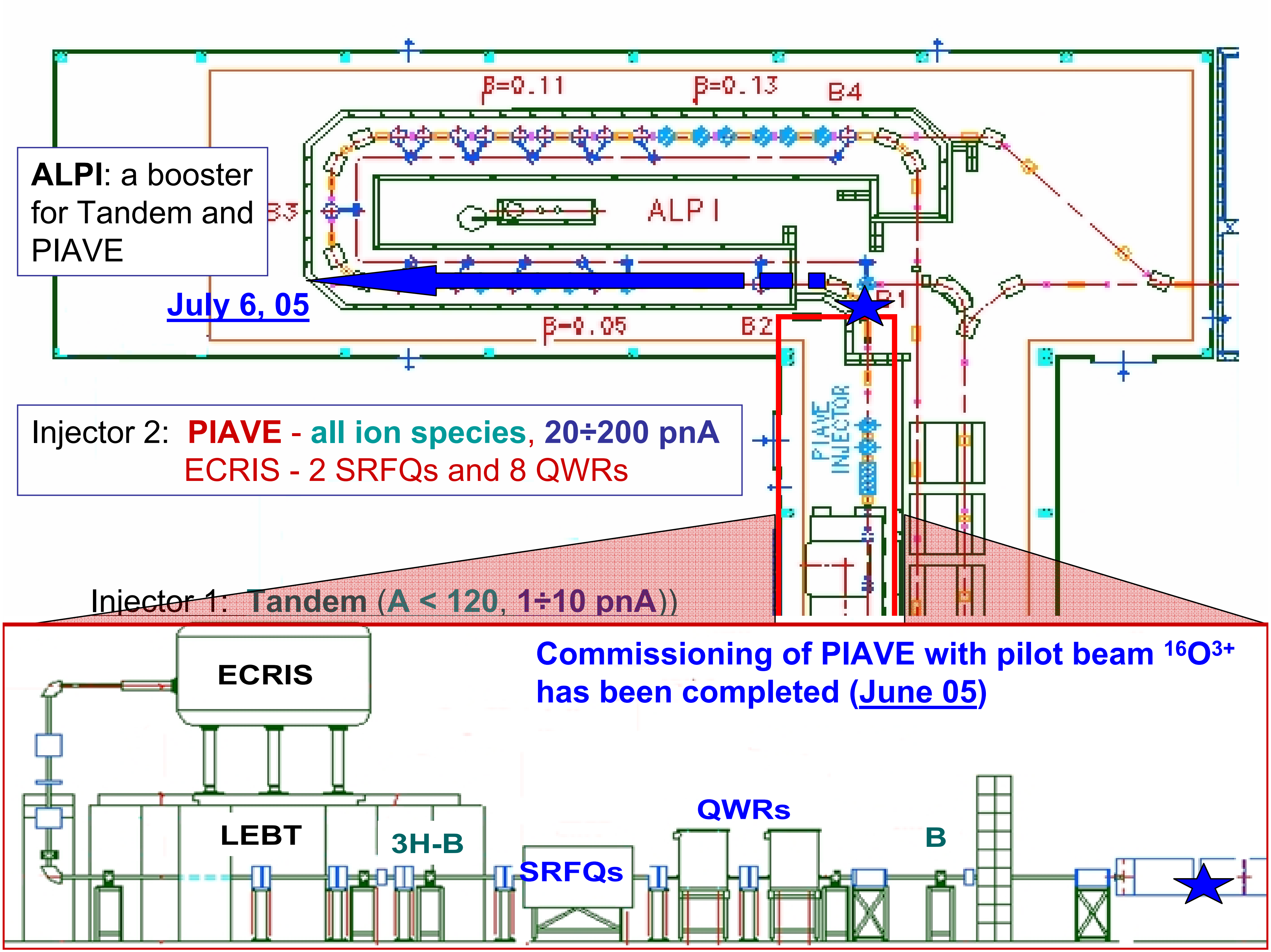
SUPERCONDUCTING RFQs

1. RF operation
2. Beam operation and results

3. *SRFQ for high I linacs*

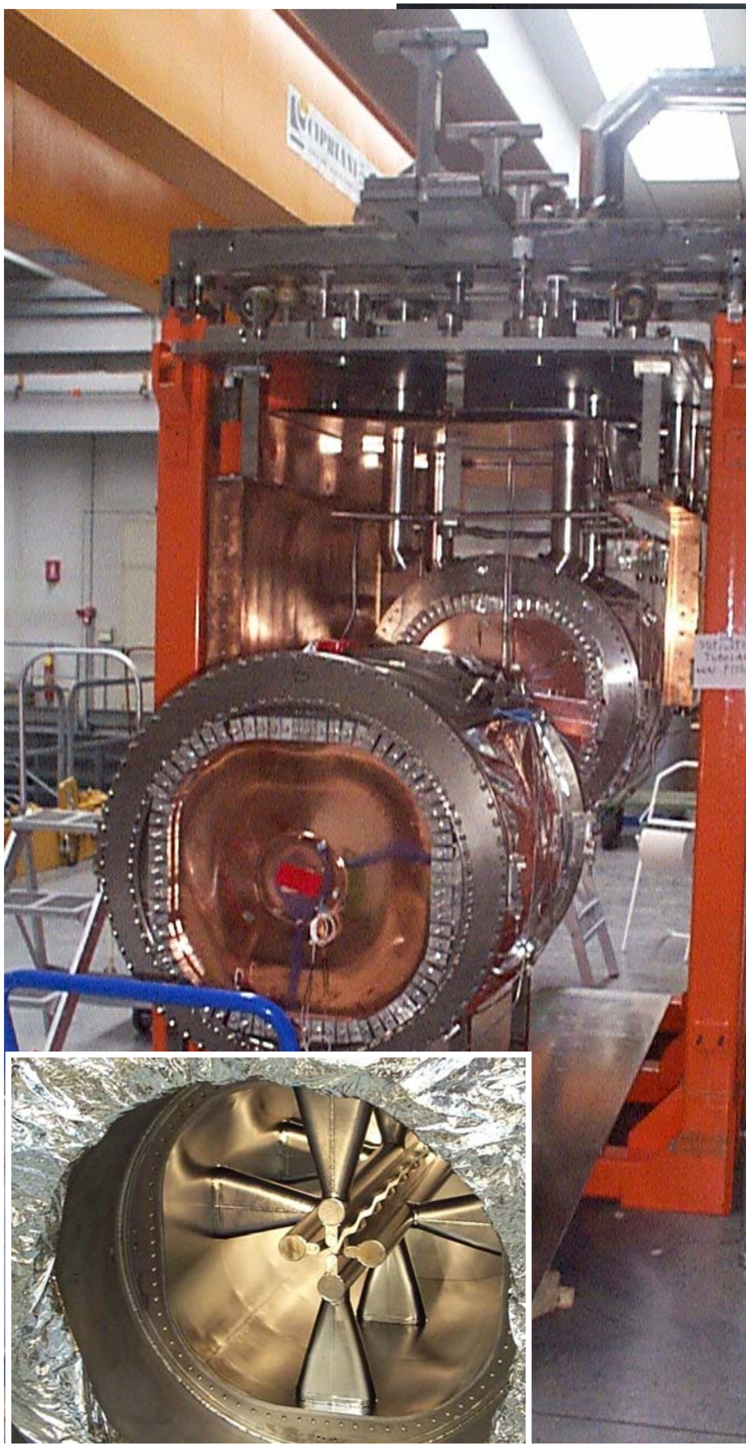
Giovanni Bisoffi INFN-LNL

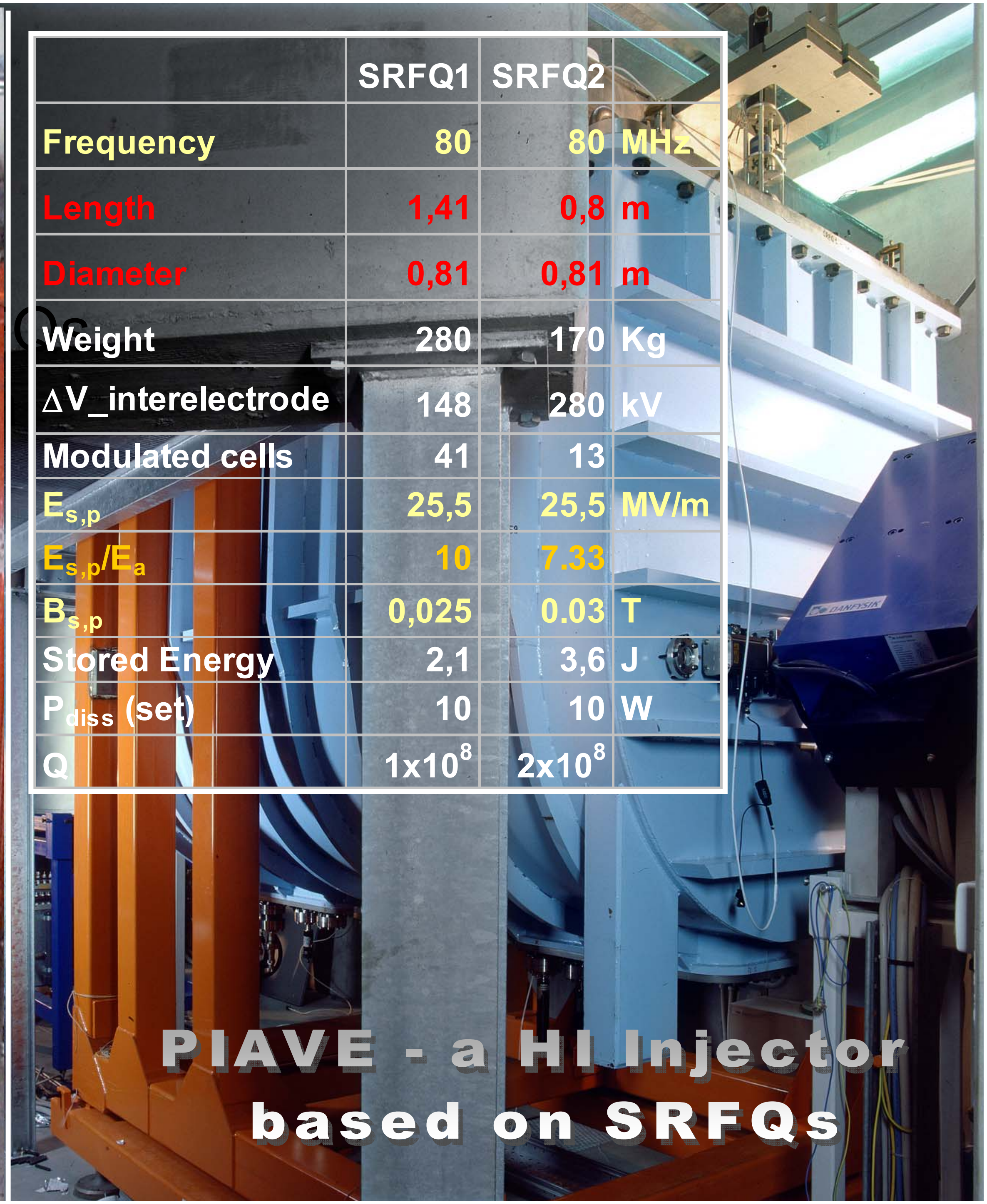
SRF2005


ALPI: a booster for Tandem and PIAVE
β=0.11
β=0.13
B4
B3
ALPI
July 6, 05
β=0.05
B2
B1
PIAVE INJECTOR
Injector 2: PIAVE - all ion species, 20÷200 pnA
ECRIS - 2 SRFQs and 8 QWRs
Injector 1: Tandem (A < 120, 1÷10 pnA))
Commissioning of PIAVE with pilot beam $^{16}O^{3+}$ has been completed (June 05)
ECRIS
LEBT
3H-B
SRFQs
QWRs
B

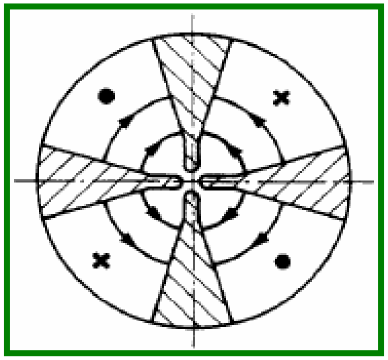
PIAVE - a HI Injector based on SRFQs

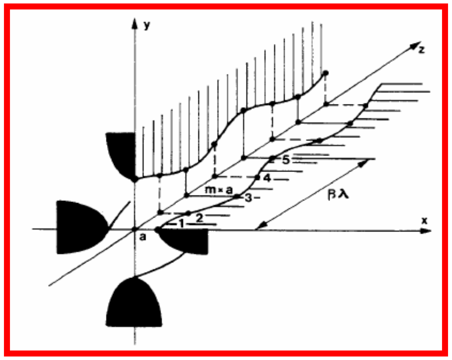
	SRFQ1	SRFQ2	
Frequency	80	80	MHz
Length	1,41	0,8	m
Diameter	0,81	0,81	m
Weight	280	170	Kg
ΔV_interelectrode	148	280	kV
Modulated cells	41	13	
$E_{s,p}$	25,5	25,5	MV/m
$E_{s,p}/E_a$	10	7.33	
$B_{s,p}$	0,025	0.03	T
Stored Energy	2,1	3,6	J
P_{diss} (set)	10	10	W
Q	$1x10^8$	$2x10^8$	





Radio-Frequency Quadrupoles





- **Focusing** ⇐ **main quadrupolar E_T**
- **Acceleration** ⇐ **small effective E_L**
  modulation of 4 vanes
  (synchronous with beam bunches)
  one modulation period = βλ

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

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

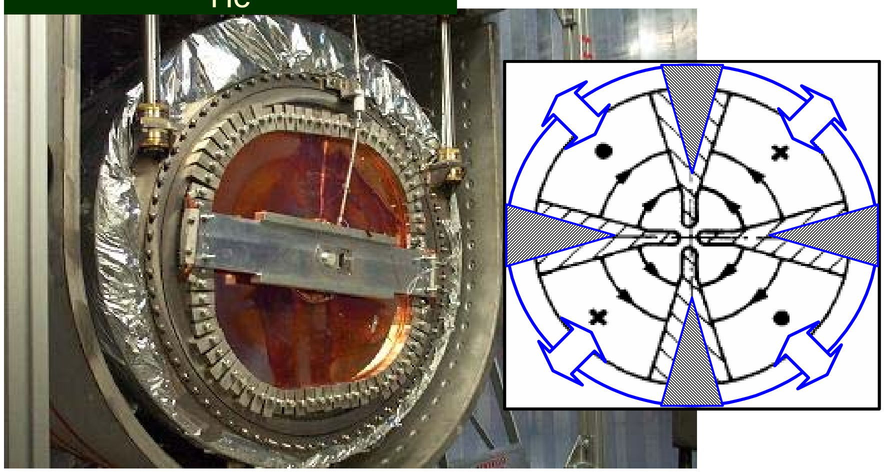
NORMAL CONDUCTING
ΔU ~ 100 kV, **Q ~ 10^4**, **d.c. < 20%**
with a few remarkable exceptions
(**LEDA**: 2.2.MW rf, 100 mA-beam)

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

The main issues of S-RFQs

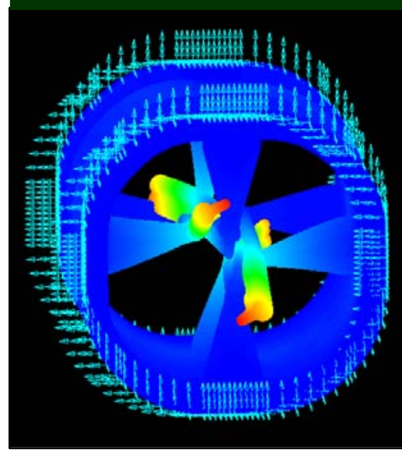
1. To reach spec E_a @ $P_{cav} \le 10$ W): **Q vs Ea** curve
2. To keep **frequency locking** to M.O. vs slow volume changes (drifts of the liquid He P) and fast vibrations

SLOW P_{He} DRIFTS



- Mechanical tuner coping with the $\Delta f/\Delta t$, induced by $\Delta P_{He}/\Delta t$
- Cryo-plant operation minimizes $\Delta P_{He}/\Delta t$

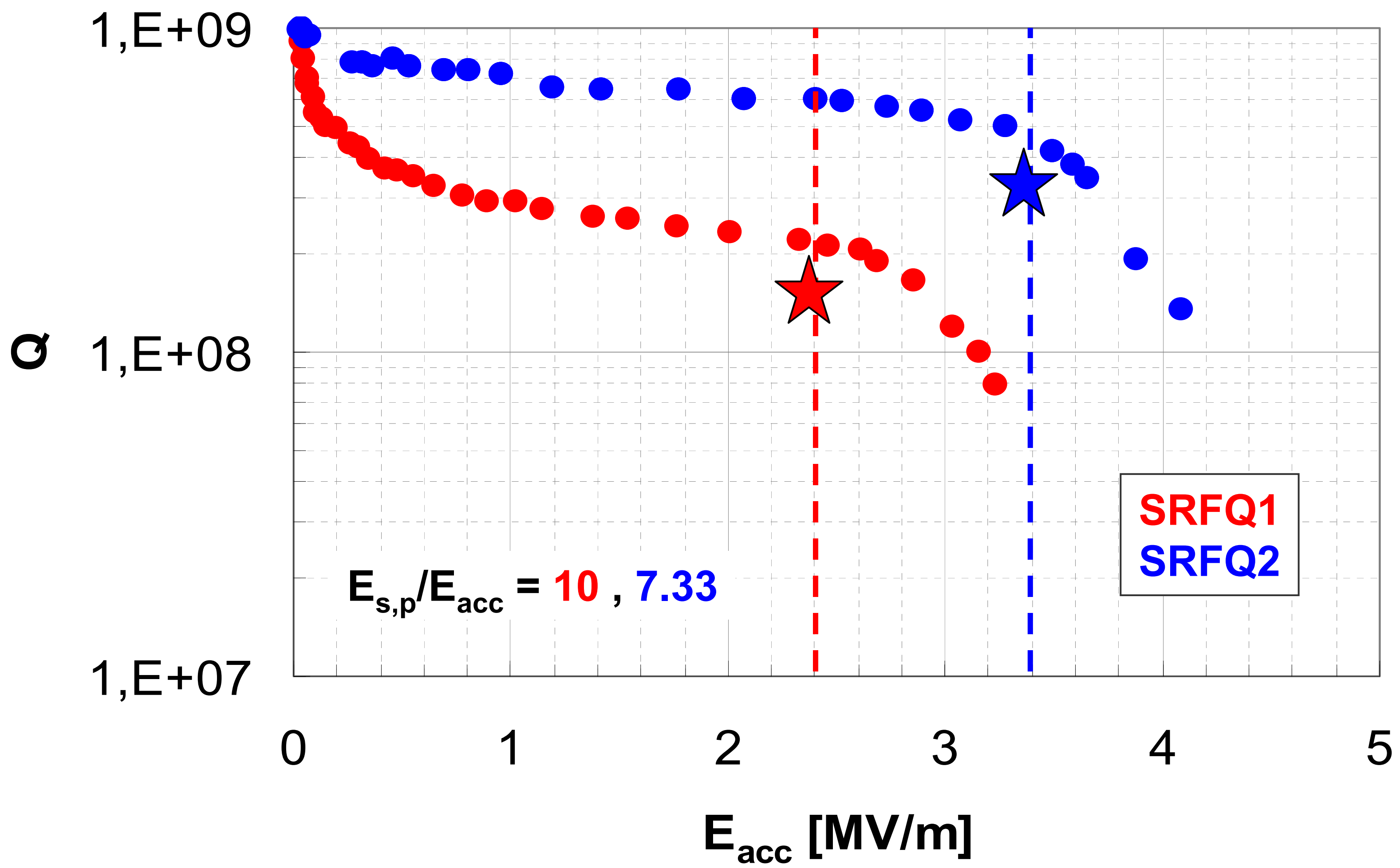
MICROPHONICS EXCITATIONS



- Rigid mechanical design
- Use of VCX fast tuners (ANL)
- Gentle cryo-plant operation

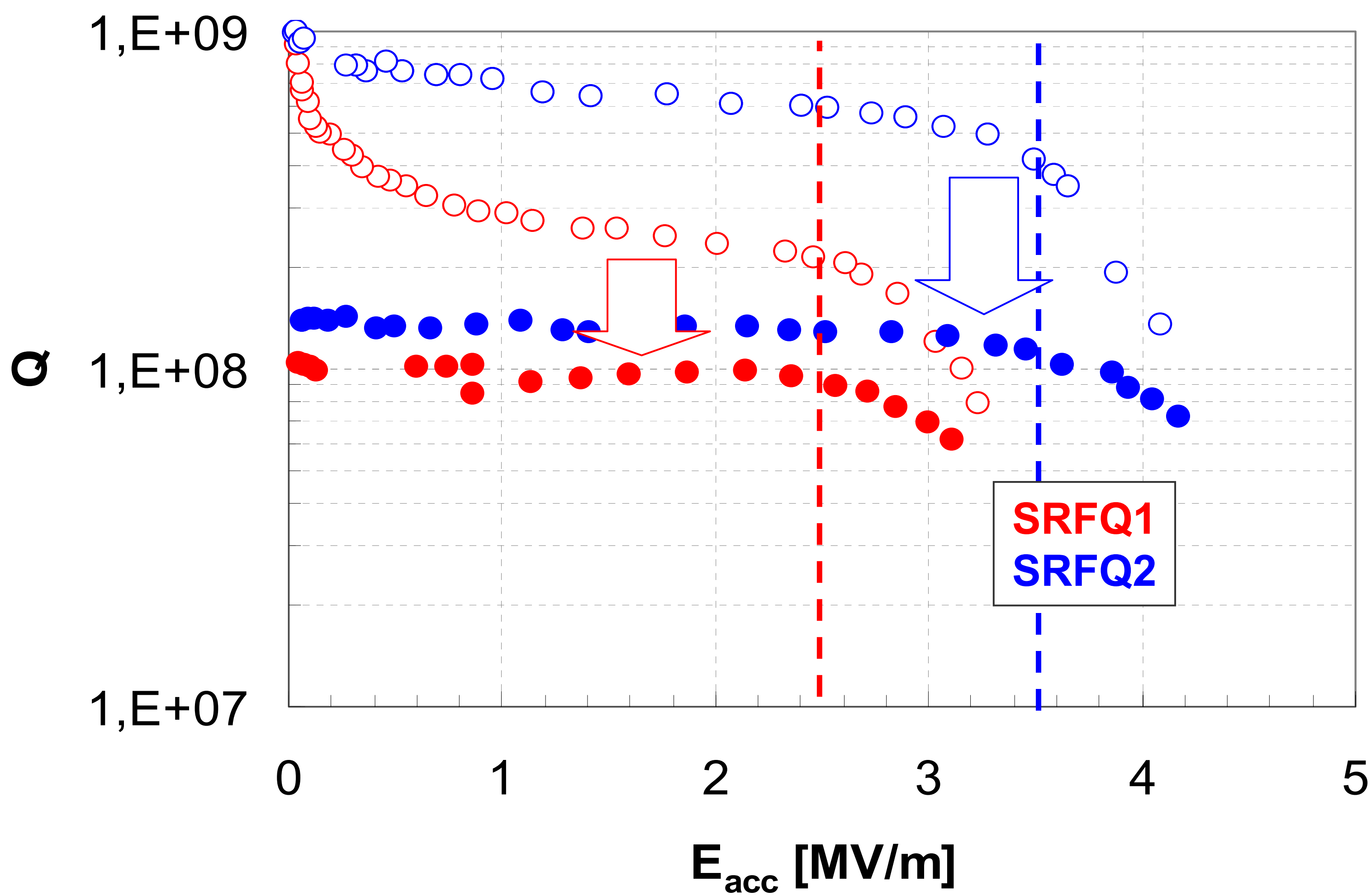
3. **Setup for beam acceleration** ("classical" RFQ is <u>split into 2, with ext. bunching</u>)
4. **RFQ alignment** on beam axis (better than ± 0.2 mm for <u>good beam transmission</u>)

1. Off-line Q-curves in a test cryostat



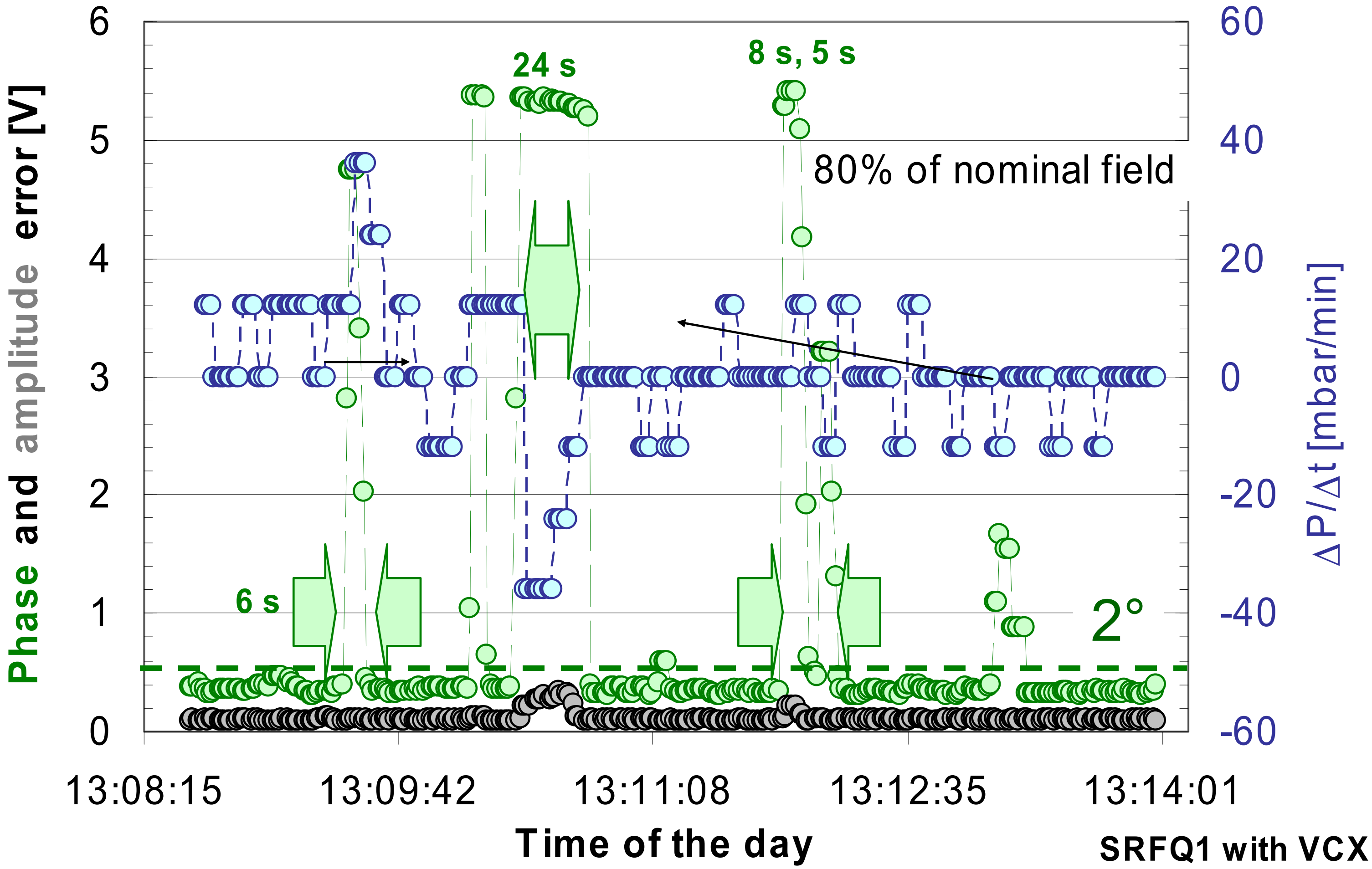
No VCX fast tuners in the test cryostat

1. On-line Q-curves (loaded by VCX)



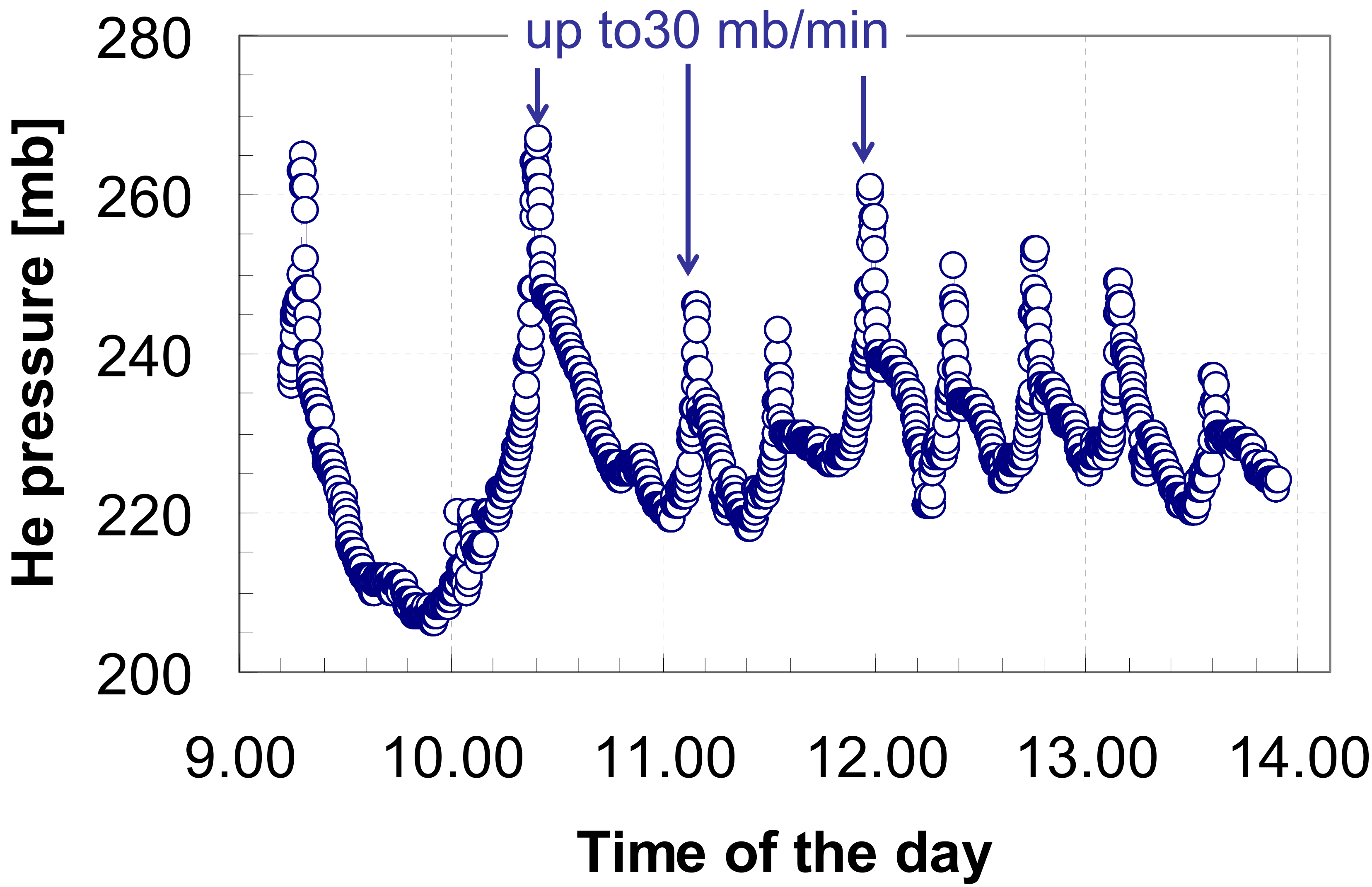
Frequency window controlled by VCXs:
80 Hz (SRFQ1), 200 Hz (SRFQ2)

2. Phase locking difficult before optimizing the cryo-plant parameters



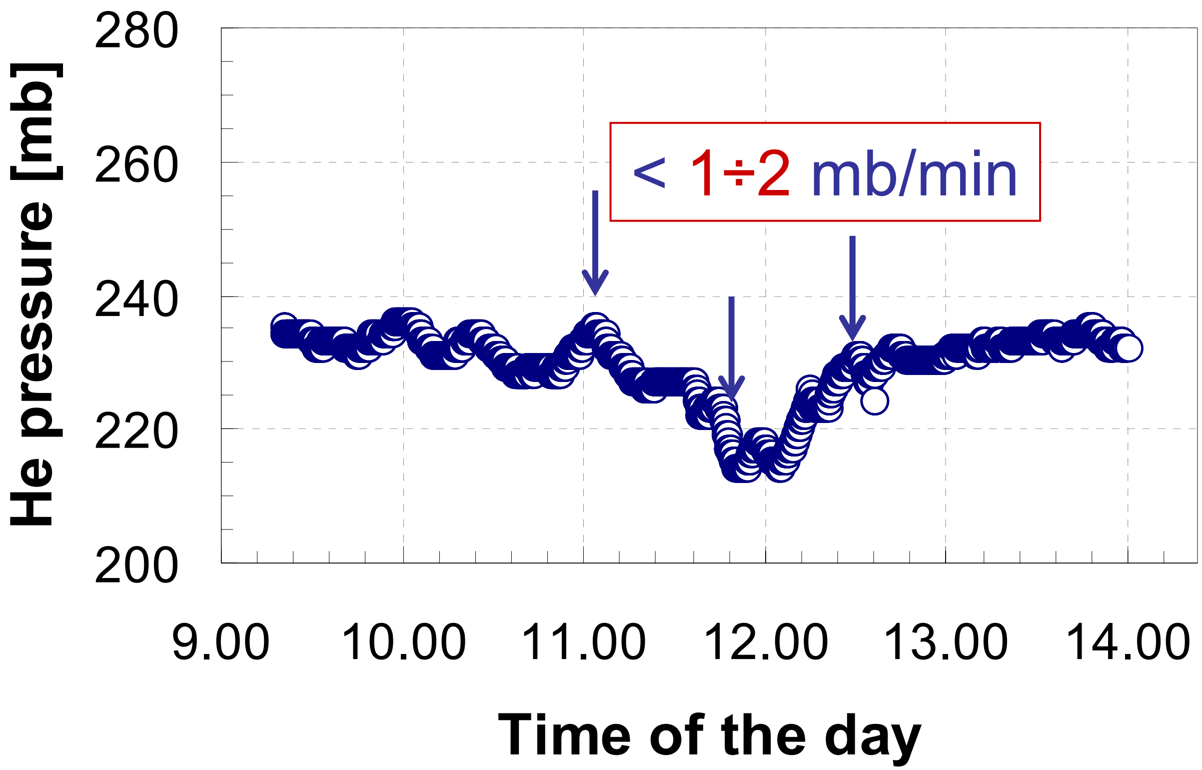
June 2004, a 6 min sample

Mechanical tuners react at 2 Hz/s
(corresponding to $\Delta P/\Delta t$ =2.5÷3 mb/min)
SPECS – 5 mb/min


up to30 mb/min
280
260
240
220
200
He pressure [mb]
9.00
10.00
11.00
12.00
13.00
14.00
Time of the day

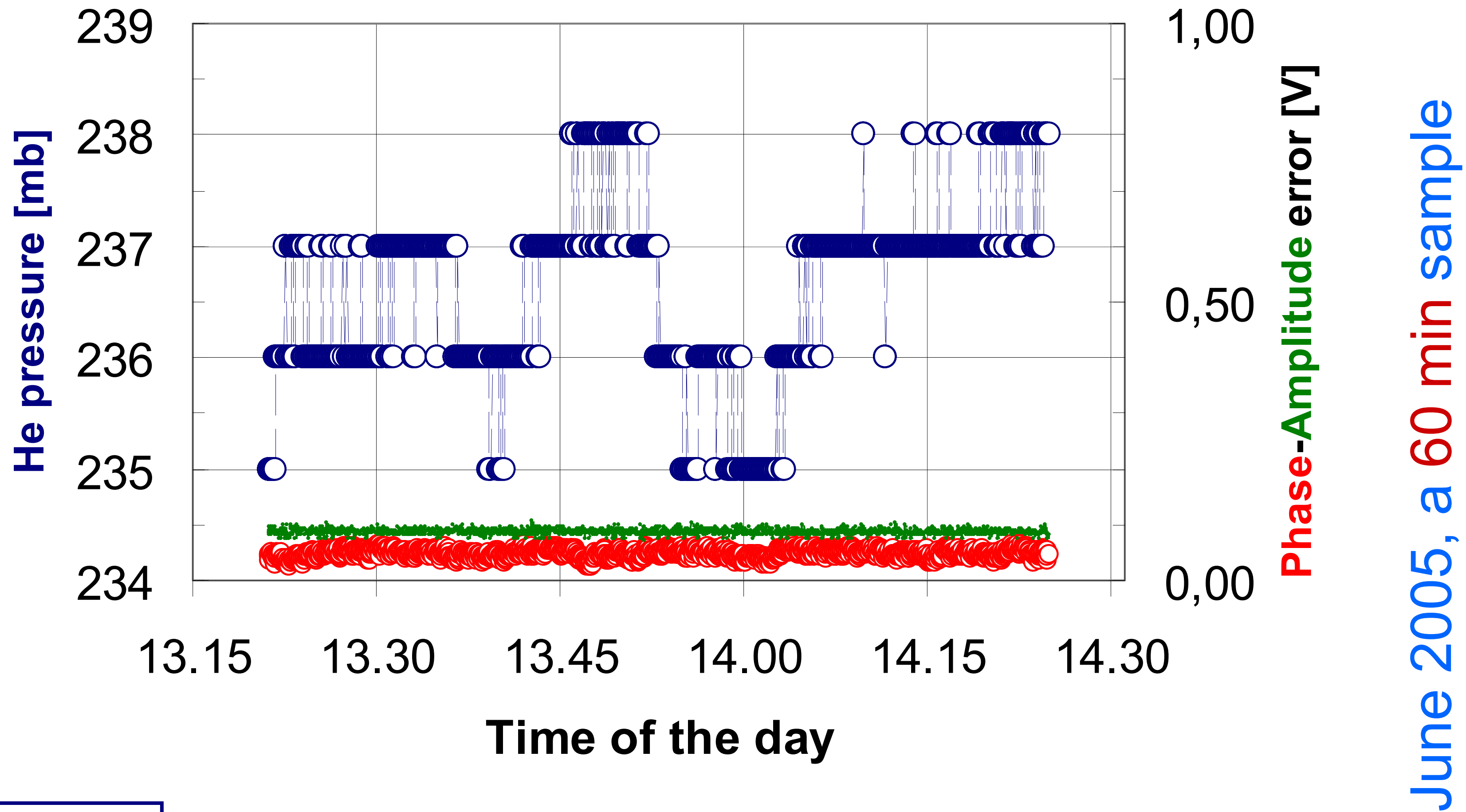
June 2004

2. P changes smaller in range and speed after optimizing the cryo-plant parameters



- *Careful setup of the P.I.D. parameters controlling cryostat valves opening (continuous filling mode)*
- *Control of additional heating or increased production rate of liquid He vs cavity rf power.*

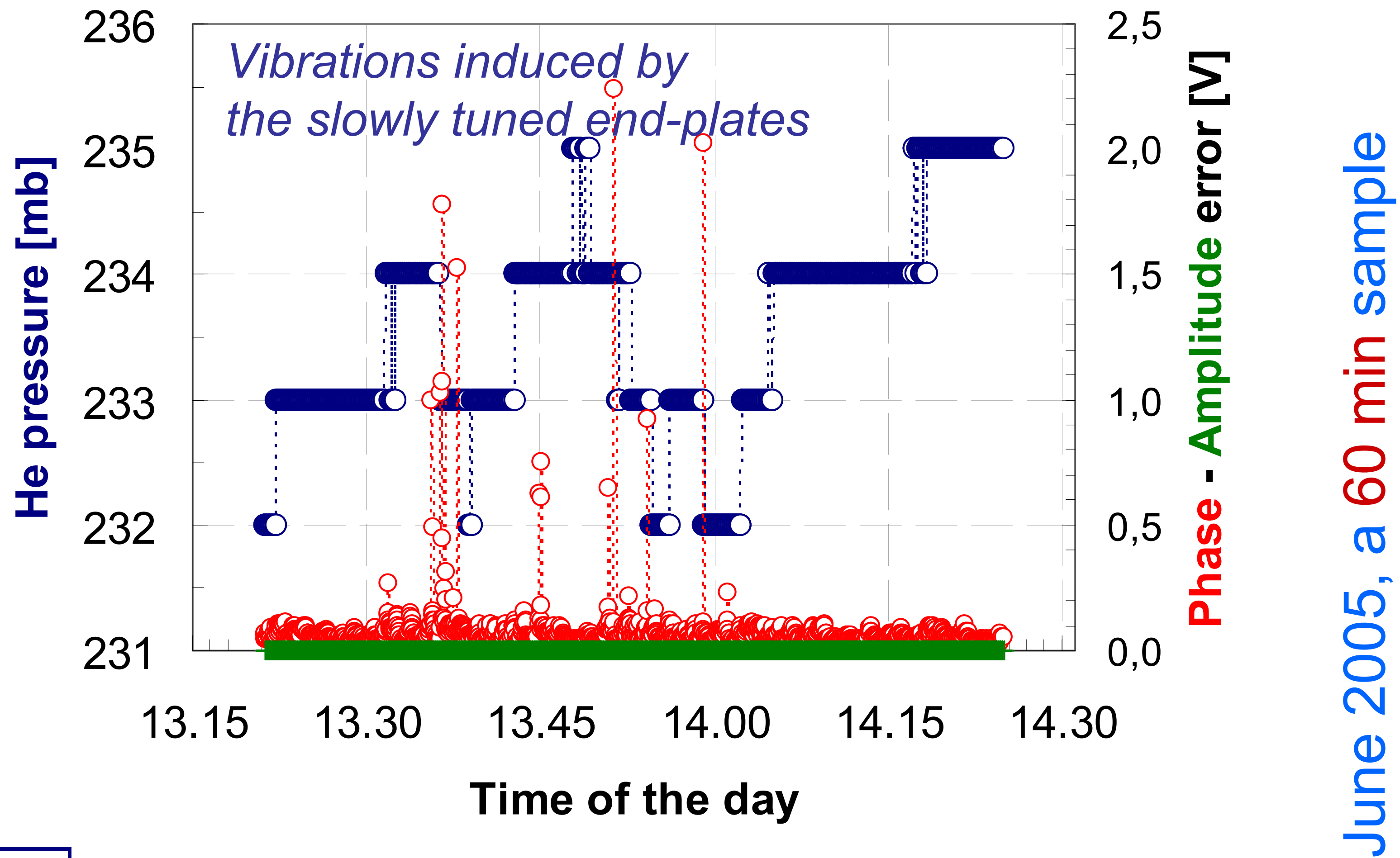
2. φ & A errors on SRFQ2 after optimization of the cryo-plant parameters



SRFQ2

VCX fast tuner window 200 Hz (specs)

2. φ & A errors on SRFQ1 after optimization of the cryo-plant parameters



SRFQ1

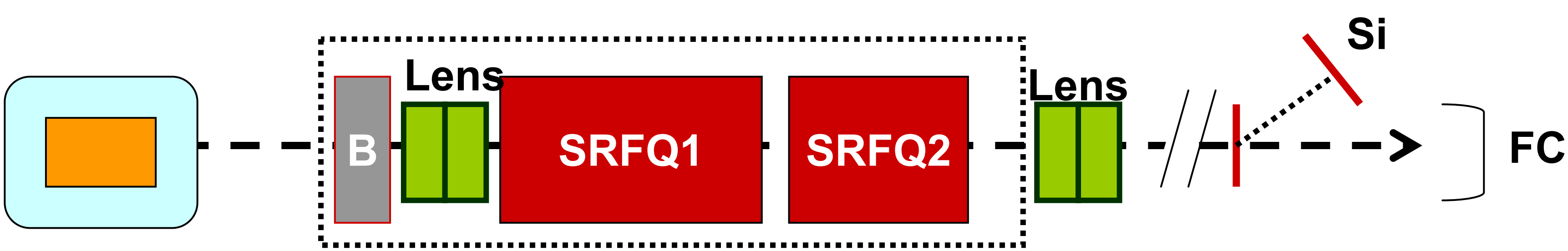
VCX fast tuner window 80 Hz (specs 200 Hz)

INFN

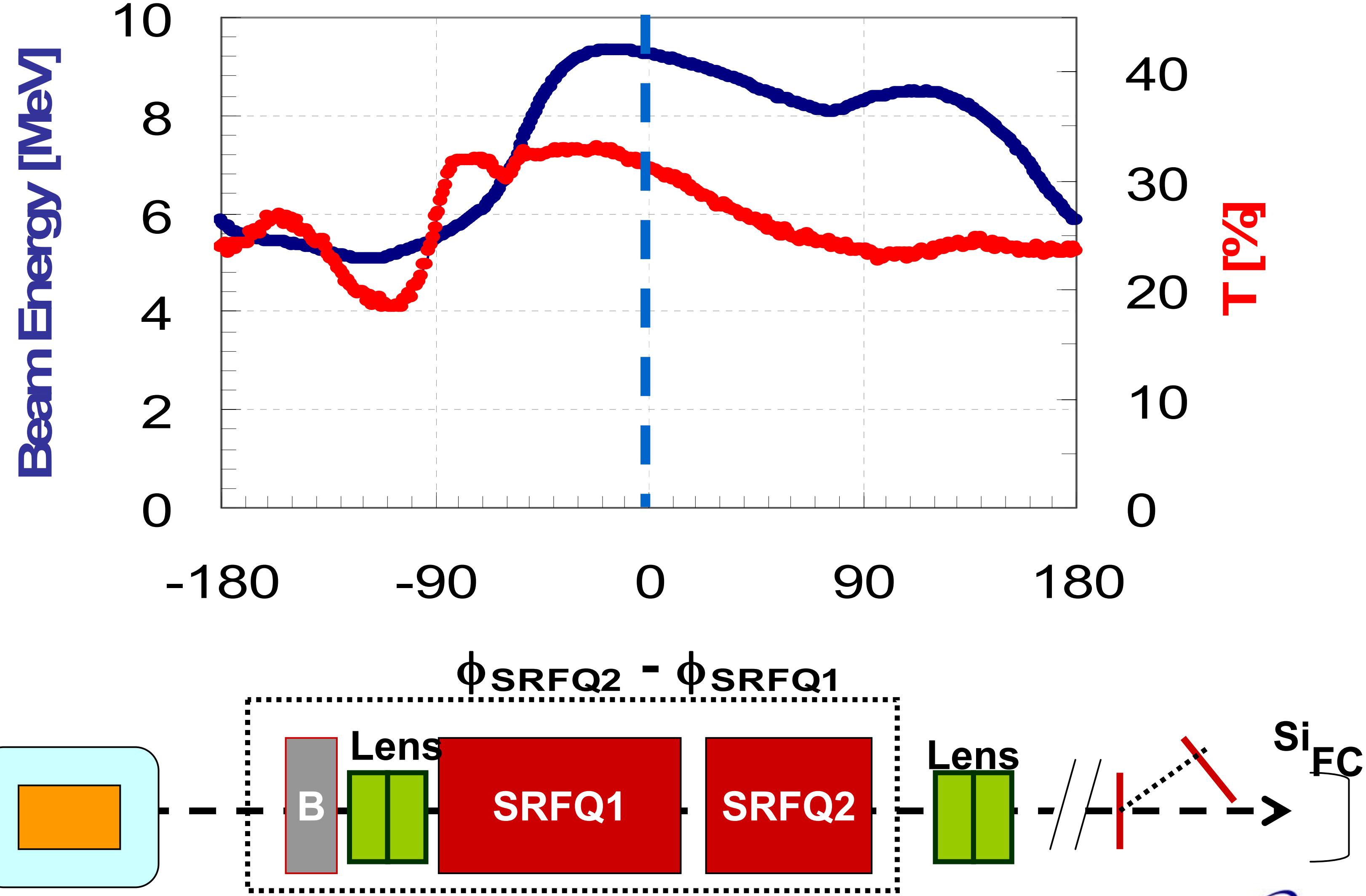
SRFQs: beam-related aspects

3. Setup for beam acceleration
("classical" RFQ is here split in 2, with ext. bunching)

4. RFQ alignment on beam axis
(better than ± 0.2 mm for good beam transmission)

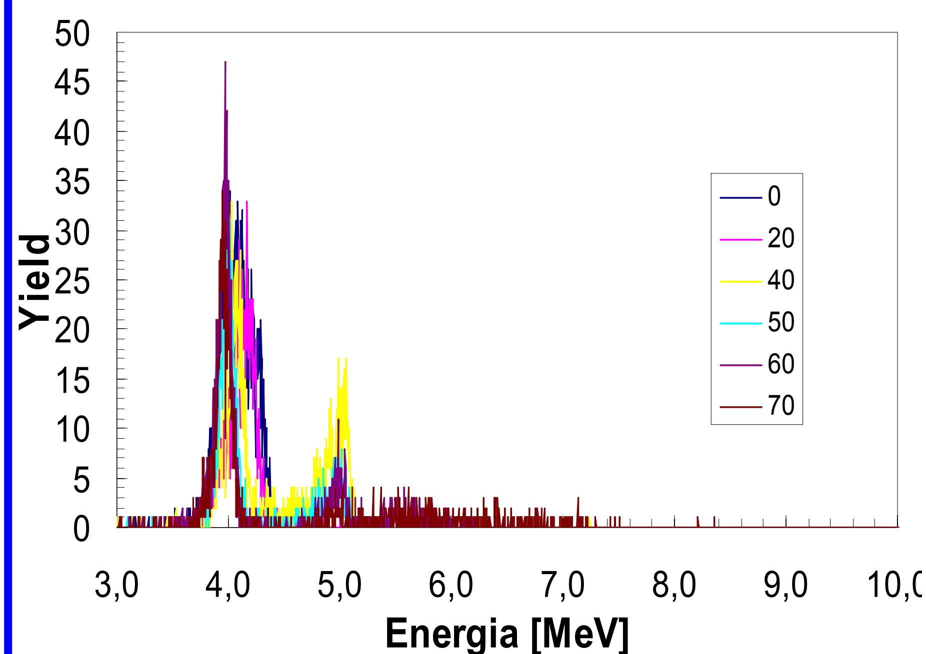


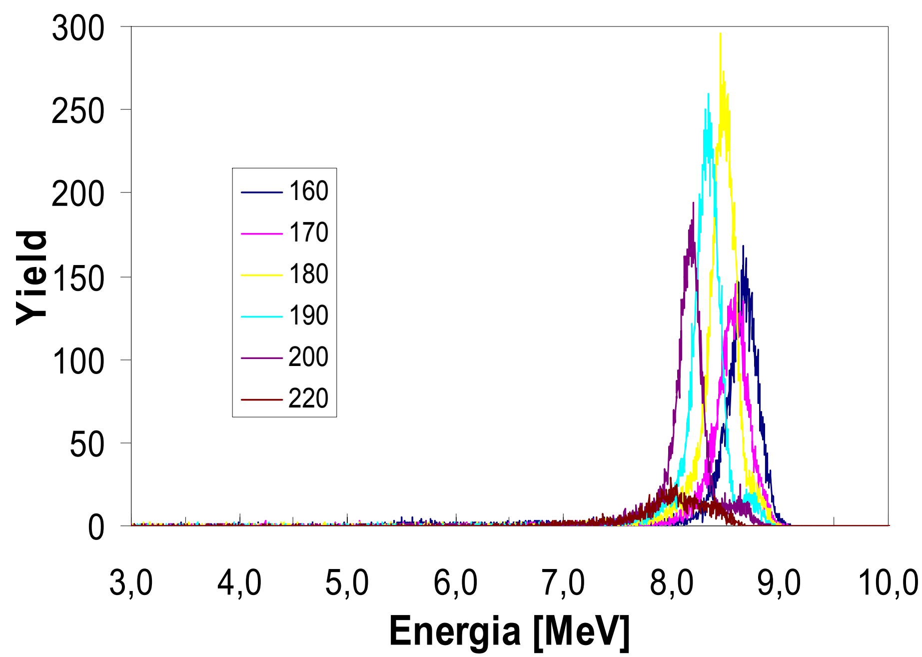
3. Setup of the relative phase between the SRFQs

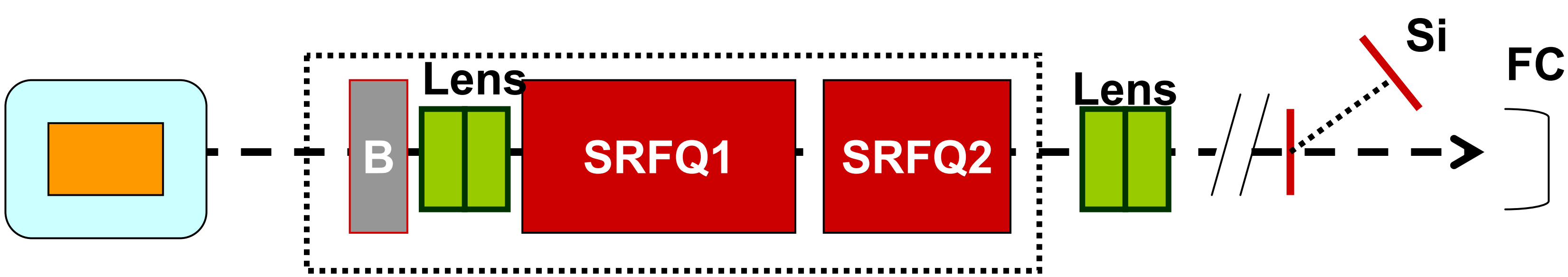


3. Energy plots at varying

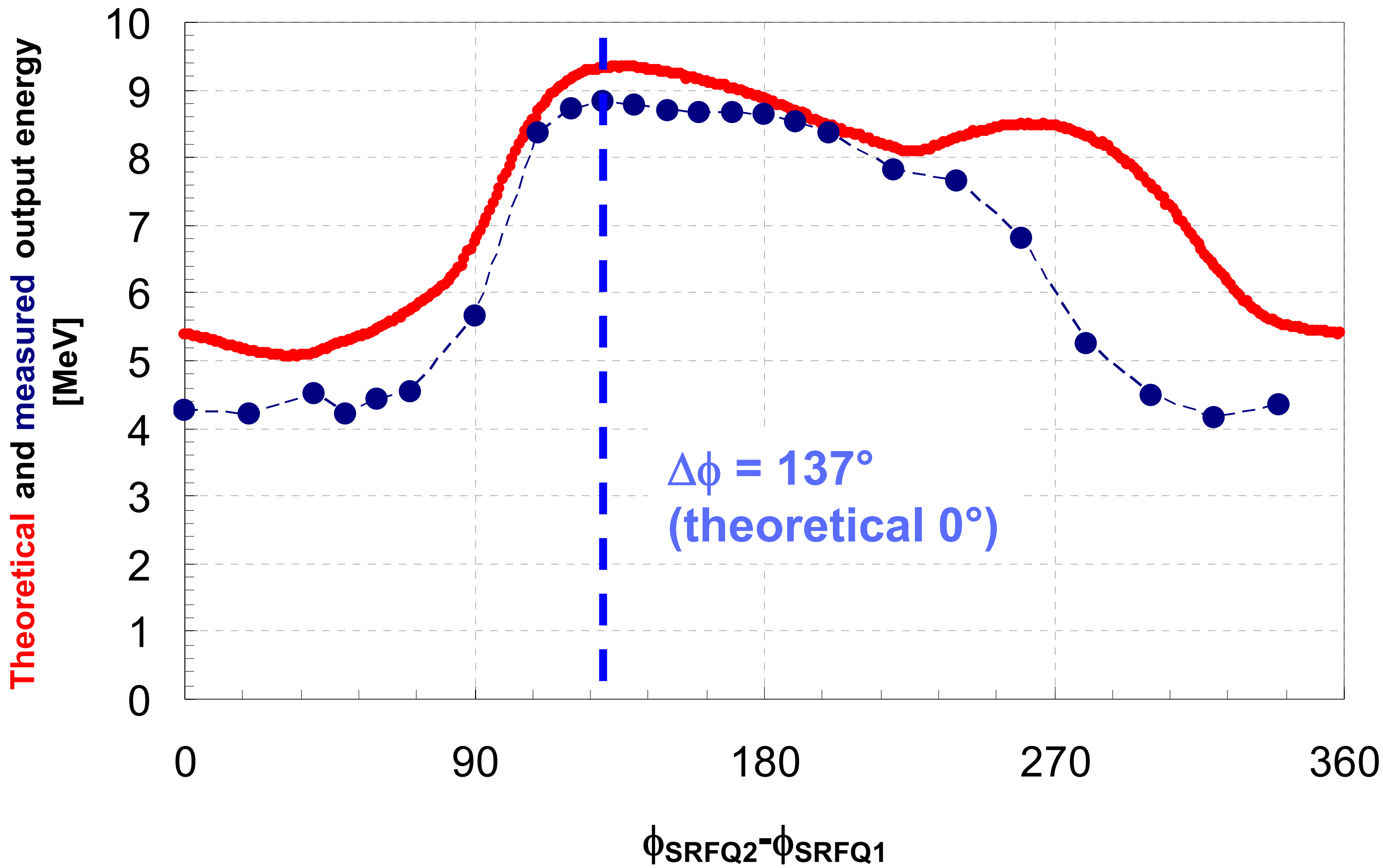
$\varphi_{SRFQ2} - \varphi_{SRFQ1}$







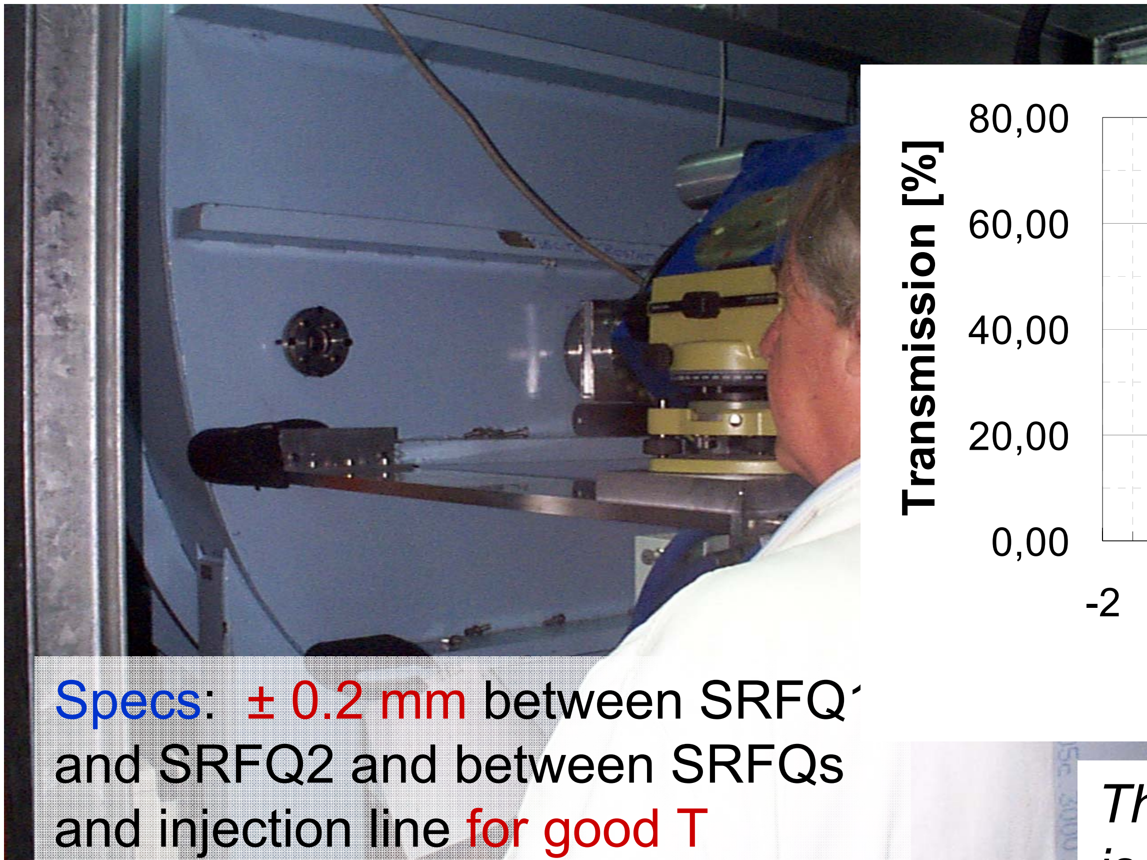
3. φ_{SRFQ2} is scanned, while φ_{SRFQ1} = k

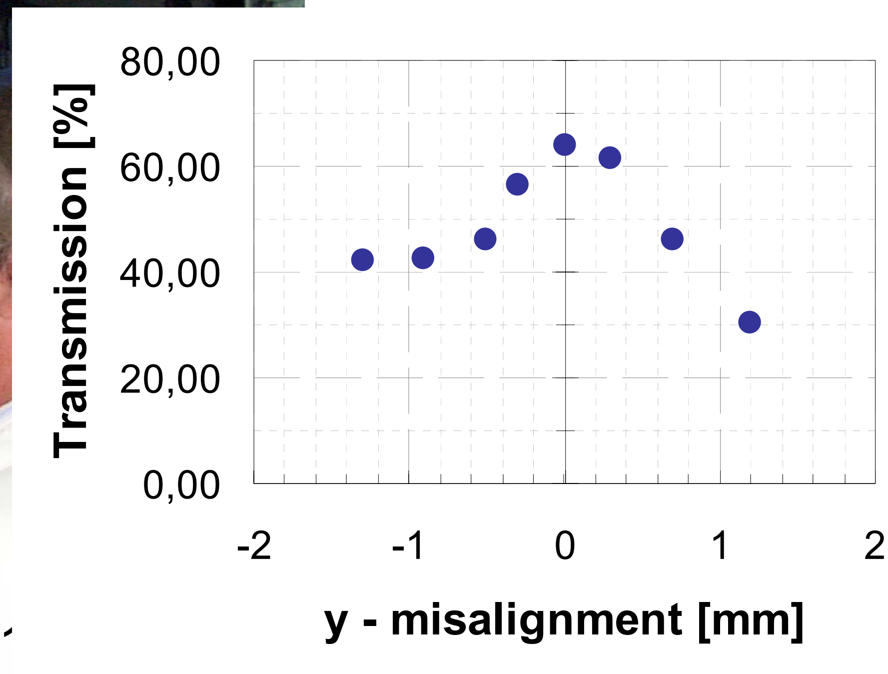


T ~ ***30 %,*** *as expected from the theory*

T ~ 30 → ***68%*** *(expected : 70%) after switching on the 3H-buncher*

4. Control of alignment tolerances

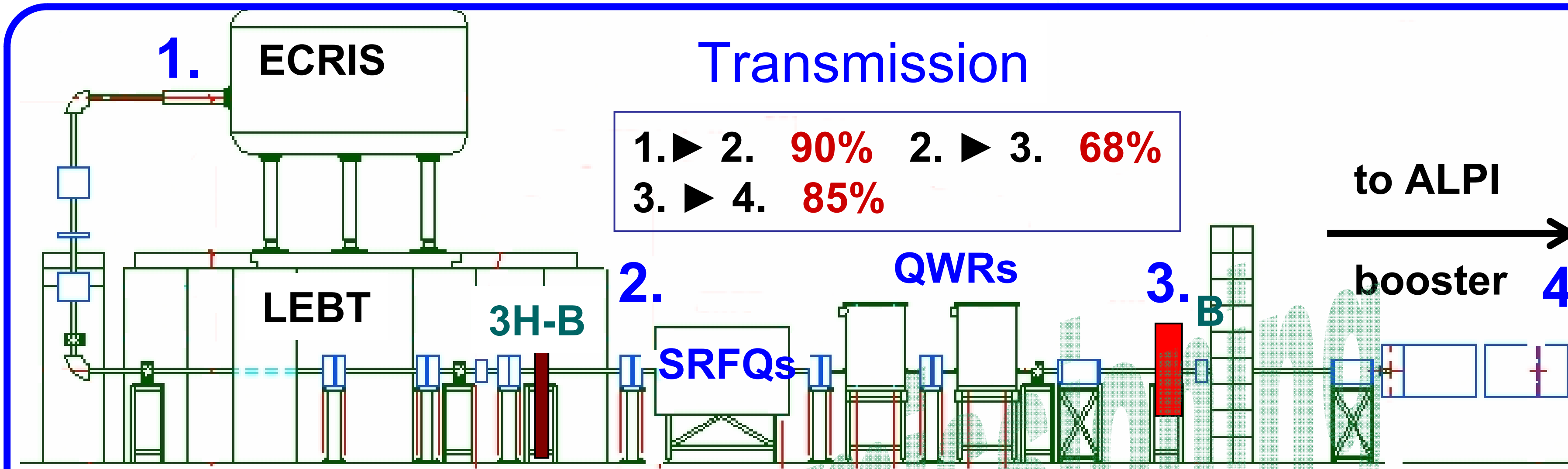




Specs: ± 0.2 mm between SRFQ1 and SRFQ2 and between SRFQs and injection line for good T

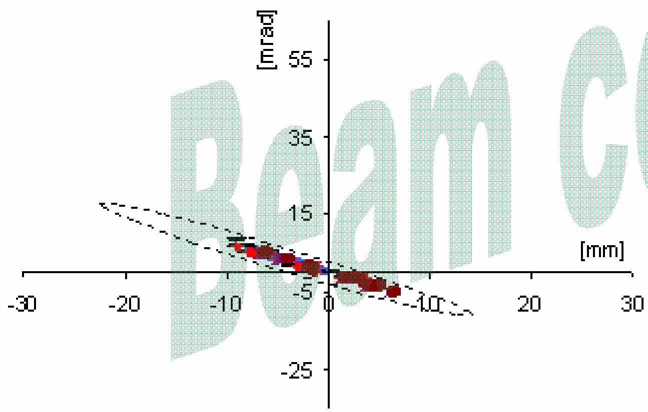
*The **quad in front of SRFQs** is moved vertically and horizontally around the SRFQs' axis*

Beam commissioning



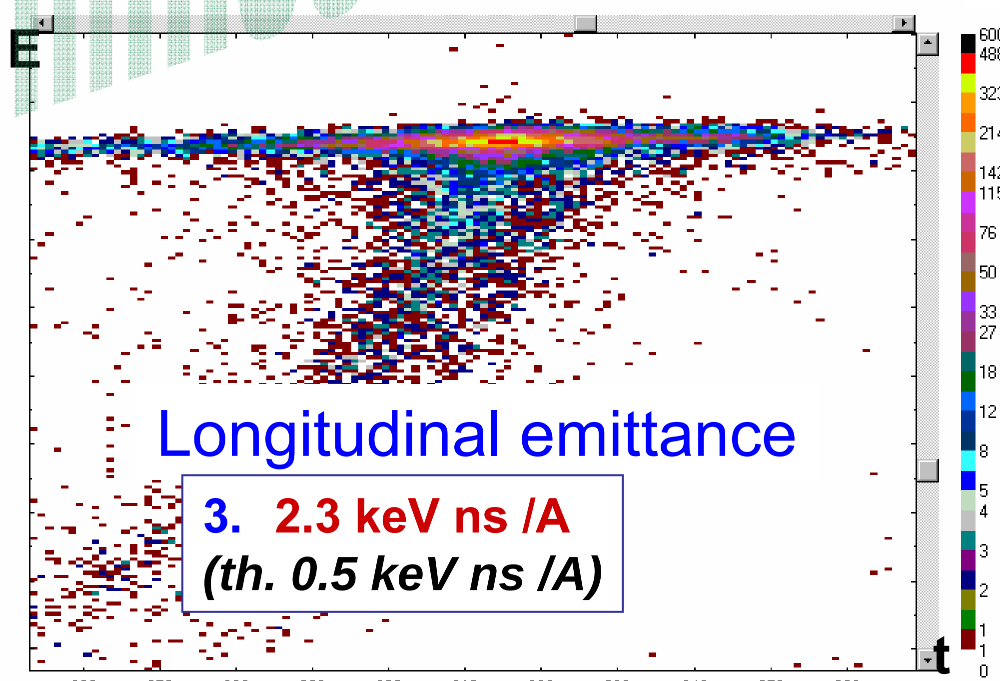
Transmission

1. ▶ 2. 90% **2. ▶ 3. 68%**
3. ▶ 4. 85%



Hor & Ver emittances

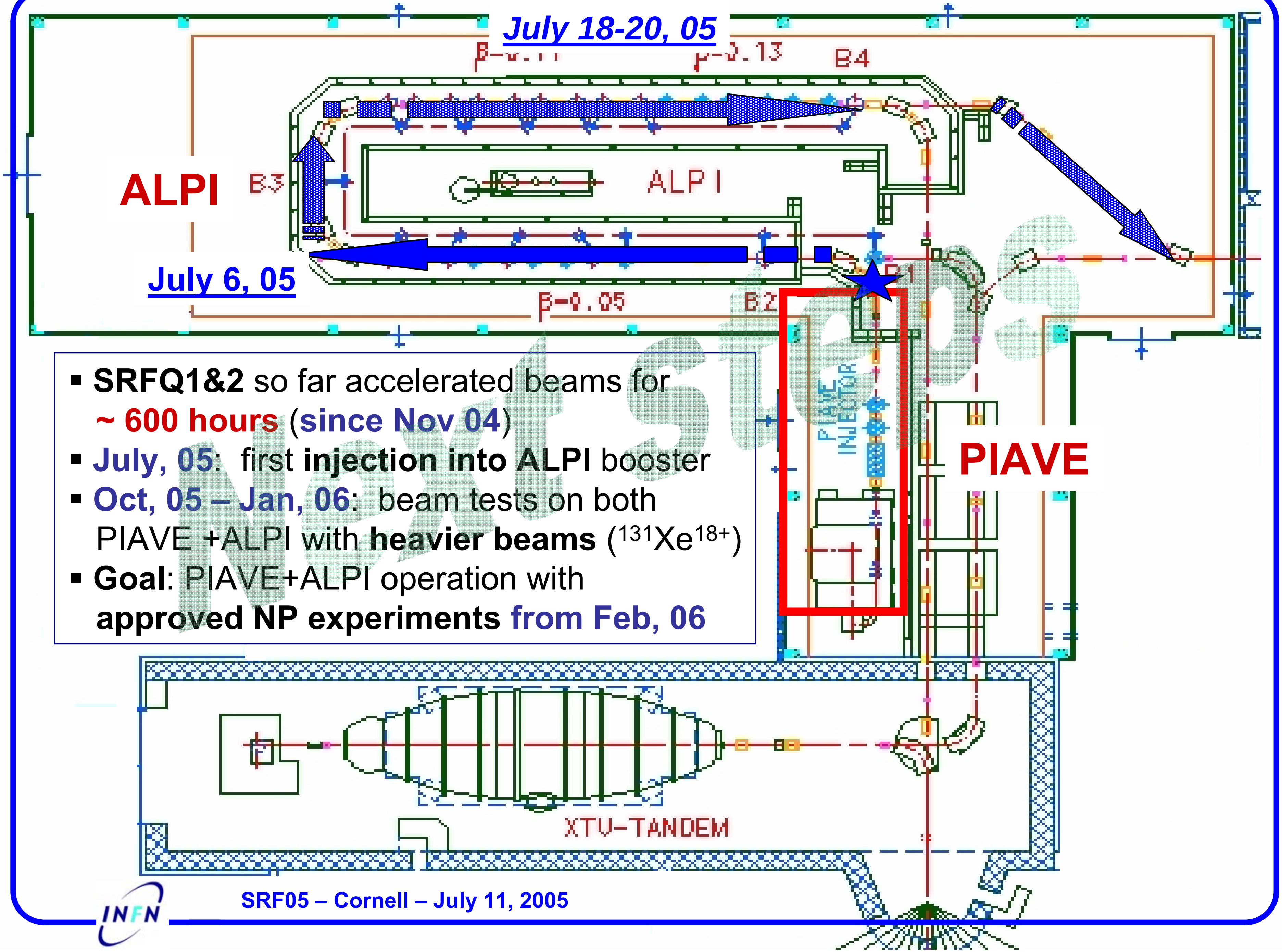
1. 2. 0.08÷0.1 mm mrad
3. 0.1÷0.2 mm mrad
th. 0.1 mm mrad



Longitudinal emittance

3. 2.3 keV ns /A
(th. 0.5 keV ns /A)

Next steps

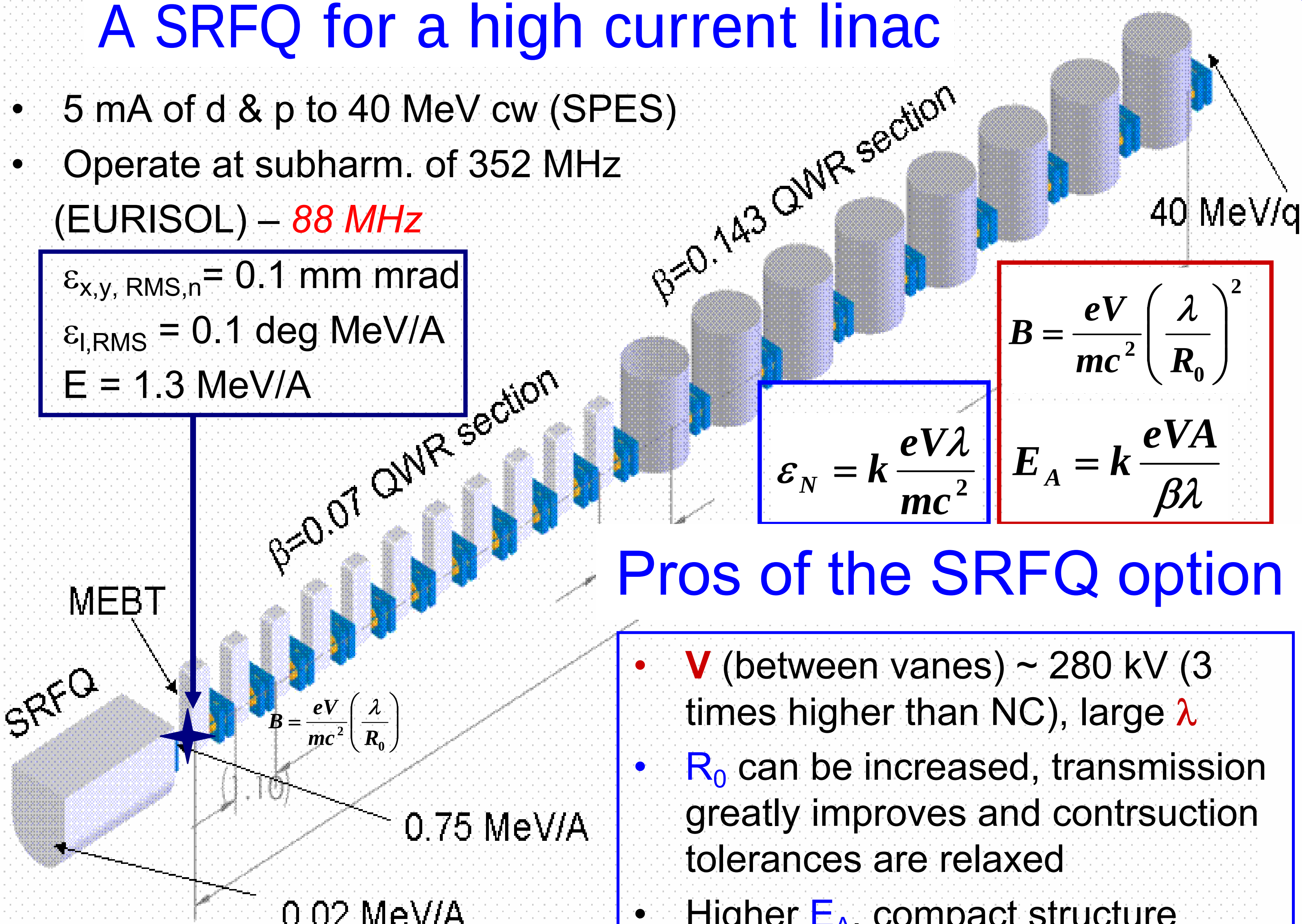


- **SRFQ1&2** so far accelerated beams for **~ 600 hours** (**since Nov 04**)
- **July, 05**: first **injection into ALPI** booster
- **Oct, 05 – Jan, 06**: beam tests on both PIAVE +ALPI with **heavier beams** ($^{131}Xe^{18+}$)
- **Goal**: PIAVE+ALPI operation with **approved NP experiments from Feb, 06**

A SRFQ for a high current linac

- 5 mA of d & p to 40 MeV cw (SPES)
- Operate at subharm. of 352 MHz (EURISOL) – *88 MHz*

$\varepsilon_{x,y,\ RMS,n}$ = 0.1 mm mrad
$\varepsilon_{l,RMS}$ = 0.1 deg MeV/A
E = 1.3 MeV/A



$$\varepsilon_N = k\frac{eV\lambda}{mc^2}$$

$$B = \frac{eV}{mc^2}\left(\frac{\lambda}{R_0}\right)^2$$

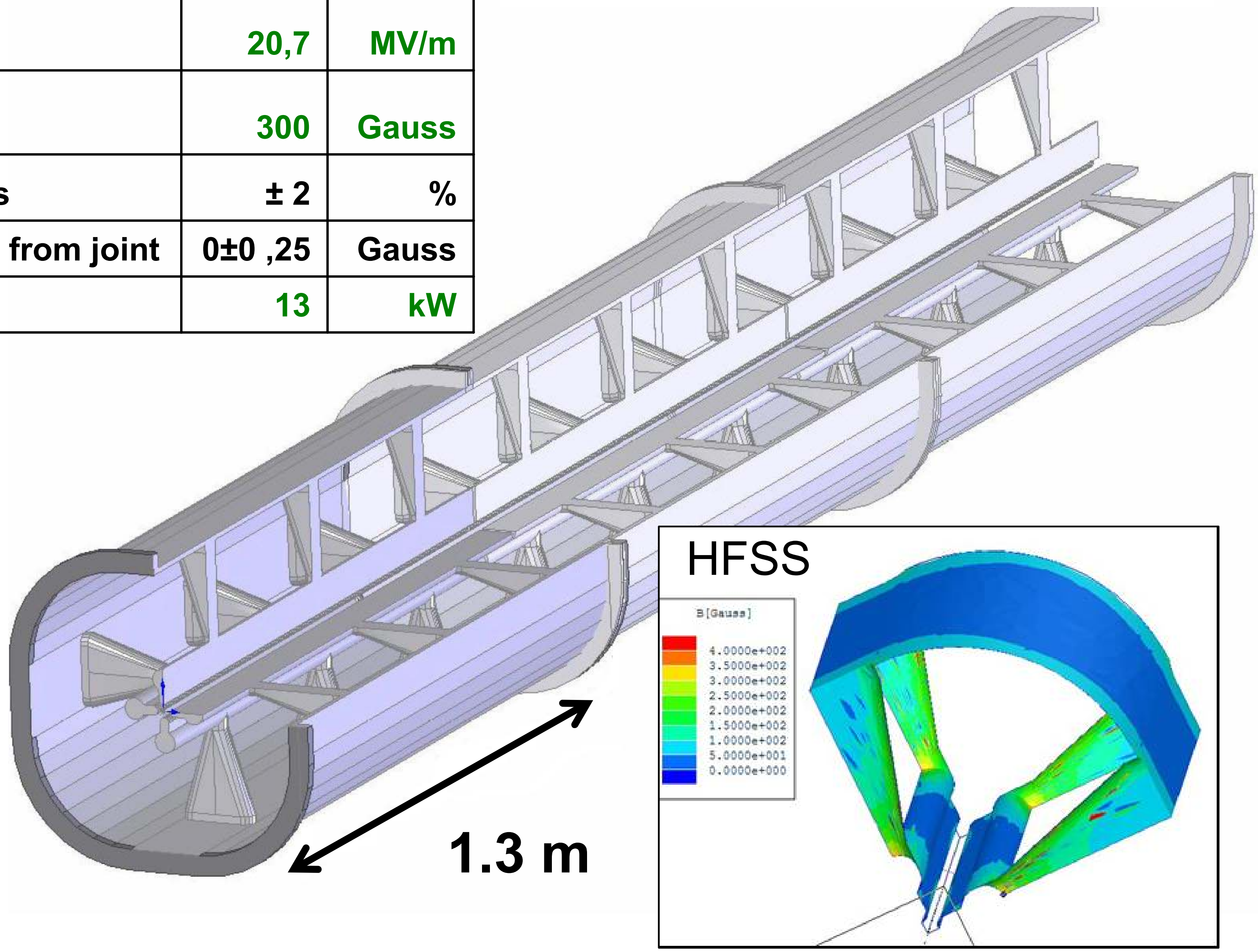
$$E_A = k\frac{eVA}{\beta\lambda}$$

Pros of the SRFQ option

- **V** (between vanes) ~ 280 kV (3 times higher than NC), large λ
- R_0 can be increased, transmission greatly improves and contrsuction tolerances are relaxed
- Higher E_A, compact structure

A 88 MHz PIAVE-like SRFQ

Frequency	88	MHz
Dipole mode	94,2	MHz
$E_{s,p}$	20,7	MV/m
$B_{s,p}$	300	Gauss
Voltage flatness	± 2	%
B within ±1 mm from joint	0±0 ,25	Gauss
Beam loading	13	kW




SRFQs work and accelerate beams!
Work in progress!
Sun
Timur
Enrico F.