CERN developments for 704MHz superconducting cavities

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Introduction

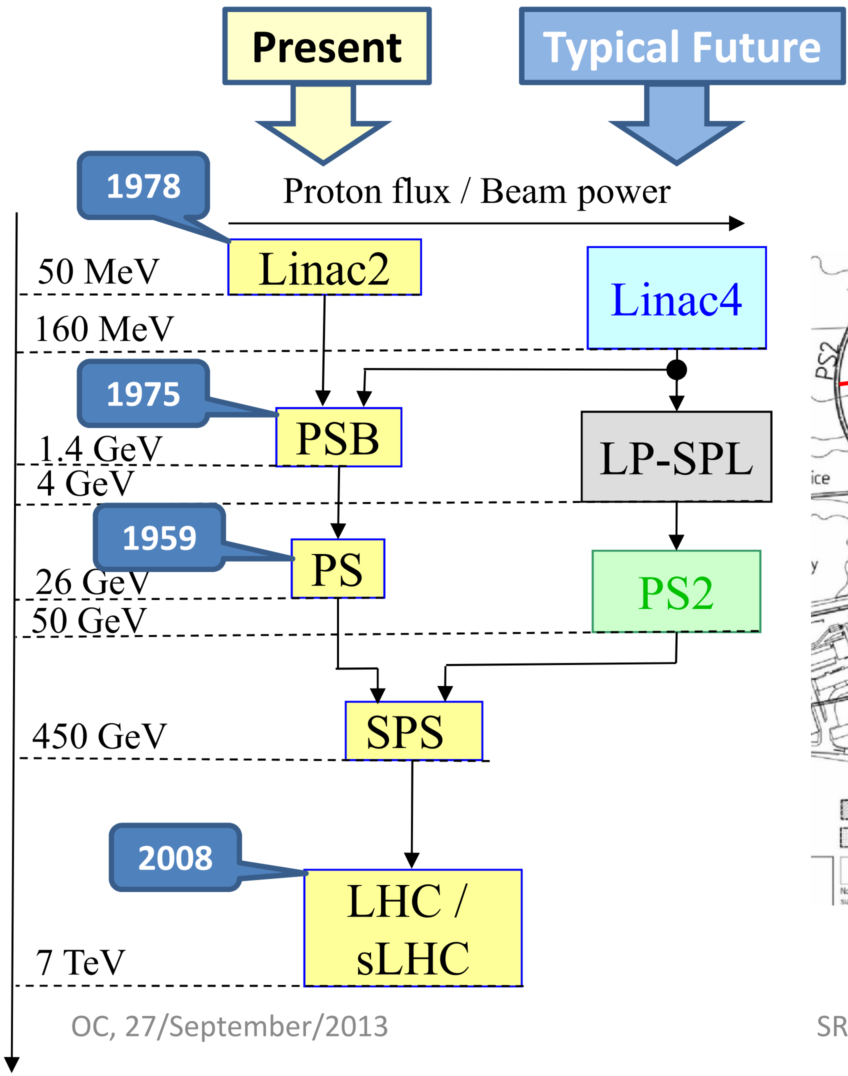
- CERN SRF has been "State of the Art" in 1990's during LEP200 energy upgrade and LHC SRF cavity production.
- Almost one decade of inactivity in SRF at CERN due to LHC construction and commissioning resulted in specific knowhow lost and installations/tools not further developed.
- Strengthening know-how in SRF started being a priority in view of the recent and future CERN activities.

Introduction

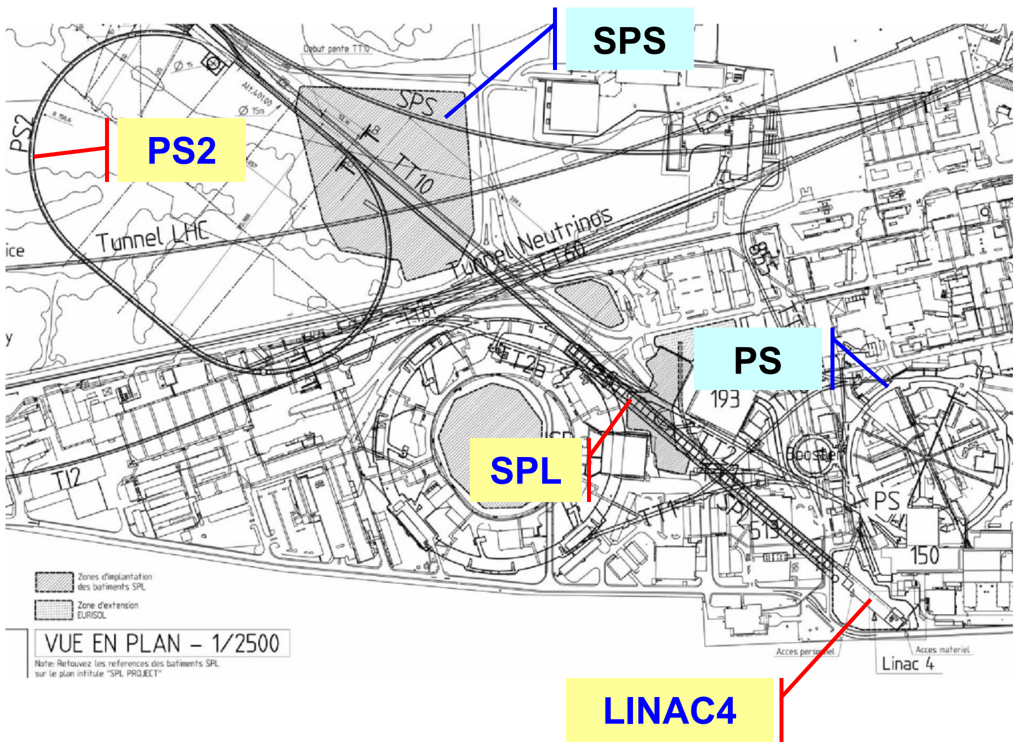
- Main SRF activities at CERN (including many collaborations):
  - LHC: 400 MHz, elliptical, niobium on copper
  - HIE Isolde: 101 MHz, quarter-wave, niobium on copper
    Talk Walter Venturini on Wednesday + posters
  - Crab cavities for LHC upgrade: 400 MHz, bulk niobium
    Talk Rama Calaga today + posters
  - Superconducting Proton Linac (SPL) R&D – this talk: 704 MHz, elliptical, bulk niobium
  - High-power impulse magnetron sputtering (HiPIMS) developments *Poster TUP078*
  - Fundamental studies on loss mechanisms
    Talk Sarah Aull on Wednesday

CERN motivation for the SPL R&D

- Preserve the possibility of new injectors in the future (HE-LHC…)

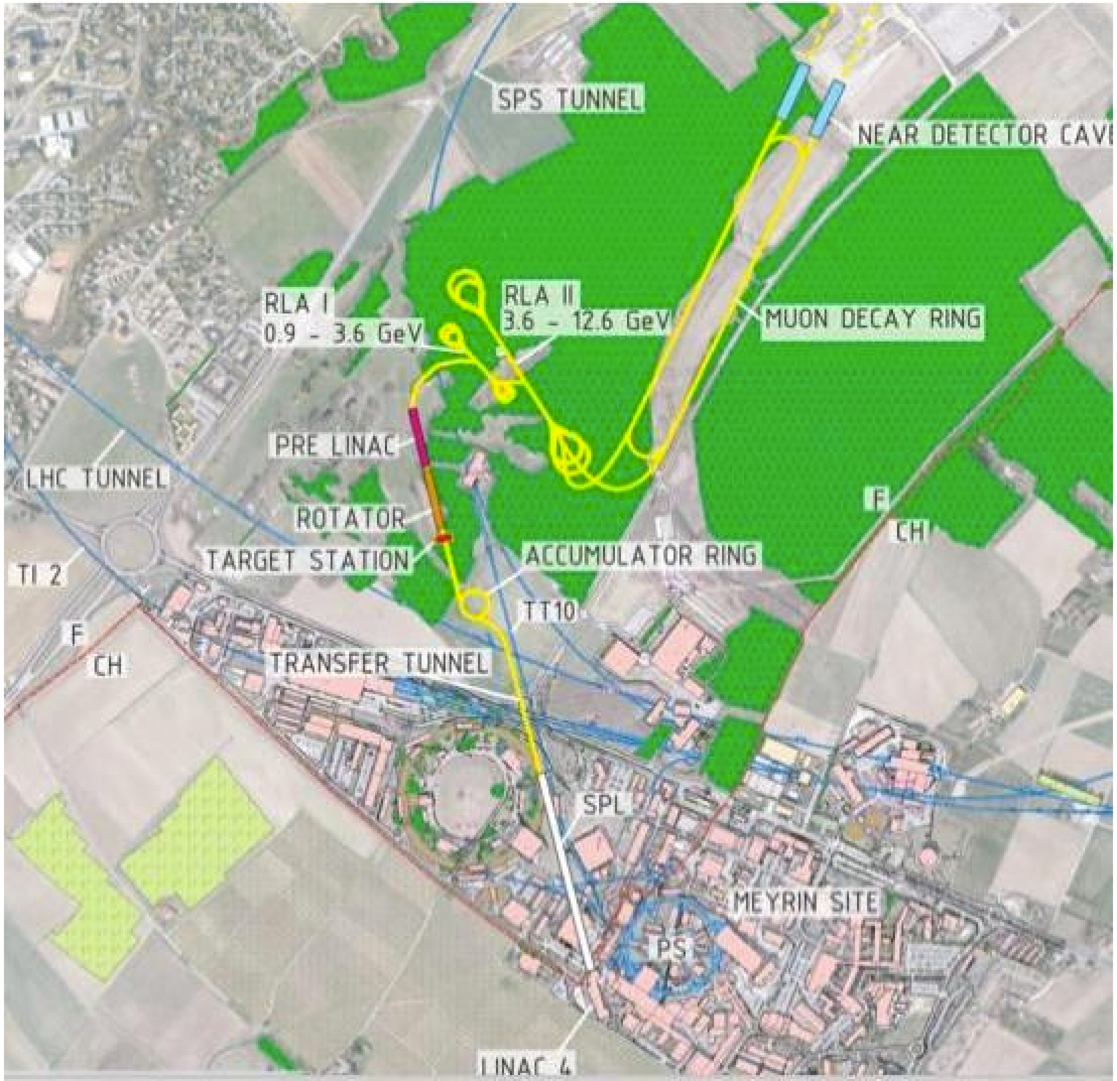


LP-SPL: Low Power-Superconducting Proton Linac
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
sLHC: "Super-luminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)



CERN motivation for the SPL R&D

- Options for neutrinos physics and/or Radioactive Ion Beam
  - Draft layout of neutrino factory at CERN

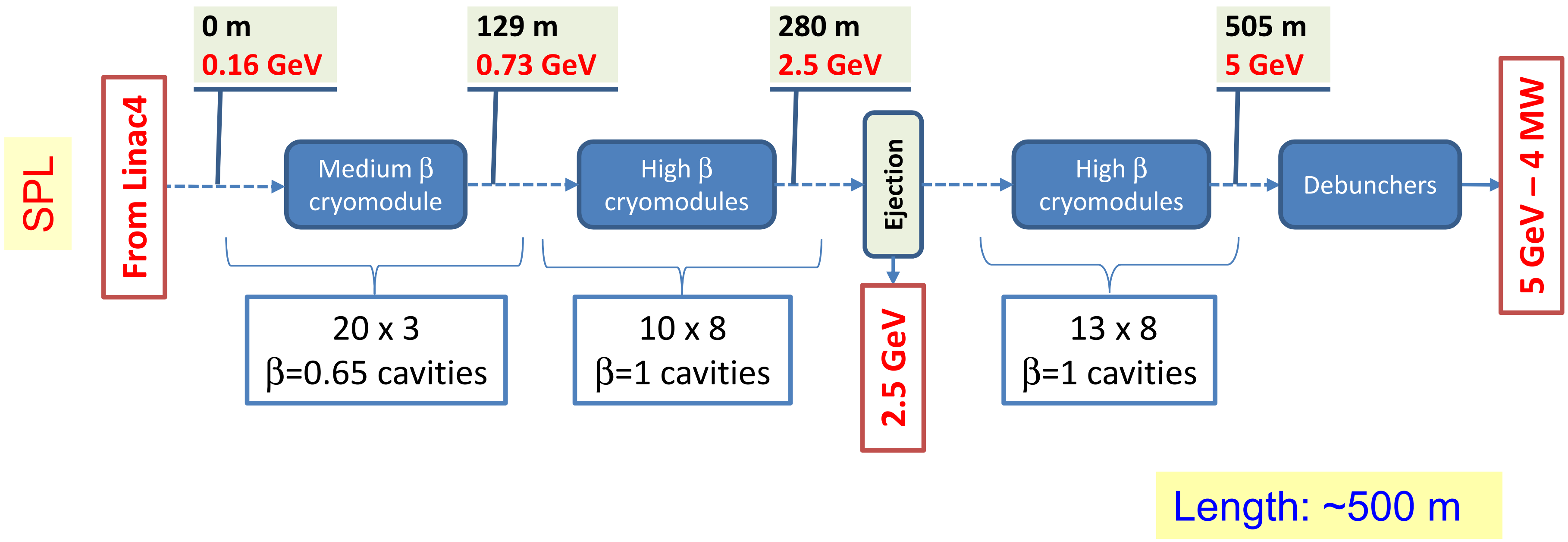


CERN motivation for the SPL R&D

- Update of CERN competencies in superconducting RF
- Upgrade of CERN infrastructure for superconducting RF (SM18 clean room, High Power RF, High Pressure Water Rinsing facility, Diagnostics for SC RF, New e-beam welding machine, Electropolishing installation, etc.)
- Synergy with other applications at CERN (LHeC electron linac, LEP-3…) as well as outside of CERN (ESS, ADS…)

SPL block diagram

- SC-linac [160 MeV ® 5 GeV] with ejection at intermediate energy



- Medium beta cavities beta = 0.65
- High beta cavities beta = 1

SPL developments for cavities

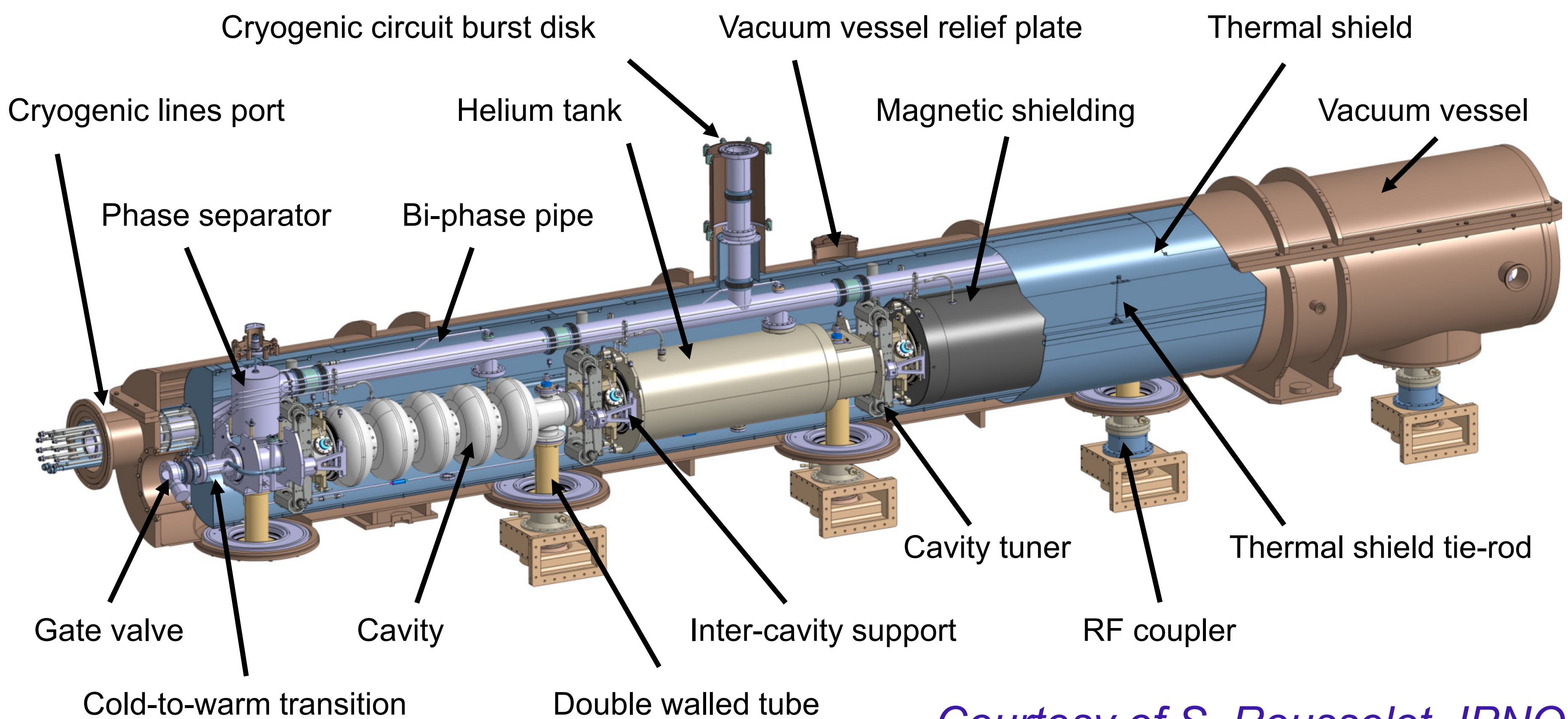
- Medium beta cavities beta = 0.65
  - Developed by IPN Orsay (Guillaume Olry et al.) to be tested at CEA Saclay in Cryholab

- High beta cavities beta = 1
  - Developed by CEA Saclay (Guillaume Devanz et al.) to be tested at CEA Saclay in Cryholab

  - Developed by CERN for tests at CERN in Short cryo-module

SPL Short Cryomodule

- A string of 4 equipped beta=1 bulk niobium cavities to be tested in short cryo-module by 2015



Courtesy of S. Rousselot, IPNO

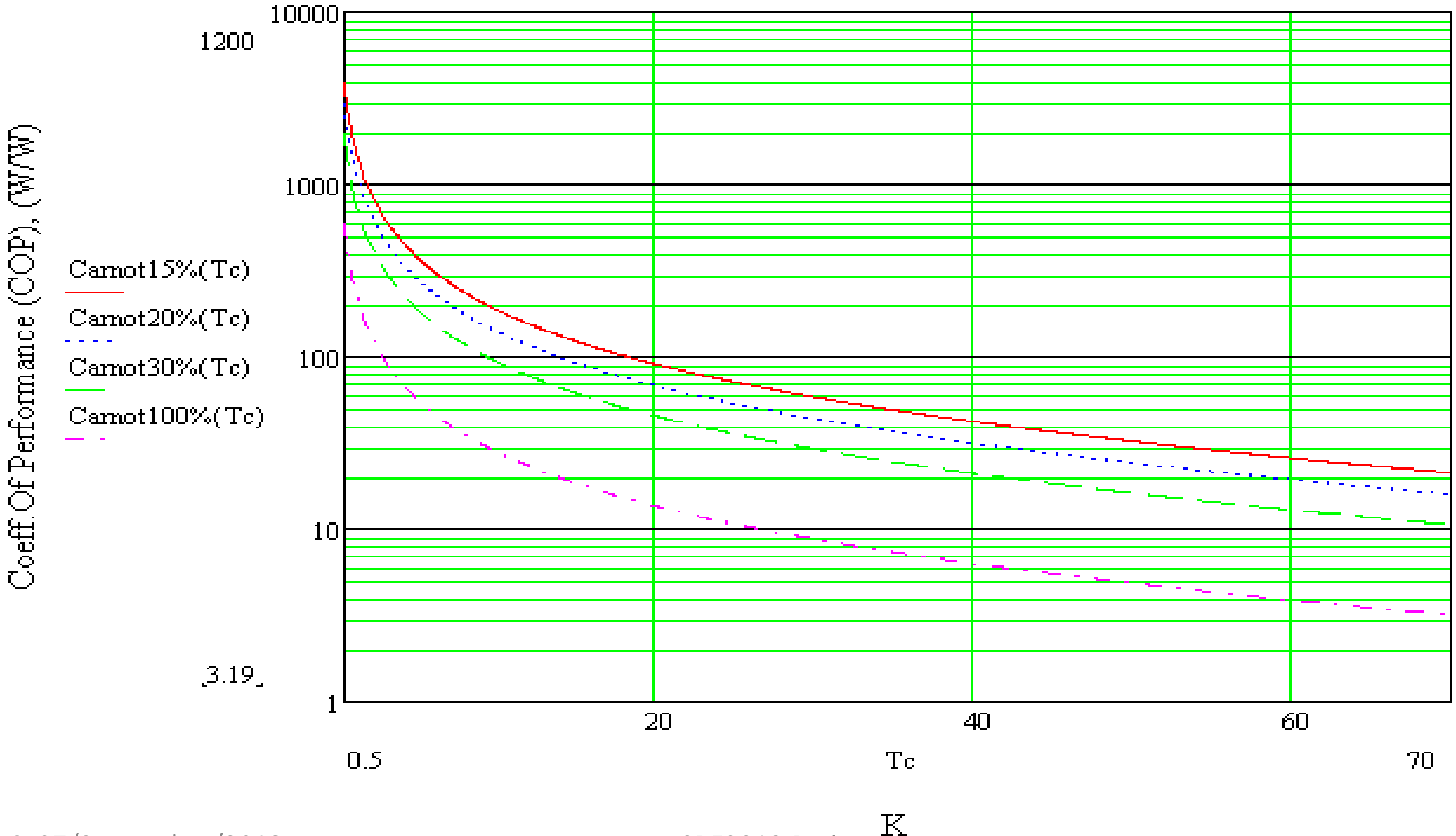
- V. Parma et al. poster MOP085

SPL Short Cryomodule

COP of cryogenic refrigeration

State-of-the-art figures (LHC cryoplants):

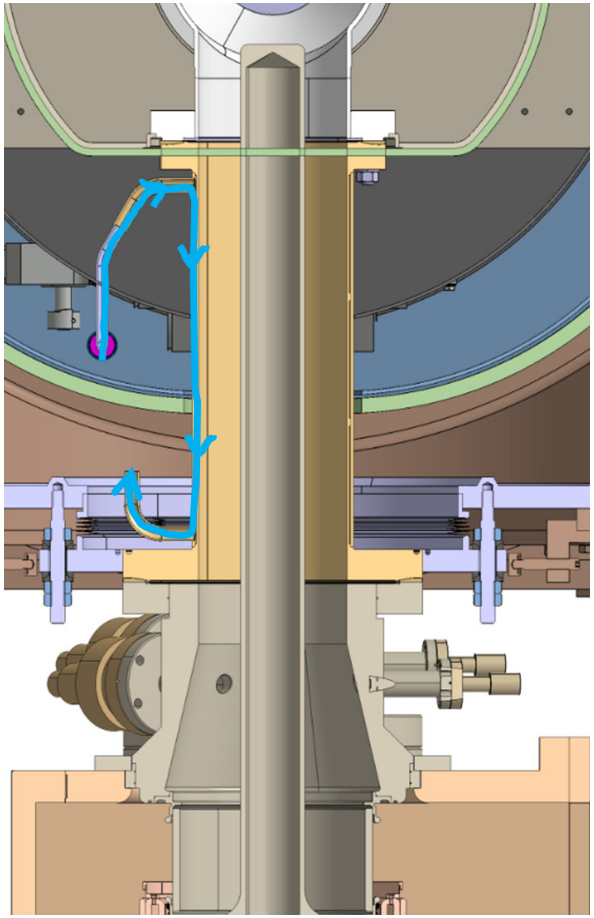
- COP @ **2 K** → ~ 15% Carnot **(990 W_{el}/W_{th})***
- COP @ **4.5 K** → ~ 30% Carnot **(210 W_{el}/W_{th})***
- COP @ **50 K** → ~ 30% Carnot **(16 W_{el}/W_{th})**

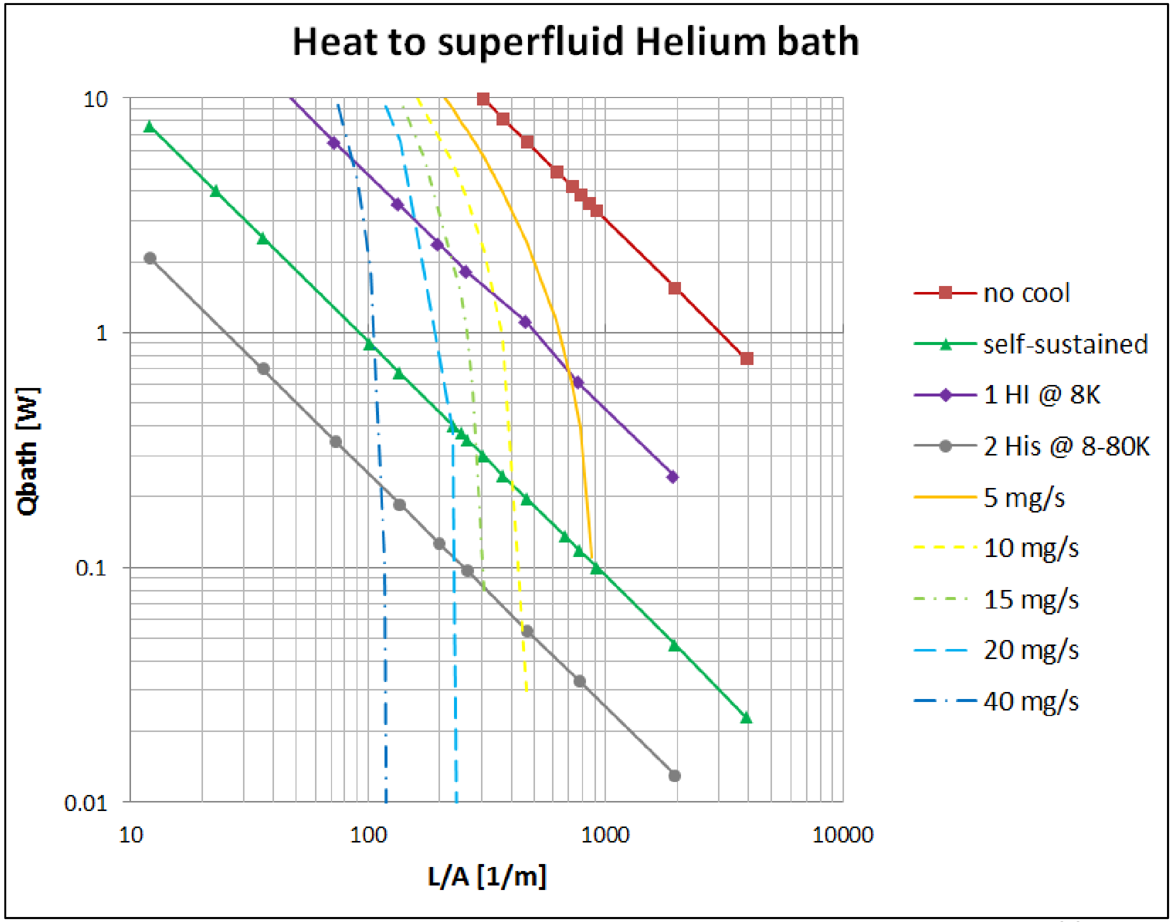


* S. Claudet et al. “1.8 K Refrigeration Units for the LHC: Performance Assessment of Pre-series Units”, proceedings ICEC20

SPL Short Cryomodule

- New supporting system concept minimizing heat loads to 2K bath
  - Optimization gets to one order of magnitude savings for heat loads to 2K from as well as total power consumption

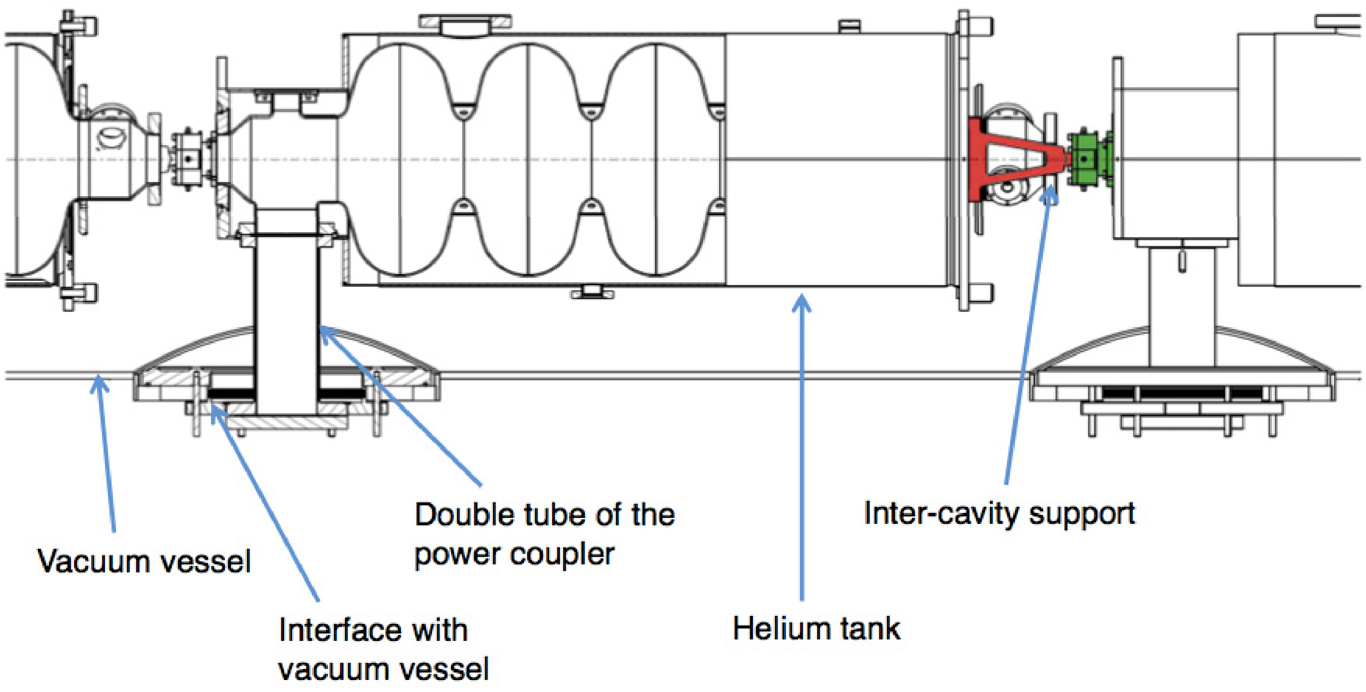




- R. Bonomi et al. poster THP049

SPL Short Cryomodule

- New supporting system concept minimizing heat loads to 2K bath



- V. Parma et al. poster MOP085

Cavity

- Equipped beta=1 cavity main design properties & operation

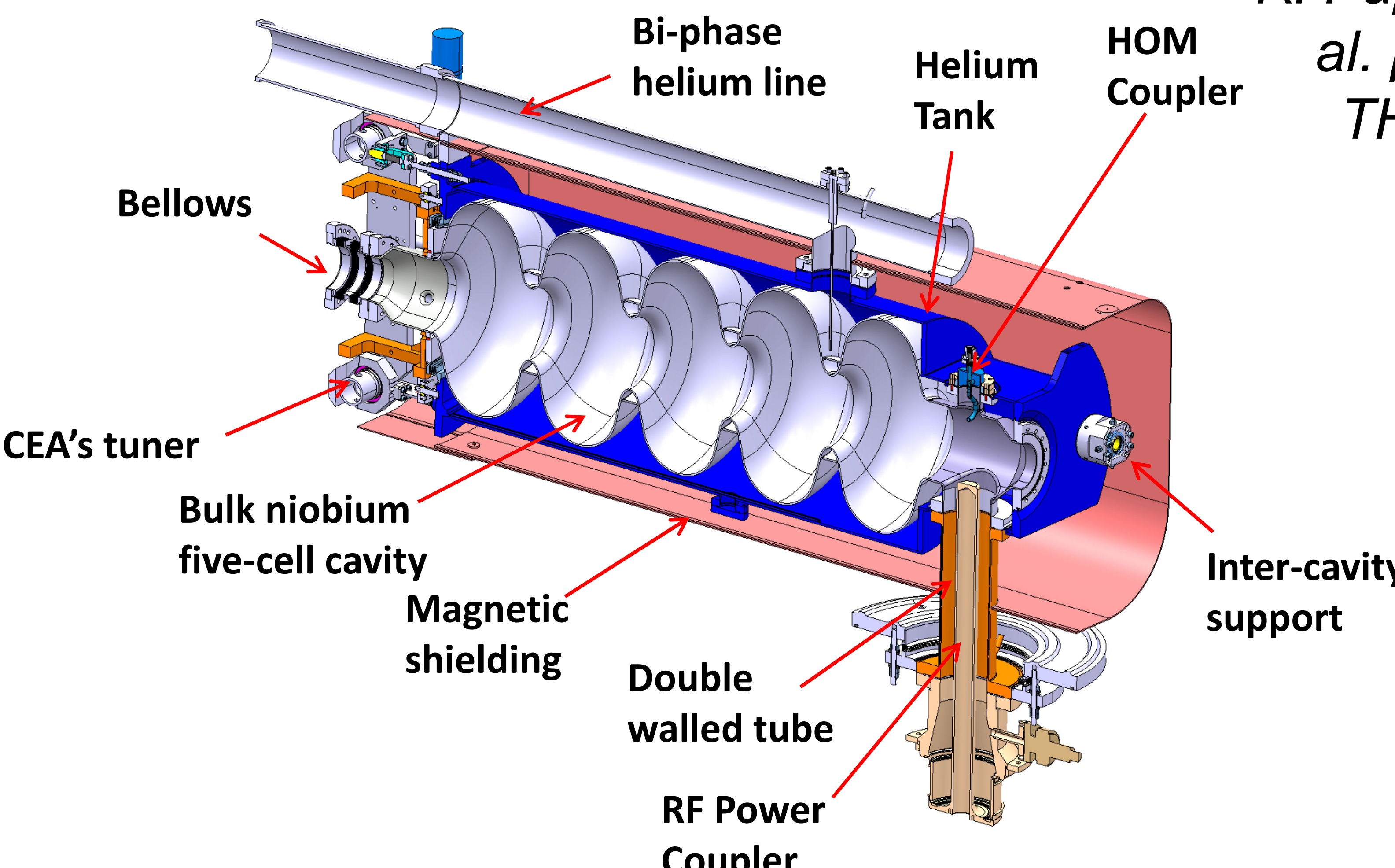
Property	units	Value
Fundamental frequency	[MHz]	704.4
Cavity material	-	bulk niobium
Gradient	MV/m	25
Quality factor* Q_0	-	$5 \cdot 10^9$
R/Q	Ohms	570
Operating Temp.	K	2
Cryo duty cycle	%	8.22
Dynamic heat load	W	20.4

*worst case assumption

Cavity

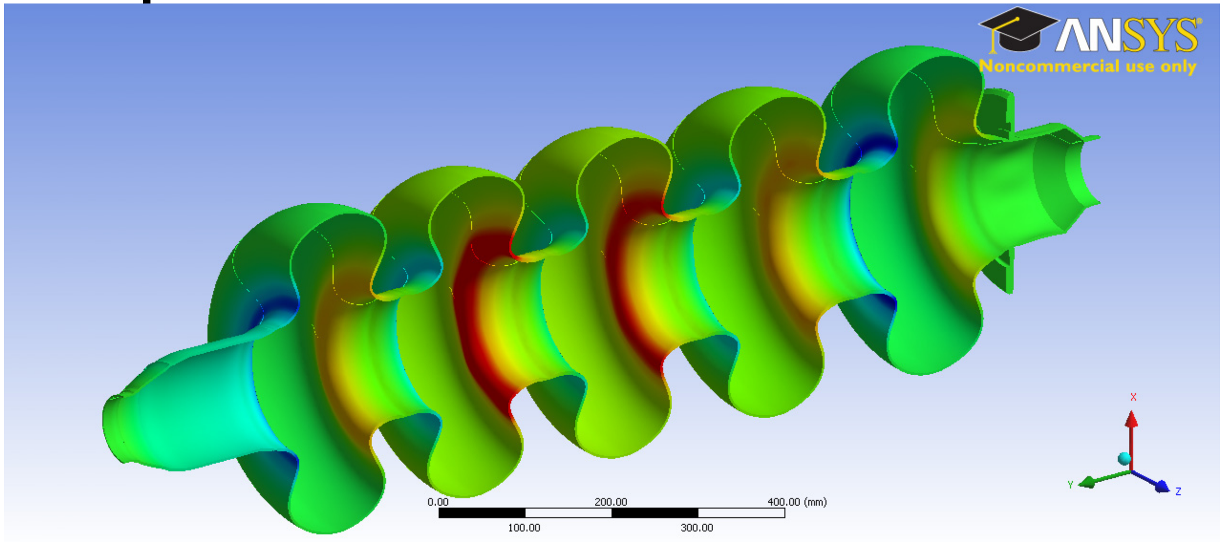
- Equipped beta=1 cavity

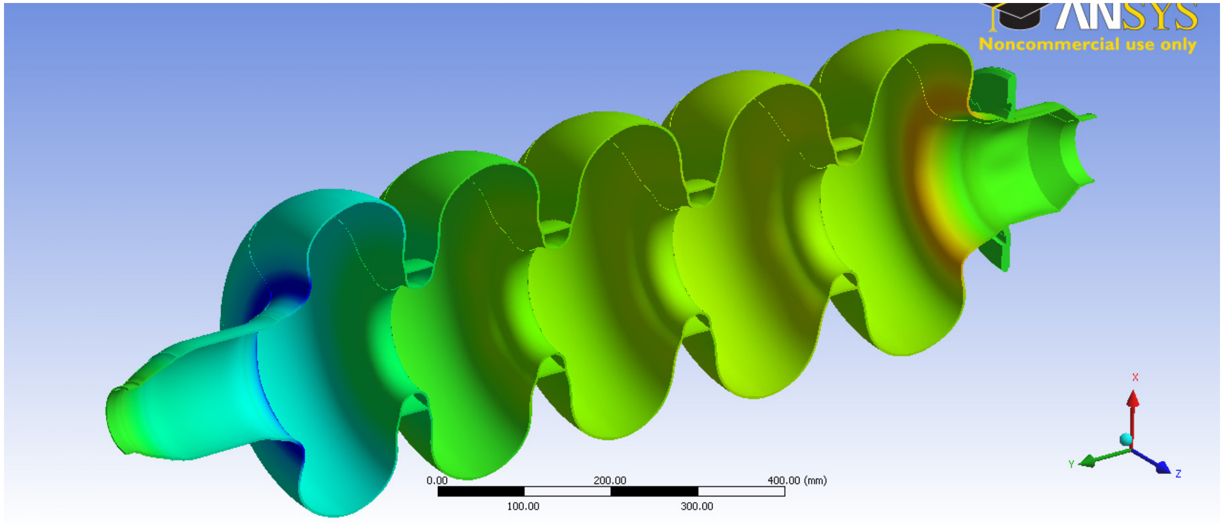
K. Papke et al. poster THP064



Cavity

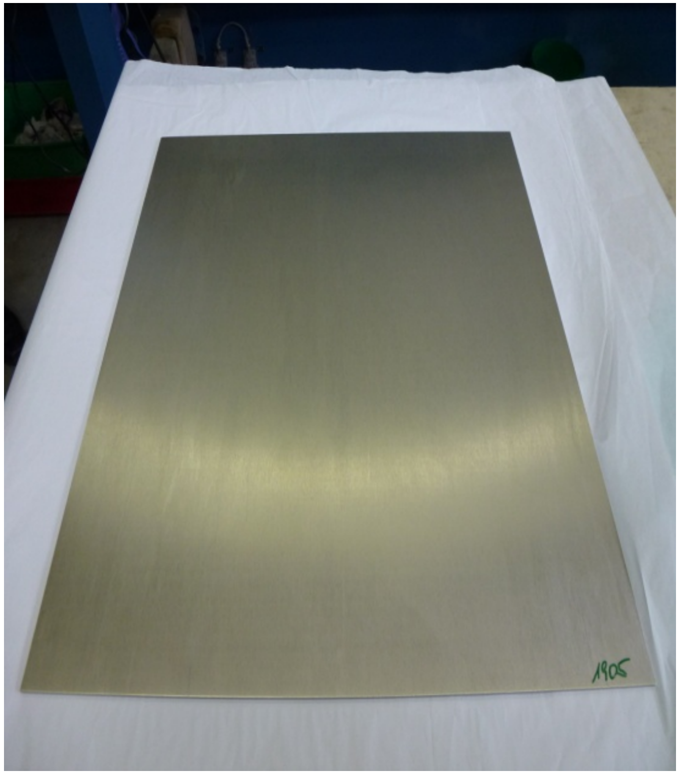
- Pulsed mode operation – Lorentz detuning had to be optimized





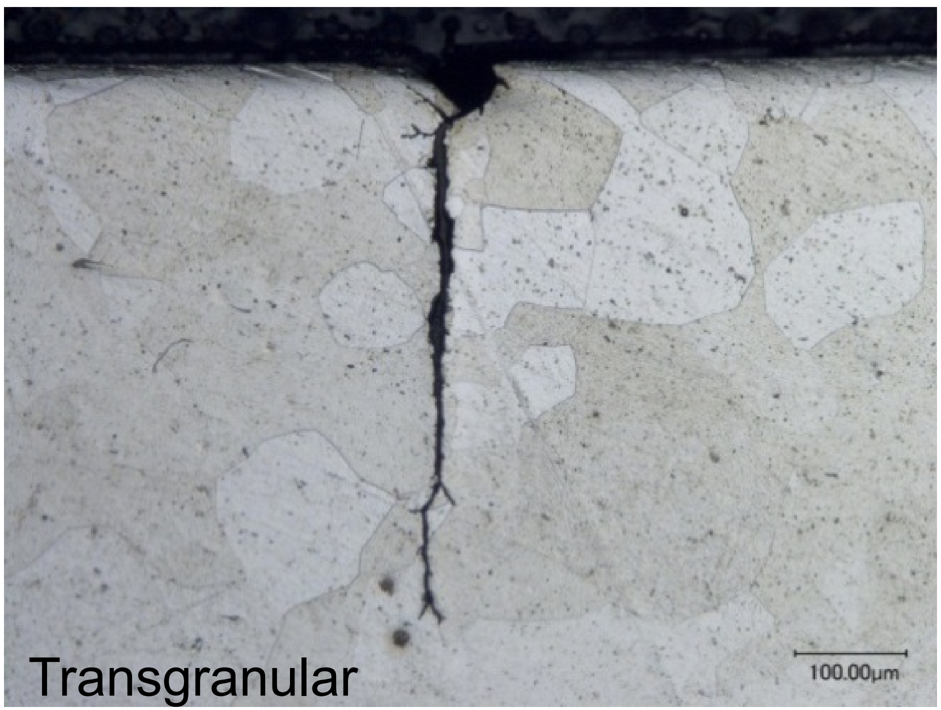
Cavity

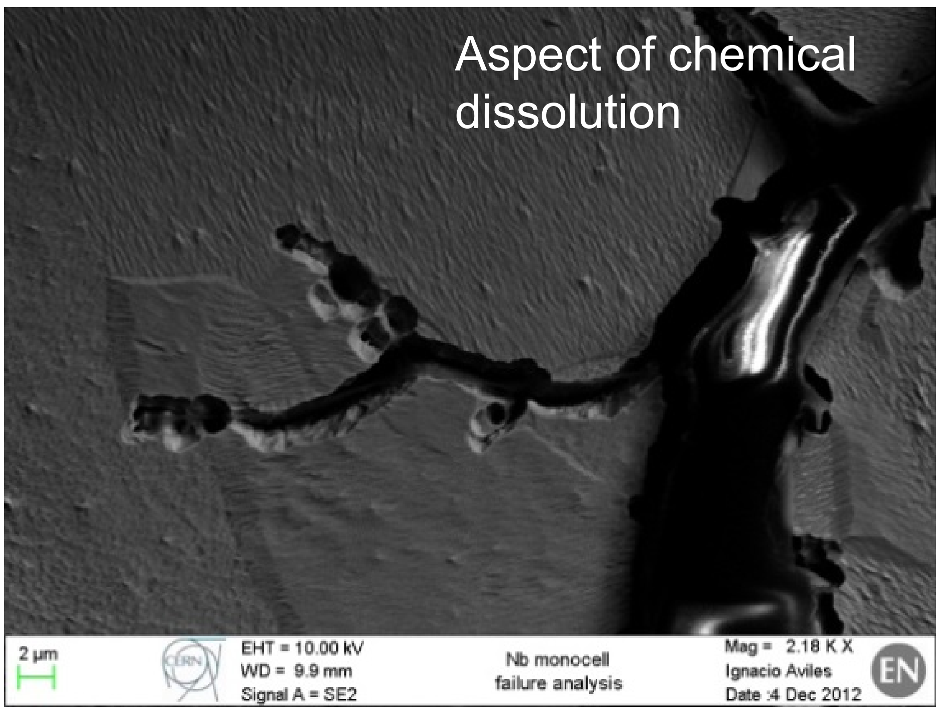
- Niobium material in plates and seamless tubes fully characterized at company and at CERN



Cavity

- Niobium material - issues with seamless tubes
  - Stress corrosion cracking ? (very well known for the stainless steel but not found in literature for niobium)

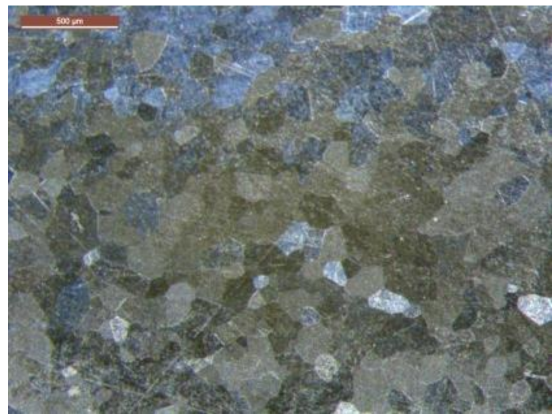




Cavity

- Niobium material - issues with seamless tubes for necking out of cut-off (ok for plates)

From seamless tube



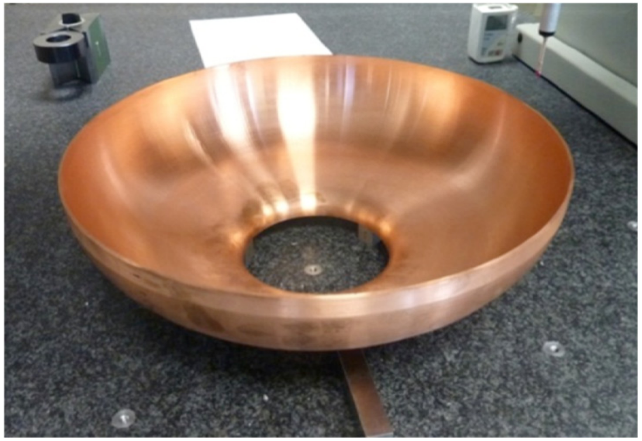
- Recrystallized equiaxial grains
- Hardness: 57,1 HV10 (technical specification: < 60 HV10)

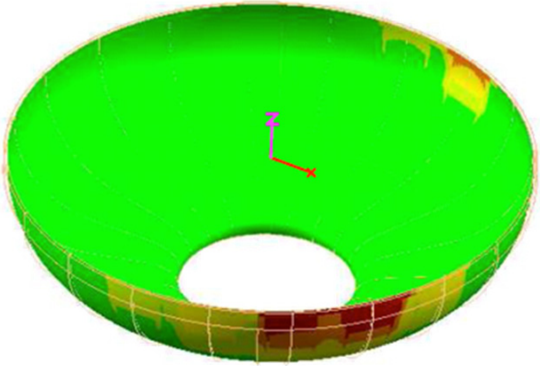
From rolled plate

From spun plate

Cavity

- Manufacture technology chosen: spinning + EB welding
  - Good shape accuracy for Cu half-cells after spinning + machining of inner part (~ 0.2 mm range)
  - Challenging shape accuracy for Nb half-cell after spinning no machining (~ 0.5 to1 mm); new shaping techniques under development

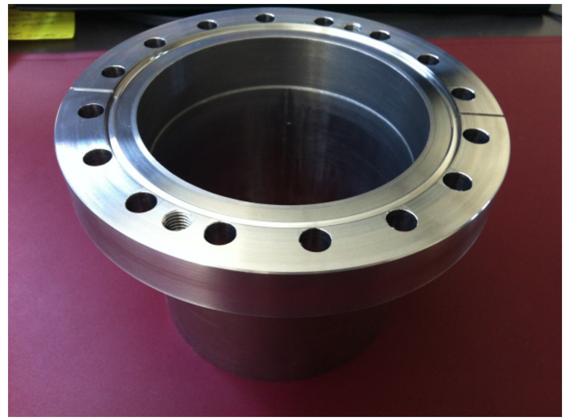


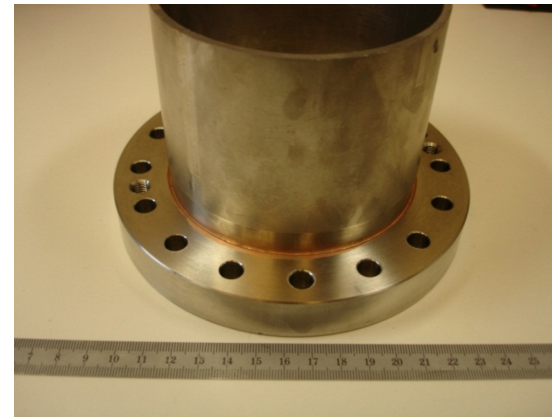


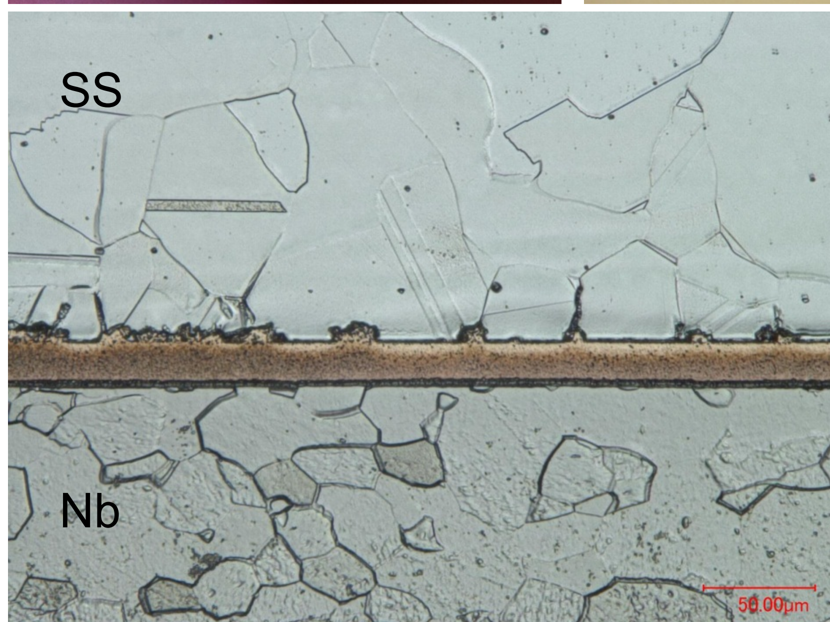
Cavity

- Material choices / joining techniques
  - Stainless steel (316LN) – niobium: vacuum brazing

Ultrasonic examination
Leak test
Thermal shock liquid N_2 (x5)
Ultrasonic examination
Leak test
Electropolishing
HT (600°C/24h)
Electropolishing
Leak test
Ultrasonic examination
Thermal shock liquid N_2 (x5)
Ultrasonic examination
Leak test
Shear test
Leak test
Ultrasonic examination
Assembly test
Metallographic examination
Fractography
SEM assesment + EDS







316LN to Nb vacuum brazing fully qualified

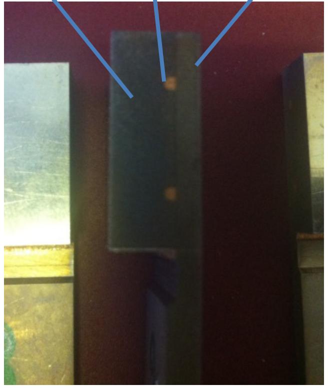
Cavity

- Material choices / joining techniques
  - Stainless steel (316LN) – niobium: vacuum brazing
    - Effect of Chemical etching to the brazing?

      10 samples introduced in the chemical bath
      [bath: (1:1:2) 40%HF, 65% HNO_3, 85% H_3PO_4]
      at different conditions without masking the brazed joint

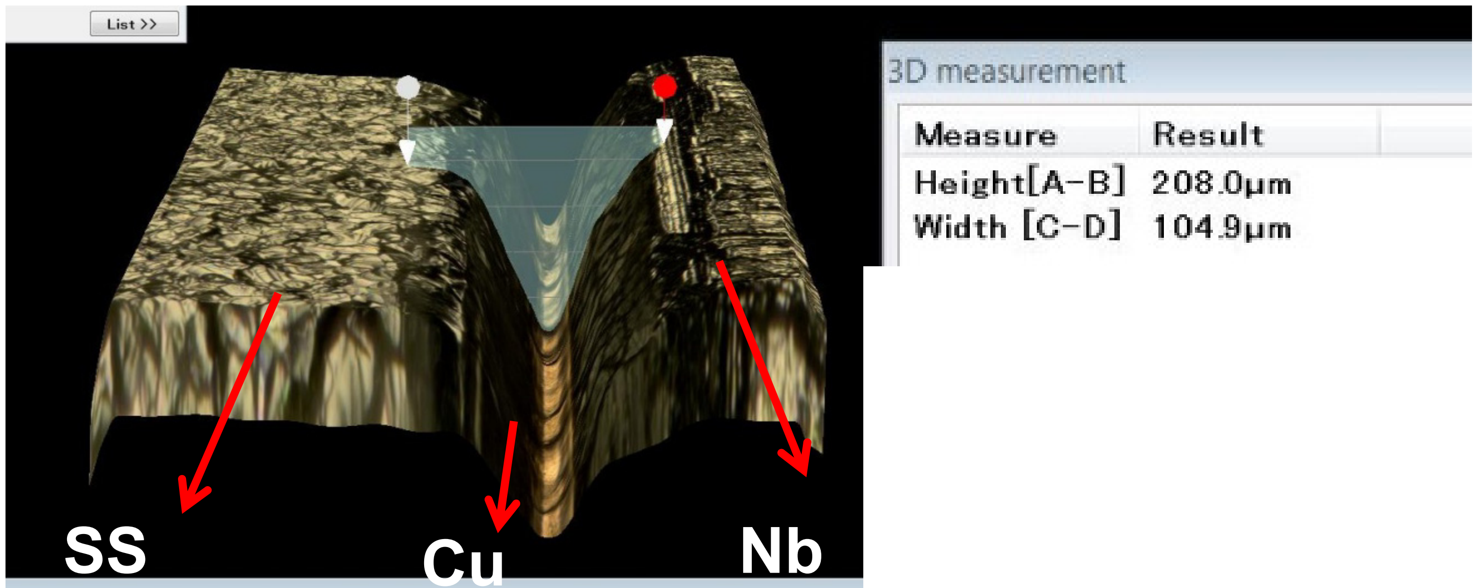
SS
Nb

SS
Cu
Nb



Cavity

- Material choices / joining techniques
  - Stainless steel (316LN) – niobium: vacuum brazing
    - Effect of Chemical etching to the brazing?

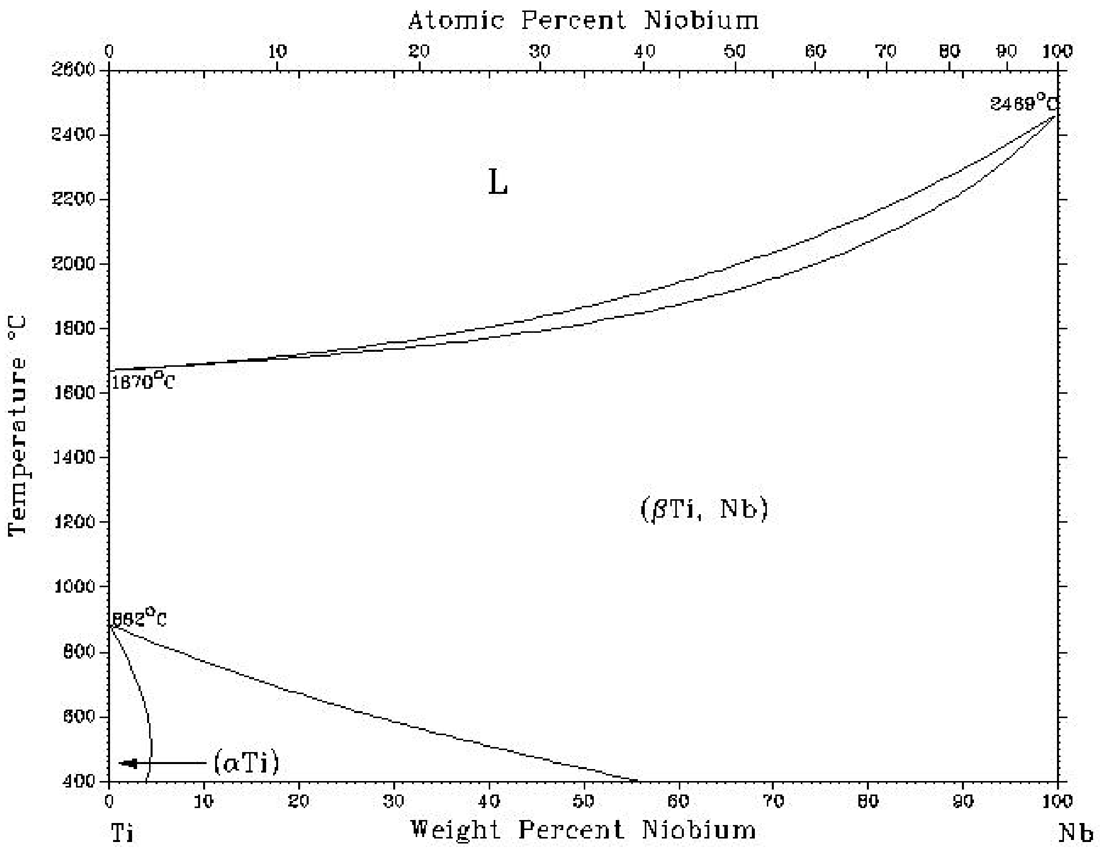


- About 300μm of Cu removed for ~ 50μm of Nb removed
- Decided to mask the brazing during etching

Cavity

- Material choices / joining techniques
  - Titanium (Ti6Al4V) – niobium: welding

A ssessed Ti-Nb phase diagram.

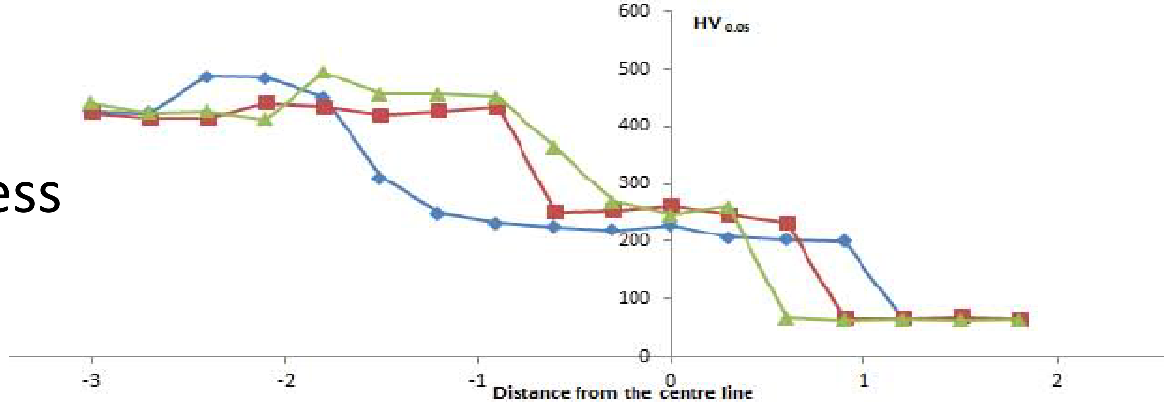


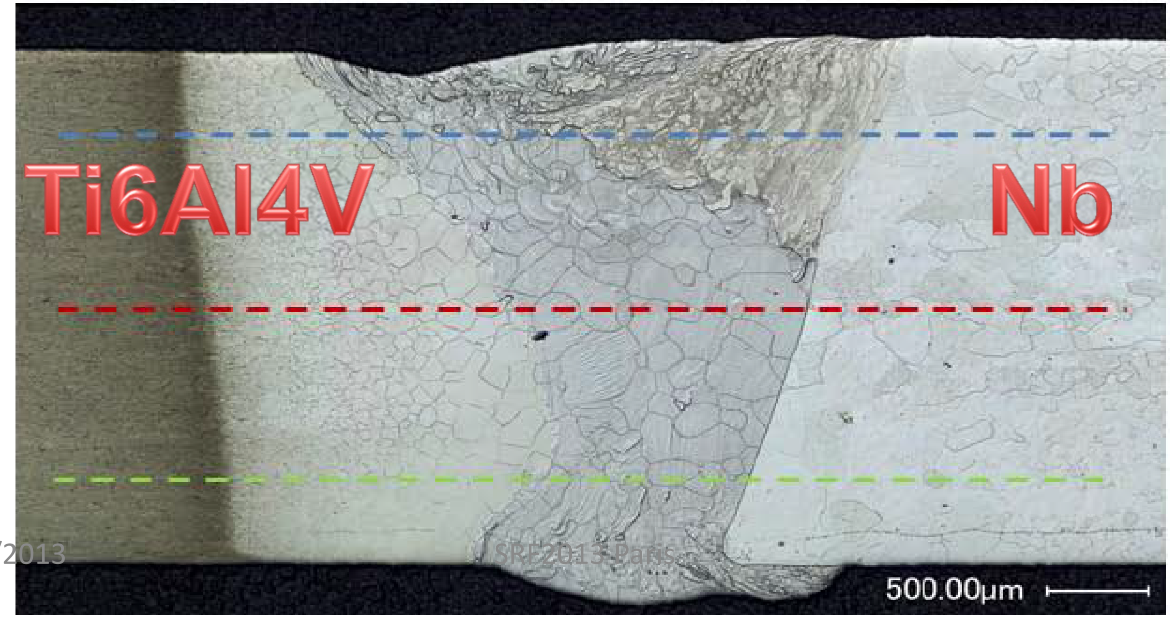
Ti6Al4V to Nb EB welding fully qualified

	Nb	Ti6Al4V
ρ (Kg/m³)	8600 – 8700	4410 – 4450
T_m (ºC)	2460 – 2470	1610 – 1660
K (W/m ºC)	54 – 57	7.1 – 7.3

- Material choices / joining techniques
  - Titanium (Ti6Al4V) – niobium: welding

Microhardness





Ti6Al4V to Nb EB welding fully qualified

Cavity

- Some material choice considerations

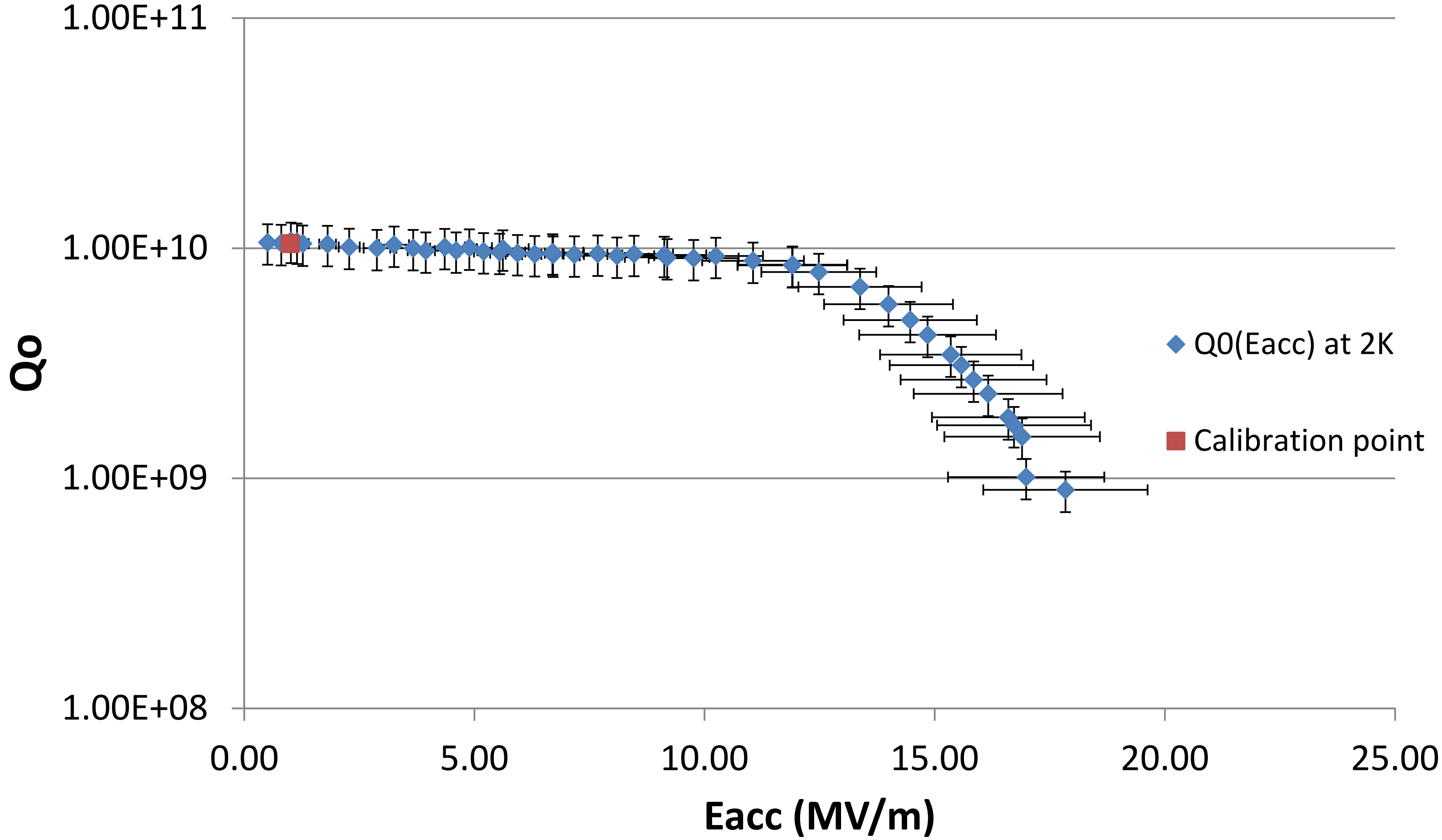
Material	~ Price / kg [Euro]	~ Yield Strength at 300K [MPa]	~ HV at 300K
316 LN	10	280	220
Ti grade 2	65	300	160
Ti grade 5 (Ti6Al4V)	65	800	350
NbTi55	450	370	170

Cavity

- Manufacturing of beta=1 cavities developed at CERN
  - 2 five-cell copper cavities manufactured
  - 1 monocell niobium manufactured by RI
  - 4 five-cell niobium under manufacturing by RI
  - 1 five-cell niobium under manufacturing at CERN

Cavity

- First results of RF measurement at 2K (after partial cavity processing)



Infrastructure upgrade

- New Electron-Beam welding machine

Infrastructure upgrade

- Tuning and bead-pull measurement machine

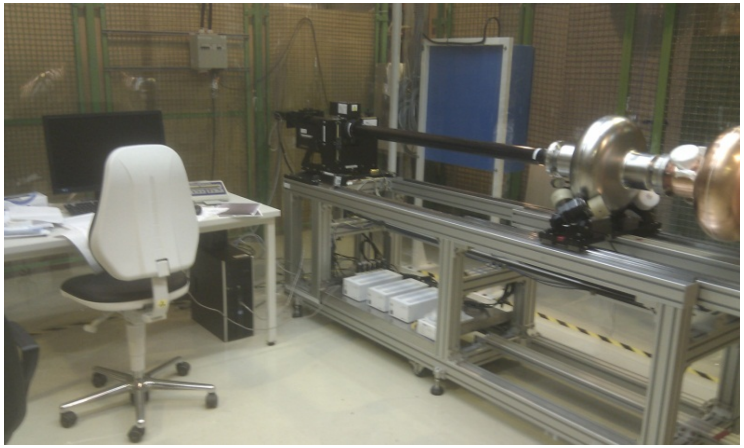
Infrastructure upgrade

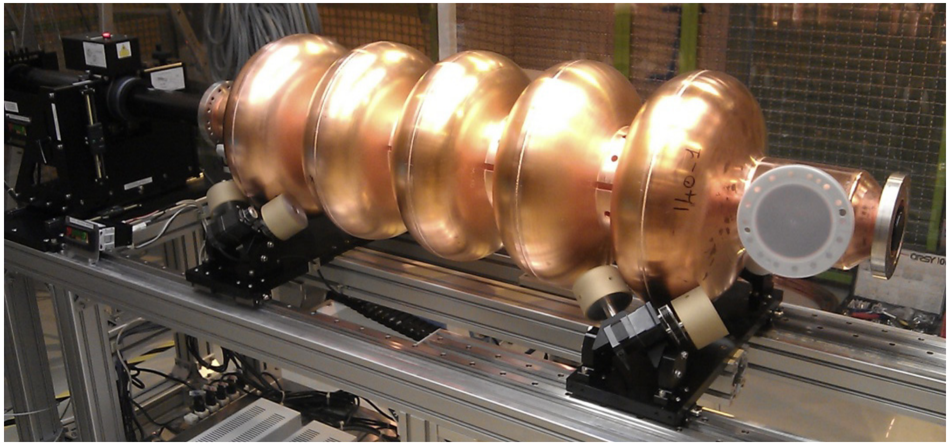
- Electropolishing

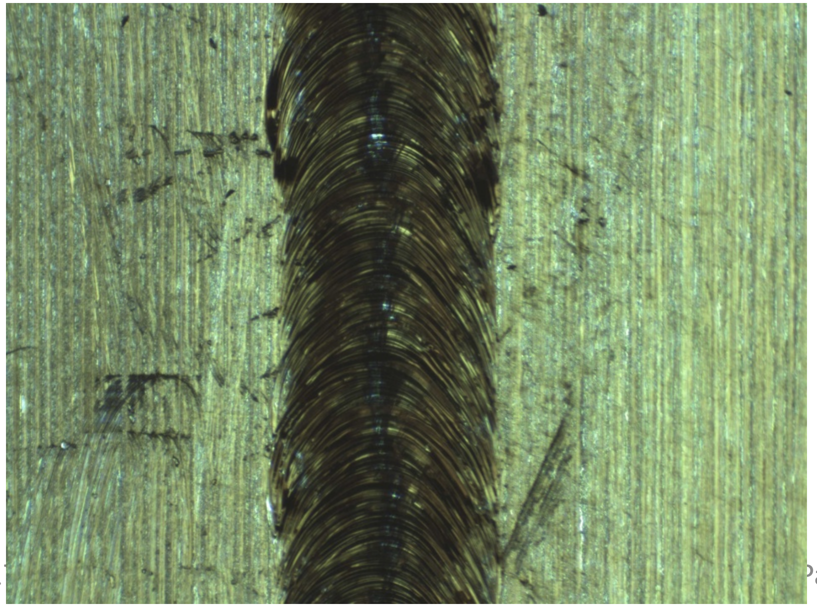
L. Marques et al.
poster TUP047

Infrastructure upgrade

- Optical inspection

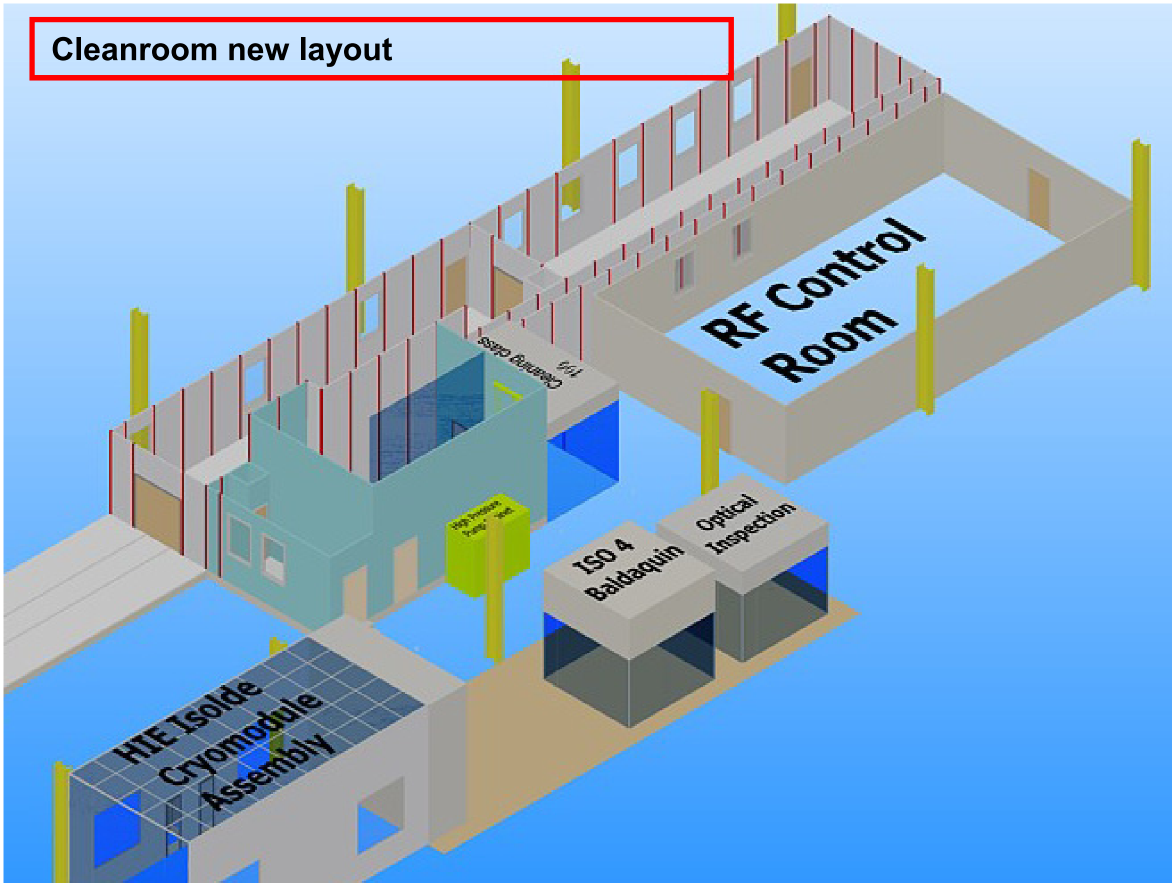






Infrastructure upgrade

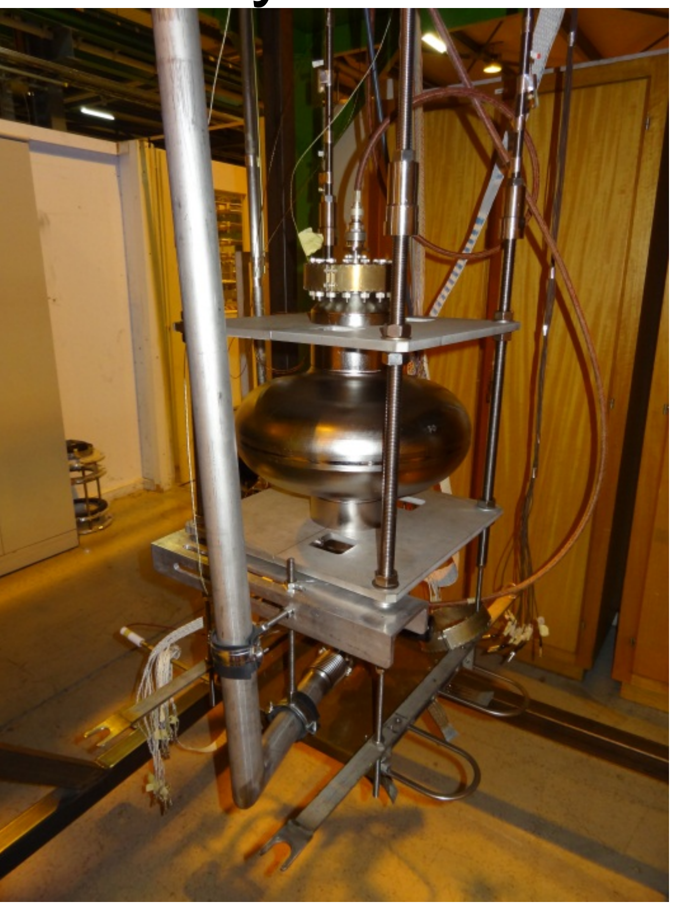
- Clean room upgrade

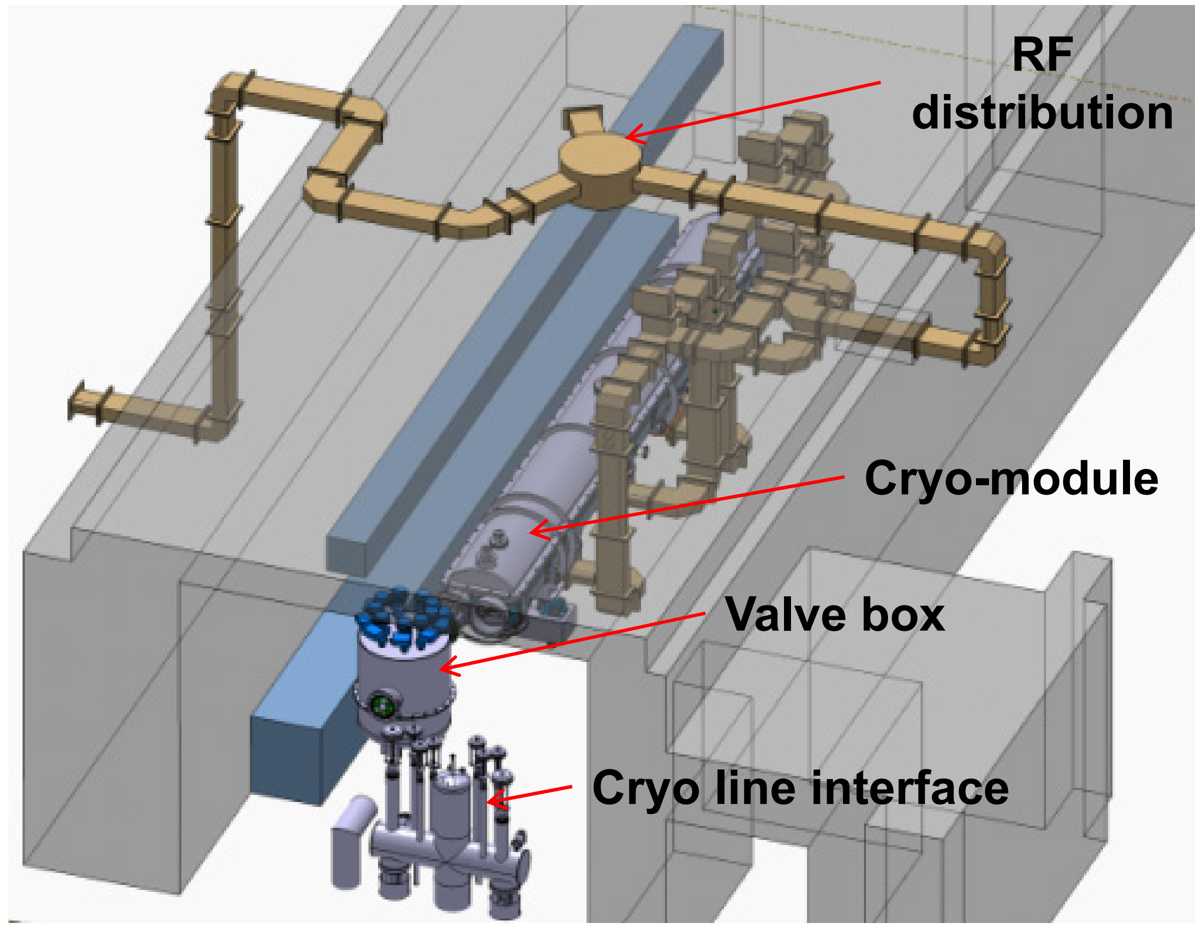


Including support from CRISP program

Infrastructure upgrade

- Cryogenics infrastructure for vertical tests and cryomodule

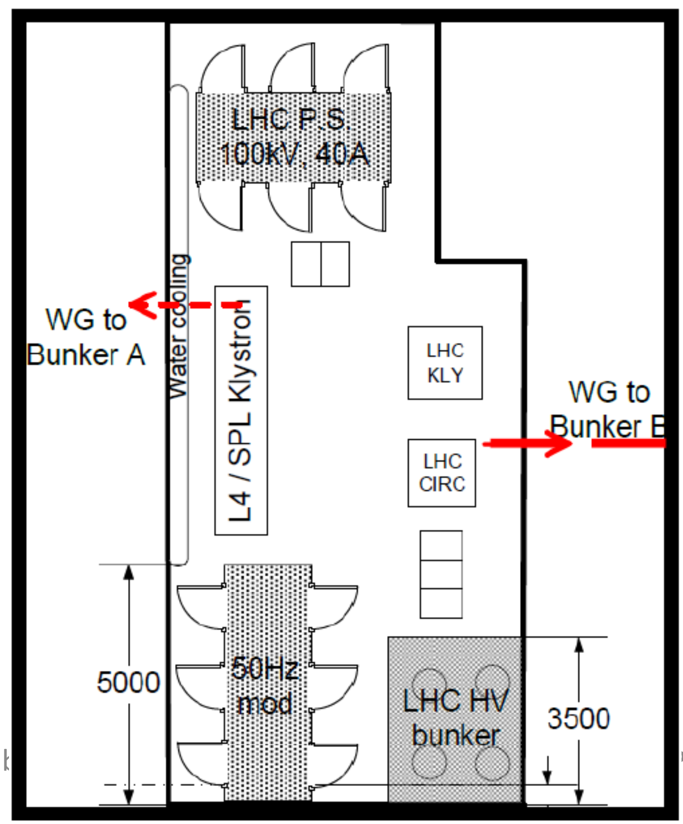




Including support from CRISP program

Infrastructure upgrade

- RF infrastructure upgrade
  - 1.5 MW klystron – delivery beginning 2014
  - Klystron modulator – delivery this year
  - New Low Level RF at 704 MHz – by end of 2014



Courtesy of Olivier Brunner

Summary

- Update of CERN competencies in superconducting RF.
- Extensive studies and investment done for 704MHz dressed cavities, cavity processing, cryo-module, and infrastructure.
- Two five-cell copper cavities, one bulk-niobium monocell produced; Four five-cell bulk-niobium under manufacturing by industry (RI) and one at CERN with an R&D development approach.
- A string of four SPL 704 MHz beta=1will be tested by 2015 in Short cryo-module at CERN.