Elettra Sincrotrone Trieste

RF System at Elettra: present status and outlook

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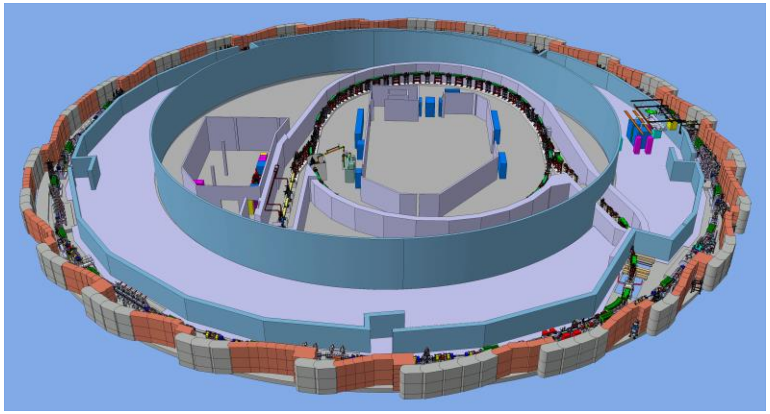
Outline

- ✓ Elettra, RF and 3HC systems parameters
- ✓ 3HC commissioning and operational experiences
- ✓ 3HC and RF systems DOWN-TIME
- ✓ RF system main issues
- ✓ Elettra 2.0 project
- ✓ RF system for Elettra 2.0

* 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)	**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 meters data

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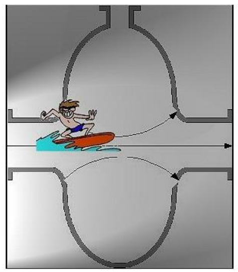
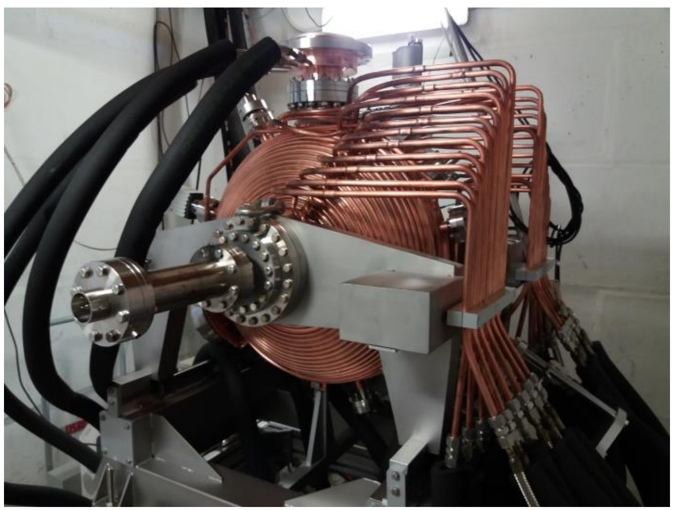
RF System

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 freqeuncy shift	temperature tuning
L9 frequency shift vs temperature set (40 ^{0}C range) [kHz/ ^{0}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 (planned)	*90 kW/each*

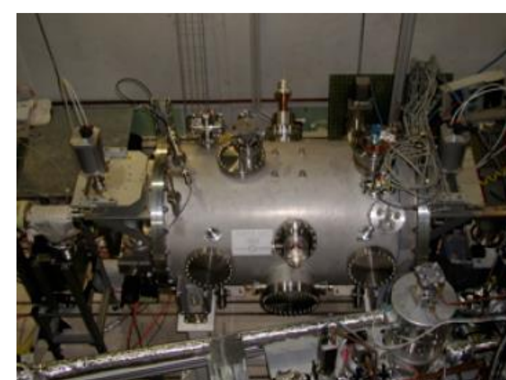
Booster cavity:

- ✓ 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 !**

3HC System

- ✓ The 3HC system comes from a joint project among CEA (France) , PSI (Switzerland), Elettra and CERN and it is based on the SOLEIL (scaled) cavity.
- ✓ CEA lab has designed, fabricated and tested two cryomodules.
- ✓ CERN lab has built two resonant cavities and made the vertical tested .
- ✓ One system has been installed at SLS and it is in operation since June 2002.
- ✓ The second system has been installed at Elettra and it is in operation since January 2003.

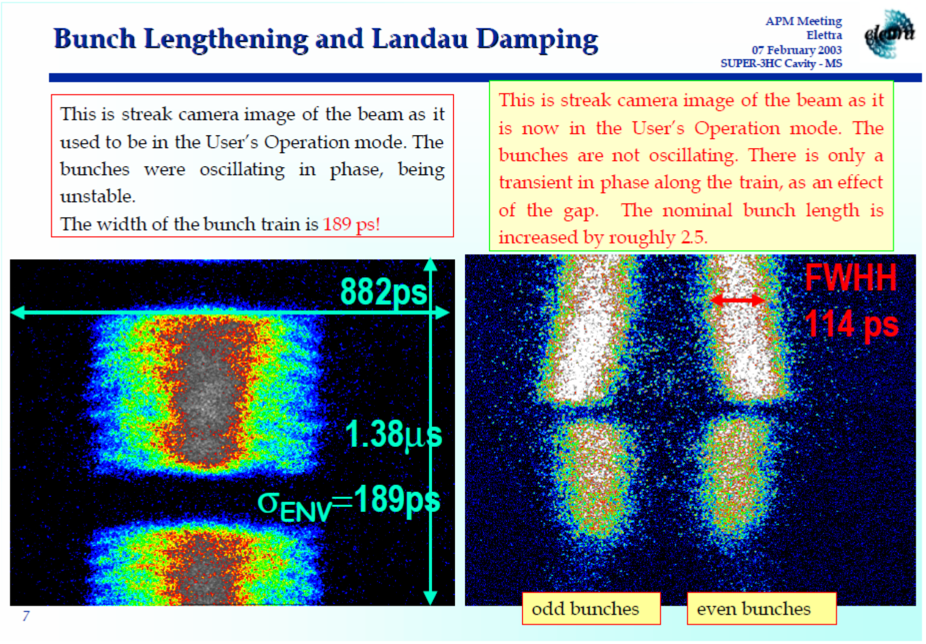
3HC specifications	
Frequency 3 x f_{RF} [MHz]	1498.96
Cavity EM profile	SC double cells in a single cryomodule
Cavity EM profile	Nb/Cu sputtered
Cryomodule length (without external tapers) [mt]	1.1
Operating mode	passive + voltage FB
Operating temperature [K]	4.5
Maximul voltage- both cells [MV]	1.0
Q_0 vertical test @ 5MV/m, 4.5 K	$2\ 10^8$
Q_L loaded test @ 4MV/m, 4.4 K	$1\ 10^8$
Tuning range [kHz]	± 500
Longitudinal HOMs damping fR R$\|$ [kOhm GHz]	7 (both 0.9 & 2.0 GeV)
transverse HOMs damping R$\perp$ [kOhm/m]	130 (both 0.9 & 2.0 GeV)
Long. & Trans HOMs dedicated damping tools	2 L+ 4 T couplers
Refrigeration power at 4.5 K [W]	65

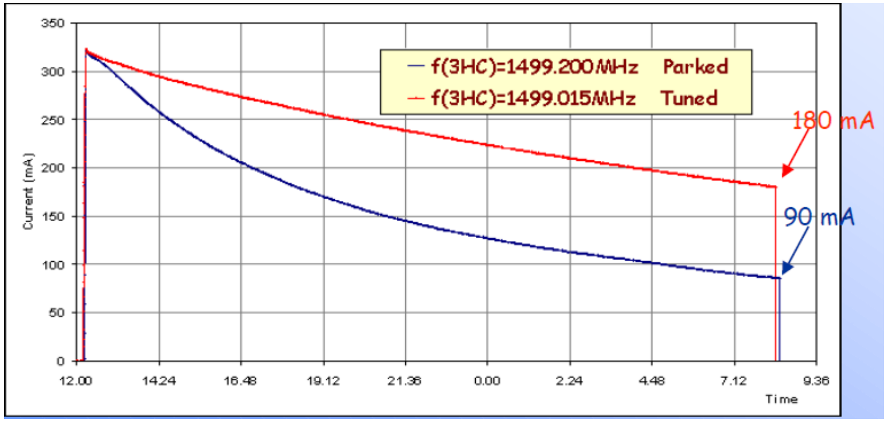


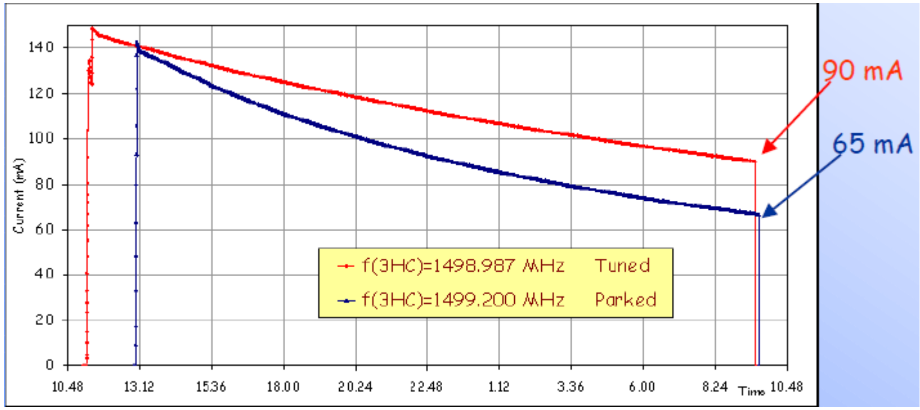
3HC Commissioning

3HC commissioning started in January 2003.

M. Svandrlik, G. Penco







Burn-in phase of the failure rates:

50% of the total user down time in run 81 (Jan 16 – Mar 2; 2003) was due to the 3HC system:

- Turbine control board, vacuum interlock logic to check, high pressure alarms, vacuum insulation leak on the return line, gearbox of the tuning system motor in fault and to be replaced…
- The gearboxes became the main hardware issue: even after their replacement some atypical overheating occurred (design and/or implementation error ? ⟹ Mitigated by minimising the tuning stroke movements)

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3HC Planned & Achieved Operation

3HC installed to:

- ✓ Longitudinally stabilize the beam due to the induced by Landau damping
- ✓ Increase the beam lifetime

WARM PARKED
to safely operate 3HC in case of cryomodule's failure

Operating Conditions:
No induced beam voltage with de-tuning range Δf = 5 MHz+500 kHz

OC FAILED @ 2.0 Gev 320 mA
OC ATTAINED @ 2.4 GeV 160 mA

COLD PARKED
to avoid any effect on the beam due to 3HC

Operating Conditions:
No induced beam voltage with De-tuning range Δf = 500 kHz

OC ATTAINED
at 0.9, 2.0 and 2.4 GeV at any current value

COLD TUNED
to implement all the 3HC benefits

Operating Conditions:
up to 1 MV induced voltage kept constant by automatic feedback loop

OC NON FULLY ATTAINED
induced voltage limited to 400 kV and no voltage FB

From July 2003 a LONGITUDINALLY STABLE BEAM was routinely delivered to the Elettra USER!

→ SIDE EFFECT: the **M**ulti **B**unch **T**ransverse **F**eedback could be set into operation easily

Operation with/with out 3HC

DECAY MODE

Daily, injection and beam storage at 0.9 GeV then ring energy was ramped to the final value 2.0/2.4 GeV

Refill procedure average time <1 hours.

Before 3HC

User operation achieved by exciting a longitudinal CBM from a HOM cavity at constant level to overtake any transverse and longitudinal "competitors" instabilities. Constant level of the CBM instability was tolerated by the beam lines and the CBM mode was also harmless for the cavity equipment.

WITH 3HC

Beam injection and storage at 0.9 GeV achieved by exciting a longitudinal the very same CBM and 3HC nearly parked (no induced voltage but close to the tune position to minimize the motor tuning steps). Before the energy ramping, 3HC was tuned to kill the longitudinal oscillation mode Energy was ramped and beam delivered to user.

TOP UP

First injection at the beginning of the run, then refill of 1 mA each 10/20 minutes depending on beam energy and lifetime.

WITH OUT 3HC

Warm operation only at 2.4 GeV, due to the equipment overheating.

Cold parked not useful at all @ 2.0 & 2.4 GeV.

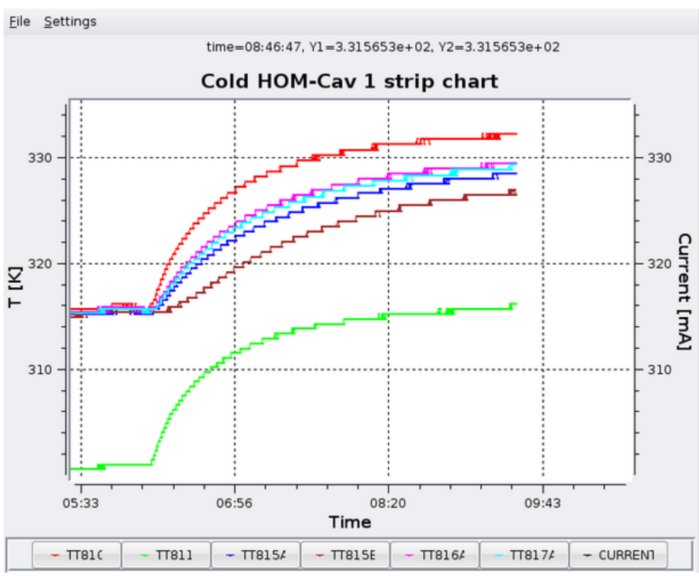
WITH 3HC

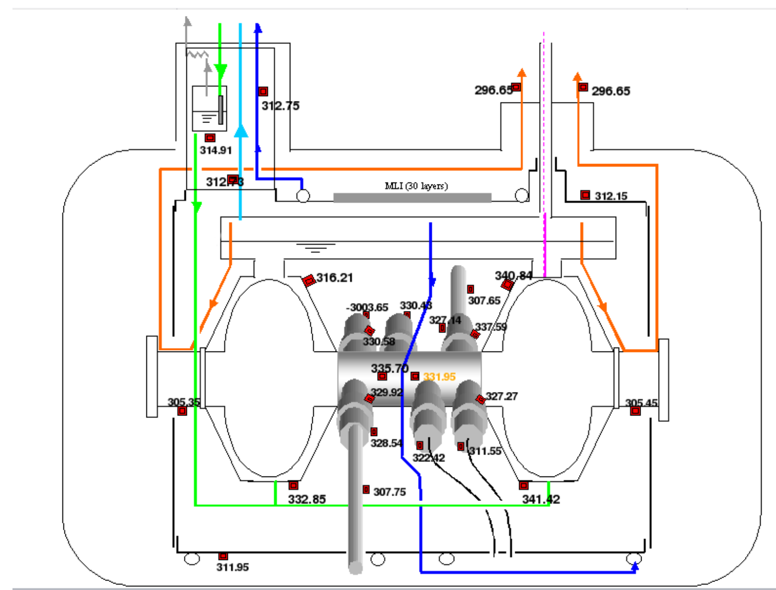
At 2.4 GeV 3HC is cold with no beam induced voltage.

At 2.0 GeV 3HC is tuned: as soon as the beam intensity reaches 200 mA , 3HC starts to accumulate some induced voltage and eventually, at 310 mA the last longitudinal oscillation are killed and the maximum 3HC voltage, 400 kV, is achieved.

3HC warm mode operation

- ✓ After a cold to warm unwanted failure, if feasible, the 3HC system wall always cool down as soon as possible (typical user down time 10-12 hours)
- ✓ 3HC warm parked operation arranged ONLY to cover the time request to procure the components or helium gas to recover the ongoing cryogenic system failure. It works at 2.4 GeV only.

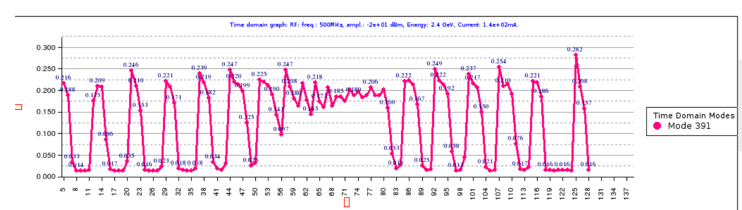




Monitored heating increase, measured in May 2011

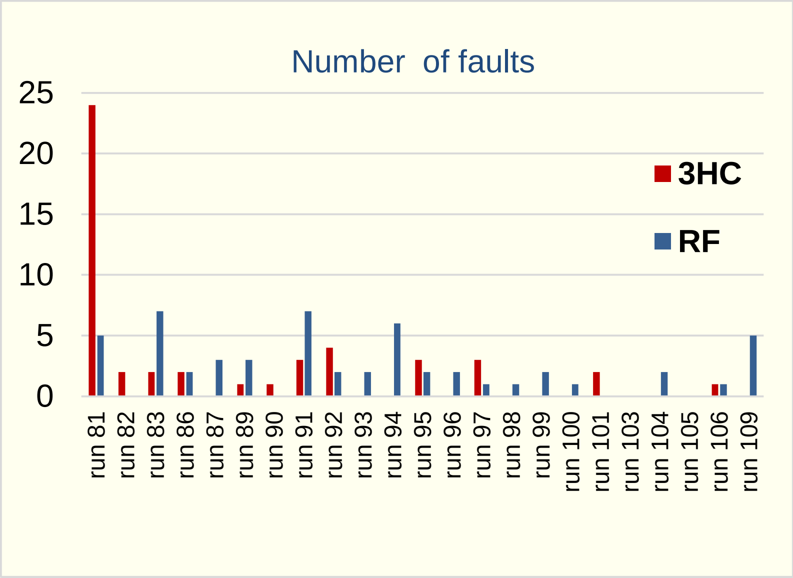
To prevent further harmful heating of the warm 3HC, the RF temperature of one cavity is carefully adjusted to cure the longitudinal CBM excitation

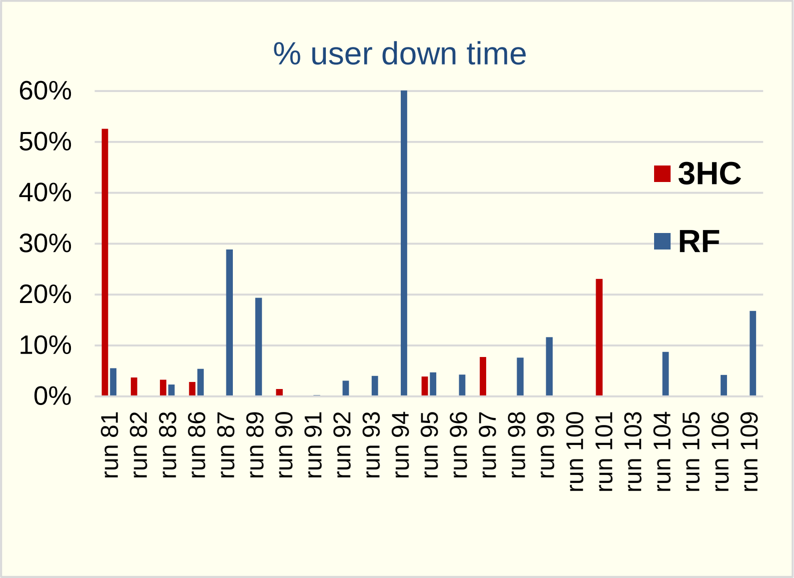
for example:Cavity #8 from 58.2 ^{0}C to 58.8 ^{o}C to stabilize the CBM 391 in may 2011.



Down-Time in decay mode

RF and 3HC faults number (all) and user down time during the Elettra operation in decay mode (2003-2007)





3HC performances:

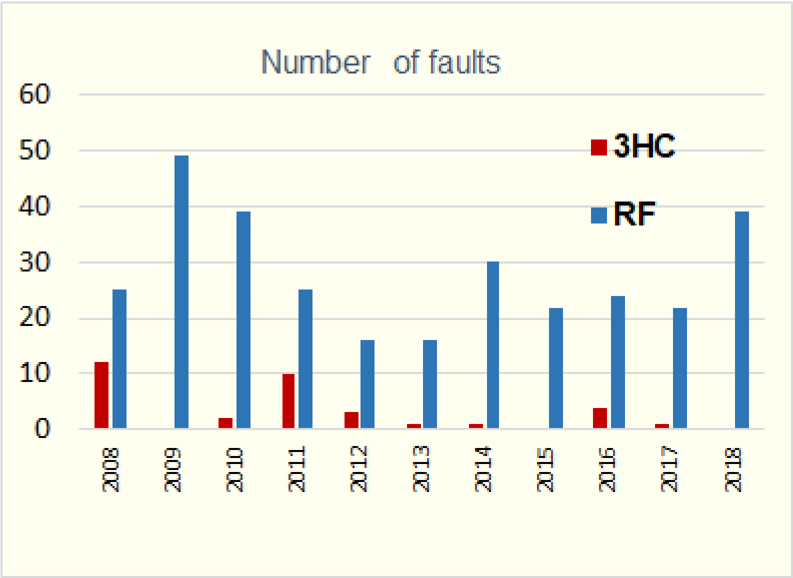
After the commissioning phase, run 81 and 82, 3HC fault number mainly due to the need to check the cell tuning (setting troubles) not to the hardware but during run 101 when 9 hours of user down time occur due to the cryogenic compressor failure

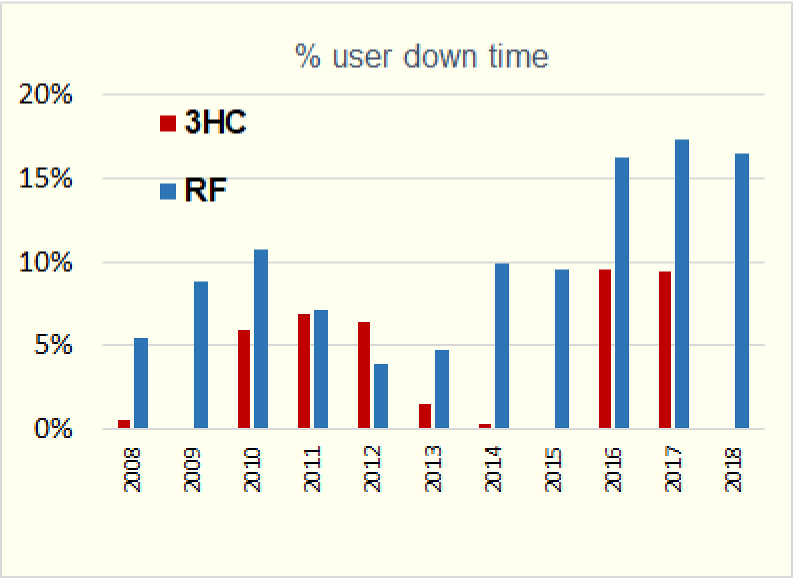
RF performances:

As usual, but during run 94 the IPC from cavity RF#9 had to be replaced (HOMs damages) due to the wrong temperature setting after a 4 beam SR laser operations.

Down-Time in TOP-UP mode

RF and 3HC faults number and user down time during the Elettra Full Energy Injection (2008) and TOP-UP mode (from 2010 to date)





3HC performances: Few but fatal faults!

2010 a cold down during user operation performed +turbine failure fixed:15 hours User Down Time (UDT)

2011 cryogenic system failure 18 h UDT + several days in “3HC warm operation” user operation

2012 insulation vacuum above the threshold. Fixed and 18 h of UDT

2016 insulation vacuum above the threshold. Fixed but recovering the cryogenic temp was difficult (18 h of UDT)

2017 cell tuning problems (wrong calibration) and compressed air + pressure problem on the compressor (18 h UDT)

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3HC and beam stability

QUALITATIVE snapshot taken on May 2018 ; Energy 2.0 GeV; beam current 310 mA

CBM 388 instability intentionally excited driven by one RF cavity width huge excitation level (CBM 388 10-20 degree unstable)

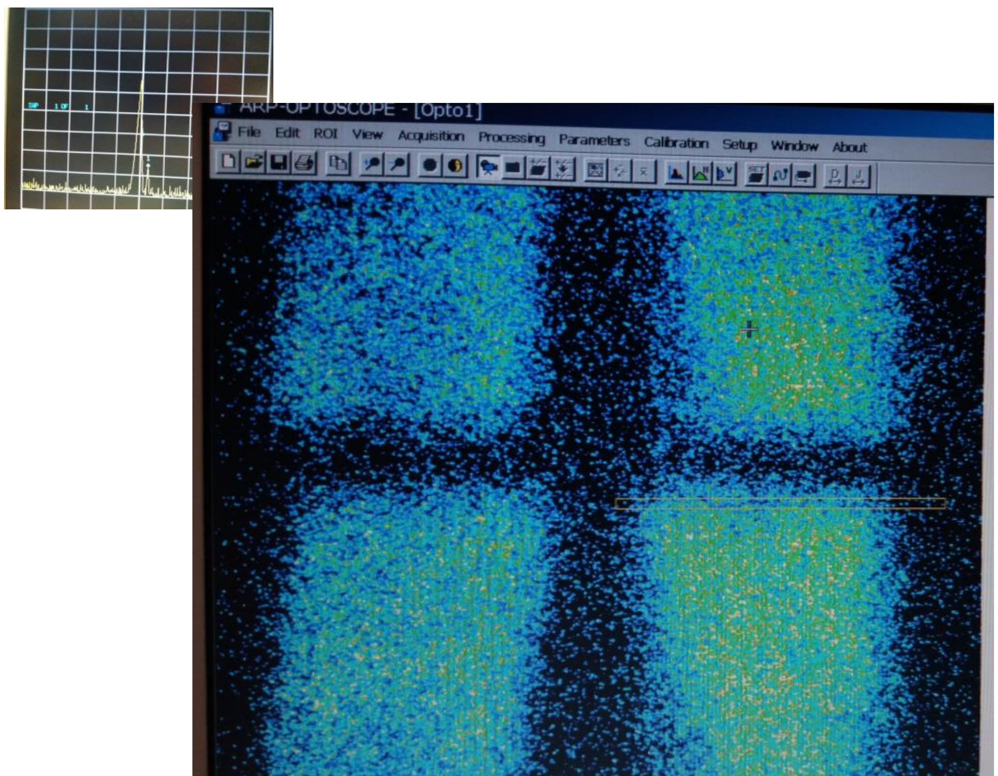
Lifetime drop: - 6 %

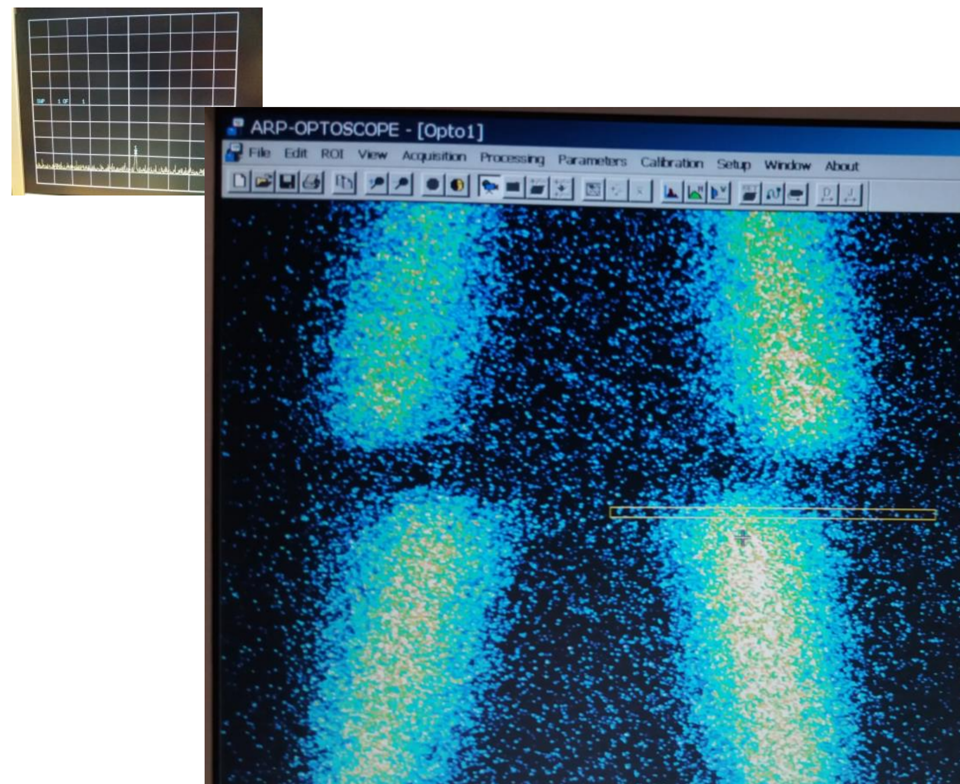
3HC parked: Δf =-19 kHz, V_{3HC} /cell < 140 kV (RF pick up reading unstable)

NO CBM : beam longitudinally stable

3HC tuned:

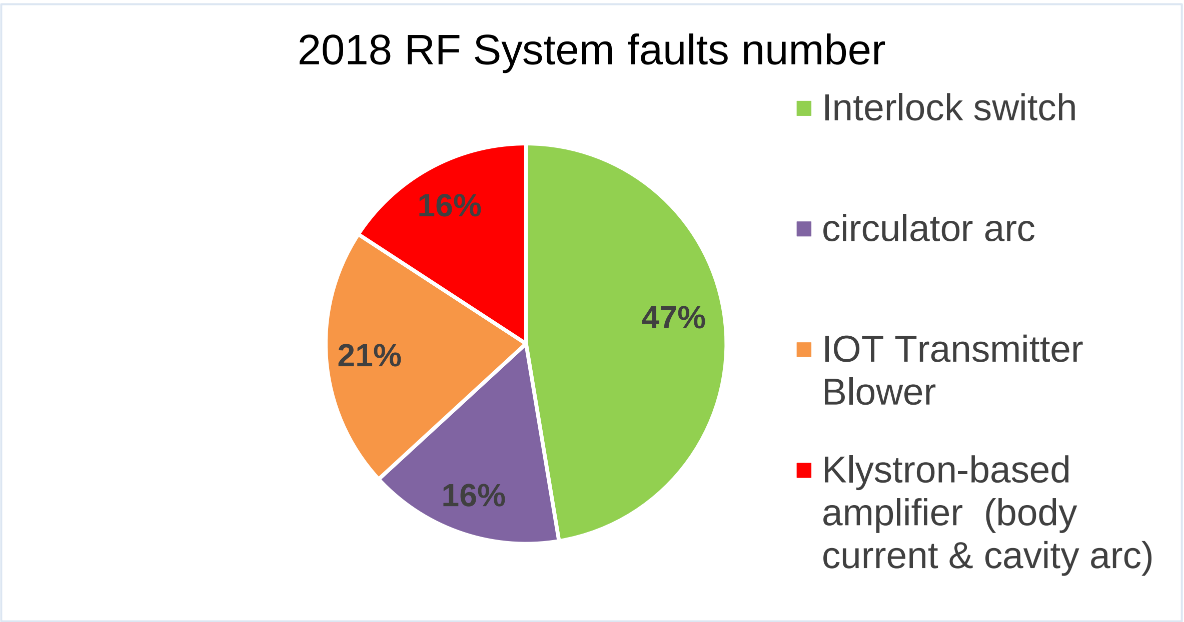
V_{3HC} /cell = 180 kV (stable reading)





RF System & down time

RF performances in 2018: **high failure rate** due to the interlock analogue electronics!



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…

Circulator arc detector doubled…each interlock has risen both the detectors!

RF Power Station

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- ✓ BOOSTER SSA is working fine, no down time so far , ≈ 6500 operating hours.

  Warranty repair:

  - Two RF power transistors replaced (out of 96)
  - One water pump replaced and the water liquid cleaned (cold plate maximum temperature drop of 8 ^{0}C)

- ✓ IOTs still the original ones, but their operating power is around 35-40 kW each.

- ✓ Klystron-based amplifier: two klystrons replaced during shut down (only one spare left).

  - Removed klystron operation hours 49800 and 42600 (Standard operating hours ≈ 30000)

Philips YK1256 Klystron set into operation in **1991** in RF lab and then in RF# 3 in 2014, removed for low collector current after 42600.

Transmitter	Tx-A	Tx-B
Heater time	53800	52700
Tube	E2V D2130	E2V D2130
Serial number	302 -1017	368 - 1208
Installation date	2010 June	2012 June
TX heater hours	66843	65718
Tube hours	49971	38958
Grid Current @ 35 kW	30 mA	85 mA

RF station	klystron	SN	tube hours	Amplifier heater hours
RF #2	K3672 BCD	1184-0823	**54488**	146478
RF #3	K3672 BCD	1177 -1335	**0**	148465
RF #8	K3672 BCD	1184-0823	**5180**	148168
Booster	18 kW solid state amplifier			

Elettra 2.0

Courtesy of **E. Karantzoulis**

The future for Elettra?

A new machine following the Ultimate Storage Rings developments

Established items in 2017:

- Same building, same position Circumference ~259.2 m
- Energy 2.0 GeV
- Brilliance increase at 1 keV by more than 1 order of magnitude
- Spot size less than 40 um

and

- Maintain the existing ID straight sections
- Maintain the existing bending magnet beam lines
- Multi-bunch current 400 mA, maintain the filling patterns as before (hybrid, single bunch etc.)
- free space not less than that of Elettra, LS: 6 m (4.5 for Ids) + (SS: 1.1 m , SLS: 1.46) total 8.56 m
- Use off axis injection

** MOPRO075, IPAC2014*

Elettra 2.0

Courtesy of **E. Karantzoulis**

New optic design with a 6-bend achromat

Elettra 2 will have:

- larger magnets number with higher field strength
- larger power supply number
- Smaller diameter vacuum chamber (halved)
- Upgraded injection system
- Dedicated wiggler for the dipole beam line (user request)

Parameter	Units	Current Elettra	Elettra 2.0
Circumference	m	259.2	259.8
Energy	GeV	2 - 2.4	2
Horizontal emittance	pmrad	7000	250
Vertical emittance	pmrad	70 (1% coupl)	2.5 (250 round beam)
Beam size @ ID (σx, σy)	μm	245 , 14 (1% coupl)	43,3 (31,22 round beam)
Beam size at short ID	μm	350 , 22 (1% coupl)	45,3 (39,21 round beam)
Beam size @ Bend	μm	150, 28 (1% coupl)	17,7 (12,48 round beam)
Bunch length	ps	25 (100 with 3HC)	12.5 (70-100 with 3HC)
Energy spread	ΔE/E %	0.08	0.07
Bending angle	degree	15	5.5 and 4

A 4-bend achromat optic design solution is ready too…

Waiting for the final decision from the User community:

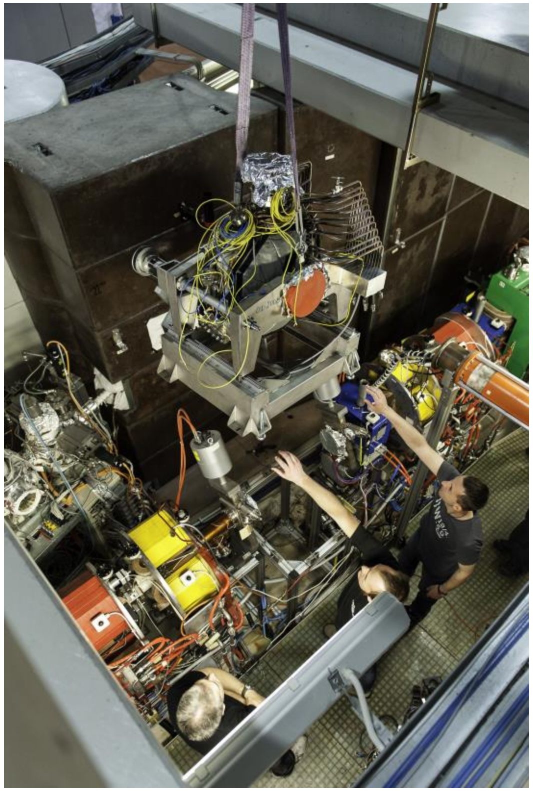
high brilliance and low emittance machine

or

time resolved experiments machine

RF for Elettra (2.0)

The RF system for (Elettra) Elettra 2.0:

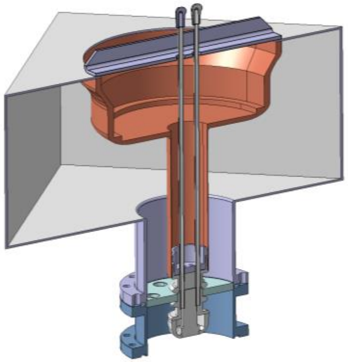


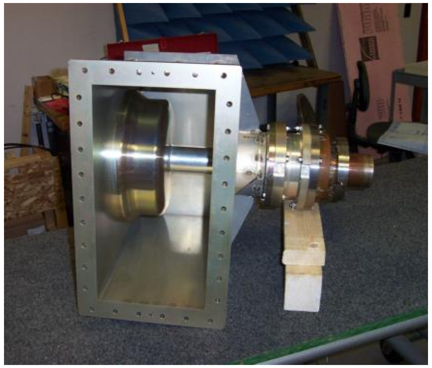
- ✓ Keep the same RF Frequency (trade off between the Elettra revamp needs and Elettra 2.0 parameters, mainly for the RF power)
- ✓ Elettra Cavity performances:

  60 kW copper losses + 60 kW beam /each cavity

  Total accelerating voltage 2.4 MV (4 cavities)

- ✓ From 2003 up to 2015 all the four Elettra cavities has been replaced. One spare cavity ready in RF laboratory
- ✓ Input Power Coupler: water cooled WG to coaxial transition installed to withstand full reflection due to beam losses for 60 seconds.
- ✓ 100 kW SSA transmitters procurement is running.

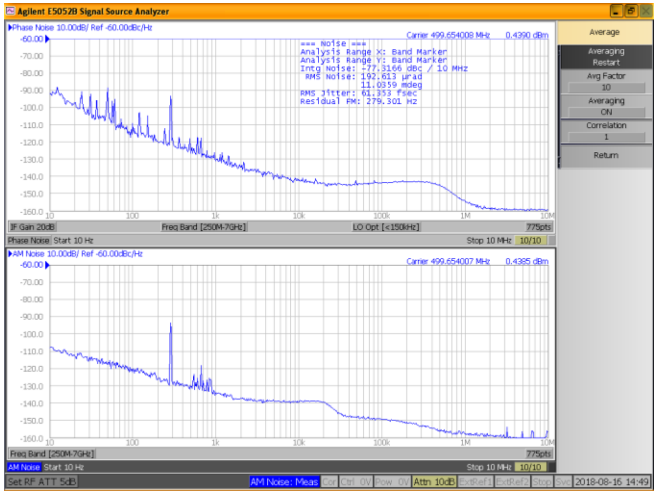




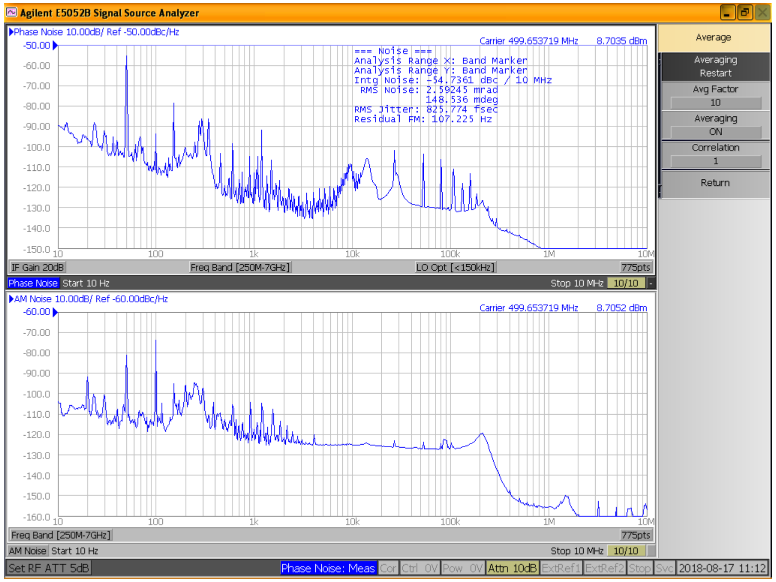
RF for Elettra (2.0)

The RF system for (Elettra) Elettra 2.0:

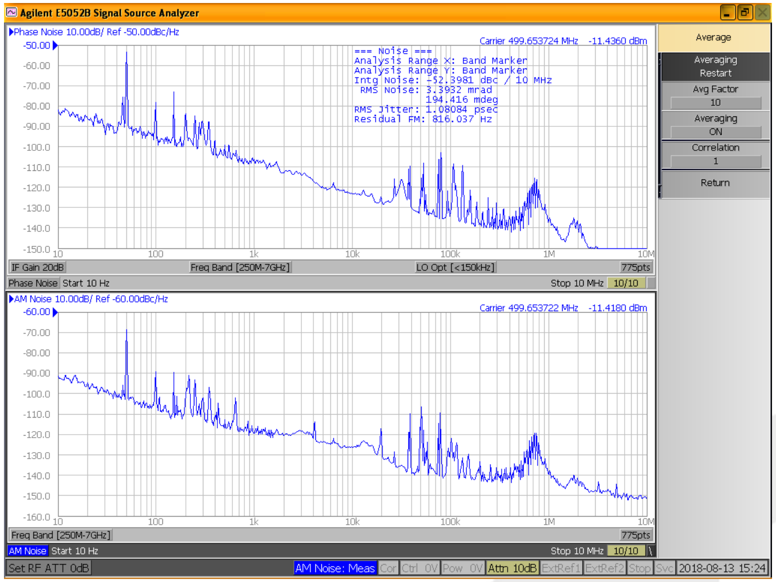
✓ RF distribution and lay out: to be re-designed. More attention to the spectral purity of the RF pre-drivers amplifier (2 W and 25 W).



Phase and Amplitude noise from the MASTER OSCILLATOR



Klystron amplifier: phase and amplitude noise of the RF output power



IOT amplifier: phase and amplitude noise of the RF output power

✓ Room for improvement for the spectral purity of the RF output power: RF pre-drivers first!

✓ **DLLRF : project coming soon !!!**

Conclusion 1/2

3HC passive system is:

- ✓ **essential for the beam stability of the user operation at 2.0 GeV 310 mA. Without 3HC, the maximum stable beam current is around 200 mA and it is gained "playing" only with the RF cavities HOM (no MB Longitudinal Feedback in operation at Elettra). At 2.4 GeV the beam stability is achieved at 160 mA without 3HC induced voltage. 3HC warm parked operation it should be avoided (if possible) due to 3HC components overheating.**
- ✓ **helping the MBTF operations. TOP-UP operations somehow masks the beam lifetime increase effect, however it make a huge difference starting the user operation after recovering from any the vacuum troubles.**

BUT:

- ✓ **Elettra TOP- UP operation has greatly lessened the requirements on the 3HC operations (induced voltage feedback loop is not need any more).**
- ✓ **Cryogenic system maintenance and fixing is a "hard task": at Elettra only part–time resources take care of it. The Elettra open position for a cryogenic expert not answered for so far.**

Conclusion 2/2

The RF system for Elettra 2.0

- ✓ revamp already started for the very Elettra machine.
- ✓ RF distribution system and RF pre-drivers will be revamped ASAP, improving the RF noise.

BUT:

- ✓ DLLRF is the next priority project of fundamental importance. A crucial decision shall be made first: in house development and expertise (the DLLRF prototype successfully tested on storage ring in 2011/2012) or turn key system? More people shall join the RF group.
- ✓ RF Interlock system shall be revamped as well: digital to analogic technique?

Elettra 2.0 RF power requirement seems relaxed (6-bend bare achromat losses ΔE/turn = 180 keV)

If not:

- ✓ Possibility to add one more 500 MHz cavity and another 3HC cavity for beam stabilization, but room for these devices is uncertain & Longitudinal Feedback system project is also started.
- ✓ 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".

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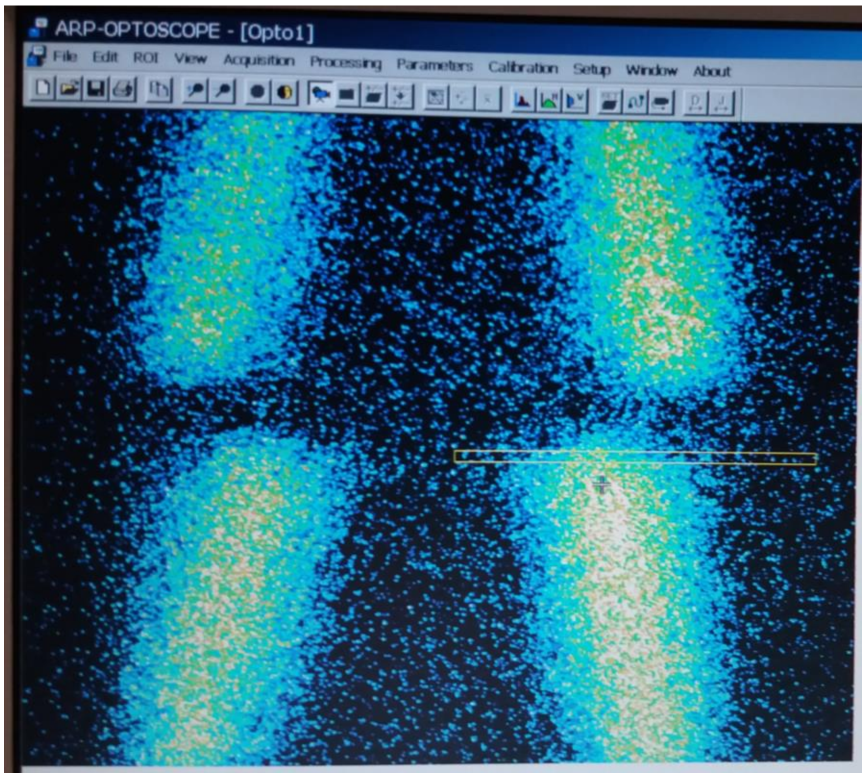
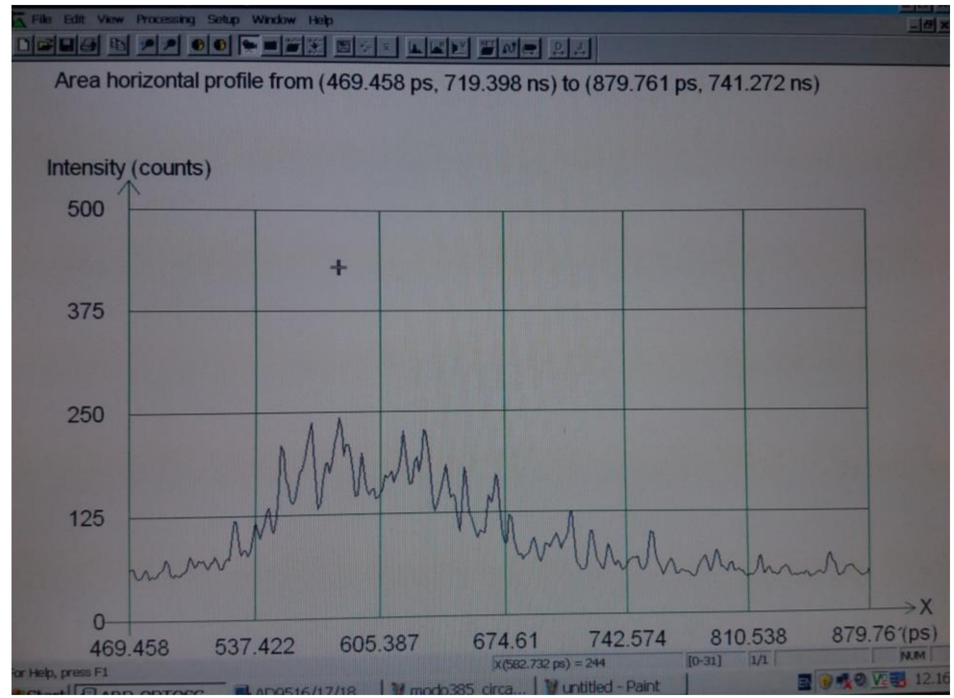
Bunch Length ≈ 137 psec (but signal to noise ratio too bad!





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