Short summary on the study of the ET Cryogenic Plant

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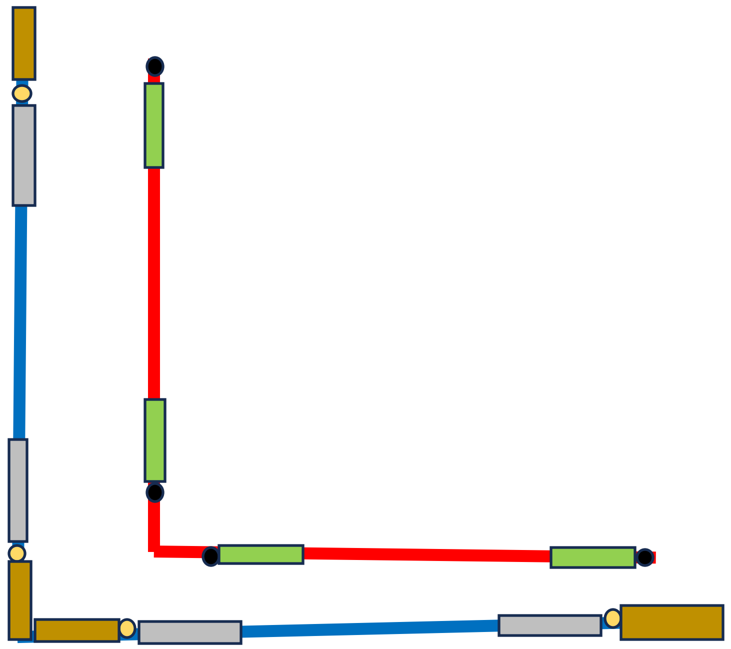
Task Force Meeting -- April 7, 2025

Cryogenics for the L shape configuration

At the L vertex n. 6 Cryopumps, 2 Cryostats
At each end n.3 Cryopumps, 1 Cryostat



n. 4 Cold test mass

n. 4 Hot test mass

n. 4 Cryopump of the Hot Interferometer

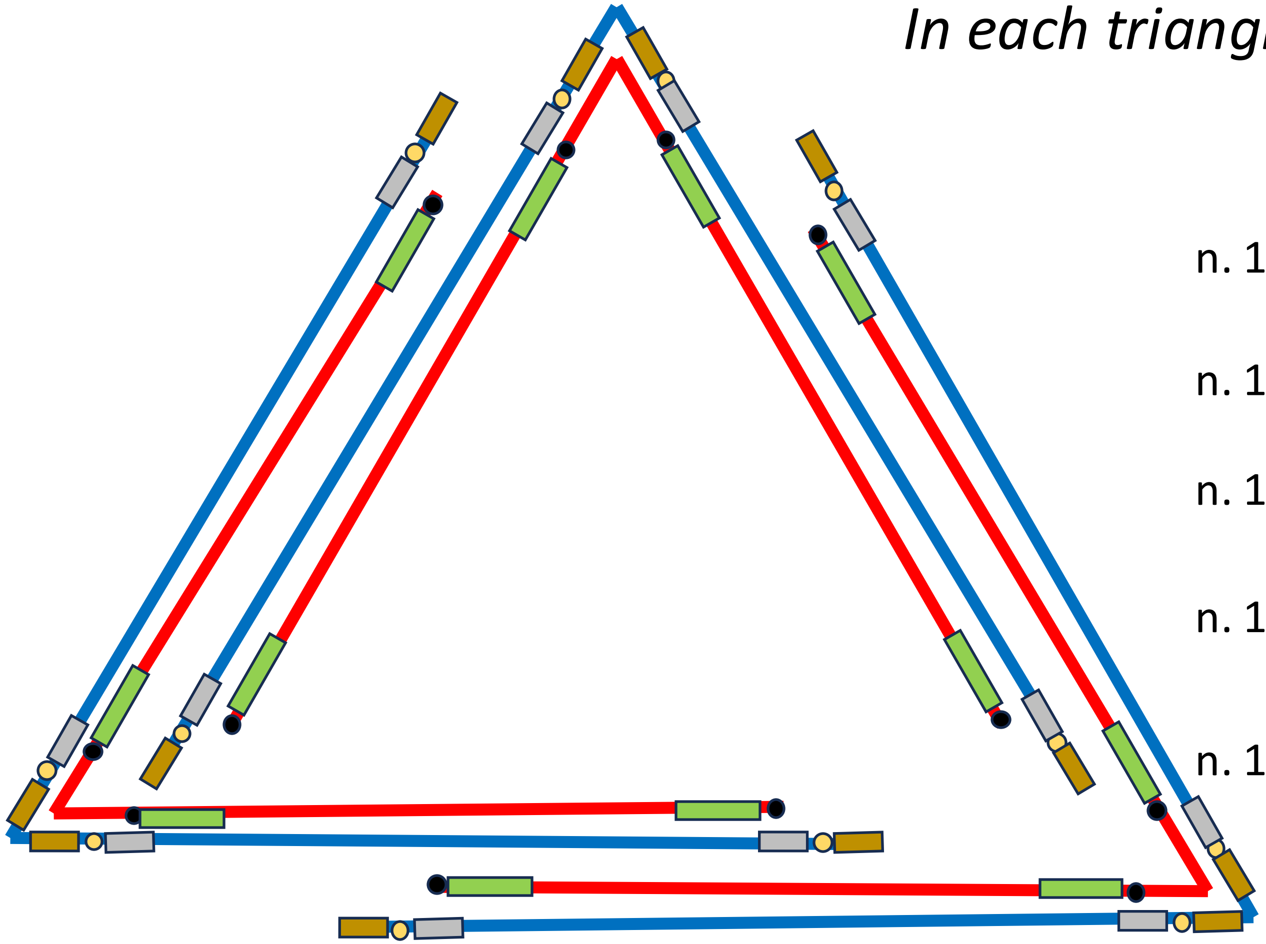
n. 4 Cryopump set in the front of the cold mirror:

n. 4 Cryopump at the back of the cold mirror:

Disclaimer: the inclusion in the project of addition cryopumps (shorter) is under study !!

Cryogenics for the triangular configuration

In each triangle vertex n. 12 Cryopumps, 4 Cryostats



n. 12 Cold test mass

n. 12 Hot test mass

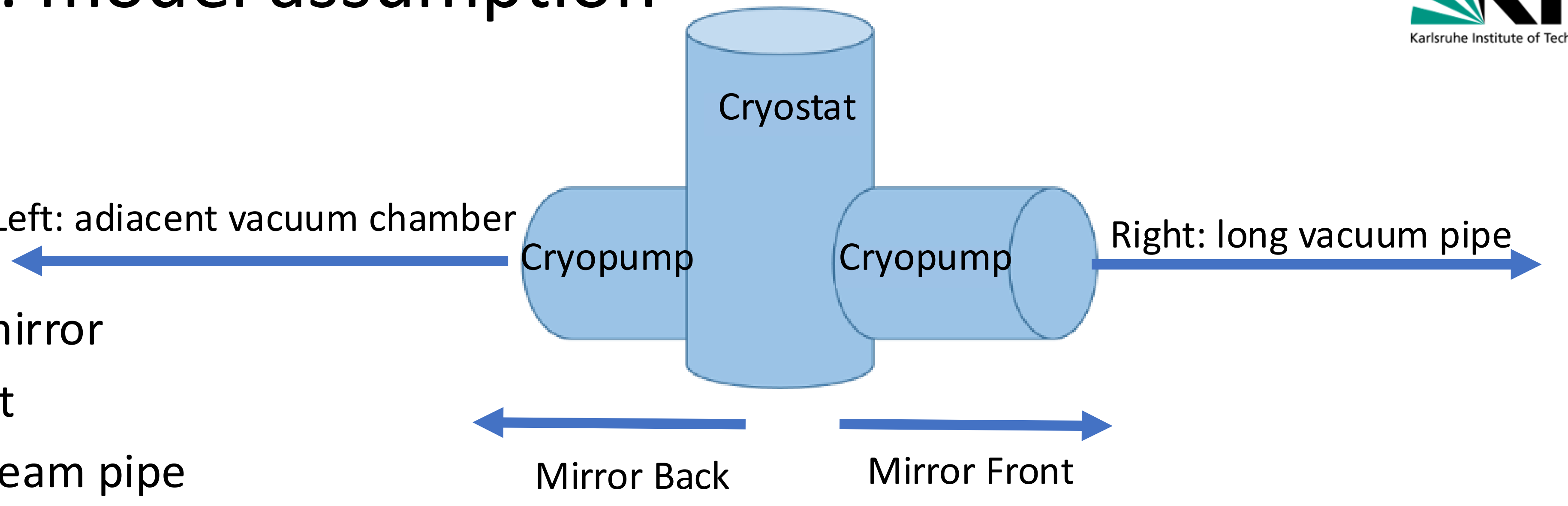
n. 12 Cryopump of the Hot Interferometer

n. 12 Cryopump set in the front of the cold mirror:

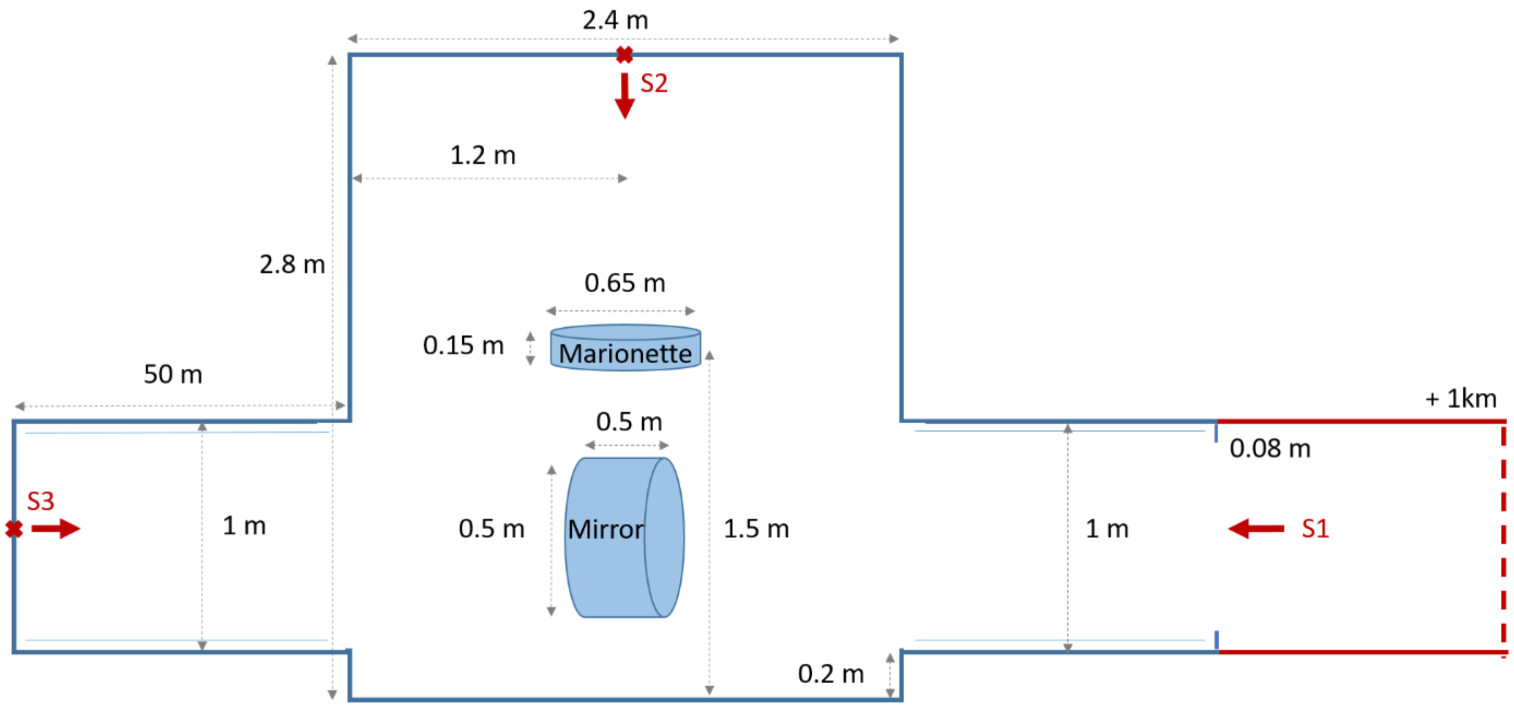
n. 12 Cryopump at the back of the cold mirror:

Disclaimer: the inclusion in the project of addition cryopumps (shorter) is under study !!

ET- LF vacuum: model assumption



- Cryostat with 10-20 K mirror
- Suspension not relevant
- S1: source by 1000 m beam pipe outgassing (right)
- S2: upper tower source (with developed pre-concept for semi-closure drastically reduced to $2 \cdot 10^{-9}$ Pa·m^3/s for H_2 and H_2O each)
- S3: adjacent tower source (10^{-7} and 10^{-6} Pa·m^3/s for H_2 and H_2O)



- First finding: beam pipe vacuum strongly decoupled

Credits S. Hanke

Montecarlo results for LF vacuum

- All gas sources managed for hydrogen and water (non-sticky and sticky ones)
- Cryopumps:

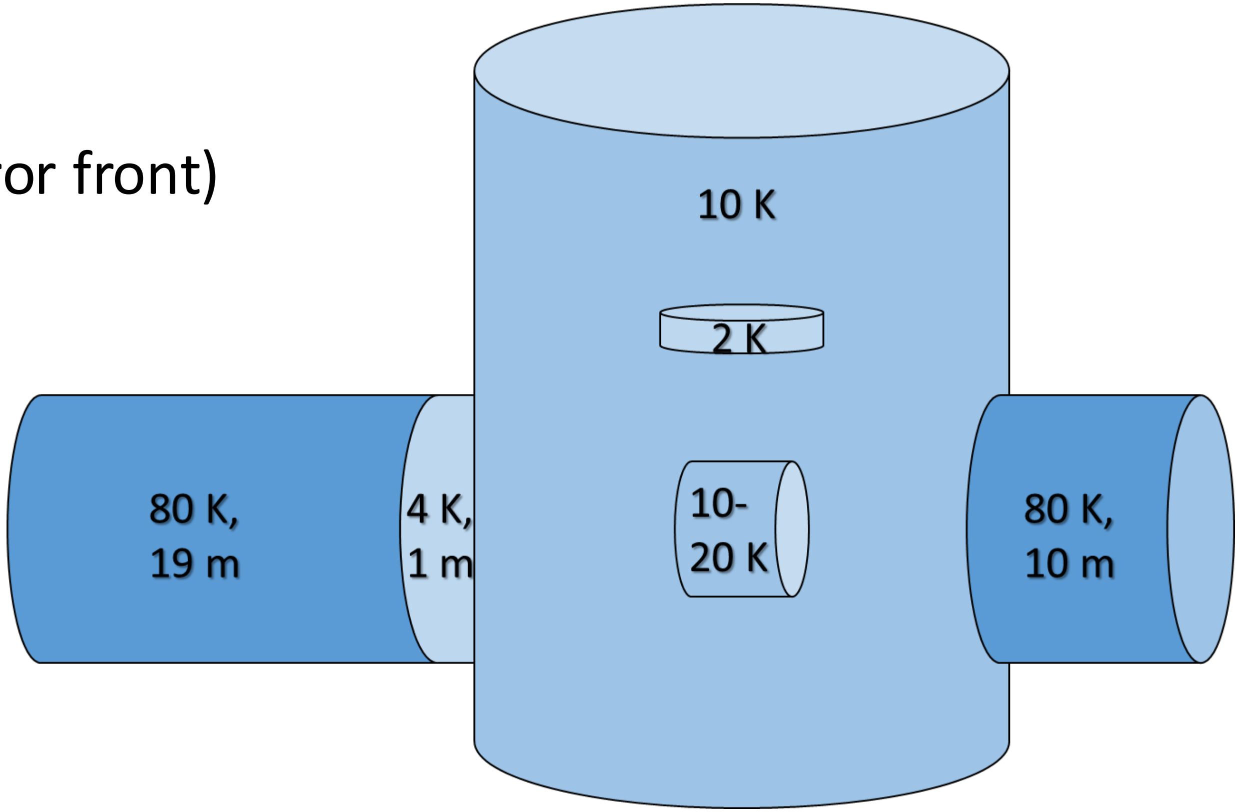
H_2O: 20 m left (Mirror back) + 10 m right (Mirror front)

H_2: 1 m left (Mirror back)

- **Pressure requirements fulfilled:**

H_2: $3 \cdot 10^{-11}$ Pa, H_2O: $1 \cdot 10^{-12}$ Pa

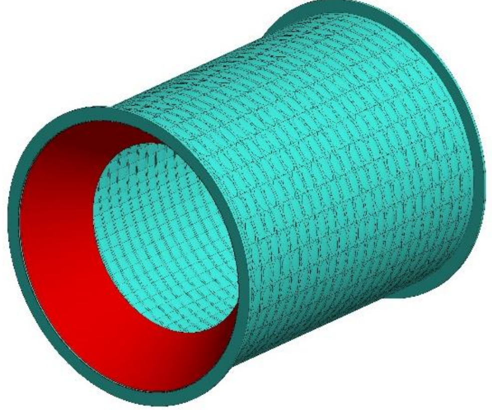
Water ice build-up ~2 years for 1 ML



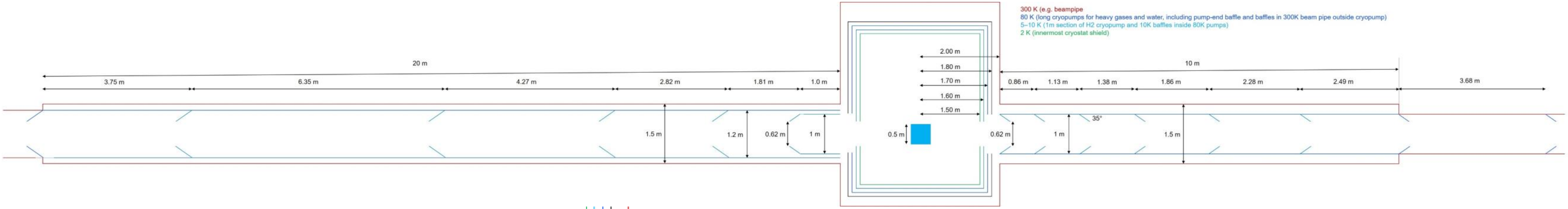
Credits S. Hanke

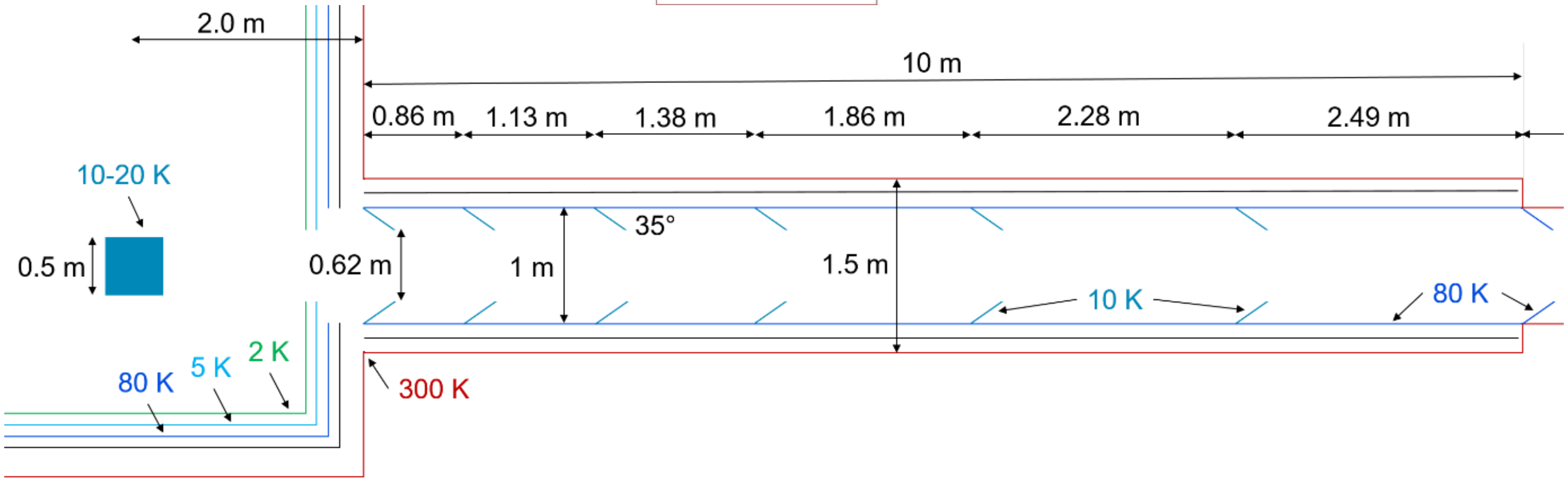
Heat load simulation

Cryopumps with baffles to avoid 80 K radiation onto 10 K mirror



Concept: Tubular cryopump segment with baffle





Credits S. Hanke

ET-LF: role of the 10 K baffles

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Disclaimer: Losses, thermal conductivity by supports and other details are not yet considered

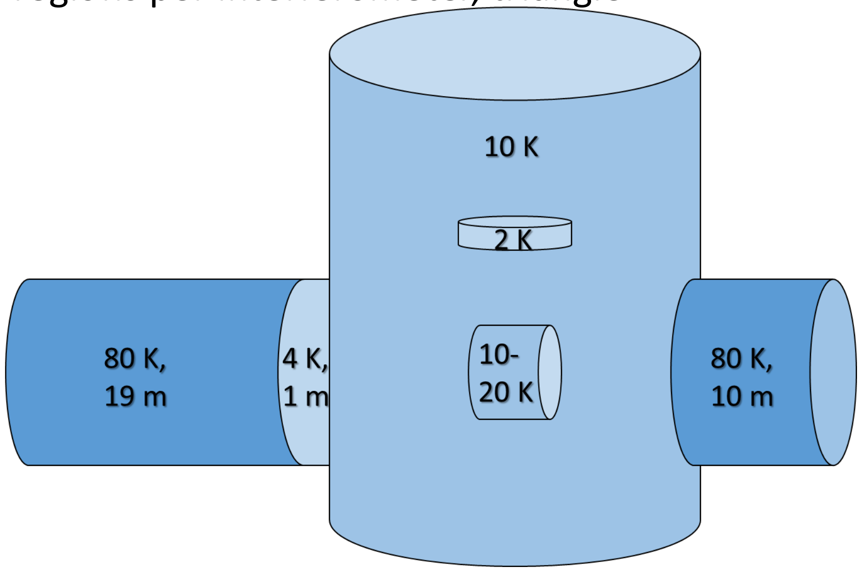
Mirror with1% emissivity (99% reflectivity)	80 K system	3.7 K system	10 K system	Mirror (10 K)	Cryostat (2 K)
System with10 K baffles in cryopumps	7.1 kW*	1.65 W	43 W	1.3 mW	263 mW
No baffles in cryopumps (80 K in simulation)	7.2 kW*	2.41 W	-	3.4 mW	892 mW
Total value for ET-LF with baffles**	~52 kW	20 W	516 W	-	3.2 W

Impact of 10 K baffles on mirror load: reduction by factor 2.6

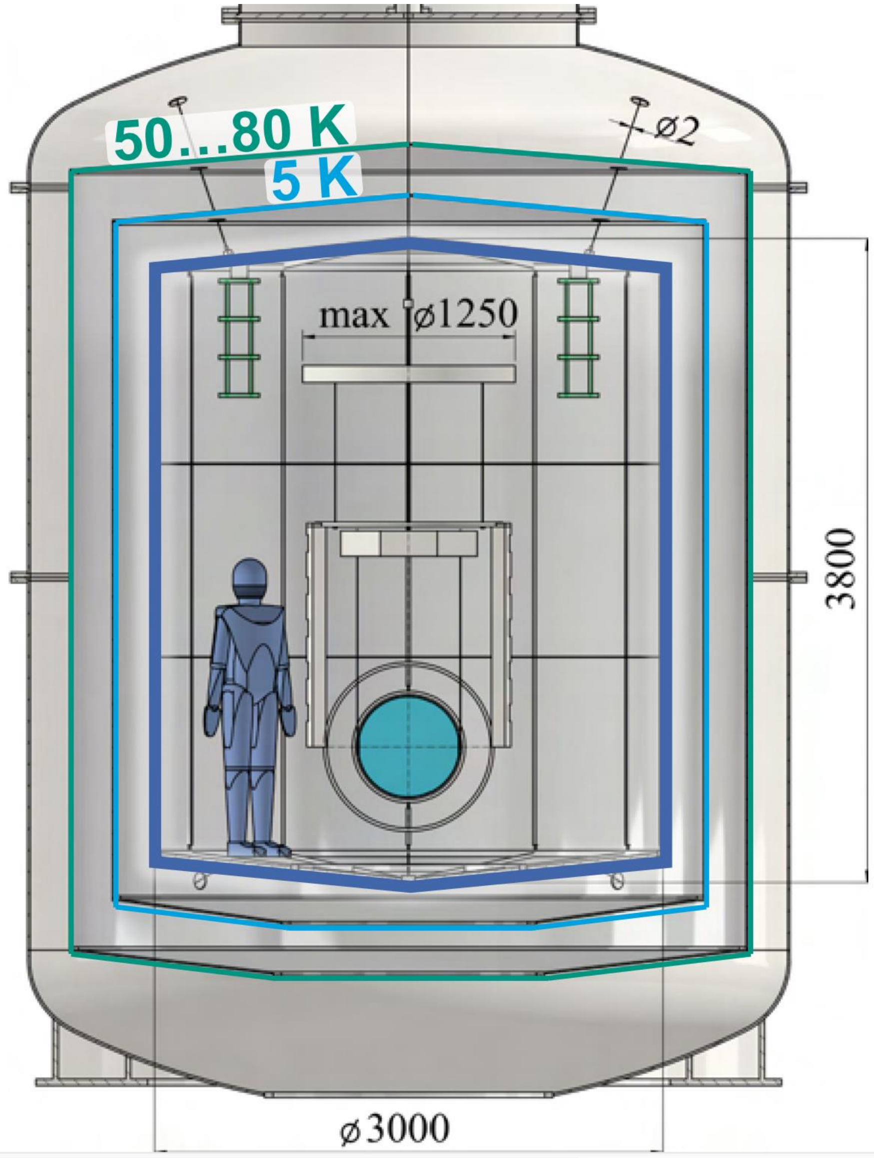
*more real values reduced to ~60% via passive shielding between cryopump and beam pipe (theoretical 50% reduction by one passive shield layer, plus margin)

For the entire ET instrument **factor 12 this value of the LF region simulated here (4 LF regions per interferometer, triangle configuration means 3 interferometer)

Thermal load on:	ε of mirror 0.01	ε of mirror 0.1	ε of mirror 0.3	ε of mirror 0.5
Mirror	1.3 mW	13 mW	37 mW	59 mW
Cryostat	262 mW	253 mW	232 mW	213 mW
3.7 K	1.65 W	1.65 W	1.65 W	1.65 W
10 K	43 W	43 W	43 W	43 W
80 K	7.1 kW	7.1 kW	7.1 kW	7.1 kW



The cryostat

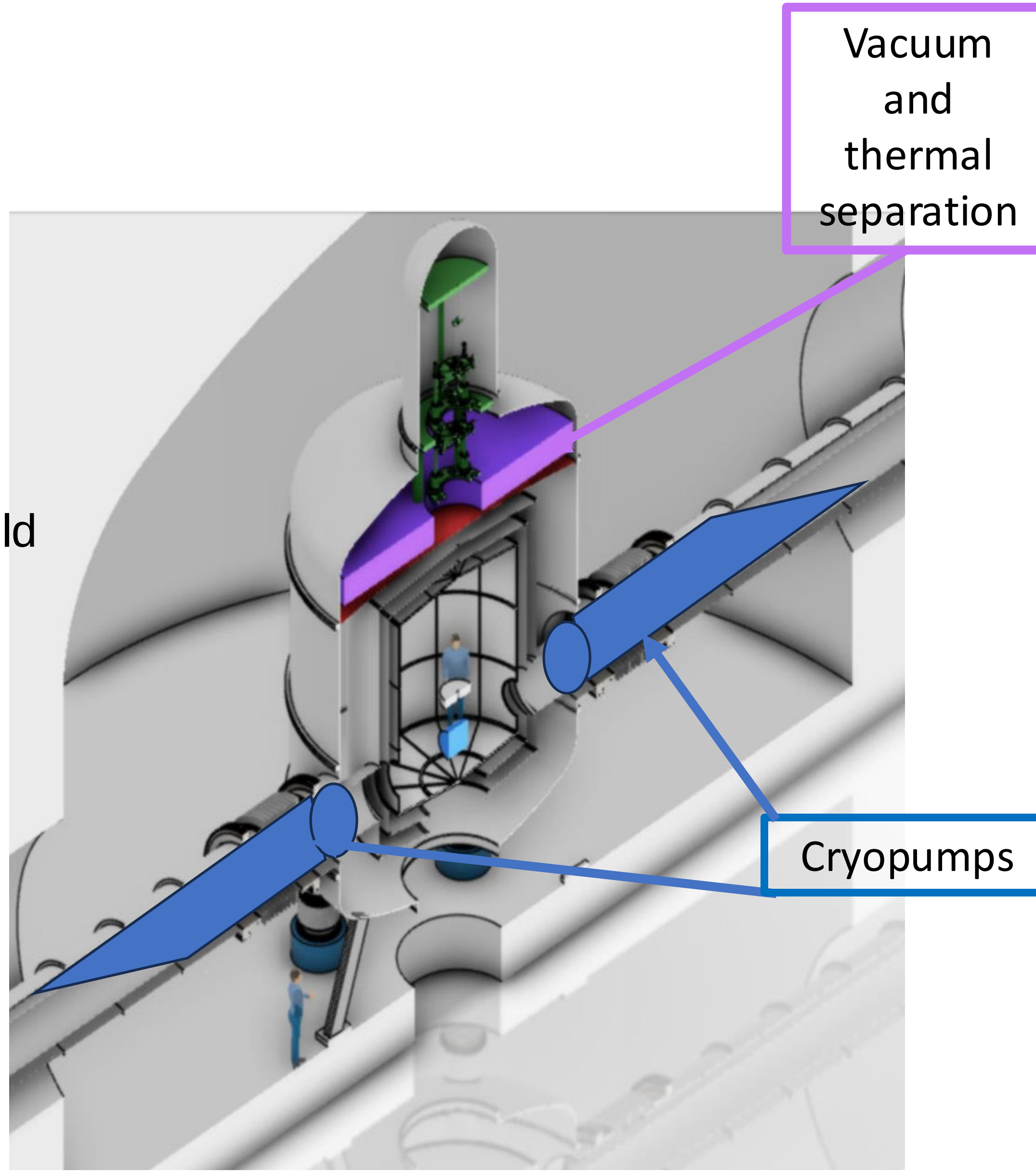


Key features of the cryostat

- Bottom access
- Several layers of thermal shielding
- Vacuum separation between the upper warm tower and the cold cryostat
- External dimensions

$\phi \approx 4.5$ m $h \approx 6.4$ m

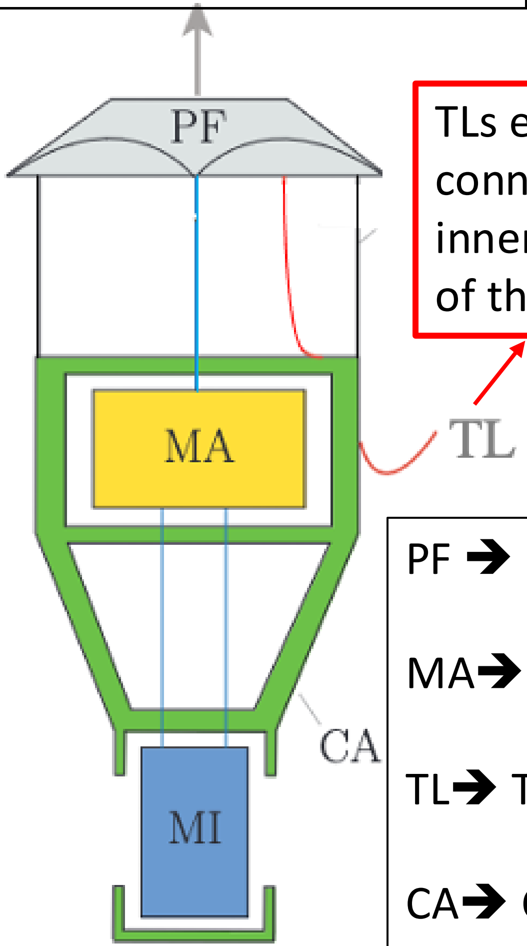
Innermost shield h=3.8 m , ϕ =3.0 m @ 2K
Payload 1250 mm height
Mirror 550 mm diameter
Cooling the shields
2 K ➔ He II
5 K ➔ He^4
50 - 80 K ➔ Helium Gas exchange
+ Extra shields to insure superinsulation



Mirror @10/20 K: thermal links, path of vibrations and additional dissipation

ET –LF Payload

To the superattenuator



TLs end thermally connected to the innermost shield of the cryostat

PF ➔ Platform

MA➔ Marionette

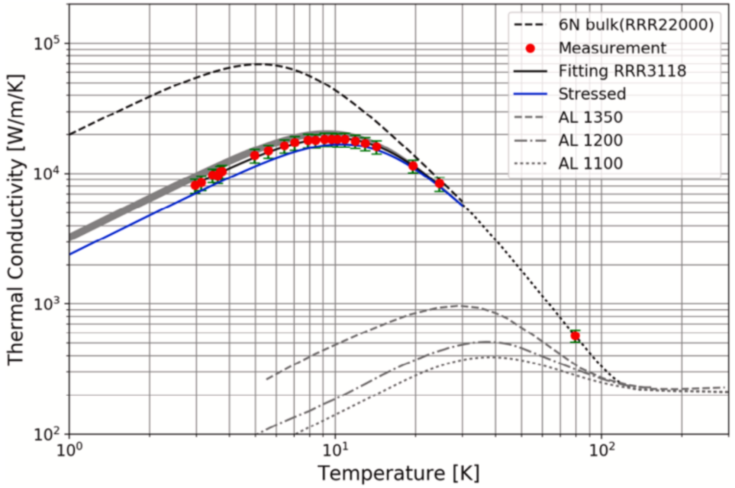
TL➔ Thermal links

CA➔ Cage

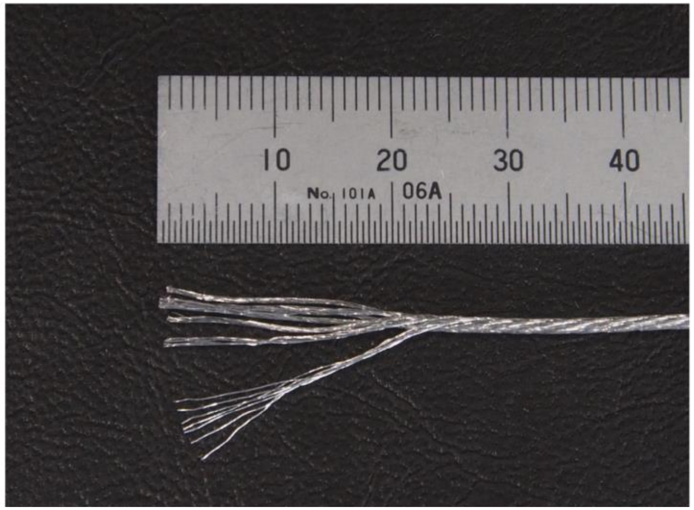
MI ➔ Mirror

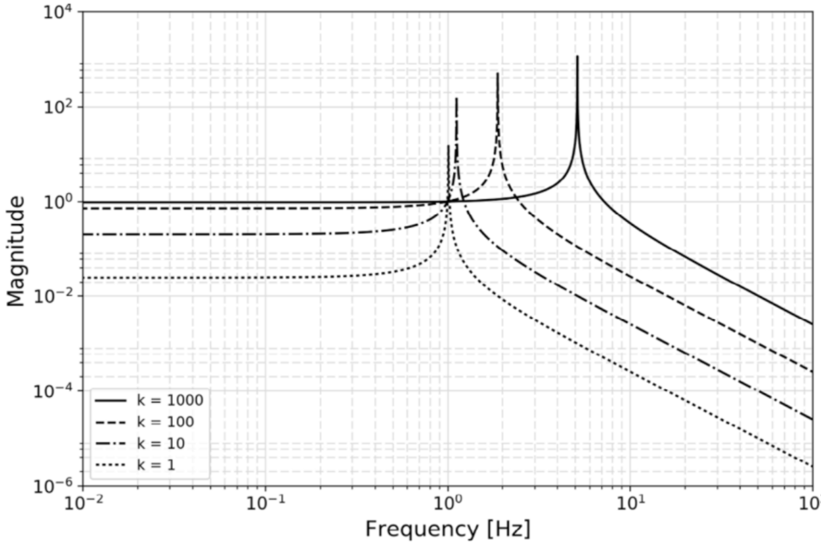
Tomohiro Yamada Et al.
Cryogenics Volume 116, June 2021, 103280

KAGRA study: stress changes the thermal conductivity

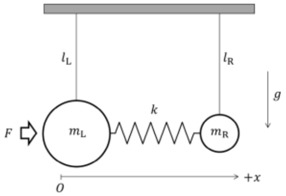


KAGRA:
TL anchored to vibration dampers set inside the innermost shield of the cryostat





TLs with smaller spring constant k to reduce overall vibration transfer.



Cryogenic Infrastructures

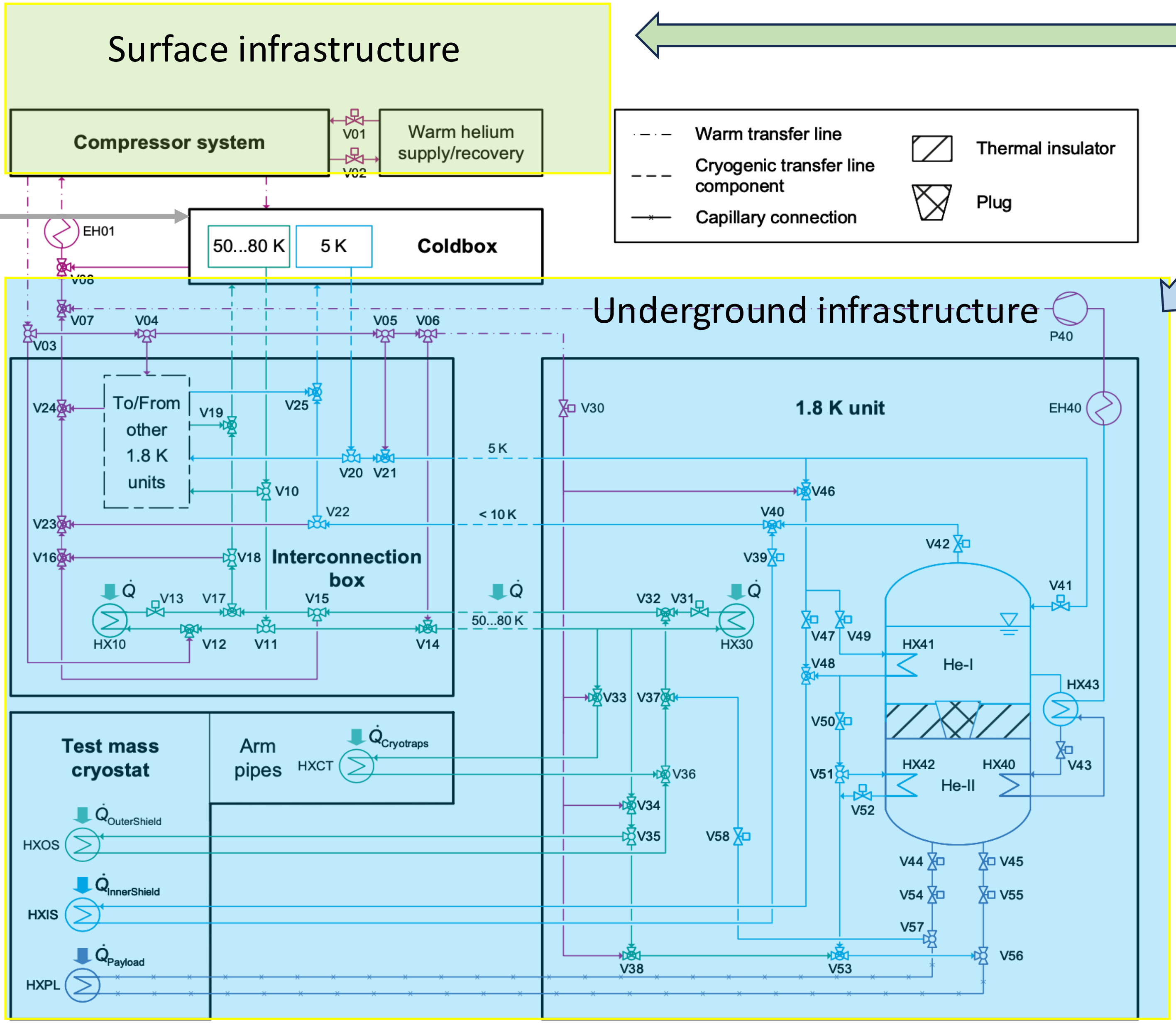
Baseline solution:
--Just 1 cryo-facility for each vertex based on the use of He fluid

Alternative approach
-- KAGRA solution considered

Cooling Infrastructure based on Cryogenic fluids

Lennard Busch, Steffen Grohmann - ET-0376A-2

Cold bx in an intermediate caverne: a noisy room



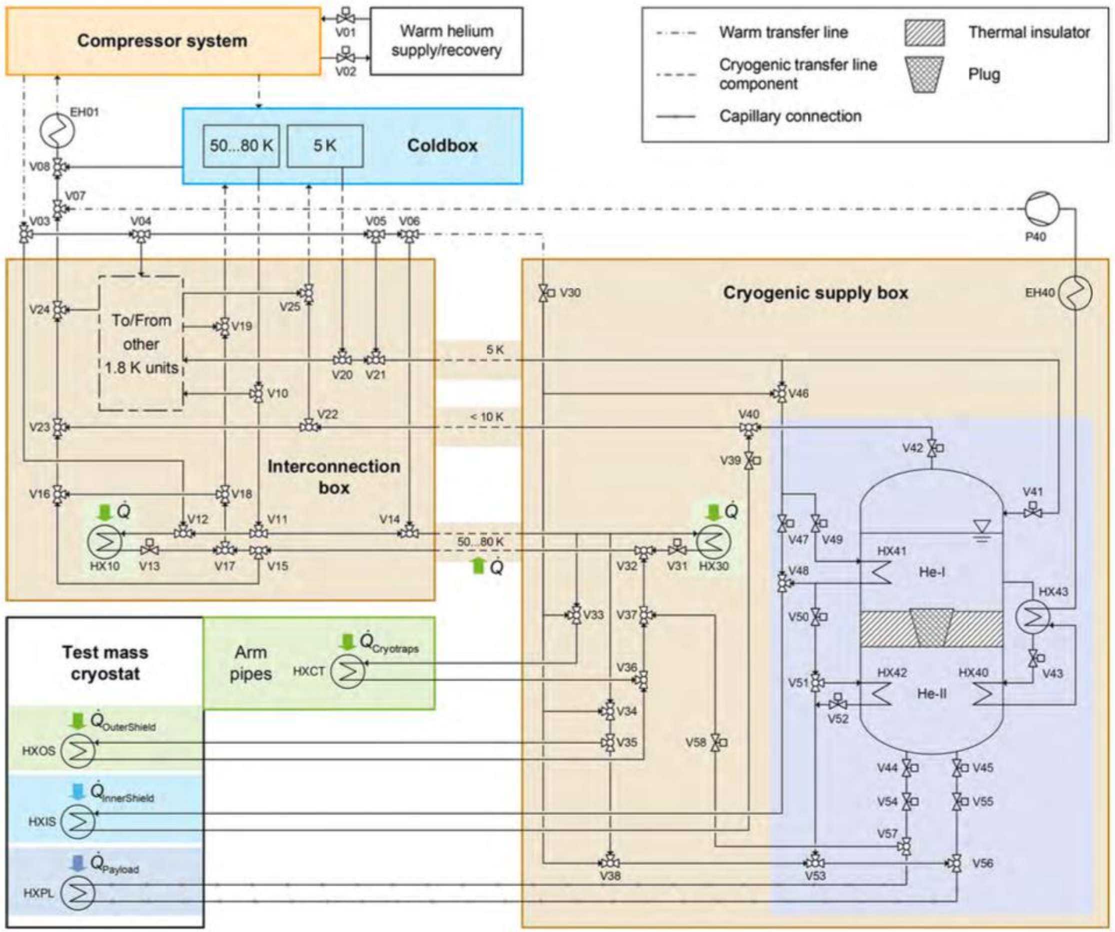
Noise generators:

Level of noise to be evaluated by measuring similar systems installed In HEP laboratories

IOP Conf. Series: Materials Science and Engineering 1240 (2022) 012095 doi:10.1088/1757-899X/1240/1/012095

[**] Busch L and Grohmann S, IOP Conf. Ser.: Mater. Sci. Eng. 1240(1) p. 012095, doi: 10.1088/1757-899x/1240/1/012095 (2022)

Cryogenic infrastructure concept [**]



- No underground LN2 (safety)
- One He refrigerator at each vertex
  - ➢ (Remote) surface compressors
  - ➢ Underground cold box
  - ➢ Interconnection box to several cryogenic supply boxes (1 for each tower/cryostat)
  - ➢ Up to c. 500 m long transfer lines
  - ➢ 1-phase cooling for 80 K cryopumps/ outer shields
  - ➢ 1-phase cooling for 10 K baffles, 5 K inner shields and 3.7 K cryopumps
  - ➢ He-II payload cooling/inner shield

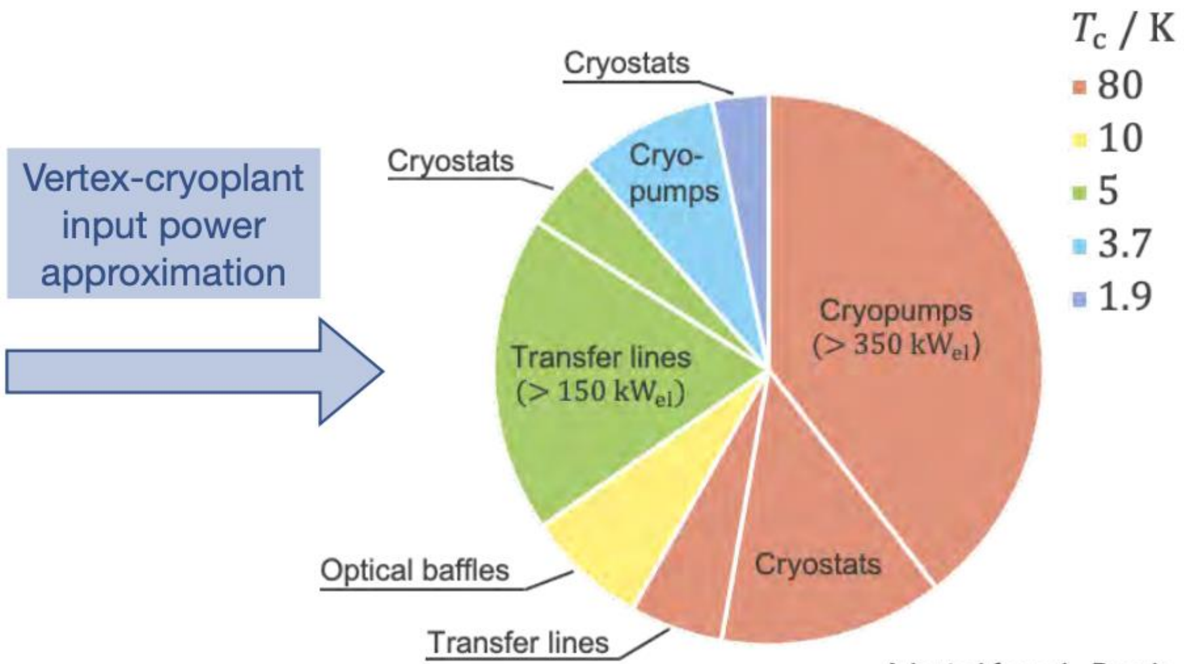
Credits : S. Grohmann

Summary for the civil infrastructure design

- Compressor hall on surface not far from the service pit of the each vertex: a mean size technical building (100/200 m^2 [??] equipped with a crane)
- Noisy room to host the old box (and other noisy devices even not related to cryogenics decoupled to the main cavern (50/100 m^2 , 6 m height)
- Interconnection box near the cryostat
- Transfer lines between noiy room and iterconnection box up to 500 m

He plant: rough evalution of the electric power request

In the case of the ET vertex in the triangular configuration



Adapted from: L. Busch, “Helium-based cryogenic infra-structure and payload cooling concepts for the Einstein Telescope”, Dissertation (in preparation)

Total: ~ 1 - 1.2 MW

Credits :
L. Busch, S. Grohmann

In the case of the L configuration these numbers must be divided

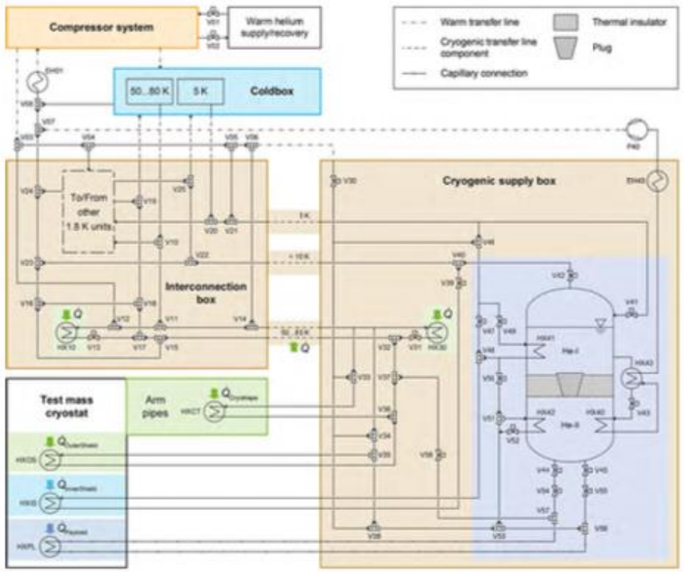
– by a factor 2 at the L vertex

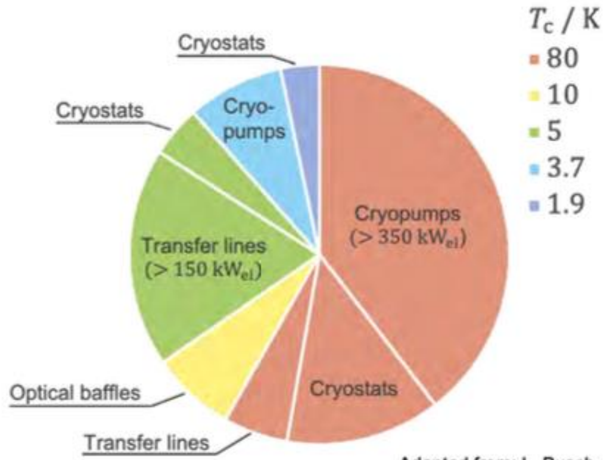
– by a factor 4 at the interferometer end

Total: ~ 500 – 600 kW

Total: ~ 250 – 300 kW

Cryogenic Infrastructure planning





Adapted from: L. Busch, "Helium-based cryogenic infrastructure and payload cooling concepts for the Einstein Telescope", Dissertation (in preparation)

Additional cryopump evaluation in progress !!

- CERN contract tb. discussed/initiated by Project Office
- Needed to coordinate industry design studies
  - ➢ Technical expertise, manpower ➔ Reliable cost estimates
- No resources in ISB Division IV !

Concept → **Update** → **CERN contract** → **Industry design studies** → **TDR**

KAGRA cooling trategy: PT Cryocoolers

Pulse Tube nominal performances - CRYOMEC

PT407 - 0.7 W@4.2 K -- 25 W @55K

+ compr. CPA 2870 ➔ 7 kW

PT410 - 1.0 W@ 4.2 K -- 40 W @ 45 K

+ compr. CPA 289 C ➔ 7.9 kW

PT420 – 2W@ 4.2k – 55 W @45 K

+ compr. CPA1114 – 11.4 kW

PT425 – 2.7W@4.2 K – 55W@45 K

+ compr. CPA1114 ➔12kW

PT450 -- 5 W @ 4.2K – 65 W@ 45 K

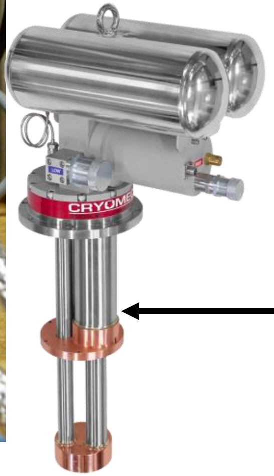
+ compr. CPA3027 ➔ 25 kW

$COP_r \sim 10^{-4}$@4 K ➔ $\sim 3 \times 10^{-3}$@50K

(COP_r - Coefficient Of $Performance_{refrigeration}$)

Compressor to be located in a noisy room

High pressure lines of He gas: maximum length 100 m



Cold head attached to the element to be cooled (cryostat or cryopump)

Civil Engineering Impact of the KAGRA cooling strategy

- A cryoplant based on PTs asks for more than a factor 10 of electric power
  - COP_r coefficient ➔ *~1x10^{-4} @ 4K* , lower than a LHe plant

    Example of COP_r of He plants: LR70 system of Linde Kryotechnik AG

    T < 4.4 K COP_r ~ 1.7 x10^{-3} (without LN_2 precooloing)

    T < 4.4 K COP_r ~ 2.5 x10^{-3} (with LN_2 precooling)

    Running cost of the electric power significantly higher

- Noisy room at 100 m distance of the main cavern

- High flow of refrigeration water to be provided in the noisy room

- Electric power to run the cryo facility to be provided underground: *higher fire harzard* ?