Accelerators at LNF

Fabio Bossi INFN-LNF

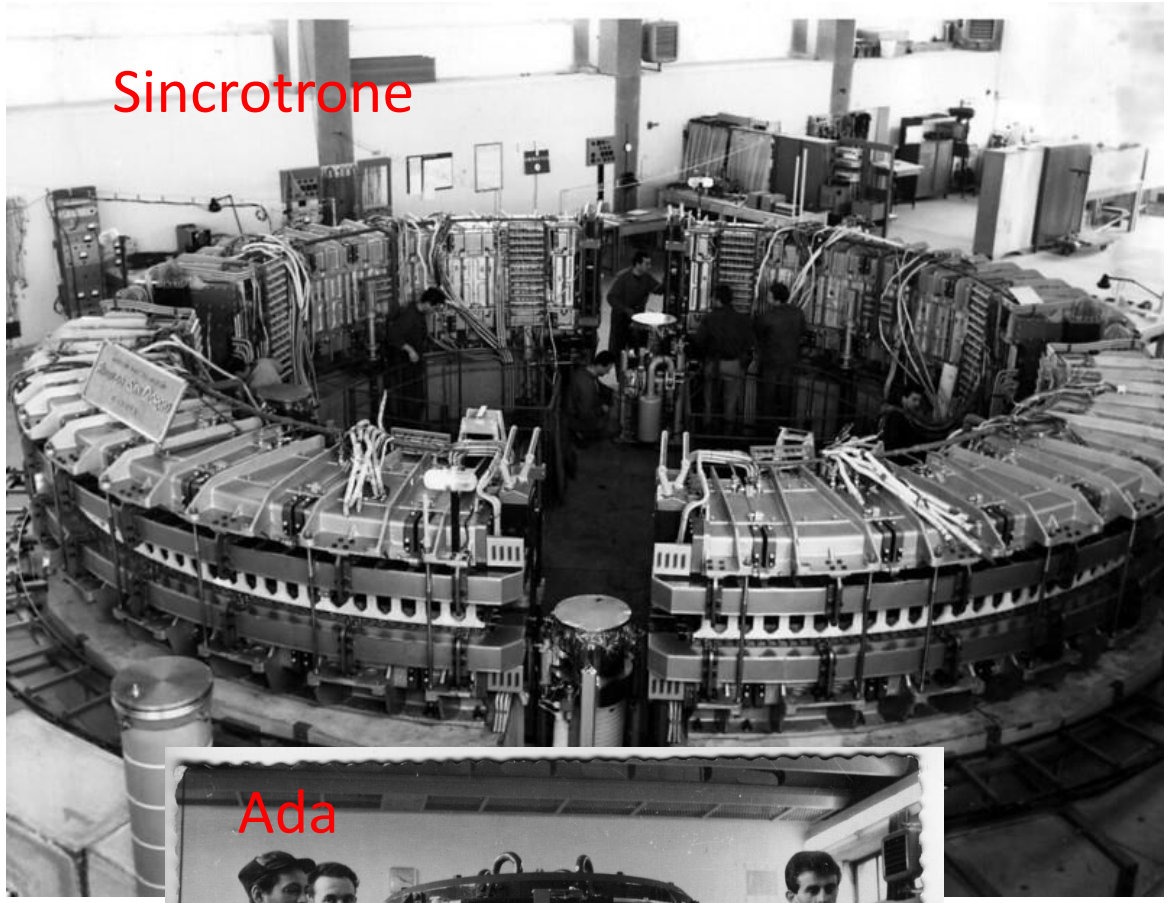
Workshop Nazionale Acceleratori

Milano, 7-8 Aprile 2022

70 Years of LNF History

Since its foundation, the main mission of LNF has been the construction and operation of accelerators for nuclear and particle physics

- 1954: Foundation of the Laboratori Nazionali di Frascati
  - 1959: First accelerator built: the Sincrotrone
    - 1961: First electron-positron collisions with Ada
      - 1969: Start of operations of ADONE
        - 2000: Start of operations of DAΦNE
          - 2004: Start of operations of SPARC
            - 2028: Start of operations of EuPRAXIA



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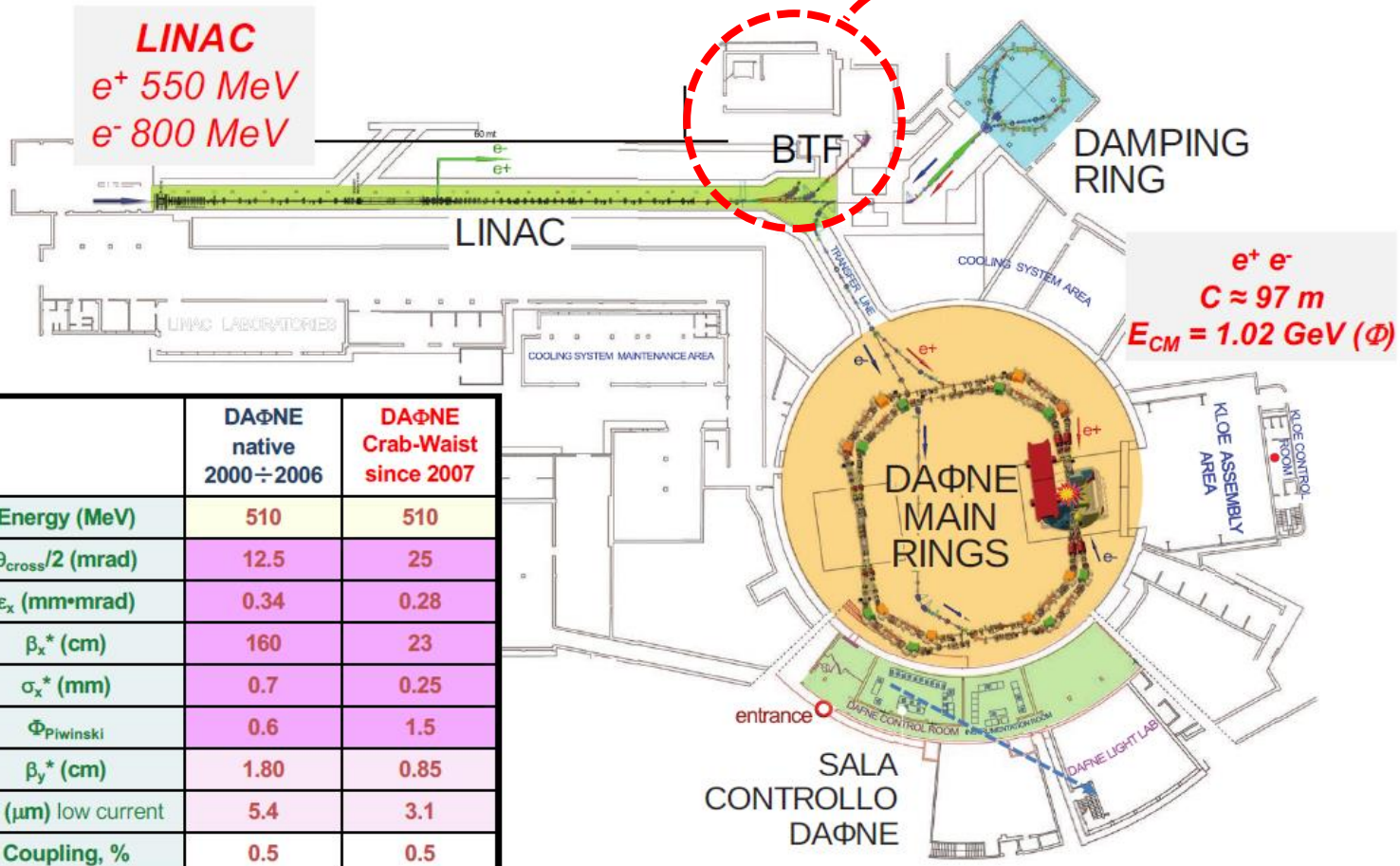
At present we have two **running accelerators**, DAΦNE and Sparc_Lab, and operate several **technical infrastructrures** devoted to accelerators R&D

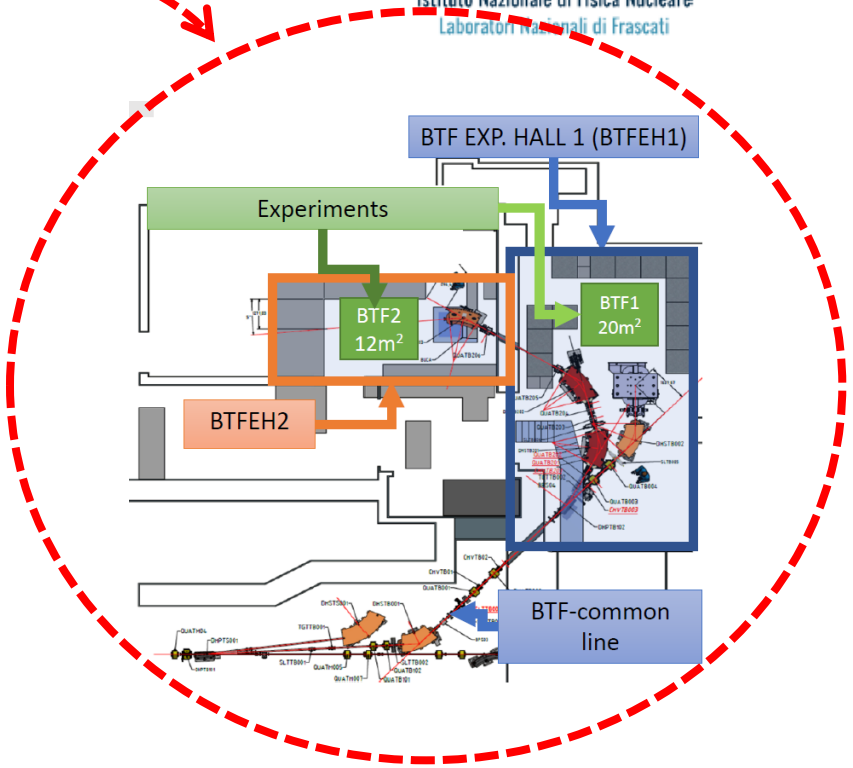
The DAΦNE Complex



	DAΦNE native 2000÷2006	DAΦNE Crab-Waist since 2007
Energy (MeV)	510	510
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm•mrad)	0.34	0.28
β_x^* (cm)	160	23
σ_x^* (mm)	0.7	0.25
$\Phi_{Piwinski}$	0.6	1.5
β_y^* (cm)	1.80	0.85
σ_y^* (μm) low current	5.4	3.1
Coupling, %	0.5	0.5
Bunch spacing (ns)	2.7	2.7
I_{bunch} (mA)	13	13
σ_z (mm)	25	15
N_h	120	120

DAΦNE implemented and tested succesfully a new approach to beam-beam interaction: the ***Crab-Waist*** **collision scheme.**

$L_{peak} = 4x10^{32}\ cm^{-2}s^{-1}$



BTF #1/2

DAΦNE Collider Operations

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The **DAΦNE** collider has entered into operations in year 2000, and has provided luminosity since then to 6 different particle and nuclear physics experiments

Experiment	Data Taking period	Int. Luminosity (pb-1)
KLOE	2000-2006	2500
DEAR	2003	60
FINUDA	2003-2007	1200
SIDDHARTA	2008-2009	600
KLOE-2	2012-2018	5000
SIDDHARTA-2	running	800 (goal)

Currently the **SIDDHARTA-2** experiment is in run

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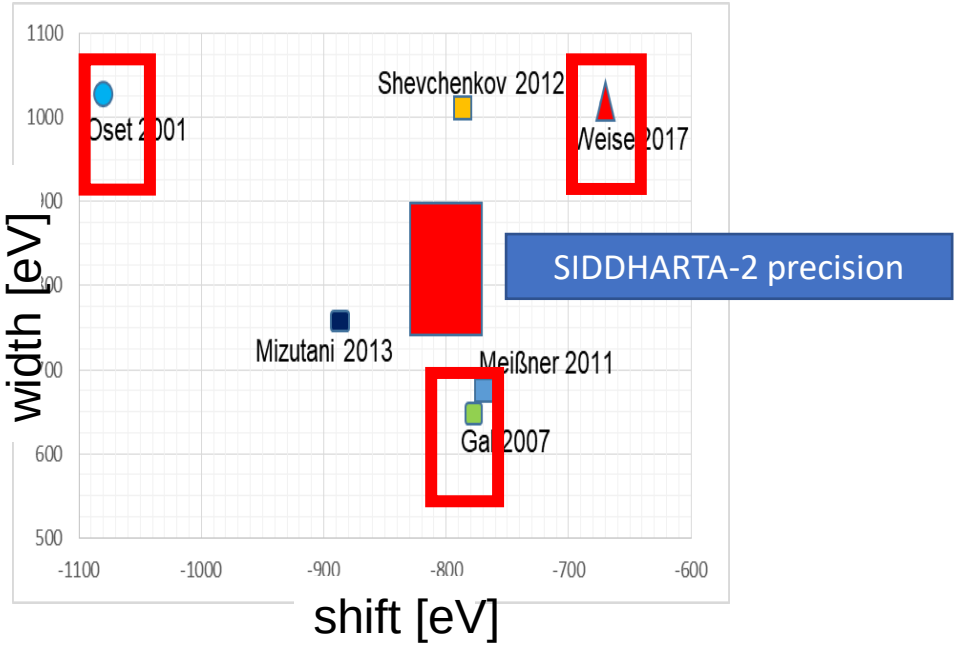
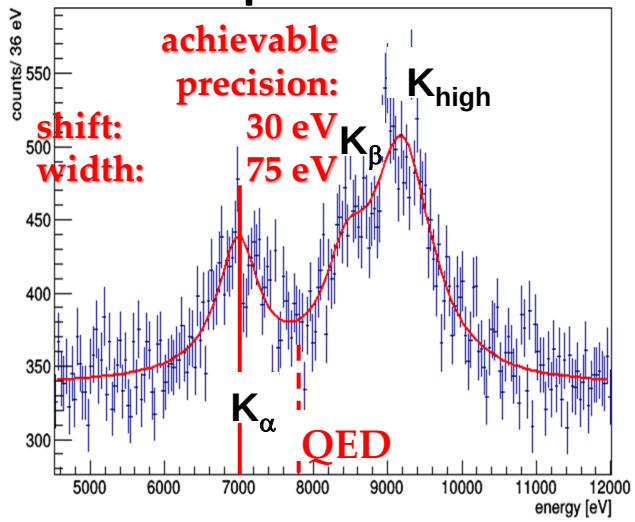
The goal of the experiment is to perform precision measurements of kaonic atoms X-ray transitions, in particular of the shift and of the width of the 1s level of the kaonic deuterium to be compared with various theoretical models



MCarlo Kd spectrum for 800 pb^{-1}



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Beam Test Facility

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Parameters	BTF1 Time sharing		BTF1 Dedicated		BTF2 Time sharing	BTF2 Dedicated
	With Cu target	Without Cu target	With Cu target	Without Cu target	With Cu target	With Cu target
Particle	e^+ / e^- (User)	e^+ / e^- (DAΦNE status)	e^+ / e^- (User)		e^+ / e^- (User)	
Energy (MeV)	25–500	510	25–700 (e^-/e^+)	167–700 (e^-) 250–550 (e^+)	Expected 25–500 to be confirmed	Expected 25–700 to be confirmed
Best Energy Resolution at the experiment	0.5% at 500 MeV	0.5%/1%	0.5%	Energy dependent	Expected 1% at 500 MeV to be confirmed	
Repetition rate (Hz)	Variable from 1 to 49 (DAΦNE status)		1–49 (User)		Variable from 1 to 49 (DAΦNE status)	1–49 (User)
Pulse length (ns)	10		1.5–320 (User)		Expected 10 To be confirmed	Expected 10-100 To be confirmed
Intensity (particle/bunch)	$1–10^5$ (Energy dependent)	1 to 10^7 / $1.5x10^{10}$	$1–10^5$ (Energy dependent)	1 to $3x10^{10}$	Expected $1–10^4$ (Energy dependent, To be confirmed)	
Max int flux	$3.125x10^{10}$ part./s				$1x10^6$ part./s	
Beam waist size(mm)	0.5–55 X / 0.35–25 Y (vacuum window dependent)				1x1, To be confirmed	
Divergence (mrad)	Down to 0.5				Expected Down to 0.5, To be confirmed	

- Pulsed **electron** and **positron** beams (up to 49 pulses/second)
- Wide range: from 10^10 down to single particle per bunch, continuous energy selection
- Different ranges of parameters in the **two running modes**:
  - Dedicated: only when DAΦNE collider shutdown, exclusive BTF users
  - Time sharing: DAΦNE spare pulse injections mode via pulsed magnet
    - Beam top parameters defined by DAΦNE injections

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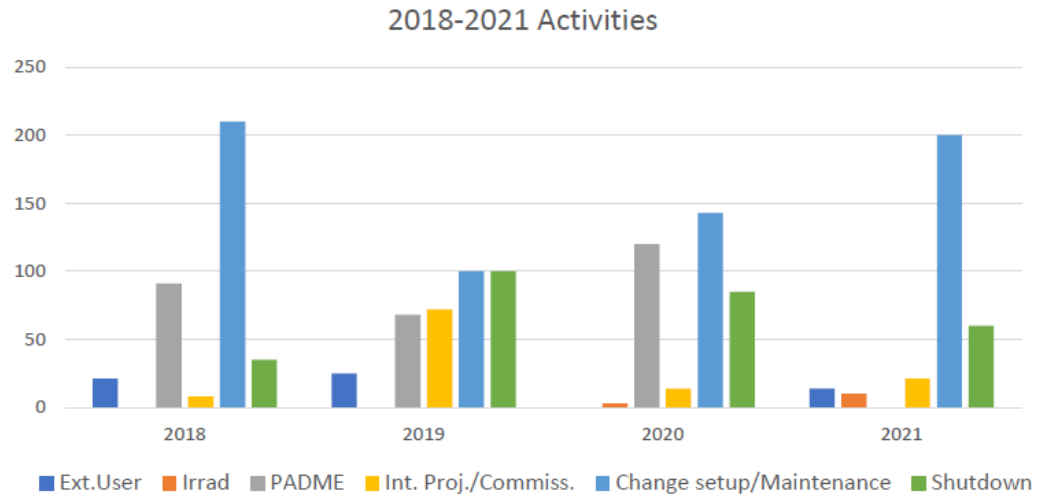
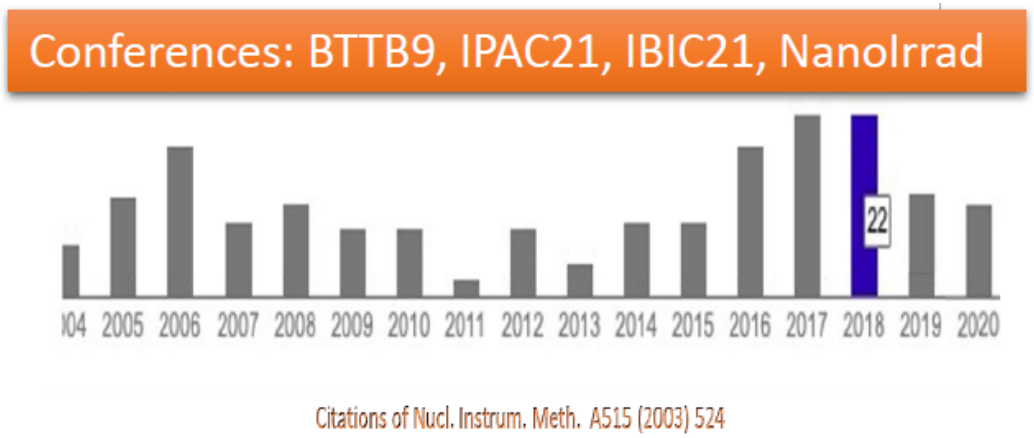
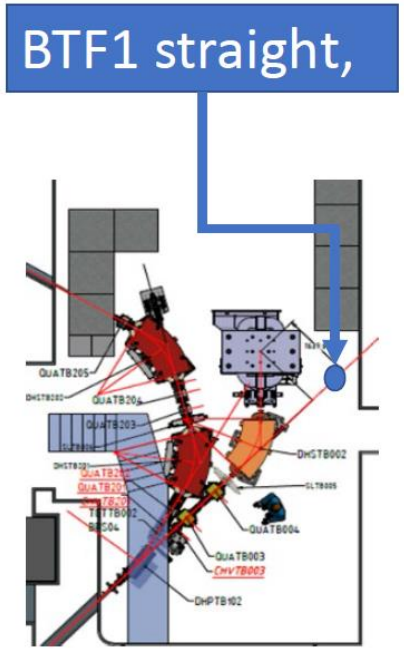
BTF Summary 2018-2021





Year 2021 Users – only BTF1 straight

- SHIP (Jan, before BTF installation, more publications)
- KLEVER (July, after BTF install., usable 1w before BTF2 Phase1)
  - Opportunistic run and test (passed) of user BTF1 subsystem
- ERAD (July, after BTF2 Phase1)
  - Scheduled with dedicated LINAC&BTF beamtime



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In 2005 the facility **SPARC_LAB** was put into operation as a test and training facility for advanced accelerator developments

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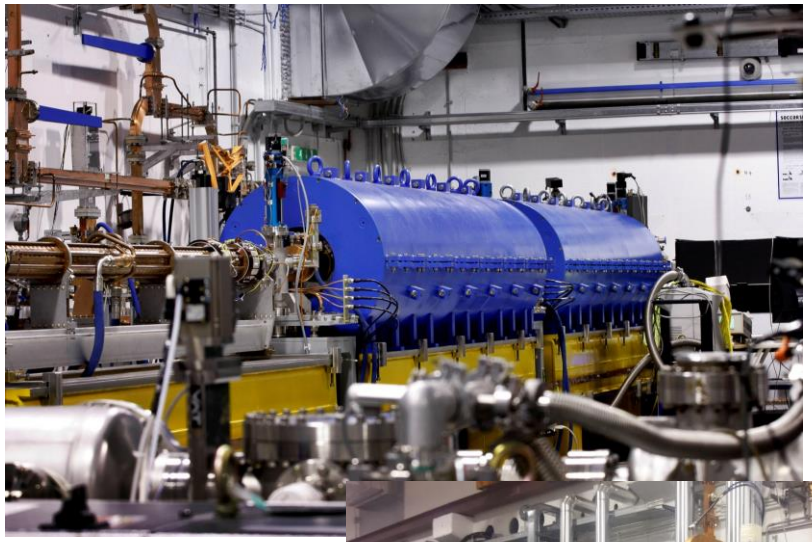
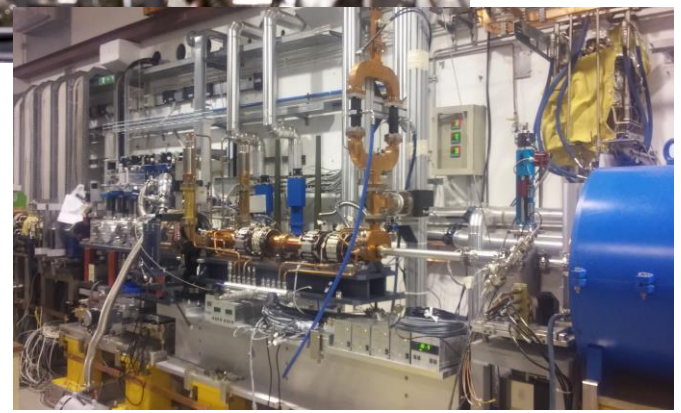
It consists of a high-brightness RF photoinjector, **SPARC**, and a multi-hundred terawatt laser, **FLAME**, and was initially focussed on performing FEL experiments and in general on the production of new radiation sources



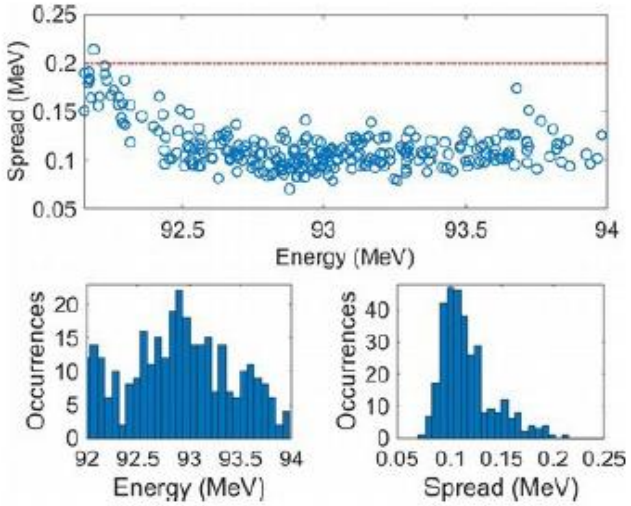
Photoinjector

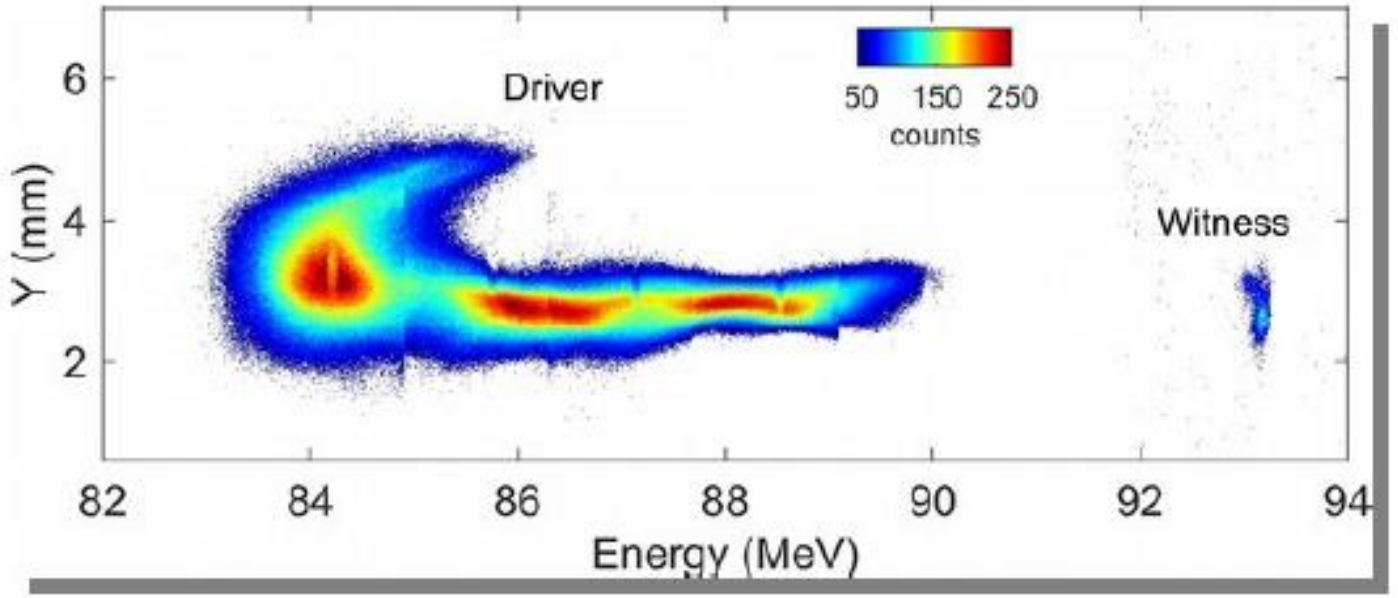
In recent years a dedicated effort has been put in the research on very high acceleration gradients with the **plasma wake field** technique



Plasma Vacuum Chamber

SPARC_LAB Results





Pompili, R., et al. "Energy spread minimization in a beam-driven plasma wakefield accelerator." Nature Physics (2020): 1-5.

Achieved 4 MeV acceleration in 3 cm plasma with 200 pC driver

- *~133 MV/m accelerating gradient*
- *$2x10^{15}$ cm^{-3} plasma density*

→ demonstration of energy spread compensation during acceleration

- *Energy spread reduced from 0.2% to 0.12%*
- *99.5% energy stability*

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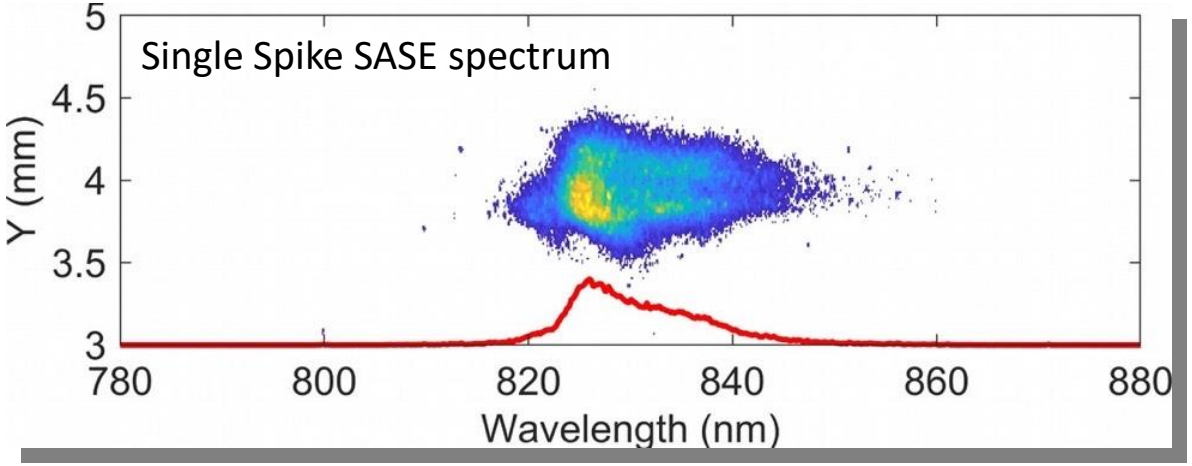
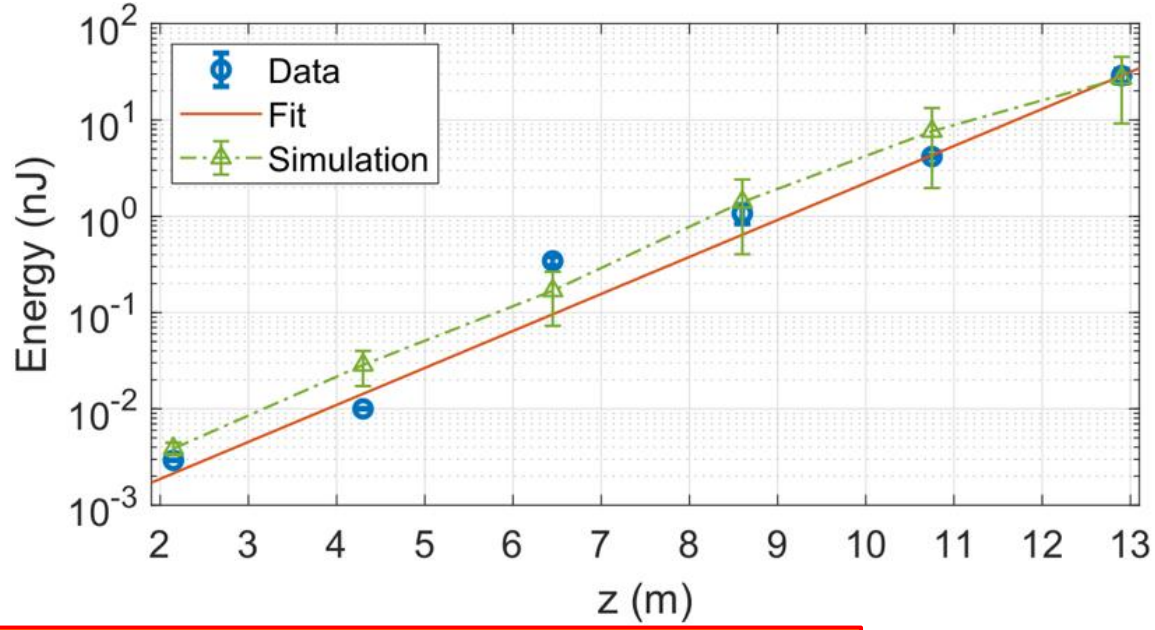


First SASE-FEL Lasing at SPARC_LAB in a beam-driven plasma accelerator

Nature paper coming soon (accepted for publication)



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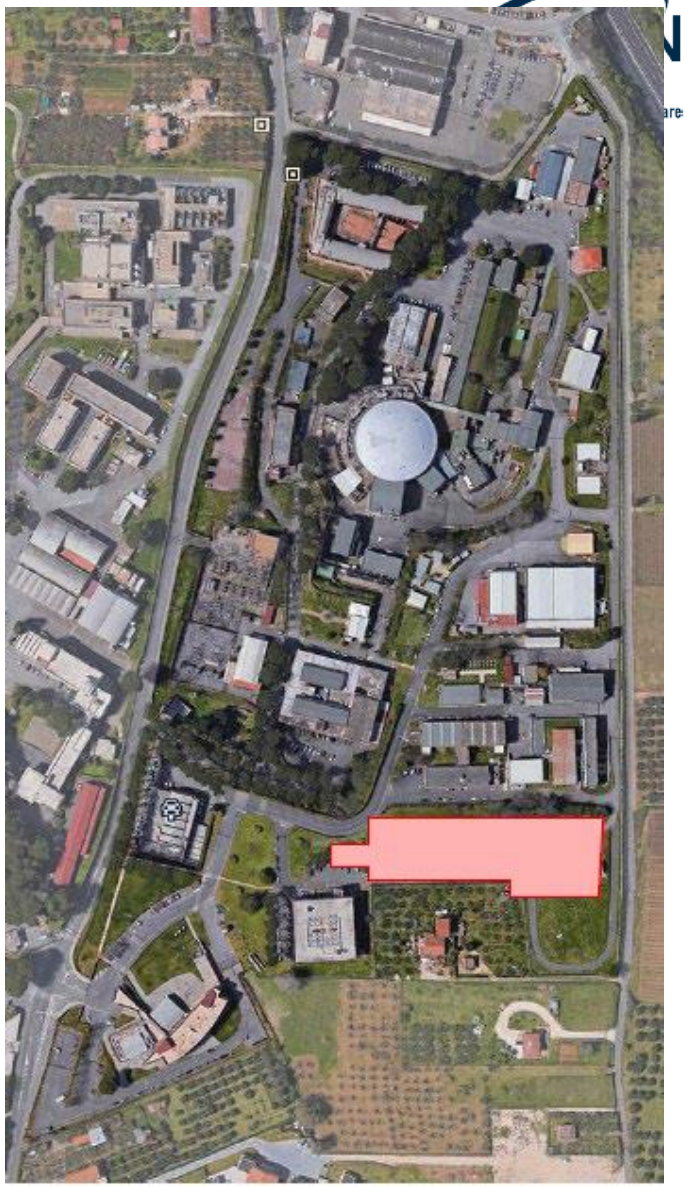
The EuPRAXIA Project

The operation and success of SPARC_LAB is the natural preparation for the next big scientific enterprise of the Laboratory: **EuPRAXIA**

A dedicated talk on this topic by Massimo Ferrario is foreseen in this meeting so I will not spend more time on it. Let me just underline a few important things

- EuPRAXIA must be seen already now as the flagship of the Laboratory, so most of our efforts must be dedicated to it
- How shall we drive the transition from the «DAΦNE era» to the «EuPRAXIA era» is a delicate matter
- In the end, however, the Laboratory will change its skin, both in terms of machine expertise and in terms of potential users. This is again a non trivial issue



Magnetic Measurement Laboratory

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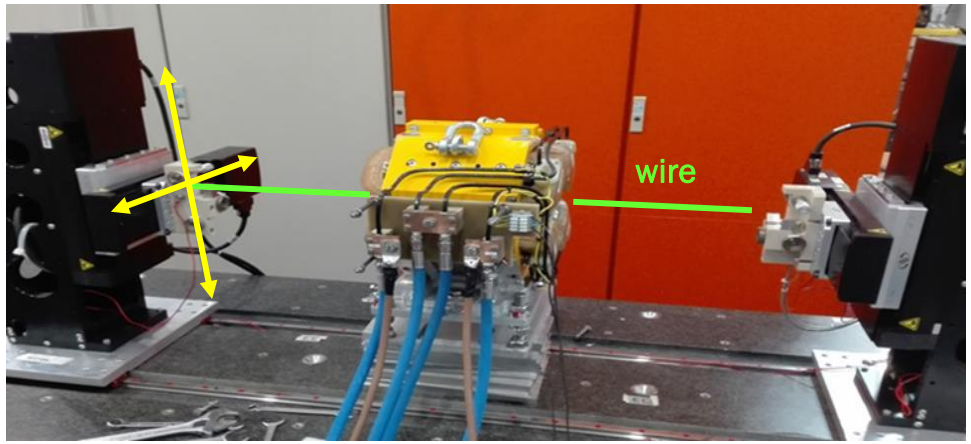
FACILITY SERVICES

- Full characterization of warm magnets (electromagnets and permanent)
- High precision measurements on power converters
- Reparations of electronics board and power components of power supplies

FACILITY EQUIPMENTS

- High precision 5 Axes Movement device with Hall probe housing (10 µm resolution)
- Several Digital Teslameter compatible with Hall probes with a wide full-scale range from 0,03 T to 3 T.
- Stretched Wire Bench for integrated multipolar fields measurement.
- Demineralized water cooling system for magnets and power supplies cooling.
- Soldering stations for electronic boards reparations.
- Equipment for Power supply high precision measurements as DCCT, oscilloscope, multimeter, Data logger, etc.
- Equipment for insulation test of magnets as Megger and for their electric characterization (micro-ohmeter and LCR).

5-axes digital Movement device equipped with Hall Probe



Stretched Wire Measurement Bench

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Vacuum Laboratory

System for UHV material characterization.

- Specific outgassing rate properties of new materials
- Pumping speed
- New deposition techniques
- Surface treatments

Vacuum furnace.

- Brazing in vacuum and in a controlled atmosphere
- Thermal treatment of materials up to 1200 ^{o}C
- Currently used for brazing test of the X band structures of EuPRAXIA

Plasma Laboratory

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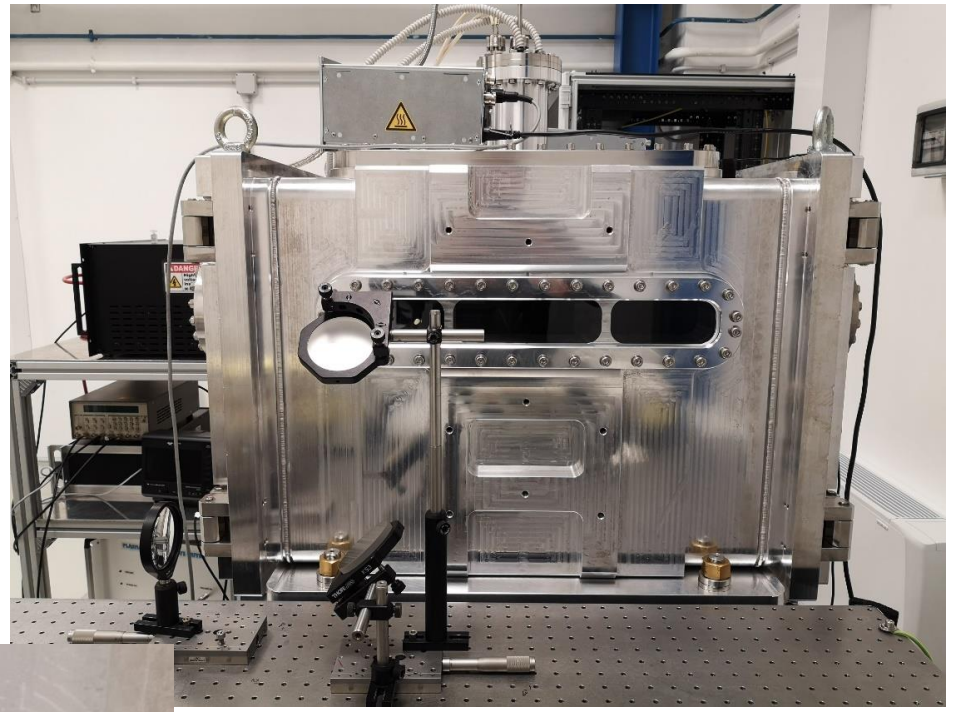
Laboratori Nazionali di Frascati

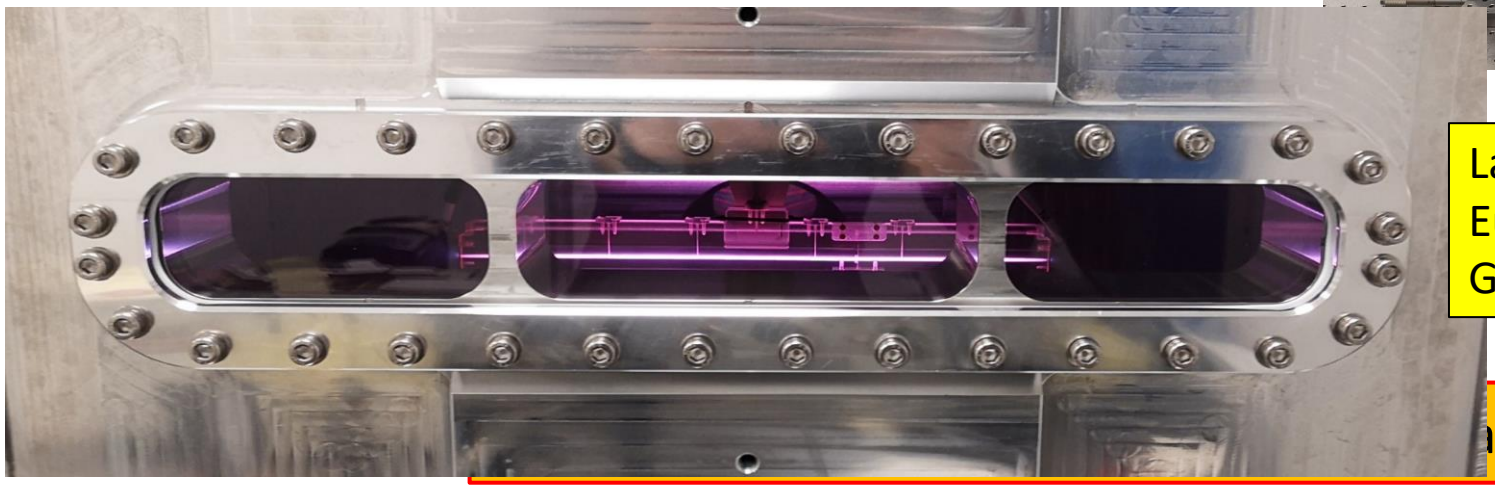
Activities

- Plasma formation techniques with lasers
- Plasma formation techniques with HV discharges
- Plasma source design and characterization
- Long source design for EuPRAXIA

Instrumentation

- Chamber for testing plasma formation
- Pumping system
- HV source
- Laser system





Last result in the Plasma_Lab: First EuPRAXIA plasma source to reach 1.1 GeV (1.5 GV/m) - **40 cm long**

TEX Facility

Activities

- Test of high-gradient X-band accelerating structures
- R&D for RF components, LLRF systems, Beam Diagnostics, Vacuum and Control Systems

Instrumentation

- K400 Scandinova modulator
- CPI VKX8311 Klystron
- Microwave Amplifier
- Commercial S-band LLRF system

Concrete Bunker and Modulator Cage with the RF Source

RF Laboratory

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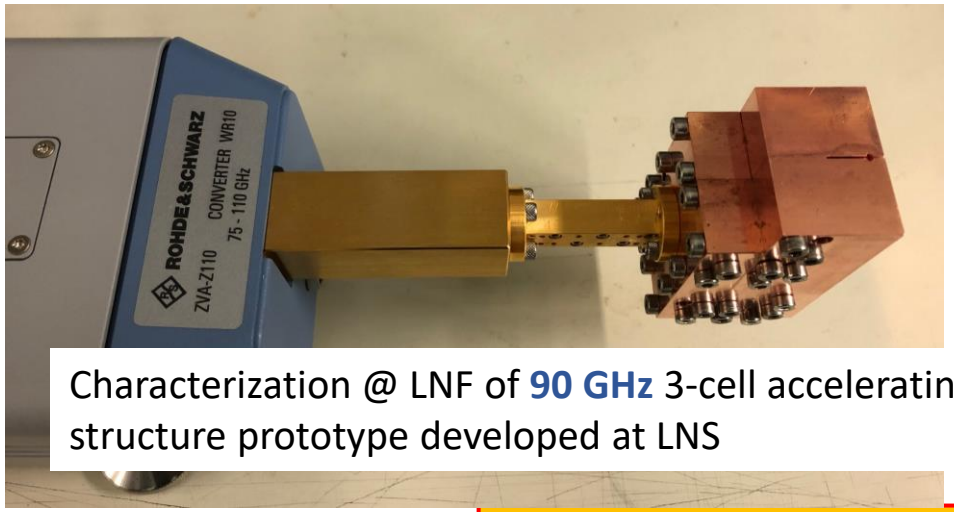
Laboratori Nazionali di Frascati

Activities

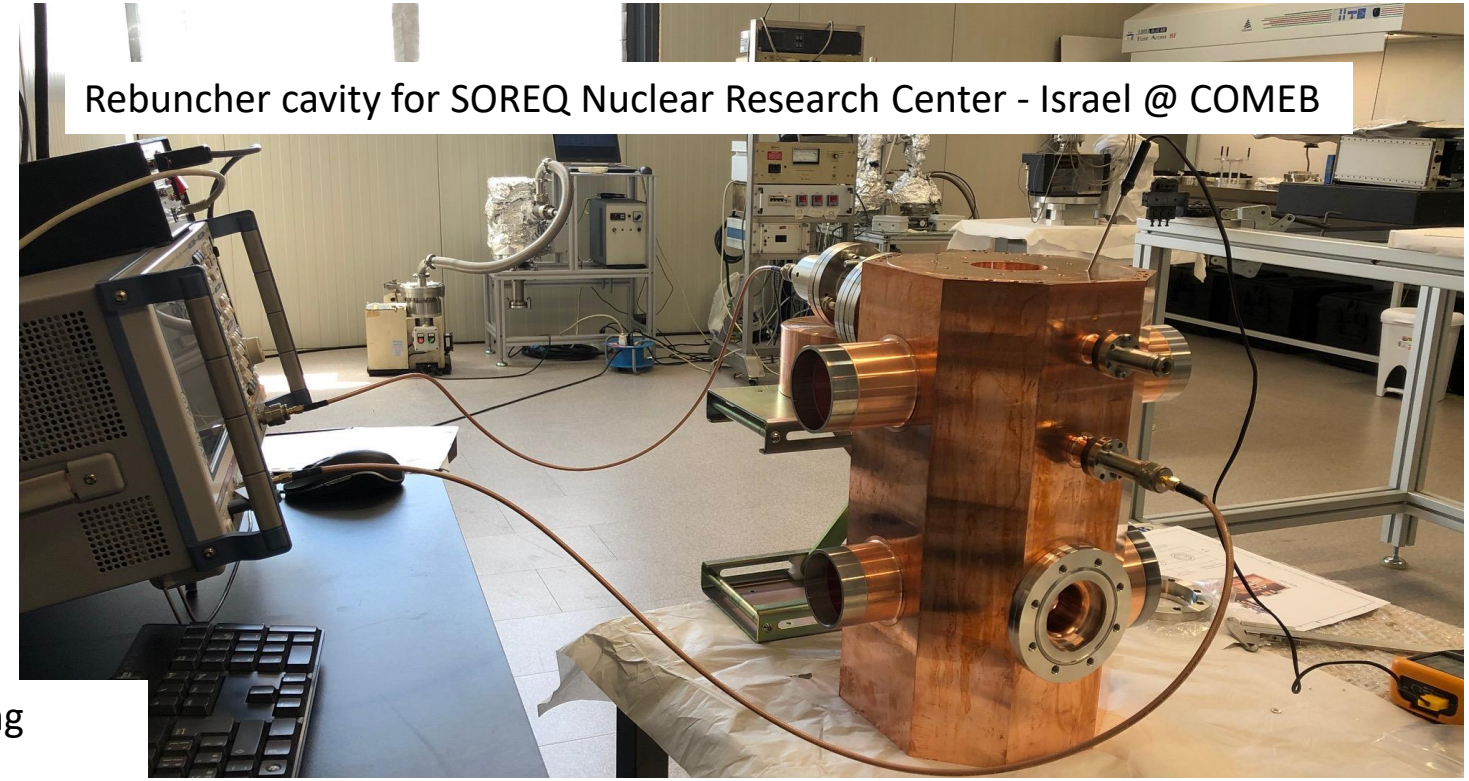
- Measurements on frequency domain up to 110 GHz
- Measurements on time domain up to 20 GHz

Instrumentation

- 110 GHz Network Analyzer
- 26.5 GHz Spectrum Analyzer
- 20 GHz – 8 bit Oscilloscope
- 6 GHz – 12 bit Oscilloscope



Characterization @ LNF of **90 GHz** 3-cell accelerating structure prototype developed at LNS



Rebuncher cavity for SOREQ Nuclear Research Center - Israel @ COMEB

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Accelerators outside LNF

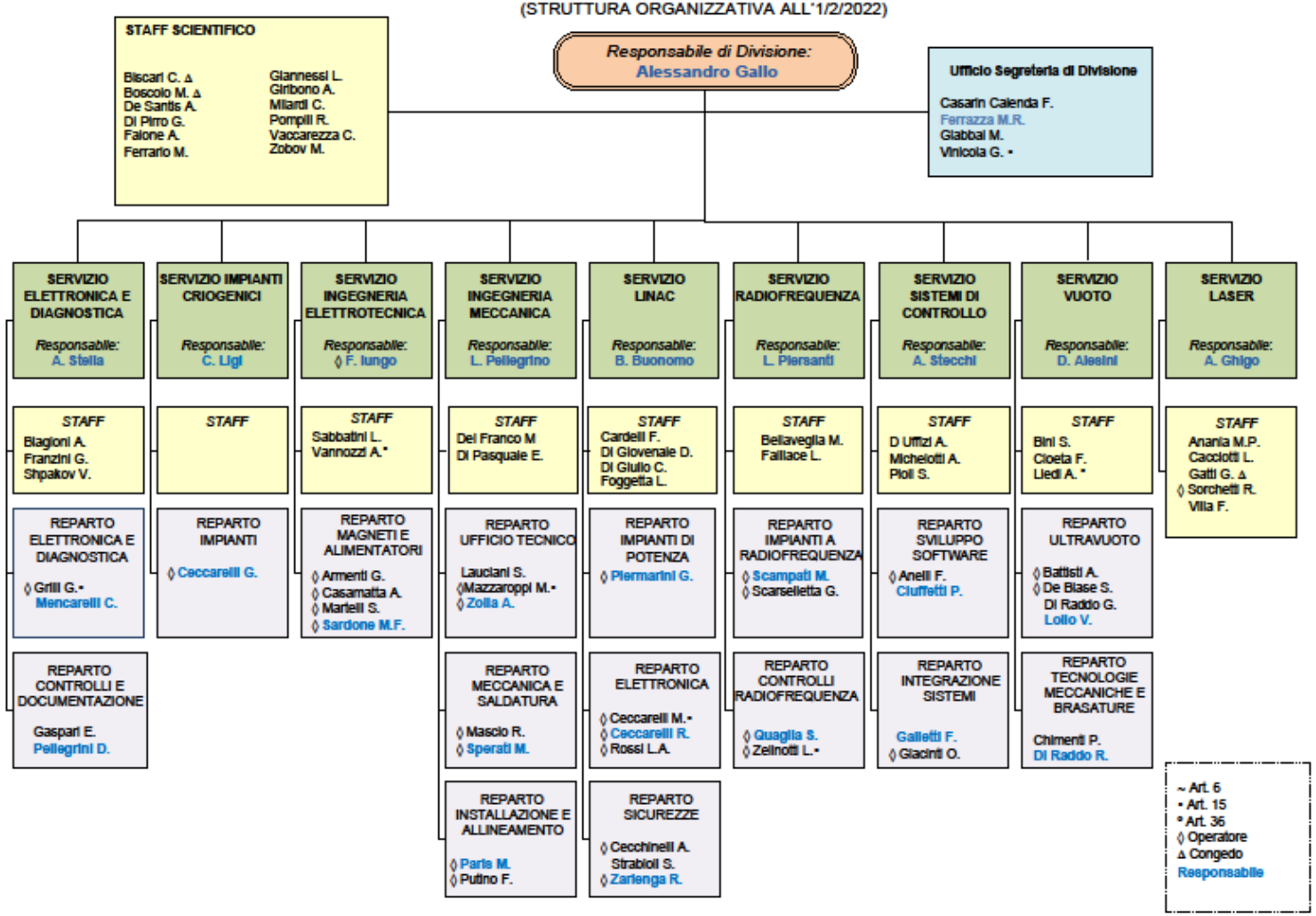
The LNF-AD gives also relevant contributions to the design and construction of accelerators outside the laboratory's area, as well as to R&D projects at the national and european level

- **STAR-HE,** a Compton source of monochromatic tunable X-rays to be installed in the University of Calabria (see L. Serafini's talk)
- **ELI-NP,** originally an advanced source of up to 20 MeV photons, to be installed in Romania. Project now being reconsidered due to legal and political issues

- **iFAST,** R&D on high gradient RF technology
- **FCCee,** contributions on various aspects of the machine's design
- **CREMLIN+**, Study on a 4th generation SR machine in Russia
- Various **CSN5** projects

Divisione Acceleratori

(STRUTTURA ORGANIZZATIVA ALL'1/2/2022)



41 + 2 Res-Eng

36 + 6 Tec

3 + 1 Adm

6 PostDoc

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Management Issues (I)

It is common belief that the manpower resources listed above, are not sufficient to face the present and future challenges of the laboratory

- We need to reinforce several specific areas of competence:
  - Beam dynamics and plasma physics
  - Lasers
  - Contol systems
  - Magnets
  - RF systems
  - Project management
  - Collider physics (see considerations at next slide)

We need also to renew and reinforce the technical staff, which is facing a dramatic period of turn-over

Note also that similar considerations have to be applied also to the Techical Division

Management Issues (II)

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On more general grounds we need to take important decisions regarding the long term strategy of the laboratory

- What will be the future (if any) of DAΦNE, in the era of operation of EuPRAXIA?
- How, and how much do we want to keep alive the competence on the physics of the colliders?
- EuPRAXIA is a multinational enterprise headquartered in Frascati. How do we intend to manage the technical and administrative consequences of this?

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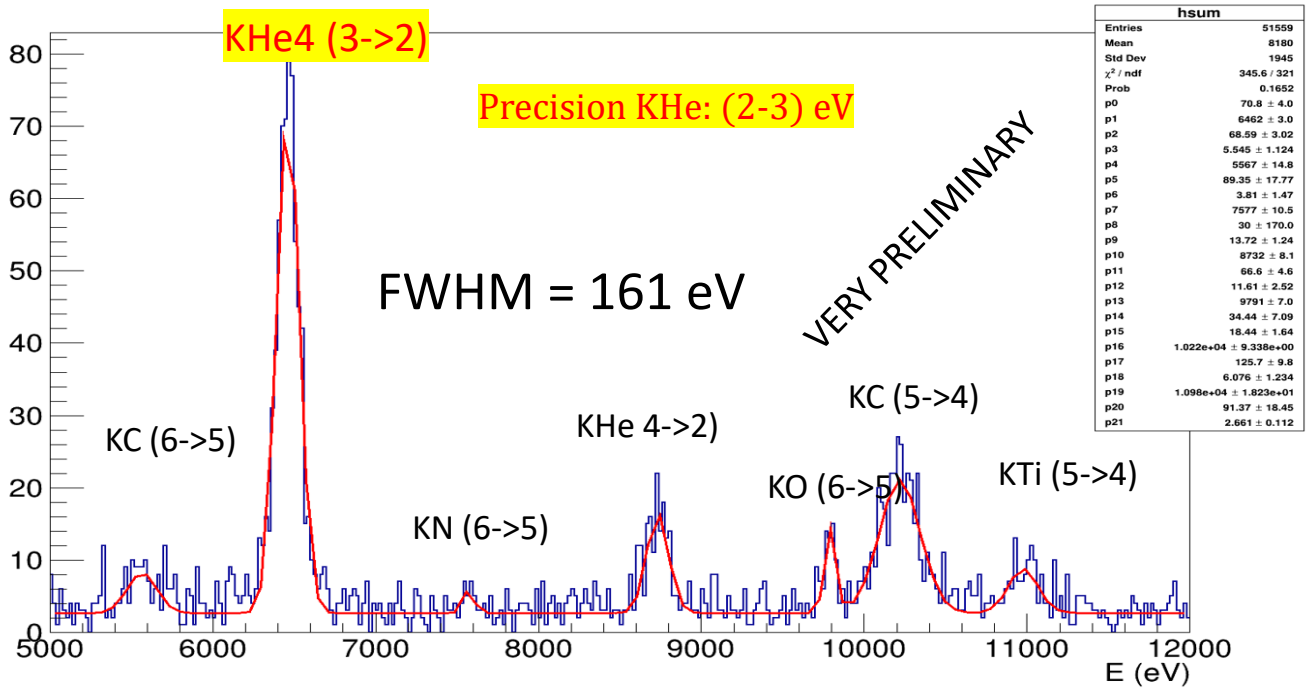
Spare Slides

First phase of data taking with 1/6 of SDD detectors performed to optimize run conditions and experimental setup through kaonic helium measurement



Thanks to the excellent performance of the detector interesting results can be extracted by this relatively small ($O(50\ pb^{-1})$) data set, possibly worth of physics publication

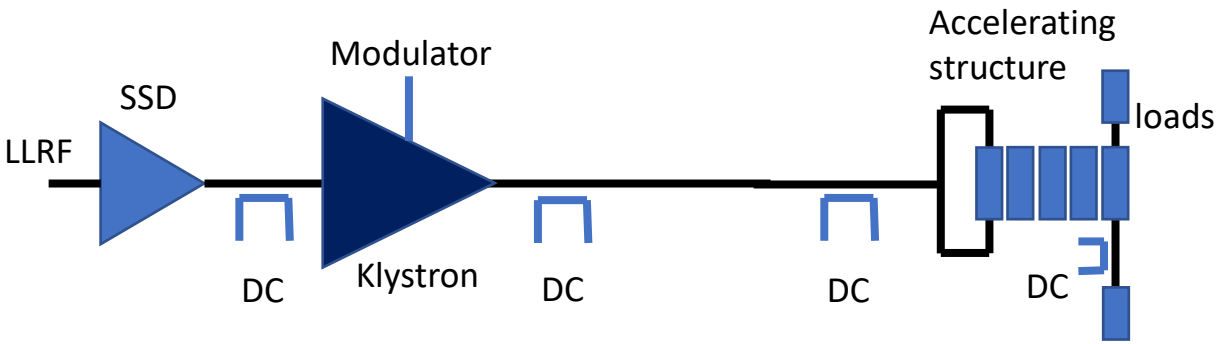
- The *TEst-stand for X-band* (**TEX**) is a facility conceived for R&D on high gradient X-band accelerating structures and waveguide components in view of Eupraxia@SPARC_LAB project. TEX is located in bld. 7 of LNF, which is being fully refurbished and upgraded.
- TEX has been co-funded by INFN and Lazio regional government in the framework of **the LATINO project** (*Laboratory in Advanced Technologies for INnOvation*) to enhance collaboration with SME.
- It is not only a facility for accelerating structures but also R&D for RF components, LLRF systems, Beam Diagnostics, Vacuum and Control System.
- Technical Coordinator: Stefano Pioli
- Scientific Coordinator: Fabio Cardelli

Concrete Bunker and Modulator Cage with the RF Source

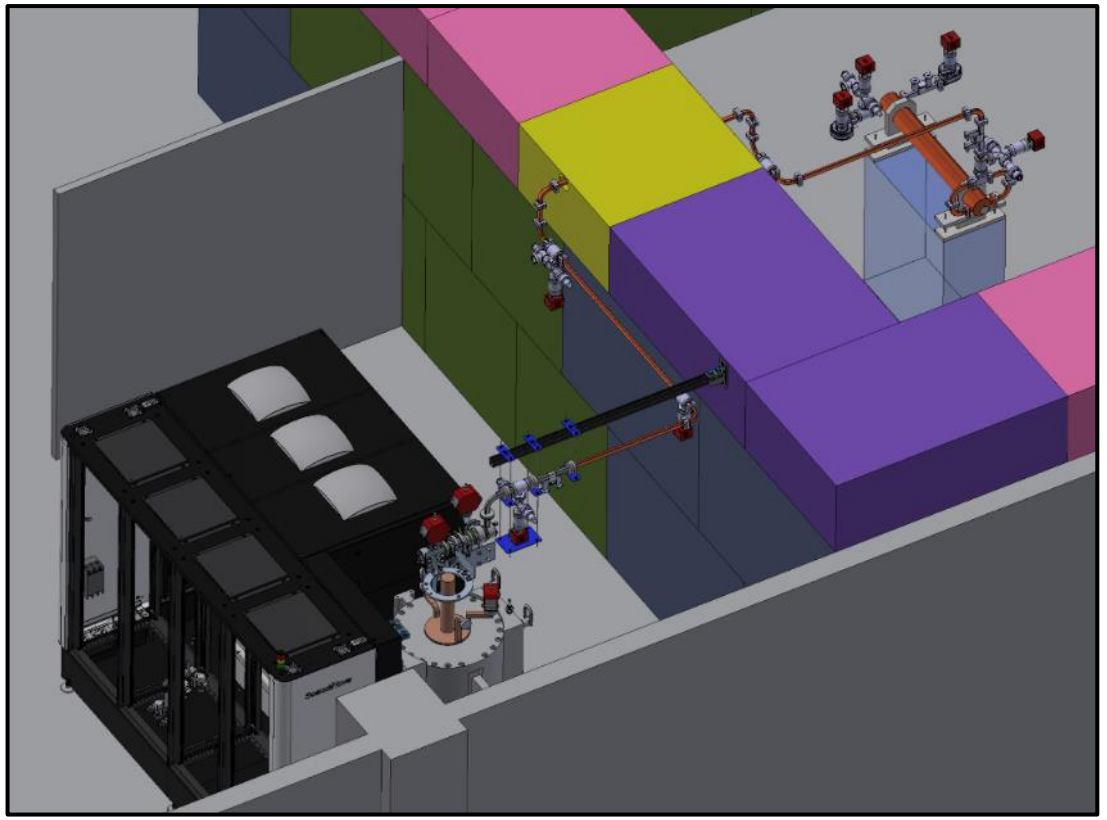
Building 7 at LNF

Control room and Rack room

- The facility is currently in the **commissioning phase** and will be mainly used for testing X-band prototypes, RF sources, radiofrequency components and their sub-systems. The setup has been done in **collaboration with CERN** and it will be also used to test CLIC accelerating structures. Moreover, new conditioning procedures, dark current studies, beam diagnostics, high level applications and safety systems will be also tested.
- It will be also **accessible to external users**, including national and international laboratories and companies. The open access to TEX is one of the services offered by INFN to the external community through LATINO project, whose aim is to promote and increase the technology transfer between research centers and the surrounding economic framework.
- The **present TEX setup** is based on:
  - K400 ScandiNova Modulator (HV pulses 430kV, 3.5us, 100Hz)
  - CPI VKX8311 Klystron (RF pulse 50MW, 1.5us, 50Hz)
  - Microwave Amplifier 1300 W solid state driver (SSD) amplifier
  - Commercial S-band LLRF system (ITech) adapted to work at 11.994 GHz with an Up/Down converter developed at LNF.
- The source is able to deliver **50 MW** peak power, **1.5 us** RF pulses at **50 Hz** rep. rate.



TEX Layout



RF measurements LAB within LATINO infrastructure

(CONTACT PERSON: L. Piersanti)

The RF laboratory of LATINO allows users (both INFN and external) to perform **frequency domain** measurements up to **110 GHz** and **time domain** measurements up to **20 GHz**

LABORATORY: equipped with state-of-the-art and unique instrumentation:

- **110 GHz** Network Analyzer (Rohde&Schwarz ZVA 50-110 **financed with LATINO funds**)
- **26.5 GHz** Spectrum Analyzer (Rohde&Schwarz FSU 26.5 **in kind**)
- **20 GHz – 8 bit** Oscilloscope (Lecroy WaveMaster 820Zi-B **in kind**)
- **6 GHz – 12 bit** Oscilloscope (Lecroy wavePro 604HD **in kind**)

COMPANIES: we have performed RF measurements for **COMEB** (high precision machining company in Rome area) during the realization of accelerating and diagnostics structures for international research laboratories:

- **175 MHz** rebuncher cavity for **SOREQ Nuclear Research Center - Israel**
- **3 GHz RF** deflecting cavity for **CLARA at STFC – England**

INFN: we also collaborated with LNS colleagues (G. Torrisi et al.) for **90 GHz** 3-cell accelerating structure prototype characterization (**DEMETRA** and **MICRON** CSN5 projects)

FUTURE: increase the visibility of such remarkable instrumentation to attract both colleagues from other sections/labs for possible collaborations, and private companies (not necessarily involved with particle accelerators)

⇒ **Co-funded by Regione Lazio in the framework of the LATINO** (**L**aboratory in **A**dvanced **T**echnologies for **IN**n**O**vation) program with the **goal to open research labs to industries and other research center.**

⇒ **The furnace with a vacuum chamber 1.3 m long and a diameter of 400 mm allows to:**

- **Brazing in vacuum and in a controlled atmosphere**
- **Perform thermal treatment of material under vacuum and controlled atmosphere up to 1200 °C**
- **It is currently used for the brazing test of the X band structures of EUPRAXIA**

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REGIONE LAZIO

fesr FONDO EUROPEO DI SVILUPPO REGIONALE 2014 2020 POR PROGRAMMA OPERATIVO REGIONE LAZIO

⇒ **Co-funded by Regione Lazio in the framework of the LATINO** (**L**aboratory in **A**dvanced **T**echnologies for **IN**n**O**vation) program with the **goal to open research labs to industries and other research center.**

⇒ The system allows to characterize material, pumps and component in term of:

- **Specific outgassing rate properties of new materials**
- **Pumping speed**
- **new deposition techniques**
- **Surface treatments**

FACILITY SERVICES

- Full characterization of warm magnets (electromagnets and permanent)
- High precision measurements on power converters
- Reparations of electronics board and power components of power supplies

FACILITY EQUIPMENTS

- High precision 5 Axes Movement device with Hall probe housing (10 µm resolution)
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- Stretched Wire Bench for integrated multipolar fields measurement.
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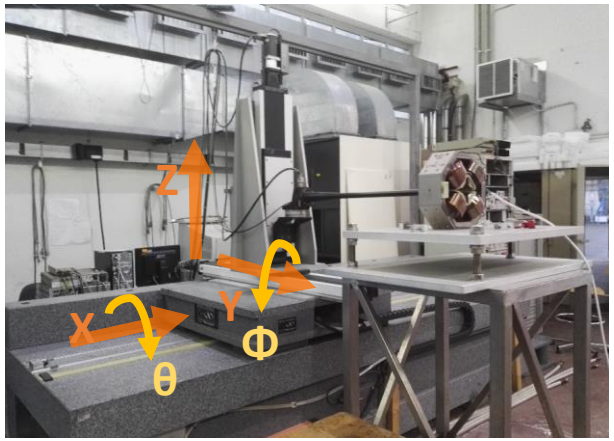
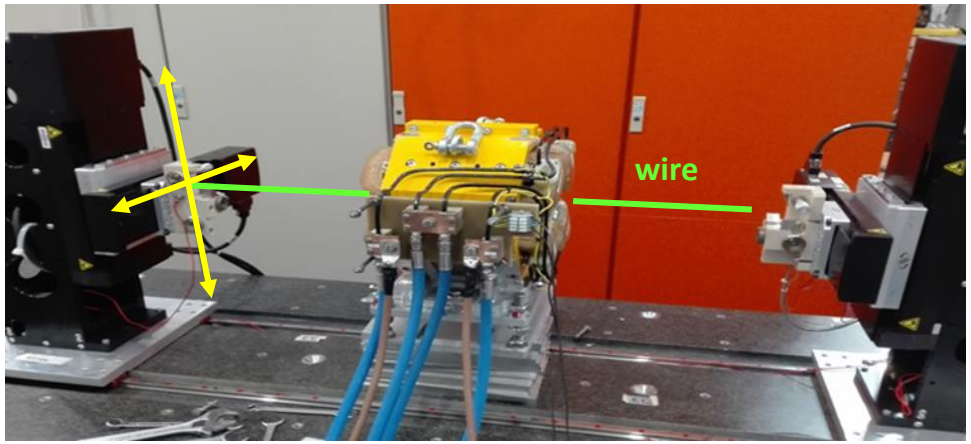
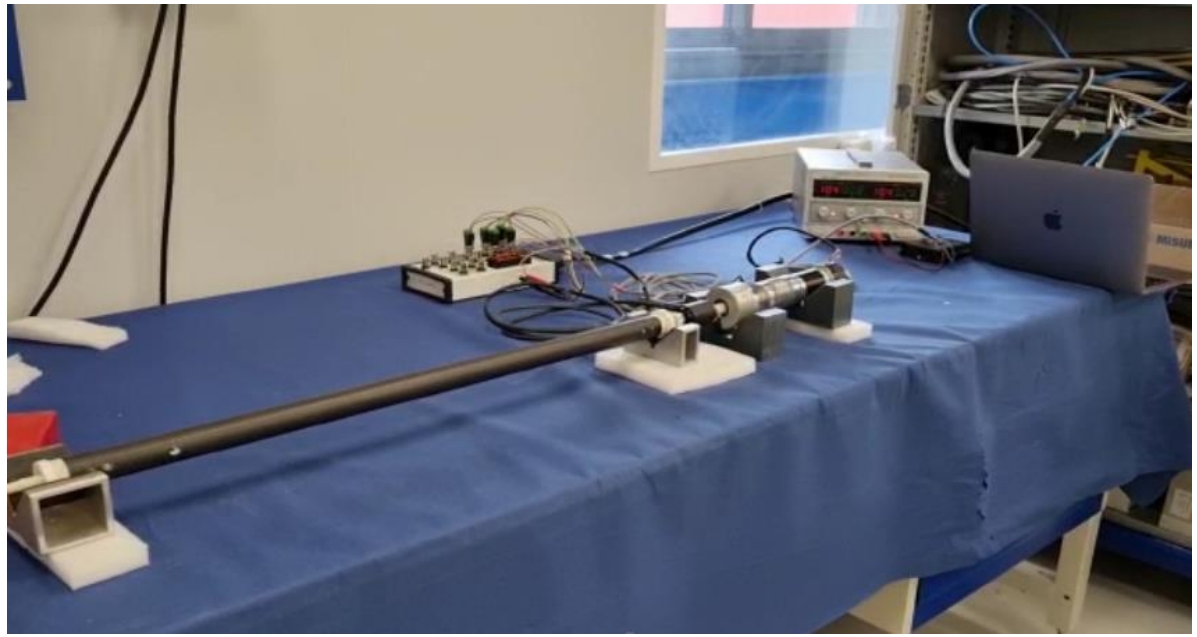


5-axes digital Movement device equipped with Hall Probe



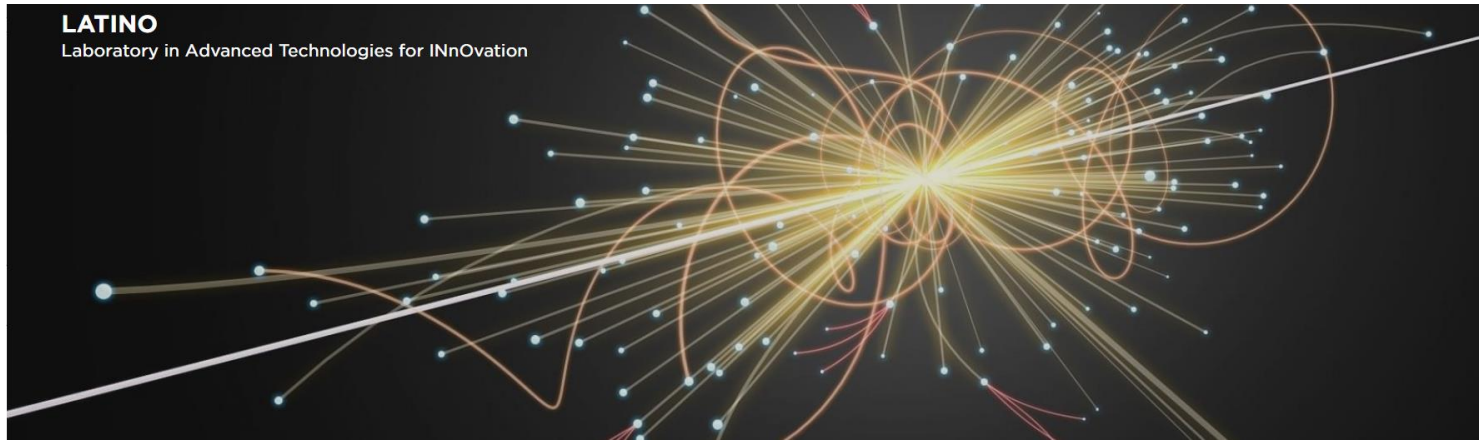
Stretched Wire Measurement Bench



Rotating Coil under test at CERN

FUTURE UPGRADES AND FUNDING

- A rotating coil to measure multipolar fields with accuracy with respect to the fundamental harmonic of 3E-4.
- The coil will be provided by CERN. Actually is under test.
- Stretched wire bench, rotating coil bench are part of the Laboratory in Advanced Technologies for INnOvation (LATINO) open research infrastructure co-funded by LAZIO Regional government.



Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Workshop Nazionale Acceleratori Milano, 7-8 Aprile 2022