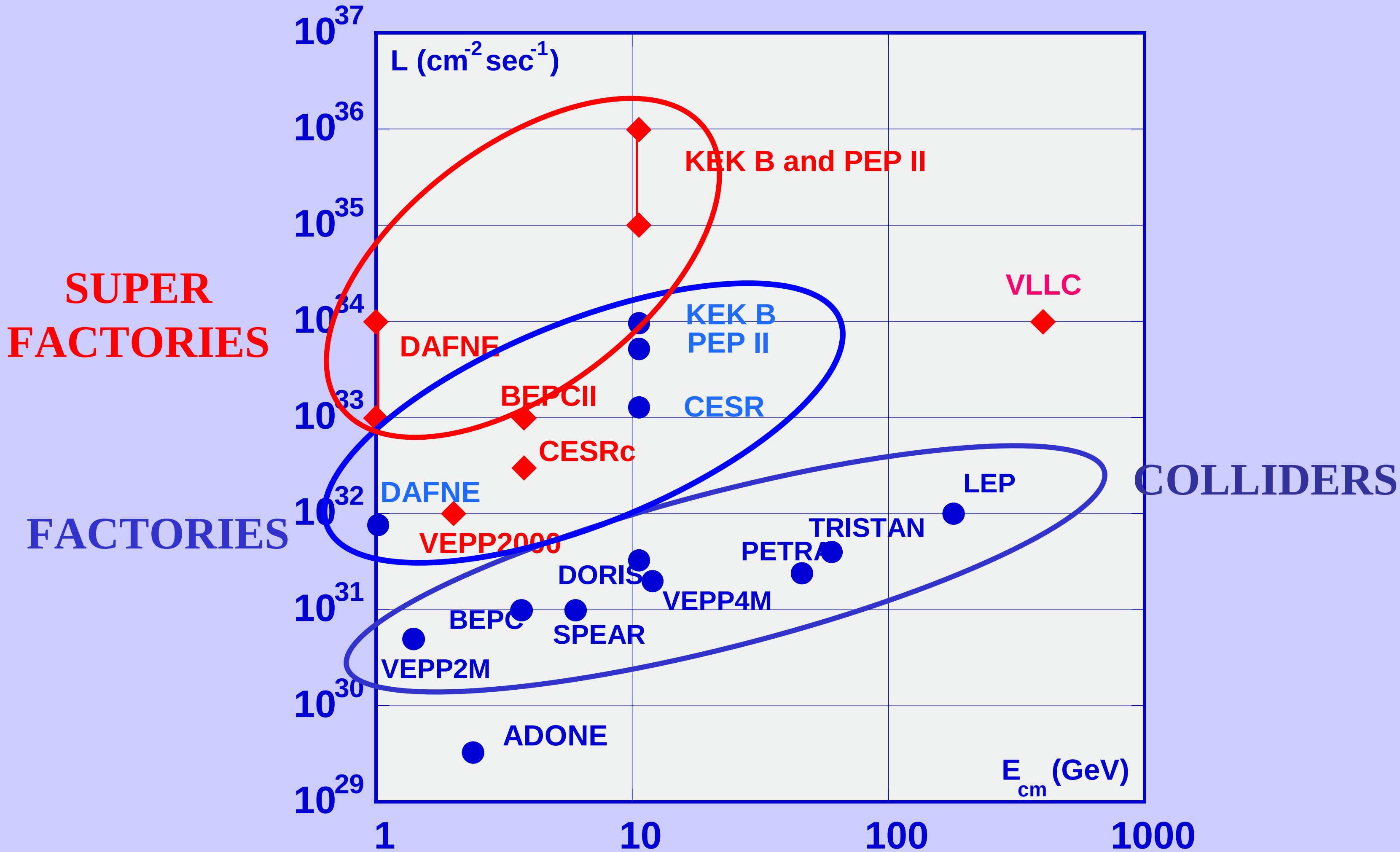
Design study for a Super Φ Factory at LNF

C. Biscari

for the DAΦNE team

LNF, INFN

PAST, PRESENT AND FUTURE

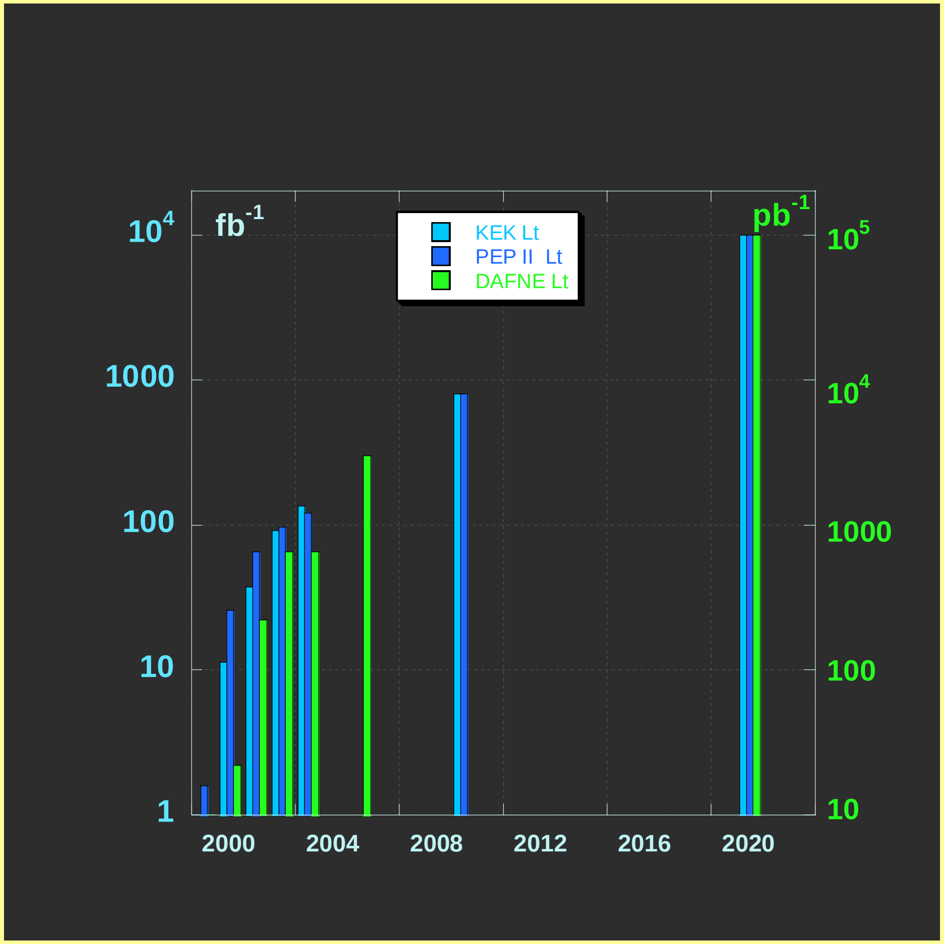


“No first generation machine has ever improved by more than a factor 10 a crucial parameter”

J.P.Delahaye, CLIC Project Leader, october 2003

	E_{cm} GeV	logged ∫L	requested ∫L
B	10.6	~ 300 fb^{-1}	10ab^{-1}
τ	3.9	< 1 fb^{-1}	>100fb^{-1}
light quarks	2	< 10pb^{-1}	500pb^{-1}
Φ	1	< 1 fb^{-1}	> 100fb^{-1}

requested ∫L for next collider generations



Frascati colliders

		E_{cm} (GeV)	L (10^{32})
ADA	1960	0.4	
ADONE	1969/78 1990/93	0.6/3.1	0.003
DAΦNE	1998/2003.. .. 2003/2006	1.	1.

FUTURE x 2 x 100


Workshop on
e+ e- in the 1-2 GeV range:
Physics and Accelerator Prospects
ICFA Mini-workshop - Working Group on High Luminosity e+e- Colliders
10-13 September 2003, Alghero (SS), Italy
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PEAK Luminosity

increase **bunch density**

increase **collision frequency**

AVERAGE Luminosity

continuos injection

$$L = \frac{f_{coll}}{4\pi} \frac{N^+ N^-}{\sigma_x^* \sigma_y^*}$$

high currents

Singlebunch instabilities
Multibunch instabilities
Feedbacks
impedance
ECI
CSR
Power : vacuum, rf, cooling

beam-beam

crossing angle
low β_y – short bunch length
resonances
dynamic aperture
blowup

Background

masks
collimators
cooling
touschek scattering
lattice phase advances
IR designs

lifetime - injection

beam-gas scattering
touschek effect
beam-beam loss rate

$\tau \sim$ hours -> $\tau \sim$ few minutes
$L \sim 10^{34}$ -> $L \sim 10^{36}$

continuos injection

Basic concepts:

Luminosity is generally higher for high energy rings for several reasons, some of the more beneficial are:

1) Tune shifts scales with 1/Energy (E) leading to a fundamental linear increase of the luminosity vs Energy

2) Radiation damping-time decrease with $1/E^3$ leading to higher limits for tune-shifts

3) Touschek effect decrease with $1/E^3$

4) Natural bunch lenght shorter

5) Beam stiffer, single and multi bunch instabilities decrease with 1/E

P. RAIMONDI

DAFNE2

Energy x 2

DAFNE2

Specifications

Upgrade of DAΦNE from the present energy of 1.02 GeV c.m. up to and above the neutron-antineutron threshold, 2-2.4 GeV c.m., using the existing systems and structures.

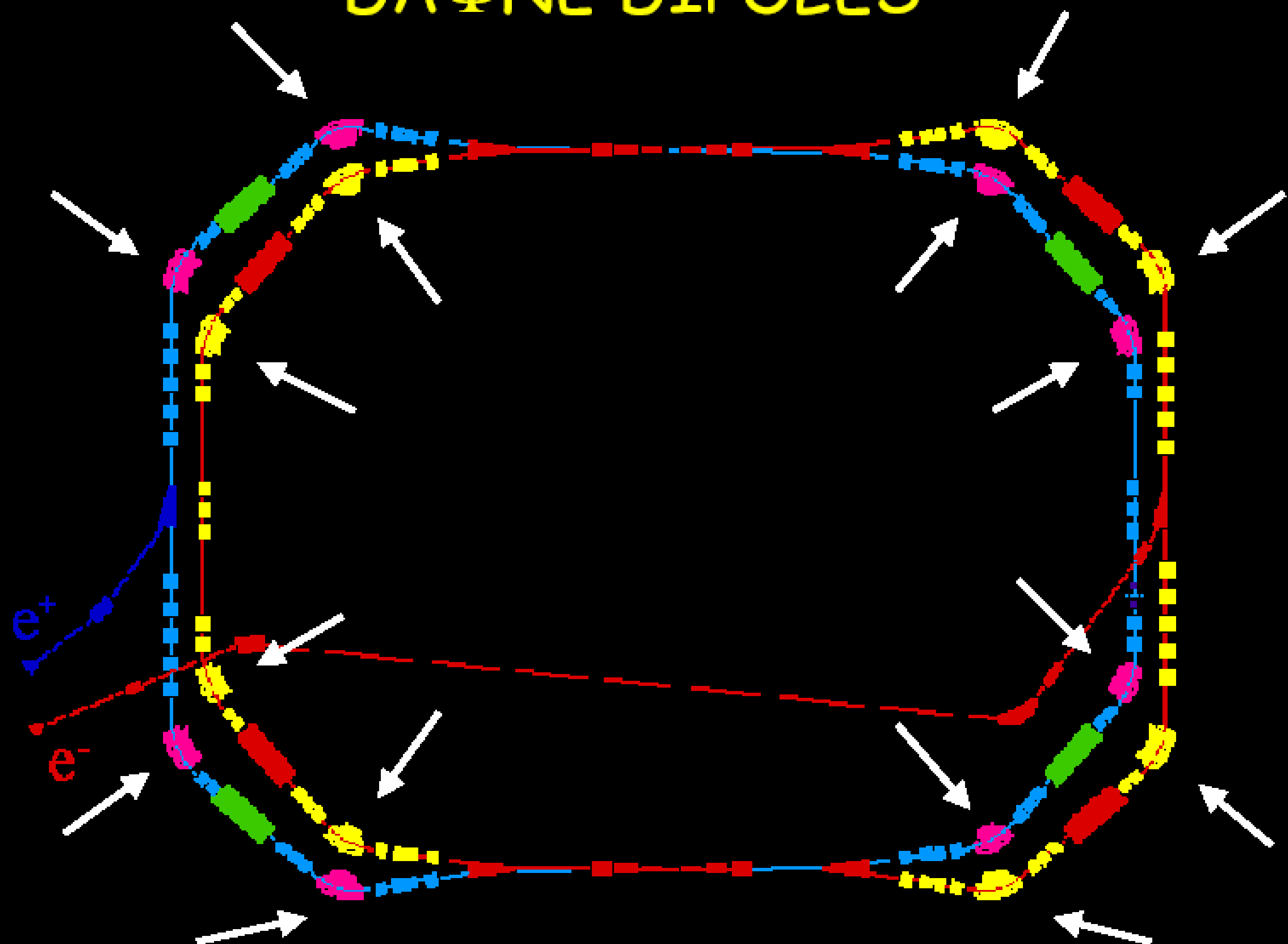
Luminosity ~ 10^{32} cm^{-2} s^{-1}

Compatibility with present operation at Φ

WHAT CAN BE USED FROM DAΦNE

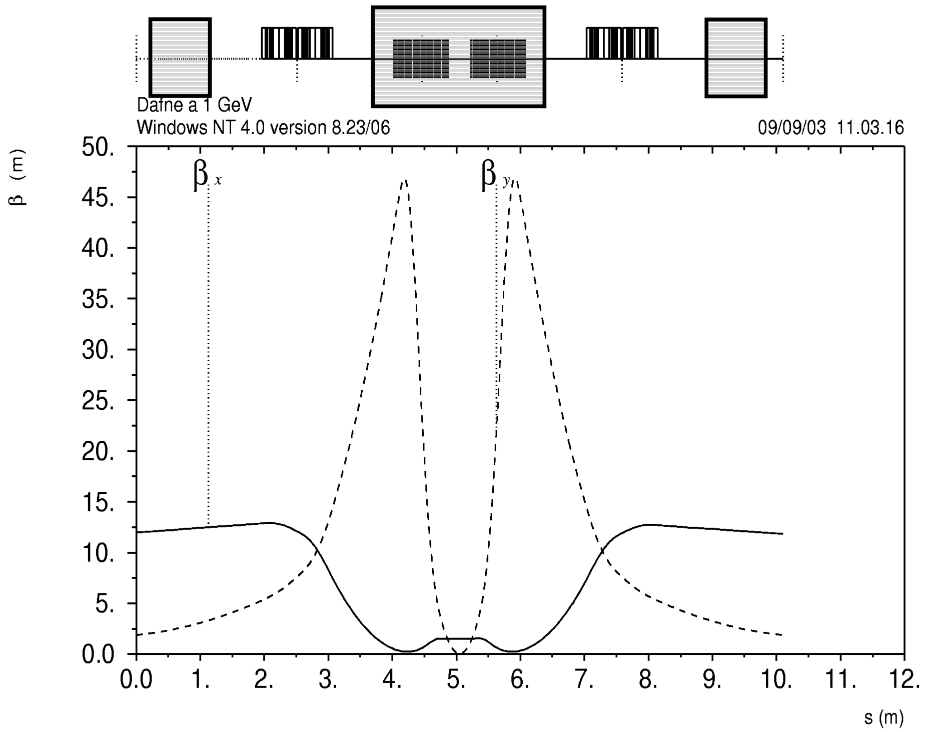
- **DAFNE2 can exploit DAΦNE hardware:**
  - **vacuum chamber**
  - **all quads and sexts**
  - **RF cavity**
  - **Feedback, vacuum system...**
- **But needs new:**
  - **stronger bending dipoles**
  - **4 SC quads in IR2**

DAΦNE DIPOLES



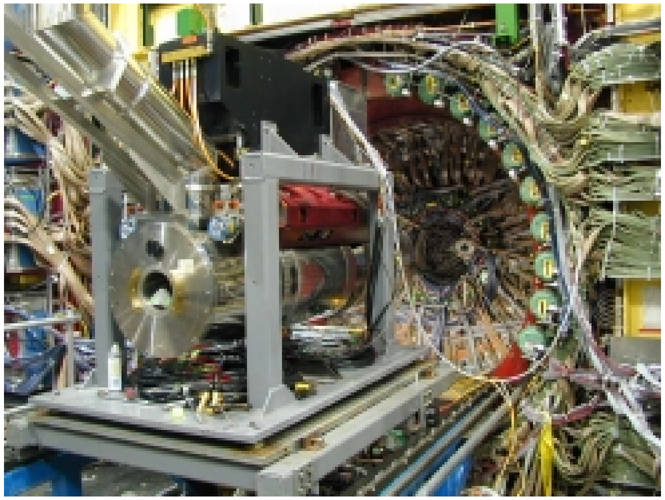
IR2 BETA FUNCTIONS

- $\beta_{\mathbf{x}}$ =2.5 *m* and $\beta_{\mathbf{y}}$ =2.5 *cm*, already achieved at DAΦNE
- FF DFFD FF quad sequence



Superconducting IR Quadrupoles

Requirements



CESR IR

Tunable

510MeV -> 1.2GeV

Solenoid compensation

Superimposed skew quad windings

Alghero workshop
HE working group Conclusions

Energy upgrade to 1.1 GeV/beam straight forward
and at moderate cost

Exploit most of existing hardware

Preliminary design for dipoles
with some questions about
- current dependence of field quality
- current dependence

Parameters of superconducting IR quadrupoles
are well within the range of existing designs

Super DAΦNE

Luminosity x 100

Ideas for Luminosity increase

Some will be tested in near future:

- ❑ Crab cavities (KEK-B)
- ❑ Collisions with round beams (VEPP2000)
- ❑ Negative α_C (KEK-B, DAΦNE)

Others …

- *collisions with neutralized beams (four beams) + feedback system*
- *ring against linac*
- *Monochromators*
- *Collisions with large crossing angle:*

$E_{cm} = 2E_{beam}\cos(\theta_c/2)$,

e.g. $\theta_c/2 = 60°$, $E_{beam} = 1GeV$

Main guidelines for the design
$L > 10^{34}$ at Φ energy

- **Powerful damping**
- **Short bunch at IP**
- **Negative momentum compaction**

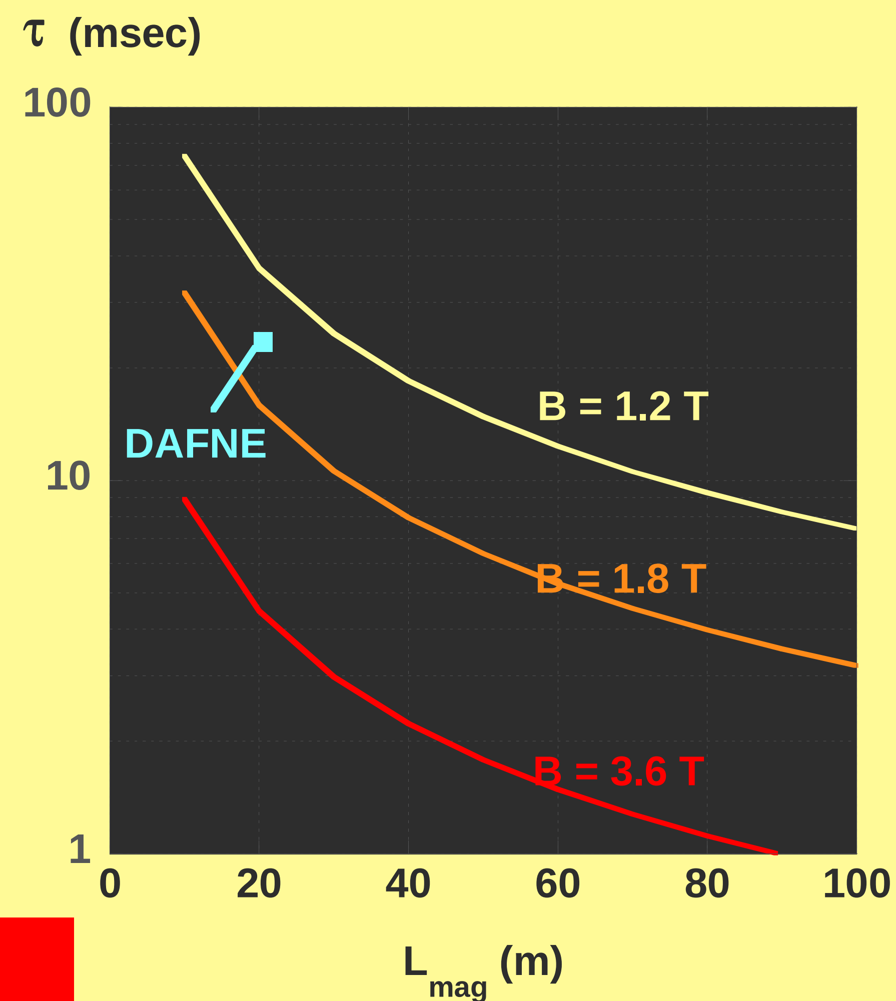
Which kind of collider is possible at Frascati using present infrastructures?

Damping time on magnetic field

$$\alpha_x \approx \frac{C_\alpha}{C} E^3 I_2$$

For C = 100 m
E = 510 MeV

$$\tau_x(\mathrm{sec}) \approx \frac{\rho^2}{2.8\, L_{dip}}$$



Factor 2 on tuneshift
by factor 10 on damping time

Beam Dynamics with $\alpha_c < 0$

- **Bunch is shorter with a more regular shape**
- **Longitudinal beam-beam effects are less dangerous**
- **Microwave instability threshold is higher (?)**
- **Sextupoles are not necessary**

M. ZOBOV

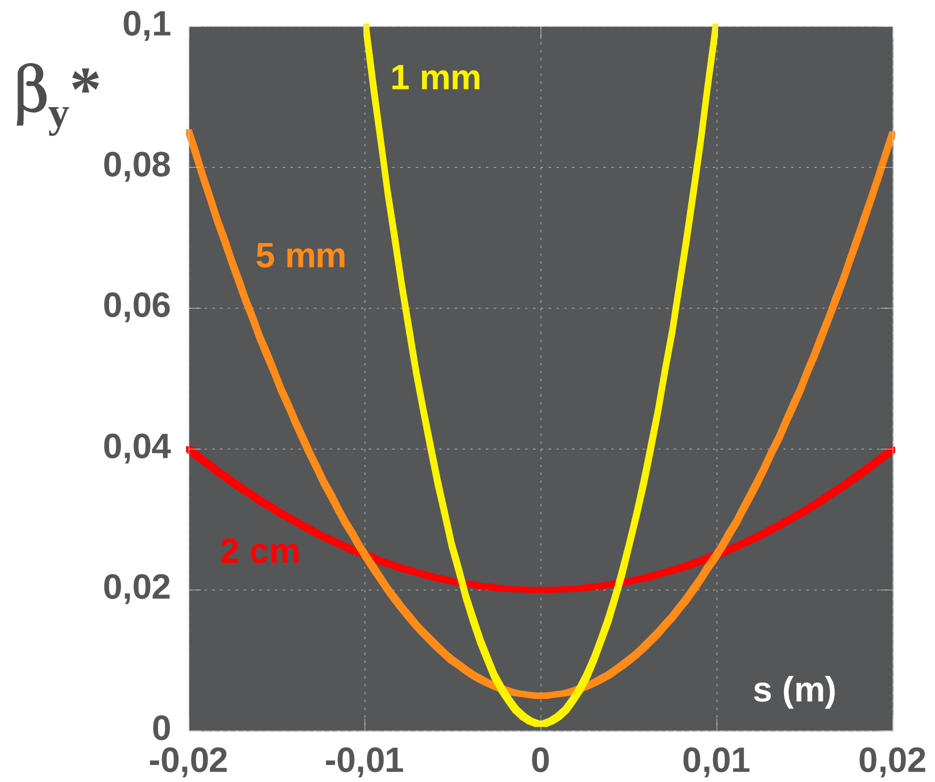
- **It is worthwhile to try a collider operation with a negative momentum compaction factor since this can provide several advantages in beam dynamics**

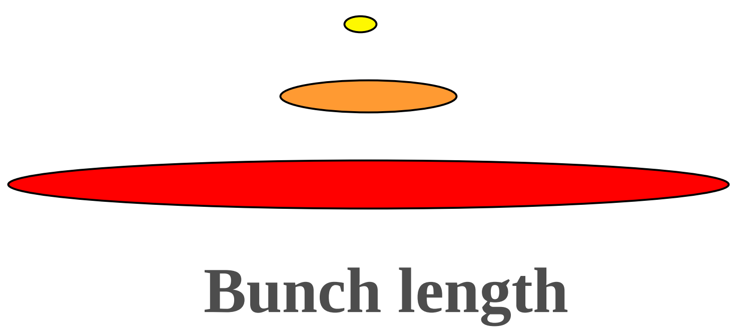
- **Simulations indicate that by shifting the working point close to the integers and applying a lattice with the negative momentum compaction we have a possibility to push DAΦNE luminosity to 10^{33} $cm^{-2}s^{-1}$ level**

M. ZOBOV

Hour-glass effect

Squeezing vertical dimensions is effective only if bunch length is also decreased to the same dimension

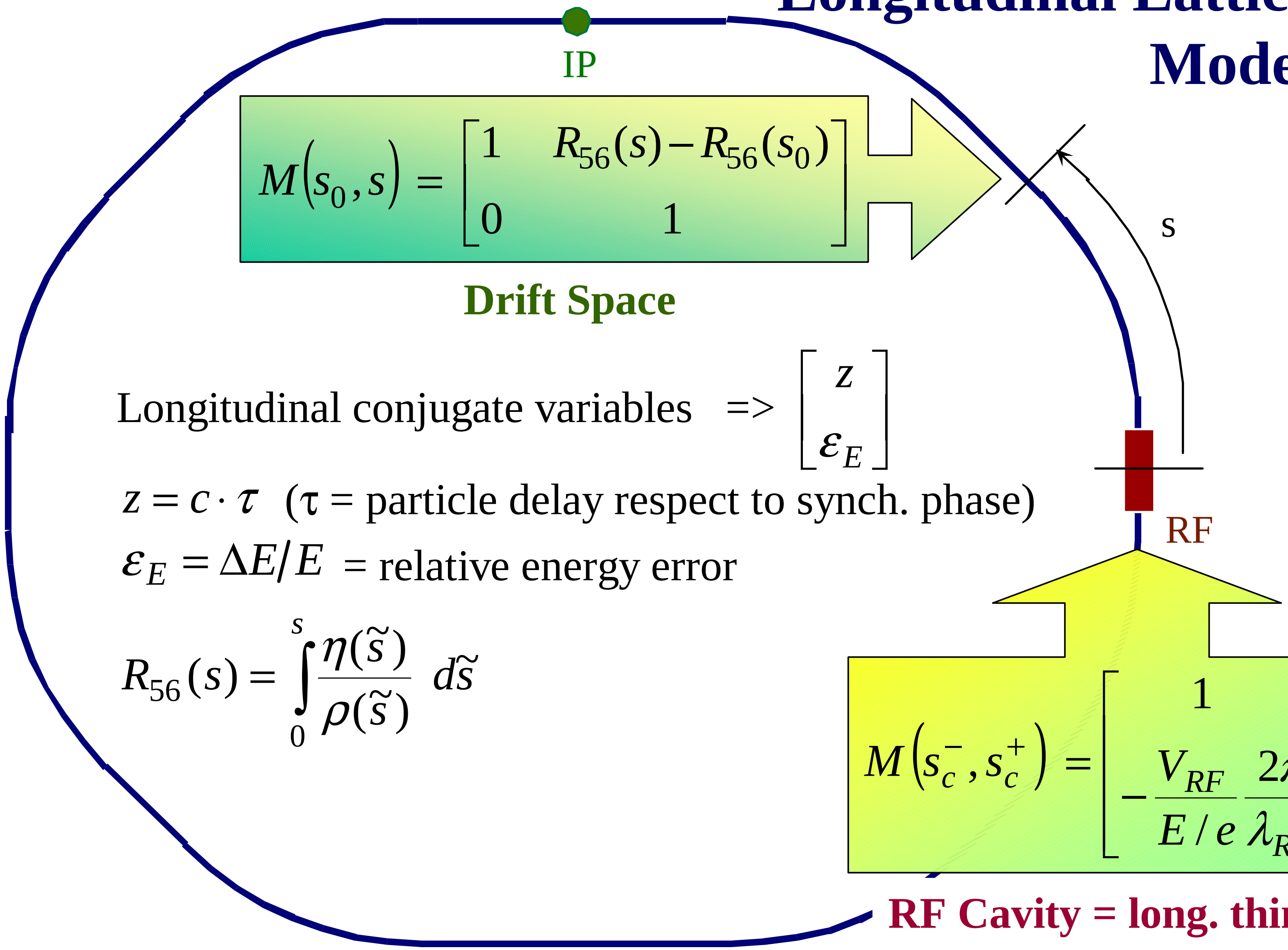




Strong RF Focusing for Luminosity Increase

A. Gallo, P. Raimondi, M.Zobov

Longitudinal Lattice Model



$$M\left(s_0, s\right) = \begin{bmatrix} 1 & R_{56}(s) - R_{56}(s_0) \\ 0 & 1 \end{bmatrix}$$

Drift Space

Longitudinal conjugate variables => $\begin{bmatrix} z \\ \varepsilon_E \end{bmatrix}$

$z = c \cdot \tau$ (τ = particle delay respect to synch. phase)

$\varepsilon_E = \Delta E / E$ = relative energy error

$$R_{56}(s) = \int_0^s \frac{\eta(\tilde{s})}{\rho(\tilde{s})} \, d\tilde{s}$$

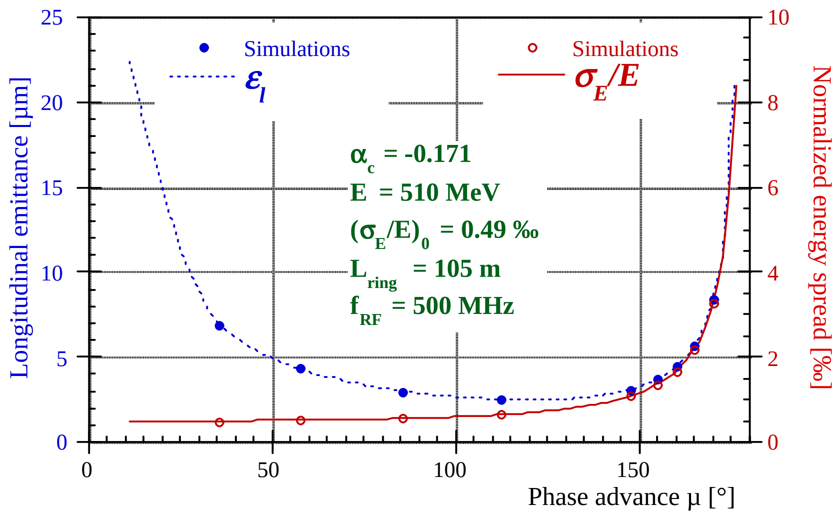
$$M\left(s_c^-, s_c^+\right) = \begin{bmatrix} 1 & 0 \\ -\frac{V_{RF}}{E/e} \frac{2\pi}{\lambda_{RF}} & 1 \end{bmatrix}$$

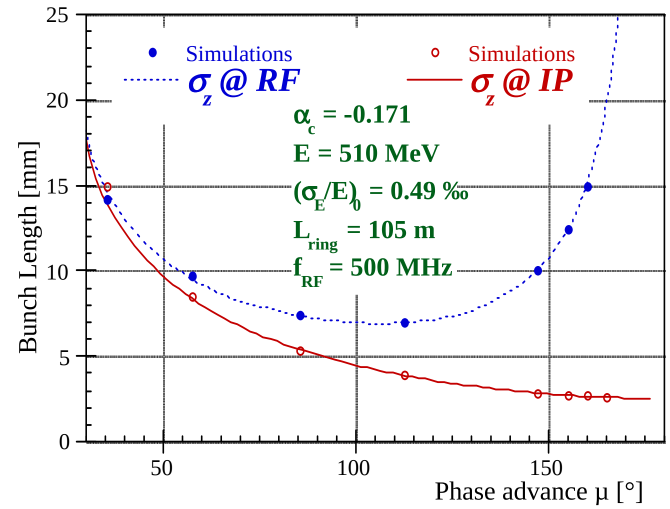
RF Cavity = long. thin lens

Varying bunch length along the ring

Comparison with Numerical Results:

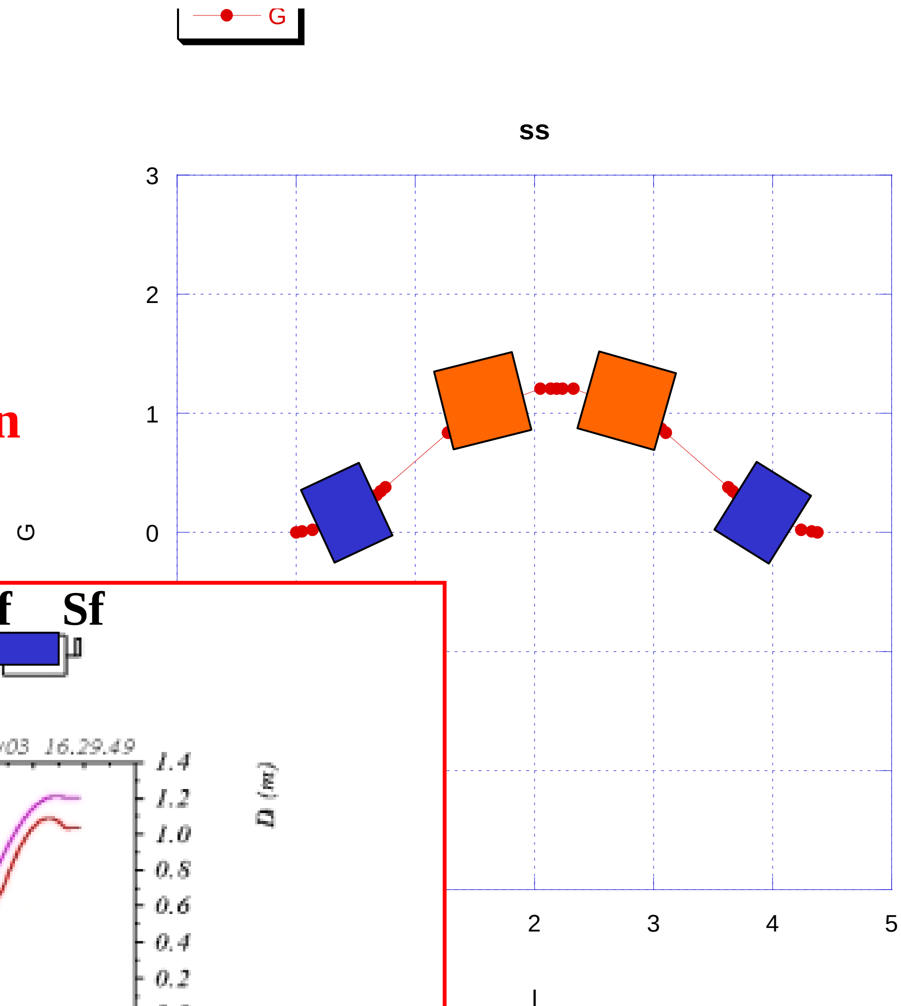
These analytical results have been compared with multi-particle tracking simulations of the bunch longitudinal dynamics in a strong RF focusing configuration. Uniform R_{56} growth and emission rate in the arcs have been assumed in the tracking. The agreement is evident.

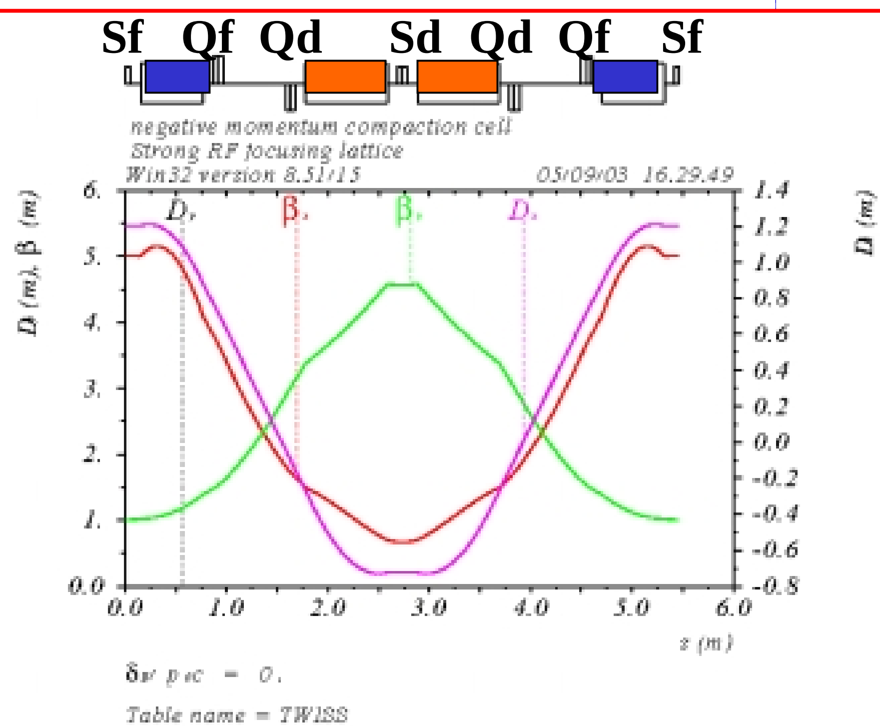




HIGH and NEGATIVE MOMENTUM COMPACTION

strong RADIATION emission

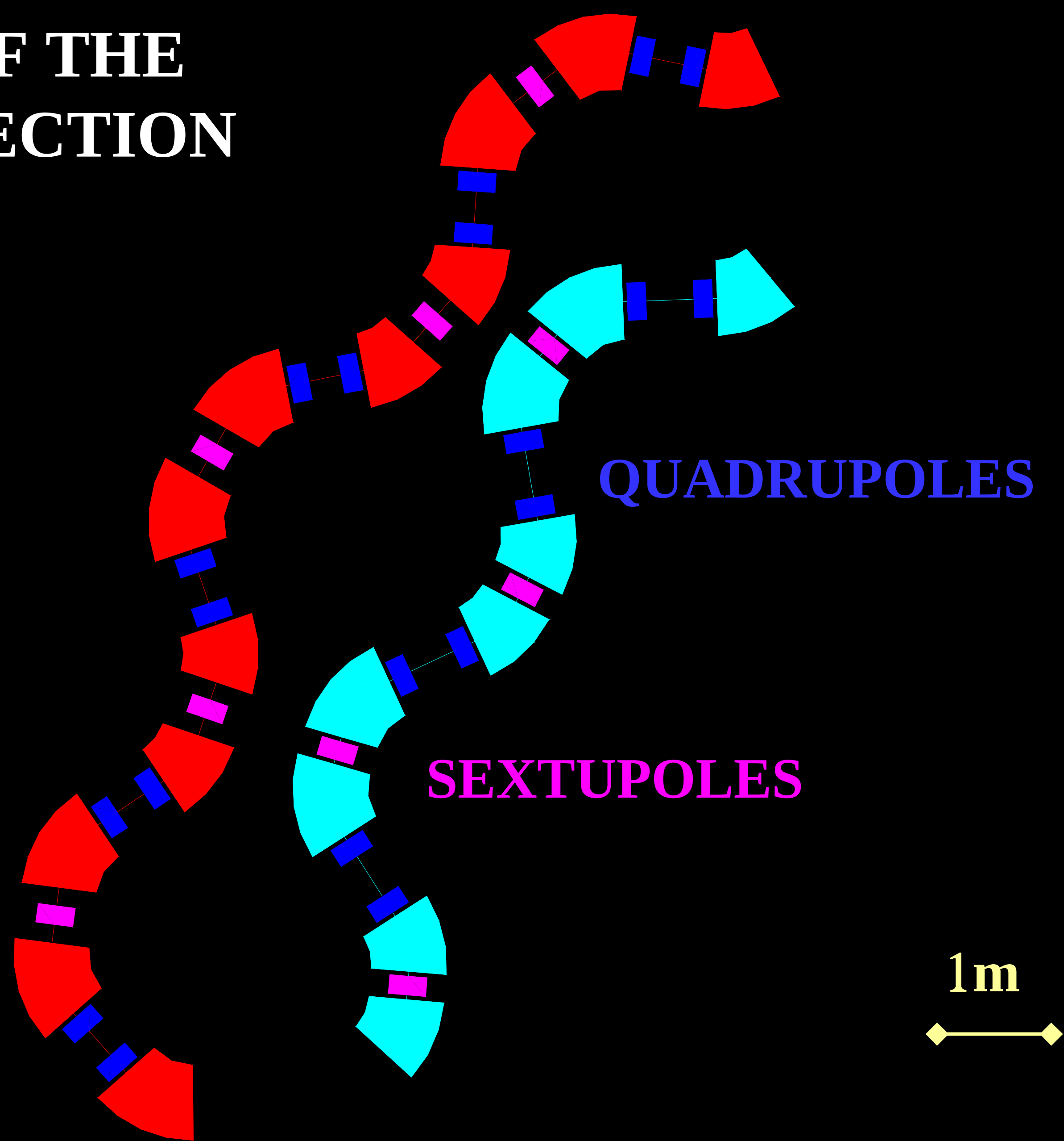




Alternating positive and negative bending dipoles

(proposed by Raimondi)

ZOOM OF THE RINGS SECTION



WORKING POINT OPTIMIZATION FOR A SUPER Φ-FACTORY DESIGN BASED ON THE STRONG RF FOCUSING

A. Gallo, 25/09/2003 DAFNE2 meeting

The Working Point of a strongly RF focused ring consists in a set of values for the following fundamental parameters:

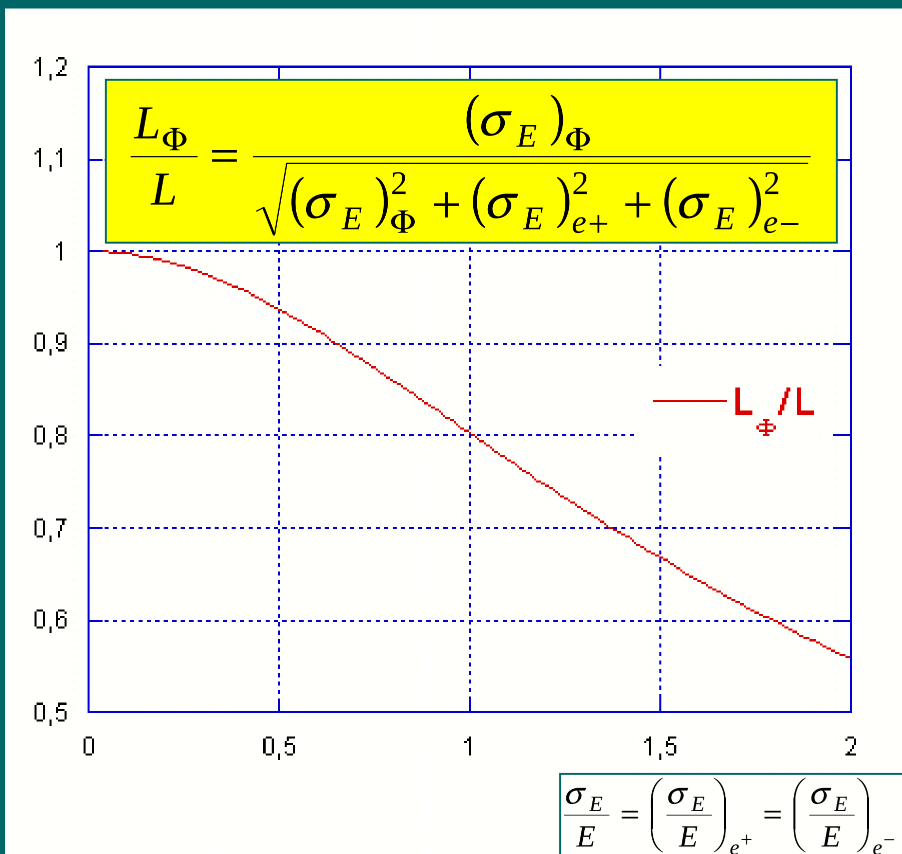
1	μ	One-turn synchrotron phase advance
2	$\frac{\sigma_E}{E}$	Energy spread of the equilibrium distribution in the strong RF focusing regime
3	$R_{56}(L) = \alpha_c L$	One-turn normalized path elongation (total $\boldsymbol{R_{56}}$)
4	$\left.\frac{\sigma_E}{E}\right\|_0$	Energy spread of the equilibrium distribution in the "weak" focusing regime (μ <<1)
5	V_{RF}	RF Voltage
6	λ_{RF}	RF wavelength

to obtain the required bunch length $\boldsymbol{\sigma_z}$ at the IP.

2. Bunch energy spread in the strong RF focusing regime

The bunch energy spread rapidly grows with the phase advance and its maximum acceptable value is limited by:

- The Φ-resonance width;
- The machine energy acceptance (quantum lifetime)



To avoid Φ production degradation:

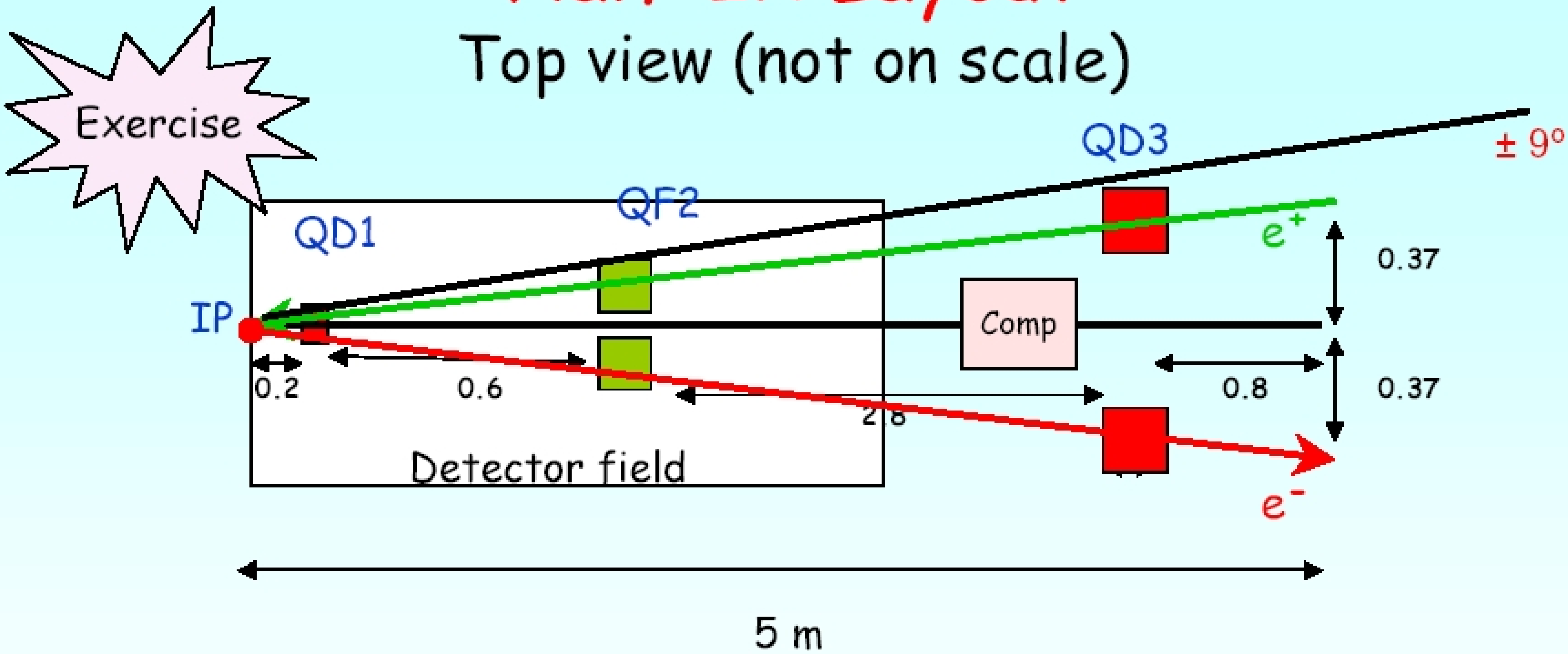
$$\sigma_E/E \leq 1.4\ ‰$$

The beam quantum lifetime requires a ring energy acceptance of ≈1% at least.

$\sigma_z(IP)$	σ_E/E
3 mm	1.2 ‰
2 mm	1.4 ‰
1 mm	1.4 ‰

Half-IR Layout

Top view (not on scale)



With $\pm 10\sigma_x$ clearance, $\pm$ 9° cone, ±30 mrad angle:

QD1: L= 20 cm, pole radius = 1.5 cm, R_{ext} = 3 cm, pm thickness= 1.5 cm small

QF2: L= 20 cm, pole radius = 11 cm, R_{ext} = 16 cm, pm thickness= 1.5 cm,
4 cm space between 2 quads

QD3: L= 20 cm, pole radius = 15 cm , R_{ext} = 63 cm, 25 cm space between 2 quads

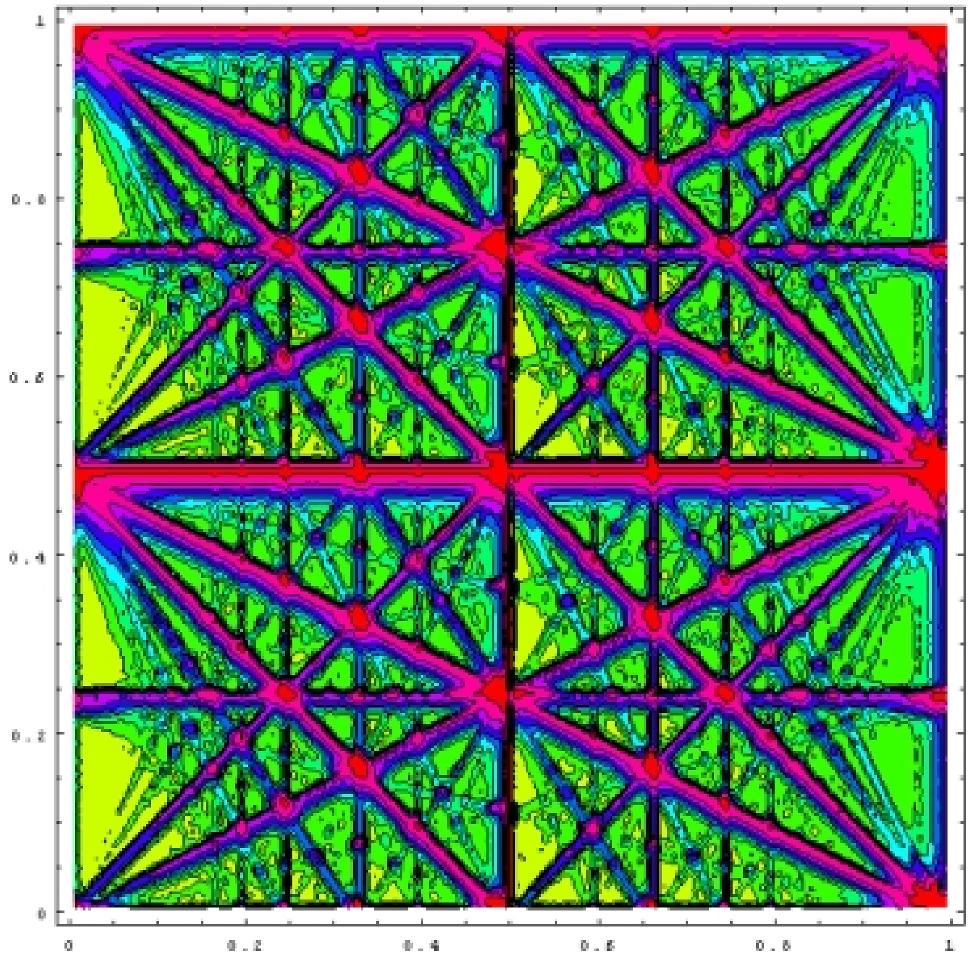
Dynamic aperture

First evaluation by
E.Levichev, P.Piminov [*)]
BINP, Lavrentiev 13, Novosibirsk 630090, Russia

ACCELERATICUM computer code [*]
Symplectic 6-D tracking for transversely and longitudinally coupled magnetic lattice

[*] Tracking code ACCELERATICUM, VEPP-4M Internal Note, BINP, Novosibirsk, 2003.

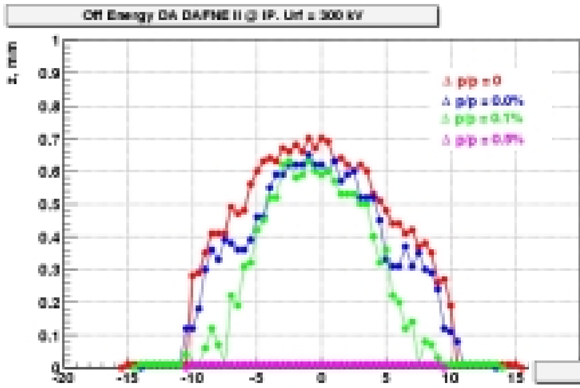
Choice of the working point



Tune footprint
in 2D - transverse

Adding the longitudinal phase plane:

3D – resonances



----- no synchr oscill

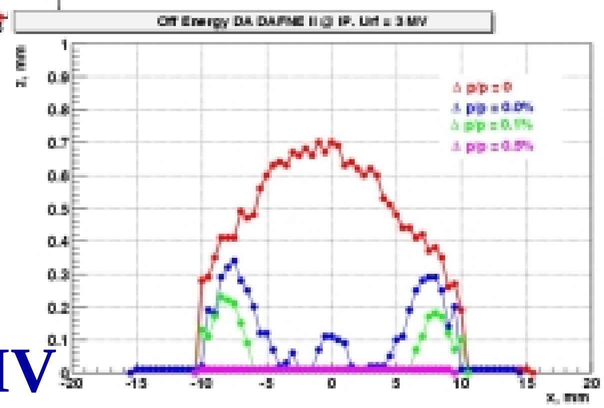
----- Dp/p = 0

----- Dp/p = 0.1%

----- Dp/p = 0.5%

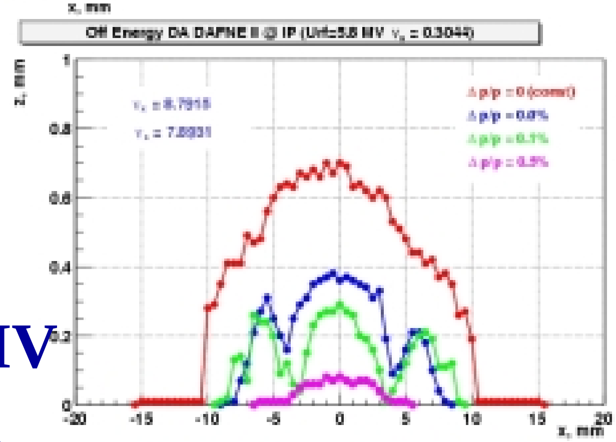
V = 300 kV

Q_s = 0.059



V = 3 MV

Q_s = 0.2



V = 5 MV

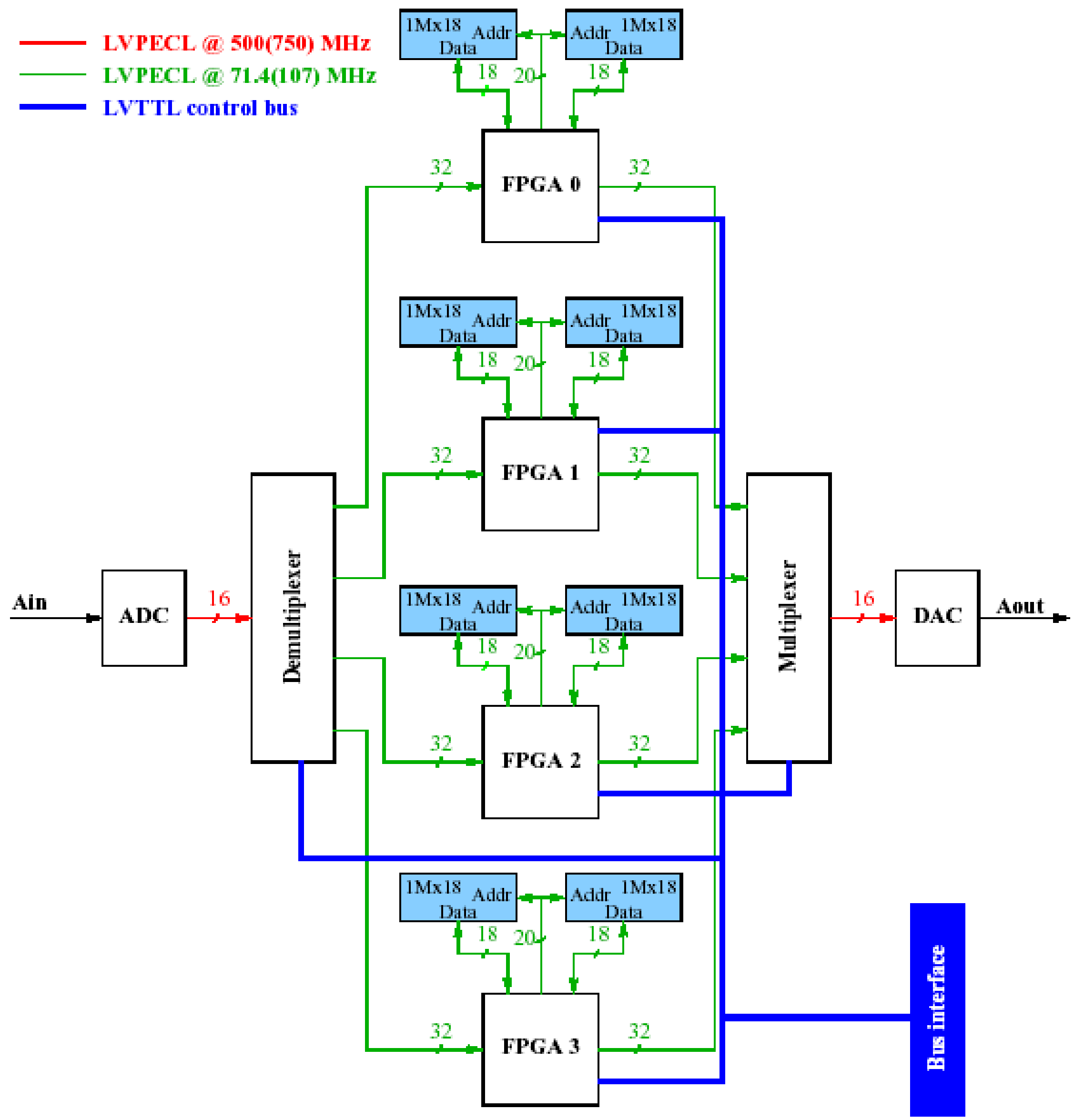
Q_s = 0.3

Strong dependence on V
but specially on Q_s
=> Resonances in 3D

Feedback systems
First analysis
by J.Fox, D. Teitelmann
SLAC

GBoard 1.5 GS/sec. processing channel

- Next-generation instability control technology
- SLAC, KEK, LNF-INFN collaboration - useful at PEP-II, KEKB, DAFNE and several light sources.
- Transverse instability control
- Longitudinal instability control
- High-speed beam diagnostics (1.5 GS/sec. sampling/ throughput rate)
- Builds on existing program in instability control and beam diagnostics.
- Significant advance in the processing speed and density previously achieved.



DAΦNE with strong RF focusing

As an example we will consider the effect of proposed RF configuration on longitudinal feedback

The proposed design has a much higher gap voltage which results in significantly shorter bunches at the IP and higher synchrotron frequency.

Parameter	Current	Proposed
RF frequency (f_{rf})	368.25 MHz	500 MHz
Momentum compaction (α_c)	0.029	-0.171
Circumference (L)	97.69 m	105 m
Revolution frequency (f_{rev})	3.069 MHz	2.857 MHz
Harmonic number	120	175
RF voltage (V_{rf})	120 kV	10.677 MV
Synchrotron frequency (f_s)	30 kHz	1.31 MHz
Revolutions per synchrotron period	~102	2.18
Bunch length (σ_z)	19 - 38 mm	2.6 - 20.4 mm

Beam lifetime (S.Guiducci)

Touschek lifetime has been calculated with a preliminary set of longitudinal parameters. A further optimization is possible.

Anyway

At **$L = 10^{34}$**

lifetimes are of the order of 10 minutes

- continous injection is needed

Background

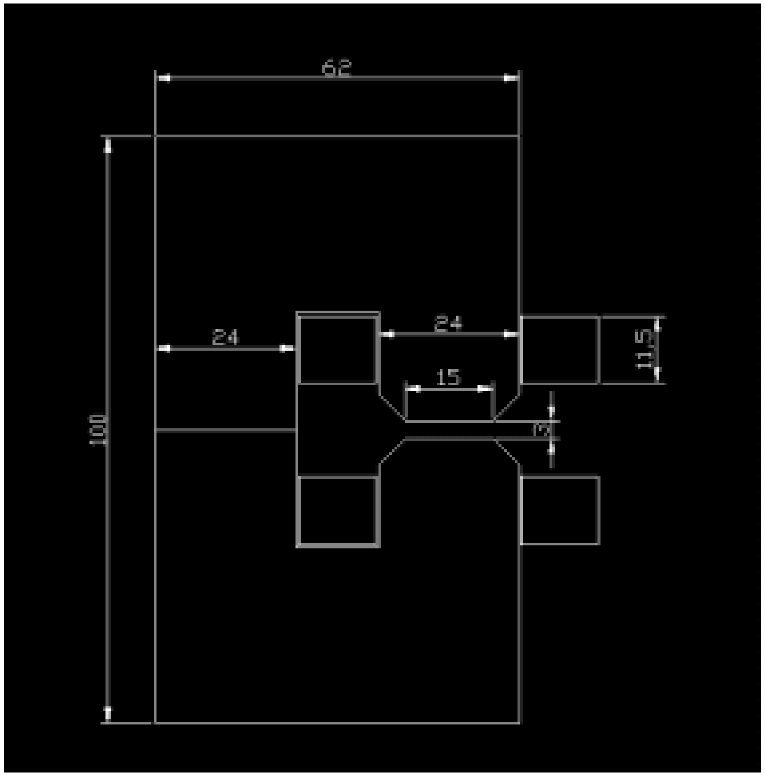
High current
Short beam lifetime
Continuos injection

} **High rate of particle losses**

Dominated by Touschek lost particles
IR design together with detector design

Dipole parameters

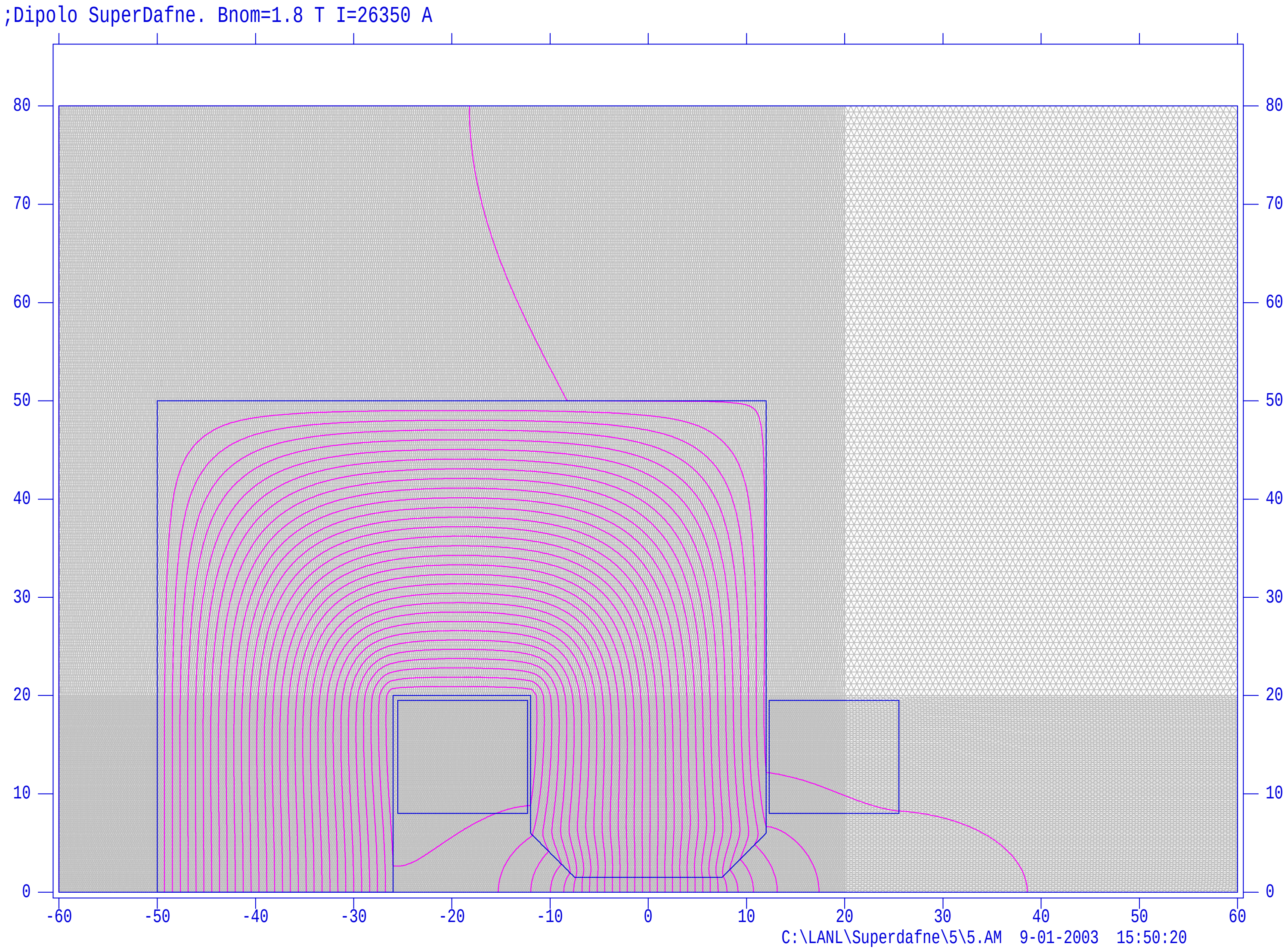
Type	A	B	C
N	22	22	4
Alfa [rad]	0.6545	0.8528	0.5236
Chord [m]	0.607	0.781	0.489
Sagitta [m]	0.050	0.085	0.032
Mag lenght	0.618	0.805	0.494
Vol Fe [mc]	0.282	0.362	0.227
Vol Cu [mc]	0.041	0.047	0.037
Weight Fe [kg]	2222	2859	1789
Weight Cu [kg]	359	410	324
Total Weight [kg]	2581	3269	2113
Power [W]	7234	8260	6537

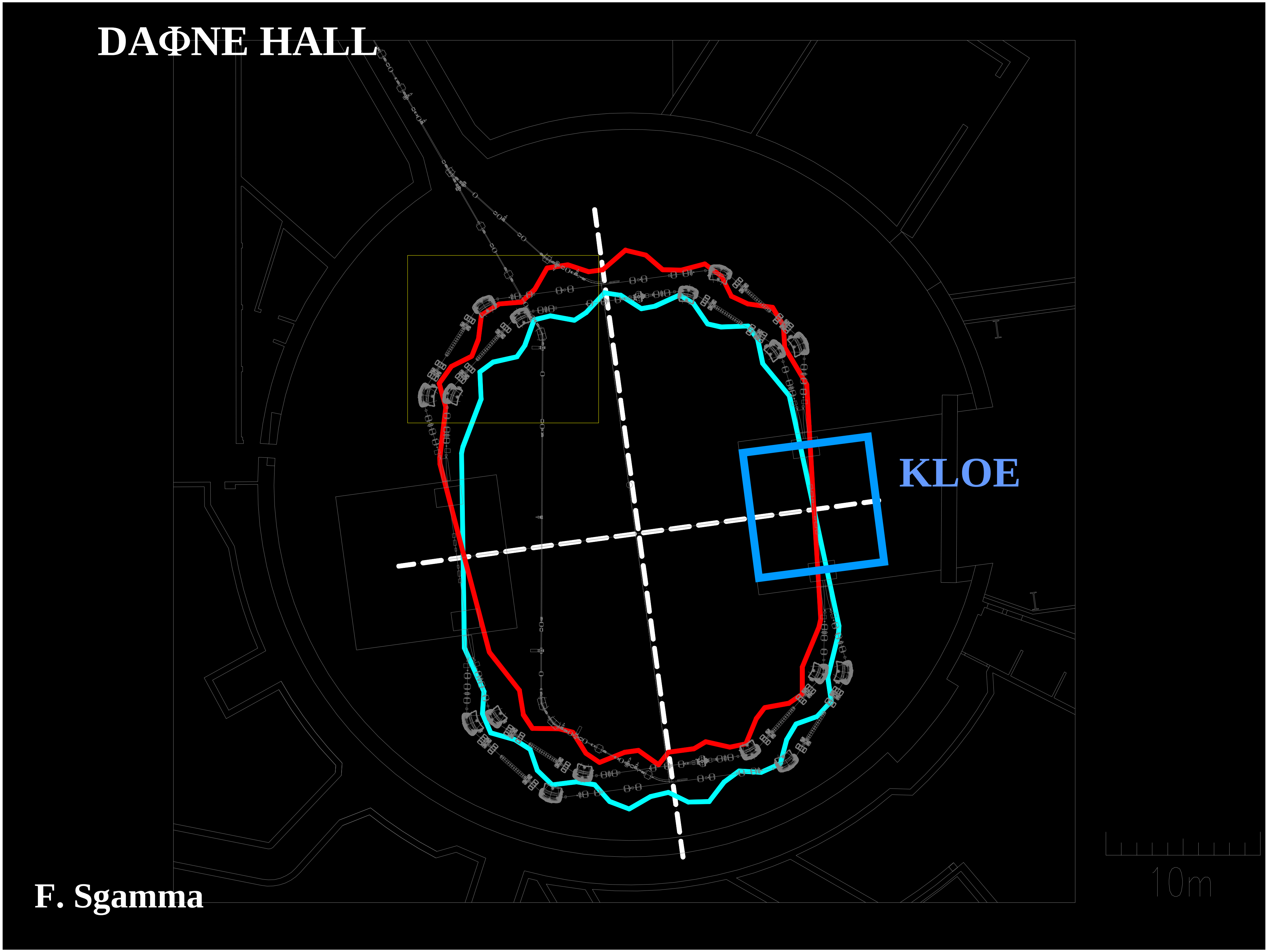


NI [A]	26350
J [A/mmq]	3.2
Total power [kW]	370

Cost evaluated: 1600 k€

Poisson FEM simulation

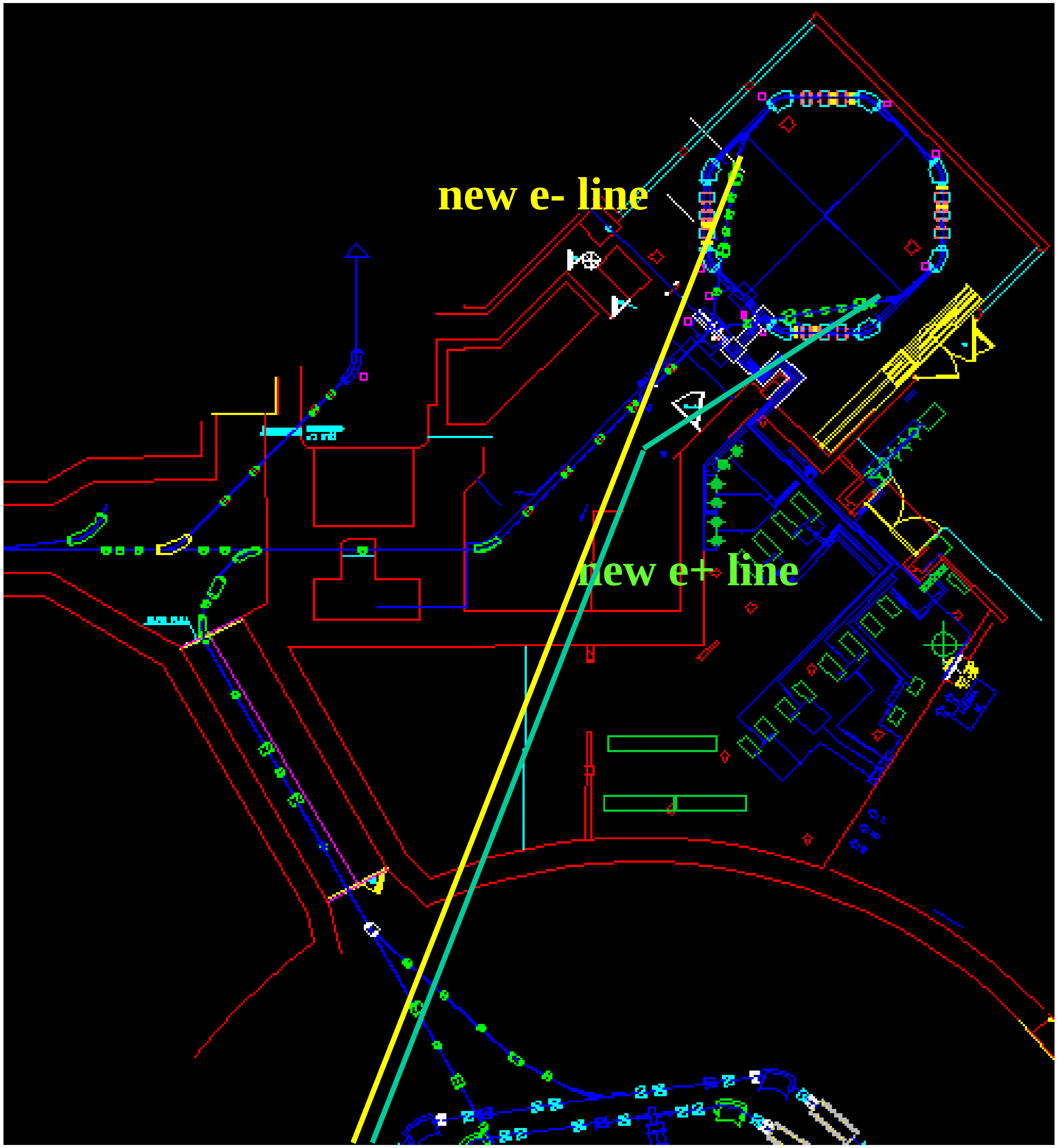



DAΦNE HALL
KLOE
10m
F. Sgamma

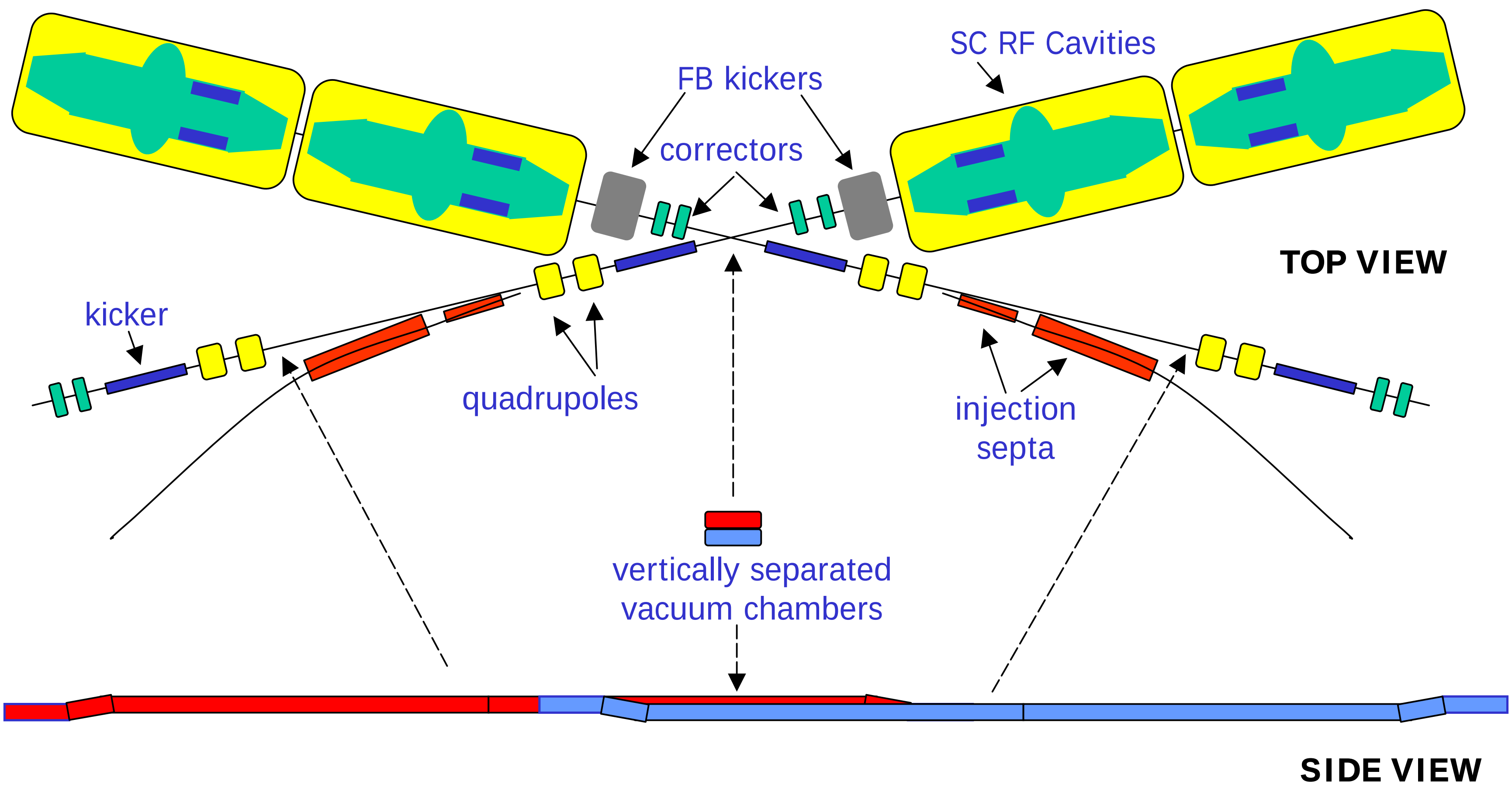
Injection system upgrade

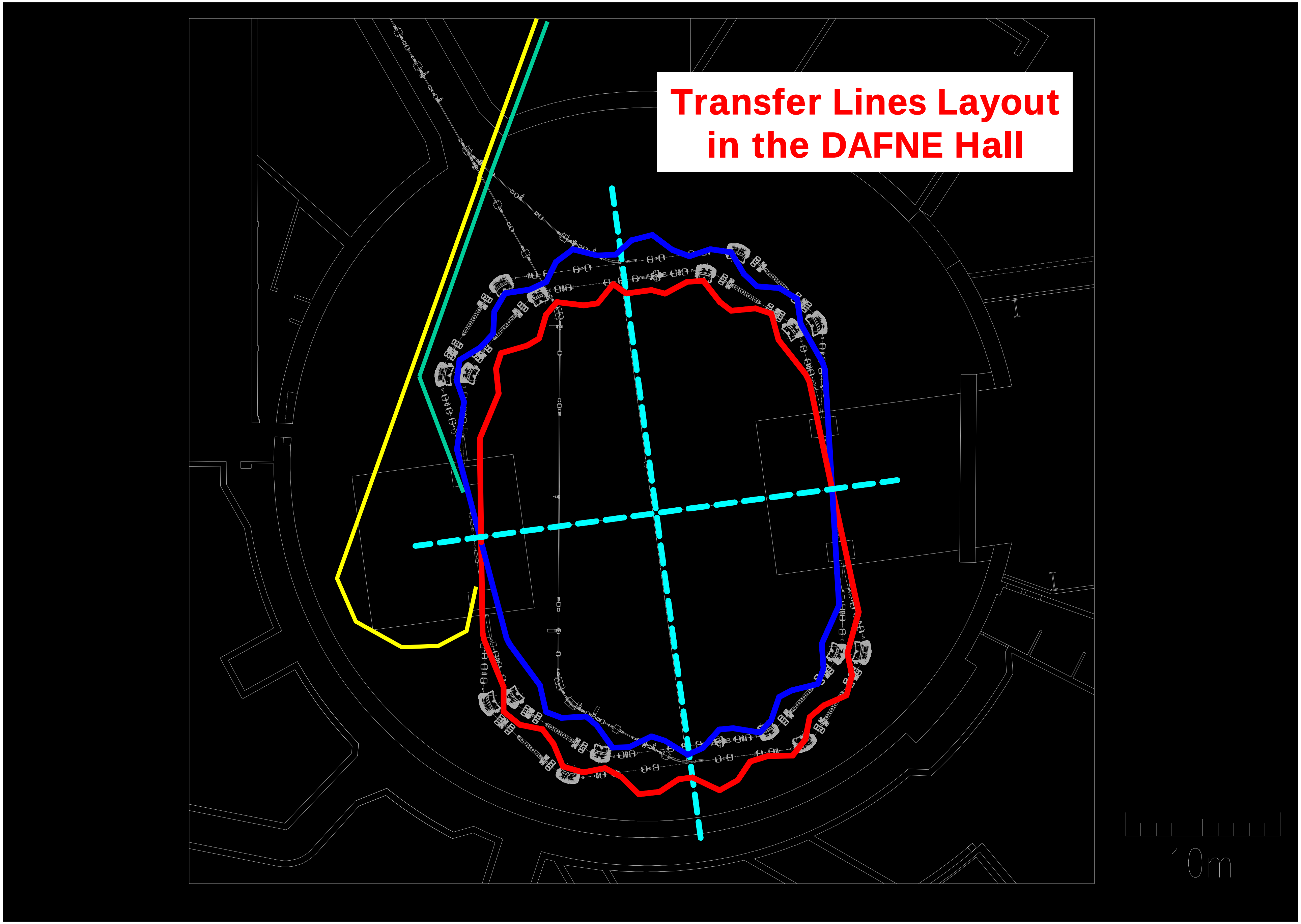
- The proposed transfer lines pass in existing controlled area

- Additional shielding needed in the area between the accumulator and DAFNE buildings



Crossing point section schematic layout




Transfer Lines Layout
in the DAFNE Hall
10m

Luminosity 10^{34}

set of consistent parameters

new → $\alpha_C = -0.17$

$N^{+,-} = 5\ 10^{10}$

$\beta_x = 0.5\,m$

$\beta_y = 2\,mm$

$\varepsilon_x = 0.26\,\mu rad$

$\kappa = 0.6\%$

$n_b = 150$

$I_b = 22\,mA$

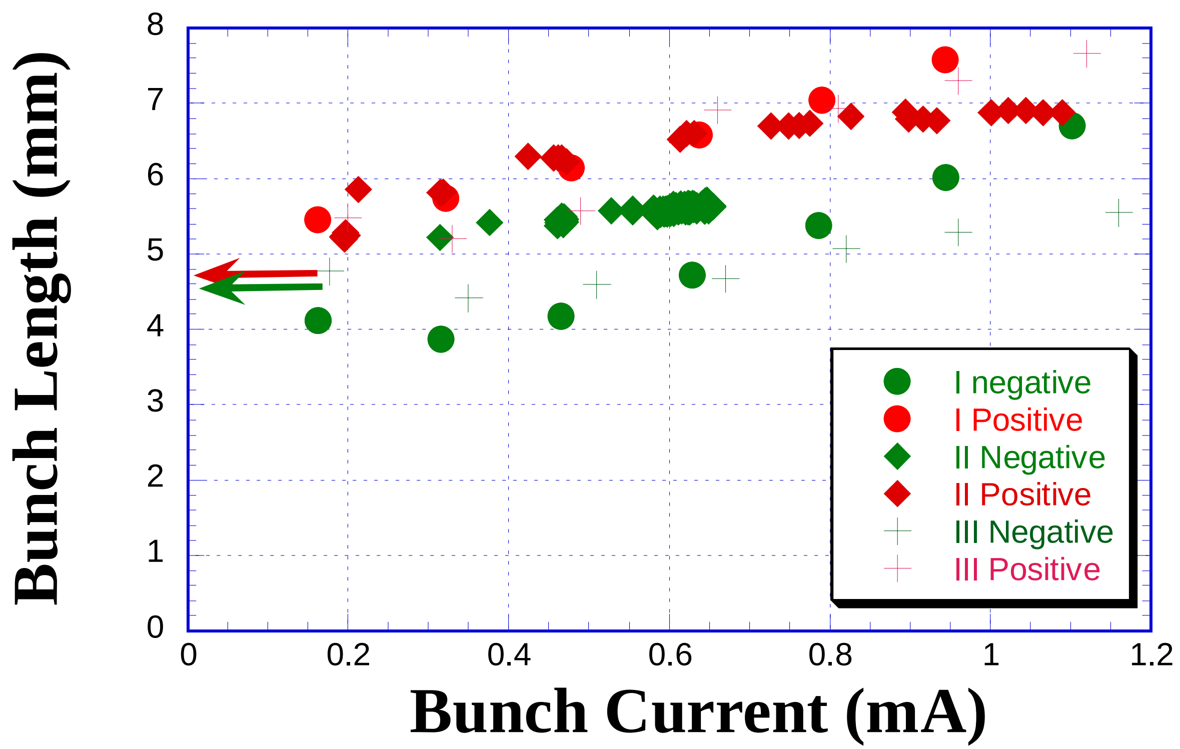
$I_{tot} = 3.3\,A$

challenges → β_y, I_b

MAIN PARAMETERS	
C (m)	105
E (MeV)	510
f_{rf} (MHz)	497
V (MV)	10
ε_x (μ rad)	0.26
ε_y (μ rad)	0.002
α_c	- 0.165
β_x^* (m)	0.5
β_y^* (mm)	2.0
N / bunch	5 e10
h	180
L /bunch (cm^{-2} sec^{-1})	$9\ 10^{31}$
L tot (cm^{-2} sec^{-1})	1.4 (1.@Φ) 10^{34}

Tests foreseen in collaboration with other machines

Negative alfa tests at KEKB



Ikeda, KEKb

We are considering the possibility of testing the strong RF focusing
in PEP2, KEK-B, CESR, ALS, …

10^{33}

Optimistic extrapolation of present knowledge and technologies

10^{34}

Very challenging design based on new ideas

Proofs of principle and validation needed

10^{35}

……………

DAFNE status and outlook

- Adiabatic changes on DAFNE approaching to an end.
- DAFNE performances expected to reach the original design goals (L= 5 * 10^{32}), within the next 2 years.
- 3- 4 years of physics program fully booked with current (or slightly upgraded) detectors.
- After that, only radical changes possible

S. Bertolucci, closing Alghero workshop

Conclusions

Energy X 2

Feasible, reasonable cost and time

AND / OR

L X 100

Challenging

Interesting

Worth preliminary design report

in collaboration with other Institutes (already begun)

Depends strongly on physics community interest