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Challenges and limitations of thermosiphon cooling

What we learned from CMS…

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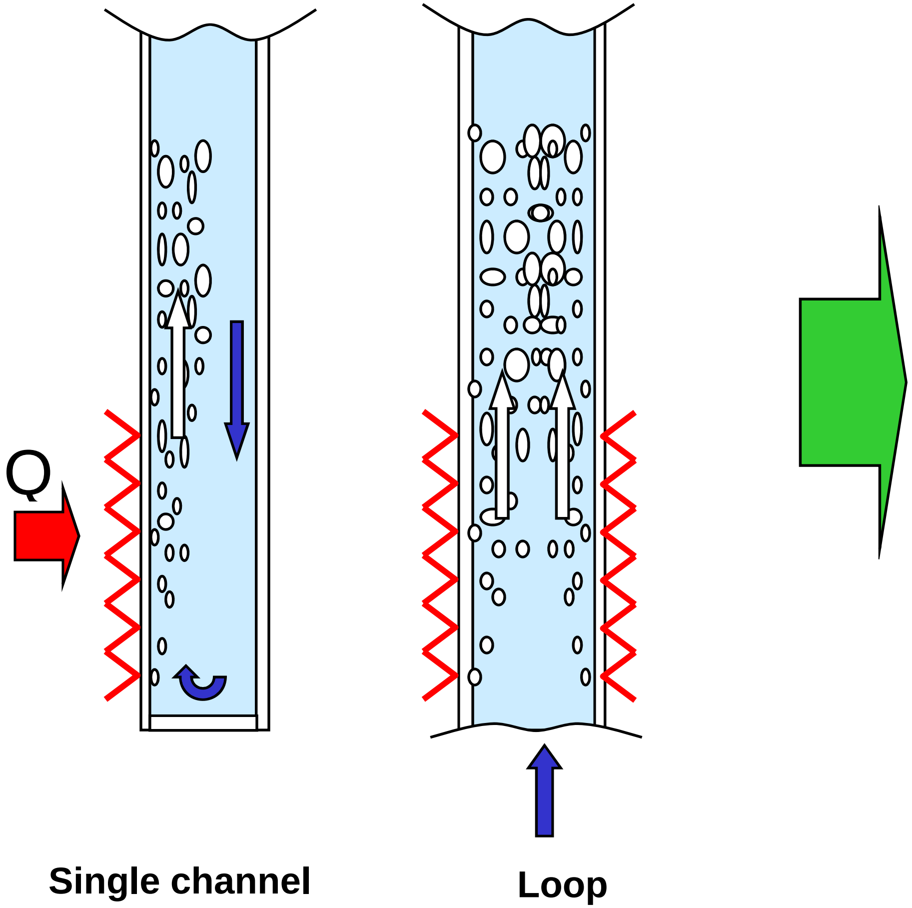
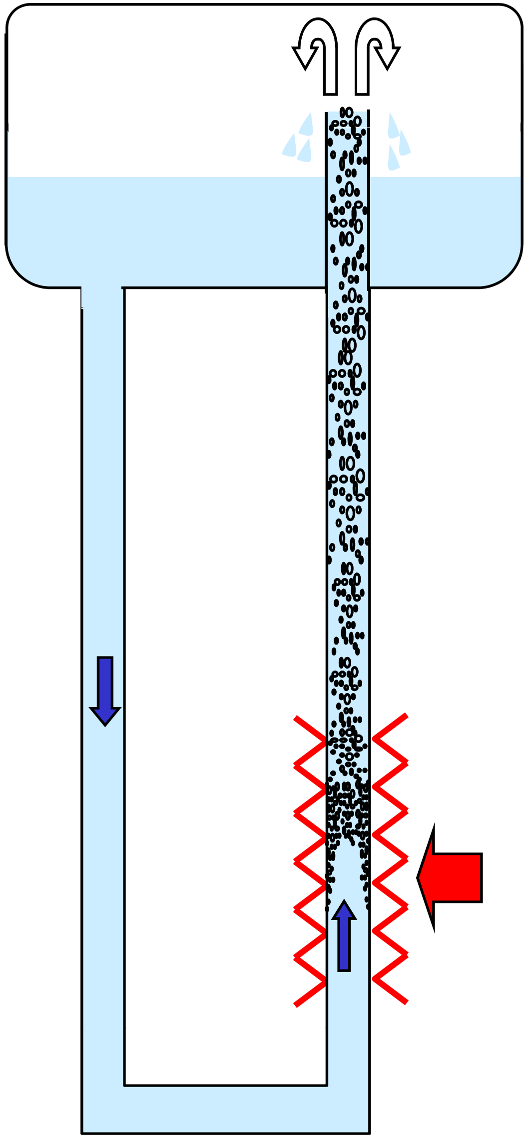
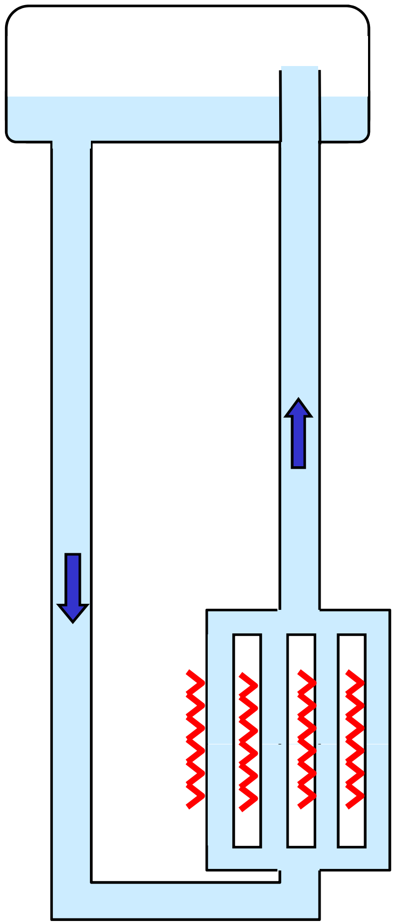
- The thermosiphon principle (example of two phase)
  - Self sustained natural boiling convection
    - Heating applied (Heat to be removed)
      - Boiling
      - Weight unbalance between legs of a loop
      - Induced flow limited by friction





- Rising heat exchangers with various geometry
- A mass flow and a flow quality deduced from geometry and heat load
- An upper tank –the well-named phase separator- is needed
  - to recover gas and to supply supply or condensation of gas (cryocooler)
  - for separation of the two phases

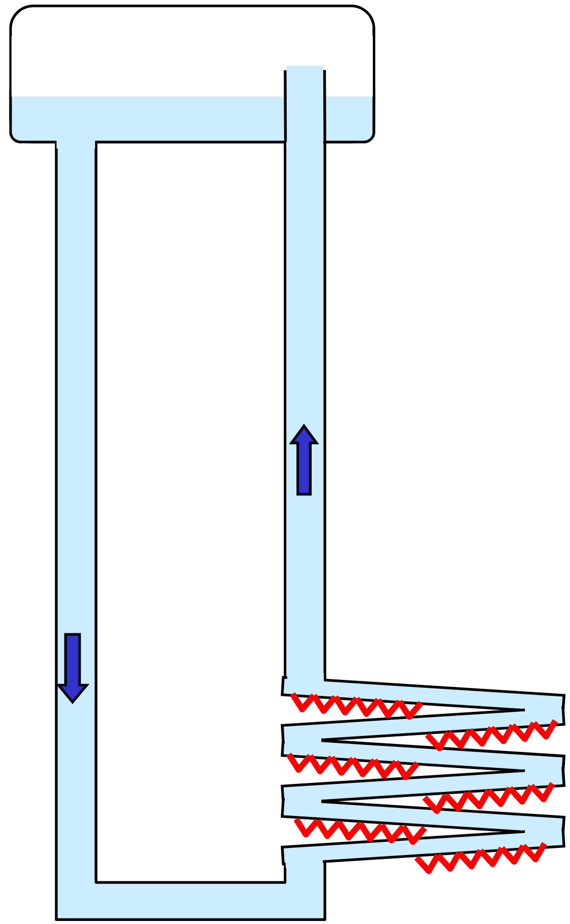


ΔP flow (m,x,geometry)

⇔

ΔP (x, hi)

Hyp: homogenous model
(x << 10%)



Advantages vs Inconveniences

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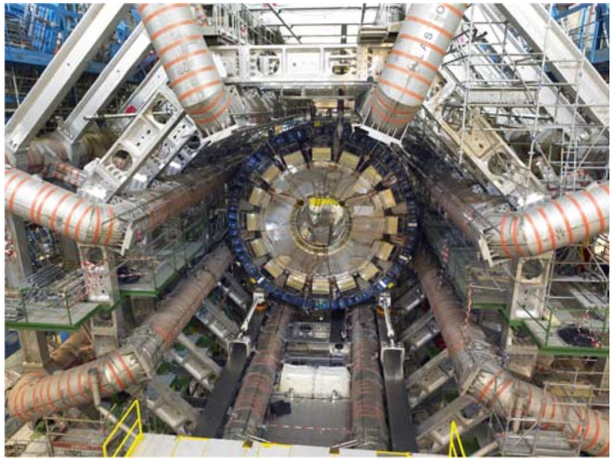
- A **passive** creation of flow
  - no pumps or regulation valves
- **Autonomy** in case of external cryogenic failure (volume of liquid in the phase separator)
- Minimization of the liquid volume
  - use of the phase separator as a back-up volume for liquid
- A **quasi-isothermal** loop
  - mainly function of height

- Need a **minimum height**
  - Pressure head to create flow
- Circuit geometry must **avoid any high point or strong singularities**
  - separation of the phases
  - risk of vapor lock
- **No** possible **external action**
  - and a possible frustration for the operator !
- **Pre-cooling** before starting the ThS effect

Examples of applications on large superconducting magnets with LHe/GHe loop at Tsat



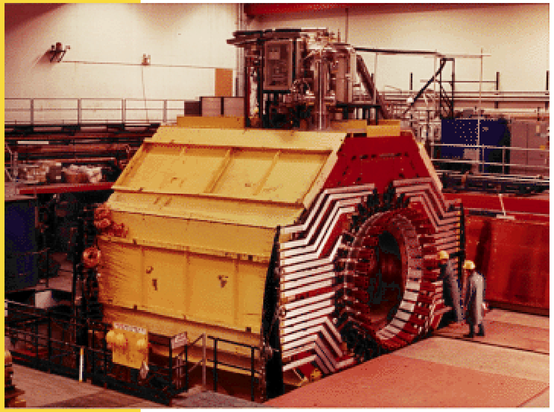
ATLAS CS (LHC)

ALEPH (LEP)

...

SMS G0 (JLAB)

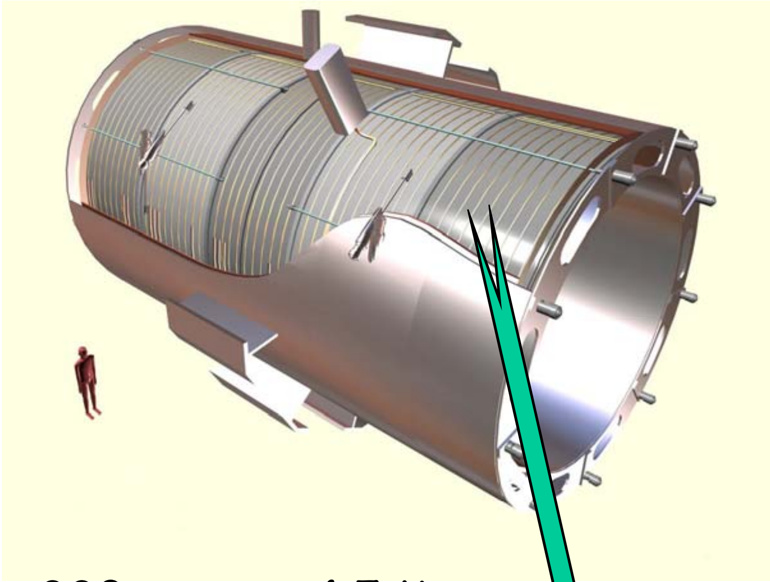
CMS (LHC)



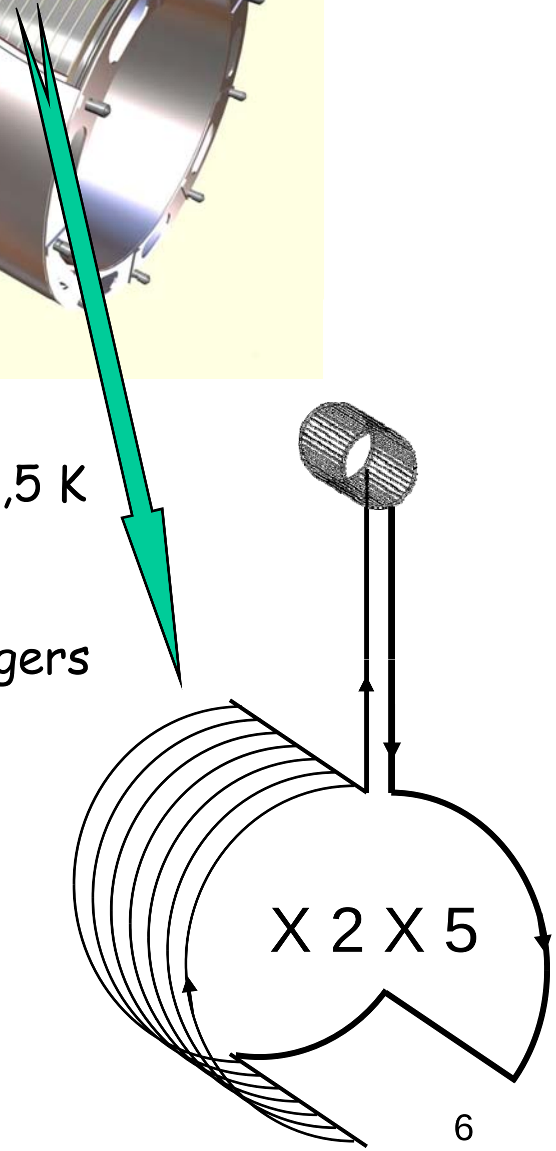
CLOE (CORNELL)

PANDA. R3B (GSI)…

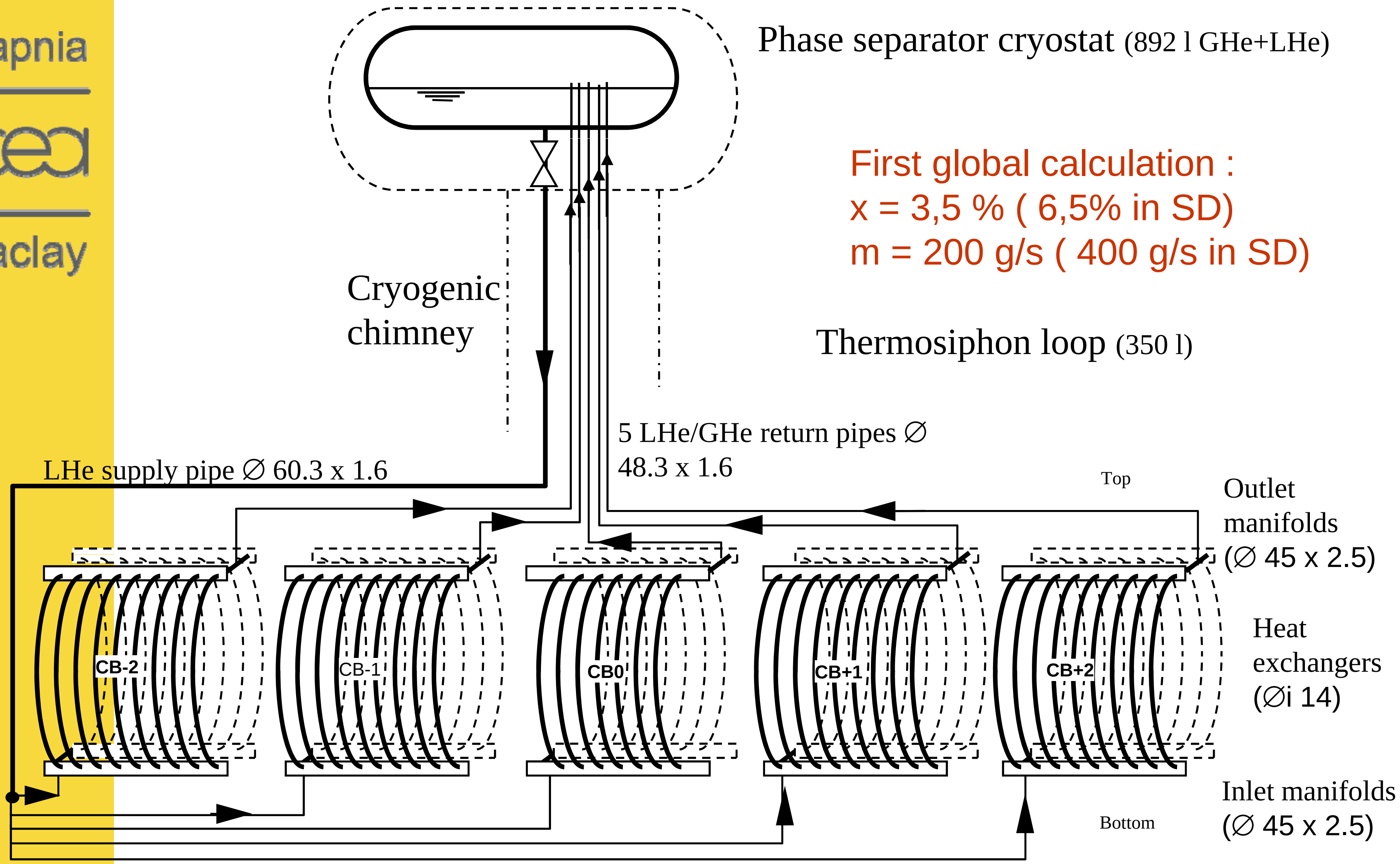
CMS



- 220 tons at 4.5 K
- 174 to 500 W at 4,5 K
- 5 modules
- 86 parallel exchangers



CMS thermosiphon



First global calculation :
x = 3,5 % (6,5% in SD)
m = 200 g/s (400 g/s in SD)

CMS R&D

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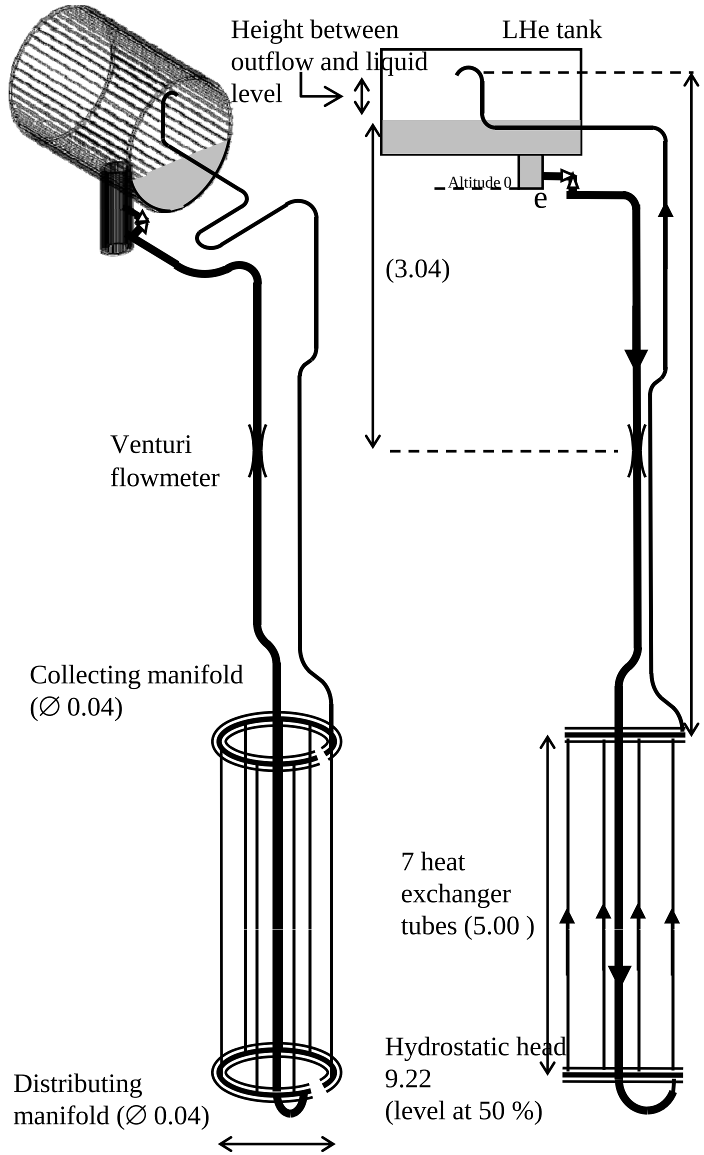
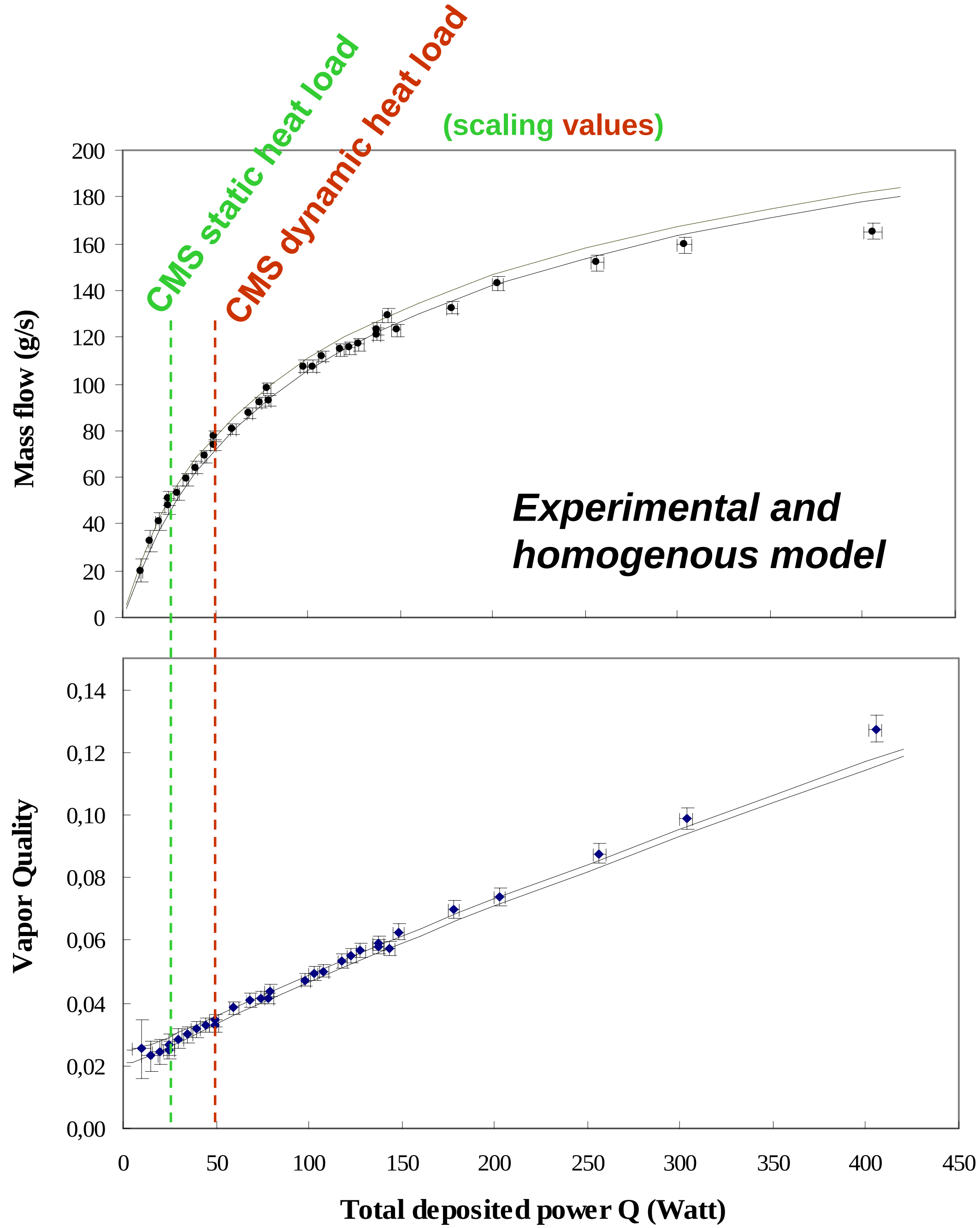
Experimental test loop scaling CMS design



CMS R&D

(on experimental test loop ≈ 1/10 CMS)

- A strong mass transfer in comparison with heat deposit
- A large margin
- Homogenous model correct still above 14%
- h > 1600 W.m².K
- ΔPr/Δps ~ 1
- ΔT height ~ 60 mK
- x < 3% (CMS nominal)



CMS R&D

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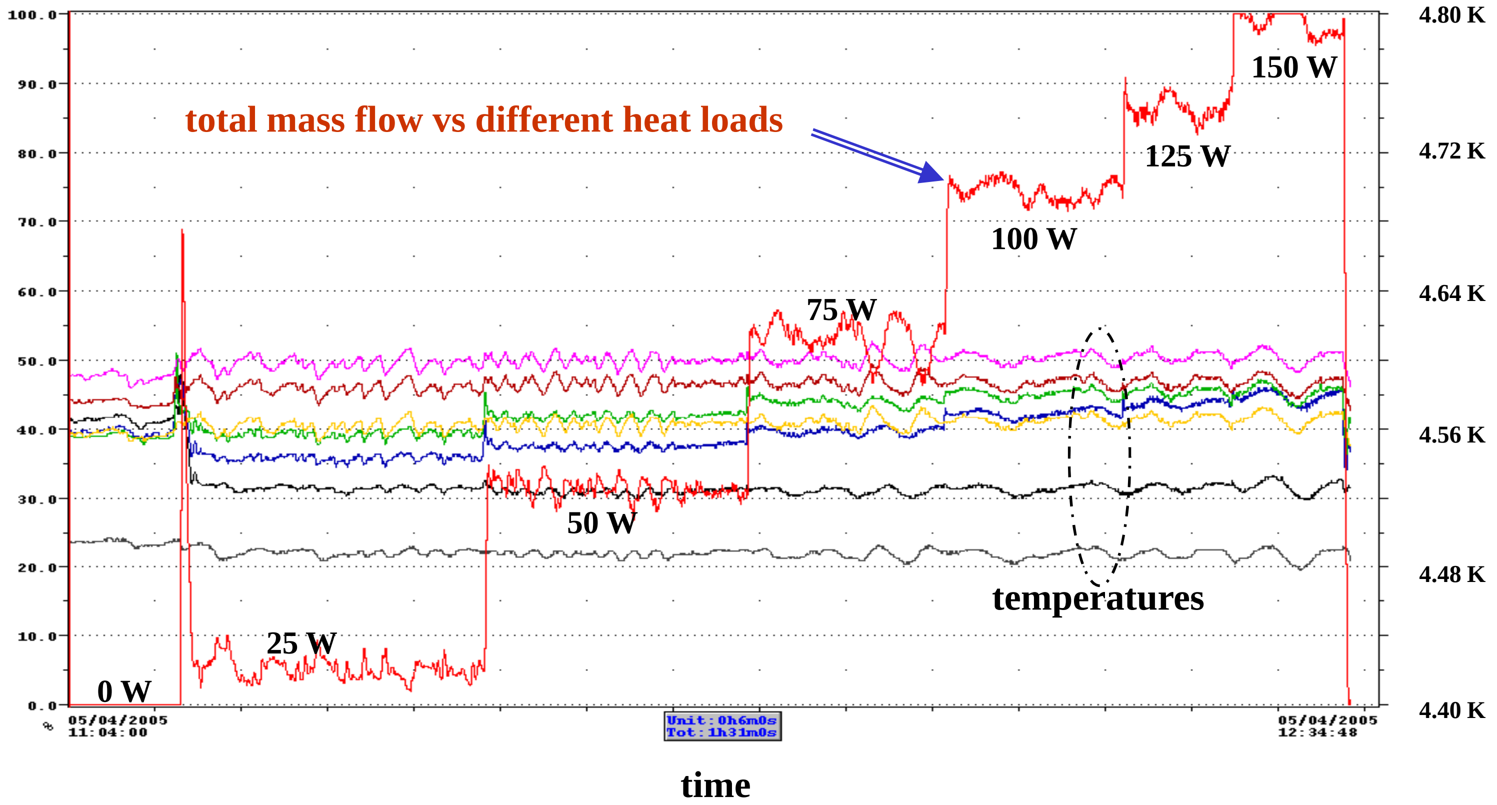
- Self-sustained circulation with the heat deposited

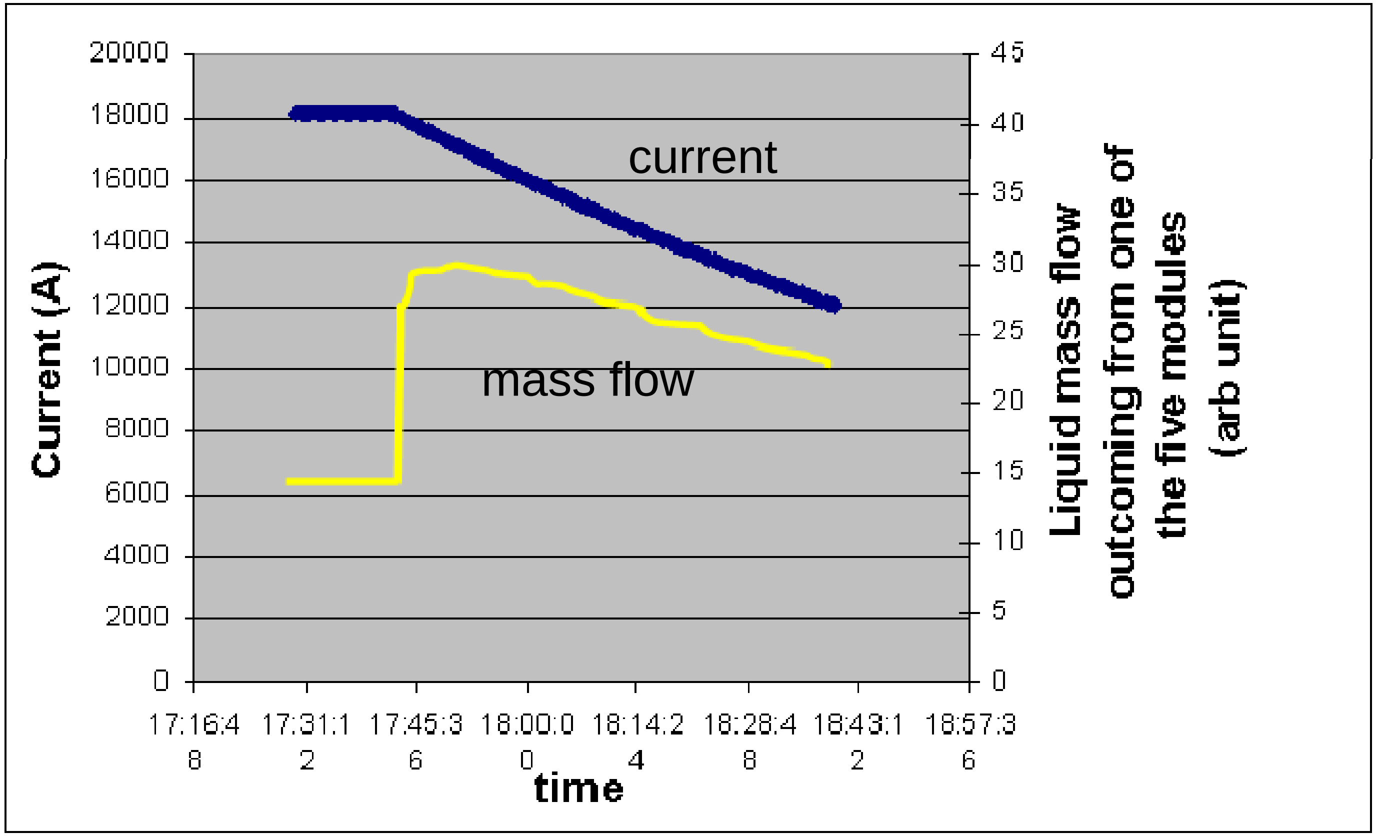
(on experimental test loop)



CMS on site

- Self-sustained circulation with the heat deposited

(on site, at the beginning of a slow dump with dynamic heat load)



CMS on site

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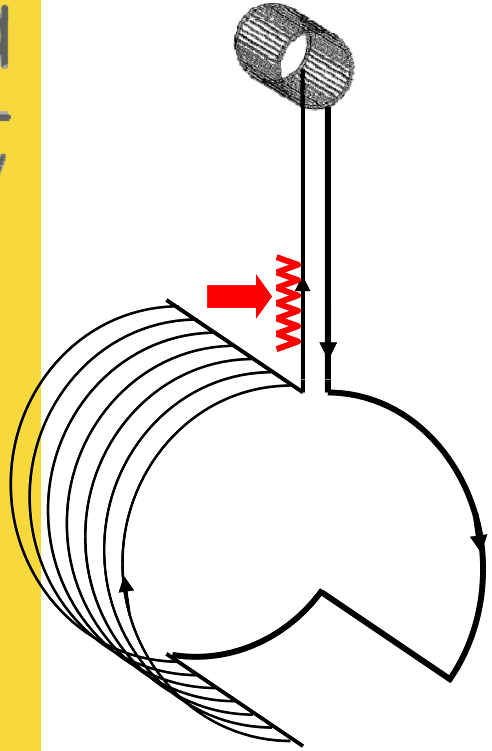
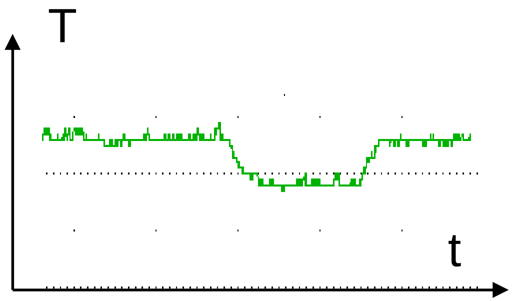
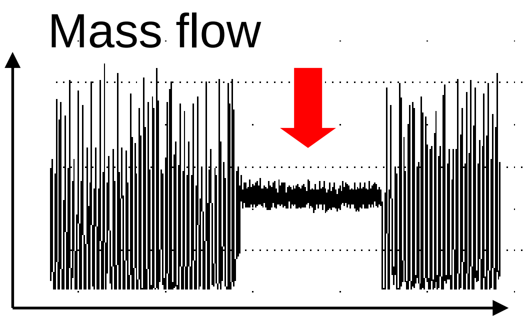
• Stabilisation and increase of the mass flow by heating the return lines





Effect on the coil temperatures

- 0.01 K temperature decrease on coil



Effect on the mass flow

- Increasing and stabilization of mass flow rate

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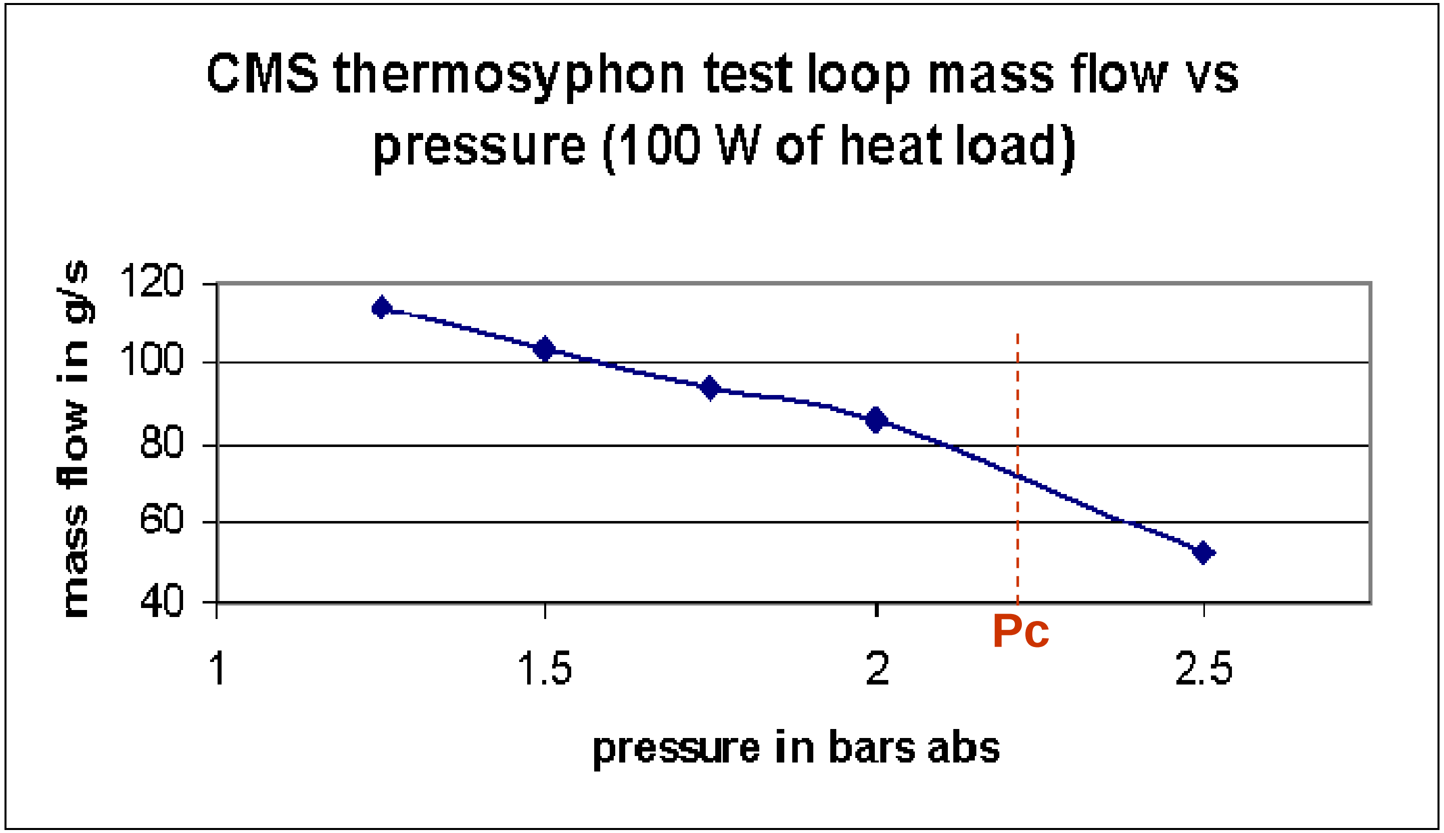
- Smooth sensitivity near and above the critical point



Limitations and Extensions

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- Circuit geometry :
  - A minimum height
  - Risk of high point or singularities where gas could be separated from the liquid
  - Minimization of pressure drop (singularities)

- A quasi-adiabatic supply line

- Good separation phase in the upper tank
  (**what could be its minimum size**?)

- Feeding of several parallel circuits with different heat deposits is possible (in CMS design, in ratio of 5)
  (feeding and collecting pipes must be designed to be as isobaric)

- Starting the natural circulation is achievable before the liquid presence (between 15 and 20 K for CMS design)

- Heaters on the return pipes could be used to limit instabilities due to gas/liquid separation at low velocity
  (low heat load or over-sizing)

- Flow quality could be chosen well higher than the traditional limit of 5 %

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Conclusion

Confirmed by these tests and operation measurements, thermosiphon loop stays a convenient way to insure the indirect cooling of large equipment and must be taken into account during a design study without preconceived fears.

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