Accelerator Collaboration of CEA & CNRS with ESS

Sébastien Bousson and Pierre Bosland

For the CNRS/IN2P3/IPNO and CEA/Irfu teams

ESS industrial day – MESR, Paris – 7 Feb. 2014

Outlook

- ❑ A bit of history & quick overview of the accelerator layout
- ❑ CEA & CNRS actual responsibilities in ESS (2009-2015)
- ❑ Overview of the systems under design by CEA & CNRS
  - ❖ Injector
  - ❖ Spoke Cryomodules
  - ❖ Elliptiques Cryomodules
- ❑ Expression of interest of CEA & CNRS for the construction of the ESS accelerator and potential area of in-kind contribution

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A bit of history…

CEA (mainly) and CNRS has started to work on ESS since mid-1990s ! But at that time the machine was quite different from ESS today.

After the choice of Lund as the host site in May 2009, CEA & CNRS has restarted the accelerator design activity on ESS (1st meeting in Aarhus, oct. 2009) with the objective of integrating the most up-to-date accelerator technology.

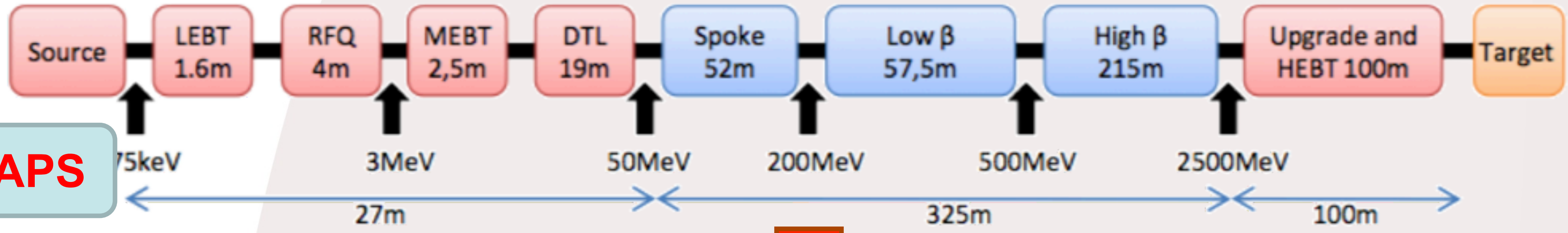
At that time, the ESS Accelerator Division (which is > 60 people today) was… Mats Lindroos and Steve Peggs !

ESS accelerator layout evolution

EUROPEAN SPALLATION SOURCE

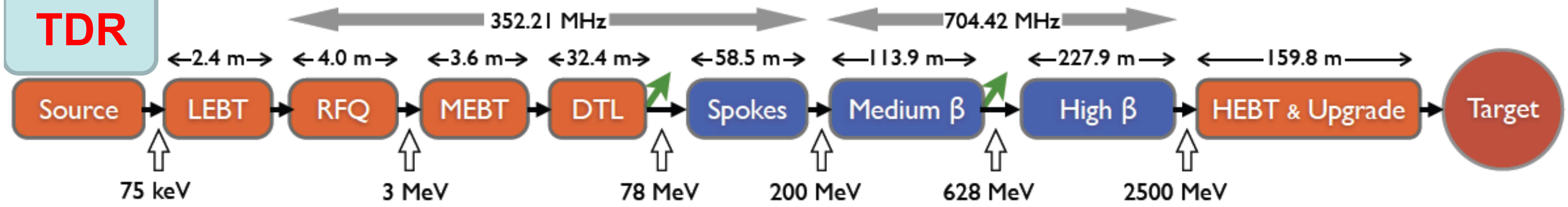
Between 2009 and now, many evolutions of the accelerator have been integrated (optimization of perfomance and cost)

APS



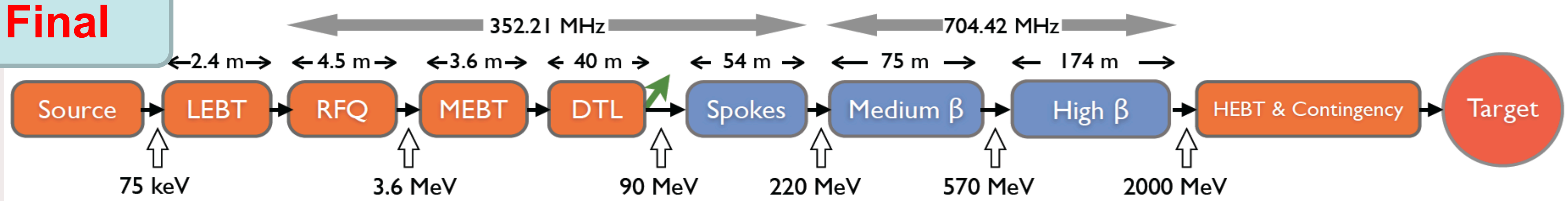
FDSL 2012_10_02

TDR



Optimus

Final



Evolution of the ESS linac

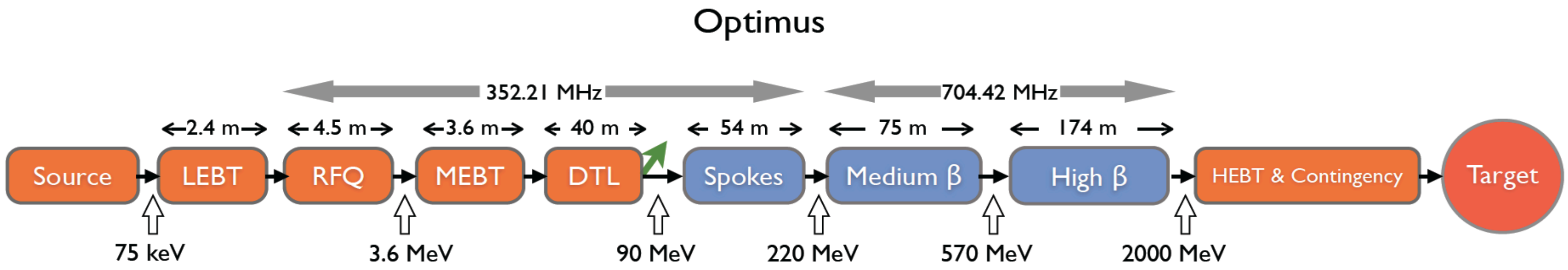
Between 2009 and now, many evolutions of the accelerator have been integrated (optimization of perfomance and cost)

	2009 (APS)	10/2012 (TDR)	10/2013 (Optimus)
E (Gev)	2.5	2.5	2.0
I (mA)	50	50	62.5
Length (m) *	352	443	353
Duty cycle	4 %	4 %	4 %
Rep rate (Hz)	14	14	14
Pulse length (ms)	2.5	2.86	2.86
SC cavity count	234	208	146
Epk elliptical cavities (MV/m)	40	45	45

The main and fundamental unchanged parameter: P = 5MW (or 125 MW peak !)

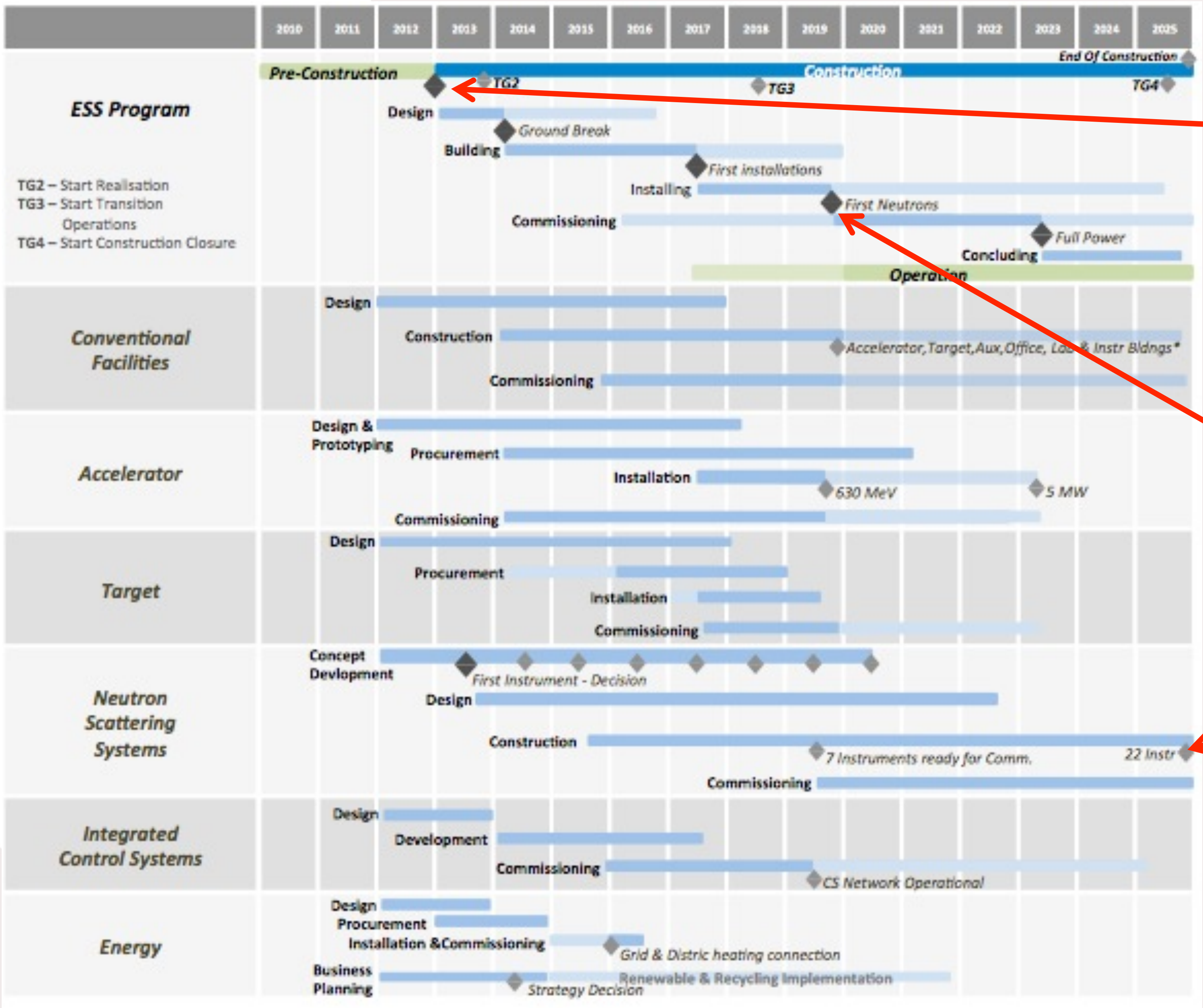
ESS linac layout

The ESS linac: accelerating high ointensities of protons



Section	Cavity β	Total number of Modules	Cavity frequency	# Cavity per module	# Cavity per section	Cryomodule length	Section length
Spoke	0.50	13	352 MHz	2	26	~ 2.9 m	54 m
Medium-beta	0.67	9	704 MHz	4	36	~ 6.7 m	75 m
High-beta	0.92	21	704 MHz	4	84	~ 6.7 m	174 m
Total		**43**			**146**		**~ 300 m**

Overall ESS planning



Since Feb. 2013:
Construction phase

End 2019:
1st neutrons with linac @ 570 MeV

In 2025:
ESS @ full power & 22 instruments

Prototyping and series construction

For several accelerator components, 2012-2015 is an active prototyping phase (cavities, power couplers, cryomodules, 352 MHz RF sources, 704 MHz RF sources…)

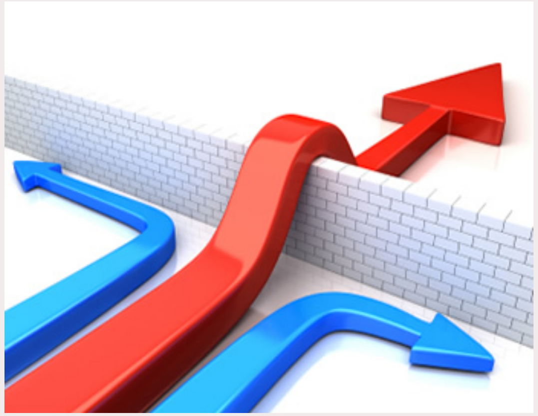
Some pick-up planned dates for series call for tender:

- RFQ : mid 2015
- SC linac parts:

SC Section	Cavities	Couplers	Cryomodules	RF amplifier
Spoke	Early 2016	Early 2016	Mid 2016	Early 2016
Medium β	Mid 2016	Mid 2015	Mid 2015	End 2015
High β	Early 2018	Early 2016	Mid 2015	Early 2018

- Accelerator cryoplant: end 2014
- Accelerator cryo distribution: early 2015
- LEBT to DTL beam diagnostics: early 2015 to end 2015

ESS Accelerator main challenges



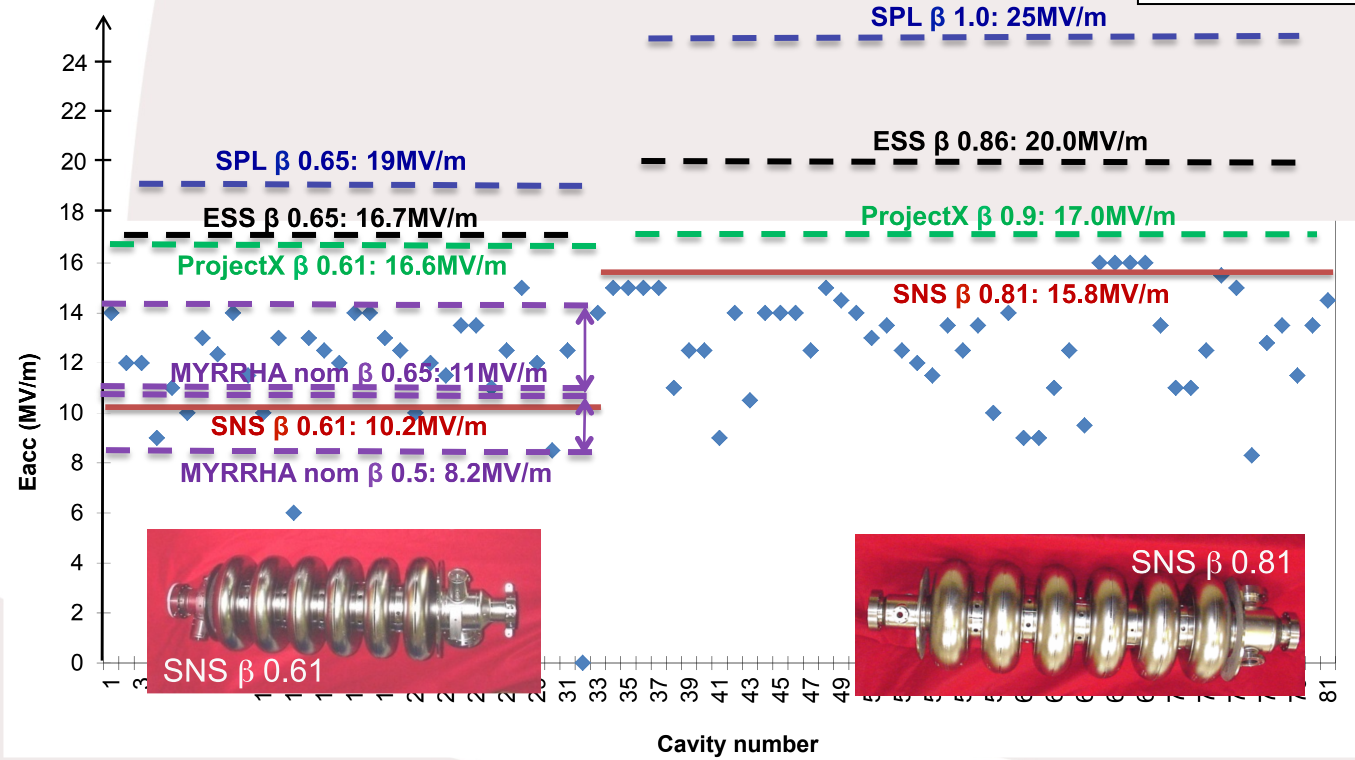
1. Use of spoke cavities (never done before)
2. Planning: first neutrons in 2019 @ 570 MeV
3. High peak power in high β elliptical power couplers (close to 1.1 MW peak)
4. Accelerating gradients goal in the final accelerator layout

Challenge: gradients accélérateurs

J-Luc Biarrotte, SRF2013, Paris, 23-27 September 2013

- **Cavity gradient is directly related to cost** -> tendency to push the gradients
- **SNS experiences a huge gradient variability -> needs for margins & operational flexibility !!**
  - ✓Almost every SNS run, a few cavities have problems, resulting in lower E_{acc} or turn-off -> linac retuning
  - ✓ Achievable gradients are mainly limited by heating by electron activity at high duty factor (especially by induced collective limits)

Ex. CM13 individual limits; 19.5, 15, 17, 14.5 MV/m
Ex. CM13 collective limits; 14.5, 15, 15, 10.5 MV/m



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Actual contribution of CNRS to ESS

Contribution & responsibilities of CNRS/IN2P3/IPNO on the ESS accelerator:

- **WP4 leader** (Spoke)
- **Design** of all components of the spoke cryomodule
  - Double spoke cavities
  - Power couplers
  - Cold tuning system (motor & piezo actuators)
  - Cryomodule
- **Fabrication and test** at low RF power in Orsay of a spoke prototype cryomodule, and then test at nominal RF power at Uppsala University
- **Design of the medium beta elliptical cryomodule prototype** (vacuum tank, thermal screen, cryogenic system & parts), in collaboration with CEA
- **Fabrication and test** in collaboration with CEA of this prototype at CEA Saclay's premises

Actual contribution of CEA to ESS

Contribution & responsibilities of CEA/Irfu on the ESS accelerator:

- **WP5 leader** (medium and high β elliptical cryomodules)
- **Design** of the medium and high beta elliptical cavity packages
  - 5-cells elliptical cavities (high β) and 6-cells (medium β)
  - Power couplers
  - Cold tuning system (motor & piezo actuators)
- Participation to the **Design of the medium beta elliptical cryomodule prototype** in collaboration with CNRS/IN2P3/IPNO
- **Fabrication and test** in collaboration with CNRS of this prototype at CEA Saclay's premises
- **Reliability test** of the IPHI injector with ESS parameters (« ESS-like »)
- **Design** of the ESS RFQ

❑ A bit of history & quick overview of the accelerator layout

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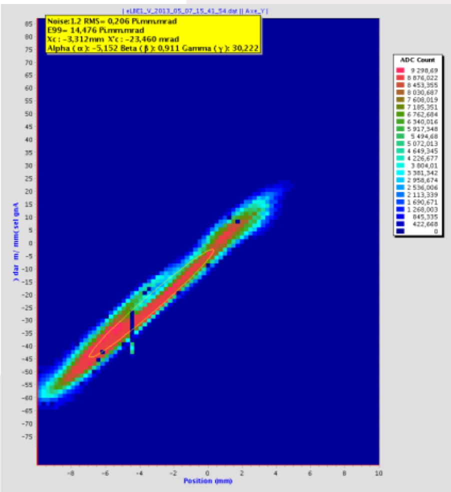
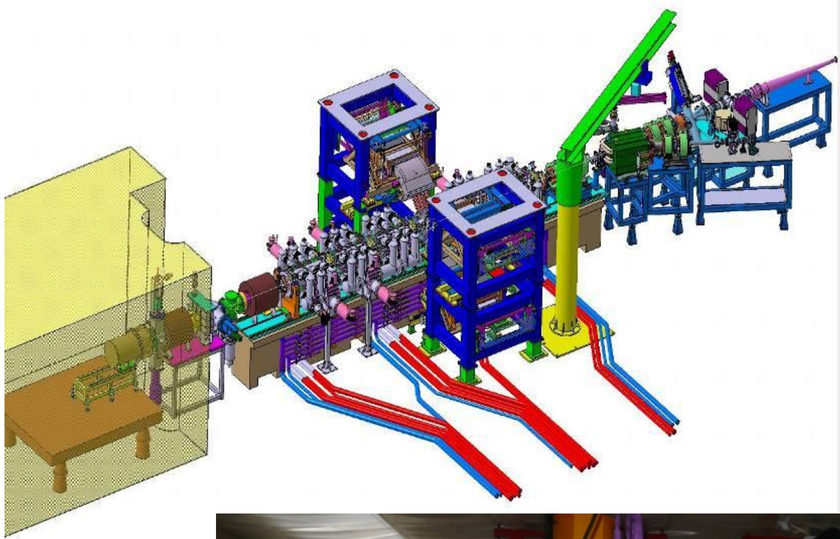
Tests of the SILHI Source in ESS-like



- Upgrade of C/C system
- Recent production of proton beams: validation of teh source main parameters for several beam structures
  1. ESS
  2. EUROTRANS
  3. IPHI

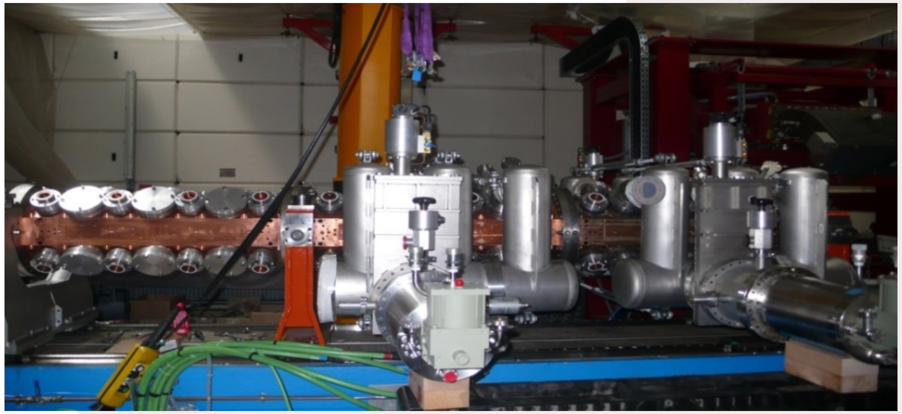
In Sept 2013: successful test of the SILHI source in ESS-like: I=65mA (ESS parameters)

Tests of the IPHI injector in ESS-like



<u>Objective</u>:

3 months tests on IPHI with a proton beam having the characteristics of the ESS beam.

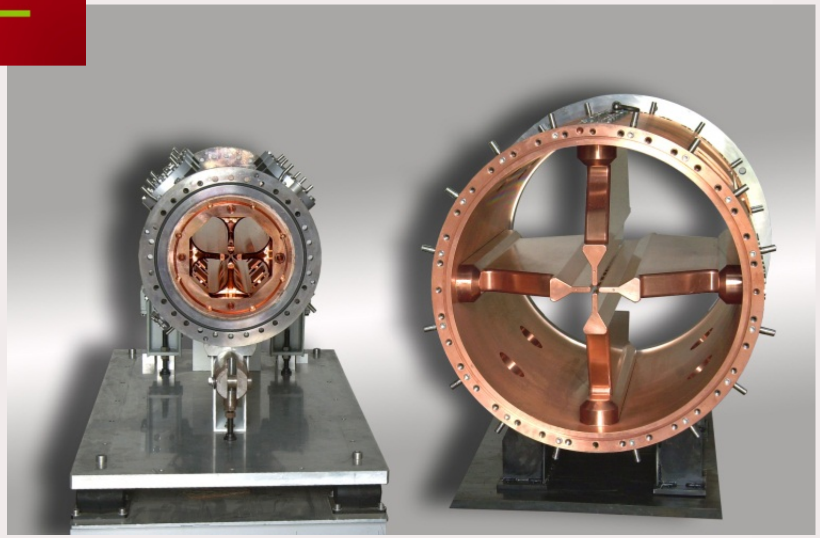


Status: The 6 RFQ sections are installed and assembled. Fine tuning operations are ongoing.

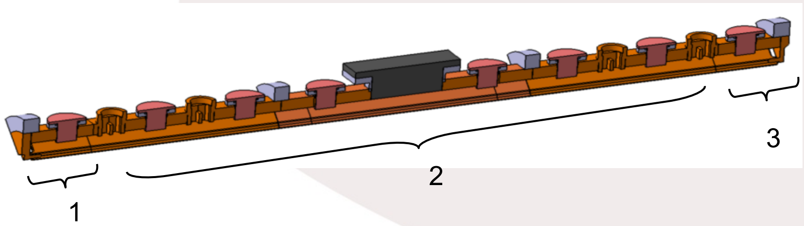
RF Conditionning RF of RFQ will start in this 1st quarter 2014

Design completed

RFQ in 5 0.9 meter long sections sections , equipped with power coupling loops



Ongoing: thermo-mechanical calculations based on the IPHI, SPIRAL-2 and LINAC4 experience.



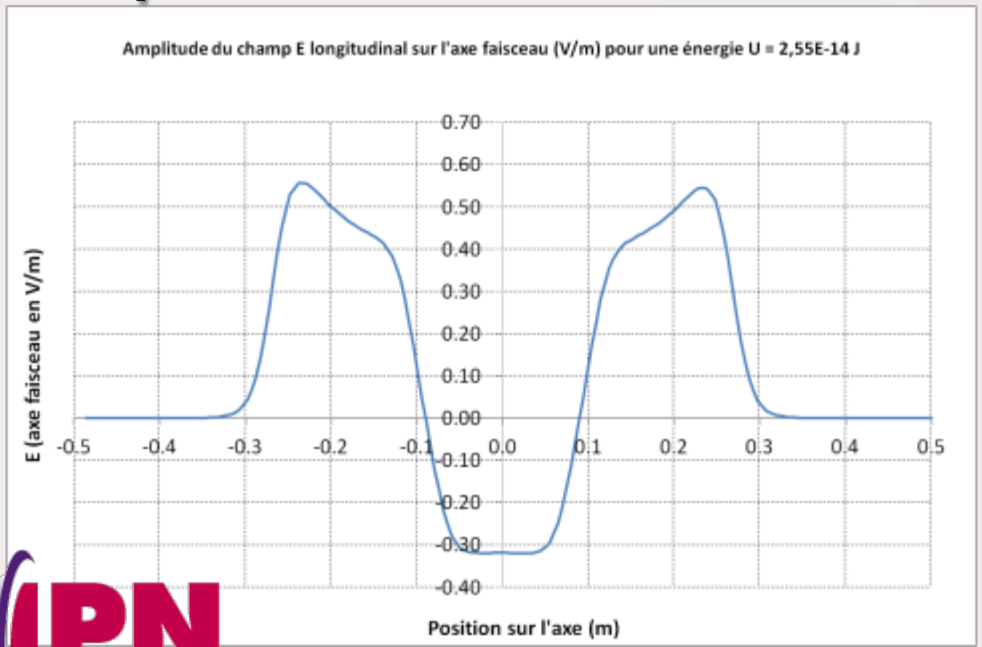
Power deposition generated differently:
1- entry
2- center
3- output

Spiral-2 RFQ coupling loop

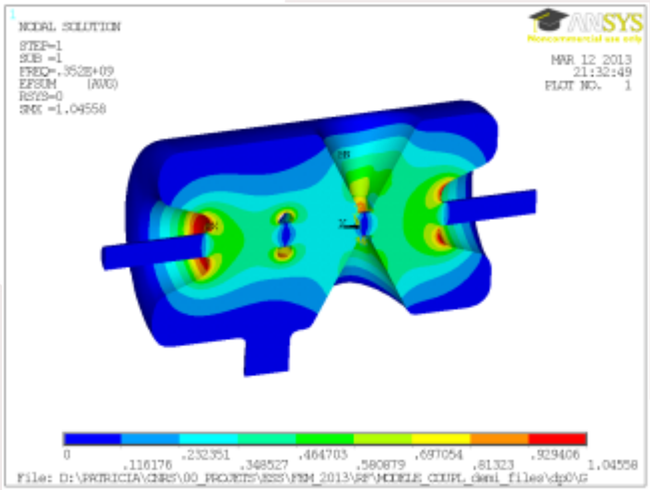
ESS Spoke cavities Design

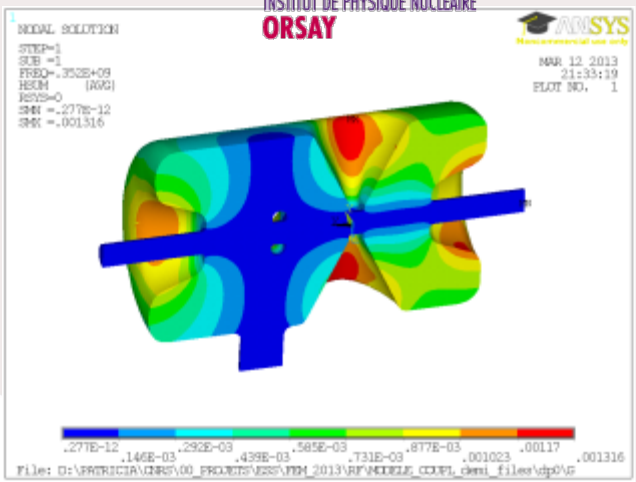
DOUBLE-SPOKE CAVITIES	
Frequency [MHz]	352.2
Beta_optimal	0.50
Operating gradient [MV/m]	9
Temperature (K)	2
Bpk [mT]	61
Epk [MV/m]	38
G [Ohm]	133
r/Q [Ohm]	427
Lacc (=beta optimal x nb of gaps x λ /2) [m]	0.639
Bpk/Eacc [mT/MV/m]	6.8
Epk/Eacc	4.3
P max [kW]	300

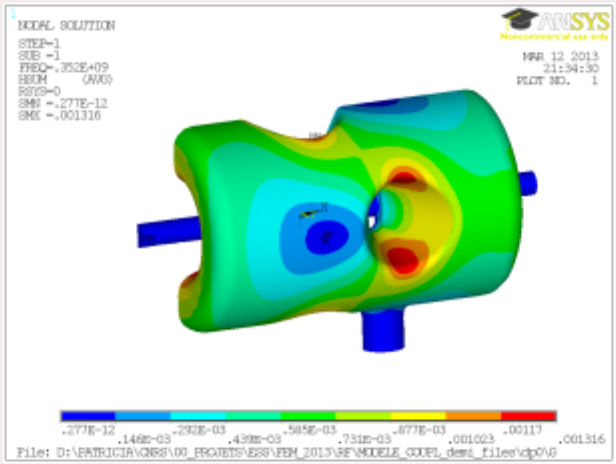
RF parameters



INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY



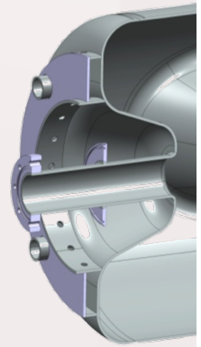




P. Duchesne, G.Olry

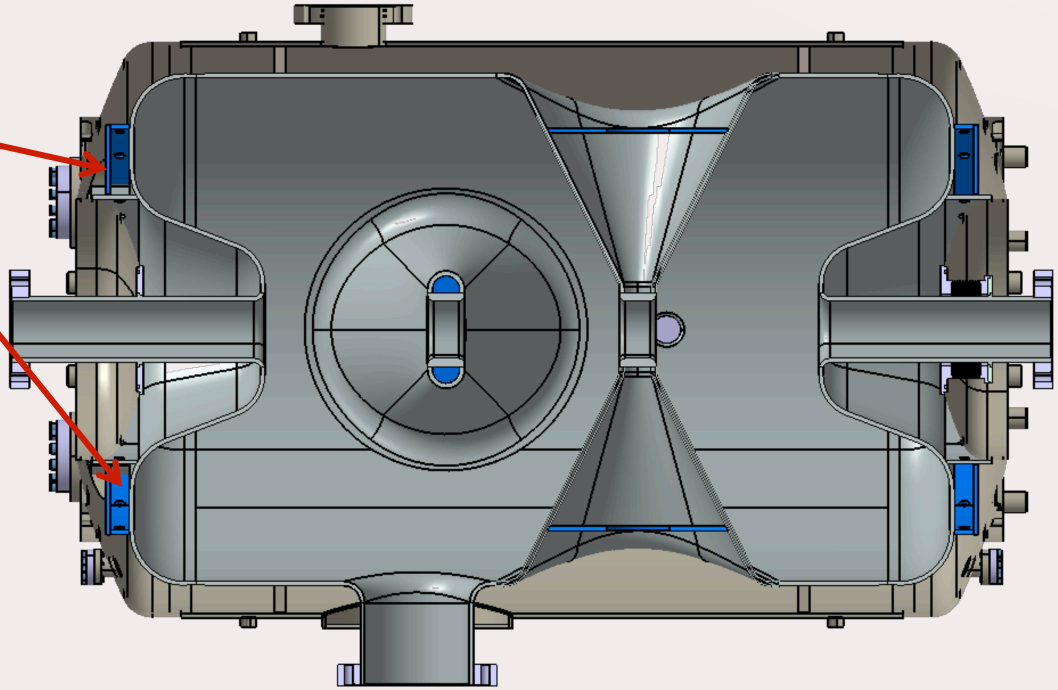
ESS Spoke cavities Design

P. Duchesne, G. Olry



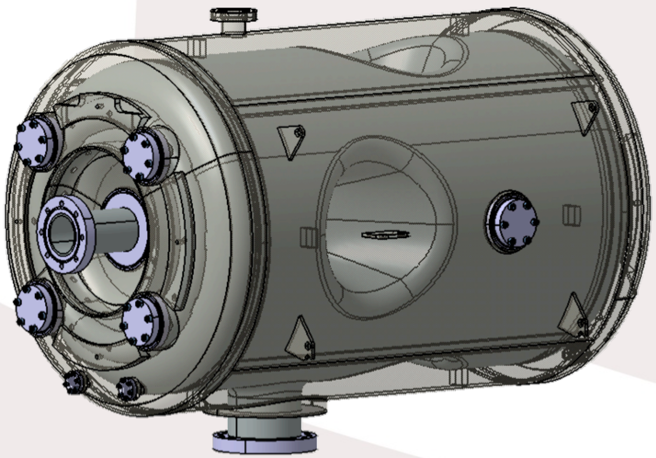
❑ Cavity

- Niobium – 4 mm
- **2 Titanium disks**
- **2 niobium rings**
- 4 HPR ports
- 1 power coupler port
- 1 bellow
- **4 stem stiffeners**



❑ Helium Tank

- Titanium – 4 mm



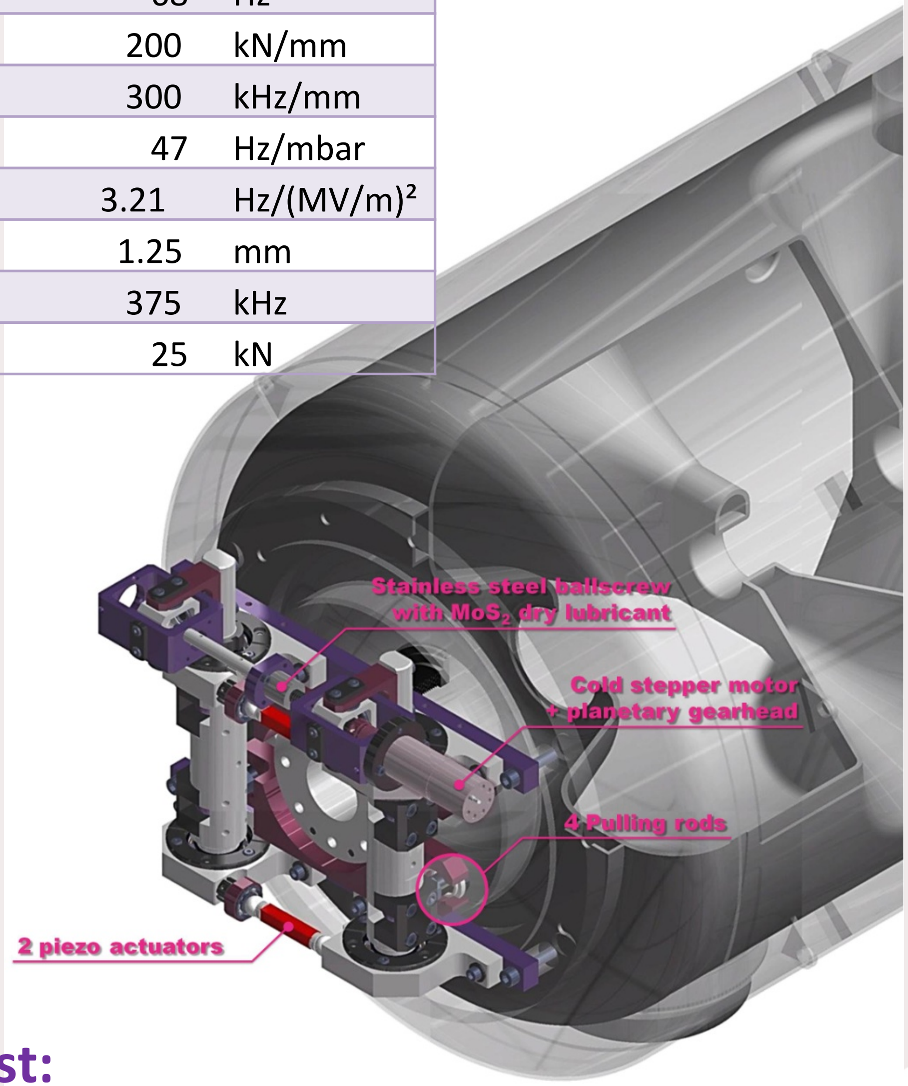
<u>3 prototypes under construction:</u>

Delivery expected in July 2014

ESS 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
CTS stroke	1.25	mm
Max tuning range	375	kHz
Max strength	25	kN

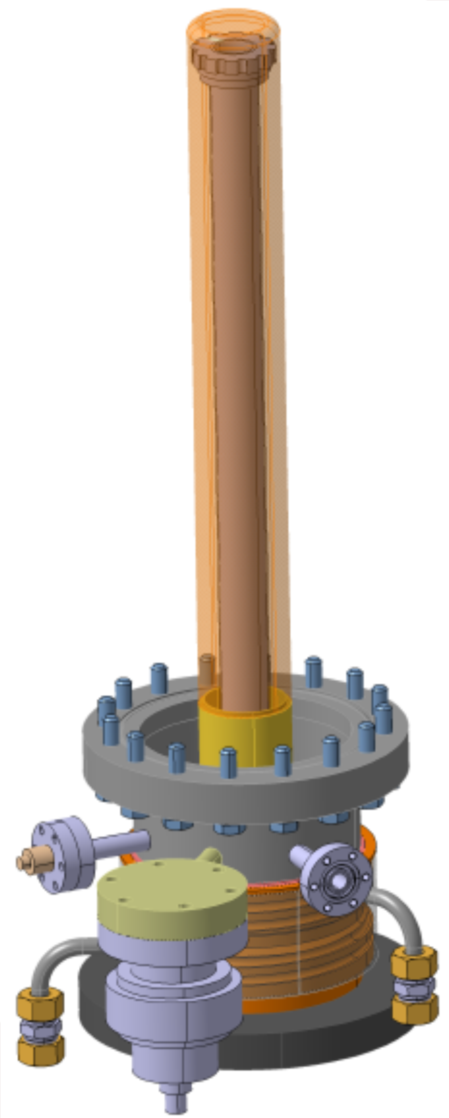
Parameter	Unit	Value
Cavity sensitivity	kHz/mm	110
Cavity RF Bandwidth	Hz	1,355
Cavity stiffness	kN/mm	20
Max. cavity deformation	mm	1.0
Max. strength	kN	20
Resolution	Hz/step	< 1.0 Hz
LFD	Hz	400

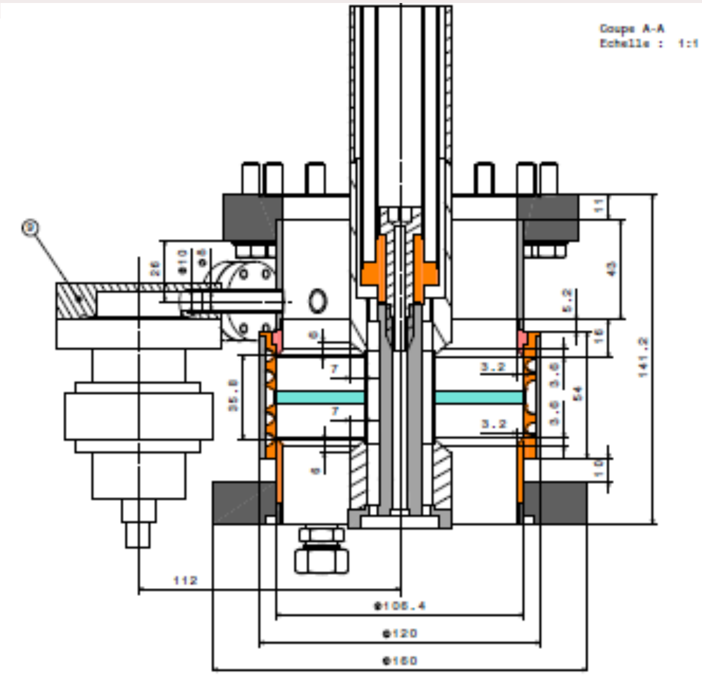


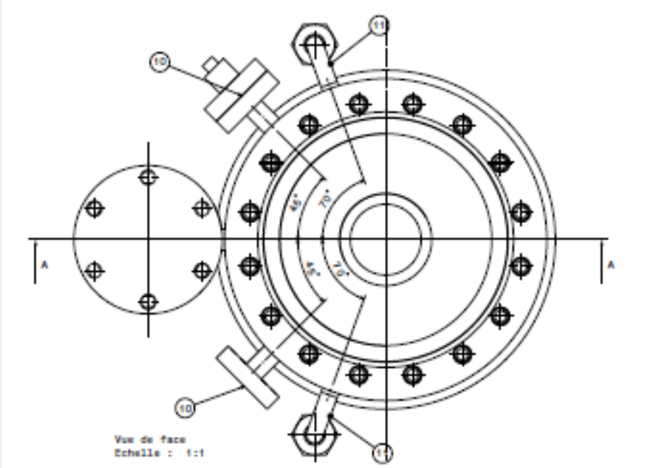
2 prototypes fabricated and under test:

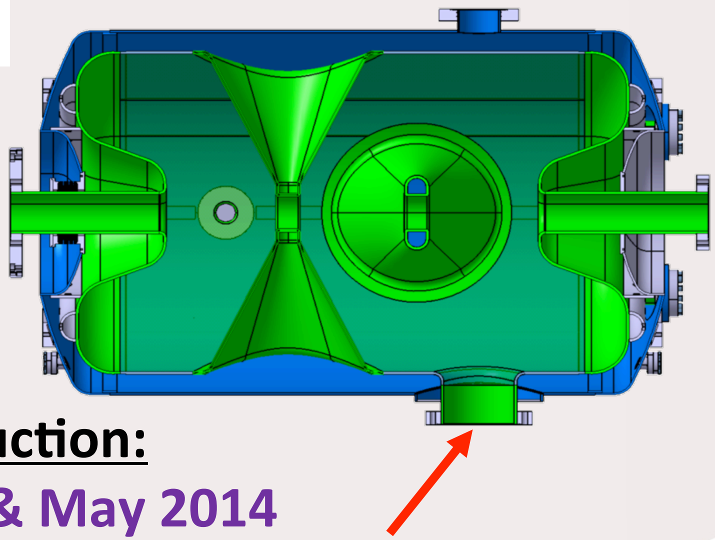
N. Gandolfo

Spoke power coupler









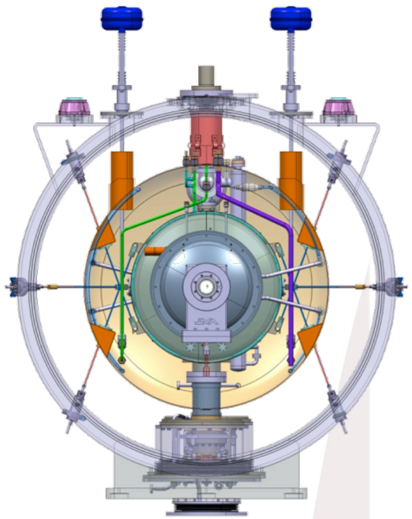
<u>4 prototypes under construction:</u>

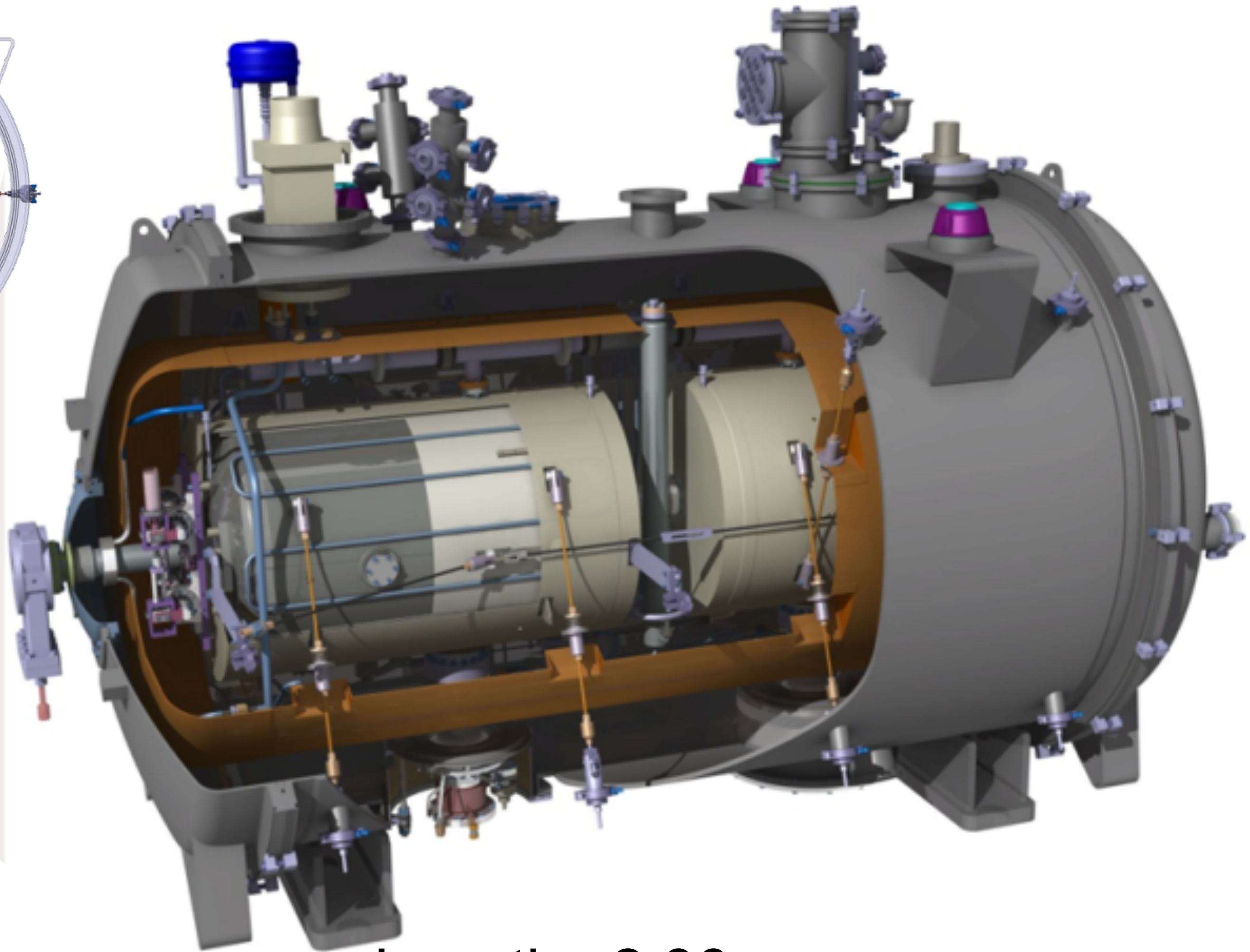
Delivery expected in April & May 2014

Coupler port:
100 mm diameter

E. Rampnoux, D. Reynet, S. Brault, P. Duthil

Spoke cryomodule design





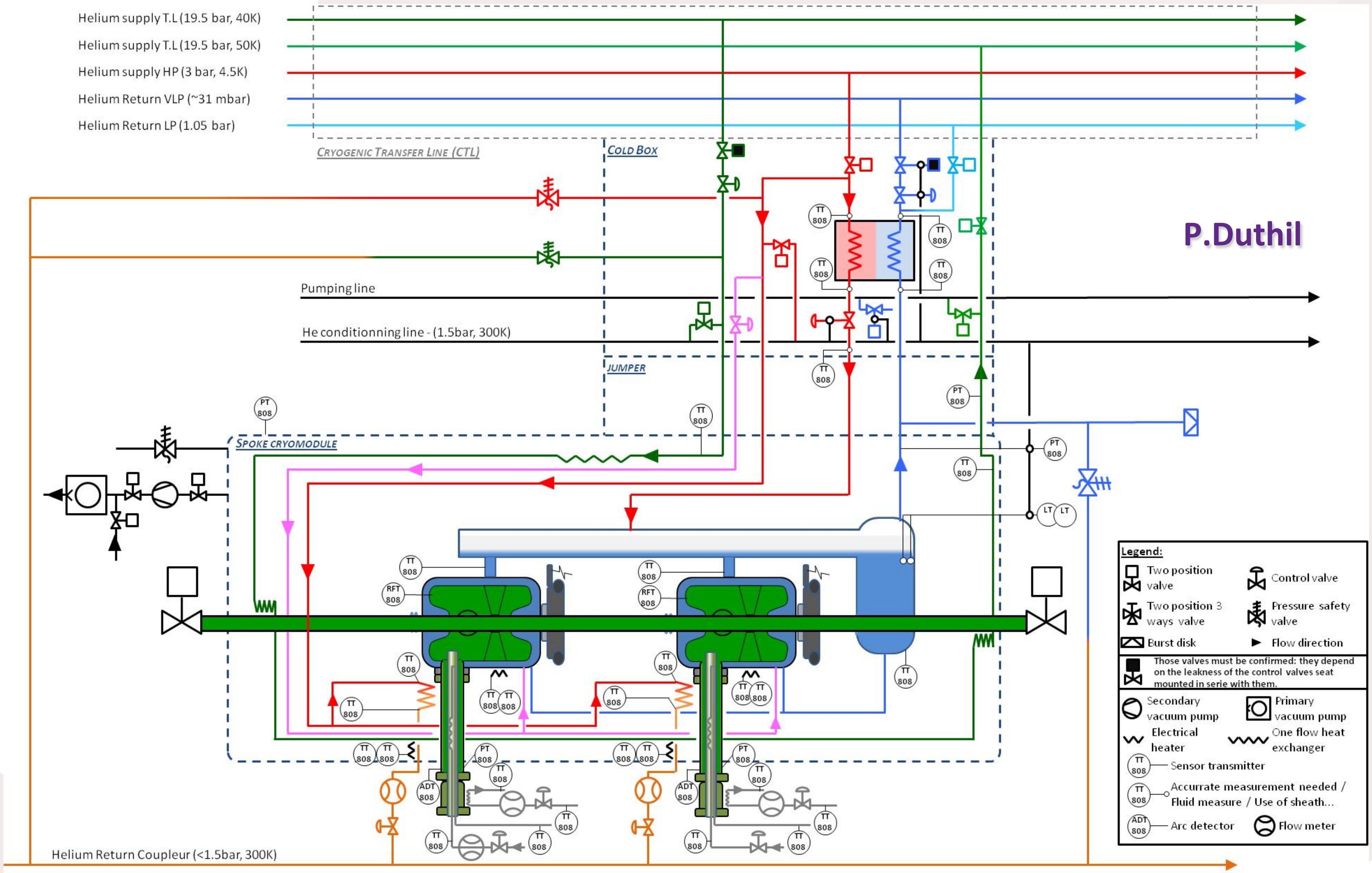
Length : 2.86 m

Internal diameter: 1.29 m

D. Reynet, S. Brault

Spoke cryomodule design

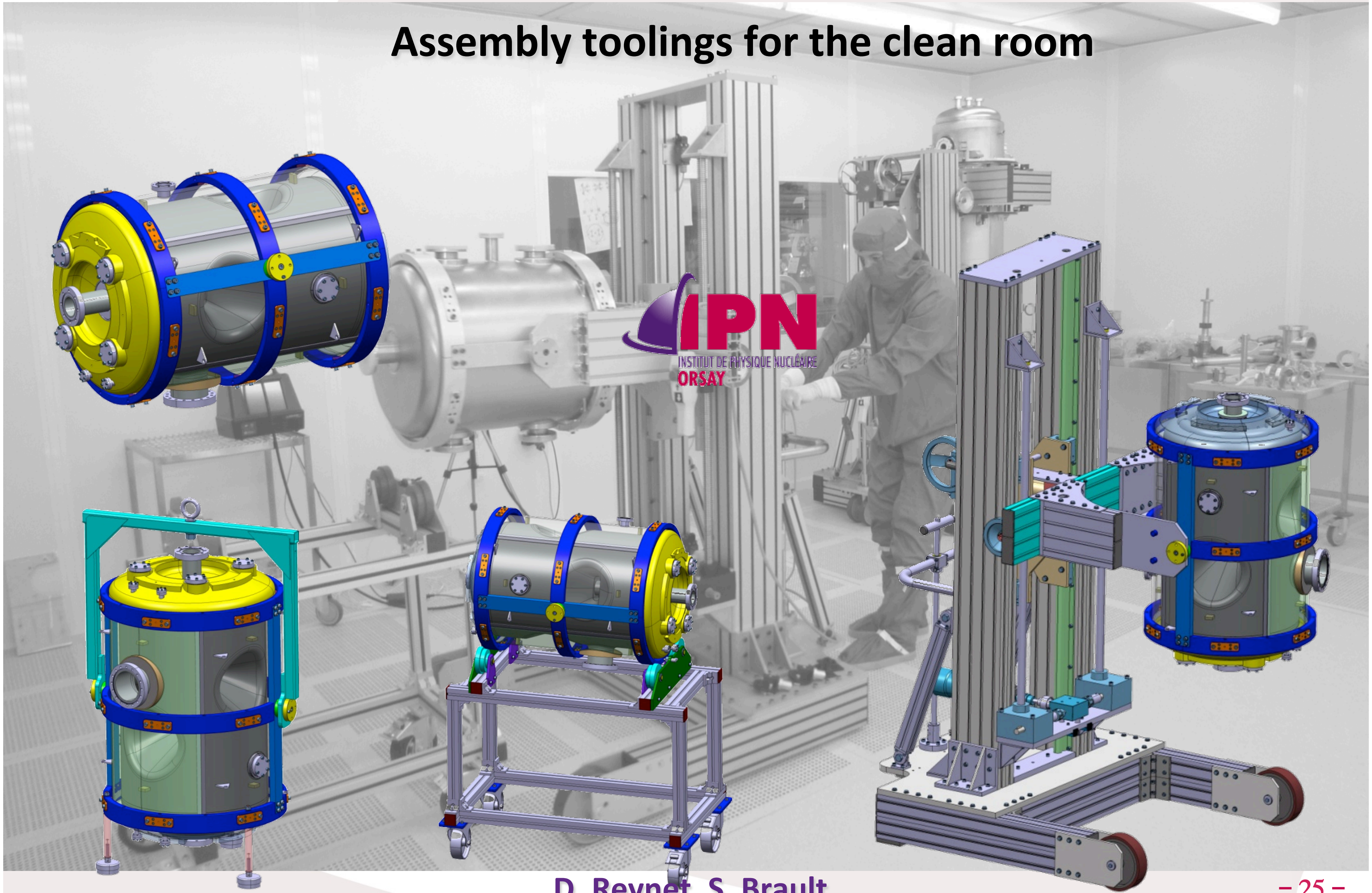
P.Duthil



Cryomodule PID

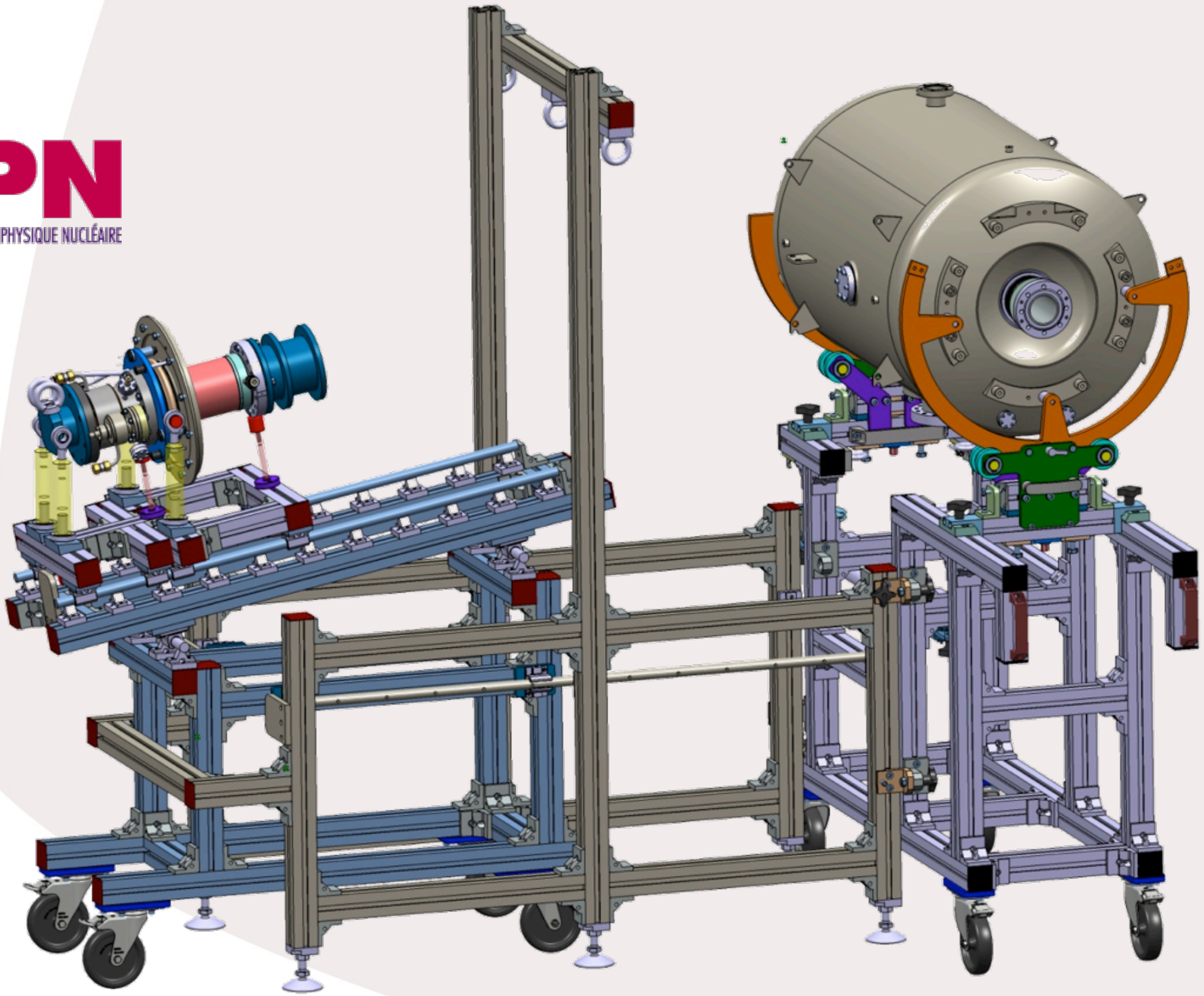
Spoke cryomodule design

Assembly toolings for the clean room



Spoke cryomodule design

Assembly tooling: power coupler assembly

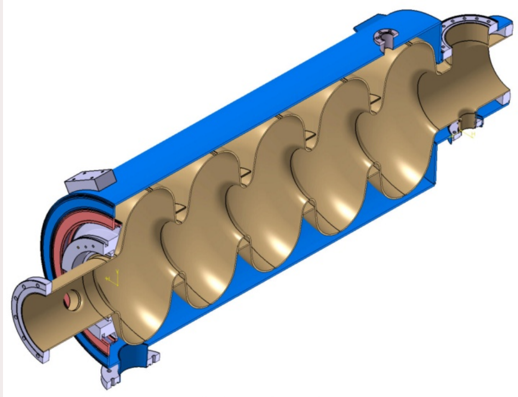


D. Reynet, S. Brault

Elliptical cryomodule Design

IPNO responsible for the cryostat – design et fabrication

- Vacuum tank
- Space frame – cavity support
- Thermal screen
- MLI
- Internal cryo piping
- Instrumentation



IRFU in charge of the "cavity package", cryomodule assembly and test at high RF power

- Cavity + helium tank
- Power couplers
- Piezo tuner
- Magnetic shielding

} design, construction, RF tests

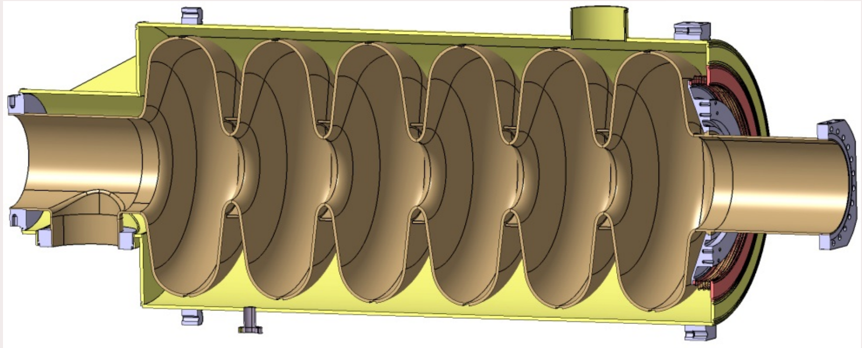
- Tooling for all cavity preparation steps
- Cryomodule asembly
- Test stand: cryogenic system, RF source, C&C
- Tests od the prototype cryomodude (ECCTD)

Elliptical cavity design

Similar design for medium and high beta cavities

1st high beta beta prototype cavity
5-cells – β=0,87
Before He tank welding

A 2nd cavity is under construction



Scheme of the 6-cells médium beta cavity – β=0,87

Tendering for the construction of 6 prototypes.

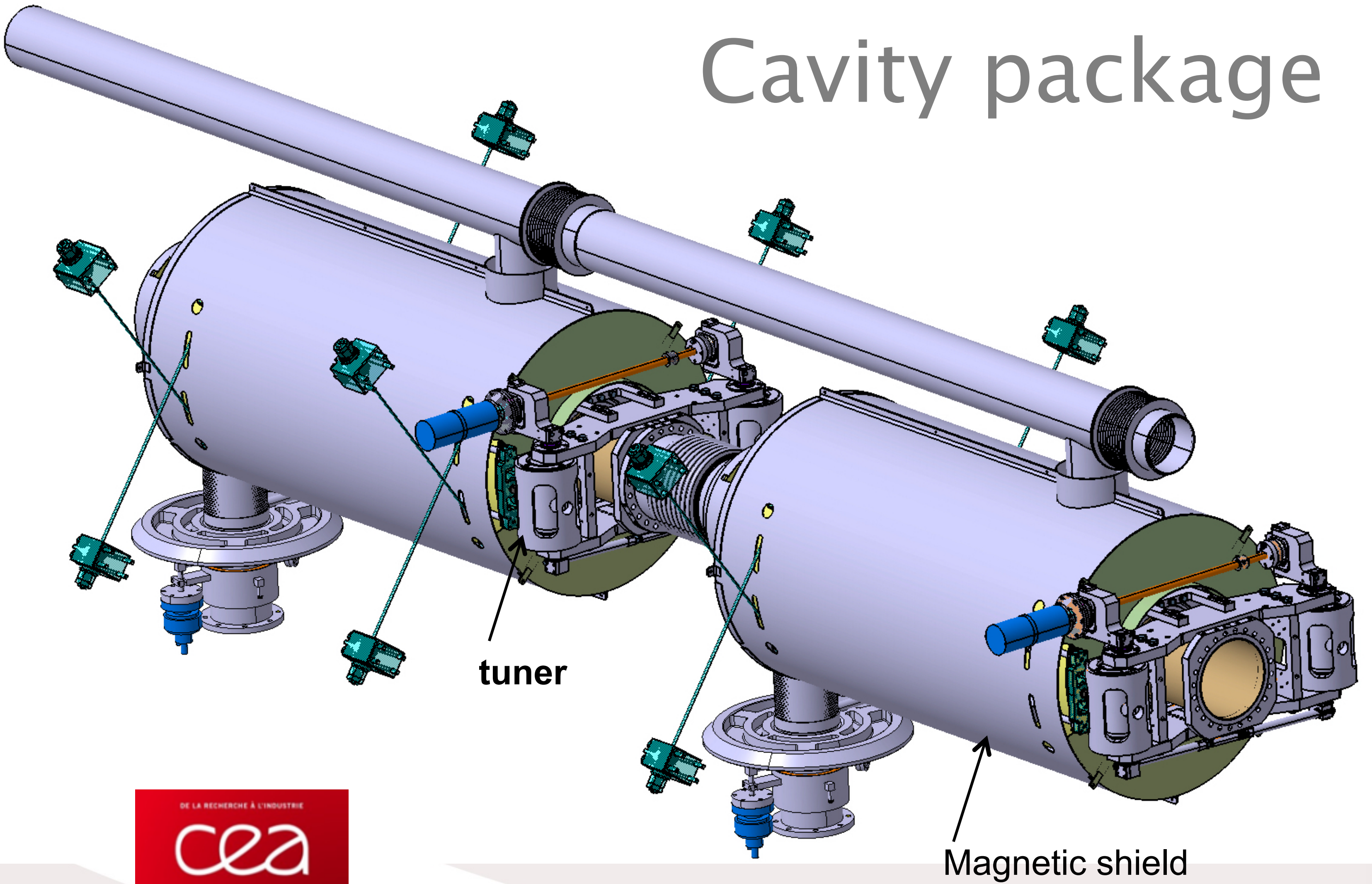
Elliptical cavity design

RF parameters of elliptical cavities

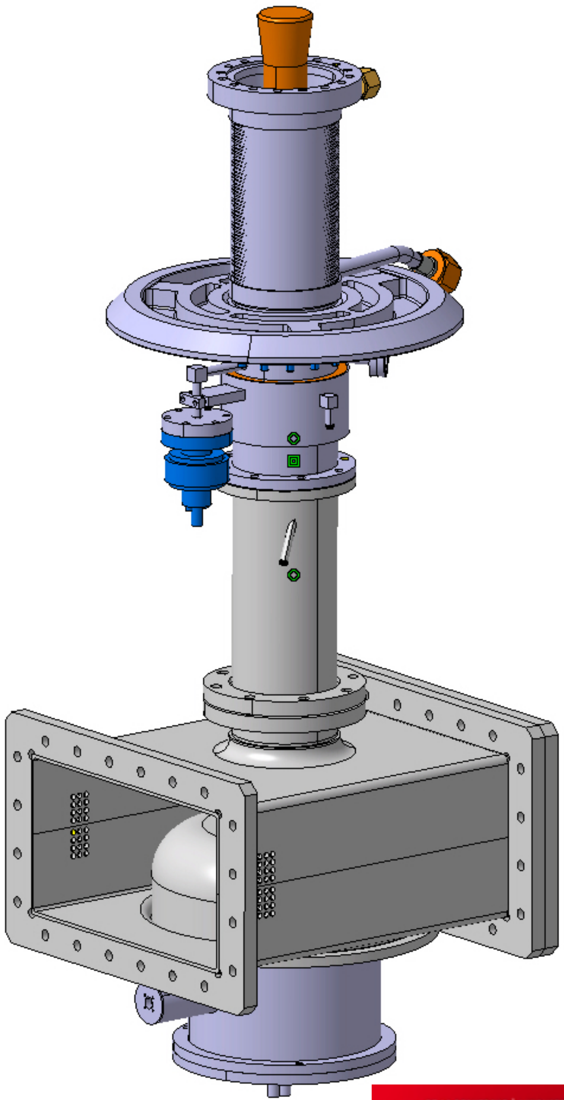
	Medium	High
Geometrical beta	0.67	0.86
Frequency (MHz)	704.42	
Number of cells	6	5
Operating temperature (K)	2	
Maximum surface field in operation (MV/m)	44	44
Nominal Accelerating gradient (MV/m)	16.7	19.9
Q_0 at nominal gradient	> 5e9	
Q_{ext}	$7.5\ 10^5$	$7.6\ 10^5$

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

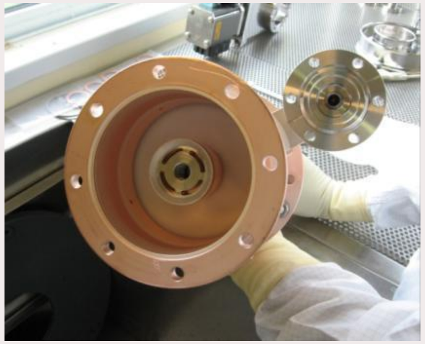
Elliptical cavity design

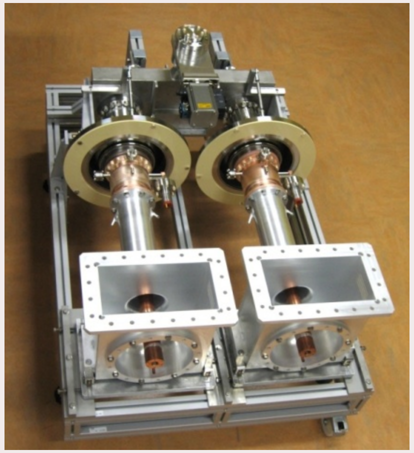


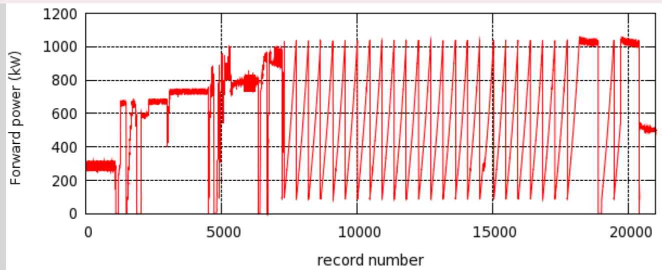
Elliptical power coupler design



HIPPI coupler (KEK type window) tested at Saclay up to 1.2 MW with a 10% duty cycle





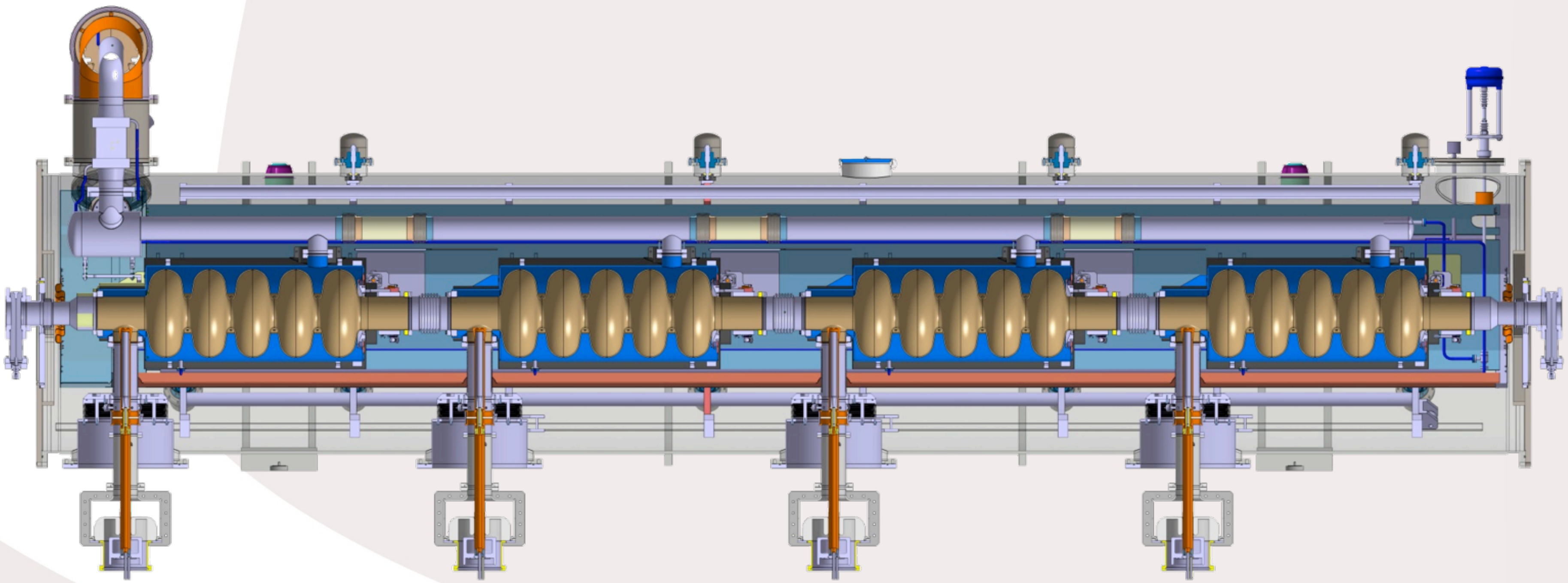


Test of the HIPPI power coupler on the HIPPI cavity at 1.8 K, full reflection

Call for tender ongoing for 6 prototypes

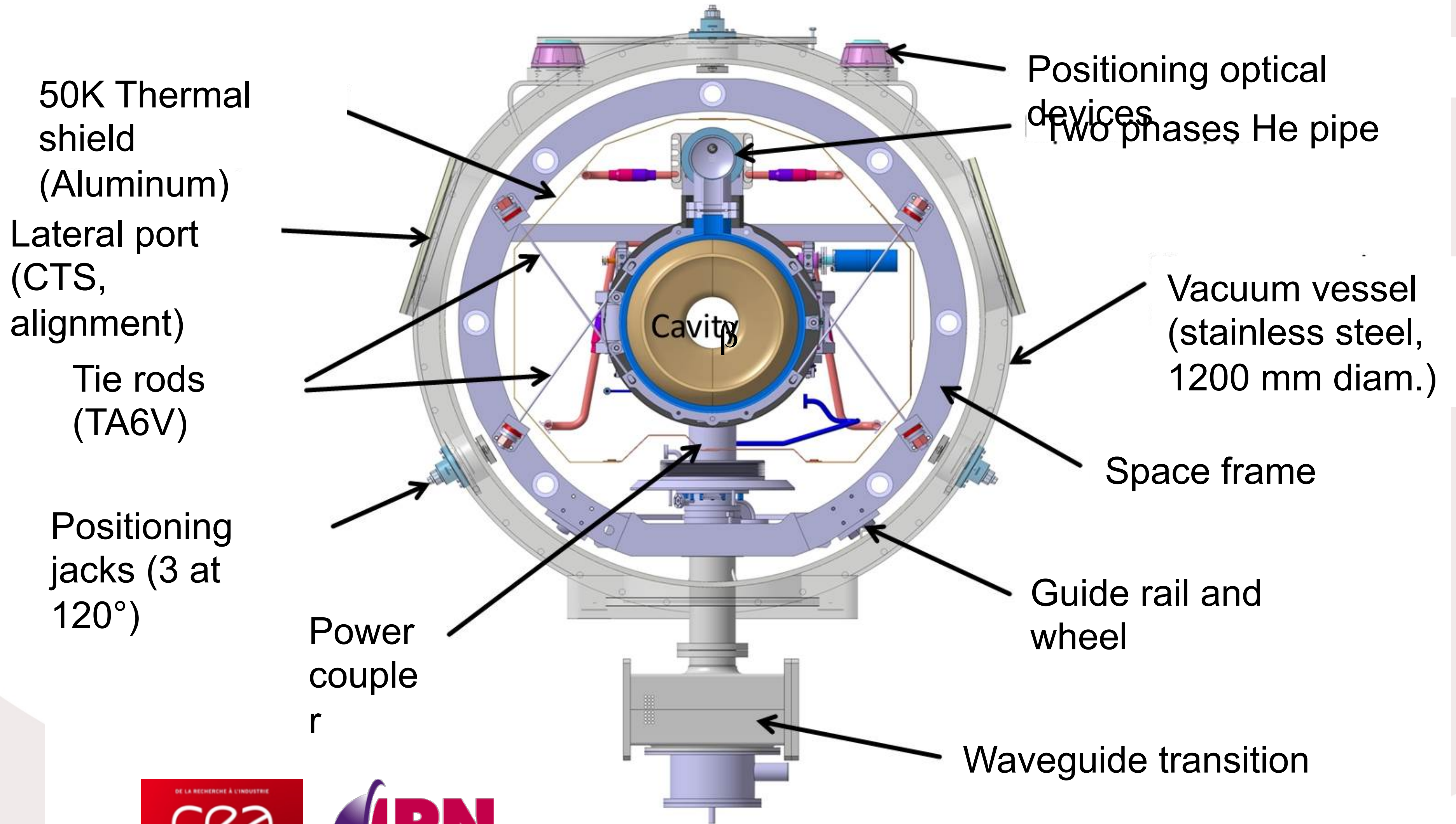
Elliptical cryomodule design

- Design inspired from SNS
- Same design for medium and high beta cavities
  - ✓ Only a small difference in length between the 5-cells Hβ and 6-cells med β
  - ✓ Main components are the same: vacuum tank, thermal shield, support system, alignment devices…
  - ✓ Only small differences: inter cavity belows, cryo piping,…



6600 mm

Elliptical cryomodule design



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Potential In-Kind contributions

Expression of Interest from CEA on ESS Accelerator parts

Accelerator sub-system	Proposed IKC
Proton source & LEBT	100 %
RFQ	100 %
Front end test @ Saclay	100 %
Medium β cavities fabrication & tests	In part (follow-up)
High β cavities fabrication & tests	In part (follow-up)
Mβ & Hβ Cryomodules fabrication	In part
Mβ & Hβ Cryomodules assembly	100 %
Cryomodules RF tests	20 %
Mβ & Hβ power couplers fabrication	100 %
Integration: C&C	In part
Beam diagnostics	In part

Potential In-Kind contributions

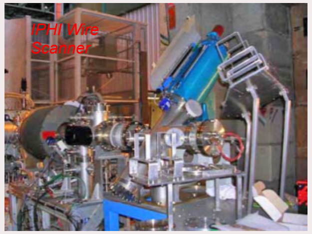
Expression of Interest from CEA on ESS Accelerator parts

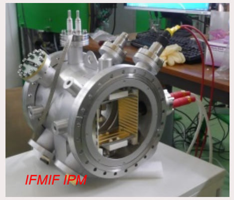
Diagnostics:

- *Emittance measurements (EMU)*
- *Profile measurements with luminescence*
- *Species fraction measurements with Doppler shift method*
- *Beam Position Measurements*
- *Wire Scanner*
- *Ionization Profile Measurements*
- *Diagnostics box:*

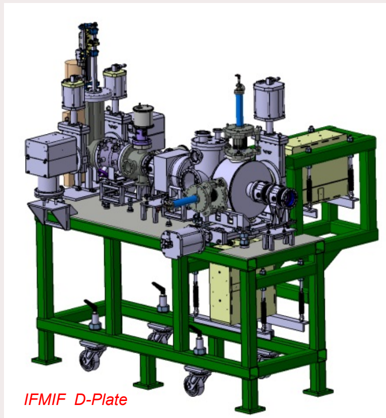
  System to validate the different parts of accelerator from source to DTL

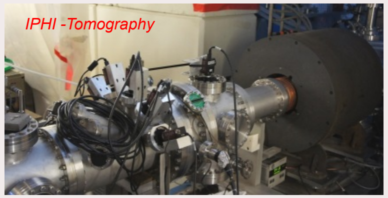
  - ➢ *Magnetic system*
  - ➢ *High power slit (like IPHI)*
  - ➢ *Wire Scanner*
  - ➢ *Emittance Measurement Unit*
  - ➢ *Beam Position Monitor*
  - ➢ *Bunch Length monitor*
  - ➢ *Camera, Tomograph*
  - ➢ *Ionisation Profile Monitor*
  - ➢ *Beam dump (like IPHI)*
  - ➢ *Doppler shift Spectrometer (like IFMIF)*
  - ➢ *Command Control with EPICS*





Ionization Profile Measurements:





Control & Command system (EPICS):

- *Ion source*
- *LEBT: optical elements , RFQ , beam diagnostics*
- *MEBT and HEBT: beam diagnostics*
- *Full Diagnostics Box control system (if diagnostics box is chosen by ESS)*

Potential In-Kind contributions

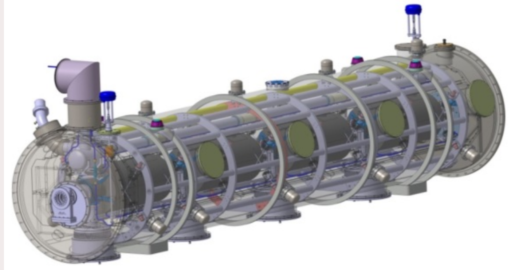
Expression of Interest from CNRS on ESS Accelerator parts

Accelerator sub-system	Proposed IKC
Spoke cavities (Fabrication and + tests in VC)	100 %
Spoke power couplers and tuners	100 %
Spoke cryomodules fabrication and assembly	100 %
Spoke Cryomodule tests at high power	10 % (follow-up)
Accelerator cryoplant	~ 90 %
Accelerator cryo-distribution	~ 65 %

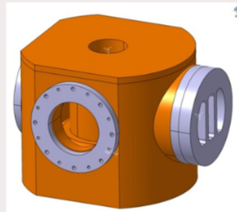
Early In-Kind contributions

Work on some packages for in-kind contribution may start even in 2014 for urgent parts: early IKC

- **High beta elliptical prototype cryomodule**



- **Prototyping and copper supply for the RFQ**



- **C&C system for the ion source developed by INFN-Catania**

- **Niobium for the spoke series production ?**


To be actively continued...