Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

DAΦNE as Open Accelerator Test Facility

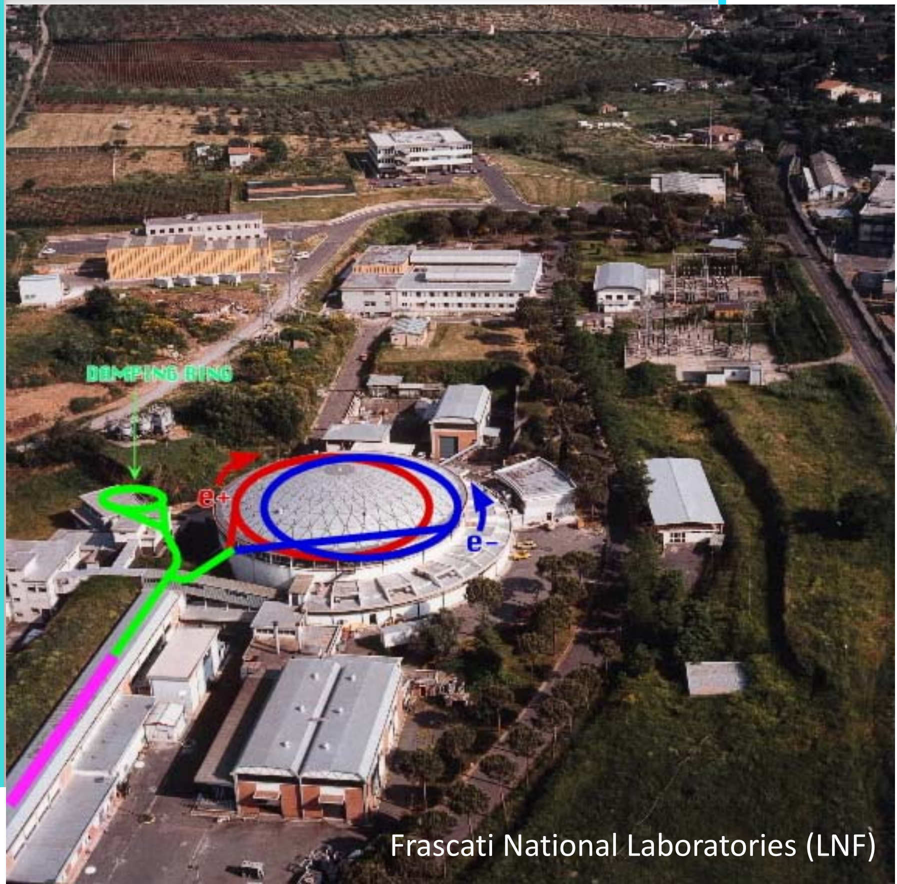
aimed at studying physics and innovative technology for particle accelerators

Catia Milardi

on behalf of the DAΦNE-TF Workshop Scientific Committee

eeFACT18 – 24÷27 Spt 2018 – Hong Kong

The DAΦNE Accelerator Complex

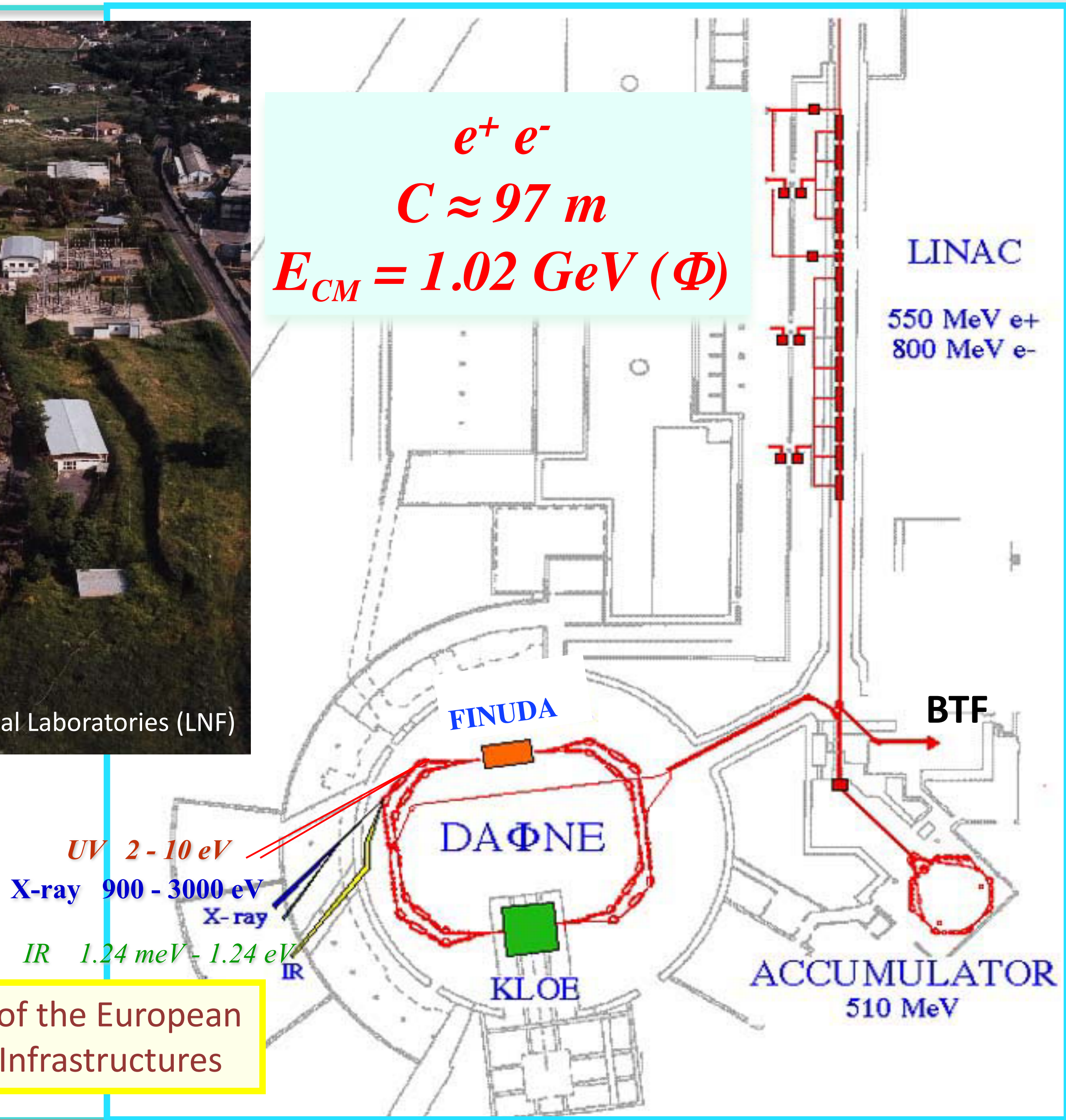


Frascati National Laboratories (LNF)

$e^+ e^-$

$C \approx 97\ m$

$E_{CM} = 1.02\ GeV\ (\Phi)$



LNF are also part of the European synchrotron light Infrastructures

DAΦNE History

- DAΦNE is an electron-positron collider designed in the mid ‘90s which came into operation in 2000

- It has been providing data, in consecutive data-taking periods, for:
  the **KLOE**, **DEAR** and **FINUDA** experiments until 2006
  Siddharta from 2007 to 2009
  again for the upgraded **KLOE-2** apparatus between November 2014 and March 2018

  Presently the DAΦNE LINAC is operating for **PADME**

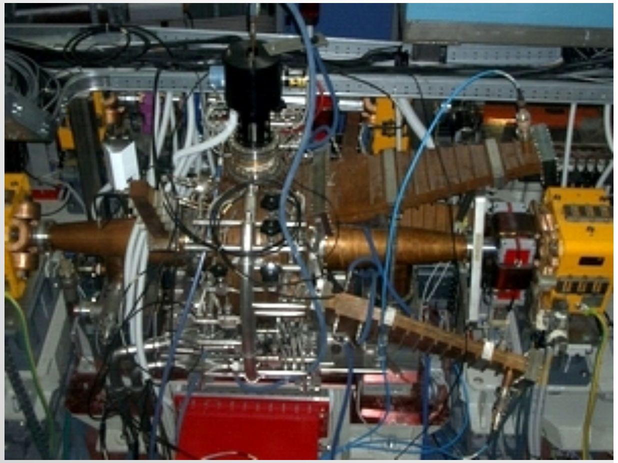
  eventually in 2019 it will provide physics events to the **SIDDHARTA-2** detector.

In 2020 *DAΦNE will stop running as a collider and will be most likely transformed in an* ***open accelerator test facility****.*

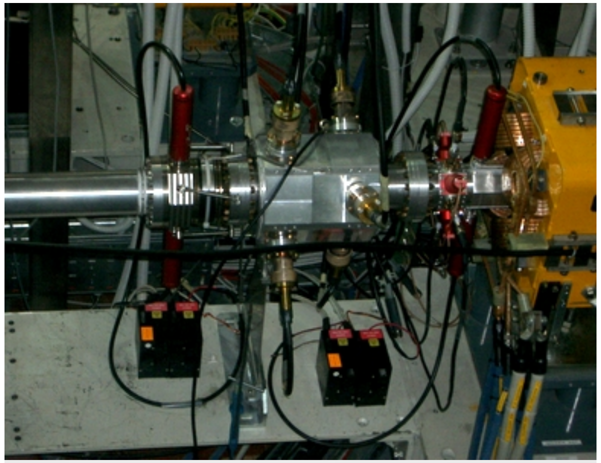
DAΦNE achievements

- luminosity achieved at DAΦNE is almost an order of magnitude higher than the one obtained at other colliders operating in the same energy range
- Impedance budget is a factor 80 lower than in similar storage ring (EPA)
- Collisions with negative momentum compaction gave a 25% gain in terms of specific luminosity at low current without sextupoles
- Longitudinal feedback kicker designed for DAFNE has been adopted at: KEKB, BESSYII, PLS, SLS, HLS, ELETTRA, KEK Photon Factory, PEP II …
- Maximum current stored in the DAFNE electron ring, 2.45 A, is the higher ever stored in particle factories and modern synchrotron radiation sources.
- DAΦNE is the only collider operating routinely with, and thanks to the electrodes for e-Cloud mitigation
- *Crab-Waist collision scheme proved to be an effective approach to increase luminosity in circular colliders even in presence of an experimental apparatus strongly perturbing beam dynamics.*

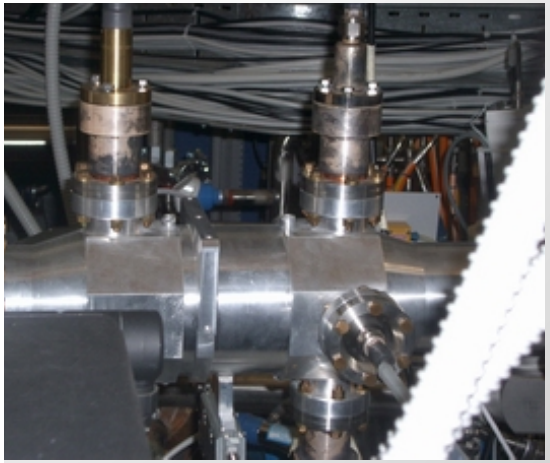
HOM Damped Vacuum Chamber Elements



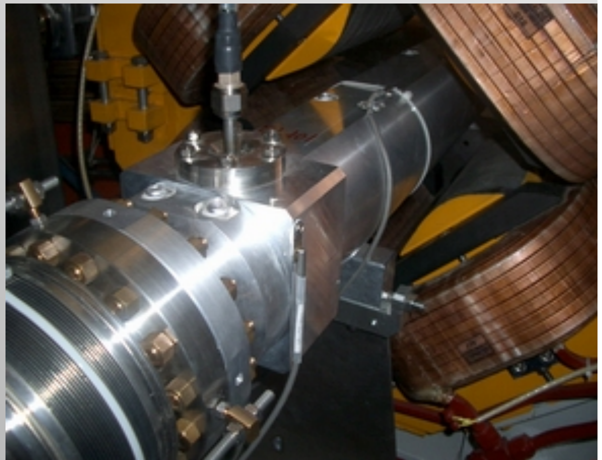
RF CAVITY



LONGITUDINAL KICKER

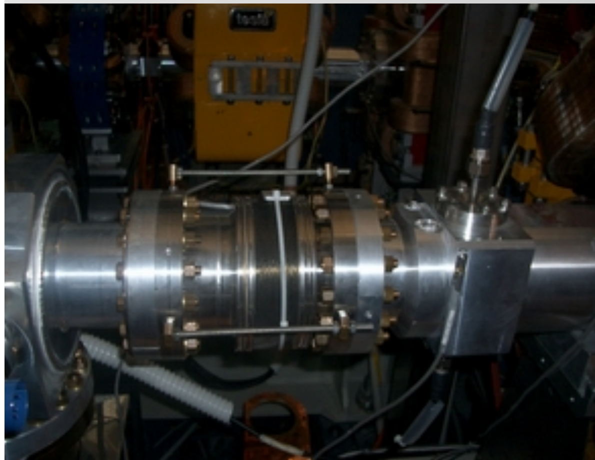


TRANSVERSE KICKER



INJECTION KICKER

WALL CURRENT & DCCT MONITOR



SHIELDED BELLOWS

DAΦNE is a collider operating with high currents

Lepton Beam Currents achieved so far

	beam current I [A]	bunch population N_b [10^{11}]	rms bunch length [mm]	bunch spacing [ns]	comment
PEP-II	2.1 (e^-), 3.2 (e^+)	0.5, 0.9	12	4.2	closed
superKEKB	2.62 (e^-), 3.6 (e^+)	0.7, 0.5	7	6	commissioning
DAFNE	**2.4 (e^-), 1.4 (e^+)**	**0.4, 0.3**	**16**	**2.7**	
BEPC-II	0.8	0.4	<15?	8	
CesrTA	0.2	0.2	6.8	4	
VEPP-2000	0.2	1	33	80 (1 b)	
LHC (des)	0.58	1.15	75.5	25	
ESRF	0.2	0.04	6.0	2.8	
APS	0.1	0.02	6.0	2.8	
Spring8	0.1	0.01	4.0	2.0	
SLS	0.4	0.05	9.0	2.0	

Contributions to particle accelerator physics

Ideas and studies aimed at improving beam dynamics and beam-beam performances:

- Low impedance vacuum chamber components
- innovative bunch by bunch feedback systems
- short pulse PS for injection kickers
- non-linearities mitigation in magnet fields especially in wigglers
- **collisions with negative momentum compaction**
- **parasitic crossing compensation by current carrying wires**
- collisions with very high crossing angle
- strong RF focusing
- *Crab-Waist collision scheme has become a basic design concept for future new projects*
- **electrodes for e-cloud compensation**

Proposals:

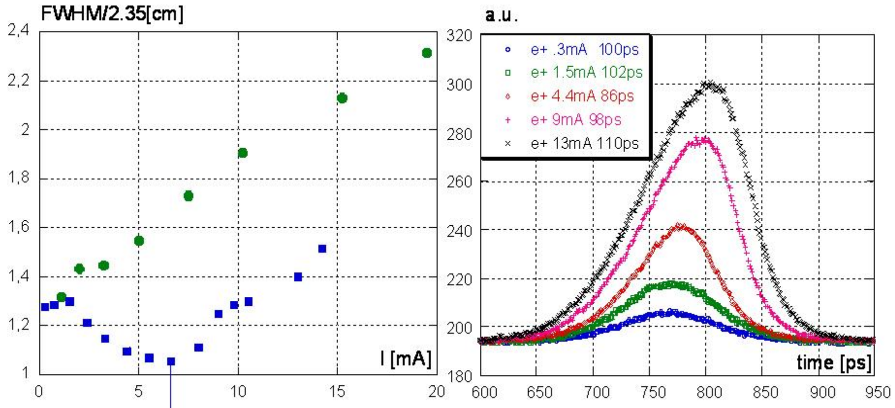
- DANAE (1.02 GeV ÷ 2.4 GeV)
- Bunch lenght modulation experiment
- DAFNE-VE (0.6 GeV ÷ 3 GeV with CW)

Crab-Waist Colliders

Colliders	Location	Status
DAΦNE	Φ-Factory Frascati, Italy	In operation
SuperKEKB	B-Factory Tsukuba, Japan	Under commissioning
SuperC-Tau	C-Tau-Factory Novosibirsk, Russia	Russian mega-science project
FCC-ee	Higgs-Factory CERN,Switzerland	100 km, CW baseline design option
CEPC	Higgs-Factory China	54 km, local double ring option with CW
LHC Upgrade	LHC CW Option CERN,Switzerland	LHC with very flat beams (low priority)

$\alpha_c < 0$ at DAΦNE

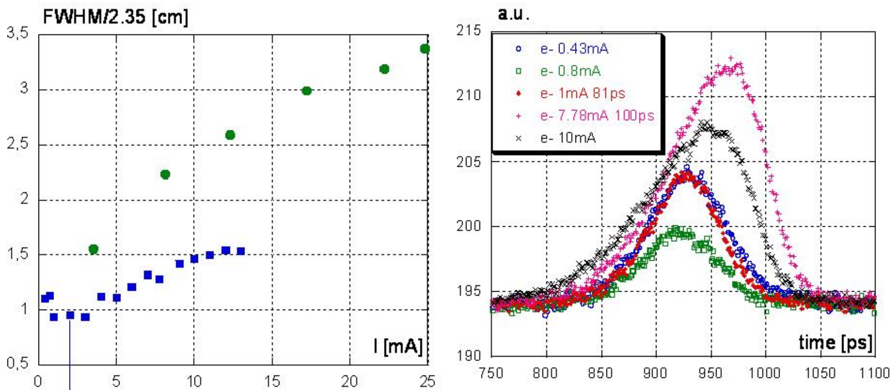
Bunch Shortening in the Positron Ring



I_{th} = 7 mA at $\alpha_c < 0$

I_{th} = 9 mA at $\alpha_c > 0$

Bunch Shortening in the Electron Ring



Low microwave instability threshold

Experimental Results

- DAΦNE flexible optics

$$-0.036 \leq \alpha_c \leq +0.034$$

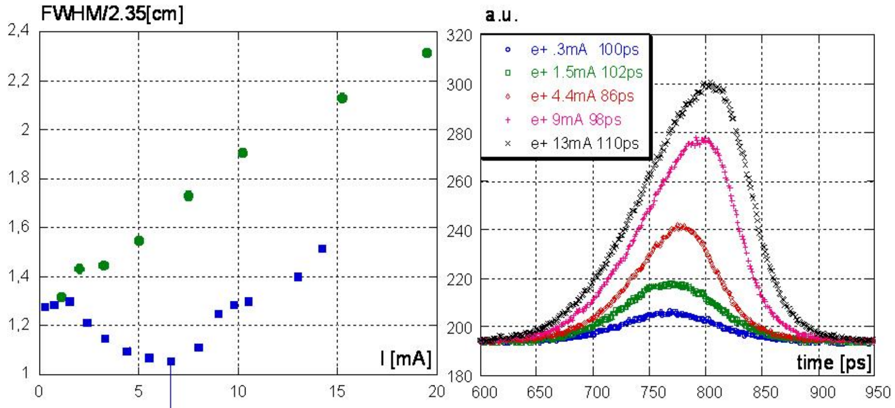
- Bunches shorten as predicted by numerical simulations.
- It was possible to store high bunch current with large negative chromaticity

I_b ~40 mA

- Stable multibunch beams with ***I > 1 A***
- **Specific luminosity gain of about 25%** till 300 mA per beam without SXTs
- Higher current beam-beam collisions failed due to σ_y^- above the microwave instability threshold

$\alpha_c < 0$ at DAΦNE

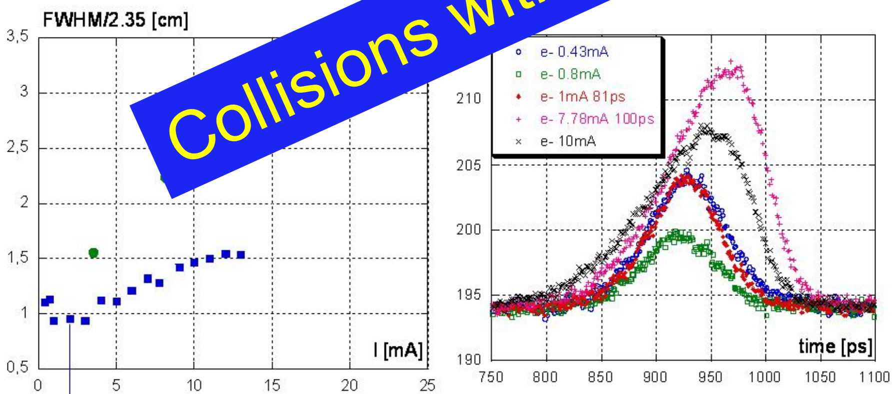
Bunch Shortening in the Positron Ring



I_{th} = 7 mA at $\alpha_c < 0$

I_{th} = 9 mA at $\alpha_c > 0$

Bunch Shortening in the ... Ring



Low microwave instability threshold

Collisions with $\alpha_c < 0$ have never been tested elsewhere

Summary of Results

- DAΦNE flexible optics

  $-0.036 \leq \alpha_c \leq$ ...

- Bunches short... ...cted by numeri... ...ons.
- ...ossible to store high bunch ...urrent with large negative chromaticity

  I_b ~40 mA

- Stable multibunch beams with ***I > 1 A***
- **Specific luminosity gain of about 25%** till 300 mA per beam without SXTs
- Higher current beam-beam collisions failed due to σ_y^- blow up above the microwave instability threshold

Then ….

The aforementioned considerations, and not only, led to conclude that DAFNE a unique facility to realize tests and measurements finalized to:

- study physics problems and innovative technologies which are of interest for the particle accelerator community
- test innovative concepts
- implement short term experiment about fundamental and applied physics
- train young generations of particle accelerator physicists

Field of Reserch at DAΦNE-TF

The lines of scientific and technological research identified so far are compliant with the following items:

- machine operating parameters
- impact that tests can have in terms of machine layout and components modification, invasive measurements and experimental activities hardly compatible with the actual machine configuration are unlikely to be considered
- maturity level of the experimental programmes proposed.

General Considerations about DAΦNE-TF

- Much of the **hardware** installed in DAΦNE, although constantly maintained and improved, dates from the mid '90s.
- An **overhaul** focused on the most relevant aspects (for an amount of about 1000 kE) was realized in 2013, and continued in the following years.
- A significant upgrade of the **Linac** is now in progress, including the split of the Beam Test Facility (**BTF**) in order to increase the number of future users.
- The current value of the infrastructure exceeds 200 ME.

- Despite the relatively obsolete nature of part of its components, DAΦNE and BTF were able to regularly provide beams for more than 6,000 hours per year, keeping their **operational efficiency** at levels above 80% for long periods.
- During the last decade, the Linac has powered the BTF for external users with great success, while DAΦNE was simultaneously operating in collider mode.

- In the same years, the **synchrotron-light laboratory** has benefited from radiation in parasitic mode, hosting external users for about 800 hours per year, and getting the CALYPSO program of Horizon 2020. The synchrotron-light activity allowed the Laboratory to be included into LEAPS, *League of European Accelerator-based Photon Sources*

- The DAΦNE complex hosts also a **cryogenic plant**, recently modernised, enabling to operate superconducting magnets, experimental setups, and superconducting radiofrequency systems (although the latter have never been used at DAFNE).

General Considerations about DAΦNE-TF

It is the only existing phi-factory and, until the entry into operation of SuperKEKB, it will be the only collider on which the ***Crab-Waist*** **Collision scheme has been successfully implemented** with and without the experiment solenoid.

If converted into a facility for the study of physics and technologies for accelerators, **DAΦNE-TF** would add to the small number of accelerators available to this purpose.
If one considers just electron machines, this list includes **ATF2** (KEK), a top-class facility designed for the development of the International Linear Collider, **CLASSE** (Cornell Laboratory for Accelerator Based Science and Education), a centre of excellence in the development of accelerator technologies located in an university campus, and **ANKA** (Karlsruhe), devoted to R&D of machines and applied research. In the case of **DAΦNE-TF** users would benefit from a level of scientific and technical support, provided by the LNF personnel.

Furthermore, **DAΦNE-TF would operate when CERN won't have beams,** i.e. over 2019-20, due to the realization of the upgrade of LHC injectors and during each of the long stops *LS3 (2024, HL-LHC installation*) and *LS4 (2030)*, which will make the availability of DAFNE-TF for accelerator studies even more interesting.

Possible activities

- ***Study of low SEY (Secondary Electron Yield) elements and impedances; Graphitization of chambers and other technologies.***

  The **reduction of SEY** of the vacuum chambers allows to inhibit or reduce the resonance originating the *electron cloud* and the resulting instabilities. The effect of **graphitization** on the SEY has already been proven, but machine tests remain central to assess the impact in terms of impedance budget. Special devices, like **coldDIAG**, (superconducting vacuum chamber, a very preliminary version of which has been realized at ANKA), could be installed in the present interaction region of KLOE to implement measurements also as a function of temperature, both with electron and positron beams. Such apparatus could be also useful to characterize and study new technologies to construct collimators. These studies are declared to be of CERN interest in view of HL-LHC and, in future, for FCC.
- ***Accelerator components realized with 3D printers.***

  The new technologies related to 3D printing seem to be particularly suitable, especially for high-precision mono-block structures, as recently proven at BNL with the realization of the structures for the permanent magnets.

Possible activities

- ***Wide-excursion adjustable permanent magnets***

  The development of the technology to realize adjustable permanent magnets is of particular interest *for synchrotron-light machines*, since it would make possible to drastically reduce operation costs maintaining, at the same time, an appropriate level of flexibility for machine configuration now guaranteed only by the use of electromagnets.
- ***High power solid state RF amplifiers***

  Solid state amplifier technologies have already been implemented and successfully tested as RF power source in many circular machine (SOLEIL, ESRF, DAFNE Damping Ring, etc...). That enabled a significant increase of the accelerator up-time, avoided configurations with high-voltage gradients, and reduced costs of acquisition, operation, and maintanance. The future trends will aim at reaching frequencies near 500 MHz, with efficiencies greater than 50%, and at extending the technology to the L band structures.
- ***High-power positron sources: peak Energy Deposition Density in the targets, wide aperture capture, accelerating sections in S Band***

  One of the most advanced challenges for the future projects of linear colliders is the realization of *medium-current positron sources* (e.g. for ILC).

Possible activities

- ***Components for future SLED and pulse flatness compensation***

  For multi-bunch operations, the regulation of SLED pulses is fundamental. It can be performed by the study and realization of high precision LLRF masks in the classical systems, or by developing new techniques such as the dual mode SLED ones.
- ***Components for accelerators (vacuum chambers, collimators, masks, kickers) and innovative beam diagnostic techniques***

  This item represents an extention of statement *2)* to the accelerator components, regardless of the production technique used. The chance to test with beams the performances of diagnostic tools based on innovative concepts and materials is of particular importance not only for the particle accelerator community, but also for specialized companies, which would have at their disposal an exceptional test-bed.

Possible activities

- ***Emittance manipulation***

  The transfer of radiant emittance in 6D from a level to another, would provide beams with different characteristics for a variety of purposes, ranging from low emittance beams mandatory for FEL or Compton emission experiments, to beams with really small energy spread essential in order to accurately define initial states as a function of the energy.
- ***Beams interacting with amorphous materials, crystals, lasers, plasma***

  Beam tests at high beam current with insertion of targets, lasers or plasma are particularly relevant. Measurements of the average lifetime of the interacting beams and the characterization of sources derived from the interaction, would represent a desirable progress. In the case of targets, it is important to study how a very high-flux source can be achieved, preserving the chemical-physical characteristics of the target, and how to measure the beam dynamics in this regime. Activities related to the exploration of the future use of crystals to manipulate particle beams (as focalization or acceleration) may be of great interest at DAFNE-TF. In the field of plasma

Possible activities

DAΦNE-TF might also host small size experiments in the field of fundamental and applied physics requiring a small size data sample. The qualifying element of every possible proposal in this field is temporal scale.

Therefore, among the possible proposals still to be assessed, there are the measurement of processes with high effective cross sections, which are feasible with small experimental set-ups such as study of interactions K^0_L or K charged with specific materials or small-angle scattering, where interesting possibilities of testing small-angle detection systems in vacuum exist, e.g. with Roman Pot detectors highly demanding in terms of spatial and temporal resolution, high rate, radiation resistance, etc ....

DAΦNE-TF Workshop

(December 17th 2018 in Frascati)

Organized under the auspices of the LNF Director Dr. Pierluigi Campana

Scientific Committee:

L. Rivkin (EPFL and PSI, chair)
C. Bloise (INFN-LNF)
A. Ghigo (INFN-LNF)
M. Giovannozzi (CERN)
C. Milardi (INFN-LNF),
N. Pastrone (INFN-Torino)
A. Variola (INFN-LNF)

Local Organizing Committee

A. Drago (INFN-LNF, chair)
A. De Santis (INFN-LNF)
O. R. Blanco Garcia (INFN-LNF)

Website under preparation

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DAFNE-TF Workshop 2018

17 December 2018 *INFN - Laboratori Nazionali di Frascati*

HOME LNF HOME PROGRAM REGISTRATION HOW TO REACH US CONTACT

ICFA Mini-Workshop on

DAFNE as Open Accelerator Test Facility in year 2020

The workshop will take place on December 17th, 2018 at the Touschek Auditorium, Frascati Laboratory of INFN, Italy.

The workshop is intended to discuss the interest from scientists to access the DAFNE $e^+ e^-$ complex, which will conclude its physics program as collider by the end of 2020. An infrastructure almost unique, that could open as Test Facility (DAFNE-TF) to the international community for studies of accelerator technologies and beam physics, for small experiments, and to be used as a test bed for enterprises active in the sector of components for accelerators.

Scientific Committee
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Organizing Committe
O. R. Blanco Garcia (INFN-LNF), A. De Santis (INFN-LNF), A. Drago (INFN-LNF, chair)

Secretariat
D. Ferrucci (INFN-LNF), M. Luciani (INFN-LNF)

Webmaster: S. Reda

Dates: 17 December 2018 (09:00-17:00)
Timezone: Europe/Rome

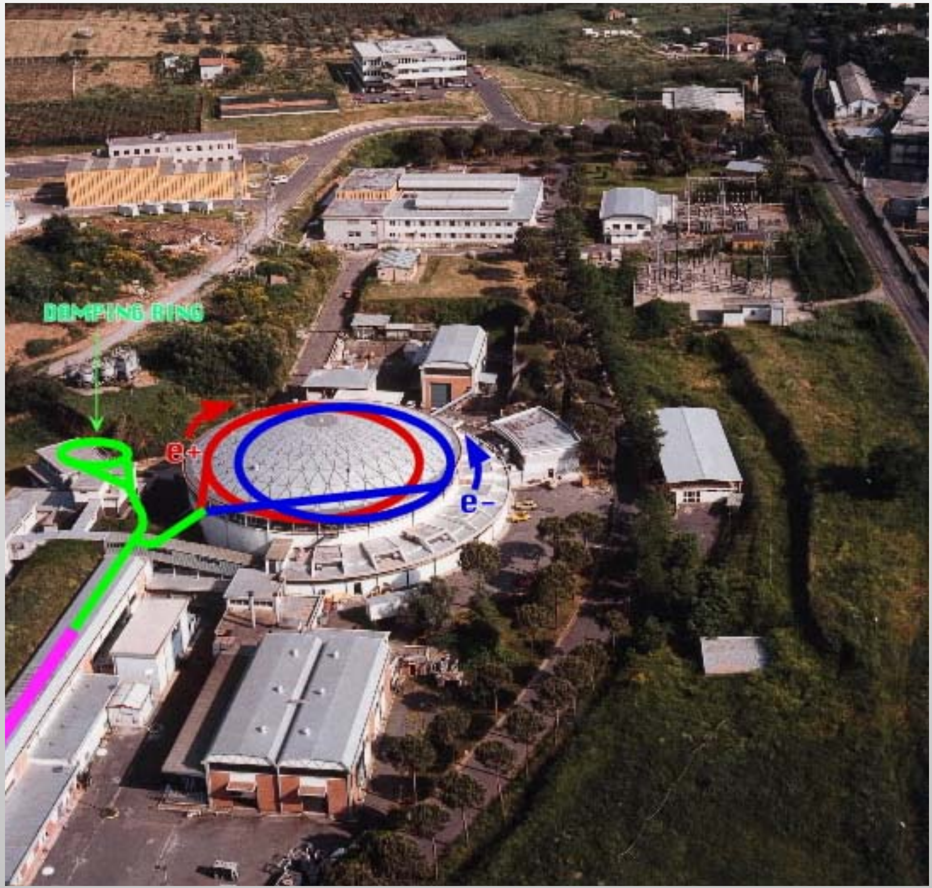
https://agenda.infn.it/conferenceDisplay.py?confId=16334

The DAΦNE Collider Parameters

	DAFNE Frascati
Physics start date	1999
Physics end date	---
Maximum beam energy (GeV)	0.510
Luminosity (10^{30} cm^{-2} s^{-1})	453
Time between collisions (μs)	0.0027
1. Full crossing angle (μ rad)	$5.*10^4$
Energy spread (units 10^{-3})	0.40
Bunch length (cm)	1.4 (at 10 mA)
Beam radius (μ)	H: 260 (at IP) V: 4.8
Free space at interaction point (m)	±0.295
Luminosity lifetime (h)	0.2
Maximum achieved current e^-/e^+ (A)	2.45 / 1.4
Turn-around time (min)	2 (topping up)
Injection energy (GeV)	on energy
Transverse emittance (10^{-9} π rad-m)	H: 260 V: 2.6
β* amplitude function at interaction point (m)	H: 0.26 V: 0.009
Beam-beam tune shift per crossing (units 10^{-4})	440 (at L_{MAX} SIDDHARTA run)
RF frequency (MHz)	368.667
Particles per bunch (units 10^{10})	e^-: 3.2 / e^+: 2.1
Bunches per ring per species	100 ÷ 105 (120 buckets)
Average beam current per species (mA)	e^-: 1500 e^+: 1000
Circumference (km)	0.098
Interaction regions	1 (a second one can be restored)
Magnetic length of dipole (m)	Outer ring: 1.2 Inner ring: 1
Length of standard cell (m)	No standard cell
Phase advance per cell (deg)	---
Dipoles in each ring	8
Quadrupoles in each ring	48
Peak magnetic field in dipoles (T)	1.2
Wigglers in each ring	4
Damping Times (t_E/t_x), ms	17.8 / 36.0

Conclusions

DAΦNE is a valuable and unique infrastructure that can still play a role in the particle accelerator community.



Thank you for your attention

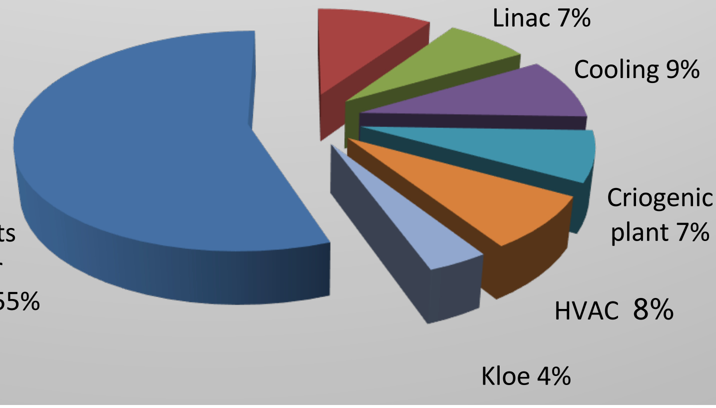
I hope to see you in Frascati!

DAΦNE Energy Saving and run cost

	kW	€cent/kWh	K€/day	1 year bill (200 run days) [M€]	Up-to date 1 year bill [M€]
Run KLOE 2005-2006	5.900	9,8	13,88	2,78	5,12
Run KLOE (Dec 2013)	3.340	18,08	14,49	2,90	2,90
Power demand reduction =	**2.560**		**200 days run saving =**		**2,22**

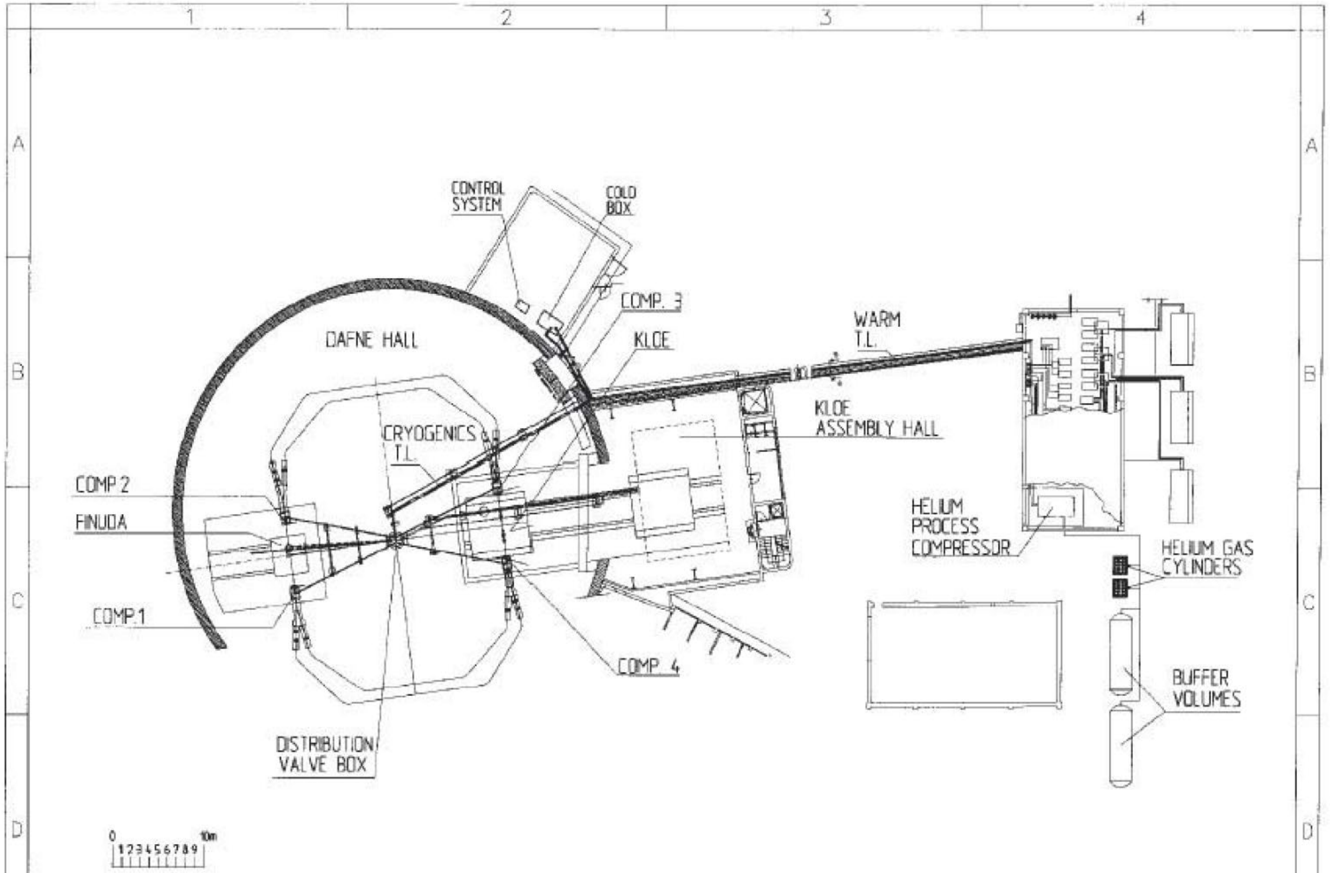
	dec-2005	NOW
Magnets Power supplies	3.984	1.850
RF MR	524	320
Linac	201	233
Cooling	600	300
Criogenic plant	250	250
HVAC	250	260
Kloe	150	120
tot	5.959	3.333

Wiggler pole shaping and current reduction (730-> 400 A)	1700 kW
n. 4 Septa 34° magnets new coils	250 kW
n. 4 Splitter magnets removal (new interaction zone for the crab-waist)	160 kW
Dafne RF system optimization	170 kW
Dafne cooling system optimization	280 kW
Total power demand reduction	2.560 kW



existing DAΦNE cryogenic system

layout of DAFNE cryo
system for 6 SC magnets



G.O. Delle Monache, DAFNE, CR-1 (2005)

marginal for 4.4 K operation of 1 cavity ?

refrigerator plant LINDE TCF 50
nominal compressor power of 250 kW, delivering two cold He lines:

- **4.4 K @ 3.0 bar (100 W nominal power** + 1.14 g/s LHe);
- 77 K @ 10 bar (900 W nominal power).