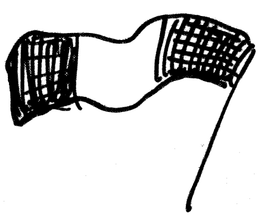
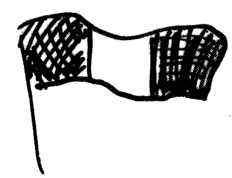
CHALLENGES (several kinds) and R&D (beam dynamics + hardware) for NEW FACILITIES (high-intensity and high-power proton linacs (HPPL))

Jean-Michel LAGNIEL
CEA-Saclay

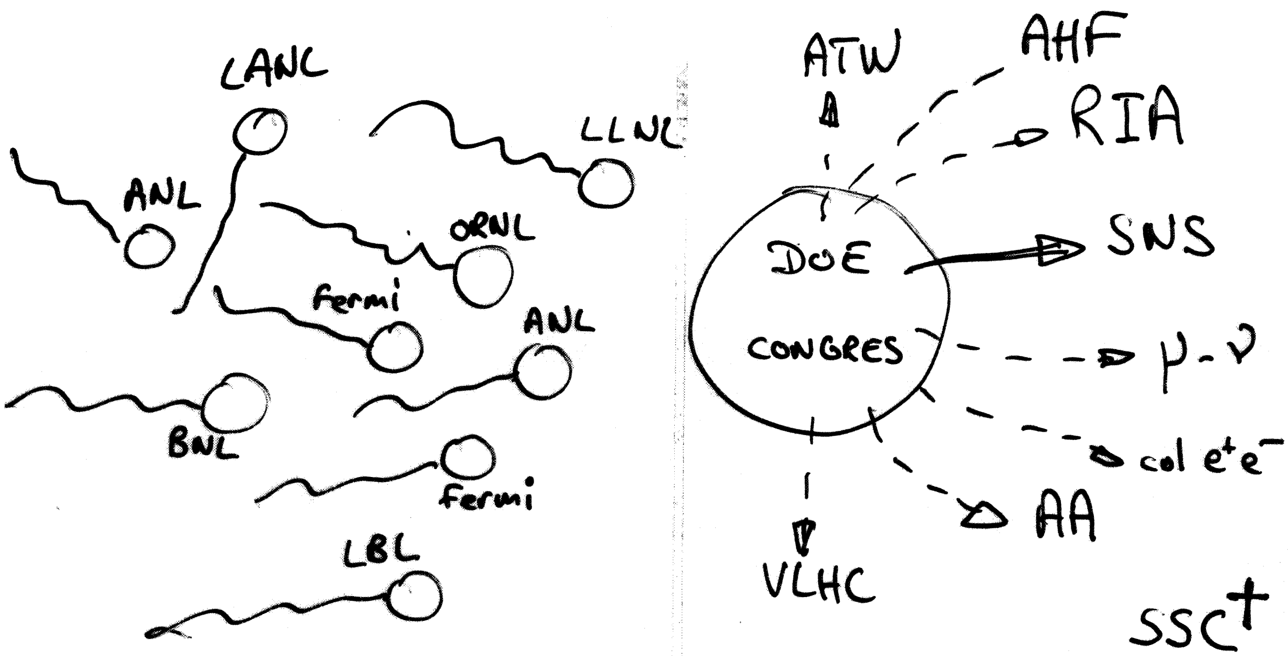


Samedi 14 juillet 2001



CHALLENGE # 1 for a new facility :

DECISION of construction / FERTILIZATION project → new facility



" BE SEXY "

(or try "in vitro" fertilization)

CHALLENGE # 2 for a new facility:

BORN : Organization + Project TEAM

(1) Learn from the past success and failures

(2) Attract and keep the best folks :

* Attractive project
* Develop good relationships +
* Attractive location
* Attractive salaries

MOTIVATED STAFF = SUCCESS

CHALLENGE # 3 for a new facility:

GROWN_UP : Solve the Scientific and Technical problems:

(The right organisation has to take the right decisions)

1) Focus the efforts on major items (no dispersion on minor subjects)

2) Attract the experience / knowledge accumulated in your field before developping new tools or new techniques

3) Develop broad collaborations with other Labs & their expertise

4) Focus a as large as possible community of users on your project (science oriented project)

CHALLENGE # 3 : Scientific and Technical challenges

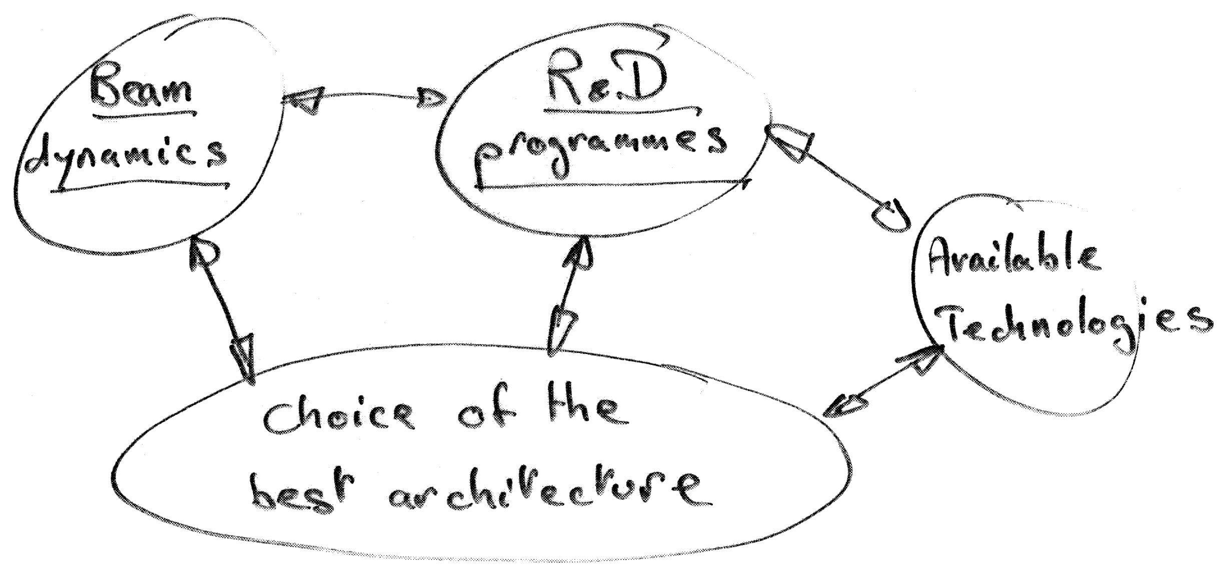
High-Intensity ■ High-Power LINACS

Goals : - Beam losses for hands-on maintenance
- Minimum cost
- Availability - beam trips (not only ATW)
- (Crazy) Time Schedule (SNS)

CHALLENGE

= find the best

COMPROMIZE



HPPL Beam Dynamics Challenge #1:

UNDERSTAND THE PHYSICS (1/2)

1) <u>Start with the right Physics</u>

HPPL beam = N-body dynamical system

Beam dynamics, not beam thermodynamics

~~temperatures~~, ~~pressures~~ ...

2) <u>Be right more than be rigorous</u> (AE?)

Simplified models with the right physics always more useful than self-consistent models far from ~~the~~ physics of real beams

Ex: study of the $2\sigma_x - 2\sigma_y = 0$ coupling resonance using a KV distribution: no excitation except code noise, no tune spread!

+ Y. Shimosaki talk, M6, July 10
  Probably the most significant progress since 5 years!

+ More work needed on accelerated beams!
  (bucket escape, large bores do not help)

Nonlinear equation of motion in the longitudinal plane

$$\frac{d^2\delta\varphi}{ds^2} + A(s)\frac{d\delta\varphi}{ds} + B(s)\left[\cos(\varphi) - \cos(\varphi_s)\right] + SC(s,\delta\varphi) = 0$$

A(s) = damping term   B(s) = "synchrotron frequency"

SC = space-charge "force"   or « perturbing force »

Can be reduced to the standard forms :

$$x'' + \alpha x' + (1 + F\cos(\omega z))\, x - x^2 = 0$$

(Nonlinear Mathieu's equation)

$$x'' + \alpha x' + x - x^2 = F\cos(\omega z)$$

(Model for capsizing of ships in waves J.M.T. Thompson 1982...)

For a linac with 1 MeV/m, Φ_s = -30°, 352 MHz
the damping term $\alpha \sim 0.1$

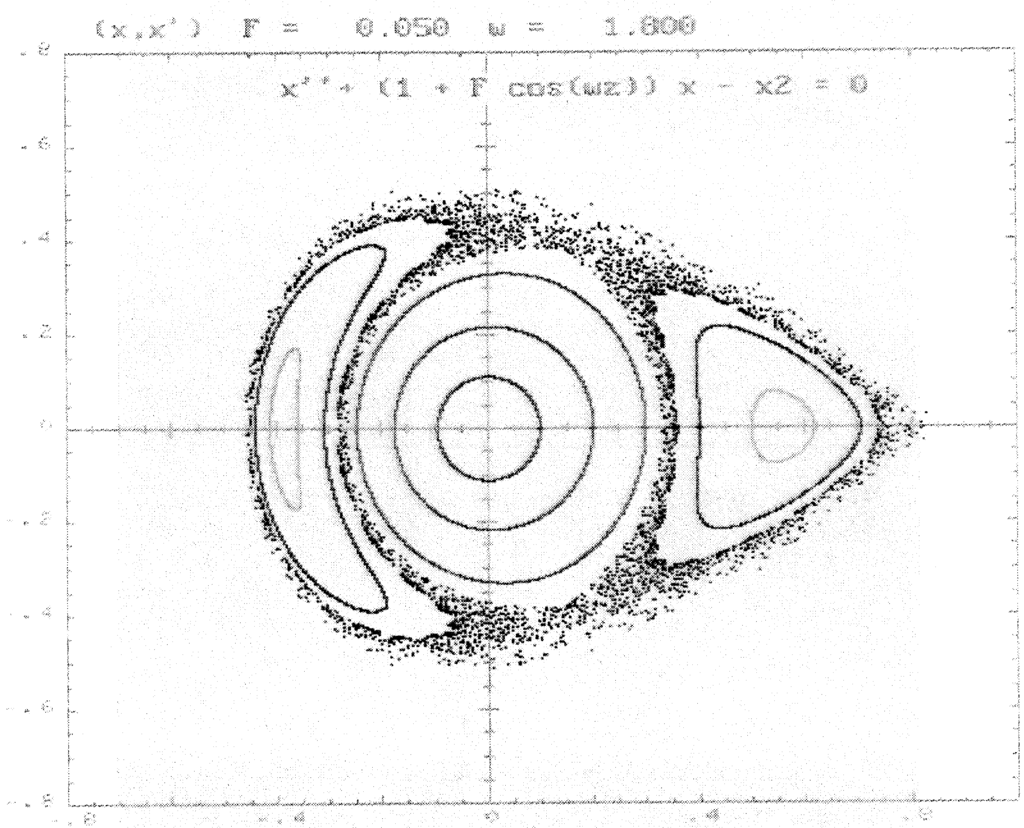
To estimate the sensitivity
of the longitudinal motion to perturbations

$$x'' + \alpha x' + (1 + F \cos(\omega z)) x - x^2 = 0$$

$\alpha = 0$ (look only the nonlinear term)

$\omega = 1.8$

$F = 0.05$ (only 5% !)



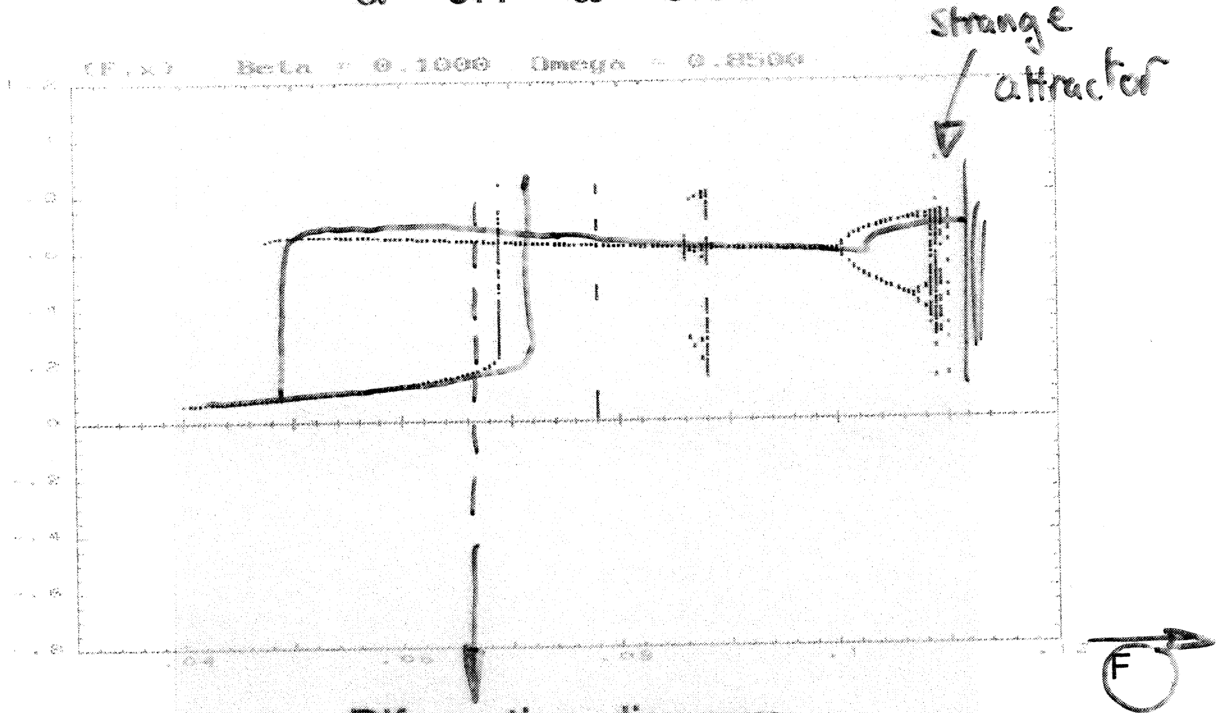
Perturbation

⇒ reduction of the stable area

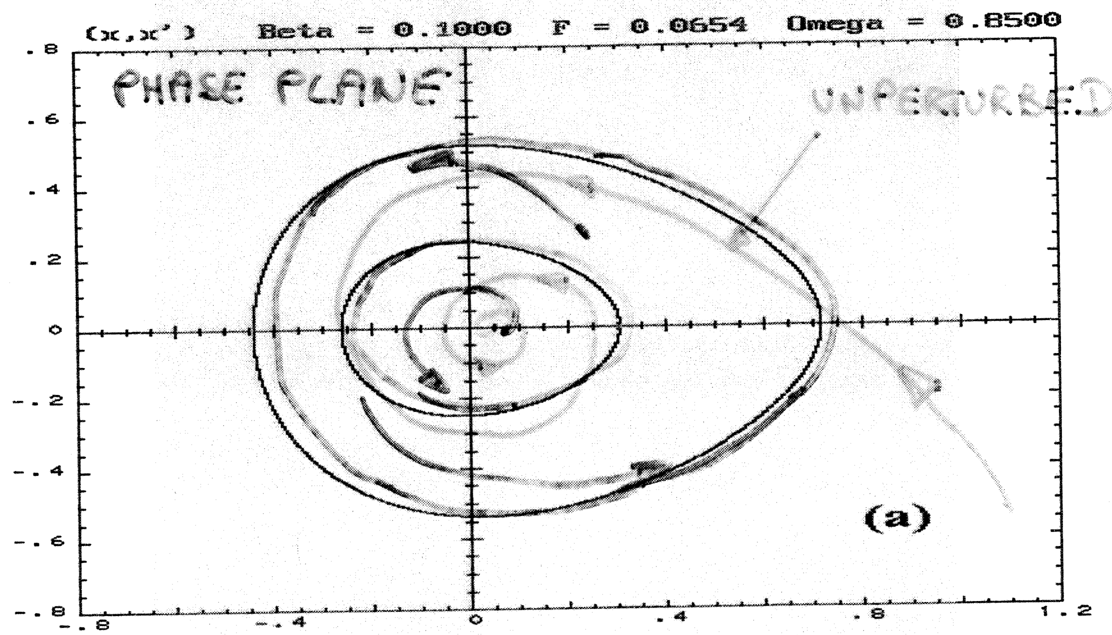
⇒ escape from the longitudinal potential well

$x'' + \alpha x' + x - x^2 = F \cos(\omega z)$

$\alpha = 0.1 \quad \omega = 0.85$



Bifurcation diagram

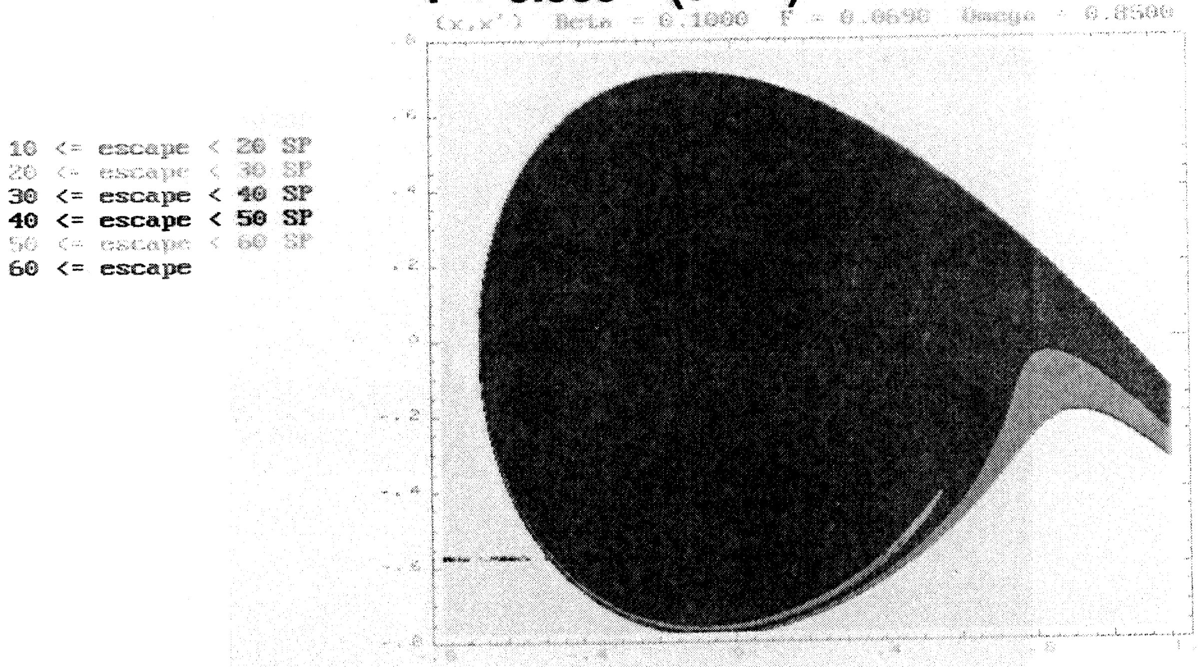


Attractors for F = 0.065 (6.5%)

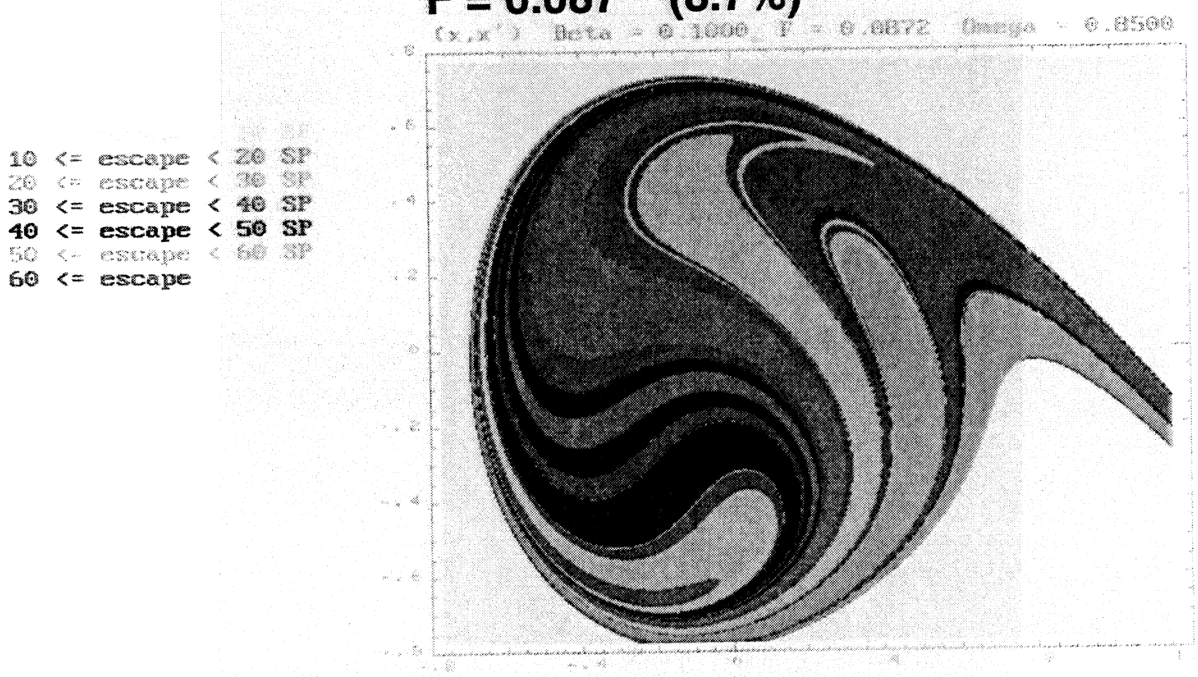
The unnormalized emittance will not damp as expected!

Erosion of the bassin of attraction

F = 0.069 (6.9%)



F = 0.087 (8.7%)



GREEN AREAS = STABLE AREAS

UNDERSTAND THE PHYSICS (2/2)

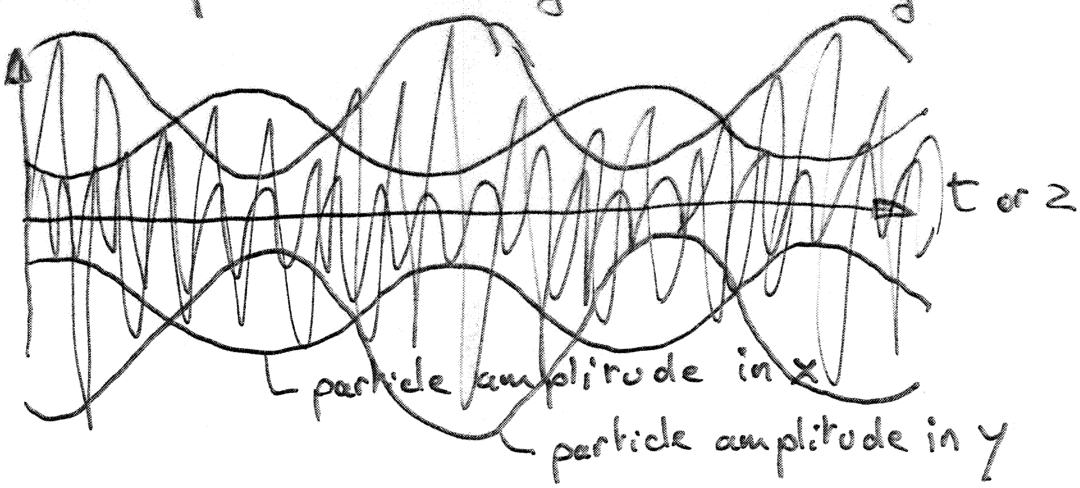
3) Look to the basis before going to exotic theories

Ex : $2\nu_x - 2\nu_y = 0$ again
(fashionable subject, well understood in circular accel and synchrotron radiation sources since ....)

Coupling resonances well explained in CERN - US Accel Schools

"Sum" resonances $i\,\nu_x + j\,\nu_y = k$ → instability

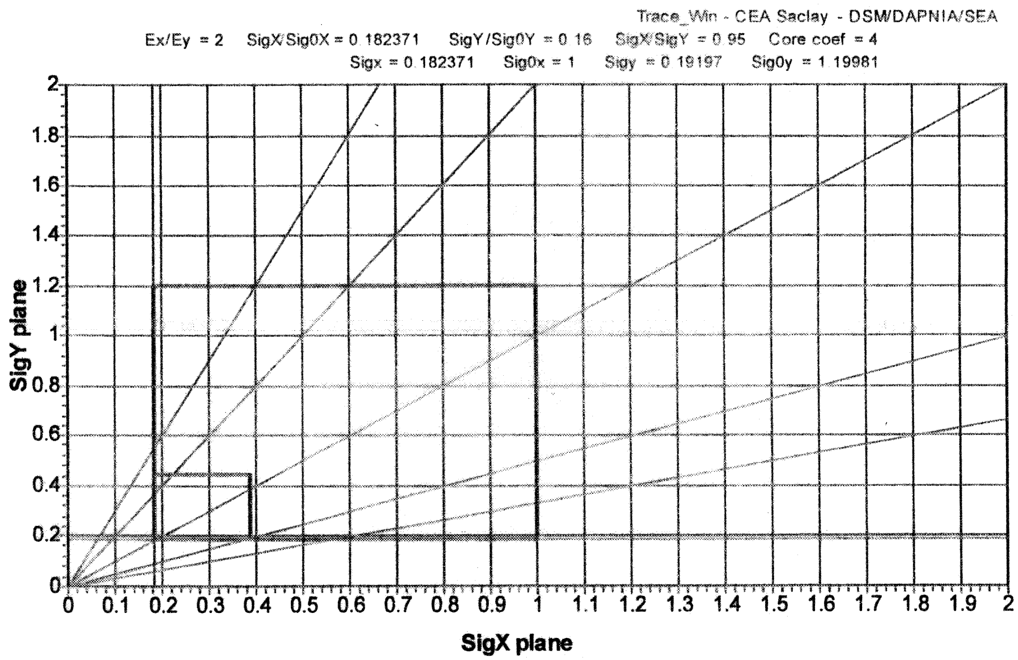
"Difference" res $i\,\nu_x - j\,\nu_y = k$ → emittance exchanges
↳ amplitude beating - No instability



Excitation or non-excitation can be simply checked looking (as usual) to the tune diagram

Tune diagrams

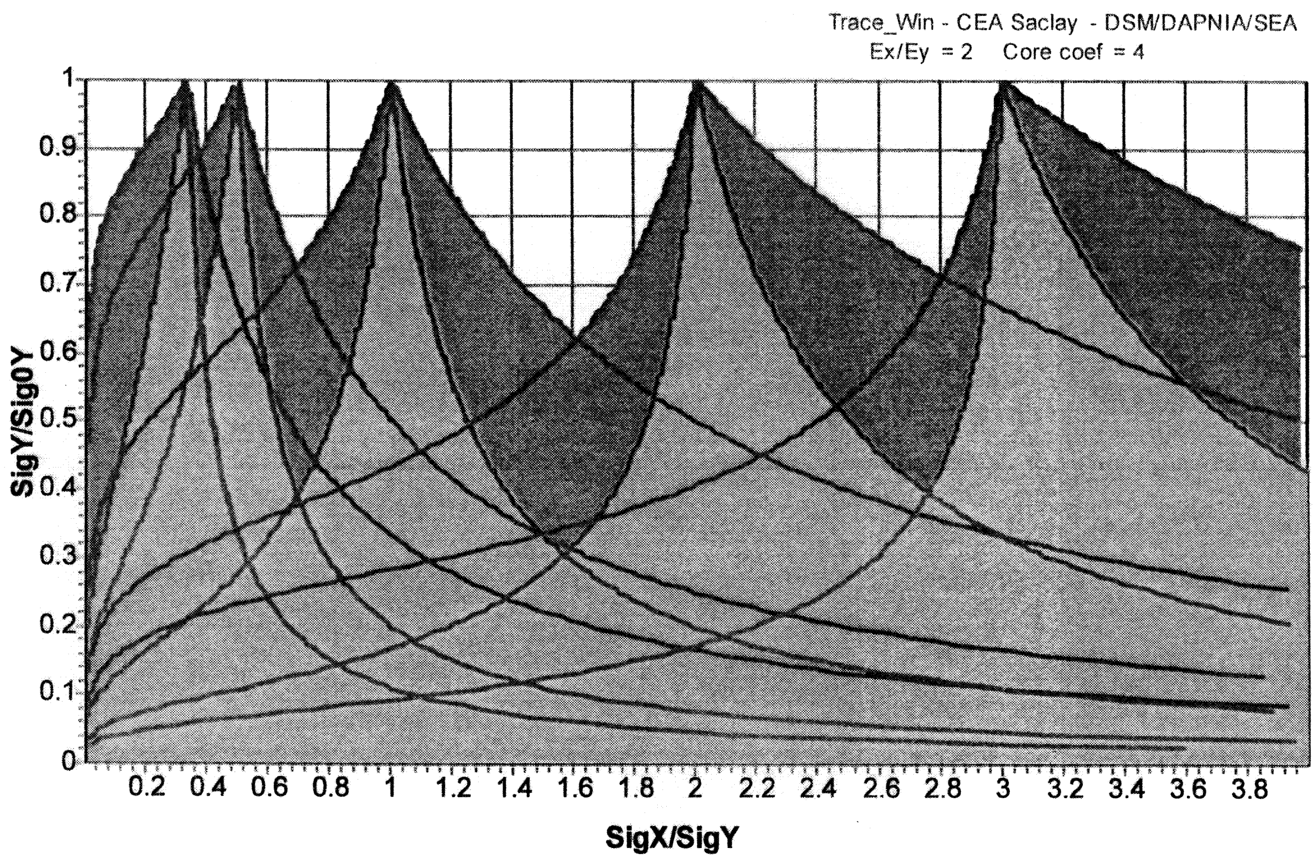
Fixing arbitrarily $\sigma_{ox} = 1$ without loss of generality for the coupling resonance study, the other tunes are then easily calculated : $\sigma_x = \eta_x$ $\quad \sigma_y = \alpha \, . \, \sigma_x$ $\quad \sigma_{oy} = \sigma_y / \eta_y$



Tune diagram for $\varepsilon_x / \varepsilon_y = 2$ $\quad \alpha = \sigma_y / \sigma_x = 1.05$ and $\eta_y = 0.16$
leading to $\eta_x = 0.18$ $\quad \sigma_x = 0.18$ $\quad \sigma_{ox} = 1.00$ $\quad \sigma_y = 0.19$ $\quad \sigma_{oy} = 1.2$

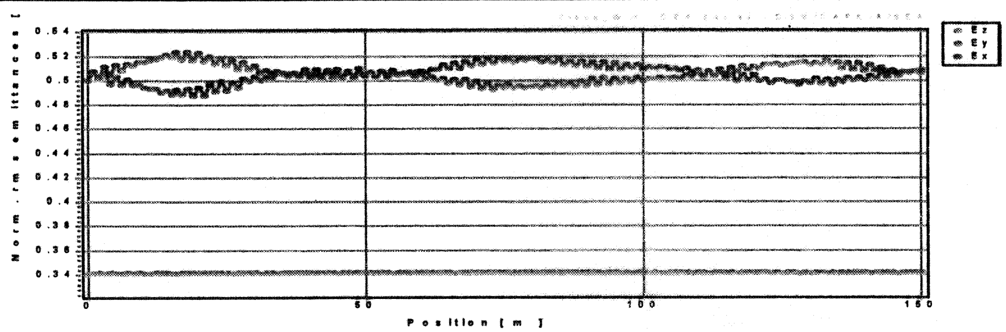
⚠ NOT RESONANCE STOP BANDS ! LOCATIONS WHERE THE BEAM IS ON THE RESONANCES

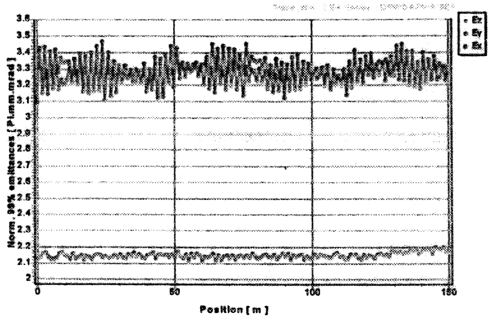
Stability charts of the coupling resonances

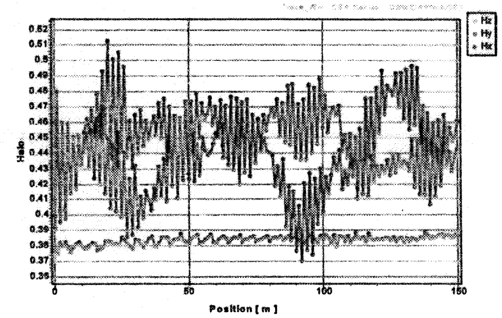


Example of stability chart for the coupling resonances $\alpha = 1/3, 1/2, 1, 2$ and 3 $(Ex/Ey = 2)$

3D multi-particle simulations







T = 0.5 $\alpha = 2.94$ $\varepsilon_x / \varepsilon_z = 1.47$ $\eta_x = 0.60$ $\sigma_{ox} = 1.0$

$\eta_z = 0.822$ $\sigma_z = 1.763$ $\sigma_{oz} = 2.145$ $\varepsilon_x = 0.5$ $\varepsilon_y = 0.34$ $I = 12.7$ mA

HPPL BEAM DYNAMICS STUDIES

1) Study YOUR accelerator (better than academic studies)

Beam dynamics strongly linked to your parameters

- Use your favorite enveloppe codes and multiparticle codes to optimize your design,
- Check vs other codes / discuss with colleagues from other Labs,
- Do not forget error studies and correction schemes using the right diagnostics (multi-processor error studies prefered to // codes at Saclay - more efficient)

AND - Use the understanding gained with the "toy models" to improve your design @ beam losses, minimum cost, availability

2) Guide the theoreticians

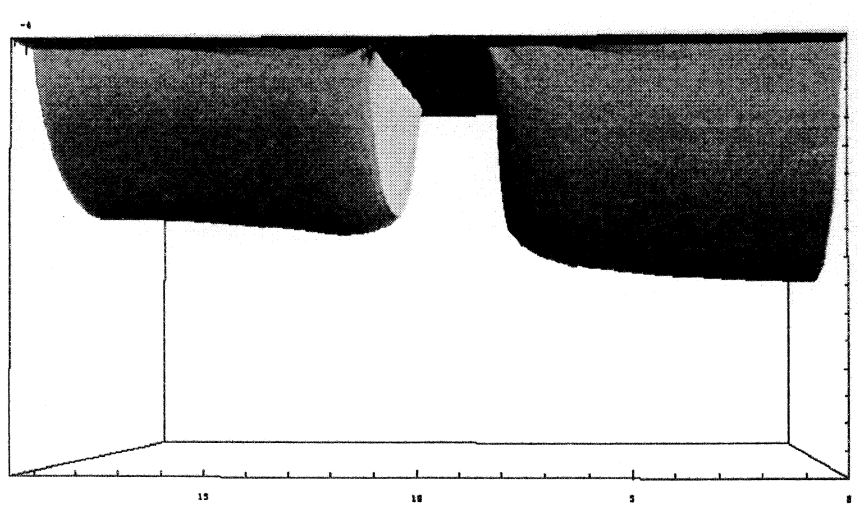
- More instabilities = more work for them !
- Smoke the house to make appear the problems more difficult than they are !

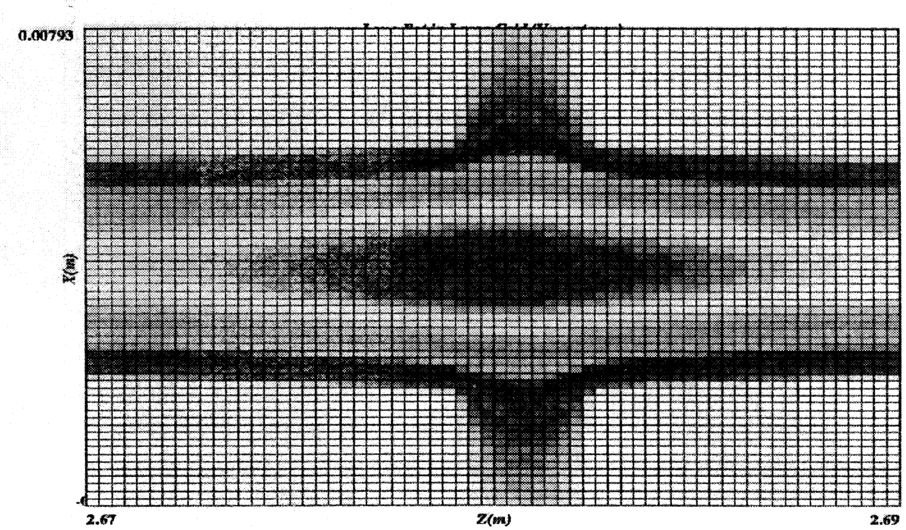
→ work on your parameters / avoid generic studies

→ experiments (MG) as simple as possible

RFQs Transport code (TOUTATIS)

- Time code
- 3D numerical calculation based on multigrid method
- Includes: space charge, image effects, real shape of the electrodes (mechanical defects, discontinuities as coupling gaps can be easily simulated)





HPPL R&D CHALLENGES

duty cycle > 5%

→ High-power proton linacs (~1GeV ~100 mA)

≠ High-intensity low-duty cycle

⊛ <u>Challenge # 1 :</u> remember the goals :

Beam losses + Cost + availability
vs schedule

⇒ <u>Quantify</u> the potential cost savings, beam losses reductions and availability gains – On schedule !

⊛ Take into account well proven technologies — participate – take benefit of R&D program in other Labs — develop collaborations — look at SNS : a scale one R&D prog !

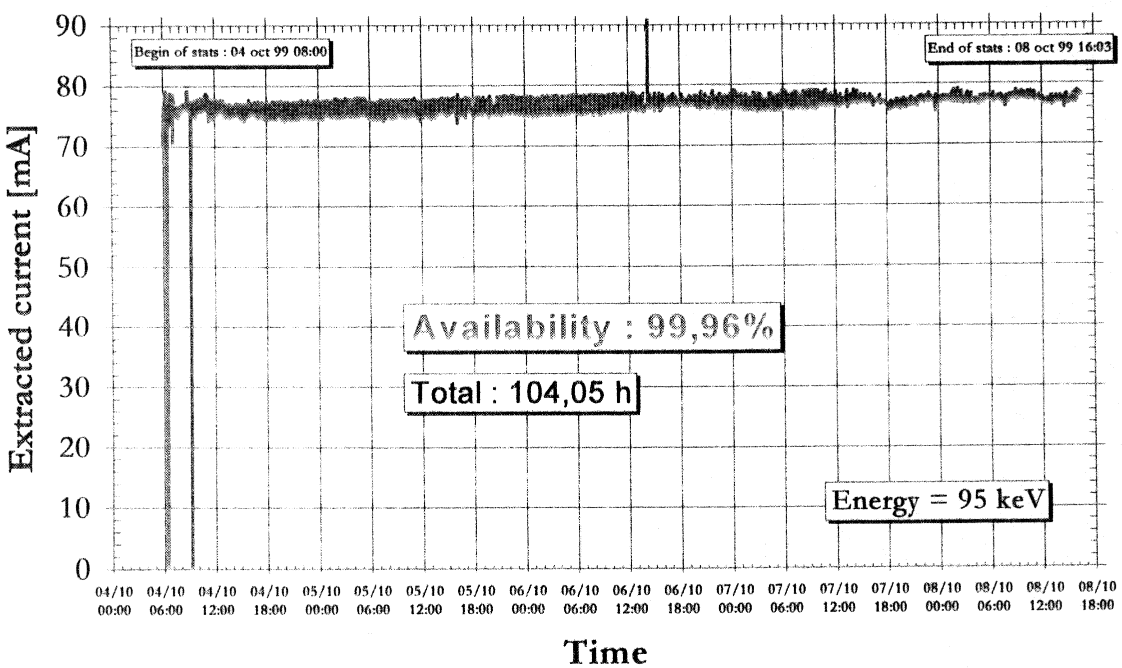
⊛ <u>Focus the R&D programmes on major topics</u>

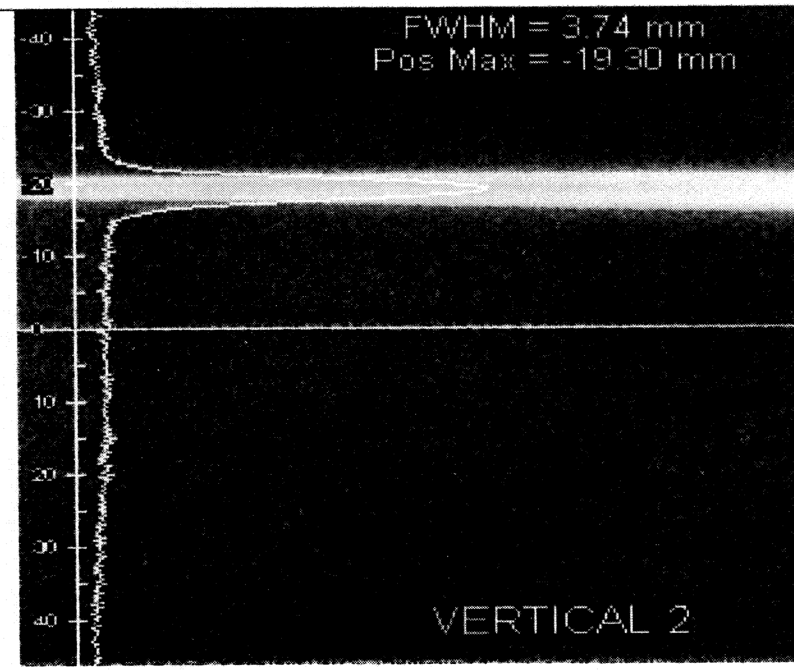
- Front ends and H^- sources
- Funneling (if needed)
- RF control
- Commissioning / tuning / diagnostics

---- As described by the MG group

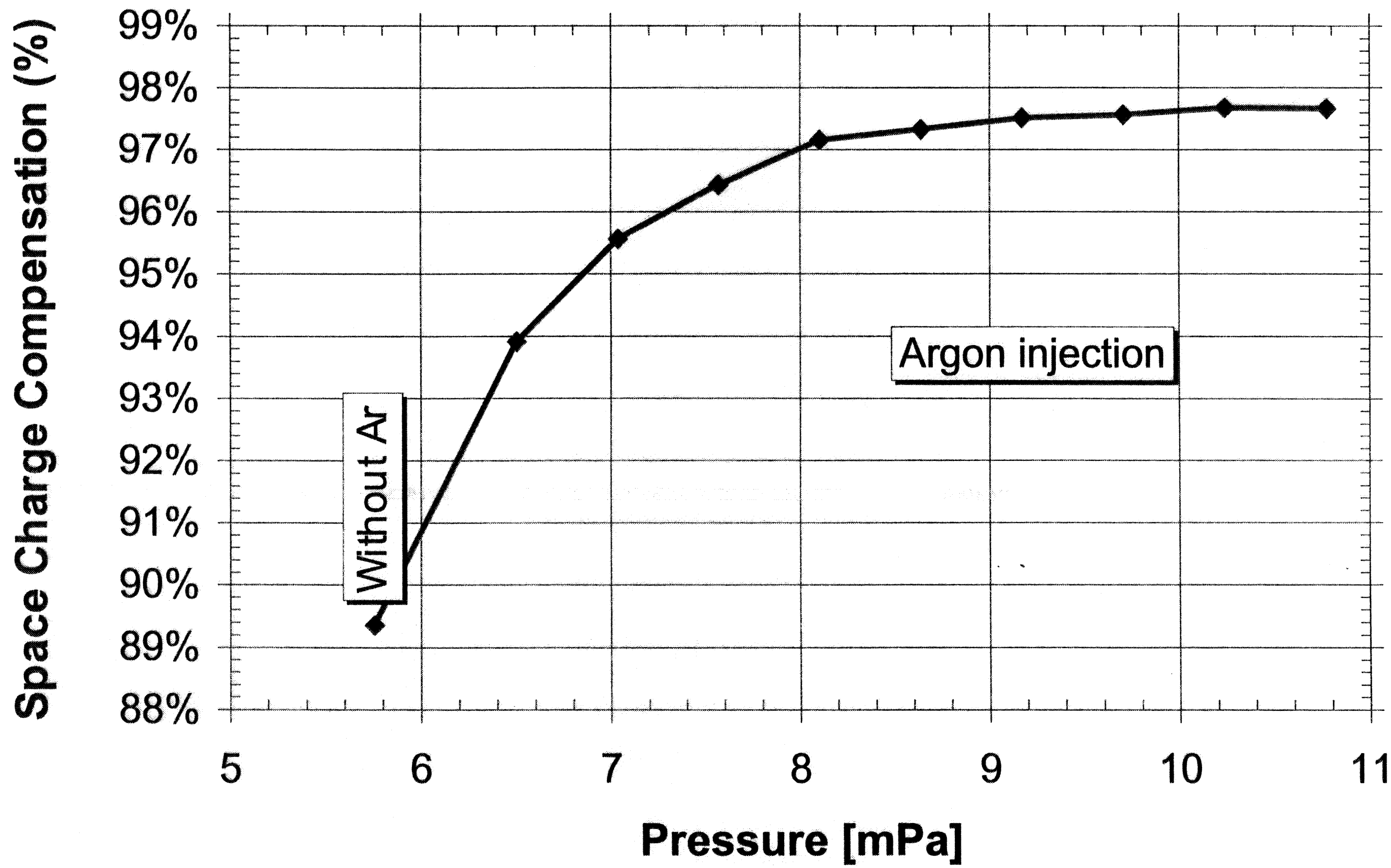
Accelerator Front End : Ion source SILHI

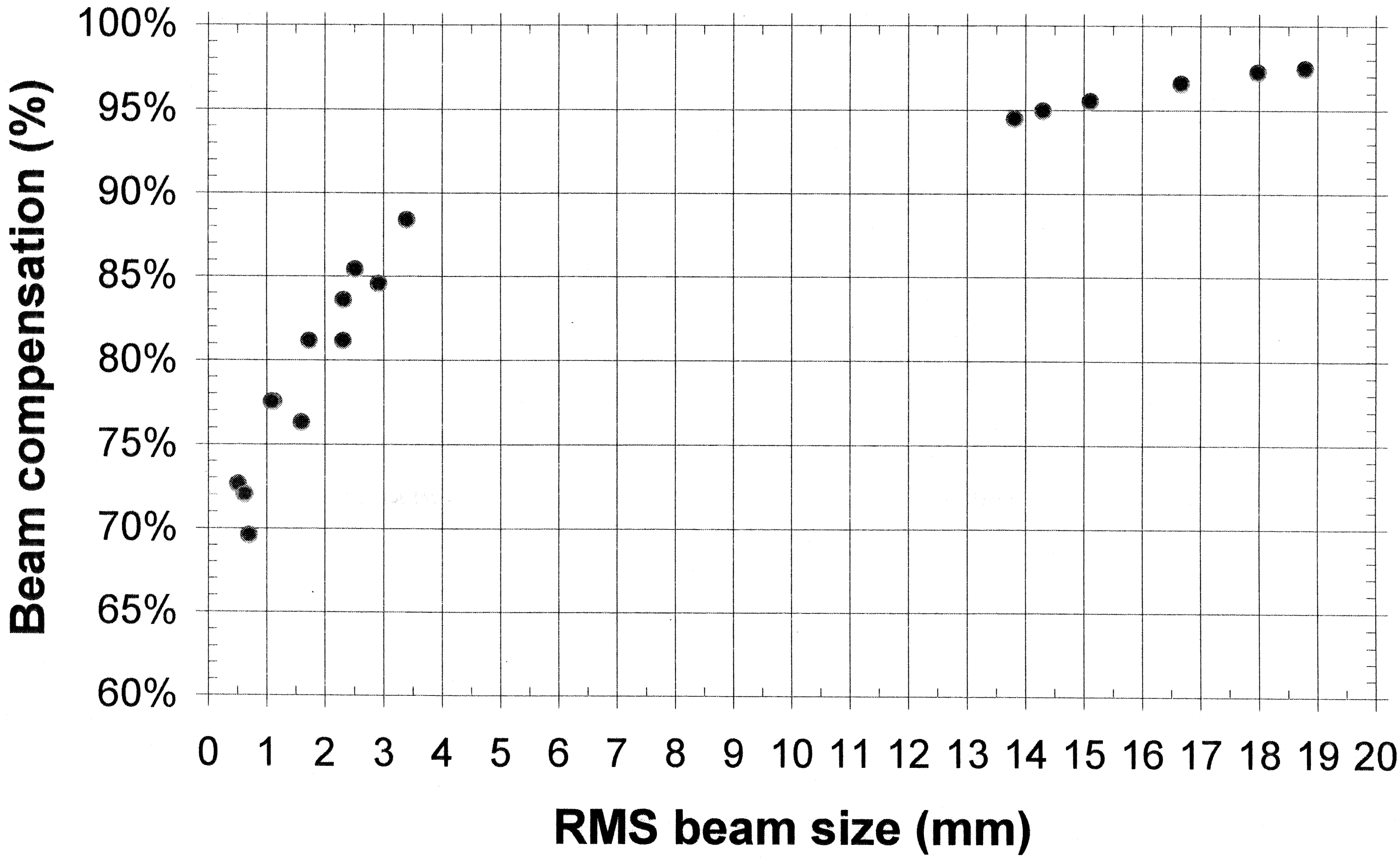
An international reference for HPPA



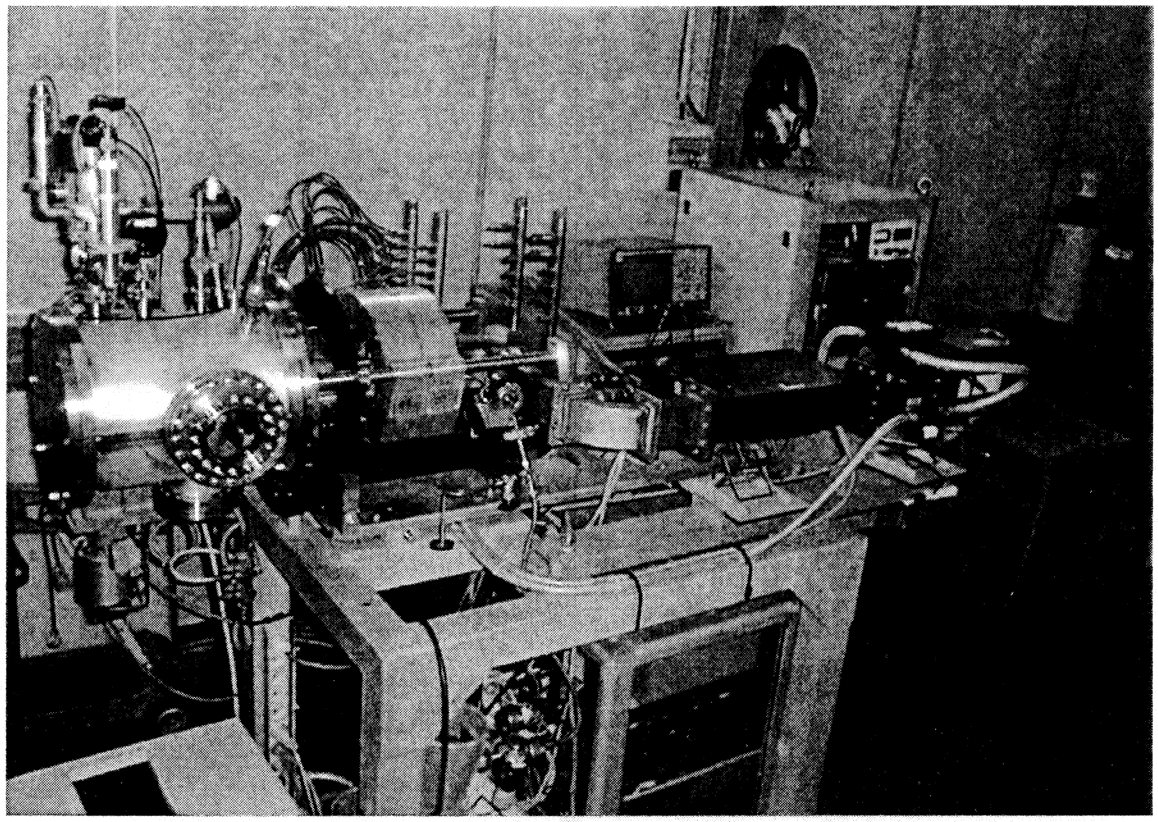


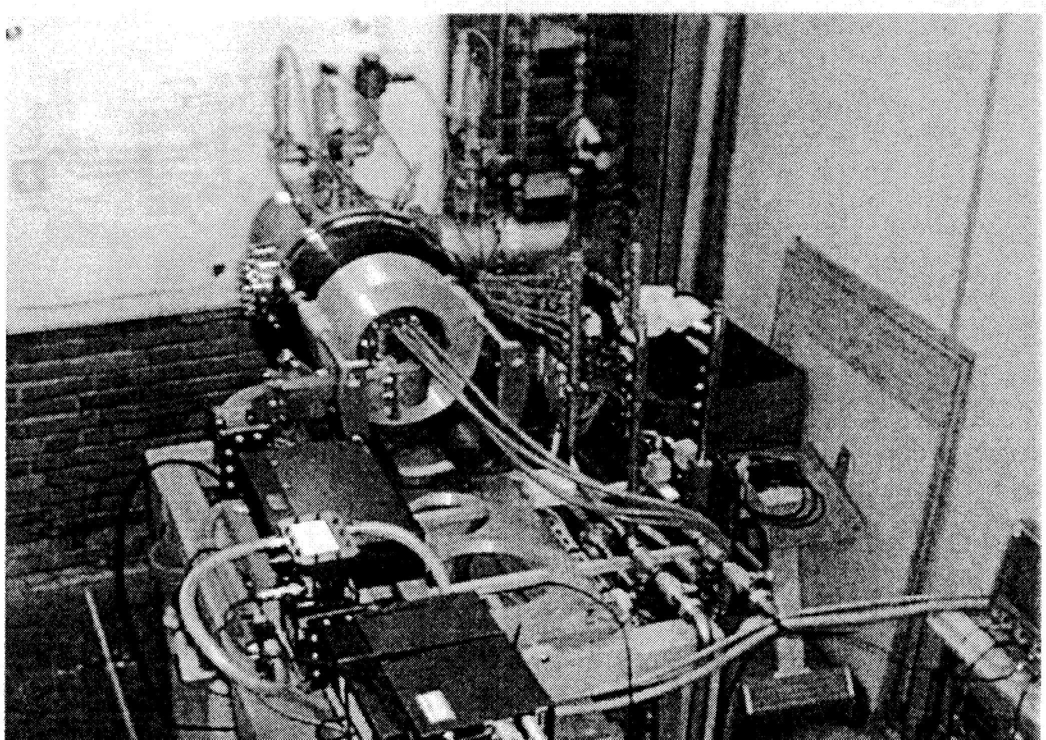
Test run at 75 mA cw 95 keV (nominal) with 103 hours of uninterrupted beam (October 1999)
Development of non-interceptive diagnostics
Big step towards the "ADS Quality"


Space Charge Compensation (%)
99%
98%
97%
96%
95%
94%
93%
92%
91%
90%
89%
88%
5
6
7
8
9
10
11
Pressure [mPa]
Without Ar
Argon injection



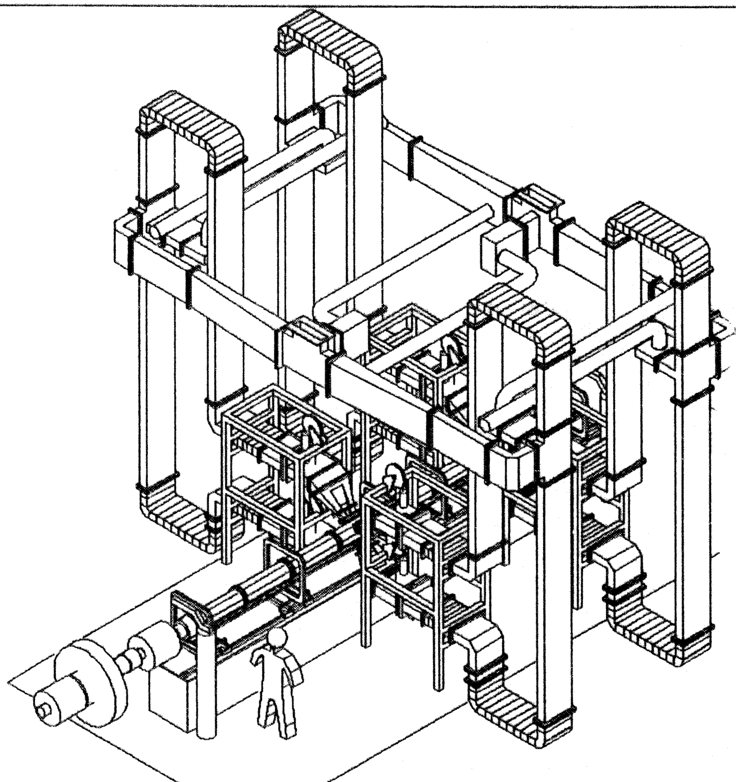
100%
95%
90%
85%
80%
75%
70%
65%
60%
Beam compensation (%)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
RMS beam size (mm)

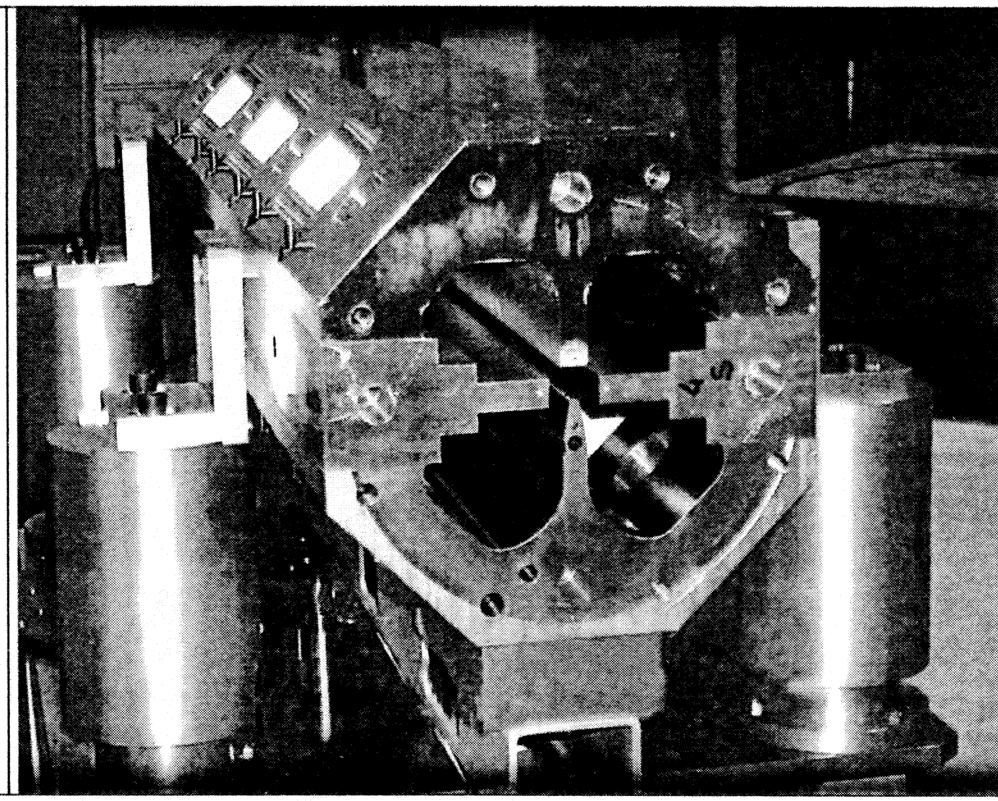




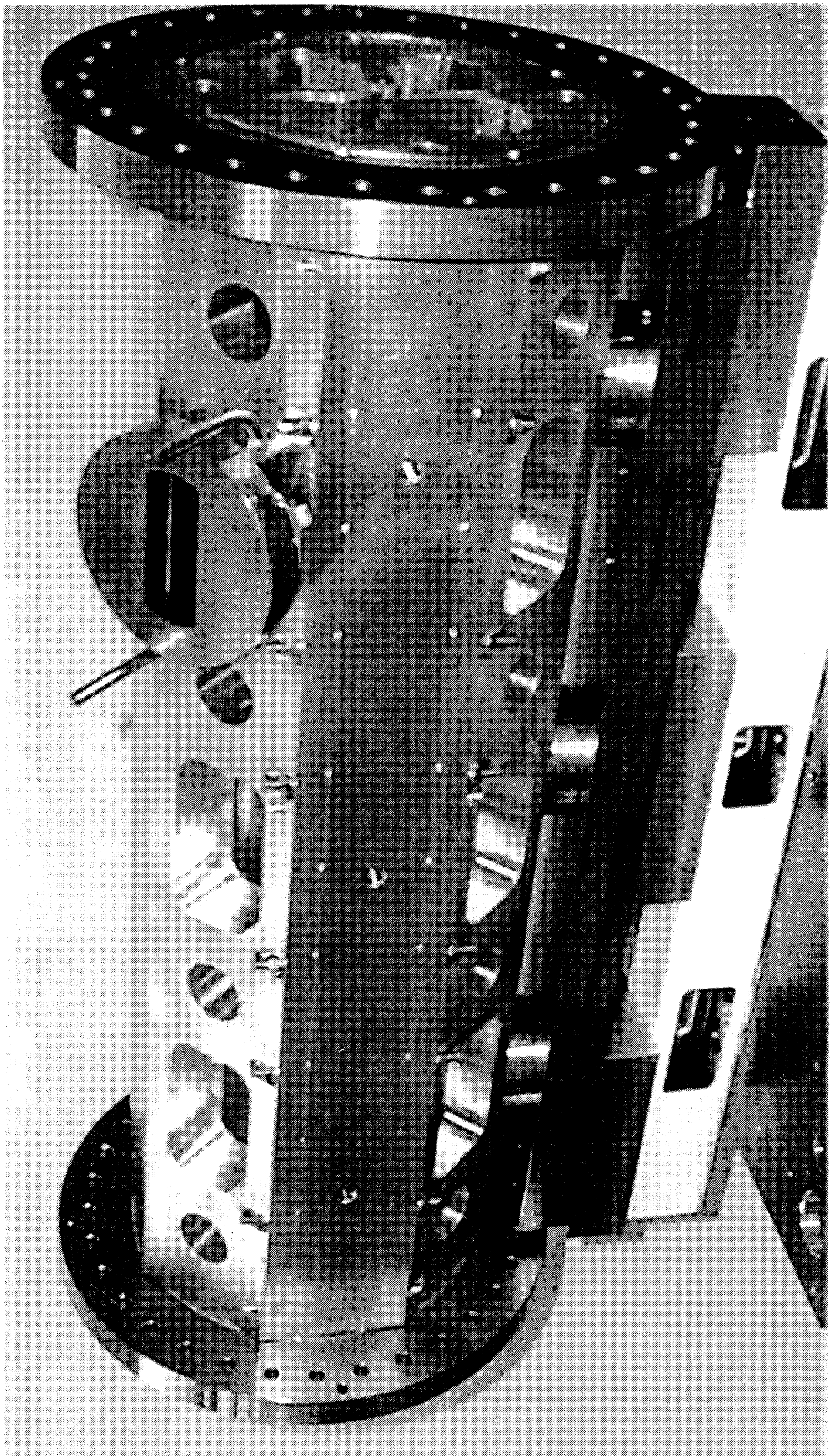
Accelerator Front End : RadioFrequency Quadrupole

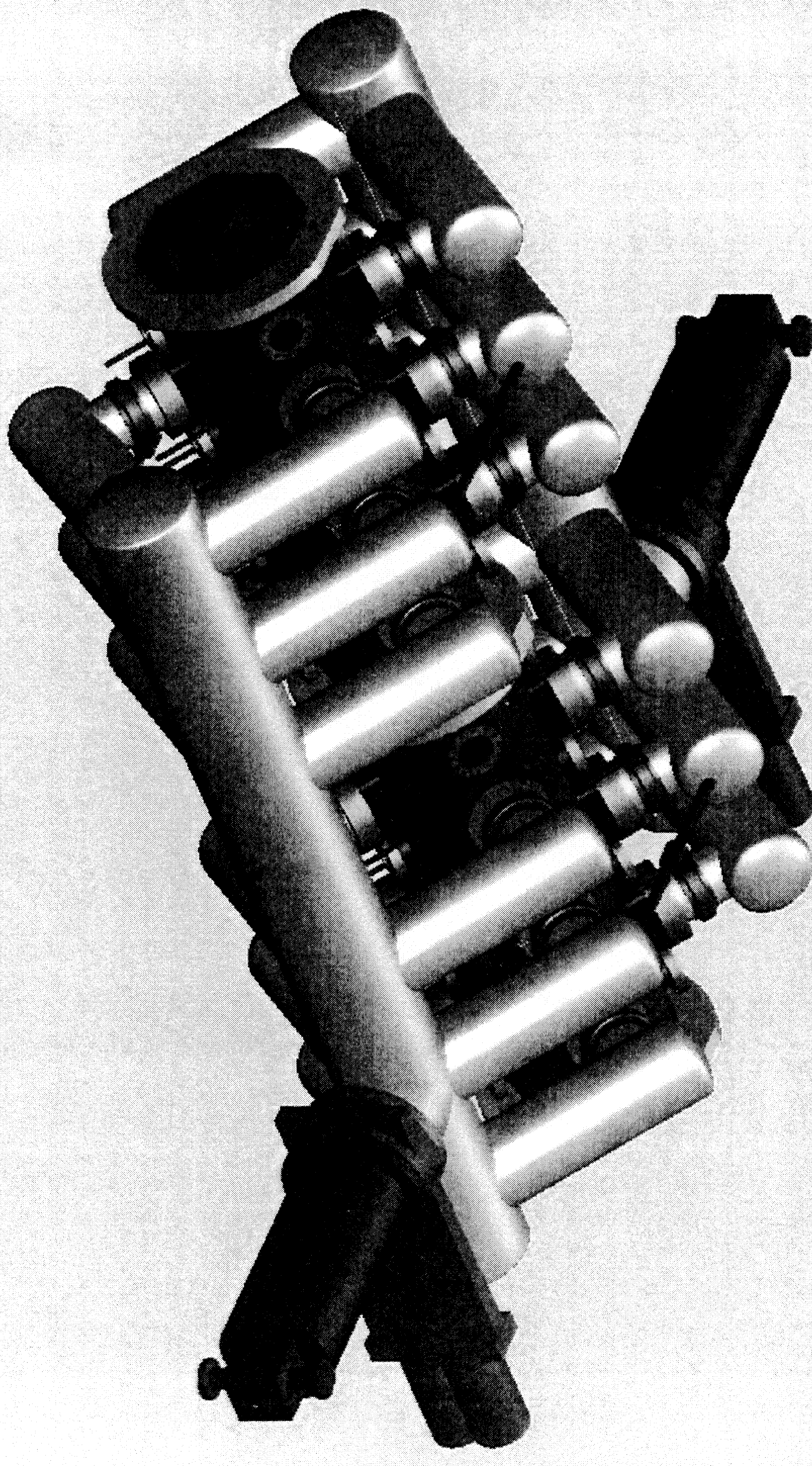
Bunching and acceleration up to 5 MeV **8 m long - 30 μm mechanical accuracy - 100 kW/m RF losses**





Under construction, tuning procedure tested on a cold model





LEL/ DTL :

First construction / test
and 4 cells high-duty cycle prototype

Collaboration with CERN (+ INFN ?)
→ Hot test next year at CERN