Abstract:
For the WP11 ANAC (Assessment of Novel Accelerator Concepts) Task 2 a new Interaction Region (IR) has been designed and built at the Italian electron-positron Ï•-Factory DAΦNE, with the aim to increase the luminosity for the KLOE-2 detector run in 2011-2013. The IR is based on a new collision scheme called Crab-Waist developed at Frascati by P. Raimondi, and already tested at DAΦNE in 2009 with a compact experimental apparatus for nuclear physics, with an improvement of about a factor of 3 on the peak luminosity. The main issue of this R&D activity has been finding the theoretical and technical solutions necessary to make the Crab-Waist compatible with a large experimental detector.

Crab-Waist collisions are based on strong focusing, large Piwinski angle and Crab-Waist compensation of the synchro-betatron resonances by means of two sextupoles installed at proper phase advance with respect to the Interaction Point (IP). Integrating the high luminosity collision scheme with the KLOE-2 detector introduces new challenges in terms of IR layout and optics, beam acceptance, coupling correction, lifetime and backgrounds, as well as collective effects which are increased due to the small beam sizes.
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1. EXECUTIVE SUMMARY

The EuCARD Work Package 11 ANAC (Assessment of Novel Accelerator Concepts) contains three Tasks which cover different aspects of state-of-the-art accelerators technology.

Task 11.2, “Design of Interaction Regions for high luminosity colliders”, is led by INFN-Frascati National Laboratories (Italy), with as partners CNRS-LAL (France), CERN (Switzerland), BINP-Novosibirsk (Russia).

The Task is divided in two Subtasks:

- 11.2.1 “Design of a new interaction region based on the crab-waist concept for the KLOE upgraded experiment at DAΦNE”
- 11.2.2 “Study of an interaction region based on the crab-waist concept for the LHC collider upgrade”

This Report describes the achievement of Deliverable 11.2.1 relative to Subtask 11.2.1, “DAΦNE IR design for the upgraded KLOE detector”.

The main purpose of this work is to demonstrate the compatibility of large magnetic detectors with a new collision scheme based on large Piwinski angle, low-β and Crab-Waist compensation of the synchro-betatron resonances.

This collision scheme was successfully tested at the Italian electron/positron collider DAΦNE during the run for the SIDDHARTA detector in 2008. The collider Interaction Region (IR) had been modified and the peak luminosity increased by a factor 2.8 with respect to the original configuration, very close to expectations from numerical simulations. This success is a strong motivation to study applications of this collision schemes to other more demanding upgrades of existing machines, in order to reach unprecedented luminosities.

The Crab-Waist collision scheme requires two sextupoles installed at proper phase advance with respect to the Interaction Point (IP). Integrating the high luminosity collision scheme with the KLOE-2 detector introduces new challenges in terms of IR layout and optics, beam acceptance, coupling correction, lifetime and backgrounds, as well as collective effects which are increased due to the small beam sizes.

In the framework of EuCARD, a new Interaction Region (IR) has been designed and built at the Φ-Factory DAΦNE, with the aim to increase the luminosity for the KLOE-2 detector run in 2011-2013. The work performed covered several aspects, both theoretical and hardware:

- the design and optimization of the IR layout, and construction of the IR (INFN),
- the study of the beam-beam and collective effects, including Touschek lifetime calculations (BINP, INFN),
- the beam optics and dynamic aperture studies (BINP, INFN),
- the construction of the IR (beam pipe, magnets, vacuum) (INFN),
- the upgrade of the luminosity monitor, background simulations and measurements (CNRS, INFN),
- the upgrade of the transverse and longitudinal feedbacks and injection kickers (INFN),
- the upgrade of existing diagnostics, including the design and implementation of clearing electrodes for the suppression of the e-cloud instability in the positron ring (INFN).
The IR layout needs to comply both with the requests of the new scheme and the need to be matched as much as possible to the existing infrastructure. Particular attention has been devoted to design a flexible IR with the possibility to run at different values of the detector magnetic field, at the same time having a good beam stay-clear and low backgrounds and low coupling, in order to have high luminosity performances.

The IR design has been carried out on time, Milestone 11.2.1 “DAΦNE beam parameters definition for KLOE2” delivered in March 2010, (EuCARD-NOT-2010-002). The installation of the IR was completed ahead of time by the end of May 2010. The commissioning of the rings with the new IR is still in progress (April 2011).

For the next year, until the foreseen completion of the WP11, the efforts will focus on the commissioning of the IR and the measurements of beam-beam, backgrounds and e-cloud instability with the new equipment, and compare with the design expectations.

It is worth noting that the experience gained in this study will be very important for future high luminosity colliders such as for example the SuperB project for a new e+/e- asymmetric collider at the Y(4S) energy, which will be built in Italy in the next few years.

2. INTRODUCTION

ANAC Task 11.2 aims to perform the feasibility study of a new collision scheme for storage-ring colliders, characterized by “large Piwinski angle, low β* and Crab-Waist for compensation of the synchro-betatron resonances”. This scheme holds the promise of increasing the luminosity by more than two orders of magnitude beyond the current state-of-the-art, without any significant increase in beam current and without reducing the bunch length. Tests of this scheme were successfully performed in 2008 at the INFN National Frascati Laboratories Φ-Factory DAΦNE.

In ANAC the feasibility of the scheme is studied for both an upgrade of the DAΦNE collider for the KLOE2 experiment (Subtask 11.2.1) and a possible application to the upgrade of LHC luminosity (Subtask 11.2.2).

The main purpose of Task 11.2, Subtask 11.2.1, is to prove the compatibility of large magnetic detectors with the new collision scheme. In 2008 this new configuration has been successfully tested on the DAΦNE electron/positron collider during the run for the SIDDHARTA detector. The IR was modified, and the measured peak luminosity was increased by a factor 2.8 with respect to the original configuration. It is worth remarking how the measured peak luminosity (~4.5x10^{32} cm^{-2}s^{-1}) is satisfactorily close to the one (5·10^{32} cm^{-2}s^{-1}) predicted by numerical simulations. Subtask 11.2.1 aims to apply this collision scheme to the new DAΦNE Interaction Region (IR) for the upgraded KLOE2 detector running from 2011 to 2013.

The IR design has been carried out on time, Milestone 11.2.1 “DAΦNE beam parameters definition for KLOE2” delivered in March 2010, (EuCARD-NOT-2010-002). The installation of the IR was completed ahead of time by the end of May 2010.

It is worth to note that the experience gained during with the work performed for Task 2 will be very important also for future high luminosity colliders such as for example the SuperB project for a new e+/e- asymmetric collider at the Y(4S) energy, which will be built in Italy in the next few years.
In the following sections the work performed for Task 11.2.1 is described in detail.

3. DESIGN OF IR FOR HIGH LUMINOSITY COLLIDERS

3.1. DEVELOPMENT OF A HIGH LUMINOSITY INTERACTION REGION FOR THE KLOE2 EXPERIMENT AT DAΦNE

A detailed study has been done to understand the compatibility between the conflicting requirements of high luminosity IR and experimental detectors in terms of mechanical structure design, collider optics, beam dynamics and background rejection, in view of a new run for the KLOE2 experiment scheduled at DAΦNE.

The KLOE detector itself was upgraded in order to cope with the higher acquisition rates expected from the improved collision scheme. The IR optics has been designed in order to fulfil all the requirements in terms of low beta functions at the IP, coupling correction and requirements for the Crab-Waist sextupoles. Tracking studies have been performed to ensure compatibility of the IR new structure with the mechanical layout of the ring arcs; a new IR vacuum chamber was designed and built. The IR optics has been optimized to increase the Crab-Waist sextupoles effectiveness. Coupling correction fine-tuning for each beam has been provided by adding a skew quadrupole in each branch of the IR and powering independently the four anti-solenoids.

Milestone 11.2.1 "DAΦNE beam parameters definition for KLOE" (EuCARD-NOT-2010-002) has been achieved on time in March 2010.

The original IR magnetic layout, used for the SIDDHARTA run in 2008, has been modified in order to maximize the beam stay clear letting the beam trajectory pass as much as possible through the centre of the magnetic elements. The resulting vacuum pipe geometry is largely simplified: it consists of three straight sections, with fewer junctions and bellows. The IR pipe is Aluminium (AL6082), with the exception of the sphere surrounding the IP, which is built in ALBEMET. Such a structure could trap high order modes and for this reason it is shielded from to the beam by means of a Beryllium cylinder. The design was completed ahead of time. The installation of the new IR on DAΦNE was completed by the end of May 2010. A sketch of the KLOE2 IR is in Figure 1.
The IR is formed by 4 branches, connected to the left and right arcs of the positron and electron rings.

In parallel with the development of the ring optics work started on the beam dynamics topics related to the new collision scheme. Dynamic aperture calculations have been performed to study the performances of the IR in terms of backgrounds and lifetime. Simulations of the e-cloud instability in the positron ring have been performed and electrodes to overcome this problem were designed, built and installed.

Operation with DAΦNE has restarted in mid-September 2010 with the detector solenoid off, due to a technical problem in the cryogenic plant. A dedicated optics without solenoid has been applied and electrons and positrons have been stored in the rings. This allowed to check all the rings components, the diagnostics and to start the vacuum conditioning with the beam. In the following months the effort has been addressed to setup and optimize experimentally the DAΦNE main rings optics with the KLOE2 detector solenoid on, as well as to compare beam-beam and e-cloud simulations with measurements, as well as optimization of backgrounds in the detector.

3.2. IR LAYOUT AND VACUUM CHAMBER

The low-β section is based on permanent magnet quadrupole doublets. The quadrupoles are made of SmCo alloy and provide gradients of 29.2 T/m for the first one from the IP and 12.6 T/m for the second one.
The first quadrupole is horizontally defocusing and is shared by the two beams, the second one, horizontally focusing, is installed just after the point where the beam pipes of the two rings are separated and is therefore on axis. Being the defocusing quadrupole much stronger than in the old KLOE low-β setup and having doubled the horizontal half crossing angle, now ~25 mrad, a very efficient beam separation is achieved in the ~1.6 m long section of the IR common to the two rings, making the impact of a single parasitic crossing completely negligible. As a drawback the horizontal and vertical displacement of the beam in the IR, the latter strongly affected by the detector solenoidal field, becomes an order of magnitude larger than in the past KLOE run. To keep the beam vertical trajectory within reasonable values a permanent magnet dipole has been added just after the focusing quadrupole, inside the detector magnetic field, in each one of the four IR branches.

The IR magnetic layout has been designed in order to maximize the beam stay clear letting the beam trajectory pass as much as possible through the center of the magnetic elements.

The beam trajectory and positions of the magnetic element centers are shown in Fig. 2 with reference to the IR branch of the positron ring pointing to the short arc, the corresponding branch for the electron ring being symmetric.

![Figure 2: Horizontal (left) and Vertical (right) beam trajectory in the IR (solid line), dots represent the position of the magnetic element centers.](image)

The evident advantage of this approach consists in keeping the maximum excursion of the vertical beam trajectory within ~12 mm providing, at the same time, the maximum aperture for the beam.

The horizontal and vertical beam stay-clear requirements have been defined as:

\[
X_{SC} = x_{trj} \pm 10\sigma_x \\
Y_{SC} = y_{trj} \pm 10\sigma_y
\]

where \(\sigma_x\) and \(\sigma_y\) are the horizontal and vertical rms beam sizes respectively.
Their values, computed with the collider emittance $\epsilon = 0.4 \times 10^{-6}$ m for the horizontal plane and full coupling for the vertical one, are presented in Figure 3 together with the vacuum pipe profile evaluated with respect to the beam trajectory. The beam envelope shown represents an upper limit: in fact it has been obtained by using a quite large value for the beam emittance. Relaying on this analysis the radius of the vacuum pipe, in the section between the IP and the anti-solenoid, has been reduced to 2.75 cm, while it was 4.4 cm during the Crab-Waist test run.

A narrower vacuum chamber contributes to lower the ring impedance budget, to minimize the strength of trapped High Order Modes and to shift their frequencies away from the beam spectral lines.

![Figure 3: Horizontal (upper) and Vertical (lower) beam stay clear.](image)

The resulting vacuum pipe geometry is largely simplified; in fact it consists of three straight sections, with few junctions and bellows. The detector efficiency also profits from the larger free space around the IP where a precision vertex tracker can be placed. The IR pipe is aluminium (AL6082) made with the exception of the sphere surrounding the IP, which is built in ALBEMET. Such a structure could trap HOMs and for this reason it is shielded from the beam by means of a Be cylinder. To minimise K meson regeneration the shield thickness has been almost halved (35 $\mu$ instead of the 65 $\mu$ of the last KLOE run).

Additional W screens have been added just before the PMQDs quadrupoles (w.r.t. the IP) to protect the experimental detector.
3.3. IR OPTICS

The design of the IR optics is constrained by several criteria. It must provide the prescribed low-β parameters at the IP (β_x = 0.265 m, β_y = 0.0085 m, α_x = α_y = 0.0, η_x = η_y = 0.0), matching at the same time the ring original layout in the arcs. The phase advance between the Crab-Waist Sextupoles and the IP must be π for the horizontal-like mode and π/2 for the vertical one. The value of the β-functions at the Crab-Waist sextupoles must be tuned to the values that fully exploit the strength of the existing devices. Particular care has been devoted to the study of the coupling correction, which is crucial for the achievement of the goal luminosity.

3.4. COUPLING CORRECTION

To cancel beam coupling, the field integral introduced by the detector solenoid is almost cancelled by means of two anti-solenoids, installed symmetrically with respect to the IP in each ring, which provide compensation also for off energy particles. The rotation of the beam transverse plane is compensated by rotating some of the IR quadrupoles around their longitudinal axis. The first low-β quadrupole has been kept in the upright position, since the nominal rotation suitable for coupling correction significantly increases the displacement of the beam vertical trajectory. Coupling correction fine-tuning, for each beam, is assured by a skew quadrupole added in each branch of the IR and by the two independently powered anti-solenoids.

3.5. KLOE2 IR ASSEMBLY AND INSTALLATION

The KLOE2 IR assembly has been completed in June 2010. It has been realized in two steps:

a) assembly of the beam pipe, low-β magnetic elements and beam diagnostics
b) insertion of the IR low-β section inside the KLOE2 detector.

As a first step the low-β permanent magnet quadrupoles have been positioned around the beam pipe, rotating the focusing ones by the angle suitable to compensate the rotation introduced by the experimental solenoid. The eight permanent magnet dipoles (two on each IR branch), used to maintain the beam vertical trajectory within reasonable values in the IR, have been added just after the low-β doublets. The magnetic fields of the magnets have been measured and their position checked by means of a laser tracker. At last the sphere surrounding the IP, which is built in ALBEMET, has been welded to the beam pipe (see Figure 4 below). Eventually the IR low-β has been moved in the DAΦNE hall, inserted inside the KLOE2 detector and connected to the IR end sides.

Operation with DAΦNE have been restarted in the mid of September 2010 with the detector solenoid off, due to a technical problem in the cryogenic plant. This allowed to check all the rings components, the diagnostics and to start the vacuum conditioning with the beam.

The KLOE2 detector has been switched on in the second half of December 2010. After applying the nominal optics the ring tune up procedure has started. Presently a current ~ 1000 mA has been stored in both beams and the transverse betatron coupling is ~ 0.5%.
To reduce backgrounds in the detector, in February 2011 an additional lead screen, 1 cm thick, has been added around the inner layer of the detector. Preliminary measurements have shown a reduction of a factor of 2 in the background hitting the experimental apparatus. The new stripline injection kickers which have been modified in order to improve the kick strength by a factor ≈3, with the same amplifier power have been commissioned and proved to work finely.

Fig.4: IP beam pipe with the pm magnets (left) and final assembly with the ALBEMET round IP pipe (right).

4. FUTURE PLANS AND CONCLUSIONS

The IR for the KLOE2 experiment, based on the Crab-Waist collision scheme, has been designed, built and installed on the DAφNE collider. In the next months the efforts will be addressed to commission DAφNE with the KLOE2 detector, as well as to compare beam simulation studies about beam dynamics, beam-beam and backgrounds hitting the experimental detector, with measurements. The commissioning of the clearing electrodes for the e-cloud instability will also be carried out. This work will be extremely important for the design of future positron rings.

5. PUBLICATIONS

www.lnf.infn.it/acceleratori/dafne/NOTEDAFNE/IR/IR-14.pdf
C.Milardi et al., THE DAφNE INTERACTION REGION FOR THE KLOE-2 RUN, EuCARD NOT-2010-002.


**ANNEX: GLOSSARY**

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<td>IR</td>
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