EUROPEAN SPALLATION SOURCE

The Superconducting cavities of the European Spallation Source

Sébastien Bousson (CNRS/IN2P3/IPN Orsay)
&
Pierre Bosland (CEA/IRFU)

On behalf of the CEA/IRFU and CNRS/IPNO teams

Irfu

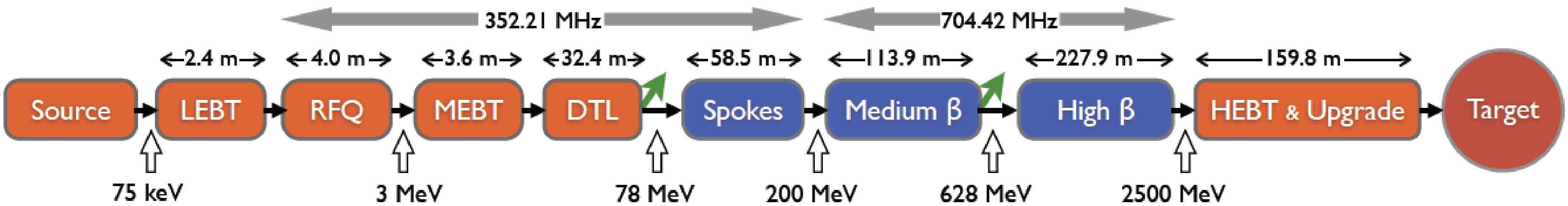
IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

SUPERCONDUCTING TECHNOLOGIES
FOR THE NEXT GENERATION OF ACCELERATORS
WORKSHOP

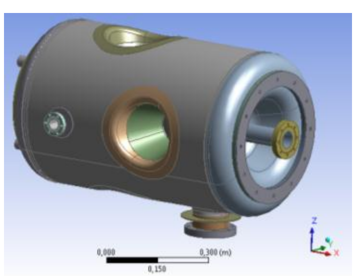
Superconducting Technologies Workshop CERN – 4 & 5 December 2012

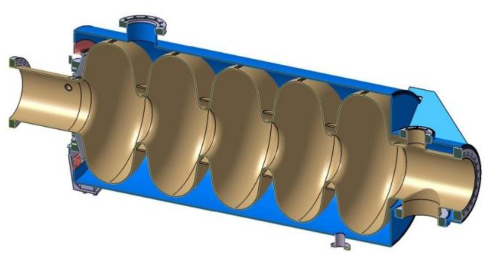
ESS Linac Layout

FDSL 2012_10_02



Section	Cavity β	Total number of Modules	Cavity frequency	# Cavity per module	# Cavity per section	Cryomodule length	Section length
Spoke	0.50	14	352 MHz	2	28	~ 2.9 m	58.5 m
Medium-beta	0.67	15	704 MHz	4	60	~ 6.7 m	113.9 m
High-beta	0.92	30	704 MHz	4	120	~ 6.7 m	227.9 m
Total		**59**			**208**		**~ 400 m**





Spoke Cavities

Spoke cavities specifications

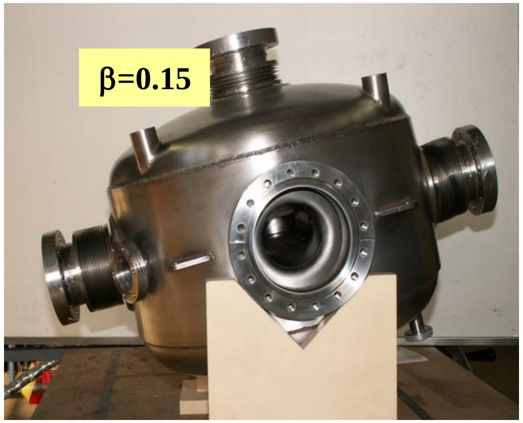
EUROPEAN SPALLATION SOURCE

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

DOUBLE-SPOKE CAVITY SPECIFICATIONS	
Beam mode	Pulsed (4% duty cycle)
Frequency [MHz]	352.2
Beta_optimal	0.50
Temperature (K)	2
Bpk [mT]	70 (max)
Epk [MV/m]	35 (max)
Gradient Eacc [MV/m]	8
Lacc (=beta optimal x nb of gaps x λ /2) [m]	0.639
Bpk/Eacc [mT/MV/m]	< 8.75
Epk/Eacc	< 4.38
Beam tube diameter [mm]	50 (min)
P max [kW]	300 (max)

Specs from beam dynamics

Design based on Eurisol experience

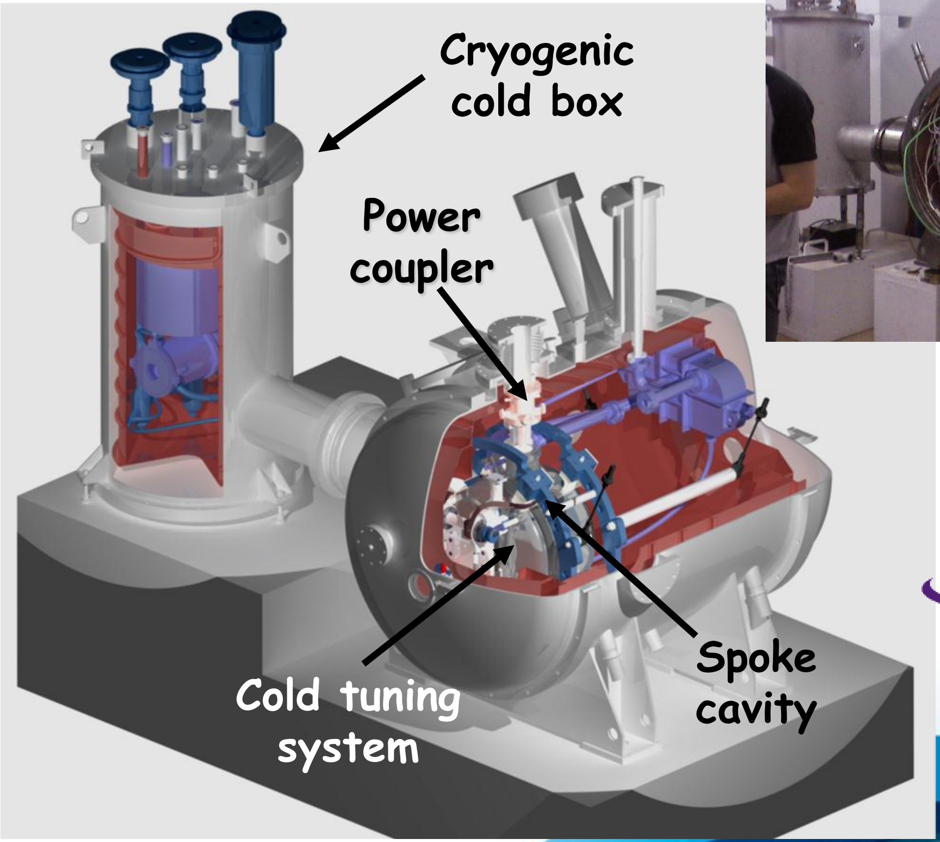


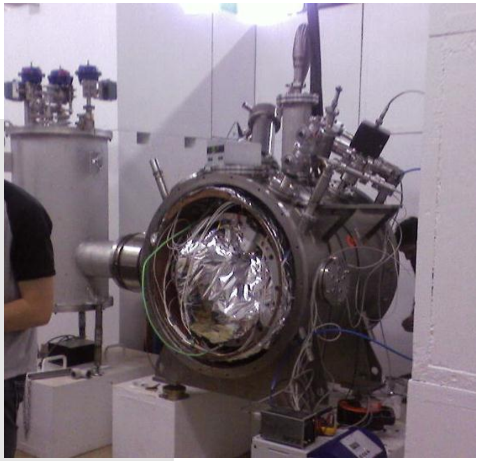
Spoke resonators

Two prototypes @ 352 MHz (β 0.15 and β 0.35) fabricated and tested.

Horizontal cryostat

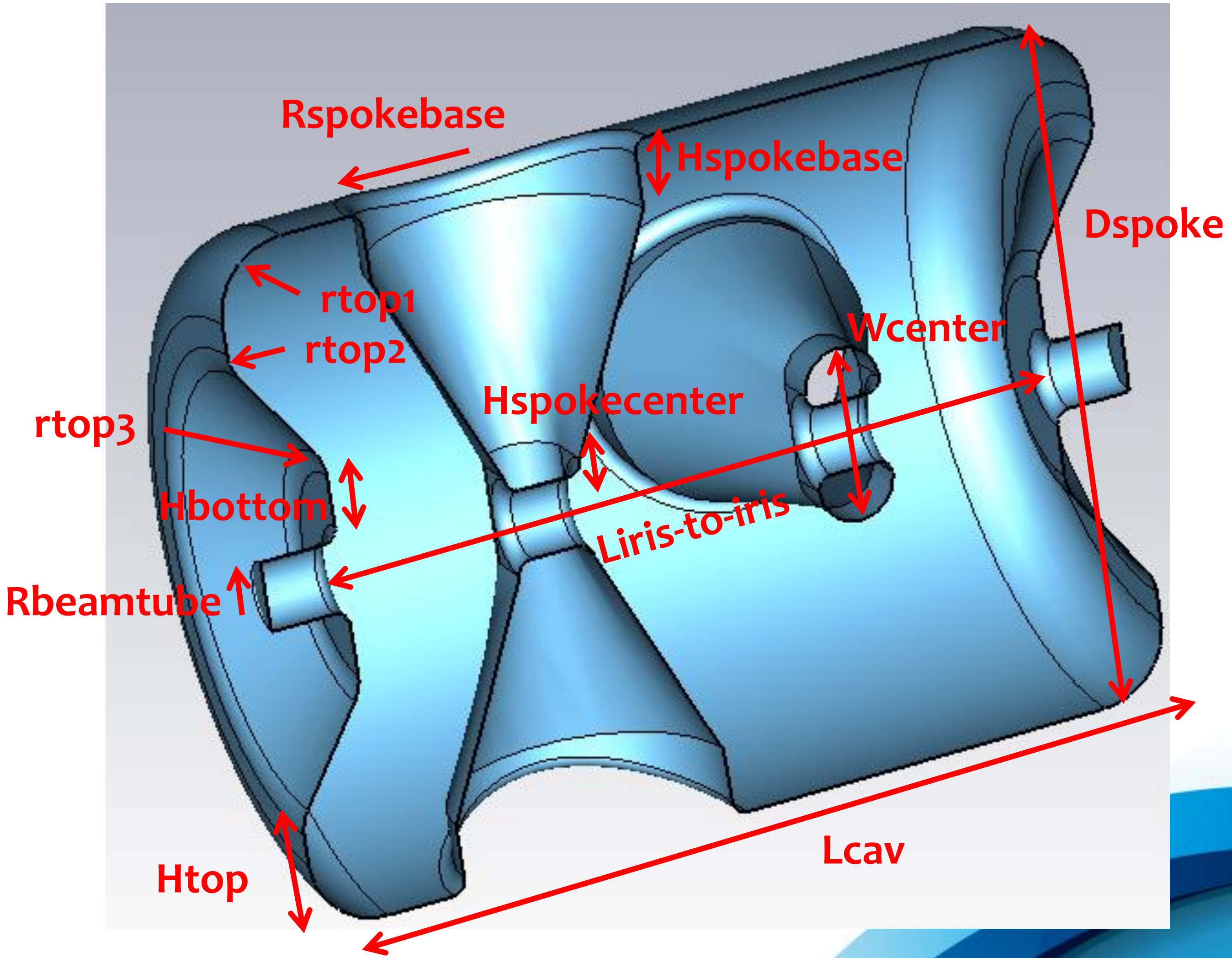
Adapted to spoke cavities for 4K and 2K tests





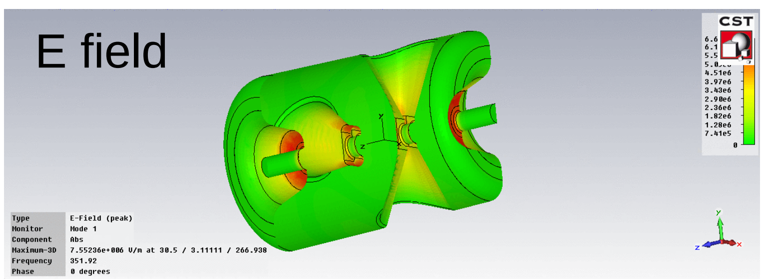
Spoke cavities geometry

The main parameters to play with…

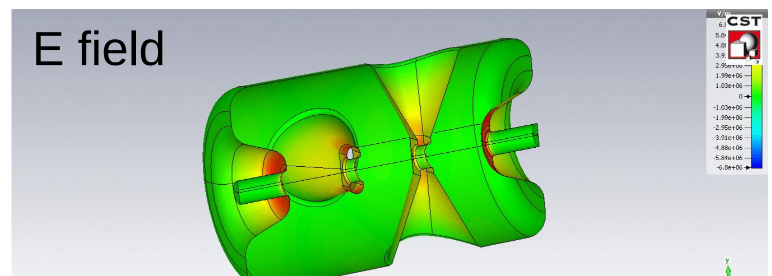


Spoke cavities RF Results

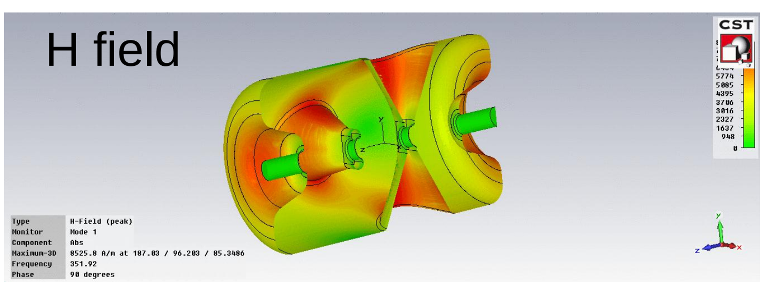
Mesh type	Hexahedral (1.2 millions)	Tetrahedral (650000)	
Beta optimal	0.50	0.50	☑
Epk/Ea	4.96	4.47	☒
Bpk/Ea [mT/MV/m]	7.03	6.74	☑
G [Ohm]	133	133	☑
r/Q [Ohm]	428	427	☑

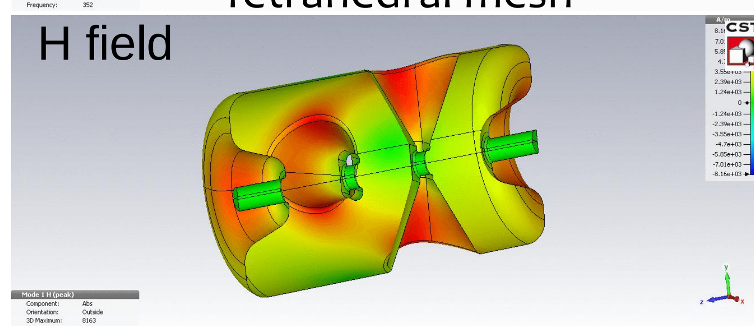


Hexahedral mesh



Tetrahedral mesh





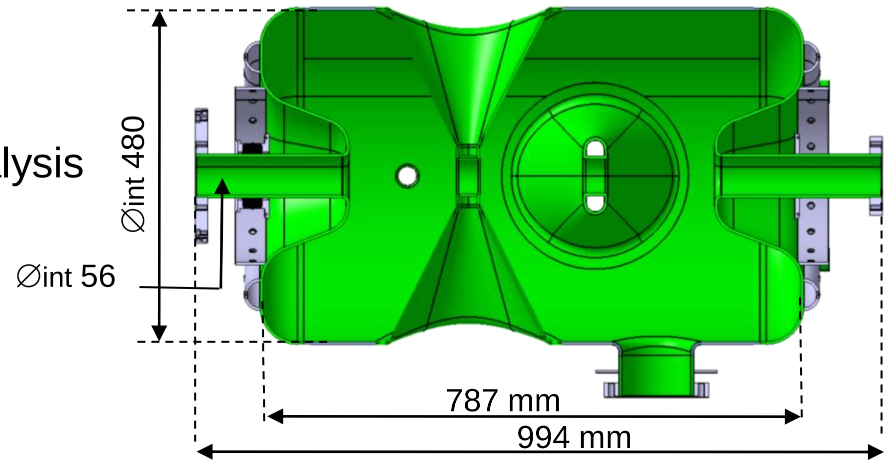
Spoke cavities final geometry

EUROPEAN SPALLATION SOURCE

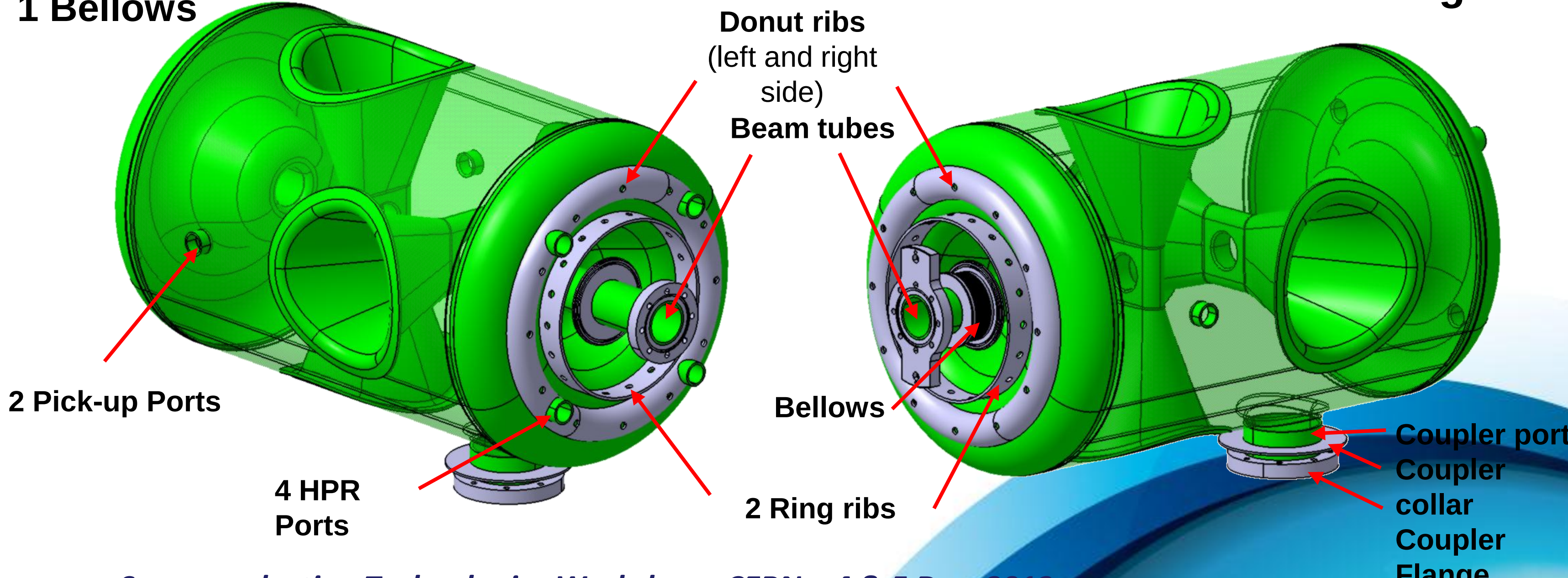
Cavity final configuration

- **Design:** Spoke 3-gap cavity defined by RF analysis
- **Material**: niobium
- **Thickness**: 4 mm
- **Stiffeners**:
  - 2 Donut ribs
  - 2 Ring ribs
- **Ports:** 1xCoupler ∅int=100, 2xPick-up ∅int=28, 4x ∅int28 HPR
- **1 Bellows**

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY



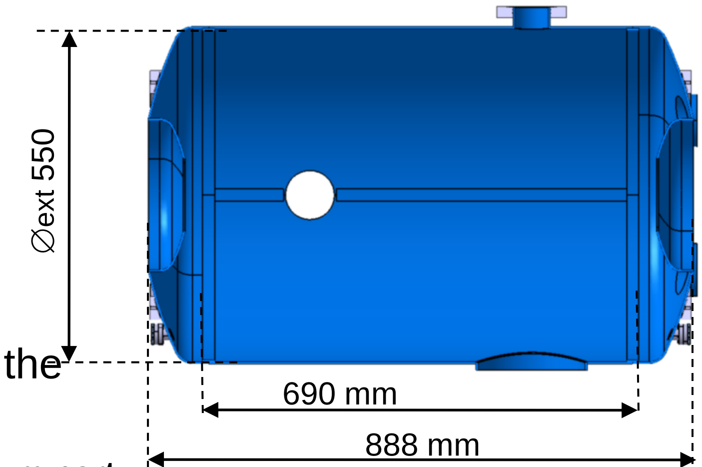
Total weight: 77 Kg



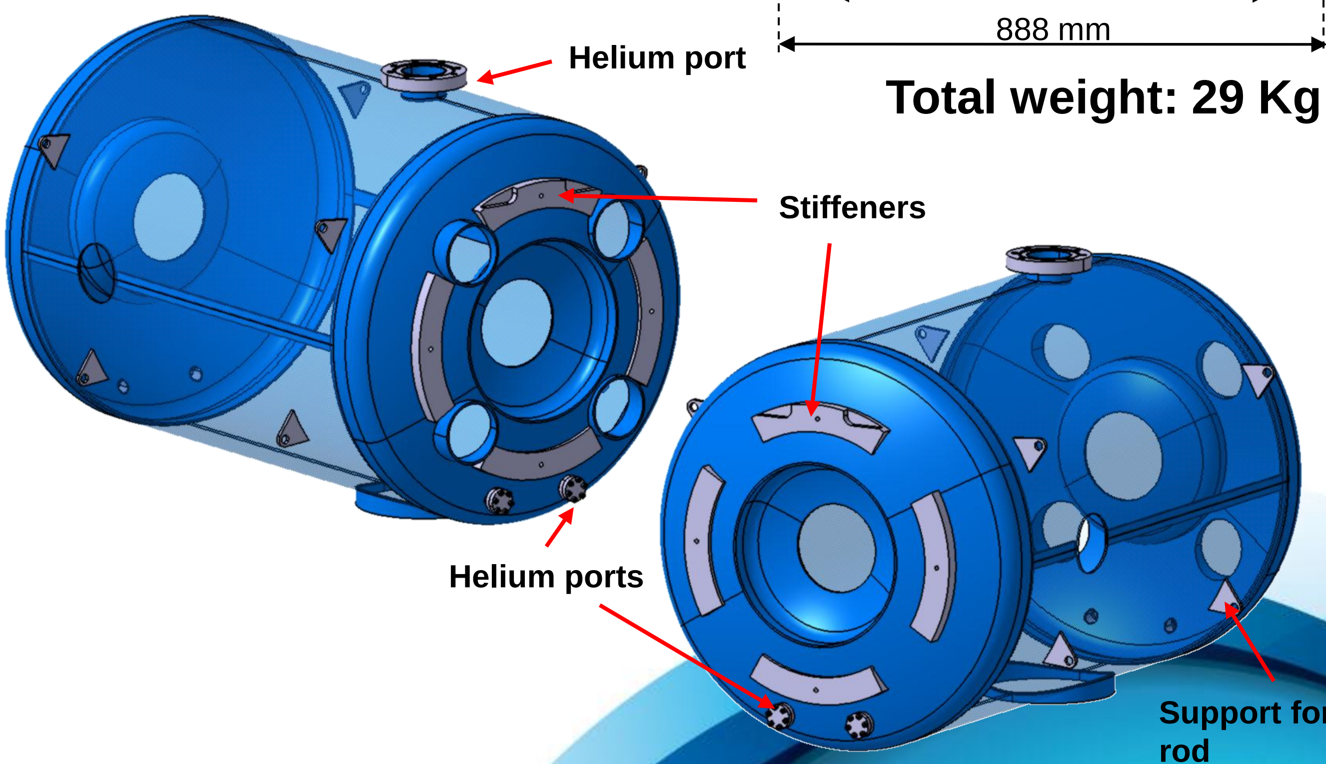
Spoke cavities helium tank

Helium vessel

- **Material**: titanium grade 2
- **Thickness**: 3 mm
- **8 Stiffeners** (handling tools and cold tuning system)
- **Helium Ports** (cooling and filling)
- **8 Supports for rods** (proposal for the supporting within the cryomodule)



Total weight: 29 Kg



Spoke cavities final design

Cavity + He vessel Assembly

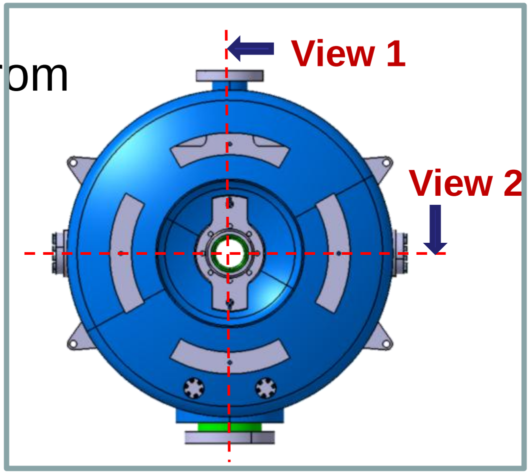
As the thermal expansions of the niobium and titanium from 300K to 2K are similar, rigid connections are possible.

⇒ **Improvement of the stiffness of the cavity**

Rigid connections :

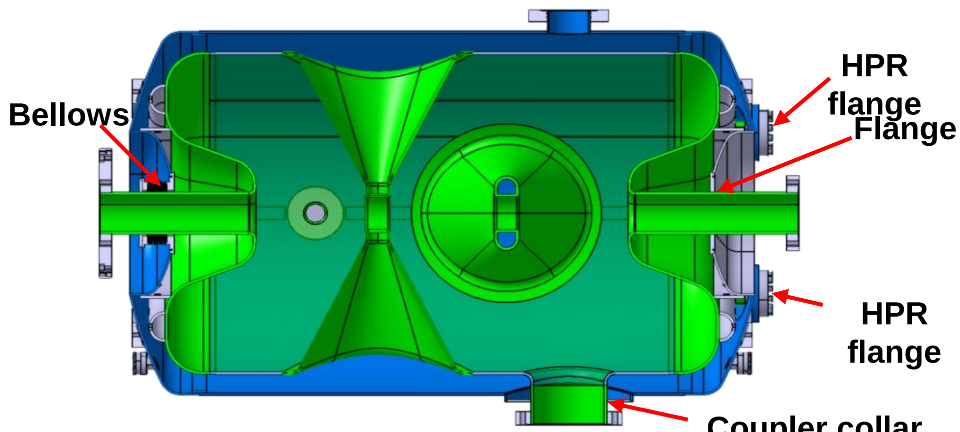
- Ring ribs
- HPR ports
- Pick-up ports
- Coupler port
- Flange between a beam tube and the helium vessel

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

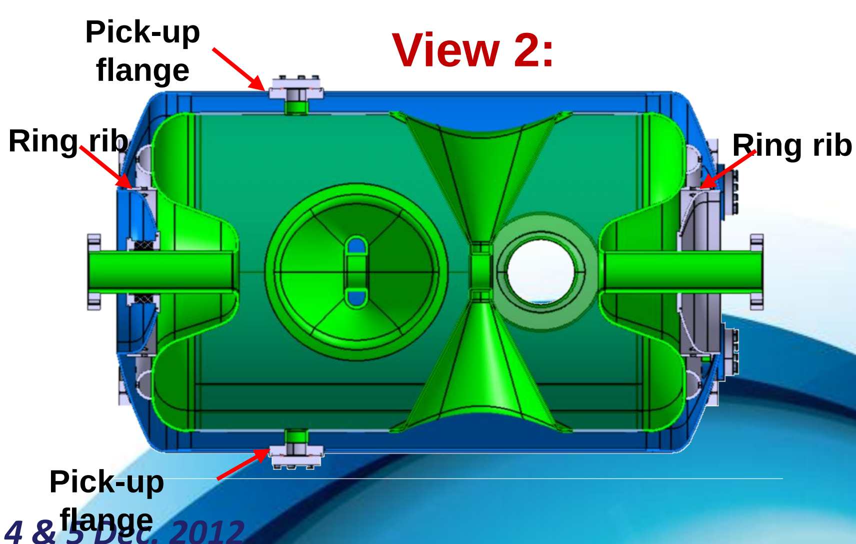


Total weight: 109 Kg

View 1:



View 2:

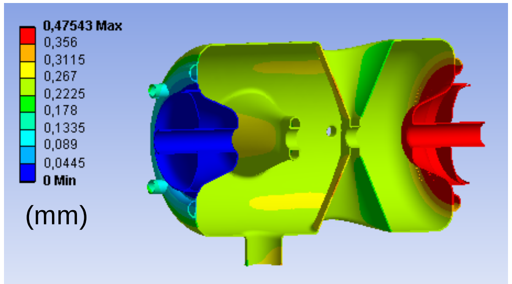


Spoke cavities mechanical properties

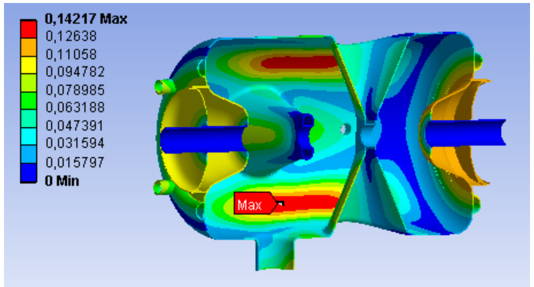
RF sensitivity due to helium pressure fluctuation

Static results of the simplified model (1/4) are verified on the entire model:

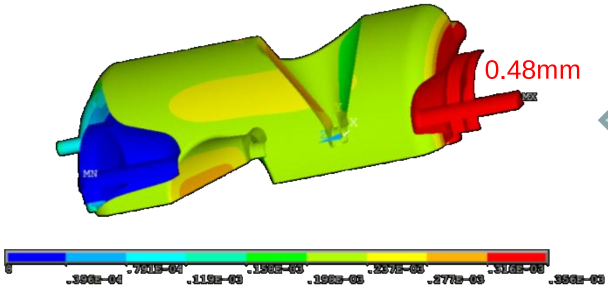
One free end:



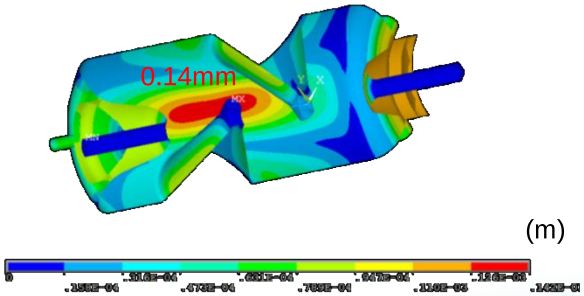
Fixed ends:



Entire model (Mechanical Ansys)



1/4 model (Mechanical APDL - Ansys)



Mechanical characteristics	
Cavity with a part of the end cups of the helium vessel	
Sensitivity to He pressure K_P [Hz/mbar] (free ends)	120.
Sensitivity to He pressure K_P [Hz/mbar] (fixed ends)	40.

Spoke cavities mechanical properties

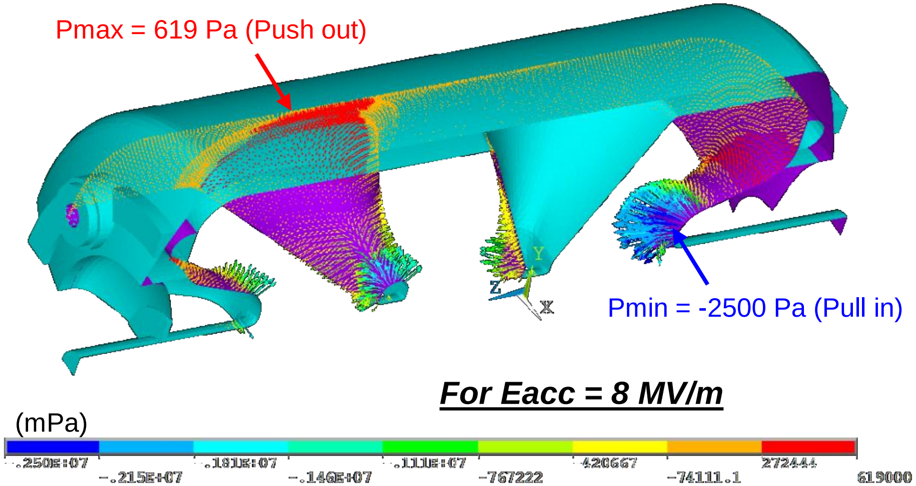
IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

RF frequency change due to Lorentz detuning

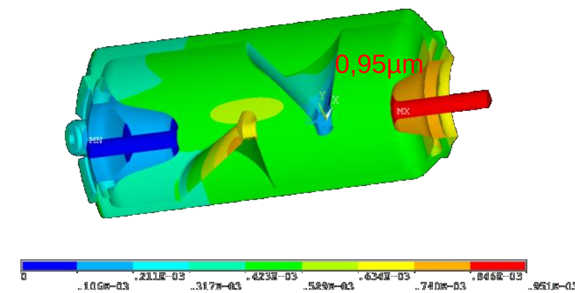
Configuration type cryomodule

Distribution of the pressure on cavity walls:

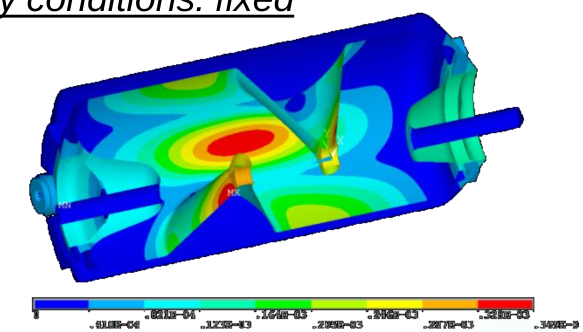
Lorentz pressure: $P = \frac{1}{4}(\mu_0 H^2 - \varepsilon_0 E^2)$
calculated from RF analysis (ANSYS)



Boundary conditions: one free end



Boundary conditions: fixed ends

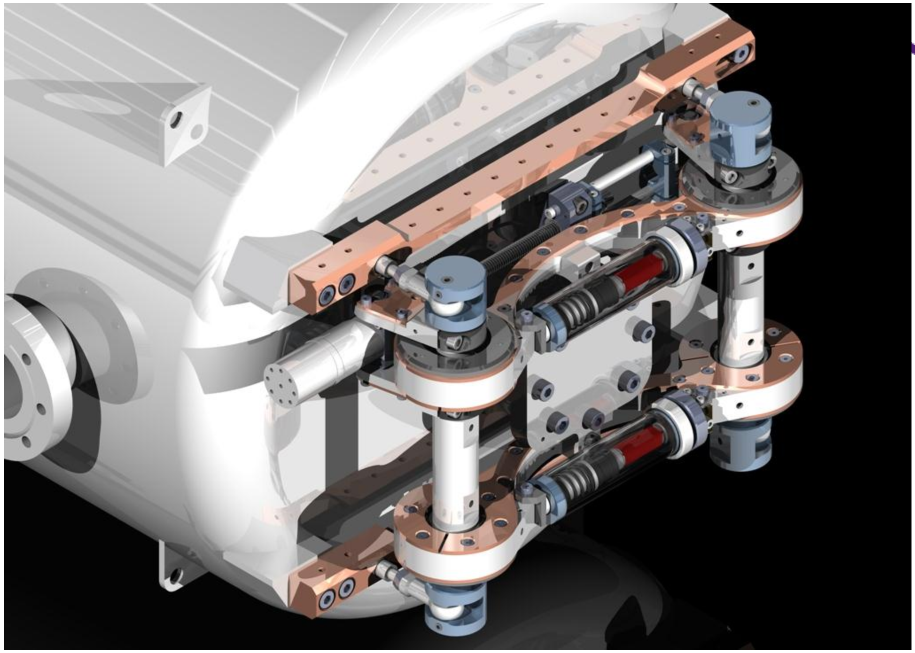


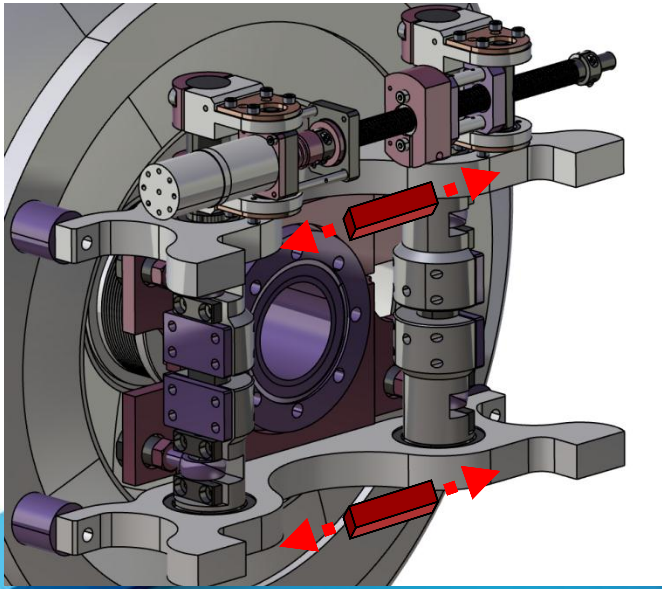
Lorentz Factor: $K_L = \Delta f / E^2acc$		
Cavity with helium vessel		*For 8MV/m*
K_L [Hz/(MV/m)^2] (one free end)	**K_L =-5.3**	**Δf = 340 Hz**
K_L [Hz/(MV/m)^2] (fixed ends)	**K_L =-2.8**	**Δf = 180 Hz**

Remark:
Bandwith
Δf = 1355 Hz

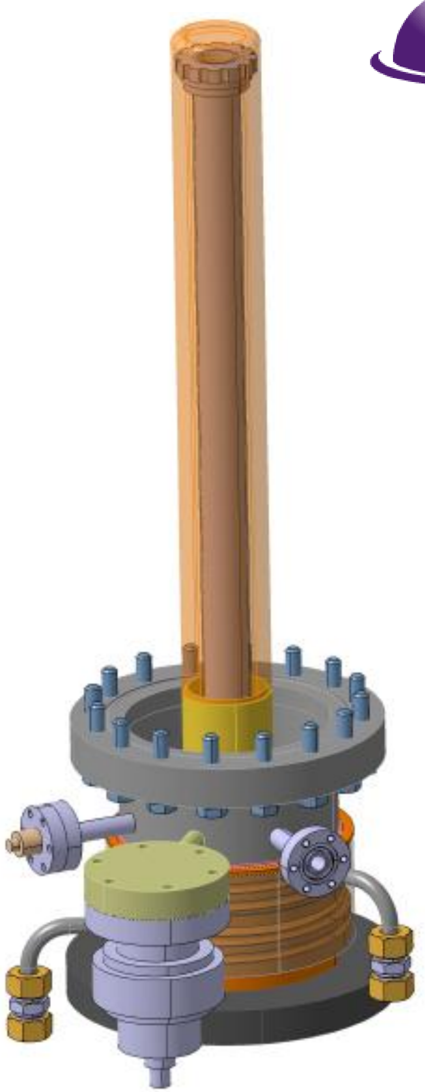
Spoke cold tuning system

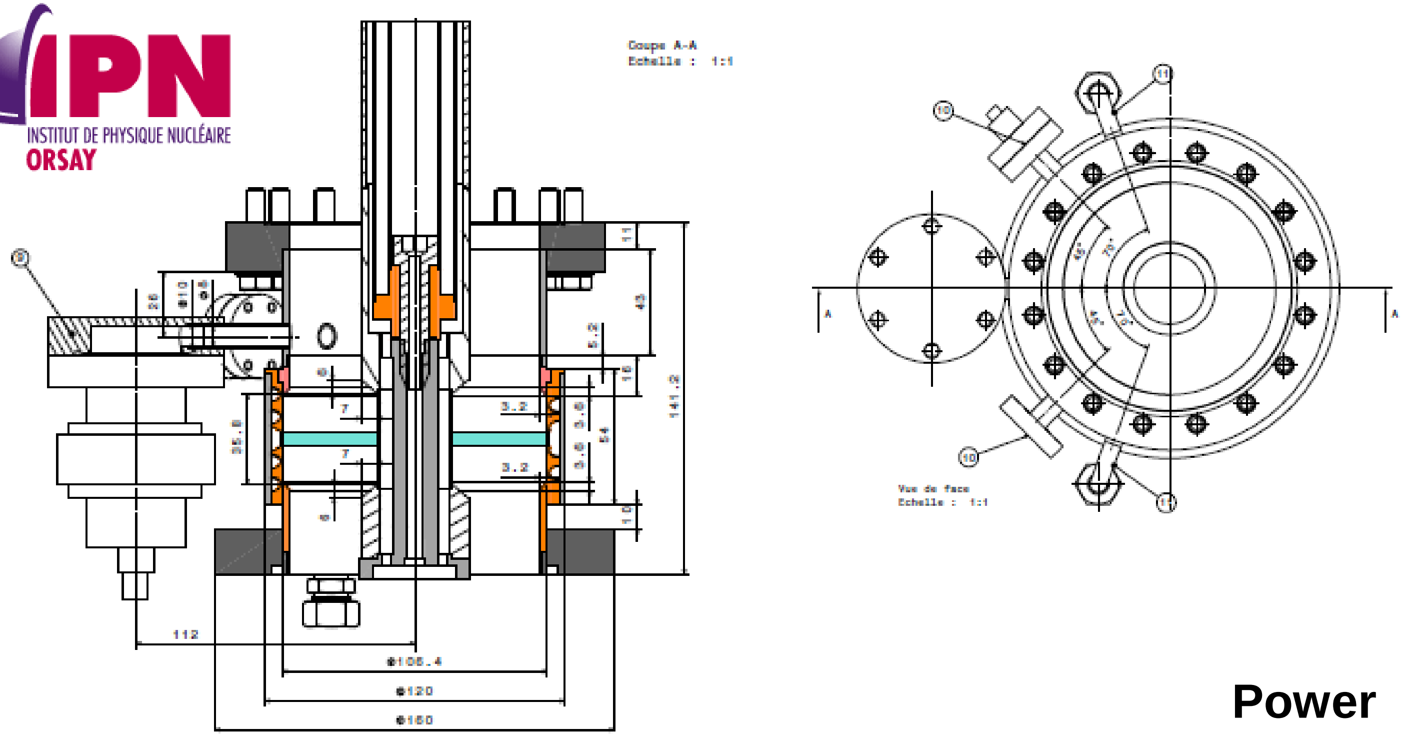
CTS data		
Mechanical resolution (1/20 bandwidth)	68	Hz
Expected Stiffness	200	kN/mm
Cavity sensitivity (CTS stiffness taken in account)	300	kHz/mm
LHe pressure coefficient (CTS stiffness taken in account)	47	Hz/mbar
Lorentz forces coefficient (CTS stiffness taken in account)	3.21	$Hz/(MV/m)^2$
Lorentz forces detuning	205	Hz
CTS stroke	1.25	mm
Max tuning range	375	kHz
Max strength	25	kN

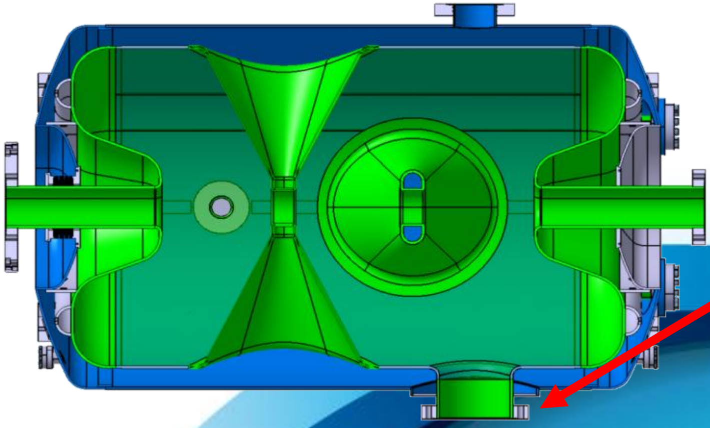




Spoke power coupler

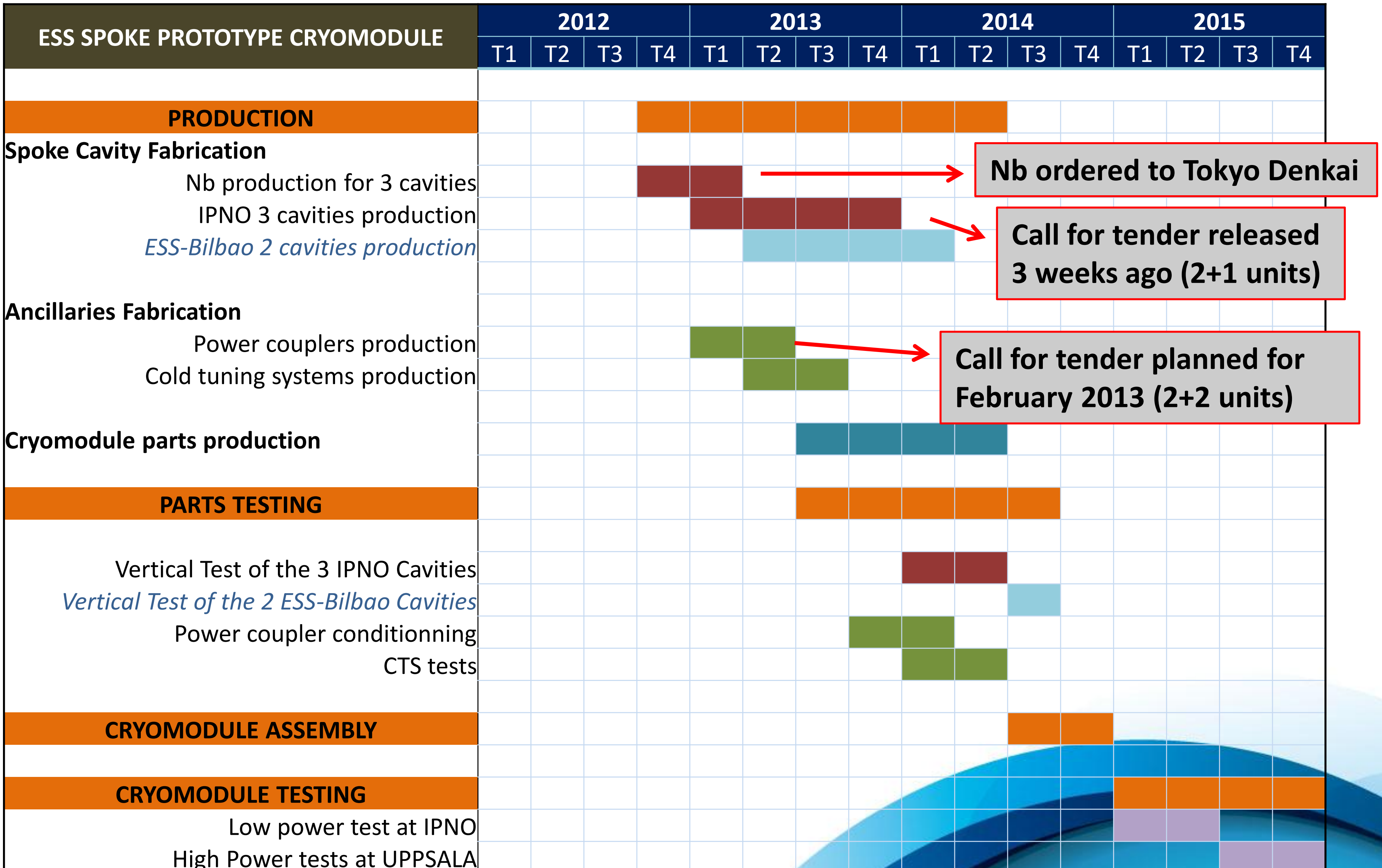






Power coupler port 100 mm diameter

ESS Spoke prototyping strategy



ESS Spoke series construction planning

Task Name	Start date	End date
Procurement	1-Nov-15	30-Apr-18
Niobium Procurement	1-Nov-15	30-Dec-16
Spoke cavities procurement	1-Apr-16	30-Apr-18
Power couplers procurement	1-Sep-16	30-Apr-18
Cold tuning systems procurement	1-Sep-16	30-Apr-18
Cryomodules and valves boxes parts procurement	1-Jul-16	28-Feb-18
Cavity packages preparation and testing	1-Mar-17	31-Jul-18
Spoke cavity preparation and VT testing	1-Mar-17	31-Jul-18
Power couplers preparation and conditioning at high power	1-Mar-17	31-Jul-18
Cold tuning systems preparation and test at room T	1-Mar-17	31-Jul-18
Spoke cryomodules assembly	1-May-17	30-Oct-18
Spoke cryomodules tests at high power	1-Aug-17	31-Dec-18

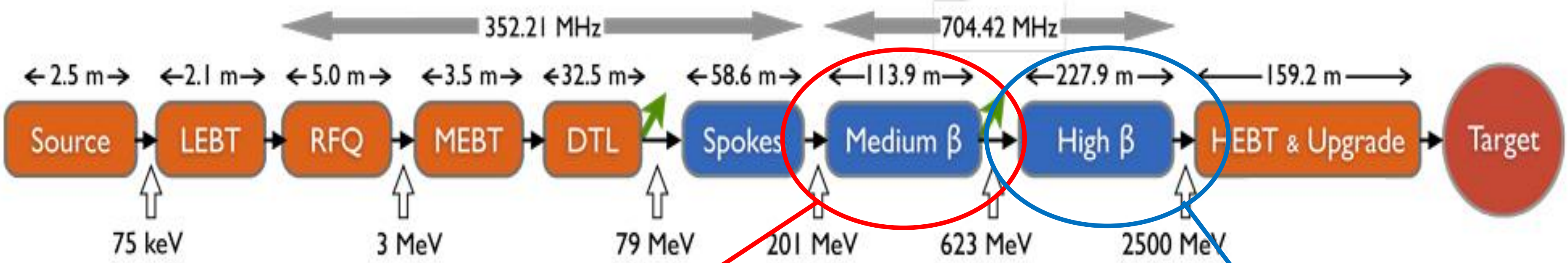
Associated milestones

First cryomodule ready @ ESS 01/10/2017

Last cryomodule ready @ ESS 31/12/2018

Elliptical Cavities

The Elliptical cavities for ESS



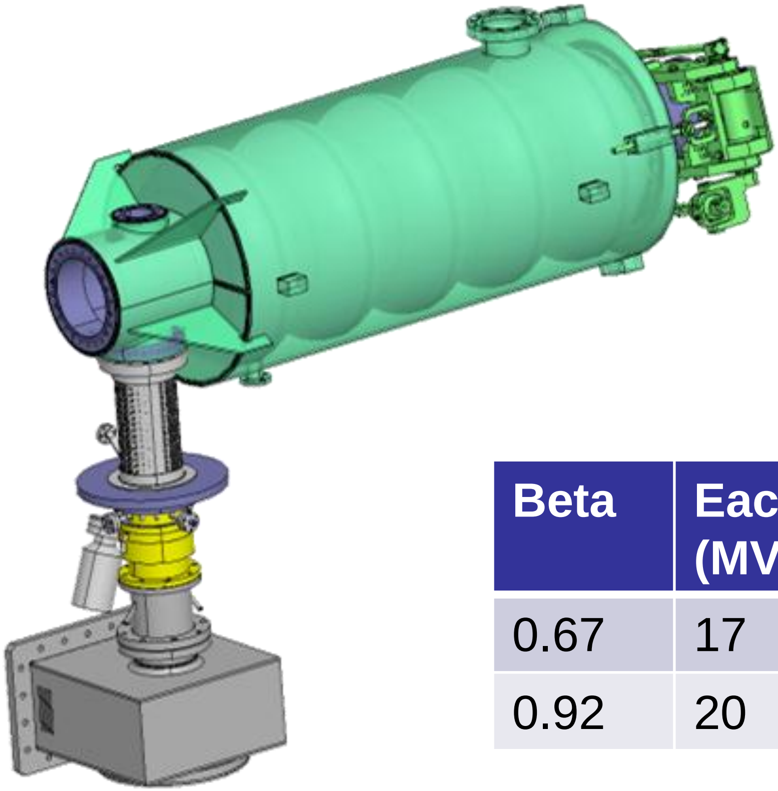
Medium beta :
15 cryomodules - 4 cavities at β= 0.67
(60 cavities)

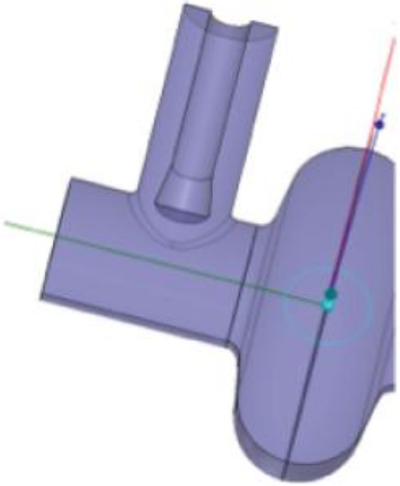
High beta:
30 cryomodules - 4 cavities at β= 0.92
(120 cavities)

Irfu

The Elliptical cavities for ESS

- 5-cell cavities, bulk niobium (Thickness: 3,9mm)
- frequency = 704.42 MHz
- performance specifications (T = 2 K):





Beta	Eacc VT (MV/m)	Eacc Linac (MV/m)	Qo @ nominal Eacc
0.67	17	15	5e9
0.92	20	18	6e9

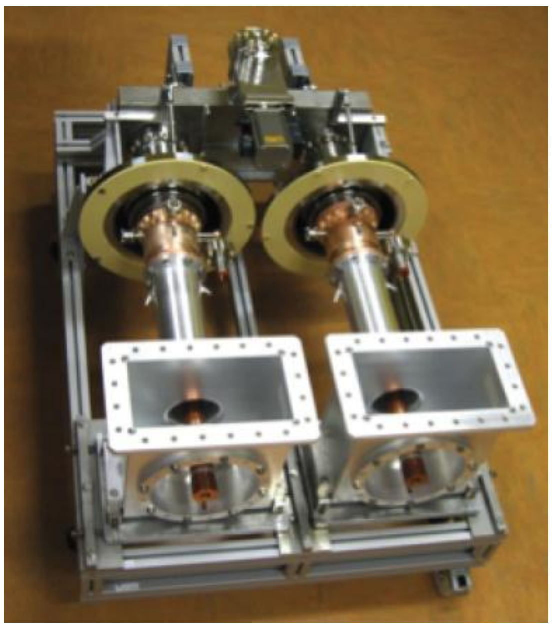
The Elliptical cavities for ESS

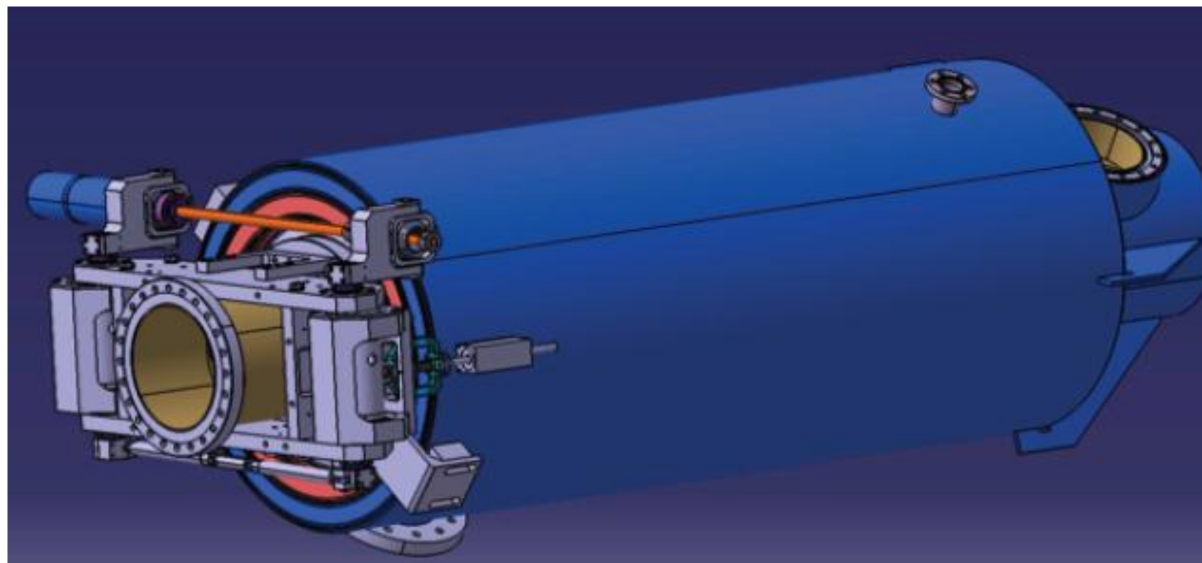
- P_{RF} max = 1.2 MW   <= HIPPI power coupler
- Piezo tuner   <= Saclay V tuner (HIPPI / SPL tuner)

} Adapted to ESS cavities

- Titanium helium vessel (Thickness: 5 mm)
- Flanges material: NbTi
- Pulsed mode: 14 Hz - 2.86 ms

Irfu





Elliptical cavities main parameters

Parameter	Unit	Value
RF frequency	MHz	704.42
Temperature	K	2
MEDIUM-BETA		
Output energy	MeV	654
Number of cells per cavity		5
Geometric beta		0.67
Cavity length	m	1.145
Expected gradient, horizontal	MV/m	15
Expected gradient, vertical test	MV/m	17
Cavity Q_0		6×10^9
Fundamental mode Q_{ext}		6.8×10^5
Fundamental mode R/Q	W	340
Average heat load at nominal gradient	W	5.9
Power coupler power forward power	MW	1.2
Maximum Power transmitted to beam	MW	0.6

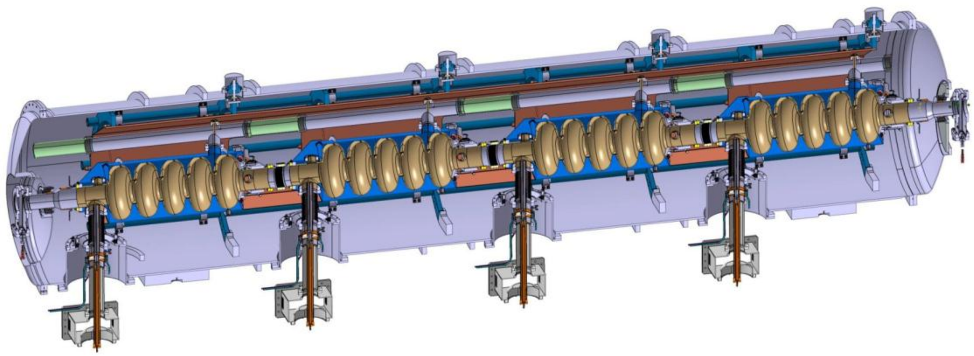
Elliptical cavities main parameters

Parameter	Unit	Value
HIGH-BETA		
Output energy	MeV	2500
Number of cells per cavity		5
Geometric	beta	0.9
Cavity length	m	1.356
Nominal gradient in the linac	MV/m	18
Expected gradient, vertical test	MV/m	20
Geometric beta prototype		0.86
Optimum beta prototype		0.92
Cavity length prototype	m	1.315
Fundamental mode R/Q prototype	W	477
Fundamental mode Q_{ext} prototype		7.1×10^5
Cavity Q_0 at nominal gradient, prototype		6.0×10^9
Average heat load at nominal gradient, prototype	W	4.5
Power coupler power rating	MW	2
Power coupler forward power	MW	1.2
Maximum power transmitted to beam	MW	0.9
Cell to cell coupling	%	1.8
Epk/Eacc		2.2
Bpk/Eacc	mT/(MV/m)	4.3
Separation between π and $4\pi/5$ modes	MHz	1.2
Iris diameter	mm	120

EUROPEAN SPALLATION SOURCE

The prototype cryomodules ECCTD
Elliptical Cavity Cryomodule Technical Demonstrator

Beta	0,67	0.86
Eacc VT (MV/m)	18	20
Eacc Linac (MV/m)	15	18
Qo @ nominal Eacc	6^e9	6e9



2 prototype cavities already ordered – delivery scheduled in june 2013

Cryomodule studies in progress

Call for tender of the components: 2013

Cavities ~ July 2013 and Power Couplers ~march 2013

Assembling in the new clean room at Saclay

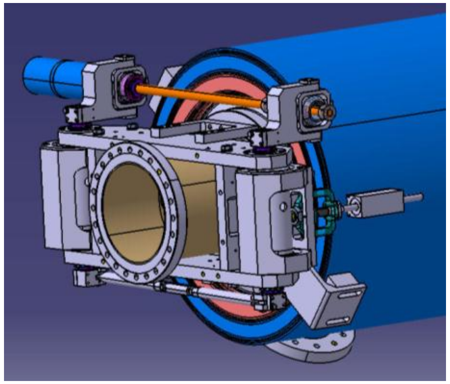
RF power tests at Saclay: 2015

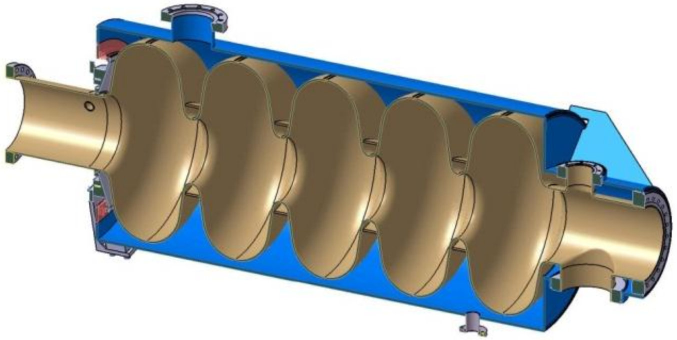
Irfu

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

ESS master schedule Procurements

	start	end
Medium beta cryomodules	28/10/2015	23/08/2016
Medium beta cavities	19/05/2015	12/07/2016
High beta cryomodules	14/01/2016	06/08/2017
High beta cavities	19/01/2015	11/08/2016





…

and a little advertisement

…

Superconducting RF Conference - SRF 2013

Superconducting RF Conference - SRF 2013