Industrialization process

Power couplers for XFEL project as an example

Industrialization: Why ?

Start: Prototypes

(30 Couplers)

Industrialization process

End: Large series

(1000 Couplers)

<u>Quality:</u>	- uneven
	- random anomalies
<u>Manufacturing:</u>	- long and difficult
	- lack of procedure
	- only a few people have the competence
<u>High cost</u>	

<u>Quality:</u>	- equal for all items
	- reliable
<u>Manufacturing:</u>	- regular process
	- written procedures
	- standard competence
<u>Lower cost</u>	

Industrialization: What for ?

Objectives:

1. To improve the quality
2. To define precisely:
    - all manufacturing processes
    - the control plan for quality assurance
    - the necessary equipment
    - the competences and the people
    - the manufacturing sequences
    - the schedule
    - the room space needed for all steps
    - the **costs**
    - the **risks** (technical, of procurement, financial)
3. To reduce the manufacturing costs

Use the experience gained in previous fabrications

During the fabrication of 30 power couplers type TTF-3, several critical points were identified:

1. 316LN steel (procurement is difficult)
2. TIG welding (uniform and smooth)
3. Ceramic / copper brazing
4. Steel / copper brazing
5. Cu plating
6. TiN coating (10nm) on ceramic windows
7. EB welding (full penetration but protect RF surfaces)
8. Geometrical tolerances (very difficult to respect)
9. Tooling and fixtures
10. RF conditioning (long time process)
11. Handling, transport and cleanliness issues (special care)

→ Each critical point has to be investigated for solutions

Conclusions on technology issues concerning fabrication of 30 prototype couplers

- Solutions were found for technological difficulties, acceptable for a small series, but not for mass production (inadequate tooling, costly and long processes, only a few operators achieve good results, quality not reliable)

- industry proposed some alternative solutions, in function of its knowledge in the domain (brazing in partial pressure oven, automatic TIG welds, laser welds)

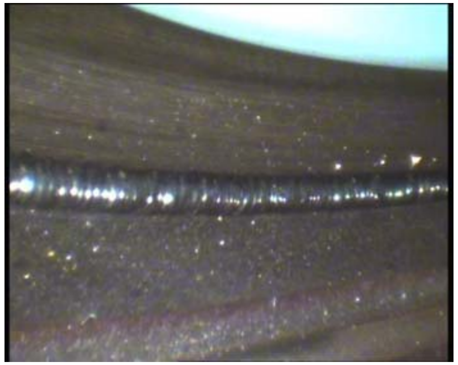
- Cu coating is a major difficulty (several anomalies, thickness non-uniformity, unreliable process, unclear which process is adequate)

- delicate technologies are often industrial secrets, and represent a know-how acquired through many years of experience by a small number of persons (vacuum brazing, Cu coating, TiN coating …)

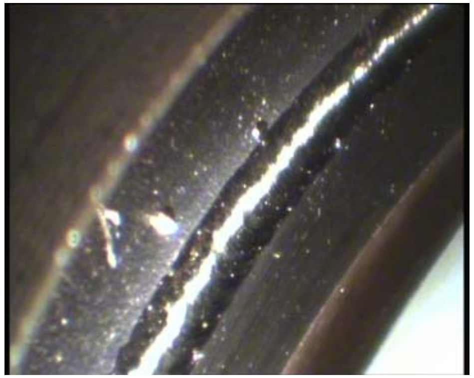
- Assembly tolerances were very difficult to meet (circularity, concentricity, perpendicularity) and should be relaxed for the future series (study was done at DESY and LAL, many tolerances were relaxed)

Prototypes: manufacturing problems – 1

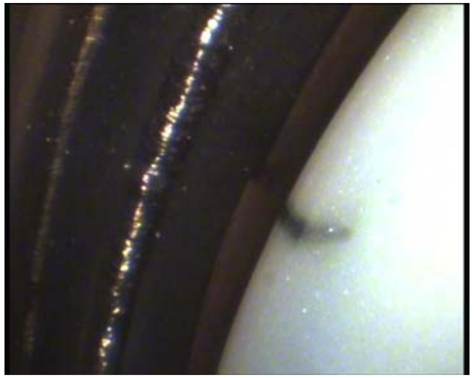
Bad centering



Excessive penetration



Spatters of particles

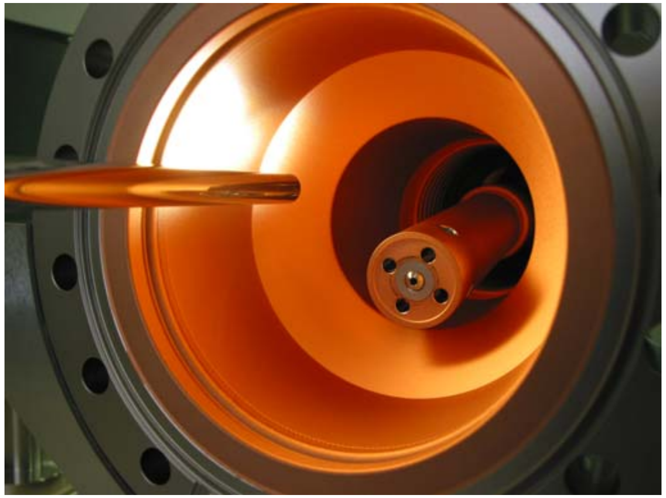


Black stain on ceramic

Lack of penetration

Braze splatters

Prototypes: manufacturing problems – 2



Perfect Cu coating

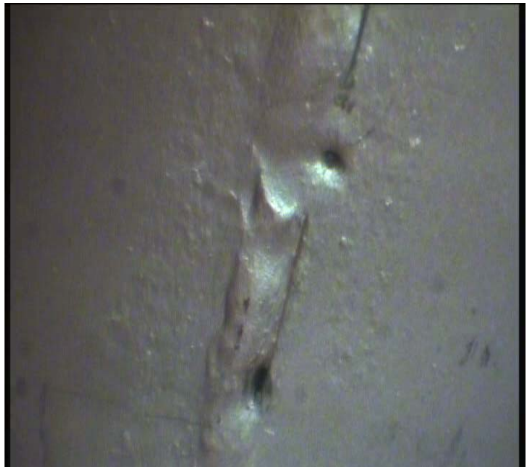
Perfect junction

Stains in Cu coating

Stains and unevenness

Prototypes: manufacturing problems - 3

Bent bellows



Pits in TIG weld

Smooth outer weld

Damaged bellows

Indent

Uneven outer weld

Prototypes: manufacturing mistakes

Wrong pick-up orientation

Wrong flange orientation

Prototypes: high cost

Cost for 30 couplers:

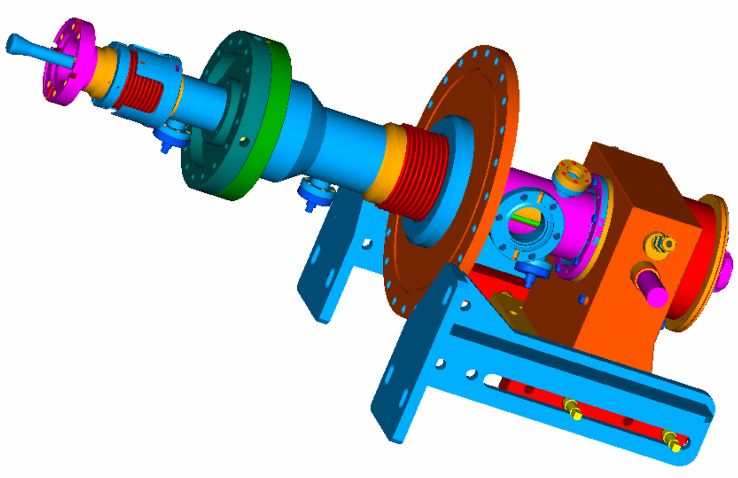
• Fixed costs	155 360 €
• Toolings costs	132 595
• Recurrent cost	25 190 / unit

Cost objective for 1000 couplers:

• Fixed costs	?
• Toolings costs	?
• Recurrent cost (fabrication only)	10 000 € / unit

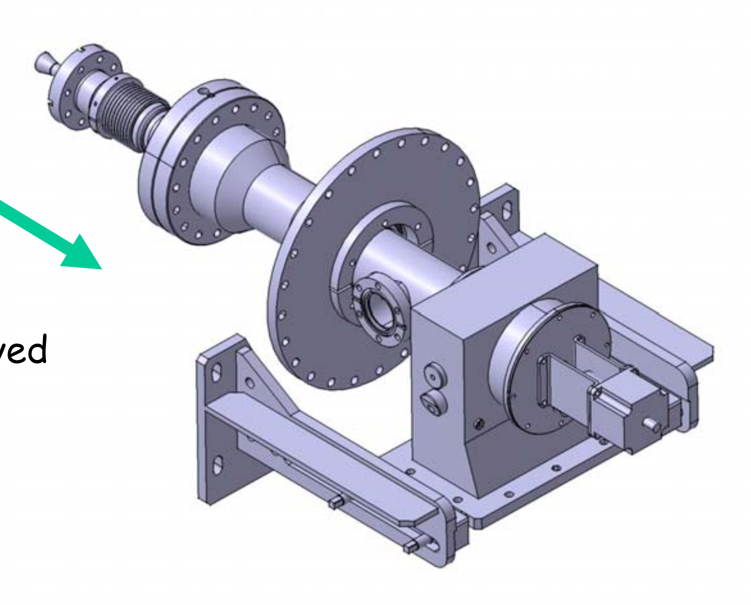
Cost reduction 60% → Great effort is needed through industrial studies

Before industrialization: specifications changes



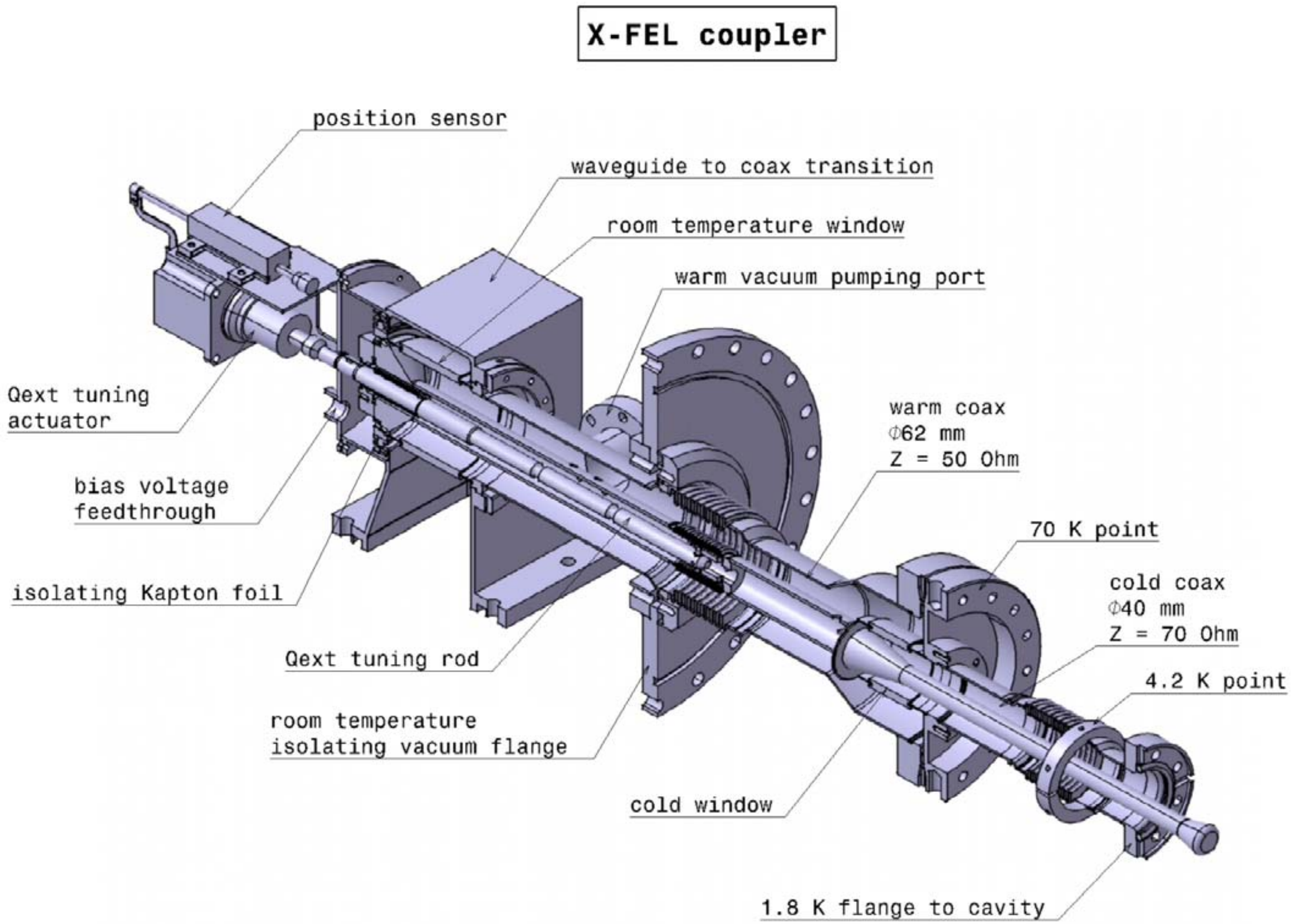
TTF-3 Coupler

- 4 diagnostics removed
- motorized tuning



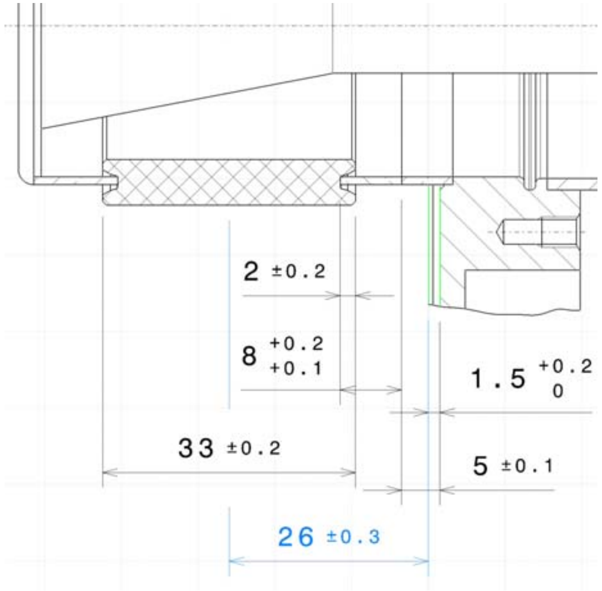
XFEL Coupler

Before industrialization: final design

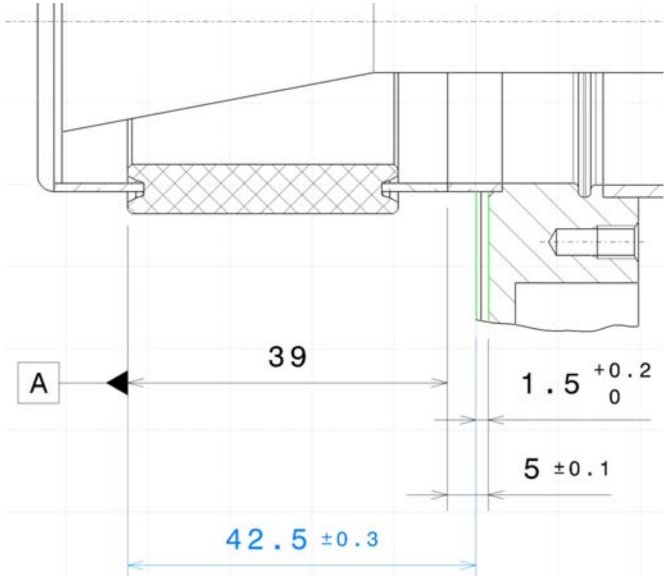


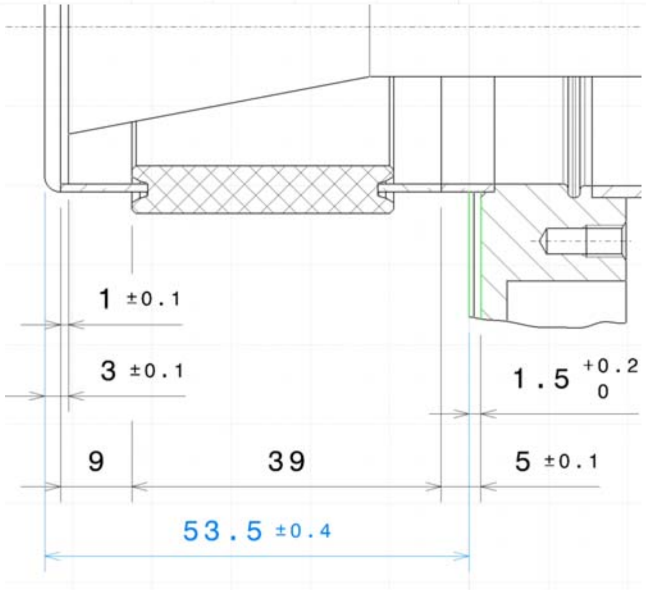
→ Review drawings of each component in terms of tolerances

Example of analysis of chain of tolerances



XFEL design:





TTF-3 design:

- the length in blue cannot be verified directly
- the tolerance in blue cannot be respected

Industrialization: How ? - 1 -

Necessary starting step: <u>Functional analysis</u>

→ Difficult thought process: **all actors should accept to put in question everything in the existing design:**

- technical specifications and performance
- global design architecture
- material
- geometry and tolerances
- assembly process: types of welds, brazes
- interfaces
- mounting sequences

→ *Organize several brainstorming sessions focused on a precise subject*

Product tree analysis: example of coupler's cold part

Component Function	Ceramic Window + TiN	Outer conductor	Big flange	Bellows	Cu rings	Cavity flange	Cu coating	Antenna	Inner conductor connexion
Electrical conductivity									
Thermal functions									
Vacuum									
Tuning									
Minimize multipacting									
Assembly sequence									

→ **Write the functional specifications in each concerned square**

Analysis of each function results in:

- options for design
- options for material
- options for geometry
- options for components junctions

Each options has to be investigated in terms of:

- performance compatibility
- feasibility
- availability
- cost

Industrialization: How ? - 2 -

Fabrication process for Prototypes :

In general, a system is composed of several parts produced by material removal processes:

- lathe turning
- milling
- drilling
- abrasion, erosion

→ Large number of parts: long manufacturing time

→ large number of junctions (welds or brazes)

Fabrication process for large series: look for simple and reliable processes

Prefer deformation processes:

- spinning
- embossing
- hydroforming
- casting, molding

→ Smaller number of parts: short manufacturing time

→ Smaller number of junctions: short assembly time

Example of part number decrease by choice of fabrication process

Number of parts

	Prototype coupler	XFEL coupler
Cold assembly	13	9
Warm assembly	22	14
Total	35	23

Number of junctions

	Prototype coupler	XFEL coupler
Cold assembly	12	8
Warm assembly	21	13
Total	33	21

advantages:

- gain in manufacturing time: cheaper process and 30% smaller number of parts
- gain in assembly time: 30% smaller number of junctions

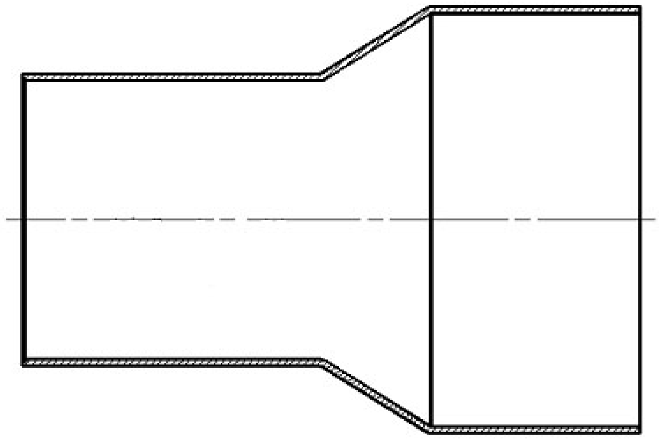
→

- Cost reduction
- Gain in quality assurance

Identify cost reductions by component
- 1 -

→ Fabrication Methods

Example: conical tube



Unit price for a series of 1000:

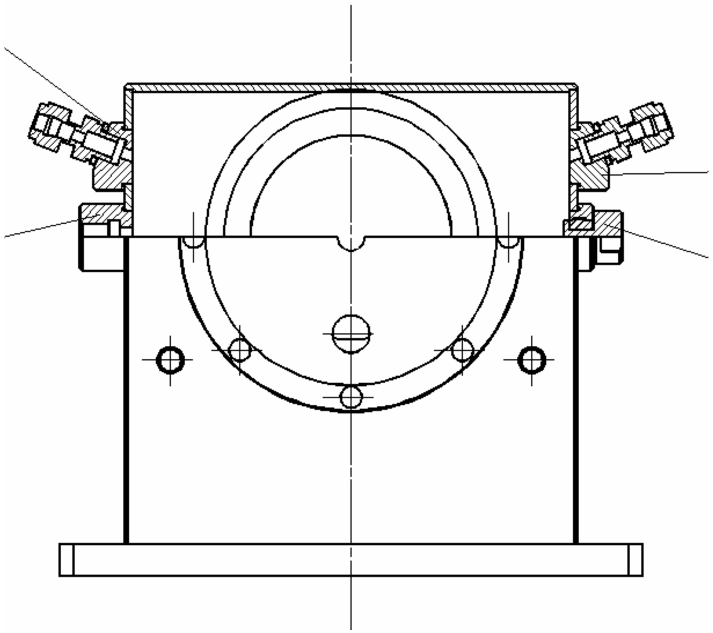
- fabrication by machining: 58 €
- fabrication by spinning: 25 €

According to a recent survey by LAL

Identify cost reductions by component - 2 -

→ Simplify design

<u>Example:</u> Transition box



Present design: 5 Cu plates and 7 other parts machined and soldered

→ unit cost: **3140 €**

Alternatives:

- CuBe cast (lost wax technique), replaces 12 parts by a single one

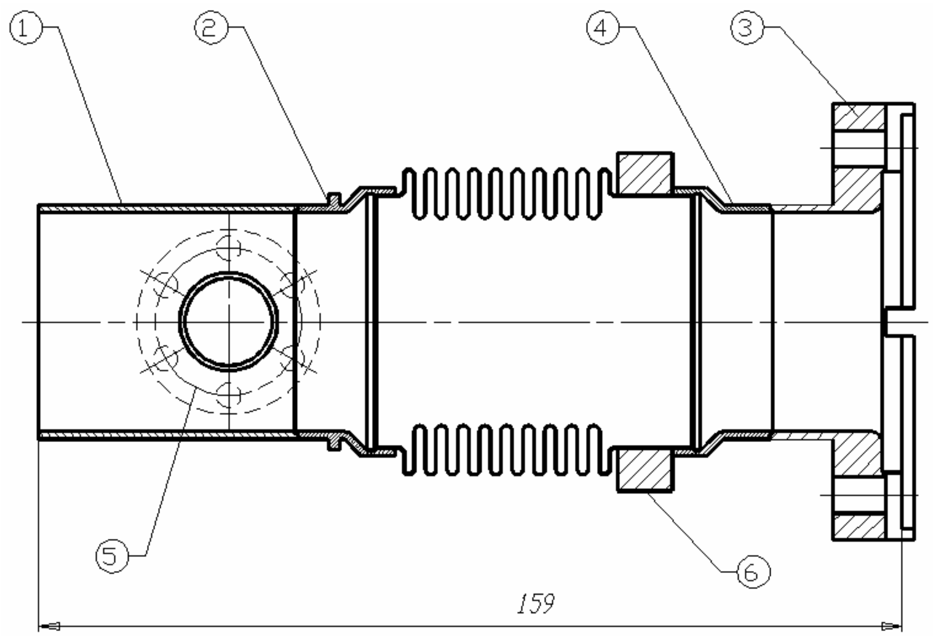
→ unit cost: **1400 €** (- 55 %)

- Zamac cast + conductive coating (even cheaper)

Identify cost reductions by component
- 3 -

→ Simplify concept

Example: Cold external conductor



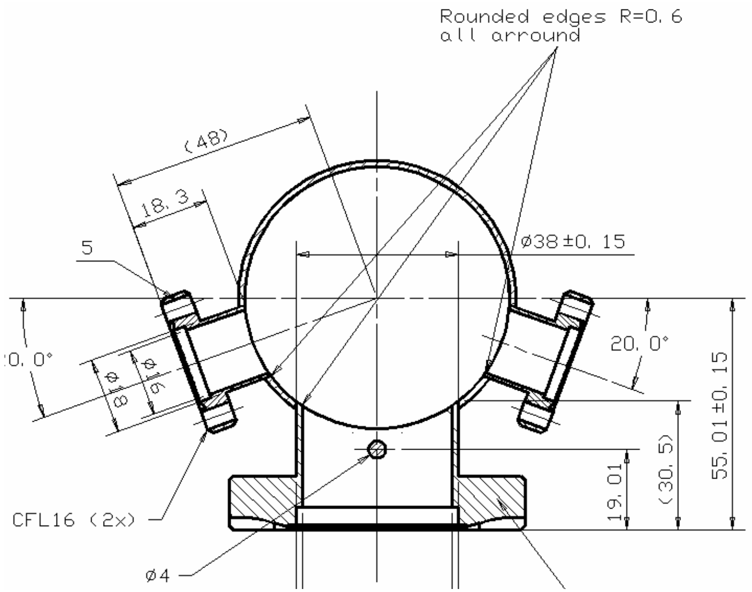
Present design: bellows collars are machined + welded to standard bellows

Alternative: bellows including special collars are hydroformed together in 1 part

Identify cost reductions by component
- 4 -

→ Adapt design to methods

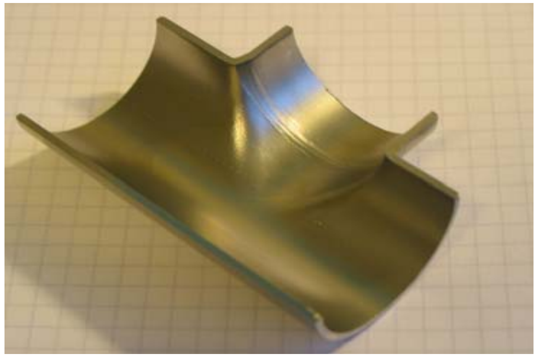
Example: Connexions to warm tube



Present design:

connexions are cut and welded

Alternative: connections made by pull-out →



Industrialization: Topics of development -1-

→ Design for « manufacturability »

- Review existing design
- Identify the necessary functions
- Determine maximum acceptable tolerances
- Identify possible options for design
- Seek functional simplicity :
  - to minimise the number of parts
  - use standard products whenever possible
  - design for ease of assembly: several assembly solutions are possible, investigate and optimise
  - design for ease of control and test
  - design in view of packing and transport

Industrialization: Topics of development -2-

- Risk mitigation:
  - Assessment and re-design of areas af technical and process risk
  - Generation of product and process specifications
  - Update design
- Validation phase:
  - Modelling of component and process
  - Testing
  - Prototypes
  - Update design
- Other design topics to be considered:
  - reliability (of components, welds, coatings)
  - other risks (of procurement, logistics, financial)
  - MTBF, failure analysis (welds, windows, motions)
  - maintainability (easiness of replacement)
  - ergonomy (handling, assembly)

• Interfaces: define characteristics of interfaces with other WPs

1. Mechanical parameters
   - Authorized volume and mass
   - Interface surface: position, orientation, dimensions, tolerances, surface finish, material, limit of deliverables
2. Vacuum parameters
   - Flange type, vacuum, desorption rate, port conductance
3. Thermal parameters
   - Dissipated thermal power, interface with thermal screens
4. Electrical parameters
   - Limit of deliverables, connectors, power supply, data protocol
5. Constraints on stability, position
6. Constraints on cleanliness
7. Environmental parameters: temperature, hygrometry, X radiations, EMI
8. Assembly and integration constraints
   - Alignment, references, tooling and fixtures, storage and handling
   - Assembly sequences, cabling
9. Time schedule constraints

Industrialization: Check ?

→ Iterative process after every change

Verification phase

Several possible new designs result from the functional analysis:

- → Verify that the desired specifications are fulfilled
- → Check the coherence of interfaces
- → Produce prototypes
- → Follow a test program
- → Analyze the results
- → Corrective actions if necessary
- → Decide on the final solution
- → Finalize Manufacturing Control Plan

For the XFEL power couplers, industrialization studies will be performed through "Definition contracts" :

- Essentially intellectual work (in dialog between the industry and our Lab) :
  - Define all manufacturing processes (analysis and validation models)
  - Risk analysis (process, logistics)
  - Determine cost in series and justify
- Produce 2 prototypes (to be tested at LAL – Orsay)

Particularities

- 3 contracts will be awarded on the same subject: « Industrial studies »
- 2 teams will be selected after final evaluation
- contracts for manufacturing 2 series of 500 XFEL couplers will be awarded without a new call for tenders
- the 2 contracts may be awarded to a single company

What are the stakes

For DESY / IN2P3:

- minimize risks related to project:
  - all technical issues will be solved
  - development plan ready

- minimize financial risks:
  - precise estimation of cost in series
  - assurance that the chosen contractors will succeed

- gained time on manufacturing contract: all studies are done

How much does the industrialization phase cost ?

Number of contracts:

- it is desirable to run several simultaneous contracts:
  - to profit from different expertises and know-how
  - to encourage competition
- a number of 3 contracts is optimum

→ But difficult to control 3 contracts at the same time !

Costs: evaluation by duration

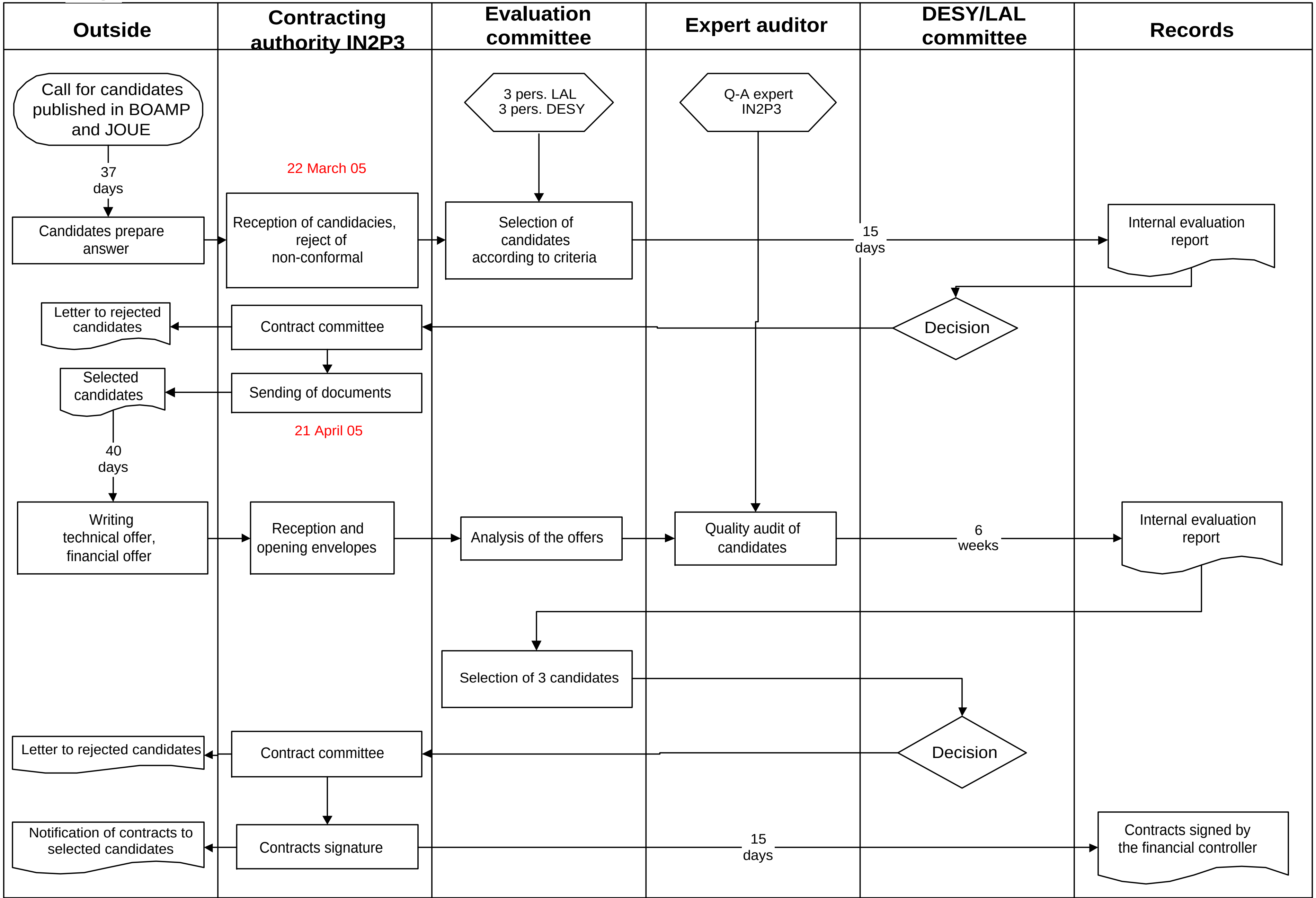
Example of industrial studies for XFEL couplers:

- 1500 hours engineer x 80 € → 120 000 €
- 1500 hours technician x 50 € → 75 000
- 2 prototypes x 40 000 → 80 000
- Total: 275 000 reduced to **250 k€** as a package deal
- 3 contracts + follow-up costs → 800 k€

XFEL couplers budget estimated at 20 M€:

- industrial studies represent only 4%

PROCEDURE FOR RESTRICTED CALL FOR TENDERS



Criteria of selection of tenders for industrial studies

The method and the means proposed to fulfil the intellectual work requested by the definition contract: • the understanding of the subject • the estimated intellectual contribution • the relevance of dedicated staff to perform the industrialization studies • the organization of quality assurance in the company	50 %
The means to produce the models and the prototypes of the definition contract: • the internal know-how in the specific technologies necessary to produce couplers • the technological means available	25 %
Means and logistics possibly available for a future contract of manufacturing couplers in series	25 %

Follow-up and evaluation of definition contracts

1. Continuous evaluation of performance
   - contracts will run simultaneously during 21 months
   - Regular progress reports
   - Continuous control of industry activity

2. Formal reviews are key points with delivery of documents, models and prototypes
   - SDR (System Design Review)
   - PDR (Preliminary Design Review)
   - CDR (Critical Design Review)
   - Final Review

Keypoints of the definition contracts

Contract Award: T_0

Kickoff meeting: soon after T_0

System Design Review: T_0 + 3 months

- functional analysis
- identification of processes and proposal for models
- preliminary development plan, management plan

Preliminary Design Review: T_0 + 8 months

- models for welding, brazing, specific materials, Cu coating
- Quality assurance plan
- development plan, management plan
- Technical design review
- preliminary risk analysis

Critical Design Review: T_0 + 14 months

- final models for validation of Cu coating
- final justification design file
- final risk analysis
- preliminary cost analysis

Final Review: T_0 + 21 months

- delivery of 2 prototypes
- plan for logistics of manufacturing and conditioning
- final cost report

Deliverables for the definition contracts

1 - Technical reports: *spread over 3 intermediate reviews (see time schedule)*

- Conduct and comment all **studies** necessary for the fabrication of couplers, including TiN deposit
- Determine and explain the manufacturing **processes**, provide **models** for validation of each process
- Finalize and justify the mechanical **design** in view of lower cost in series and shorter time of assembly, evaluate risks
- Define and comment the sequences of **assembly** and **conditioning** of couplers, estimate time for assembly sequences
- Determine and comment the manufacturing **logistics** (in manpower, in building area) including conditioning, and evaluate difficulties and risks
- Establish a project **management plan** for the manufacturing in series:
  - . PBS, WBS
  - . interfaces
    - . Cost control, time schedule control
    - . Management of changes
      - . Quality assurance
      - . Risk management
      - . Documentation control
- Establish a manufacturing **schedule** including conditioning and delivery

2 - Deliver validation models and 2 prototypes:

- models to validate each manufacturing process (welding, brazing, spinning, Cu coating, …)
- 2 prototypes assembled on test stand ready for conditionning:
  - already cleaned, baked, assembled, vacuum pumped and leak tested

3 - Financial report:

Objective: → Commitment to a unit price in series, for 500 and for 1000 couplers

- Fill out a detailed price list including manufacturing, assembly and HF conditioning (Klystrons and modulators could be provided by the XFEL project), packing and transport on site
- Deliver a detailed report on price justification analysis

Financial report includes:

Price lists for 500 and 1000 couplers

Item	Description	Unit cost	Quantity	Total cost
A1	Manufacturing file		1	
A2	Project management		1	
A3	Quality assurance		1	
A4	Documentation		1	
A5	Equipment and logistics for assembly and conditioning		1	
A6	Tooling and fixtures for manufacturing			
A7	Tooling and fixtures for assembly and conditioning			
A8	Other fixed costs		1	
A9	Pre-series prototypes			
A10	Coupler manufacturing (to be detailed in the justification report)		500	
A11	Quality control		500	
A12	Cleaning, assembly and preparation for conditioning		500	
A13	Conditionning		500	
A14	Packing and transport		500	
A15	Other recurrent costs		500	
A	**Total project cost for 500 couplers**			

At the end of the definition contracts:

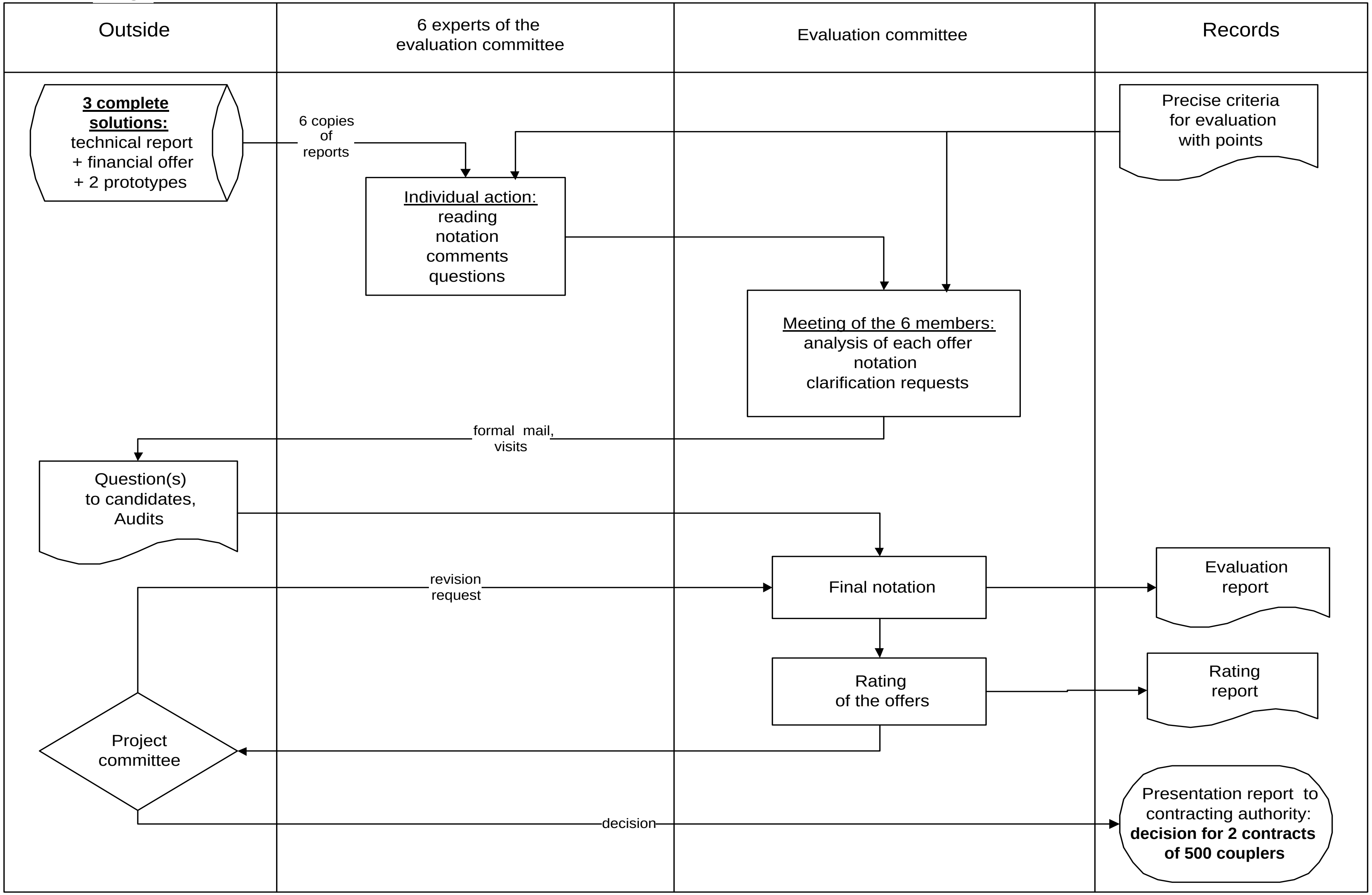
- Overall performance of candidates must be rated by an evaluation procedure

- Questions must be answered for each contract:
  1. Is it technically acceptable ?
  2. Is it financially acceptable ?

- For the future mass fabrication:

  1 or 2 manufacturing contracts ?

PROCEDURE OF EVALUATION OF THE DEFINITION CONTRACTS



Criteria of evaluation of definition contracts - 1

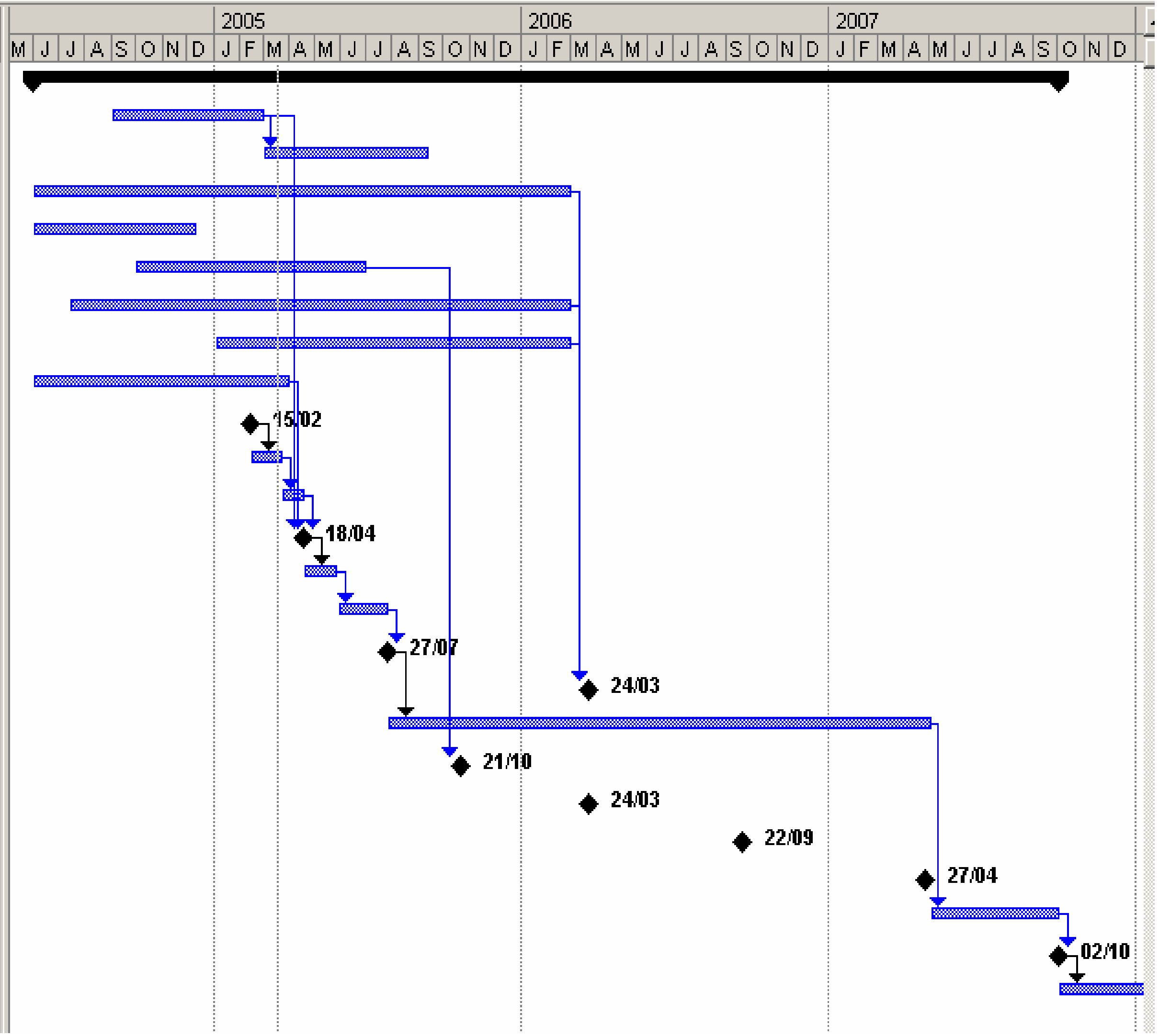
Item	Points
<u>Evaluation of technical report:</u>	
1. criteria concerning the design : - completeness of resolution of manufacturing technical problems - functional adequacy of design - reliability of proposed manufacturing process - completeness of procedures definition and knowledge - credibility of quality assurance - easiness of assembly, of conditioning and integration - originality of proposed solutions in terms of cost reduction - credibility of technical risks analysis	50
2. criteria concerning project management : - management plan - tools for quality assurance management - relevance of logistical means foreseen - competence and adequacy of the team - reactivity to changes in technological choices - credibility of project risk analysis	25
3. criteria concerning schedule : - relevance of manufacturing schedule - tools for schedule control	15

Criteria of evaluation of definition contracts - 2

Item	Points
Evaluation of demonstration models: - tests results - technical functionalism and cost impact - easiness of implementation of represented process	 10 10 5
Evaluation of prototypes: - quality of manufacturing - pumping speed, vacuum values, desorption rate, residual gasses - time for conditioning at LAL’s test station - originality of design with respect to simplicity - easiness of assembly	 10 7 8 5 5
Evaluation of the financial report: - price list for manufacturing in series (to which will be added the costs of project follow-up taken in charge by IN2P3) - price justification report - financial risk analysis	150
Total points	**300**

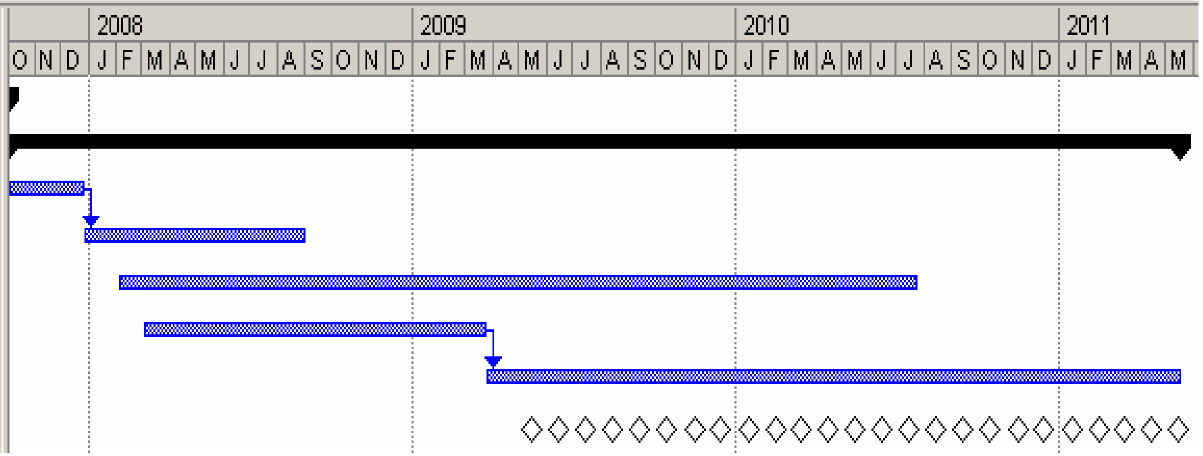
Time schedule of industrial studies for XFEL Power Couplers

	Nom de la tâche	Début	Fin
1	**Industrialization phase**	**01/06/04**	**02/10/07**
2	Drawings preparation	01/09/04	28/02/05
3	Drawings update	01/03/05	12/09/05
4	Thermal studies	01/06/04	28/02/06
5	HF analysis (tolerances studies)	01/06/04	10/12/04
6	Studies of motorized tuning and control	01/10/04	30/06/05
7	Coupler conditioning studies	13/07/04	28/02/06
8	TiN coating technology development	03/01/05	28/02/06
9	Call for tenders preparation	01/06/04	31/03/05
10	Notification for tenders	15/02/05	15/02/05
11	Time for receipt of candidacy	15/02/05	22/03/05
12	Selection of candidates	23/03/05	18/04/05
13	Tender documents are sent	18/04/05	18/04/05
14	Time for receipt of tenders	19/04/05	27/05/05
15	Tenders analysis and audits	30/05/05	27/07/05
16	Award of 3 definition contracts	27/07/05	27/07/05
17	Technology transfer to industry	24/03/06	24/03/06
18	Progress of 3 definition contracts	28/07/05	02/05/07
19	System Design Review	21/10/05	21/10/05
20	Preliminary Design Review	24/03/06	24/03/06
21	Critical Design Review	22/09/06	22/09/06
22	Final Review	27/04/07	27/04/07
23	Analysis of results	03/05/07	02/10/07
24	Award of manufacturing contract(s)	02/10/07	02/10/07
25	**XFEL couplers manufacturing phase**	03/10/07	20/04/11



Schedule of manufacturing phase for XFEL Power Couplers

	Nom de la tâche	Début	Fin
1	**Industrialization phase**	**01/06/04**	**02/10/07**
25	**XFEL couplers manufacturing phase**	**03/10/07**	**16/05/11**
26	Manufacturing plan development	03/10/07	25/12/07
27	Logistics and equipment	25/12/07	01/09/08
28	Material procurement	04/02/08	22/07/10
29	Prototypes and pre-series manufacturin	03/03/08	23/03/09
30	Manufacturing in series	24/03/09	16/05/11
31	**Delivery of 25 series of 40 couplers**	**15/05/09**	**15/05/11**



- Couplers delivered assembled and conditionned, mounted on test stands

- Delivery by series of 40 couplers every month (for assembly of 5 modules) during ~ 2 years