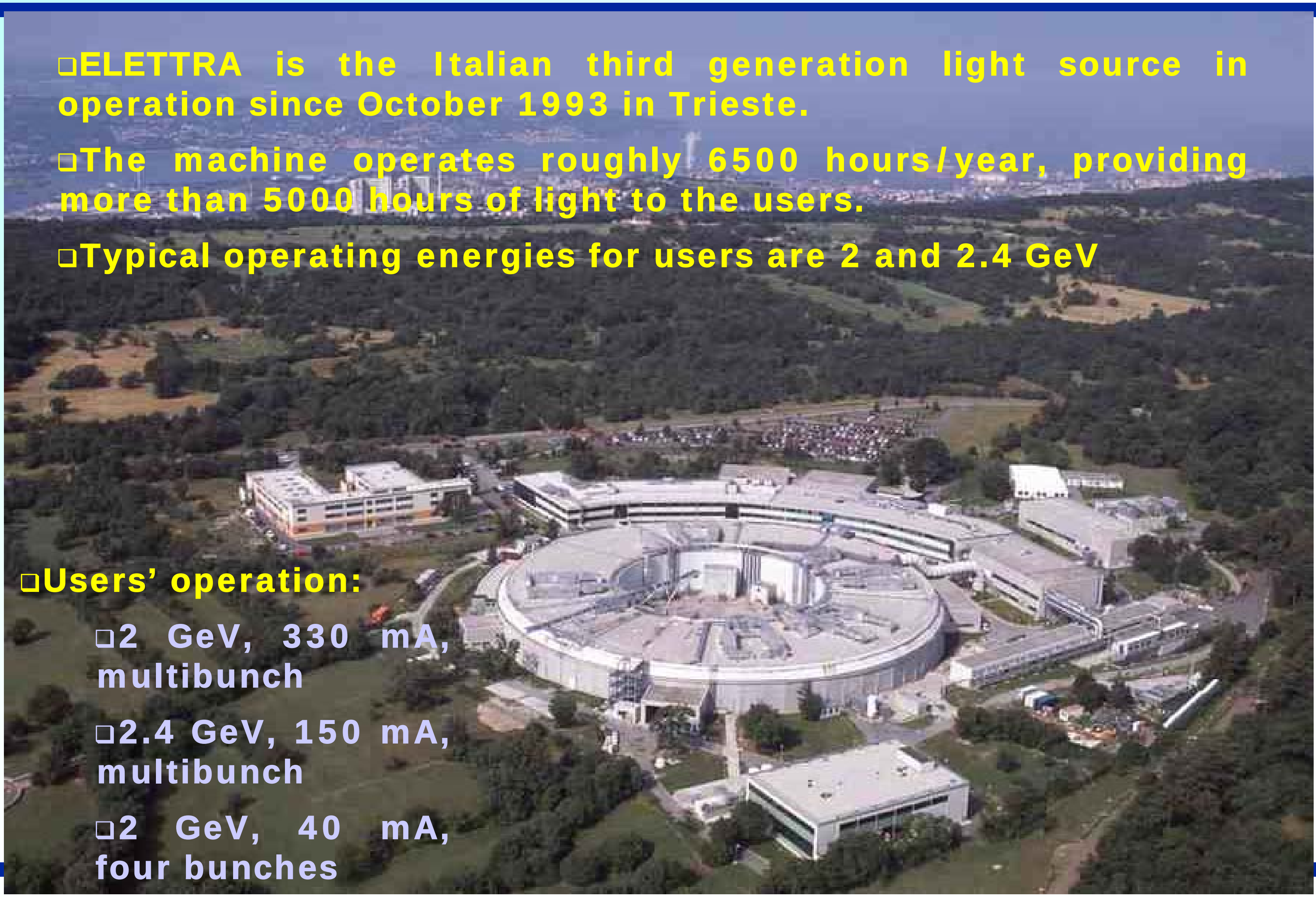
Elettra RF System Upgrade: Commissioning and Operation of the 500 MHz 150 kW Plant

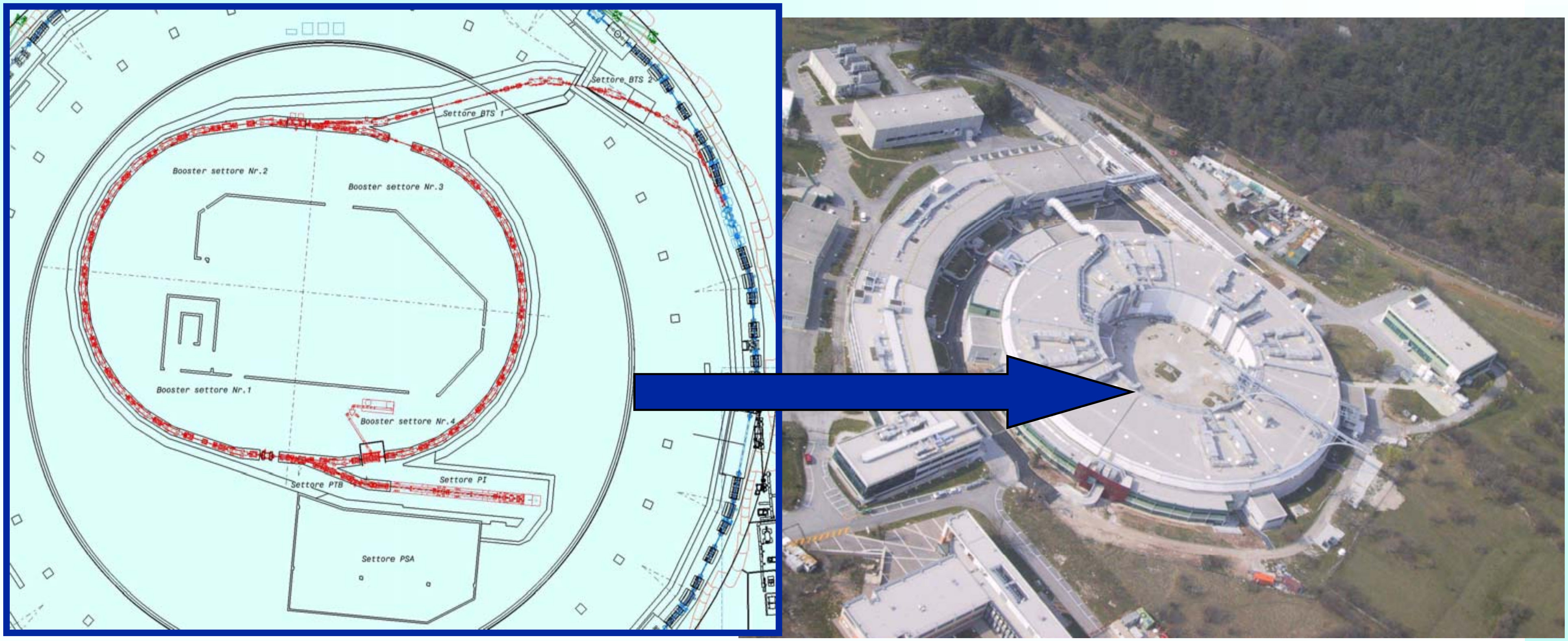
Alessandro Fabris
on behalf of the Elettra RF Group
Sincrotrone Trieste, Trieste, Italy.



- ELETTRA is the Italian third generation light source in operation since October 1993 in Trieste.
- The machine operates roughly 6500 hours/year, providing more than 5000 hours of light to the users.
- Typical operating energies for users are 2 and 2.4 GeV

- Users' operation:
  - 2 GeV, 330 mA, multibunch
  - 2.4 GeV, 150 mA, multibunch
  - 2 GeV, 40 mA, four bunches

- From the first run of 2008, injection is performed by a new full energy injector.



- Old linac is being upgraded and it will be used for FERMI, a single-pass FEL user facility.

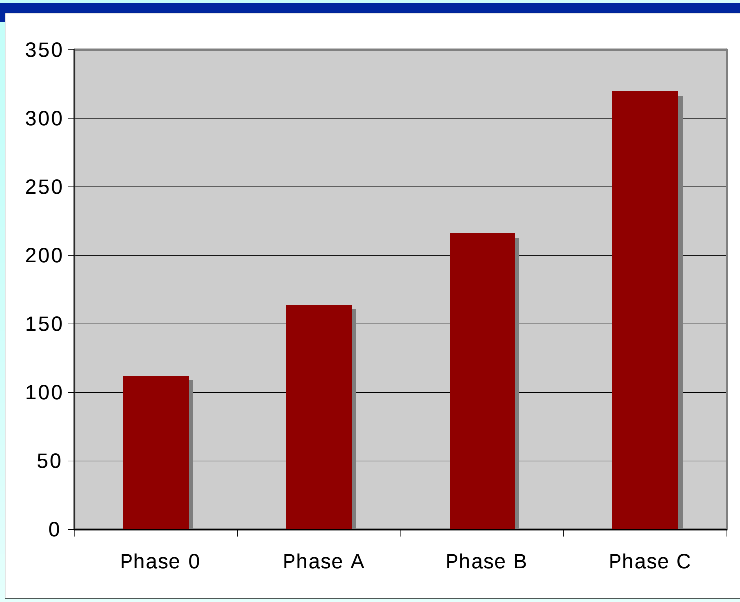
❑ORIGINAL RF SYSTEM:

- ❑Four 500 MHz 60 kW plants, using a UHF TV klystron as the main amplifying stage.
- ❑Each plant feeds an ELETTRA type cavity.

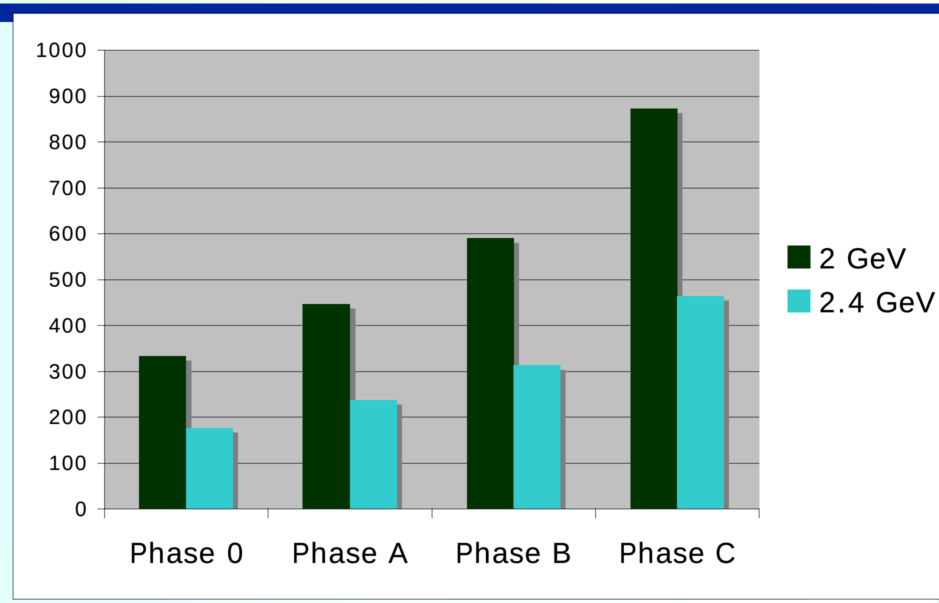
❑LIMITS OF THE ORIGINAL RF SYSTEM:

- ❑The demand of RF power has substantially increased during the years (121 kW for 330 mA at 2 GeV when the superconducting wiggler will be fully operational).
- ❑During the years this has been compensated by decreasing the gap voltage.
- ❑The higher RF power requirements also have reduced the safety margins on RF system operation.

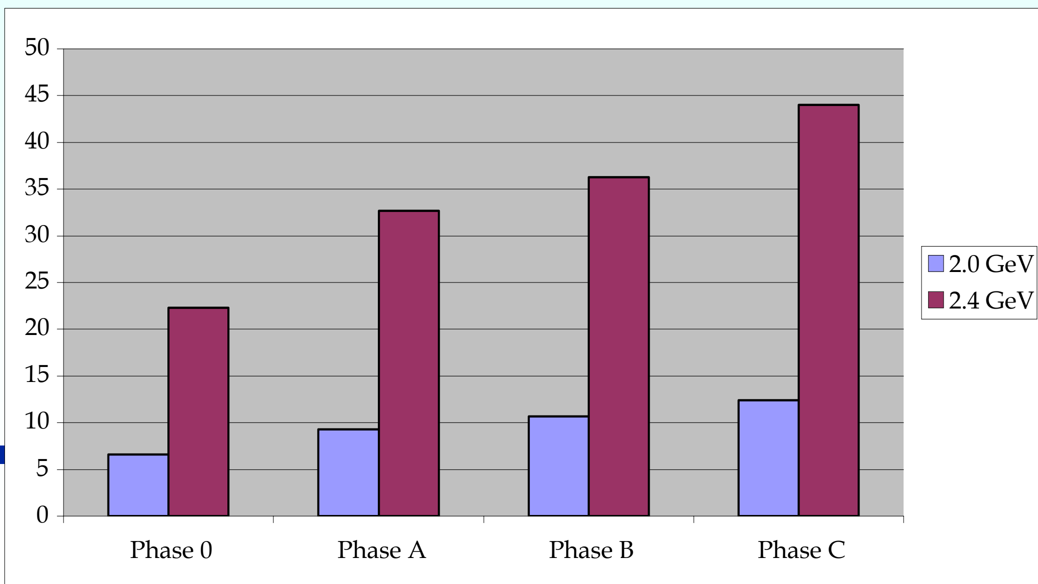
- **TARGET OF THE RF UPGRADE PROJECT:**
  - Provide the RF system with the necessary **operating margins**, when all IDs are operational.
  - Increase available RF power in view of possible increase of beam current and energy.
- **DESIGN STRATEGY:**
  - **Consistency** with other upgrades of the facility.
  - **Minimum interference** with machine operation.
    - Gradual approach.
    - No increase of the space for RF components in the machine.
  - Increase in three steps the available RF power from **4x60 to 4x150 kW**.
    - Phase A: 1x150 kW + 3 x60 kW
    - Phase B: 2x150 kW + 2x60 kW
    - Phase C: 4x150 kW
  - **Take benefit of working in the UHF band.**



➤Available beam power (in kW).



➤Maximum current (mA), RF power only.

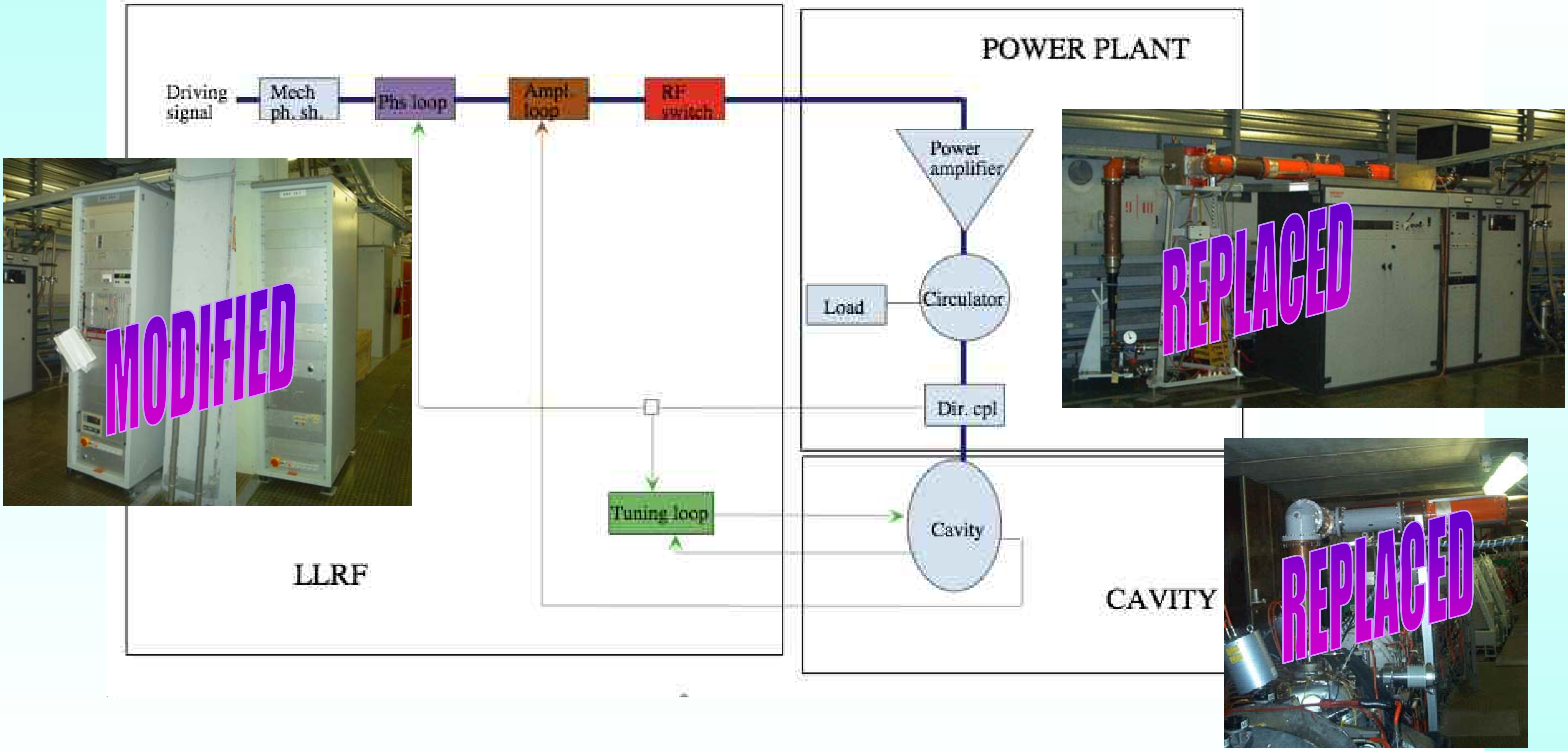


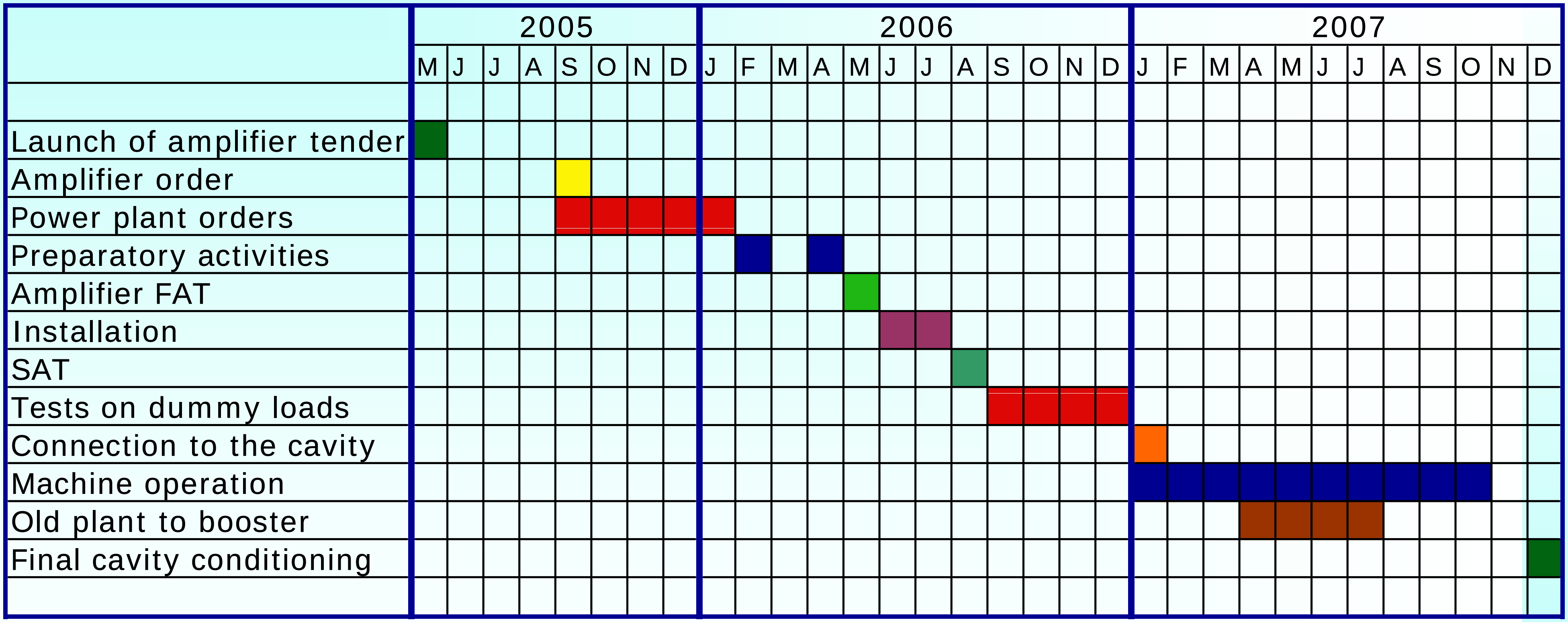
➤Touschek lifetime (hours) at the usual currents and energies (3HC not taken into account).

Note: Phase 0 is the original system

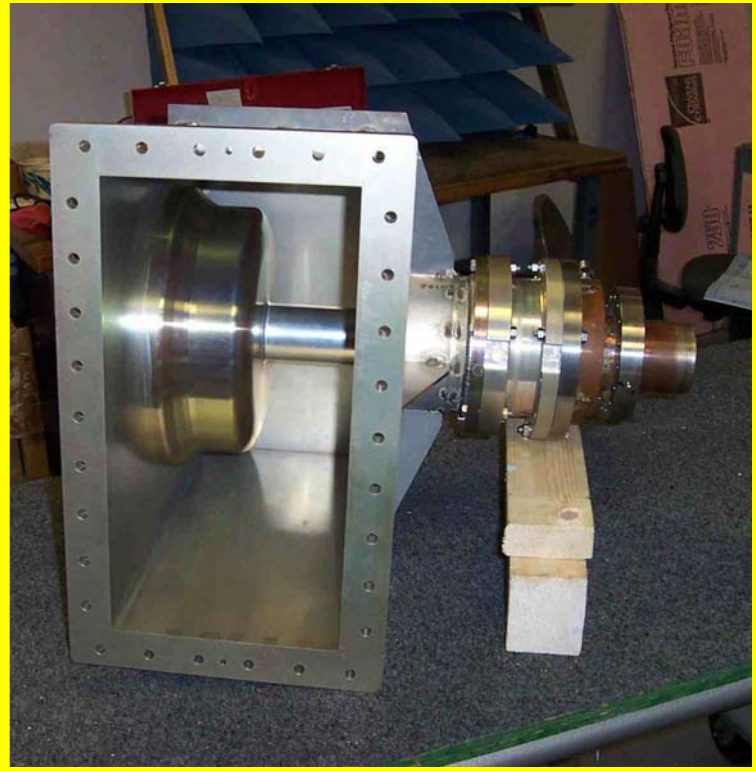
- **TECHNICAL CHOICES FOR PHASE A:**
  - **Target power : 150 kW cw at 500 MHz.**
  - Replace plant in section 9.
  - Restore and widen the safety margin of the storage ring RF system.
  - Build the amplifier combining two 80 kW IOTs.
  - Use 60 kW power plant for the new booster RF system.
  - Look for turn-key solutions to minimise internal work.
  - **Installation activities must be concentrated in the machine shutdowns.**
  - **Try to adapt the layout to the existing boundary conditions:**
    - Fit the amplifier between storage ring building columns.
    - Waveguide run suspended in order to save space.
  - Upgrades of cooling and electrical plants to be done considering the requirements of four 150 kW plants.

PHASE A


Driving signal
Mech ph. sh.
Phs loop
Ampl. loop
RF switch
POWER PLANT
Power amplifier
Load
Circulator
Dir. cpl
Tuning loop
Cavity
LLRF
CAVITY
MODIFIED
REPLACED
REPLACED

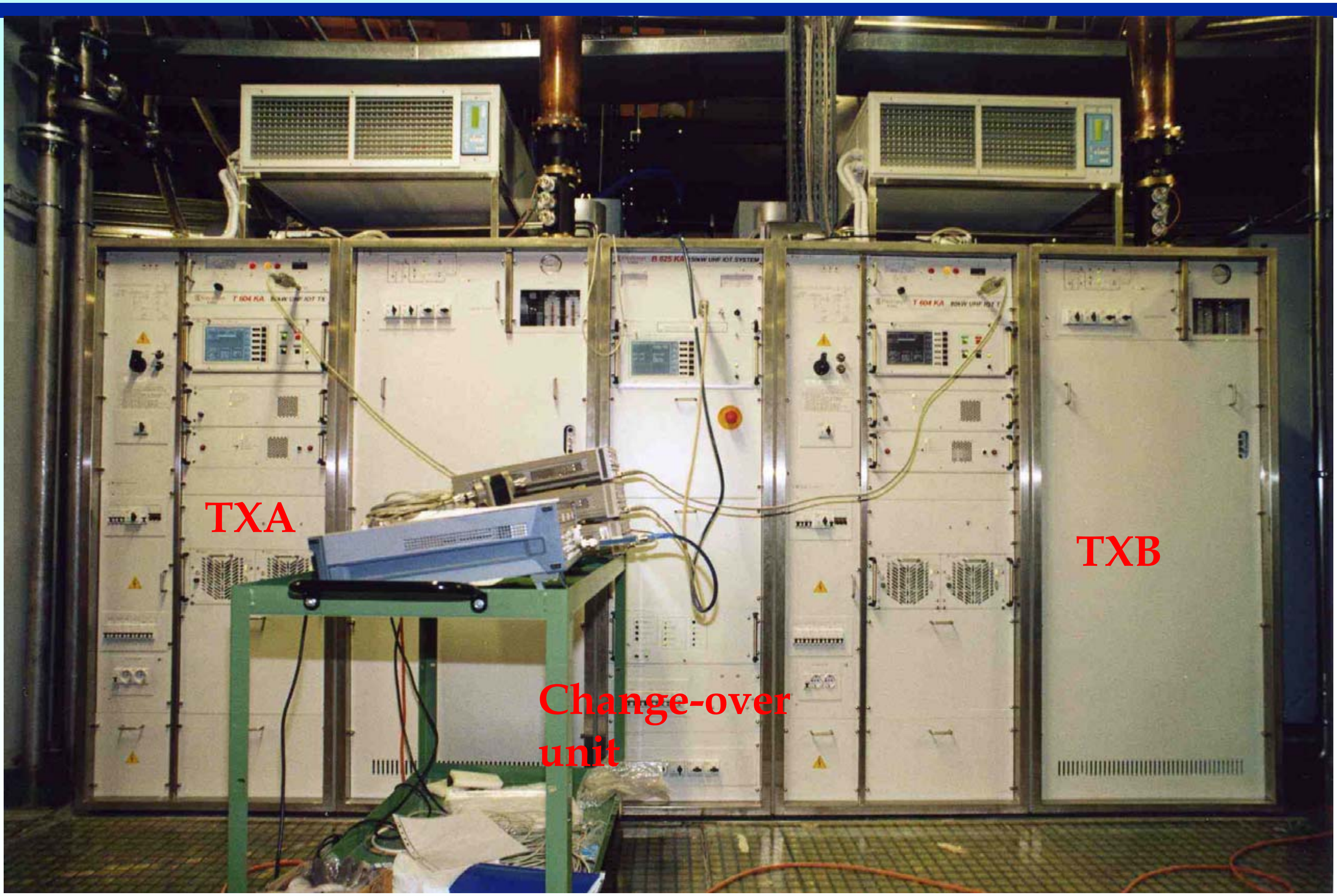

2005
2006
2007
M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
Launch of amplifier tender
Amplifier order
Power plant orders
Preparatory activities
Amplifier FAT
Installation
SAT
Tests on dummy loads
Connection to the cavity
Machine operation
Old plant to booster
Final cavity conditioning

- The cavity in section 9 was replaced.
- Internal shape similar to the original ones.
- Upgraded cooling efficiency to operate at higher power (120 kW through the coupler, 60 kW wasted on cavity walls).



- In parallel with power plant activities:
  - Improvements to coupler diagnostics.
  - Design of an optimized door-knob waveguide to coaxial transition.

- The 150 kW power amplifier is made combining two 80 kW transmitters.
- **The final stage of each transmitter is a 80 kW IOT.**
- Each transmitter is completely independent to allow standalone operation.
- The output of the two transmitters is combined by means of a **switchless combiner.**
- It has been acquired as a **turn-key system from industry (ELECTROSYS, Orvieto, Italy).**


TXA
TXB
Change-over unit

❑RF CHAIN

- ❑The tube installed is Thales TH 793.
- ❑RF drive is a 400 W solid state LDMOS amplifier.

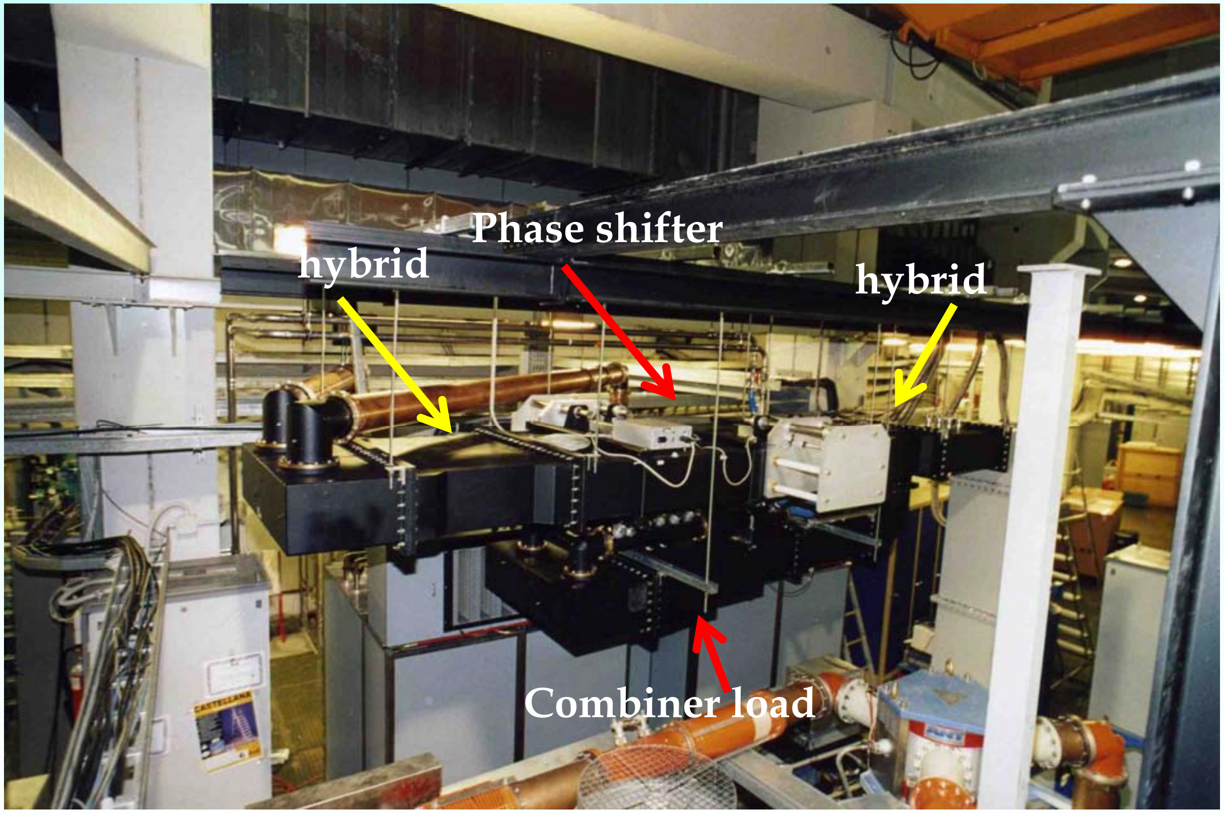
PS specifications (one tube)	
Power	80 kW
High Voltage Supply	37 kV, 3.8 A
Heater supply	12 V ,40 A
Ion Pump Supply	4 kV, 3 mA
Grid Supply	-150 V, ± 130 mA
Focus Supply	12 V, 30 A

Electrical Consumption (one tube)	
Solid state	1.5 kW
IOT amplifier	123 kW
Cooling unit	2.5 kW
Blowers	3.5
Ancillaries	3 kW
TOTAL	133.5 kW
Power factor	>0.9

- **HV POWER SUPPLY:**
  - **37 kV, 3.8 A (for each transmitter)**
  - **Switched mode power supply.**
  - Compactness.
  - Low residual ripple.
  - Beam voltage is stabilised independently of:
    - Output power variations.
    - Mains input variations.
  - Switching frequency: 17 kHz
  - **Switching frequency can be adjusted** in the range 16 to 21 kHz.
  - No oil capacitors or transformers are used.
  - No crowbar tube.

❑SWITCHLESS COMBINER

- ❑Four ports device made up from two hybrids and a variable phase shifter.
- ❑Depending on the phase shifter position one has four modes of operation.



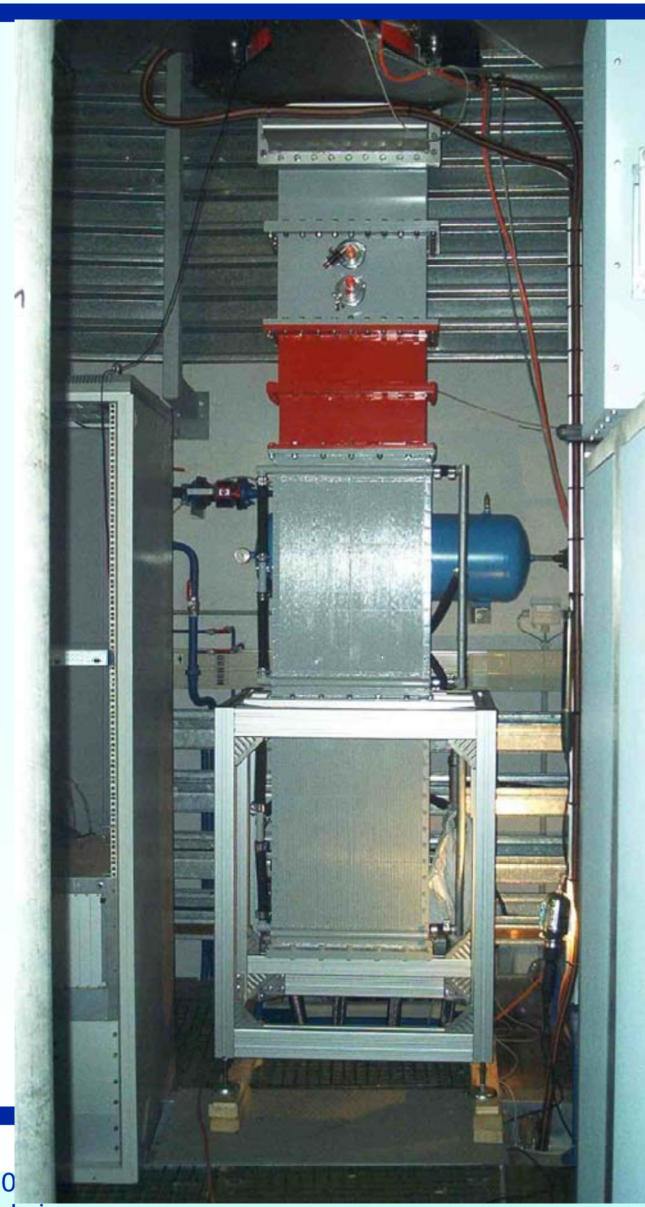
❑**Advantages**:

- ❑3 dB power loss when one transmitter is out of service
- ❑Maintenance of one transmitter can be made while the other is in service
- ❑Already on the market

❑**Disadvantages:**

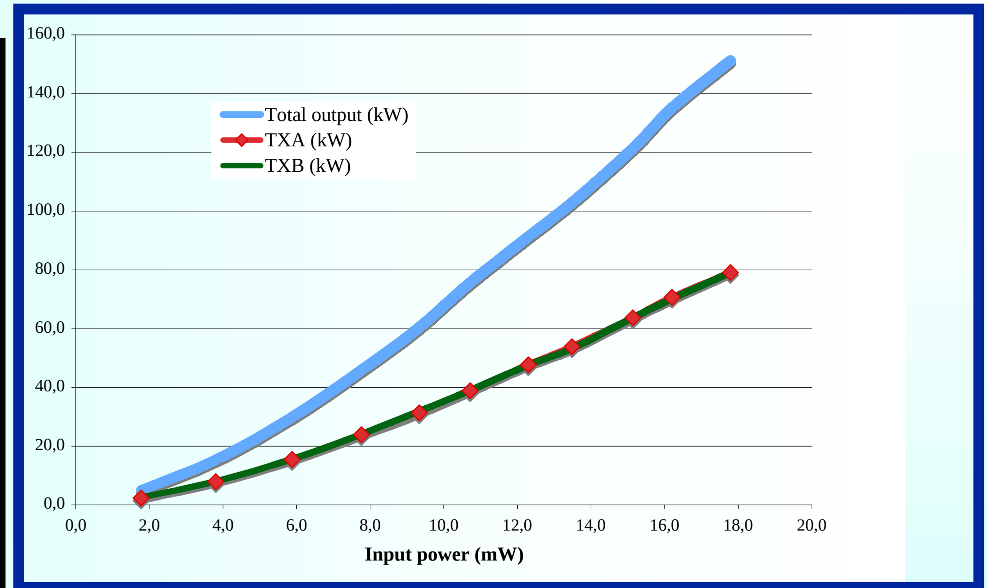
- ❑Dimensions

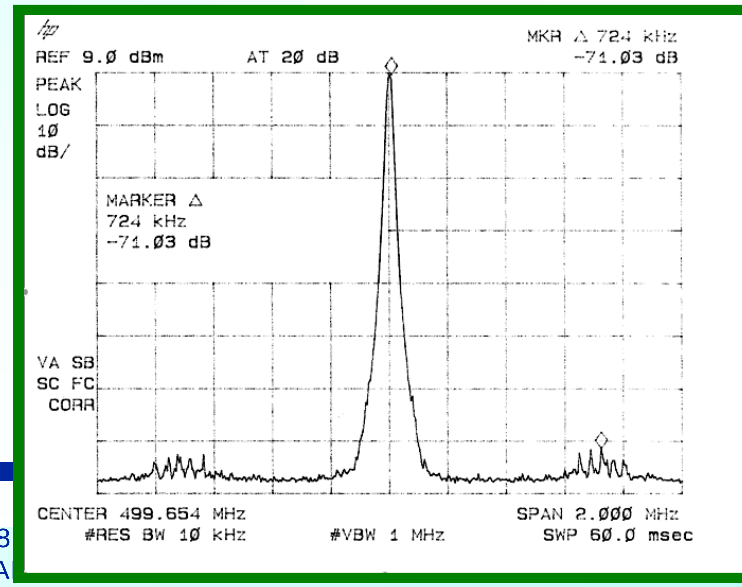
- **Other components:**
  - 200 kW circulator from AFT (Germany)
  - 200 kW Loads from S.P.A. Ferrite (Russia)
  - Waveguide components from MEGA (USA)

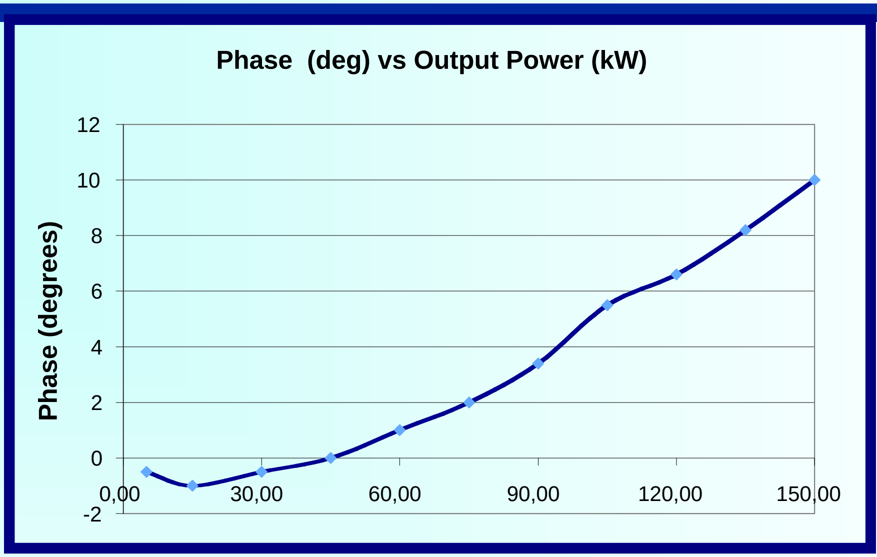


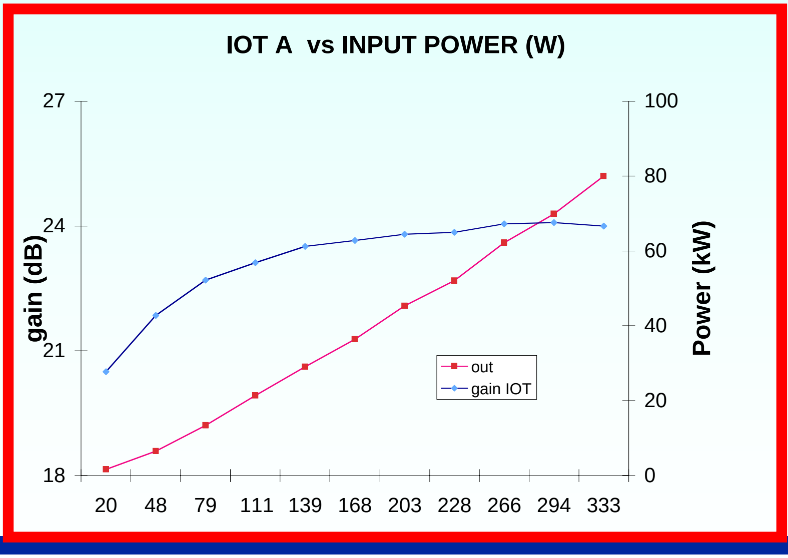
- **Combiner, circulator and waveguide run are suspended**

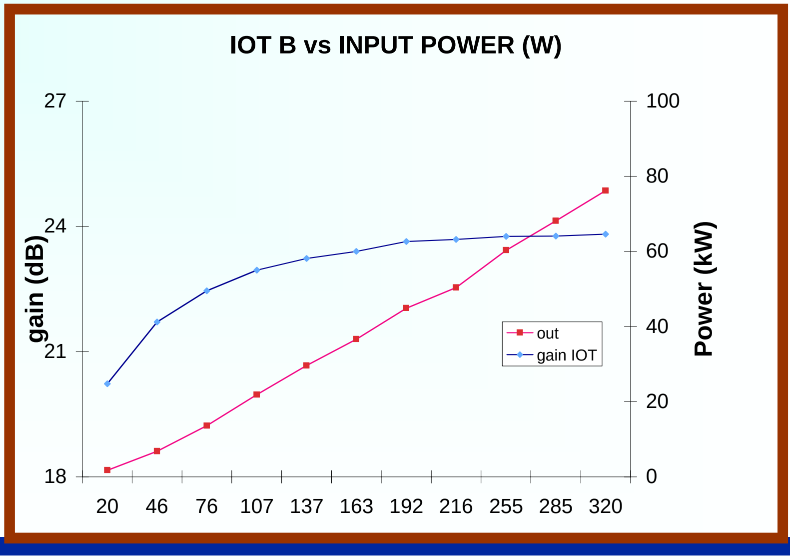
Output power	150 kW
Frequency	499.654 MHz
Bandwidth (± 0.5 dB)	> ± 2MHz
Total gain	69.3 dB
Gain IOT A	24 dB
Gain IOT B	24.1 dB
I.L. Combining system	<0.1 dB
Total phase variation (0 to 150 kW)	11 degrees
Harmonics	< 41 dB
Signal to noise	<71 dB






Phase (deg) vs Output Power (kW)
Phase (degrees)
12
10
8
6
4
2
0
-2
0,00
30,00
60,00
90,00
120,00
150,00


IOT A vs INPUT POWER (W)
gain (dB)
Power (kW)
27
24
21
18
100
80
60
40
20
0
20
48
79
111
139
168
203
228
266
294
333
out
gain IOT


IOT B vs INPUT POWER (W)
gain (dB)
Power (kW)
27
24
21
18
100
80
60
40
20
0
20
46
76
107
137
163
192
216
255
285
320
out
gain IOT

❑LONG TERM DUMMY LOADS TEST

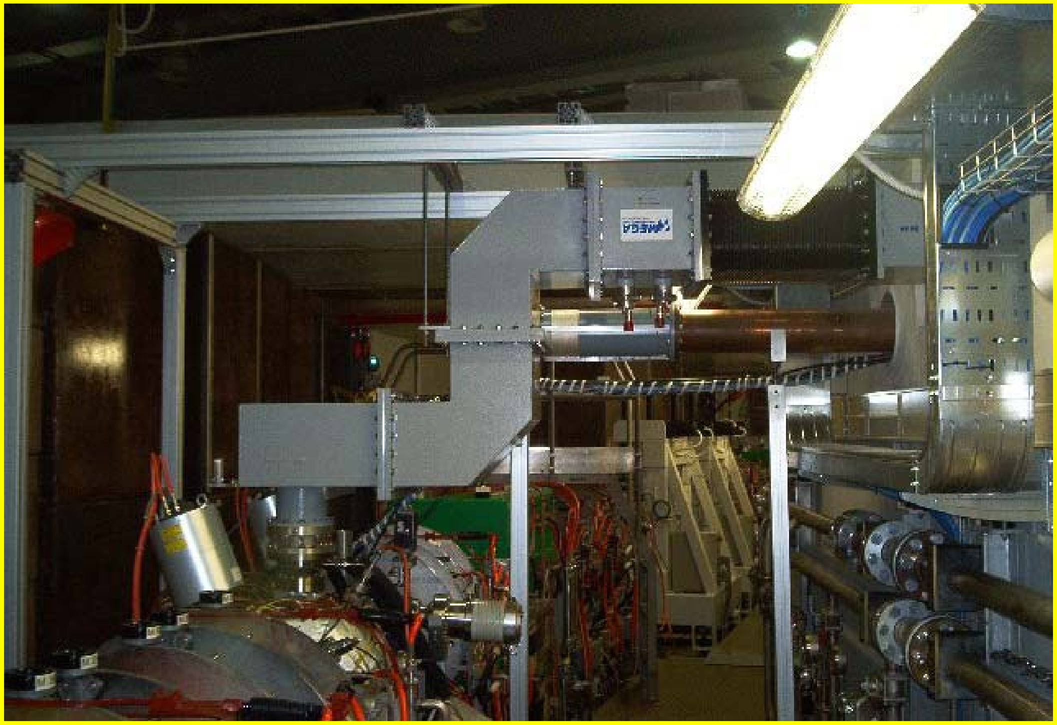
❑Before connecting the new system to the cavity, **the amplifier was let in operation** connected to the circulator and two dummy loads **24 hours/day** at different power levels from 100 to 150 kW in parallel with machine operation (almost 2000 hours).

❑The purpose of this text was to debug the new plant before starting operation on the storage ring.

❑MAIN IMPROVEMENTS FOLLOWING THE TEST (performed by the tube and/or the amplifier manufacturers):

- ❑**Improvement to input cavity** to improve behaviour at high beam current.
- ❑**Improvement to arc detectors** to have more light intensity on the photo resistor.
- ❑**Improvement to coax line** just after the tube, to avoid effects due to heat load.

- **Operation on the machine started in January 2007.**
- A standard WG to coaxial transition has been used for the first year of operation.
- Since the cavity was not yet been conditioned at full power, input power was limited to 60 kW.



- **FIRST YEAR EXPERIENCE**

- **The change of the power source was very smooth.**

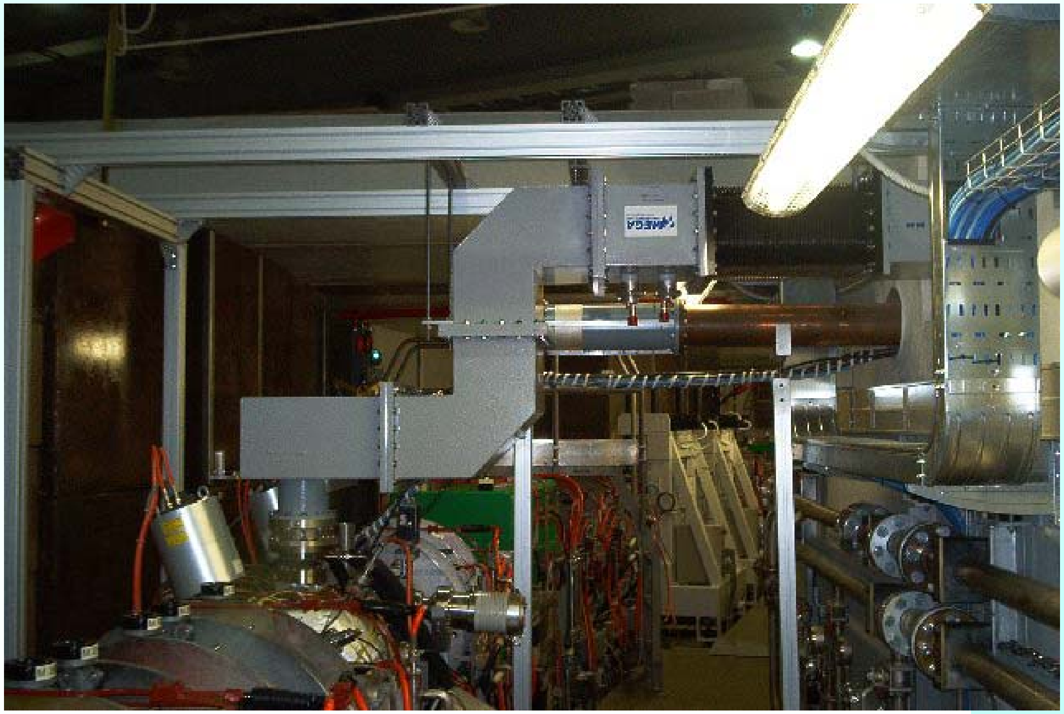
- Operation of the new system has been very reliable (no faults) till middle September 2007 (i.e. roughly 5000 hours of machine operation).

- In September **TXA had few trips** (four trips totally).
  - **Trips were related to a dI_b/dt increase.**
  - **At the second trip in one day, since it was not possible to investigate the problem with the machine on and the shutdown was near, we took benefit of the flexibility of the system:**
    - **TXA switched to the combiner load.**
    - **Cavity powered by TXB only.**

- **Flexibility of the layout has greatly helped in minimising downtime.**

- **TRIPS INVESTIGATION**
- The tests showed that the trips were related to tube A.
- **During the autumn shutdown a high voltage reconditioning on tube A was performed which solved the problem.**
- However during the maintenance of the system, tube B needed to be replaced.
- **Replacement of the tube was very fast and operation at 150 kW was re-established.**
- **Now working on understanding of the fault and measures to avoid it.**
- Interlocks have been added to limit output power and exclude automatic re-start.
- **TUBE STATISTICS:**
    - **TXA: same tube till the beginning (now 9700 hours)**
    - **TXB: tube now has 3100 hours (in two periods: 2500+600 hours)**
- **Up to now no faults in 2008.**

- **Completion of cavity conditioning at full power.**
  - Requires the machine tunnel closed and searched.
  - Allowed to do it only in December 07.
  - Installed the new waveguide to coaxial transition.
- **Amplitude modulation**
  - Reached 65 kW cw (wasted power).
  - Pressure at 65 kW after 2 days of conditioning = 1 e-9 mbar.
- **Frequency modulation:**
  - 150 kHz depth, 150 Hz mod frequency.
  - 60 kW reached in one day.
  - Final pressure=3 e-9 mbar.



- **Completion of the conditioning concludes the first phase of the Elettra storage ring RF upgrade.**
- At this point:
  - ***A 25 % increase of the total available RF power*** for cavity and beam is available.
  - ***The gap voltage in one cavity can be increased by a factor 1.4.***
  - ***A 20% increase of the total RF voltage is possible.***
- **Safety margin to the Elettra RF system has been restored.**
- **In addition removed power plant is in operation in the booster.**

- ***TASKS FOR 2008:***
  - **Investigate and define new operative conditions** for the machine to exploit the increase in available power (also in relation with the new injector):
    - Different cavity temperatures.
    - Maximization of total RF voltage.
  - **Test with beam of the WG to coaxial transition.**
    - Increase of power.
    - Test of all diagnostic and interlock devices added to the coupler.
  - **Implement HOM board.**
  - **Investigate reliability aspects in collaboration with the manufacturers.**
  - **Since now RF in not the limiting factor to higher currents, examine upgrade of the remaining plants** in relation with:
    - ***The other upgrades of the facility.***
    - ***The possibility of providing a spare plant for the booster.***

THANK YOU FOR YOUR ATTENTION

➤**ACKNOWLEDGEMENTS**

- ➤The contribution of the colleagues of the Elettra RF Group is gratefully acknowledged:
  - ➤Cristina Pasotti
  - ➤Mauro Rinaldi
  - ➤Mauro Bocciai
  - ➤Luca Bortolossi
  - ➤Marco Ottobretti