DAΦNE TECHNICAL NOTE
INFN - LNF, Accelerator Division

Frascati, July 29, 2005
IR-13

TUNABLE INTERACTION REGION FOR DAΦNE UPGRADE

M. Biagini, C. Biscari

Introduction

DAΦNE runs at fixed energy, i.e. 0.510 GeV per beam, corresponding to the Φ resonance, and the maximum peak luminosity reached so far is 1.4 10^{32} $cm^{-2}sec^{-1}$. The possibility of upgrading the collider to reach higher luminosity at the present energy and higher energies at the present luminosity is being investigated.

Following several discussions among the experimental groups, we consider that the present KLOE detector could be used to explore the whole energy range, housing different experiments at different times.

We present here a preliminary design of an Interaction Region which can be used for the two main energies, with no need to change the hardware between different runs.

Main collider parameters

The requested luminosity for the two different energies differs by about one order of magnitude. Usually the higher the energy the higher the luminosity, but in our case the higher luminosity must be reached at the lower energy. The main difference between the two set-ups in terms of luminosity related parameters is the total current, much lower in the high energy case, and the beam-beam tune shifts, due to their dependence on energy.

Table I summarizes the luminosity related parameters considered for the IR design. Luminosity and tune shifts have been computed neglecting crossing angle and hour-glass effect, therefore they are overestimated. The effective luminosity will be about 15% lower. The coupling value is the estimated ratio of vertical to horizontal emittance in collision, namely lower values are expected in single beam operation. The KLOE Solenoidal field is lower than the present one at both energies, according to the experiment requests [1]. The emittance and the vertical β* are twice smaller at low energy. It is clear from all above considerations that the low energy case is much more challenging.

Table I – Luminosity related parameters at two different energies

Energy (GeV)	0.51	1.2
Luminosity (cm^{-2} sec^{-1})	10^{33}	10^{32}
Rf frequency (MHz)	500	500
N_{umber} of bunches	150	30
Particles per bunch (10^{10})	3.1	3.4
Emittance (mm mrad)	0.3	0.6
Horizontal β^* (m)	1	1
Vertical β^* (cm)	1	2
Emittance coupling	0.01	0.007
Horizontal beam-beam tune shift	0.051	0.010
Vertical beam-beam tune shift	0.051	0.012
Half crossing angle (mrad)	15	12
Bunch length (cm)	1	2
B_{KLOE} (T)	0.4	0.2

Interaction Region design

The need to go to a large number of bunches with flat beams requires collisions at a horizontal crossing angle. Being the distance between adjacent bunches 60 cm, the parasitic crossings are spaced by 30 cm for the low energy case and 1.5 m for the high energy one, where only one out of five buckets will be filled.

We have taken into account the possibility of separating the two rings vacuum chambers just after the first quadrupole, but this choice would limit the flexibility of the IR design in terms of trajectory, ratio between solenoidal field and energy and apertures. We have therefore decided to keep a design very similar to the present one.

The coupling introduced by the solenoid is presently corrected in DAΦNE following the Rotating Frame Method [2]: the solenoidal field is compensated with anti-solenoids on both sides of the detector, and the low-beta quads are tilted by the angle corresponding to the rotation of the transverse plane at their position. Residual coupling is corrected with a system of eight skew quadrupoles in the ring. Permanent magnets are used in the low-beta quadrupoles which are therefore optimized at the nominal energy. Since the beams cross with a horizontal angle and pass off-axis in the quadrupoles, the beam trajectories inside the IR are determined both by the crossing angle value and by the quadrupole gradients, and it is not possible to use the same quadrupoles at different energies and similar beam trajectories.

The need of a flexible IR and the recent development of SC magnets for many colliders [3] led us to the choice of SC technology for the low-beta quadrupoles of the new IR design.

The tilts of the quads are substituted with skew coils wrapped around the main quads. In fact a skew coil on a normal quadrupole is equivalent to a rotation in the transverse plane [4].

A quadrupole with normalized integrated gradient Kl is represented in the thin lens approximation by the 4x4 matrix **Q**:

$$\mathbf{Q} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ Kl & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -Kl & 0 \end{pmatrix} \tag{1}$$

while the matrix of a quadrupole tilted by the angle α is:

$$\mathbf{Q}_\alpha = \mathbf{R}(\alpha)\mathbf{Q}\mathbf{R}(-\alpha) \tag{2}$$

where $\mathbf{R}(\alpha)$ is the rotation matrix:

$$\mathbf{R}(\alpha) = \begin{pmatrix} \mathbf{I}\cos\alpha & \mathbf{I}\sin\alpha \\ -\mathbf{I}\sin\alpha & \mathbf{I}\cos\alpha \end{pmatrix} \tag{3}$$

being **I** the 2x2 identity matrix. $\mathbf{Q}_\alpha$ can be written as:

$$\mathbf{Q}_\alpha = \begin{pmatrix} 1 & 0 & 0 & 0 \\ Kl\cos 2\alpha & 1 & -Kl\sin 2\alpha & 0 \\ 0 & 0 & 1 & 0 \\ -Kl\sin 2\alpha & 0 & -Kl\cos 2\alpha & 0 \end{pmatrix} \tag{4}$$

A skew quadrupole with gradient K_{sk} is represented by the matrix $\mathbf{Q}_{\mathrm{sk}}$:

$$\mathbf{Q}_{sk} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -K_{sk}l & 0 \\ 0 & 0 & 1 & 0 \\ -K_{sk}l & 0 & 0 & 0 \end{pmatrix} \tag{5}$$

A normal quadrupole with gradient K_{normal} with a skew superimposed is given by the product of expressions (1) and (5):

$$\mathbf{QQ}_{sk} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ K_{normal}l & 1 & -K_{sk}l & 0 \\ 0 & 0 & 1 & 0 \\ -K_{sk}l & 0 & -K_{normal}l & 0 \end{pmatrix} \tag{6}$$

Equalizing expressions (4) and (6), a quadrupole defined by the gradient K and tilted by an angle α is equivalent to a normal quadrupole with gradient K_{normal}, with a superimposed skew quadrupole with gradient K_{sk}, satisfying

$$\begin{aligned} K_{normal} &= K\cos 2\alpha \\ K_{sk} &= K\sin 2\alpha \end{aligned} \tag{7}$$

The transverse plane along the solenoid is rotated by an angle $\alpha(s)$ defined by the solenoidal field, the distance from the IP and the energy:

$$\alpha\left(s\right)=\frac{1}{2B\rho}\int_{IP}^{s}B_{sol}ds \tag{8}$$

and tuning the skew windings according to the above parameters is much more flexible than rotating mechanically the quads, as is done now.

The two present SC compensators can still be used to compensate the solenoidal field integral of the detector.

IR lattice

The IR lattice is based on low-beta doublets, following the present KLOE IR scheme [5]. The SC technology allows to add dipole windings which can be used to adjust the crossing angle and the beam trajectory along the IR. Figures from 1 to 4 show the optical functions, the beam trajectories and the beam stay-clear corresponding to the two different energies. The horizontal and vertical beam stay clear are computed as

$$\begin{aligned} HB_{sc} &= \Delta x + 10\sigma_x \\ VB_{sc} &= 10\sigma_y\ (full\,coupling) \end{aligned} \tag{9}$$

where Δx is half the separation between the beam trajectories. The effect of the solenoid is here neglected.

The crossing angle has been chosen to be larger in the low energy case (15 mrad), in order to increase the beam separation at the PC points, which are critical as shown in the following paragraph, and smaller (12 mrad) in the high energy case to decrease the beam stay clear values at the quadrupole position, keeping almost equal the ‘badness factor’ defined as:

$$q=\theta_{cross}\frac{\sigma_l}{\sigma_x}=0.31\,(0.27)\quad @0.51(1.2)\,GeV \tag{10}$$

Table II summarizes the IR design parameters at both energies. The skew windings are stronger in the low energy case, due to the larger rotation angle, but in any case much lower than the main quadrupolar component.

Table II – IR design parameters

Energy (GeV)	0.51	0.51	1.2	1.2
Quadrupole	Q_1	Q_2	Q_1	Q_2
Magnetic length (m)	0.40	0.40	0.40	0.40
Center distance from IP (m)	0.60	1.20	0.60	1.20
K_1 (m^{-2})	7.6	3.6	7.7	3.7
G (T/m)	12.92	6.12	30.80	14.80
Alfa rot (deg)	4.04	8.1	0.86	1.8
K_{sk} (m-1)	1.07	1.00	0.23	0.23
G_{sk} (T/m)	1.82	1.70	0.92	0.93

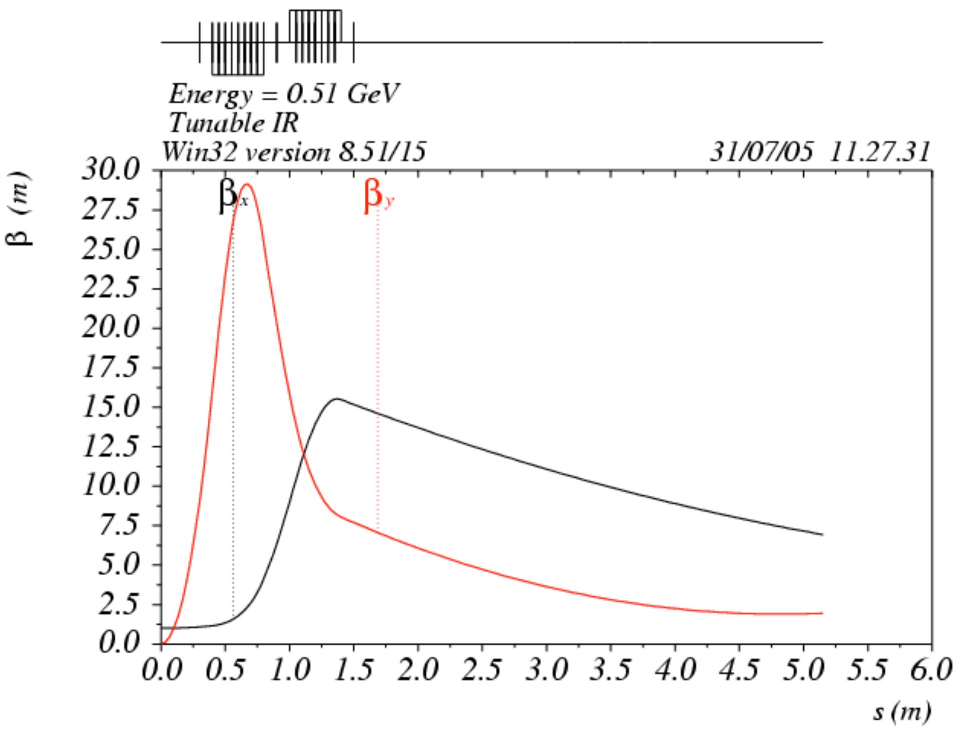

Figure 1 – Optical functions in half IR for E = 0.51 GeV

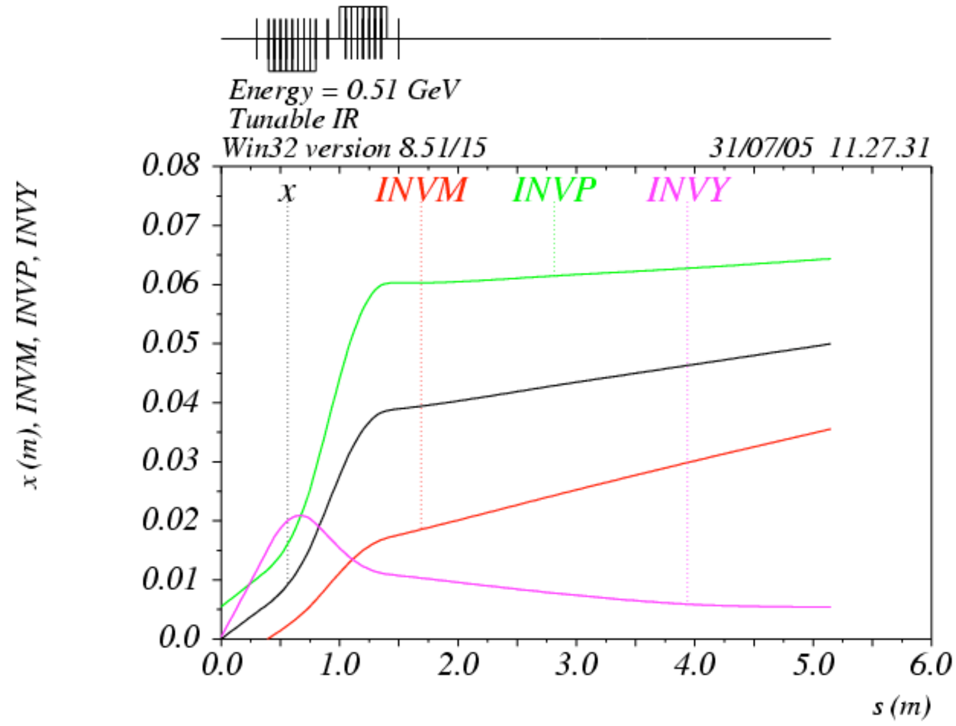

Figure 2 – Horizontal beam separation and beam stay clear in m for E = 0.51 GeV

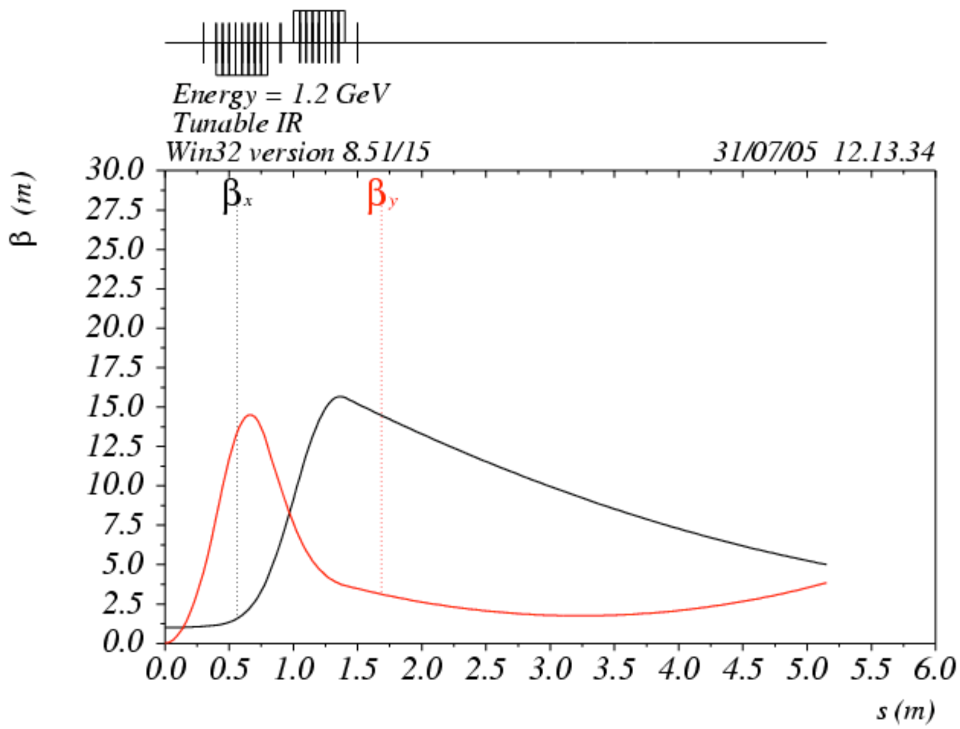

Figure 3 – Optical functions in half IR for E = 1.2 GeV

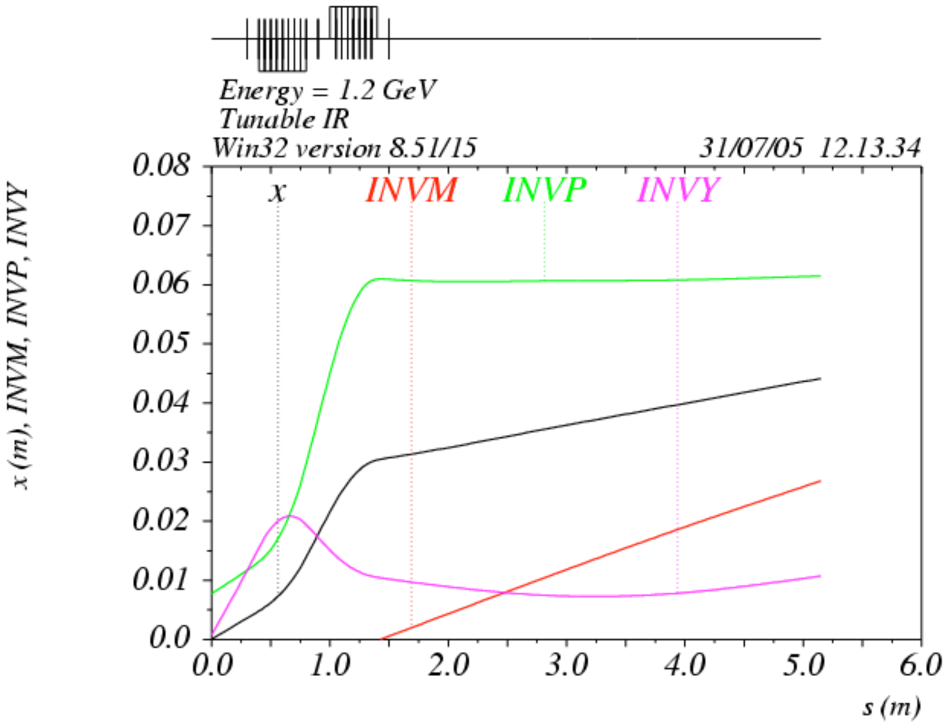

Figure 4 – Horizontal beam separation and beam stay clear in m for E = 1.2 GeV

Parasitic crossing position and tune shift

The beam-beam tune shift is given by:

$$\begin{aligned} \xi_{xo} &= \frac{N r_e}{2\pi\gamma}\frac{1}{\varepsilon_x} \\ \xi_{yo} &= \xi_{xo}\sqrt{\frac{\beta_y}{\kappa\beta_x}} \end{aligned} \tag{11}$$

and the value for the nominal parameters is reported in Table I.

The parasitic crossings occur every 30 cm when all buckets are filled, while they are much more spaced in the high energy case. The corresponding beam-beam tune shifts have been computed according to [6]:

$$\begin{aligned} \xi_x &= -\frac{N r_e}{2\pi\gamma}\frac{\beta_x}{x^2} \\ \xi_y &= +\frac{N r_e}{2\pi\gamma}\frac{\beta_y}{x^2} \end{aligned} \tag{12}$$

where x is the horizontal separation between the two beam centroids at the parasitic crossing position.

Figures 5 shows the total separation between the two beams in terms of σ_x in the low energy case along half IR, and figure 6 shows the beam-beam tune shifts due to parasitic crossings. While the horizontal tune shift is always very small, the two first PCs contribution is 13% and 10% of the principal one.

At 1.2 GeV even if the separation in terms of σ_x is smaller due to the higher emittance (see Fig. 7), the PC contribution is always negligible (see Fig.8), mainly because the first crossing occurs at 1.5 m from the IP.

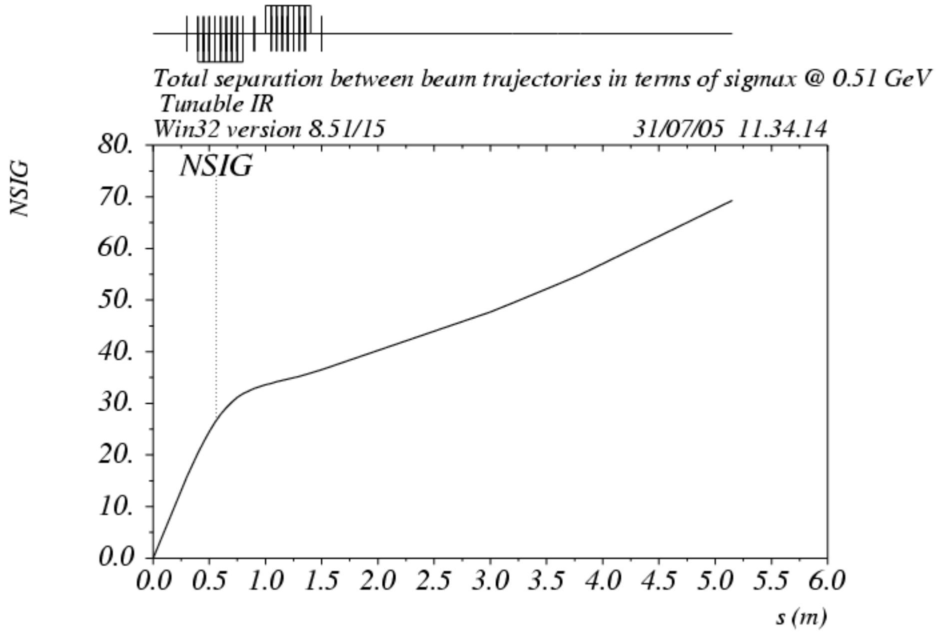

Figure 5 – Total separation between beam trajectories in terms of σ_x for E = 0.51 GeV, θ_{cross} = 15 mrad.

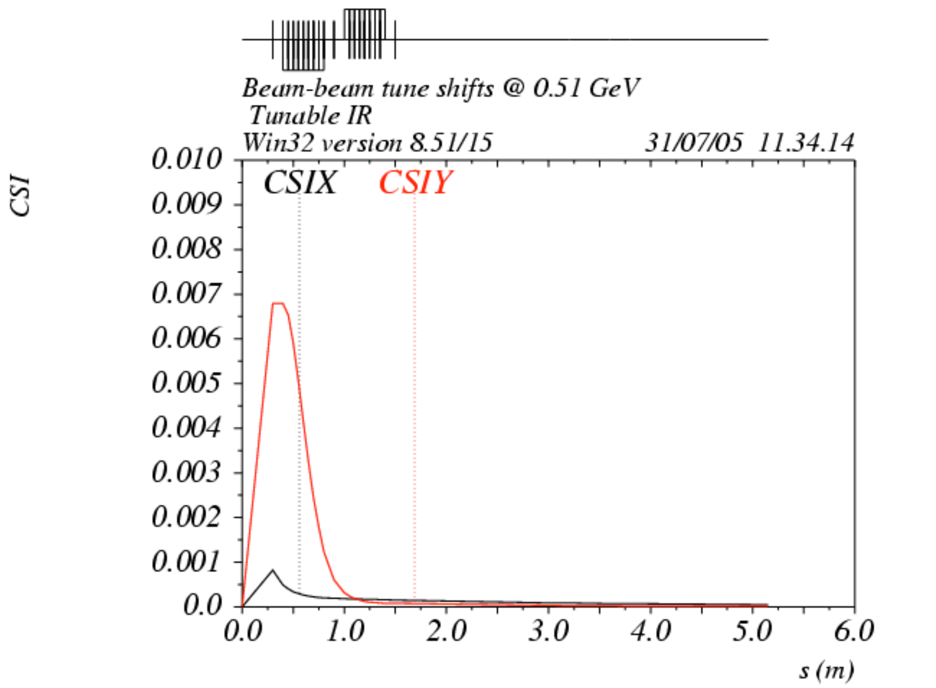

Figure 6 – PC beam-beam tune shift for E = 0.51 GeV, θ_{cross} = 15 mrad

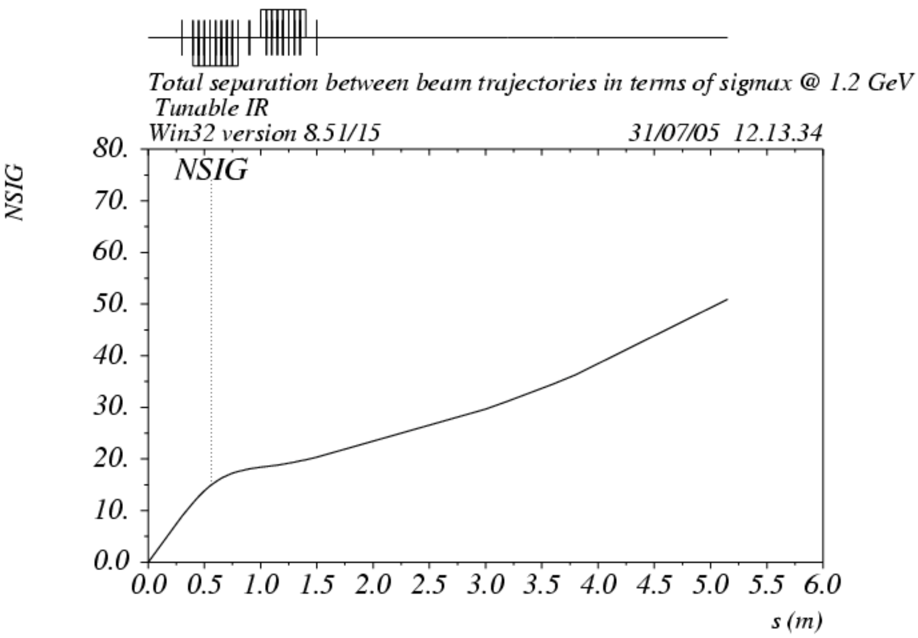

Figure 7 – Total separation between beam trajectories in terms of σ_x for E = 1.2 GeV, θ_{cross} = 12 mrad.

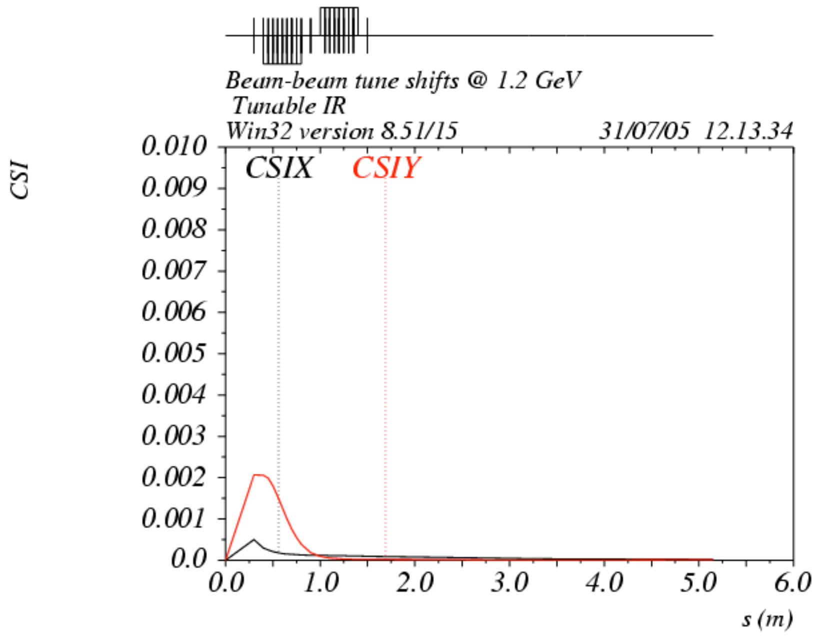

Figure 8 – PC beam-beam tune shift for E = 1.2 GeV, θ_{cross} = 12 mrad

Quadrupole characteristics

According to the experimental requirements [1], the maximum free space available for machine equipment is inside a 10° cone, while Q-cal will be used in the new experiment.

Considering the necessary beam stay clear at both energies, the minimum and maximum radii of the quadrupole, including the cryostat, are shown in the following table and sketched in Figure 9, together with the maximum beam stay clear. The required maximum gradients are listed in table IV. A collaboration with the Brookhaven group will be established to study the feasibility of such magnets.

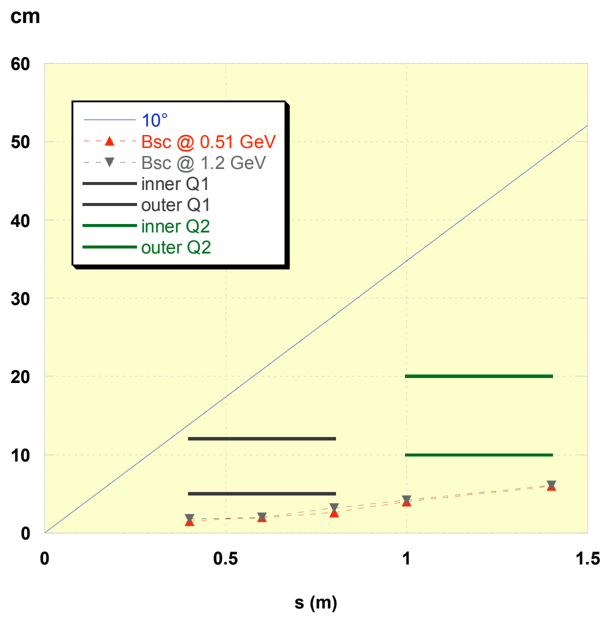

Figure 9 - Sketch of quadrupole dimensions (radius) in cm, beam stay clear and free zone inside the detector.

Table IV – Quadrupole design characteristics

Quadrupole	Q_1	Q_2
Magnetic length (cm)	40	40
Inner radius (cm)	5	10
Outer radius (cm)	12	20
G_{max} (T/m)	32	16
G_{sk} (T/m)	2	2

Conclusions

A preliminary design of an Interaction Region fitting different energies and using the KLOE detector has been done. The low-beta quadrupoles are based on superconducting technology, including skew and dipole coils, avoiding the mechanical rotation of quadrupoles. The possibility of adding sextupolar components to help in chromaticity correction will be studied in the future.

A first estimate of parasitic crossing effect has also been performed.

References

[1] R. Baldini , F. Bossi, private communication.

[2] M.Bassetti, M.E.Biagini, C.Biscari, “Solenoidal Field Compensation”, Frascati Series Vol X (1998), pp.209, 14^{th} Advanced ICFA BD Workshop, Frascati, 1997.

[3] Brett Parker et al.: “Compact Superconducting Final Focus Magnet Options for the ILC”, PAC05 proceedings.

[4] C. Biscari, DAΦNE Technical Note IR-7, 1996.

[5] M. Zobov and DAΦNE team, “DAΦNE Operation and Plans for DAFNE2”, Proceedings of PAC05.

[6] M- Biagini, “Long Range Beam-Beam Interactions in PEP-II”, Proceedings of 30th Advanced ICFA Beam Dynamics Workshop on High Luminosity e^+e^- Collisions, October 13-16, 2003, Stanford, California - PSN WGA21,