8th European Light Source Radio-Frequency Meeting

29-30 September 2004
Daresbury Laboratory

STATUS OF THE SOLEIL 352 MHZ RF SYSTEMS FOR THE BOOSTER AND STORAGE RING

P. Marchand

SOLEIL building site

Commissioning schedule

LINAC : December – February 2005 (installation is starting)
BOOSTER : April – May 2005
STORAGE RING : Start in July 2005

300 mA Ibeam (for users) before the end of 2005

Booster main parameters

Circumference	156.6 m
Revolution frequency	1.91 MHz
Repetition rate	3 Hz
Injection energy , E_i	100 MeV
Final energy , E_f	2.75 GeV
Energy loss / turn @ E_f	410 keV
Beam current (max)	12 mA
RF acceptance @ E_f @ E_i with V_{RF} = 200 kV	± 0.35 % ± 1.5 %
Harmonic number	184
RF frequency	352.2 MHz
RF voltage @ E_f	0.85 MV
Beam power @ E_f	5 kW

RF SYSTEM

→ 1 CERN-LEP 5-cell Cu cavity, R_s = 26 MΩ
P_{dis} : 15 kW, P_{beam} : 5 kW, P_{tot} : 20 kW

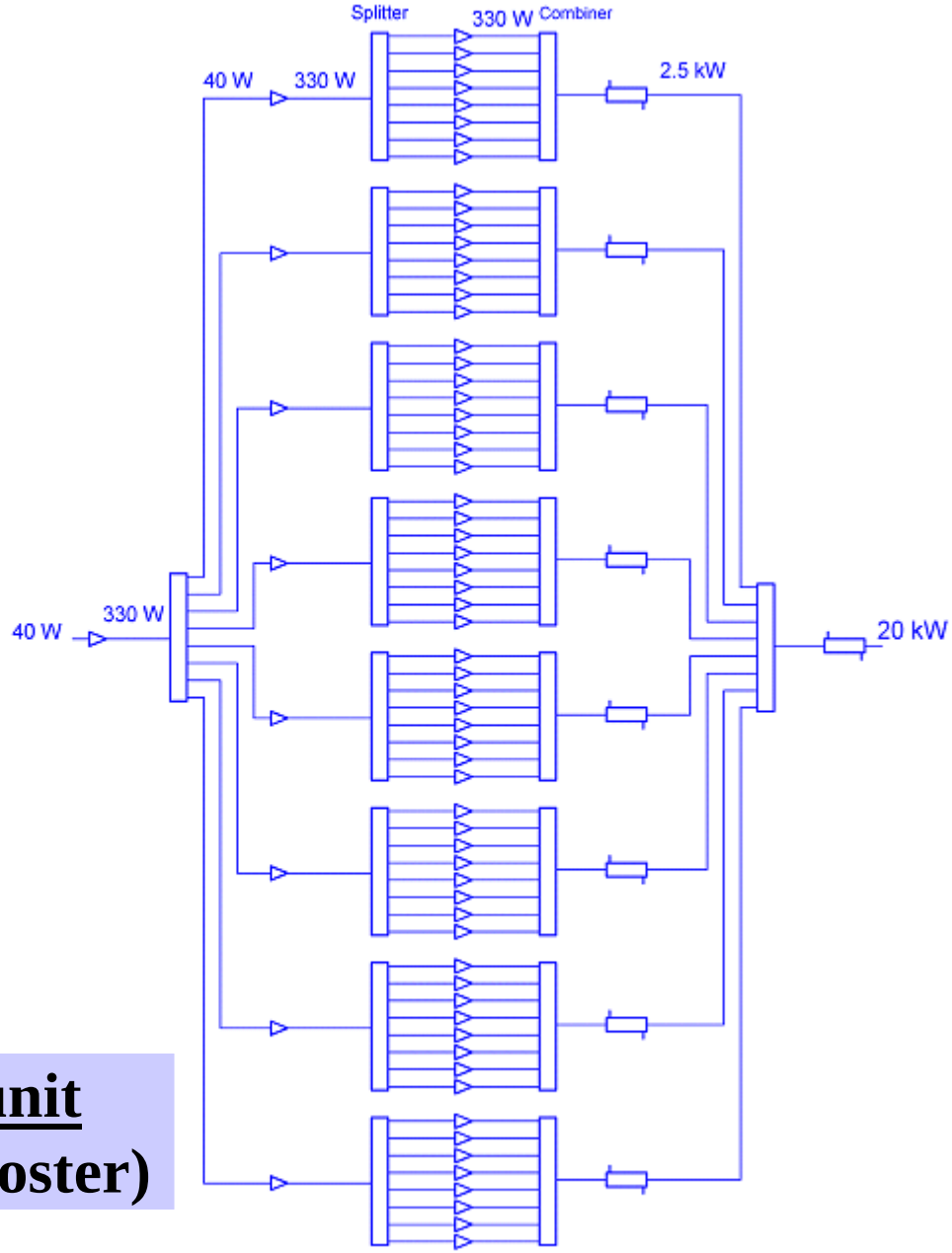
→ 1 solid state amplifier, $P_{available}$: 35 kW

Booster amplifier principle

330 W solid state amplifier modules

2 x [8 x 8 + 8 + 1] = 146 modules

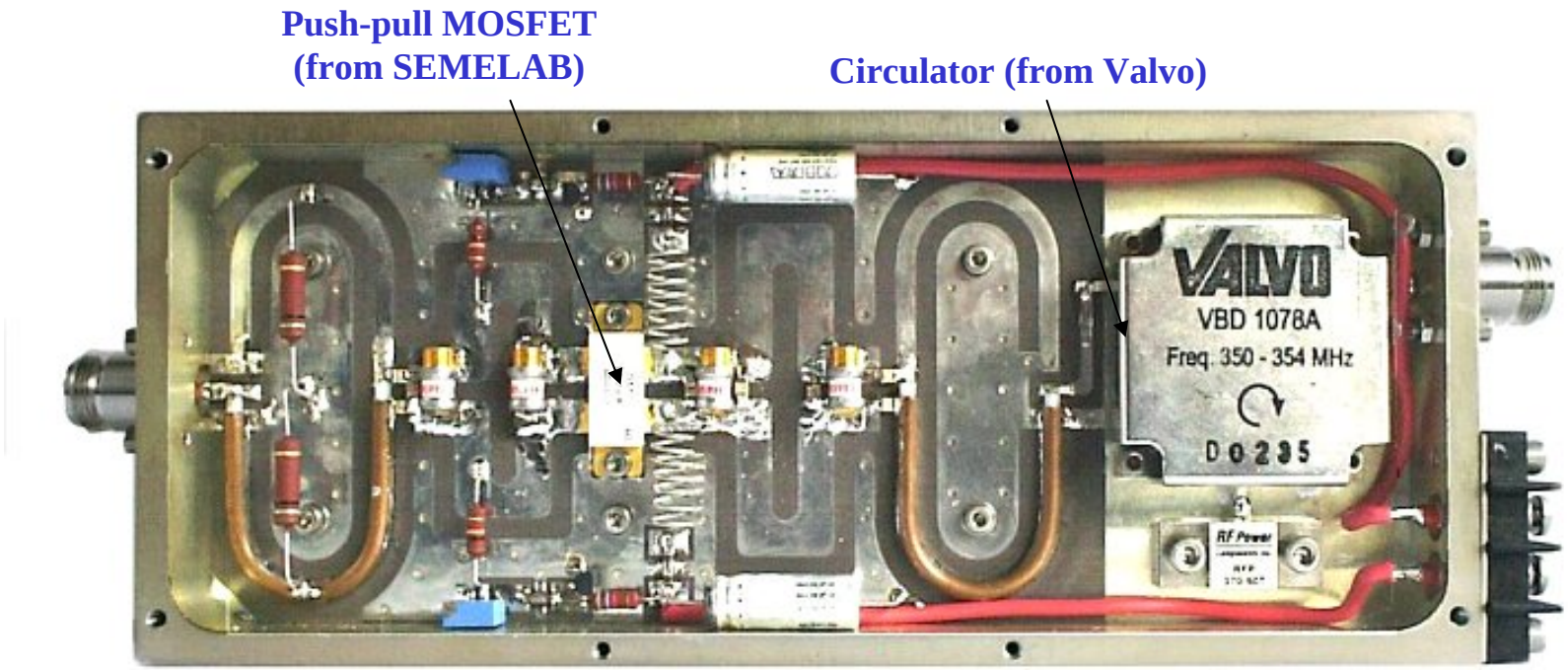
2 x [8 x 2.5 kW] = 40 kW



RF BOOSTER AMPLIFIER : 2 ways 20 kW = 40 kW

20 kW unit
(x 2 for Booster)

330 W - 352 MHz amplifier module

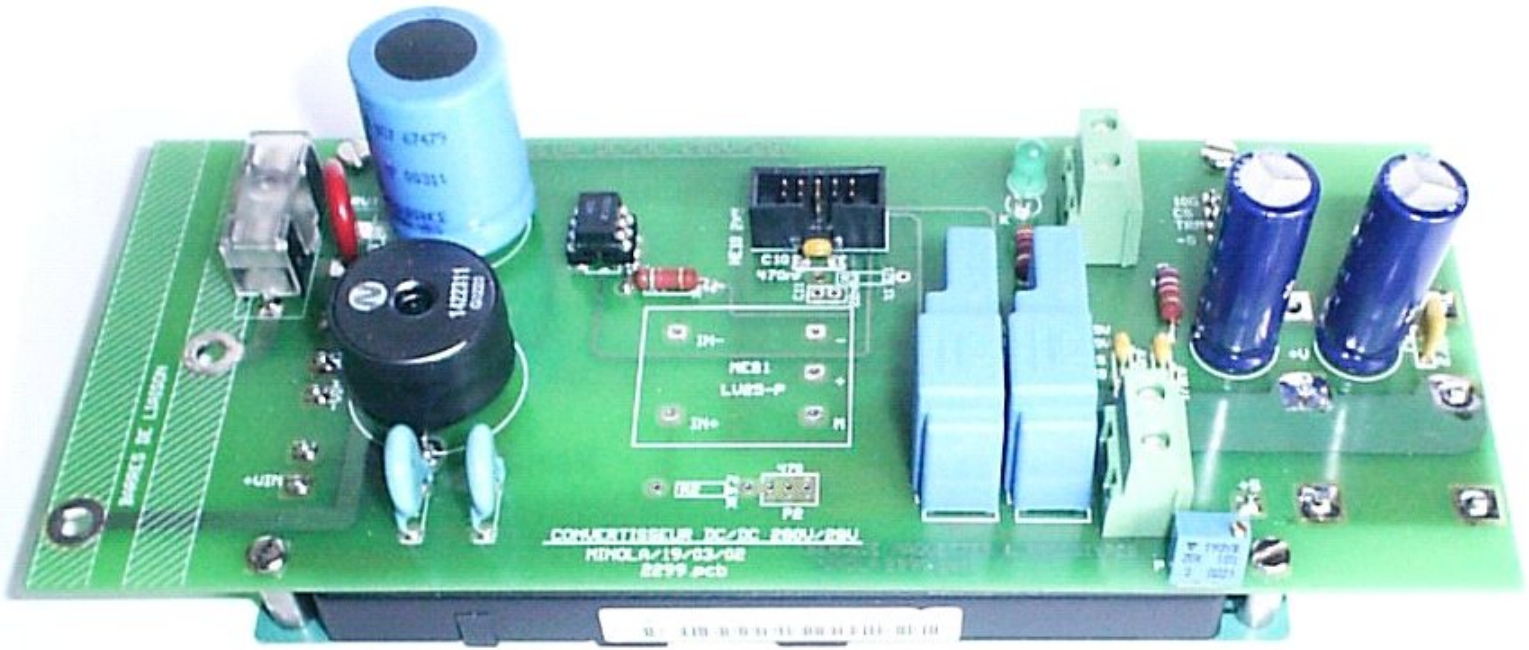


Complete modules supplied (tested) by RFPA

Specifications : @ f = 352.2 MHz and P = 330 W

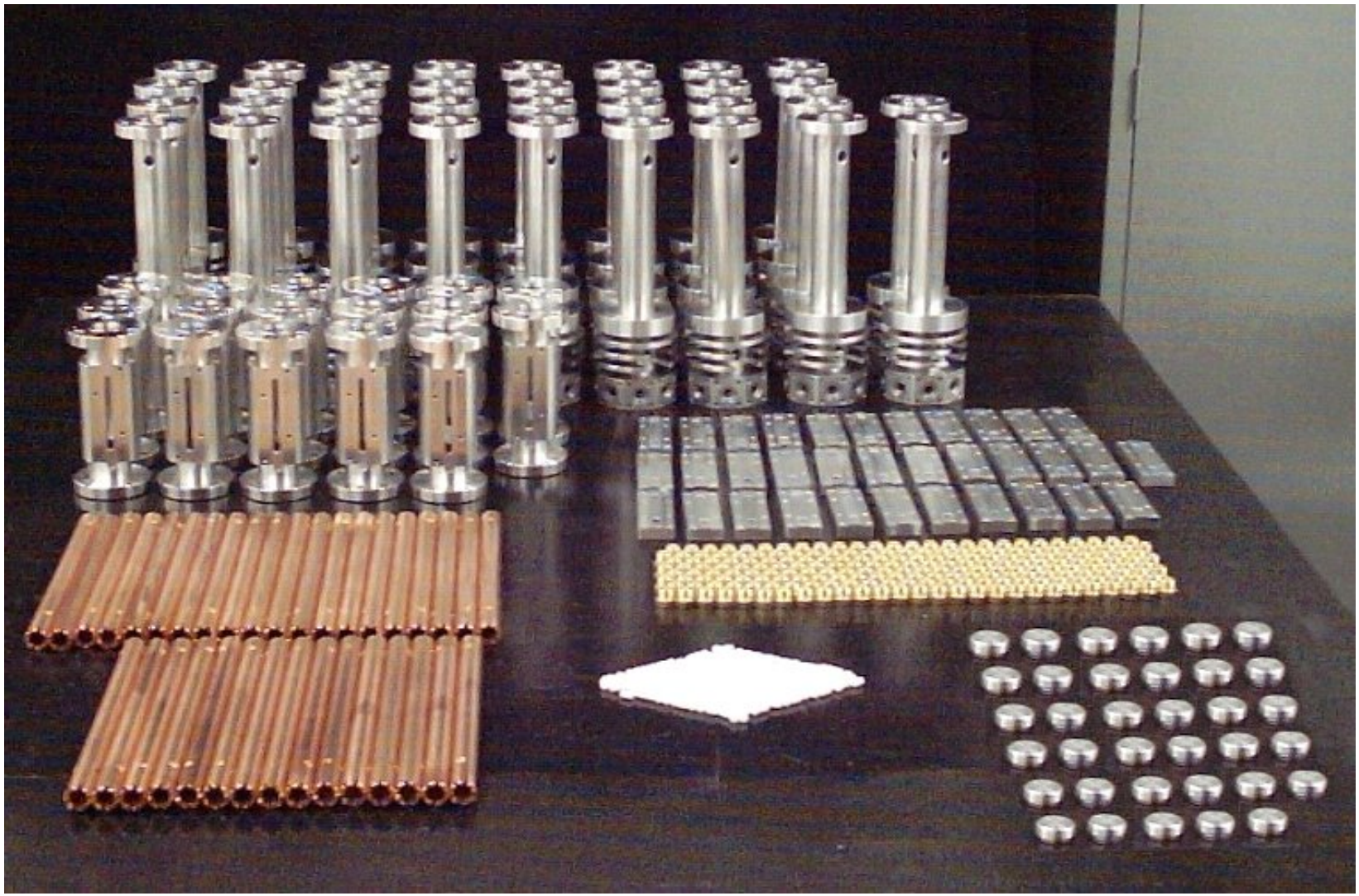
- → 10 dB < G < 11.5 dB
- → S_{11} (P_{ref}) < - 30 dB
- → Δφ between modules < 10 °
- → Unconditionally stable with stability margin, K > 8 dB

Power supply board

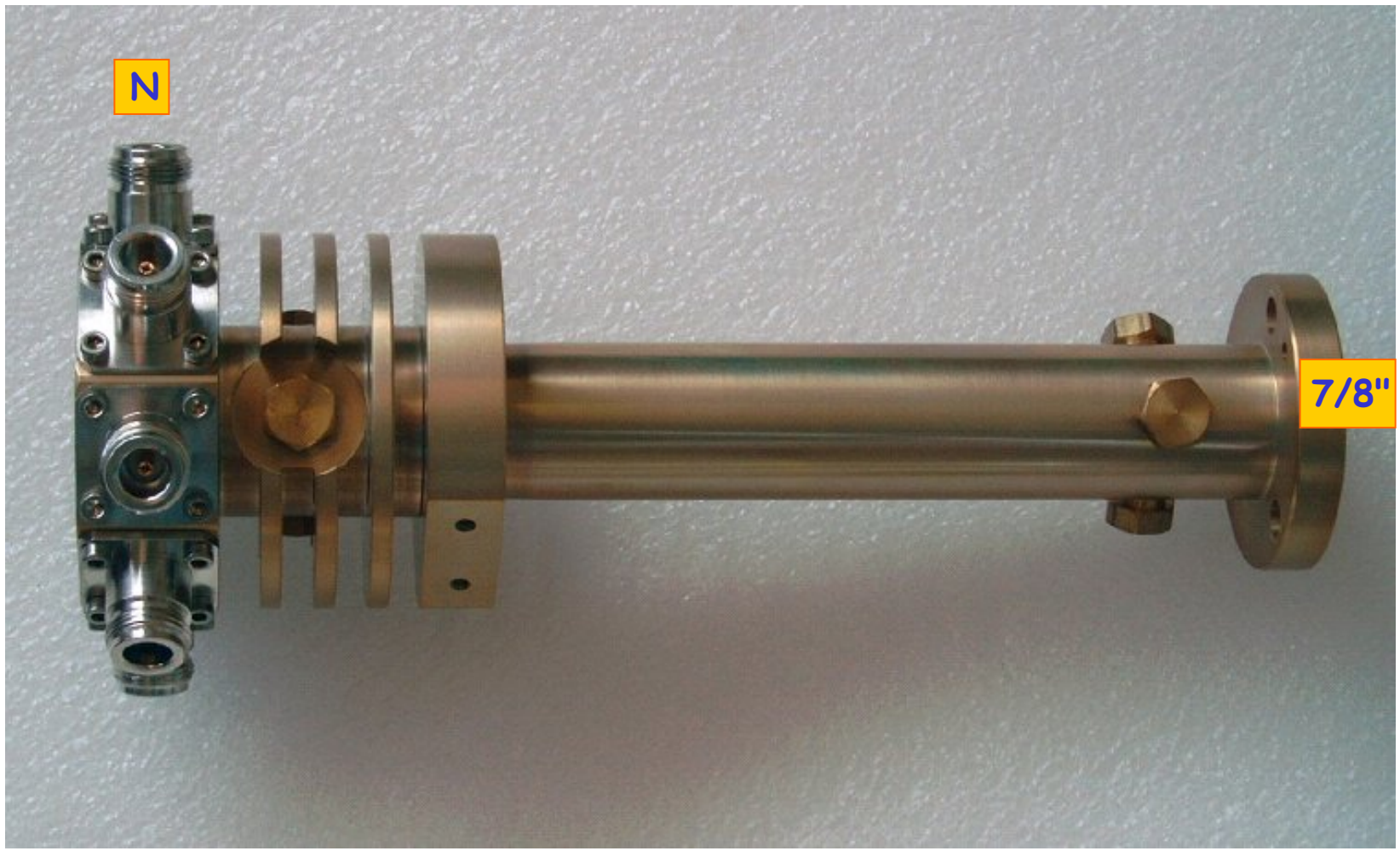


300V/30V DC/DC converter
(from INVENSYS LAMBDA)

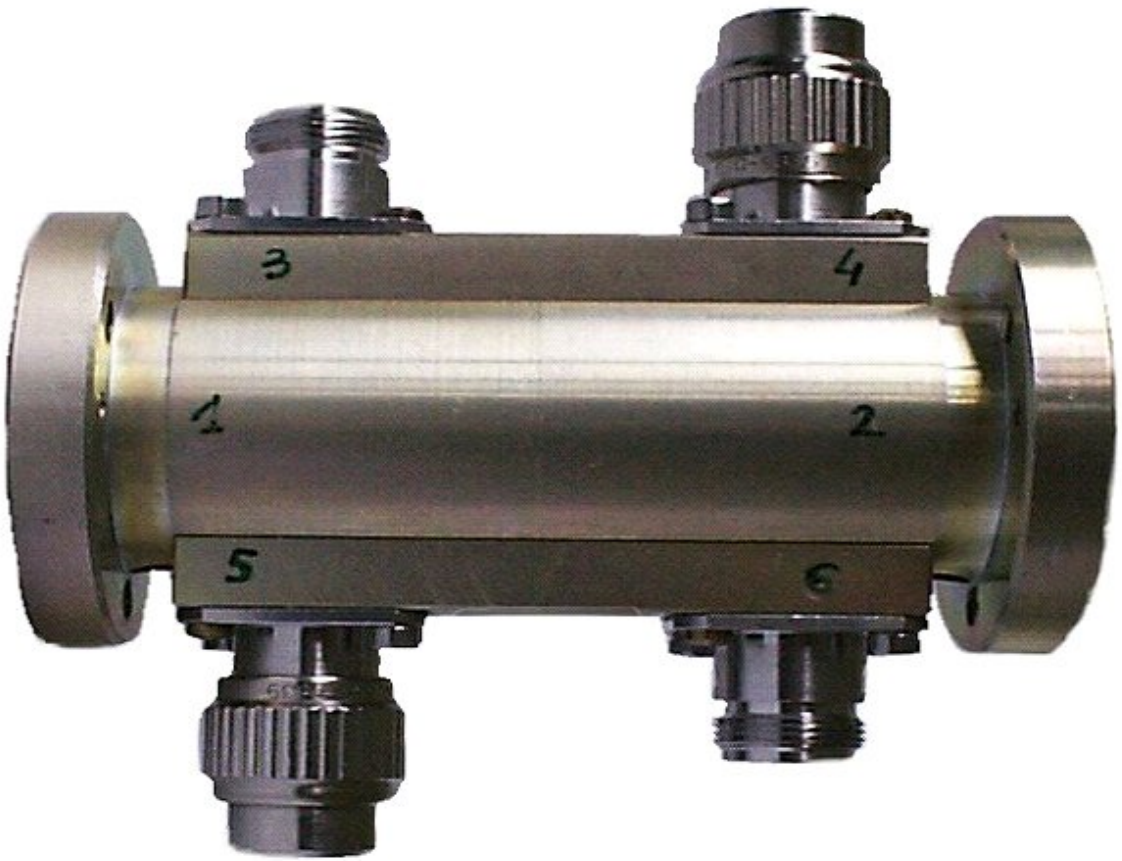
Component parts for the 2.5 kW couplers & combiners (supply from LNLS - Brasil)



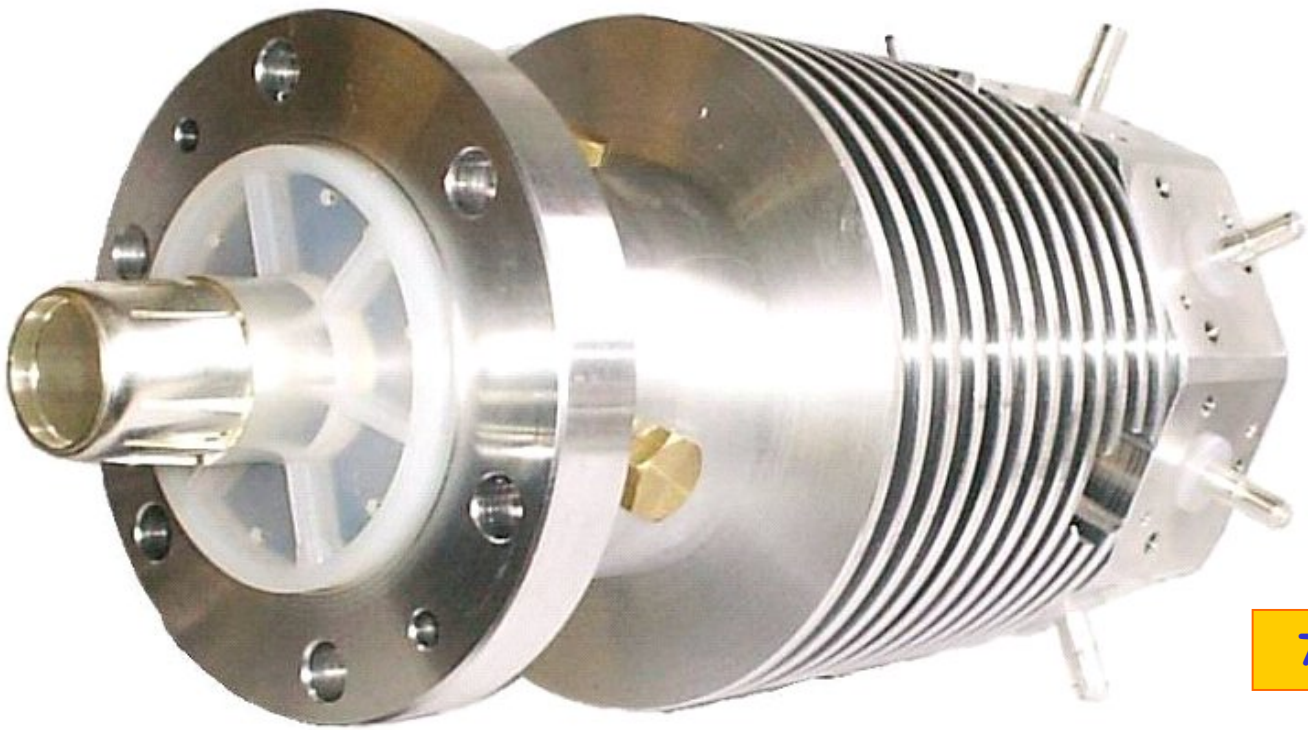
8 x 330 W combiner or 8-way divider



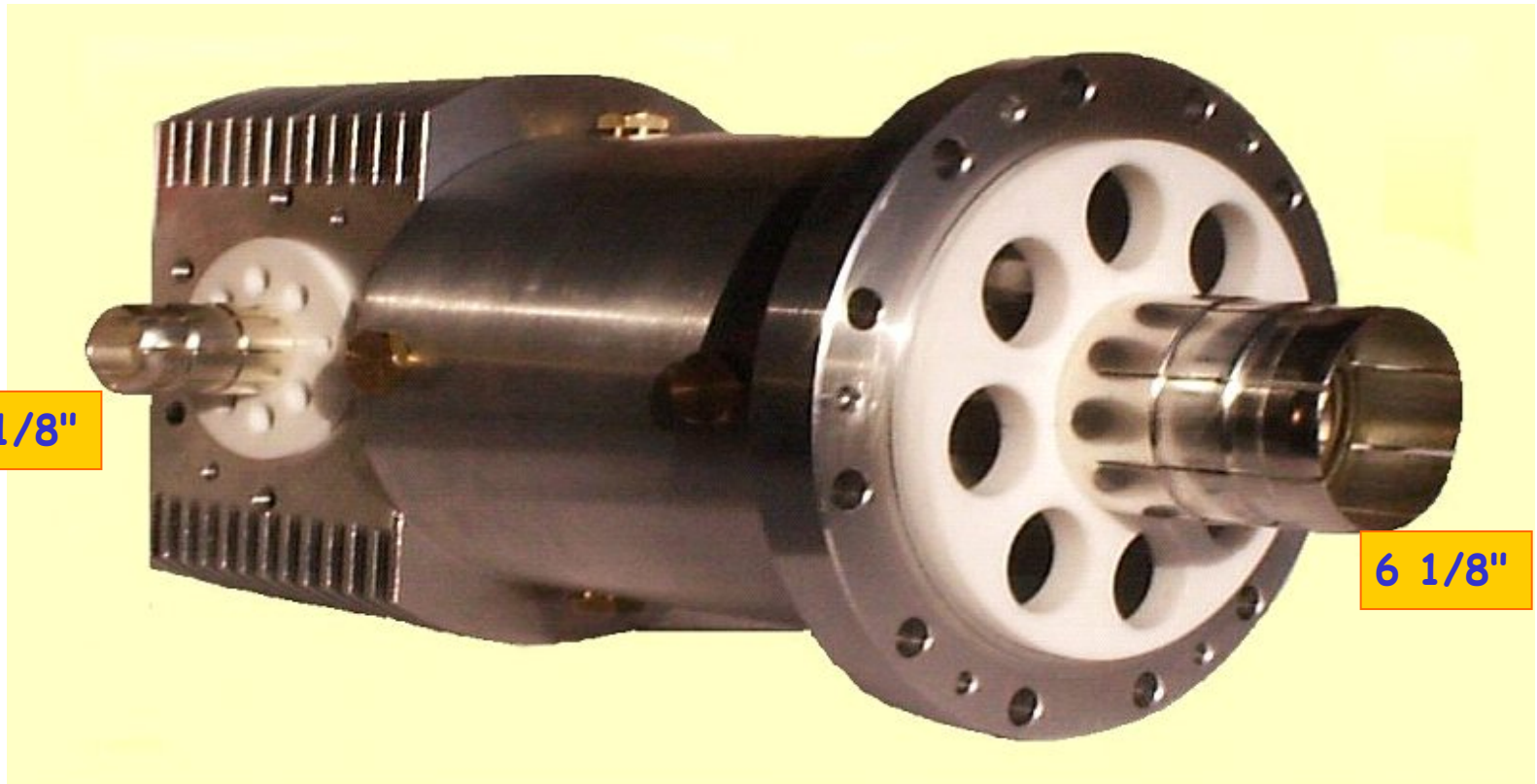
2.5 kW bi-directional coupler

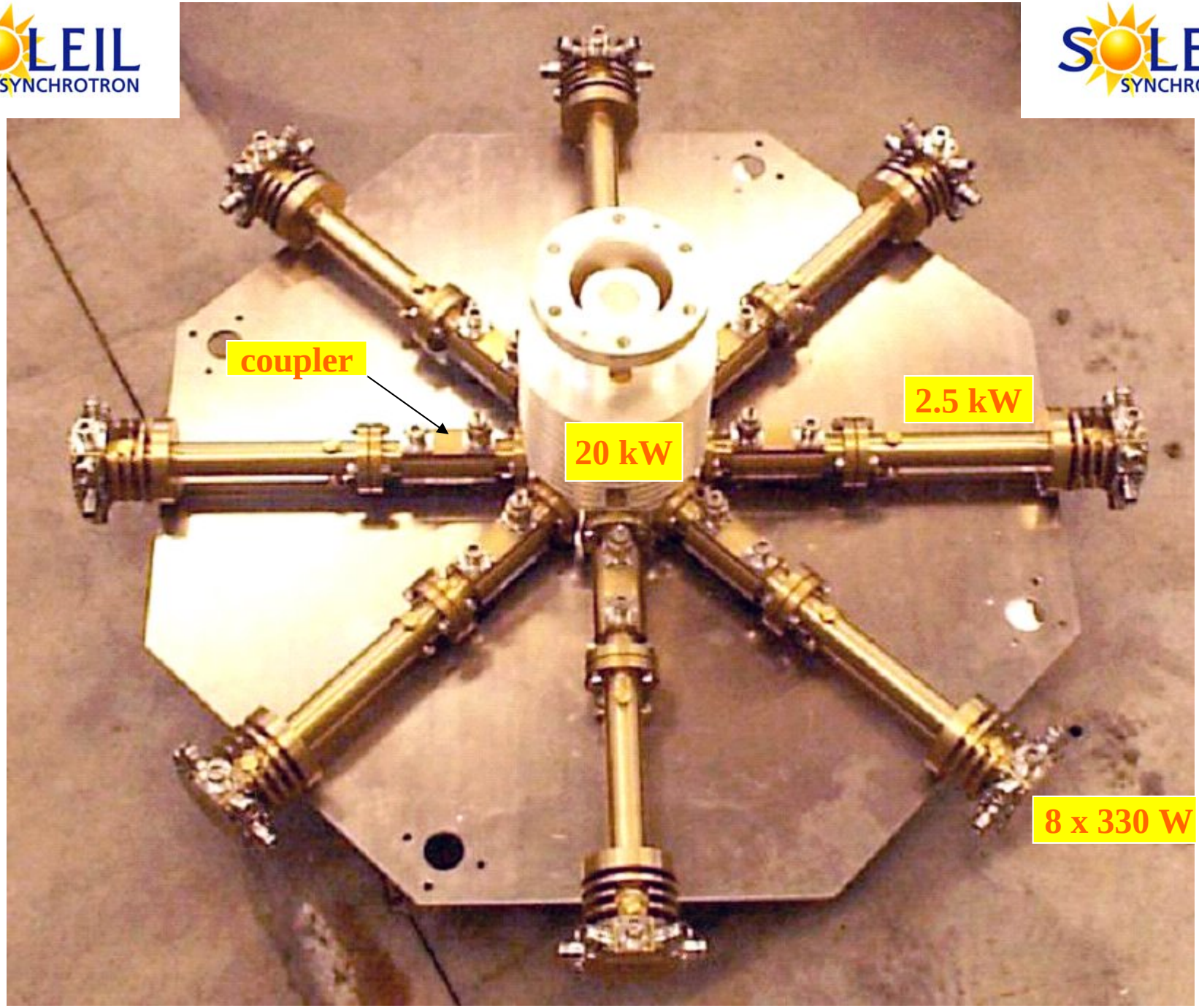


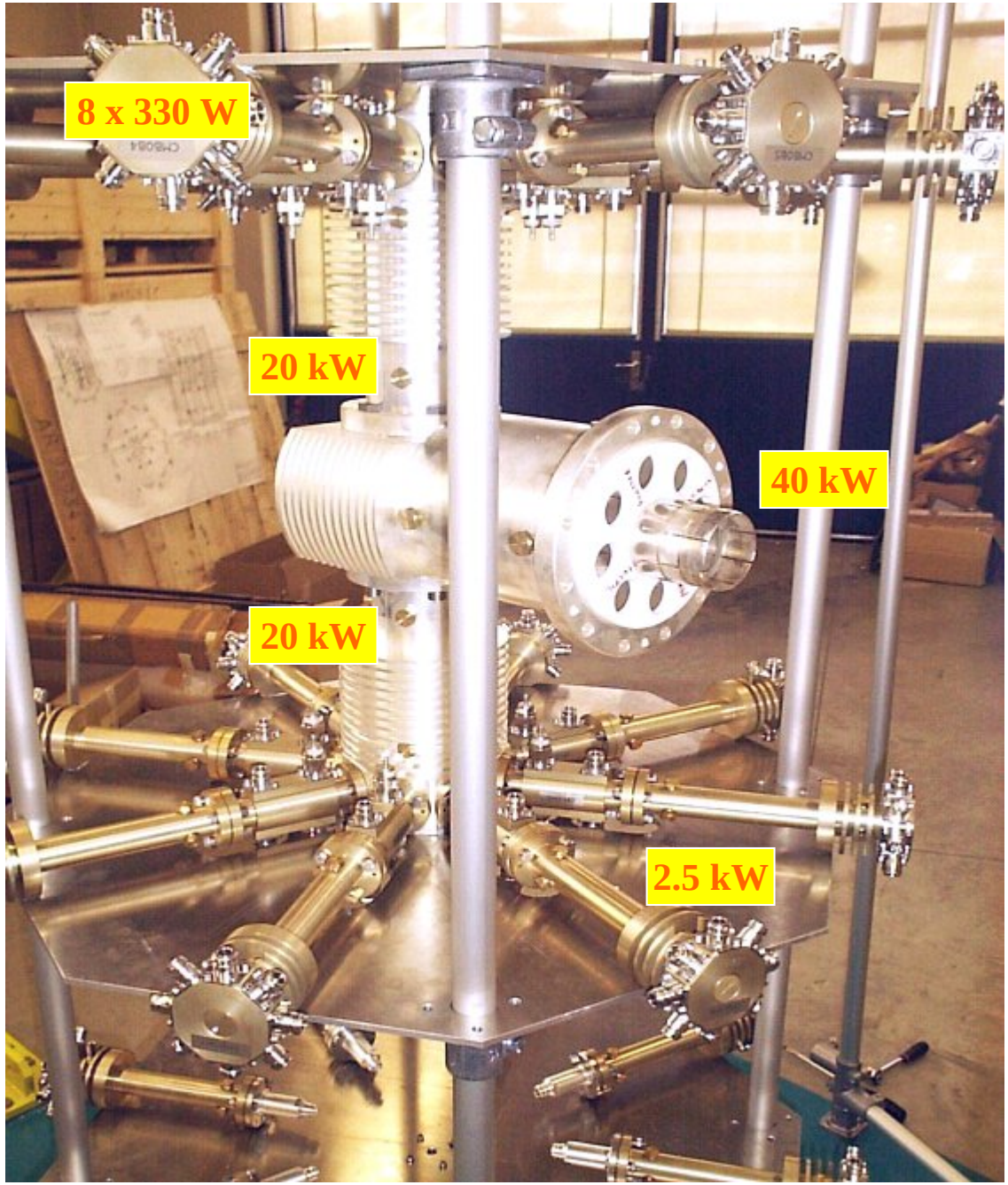
8 x 2.5 kW combiner (in-house fabrication)

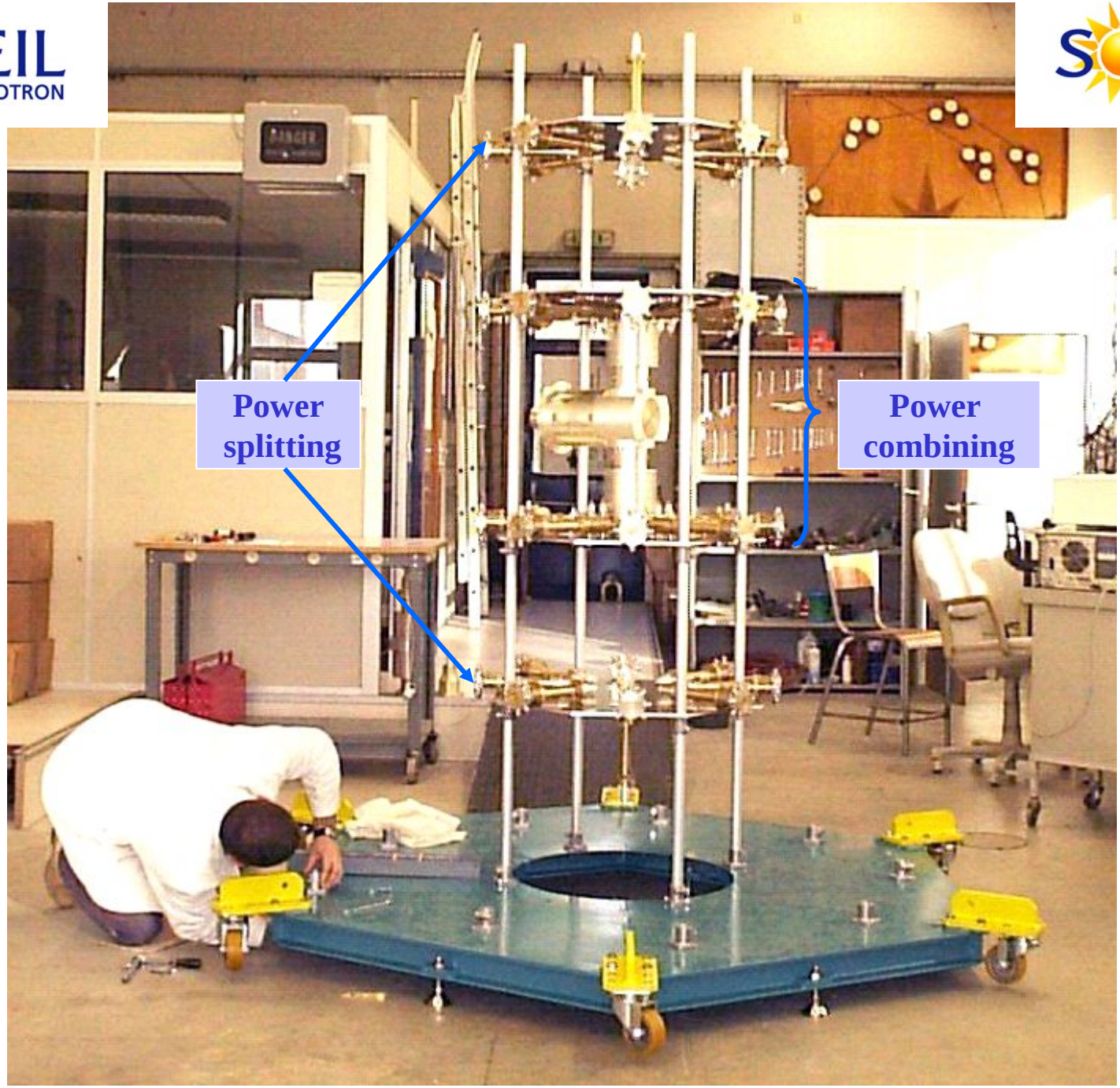


2 x 20 kW combiner (in-house fabrication)

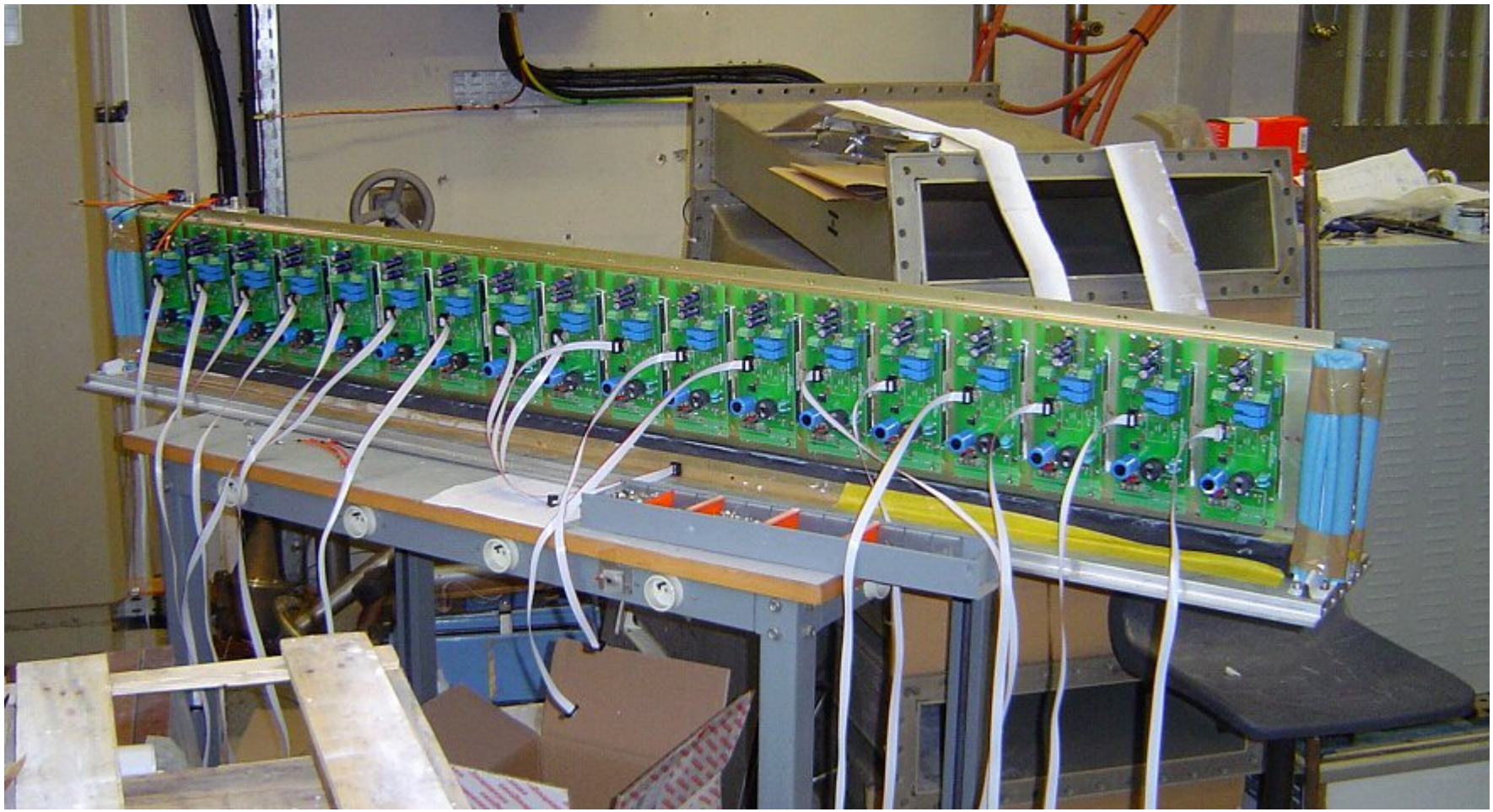



coupler
20 kW
2.5 kW
8 x 330 W


8 x 330 W
20 kW
40 kW
20 kW
2.5 kW


Power splitting
Power combining

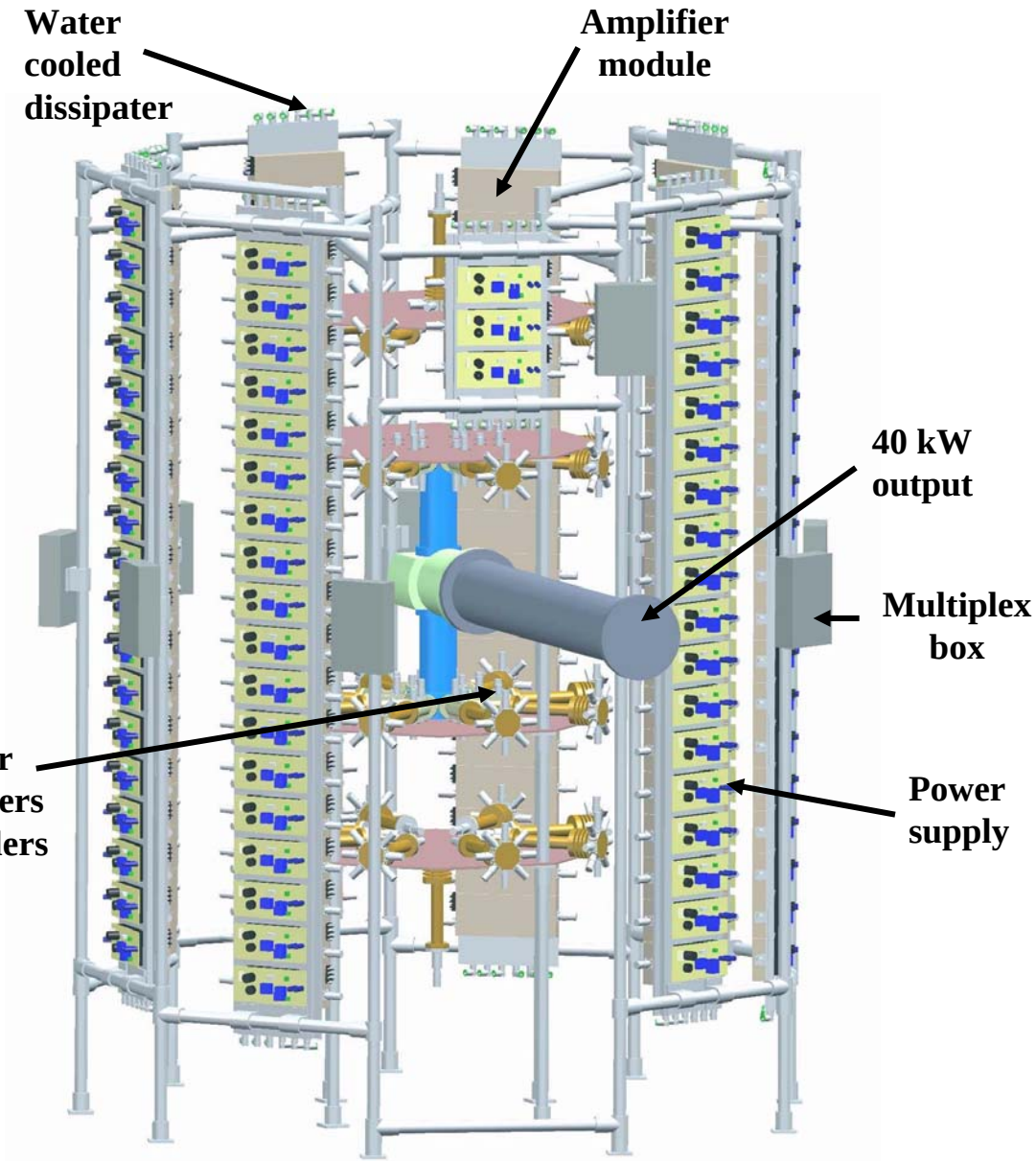
Dissipater with 18 DC/DC converters and amplifier modules



Booster amplifier (« virtual one »)

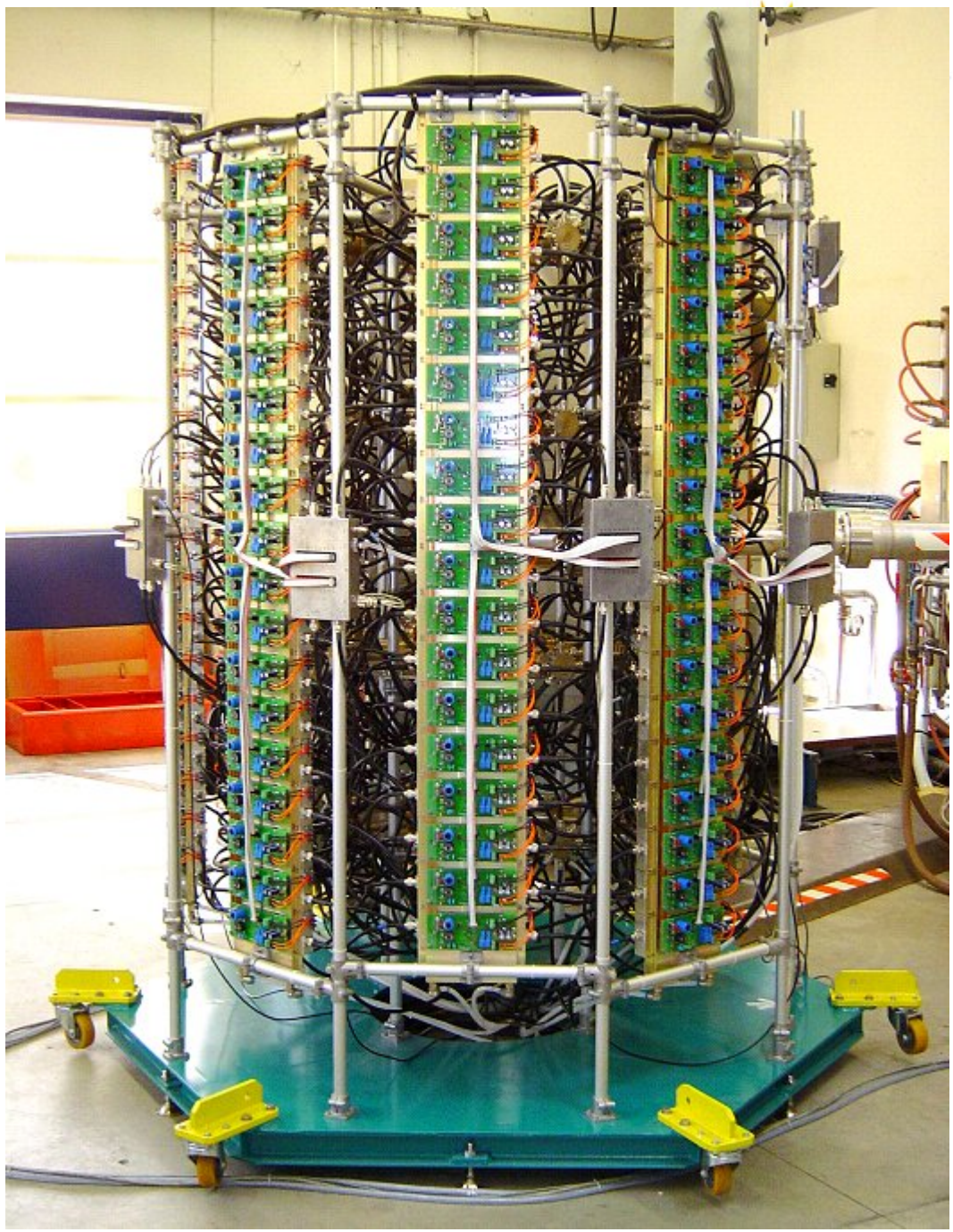
147 amplifier modules
& DC/DC converters

8 long dissipaters with
18 modules and
1 short dissipater
with 3 modules
(1 « stand-by » included)



Booster amplifier
(« actual one »)

On March 5th , 2004
35 kW CW
into a dummy load



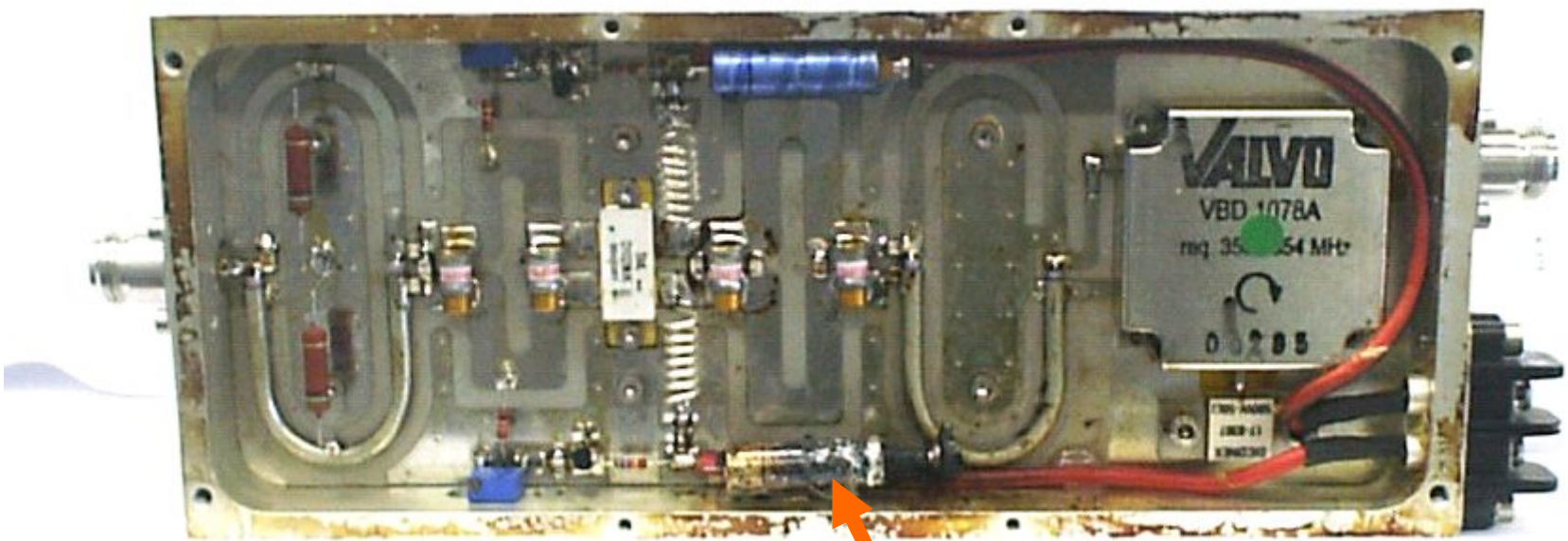
Booster amplifier power tests with a dummy load

- **Tests of the « 2.5 kW » units (8 modules), individually :**
  - **From start, 3 « defective » modules (amongst 147) : 1 module not well set, 1 bad soldering and 1 in / out cable inversion**
  - **Each unit tested up to about 2.5 kW**
    - **Gain dispersion : 0.3 dB**
    - **Phase dispersion 11.5° (partially compensated with proper cable selection → 4°)**

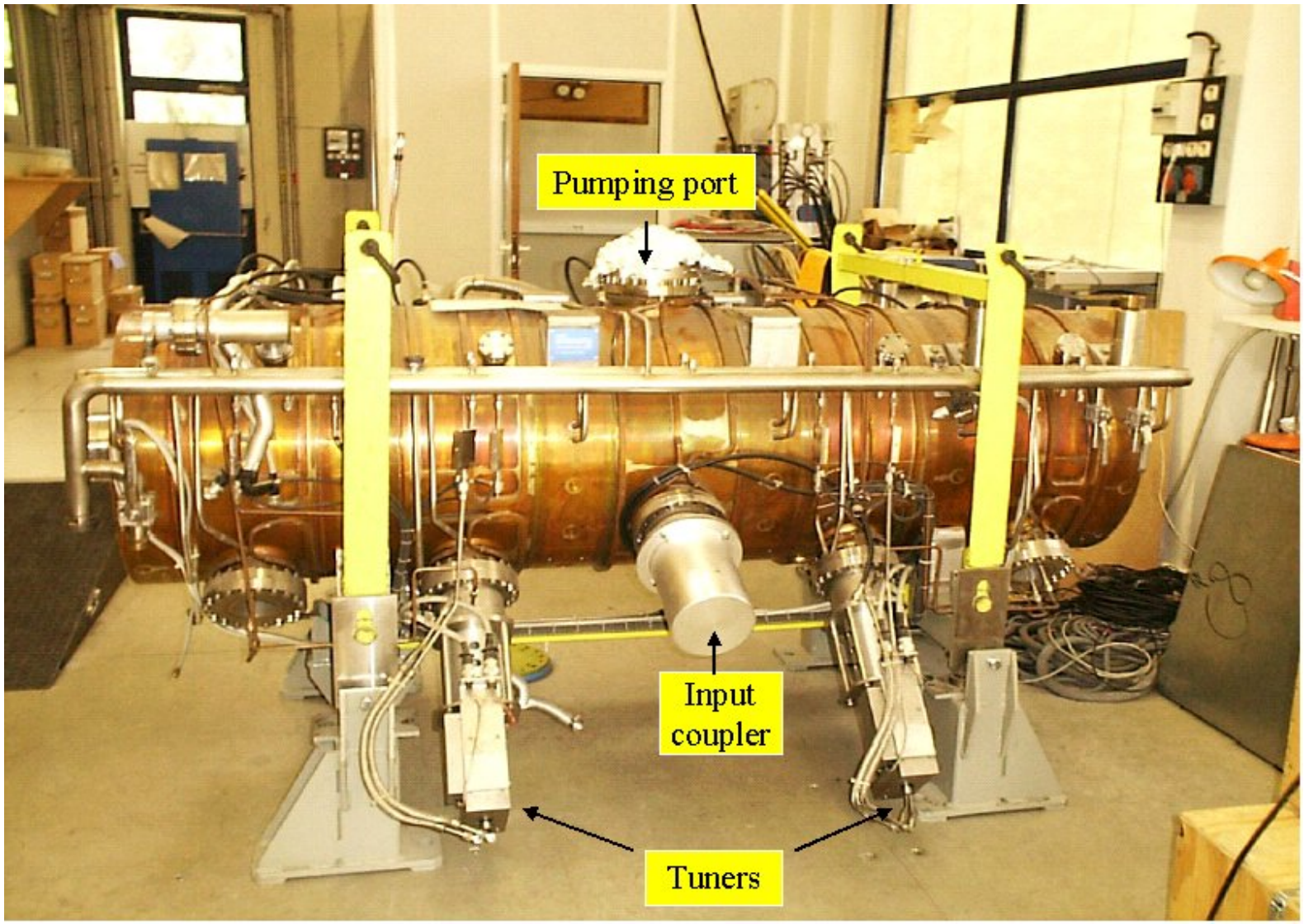
- **Full power combination :**
  - **Tests up to 35 kW for about 1 hour without any problem (It < 8.6 A)**
    - **→ global efficiency of 50 % (circulators + power supplies included)**
    - **→ 55 % (power supplies excluded)**
  - **Over useful power range, 1.5 – 25 kW, $\Delta\phi$ = 7 ° and ΔG = 2.5 dB**
  - **Long run test of ~ 500 h at 30 kW CW → no interruption & unchanged performance (max required in operation : 20 kW)**

Booster amplifier « operational » experience

- 30 kW CW into a dummy load for ~ 500 h without problem
- Cavity connection → conditioning + tests of the LLE & control systems
- Detection of 2 module failures **(amplifier still running)**;
  bad contact due to « cold » soldering that was rapidly fixed
- Sept. 22, 2004 (~ 900 h op.), smelted capacitor on 2 modules (wrong polarity);
  the amplifier and **the 2 modules were still normally running !**



Booster cavity



Booster cavity input power coupler

Coupler loop and ceramic window

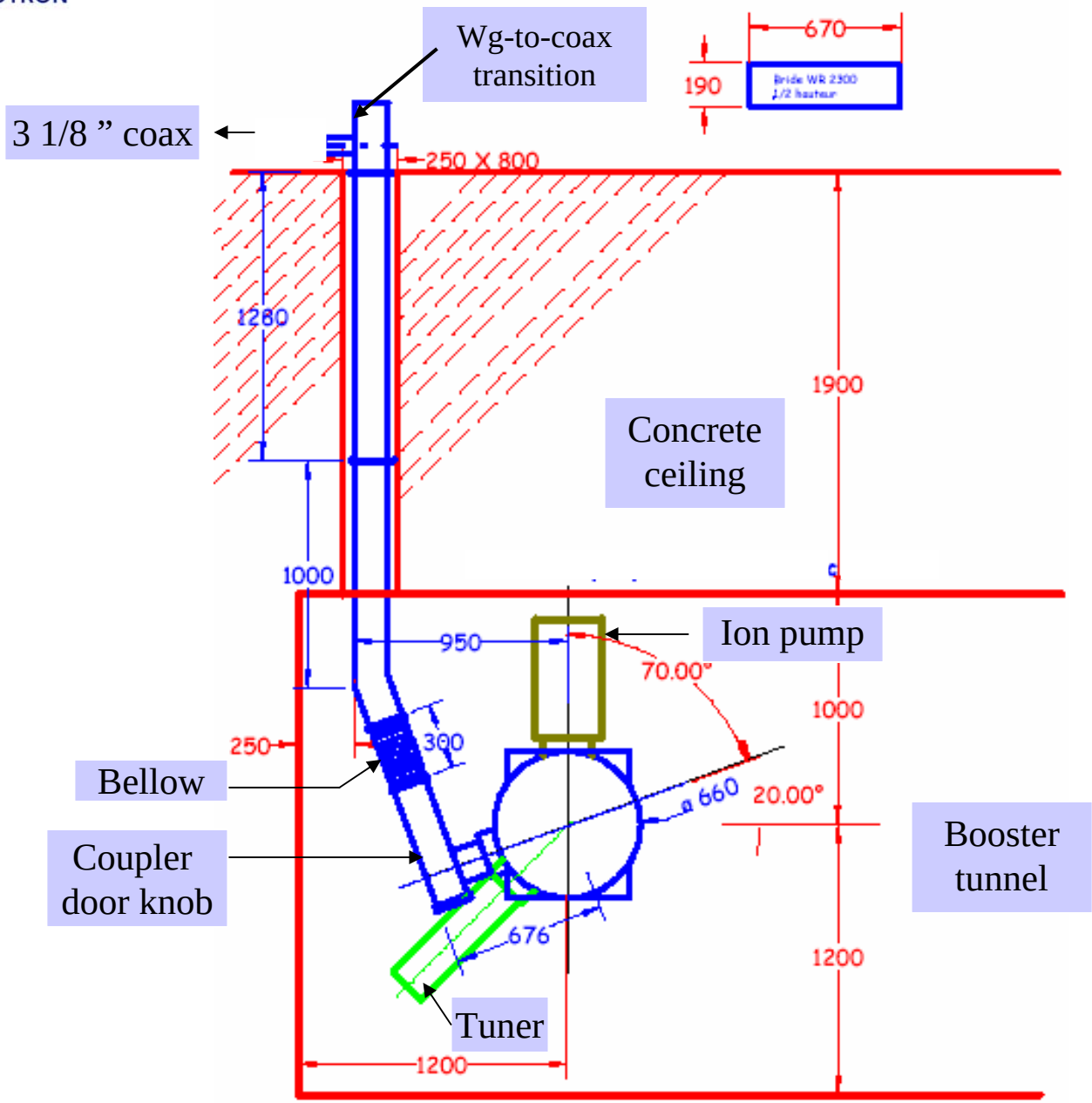
Coupler mounted on its door-knob

In the test area, cavity RF conditioning

After ~ 8 hours

~ 3 10^{-9} mbar @ 30 kW CW
< 1 10^{-9} mbar without RF
(no previous bake-out)

Booster cavity layout



Booster RF status & schedule

- Amplifier and cavity tested up to 30 kW; they are operational (with only a part or the LLE and control systems)
- LLES (amplitude, phase, frequency loops) « à la LURE »
- PLC – based control – command system

} under test

- Transfer to SOLEIL RF room : Nov. 2004 → test carrying on
- Cavity installation in Booster ring : Jan. 2005
- Booster commissioning : March 2005

Storage ring main parameters

Circumference	354 m
Revolution frequency	0.85 MHz
Energy	2.75 GeV
Energy loss / turn	1.15 MeV
Beam current	500 mA
Momentum compaction	4.4 E-4
Momentum spread	0.1 %
RF acceptance	± 6.15 %
Bunch length	4.2 mm
Synchrotron frequency	5.9 kHz
Harmonic number	416
RF frequency	352.2 MHz
RF voltage	4.8 MV
Beam power	575 kW

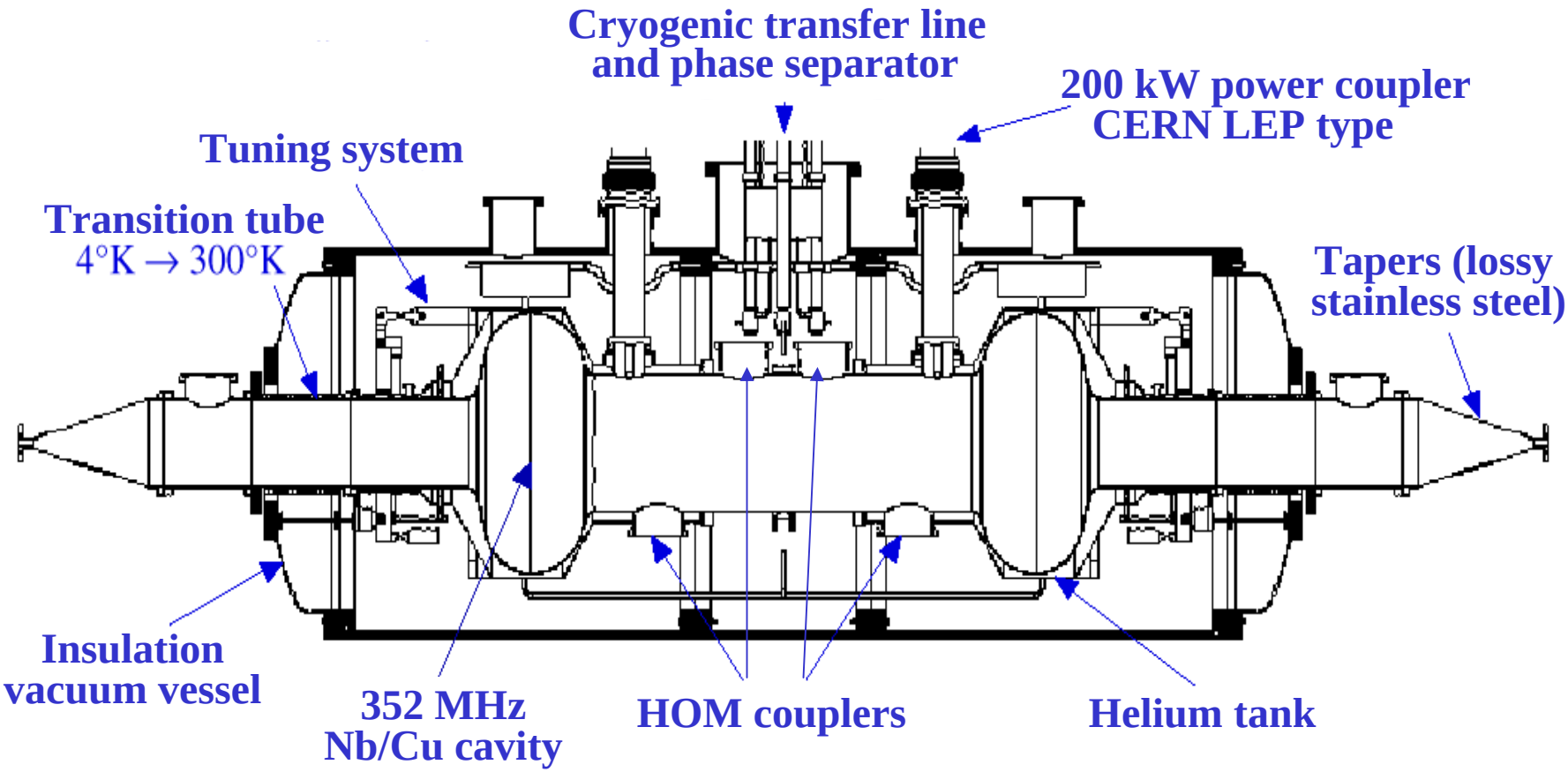
RF SYSTEM

→ 4 superconducting cavities (inside 2 cryomodules)

V_{cav} = 1.2 MV ; P_{cav} = 145 kW

→ 4 solid state amplifiers : 4 x 190 kW

Soleil cryomodule design



200 kW / coupler → need for 2 cryomodules @ 2.75 GeV

with all ID's and full beam current of 500 mA

Soleil cryomodule history

In 1998, decision to develop a 350 MHz cryomodule for SOLEIL (CERN/CEA collaboration)

In 2002, tests of the « prototype » in ESRF storage ring (1st day after each of the 4 scheduled shutdowns, using LHe Dewar)

⇩

Vacc > 3 MV
200 kW per coupler
(limited by overheating of HOM couplers)

This level of performance should allow to store up to 400 mA with a lifetime of about 30 hours in phase 1 (reduced number of ID's → ΔU = 1 MeV/turn)

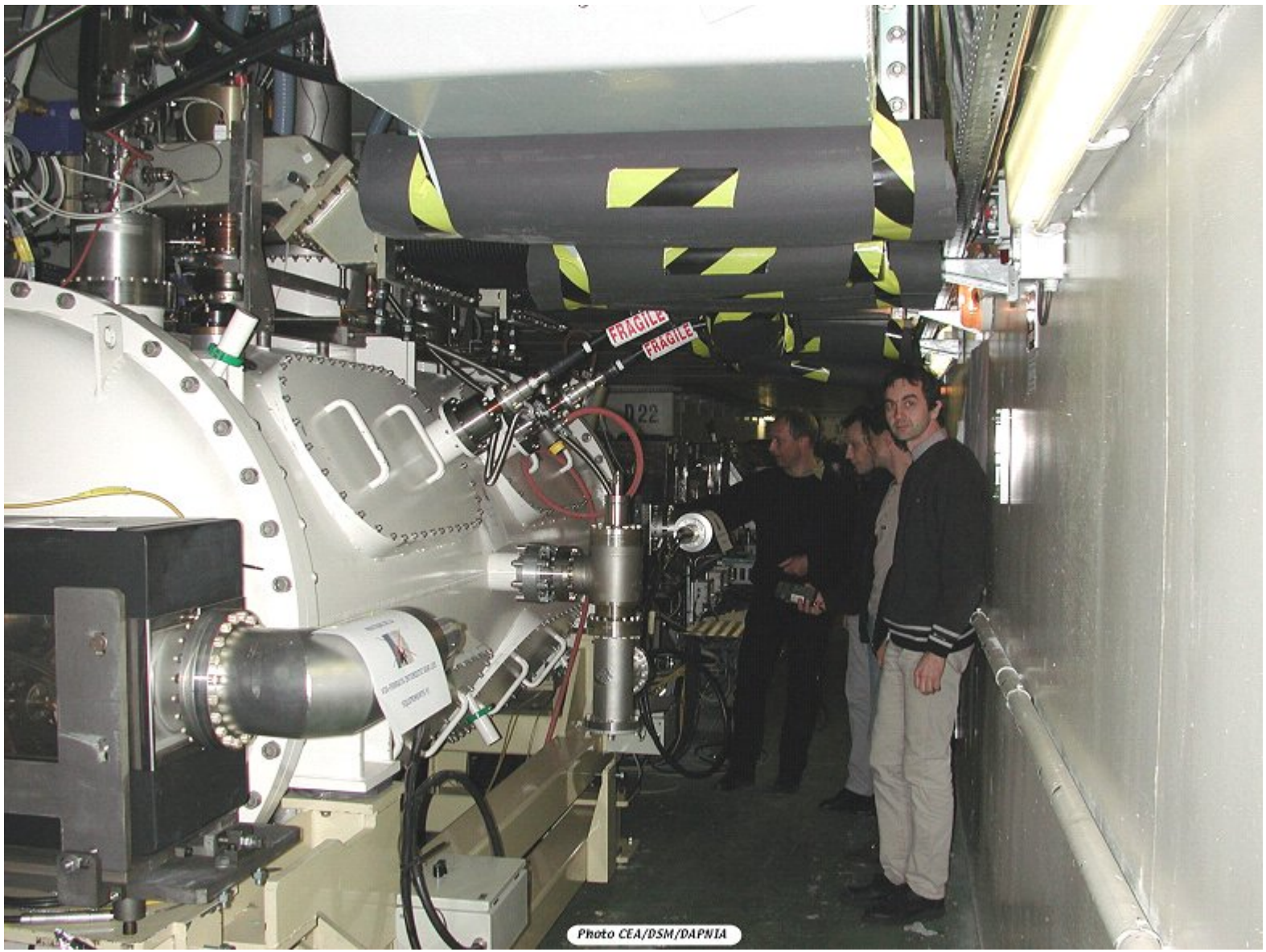
⇩

After « refurbishment », use of the prototype for the SOLEIL commissioning in June 2005 and fabrication of a second cryomodule (installation in Autumn 2006)

Status/planning of SOLEIL Cryomodule N°1 (modified prototype)

- ✓ **Collaboration agreements with CERN & CEA for the "refurbishment" tasks : replacement of the D-type HOM couplers, insertion of a copper thermal shield (LN2-cooled), lengthening of the power coupler antennas**
- ✓ **Cryomodule disassembly at CERN end of 2003**
- ✓ **Cavity rinsing and RF tests in vertical cryostat ($Q_o > 3\ 10^9$ @ 4.2K & 6 MV/m)**
- ✓ **All components (modified HOM couplers, thermal shield, …) are available at CERN and the re-assembly is on going → end of Oct. 2004**
- ✓ **RF and cryogenic power tests → end of 2004**
- ✓ **Transfer to SOLEIL and installation → early 2005**
- ✓ ***Power couplers*** **(7 pieces from CERN)**
  - **for better matching , + 9.8 mm antenna length; then re-conditioning**
  - **2 pieces ready for mounting on CM1**

2002 , SOLEIL cryomodule in the ESRF storage ring



End of 2003, at CERN, the cryomodule waiting for access into the clean room

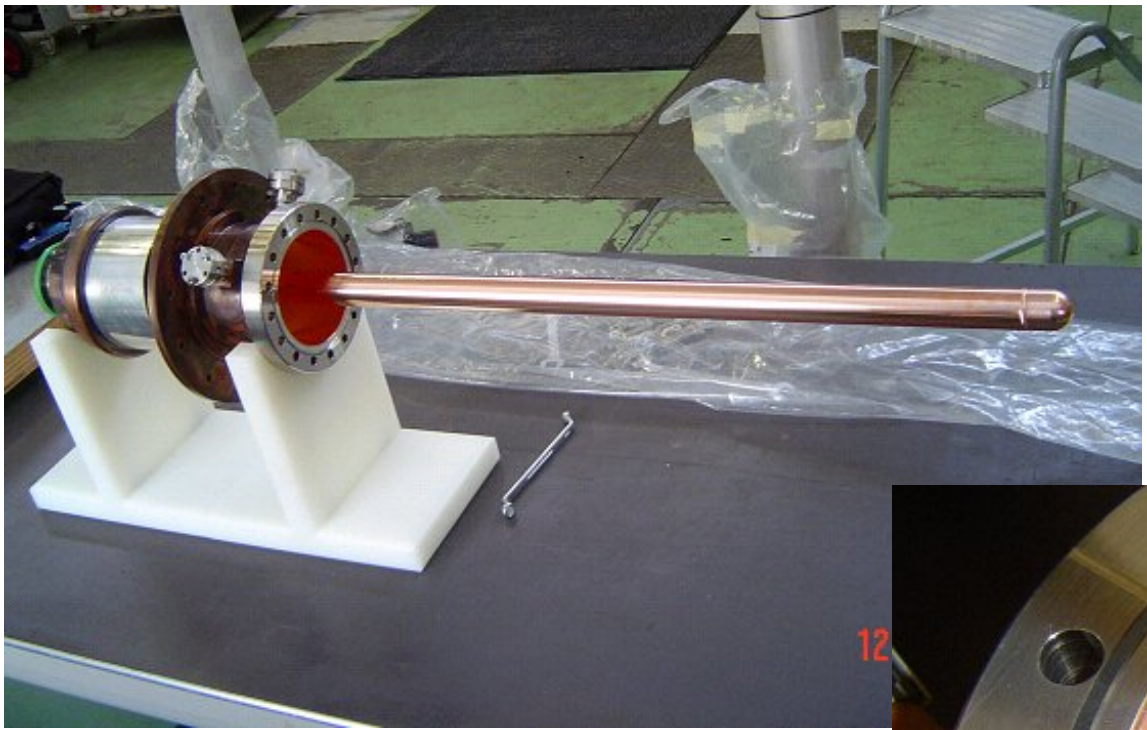
Feb. 04, inside the CERN clean room, input power coupler removal

1

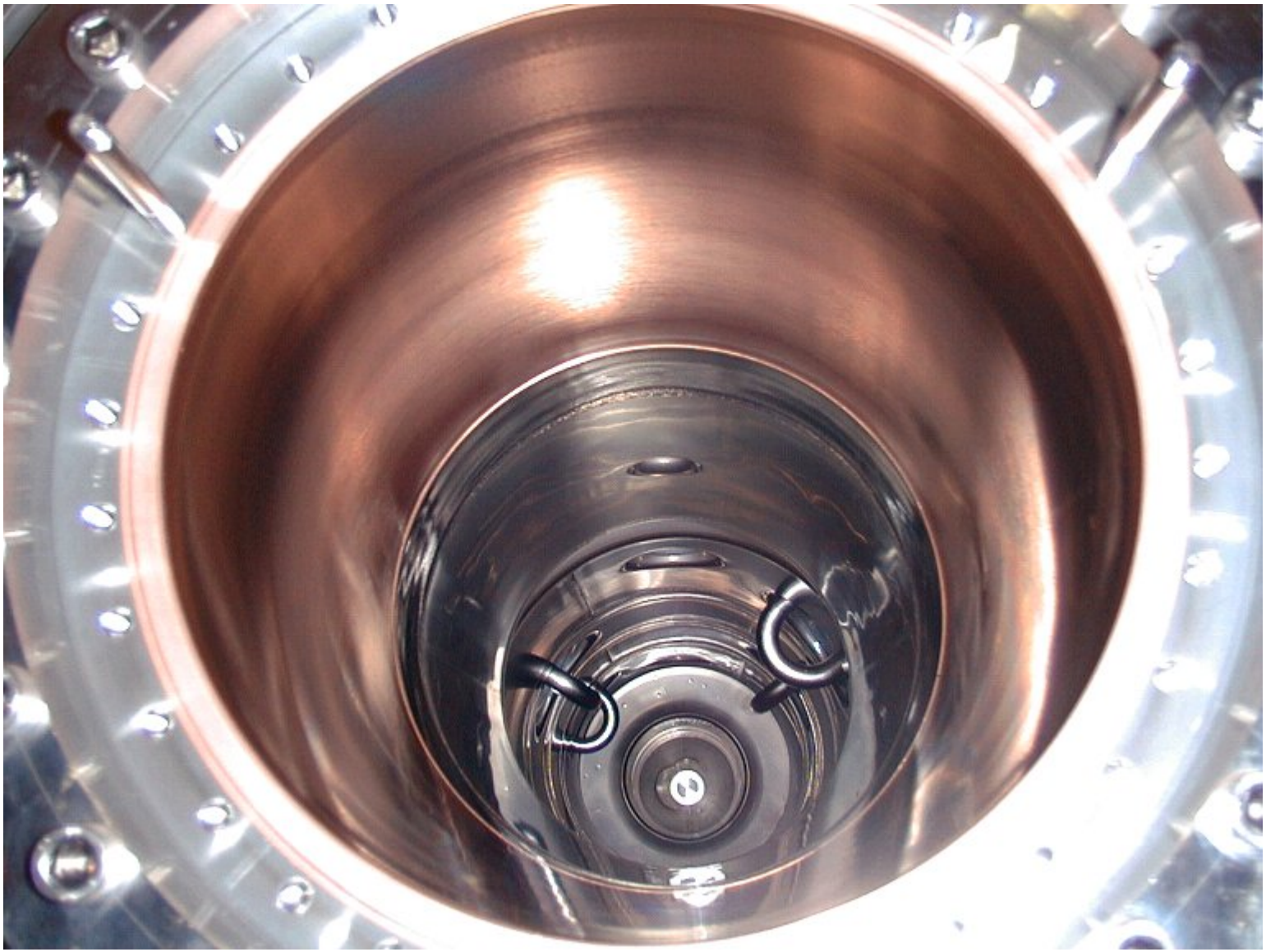
2

3

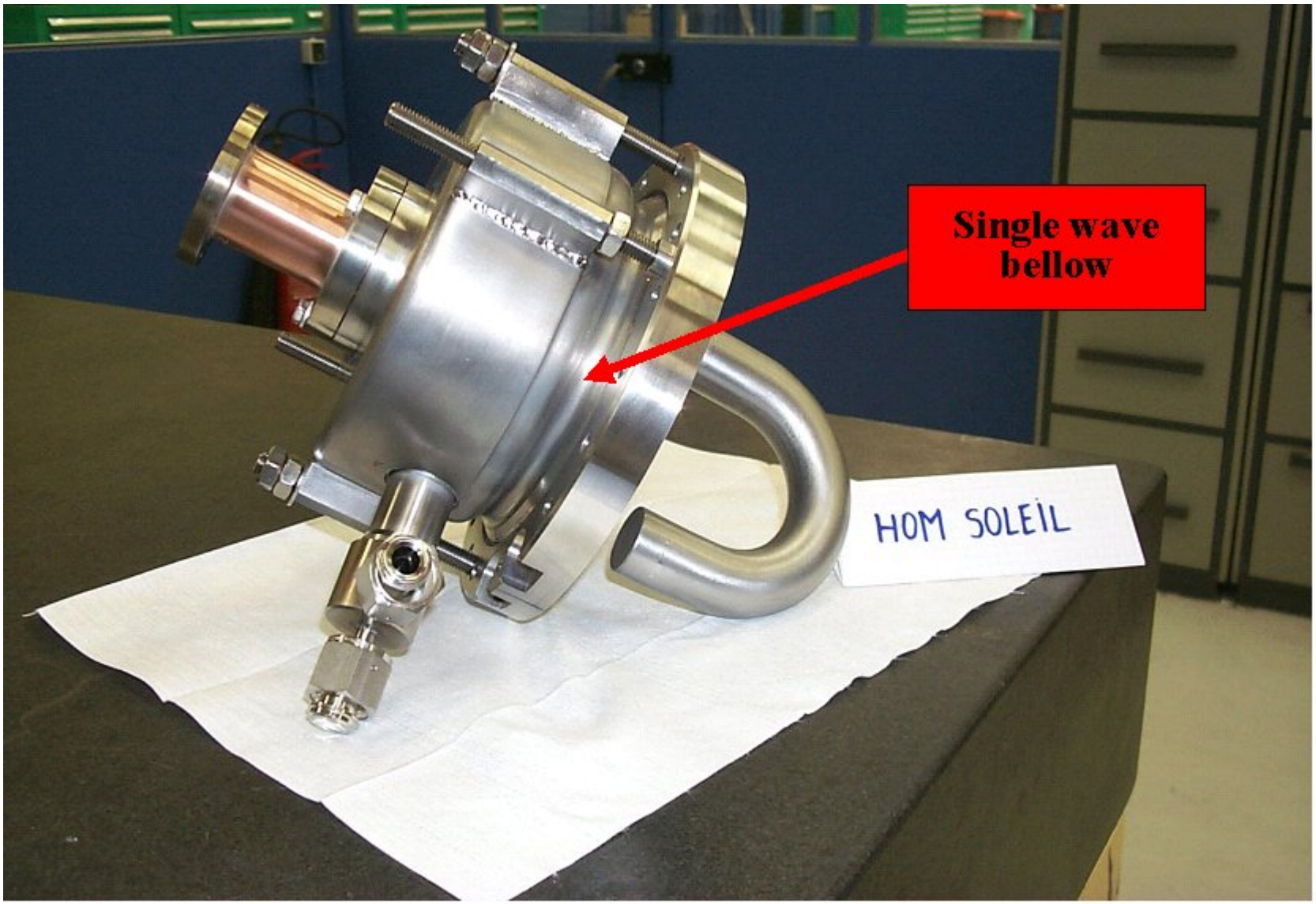
Input power coupler



What the electron beam will see when entering into the cavity



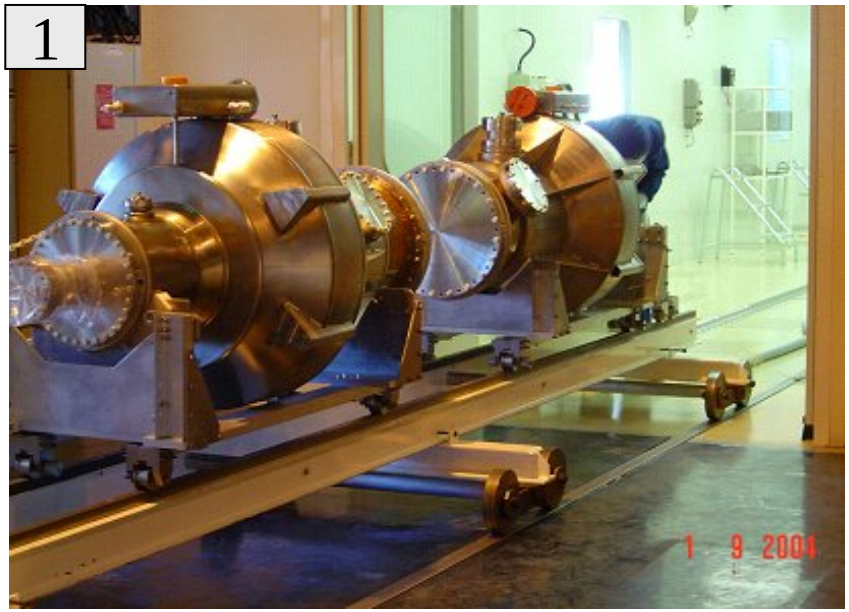
D -type HOM coupler



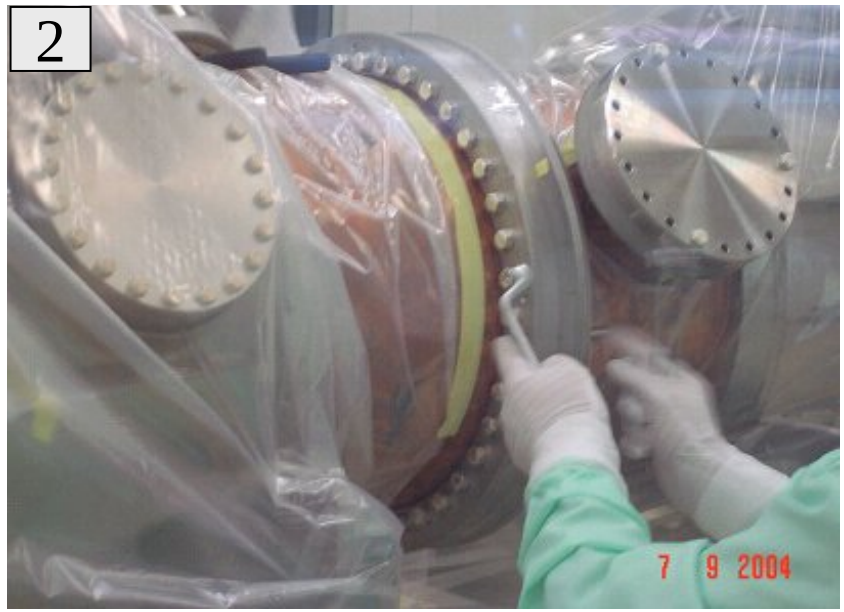
CERN, June 2004: Cavity transfer and mounting for tests in the vertical cryostat

Sept. 2004: cavity re-assembly

1



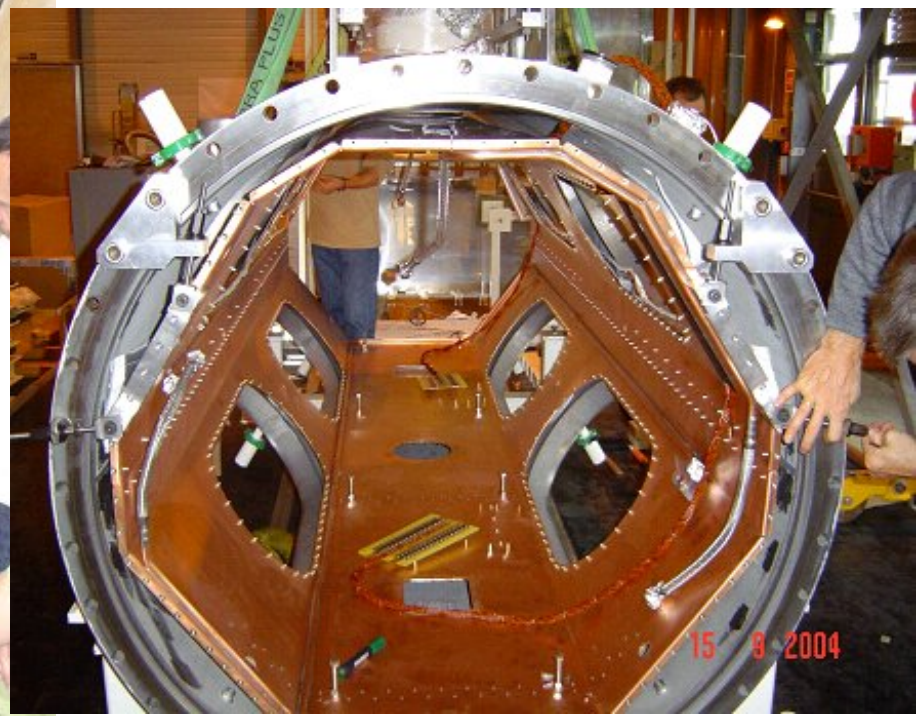
2



3

4

LN2-cooled copper thermal shield



Cryomodule N° 2

- Twin brother of N° 1
- A process of call for tender for a « turn-key » supply is on going
- Offers → November 2004
- Order before the end of 2004
- Installation in SOLEIL : Autumn 2006

Storage ring 352 MHz power source

Technological options

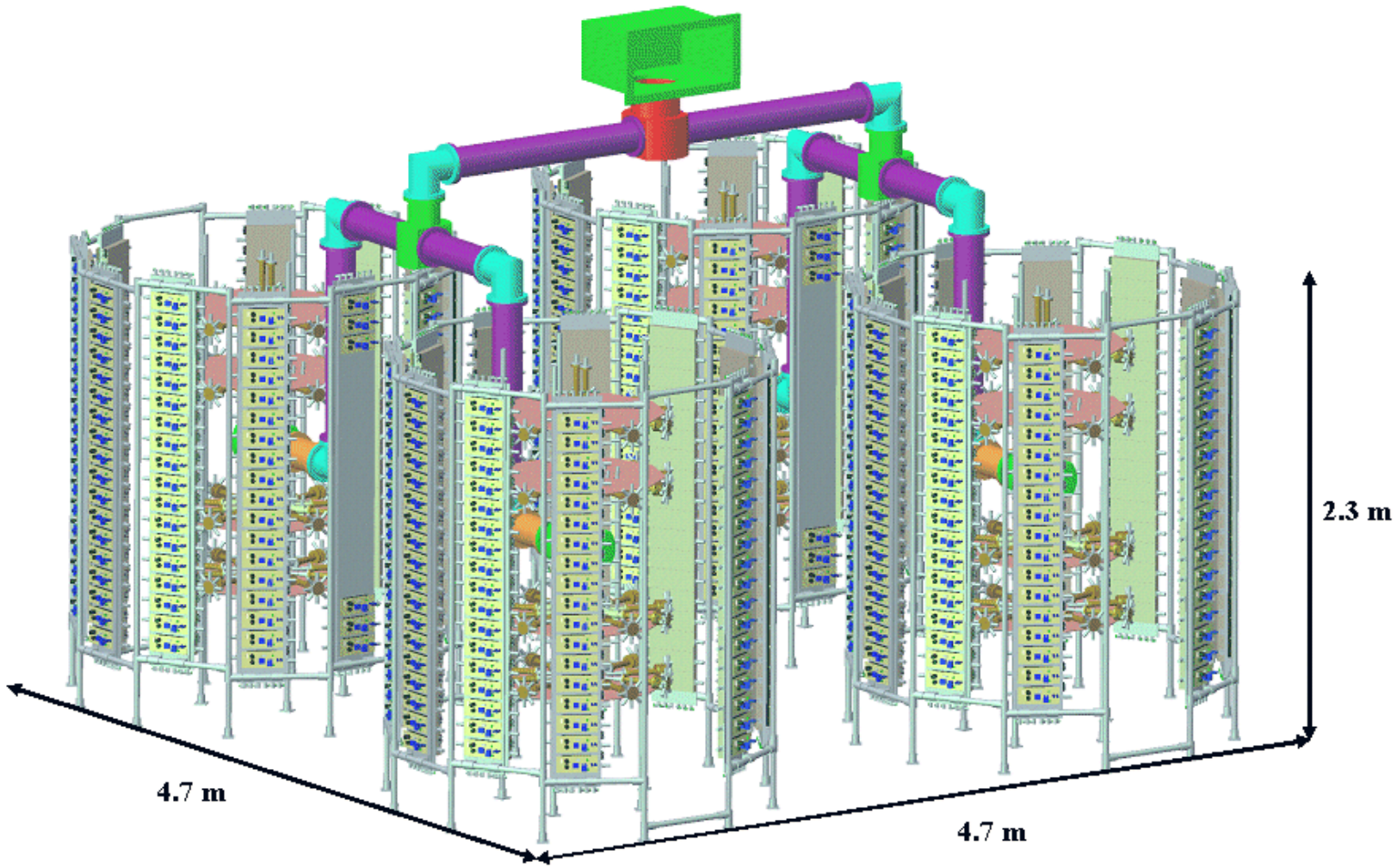
- Vacuum tubes
  - Klystron
  - IOT
  - Diacrode

→ Lack of commercial products @ 352 MHz & 200 – 400 kW

- Solid state version →
  - Modularity → redundance
  - No HV, no high power circulator
  - Simple start-up procedures & controls
  - Low cost (investment, running and maintenance)
  - In house expertise

→ **Four 190 kW solid state amplifiers**

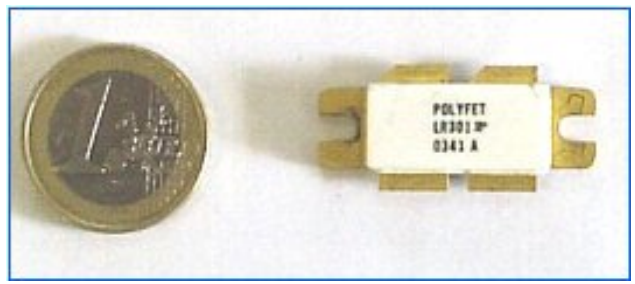
Storage ring 190 kW RF amplifier



Storage ring amplifier modules

TRANSISTORS

LDMOS from POLYFET (USA) instead of VDMOS from SEMELAB (UK)
Result from a close collaboration between SOLEIL and POLYFET



- **Higher gain : 14 - 15 dB at $P_{nominal}$ of 315 W**
- **Higher power capability → at 350 W, G > 12 dB**
- **Improved stability margin (K > 13 dB)**
- **Smaller $\Delta\phi$ versus power (50 – 350 W → ~ 1°)**
- **Smaller gain and phase dispersion**
- **Better input matching → P_{ref} < 30 mW (Z_{input} vs P_{out} nearly constant)**
- **Better linearity → 1.5 dB gain compression with 63 % efficiency**
- **No use of toxic BeO**

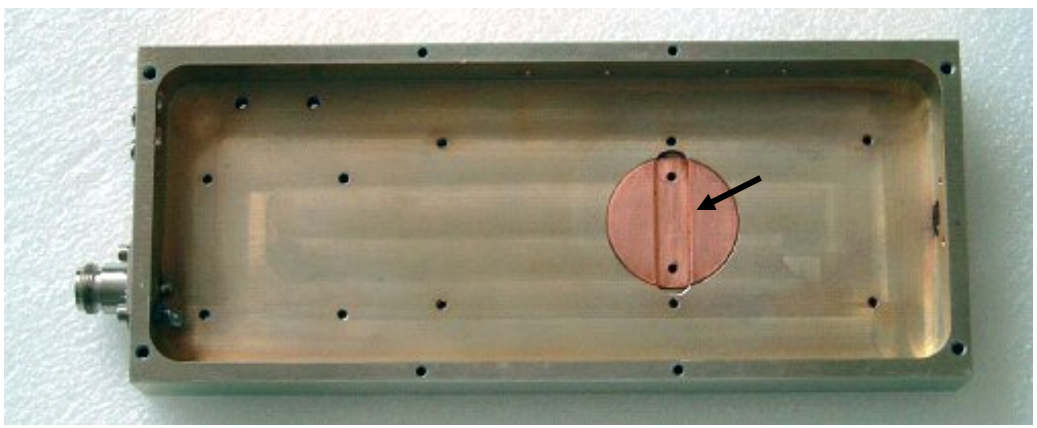
Storage ring amplifier modules

COMPLETE MODULES (3000 pieces)

Produced and tested, according to the SOLEIL specifications, by BBEF (Beijing)

- All material components procurement (including the POLYFET transistors, but not the circulators supplied by SOLEIL*), integration and assembly
- Tests and setting in order to achieve the *specified performance* :
  G > 13 dB ± 0.5 dB , η > 63 % at 315 W and G > 12 dB at 350 W
- ***Schedule*** :
  - 10 pieces (pre-series) in May 04 → successful test of a 2.5 kW unit (8 mod.)
  - 200 pieces in Oct. 04 → test of a 50 kW unit before the end of 2004
  - Remaining pieces in 2005

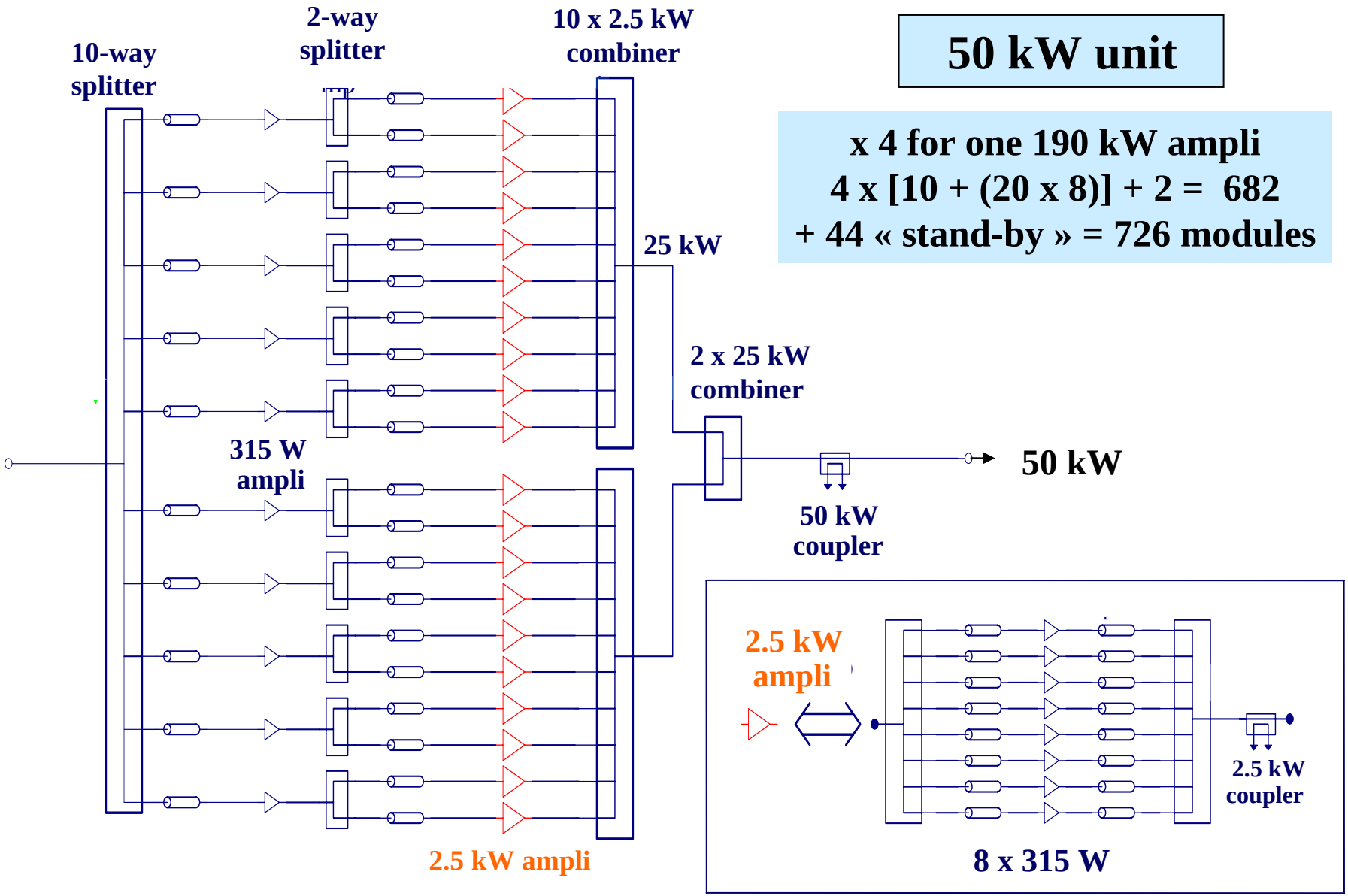
* ***Circulators***, built and tested by VALVO GmbH (1000 pcs already at BBEF, 600 pcs at VALVO and production rate maintained at 150 pcs / month)



Aluminium case with copper slug

→ ΔT = - 15°C

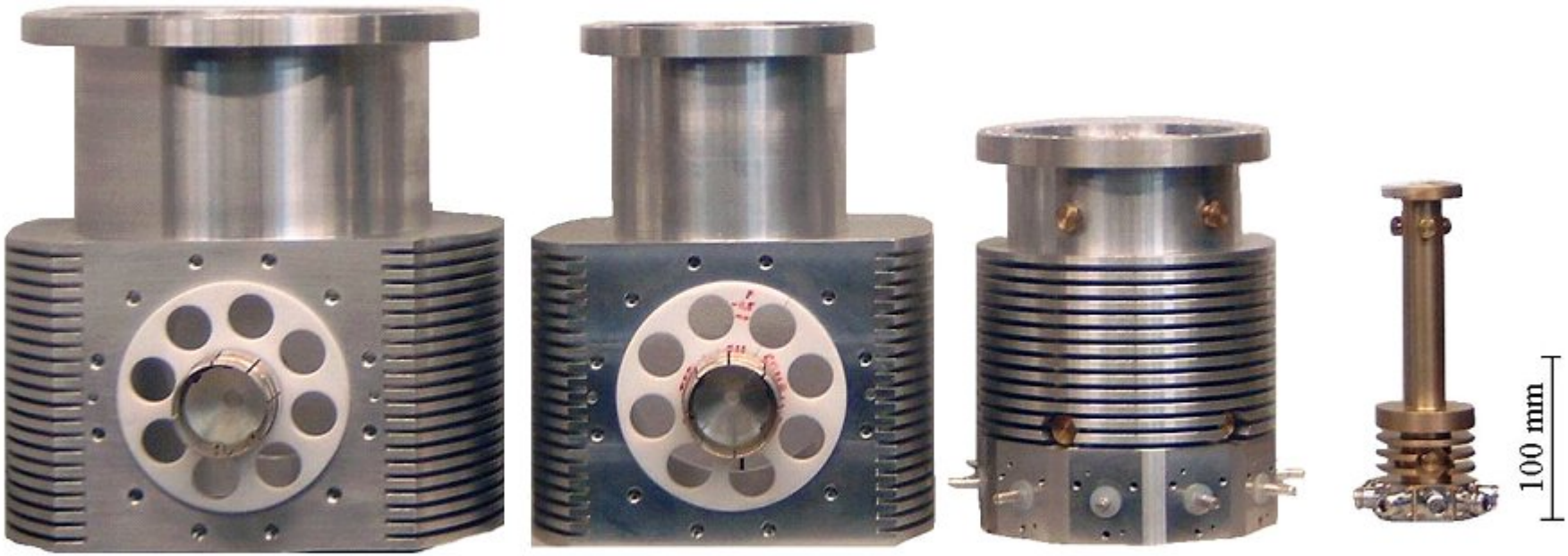
Storage ring amplifier power combination scheme



50 kW unit

x 4 for one 190 kW ampli
4 x [10 + (20 x 8)] + 2 = 682
+ 44 « stand-by » = 726 modules

Storage ring amplifier power combiners



2 x 100 kW **2 x 50 (or 25) kW** **10 x 2.5 kW** **8 x 315 W**

Storage ring amplifier power dividers

10, 8 and 2 – way microstrip dividers

Storage ring amplifier component survey / schedule

- *Cables and connectors*
- *Dissipater plates*

} **available**

- *DC / DC converters*

  1500 pieces (A1 & A2) → available

  1500 pieces (A3 & A4) → March 2005

- ***Splitters / combiners / couplers* : delivery completed before end of 2004**
- ***Assembly and tests of a complete 50 kW unit* : Oct. 2004 → Dec. 2004**
- ***AMP1: March 2005, AMP2: June 2005 (SR commissioning with CM1)***
- ***AMP3 & AMP4 on CM2 in 2006***
- ***280 V – 2 MVA DC supply***

  4 units (transfo + rectifier) of 500 kW (from Bruker – France)

  Delivery and installation → January 2005

Cryogenics

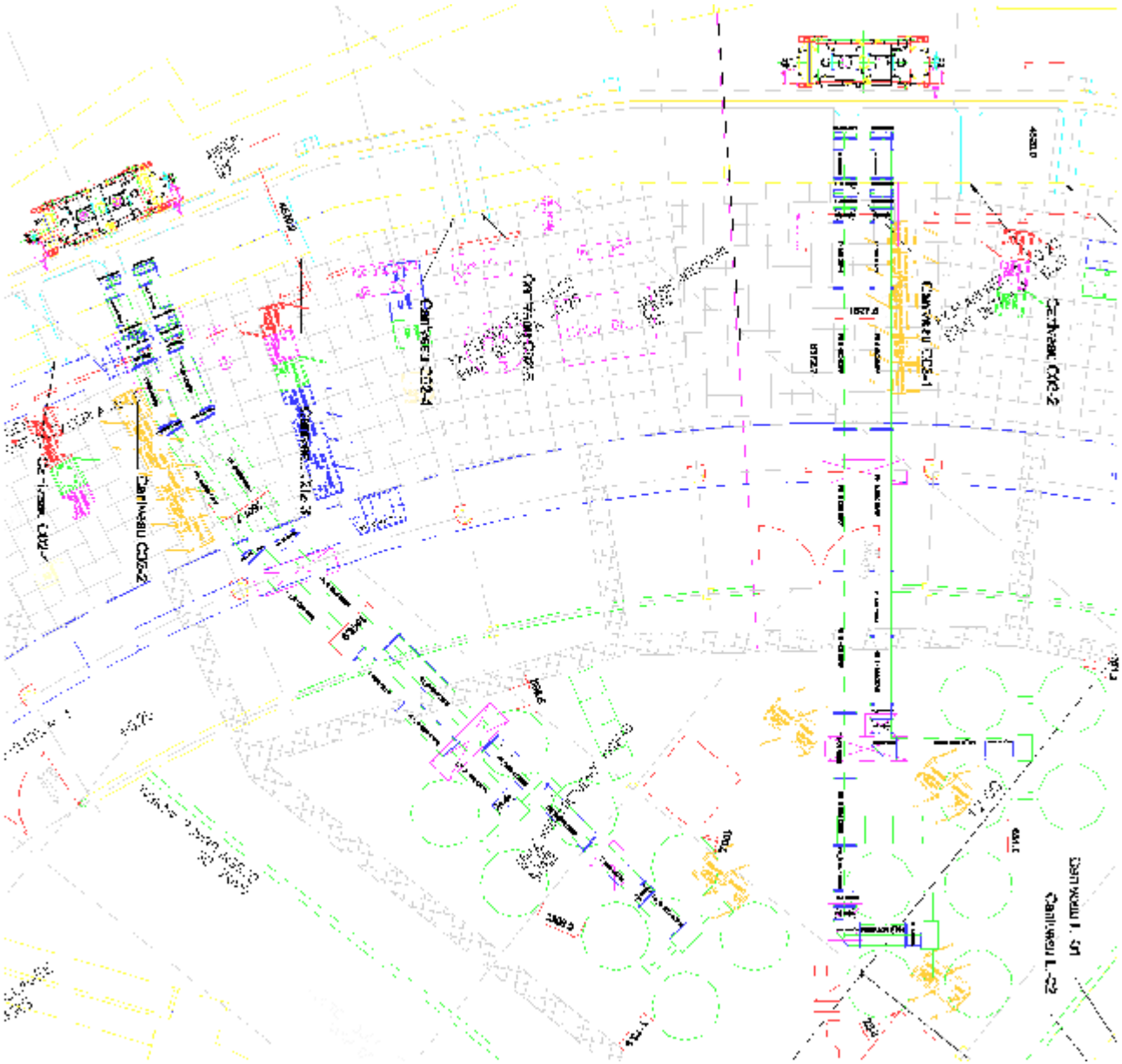
Single cryo-plant for the 2 cryomodules, based on the HELIAL 2000 liquefier (Air Liquide), specified for 40 l/h of LHe and 350W @ 4.5K

***Delivery schedule* :**

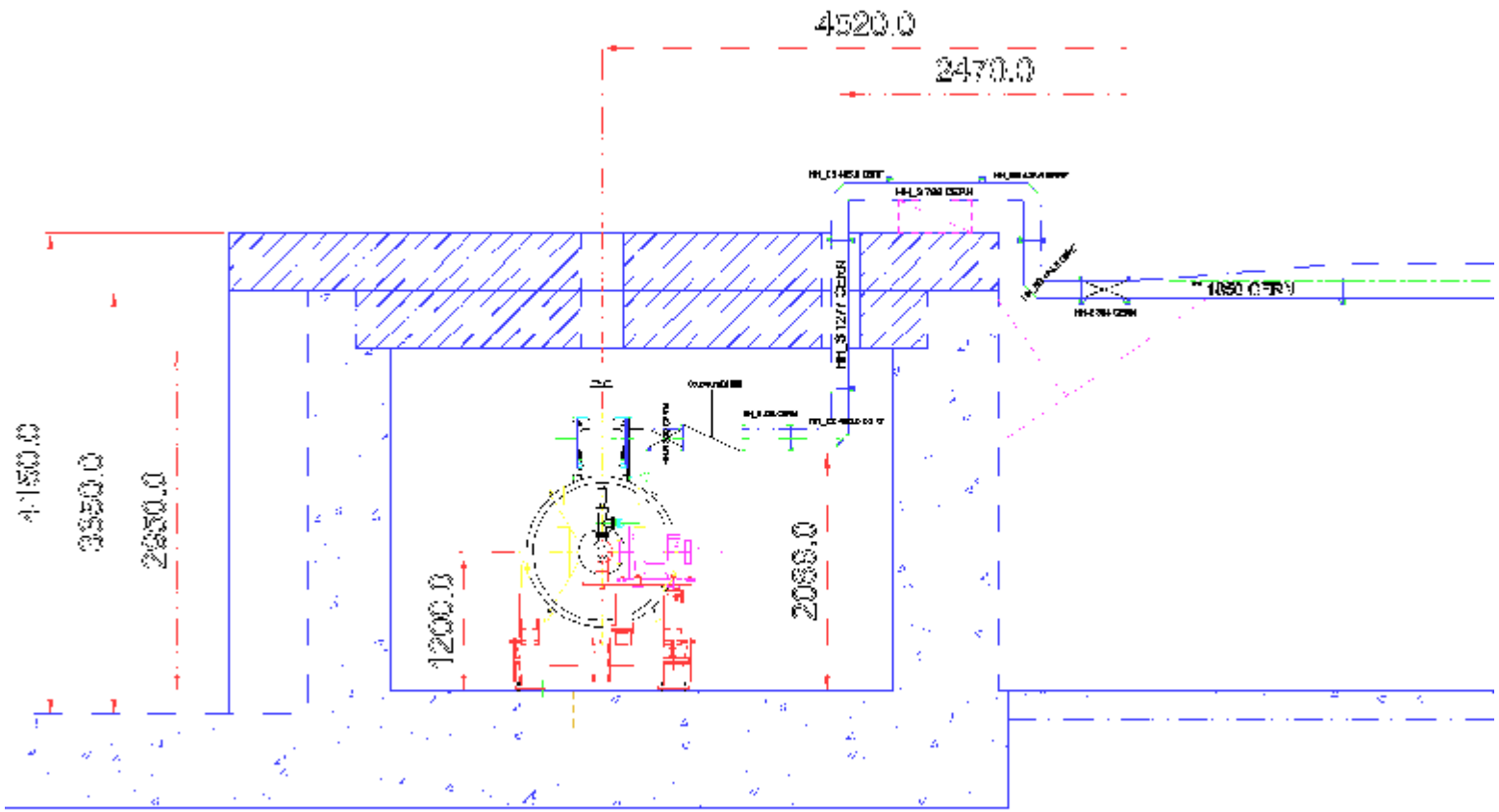
- **Compressor, GHe buffers → early 2005**
- **Cold-box, valve boxes, cryo-lines, dewar → March 2005**

HELIAL 2000

Storage ring RF system layout



Cryomodule / waveguides layout



Acknowledgement

SOLEIL RF GROUP

Jean POLIAN

Patrick MARCHAND

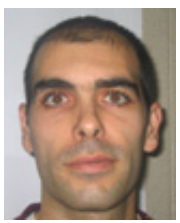
Ti RUAN

Fernand RIBEIRO

Massamba DIOP

Catherine THOMAS-MADEC

Engineer



Robert LOPES

Helder Antonio DIAS

Jocelyn LABELLE

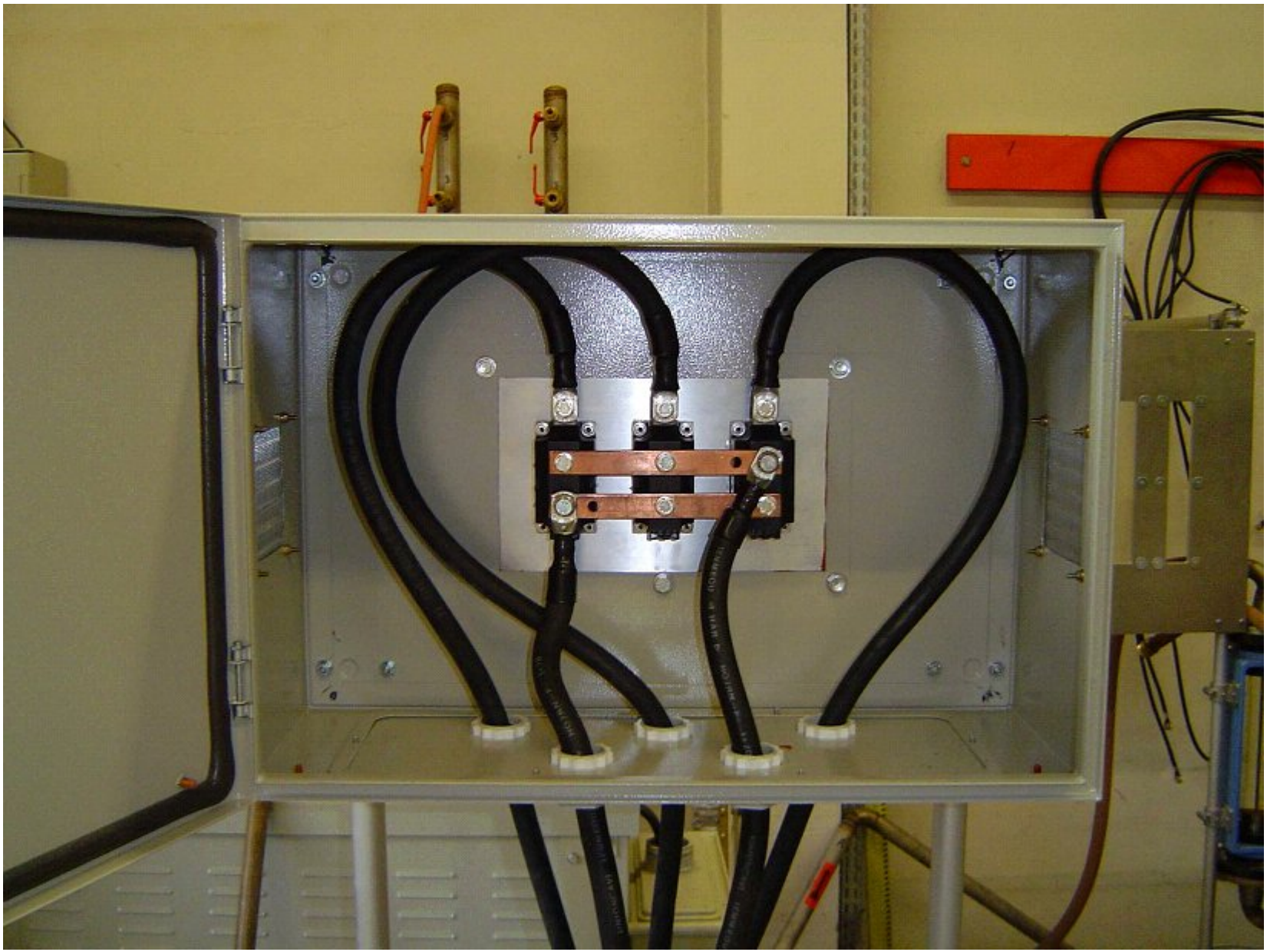
Cyril MONNOT

Moussa EL AJJOURI

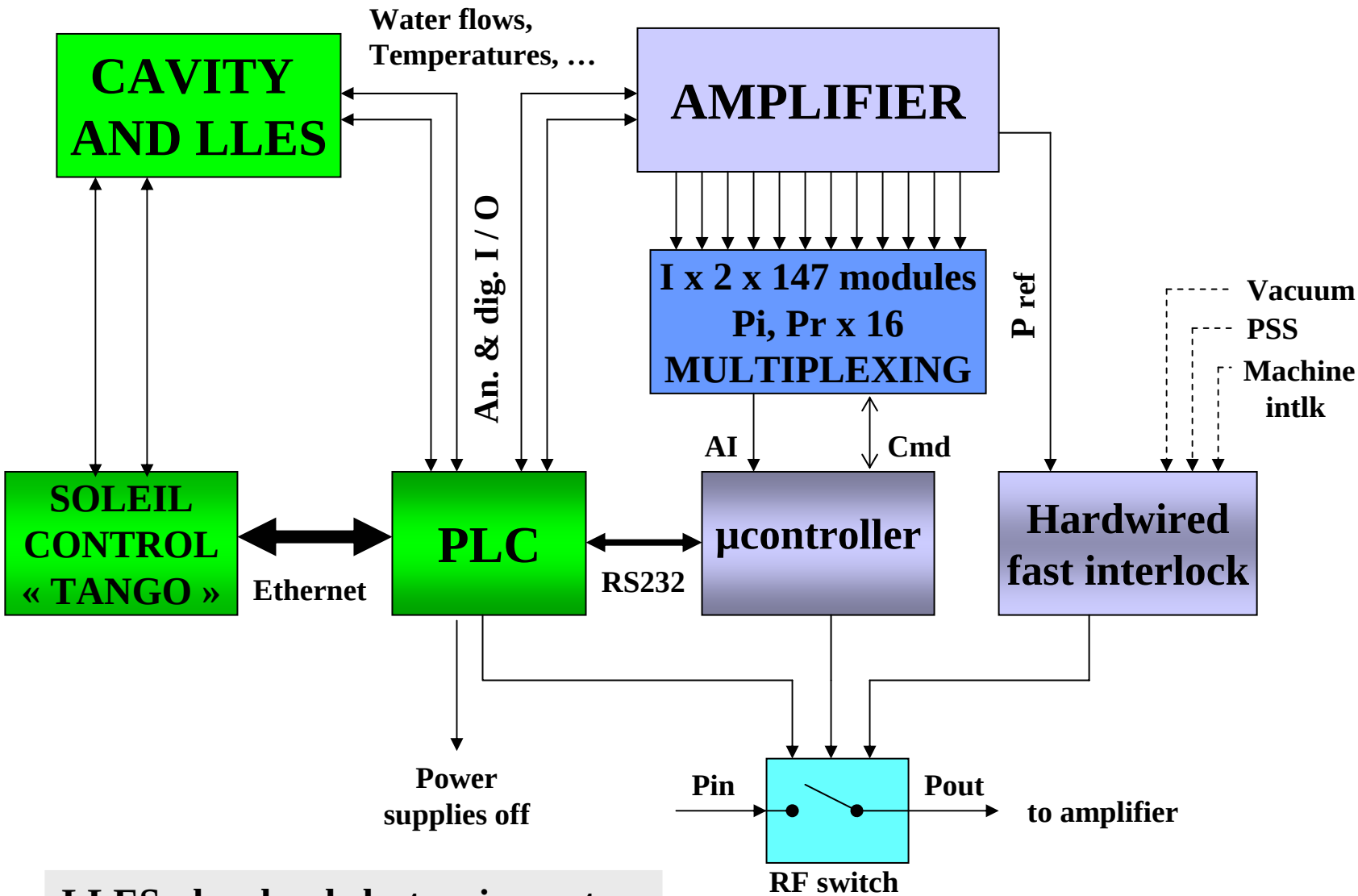
Technician

SOLEIL, CEA, CERN, ESRF, LURE

Booster RF amplifier diode rectifier



Simplified diagram of the control system



LLES : low level electronicc system