
WEIOA01

# *Construction and RF Conditioning of the Cell-Coupled Drift Tube Linac (CCDTL) for Linac4 at CERN*

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# CCDTL for Linac4: the collaboration.

*CERN – European Organization for Nuclear Research, Geneva, Switzerland*

*BINP – Budker Institute of Nuclear Physics of Siberian Branch of Russian Academy of Sciences, Novosibirsk*

*VNIITF – Russian Federal Nuclear Center – Russian Scientific Research Institute of Technical Physics, Snezhinsk*

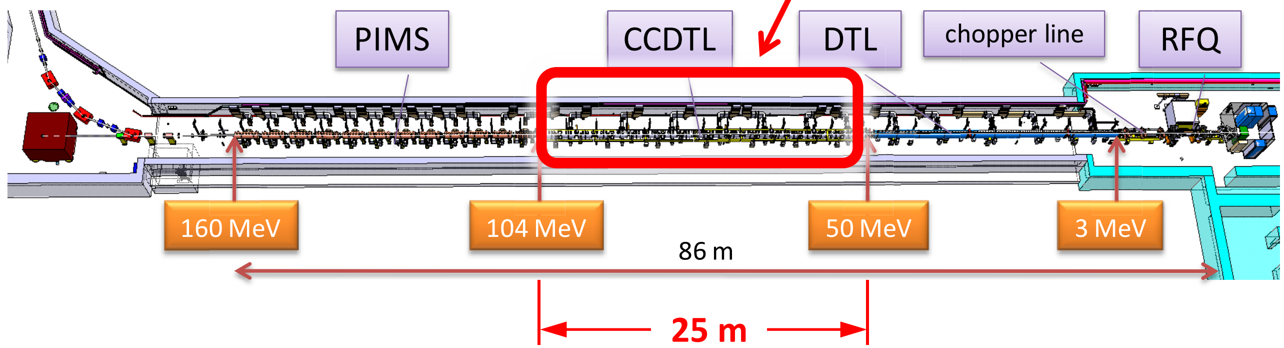
*ISTC – International Science and technology Center, Moscow (now in transition to Kazakhstan)*

| *Distribution of works* | *CERN* | *BINP* | *VNIITF* | *ISTC* |
|---|---|---|---|---|
| *Design* | ● | ● | ● | |
| *Prototyping* | ● | ● | ● | |
| *“Series” production* 1) | | ● | ● | |
| *Tests & measurements*<br>*(low power RF, vac., alignment etc.)* | ● | ● | | |
| *RF conditioning* | ● | | | |
| *Management*<br>*(procurement, shipping arrangements etc.)* | ● | ● | | ● |
| *Funding* | ● | | | ● |

1) The tanks were constructed at VNIITF while the drift tubes and supports were made at BINP.

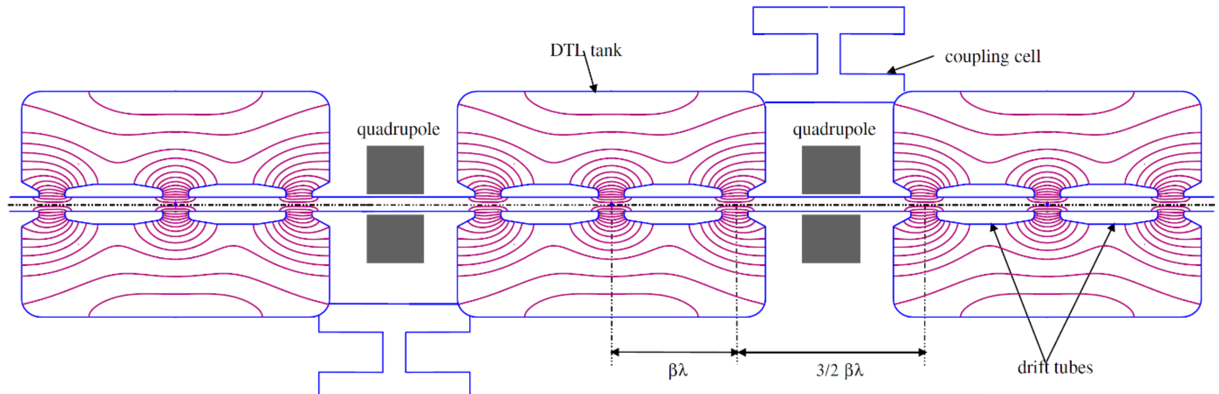
# CCDTL for Linac4: the scope.

*Linac4, a new 160 MeV H- accelerator will replace the 50 MeV proton Linac2 as an injector to the PS Booster.*



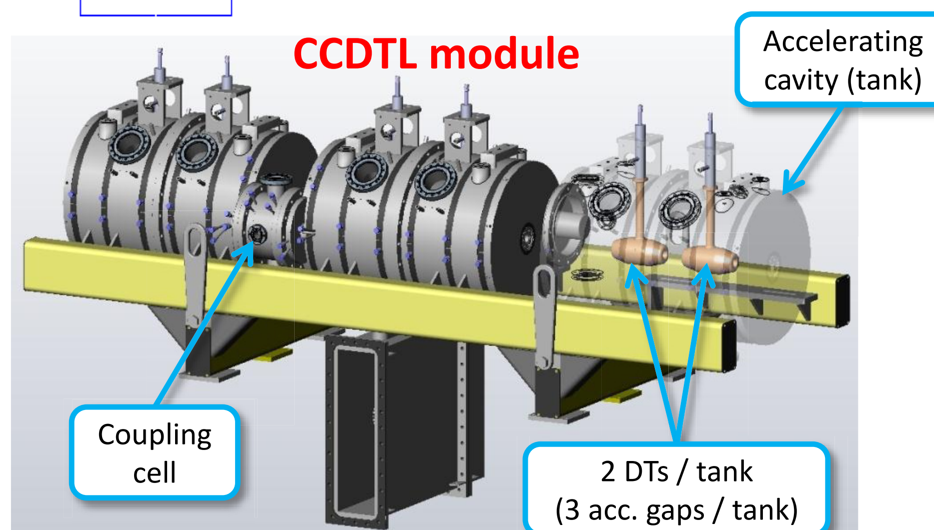

## ***CCDTL features:***

1. *Separate accelerating cavities (tanks) with 2 drift tubes / tank,*
2. *single cell off-axis coupling cavities (cells),*
3. *operates in the stable π/2 mode,*
4. *Quads placed between the tanks.*



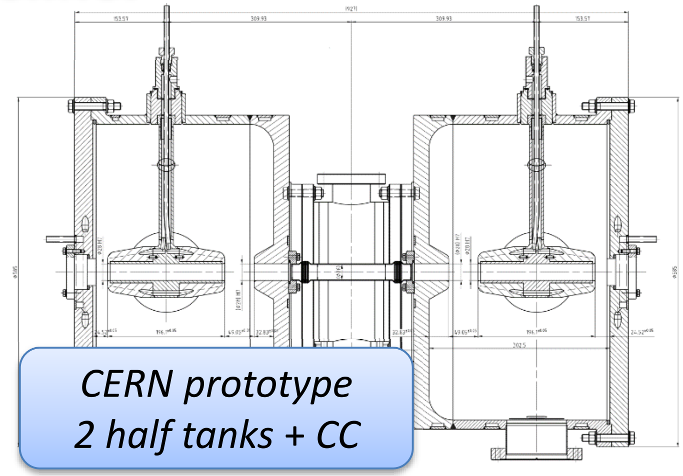

## ***CCDTL advantages:***

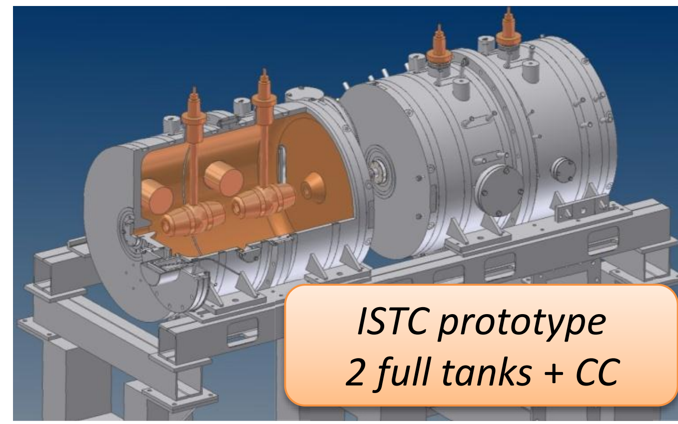
1. *Small drift tube diameter ⇒ high RF efficiency.*
2. *EMQs between the modules ⇒ flexibility for transverse beam dynamics.*
3. *Quads can be aligned on the supports independently from the cavities ⇒ relaxed tolerances of the drift tube positioning.*

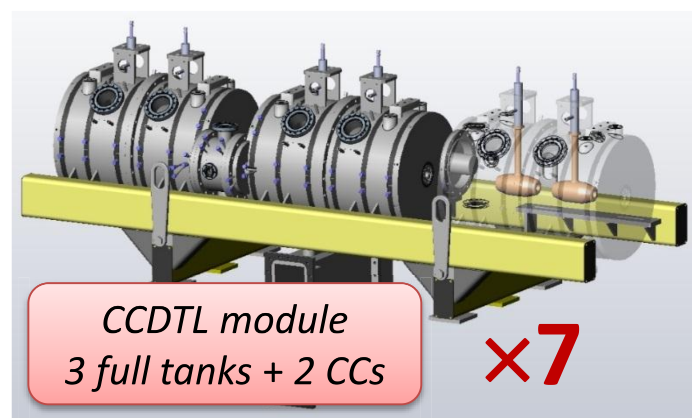


# CCDTL for Linac4: the timeline.

| | |
|---|---|
| **1994** | **1st CCDTL concept at LANL** |
| **2000** | **Conceptual CCDTL design for a new proton linac at CERN** |
| 2001 | 12-cell scaled (1:3) Al "cold model" at CERN |
| **2004 2005** | **Design and construction of the CERN 352 MHz prototype** |
| **2006** | **Successful high power tests of the CERN prototype** |
| **2004** | **Start of an ISTC project for the construction of a CCDTL "pre-series" prototype in Russia** |
| 2005 2006 | Design and construction of the ISTC prototype at BINP / VNIITF |
| **2007** | **Successful high power tests of the ISTC prototype at CERN** |
| **2009** | **Start of 2 ISTC project for the construction of the 7 CCDTL modules in Russia** |
| 2010 2013 | Design and construction of the 7 CCDTL modules at BINP / VNIITF |
| **2013** | **Successful high power tests of the first CCDTL module at CERN, delivery of the last module to CERN** |
| 2014 | On-going high power tests of the CCDTL modules at CERN, installation into the Linac4 |

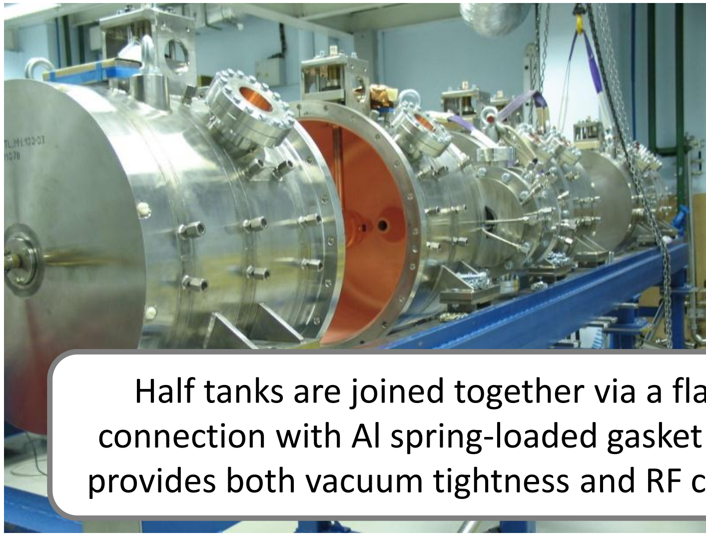


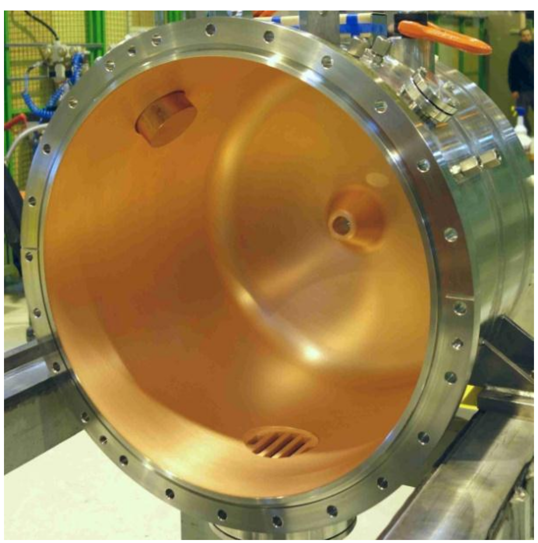
# CCDTL for Linac4: tank design.

## *Each AC tank consists of two halves:*

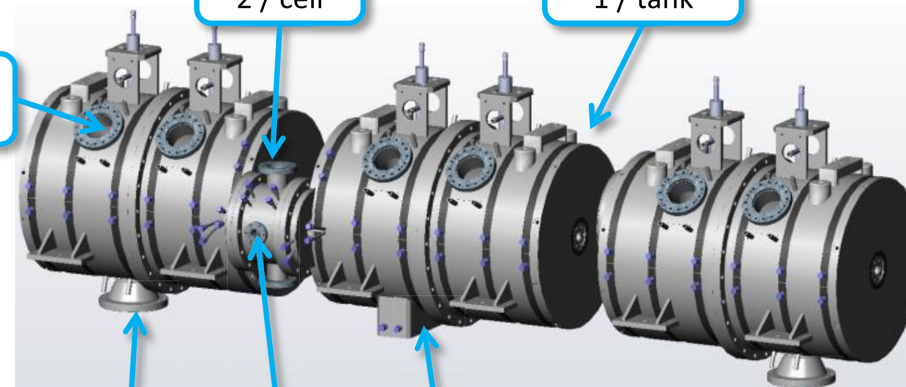


Half tanks are joined together via a flange connection with Al spring-loaded gasket which provides both vacuum tightness and RF contact.

All inner SS surfaces are 30÷50μ Cu plated.



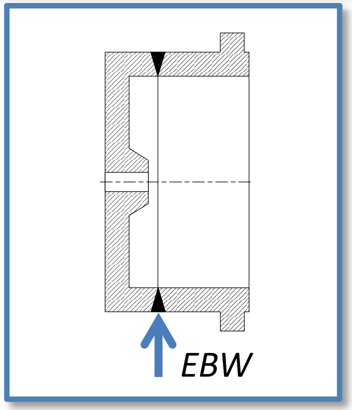
## *The module has various ports welded onto the cavities :*

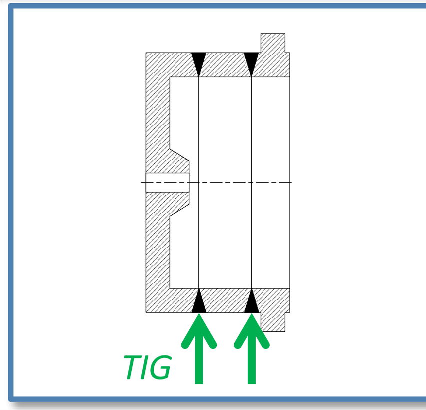


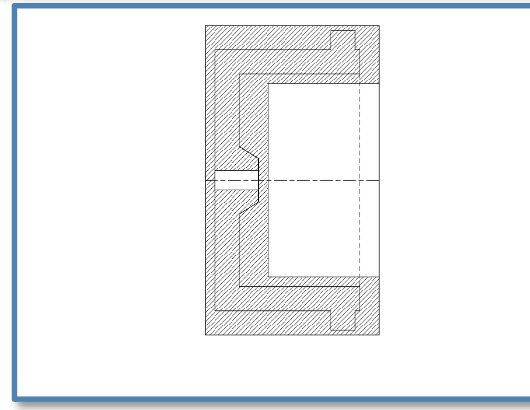

The cavities are water cooled, cooling channels are machined in the SS walls: *either drilled radially (in the end walls) or cut and welded up (in the side walls).*

# CCDTL for Linac4: tank design evolution.

| Major changes | CERN prototype | ISTC prototype | L4 modules |
|---|---|---|---|
| Stainless steel type | 304L | 12X18H10T (Russian) | 304L |
| Part joining technique | EBW | Multi-pass TIG welding | Pre-shaped single “bucket” [1] |



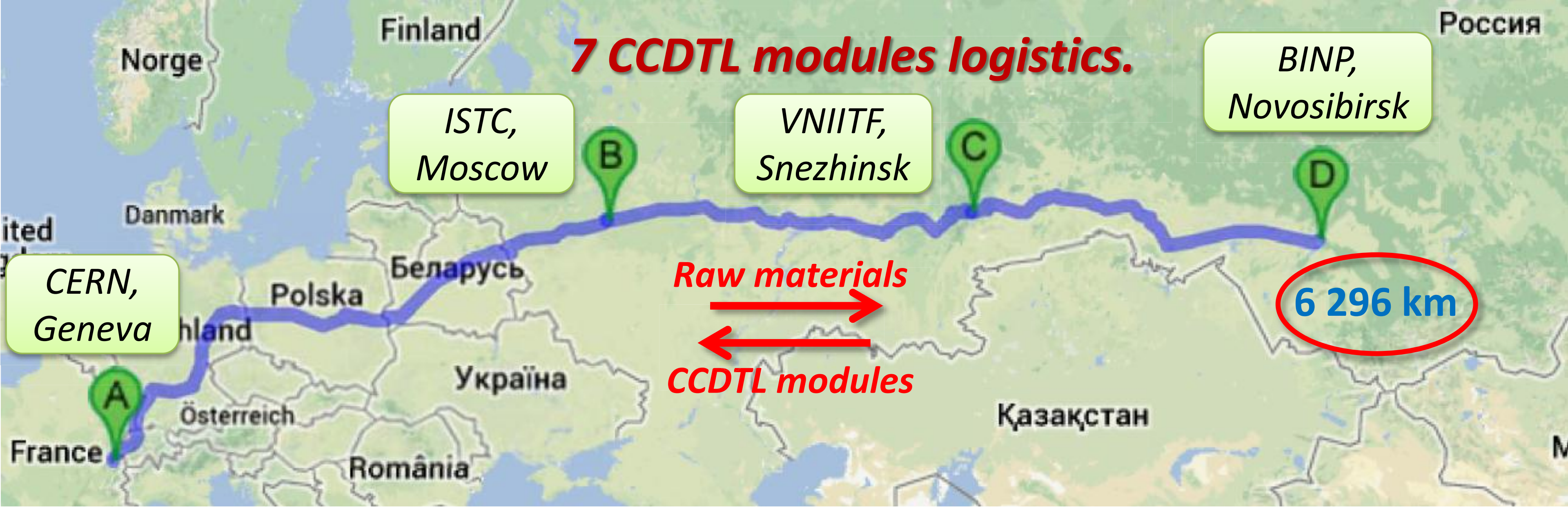



| Major changes | CERN prototype | ISTC prototype | L4 modules |
|---|---|---|---|
| Port / water chnl welding | TIG / EBW | TIG | TIG [2] |
| Cu plating | at CERN | at VNIITF | at VNIITF [3] |
| Flange sealing surface | No plating | No plating | Cu plated |
| Machining tolerances [4] | Tight (≤ ±50μ) | Relaxed (≥ ±50μ) [5] | Relaxed (≥ ±50μ) [5] |
| Water fittings | Swagelock® | Swagelock® | Serto® |

1) Long term reliability of L4 structures ⇒ strict material specs ⇒ **raw materials were provided by CERN.**
2) TIG welding of SS at VNIITF was qualified by CERN on samples according to level B of ISO 5817.
3) Facilities at VNIITF were upgraded, Cu plating was qualified by CERN and BINP on samples and confirmed by actual Q-values of CCDTL cavities (tank 1: $Q_0$ = 42 500, tank 21: $Q_0$ = 47 100 which is 80÷86% of 2D simulations w/o stems).
4) Tolerances for the dimensions which define half tank inner geometry.
5) Tolerances relaxed due to 2-steps tuning sequence.

# 7 CCDTL modules logistics.



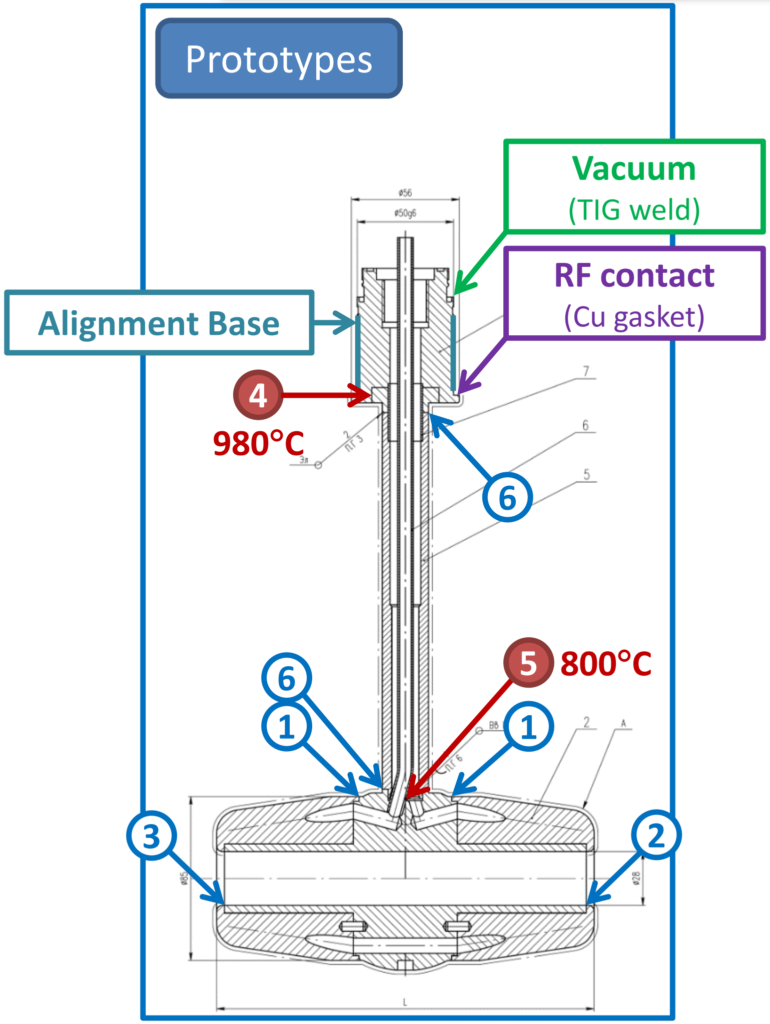

| | Delivery | A | B | C | D |
|---|---|---|---|---|---|
| 1 | Materials for CCDTL tanks | CERN | ISTC | VNIITF | |
| 2 | Materials for DTs and tuners | CERN | ISTC | | BINP |
| 3 | Materials for supports | CERN | | | BINP |
| 4 | CCDTL tanks | | | VNIITF | BINP |
| 5 | CCDTL modules | CERN | ISTC | | BINP |
| 6 | CCDTL supports | CERN | | | BINP |

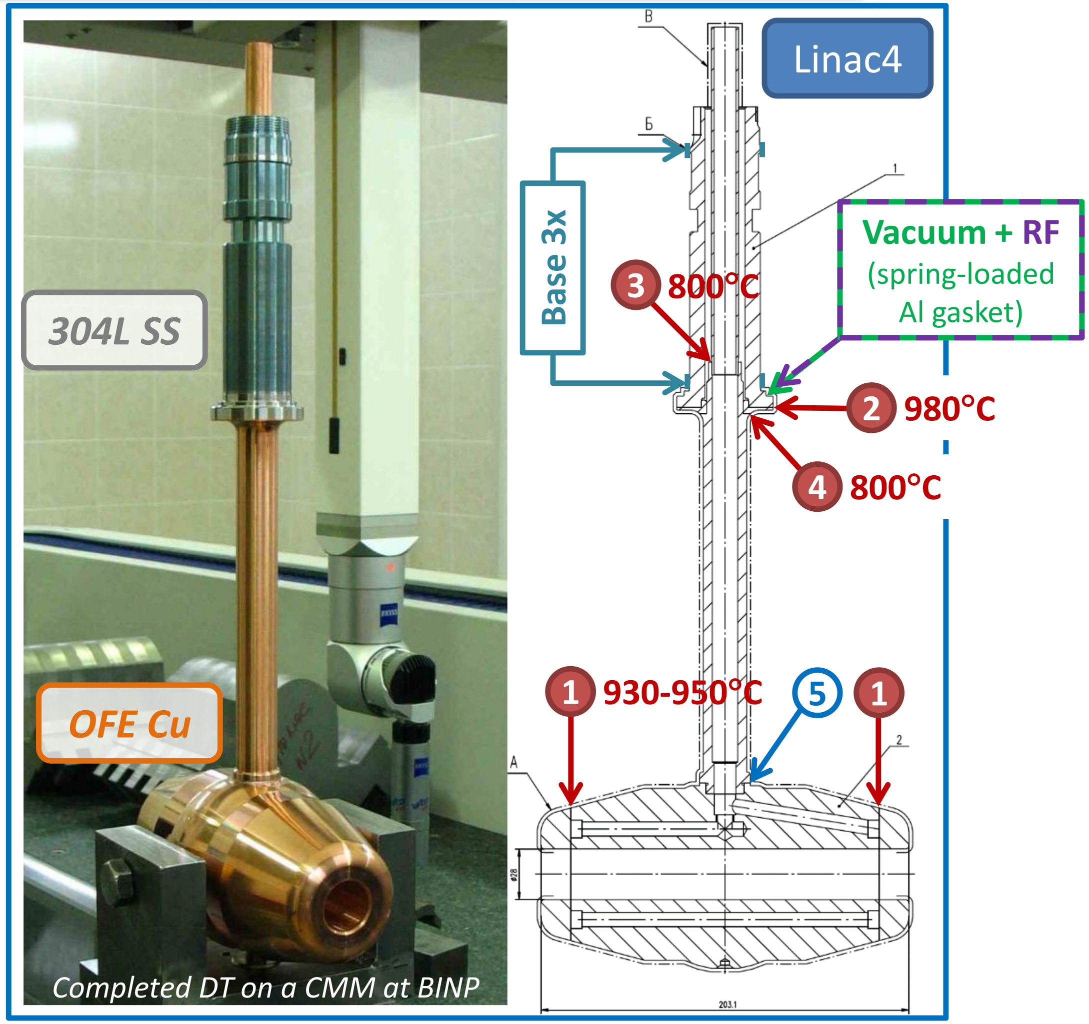
**Balance:** CERN → VNIITF + BINP = 34.4 + 11.7 = 46.1 tons

(according to shipping docs) CERN ← BINP = 16.1 tons

# CCDTL for Linac4: drift tube design and its evolution.

| Major changes | CERN prototype | ISTC prototype | Linac4 modules |
|---|---|---|---|
| Parts joining technique | EBW | EBW | EBW + Brazing |
| Connection to half tank | Fixed | Fixed | Dismountable |




*Legend: Empty circle – EBW, solid circle – vacuum brazing, value in the circle – operation order number*

# CCDTL for Linac4: alignment (1/3).

***Alignment was a special concern because a module consists of a number of parts connected together.***

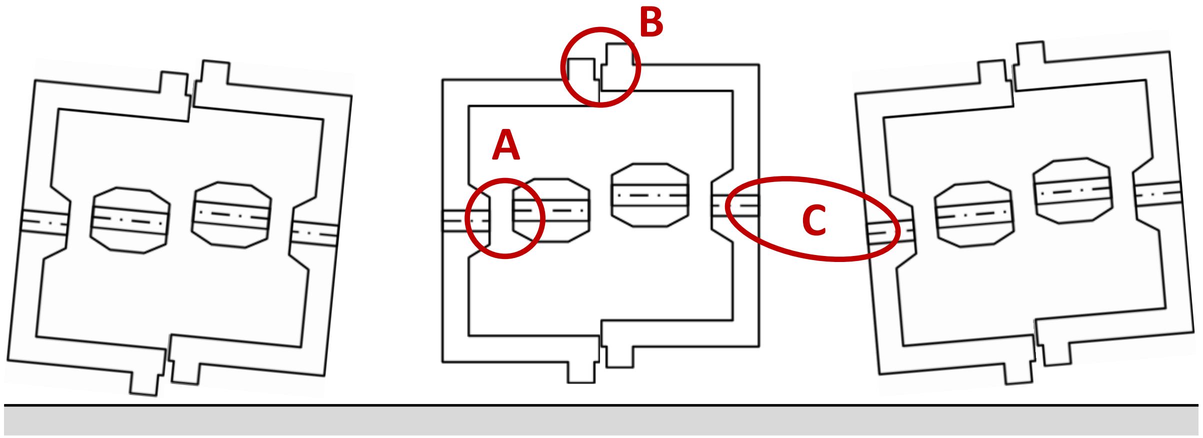
The requirement on the alignment of all beam holes *(in the DTs and end wall nose cones)* within a single module came out from the beam dynamics simulations done at CERN and was set to ±0.3 mm.

**Sources of errors:**

A. Drift tube misalignment in a half tank.

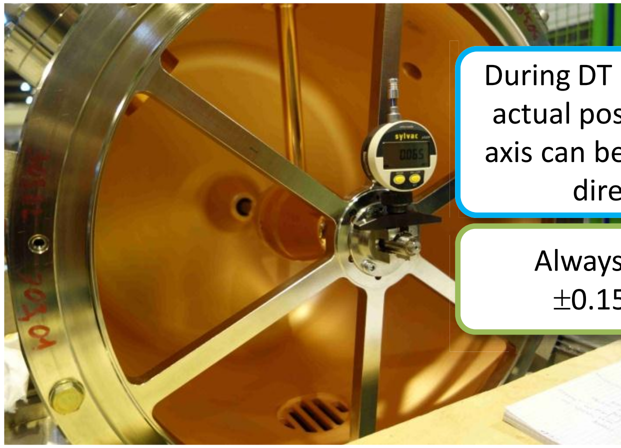
B. Misalignment of 2 halves constituting a tank.

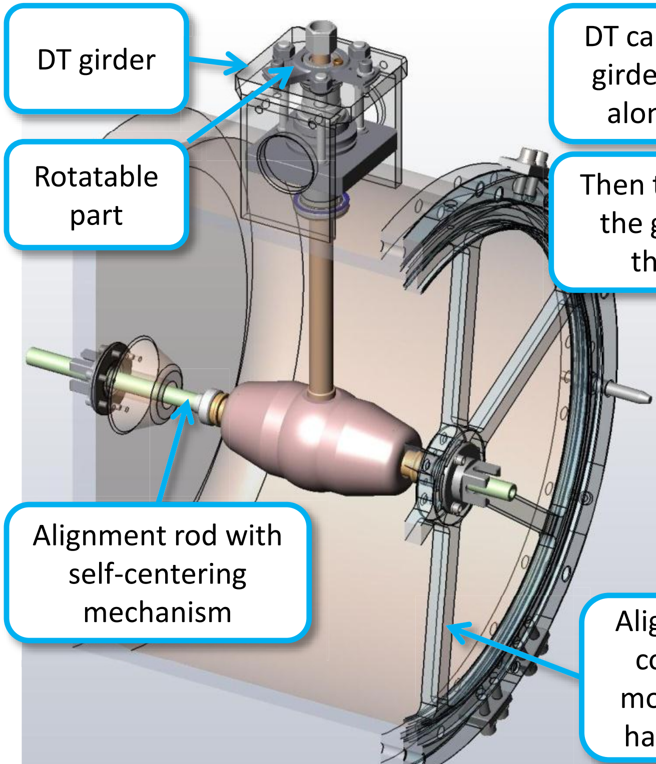
C. Misalignment of 3 tanks of a module.




Precision of the support plays an important role in the alignment of the complete module.

# CCDTL for Linac4: alignment (2/3).




**A. Drift tube installation:**

1. DT position in the vertical plane ⇒ machining and EBW tolerances (EBW: non-⊥ of the stem and drift tube < 0.1°, welding shrinkage < 0.1 mm).
2. DT rotation in the horizontal plane ⇒ installation procedure.

**B. Single tank assembly:**

1. ⇒ Machining tolerances and assembling procedure: two half tanks are bolted together on a flat assembly table, both halves being forced to follow the side guiding rail.


**C. Module assembly:**

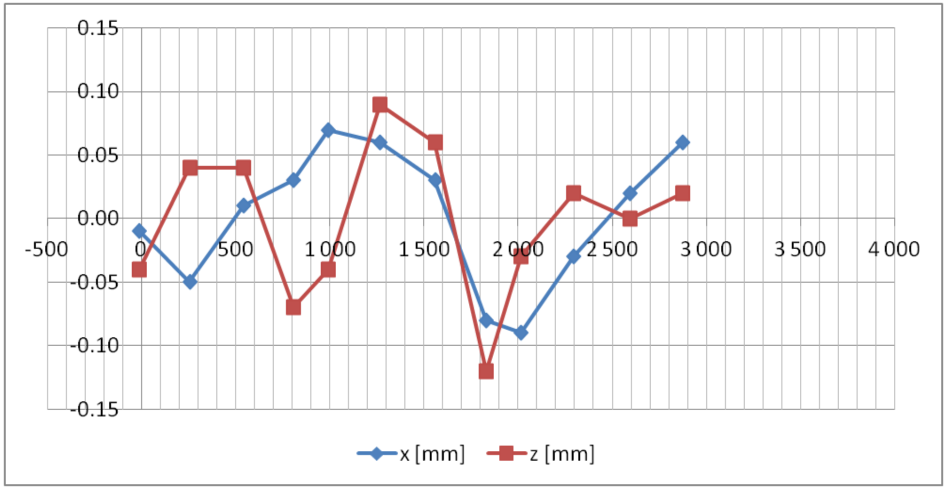
1. ⇒ connecting 3 tanks in a module is done on the final Linac4 support using same principle as for B.

# CCDTL for Linac4: alignment (3/3).

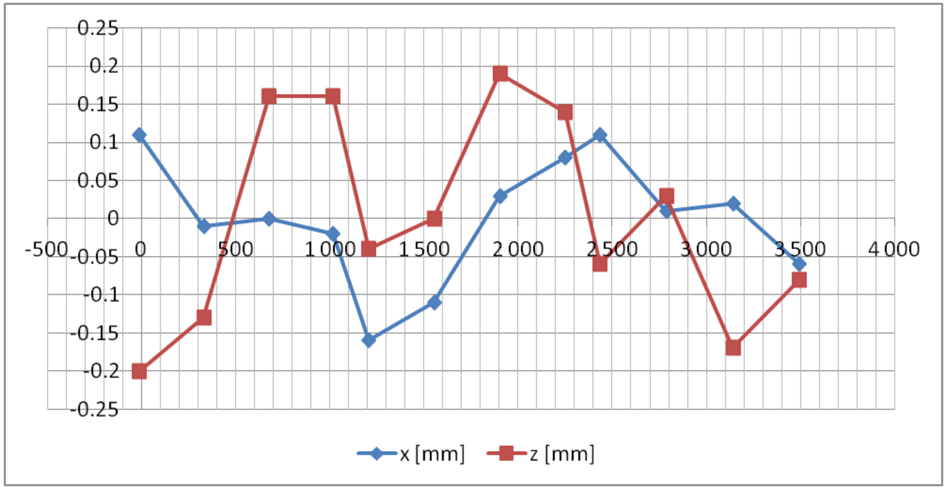

LT survey was done for 1 completely assembled module at BINP and for all modules at CERN.

All modules are within the spec of ±0.3 mm.

*Measured displacement of the beam hole centres (end wall Left / DT1 / DT2 / end wall Right) × 3 tanks.*




Module #2 – the best case -0.12…+0.1 mm




Module #6 – the "worst" case -0.2…+0.2 mm

*… well within the required range!*

# CCDTL for Linac4: RF tuning (1/2).

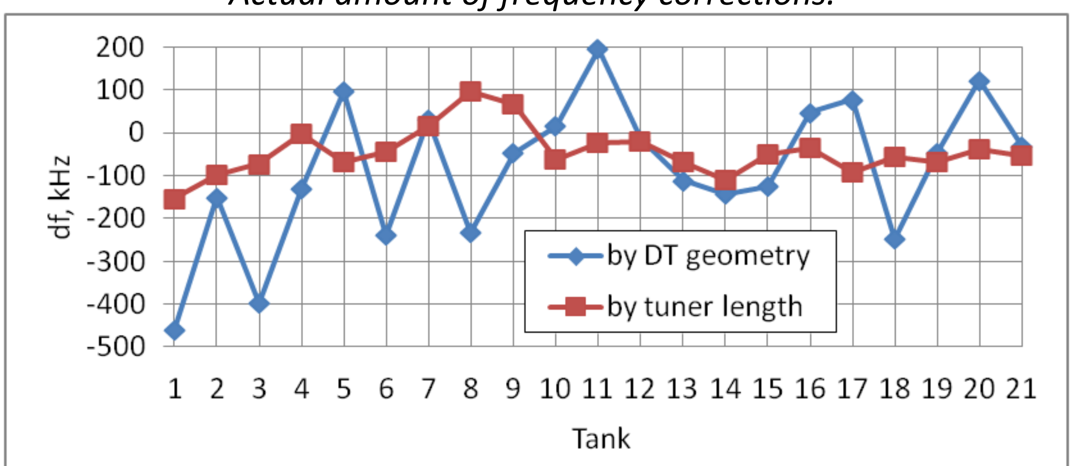
## Tuning sequence (for each accelerating cavity):

| N | Action | Tank | | Drift tube | | Frequency |
|---|---|---|---|---|---|---|
| | | Material | Dims | Material | Dims | |
| 1. | 3D simulation | PEC [1] | Dwg [2] | PEC | Dwg | $f_0$ = design value |
| 2. | Measurement | Cu plated | "as is" | Al | Known | $f_1$ |
| 3. | 2D simulation | PEC | Dwg | PEC | As above | $f_2$ |
| 4. | 2D simulation | PEC | Dwg | PEC | Corrected [3] | $f_c = f_0 - (f_2 - f_1)$ |

1) Perfect electrical conductor (used here to designate simulations only).
2) Dimensions as in the drawings.
3) DT length and cone angle are fixed for each tank, only the length of centre cylinder is changed.

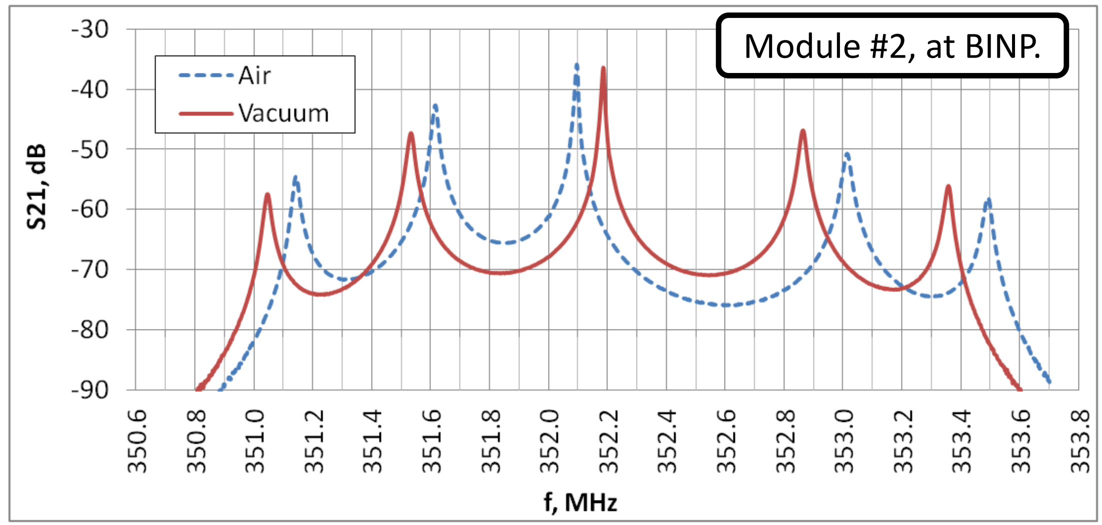
5. Cu DTs are machined to their corrected dimensions (+ actual tank $\Rightarrow f_0$).
6. Final frequency tuning is done by cutting fixed tuners length (2/cavity).

*Actual amount of frequency corrections.*



# CCDTL for Linac4: RF tuning (2/2).

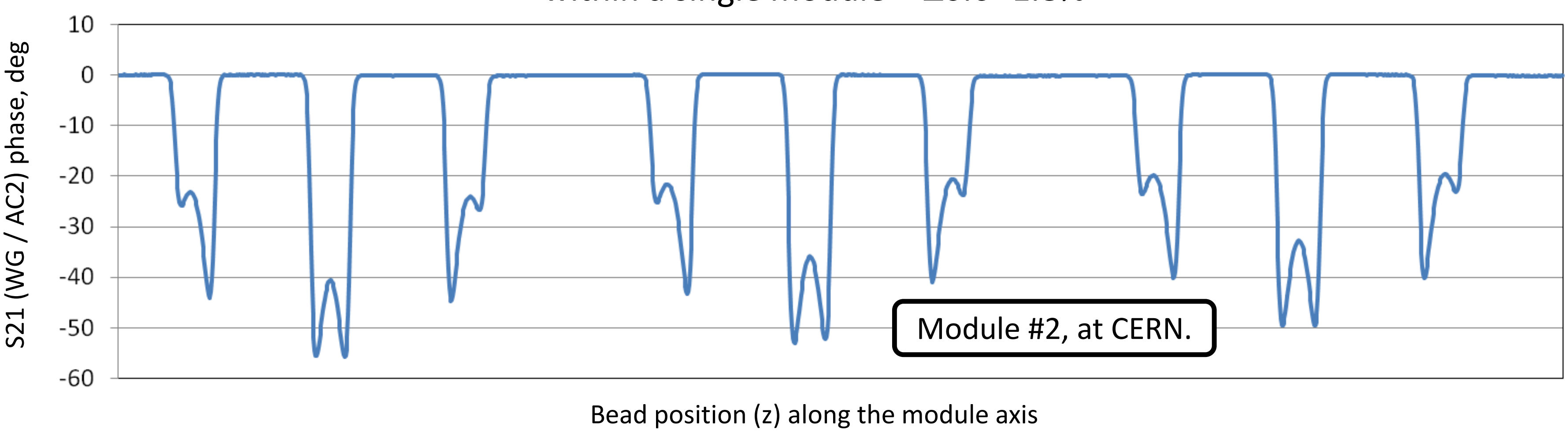
Actual ($f_{vac} - f_{air}$) for each cavity was accounted during the tuning and resulted in non-symmetric mode spectrum of an air filled module, which recovers under vacuum:




Field non-flatness

(*difference of the total gap voltages across each of 3 tanks*)

within a single module = ±0.6÷1.8%

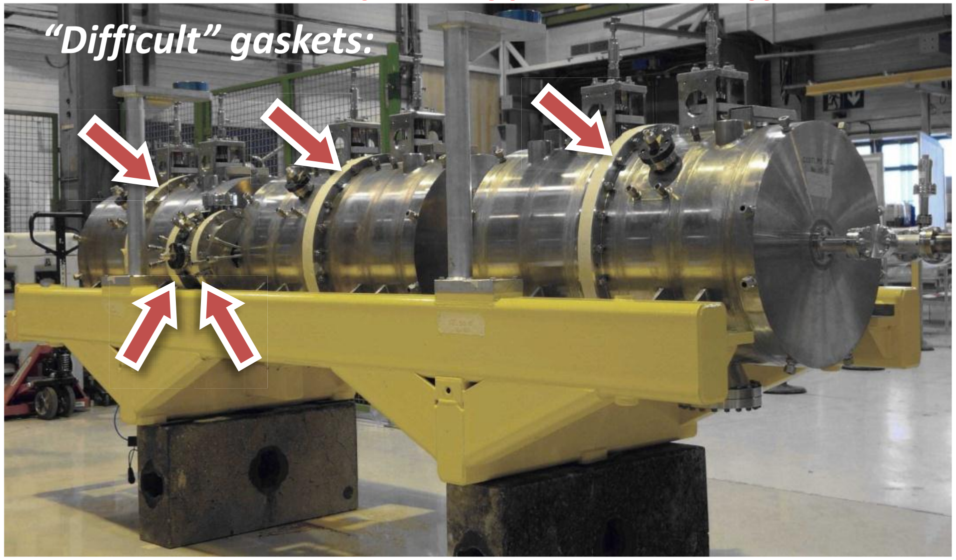


# CCDTL for Linac4: Vacuum (1/3).

## List of vacuum gaskets used in the linac4 CCDTL modules.

| | Connection | Type | Size | N / module | |
|---|---|---|---|---|---|
| Conflat® | AC tuner | CF | DN 100 | 6 | No problems |
| | CC tuner | CF | DN 63 | 4 | |
| | RF pick-up, vac. gauge | CF | DN 40 | 5 | |
| | Ion pump | CF | DN 150 | 2 | |
| Spring-loaded, aluminum jacket | DT / Half tank | HNRV 120 | OD 52.1 / Tore ∅ 3.4 | 1 | |
| | WG coupler | HN 200 | Rect. 323.88 x 70.88 / Tore ∅ 4.84 | 1 | |
| | Beam pipe | HN 200 | OD 50.0 / Tore ∅ 4.5 | 6 | |
| | Half tank / Half tank | HN 200 | OD 534.0 / Tore ∅ 6.0 | 3 | |
| | Half tank / CC | HN 200 | OD 228.0 / Tore ∅ 5.5 | 4 | |

***Worked well in the prototypes, VERY difficult now!***



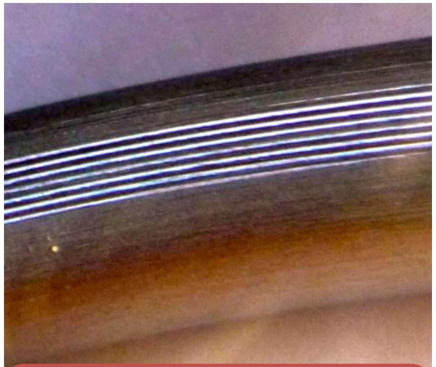
# *CCDTL for Linac4: Vacuum (2/3).*

## Preparation of the sealing surfaces.

| CCDTL | Surface material | Surface finishing | Actual surface roughness Ra, μ | Recm. Roughness Ra, μ | Compression resistance [2)], N/mm |
|---|---|---|---|---|---|
| Prototypes | SS | Hand polishing with sand paper & Scotch Brite® | Smooth, < 1 | 1.6…3.2 | 245 (CC)<br>230 (AC) |
| Linac4 | Cu plated SS [1)] | Guided hand grinding<br>*(using a plastic wheel with either sand paper strips glued onto it or diamond abrasive bits imprinted into it)* | Rough, ≈ 2.5 | 1.6…3.2 | 245 → 310 (CC)<br>230 → 285 (AC) |

1) in some cases the plating was partially or completely grinded off later on by sand paper if either visible flaking was found on Cu or the plating looked fine but repeated assemblies resulted in a leaking connection;
2) linear load corresponding to the working point Y2 on the characteristic compression curve.

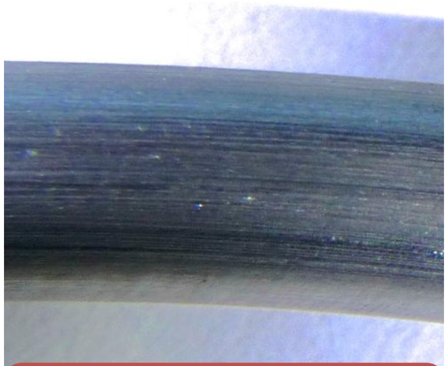
Finally all the modules were leak tight ($Q_{He} < 5\cdot10^{-10}$ mbar·liter/sec) with **no clear indication of general solution** of the problem.



***Machined*** surface imprints on the gasket

**The lessons learned are:**

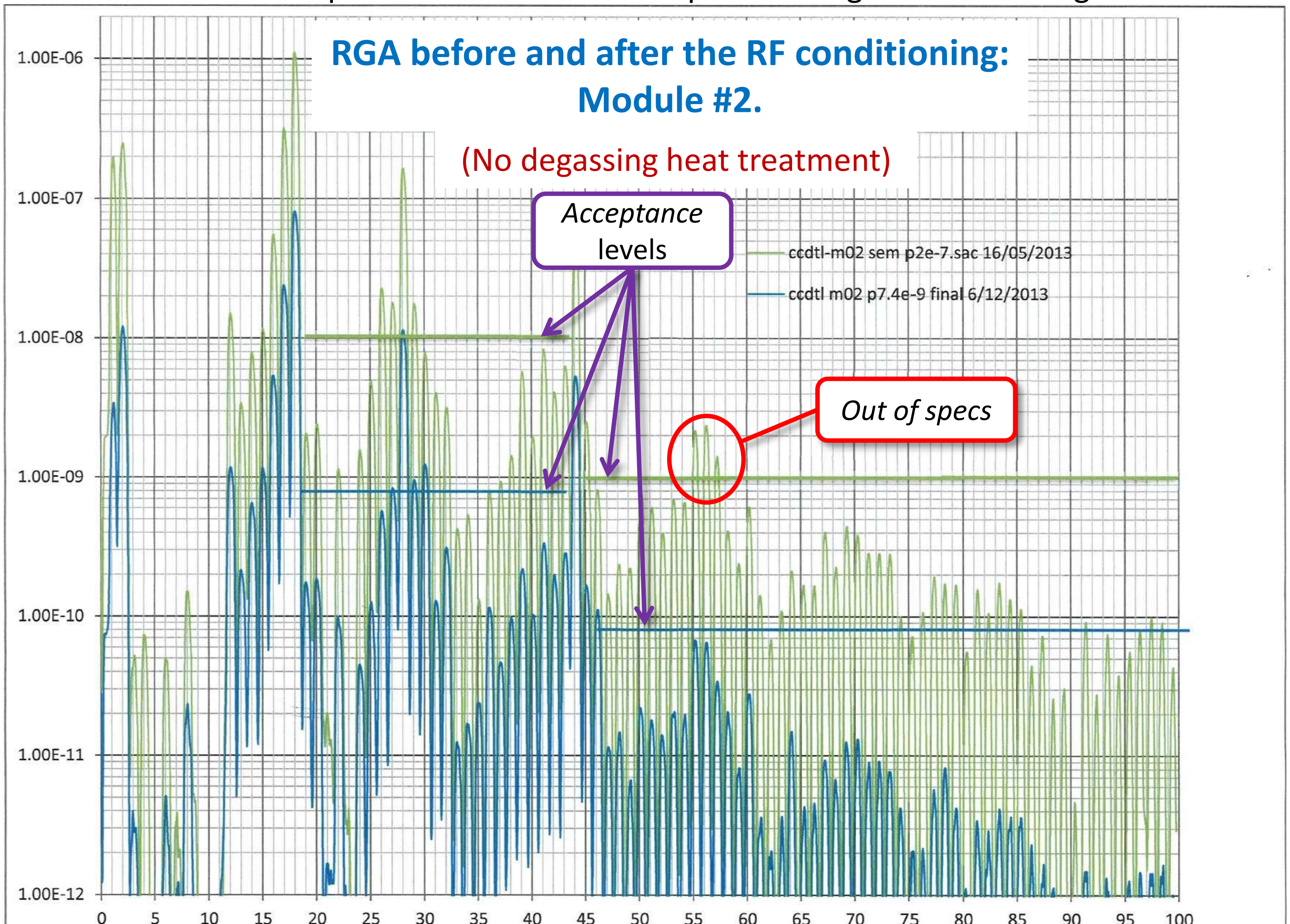
1. the specified Ra of the sealing surfaces should be created during the ***lathe machining***,
2. if sealing surfaces have lower Ra using gaskets with higher compression resistance might help,
3. Cu surfaces are more difficult than SS ones.



***Hand grinded*** surface imprints on the gasket

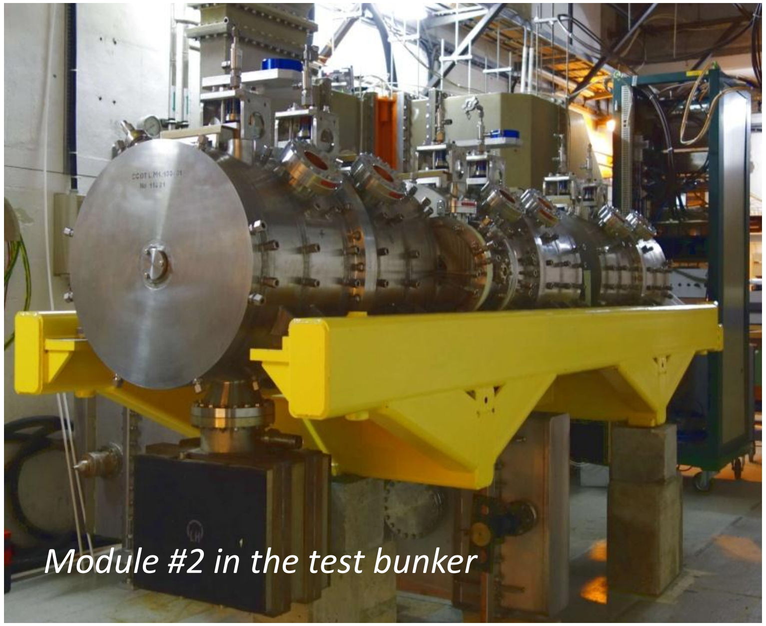
# CCDTL for Linac4: Vacuum (3/3).

CCDTL tanks were transported between Snezhinsk, Novosibirsk and Geneva sealed with rubber O-rings and filled with dry $N_2$. It turned out that the O-rings were contaminated with hydrocarbons and thus the initial RGA spectra were outside the specs ⇒ long RF conditioning times.



# CCDTL for Linac4: high power RF conditioning (1/2).

Modules #1, 2 and 3 were tested in a shielded bunker in the CERN SM18 test area.
The remaining 4 modules will be conditioned *in situ* after their installation in the Linac4 tunnel.



*Module #2 in the test bunker*

The test stand was undergoing an upgrade in parallel with the CCDTL conditioning.
That caused many interruptions of the conditioning, sometimes for quite long times.

## CCDTL operating and test parameters.

| Parameter | Unit | Linac4 1) | Test |
|---|---|---|---|
| Energy range | MeV | 50…104 | |
| Beam Pulse Current | mA | 40 | |
| Beam Pulse Length | ms | 0.4 | |
| Rep. Frequency | Hz | 1 | 2 |
| Beam Duty Cycle | % | 0.04 | |
| RF Pulse Length 2) | ms | 0.7 | 0.8 |
| RF Duty Cycle 3) | % | 0.07 | 0.16 |
| RF Power per module (w/o beam) | kW | < 700 | ≥ 700 4) |

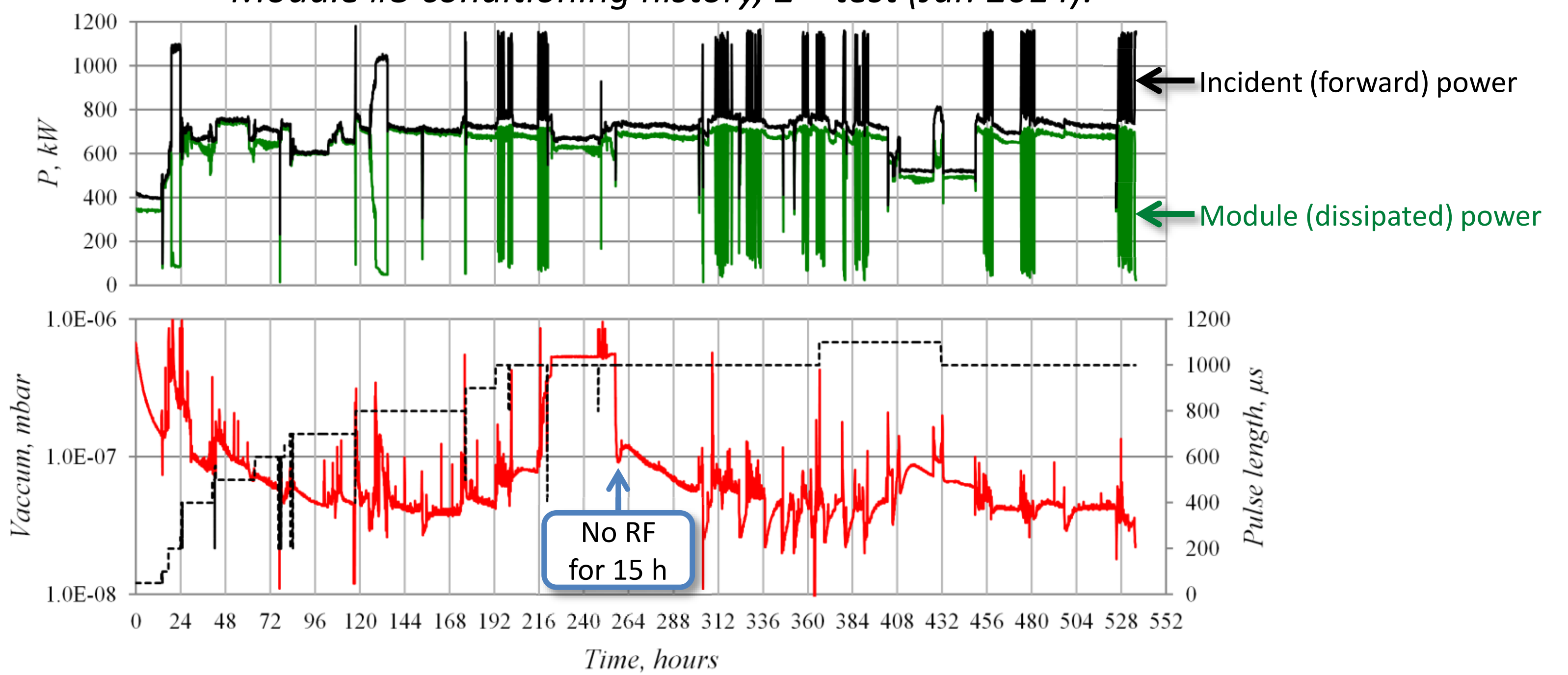
1) in the PSB injection mode;
2) including the time for LLRF electronics for field stabilization;
3) all the Linac4 accelerating structures are designed to operate at up to 10% duty cycle foreseen for the future upgrades of CERN facilities;
4) 700 kW corresponds to 3.6 MV gap voltage per tank and peak surface field $E_{Spk}$ = 34 MV/m that is 1.85 Kilpatrick.

# CCDTL for Linac4: high power RF conditioning (2/2).

| Module | Test | Start | Duration | Result | Comments | Vacuum pumps |
|---|---|---|---|---|---|---|
| 3 | 1 | Nov 2012 | 2 weeks [1)] | 720 kW, ~100 μs | Limited by RF source | 2 turbo |
| 3 | – | Dec 2012 | 1 year | | Vented, stored air filled | |
| 3 | 2 | Jan 2014 | 200 eff. hrs | Test goal reached | | 3 turbo |
| 2 | 1 | Aug 2013 | 600 eff. hrs | Test goal reached | Including the periods when the amplifier freq. fdbk loop was not engaged and the module became detuned as its t° changed | 2 ion |
| 1 | 1 | Jul 2014 | In progress | | | 3 turbo |

1) The log system was not ready.

*Module #3 conditioning history, 2nd test (Jan 2014).*



# CCDTL for Linac4: status & plans.

- 2 CCDTL modules have been conditioned at the CERN high power test stand above the nominal RF power levels, 1 moule is being conditioned now.
- 4 modules have been lowered into the accelerator tunnel, installed in the linac and will soon be connected to waveguides.

*Lowering a CCDTL module …*

*Moving around in the tunnel …*

- RF conditioning of the modules in the tunnel will take place in parallel with the beam commissioning of the DTL.
- Commissioning with beam of the complete CCDTL section will take place in the second half of 2015.
- **Linac4 will be the first operating machine, where a CCDTL is used to accelerate beam!**

*First CCDTL modules installed in the linac.*

# Thank you for your attention!

A. Tribendis for