Rough and incomplete power/cost estimates for the SIGRUM-project's cryogenic system

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Heat loads at 4.5 K – 5.0 K (excluding powering)

There are two cryo-assemblies on the gantry

At the back consisting of:
2 x 22.5° dipole magnets including 1 pair of 2.5 kA current leads + 1 x quadrupole including 1 pair of 1.25 kA current leads + 2 cold-warm transitions
Total power = 1.24 (dynamic) + 1.10 (static) +CLs = ~2.9 W + CLs

At the top
3 x 45° dipole magnets including 1 pair of 2.5 kA current leads + 2 x quadrupoles including 1 pair of 1.25 kA current leads + 2
Total power = 6.73 (dynamic) + 2.22 (static) +CLs = ~9.4 W + CLs

Loads at 4.5 K – 5.0 K	Static	Dynamic
45° dipole magnet	0.3 W/m	1.25 W/m
22.5° dipole magnet	0.3 W/m	1.25 W/m
quadrupole	0.3 W/m	1.25 W/m
cold-warm transition		< 0.5 W

Powering - Current leads (CLs)

- In total 2 pairs of CLs for the dipoles + 2 pairs of CLs for the quadrupoles are necessary
- The heat brought onto the magnet operating temperature level varies considerably amongst the current-leads concepts and is linearly dependent on the current level
- The high current magnet option considers 2.5 kA for the dipoles and 1.25 kA for the quadrupoles
- Technology bringing the current from leads to magnets via cold links exists and is used at Cern

CL-type	Power to 4.5-5.0 K (W/kA)	comment
Conduction cooled (with intermediate heat intercepts)	~ 3 to 4	high load for high current magnet option (45 W – 60 W). *Unreasonable for cryo-coolers*
Vapour cooled	~ 1	15 W for high current magnet option, *dedicated cryo necessary*
HTS –vapour cooled	<< 1	Dedicated cryo necessary, working 600 A, 6 kA, 13 kA, 17 kA leads designs exists. Cryopower, gaseous, levels 50 K and 4.5 K, can be provided by *dedicated cryo-coolers*

Cooling power at 4.5 K – 5.5 K

Magnet cold-masses

- **Total cold-mass cooling needed : ~ 12-13 W**

  This can be achieved with 7 x 2-stage cryo-coolers

  This can be achieved with small scale refrigerator providing 5 K supercritical Helium

- **Thermal screen cooling + cool-down**

  This can be achieved with one, 1st stage only high power cryo-cooler

  This can be achieved with small scale refrigerator providing supercritical Helium

Powering

Current leads cooling power and associated cryo-needs **is to be optimized** as function of current level and current lead type.

- **Cryo-coolers:** Only the HTS-leads option looks suitable
- **Small-scale refrigerator:** could manage any lead-type

Courtesy P. Tavares De Sousa

Readily available cryo-cooler options

Cryocooler	Type	Cooling power (W)	Price (EUR)	Cold head weight (kg)	Compressor dimensions
Cryomech PT420	Pulse tube	2.0 W @ 4.2 K (2nd stage) 55 W @ 45 K (1st stage)	55,000	26.3 kg	61 x 61 x 79 cm 190 kg
Sumitomo RDE-418D4	Gifford-McMahon	1.8 W @ 4.2 K (2nd stage) 42 W @ 50 K (1st stage)	41,000	20.0 kg	59 x 45 x 59 cm 100-120 kg

- Cryocooler motor must not be subjected to magnetic fields higher than 30-50 mT (for either type); shielding is difficult due to the relatively large opening required from the motor to the cold part of the cryocooler.
- PT-type cryocoolers are sensitive to orientation and drastically lose cooling capacity if tilted > 45°; 1st stage starts to lose cooling power from 10°.
- PT-type cryocoolers require maintenance on compressorsw only; GM cryocoolers require also the cold head to be serviced.
- Both cryocoolers require compressor units connected to flexible lines to the cryocooler head; each compressor unit.
- Both cryocoolers require water cooling and 3-phase power supply to their compressor units **(7-11 kW/unit).**

→ Electrical power for ~ 8 – 10 cryo-coolers: 88 kW – 110 kW (cold masses only!)

Cryo-cooler cost per power *P* needed : cost =37*$P^{0.38}$ (k$)

Courtesy P. Tavares De Sousa

Small refrigerator cost

- Cold-mass refrigerator should probably be combined with the accelerator one
- Use of ~ 5 K, supercritical helium. Two-phase flow cooling is excluded by the requirement of rotating the gantry magnets
- Refrigerator cost per power P needed : cost $=2600*(P/1000)^{0.63}$ (k$)

Source: THE COST OF HELIUM REFRIGERATORS AND COOLERS FOR SUPERCONDUCTING DEVICES AS A FUNCTION OF COOLING AT 4 K

M. A. Green, AIP Conference Proceedings, 2008

Compared costing

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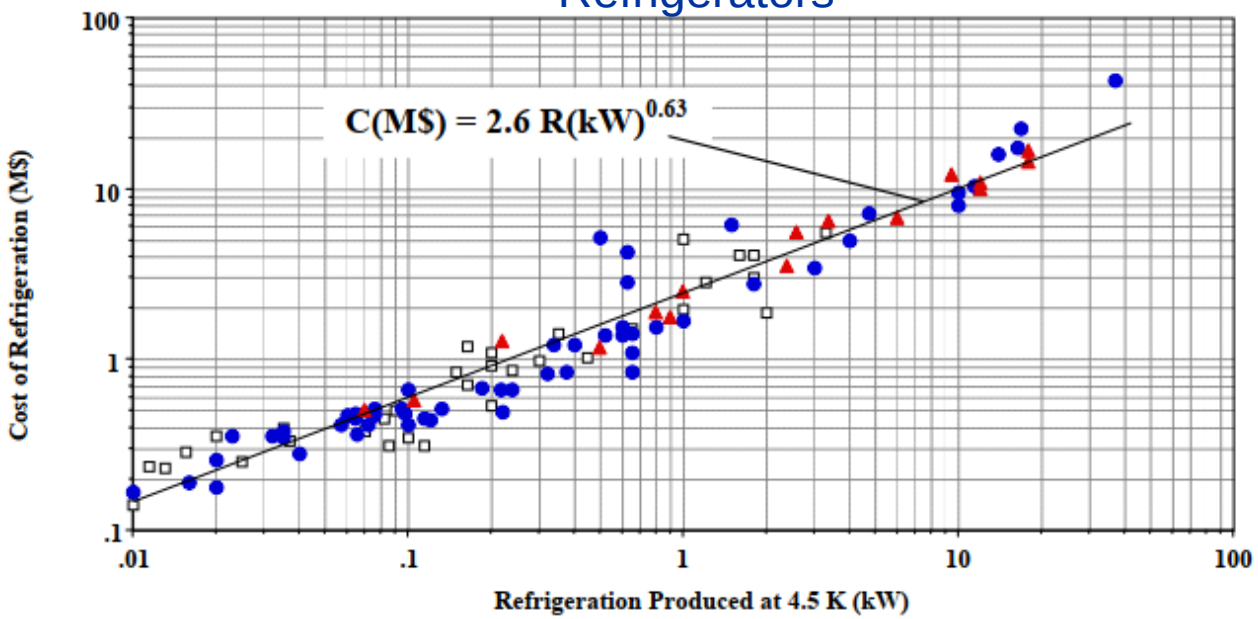
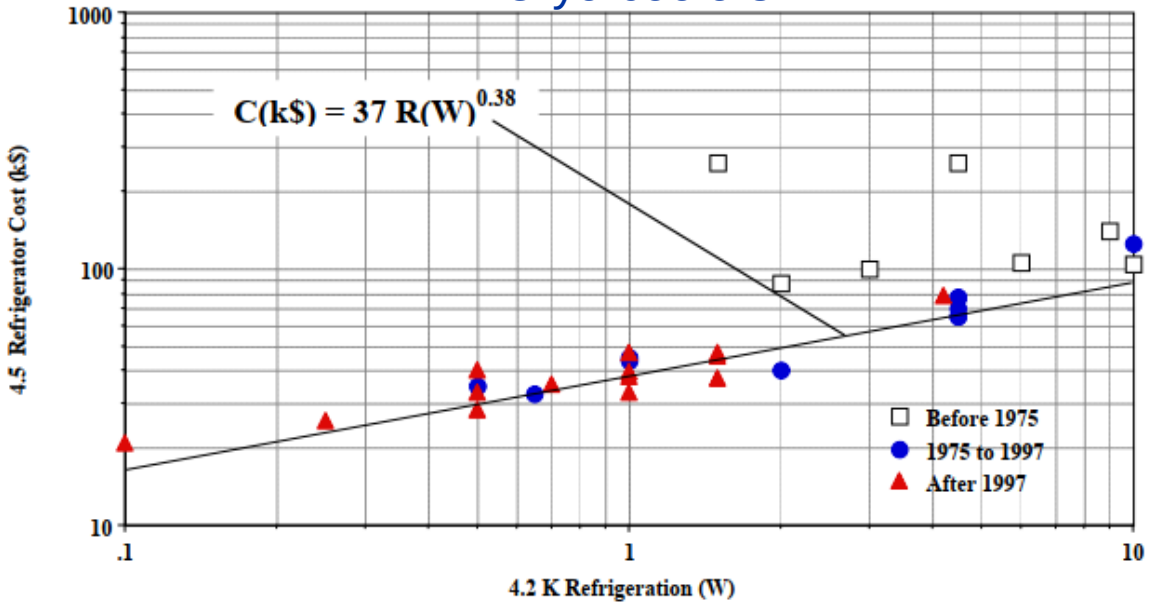
Refrigerators



Cryo-coolers



For our use the cost (investment) ratio of cryo-coolers wrt using a refrigerator is ~ < 50 %

So if cooling can share a refrigerator with the accelerator: → go for refrigerator
If cooling is to be uniquely for the Gantry: → go for cryo-coolers + HTS-leads