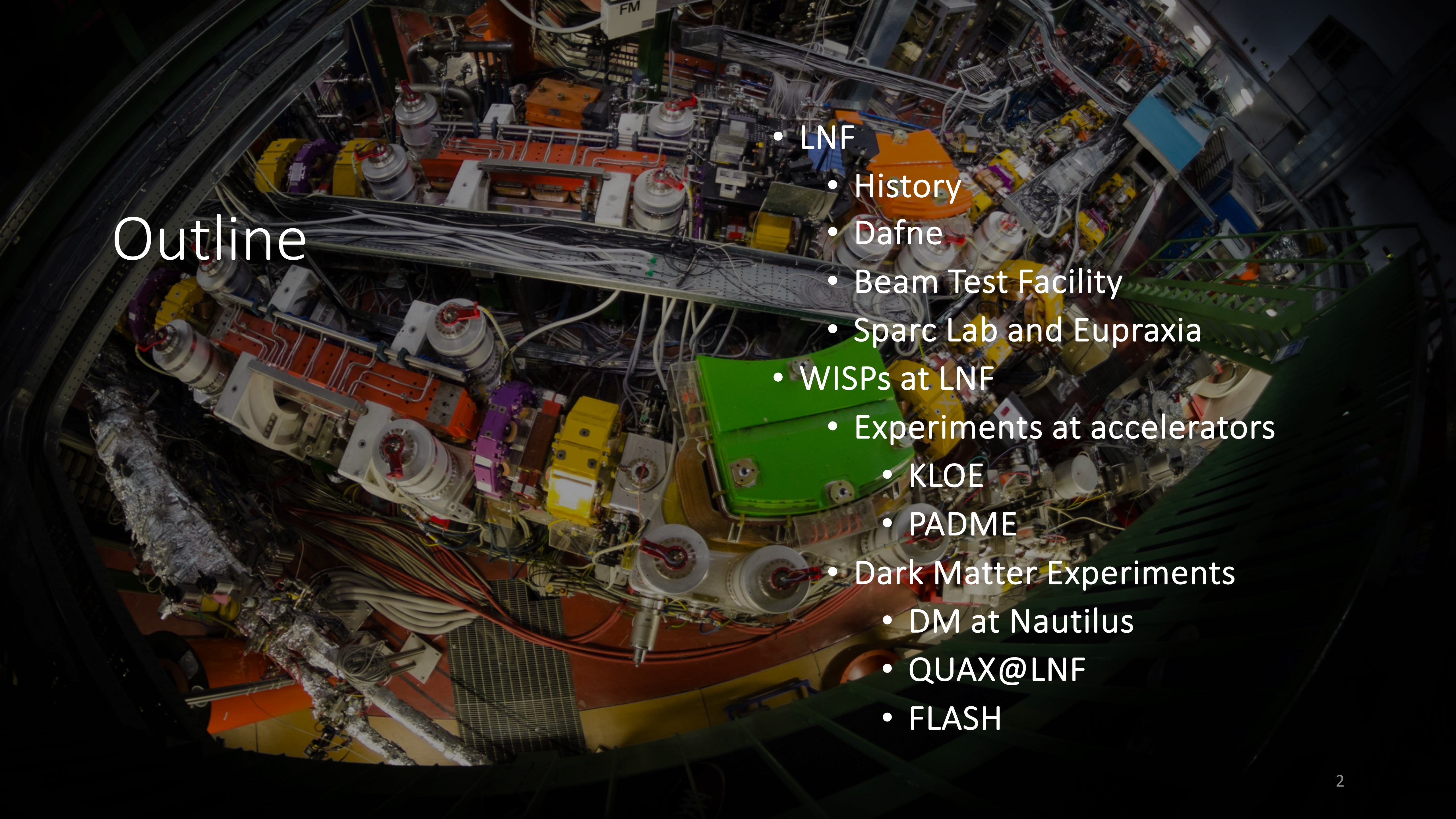
COSMIC WISPERS at LNF

Claudio Gatti - LNF

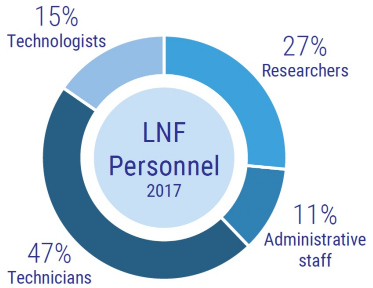


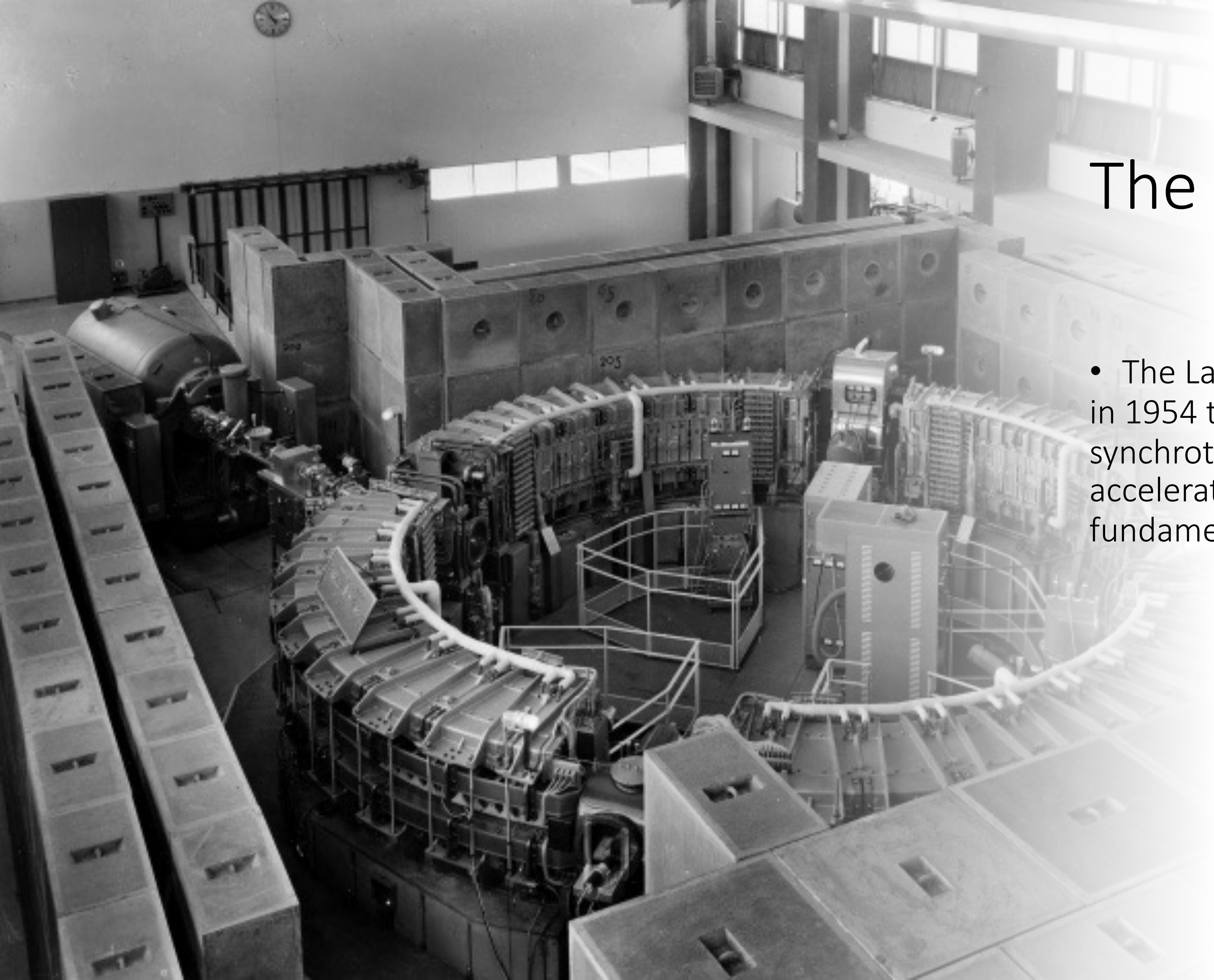
Outline

- LNF
  - History
  - Dafne
  - Beam Test Facility
  - Sparc Lab and Eupraxia
- WISPs at LNF
  - Experiments at accelerators
    - KLOE
    - PADME
  - Dark Matter Experiments
    - DM at Nautilus
    - QUAX@LNF
    - FLASH

Laboratori Nazionali di Frascati

- LNF is the biggest of the INFN laboratories, with a total staff of over 320 permanent and fixed-term employees accompanied by about 200 scholars and associates, employees from other institutes and universities who carry out their activity mainly at LNF.



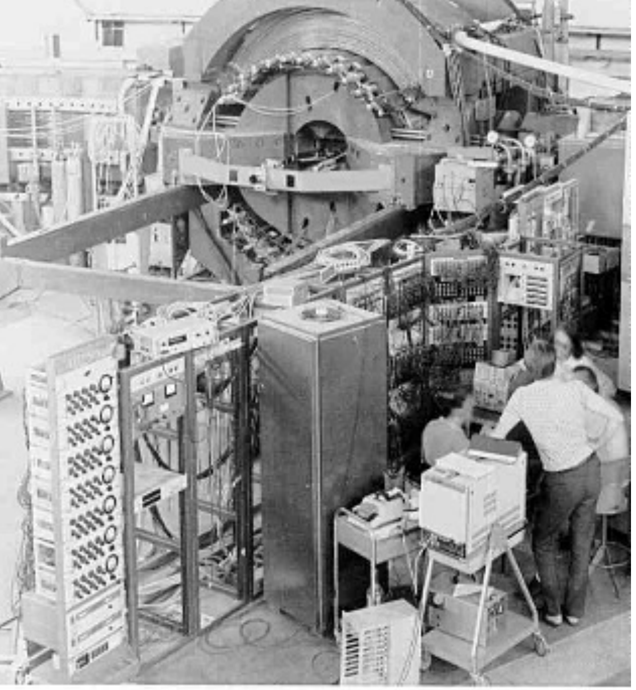


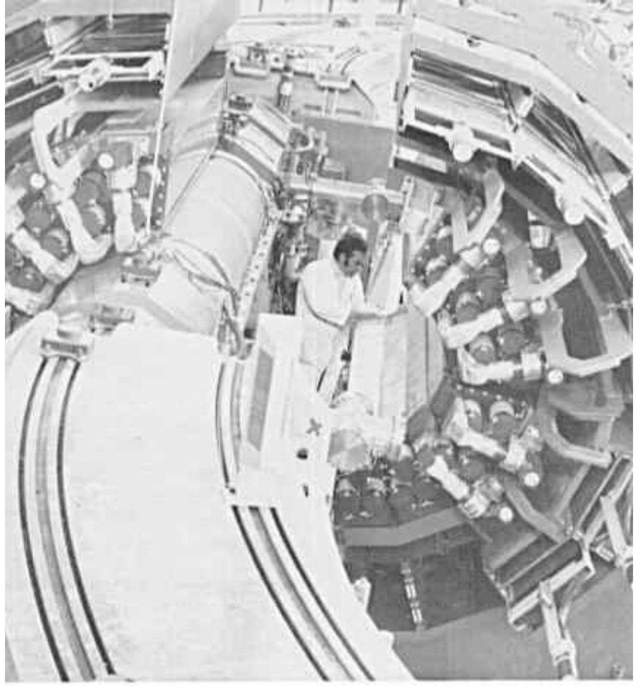
The Synchrotron

- The Laboratories were founded in 1954 to host a 1.1 GeV electron synchrotron, the first Italian particle accelerator dedicated to fundamental research.

ADA the first collider

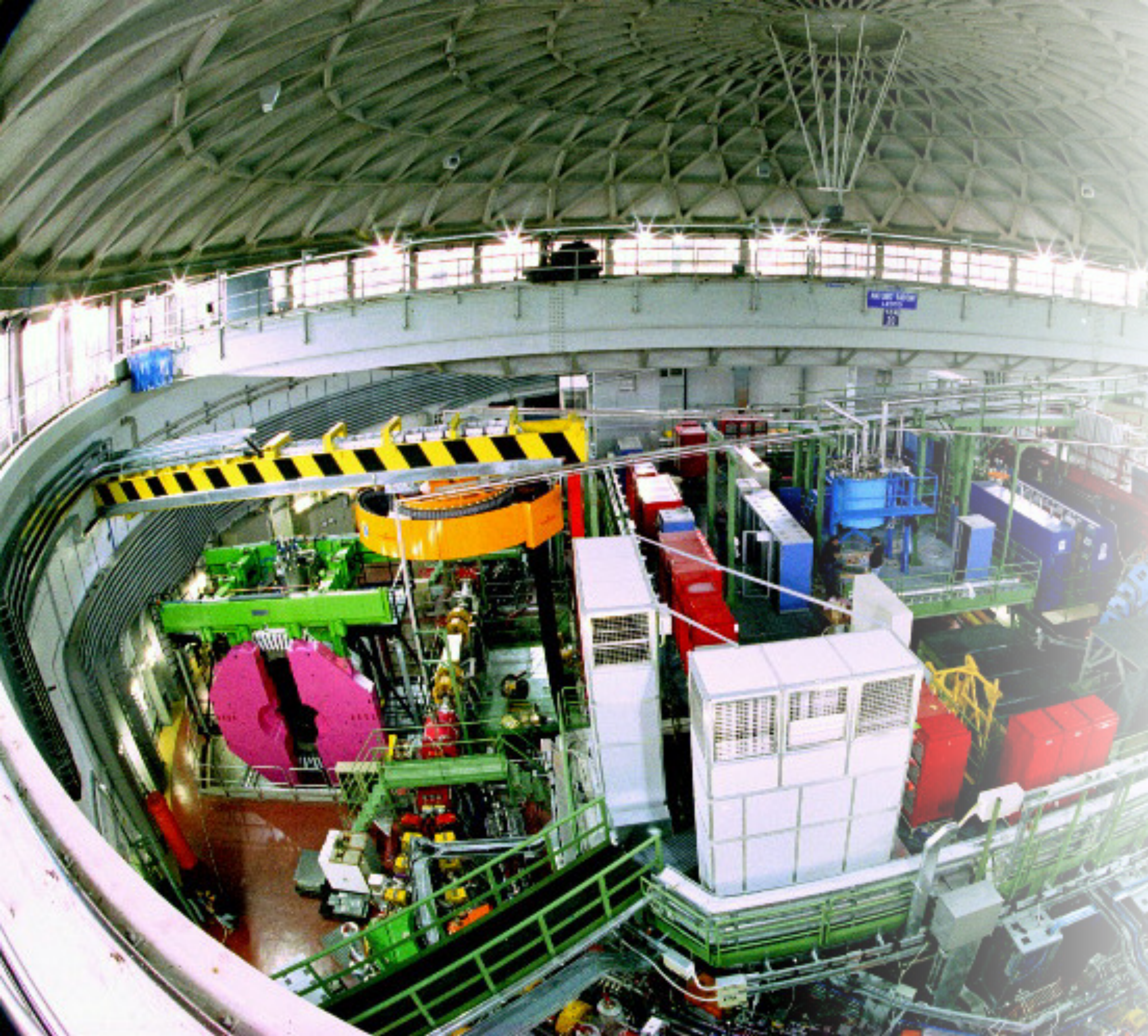
- In 1960, during a memorable seminar, Bruno Touschek suggested injecting both electron and positron beams circulating in opposite directions into the same vacuum chamber to analyze their collisions. This idea set in motion the construction of the storage ring AdA (Anello di Accumulazione), a small accelerator made of an electromagnet with a diameter of a little less than 2 meters, in which the radio frequency field accelerated the beams to an energy of 250 MeV. **In AdA, the first artificial collisions between electrons and positrons in the world took place**.





Adone

- After AdA, ADONE, a larger storage ring dedicated to the study of fundamental physics, was constructed. The two colliding beams could reach a c.o.m. energy of 3 GeV in a toroidal vacuum chamber about 100 m long.



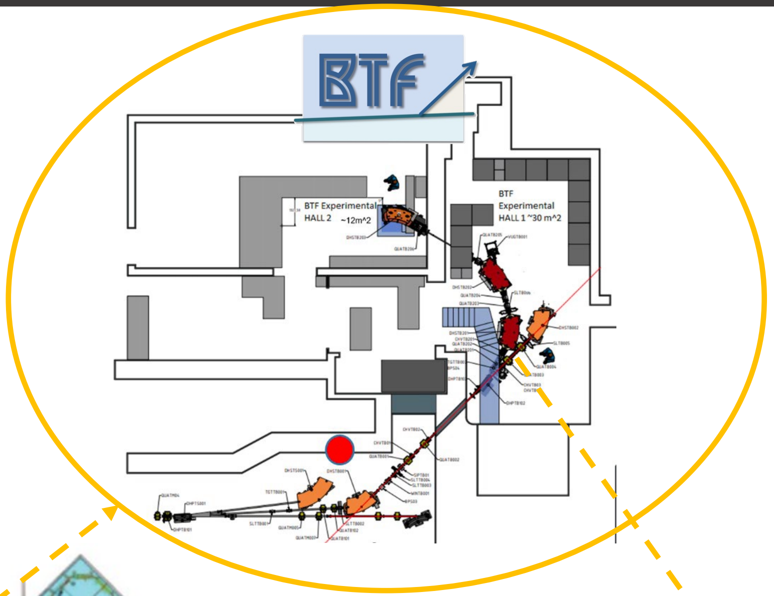
DAΦNE

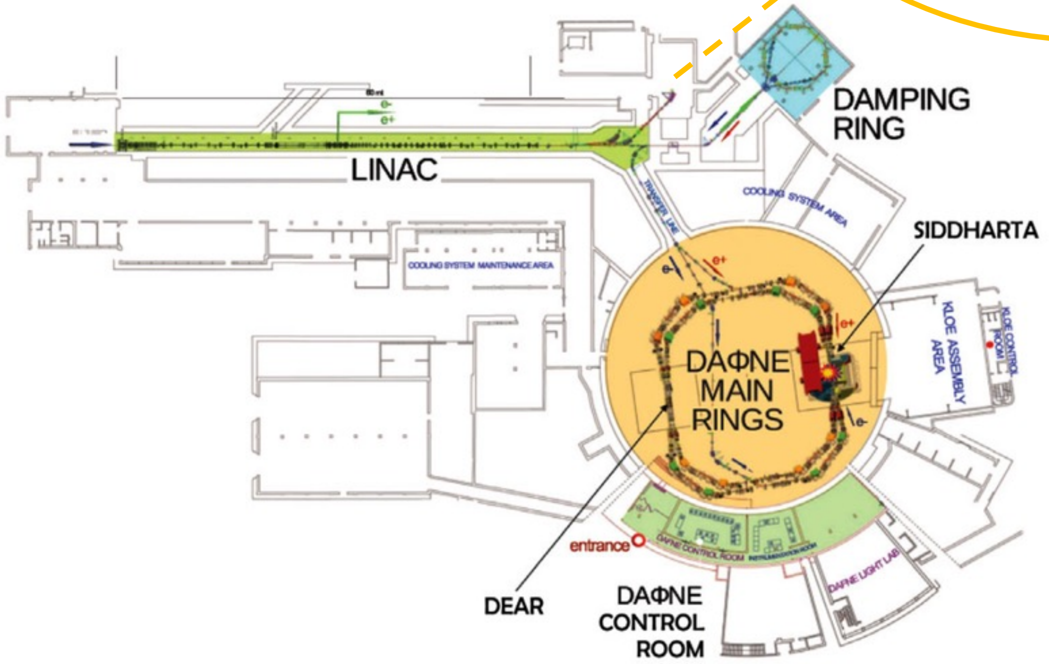
- DAΦNE is the collider currently in operation in Frascati. The accelerator consists of 2 rings approx. 100 m in length. The total energy of the c.o.m. is equal to 1.02 GeV, corresponding to the mass of Φ mesons. The first particle beams started circulating in DAΦNE in 1997.

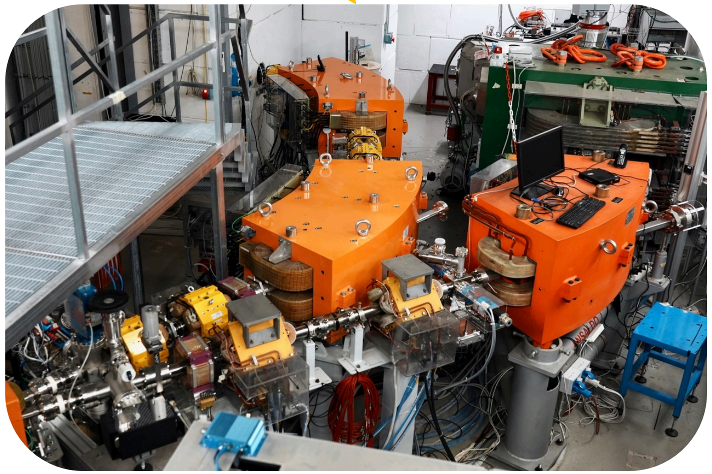
Beam Test Facility

Electron and positron beams from the DAFNE LINAC are sent to the Beam Test Facility (BTF) to test particle detectors and for experiments (PADME).

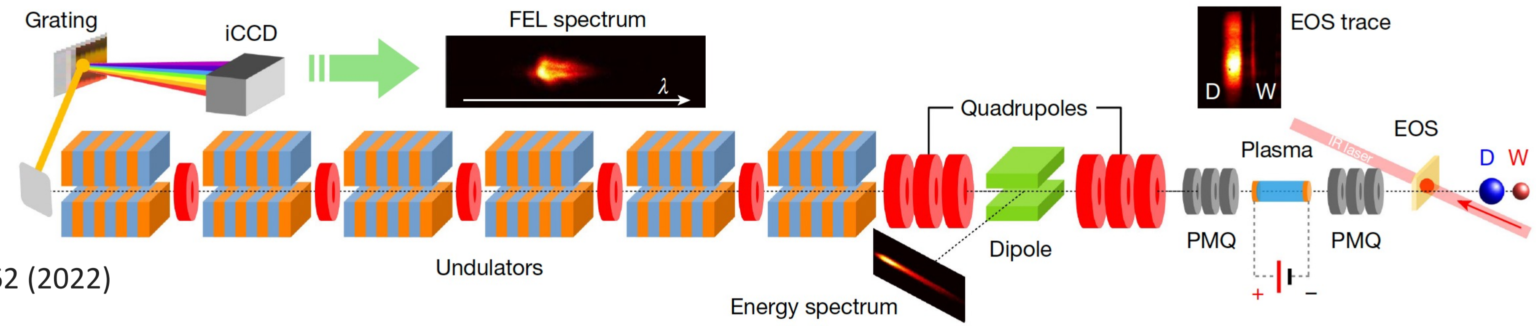
e^- beam energy	510 MeV
e^+ beam energy	510 MeV
Beam pulse rate	1 to 50 Hz
Electron current	500 mA
Positron current	85 mA



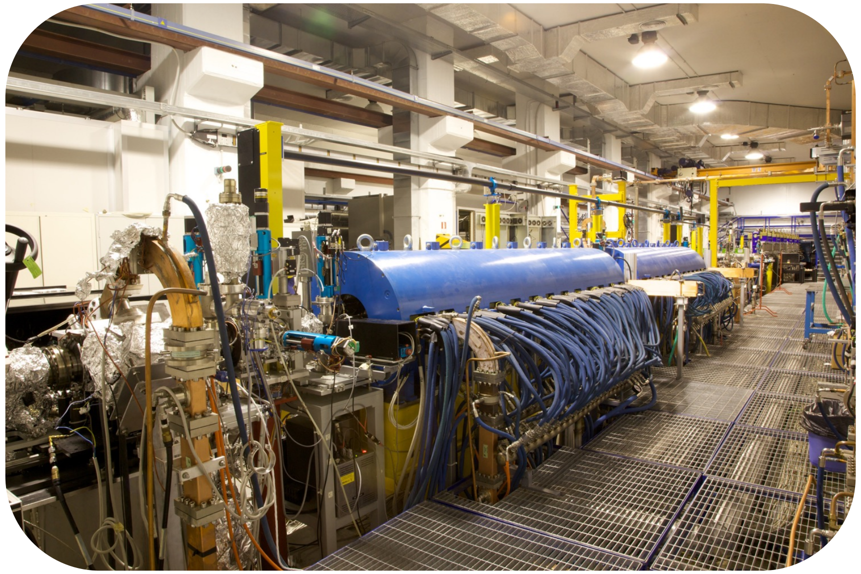


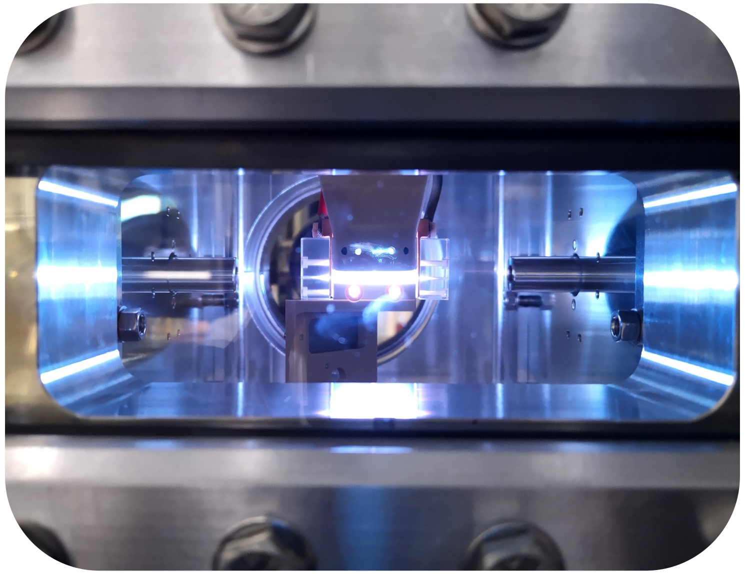


Free-electron lasing with compact beam-driven plasma wakefield accelerator

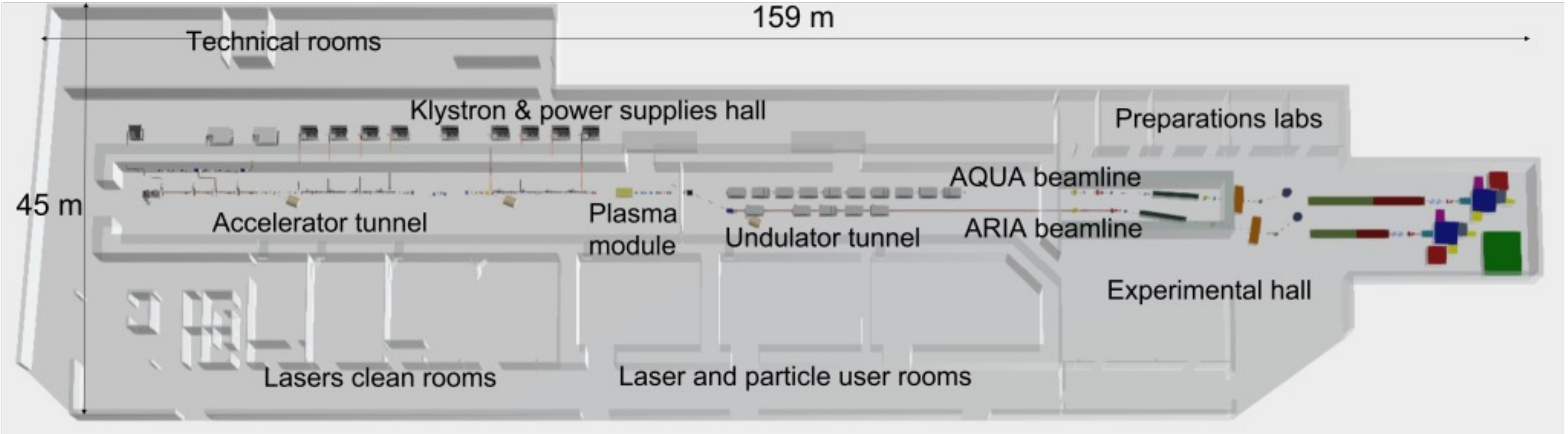


Nature **605**, 659–662 (2022)

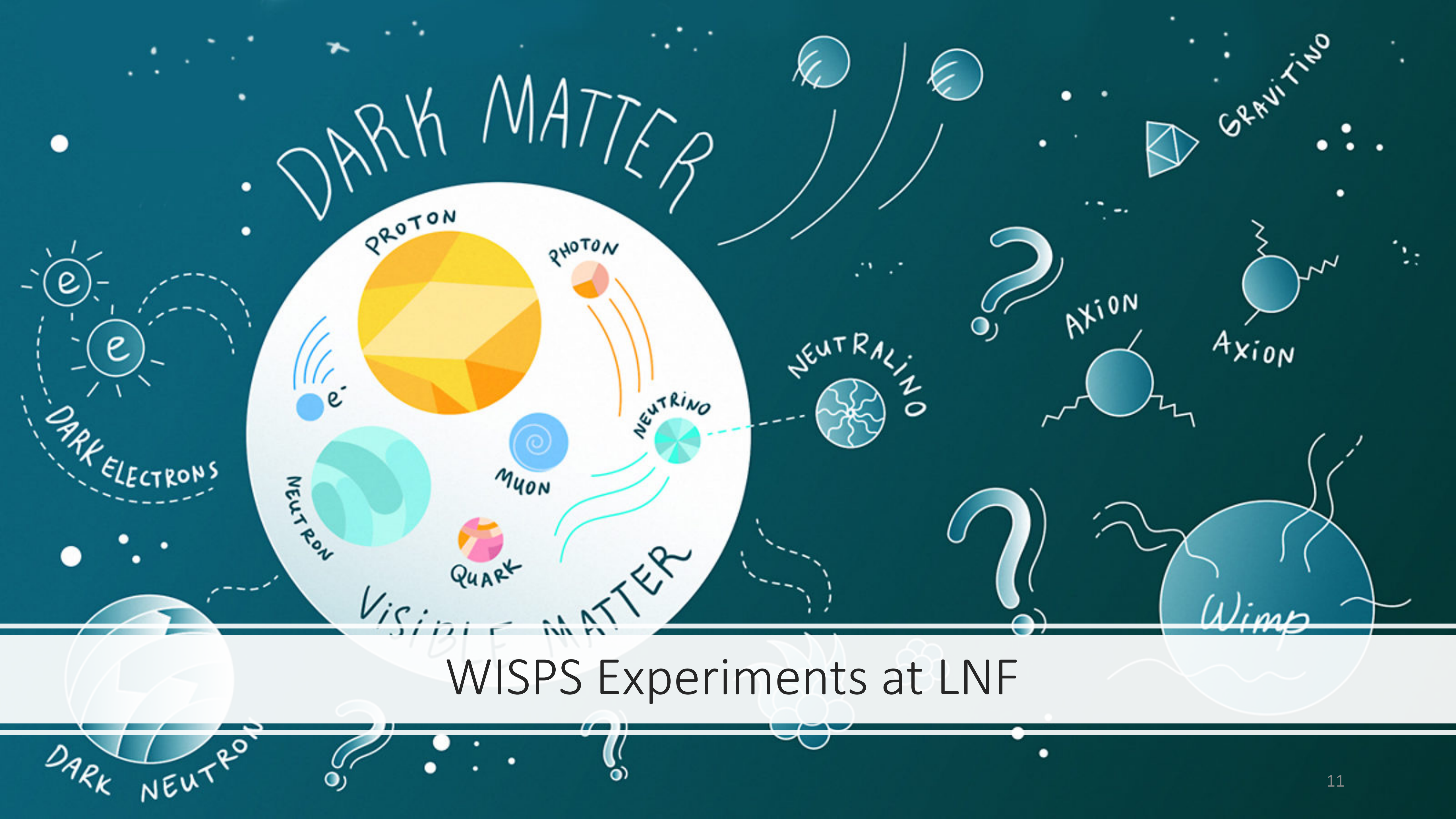




EuPRAXIA@SPARC_LAB



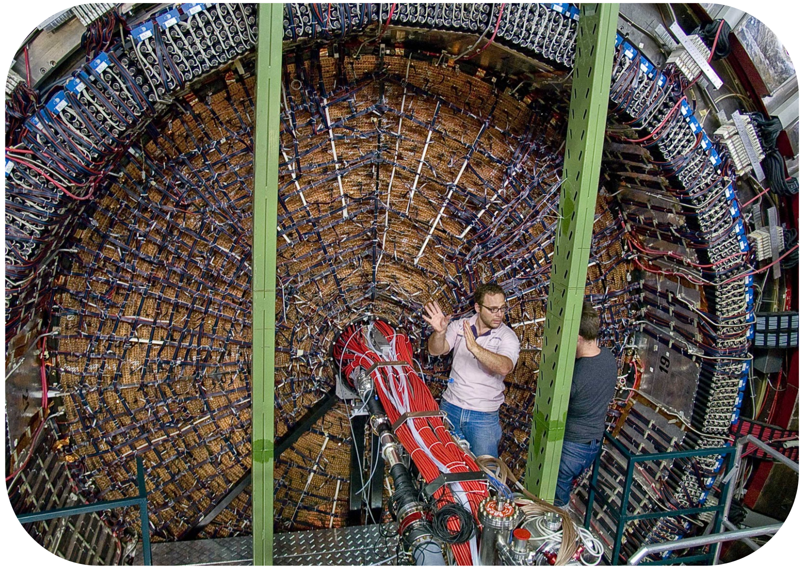
EuPRAXIA (European Strategy Forum on Research Infrastructures (ESFRI) Roadmap of 2021): a compact FEL source, equipped with user beamline at 4 nm wavelength, driven by a high gradient plasma accelerator.

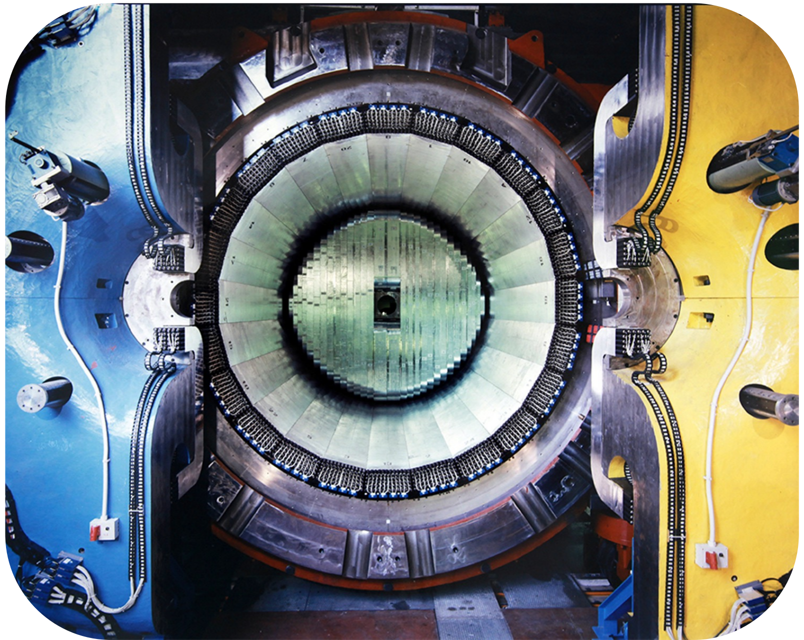


WISPS Experiments at LNF

WISPS at Accelerators

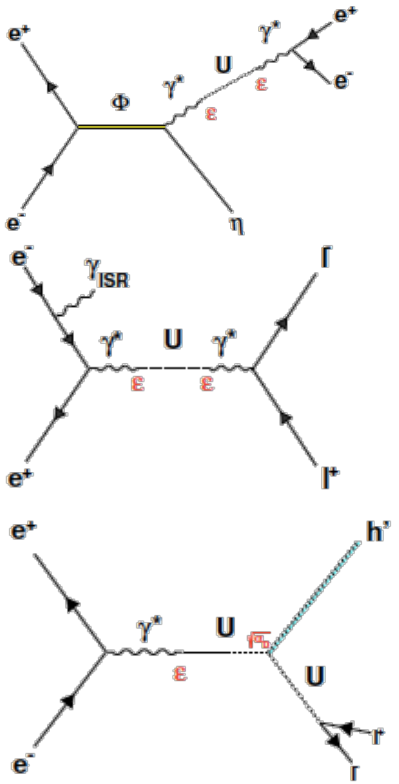
Dark Photons at KLOE

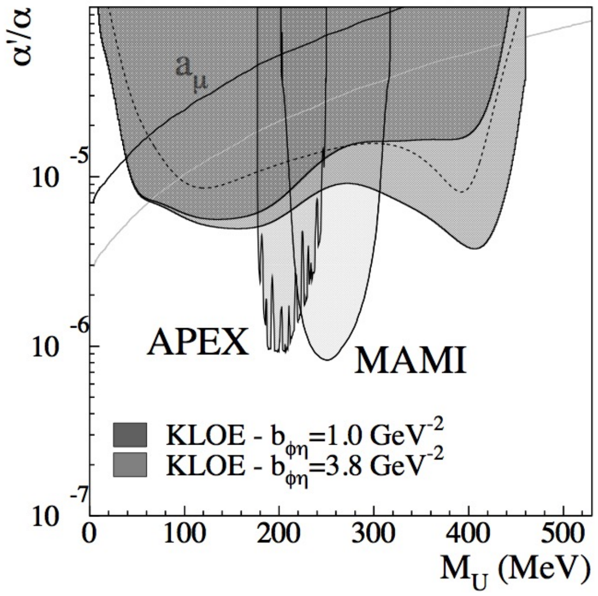


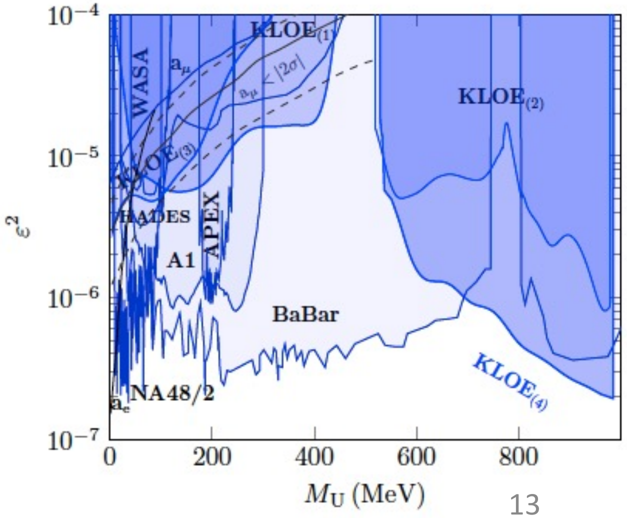


Kloe searches of dark photons

$$\phi \to \eta U \; with \; \eta \to \pi^+\pi^-\pi^0 or \; 3\pi^0$$
$$e^+e^- \to U\gamma \to e^+e^-\gamma, \mu^+\mu^-\gamma, \pi^+\pi^-\gamma$$
$$e^+e^- \to Uh' \to \mu^+\mu^-\gamma + E_{Miss}$$

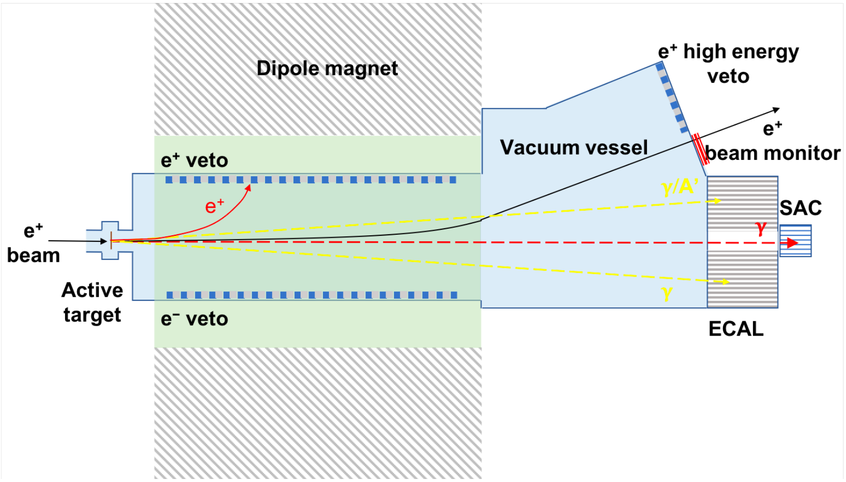


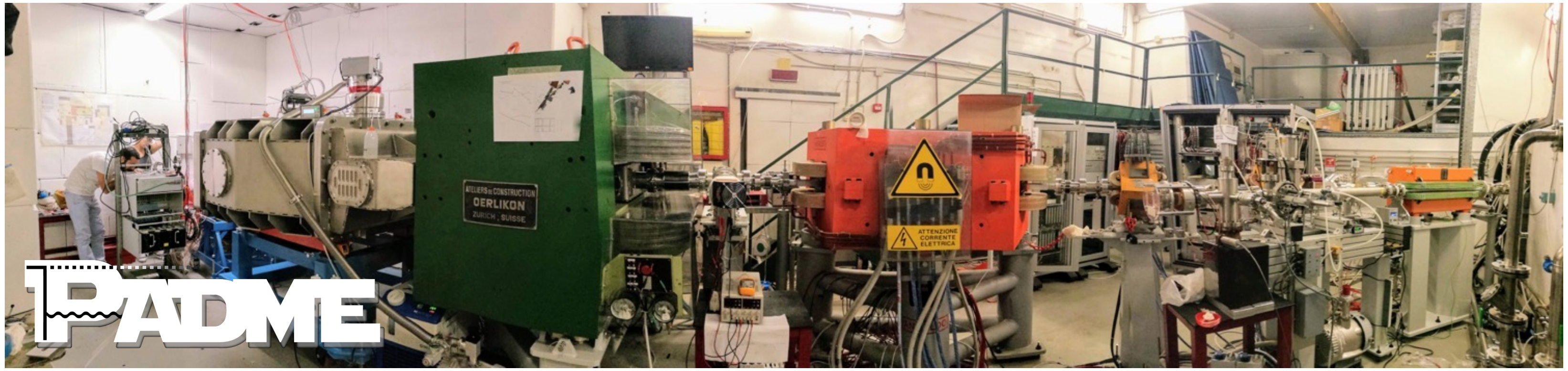




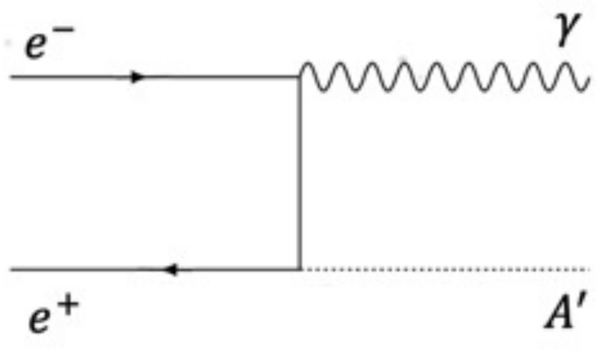
Phys Lett B 706 (2012) 251, PLB 720 (2013) 111, PLB 747 (2015) 365, PLB 736 (2014) 459, PLB 750 (2015) 633, PLB 757 (2016) 356

The Positron Annihilation into Dark Matter Experiment



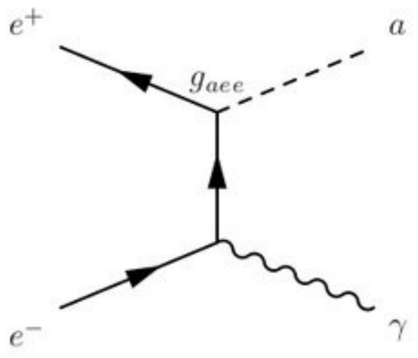


Dark Photons $m_{A'} < 23.7 MeV$



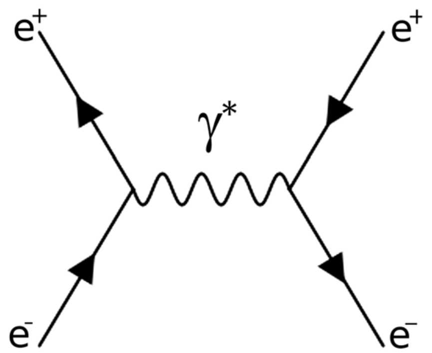
PoS PANIC2021 (2022) 043

Alps



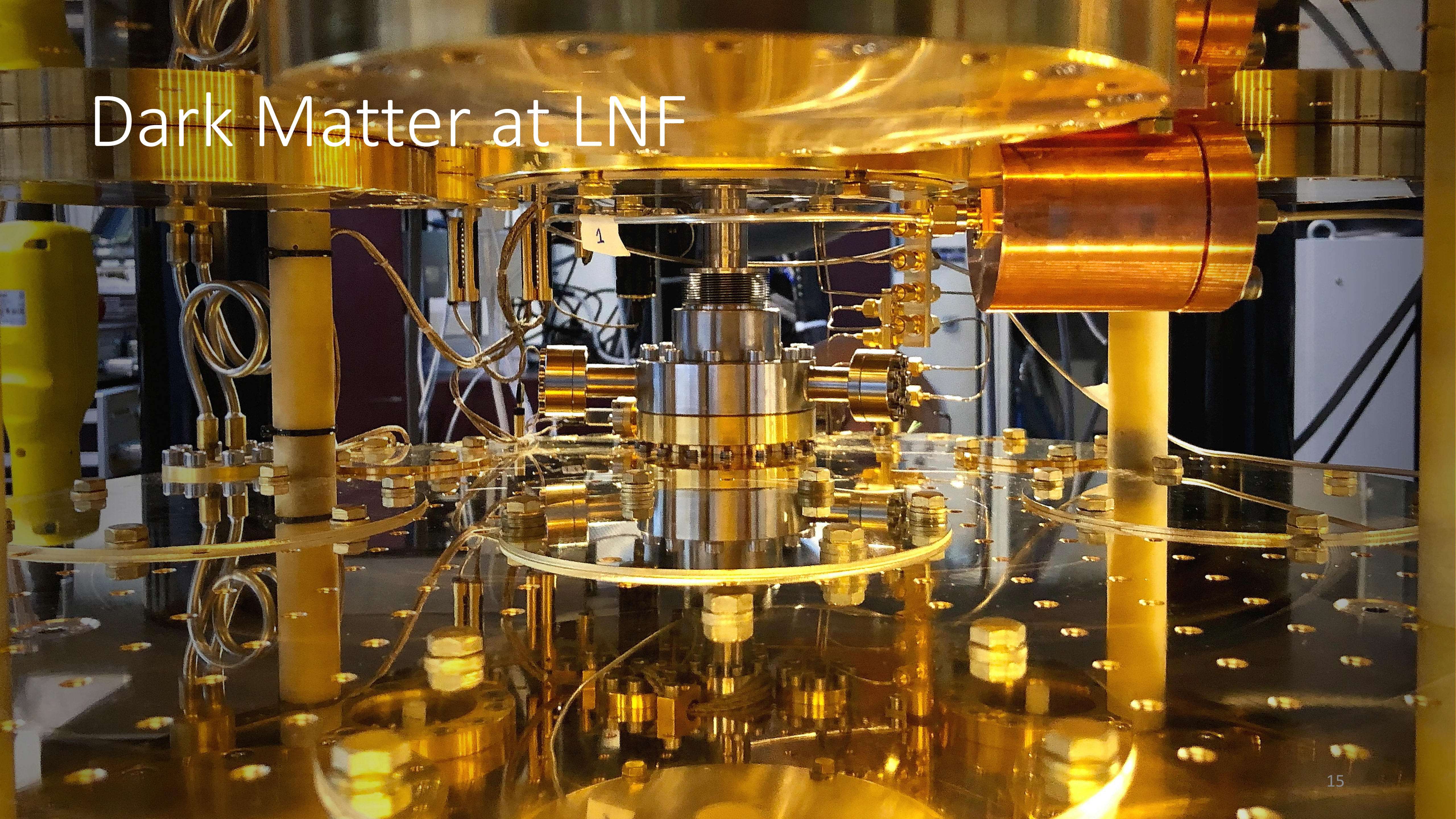
J. High Energ. Phys. 2021, 9 (2021)

X17 resonant production



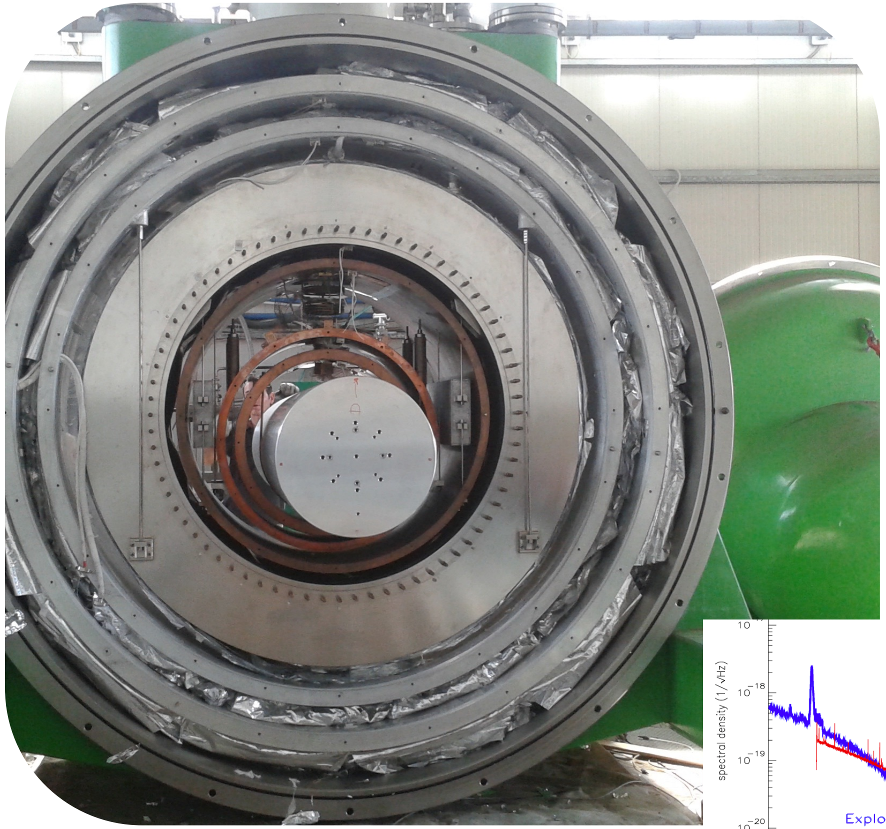
PHYSICAL REVIEW D 106, 115036 (2022)

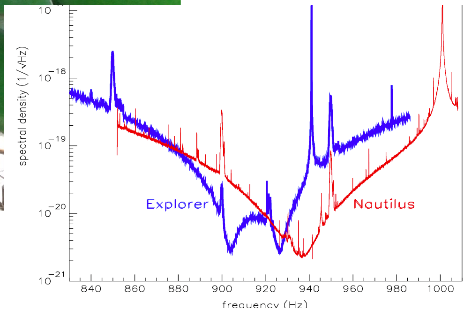
Dark Matter at LNF



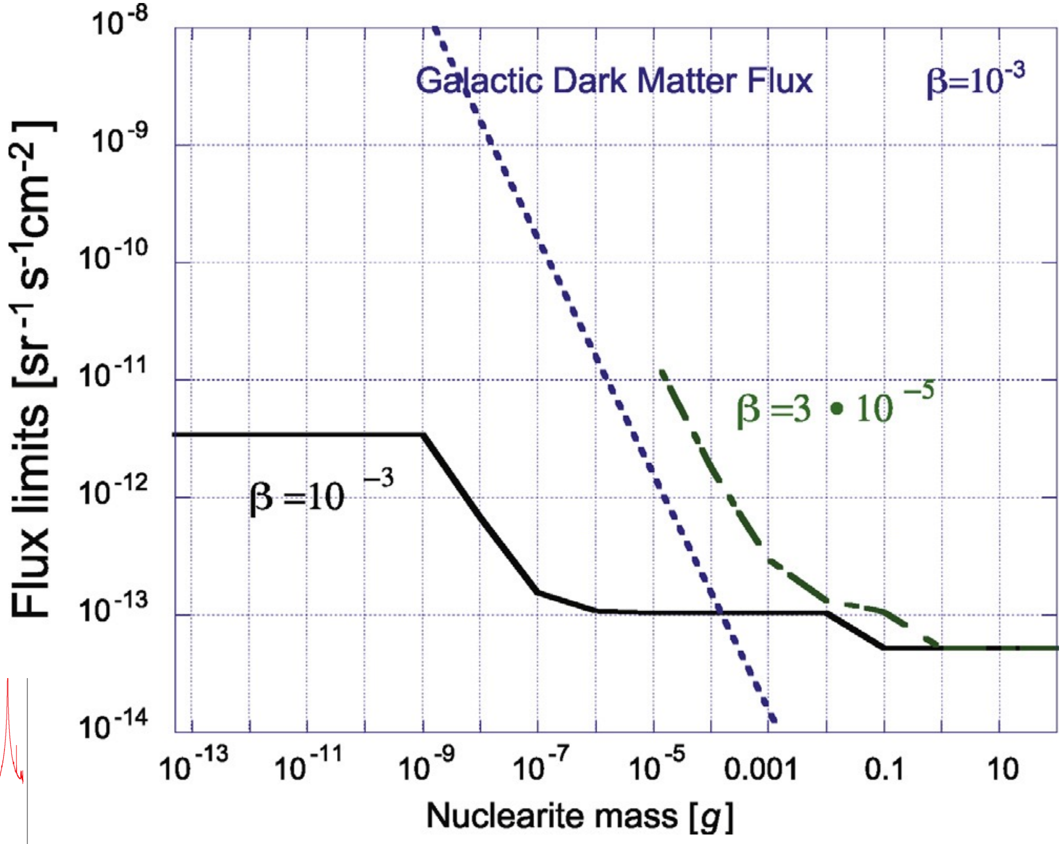
Dark matter searches using gravitational wave bar detectors: Quark nuggets and newtorites

- NAUTILUS gravitational wave detector
  - 2.3 ton resonant bar at T=0.1-4 K
  - In operation from 1995 to 2016



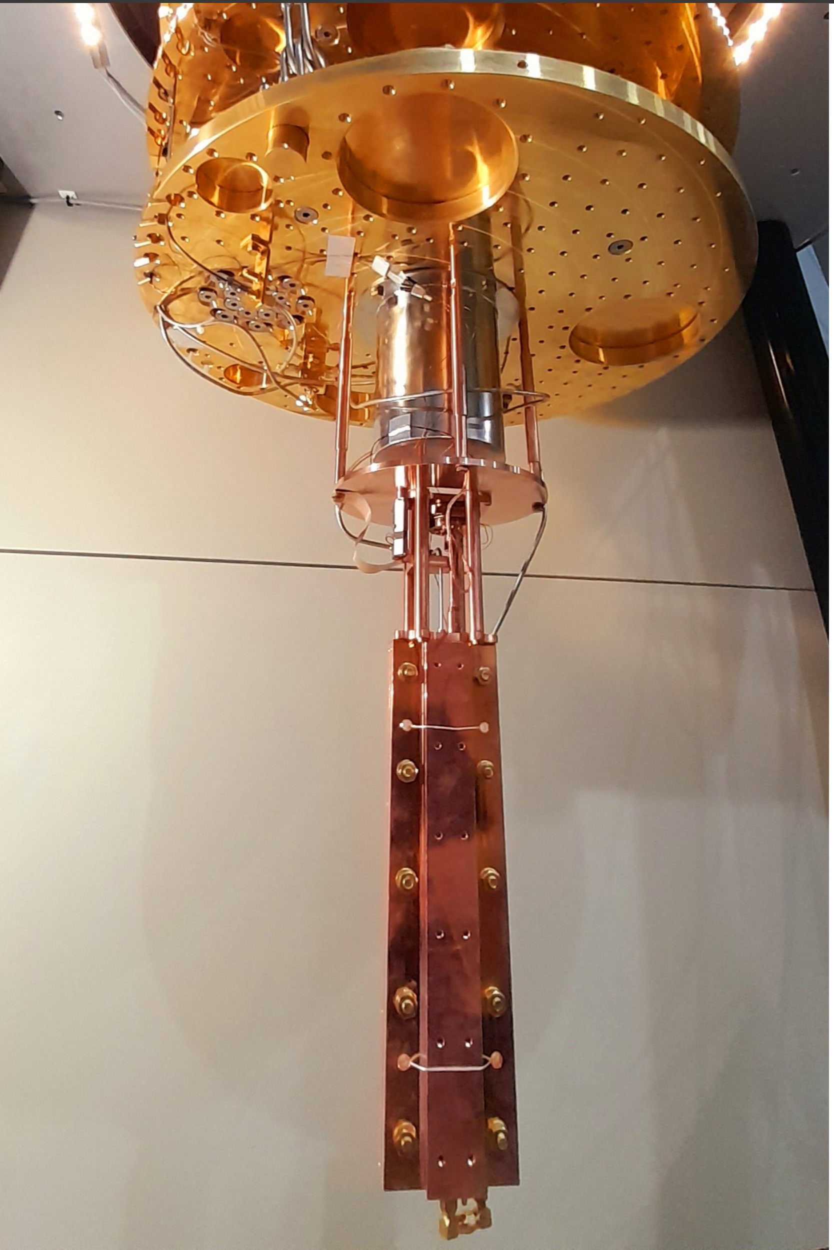


Quark nuggets Dark Matter searches



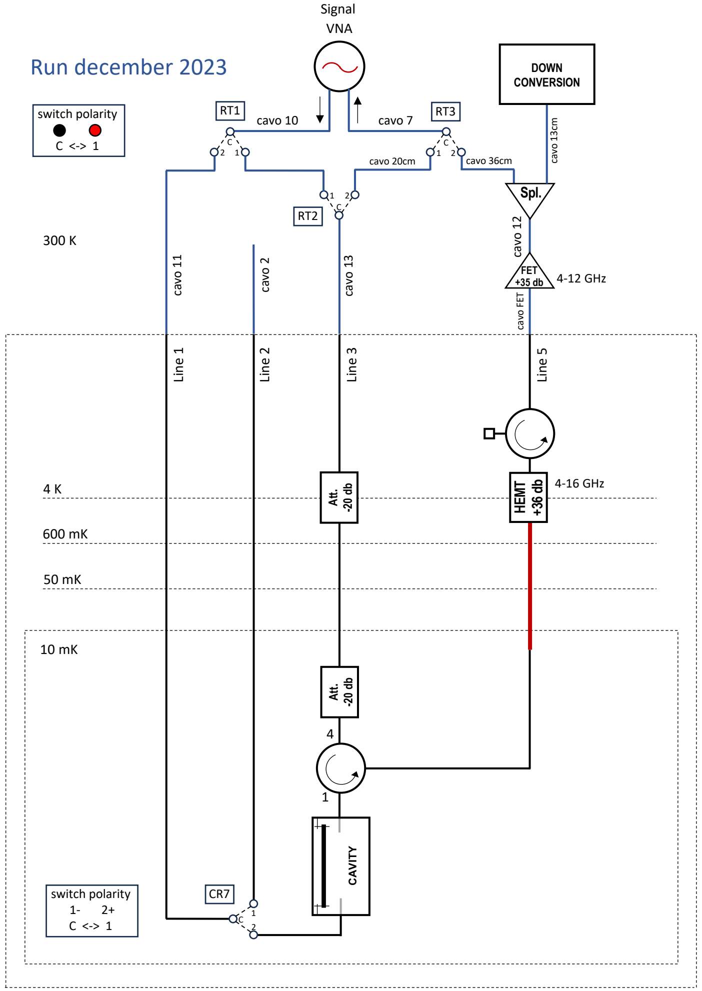
Astroparticle Physics 78 (2016) 52–64

QUAX@LNF: The LNF Axion Haloscope

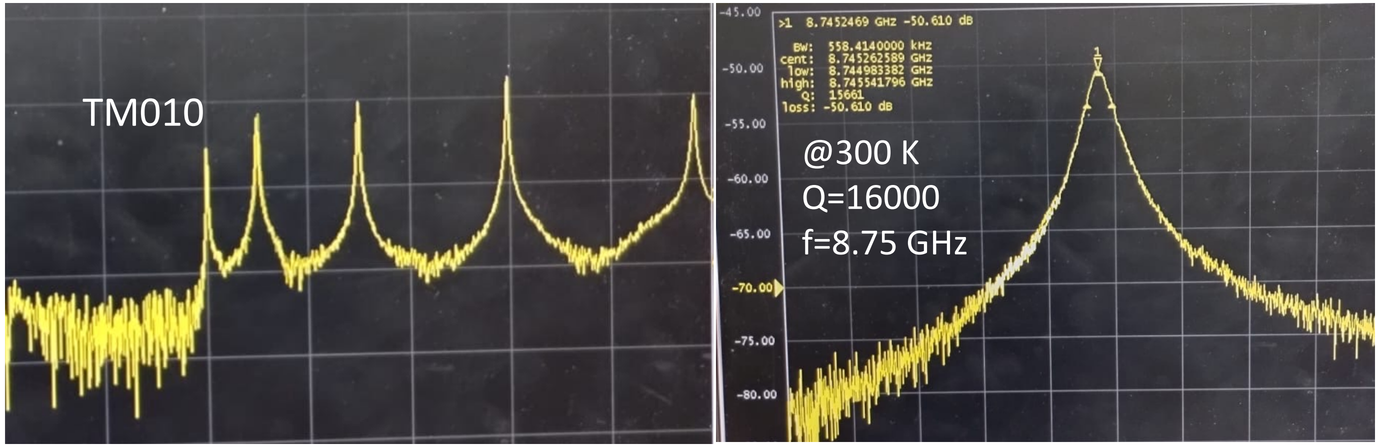


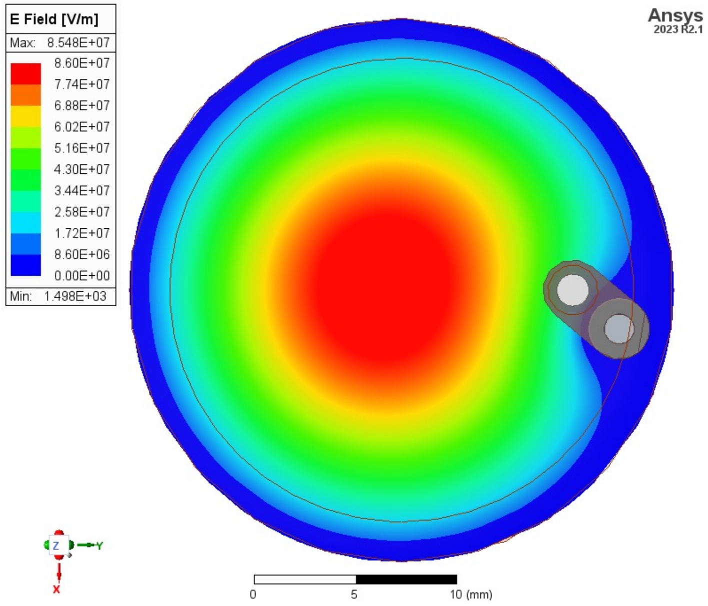
December 2023 Run

- Cavity temperature 30 mK
- Magnetic Field B=8 T
- Frequency 8.8 GHz
- Copper cavity Q_0=50,000 with tuner
- Tnoise 4K
- 2 weeks data taking
- 6 MHz scan



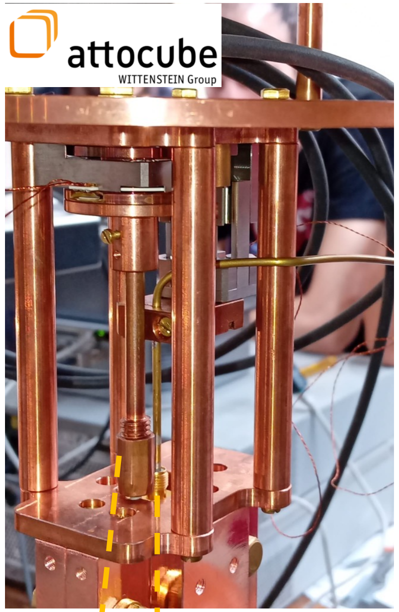
QUAX@LNF: Cavity Tuning





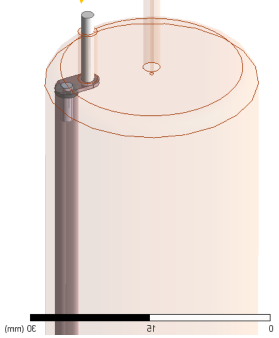
- Starting frequency ($\alpha = 0°$): 8.83 GHz
- Tuning ~ 300 MHz with $\Delta\alpha \sim 100°$

QUAX@LNF: Cavity Tuning

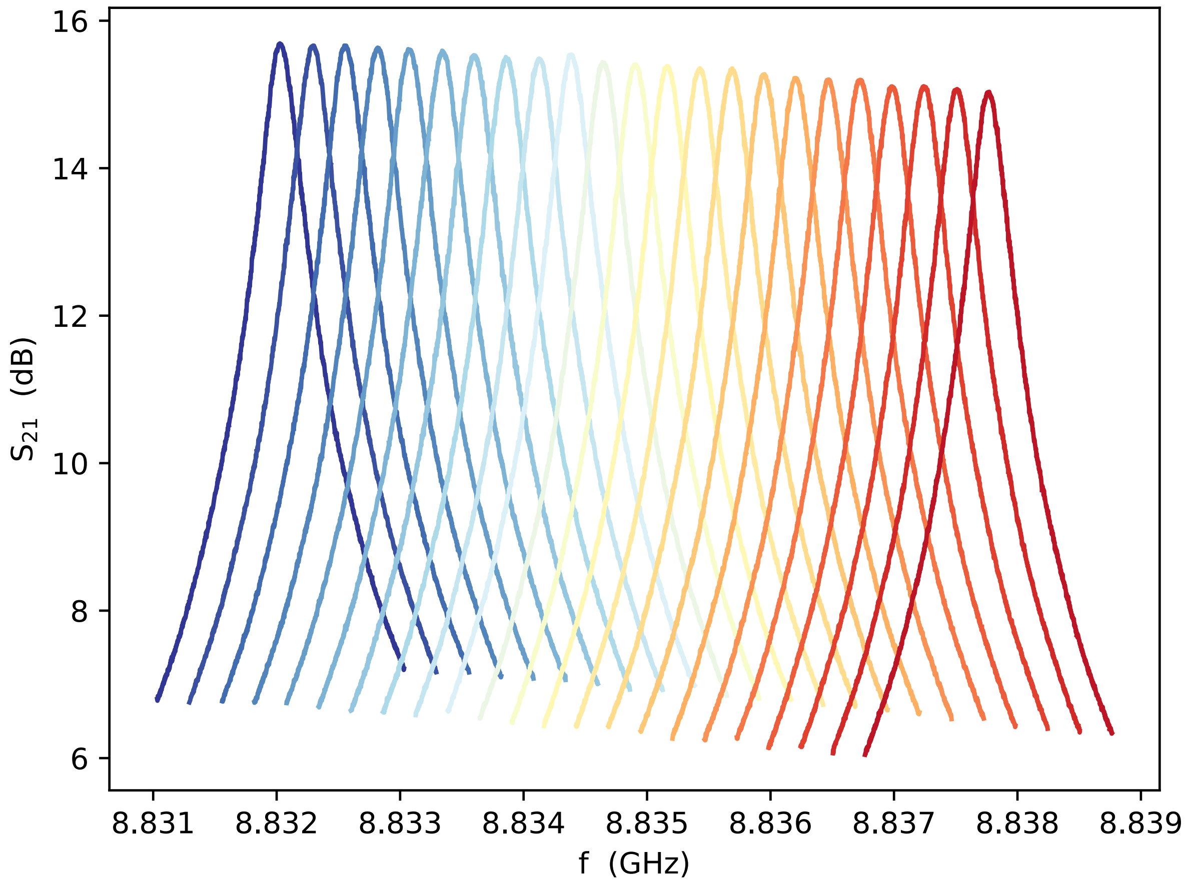


Antenna

Tuner



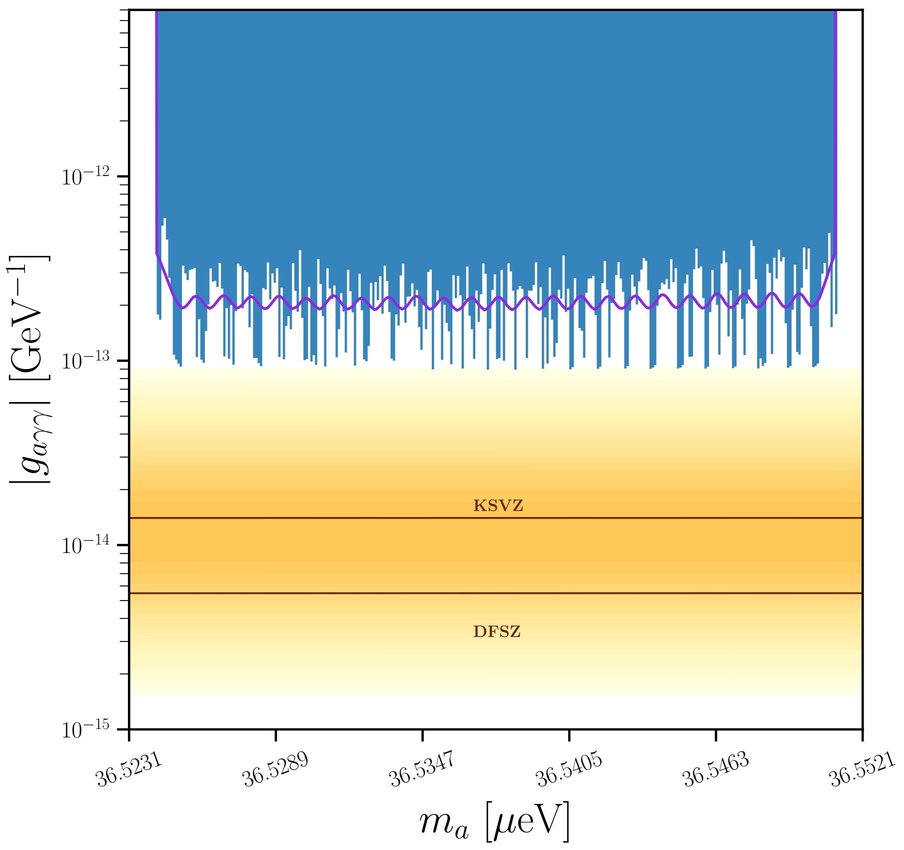
6 MHz scan

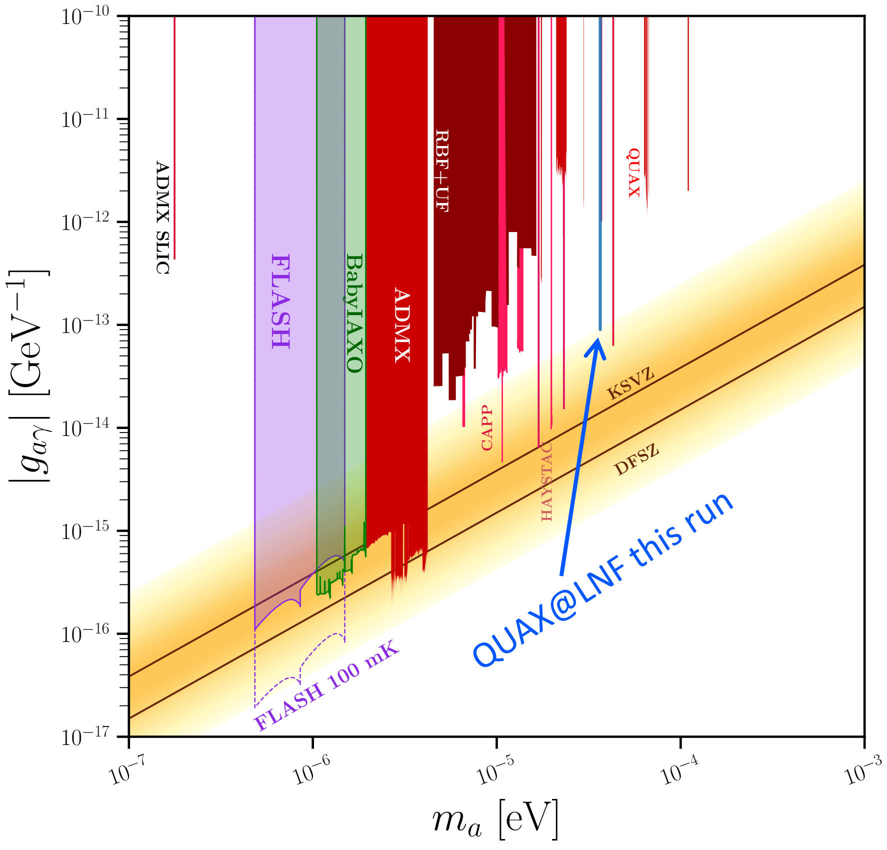


QUAX@LNF: Preliminary Results

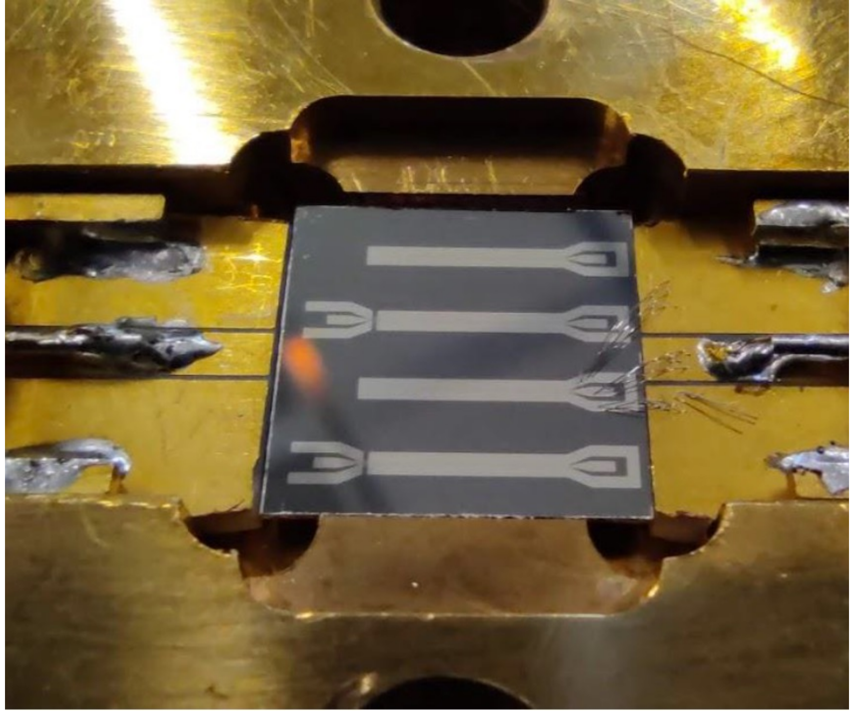
See talk by A. Rettaroli - WG4 parallel meeting - for more details

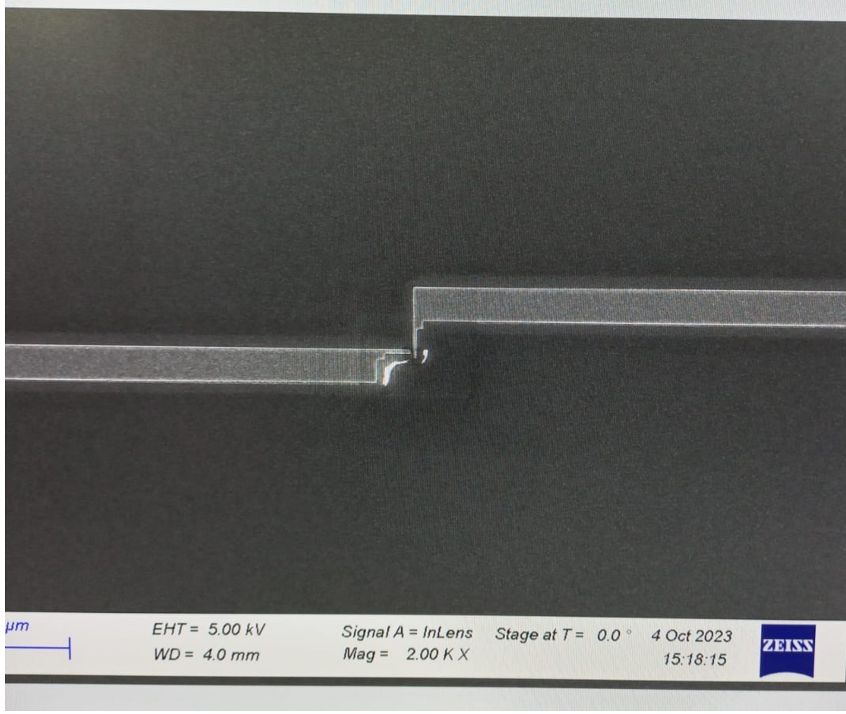
24 runs, 1 hour each, 250 kHz of frequency steps
Average exclusion about $g_{a\gamma\gamma} = 2\times10^{-13}\ GeV^{-1}$

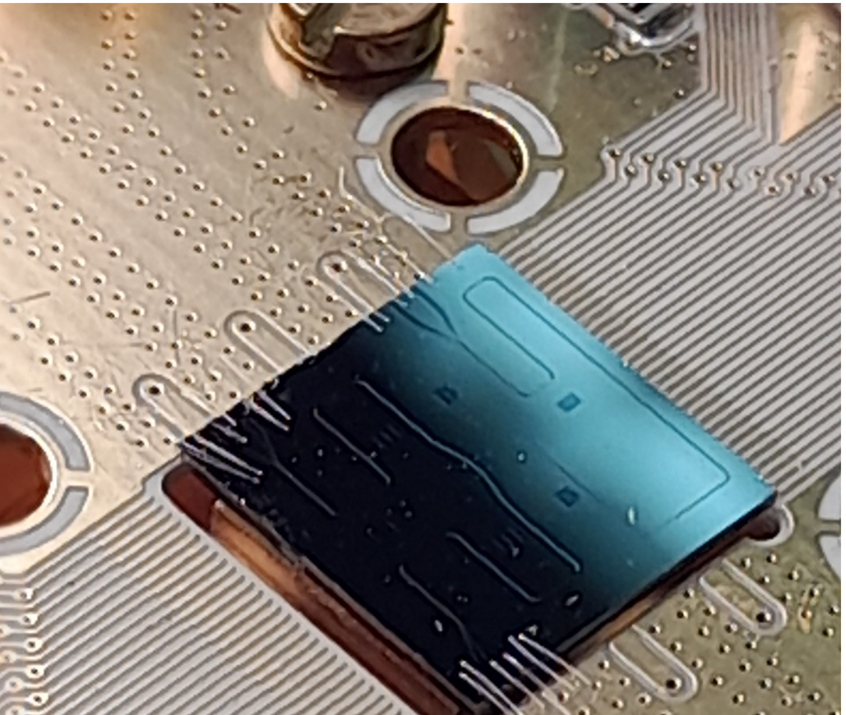


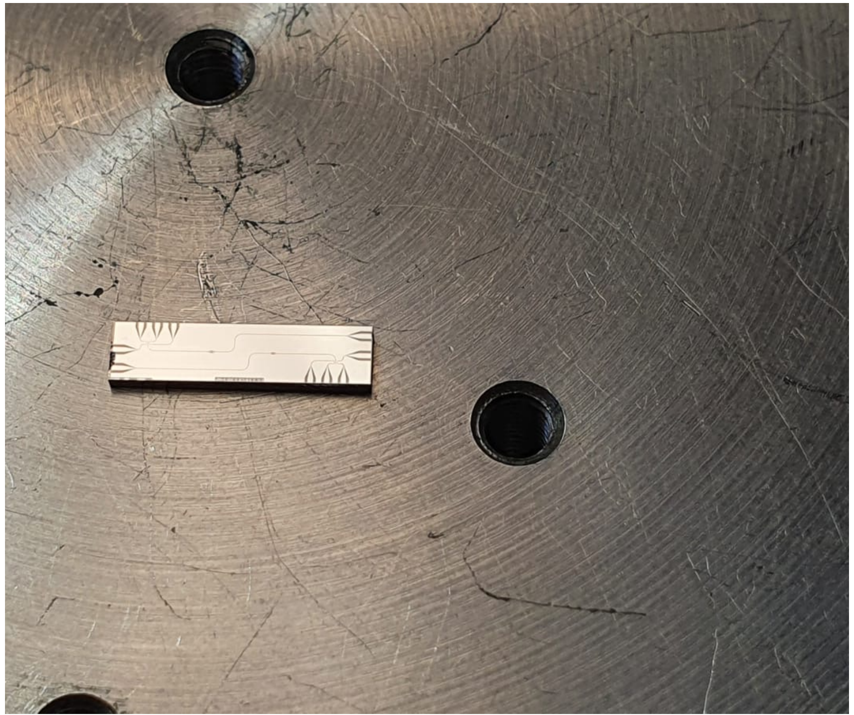


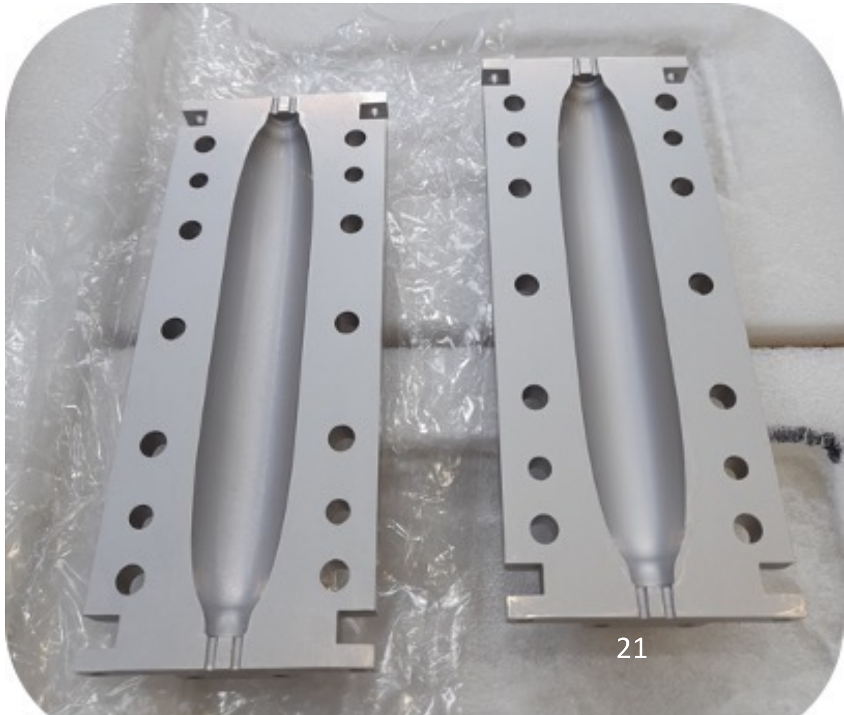
Expected improvements in 2024: higher Q_0 by a factor 2 from better tuner design; T_{noise} reduced by 10 with JPA.




µm
EHT = 5.00 kV
WD = 4.0 mm
Signal A = InLens
Mag = 2.00 K X
Stage at T = 0.0 °
4 Oct 2023
15:18:15

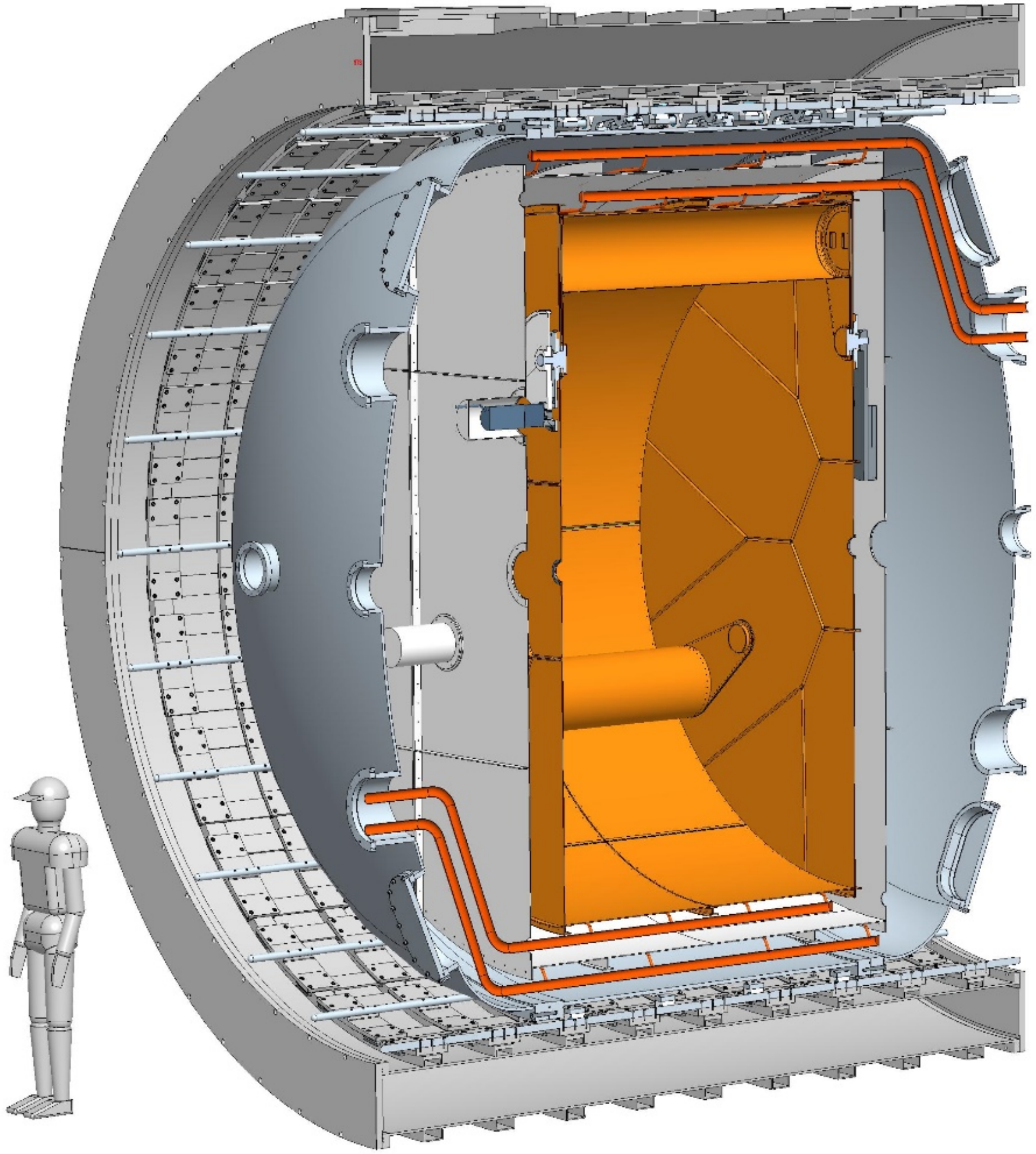




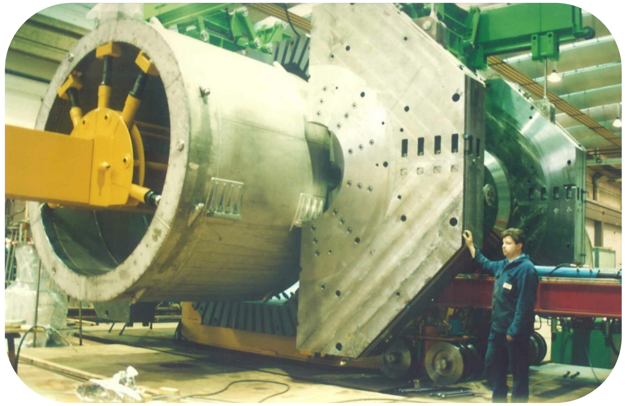


FLASH
Finuda magnet for Light Axion SearcH

Galactic axion search at 100 MHz (0.5-1.5 μeV)

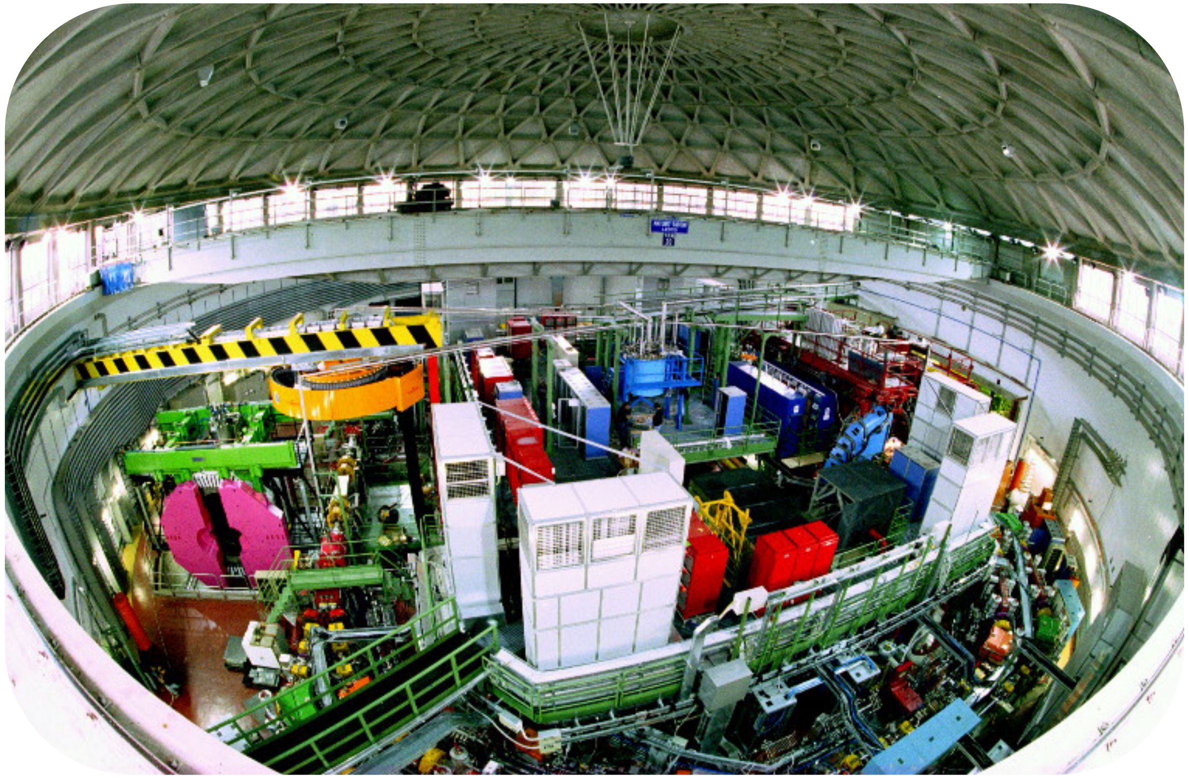


Large Superconducting Magnets at LNF



FINUDA→FLASH

B(T)	1.1
I(A)	2845
R(m)	1.4
L(m)	2.2



KLOE→KLASH

B(T)	0.6
I(A)	2300
R(m)	2.43
L(m)	4.4

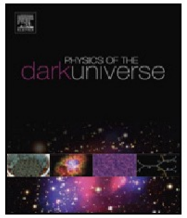
FLASH

Physics of the Dark Universe 42 (2023) 101370

Contents lists available at ScienceDirect

Physics of the Dark Universe

journal homepage: www.elsevier.com/locate/dark



Full Length Article

The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories

David Alesini [a], Danilo Babusci [a], Paolo Beltrame [b], Fabio Bossi [a], Paolo Ciambrone [a], Alessandro D'Elia [a,*], Daniele Di Gioacchino [a], Giampiero Di Pirro [a], Babette Döbrich [c], Paolo Falferi [d], Claudio Gatti [a], Maurizio Giannotti [e,f], Paola Gianotti [a], Gianluca Lamanna [g], Carlo Ligi [a], Giovanni Maccarrone [a], Giovanni Mazzitelli [a], Alessandro Mirizzi [h,i], Michael Mueck [j], Enrico Nardi [a,k], Federico Nguyen [l], Alessio Rettaroli [a], Javad Rezvani [m,a], Francesco Enrico Teofilo [n], Simone Tocci [a], Sandro Tomassini [a], Luca Visinelli [o,p], Michael Zantedeschi [o,p]

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[i] INFN sezione di Bari, Via Orabona 4, Bari, 70126, Italy
[j] ez SQUID, Herborner Strasse 9, Sinn, 35764, Germany
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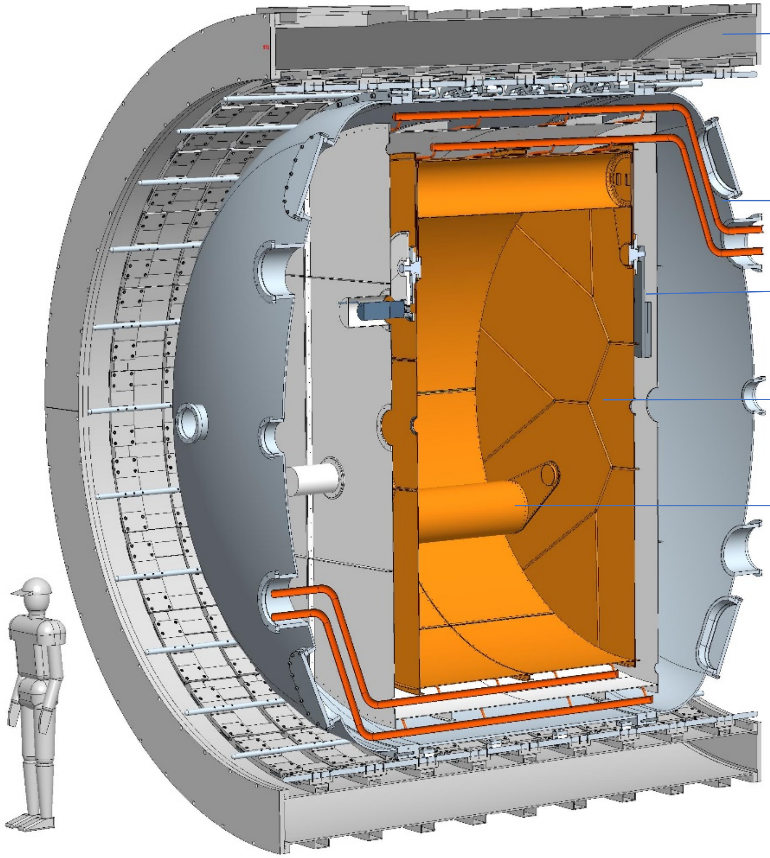
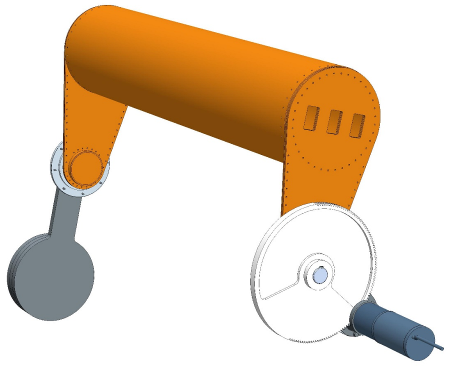
[o] Tsung-Dao Lee Institute (TDLI), 520 Shengrong Road, Shanghai, 201210, China
[p] School of Physics and Astronomy, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, 200240, China

THE F(K)LASH Cryostat and Resonant Cavity



- KLOE/FINUDA Magnet
- Vacuum vessel made by a-magnetic stainless steel
- Shield in aluminum alloy, to be cooled to 70 K by gaseous Helium
- OFHC Cu resonant cavity, cooled to 4.6 K by saturated liquid Helium
- 3 OFHC Cu tuning bars mounted on eccentric cranks with reduction gearboxes

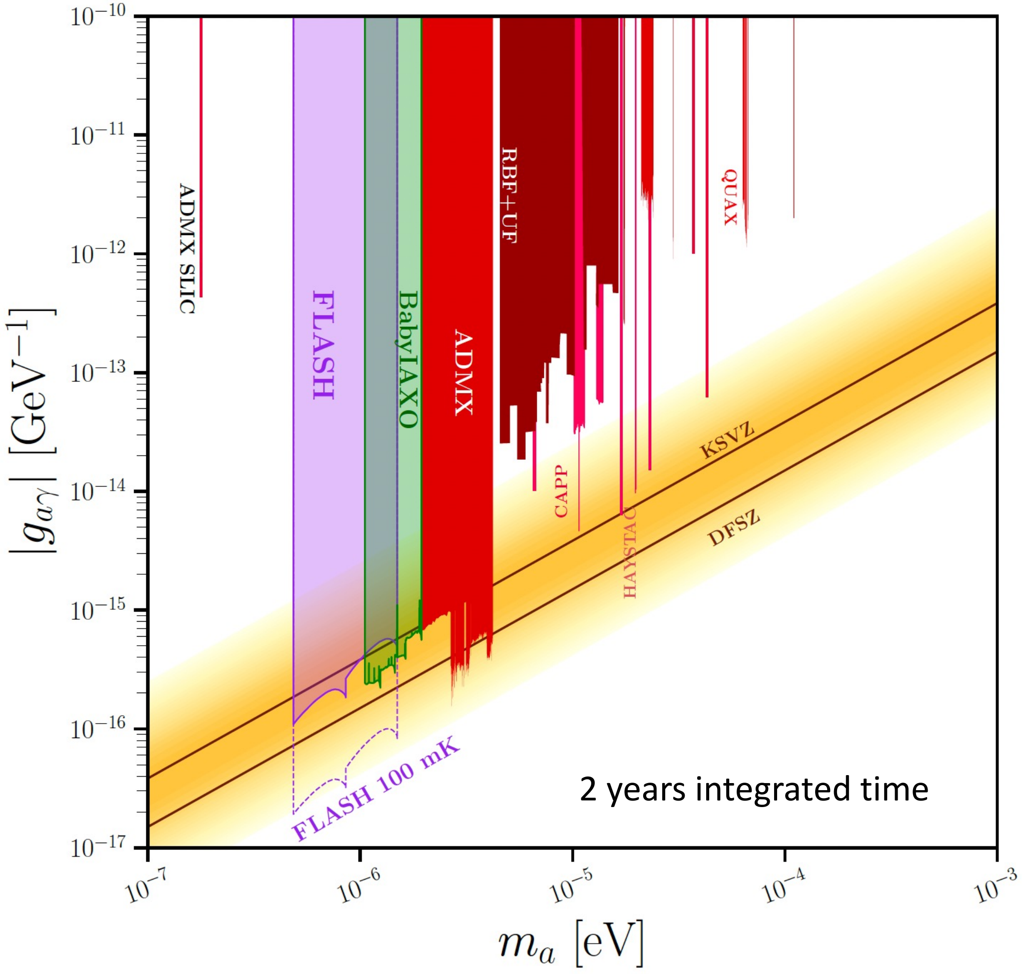


Design by FANTINI Sud Mechanical Div.

counterweight

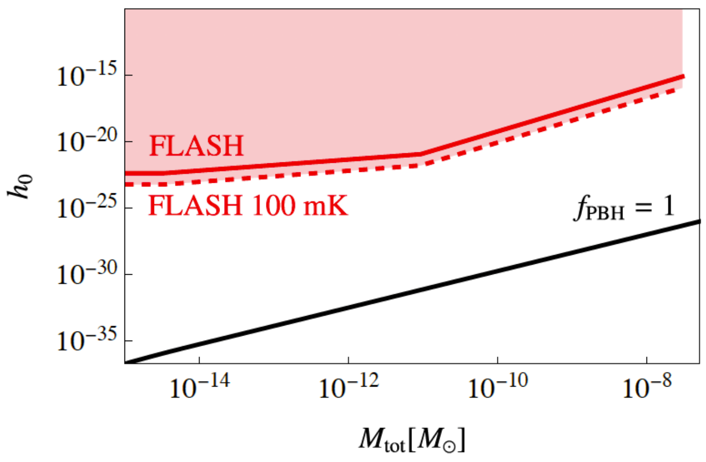
Stepper motor (2.5 μrad)

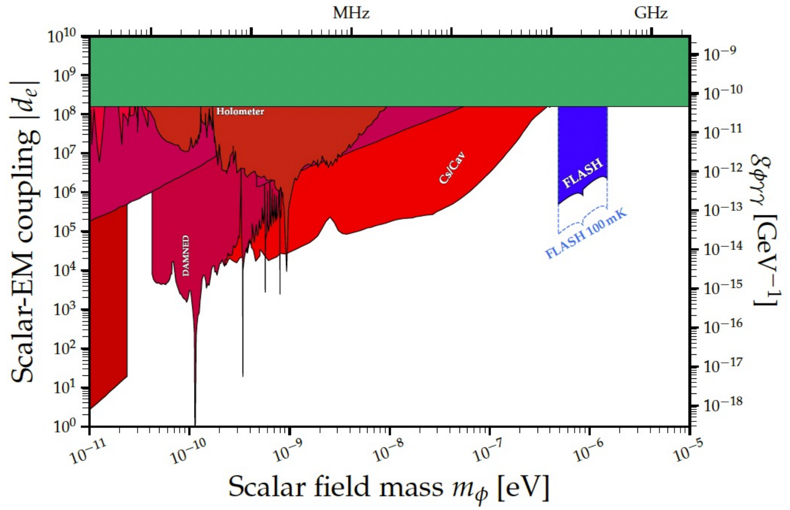
Sensitivity to Axions and ALPS

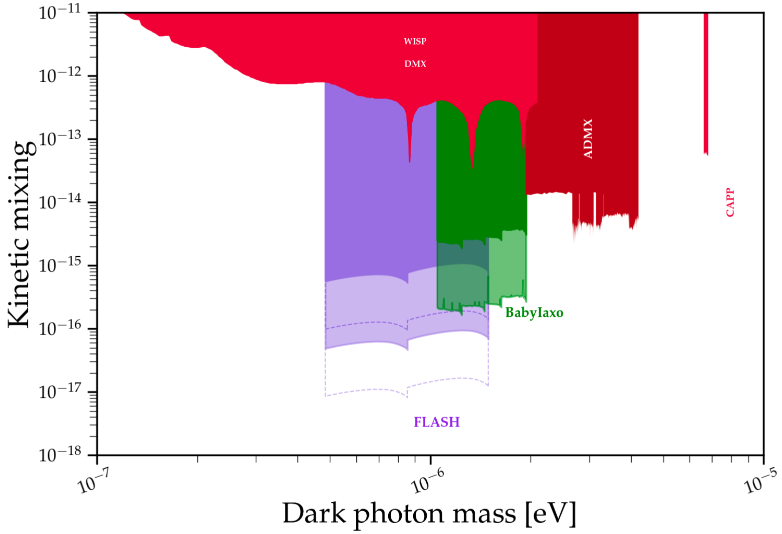


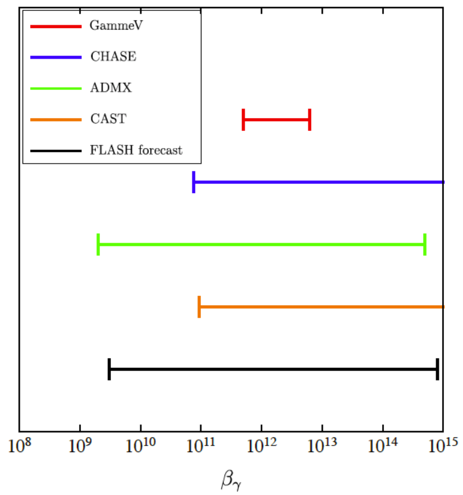
Parameter	Value
ν_c [MHz]	150
m_a [μeV]	0.62
$g_{a\gamma\gamma}^{\mathrm{KSVZ}}$ [GeV^{-1}]	2.45×10^{-16}
Q_L	1.4×10^5
C_{010}	0.53
B_{max} [T]	1.1
β	2
τ [min]	5
T_{sys} [K]	4.9
P_{sig} [W]	0.9×10^{-22}
Scan rate [Hz s^{-1}]	8
m_a [μeV]	0.49 - 1.49
$g_{\gamma\gamma}$ 90% c.l. [GeV^{-1}]	$(1.25 - 6.06) \times 10^{-16}$

$$\mathcal{L} \supset -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2}(\partial^\mu a)(\partial_\mu a) - \frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{a\gamma\gamma}\, a \tilde{F}_{\mu\nu} F^{\mu\nu}$$


FLASH
FLASH 100 mK
$f_{PBH} = 1$
h_0
$M_{tot}[M_\odot]$


MHz
GHz
Holometer
Cs/Cav
FLASH
FLASH 100 mK
DAMNED
Scalar-EM coupling $|d_e|$
$g_{\phi\gamma\gamma}$ [GeV^{-1}]
Scalar field mass m_ϕ [eV]

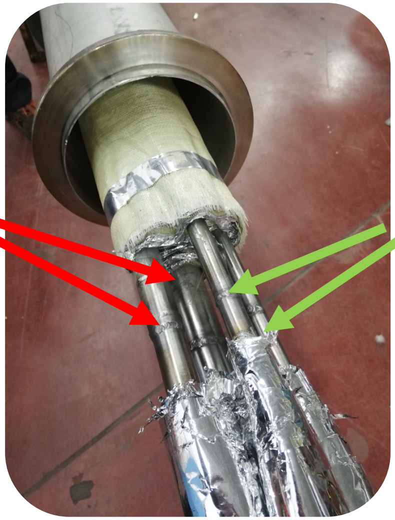

WISP
DMX
ADMX
CAPP
BabyIaxo
FLASH
Kinetic mixing
Dark photon mass [eV]


GammeV
CHASE
ADMX
CAST
FLASH forecast
β_γ

Commissioning of the FINUDA Magnet

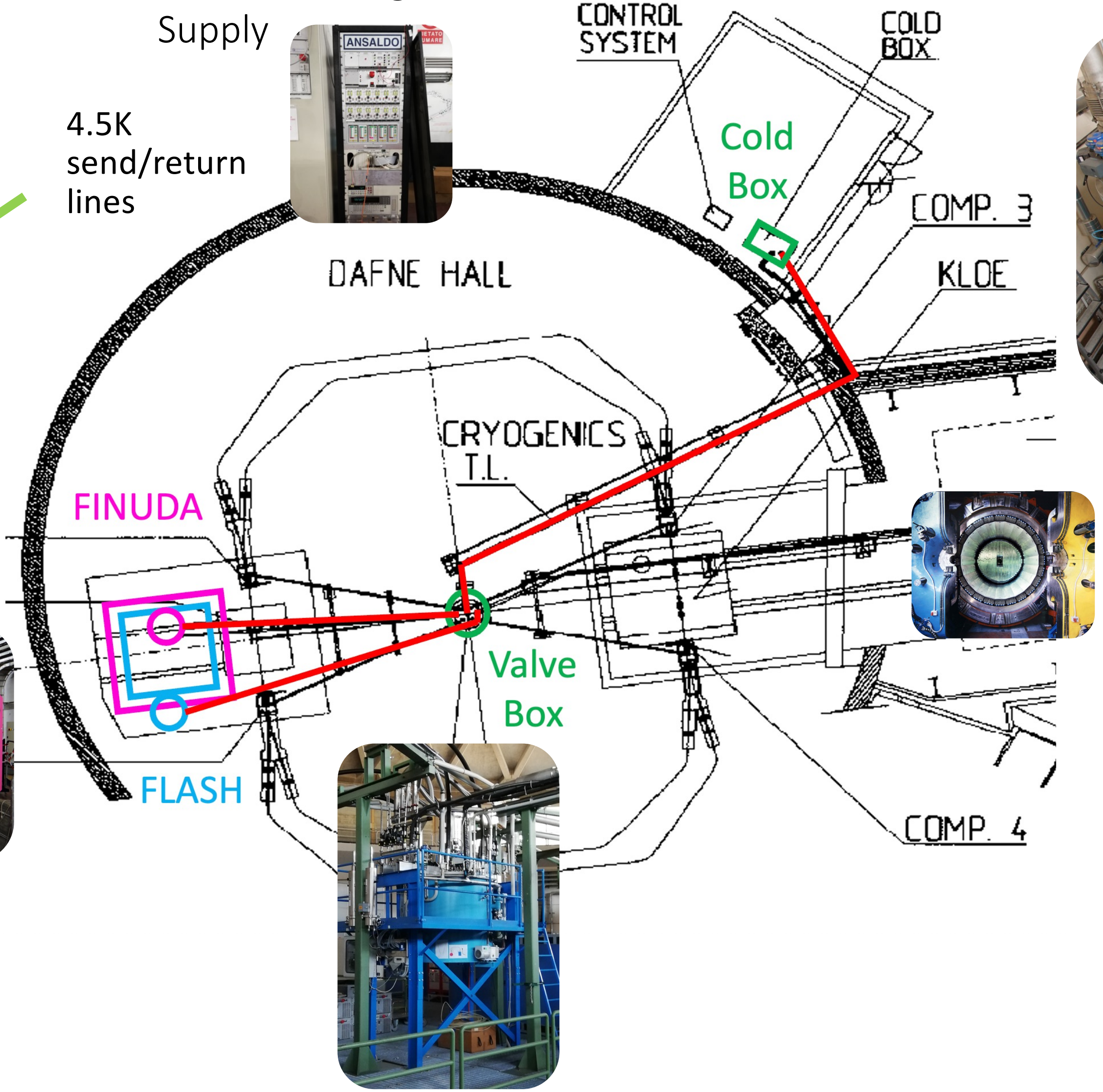
70K send/return lines

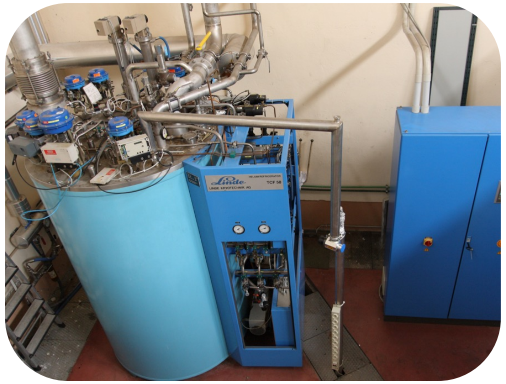
4.5K send/return lines



Reconnection of He transfer line

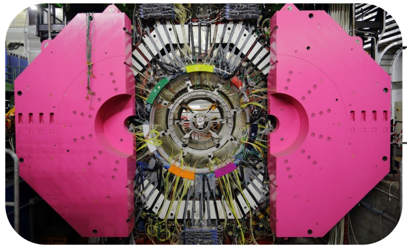
Control of Magnet Power Supply





Cryogenic plant

KLOE



FINUDA/FLASH

FINUDA Transfer Line Reconnection

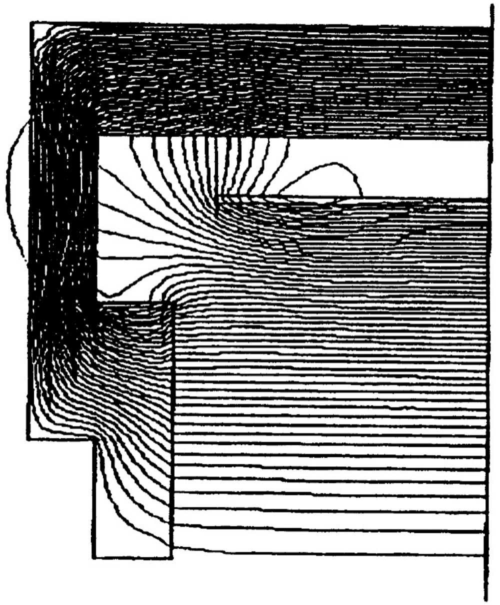
Closing of Iron Endcaps

- Field homogeneity assured by the iron endcaps:

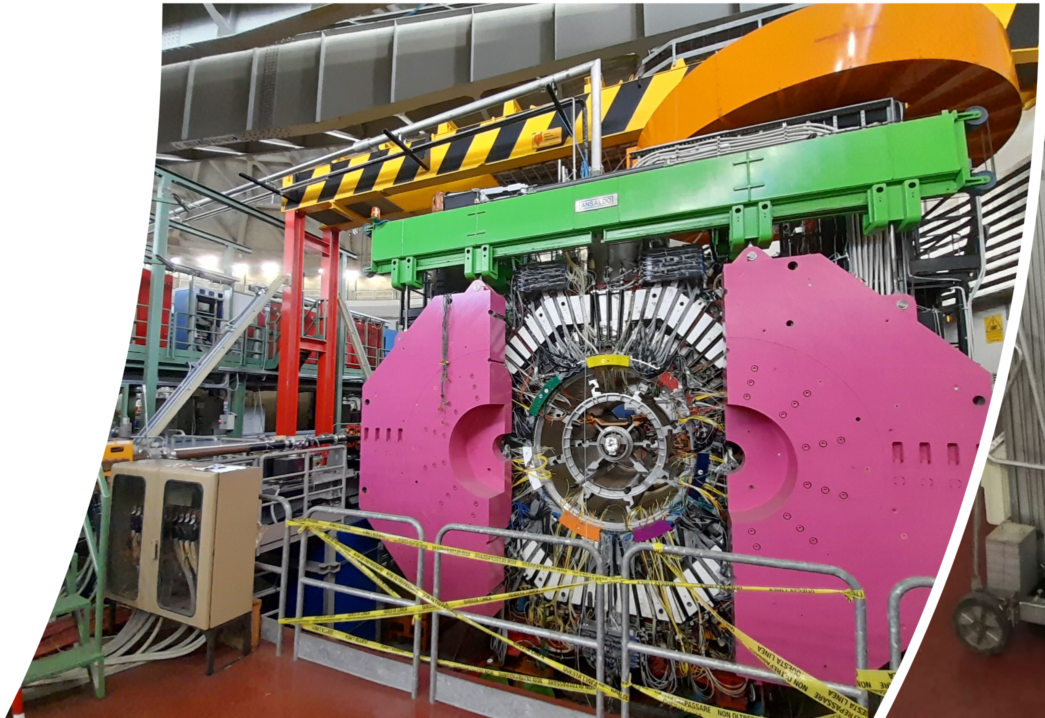
a) dBz/Bz<5%

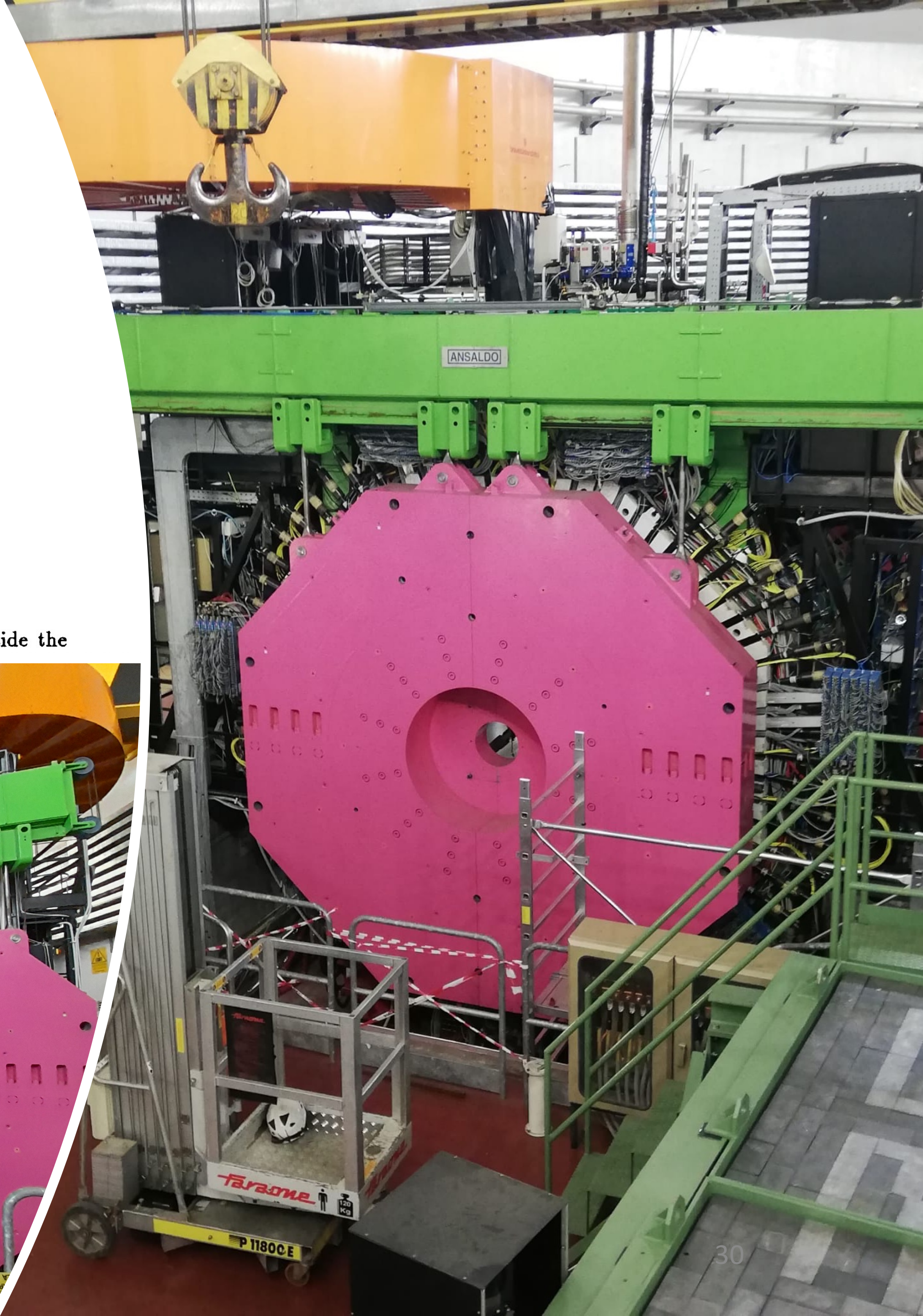
b) dB_T/B_T<1%

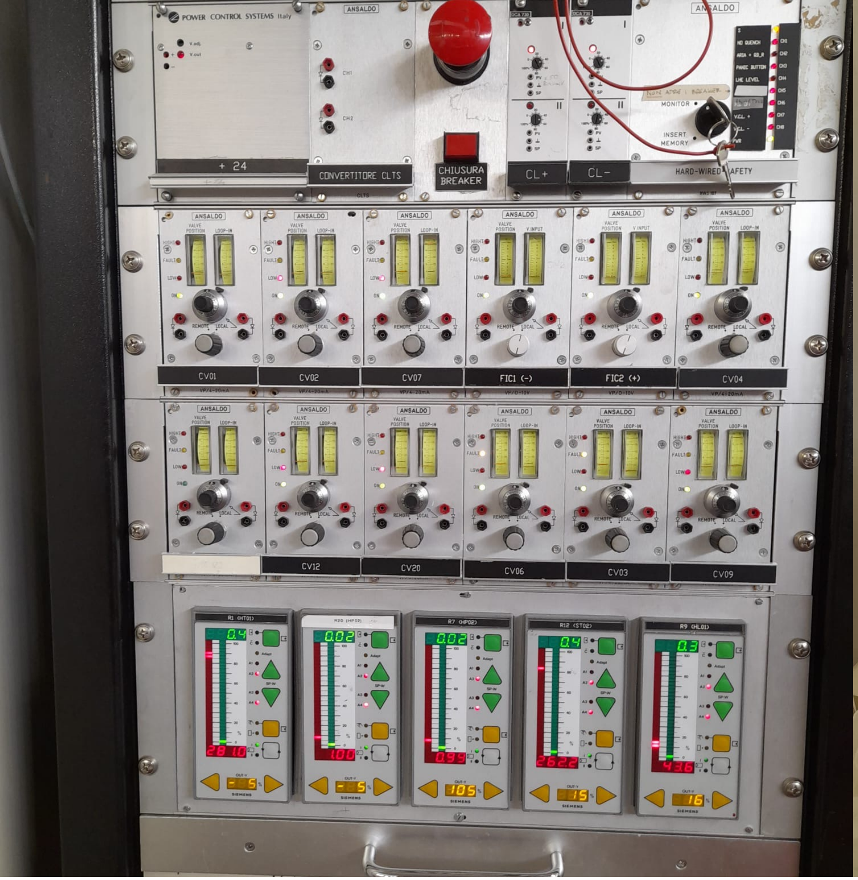
Checked the pressure tightness of hydraulic pipes and endcaps succesfuly closed!

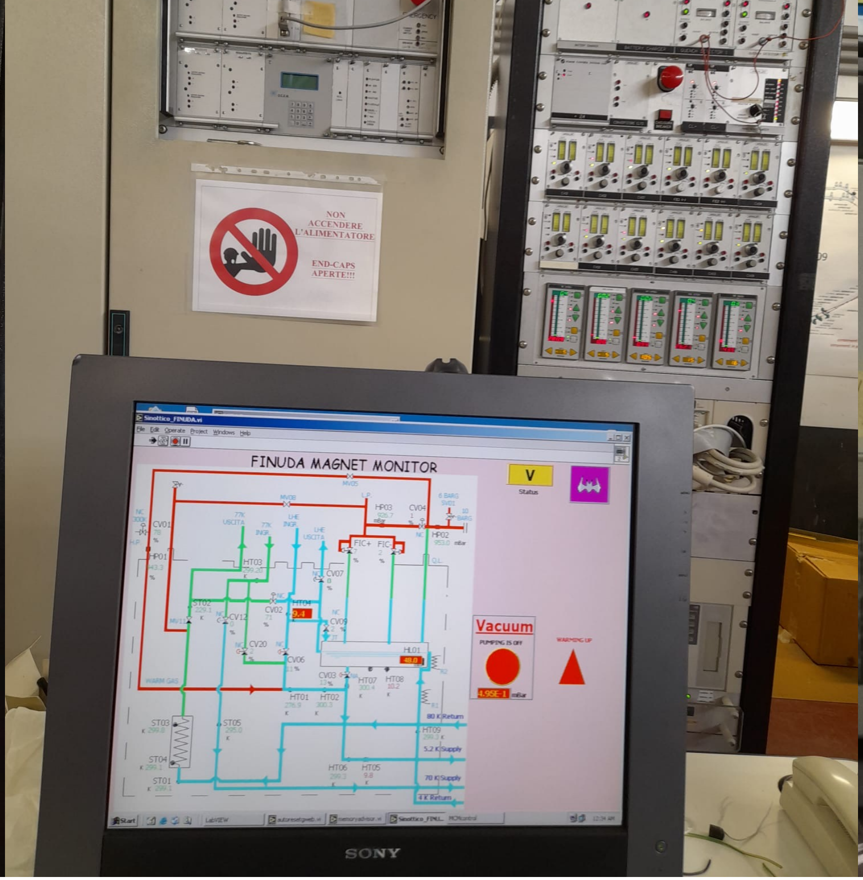


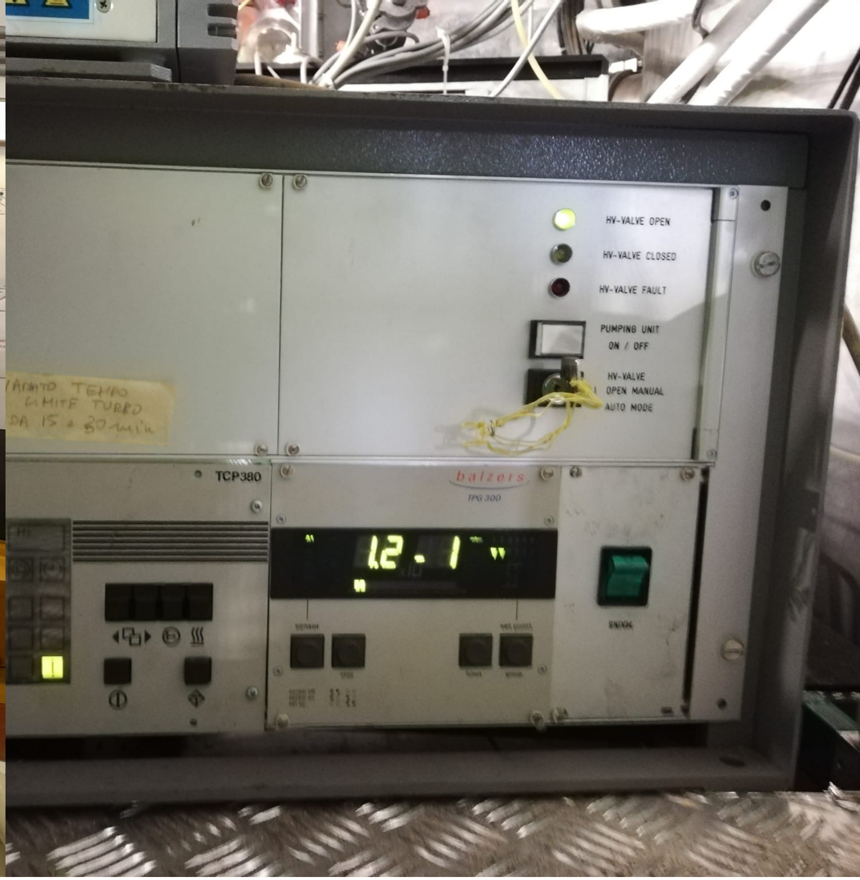
e 3.6: Map of the value of the z-component of the magnetic field inside the











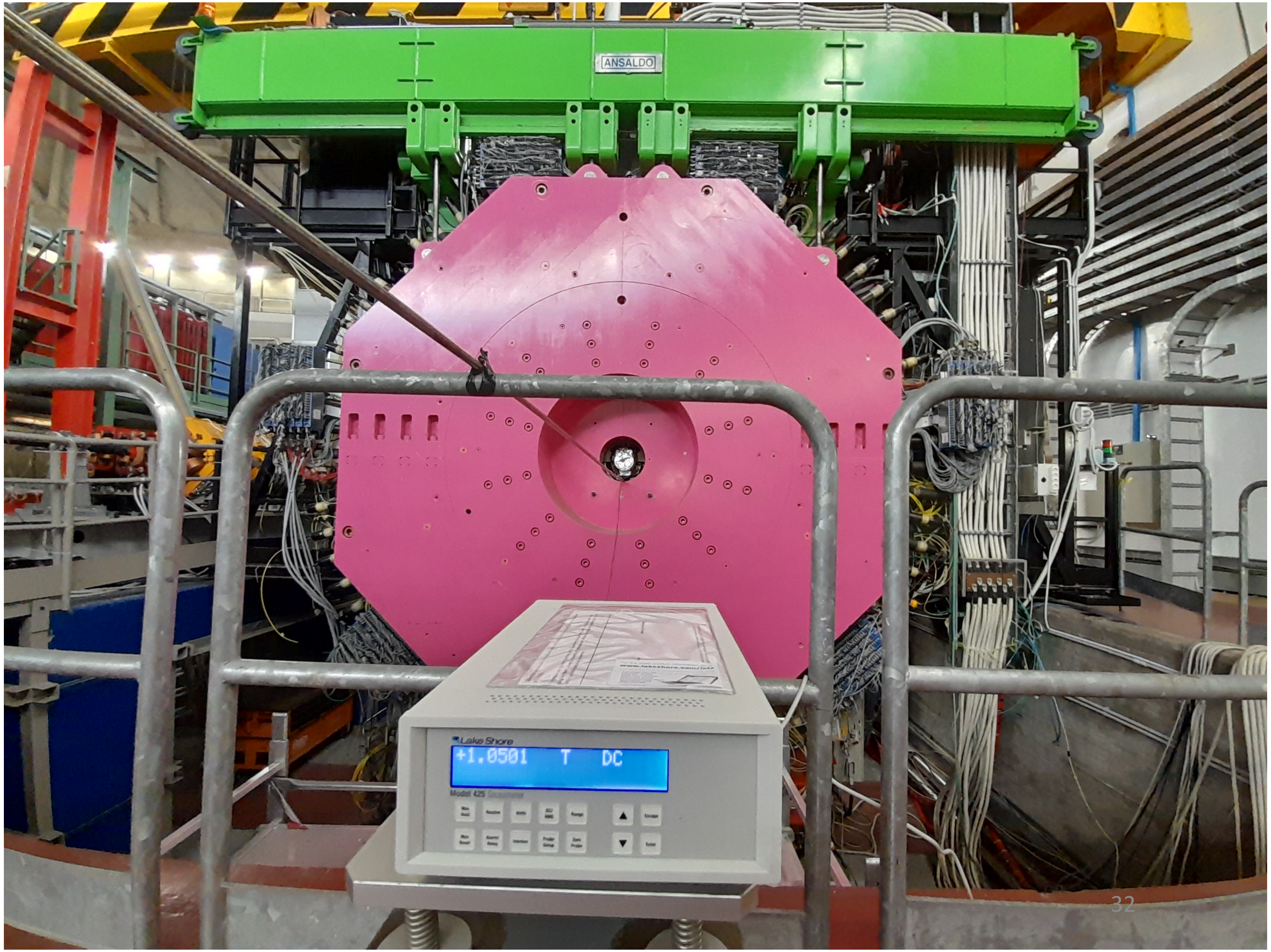
Magnet control panel and vacuum system

- Fixed manual valve-controls
- Valve PIDs repaired
- Replaced fuses of power supply
- PXI restored
- Electronic rack for pump and sensors control repaired: pumping system restarted!

Succesful Test of the FINUDA Magnet

After a series of operations, the cryogenic plant was finally put back into operation. On Jan the 19th 2024, FINUDA was cooled down to 4 K and energized with a current of 2706 A, generating a magnetic field of 1.05 T.

Next step now is preparing the Technical Design Report.



CONCLUSIONS

- Since the construction of the synchrotron in 1954, the Frascati National Laboratory has always been at the forefront in the development of particle accelerator for physics experiments.

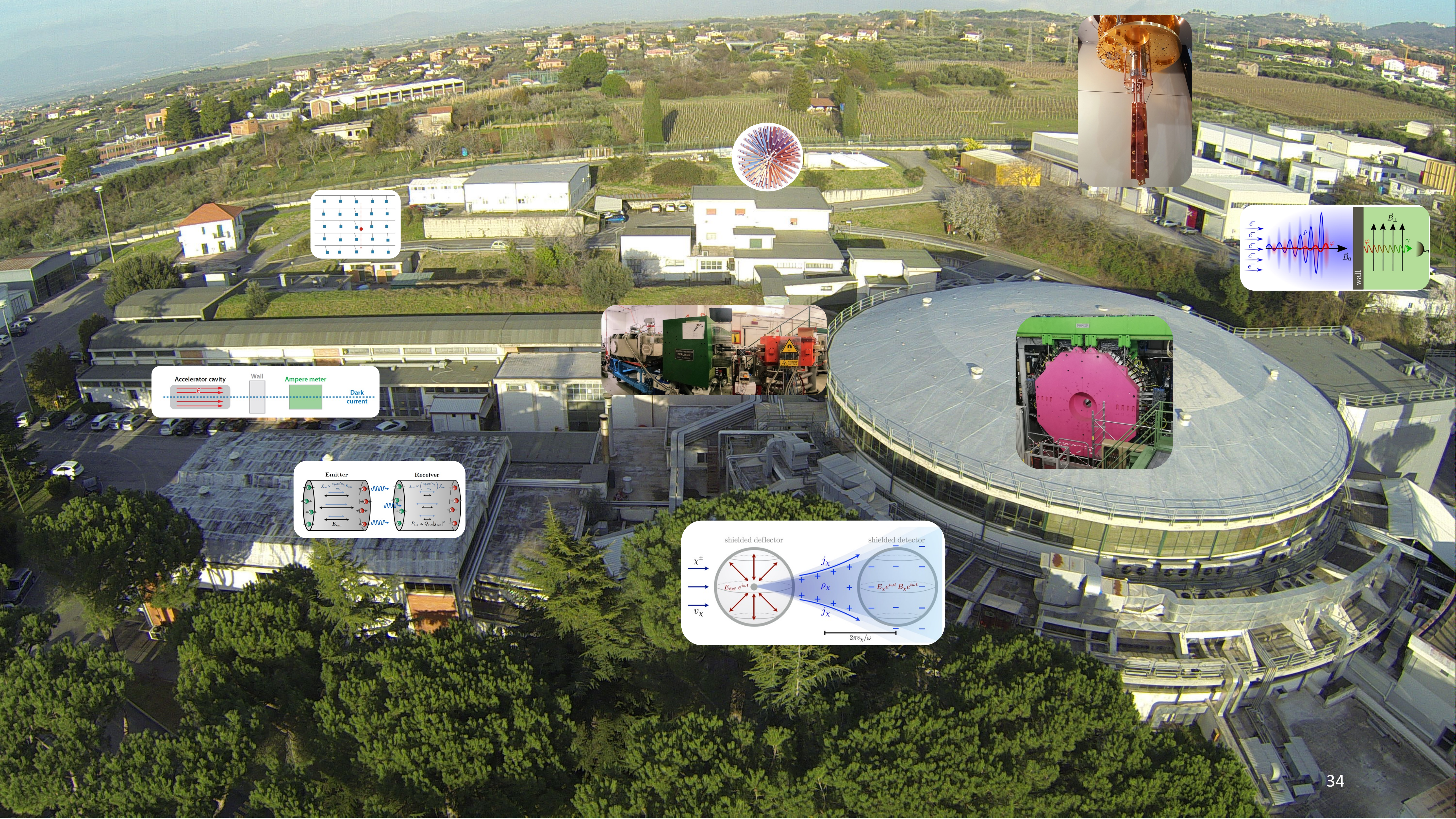
- The new facility for plasma acceleration, EuPRAXIA, is instead oriented to a new multi-disciplinary community of users.

- However, our understanding of the universe is still incomplete (DM, DE, QV, QG) and some of the answers may still come from the Low Energy Frontier of particle physics.

- Thanks to existing infrastructures and skills, new experiments are operating or will at LNF in this direction: PADME at the BTF, QUAX@LNF and FLASH with the FINUDA magnet.

- At the same time (thanks to Enrico) the theory group is now strongly involved in this activity.

May the future bring us more WISPS experiments …


Accelerator cavity
Wall
Ampere meter
Dark current
Emitter
Receiver
shielded deflector
shielded detector
wall