UNIVERSITY OF LIVERPOOL

The FLASH experiment and Quantum R&D in Liverpool

HEP Annual Meeting
21-22 May 2026

Paolo Beltrame - 21 May 2026

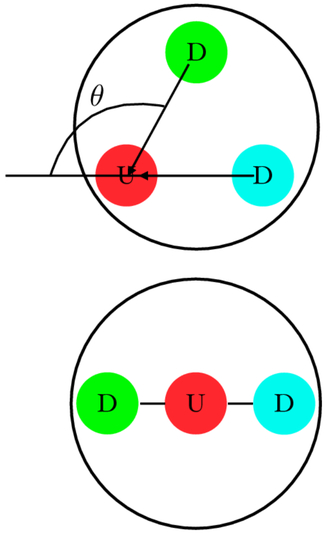
1. FLASH physics

2. The FLASH detector and collaboration

   - UoL involvement

3. Frascati CryoMagnet and Quantum R&D prospect

Axions



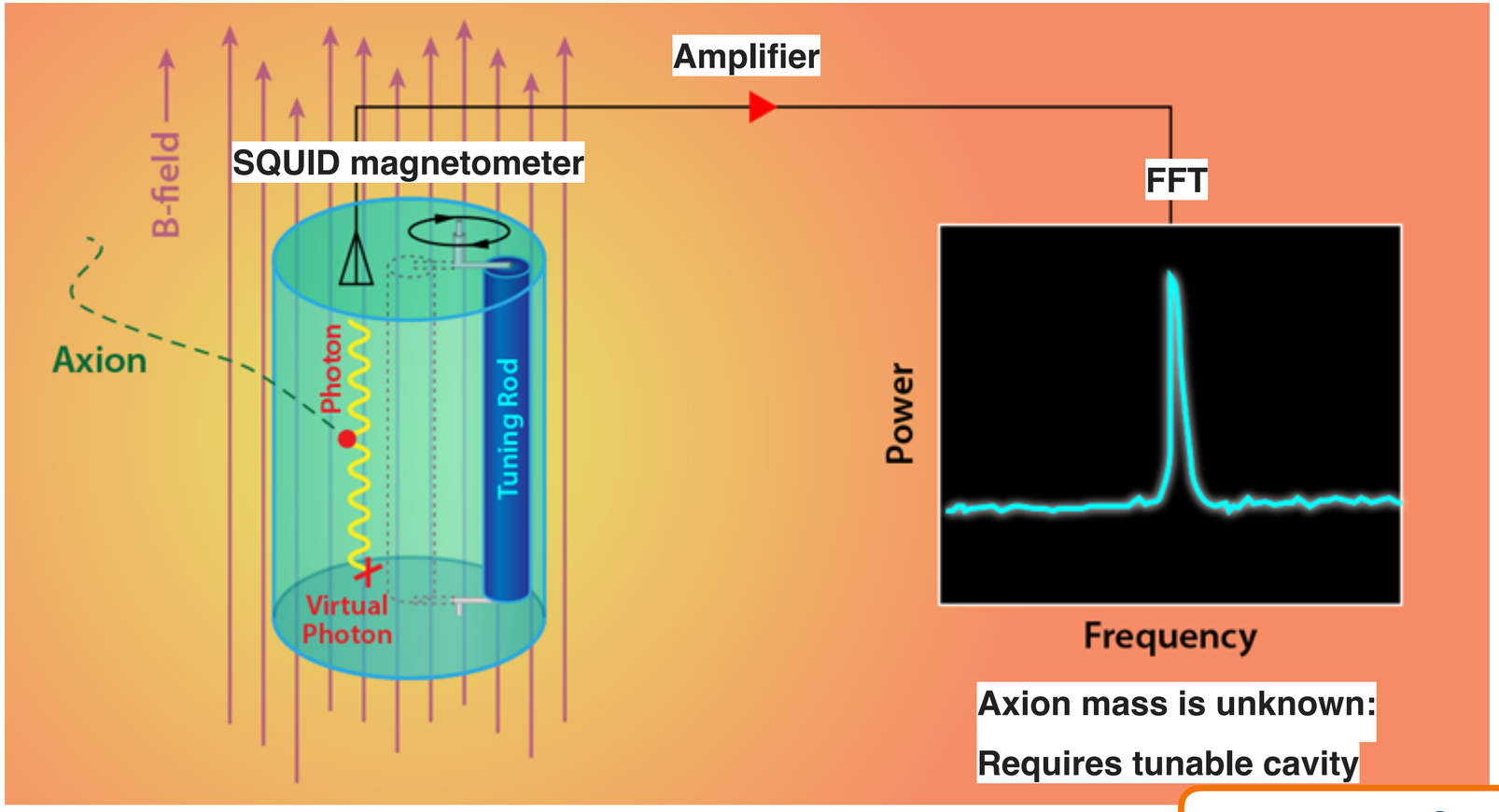
- QCD sector needs a solution for the "strong-CP problem"
  - Distribution of the quark in nuclei => electric dipole moment (EDM)
  - Experimentally: $|\theta| \leq 10^{-10}$

$\Rightarrow \theta$ not a parameter but -> field a the axions $\mathscr{L}_{QCD} \supset \theta \tilde{G} G \rightarrow \frac{a}{f_a} \tilde{G} G$

$$\mathscr{L} \supset \boxed{g_{a\gamma}\, a\, \mathbf{E} \cdot \mathbf{B}} + g_{af} (\nabla a) \cdot \mathbf{S} + g_{EDM}\, a\, \mathbf{S} \cdot \mathbf{E}$$

- Coupling of the axion with the photons
- Axion also viable Dark Matter candidate

Haloscope searches



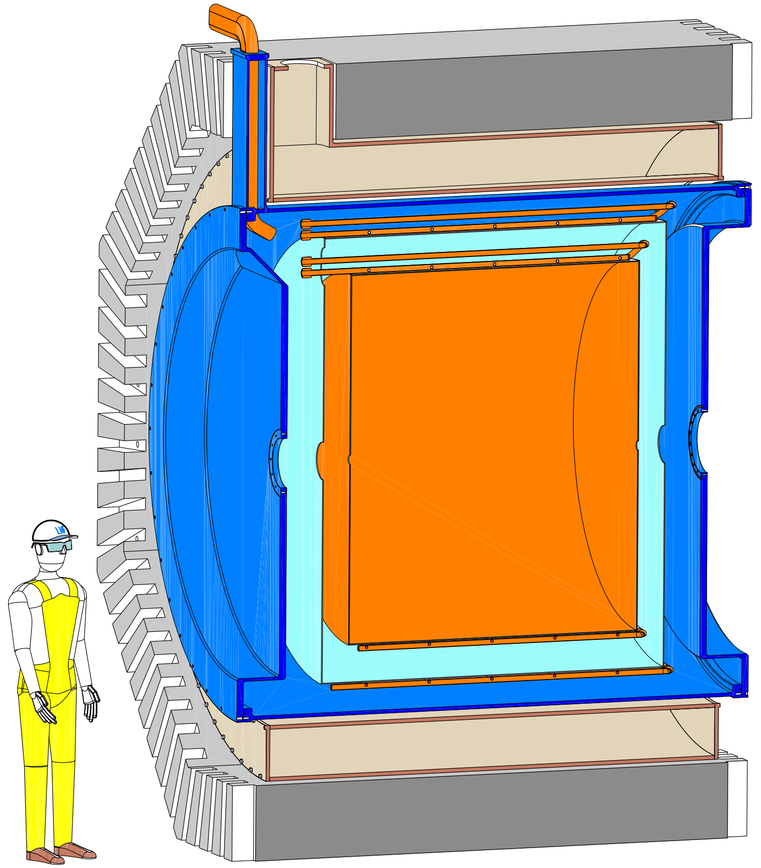
Sikivie Phys. Rev. D 32,11 (1985)

- Cavity resonates at ν_c
  When $2\pi\nu_c \simeq m_a$ and $m_a \sim \mu eV$ then $\rightarrow \nu_c \sim GHz$

$$P = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} \left(B_0^2 V C \frac{\beta}{1+\beta} Q_L \right)$$

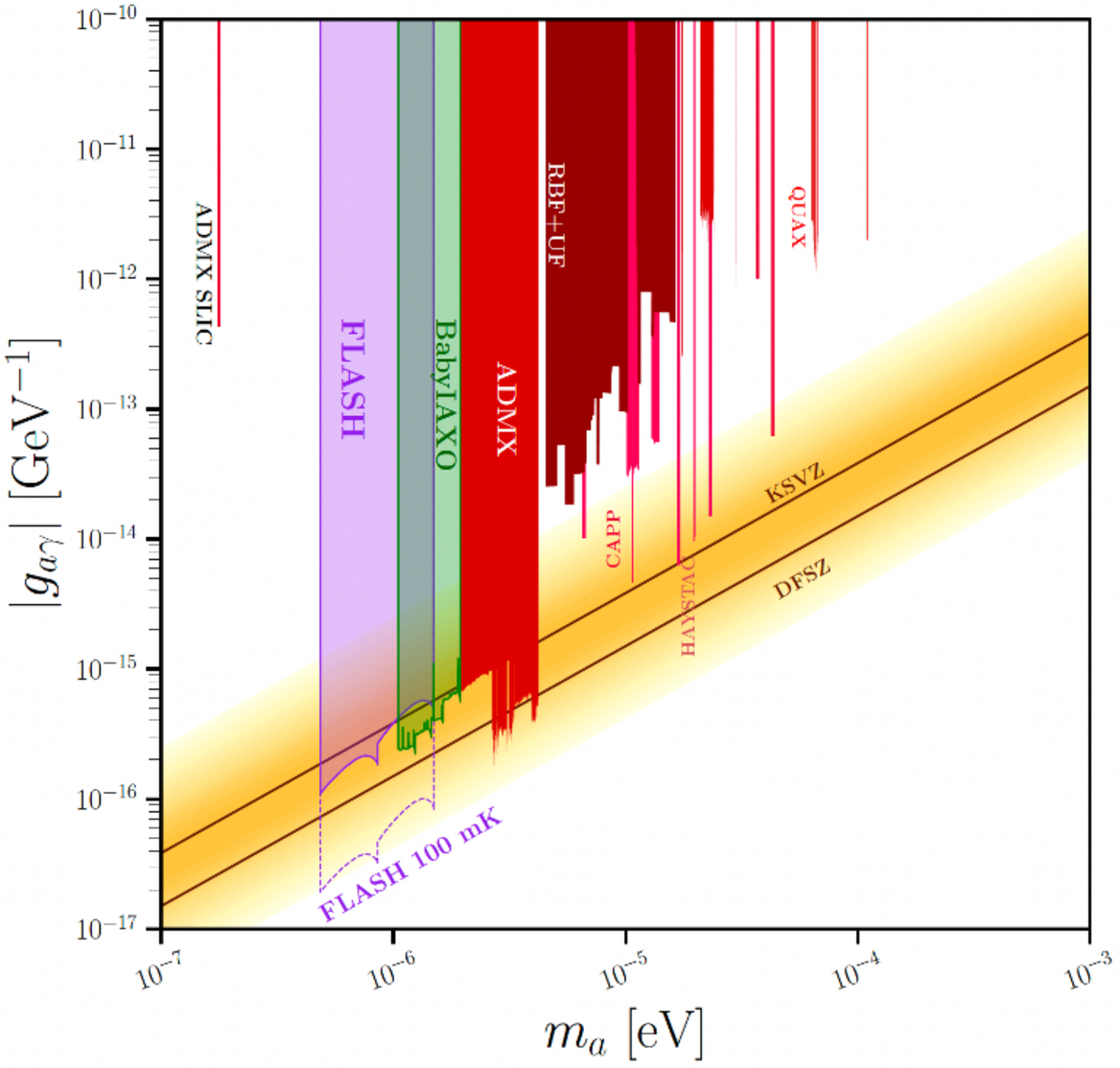
FINUDA magnet for Light Axion Search Haloscope

- Frequency range $\nu_c \sim (117 - 360)\, MHz$
  cosmic axion masses $\sim 10^{-6}\, eV$
- Resonant frequency tunable, mode TM_{010} for axion search
- Two cylindrical resonant cavities of different volumes, each with its tuning system
- Lagrer cavity $L = 1200\, mm$ and $R = 1050\, mm$
- Cryostat and cooled at $4.5\, K$ using liquid He
  - External stainless steel vacuum vessel, aluminum-alloy radiation shield $\sim 70\, K$ cooled by gaseous He



"The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories" Physics of the Dark Universe 42 (2023) 101370

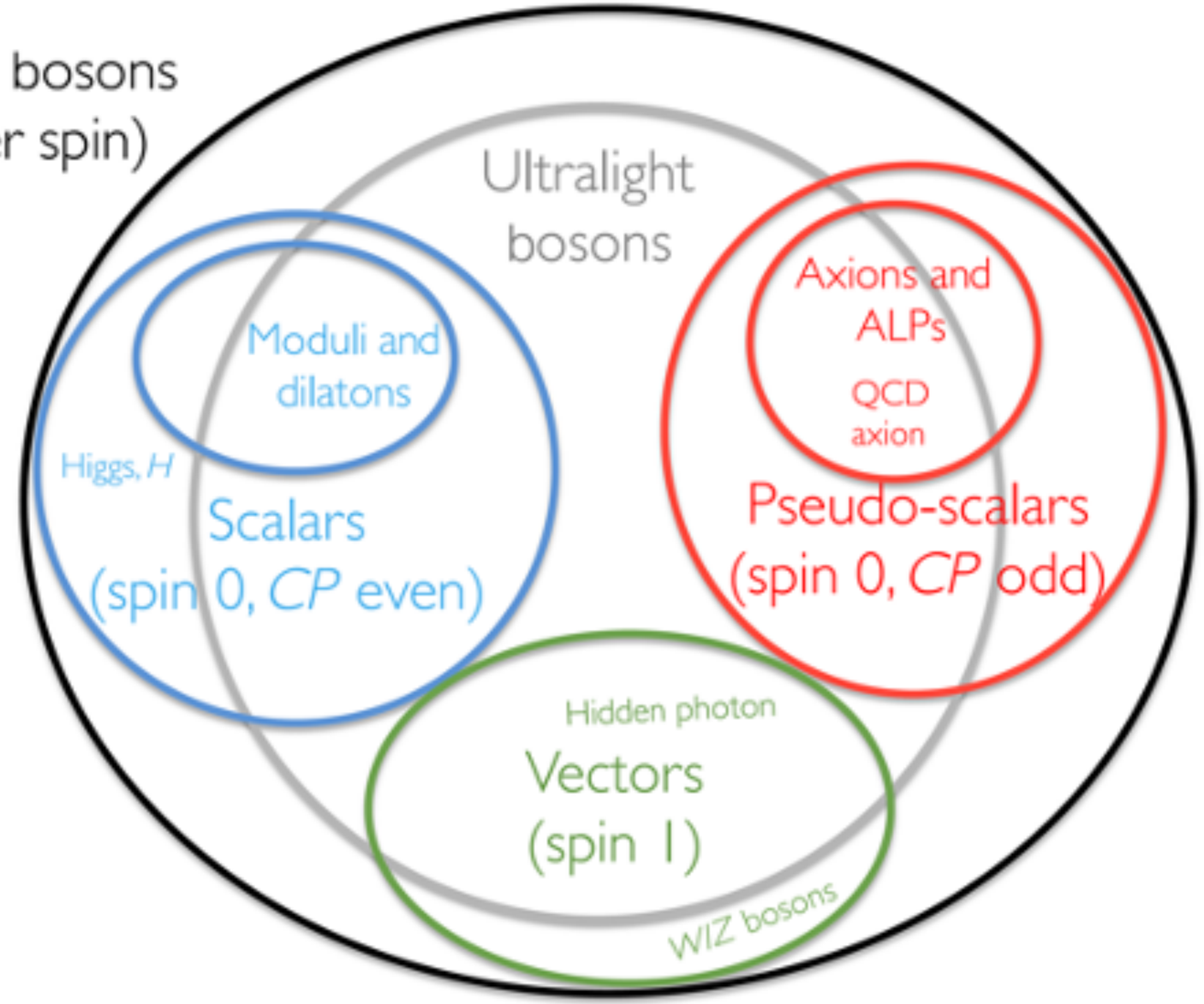
FLASH Physics reach: axion search



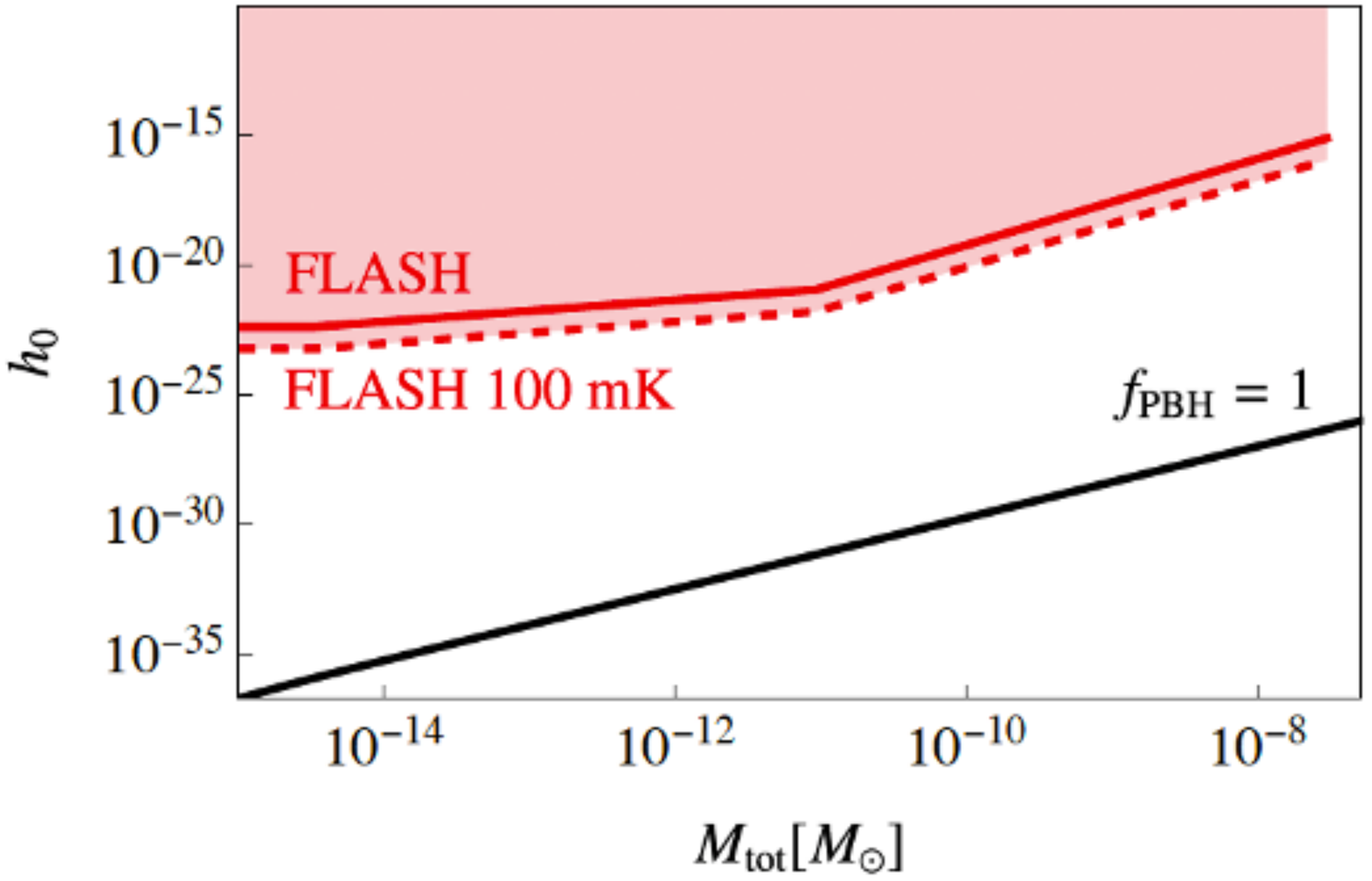
Parameter	Value
ν_c [MHz]	150
m_a [μeV]	0.62
$g_{a\gamma\gamma}^{\mathrm{KSVZ}}$ [GeV^{-1}]	2.45×10^{-16}
Q_L	1.4×10^5
C_{010}	0.53
B_{max} [T]	1.1
β	2
τ [min]	5
T_{sys} [K]	4.9
P_{sig} [W]	0.9×10^{-22}
Scan rate [Hz s^{-1}]	8
m_a [μeV]	0.49 - 1.49
$g_{a\gamma\gamma}$ 90% c.l. [GeV^{-1}]	$(1.25 - 6.06)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

Multiple models searched

Interaction with the Electromagnetic field



High Frequency Gravitational Waves



Liverpool involvement

Tyler Jameson (MPhys Student)

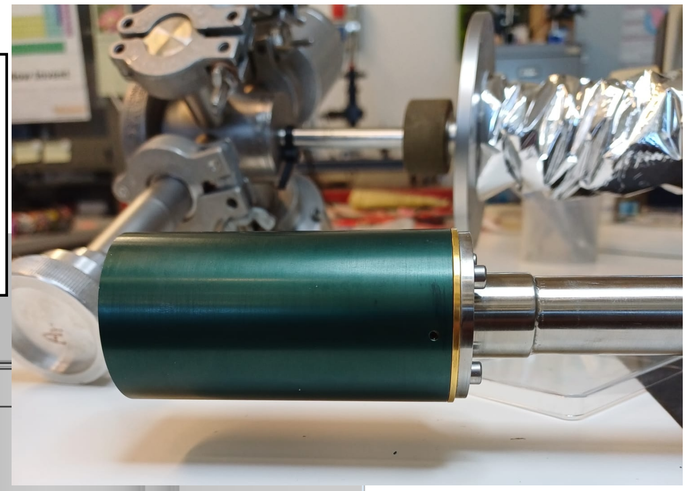
David Sim (Senior research technician)

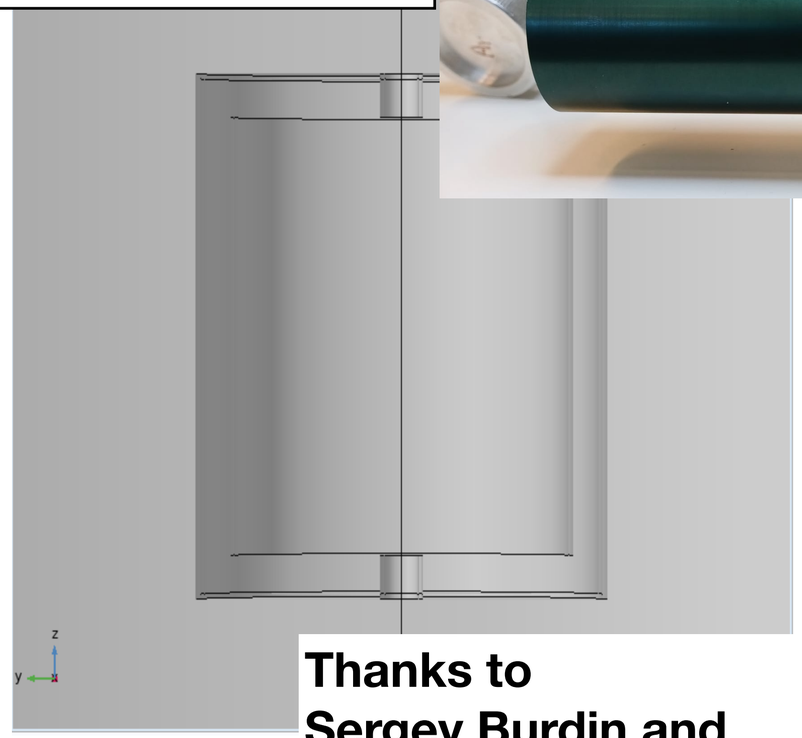
Paolo Beltrame

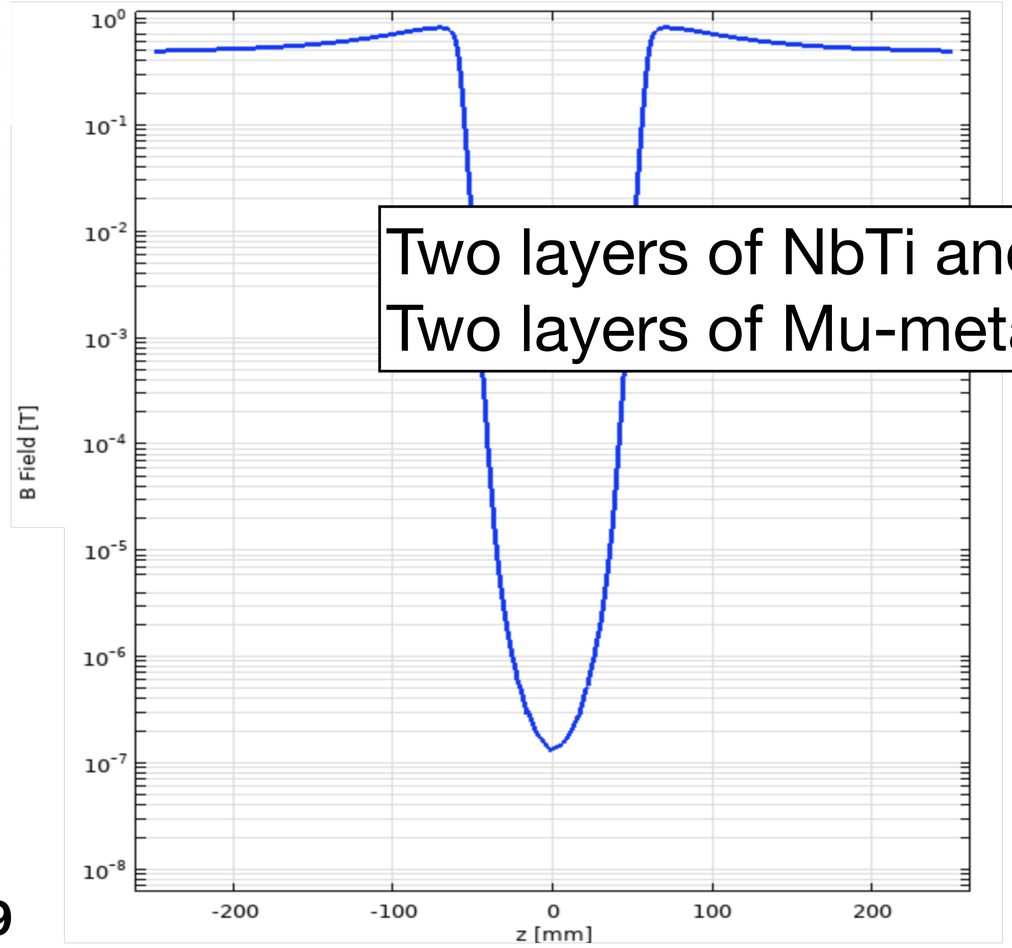
Magnetic field studies

SQUID shielding

Simulation performed for SQUID shielding with COMSOL





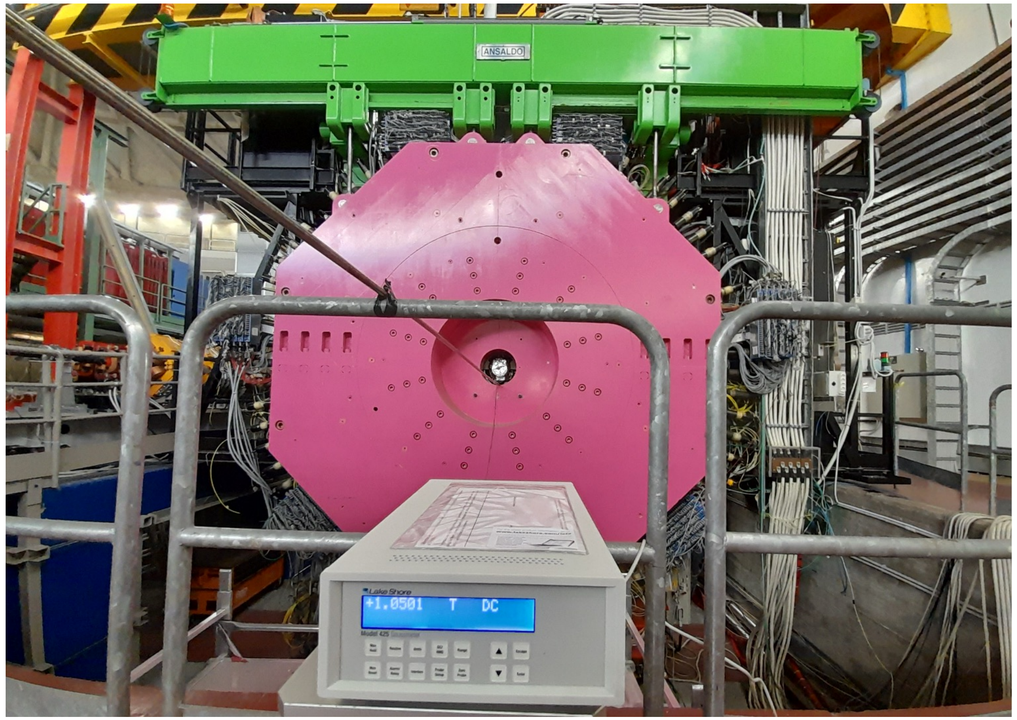


Two layers of NbTi and
Two layers of Mu-metal

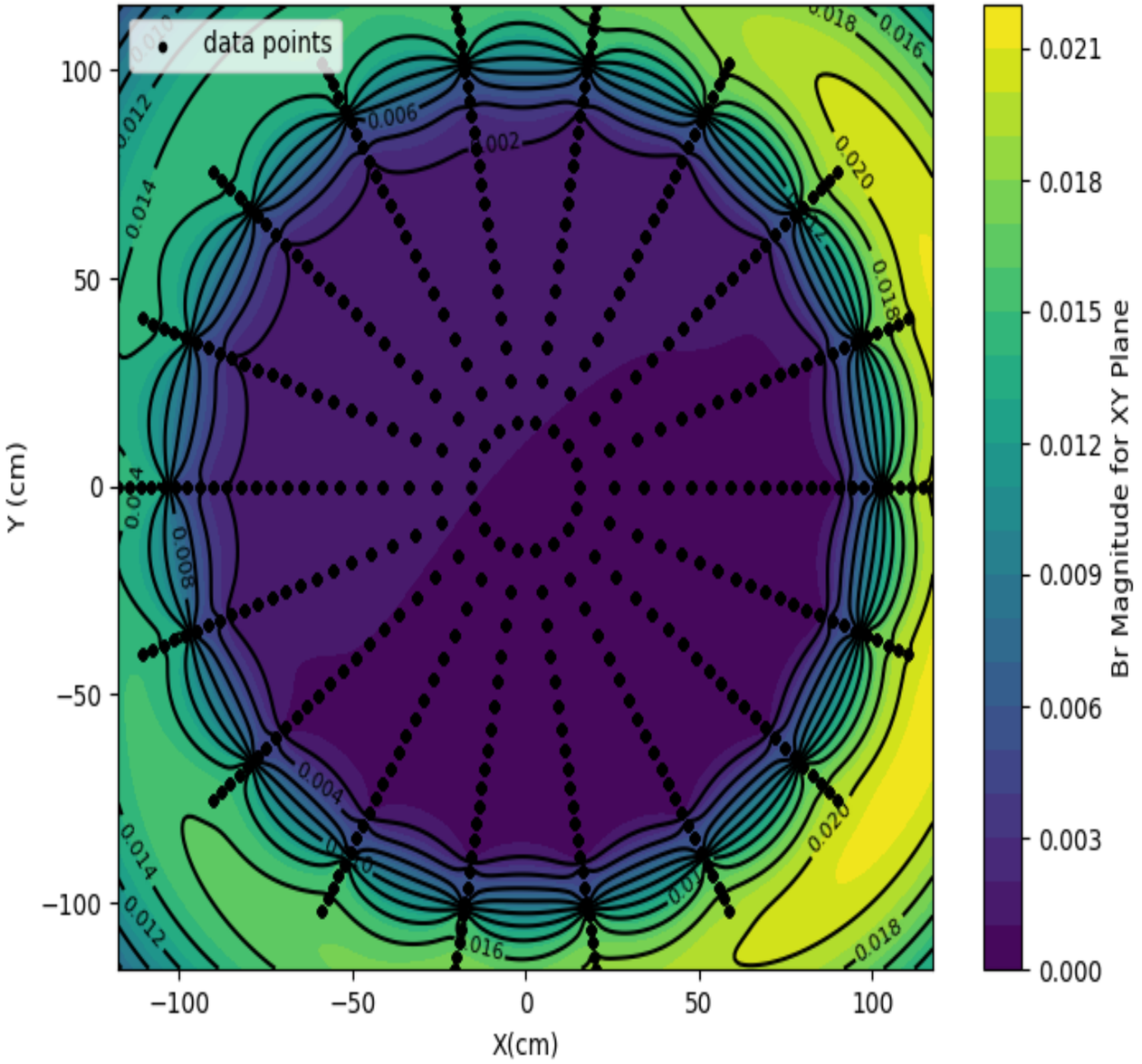
Thanks to
Sergey Burdin and
Sean Hughes for COMSOL in hep49

Magnetic field studies

FINUDA filed map

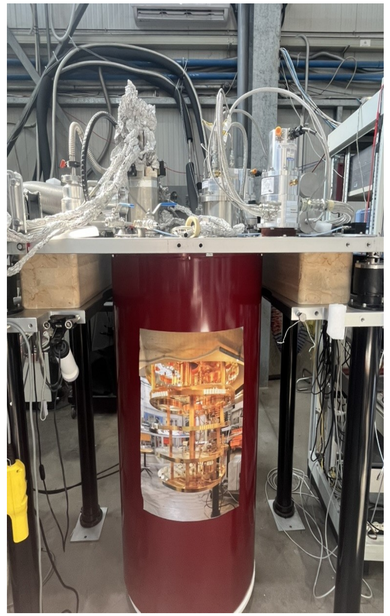


Interpolate the data point of the measurement performed in late ‘90s



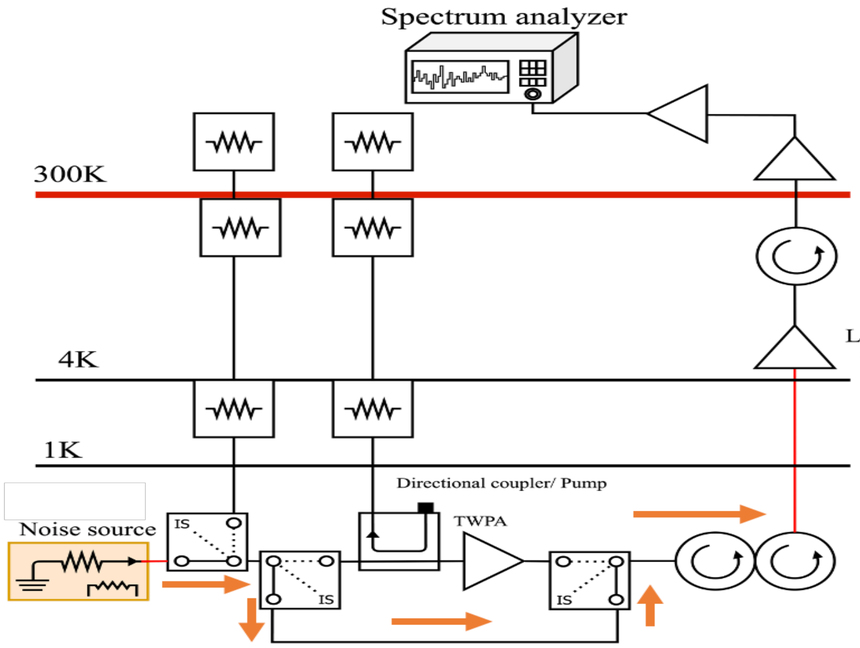
Magnetic field studies

Amplifier tests at LNF and at the Camerino University



LNF Dilution refrigerator

- $1\,T$ and $1.7\,K$
- Testing the HEMT and the TWPA amplifier



Microstrip SQUID amplifier test

- $6\,T$ at $1.6\,K$

FLASH timeline

Design studies and R&D
for the TDR:
Approved by INFN in 2024

Six WPs ranging
from Physics reach to
FINUDA decommissioning

- WP4:
Signal Amplification and DAQ
- WP5:
Data Analysis and Computing

FLASH timeline

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Initial UoL involvement
SQUID magnetic field shielding
and FLASH magnetic field
mapping

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2025
- FINUDA decommissioning
- Design FLASH and R&D
- Formalisation of FLASH Collaboration

2026
- Cryogenic system and magnet
- Finalising FLASH design
- Fabrication $500\,MHz$ prototype (Bonn University)
- Prototype characterisation at $4\,K$

2027
- Technical Design Report
- Call of tender for cavity cryostat and RF cavity

2028/ 2030
- Construction, Commissioning & Data Taking

Quantum R&D in Liverpool

Steps and medium-term projects

- Quantum Science and Technologies Developments in Liverpool
- Experimental strategy:
  - Cooperation with FLASH and independent line of R&D and research

1. Cryostat and superconducting magnet from LNF (Frascati Laboratory)
   - Cooling down → Liquid He
     - Purchasing the LHe, applying for a recovery/liquefying system
2. Testing SQUID in magnetic field
   - Electronics and DAQ system
   - Magnetic field shielding
3. Amplifiers response
   - Electronics and DAQ system
   - HEMT+TWPA amplifiers

Cryostat+Magnet and LHe

- Arrival of the cryostat and superconducting magnet from the LNF in Liverpool
  - Preparatory trip to the LNF, 4–7 May (many thanks to David Sim)
  - Transport to Liverpool by mid-June (trip already planned for the 8-12 June)

- Liquid He facility Quantum Design UK AND IRELAND
  - Liquefaction Rate: 20+ liters/day
  - Dewar Capacity: 160 liters (250 liters)
  - Delivery Time: 6 months from the order
  - Visit from QD the 21 April

  - Location in Chemistry B53 room


NexGen 160

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MPhys Student James Taylor (23 March - 5 April)

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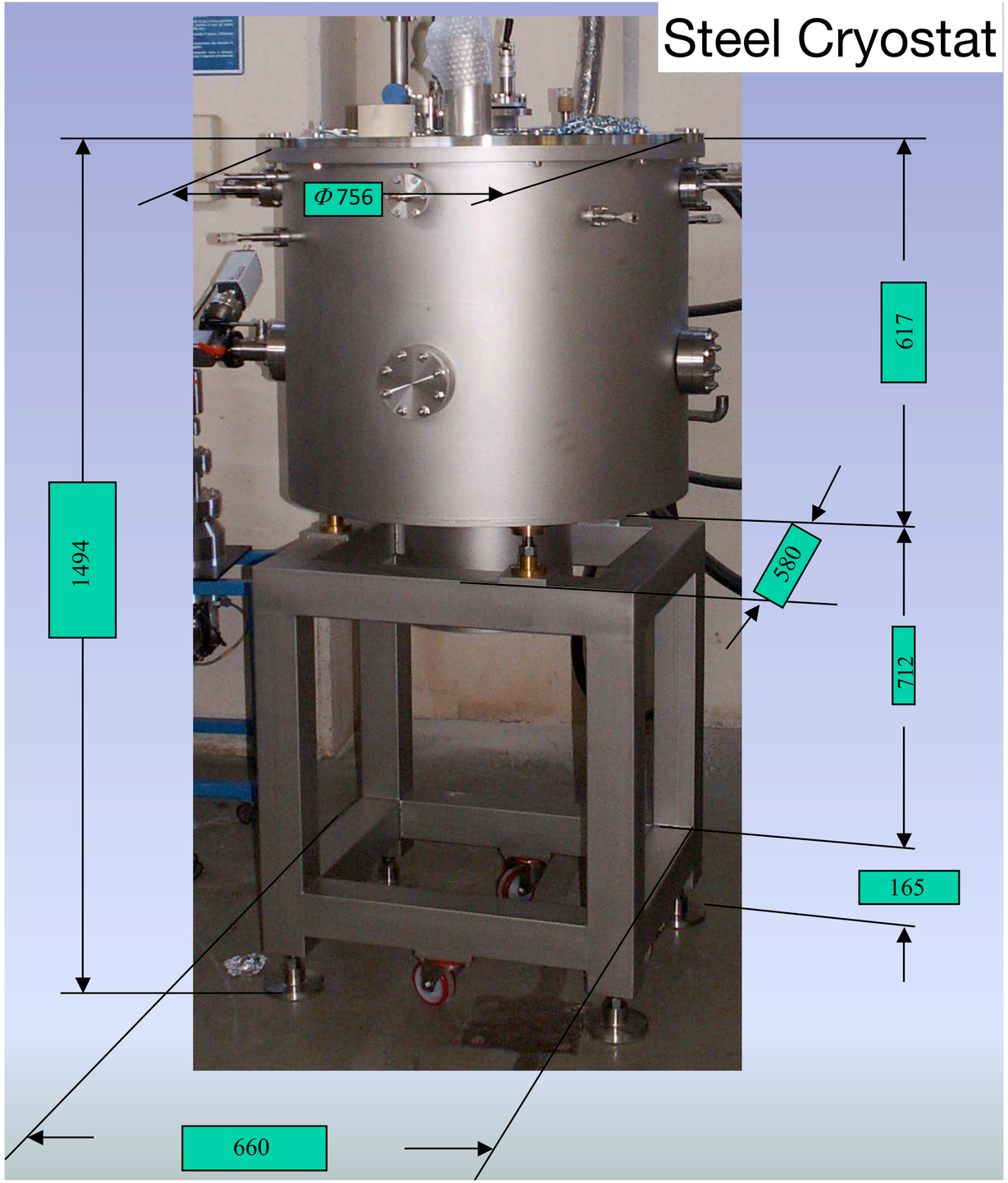
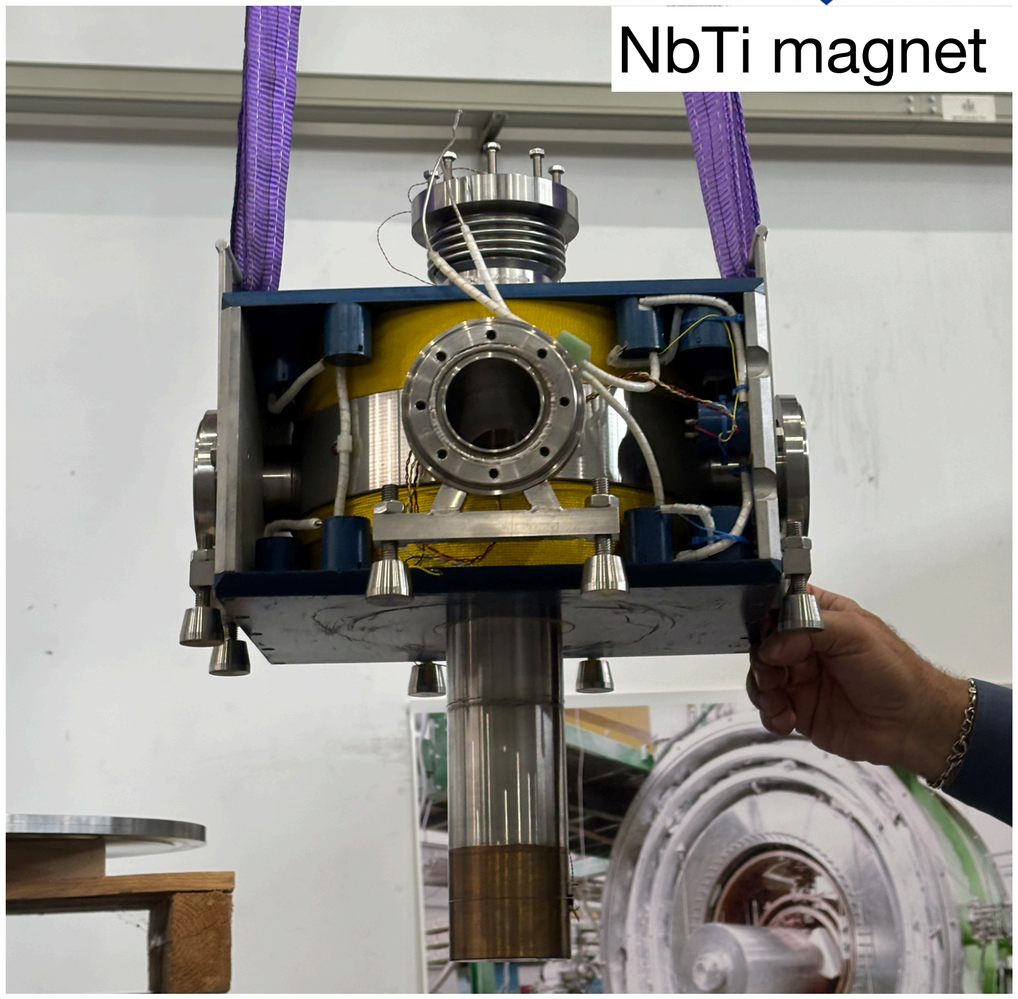
NexGen 160

Steel Cryostat



NbTi magnet

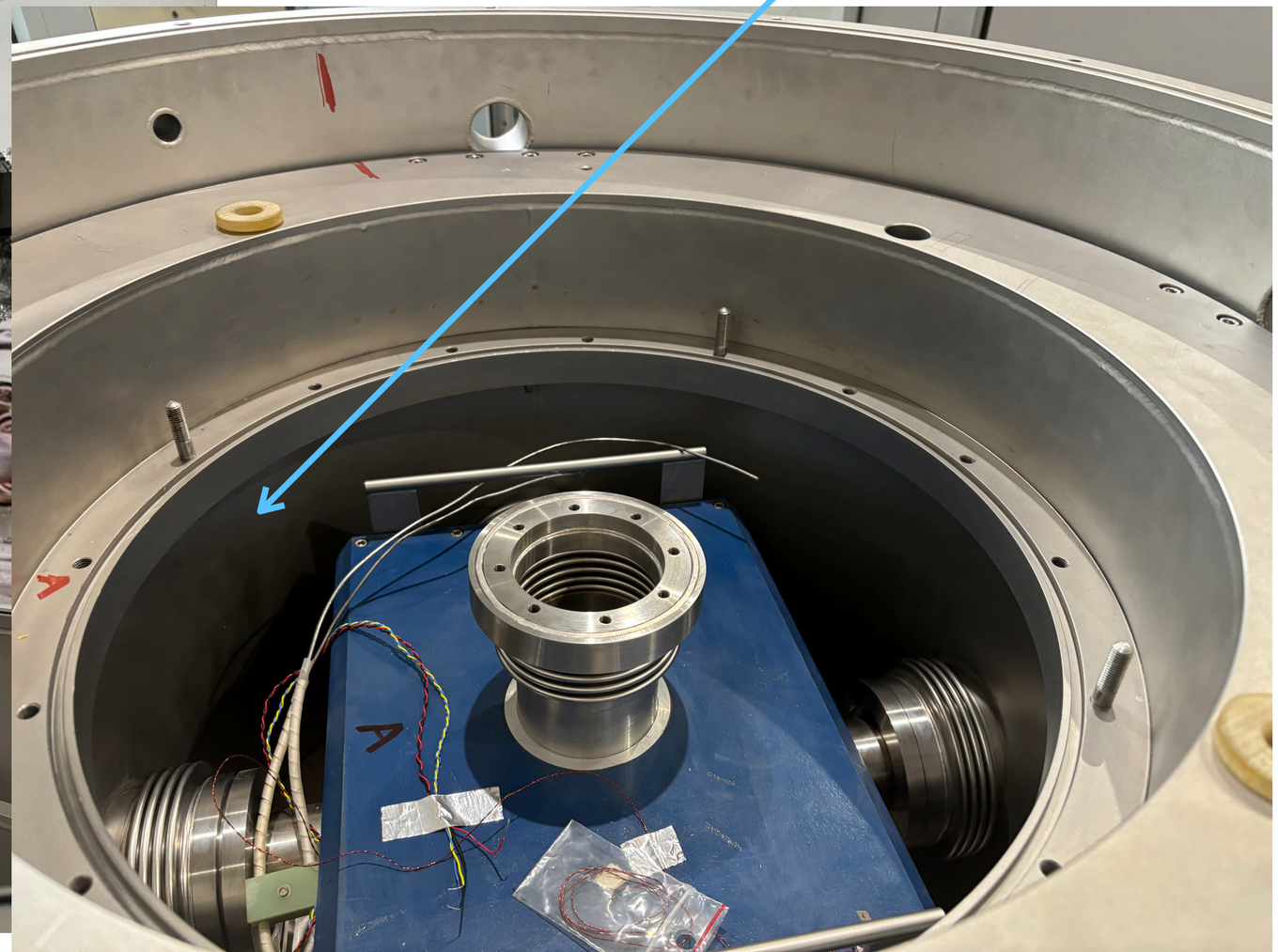


Magnetic field: $8\,T$ @ $4.2\,K$

Homogeneity: $\pm 0.5\,\%$ (1 cm dsv)

Max current: $85\,A$

Liquid He
for temperature @ $4.2\,K$



Quantum R&D @ UoL

1. Collaboration with FLASH experiment

2. Line of research and R&D at Liverpool
   - Cryo+Magnet at UoL

3. Cooperation with Lancaster and Manchester Universities

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Mid-June
- Cryostat ad superconducting magnet in Liverpool

July-August
- Installation of the cryostat and magnet

End 2026
- Cooling with LHe

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- SQUID and Amplifier procurement + development of DAQ
  - Testing the Magnetic Field Shielding for SQUID
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Exploring new approaches for Quantum Technology R&D and DM search

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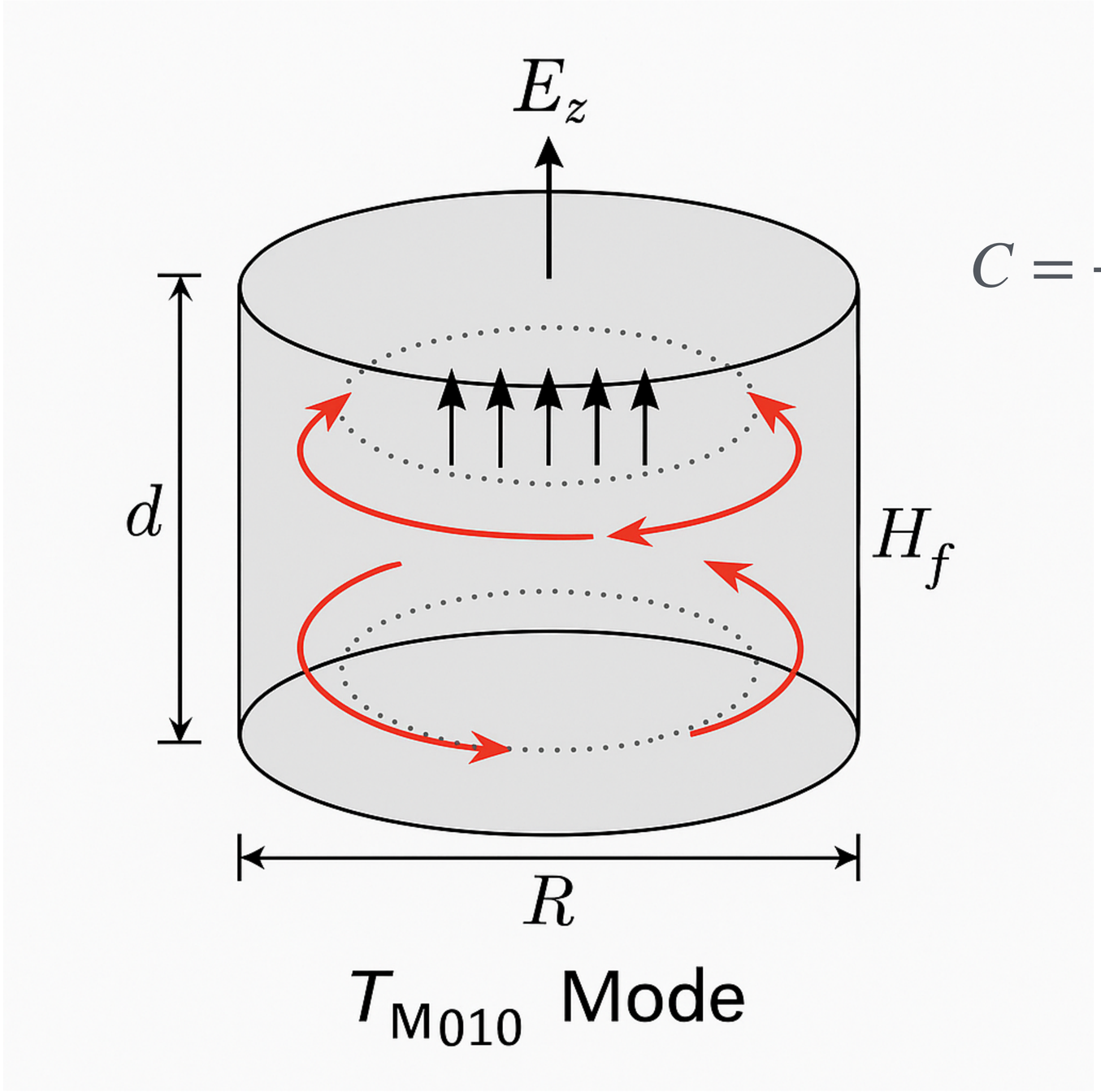
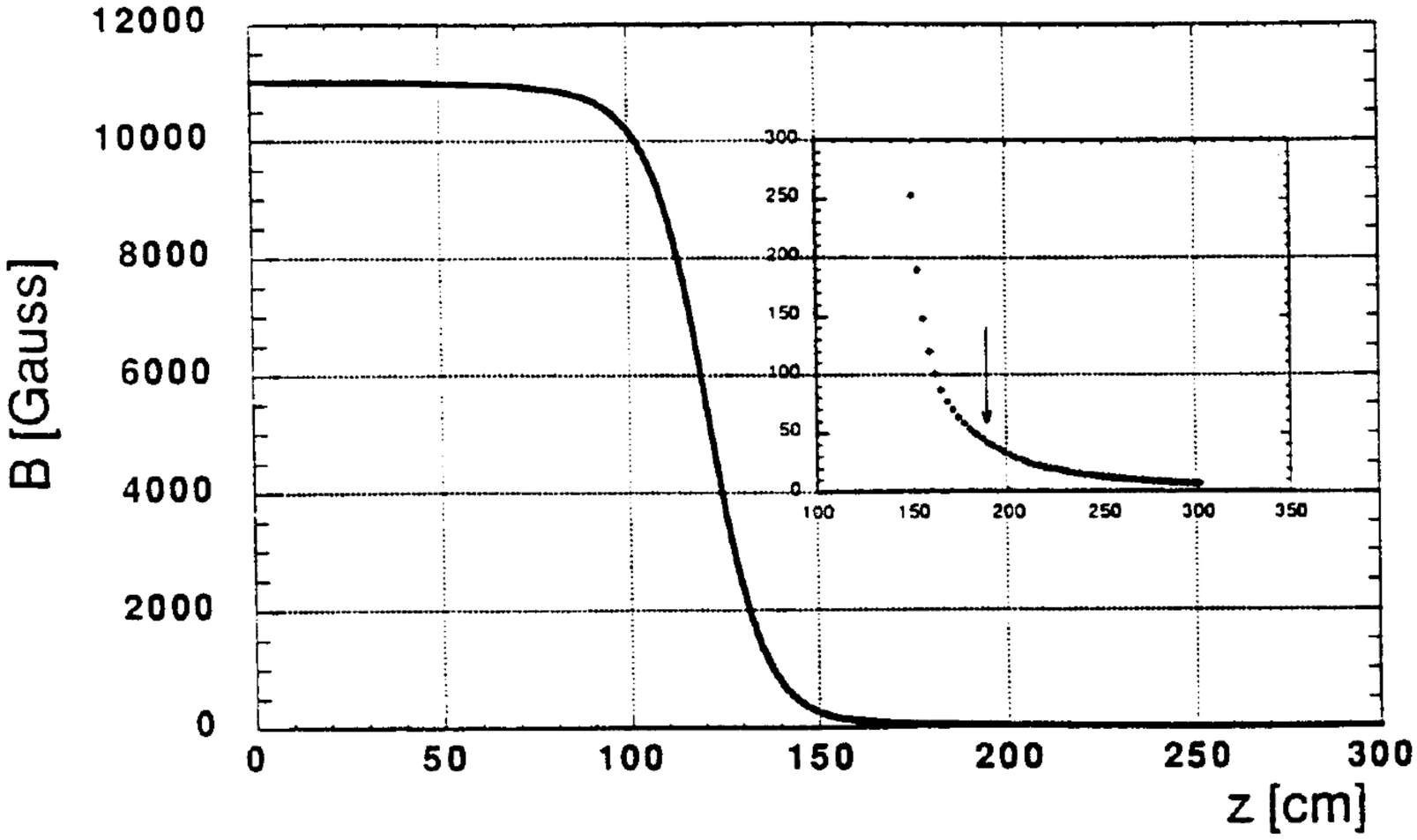
Back up slides



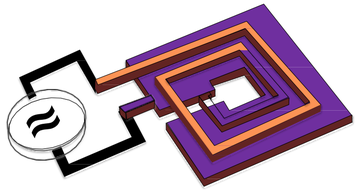
$$C = \frac{\left| \int_V (\vec{E} \cdot \vec{B}_0)\, dV \right|^2}{V \int_V \varepsilon |\vec{E}|^2\, dV}$$


B [Gauss]
12000
10000
8000
6000
4000
2000
0
0
50
100
150
200
250
300
z [cm]
300
250
200
150
100
50
0
100
150
200
250
300
350

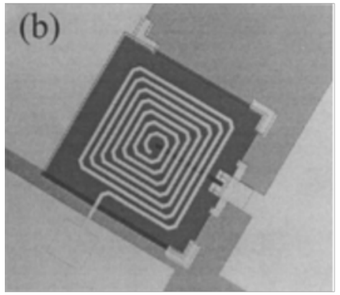
Design Study and R&D for the TDR

Approved by INFN in Sept. 2024 ⇒ TDR ready in 2026

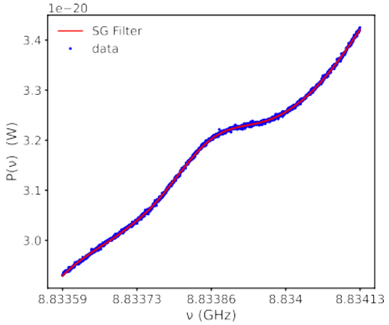
- Six WP ranging from Physics reach to old FINUDA detector and magnet decommissioning
- WP4: Responsibility for Signal Amplification and DAQ



- INFN Pisa
- INFN Trento
- Mainz University
- Università di Camerino
- University of Liverpool



- WP5: Responsibility for Data Analysis and Computing



- Mainz University
- Bonn University
- INFN Pisa
- INFN Frascati
- University of Liverpool