Preliminary studies of the MINERVA cryogenic supply system

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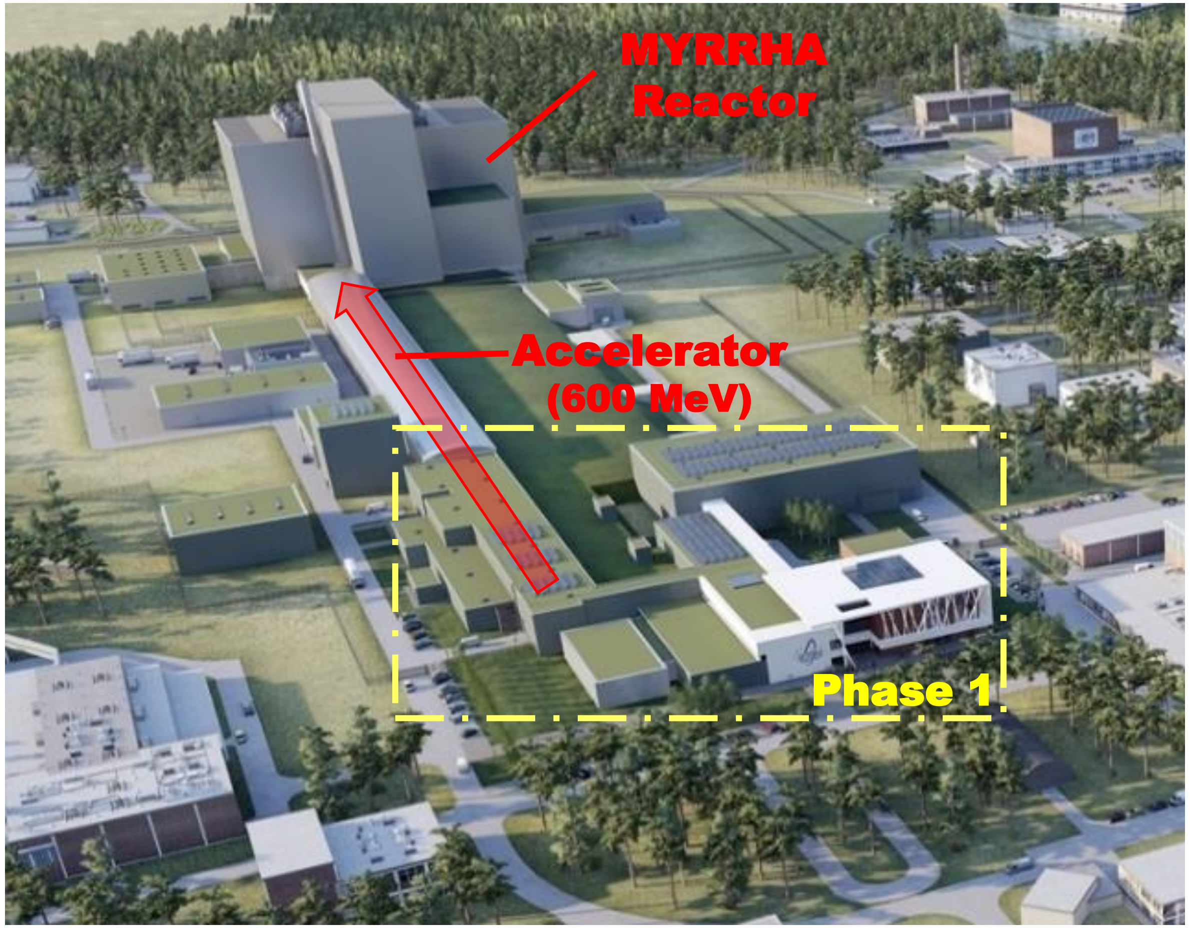
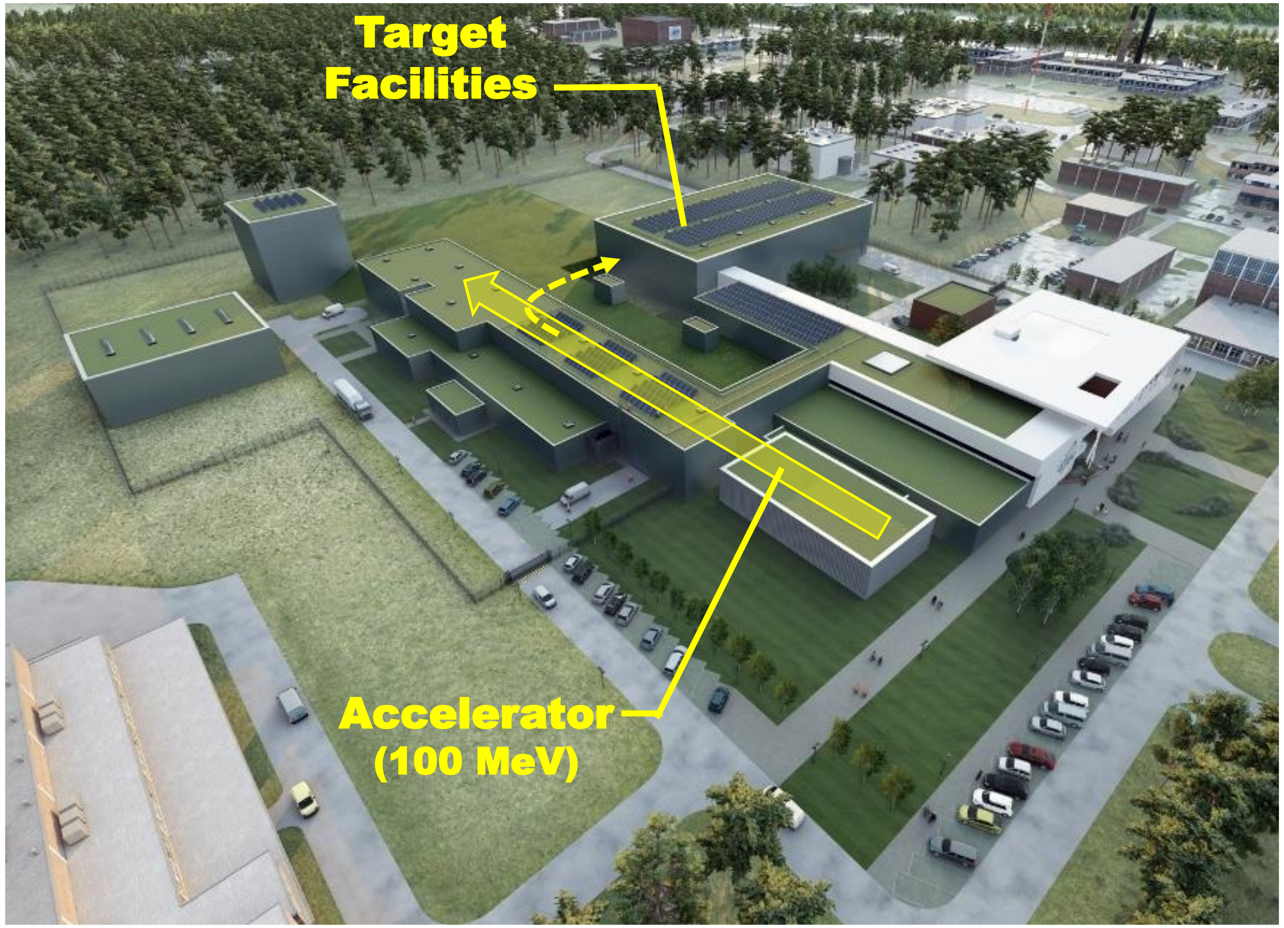
INTRODUCTION– MYRRHA – Phase 1 implementation (1/2)

MYRRHA (fully implemented)



MYRRHA Phase 1 (= MINERVA)



INTRODUCTION- MYRRHA – Phase 1 implementation (2/2)

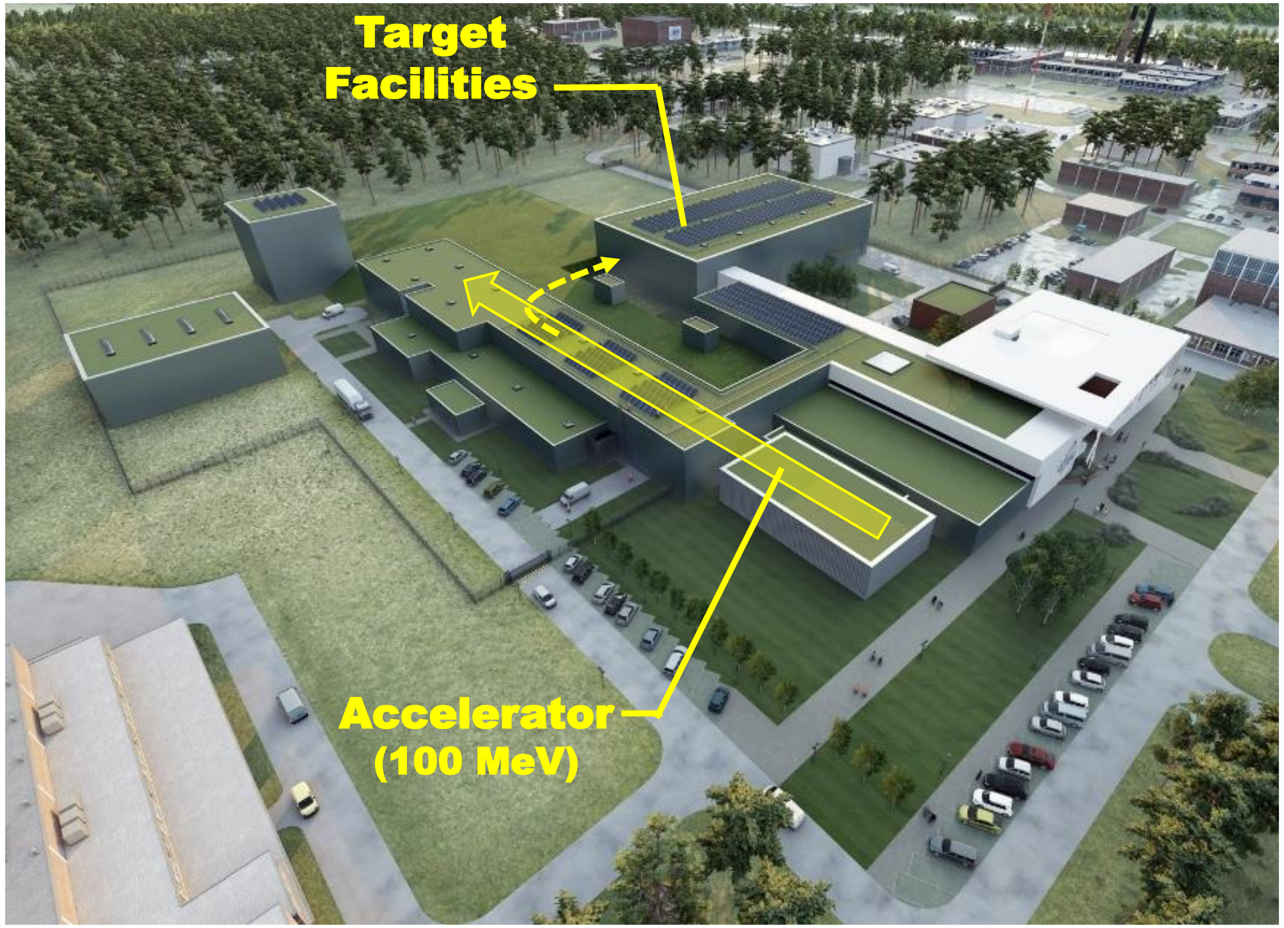
Objectives of MINERVA

- Demonstrate reliability as required for an Accelerator Driven System (ADS)
- In parallel, use of the proton beam for
  - Production of radio-isotopes
    - Fundamental research
    - Developing new medical isotopes
  - Material research for fusion applications

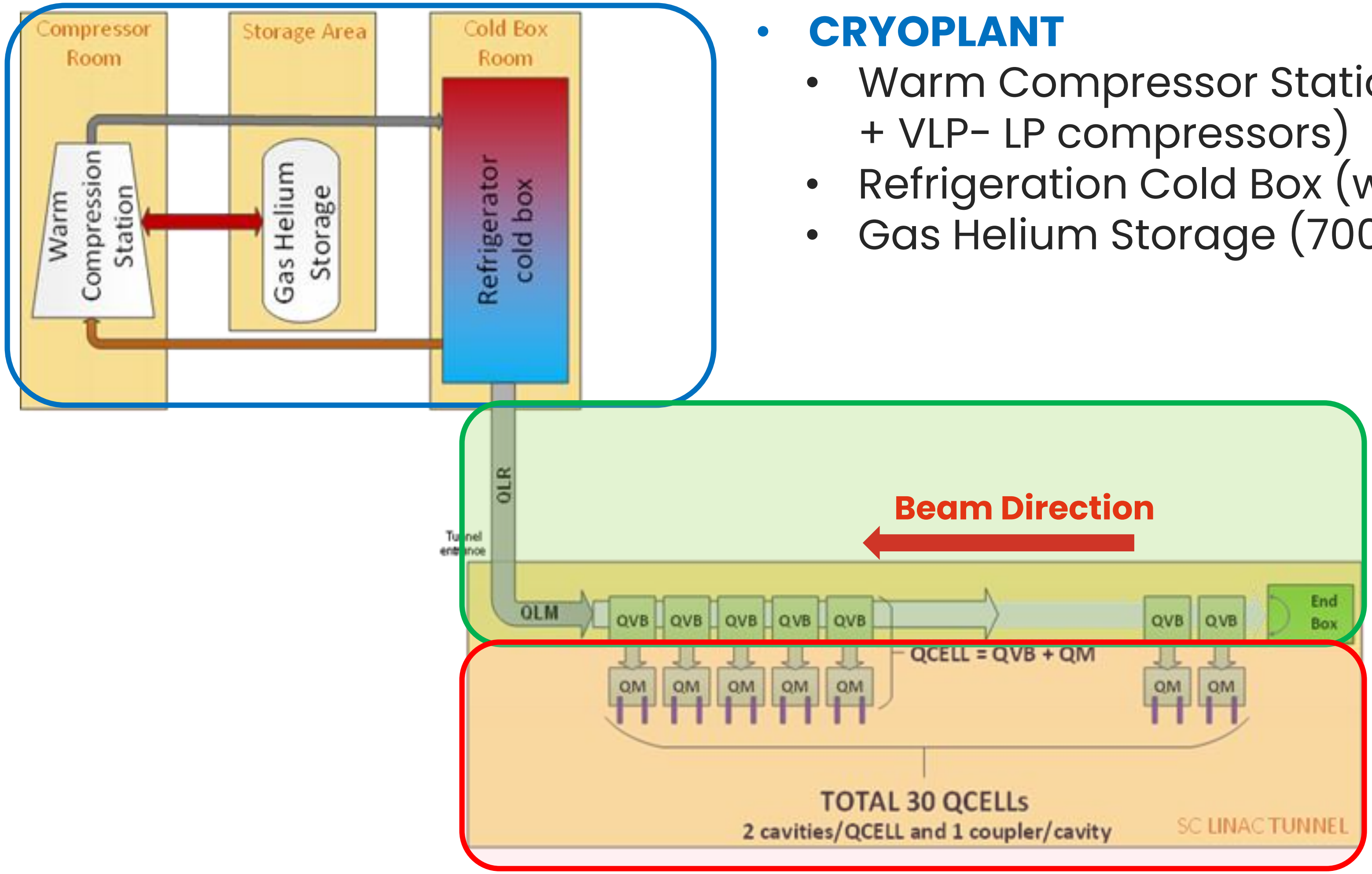
MINERVA Linear Accelerator

- 60 superconducting cavities in Nobium installed in 30 cryomodules.
- Cavities cooled at 2 K by saturated superfluid helium bathes.
- Length about 100 meters.

MYRRHA Phase 1 (= MINERVA)



MINERVA CRYOGENIC SYSTEM BLOC DIAGRAM



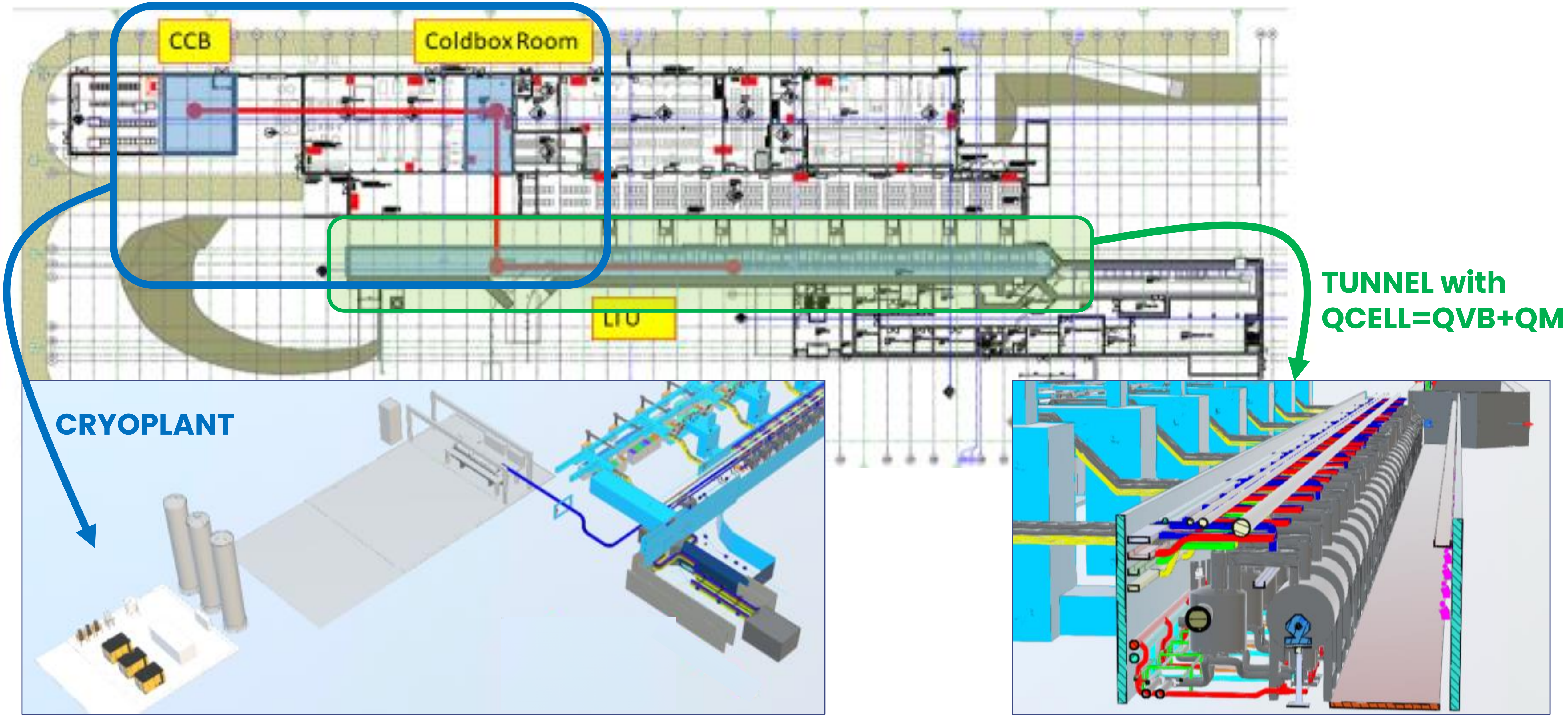
- **CRYOPLANT**
  - Warm Compressor Station (LP-HP compressors + VLP- LP compressors)
  - Refrigeration Cold Box (with Cold Compressors)
  - Gas Helium Storage (700 kg of helium to store)

- **CRYOGENIC DISTRIBUTION**
  - Cryogenic lines (QLR+QLM)
  - Cryogenic Valve Boxes* (QVB)
  - End Box (QVE)

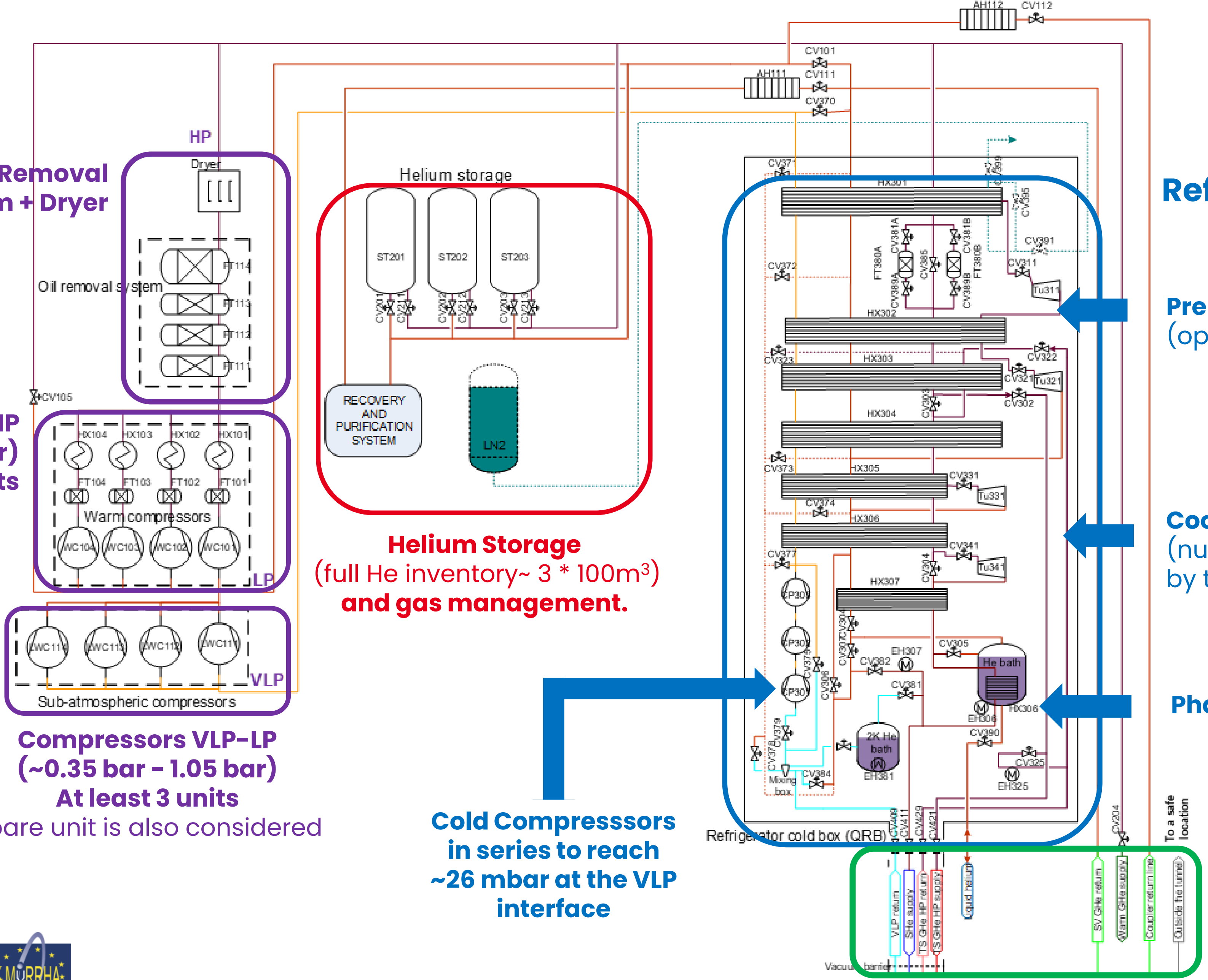
* QVB's operation is scope of the LINAC

- **CRYOGENIC USERS**
  - Cryomodules (QM), each with
    - 2x superconducting RF cavities submerged in a 2 K bath
    - 2x RF couplers at 5 K - 300 K
    - Thermal Shields at 40 K - 60 K

MINERVA CRYOGENIC SYSTEM OVERALL LAYOUT



THE CRYOGENIC PLANT FOR MINERVA



Oil Removal System + Dryer

Compressors LP-HP (1.05 bar- ~15 bar)
At least 3 units

Compressors VLP-LP (~0.35 bar - 1.05 bar)
At least 3 units
Spare unit is also considered

Helium Storage
(full He inventory~ 3 * 100m^3)
and gas management.

Cold Compresssors in series to reach ~26 mbar at the VLP interface

Refrigeration Cold Box

Pre-cooling 300K-80K: Turbine
(option LN2)

Cooling 80 K-5 K: Turbines
(number and arrangement to be defined by the croyplant supplier)

Phase separators at 4.5 K and 2 K

Interfaces with Cryodistribution
-4 Cryogenic lines
-4 Warm lines

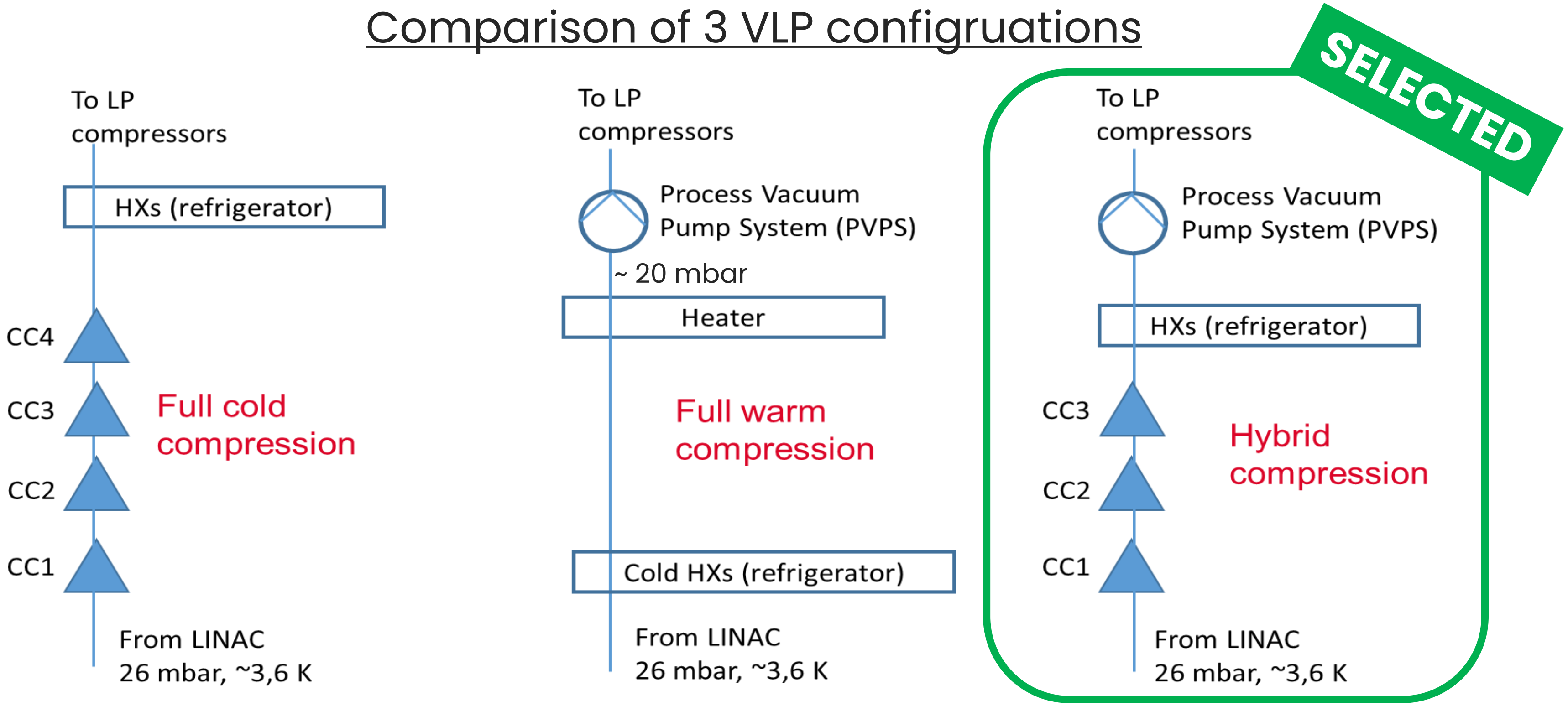
Michel et al., Preliminary studies of the MINERVA cryogenic supply system, CEC-ICMC 2023, Honolulu

THE SUB-ATMOSPHERIC COMPRESSION SELECTION

Comparison of 3 VLP configurations

Requirements:
- Suction pressure at **26 mbar** (~ 31 mbar required at cryomodules for 2 K bath)
- Max/Min mass flow **ratio ~ 3** (considers 2 K heat loads at different operational scenarios)

(Equipment cost is not discussed here)



Key aspects:			
Footprint	**Smallest** (no need of PVPS)	**Largest** (due to large PVPS)	**Intermediate** (requires smaller PVPS)
Expected electrical consumption (for compressors)	**~ 0.9 MW**	**~ 1.9 MW** (difficult enthalpy recovery)	**~ 0.9 MW**
Flexibility of operation for large mass flow ratios	**Least flexible** (limited by narrow operation range of the CC train)	**Flexible** (thanks to wide operation range of PVPS)	**Flexible** (combines avantages of both methods.)

THE OPERATION MODES (1/2)

- **Steady-state modes:**

Main steady-state modes	LINAC configuration	Heat loads and margins
2 K nominal mode (**Max** Design Mode)	For 30 cryomodules	Static + Dynamic (includes margins)
2 K stand-by mode (**Min** Design Mode)	For 24* cryomodules	Static only (without margin)

* Minimal staged installation (hypothetical)

Note:
Dynamic heat loads correspond to RF and resistive losses at cavities and power couplers.

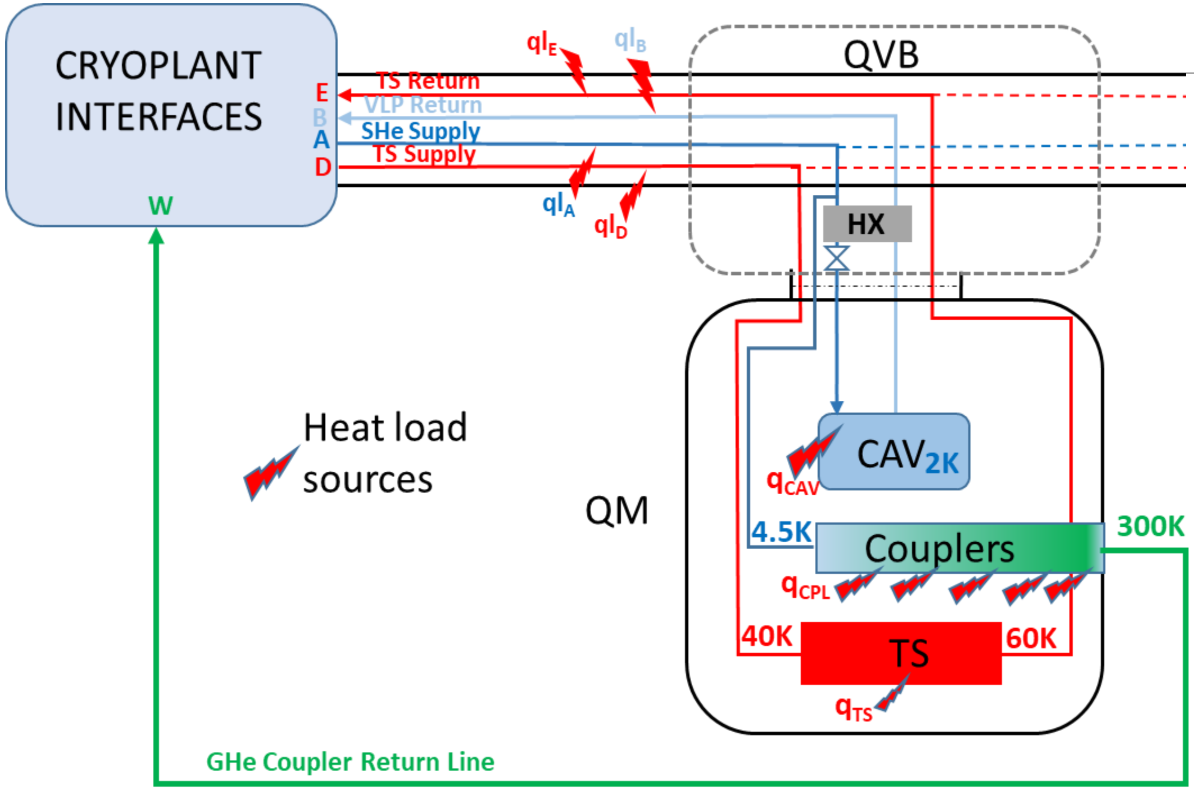
THE OPERATION MODES (2/2)

- **Transient modes**
  - Considers 11 Tons of cold masses (<5 K), 10 Tons at TS temperature (40 K-60 K), and a speed average for cool-down/warm-up of 4 K/h.

  - **Cool-down** (Total duration of 5 days, including 3 days to reach 4.5 K)
    - Cool-down 300 K to 50 K.
      Refrigeration power from ~ 13 kW@300 K to 10 kW@50 K, peak value ~ 17 kW@200-150 K.
    - Cool-down from 50 K to 4.5 K.
      Refrigeration power on the TS ~ 8.5 kW and on the colder masses from 1.2 kW at 50 K to ~ 650W below 30 K.
    - Liquid Helium filling: ~ 2800 liters of liquid helium in cryomodules.
    - 2 K stage: Cool-down of 2 K cavity circuits (starts of VLP compressors)

  - **Warm-up** (Main expected phases)
    - Warm-up to 4.5 K: Stop of the Very Low Pressure Compressors
    - Evaporation of the Liquid helium baths
    - Warm-up from 4.5 K to 300 K (speed average of 4 K/h)

HEAT LOAD REQUIREMENTS FOR MINERVA CRYOPLANT



30 QCELLs installed in parallel along the Cryogenic Manifold

Main Heat load sources

- Cryomodules
  SRF cavities (CAV), RF power couplers, thermal shields
- Cryogenic Lines

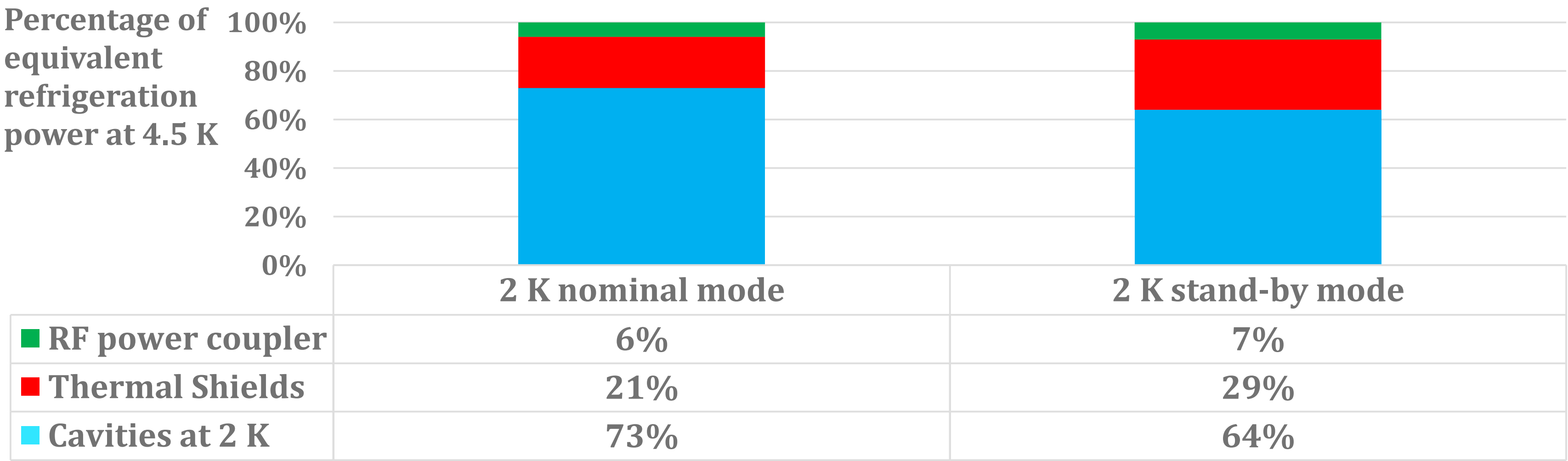
Operating condition at Cryoplant interfaces:

	Mode	Interface A SHe Supply DN 25	Interface B VLP Return DN 150	Interface W GHe Return DN 32	Interface D TS Supply DN 40	Interface E TS Return DN 40
Pressure (bar)	2 K nominal mode 2 K standby mode	~ 3	0.026 0.029	1.05	~ 14	~13
Temperature (K)	2 K nominal mode 2 K standby mode	4.5	3.5 3.8	300	40	60
Mass Flow rate (g/s)	2 K nominal mode 2 K standby mode	47 18	45 17	2 1	80 48	80 48

HEAT LOAD REQUIREMENTS FOR MINERVA CRYOPLANT

Mode	Isothermal Heat Loads (W)	Non-Isothermal Heat Loads (W)				Equivalent Refrigeration Power
	Bath at 2 K	VLP Return Line	SHe Supply Line	**TS (40-60 K)**	**Couplers 5K-300 K (g/s)**	@4.5K (W)
2 K nominal mode	**890**	35	11	**8500**	**2**	3430
2 K stand-by mode	**330**	25	8	**5070**	**1**	1490

Allocation of refrigeration power per operation mode



	2 K nominal mode	2 K stand-by mode
🟩 RF power coupler	6%	7%
🟥 Thermal Shields	21%	29%
🟦 Cavities at 2 K	73%	64%

SPECIFIC REQUIREMENTS FOR MINERVA CRYOPLANT

Key operational requirements

- High operational reliability with a limitation of thermal cycles (full warm-up every 5 years)

To improve the cryoplant availability the following specifications are considered:

1. Number of compressor units: **≥ 3 for LP-HP compressors**
   Allows reduced operation even in case of failure or maintenance on one unit.
2. VLP configuration: **Hybrid VLP Compression**
   For cold compressors, **magnetic bearings** are required for high reliability.
   For VLP-LP compressors, **≥ 3 units + additional unit** is also under consideration.
3. Maintenance and repair strategy: **Preventive maintenance and spare-part policy**
   Strategy to consider preventive maintenance and on site capital and operational spare parts to allow maintenances and repairs.
4. Helium storage: **Full inventory on site** (incl. +20 % margin to cover for leaks)
   To mitigate risks related to helium supply chain.

Conclusion

- The installation of the MINERVA Cryogenic Supply System is set for 2027 at the SCK-CEN site in Mol, Belgium.
- The cryogenic users and the main cryogenic requirements are defined.
  - For the cryoplant, the required total refrigeration power at 4.5K is **approximately 3.5 KW**.
  - The 60 superconducting cavities contribute, with **900 W @ 2 K,** to **70%** of the total heat loads.
  - An **hybrid sub-atmospheric compression** has been selected for its efficiency and flexibility in covering nominal and stand-by modes.
  - The study results were consolidated using **two industrial pre-studies** performed by Linde Kryotechnik and Air Liquide Advanced Technologies.
- The technical specifications for the Cryoplant are under preparation; the launch of the **tendering phase is projected by end of 2023**.

References and Acknowledgments

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Acknowledgments

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