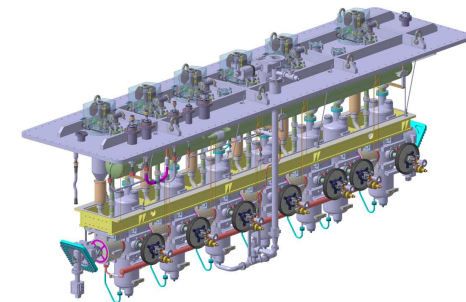
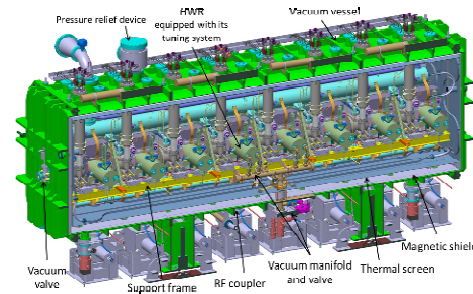
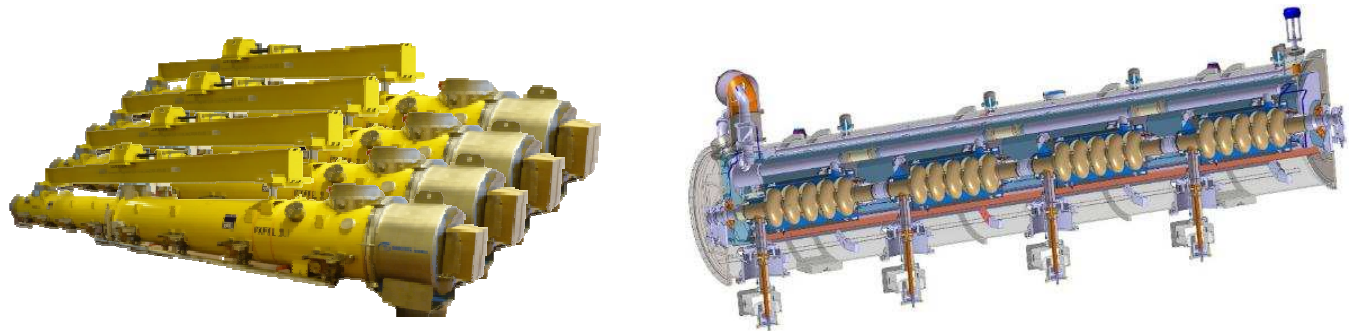


DE LA RECHERCHE À L'INDUSTRIE

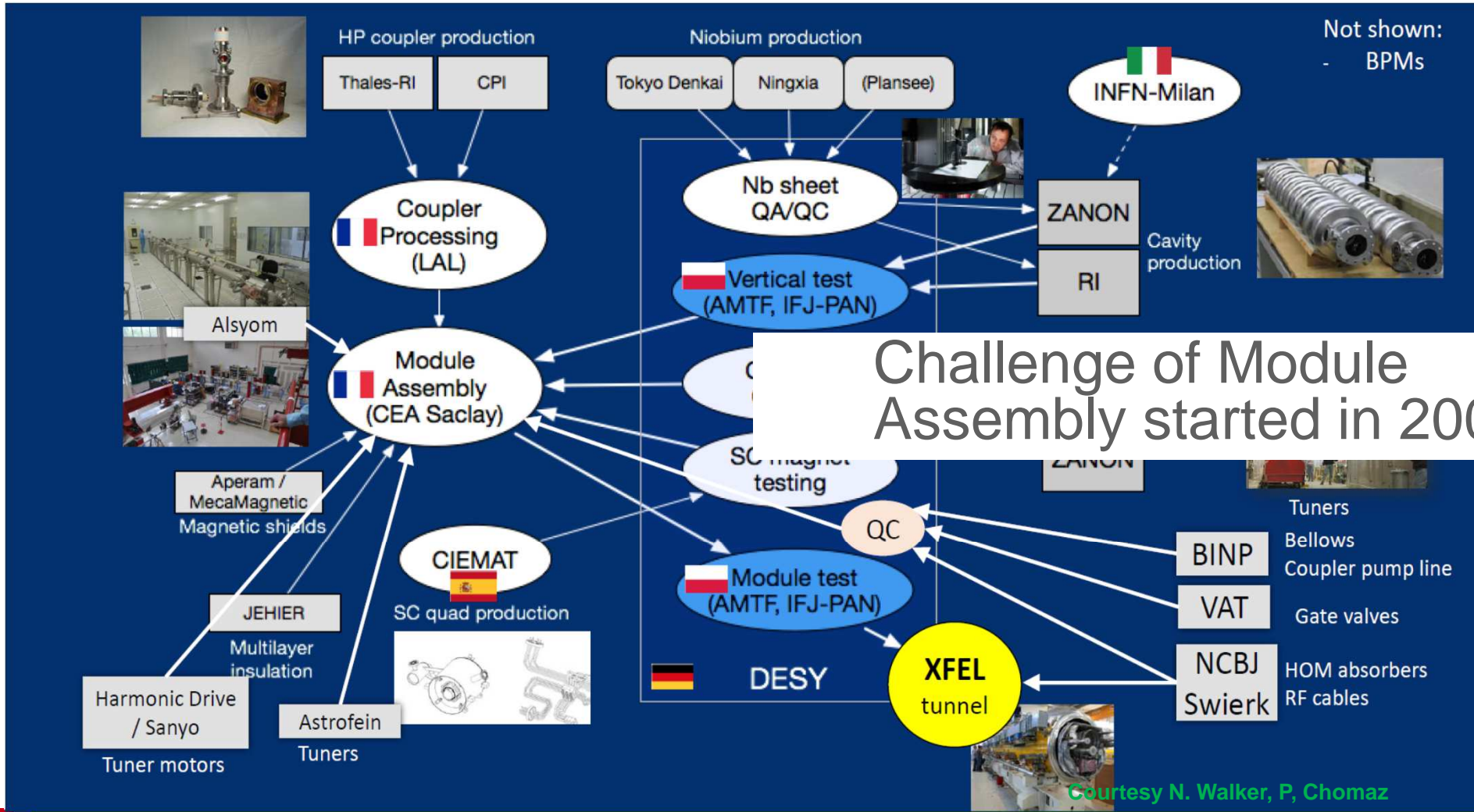
cea



CRYOMODULES @ CEA :

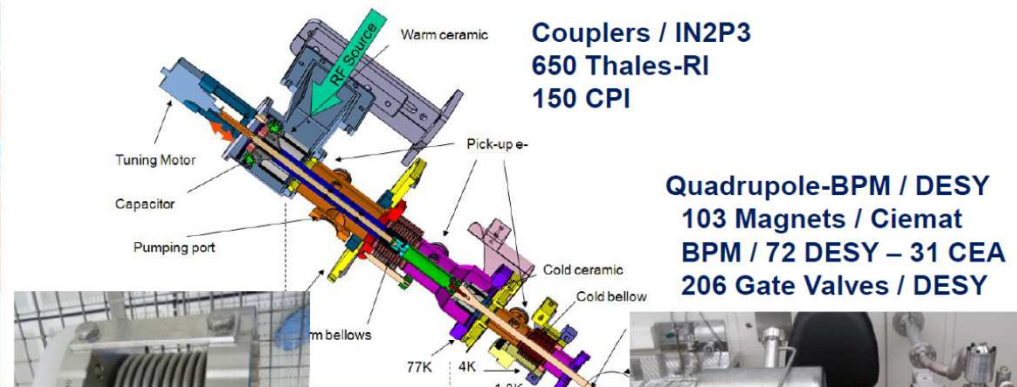


C. Madec – CEA/DRF/IRFU/DACM/LIDC2 – 09-04-2018

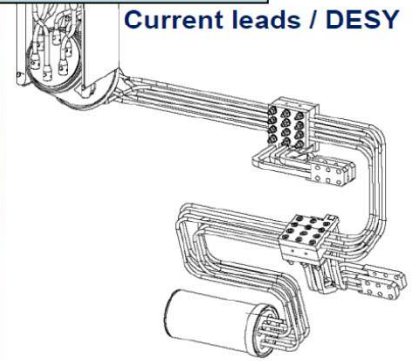
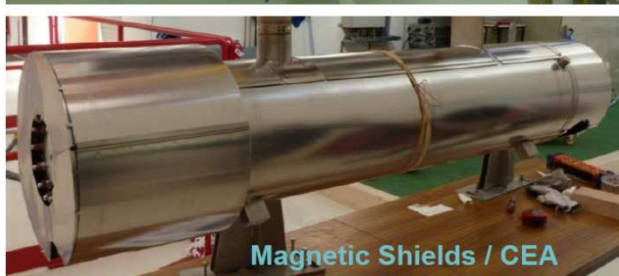


Challenge of Module Assembly started in 2007

Courtesy N. Walker, P. Chomaz



**There are 9 422 individual components integrated
and over 12 400 individual parts manipulated
per cryomodule**



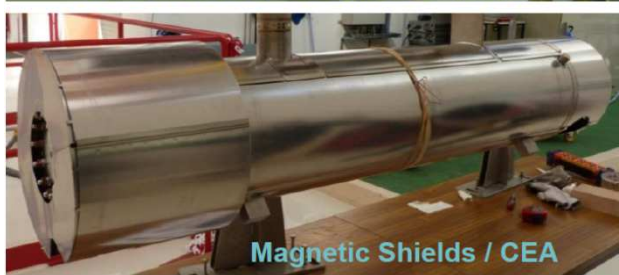
Cryo-systems



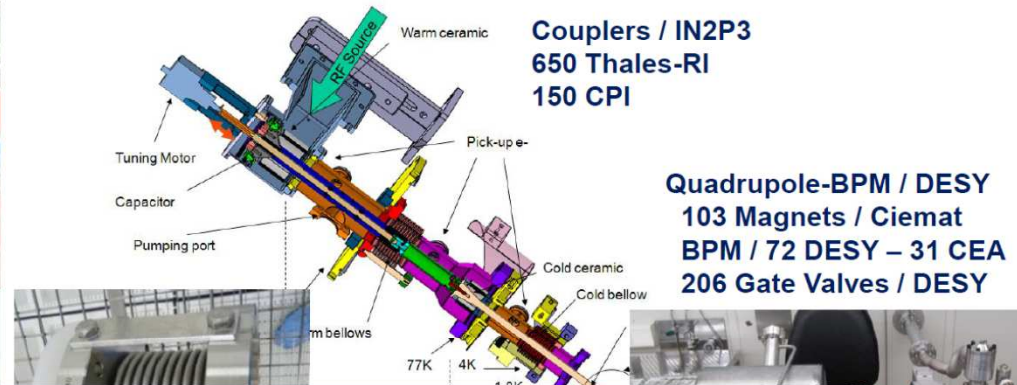
Vacuum vessels



45 from Zanon, 58 from IHEP/DESY



Magnetic Shields / CEA

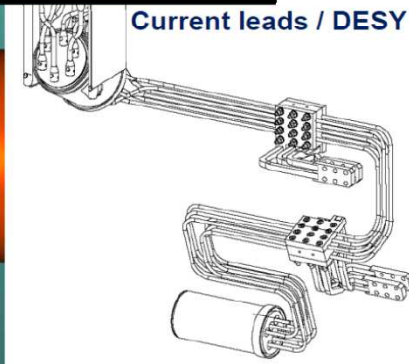


About 1 million parts manipulated
from April 2013 (XM-2) till July 2016
(XM100)

800 Cavities / DESY
400 Zanon / 400 RI



Current leads / DESY



- | | |
|--|-------------|
| 1. Decision | 2007 |
| 2. Set up the infrastructure | 2008 |
| 3. Training at DESY | 2008 – 2009 |
| 4. Preparation of Tooling | 2009 – 2010 |
| 5. Prototyping at Saclay | 2010 – 2012 |
| Preindustrial study | |
| Training of the team | |
| Documentation | |
| Commissioning of the infrastructure with XFEL Prototype Modules (PXFEL2&3) | |
| Call for tenders for MLI, magnetic shields, Al gasket and nuts and bolts | |
| 6. XFEL module assembly by industrial operator | 2012 – 2016 |

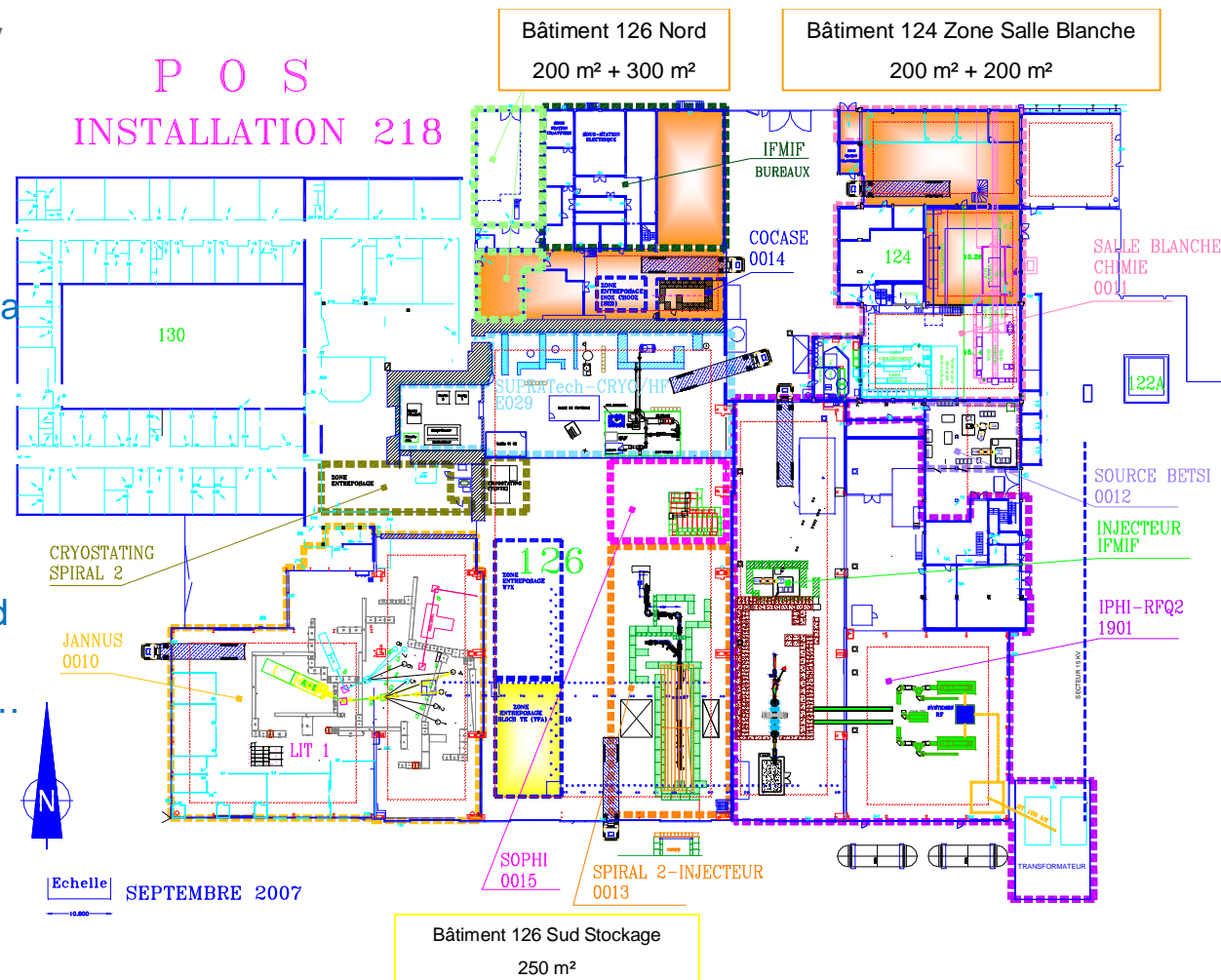
Minutes of Cold Linac Meeting @ DESY (2-3 July 2007) : “...The string and module assembly done at Saclay was described as another possible in-kind contribution. *Details have to be figured out.* So far, these steps in module production are foreseen to be done in industry.”

...an idea set forward by B. Visentin and C. Cavata

Minutes of Cold Linac Meeting @ Saclay (3-4 September 2007) : “...Saclay is interested to take 50% of the 1.3 GHz cryomodule assembly and will check whether 100% would also be feasible (*Remark: In the meantime, Saclay confirmed the wish to take the responsibility for 100%.*)” though the XFEL budget book did not include 2 module assembly plants !

→ 2-week to 1-week throughput, a small detail...

Cold Linac Meeting @ DESY (12-13 November 2007) : *the XFEL Village was born*, created by a group of 7 people (CM, SB, BV, AD, SC, JPC, ON), proving a successful concept.



2008 : Year of the worldwide financial crisis, led to French 'Stimulus Plan':

→ 2.3 M€ budget available in 2008 for CEA expenditures over 2009-2010, with 'simplified' procedures





Irfu 2010 – 2012 : Prototyping and call for tendersⁱ



After an early participation of CEA staff to M3-M8 FLASH modules at DESY, the **transfer of knowledge** between DESY and CEA took place at Saclay with the disassembly-reassembly of the 'prototype cryomodules' P-XFEL2, down to its cavity string, and later assembly of P-XFEL3 'in kit'.




P-XFEL2



and back




Tuning system assembly on cavity n
n=[2,8]



Written by		Checked by		Approved by	
Name	Yannick SAUCIE	Name	Jean-Pierre CHARRIER	Name	Christophe L...
Function	Technicien	Function	Responsable hat manager	Function	System eng
Date		Date		Date	
Signature		Signature		Signature	

Irfu XFEL		GOM n°FAS5_AIR_02		V 2.0	
		Tuning system assembly on cavity n=[2,8]		Page 6/17	
				Date: 21/09/2011	

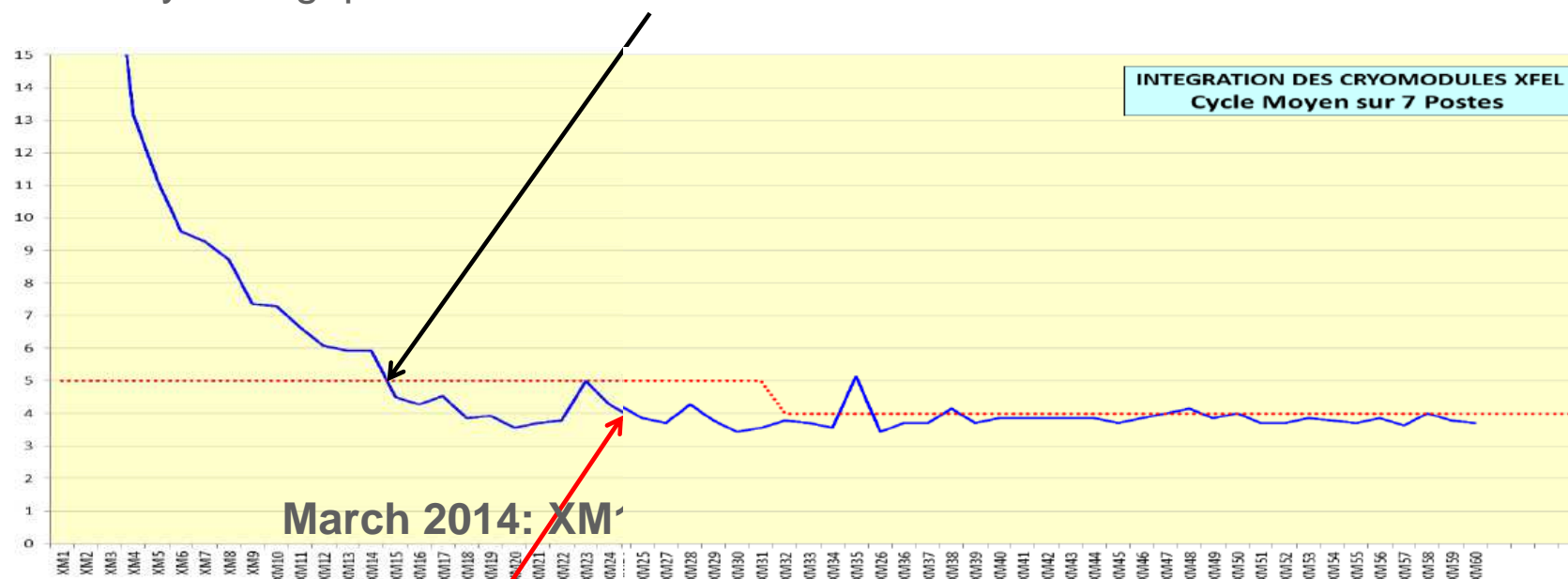
1. Identify the correct side of the cavity assembly, it is opposite to the side and 8 support magnets are edge of the tank.
2. Check and verify that all the screws the cavity ring are well fixed (4 M4 and 2 M4 tangential).
3. Check and verify that the M10 with its washer is inserted in the support magnet on the motor side from the pad axis.
4. Remove the MDM cable and the support magnet and the PU cable (MMA support).
5. Remove the cavity clamp on the side of the inner rod pool, leave the bottom side on its place.
6. Screw the first solid joint on the turner frame in the lower part from the motor) with the M10 screw it by hand leaving it loose shaped and should point towards...



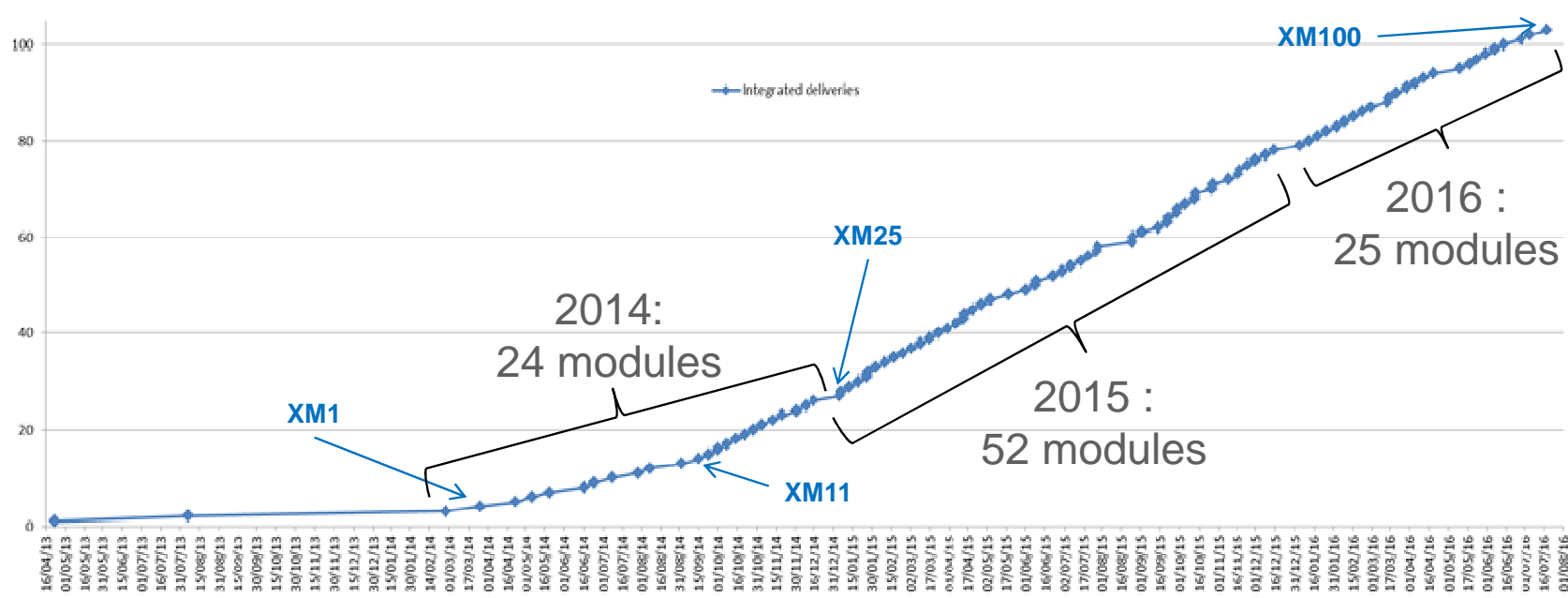
50. Place the two smallest ball bearings 19x7x5 in the corresponding hole in the motor housing of the drive unit.
51. Holding the drive unit by hand, place it briefly in the correct position in order to evaluate the required position of the nut along the Q10 screw. Then move it as needed to install it easily.
52. Place the drive unit in place with the motor wire pointing up (to ease cabling after the magnetic shielding installation), insert the two special drive unit axia.
53. Screw the 6 M4 12 mm screws to fix the drive unit axia, install the two last ball bearings 24x20 over the nut and fix them with two safety washers.
54. While holding the position start screwing (with the proper special tool) the adjusting screw on the bottom (the one with spherical head).
55. Screw the adjusting screw at the bottom until a good contact between frame, solid joint and cavity is reached, then screw 1/8 turn more for further fastening.

'ANNUS HORRIBILIS'

- 5-day throughput was reached mid-October 2014 with XM15



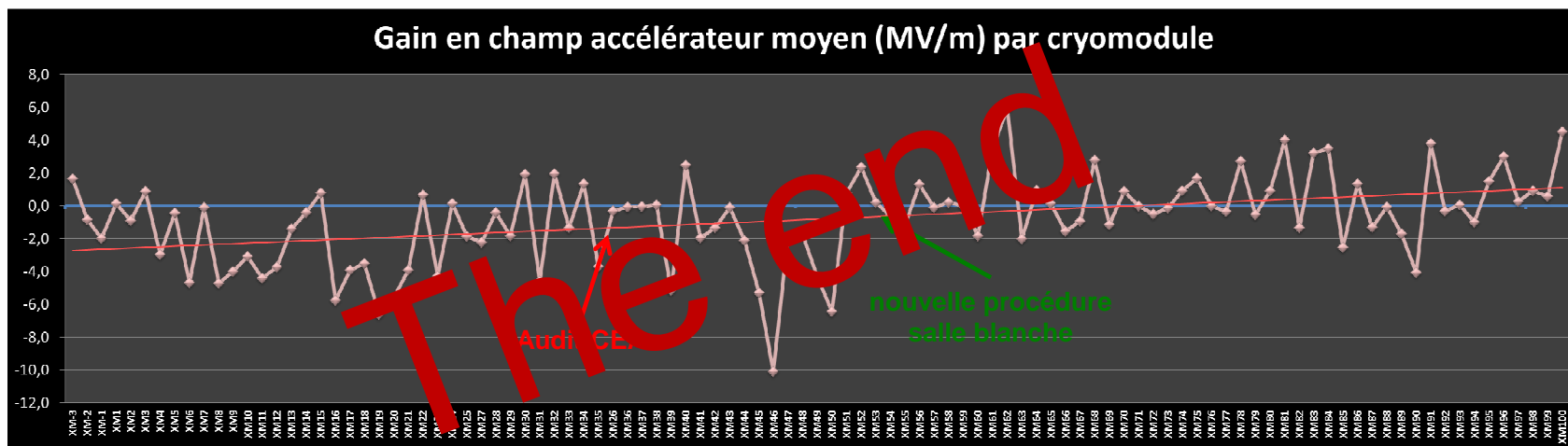
4-day throughput was reached in January 2015 with XM25



Shipment schedule of 103 cryomodules:

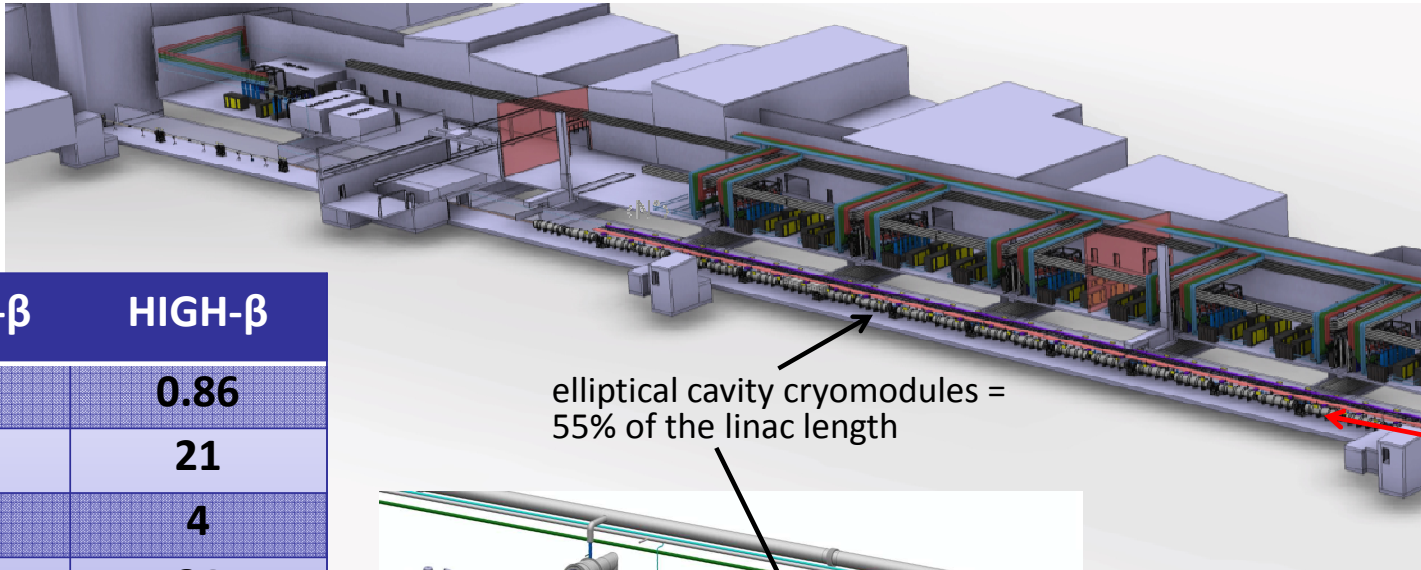
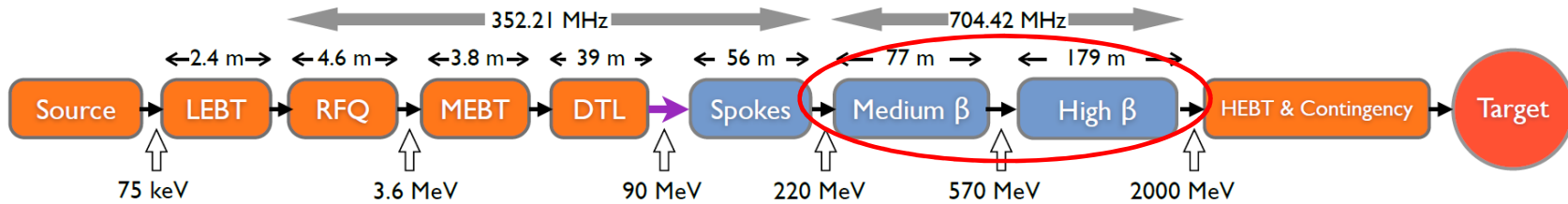
- Start of integration on 10 September 2012 (XM-3)
- Nominal throughput of 5 days reached in September 2014 (XM11)
- Acceleration of production to 4-day throughput in January 2015 (XM25)
- Slow-down of production in December 2015 (XM78) with RF-coupler delivery
- Shipment of last module (XM100) on 27 July 2016.

Gain in Average accelerating gradient Gain (MV/m) per cryomodule, comparing vertical tests results and tests in cryomodules



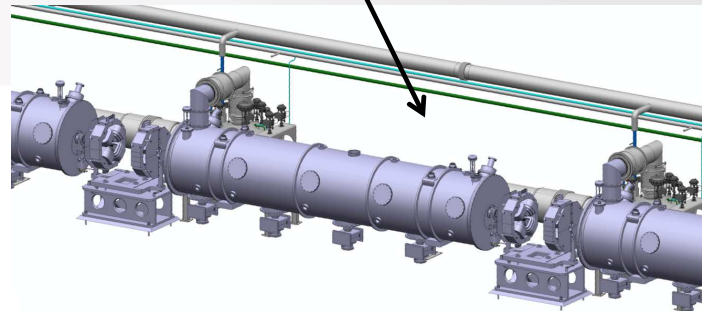
- $\langle E_{acc} \rangle = 27.6$ MV/m higher than the specifications 23,6 MV/m.
- degradation of accelerating field in cavities after integration until XM23, when CEA et ALSYOM target was to reach a throughput of 5 days, then audits from CEA
- From XM54, new assembly procedures in clean room from CEA, lead to produce cryomodules with higher performances than vertical tests

ELLIPTICAL CRYOMODULES IN THE ESS LINAC



elliptical cavity cryomodules = 55% of the linac length

Proton Beam



	MEDIUM-β	HIGH-β
β	0.67	0.86
# CM	9	21
Cav. /CM	4	4
# Cav.	36	84
CM L [m]	6.584	6.584
Sector L [m]	77	179

704 MHz



- Cryomodule requirements and interfaces
- Cryomodule transport
- Cryomodule test stand
- Tunnel installation and operation



- Medium Beta Cavity design
- Medium Beta Cavity procurements
- Medium Beta Cavity vertical tests



Science & Technology
Facilities Council

- High Beta Cavity procurements
- High Beta Cavity vertical tests



- Cryomodule and cavity design
- M-ECCTD and H-ECCTD construction and test
- Series cryomodule components procurement and assembly
- Series couplers
- Cryomodule test stand

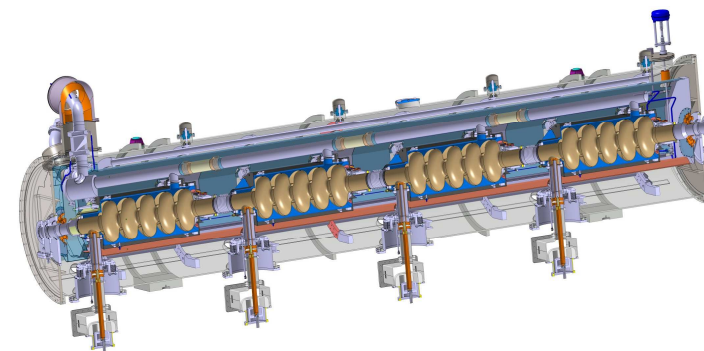


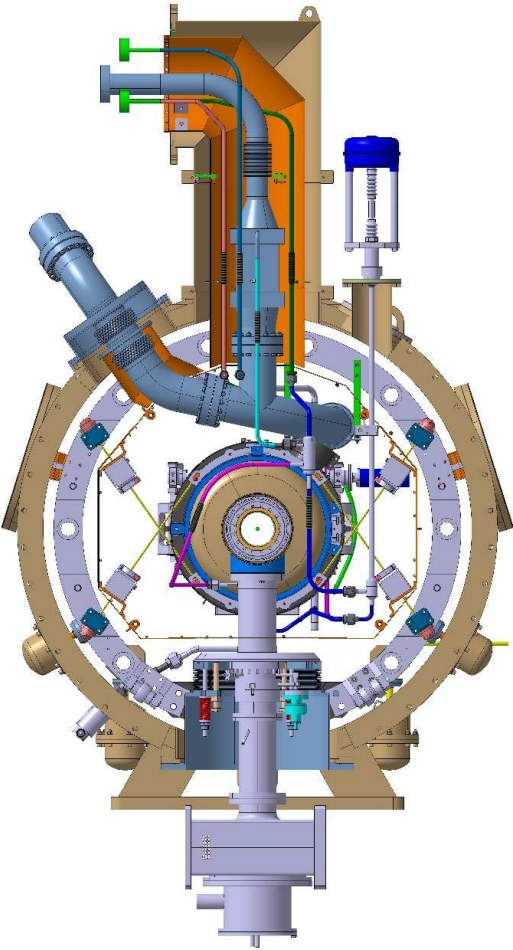
UPPSALA
UNIVERSITET

- Cavity horizontal test

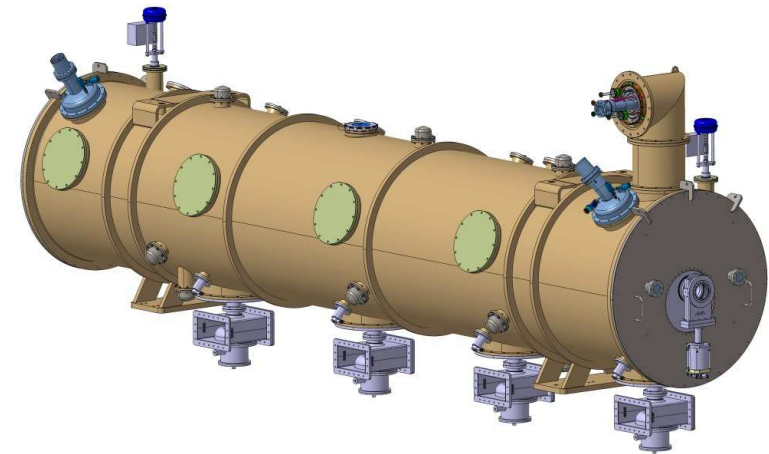
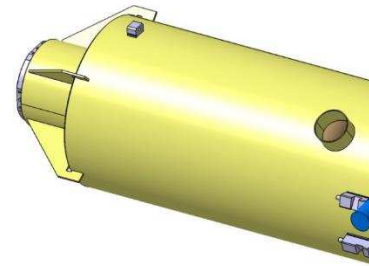


- Cryomodule engineering design
- M-ECCTD cryostat components procurements



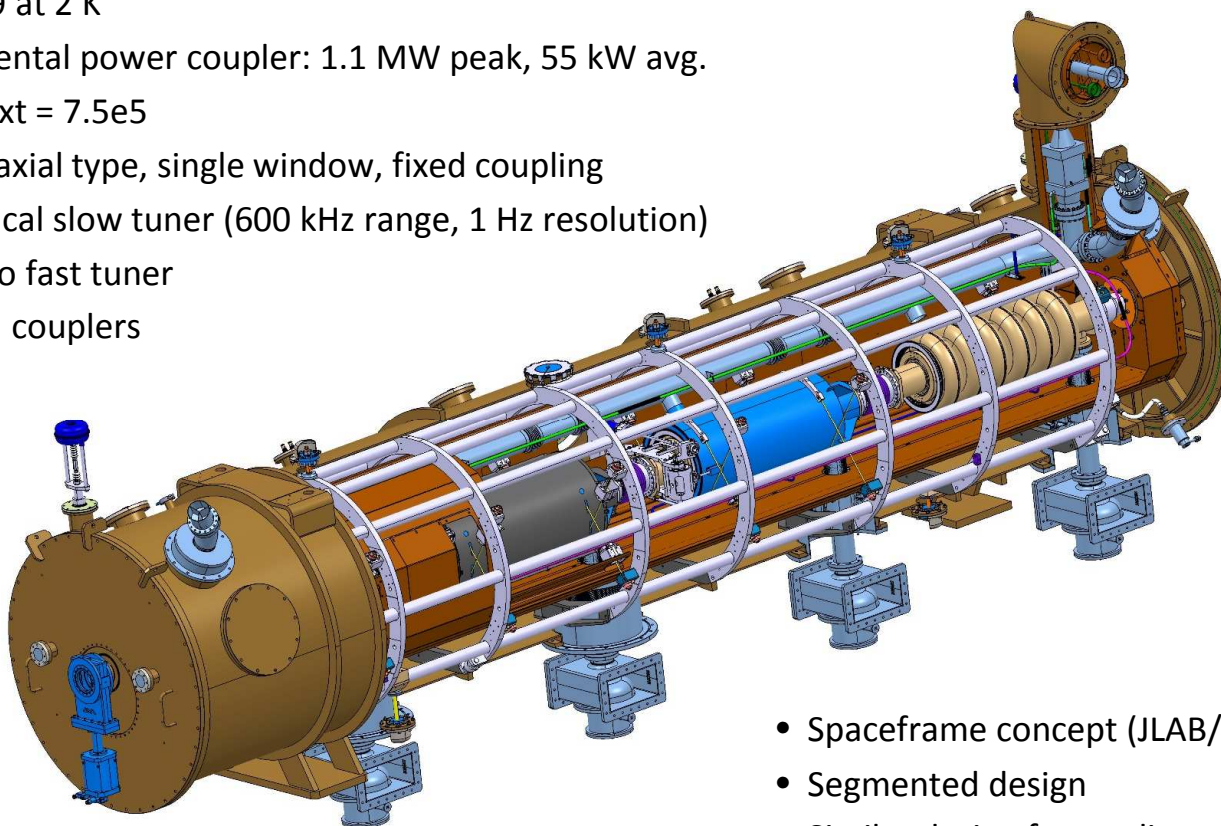


- ✓ ESS elliptical cryomodule design
- Medium beta cryomodule demonstrator M-ECCTD
 - Cavities and couplers individual performances
 - Cryomodule assembly
- ☐ High beta cryomodule demonstrator H-ECCTD
- ☐ Series cryomodule production preparation
 - Procurement plan
 - Series power couplers RF conditioning
 - Series cryomodules integration plan

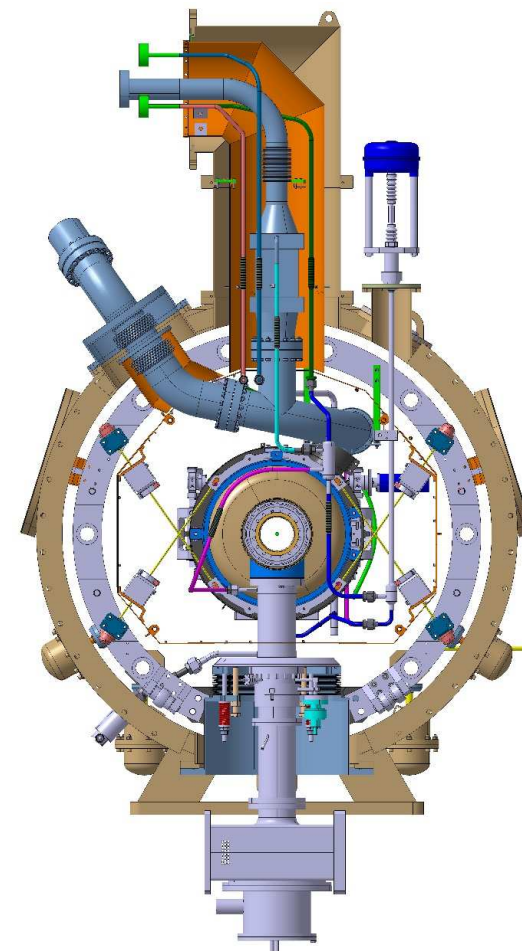


ELLIPTICAL CRYOMODULE MAIN FEATURES

- 704 MHz, 3.6 ms RF pulse at 14 Hz
- Eacc = 16.7 MV/m (MB) and 19.9 MV/m (HB) (Epeak = 40/44 MV/m)
- Q0 > 5e9 at 2 K
- Fundamental power coupler: 1.1 MW peak, 55 kW avg.
 - Qext = 7.5e5
 - Coaxial type, single window, fixed coupling
- Mechanical slow tuner (600 kHz range, 1 Hz resolution)
- 1+1 Piezo fast tuner
- No HOM couplers

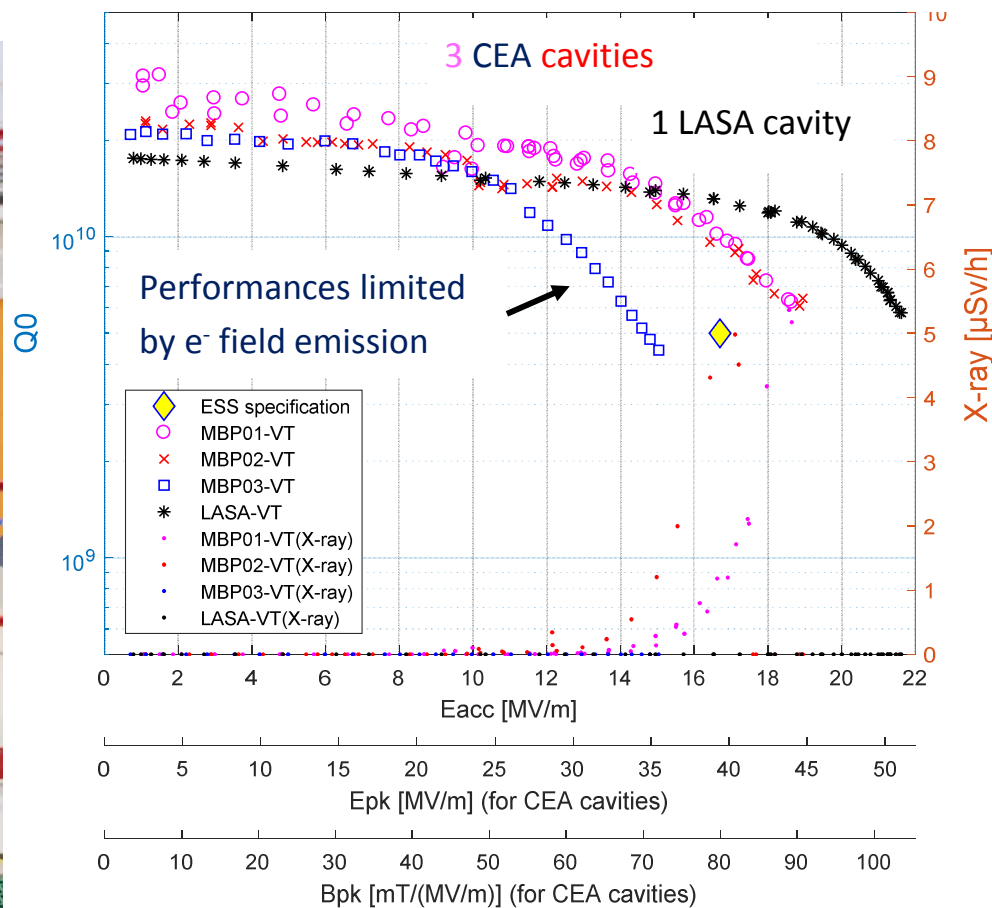


6.6 m long



- Spaceframe concept (JLAB/SNS)
- Segmented design
- Similar design for medium and high beta cavities

M-ECCTD CAVITIES PERFORMANCES IN VERTICAL CRYOSTAT

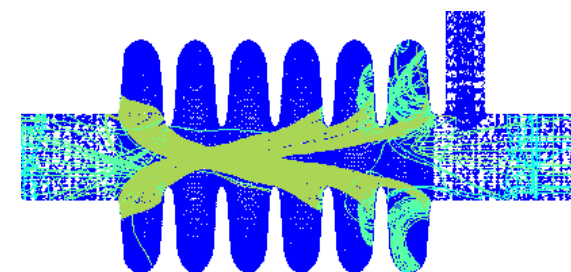


All cavities chemically treated with BCP

Three cavities reach the ESS specification

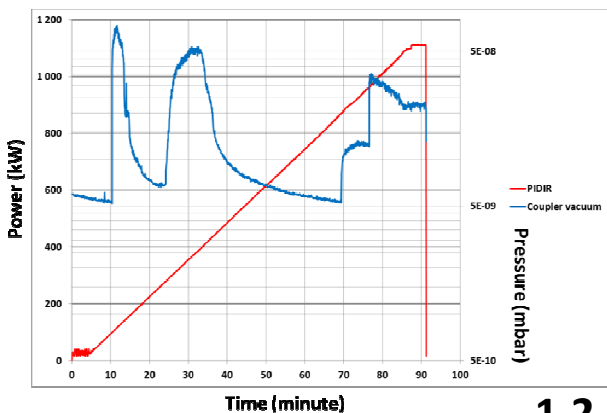
Very good Q_0 at low field for CEA cavities, very good accelerating gradient for LASA cavity

Origin of this Q drop is not fully understood, but probably due to field emission and secondary emission effect inside inner cells (triggered by surface quality obtained after chemical treatment)



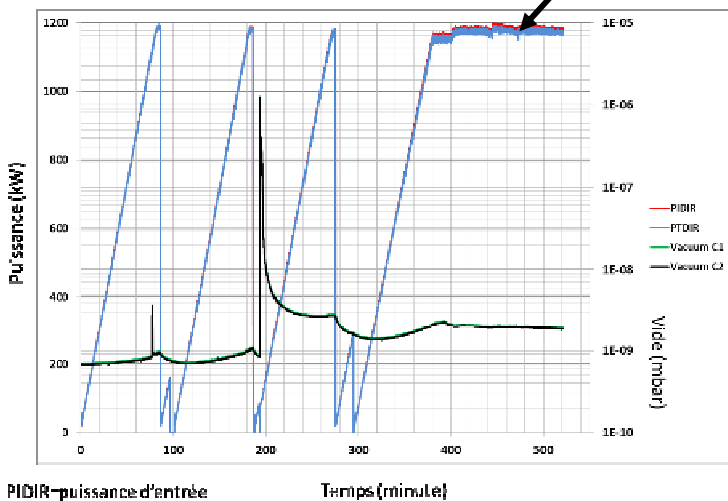
M-ECCTD POWER COUPLER RF CONDITIONNING

PIDIR: Incident Input power

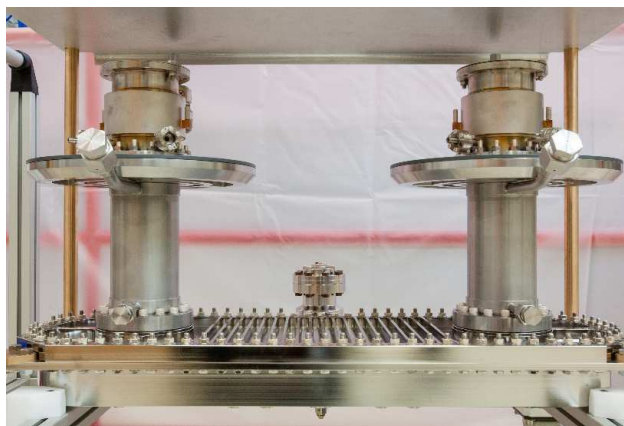


1.2 MW peak

Ondes progressives, 14Hz, 3600ms



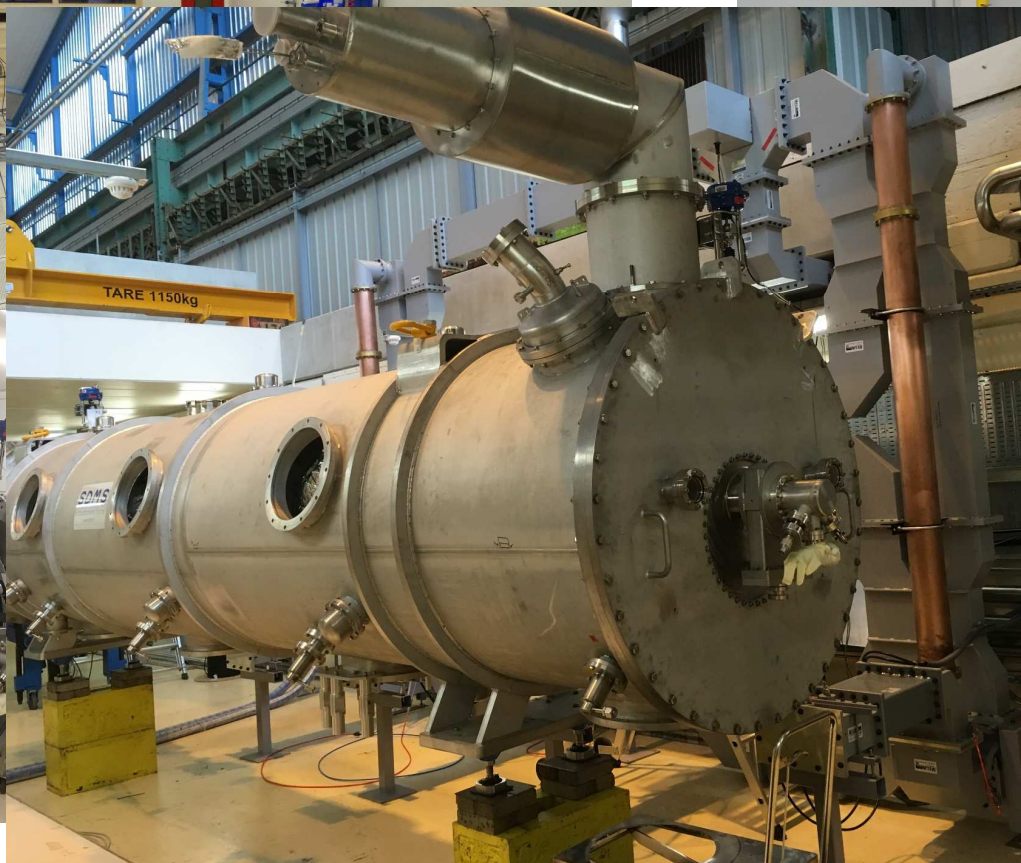
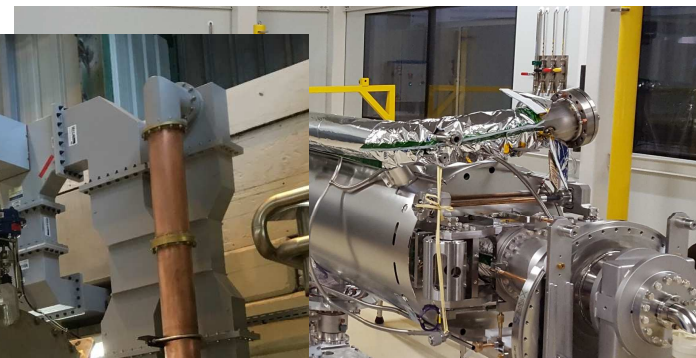
PIDIR=puissance d'entrée
PTDIR=puissance transmise



- Coupler pairs mounted on stainless steel air cooled coupling boxes in clean room
- Baking at 170 °C
- Multipactor regions found at 100, 300 and 900 kW during power ramping but easily conditioned without the use of the DC bias system
- **Three pairs have been successfully tested for now**



M-ECCTD CRYOMODULE ASSEMBLY

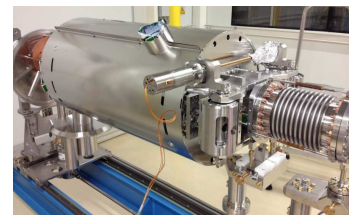
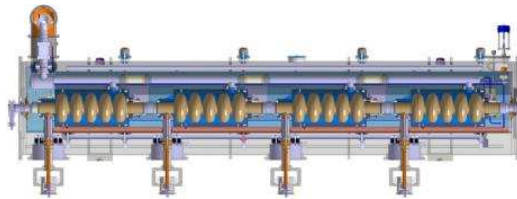
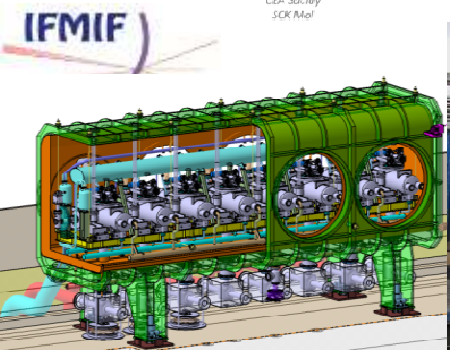
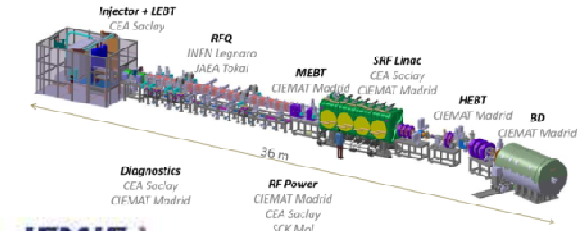


CONCLUSIONS

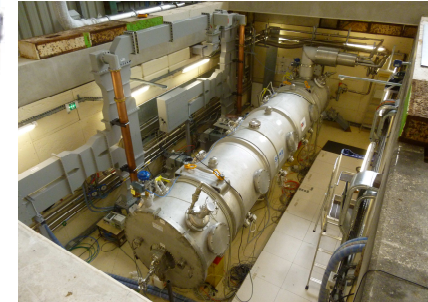


Produce 12 CM installed, beam in 2019

Spiral2



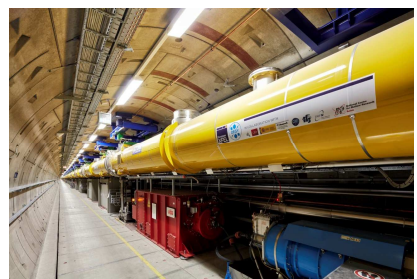
ESS EUROPEAN SPALLATION SOURCE



European XFEL

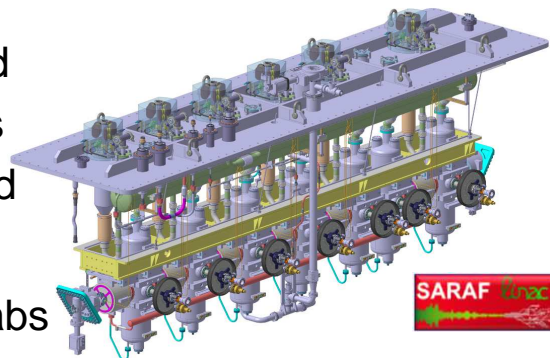


Produce XM100 end July 2016



CEA Saclay has skills and know-how in cryomodules design, manufacturing and integration

Used to work with other labs to build accelerators



SARAF LINAC

POINTS OF DISCUSSIONS

1. Design of cryomodule

Where do we start ? From SSR1-HB650 module, from ESS module, from others ... ? What are the technical interfaces ? What are the specifications ?

2. Design of RF couplers: is the design ready for fabrication ? What could be our contribution ? Reviews, design, manufacturing, conditioning (RF power source) ?

3. Module tests : how many (1-11) ? and pulsed/CW qualification ? CM requalified at Fermi ?

	ESS M β	PIP2 L β
β	0.67	0.61*
# CM	9	11
Cav. /CM	4	3
# Cav.	36	33
CM L [m]	6.584	5.25*
Energy	220-570	185-500

	ESS	PIP2
Freq.	704 MHz	650
Eacc /Epk MV/m	16.7 /40	16.9/40
Q0	> 5e9	2.15e10
Temp.	2 K	2K
FPC of Coaxial type, single window, fixed coupling	1.1 MW peak, 55 kW avg, Qext = 7.5e5	10.36e6*
Mechanical slow tuner	600 kHz range, 1 Hz resolution	200kHz/3Hz