# ESS SRF Linear Accelerator Components Preliminary Results and Integration

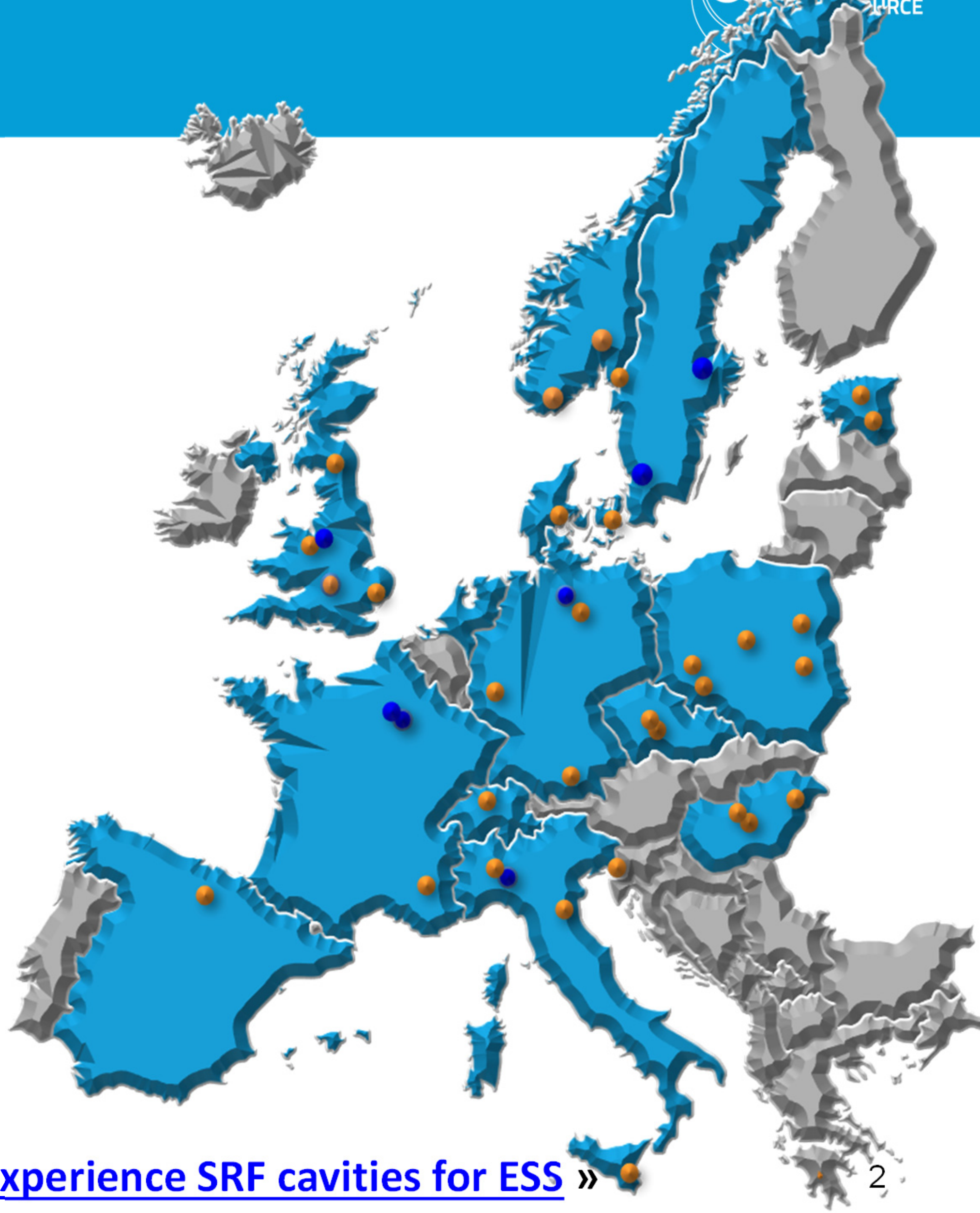
***Christine Darve***
***Deputy Leader of SRF Work Packages: WP04 (Spoke) and WP05 (Elliptical)***

***on behalf of the Cryomodule Collaboration***
**European Spallation Source ERIC**
**CEA / IRFU Saclay (Pierre Bosland – WP05 leader)**
**CNRS / IPN Orsay (Guillaume Olry – WP04 leader)**
**INFN / LASA (Paolo Michelato-Work Unit leader)**
**STFC / Daresbury (Mike Ellis-Work Unit leader)**
**Uppsala and Lund Universities – Roger Ruber**
**(Desy – Serie Medium-beta cavity testing)**

https://confluence.esss.lu.se/display/CRYOM
www.europeanspallationsource.se
18 May 2017

# Outline

- Accelerator & SRF layout
- Spoke Results
- Elliptical Results
- Integration

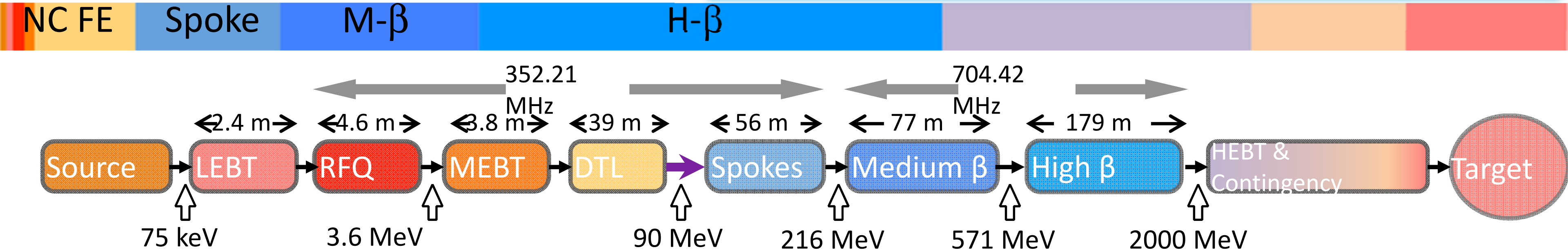


Follow-up on TTC2014 Plenary «Prototype experience SRF cavities for ESS »

# Linac redesign to meet ESS cost objective

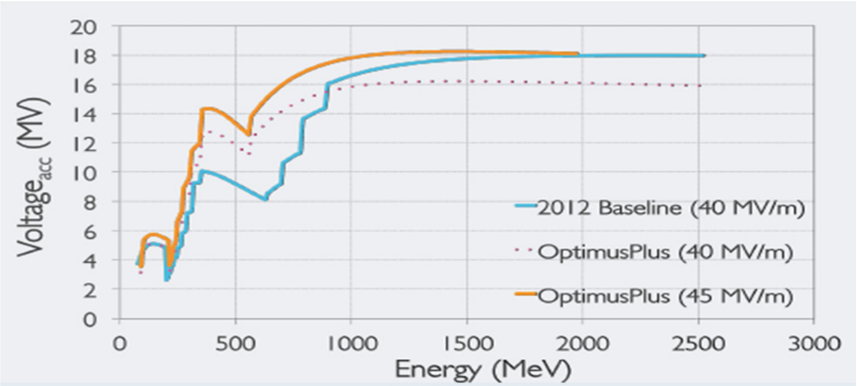
EUROPEAN SPALLATION SOURCE

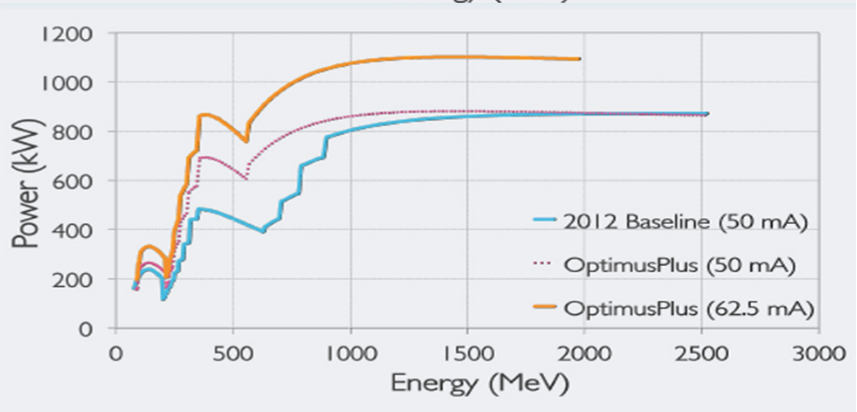
D. McGinnis "New design approaches for high intensity superconducting linacs – The new ESS linac design"- IPAC'14




R. Garoby "Progress on the ESS Project Construction" - MOXBA1

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



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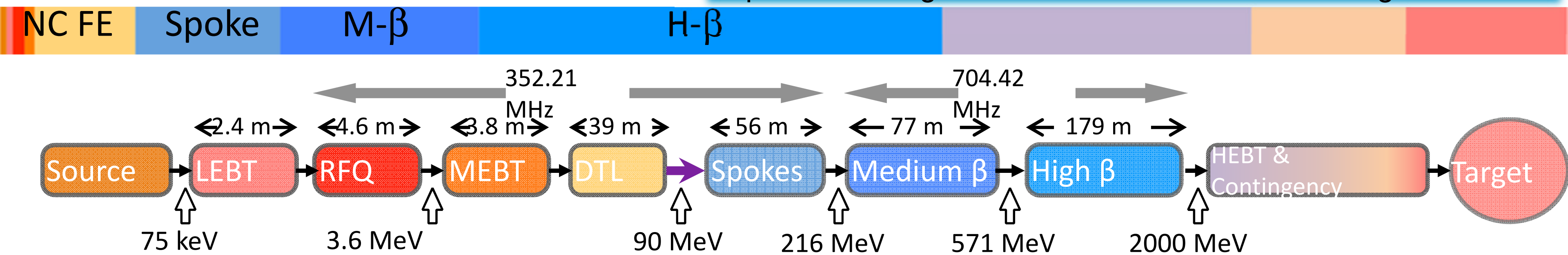


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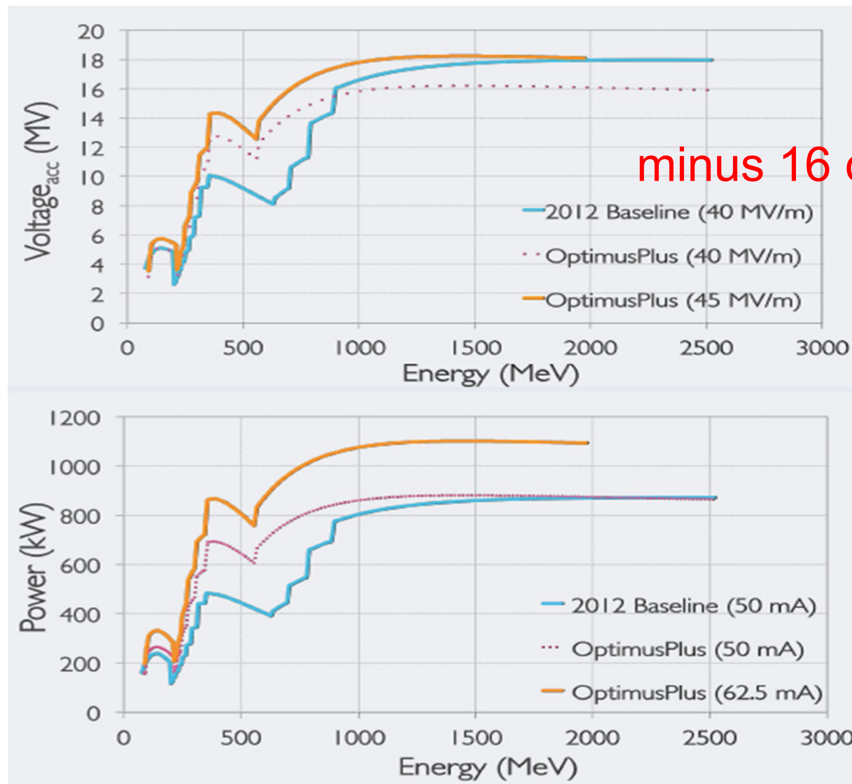


➔ Peak field: 45 MV/m

minus 16 cryomodules

Using cavities at their best !

➔Elliptical power-coupler 1.1 MW

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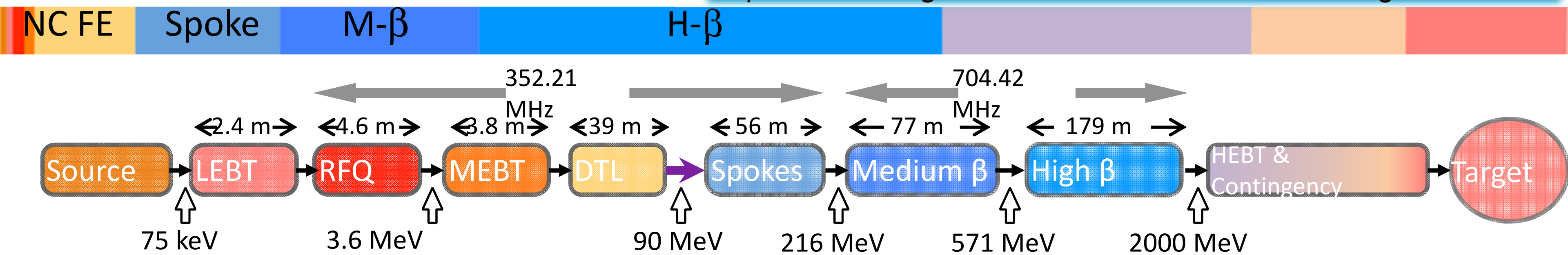


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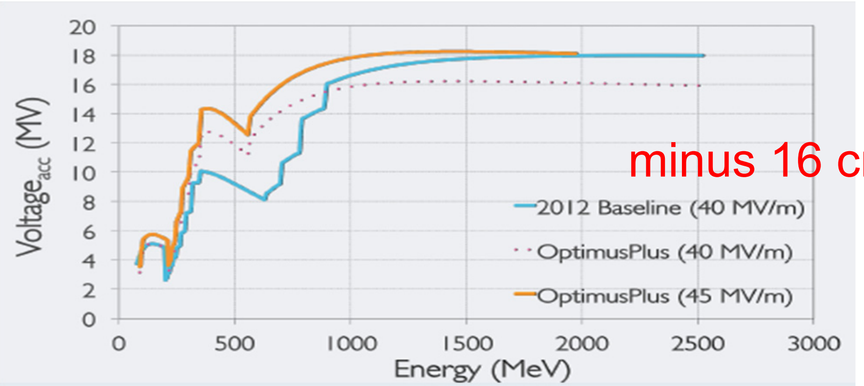


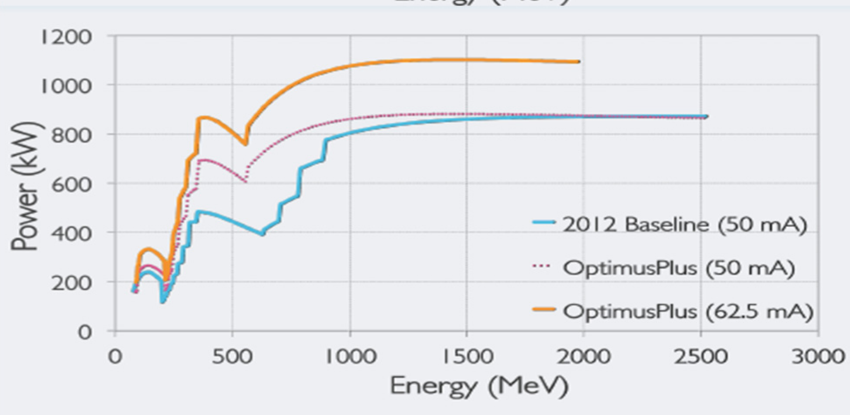


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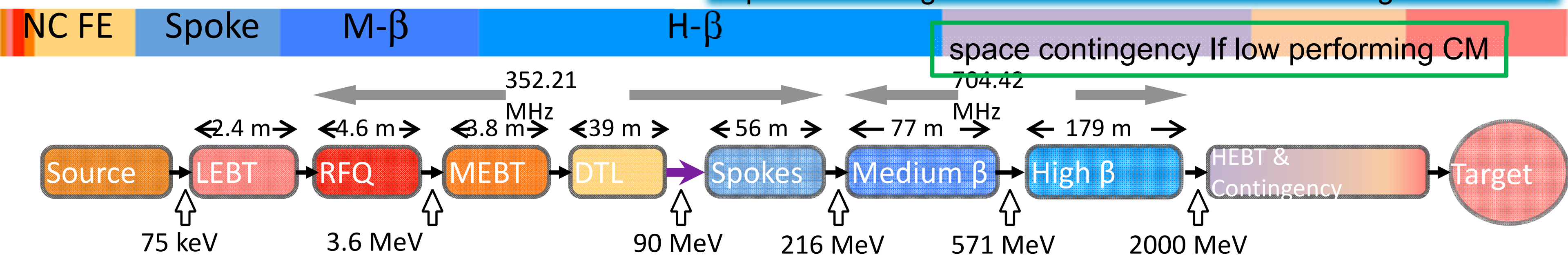


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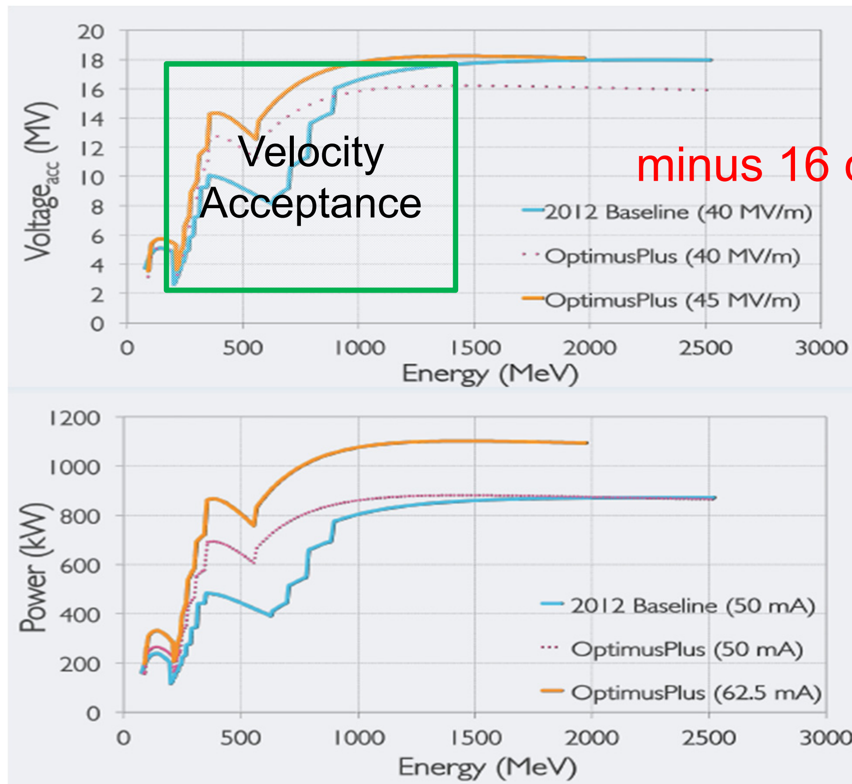


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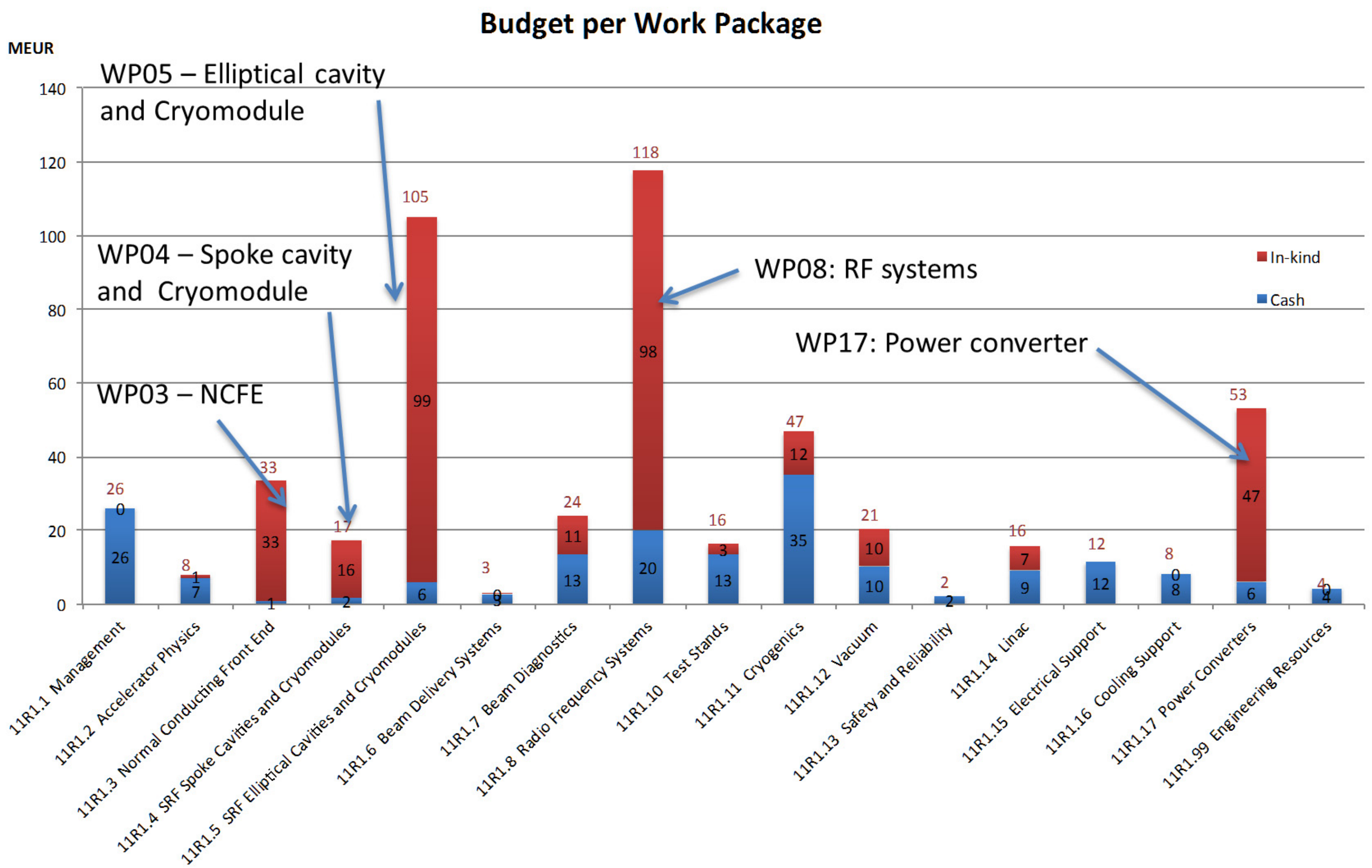
# ESS ACCSYS project organization: using Work Packages



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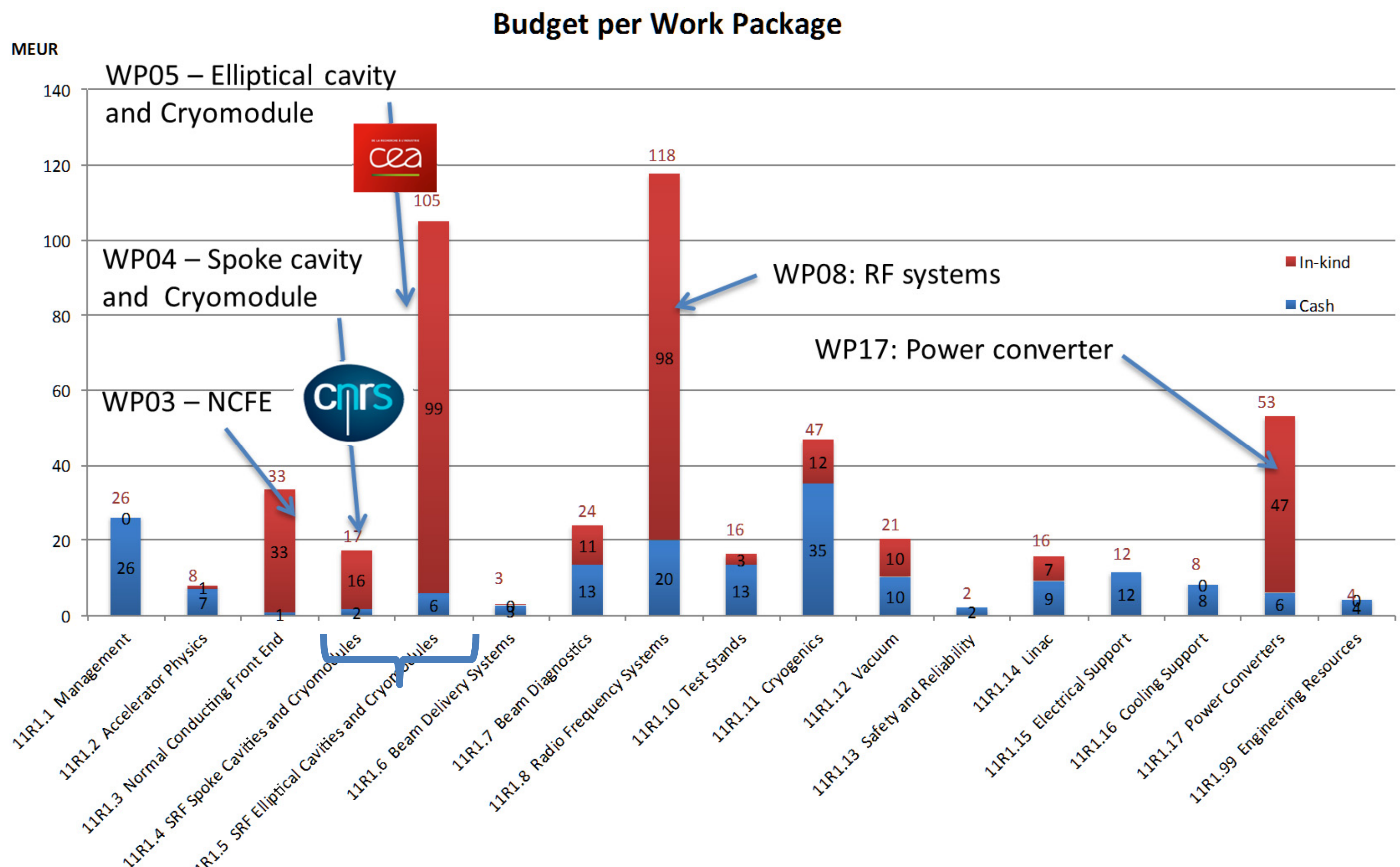
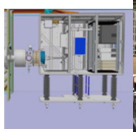


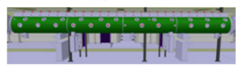
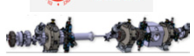

External WP → Cooperation agreements - Prototypes to Kick-start the linac design and production !

# ESS Linac – A Collaborative project

EUROPEAN SPALLATION SOURCE

| WP03 | WP04 | WP05 | WP05 |
|---|---|---|---|
| NC FE | Spoke | M-β | H-β |



C. Darve "ESS Superconducting RF Collaboration" - THOBB3

352.21 MHz

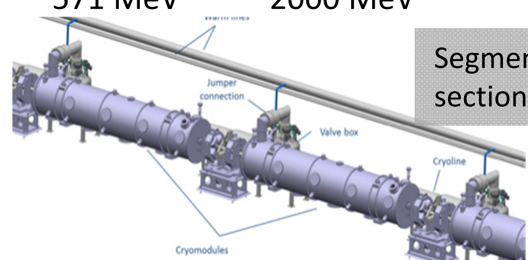
704.42 MHz

| 2.4 m | 4.6 m | 3.8 m | 39 m | 56 m | 77 m | 179 m | |
|---|---|---|---|---|---|---|---|

Source → LEBT → RFQ → MEBT → DTL → Spokes → Medium β → High β → HEBT & Contingency → Target

75 keV | 3.6 MeV | 90 MeV | 216 MeV | 571 MeV | 2000 MeV

L.Neri "Beam Com. of the High Intensity Proton Source Developed at INFN-LNS for ESS" - WEOBB2




Segmented cryomodules section

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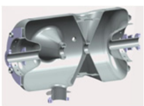

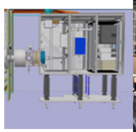

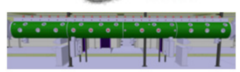

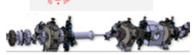

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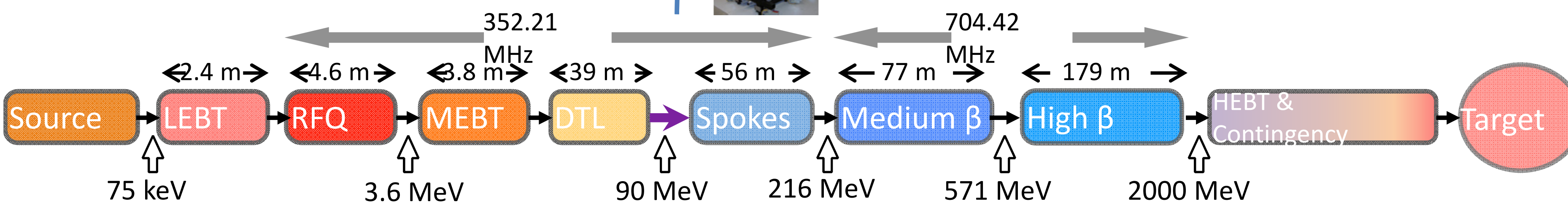


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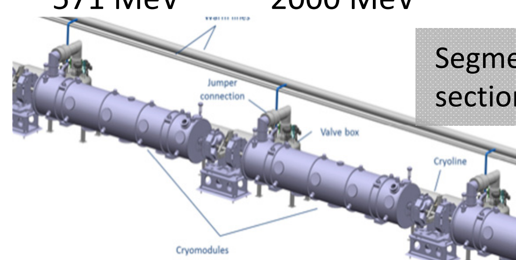


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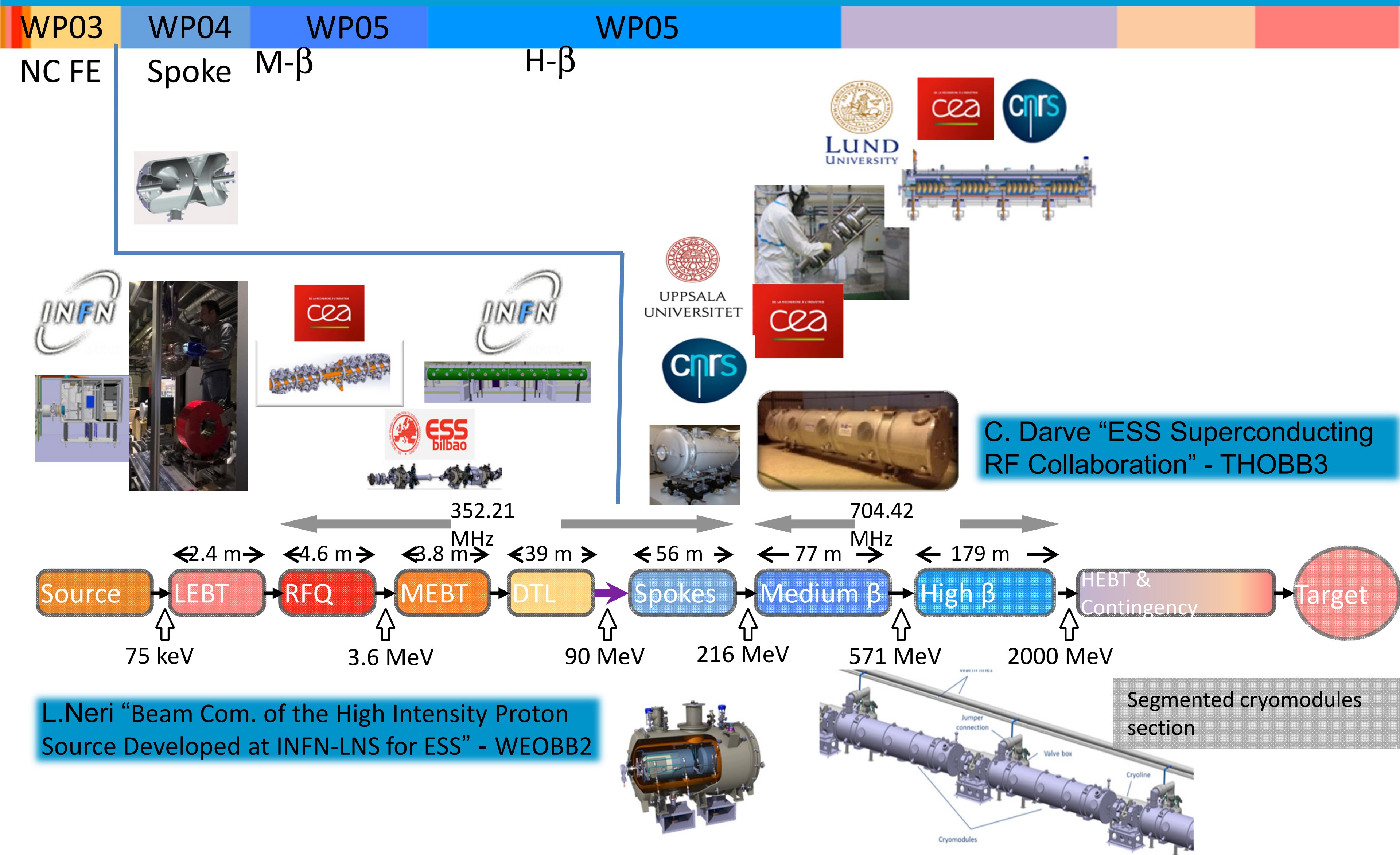


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EUROPEAN SPALLATION SOURCE

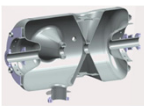
WP03 | WP04 | WP05 | WP05

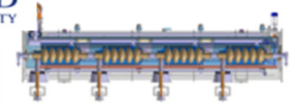
NC FE

Spoke

M-β

H-β





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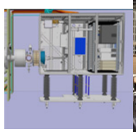

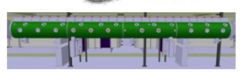

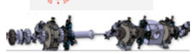

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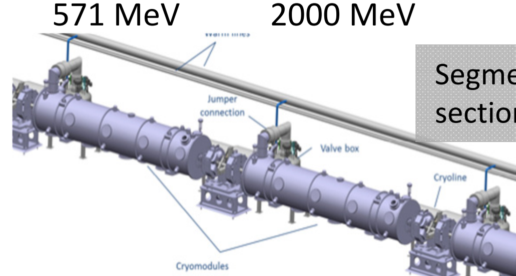


Segmented cryomodules section

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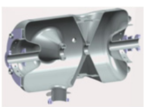



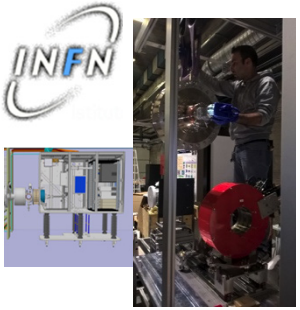


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| | Spoke | Medium-β | High-β |
|---|---|---|---|
| β | 0.5 | 0.67 | 0.86 |
| # CM | 13 | 9 | 21 |
| Cav. /CM | 2 | 4 | 4 |
| **# Cav.** | **26** | **36** | **84** |
| CM L [m] | 2.9 | 6.6 | 6.6 |
| Sector L [m] | 56 | 77 | 179 |


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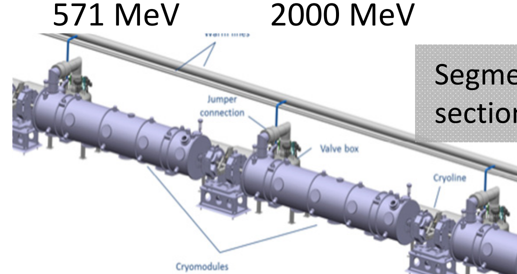


Segmented cryomodules section

96 % of the beam acceleration by SRF

# Outline

- Accelerator & SRF layout
- Spoke Results
- Elliptical Results
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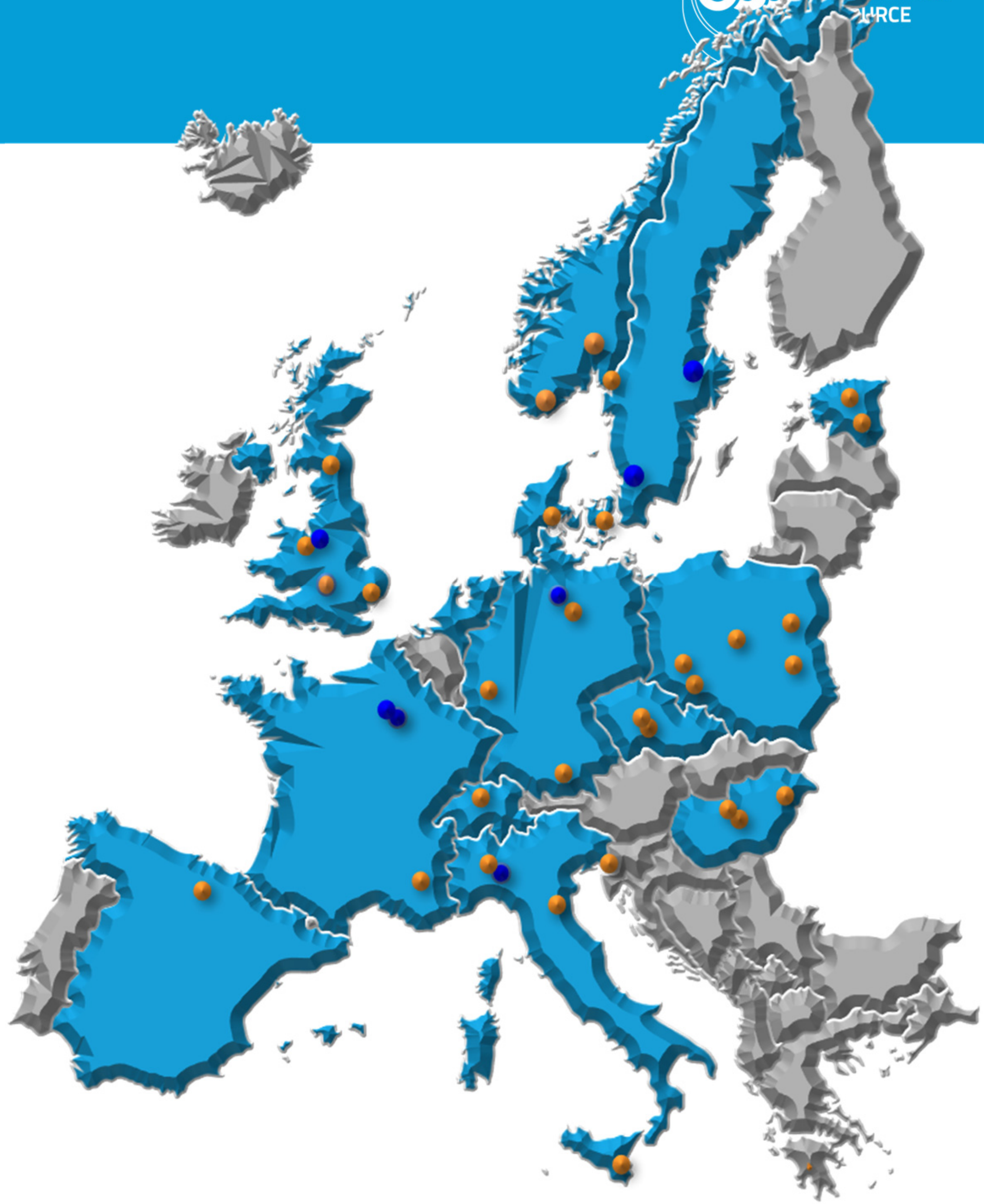

# Validation of spoke cavity performance

**Step 1:** **Spoke cavity**
**@ IPNO**
**@ Uppsala University - HNOSS**

**Double spoke cavity, 352.2 MHz, $\beta$=0.50**

**Goal: Eacc = 9 MV/m** *[Bp= 62 mT; Ep = 39 MV/m]*

**Lorentz detuning coeff.: ~-5.5Hz/(MV/m)$^2$**

**Tuning sensitivity $\Delta f/\Delta z$ = 130 kHz/mm**

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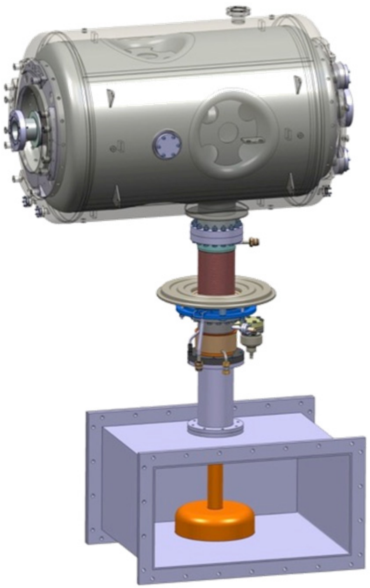
**Step 2:** **Spoke cavity packages**
***@ IPNO - Warm and 4 K***
***@ UU - HNOSS***

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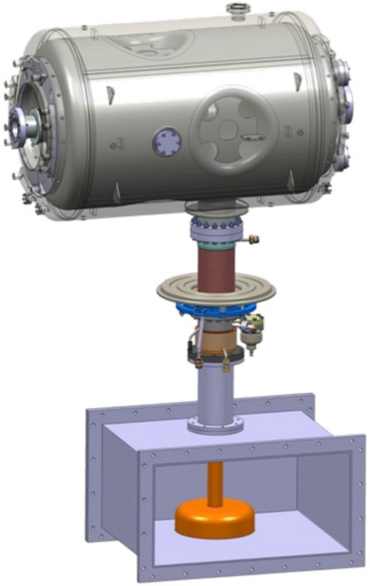
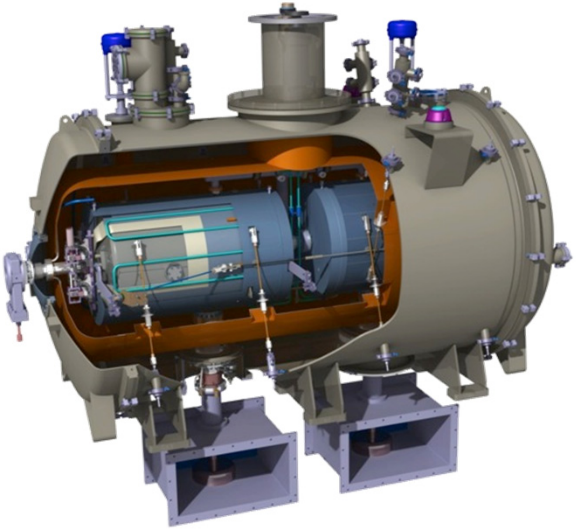



**Step 3:** Cryomodule w/ prototype valve box
*@ IPNO*
*@ UU - HNOSS*



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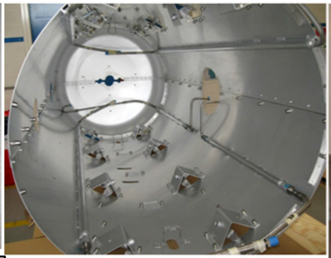
# Spoke cavities results @ IPNO

EUROPEAN SPALLATION SOURCE

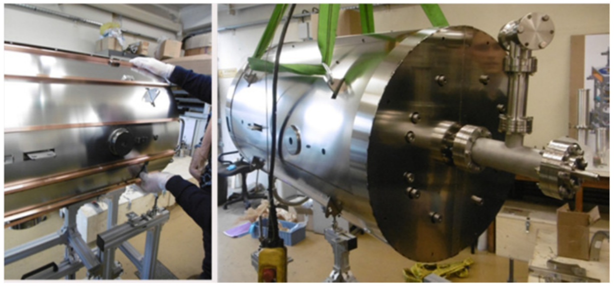


View of the spoke cavity bars

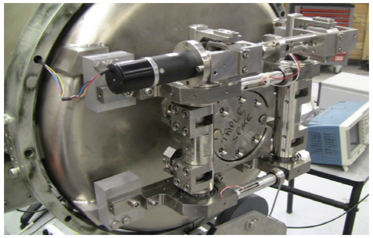
Inter-cavity bellows



Thermal shield



Magnetic shield



Cold Tuning System

Spoke cryomodule vacuum vessel: Fabrication achieved (FAT done)

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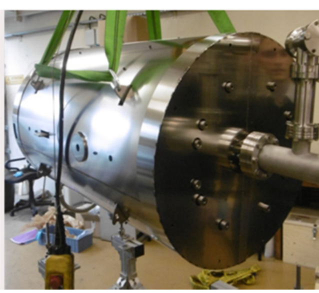
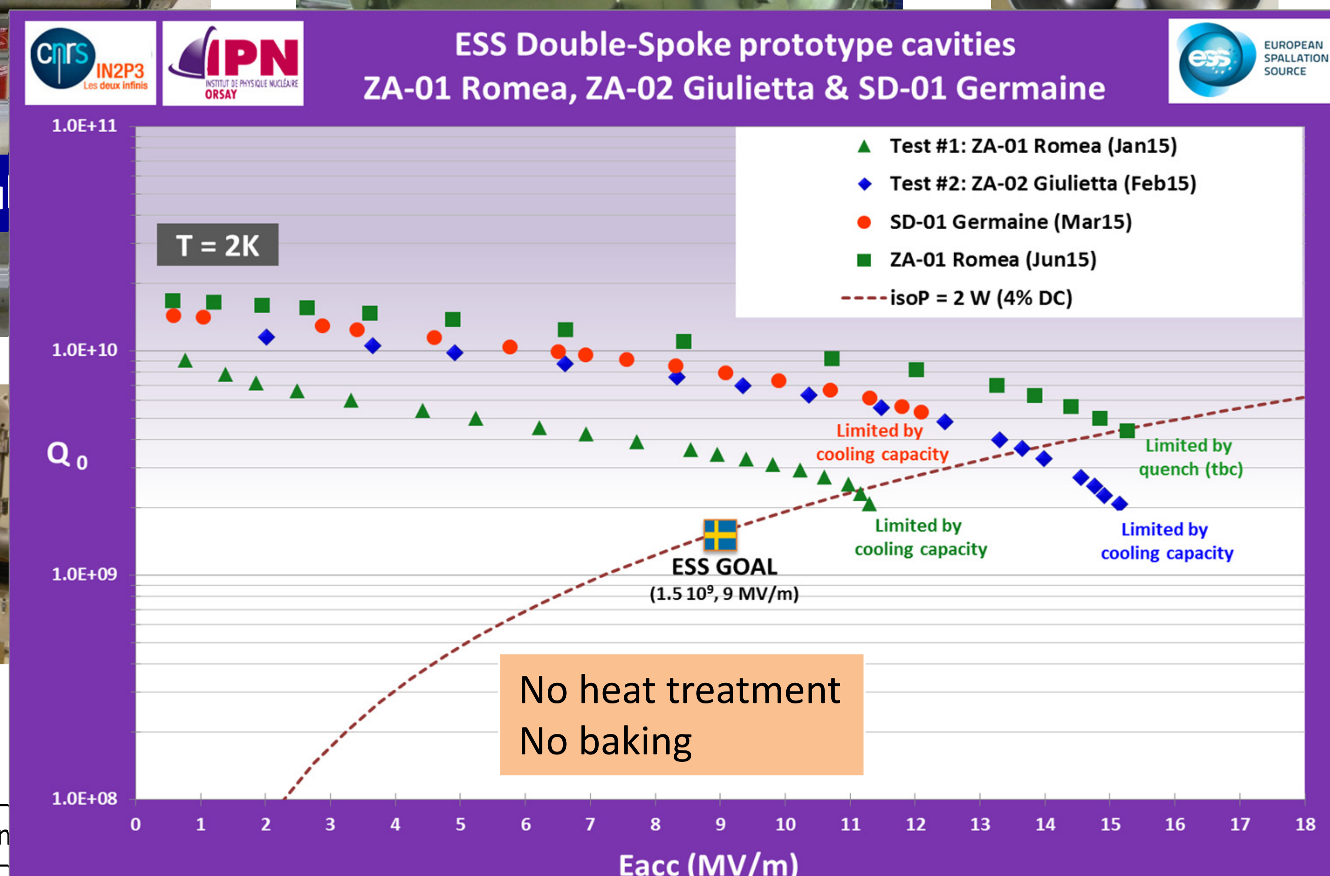


Cold Tuning Systen



# Spoke cavities results @ IPNO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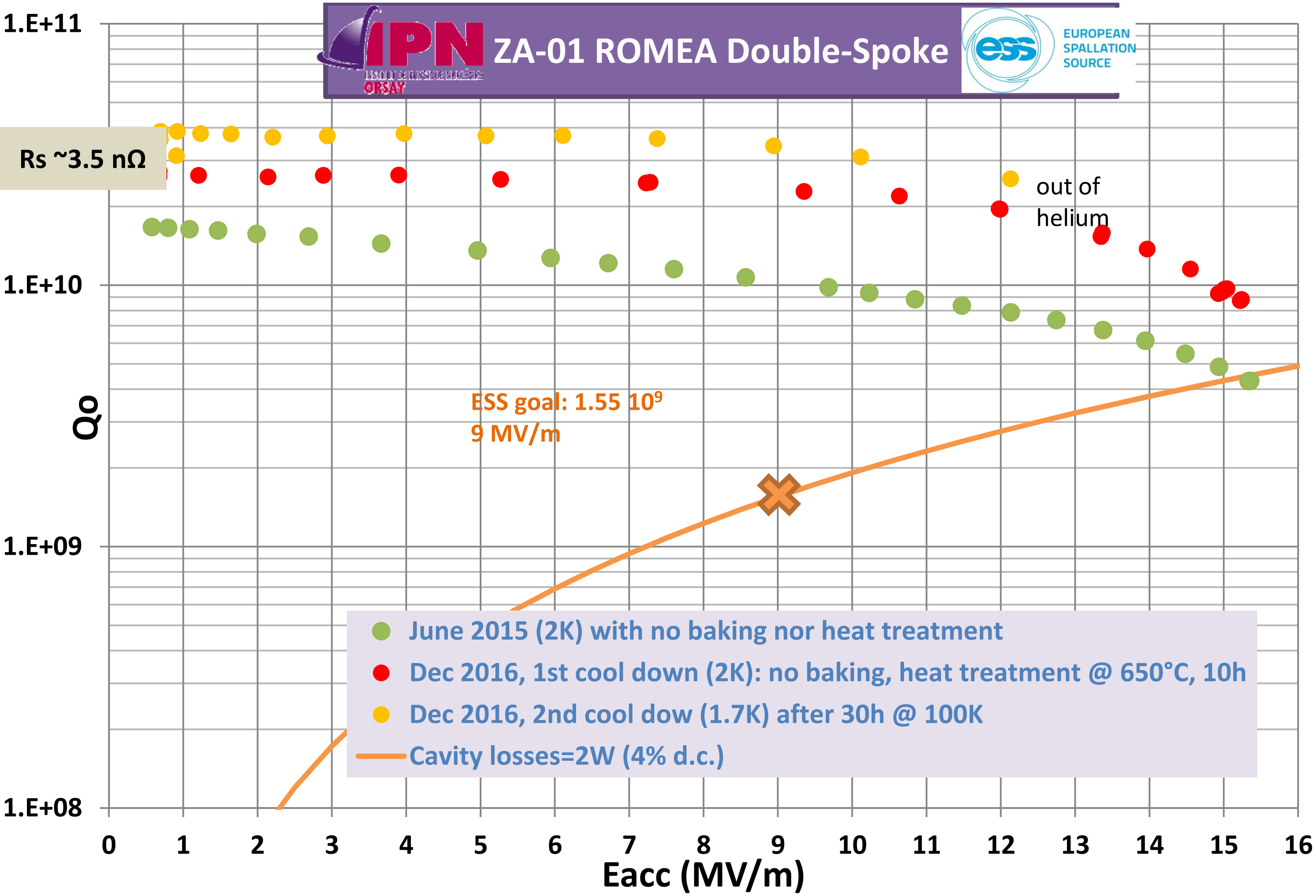


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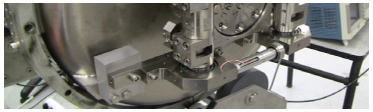
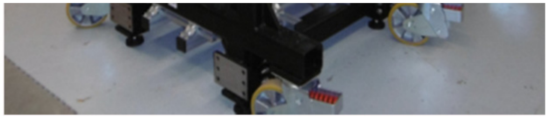


achieved (FAT done)



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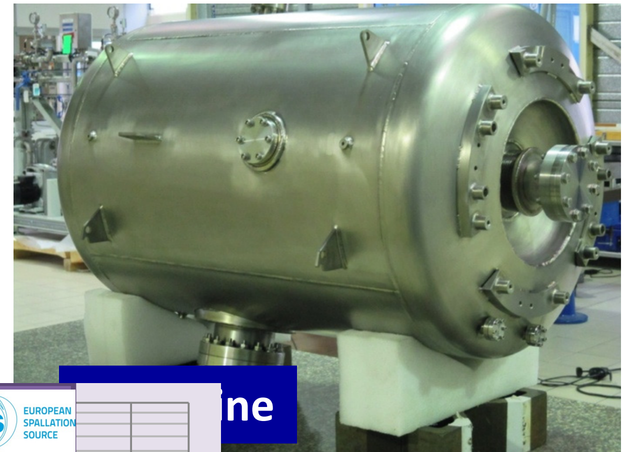
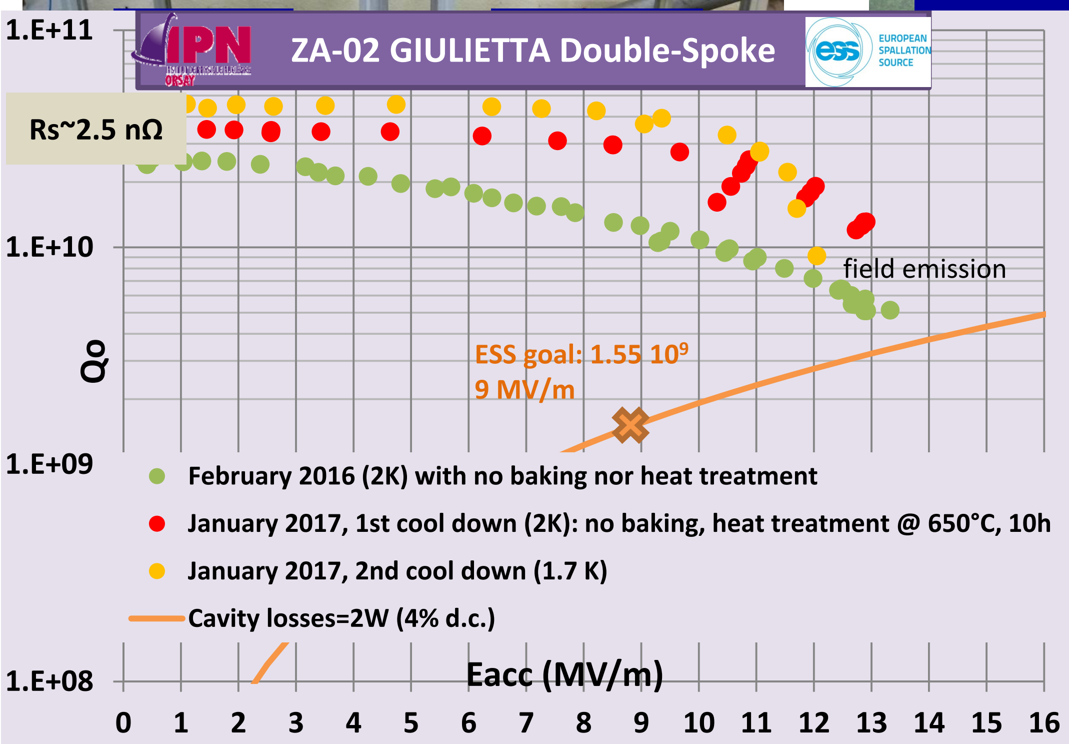
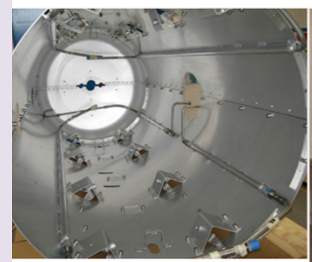



View of the spoke cavity bars



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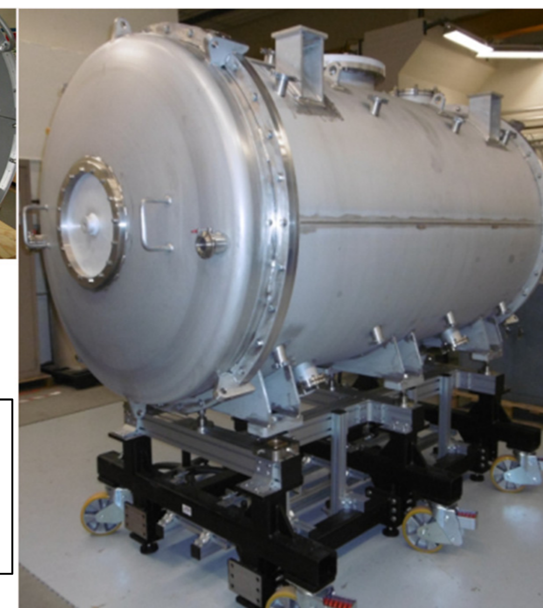


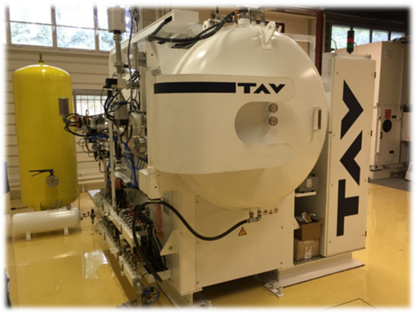
Spoke cryomodule vacuum vessel: Fabrication achieved (FAT done)

# Test Stand and coupler conditioning @ IPNO

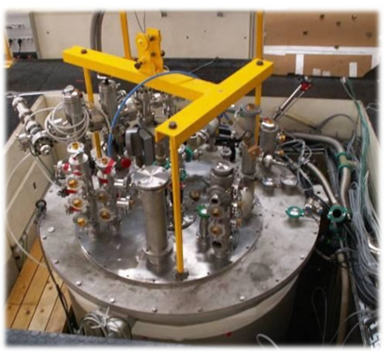
EUROPEAN SPALLATION SOURCE

Clean room ISO 4

Surface treatment lab

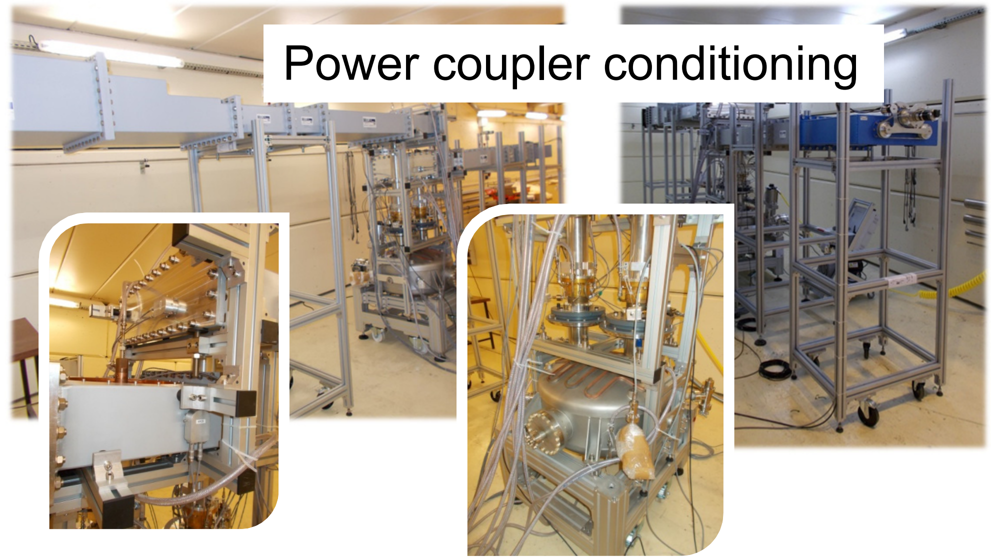


Furnace



Vertical cryostats

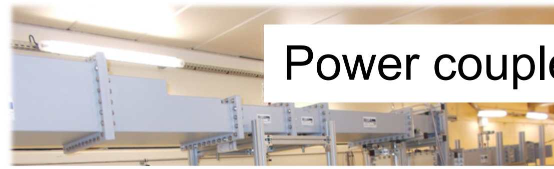
Power coupler conditioning



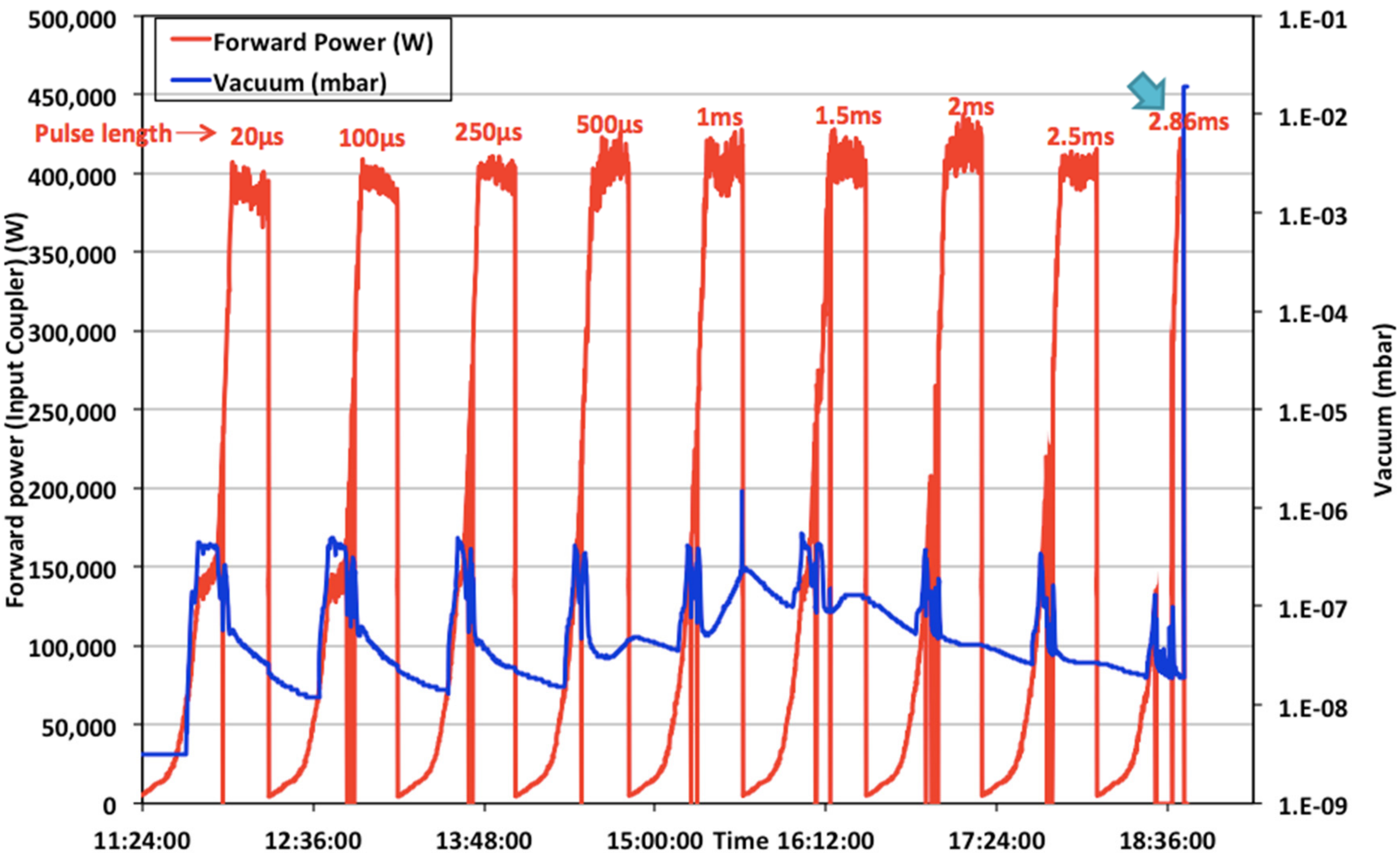
Control and security rack (with fast interlocks)

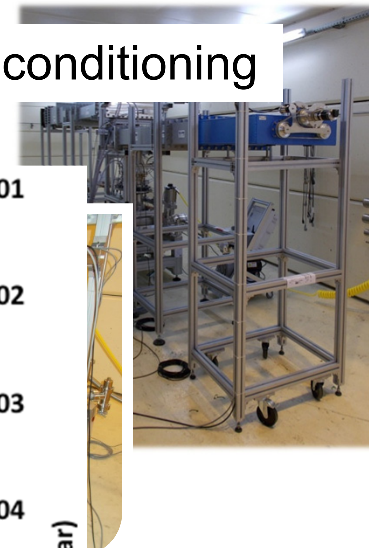
# Test Stand and coupler conditioning @ IPNO

EUROPEAN SPALLATION SOURCE



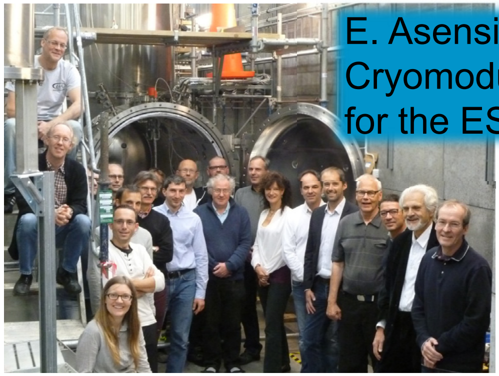
Power coupler conditioning



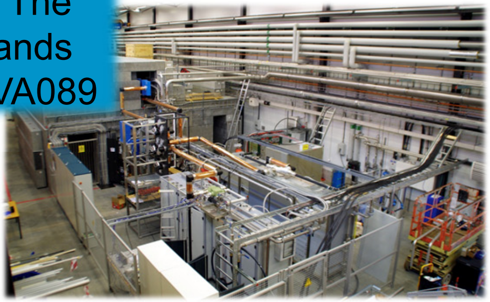



Control and security rack (with fast interlocks)

# Test Stand @ Uppsala (FREIA)



E. Asensi Conejero "The Cryomodule Test Stands for the ESS" - MOPVA089

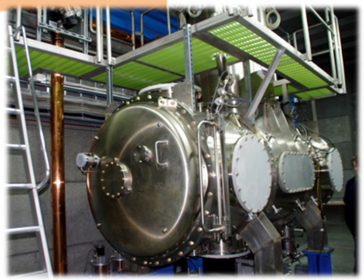


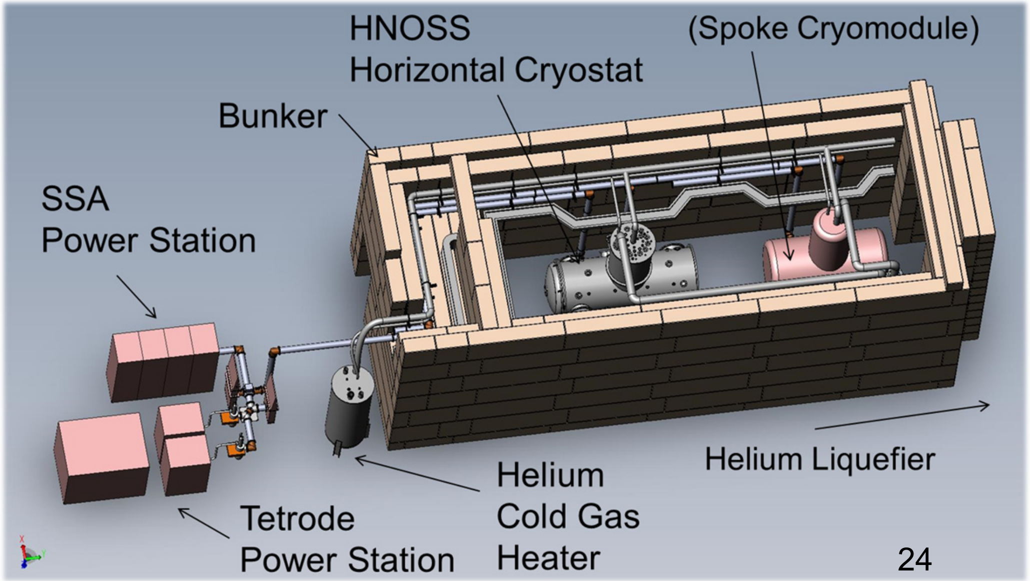
RF Power Source + LLRF

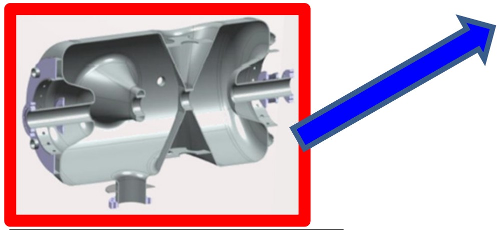
Control System & Interlock

Cryogenics

HNOSS

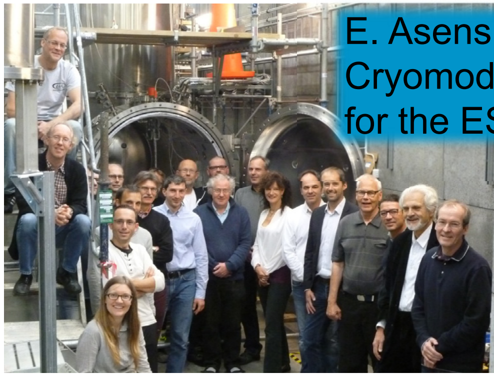




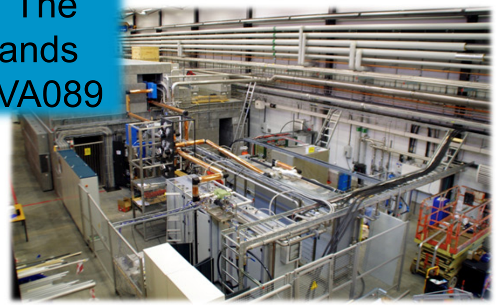



SRF cavity

# Test Stand @ Uppsala (FREIA)



E. Asensi Conejero "The Cryomodule Test Stands for the ESS" - MOPVA089

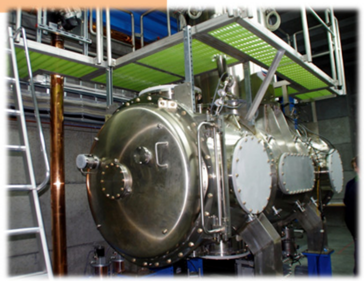


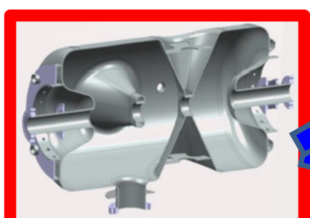
RF Power Source + LLRF

Control System & Interlock

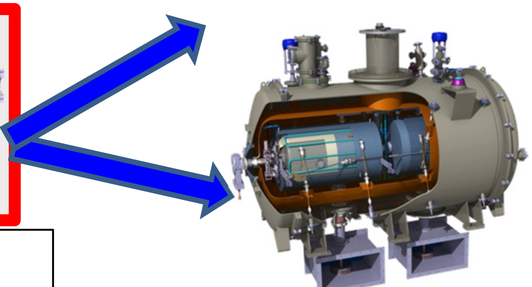
Cryogenics

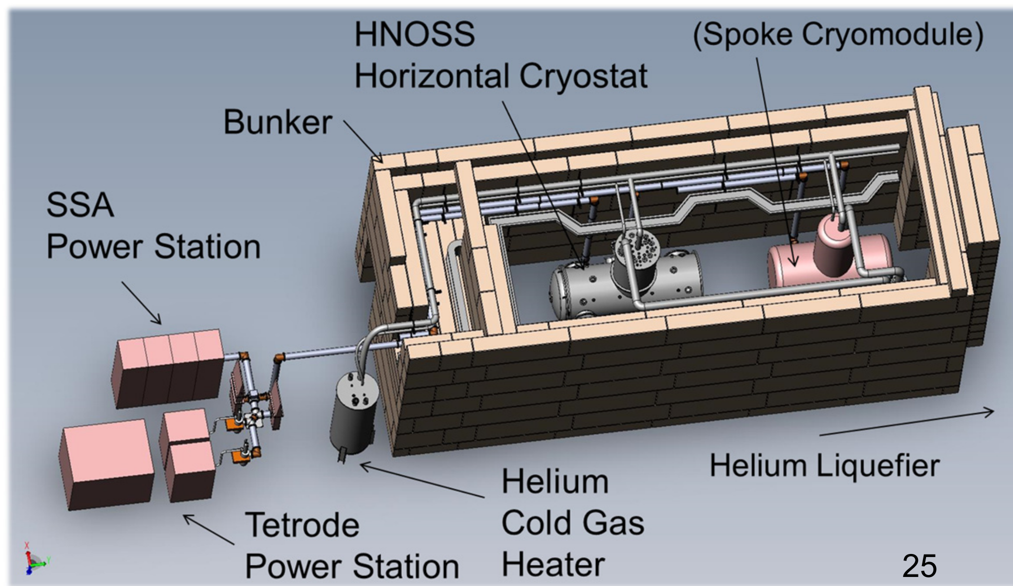
HNOSS



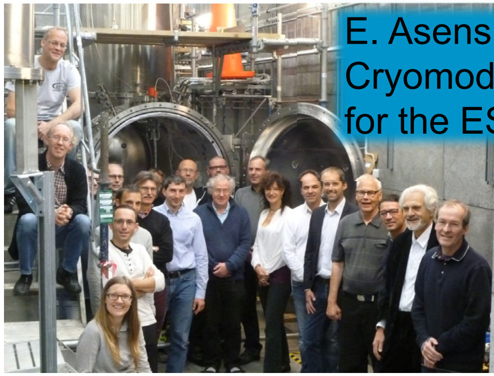


SRF cavity

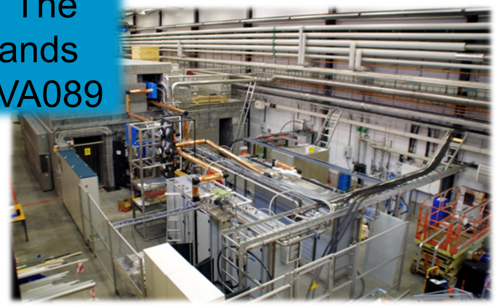




# Test Stand @ Uppsala (FREIA)



E. Asensi Conejero "The Cryomodule Test Stands for the ESS" - MOPVA089



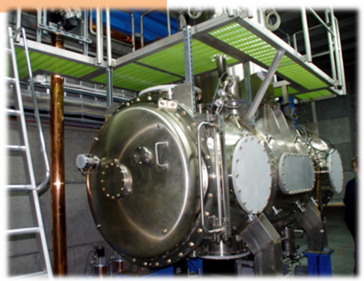
RF Power Source + LLRF

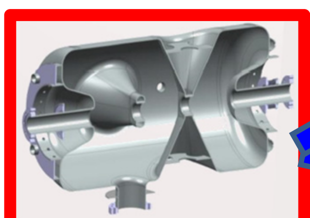
Control System & Interlock

Cryogenics

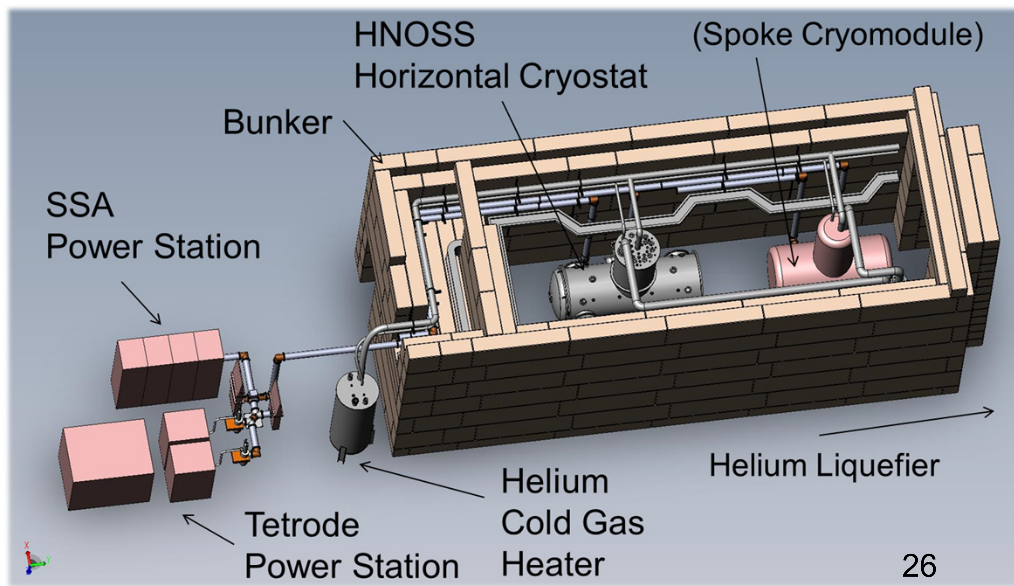
Spoke & Elliptical cavity package

HNOSS





SRF cavity

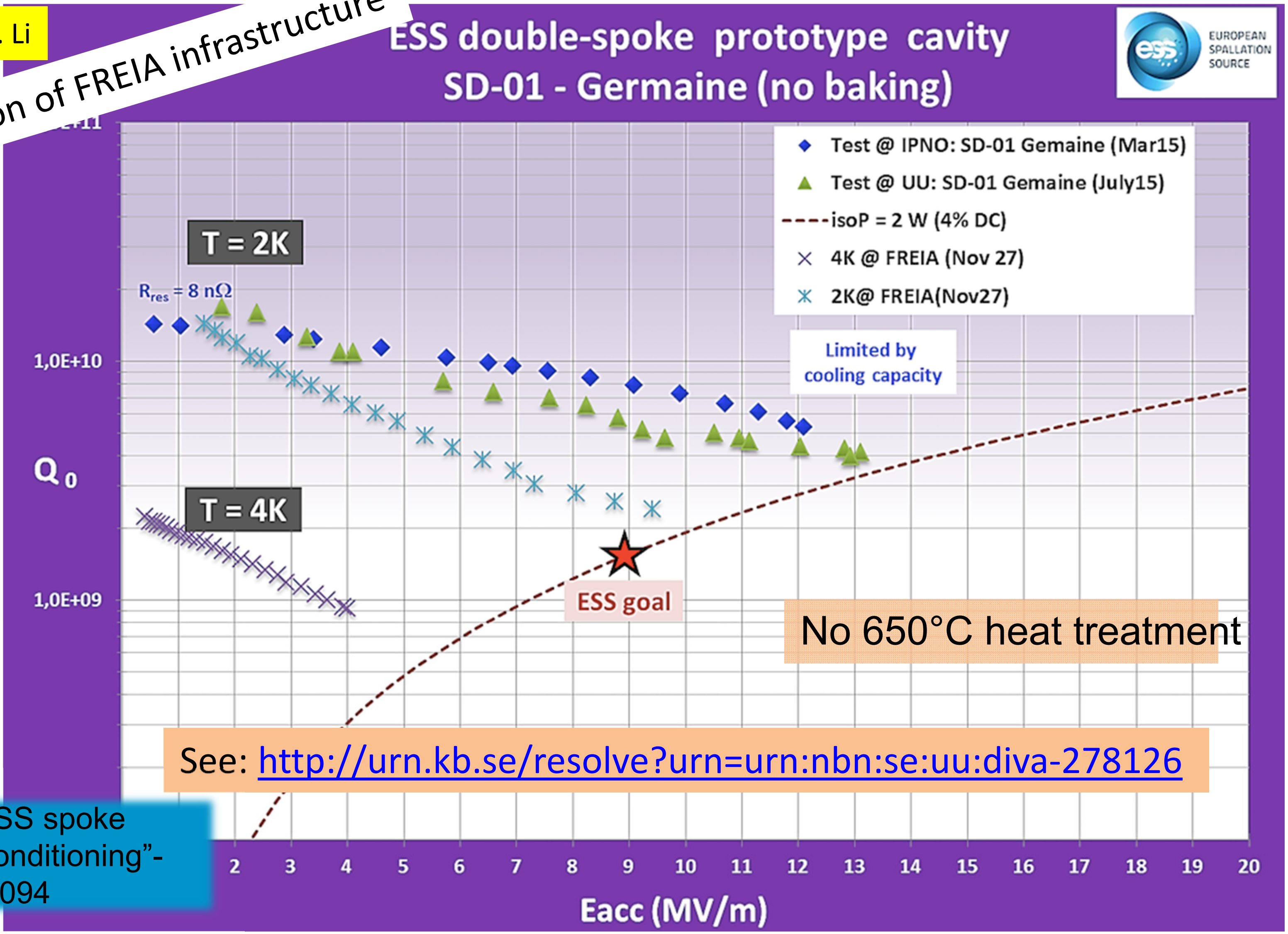


# Spoke prototype cavity results @ UU

EUROPEAN SPALLATION SOURCE

Courtesy H. Li

Validation of FREIA infrastructure




No 650°C heat treatment

See: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-278126

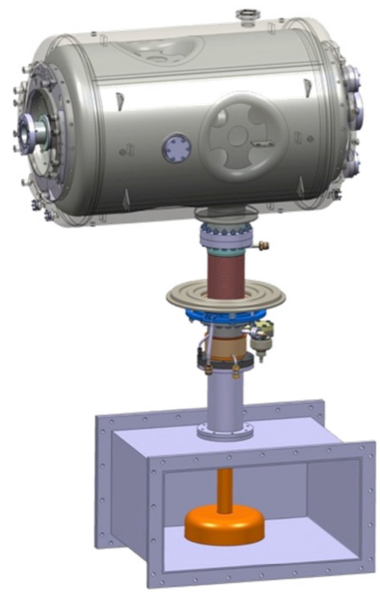
H. Li "ESS spoke cavity conditioning"- MOPVA094

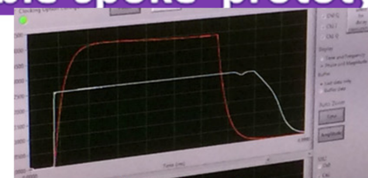
# Spoke prototype cavity results @ UU

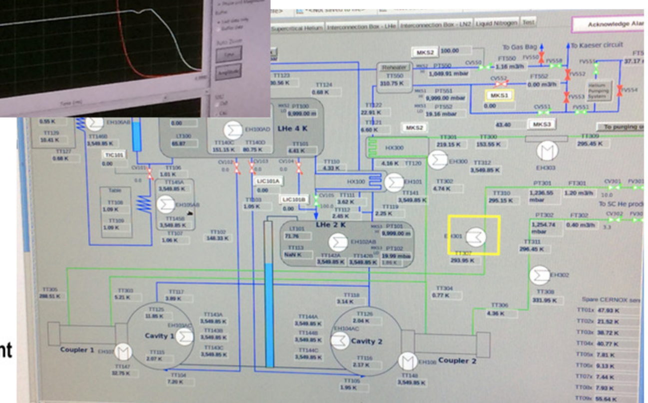
Courtesy H. Li

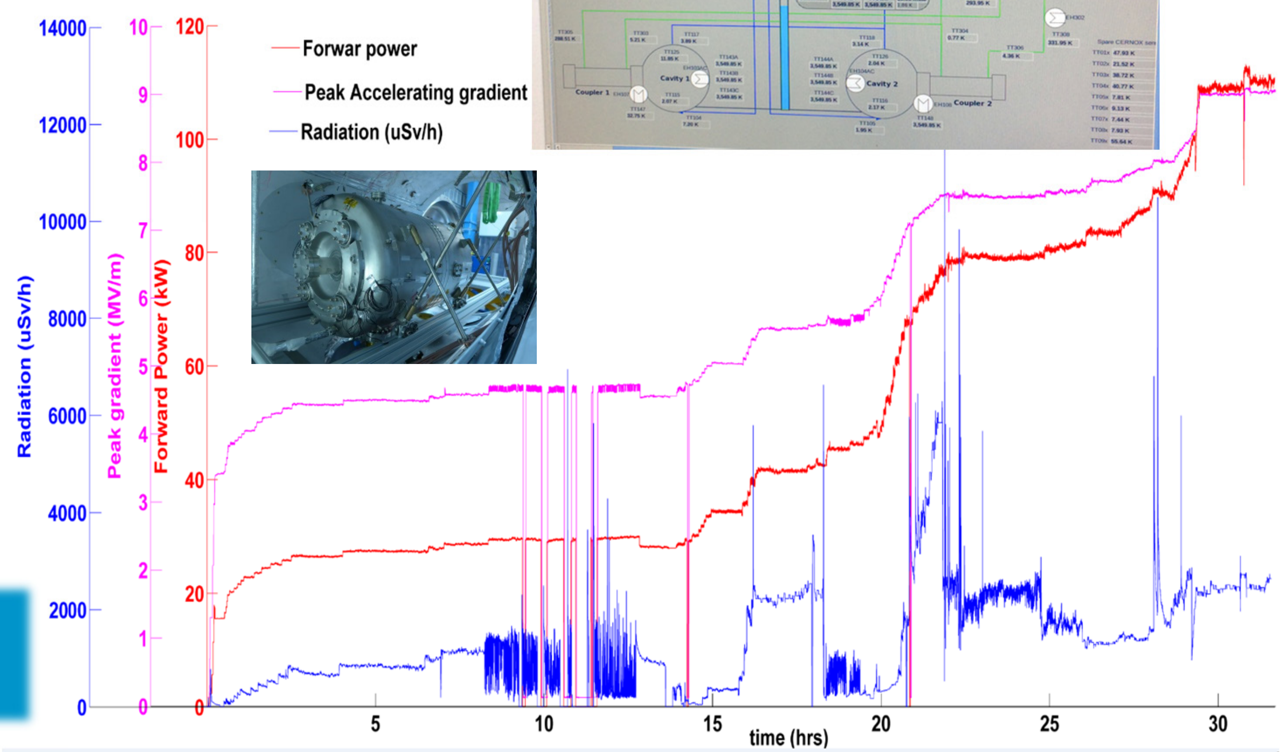
Validation of FREIA infrastructure


➔ Reached 9 MV/m accelerating gradient corresponding forward power: 110 kW



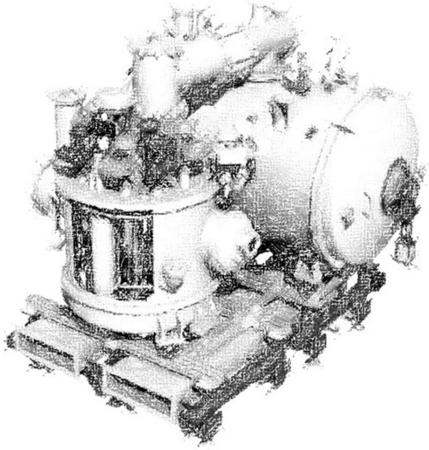




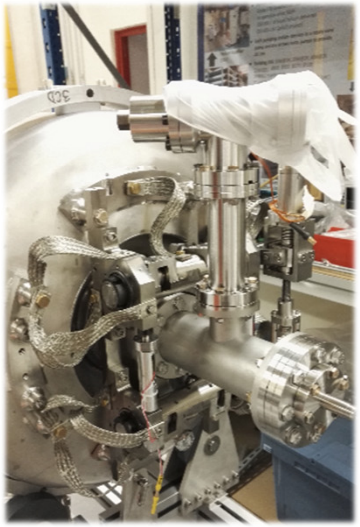
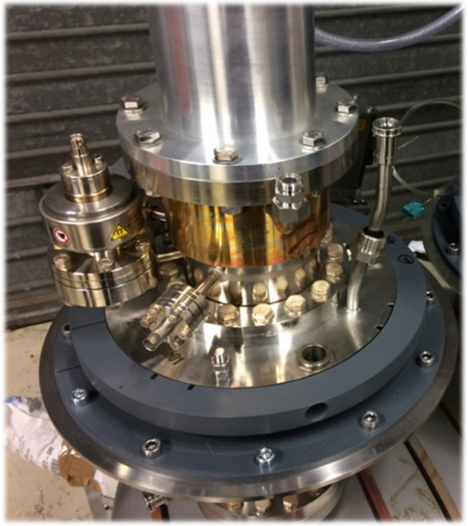
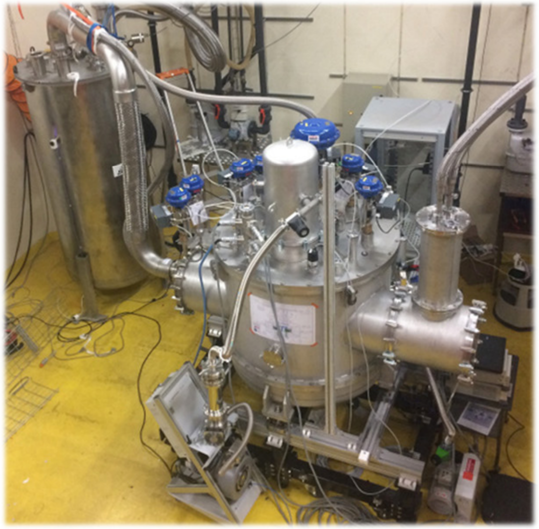



H. Li “ESS spoke cavity conditioning”- MOPVA094

# Spoke cryomodule assembly and tests

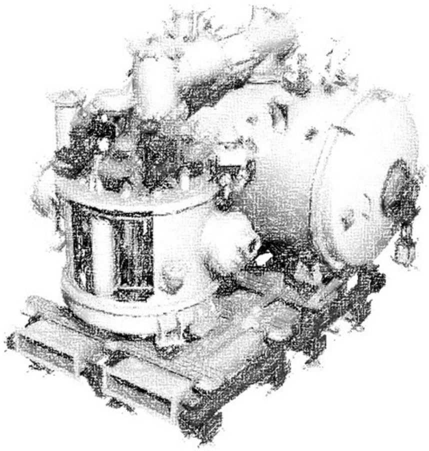




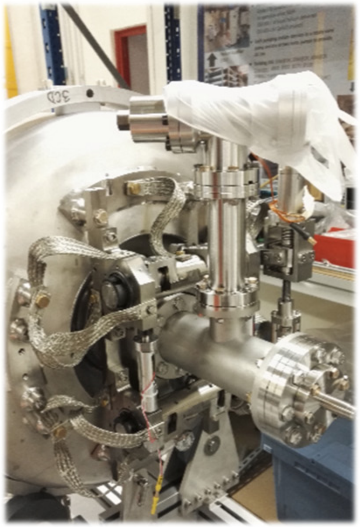
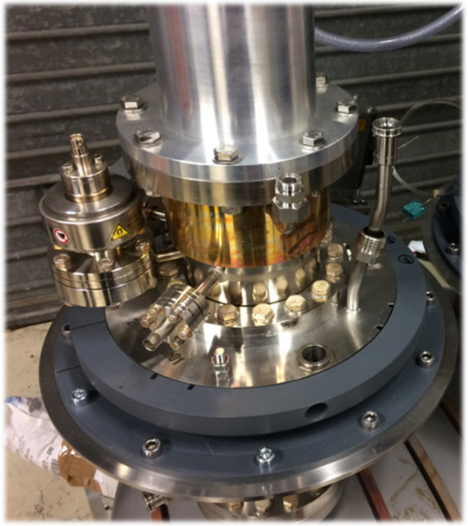
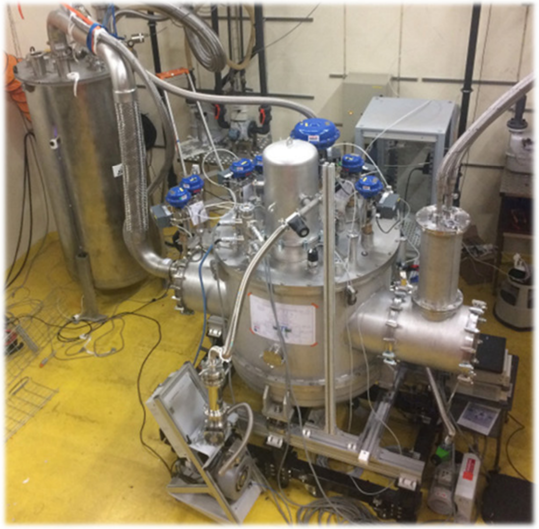




# Spoke cryomodule assembly and tests

EUROPEAN SPALLATION SOURCE

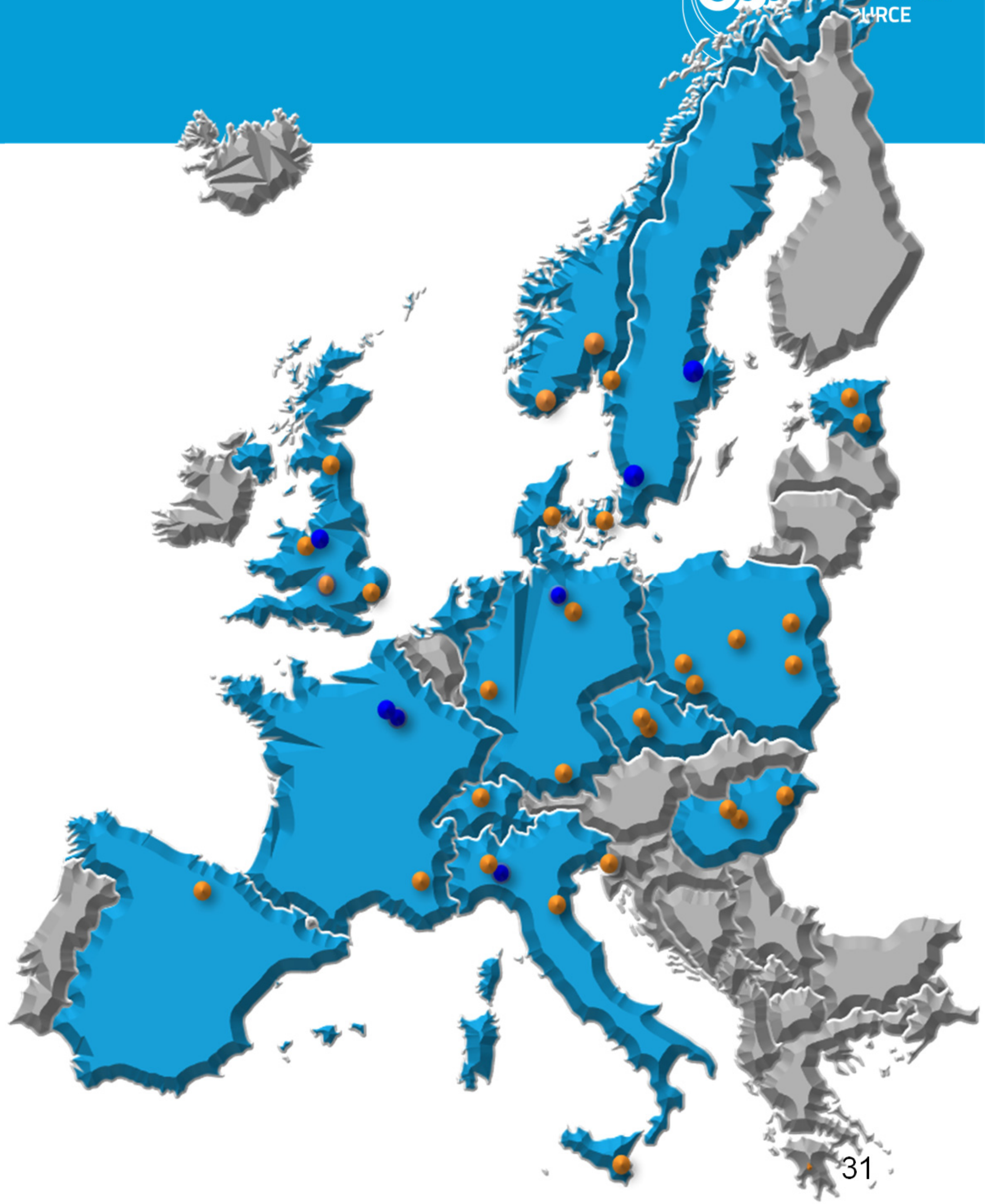


Next Step cryomodule testing in Uppsala

# Outline

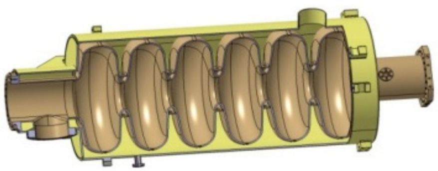
- Accelerator & SRF layout
- Spoke Results
- Elliptical Results
- Integration

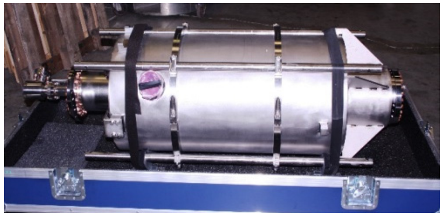


# Validation of Elliptical Medium-β Technology Demonstrator

**Step 1: Elliptical cavities**

***Medium-beta***
***@ Saclay***
***@ LASA***





| | LASA | CEA |
|---|---|---|
| $Q_{ext}$ | $7.7 \times 10^5$ | $7.5 \times 10^5$ |
| k | 1.55% | 1.22% |
| sep. (MHz) | 0.70 | 0.54 |
| G (Ohm) | 198.8 | 196.6 |
| r/Q (Ohms) | 374 | 394 |
| $E_{peak}/E_{acc}$ | 2.55 | 2.36 |
| $E_{peak}$ (MV/m) | 42.6 | 40 |
| $B_{peak}/E_{acc}$ (mT/MV/m) | 4.95 | 4.79 |

E. Cenni "Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank"-MOPVA041

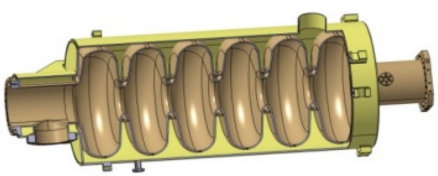
P. Michelato "Vertical Tests of ESS Medium Beta Prototype Cavities at LASA"- MOPVA063

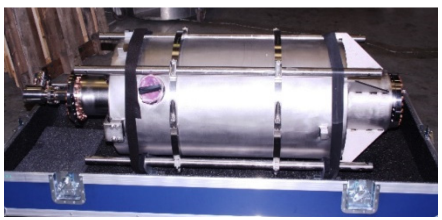
P. Bosland "Status of the ESS Elliptical Cryomodules at CEA Saclay"- MOPVA040

# Validation of Elliptical Medium-β Technology Demonstrator

**Step 1: Elliptical cavities**

***Medium-beta***
***@ Saclay***
***@ LASA***





| | LASA | CEA |
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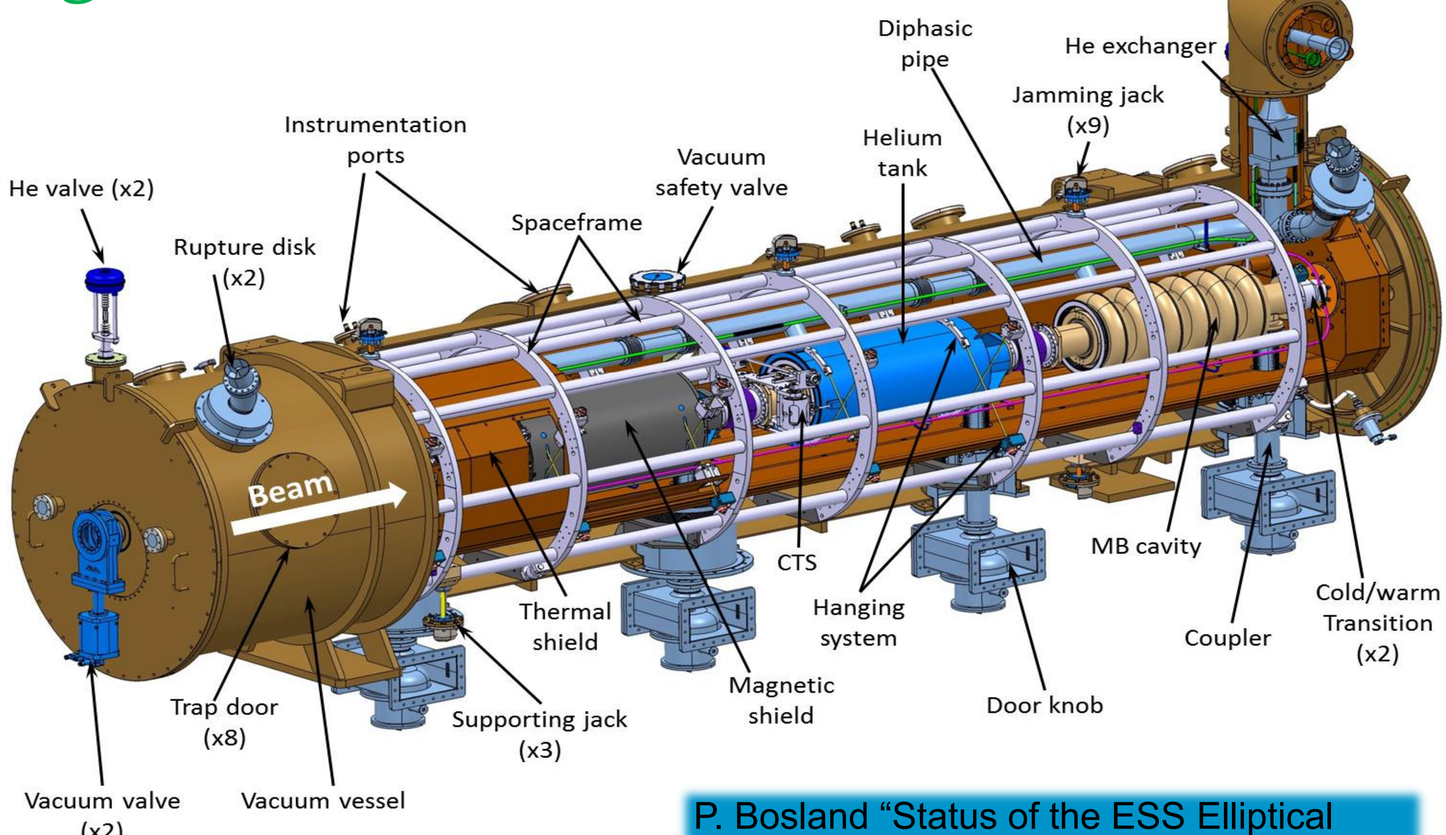
**Step 2: M-Elliptical Cavity Cryomodule Technology Demonstrator**

***@ Saclay***
***@ Lund***




M-ECCTD = 3 CEA cavities + 1 LASA cavity

P. Bosland "Status of the ESS Elliptical Cryomodules at CEA Saclay"- MOPVA040

EUROPEAN SPALLATION SOURCE

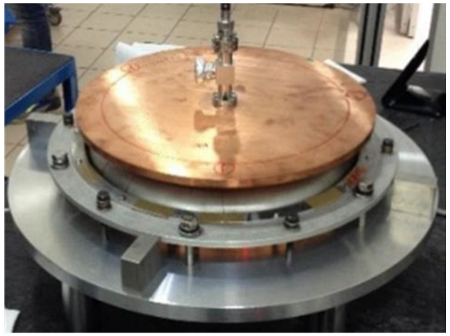
# Medium-beta cavity fabrication @ CEA

E. Cenni "Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank"-MOPVA041

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

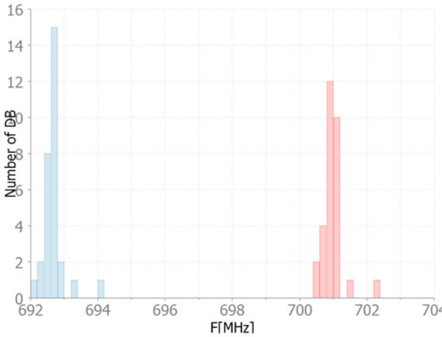
| Parameter | Average deviation respect computed values |
|---|---|
| Length | 0.767 mm |
| π-mode frequency | 0.292 MHz |

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

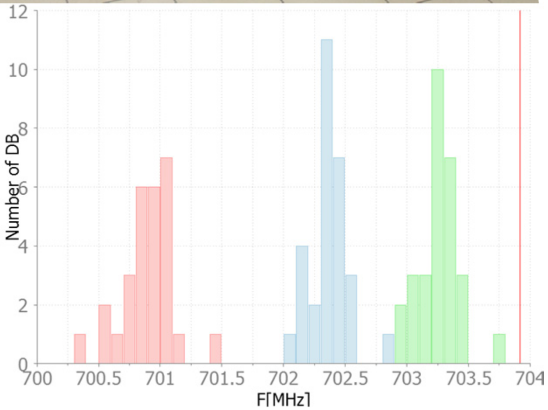


RF measurements system (on half cell)

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).

# Medium-beta cavity fabrication @ CEA

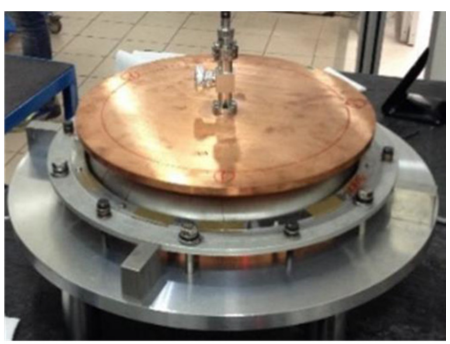
E. Cenni “Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank”-MOPVA041

No HOM couplers used → systematic fabrication check to guarantee Req:

“All higher order modes (HOMs) shall be at least 5 MHz away from integer multiples of the beam-bunching frequency (352.21 MHz) for any HOMs whose resonant frequencies are below the cut-off frequency of the beam-pipe”

| | |
|---|---|
| **π-mode frequency** | 0.292 MHz |

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



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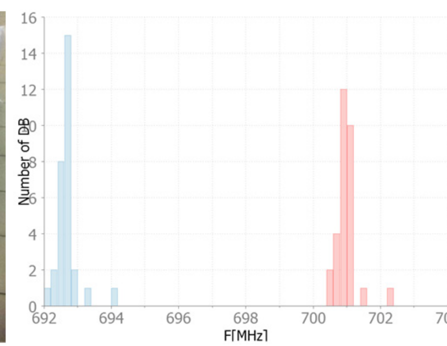


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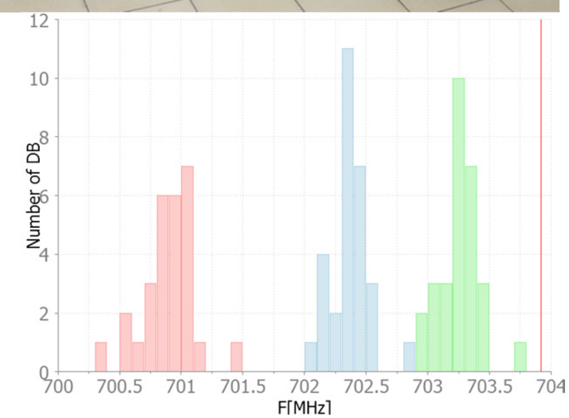


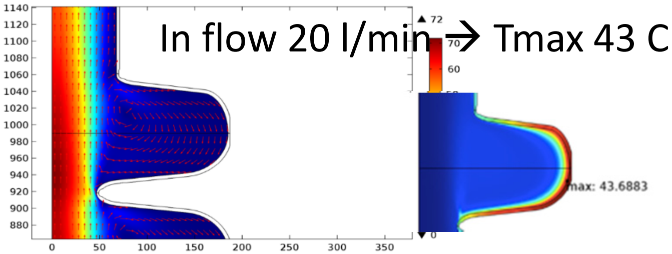

π-mode frequency measurement welding (red), trimming (blue) and trimming+welding shrinkage (green).

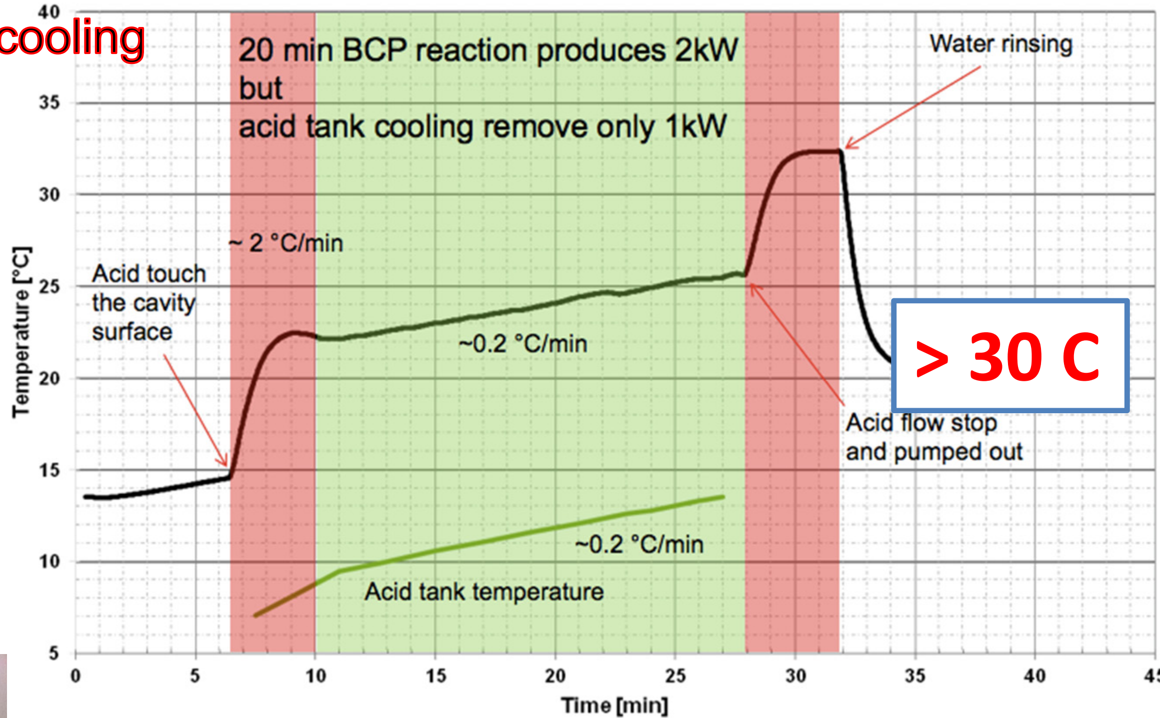
# Lesson-learned: chemical treatment @ CEA

EUROPEAN SPALLATION SOURCE

Naked cavity, no exterior cooling

In flow 20 l/min → Tmax 43 C



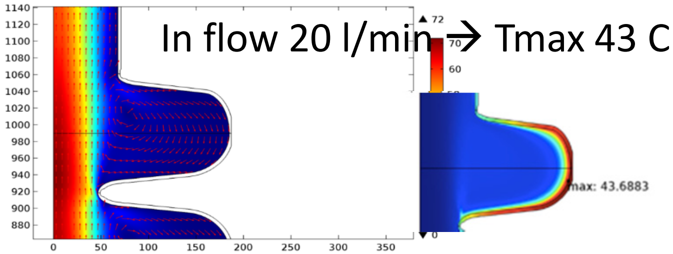



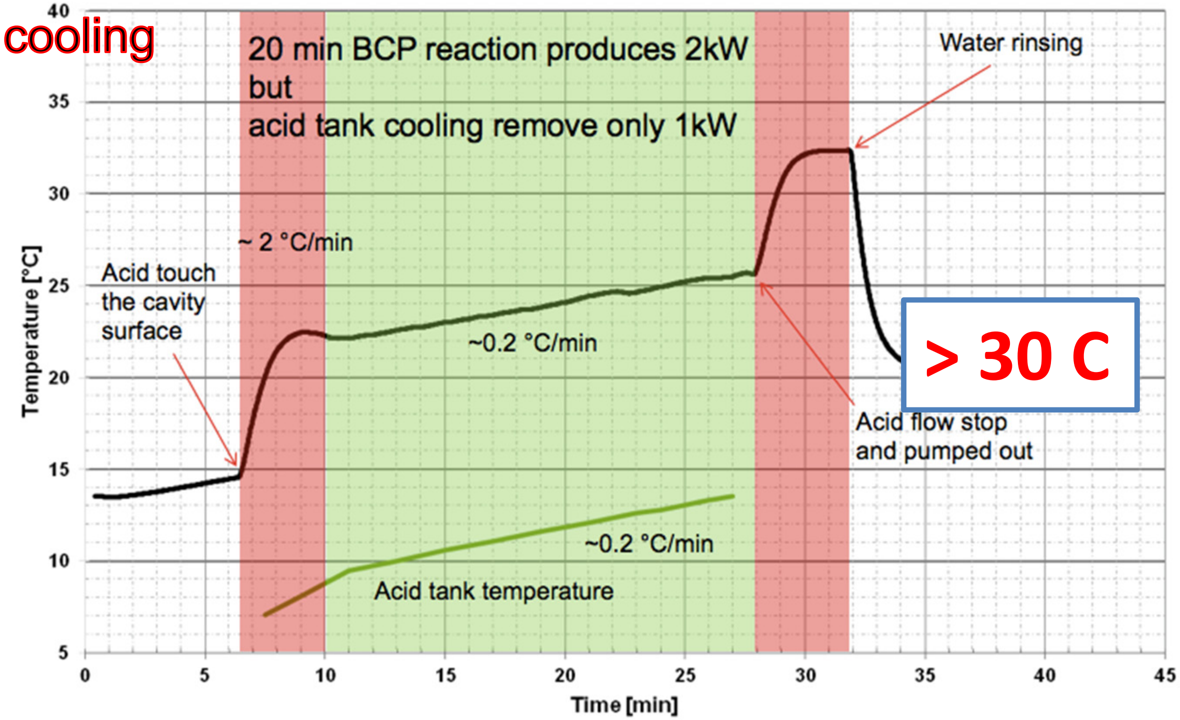

> 30 C

# Lesson-learned: chemical treatment @ CEA

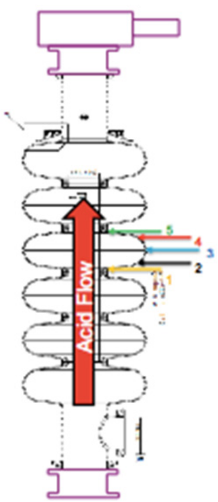
Naked cavity, no exterior cooling

In flow 20 l/min → Tmax 43 C






> 30 C

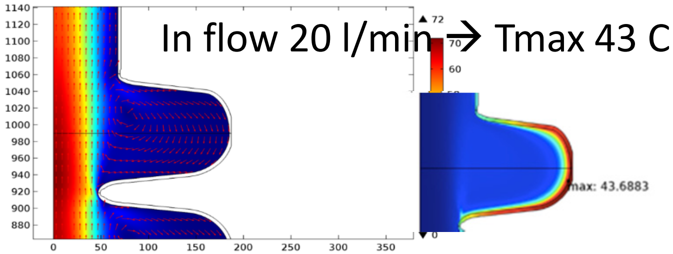


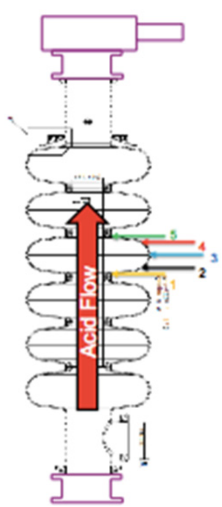
# Lesson-learned: chemical treatment @ CEA

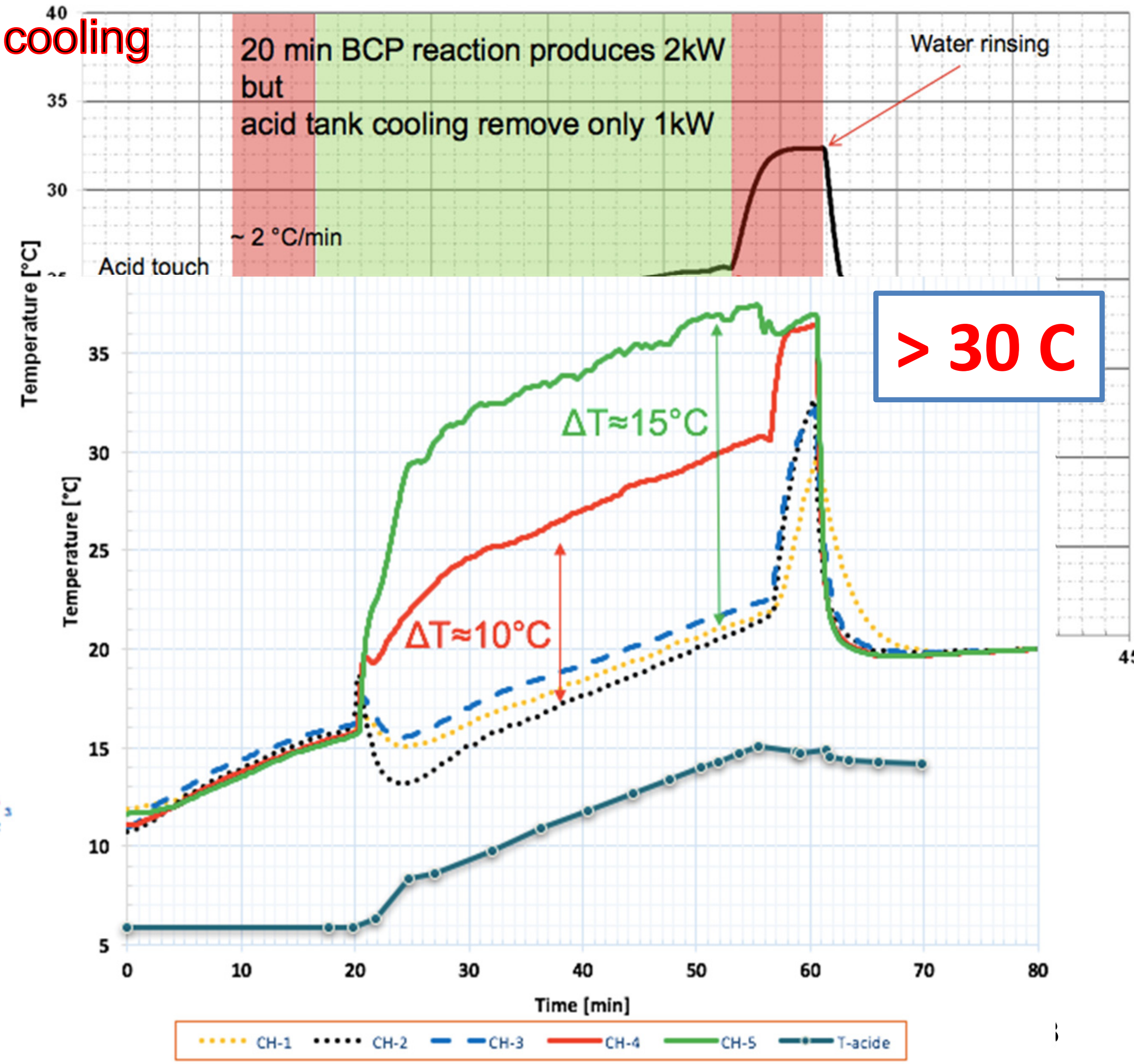
EUROPEAN SPALLATION SOURCE

Naked cavity, no exterior cooling

In flow 20 l/min → Tmax 43 C



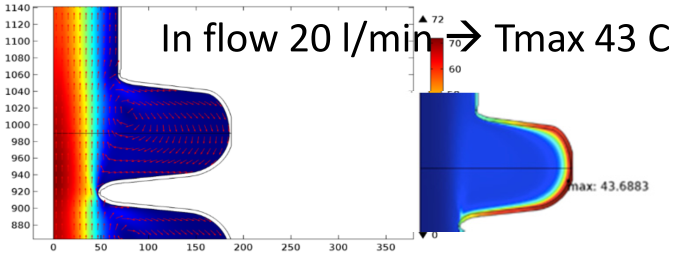



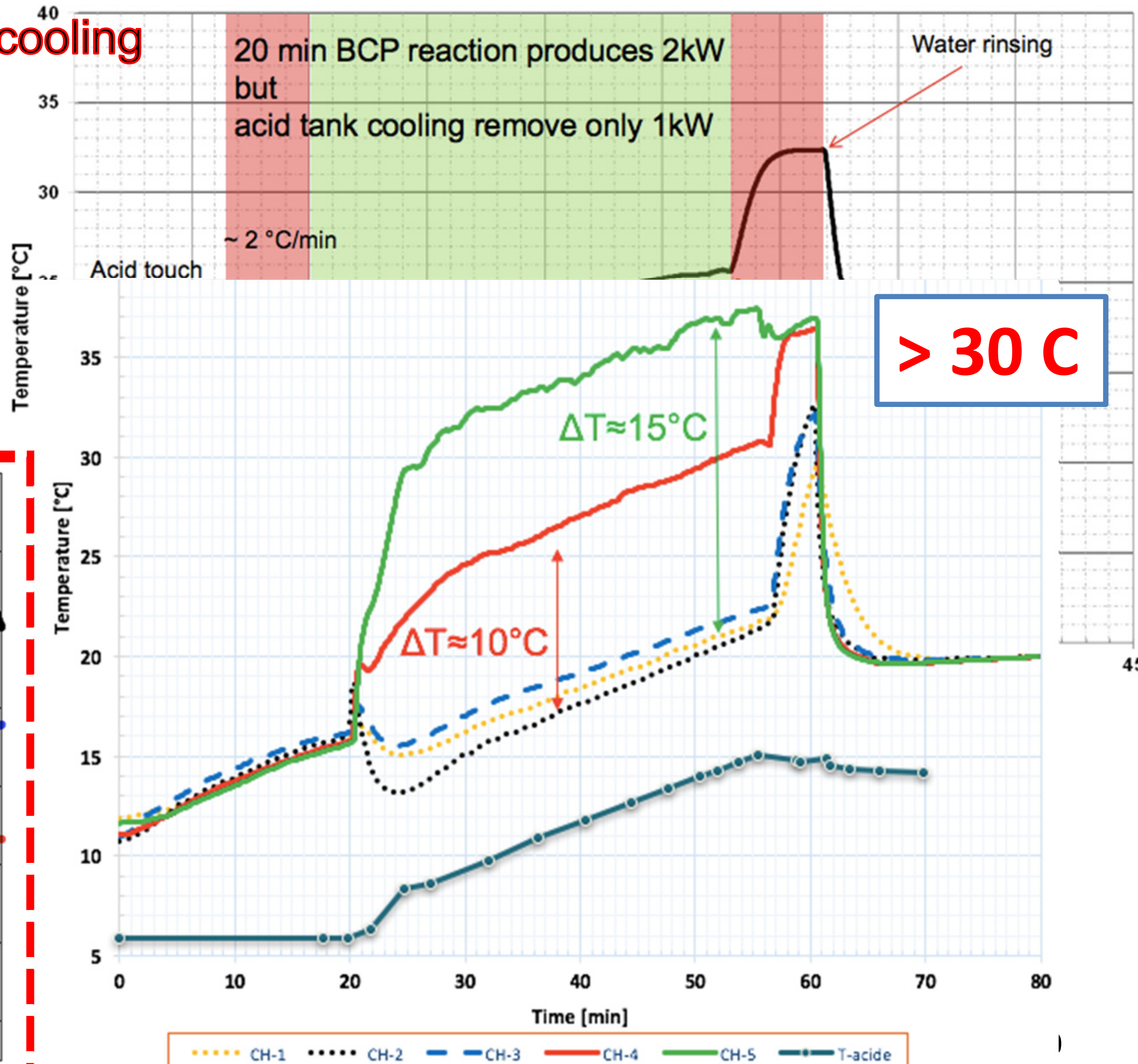

**> 30 C**

# Lesson-learned: chemical treatment @ CEA

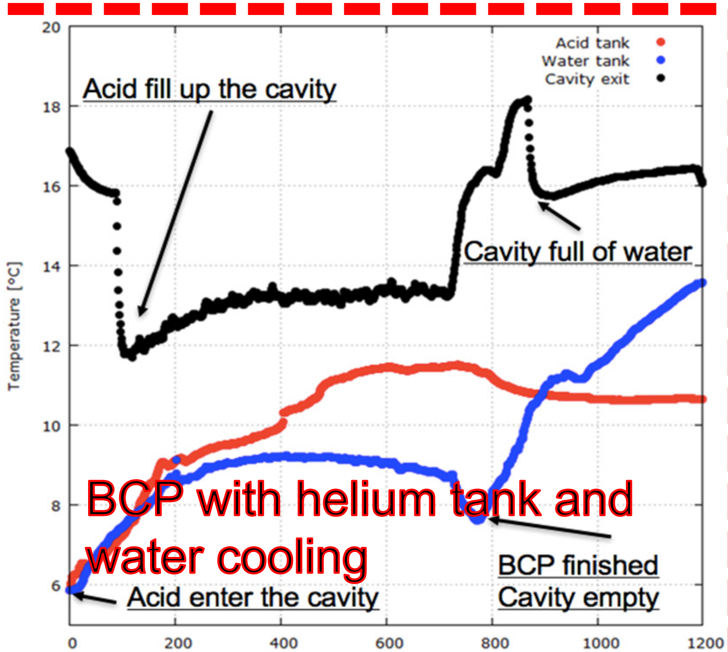
EUROPEAN SPALLATION SOURCE

Naked cavity, no exterior cooling




> 30 C

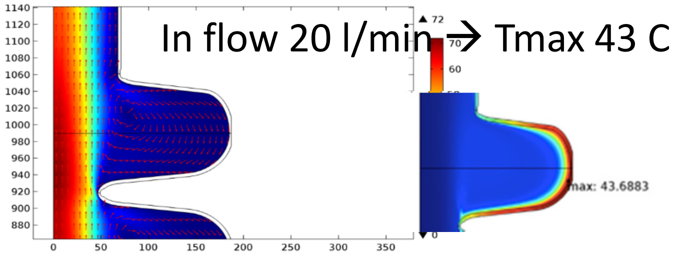


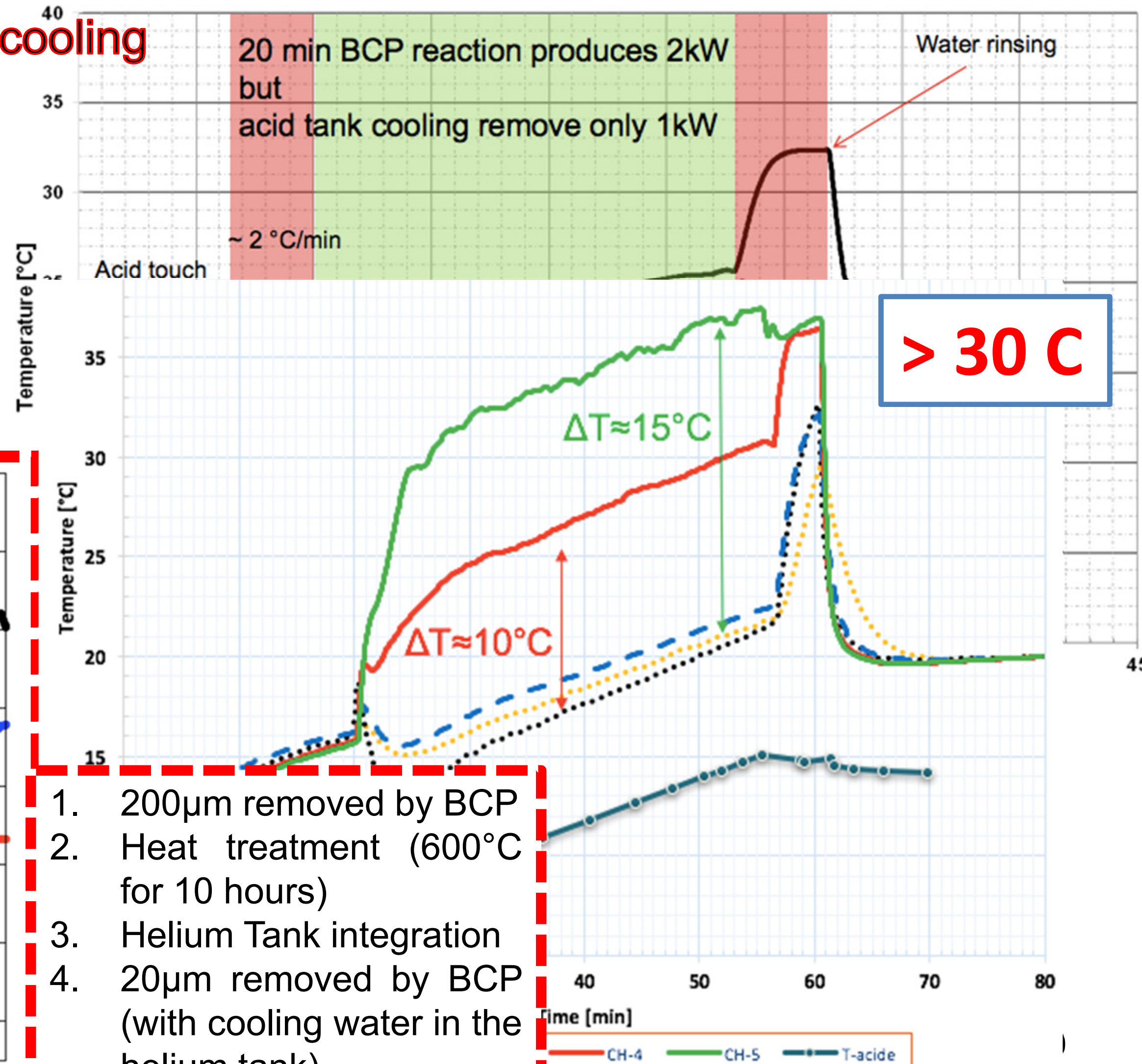

BCP with helium tank and water cooling

# Lesson-learned: chemical treatment @ CEA

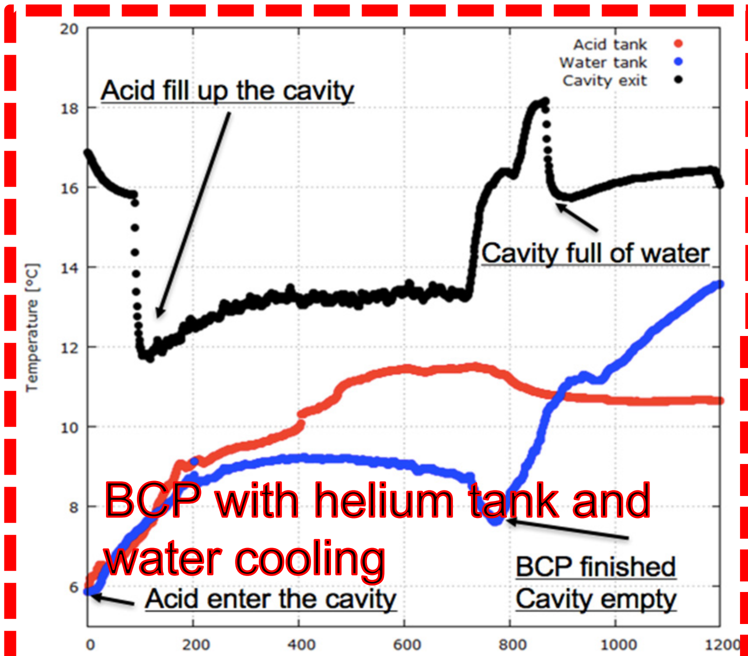
EUROPEAN SPALLATION SOURCE

Naked cavity, no exterior cooling




> 30 C



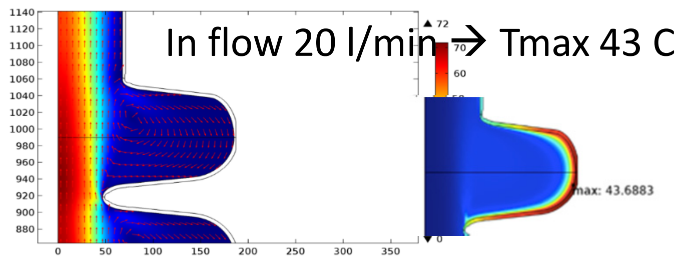

BCP with helium tank and water cooling

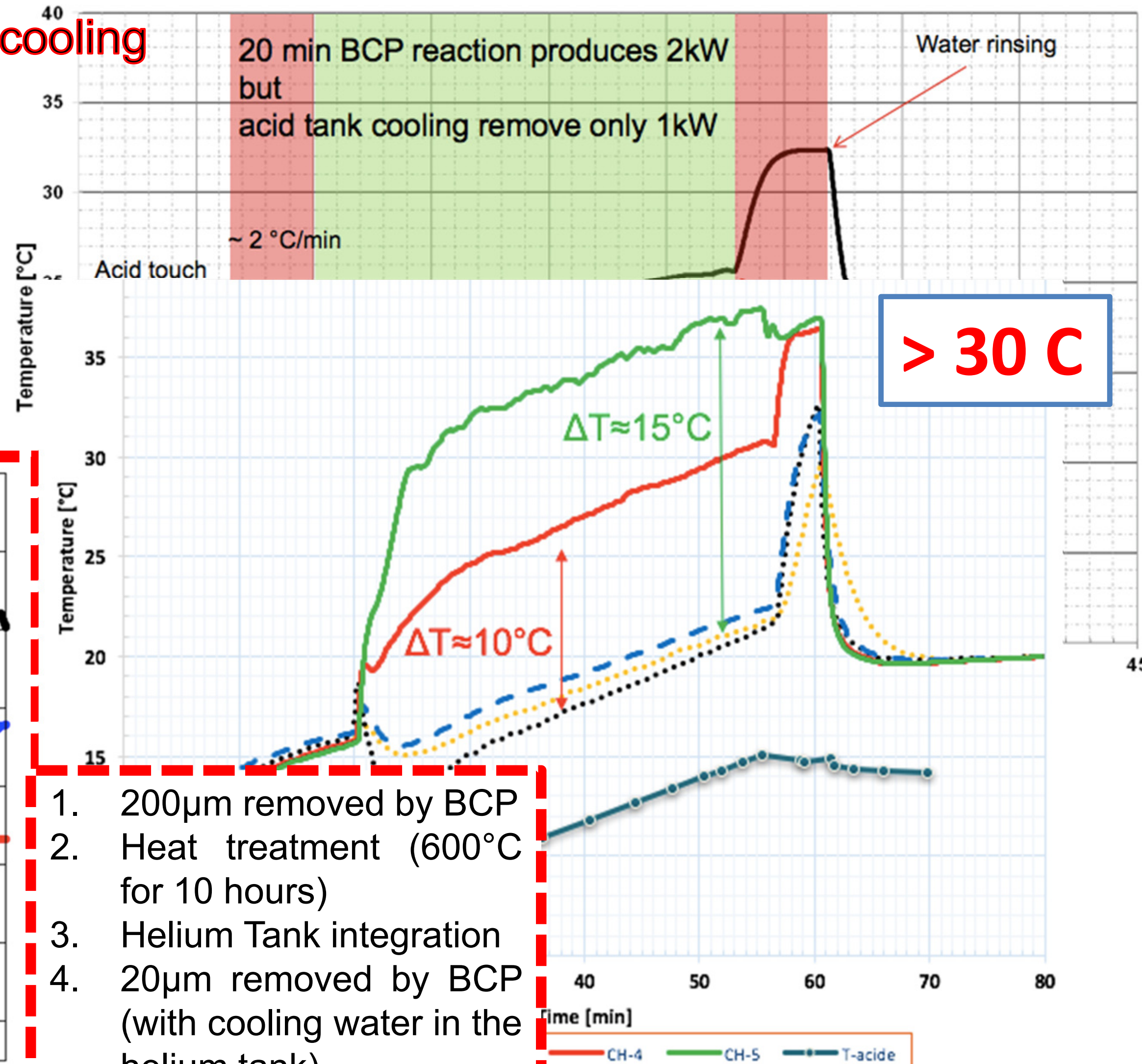
1. 200µm removed by BCP
2. Heat treatment (600°C for 10 hours)
3. Helium Tank integration
4. 20µm removed by BCP (with cooling water in the helium tank)

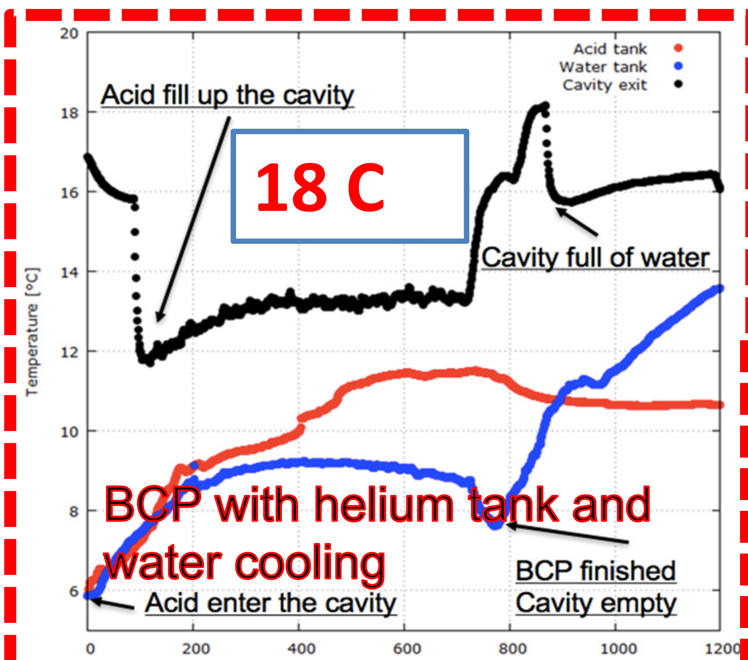
# Lesson-learned: chemical treatment @ CEA

EUROPEAN SPALLATION SOURCE

Naked cavity, no exterior cooling

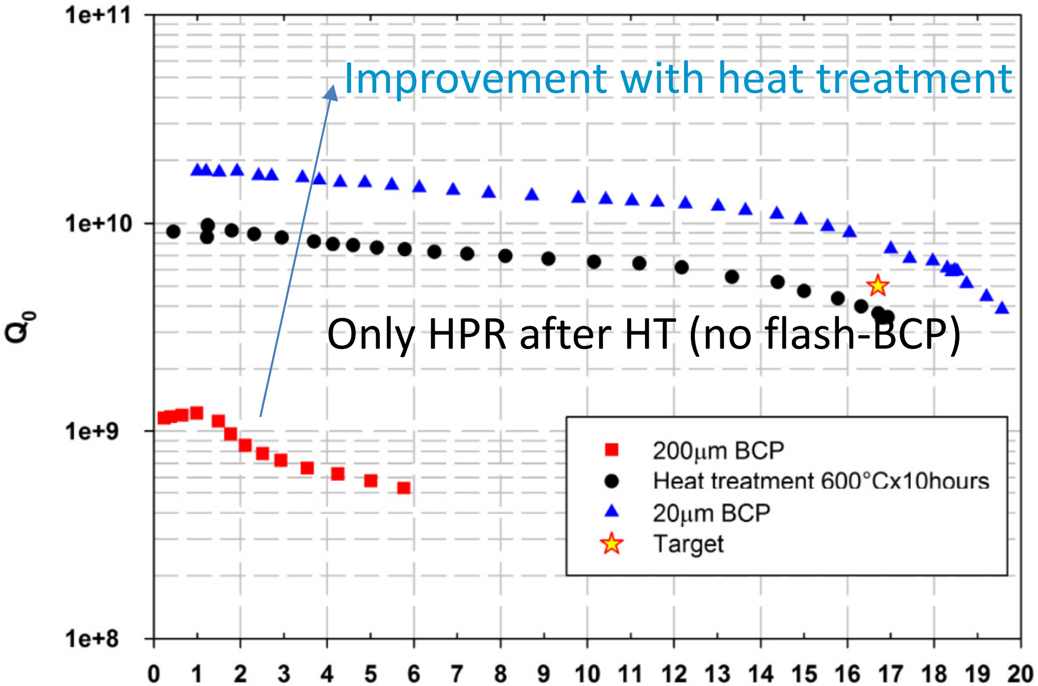


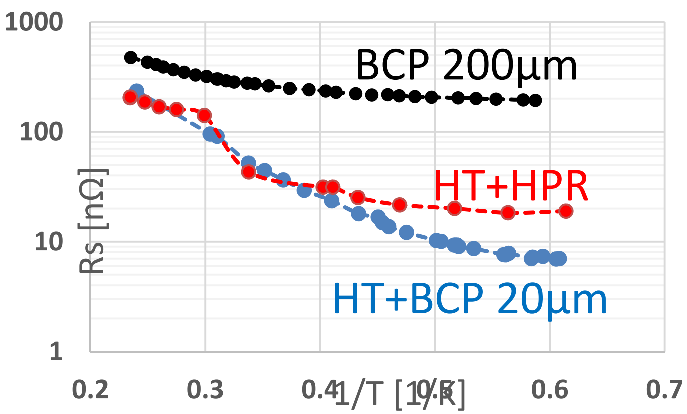



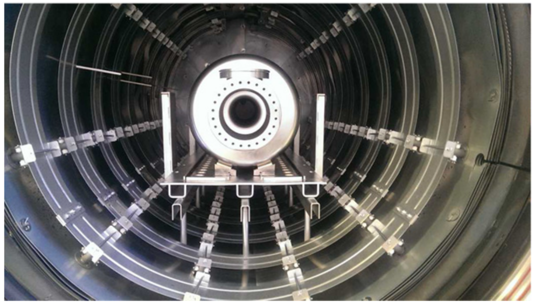

1. 200µm removed by BCP
2. Heat treatment (600°C for 10 hours)
3. Helium Tank integration
4. 20µm removed by BCP (with cooling water in the helium tank)

# Lesson-learned: heat treatment

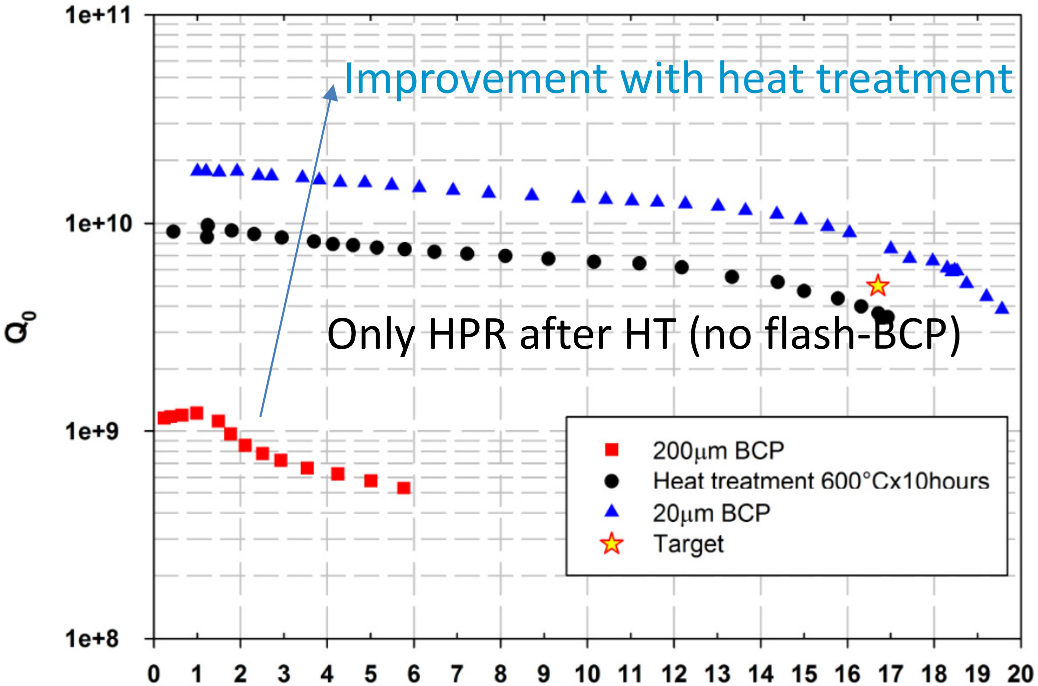


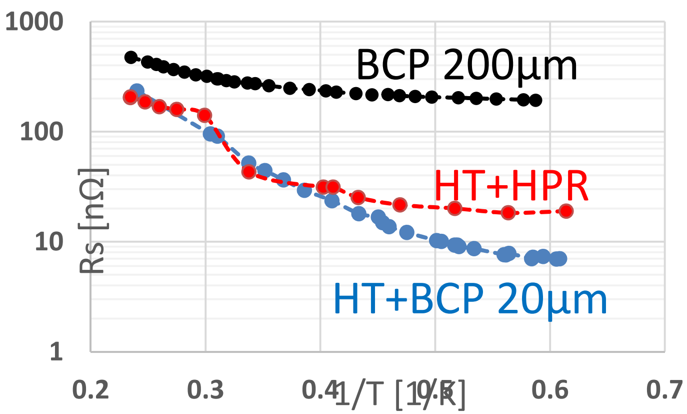




→ Heat treatment at 600°C for 10 hr to cure from Q-disease @ industry



# Lesson-learned: heat treatment

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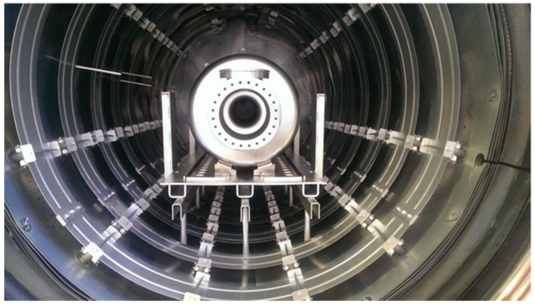
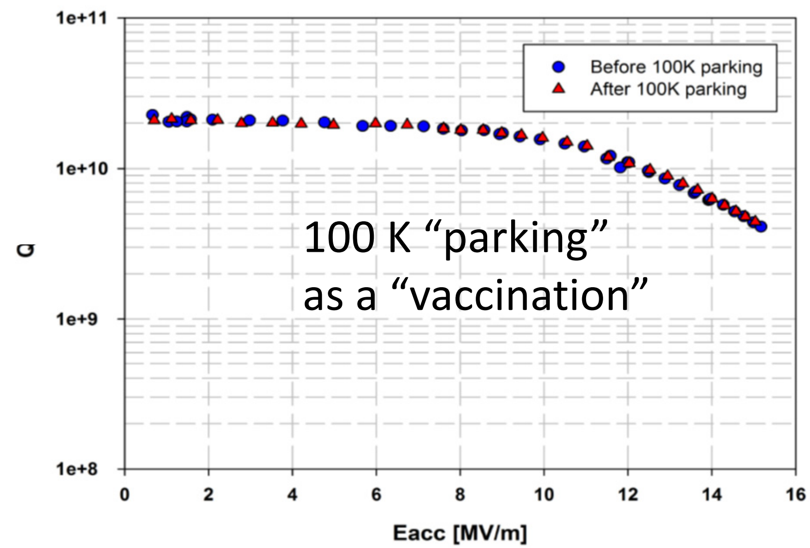
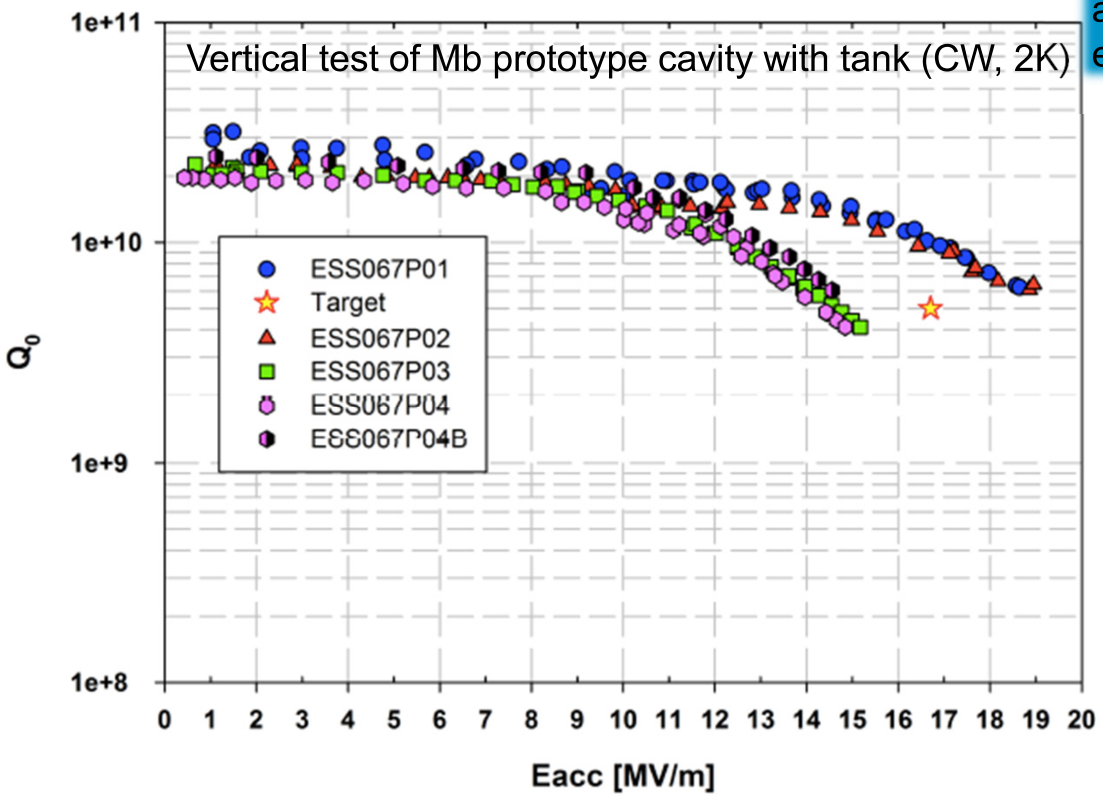




# Mβ cavity results @ CEA

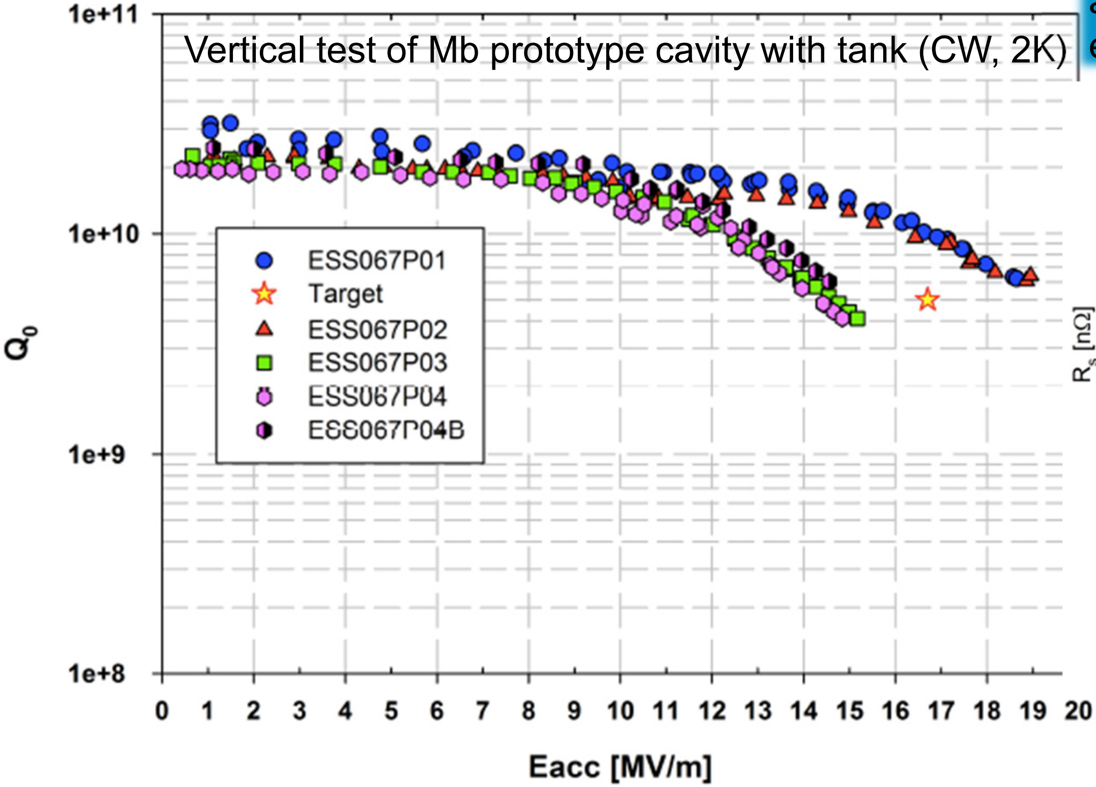
E. Cenni “Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank”-MOPVA041

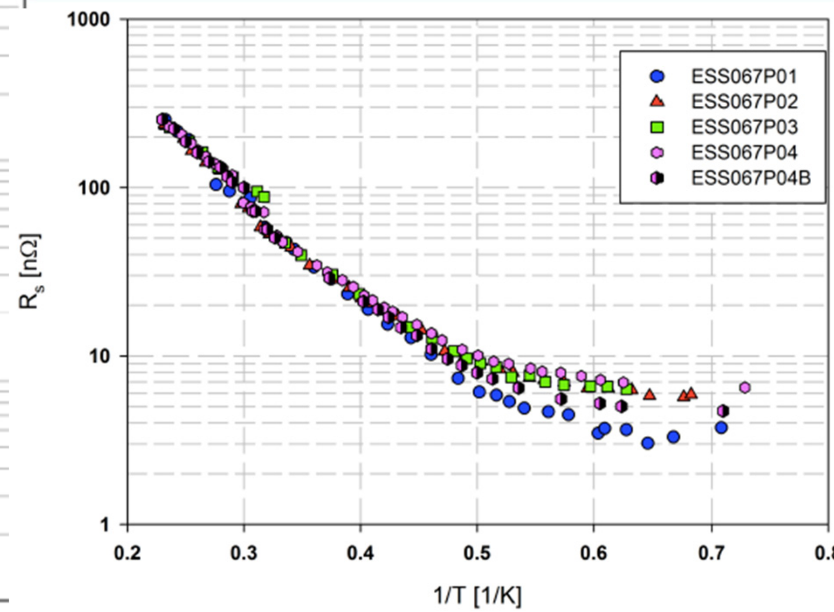


EUROPEAN SPALLATION SOURCE

# Mβ cavity results @ CEA

E. Cenni "Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank"-MOPVA041

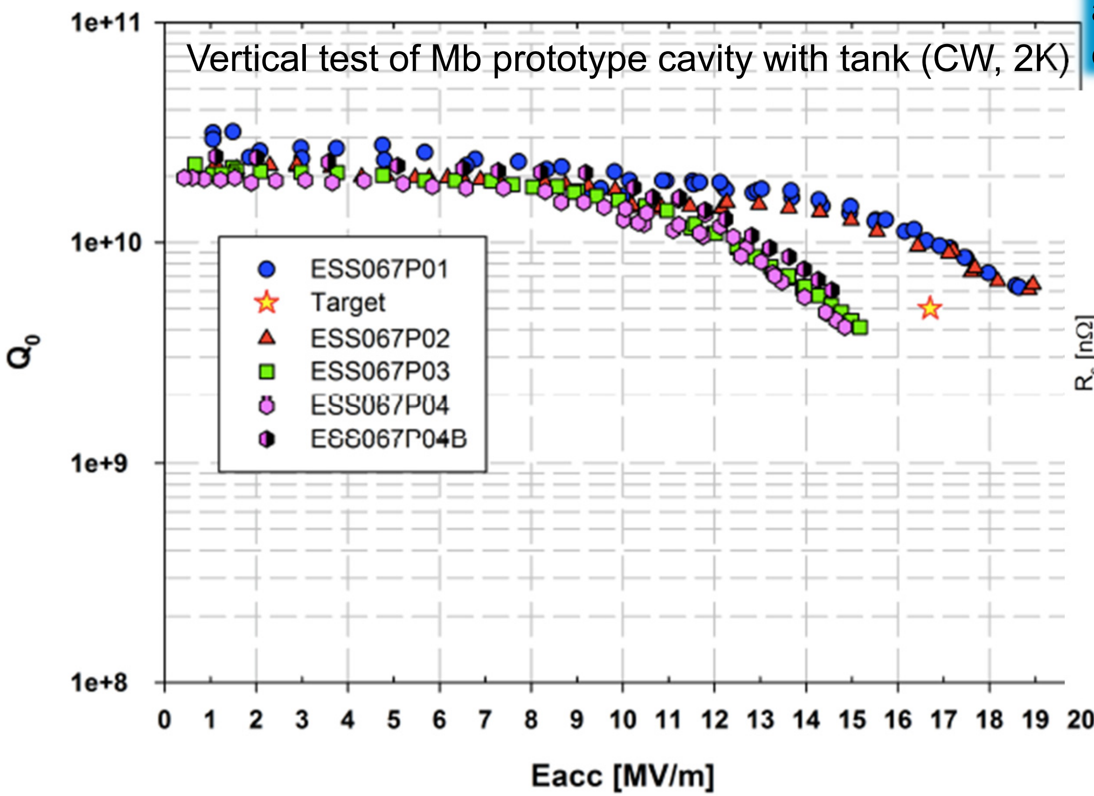


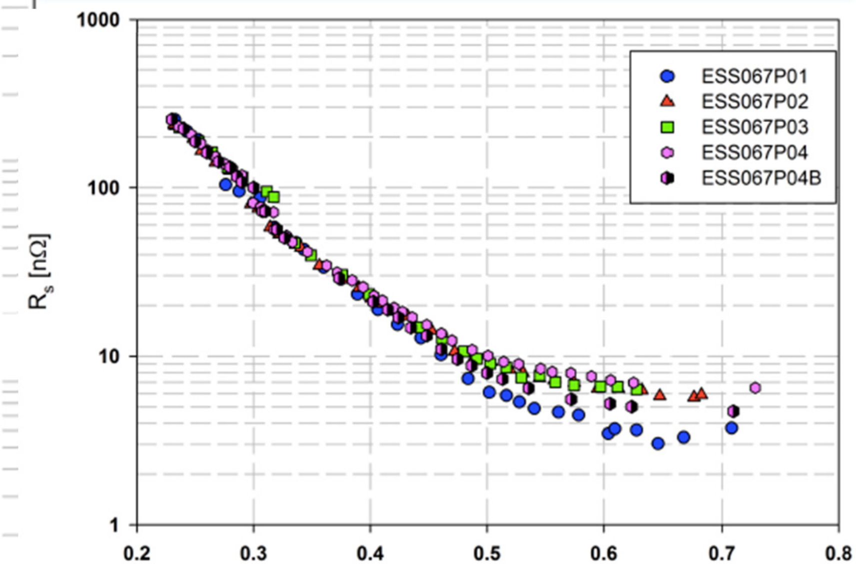



EUROPEAN SPALLATION SOURCE

# Mβ cavity results @ CEA

E. Cenni "Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank"-MOPVA041



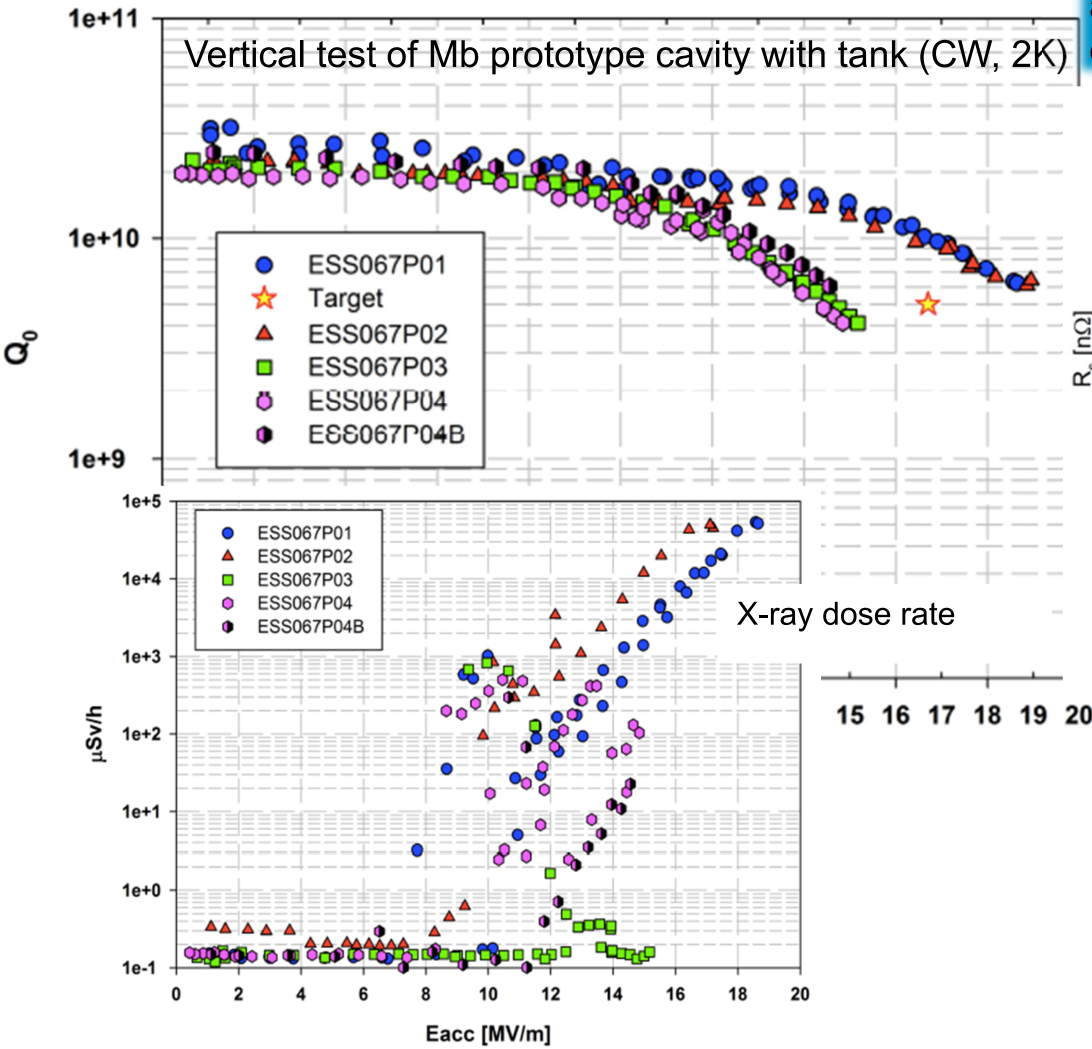



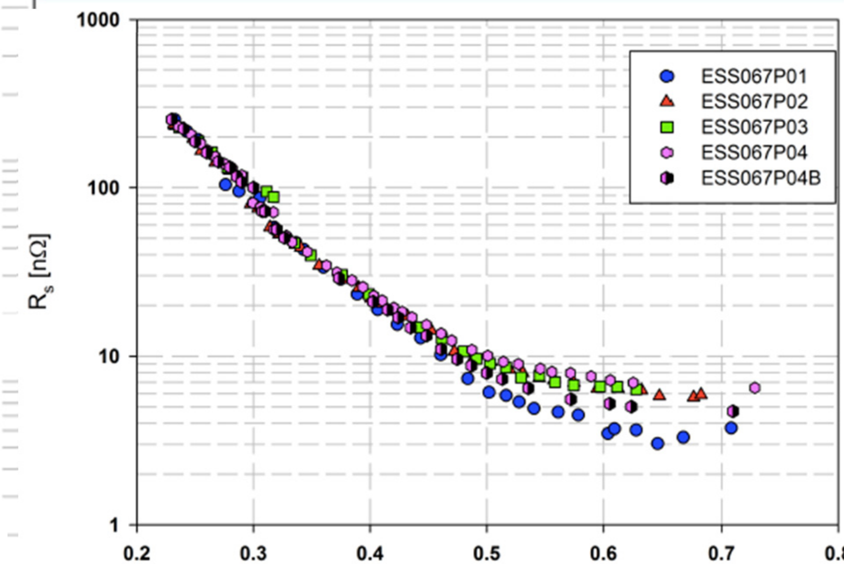

| Cavity | Rs (nΩ) | Q0 at 1MV/m@2K |
|---|---|---|
| MP01 | 3.14 | $3.2x10^{10}$ |
| MP02 | 6.09 | $2.2x10^{10}$ |
| MP03 | 6.06 | $2.1x10^{10}$ |
| MP04 | 7.09 | $1.9x10^{10}$ |
| MP04 (b) | 4.85 | $2.5x10^{10}$ |

EUROPEAN SPALLATION SOURCE

# Mβ cavity results @ CEA

E. Cenni “Vertical Test Results on ESS Medium and High Beta Elliptical Cavity Prototypes equipped with helium tank”-MOPVA041

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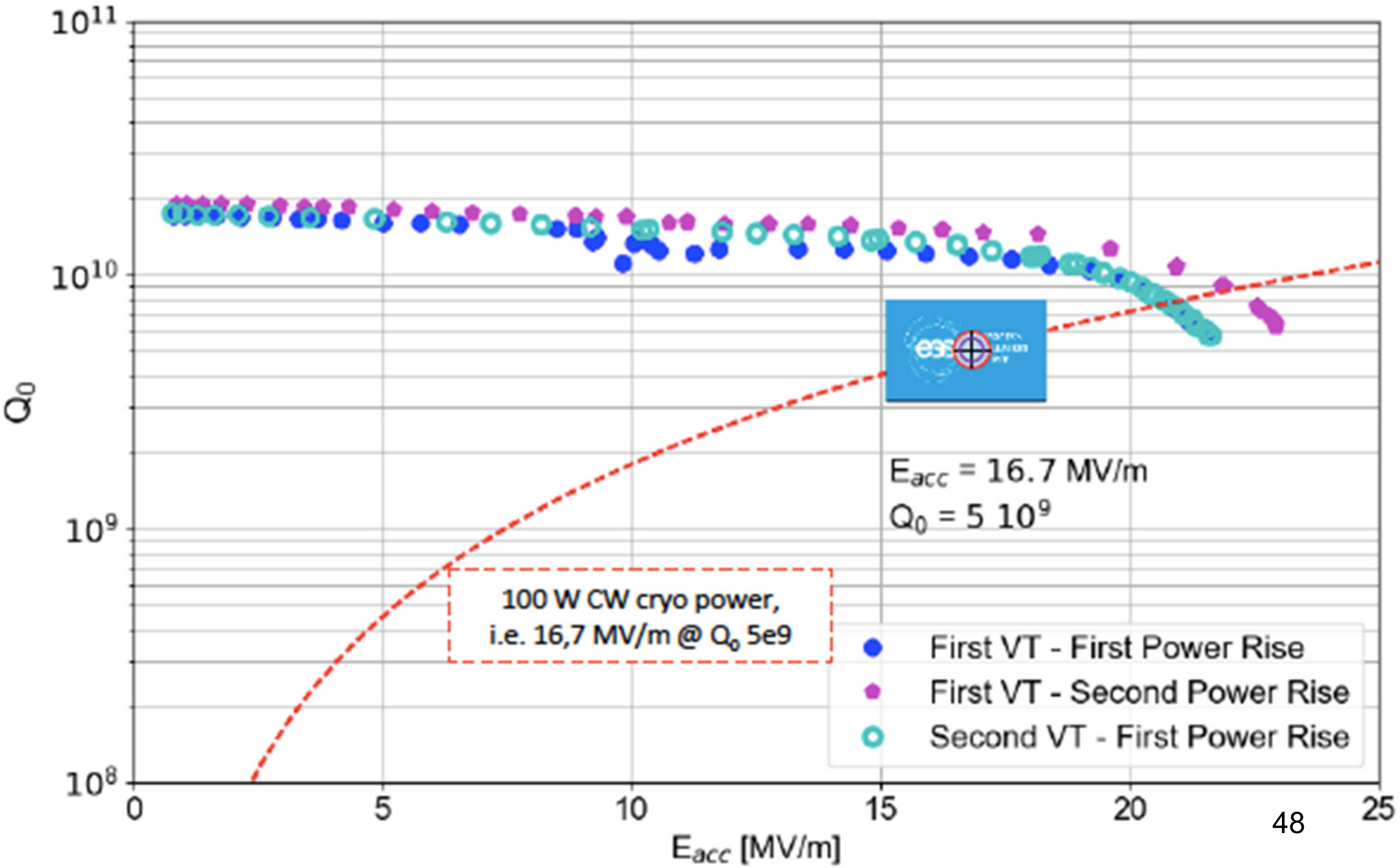
EUROPEAN SPALLATION SOURCE

# Mβ cavity results @ LASA

→ Follow the industrialization processes (XFEL)

BCP 1:1:2

P. Michelato "Vertical Tests of ESS Medium Beta Prototype Cavities at LASA"- MOPVA063



EUROPEAN SPALLATION SOURCE

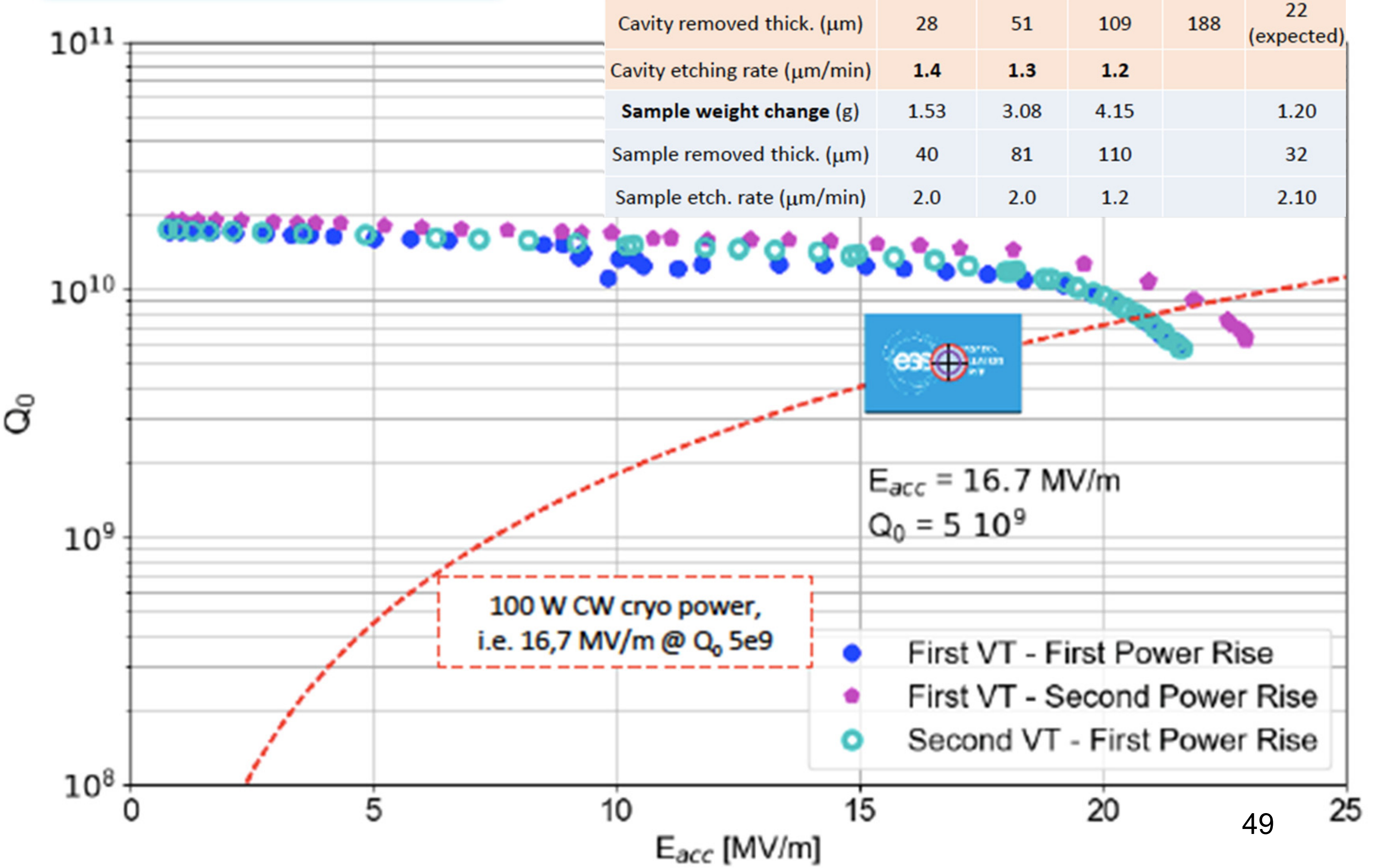
# Mβ cavity results @ LASA

→ Follow the industrialization processes (XFEL)

BCP 1:1:2

P. Michelato "Vertical Tests of ESS Medium Beta Prototype Cavities at LASA"- MOPVA063

| STEP | BCP1 A 20 min | BCP1 B 40 min | BCP2 90 min | BULK BCP total | Final BCP 15 min |
|---|---|---|---|---|---|
| **Cavity weight change** (g) | 434 | 795 | 1685 | 2914 | |
| Cavity removed thick. (μm) | 28 | 51 | 109 | 188 | 22 (expected) |
| Cavity etching rate (μm/min) | **1.4** | **1.3** | **1.2** | | |
| **Sample weight change** (g) | 1.53 | 3.08 | 4.15 | | 1.20 |
| Sample removed thick. (μm) | 40 | 81 | 110 | | 32 |
| Sample etch. rate (μm/min) | 2.0 | 2.0 | 1.2 | | 2.10 |



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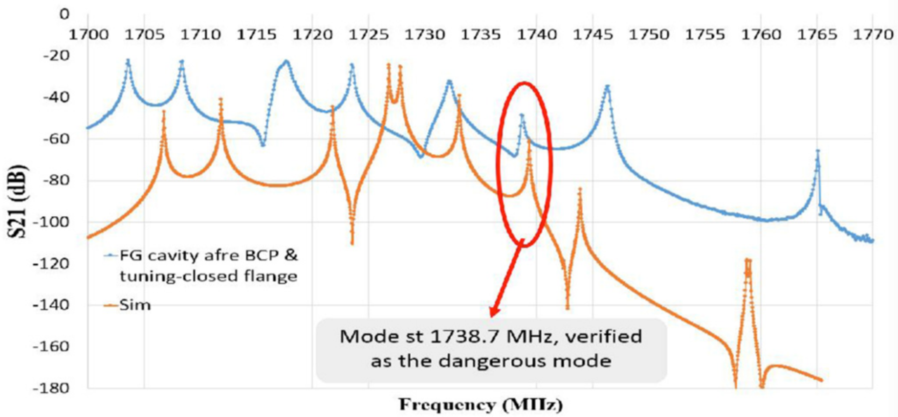
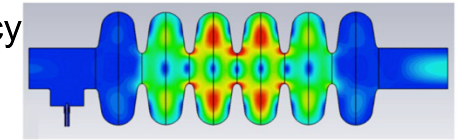
# Mβ cavity results @ LASA

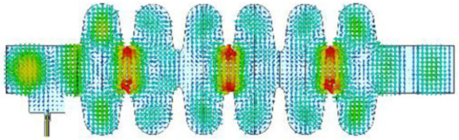
6-Cell Cavity 3rd Passband Monopole HOM frequency Shift vs. Errors in Cavity Geometry (kHz/mm)

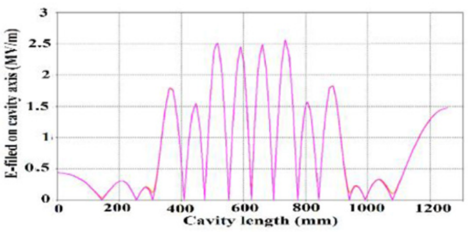
| | cell 1 | cell 2 | cell 3 | cell 4 | cell 5 | cell 6 |
|---|---|---|---|---|---|---|
| $R_{eq}$ | -40 | -3300 | -7200 | -7300 | -3500 | -100 |
| $R_{iris}$ | 80 | 940 | 2100 | 2100 | 1000 | 100 |
| A | -150 | -2800 | -7800 | -8000 | -3000 | -290 |
| B | 50 | 960 | 2200 | 2200 | 1000 | 70 |
| a | -35 | -190 | -400 | -400 | -200 | -40 |
| b | 20 | 110 | 250 | 250 | 120 | 30 |

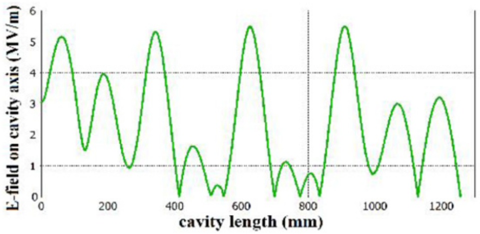



Simulation and measurement result comparison around 5th machine line at 300 K.



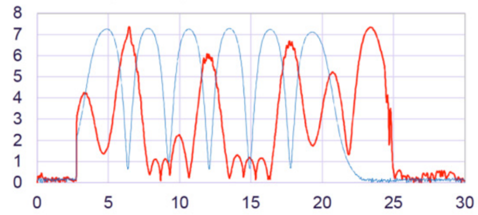





Field profile measured via bead-pulling for mode at 1738.7MHz


Bead-pull field profile for mode at 1732.6 MHz



E-Field profile measured on cavity axis by bead-pulling for mode at 1739 MHz at 300 K.

E-Field profile measured on cavity axis by bead-pulling for mode at 1732 MHz at 300 K.

Considering 0.2 mm shape tolerance and 0.1 mm length error and adding the numbers in above table as absolute values, **the 1742 MHz mode frequency shift is less than 9 MHz.**

EUROPEAN SPALLATION SOURCE

# Mβ cavity results @ LASA

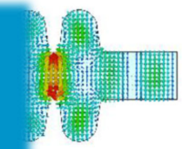
**S. Pirani, "Investigation of HOM Frequency Shifts Induced by Mechanical Tolerances" MOPVA091**

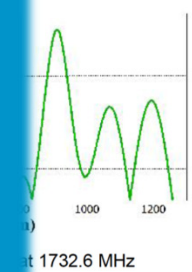
J. Chen, "Multipacting Studies in ESS Medium-Beta Cavity" - MOPVA064

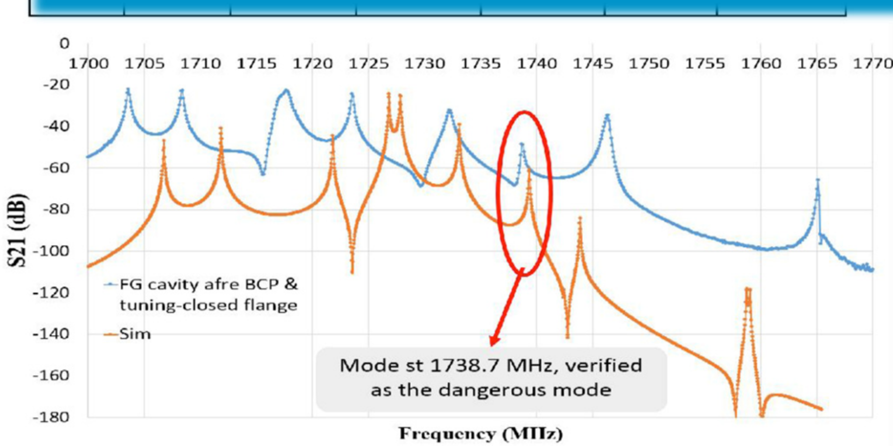
L. Monaco "Fabrication and Treatment of the ESS Medium Beta Prototype Cavities" - MOPVA060

M. Bertucci, "Quench and Field Emission Diagnostics for the ESS Medium-Beta Prototypes Vertical Tests at LASA" - MOPVA061

D. Sertore, "Experience on Design, Fabrication and Testing of a Large Grain ESS Medium Beta Prototype Cavity"- MOPVA068



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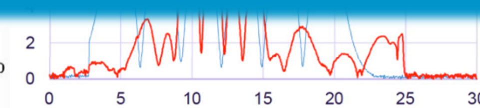
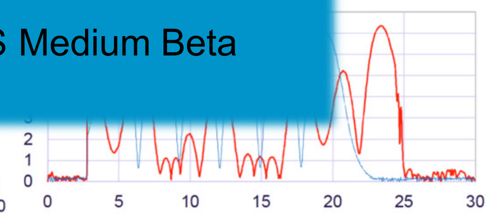



E-Field profile measured on cavity axis by bead-pulling for mode at 1739 MHz at 300 K.




E-Field profile measured on cavity axis by bead-pulling for mode at 1732 MHz at 300 K.

Considering 0.2 mm shape tolerance and 0.1 mm length error and adding the numbers in above table as absolute values, **the 1742 MHz mode frequency shift is less than 9 MHz.**

# Power-coupler conditioning @ CEA

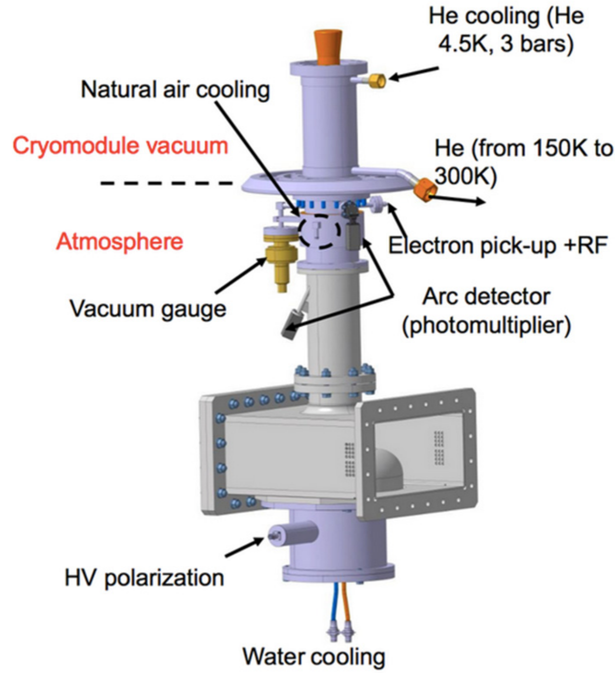
The coupler is equipped with:

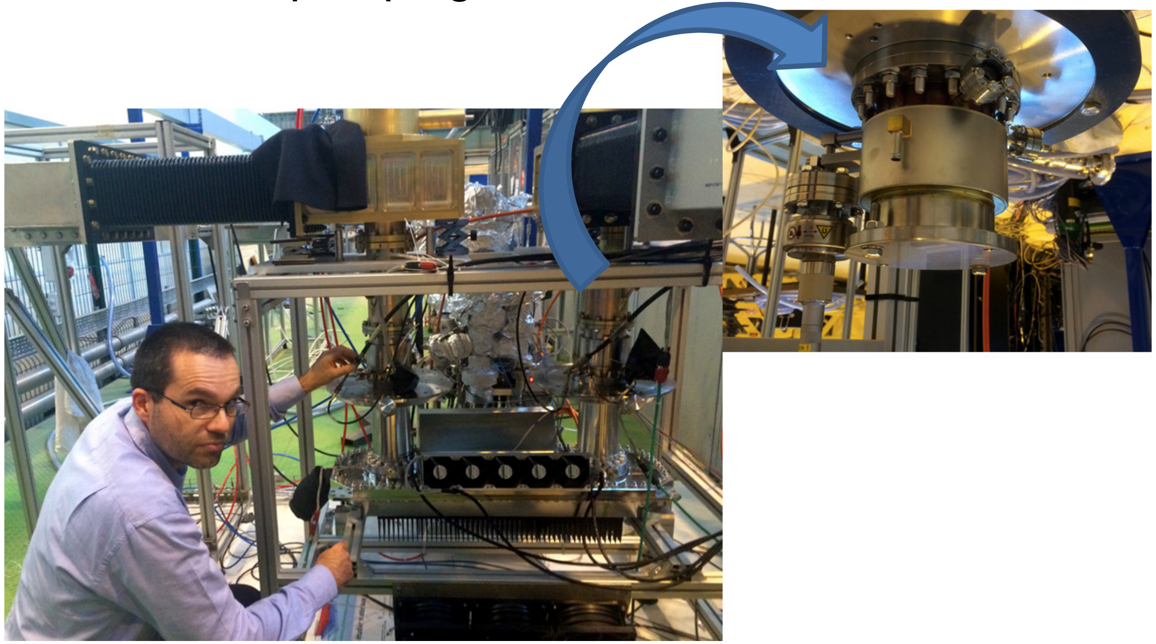
- Photomultiplier (arc detectors) vacuum and air sides
- Pressure gage
- Electron pick-up

C. Arcambal "Conditioning of the RF Power Couplers for the ESS Elliptical Cavity Prototypes"- MOPVA044

Preparation:

- Baking at 170°C for 96 hr
- Vacuum pumping at 120°C for 48h then 60°C for 48 hr



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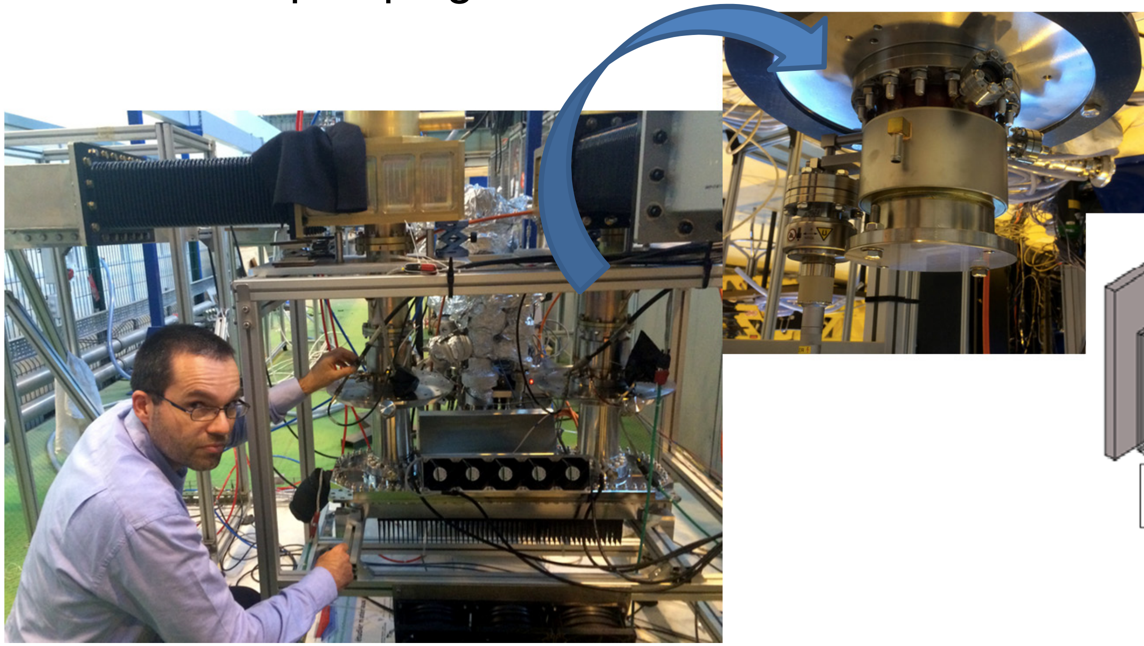
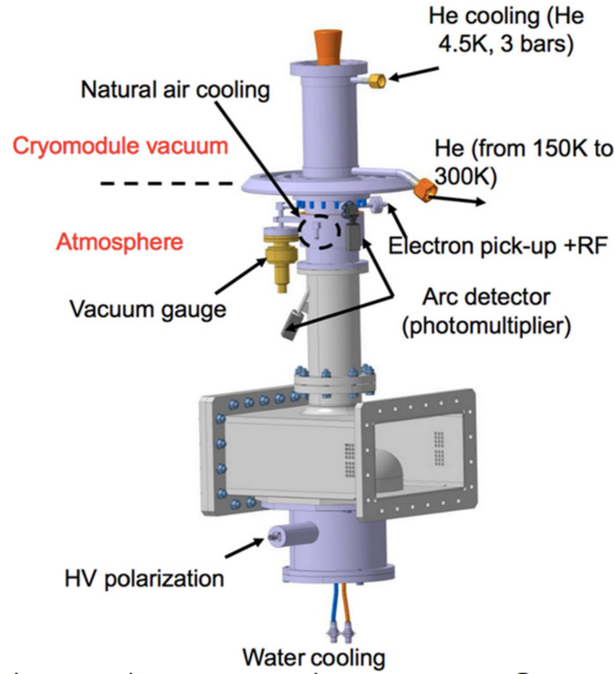
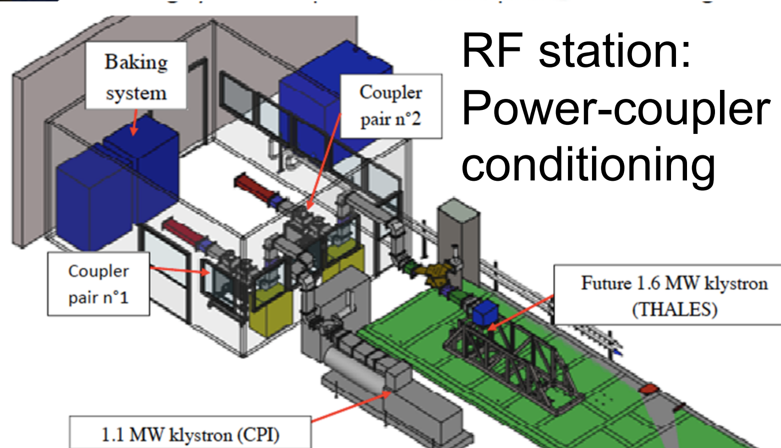





RF station: Power-coupler conditioning

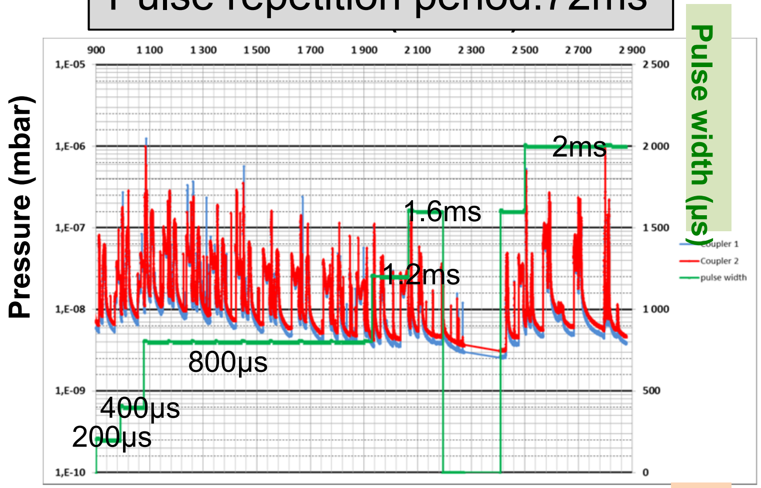


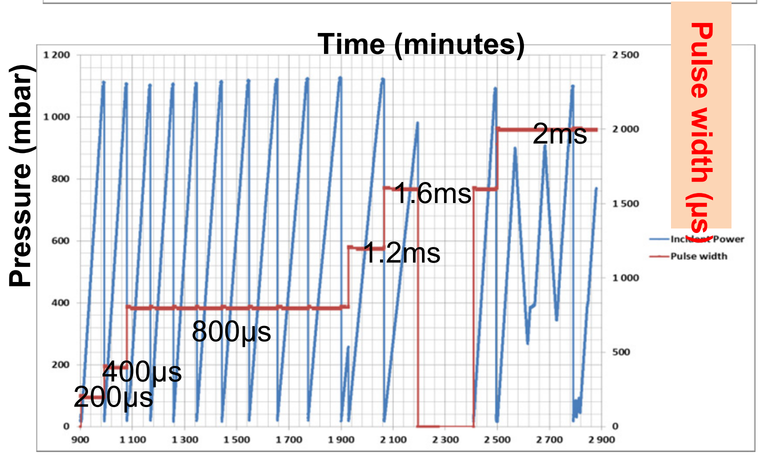
# 1.1 MW power-coupler conditioning @ CEA

➔ First results for the conditioning of the coupler loaded by 50 ohm in traveling wave.

➔ Successful test at 1Hz, 14 Hz, 3.6 ms. Power increased up to 1.2 MW.

Pulse repetition period:72ms

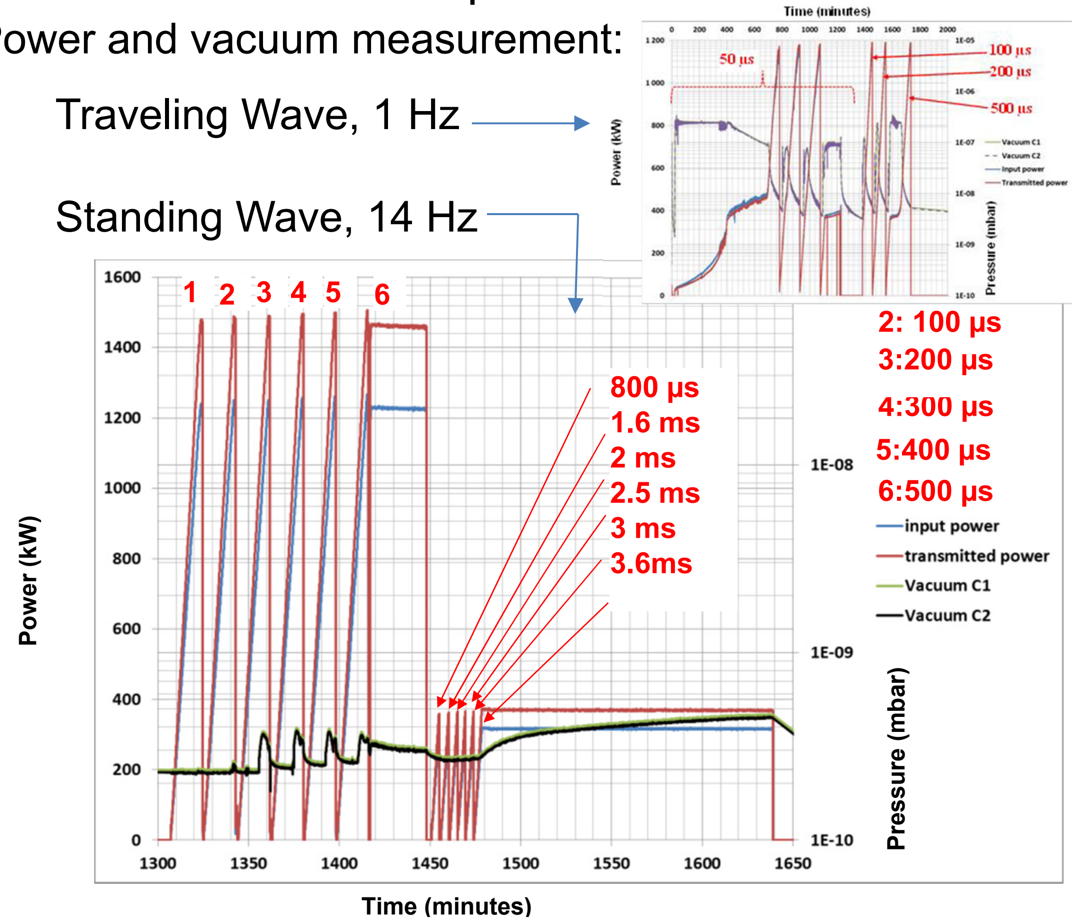



Power and vacuum measurement:

Traveling Wave, 1 Hz

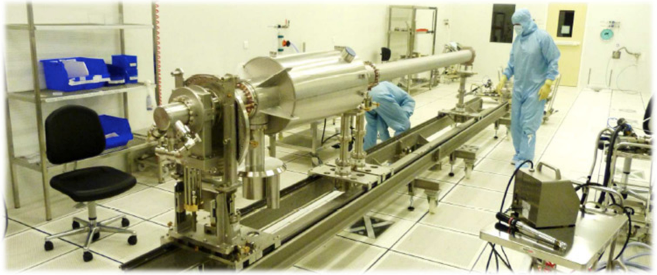
Standing Wave, 14 Hz

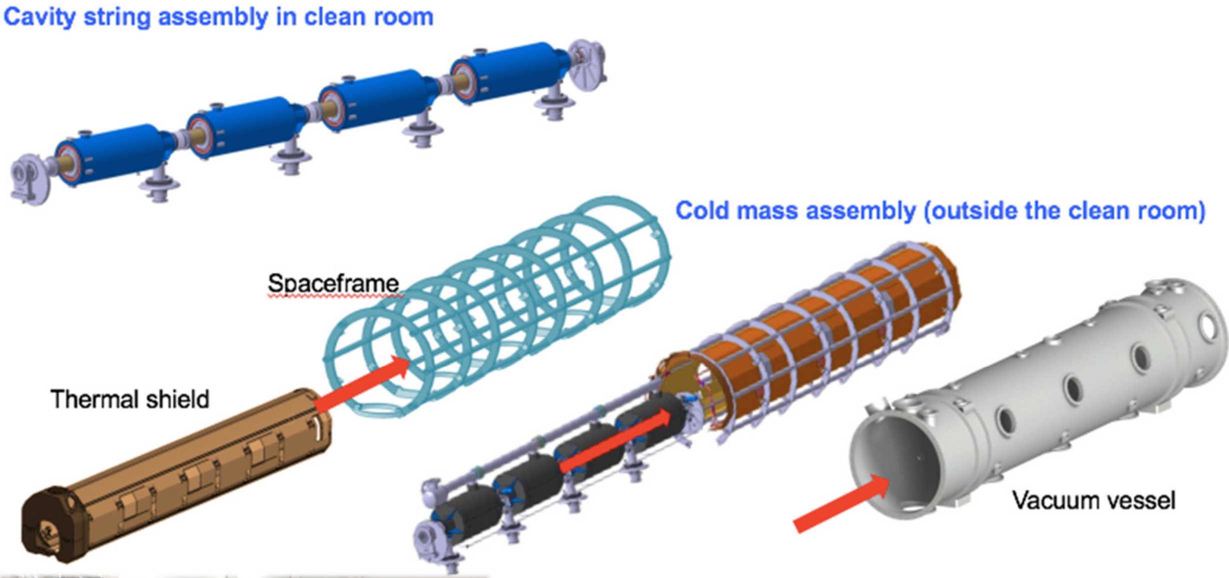


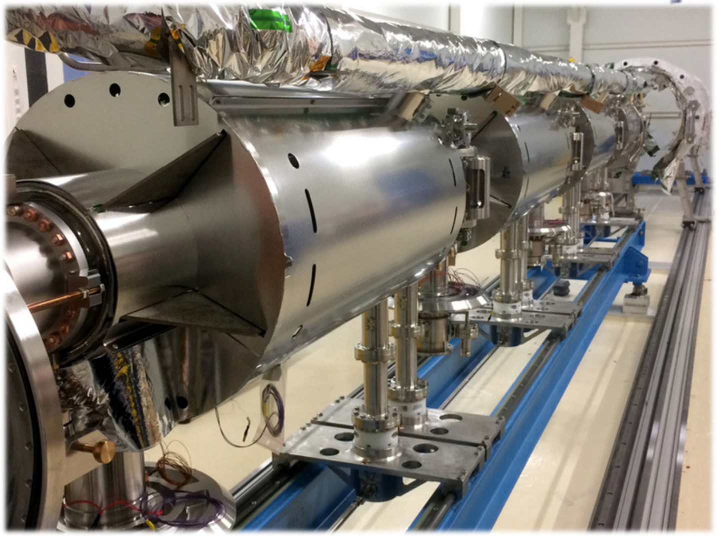

➔ Emax on the ceramic windows in SW at 14 Hz

# Cryomodule assembly

Clean room assembly (ISO 4)

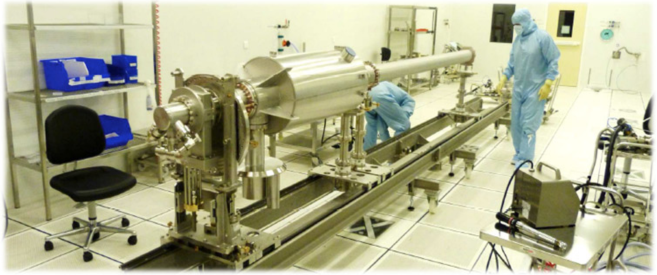




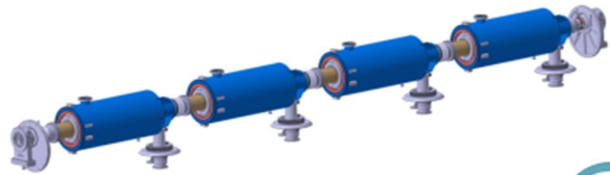



# Cryomodule assembly

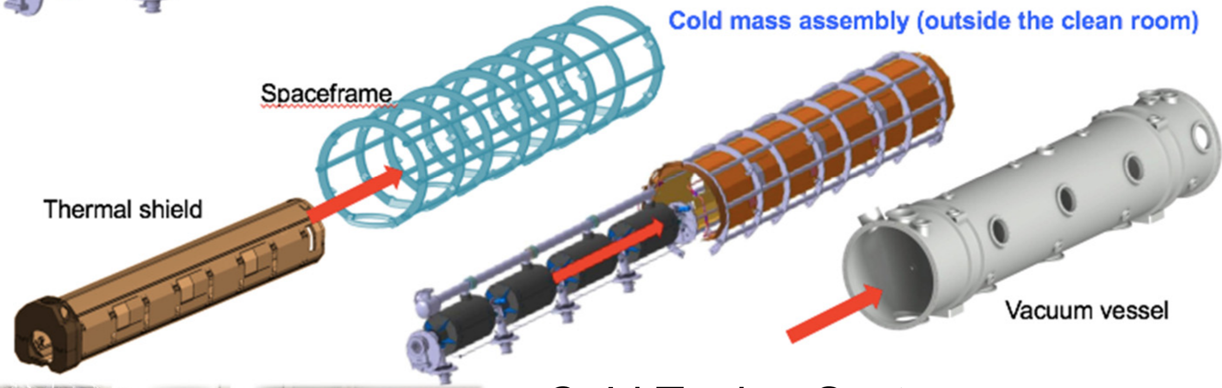
## Clean room assembly (ISO 4)



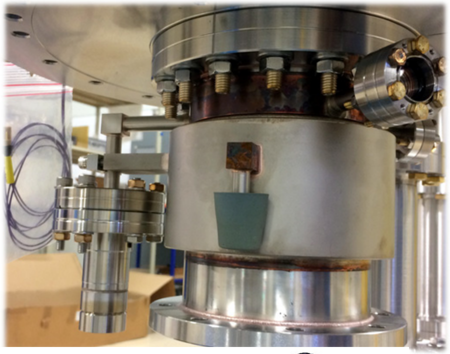
Cavity string assembly in clean room

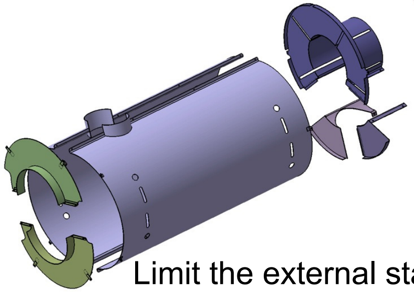


Cold mass assembly (outside the clean room)

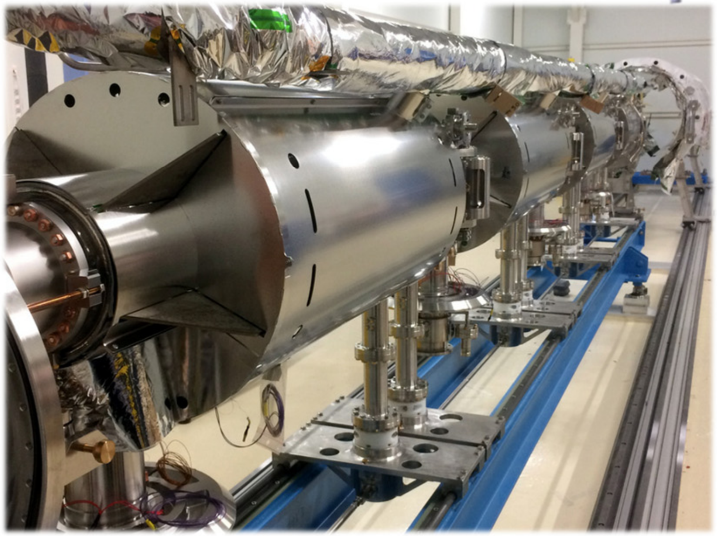



## Power-coupler 1.1 MW

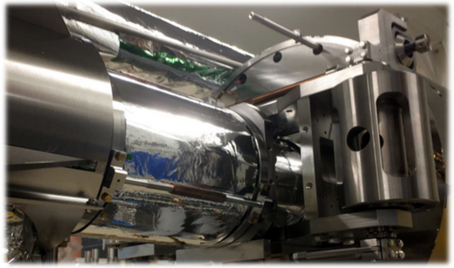




Limit the external static field to Bext = 14 mG



## Cold Tuning System

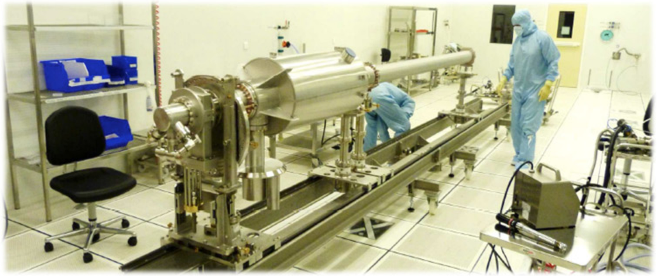


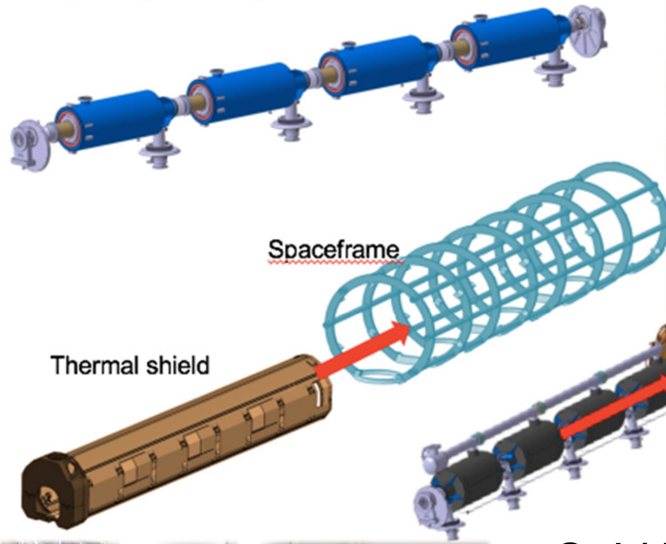
- Stepper motor + gear box at cold
  - Max tuner stroke: ± 3 mm
  - Max tuning range: ~ 600 kHz
  - Tuning resolution: ~1 Hz
- 2 piezo stacks

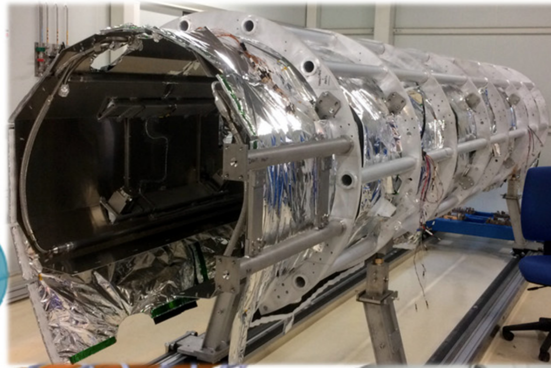
EUROPEAN SPALLATION SOURCE

# Cryomodule assembly

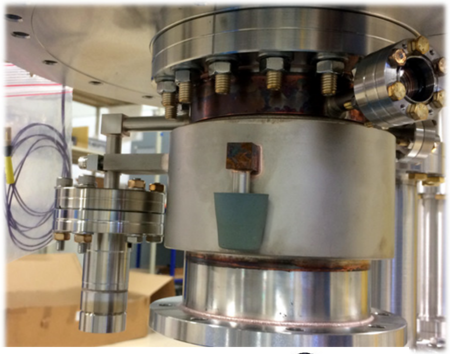
## Clean room assembly (ISO 4)

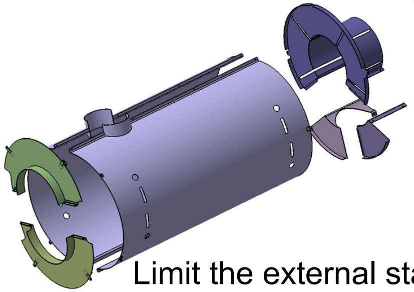




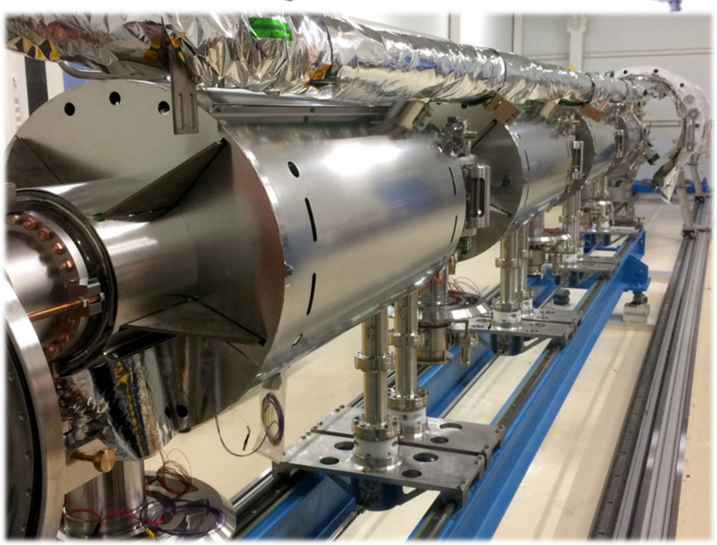



## Power-coupler 1.1 MW

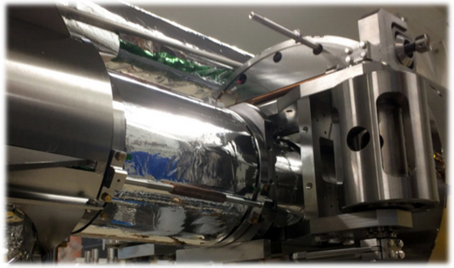




Limit the external static field to Bext = 14 mG



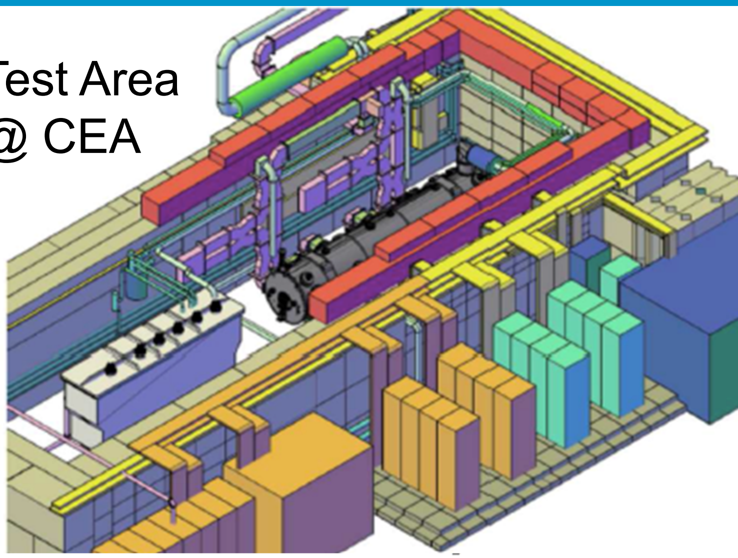
## Cold Tuning System



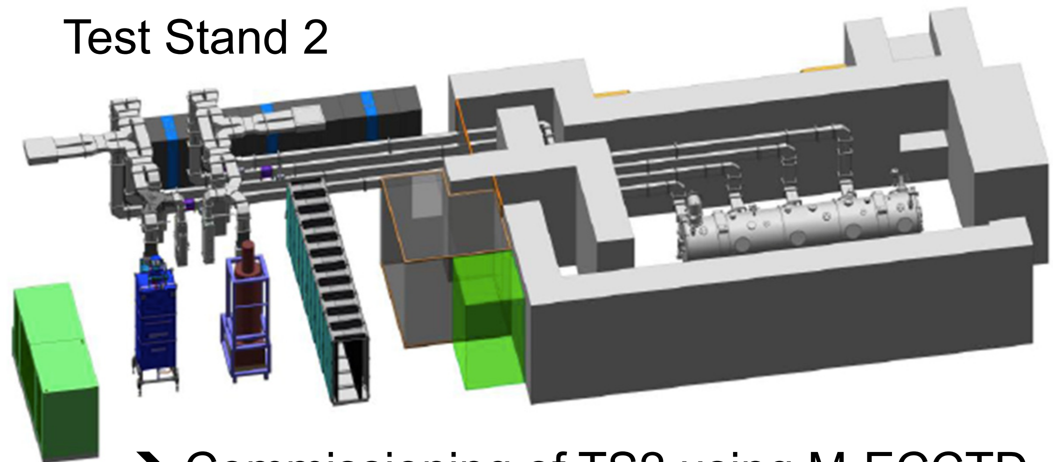
- Stepper motor + gear box at cold
  - Max tuner stroke: ± 3 mm
  - Max tuning range: ~ 600 kHz
  - Tuning resolution: ~1 Hz
- 2 piezo stacks

# Test Stand Mβ @ CEA and @ Lund

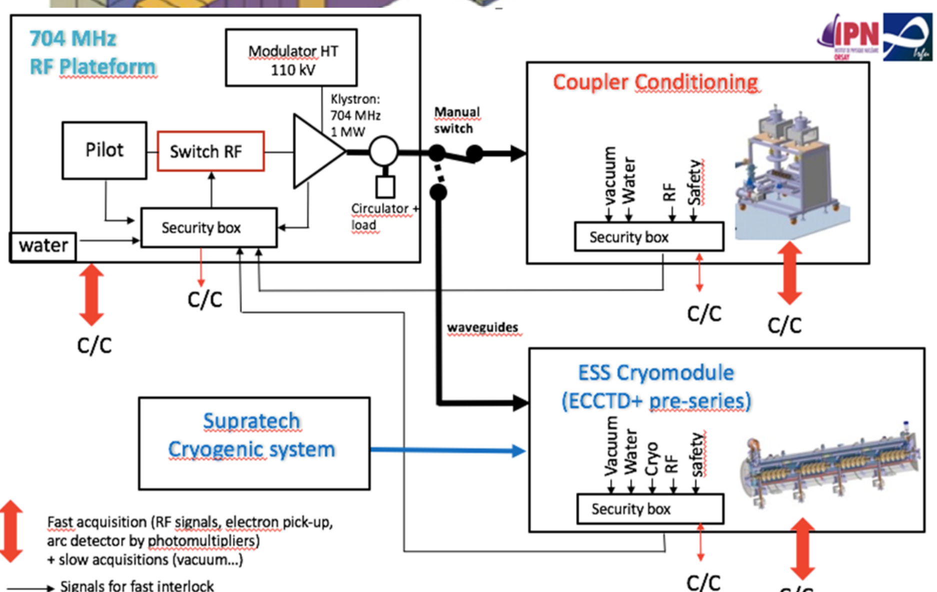
Test Area @ CEA



Test Stand 2



➔ Commissioning of TS2 using M-ECCTD

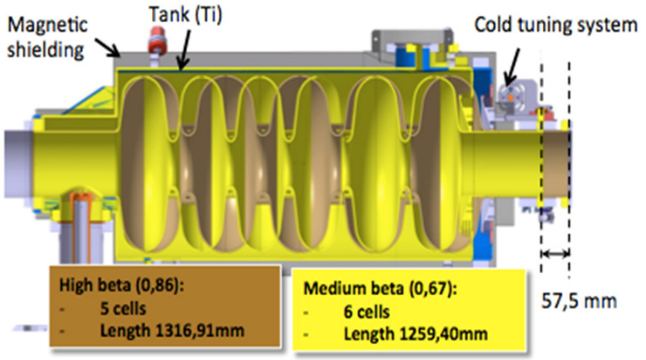



| Parameters | ESS operation | ECCTD tests at CEA |
|---|---|---|
| Acc. gradient | 16.7 and 19.9 MV/m | |
| Peak RF power | 1.1 MW max | 400 kW max |
| RF pulse length | 2.86 ms | 3 ms |
| RF pulse rate | 14 Hz | 16.7 Hz |
| Cavity cooling | LHe at 2K | |
| Coupler cooling | SHe at 4.5 K & 3 bara | GHe at about 4.64 K & 1.2 bara |
| Thermal shield temperature | GHe at 50 K & 19 bara | $LN_2$ at 77 K |

E. Asensi Conejero -“The Cryomodule Test Stands for the ESS” - MOPVA089

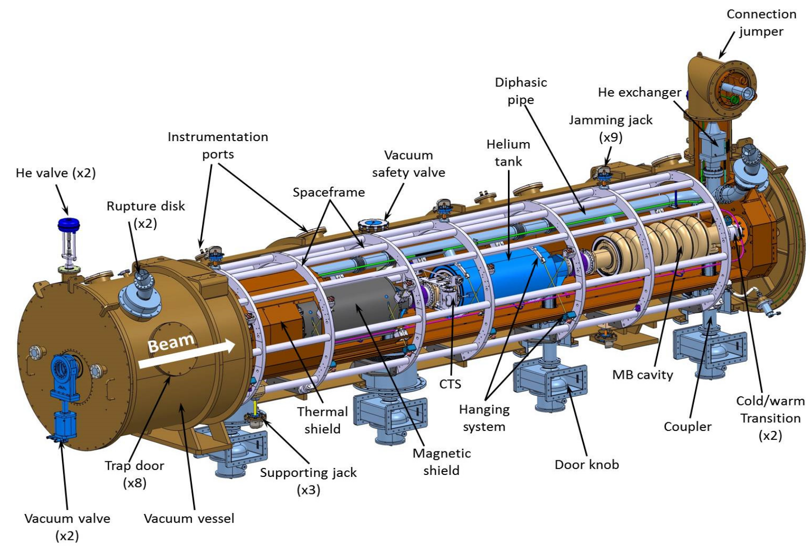
# Validation of Elliptical High-β Technology Demonstrator

EUROPEAN SPALLATION SOURCE




## Step 1: Hβ cavities

| Parameter | Medium beta | High beta |
|---|---|---|
| Frequency [MHz] | 704.42 | |
| Accelerating length [mm] | 0.855 | 0.915 |
| # cells | 6 | 5 |
| Operating temperature | 2K | |
| Beta | 0.67 | 0.86 |
| Nominal $E_{acc}$ [MV/m] | 16.7 | 19.9 |
| $Q_0$ at nominal $E_{acc}$ | >5x$10^9$ | |
| $E_{pk}$/ $E_{acc}$ | 2.36 | 2.2 |
| $B_{pk}$/ $E_{acc}$ mT/(MV/m) | 4.79 | 4.3 |
| $E_{pk}$ at nominal $E_{acc}$ [MV/m] | 39.4 | 43.8 |
| G [Ω] | 196.63 | 241 |
| Cell to cell coupling | 1.2% | 1.8% |

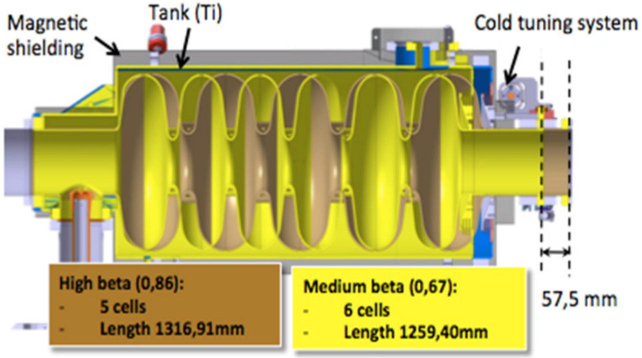



## Step 3: Cryomodule

*@ Saclay → Summer 2018*

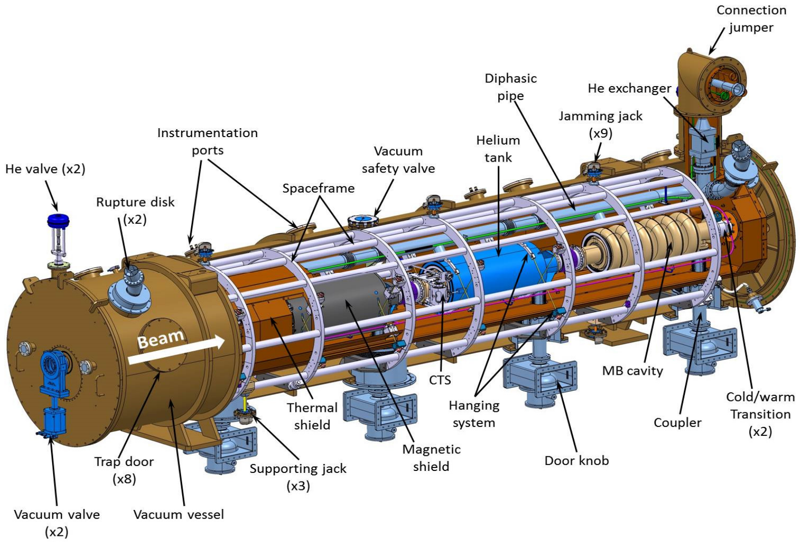
*@ Lund*

# Validation of Elliptical High-β Technology Demonstrator




**Step 1: Hβ cavities**

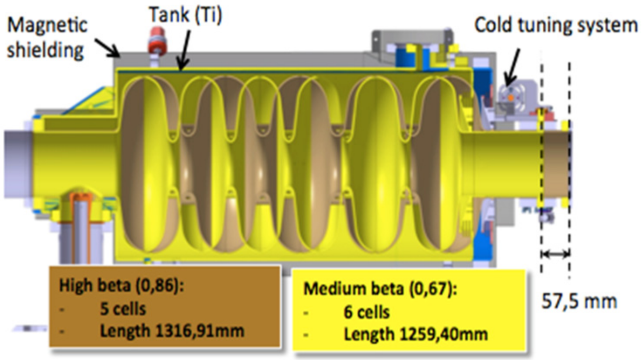
***@ Saclay (2014)***
***@ STFC (pre-serie)***




**Step 3: Cryomodule**
***@ Saclay → Summer 2018***
***@ Lund***

# Validation of Elliptical High-β Technology Demonstrator

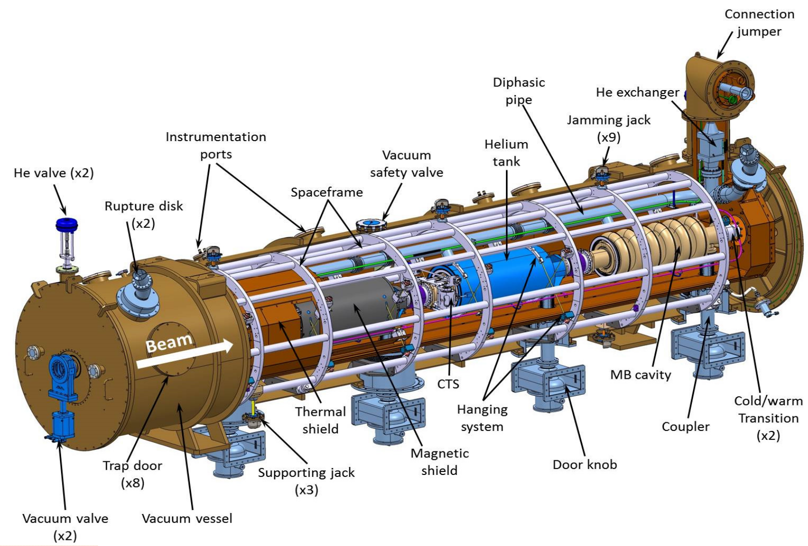
EUROPEAN SPALLATION SOURCE




**Step 1: Hβ cavities**

***@ Saclay (2014)***
***@ STFC (pre-serie)***

**Step 2: Elliptical cavity package**
***@ Uppsala - HNOSS***




**Step 3: Cryomodule**
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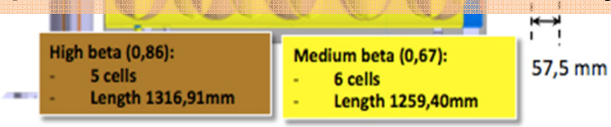
***@ Lund***

# Validation of Elliptical High-β Technology Demonstrator

EUROPEAN SPALLATION SOURCE

Lesson-learned after 2 cavities fabricated in 2014:
1) HOMs measured close to 1408.8 kHz < 5 MHz → Mβ fabrication lesson-learned
2) Degradation of performances after thermal treatment (pollution) → Heat treatment process studied with industry and succesfully implemented for Mβ




**Step 1: Hβ cavities**

***@ Saclay (2014)***
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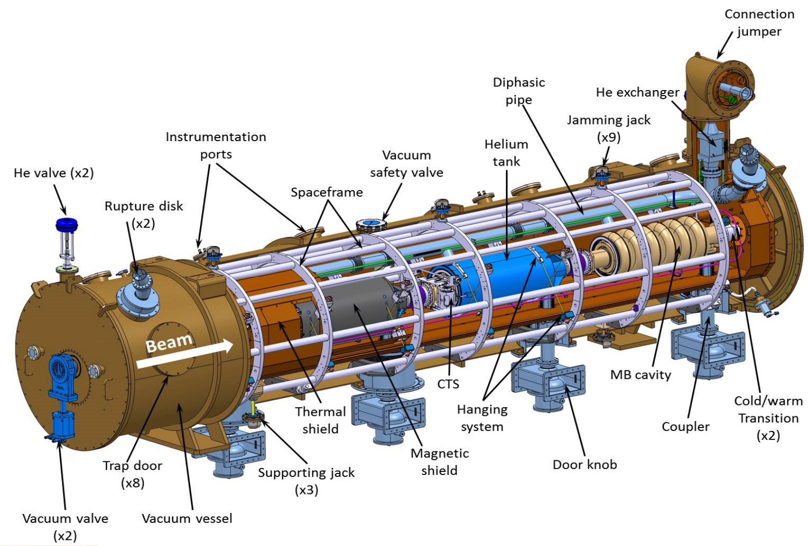


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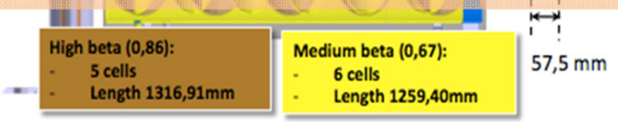


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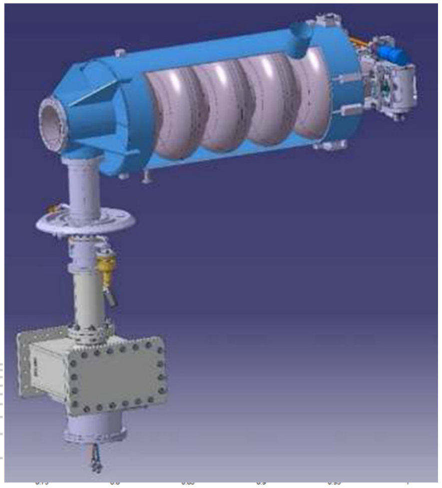
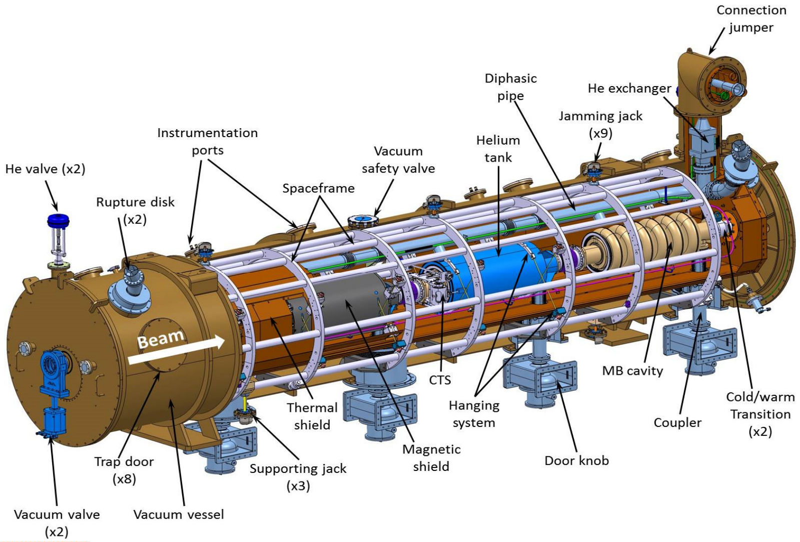
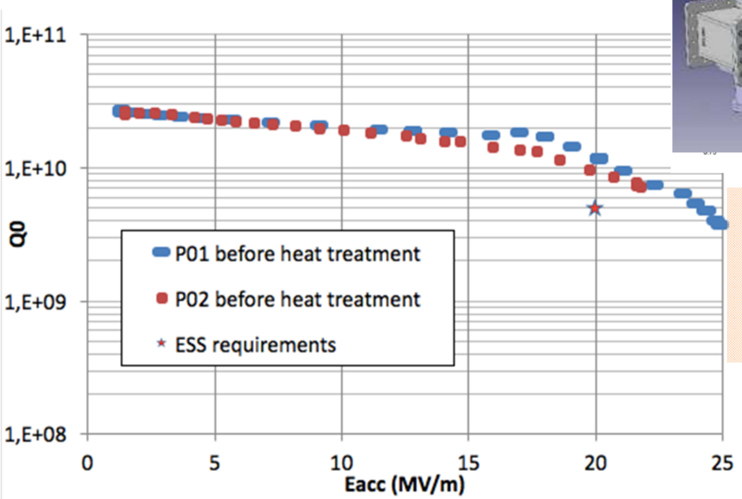




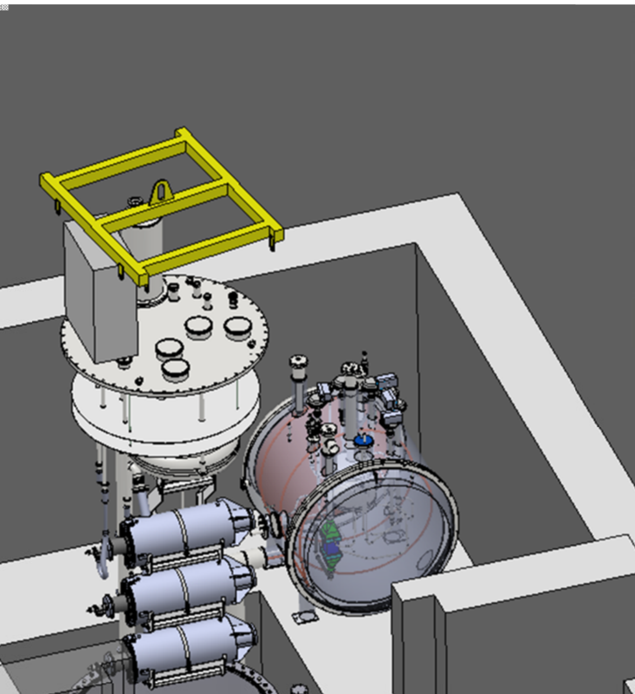



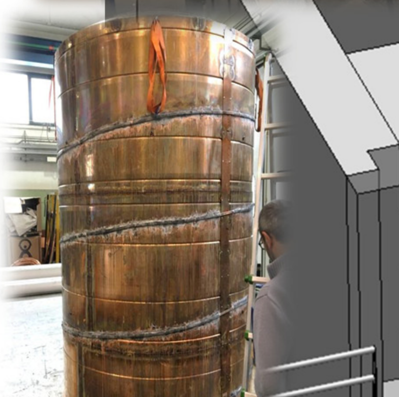

**Step 2: Elliptical cavity package**
*@ Uppsala - HNOSS*

**Step 3: Cryomodule**
*@ Saclay → Summer 2018*
*@ Lund*

# ESS: STFC (H)VTF @ STFC

Three-cavities-insert





Magnetic shield

Vertical test cryostat for ESS Hβ cavities:
3 cavities in cryostat

- Horizontal test configuration:
- 1500L LHe per test vs. 7500L He(l)
- <4g/s He(g) HVTF vs. 20g/s

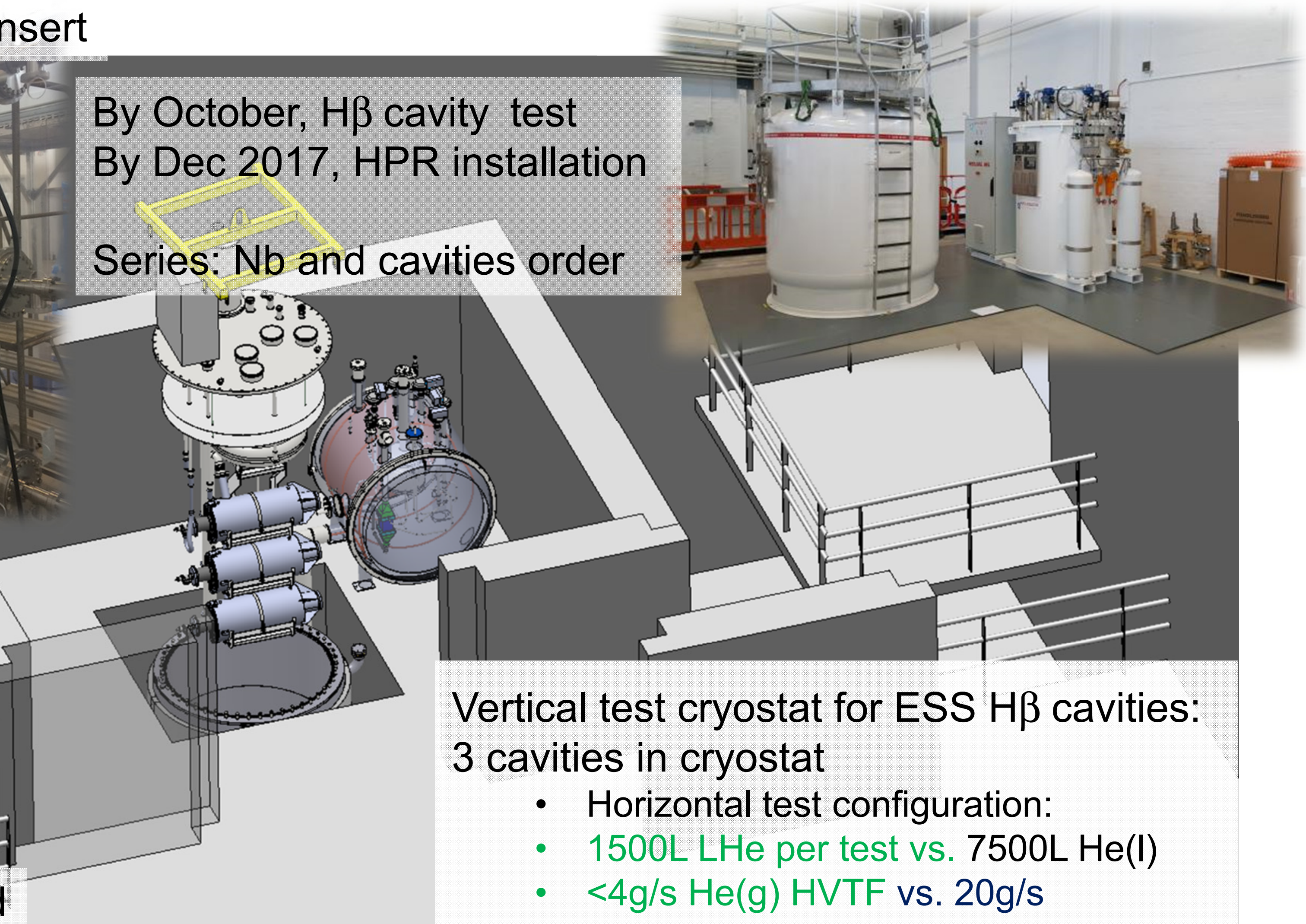
# ESS: STFC (H)VTF @ STFC

EUROPEAN SPALLATION SOURCE

Three-cavities-insert

By October, Hβ cavity test
By Dec 2017, HPR installation

Series: Nb and cavities order



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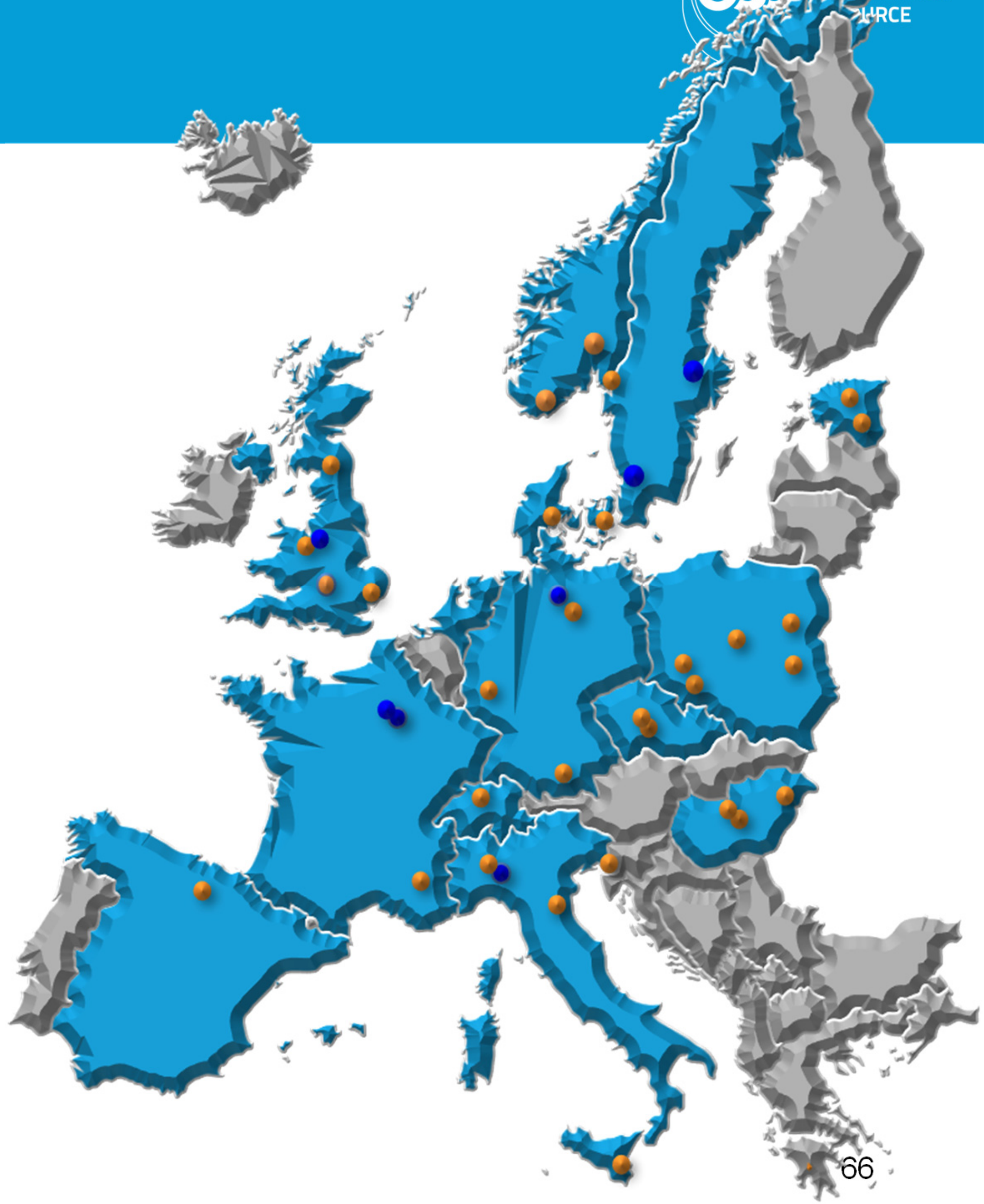
# Outline

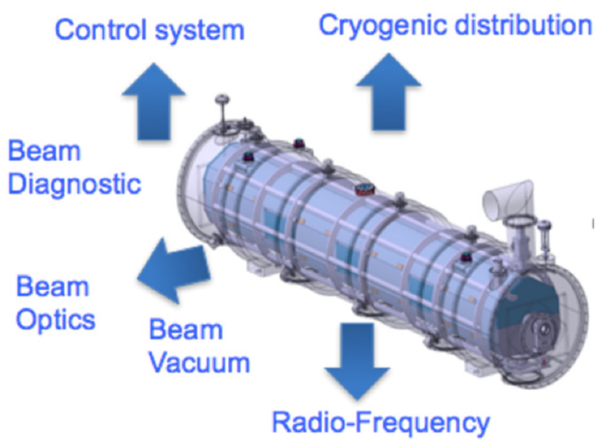
- Accelerator & SRF layout
- Spoke Results
- Elliptical Results
- Integration

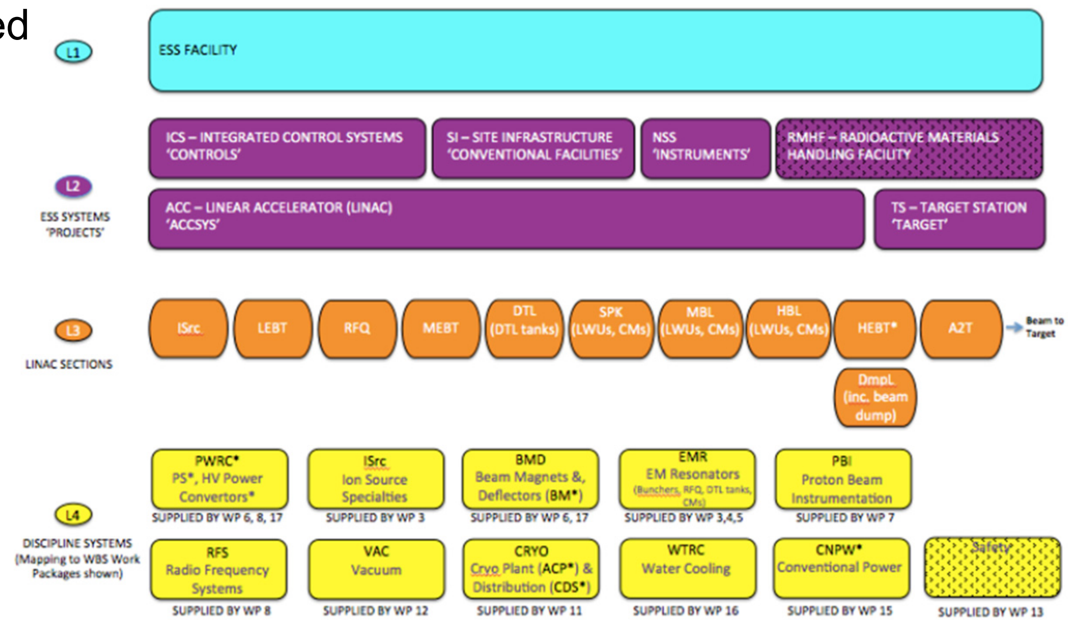


# Integration in Lund Test Stand and in ESS tunnel

EUROPEAN SPALLATION SOURCE

→ Technology Demonstrator lesson-learned




Prototypes and Proof the concept:

- From Design to Performance measure (In-Kind)
- Functional Analysis of each system
- RF (Klystron, Modulator, Interlock, WG, LLRF)
- Cryo, vacuum, electrical, cooling, survey, etc
- Controls and Command, operating modes
- ES&H, QA/QC

**➔ Build a solution and success oriented Collaboration**

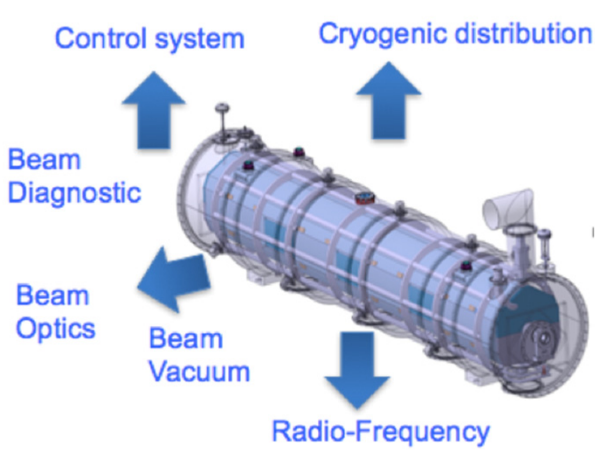
# Integration in Lund Test Stand and in ESS tunnel

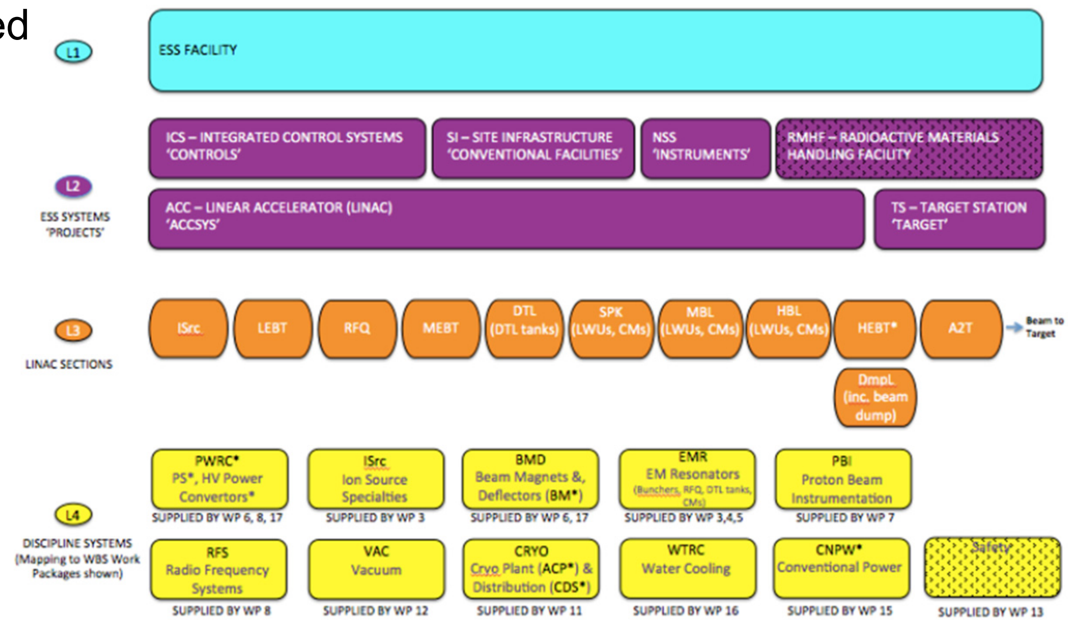
EUROPEAN SPALLATION SOURCE

→ Technology Demonstrator lesson-learned

→ Requirements - physical, functional

→ Interface Reqs - disciplines/WP

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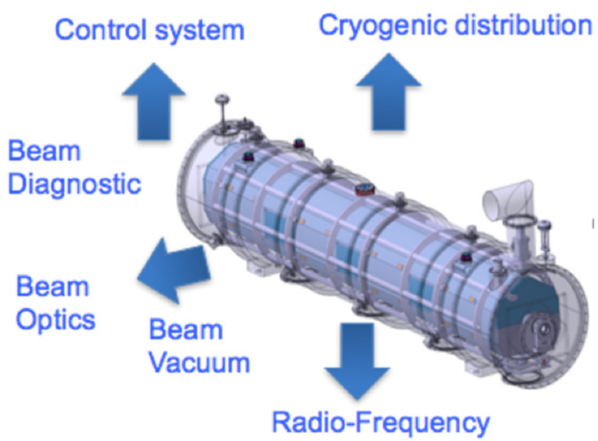


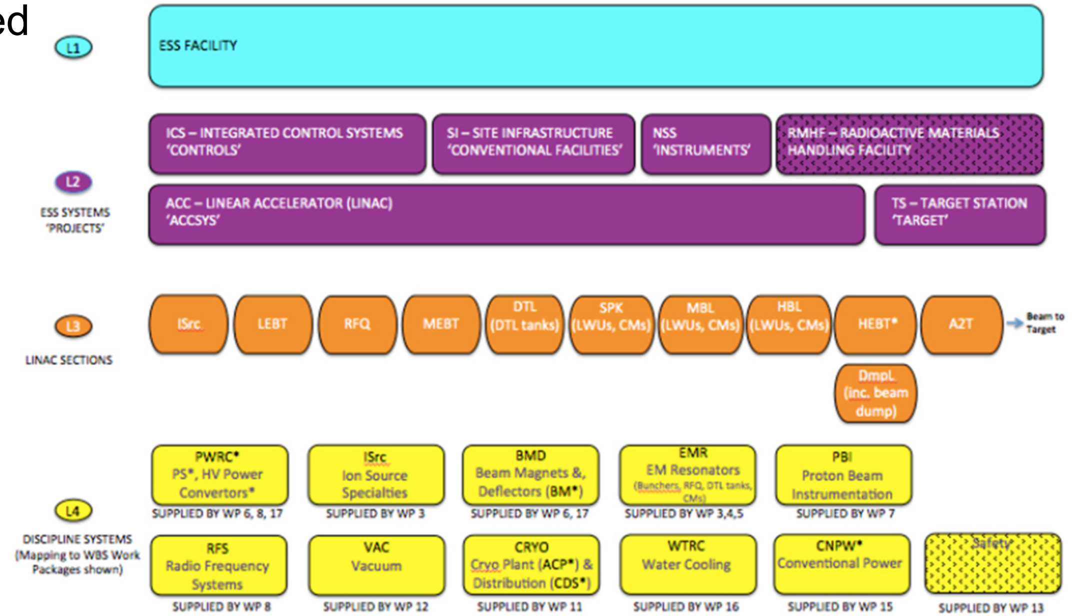


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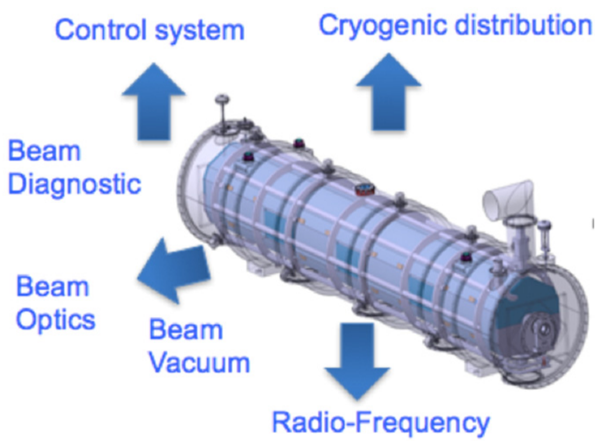


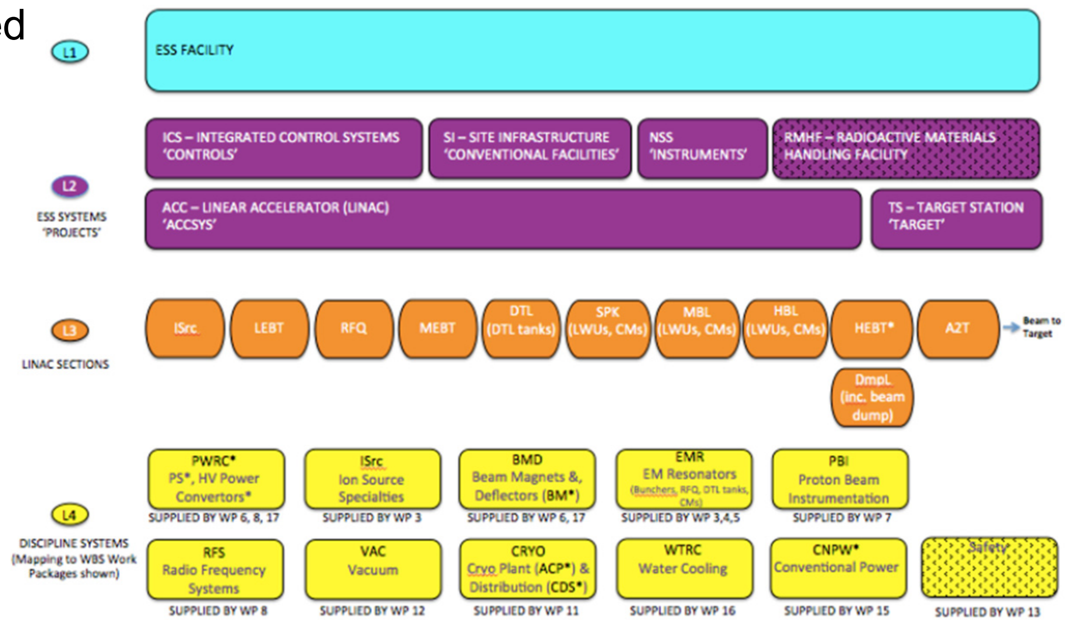


- Validation of all requirements in-situ, SAT, FAT
- Engineering Data management

**➔ Build a solution and success oriented Collaboration**

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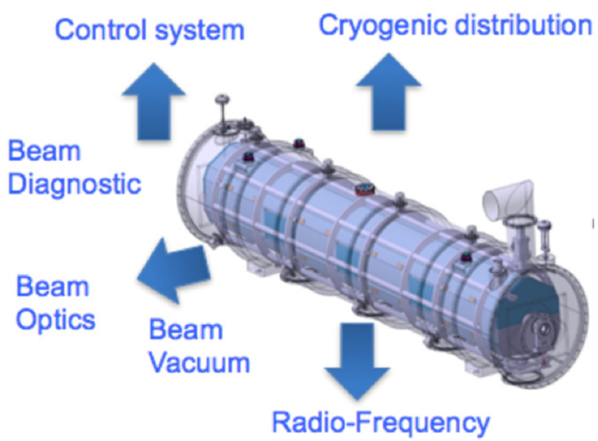


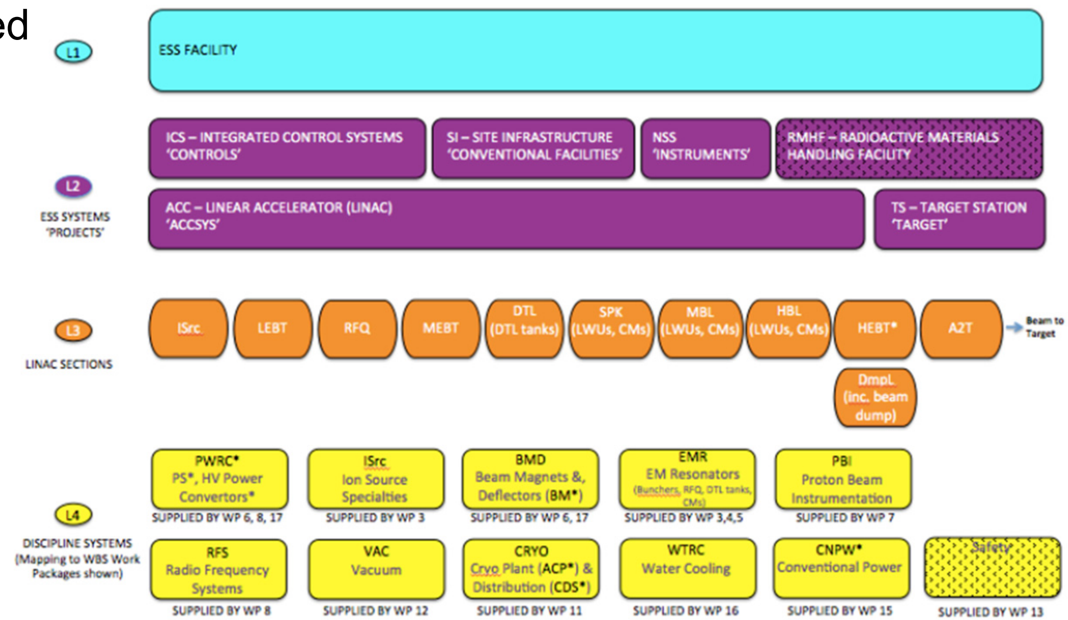


- Validation of all requirements in-situ, SAT, FAT
- Engineering Data management
- Installation in Lund Test Stand of elliptical CM
- Installation in the ESS tunnel

**➔ Build a solution and success oriented Collaboration**

# Integration in Lund Test Stand and in ESS tunnel

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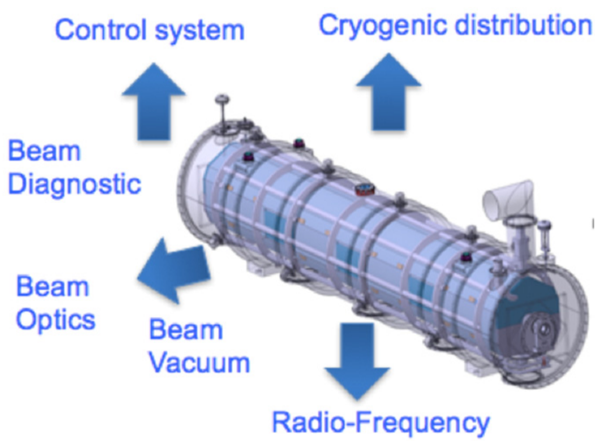


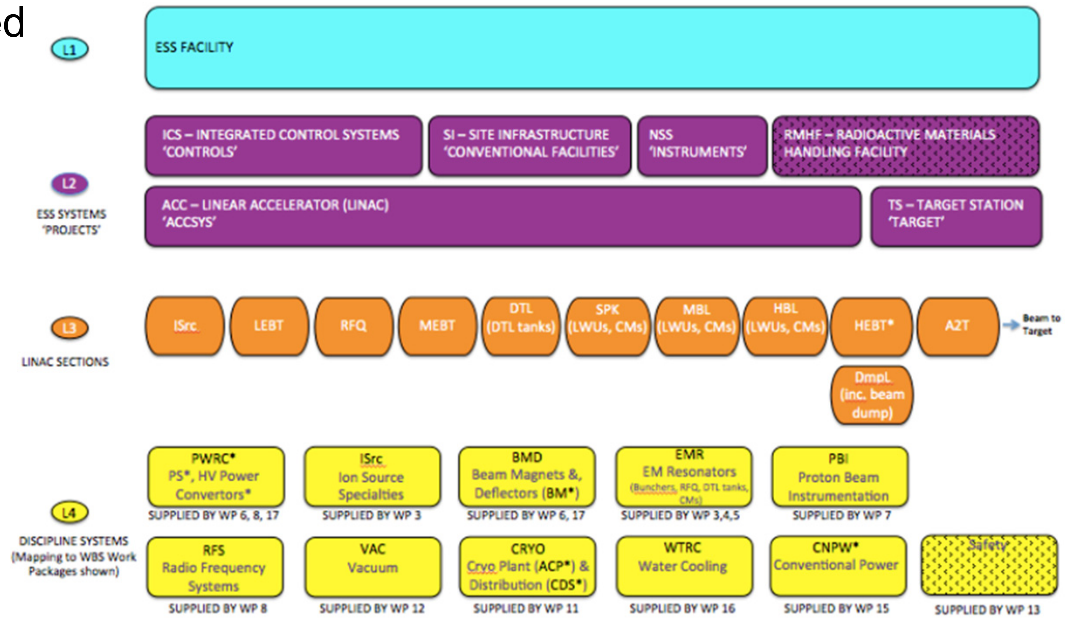


- Validation of all requirements in-situ, SAT, FAT
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- Preparation of commissioning phase

**→ Build a solution and success oriented Collaboration**

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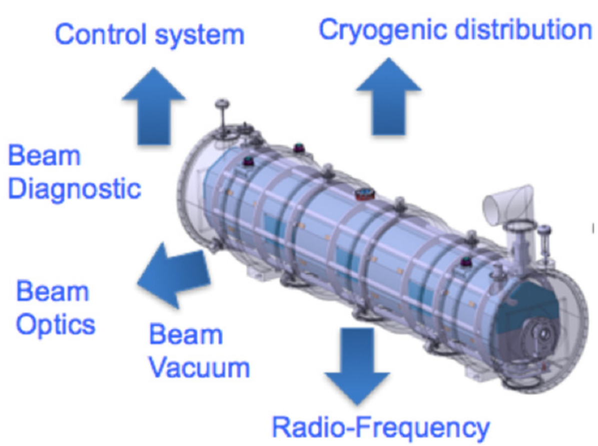


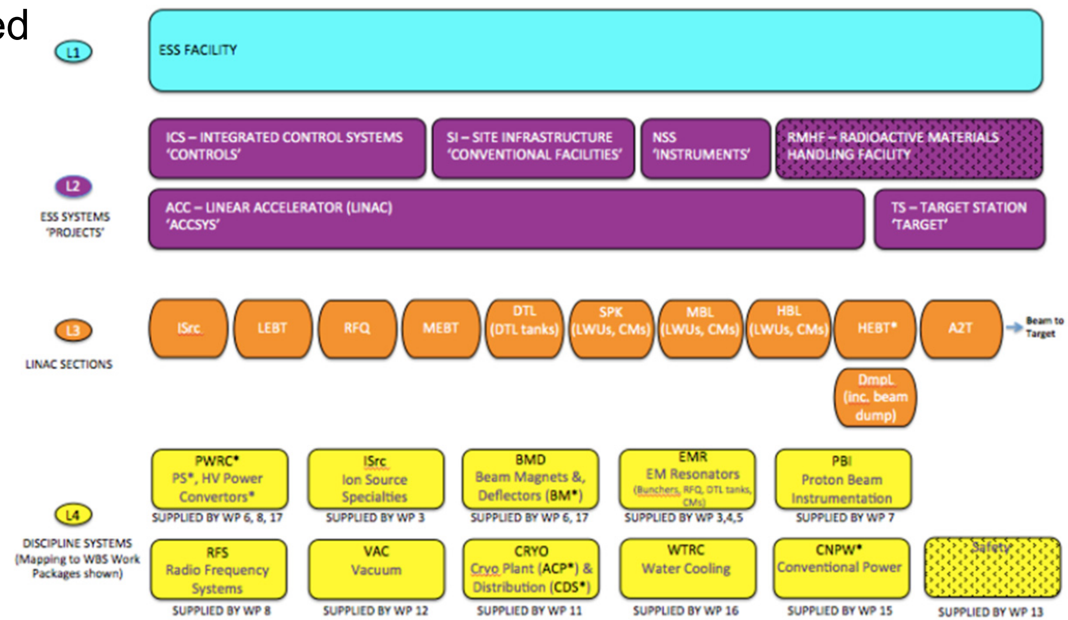


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Main integration challenges:

- Systems owned by several In-Kind partners, geographically remote
- Large number of interfaces
- Coordination with multi-disciplines
- Schedule

**→ Build a solution and success oriented Collaboration**

# Coordination Team !

[Web Platform: Cryomodules Collaboration space](https://confluence.esss.lu.se/display/CRYOM)
to gather documents for the SRF Collaboration
➔ [https://confluence.esss.lu.se/display/CRYOM](https://confluence.esss.lu.se/display/CRYOM)

- Weekly video-conferences:
  - Interface Uppsala – Mondays
  - Interface Saclay – Tuesdays
  - Interface IPNO – Wednesdays (bi)
  - Interface SRF Collaboration – Fridays
  - Overall Schedules – Fridays (bi)
- Every 3 months: SRF Collaboration Meetings elliptical (@CEA, LASA, STFC)
- ESS Review Process

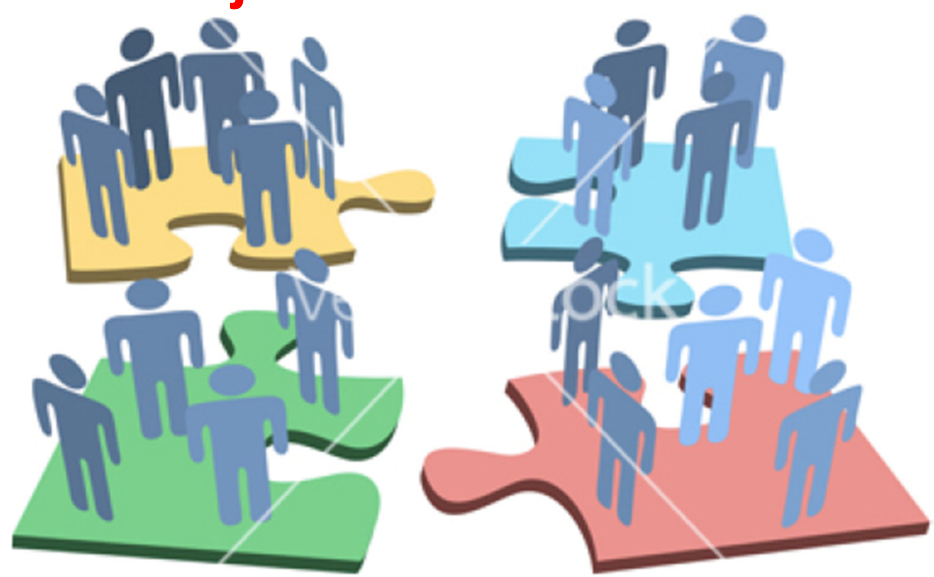
@ ESS: Christine Darve, Nuno Elias, Fredrick Hankansson, Cecilia Maiano, Felix Schlander
➔ to coordinate daily activities with all In-Kind partners and ESS other Work Packages

# Concluding comments

- First results for the SRF components are promising. Many lessons-learned !
- The Devil is in the details and in the Interfaces !
- Challenging but exciting collaboration based on a new project,

  new ESS institute and new concept of In-Kind (WPs).

**Acknowledgment to the ESS SRF teams and thanks for the excellent progress in this Collaborative Project !**




Thank you for your attention!

EUROPEAN SPALLATION SOURCE

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cea

cnrs IN2P3 Les deux infinis

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

FREIA UPPSALA UNIVERSITET

LUND UNIVERSITY

INFN Istituto Nazionale di Fisica Nucleare

Science & Technology Facilities Council