Superconducting RFQ’s Ready for Ion Beam Operation at INFN-LNL

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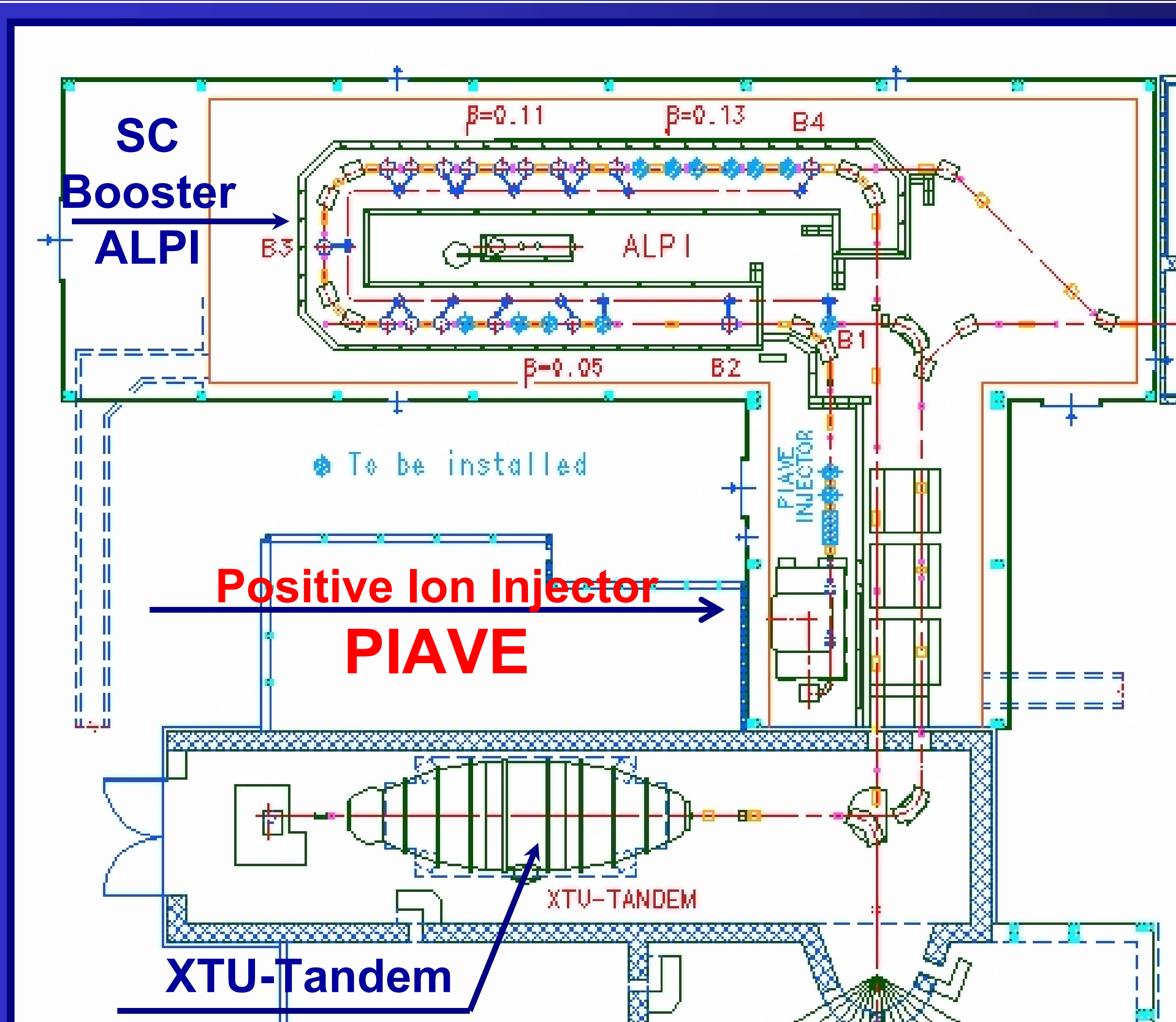
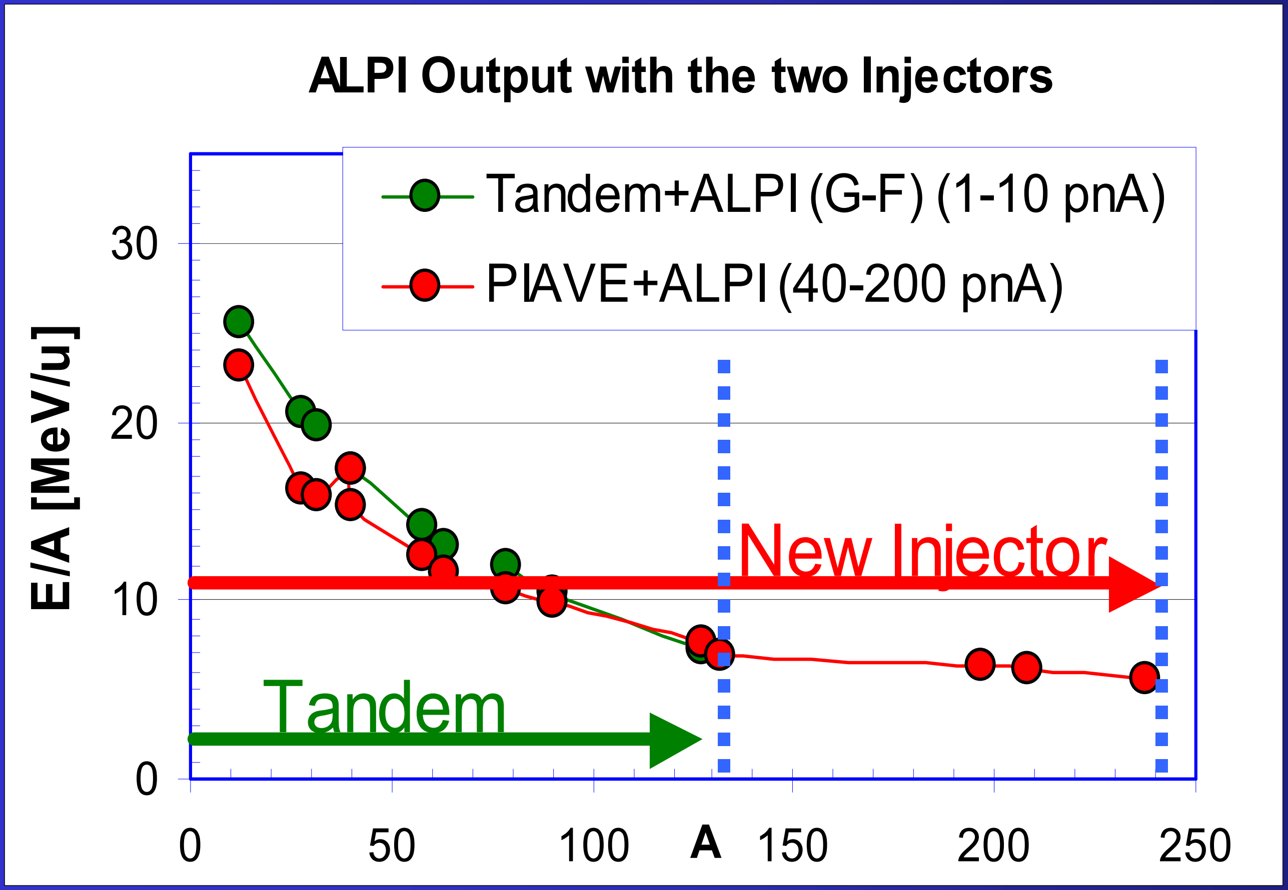
Context: an injector of q+ heavy ions for INFN-LNL SC linac

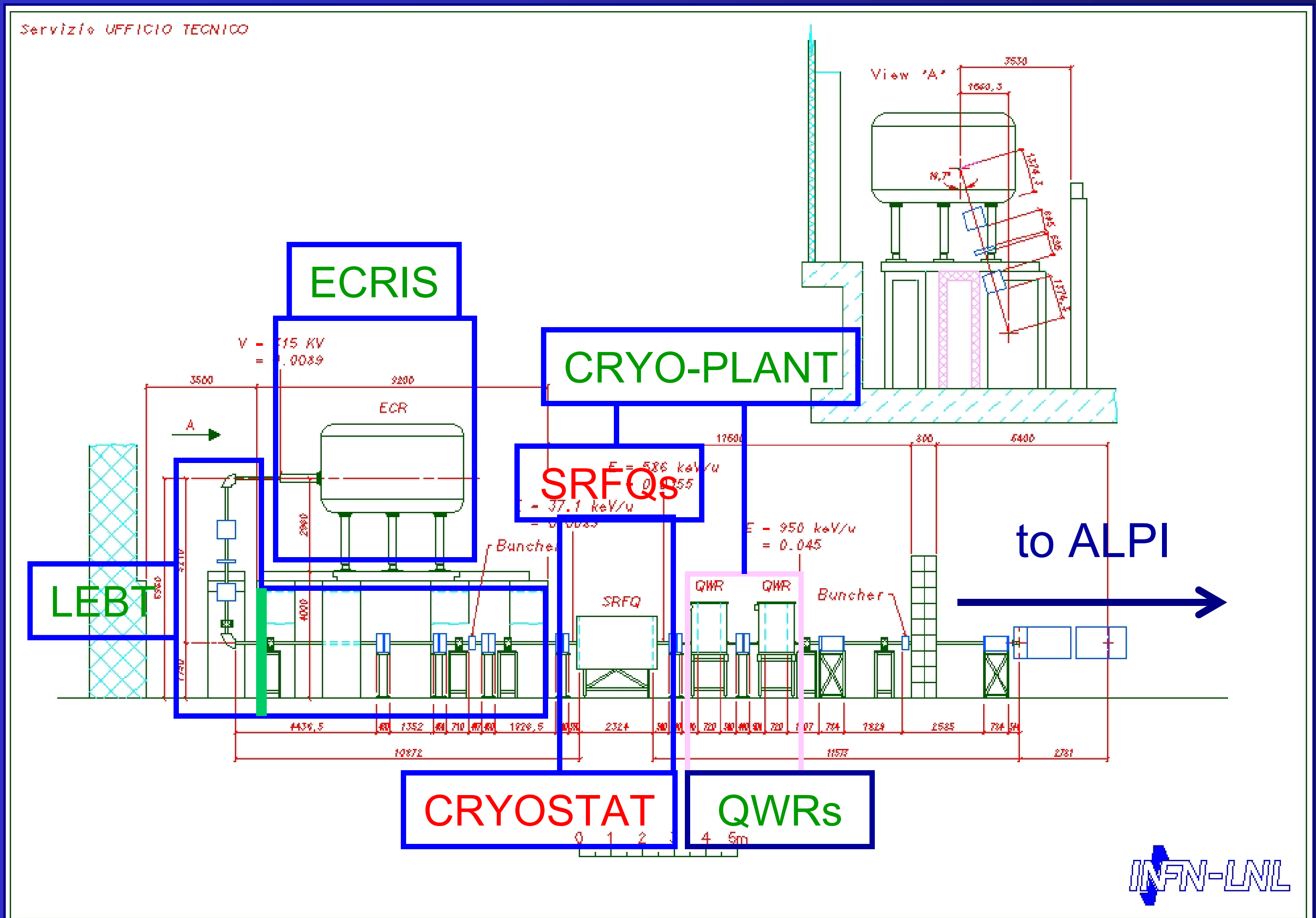


Why to switch from a Tandem to a q+ injector?

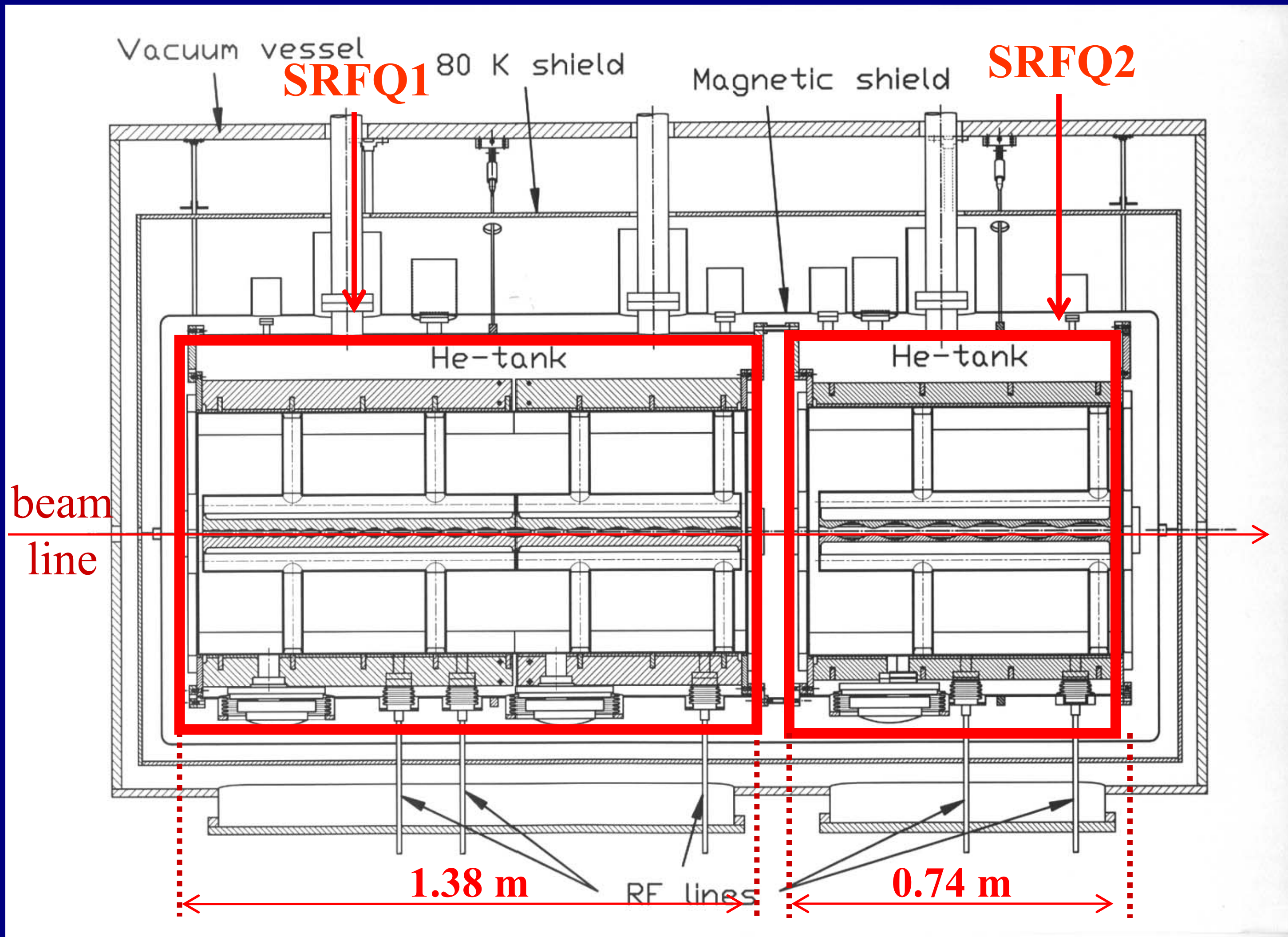


- **MORE CURRENT**
- **HEAVIER MASSES**
- **MORE BEAM TIME AVAILABLE (TWO INECTORS)**

PIAVE Injector Layout



Two SC-RFQs in a cryostat

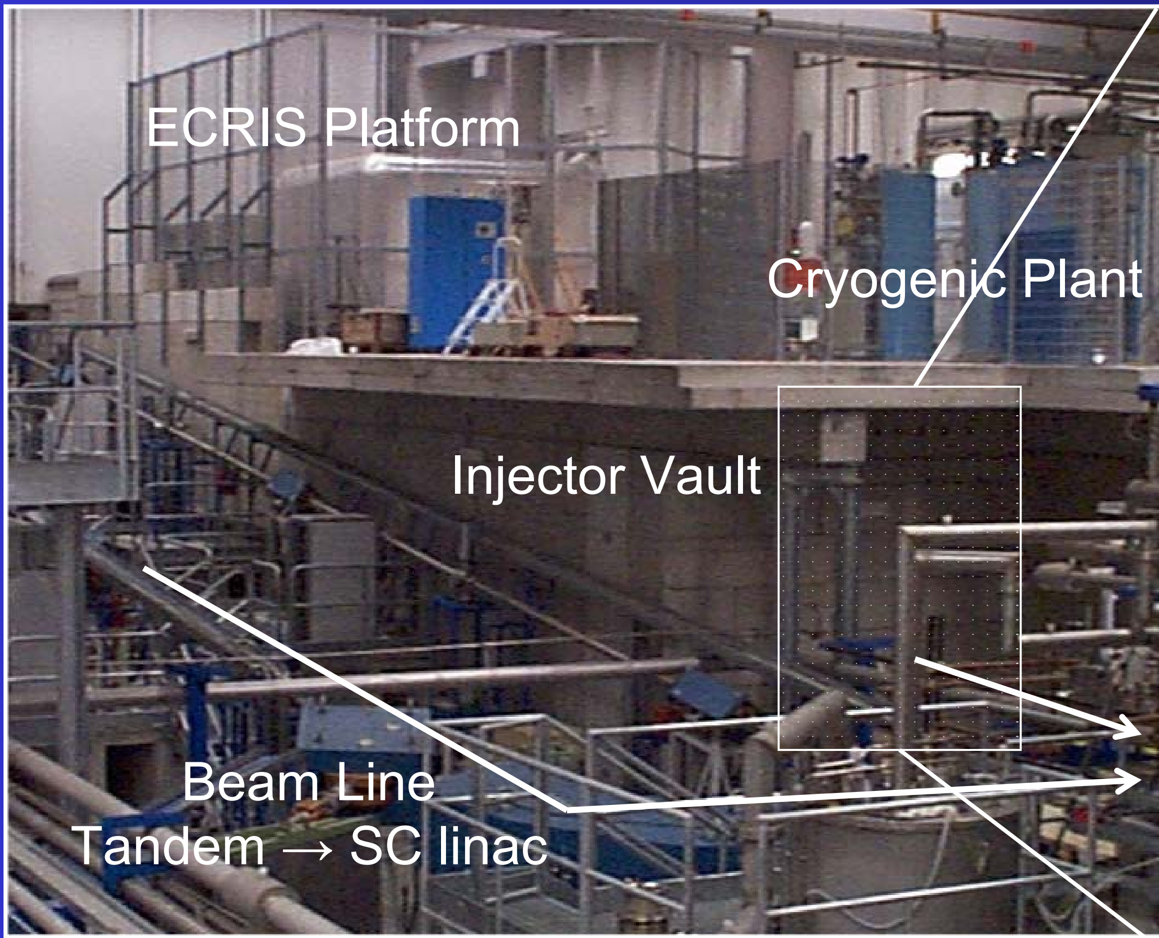


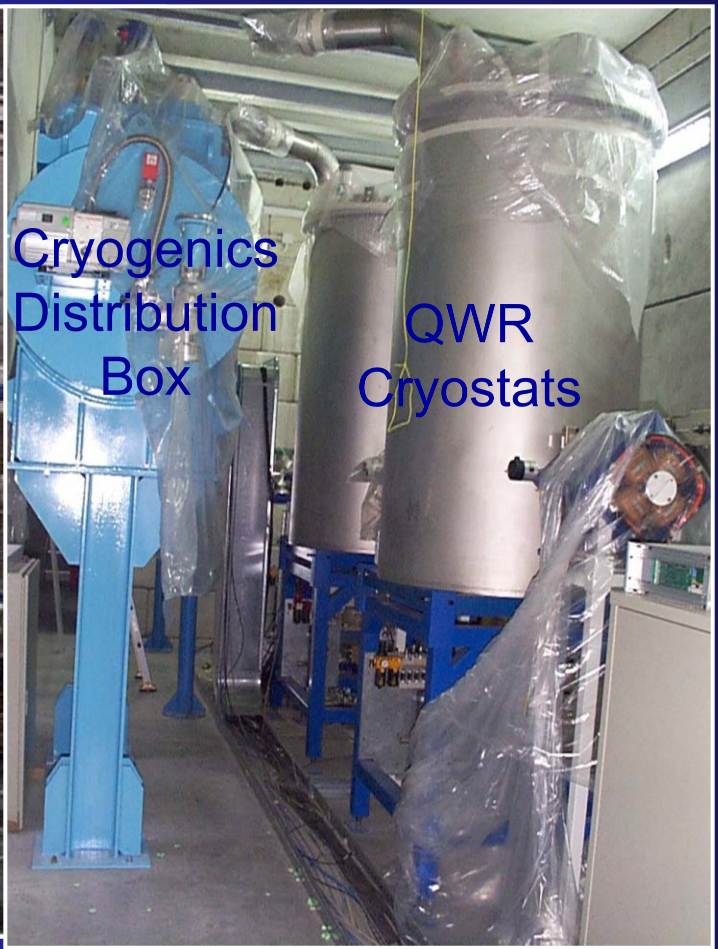
f_0=80 MHz

37 keV/u (β = 0.0089) → 585 keV/u (β = 0.035)

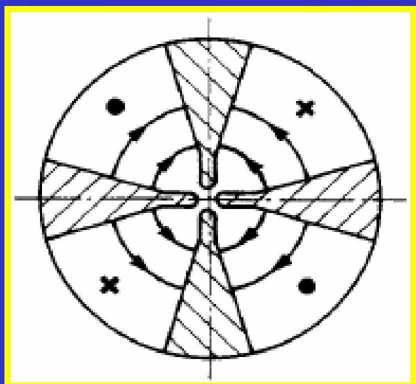
Approaching Beam Commissioning

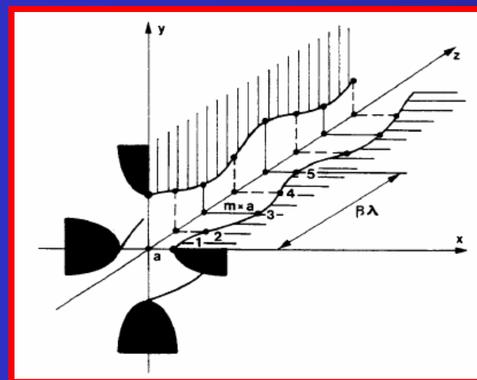
Under the Vault





How it works





• **Focusing** ⇐ **main quadrupolar $E_{\perp}$**
• **Acceleration** ⇐ **small but effective $E_{\parallel}$**
modulation of 4 vanes
(synchronous with beam bunches)
one modulation period = $\beta\lambda$

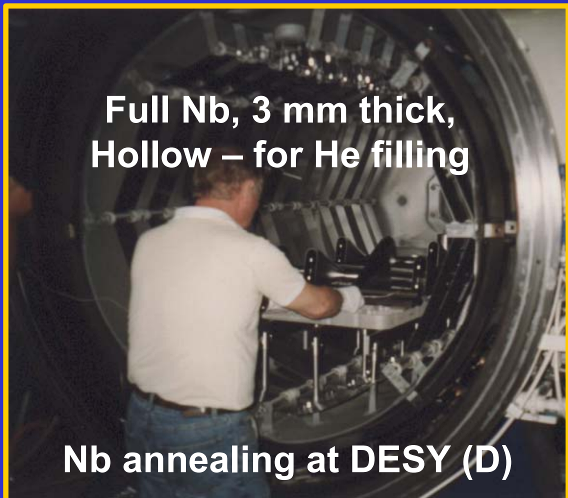
$$U(r,\theta,z) = \frac{V}{2}\left[A_{01} r^2 \cos 2\theta + A_{10} I_0(kr) \cos kz\right]$$

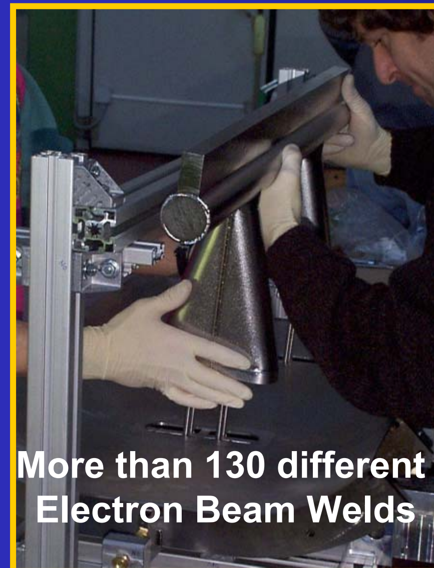
Ideal for **β=v/c < 0.05**
Typically **NC**, **50-400 MHz**

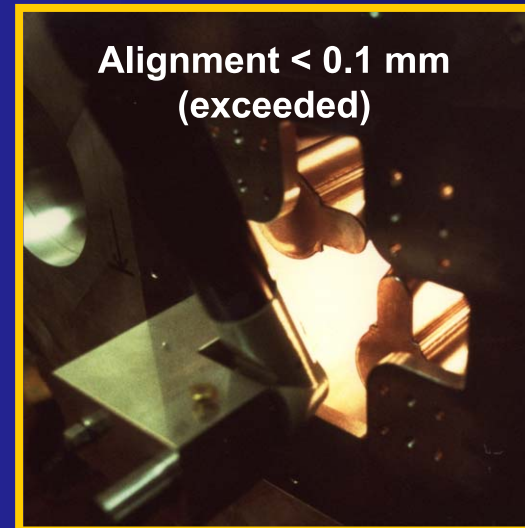
NORMAL CONDUCTING
ΔU ~ 100 kV, **Q ~ 10^4**, **d.c. < 20%**
with a few remarkable exceptions
(LEDA: 2.2.MW rf, 100 mA-beam)

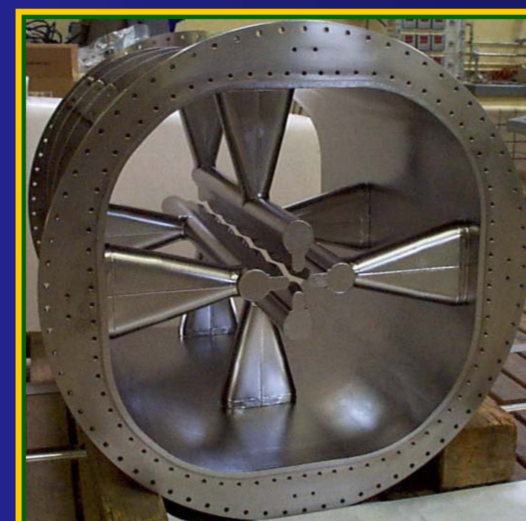
SUPERCONDUCTING
ΔU~ 300 kV, **Q~10^9**, **d.c. = 100%**
Motivated by lower rf power (and
μA beam) + existing SC booster

Construction Issues







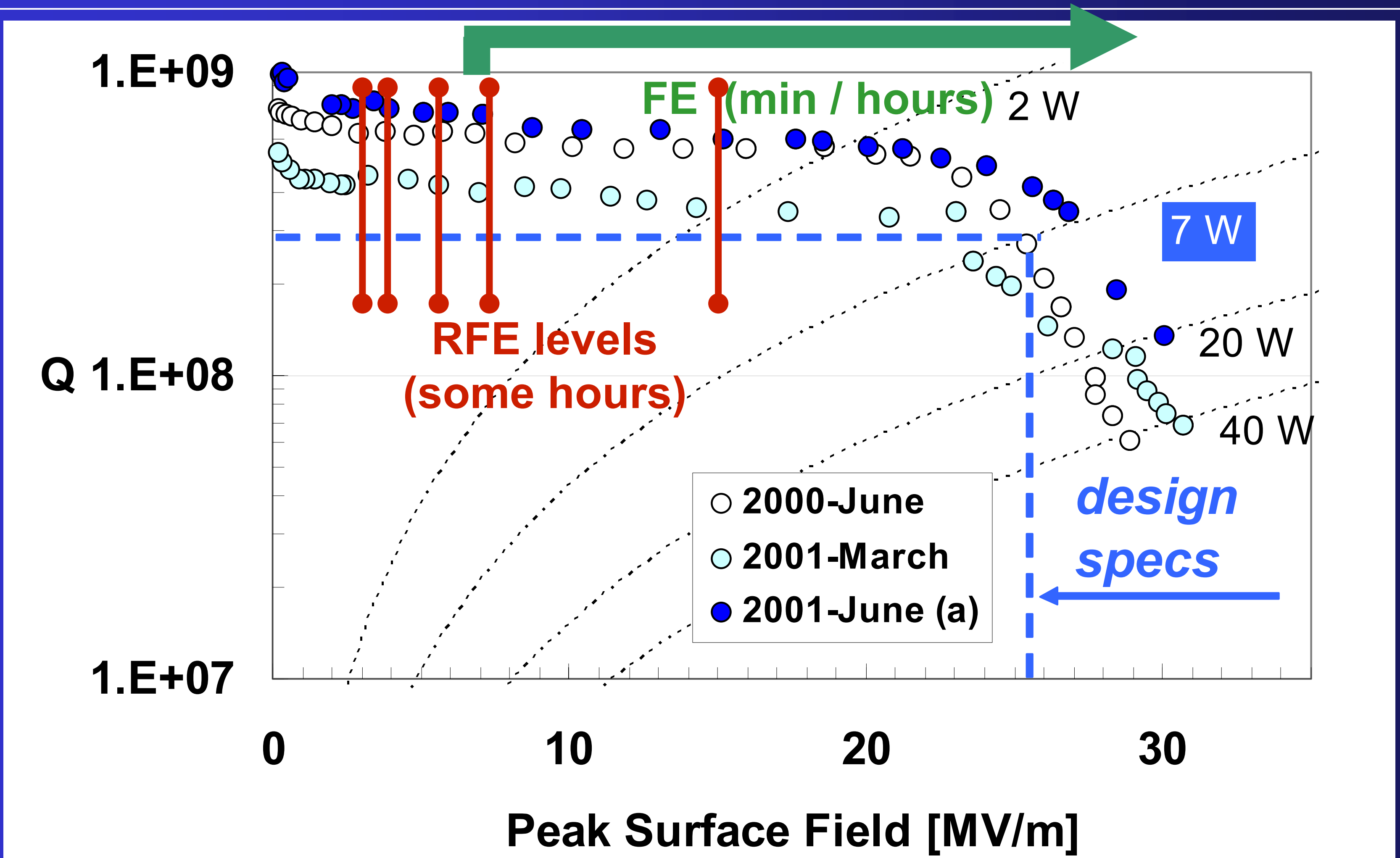


SRFQ2 (SS), SRFQ2 (NB), SRFQ1

18 MONTHS/EACH FOR CONSTRUCTION

- Q-curves with SRFQ2 (2000-2002): troublesome life of a huge SC resonator
- Preparing for Beam Operation: locking in f and A with natural drifts, He-P induced drifts, Lorenz detuning, microphonics
- A few more steps to take ...

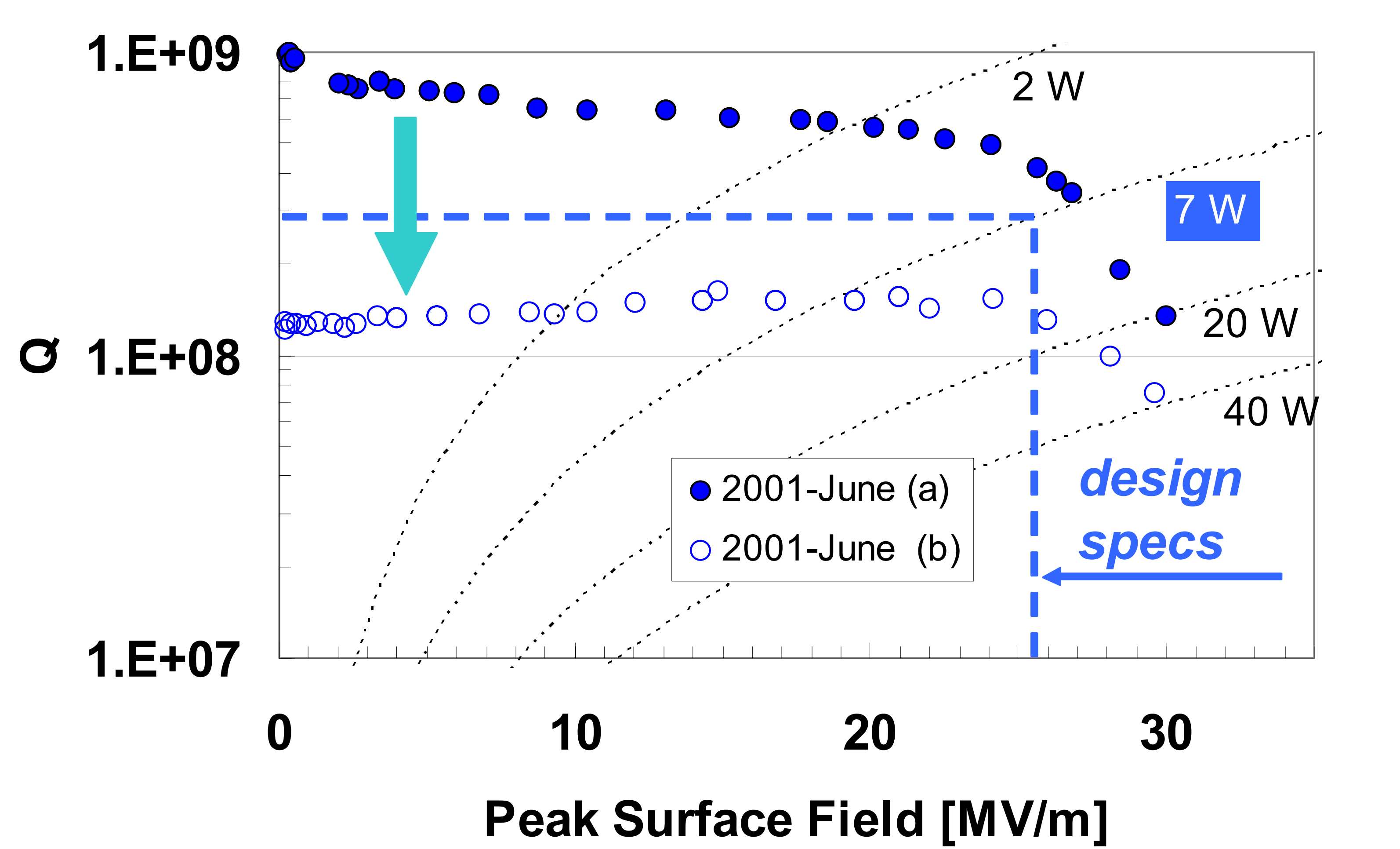
Evolution of SRFQ2 Performance (1)



High Pressure Water Rinsing

- 5 liters **acetone**
- 500 liters 80 bar demineralized **water**
- 10 liters **ethanol**
- **Drying** by filtered **warm air**
- **Immediate closing** by end-plates

Evolution of SRFQ2 Performance (2)

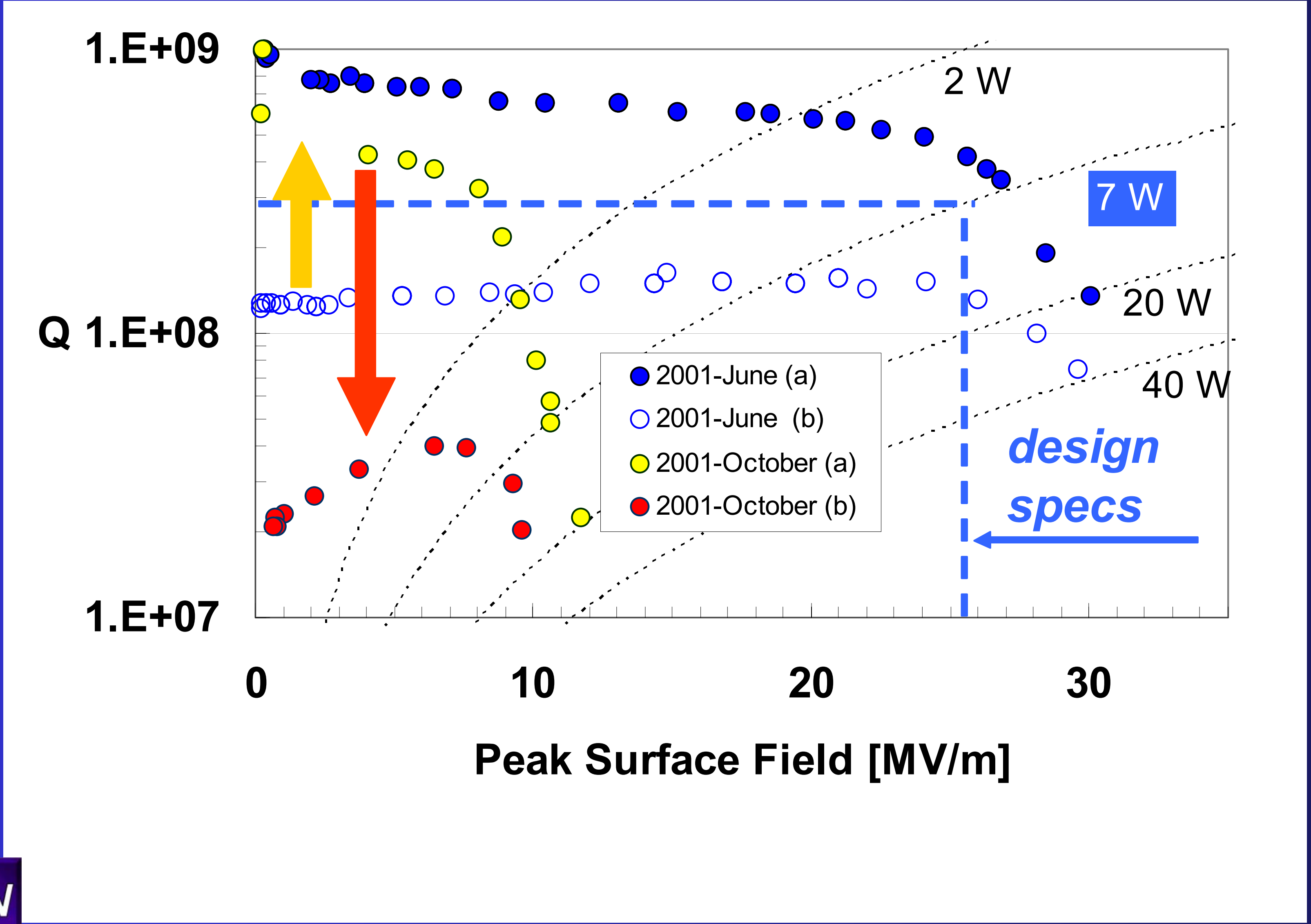


Erosion of high power coupler

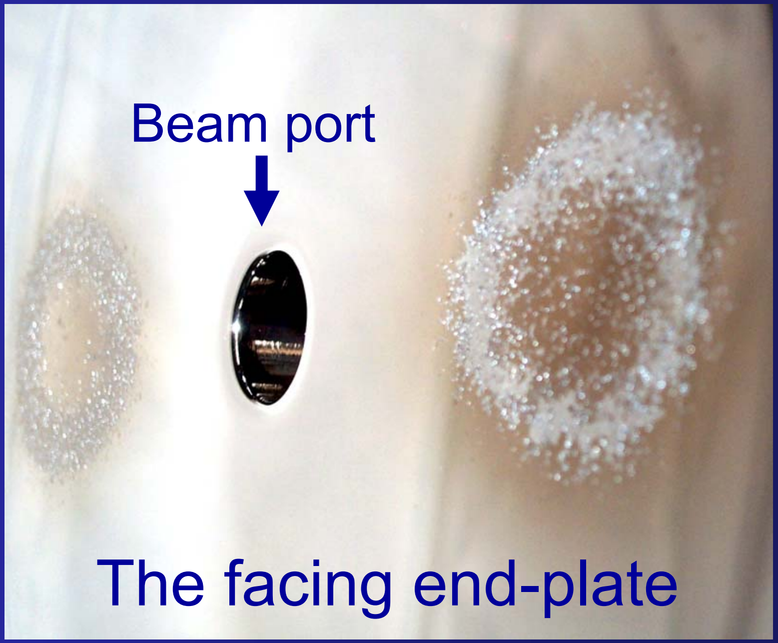
- Plasma discharge: sputtering of Cu and stainless steel layer in a high-j region of tens of cm^2 in SRFQ2
- Chemical Polishing would have taken months
- 3M – Scotch Brite **lapping followed by HPWR** (2 weeks)

ACTIONS

Evolution of SRFQ2 Performance (3)



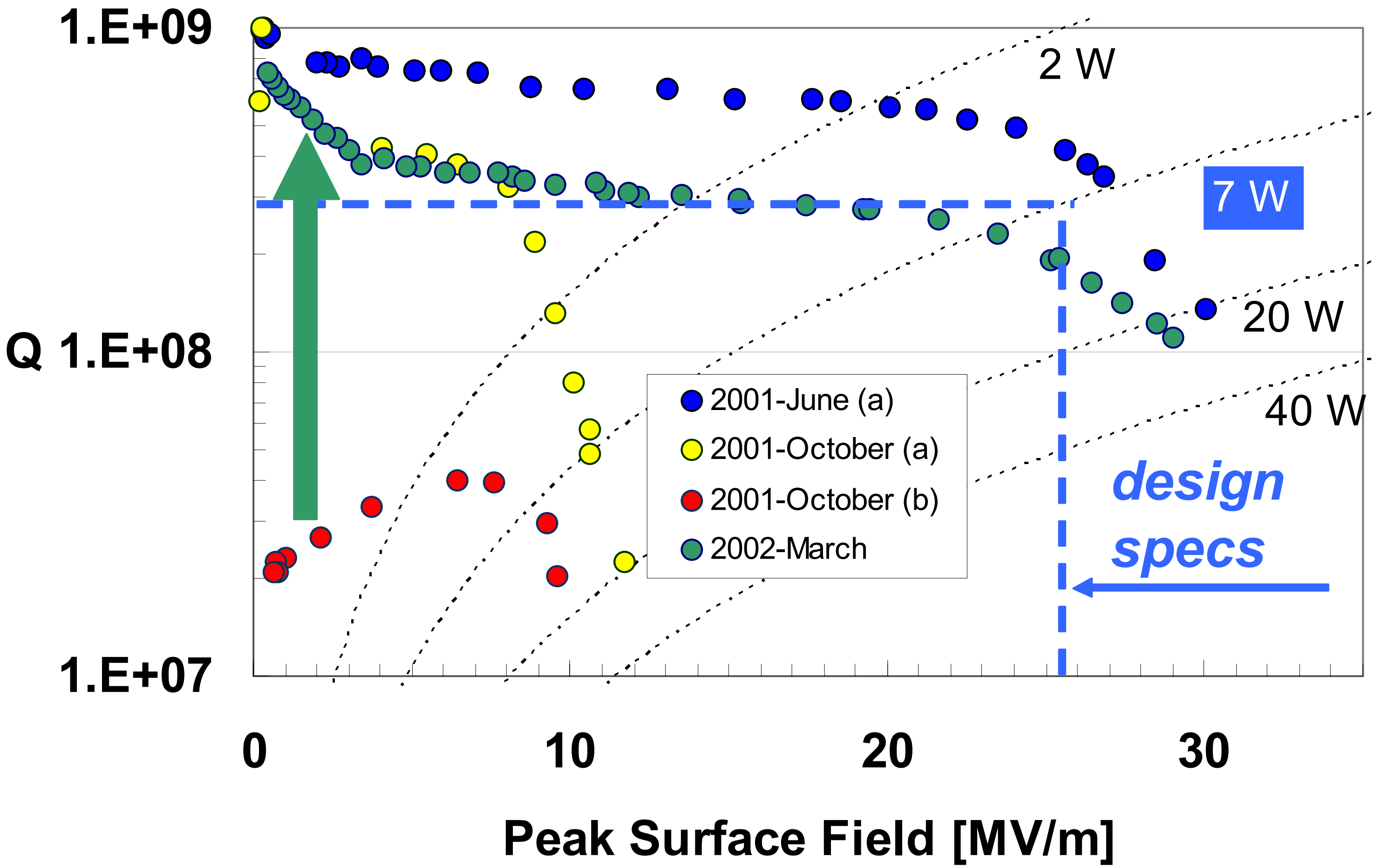
Discharges between electrodes and one end-plate



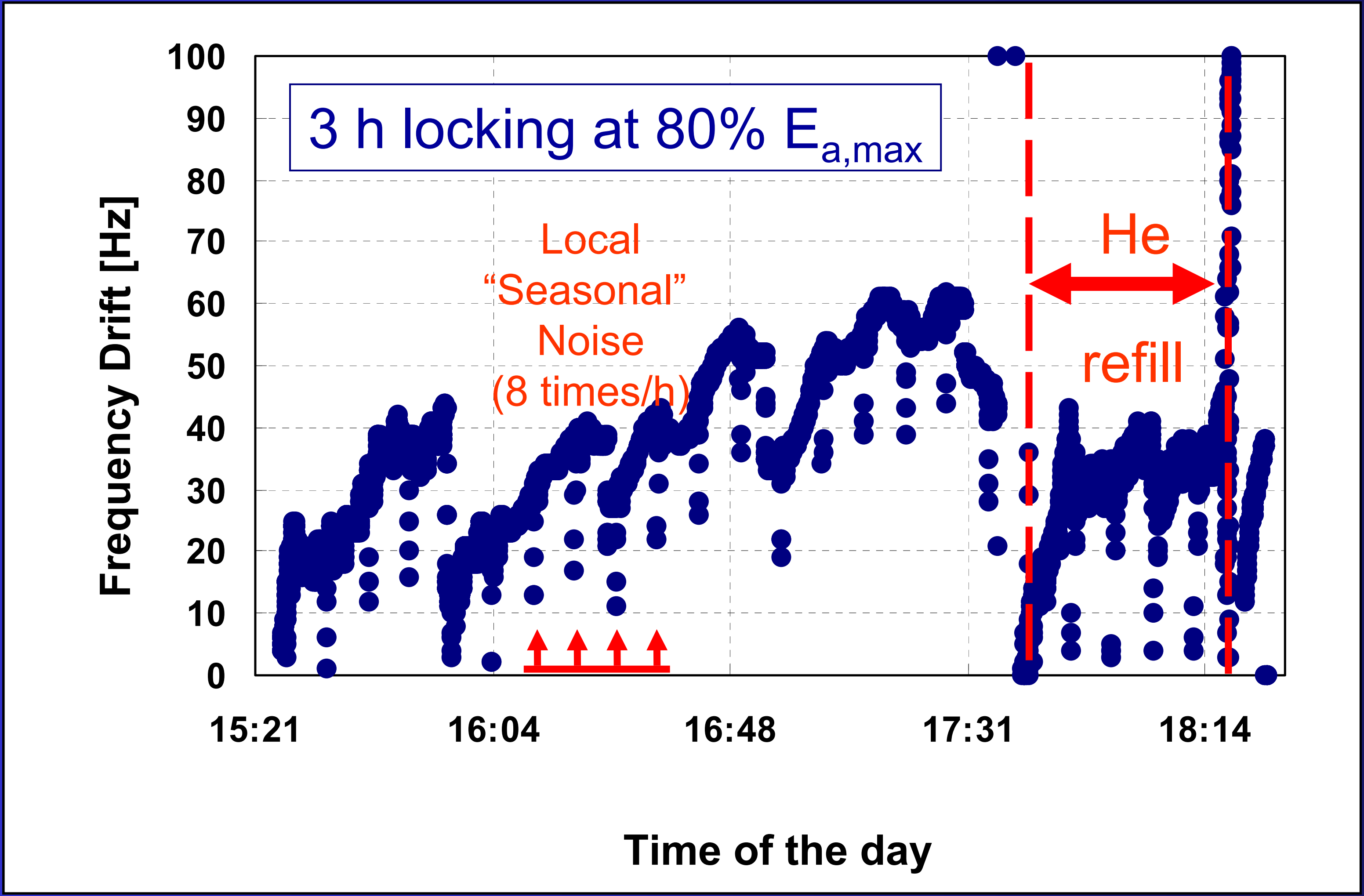
- Chemical Polishing again avoided in a first instance
- 3M – Imperial **lapping, with Al_2O_3 abrasive of decreasing roughness (60 ÷ 2 μm)**
- **HPWR** followed

ACTIONS

Evolution of SRFQ2 Performance (4)



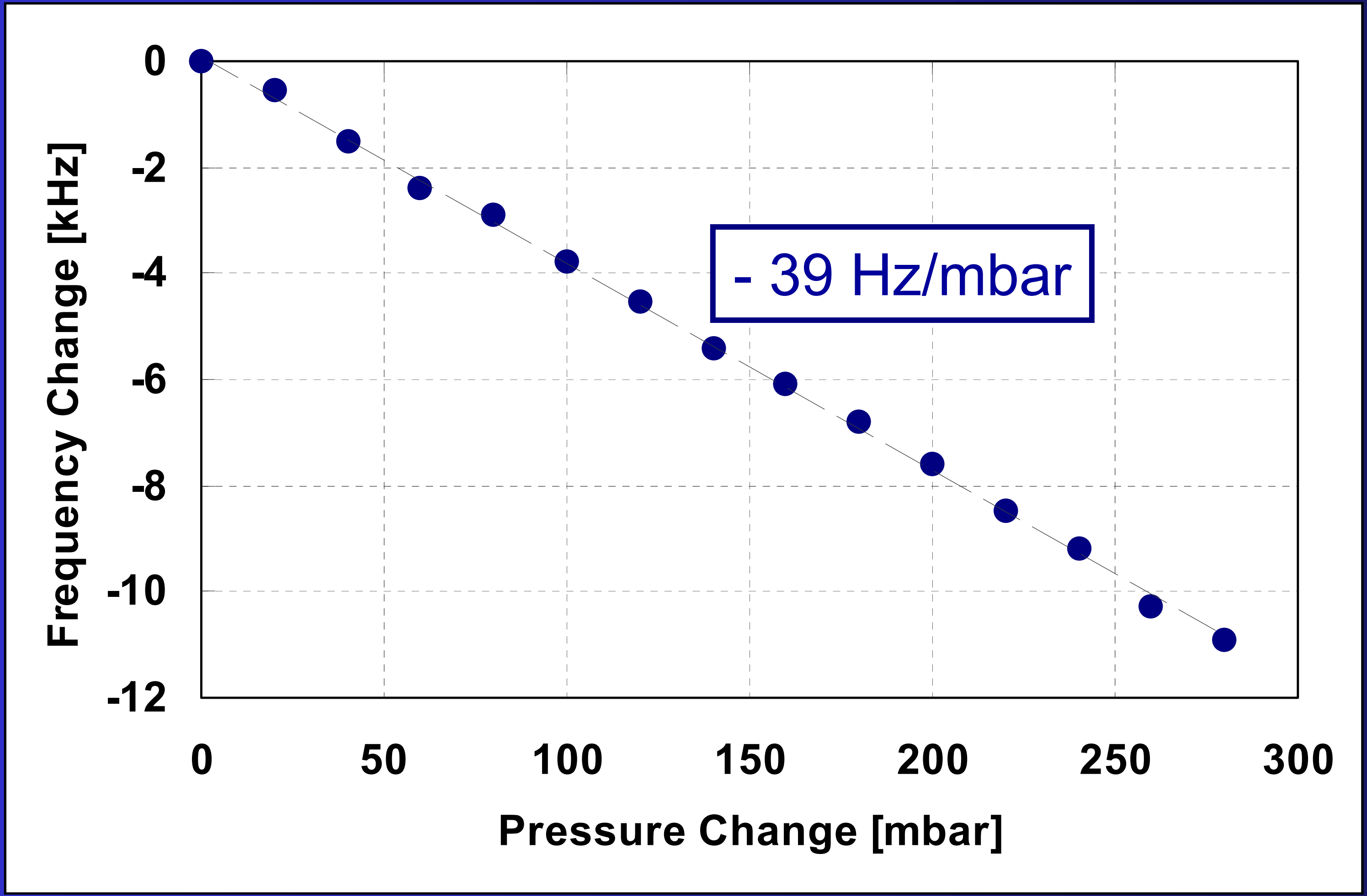
Slow EM-frequency drifts



BOILED HE TO RECOVERY

Δf < 1 kHz/day, at **< 1÷2 Hz/s**

f Changes vs. He bath-P

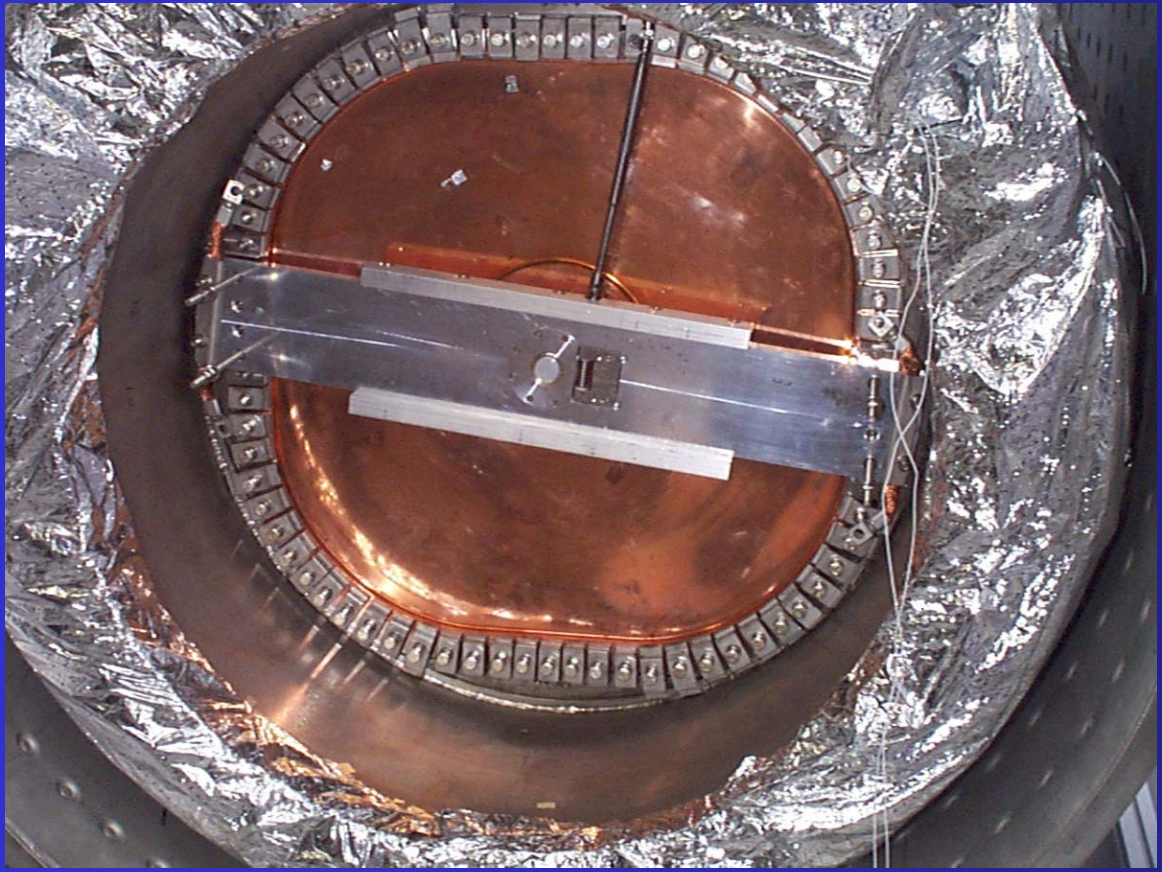


Cryogenic-Plant Specs: 1.2 ±0.05 bar;

ΔP/Δt < 2 mbar/min → 1.33 Hz/s

IMPORTANT FOR HE IN REFRIGERATION CYCLE

Capacitive slow tuning



Inward-Outward Movable by ± 3 mm

- **2 such** end-plate tuners (backlash-free system)
- Sensitivity: 0.5 Hz
- **Full f-range**: **300 kHz**

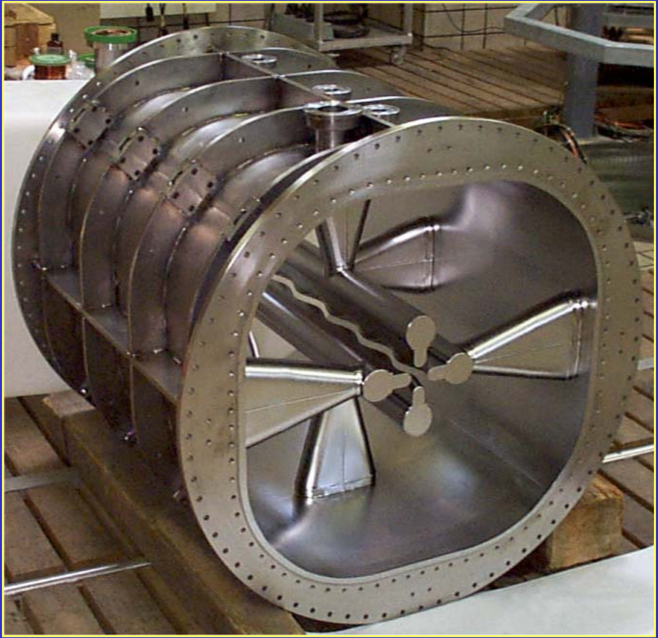
(150 kHz ⟶ **+Δf tuner**;

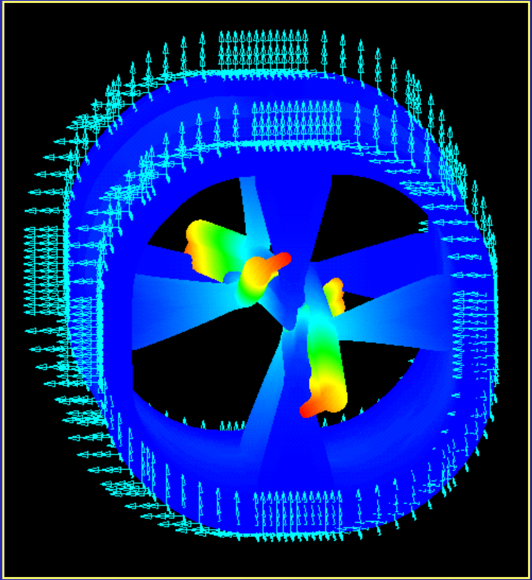
-150 kHz ⟶**–Δf tuner**)

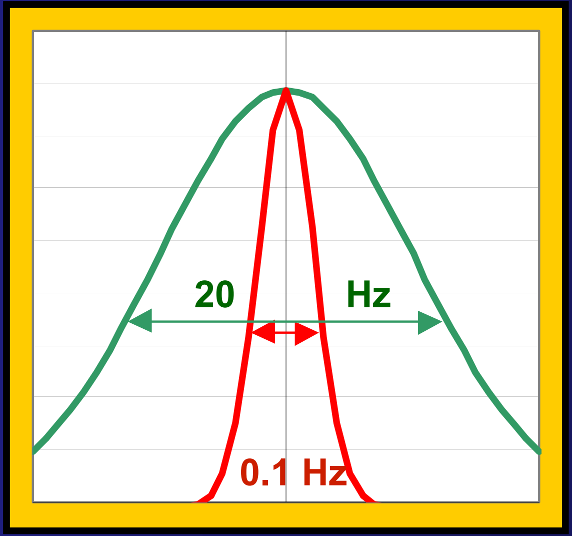
- **f change rate ≥ 2.5 Hz/s**

Fast Frequency Drifts: micro-phonics

$Q_0 = 8 \times 10^8$ @ f_0 = 80 MHz → $\Delta f = f/Q_0$ = 0.1 Hz







Δf = 20 Hz

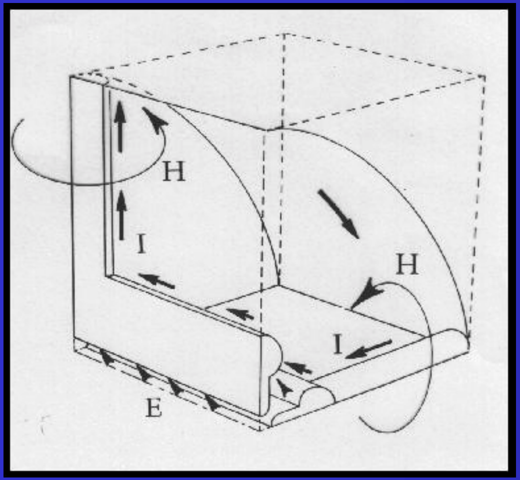
$P_{ampl} = (2\pi U\,\Delta f)$ = 500 W

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

SEL mode, φ&A locked

1. Structure **stiffened by a Ti cage**
2. **Lowest** mechanical **mode ~ 120 Hz** (vs. 40÷70 Hz of typical low b SC cavities)
3. SC-linac **hall**: resonably quiet **> 60 Hz**

Lorentz f-detuning

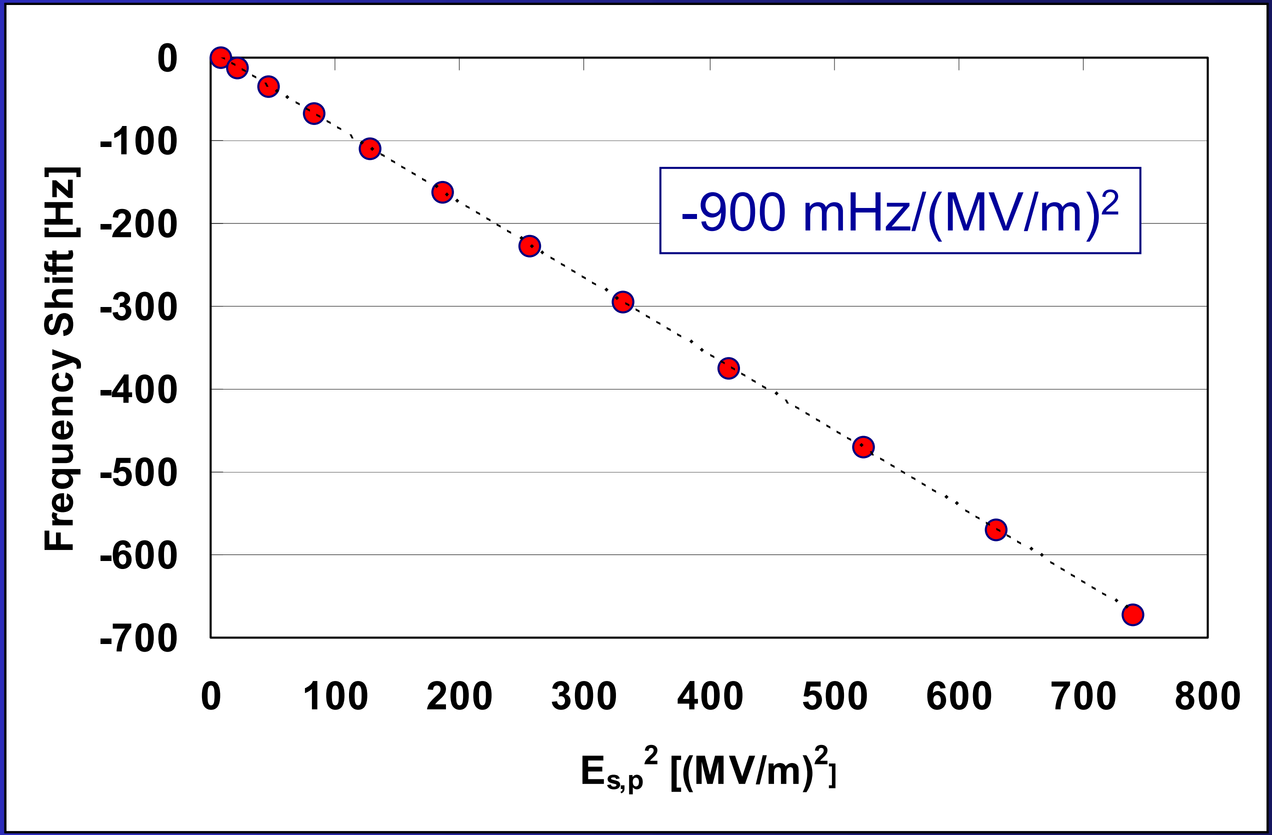


E and H concur to Lorenz frequency detuning

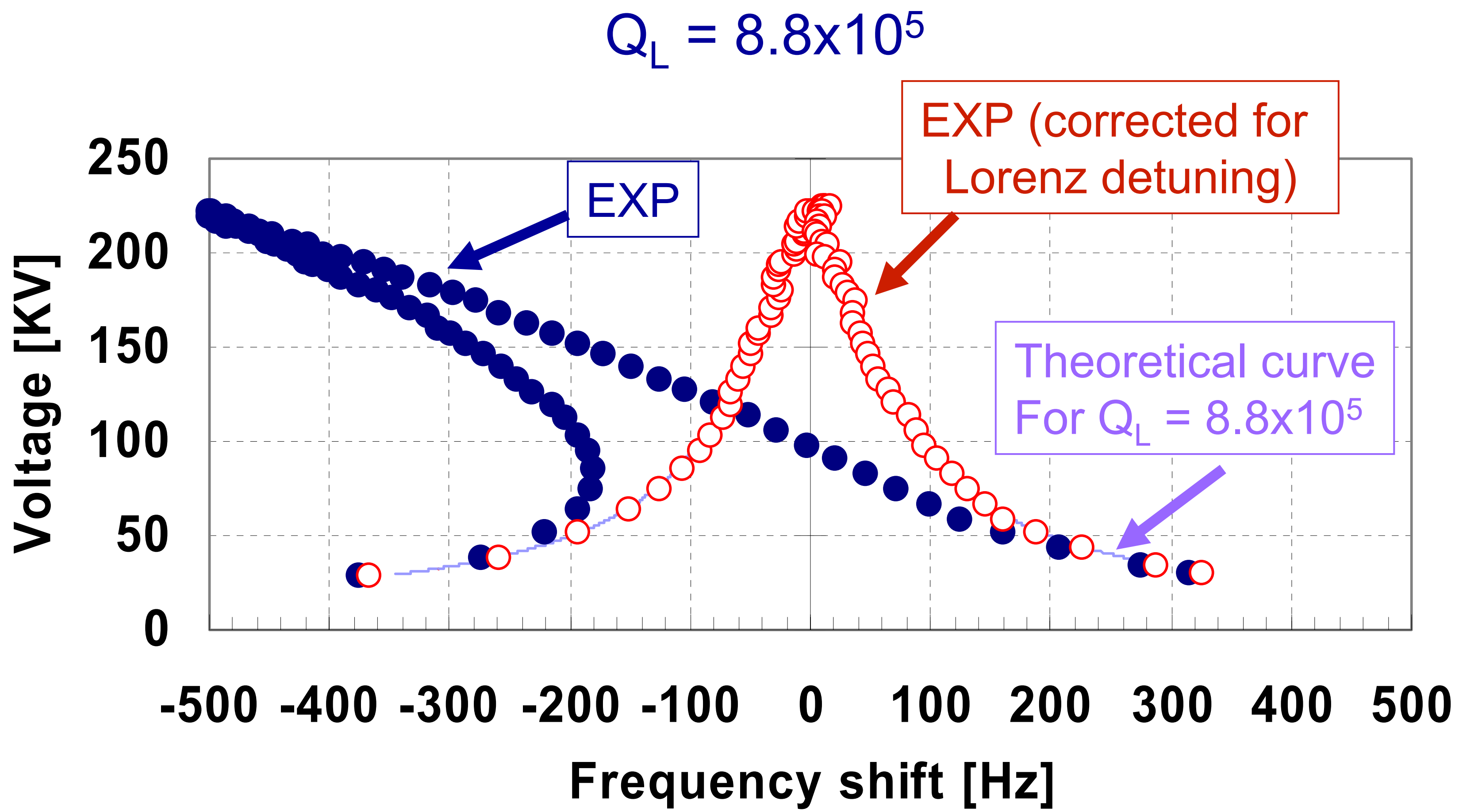
Long high-E regions among electrodes

Current flows parallel in the 4 electrodes, giving attractive force

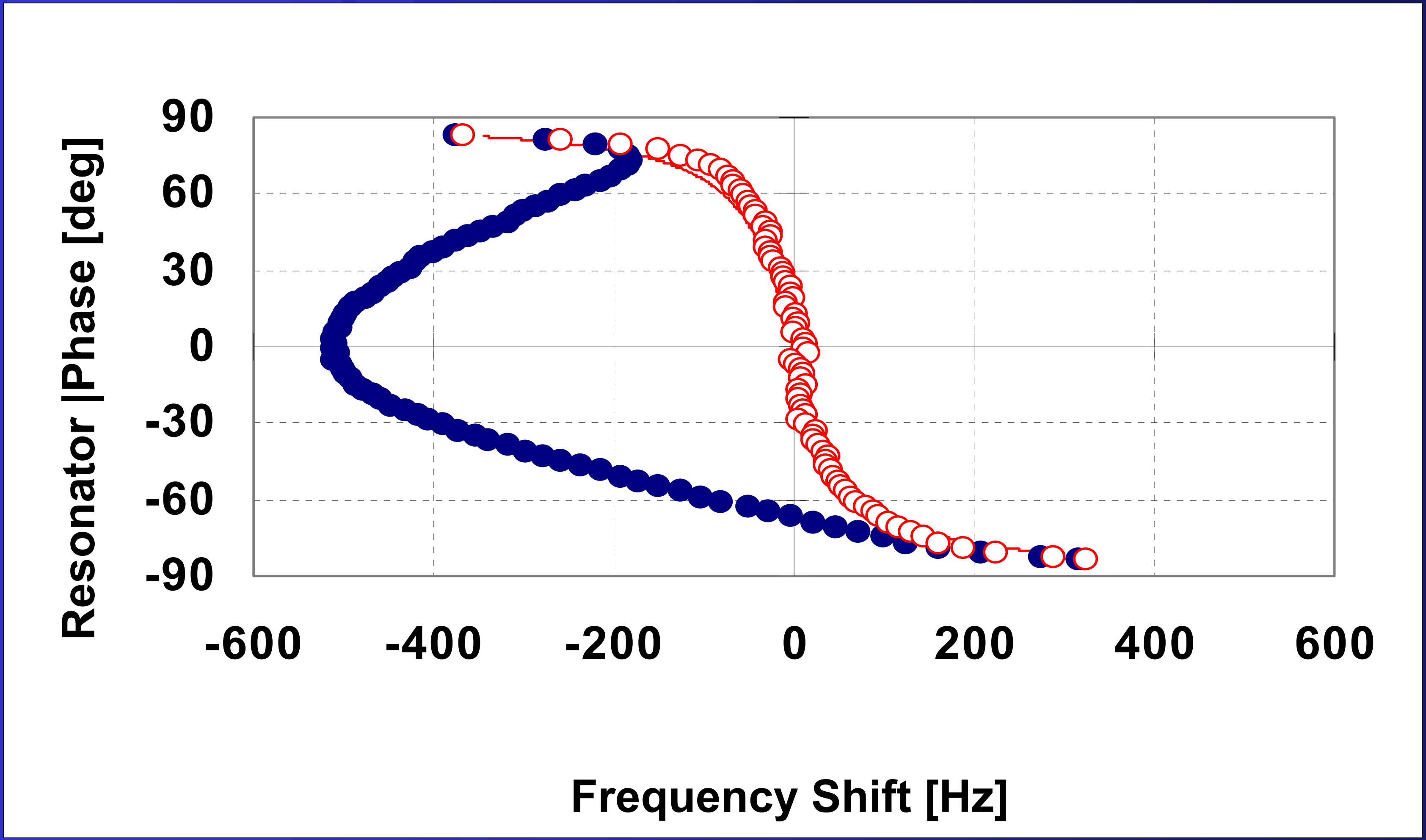
Radiation Pressure: $P = (\mu_0 H^2 - \varepsilon_0 E^2)/4$



Folded Resonance Curve



Folded Phase-Frequency Curve



Control of Frequency Drifts

- Slow Drifts (natural, induced by He pressure changes):
  1 end-plate deformation (ΔC), >2.5 Hz/s
- **Fast Drifts (micro-phonics): SEL mode with <u>amplitude & phase locking</u> (window < 20 Hz)** on a Lorenz-detuning folded curve

<u>RESULTS</u>

- **<u>SRFQ2</u> : tested in this way for 1÷1.5 hour periods**
- **<u>Locking for longer periods</u>:** when the double end-plate slow tuner will be implemented (**June 2002**).
- **A strong <u>mechanical vibrator</u>** was located both on the cryostat and on the floor, driven up to 300 Hz. Unlocking at 80 and 161 Hz: it is a **stiff resonator**
- **Window < 200 Hz, <u>Fast Tuners</u> (ANL→LNL, July 02)**

SRFQ1 under test …

- **SRFQ2** was dismounted (03/02)
- **SRFQ1** in the test-cryostat: May-September 2002
- Q-curves, cavity characterization and locking tests with the double-end-plate slow tuner
- October 02– March 03: mounting of SRFQ1 and SRFQ2 in the final cryostat, tests
- Beam commissioning to follow

Last word on locking...

(beg. 2003)

- When both SRFQ's will be tested on the final cryostat
- In the Injector Vault (local noise)
- With the Cryogenic Plant feeding liquid He at 1.2 bar in refrigeration cycle

Final Cryostat for SRFQ1 & 2 @ the Budker Institute (Novosibirsk, Russia) prior to shipment to INFN-LNL

PIAVE design values

Designed for $^{238}U^{28+}$ (pre-bunched) beam from an ECR on a 315 kV platform

	SRFQ1		SRF2		
	In	Out	In	out	
Energy	37.1	351.3		585.4	KeV/u
	8.82	83.61		139.33	MeV
Beta	0.0089	0.0275		0.0355	
Voltage	148.0	148.0	280.0	280.0	kV
Length		138.9		74.4	cm
N of cells		43		13	
m	1.2	2.8	2.7	2.8	
a	0.7	0.4	0.8	0.8	cm
R_0	0.80	0.80	1.53	1.53	cm
ϕ_s	40.0	18.0	12.0	12.0	deg
$E_{p,s}$		24.		25.5	MV/m
U		1.8		3.5	J

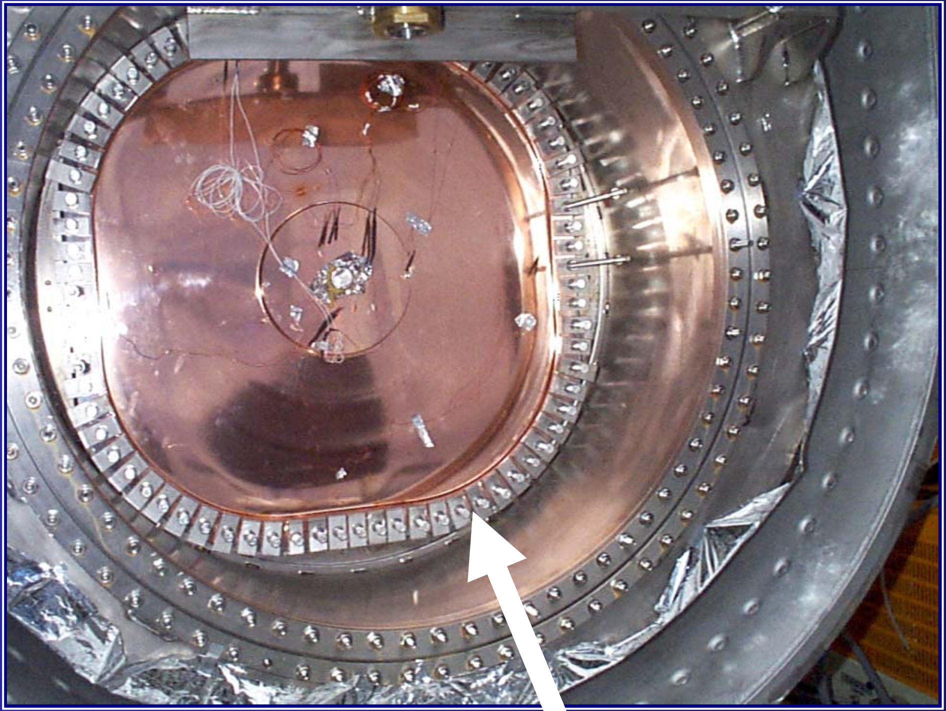
Acceptance (norm)	**0.8**	**mm mrad**
Output long. emittance	**0.7**	**ns keV/u**

End-Plate RF Joint

NO JOINT: with sufficient pressure
(Nb/Cu end plate might help)

<u>OPTIONS</u>

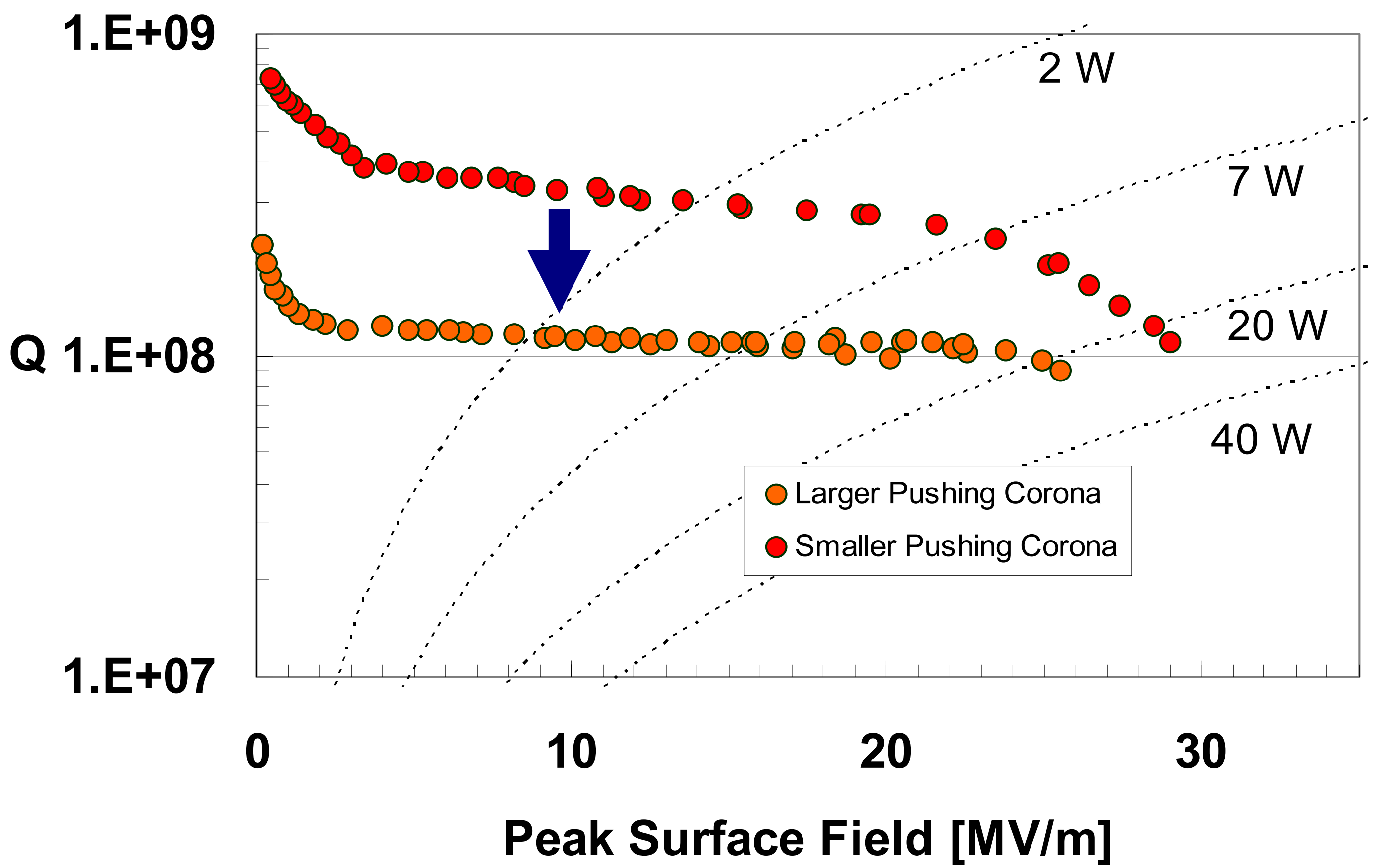
- **INDIUM WIRE (NC):**
  → **0.5 mT** (LNL QWRs)
- **LEAD WIRE:**
  → **2 mT** (ANU-Canberra SLRs)
- **NIOBIUM WIRE & GASKET** :
  beyond 2 mT (Argonne SLRs),
  <u>if sufficient pressure is exerted to break the surface oxide film</u>
  (K.W. Shepard, p.c.)
  BUT **huge, non-circular**, complicated for the SRFQ.



SRFQ2 field at the RF joint:

H ~ 3 ÷ 6 mT

Effect of Mechanical Pressure on the End-Plate SC joint



Effect of 25 % smaller pushing pressure

Cryogenic System of PIAVE

- Feeding the SRFQs' and the QWRs' cryostat with a refrigeration power of 300 W @ 4 K and 500 W for thermal radiation shields (proper redundancy)
- Received **from INFN-Frascati's dismantled LISA linac**, adapted by **Linde Cryogenics**, **delivered** to LNL. Power tests in May 2002.

Cryo-plant and RF racks on top

SRFQs Cryostat

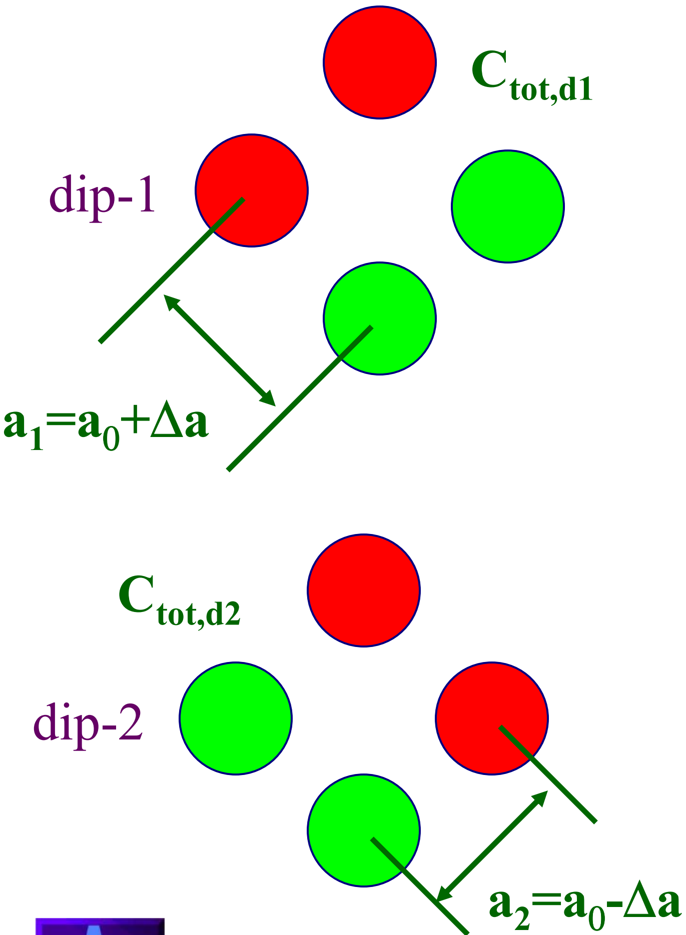
Joint design LNL-Budker Institute
May 2002: delivery to LNL

It features:

- **Ti liquid He dewars** (thermal contr.)
- **Liquid N thermal shield**

- **Alignment procedure**: separate for the 2 cavities, cold-adjustable with external actuators, 0.1 mm precision specified and possible
- **Alignment test with dummy cavities**: to be done at Budker I. @ 300 and 77 K prior to shipment.

Assessment of the alignment at 4 K by measuring frequency splitting between dipole modes



$f_{d,1}$ = 100.6933 MHz
$f_{d,2}$ = 100.9633 MHz
} $\Delta f/f = 0.34\ \%$

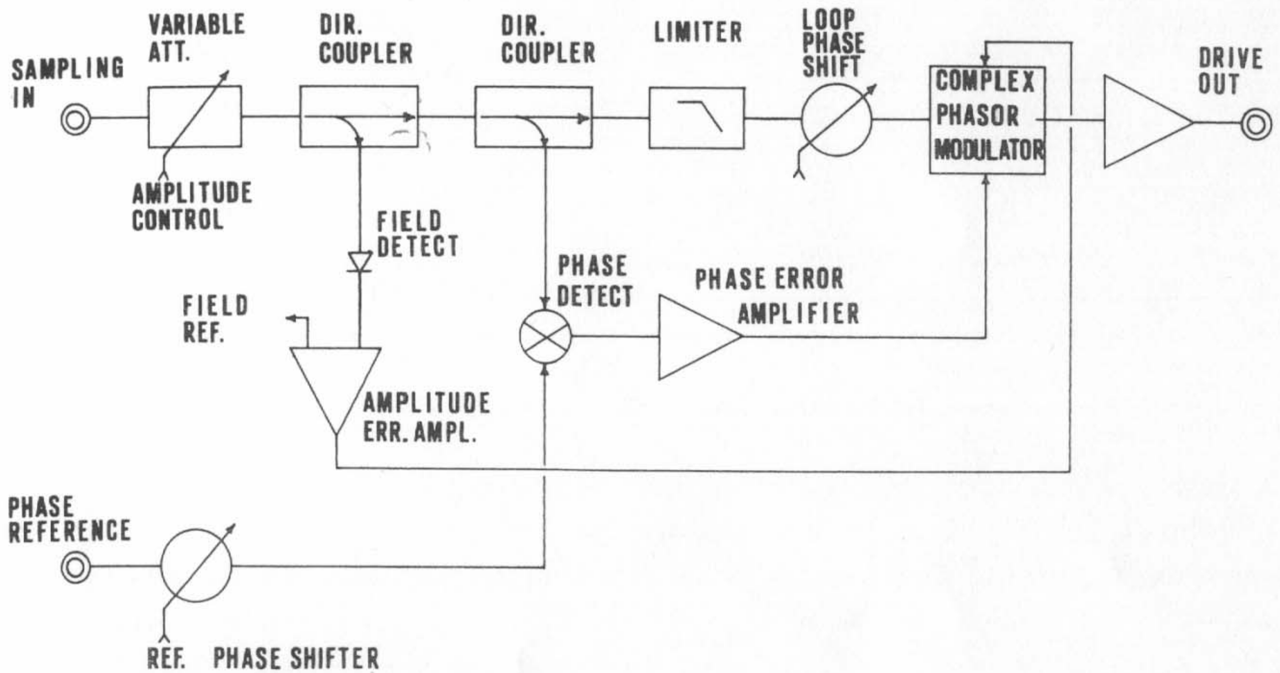
↓

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

↓

$\Delta a \sim$ **75 µm**

Resonator Controller



RESONATOR CONTROLLER BLOCK DIAGRAM