SUPERCONDUCTING RF CAVITIES FOR SYNCHROTRON LIGHT SOURCES

S-C ACCELERATING SYSTEMS

CESR 500 MHZ CRYOMODULE → CLS, TLS, DIAMOND
SOLEIL 350 MHZ CRYOMODULE
(design, performance, transfer of technology, status)

S-C HARMONIC SYSTEM FOR BUNCH LENGTHENING

SUPER-3HC in SLS and ELETTRA; BESSY II and PLS projects

P. Marchand, Synchrotron SOLEIL

RF accelerating systems for synchrotron light sources (s.l.s)

SOLEIL SYNCHROTRON

Requirement **: rather low RF voltage and high RF power**

Achievable with a few n-c cavities and relatively small dissipation (typically $P_{diss} < 1/3\ P_{tot}$)

Major issue **: HOM impedances that can drive coupled bunch instabilities (the lower the energy, the more critical the effect)**

Possible cures **:**

- **HOM frequency control → avoid resonance excitation**
- **HOM couplers → de-Qing of HOM impedances**
- **Active feeback systems → oscillation damping**
- **Generation of additional damping from « Landau cavities » or/and proper filling pattern**

Until recently, all s.l.s were run with n-c cavities and could cope with the HOM (up to a few 100 mA) using one or combining several of the above cures

RF accelerating systems for synchrotron light sources

Another attractive alternative : « HOM free s-c cavities »

Very low dissipation ⟹ one can afford larger beam tube diameters
HOM propagation and damping in the beam tubes out of the cavity cell

Two techniques of damping the HOM in the beam tubes **:**

- **using HOM absorber material, located directly in the UHV at room temperature (CESR * / KEK designs)**
- **using coaxial couplers that extract and transfer the HOM power towards external loads (SOLEIL * / LHC designs)**

**** Used in s.l.s***

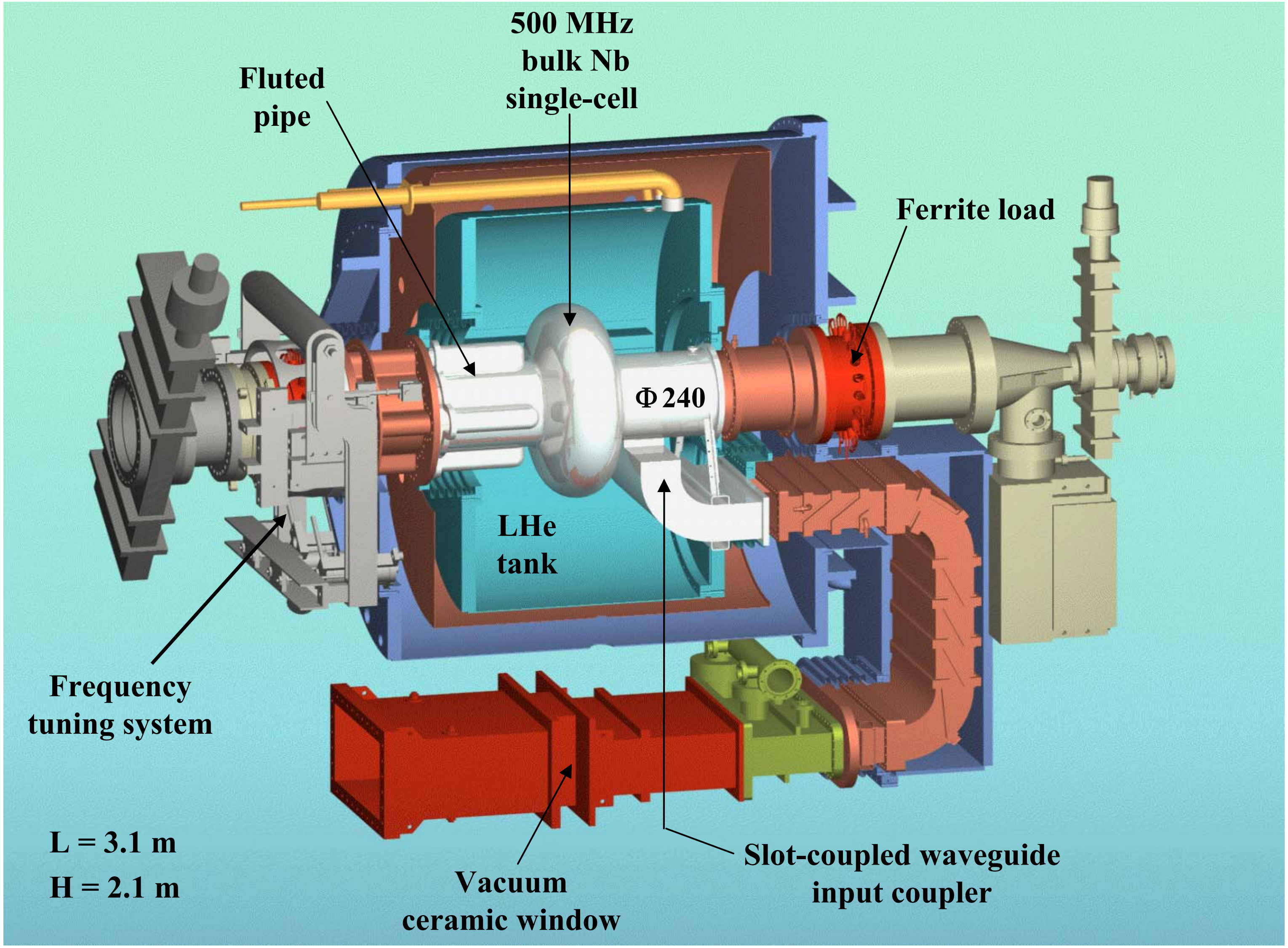
Other features of s-c cavities

Higher achievable E_{acc} ⟹ fewer cavity cells
(provided that the input coupler can handle the extra power)

Could affect the reliability, especially when reducing to a single plant
Most s.l.s using n-c cavities can still operate (~ full perf.) when 1 cav. out of use

High beam loading ⟹ zero Robinson stability margin ⟹ need for RF feed-back

CESR Cryomodule (500 MHz)

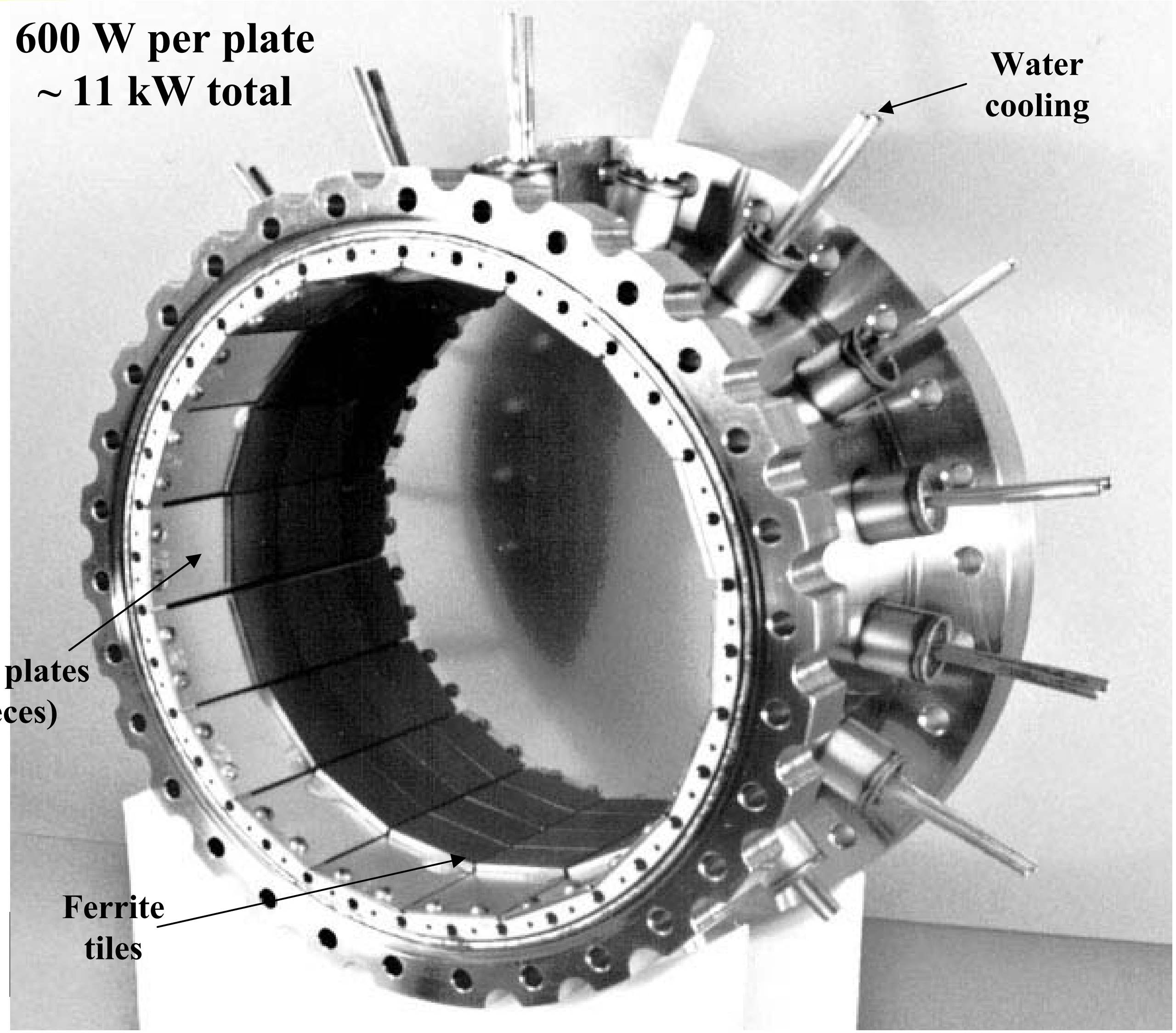


By courtesy of S. Belomestnykh, Cornell

Naked cavities prior to cold RF test

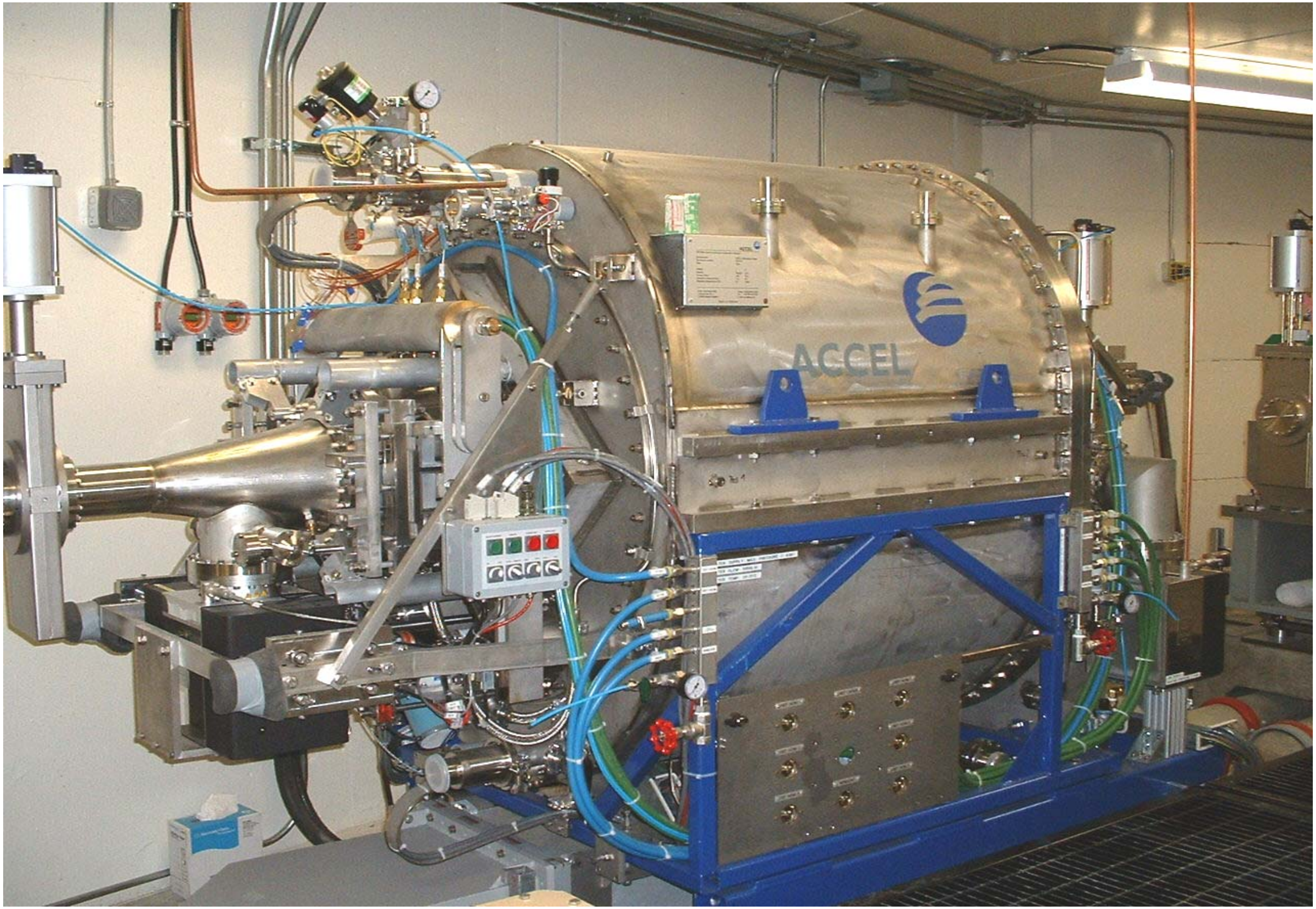
By courtesy of H. Vogel, ACCEL

CESR ferrite absorber



By courtesy of S. Belomestnykh, Cornell

CESR type cryomodule



By courtesy of Mark de Jong, CLS

Technology transfer Cornell → ACCEL → s.l.s

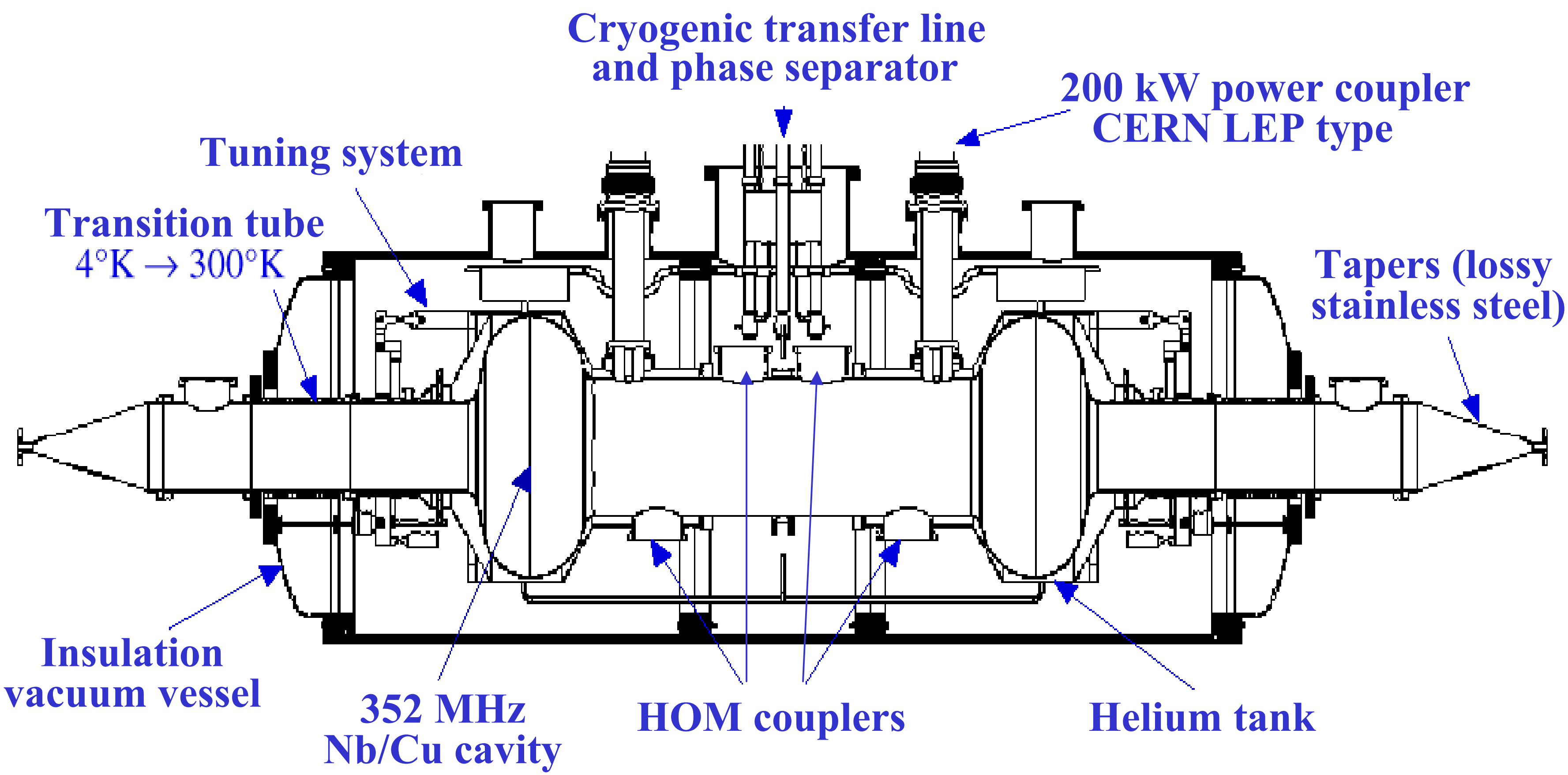
In 2000, CORNELL and ACCEL concluded a technology transfer agreement for the production of 2 CESR type cryomodules → available for other users

Availibility of a « turn key » product in the industry + successfull operation in CESR
Several new s.l.s decide to adopt this technology → 9 modules ordered at ACCEL (2 for CESR, 2 for TLS, 2 for CLS, 3 for Diamond)

	Nb of cells	Energy [GeV]	I_{beam} [A]	E_{acc} [MV/m]	Power [kW]	Status
CESR	4	5.3	0.75	6.7	350	2 c-m are in operation in CESR
TLS	1*	1.5	0.45	5.3	80	• c-m-1 under repair (window break-down during power test) • c-m-2 ready for power test at NSRRC • commissioning in TLS in Dec. 04
CLS	1*	2.9	0.28	8.0	250	• c-m-1 in operation since Oct. 03 for CLS commissioning @ 2MV, 100mA • c-m-2 under fabrication
Diamond	2*	3.0	0.30	6.7	280	under fabrication

For all cryomodules, $Qo \approx 1\ 10^{9}$ *@ 8 MV / m*
** + another one available as spare part or for further upgrade*

SOLEIL cryomodule design (352MHz)



200 kW / coupler → need for 2 cryomodules for $P_{RF} = 600$ kW with all IDs @ 2.75 GeV & 500 mA

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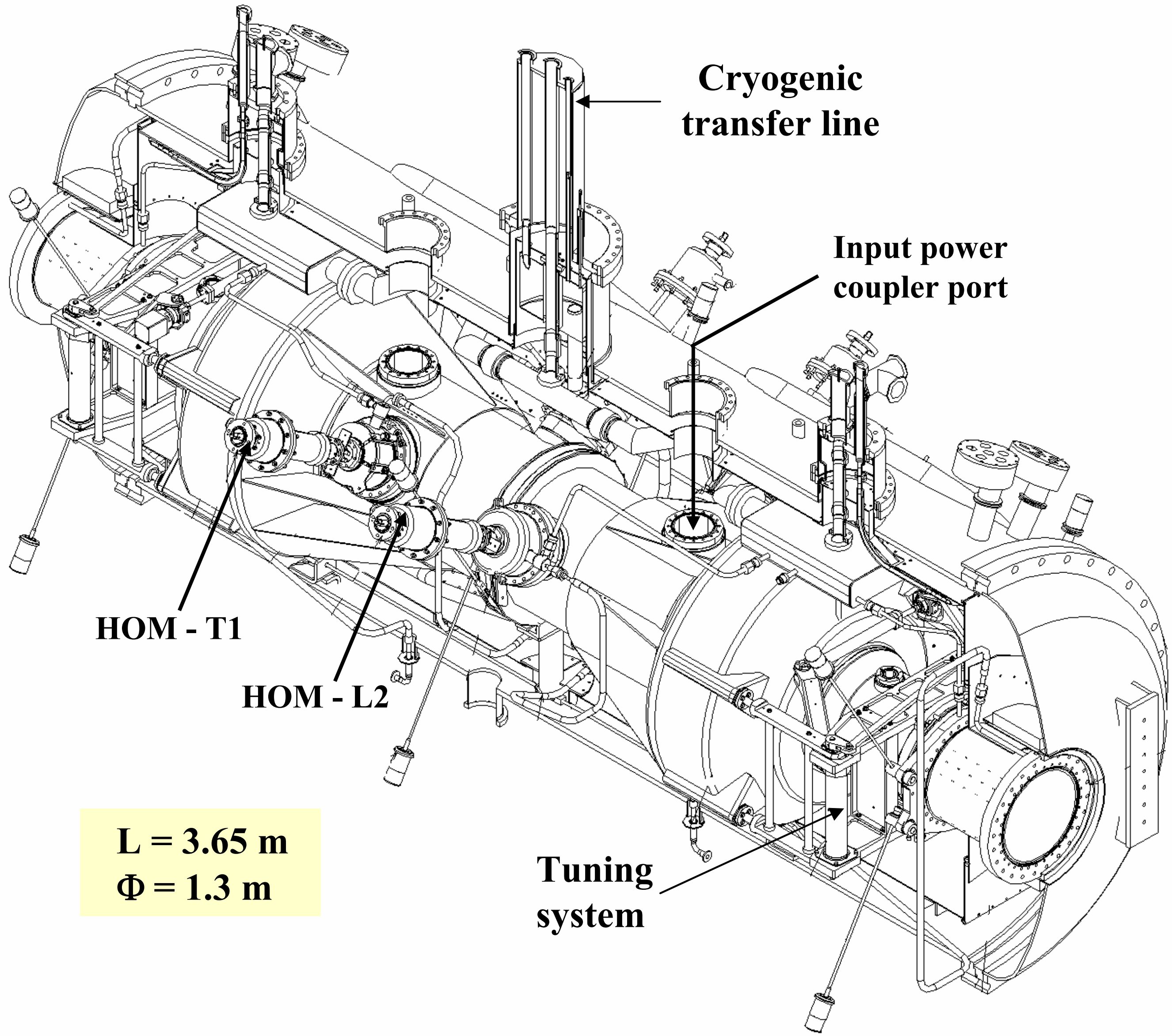
3D view of the SOLEIL cryomodule



L = 3.65 m
Φ = 1.3 m

SOLEIL cryomodule history

In 1998, decision to develop a 350 MHz cryomodule for SOLEIL
Prototype fabrication → CERN/CEA collaboration

In 2002, tests of the « prototype » in the ESRF storage ring

↓

V_{acc} > 3 MV
190 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 IDs)

↓

For the SOLEIL commissioning in May 2005, use of the prototype (after « refurbishment »)

Fabrication of a second cryomodule (installation in 2006)

Status of the SOLEIL RF system

SOLEIL SYNCHROTRON

Cryomodule N°1 (modified prototype)

- Collaboration agreements with CERN & CEA for the “refurbishment” tasks (replacement of the T-type HOM couplers, insertion of a LN2-cooled thermal shield, lengthening of the power coupler antennas)
- Cryomodule was de-mounted at CERN → cavity rinsing and RF tests in vertical cryostat
- Modified HOM couplers, thermal shield, …. under fabrication
  → all components available at CERN for assembling, in Sept. 2004
- Cryomodule re-assembling, cryogenic and RF power tests until end of 2004
- Installation in SOLEIL early 2005

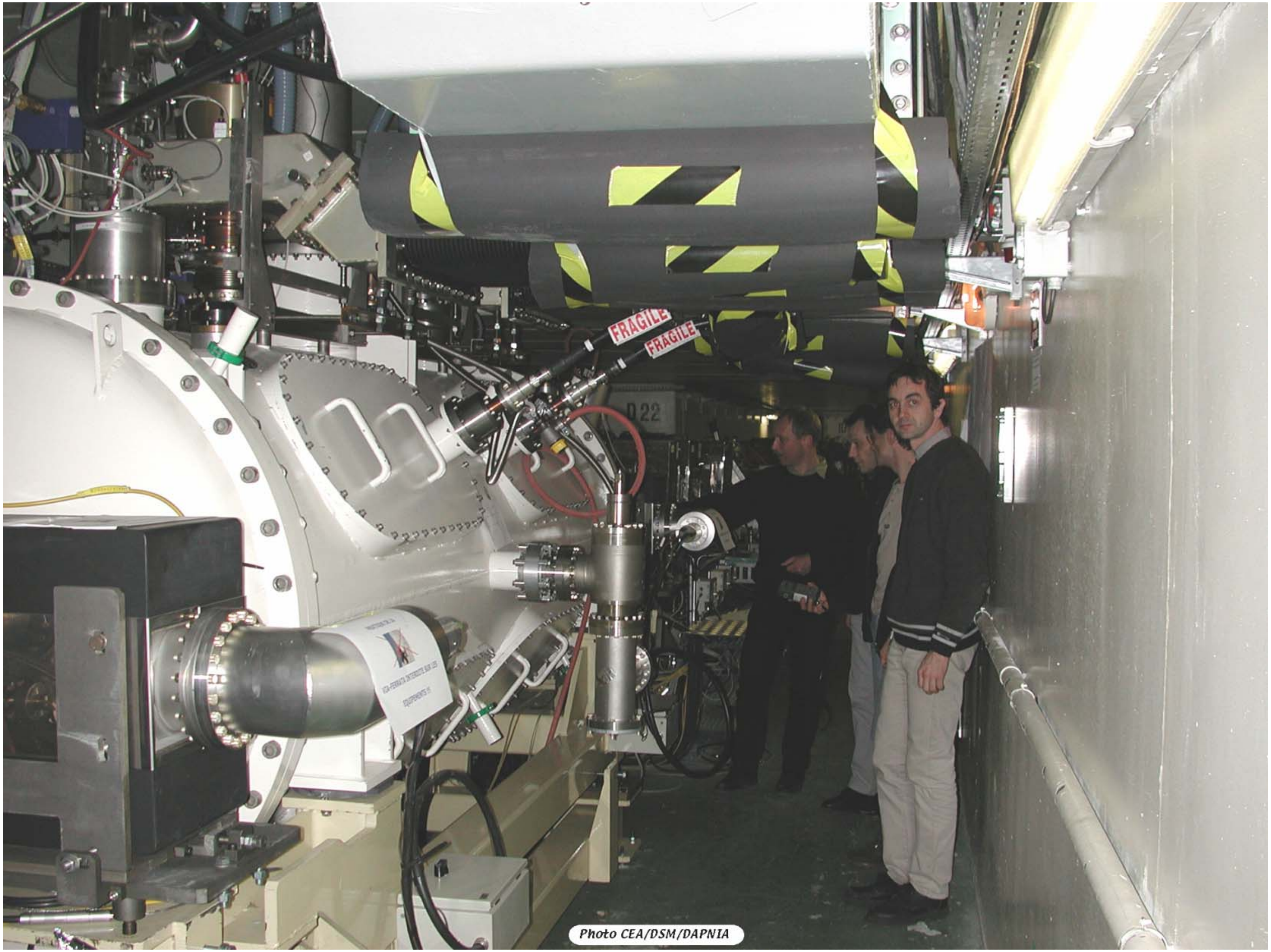
Cryomodule N°2 → Replica of N°1; call for tender process for a “turn key supply”

Cryogenic system → A single plant for the 2 cryomodules, based on a Helial 2000 from Air Liquide (40 l / h of LHe + 350 W at 4.5 K); under fabrication

RF power plants → Each of the 4 cavities powered with a 190 kW solid state amplifier; under fabrication

Start of SOLEIL SR commissioning with 1 cryomodule in May 2005; 2nd one in 2006

SOLEIL cryomodule in the ESRF storage ring



At CERN, the cryomodule waiting for access into the clean room

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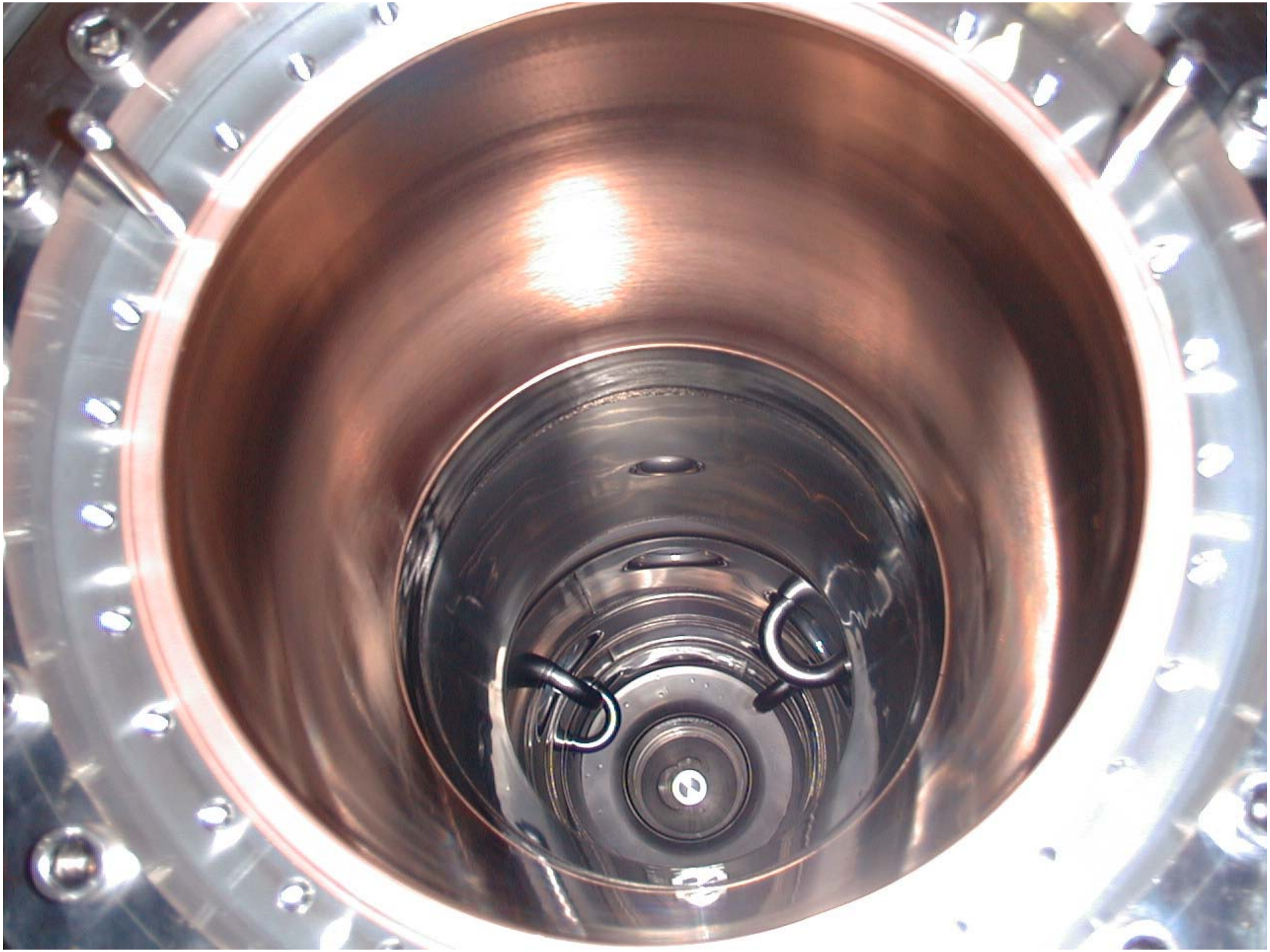
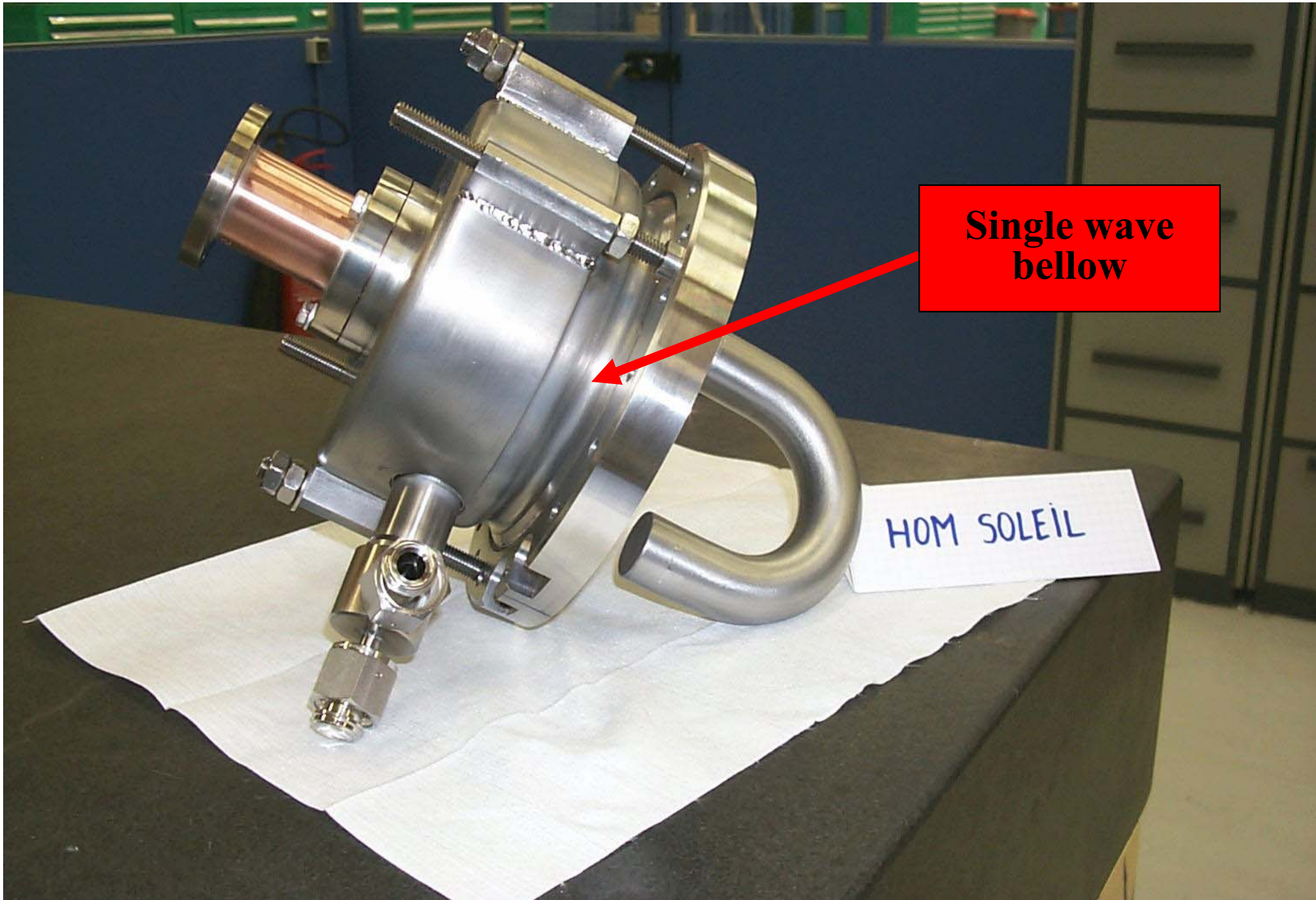
Inside the CERN clean room
Input power coupler removal

SOLEIL SYNCHROTRON

What the electron beam will see when entering into the cavity

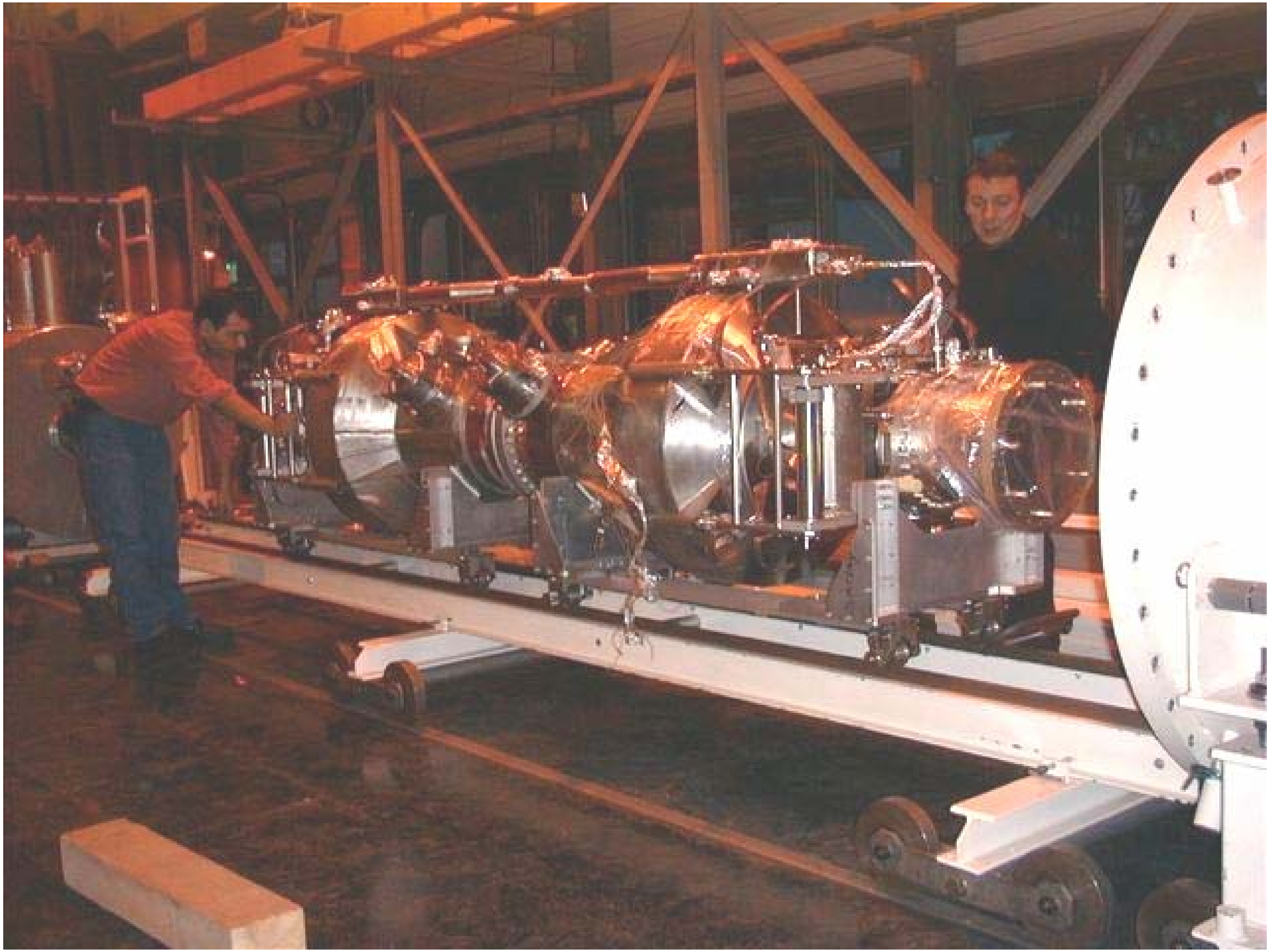


T - type HOM coupler



Back outside the clean room for removing the cavity string

Cavity string out of the cryostat



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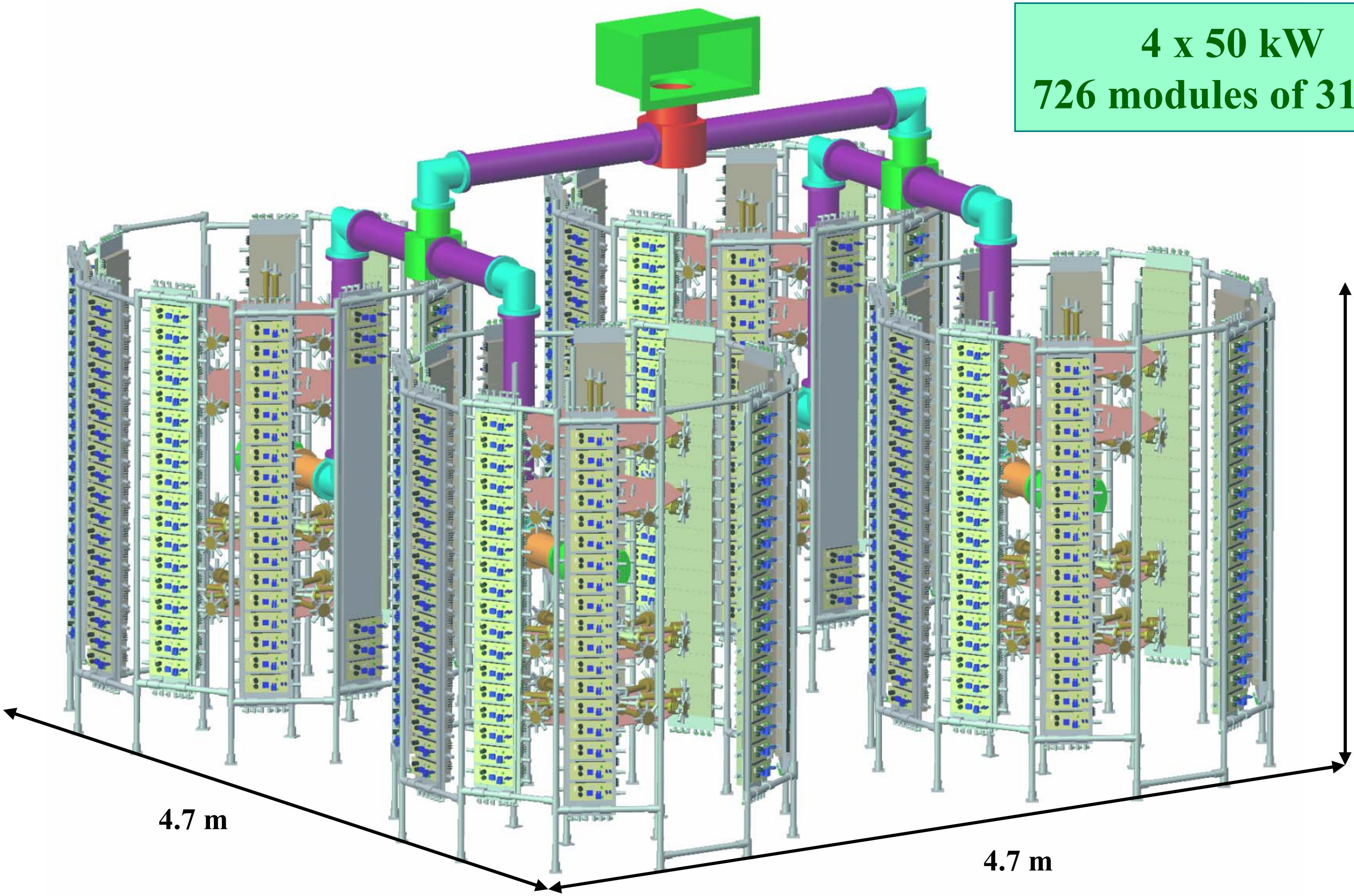
Storage ring 190 kW RF amplifier (« virtual »)

4 x 50 kW
726 modules of 315 W



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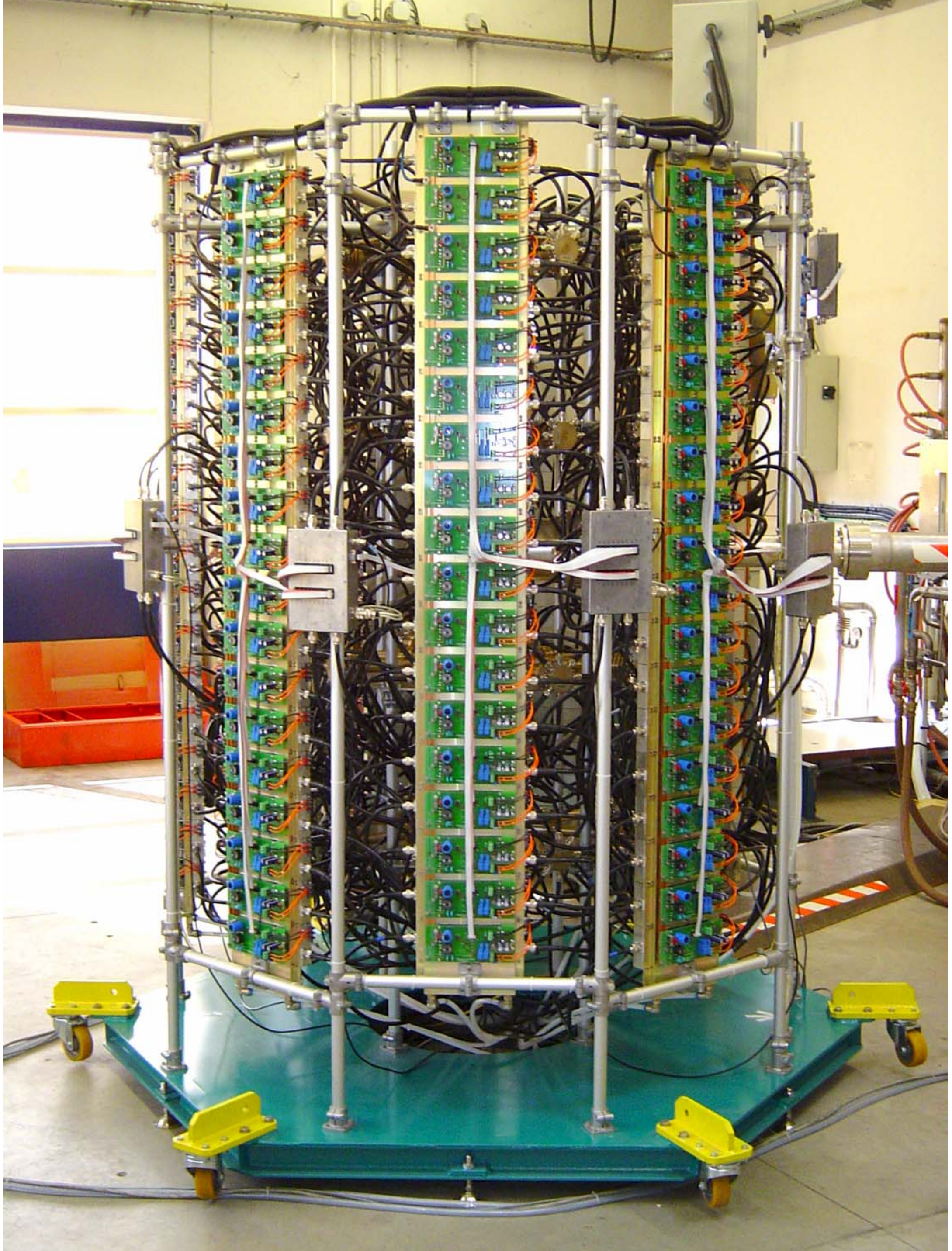
Booster amplifier (« actual »)



147 modules of 330 W

On March 5th, 2004
35 kW in dummy load

Long run test (500 h) at 30 kW without problem (max required : 20 kW)

Global efficiency ~ 50 % (circulators & power supplies included)

Electron beam lifetime and stability in s.l.s

High brightness ⟹ small tranverse dimensions (emittance)
High charge density ⟹ short lifetime (Touschek scattering)

Cure **: decrease charge density in lengthening the bunches using a harmonic RF system**

Several beneficial effects

- **Lifetime increase**
- **Additional Laundau damping (from RF non-linearity) ⟹ beam stabilisation**
- **Microwave instability (source of energy spread) ⟹ higher current threshold**
- **Bunch shortening option available, if desired for particular application**

Bunch lengthening with a harmonic RF system

SOLEIL SYNCHROTRON

Principle

$V_{sc} = V_{3h} \approx 1/3\ V_{1h} = V_{nc}$

Slope of the global RF voltage nearly zero at the bunch location

⇩

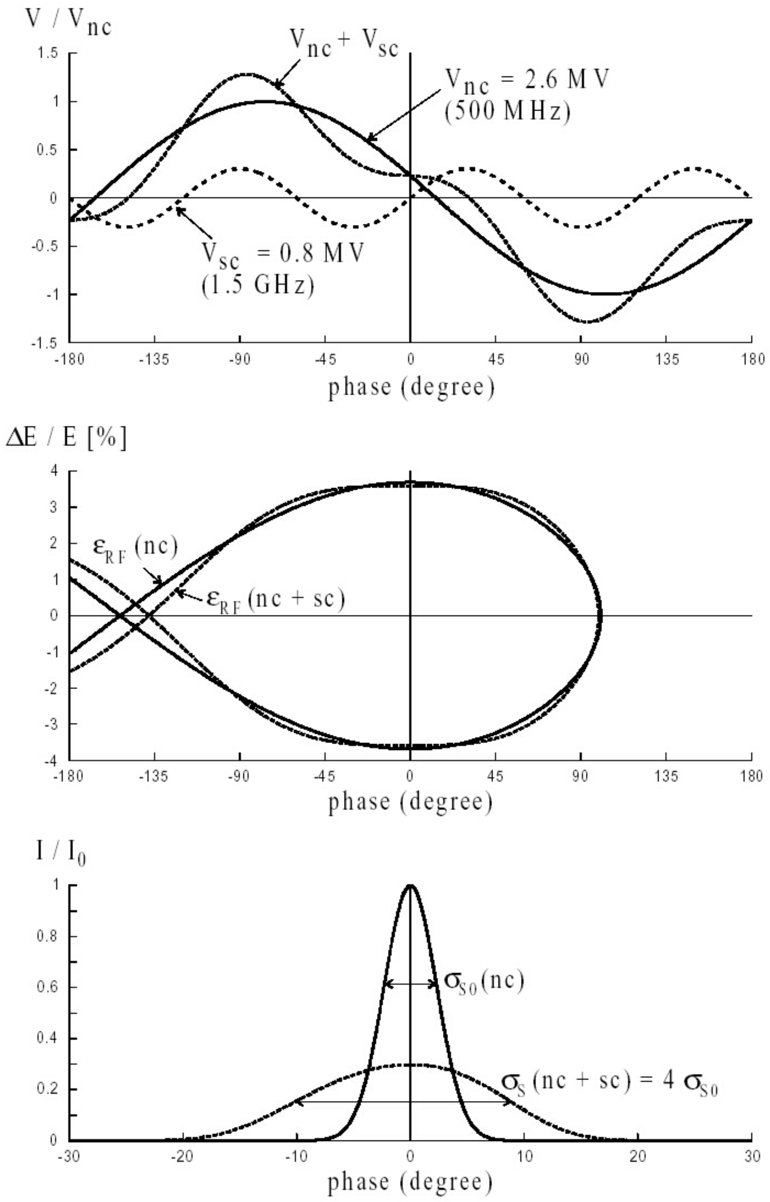
Lower longitudinal focusing

⇩

Bunch lengthening (ideally up to a factor 4)

Without affecting the energy acceptance

Exemple of the SLS combined RF system (500 MHz n-c + 1.5 GHz s-c)



Third harmonic RF systems in s.l.s

SOLEIL SYNCHROTRON

N-c systems

SUPER-ACO, BESSY II, MAX II, ALS

Efficient for beam stabilisation → « Landau cavities »

but relatively poor results in term of lifetime increase
due to transient beam loading effects
(gap of empty buckets in the bunch train for ion-clearing)

S-c systems

SLS, ELETTRA (S3HC in operation), BESSY II and PLS (projects)

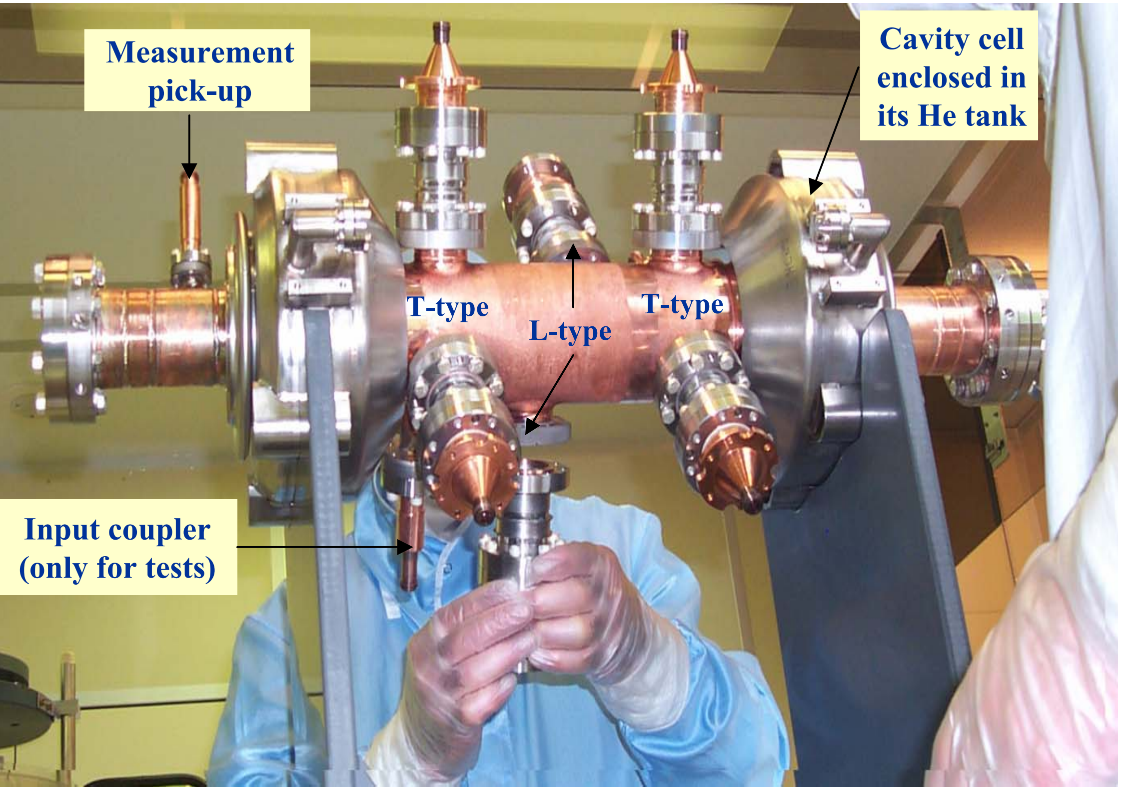
S-c systems (very high Q_o) present significant advantages as compared to n-c :

- **Ideal for passive operation : $\delta f \gg f / Q_o \rightarrow V_{ind} = R/Q \, f_r \, I_b / \delta f$, phase independant**
- **Fewer cavities with lower R/Q → lower transient beam loading effects (~ factor 10)**
- **No extra power to be supplied by the main RF system (2 systems are decoupled)**
- **Wider Robinson stability range (towards lower I_b)**
- **Easier to make it « invisible for the beam » by detuning**

SUPER-3HC design

SOLEIL SYNCHROTRON

SUPER-3HC: collaboration agreement between CEA-Saclay, ST, PSI and CERN (1999) for the design and production of 2 complete cryomodules, 1 for SLS and 1 for ELETTRA, « 1.5 GHz scaling » of the SOLEIL design



Assembling of the S3HC module at CEA-Saclay

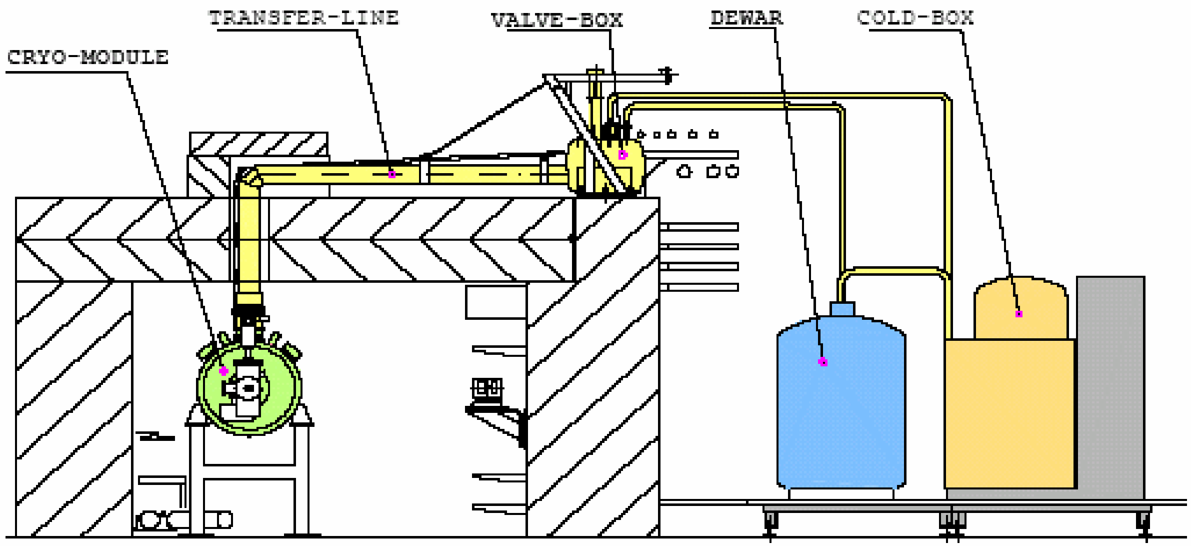
Cavity manufacturing and tests in vertical cryostat at CERN

Assembling, final cryo and RF tests at CEA Saclay

Changes from initial SOLEIL design :

- ✓ **4 T-type HOM couplers**
- ✓ **conduction-cooled HOM couplers (no He circulation)**
- ✓ **No input power coupler (operation in passive mode)**
- ✓ **GHe cooled thermal shield**

SLS S3HC cryogenic plant



Helial 1000 from AIR LIQUIDE
(10 l / h of LHe + 150 W at 4.5 K)

Component	Load	Comments
2 RF cells	22 W	Directly in LHe bath
2 L – couplers	3 W	Cooled by conduction
4 T – couplers	8.5 W	Cooled by conduction
2 Extremity tubes	0.2 W	With 2 x 0.05 g/s cold GHe
Cryomodule static losses	5.1 W	With 0.071 g/s cold GHe in thermal shield (60 K)
Transfer-lines	6.5 W	Assuming 0.5 W/m load
Total refrigeration power at 4.5 K: 45.3 W		
Total GHe flow: 0.171 g/s → 5.2 l/h of liquefaction duty		

Cryomodule component heat load estimates

SUPER – 3HC operational results in ELETTRA and SLS

S3HC (1.5 GHz) complements the existing 500 MHz n-c sytems (4 cavities)

« Warm and detuned » regime with GHe cooling → Temperature run away effect

Robinson instability (fund. of S3HC)
- Above 200 mA in SLS at 2.4 GeV
- Above 150 mA in ELETTRA at 2 GeV

Cold (4.5 K) typical operation conditions of S3HC in SLS and ELETTRA

	V_{1h}	V_{3h}	I_{beam}	δf	K_τ	Gap	$\delta\Phi$	$\delta\sigma$
SLS	2.1 MV	0.7 MV	0.32 A	60 kHz	2.2	20%	38°	24 – 66 ps
ELETTRA	1.8 MV	0.6 MV	0.32 A	70 kHz	3.	10%	30°	32 – 76 ps

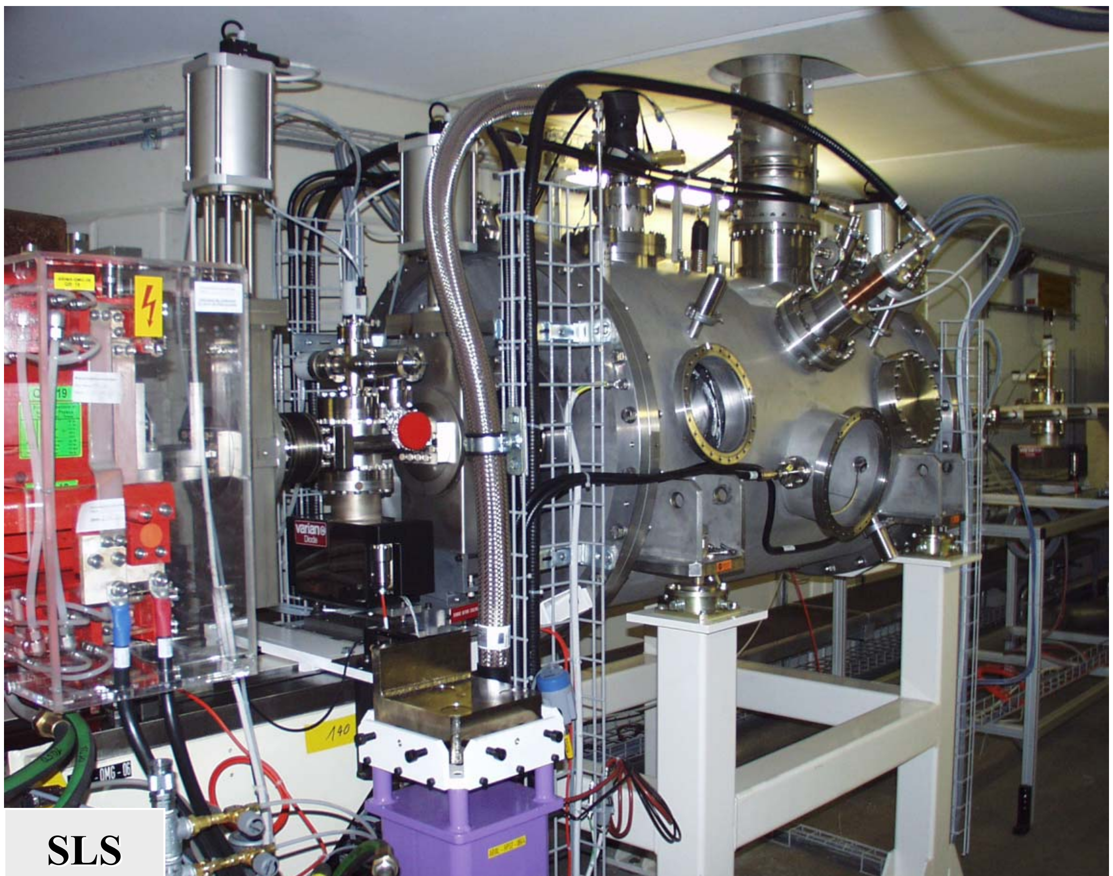
In addition to the lifetime increase ($K_\tau \approx 3$ in ELETTRA and 2.2 in SLS), complete suppression of the longitudinal multibunch instabilities (up to 320 mA @ 2 GeV in ELETTRA and 400 mA @ 2.4 GeV in SLS)

Transient beam loading : phase and bunch length modulation along the bunch train, $\delta\Phi$ and $\delta\sigma$ do not degrade too much K_τ and contribute to Landau damping.

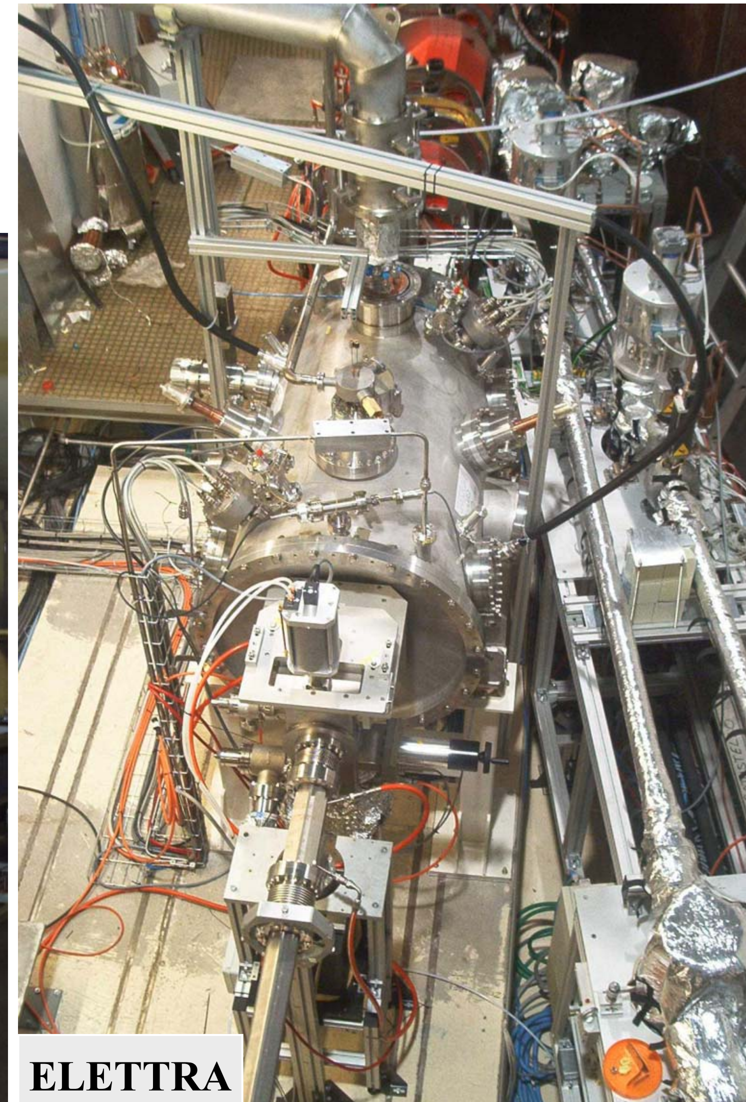
Operation :
- very flexible and easy in operation
- cryogenic plant failure in both SLS and ELETTRA
  + mechanical pb with the tuner in ELETTRA

« Teething problems »

SUPER-3HC cryomodules in SLS and ELETTRA storage rings



SLS



ELETTRA

SOLEIL SYNCHROTRON

Projects of s-c third harmonic system

BESSY II

With existing 4 n-c 1.5 GHz (3 x f_r) cavities → only 20 - 30 % gain in lifetime

Replacement of the 4 n-c cavities with a single s-c cavity :

- **1.5 GHz scaling of the CESR cavity, provided by Cornell**
- **Cryostat manufacturing and cavity integration by ACCEL**

POHANG LIGHT SOURCE (PLS)

E-S. Kim et al, WEPLT117, this conference

Summary and conclusion

Recently the s-c RF technology came into the world of the 3rd generation s.l.s, either as main accelerating systems or as bunch lengthening harmonic systems.

N.c cavities, with appropriate cures against the HOM excitation, are well suited for the first purpose and are satisfactorily running at many s.l.s. HOM free s-c cavities are regarded as an attractive alternative, provided that they prove to be as reliable in operation as the n-c version. Presently there exist two cryomodule designs, used (or planned) in s.l.s, the SOLEIL type and the CESR type → CLS, TLS, DIAMOND.

The advantages of using s-c systems for the bunch lengthening purpose are more evident. Their efficiency in improving the beam lifetime and stability has been fully demonstrated in SLS and ELETTRA. Although the reliability is also important for this application, it is less critical since, in case of cryogenic system failure, the operation remains possible, at reduced performance, with the harmonic system in "warm and detuned" state.

Acknowledgements

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At this conference

M. Pekeler et al, MOPLT041
G. Penko et al, TUPKF021
E-S. Kim et al, WEPLT117
L. Dallin, THPKF007
P. Bosland et al, THPKF028
J-M. Filhol et al, THPKF030
P. Marchand et al, THPKF031
C-C. Kuo et al, THPKF045