Recent progress of ESS Spoke and Elliptical cryomodules

Guillaume Olry

on behalf of the ESS, CNRS/IN2P3/IPN Orsay and CEA/IRFU Saclay teams

Outlook

1. Introduction
   - Presentation of ESS
   - Linear accelerator specs & layout

2. Status of Spoke and Elliptical prototype cryomodules activities
   - Cryomodule
   - Cavities
   - Cold Tuning Systems
   - RF couplers
   - Future work

ESS

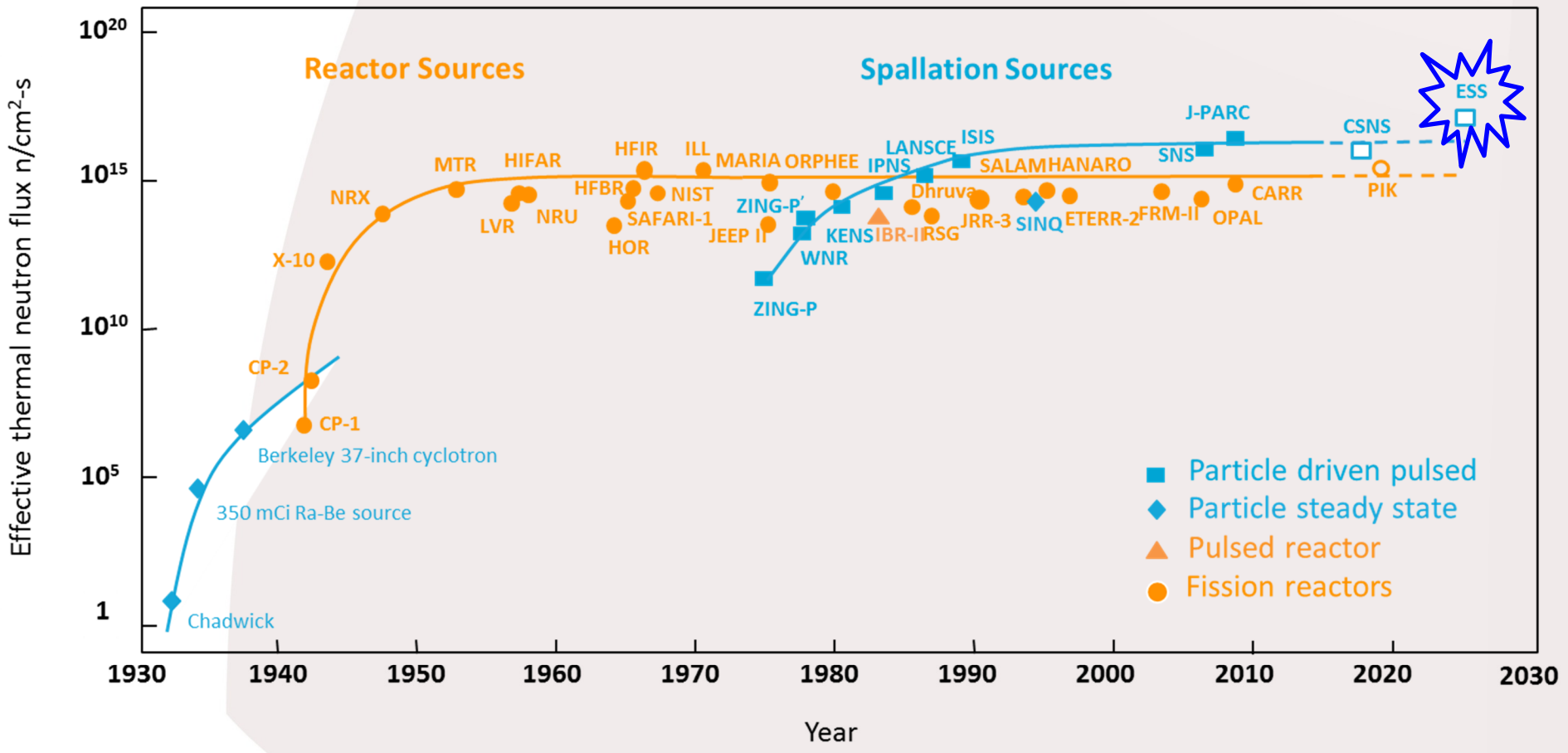
THPF080 Proceedings of IPAC2015, Richmond, VA, USA

STATUS OF THE ESS ACCELERATOR CONSTRUCTION PROJECT

H. Danared, R. Garoby, D. McGinnis and E. Tanke, ESS AB, Lund, Sweden
M. Lindroos, ESS AB, Lund, Sweden and Lund University, Lund, Sweden

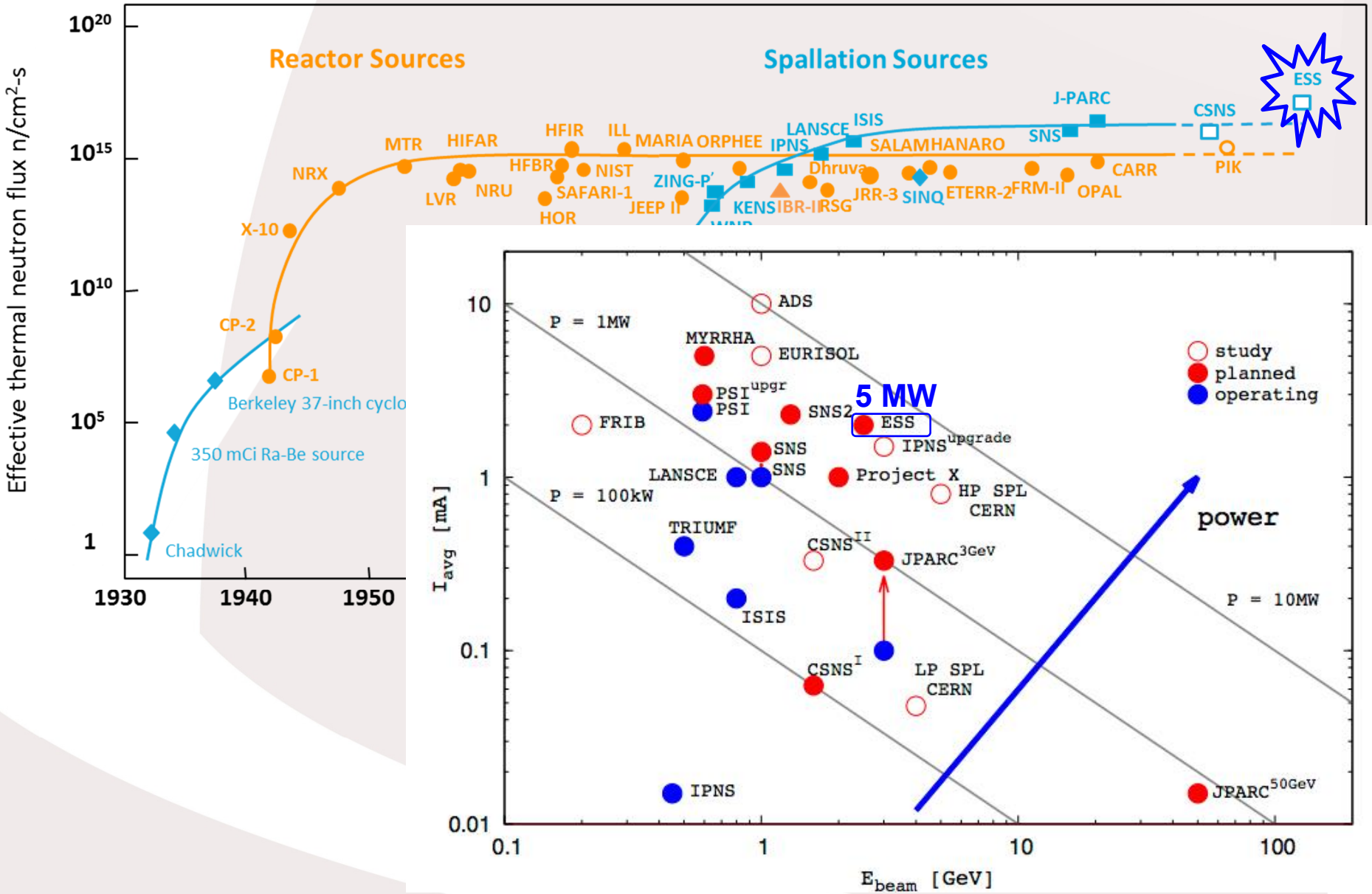
https://europeanspallationsource.se/european-spallation-source

World's leading facility for research using neutrons

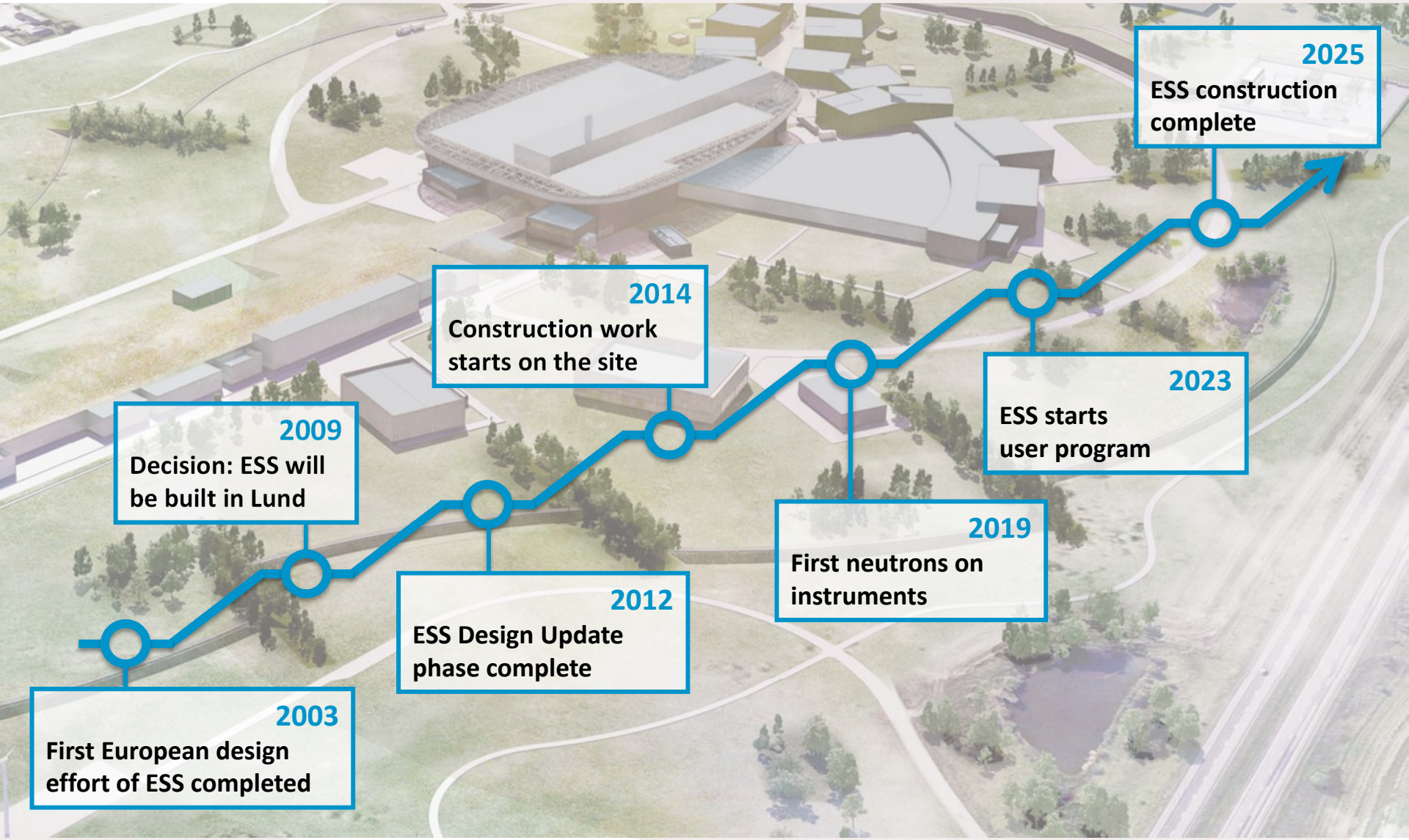


(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

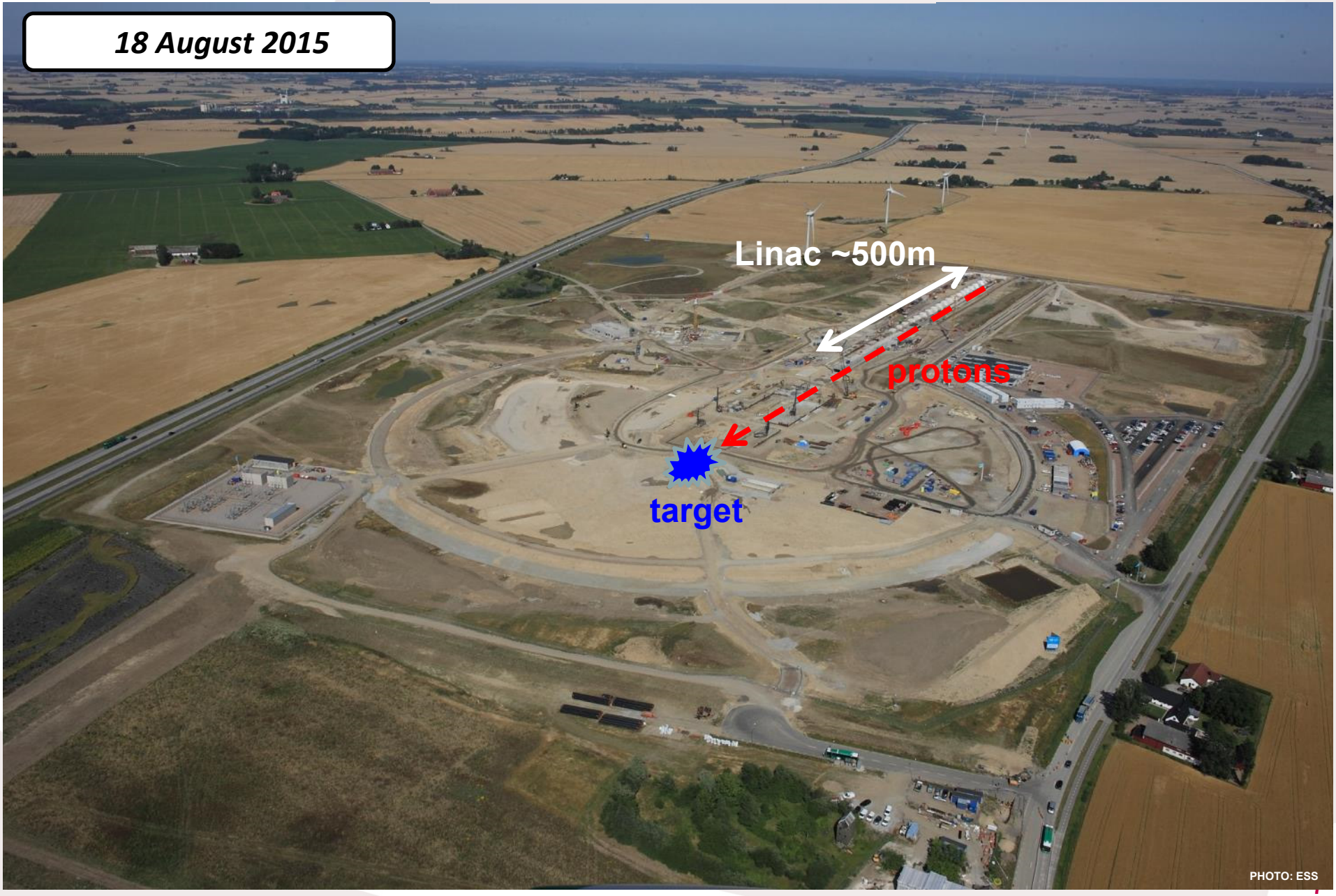
World's leading facility for research using neutrons



Roadmap


2003
First European design effort of ESS completed
2009
Decision: ESS will be built in Lund
2012
ESS Design Update phase complete
2014
Construction work starts on the site
2019
First neutrons on instruments
2023
ESS starts user program
2025
ESS construction complete

Civil construction



19 countries committed to build ESS

Construction cost: 1843 M€$_{2013}$
Operation cost: 140 M€$_{2013}$
Decommissioning cost: 177 M€$_{2013}$

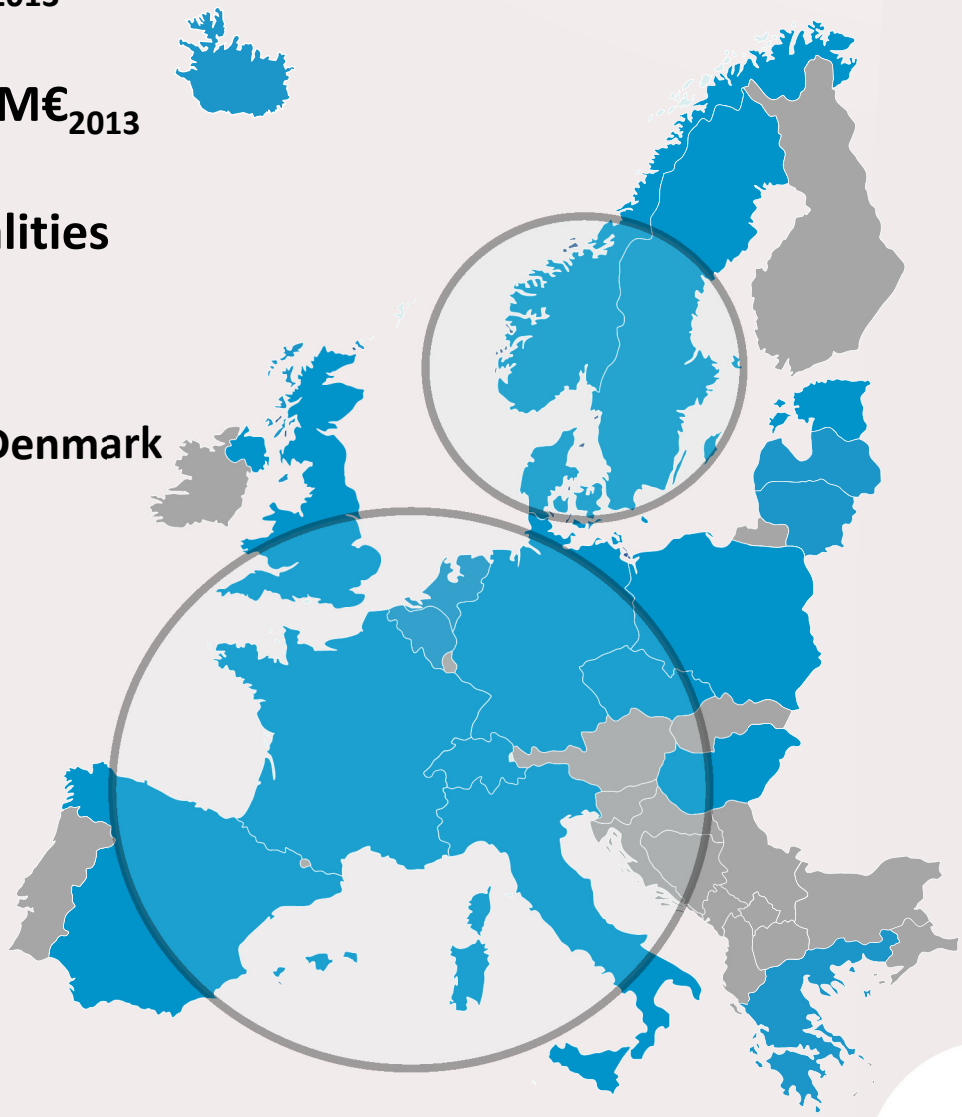
~350 employees, 40 nationalities

Host Countries of Sweden and Denmark

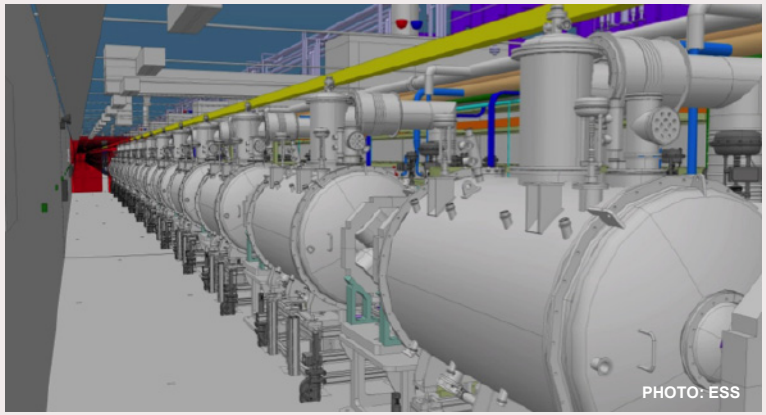
47,5% Construction
15% Operations
In-kind Deliverables ~ 3%
Cash Investment ~ 97%

Non Host Member Countries

52,5% Construction
85% Operations
In-kind Deliverables ~ 70%
Cash Investment ~ 30%



ESS Linac



Proceedings of SRF2013, Paris, France MOP004

THE ESS SUPERCONDUCTING LINEAR ACCELERATOR

C. Darve, M. Eshraqi, M. Lindroos, D. McGinnis, S. Molloy, ESS, Lund, Sweden
P. Bosland, CEA/IRFU, Saclay, France
S. Bousson, CNRS/IPN Orsay, France

Proceedings of IPAC2014, Dresden, Germany MOYBA02

NEW DESIGN APPROACHES FOR HIGH INTENSITY SUPERCONDUCTING LINACS - THE NEW ESS LINAC DESIGN

D. McGinnis, ESS, Lund, Sweden

https://europeanspallationsource.se/accelerator

Linac contributors

26 partners in 12 countries
~50% of the accelerator cost

In-kind (main contributions)

Univ Agder (Ion source expert)
ATOMKI (RF-LPS)
CEA (RFQ, SRF, Diagn)
CNRS (SRF, Cryo)
Cockcroft Inst (Diagn)
Daresbury Lab (SRF, Vacuum)
Elettra (RF, Magn, PS, Diagn)
ESS-Bilbao (MEBT, RF)
GSI (Diagn, Vacuum, Cryo)
Huddersfield Univ (RF distrib)
IFJ PAN (Installations)
INFN Catania (Source, LEBT)
INFN Legnaro (DTL)
INFN Milan (SRF)
NCBJ (LLRF)
RAL (Diagn)
RHUL (Diagn)
Tallinn UT (RF)
TU Lodz (LLRF)
Univ Oslo (Diagn)
Warsaw UT (LLRF)
Wroclaw UT (Cryo)

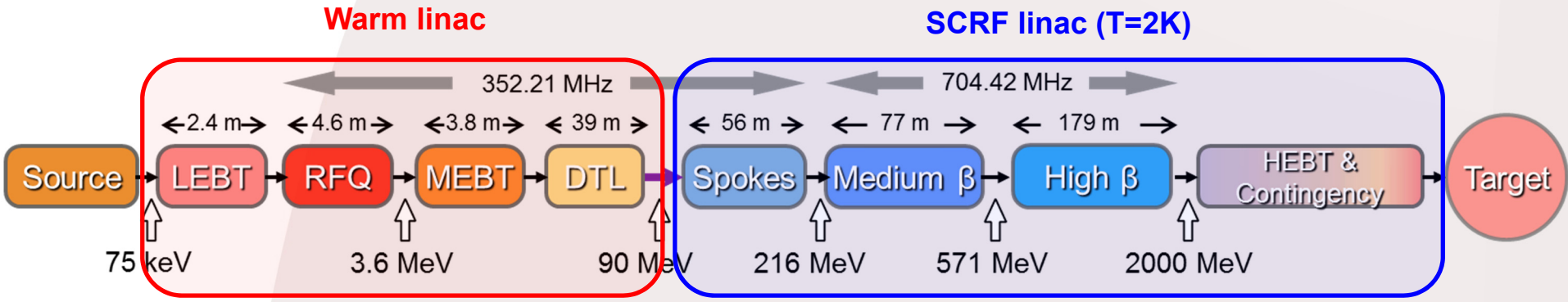
Paid contracts

Aarhus Univ (Beam del)
DESY (Diagn)
Lund Univ (LLRF, RF)
PSI (Diagn)
Uppsala Univ (Tests)

Linac specifications

Top-level requirements	
Pulse length (ms)	2.86
Energy (GeV)	2
Peak current (mA)	62.5
Pulse repetition frequency (Hz)	14
Average power (MW)	5
Peak power (MW)	125

Linac specifications



95% of the energy gain with 146 SCRF cavities

2 types of cavities & 3 beta families

Beta 0.50 Spoke Cryomodules	
Cryomodule #	13
Double-Spoke cavity #	26
Eacc [MV/m]	9

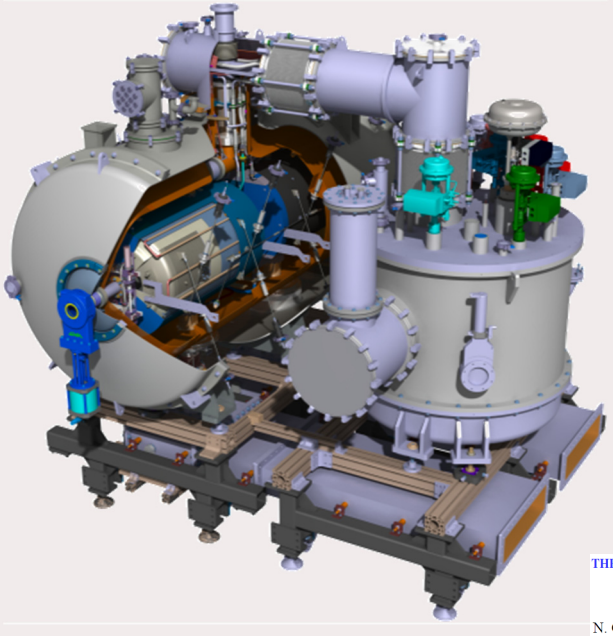
Medium Beta 0.67 Elliptical Cryomodules	
Cryomodule #	9
6-cell cavity #	36
Eacc [MV/m]	16.7

High Beta 0.86 Elliptical Cryomodules	
Cryomodule #	21
5-cell cavity #	84
Eacc [MV/m]	19.9

Prototypes & Series: IPN Orsay

Prototypes: CEA/Saclay + IPN Orsay (CM design)
Series: CEA/Saclay + INFN for medium β cav
CEA/Saclay + STFC for high β cav

Spoke Cryomodule prototype



Proceedings of SRF2013, Paris, France MOP089

DESIGN OF THE ESS SPOKE CRYOMODULE

Denis Reynet, Sylvain Brault, Patxi Duthil, Patricia Duchesne, Guillaume Olry, Nicolas Gandolfo, Emmanuel Rampnoux, Sébastien Bousson, IPNO, UMR 8608 CNRS/IN2P3 - Université de Paris Sud 15, rue G. Clémenceau, BP1, 91406 ORSAY cedex - FRANCE

THPP077 Proceedings of LINAC2014, Geneva, Switzerland

FAST TUNER PERFORMANCE FOR A DOUBLE SPOKE CAVITY

N. Gandolfo, S. Bousson, S. Brault, P. Duchesne, P. Duthil, G. Olry, D. Reynet, IPN, Orsay, France
C. Darve, M. Lindroos, ESS, Lund, Sweden

FRIOC01 Proceedings of SRF2013, Paris, France

DESIGN OF THE 352 MHz, BETA 0.50, DOUBLE-SPOKE CAVITY FOR ESS

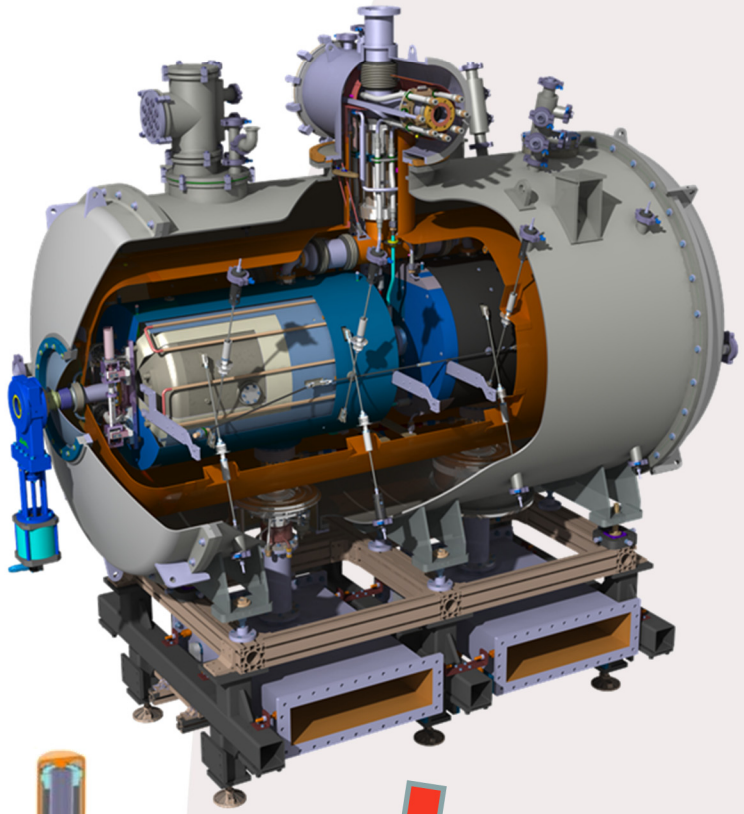
P. Duchesne, S. Bousson, S. Brault, P. Duthil, G. Olry, D. Reynet, IPN Orsay, CNRS/IN2P3, France
S. Molloy, ESS, Lund, Sweden

Proceedings of SRF2013, Paris, France THP065

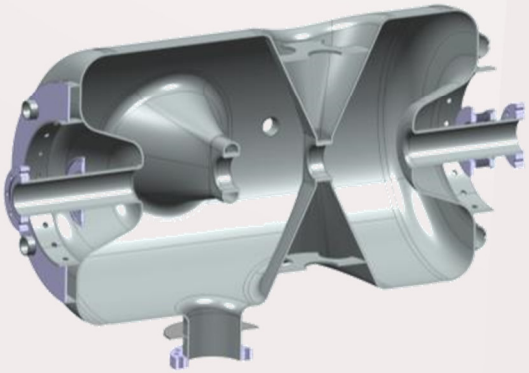
DESIGN OF 352.21 MHz RF POWER INPUT COUPLER AND WINDOW FOR THE EUROPEAN SPALLATION SOURCE PROJECT (ESS)

E. Rampnoux#, S. Bousson, S. Brault, P. Duchesne, P. Duthil, G. Olry, D. Reynet, CNRS/IN2P3, IPN Orsay, France

Spoke Cryomodule components

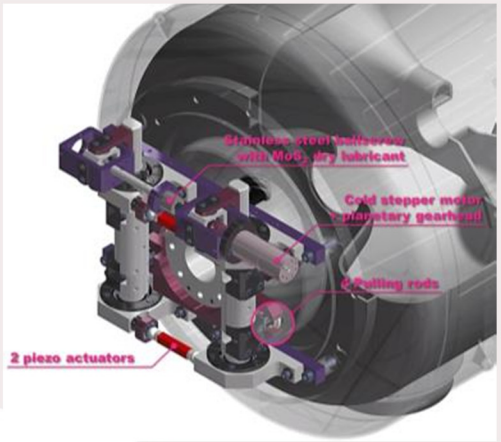


Double Spoke SRF Cavities

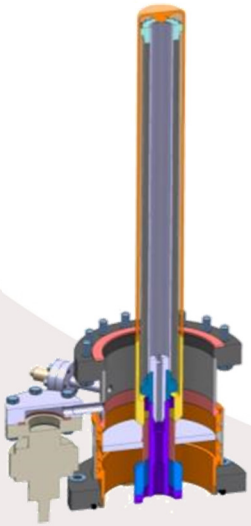


- Double spoke cavity (3-gaps), 352.2 MHz, β=0.50
- Goal: Eacc = 9 MV/m *[Bp= 62 mT ; Ep = 39 MV/m]*
- 4.2 mm (nominal) Niobium thickness
- Titanium Helium tank and stiffeners
- Lorentz detuning coeff. : ~-5.5 Hz/(MV/m)^2
- Tuning sentivity $\Delta f/\Delta z$ = 130 kHz/mm

Cold Tuning System



- Slow tuning (stepper motor):
  - Max stroke: ~ 1.3 mm
  - Tuning range: ~ 170 kHz
  - Tuning resolution: 1.1 Hz
- Fast tuning (piezo-actuator):
  - Applied voltage up to +/- 120V
  - Tuning range at 2K: 675 Hz (min)



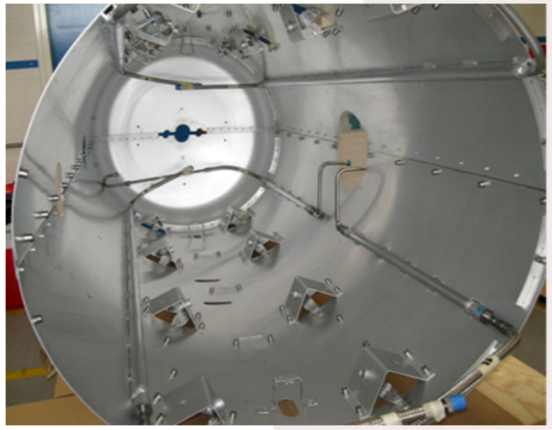
Power Coupler

- Ceramic disk, 100 mm diameter
- 400 kW peak power (335 kW nominal)
- Antenna & window water cooling
- Outer conductor cooled with SHe
- Doorknob transition from coaxial to ½ height WR2300 waveguide

Spoke Cryomodule fabrication [1]

Most of the parts are fabricated and delivered

Thermal shield



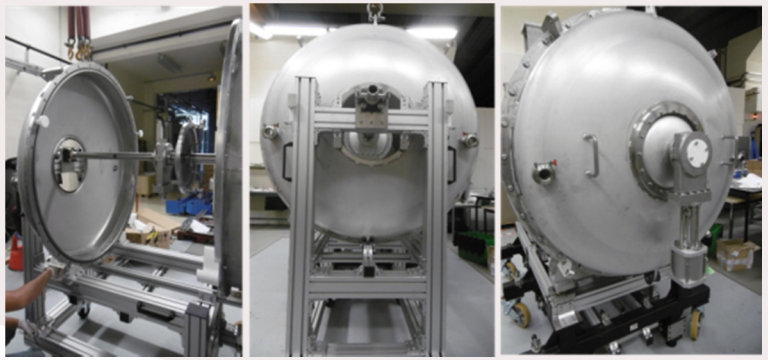
Vacuum vessel & Mechanical support

Gate valves

Cold/warm transition

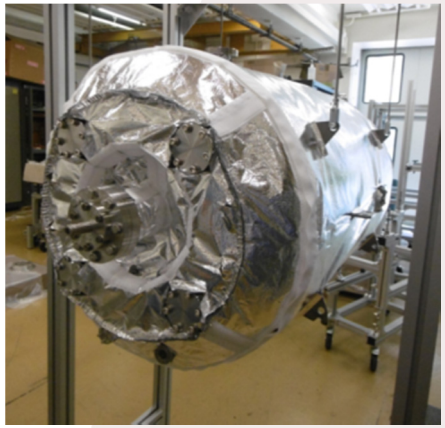
Inter-cavity belows

First blank assembly of some parts

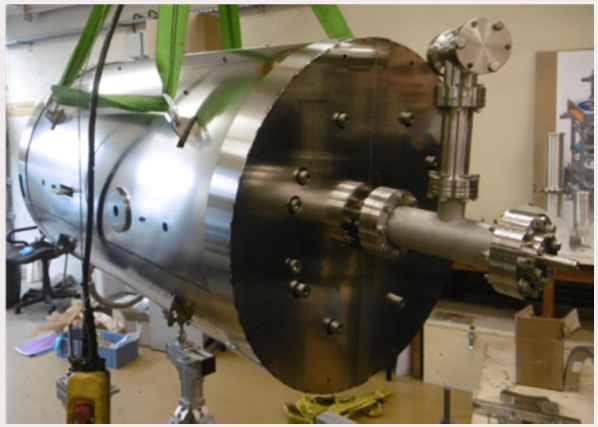


Spoke Cryomodule fabrication [2]

MLI for the cavity



Magnetic shield
(2-layer Cryophy, actively cooled)



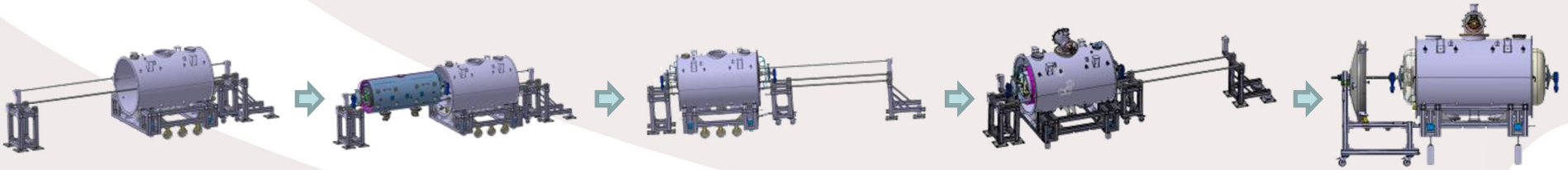
Fabrications in progress

- Cryogenic circuits
- MLI for the thermal shield
- Valve box

Poster THPB109
"ESS Spoke cryomodule and test valve box"

Studies in progress

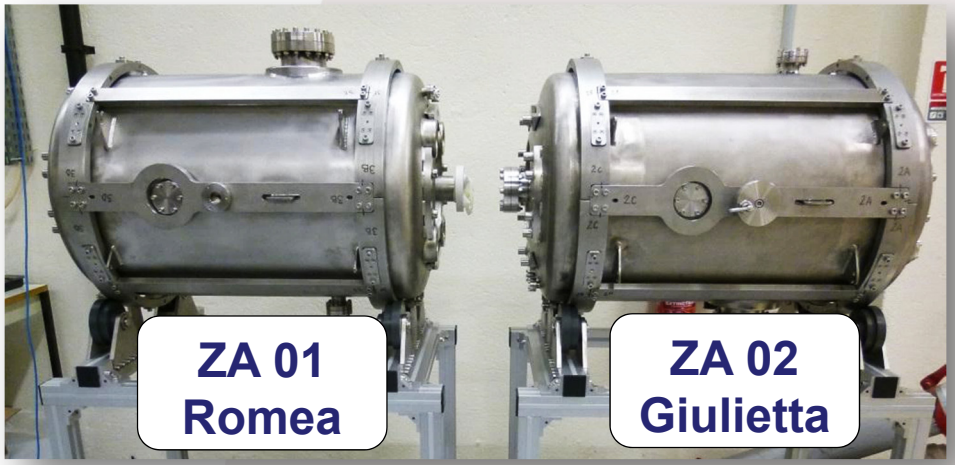
- Tooling and assembly procedures

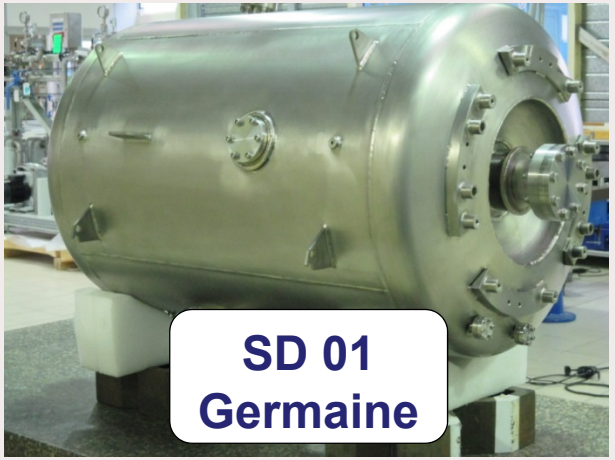


Double-Spoke cavities

3 prototypes fabricated

2 by ZANON (It) & 1 by SDMS (Fr), delivered in Oct/Nov 2014





Double-Spoke cavities

3 prototypes fabricated

2 by ZANON (It) & 1 by SDMS (Fr), delivered in Oct/Nov 2014


Phase 1&2: Horizontal position


Phase 3: Vertical position

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

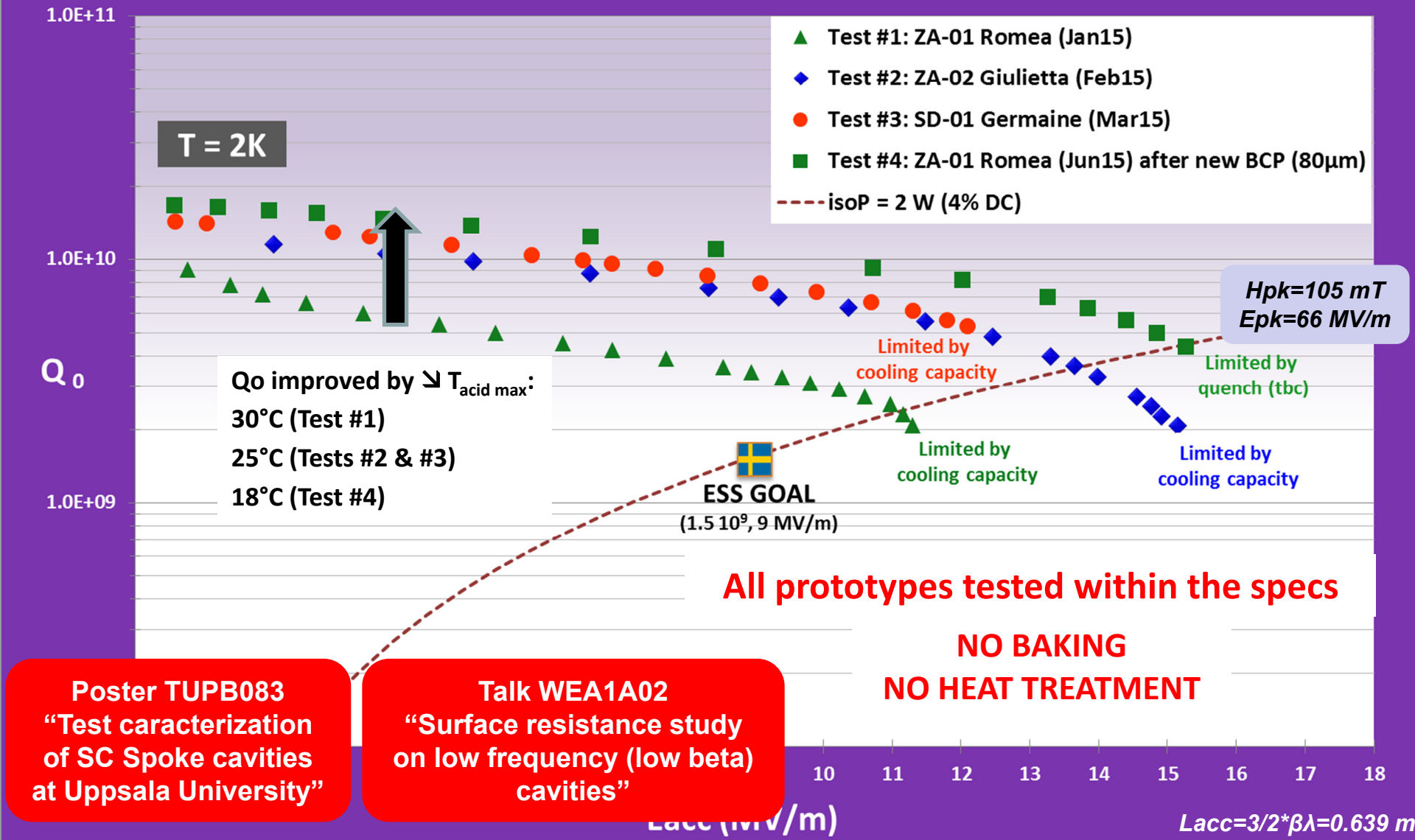
Why H & V positions?

  - Better homogeneity
  - Frequency shift compensation: $\Delta f_{200\mu m} < -20$ kHz

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

Vertical Test results

ESS Double-Spoke prototype cavities
ZA-01 Romea, ZA-02 Giulietta & SD-01 Germaine

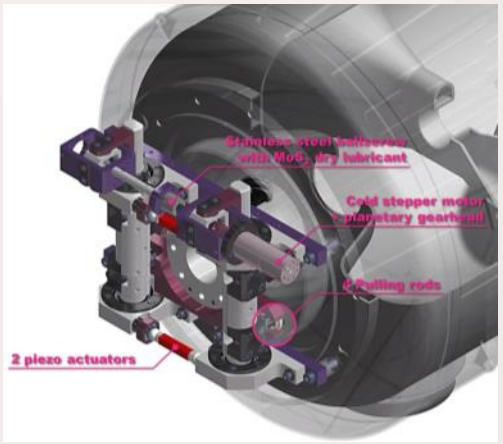


Poster TUPB083
"Test caracterization of SC Spoke cavities at Uppsala University"

Talk WEA1A02
"Surface resistance study on low frequency (low beta) cavities"

Cold Tuning System

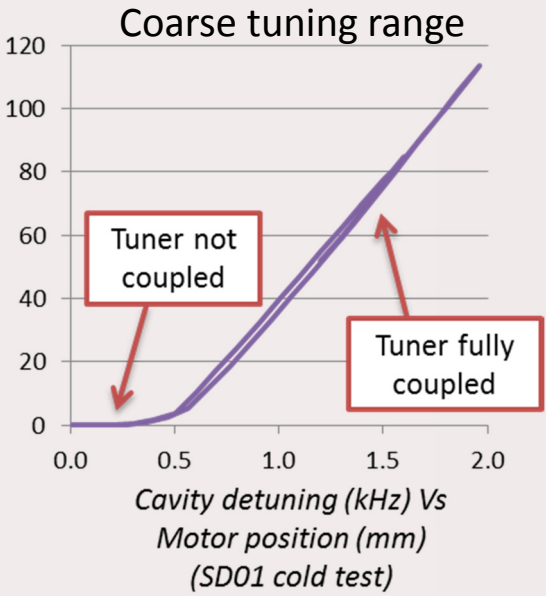
Double lever arm tuner.
Actuators : One stepper motor and two piezos per tuner (one for redundancy).



4 prototypes tuners fabricated by ESIM (Fr) and tested :

- With 50 mm piezos length → All specifications reached
- With 90 mm piezos length → Bad performances. Analysis in progress: pre-load? high stress (differential thermal shrink)?...

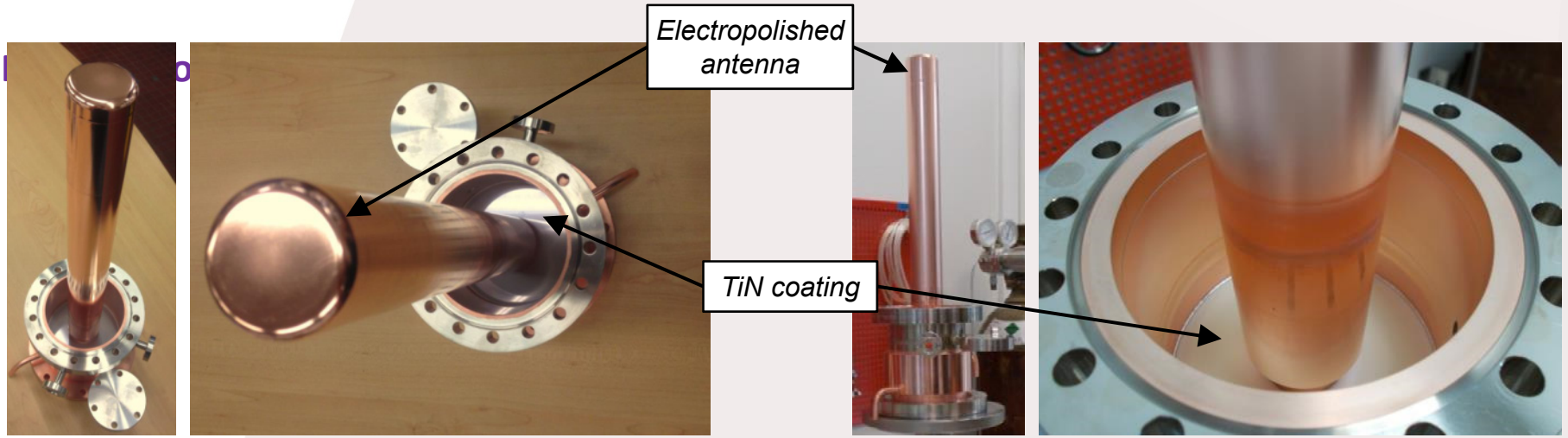
Cavity ID		ZA01 Romea	ZA02 Giulietta	SD01 Germaine	ZA01 Romea
VT date		janv-15	feb-15	apr-15	juin-15
Piezo #1		Noliac 50 mm	Noliac 50 mm	PI 36 mm	PiezoMec. 90 mm
Piezo #2		Noliac 50 mm	Noliac 50 mm	Noliac 50 mm	PI 90 mm
Tuner sensitivity @2K	kHz/mm	78	88	68	-
Tuner sensitivity @4K	kHz/mm	79	92	73	82
Tuner sensitivity @300K	kHz/mm	-	-	67	-
Cavity sensitivity @300K	kHz/mm	-	-	144	-
Detuning range Piezo #1 @2K	Hz	930	953	542	306 (+/- 120V)
Detuning range Piezo #2 @2K	Hz	680	717	791	0 (issue)
Frequency @4K (w/o tuner)	MHz	352.453	352.123	352.038	352.409
Frequency @2K (w/ tuner)	MHz	352.429	352.100	352.032	352.419
Pressure sensitivity (w/o tuner)	Hz/mbar	25.5	23.3	5.5	-
Pressure sensitivity (w/ tuner)	Hz/mbar	28.8	28.8	14.5	-
Static Lorentz coefficient	Hz/(MV/m²)	-8.5	-6.8	-8.1	-



Talk of R. Paparella on Friday
"Overview of recent tuner development on elliptical and low-beta cavities"

RF couplers

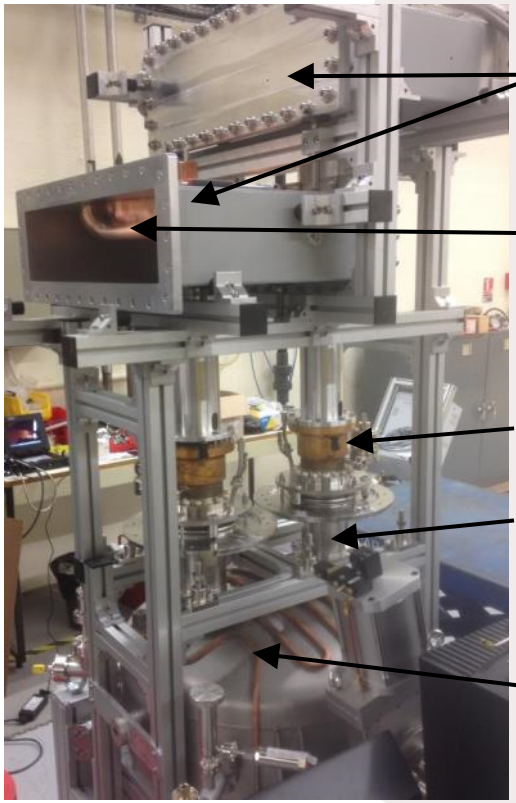
RF Power Couplers: 4 prototypes built by two french companies (SCT & PMB) and delivered

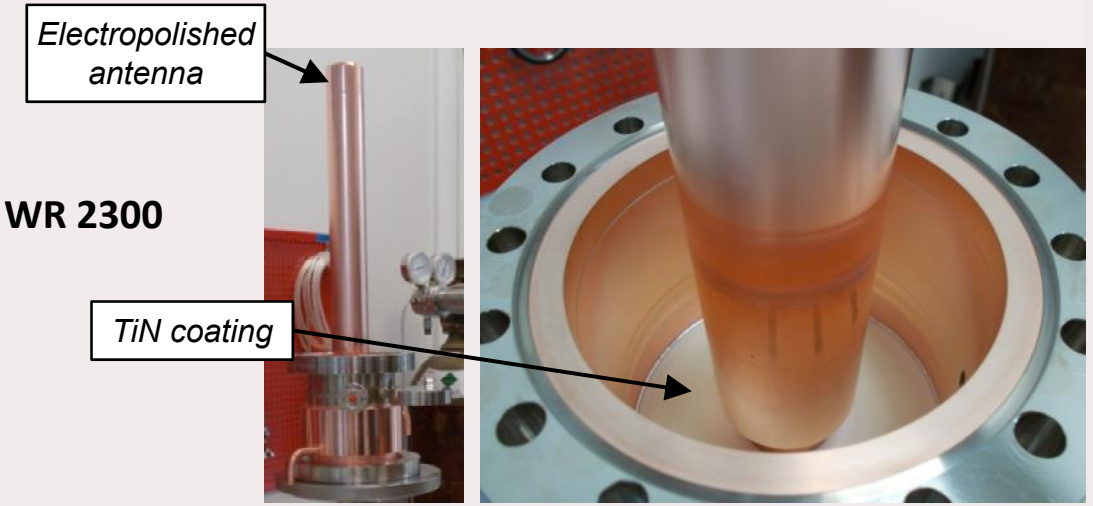


RF couplers

RF Power Couplers: 4 prototypes built by two french companies (SCT & PMB) and delivered

RF conditioning test bench:





Baking stand

- Ramp-up to 155°C in 24 h
- 155°C is kept for 24h
- 10^{-9} mbar pressure level is reached

- Tuning of the coupling cavity
- Assembly in ISO4 clean room
- Baking (24h@155°C)

Future work

Prototype Cavities

- Baking (@120°C) & heat treatment (@600 °C, H degassing) studies
- Test of a cavity equipped with its power coupler at Uppsala University in the horizontal cryostat (HNOOS)

Furnace delivered on 09/11

RF coupler

- RF conditioning (@CEA/Saclay): pulsed mode, TW
  - Pair of couplers #1: up to 400 kW
  - Pair of couplers #2: up to 400 kW then, up to 1MW

Poster TUPB026 "Cryogenic performance of the HNOOS test facility at Uppsala University"

Tuner

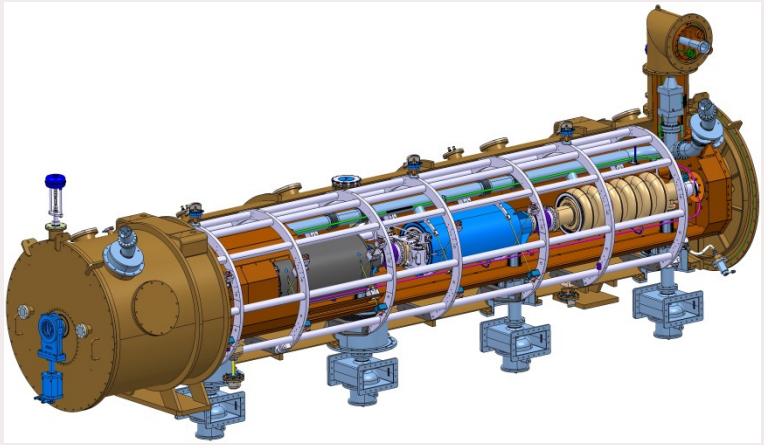
- New tests of the 90mm long piezos
- Long life testing campaign @ cold temperature

Prototype cryomodule

- First cool-down @ IPN Orsay (only at 2K, no RF power) before transportation to Uppsala University for high-power tests

Series production: Niobium and cavities call for tenders (end of 2015).

Elliptical Cryomodule prototype



Proceedings of IPAC2014, Dresden, Germany WEPRI002

STATUS AND FIRST TEST RESULTS OF TWO HIGH BETA PROTOTYPE ELLIPTICAL CAVITIES FOR ESS

F. Peauger, P. Bosland, P. Carbonnier, G. Devanz, F. Eozenou, X. Hanus, P. Hardy, V. Hennion, L. Maurice, J. Plouin, D. Roudier, C. Servouin, CEA Saclay, Gif-sur-Yvette, France
G. Olivier, IPN, Orsay, France
C. Darve, S. Molloy, ESS, Lund, Sweden

Proceedings of SRF2013, Paris, France MOP084

ESS CRYOMODULE FOR ELLIPTICAL CAVITIES

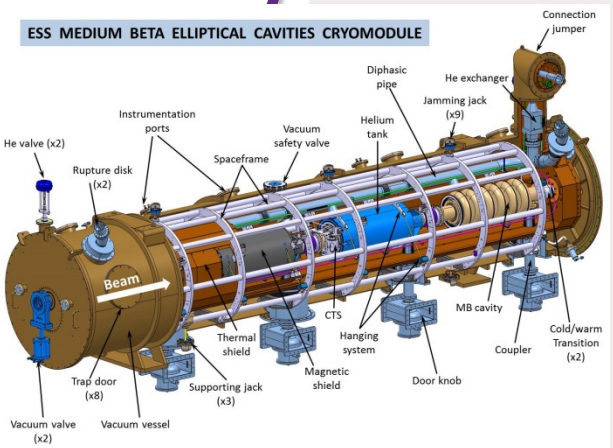
G. Olivier, JP. Thermeau, IPN, Orsay, France
P. Bosland, CEA, Saclay, France
C. Darve, ESS, Lund, Sweden

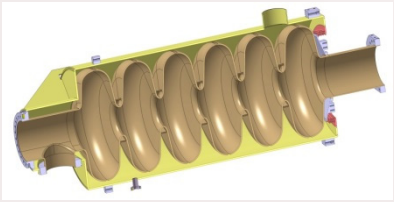
FRIOC02 Proceedings of SRF2013, Paris, France

ESS ELLIPTICAL CAVITIES AND CRYOMODULES

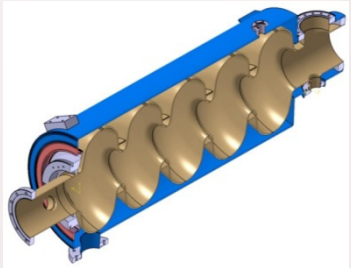
G. Devanz, N. Bazin, M. Desmons, P. Bosland, P. Hardy, F. Leseigneur, M. Luong, F. Peauger, J. Plouin, D. Roudier, Irfu, CEA-Saclay, Gif-sur-Yvette, France
G. Olivier, IPN Orsay, France.
G. Costanza, Electrical and Information Technology, Lund University, Lund, Sweden

Cryomodule & main components





6-cells medium beta (0,67) cavity



5 cells high beta (0,86) cavity

- Similar to CEBAF/SNS cryomodule concept with 4 cavities per cryomodule
- Common cryomodule design for medium and high beta cavities

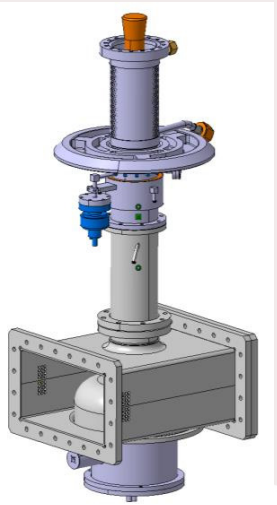
Cavities without HOM coupler

	Medium	High
Geometrical beta	0.67	0.86
Frequency (MHz)	704.42	
Maximum surface field in operation (MV/m)	40	44
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

Power Coupler

(HIPPI type coupler)

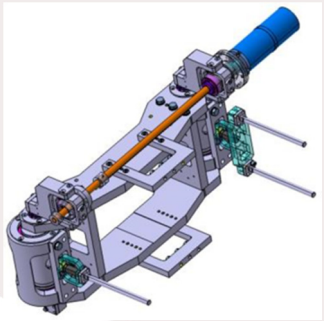
- Diameter 100 mm
- 1.1 MW peak power
- Antenna & window water cooling
- Outer conductor cooled with SHe
- Doorknob transition equipped with a bias system



Poster THPB078
& Talk of W. Kaabi on Thursday

Cold Tuning System

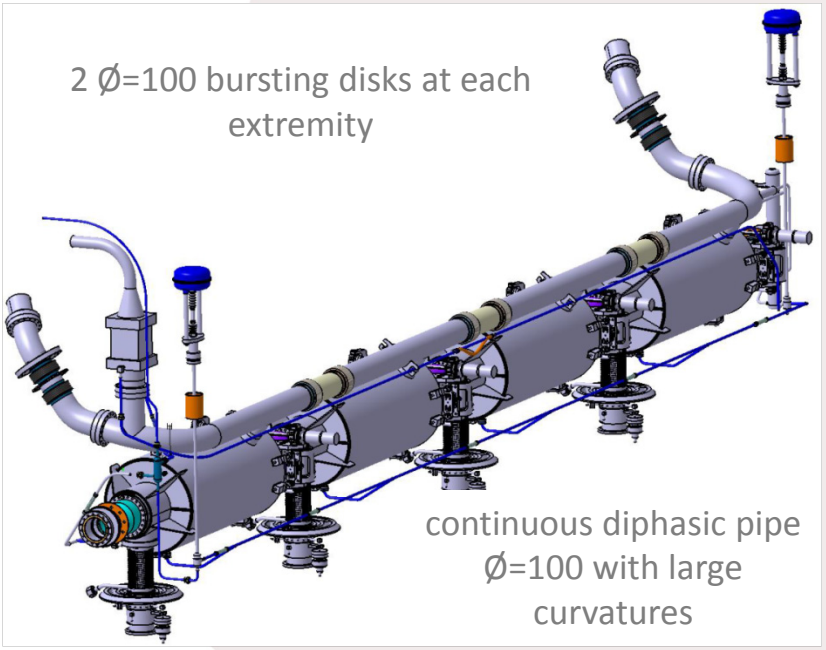
(Saclay V5 type modified for ESS cavities)



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

Compliance with European Pressure Equipment Directive (PED) 97/23/EC

Cryo pipes designed to reduce the overpressure in case of beam vacuum failure



TUV Nord analysis report:
The Elliptical and Spoke cryomodules are classified according to PED article 3.3

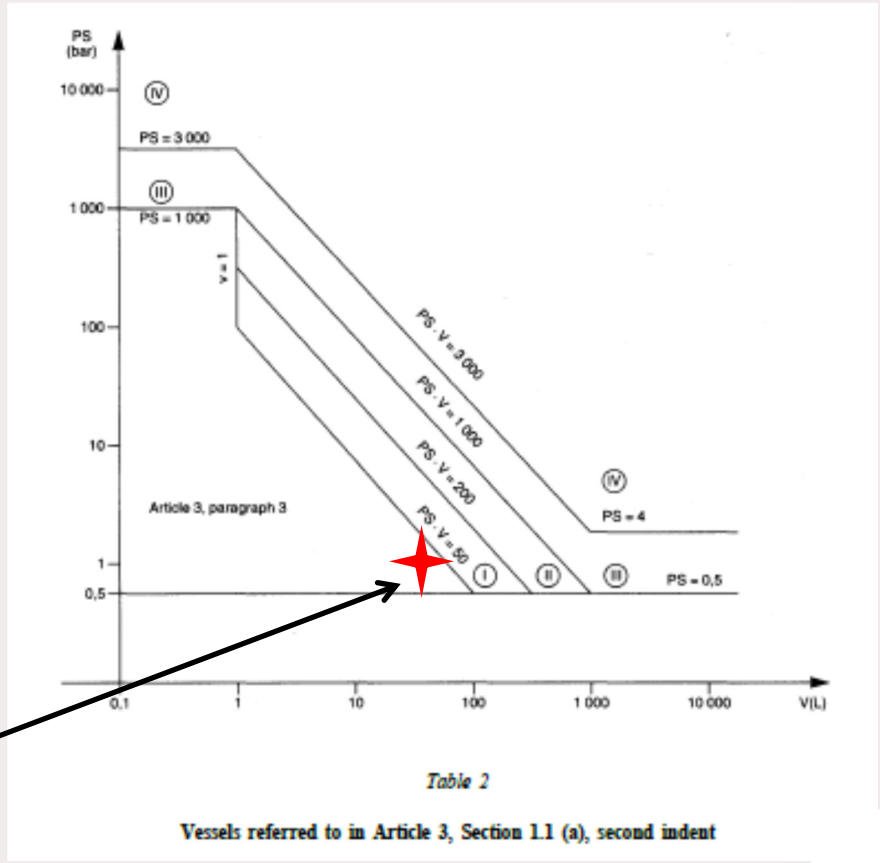


Table 2

Vessels referred to in Article 3, Section 1.1 (a), second indent

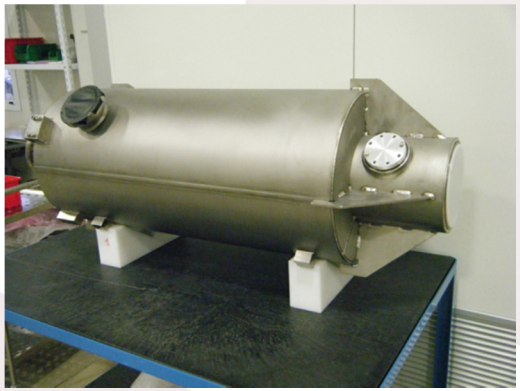
- **Volumes of the helium circuits and vessels < 48 l**
- **30 mbar < Working pressure < 1.431 bara**
- **PS = 1.04 barg**

Vertical Tests of two β0.86 prototype cavities

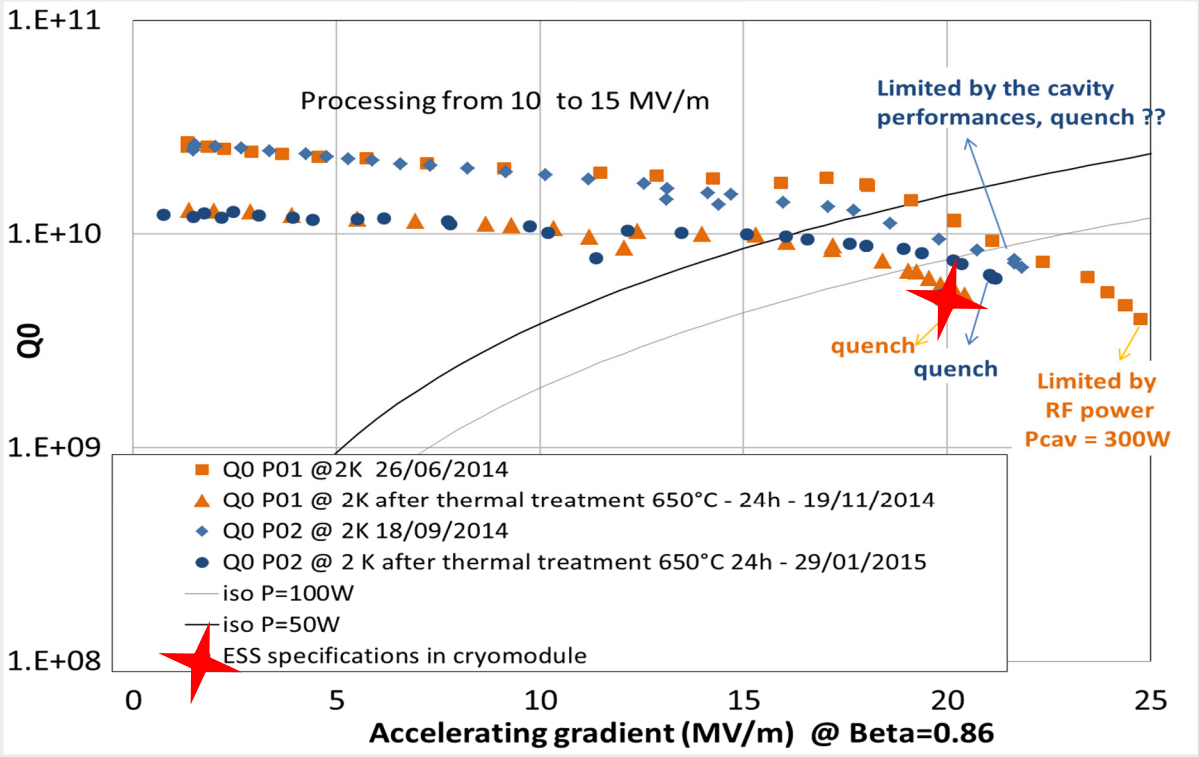
Poster TUPB007

P01 - E. ZANON

P02 - RI



P01 with LHe tank welded after heat treatment



Both prototype cavities met the ESS requirements after the first test
Slight degradation (pollution) of performances after 600°C heat treatment for hydrogen removing

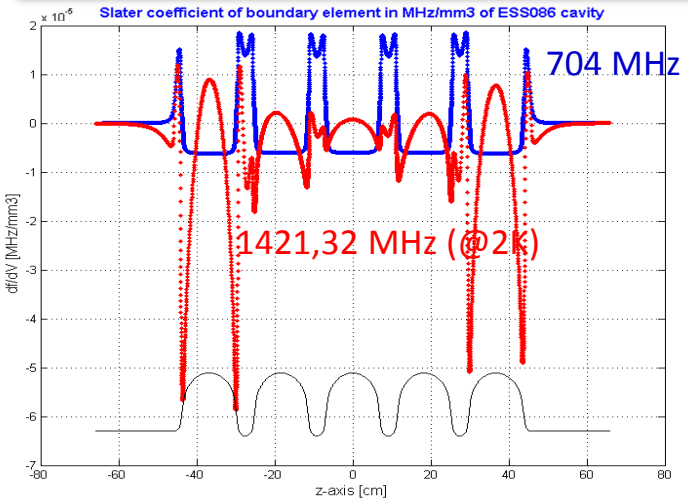
LHe tank welding: no frequency shift – no field flatness modification
Next test of P01 dressed with its LHe tank: 100µm BCP for removing the pollution

Dangerous HOM close to 1408.8 MHz

Both high beta prototype cavities are not conform with the ESS HOM Requirement

Reminder: "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"

Slater coefficient analysis which represents frequency sensitivity to volume changes:



Cavity ID	P01		P02	
Design (at 300K)	Meas.	Calc. from 3D geom. controls	Meas.	Calc. from 3D geom. controls
1418.178	1402.254	1403.8	1407.848	--
1418.674	1404.666	1406.8	1408.258	--

- 3D geometrical controls of the cavity shape have been performed
- Shape reconstructed in the simulation software HFSS

The strong internal shape deviation close to the equator > 1 mm explains very well the frequency decrease of the two dangerous HOMs.

→ Cells reshaping has to be implemented in the fabrication process of next cavities

Production of six beta0.67 prototype cavities (@ZANON)


End groups


Helium tank


Dumbbells

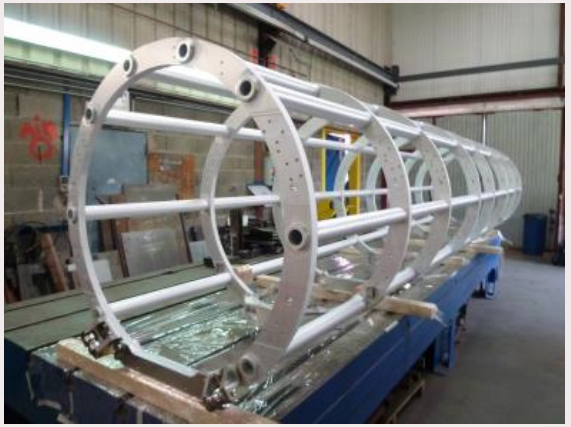
- All **dumbbells** completed and frequency measurements performed
- **End groups** completed by the end of September
- **Helium tank** prepared for welding

- **First cavity** delivered to CEA by the **end of October**
- Once the 1st cavity is approved by CEA, Zanon can deliver **one bare cavity every 2-3 weeks**.

Medium β cryomodule fabrication

Production of the main components and the toolings has been launched

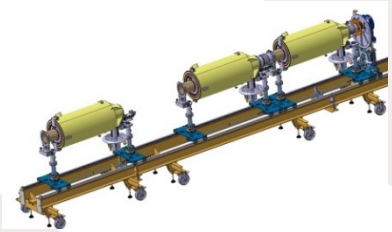
Vacuum vessel & space frame delivered



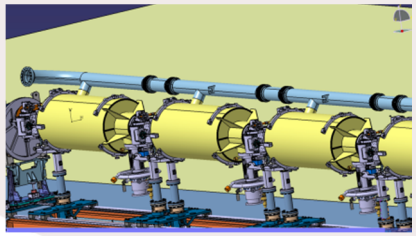
The detailed study of the assembling procedures is in progress.

XFEL cryomodules assembly lessons learn applied, QA process

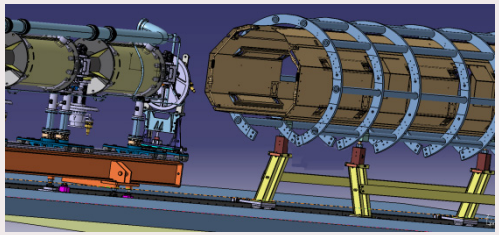
(N_2)



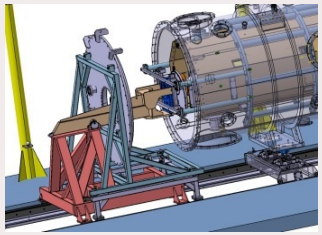
Assembling of the cavity string with a N_2 flow for protection against dust particles



Welding the titanium diphasic tubes



The cavity string is inserted in the spaceframe already equipped with the thermal shield



Closing the vacuum vessel

...

Future work

Finalize and test the medium beta prototype cryomodule

- cavities & couplers reception & test
- assembly with new toolings in a new clean room
- RF power test stand to be completed at Saclay

Realize and test of a high beta prototype cryomodule

Prepare the production of the 30 series cryomodules

- Production of the cavities
  - INFN Milano: 36 medium beta cavities
  - STFC Daresbury: 84 high beta cavities
- Production of the cryostat components
- Prepare the assembly infrastructure at Saclay after the XFEL cryomodules assembly

Thank you for your attention

Acknowledgments

Mats Lindroos (ESS)

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Emmanuel Rampnoux (IPN Orsay)

Pierre Bosland (CEA saclay)

Linac tunnel close-up

ALL PHOTOS: ESS

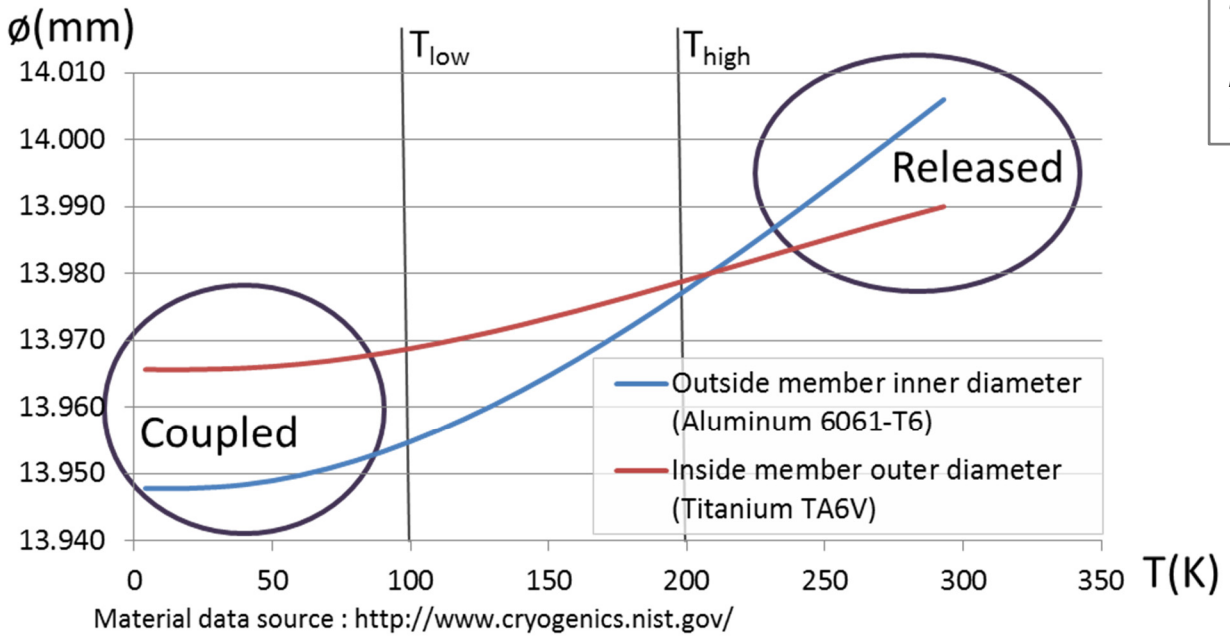
Cold Tuning System: shrink-fit coupling

Issue : during operation, parts of the cavity body are highly stressed (up to 311 MPa) by the tuner action. This can lead to cavity damage in a case the tuner is blocked.

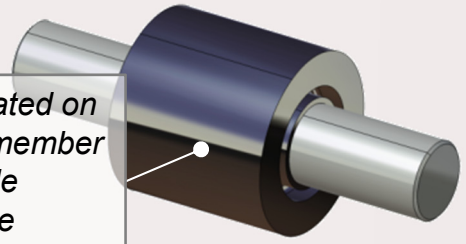
Goal : release the cavity from the tuner prior any warm-up, even in case of failure of motor/gearbox/ballscrew.

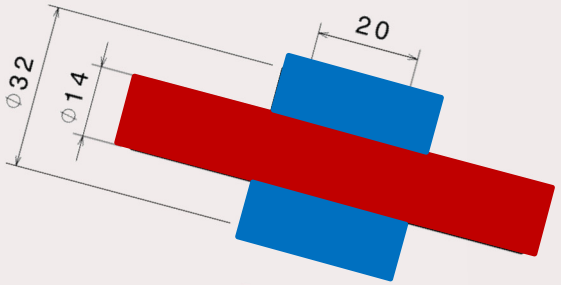
Idea : Put on the tuner a shrink-fit coupling. Differential thermal contractions of materials could:

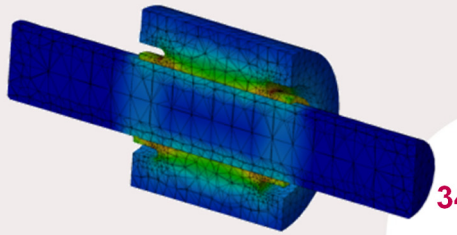
- Release the system above high temperature (> T_{high})
- Couple the system at low temperature (< T_{low})



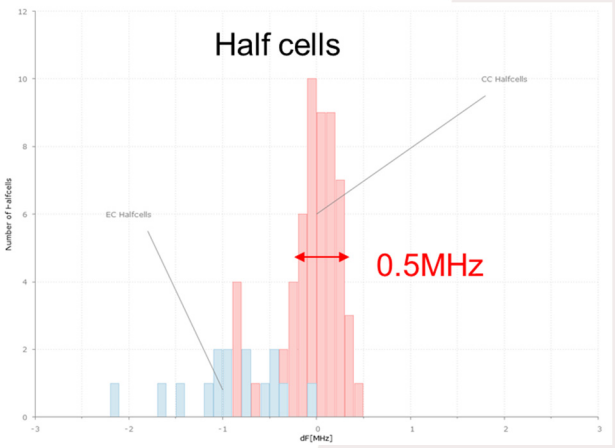
A heater located on the outside member would provide heating to the whole assembly.



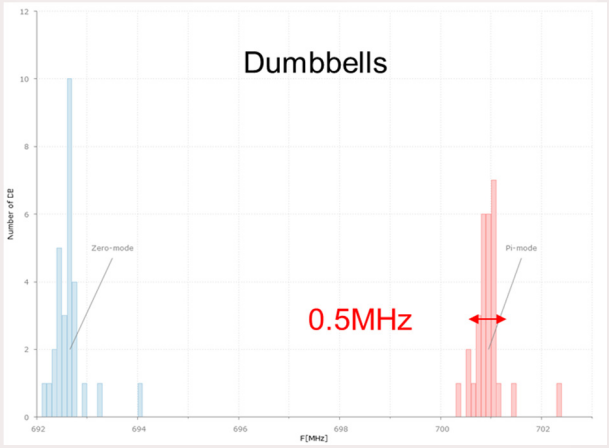




RF measurements on ½ cells and dumbbells



The copper plate used for ½ cells mesurements replaced by Nb plate for dumbells



The frequency spread (~0.5MHz) is similar between halfcells and after welding the dumbbells (reshaping was applied)

Dimensions control: 3D and lengths