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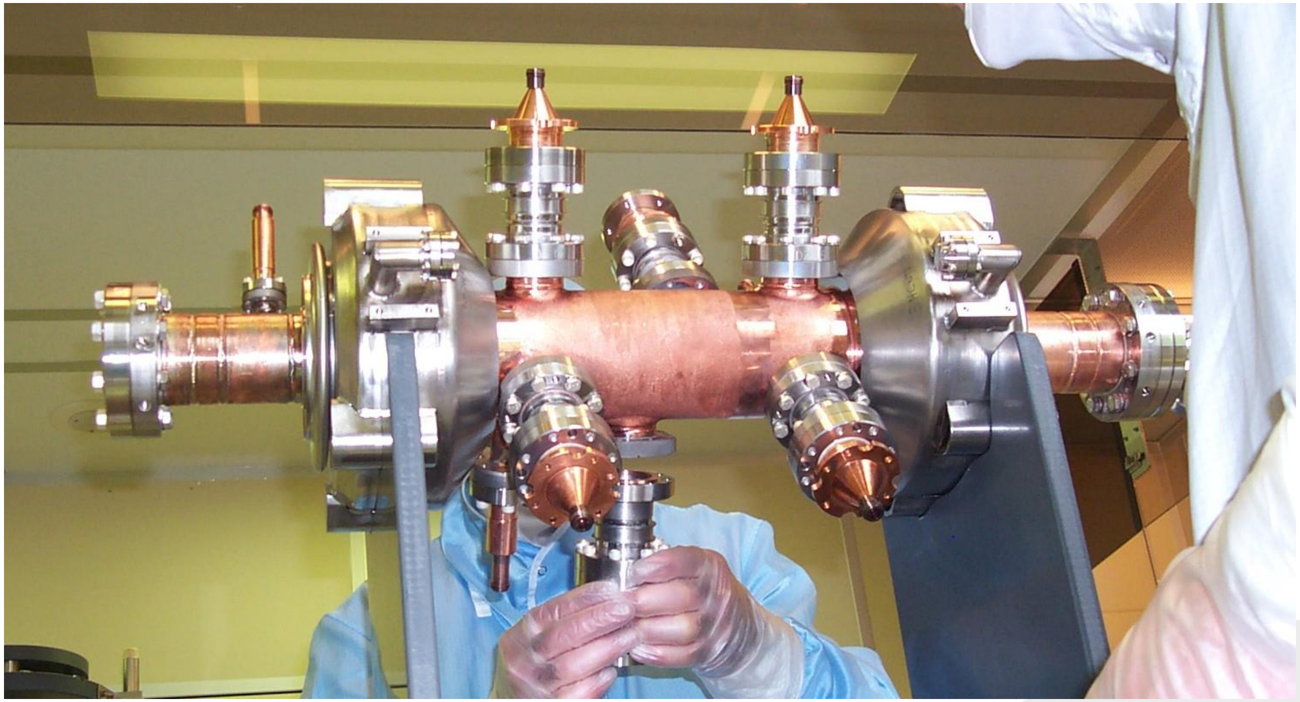
Operation of the Superconducting Third Harmonic Cavity at ELETTRA

Giuseppe Penco



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Introduction

- The main challenge of the third generation Synchrotron Light Sources is the increase of the radiation brightness, principally through the reduction of the electron beam dimensions (i.e. emittance).
- Unfortunately, the associated enhancement of the bunch charge density results in a significant degradation of the electron beam lifetime (Touschek effect: due to a scattering effect two particles can transform their transverse momenta into longitudinal momenta).

ATTRACTIVE SOLUTION:

- A higher harmonic RF cavity can be used to flatten the potential in the main RF bucket causing an increase in the bunch length with a consequent reduction of the intrabeam scattering and an **improvement in the Touschek lifetime**.
- In addition the non-linearity of the RF waveform should also help in fighting the coupled bunch instabilities **(Landau Damping)**.

References

- ✓ A. Hofmann and S. Myers, LEP Note 158 (**1979)** and "Beam dynamics in a double RF system", CERN-ISR-TH-RF-80-26 **(1980)**.
- ✓ M. Migliorati et al., Nucl. Inst. Meth. A 354 pp. 215-223 (**1995**).
- ✓ M. Georgsson, Nucl. Instr. and Meth. A 416 pp. 465-474 (**1998**).
- ✓ J.M. Byrd et al.,
  - Nucl. Inst. Meth. A 439 pp.15-25 (1999),
  - Nucl. Inst. Meth. A 455 pp. 273-284 (2000),
  - Phys. Rev. ST-AB 4, 030701 (2001),
  - Phys. Rev. ST-AB 5, 092001 (2002)
- ✓ …..
- ✓ G. Penco and M. Svandrlik, Phys. Rev. ST-AB 9, 044401 (2006)
- ✓ ….

The ELETTRA storage ring in Trieste (Italy)

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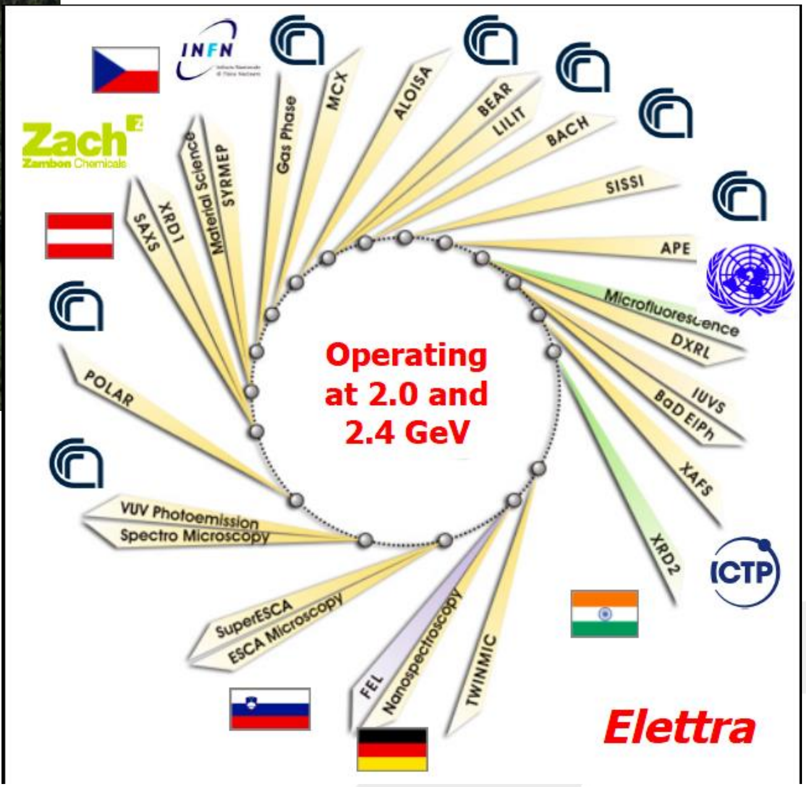
ELETTRA delivers photons to users for 5,000h a year with an uptime of 97-98%. Including machine studies and optimisations the total amount of operating hours per year attains 6,000h.



ELETTRA operates at **2.0-2.4 GeV**, in Top-Up Mode with an uptime of 97-98%.
~1000 proposals from 50 countries every year.
Almonst **1000** users/year on the **26** beamlines

Ref.: E. Karantzoulis

The super-3HC project

- An idle superconducting 3rd harmonic RF cavity based on a scaling to 1.5GHz of the 350MHz cavity developed for the SOLEIL cavity.
- The project was a collaboration between European laboratories:
  - CEA-DAPNIA Saclay:
    - *Cryomodule fabrication: tuning system working in vacuum and at cryogenic environment, thermal insulation, shield, etc…*
    - *Structure optimization and HOM studies with ELETTRA*
  - CERN : Cavity construction and final assembling in clean room
- INSTALLATION
  - Paul Scherrer Institute (PSI)
  - ELETTRA-Sincrotrone Trieste

Double RF system: the ELETTRA case (500 MHz + 1.5 GHz)

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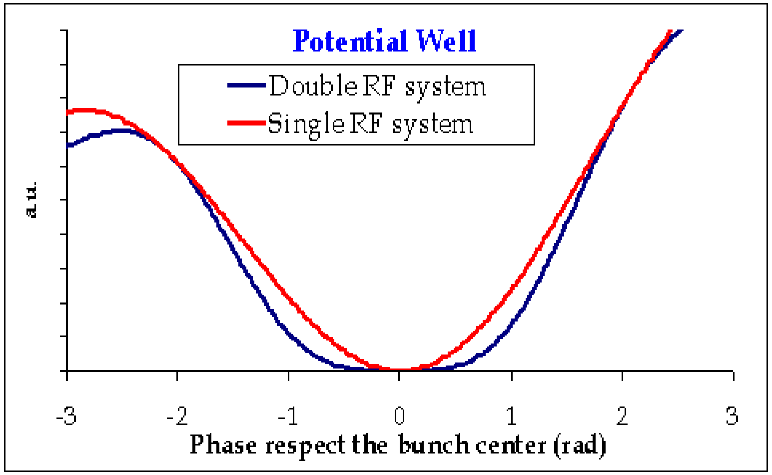
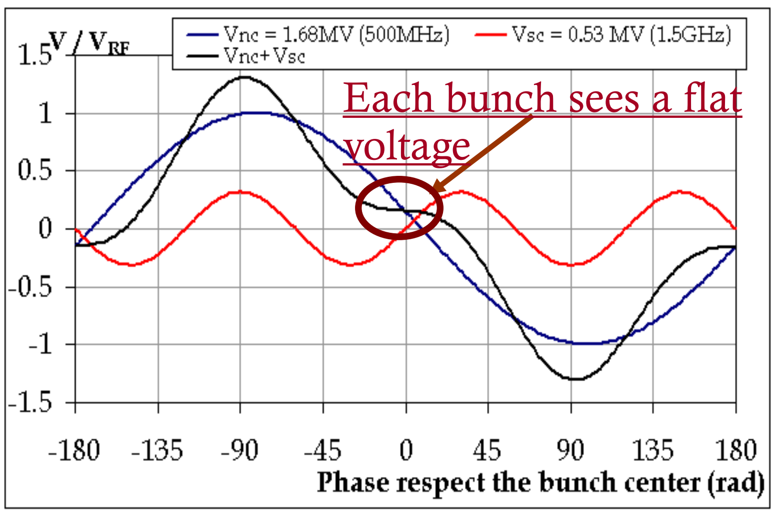
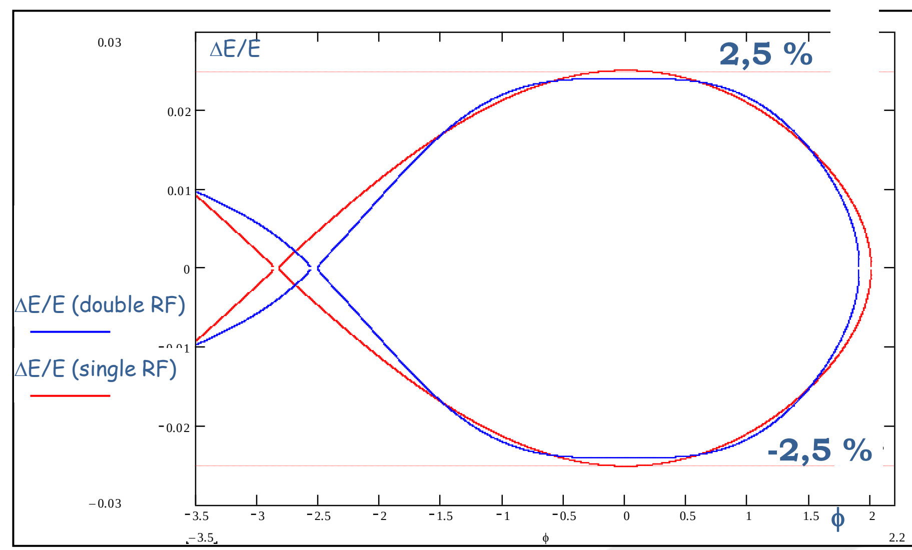


The particle distribution is function of the RF potential.

To lengthen the bunch V_{harm} and ϕ_h should be adjusted to flatten the potential well at the bunch center

$$\begin{cases} V_{harm} = V_{RF}\sqrt{\dfrac{1}{n^2} - \dfrac{(U_0/V_{RF})^2}{n^2-1}} \\ \tan n\phi_h = \dfrac{nU_0/V_{RF}}{\sqrt{(n^2-1)^2 - (nU_0/V_{RF})^2}} \end{cases}$$





The RF acceptance is not significantly modified by adding an harmonic cavity

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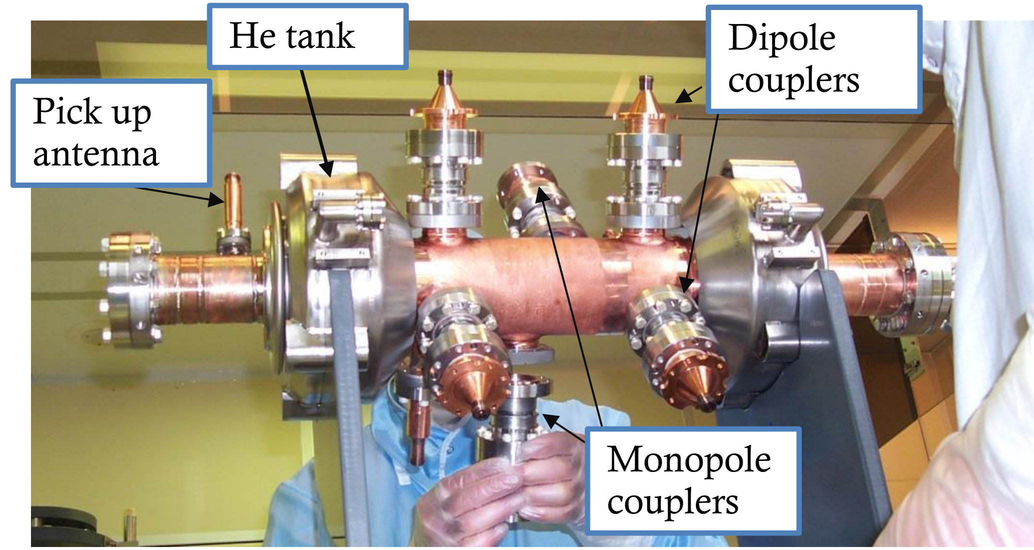
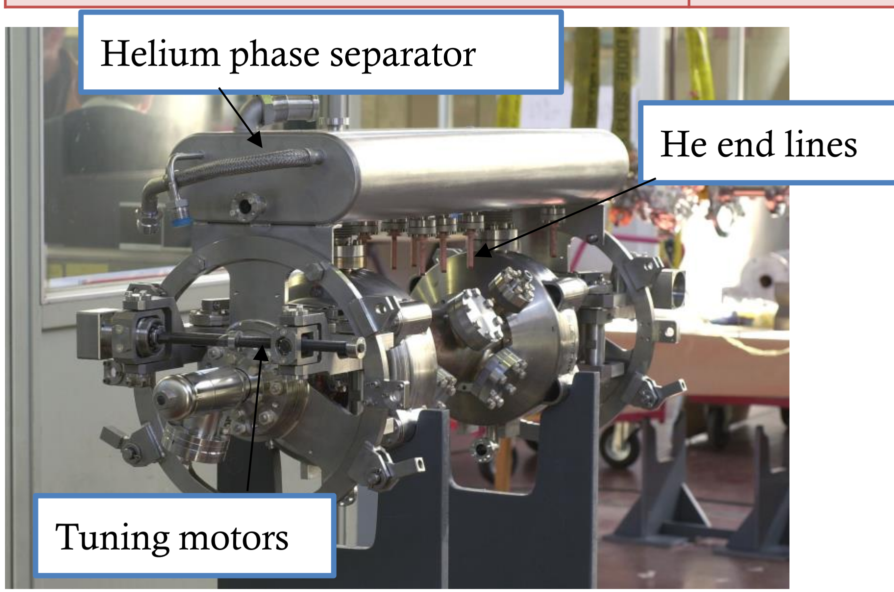
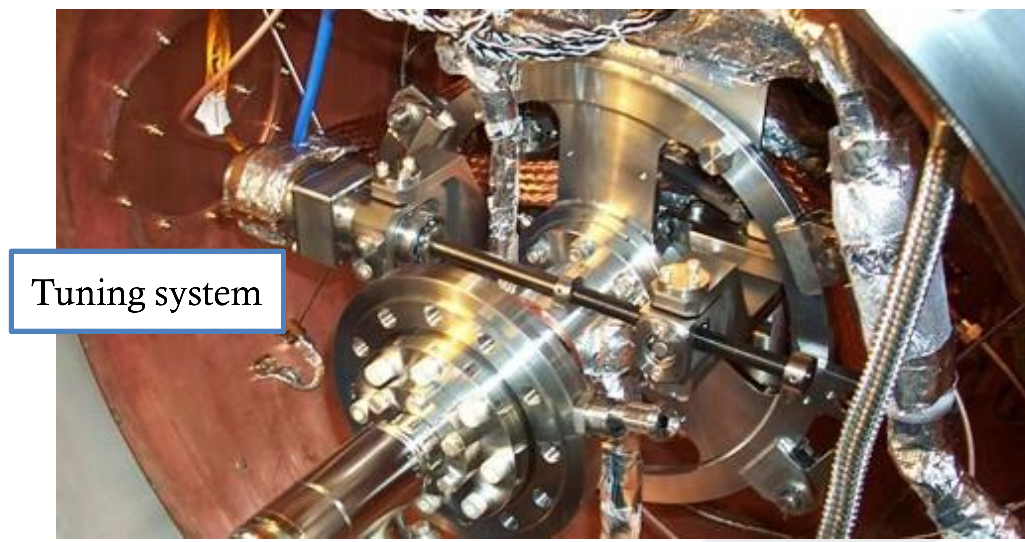
The Third Harmonic SC Cavity

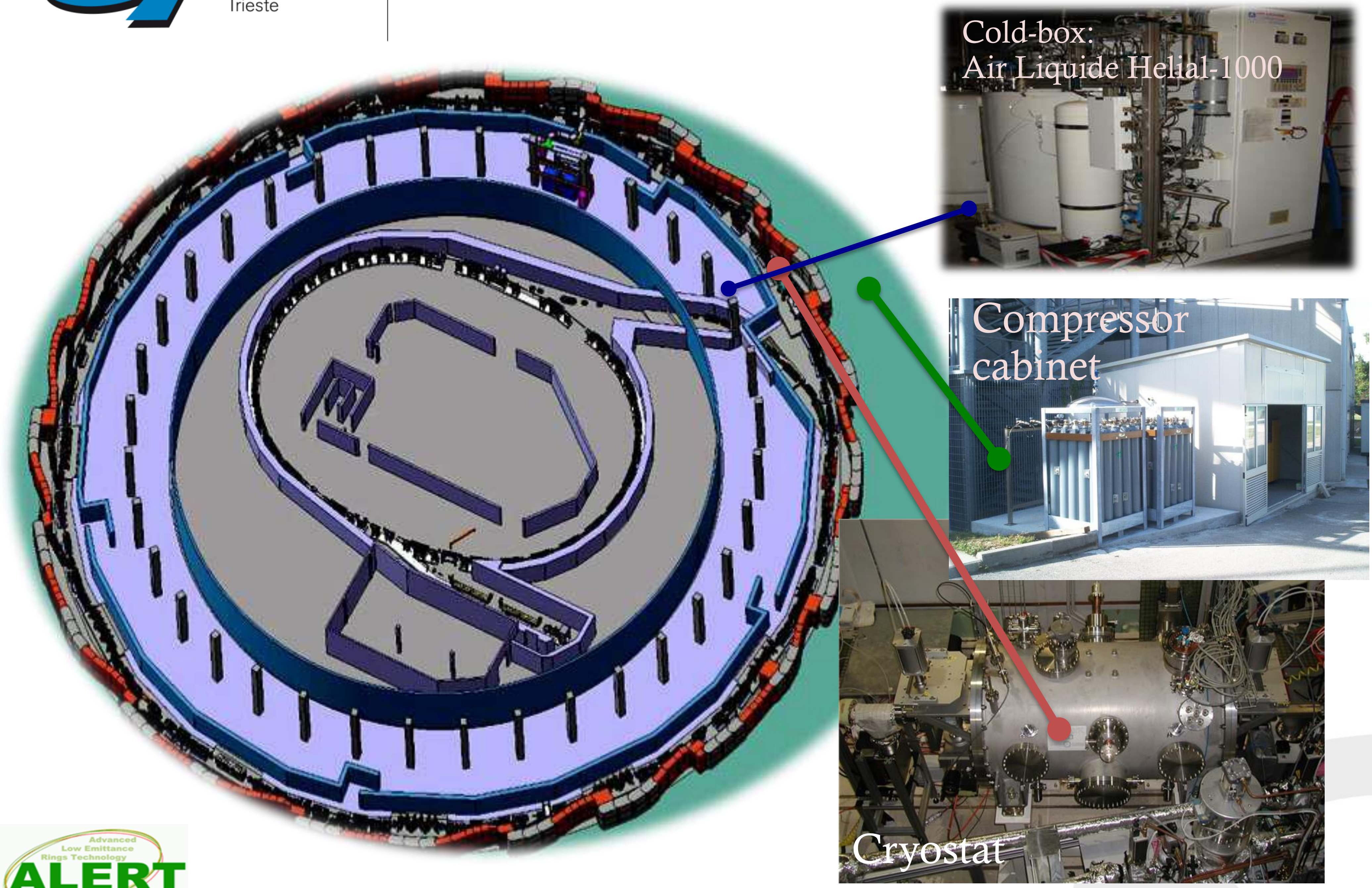
Main Cavity Parameters	
Third Harmonic Frequency	1498.958 MHz
Cavity freq. at 320 mA	1499.020 MHz
Max. Accelerating Voltage	1 MV
Nominal Voltage per cell	250 kV
Quality factor @ 3MV/m (4.5K)	$Q_0 > 2\ 10^8$
Cavity freq. regulation range	± 500 kHz
RF Power dissipated at 800kV (4.5K)	22 W







S3HC@Elettra : Overview



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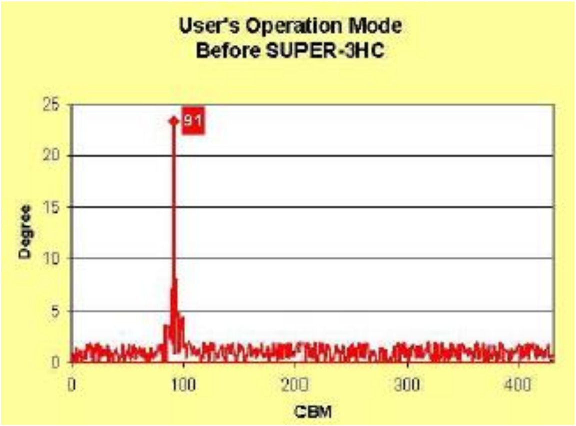
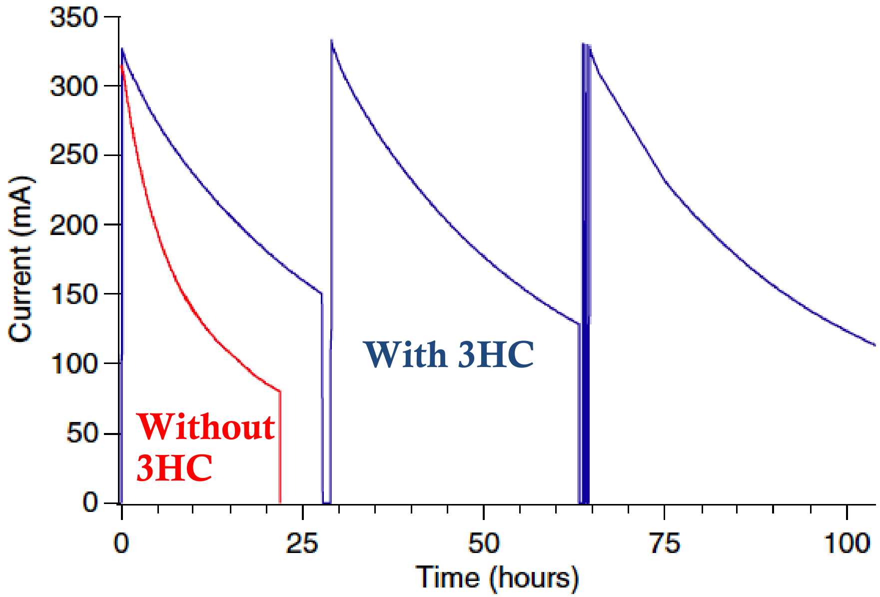
ELETTRA benefits from S3HC



- Before Super-3HC implementation, ELETTRA worked with a CBM excited in a "controlled" way.
- 3HC was installed in ELETTRA in 2002 and before the Booster advent it has allowed to refill at 2.0GeV every 48h instead of 24h (from 2005) and to operate **without CBMs.**
- **At 320mA the lifetime is about 27h that is almost 3.5 times the nominal lifetime (before 3HC).**



- **In top-up operation (from May 2010) the lifetime improvement has been translated in injecting 3 times less frequently. Stable operation are yet dependent on the 3HC activation.**

S3HC beam dynamics studies

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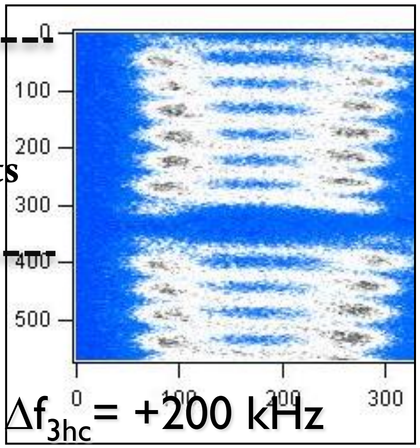
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **9**, 044401 (2006)

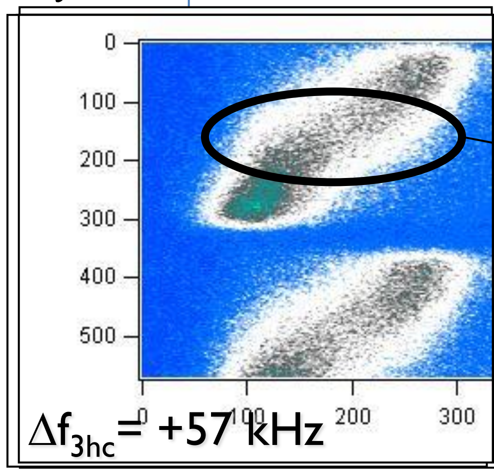
Experimental studies on transient beam loading effects in the presence of a superconducting third harmonic cavity

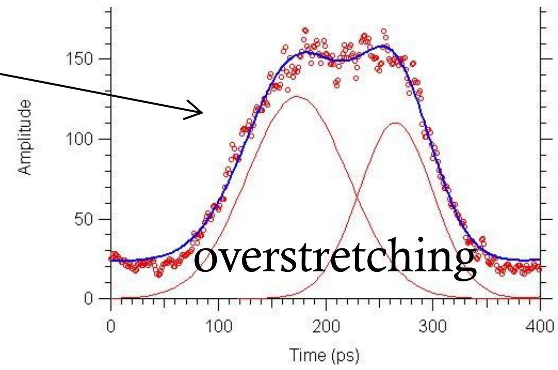
Giuseppe Penco and Michele Svandrlik

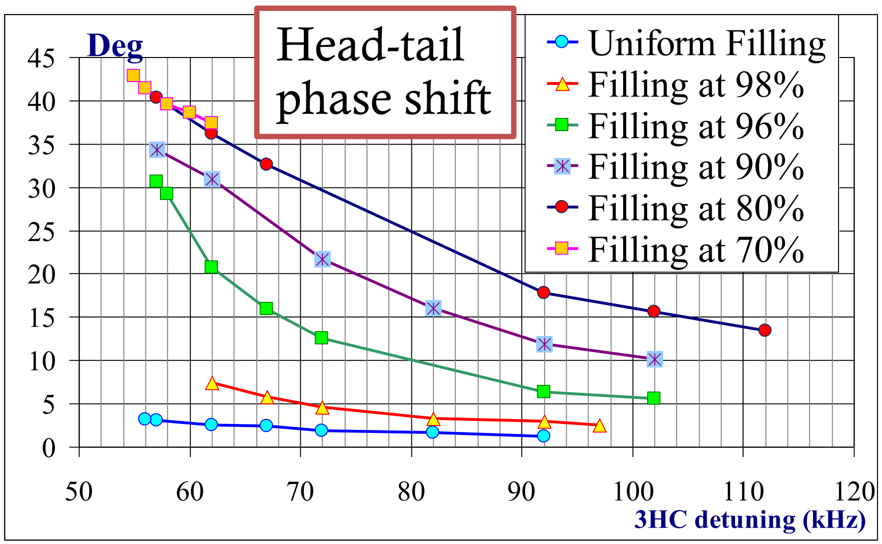
Landau Damping of Synch. Instability

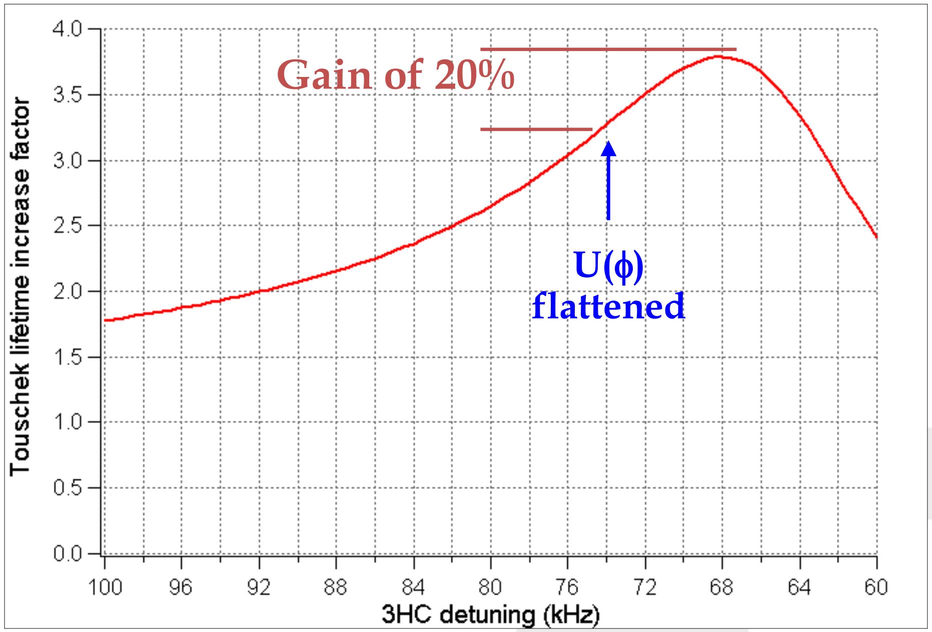
432 buckets











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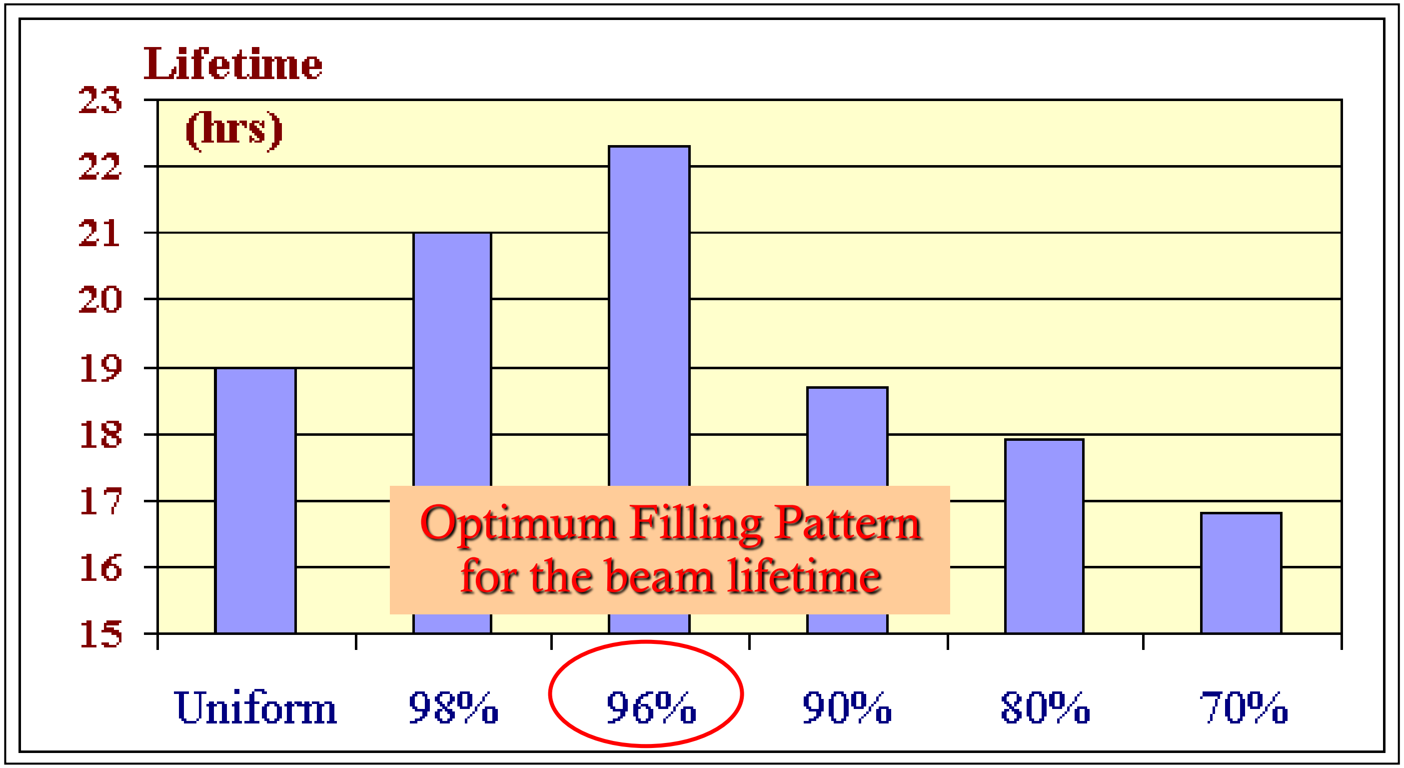
Beam Lifetime improvements

The best performance in terms of lifetime is obtained with a fractional filling of 96%. By further increasing the filling, the maximum lifetime (in stable condition) is lower, suggesting that the optimum setting for ELETTRA requires a small amount of "empty gap". The effective fractional filling at 96% is now taken as the new standard filling pattern for User's Operation Mode (320mA, 2.0GeV).



* Measurements taken during a vacuum conditioning time. The present lifetime at 320mA, 2.0GeV, 96% fractional filling is **27h** (nominal is 7.7h without 3HC)

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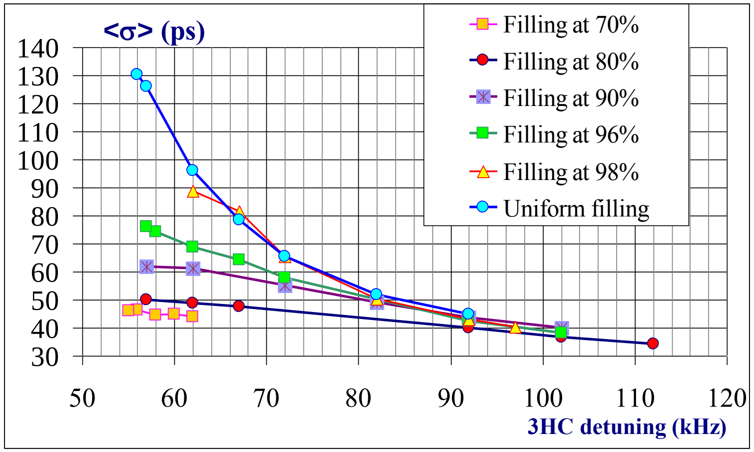
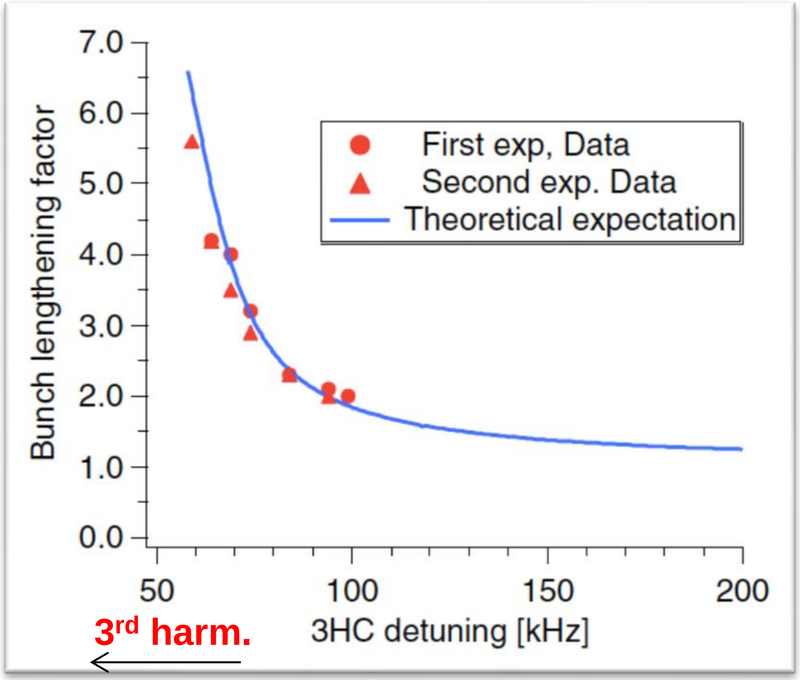
Bunch length manipulation experiments

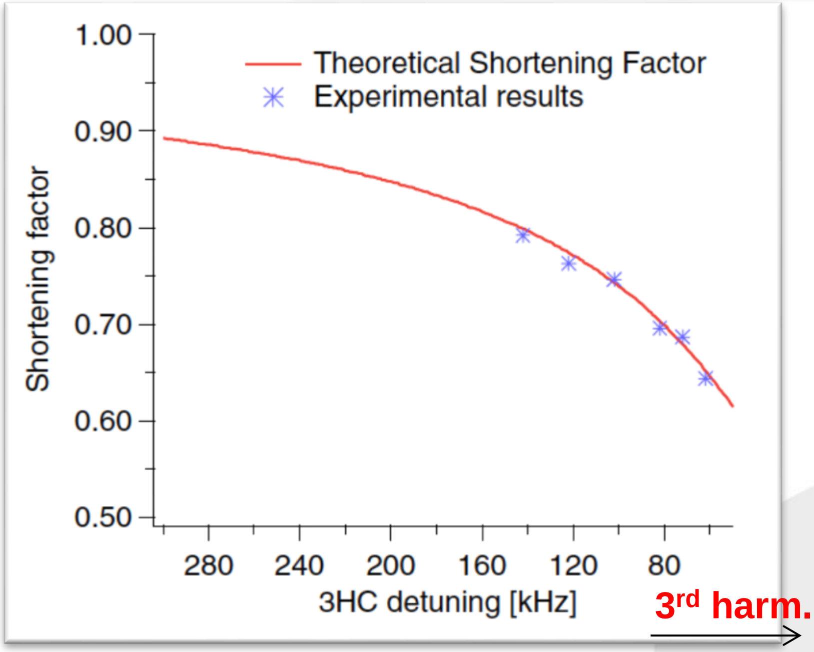
- Bunch lengthening (measurements with Streak Camera equipment):





- Bunch shortening: the increase of the voltage slope around the synchronous phase allows for considering the **synchrotron frequency** as a reliable parameter to calculate the rms bunch length, which in linear approximation is inversely proportional to synchrotron frequency

$$f_s \propto \frac{1}{\sigma_b}$$



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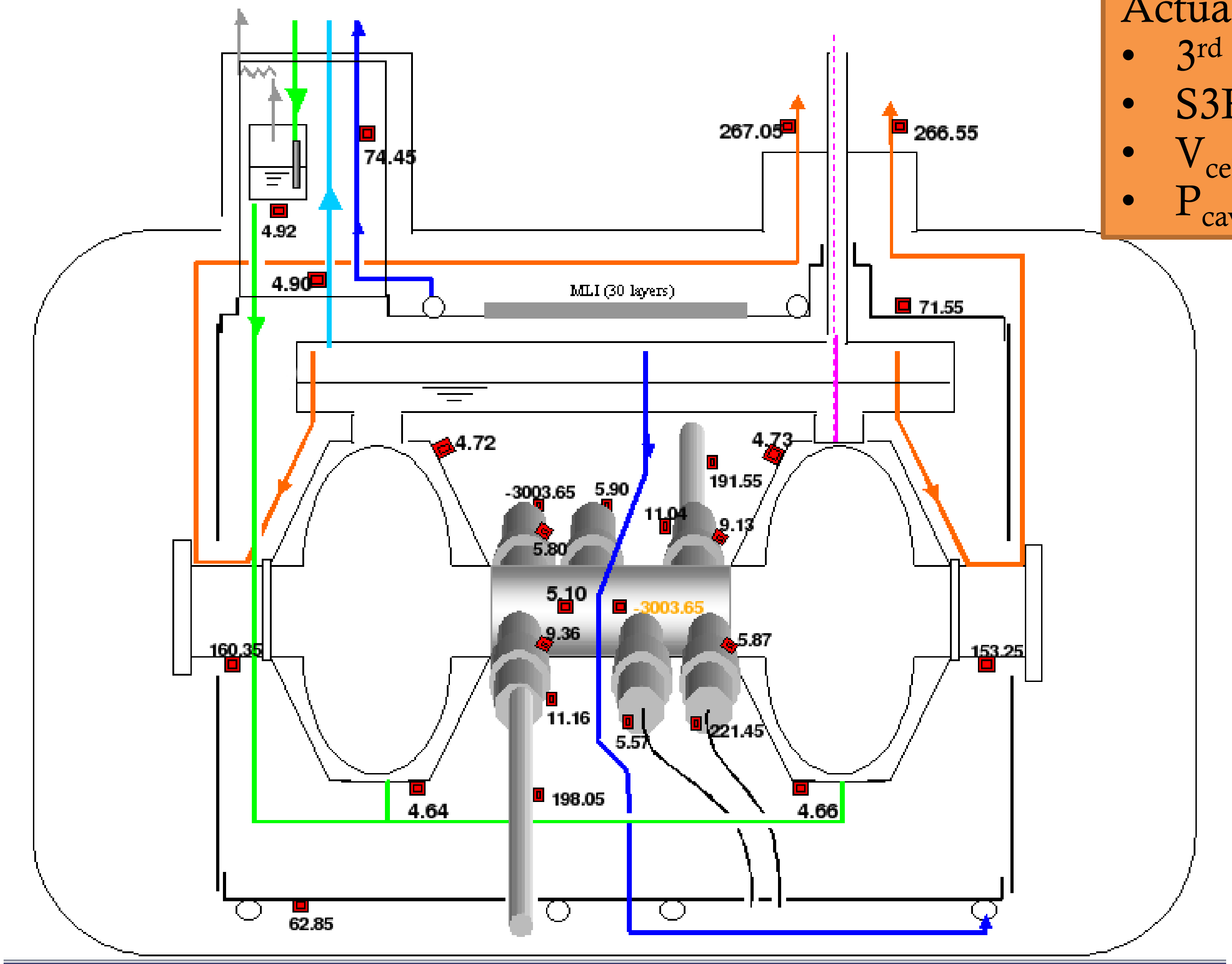
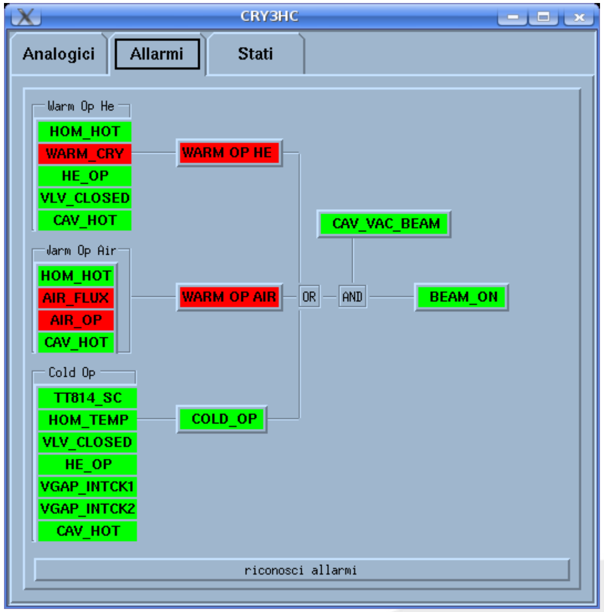
Current status and operation



Actual settings:

- 3rd harm freq.: 1498.955 MHz
- S3HC freq.: 1499.020-040MHz
- V_{cell} ~ 200 kV
- P_{cav} ~ 10^{-10}mbar; P_{ins}~10^{-8} mbar



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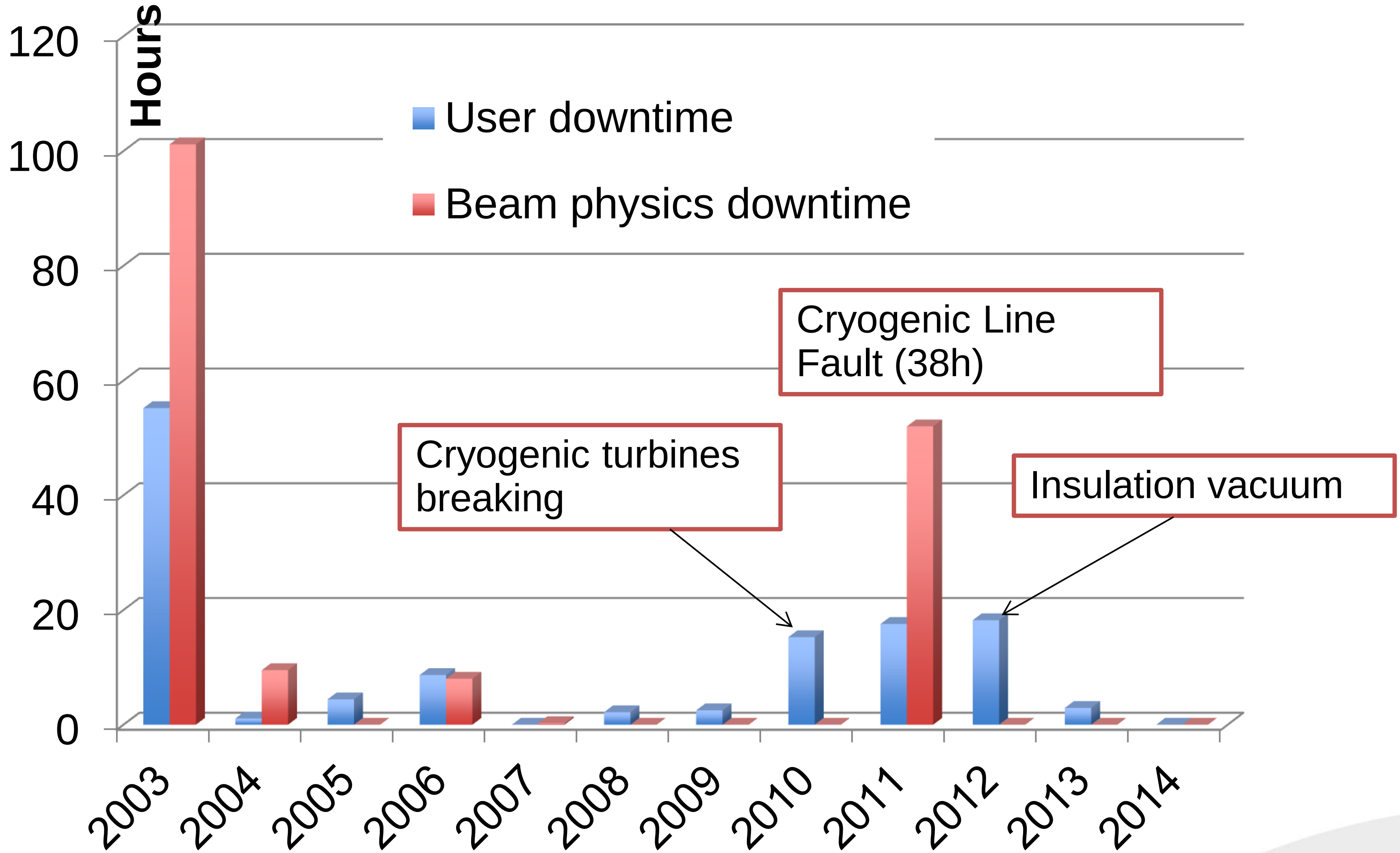
Downtime in 12 years

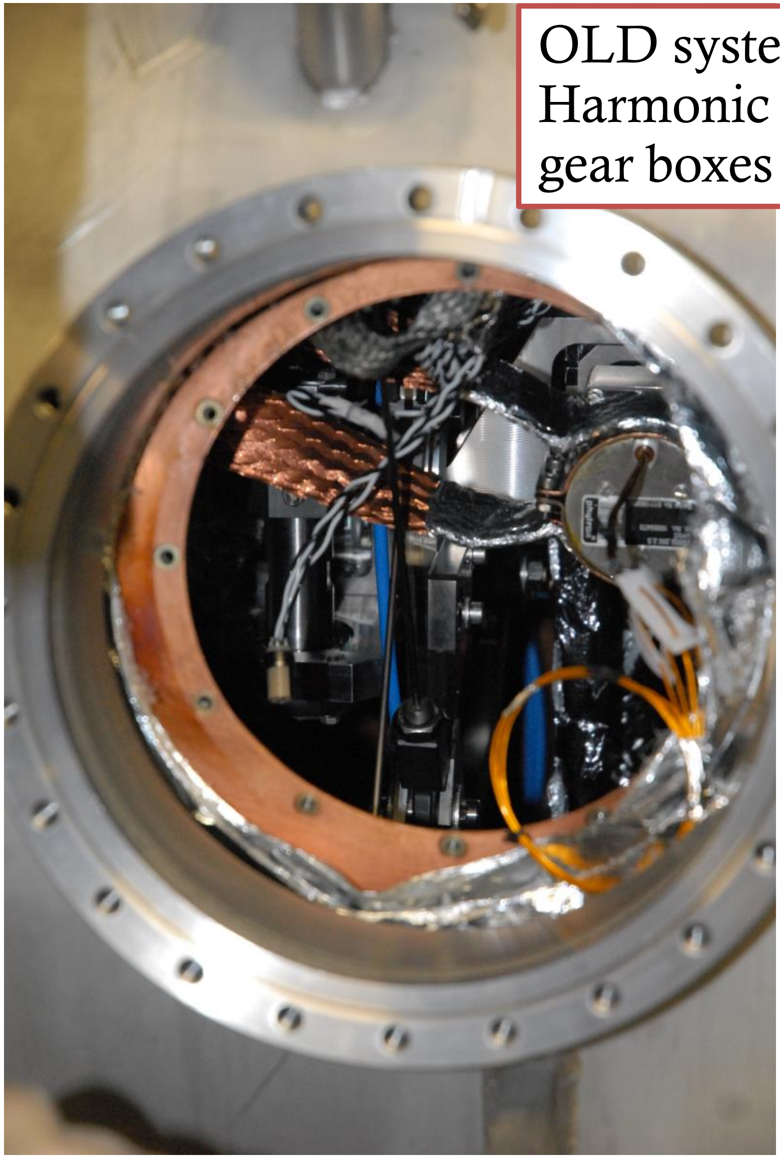


Courtesy of S. Krecic

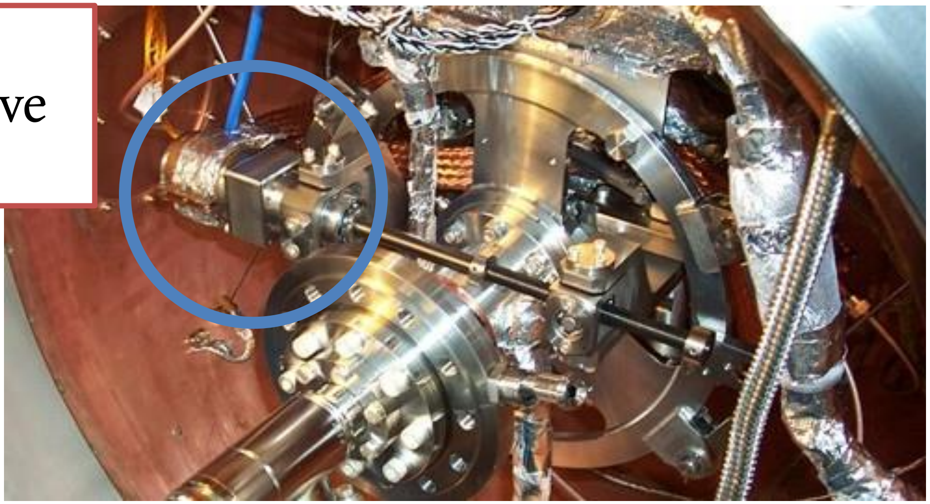
Main faults events

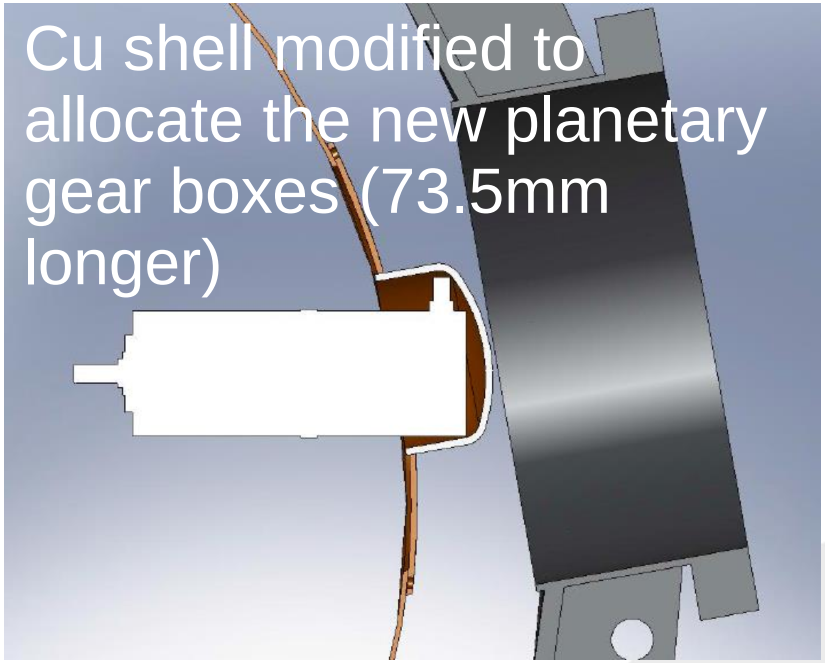
- The cells tuning system (separate for each cell, in vacuum and at cryogenic temperature) after using several harmonic drive gear boxes models, we substituted them with more reliable planetary gear boxes (necessary a intervention on the motor system).
- HOMs couplers tuning
- Cryogenic plant: it is in general reliable but we suffered from some issues:
  - Mishandling of the turbines cooling circuits.
  - He contamination during warm-up/cool-down cycles.
  - Insulation vacuum of the cryostat and cryogenic lines

Motor Gear boxes replacement



OLD system: Harmonic drive gear boxes





Cu shell modified to allocate the new planetary gear boxes (73.5mm longer)

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HOMs couplers

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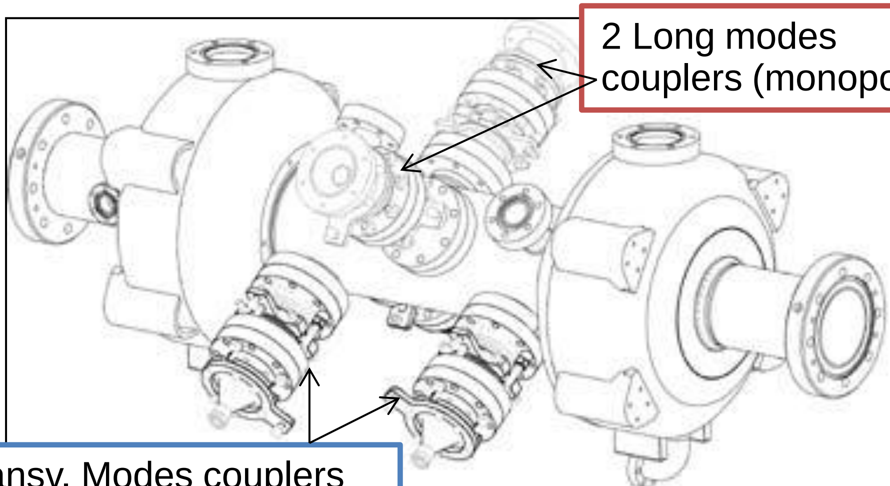
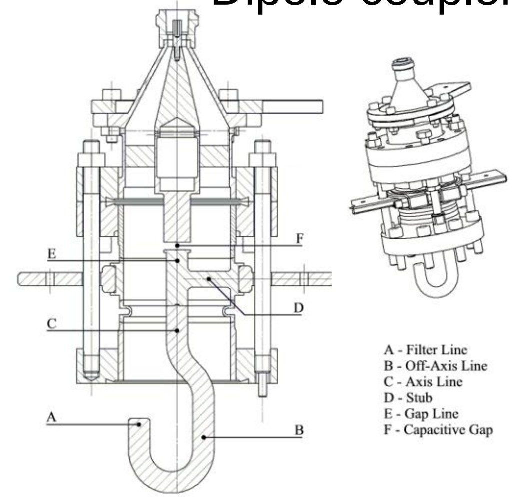
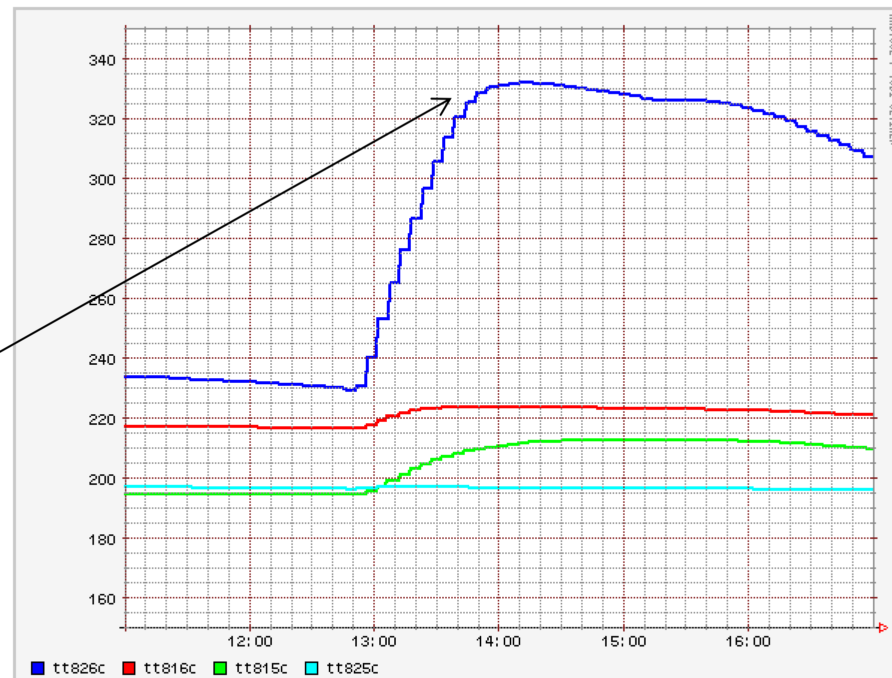


Dipole coupler



Craievich et al. “HOM couplers design for the super-3HC cavity” PAC2001

- During Booster installation works (2008), S3HC has suffered a detuning of the HOMs couplers.
- One of the dipole coupler was found to be strongly coupled with the fundamental mode: a room temperature cable reached 330K!
- It was necessary to slightly tune it in order to improve the fundamental mode rejection.



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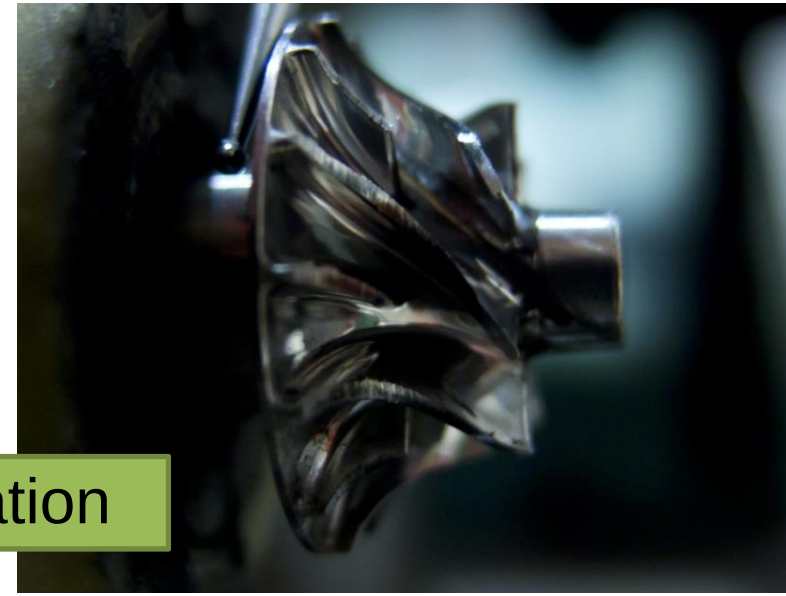
Cryogenic turbines breaking



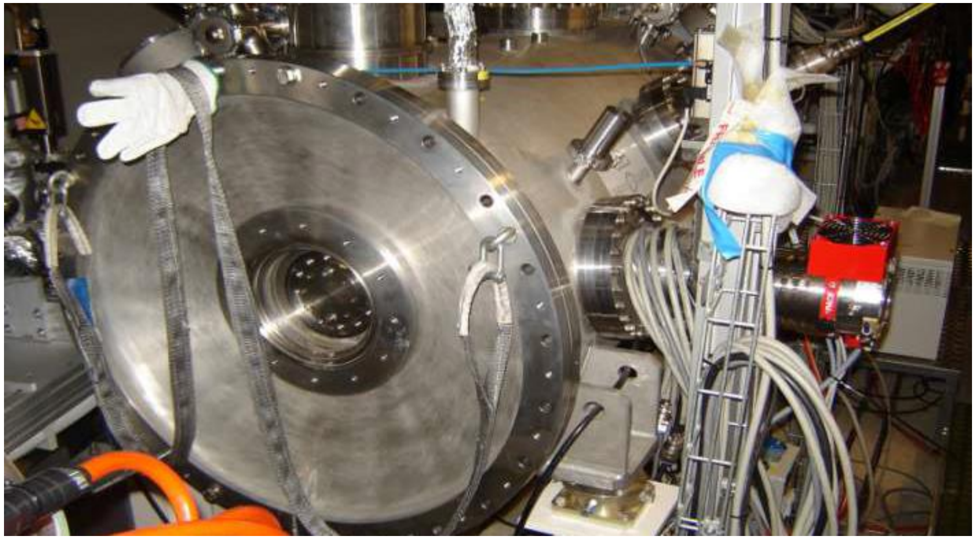
He contamination

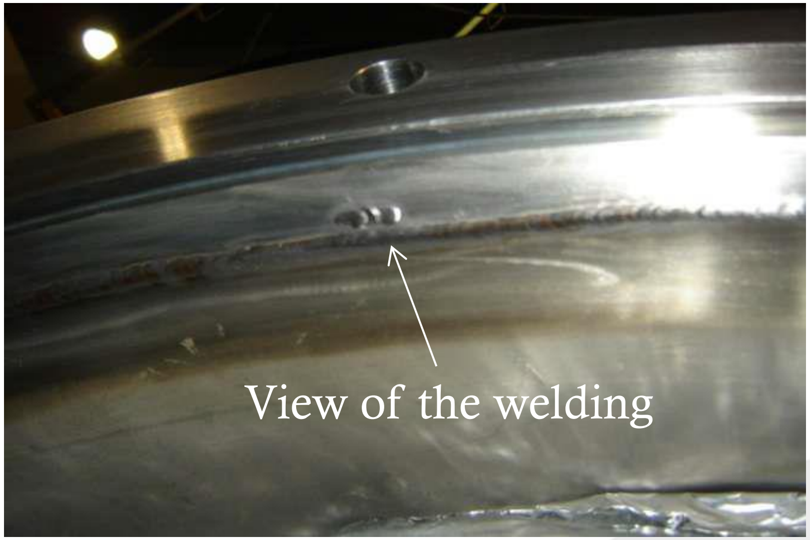
Corrosion due to demineralized water in the cooling system

Over-heating (mishandling of the cooling system)

Vacuum insulation problem

- In 2010 all Viton gasket were replaced. (LHe level gauge)
- In 2012 a leak on the the cryostat vacuum insulation was detected and this leaded to a bad cryogenic efficiency:
  - An important intervention was scheduled, consisting in venting dry nitrogen in the cavity with a slow controlled flux, removing the main flange and fix the leak by a new TIG welding torch.
  - The SC cavity did not suffer any pollution and a very high cryogenic efficiency has been restored.





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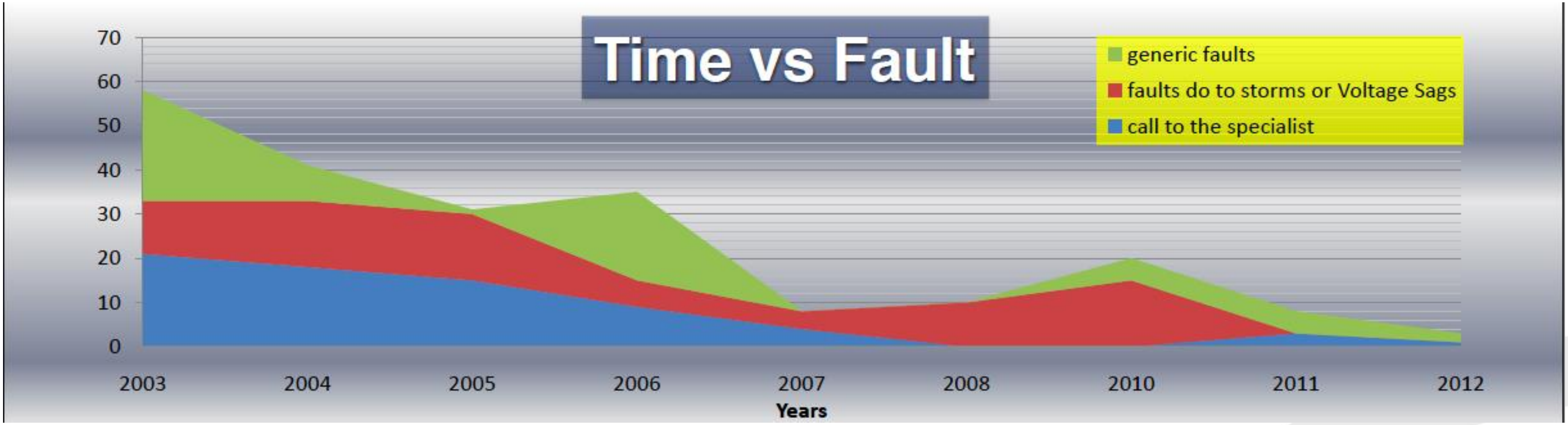
Uninterruptable Power Supply System

In **2011** all the system of S3HC was connected directly to the **trigeneration plant (CHCP: Cogeneration of Heating, Cooling and Power)**. This unit was designed as a no-break system and to sustain the UPS electric loads (**250KW** only for the main compressor) during micro-interruptions or interruptions of the external electric power supply. This was very useful for system reliability, faults due to voltage sags are almost forgotten!



Courtesy of P. Zupancich

Conclusion

- Super-3HC contributes to increase ELETTRA brightness:
  - Lifetime is increased by a factor 3 to 3.5
  - Suppression of longitudinal Coupled Bunch Modes
- High reliability of the superconducting cavity and of the cryogenic plant thanks to:
  - UPS system
  - Annual careful maintenance
  - Highly reliable ancillary systems (water, electricity and vacuum)
  - New tuning system based on planetary gear boxes
- Beam dynamics experiments have proved:
  - Filling pattern of the bunch train has to be optimized for the best S3HC efficiency.
  - Bunch lengthening: good agreement between experimental results and expectation
  - Possible to operate in shortening mode

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Thank you!

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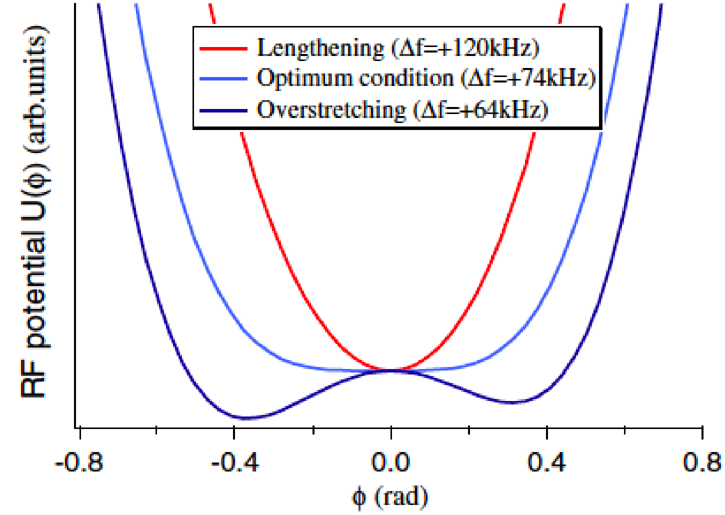
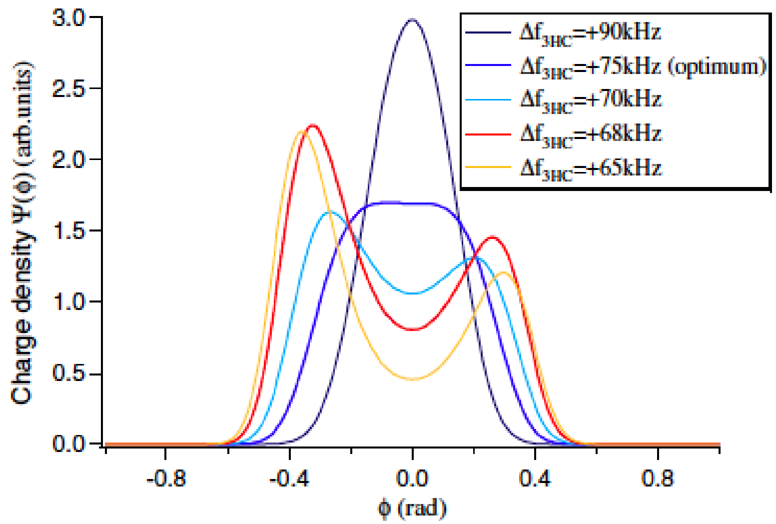
Improving in the Touschek lifetime

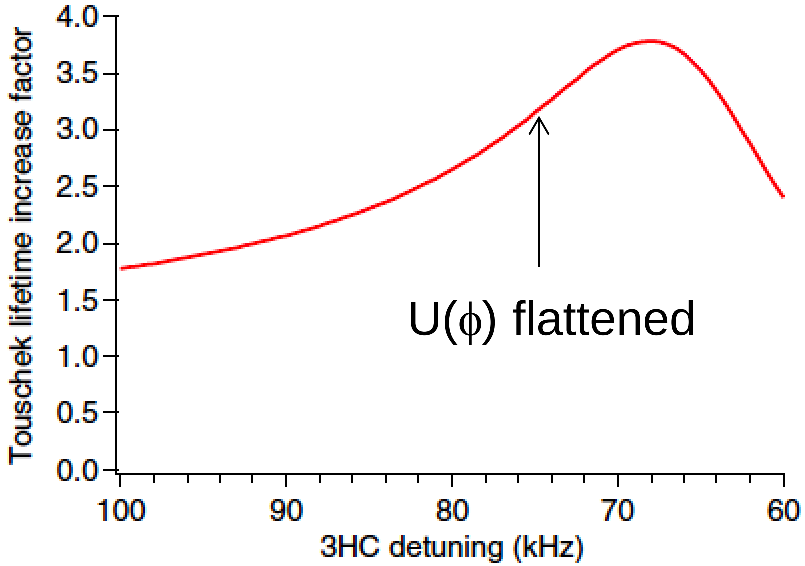
Particle distribution $\Psi(\phi) = \bar{\Psi} \exp\left(-\frac{U(\phi)}{\alpha^2 \sigma_\epsilon^2}\right)$ ← Potential well





Touschek lifetime $\tau_{T,h} = \tau_{T,0} \frac{\epsilon^2_{\mathrm{rf},h}}{\epsilon^2_{\mathrm{rf},0}} \frac{\int \Psi_0^2(\phi)\, d\phi}{\int \Psi_h^2(\phi)\, d\phi},$

RF acceptance



- Byrd and Georgsson, PRST-AB 4, 030701 (2001)
- Penco and Svandrlik, PRST-AB 9, 044401 (2006)

Overstretching: uniform and 96% filling cases

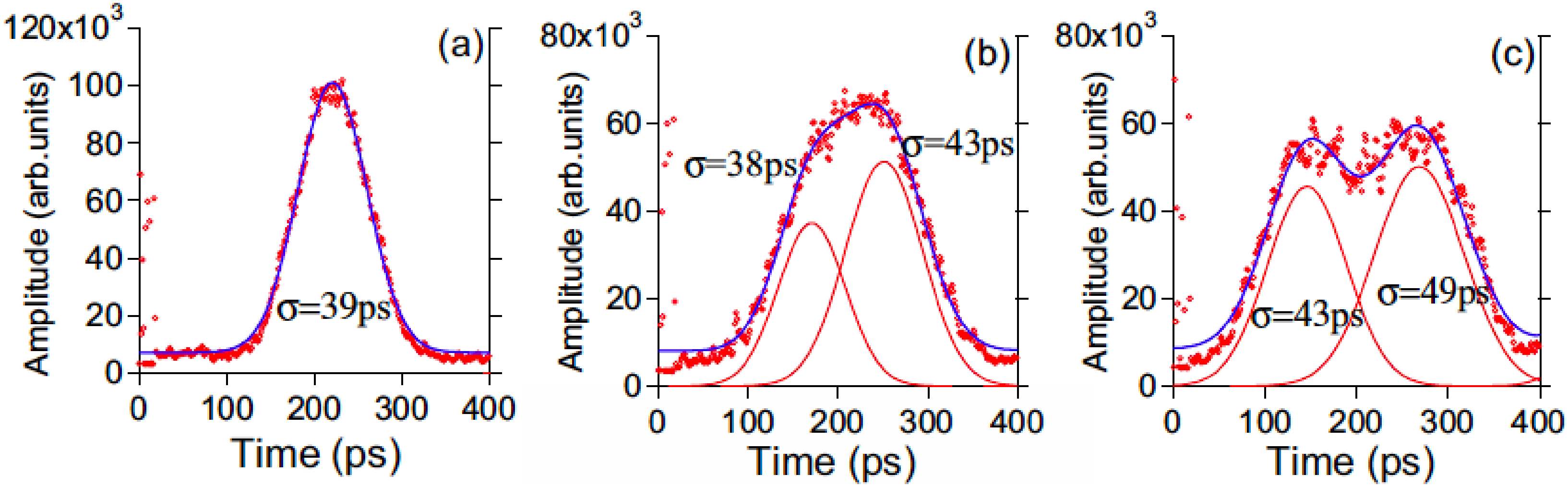


FIG. 16. (Color) Average bunch profile with the corresponding best fitting curves in case of a uniform filling for a 3HC detuning of +114 kHz (a), +74 kHz, (b), and +61 kHz (c); I_{beam} = 315 mA, 2.0 GeV.

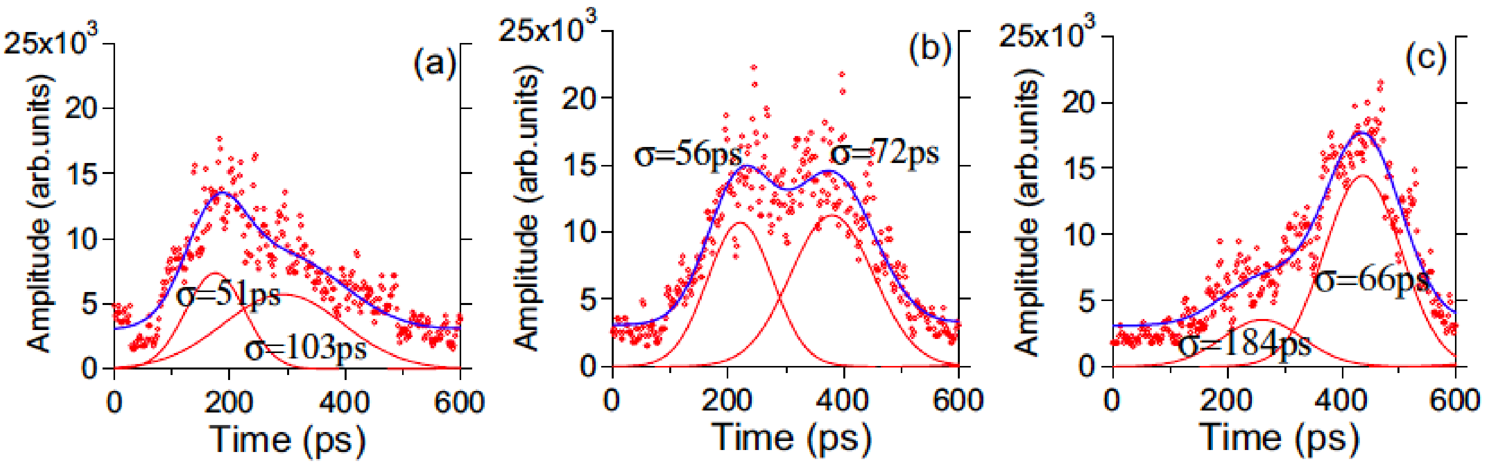
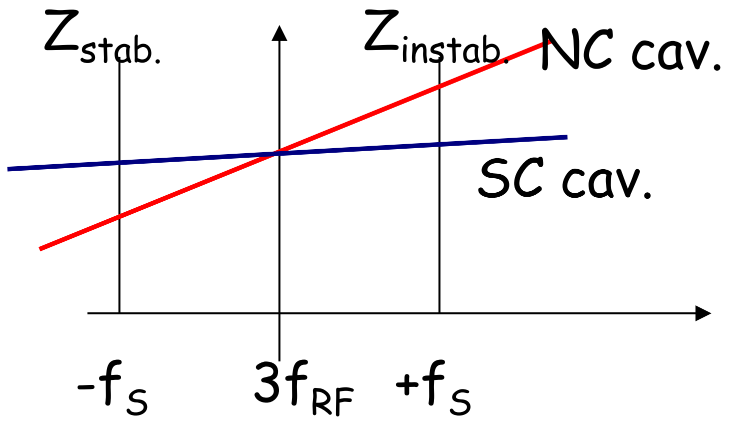


FIG. 17. (Color) Bunch profile in the tail (a), in the middle (b), and in the head (c) of the bunch train in case of a fractional filling of 96%, 3HC detuned of +64 kHz; I_{beam} = 315 mA, 2.0 GeV.

Advantages of the SC choice

- Low power dissipation in the cavity
- Reduced number of cells (a NC system with the same voltage with a reasonable Power dissipation would require 6-10 NC cells!). The phase modulation effect in case of non uniform filling is thus reduced ($\Delta f_{\text{bunch-bunch}}$ depends on R/Q).
- Possibility to have an EFFICIENT HOM free structure (Low R/Q, Very high Q)
- The cavity can be easily made "invisible" to the beam
- Less contribution to the anti-damping impedance for the Robinson stability (the cavity is detuned on the unstable side for the Robinson criterion!)



$$\sum_{k=-\infty}^{+\infty}\left[Z_{stab}(k\varpi)-Z_{instab}(k\varpi)\right]>0$$

$(Z_{instab}-Z_{stab})_{NC} >> (Z_{instab}-Z_{stab})_{SC}$

In the NC case the contribution to the unstable component should be compensated by the main RF system.