INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

GL 2022
TRONDHEIM - NORWAY
JUNE 13-15

Krypton, applied as refrigerant for cooling of silicon detector trackers

Luca Contiero & Armin Hafner & Pierre Barroca & Krzysztof Banasiak | Norwegian University of Science and Technology

Bart Verlaat & Paolo Petagna | CERN

Paper 203

Summary

- Introduction
- Low-T cooling fluids in HEP (High Energy Physics)
- Hybrid cycle
- Cooling strategies & challenges
- Conclusions and further work

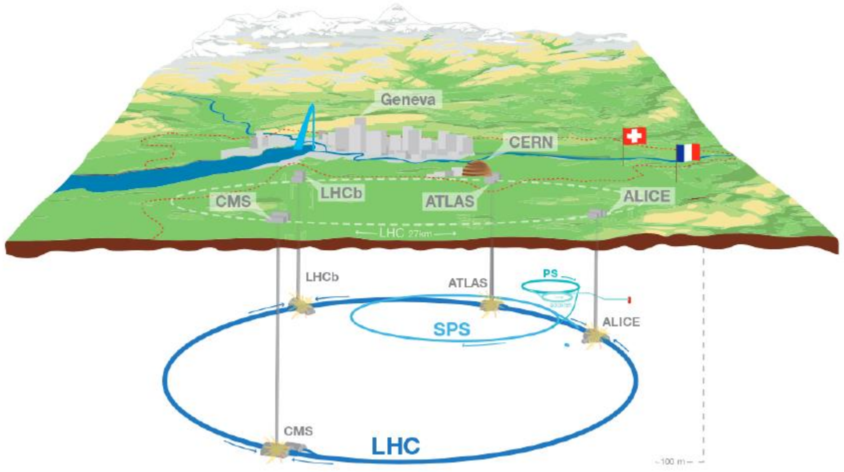
The LHC experiment

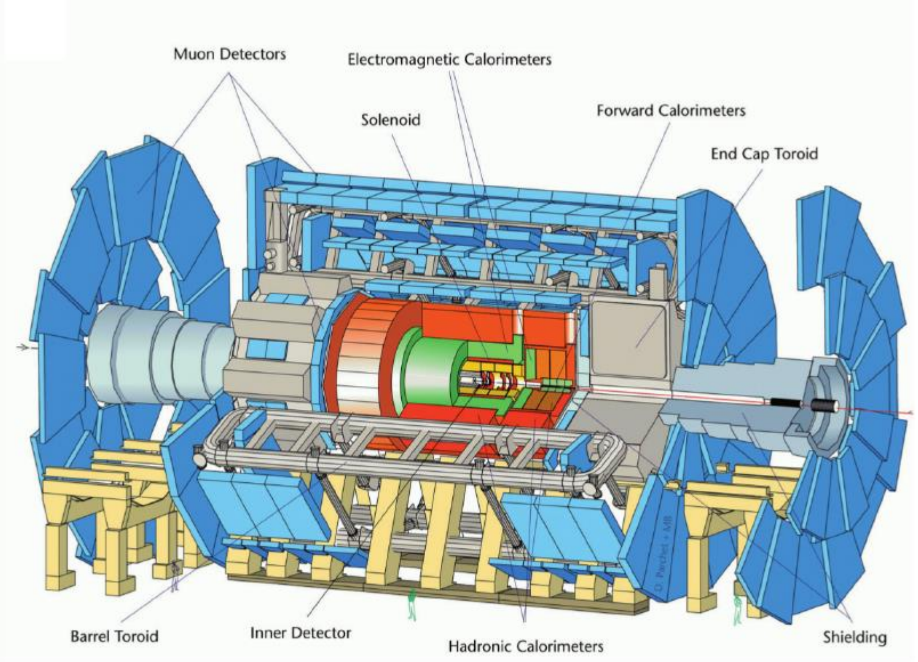
- High-luminosity Large Hadron Collider (HL-LHC) largest and most energetic collider in operation worldwide

- High-energy proton-proton collision might produce new heavy particles to discover

- Extremely high level of radiation → underground application to be shielded

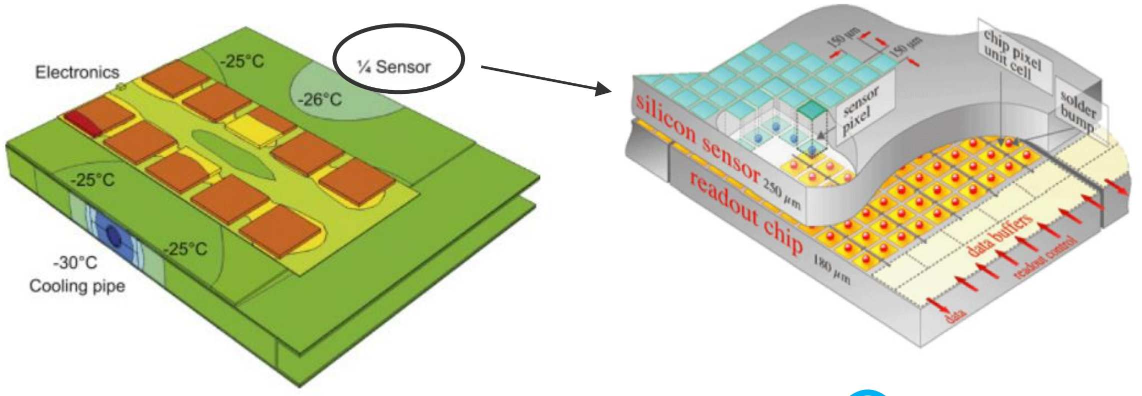
- Hadron-Hadron colliders tendency for colder cooling at increased power density

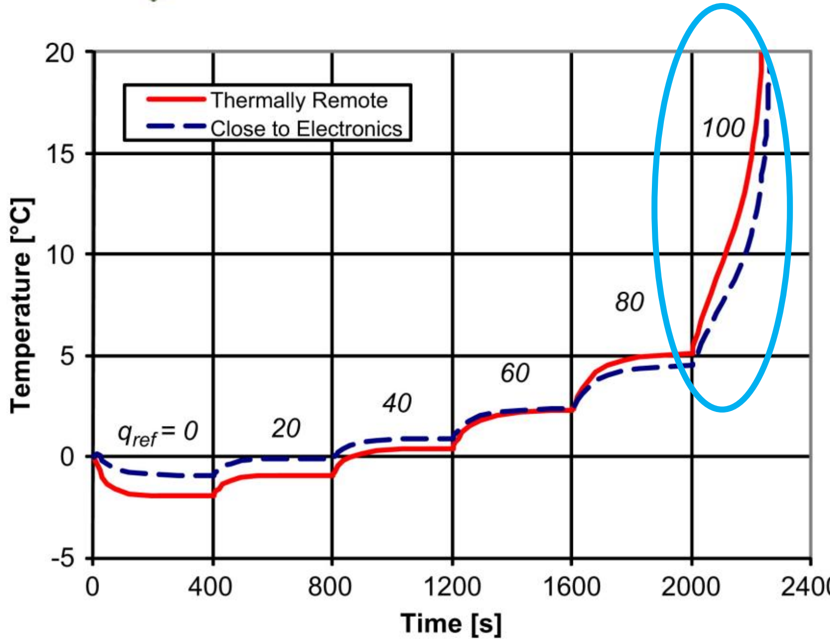




Why the need to keep the detector cold ?

- On the inner side of the beam pipe the particles travel and collide
- The deviation & path of the particles are recorded by producing an electrical signal on the silicon sensors
- Silicon sensors are the most delicate components
- The cooling unit aims to maintain the sensor's temperature below the critical value
- **Thermal runaway →** Sensor's temperature starts increasing excessively and the cooling unit cannot longer keep them cold





https://www.sciencedirect.com/science/article/pii/S0168900210005498#bib6

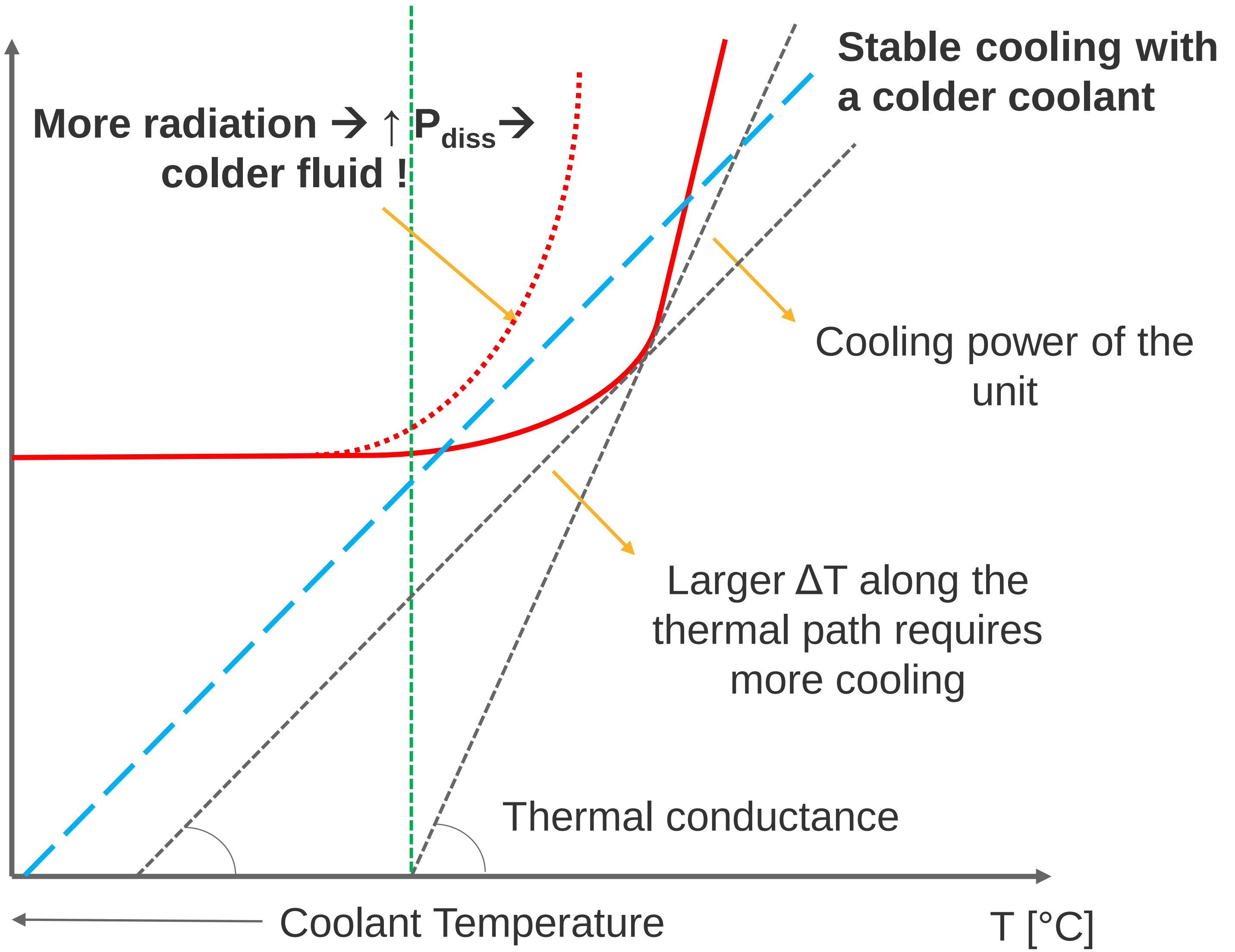
Why the need of a colder coolant ?

- Power dissipation = f(T)
- Thermal runnaway → the T° increases faster than the heat removal capability of the unit

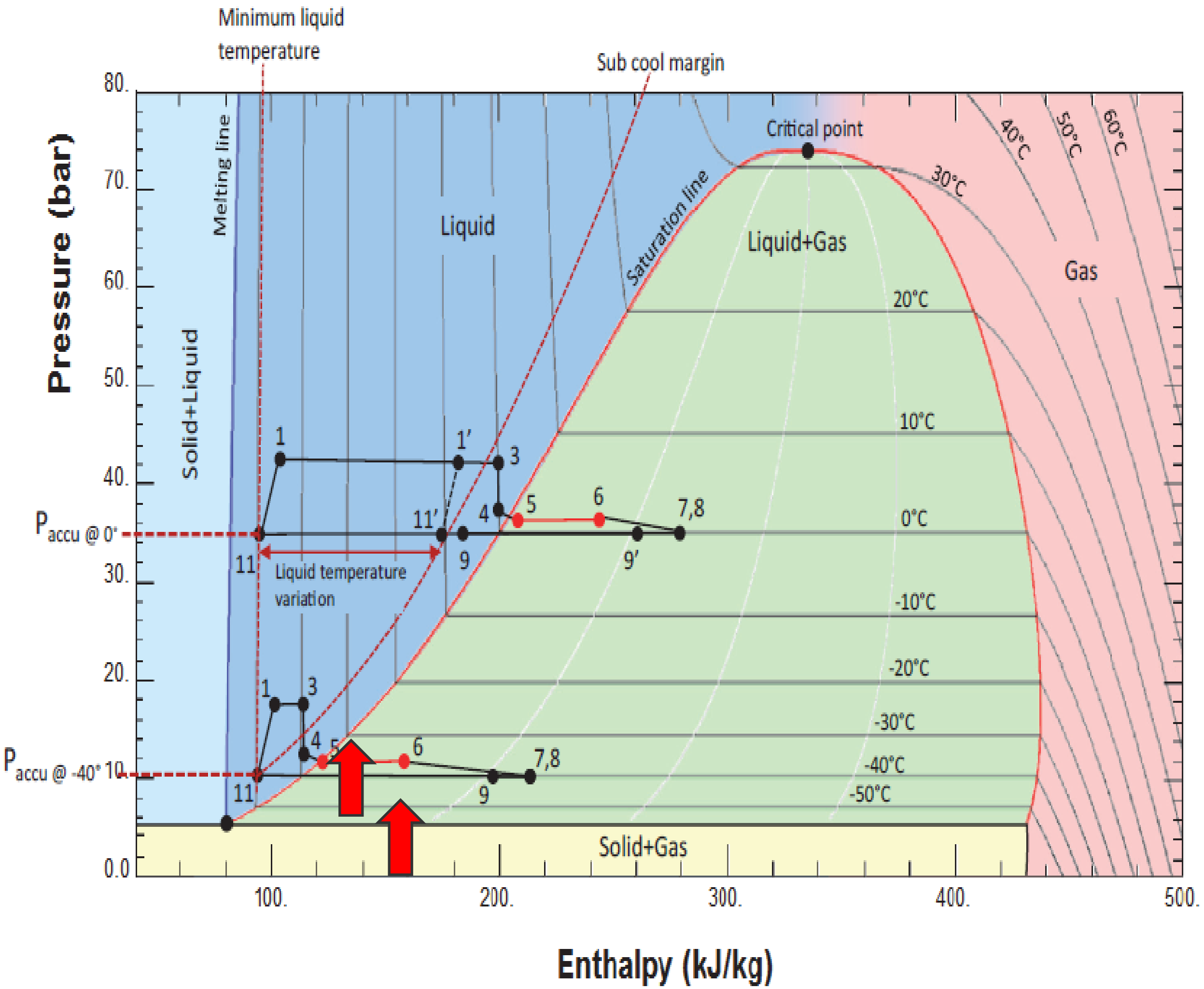
Two things must be considered:

A) High thermal conductance (low ΔT) and light weight of the structure surrounding the cooling pipe

B) Need to go much colder to be stable



Why the need of a colder coolant than CO_2?



- 2PACL (two-phase oil free pumped loop)
- CO_2 triple point ≈ -56°C → lowest possible evaporating temperature
- The current limit is ≈ -45°C (≈ -50°C on the primary chiller side) → pump subcooling
- The condensation of the returning two-phase flow is done via a primarly chiller with CO_2
- **New temperature domain expected to be around -50 to -80°C → New environmental-friendly refrigerant!**

https://indico.cern.ch/event/957057/page/23281-the-roadmap-document

Detector & coolant's requirements

a) Mass minimization → less interaction with tracking process

b) Temperature stable over all the detector → Thermal runaway must be avoided

The coolant shall be:

c) No toxic and preferably no flammable (HCs)

d) Radiation hardness → radiation induces chemical modifications

e) High radiation length (less interaction with the tracking process)

g) High working pressure fluid → by having smaller pipes point e) becomes less important

h) Natural fluid → meet CERN environmental policy

Low-T candidates:

- N_2O & N_2O+CO_2
- Ethane & Ethylene
- Xenon
- Krypton

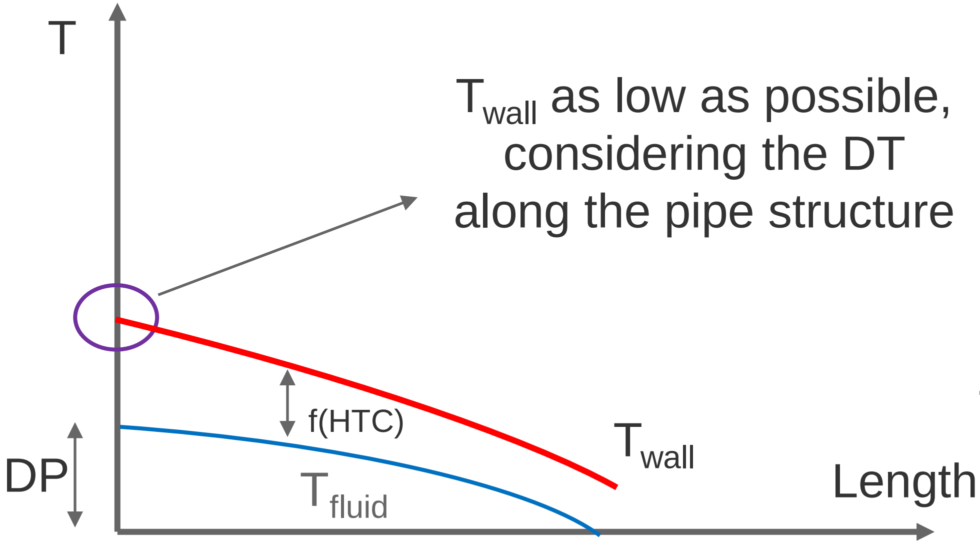
Selection of the best natural cooling choice in HEP

In a detector cooling application the choice of the coolant is twofold:

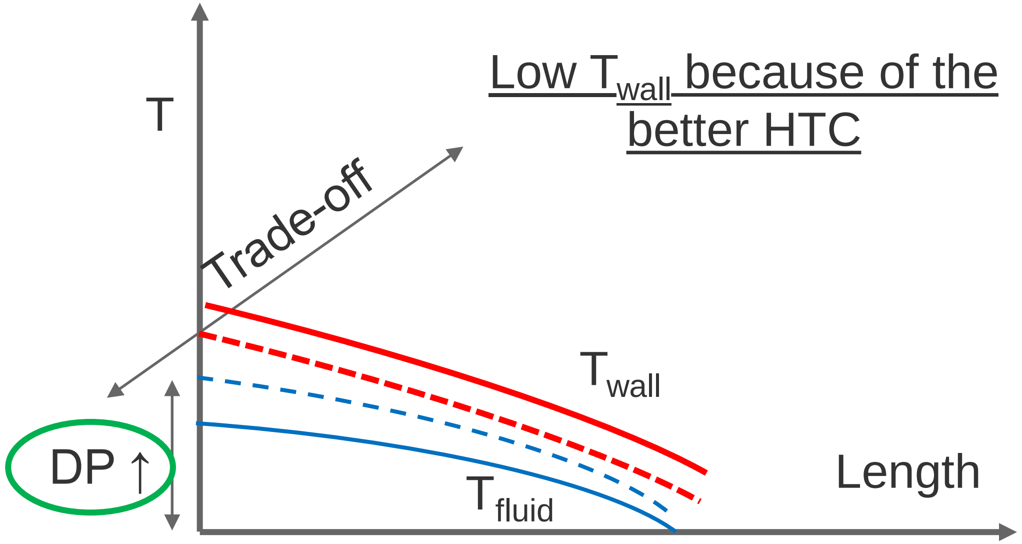
- Having the best thermal performance with the smallest possible cooling pipe
- Avoid an uneven temperature distribution along the silicon sensors

Volumetric Heat Transfer Coefficient

$$\frac{Q}{Volume * DT(HTC + DP)}$$

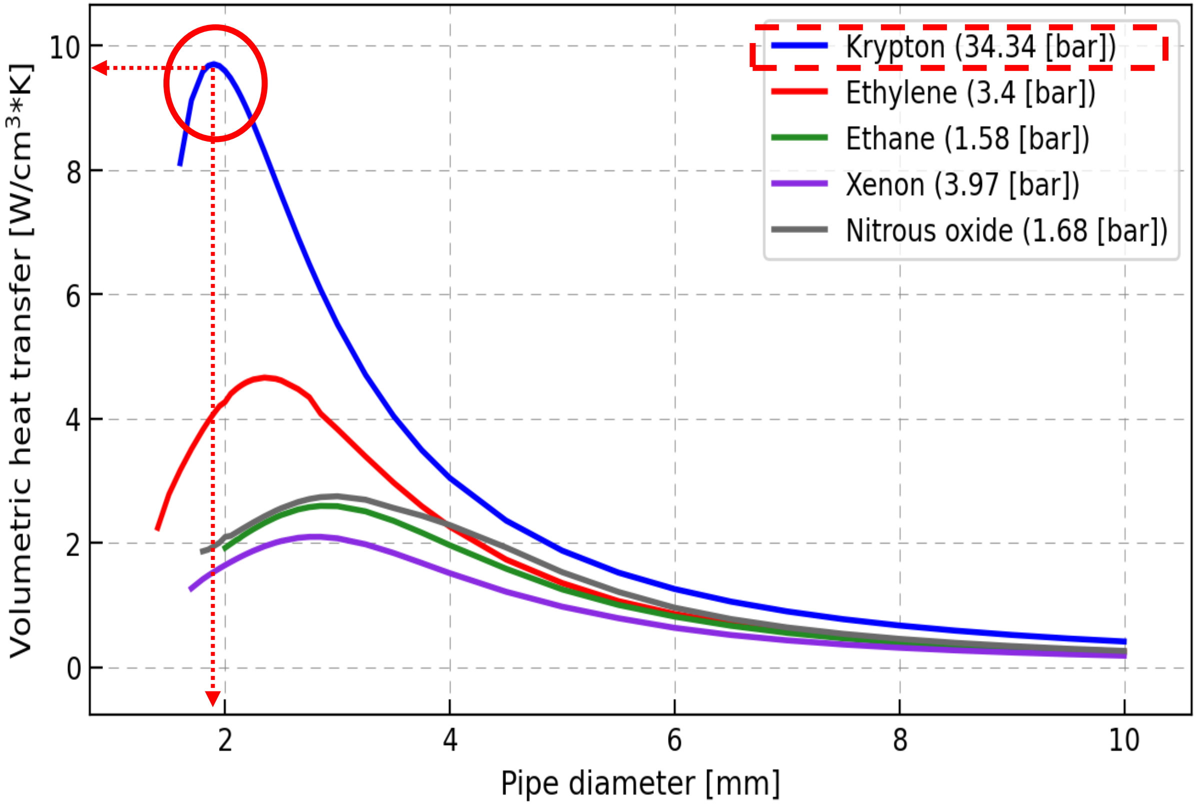


By decreasing the diameter



https://indico.cern.ch/event/233332/contributions/1546088/

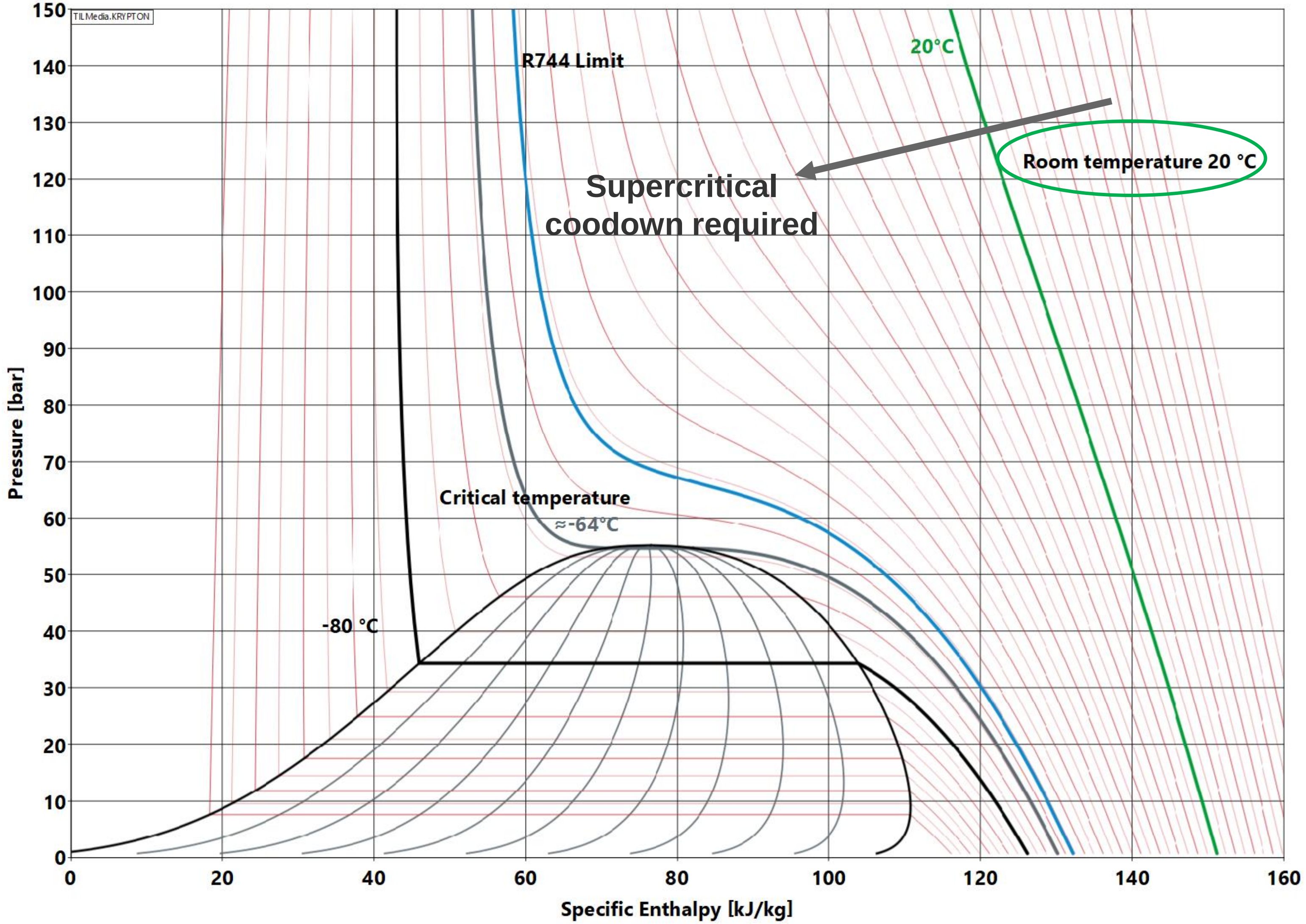
Selection of the best natural cooling choice in HEP



Length = 2 [m]; Q = 200 [W] ; Vapor quality change = 0-35%; T = -80 [°C]
(standard data low-mass detector)

- Larger diameters unaccepatble for low-mass detector design
- High pressure fluids are less sensitive to pressure changes → beneficial for stable temperature systems
- Pressure losses acceptable (for same DT) for Krypton up to 7 times those occuring with Xenon, HCs or N_2O
- Larger DP are acceptable with Krypton, resulting in higher velocities in the evaporator and thus better HTC
- **Krypton as the most promising coolant for the future in HEP**

Challenges with Krypton cooling unit

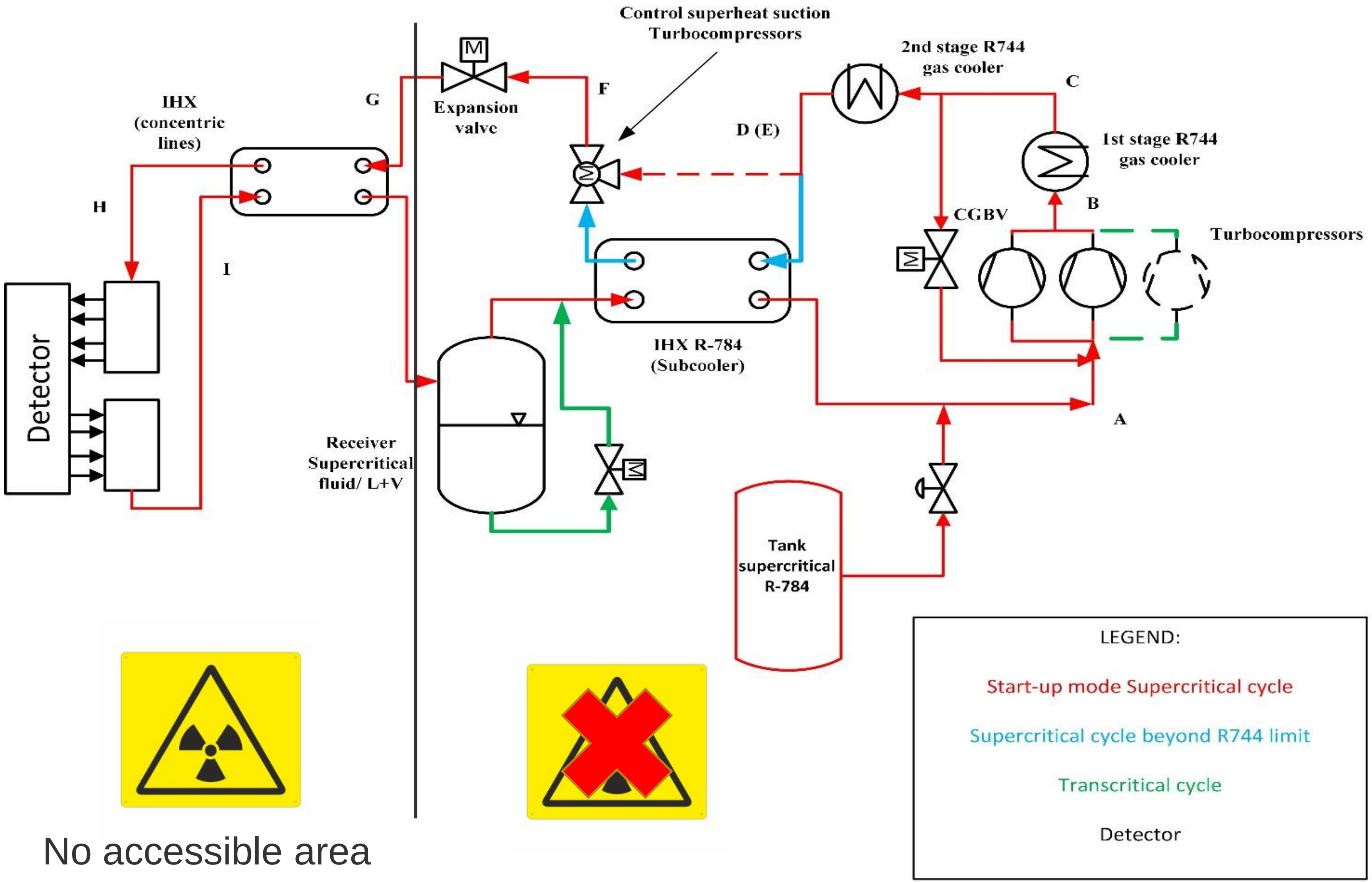


- **Starting in gas phase** (room temperature) requires a special cycle
- Supercritical cooldown to avoid thermal shock inside the detector
- Delicate components must be cooled down slowly (1 K/min)
- Colder temperatures are required to remove heat generated by sensors & electronics

Requirements for Krypton cooling unit

- Oil-free unit → use of oil not contemplated in a high-irradiated area, risk of decomposition → potential clogging of the pipes & production of corrosive compounds
- All the instrumentation must be placed faraway from the irradiated area
- No active components in the non-accessible area (for reliability)
- T-p level in the evaporator shall be controlled remotely
- For flow boiling condition, evaporation stopped in the low-quality region (≈35%) for two reasons:
  - High HTC
  - Safe operation faraway from the dry-out point

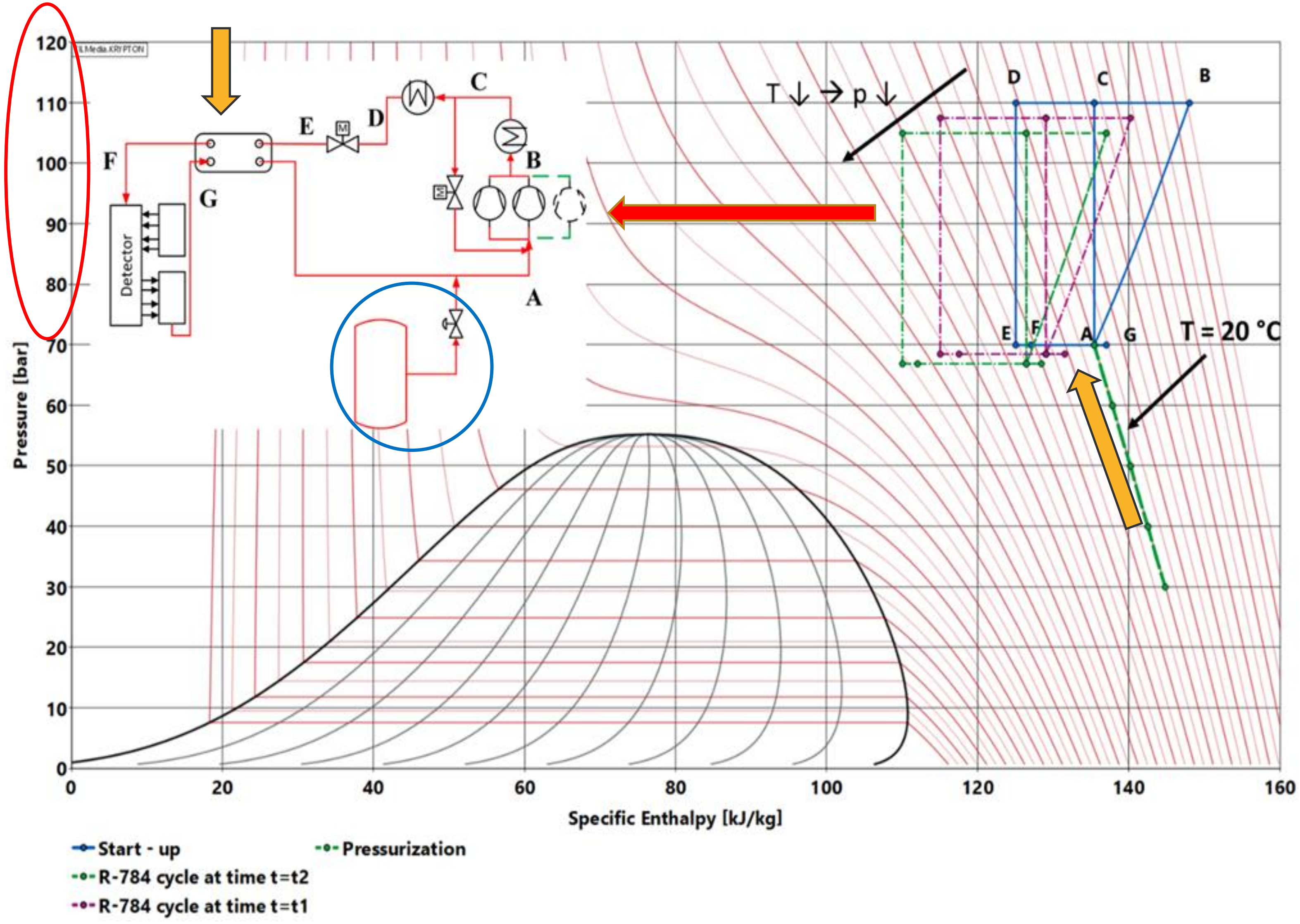
PID Hybrid cycle with Krypton



No accessible area

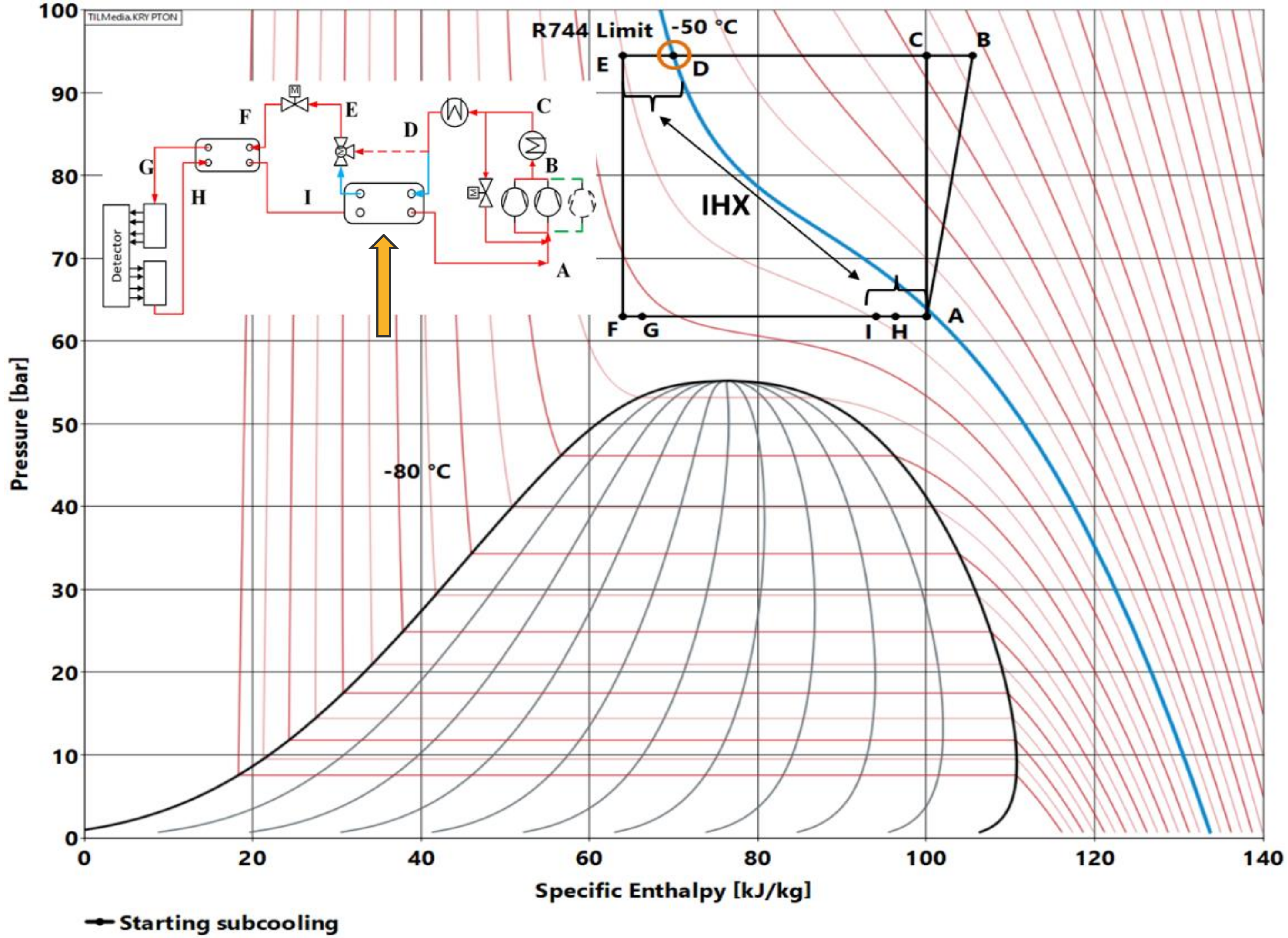
- Turbocompression stage (A-B)
- Gas cooler section (B-D)
- CGBV (C-A)
- High-pressure control (F-G)
- Concentric line (G-H-I)
- Detector (H-I)
- Liquid receiver & supercritical tank

Start-up process

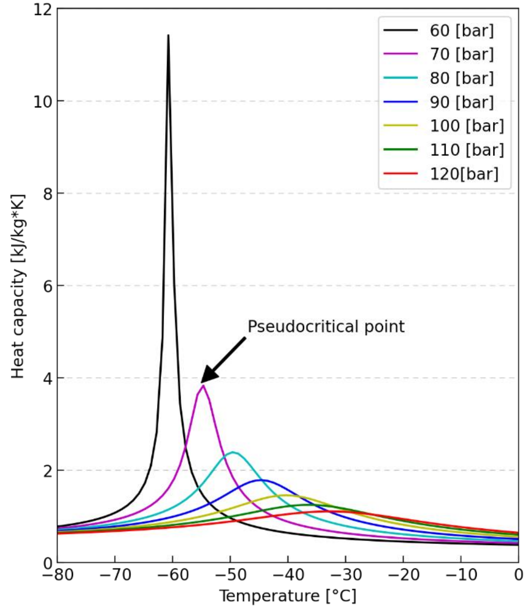


- Unit's charging to the desired pressure level
- Operating at high-pressure
- Concentric line as safety against fast overcooling
- Simultaneous charging during the cooldown process to operate in the zone of nearly isothermal lines → buffer against possible pressure's collapse

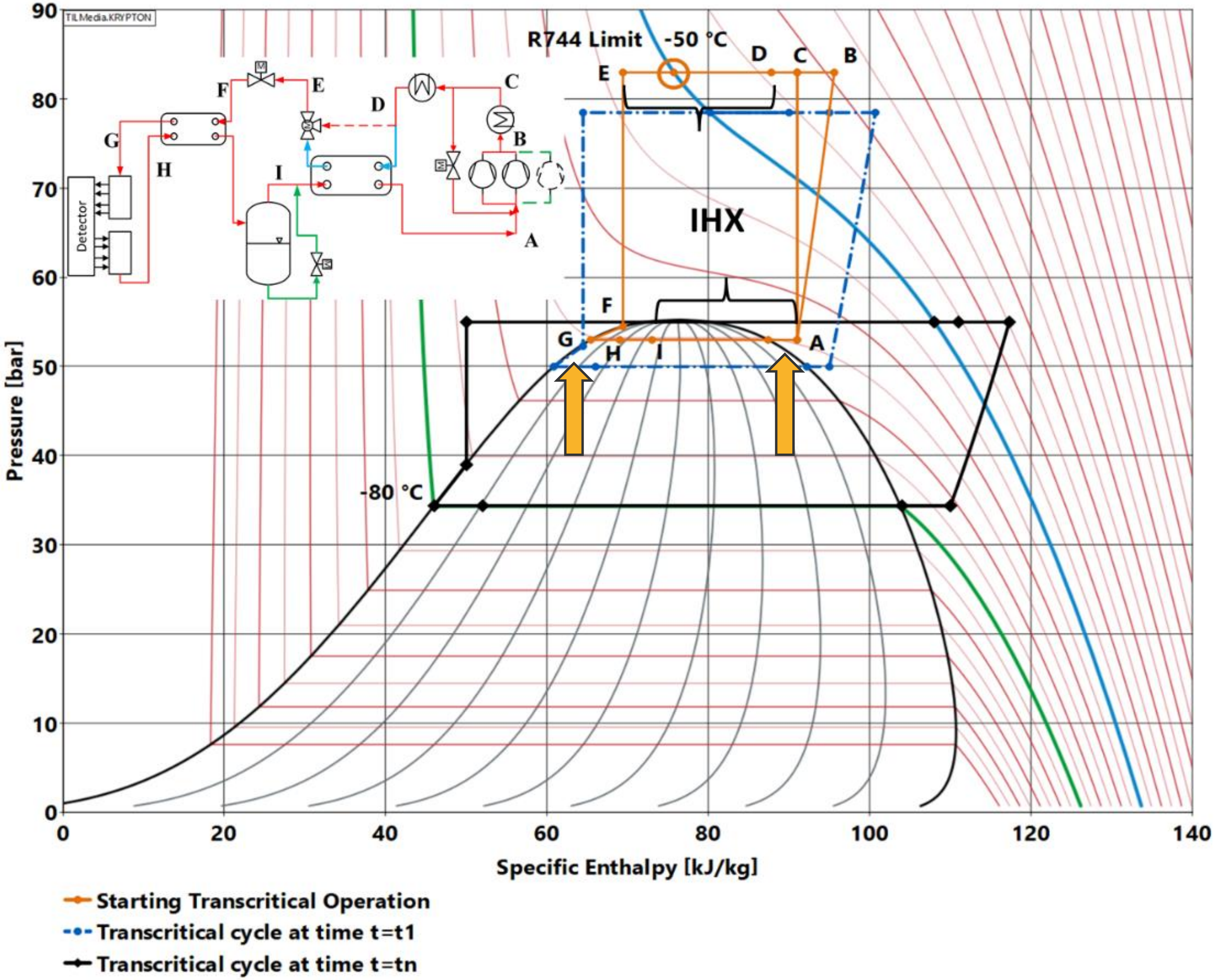
Supercritical operation



- Temperatures below -50°C via the use of an internal subcooler + CO_2 gas coolers
- Fully supercritical cycle in a temperature range -50 to -60 °C
- Working too close to the critical point must be avoided (rapid change of the physical properties)



Transcritical – subcritical operation



- Evaporative cooling required during the lifetime of the detectors
- Turbocompressors must always be fed by superheated vapor
- Specific control on the heat rejection rate bewteen 2nd gas cooler - IHX
- Concentric line permits to fully liquify at the detector inlet → avoiding maldistribution

Conclusion and further work

Aim of the study:

- Compared different natural fluids to cool the future highly irradiated detectors.
- Krypton stands out as the most performant coolant for the future particle infrustructure at CERN, presenting similar pressure level of CO_2 and ≈ diameters.
- Propose a new hybrid cooling cycle with Krypton for the T range -60 to -80°C.
- Evaluate the transient behavior from room temperature down to the cold region.

Further work:

- Evaluate possible improvements of the cycle → Ejector for liquid recirculation – subcooled liquid before manifold inlets
- Test the thermal perfomance in the subcritical – supercritical domain (HTC&DP) → setup at CERN
- Using another medium (i.e. Xenon), prove the cooling concept of the cycle

INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

GL 2022
TRONDHEIM - NORWAY
JUNE 13-15

NTNU

CERN | EP-DT Detector Technologies

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA no 101004761.

Thanks for your attention!

Luca Contiero , PhD candidate

Luca.contiero@ntnu.no