LINAC 16

28TH LINEAR ACCELERATOR CONFERENCE

East Lansing, MI USA
25-30 September

EUROPEAN SPALLATION SOURCE

The SRF Linac Components for the European Spallation Source: First Test Results

Christine Darve - Deputy Leader of SRF Work Packages, WP04 and WP05
ESS Accelerator Division

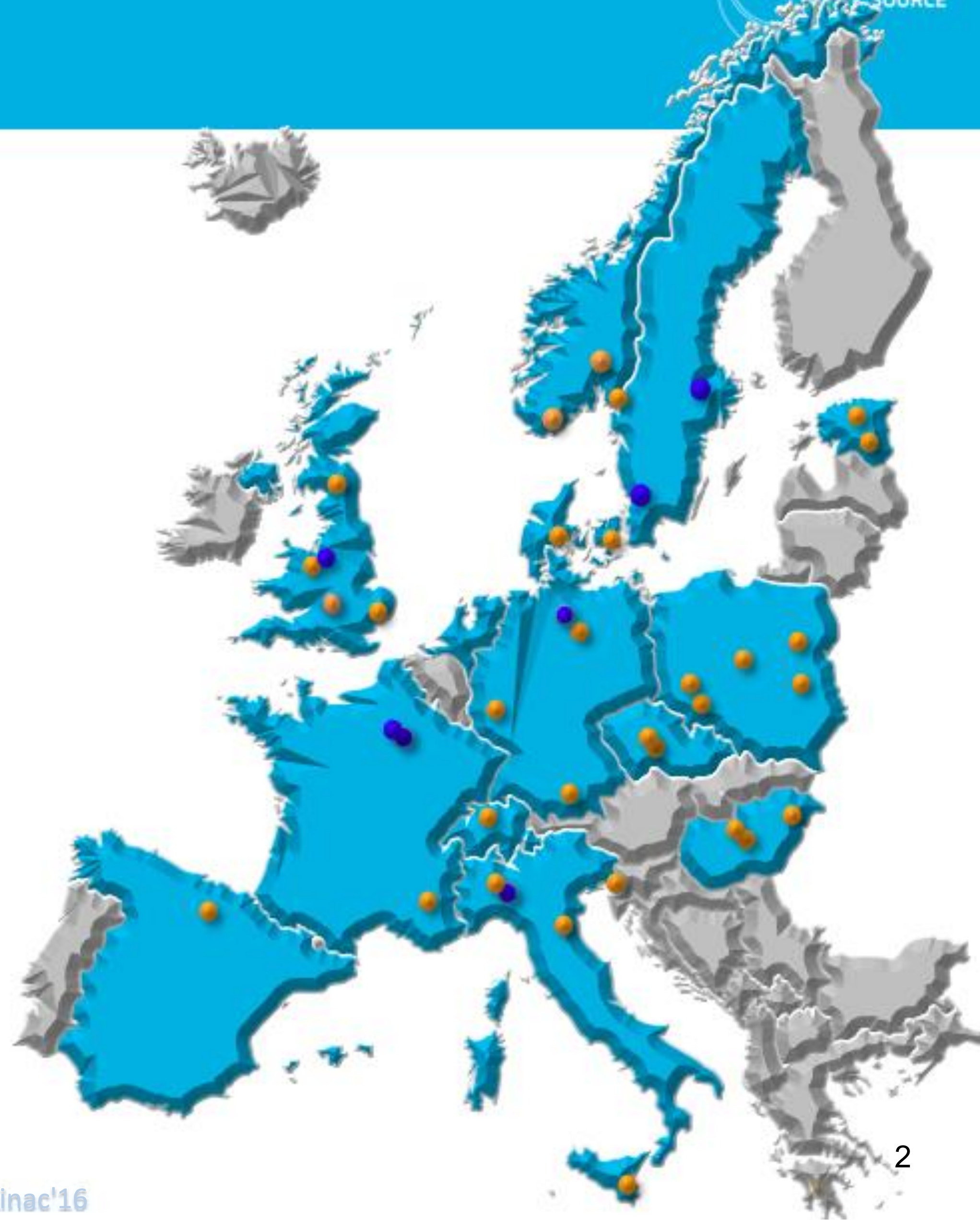
on behalf of the SRF teams from
CEA/IRFU Saclay [Pierre Bosland]
CNRS/IPN Orsay [Guillaume Olry]
Uppsala and Lund Universities
ESS ERIC

www.europeanspallationsource.se

28 September 2016

Outline

- Introduction to European Spallation Source
- SRF linac design
- SRF linac component performance measurements



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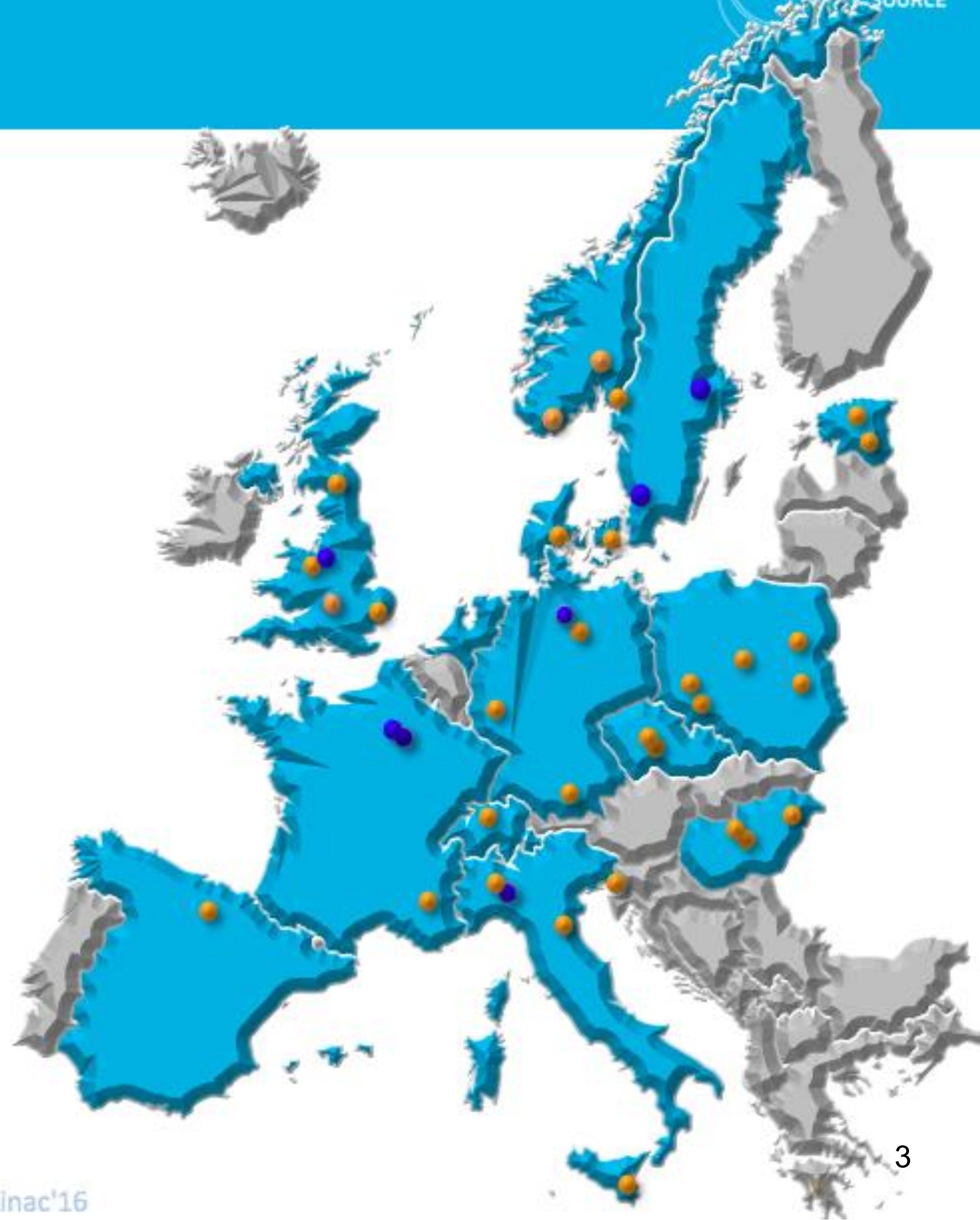

Spallation Sources

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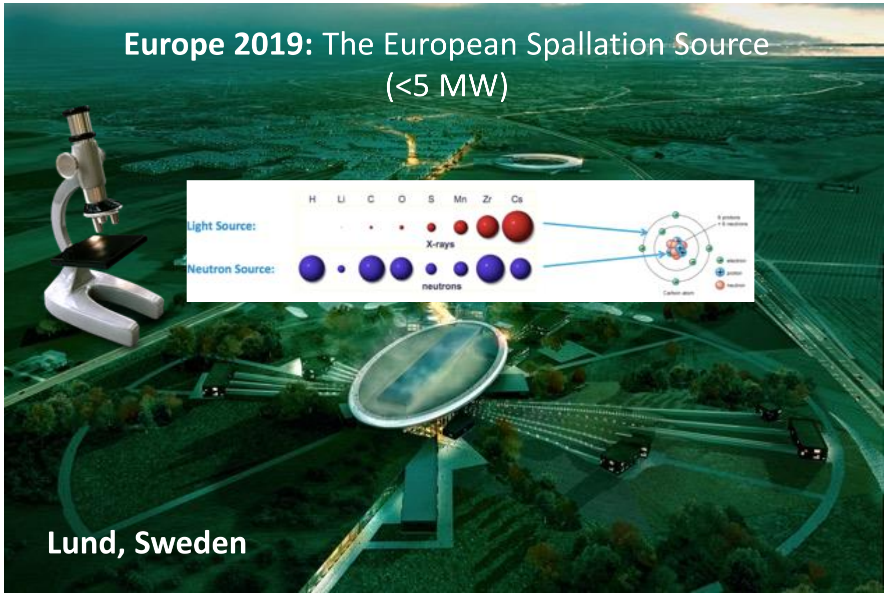
Greenfield: Philosophie a la "Pré-vert"



Europe 2019: The European Spallation Source (<5 MW)

Japan 2008: JPARC (1MW)

USA 2006: SNS (1.4 MW)

The European Spallation Source (ESS) is a multi-disciplinary research centre based on the world's most powerful neutron source. This new facility will be up to 100 times brighter than today's leading facilities, enabling new opportunities for researchers in the fields of life sciences, energy, environmental technology, cultural heritage and fundamental physics.

Collaborative project: >17 European countries

ERIC (European Research Infrastructure Consortium) on October 1, 2015

2014: Start of construction phase
2019: Beam to target
2023: ESS starts user program
2025: Construction Complete
~ 450 employees; for more than 2500 users / year

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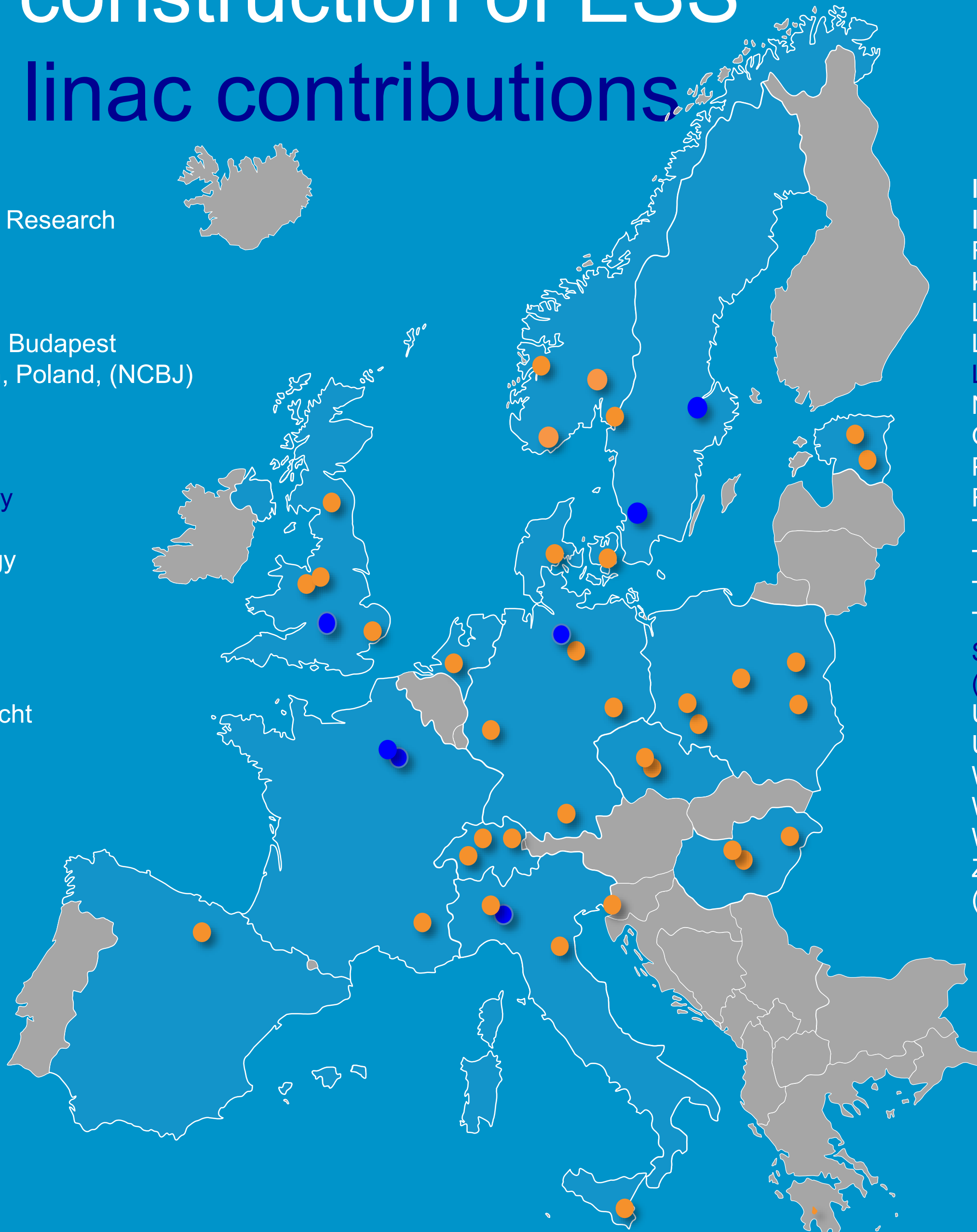
ESS design


High Power
Linear Accelerator:
• Energy: 2 GeV
• Rep. Rate: 14 Hz
• Current: 62.5 mA
Target Station:
• He-gas cooled rotating W-target (5MW average power)
• 42 beam ports
16 Instruments in Construction budget
Ion Source
Committed to deliver 22 instruments by 2028
Peak flux ~30-100 brighter than the ILL
Total cost: 1843 MEuros 2013

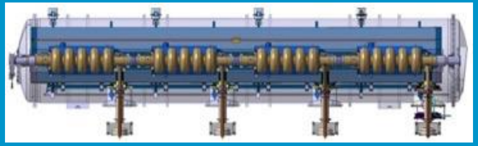
Partner institutions responsible for delivering the design & construction of ESS

and SRF linac contributions

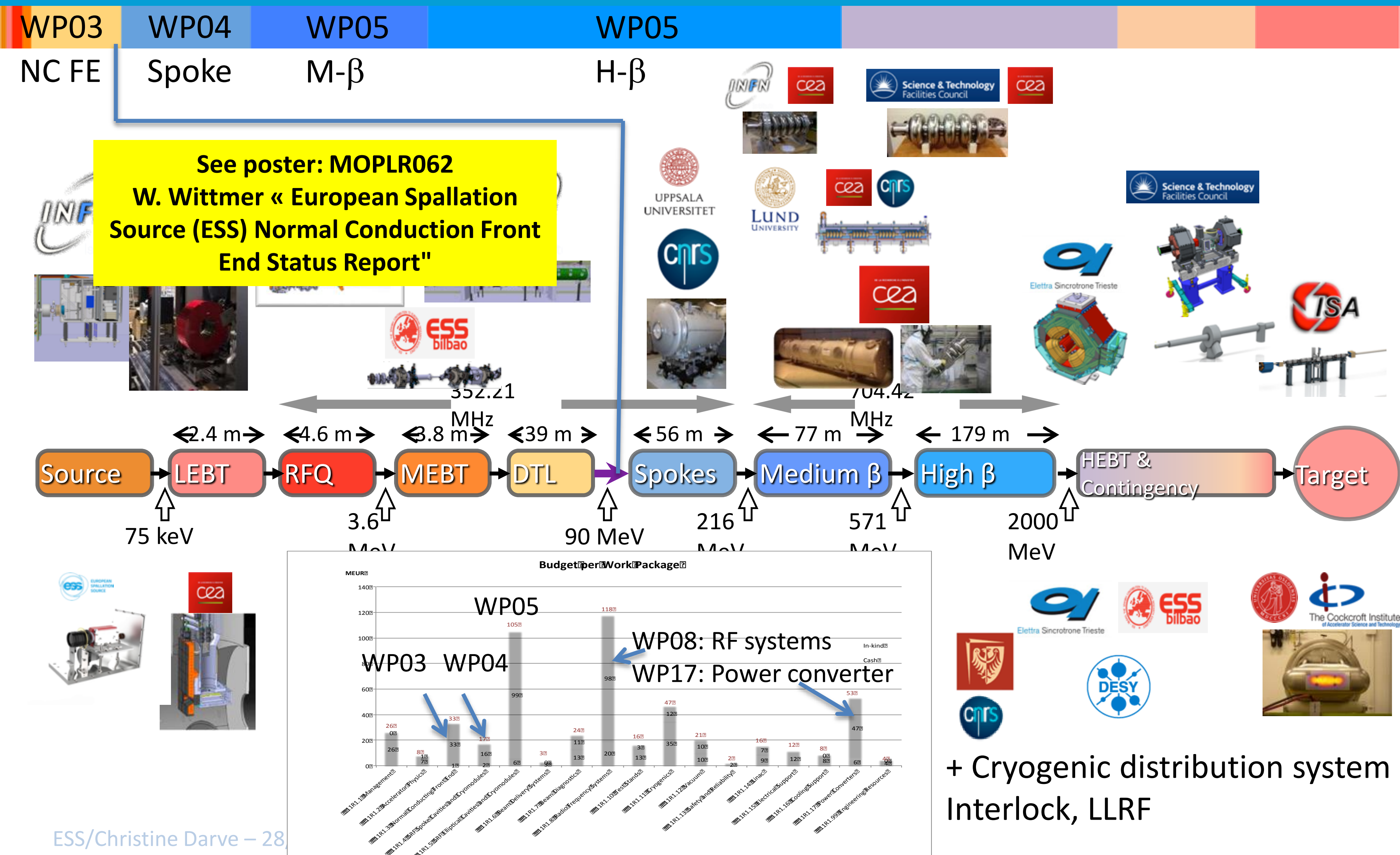
Aarhus University
Atomki - Institute for Nuclear Research
Agder University
Bergen University
CEA Saclay, Paris
Centre for Energy Research, Budapest
Centre for Nuclear Research, Poland, (NCBJ)
CERN, Geneva
CNR, Rome
CNRS Orsay, Paris
Cockcroft Institute, Daresbury
DESY, Hamburg
Delft University of Technology
Edinburgh University
Elettra – Sincrotrone Trieste
ESS Bilbao
Forschungszentrum Jülich
Helmholtz-Zentrum Geesthacht
Huddersfield Univesrity
IFJ PAN, Krakow
INFN, Catania
INFN, Legnaro
INFN, Milan



Institute for Energy Research (IFE)
Institut Laue-Langevin (ILL)
Rutherford-Appleton Laboratory, Oxford (ISIS
Kopenhagen University
Laboratoire Léon Brilouin (LLB)
Lodz University of Technology
Lund University
Nuclear Physics Institute of the ASCR
Oslo University
Paul Sherrer Institute
Roskilde University
Tallinn Technical Univesrsity
Technical University of Chemnitz
Technical University of Denmark
Technical University Munich
Science and Technology Facilities Council (STFC)
University of Tartu
Uppsala University
WIGNER Research Centre for Physics
Wroclaw Univesrity of technology
Warsaw University of Technology
Zurich University of Applied Sciences (ZHAW)

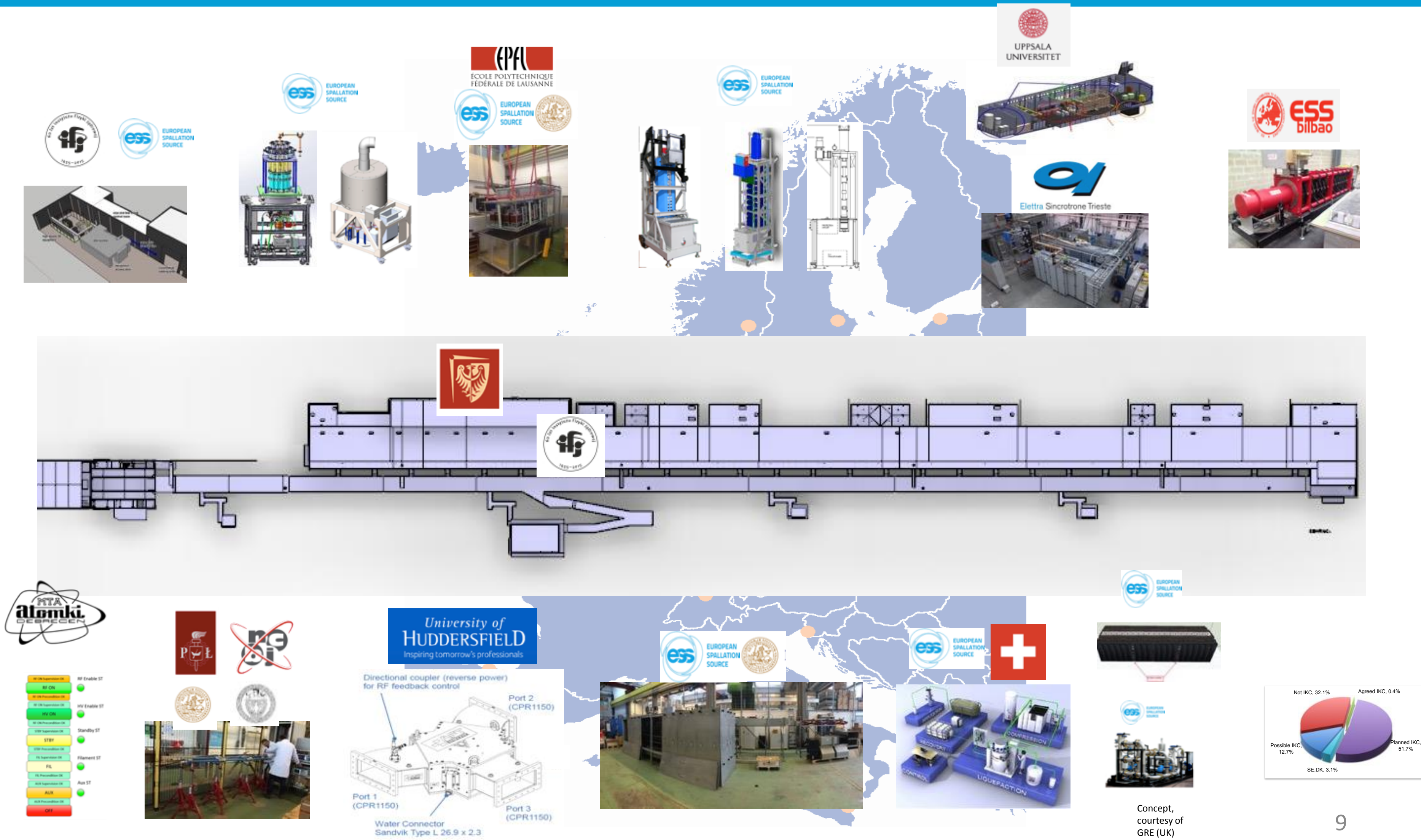


ESS Linac – A Collaborative Project



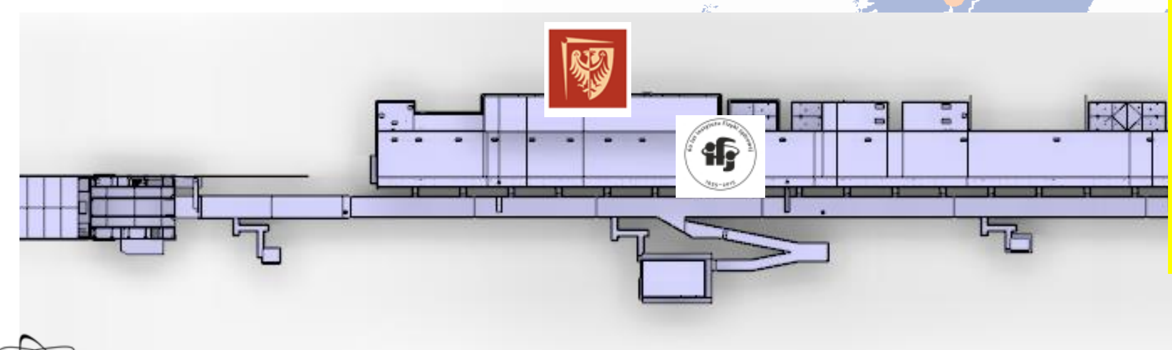
+ Cryogenic distribution system
Interlock, LLRF

ESS Linac gallery – RF, Test stands, Integrated Control System



Concept, courtesy of GRE (UK)

ESS Linac gallery – RF, Test stands, Integrated Control System



See oral: TU2A02
C. Martins
”Pulsed High Power KlystronModulators for the ESS Linac Based on the StackedMulti-Level Topology"

Concept, courtesy of GRE (UK)

Superconducting linac

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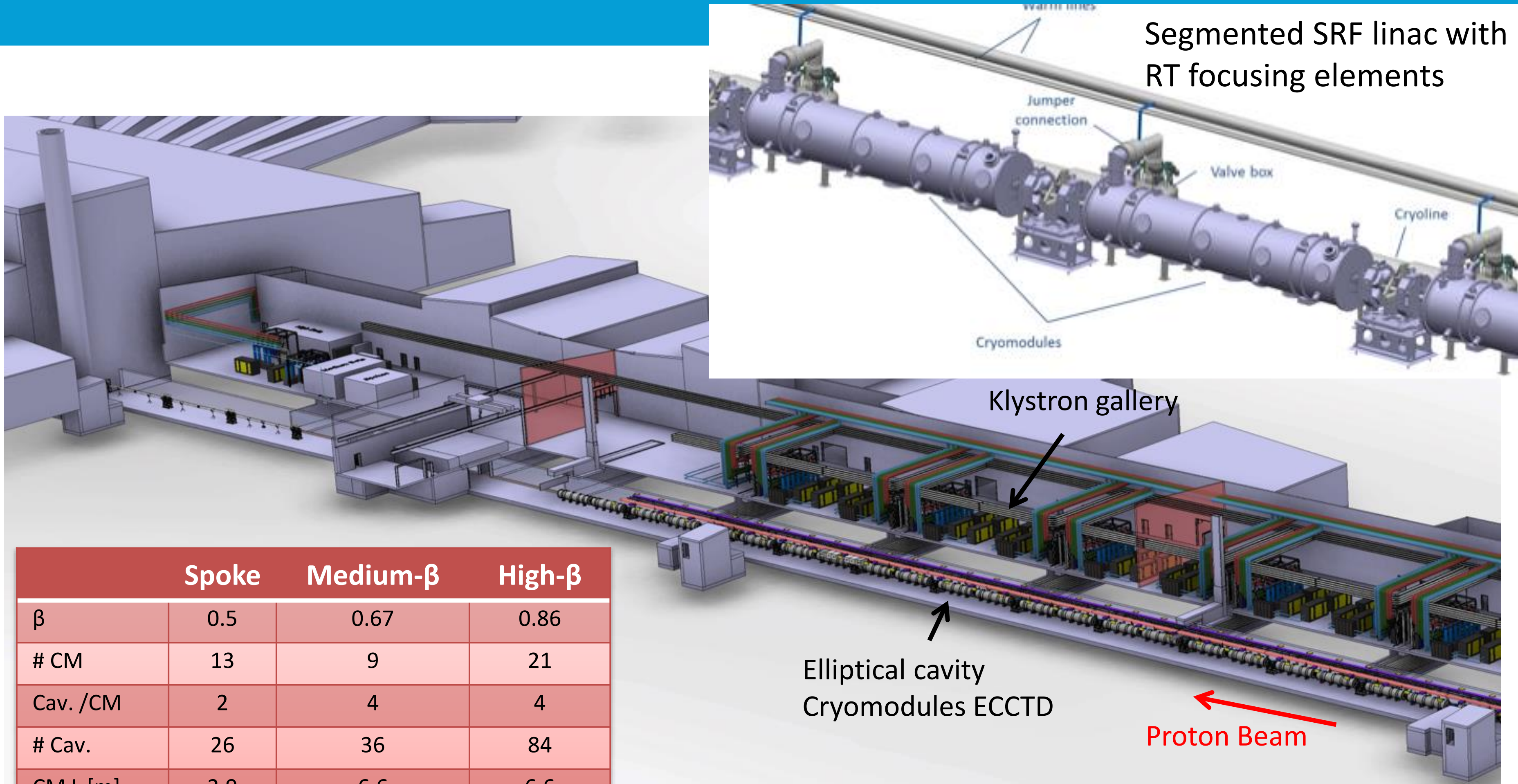
Segmented SRF linac with RT focusing elements

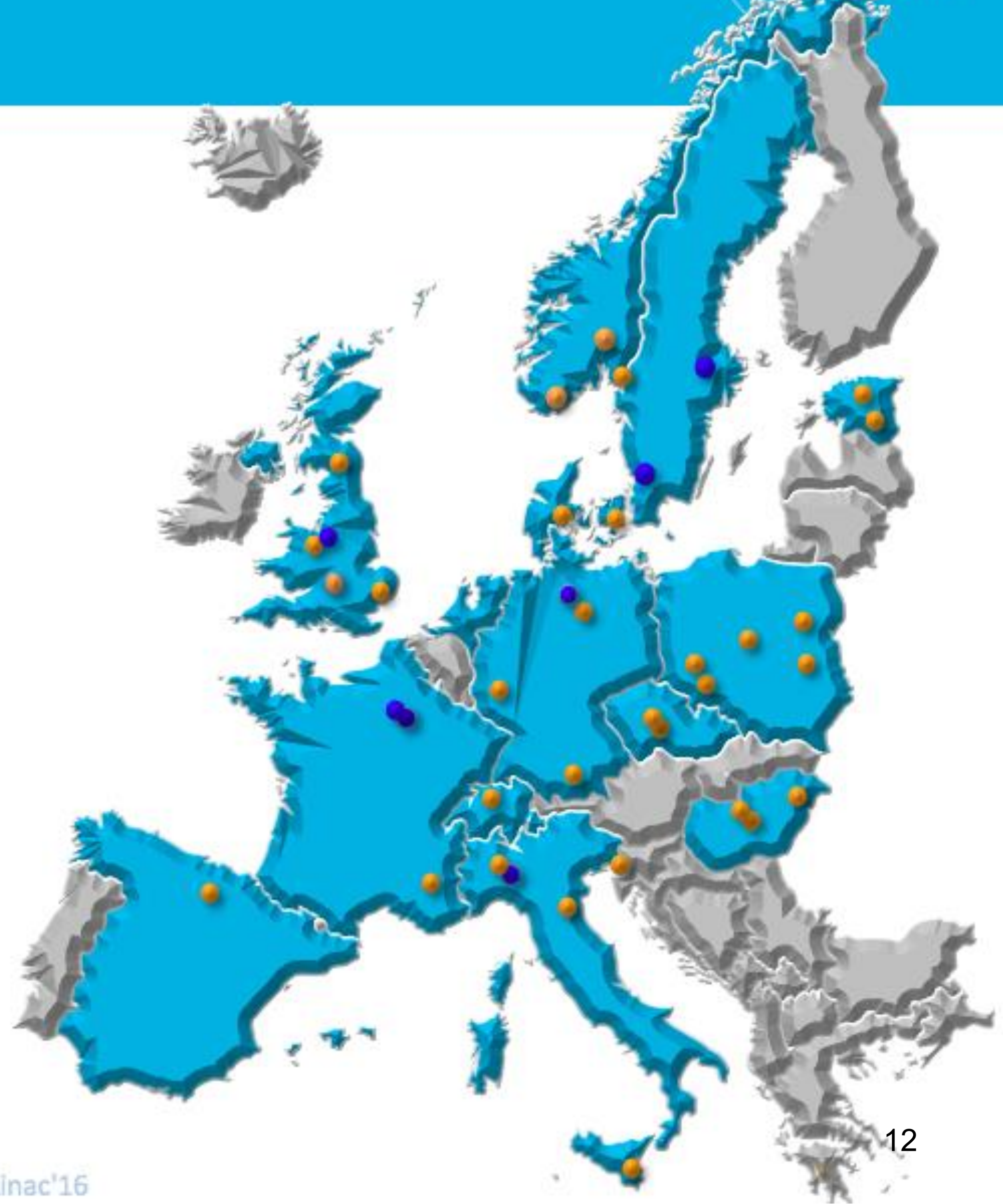


	Spoke	Medium-β	High-β
β	0.5	0.67	0.86
# CM	13	9	21
Cav. /CM	2	4	4
# Cav.	26	36	84
CM L [m]	2.9	6.6	6.6
Sector L [m]	56	77	179

The SRF section represents 70% of the total lenght of the linac and 98 % of the beam acceleration

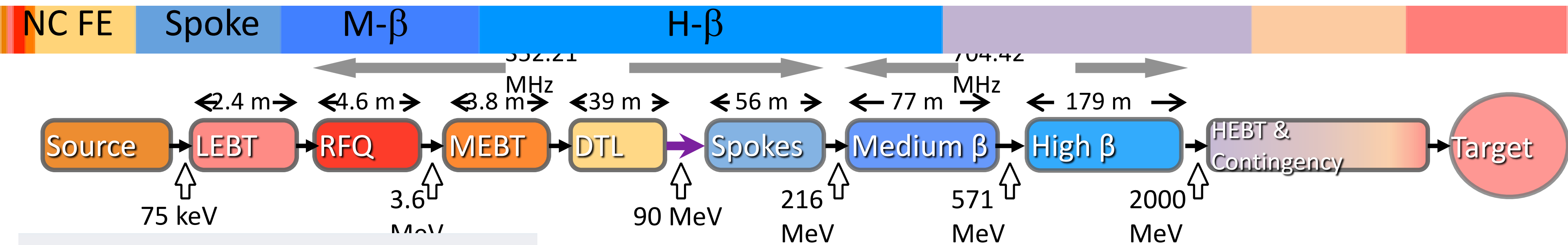
Outline

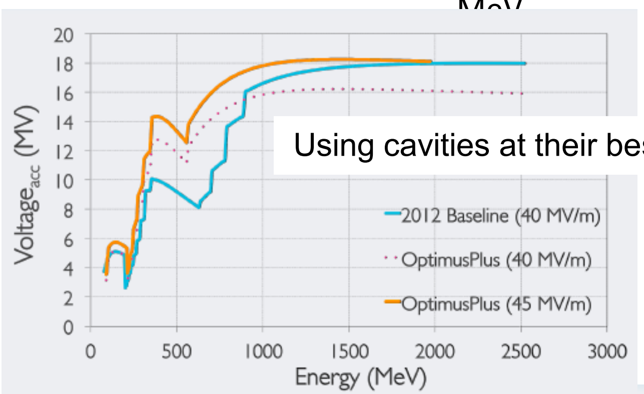
- European Spallation Source project
- SRF linac design
- SRF linac component performance measurements

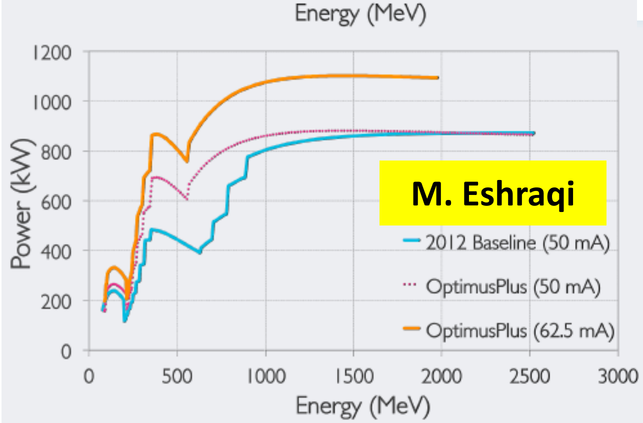


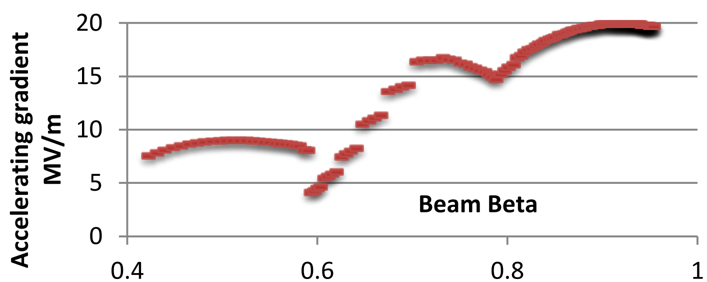
Linac redesign to meet ESS cost objective

D. McGinnis









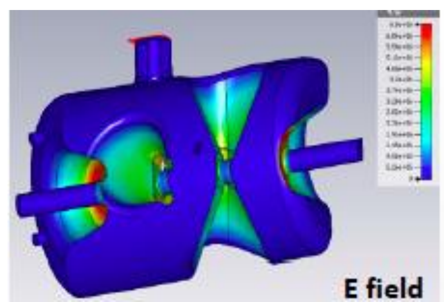
Style	Spoke	Medium-β	High-β
Freq. (MHz)	352.21	704.42	704.42
Cavity #	26	36	84
Velocity range	0.42 to 0.58	0.58 to 0.78	0.78 to 0.95
Nom. Acc. Voltage (MV)	5.74	14.3	18.2
Loaded quality factor	2.85×10^5	8×10^5	7.6×10^5

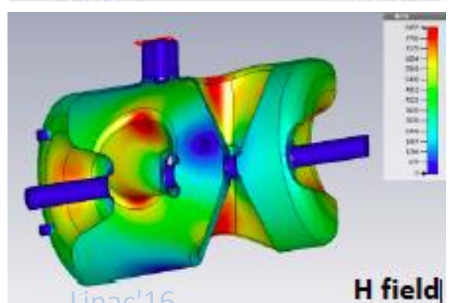
Key parameters:
- 5 MW beam power
-2.86 ms pulses
-2 GeV
-62.5 mA peak
-14 Hz
- 4 % DC
-Protons (H+)
-Low losses
-Minimize energy use
-Flexible design for mitigation & future upgrades

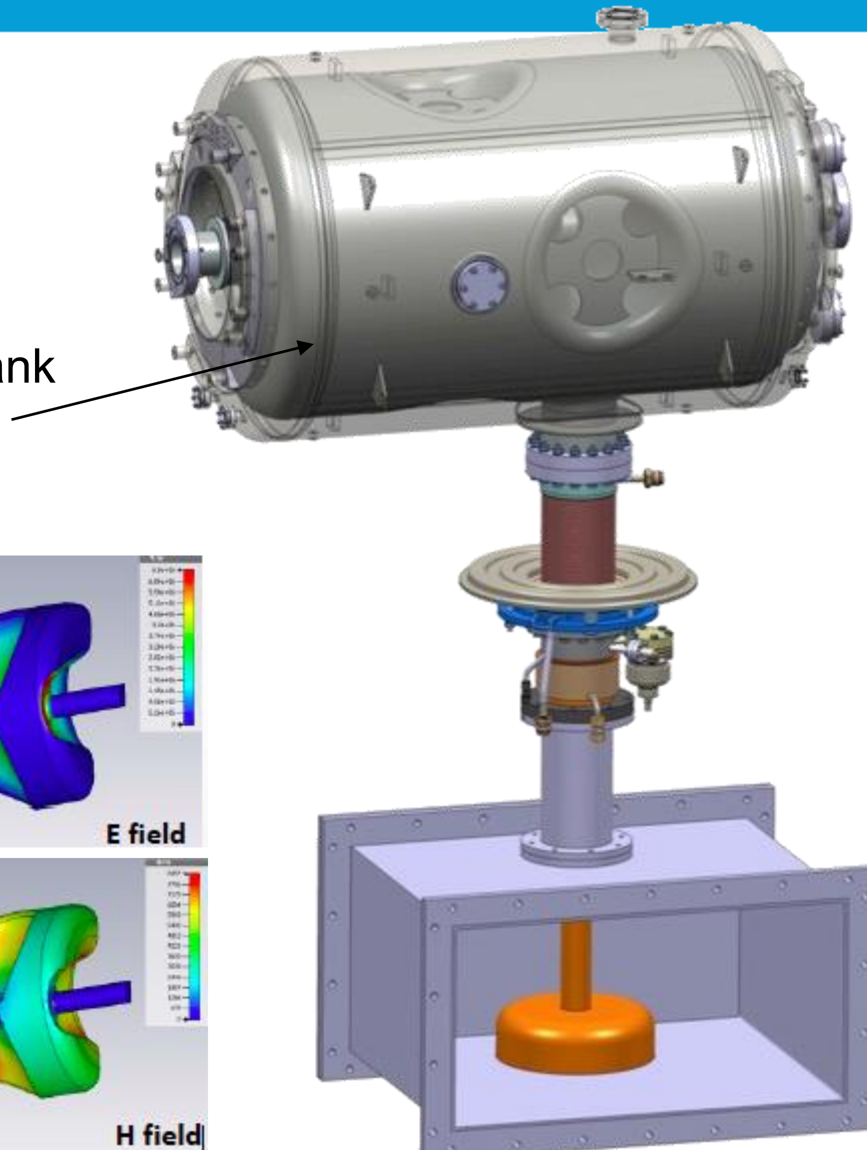
Spoke cavity and cryomodule design

Double spoke cavity

Item	Values	Unit
Beam mode	Pulsed (4 % duty cycle)	
Frequency	352.21	MHz
Optimal β	0.50	
Temperature	2	K
Bpk	70 (max)	mT
Epk	39 (max)	MV/m
Eacc	9	MV/m
Lacc	0.639	m
Bpk/Eacc	6.80	mT/(MV/m)
Epk/Eacc	4.28	
Beam tube dia.	56	mm
Pmax	335	kW







Elliptical cavity design

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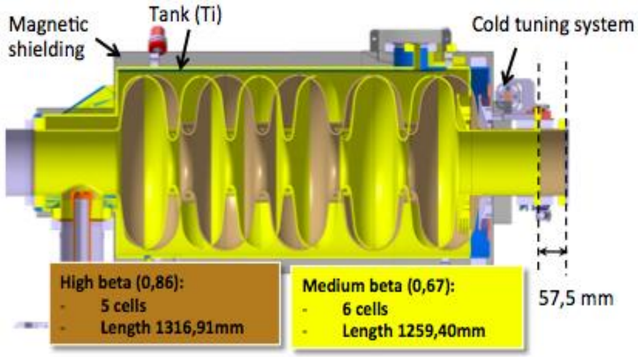
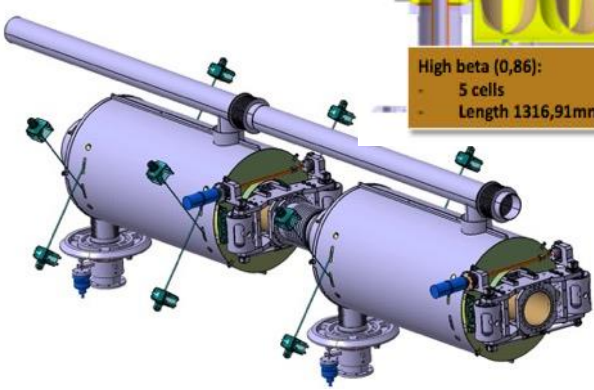




	Medium	High
Iris diameter (mm)	94	120
Cell to cell coupling k (%)	1.22	1.8
π and $5\pi/6$ (or $4\pi/5$) mode separation (MHz)	0.54	1.2
E_{pk}/E_{acc}	2.36	2.2
B_{pk}/E_{acc} (mT/(MV/m))	4.79	4.3
Maximum. r/Q (Ω)	394	477
Optimum β	0.705	0.92
G (Ω)	196.63	241

	Medium	High
Geometrical beta	0.67	0.86
Frequency (MHz)	704.42	
Operating temperature (K)	2	
Maximum surface field in operation (MV/m)	45	45
Nominal Accelerating gradient (MV/m)	**16.7**	**19.9**
Nominal Accelerating Voltage (MV)	14,3	18,2
Q_0 at nominal gradient	**> 5e9**	
Cavity dynamic heat load (W)	4,9	6,5
Q_{ext}	$7.5\ 10^5$	$7.6\ 10^5$

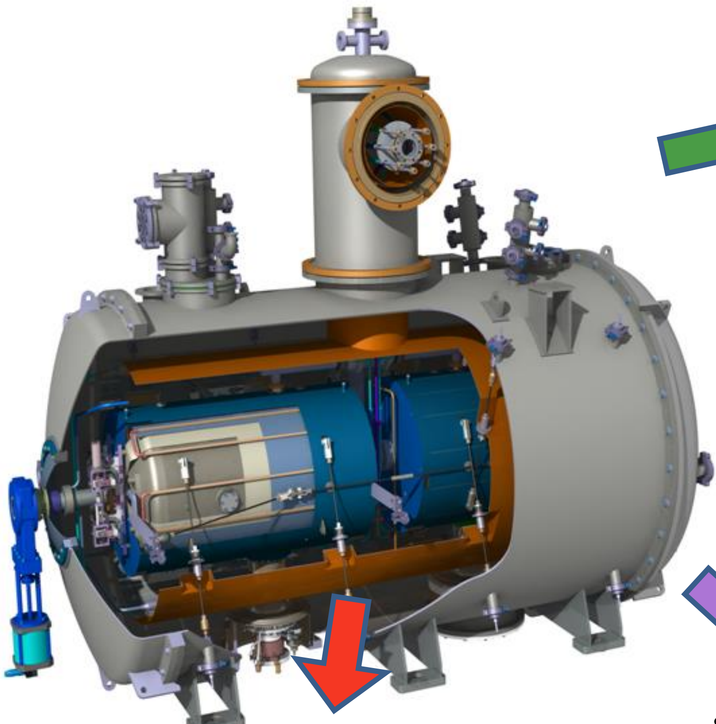
- **Challenging accelerating gradients and Q_0**
- **No HOM couplers**

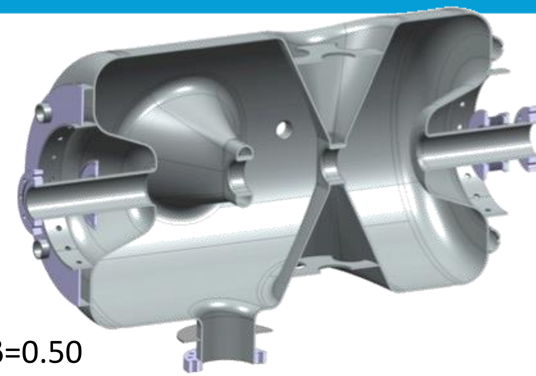
HOM frequencies and internal cavity shape must be carefully controlled

G. Devanz, J. Plouin, G. Constanza

Spoke cryomodule design

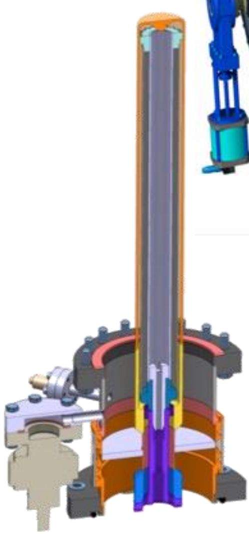
EUROPEAN SPALLATION SOURCE





Double Spoke SRF Cavities

- Double spoke cavity
  (3-gaps), 352.2 MHz, β=0.50
- Goal: Eacc = 9 MV/m *[Bp= 72 mT ; Ep = 39 MV/m]*
- 4 mm (nominal) Niobium thickness
- Titanium Helium tank, Ti stiffeners
- Lorentz detuning coeff. : -4.4 Hz/(MV/m)^2
- Tuning sentivity $\Delta f/\Delta z$ = 128 kHz/mm

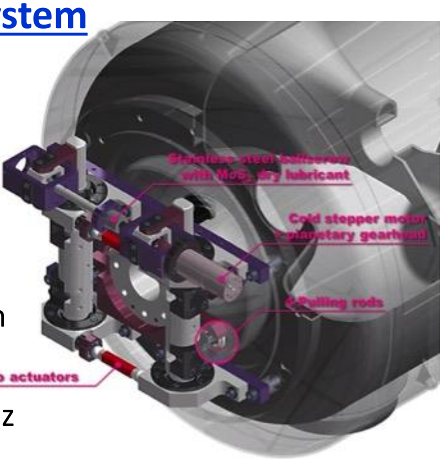


Power Coupler

- Ceramic disk, 100 mm diameter
- 400 kW peak power (330 kW nominal)
- Antenna & window water cooling
- Outer conductor cooled with LHe
- Doorknob transition from coaxial
  to ½ height WR2300 waveguide

Cold Tuning System

- Slow tuner (stepper motor):
  Max tuner stroke: 1.28 mm
  Max tuning range: ~ 170 kHz
  Tuning resolution: 1.1 Hz
- Fast tuning by 2 piezo-actuators
  Noliac 50x10x10 or PI 36x10x10 mm
  Applied voltage up to +/- 120 V
  Estimated tuning range at 2K: 800 Hz



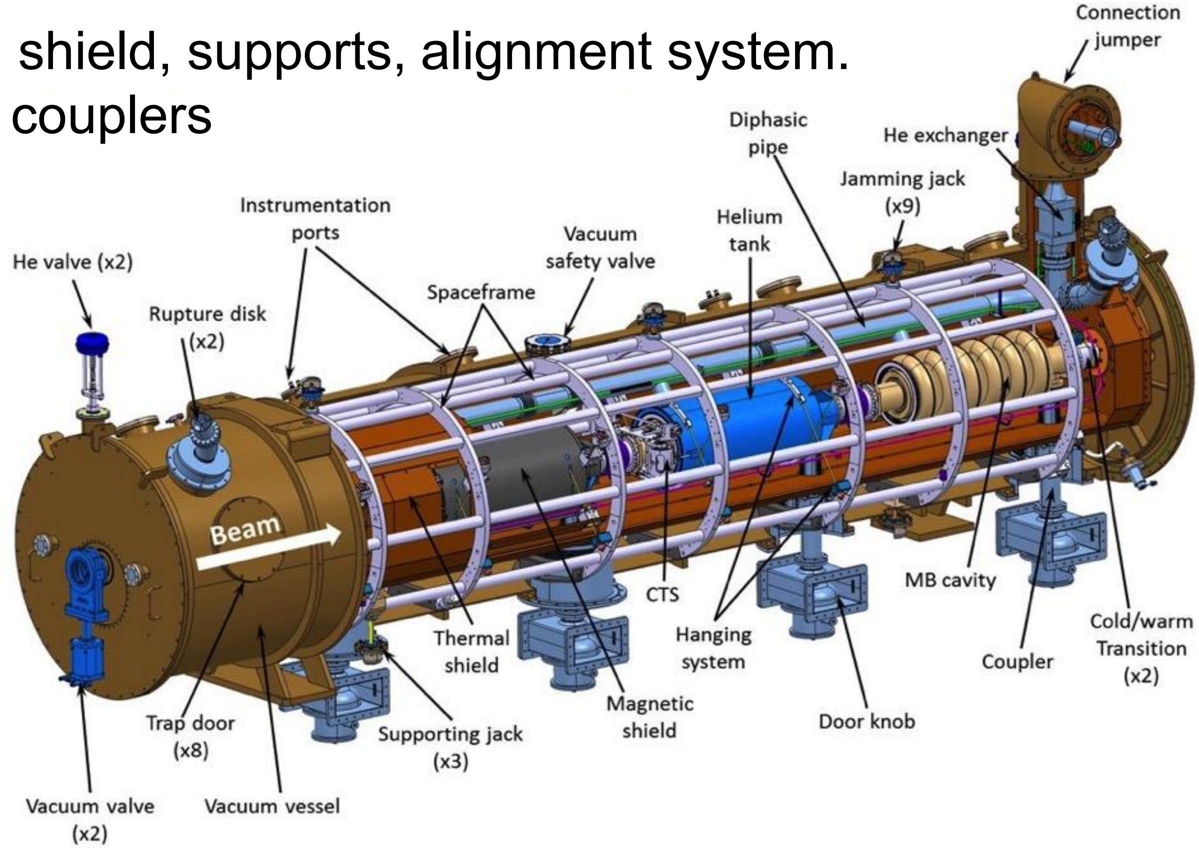
Elliptical cryomodule design

Similar medium and high-beta cavity cryomodules

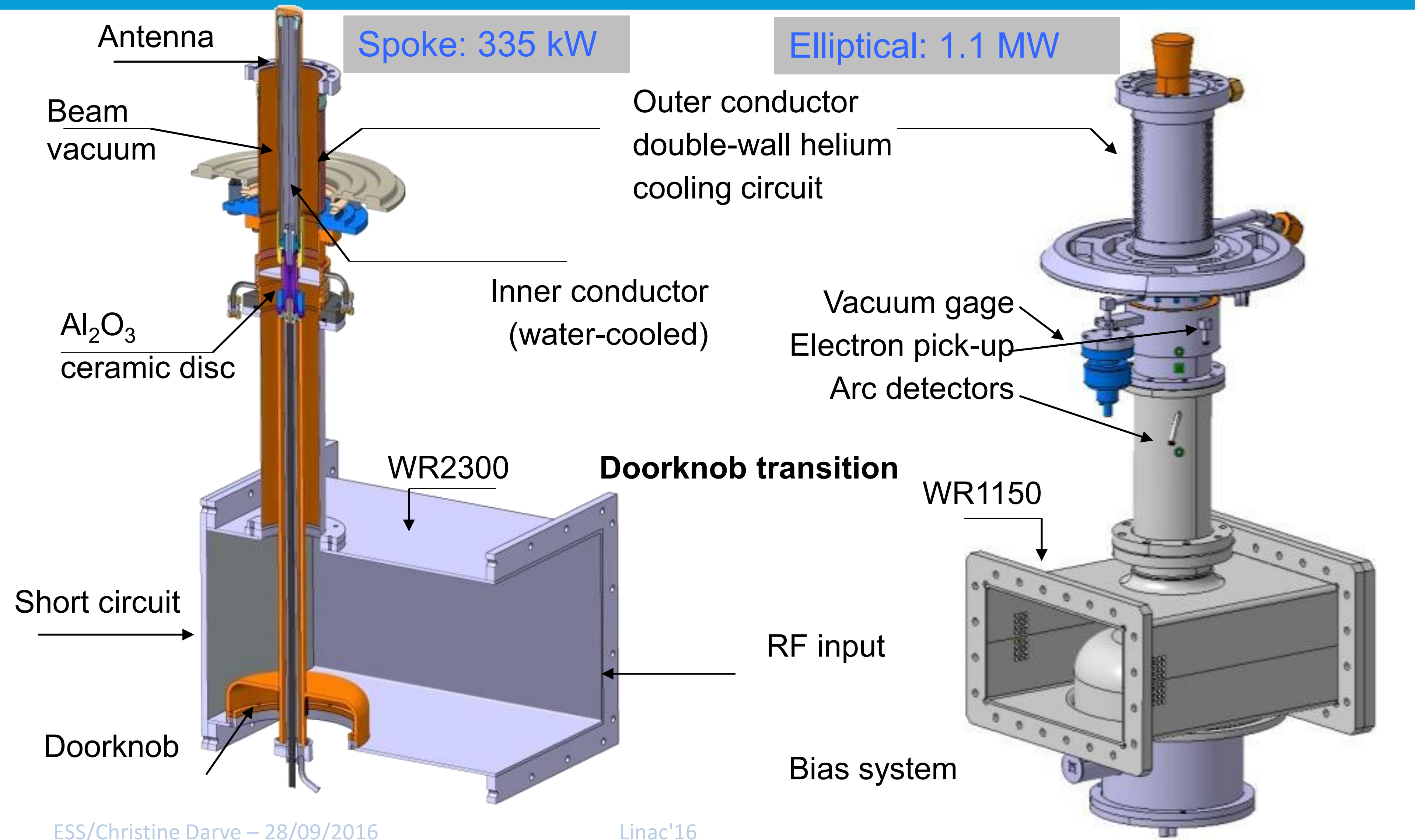
- Common design: Small length difference between medium & high-beta cavities
- Vacuum vessels, thermal shield, supports, alignment system.
- Distance between power couplers

Only minor differences:

- Length of the inter-cavity bellows,
- Details in cryo piping, beam pipe bellows
- Penetration of the antenna for Q_{ext} adjustment
- Tuner piezo frames



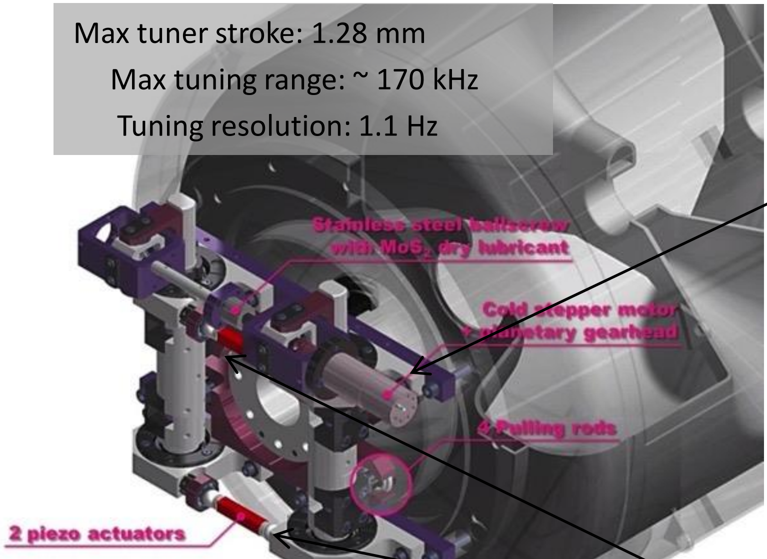
Power-coupler designs



Cold Tuning System designs

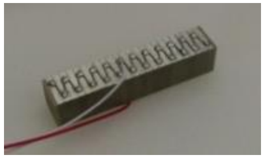
Spoke CTS

Max tuner stroke: 1.28 mm
Max tuning range: ~ 170 kHz
Tuning resolution: 1.1 Hz



Noliac 50x10x10 or PI 36x10x10 mm
Applied voltage up to +/- 120 V
Estimated tuning range at 2K: 800 Hz

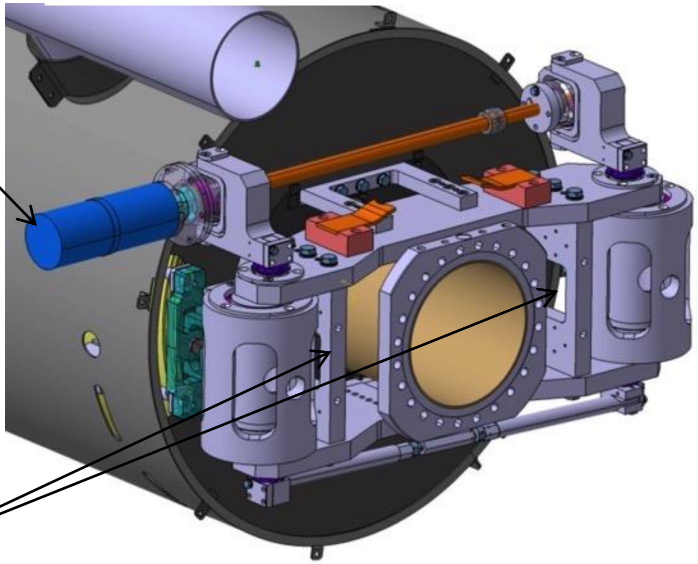
Stepper motor and planetary gearbox (1/100e) at cold and in vacuum



2 piezo stacks

Elliptical CTS

Type V ; 5-cell prototype
+/- 3 mm range on cavity



Slow tuner
Main purpose : Compensation of large frequency shifts with a low speed
Actuator used : Stepper motor

&

Fast tuner
Main purpose : Compensation of small frequency shifts with a high speed
Actuator used : Piezoelectric actuators

Assembly Procedures

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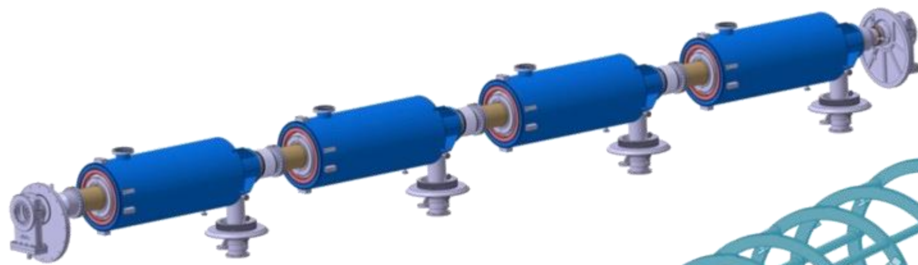
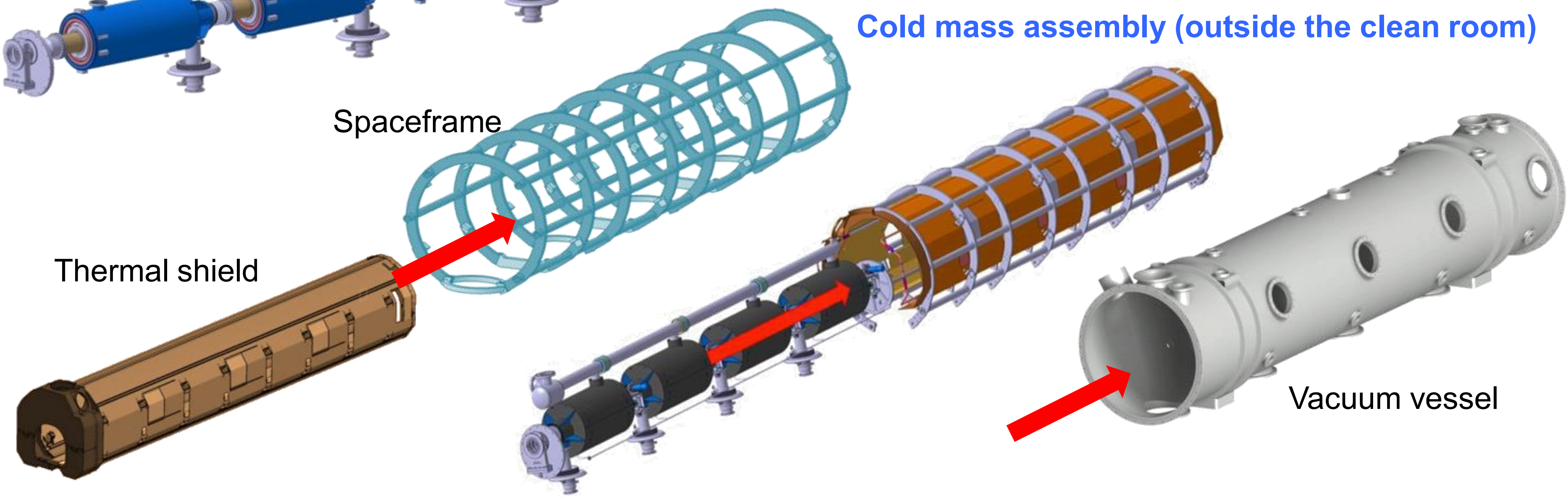
Build on existing knowledge (SNS, XFEL)

- Develop Training and “Fabrication file”
- Pre-industrialization
- Industrialization

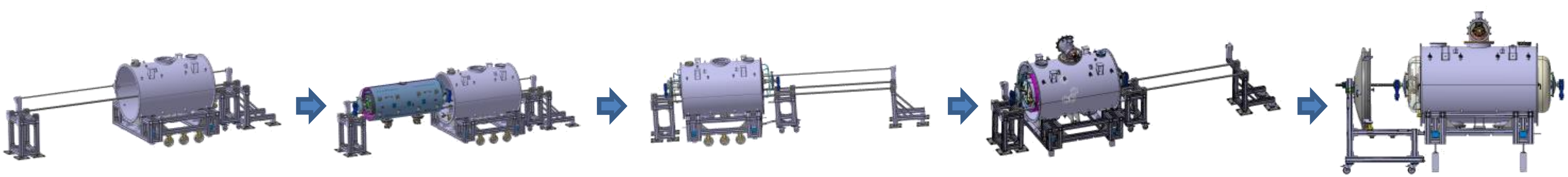
Cavity string assembly in clean room



Cold mass assembly (outside the clean room)

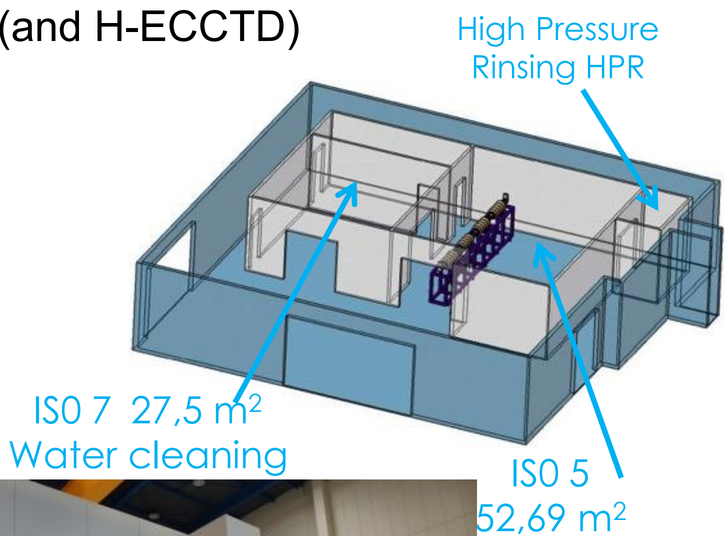


Design concept of the tooling: most of parts will be used for both types of elliptical cryomodules



Infrastructures (ex. Clean room in Saclay)

Clean room for the M-ECCTD (and H-ECCTD)



The clean room inauguration on May 13th 2014

Assembly room in Saclay

- Uses the current infrastructure of XFEL
- Benefits from the experience of the XFEL cryomodule assembly (ALSYOM)

Outline

- Introduction to European Spallation Source
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Spoke and cryomodule prototypes

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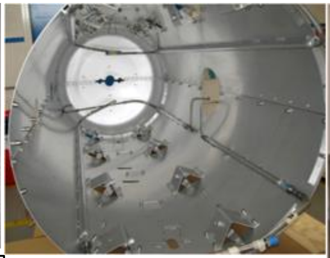
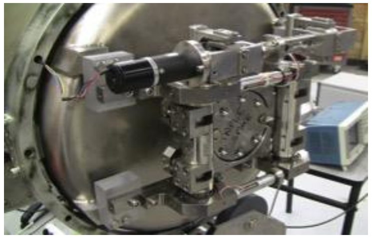
View of the spoke cavity bars

Inter-cavity bellows



Thermal shield

Magnetic shield



Cold Tuning System

Spoke cryomodule vacuum vessel: Fabrication achieved (FAT done)

Spoke cavity surface preparation

- Ultra-sonic degreasing

- Chemical etching: BCP

Goal: 200 μm (min)
  - Phase 1: Horizontal, 120 minutes
  - Phase 2: Horizontal (180° rotation), 120 minutes
  - Phase 3: Vertical, 240 minutes

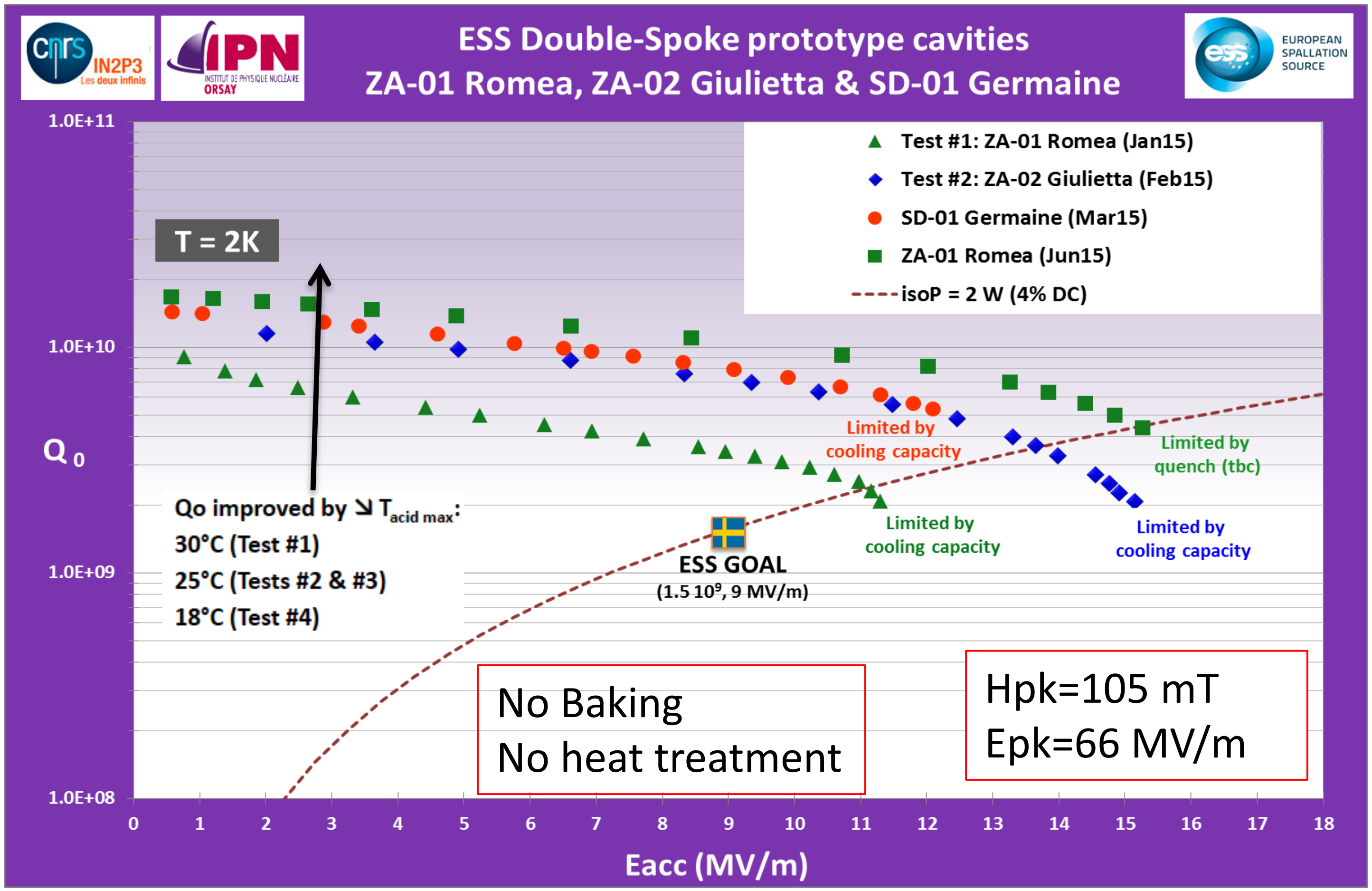
Why H & V positions?
  - Better homogeneity
  - Frequency shift compensation: $\Delta f_{200\mu m} < -20$ kHz

- HPR: 4 passes through all ports (6000 liters & 12h /cavity)

➔ No Baking and no heat treatment on the prototype cavities

Spoke cavity performances @ IPNO

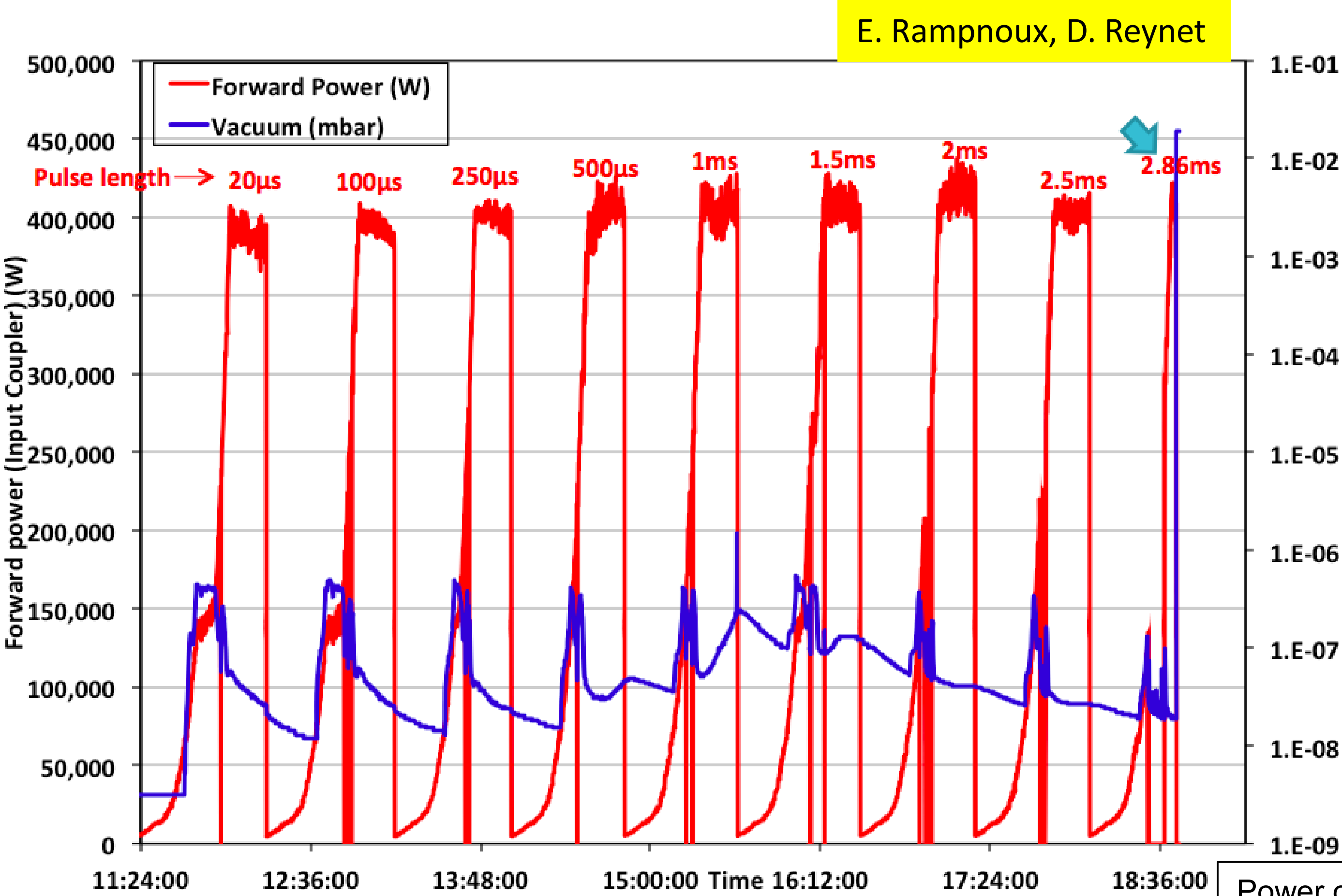
➔ Spoke cavity exceeding ESS requirements in vertical test on both Eacc and Qo



- E_{acc_max}=15.3 MV/m achieved with "Romea"
- Several MP barriers but easily processed.
- Qo > 1.6 10^{10}
- Strong FE at max gradient
- Limitation is the cooling capacity (unstable conditions, cavity in vertical position)

Spoke power-coupler performances @IPNO

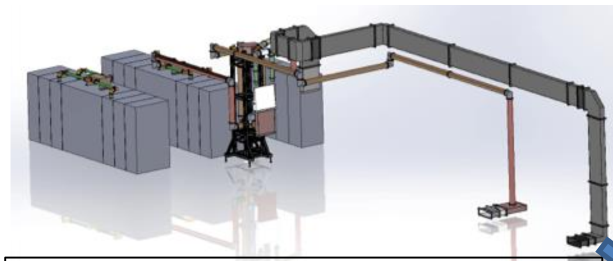
➔ One spoke power coupler reached ESS requirements (sept. 2016)



RF conditioning stopped after output coupler failure (vacuum level raised up to 0.01 mbar)

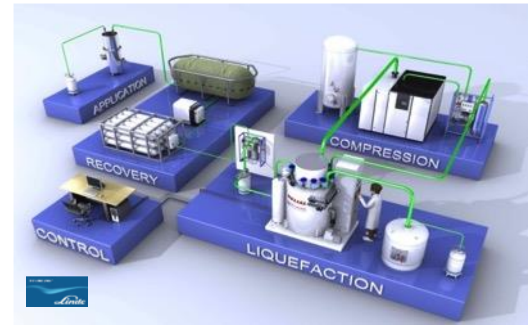
Power coupler conditioning bench: all parts realized, dry assembly done.

Horizontal SRF Test Stand @ Uppsala University

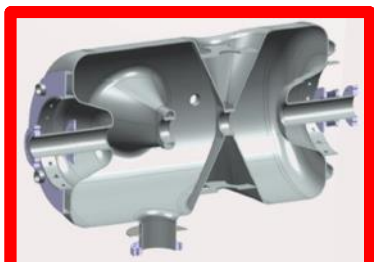


RF Power Source + LLRF

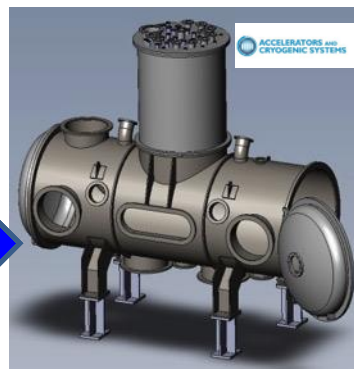
Control System

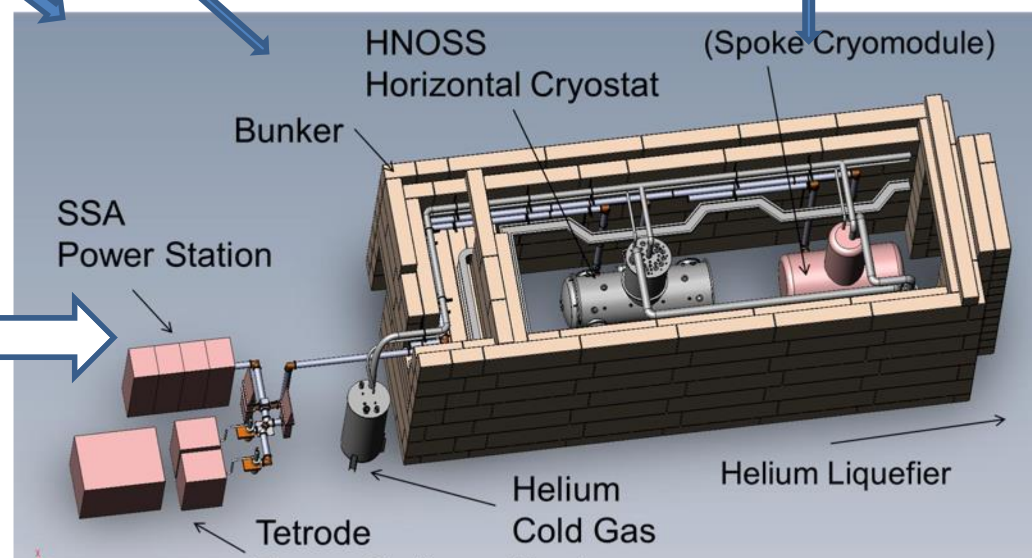


Cryogenics + valve box



SRF Cavity

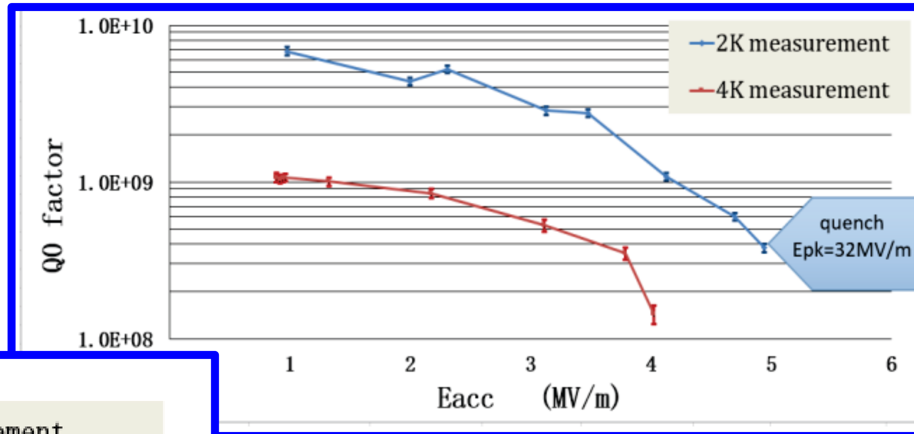


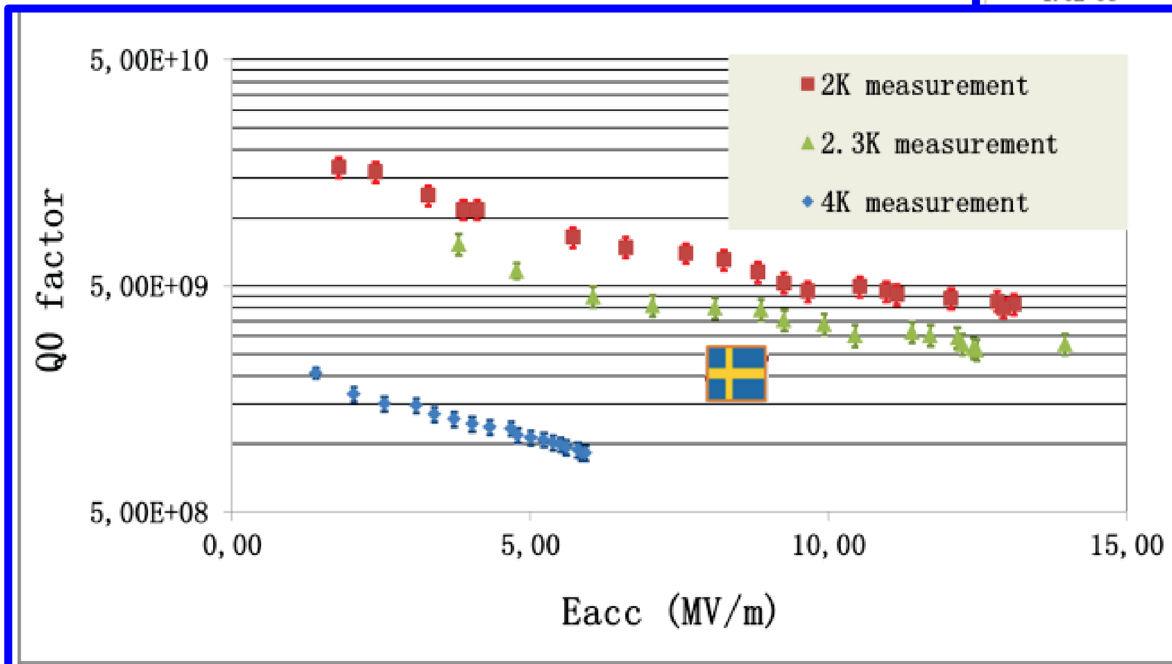


Spoke cavity performances @ Uppsala University

➔ Spoke cavity (Germaine) exceeding ESS requirements in vertical test on both Eacc and Qo

ESS Goal:
Eacc_max > 9 MV/m
Qo > 1.5 10^9





Elliptical selected technologies

Medium beta cavity prototype

High beta cavity prototype with its helium tank

Magnetic shield

Tubes for rupture disks under manufacturing (left), inter-cavity bellows (middle) and cold-warm transitions (right)

Blank assembly of the jumper cryogenic connection

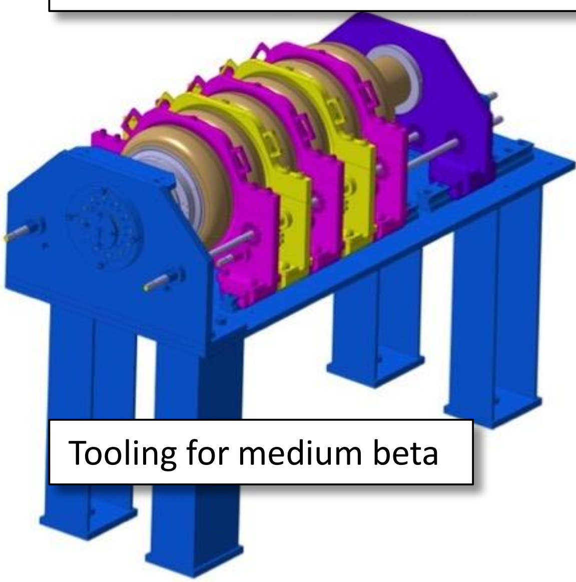
Validation tests of cavity string handling tools for clean room assembly (using a cavity mock-up)

New barometric compensation system for coupler flange under test

Blank assembly of the spaceframe inside the vacuum tank

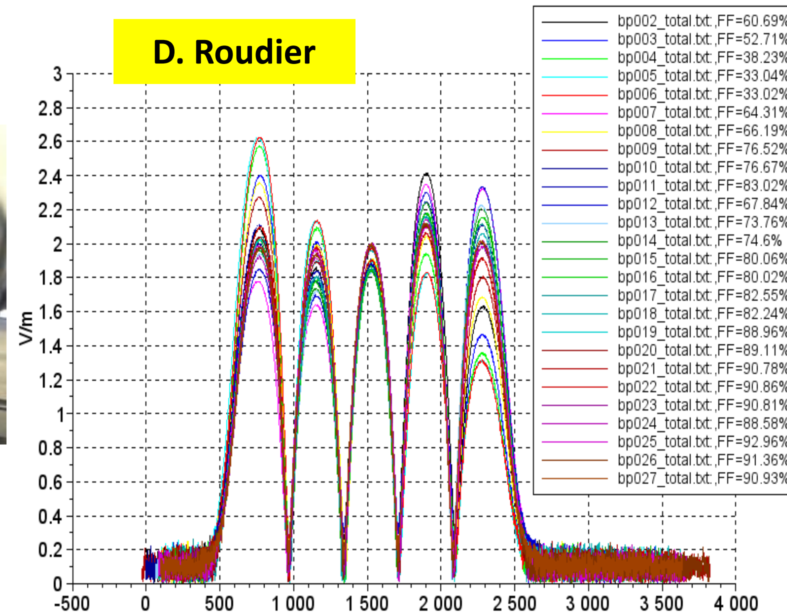
Field flatness tooling @ CEA-Saclay

Tooling for high beta ready



Tooling for medium beta

D. Roudier



Exemple of cavity tuning (High beta Prototype n°2 from RI)

Not adapted for large series cavities production

Cavity clean room assembly with High Pressure Rinsing @ CEA-Saclay

HPR 100 bars - Ultra pure water

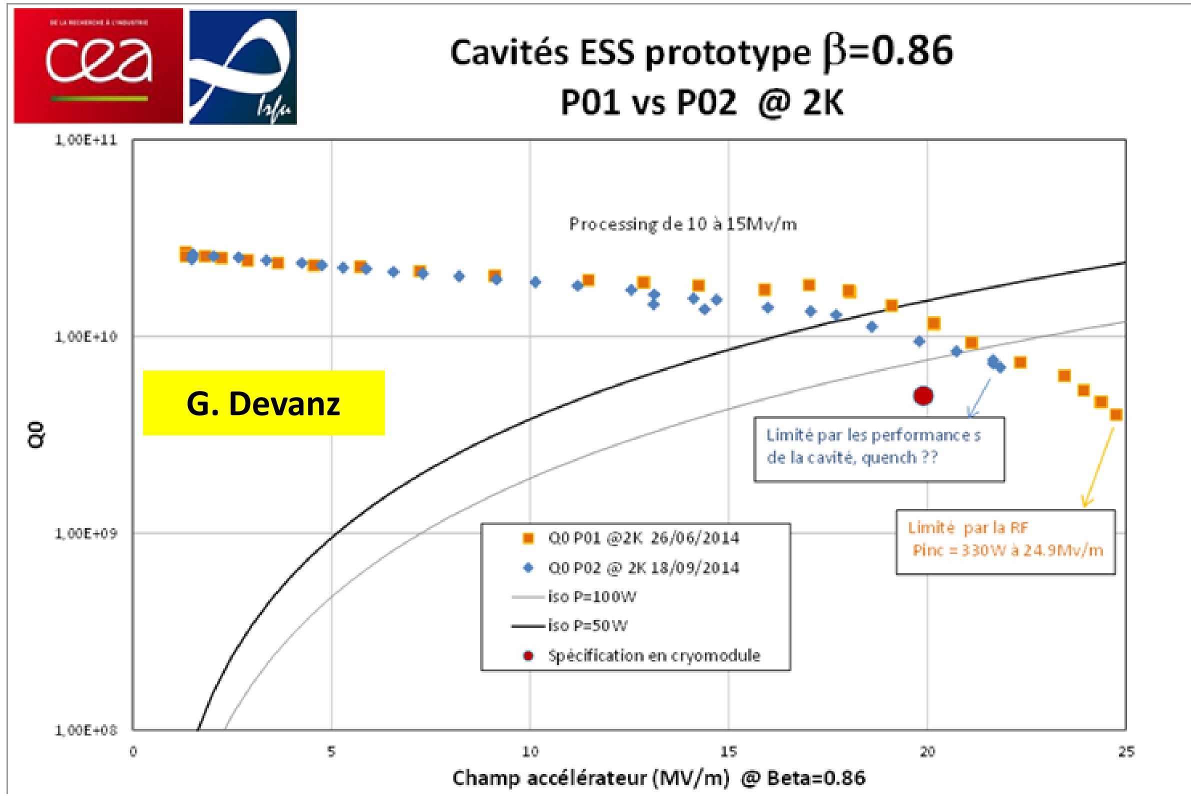
Flanges and antenna pick-up assembly under class 100 laminar flow

F. Eozenou, C. Servouin

High-beta cavity results, HBP01, HBP02

➔ Q curves of the cavities HBP01 and HBP02 exceeded ESS goal, w/o heat treatment

Mounting on vertical insert , Connexion to RF system and vacuum pumping station

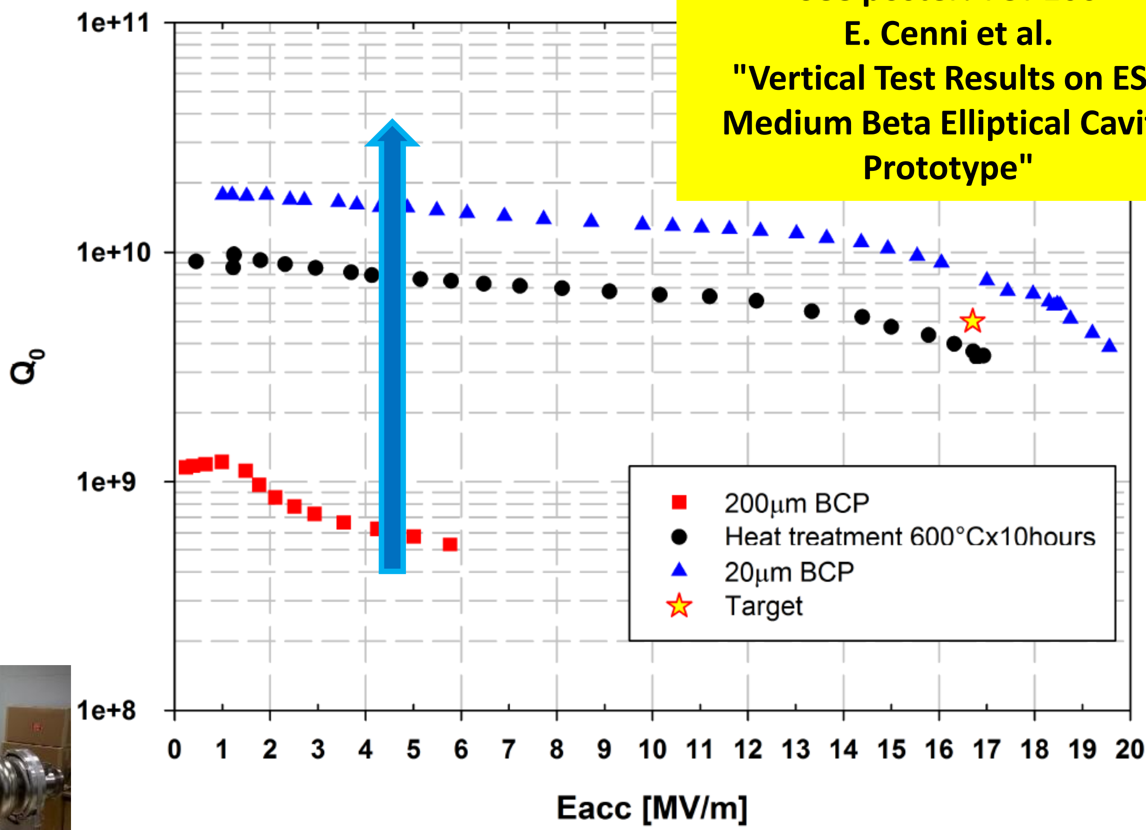


- Heat treatment for hydrogen removing, performed on the high-beta cavity, HP01, failed to improve the accelerating gradient.
- Lessons learned: heat treatment process has been studied with industry and succesfully implemented for medium-beta cavities.

Medium-beta cavity results, MBP01

- ➔ MBP01 reached the ESS goal after proper heat treatment (July 2016)
- ➔ MBP02 tested after 200µm BCP shows better results than MBP01 at the same phase (September 2016)

See poster: TUP106
E. Cenni et al.
"Vertical Test Results on ESS Medium Beta Elliptical Cavity Prototype"

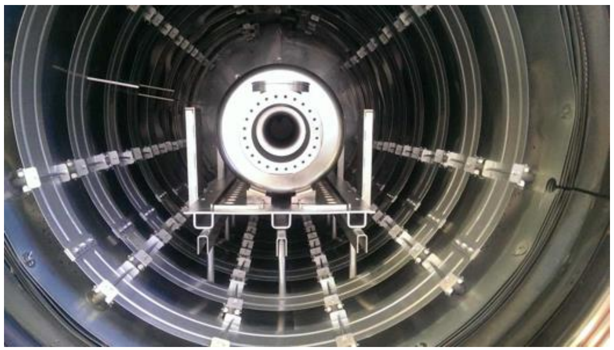


Lessons learned:

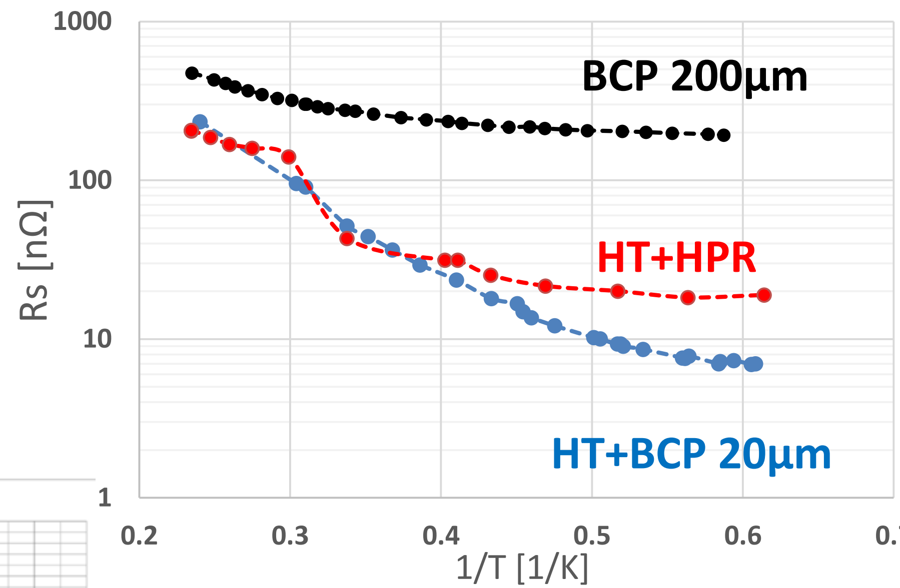
- Mechanical and Freq stats
- BCP
- Heat treatment
- Neutron during VT

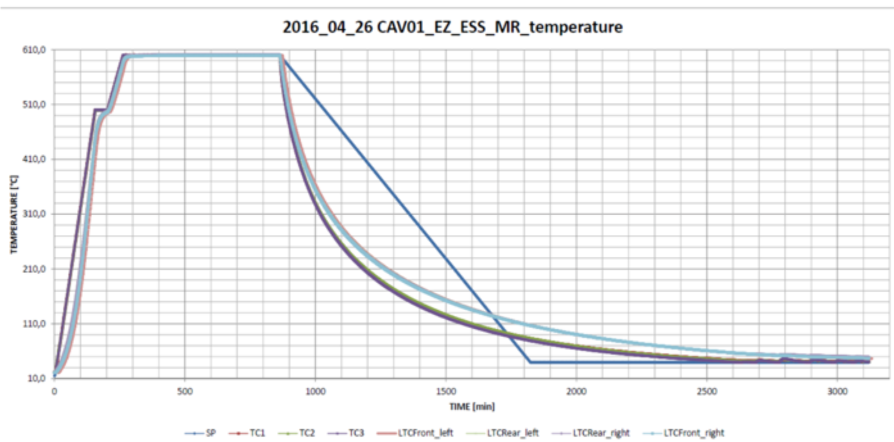
Heat treatment, MBP01

→ Heat treatment at 600°C for 10 hours proved to be effective to improve cavity performance, MBP01 (May 2016)



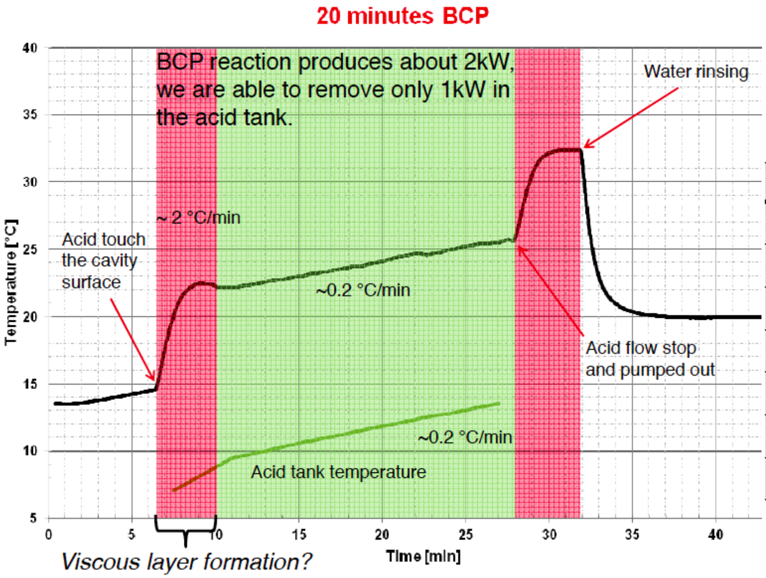
Cavity in oven @ Zanon

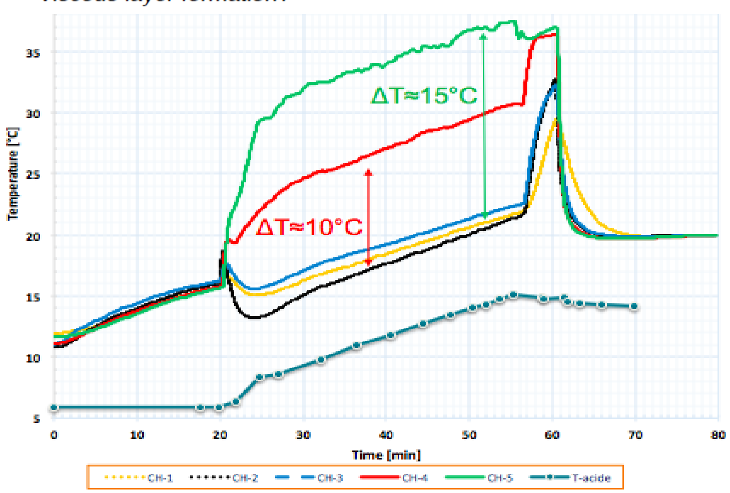




Process	Rs @2K [nΩ]
BCP ~200µm	205
Heat treat.+HPR	20
HT+BCP ~20µm	10

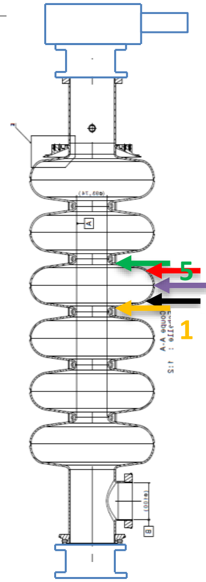
BCP preparation, MBP02

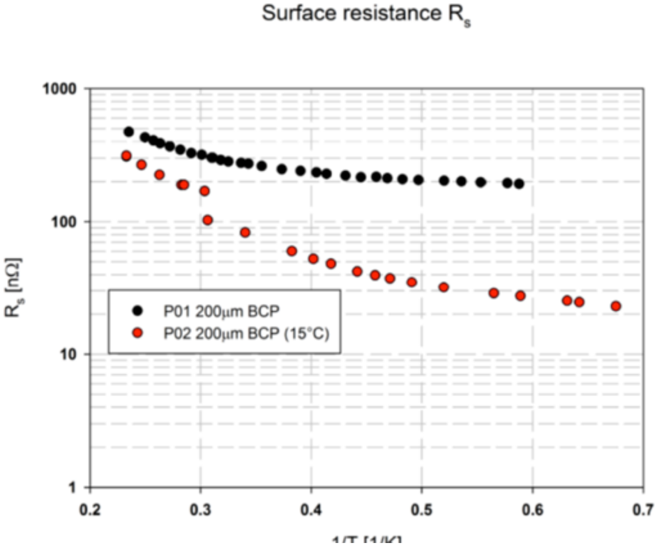


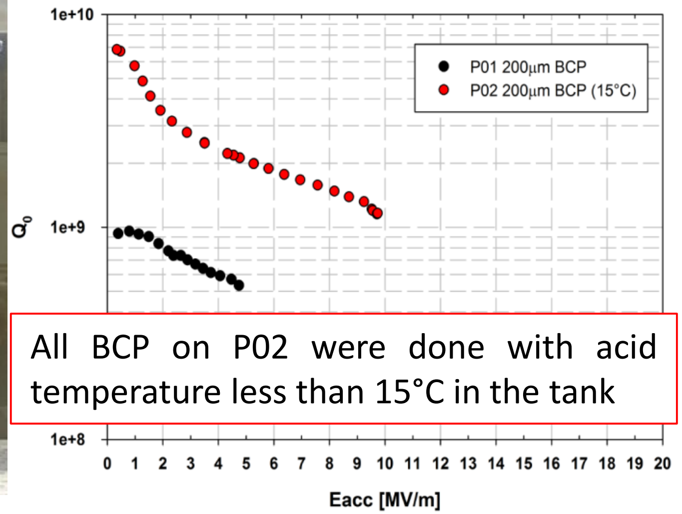


TUP106
E. Cenni et al.

Cavity data	
Surface	1.8 m^2
Volume	67 liters
Length	1258 mm
Equator diameter	370 mm
Iris diameter	94 mm
# cells	6
Frequency	704.42 MHz







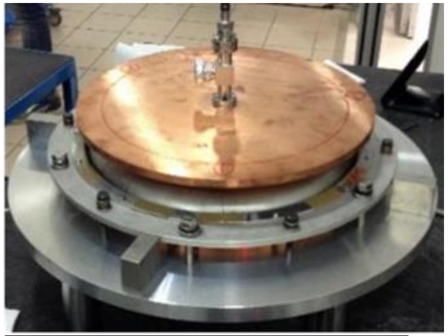
All BCP on P02 were done with acid temperature less than 15°C in the tank

Lessons learned: Manufacture

From Dumbbell measurement it is possible to compute cavities frequency and length.
The observed deviation are:

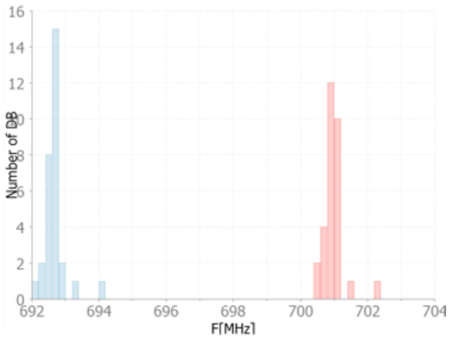
Parameter	Average deviation respect computed values
Length	0.767 mm
π-mode frequency	0.292 MHz

Length can be predicted within 1 mm accuracy and frequency within 300kHz.

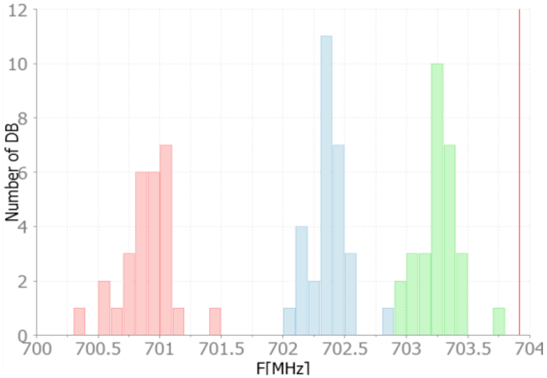


RF measurements system (on half cell)

Dumbbells after welding in the control area



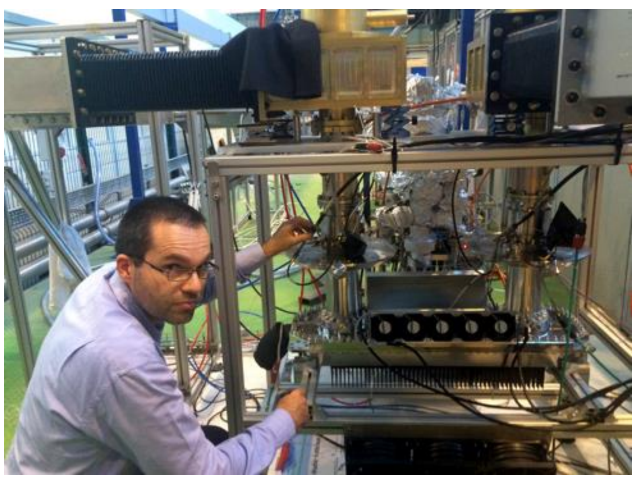
Dumbbells RF measurements for 0-mode (blue) and π-mode (red). Each bin has 0.2MHz width.

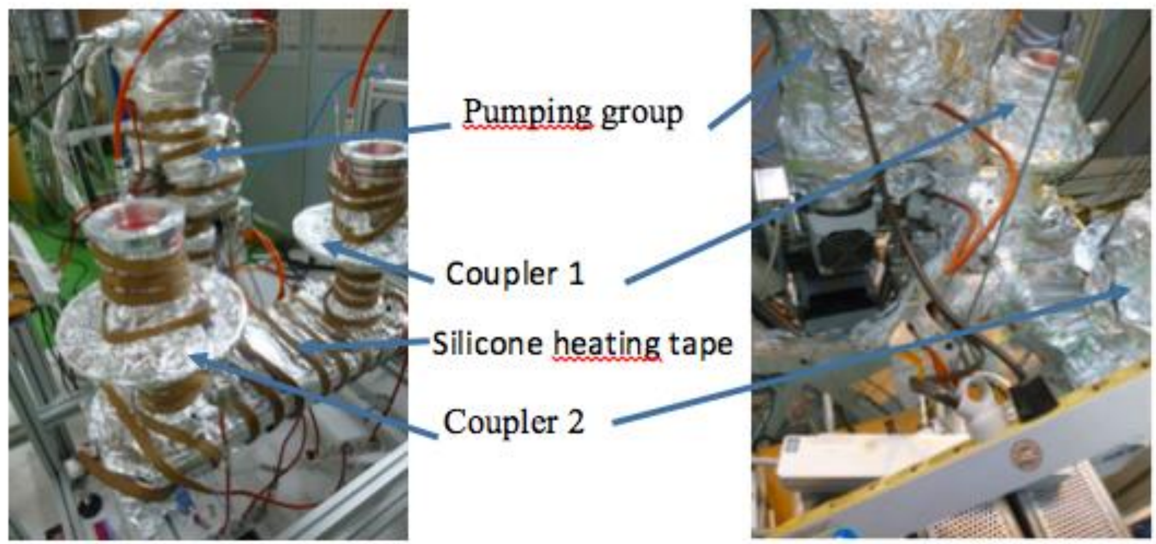


π-mode frequency measurement welding (red), trimming (blue) and trimming+welding shrinkage (green).

1.1 MW power-coupler conditioning

The coupler is equipped with different diagnosis elements: on the window, a pressure jauge, an electron pick-up (that is also used to measure the RF power close to the ceramic level) and a photomultiplier are mounted.
A baking is performed with silicon heating tapes: the temperature of the coupler and the box is set up at 170 °C for 96hours and the vacuum pumping group at 120 °C for 48 hr then 60 °C for 48 hr.





1.1 MW power-coupler conditioning

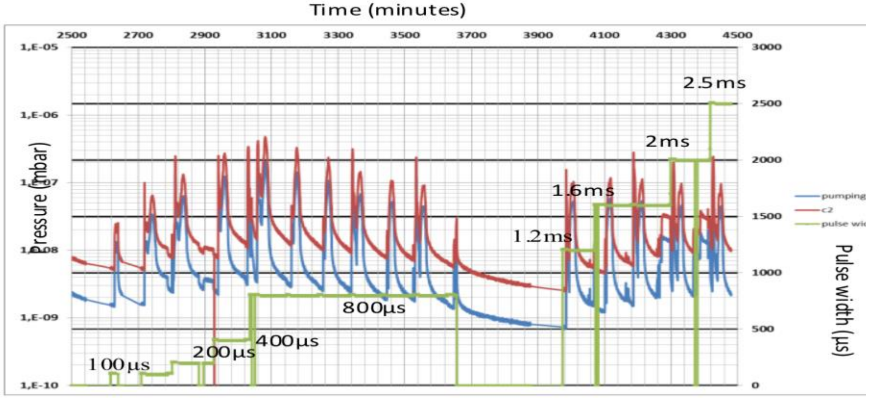
EUROPEAN SPALLATION SOURCE

- ➔ First results for the conditioning of the coupler loaded by 50 ohm in traveling wave.
- ➔ Successful test with 14 Hz, 3.6 ms. Power increased up to 1.2 MW.

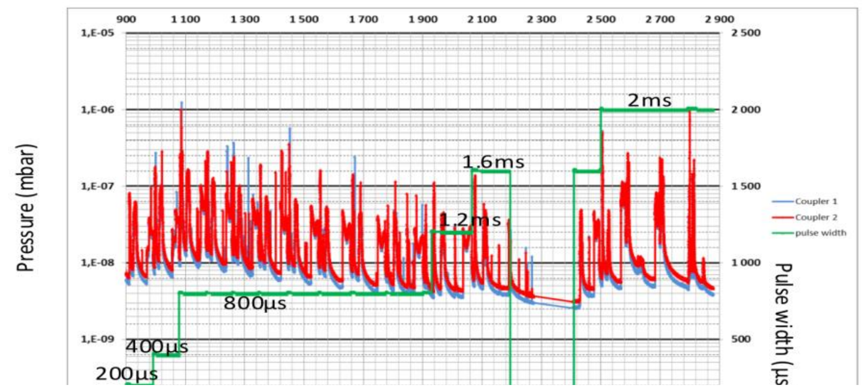
Pulse repetition period:1.2 s

Pulse repetition period:72 ms

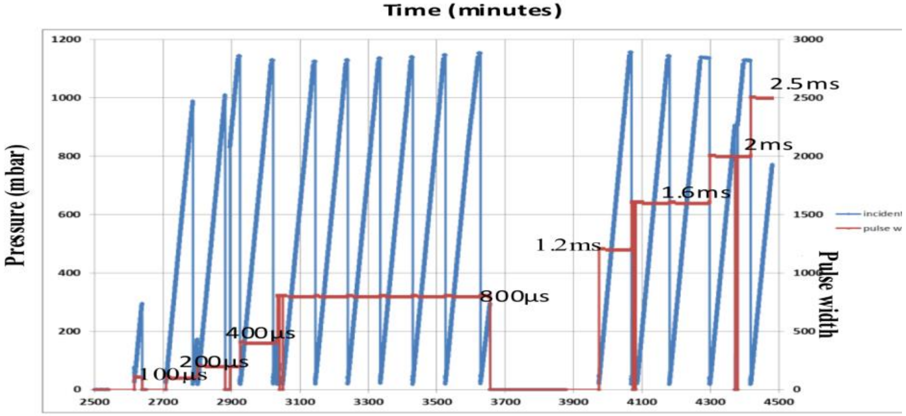
Time (minutes)



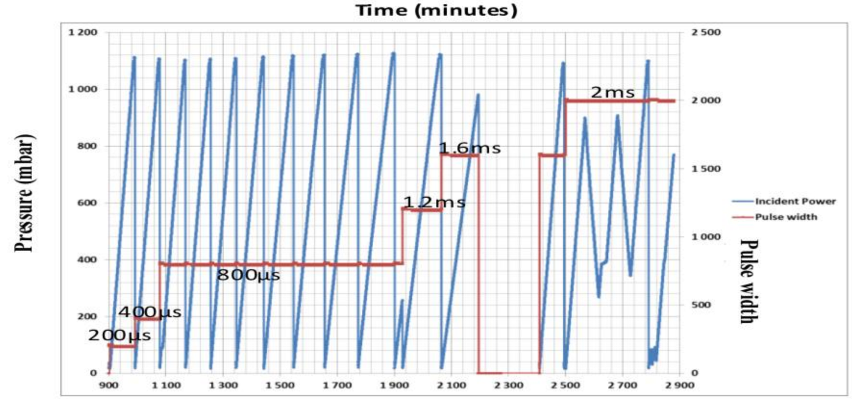
Time (minutes)



Time (minutes)



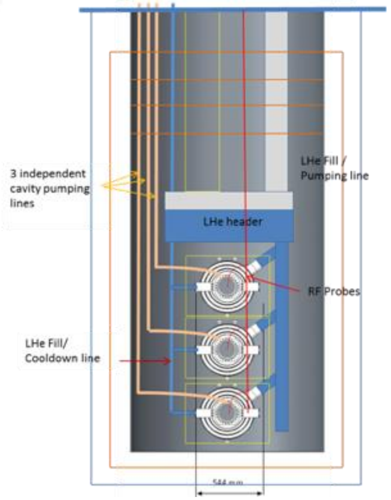
Time (minutes)

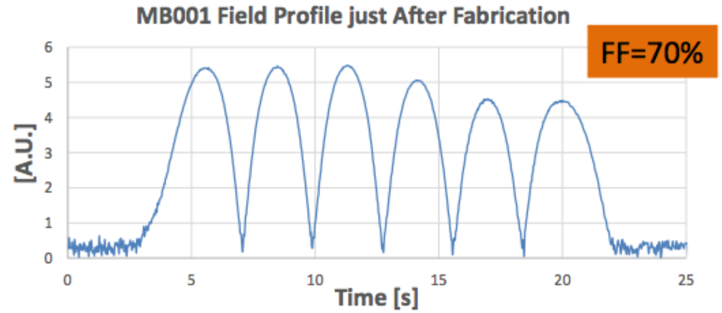


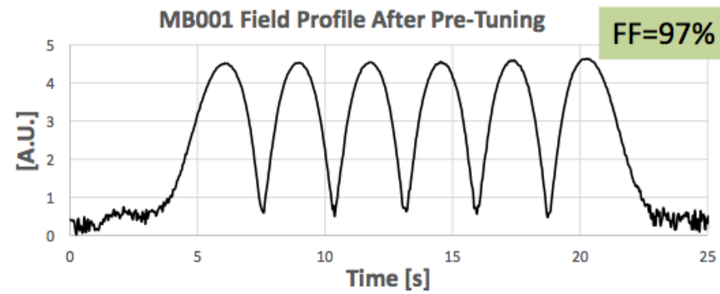
First results from LASA and STFC

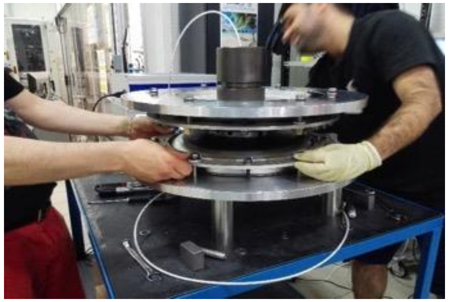
@ LASA: Medium-beta cavity after electron beam welding

@ STFC: Cavity testing in cryostat









Preparation for DumbBell Frequency measurement

Thank you for your attention!

EUROPEAN SPALLATION SOURCE

- A new collaborative project for Spallation.
- The first results for the SRF linac are promising even if many challenges still need to be addressed.
- Many lessons learned from results and other experiments.
- Build further capacity using industrialization process.
- Coordination of interfaces and integration is a challenging and on-going effort !

Acknowledgment and thanks to the excellent progress of the ESS SRF teams

Irfu cea

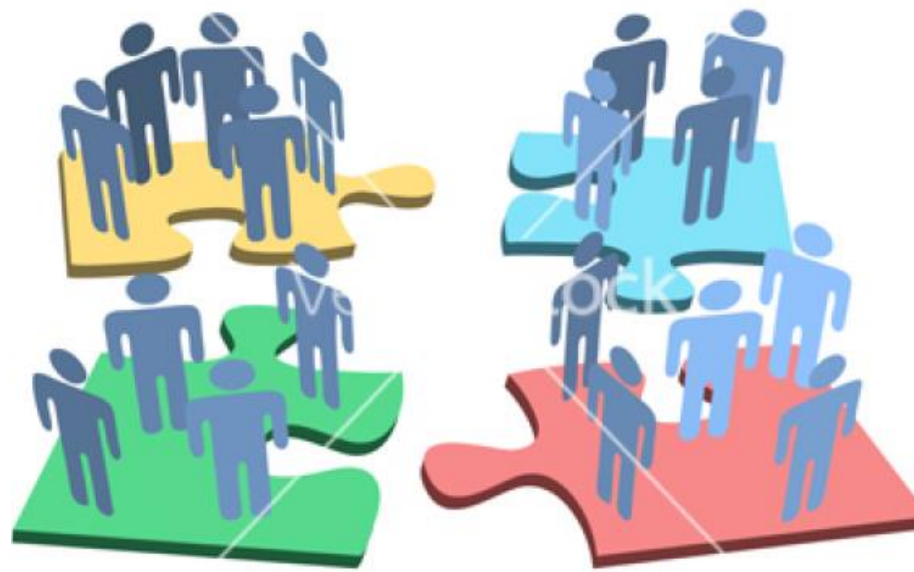
LUND UNIVERSITY

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY cnrs IN2P3 Les deux infinis

INFN Istituto Nazionale di Fisica Nucleare

FREIA UPPSALA UNIVERSITET

Science & Technology Facilities Council



CEA and IPNO test areas people













More reading

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