FEASIBILITY STUDY OF A 2 GeV LEPTON COLLIDER AT DAFNE

G. Benedetti, D. Alesini, M. E. Biagini, C. Biscari, R. Boni, M. Boscolo, A. Clozza, G. Delle Monache, G. Di Pirro, A. Drago, A. Gallo, A. Ghigo, S. Guiducci, M. Incurvati, C. Ligi, F. Marcellini, G. Mazzitelli, C. Milardi, L. Pellegrino, M. A. Preger, P. Raimondi, R. Ricci, C. Sanelli, M. Serio, F. Sgamma, A. Stecchi, A. Stella, C. Vaccarezza, M. Vescovi, M. Zobov
LNF-INFN, Frascati, Italy

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 [1] 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.

ENERGY UPGRADE OF THE FRASCATI FACTORY: GENERAL PROJECT

In the discussion about the future plans for the Frascati e^+e^- factory, one of the possibilities the DAϕNE team is considering is the upgrade of the collider energy for new experiments up to about 2 *GeV* c.m. The hypothesis called DAFNE2 (Double Annular Frascati e^+e^- factory for Nice Experiments 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 [2]. This experimental program can be realized with the FINUDA [3] detector at a solenoid field of 0.3 *T*.

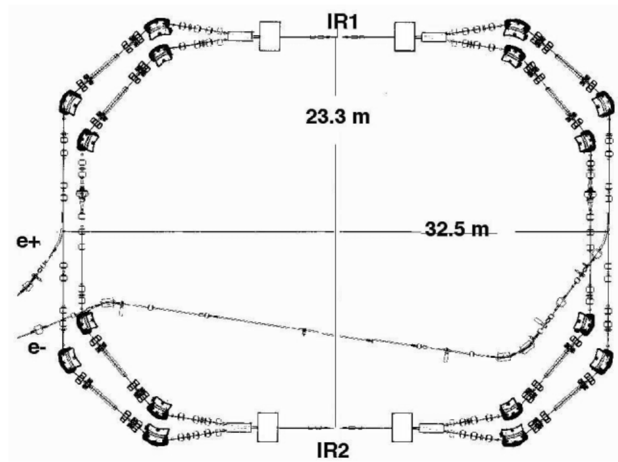

Figure 1: Main Rings layout.

DAFNE2 can use without any change the DAϕNE 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.

Table 1: DAFNE2 Parameters

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*

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. We have worked out new parameters at the beam collision energy of 1 *GeV*.

Choosing an emittance $\varepsilon = 0.5{\cdot}10^{-6}$ *rad m* compatible with the ring aperture, a vertical beta function at the Interaction Point (IP) 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's angle:

$$\phi = \theta_x^* \frac{\sigma_L}{\sigma_x^*} = 0.22$$

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 RF phase jump [4] after having ramped the beam energy to 1 *GeV*.

Once fixed such parameters (Table 1), a luminosity of $1{\cdot}10^{32}$ s^{-1} cm^{-2} is straightforward to achieve with 15 *mA* per bunch and a total current of 0.45 *A*.

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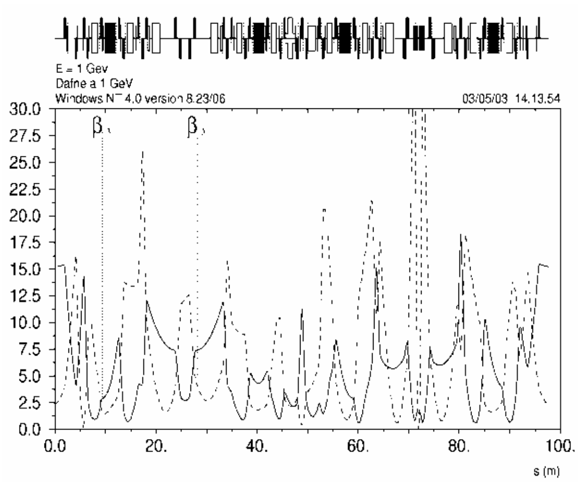

Figure 2: DAFNE2 ring beta functions calculated by MAD.

MAIN RINGS

The design of the two collider Main Rings is unchanged (Figure 1): two different rings for positrons and electrons with two 10 *m* long Interaction Regions where the opposite beams travel in the same vacuum chamber. Four wigglers per ring are installed in the arcs. The existing vacuum chamber is reused.

The experiment FINUDA is in the Interaction Region 2 (IR2) and in the opposite Interaction Region (IR1) two quadrupole doublets are installed: a lattice already used when only the KLOE detector was installed [5].

More study has to be done on the energy ramping, to be performed keeping the betatron tunes constant.

Optics

The main optical features at 1 *GeV* are (Figure 2):

- Only one low beta insertion in IR2, where the experimental detector is housed and the positron and electron beams collide at a horizontal angle of ±15 *mrad*.
- In 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 chromaticities with chromatic sextupoles.
- The horizontal beta function and the dispersion are shaped in such a way that the natural emittance does not change from 0.51 to 1 *GeV* as explained in the next section.

Interaction Region 2

The low beta insertion is realized with four FDDF quadrupoles housed inside the experimental detector (Figure 3). Since they must be powered for variable beam energy, the only solution to fit them inside the detector is developing superconducting quadrupoles as for example at upgraded HERA [6]. Two further doublets outside the detector are realized with conventional quadrupoles.

The FINUDA solenoid field integral of 0.3 *T* x 2.4 *m* at the collision energy rotates the beam by an angle of 6° around the longitudinal axis. The coupling at the Interaction Point and outside IR2 is corrected with the rotating frame method [7]: each quadrupole is rotated around its longitudinal axis following the rotation of the beam and two compensating solenoids 0.36 *T* x 1 *m* provide cancellation of coupling outside the IR. The solenoid fields and the quadrupole rotation angles are fixed. 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 ramping and can be controlled with the skew quadrupoles in the ring.

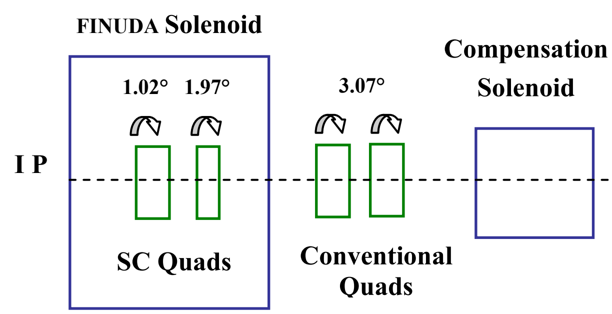

Figure 3: half Interaction Region 5 *m* long layout: from the Interaction Point (IP) to the splitter magnet.

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 2).

The emittance in electron storage rings depends on the second power of the energy according to:

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

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

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

is fairly reduced by changing the Twiss parameters in the arcs when the energy goes from 0.51 to 1 *GeV*.

Table 2: Energy loss with and without wigglers

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

Table 3: RF System and Bunch Parameters

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*

Magnets

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.

Existing quadrupoles and sextupoles allow doubling the ring energy, some quadrupoles reach saturation, but we assume to avoid it with further optics optimisation.

RF Parameters and longitudinal bunch distribution

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 correspinding wake fields calculated for the present vacuum chamber [8] 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 4) 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 [9]. 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

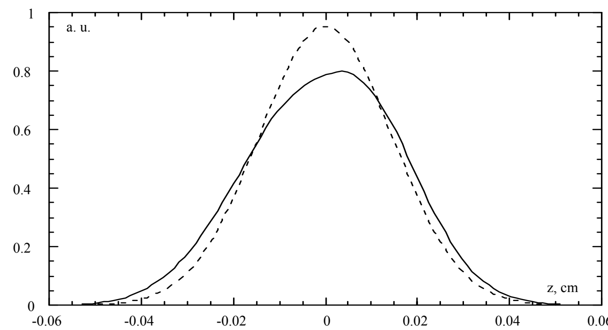

Figure 4: Charge density bunch distribution at zero current (dashed line) and at 15 *mA/bunch* (solid line).

parameters in Tables 1 and 3 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 that consider the physical aperture of the vacuum chamber along the rings.

Vacuum System

Present layout can withstand the new configuration. In fact in DAFNE2 (0.45 *A* and 1 *GeV*) synchrotron radiated photon flux is $1.8 \cdot 10^{20}$ *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*).

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