The DAΦNE Strong RF Focusing Experiment

presented by ***A. GALLO***

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SUMMARY

- ✓ **Introduction;**
- ✓ **A SRFF experiment at DAΦNE: study of different short bunch regimes;**
- ✓ **Lattice design for the experiment and choice of the working points;**
- ✓ **Hardware upgrade required for the experiment;**
- ✓ **Cost estimate and schedule;**
- ✓ **Conclusions**

THE NEED FOR SHORT AND INTENSE BUNCHES IN STORAGE RINGS

- The interest for short and intense bunches is growing in the storage ring physics community;

- Super-factory projects ask for short bunches to avoid the hourglass effect while reducing the vertical beta-function at the Interaction Point (IP) to increase the luminosity;

- Synchrotron light users are interested in stable production of Coherent Synchrotron Radiation (CSR) that also requires short bunches, which have been so far obtained only at very low current with quasi-isochronous lattices .

The bunch shortening puzzle

In standard storage rings (regular lattice, low synchrotron tune) the natural rms length σ_z of the equilibrium charge distribution in the bunch is given by:

$$\sigma_z = c\,\sigma_\tau = c\frac{\sigma_E}{E}\frac{\alpha_c}{\omega_s} = L_{ring}\frac{\sigma_E}{E}\sqrt{\frac{\alpha_c(E/e)}{2\pi h\,V_{RF}}}$$

with

$$\alpha_c = \left.\frac{\Delta L/L}{\Delta E/E}\right|_{one\ turn}$$

Because of the short-range wakefields the bunch starts lengthening with current above a certain threshold. The Boussard criterion can be used to estimate the μ-wave current threshold:

$$I_{th} = \alpha_c(2\pi)^{3/2}\left(\frac{\sigma_E}{E}\right)^2\frac{E/e}{(Z/n)_{eff}}\frac{\sigma_z}{L_{ring}}$$

The synchrotron tune is given by:

$$Q_s = \sqrt{\frac{h\,\alpha_c\,V_{RF}\cos\phi_s}{2\pi\,E/e}}$$

The need for short and intense bunches asks for **large α_c value** and **very high RF gradients**, ending up with **large Q_s**. But if Q_s exceeds ≈ **0.1** the longitudinal dynamics of the storage ring enters in a **new regime** (much more similar to the transverse one) and the previous relations **do not hold any more**.

The Strong RF Focusing Concept

- **Large** momentum compaction factors α_c and **very high RF gradients** across the bunch together establish a strong correlation of the two coordinates (position and energy deviation) of the particle longitudinal motion;

- The correlation ends up in a **modulation** of the bunch length along the ring, which can be **minimized** at the **Interaction Point** (IP). No storage ring has been so far operated in such a peculiar regime.

- The bunch length modulation can be also obtained with "standard" α_c values, provided that the $\mathbf{R_{56}}$ element of the linear transport matrix (which represent the path elongation normalized to the relative energy error of a particle) executes a **large oscillation** along the ring.

- Large α_c values are helpful to increase the microwave threshold limiting the bunch lengthening with current. On the other hand lower α_c values are preferable for dynamic aperture and beam-beam performances since a reduced synchrotron tune weakens the synchro-betatron coupling resonances.
  Both bunch length modulation options need to be explored.

Strong RF Focusing –monotonic R_1

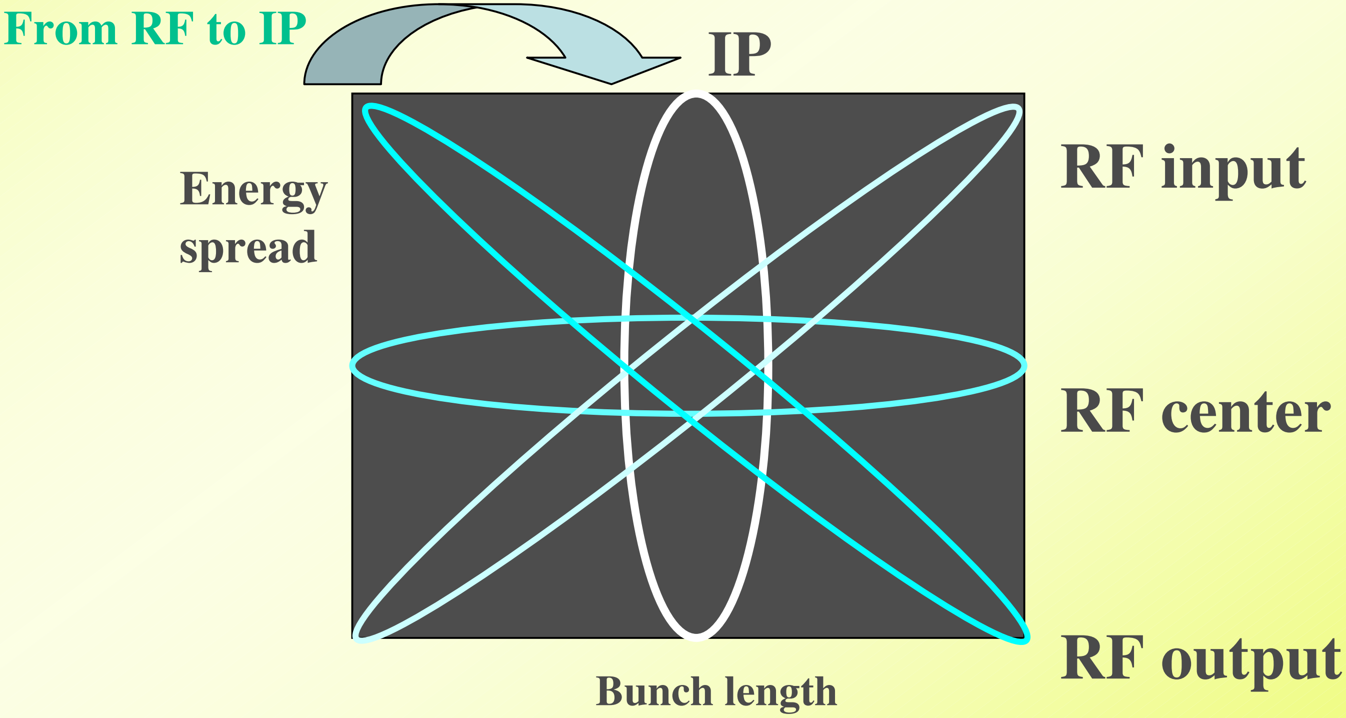
$$R_1(s) = \int_s^{s_{rf}} \frac{D(s')}{\rho(s')} ds'$$

High rf voltage + high momentum compaction:

High synchrotron tune

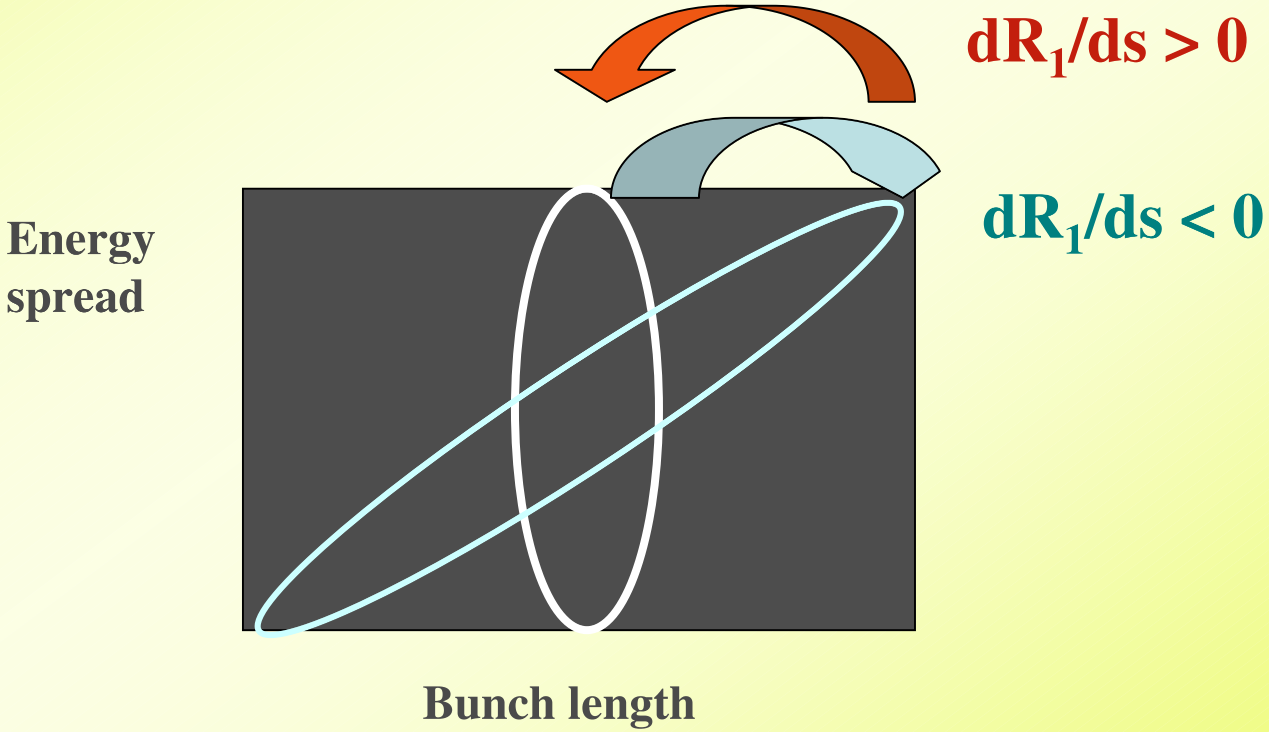
Ellipse rotates always in the same direction

Longitudinal phase space



Evolution of Strong RF Focusing – non monotonic R_1

High rf voltage + high derivative of R_1 (s):
Low synchrotron tune
Ellipse rotates on both directions



The DAΦNE Strong RF Focusing Experiment

Motivation for a Short Bunch Experimental Activity at DAΦNE

With the existing hardware, short bunches can be obtained at DAΦNE only by implementing quasi-isochronous lattices. Although useful information can be obtained, this configurations is definitely unsuitable for a collider requiring high single-bunch current.

With the proposed hardware upgrade, mainly consisting in the SC multicell RF cavity installation, the machine is capable to operate in any short bunch regime. The measurement of the SRFF bunch length modulation, both with high and low α_c, would be the first experimental validation of this approach ever.

Nevertheless, the possibility of keeping the bunch length in the 5-10 mm range up to currents of 10-15 mA with no modulation as required by any DAΦNE upgrade under study in this moment can be also fruitfully investigated.

Experimental Measurements (listed by increasing challange)

Short Bunch (5-10 mm) with no modulation:

- ✓ Bunch lengthening measurements

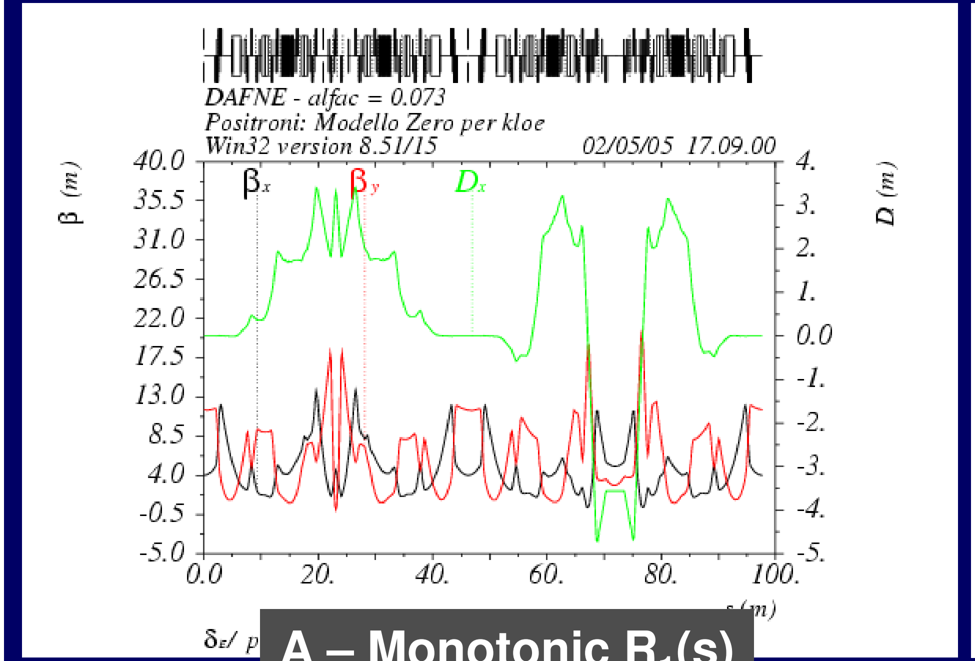
Ultra-Short Bunch (1-3 mm) with modulation (SRFF) obtained with large or small α_c options:

- ✓ Demonstration of the bunch length variation along the ring;
- ✓ Study the single bunch dynamics (effects of the distributed wake on the bunch length) and measurements of the bunch lengthening;
- ✓ Study of the 6D coupled dynamics and Touschek lifetime;
- ✓ Production of CSR;
- ✓ Study the multibunch dynamics and LFB behaviour at very large synchrotron tunes;
- ✓ Storing high multibunch current (> 500 mA)
- ✓ Collisions of short bunches (with β_y < 1 cm)

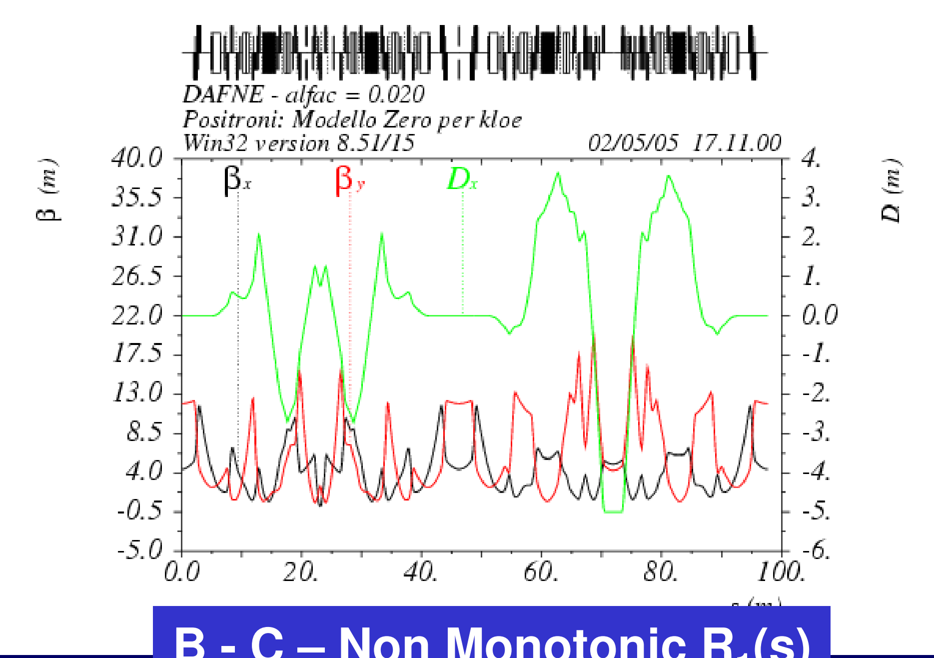
Lattice Design and Working Point Choice

DAΦNE LATTICE

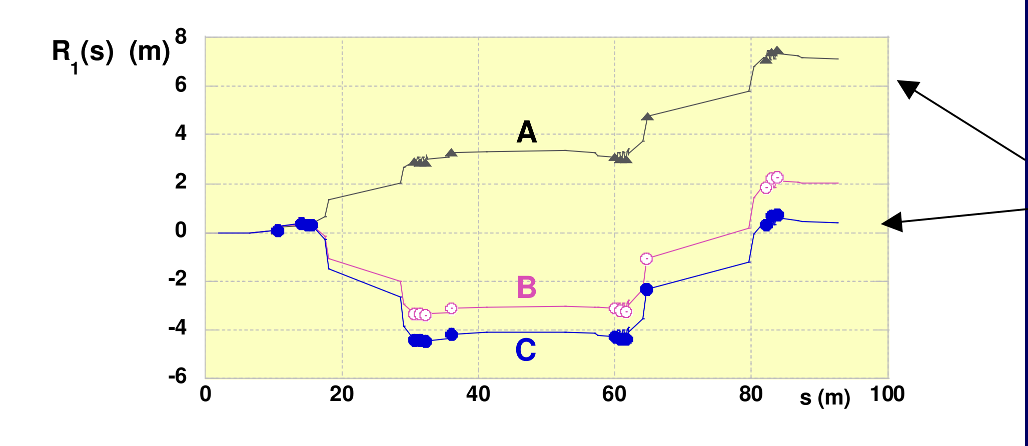
$\alpha_c = 0.073$ $\alpha_c = 0.020, 0.004$



A – Monotonic $R_1(s)$

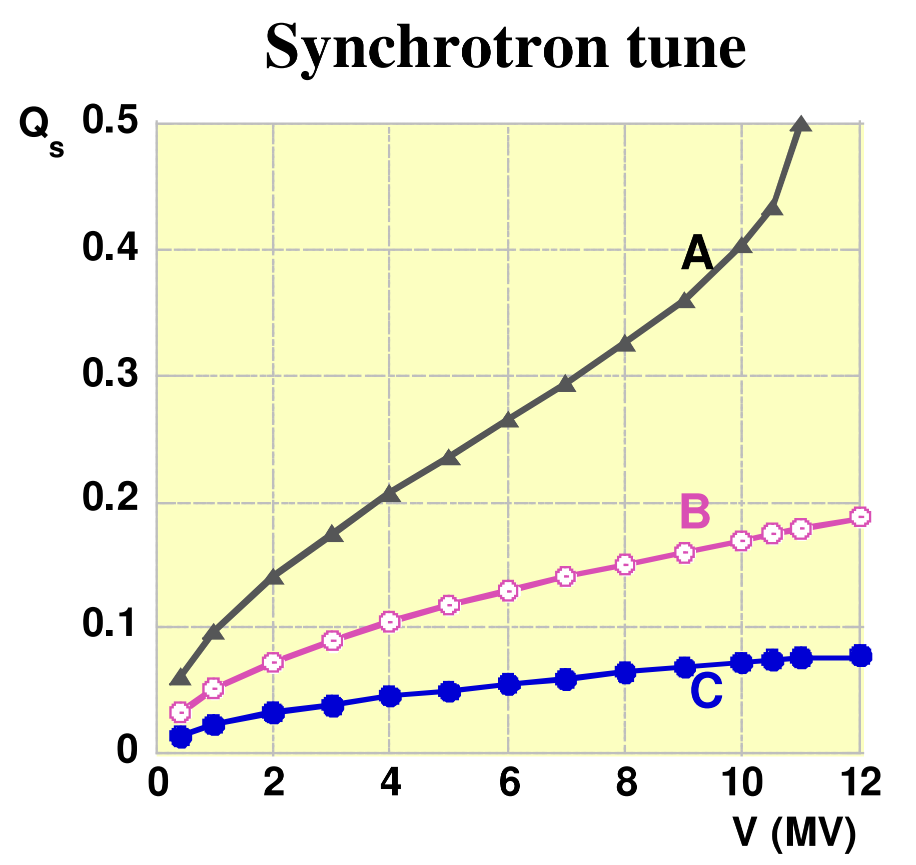


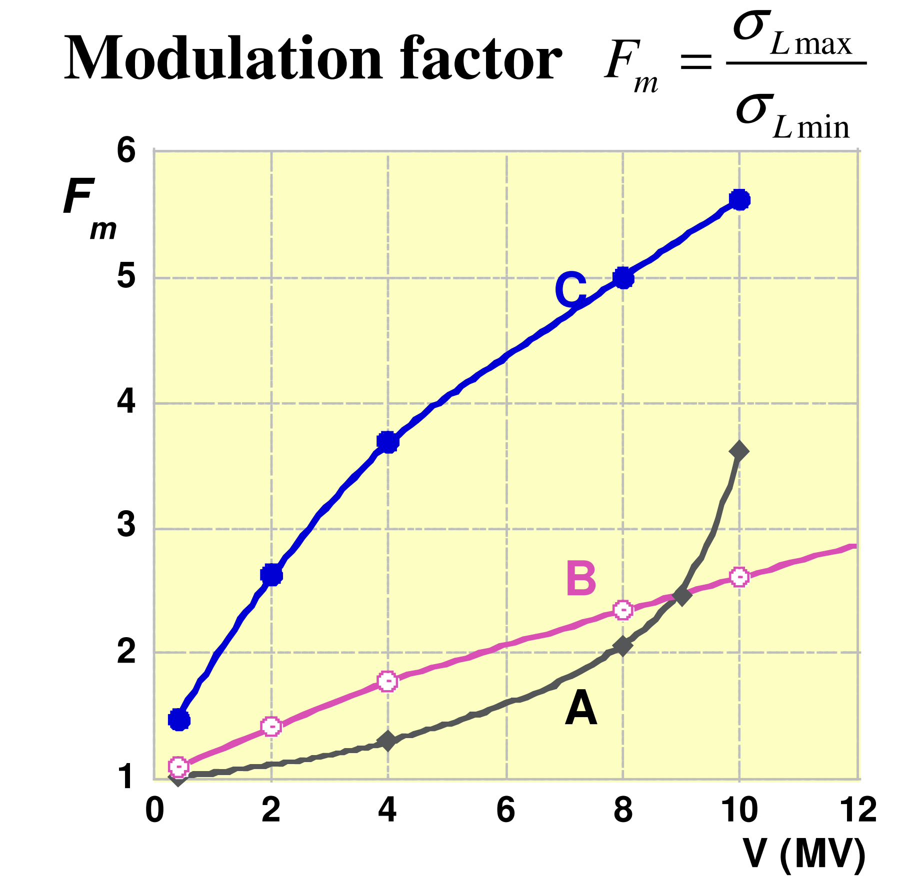
B - C – Non Monotonic $R_1(s)$



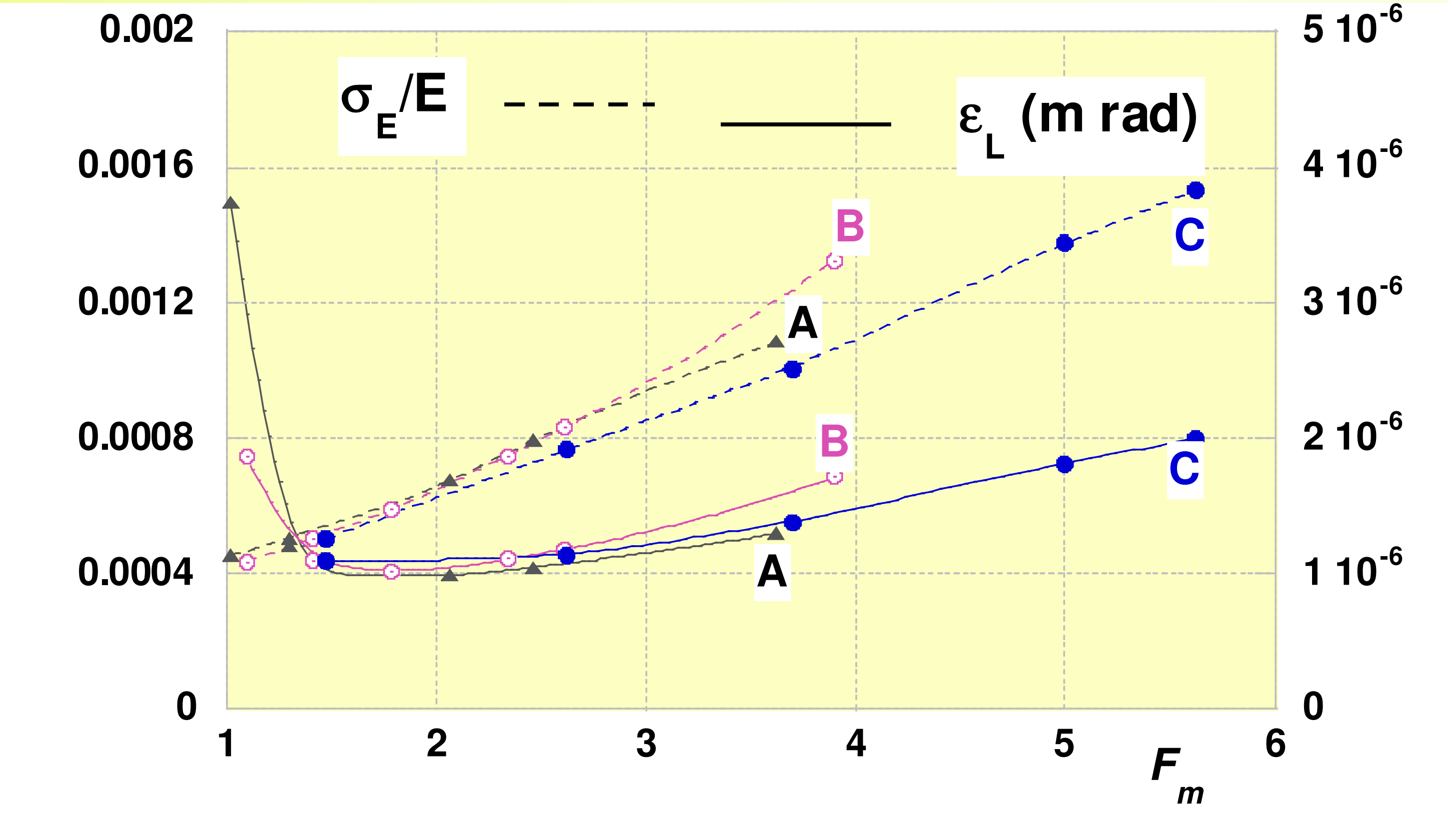
$$R_1(L) = \alpha_c L$$

SBSR05, A. Gallo: "The DAFNE SRFF Experiment"

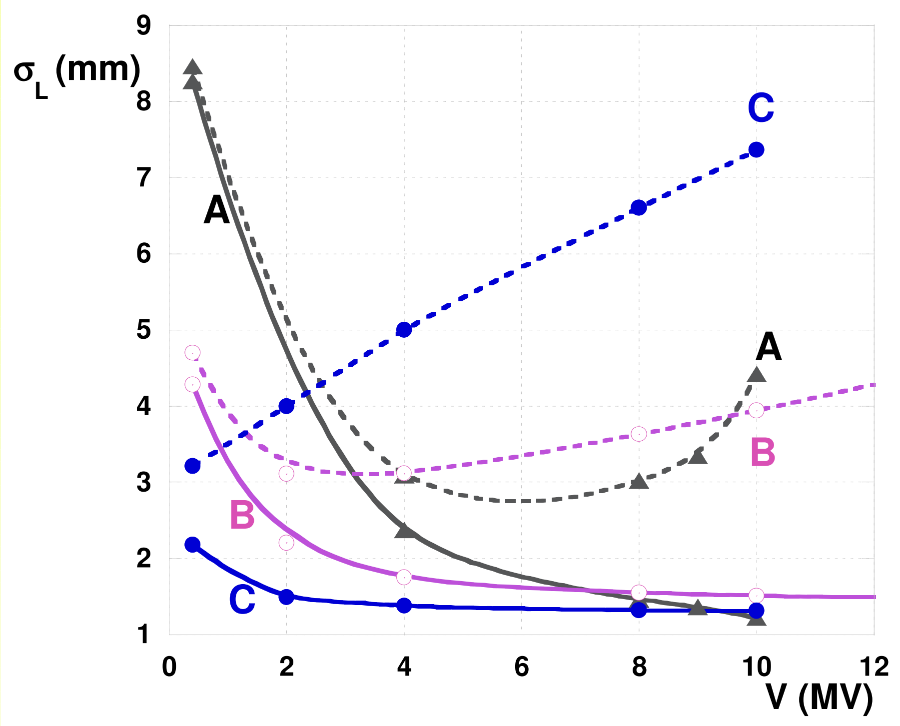

Synchrotron tune
Q_s
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
V (MV)
A
B
C

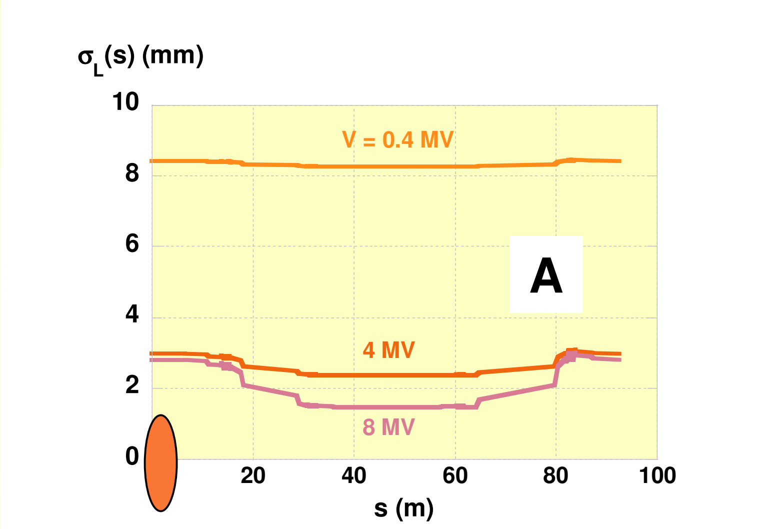

Modulation factor $F_m = \frac{\sigma_{L\max}}{\sigma_{L\min}}$
F_m
6
5
4
3
2
1
0
2
4
6
8
10
12
V (MV)
C
B
A

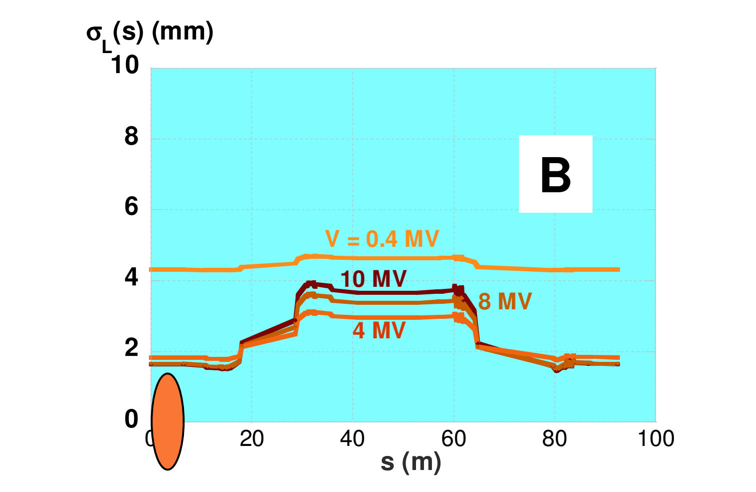
Energy spread and emittance

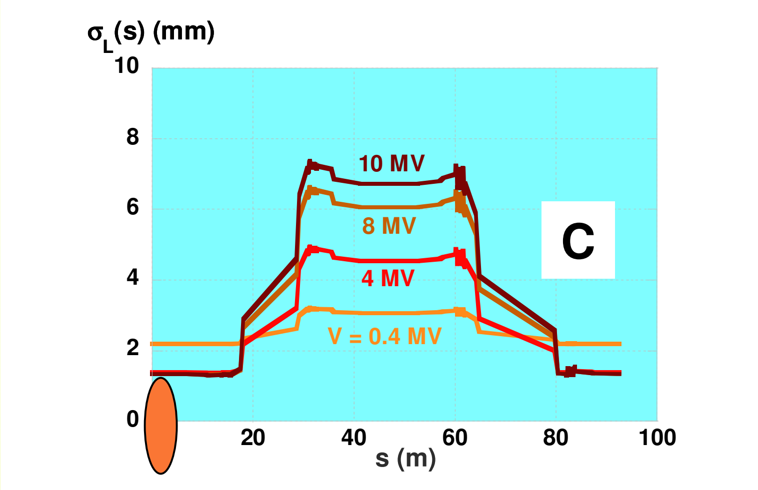


Bunch length along the ring



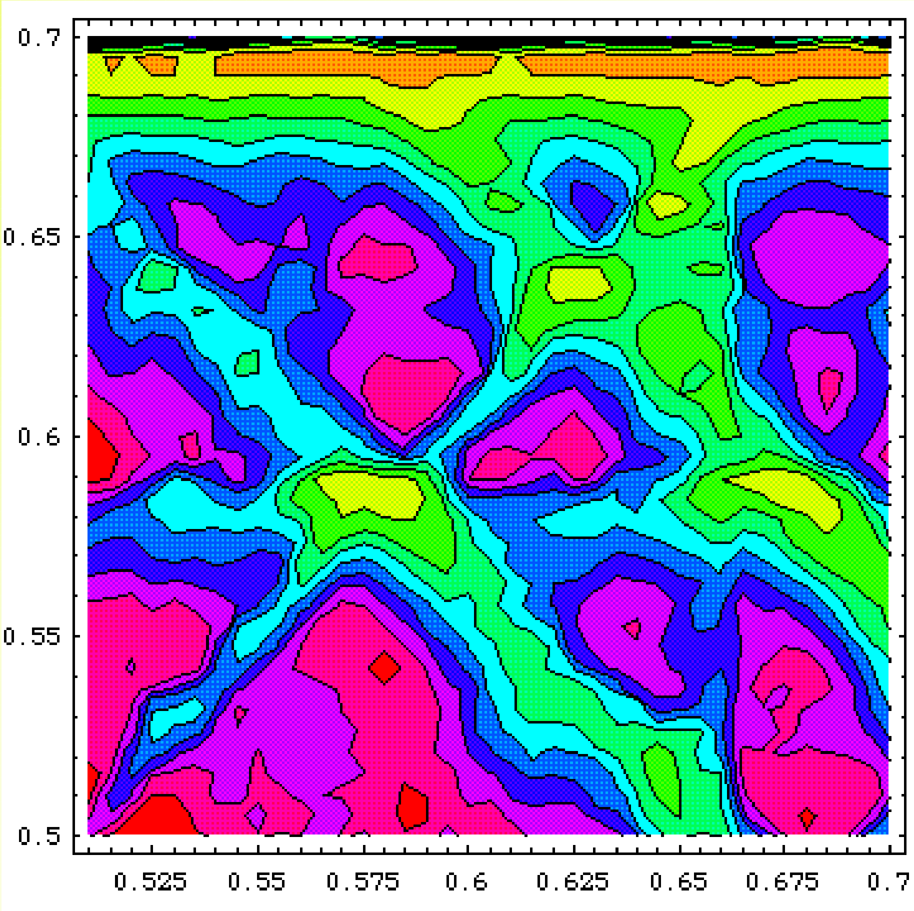


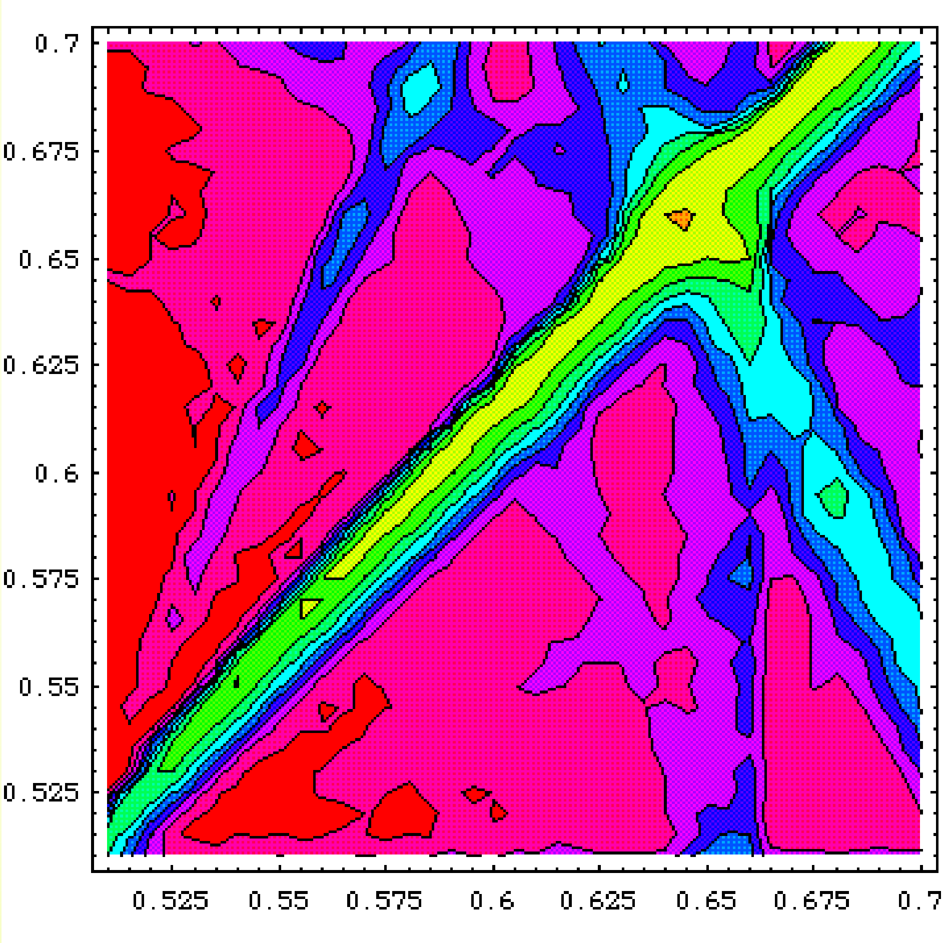




Luminosity Tune Scans with Different Synchrotron Tunes

$Q_s = 0.40$ **$Q_s = 0.01$**



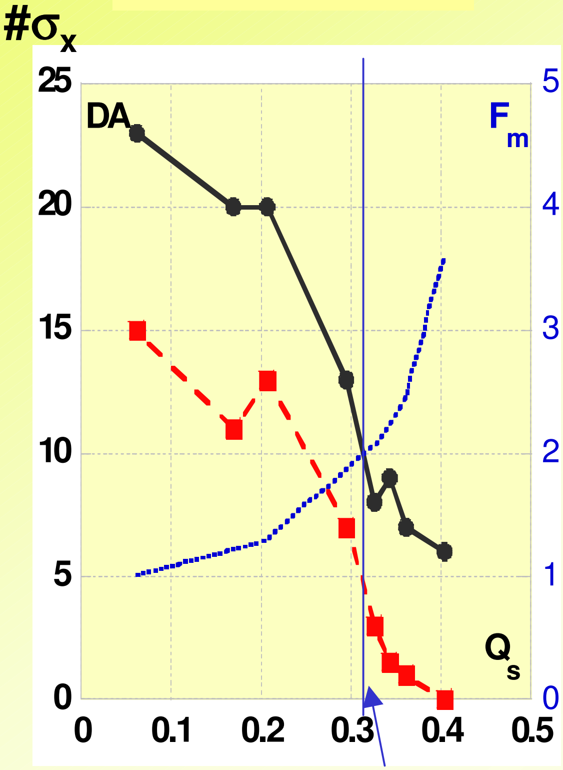


DYNAMIC APERTURE —— On energy

—— @ 6 σ_p

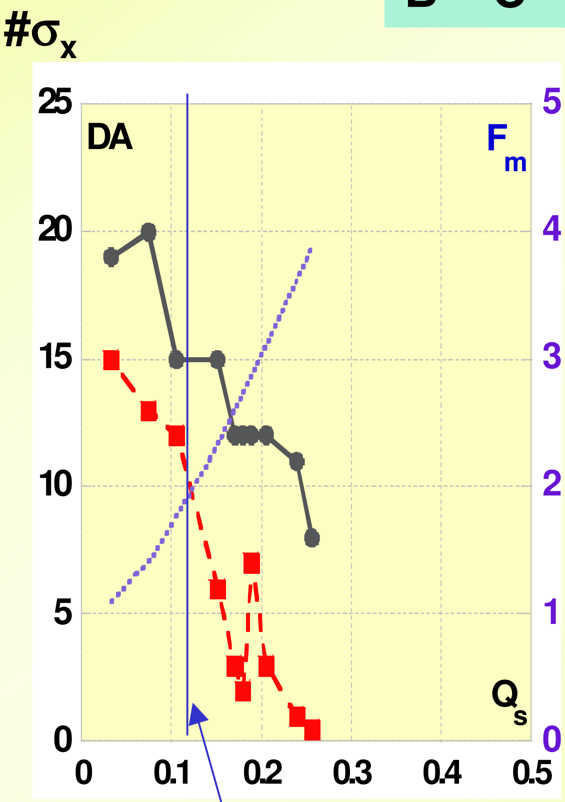
A - monotonic

B – C - non monotonic



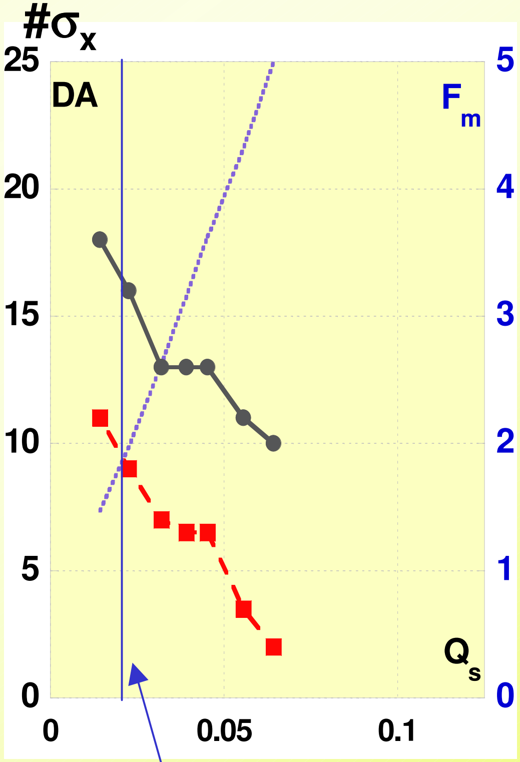
V = 8 MV

ε_x = 0.54 mm mrad
Q_x = 4.81; Q_y = 5.21
α_c = 0.073



V = 5.6 MV

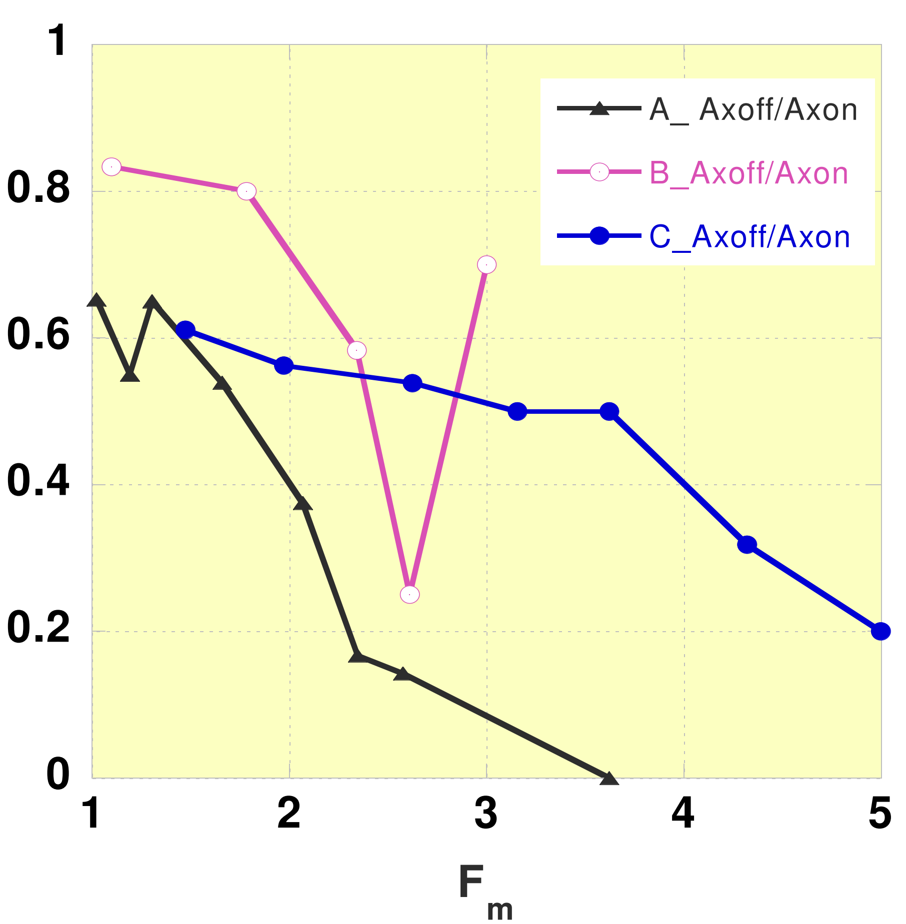
ε_x = 0.60 mm mrad
Q_x = 5.81; Q_y = 5.15
α_c = 0.020

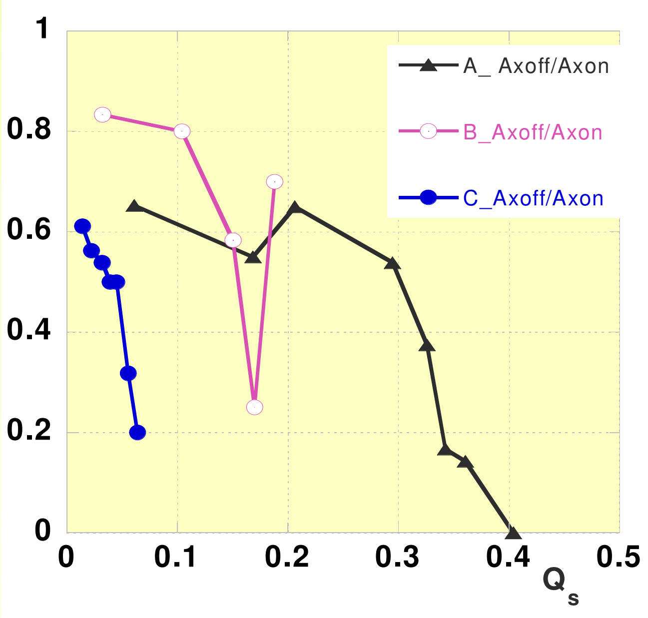


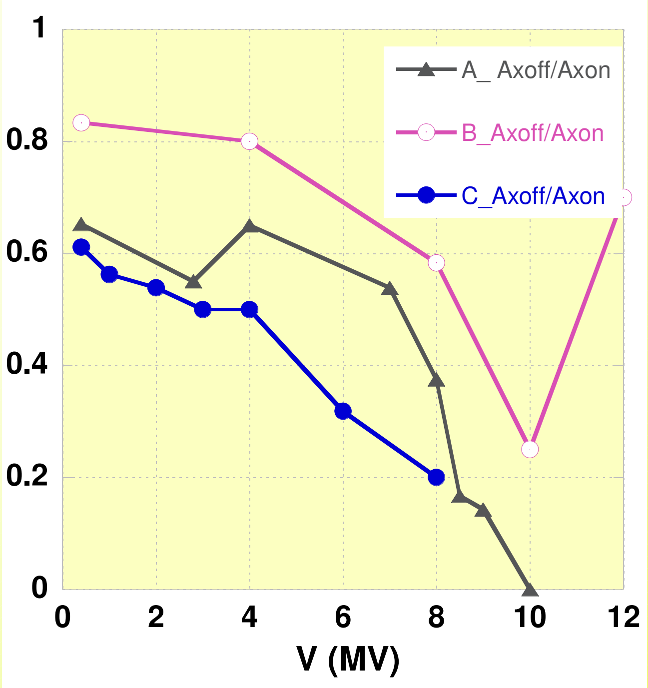
V = 1 MV

ε_x = 0.50 mm mrad
Q_x = 5.76; Q_y = 5.21
α_c = 0.004

Off energy vs. on energy as a function of Q_s, F_m, V

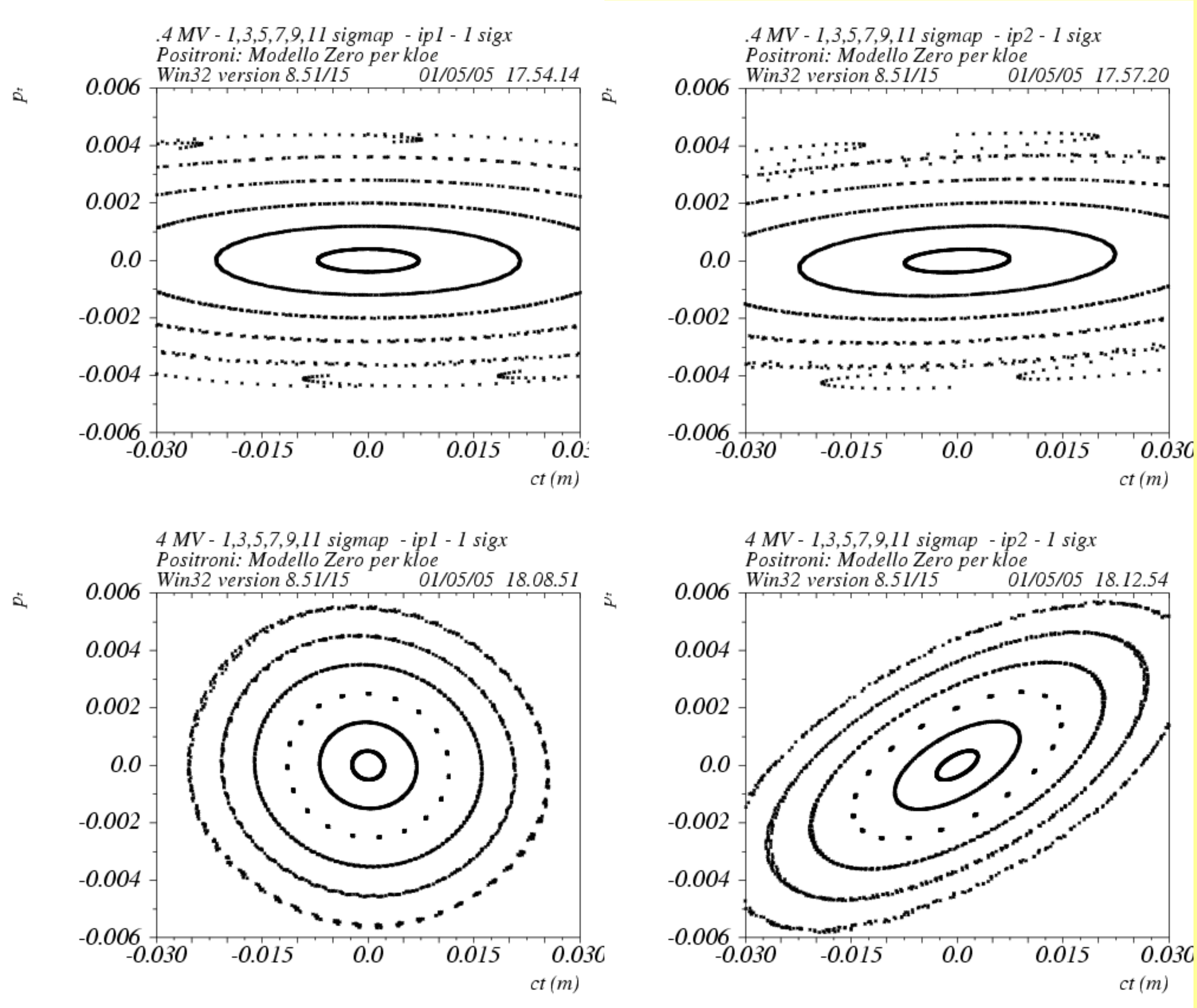






A - monotonic

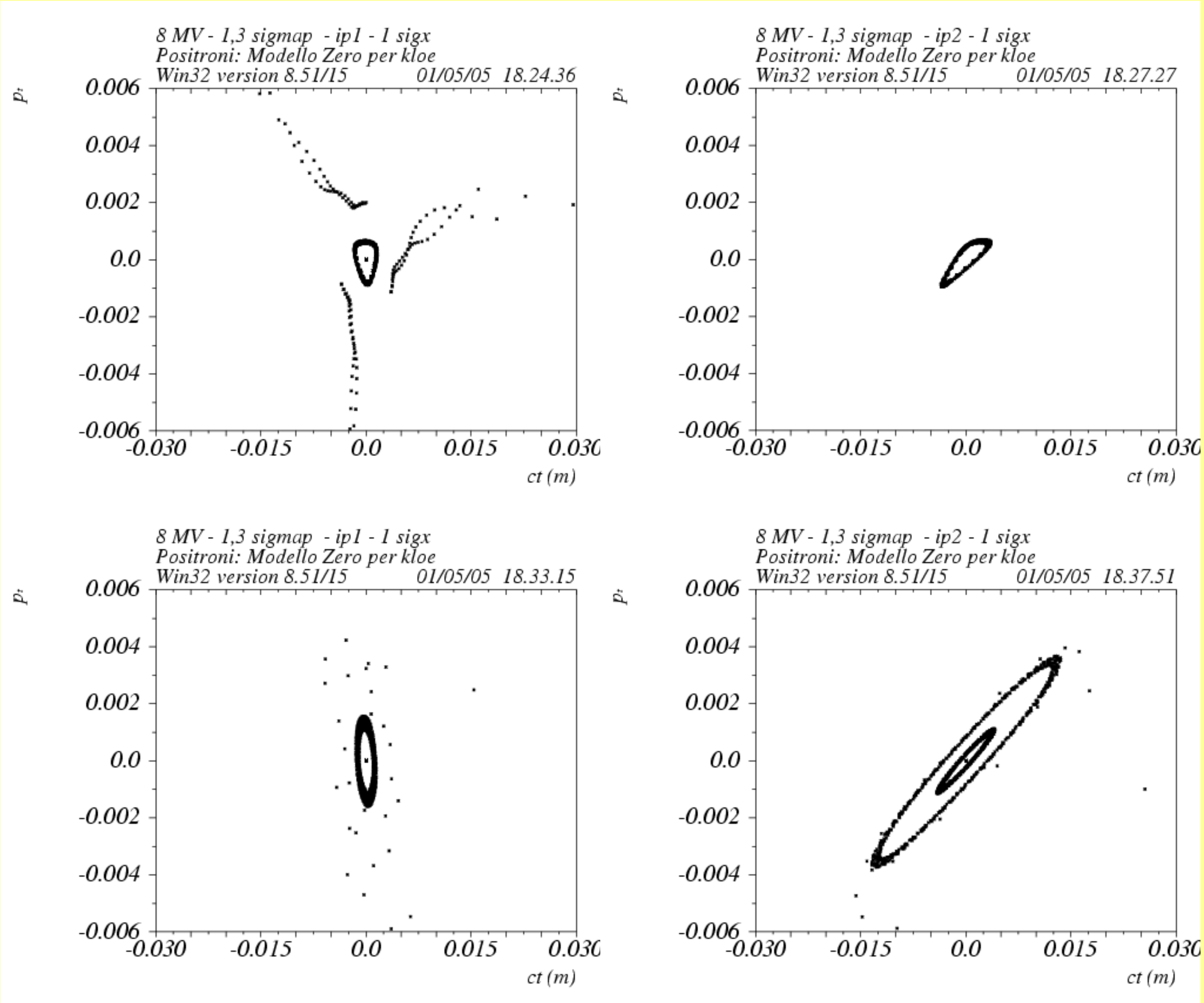
IP1 **IP2**



$V = 0.4$ MV
$Q_s = 0.061$
$\sigma_p = 4.5\ 10^{-4}$
$A_x = 22\ \sigma_x$

$V = 4$ MV
$Q_s = 0.206$
$\sigma_p = 5.1\ 10^{-4}$
$A_x = 18\ \sigma_x$

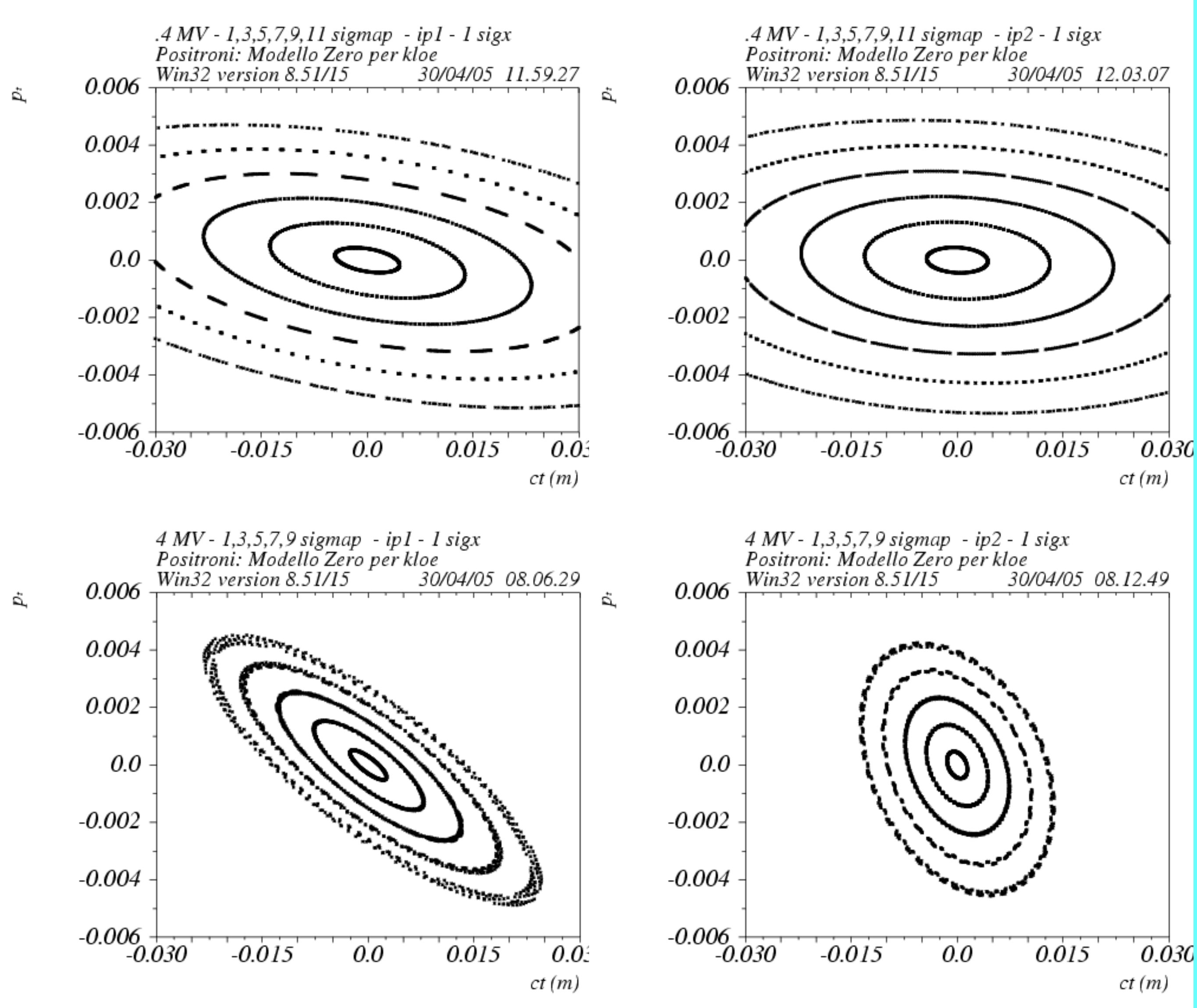
IP1 **IP2**



V = 8 MV
Q_s = 0.325
σ_p = 6.7 10^{-4}
A_x = 10 σ_x

V = 10 MV
Q_s = 0.404
σ_p = 10.1 10^{-4}
A_x = 6 σ_x

IP1 IP2 B – Non monotonic



$V = 0.4$ MV

$Q_s = 0.032$

$\sigma_p = 4.3\ 10^{-4}$

$A_x = 18\ \sigma_x$

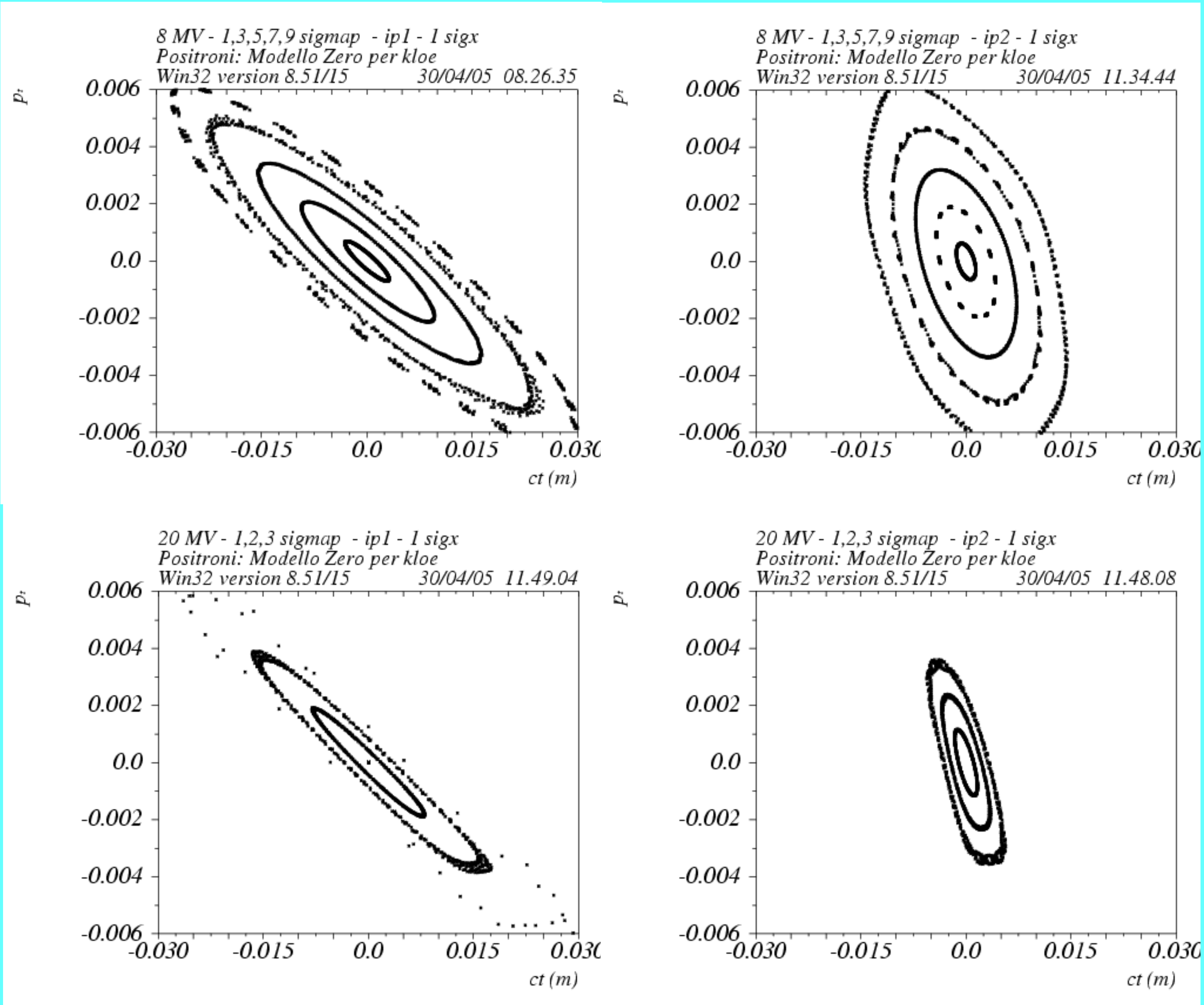
$V = 4$ MV

$Q_s = 0.104$

$\sigma_p = 5.8\ 10^{-4}$

$A_x = 16\ \sigma_x$

IP1 **IP2**

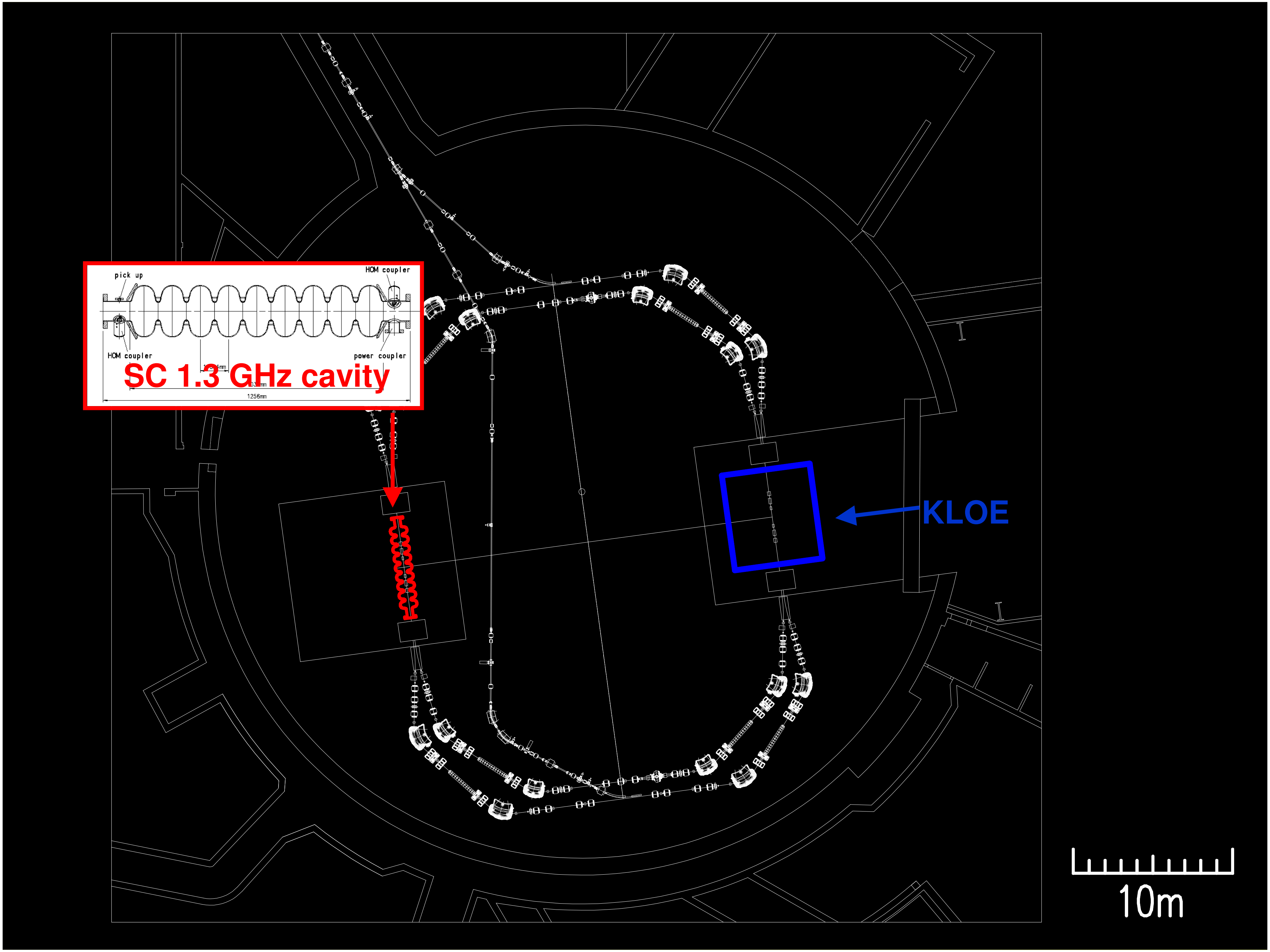


V = 8 MV
Q_s = 0.150
σ_p = 7.4 10^{-4}
A_x = 12 σ_x

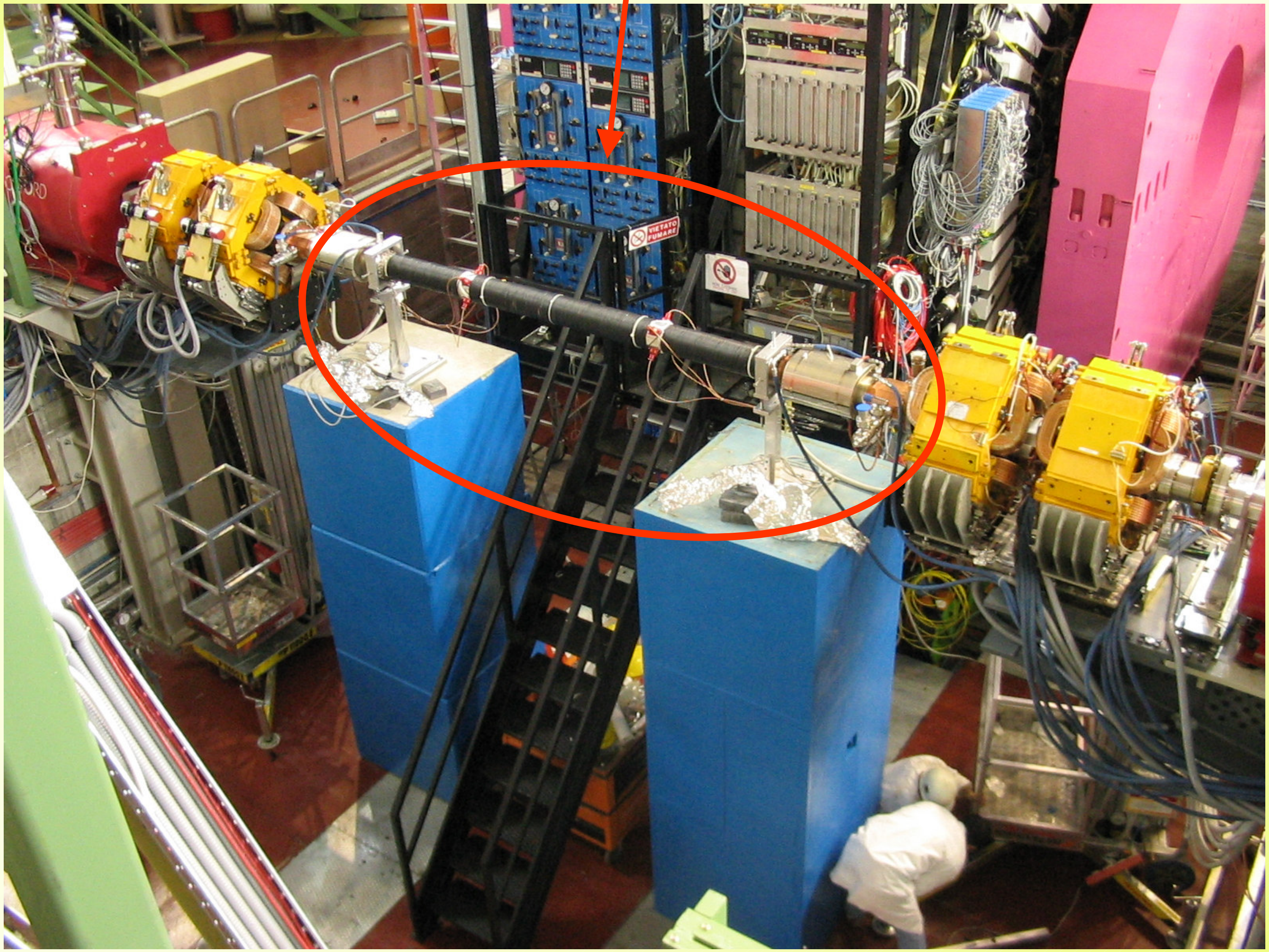
V = 20 MV
Q_s = 0.250
σ_p = 13.2 10^{-4}
A_x = 8 σ_x

Hardware Required for the Experiment

- RF Cavity @ 1.3 GHz up to 10 MV
- Cryostat
- Cryogenic system upgrade (4.5 K $\Rightarrow$ 1.8 K)
- Diagnostics for short bunch measurements


pick up
HOM coupler
HOM coupler
power coupler
SC 1.3 GHz cavity
1256mm
KLOE
10m

Cavity on IR2

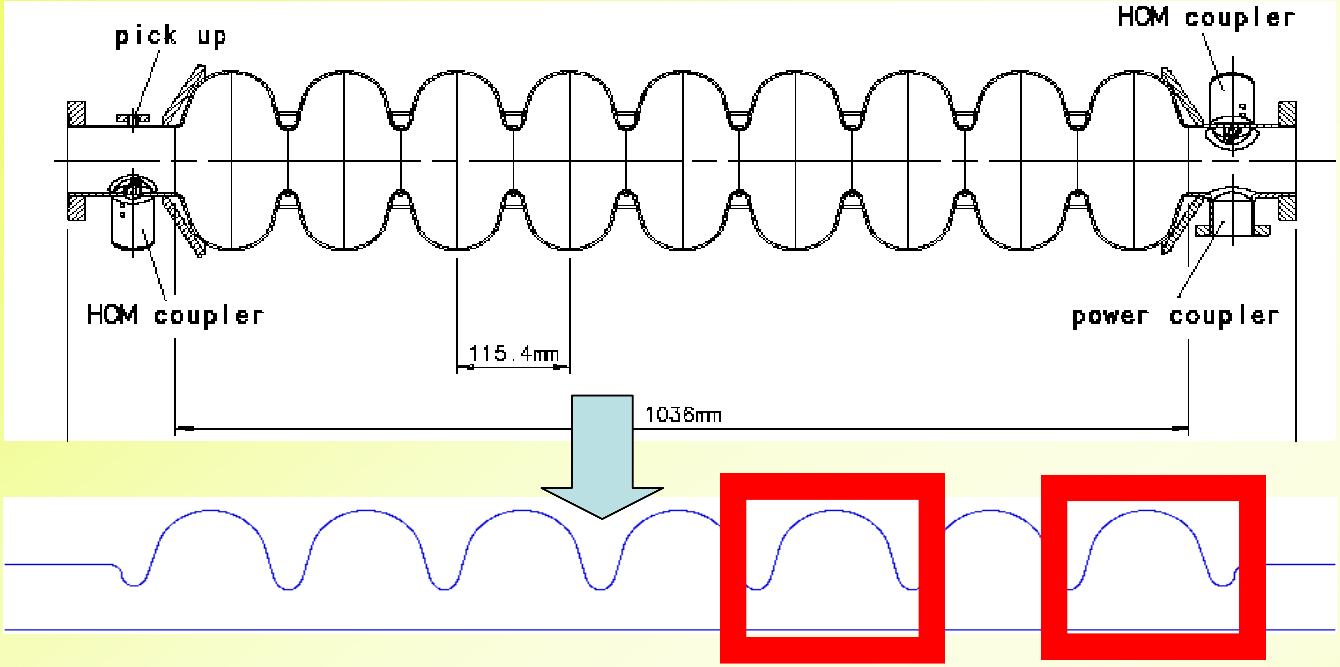


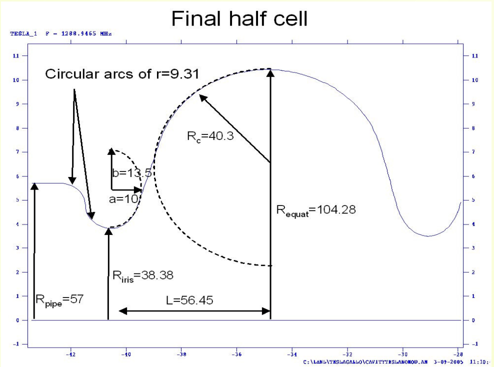
DESIGN OF A MULTI-CELL, HOM DAMPED SUPERCONDUCTING CAVITY FOR THE STRONG RF FOCUSING EXPERIMENT AT DAΦNE

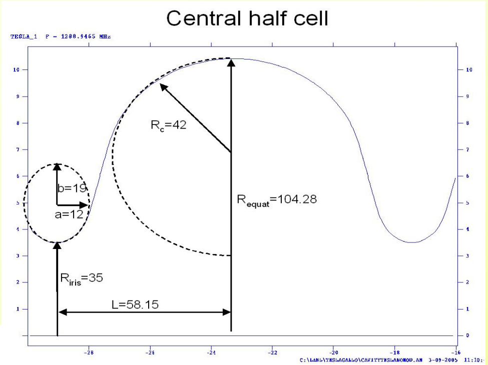
David Alesini, Caterina Biscari, Roberto Boni, Alessandro Gallo, Fabio Marcellini, Mikhail Zobov,
INFN/LNF, Frascati, Italy
Carlo Pagani, INFN/LASA, Segrate (MI) and DESY, Hamburg

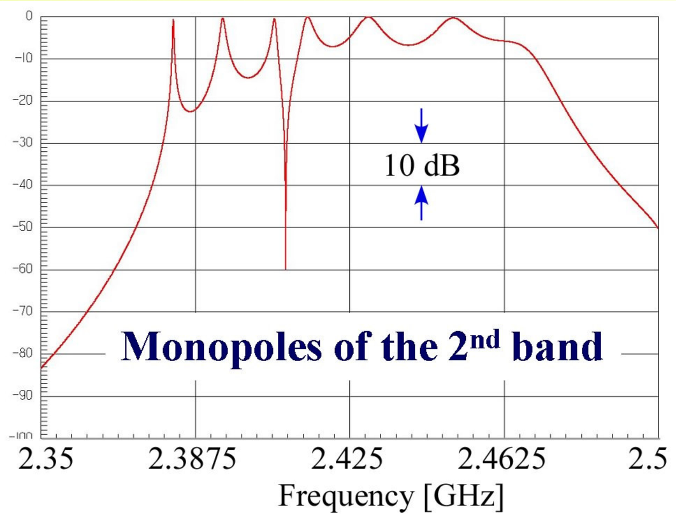
PARAMETR LIST	
Cavity Type: 1.8 K SC, 7-cells, Tesla-like	
RF frequency [MHz]	1288.9
Max RF voltage [MV]	8
R/Q geometric factor [Ω]	390
Quality factor (@ 1.8 K)	$1 \cdot 10^{10}$
Cavity wall power [W @ 1.8 K]	8
Loaded quality factor	$(2 \div 4) \cdot 10^{7}$
Cavity detuning for Beam Loading [kHz] (@ 8MV, Ib=1A)	- 60
RF generator power [kW]	1
Cavity length [m]	0.8

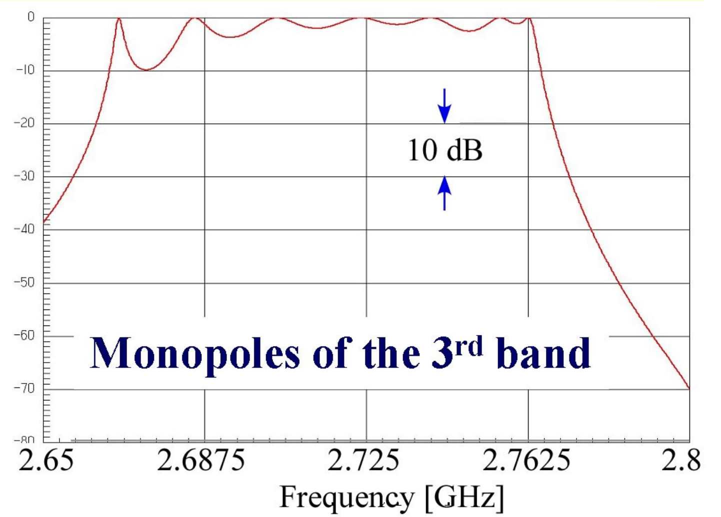
Particle Accelerator Conference PAC 05
Knoxville – USA
May 16-20, 2005
TPPT_060 paper





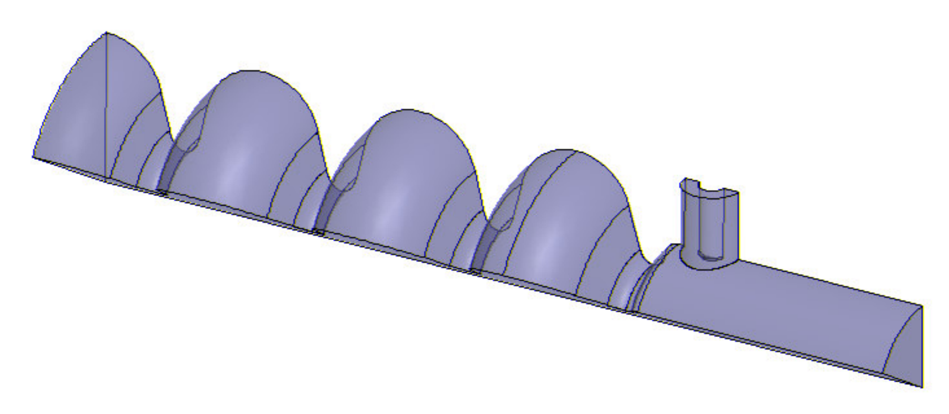






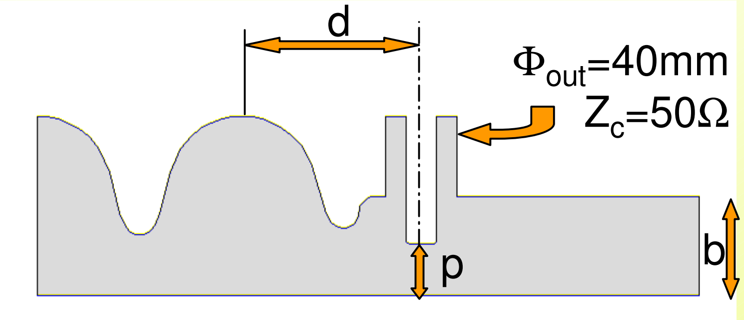
HFSS Simulations of damped HOMs through the large beam tubes

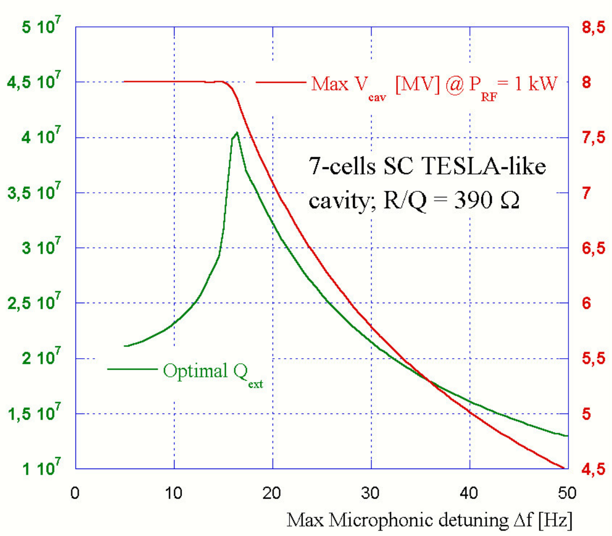
COUPLER DESIGN

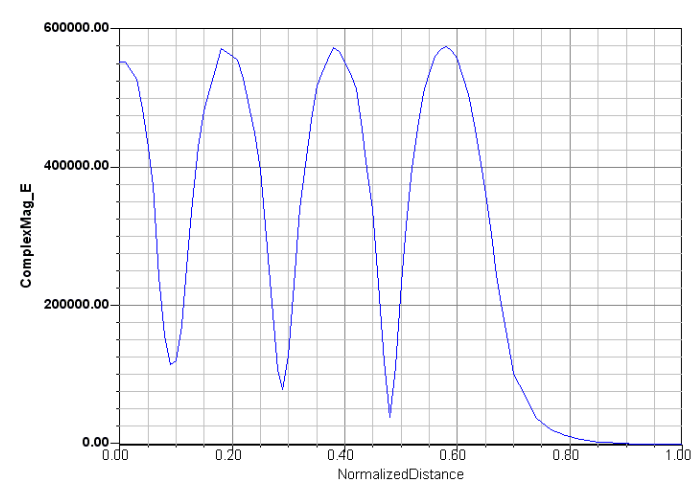


The Coupler is the standard TESLA one and has been re-positioned with HFSS to account for the modifications in our design.

With the dimensions shown we have obtained $Q_{EXT} = 1 \cdot 10^7$ with a good field flatness. As in the TESLA case different external Q factors can be obtained with different penetration of the inner in the tube.



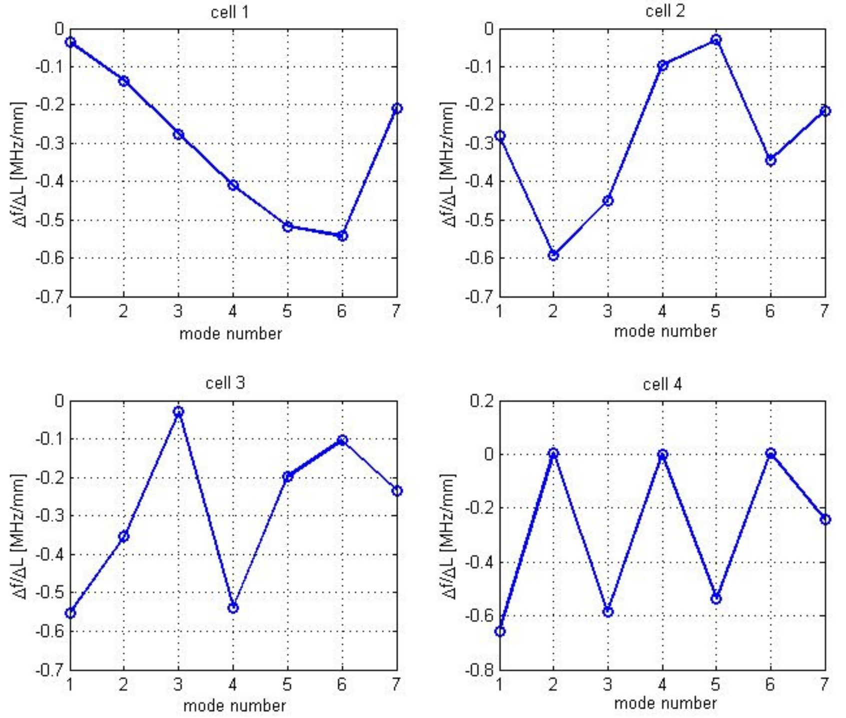




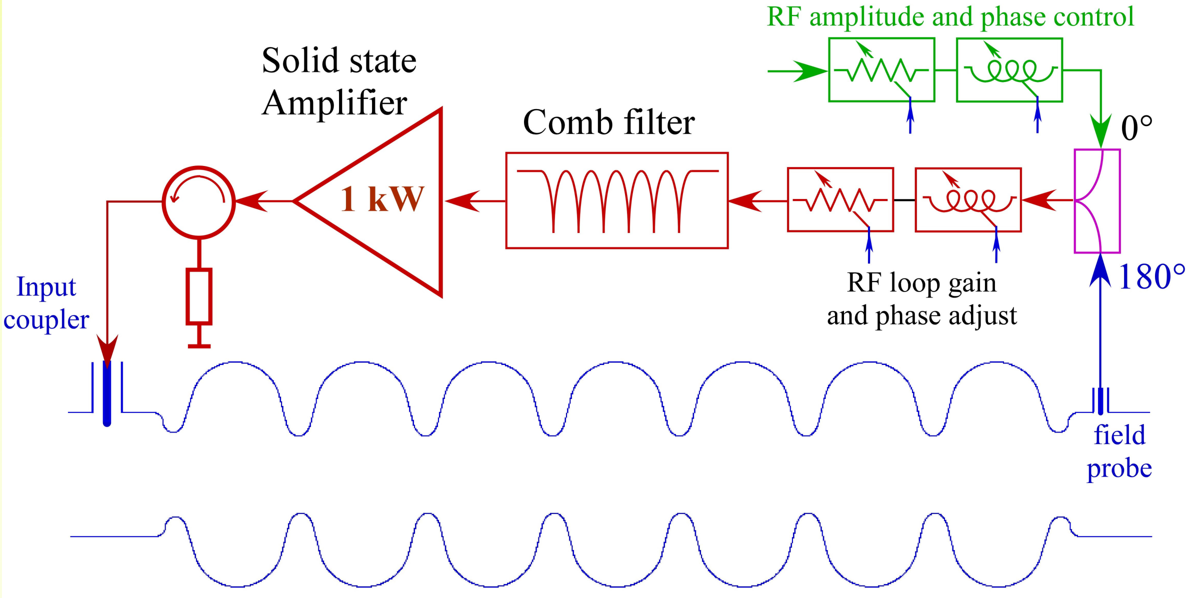
The optimum Q_{EXT} value depends on the maximum tolerable frequency deviation of the accelerating mode.

CONTROL OF THE MODES OF THE 1ST BAND

Mode	*f [GHz]*	*R/Q[Ω]*
π/7	1266.73	$1 \cdot 10^{-2}$
2π/7	1269.90	$1.4 \cdot 10^{-5}$
3π/7	1274.53	$1 \cdot 10^{-1}$
4π/7	1279.72	$4 \cdot 10^{-4}$
5π/7	1284.45	1.4
6π/7	1287.75	$1.6 \cdot 10^{-3}$



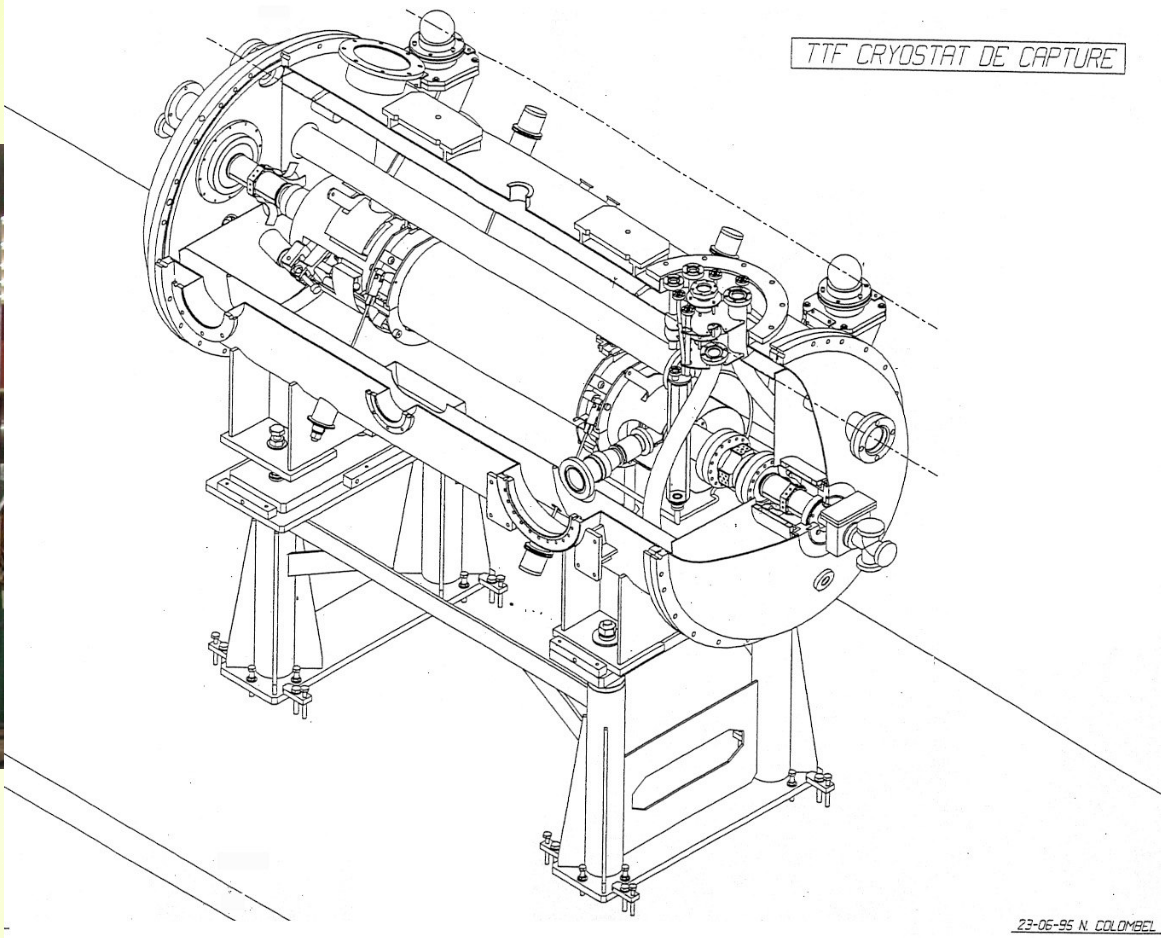
Modes resonant frequencies sensetivity on the cell deformations

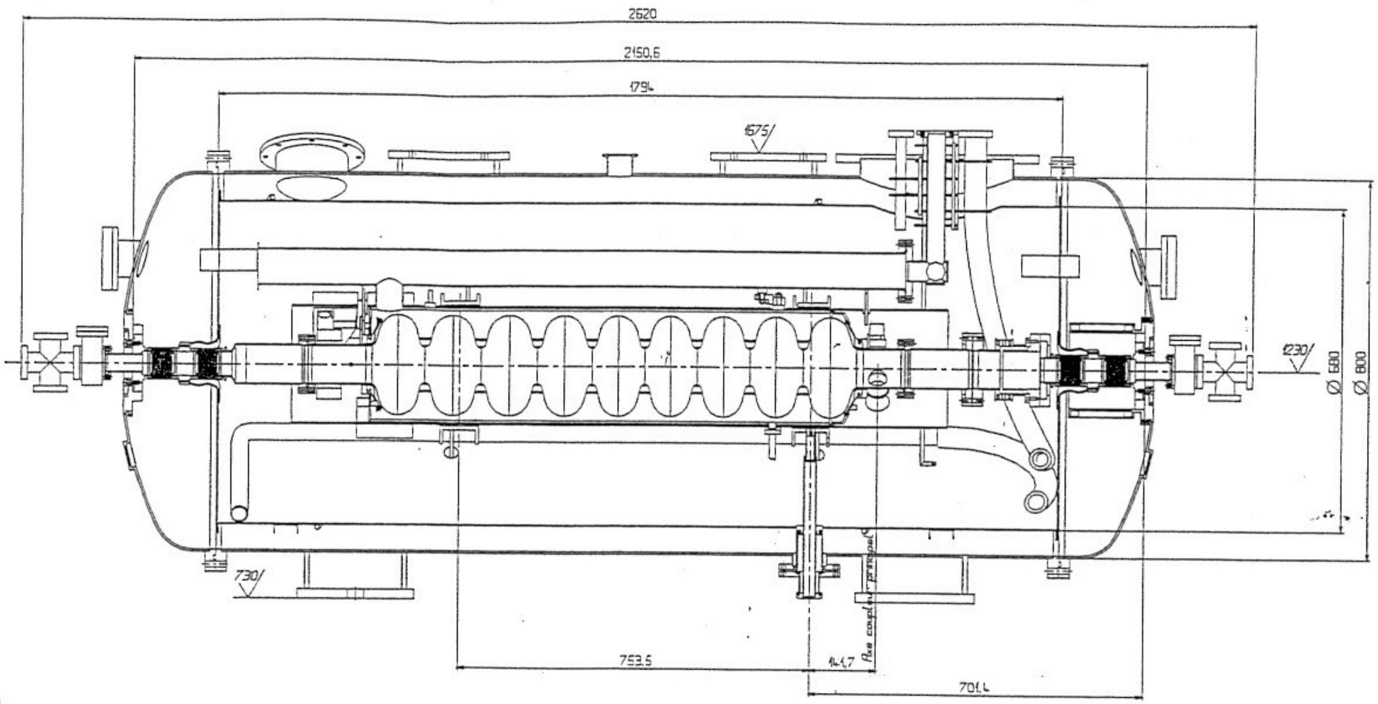


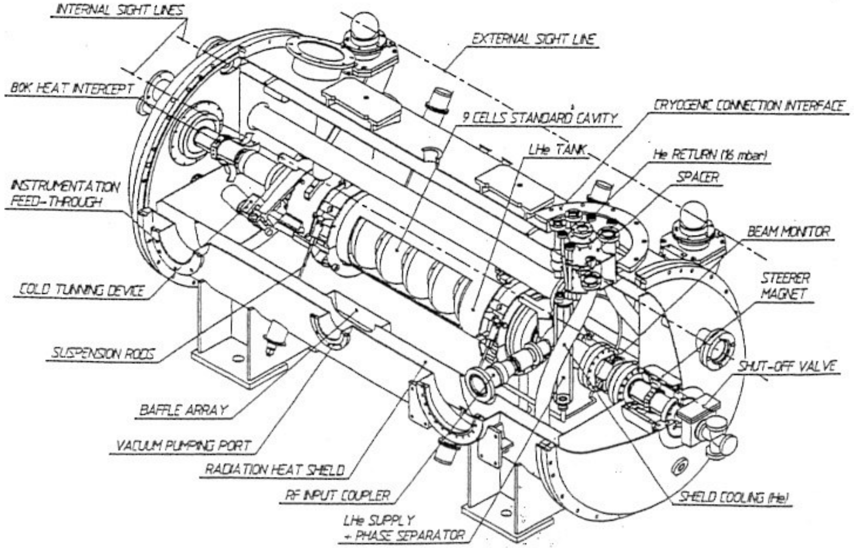
Cavity powering through a fast direct RF feedback

SBSR05, A. Gallo: "The DAFNE SRFF Experiment"

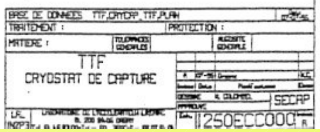
Cryostat – TTF capture section



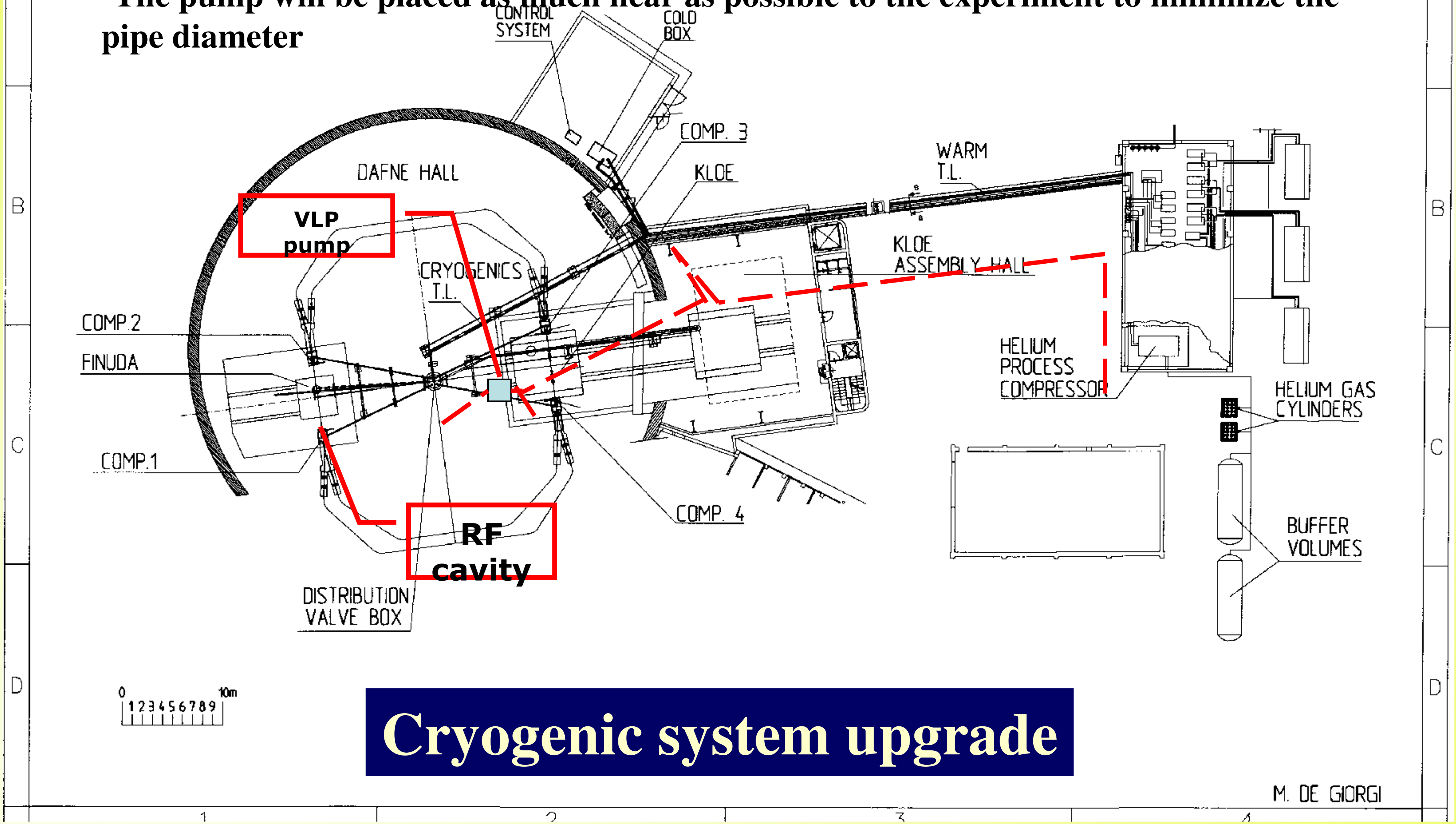




Constructive drawings from ORSAY



- The 1.8 K is obtained by 4.4 He bath pumping down to 16 mbar
- A new heat exchanger (cold) box will be placed above the cryostat
- The pump will be placed as much near as possible to the experiment to minimize the pipe diameter



Cryogenic system upgrade

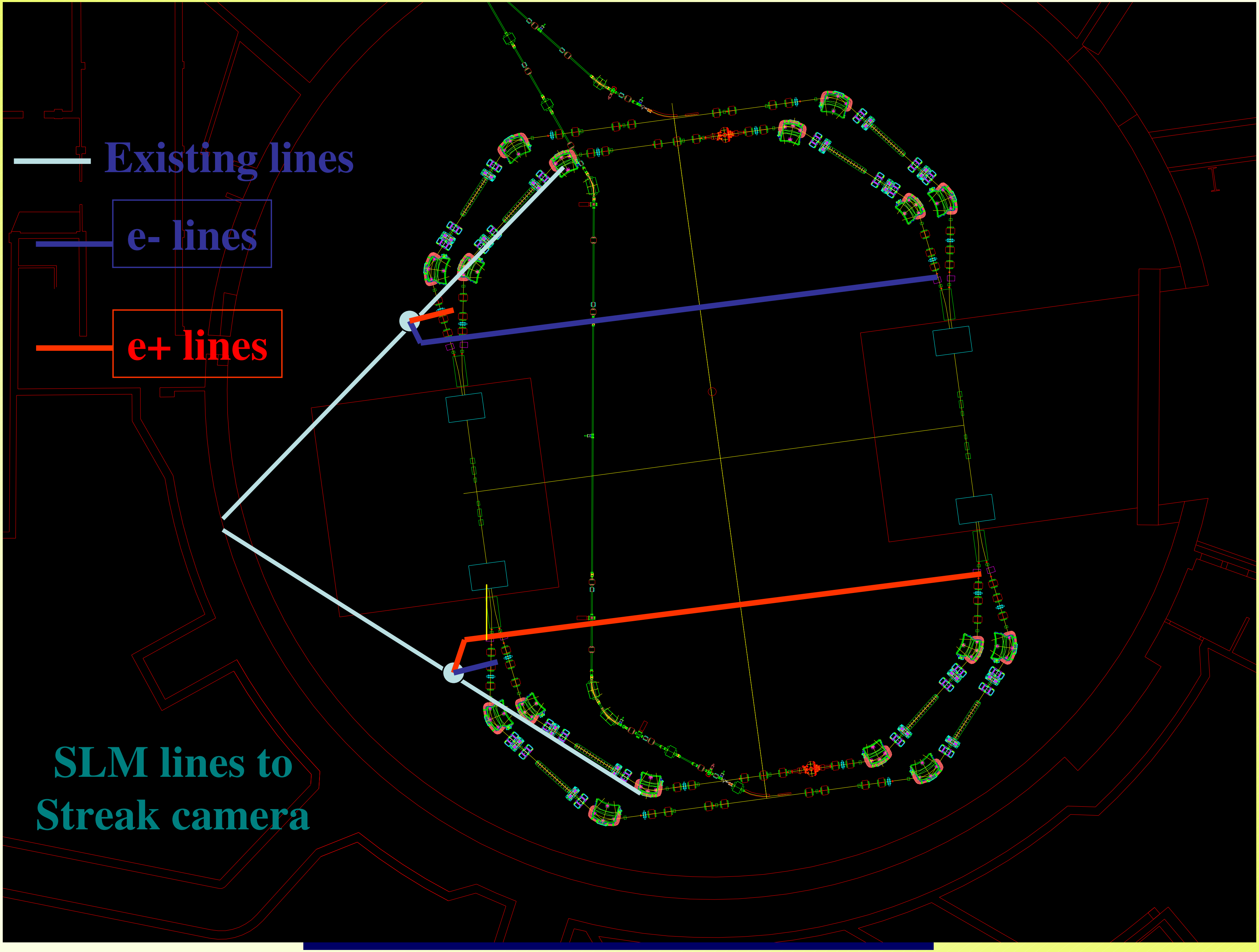
Diagnostics for the Experiment

- Measurement of the bunch length along the ring is the main goal of the experiment. The minimal required diagnostics consists in 2 lines transporting the synchrotron radiation sampled in 2 different points of the ring to a ≈1 ps resolution streak-camera.

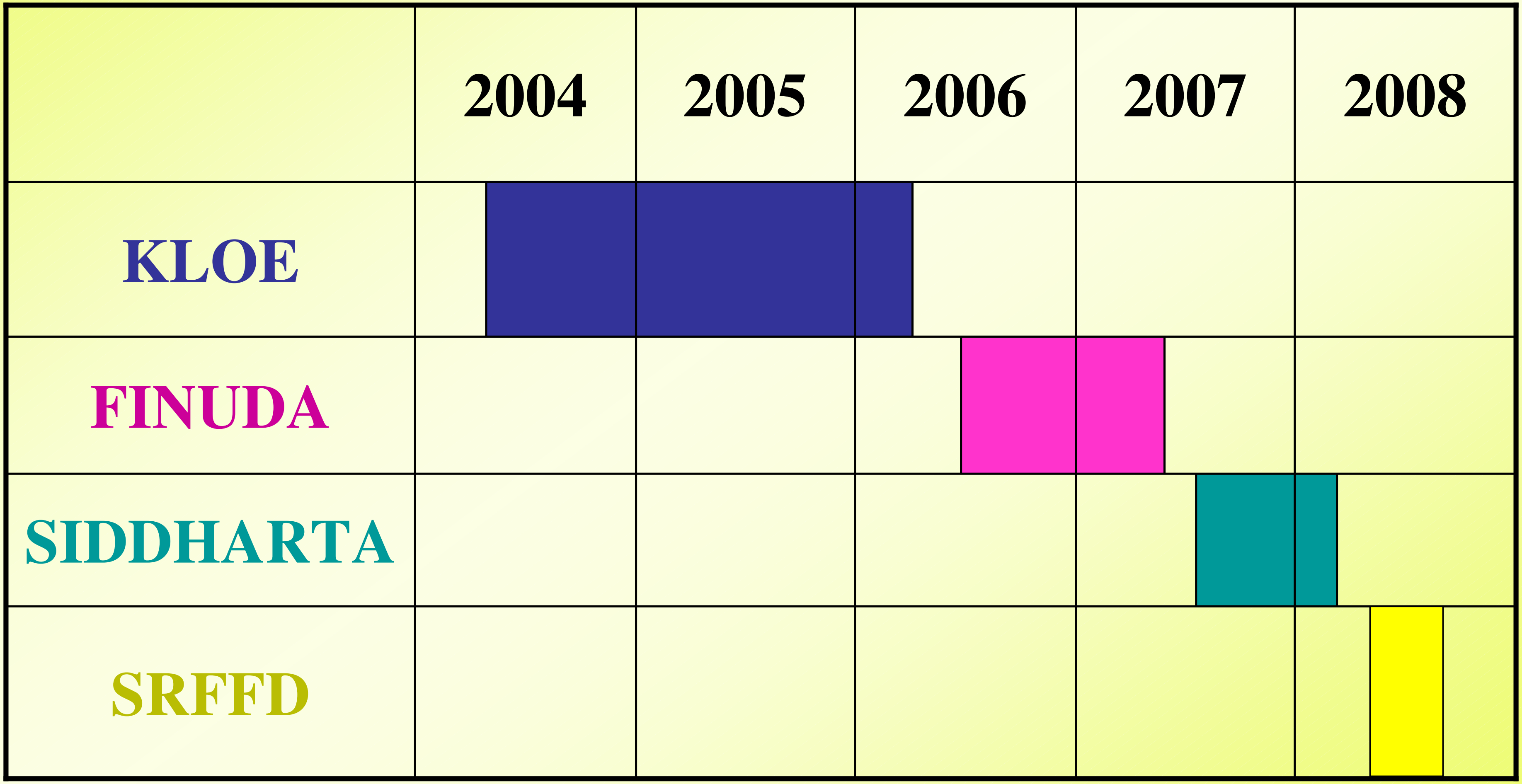
- Monitoring the bunch length in more than 2 points adding more optical lines would be preferable, but also more complicated and expensive.

- An interesting alternative consists in measuring the bunch length from the signal relised by the bunch to broadband position monitors, such as small windows in the vacuum chamber connected to high frequency waveguides. A multi-point measurement based on this method would be easier and cheaper, but calibration problems have to be considered.

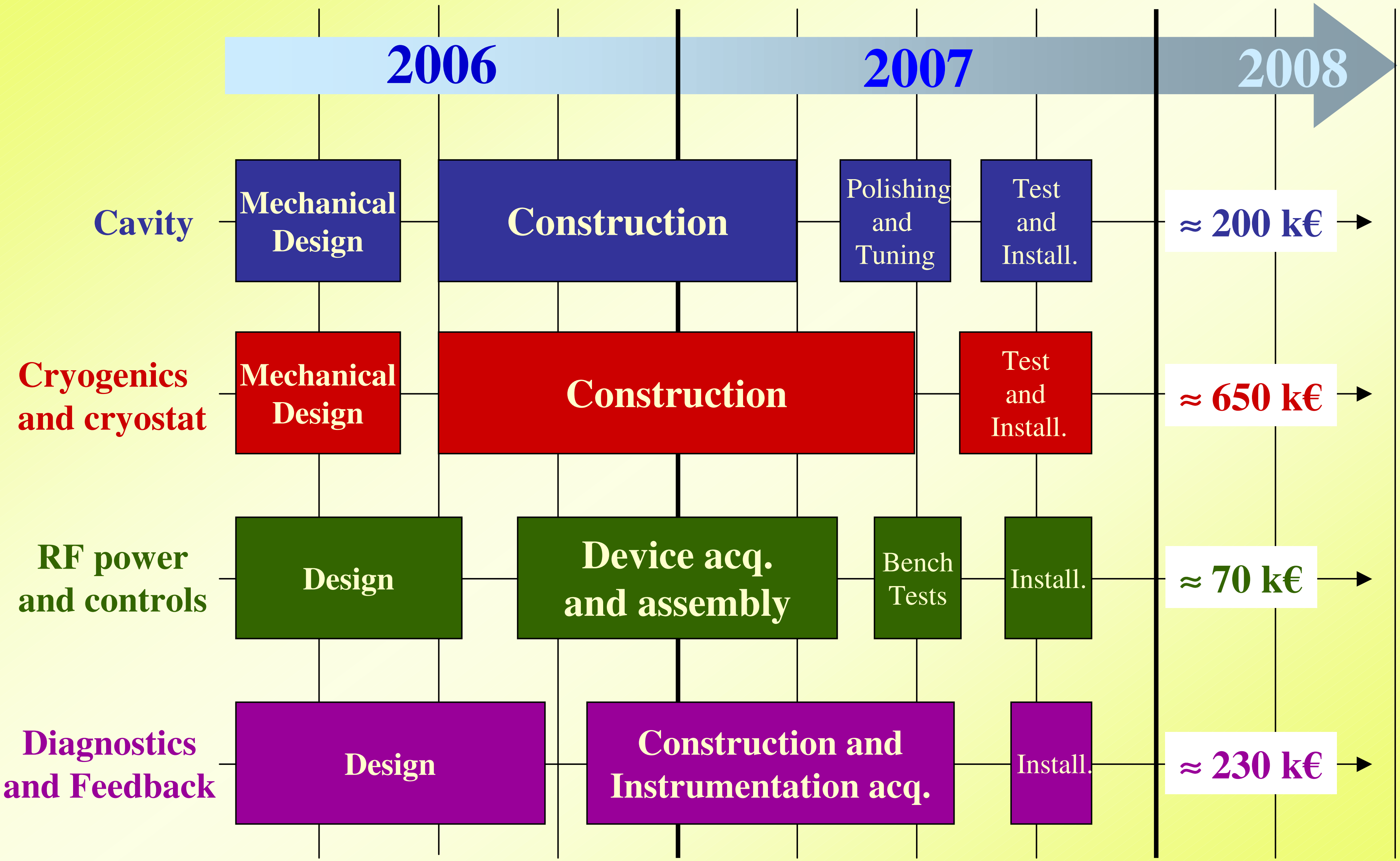
- The longitudinal feedback system has to be upgraded for allowing multibunch operation even at high synchrotron tune values.


Existing lines
e- lines
e+ lines
SLM lines to
Streak camera

PROPOSED DAΦNE SCHEDULE



Time Schedule and Costs



EXPERIMENT BUDGET [k€]

	2005	2006	2007
TRAVELS			
Internal	4	4	4
Abroad	16	16	16
CONSUMABLES			
RF Ampl. and controls		70	
7-cells SC Cavity	200		
Cryostat		500	
Cryogenics		150	
Diagnostics	50	30	90
Feedback			50
TOTAL	**270**	**770**	**160**

GRAND TOTAL

1200 k€

CONCLUSIONS

Proposal of an accelerator physics experiment to be funded in few months for realization in 2008

- **Large interest for short and intense bunches in storage rings;**
- **Possibility of studying experimentally at DAΦNE novel ideas to obtain short bunches;**
- **Possibility of measuring for the first time the bunch length modulation along the ring, also in the high-current multi-bunch regime;**
- **Concluding the scientific activity at DAΦNE with an accelerator physics experiment opening the way to the next-generation factory colliders.**