DAΦNE TECHNICAL NOTE

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THE HORIZONTAL VERSUS VERTICAL CROSSING ANGLE AND THE CRAB CROSSING SCHEME FOR DAΦNE

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In a collider, due to the lack of powerful electrostatic separators, the most efficient way to push up the collision frequency and to avoid, at the same time, parasitic interactions is to make the trajectories of the two opposite beams intercepting at an angle. This scheme was adopted in DORIS I, but its effectiveness was reduced by an unexpected effect: the excitation of synchro-betatron resonances. This kind of instability, by limiting the maximum achievable tune shift and, consequently the luminosity, defeated the purpose for which the crossing-angle scheme was designed.

Very recently R. Palmer (1) proposed the well known crab-crossing idea to increase the luminosity in multibunch linear colliders.
K.Oide and K.Yokoya (2), by showing that the crab-crossing does not induce synchro-betatron resonances, made this scheme attractive also for circular colliders, as confirmed also by computer simulations (3).

Purpose of this paper is to show that a radial crossing, in the case of flat beam, is more favourable then the vertical one for the crab-scheme and, due to the parameters chosen for DAΦNE (4), the crab-crossing can be, in principle, not necessary.

A discussion of the reasons which make horizontal beam crossing preferable in a τ-charm facility has been given by Kheifets, Paterson and Voss (5). Some of their arguments are still valid for our machine, others, due to the different design features, are not, and must be modified.
Let us recall, briefly, the physics involved and how the crab-crossing scheme works. We will consider horizontal crossing only, but similar argumentations are applicable to the vertical one.

The angular kick that a particle receives during a horizontal head-on collision is, in general, a function of its transverse position, namely

$$\Delta x' = F\ [x, y]$$

while for a horizontal crossing at an angle θ it must be written as

$$\Delta x' = F\ [x - z * tg\theta, y]$$

where z is the longitudinal coordinate. By measuring x and z in σ's units and approximating $tg\theta$ by θ, the last formula can be rewritten as

$$\Delta x' = F\ [n_x\sigma_x(1-\theta\frac{n_z\sigma_z}{n_x\sigma_x})]$$

We have dropped here, for simplicity of notation, the dependence on y. For gaussian independent distributions in x and z, n_x and n_z are equal, therefore the effect of the crossing angle can be characterized by the geometrical factor

$$\mathbf{a} = \theta\frac{\sigma_z}{\sigma_x}$$

The parameter **a** is a measure of the coupling between the radial and the longitudinal phase spaces generated by the crossing angle. This coupling, experimentally observed in DORIS I, limits the maximum achievable tune shift and, consequently the luminosity.

The crab-crossing can eliminate the coupling between radial and longitudinal phase spaces in the following way:
a transverse deflecting RF cavity, located at a betatron phase advance of $\pi/2$ from the IP and with the zero-crossing of the electrical field synchronous with the bunch center, gives to a particle an angular kick proportional to its distance z from the bunch centre. This kick transformsinto a transverse displacement at the IP, thereby making the two bunches tilt and collide head-on. A symmetrical RF cavity cancels the angular kick after the interaction. The required cavity voltage, assuming that the bunch length σ_z is small compared with $\lambda/4$ (λ = cavity wavelength), is given by:

$$V_{RF} \sim \frac{cE}{e}\frac{1}{\omega_{RF}}\frac{\theta}{\sqrt{\beta_c\beta_x}}$$

where β_x and β_C are the values of the β-function at the IP and at the cavity position respectively. For a RF frequency ~350 MHz a peak voltage of ~ 100 kV is required, if we assume β_c ~ 10 m.

In the vertical plane, instead, since at the IP $\kappa_\beta = \beta_y/\beta_x = .01$, a peak RF voltage ten times more would be necessary, if one assumes the same β_c value.

The tolerances on the RF voltages and relative phases of the two RF deflectors are given by [2]:

$$\frac{\Delta V}{V} << \frac{1}{\sqrt{N_x}} \frac{2\sigma_x}{\theta\sigma_z} = \frac{2}{\mathbf{a}\sqrt{N_x}} \qquad \text{and} \qquad \Delta\phi << \frac{2\pi\sigma_x}{\lambda\,\theta}$$

where N_x is the number of turns corresponding to a transverse damping time. If we use the DAΦNE design values:

$$\begin{array}{llll} \sigma_x & = & 2 & \text{mm} \\ \sigma_z & = & 3 & \text{cm} \\ \theta_x & = & 10 & \text{mrad} \\ N_x & = & 72000 & \end{array}$$

we get:

$$\frac{\Delta V}{V} << .05 \qquad \Delta\phi << 1.48 \text{ rad}$$

Especially the second value suggests that, in our case, the crab-scheme could be unnecessary. In fact, if we try to express the relation among **a** and ξ, the simplest hypothesis we can make is:

$$\frac{1}{\xi} \approx \mathbf{a} \qquad \text{or} \qquad \xi\mathbf{a} = \text{const}$$

This relation can be justified by noting that, for vanishing beam-beam interaction, the value of θ and **a** can be arbitrarily large, and the previous formula is only the first Taylor term of a functional dependence between $\frac{1}{\xi}$ and **a** .

It is evident the importance of the constant value which appears in the last formula. Suggestions on this value come from both observations at DORIS I [6] and computer simulations. At DORIS I the maximum value of the tune shift ever obtained was $\xi = 0.01$ and $\mathbf{a} = 0.5$. Since our goal [4] is $\xi = 0.04$, $\mathbf{a}_{max} = 0.13$ for us. With our project values we get $\mathbf{a}$ = .15 in the horizontal case, namely very near the value obtained from the working point at DORIS I. This limit would be overcome by 2 orders of magnitude in our Φ-factory with vertical crossing, while we are just at the same level in the horizontal case.

With a collision frequency ~350 MHz, i.e. all RF buckets are filled, and a crossing angle 2θ=20 mrad, the total beam separation at the first parasitic crossing away from the interaction point (IP) is 8.6 mm, corresponding to $4\sigma_x$ in our design. Myers' criterion for vertical beam separation would be fulfilled entirely in this case ($\Delta y > 2\sigma_x$). Also Myers made some simulations in the case of horizontal beam separation(2), and found that a distance $\Delta x = 4\sigma_x$ is sufficient for LEP at 51.5 GeV with a total beam-beam parameter for head-on collision ξ=0.06. Although a bit tight, the horizontal beam separation in our machine seems sufficient to limit the effects of the parasitic crossing to a tolerable amount and avoid luminosity and/or lifetime reduction. Thus, from this point of view, there is no clear reason to prefer vertical crossing.

CONCLUSIONS

As a general remark, in the absence of a comprehensive simulation, which should take into account all relevant effects, we can state that the vertical crossing requires a correction scheme absolutely, while the horizontal one may not, although we believe it is useful to have such a scheme installed in DAΦNE, both for fine tuning purposes and for testing its validity.

Other tolerances that are imposed on the various elements of the crab crossing scheme have been investigated by simulation(7):

i) A phase error between the bunches and each crab cavity does only mean a horizontal orbit distortion at the IP, which is certainly negligible in the horizontal scheme for flat beams.

ii) A betatron phase error of about 10% between the crab cavities and the IP is tolerable without causing single beam blowup.

iii) A voltage unbalance between the two crab cavities seems less important than a wrong value of both cavity voltages, leading to a large tolerance.

iv) A non-linearity of the deflection as function of the distance from the bunch centre will not cause any serious trouble except for particles which are at an amplitude $> 3\sigma_z$. This error can be corrected by some overvoltage (less than 10%) in the cavities, if really needed.

Therefore, also from the point of view of tolerances the horizontal crossing is much less critical.

As a further advantage, the horizontal crossing scheme allows much more space for locating the crab cavities at exactly $\pi/2$ phase advance from the IP, while in the vertical case one would be obliged toplace them at $3\pi/2$, or to invent some exotic scheme, what perhaps is interesting as a machine experiment, but can't be considered a basic element of the collider design.

The last advantage to be mentioned is the simplification in the design of the interaction region where is not any more needed a vertical dispersion suppressor: the horizontal dispersion can be easily handled in the arcs.

As a conclusion, we believe that there are arguments enough to exclude any essential role for the crab crossing in our present design, while it wouldn't certainly be so if we had a vertical crossing scheme.

The crab crossing must be considered such a pure option that, in case of serious trouble (e.g. single-bunch or multibunch instabilities) the crab cavities can be easily removed without substantially affecting the performances of the machine. Nevertheless, we also believe that the crab crossing can play a role, owing to the large amount of flexibility that is contained in our design. We think, for instance, of improvements on some basic parameters, like reducing the emittance or trying to push the maximum beam-beam tune shift beyond our rather conservative goal. This might be greatly helpful, either in keeping the bunch charge lower at the same luminosity to avoid various instabilities, or in enhancing luminosity and lifetime at the same current.

REFERENCES

[1] R.B. Palmer, SLAC - PUB - 4707 (1988).

[2] K. Oide and Y. Yokoya, Phys. Rev. D40, 315 (1989).

[3] A. Piwinski, DESY HERA 90-04 (1990).

[4] PROPOSAL FOR A Φ-FACTORY - LNF-90/031(R) - April 1990.

[5] S.A. Kheifets, J.M. Paterson and G.A.Voss, SLAC-PUB - 5011 (1989).

[6] A. Piwinski, IEEE Trans. on Nucl. Sci., NS - 24, 1408 (1977)

[7] S. Myers, IEEE Trans. on Nucl. Sci., NS - 30, 2466 (1983).