Status of the MINERVA cryomodules and associated cryogenic system
(MYRRHA Phase 1)

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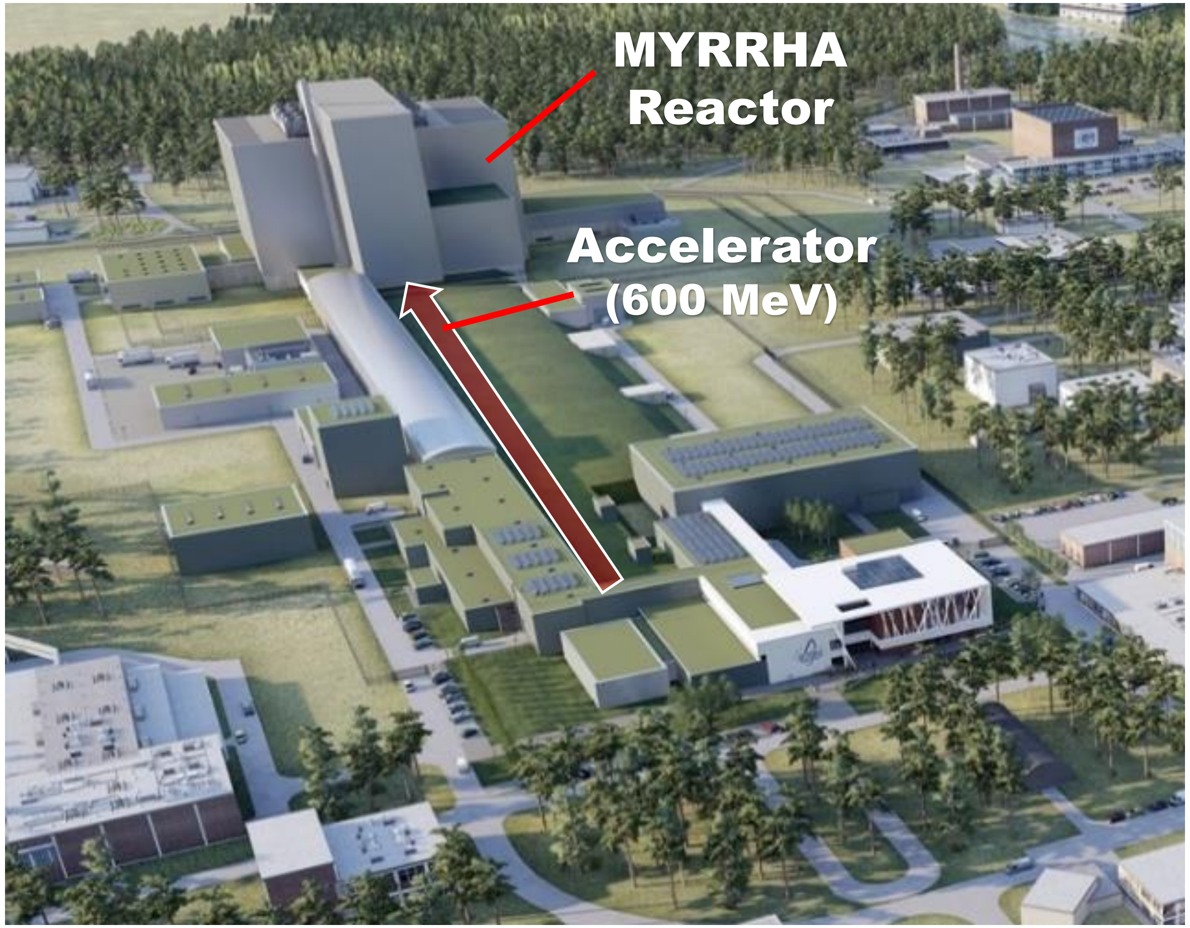
MYRRHA

11 JUL 2023

MINERVA, the 1st phase of MYRRHA

MYRRHA (fully implemented)



MYRRHA, a **M**ultipurpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications

- MYRRHA is an **A**ccelerator **D**riven **S**ystem (ADS)
  - A full ADS demo facility at pre-industrial scale, where a "subcritical" reactor core is coupled to a proton accelerator.
  - The particle beam is needed to sustain the nuclear reaction.

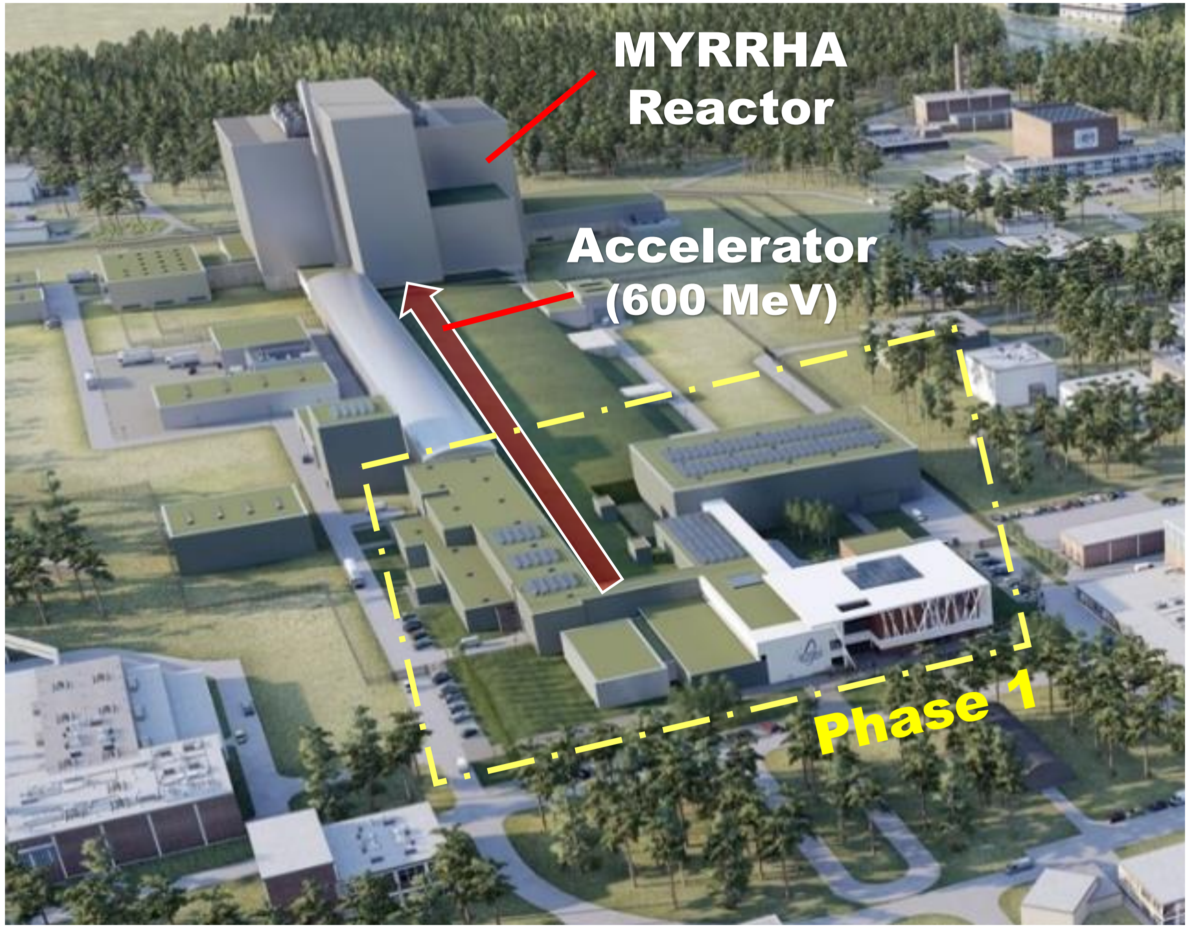
Why MYRRHA?

➢ **Nuclear waste treatment**

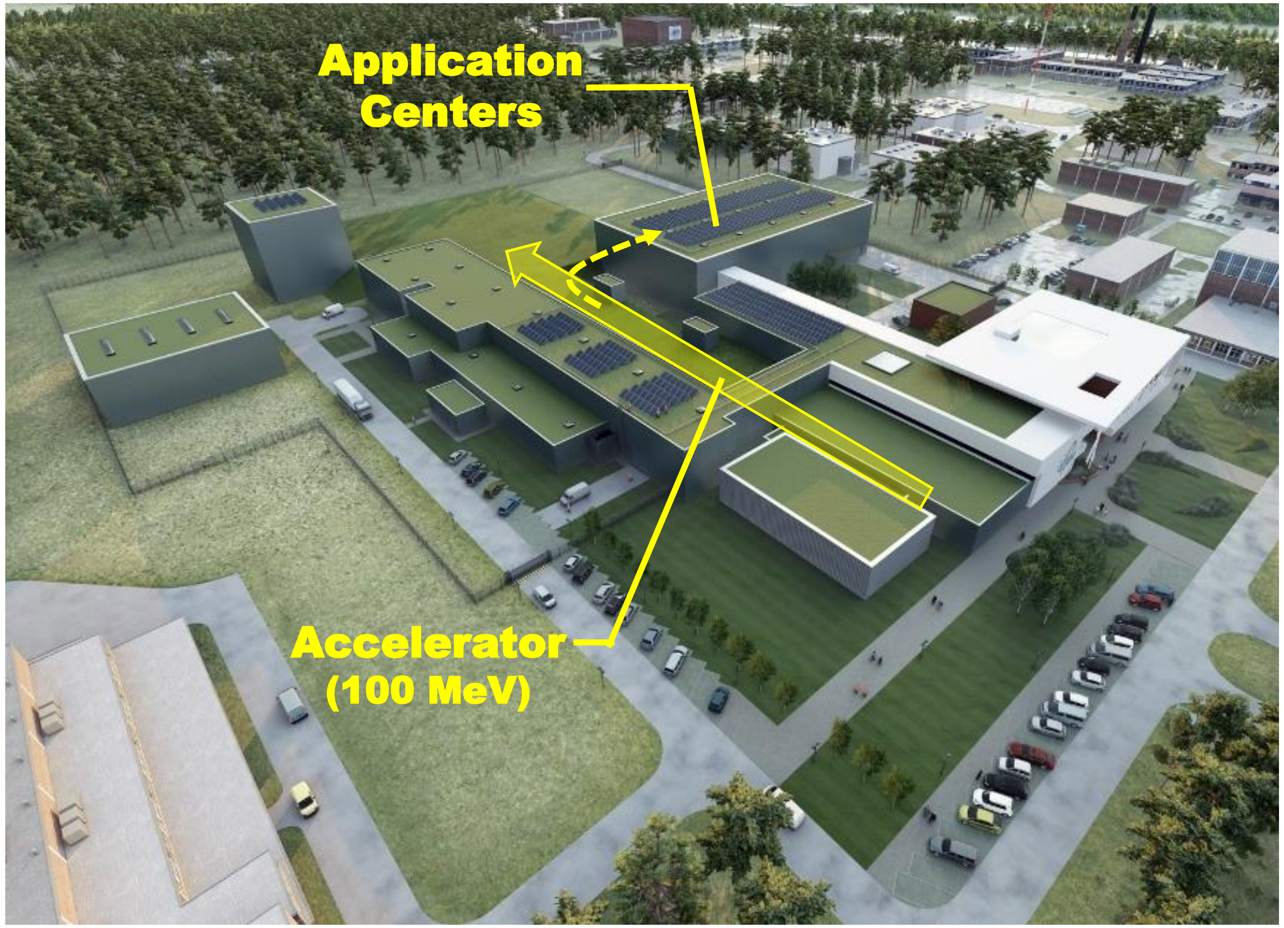
- Allow for **Partitioning & Transmutation** of nuclear waste in order to reduce its radio-toxicity.
- Reduction of 100x in volume and 1000x in duration.

MINERVA, the 1st phase of MYRRHA

MYRRHA (fully implemented)

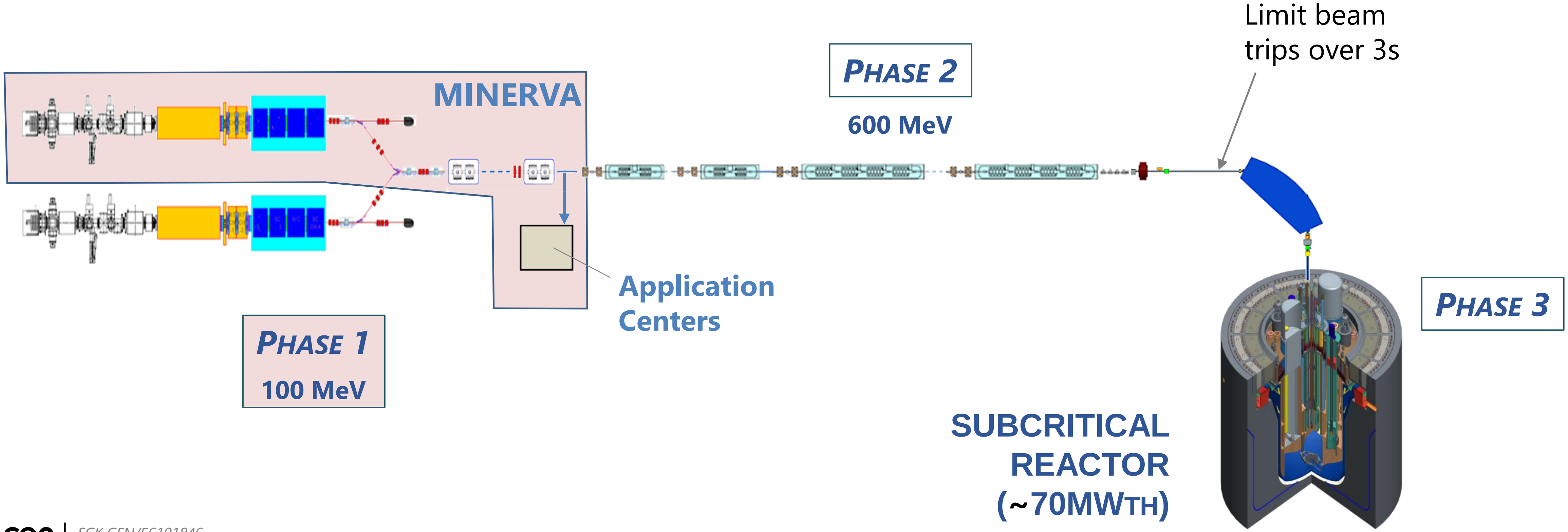


MINERVA (MYRRHA Phase 1)

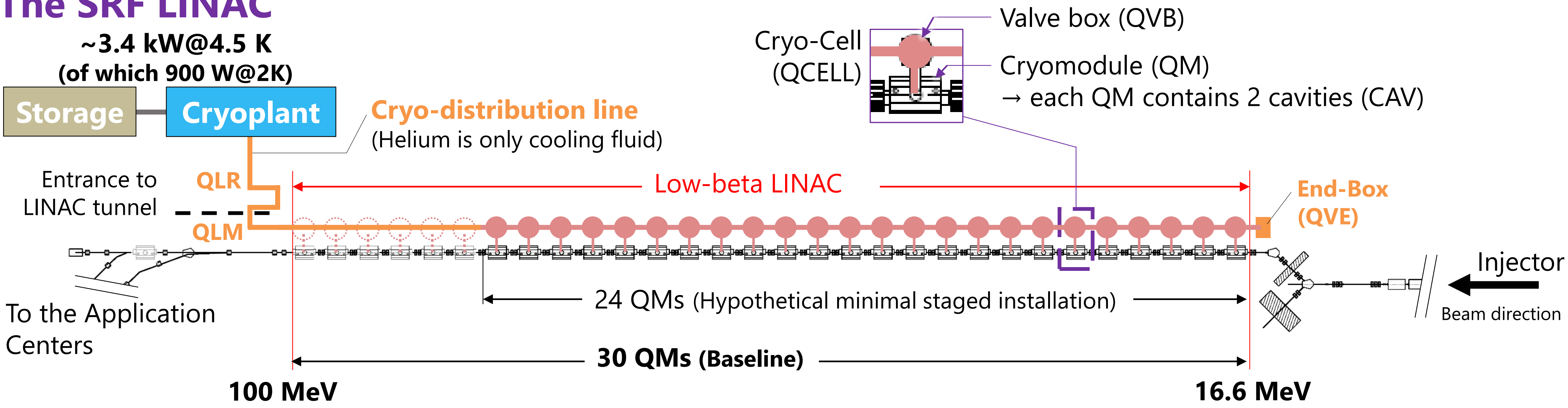


MINERVA, reliability is a core requirement

- **Beam trips**…
  - … cause severe thermal stress on the reactor materials/components limiting its lifetime.
  - … lead to a time-consuming restart of the reactor limiting its availability.
- Reliability requirement
  - Beam trips shall be resolved within 3 seconds to be transparent to the reactor
  - Max 10 beam trips > 3s within 90 day operational run (MTBF > 250 h)



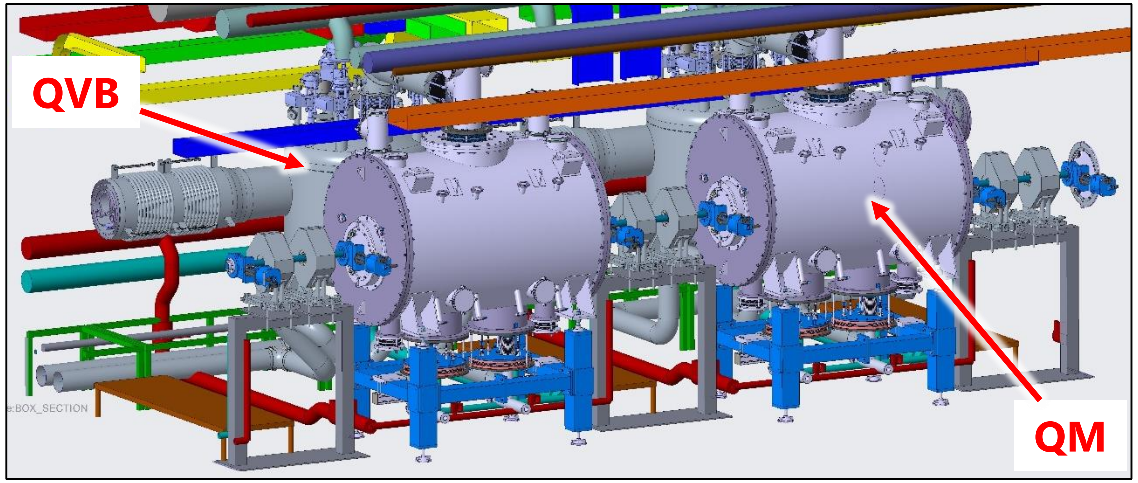
The SRF LINAC



Specifications of the SRF LINAC

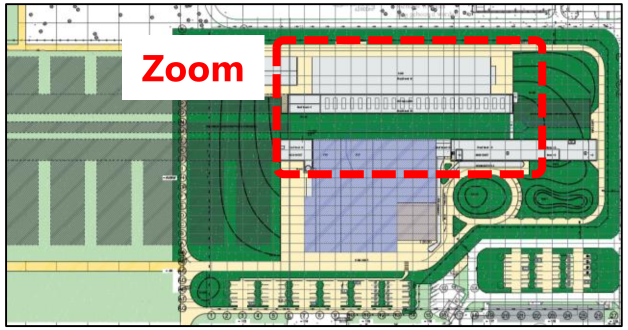
Parameter	Symbol	Value
Beam-energy range (low-beta)	E_{beam}	16.6 MeV to 100 MeV
SRF cavities (single spoke, niobium)	-	60 units (2 per cryomodule)
Duty factor, and frequency	-	CW; 352.2 MHz
Operating temperature	T_{cav}	2 K
Acceleration gradient (max. nominal | peak)	E_{acc}	7 MV/m | 9.1 MV/m
Cavity unloaded quality factor (2 K)	Q0	> 5.2 x10^9 at 9.1 MV/m
Dissipated power in cavity walls (2 K)	P_{cav}	4.25 W at E_{acc} = 7 MV/m

Cryogenic Cells (QCELL = QM + QVB) along the LINAC



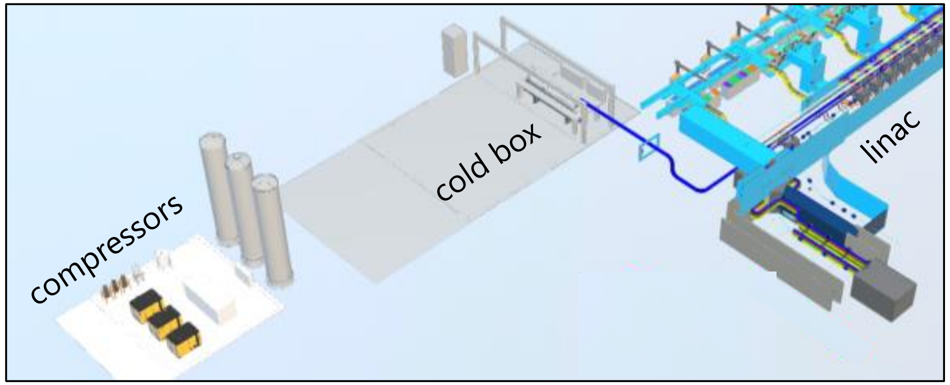
All QCELLs are **identical**, and are the **only** cryogenic “users”

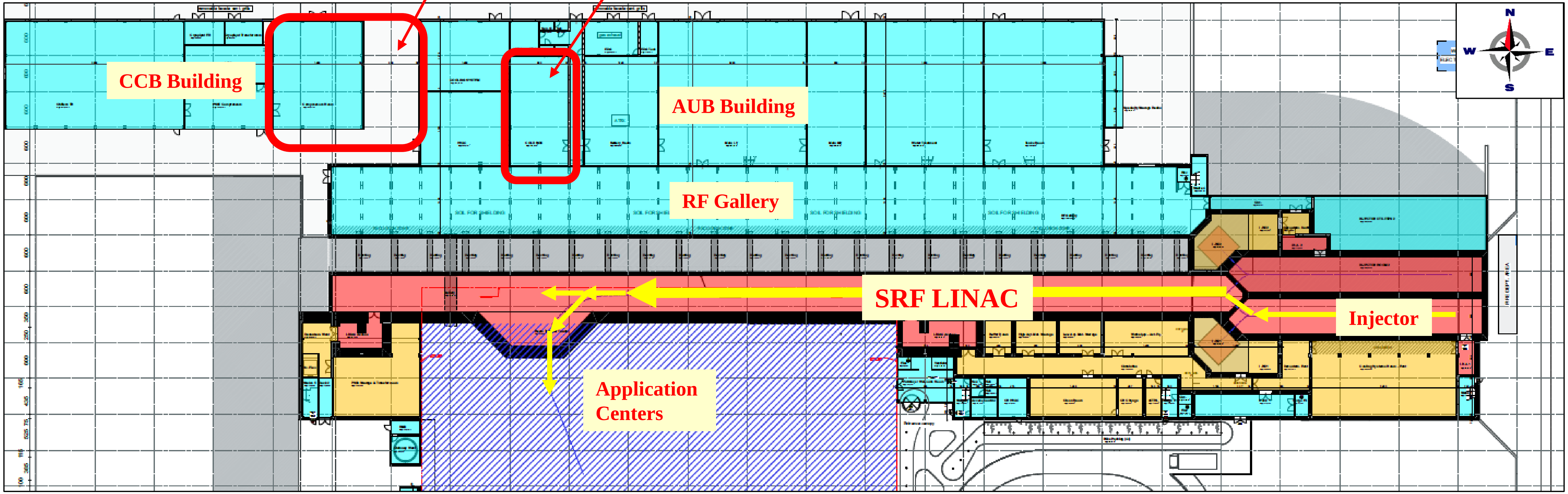
Building layout



Storage & Warm Compressor Station

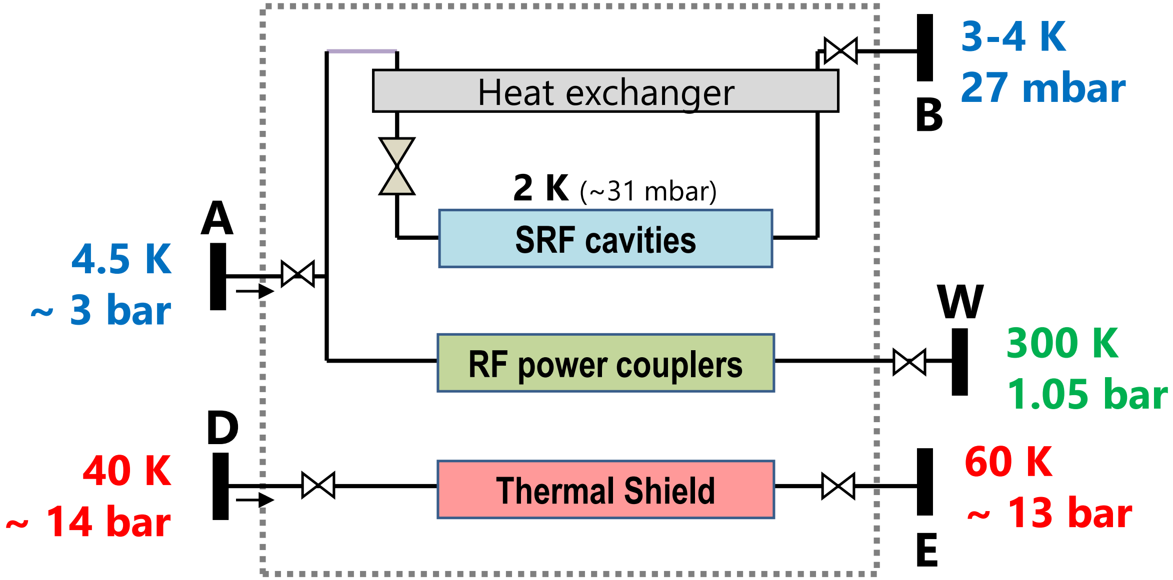
Cold-Box





Cooling circuits and heat loads

Simplified cooling circuits of one QCELL as seen by the cryogenic distribution



Required cooling capacity (static | dynamic | total), excluding contingency margins.

Equipment	2 K Circuit [W]	TS Circuit [W]	Coupler Circuit [g/s]
Single QCELL	13.9 | 9.1[a] | 23.0	184 | - | 184	0.040 | 0.012 | 0.052
- QM only	9.3 | 9.1[a] | 18.4	122 | - | 122	0.040 | 0.012 | 0.052
SRF linac			
- Min turndown [b]	334 | - | 334	4423 | - | 4423	0.96 | - | 0.96
- Nominal operation	418 | 187 | 605	5529 | - | 5529	1.20 | 0.36 | 1.56
- Max. operation	418 | 242 | 660	5529 | - | 5529	1.20 | 0.16 | 1.49

[a] 4.25 W of RF losses per cavity at 7 MV/m. [b] hypothetical staged installation of 24 QCELLs.

Margins for cryoplant sizing

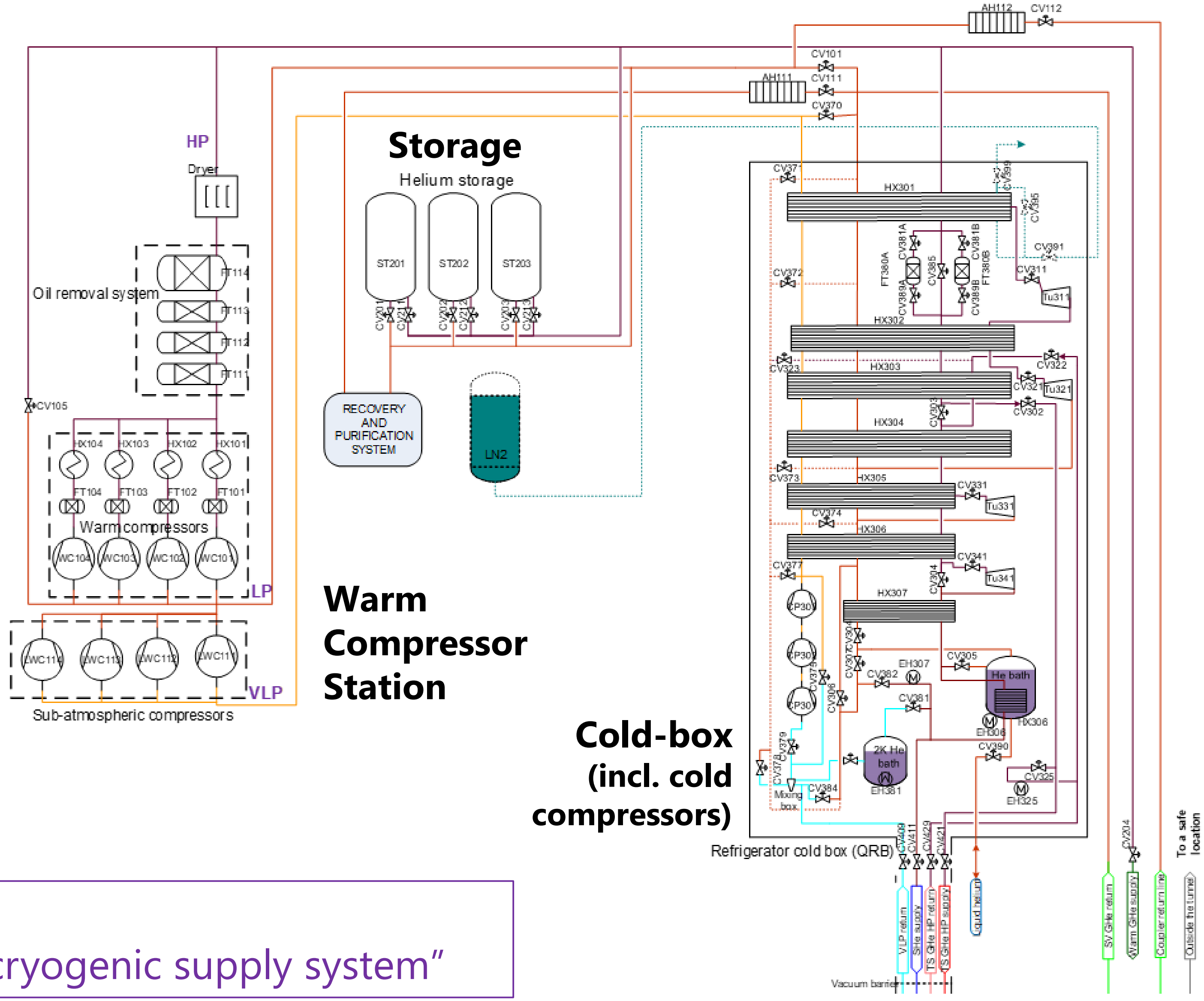
- No margin
- Full margin +50%
- Limited margin +20%

MINERVA Cryoplant

- The preliminary design of the MINERVA Cryoplant has been developed.
  - Input from two industrial pre-studies were used to consolidate the study.
  - Updated heat load values has been implemented in the ongoing conceptual design.

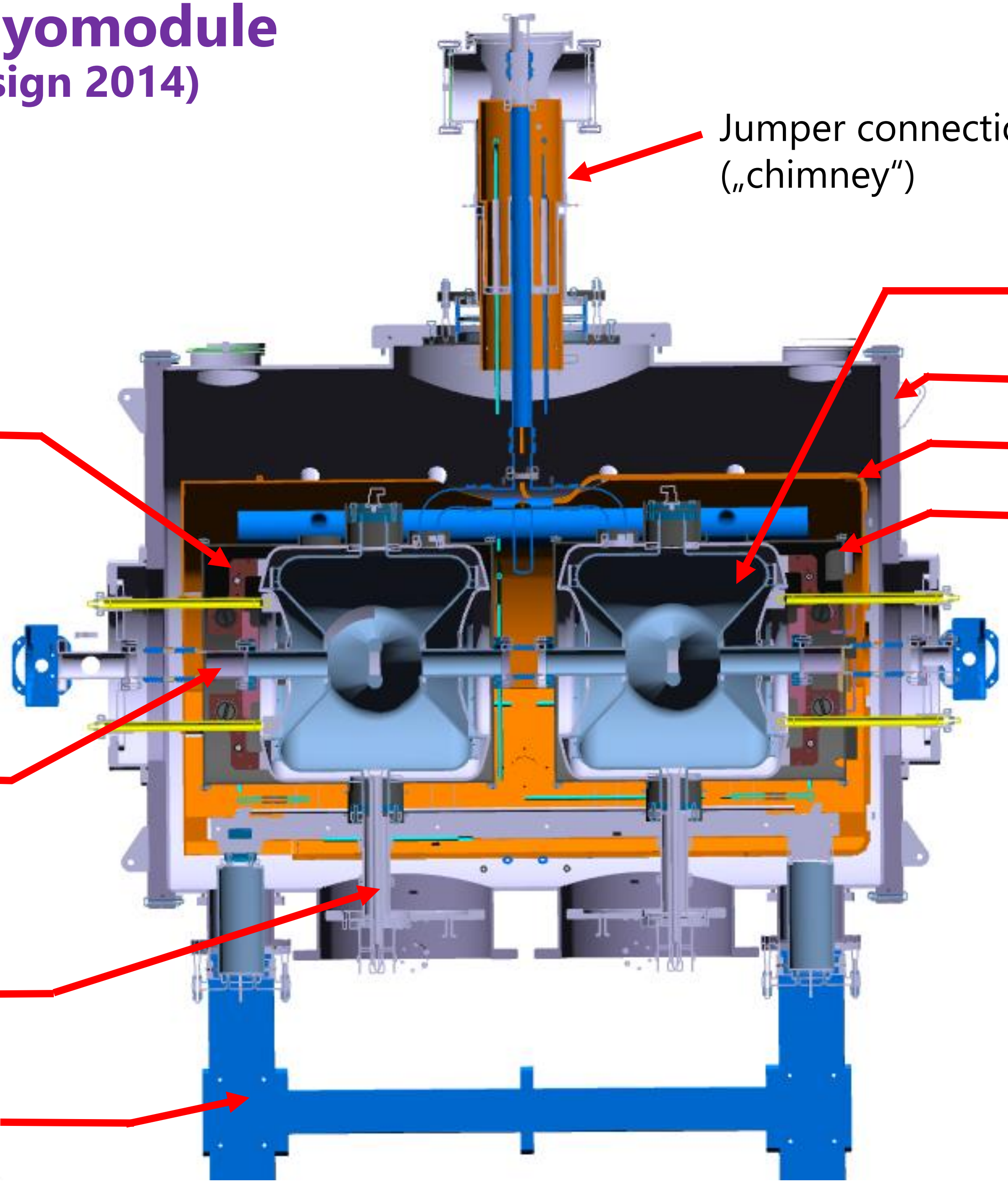
~ 3.5 kW @4.5 K, of which
~ 900 W @2 K (70% of total heat loads)
~ 700 kg of Helium inventory

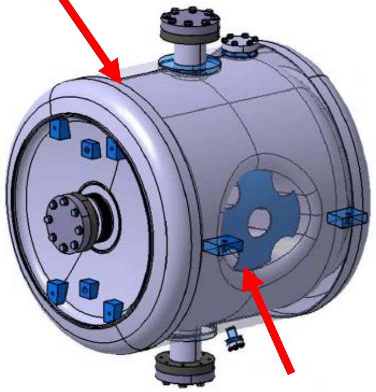
Cryoplant Architecture

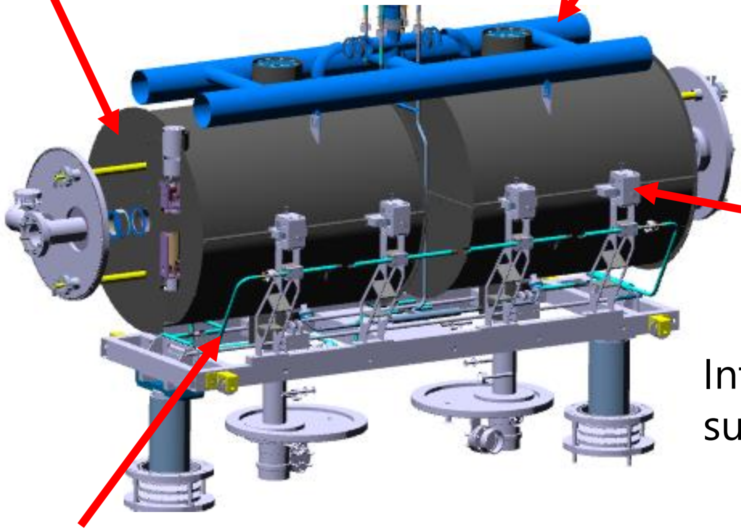


For more details, see presentation **C1Or3B-04**:
Michel et al. „Preliminary studies of the MINERVA cryogenic supply system"

Prototype Cryomodule
(MAX project design 2014)

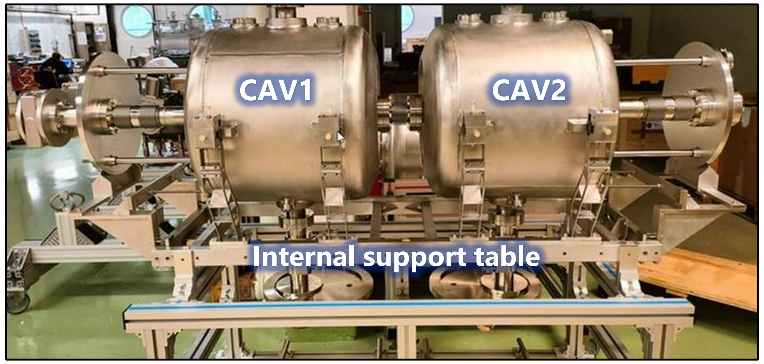


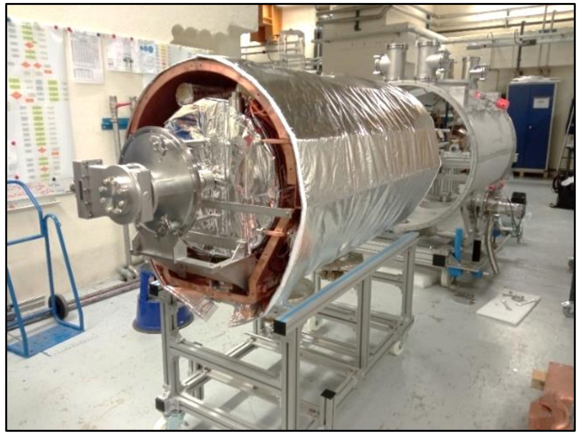


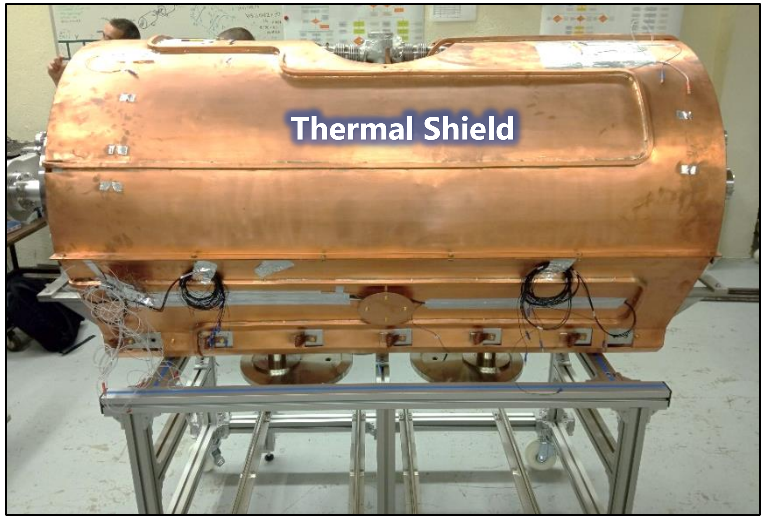


Prototype assembly and testing

Prototype cryomodule for MINERVA



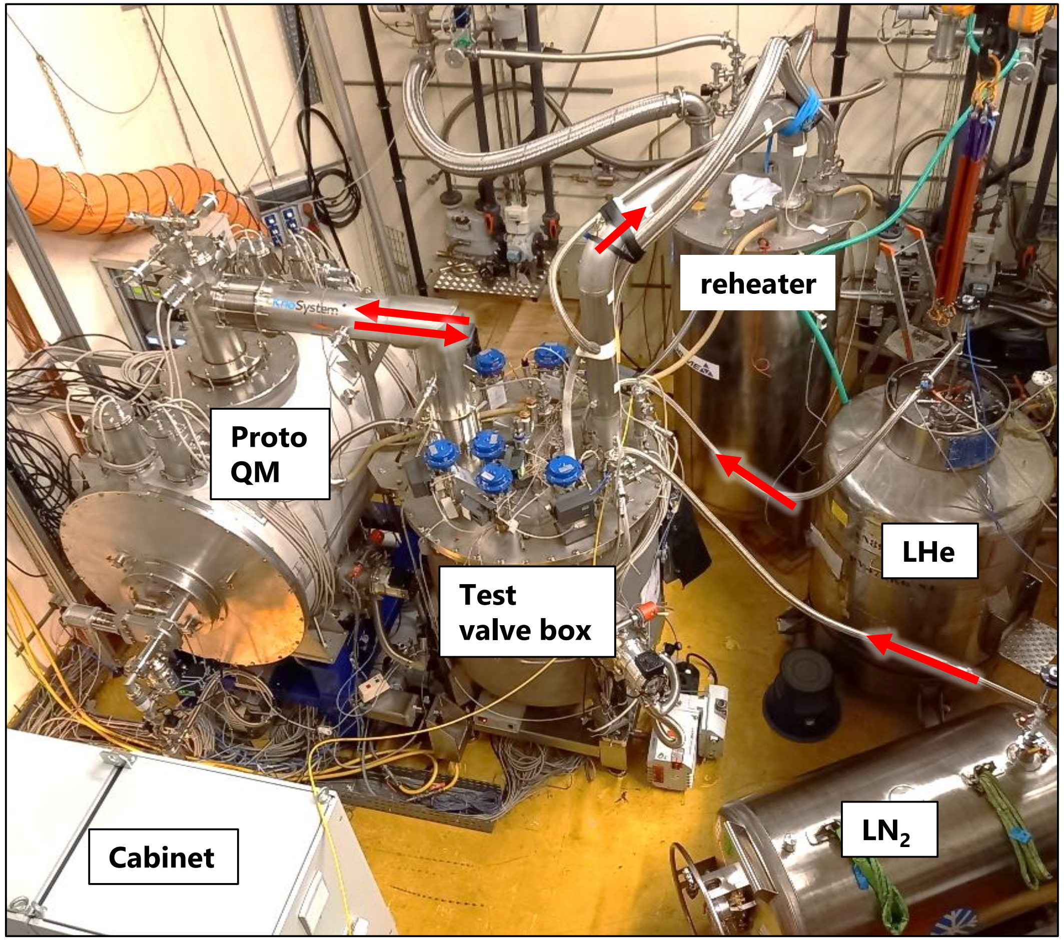




Cryomodule fully assembled in 2022

- Valuable return of experience (assembly sequence, etc...)

Test campaign at IJCLab



Test campaign 2023

- Without RF: Done. Data under analysis
- With RF: Ongoing

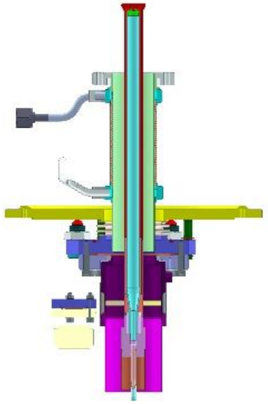
Design consolidation towards series production

- Design consolidation is ongoing for the remaining cryomodule components
  - RF power coupler
  - Cold tuning system
  - Cryostat
- The mechanical design of the valve box is ongoing

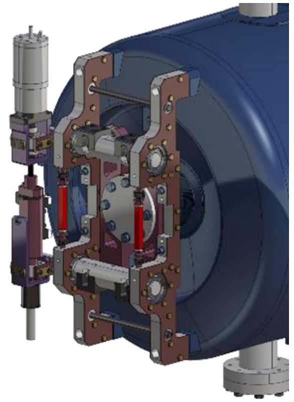
- Example of current activities
  - Implementation of latest return of experience
  - Cross-checking design and performance requirements
  - Update of 3D models and integration check
  - Preparation of tender documentation

- All components will be tendered based on detailed 3D models. The manufacturing drawings are to be prepared by the supplier.

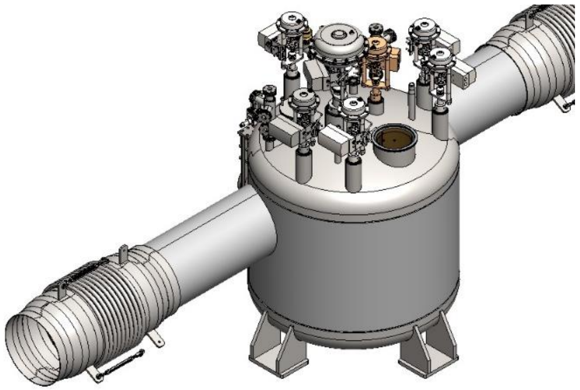
<u>Components under design consolidation in view of call for tender</u>



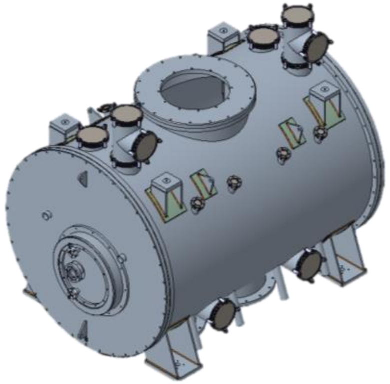
RF power coupler



Cold tuning system



Valve box



Cryostat

Ongoing series production

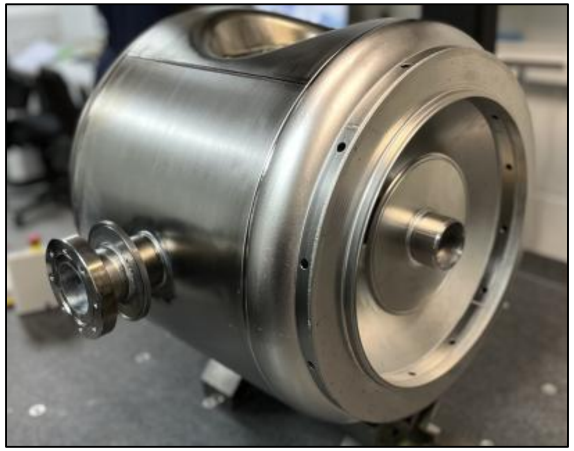
Spoke cavities

- SC spoke cavities adjudicated to Research Instruments (GER)
- **First pre-series cavity completed!**
  - 2nd and 3rd caviteis are ongoing
- Post-processing steps achieved successfully
  - BCP (rotary plant)
  - High-pressure rinsing
  - High-temperature heat treatment

research instruments

First pre-series cavity

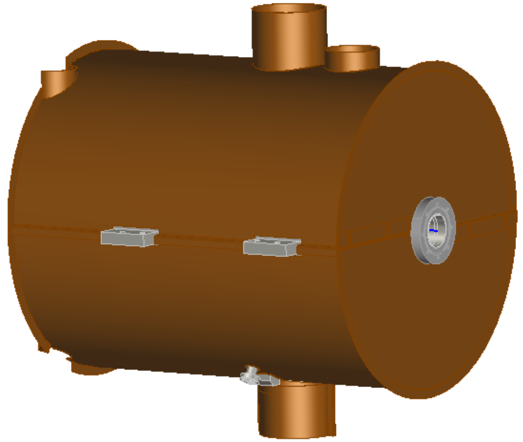
Internal spoke contour



Cavity inside helium tank

Magnetic shield

- Magnetic shields adjudicated to MECA Magnetic (FR)
- Series production started (kick-off Jan-2023)



MECA MAGNETIC magnetic shielding

Conclusion

MINERVA Cryogenic System

We have revised and updated the overall cryogenic system

- ✓ Cryogenic architecture has been defined
- ✓ System layout is now mature
- ✓ Building arrangement is consolidated
- ✓ Cooling requirements (SRF linac) are provided

Cryoplant requirements

- Total heat loads **~ 3.5 kW @4.5 K**, of which **~ 900 W @2 K** (70% of total heat loads)
- Helium inventory ~ 700 kg of Helium

Ongoing prototyping tests campaigns

- Plenty of insights on assemblability, operability, and opportunity for design iterations
- Return of experience already feeding the design consolidation of the series cryomodule

Design changes

- Various changes implemented, with a few still underway.
- Goal is to optimize heat loads, performance, and serialization efforts. Focus is on reliability!
- Continuously balancing between performance, cost, and schedule

Main cryo activities in the short term

- **Finalize prototype tests** for cryogenics and RF systems
- **Design consolidation** in view of **call for tender** for the remaining components
- **Continue series production** of cavities and magnetic shields
- **Tender out for** Cryoplant + Distribution

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