DAΦNE Activity report (2025)

Storage Ring Team
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1 Introduction

The operational performance of DAΦNE during the 2023–2024 period has been comprehensively documented in the corresponding Activity Report [1] and reported at the IPAC24 conference [2]. These reports summarize the final phase of collider operation during the SIDDHARTA-2 [3] physics run and highlights significant progress in luminosity optimization, background reduction, collective effects mitigation, and optics control.
The progress of data delivery over time (left) is shown in Fig. 1, together with the average daily efficiency (right). Excluding the planned stops for maintenance or holidays, the average efficiency has been of the order of 75%, while the experimental conditions have been constantly improved in terms of delivered luminosity and machine background pollution. The steady growth of daily integrated luminosity reflects systematic optimization of working points, nonlinear optics correction, and Crab-Waist sextupole tuning. The achieved peak luminosity of 2.4×10^{32} cm^{-2}s^{-1} confirms the robustness of the collision scheme at high stored currents and validates the long-term stability of the Crab-Waist configuration originally demonstrated at DAΦNE in Ref. [4].

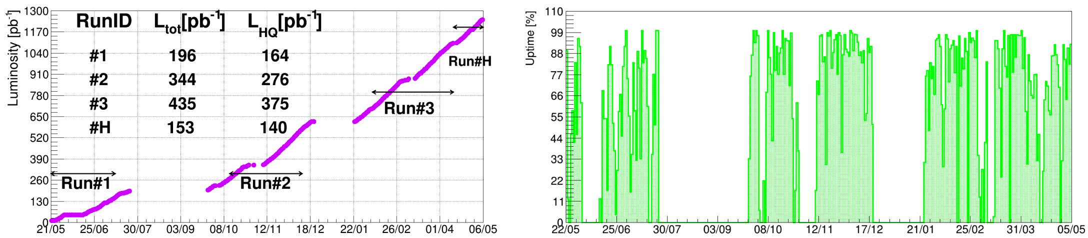

Figure 1: Data delivery during the SIDDHARTA-2 physics run: integrated luminosity (left) and average daily efficiency (right) as a function of elapsed time. The table in the left plot reports the breakdown of the luminosity delivered in different run periods. The L_{HQ} column reports the high-quality data collected. The fraction of good data steadily increased throughout the run as a result of the continuous effort in the machine tuning.

The successful completion of the SIDDHARTA-2 run therefore represents not only a physics achievement, but also the demonstration of a mature, stable and well-understood collider configuration. This performance baseline naturally motivated a strategic transition toward exploiting DAΦNE as a validation platform for future circular collider technologies while maintaining an experimental collider program..

In response to the 68th and 69th Scientific Committee recommendations, a dedicated *Storage Ring Working Group* was established in 2025 to define a medium- and long-term program for the DAΦNE complex, including, but not limited to, its evolution into a Test Facility for Future Circular Colliders.

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2 Strategic Vision: DAΦNE as a Test Facility

The proposal to operate DAΦNE as a Test Facility began at the end of the KLOE-2 physics run, with a dedicated workshop[2] held in the Laboratory in December 2018 [5]. The latest evolution of the program has been presented at the Future Tau-Charm Facilities Conference (FTCF25) [6]. The concept is based on the unique combination of operational experience, Crab-Waist collision scheme validation, high-current capability, and advanced diagnostics infrastructure.

During its latest operational phase, DAΦNE demonstrated stable operation with electron currents up to 1.3 A and positron currents up to 0.9 A. These achievements provide a solid platform for addressing R&D topics directly relevant to future circular colliders.

The Test Facility program is structured along two complementary axes: collider-mode validation studies and single-ring operational developments.

In parallel with physics-driven activities, a structured assessment of aging magnet systems, power supplies, RF infrastructure, vacuum components, and diagnostics has to be implemented in order to evaluate the resources needed for any future proposal, ensuring compatibility with other LNF facilities and long-term laboratory planning.

3 Collider-Mode Validation Studies

Collider-mode studies represent the most strategically relevant component, also considering the possibility of pursuing advanced machine studies and physics dedicated runs with the present configuration as proposed by the SIDDHARTA-2 collaboration with the EXKALIBUR proposal [7].

3.1 Monochromatization with Crab-Waist

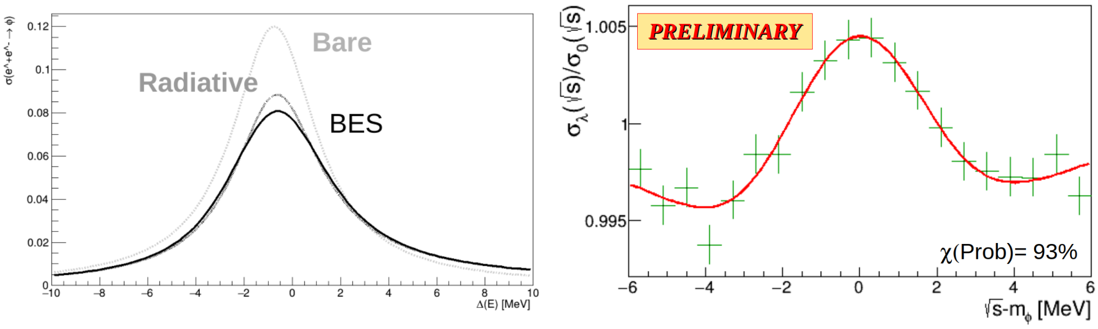
Monochromatization, originally proposed by Renieri in 1975 for ADONE [8], introduces controlled dispersion at the Interaction Point to improve the effective center-of-mass energy resolution without the needs to reduce the natural single-beam energy spread. This configuration has been studied for many colliders but was never tested experimentally. Strong interest in this option is connected to the direct production of Higgs boson at FCC_ee collider, as discussed in [9] and references therein.

A feasibility studies has been started in order to integrate the monochromatization optics into DAΦNE collider. Simulation studies show that the required sensitivity can be achieved by measuring the ratio of visible cross section for the ϕ meson production with and without dispersion at the Interaction Point. This method allows the achievement of good precision with reduced systematic uncertainties. Preliminary estimates show that achieving a relative precision of 10–15% on a monochromatization parameter $\lambda \approx 1.02$[3]

[2] The workshop homepage: https://agenda.infn.it/event/16334/

[3] The λ parameter represents the scaling factor of the center of mass energy resolution (σ_w) in the original proposal by Renieri with and without dispersion at the Interaction Point (IP). Being δ the relative beam energy spread, the incoherent convolution of the two beams will imply: $\sigma_w = \sqrt{2}\delta E_b$, where E_b is the beam energy. The introduction of the dispersion will modify as: $\sigma_w = \frac{\sqrt{2}\delta E_b}{\lambda}$. The parameter λ is connected to the increased beam size at the IP as:

$$\lambda = \sqrt{1 + \delta^2 \left(\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}} \right)}$$



(a) (b)

Figure 2: Monochromatization study for DAΦNE collider. Left: Cross section for the ϕ-meson production. The solid black line represents the visible cross section convoluted with the center-of-mass energy resolution, the dashed line is the visible cross section with radiative correction and the gray line is the bare cross section. Right: Experimental observable: ratio between standard and monochromatized visible cross section. The effect of the reduced center-of-mass energy resolution appears as a modulation of the visible cross section ratio as a function of the center of mass energy.

would require approximately 60–80 days of collisions at a luminosity of 10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

3.2 Beam–Beam Dynamics and Feedback Studies

Beam–beam interaction and collective instabilities remain key performance limitations in high-luminosity circular colliders. DAΦNE provides a mature environment for benchmarking beam–beam simulations and validating feedback system performance, as demonstrated by a dedicated study presented at IBIC2024 [11]. These measurements characterize multi-bunch instability growth rates, damping performance, and diagnostic resolution and represent important benchmarking data for simulation codes and future feedback system design.

3.3 Electron Cloud Characterization

Electron cloud effects are of particular importance in high-current positron rings. Dedicated simulations and measurements were carried out for different beam configurations and currents. Results were presented at IPAC2024 and published in Ref. [12]. These studies contribute to the validation of electron cloud models and mitigation strategies for future facilities.

4 Single Ring-Mode Developments

This chapter addresses the possibility of using a single main ring or the damping ring in order to provide beam for additional users or facilities (extracted beam for particle physics experiments, stored beam for synchrotron radiation production) or experimental environment to test specialized diagnostics or equipment. These developments aim at expanding operational flexibility and maximizing the scientific return of the complex.

4.1 Pulse Stretcher via Resonant Extraction

Motivated by the PADME-X17 Run-III results [13], a feasibility study for slow extraction from the damping ring was initiated. The scheme is based on third-order resonant extraction described by the Kobayashi Hamiltonian formalism. A first study on the subject was performed using the positron ring of DAΦNE and is reported in Ref. [14].

The target operational parameters include a beam energy of 280 ± 30 MeV, tunable in 1 MeV steps, with an average flux of approximately 4×10^6 particles/s, energy spread below 0.3%, and divergence below 1 mrad.

Two different approaches are currently under evaluation. The resonance condition can be triggered by: synchrotron radiation energy with RF off or beam continuous kicking with RF ON. The first approach allows to limit the needed equipment, because it relies only on the proper ring setup, but it implies a spill duration limited by the energy spread of the injected beam and a repetition rate limited by the injection frequency. The second option requires additional equipment, but would allow, in principle, much longer spill durations with a time microstructure due to the RF frequency. In Fig. 3 some results from the simulation in the first scenario are shown.

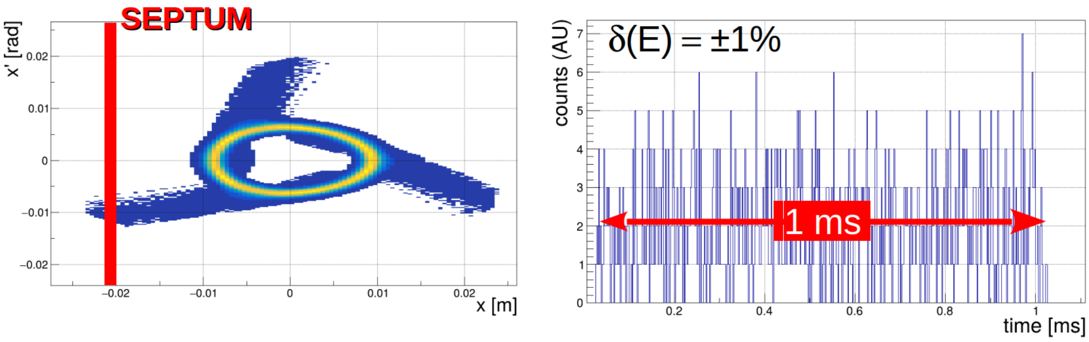


Figure 3: Left: Horizontal phase space at the extraction septum position. The ring optics has been set close to the third order resonance condition ($Q_x = 0.25$). The energy loss for synchrotron radiation (0.65 keV/turn) and the chromaticity ($\xi_x = -6$) pushes the particles toward resonance condition ($Q_x^{part} = 1/3$) and therefore start moving along the separatrix increasing the distance from the center until lost. The red vertical line corresponds to the septum blade position. Right: duration of the spill for the particles crossing the septum boundary. With present approach (the beam enters in the resonant condition because of the energy loss without RF source restoring it) the spill duration is fully driven by the ratio between the energy spread of the injected beam and the energy loss per turn.

One of the major limitations has been identified in the transport of the extracted beam to any experimental area capable of hosting a PADME-like experiment. Without modifying the present transfer line, it would be necessary to use the existing pulsed magnets, which would limit the repetition rate to 2 Hz.

5 Conclusions

The SIDDHARTA-2 run confirmed that DAΦNE can operate in stable conditions with reproducible performance. The peak luminosity, the average efficiency during data taking, and the background control obtained in the last period show that the machine parameters are well under control. Collective effects mitigation and optics tuning reached a stable configuration that can be reproduced.

Starting from these results, the Storage Ring Working Group has begun to define a possible medium- and long-term program for the machine. One option is to use DAΦNE as a Test Facility for future circular colliders, exploiting the experience accumulated in Crab-Waist collisions and high-current operation.

The monochromatization study represents one of the most interesting topics. If feasible, it would allow experimentally testing a configuration that has been discussed for future Higgs factories but never implemented in a running collider. Beam–beam studies, feedback diagnostics, and instability measurements can also provide useful data for simulation benchmarks. The electron cloud studies performed in recent years are directly relevant for positron rings and damping rings of future machines.

In parallel, single-ring developments such as resonant extraction could extend the use of the complex to additional experimental programs. These activities would require careful evaluation of existing hardware and infrastructure constraints.

Overall, DAΦNE remains a flexible accelerator complex. Any evolution toward a structured Test Facility should consider technical feasibility, available resources, and compatibility with other LNF programs. The experience accumulated over the years can be used to support future developments in circular collider design.

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