Thermal-Hydraulic cryogenic studies : CS margin exploration

WPMAG Final meeting
15/01/2026

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Thermal-Hydraulic cryogenic studies

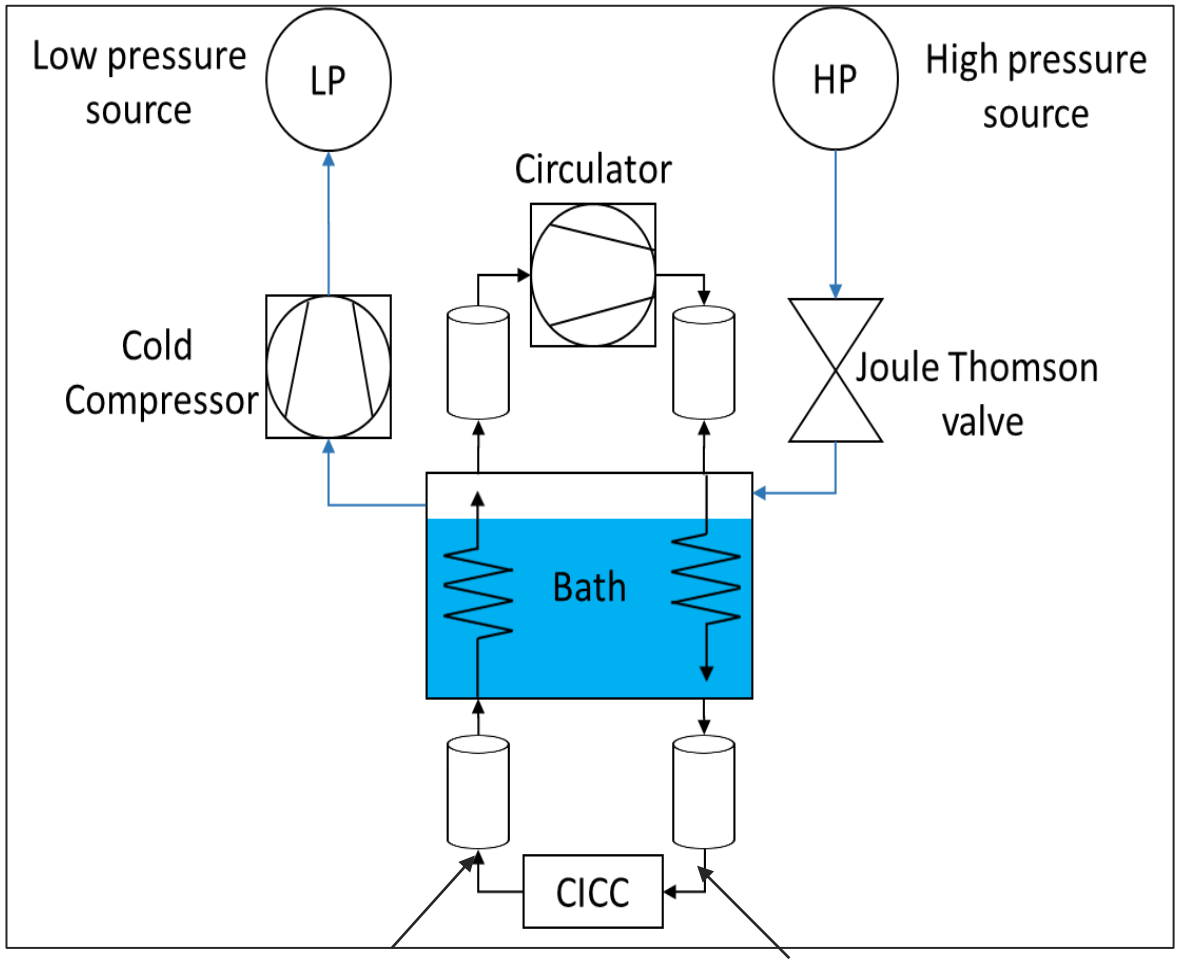
Case studied : how to increase the margin (or reduce the superconducting amount) of the a **CS** at reasonable cryogenic cost?

- Lower the inlet temperature
- Lower the Inlet Temperature when needed
- Depressurize the loop

We will take advantage of the CS margin being low for a very short amount of time

SHe helium loop

Simcryogenics to model the CS with a Supercritical helium loop → Relevant behavior of a CICC including its cooling process circuit

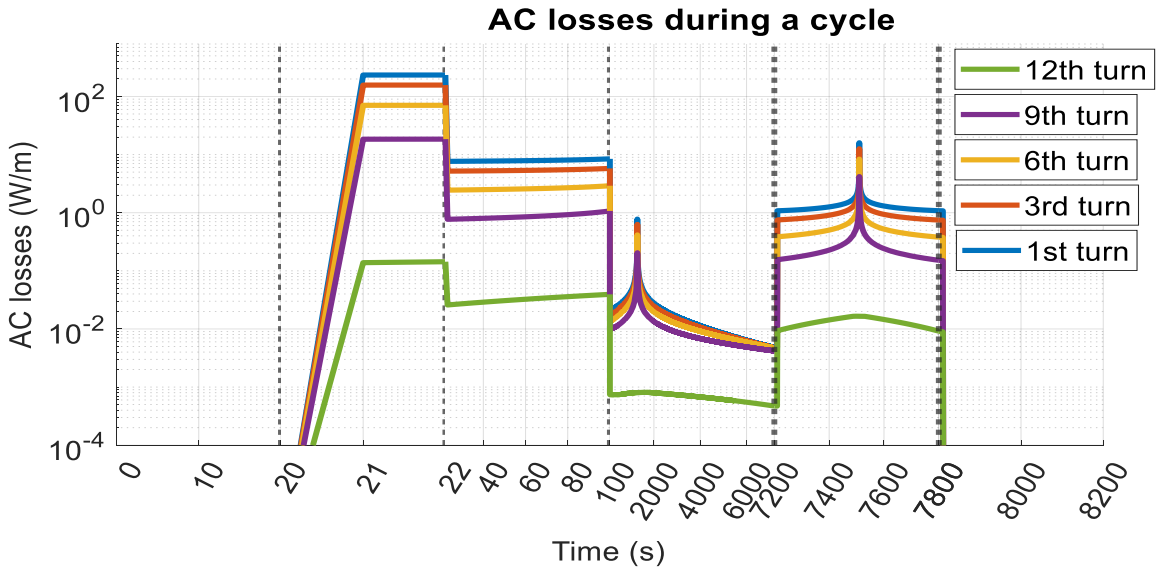


Pipe length and diameter (inspired by WPDES)

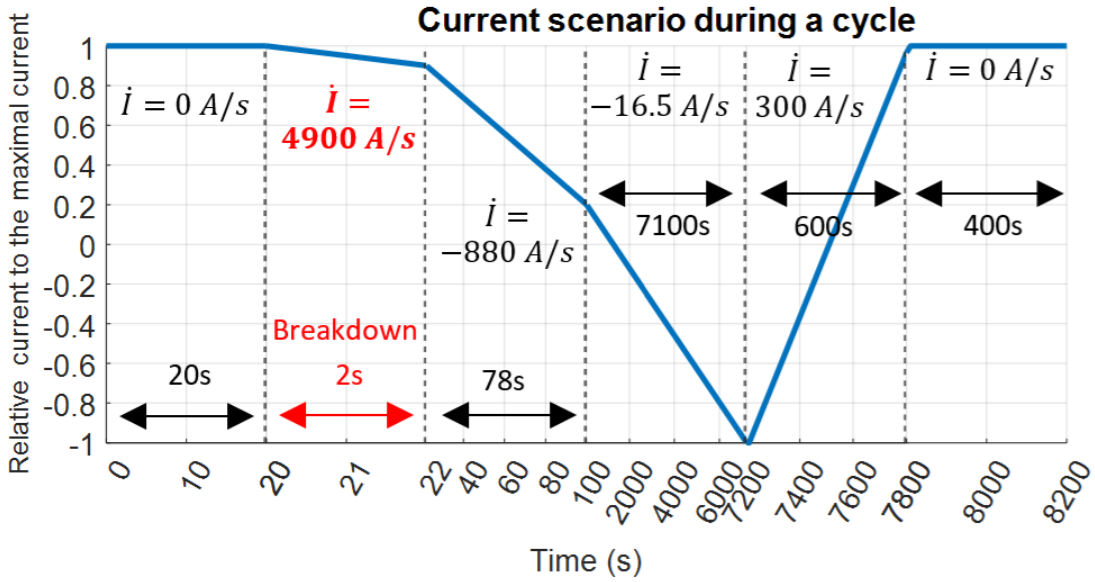
Pipe	Section	Diameter (mm)	Length (m)
Upstream and downstream the conductor	Close to the bath	125	33.5
	Middle	100	35.2
	Close to the conductor	50	1.6
Upstream and downstream the circulator		125	2.0

Current scenario and AC losses

The same current scenario is applied since 2022 to help with comparisons. The CS design has not changed for the same reason



(time not linear)

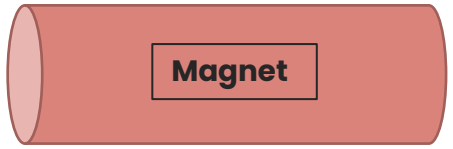


Context : Margin loss

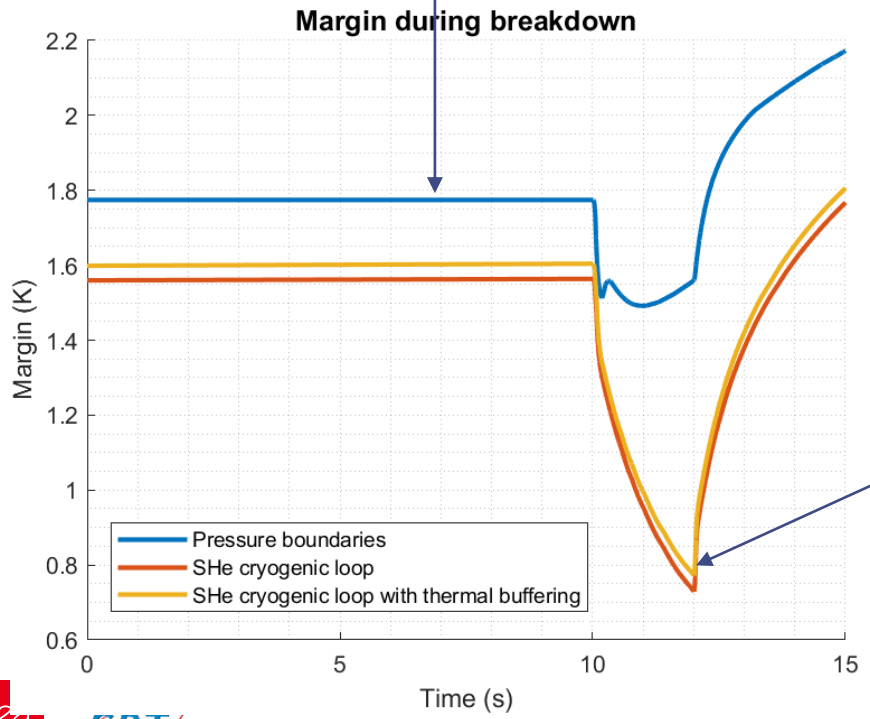
Initially, the model used pressure boundaries to compute margin.
Then, implementation of SHe cryogenic loop and thermal buffering in the model has been done. Each ones contributing of a more relevant behavior of the system but causing margin loss.

- Pressure boundaries

5 bars
4,6K

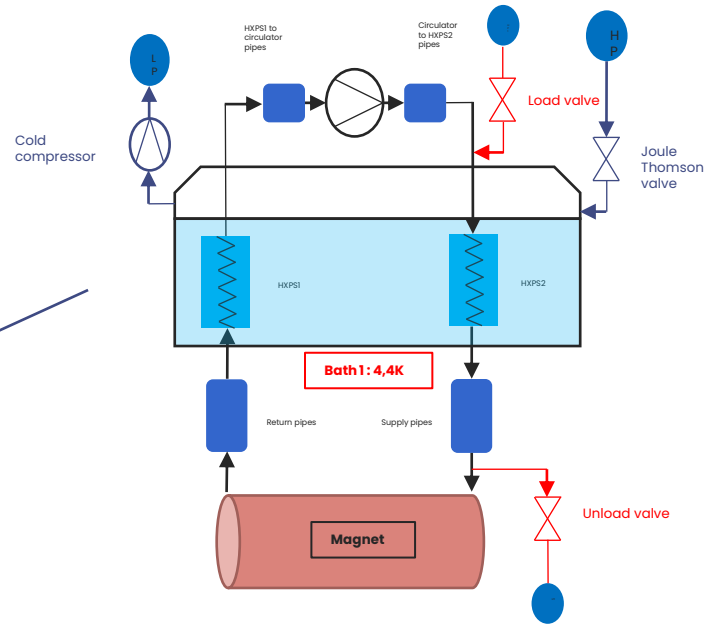


6 bars
4,5 K



- SHe cryogenic loop

With thermal buffer : +0,4K allowed inside the bath



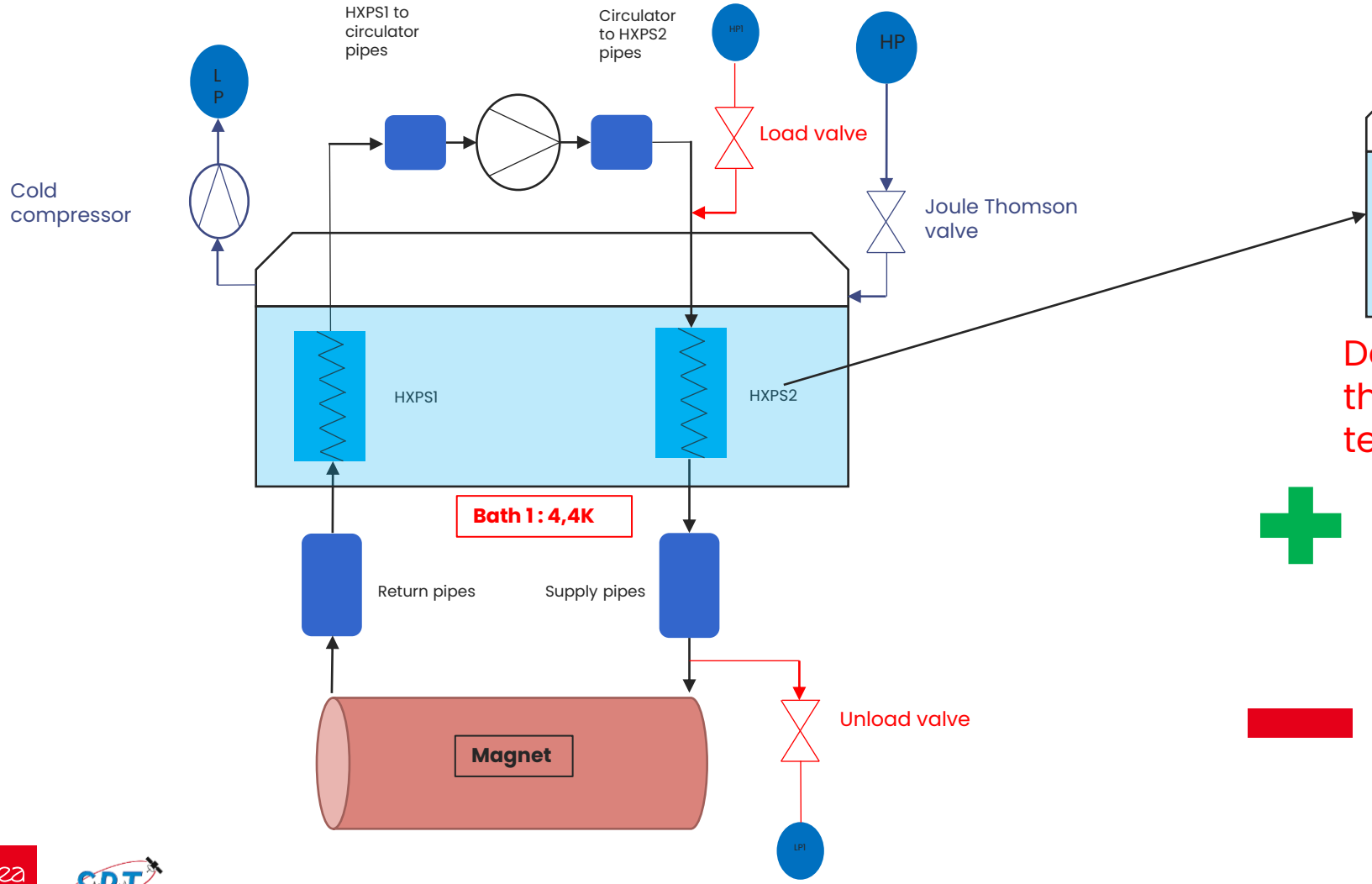
0,75 K lost due to implementation of cryogenic loop and around 50 mK lost due to thermal buffering (0,4K maximal temperature increase allowed inside the bath).

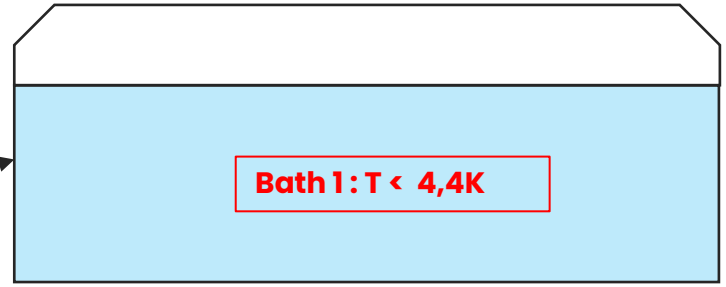
How to regain margin using different configurations ?

- Lower the inlet temperature
- Lower the Inlet Temperature when needed
- Depressurize the loop

How to regain margin ? Single bath configuration thermally bufferized

- **1 bath configuration with a nominal CICC pressure of 6 bars**





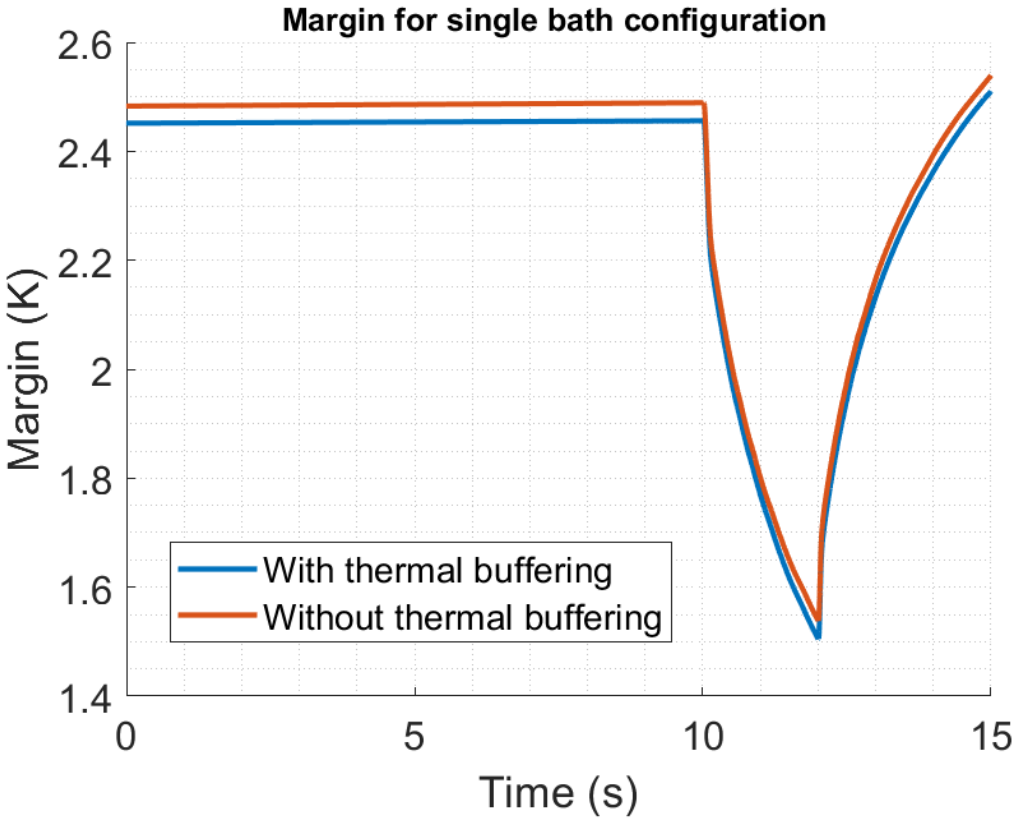
Decrease bath temperature until the magnet reaches suitable temperature margin

\+ Easiest way to regain margin

\- High « cryogenic » cost as cooler SHe during all the cycle

How to regain margin ? : Single bath configuration, thermal buffer impact on margin

Bath temperature set **to 3,43 K** to obtain **1,5 K** margin

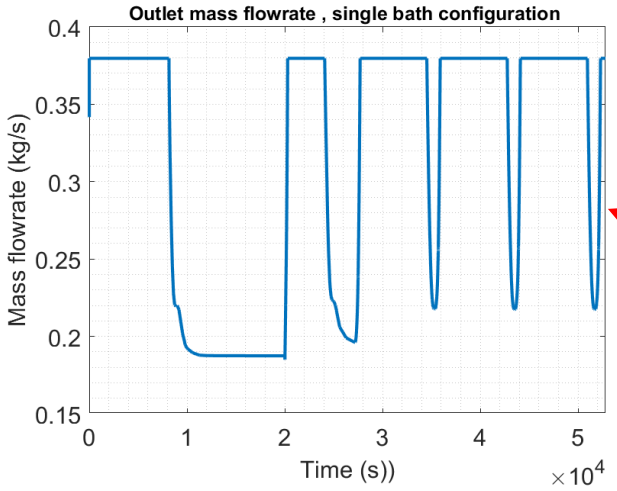


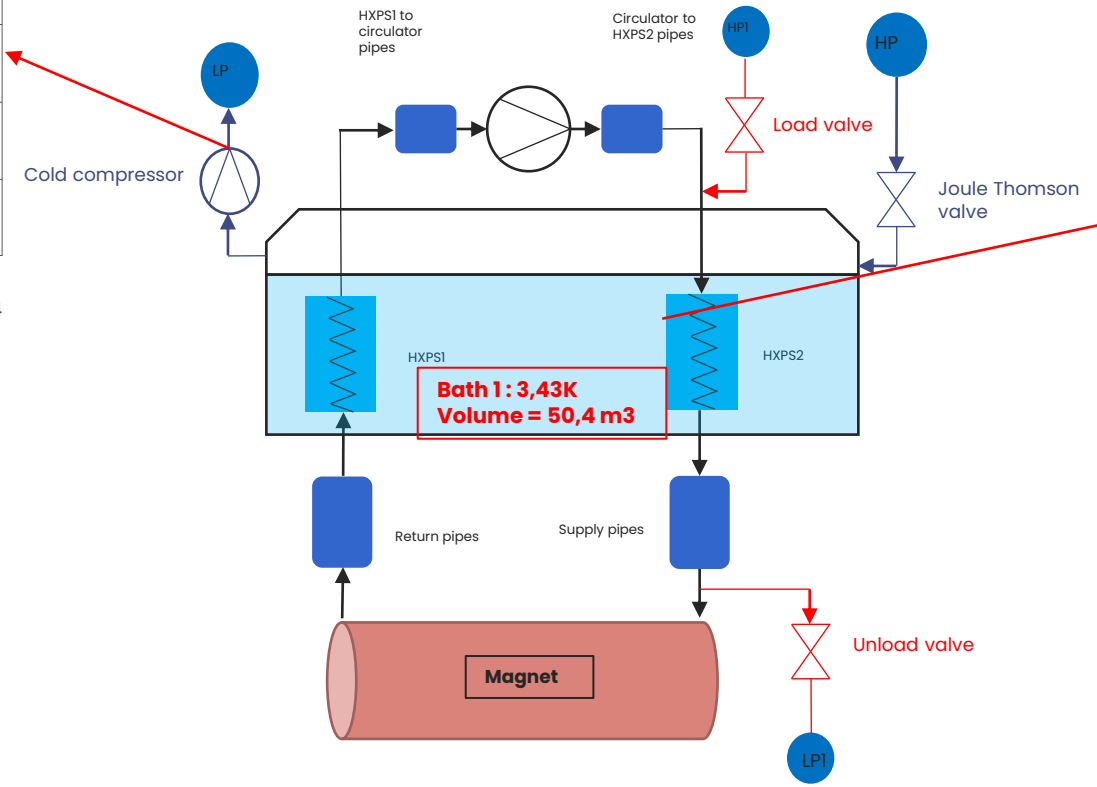
	Minimal margin (K)
With thermal buffering	1,5046
Without thermal buffering	1,5379

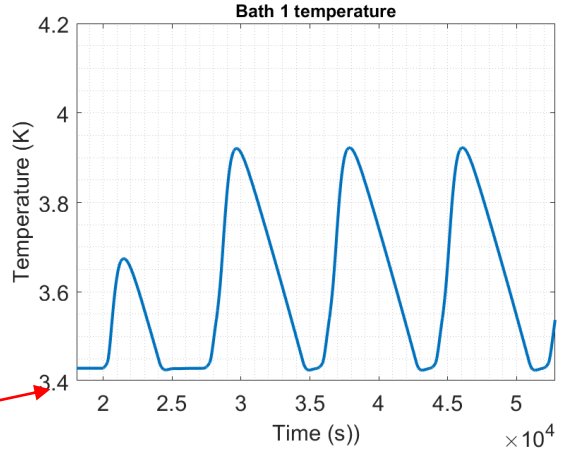
33 mK margin lost due to thermal buffering

How to regain margin ? : Single bath configuration thermally bufferized

Bath temperature set to 3,43K to obtain **1,5 K** margin



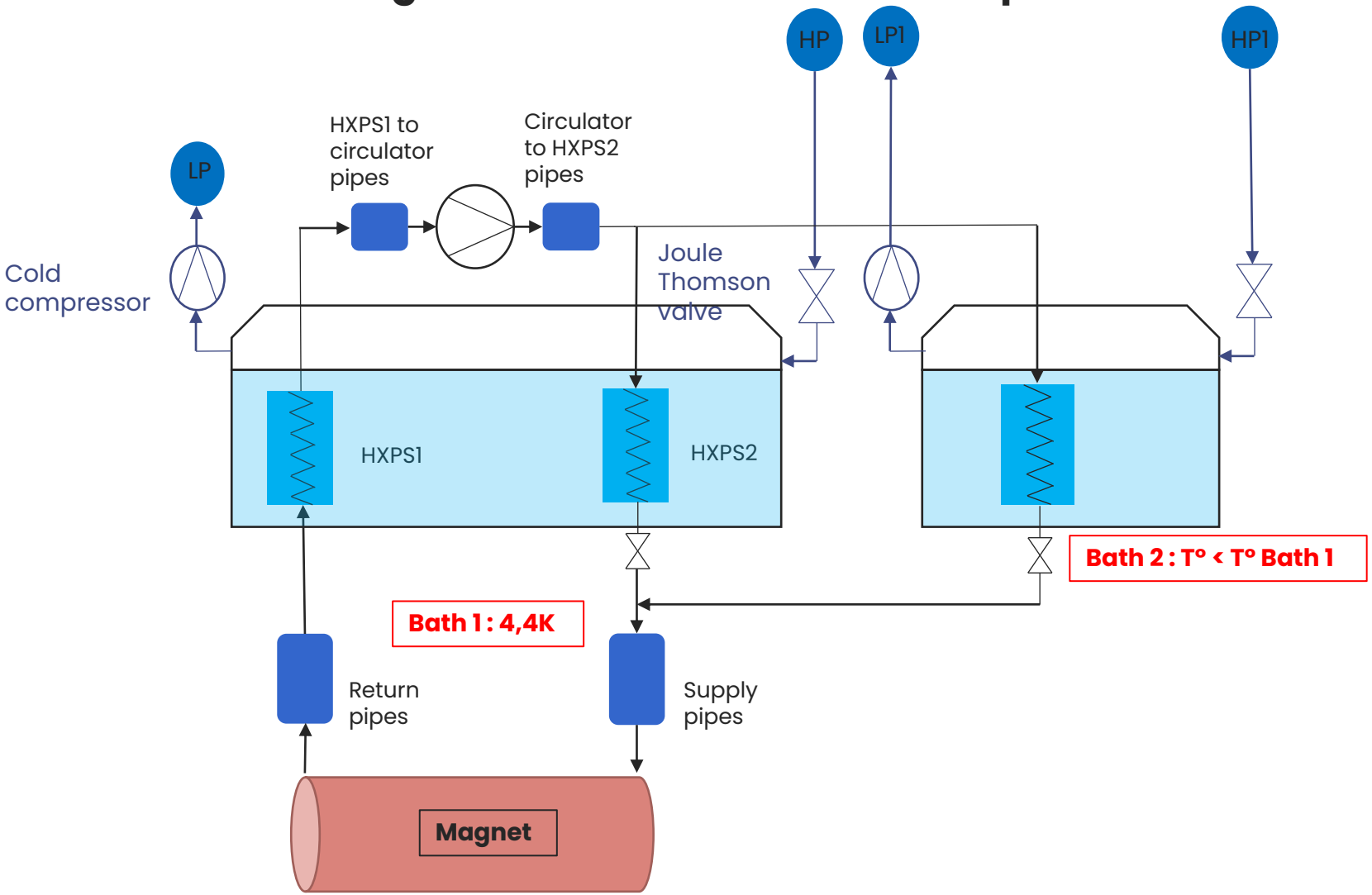




0,5 K increase

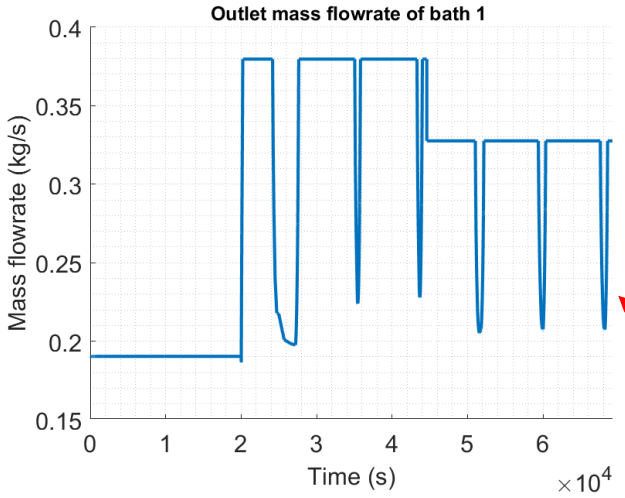
How to regain margin : 2 baths configurations

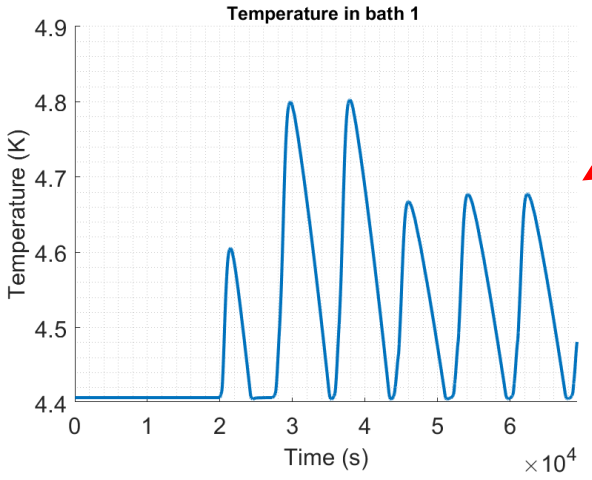
- **2 baths configuration with a nominal CICC pressure of 6 bars**



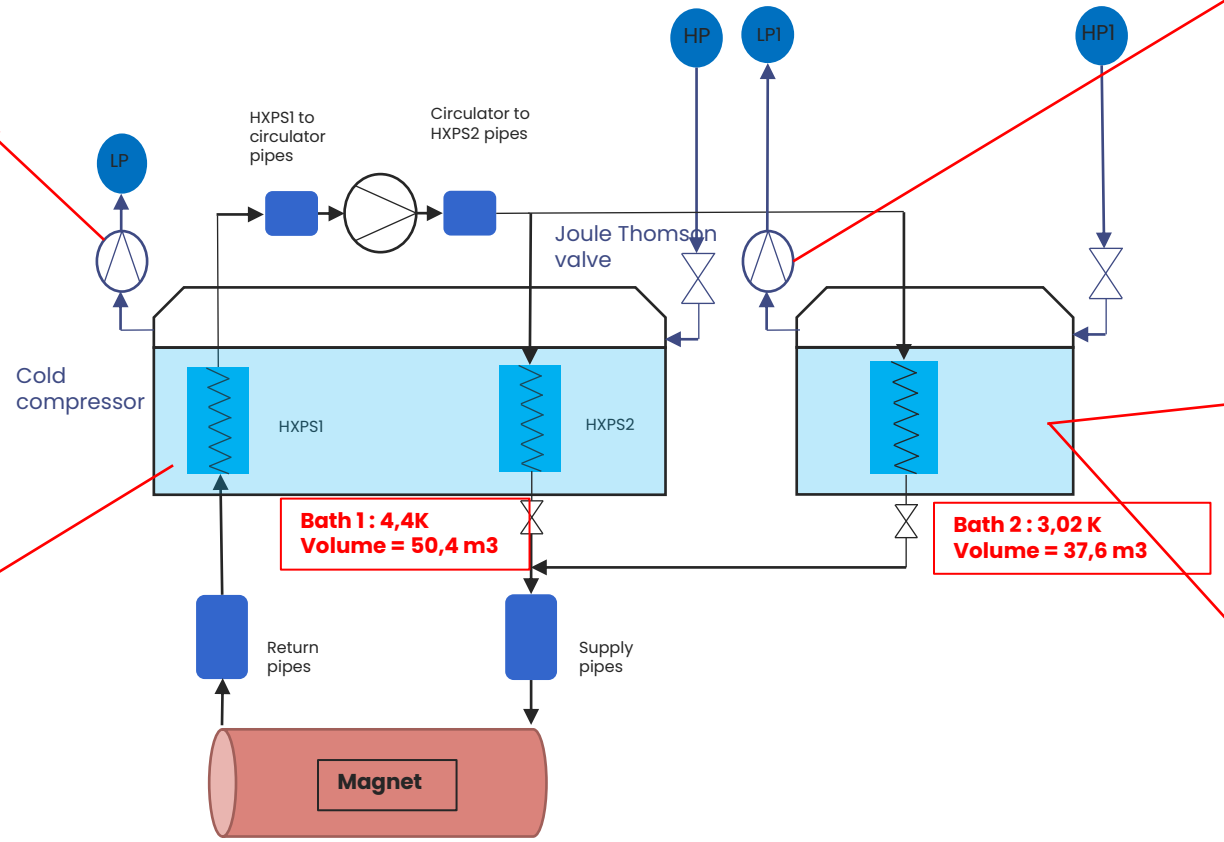
Cryogenic cost more optimized. Second bath used only preventively to cool down SHe before breakdown

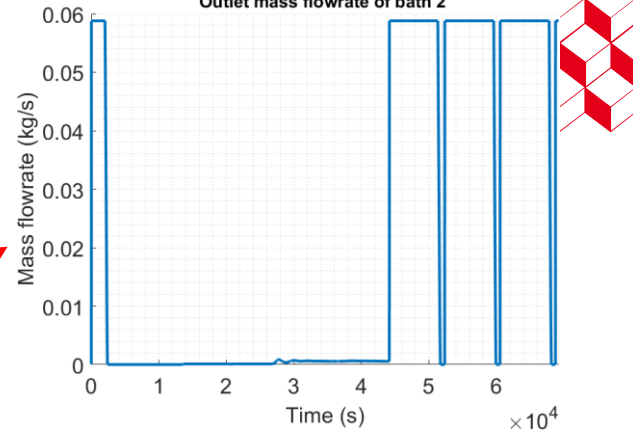
How to regain margin : 2 baths configurations

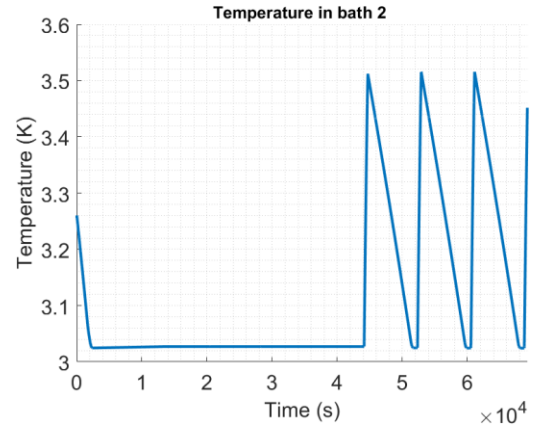




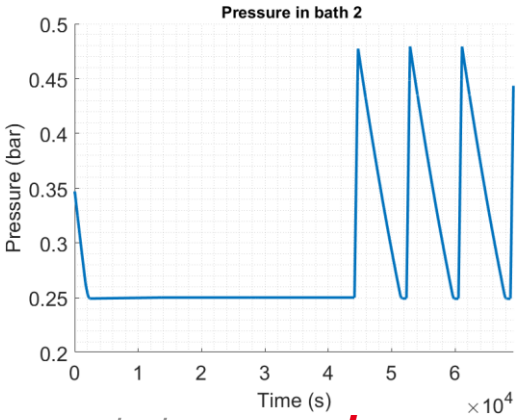
0,25 to 0,4 K increase



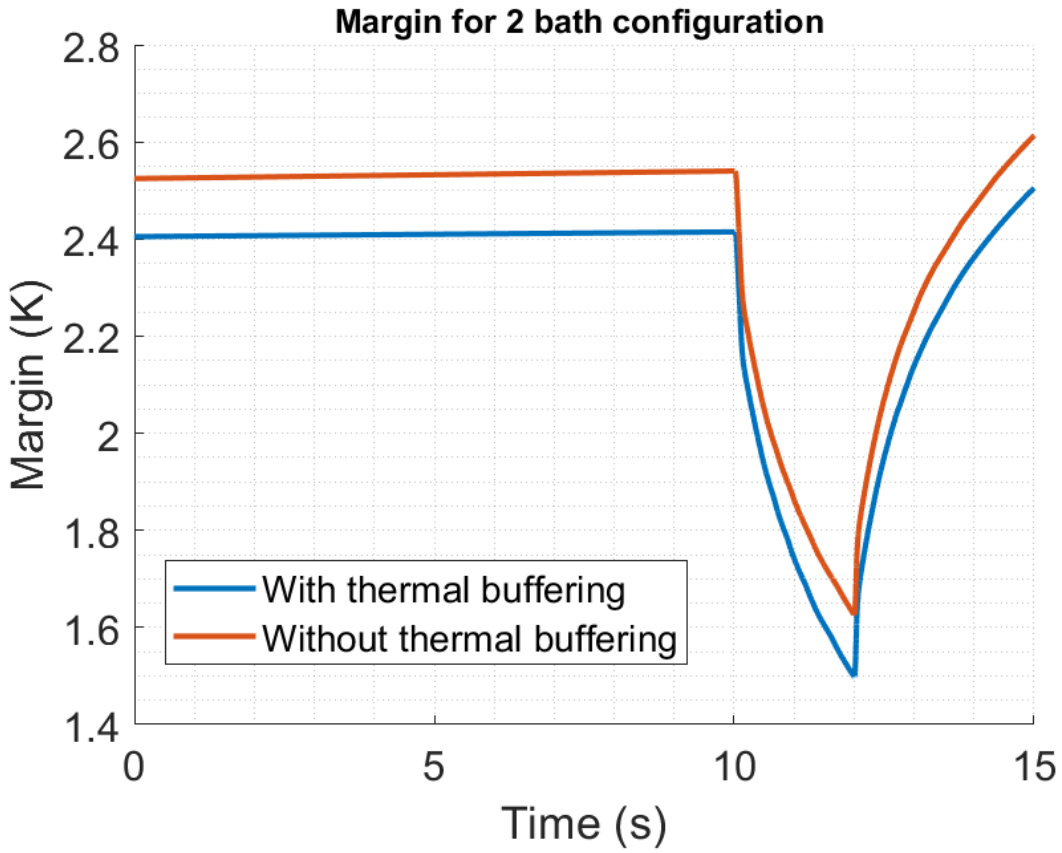




0,5 K increase



How to regain margin ? : 2 bath configuration, thermal buffer impact on margin

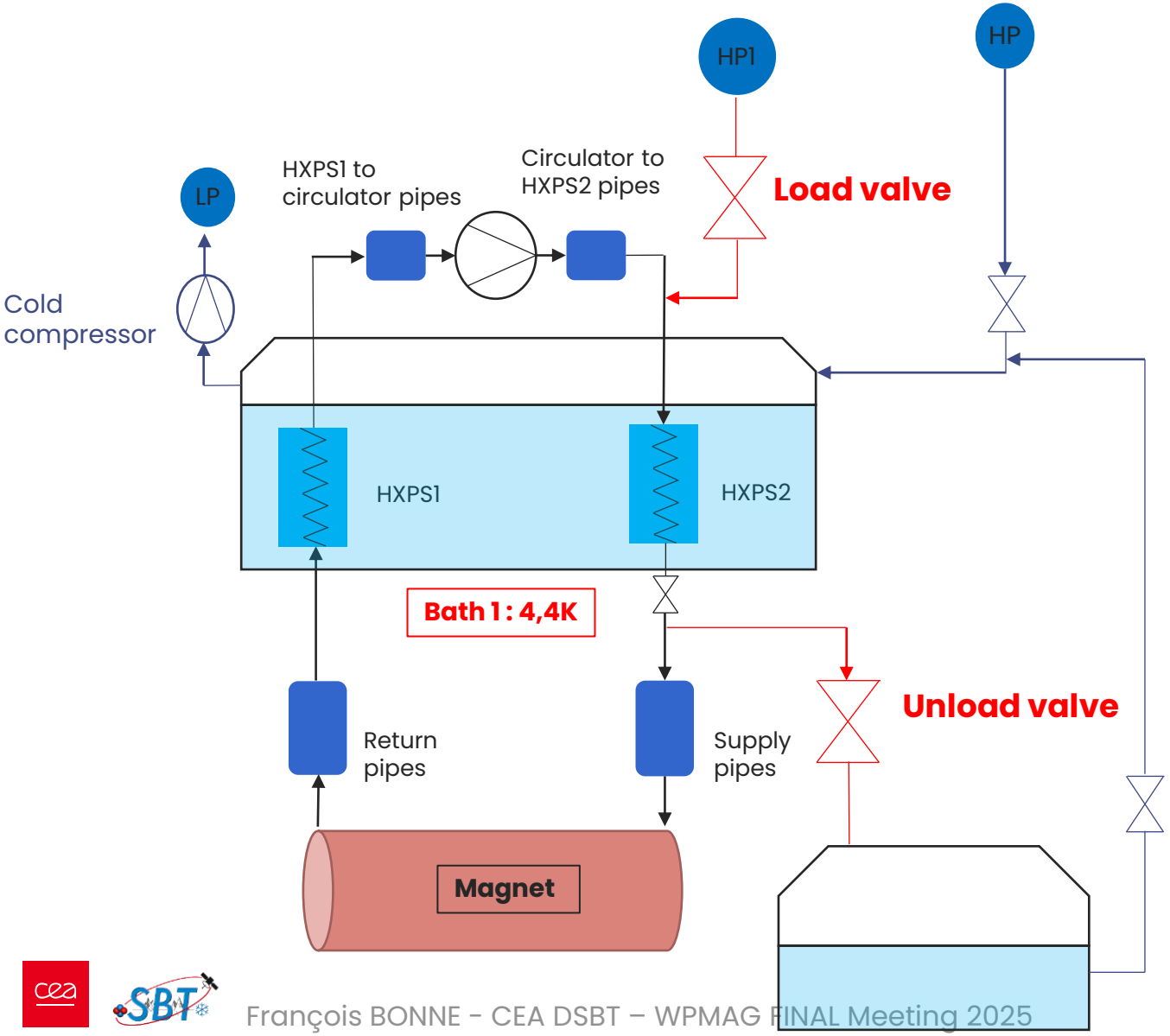


	Minimal margin (K)
With thermal buffering	1,498
Without thermal buffering	1,626

128 mK margin lost due to thermal buffering

Simcryogenics : 10 bars ramp discharge at a nominal CICC pressure of 14 bars

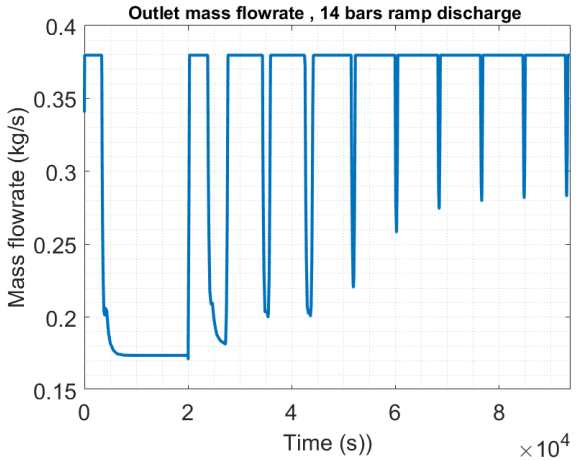
- **10 bars ramp discharge with a nominal CICC pressure of 14 bars**

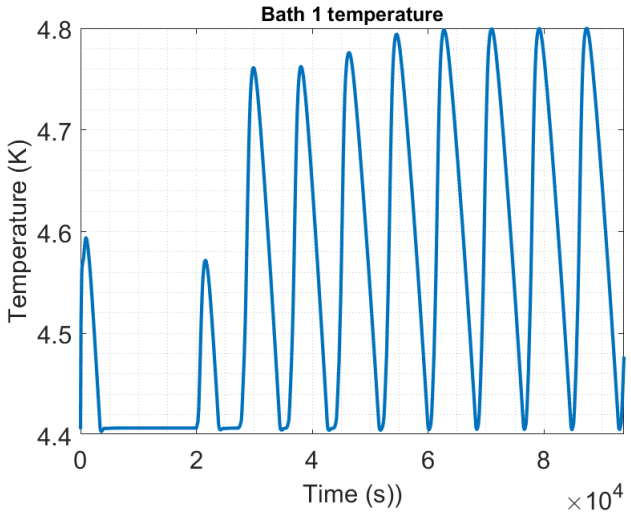


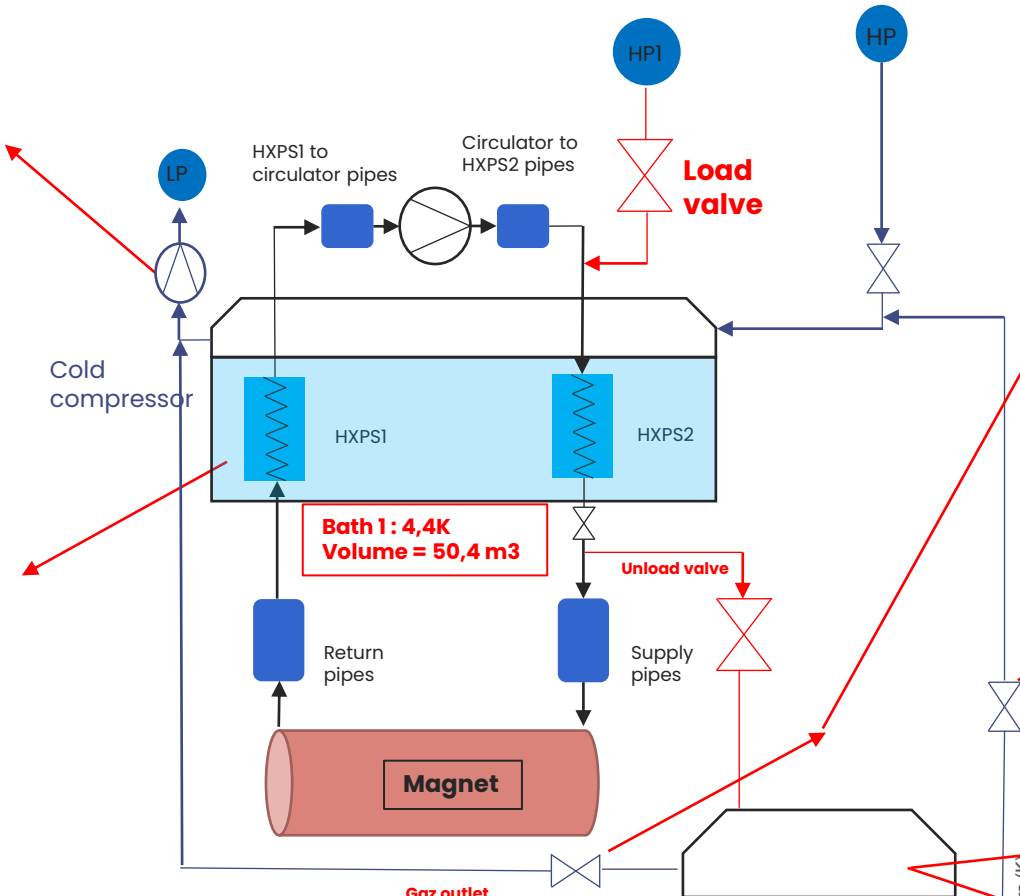
Optimal cryogenic cost as SHe is cooled down only the necessary time (about a dozen of seconds instead of hundreds)

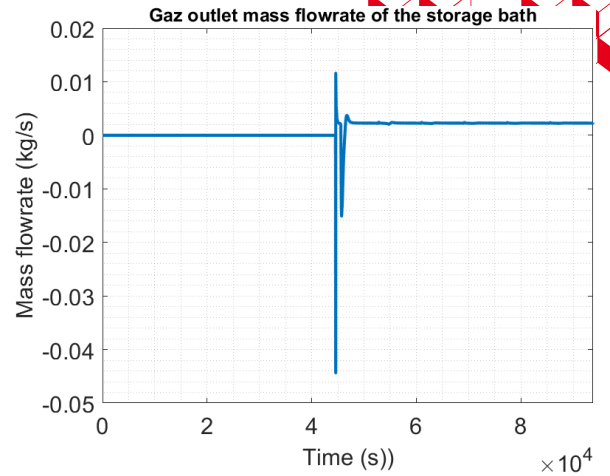
New concept

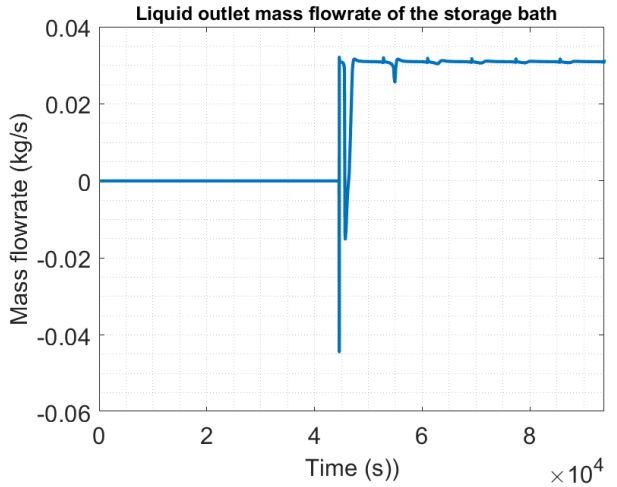
Simcryogenics : 14 bars ramp discharge

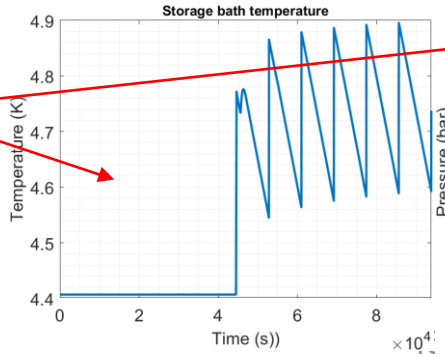


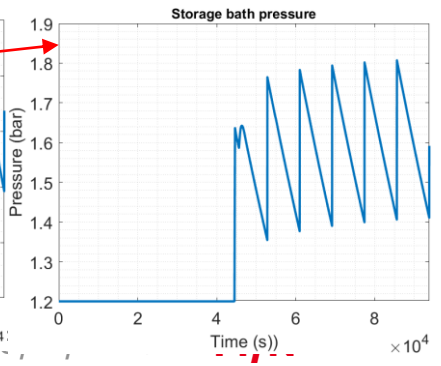






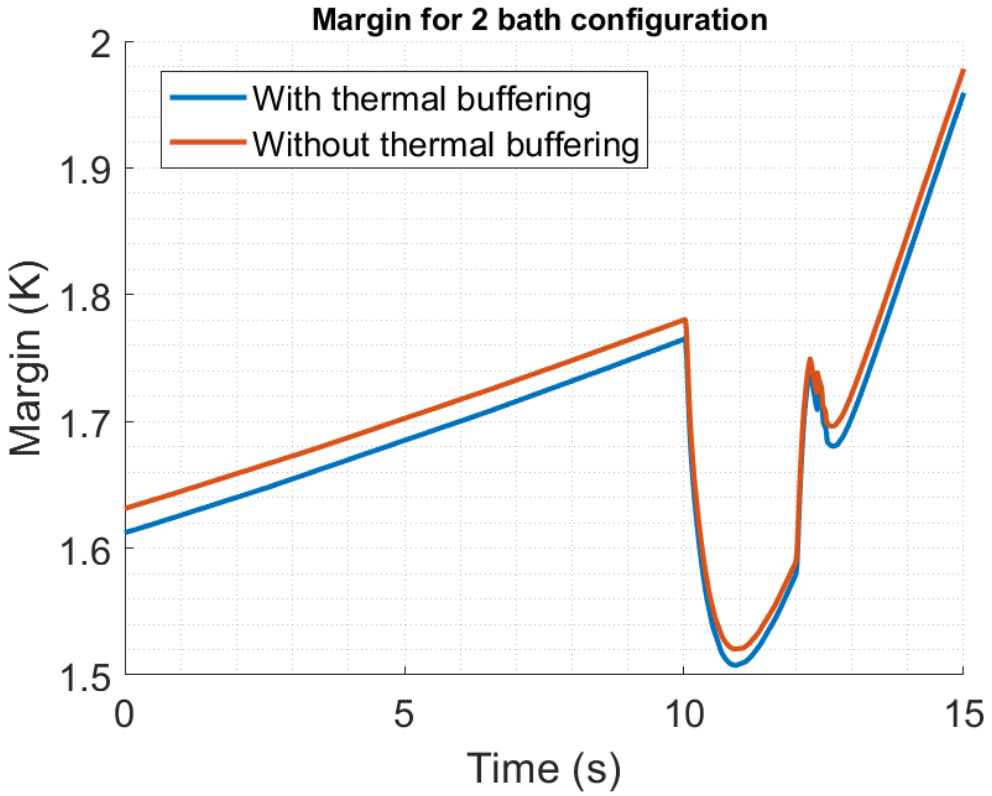






0,35 to 0,4 K increase

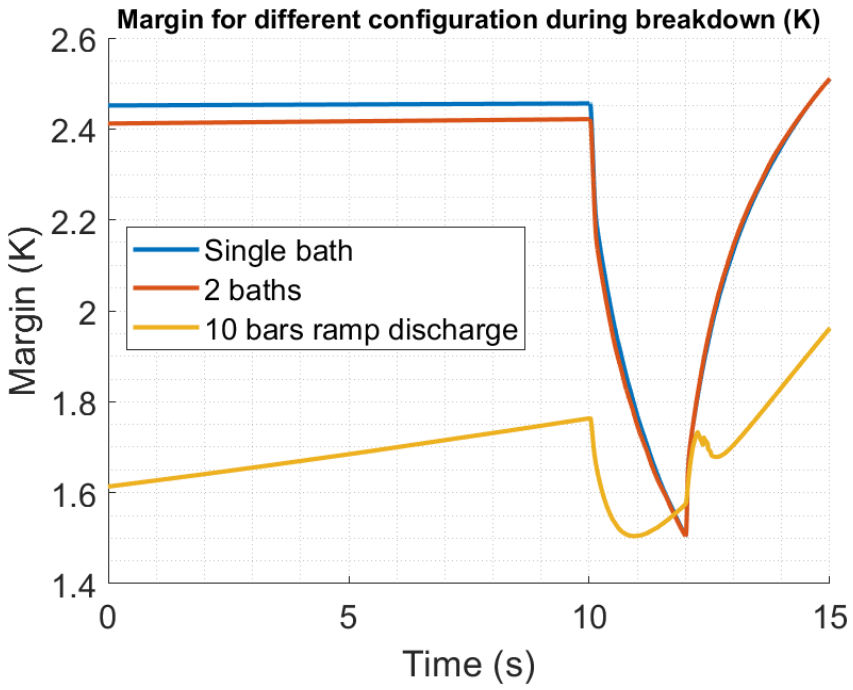
How to regain margin ? :, thermal buffer impact on margin

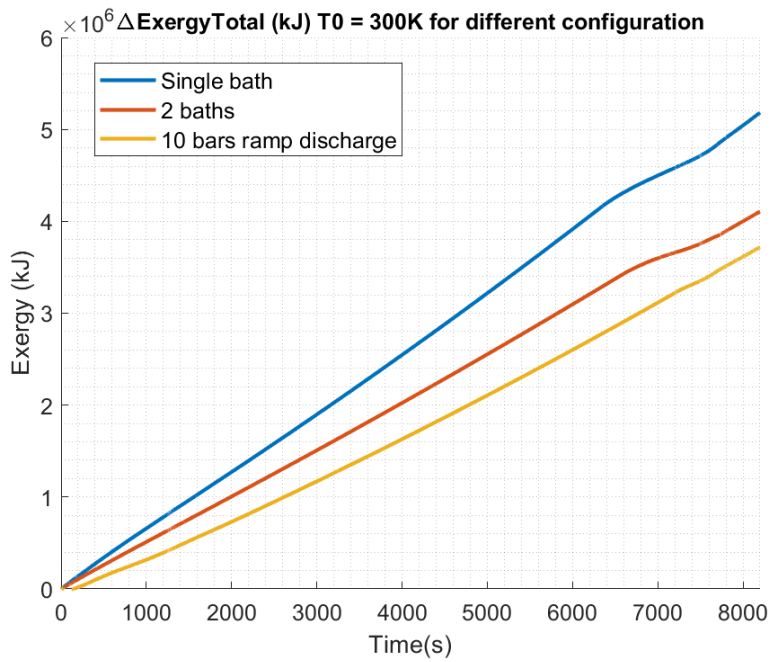


	Minimal margin (K)
With thermal buffering	1,5075
Without thermal buffering	1,52

12,9 mK margin lost due to thermal buffering

Comparison of thermally bufferized configurations : Margin





	Total exergy (GJ)
Single bath	5,18
2 baths	4,1
10 bars ramp discharge	3,72

10 bars pre cooling by ramping the discharge produce less total exergy compared to others configurations.
More particularly : **28,2 %** less than single bath configuration and **9,1 %** less than 2 baths configurations

Conclusion

Magin lost using a **realistic cryogenic configuration** can be retreive using different cryogenic schemes

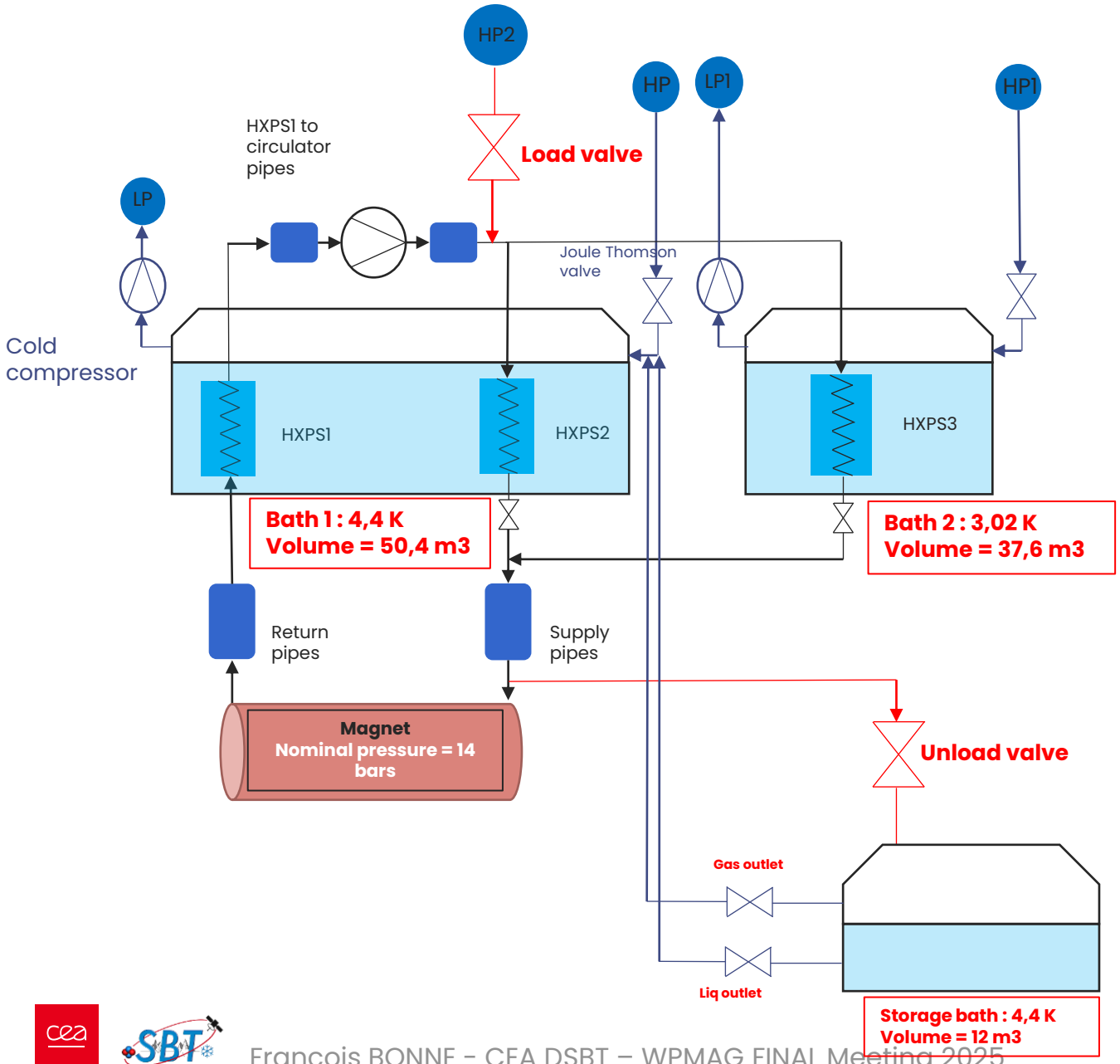
Among the presented configuration, the **10 bars ramp discharge** with a nominal CICC pressure of 14 bars shows the best results in terms of energy consumtion production (28% and 9,1 % less than single bath and 2 bath configurations respectively)

The lost margin has been recovered and it could be 1,5 K again using this solution

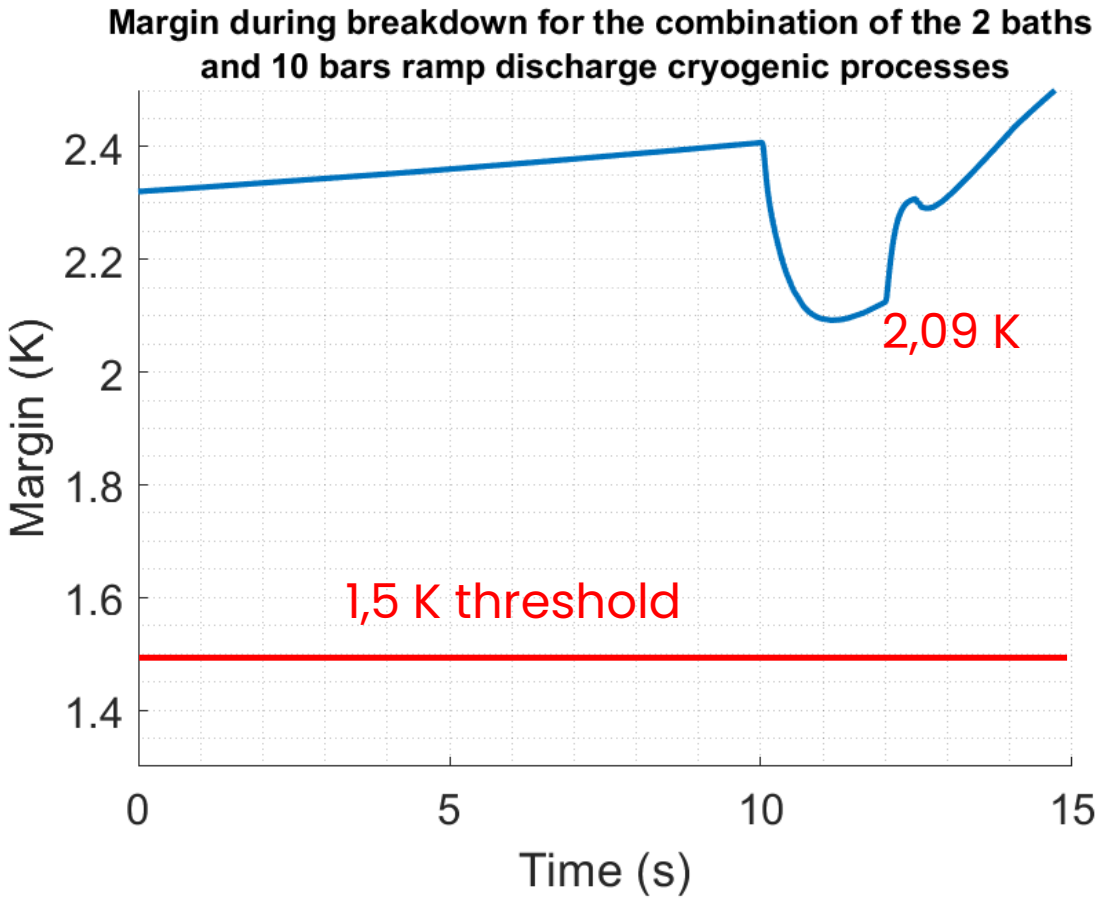
Bonus :

Combination of 2 cryogenic processes :
2 baths and 10 bars ramp discharge

Combination of 2 cryogenic processes : 2 baths and 10 bars ramp discharge with a nominal CICC pressure of 14 bars

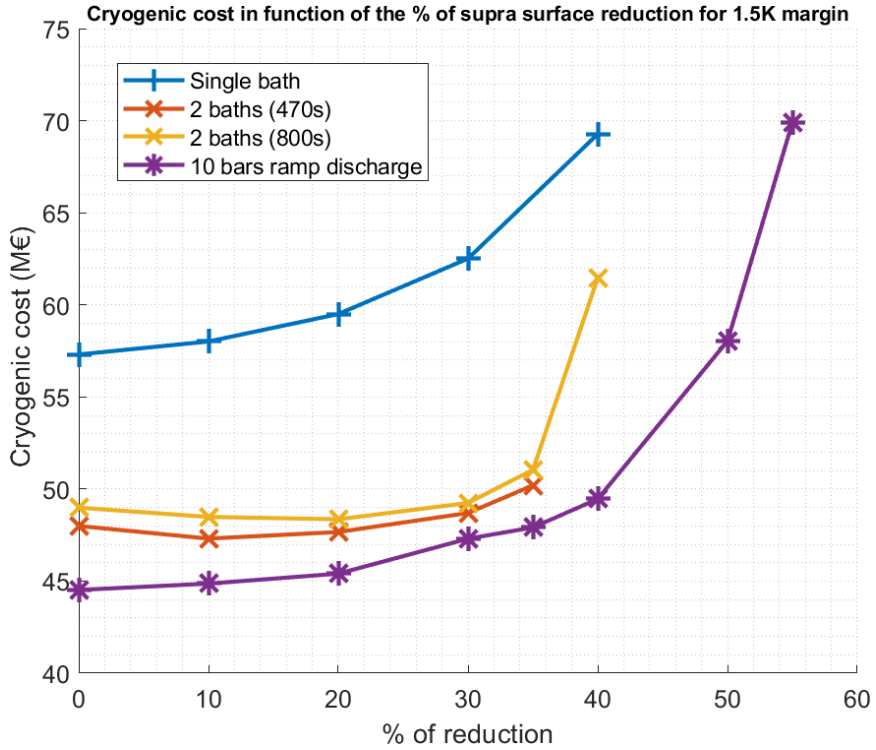


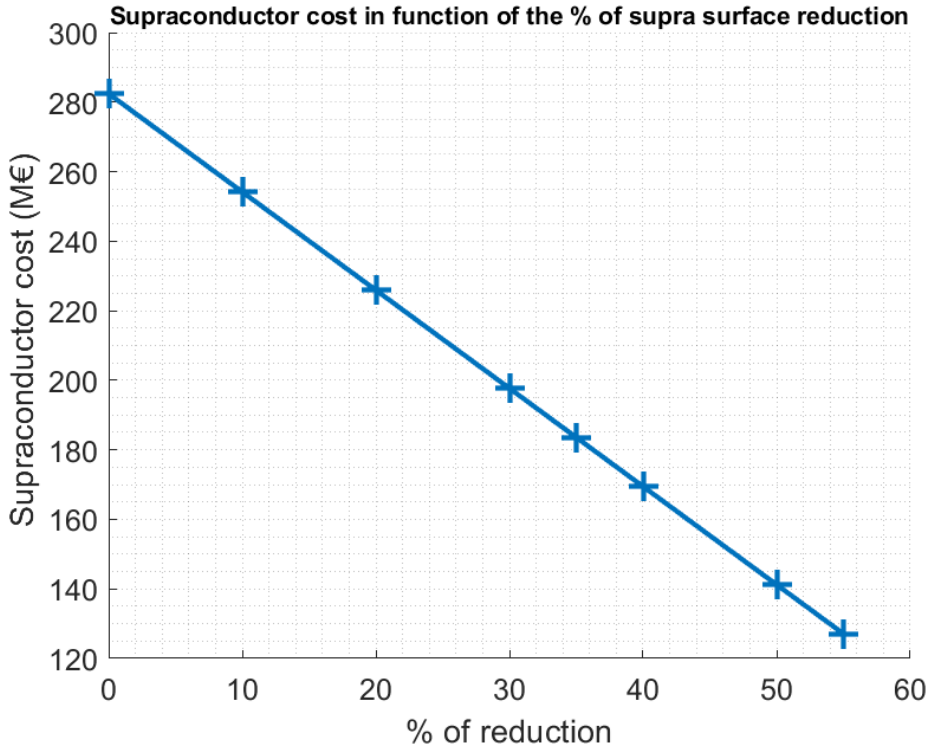
The combination of the 2 cryogenic processes allows to gain 590 mK of margin



Preliminary Costs exploration :
Reduction of the CS superconducting amont (simply proportionally, needs to be refine)

Cryogenic costs and supraconductor cost (M€)





$$P_{eq4,5K} = \left(\frac{Exergy_{300K}(J)}{time_{cycle}}\right) \times \left(\frac{4{,}5}{(300-4{,}5)}\right)$$

$$CAPEX(M€) = 2{,}9 \times P_{eq_{4,5K}}^{0,63}[kW] \times 3$$

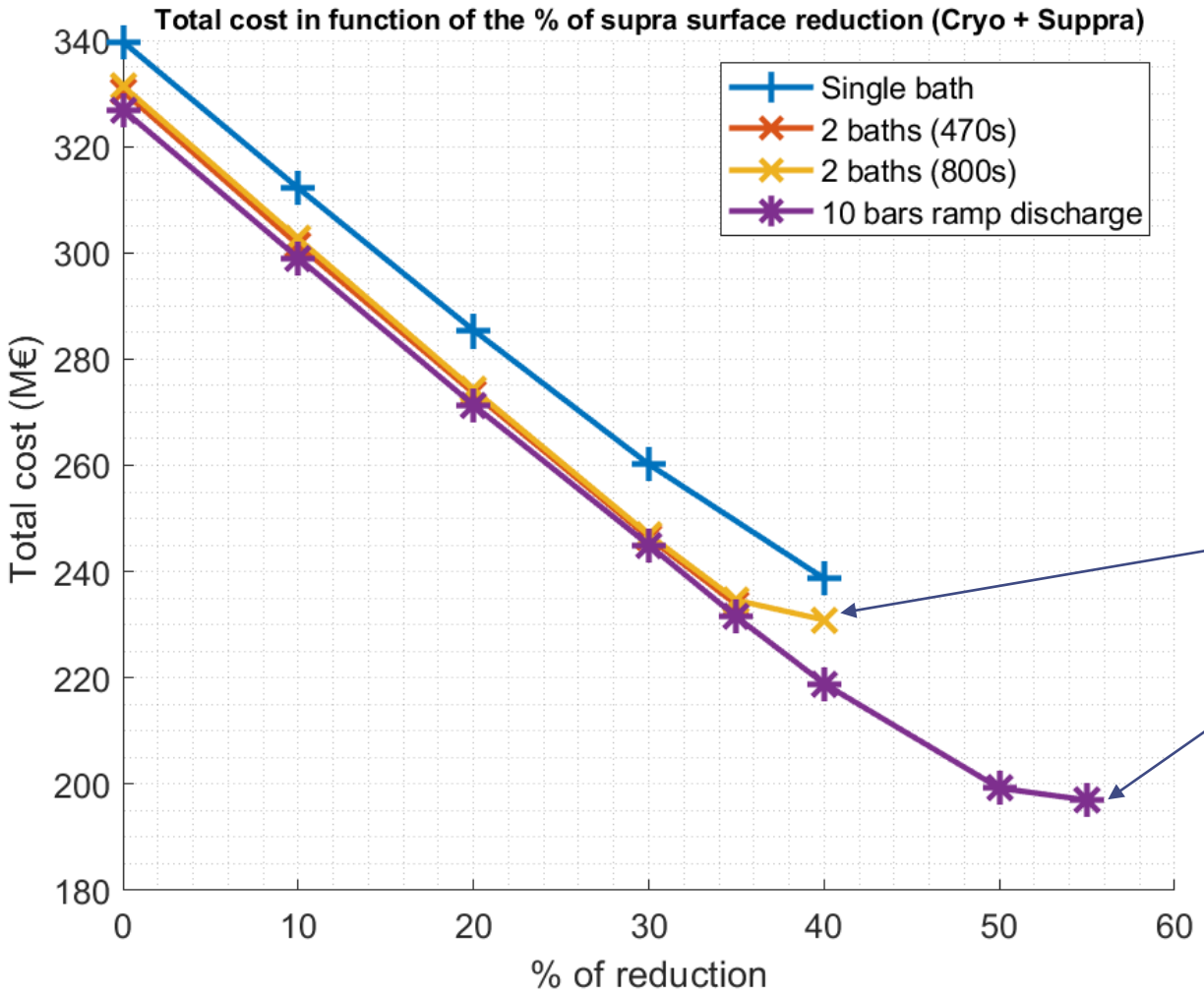
$$Elec_{cost}(M€) = 250 \left[\frac{W_{elec}}{W_{4,5K}}\right] \times P_{eq_{45K}}[MW] \times 24 \times 365 \times 20 \times \frac{50\left[\frac{€}{MWh}\right]}{1000000}$$

$$Cryogenic\ cost = CAPEX + Elec_{cost}$$

$$Cost_{supraconductor} = V_{168CICC}[m^3] \times 8\left[\frac{M€}{m^3}\right]$$

Calculation has been performed with the same current scenario, with a 1,5 K margin

Total cost (M€) : Cryogenic cost + Supraconductor cost



Calculation has been performed with the same current scenario, with a 1,5 K margin

Points which cryogenic cost starts increse to be higher than supraconductor costs diminution.

10 bars ramp discharge configuration allows to save more than 120 M€ by reducing size of the supraconductor.

Conclusion

The cryogenic process can have a **large impact** on the **CS** operation and specifically its **margin**

Using appropriate process can lead to

- **an increased margin**
- and / or
- **a CS superconducting amount reduction**

And needs to be investigate more into details