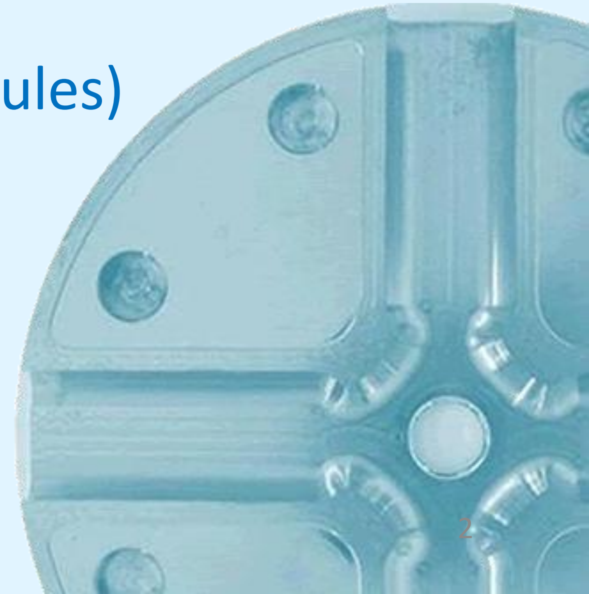
MeChanICs

RF structure production

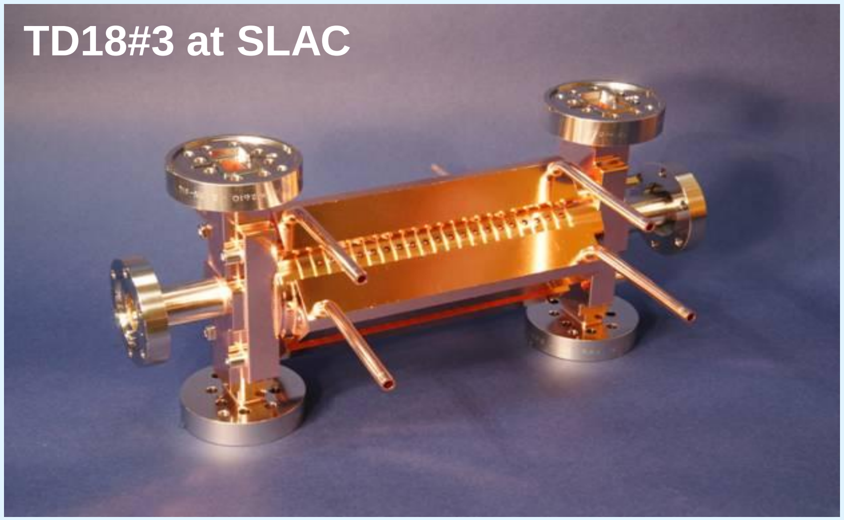
G. Riddone, 06/09/2010

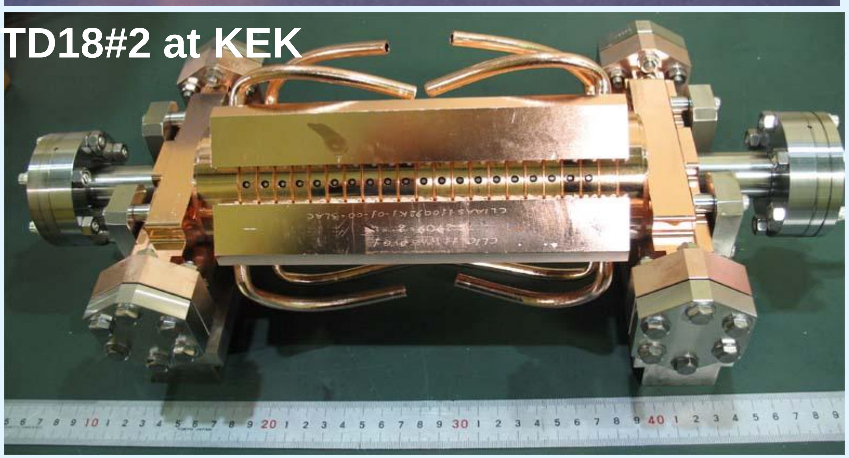
Content

- Introduction to RF structures and components
- Fabrication steps and issues
  - Engineering design
  - Machining
  - Quality control
  - Bonding
  - RF measurements
  - Baking
- Towards CLIC structures (CLIC two-beam modules)

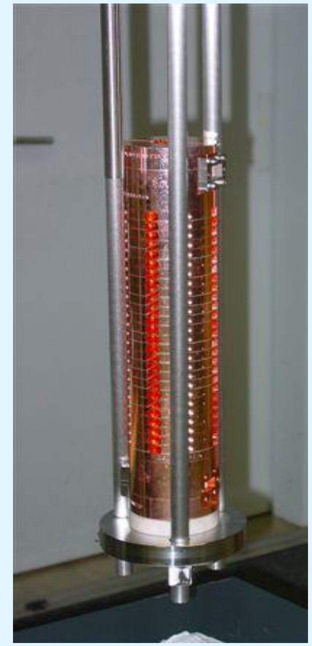


Accelerating structures



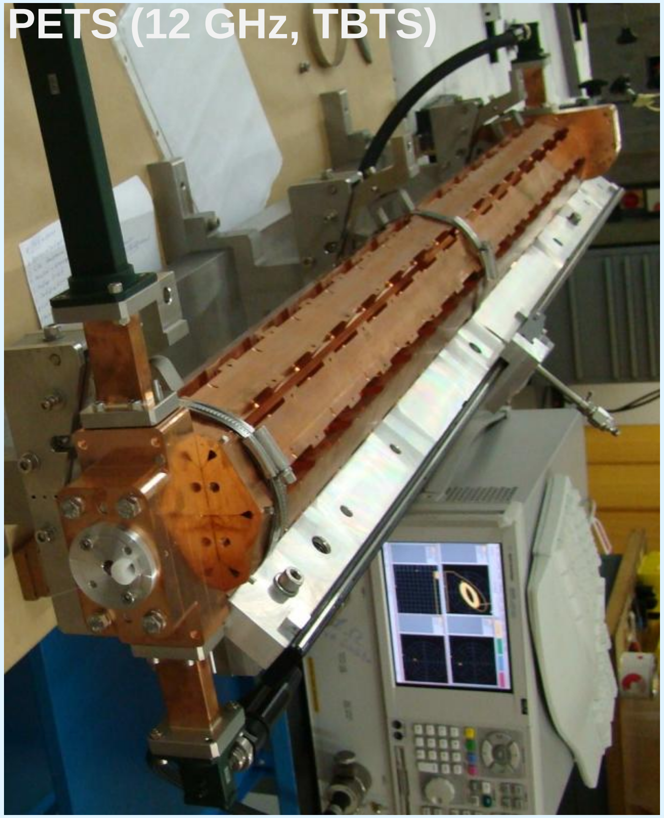


TD24#2 at CERN (12 GHz)



- *Cu OFE UNS C10100*
- *Shape accuracy ± 2.5 µm*
- *Roughness Ra 0.025 µm*
- *Ø 45 to 80 mm, 30 disks*
- *Length 300 mm*

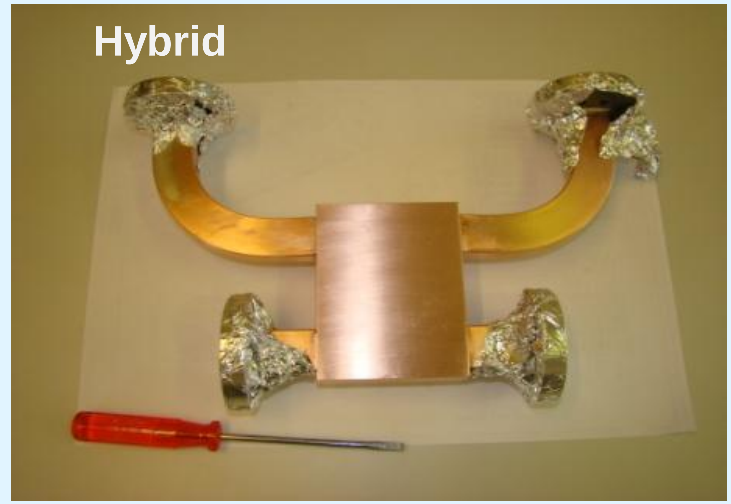
PETS


PETS (12 GHz, TBTS)


PETS (11.4 GHz, test at SLAC)

- *Cu OFE UNS C10100*
- *Shape accuracy ± 7.5 μm*
- *Roughness Ra 0.1 μm*
- *8 octants*
- *Length 300-1000 mm*

RF components



Not treated in this talk.

Production phases

Engineering design (based on RF design)

3D models and 2D drawings, including thermo-structural simulations

Machining

Tendering, contract adjudication, QC at factory (dimensional control, Ra)

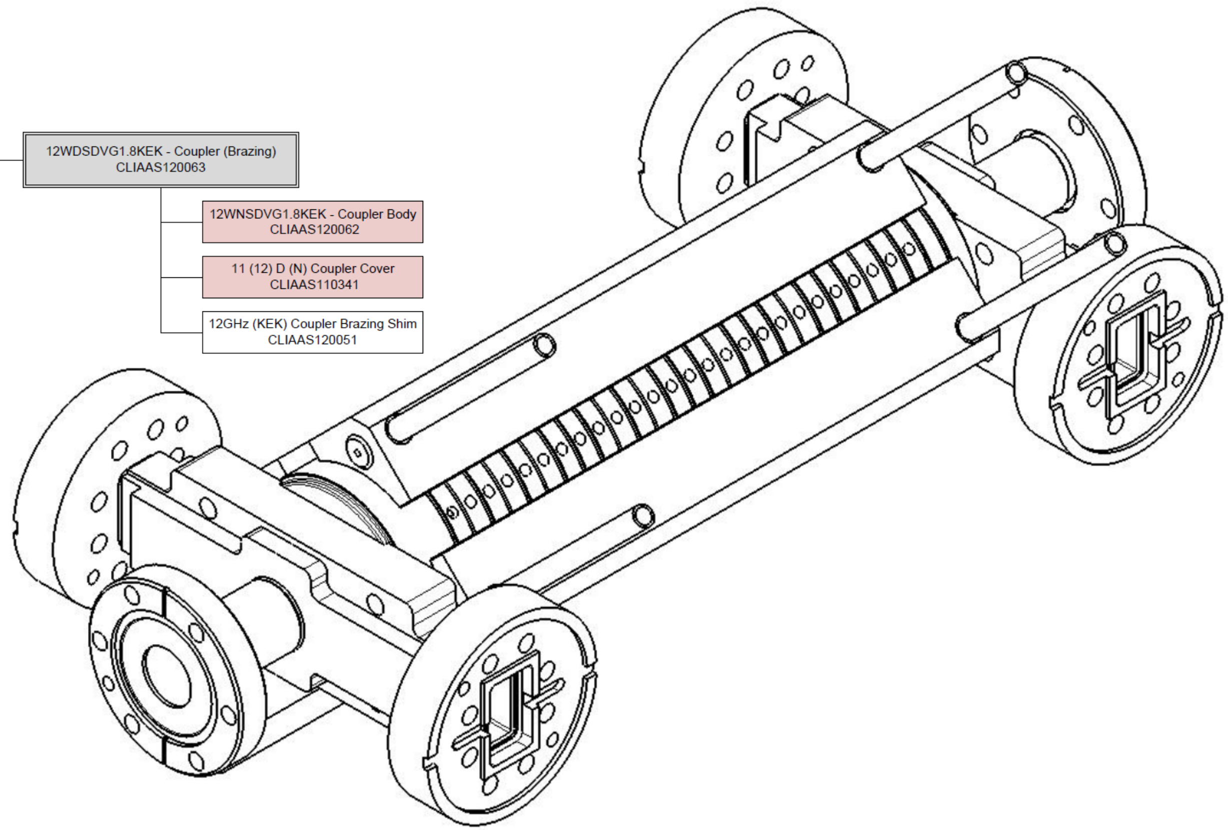
Assembly

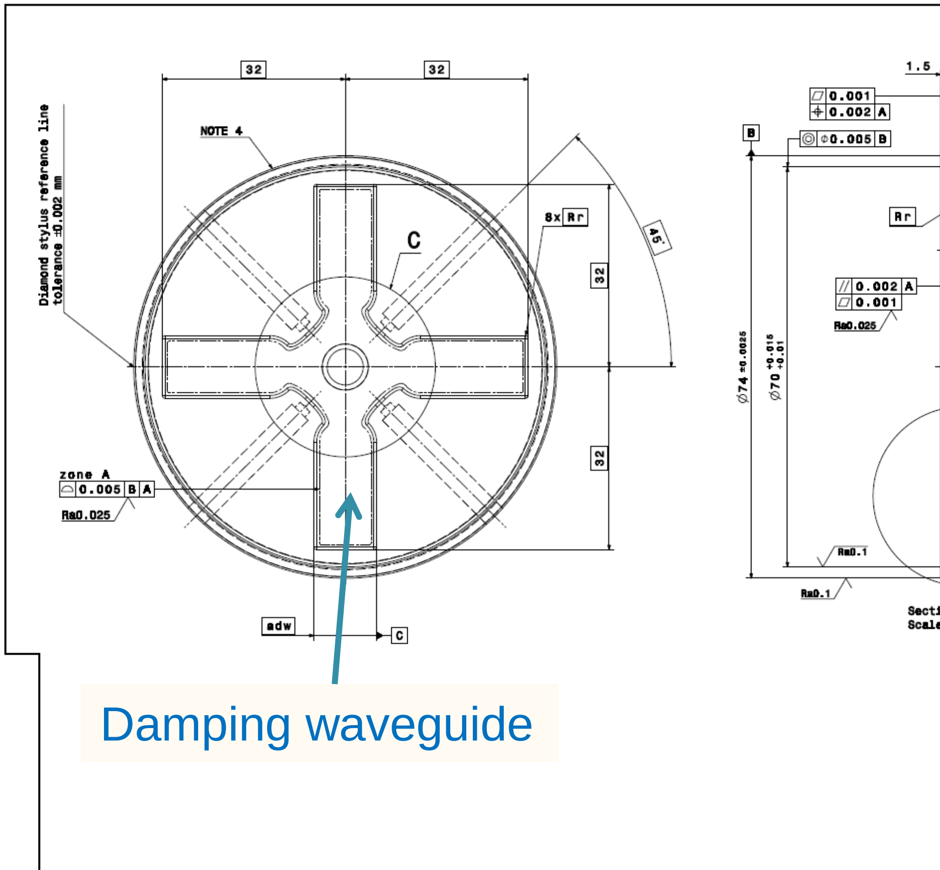
Alignment, bonding/brazing cycles, QC, RF measurements, final vacuum baking

ENGINEERING DESIGN

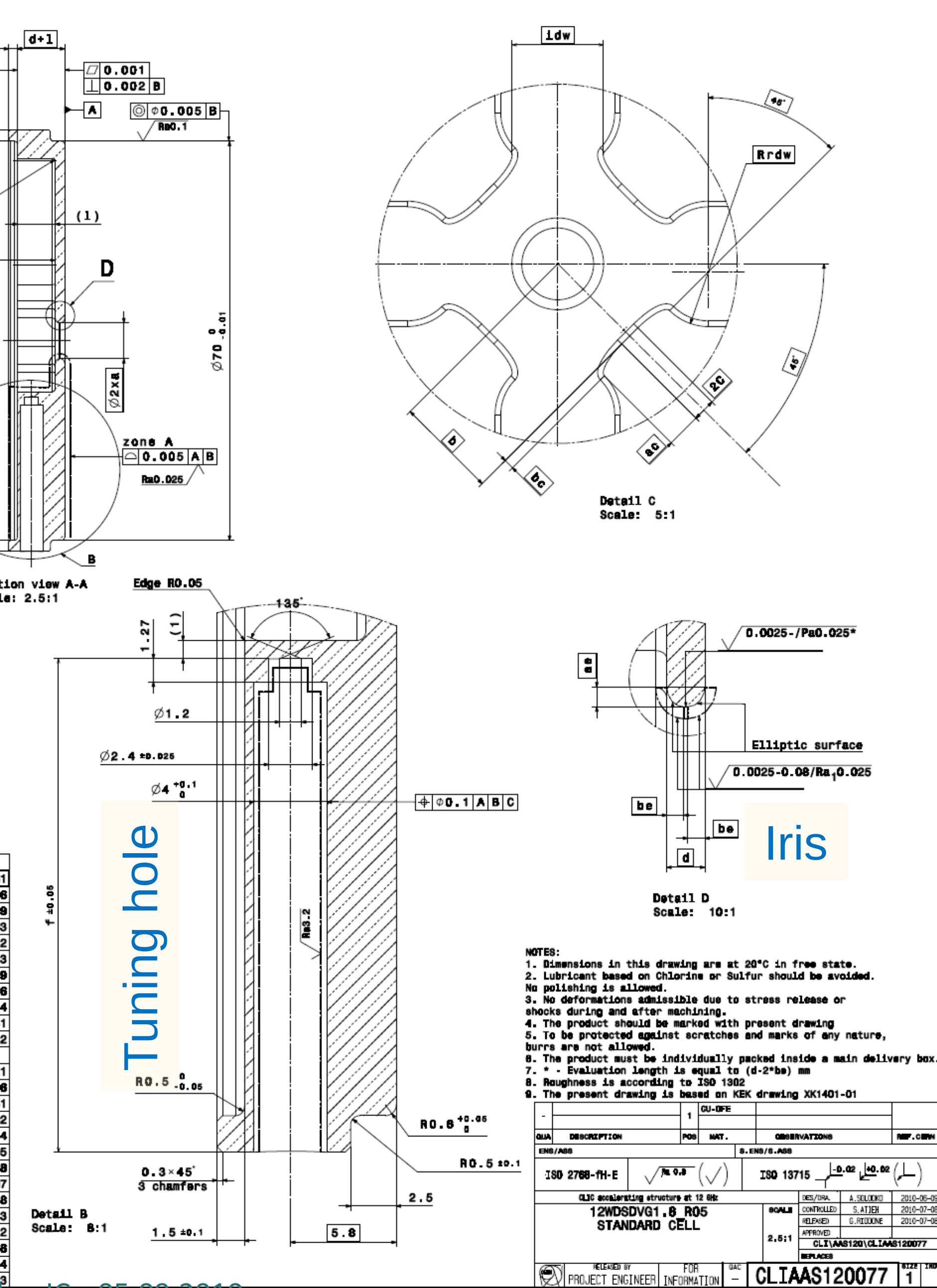
12WDSDVG1.8_R05 (Sealed)
TD24 KEK-SLAC based design

- 12WDSDVG1.8_R05 Assembly CLIAAS120079
  - 12WDSDVG1.8_R05 - Assembly (Bonding) CLIAAS120078
    - 12WDSDVG1.8_R05 – Standard Cell CLIAAS120077
    - 12WDSDVG1.8_R05 – Input Matching Iris CLIAAS120076
    - 12WDSDVG1.8_R05 – Input Ring Cell CLIAAS120066
    - 12WDSDVG1.8_R05 – Output Ring Cell CLIAAS120067
  - 12WDSDVG1.8KEK Coupler (Assembly) CLIAAS120072
    - 12WDSDVG1.8KEK - Coupler (Machining) CLIAAS120071
      - 12WDSDVG1.8KEK - Coupler (Brazing) CLIAAS120063
        - 12WNSDVG1.8KEK - Coupler Body CLIAAS120062
        - 11 (12) D (N) Coupler Cover CLIAAS110341
        - 12GHz (KEK) Coupler Brazing Shim CLIAAS120051
    - Vacuum Flange (Female) CLIAVACU0028
  - Cooling System (1/4 D74 L 235) CLIAAS120070
    - Cooling Block CLIAAS120069
    - COOLING CAP CLIAAS110332
    - COOLING TUBE CLIAAS110333
  - DN 40 - UHV CF FIXED FLANGE (TD24) CLIAAS110371
  - DN 40 - UHV CF ROTAT. FLANGE (TD24) CLIAAS110373
  - Beam Pipe CLIAAS110347
  - Brazing Shim (AS-Coupler D74 12GHz) CLIAAS120074
  - Brazing Shim (CS D74 L235) CLIAAS120073
  - Tuning Stud CLIAAS110351



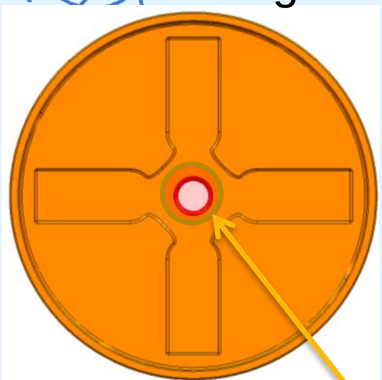


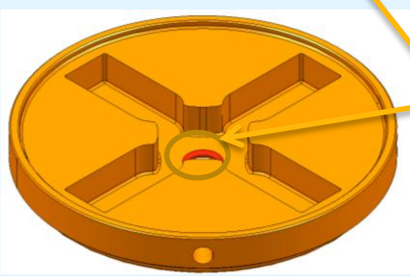
N	Cell	a (mm)	d (mm)	b (mm)	c (mm)	l (mm)	eow	ae (mm)	adw (mm)	idw (mm)	r (mm)	bc (mm)	ac (mm)	rdw (mm)
1	MATCH CELL A	3.15	1.67	8.9417	1	6.662	3.4	0.877020583	11	8	0.5	0.896126004	3.053635212	4.809069481
2	REGULAR CELL 1	3.1167	1.6421	8.6149	0.6267	6.676	3.3958	0.861603249	11	8	0.5	0.917859924	3.116868729	4.801830696
3	REGULAR CELL 2	3.0833	1.6142	8.602	0.62	6.7039	3.3875	0.846199557	11	8	0.5	0.918297219	3.110731829	4.800927309
4	REGULAR CELL 3	3.05	1.5862	8.5893	0.6133	6.7318	3.3792	0.830742258	11	8	0.5	0.918815941	3.104862828	4.799991263
5	REGULAR CELL 4	3.0167	1.5583	8.5768	0.6067	6.7597	3.3708	0.815355214	11	8	0.5	0.919412146	3.099154463	4.799014542
6	REGULAR CELL 5	2.9833	1.5304	8.5645	0.6	6.7876	3.3625	0.799982661	11	8	0.5	0.92009604	3.093822933	4.798011623
7	REGULAR CELL 6	2.95	1.5025	8.5524	0.5933	6.8155	3.3542	0.784617447	11	8	0.5	0.920663695	3.088761006	4.796974519
8	REGULAR CELL 7	2.9167	1.4746	8.5406	0.5867	6.8435	3.3458	0.769263738	11	8	0.5	0.921751347	3.083995656	4.795880876
9	REGULAR CELL 8	2.8833	1.4467	8.529	0.58	6.8714	3.3375	0.753925501	11	8	0.5	0.922729325	3.079609122	4.794759444
10	REGULAR CELL 9	2.85	1.4188	8.5177	0.5733	6.8993	3.3292	0.738595959	11	8	0.5	0.923834133	3.075628594	4.793587741
11	REGULAR CELL 10	2.8167	1.3908	8.5066	0.5667	6.9272	3.3208	0.723220172	11	8	0.5	0.925021844	3.07181254	4.792371542
12	REGULAR CELL 11	2.7833	1.3629	8.4958	0.56	6.9551	3.3125	0.707920115	11	8	0.5	0.926343235	3.068511967	4.79111141
13	REGULAR CELL 12	2.75	1.335	8.4852	0.5533	6.983	3.3042	0.692630299	11	8	0.5	0.927754121	3.065485167	4.789813321
14	REGULAR CELL 13	2.7167	1.3071	8.4749	0.5467	7.011	3.2958	0.677354681	11	8	0.5	0.929291748	3.062759743	4.788453996
15	REGULAR CELL 14	2.6833	1.2792	8.4648	0.54	7.0389	3.2875	0.662097014	11	8	0.5	0.93092545	3.060417417	4.787063341
16	REGULAR CELL 15	2.65	1.2513	8.4548	0.5333	7.0668	3.2792	0.646851347	11	8	0.5	0.932610367	3.058215915	4.785647602
17	REGULAR CELL 16	2.6167	1.2233	8.4451	0.5267	7.0947	3.2708	0.631583289	11	8	0.5	0.934425231	3.056318047	4.784168334
18	REGULAR CELL 17	2.5833	1.1954	8.4355	0.52	7.1226	3.2625	0.616353139	11	8	0.5	0.936297301	3.054669944	4.782671105
19	REGULAR CELL 18	2.55	1.1675	8.4262	0.5133	7.1505	3.2542	0.601157017	11	8	0.5	0.938305625	3.053434614	4.781117188
20	REGULAR CELL 19	2.5167	1.1396	8.417	0.5067	7.1785	3.2458	0.585978702	11	8	0.5	0.940364464	3.052234978	4.779527487
21	REGULAR CELL 20	2.4833	1.1117	8.408	0.5	7.2064	3.2375	0.570821752	11	8	0.5	0.942524139	3.0514219	4.777903318
22	REGULAR CELL 21	2.45	1.0838	8.3993	0.4933	7.2343	3.2292	0.555681174	11	8	0.5	0.944823526	3.05102413	4.776220233
23	REGULAR CELL 22	2.4167	1.0558	8.3908	0.4867	7.2622	3.2208	0.540503282	11	8	0.5	0.947217848	3.050799244	4.774483912
24	REGULAR CELL 23	2.3833	1.0279	8.3825	0.48	7.2901	3.2125	0.52540649	11	8	0.5	0.949716208	3.050963316	4.772711188
25	REGULAR CELL 24	2.35	1	8.3745	0.4733	7.318	3.2042	0.510328802	11	8	0.5	0.952357943	3.051545322	4.770877034
26	MATCH IRIS B	4.253	1	8.62136	0.85	7.332	3.2	0.483334748	11	8	0.5	0.896791096	2.876131506	4.790173923



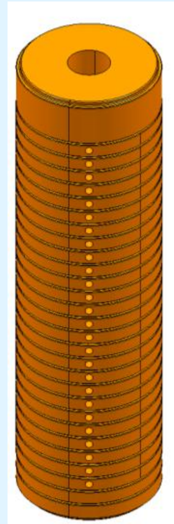
DISKs

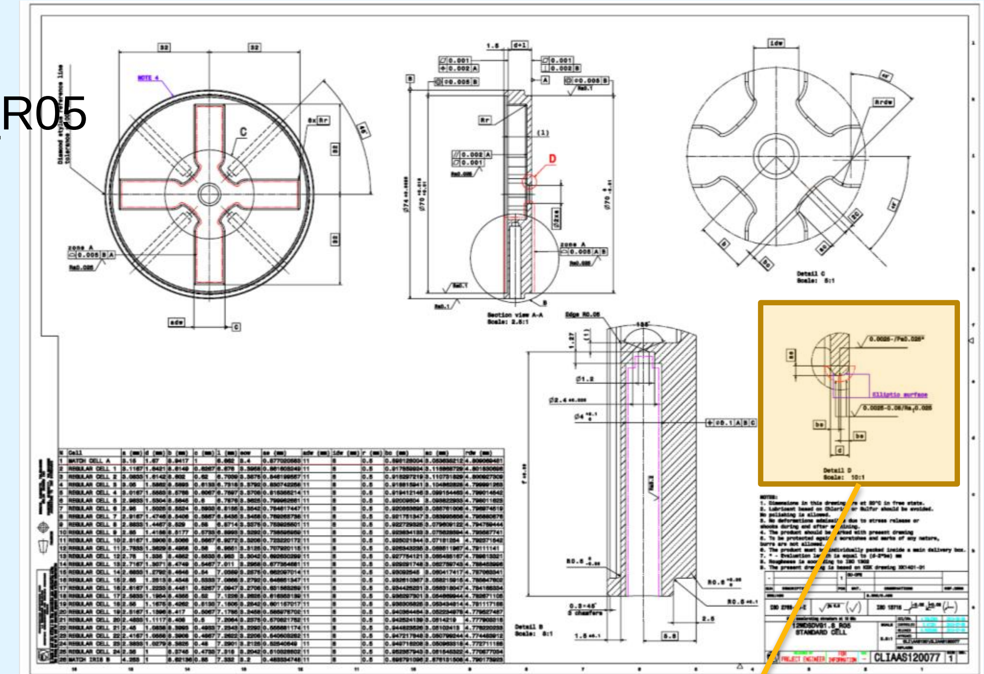
Accelerating structure - 12WDSDVG1.8_R05

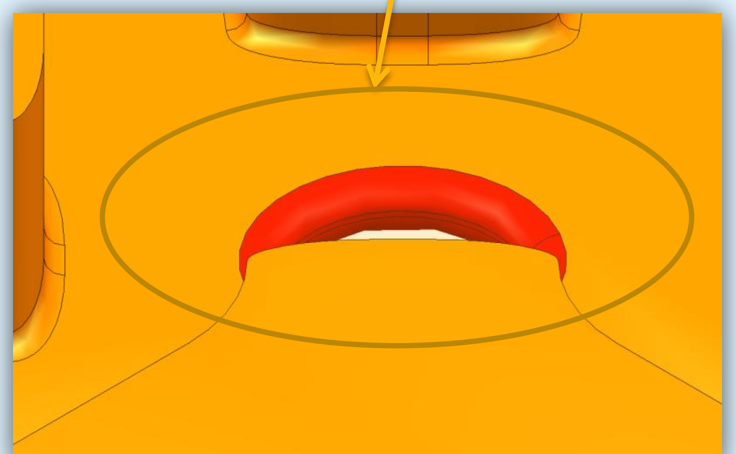




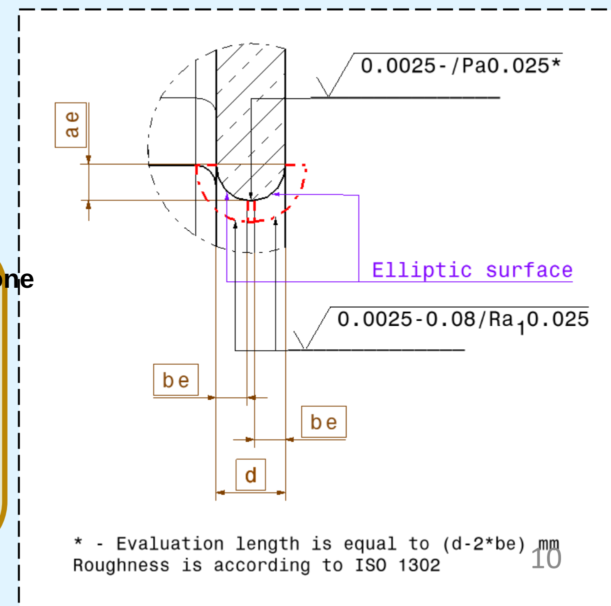
Iris







The roughness identification on our drawings for better control of the critical area



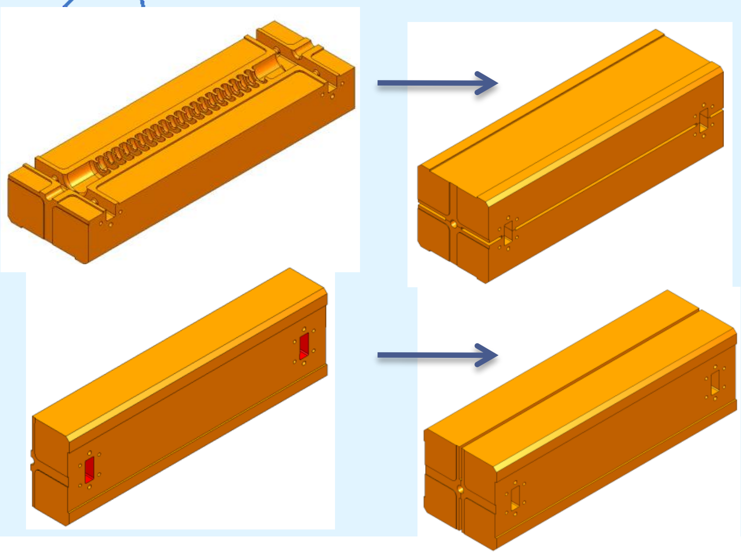
Geometrical tolerance of this zone

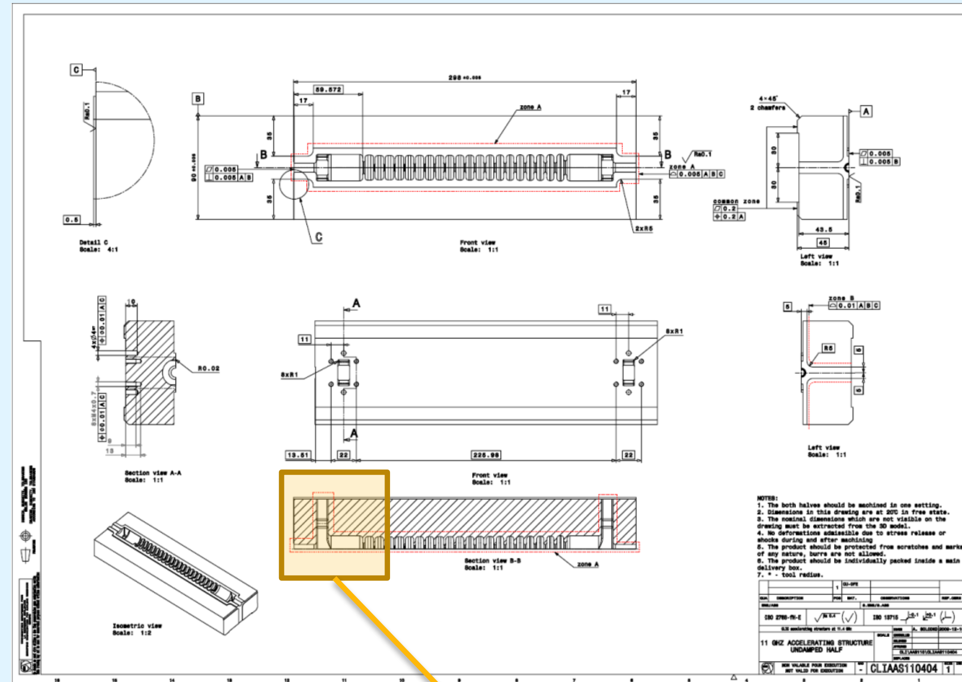
⌓	0.005	A	B
//	0.002	A	
▱	0.001		

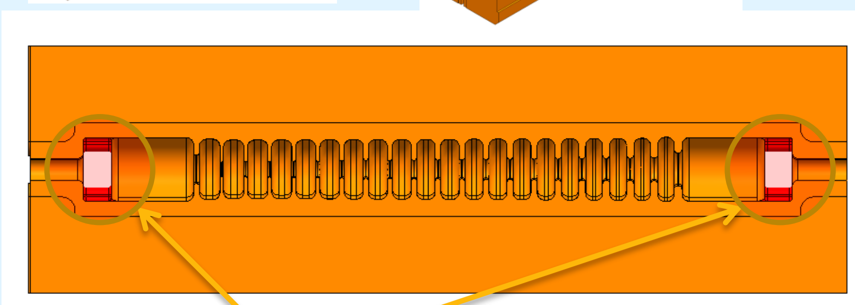
A. Solodko

HALVES

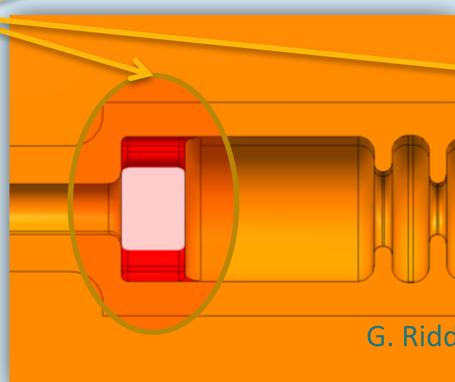
Accelerating structure – 11WNSHVG1



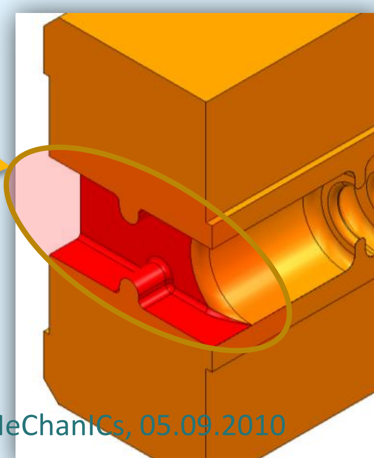


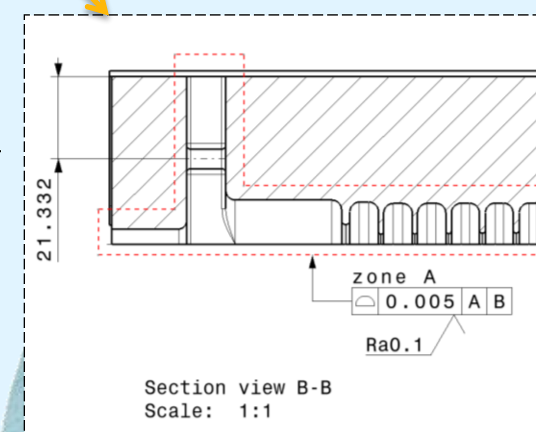


WAVEGUIDEs



Section view of critical area





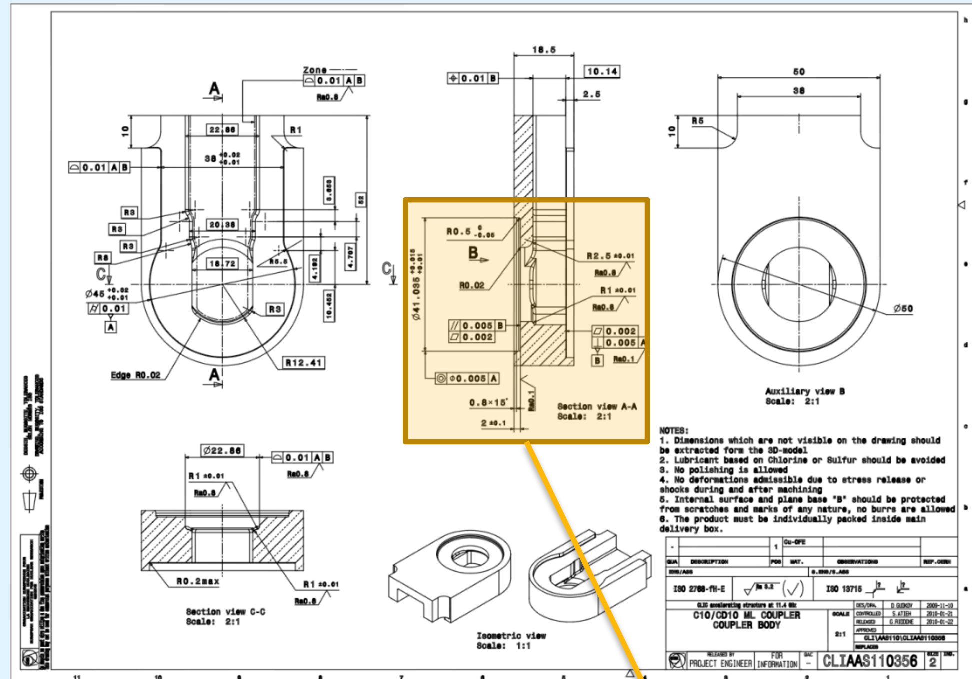
Geometrical tolerance of this zone

⌓	0.005	A	B

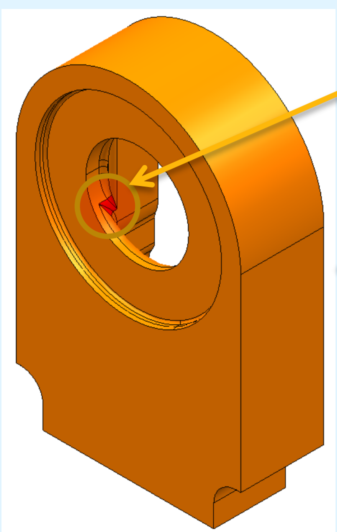
A. Solodko

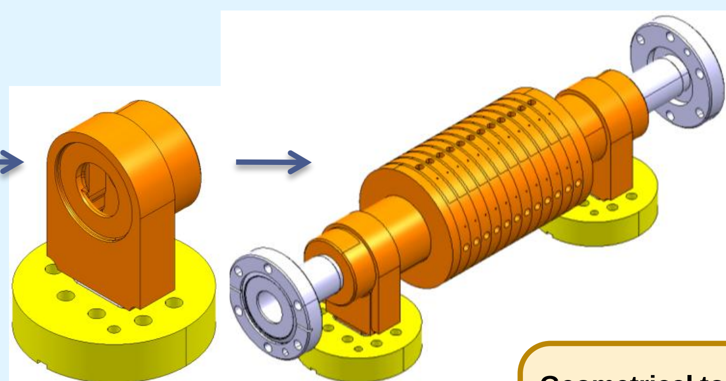
Mode Launcher COUPLER

Accelerating structure – 12CDSD1.2ML



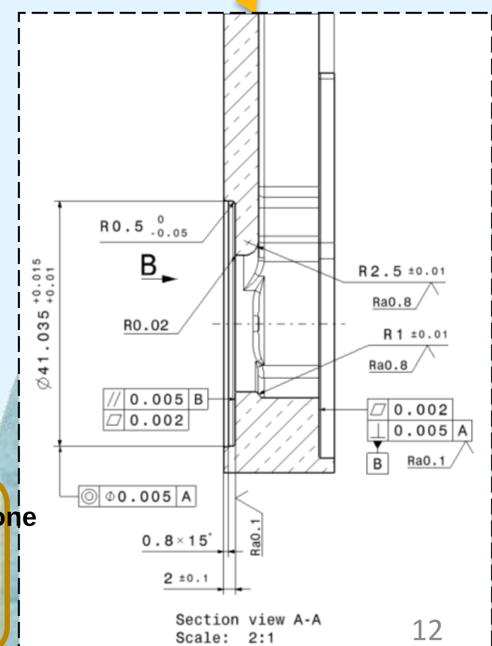
Critical area





Geometrical tolerance of this zone

⌓	0.01	A	B



A. Solodko

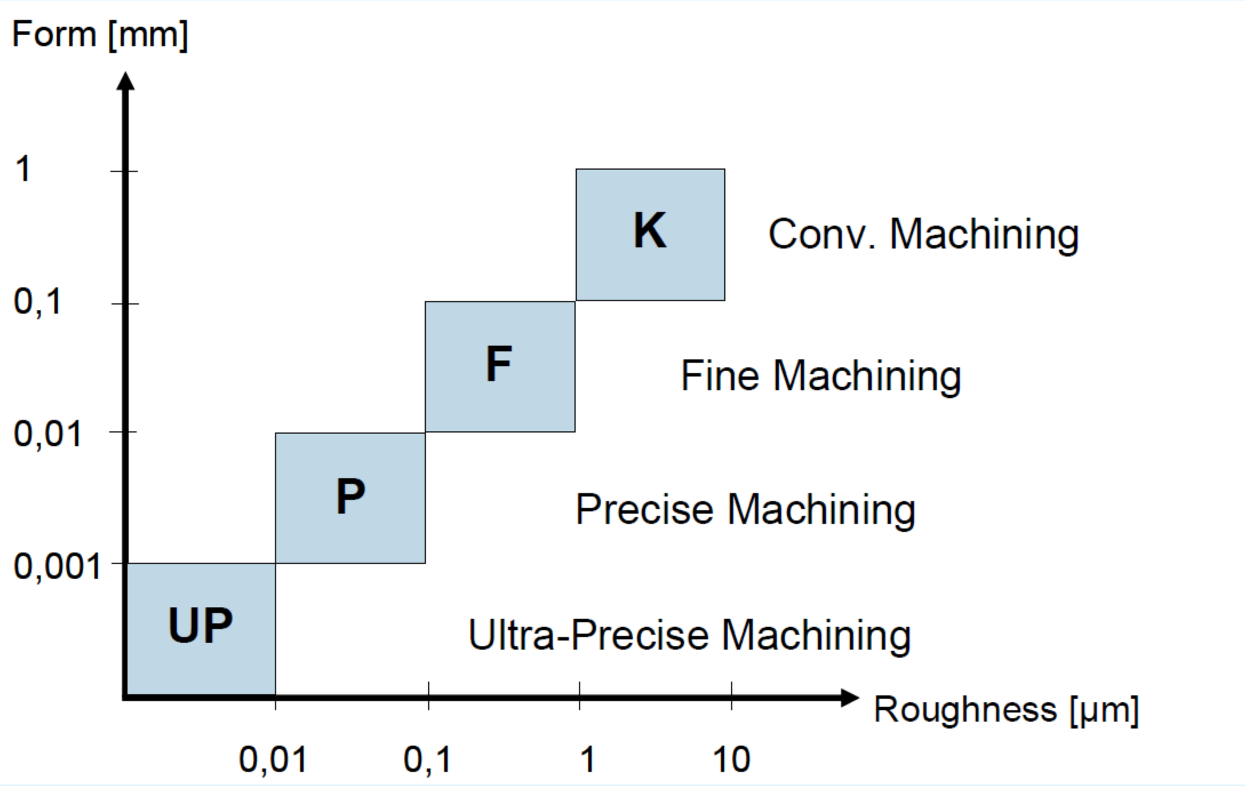
Engineering design:
To be studied/optimised

- Reduction of types of tooling
- Tolerances requirements: review of regions with stringent and relaxed tolerances
- Review of roughness requirements in the different regions
- Optimization of design for chosen assembly/joining methods

MACHINING AND DIMENSIONAL CONTROL

Why Ultra-Precision Machining

CLIC's needs:
shape accuracy± 2 µm
Roughness Ra 25 nm



S. Atieh

Technology

- Accelerating structures
  - Milling and turning (disks) -BASELINE
  - Milling (quadrants/halves) - ALTERNATIVE
  - Annealing steps between pre-machining and finishing

- PETS
  - Milling
  - Annealing steps between pre-machining and finishing

<u>Diamond tool is required</u>

- Dimensional stability

- Maintenance of tolerances

- Chips do not adhere to surface

- Expensive → well characterised

Machining at VDL

Enabling Technologies Group **Inspection Report**

Drawing no.	CLIAAS120020	Prod. Nr.	1
Description	12WDSDVG1.8T disk 007		

Profile accuracy cross

0.005 A B

Page 4 of 5

Shape tolerance ±2.5 µm

Enabling Technologies Group **Inspection Report**

Drawing no.	CLIAAS120020	Prod. Nr.	1
Description	12WDSDVG1.8T disk 007		

Dimensions

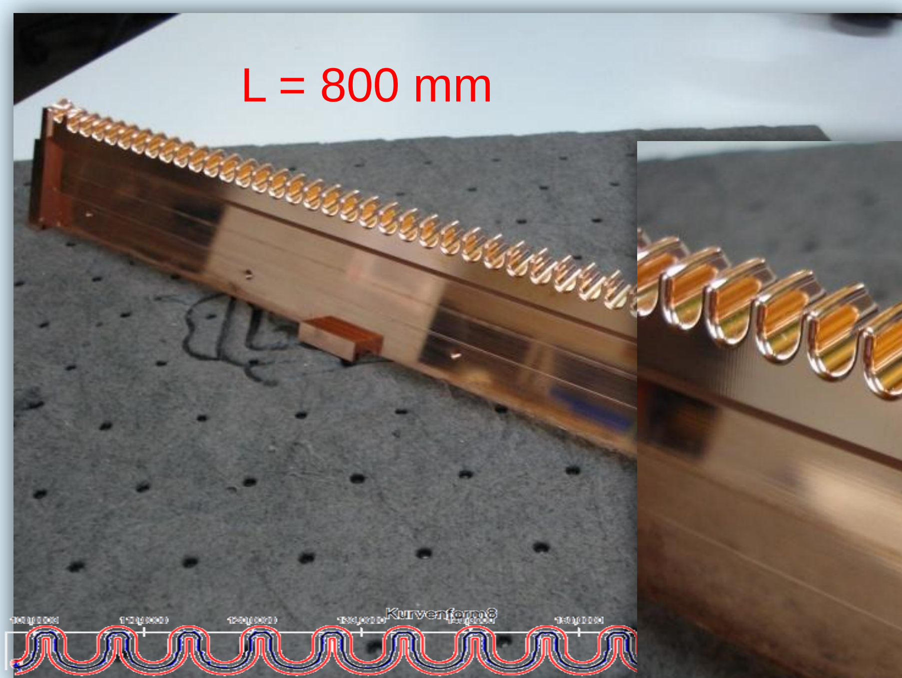
Measurand	Description	Nominal	Upper	Lower	[illegible]	[illegible]	Pass √	Fail √	Remark
1	Ref A 0.002	0.0000	0.0020	[illegible]	[illegible]	0.0015	√		
2	Outer diameter Ref B	80.0000	0.0050	[illegible]	[illegible]	0.0004	√		
3	0.002	0.0000	[illegible]	[illegible]	0.0005	0.0005	√		
4	⊥ 0.005 A	0.0000	[illegible]	0.0000	[illegible]	0.0001	√		
5	Width of cross Z+	[illegible]	[illegible]	[illegible]	[illegible]	0.0002	√		
6	Width of cross Z-	[illegible]	0.0025	[illegible]	[illegible]	0.0014	√		
7	Width of cross Y-	[illegible]	[illegible]	[illegible]	11.2501	0.0001	√		
8	Width of cr[illegible]	11.2500	[illegible]	-0.0025	11.2501	0.0001	√		
9	[illegible]	[illegible]	[illegible]	-0.0025	8.3171	-0.0004	√		
10	[illegible] 0.002	[illegible]	0.0020	0.0000	0.0006	0.0006	√		
11	[illegible] Ref A // [illegible]	[illegible]	0.0050	0.0000	0.0036	0.0036	√		
11	Cross ⊕ 0.005 A	6.8368	0.0025	-0.0025	6.8364	-0.0004	√		
12	Bottom plane cross 0.002	0.0000	0.0020	0.0000	0.0011	0.0011	√		
13	Depth of recess for solder foil	0.0300	0.0100	0.0000	0.0382	0.0082	√		
14	Diameter undulation	5.8478	0.0025	-0.0025	5.8469	-0.0009	√		
15	○ 0.002	0.0000	0.0020	0.0000	0.0004	0.0004	√		
17	◎ 0.003 B	0.0000	0.0030	0.0000	0.0012	0.0012	√		
9	Measurand t	1.4807	0.0025	-0.0025	1.4801	-0.0006	√		
18	Undulation 0.005 A B	0.0000	0.0050	0.0000	0.0038	0.0029	√		
19	Cross 0.005 A [illegible]	0.0000	0.0050	0.0000	0.0026	0.0015	√		

All dimensional checks are conform

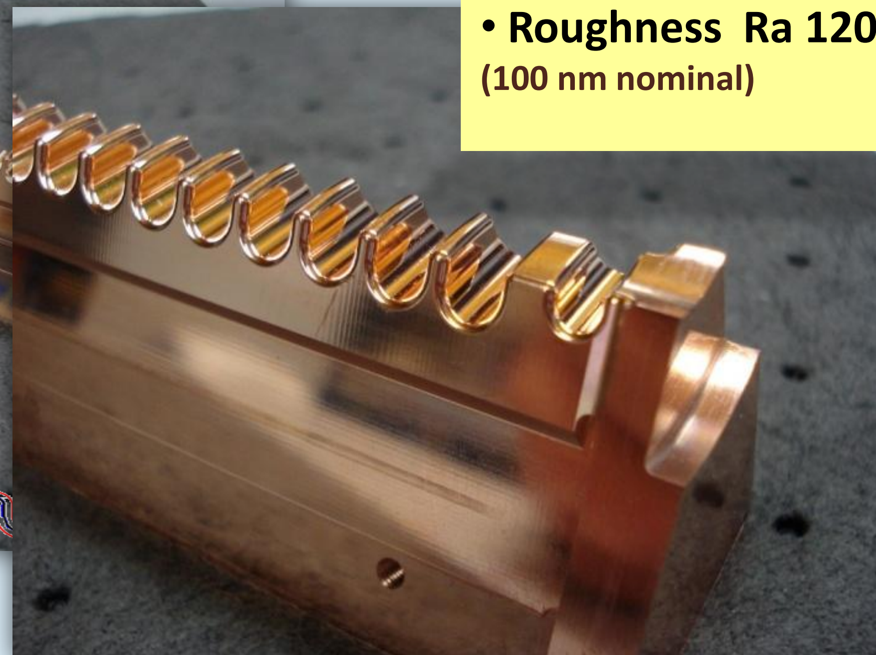
Damped disk at 12 GHz

New CMM (Coordinate Measuring Machine) at CERN

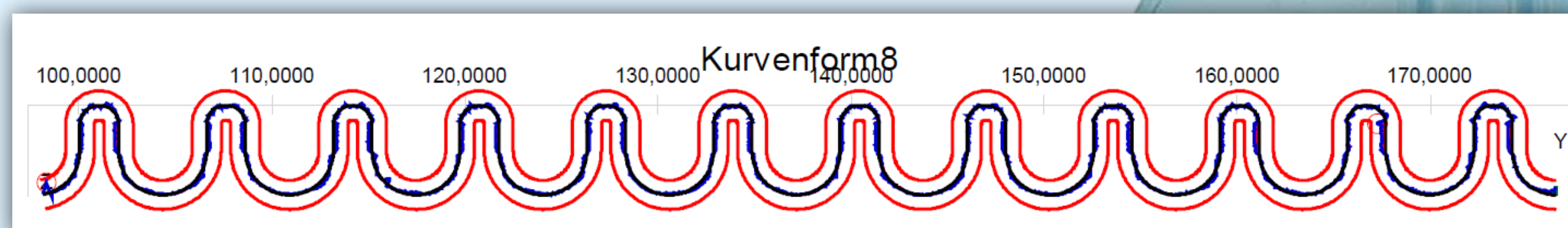
PETS (CLIAP11_0037)



KERN Micro- und Feinwerktechnik GmbH (DE)

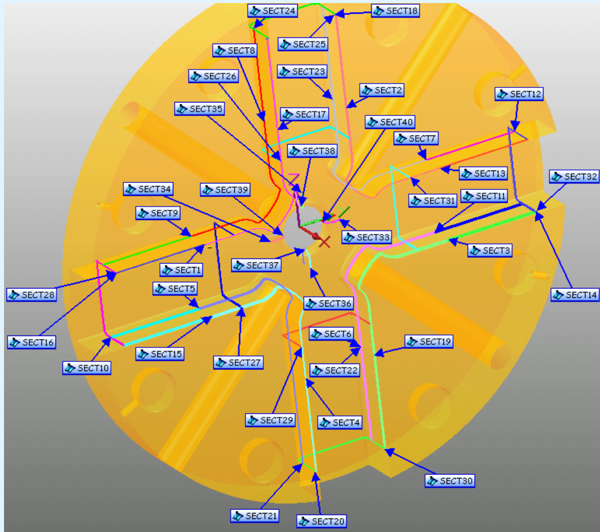


- **Shape accuracy 4.8 µm**
  (15 µm nominal)
- **Roughness Ra 120 -180 nm**
  (100 nm nominal)

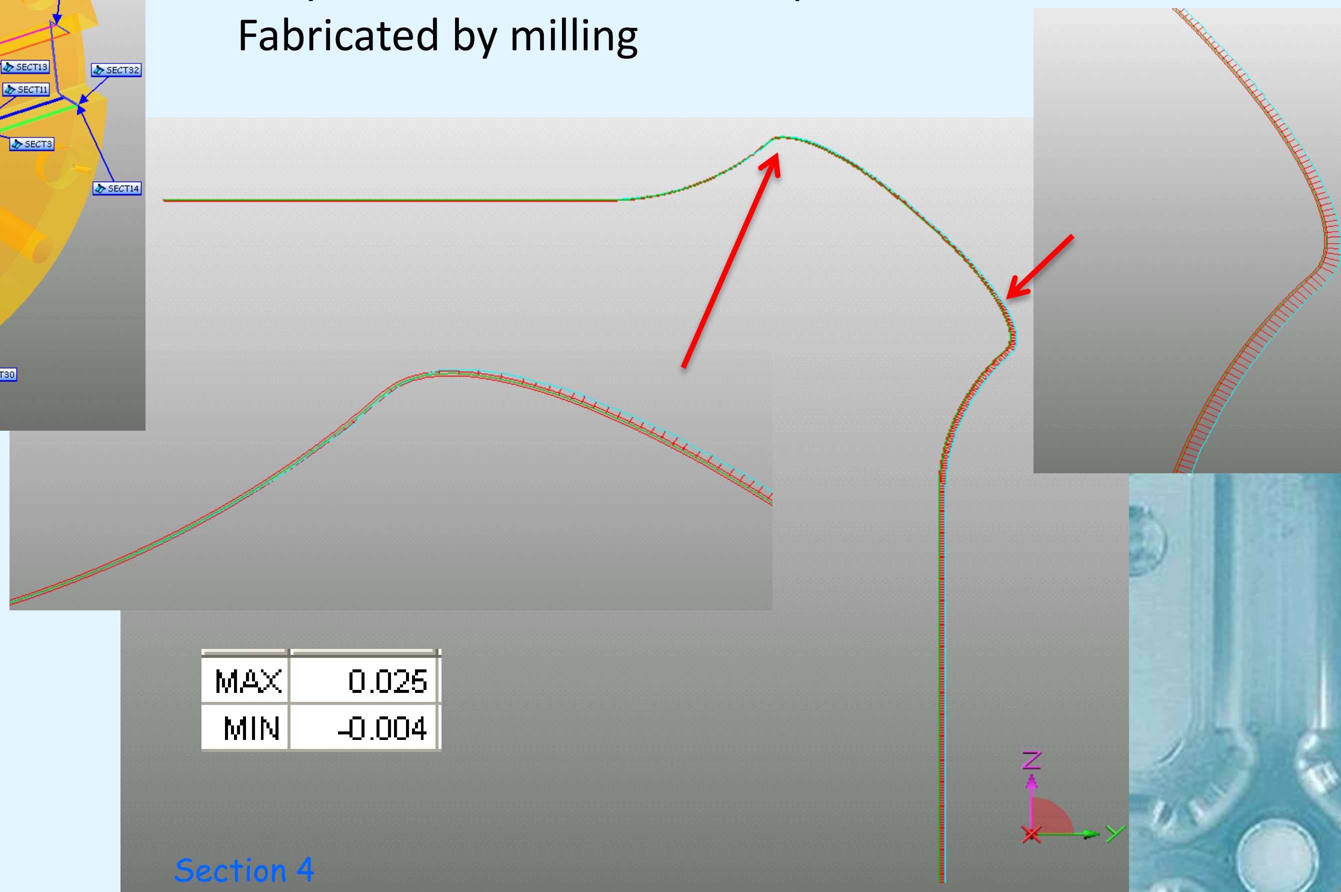


Damped disk

CLIAAS110070 VTT (FI)



- Shape accuracy of 50 µm (Deviation due localisation errors)
- Very accurate and stable shape
- Fabricated by milling

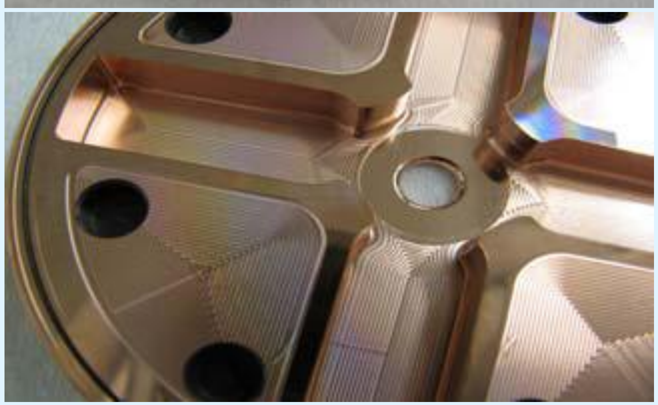


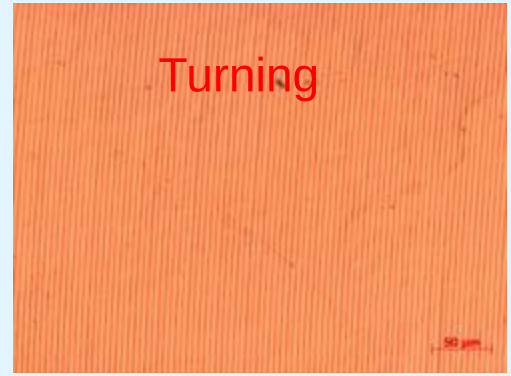
MAX	0.025
MIN	-0.004

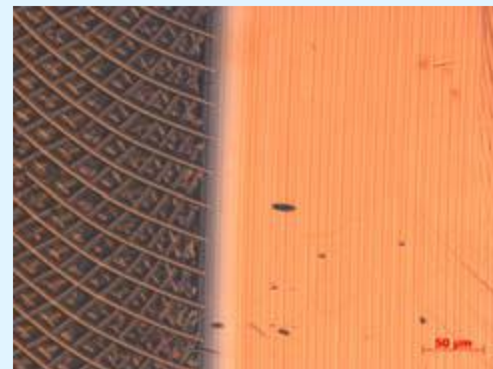
D. Glaude

Damped disk

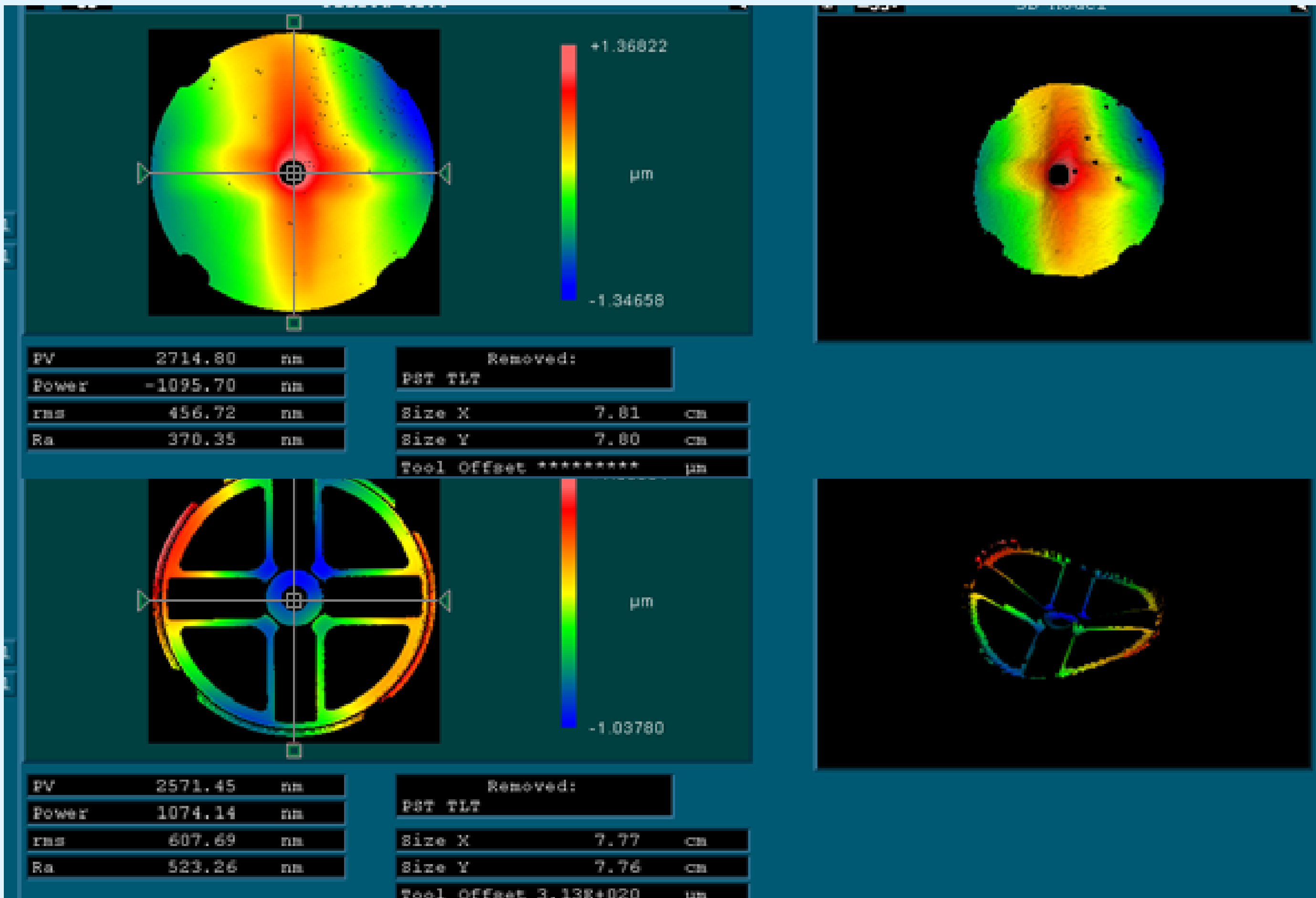
CLIAAS110188 (VDL)







Damped disk
CLIAAS110188 (VDL)



CMM at CERN

Leitz PMM-C Infinity

Measuring range in mm:

X = 1200, Y = 1000, Z = 700

Volumetric length measuring error:

E = 0.3 + L / 1000 [µm]

Volumetric probing error: P = 0.4 µm

Resolution: 0.004 µm

Continuous Scanning Probe head

LSP-S4 ANF

- probing force : 1g – 6g

-max. Styli weight : 450g

-max. Styli extension : 500mm

-max. Probing frequency: 6 – 8 pts/min

-max Moving speed: 80 mm/sec

-max. Acceleration: 100 mm/sec²

Machining:

To be studied/optimised

- Machining and annealing steps:
  - When and at which temperature (and how long)
- Unique clamping device for turning and milling
- Tool geometry and wear
- Turning vs milling regions: turning as mush as possible
- Optimization of dimensional control procedure

ASSEMBLY

Assembly of accelerating structures

T18 structures tested at SLAC/KEK
showed excellent test results

consequent validation of
design, machining and **assembly procedure**

NLC/JLC fabrication technology: validated to 100 MV/m (baseline for future CERN X-band accelerating structures)

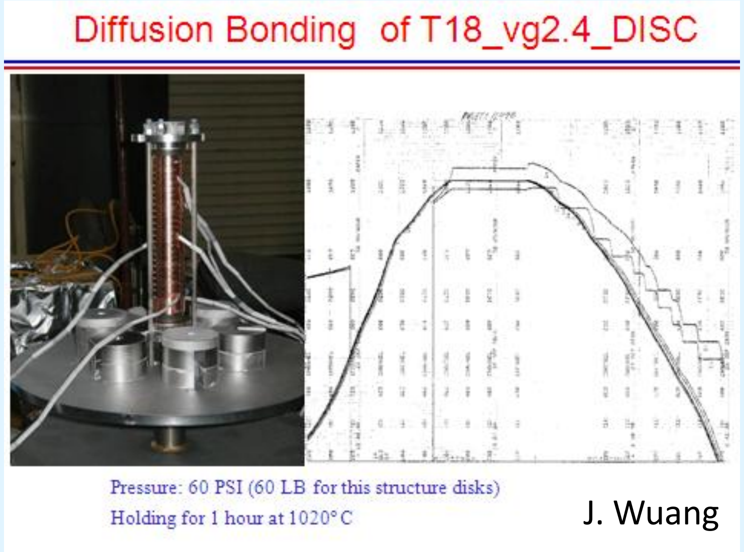
Baseline procedure

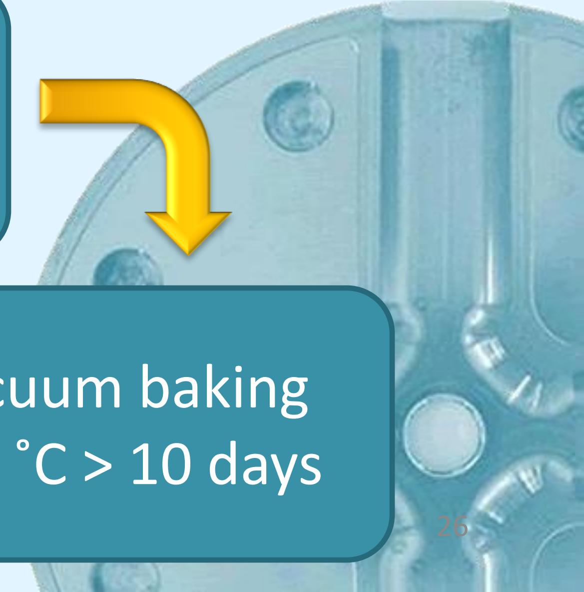
Diamond machining (sealed structures)

Cleaning with light etch

H2 diffusion bonding/brazing at ~ 1000 ˚C

Vacuum baking 650 ˚C > 10 days

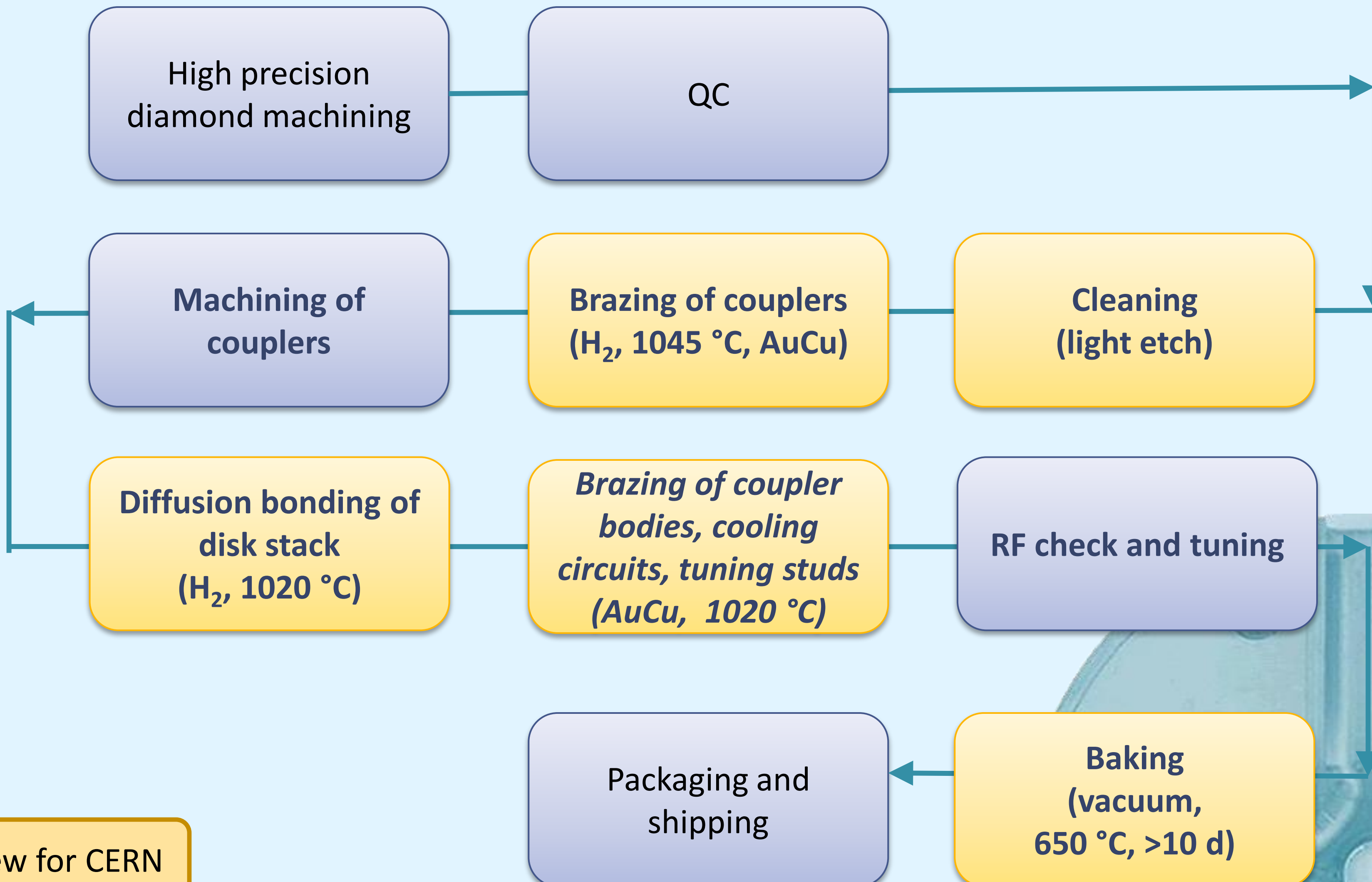




Application to CERN accelerating structures

- CERN previous assembly procedure was based on vacuum brazing at 800 ˚C ➔ several changes were needed for implementing the baseline procedure
- Following the post-mortem analysis of the two CERN accelerating structures T18 and T24, contamination (C, Ca) resulted to be the main problem ➔ cleanliness had to be seriously improved

Baseline manufacturing flow

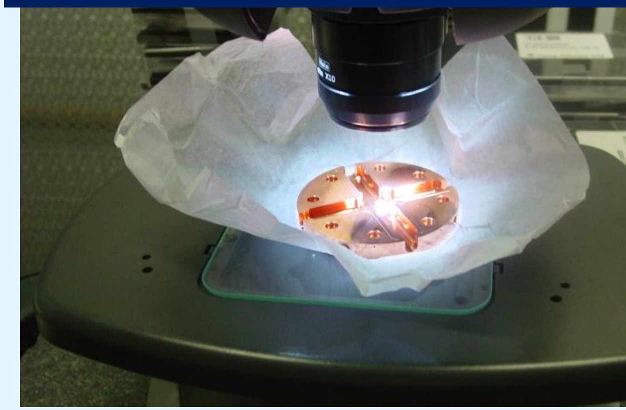


New for CERN

Inspections

Microscopic inspections before and after each relevant fabrication step

Microscopic inspection of disks before and after cleaning (on **witness pieces**)



T18 KEK/SLAC design

Video inspections, SEM and microscopic inspections

Cleaning

Cleaning of Accelerator Parts

For accelerator structure parts with single diamond tuning surfaces:

1. Vapor degrease in 1,1,1 trichloroethane or equivalent degreaser for 5 minutes.
2. Alkaline soak clean in Enbond Q527 for 5 minutes at 180°F.
3. Cold tap water rinse for 2 minutes.
4. Immense in 50% hydrochloric acid at room temperature for 1 minutes.
5. Cold tap water rinse for 1 minute.
6. Immense in the following solution for maximum of 5 seconds depending on the surface finish required:

Phosphoric Acid, 75%	21 gallons
Nitric Acid, 42° Baume	7 gallons
Acetic Acid, Glacial	2 gallons
Hydrochloric Acid	12.6 fluid ounces
Temperature	Room

7. Cold tap water rinse for minimum of 2 minutes until the film on part disappears.
8. Ultrasonic in DI Water for 1 minute.
9. Ultrasonic in new, clean alcohol for 1 minute.
10. Final Rinse to be done in new, clean alcohol.
11. Hold in clean alcohol in stainless steel containers.
12. Dry in a clean room using filtered N2.

For accelerator structure parts with regular machining surfaces:

6. Immense in the following solution for maximum of 30-60 seconds depending on the surface finish required:

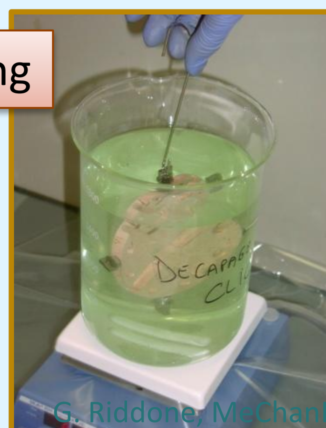
J. Wuang

SLAC cleaning procedure as a baseline

For **degreasing**
Trichloroethane ➔ at SLAC replaced by Perchloroethylene

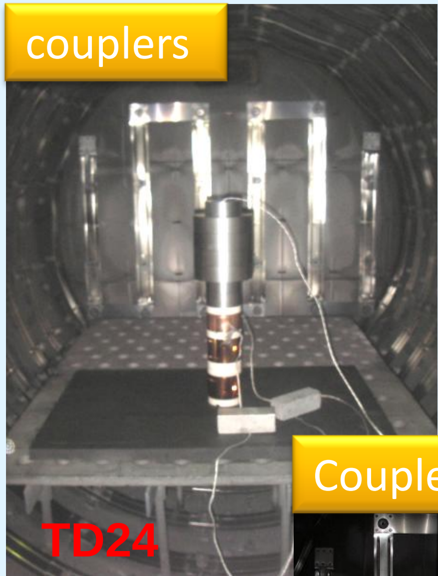
CERN procedure:
(Firm AVANTEC Performance Chemicals):
- TOPKLEAN MC 20A
- PROMOSOLV 71IPA

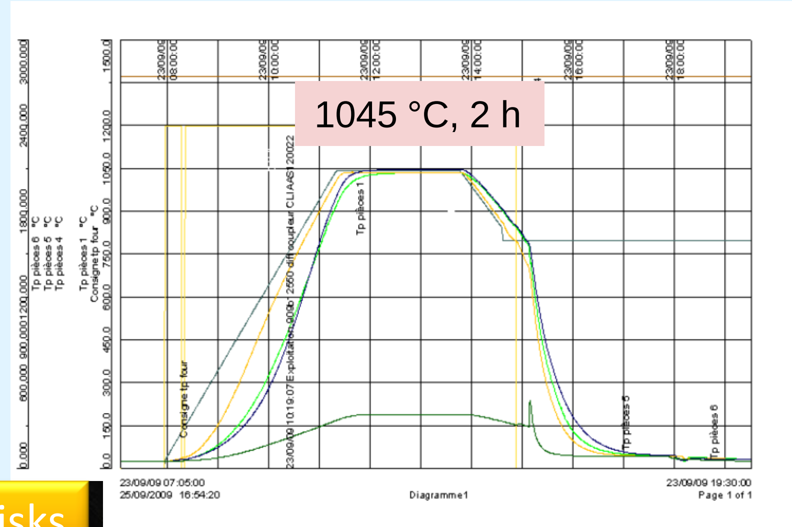
Etching

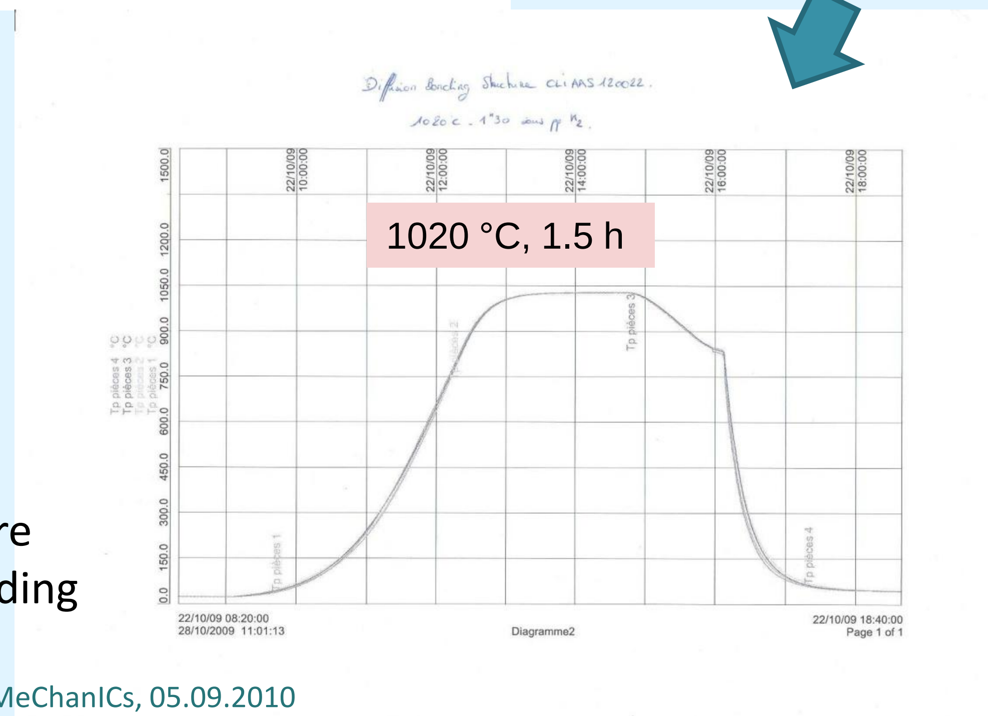


Tool for holding the disks

Diffusion bonding

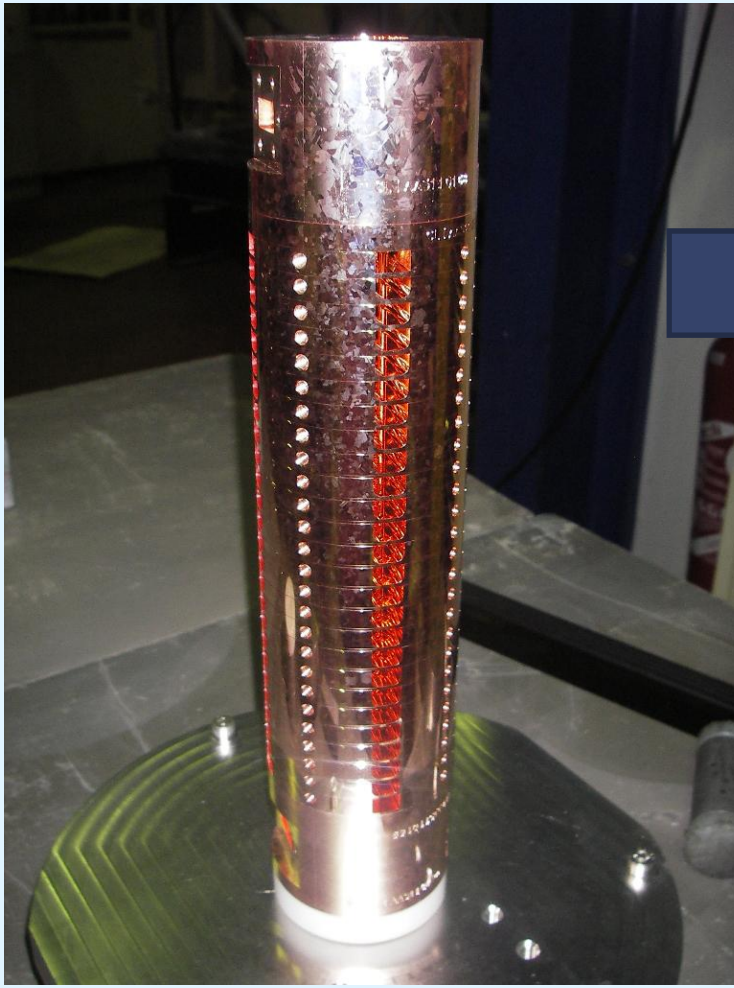




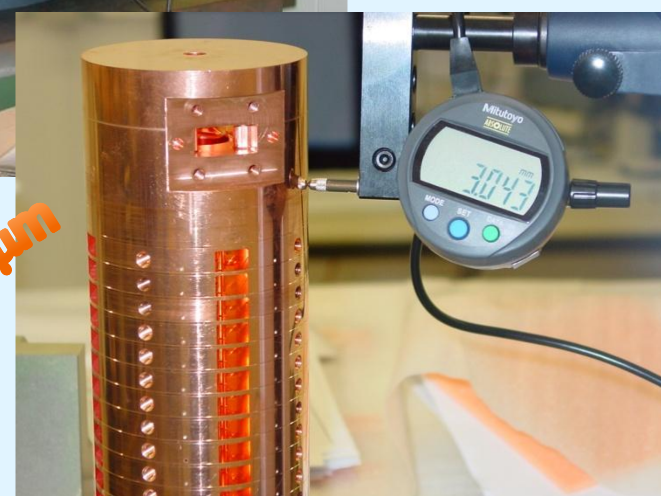


Bonding at CERN: few mbar H_2 partial pressure (difference with SLAC): we are validating bonding at 1 bar H_2 (Thales-CEA, Listenmann).

Accelerating structure TD24 after diffusion bonding under H_2



Assembly

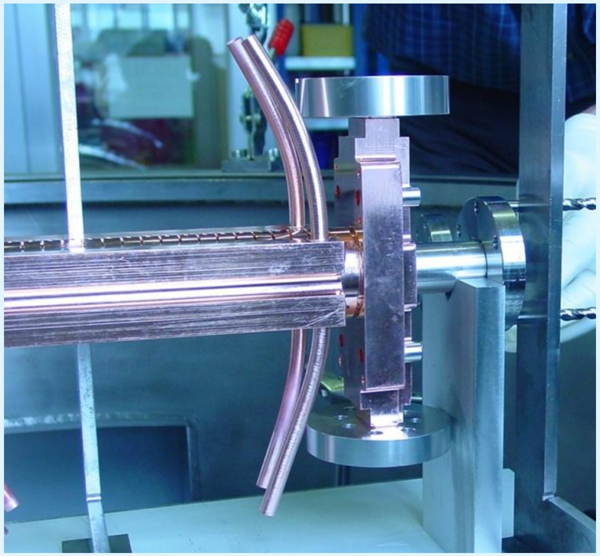


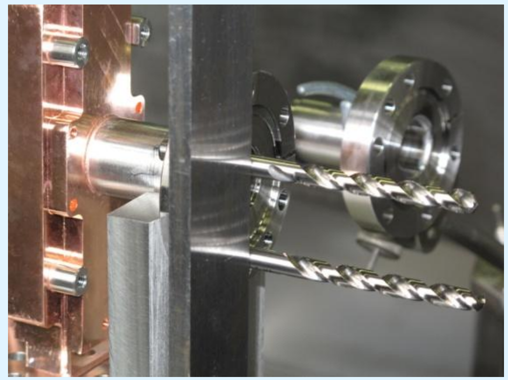
Assembly made on V-blocks
Verification of the assembly (before and after bonding) with a new measurement column: straightness and tilt

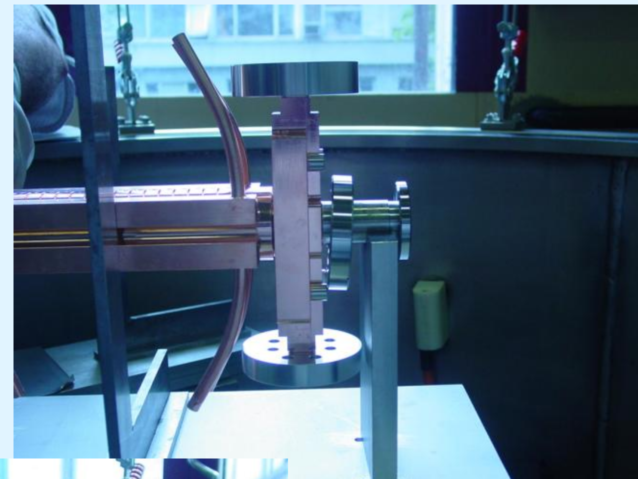
Straightness measurement ±2 μm

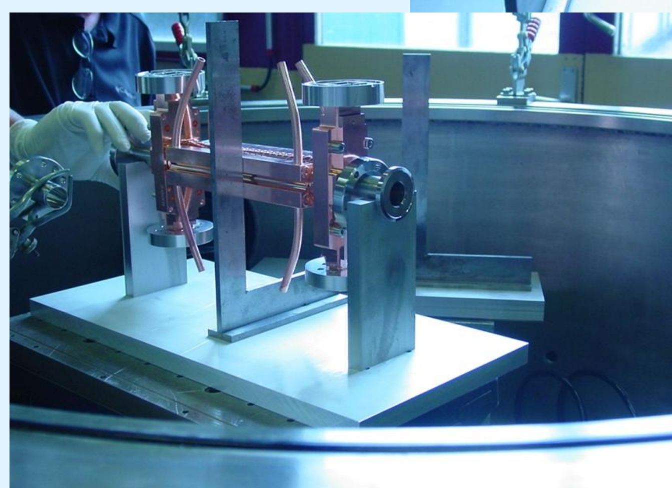
Welding of the vacuum flanges

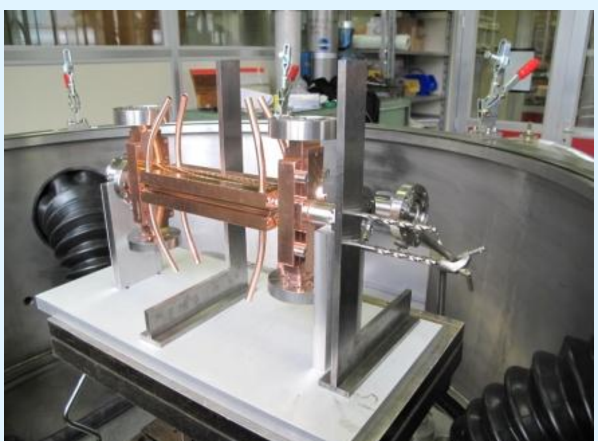
Under Argon 13 l/min in a glove box



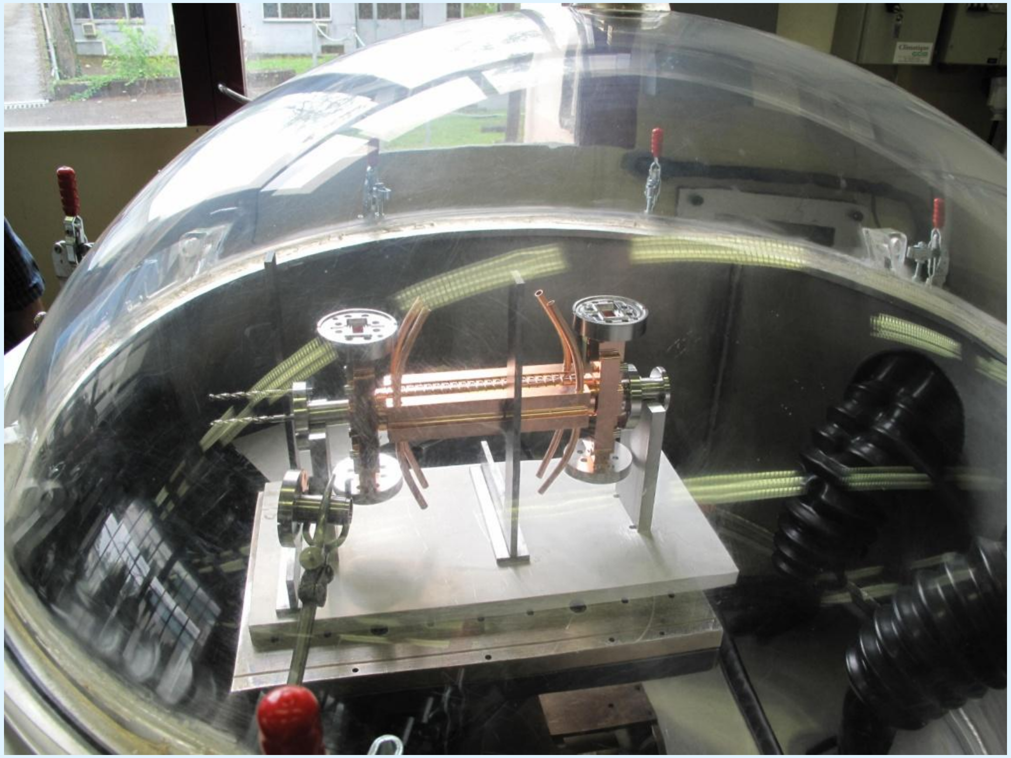


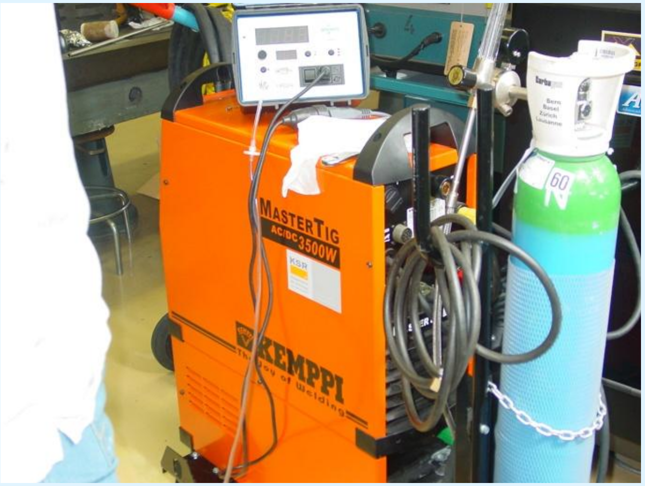




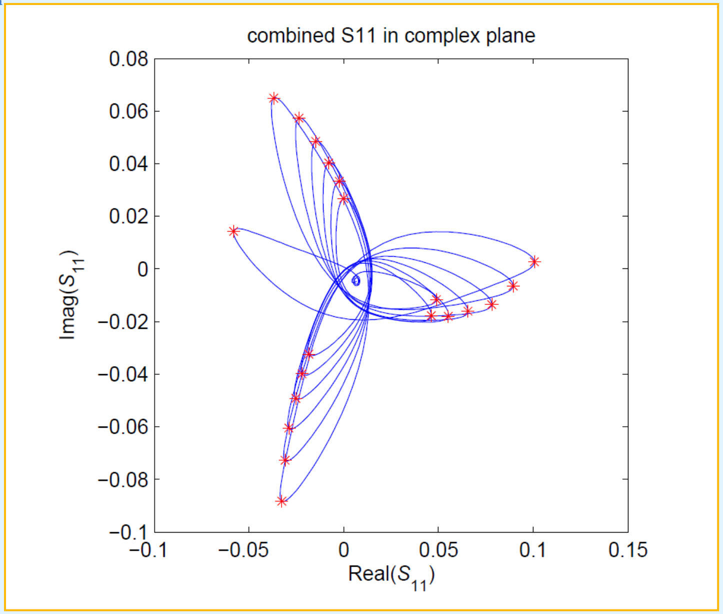


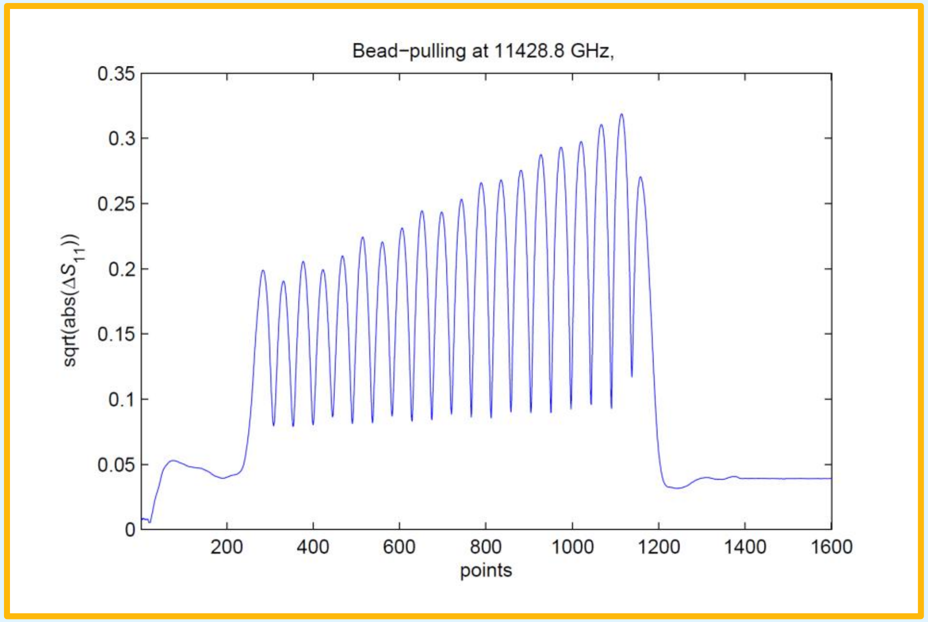
Welding of the vacuum flanges

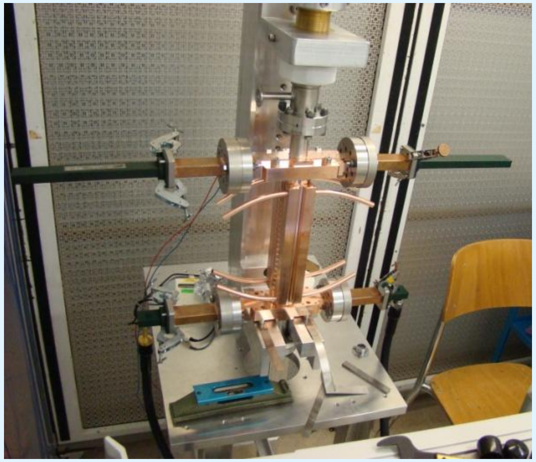




RF check and tuning





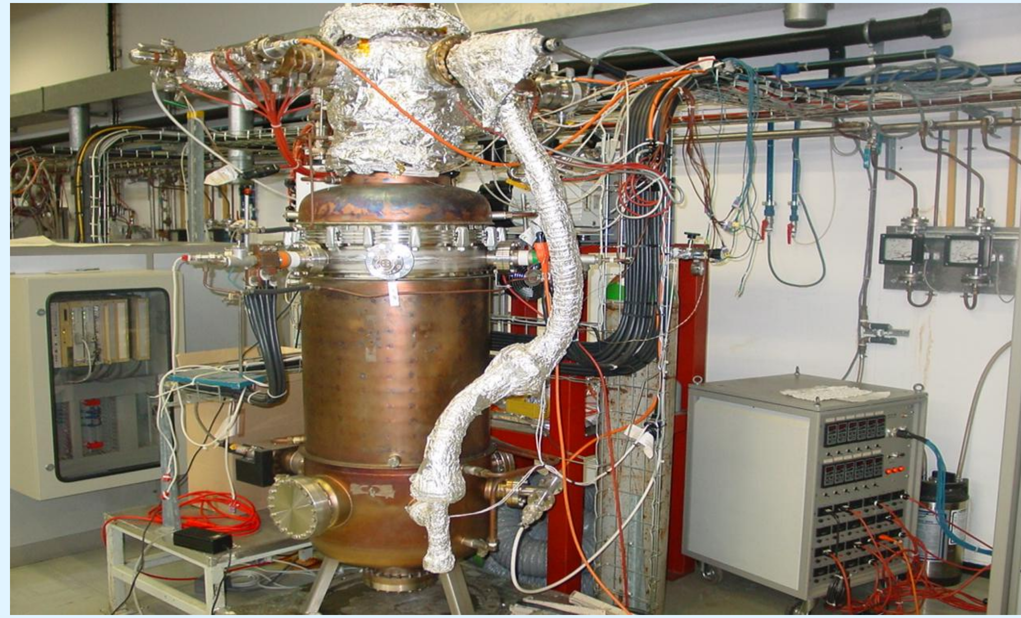


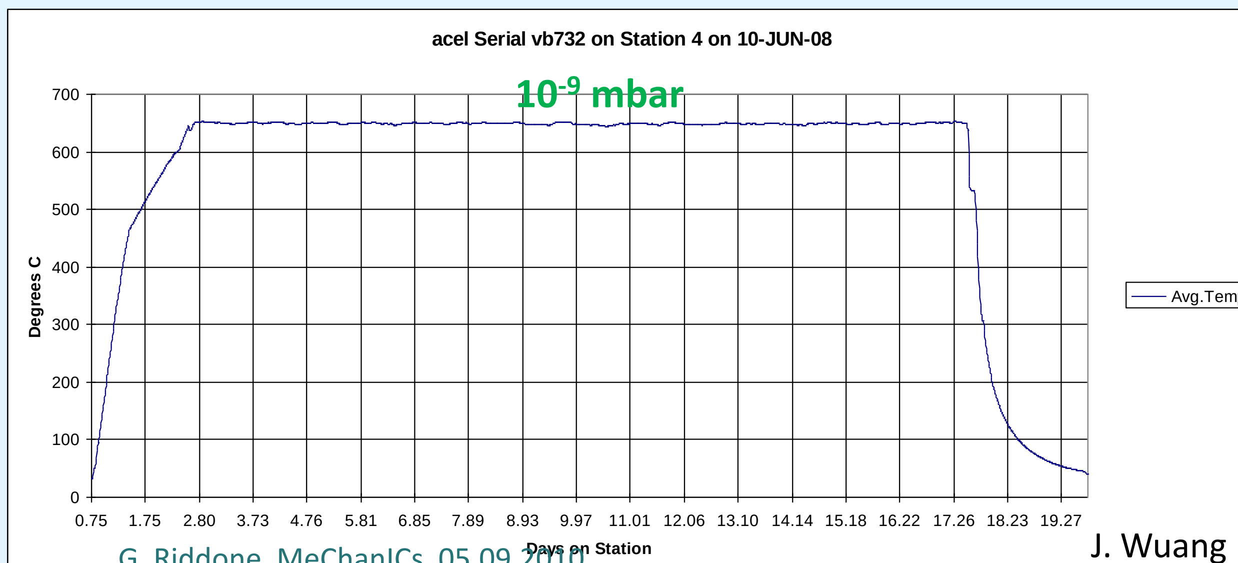
J. Shi

Vacuum baking

1st baking: TD24 for CLEX, two-beam test stand

CERN furnace
➔ several mechanical adaptations were needed



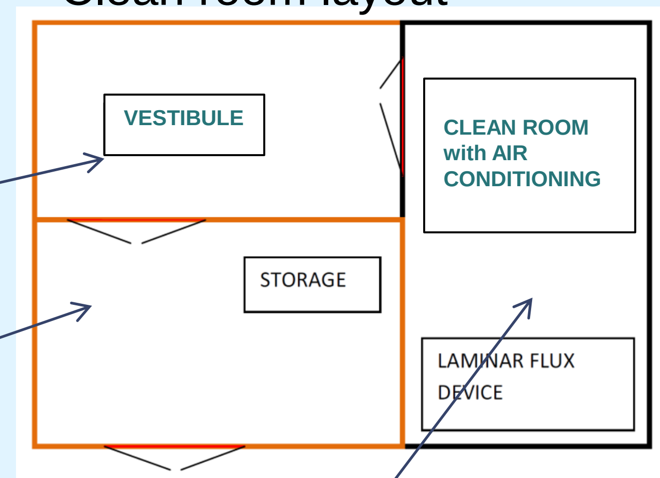


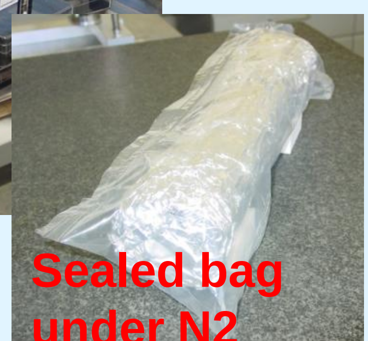
J. Wuang

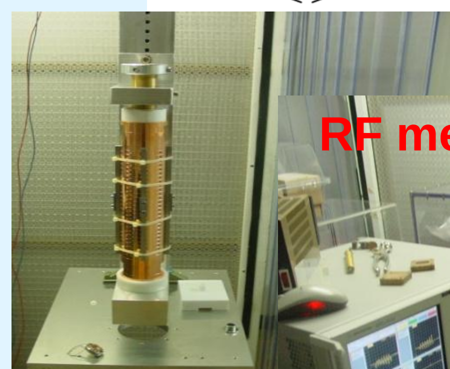
Clean room

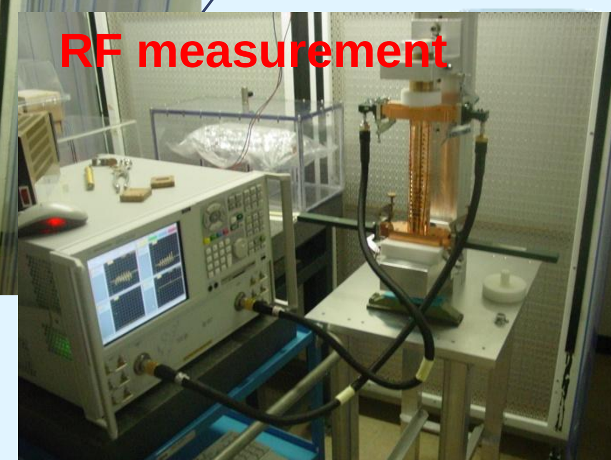
S. Lebet, visit this afternoon

Clean room layout









Production base program

F = under fabrication
D = under eng. design

2010

F — T24 undamped

F — TD24 damped

F — TD24 R05 KS reduced ΔT

CDR

D — **TD24 R05 KS – reduced ΔT with damping loads**

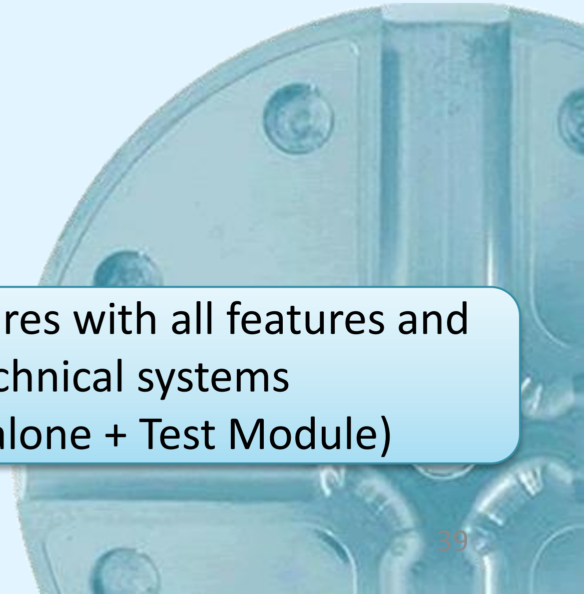
2011

D — TD26 KS – reduced ΔT with damping loads and compact coupler

2013

F — TD24 – with wakefield monitors

D — CLIC structures with all features and technical systems (Stand alone + Test Module)



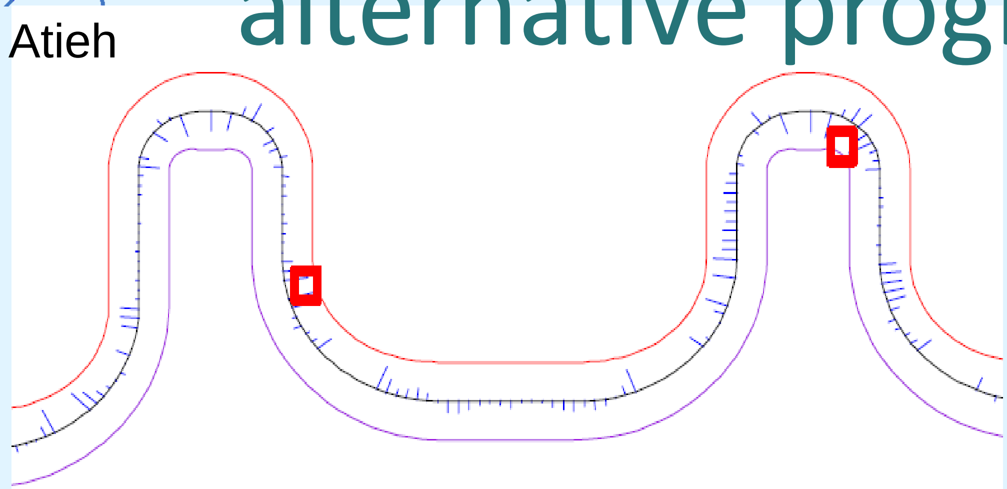
Accelerating structures fabrication procedure comparison

	SLAC/KEK	Fermilab	CERN old	CERN new (SLAC/KEK based)
Diamond machining	√	√	√	√
Etch	√	√	√	√
1000 ˚C pre-fire		√ (Ar)		
~ 1000 ˚C diffusion bonding	√			√
~ 1000 ˚C brazing	√			
~ 800 ˚C brazing		√ (Ar, Au/Cu)	√ (Vacuum, Ag/Cu)	√
Vacuum baking	√	√		√
Tank/sealed	SEALED	SEALED	SEALED	**TANK**/SEALED

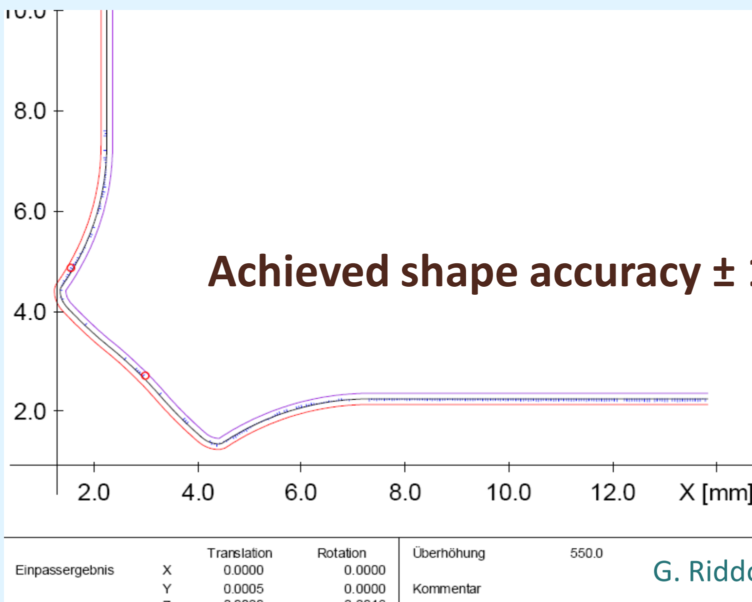
CERN procedure still needs to be optmised

Accelerating structures: alternative program

S. Atieh



Achieved shape accuracy ± 2.1 µm
Roughness Ra = 86 nm – 30 nm according to ISO 97

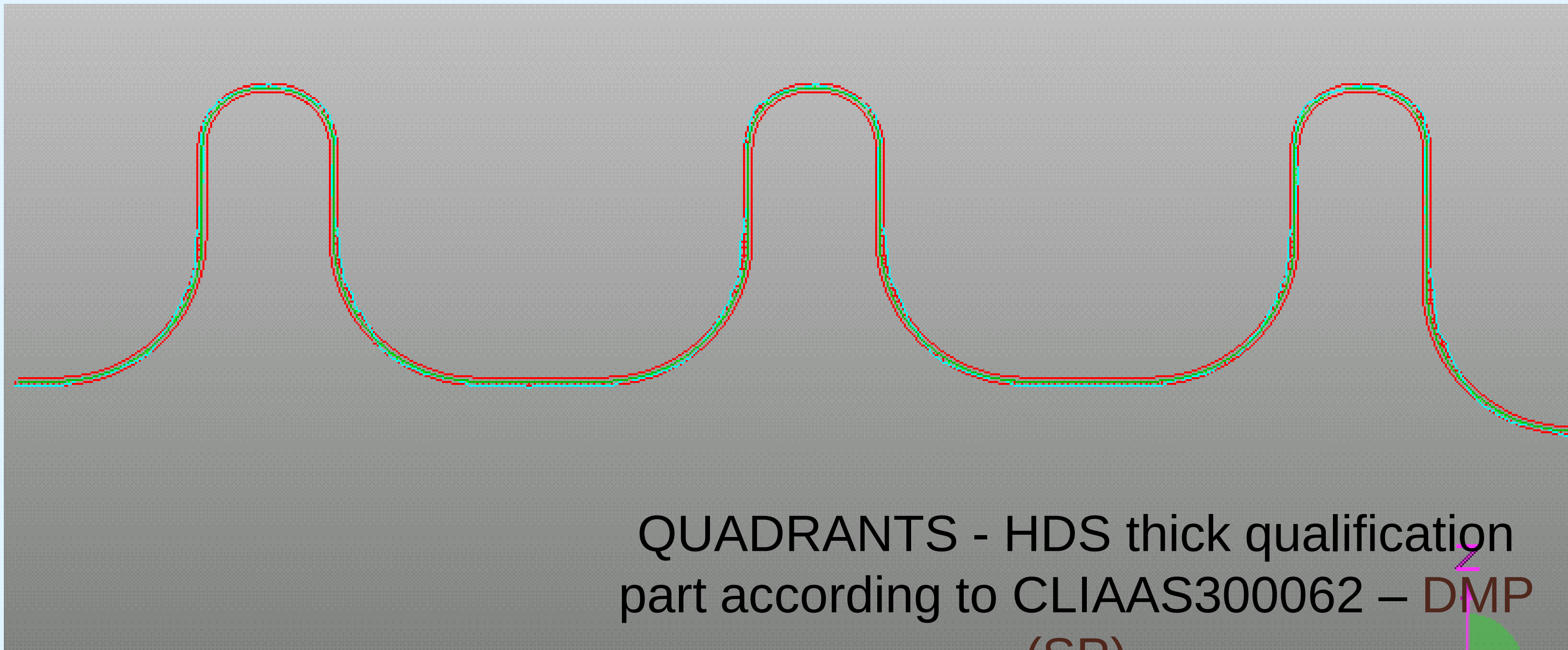


Achieved shape accuracy ± 1.3 µm

QUADRANTS - HDS thick qualification part according to CLIAAS300062 - KERN

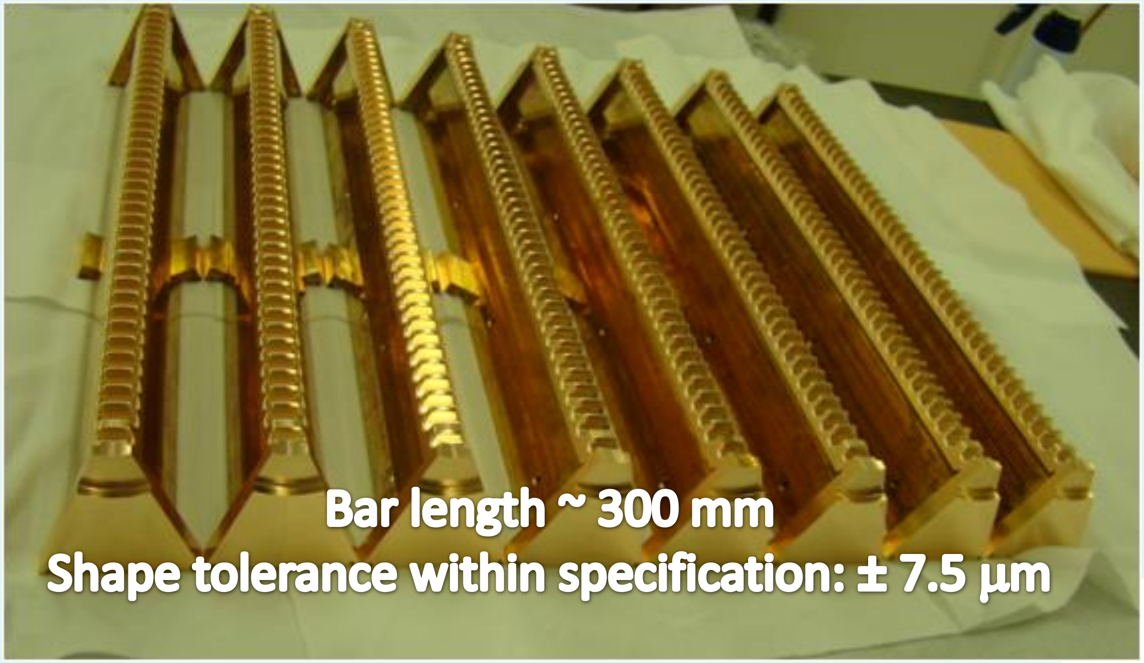
S. Atieh

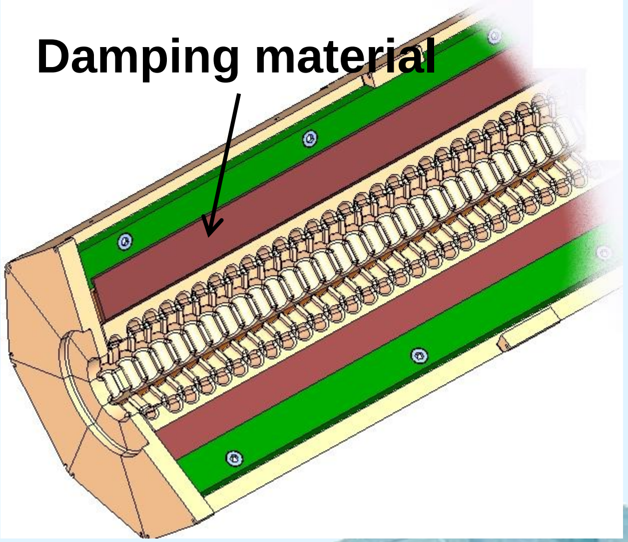
Accelerating structures: alternative program



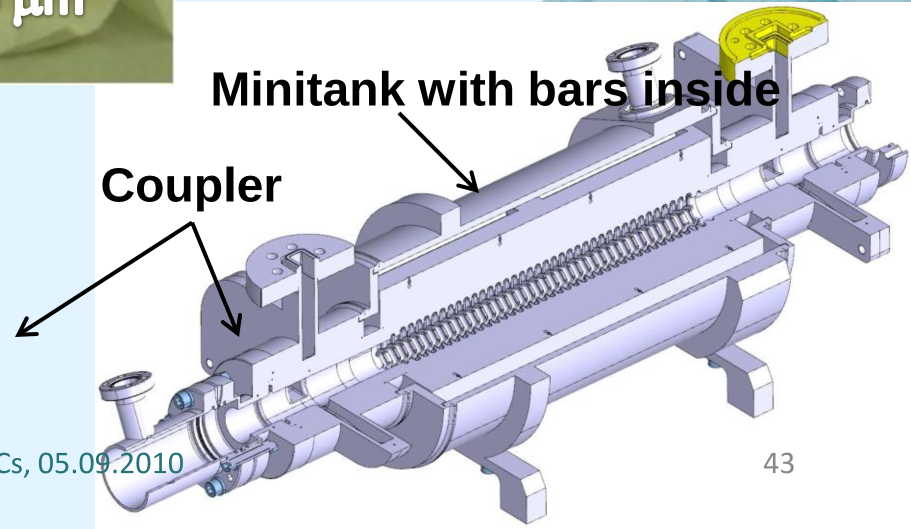
Origins translation: X 16 µm and Z -8 µm
Shape accuracy is respected ± 2.5 µm

Fabrication of PETS at 11.4 GHz with damping material





PETS for feasibility demonstration
- successfully tested at SLAC



Fabrication flow for PETS (11,4 GHz)

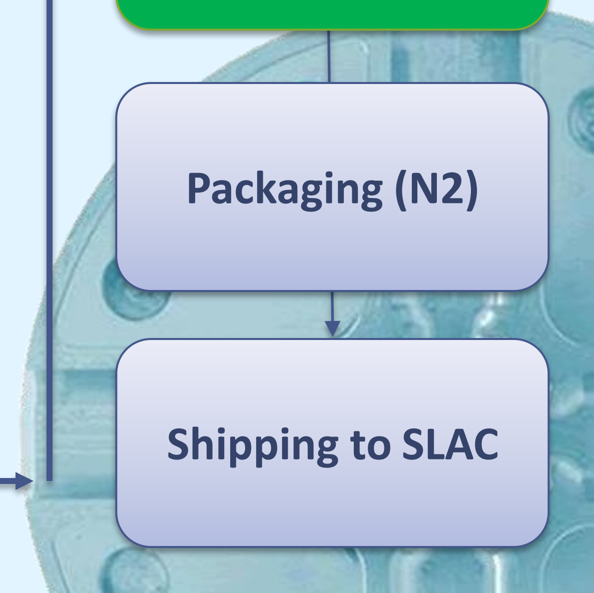
Procedure as close as possible to the baseline, but some difference due to design and infrastructures

PETS bars

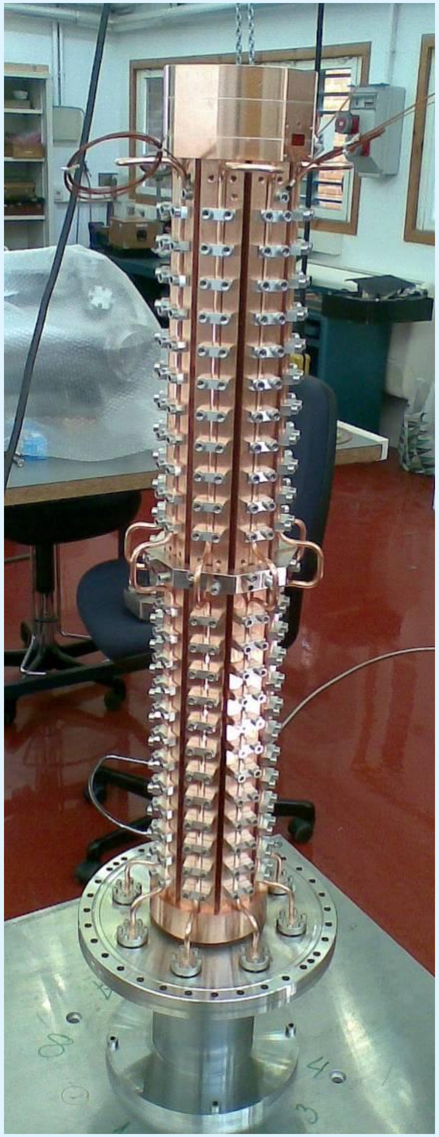
- QC
- Cleaning (NGL+solvent)
- EB welding of the bars
- Baking (vacuum, 200 C, 2 h)

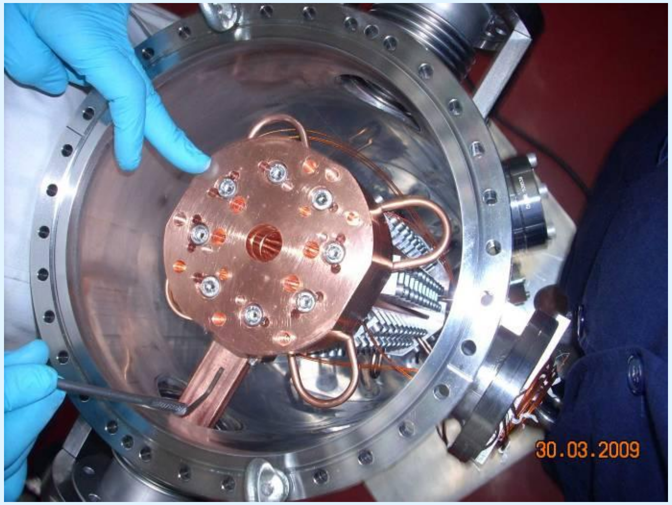
FINAL ASSEMBLY

- Assembly of the 8 bars
- EB welding of the bars
- RF check
- Assembly of couplers-bars and mini-tank
- EB welding of tank
- RF check
- Vacuum test
- Final bake-out (150 C, 2h)
- Packaging (N2)
- Shipping to SLAC



Fabrication of TBL PETS





<u>**Prototype made by CIEMAT**</u> using conventional UHV best practice for cleaning and handling
Coupler is brazed, no heat treatment for PETS itself

The <u>**CERN production**</u> will be assembled in a clean room,
The coupler will be vacuum brazed at CERN

S. Doebert

Production capability

PRODUCTION CYCLE (ac. structures)			
Manufacturing	Assembly (bonding)	Tuning	Baking
10 wks	4 wks	2 wks	3 wks
Total: 19 wks (about 5 months)			

PRODUCTION CYCLE (PETS @ 11.4 GHz)			
Manufacturing	Assembly (EB welding)	RF meas.	Baking
10 wks	6 wks	1 wk	1 wk
Total: 18 wks (about 4.5 months)			

3 laboratories:

- ac. structures ➔ SLAC/KEK and CERN
- PETS ➔ CERN

6 qualified vendors for ac. structures: 3 (CERN), 2 (KEK), 1 (SLAC)

3 qualified vendors for PETS

For each structure, at least two units per lab. are manufactured (almost in parallel)

For KEK/SLAC made structure, the assembly/baking is made at SLAC

- e.g. baking of two structures in parallel

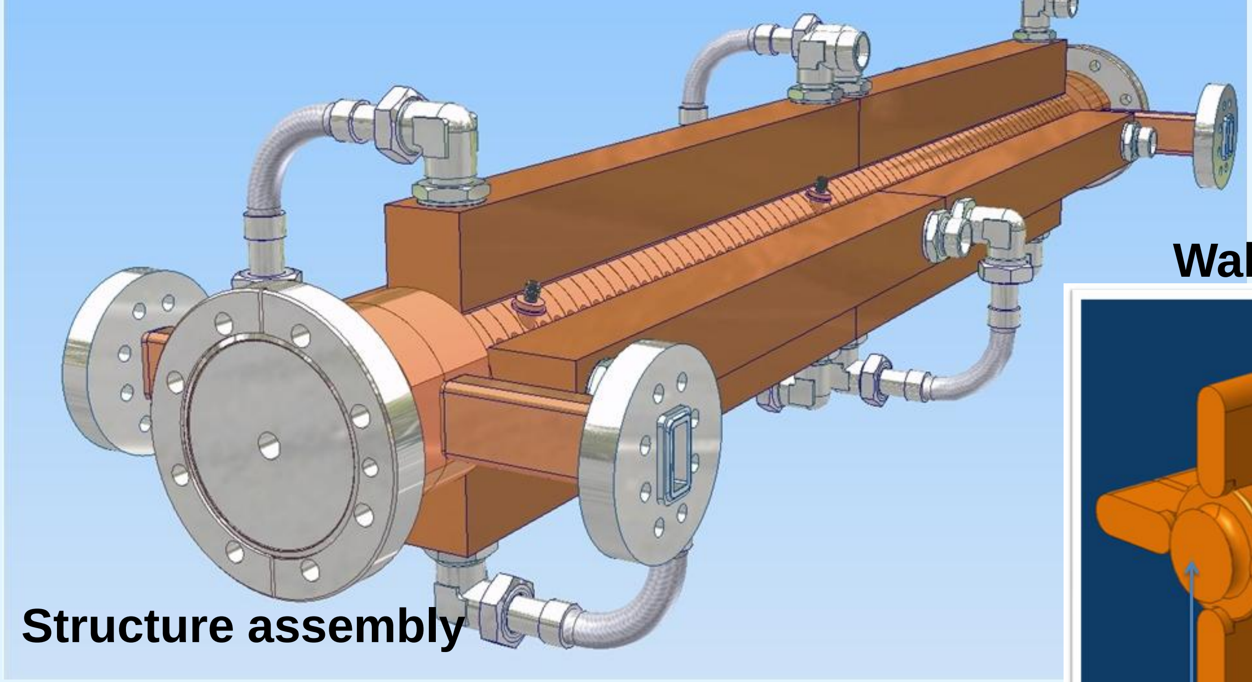
At present, potential capability up to 20. structures per year

Other structures

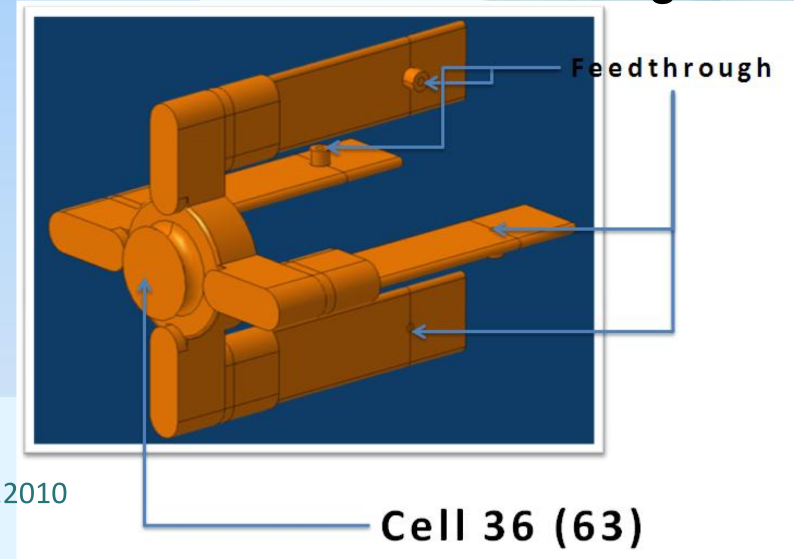
Important involvement of other laboratories to exchange experience and to increase the market

➔ 900-mm long structures for PSI (X-FEL) and Elettra (Sincrotone Trieste) with wakefield monitors

➔ 72 cells



Wakefield monitor design



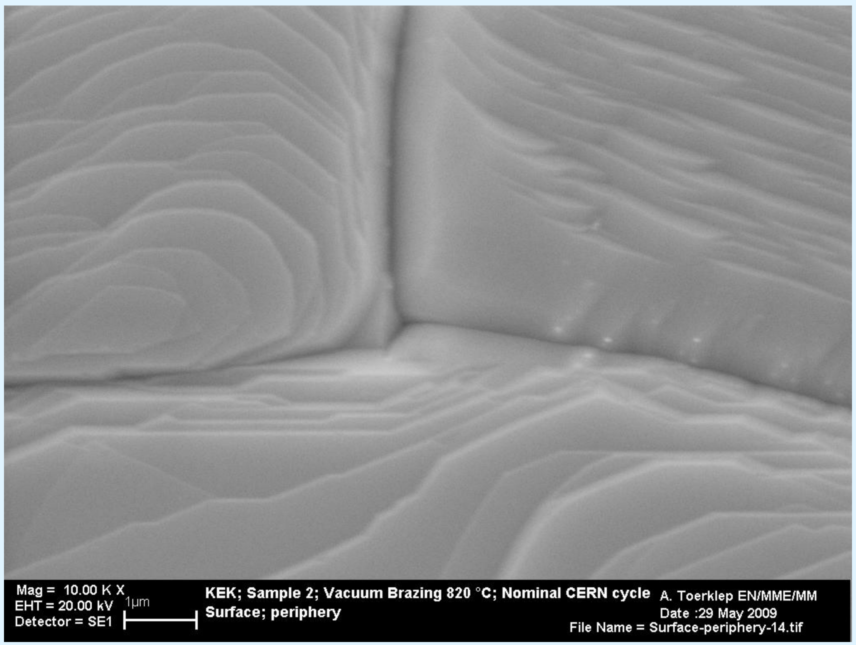
Assembly

To be studied/optimised

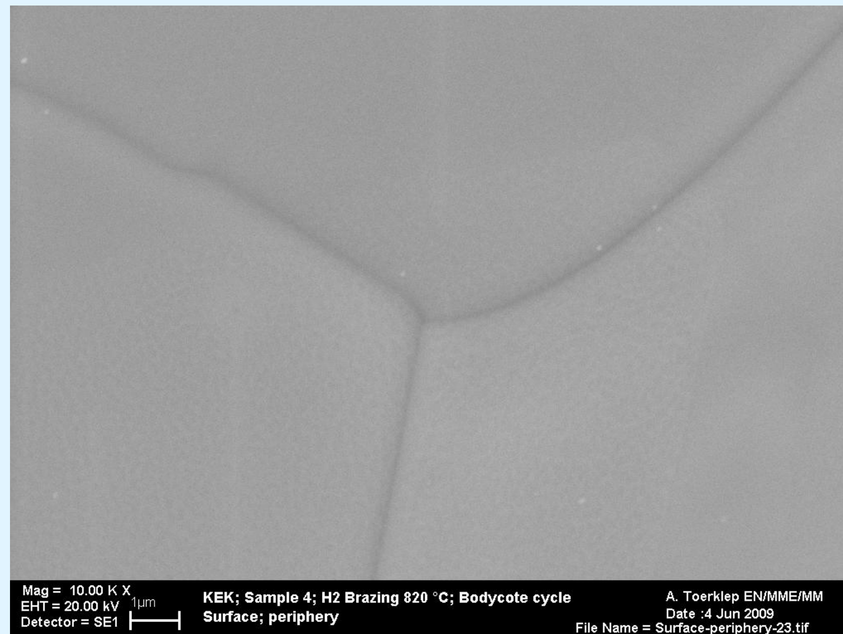
- Baseline procedure:
  - sequence of different steps to improve quality (e.g welding of flanges as one the last operations is dangerous)
  - Review of thermal cycles: T vs time
  - Minimization of thermal cycles
- Review of alignment procedure
- Cost effective assembly procedure

Vacuum brazing versus hydrogen brazing

Vacuum brazing



Hydrogen brazing

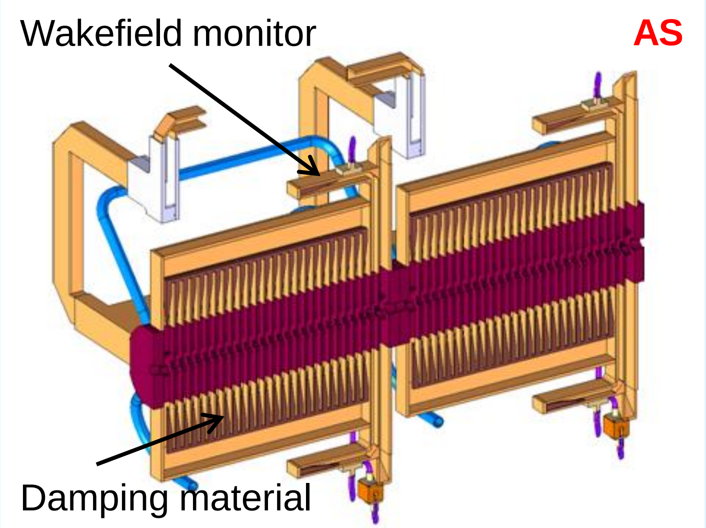


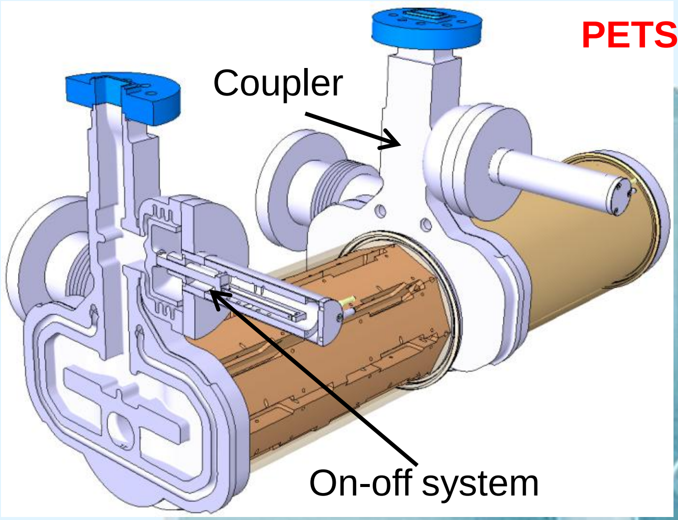
Extensive program launched to improve our understanding on the influence of different thermal cycles on the copper surface

TOWARDS CLIC STRUCTURES

Towards CLIC structures

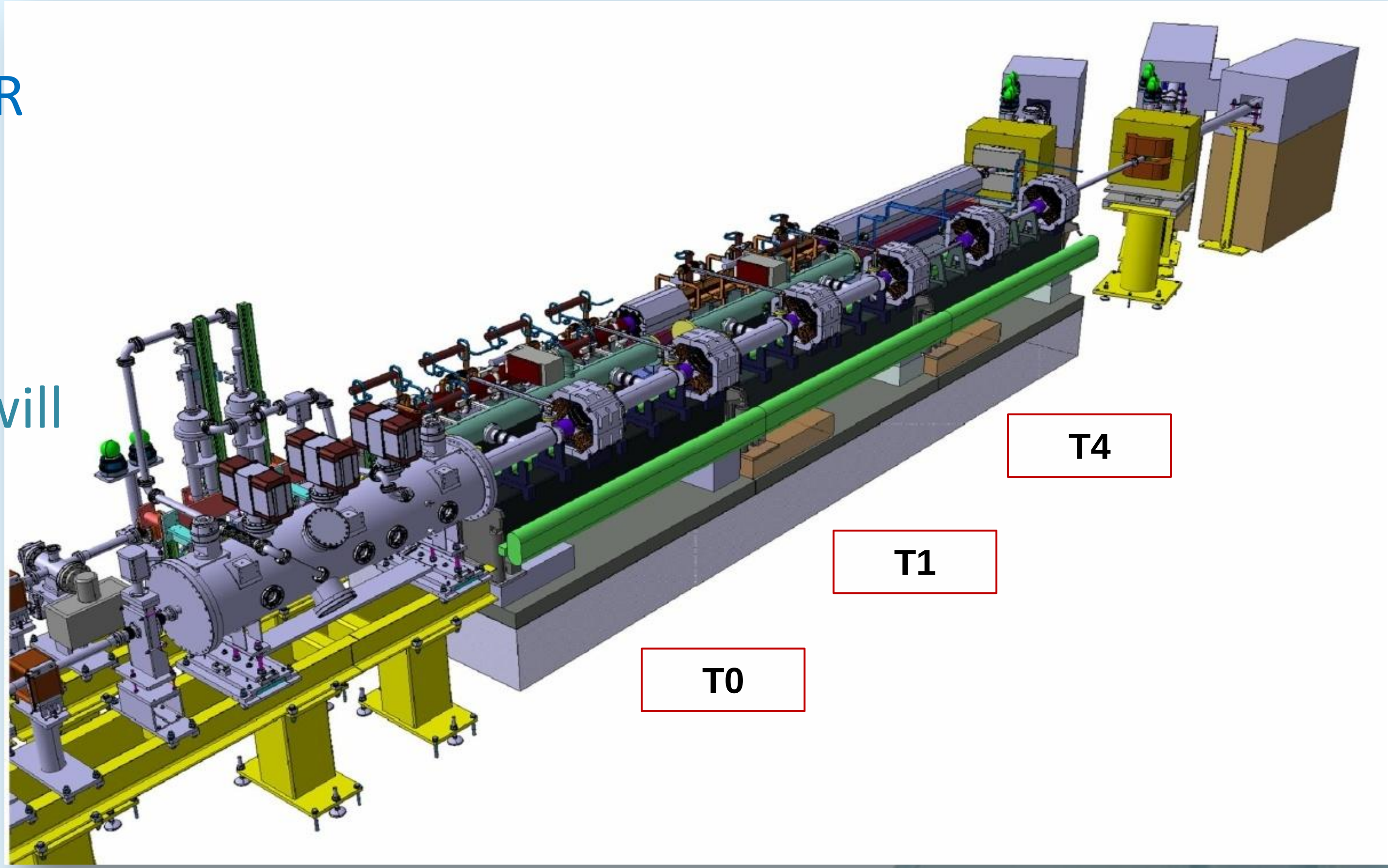
- CDR
  - Accelerating structure with all features: damping material, wakefield monitor and technical systems; under eng. design (**first structure at the end of 2010**). Assembly test with a prototype structure are scheduled in the coming weeks.
  - PETS with on-off system: under design. **On-off system to be tested in Q1, 2011**
  - **Cost estimate** is needed for CDR: dedicated studies with three companies/institutes





Towards CLIC structures

- From CDR to TDR
  - Main linac prototype modules (**3 by end of 2012**) will be built to validate the technical systems in an integrated approach.



- These modules will contain accelerating structures and PETS with all required features
- Industrialization and mass production development in collaboration with companies

Conclusions

- Fabrication of X-band micro-precision RF structure is very challenging and it involves several steps, technologies and quality controls
- NLC/JLC fabrication technology validated for CLIC accelerating structures to 100 MV/m
  ➔ CERN implementing NLC/JLC procedures, but optimization is needed
- Production capability in Europe has to increase: at present only few firms qualified and the final product is not always within tolerances ➔ involvement of other laboratories to exchange experience and expertise is mandatory
- Fabrication procedures are to be developed and cost-performance ratio improved
- CLIC structures with all features under design: first unit ready by end of this year
- Main linac prototype modules for CLEX will include CLIC several structures: 2011-2013
- Industrialization, mass production and cost study under way