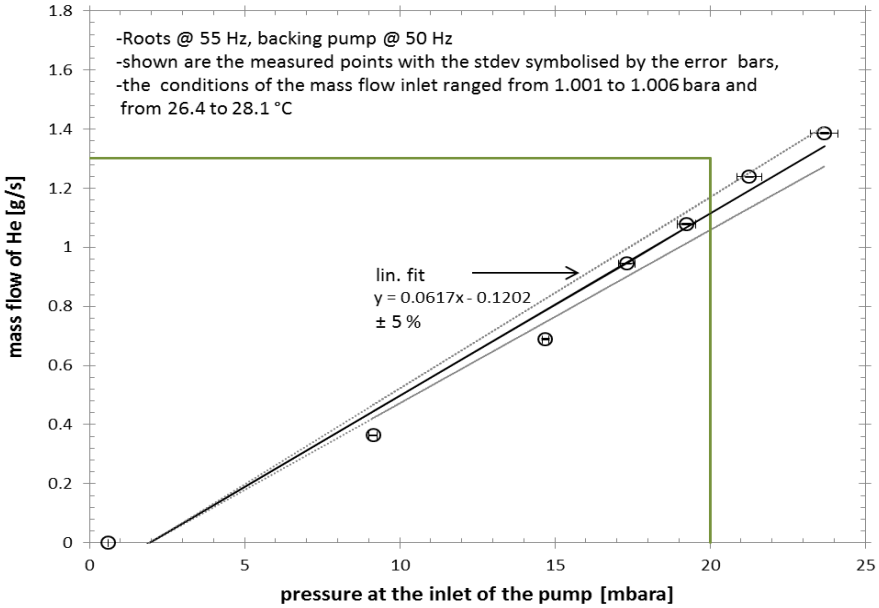
2 stage pumping group (Leybold: RUVAG WS2001 and SV630)

PT01: pressure transmitter, Rosemount, 0… 2000 mbara
TT01: Pt100
FT: flow transmitter, Brooks, 0… 1.5 g/s
PT02: pressure transmitter, GE, 0… 100 mbara

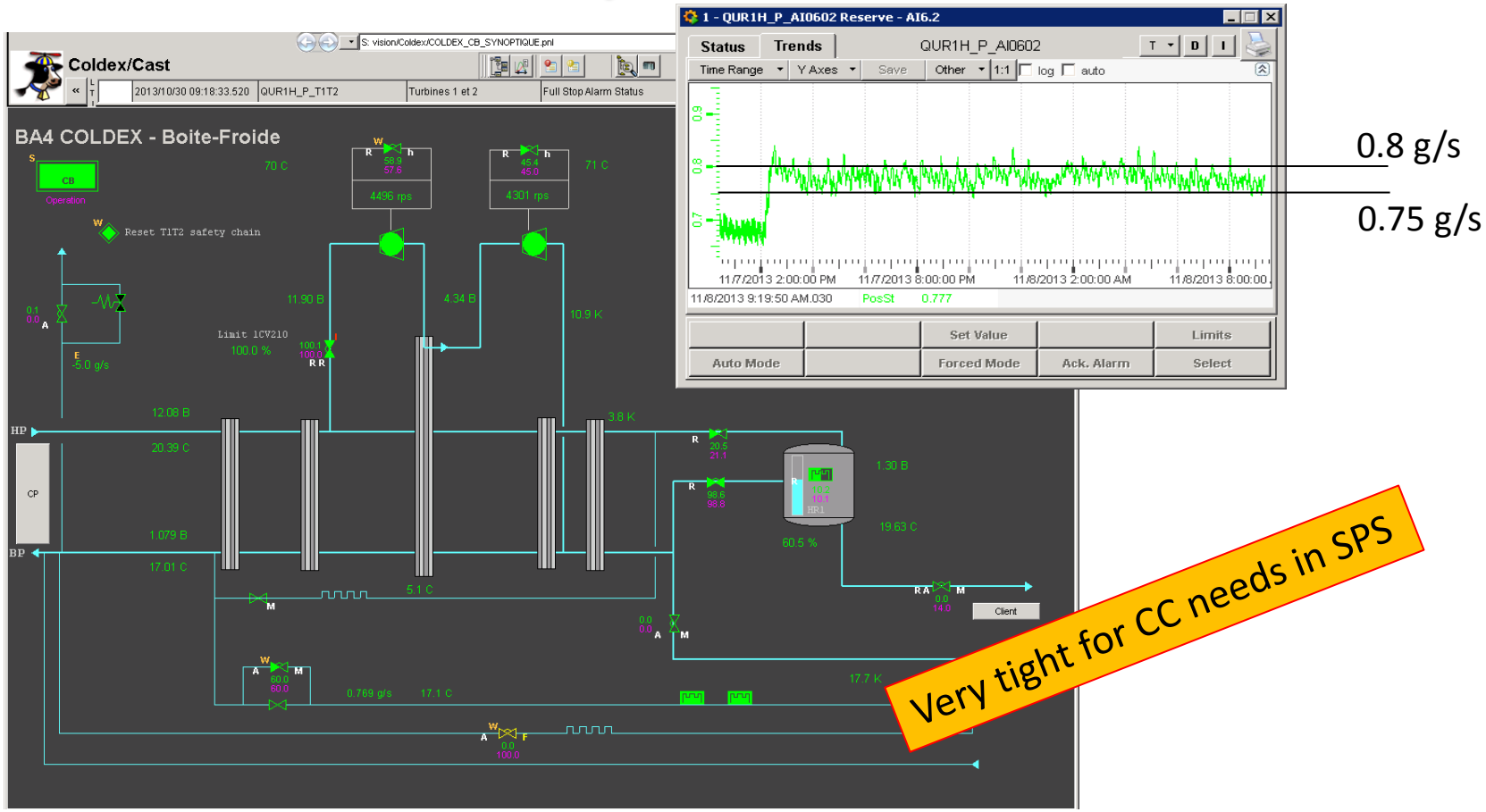
OK for CC SPS test

The check shows that assuming inlet pressure of 20 mbar two pumping units are capable to pump ~2.3 g/s of helium, what gives ~3.5 g/s at 30 mbar (2 K saturation)



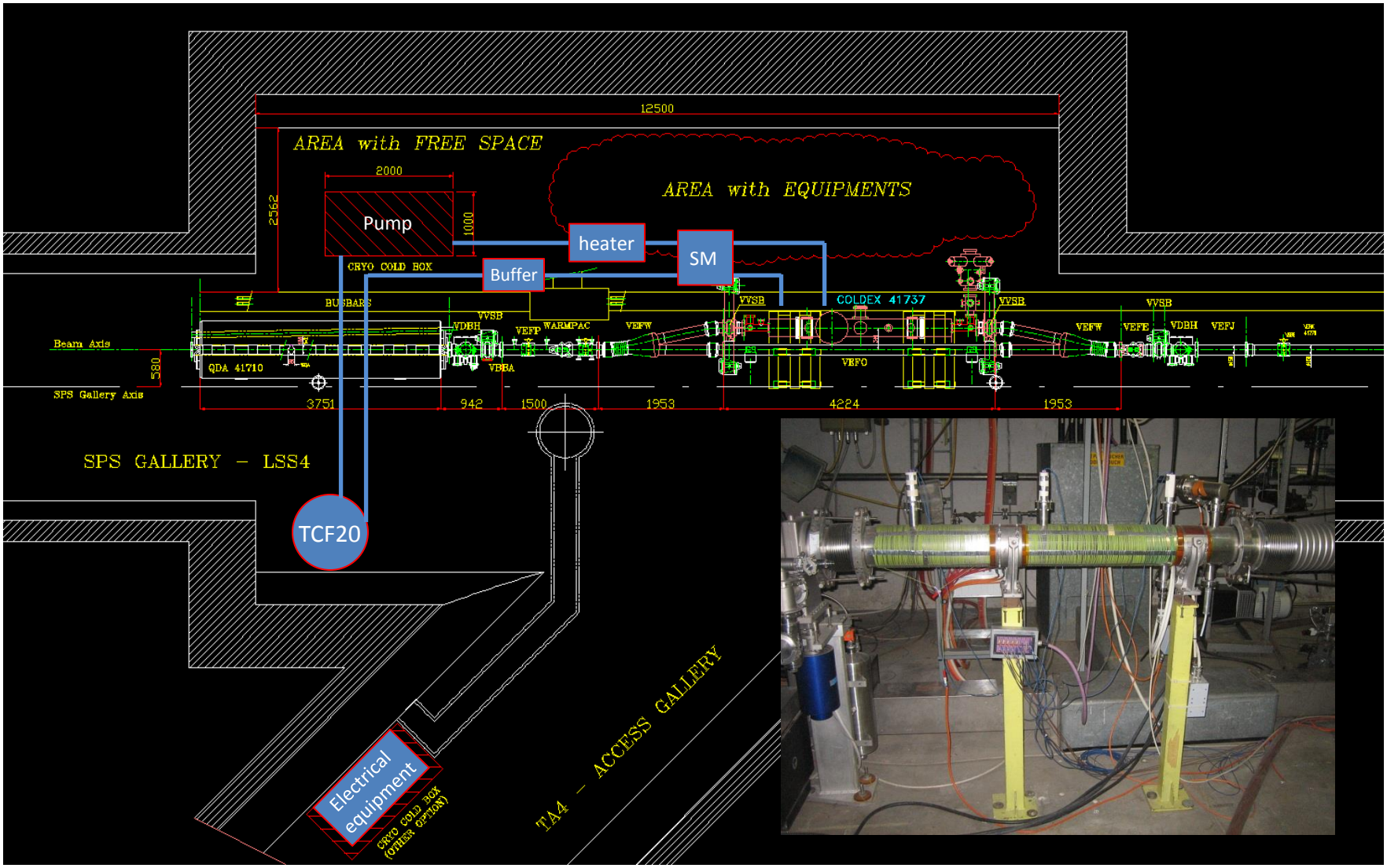


TCF20 liquefaction test



The liquefaction reached during the test was between 0.75-0.8 g/s w/o LN2 boost. The LN2 boost should double the capacity but 1.5 g/s gives very tight margin to cover CC needs.
Scenario of cold box replacement have to be studied. This operation will required additional manpower not foreseen initially for LS1.

Cryo integration in SPS



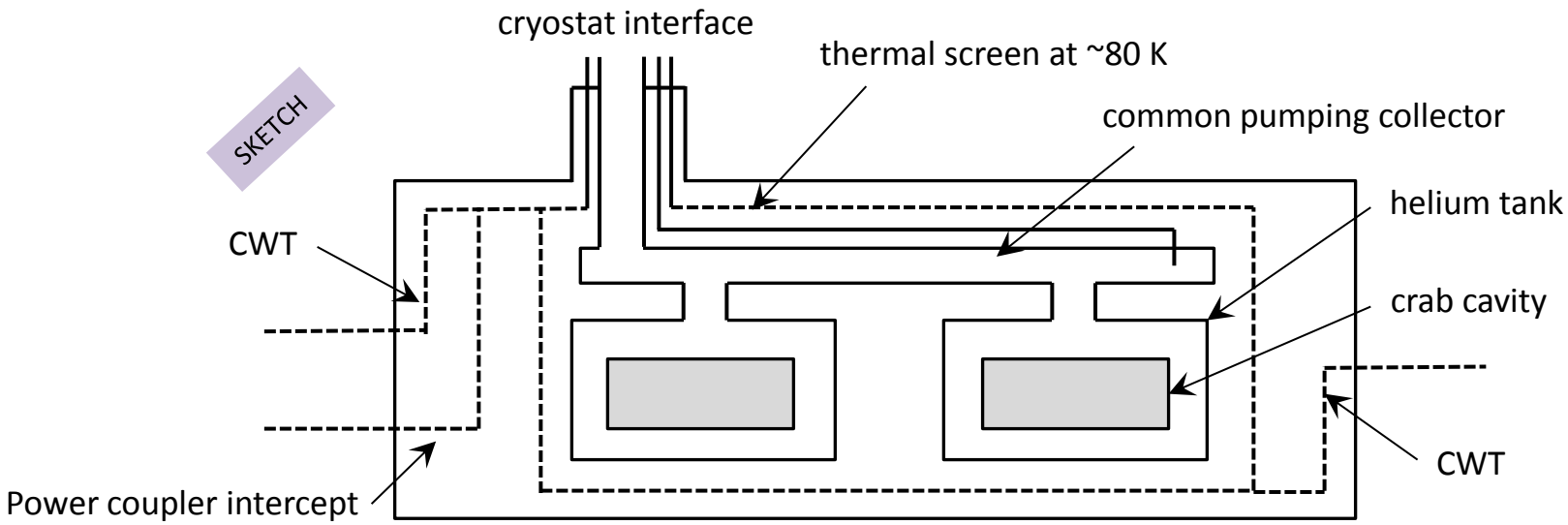
Integration details are included in Alick Macpherson presentation

Process & instrumentation 1/2

The cryostat will house 2 crab cavities and will be operated at 2 K (saturated helium bath ➔ ~30 mbar).
The design should be done in the way to minimize the static heat load at 2 K (important!)
It will be equipped with two circuits 2 K and 80 K. The main interface should be provided from the top with 4 main lines (LHe IN, GHe pumping, LN2 80 K IN and 80 K OUT).

- Proposed piping should cover nominal operation and transients (cool down and warm up),
- Interface to the cryostat: internal pipes welded, external envelope bolted (allowing opening of the jacket by means of sliding it up or down).

Power couplers and Cold/Warm Transitions will be intercepted with LN2 at 80 K.



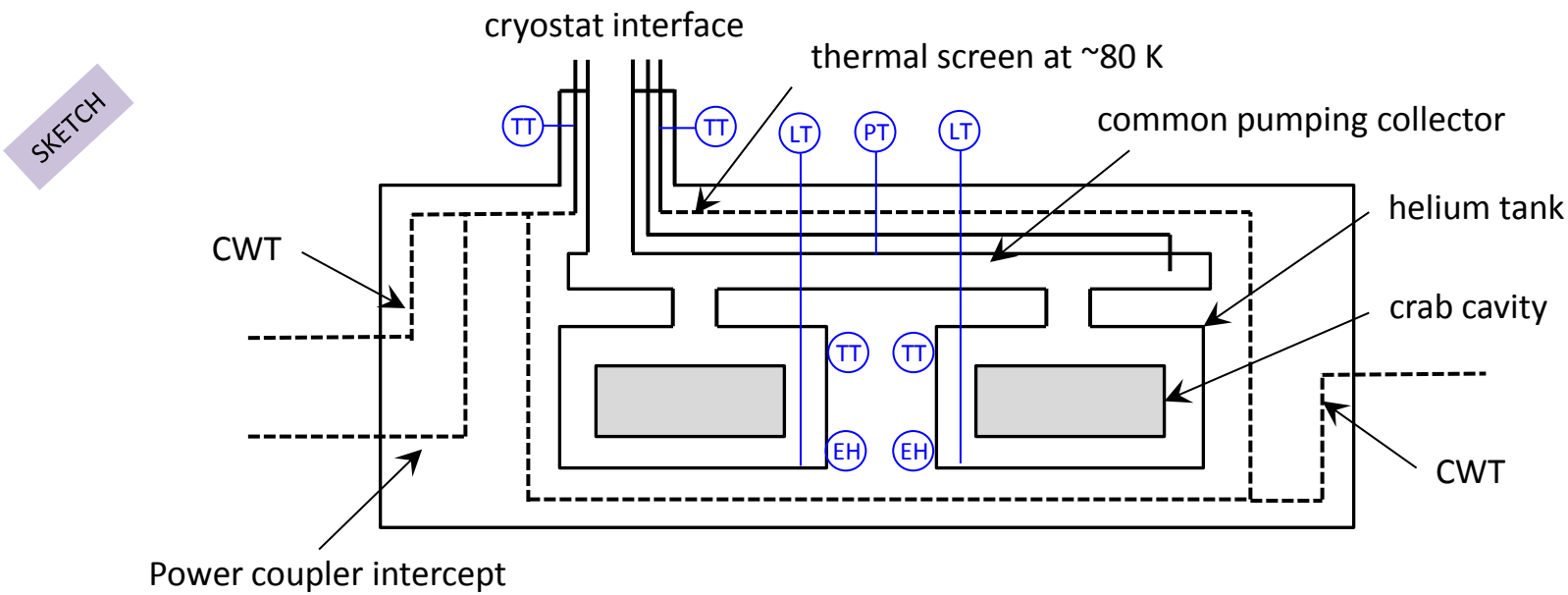
Study on dedicated 4.5 K cool down circuit is underway.

Process & instrumentation 2/2

The cryostat should be equipped with the following instrumentation:

- Helium level measurement – each helium tank should be equipped with a level gauge allowing for helium level measurement from the bottom through the phase separator (LT x 2, each gauge should allow for helium level regulation in the phase separator collector),
- Pressure measurement on the saturated helium bath is to be provided (PT x 1),
- Temperature measurement on each cavity helium tank is to be provided, installed on the bottom of each helium tank (suggested CERNOX type transducer, TT x 2),
- Electrical heaters of 50 W are to be installed on each helium tank (EH x 2)
- Temperature measurement on 80 K screen line is to be provided (TT x 2 on inlet and outlet)
- JT valve and sub-cooling HX are foreseen to be installed out of the cryostat
- *(instrumentation for 80 K intercept circuits – definition underway)*

All sub atmospheric instrumentation/safety devices with ambient air interface will have to be equipped with appropriated helium guard.

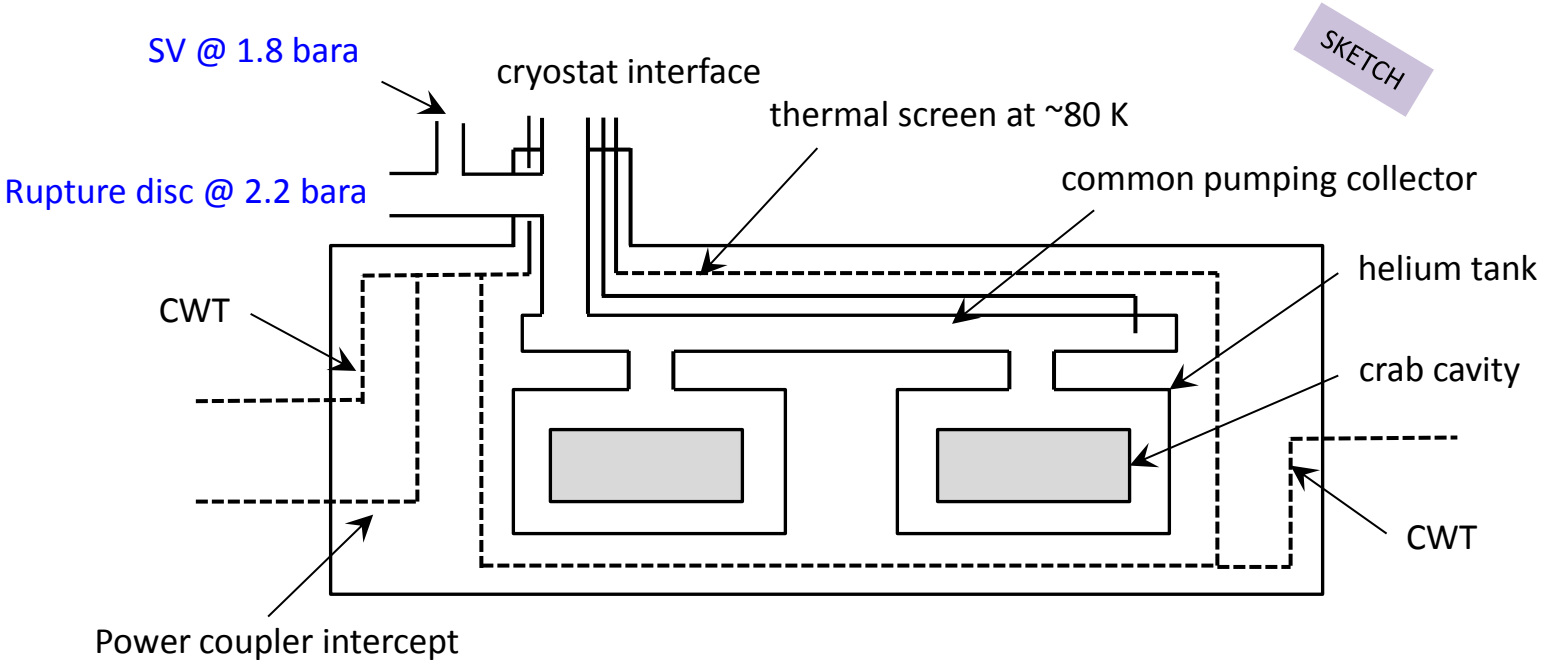


Safety devices

Assembly of cavity with helium tank have to be designed to withstand pressure of at least 2.6 bar (deltaP of 2.6 bar) without plastic deformation at ambient temperature.

Design pressure for the cryostat assembly should be based on installed safety devices according to design rules (cryostat equipped with a safety valve set at 1.8 bara* and a rupture disc set at 2.2 bara*, possibly one device could be installed … - analysis underway)

- both safety devices will be installed in the way to avoid potential projection of helium towards the passages or transport areas (deflectors installation to be analyzed, preliminary position for the rupture disc and safety valve have been proposed on transfer line close to the cryostat interface),
- Both safety devices should protect the cavity and the cryostat from pressure rise causing plastic deformations,
- Both safety devices should be equipped with appropriate helium guards.
- *sizing of the devices -> to be done*



* Value compatible with recommendations given by T. Peterson on December 2012 Fermilab meeting

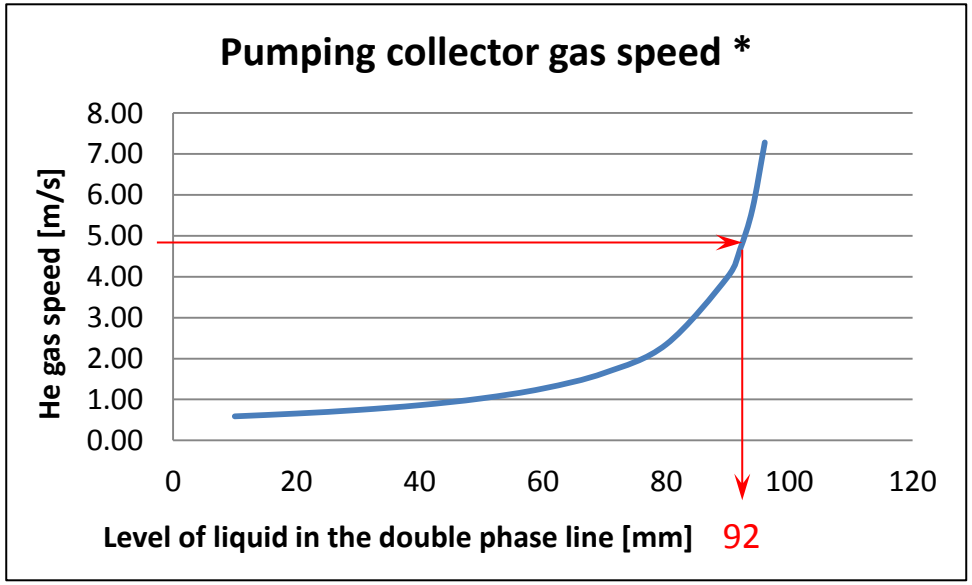
Pumping collector sizing

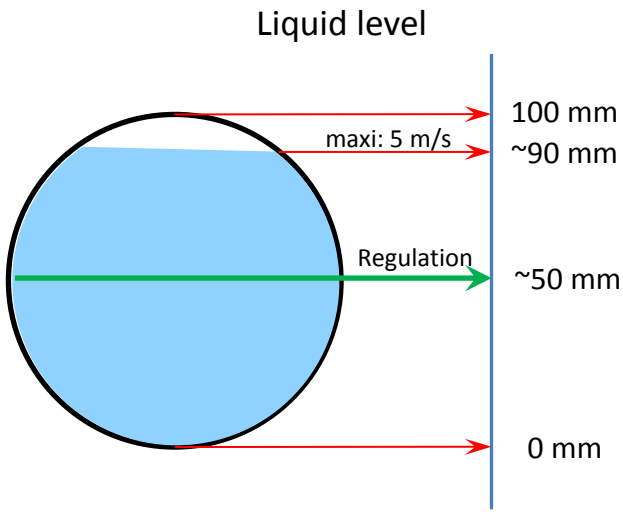
Requirements: gas speed lower than 5 m/s*, min 50 mm for level regulation, additional buffer for ~ 20 min of operation, compatibility with safety devices for pressure limit requirements.

Indications: Diameter of 100 mm (recommended) allows for:

- return gas speed below 5 m/s up to ~90 mm of liquid level in the collector (operation regulation level to be set at ~50 mm of LHe in the collector),
- buffer volume for transients/unexpected process perturbations (half filled collector allows for ~20-30 min of operation assuming collector length of ~1.6 m and 20 W of thermal load),
- *compatibility with safety valves sizing is still to be checked !*

* Value compatible with recommendations given by T. Peterson on December 2012 Fermilab meeting



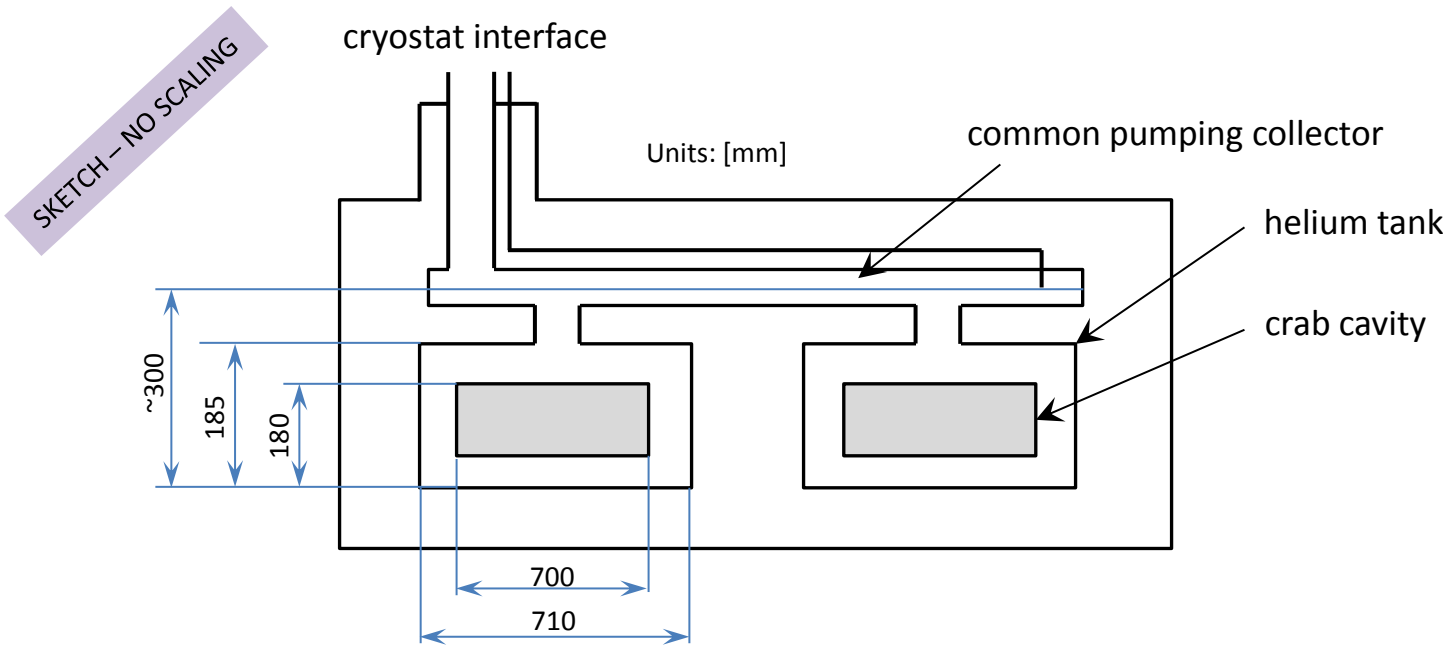


* Calculation done assuming: collector diameter of 100 mm, He mass flow = 2 g/s, GHe temp = 2 K, GHe press = 20 mbar.

Superfluid Helium layer

Requirements: superfluid helium layer must cover whole surface of the cavity and provide correct operation of the cavity at required conditions (2 K). The heat transfer capability for superfluid helium layer have to be evaluated, typically between 0.95 - 1 W/cm2

Exercise – indication: assuming round cavity from below sketch; dimensions D=175 mm x L=700 mm and heat load of 20 W, the required minimum superfluid helium layer is ~ 2.5 mm. Applied production technology will require more …. It should not be enlarged without the limits in order to minimize reasonably the liquid helium volume (max. 40 L/cavity if possible).



Cryostat operation – first approach

Pressures – safety :

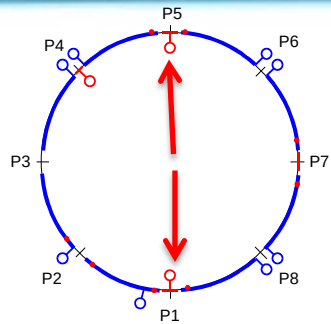
- The cavity should be designed to withstand external pressure of 2.6 bara (deltaP = 2.6 bar) at ambient temperature without plastic deformation,
- Design pressure for the cryostat should be based on installed safety devices according to design rules (cryostat equipped with a rupture disc set at 2.2 bara and safety valve set at 1.8 bara)
  - both safety devices should be placed on the cryostat in the way to avoid potential projection of helium towards the passages or transport area (deflectors installation to be analyzed),
  - Both safety devices should protect cavity and cryostat from pressure rise causing plastic deformations
- Operating pressure during the cool down can oscillate between 1.2 and 1.5 bara – estimation,
- Normal operation pressure will be set at ~ 30 mbara (for 2 K cooling)

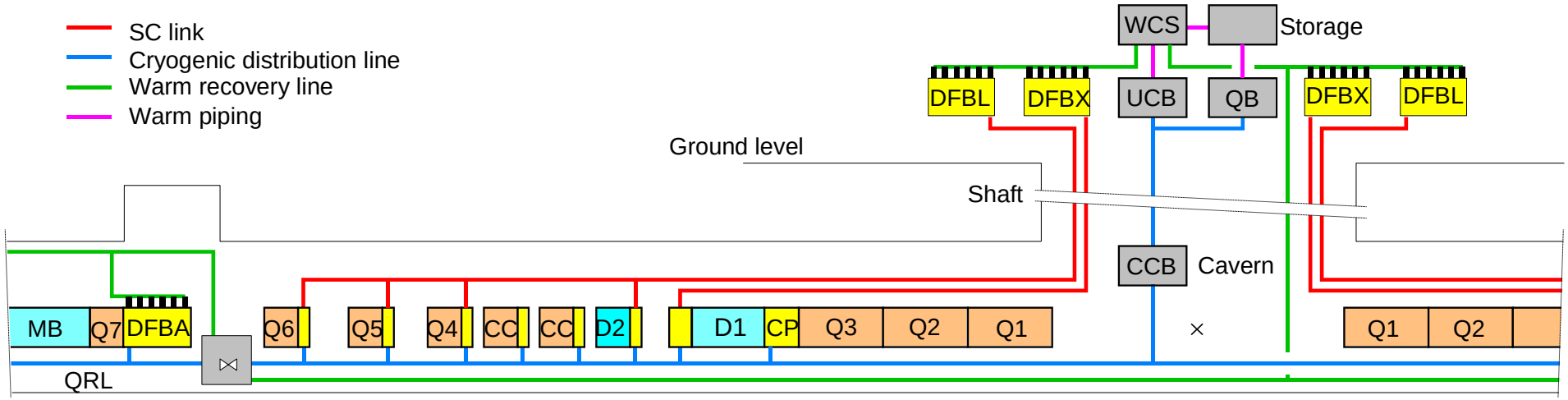
Cool down – stable operation – warm up:

- Cool down will be done with direct filling of LHe to the cavity cryostat, very roughly estimated cool down time is ~ 1 day
- Stable operation availability can be affected by impurities in the system (there is no purifier installed in the infrastructure). A few days continues availability should be guaranteed.
- Warm up of the cavities will be done by evaporation of helium and warm gas circulation

New cryogenic infrastructure at P1 and P5

L. Tavian_Daresbury 2013





- 1 warm compressor station (WCS) in noise insulated surface building
- 1 upper cold box (UCB) in surface building
- 1 cold quench buffer (QV) in surface
- 1 or 2 cold compressor boxes (CCB) in underground cavern
- 2 main cryogenic distribution lines
- 2 interconnection valve boxes with existing QRL

Suitable for cryogenics to have a common cryostat for a side CC trains (8 cavities). Supply and pumping lines architecture is being studied -> it will result in number of jumpers (consideration of tunnel slope is mandatory).

Conclusions

- Work is progressing well, heat load estimation is getting more precise, cold run of the “old” cold box done, liquefaction test with LN2 boost planned for January 2014,
- In case of needs “New” cold box is available at CERN. Its installation will require additional manpower, timing is very tight,
- 2 K pumping units – capacity test done -> 2 units to be integrated in the tunnel in January 2014,
- Buffer, Service Module and transfer lines to be ordered and installed in the tunnel out of LS1,
- Update of specification planned for February 2014,
- Close collaboration with regular working sessions is needed to merge between CERN requirements and the modules suppliers.

Thank you! Questions?