



EUROPEAN
SPALLATION
SOURCE

CERN developments for 704MHz superconducting cavities

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Introduction

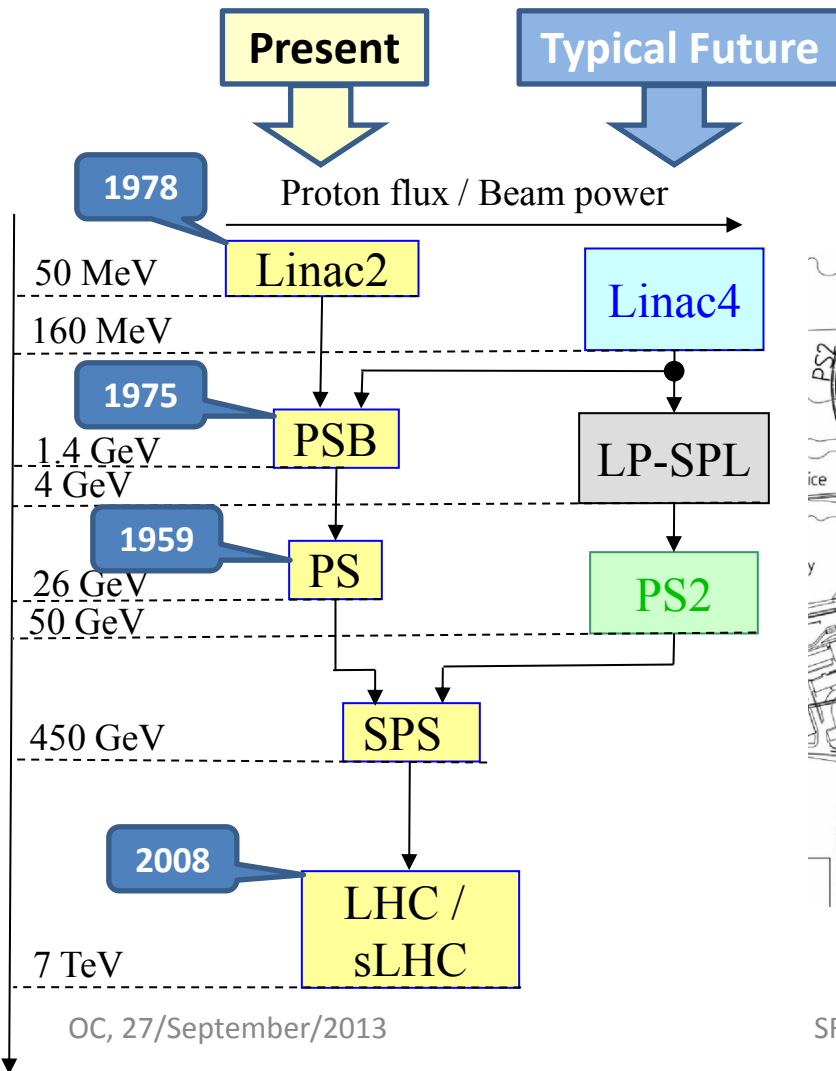
- CERN SRF has been “State of the Art” in 1990’s during LEP200 energy upgrade and LHC SRF cavity production.
- Almost one decade of inactivity in SRF at CERN due to LHC construction and commissioning resulted in specific knowhow lost and installations/tools not further developed.
- Strengthening know-how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

Introduction

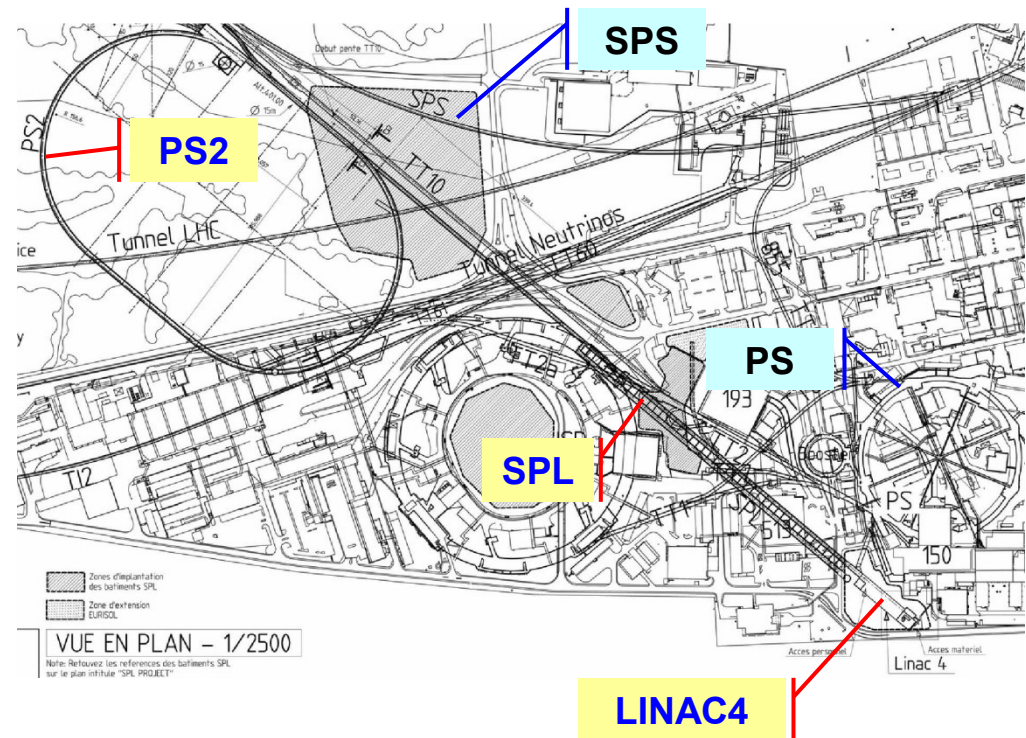
- Main SRF activities at CERN (including many collaborations):
 - LHC: 400 MHz, elliptical, niobium on copper
 - HIE Isolde: 101 MHz, quarter-wave, niobium on copper
Talk Walter Venturini on Wednesday + posters
 - Crab cavities for LHC upgrade: 400 MHz, bulk niobium
Talk Rama Calaga today + posters
 - 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 $10^{35} \text{ cm}^{-2}\text{s}^{-1}$)



CERN motivation for the SPL R&D

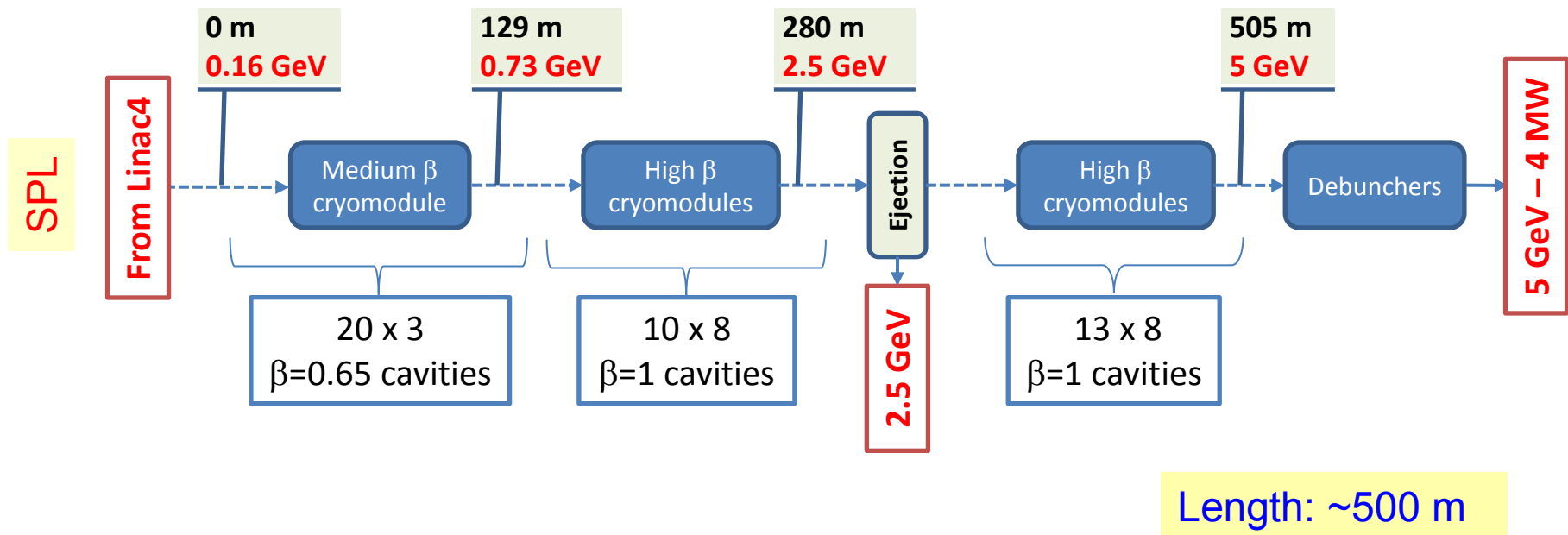
- Options for neutrinos physics and/or Radioactive Ion Beam
 - Draft layout of neutrino factory at CERN



- 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



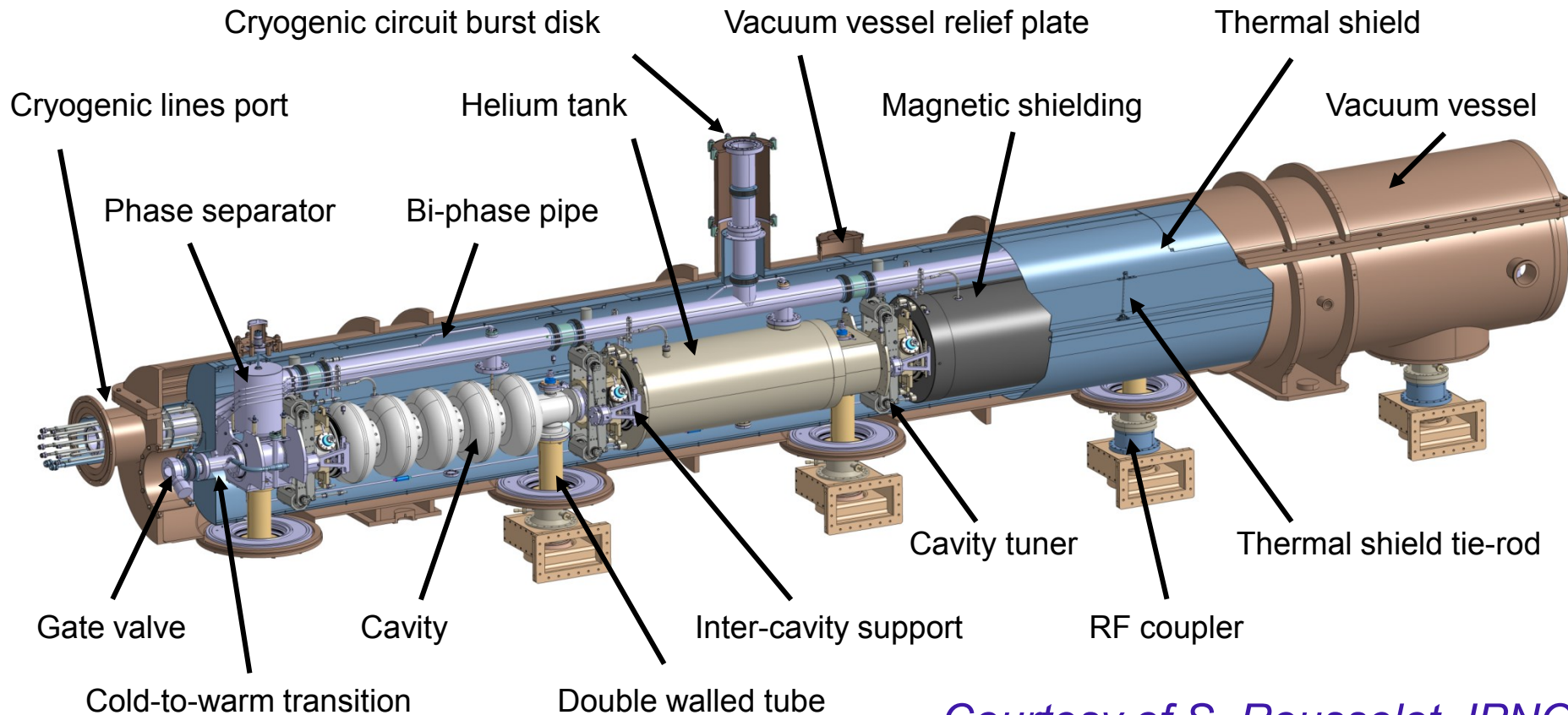
- Medium beta cavities $\beta = 0.65$
- High beta cavities $\beta = 1$

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



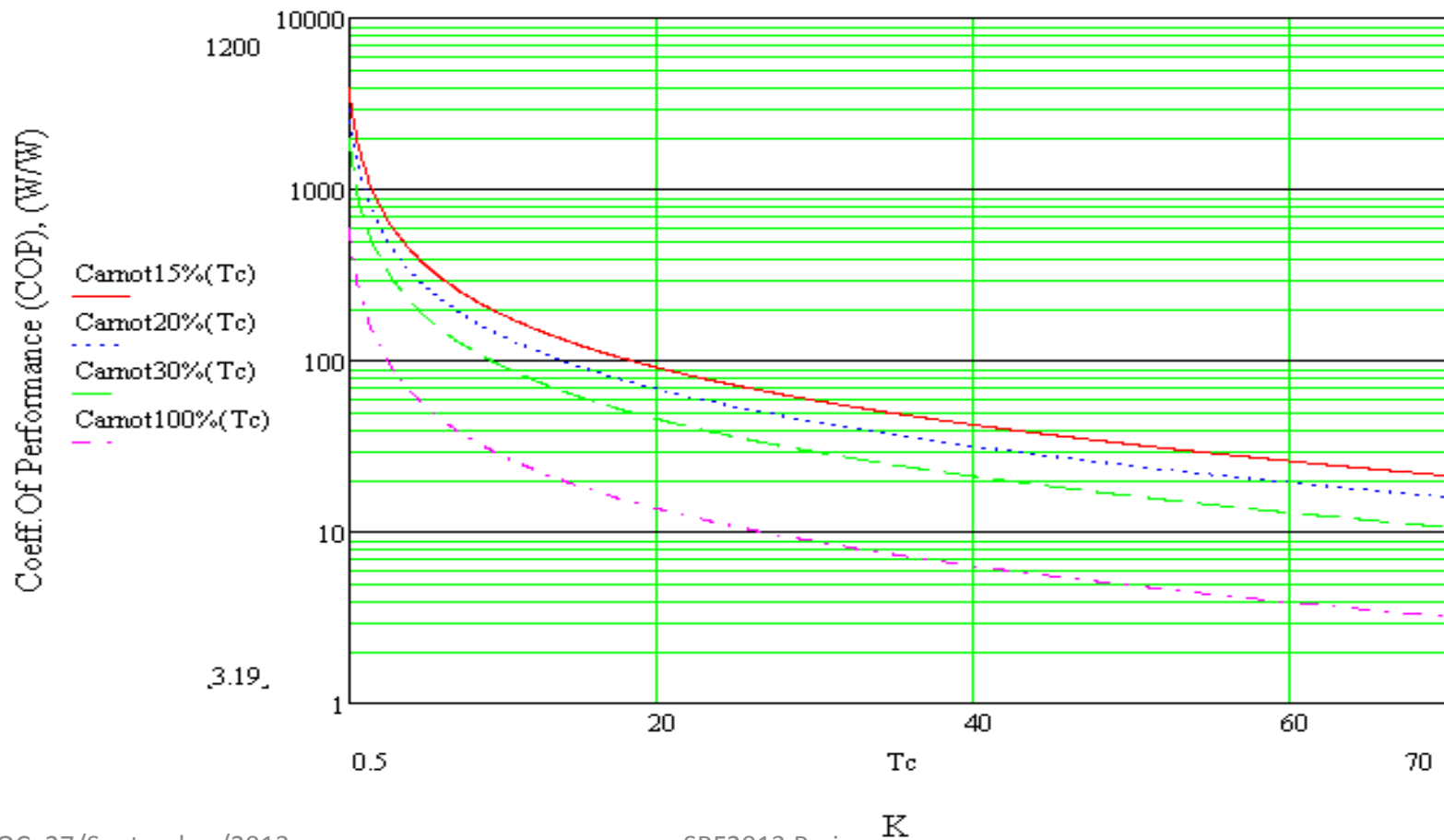
Courtesy of S. Rousselot, IPNO

SPL Short Cryomodule

COP of cryogenic refrigeration

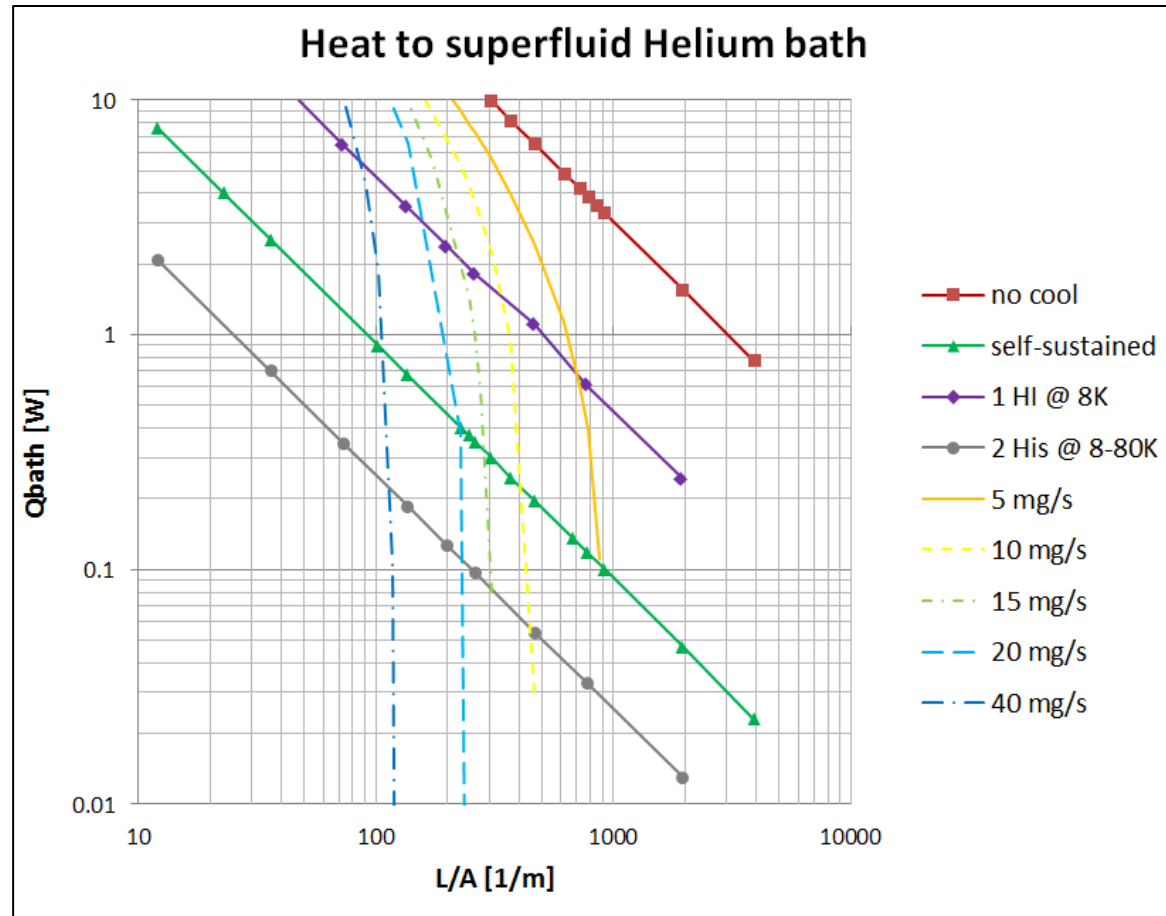
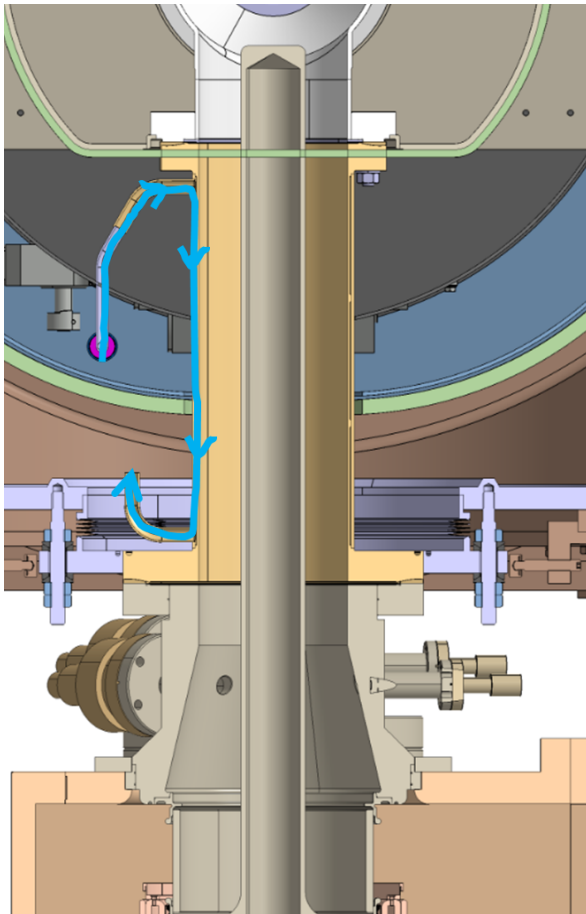
State-of-the-art figures (LHC cryoplants):

- COP @ 2 K $\rightarrow \sim 15\%$ Carnot (**990** W_{el}/W_{th})*
- COP @ 4.5 K $\rightarrow \sim 30\%$ Carnot (**210** W_{el}/W_{th})*
- COP @ 50 K $\rightarrow \sim 30\%$ Carnot (**16** W_{el}/W_{th})



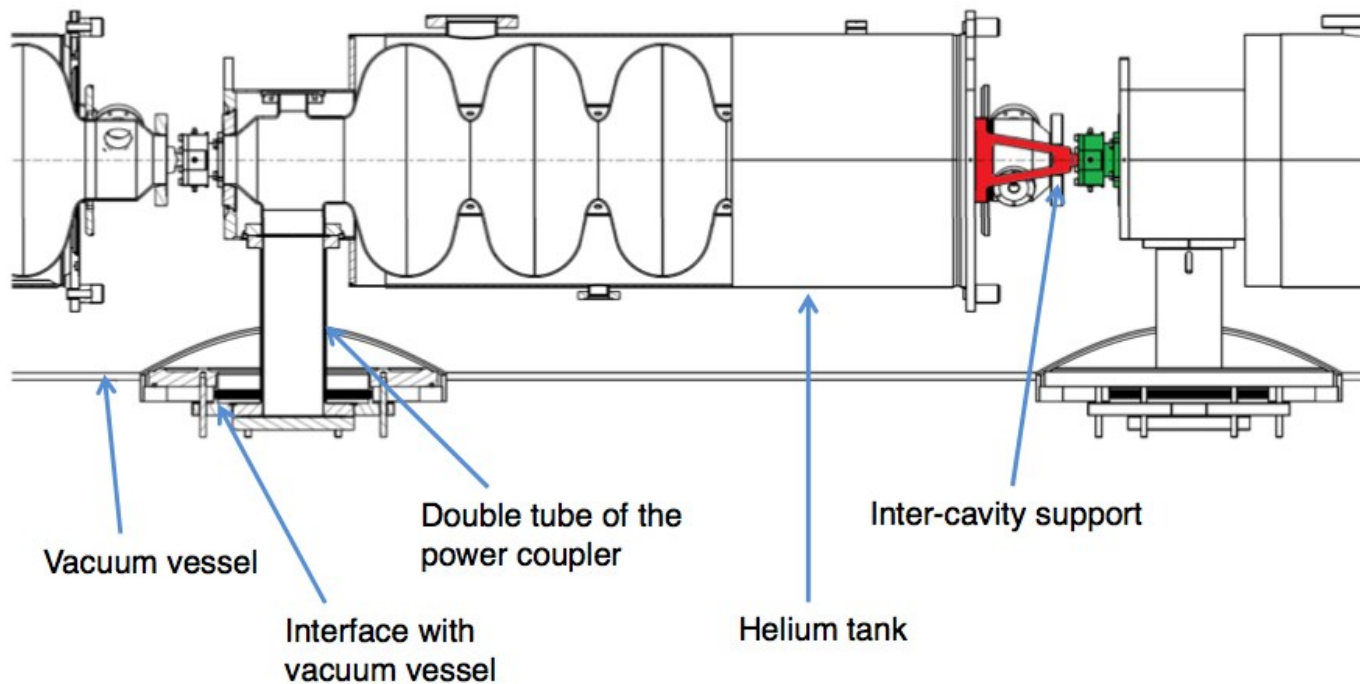
SPL Short Cryomodule

- 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



SPL Short Cryomodule

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



- V. Parma et al. poster MOP085

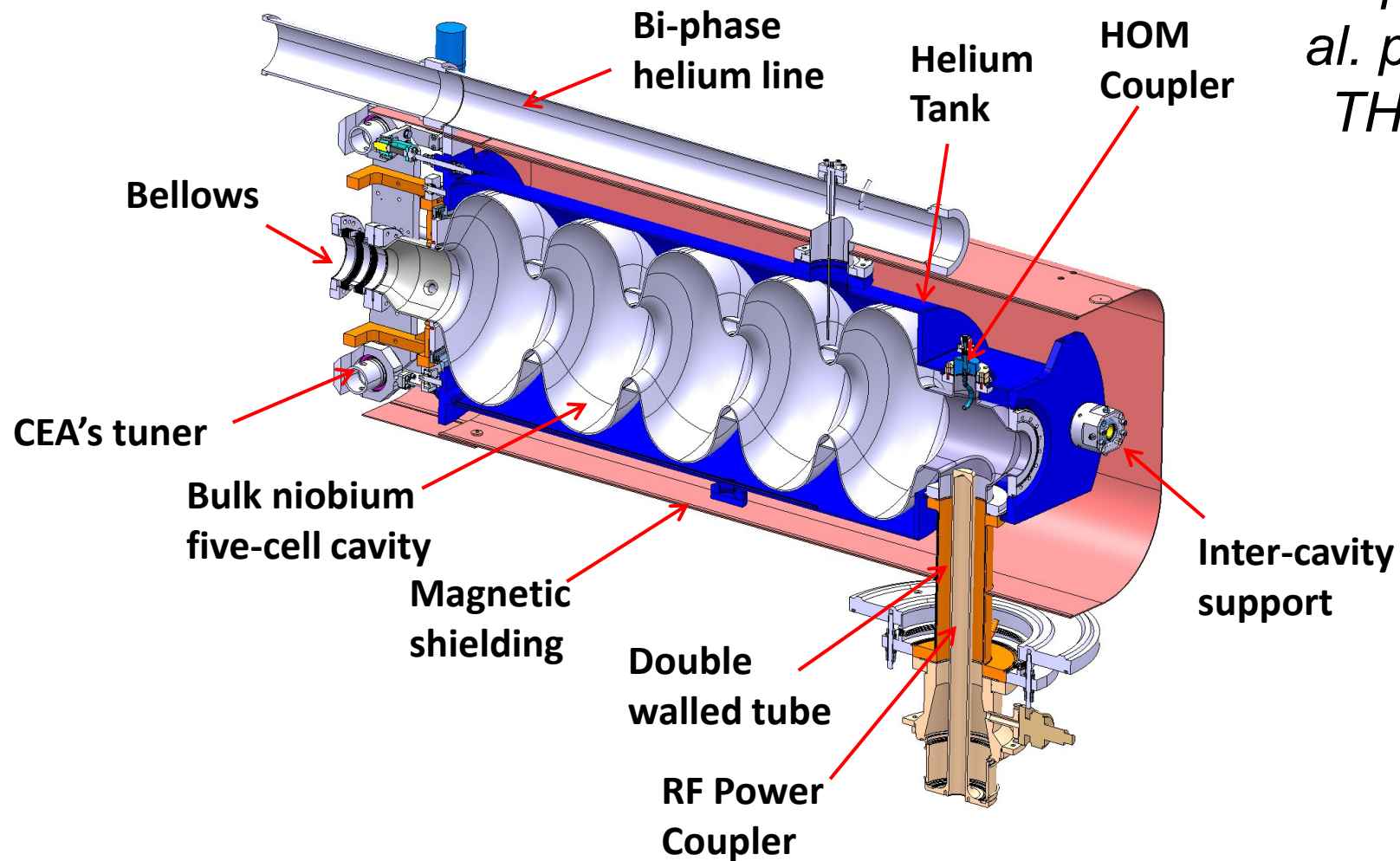
- Equipped beta=1 cavity main design properties & operation

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

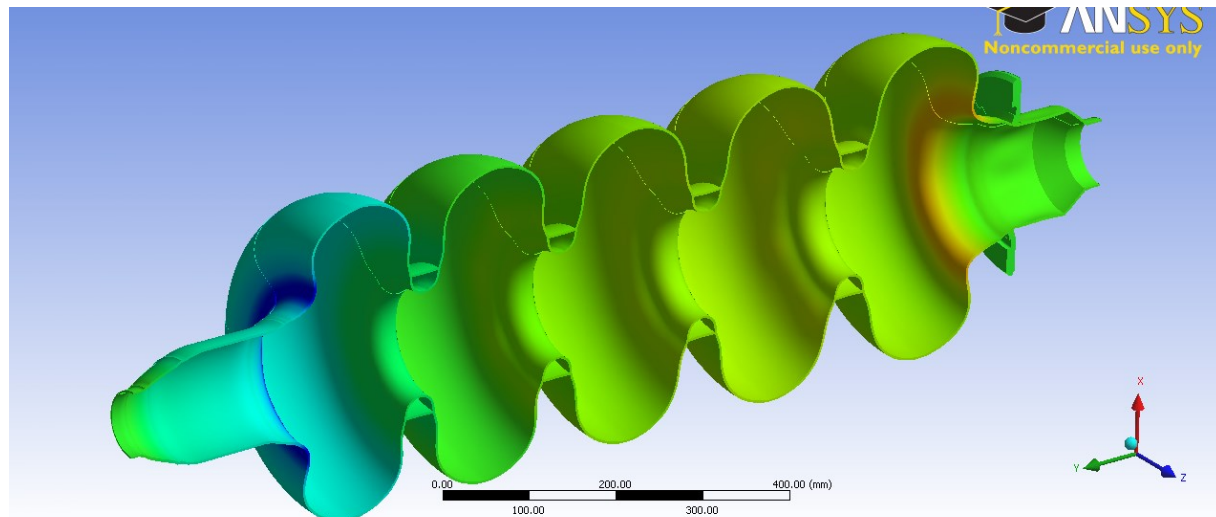
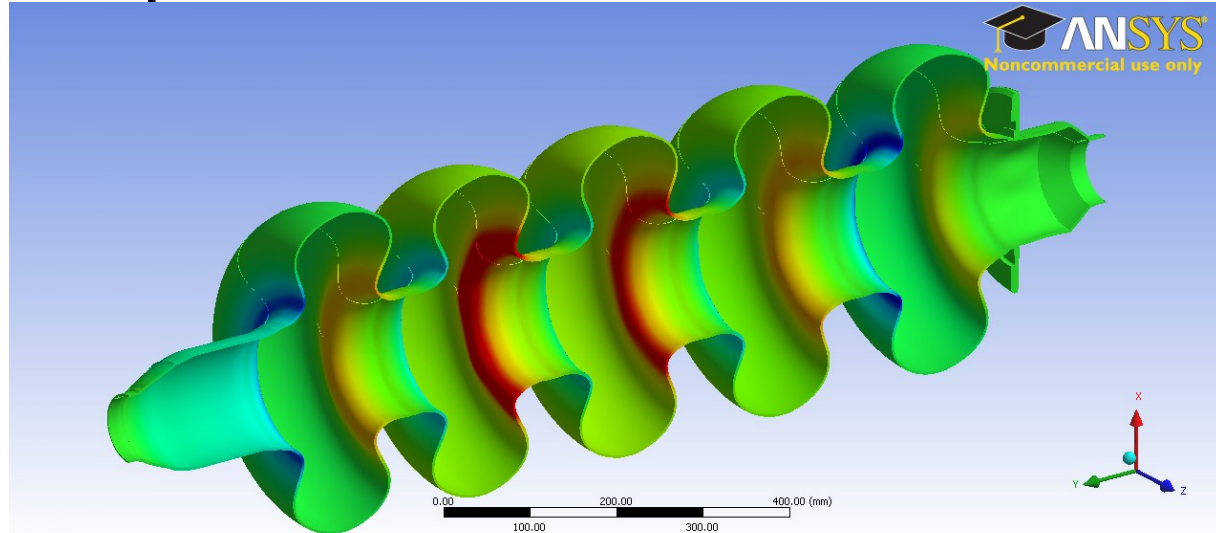
- Equipped beta=1 cavity



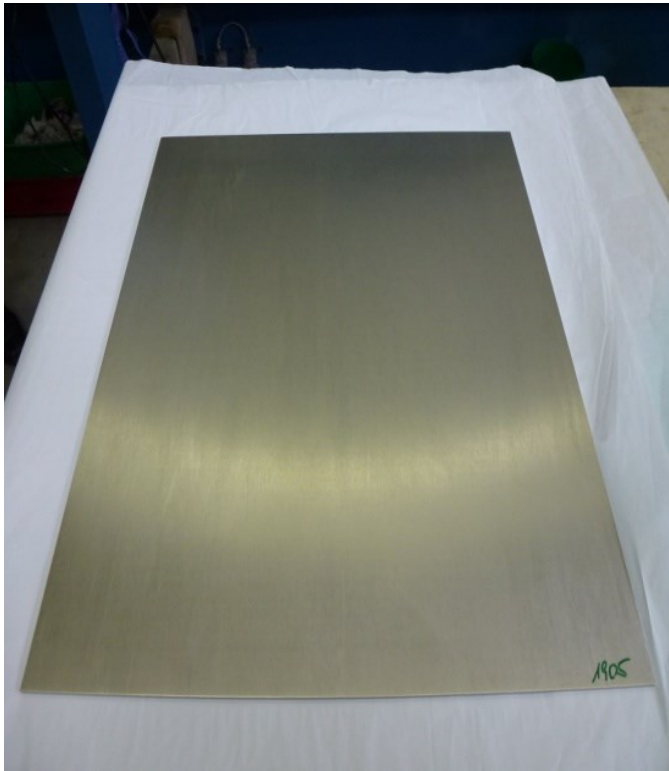
K. Papke et al. poster THP064

Cavity

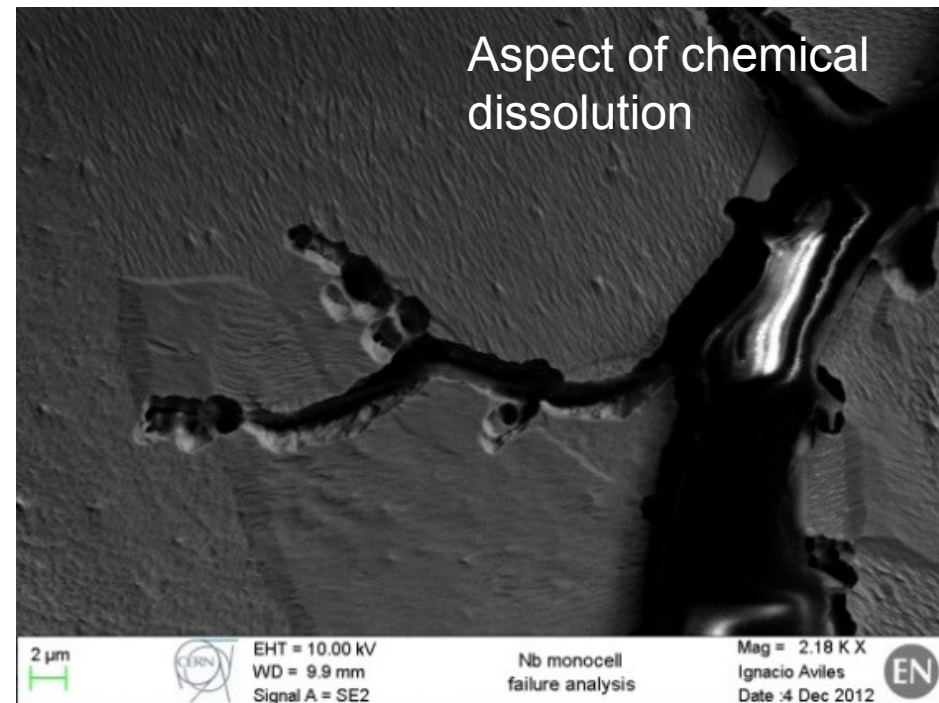
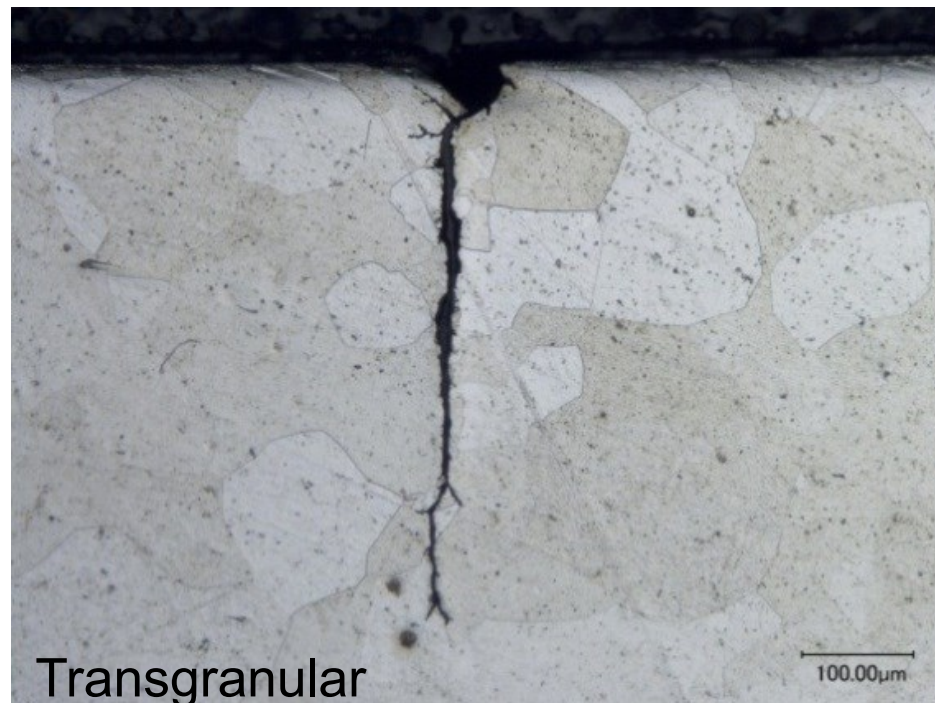
- Pulsed mode operation – Lorentz detuning had to be optimized



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



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

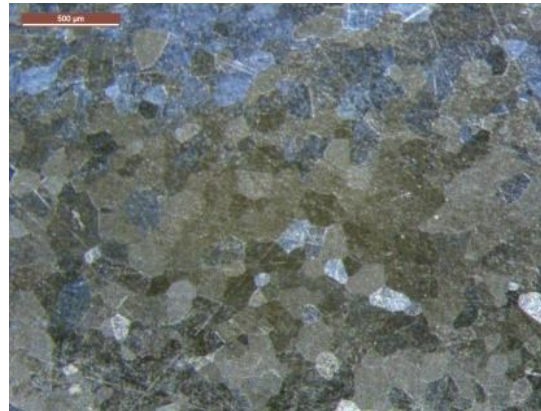


Cavity

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



From seamless tube



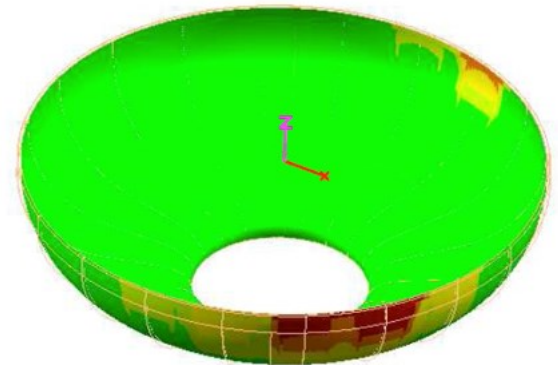
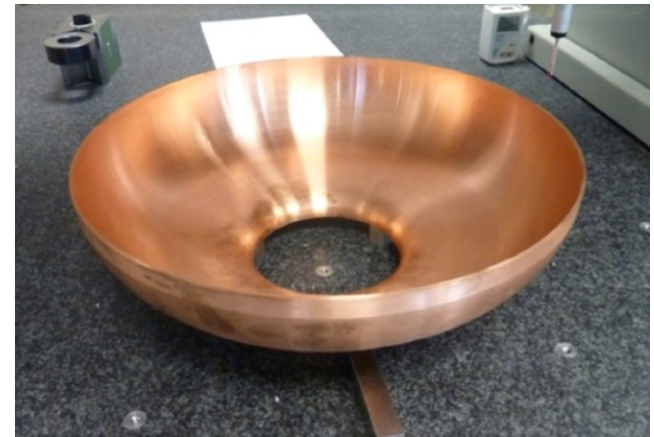
- Recrystallized equiaxial grains
- Hardness: 57,1 HV10 (technical specification: < 60 HV10)

From
rolled
plate



From
spun
plate

- 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 to 1 mm); new shaping techniques under development



Cavity

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

Ultrasonic examination

Leak test

Thermal shock liquid N₂ (x5)

Ultrasonic examination

Leak test

Electropolishing

HT (600°C/24h)

Electropolishing

Leak test

Ultrasonic examination

Thermal shock liquid N₂ (x5)

Ultrasonic examination

Leak test

Shear test

Leak test

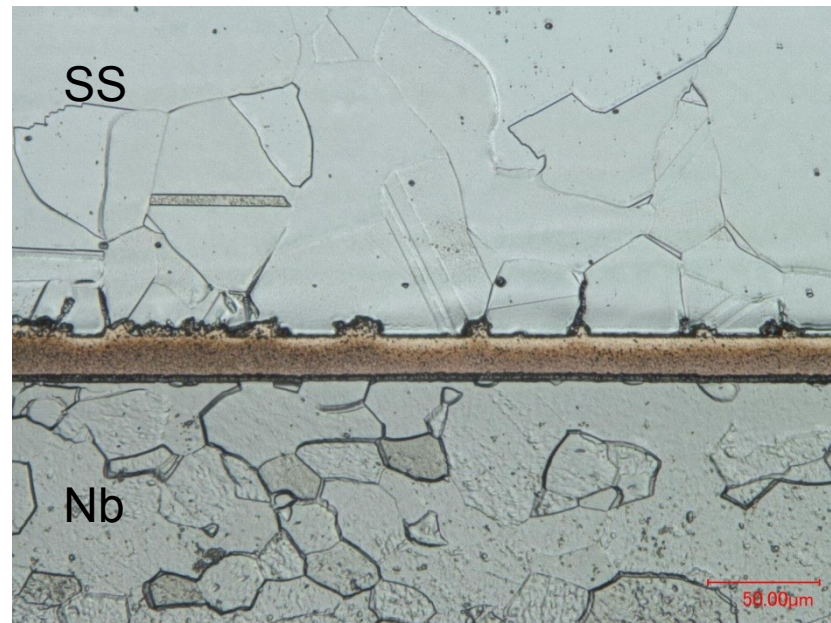
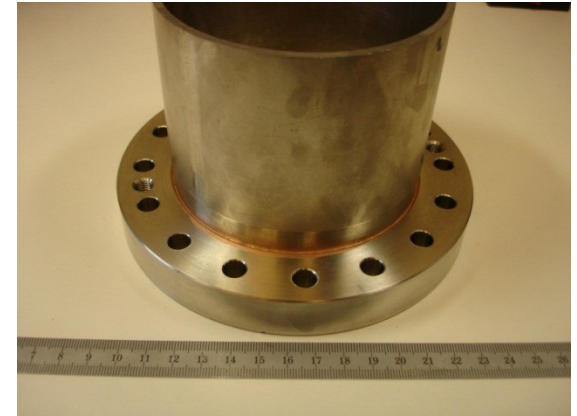
Ultrasonic examination

Assembly test

Metallographic examination

Fractography

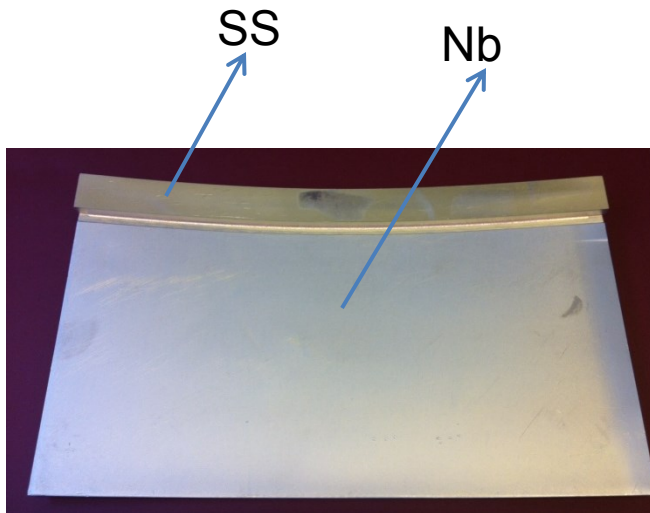
SEM assesment + EDS



316LN to Nb
vacuum
brazing fully
qualified

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

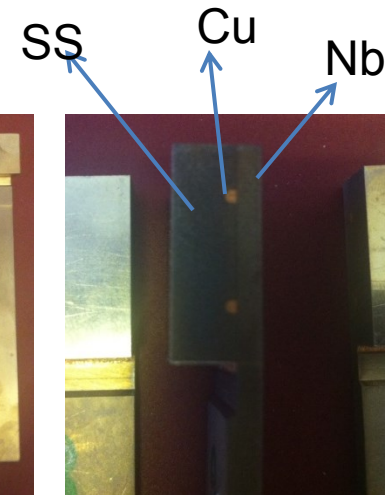
10 samples introduced in the chemical bath
 [bath: (1:1:2) 40%HF, 65% HNO₃, 85% H₃PO₄]
 at different conditions without masking the brazed joint



OC, 27/September/2013

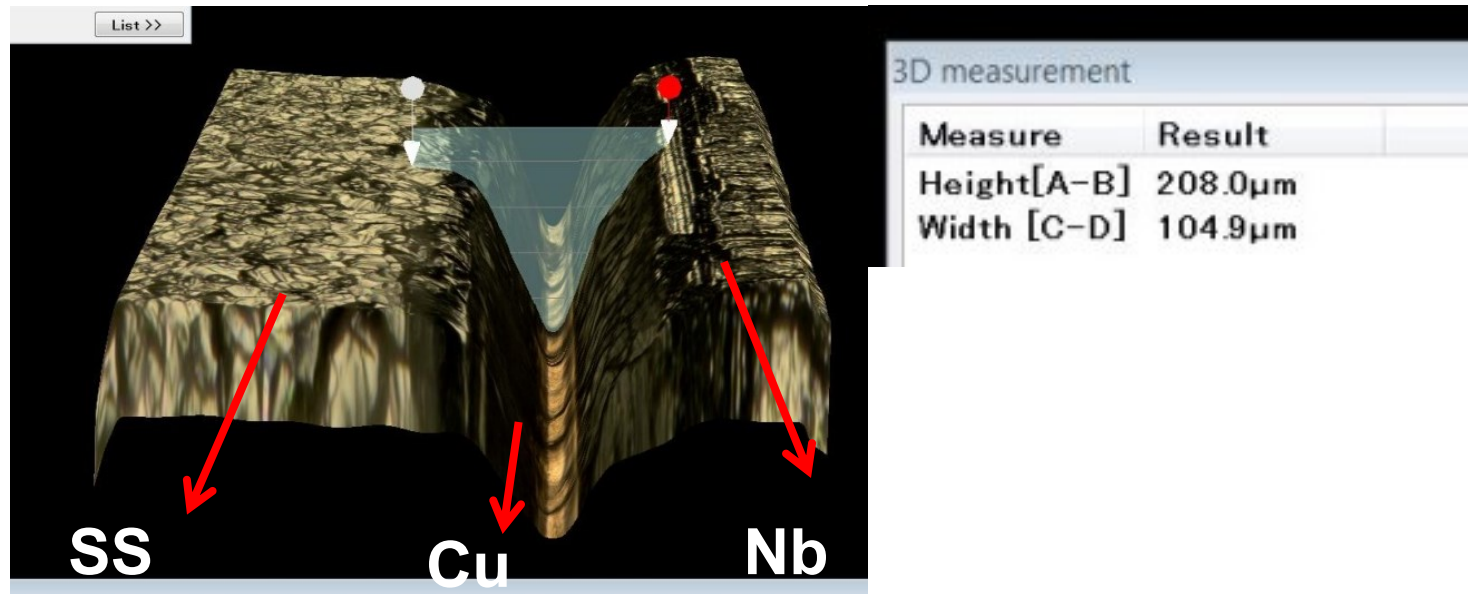


SRF2013 Paris



Cavity

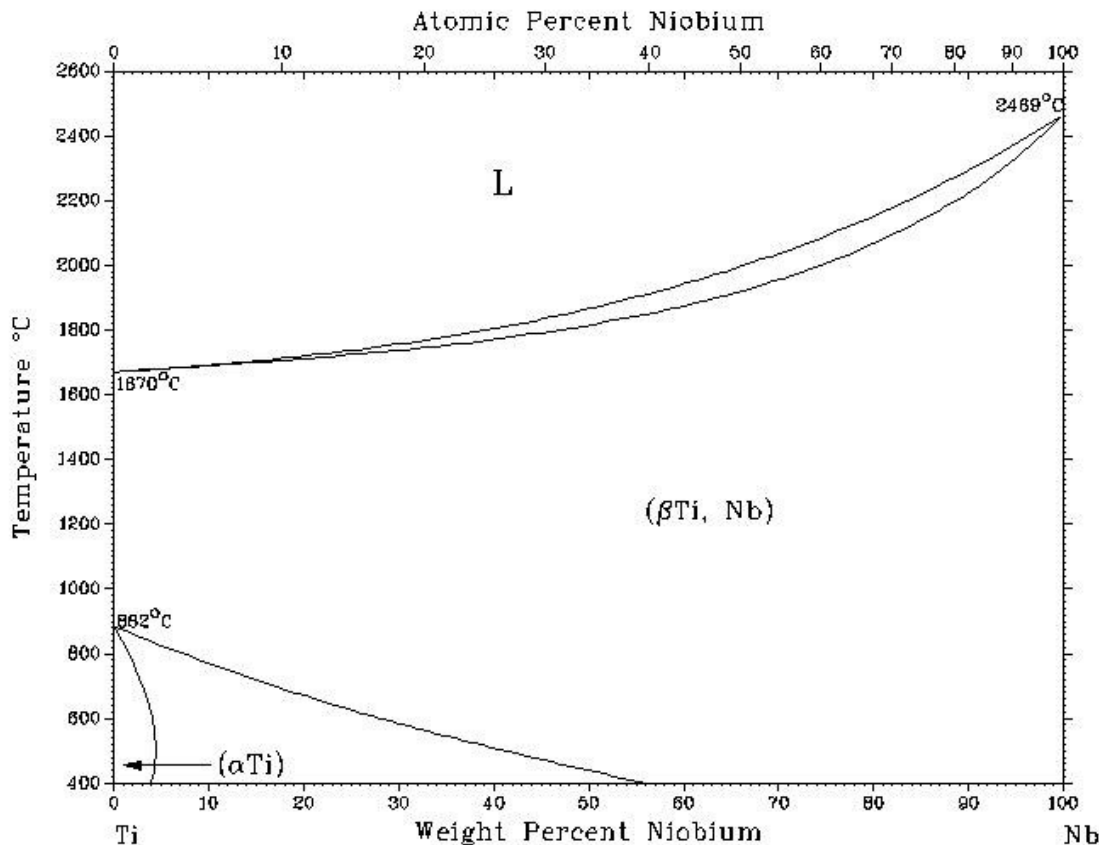
- Material choices / joining techniques
 - Stainless steel (316LN) – niobium: vacuum brazing
 - Effect of Chemical etching to the brazing?



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

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

Assessed Ti-Nb phase diagram.



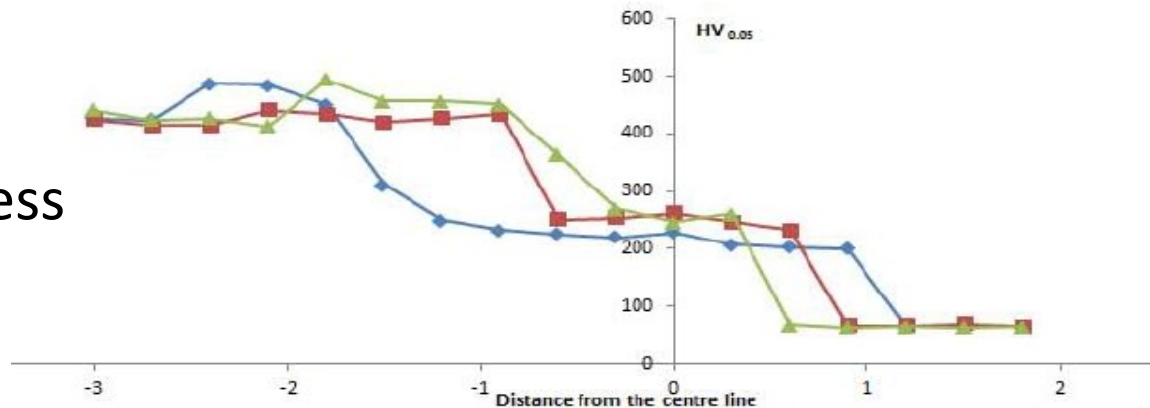
Ti6Al4V to Nb
EB welding fully
qualified

	Nb	Ti6Al4V
ρ (Kg/m ³)	8600 – 8700	4410 – 4450
T_m (°C)	2460 – 2470	1610 – 1660
K (W/m °C)	54 – 57	7.1 – 7.3

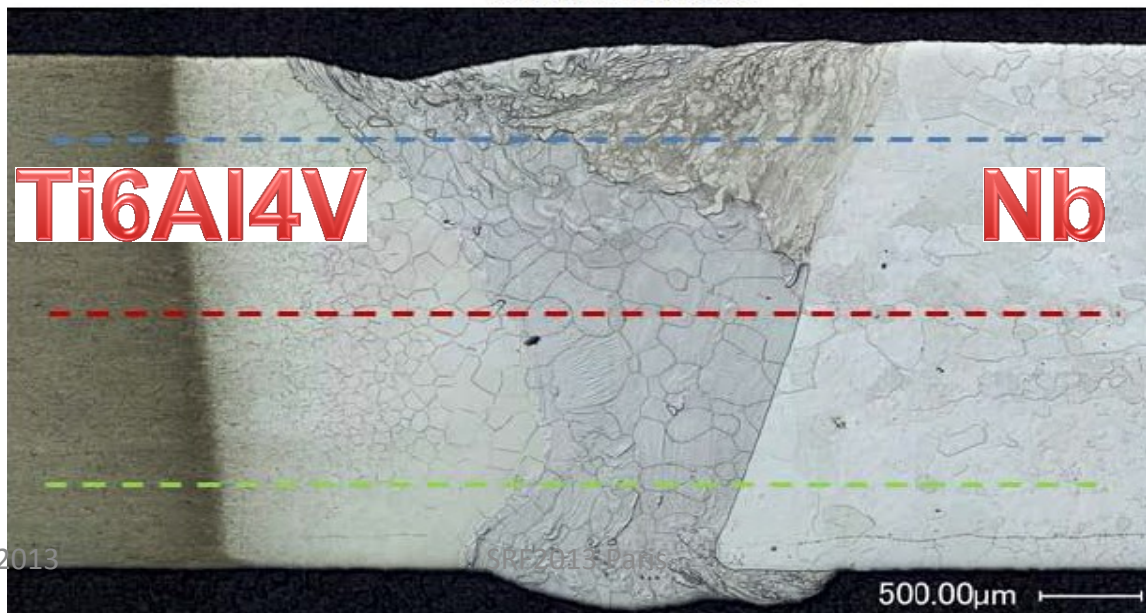
Cavity

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

Microhardness



Ti6Al4V to
Nb EB
welding
fully
qualified

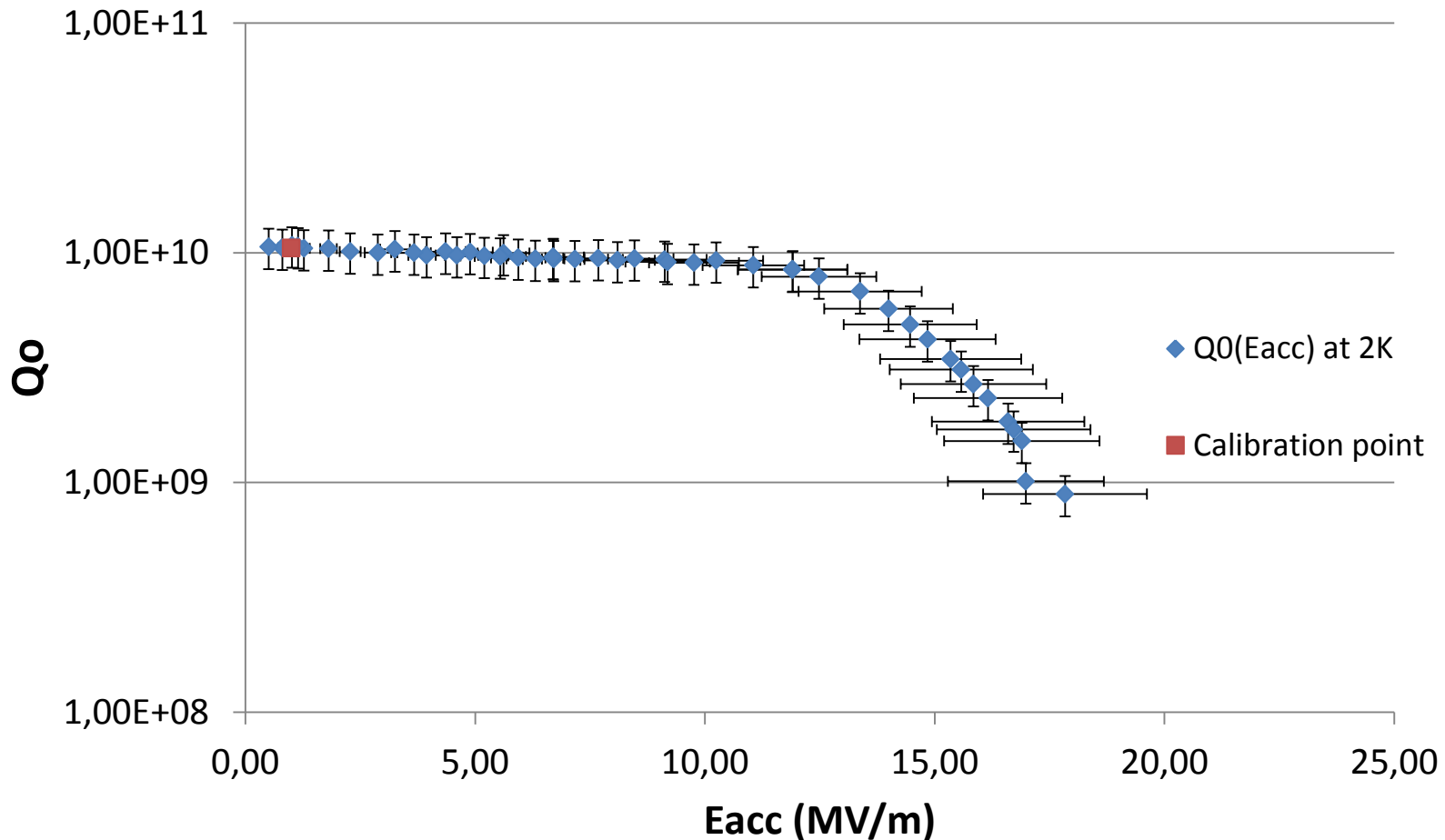


- Some material choice considerations

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

- 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

- 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



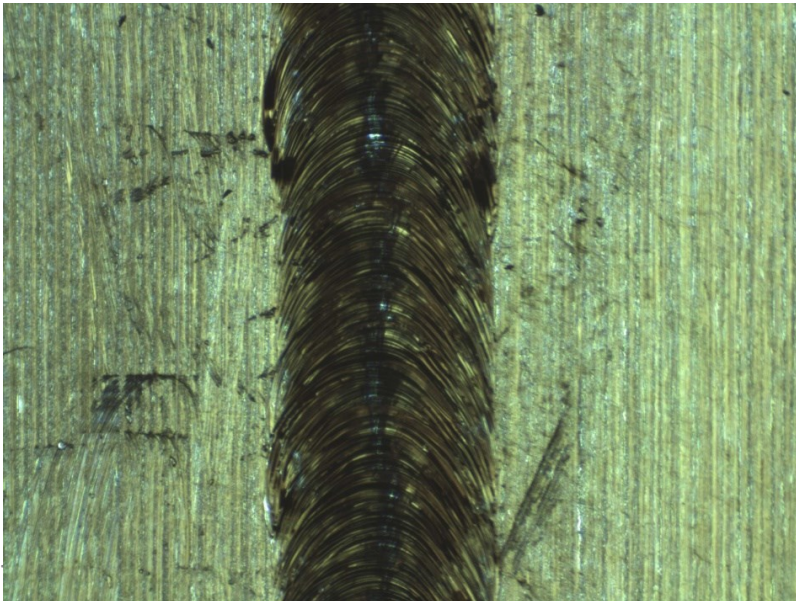
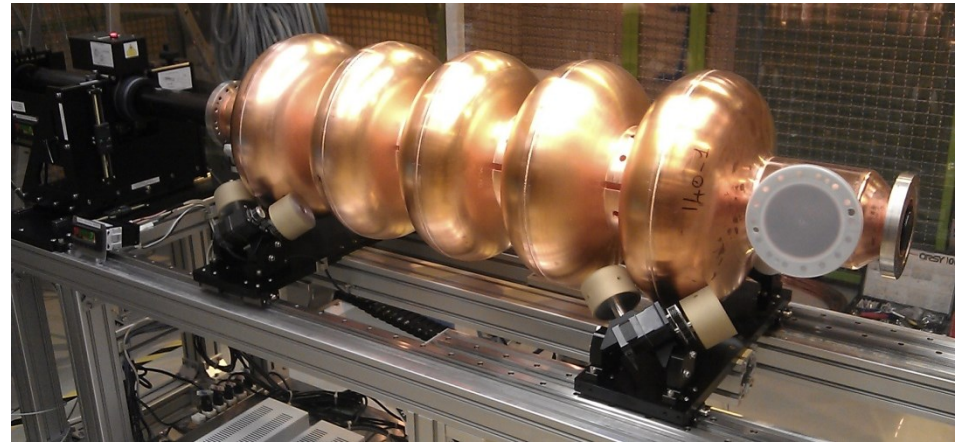
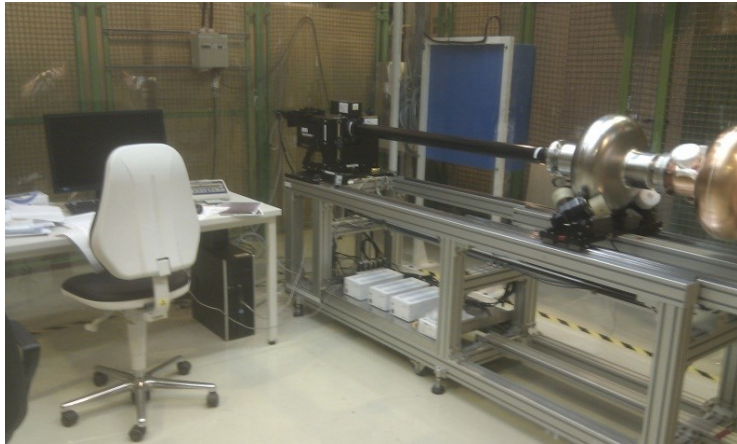
Infrastructure upgrade

- Electropolishing



L. Marques et al.
poster TUP047

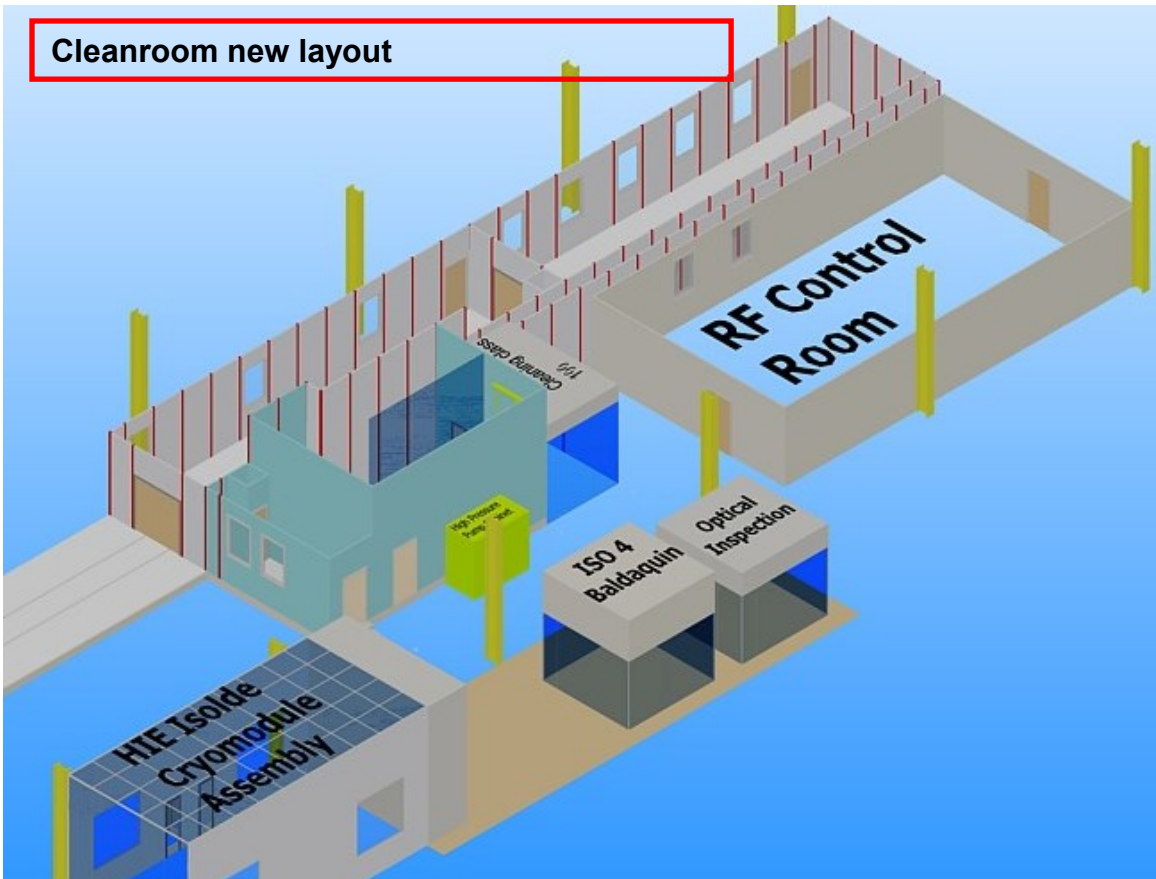
- Optical inspection



Infrastructure upgrade

- Clean room upgrade

Cleanroom new layout



High Pressure Rinsing

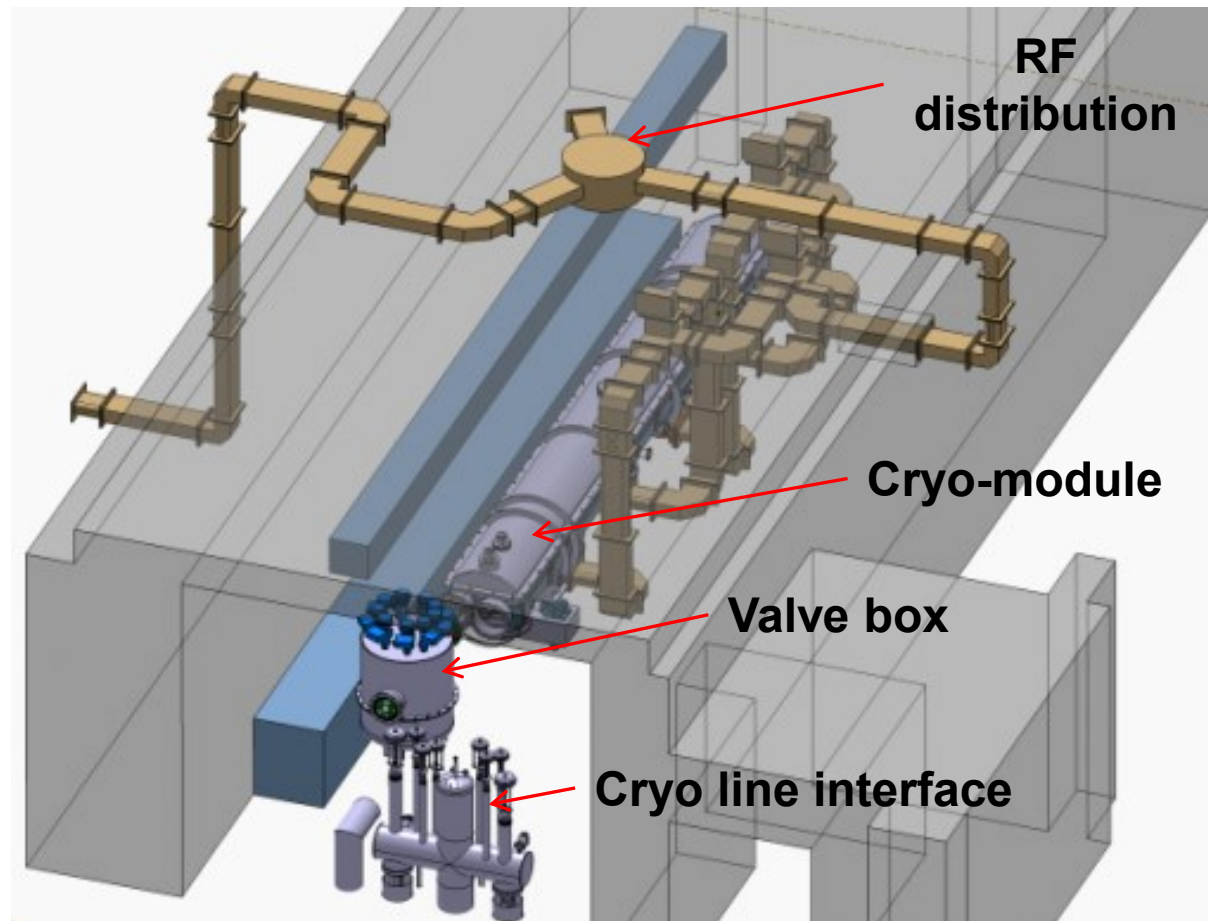


Including support from

CRISP  program

Infrastructure upgrade

- Cryogenics infrastructure for vertical tests and cryomodule

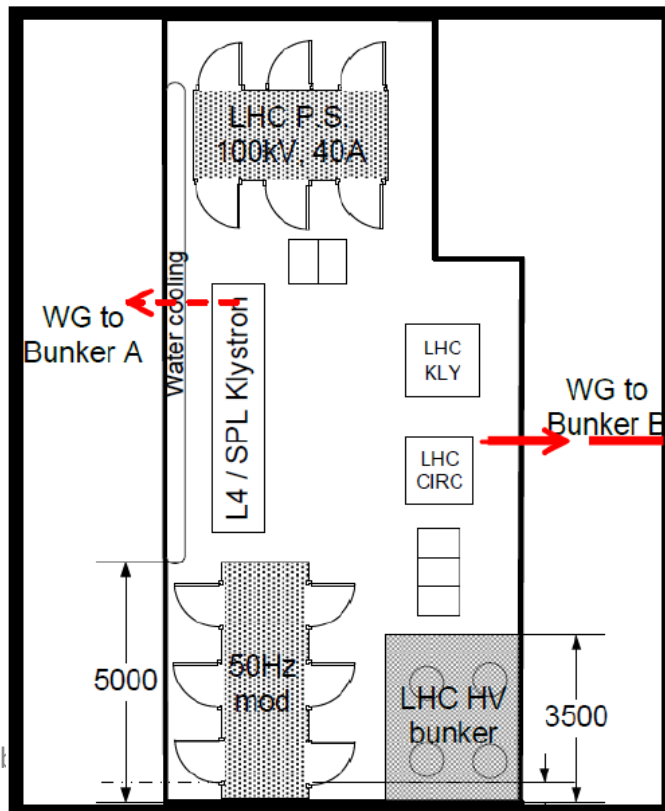


Including support from

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 $\beta=1$ will be tested by 2015 in Short cryo-module at CERN.