UPPSALA UNIVERSITET

FREIA Laboratory

Facility for Research Instrumentation and Accelerator Development

Cryogenics and Cryostats

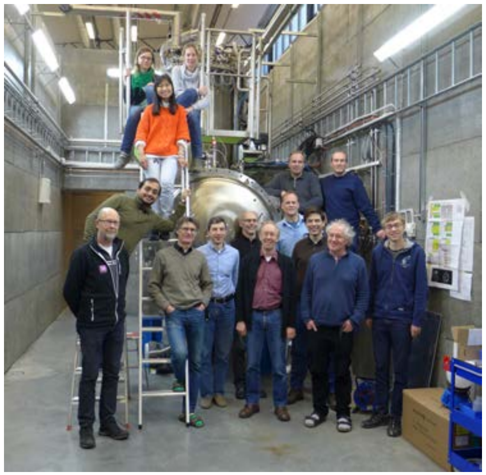
Meeting with RFR Solutions, Landskrona

24 September 2015

Roger Ruber

What & Whom?

Facility for Research Instrumentation and Accelerator Development



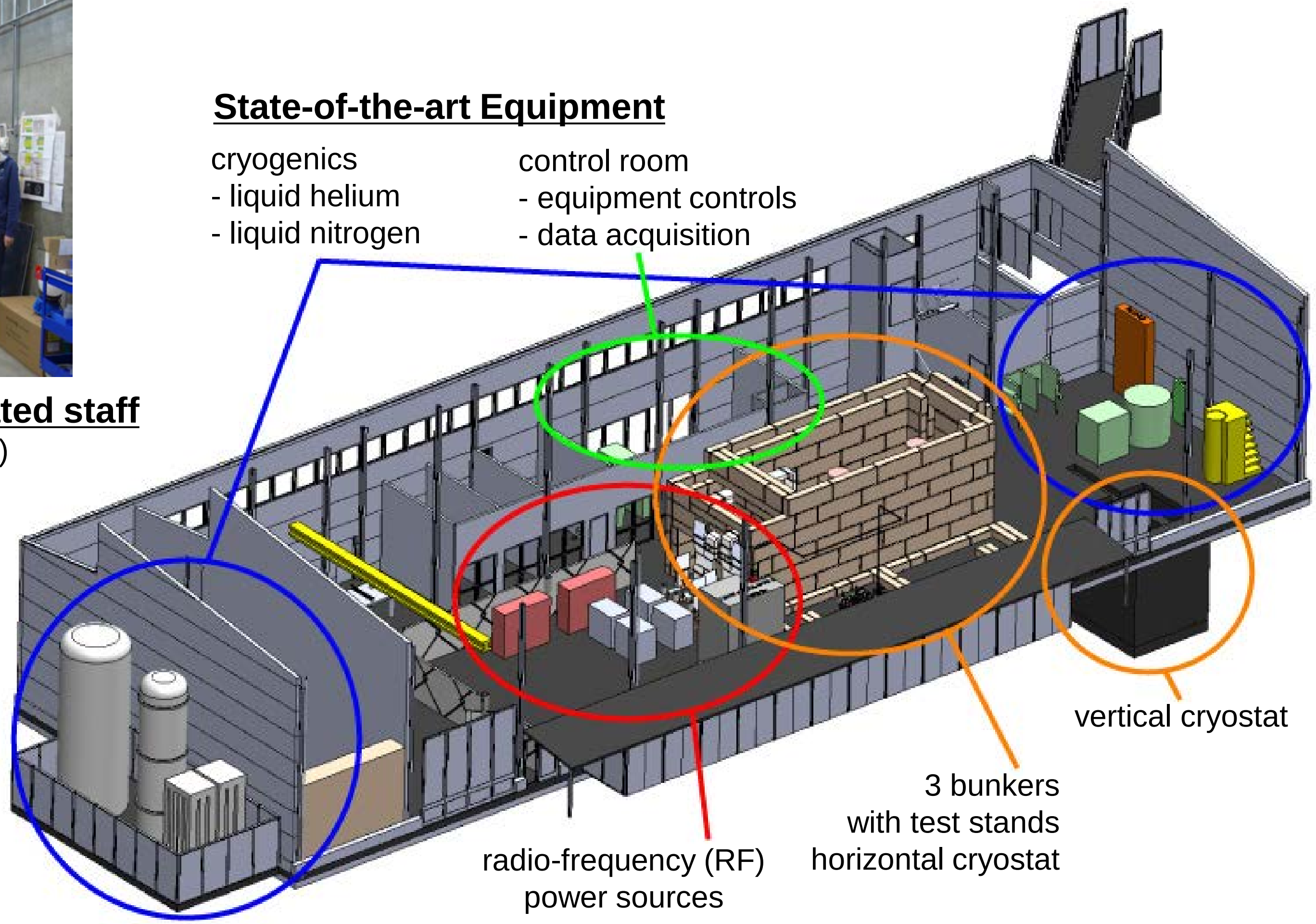
Competent and motivated staff
collaboration of physics (IFA)
and engineering (Teknikum).

Funded by KAWS, Government, Uppsala Univ.

State-of-the-art Equipment

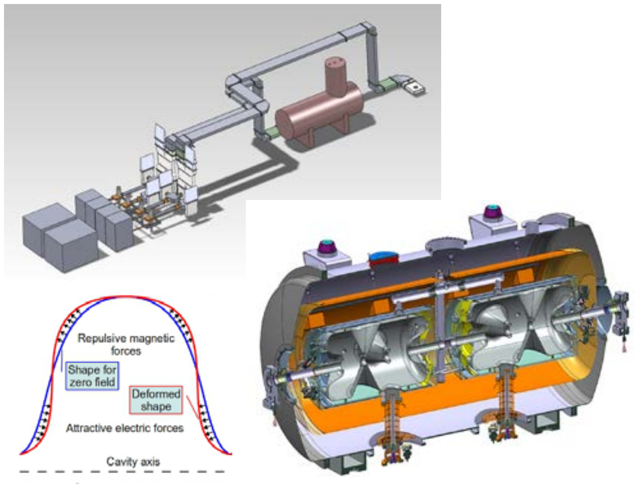
cryogenics
- liquid helium
- liquid nitrogen

control room
- equipment controls
- data acquisition



Overview of Activities

ESS Spoke Linac

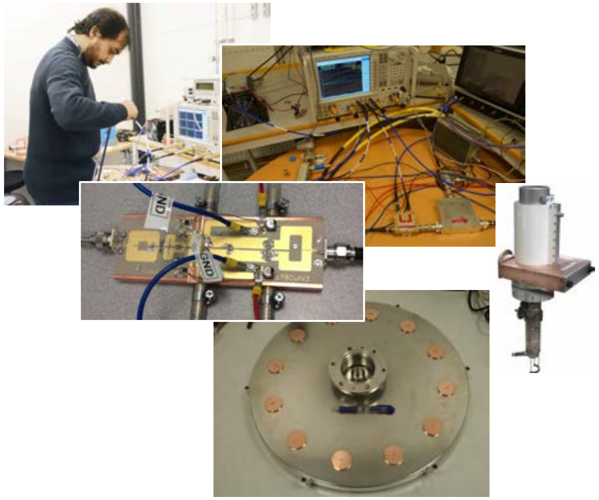


linearcollider.org/M.Grecki

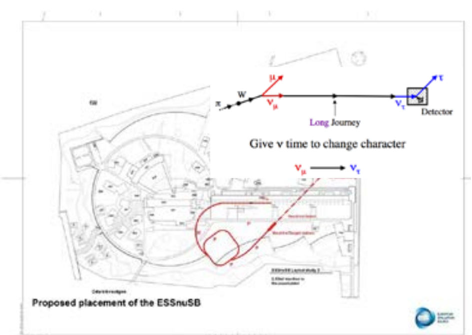
Cryogenics

SRF Test Stand

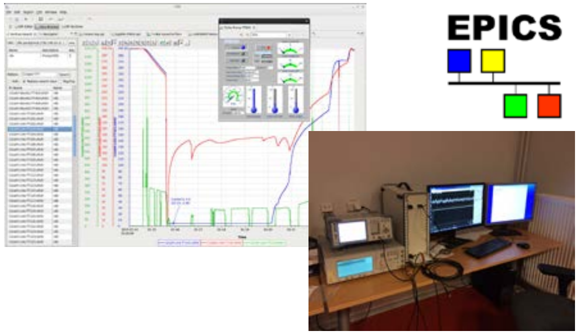
High Power RF Amplifiers Solid-state & Vacuum Tube



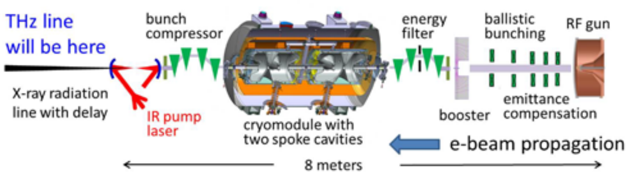
ESS neutrino Super-beam



Controls & Data Acquisition



THz-FEL



RF = Radio Frequency
SRF = Superconducting RF
FEL = Free Electron Laser

Superconductivity

[1908]: helium liquefaction

[1911]: discovery superconductivity in mercury (~4 K) by Kammerlingh-Onnes

[1960s]: practical superconductors (magnet grade) NbZr, Nb3Sn

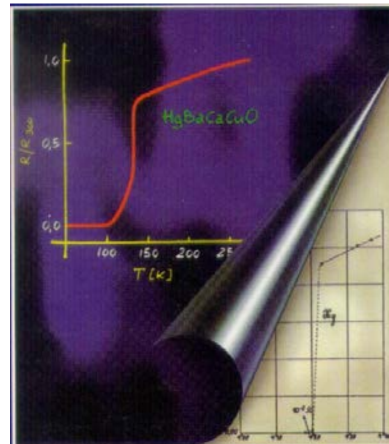
[1965]: first SRF cavity (Pb-plated) at SLAC

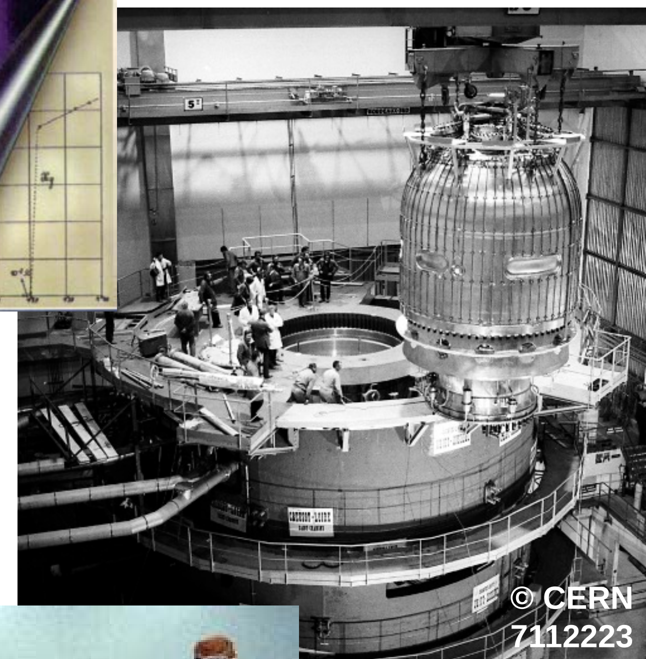
[1969]: first large scale SC magnet CERN BEBC (800 MJ)

[1970s]: commercial NMR systems

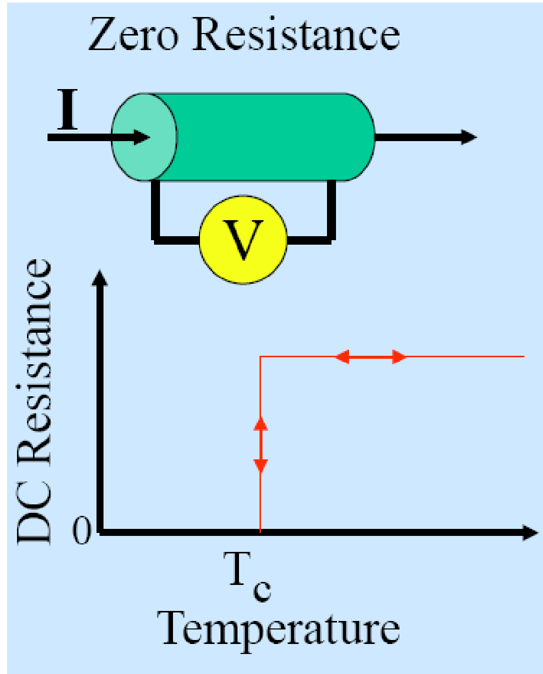
[1984]: Tevatron: 1st accelerator with SC magnets: 520 GeV; 900 GeV in 1987

[1990s]: first large scale SRF: CEBAF & LEP

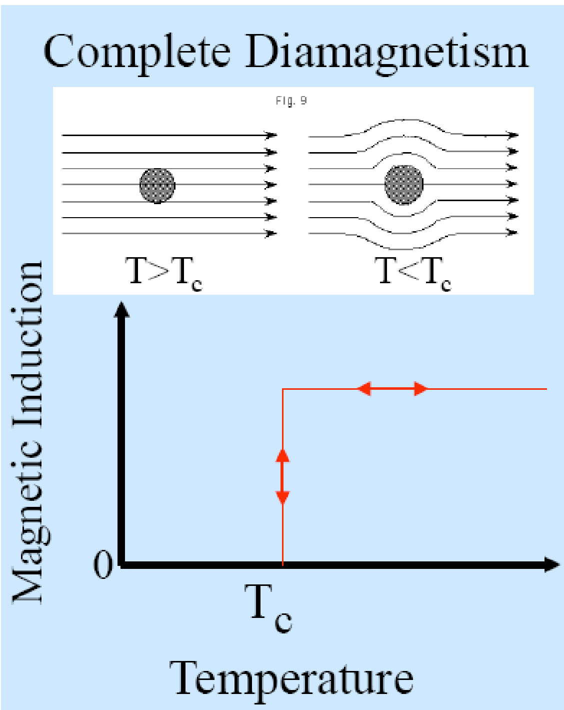




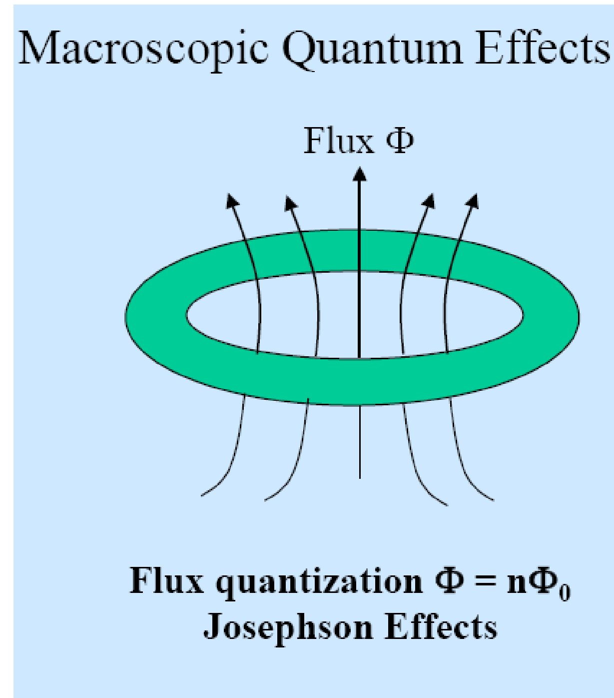
What is Superconductivity?



Kammerlingh-Onnes (1911)



Meissner and Ochsenfeld (1933)

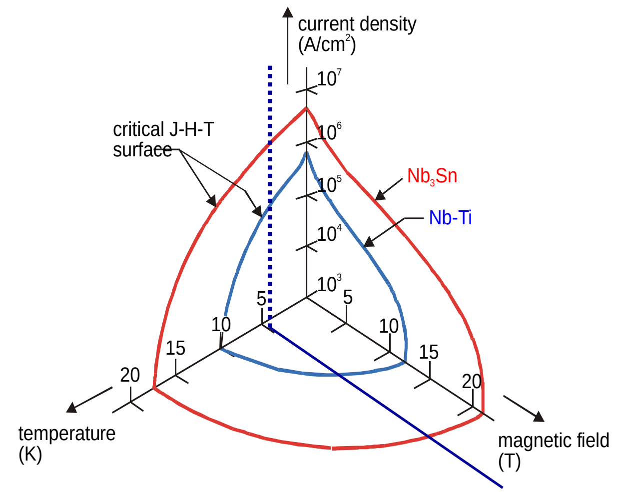


Deaver and Fairbank (1961)

The Superconducting Phase

Operate below the **critical surface**

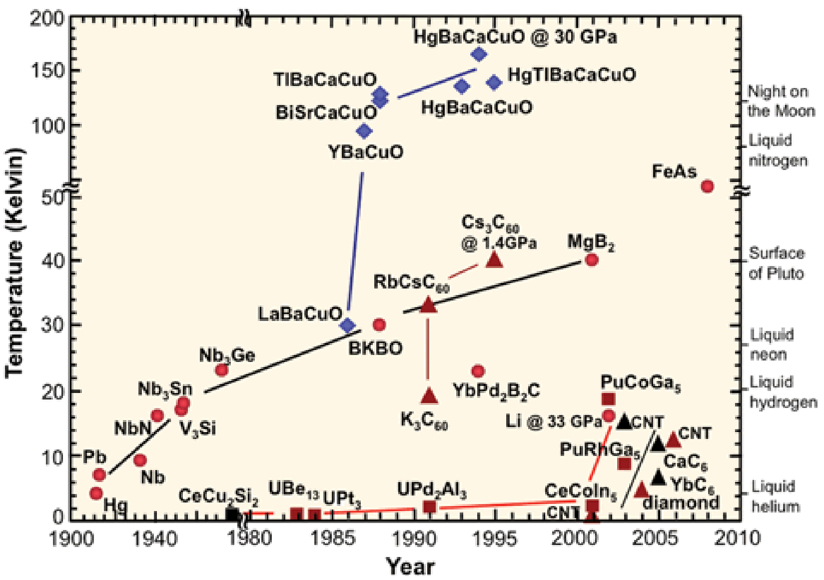
- critical current J_c
- critical temperature T_c
- magnetic field B_{c2}



For NbTi:

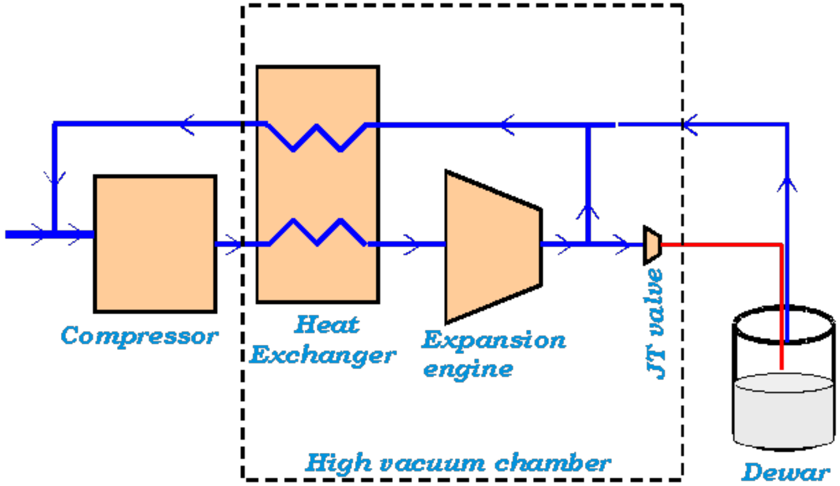
- **$T_c(0)$ = 9.2 K ; $B_{c2}(0)$ = 14.5 T**
- Critical area boundary
  $T_c(B) = T_c(0)$ {1-{B/14.5}}0.59
  $B_{c2}(T) = B_{c2}(0)$ {1-{T/9.2}1.7}
- Typical operation at 4.2 K and 5 T
  T_c(5T) = 7.16 K ; B_{c2}(4.2K) = 10.7 T

Similar relations exist for Nb3Sn.

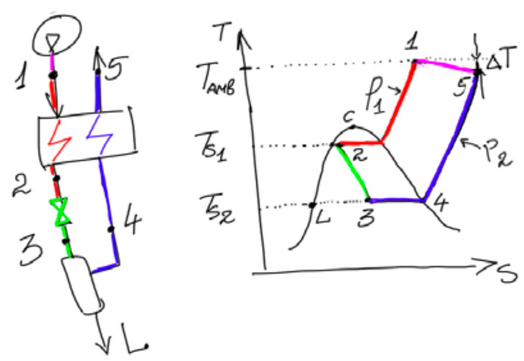


Make it cold...

Cryogenic plants



- Compress the fluid
- Cause the fluid to do work by making it expand against a piston or turbine while keeping it thermally isolated from the outside environment (Isentropic Expansion)
- Transfer heat from the fluid to a colder surface
- Cause the fluid to do "internal work" by expanding it through a valve while keeping it thermally isolated (Isenthalpic or Joule-Thomson Expansion)

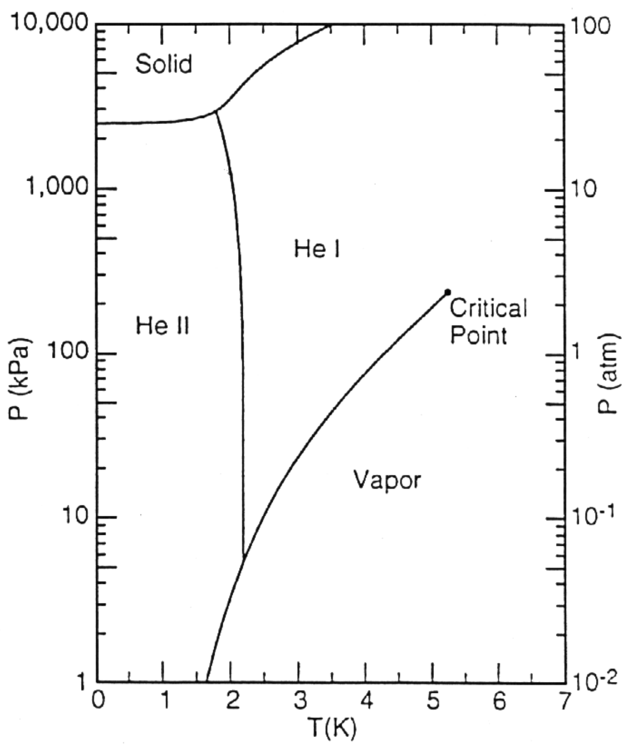


Cooling below 4.2 K

- Once the (helium) fluid is a liquid, reduce the pressure above the fluid below atmospheric pressure thus reducing the saturation temperature

Helium II

- Second liquid phase of helium (hence He II)
- Phase transition is second order (no latent heat)
  - but there is a discontinuity in the specific heat (λ transition)
  - $T_{\lambda,max} = 2.2$ K
- Has unique thermal and fluid properties
  - High effective thermal conductivity
  - Zero viscosity under certain conditions

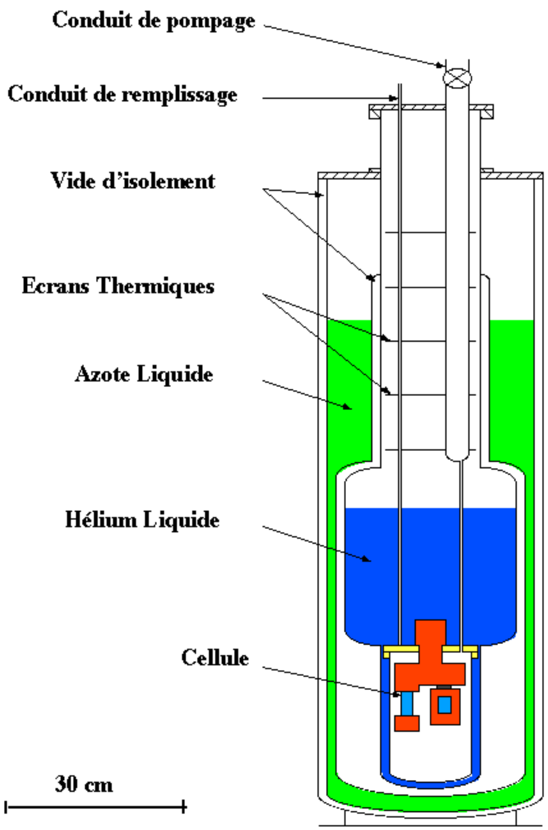


- **Advantages**
  - lower temperature, lower BCS losses
  - no bulk boiling, reduced microphonics
  - very efficient heat transfer
- **Disadvantages**
  - costly

Keep it cold...

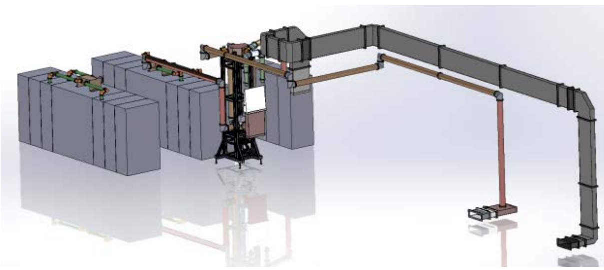
Cryostat (coffee thermos)

- Reduce the heat transfer
  - Conduction
    - Heat transfer through solid material
      - use low conductive materials
      - reduce cross section, increase length
  - Convection
    - Heat transfer via a moving fluid
    - Natural or free convection – motion caused by gravity (i.e. density changes)
      - use vacuum insulation
    - Forced – motion caused by external force such as a pump
  - Radiation
    - Heat transferred by electromagnetic radiation/photons
      - use thermal radiation shield

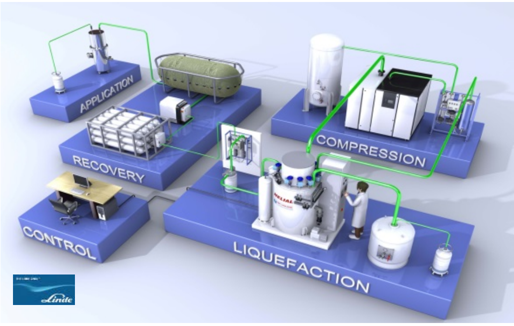


FREIA's Horizontal SRF Test Stand

Three main subsystems:



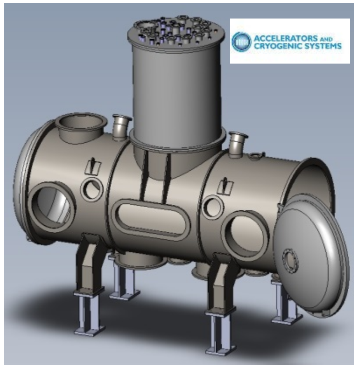
RF Power Source



Cryogenics

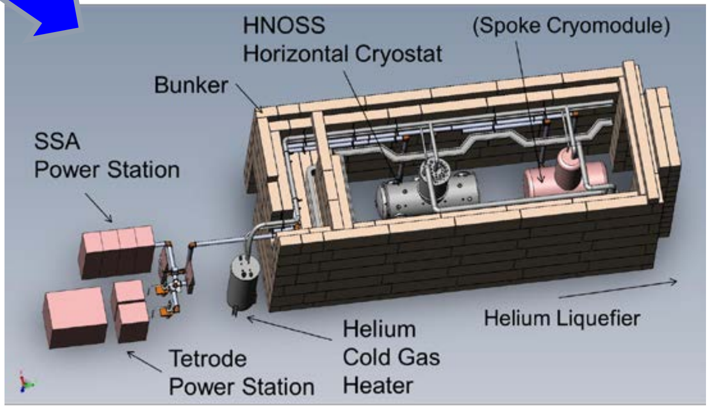
Courtesy of P. Duthil

SRF Cavity
(superconducting)



Horizontal Cryostat

Implementation



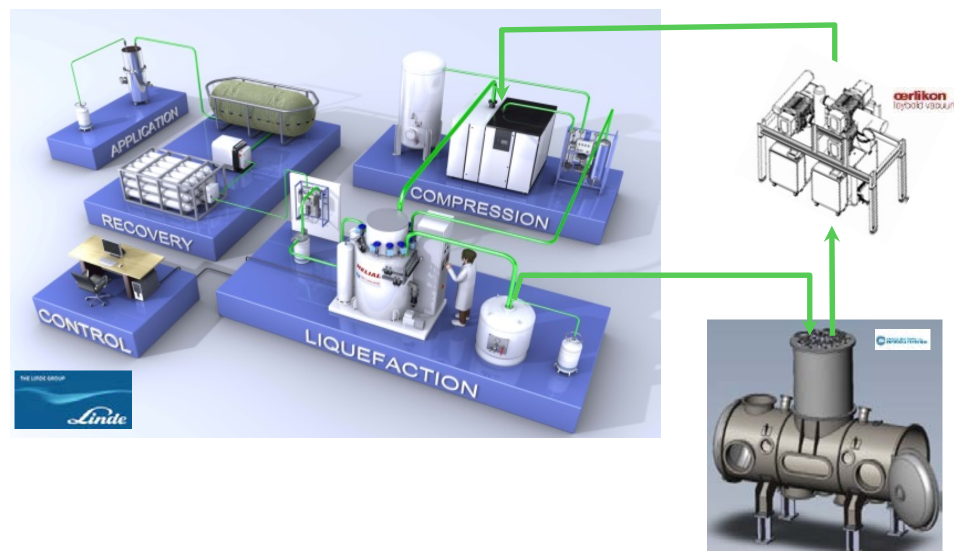
Cryogenics

Helium liquefaction

- 150 l/h at 4.5K (LN2 pre-cooling)
- 2000 l LHe dewar/buffer, 3+1 outlets
- 100 m3 gasbag + recovery system
- cryostats connected in closed loop

Liquid nitrogen

- 20 m3 LN2 tank



HNOSS Horizontal Cryostat

HNOSS: Horizontal Nugget for Operation of Superconducting Systems

- Main Vacuum Vessel
  - 3240 x ø1200mm inner volume
  - “beam” axis at 1600mm
- Valve box (on top of main vessel)
  - Distribute cryogens
  - 4K and 2K pots, JT-valve, heat exchanger
  - 5K supercritical helium
- Interconnection box (ICB)
  - Distributes cryogens to HNOSS and CM
- Cryogenic transfer lines
  - LN2 and LHe
- Cold gas heater for return flow
  - re-heating from 2K to 300K
- Control system

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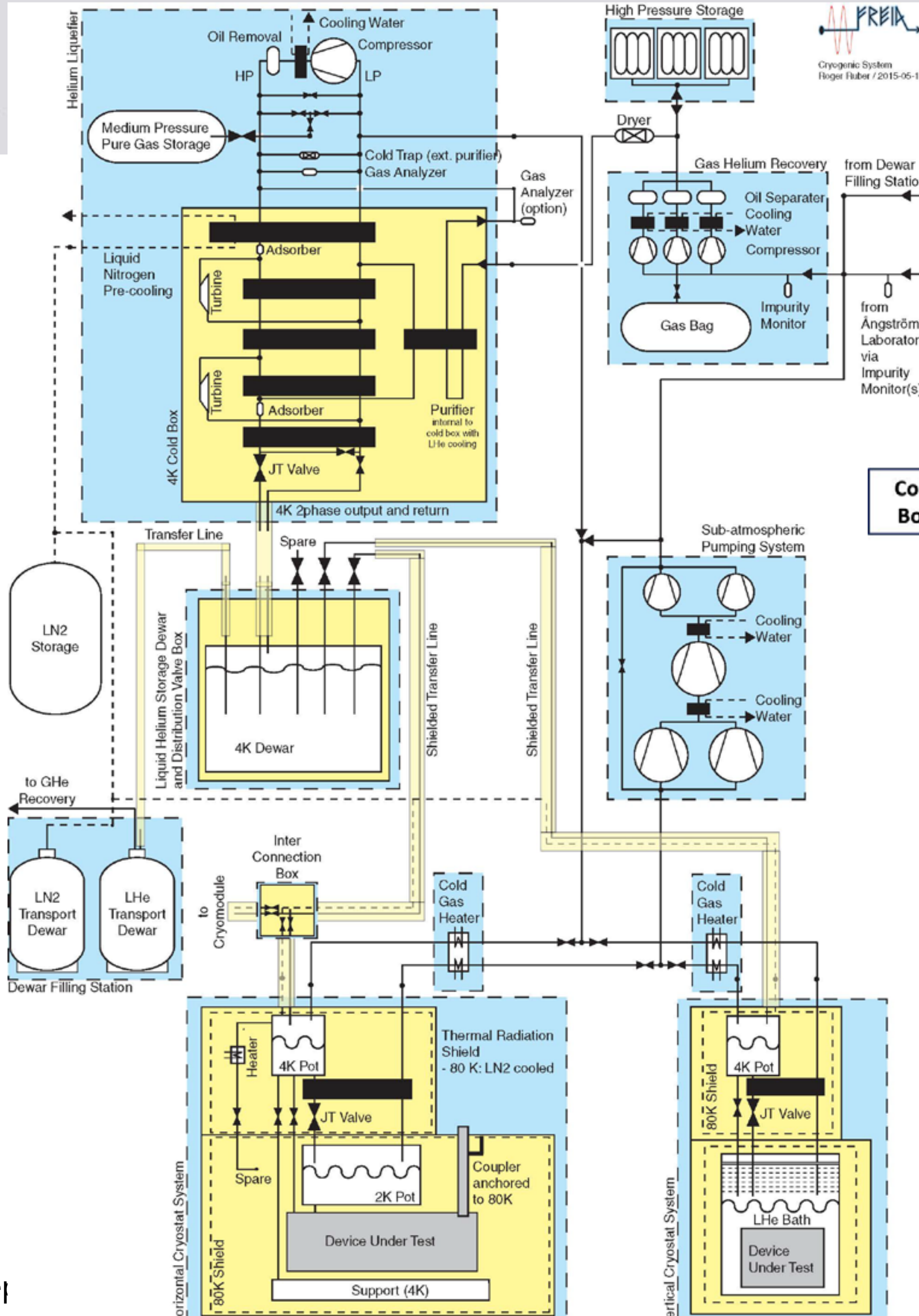
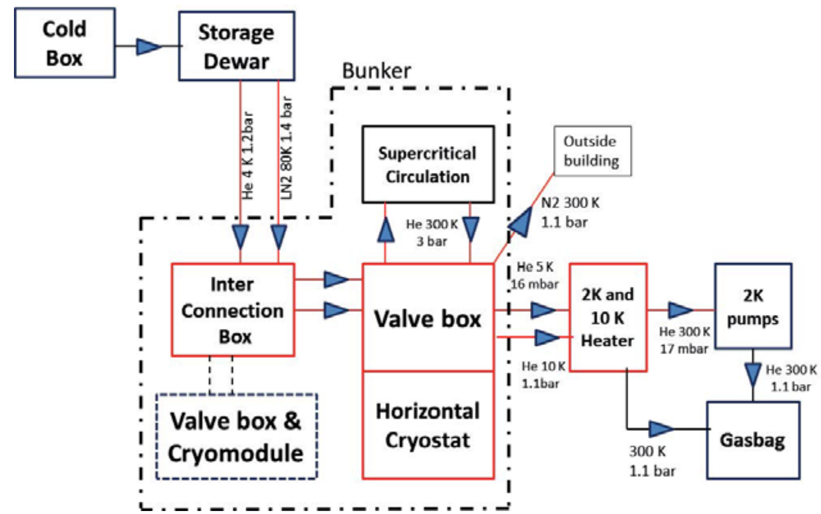
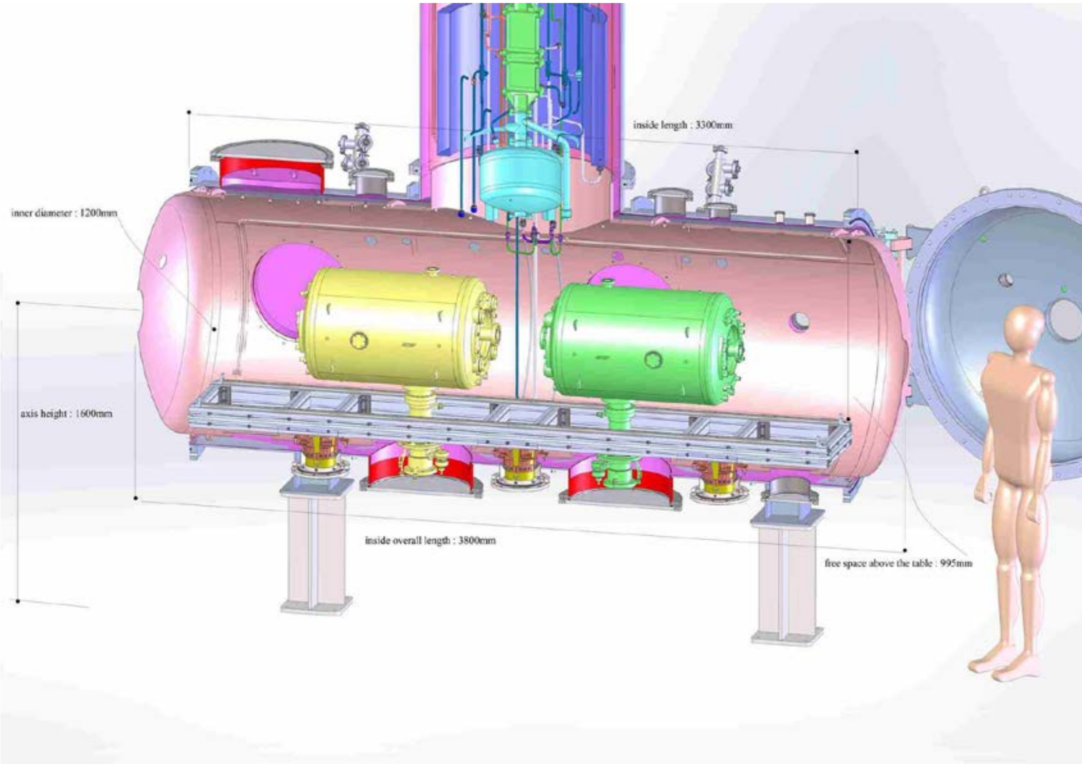
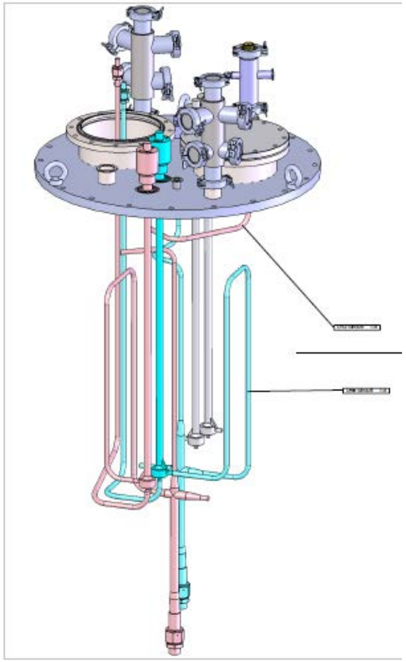
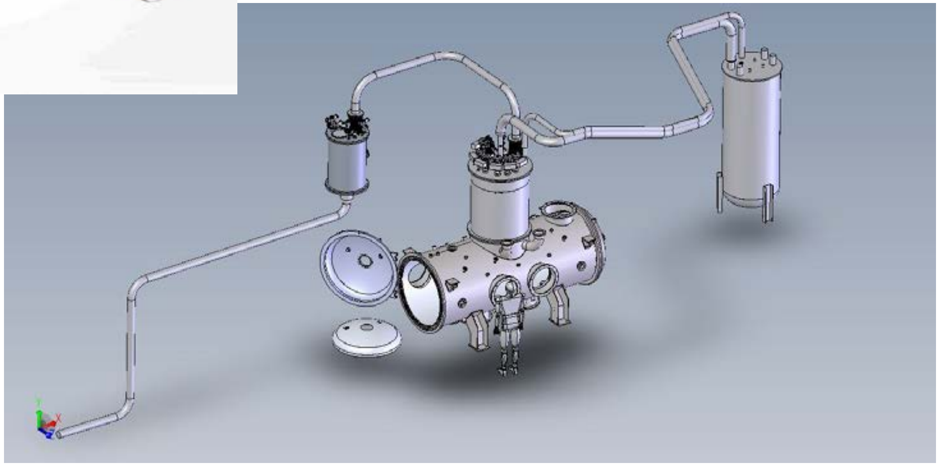




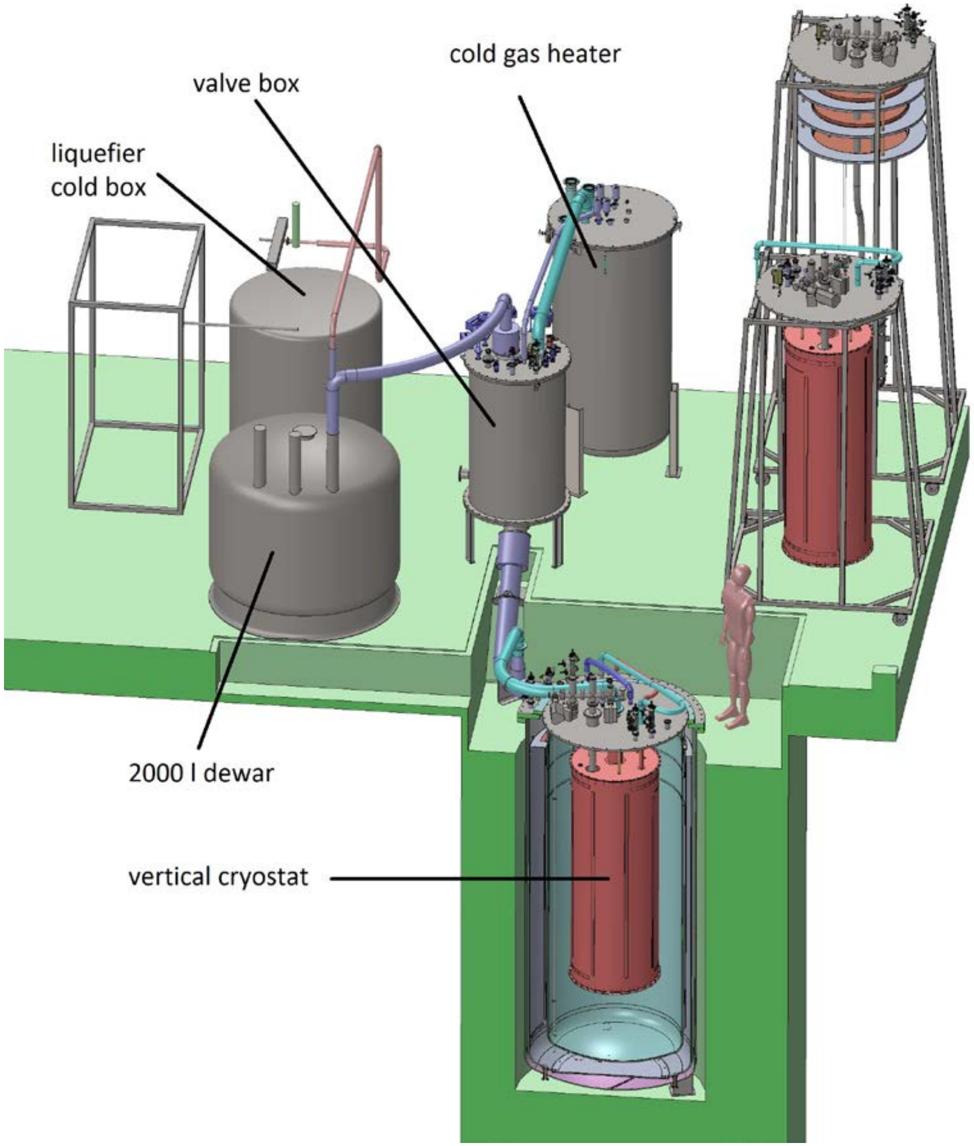
HNOSS - Horizontal Cryostat System

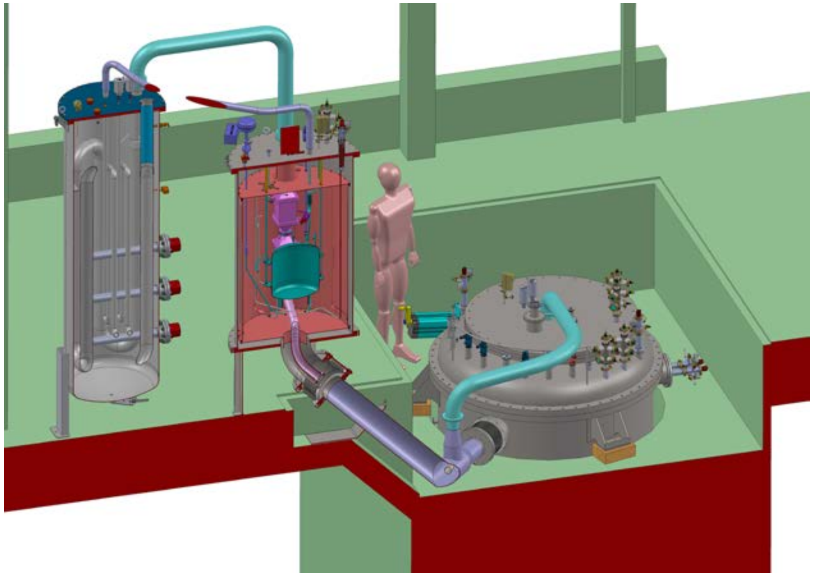




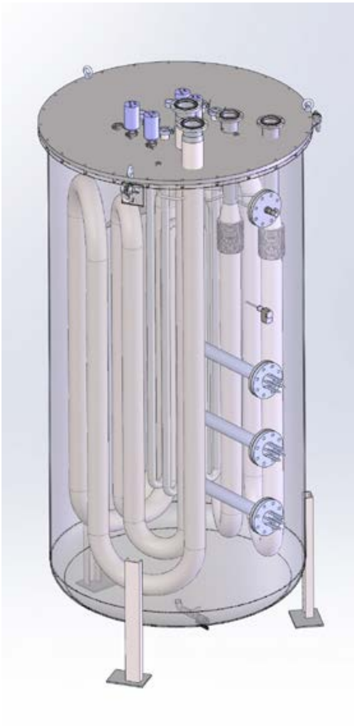


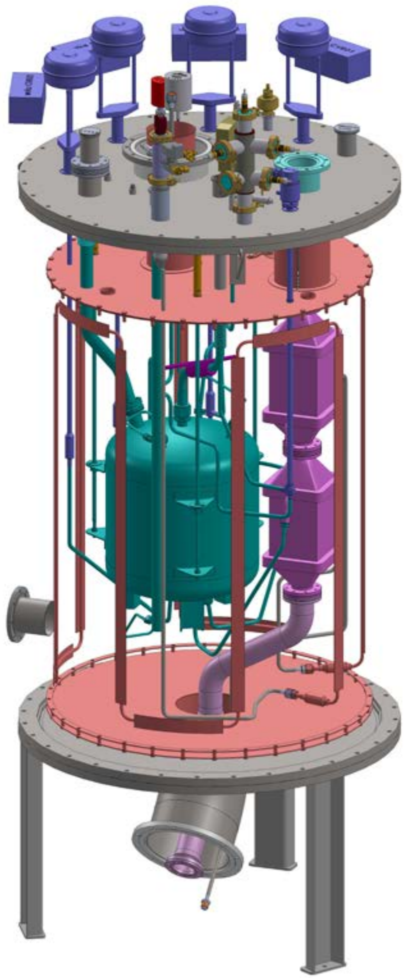
Gersemi - Vertical Cryostat System

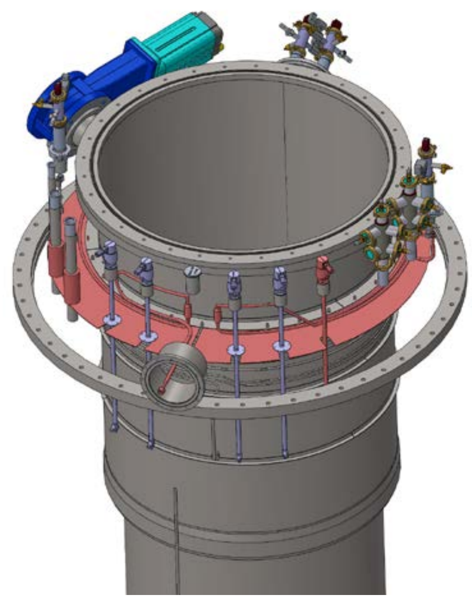


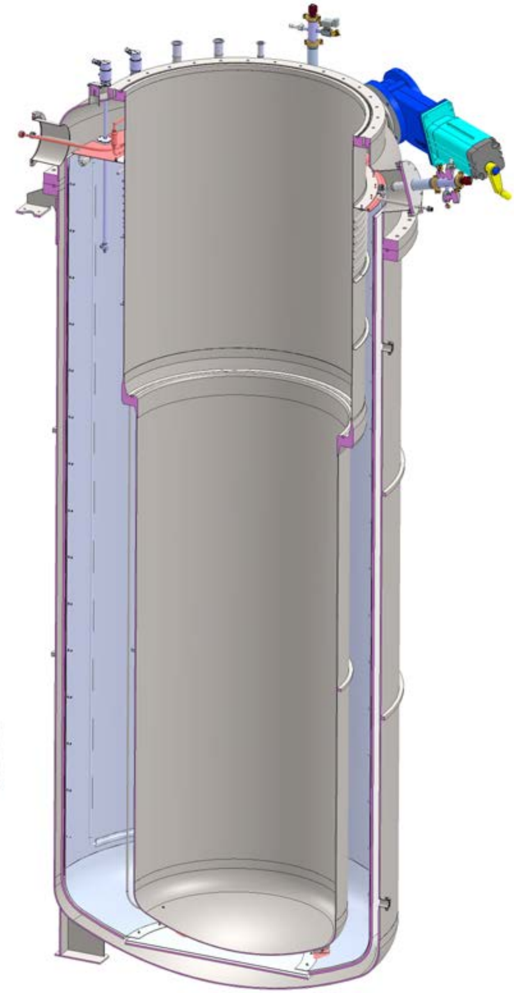


Gersemi - Details

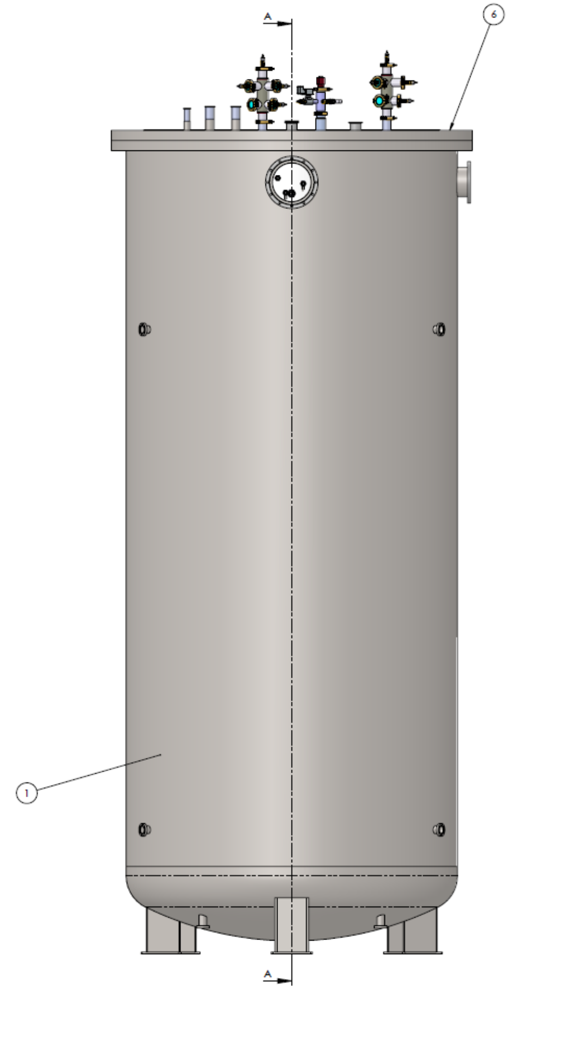


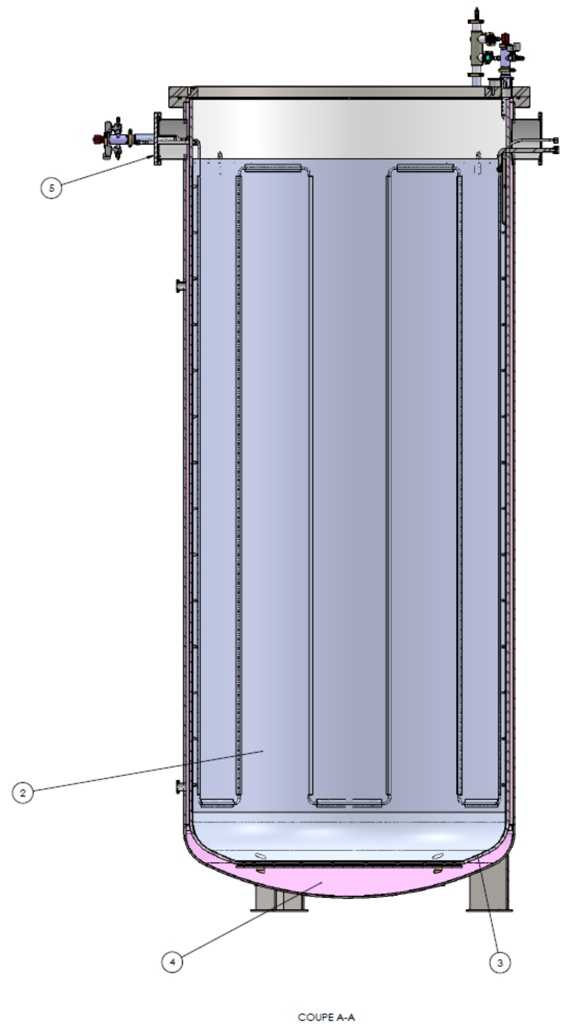


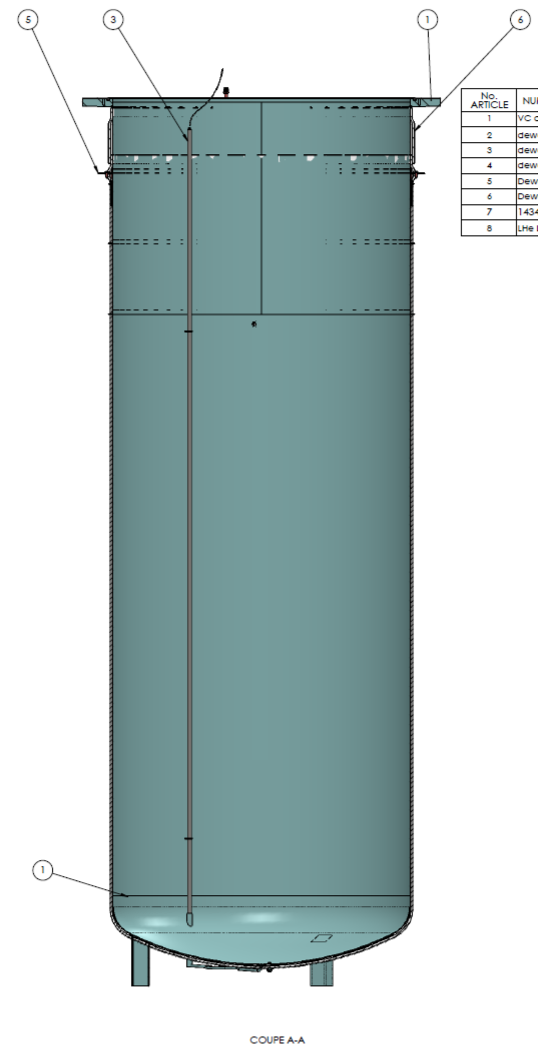




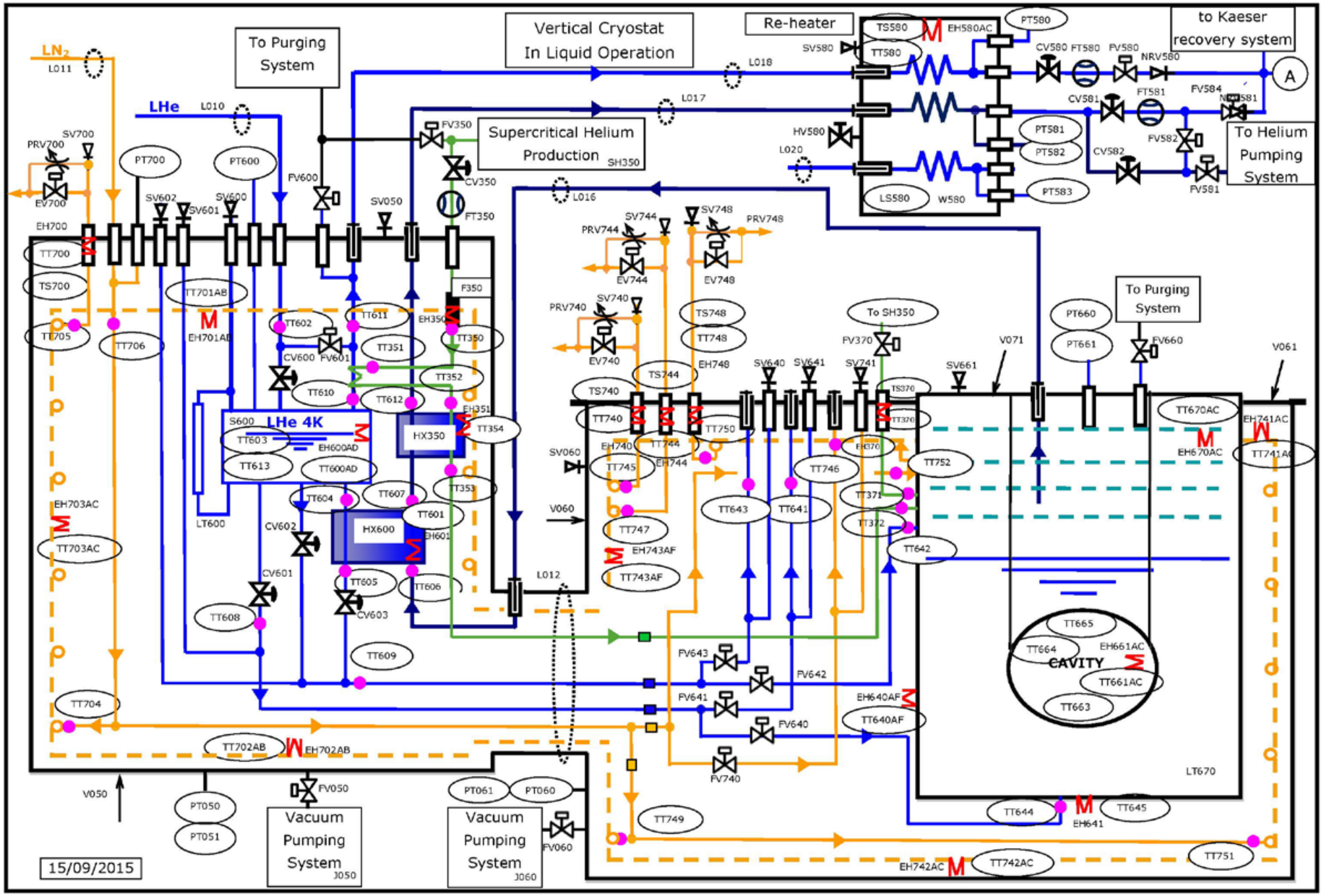
Gersemi - Details



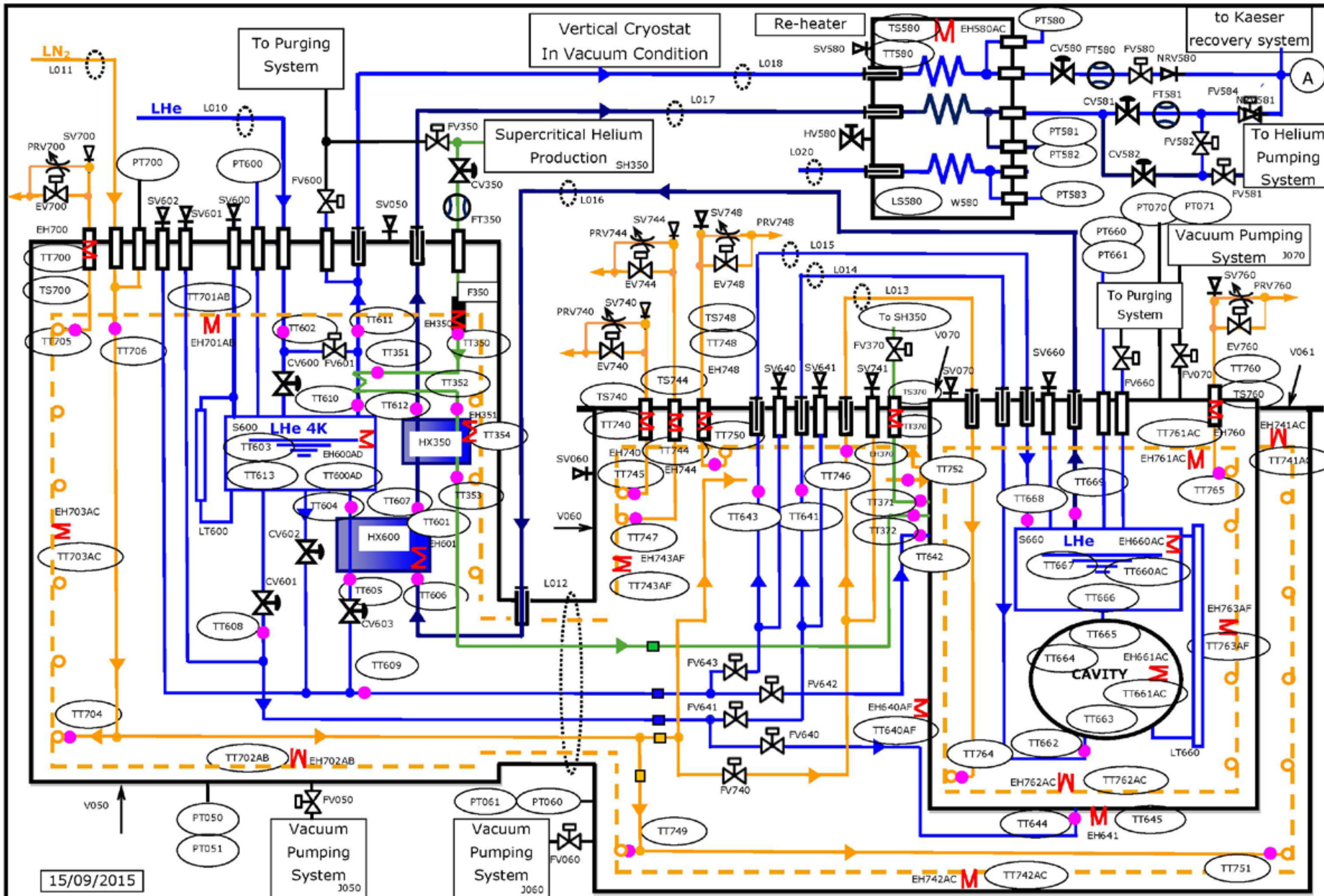




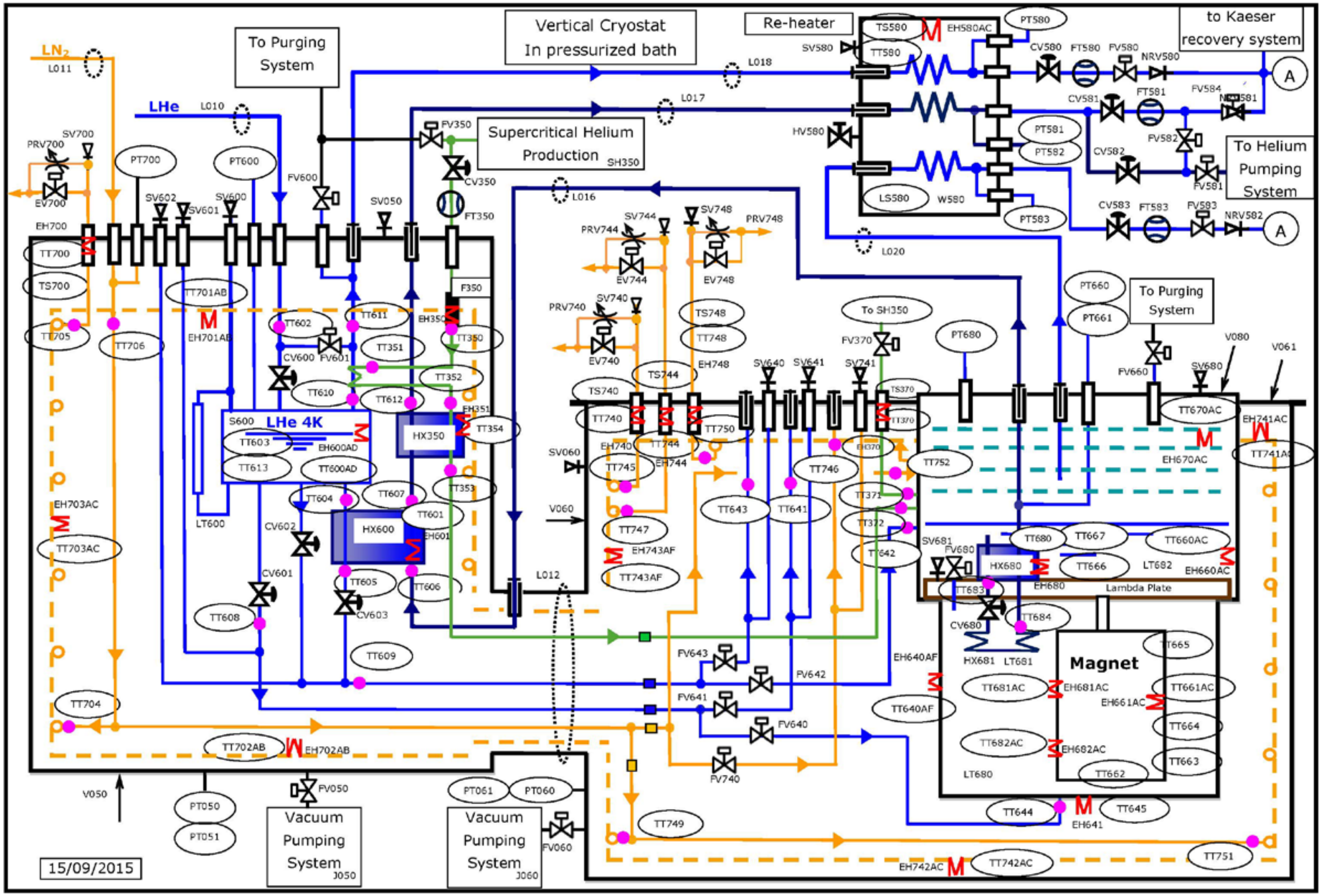
Cryogenic Operation - Liquid Bath



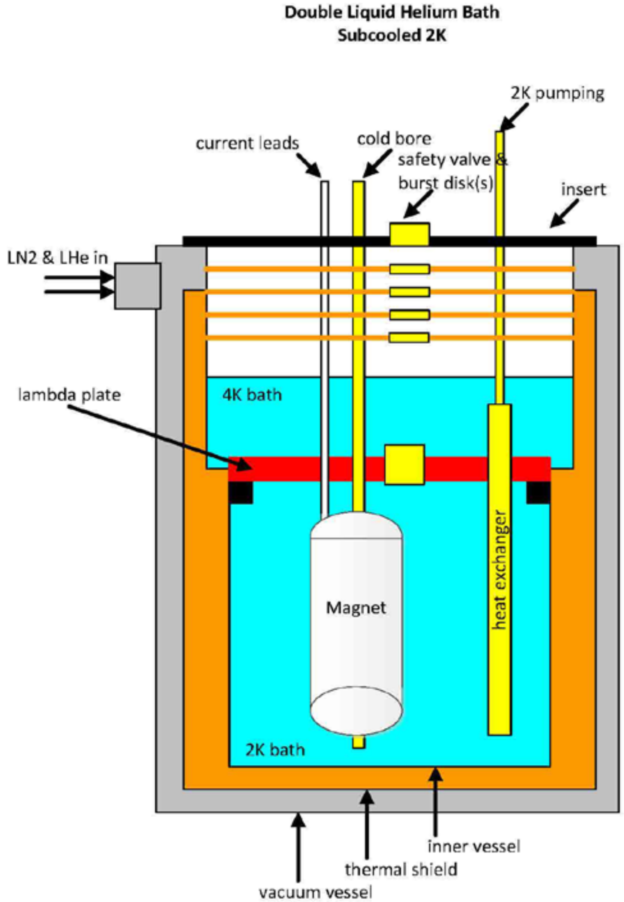
Cryogenic Operation - Vacuum

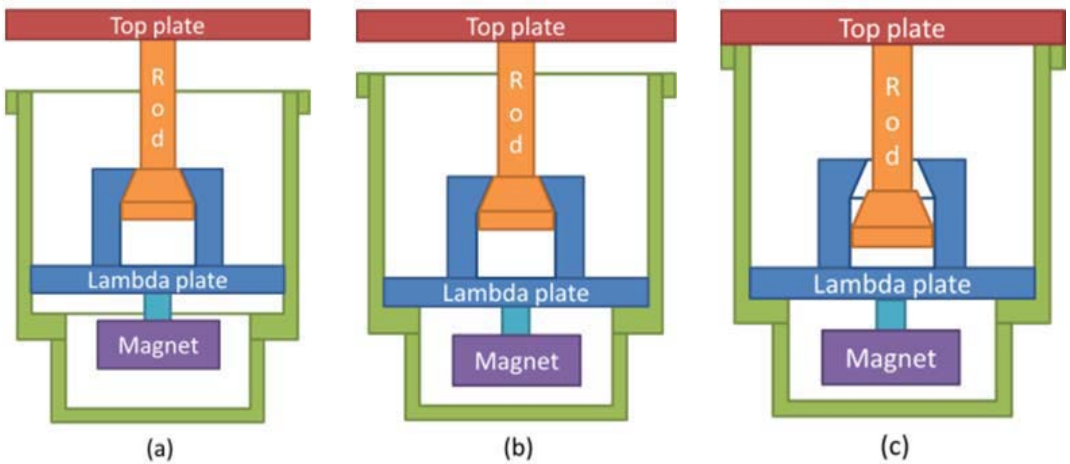


Cryogenic Operation - Sub-cooled Bath

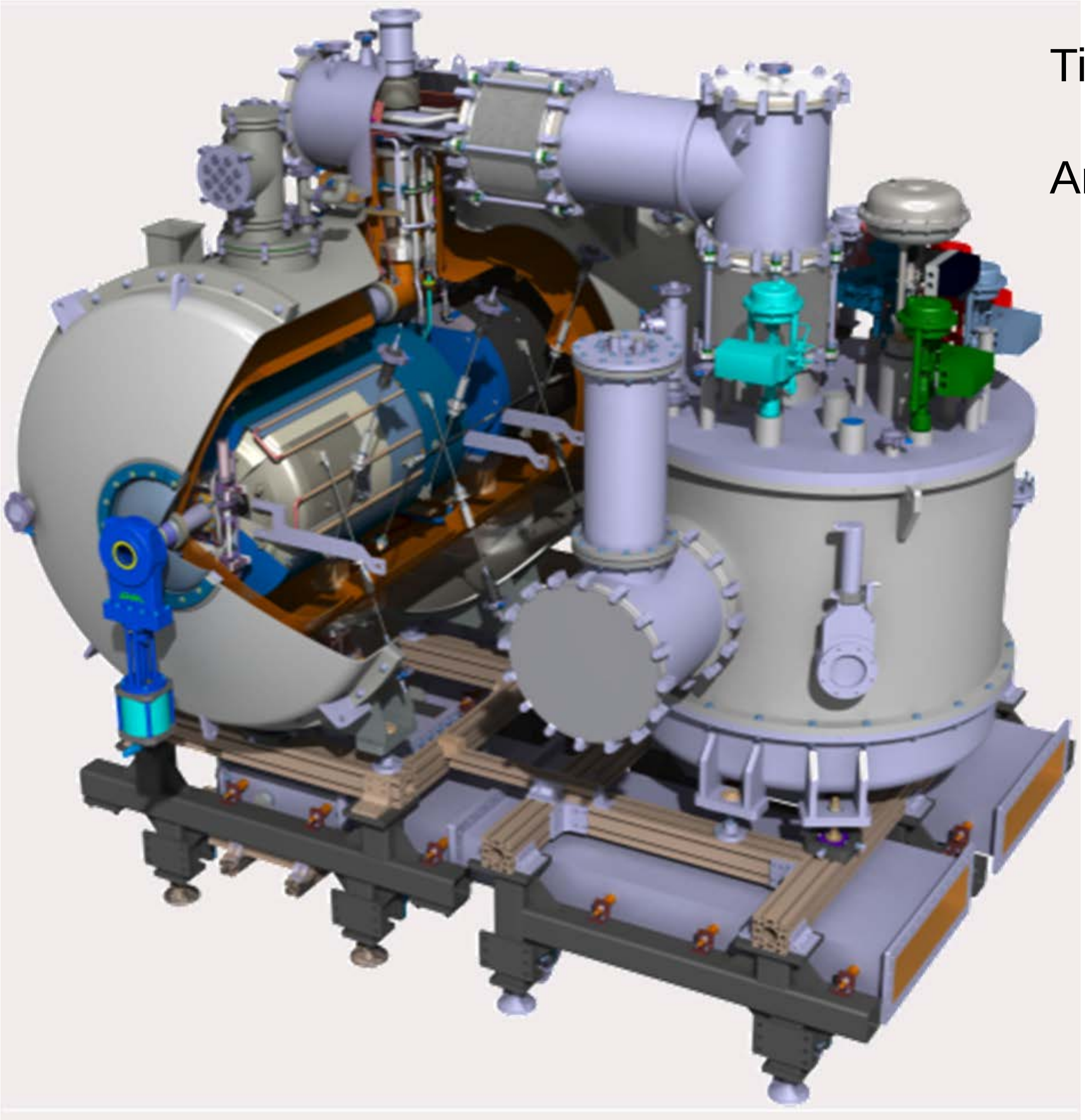


Sub-cooled Helium Bath





ESS Spoke Cryomodule and Valve Box

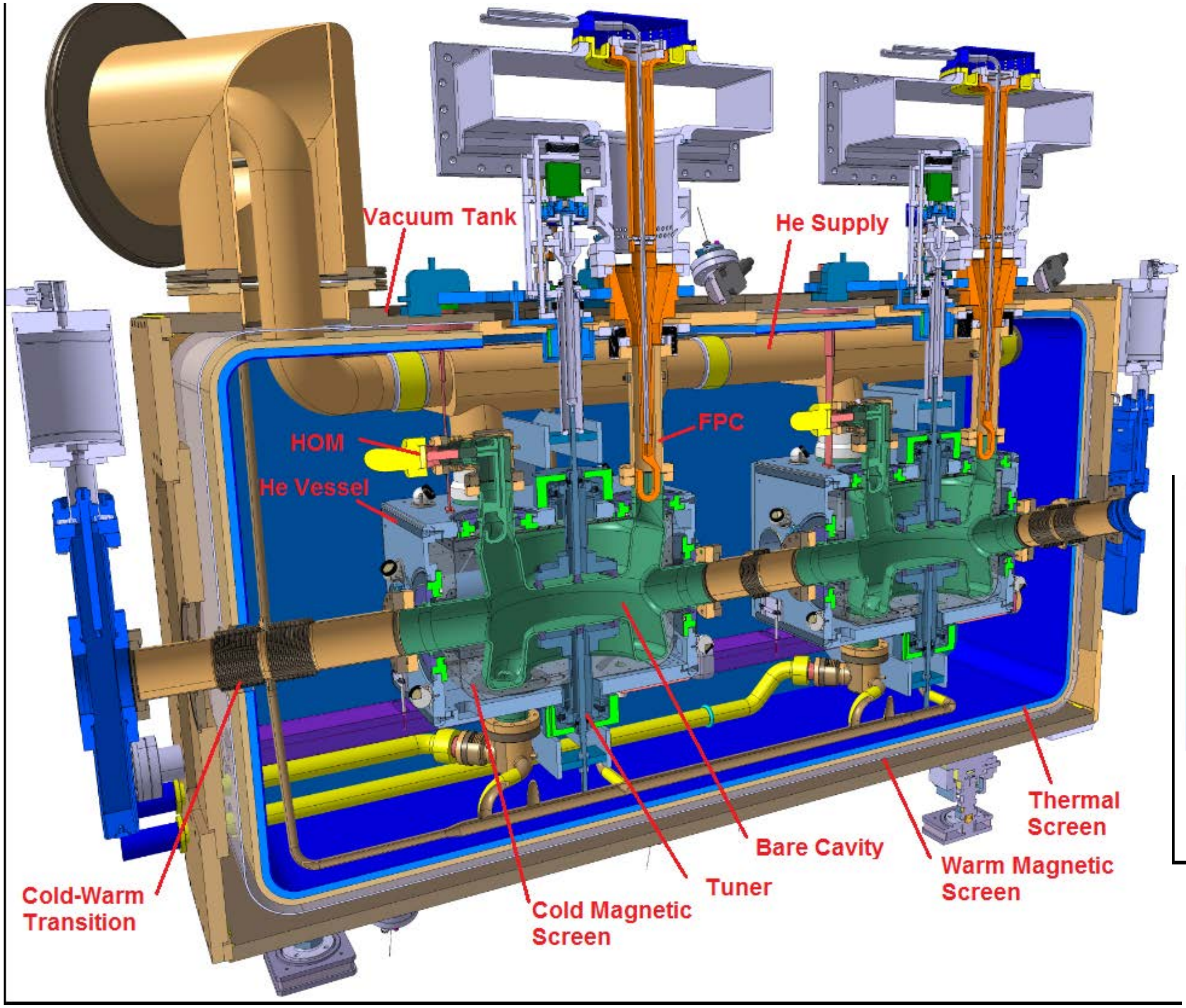


Timeline:

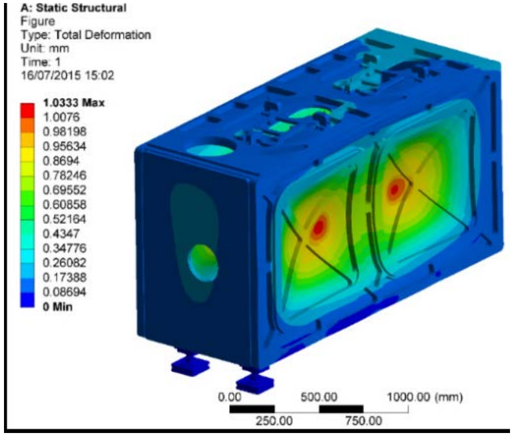
2016 - 2019

Amount: 1+13

LHC Crab Cavity Cryomodule



Timeline:
2017 - 2025
Amount: 16



Requirements

- Engineering
  - pressure vessel code (if applicable); vacuum forces
  - calculation pipe diameter, valve opening (K-value), heat exchanger
- Manufacturing
  - welding steel & aluminium
    - test with X-rays and/or colour test; thermal shock (LN2, then heat)
  - clean surfaces
    - no grease or welding residue left, ultra-sonic cleaning
- Assembly
  - helium leak testing, pressure testing
  - insulation sheets (MLI)
  - instrumentation (thermo-sensors & thermalization, feed-through)
  - magnetic shield