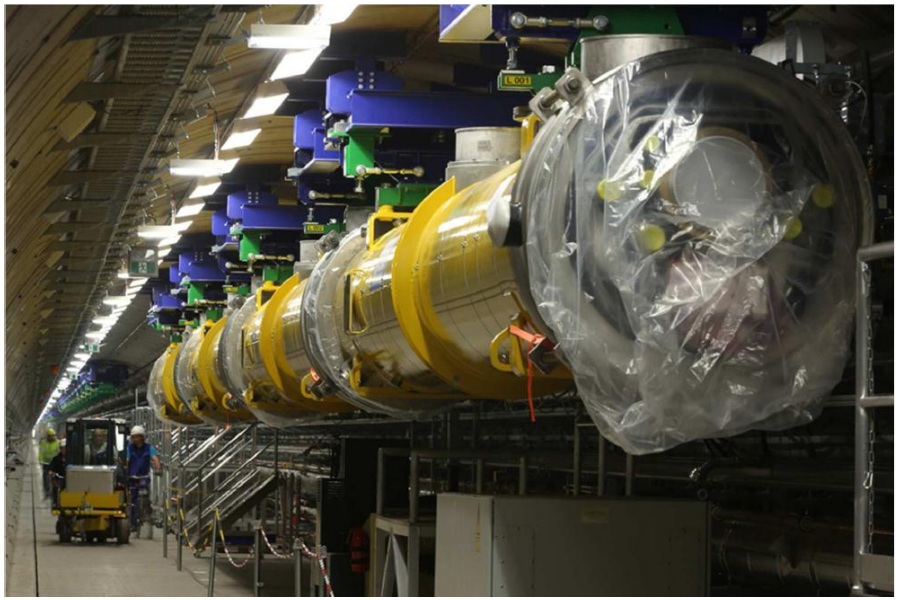
Assembly Experience from Cryomodule Large Scale Production

XFEL cryomodule integration at CEA/Saclay



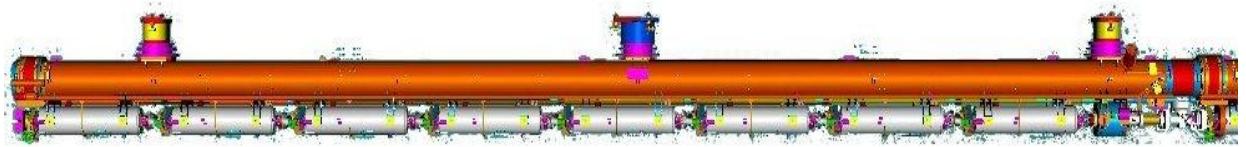
O. Napoly, CEA-Saclay, Irfu/SACM

Outline

- Introduction to the European XFEL
- Industrialization challenge
  - Assembly Infrastructure
  - Assembly Procedures
  - Integration Operators and Tools
  - Quality Control
- Conclusions

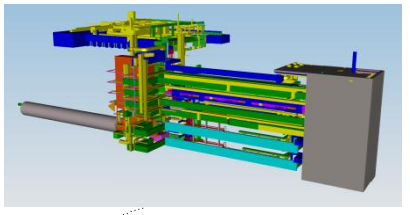
E-XFEL Accelerator 17.5 GeV

101 accelerator modules



80 accelerating cavities
1.3 GHz / 23.6 MV/m

25 RF stations
5.2 MW each



CEA In-Kind Contribution

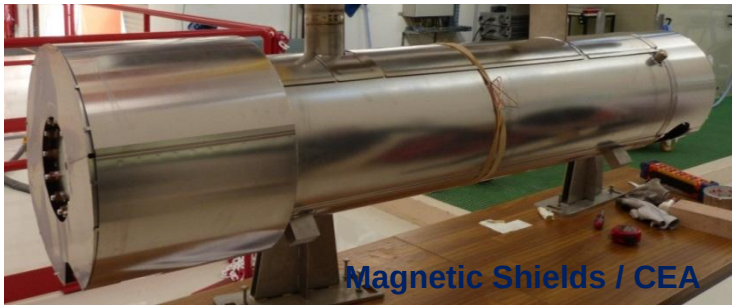
CEA contributes to the
XFEL Cold Linac construction
through
String Assembly in Clean Room (WP9)
and Module Assembly (WP3)

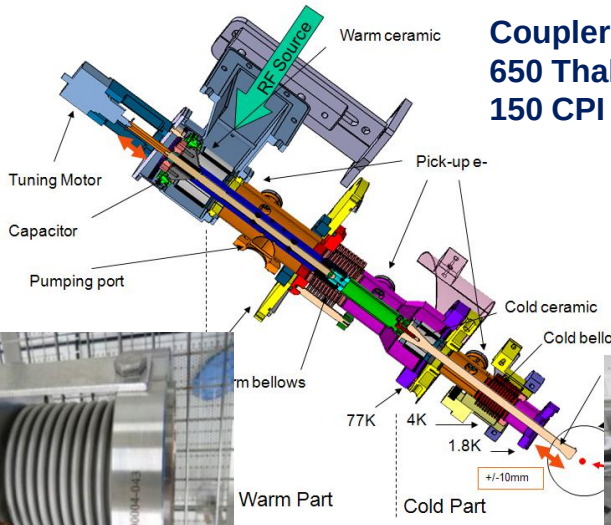
↓

Accelerator Module Assembly
assembly of 103 accelerator modules
with 1 per week throughput !
operated by an industrial contractor
on the Saclay site.

Component Industrialization / Handover

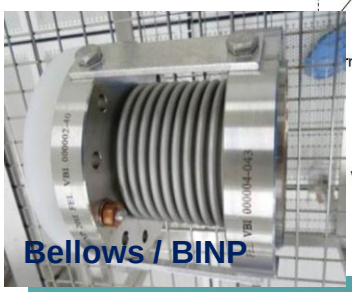
Cryo-systems

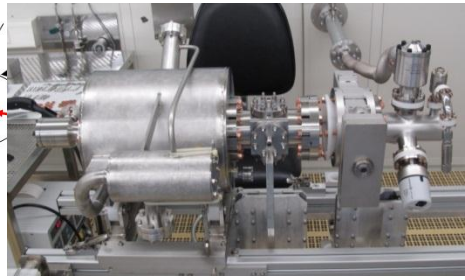


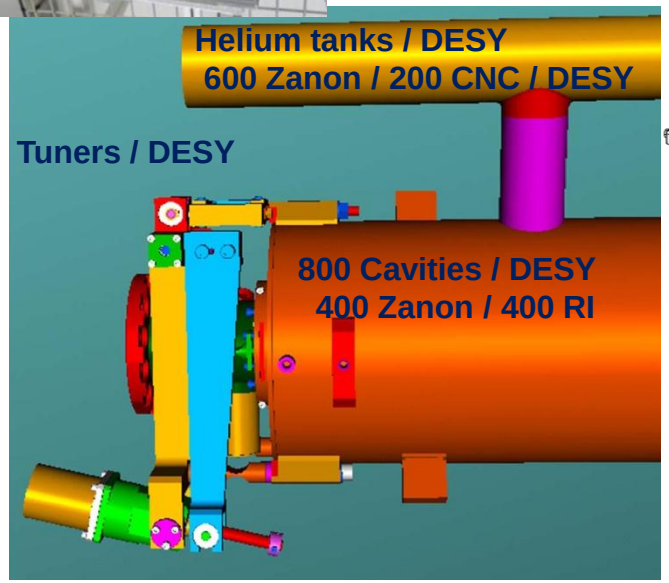


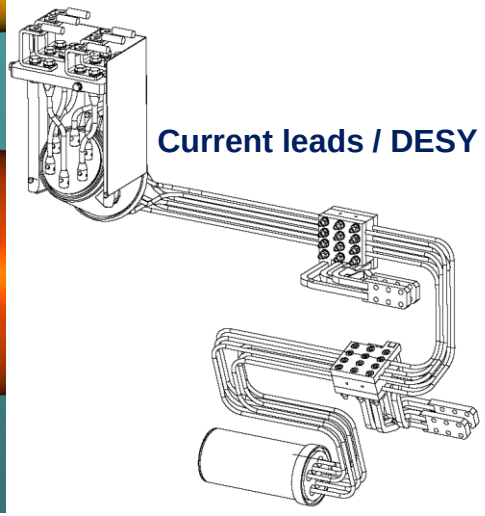
Couplers / IN2P3
650 Thales-RI
150 CPI

Quadrupole-BPM / DESY
103 Magnets / Ciemat
BPM / 72 DESY – 31 CEA
206 Gate Valves / DESY

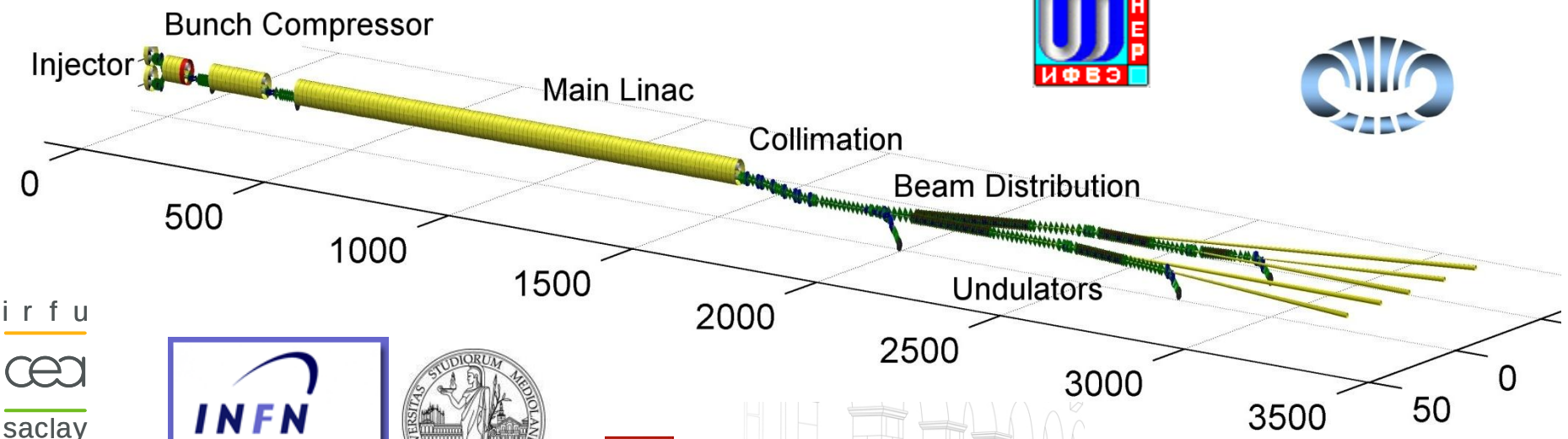








Institutes Contributing to the Accelerator Complex



Assembly Challenges

1. **Industrialization**: no company was qualified for module integration, unlike for cavities manufacturing
2. **Schedule** : throughput of 1 CM per week, or better for a steady production over 2 years
3. **Quality** : avoid gradient degradation, cryogenic losses, coupler mis-assembly, etc…
4. **Complexity** : many handover interfaces with several groups at DESY and in European labs. Many procedures and many risks during integration.

Assembly Infrastructure

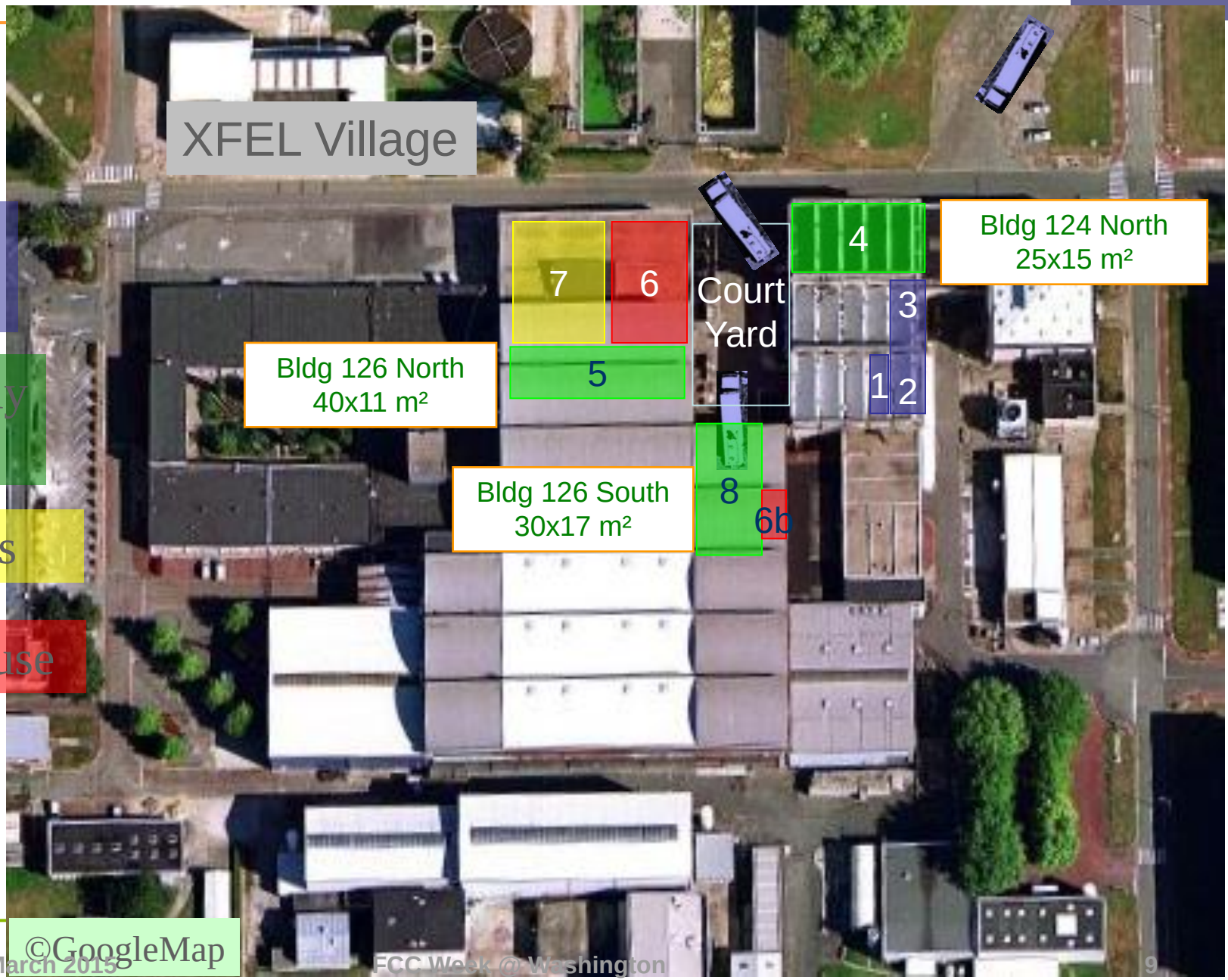
Overview of the Assembly Buildings

Clean rooms

Assembly halls

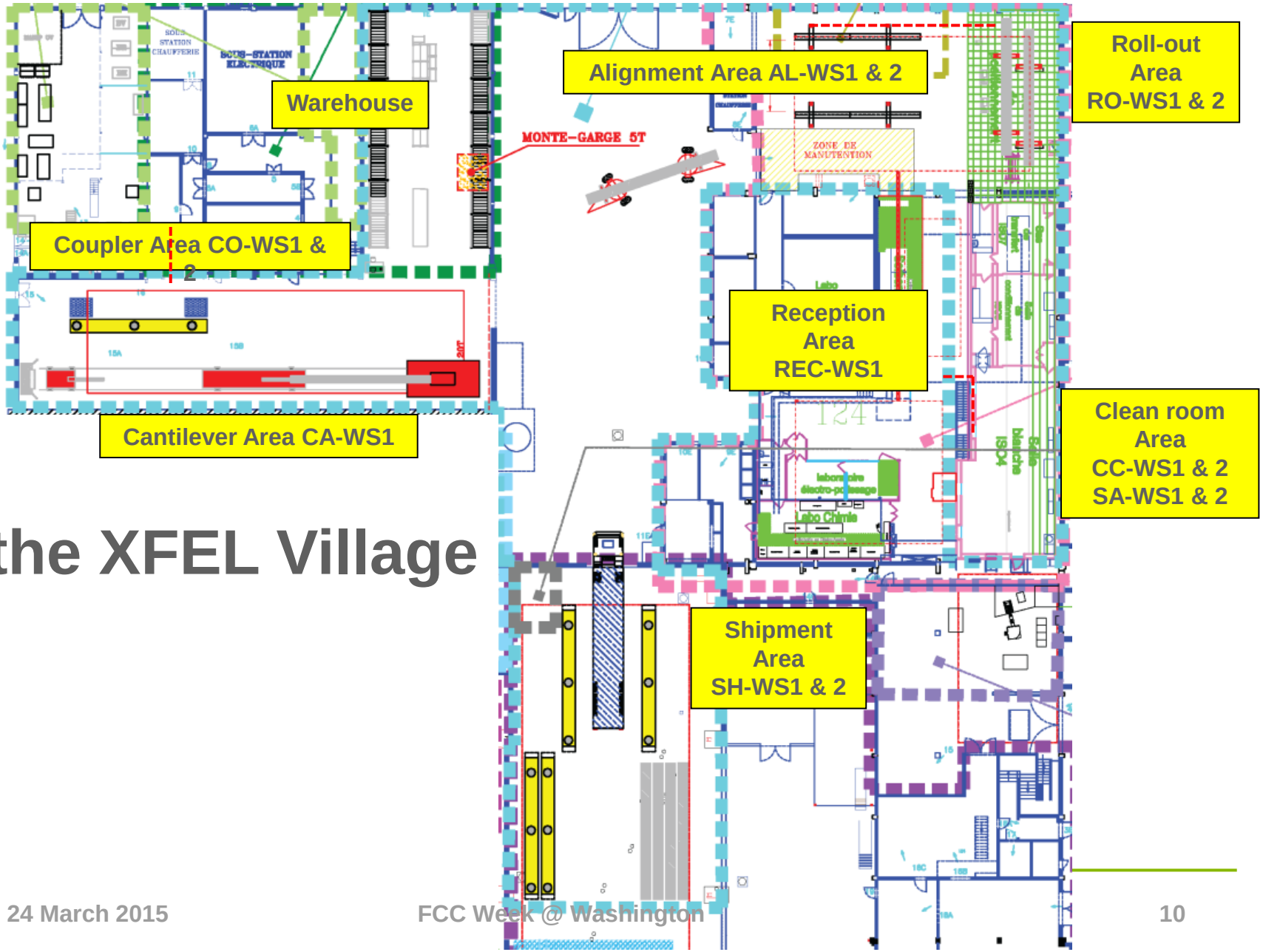
Offices

Warehouse



©GoogleMap

Assembly Hall : Workstations



the XFEL Village

Organisation of Work Stations

The breakdown of the assembly work of 7 Work Stations aims at:

- **balancing almost equally the occupancy of each WS,**
- **bringing the largest occupancy below 5 days**

1. **Clean Room Cold Coupler Area** (IS04-CC-WS1)
   - Cold coupler assembly (x8)
   - Leak check of caity-coupler connection (+RGA)
2. **Clean Room String Assembly Area** (ISO4-SA-WS1, ISO4-SA-WS2)
   - String connections (1 gate valve + 8 cavities + 1 Qpole unit)
   - Leak check of string and N_2 venting (+RGA)
3. **Roll-out Area** (RO-WS1, RO-WS2)
   - HOM adjustment, magnetic shielding, T-sensors (x6)
   - Tuner assembly (x8), coupler 4K and 80 K shields
   - 2 Ph-tube welding, NCT (LT, PT, RT)
   - Cold-mass/string connection
4. **Alignment Area** (AL-WS1, AL-WS2)
   - Cavity and quadrupole fine alignment (~100 µm)
   - Welding of 8 mm LHe filling line (x9)
   - Tuner and piezo electric tests
5. **Cantilever Area** (CA-WS1)
   - Welding of 4K and 70 K shields, 4K and 79 K super insulation
   - Cable routing and insulation, Quad current lead
   - Insertion into vacuum vessel and cold mass alignment
6. **Coupler Area** (CO-WS1, CO-WS2)
   - Warm couplers + coupler pumping line + leak checks (8 connections + coupler vacuum)
   - Cabling of flanges A (x8) and flange D
   - Quadrupole current lead connections and welding
   - Final leak check of cavity vacuum + final pumping
7. **Shipment Area** (SH-WS1, SH-WS2)
   - Control operations (RF frequency)
   - End-caps closing, N2-insulation
   - CEA-Alsyom “acceptance test”
   - Loading

ISO4 Clean Room Worksations

XM4 (String assembly) on 14/02/2014

Roll-out / Cold Mass Assembly Workstation

Transfer of cryomodule in clean room Roll-out Area

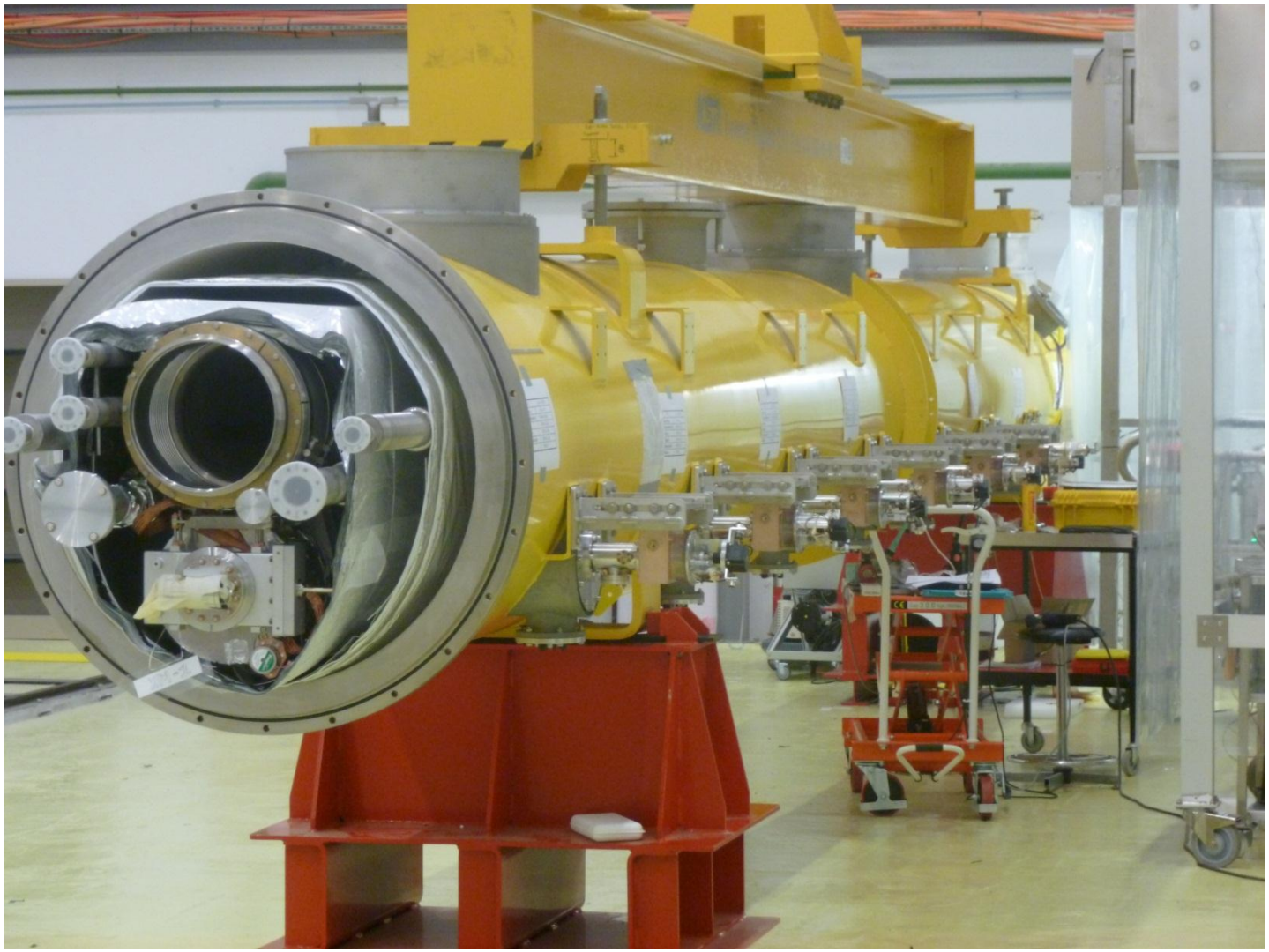
Roll-out and Alignement Workstations

XM2 (Alignment) and XM3 (Roll-out) on 14/02/2014

Cantilever Workstation

XM1 (Cantilever) on 14/02/2014

Warm Coupler Workstation



XM-1 (Warm couplers) on 14/02/2014

Cantilever and Warm Coupler Workstations

XM1 (Cantilever) and XM-1 (Warm couplers) on 14/02/2014

Irfu cea	FI_ASS_AH_149	V5	ALSYOM
	Montage de la boite de transition pour les éléments d'origine THALES (THRI)		

MONTAGE DE LA BOITE DE TRANSITION POUR LES ELEMENTS D'ORIGINE THALES (THRI)

Cette **F**iche d'**I**nstructions (**FI**) définit les opérations de montage de la boite de transition sur un Cryomodule XFEL et les moyens associés.

FICHE D'INSTRUCTIONS OPERATIONNELLES

	ALSYOM			CEA	
	Rédigé par	Vérifié par	Autorisé par	Vérifié par	Approuvé par
Fonction	Rédacteur Technique	Chargé d'Affaire Projet XFEL	Responsable Qualité Projet XFEL	Responsable Technique	XFEL Fabrication Manager
Nom	A. CLIPPET	P. PLUVY	C. ABDI	S. BERRY	T. TRUBLET
Date					
Signature					

Imprimé IM-SAQ 078 C

Irfu cea	FI_ASS_AH_149	V5	ALSYOM
	Montage de la boite de transition pour les éléments d'origine THALES (THRI)		

2. MOYENS

2.1. MATIÈRES CONSOMMABLES NÉCESSAIRES

Gant

Chiffon

Alcool isopropylique

Graisse mécanique Standard

2.2. MOYENS DE CONTROLE

Pied à coulisse

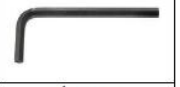
Niveau à bulle

2.3. OUTILLAGE STANDARD DE MONTAGE

Clés plates de 7-8-13-17

Embout BTR 2

Clé à cliquet



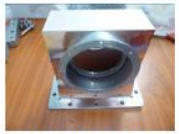
Clé BTR de 3

Clé dynamométrique

Ce document, établi par ALSYOM dans le cadre du Marché CEA n° 4000529715 du 26/07/2012, est la propriété du CEA.
Aucune utilisation ou communication ne peut être faite sans l'autorisation écrite et préalable du CEA

Imprimé IM-SAQ 078 C

2.4. PIECES ET ELEMENTS D'ASSEMBLAGE


Boite de transition


Support du coupleur


2 x Cale de support


4 x Vis entretoise


Joint cuivre RFC1


Joint cuivre RFC2


Joint en cuivre RFC3


Condensateur assemblé


16 x Vis CHC M3 x 9 argentées

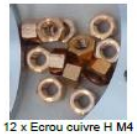
16 x Rondelles Z3


4 x Vis H M10 x 20


2 x Demi-bride


4 x Ecrou H M10


4 x Ecrou H M8


12 x Ecrou cuivre H M4


4 X Rondelle D8


6 x Vis H M10 x 25


2 x Vis H M8 x 25


14 X Rondelle large M10

Imprimé IM-SAQ 078 C

Irfu cea | FI_ASS_AH_149 | V5 | ALSYOM
Montage de la boite de transition pour les éléments d'origine THALES (THRI)

2.5. EQUIPEMENTS DE PROTECTION ET DE SECURITE


Chaussures de sécurité


Gants

2.6. INVENTAIRE DES PIECES A RETOURNER


Fourreau de protection couronne céramique

3. MONTAGE DE LA BOITE DE TRANSITION

3.1. PREPARATION DU POSTE ET DU MATERIEL

1. Préparer la F.I. référente au poste et la configuration du montage (**Fig. 1**)

2. S'assurer d'avoir au poste l'ensemble de l'outillage nécessaire au montage (**Fig. 1**)

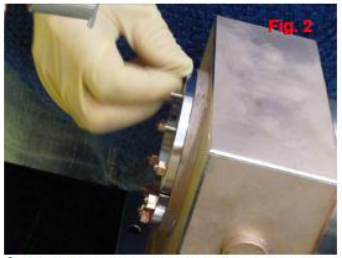
3. Suivant le bordereau de configuration préparer les pièces d'assemblage (**Fig. 1**)

Ce document, établi par ALSYOM dans le cadre du Marché CEA n° 4000529715 du 26/07/2012, est la propriété du CEA.
Aucune utilisation ou communication ne peut être faite sans l'autorisation écrite et préalable du CEA

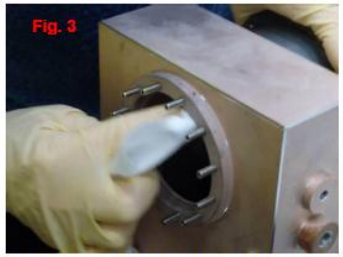
Imprimé IM-SAQ 078 C

Irfu cea	FI_ASS_AH_149	V5	ALSYOM
	Montage de la boite de transition pour les éléments d'origine THALES (THRI)		

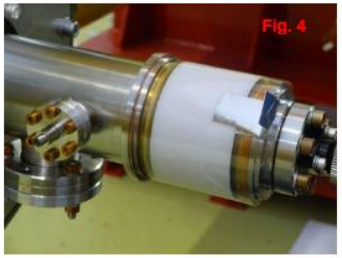
3.2. MONTAGE DE LA BOITE DE TRANSITION



1. Démonter de la boite de transition les demi-brides de serrage montées sur sa bride arrière et vérifier les goujons sont bien fixés sur la boite de transition (**Fig. 2**)

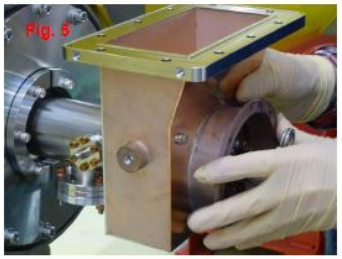


2. A l'aide d'un chiffon propre imbibé d'alcool, nettoyer la boite de transition en insistant plus particulièrement sur la portée de joint de la bride (**Fig. 3**)



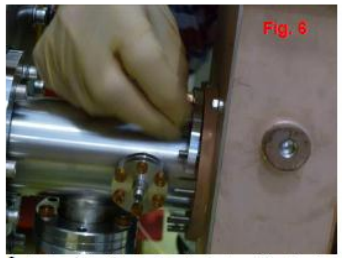
3. A l'aide d'un chiffon propre imbibé d'alcool, nettoyer la portée de joint (bague épaulée) du coupleur chaud

4. Mettre délicatement en position sur la bague épaulée du coupleur chaud, le joint en cuivre RFC3 (joint moyen des 3 à monter **(dia ext 80.2 plan I72-CA-007)**) préalablement nettoyé à l'aide d'un chiffon propre imbibé à l'alcool (**Fig. 4**)



5. Monter délicatement la boite de transition et la mettre en appui contre le joint RFC3 (**Fig. 5**)

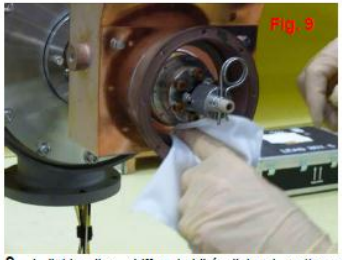
Irfu cea	FI_ASS_AH_149	V5	ALSYOM
	Montage de la boite de transition pour les éléments d'origine THALES (THRI)		



6. Monter à l'arrière de la boite de transition, les deux demi-brides initialement démontées et les maintenir à l'aide des écrous cuivre prévus à cet effet **(le serrage doit être fait à la main sans outils)** (**Fig. 6**)

7. A l'aide d'un niveau à bulle posé sur la boite de transition, s'assurer de l'horizontalité de la boite de transition, puis serrer à **la main** les écrous des demi-brides de serrage de la boite (**Fig. 7**)

8. Retirer délicatement le fourreau (film de protection de la bague céramique du coupleur) (**Fig. 8**)



9. A l'aide d'un chiffon imbibé d'alcool, nettoyer l'intérieur de la boite de transition et précisément les portées de joint (**Fig. 9**)

10. Mettre délicatement en position sur la couronne intérieure de la boite de transition le joint en cuivre

RFC1 (le plus grand des 3 joints à monter **(dia ext 90.5 plan I72-CA-006)**)
RFC2 (le plus petit des 3 joints à monter **(dia int 69.6 plan I72-CA-005)**) préalablement nettoyés à l'aide d'un chiffon propre imbibé à l'alcool (**Fig. 10**)

Ce document, établi par ALSYOM dans le cadre du Marché CEA n° 4000529715 du 26/07/2012, est la propriété du CEA.
Aucune utilisation ou communication ne peut être faite sans l'autorisation écrite et préalable du CEA

Assembly Procedures

- The preparation, assembly and control work are described in **145 procedures**, ‘Fiches d’Instruction’, ‘used’ by the operators.

- The first set of draft procedures was written by CEA, during the Prototyping phase at DESY and Saclay, in English and appended to the Call for Tender Specifications for Industrial Operator selection

- Alsyom, the selected Industrial Operator, was in charge of updating these procedures during the Pre-Series phase (3 modules) and to translate them in French for their usage during the Series production phase.

- This took much (much) longer than expected !

Integration Operators

- A good operator is worth ~100 QC tests !
- Invest in the selection of **competent** (or even qualified), **rigorous** and **motivated**, in one word **reliable** technicians.
- The **Call for Tender** for the selection of the **Industrial Operator** could be organized around its ability to write procedures and to bring qualified personnel.

The rest will come.

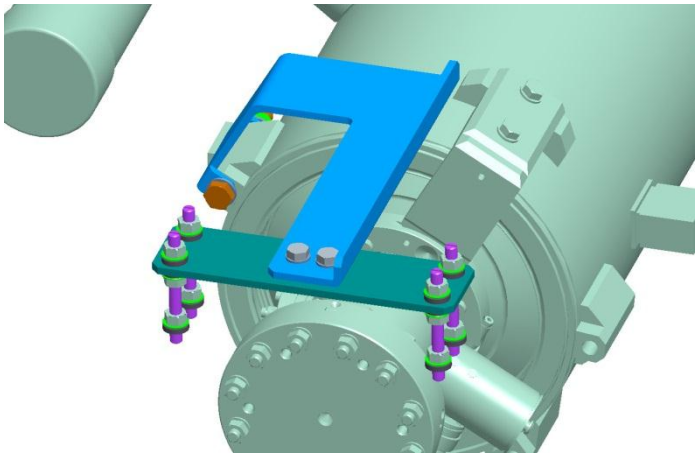
Productivity may still gain from improvement of small tools

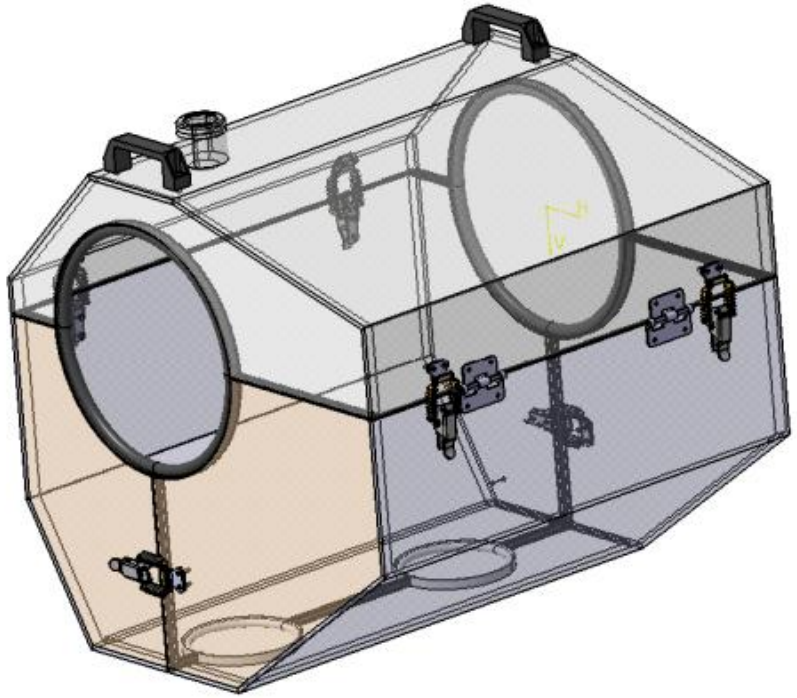
Two more examples, in use:

1) Pre-fabricated et reusable devices for the leak-check of the cavity string connections → 3 units fabricated and in use.

2) Realization of gate valve support for its assembly on Cold-Coupler WS:

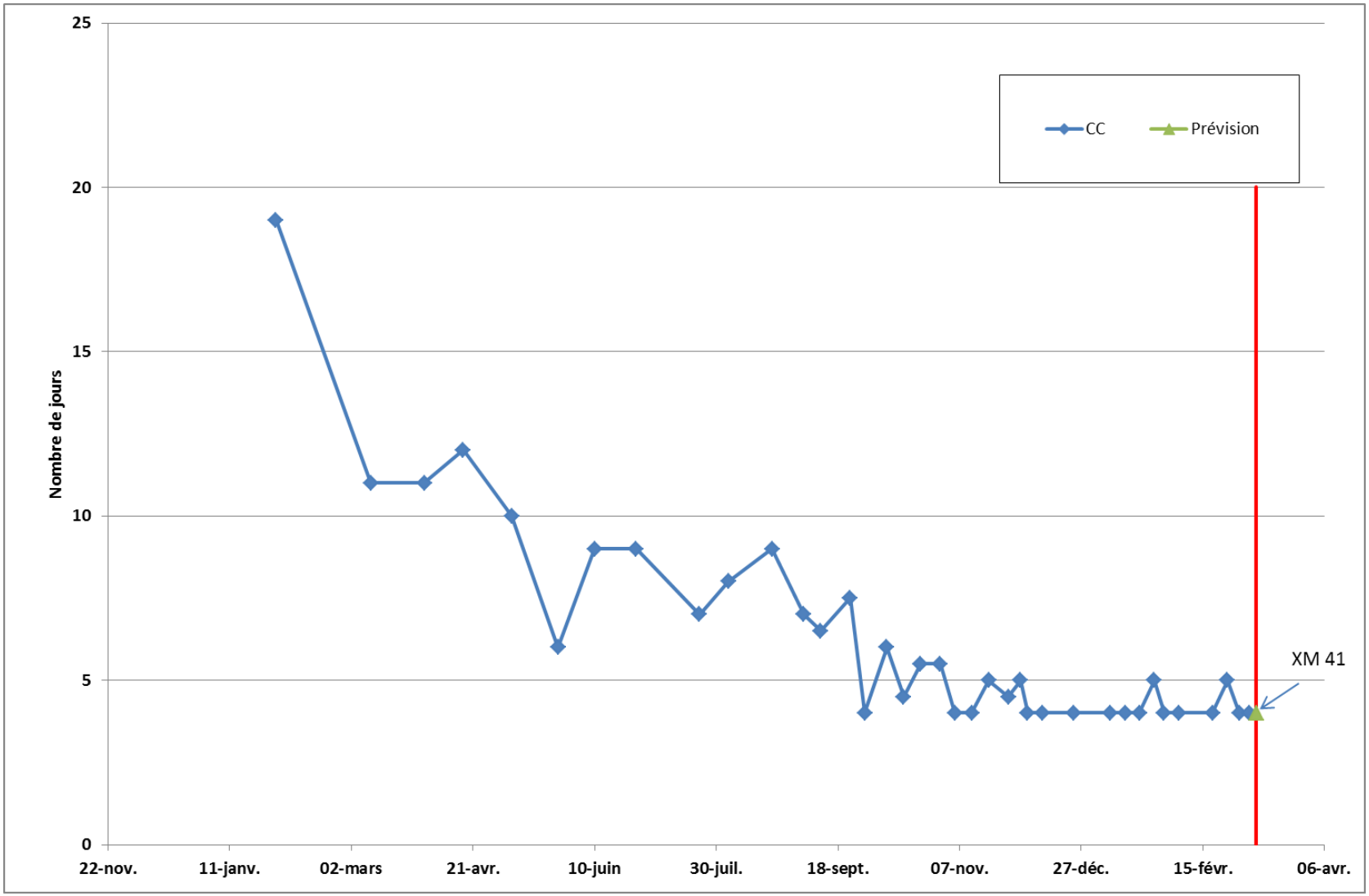
Design and fabrication taken over by Alsyom, used for XM22.



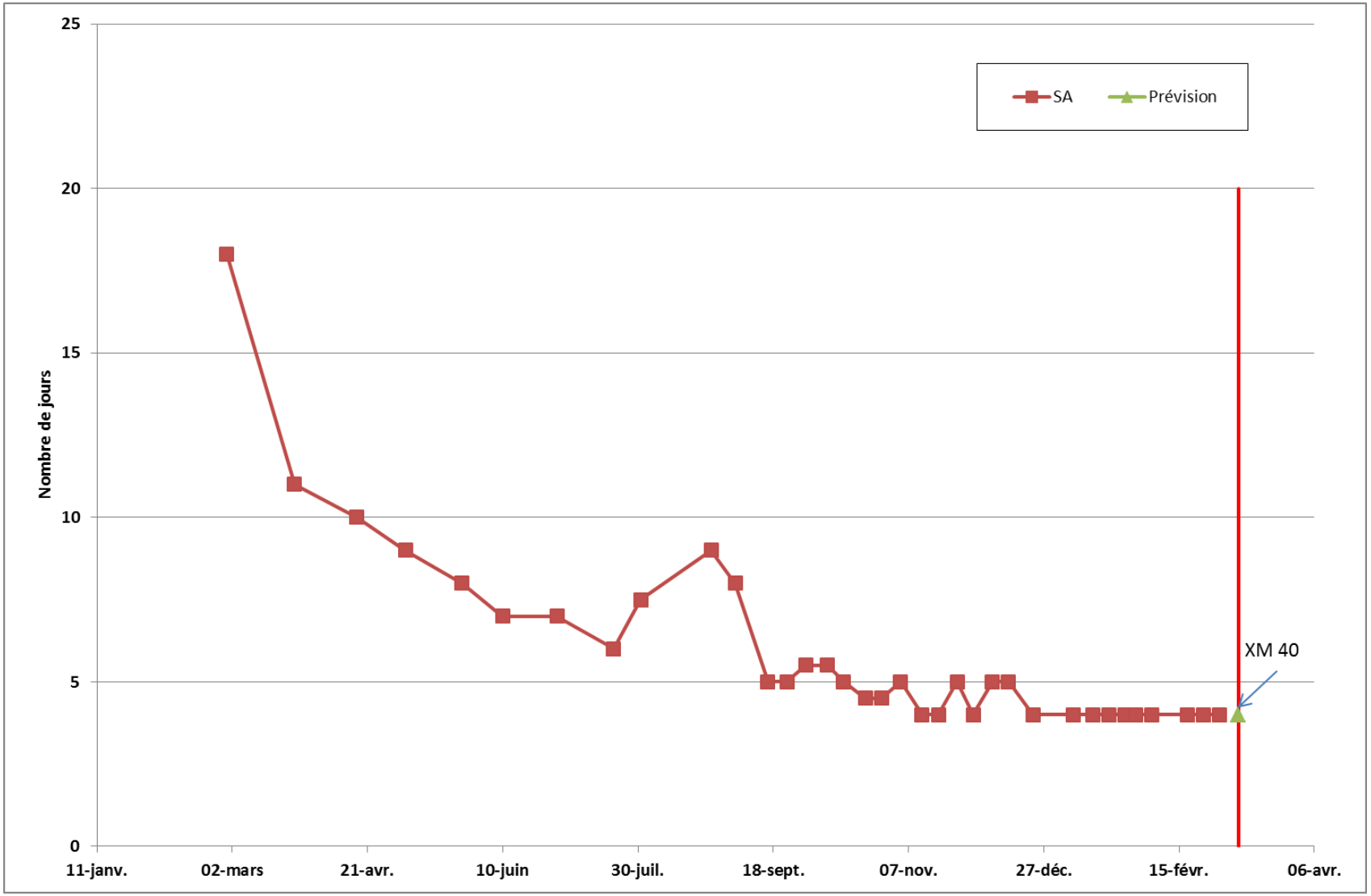


Inter-cavity connection leak-check box, including cold coupler connection, and pre-existing HOM flanges

Throughput at Cold Coupler WS

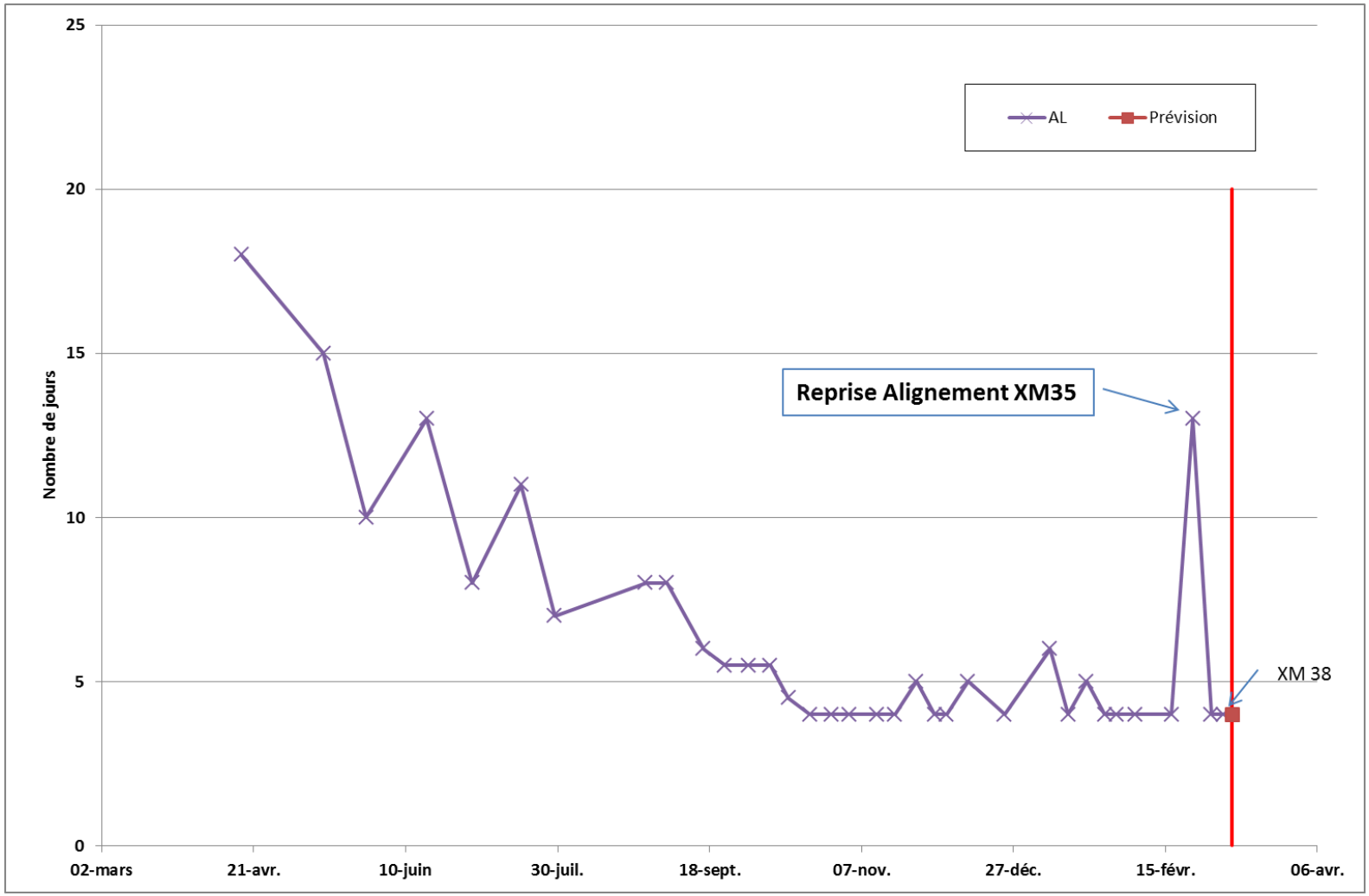


Throughput at String Assembly WS

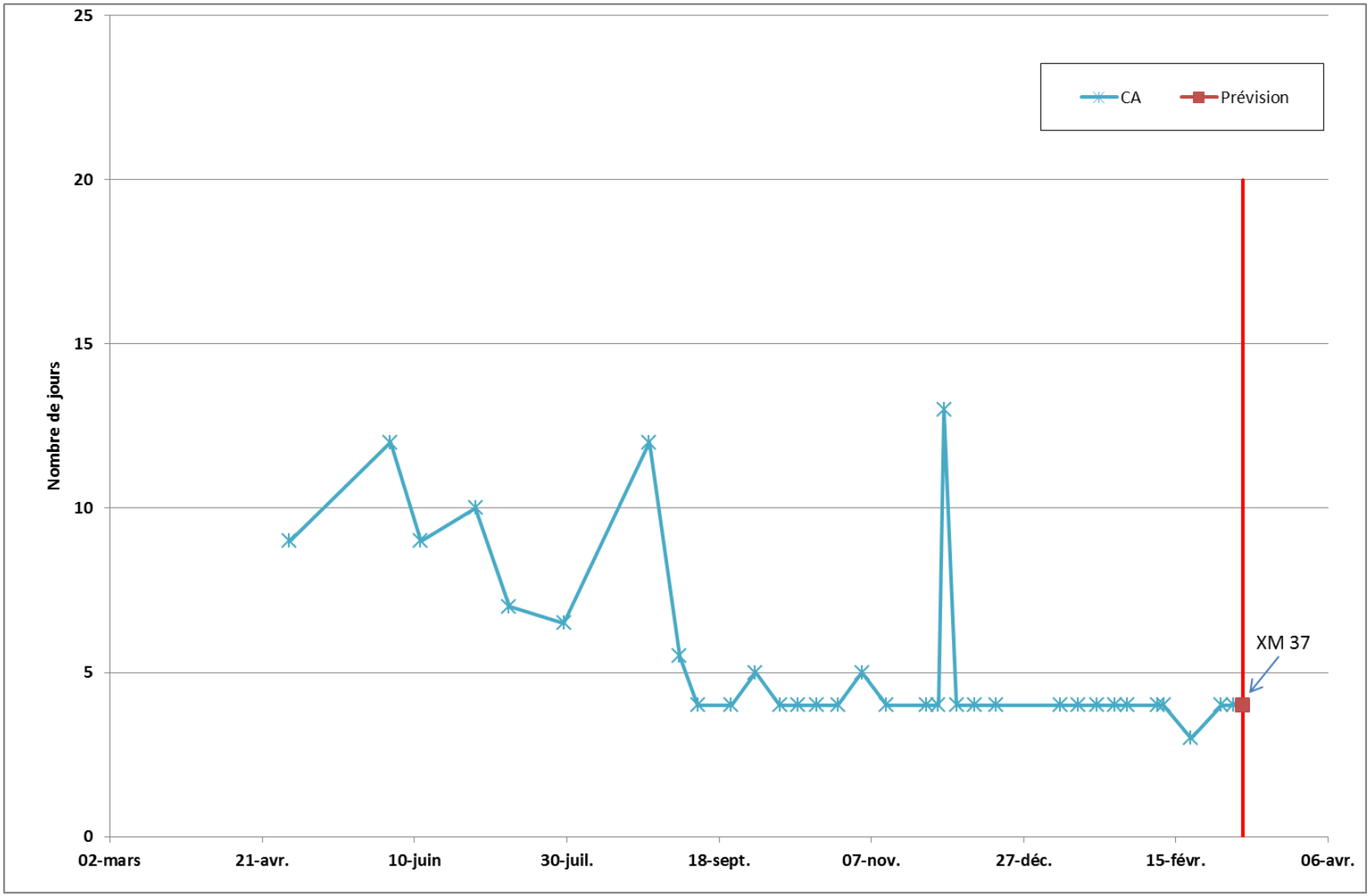


Throughput at Roll-out WS

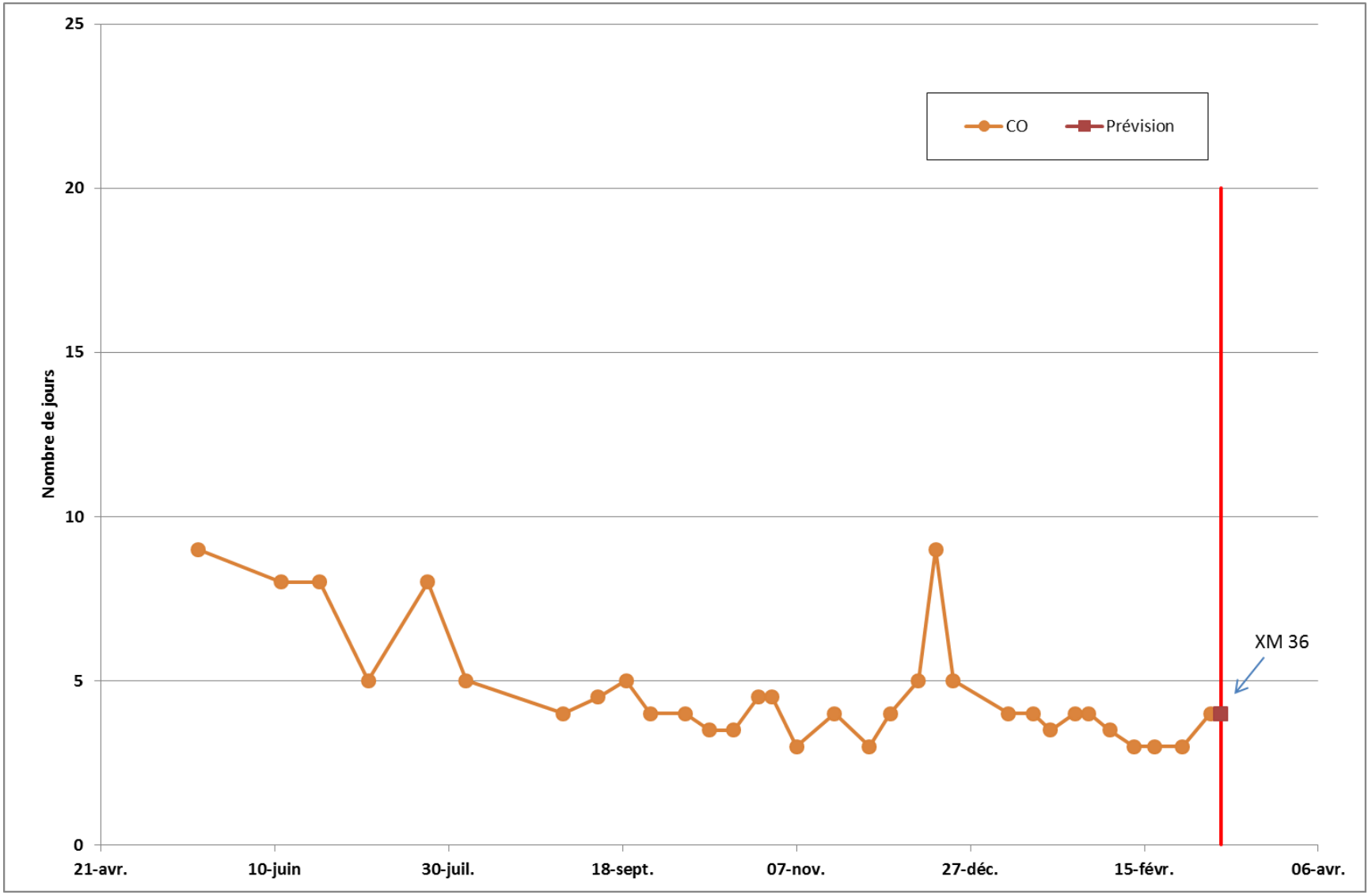
Throughput at Alignment WS



Throughput at Cantilever WS

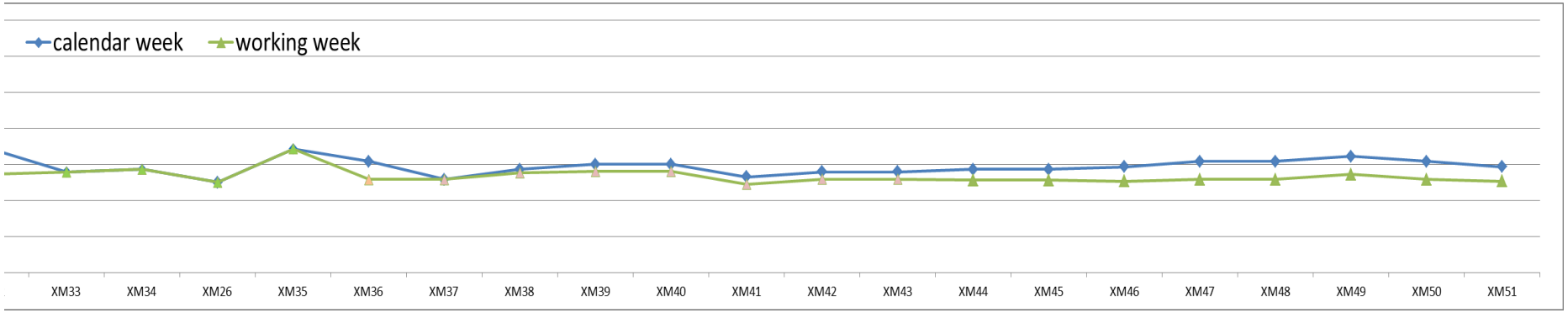


Throughput at Warm Coupler WS



Cryomodule Asssembly Time

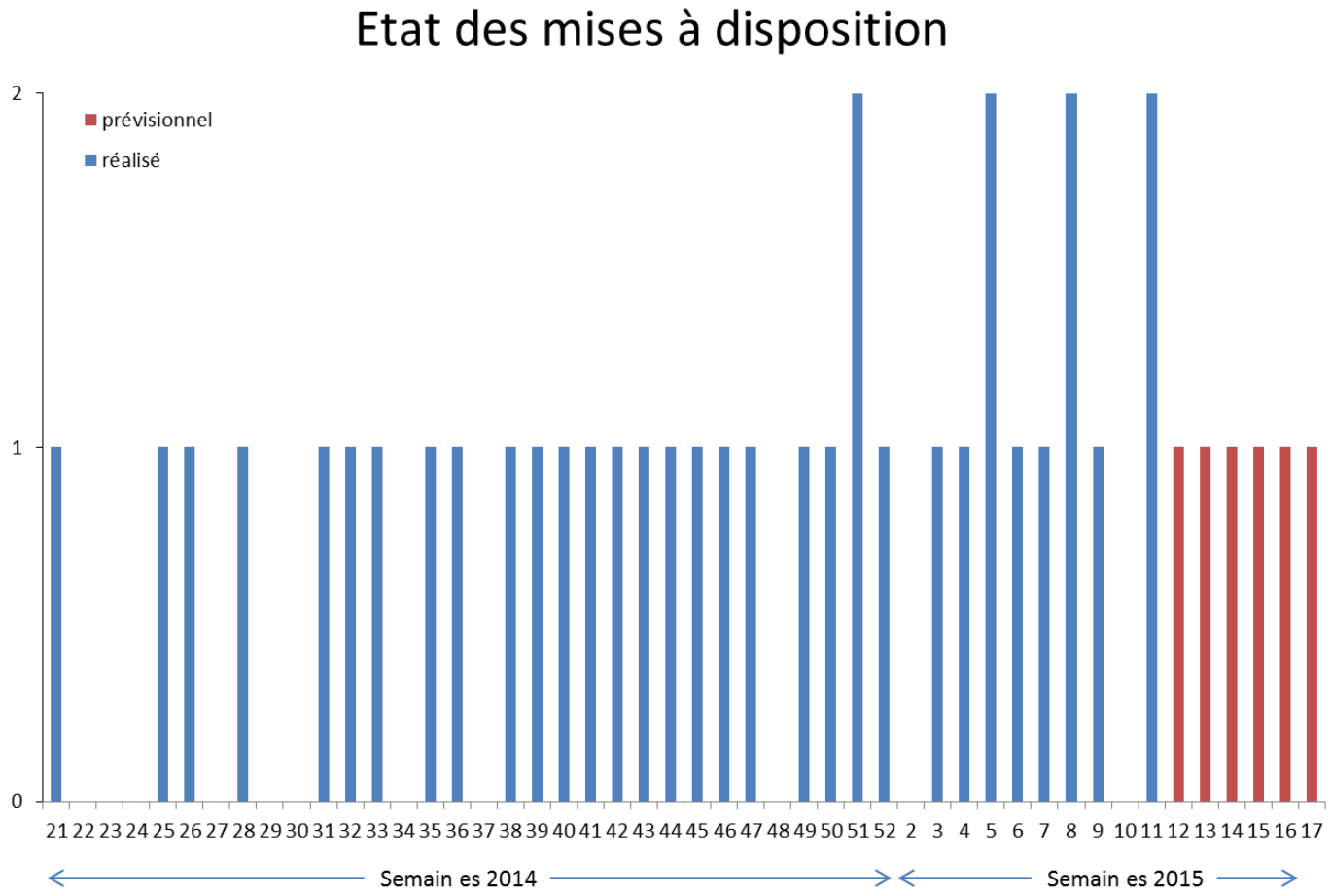
7 x 5 working days = 7 weeks was reached mid-October 2014 with XM15
⇒ the design of the Assembly Infrastructure was sound



7 x 4 working days was reached on 5 January 2015 with XM25
⇒ since Jan 2015, one cryomodule built and delivered every 4 days !

This accelerated rate is needed to close the XFEL tunnel mid-2016

Cryomodules Deliveries



Quality Control

Quality Control consists in:

1. Inspecting the incoming components
2. Controling the assembly work in person
3. Documenting the controls and non-conformities

Until end of 2014, the quality control group of Alsyom was too small (3 people) in such a way that Documenting and Incoming Inspection was performed in priority. CEA took the major part of the Assembly Work Controling, essentially during pre-defined ‘Hold Points’.

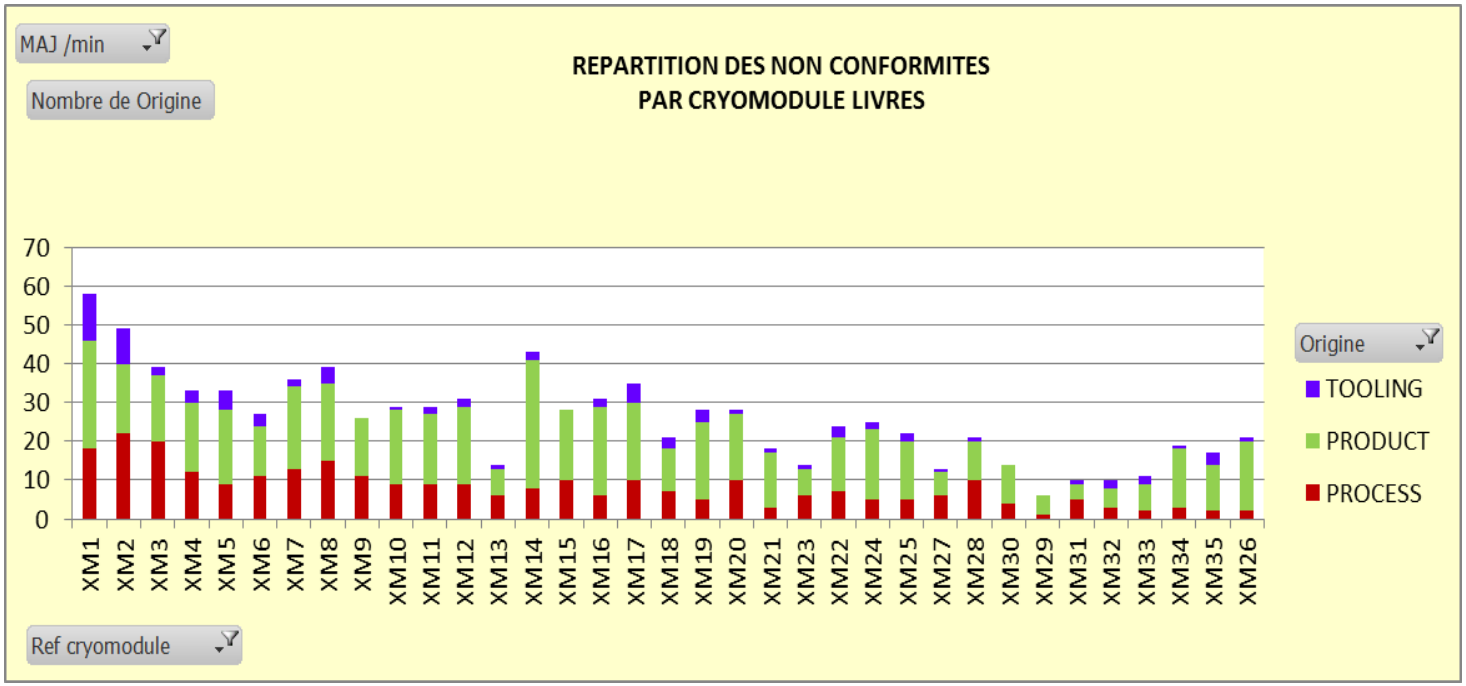
The ‘every day’ or ‘random’ controls were too few and this led to many mal-fabrication, most of them recorded at DESY before or during cryomodule cold test !

In November 2014, the quality control group of Alsyom was increased to 5 people which, together with the better organisation, covers the need of QC.

Quality Control: Non Conformities

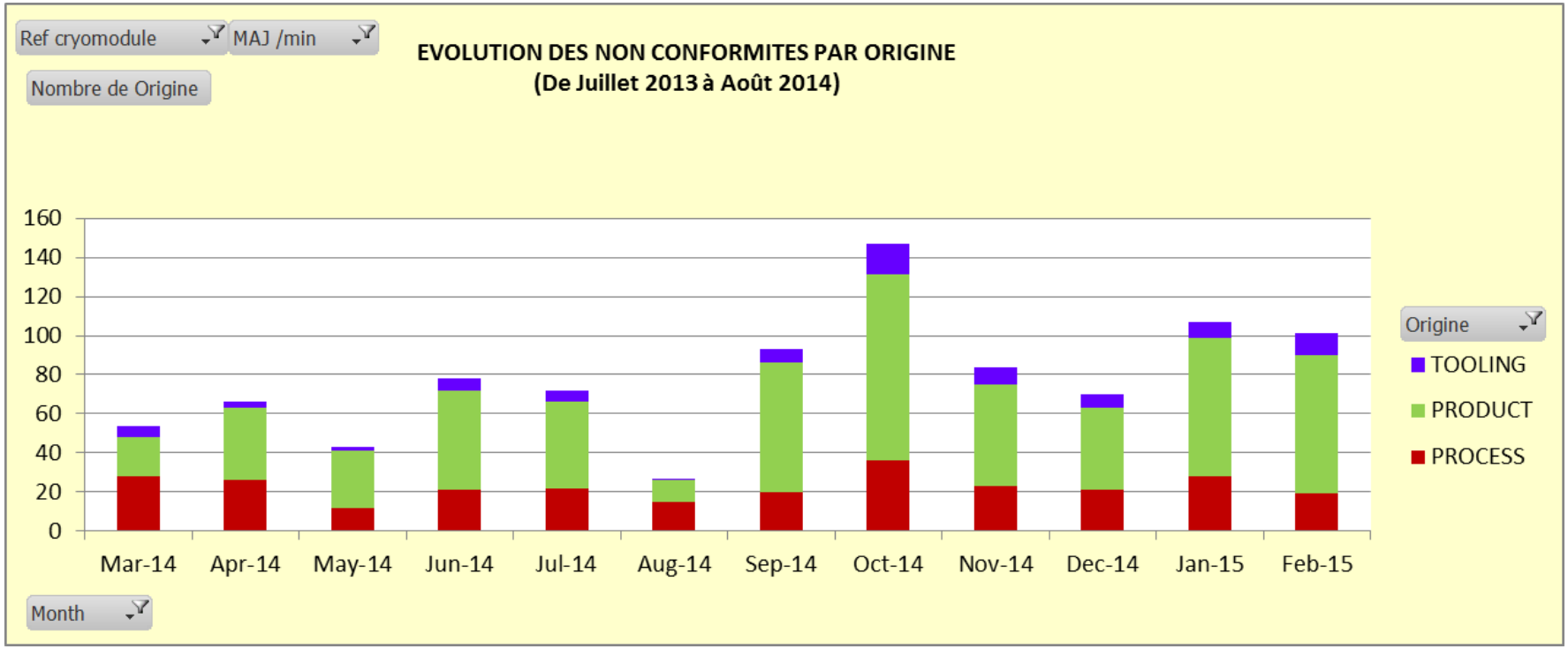
Non Conformities recorded by Alsyom fall into 3 categories:

1) Tooling and assembly equipment, from CEA and DESY (pump stations) (TOOLING)
2) Accelerator components (PRODUCT)
3) Assembly operation (PROCESS)



Quality Control: Non Conformities

The number of Non Conformities is NOT going down.



But, with better and more efficient detection at Incoming Inspection, the impact of PRODUCT NC on the module assembly has considerably decreased, compared to when many NC were discovered ‘on the fly’.

Quality Control: Non Conformities

PROCESS Auto-quality Check Matrix:

Non-conform product

Origin of Non-Conform Assembly

Detection of Non-Conformance

Lieu de détection	FOUR	REC	SUP	SA	RO	AL	CA	CO	SH	Total général
REC	47	3								50
CC	15									15
SA	17			3						20
RO	23	1			17					41
AL	1					8				9
CA	6		1			2	2			11
CO	47							3		50
SH	6								1	7
CEA	21	1	2	2	13	9	5	6		59
Total général	**183**	**5**	**3**	**5**	**30**	**19**	**7**	**9**	**1**	**262**
		60%	**0%**	**60%**	**57%**	**42%**	**29%**	**33%**	**100%**	**36%**
										TAQ

The goal is to detect all the PROCESS Non-Conformities at the Work Station where they are generated.

QC Concrete (counter)Examples

- Leak test of cavities at reception, requested for DESY-Saclay safe transport contract: abandoned after XM4 because:

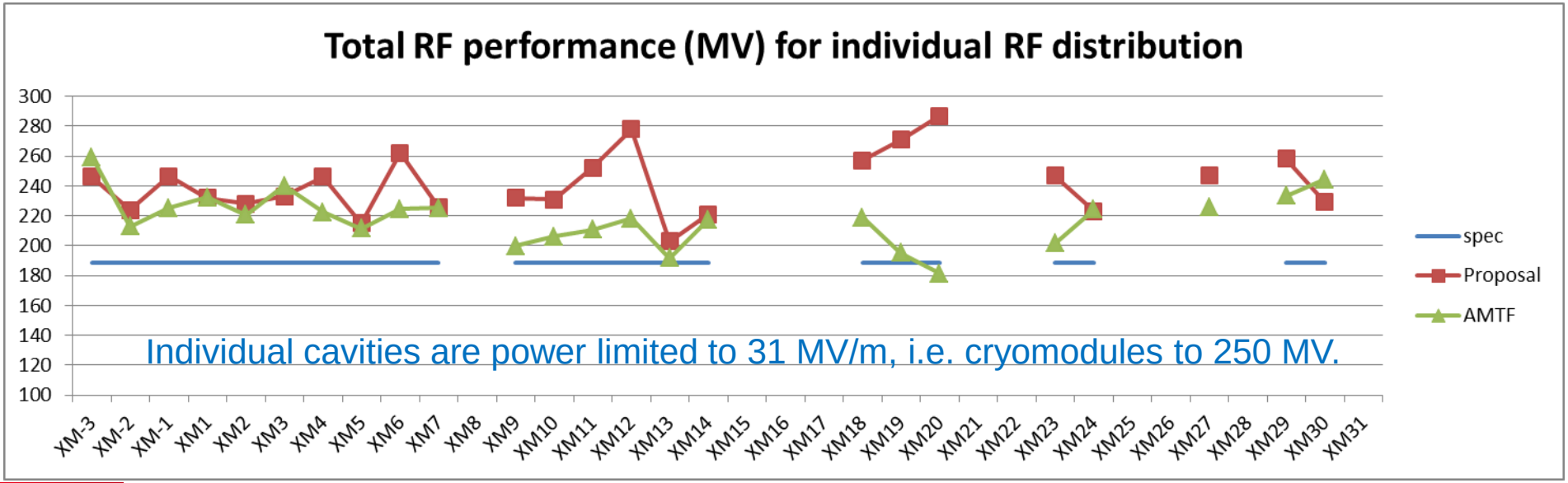
1. no cavity was found leaky
2. leak test is performed before coupler assembly
3. angle valve mis-manipulation

- RGA rejection rate: about 10 RGA tests are performed per module:

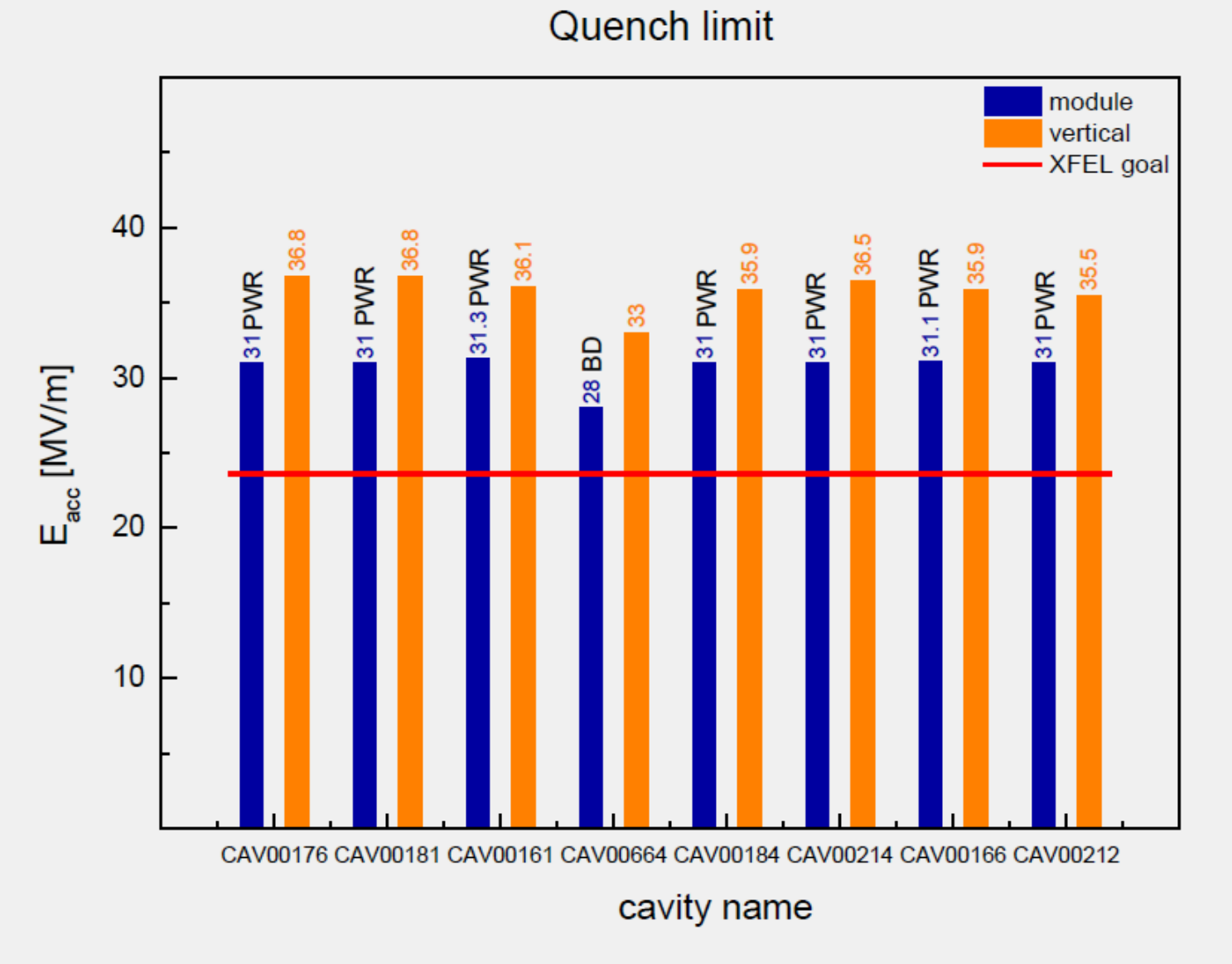
1. not a single rejection up to XM20
2. mass spectrometers are very unreliable and introduce delays on cold coupler assembly
3. Corrective action in case of negative RGA on string or module ??
4. Replace mass spectrometer by leak detector ?

Cryomodule Performance

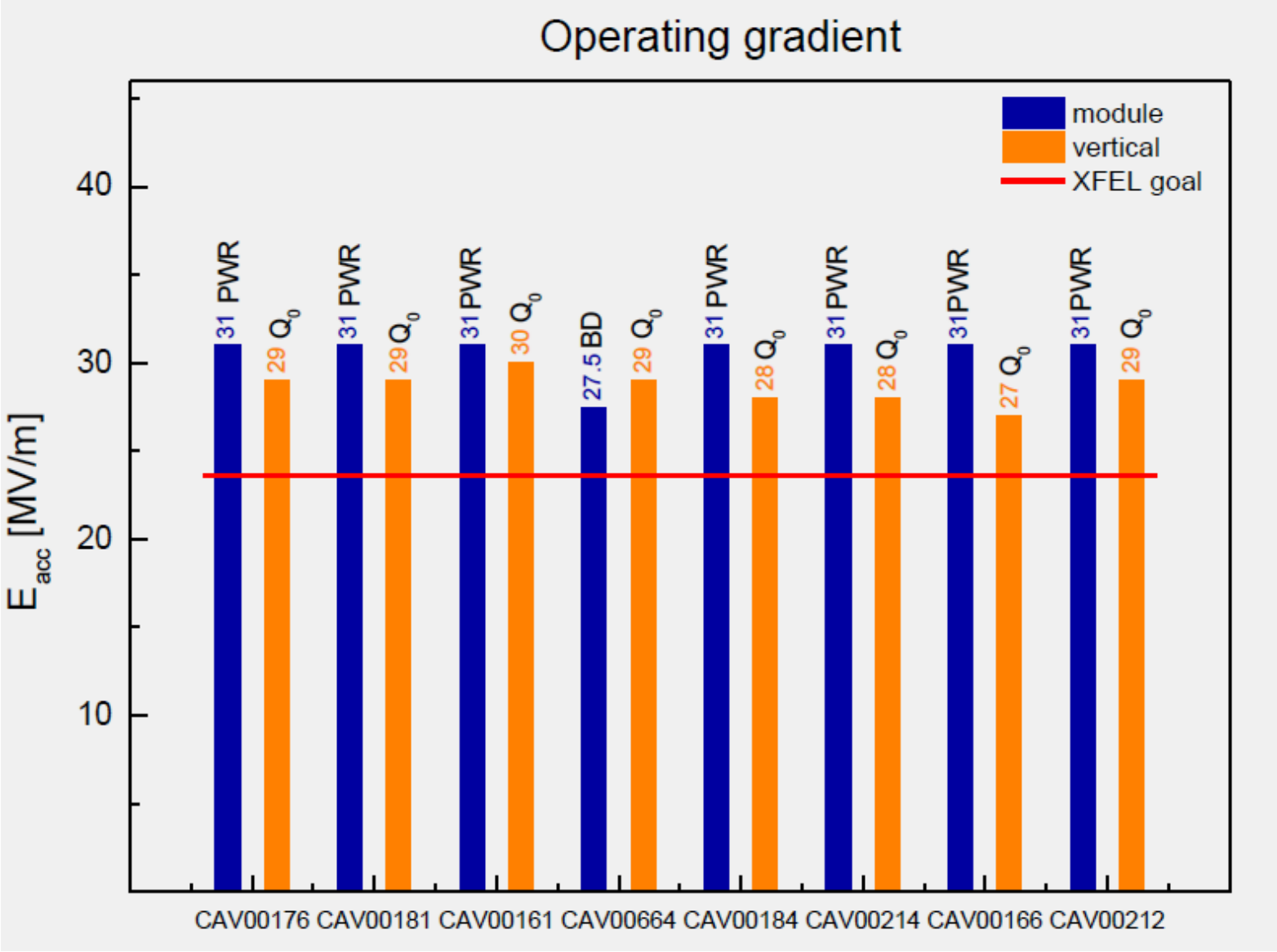
- Cryomodules are tested in cold and HLRF by a large scientist group from Krakow University in the AMTF facility at DESY.
- All tested modules are on XFEL specs (188 MV per module), on average 16 % above specs (27.3 MV/m).
- Some very important cavity gradient degradation have been recorded: XM-3 and XM30 are the two exceptions.
- Pairwise RF distribution was initially foreseen, but must be adapted to individual distribution in most cases.



Cryomodule Performance : XM30



Cryomodule Performance : XM30



Conclusions

1. Cryomodule Assembly is almost inevitably on the critical path of the acceleration contruction project, once the component production reaches steady state.
2. The difficulties of coupler production and assembly have been underestimated
    1. Unlike cavities, coupler production was discontinued (in Europe) and vendors lost their know-how
    2. Coupler assembly is the most complex operation: about 8 couplers (both cold part and warm part) have been destroyed du to bad manipulation and/or bad assembly
3. The XFEL village infrastructure and people will be used for ESS cryomodules, and are adapted for mass production of a substantial fraction of the ILC cryomodules (~2000).
4. We are following closely the FCC needs