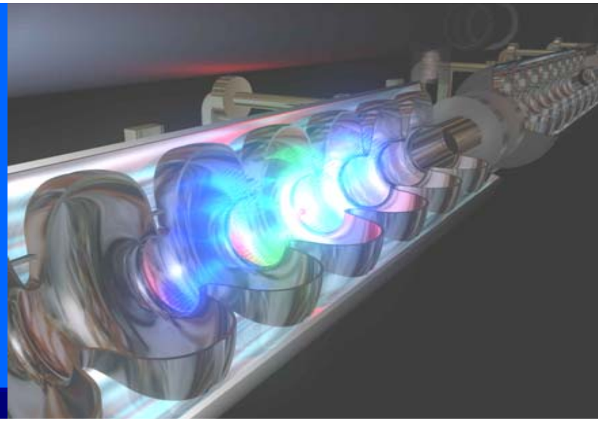


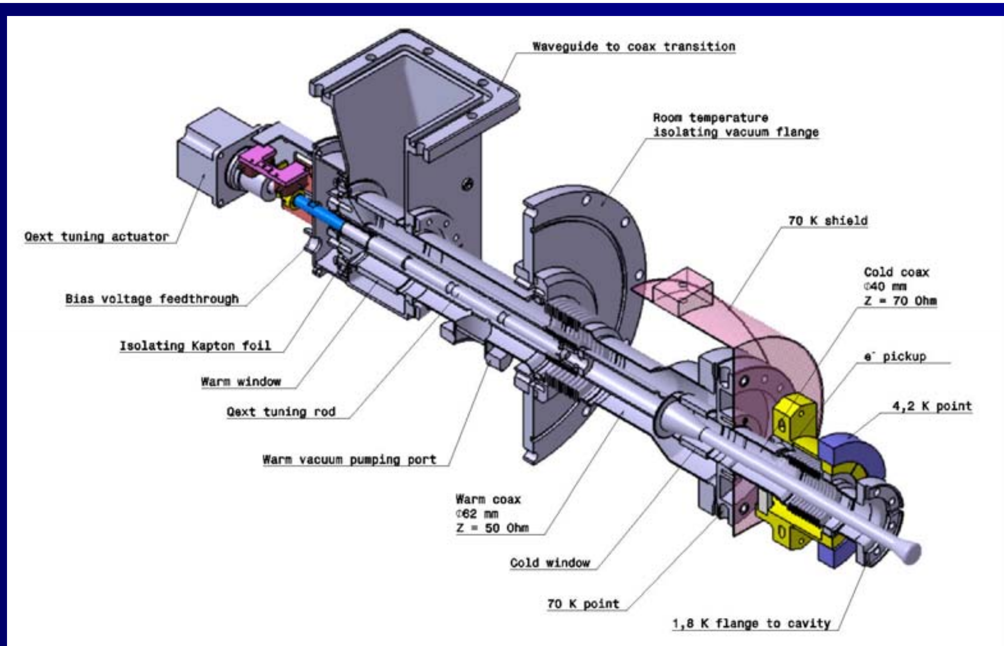
XFEL
X-Ray Free-Electron Laser

Industrialization Process for XFEL Power Couplers and Volume Manufacturing

SRF 2007 at Beijing, October 2007

Serge Prat / LAL – Orsay

presented by W.-D. Moeller / DESY - Hamburg



Scope of delivery

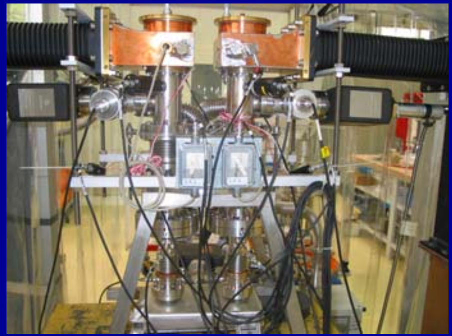
Manufacturing parts and sub-assemblies

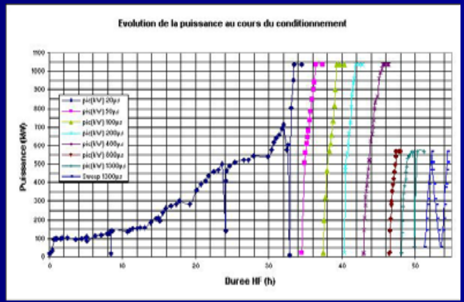
In ISO 6 and ISO 4 clean room:
- Cleaning
- pre-assembly
- Vacuum oven outgassing
- Final assembly on test stand

Final assembly

800 couplers are needed for XFEL

- Vacuum pumping
- In situ baking
- Connect to RF power





RF conditioning

- Dismount
- Pack
- Transport

Deliver 2 by 2

Expertise required from industry

EB welding

Vacuum brazing

TiN coating th. ~ 10nm

Precise geometrical tolerances

Surface finish
and cleanliness

TIG welding

EN 1.4435

EN 1.4429

Special austenitic stainless steel

Cu plating: 10 < RRR < 100

Motorized tuning

- + He leak rate < 10^{-10} Pa.m3/s
- + Careful Handling with gloves
- + Assembly in clean room
- + RF Conditioning

Industrialization studies: Why ?

Start with: Prototypes

(40 Couplers)

Industrialization process

Quality:
- uneven
- NC, several anomalies

Manufacturing:
- long and difficult
- lack of procedure
- only a few people have the competence

High cost

End objective: Large series

XFEL: 800 Couplers

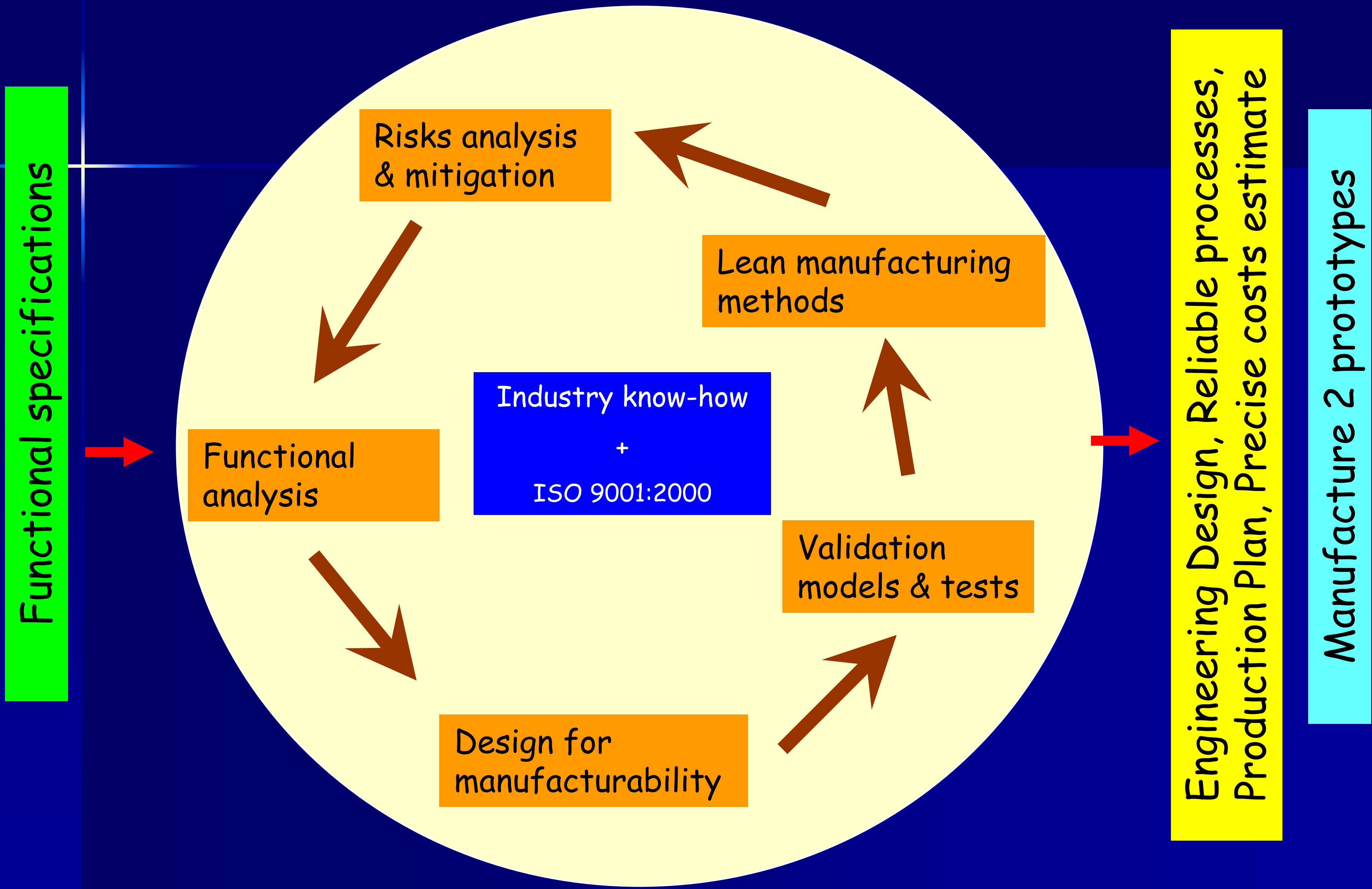
ILC: 16 000 Couplers

Quality:
- equal for all items
- reliable

Manufacturing:
- regular process
- written procedures
- standard competence

Lower cost:
- 60% cost decrease

Industrialization studies: Working process

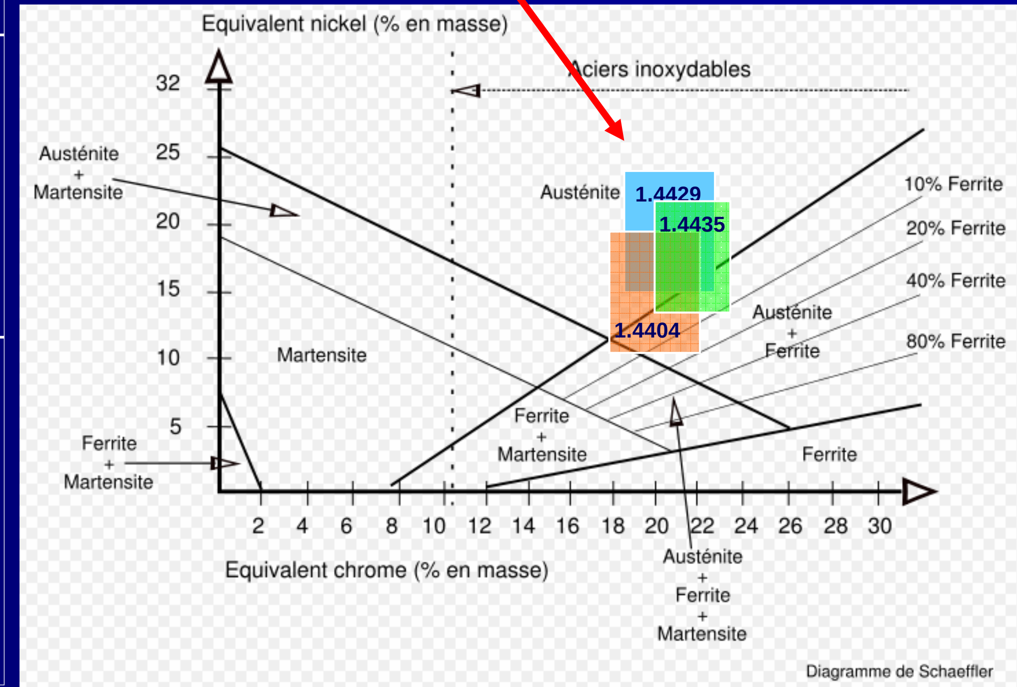


Stainless steels quality is essential

Verify the real chemical composition !
Standards have a wide range

EN 1.4404 X2 Cr Ni Mo 17-12-2 (316L) · ferrite number ~ 2 · easy to procure	Tubes, bellows, fixation parts
EN 1.4435 X2 Cr Ni Mo 18-14-3 (316L also) · ferrite number ~ 0 · μr < 1.01 · less easy to procure	Tubes in cold part
EN 1.4429 X2 Cr Ni Mo 17-13-3 (316LN) · μr < 1.005 · N2 enriched → Hardness 150 / 190 HB · refined by electroslag process · forged in bars · stands baking 2h at 950° C · difficult to procure	· CF flanges · cavity flange

EN 10088



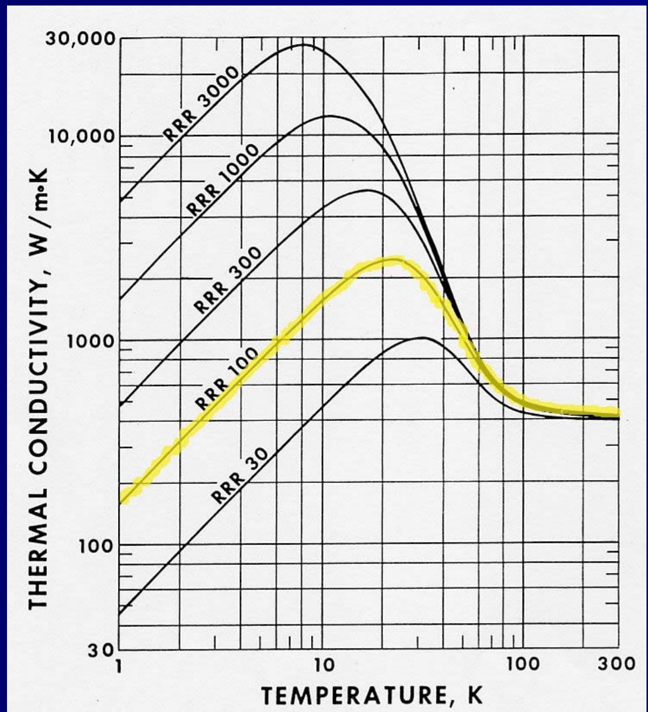
Delong model: Equivalent Chrome : (Cr)eq= (%Cr) + 1,5(%Si) + (%Mo) + 0,5(%Nb)
Equivalent Nickel : (Ni)eq= (%Ni) + 0,5(%Mn) + 30(%C) + 30(%N)

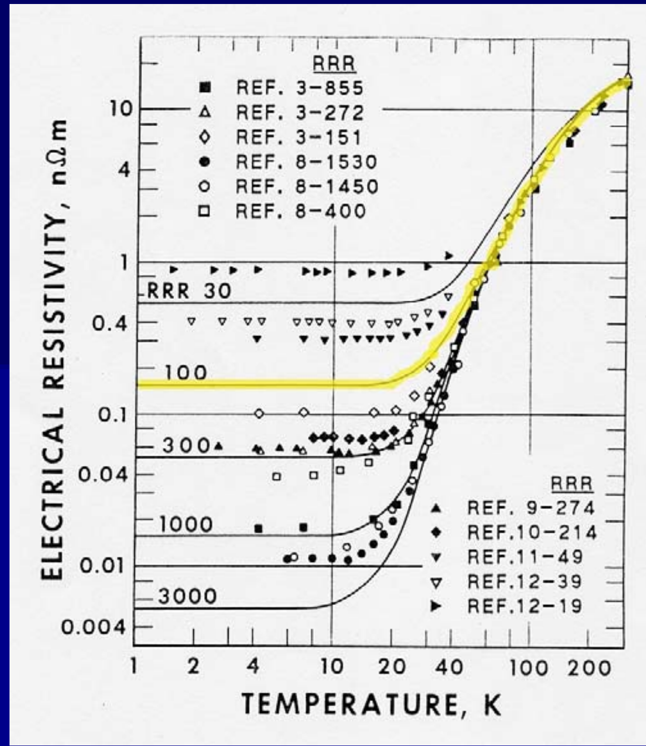
Copper for couplers

Cu-OFE: UNS C10100

« Electrolytic copper with high conductivity and oxygen free »

- state: half-hard
- 3D forged & work-hardened
- grain size < 90 µm
- US test at 4MHz: attenuation should be < 20%
- inclusions: class 1 & 2 (ASTM F 68-99)
- RRR ⩾ 100
- chemical composition:
  - Cu > 99.99%
  - O2 < 5 ppm
  - S < 18 ppm
  - Se < 10 ppm
  - Te < 10 ppm
  - Pb < 10 ppm
  - Bi < 10 ppm
  - P < 3 ppm
  - others < 40 ppm





Ref: Simon, « Properties of copper » (1992)

Ceramic for windows

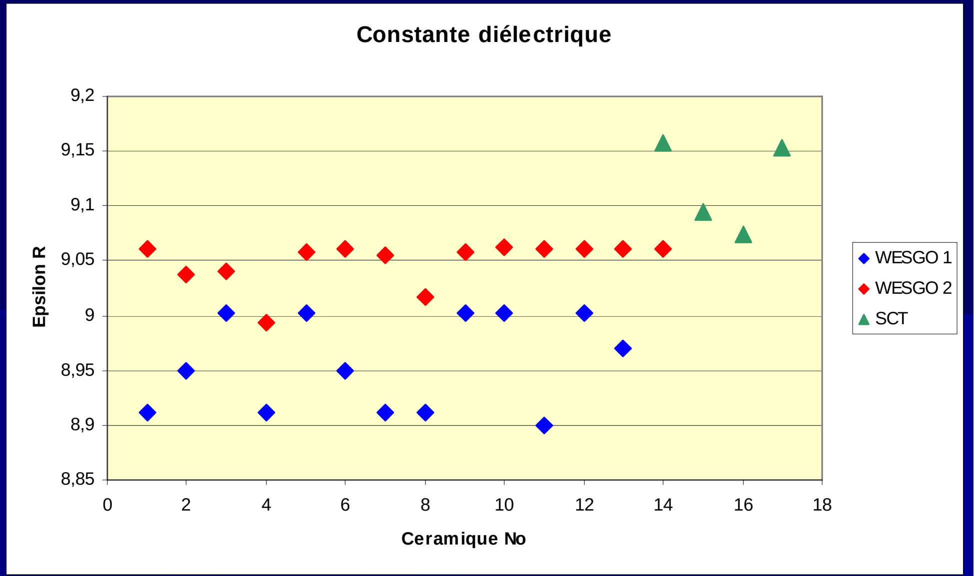
Cylindrical windows made of Al_2O_3 (97,6%):

2 qualified vendors:

- SCT (F – Tarbes)
- WESGO (D – Erlangen)

Highly controlled process:

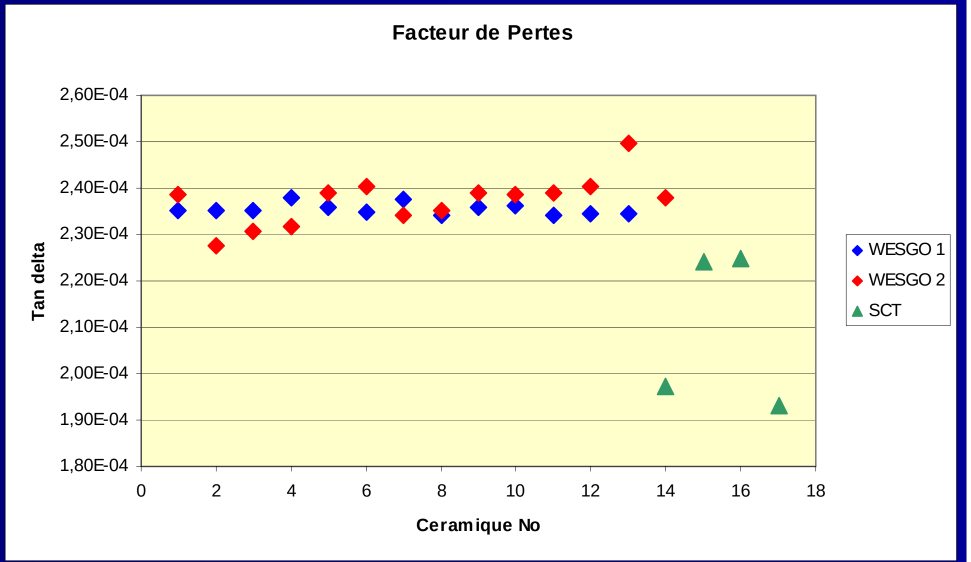
- high purity powder
- isostatic pressing
- « green » machining
- high temperature sintering
- fine grinding
- grinding of grooves
- metallisation Mo-Mn



ε_R values

Measurements done at LAL:

1,3 GHz resonator



$\tan\delta$ values

Materials resistant to ionising radiations

Dose specification for XFEL lifetime (15 years) : **1 MGy** (Absorbed energy = 10^6 J/kg)

Effects of radiations on matter:

- ionisation of atoms
- break of atomic bonds
- creation of free radicals
- organic materials are the most sensitive → degradation of properties { - mechanical - electrical }

<u>Selection of organic material which are reasonably resistant</u>

- PPS (Poly Phenilene Sulfide) → Isolating body in electrical connectors → microswitch case
- Polyester reinforced with glass fibre → actuator parts
- Composites glass fibre – epoxy resin → mechanical supports for thermal insulation
- PAI (Poly-Amide-Imide) ex.Torlon 4203 → mechanical parts for electrical insulation
- PEEK (Poly-Ether-Ether-Ketone) → insulated covers for capacitor
- PI (Poly-Imide) ex. Kapton → insulating film for capacitor → cables insulation
- grease: APIEZON → actuator
- epoxy glue ARALDITE 2011 → mechanical assemblies
- epoxy glue STYCAST 2850F → assemblies with good thermal conduction
- glue LOCTITE 638 → thread locker

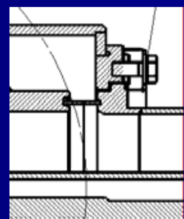
Ref: CERN Documents «Compilation of radiation damage test data » (1979, 1982, 1989, 2001)

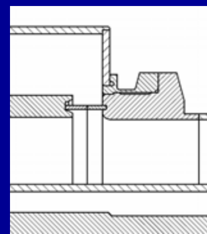
Some results of industrial studies

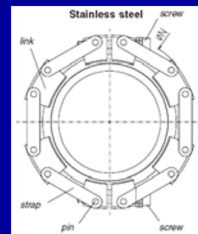
- Functional analysis
  - Small thermal emissivity coefficient → Polish the antenna (gain in radiative thermal power)
  - Thermal model → Cu rings at 4K point can be attached on thicker tube instead of bellows, brazed or glued
  - Big flange on vacuum vessel: 12 holes are enough instead of 24
  - Choose radiation resistant materials
  - Floating big flanges must be supported

- Design for manufacturability
  - Choose deformation techniques instead of machining: *deep drawing, spinning, pull-out*
  - Optimize the process for vacuum brazing by use of special tooling: *adapt tolerances & thermal expansion*

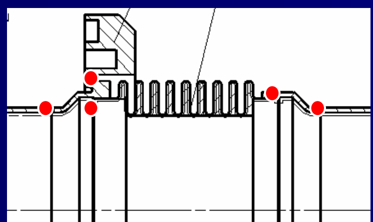
- Lean manufacturing
  - Industrial design for the capacitor
  - Use chain clamp instead of screws for assembly:





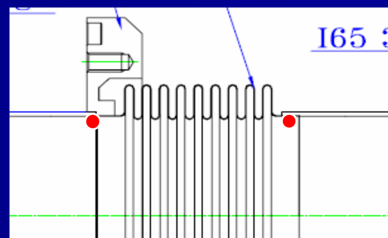


  - Decrease number of parts and junctions:

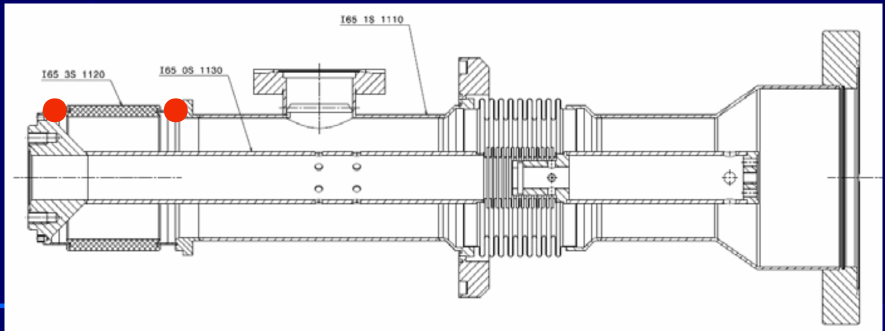


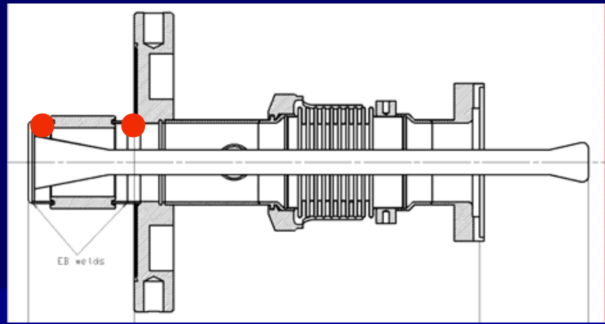
6 Parts 4

5 Junctions 2



Joining techniques



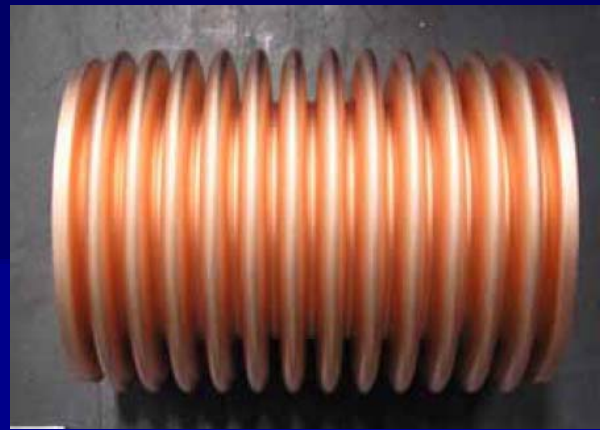


- Proposal 1
  - Joining done as for TTF3 couplers baseline:
    - Stainless steel parts: TIG welds
    - Cu to stainless, Cu to ceramics: vacuum brazing
    - Final joints by EB-weld

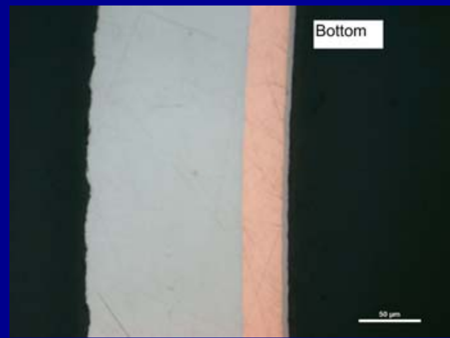
- Proposal 2
  - Final assembly by TIG welding:
    - Stainless steel parts: TIG welds
    - Cu to stainless, Cu to ceramics: vacuum brazing
    - Final joints by TIG weld

- Proposal 3
  - All metallic joints are brazed under vacuum:
    - Brazing to bellows → annealing: fatigue tetst on bellows to validate
    - Cu to ceramics: vacuum brazing
    - Final joints by brazing → problem of Ti diffusion into ceramic

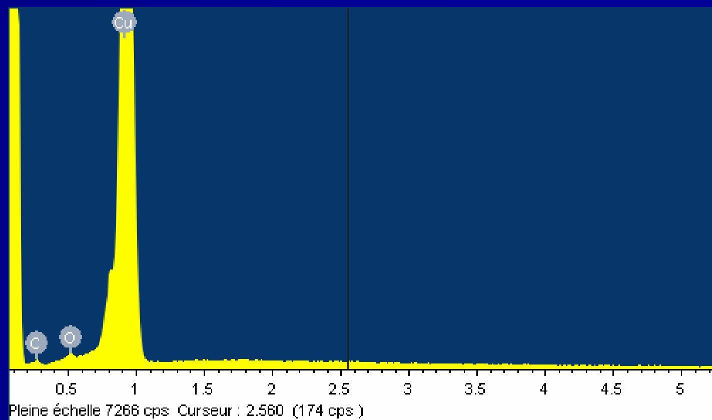
Cu coating



- Different processes are proposed for electroplating:
  - DC current
  - variable pulsed current
  - pulsed current with reverse polarity



- Different bath types are investigated:
  - alcaline cyanide bath: 0.2M CuCN + 0.5M KCN
  - acid sulfate bath: 0.1M $CuSO_4$ + 1M H_2SO_4
  - pyrophosphate bath: $Cu_2P_2O_7$ + $K_4P_2O_7$



- samples received by LAL to measure RRR

  Before baking: RRR = 22

  After baking 2h at 400° C : RRR = 63

TiN coating

→ 2 different processes are proposed:

→ vacuum evaporation techniques

- direct deposit of TiN: evaporation of Ti in N2 atmosphere

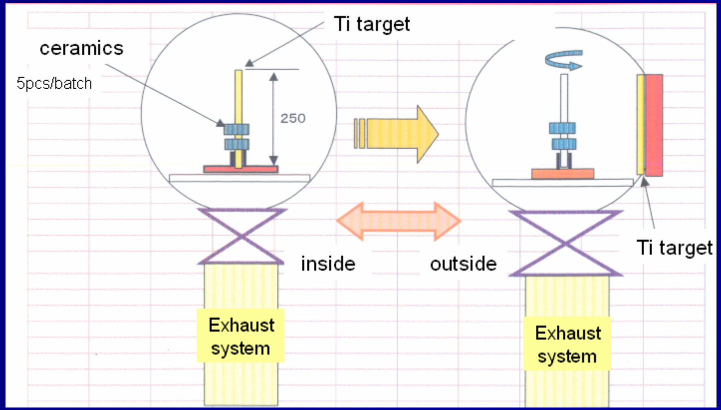
1st tests show a fast TiN buidup on Ti wires→ deposited layer limited to 15 Å, effect on multipactor under investigation

- or deposit of Ti, then transformation into TiN by introduction of NH3 gas

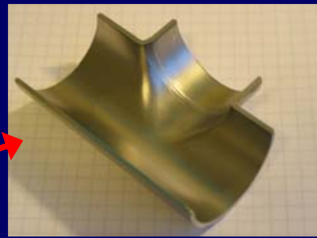
NH3 is more reactive than N2, but requires careful safety process and equipment

→ sputtering process under N2+Ar pressure

1st tests results are promising



Validation samples and tests

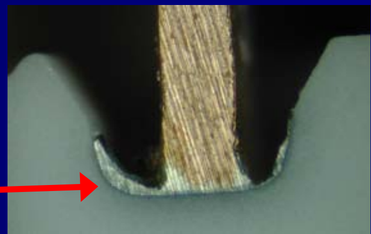


→ Manufacturing techniques:

- tube pull out for e- pickup and pumping ports
- deep drawing for conical part

→ TIG welding: Validate TIG welds from outside:

- stainless – stainless
- Cu – Cu
- stainless - Cu



OK if

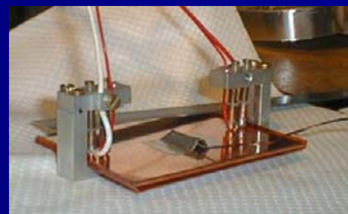
σ_m > 100 MPa

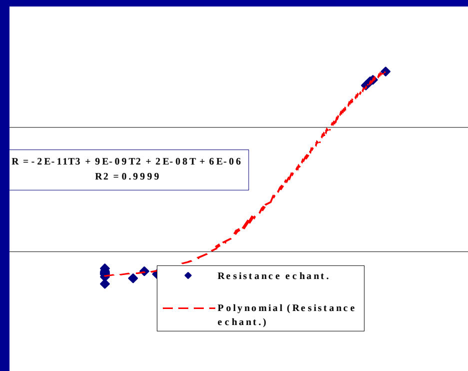
→ Vacuum brazing:

- He leak test < 10^{-10} Pa m^3/s
- pull tests on window assembly

→ Cu coating:

- adhesion test (thermal shock)
- thickness uniformity measurements on bellows: T, S, V
- RRR measurements

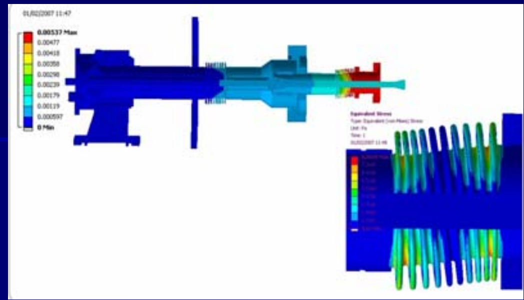


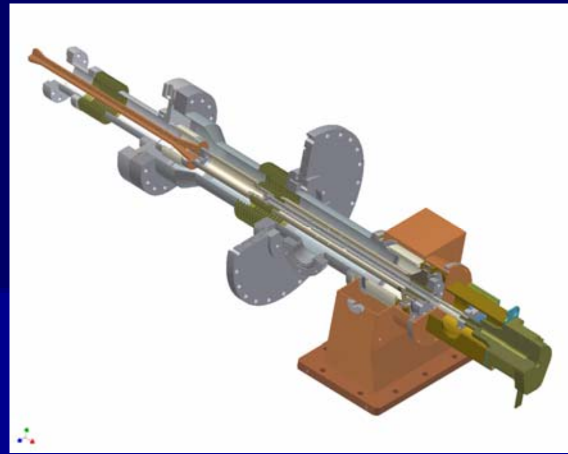


→ TiN coating:

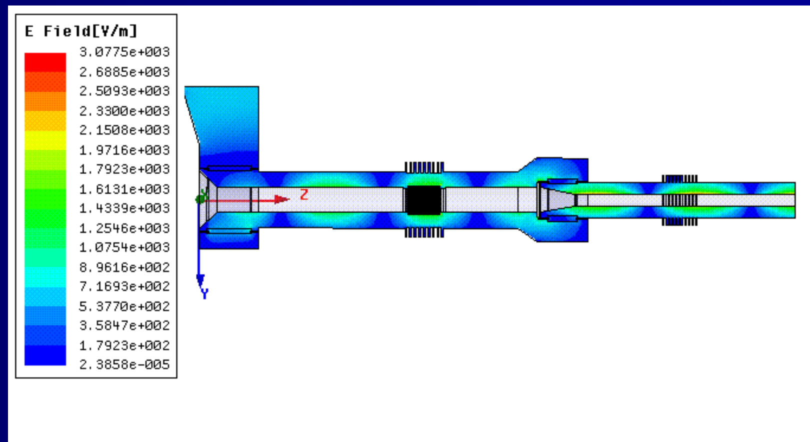
- layer thickness and stoichiometry: (RBS): 5 10^{16} at/cm2 ~ 10 nm
- ε_R and tanδ measurements on ceramic

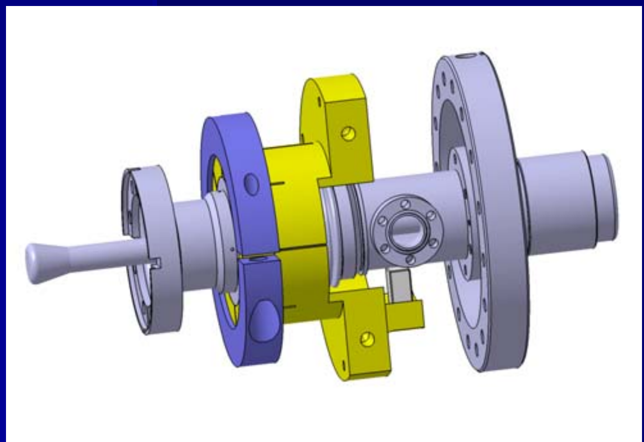
Some work results



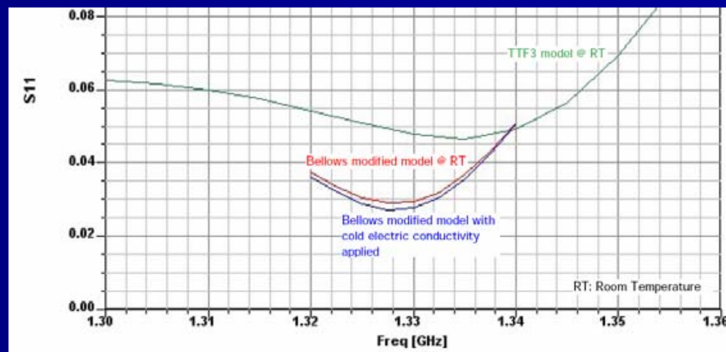


Warm window sample





Sliding support



Keypoints & Project Reviews for industrial studies

Award of 3 contracts in March 06: ACCEL, e2v, TOSHIBA

Kickoff meetings

System Design Review:

- functional analysis
- make sure requirements are well understood
- set the right amount of resources

Preliminary Design Review:

- demonstrate that the proposed design is adequate
- feasibility of the manufacturing processes
- Explain how the mass production will be organized
- deliver joining samples, machining samples

Critical Design Review:

- freeze the final design, deliver detailed drawings
- assembly in clean room: means, organization
- risks analysis
- validation samples of Cu plating and TiN coating

Final Review:

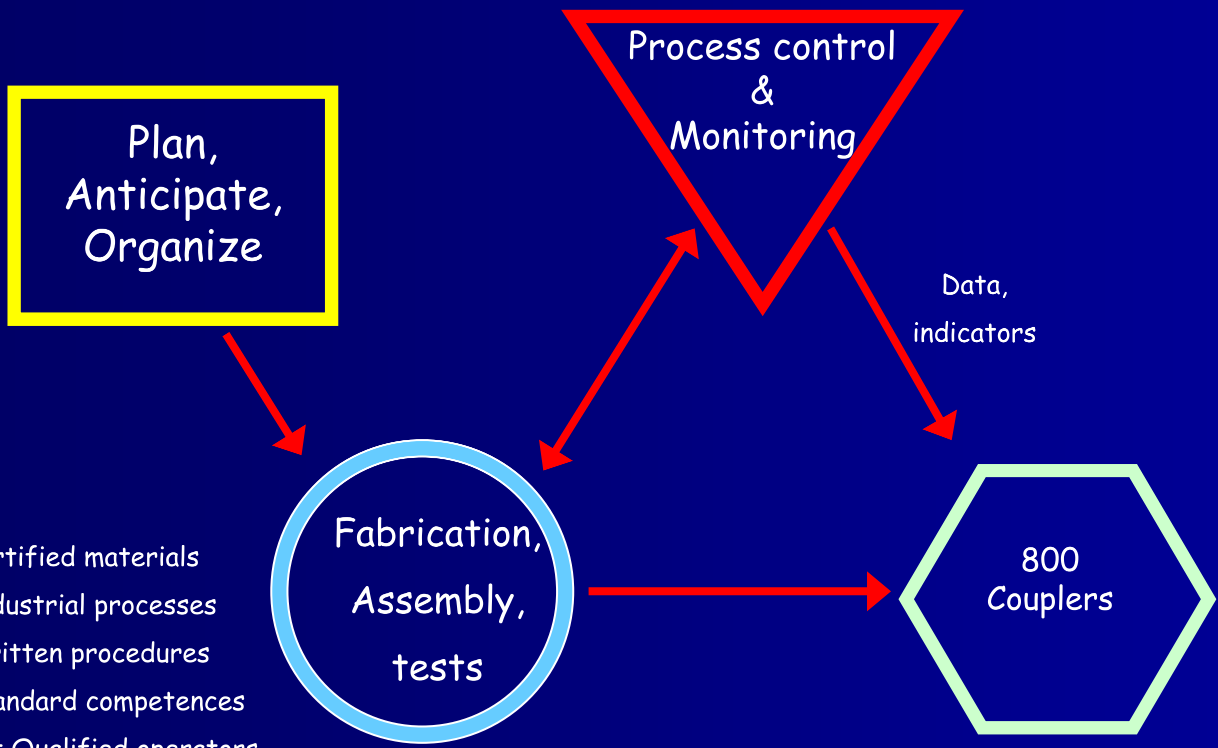
- deliver 2 prototypes with control data
- volume manufacturing plan
- costs estimate for XFEL couplers

SDR →
2006
PDR →
2007
CDR →
FR →
2008

2 full days for each review at each contractor

➢ Objective:

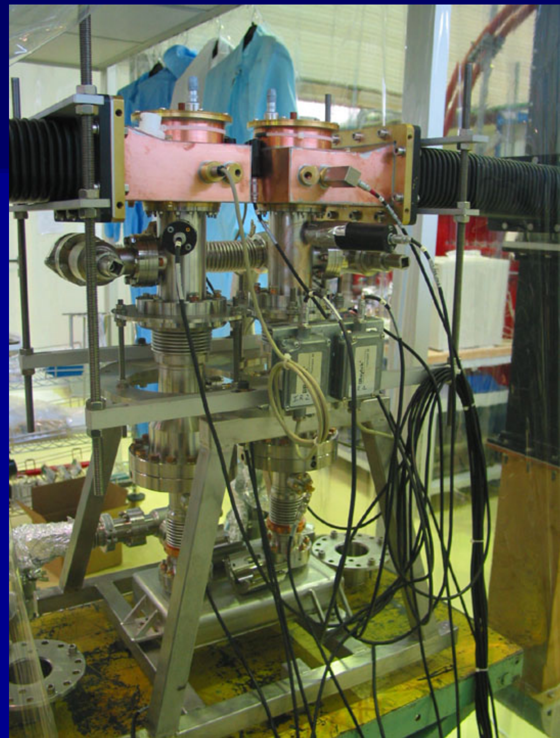
SMART COUPLER FACTORY



- Certified materials
- Industrial processes
- Written procedures
- Standard competences
- but Qualified operators
- Adequate means size
- Optimized costs

- Traceability
- Constant Quality
- Reliability
- Replaceability

Assembly and conditioning



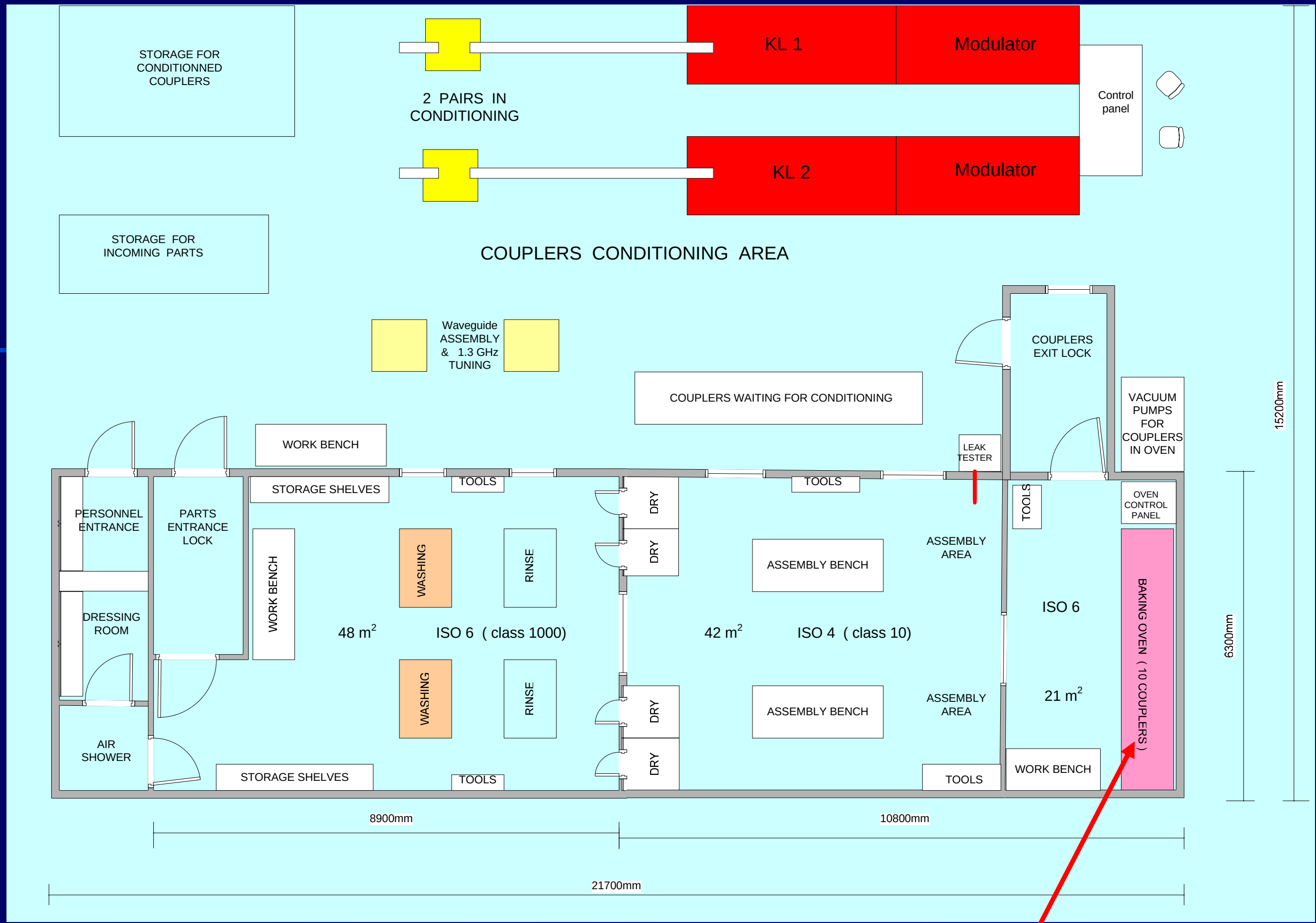
Example of test station at LAL, sized for 50 couplers /year:

- clean room with 2 zones:
  - class 1000: wash and rinse
  - classe 10: dry, bake, assemble
- Klystron 5 MW and modulator

→

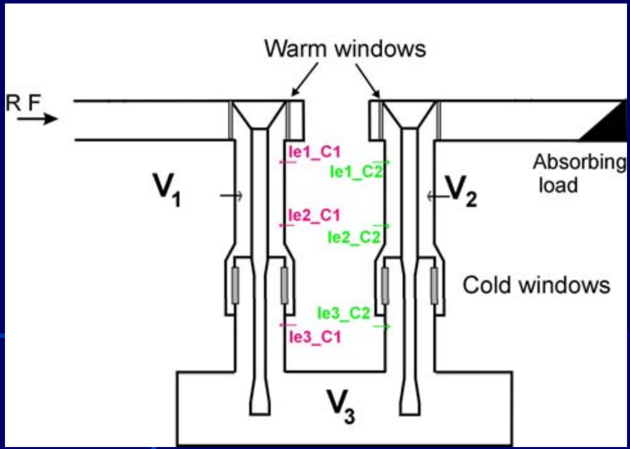
Baking each element 150° C (20h) before assembly → <u>long</u> process

+ in-situ baking just before conditioning

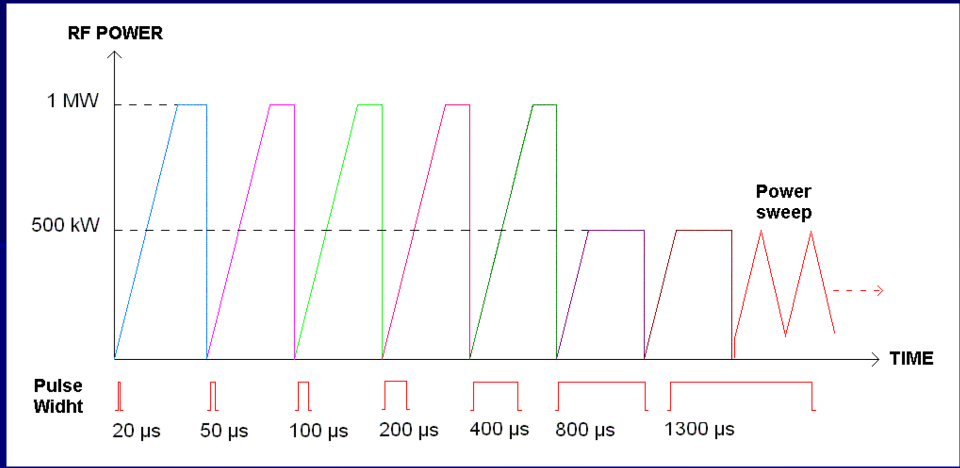


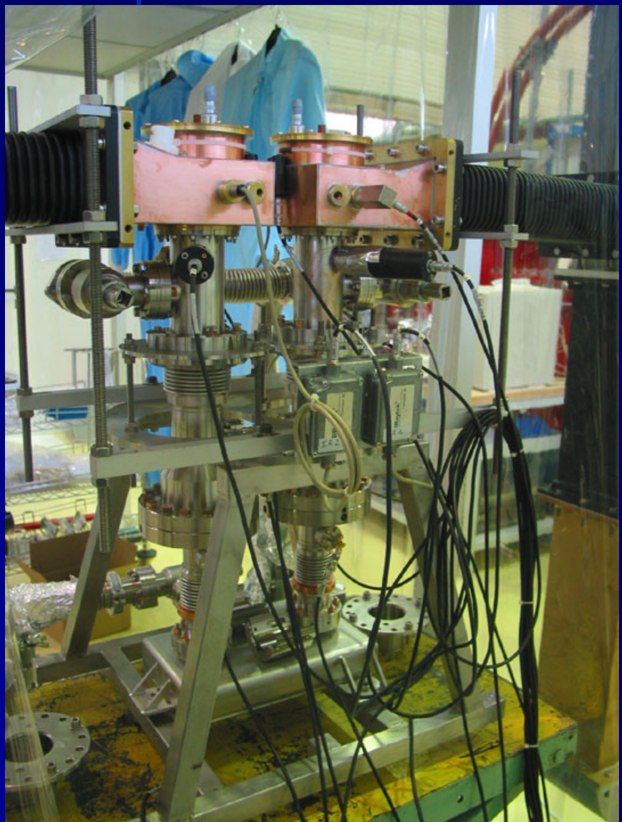
<u>Assembly, test & conditioning station for 400 couplers / year:</u>

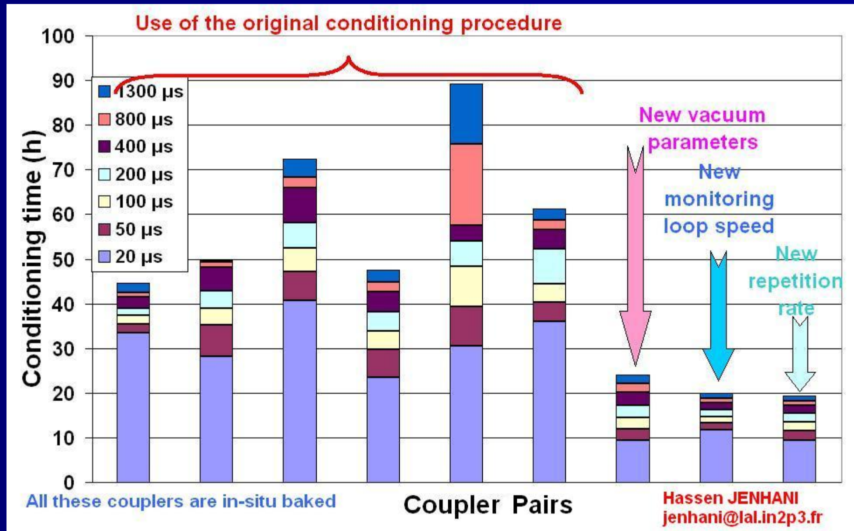
- wash, rince, store: 2 technicians
- assembly on test stand: 2 technicians
- in-situ baking after assembly while pumping (4 or 5 pairs together): → gain of time
- RF conditioning by pairs: 2 or 3 pairs / week for each RF line



RF conditioning







Total duration for conditioning + tests → 40h / pair if OK

Main phases of couplers production

Single location with 2 RF lines

- Acceptance tests
- Dismount
- Return packing + supports
- Store coupler parts in N2
- Assemble on modules

- 1.3 GHz tuning
- RF conditioning

Ind 1 → Ind 1

Ind 2 → Ind 2

Manufacturing

Clean rooms operations

Conditioning station

Cryomodules assembly

To reduce transports: single location is better

Assuming 2 industrial contracts

Industry follow-up tasks to be done by LAL

Phase 2: Manufacturing of parts and sub-assemblies

Phase 3: Cu + TiN coating and final joining

At LAL

Phase 2:
- Check project organization at industry
- verify manufacturing drawings
- control procurements: raw material, subcontractors
- check manufacturing plan
- check joining processes (welding, brazing)

\+
- Quality parameters control
- schedule control
- documents control
- collect data and watch drift
- invoices control
- report to XFEL project group

Phase 3:
- RRR measurements on samples
- test final joining on samples

At Industry

Phase 2:
- control manufacturing process: Witness points, Hold points
- collect data
- Project reviews

Phase 3:
- control Cu coating process parameters
- control final joining process: H points
- collect data

1 or 2 Contract(s) for manufacturing the 800 power couplers for XFEL will be awarded in 2008

→ Call for tenders for production of XFEL couplers will be initiated mid 2008, based on functional specifications

→ Negociation procedure: both on technical content and on price

Evaluation of tenders will include:

- Technical content and justifications
- Production schedule
- Price table
- Risks analysis: technical & financial
- Technical audit of candidates:
  - Expertise in the domain
  - Previous experience with couplers
  - Manpower and equipment
  - Logistics
  - QA audit wrt ISO 9001:2000

Schedule of « Production of Power couplers for XFEL »

	Nom de la tâche	Début	Fin
1	Award of manufacturing contract(s)	19/12/08	19/12/08
2	⊟ **XFEL couplers manufacturing phase**	**05/01/09**	**01/07/10**
3	Project organization and engineering	05/01/09	26/06/09
4	Material procurement and part production	06/04/09	18/12/09
5	Manufacturing of sub-assemblies	01/07/09	01/07/10
6	Manufacturing Follow-up by LAL	02/03/09	01/07/10
7	Joining control by LAL inspector	01/07/09	01/07/10
8	⊟ **Cu coating and final weld**	**01/09/09**	**17/12/10**
9	2 series of 20 couplers	01/09/09	30/09/09
10	4 series of 20 couplers	15/10/09	18/12/09
11	17 series of 40 couplers	01/01/10	17/12/10
12	Follow-up by LAL	01/09/09	17/12/10
13	Production control by LAL inspector	01/09/09	17/12/10
14	⊟ **Cleaning, Assembly & Baking**	**01/10/09**	**29/04/11**
15	2 series of 20 couplers	01/10/09	30/10/09
16	4 series of 20 couplers	16/11/09	18/01/10
17	17 series of 40 couplers	01/02/10	29/04/11
18	Assembly control by LAL	01/10/09	29/04/11
19	⊟ **Conditioning, shipping and delivery**	**02/11/09**	**29/07/11**
20	2 series of 20 couplers	02/11/09	18/12/09
21	4 series of 20 couplers	01/12/09	26/02/10
22	17 series of 40 couplers	01/03/10	29/07/11
23	Conditioning control by LAL	02/11/09	29/07/11
24	⊞ **Delivery of 20 series of 40 couplers**	**30/12/09**	**30/07/11**
45	Acceptance tests + storage	01/01/10	30/09/11