Results on INFN-LNL Niobium RFQs

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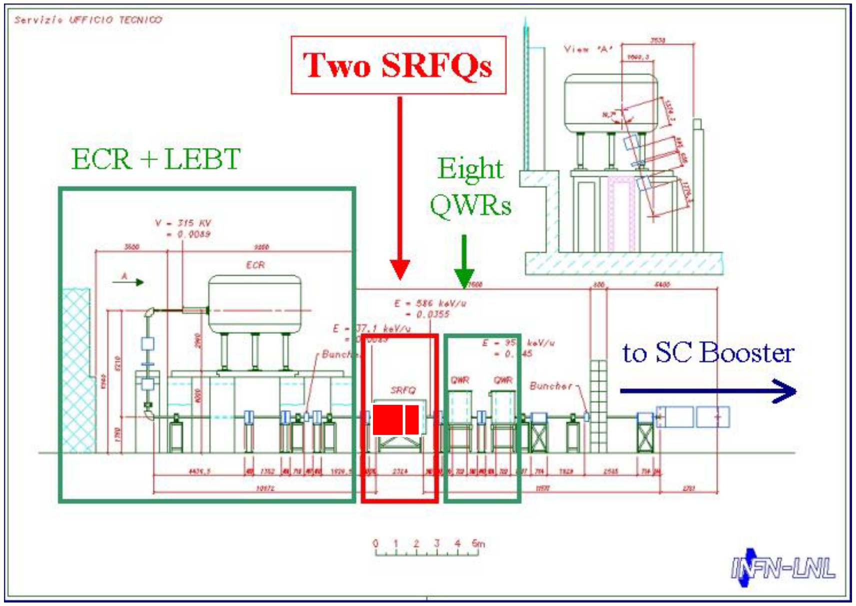
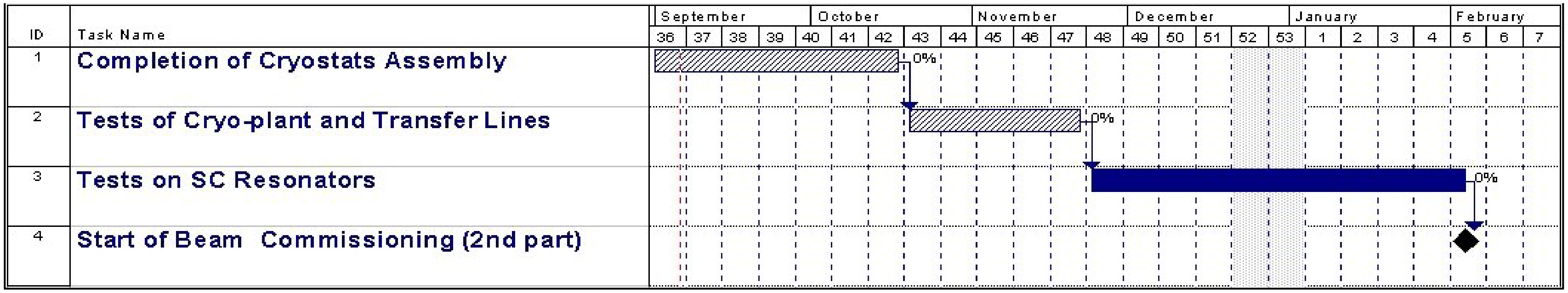
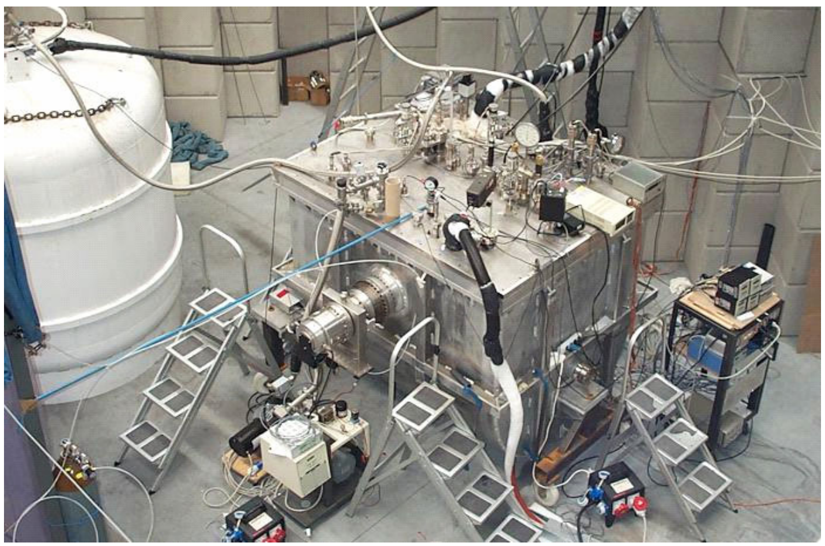
The ion injector



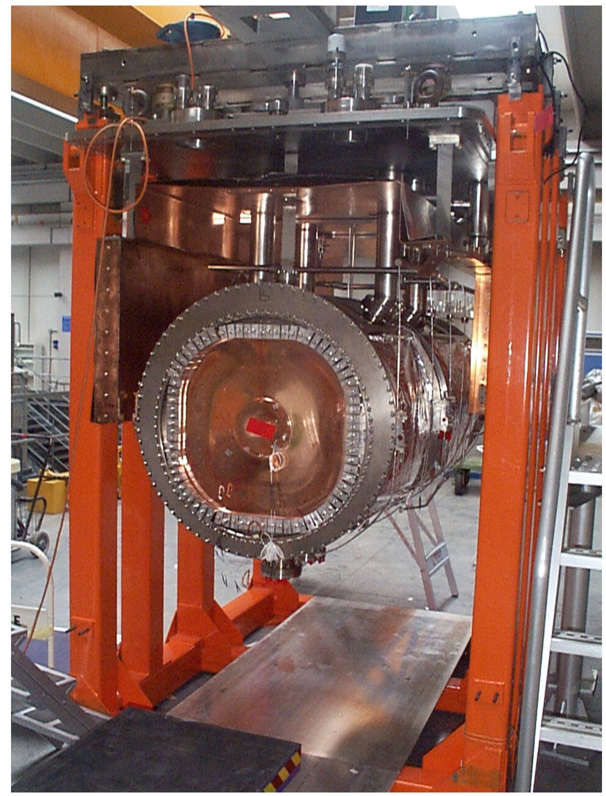
q/M	28/238	
Energy Range	38÷948	keV/m
β range	0.0094÷0.045	
Current	1	eμA
T. Emittance	0.5	mmmrad (norm)
L. Emittance	< 0.7	nskeV/u

Status: from tests to on-line operation

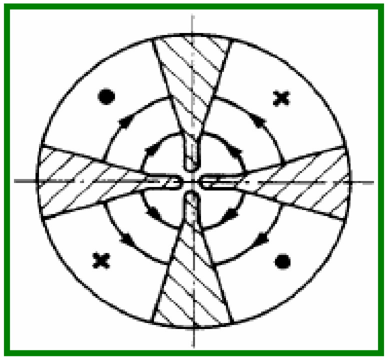


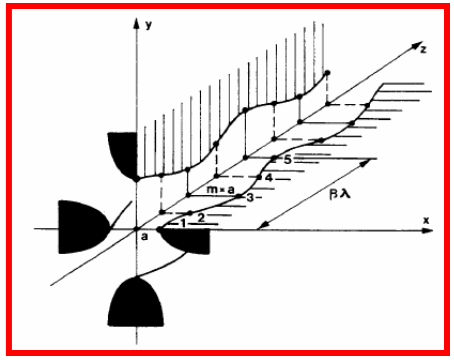


Both SRFQ1 and SRFQ2 have been fully characterized off-line



Radio-Frequency Quadrupoles





- **Focusing** ⇐ **main quadrupolar E_T**
- **Acceleration** ⇐ **small effective E_L**

modulation of 4 vanes
(synchronous with beam bunches)
one modulation period = $\beta\lambda$

$$U(r,\theta,z) = \frac{V}{2}\left[A_{01} r^2 \cos 2\theta + A_{10} I_0(kr) \cos kz\right]$$

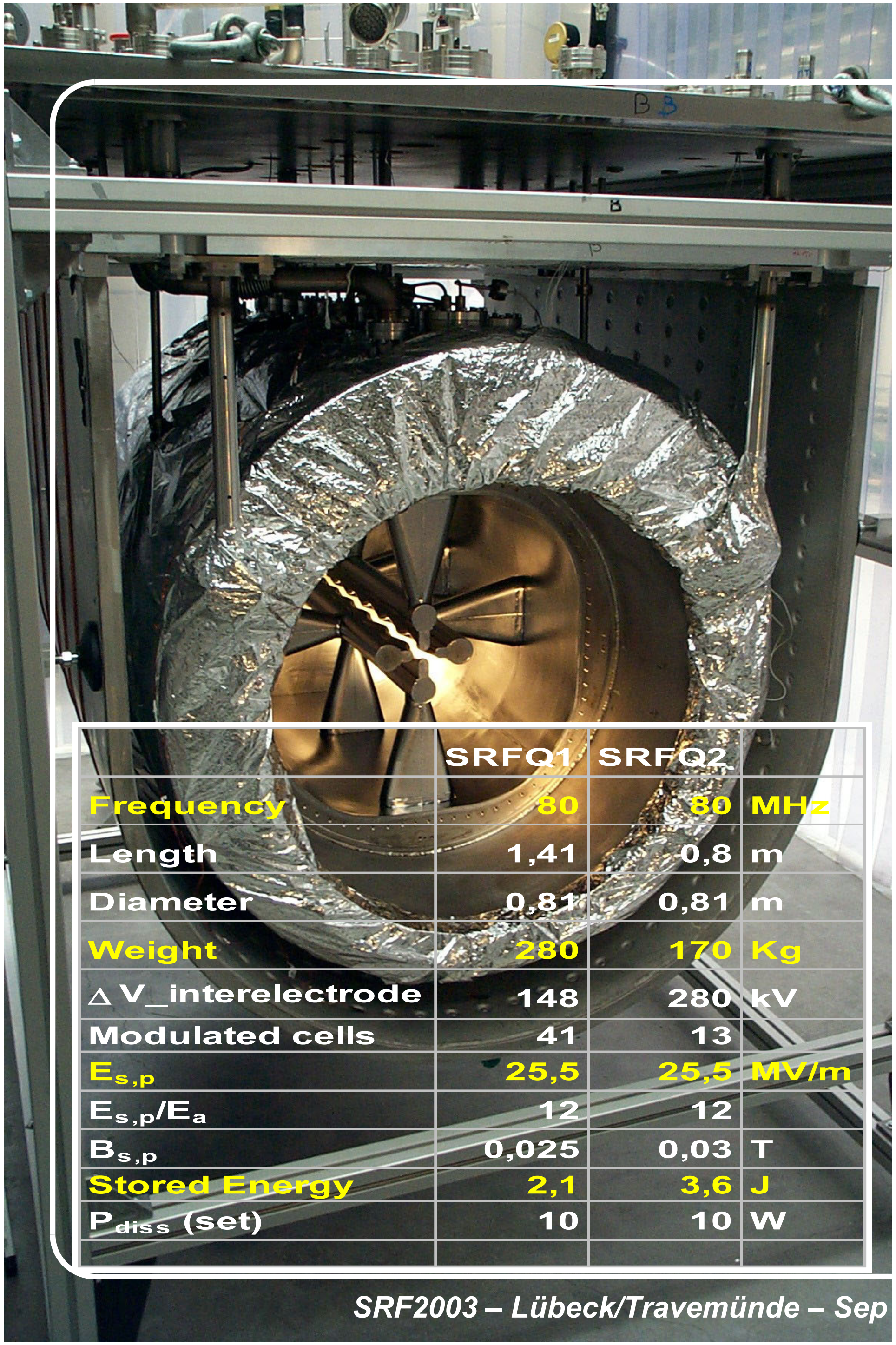
Ideal for **β=v/c < 0.05**
Typically **NC**, **50-400 MHz**

NORMAL CONDUCTING
ΔU ~ 100 kV, **Q ~ 10^4**, **d.c. < 20%**
with a few remarkable exceptions
(**LEDA**: 2.2.MW rf, 100 mA-beam)

SUPERCONDUCTING
ΔU~ 300 kV, **Q~10^9**, **d.c. = 100%**
Motivated by lower rf power (and μA beam) + expertise in cryogenics

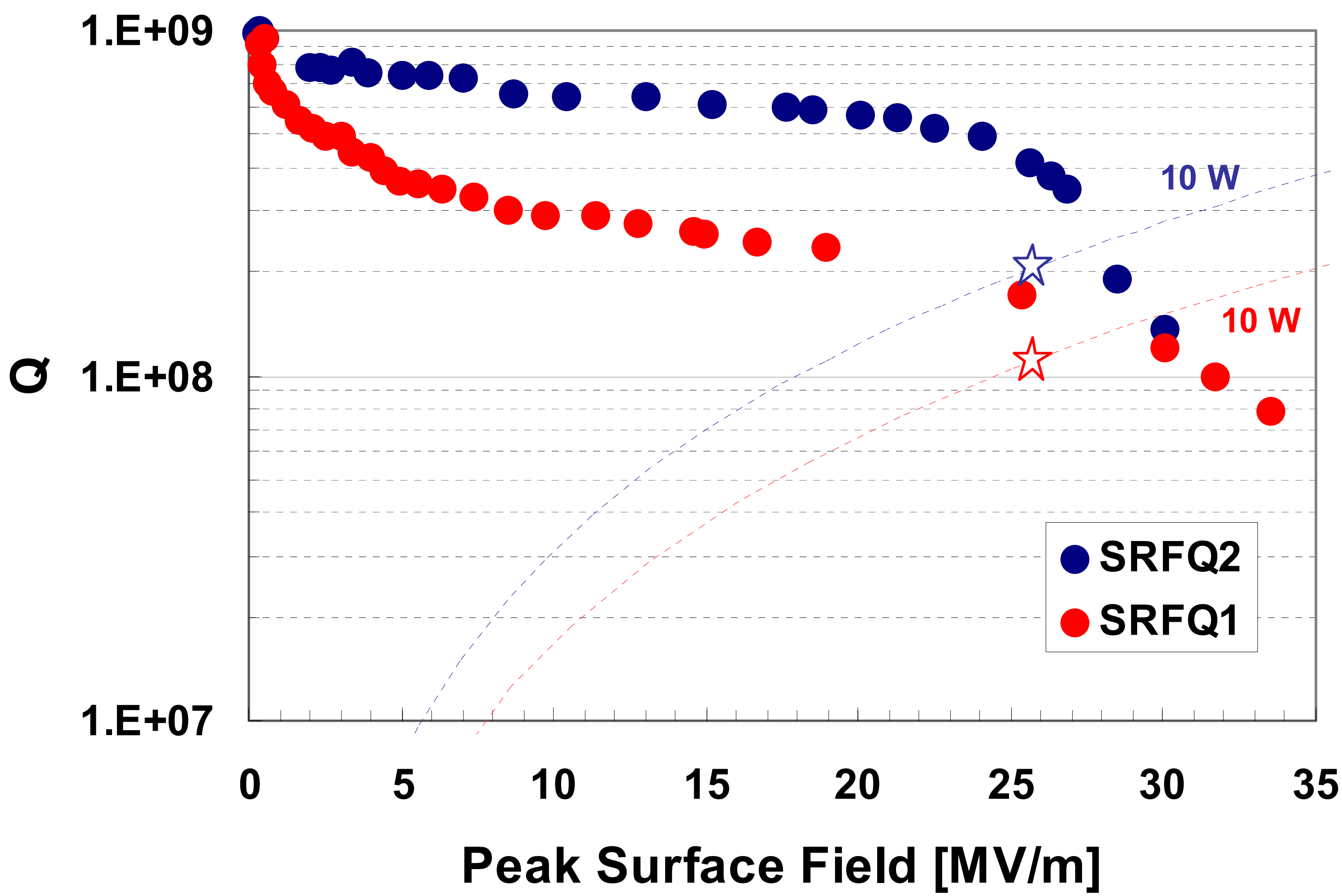
Results

1. Q_0 vs E_p: both above specs!
2. Present Q_0 limitation
3. Alignment
4. Locking conditions
5. Slow f_0 changes and their control
6. Fast f_0 changes and their control



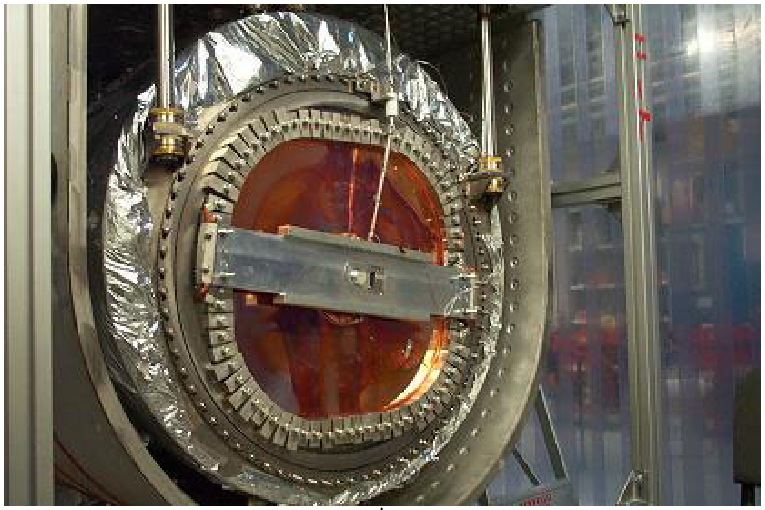
	SRFQ1	SRFQ2	
Frequency	80	80	MHz
Length	1,41	0,8	m
Diameter	0,81	0,81	m
Weight	280	170	Kg
Δ V_interelectrode	148	280	kV
Modulated cells	41	13	
$E_{s,p}$	25,5	25,5	MV/m
$E_{s,p}/E_a$	12	12	
$B_{s,p}$	0,025	0,03	T
Stored Energy	2,1	3,6	J
P_{diss} (set)	10	10	W

Q curves of SRFQ1 and SRFQ2

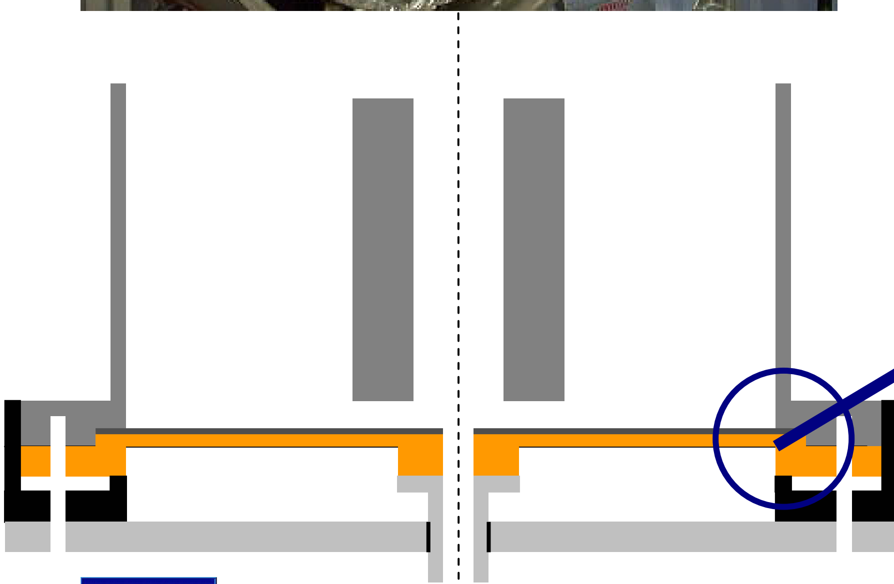


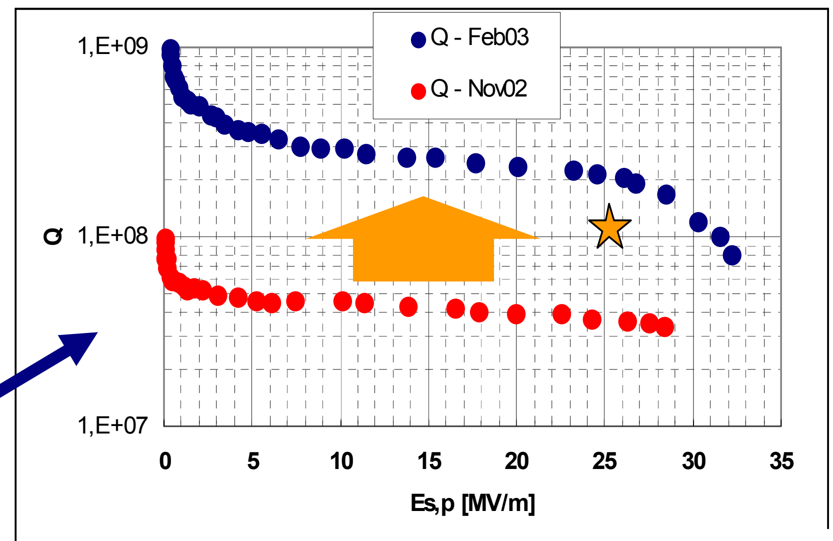
End-plates are in Nb sputtered onto Cu

Q_0-limit: rf contact at end-plate joints



- **B_s** at the joint between Nb-sputtered end-plate and Nb cavity: **3÷6 mT**
- **Tight contact + differential contraction**: Nb/Cu plate and Nb cavity get pasted together (no gasket!)
- Any looser or **imperfect contact** lead to substantial **Q_0 drops**
- **E.g.:** machining of the end-plate had to compensate for the **100 μm step on the Nb cavity due to BCP**





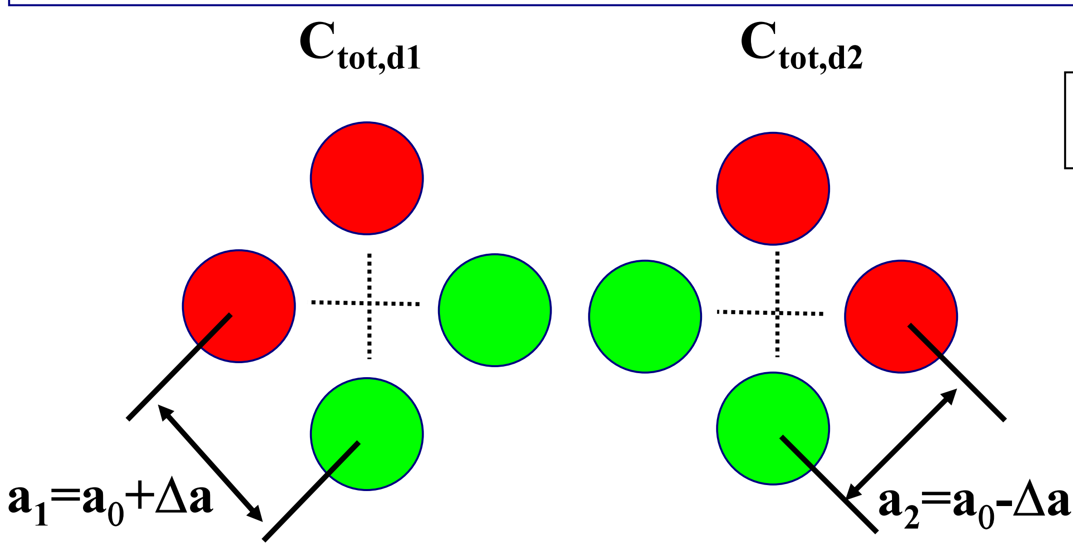
($Q_{BCS} = 1.5 \times 10^{10}$)

Alignment at 4 K

Positioning of each electrode was **specified** to be **≤ ± 100 μm** on each axis: achieved during construction (theodolite)

Perfect alignment gives a degeneration of the 2 dipole modes above the quadrupole one: a splitting of the modes can be correlated to average mispositioning between electrode couples.

Dipole modes splitting is the only alignment diagnostics from 300 to 4 K.
Results: **90.071** and **90.509 MHz** (SRFQ1),
100.15 and **100.70 MHz** (SRFQ2) - none worsened at 4 K



$$(C_2-C_1)/C = (f_2-f_1)/2f$$

↓

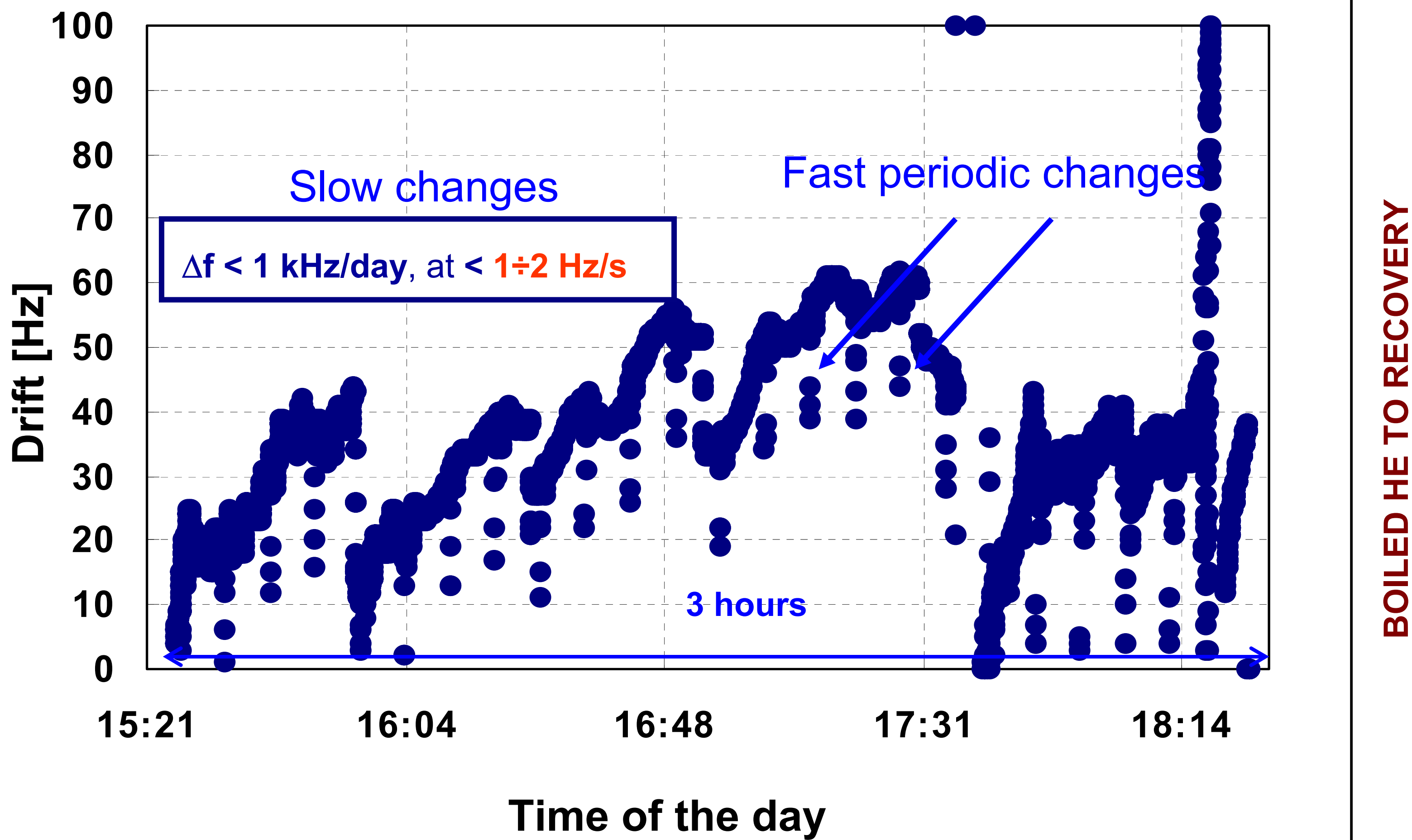
$\Delta a \sim$ **54 μm (SRFQ1), 75 μm (SRFQ2)**

Cavities in SEL locked in A and f to external reference

- Environmental excitations in the SC test stand
- Cavity tools: mech. tuner, Q_L, fast tuner

- Working operations in CW Lorenz detuned regime
- Achieved control on ΔA and $\Delta\phi$
- Artificially induced excitations

Test Cryostat: Environmental Conditions

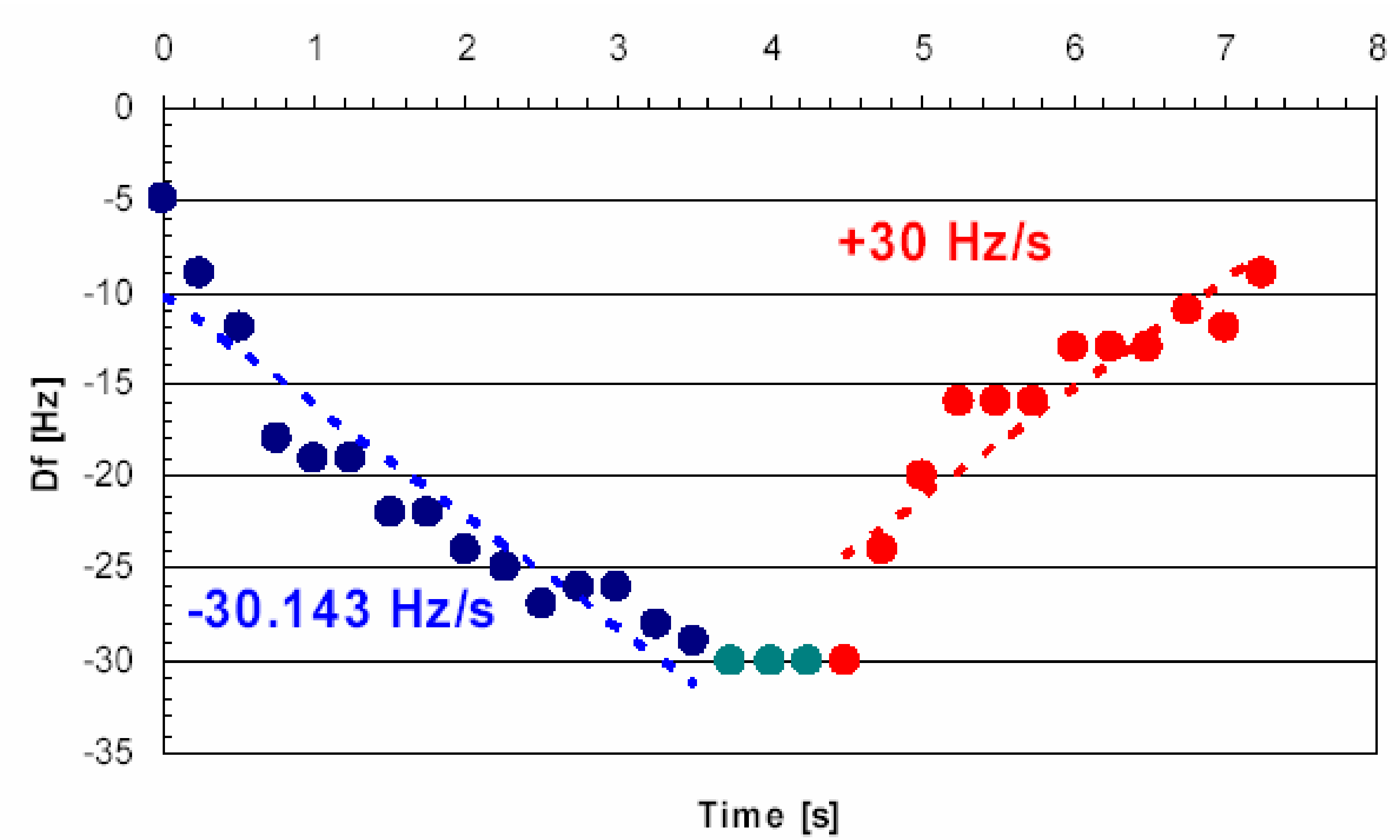


SRFQ2 Example

Free f_0 drifts in the test cryostat: slow and fast pressure drifts dominate the scene

Zooming into the fast frequency drifts

Cause: ΔP **on the dryers** in the Lab cryogenic compressor building (seen by the cavity through the gaseous He recovery line)

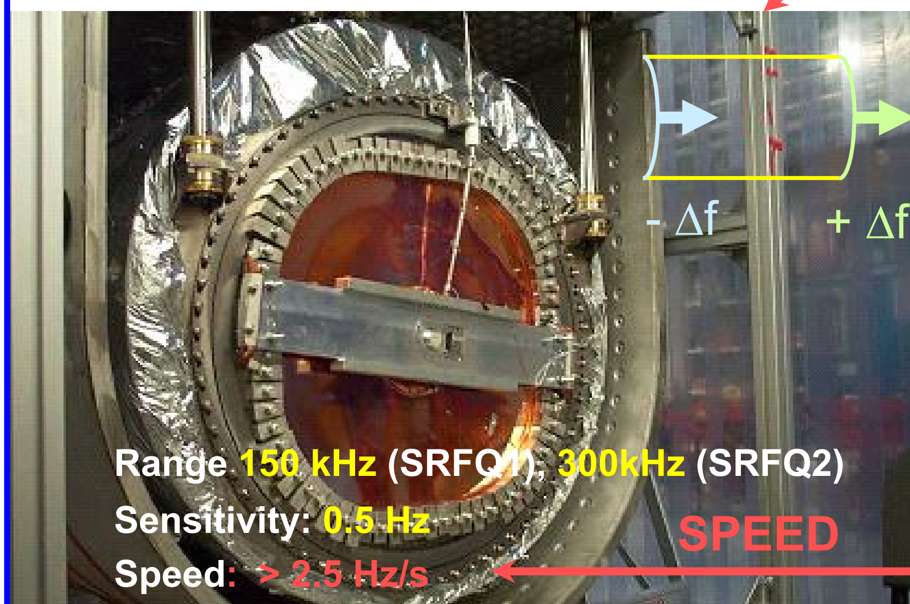


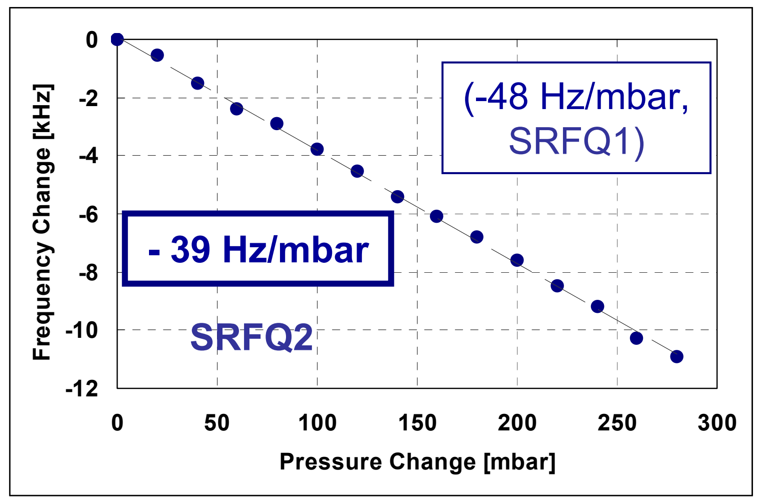
Double end-plate slow tuner for the slow drifts

Slow frequency changes are compensated for, by deforming both tuning plates (no mechanical backlash)

When $\Sigma_i (\pm\Delta f_i) > \pm 75/150$ kHz (SRFQ1/SRFQ2), the direction of motion must be inverted.
The rate is ~ 1 kHz/day in the test Cryostat (75 days!)
X (10÷50) in operation is still fine

RANGE

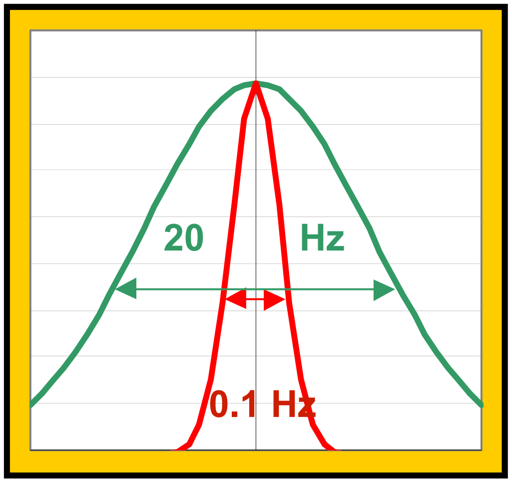




Cryogenic-Plant Specs: 1.2 ±0.05 bar;
$\Delta P/\Delta t < 2$ mbar/min → **1.33 Hz/s**

IMPORTANT FOR HE IN REFRIGERATION CYCLE

Fast drifts: low Q_L (and Fast Tuners)



@ $Q_0 = 8 \times 10^8$ $\Delta f = f/Q_0 = 0.1$ Hz

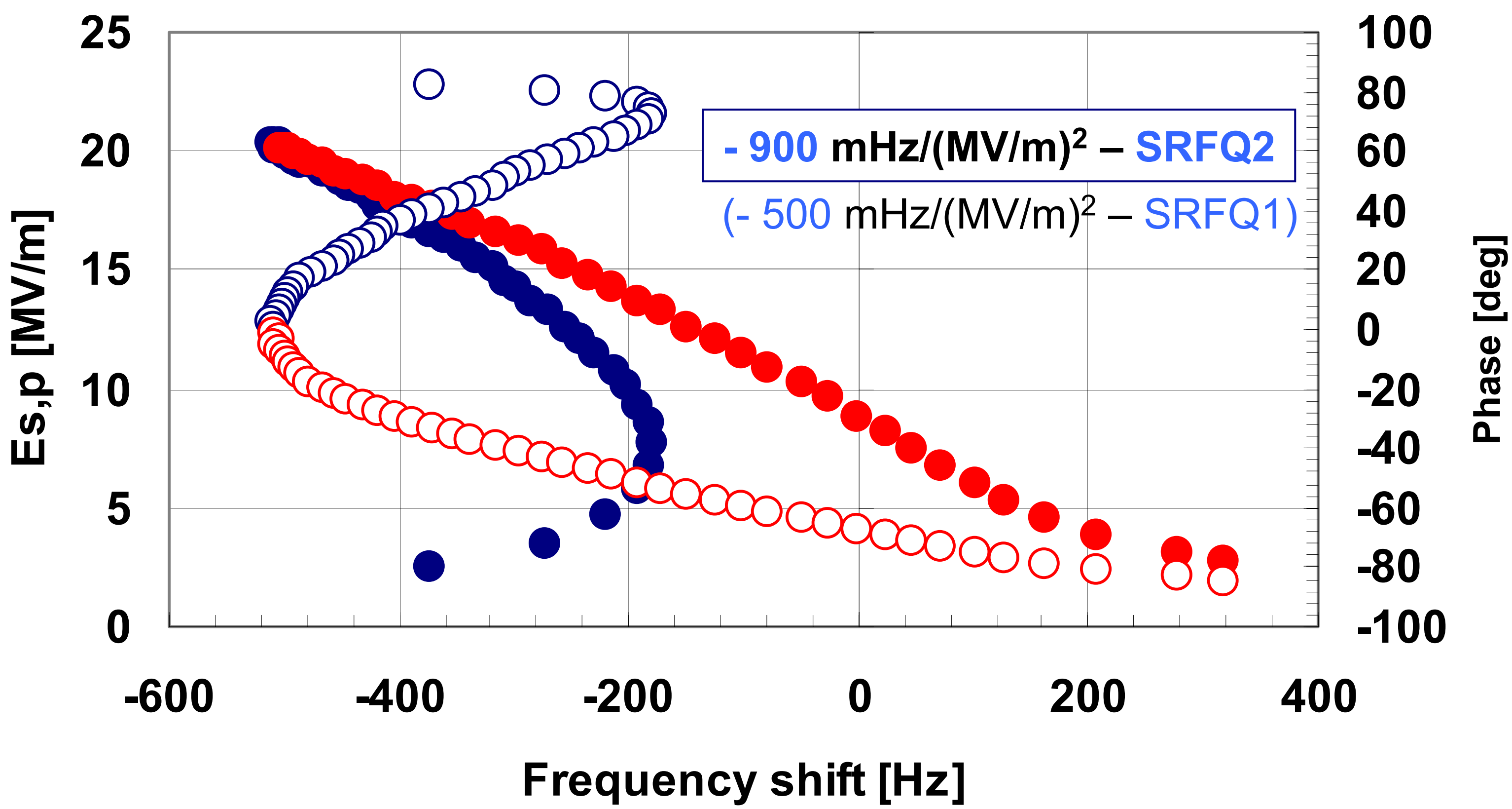
$\Delta f = 20$ Hz

$P_{ampl} = (2\pi U \Delta f) = 500$ W

1 kW Amplifier, $Q_L \sim 10^6$

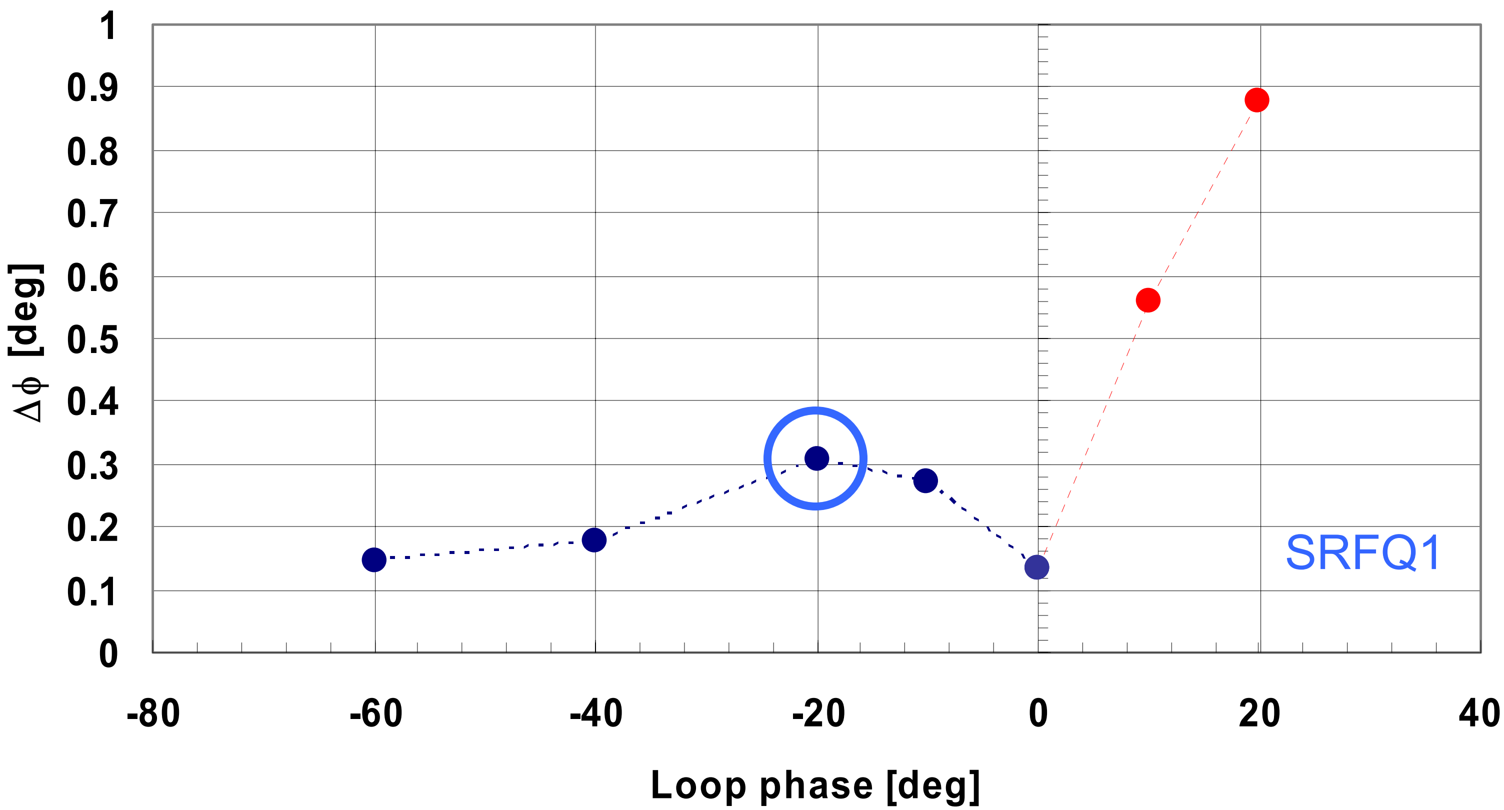
SEL mode, φ&A locked

CW Lorenz detuning

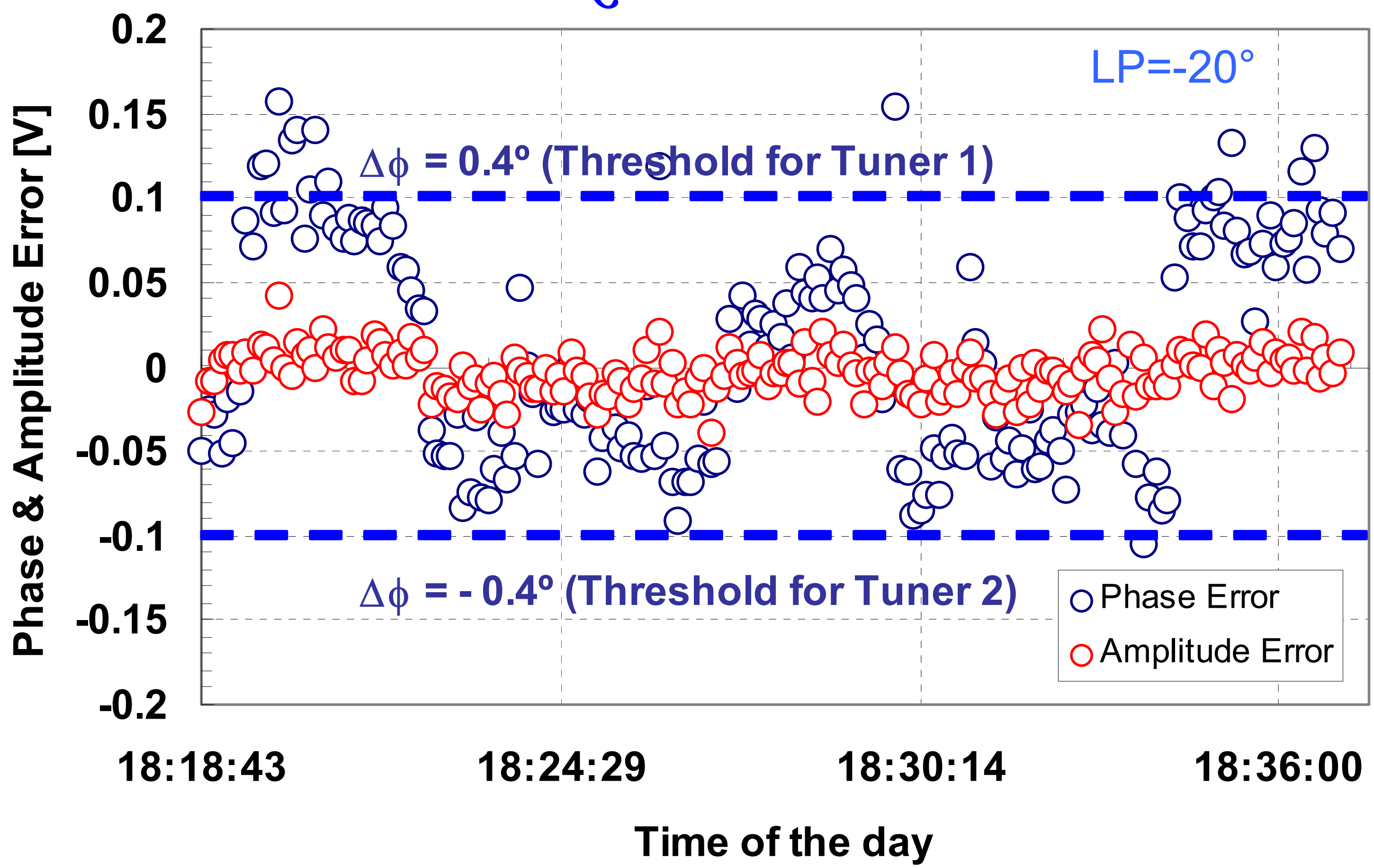


For our SEL control system, only the blue part of the folded over curve is stable

Average |Δϕ| versus SEL Phase

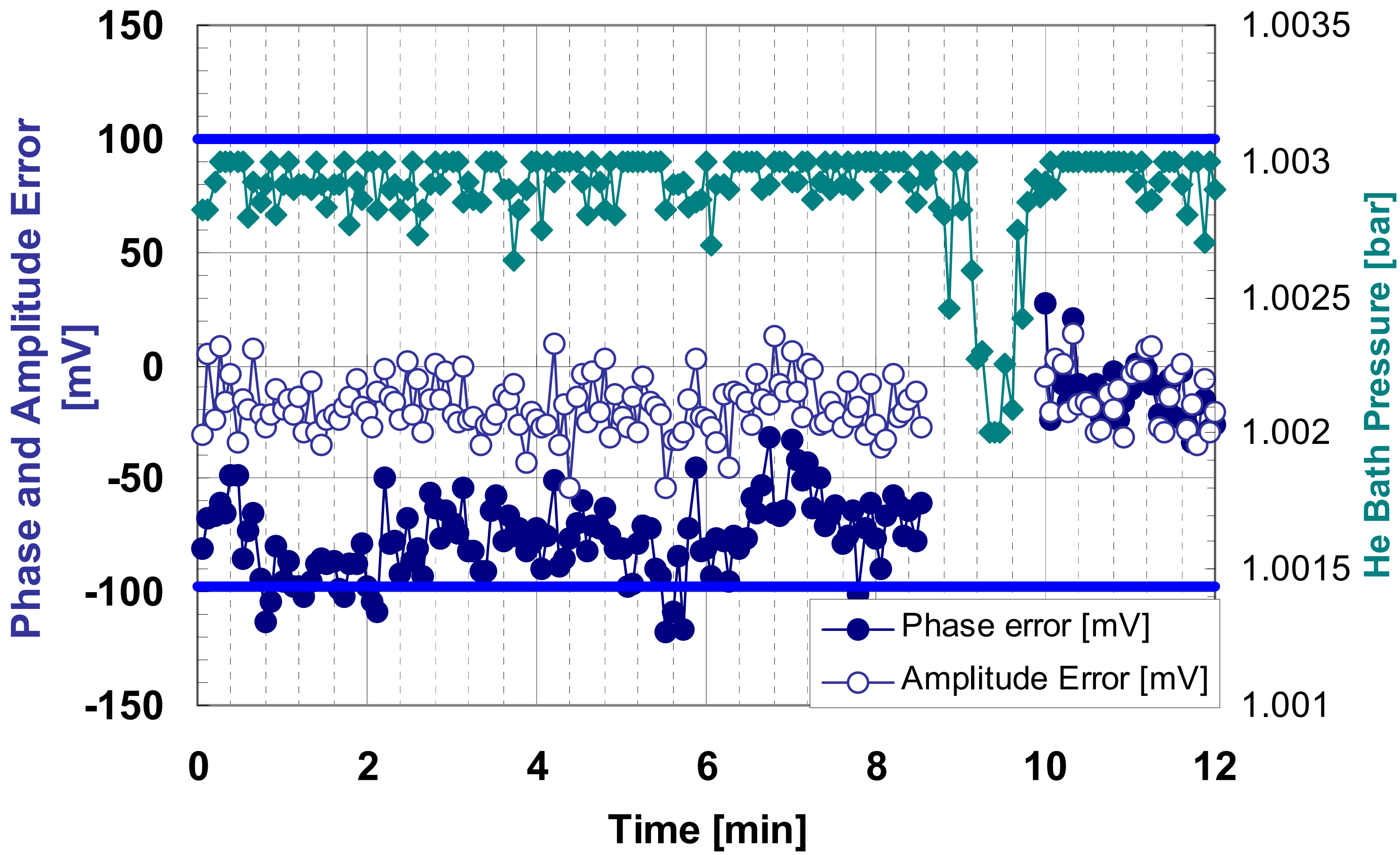


Self Excited Loop: ϕ and A locked to external values

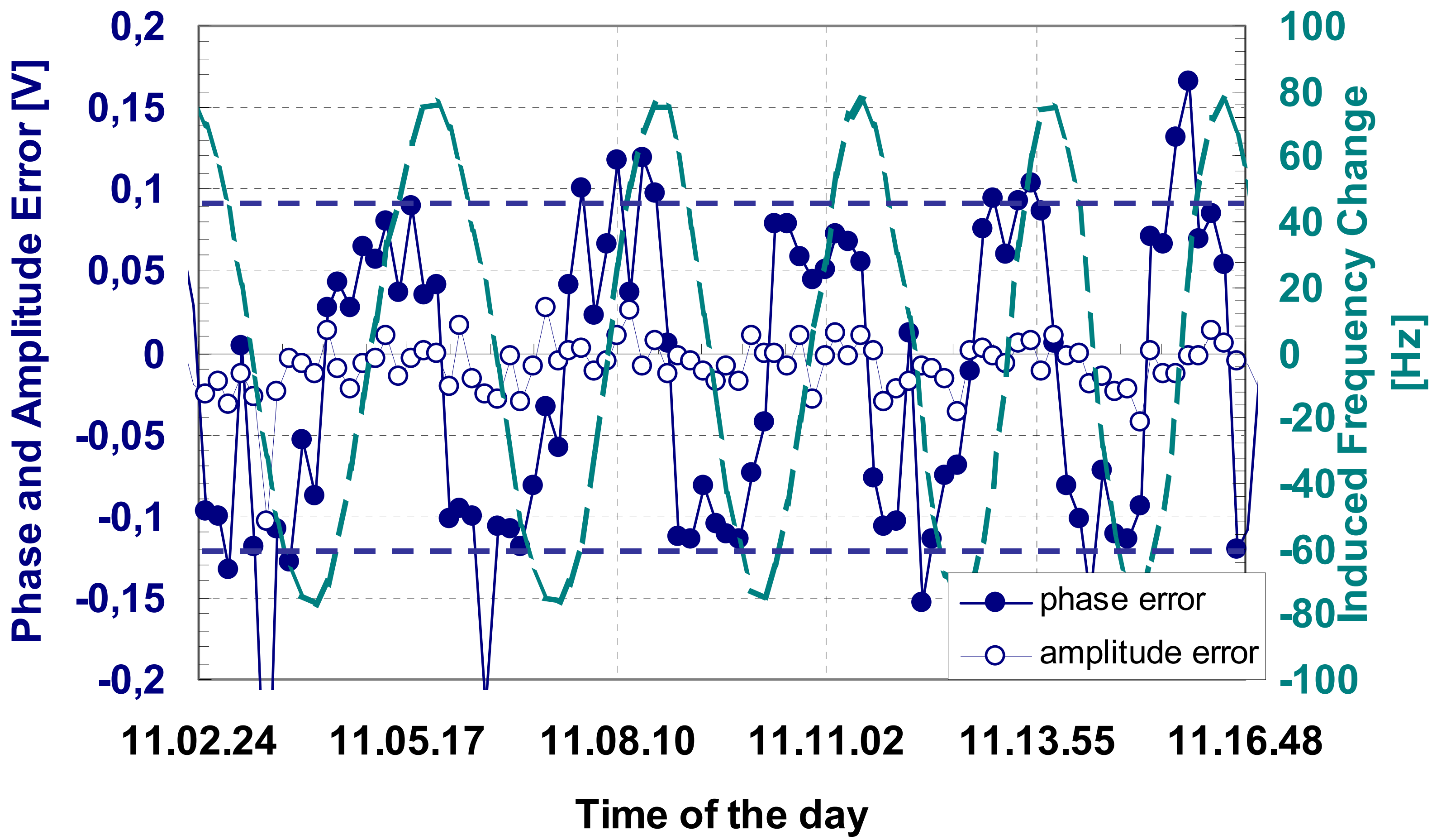


Both SRFQ1 and SRFQ2 could be kept locked, for half-day long tests, beyond 26 MV/m, in the environmental conditions shown previously.

ΔP (both slow and fast) was always the only cause of ϕ and A jitters

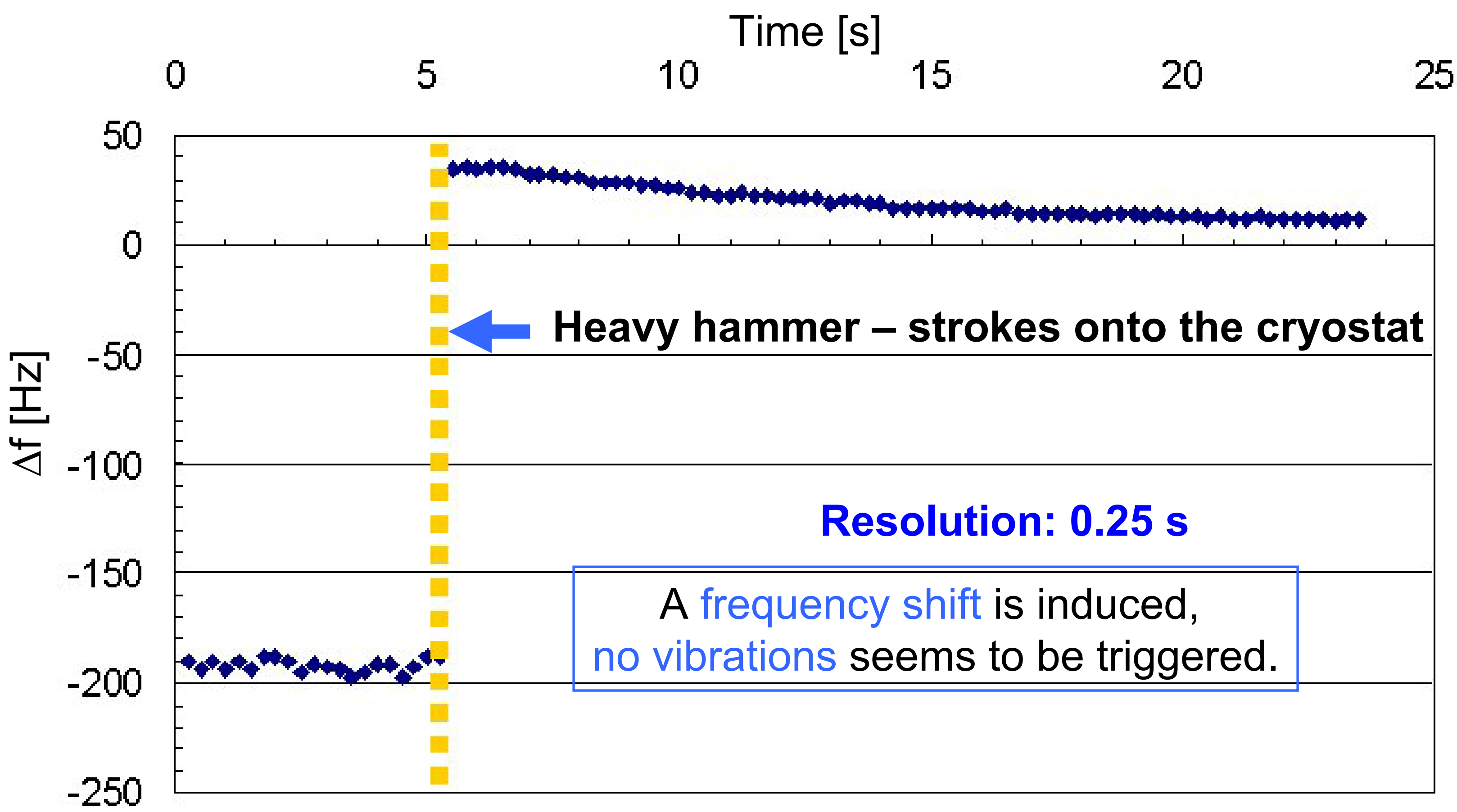


Induced f_0 changes (slow)



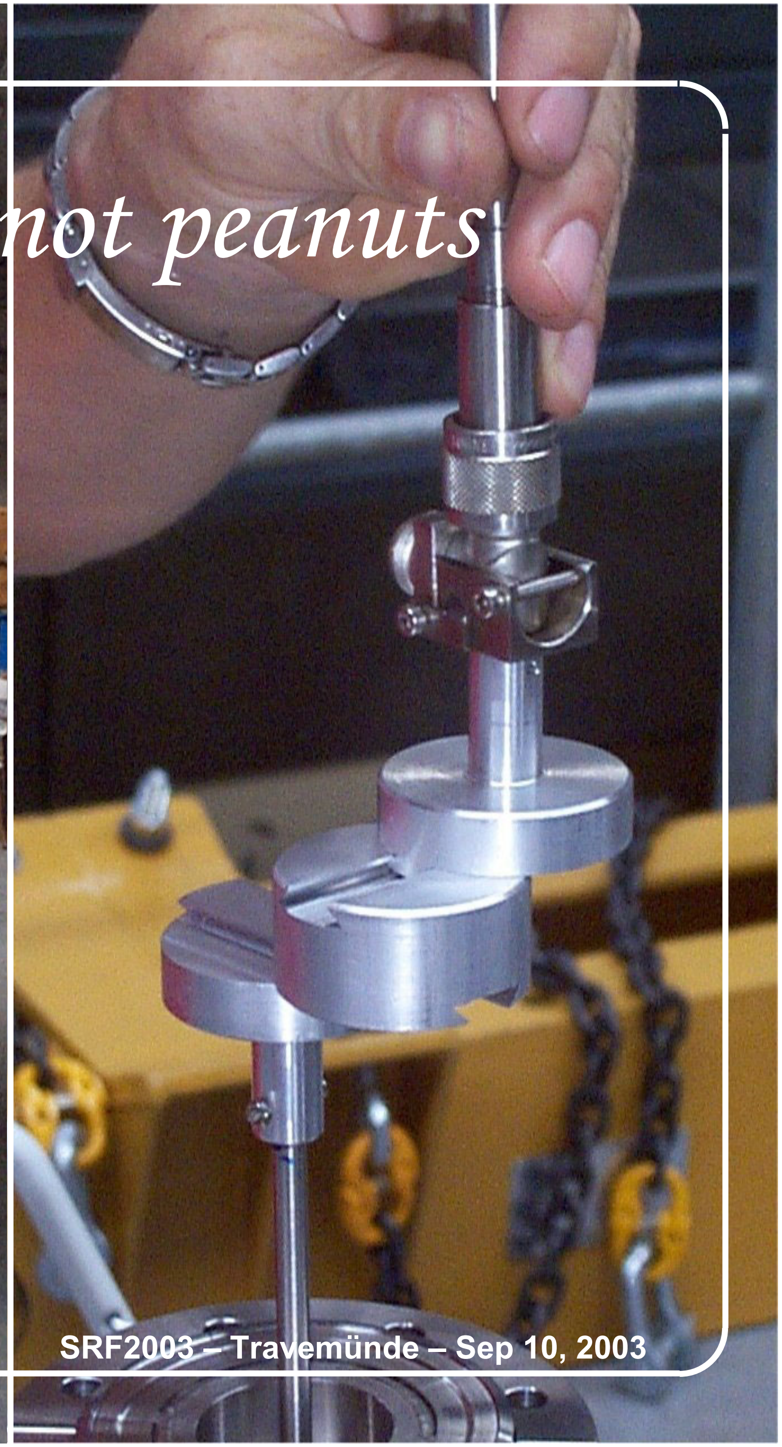
The master oscillator frequency was modulated with sine, square, saw tooth functions of various period and amplitude: the slow tuners follow up to ~ 2 Hz/s (*square function case: cavity locked only if Δf is within the bandwidth, i.e. 20 Hz*)

Induced f_0 changes (fast)



The cryostat was also excited through a powerful frequency-swept shaker ($\Delta f_{bandwidth}$ = 30 Hz) up to 1 kHz: large phase noise, a few unlocking events, SRFQ2 looked fairly stable, but no much data logging available at the time.

Cryostat assembly is not peanuts



In conclusion …

- Until the situation get … settled in the final operational environment (December)…

  … there is not much more that can be said at INFN-Legnaro on SRFQs