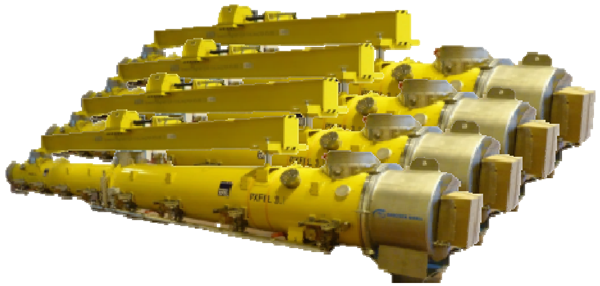
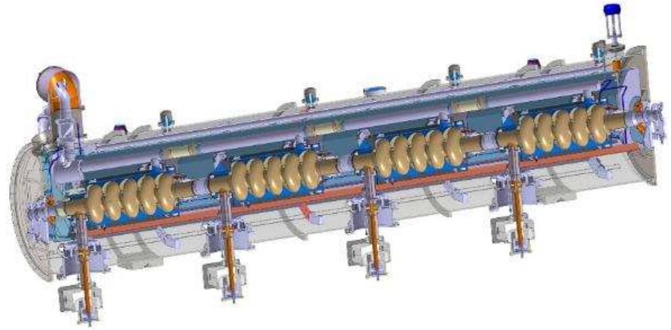
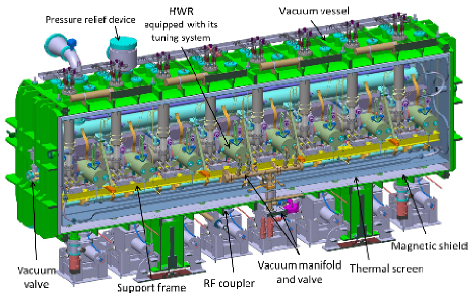
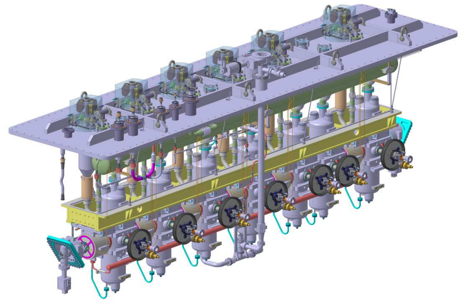
DE LA RECHERCHE À L'INDUSTRIE

CRYOMODULES @ CEA :



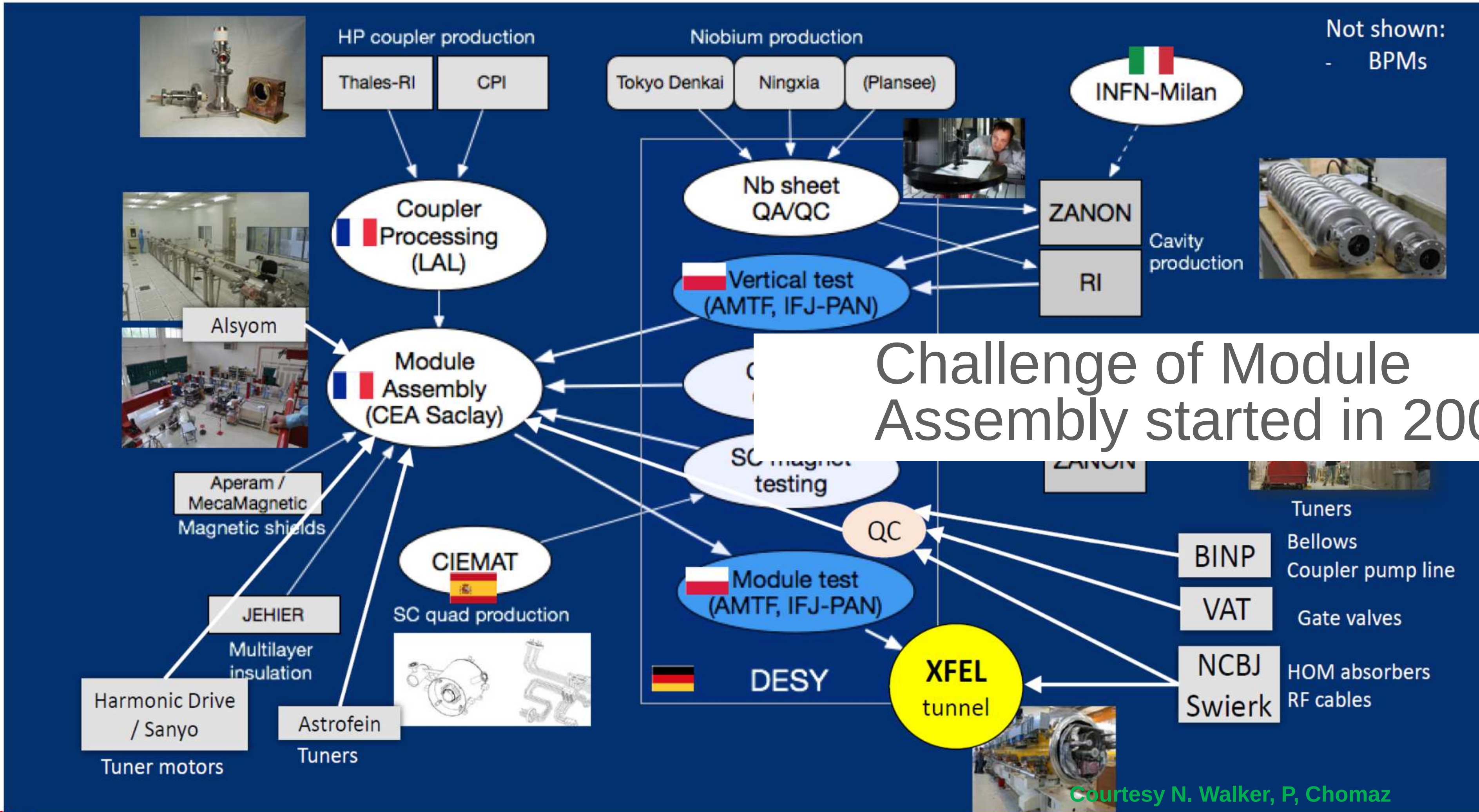






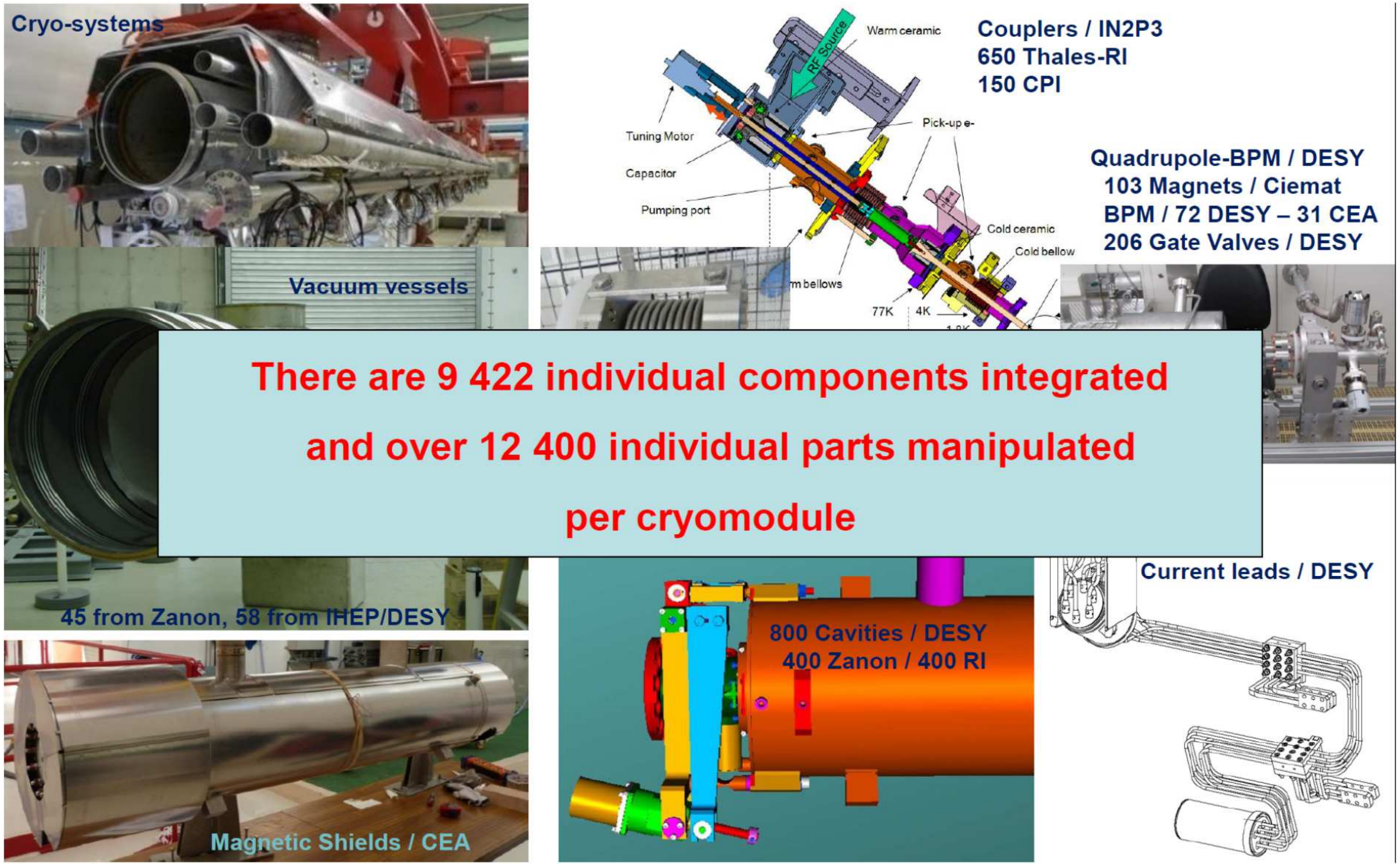
C. Madec – CEA/DRF/IRFU/DACM/LIDC2 – 09-04-2018

In-Kind Contributors to E-XFEL Cold Linac



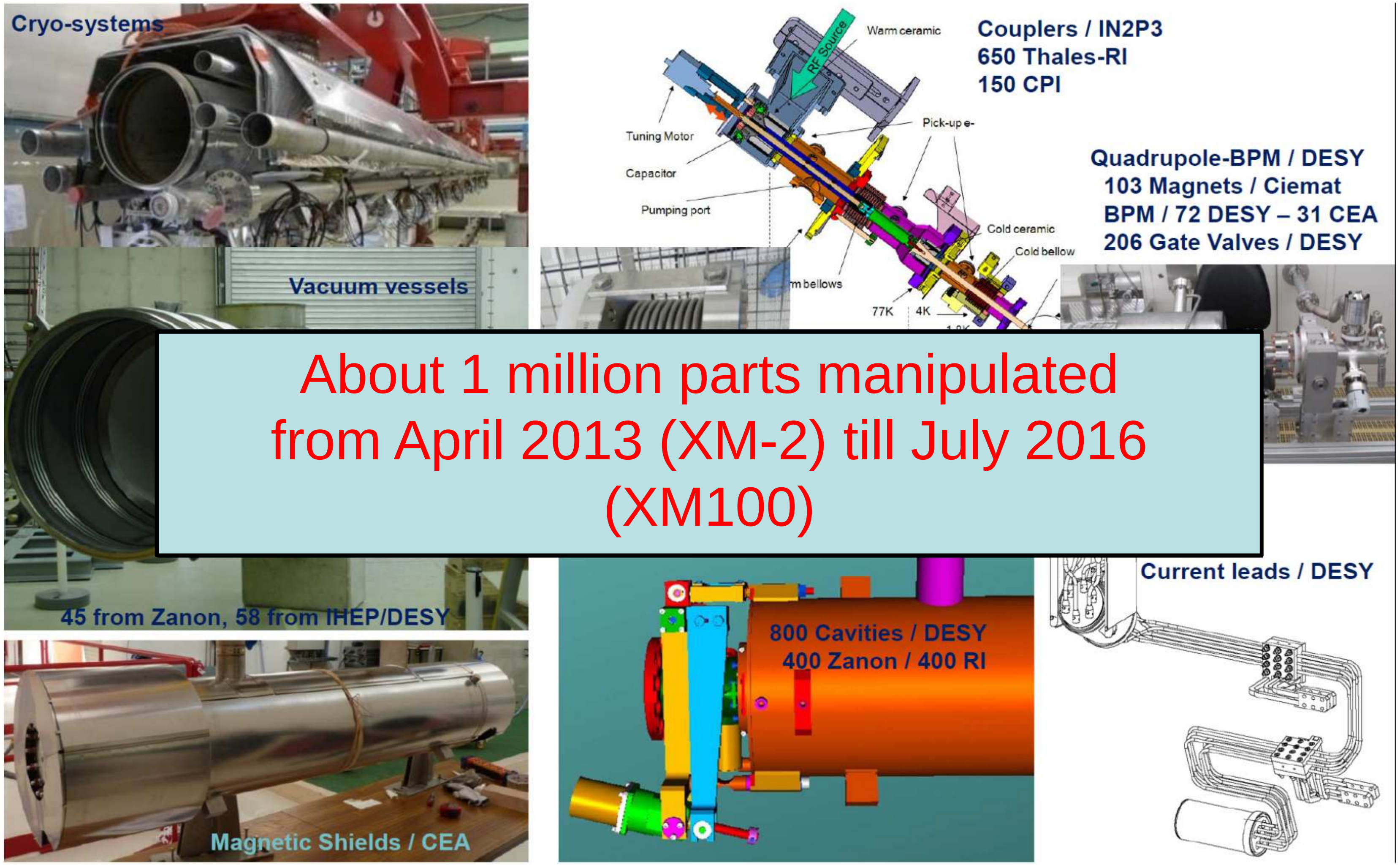
Challenge of Module Assembly started in 2007

Cryomodule In-Kind Procurements



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

Cryomodule In-Kind Procurements



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

Phases of the project

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

2007 : the Strategic Year

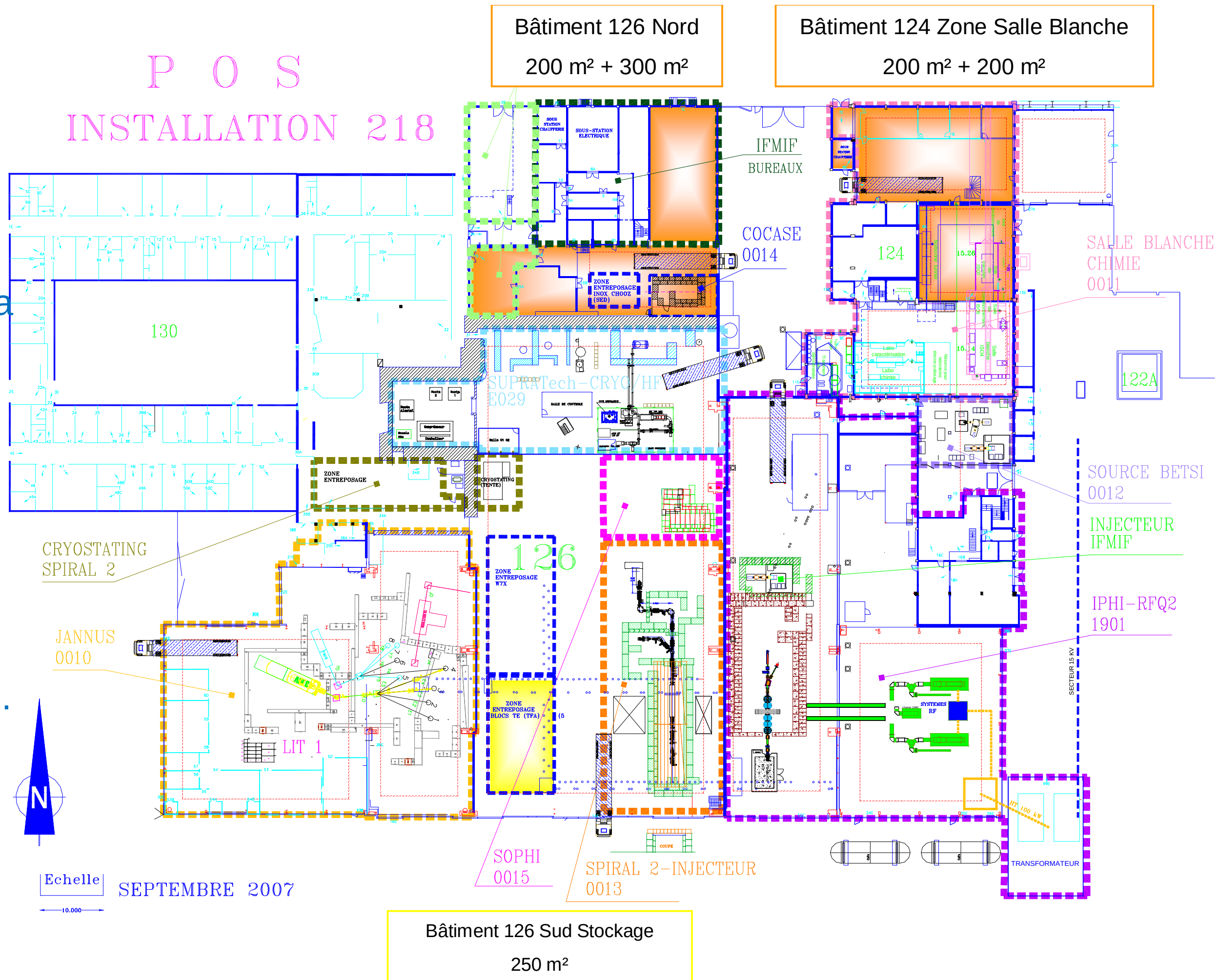
Minutes of Cold Linac Meeting @ DESY (2-3 July 2007) : "…*The string and module assembly done at Saclay was described as another possible in-kind contribution. Details have to be figured out. So far, these steps in module production are foreseen to be done in industry."*

…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 : Let’s start

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

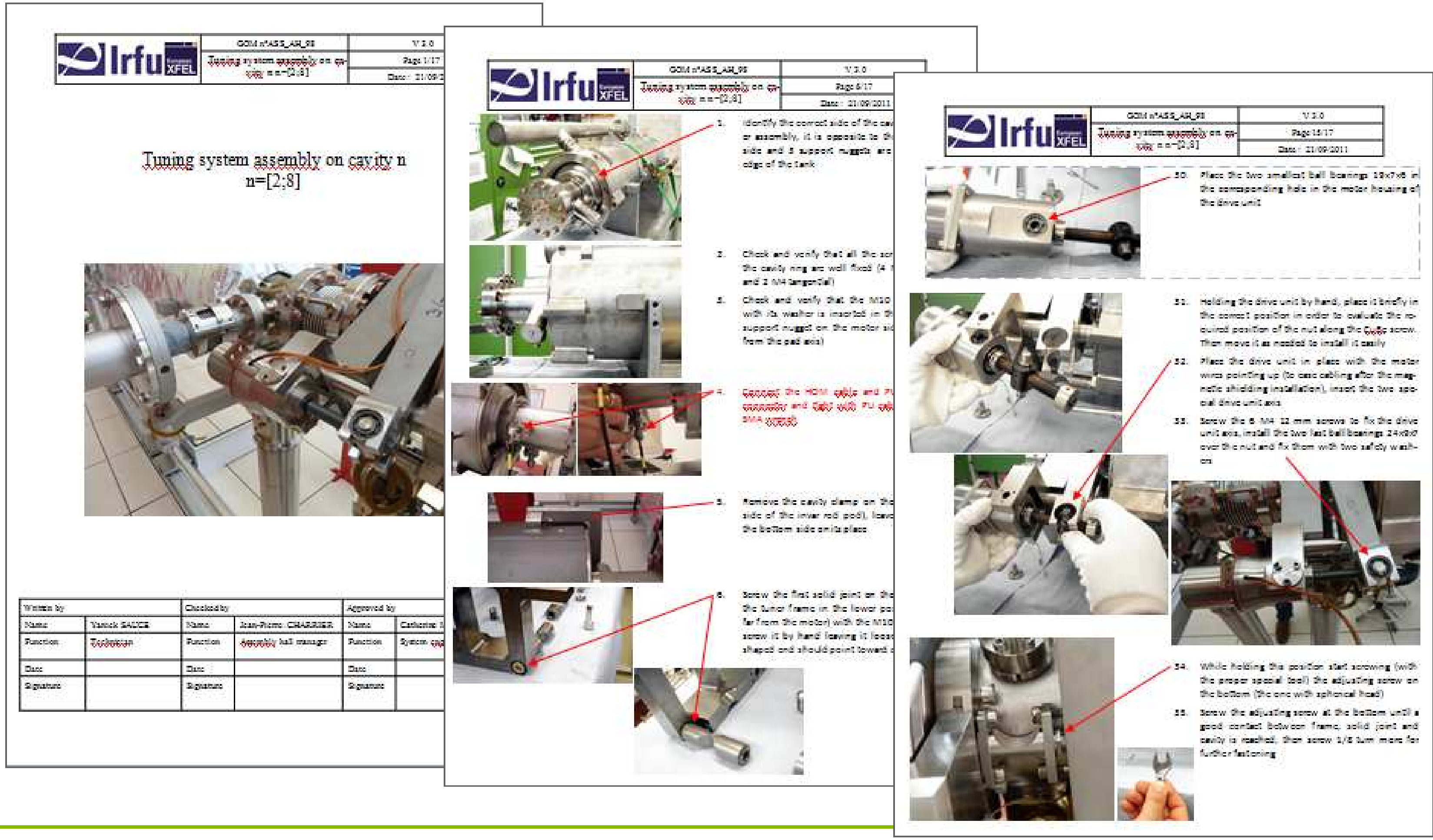
2010 – 2012 : Prototyping and call for tenders

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
→

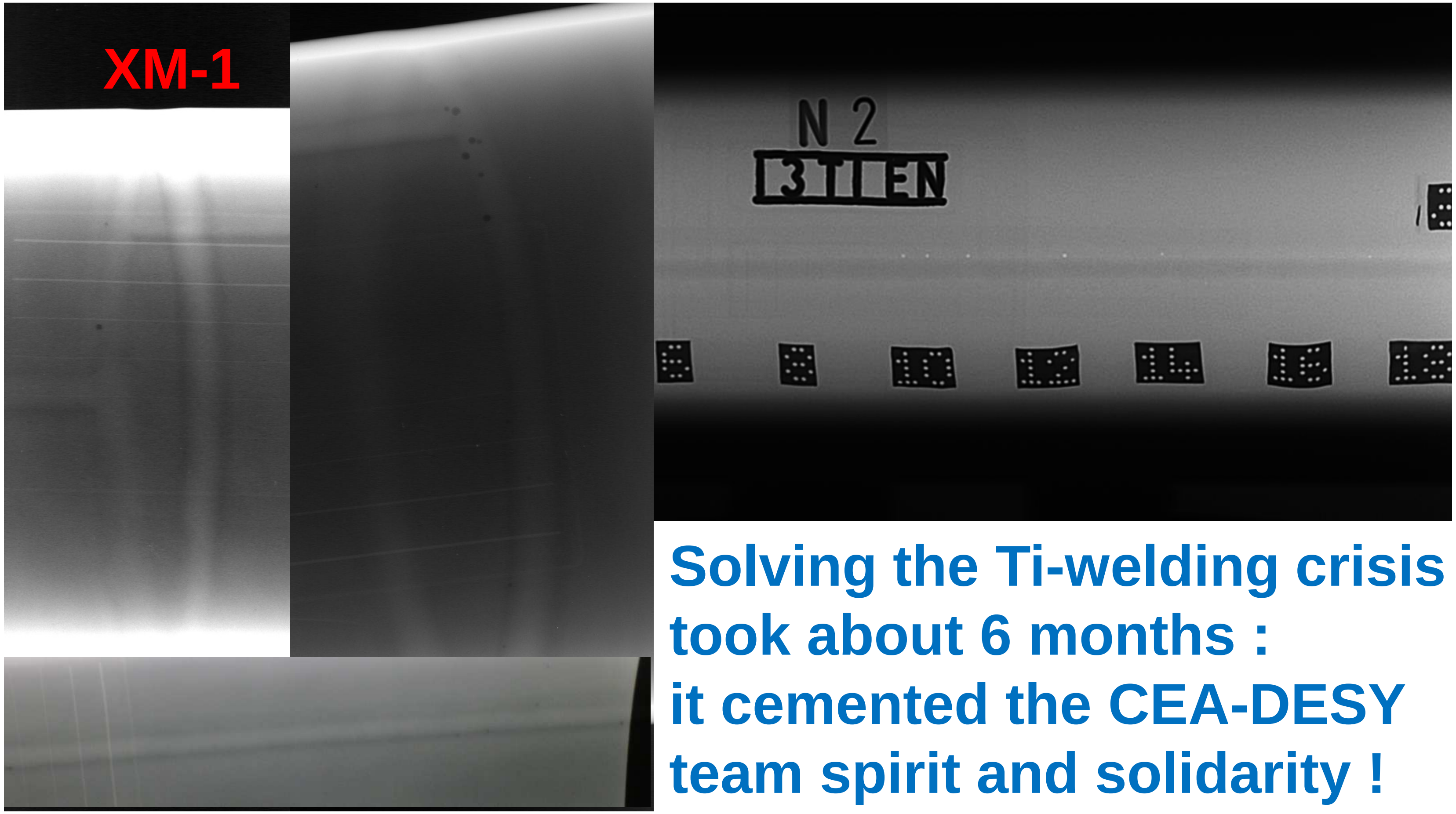
and back
←

Documentation QA/QC and E-M-BOM



2012 : the Dark Year

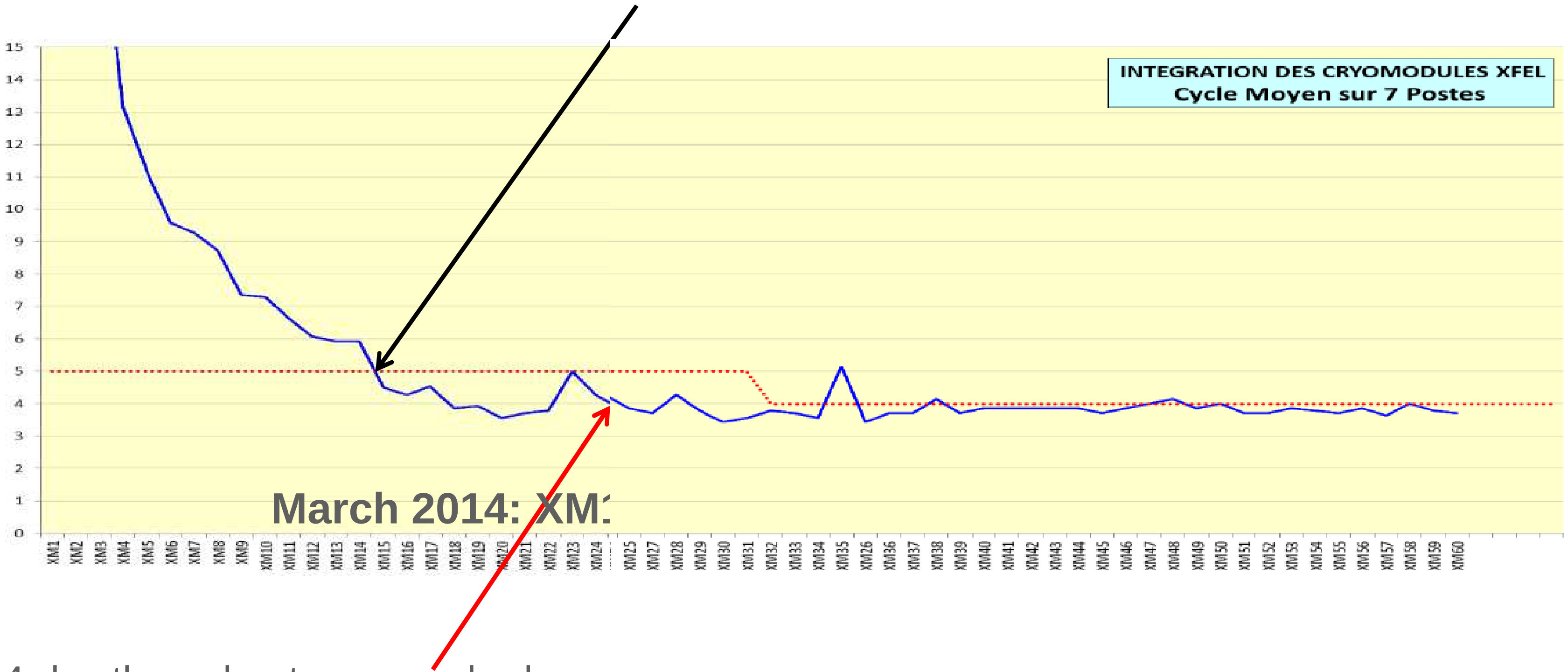
'ANNUS HORRIBILIS'



Solving the Ti-welding crisis took about 6 months : it cemented the CEA-DESY team spirit and solidarity !

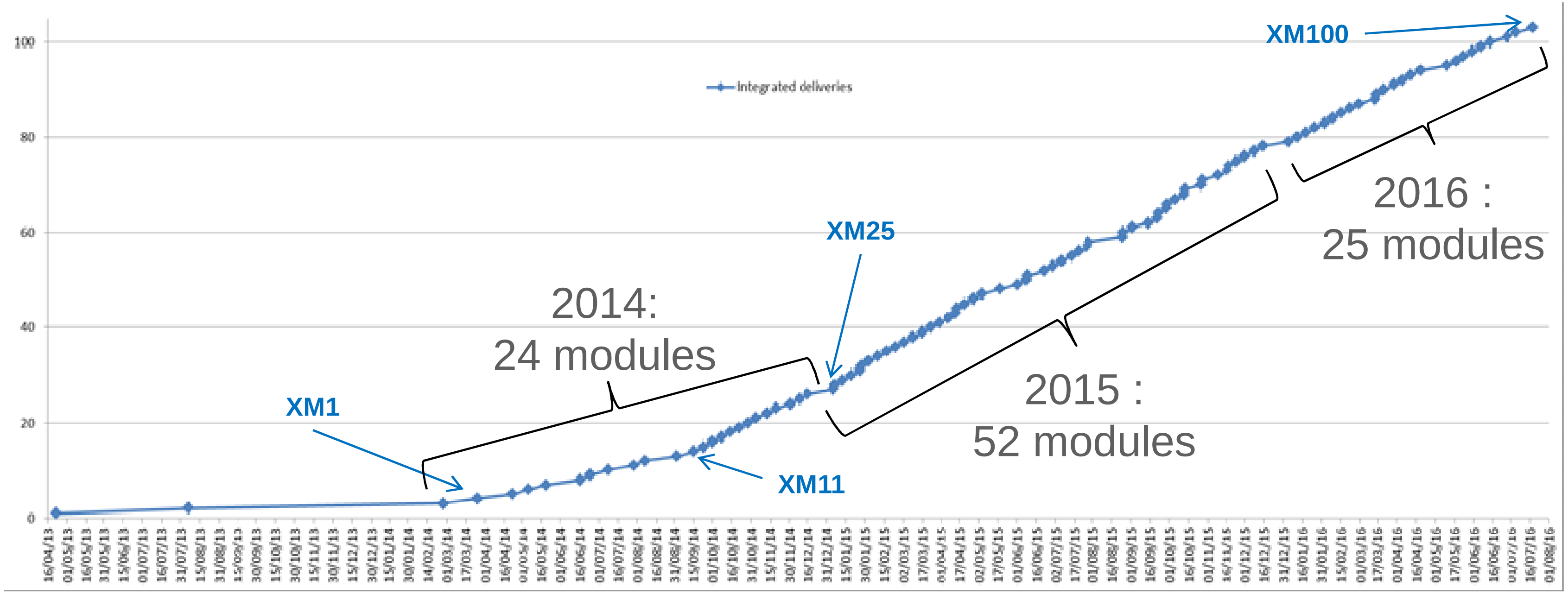
2014 to 2016

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



4-day throughput was reached
in January 2015 with **XM25**

2016 : The end

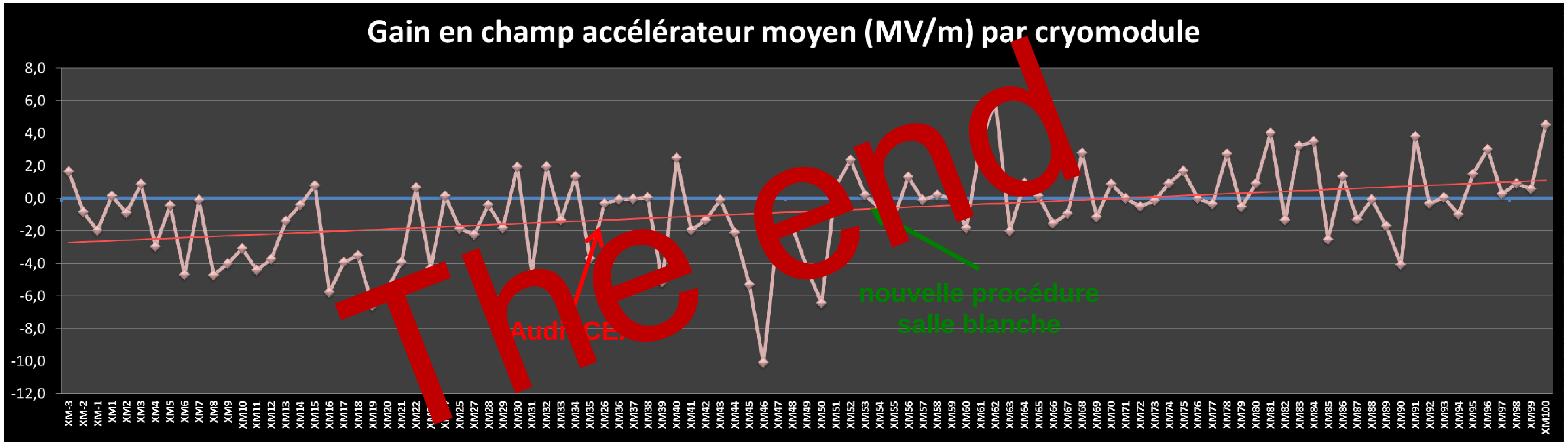


Shipment schedule of 103 cryomodules:

- 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.

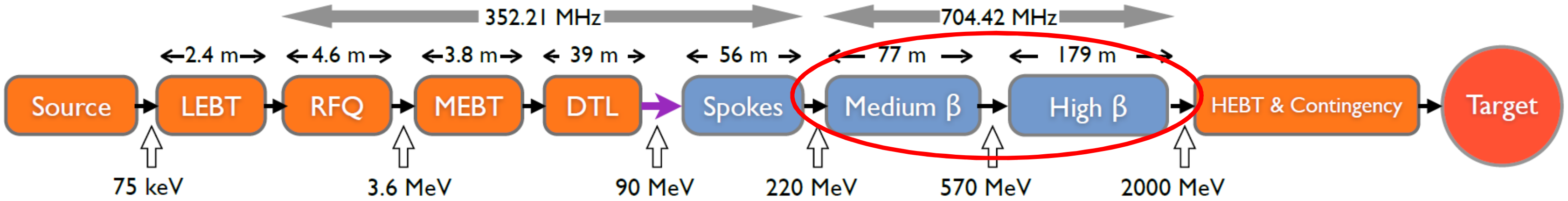
RESULTS

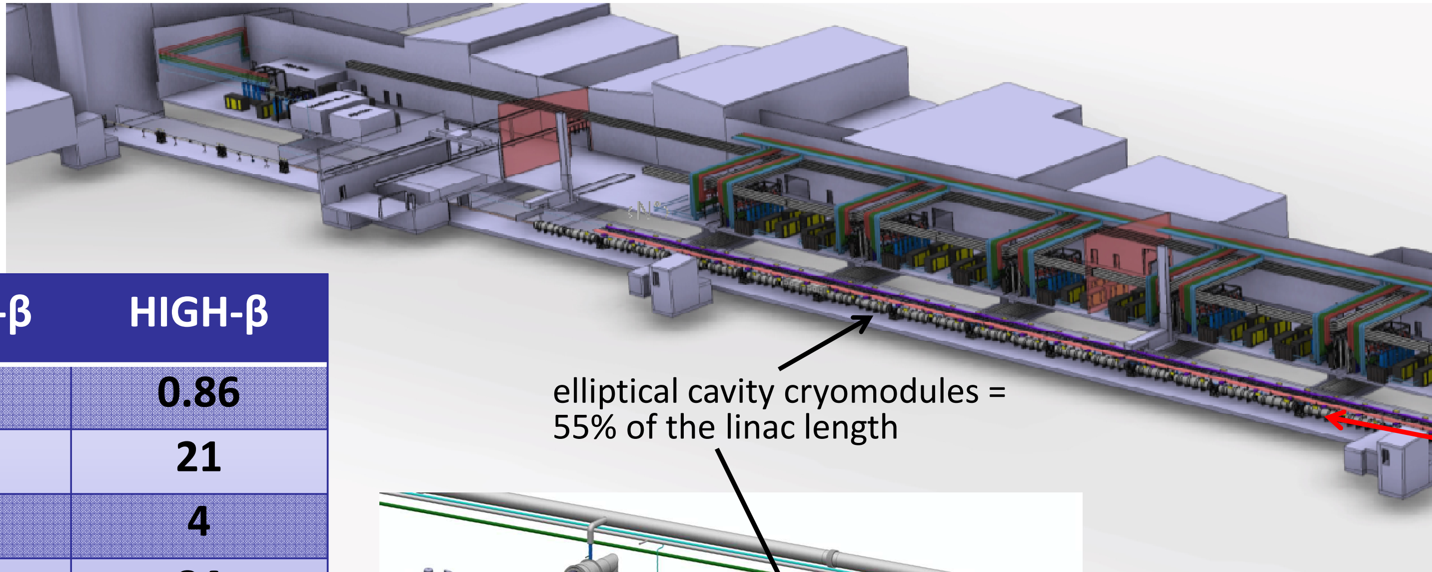
Gain in Average accelerating gradient Gain (MV/m) per cryomodule, comparing vertical tests results and tests in cryomodules

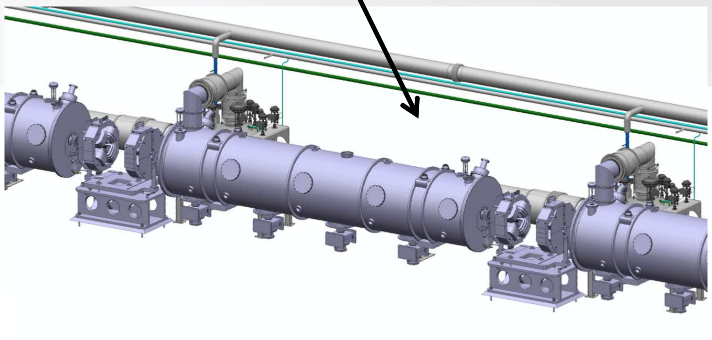


- ⟨E_{acc}⟩ **= 27.6 MV/m** higher than the specifications **23,6 MV/m**.
- degradation of accelerating field in cavities after integration until XM23, when CEA et ALSYOM target was to reach a throughput of 5 days, then audits from CEA
- From XM54, new assembly procedures in clean room from CEA, lead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

ELLIPTICAL CRYOMODULES IN THE ESS LINAC







	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

COLLABORATIONS

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

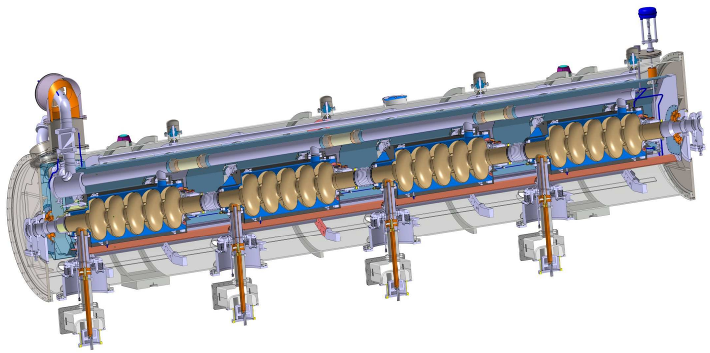
CEA
- Cryomodule and cavity design
- M-ECCTD and H-ECCTD construction and test
- Series cryomodule components procurement and assembly
- Series couplers
- Cryomodule test stand

IPN — Institut de Physique Nucléaire Orsay
- Cryomodule engineering design
- M-ECCTD cryostat components procurements

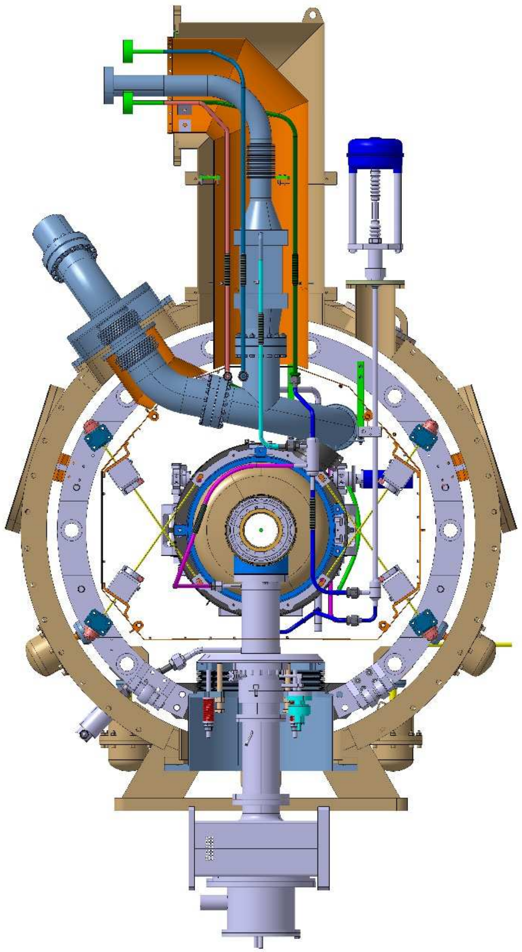
INFN / DESY
- Medium Beta Cavity design
- Medium Beta Cavity procurements
- Medium Beta Cavity vertical tests

Science & Technology Facilities Council
- High Beta Cavity procurements
- High Beta Cavity vertical tests

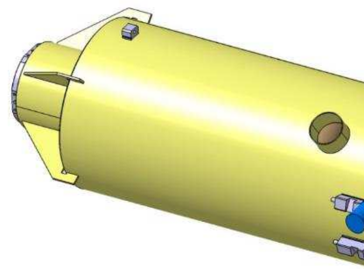
Uppsala Universitet
- Cavity horizontal test

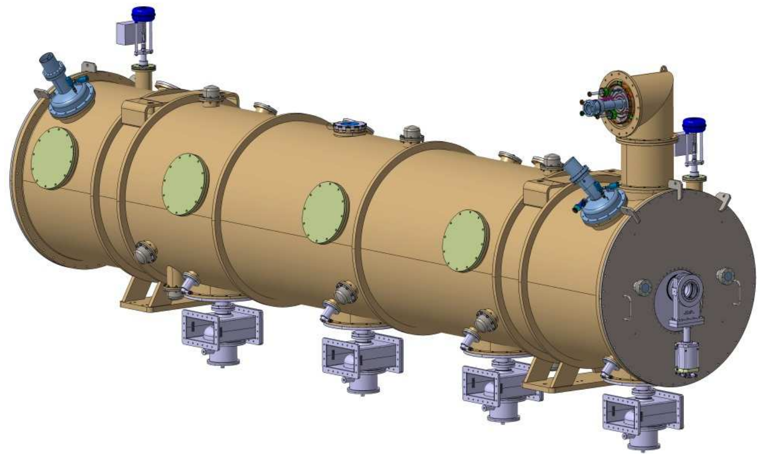


ESS ON GOING



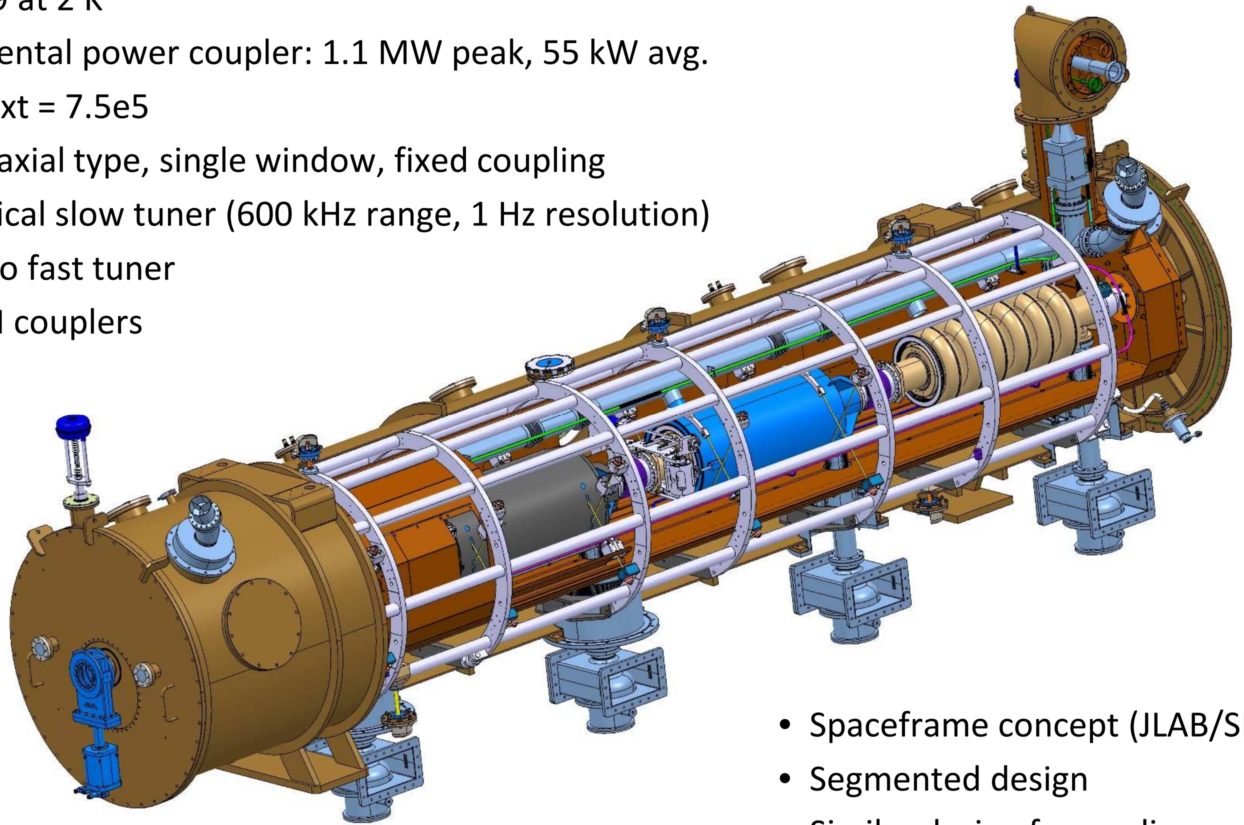
- ✓ ESS elliptical cryomodule design
- ➢ Medium beta cryomodule demonstrator M-ECCTD
  - – Cavities and couplers individual performances
  - – Cryomodule assembly
- ❑ High beta cryomodule demonstrator H-ECCTD
- ❑ Series cryomodule production preparation
  - – Procurement plan
  - – Series power couplers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



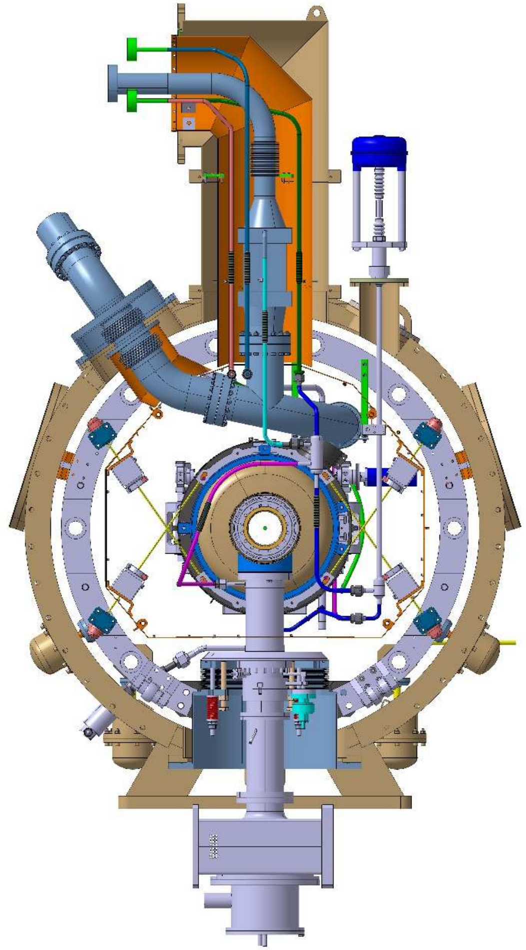


ELLIPTICAL CRYOMODULE MAIN FEATURES

- 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

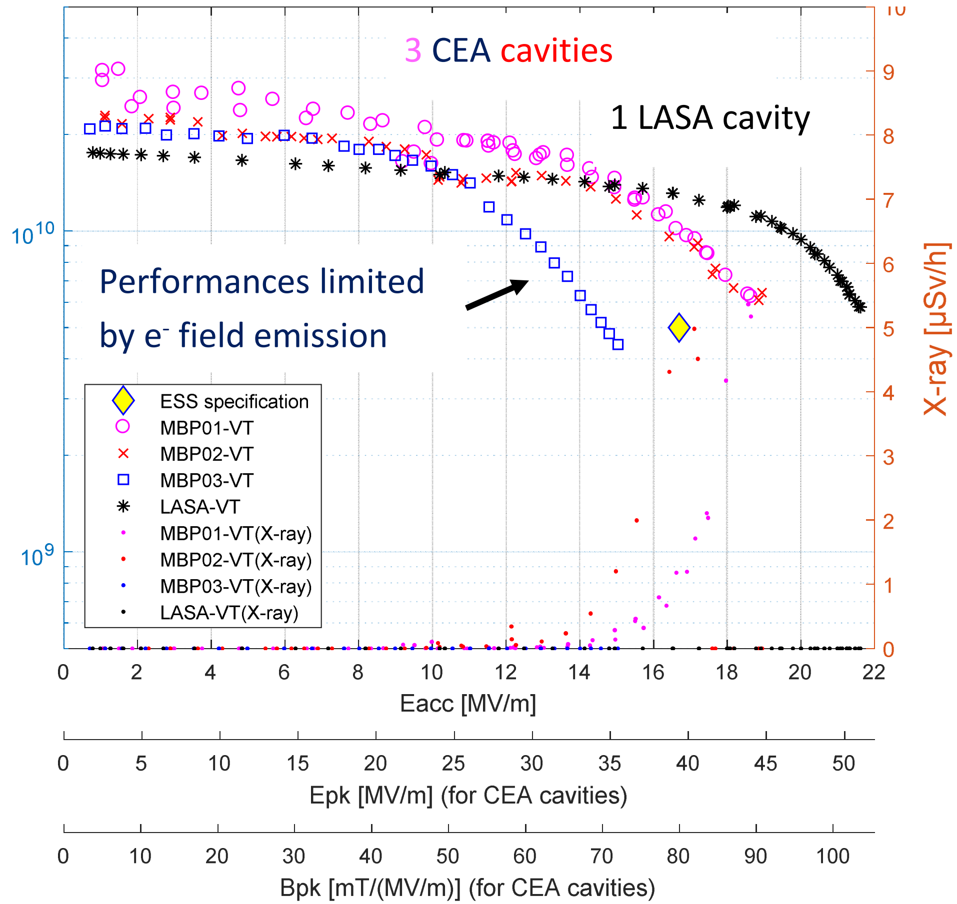


6.6 m long



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

M-ECCTD CAVITIES PERFORMANCES IN VERTICAL CRYOSTAT

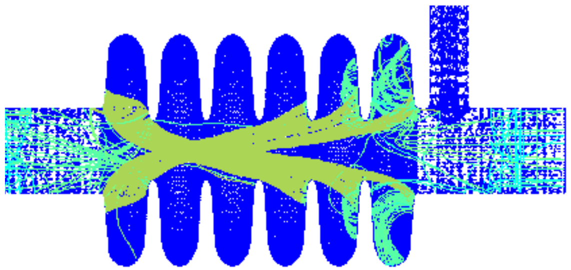


All cavities chemically treated with BCP

Three cavities reach the ESS specification

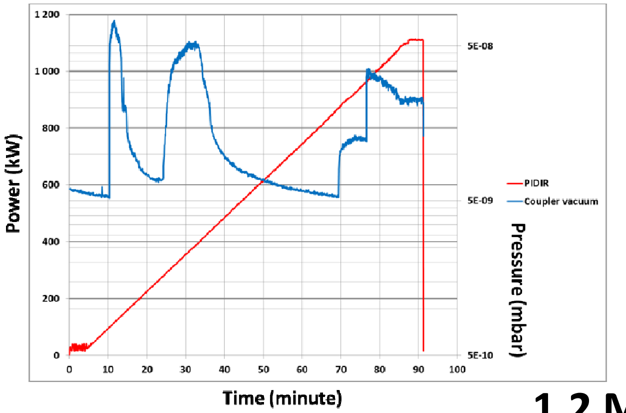
Very good Q0 at low field for CEA cavities, very good accelerating gradient for LASA cavity

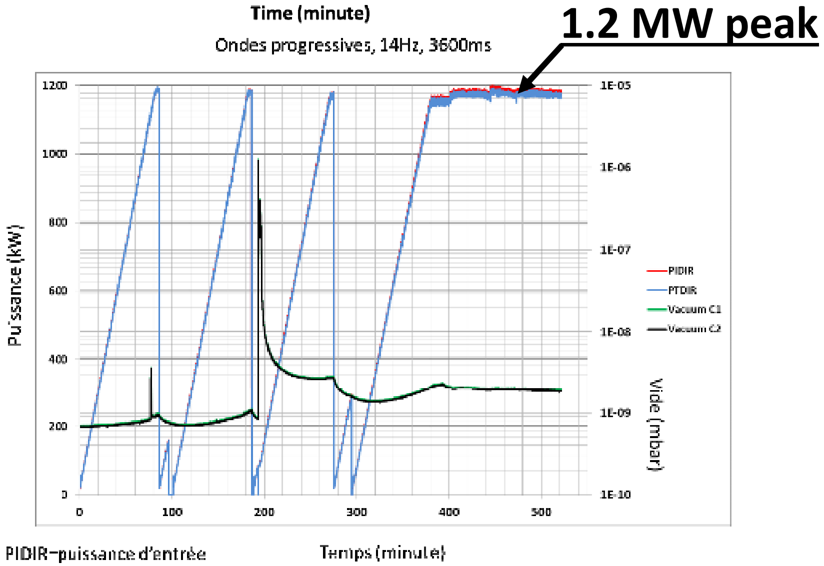
Origin of this Q drop is not fully understood, but probably due to field emission and secondary emission effect inside inner cells (triggered by surface quality obtained after chemical treatment)



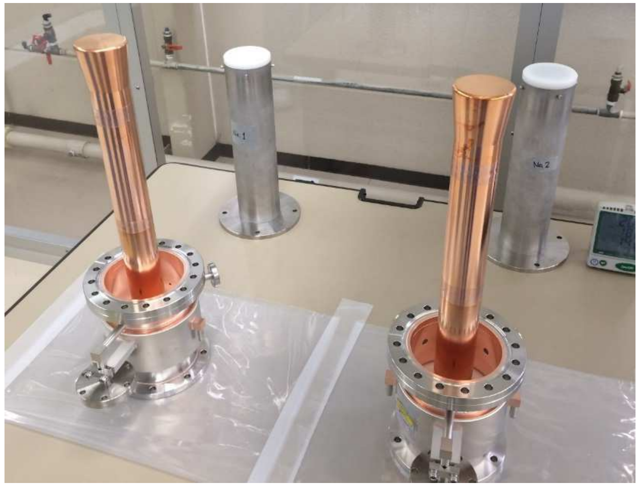
M-ECCTD POWER COUPLER RF CONDITIONNING

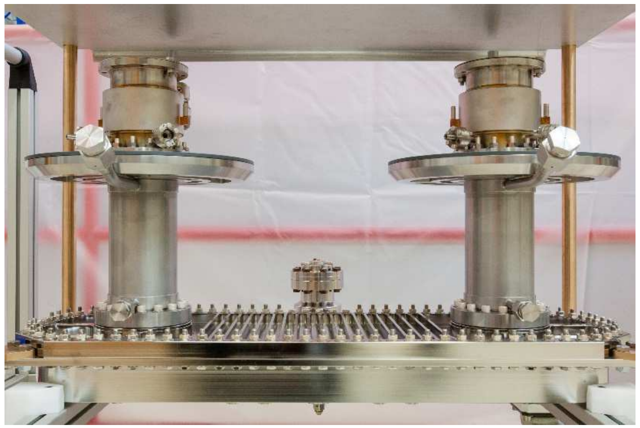
PIDIR: incident input power





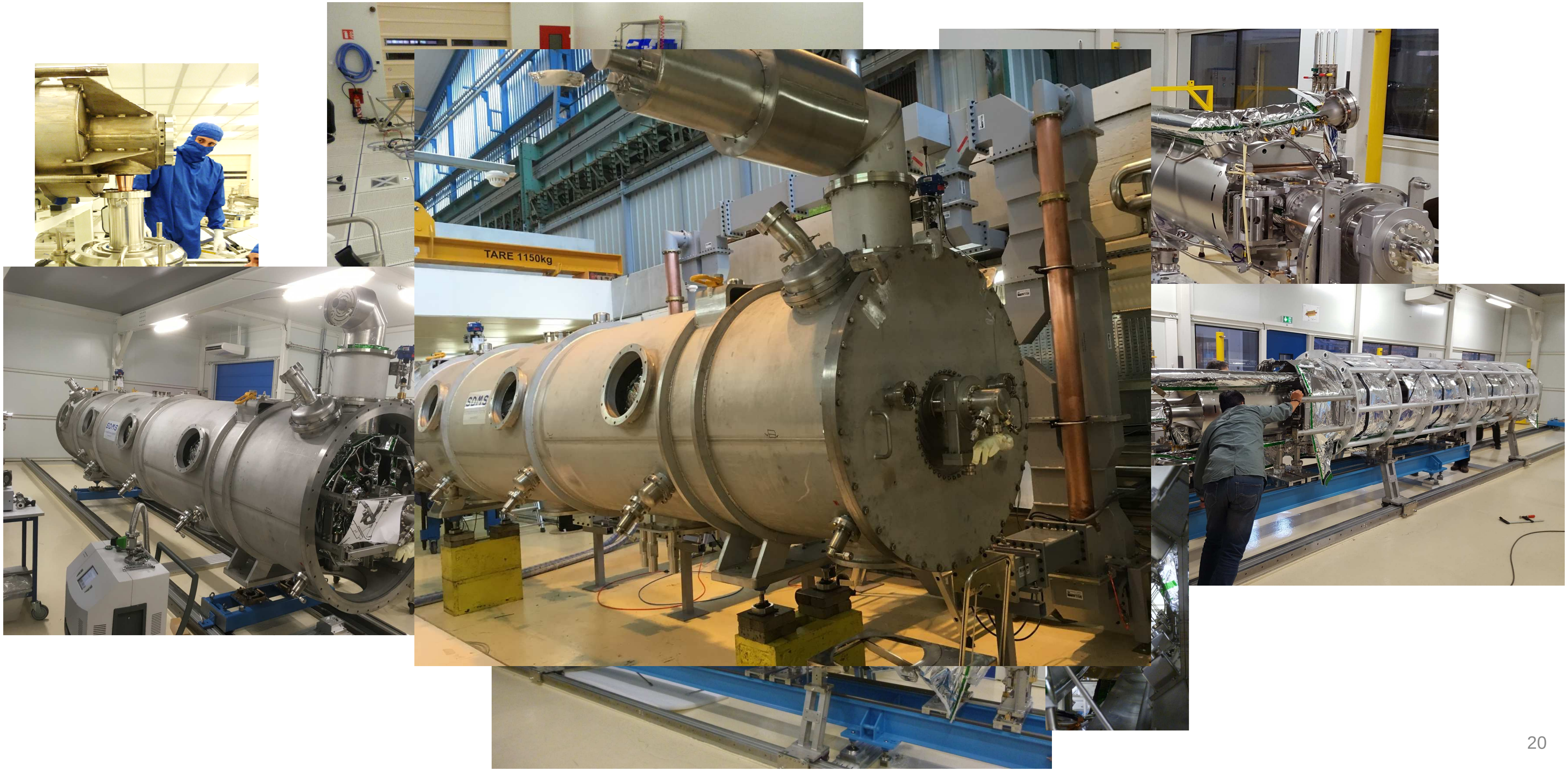
PIDIR=puissance d'entrée
PTDIR=puissance transmise





- 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**

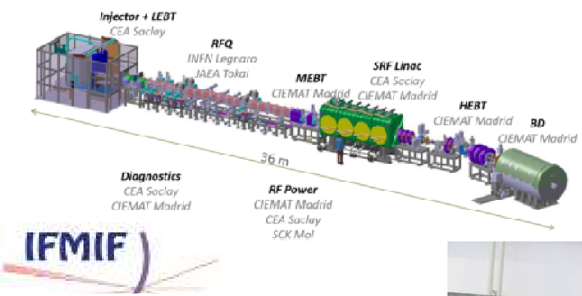
M-ECCTD CRYOMODULE ASSEMBLY

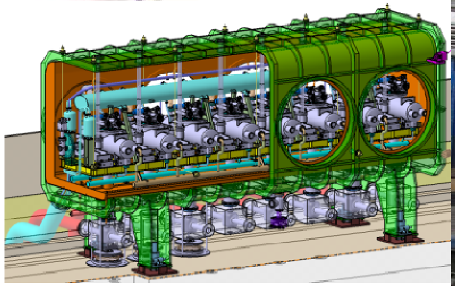


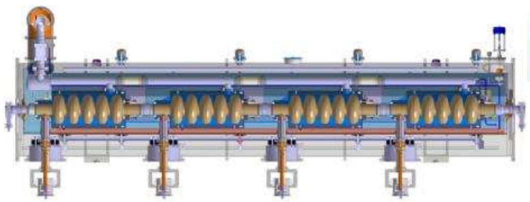
CONCLUSIONS

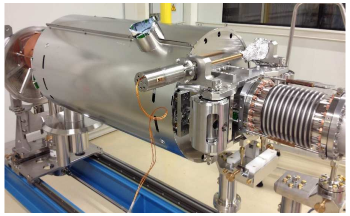
Booster → MACSE → SOLEIL TTF → SPIRAL2, XFEL → IFMIF → ESS, SARAF LUCRECE → PIP2

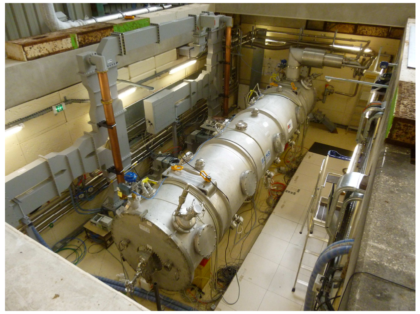
Produce 12 CM installed, beam in 2019

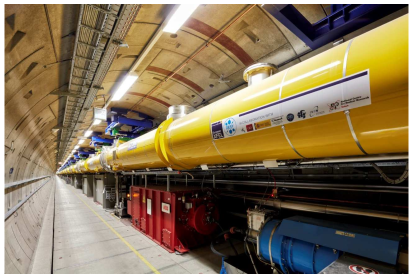








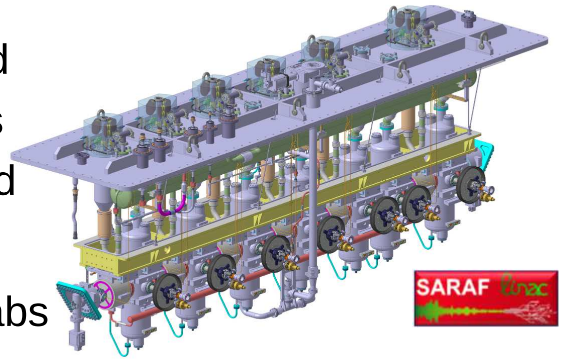




Produce XM100 end July 2016

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

Used to work with other labs to build accelerators



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 Mβ	PIP2 Lβ
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**