Elettra Sincrotrone Trieste

Elettra
Sincrotrone
Trieste

RF Status and Elettra 2.0 upgrade

M. Bocciai, C. Pasotti, M. Rinaldi

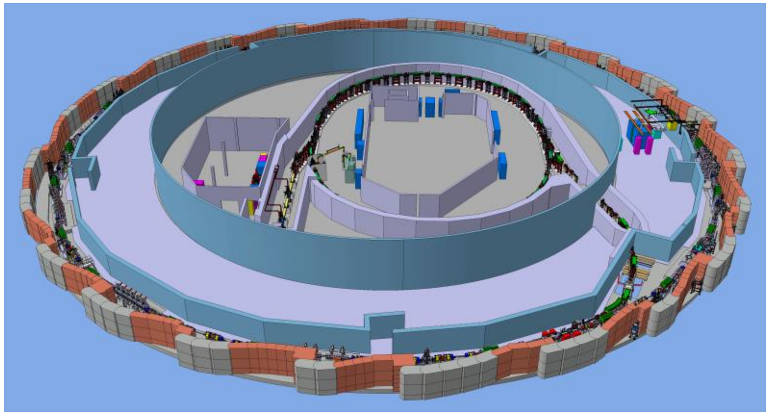
Outline

- ✓ Status of the Elettra RF System
- ✓ RF reliability
- ✓ IOT Replacement
- ✓ New vacuum Pump
- ✓ Elettra 2.0 project
- ✓ 100 (130) kW Solid State Transmitters
- ✓ Conclusion
- ✓ ESS Project

* From RF power meters data

Elettra Facility

- ✓ 2.0 / 2.4 GeV Machine in operation since 1994
- ✓ 3rd generation light source, user dedicated facility (> 5000 h/year)
- ✓ 1994 - 2008 Decay mode
- ✓ 2008 up to date Full Energy Injection and Top-Up mode



Elettra Storage Ring Parameters		
Storage ring circumference [m]	259.2	
Number of achromats	12	
Straight sections length [m]	6 (actual 4.8 for ID's)	
Beam revolution frequency [MHz]	1.157	
Harmonic number	432	
MB filling pattern (ions cleaning gap)	96%	
Tunes: horizontal/vertical	14.3 / 8.2	
Beam energy [GeV]	2	2.4
Horizontal emittance [nm-rad]	7	9.7
*Maximum energy lost per turn (ID's included) [keV]	**260**	**500**
Bending magnet field [T]	1.2	1.45
Injected current [mA]	310	160
Energy spread (rms) %	0.07	0.12
Lifetime [h] (natural)	8.5	32
Bunch length (1 σ) [mm]	5.4	7
Accelerating voltage [MV]	1.69	
Synchronous Frequency [kHz] (no 3rd HC)	11.1	9.95
RF Acceptance	± 2.45 %	± 1.94%

* From RF power measurement

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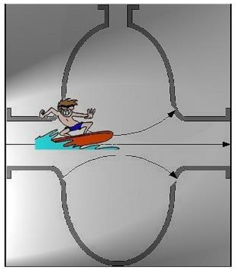
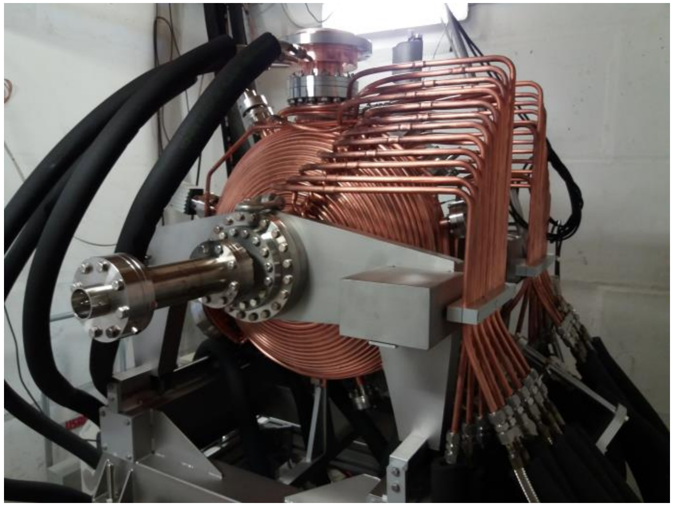
RF System

Elettra SR cavity:

- ✓ single cell
- ✓ normal conducting
- ✓ multipacting free





Storage Ring RF cavity	
Frequency [MHz]	499.654 ± 1
Cavity number	4
Cavity copper losses, maximum [kW]	62 (68)
Vaccelerating/cavity maximum [kV]	630 (670)
loaded cavity filling time [μs]	9
longitudinal radiation damping time [ms]	8
Axial tuning (shortening/stretching beam gap)	± 200 kHz
L0 R/Q , measured	80.7 ± 1.0
HOM R/Q L1 @ 950 MHz	30 ± 1.0
HOM R/Q L9 @ 2100 MHz	7.9 ± 2.5
Long. & Trans HOMs dedicated damping tools	none
L1 excitation cured by frequency shift	plunger position
L1 frequency shift vs plunger position (40 mm stroke) [kHz]	1000
L9 excitation cured by frequency shift	temperature tuning
L9 frequency shift vs temperature set (40 °C range) [kHz/ °C]	100
Transverse HOMs cured by	MBTF
Maximum available RF power for 3 cavities	55 kW/each
Maximum available RF power for 1 cavity	150 kW
Elettra 2 upgrade RF maximum available power (2018 plan)	*90 kW/each*

Booster cavity:

- ✓ 5 cell Petra type cavity
- ✓ Operating parameters (flat top) 14 kW - 600 kV
- ✓ Available RF power: **18 kW** since Oct 2017, **before it was 55 kW !**

RF Reliability

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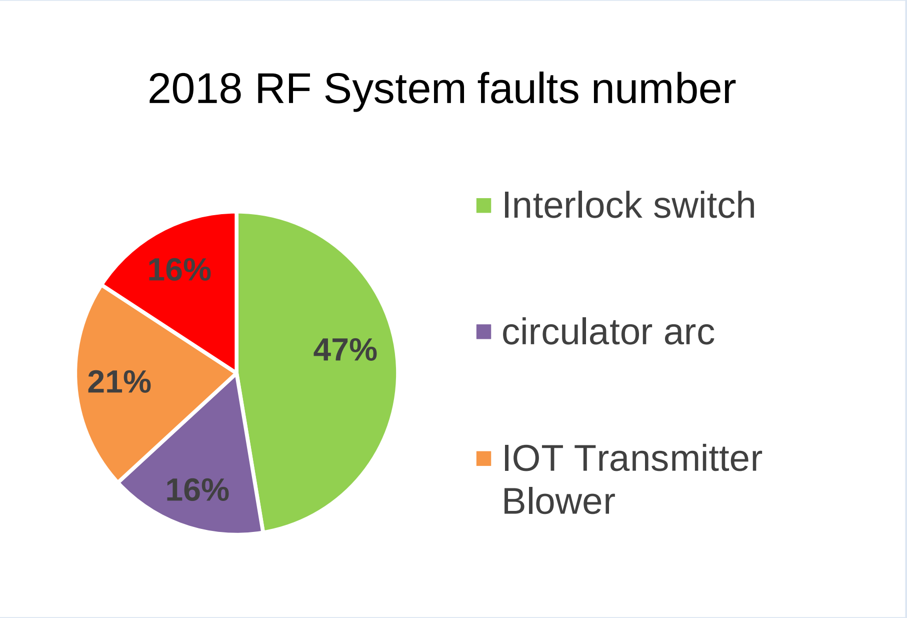
In 2018 the RF system suffers a high failure rate due to the interlock analogue electronics!

→ Interlock & Monitoring RF Project



RF interlock switch is home made and it has been built with analogue electronics, no PLC, no digital memory. Capacitors and AC/DC power supplies ageing…More than 60% of down time due to these issues…

GOAL: Replace the analogue interlock system with a COTS FPGA SoC based board to:

- ✓ Update the Interlock system to the state of the art including data log
- ✓ Have the RF interlock system "independent" from the machine interlock
- ✓ Perform additional data monitoring (DC signals only, vacuum level for example)
- ✓ Gain experience on the digital systems.
- ✓ Work together with the Photon Beam Detector group (G. Cautero).

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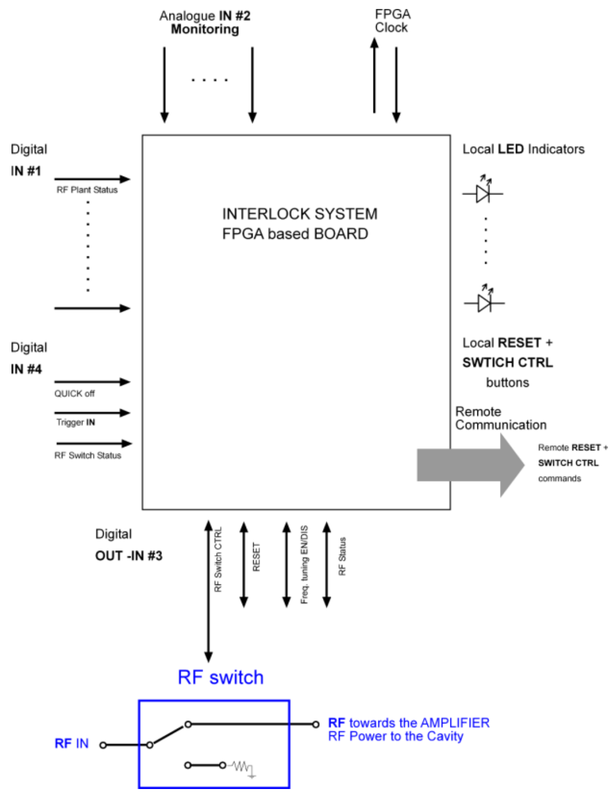
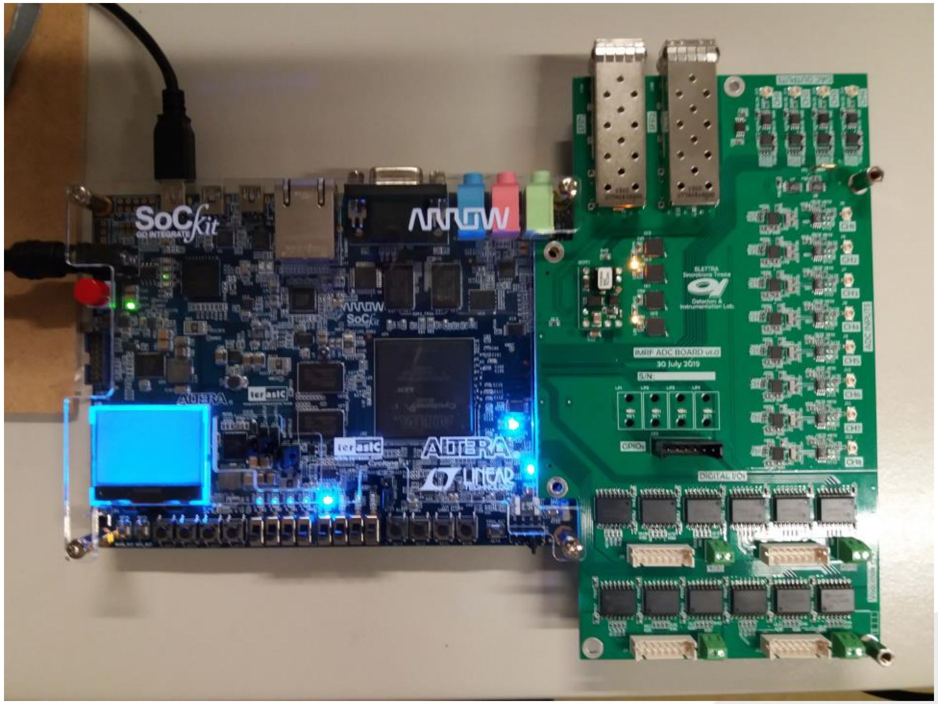
IMRF Project

Interlock & Monitoring RF Project:

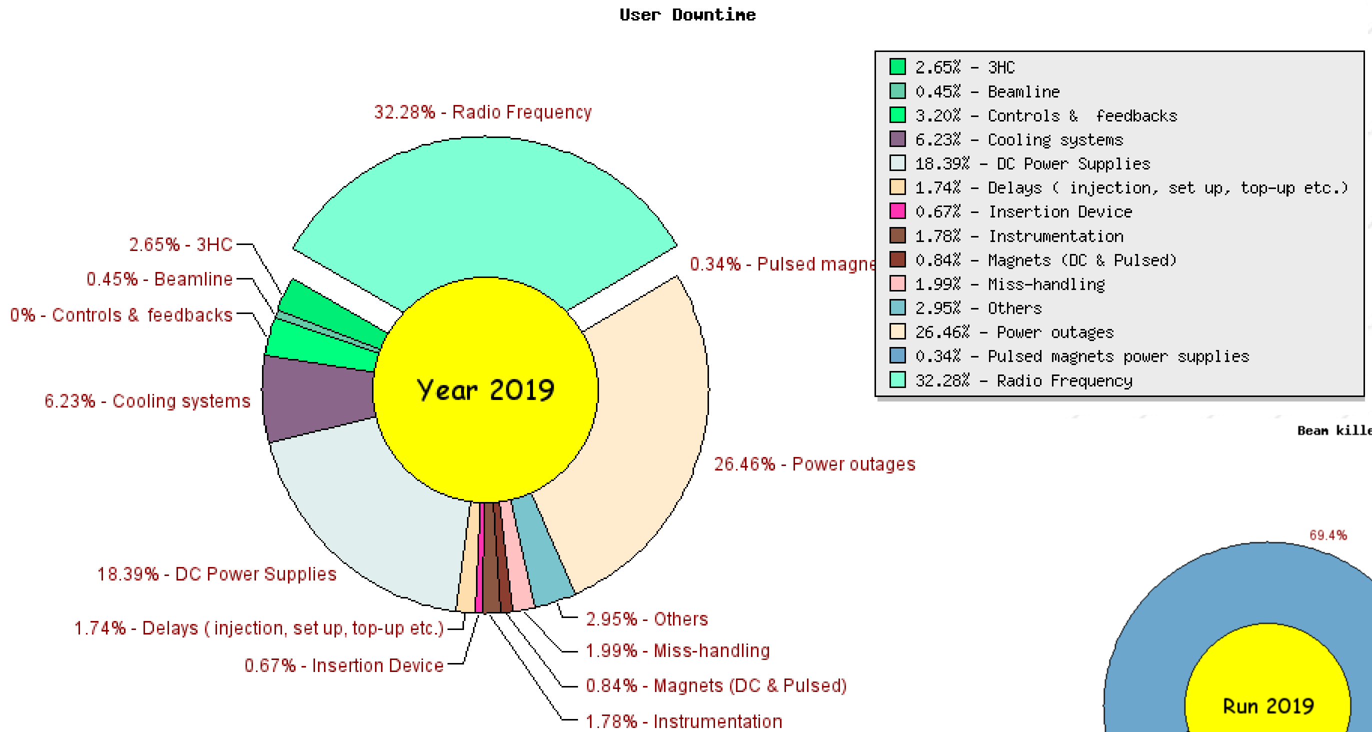
- ✓ ALTERA Cyclone FPGA SoC & In house developed ADC board
- ✓ PHD Student is writing the Verilog code
- ✓ However the ULTIMATE INTERLOCK IS ALWAYS a hardwire cable driving the **RF ANALOGIC SWITCH**

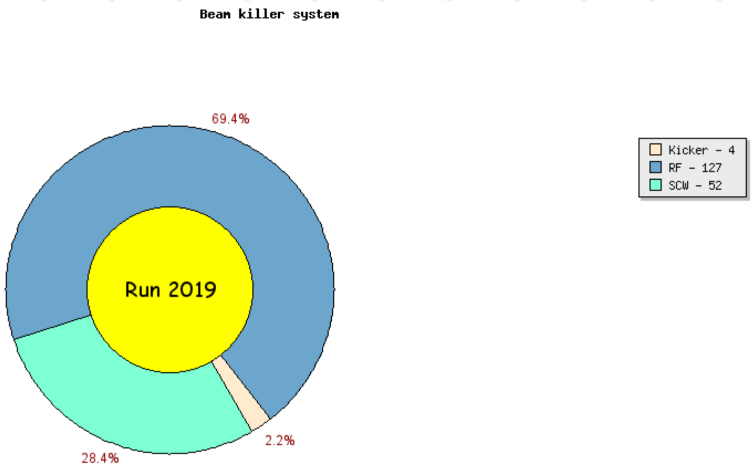




2019 RF Reliability

UNEQUIVOCALLY the RF system is nowadays the worst among the Elettra ones!





Main Source of problems:

- ✓ **HOMs in RF#2 and broken IPC (71% down time in run 177 –from Jan 10 to Apr 5**
- ✓ **IOT based transmitters, 10 beam dumps in the last run 180 – from Aug 26 to Oct 17**

IPC RF#2 Replacement

Jan 25 03:00 a.m. vacuum alarm in the storage ring and the vacuum chamber valves upstream and downstream the RF#2 cavity are definitively closed.

Jan 25 09:00 a.m. Elettra concrete shields removed to start the Input Power Coupler replacement

Jan 25 02:00 p.m. cavity + new IPC bake out starts up to 140 ˚C.

Jan 26 10:00 a.m. cavity temperature ramp down starts (flat top @ 140 ˚C lasted 18 hours).

Jan 26 03:00 p.m. cavity vacuum level 1.6 10-9 mbar

Jan 26 03:00 p.m. RF conditioning starts , very easily because the IPC has been already conditioned in the RF LAB. 4 hours to reach the full reflection capability of the IPC

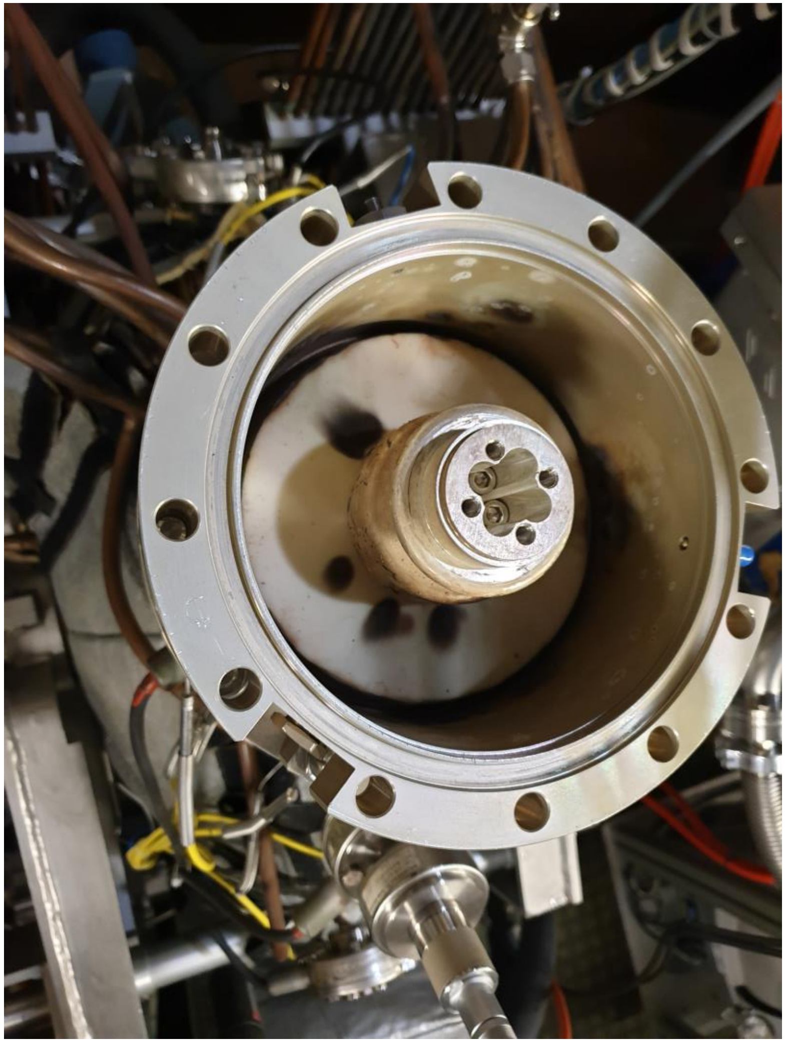
Jan 27 all day: MACHINE SHIFT Scheduled -> beam conditioning

Jan 28 07:00 a.m. USER Operation

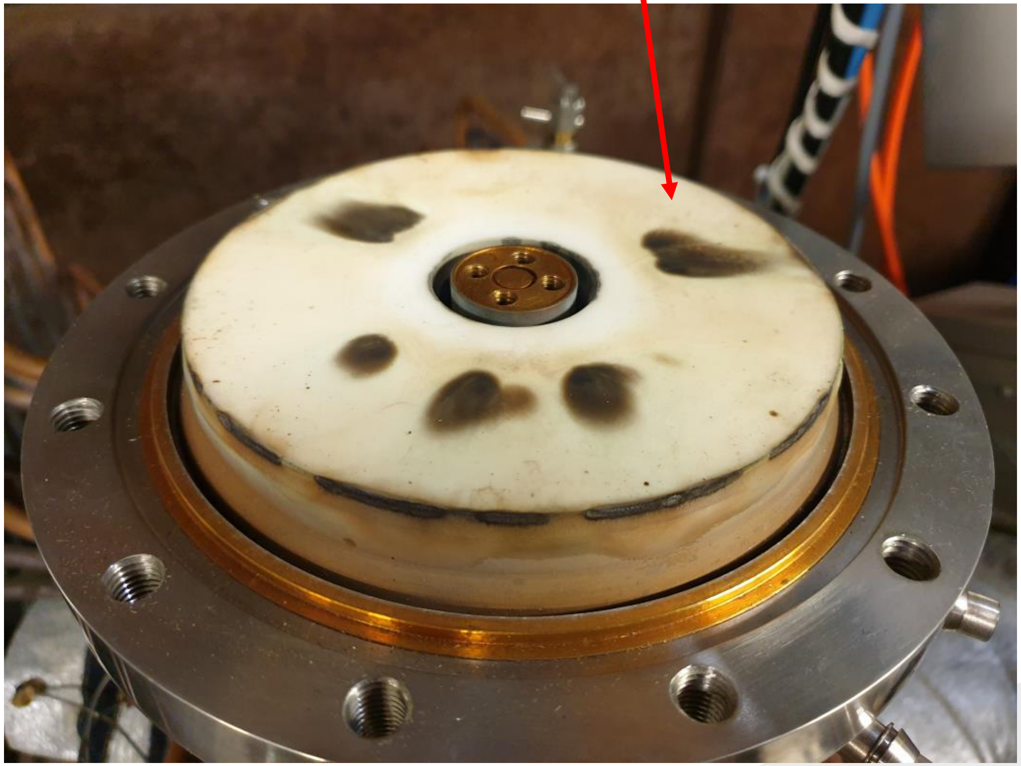
TOTAL DOWNTIME : **52 hours !**

FAULT due to the lack of care and attention to the RF parameters and the Elettra user operations!

IPC RF#2 Replacement



Damaged IPC & visible ceramic crack



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IOT RF#9 Replacement

Last run the 150 kW - IOTs based amplifier (twins 80 kW transmitters) suffered several faults:

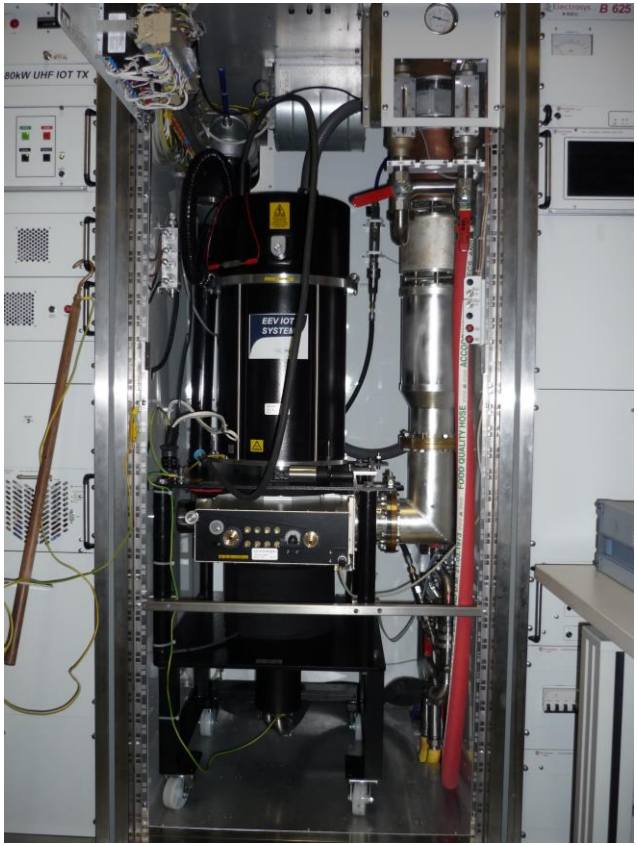
- ✓ Tx-A transmitter with several HV inhibits, switched OFF and run with Tx-B transmitter only

BUT

- ✓ Tx-B IOT tube showed an increasing grid current (110 mA @ 45 kW output power)!

OUTCOME: replacement of both tubes during this shut down!

IOT TUBE CONDITIONING foreseen for two days at least!

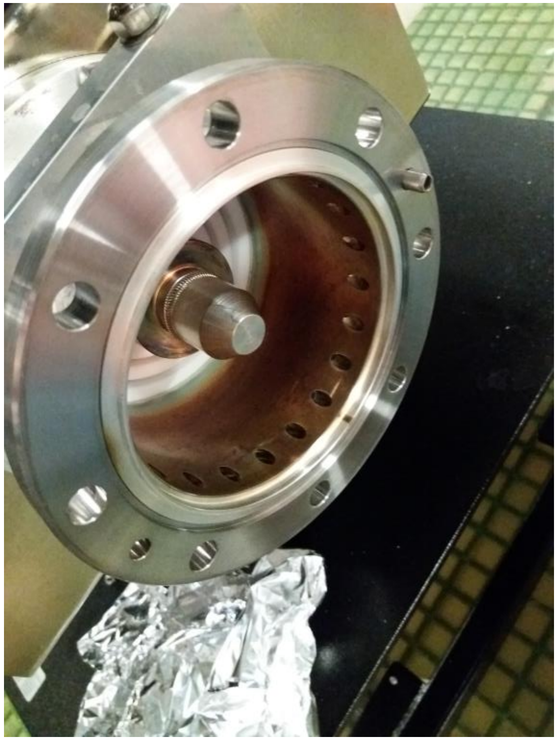


RF Station	power source	brand - model	s/n	installed in	tube hours	Transmitters heater hours
RF # 9	I.O.T.s	E2V D2130	302-1017	Jun-10	55,614	73,038
	I.O.T.s	E2V D2130	368-1208	Jun-12	45,288	72,039

IOT RF#9 Replacement

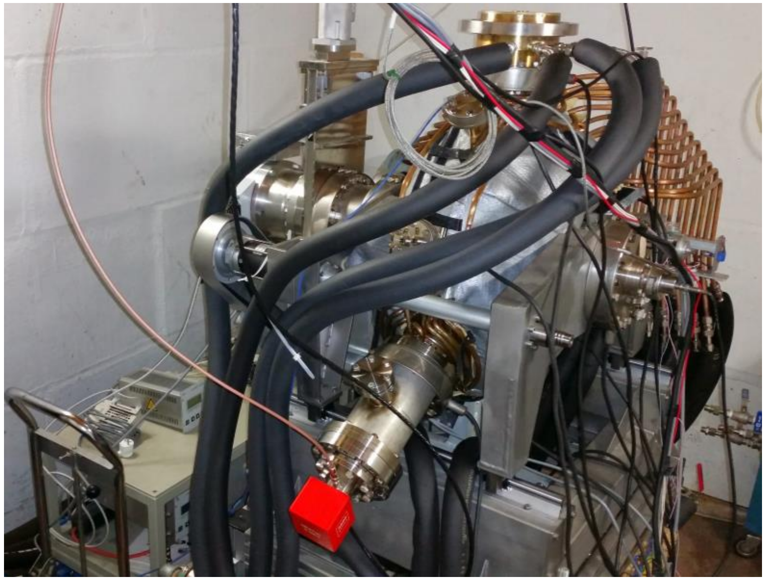
The ceramic windows of both tubes show no sign of overheating or any other damages

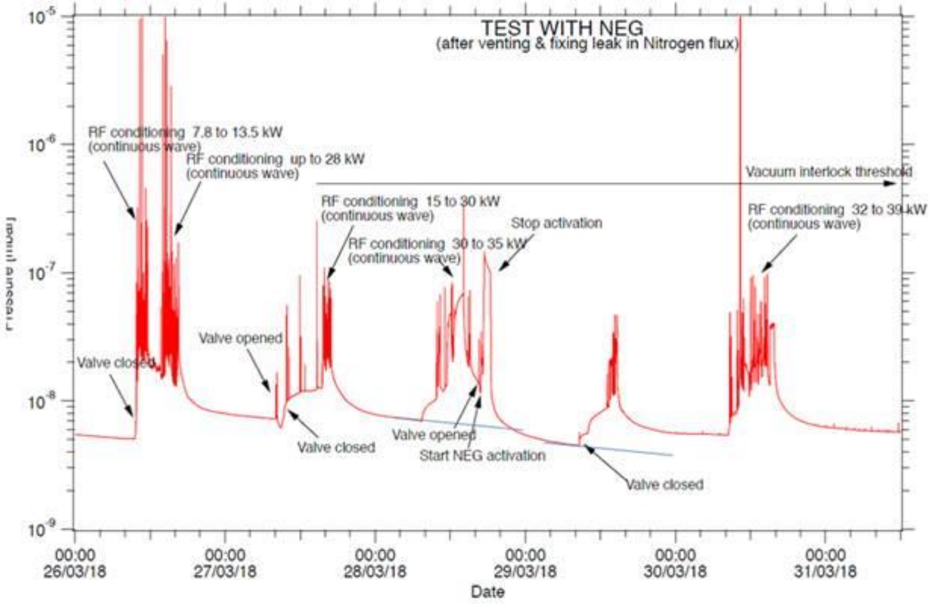
Only a visible mark on the coaxial line of the cavity output loop



RF Lab UHV NEG tests

Installed the combined NEG (500 l/S) + ION (6 l/s) pump system in the LAB cavity and High RF power conditioning procedure repeated several times with several NEG activation conditions till a good ultimate pressure value at 50 kW CW cavity input power was reached





RF power cavity conditioning with NEG, data taken by L. Rumiz and the Elettra vacuum group

UHV NEG and RF Cavity

RF system & vacuum at Elettra:

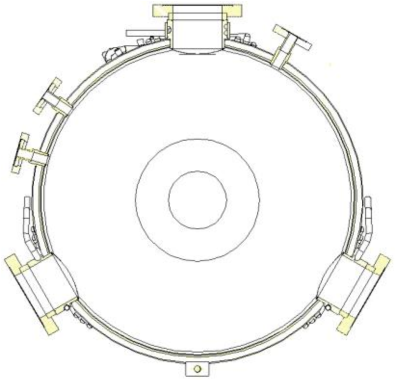
- 4 • 500 MHz RF cavities: 3 cavities are fed with 50 kW RF power and one cavity is fed with 100 kW RF power with beam
- about half of the RF power is transferred to the beam
- each cavity hosts a 120 l/s sputter ion pump and an Inverted Magnetron Gauge
- ultimate pressure < $1\cdot10^{-10}$ mbar (RF OFF and room temperature)
- operating pressure (RF power ON + 310 mA e^- beam) < $5\ 10^{-9}$ mbar

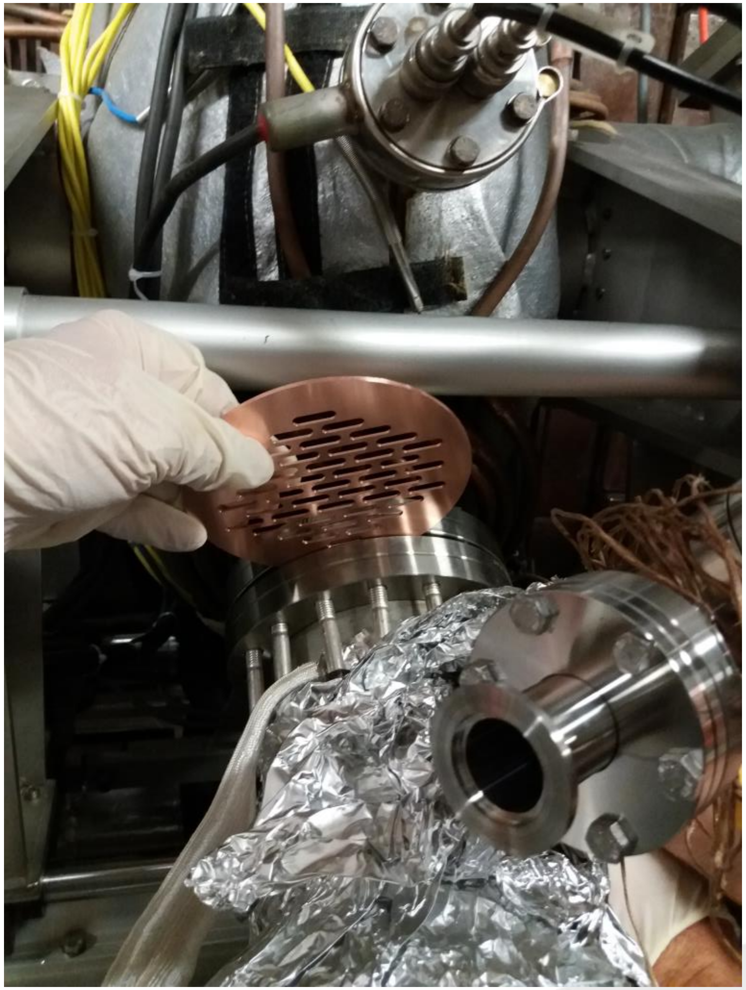
June 2019 the NEG Torr (550 l/s) + ION (6 l/s) pump was installed in Elettra cavity RF#2, replacing the SIP

- Vacuum level restored after one day of RF power conditioning
- With e-beam the vacuum level was restored after two days
- BUT with no shield the NEG temperature raises from 30 ˚C at full RF power (50 kW) to 110 ˚C with e-beam!

UHV NEG in the RF Cavity

August 2019 a in-house made high purity oxigen free copper gasket was inserted between the NEG pump and the cavity port.





- Holes to blind surface gasket ratio 65%
- The gasket was baked in vacuum lab at 200 ˚C for two days
- No cavity bake-out was performed: nitrogen ventilation only to break the vacuum and insert the gasket
- Vacuum level restored after one day of RF power conditioning
- With e-beam the vacuum level was restored after two days
- The NEG temperature raises to **40 ˚C** with e-beam!

NEG + ION pumps will be implemented in ELETTRA 2.0 in the RF cavities

Elettra 2.0, revised constrains

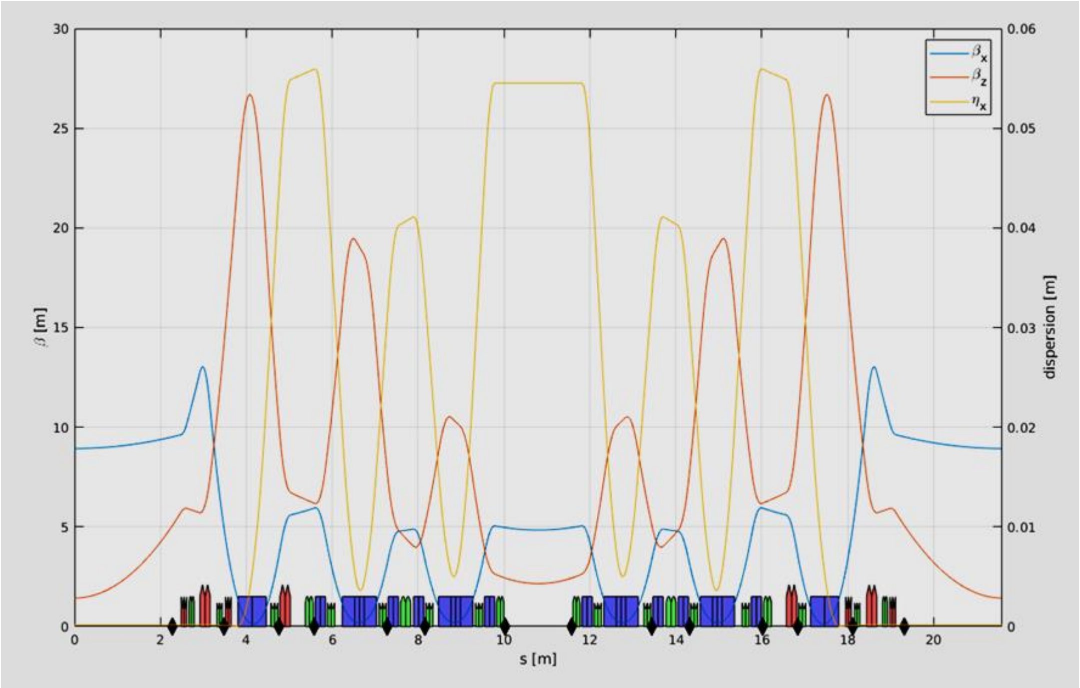
Courtesy of **E. Karantzoulis:**

- ***Operating energy 2.0 and 2.4 GeV***
- Emittance: to be reduced by more than 1 order of magnitude
- ***Increase the number of slots available for insertion devices***
- ***New micro-spot in-vacuum undulator beamlines need to go on long straight sections***
- Keep the same building and the same ring circumference
- Preserve the present intensities and the time structure of the beam
- ***Leave open the possibility for installing bunch compression scheme***
- ***Include super-bends***
- Keep the present injection scheme and injection complex
- Minimize the downtime for installation and commissioning to about 18 months (if possible less)

S6BA-E

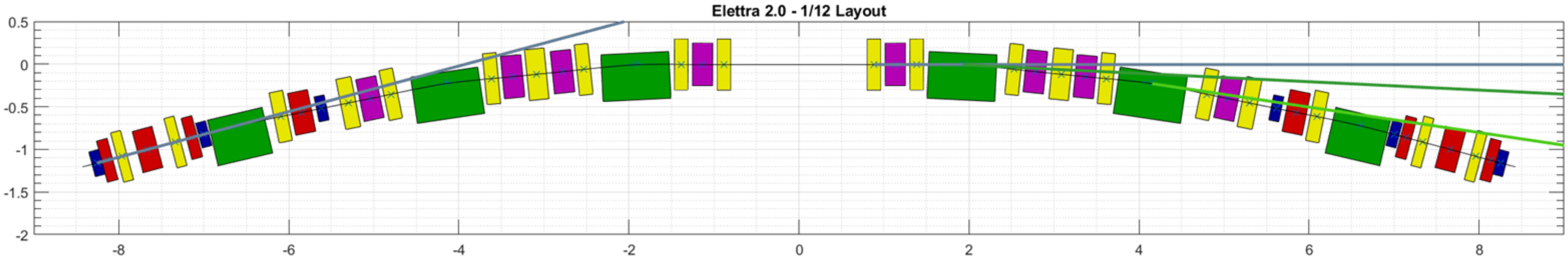
LG + quadrupole/dipole version:

Emittance 98 pm-rad (58 pm-rad if round) at 2 GeV or 140 pm-rad at 2.4 GeV (87 pm-rad if round)



Emittance reduction:
7/0.098=71
10/0.14=71

Free space for IDs (4.5 +1.55 m)
2 & 2.4 GeV



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Elettra 2.0 RF Power Requirement

		Elettra 2.0			Elettra
		4 cavities and 4 x 100 kW SSA transmitters	4 cavities and 4 x 125 kW SSA transmitters Power Added Option	5 cavities and 4 x 100 kW SSA and 1 x 145 kW IOT based amplifier	4 cavities and 3 x 55 kW transmitters and 1 x 145 kW IOT based amplifier
Beam Energy (GeV)	GeV	2.4			2.4
Beam Losses (overall)	keV	600			500
Beam Current	mA	400			160
Beam Power	kW	240			80
Momentum com. (S6BA)		3.16E-04			1.6E-03
RF Frequency	MHz	499.6			499.6
Accelerating Voltage (total)	kV	1800	2400	2400	1680
Overvoltage		3	4	4	3.4
Requested Power	kW	366	464	422	192
Available Power	kW	400	500	545	310
Losses per cavity	kW	31.5	56.0	33 - 49	25 -36
β cavity coupling		2.9	2.1	2.3	1.7
Synchrotron frequency	kHz	4.5	5.3	5.3	9.2
RF acceptance	%	4	5	5	2
Synchronous phase	degree	19.5	14.5	14.5	17.3

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500 MHz 100 kW SSA

- ✓ "SSatE" project is running to refurbish Elettra RF Transmitters and, at the same time, be ready for Elettra 2.0
- ✓ The manufacturing of the required Transmitters is outsourced
- ✓ According to the public procurement Italian Law, Elettra has launched the invitation to tender for:

"…the design, manufacture, commissioning, delivery, installation and start up at Elettra's premise of ***four identical turnkey 100 kW 500 MHz transmitters*** *operating at a single frequency (monotonic) and in continuous wave (CW) regime. These transmitters are going to replace the klystron's based amplifier for the storage ring and their installation must fit the Elettra's scheduled operation calendar…"*

" A reliable silicon based LDMOS FET or gallium nitride HEMT transistors must realize the RF amplification chain of the RF transmitter. …"

500 MHz 100 kW SSA

Three options have been included in the Contract:

1. ***Additional Power Option (APO)***. Benefitting from the SSA modularity, the machine could be ready to implement an increase of the RF power amplification capability (from 20% to 30 % of the nominal power) to cope with any Elettra 2.0 additional RF power needs. The machine will only have the “bare systems” but not the active modules yet. At later stages it could be possible and easy to implement further amplification stages with no larger machine modifications.

2. ***Storage Option***: Replacing two 60 kW klystron amplifiers out of three with two 100 kW SSA covers the Elettra RF power need (It means: 3 cavities out of four including the one fed by the150 kW IOT transmitter). Since the cavities will likely be moved from their actual position in Elettra there is no need to install the other 2 machines ahead of the Elettra 2.0 installation.

3. ***Safety Panel Board:*** RF system must follow the Personnel Safety rules and standard, SIL2 safety contactors are needed upstream the machine electrical grid connection. This can be provided by the Supplier or by the internal Elettra team.

500 MHz 100 kW SSA

Tender abridged data:

- ✓ Cost basis 2.780.000,00 Euro + V.A.T.:
- ✓ More than 10 competitors invited, only five bidders
- ✓ Contract awards based on technical evaluation (70% weight) and cost reduction (30% weight)
- ✓ Technical evaluation normalized score ranged from 70 to 22.4
- ✓ Cost reduction with respect to the cost basis ranged from 25.89% to 7.55%
- ✓ The additional power option is NOW MANDATORY for the ELETTRA 2.0 new RF power requirements

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Trieste

500 MHz 100 kW SSA

Tender awarded to CRYOELECTRA on June 2019.

Cryoelectra
RF Technology for Particle Accelerators

ELETTRA - SINCROTRONE TRIESTE S.C.p.A.
Affari Legali e Istituzionali
Repertorio dei contratti n. 989

(Mutual) Non-Disclosure Agreement

between

Cryoelectra GmbH, Linde 72, 42287 Wuppertal, Germany

- hereinafter referred to as „Cryoelectra“ -

and

Elettra - Sincrotrone Trieste S.C.p.A
Strada Statale 14 – km 163,5 in AREA Science Park, 34149 Basovizza, Trieste, Italy

- hereinafter referred to as „Elettra" -

- hereinafter collectively referred to as "Contractual Partners" -

500 MHz 100 kW SSA

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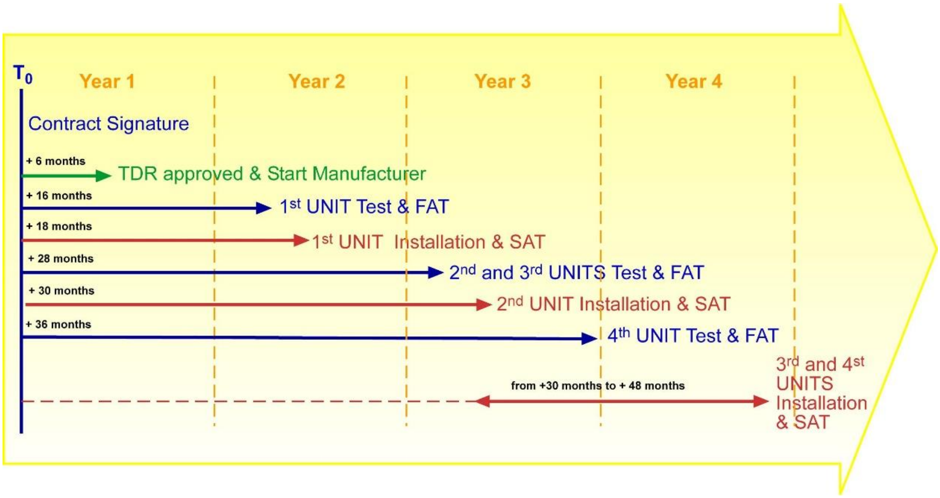
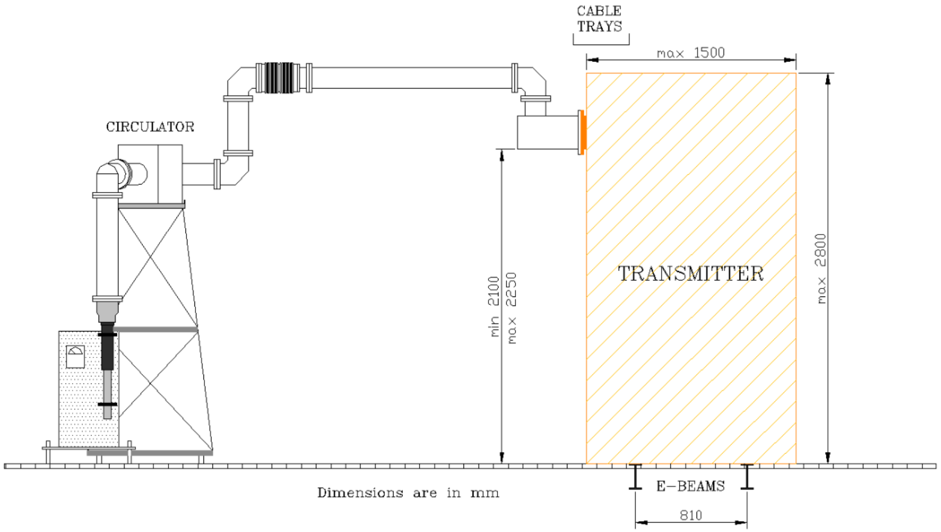
The project runs over several years:



The new transmitter installation MUST BE transparent to the user



- ✓ Fresh RF power for Elettra and, at the same time, the possibility to use the very last spare klystron, with no waste
- ✓ Machine debug and gain operational experience with these devices meant for Elettra 2.0, even if the RF power will be limited to the maximum nominal power of the coaxial line (80 kW VSWR=1 @ 500 MHz).
- ✓ Large improvement of the Elettra operation: SSA transmitter phase and amplitude noise is strongly reduced (no HV power supply).
- ✓ Some electricity bill saving…last but not least!

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Conclusion

The RF system for Elettra

- ✓ ageing and lack of resources impact on the RF reliability
- ✓ revamp already started for the very Elettra machine.

The RF system for Elettra 2.0

- ✓ Possibility to add one more 500 MHz cavity more RF power is required
- ✓ Beam quality: longitudinal Feedback system project is also started, but Is it enough?.
- ✓ New cavities design (wake fields issues) and/or SC cavity (acceptance and/or HOM issues) to be addressed in the Elettra 2.0 “second stage”.

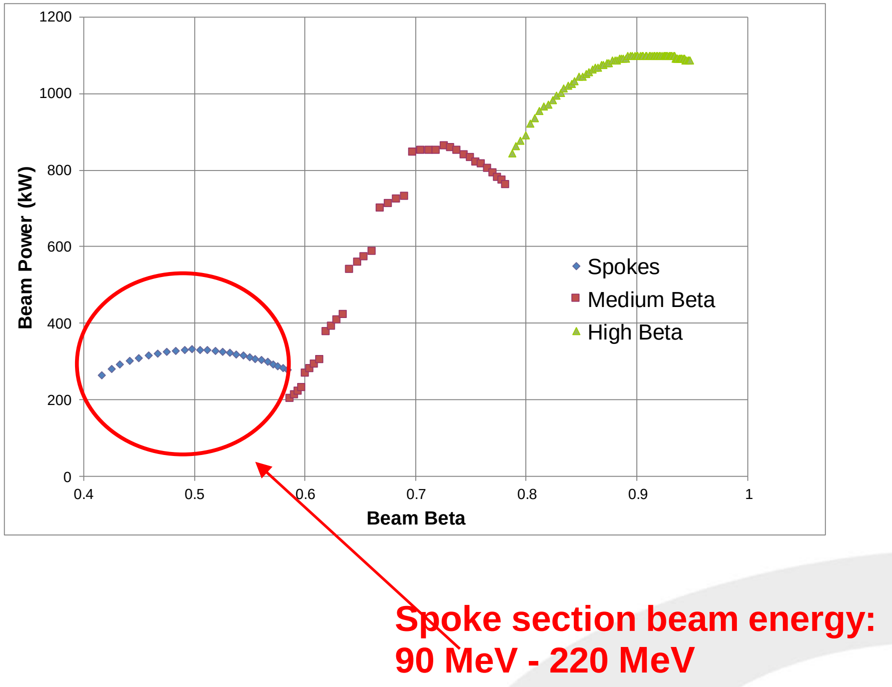
ESS IKC Project

Elettra is partner of ESS providing as In Kind Contribution magnets, power converters, diagnostic tools for the wire scanner and 26 Radio Frequency Power Stations

RFPS features:

- RF power requirement range per spoke cavity: from 260 kW to 335 kW pep* art 352 MHz
- one RFPS will power one spoke cavity to accomplish an independent setting of the RF power level, amplitude and phase regulation
- periodic pulse operation at 14 Hz, nominal flat-top width 3.5 ms
- Non standard flat-top width 140 us only for RF conditioning purpose

ESS SC Linac Beam Power need vs Beam β



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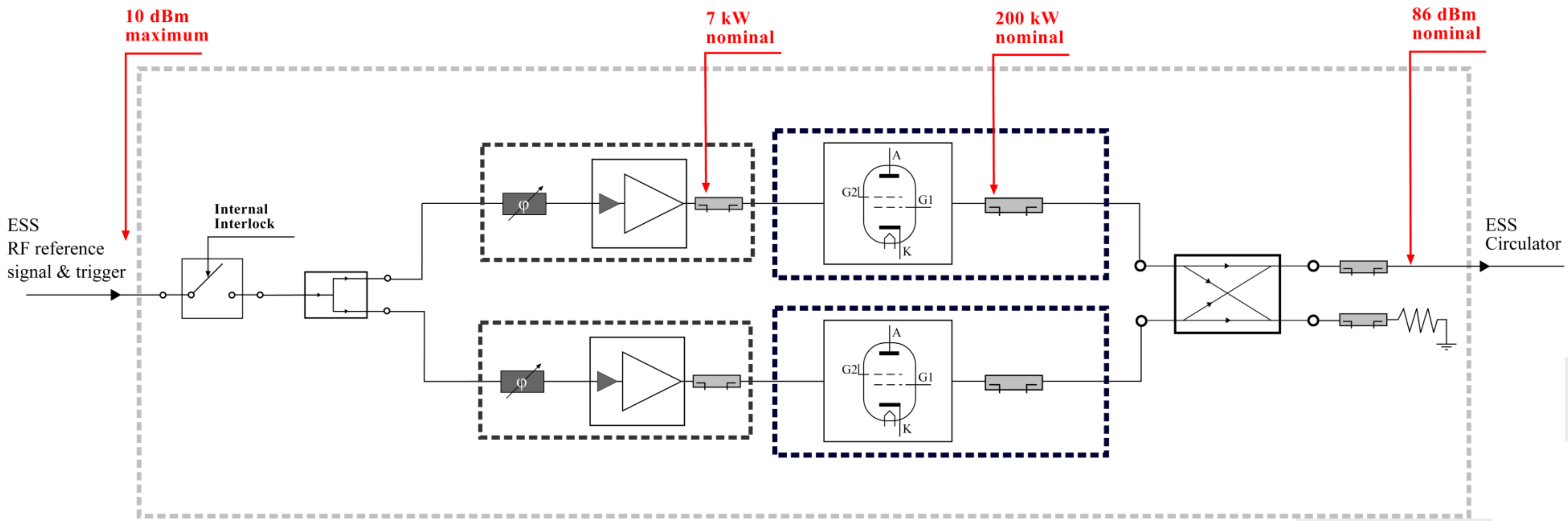
RFPS Features

- ✓ RF power amplification : two TH 595 A tetrode tubes*, 200 kW each with a 3dB hybrid combiner to add together their output power. Single tetrode branch use not expected.
- ✓ A single HV modulator feds the two anodes in parallel, while heaters and the other electrodes have its own power supply for independent regulation purposes.
- ✓ RF pre-amplifier is based on water cooled solid state transistor technology, 1dB compression point @69 dBm. Static gain adjustment is also foreseen.
- ✓ RF input distribution should also protect the RFPS against internal/external faults and allow the RF phase and amplitude balancing between the two RF branches.



RFPS Pulse Quality & Features

RF pulse quality depends:

- on the SSA pre-driver pulse quality
- on the tetrode elctrodes power supply dynamic performances and output voltage regulations
- on the heater power supply quality

RF pulse features:

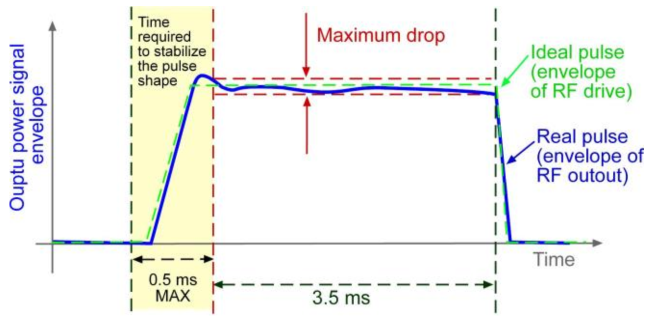
- to be measured after a «warm-up time» at constant external RF drive
- to be measured after a «stabilization time» ,Ts <0.5 ms that shall mask any overshooting and/or following errors

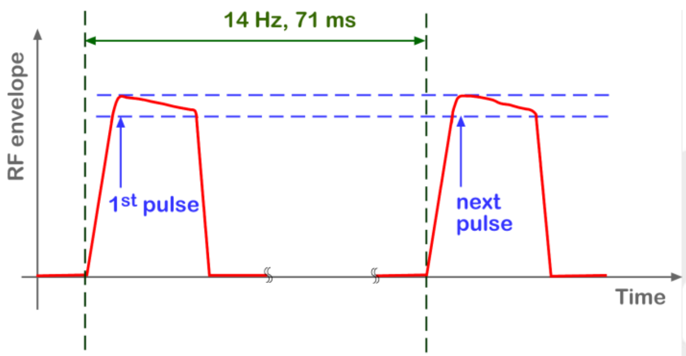
Pulse quality:

- Maximum pulse drop ≤ 0.25 dB
- Spectral quality of the amplified signal

Pulse to pulse stability:

- Average amplitude variation ≤ ±0.5%
- Average phase variation Δ f ≤ ± 0.5º

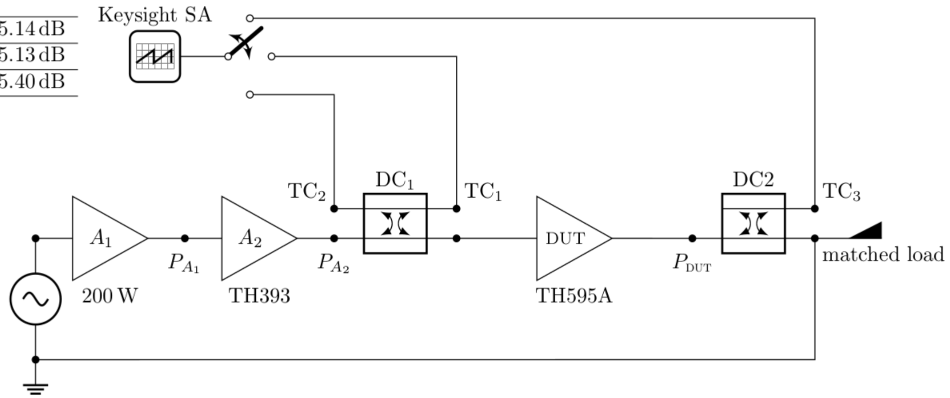




TH595A FATs

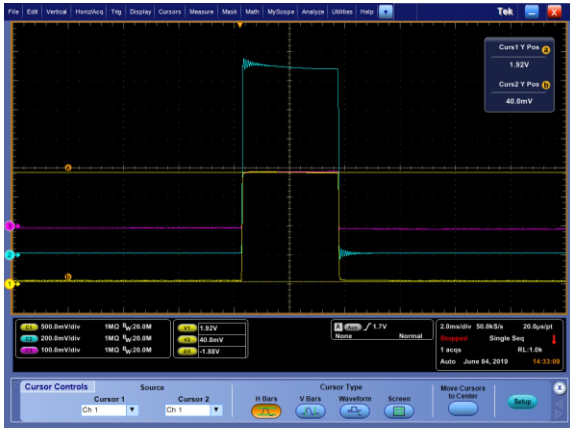
2 set of tubes + cavities successfully commissioned at Thales in June 2019:

TC_1	−55.14 dB
TC_2	−55.13 dB
TC_2	−65.40 dB



At 210 kW peak power

GAIN = 15.6 dB
Efficiency = 68%
Cycling test of 12 hours at 200 kW



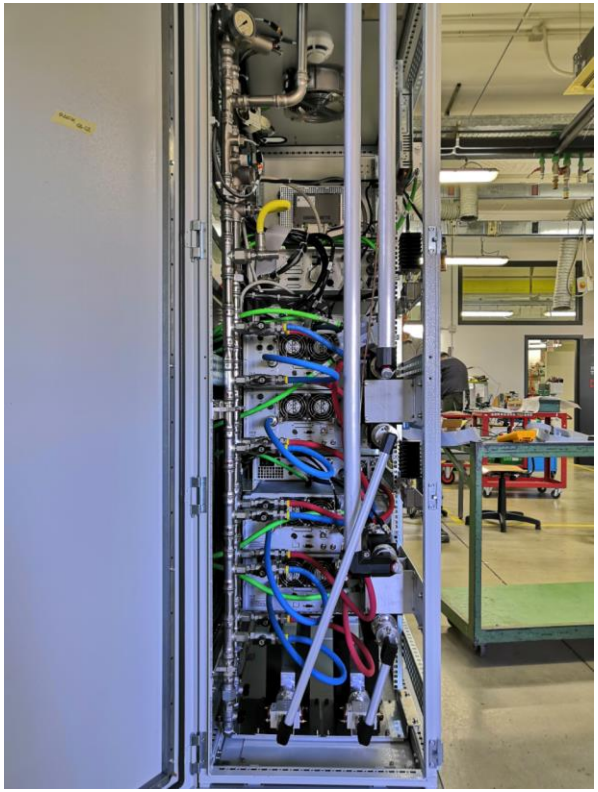
CH1 (yellow trace) – 10 A/V – anode current
CH2 (cyan trace) – 1 A/V – G1 current
CH3 (purple trace) – 1 A/V – G2 current

The RF Power Station

The RFPS is under construction in Orvieto by ESS consortium made by Itelco and DB Elettronica

The RF Power Station

RF distribution for the tetrode ready



RF drivers connections (cooling water- RF and PS) ready

RF high power combiner ready on the RFPS roof

The RF Power Station

HV Modulator rack

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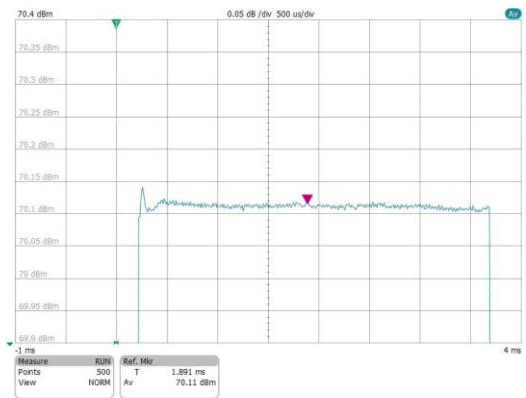
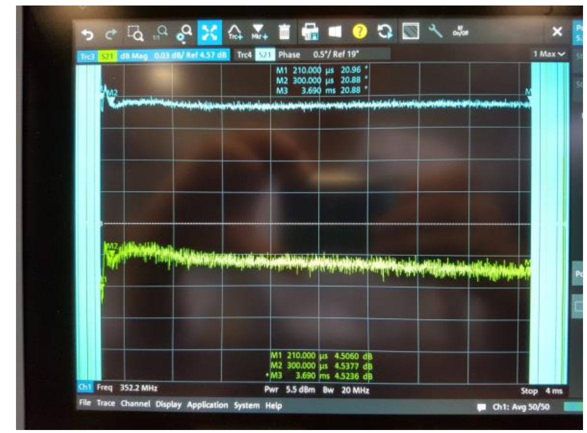
The RF Power Station

Preliminary RFPS measurement, courtesy of ESS Italian consortium

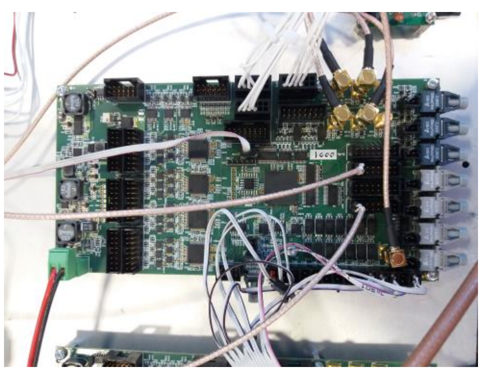
10 kW – tetrode driver - test bench



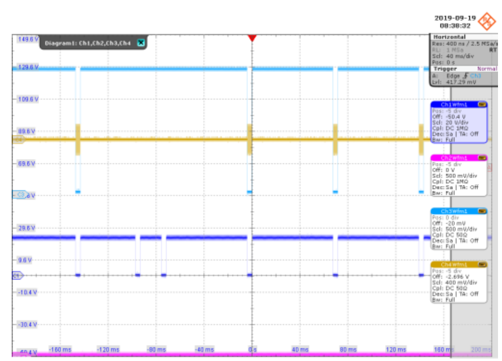
10 kW – output power pulse



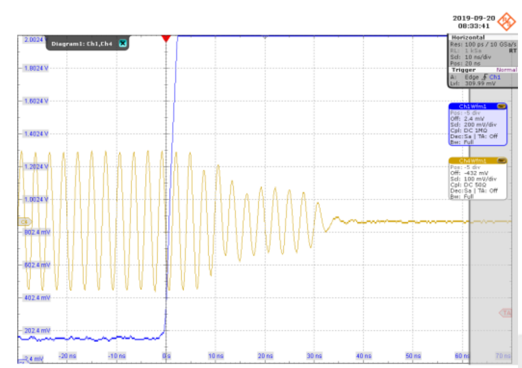
Gain and phase of the output pulse (S21)



Interlock board based on FPGA chip



External trigger signal (bottom) with wrong rep. rte. If this happens the RFPS internal trigger does not ACK



The RF switch at the RFPS input is commuted in 35 ns by the interlock board

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