FEASIBILITY STUDY of a 2 GeV LEPTON COLLIDER at DAFNE

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Abstract

While the main advances in the Standard Model probing require the construction of very high-energy colliders, many open questions still remain which can be answered by exploring low and medium energy regions.

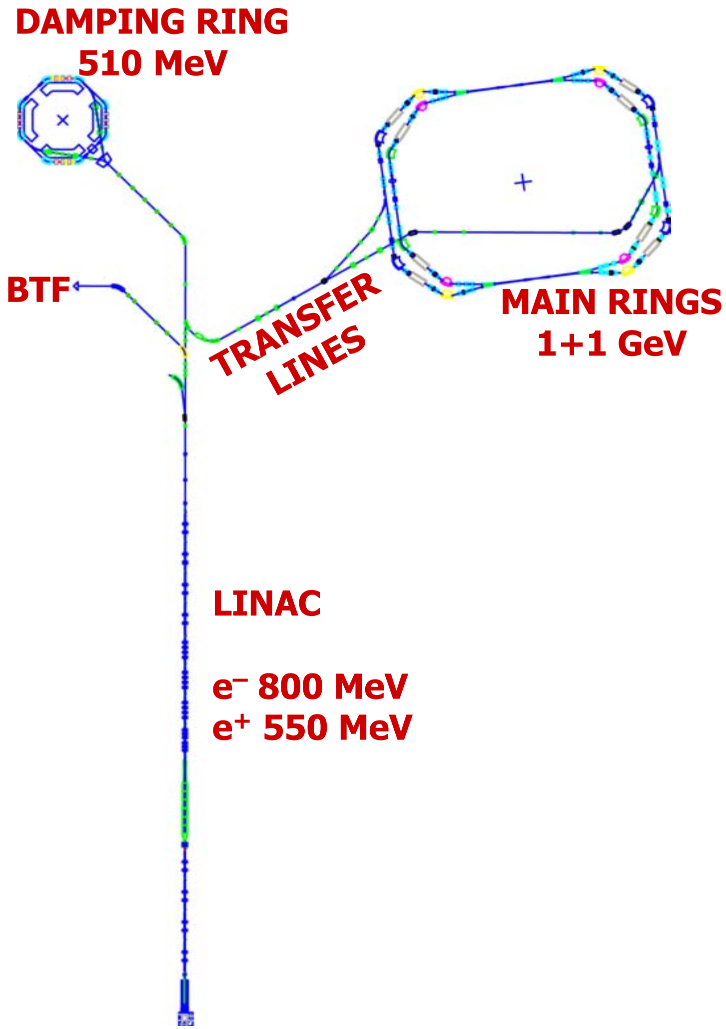
In this framework we are investigating the possibility of upgrading the ϕ-factory DAΦNE from the energy of 1.02 GeV c.m. up to the neutron-antineutron threshold (about 2 GeV c.m.) using the existing systems and structures.

The luminosity required by the experiments for a light quark factory *is of the order of few 10^{31} cm^{-2} s^{-1}, easily achievable in the particle factory era. The very first results of the feasibility study are presented.*

DAFNE2: FROM 1.02 TO 2 *GeV* c.m.

The hypothesis called DAFNE2
(**D**ouble **A**nnular **F**rascati $e^+ e^-$ factory for **N**ice **E**xperiments at **2** GeV)
is aimed at the measurement of the form factors of the nucleon and the QCD excited states in the
1.2 to 2–2.5 *GeV* c.m. energy range.

DAFNE2 can use the existing **injection system** (linac, damping ring and transfer lines) **at 0.51** *GeV* and the two Main Rings with limited changes in the hardware to reach 1–1.25 *GeV* per beam.



PHYSICS AT A LIGTH QUARK FACTORY

Neutron time-like Form Factors

Measured only once (at ADONE): ~ 100 events
Unexpected $\sigma(e^+ e \rightarrow n\ n) > \sigma(e^+ e^- \rightarrow p\ p)$

Very difficult by means of Initial State Radiation

Λ time-like Form Factors

Measured only once (at DCI): 4 events
Very difficult by means of ISR

Proton time-like Electric Form Factor and Phase

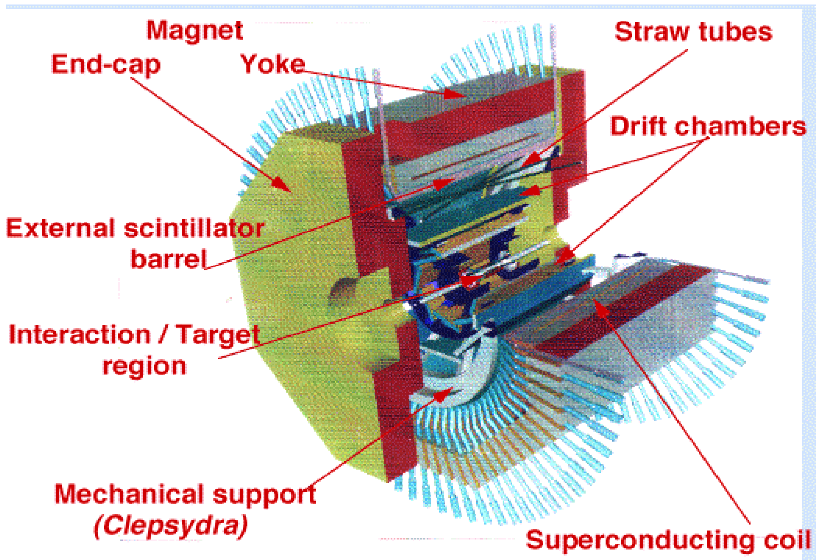
Never measured
Difficult by means of ISR

Looking for non qq states in multihadronic production

"Exotic" Isoscalars expected cross sections < 1 *nb*
Very difficult by means of ISR

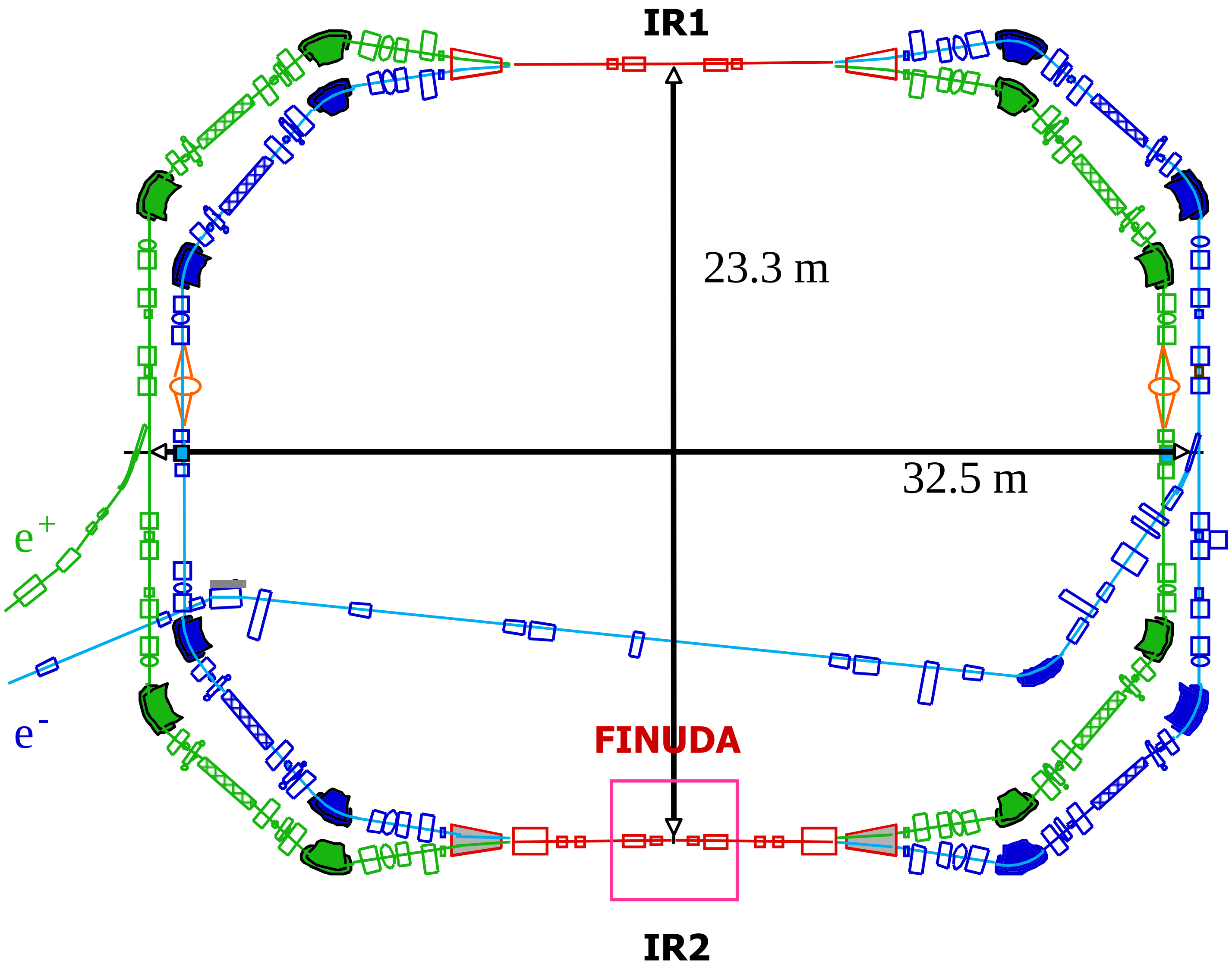
Total cross section measurement

High accuracy: < 1 %



The FINUDA Detector

DAFNE2 MAIN RINGS



DESIGN PARAMETERS

The experimental luminosity requirements are not critical for DAFNE2. This allows choosing the machine parameters with enough freedom, exploiting our commissioning know-how.
Choosing an emittance $\varepsilon = 0.5 \cdot 10^{-6}$ *rad m* compatible with the ring aperture, a vertical beta function at the Interaction Point and a coupling factor already achieved, the linear tune shift is
ξ_x / ξ_y = 0.014 / 0.024, below the limit achieved by DAΦNE.
The **horizontal crossing angle** at the interaction point is **±15** ***mrad***, corresponding to a Piwinsky factor $\phi = \theta_x \sigma_L^*/\sigma_x^* = 0.22$, which has already been exceeded in the existing factories.
The chosen number of bunches is 30 so that, leaving the harmonic number *h* = 120 unchanged, we can inject both electrons and positrons out of collision and collide the two beams by performing a fast RF phase jump after having ramped the beam energy to 1 GeV.
Once fixed such parameters, a **luminosity of** $\mathbf{1 \cdot 10^{32}}$ $\boldsymbol{s^{-1}\ cm^{-2}}$ is straightforward to achieve with 15 *mA* per bunch and a total **current of 0.45** ***A***.

Energy E_0	1.0 *GeV*
Luminosity L	$1 \cdot 10^{32}$ s^{-1} cm^{-2}
Circumference C	97.69 *m*
Emittance ε	$0.5 \cdot 10^{-6}$ *rad m*
Coupling $\kappa = \varepsilon_x / \varepsilon_y$	0.009
Beta functions at IP β_x^* / β_y^*	1.5 / 0.025 *m*
Crossing angle at IP θ_x^*	±15 *mrad*
Bunch width at IP σ_x^* / σ_y^*	0.95 / 0.008 *mm*
Bunch natural length σ_z	13.9 *mm*
Linear tune shift ξ_x / ξ_y	0.014 / 0.024
Betatron tunes ν_x / ν_y	5.15 / 5.21
Momentum compaction α_c	0.009
Number of bunches	30
Particles per bunch	$3 \cdot 10^{10}$
Beam current I_{tot}	450 *mA*

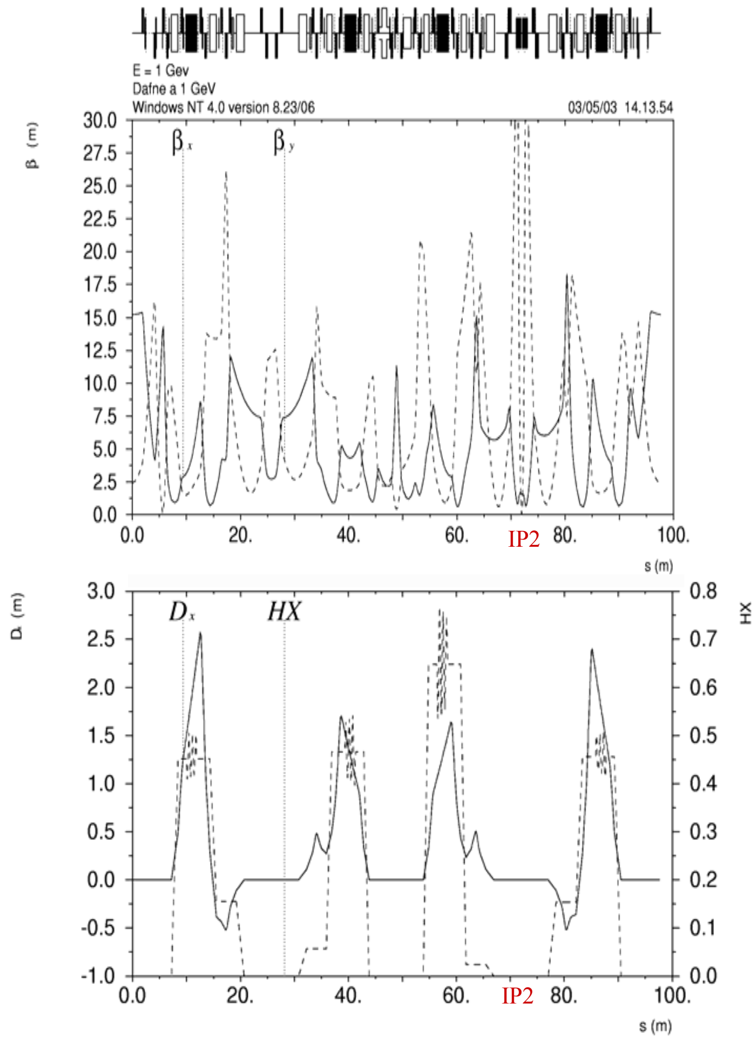
MAIN RING OPTICS AT 1 *GeV*

- Only one low beta insertion in the IR2, where the FINUDA detector is housed and the $e^+ e^-$ beams collide head-on with a horizontal angle of ±15 *mrad*.

- In the IR1, four FDDF quadrupoles allow to separate the two beam trajectories with a vertical bump of ±1 *cm*.

- Horizontal and vertical beta functions in the four achromat arcs, where the dispersion is higher, are separated to correct both horizontal and vertical natural chromaticity with chromatic sextupoles.

- The horizontal beta function and the dispersion are shaped so that the natural emittance does not change
 from 0.51 to 1 *GeV*.

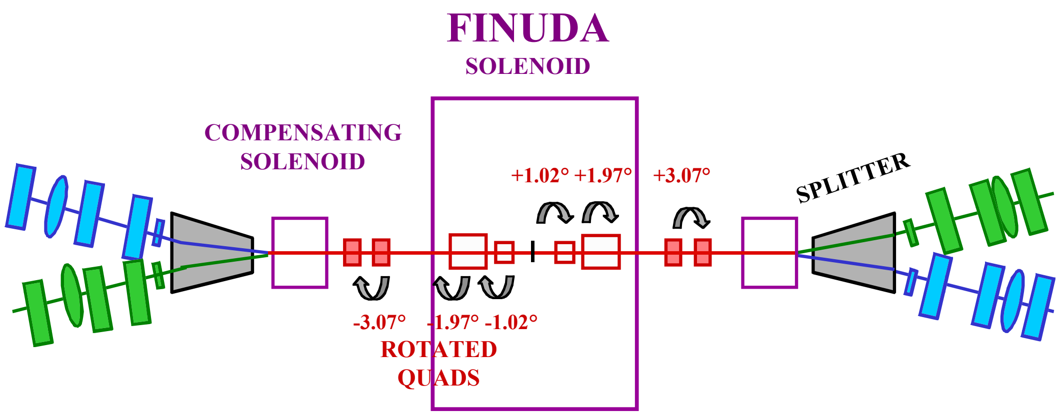


THE FINUDA INTERACTION REGION

The low beta insertion is realized with four FDDF quadrupoles housed **inside** the experimental detector. Because they have to be powered for variable beam energy, the only solution to fit them inside the detector is developing **superconducting** quadrupoles. Two further doublets outside the detector are conventional quadrupoles.

At the injection energy of **0.51 *GeV*** the non vanishing coupling from **mismatched** quadrupole rotation angles can be useful to have a long beam lifetime during the ramping and can be controlled with the skew quadrupoles in the ring.

The FINUDA solenoid integrated field of 0.3 *T* x 2.4 *m* at the collision energy of **1 *GeV*** rotates the beam of an angle of 6° around the longitudinal axe. The **coupling** at the Interaction Point and outside the IR2 is corrected rotating each quadrupole around its longitudinal axis following the rotation of the beam at and
two compensating solenoids 0.36 T x 1 *m* provide the cancellation of the coupling outside the IR.

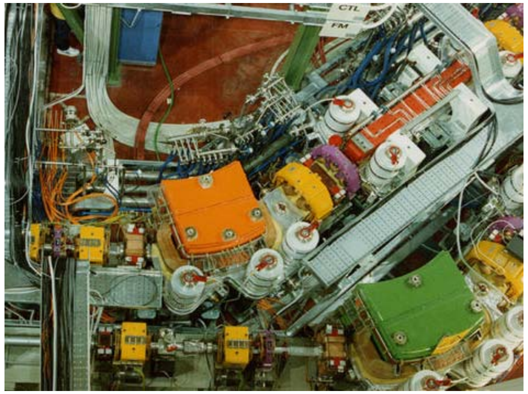


DAFNE2 DIPOLES

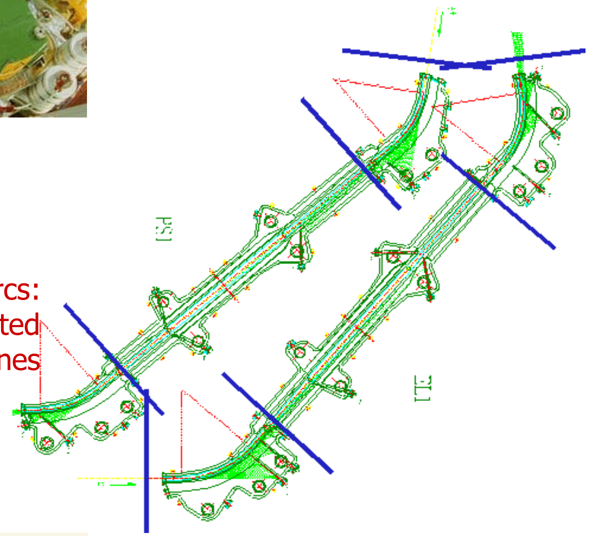
Eight dipoles are installed in each ring: four 0.99 *m* long magnets with a 40.5° bending angle and four 1.21 *m* long with a 49.5° angle. The bending field in present magnets at 0.51 GeV is 1.2 *T* and the maximum field is 1.7 *T*, insufficient to reach 1 *GeV*: **new stronger dipoles** are needed.

The existing vacuum chamber puts constraints on the dipole geometry.
With a different shape of the polar shoe, the same gap height and **10% longer** magnets, we expect to achieve the needed field of 2.2 *T* with a $\Delta B/B = 2 \cdot 10^{-4}$ field quality in the ±3 *cm* range, using a ferromagnetic alloy with higher saturation limit to realize the DAFNE2 dipoles.

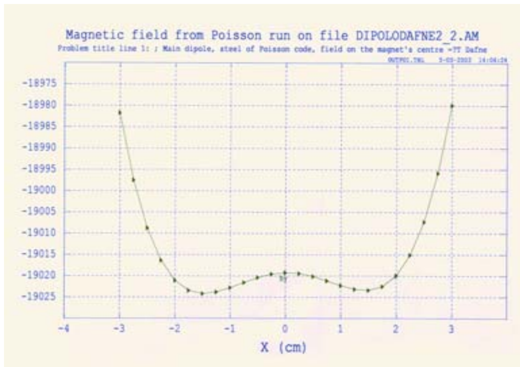
More work and simulations are in progress to study the features and the quality of such magnets.



DAΦNE dipoles
(orange e^+ and green e^-)



The vacuum chamber of the arcs:
the dipoles must be inserted
between the blue lines



The field along the radial coordinate
of a DAFNE2 steel dipole
in a 2-D simulation with POISSON.

SYNCHROTRON RADIATION AND EMITTANCE

The synchrotron radiation loss per turn depends on the energy and on the bending radius in dipoles as:

$$U_0 = C_\gamma \frac{E^4}{2\pi} \oint \frac{ds}{\rho^2}$$

The wigglers are useful at the injection energy to increase synchrotron radiation and decrease damping times. From 0.51 to 1 *GeV* the wiggler field is kept constant, since it is already near saturation and the synchrotron radiation from **the energy increase is high enough to improve damping times** (Table).

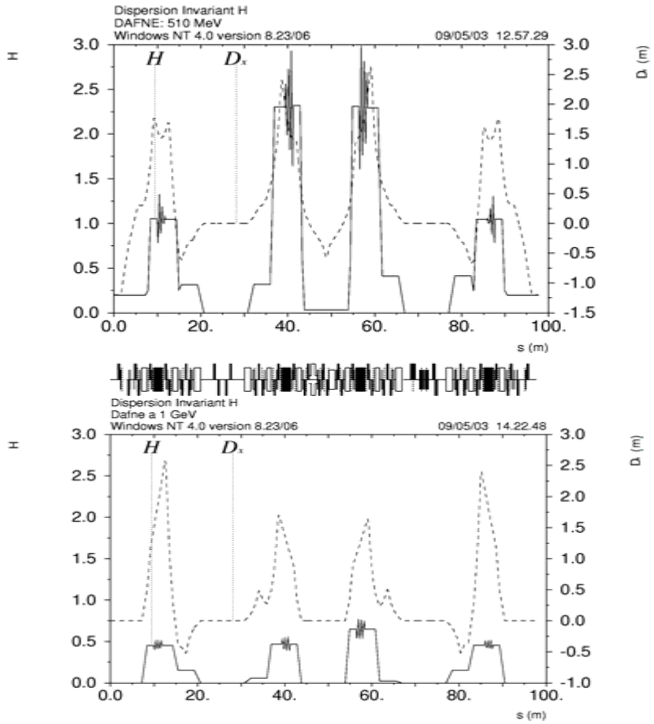
The emittance in electron storage rings depends on the energy and on the radius in the dipoles:

$$\varepsilon = C_q \gamma^2 \frac{< H \ /|\rho|^3 >}{J_x < 1/\rho^2 >}$$

and to have constant emittance at different energies the dispersion invariant H:

$$H = \gamma_x D^2 + 2\alpha_x DD' + \beta_x D'^2$$

is reduced by changing the Twiss parameters at the dipoles when the energy goes from 0.51 to 1 *GeV* (Plots).

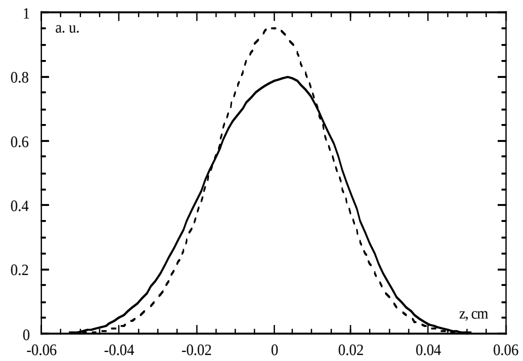


Synchrotron radiation and damping times

without / with Wigglers		0.51 GeV	1 GeV
U_0	(*keV/turn*)	4.3 / 9.3	64.0 / 83.5
τ_x	(*ms*)	68 / 40	11 / 8.6
τ_E	(*ms*)	41/ 31	5.0 / 3.5

RF SYSTEM and BUNCH LENGTHENING

RF peak voltage V_{RF}	250 *kV*
RF frequency f_{RF}	368.26 *MHz*
Energy loss $U_{rad}+U_{paras}$	83.5 +6.5 *KeV/turn*
RF power $P_{beam}+P_{wall}$	40.5 + 17.5 *kW*
Synchr. frequency f_{syn}	11.7 *kHz*



Charge density bunch distribution at zero current (dashed line) and at 15 mA/bunch (solid line)

The DAΦNE RF cavity cooling system can withstand a maximum accelerating field of 350 *kV*, corresponding to a RF power loss of 35 *kW* on the cavity walls, while the maximum RF power the klystron can supply is 150 *kW*. The RF power to be delivered to the beam is given by $P_{beam} = V_{loss}\ I_{beam} \approx 40.5$ *kW*, assuming 90 *keV/turn* of total losses (including the parasitic ones). Since the required accelerating voltage is 250 *kV* corresponding to a RF wall dissipation of ≈17.5 *kW*, **the existing RF system is completely compatible** with the required specifications.

Bunch lengthening has been estimated by performing a multiparticle tracking. Using the impedance estimates and corresponding wake fields calculated for the present vacuum chamber in the turbulent microwave threshold calculations and in the bunch lengthening simulations, the rms bunch length increases from the natural value of 13.9 *mm* (Figure) **to only 15.9 *mm* at 15 *mA*** per bunch, while the energy spread remains constant indicating that the microwave instability threshold is not reached at the nominal bunch current.

LIFETIME AND BACKGROUND

Background and beam lifetime at DAΦNE are strongly dominated by Touschek scattering.

Touschek lifetime is a complicated function of machine parameters: at the larger energy and RF voltage of DAFNE2 it will be **less critical than at the present energy**.

In fact with the DAFNE2 parameters τ_{tou} comes out to be 650 *min* as calculated by MAD, with longitudinal acceptance dominated by RF. Further quantitative simulations will be done with the programs developed and used for DAΦNE.

VACUUM SYSTEM

Present layout can withstand the new configuration. In fact in DAFNE2 (0.45 *A* and 1 *GeV*) synchrotron radiated photon flux is 1.8□1020 *phot/s* corresponding to a power of 38 *kW*, while the existing vacuum chamber is designed for a synchrotron radiation power of 50 *kW*.

FEEDBACK SYSTEM

No change is needed for the transverse feedback if the betatron tunes stay constant during the energy ramping.
The longitudinal feedback can follow the synchrotron frequency variation in a large range with eight synchronizable filters.
Timing is **not critical** with a synchronous RF phase up to 100 *ps* (the RF phase is 70 *ps* at 250 *kV*).