GraSPA2026 Summer School

Particle and Astroparticle Physics

IN SUPREMÆ DIGNITATIS 1343

GIUSEPPE TOMASELLI

MASTER'S DEGREE IN FUNDAMENTAL

INTERACTIONS PHYSICS AT THE

UNIVERSITY OF PISA

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Annecy, France | 16 July - 23 July 2026

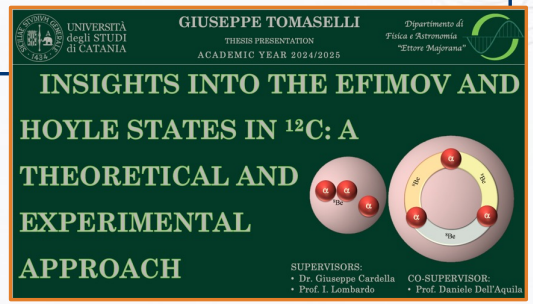
https://lapp.in2p3.fr/graspa2026

A few things about my background:

Bachelor's Degree in Physics at the University of Catania

Awarded an INFN Scholarship

Graduated with a thesis on Efimov and Hoyle states in ^{12}C



Master's Degree in Fundamental Interactions Physics at the University of Pisa. Thesis project on cryogenic detectors and technologies

2022 — 2025 — 2025 — 2025

TIME
(not in scale)

Cryogenic and SC detectors

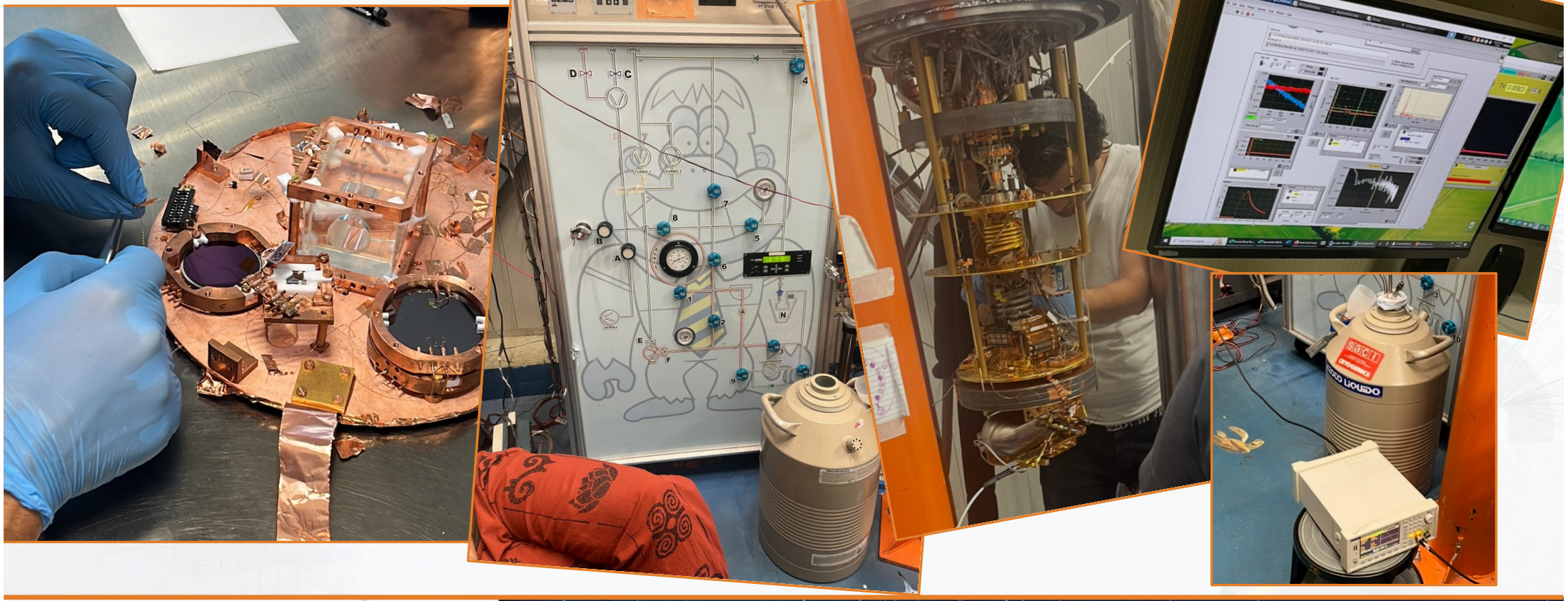
- These detectors operate at extremely low temperatures, utilizing superconducting (SC) states to measure minute energy signals

- Underground operation (e.g., at LNGS) is strictly required to shield the detectors from cosmic rays and background radiation

- Crucial for detecting rare or exotic events, such as Dark Matter candidates

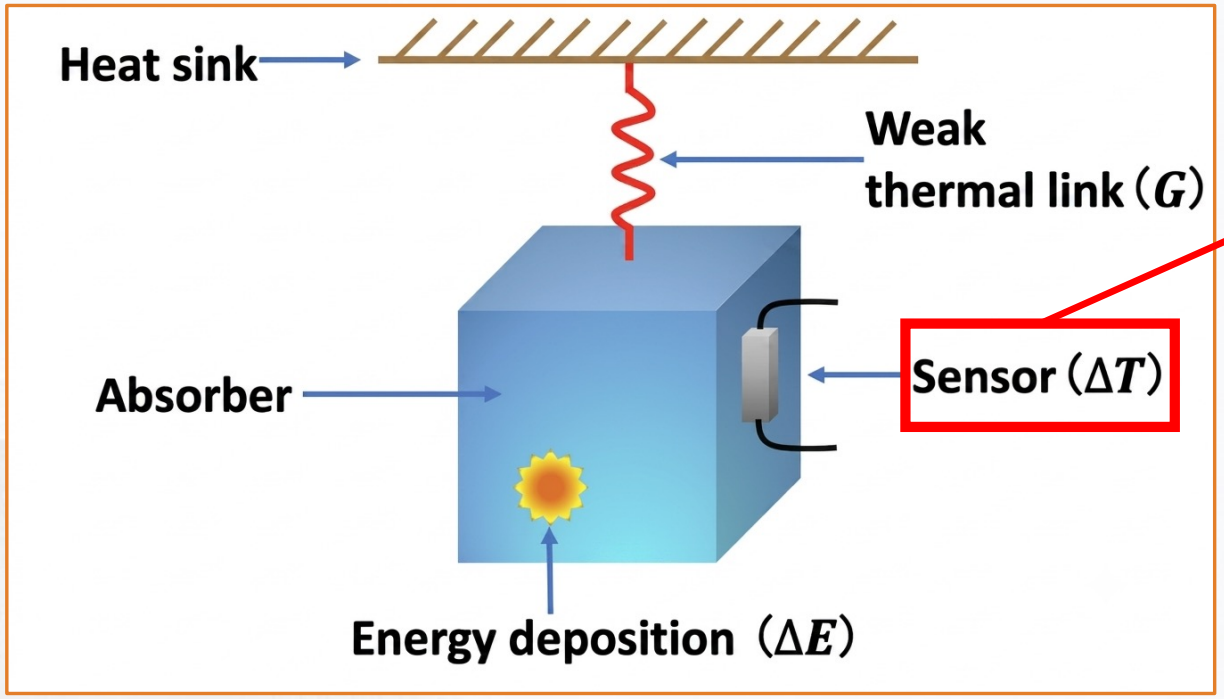
- The field encompasses various technologies, including SQUIDs, SQUIPTs, TESs, and KIDs.

Cryogenic detectors (personal gallery)

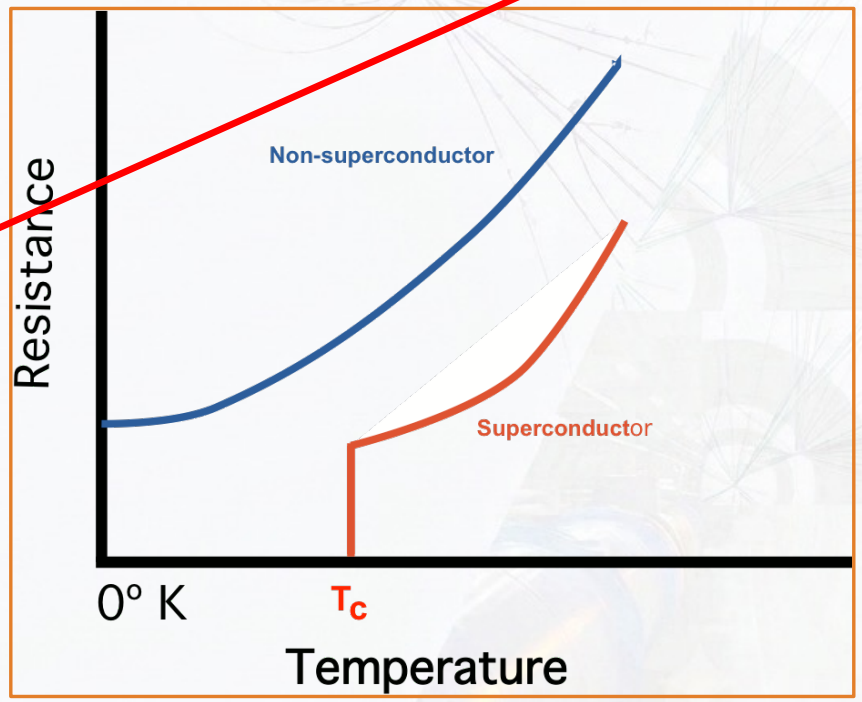


TES (Transition Edge Sensors) - 1

Basic principle: Utilizing the steep resistance response at the superconducting transition edge to measure minute temperature variations



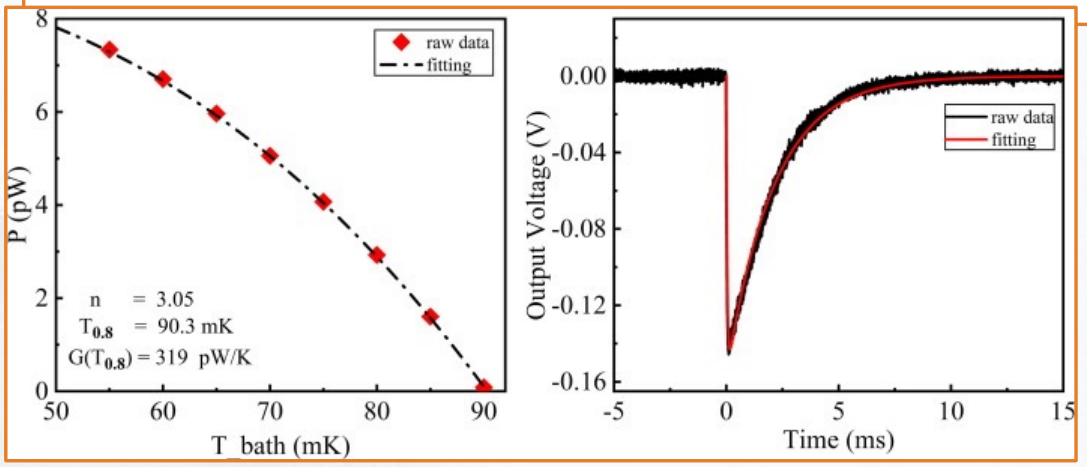
TES!



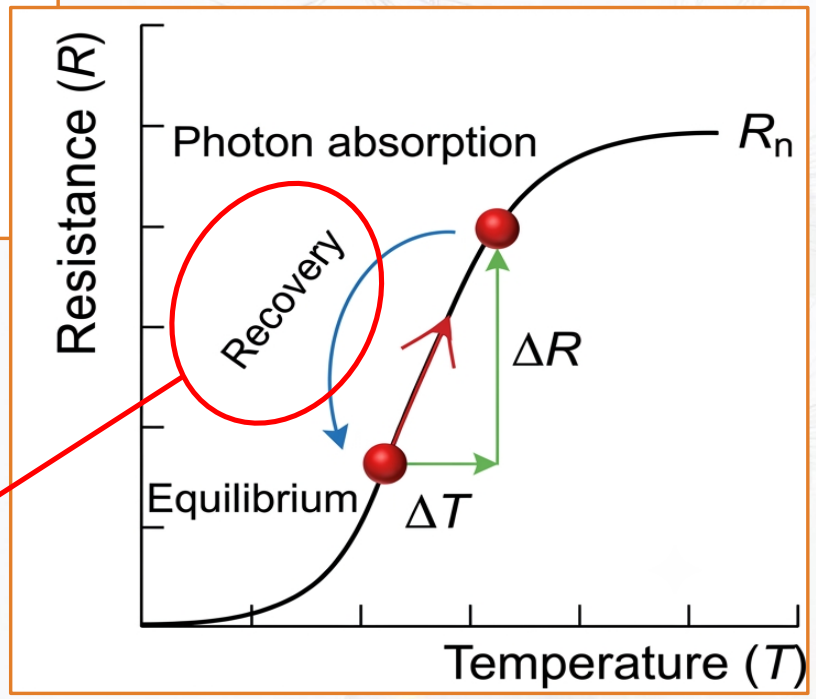
TES (Transition Edge Sensors) - 2

The core mechanism of a TES is its Strong Electrothermal Feedback: as the temperature increases, the Joule heating power decreases, intrinsically stabilizing the sensor.

$$\delta P_J \simeq \frac{dP_J}{dT}\delta T = \left(\frac{d}{dR}\frac{V^2}{R}\right)\frac{dR}{dT}\delta T = -\frac{V^2}{R^2}\frac{dR}{dT}\delta T$$



SEF

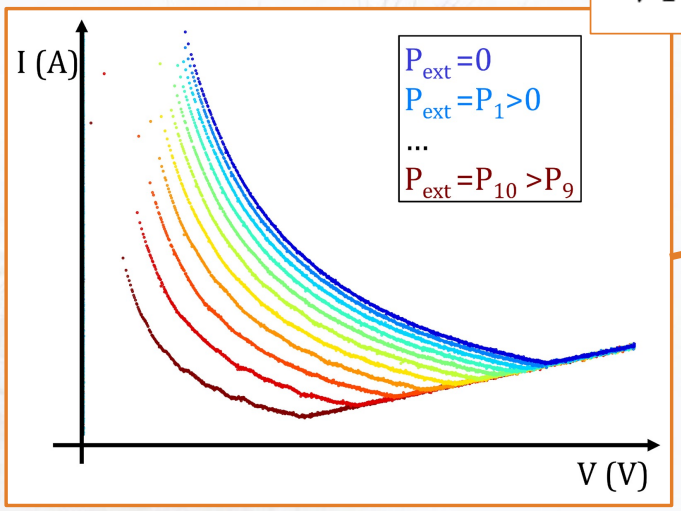


TES (Transition Edge Sensors) - 3

Definition of *Saturation Power*

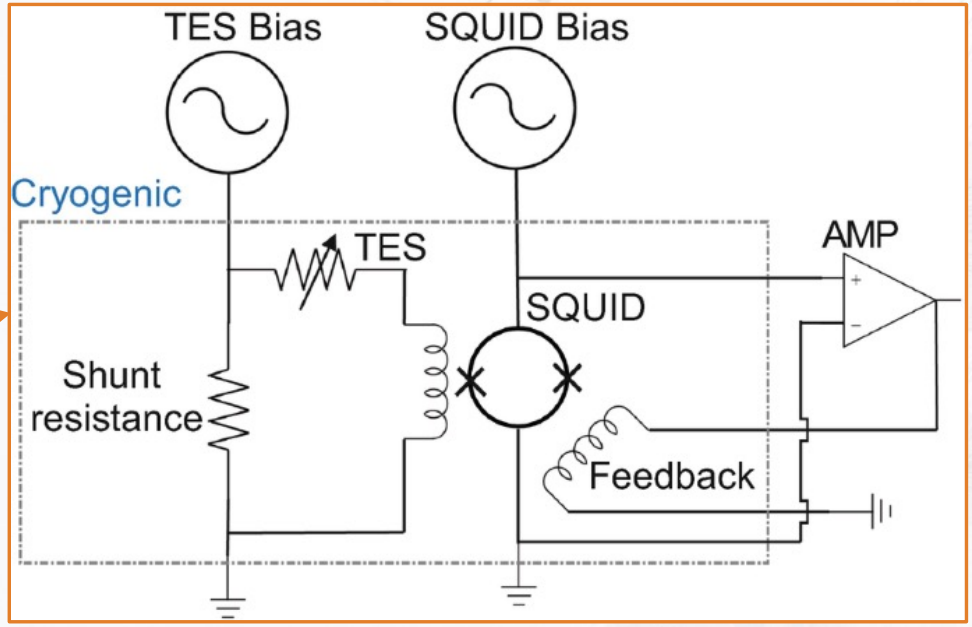
$$T_{eq} = T_{bath} + \frac{P_{sat}}{G} = T_c$$

$$VI = P_{sat} - P_S$$



An energy deposition (signal) causes a shift along the V-I characteristics

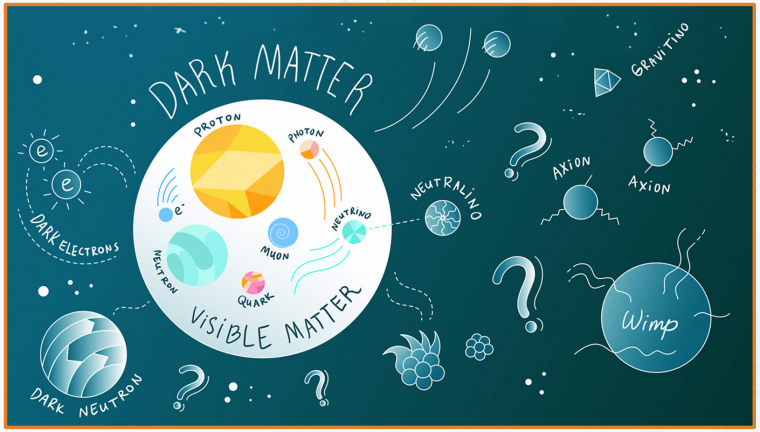
Typical TES readout circuit:

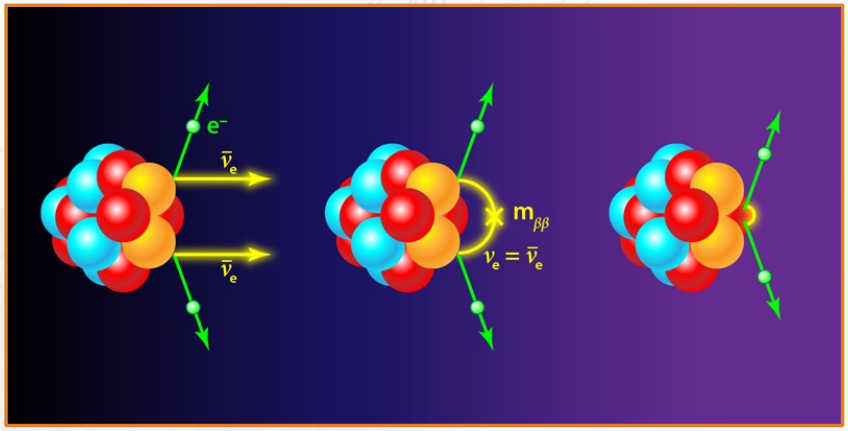


CONCLUSION AND OUTLOOK

Why are these technologies crucial? They allow us to measure minute energy signals, probing regimes that are otherwise inaccessible.

Key Physics Goals: They are fundamental for unlocking the mysteries of Dark Matter and searching for ββ0ν decay





A Rapidly Evolving Field: New types of cryogenic sensors are constantly emerging, continuously pushing the boundaries of detector sensitivity.

Looking Ahead: These ongoing advancements are laying the groundwork for future breakthroughs in particle physics.


Thank you for your attention, I am now happy to take any questions

CRYOSTAT

HELIUM CRYOGENIC STAGES: CONCEPTUAL FLOW

1 DILUTION REFRIGERATOR
- Continuous cooling to millikelvin temperatures
- Pulse tube: 300 K → ~3 K
- He-3 / He-4 dilation circuit: below 10 mK
- The core platform for superconducting QC

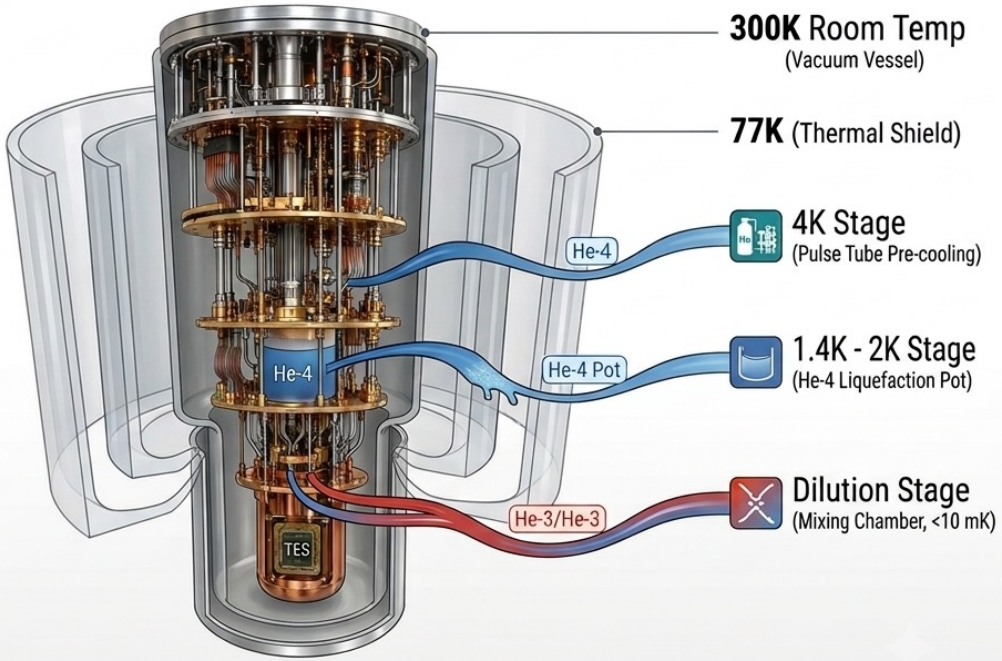
2 VENDOR MARKET
- Bluefors: LD450sl, XLD1000sl, KIDE, XLDHe
- Maybell: Big Fridge
- Oeford Instruments: Proteox, TestatronPT
- Leiden Cryogenics: custom CF-CS
- Klutra: Ne-3-free sADR alternstive

3 HELIUM-3 BOTTLENECK
- Werking fiuid derived from tritium decsy
- Rare, strategically constrained input
- Approx. $1,900–S2,600 per liter
- Recovery infrastructure mandatary

4 I/O WIRING WALL
- Coxs density and heat load lioat scaling
- Stainless-cteal coax at warm stages
- NBTi superconducting coax at cold stages
- High-density flex wiring (e.g. Cri/eFlex)

5 COOLING POWER BUDGETS
- >1 W at 50 K
- >720 wAV qt 4 K
- >5 mW at 100 mK
- >500 µW at MAC
- Heat-load margin matters

6 OPERATIONS & DOWNTIME
- Cool-doon: tyeloully 3–7 days loaded
- Warin-up / service: 2–4 days
- Planned amual sersice window
- Unplanned warm-up can cost 5–10 days recovery



300K Room Temp
(Vacuum Vessel)

77K (Thermal Shield)

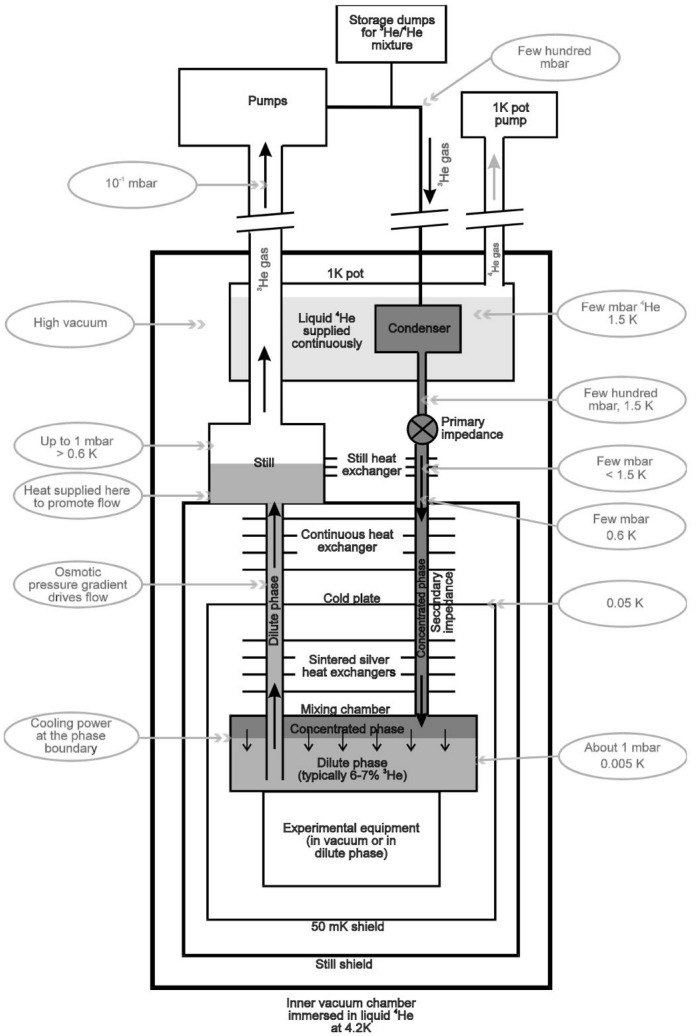
4K Stage
(Pulse Tube Pre-cooling)

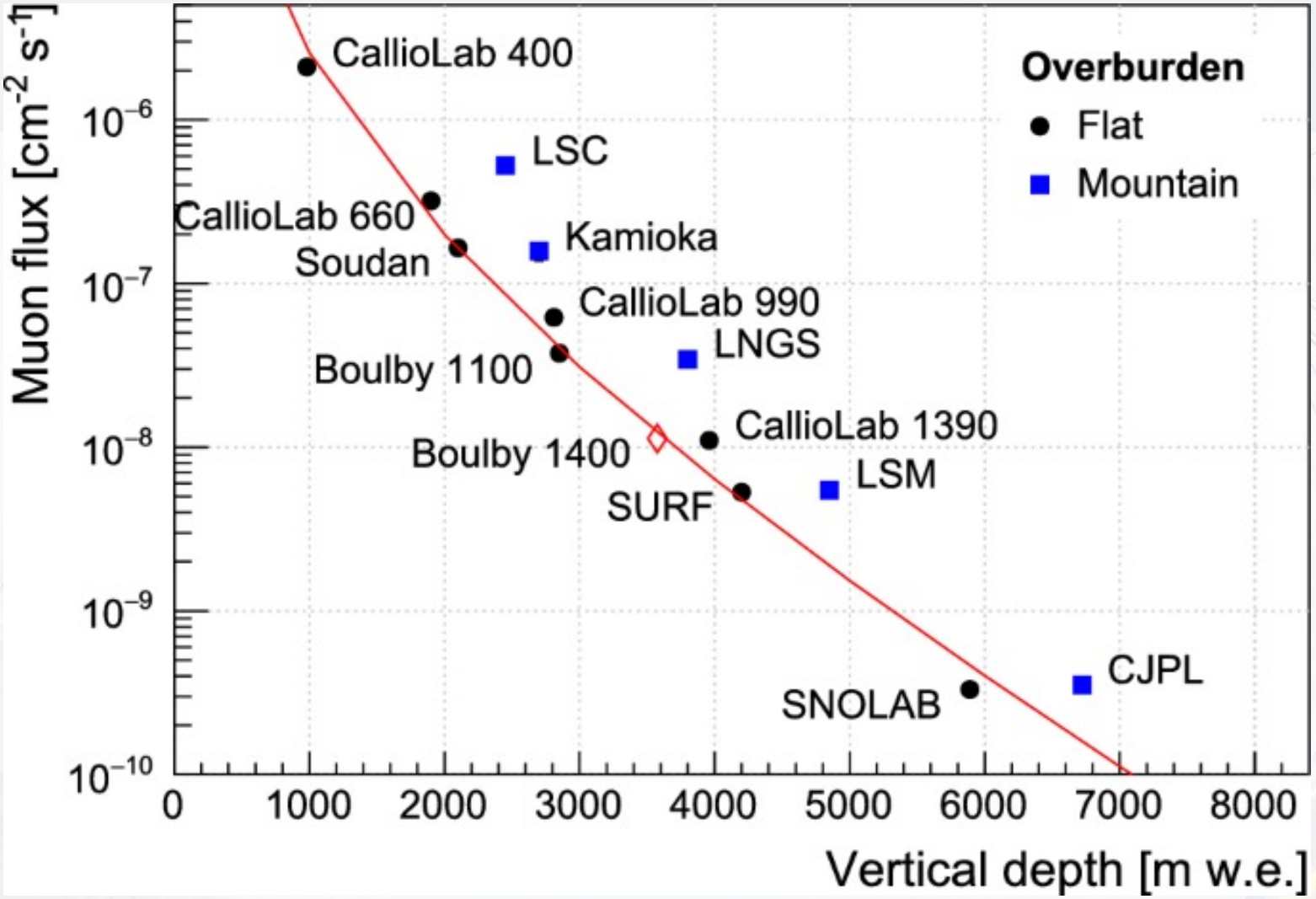
1.4K - 2K Stage
(He-4 Liquefaction Pot)

Dilution Stage
(Mixing Chamber, <10 mK)

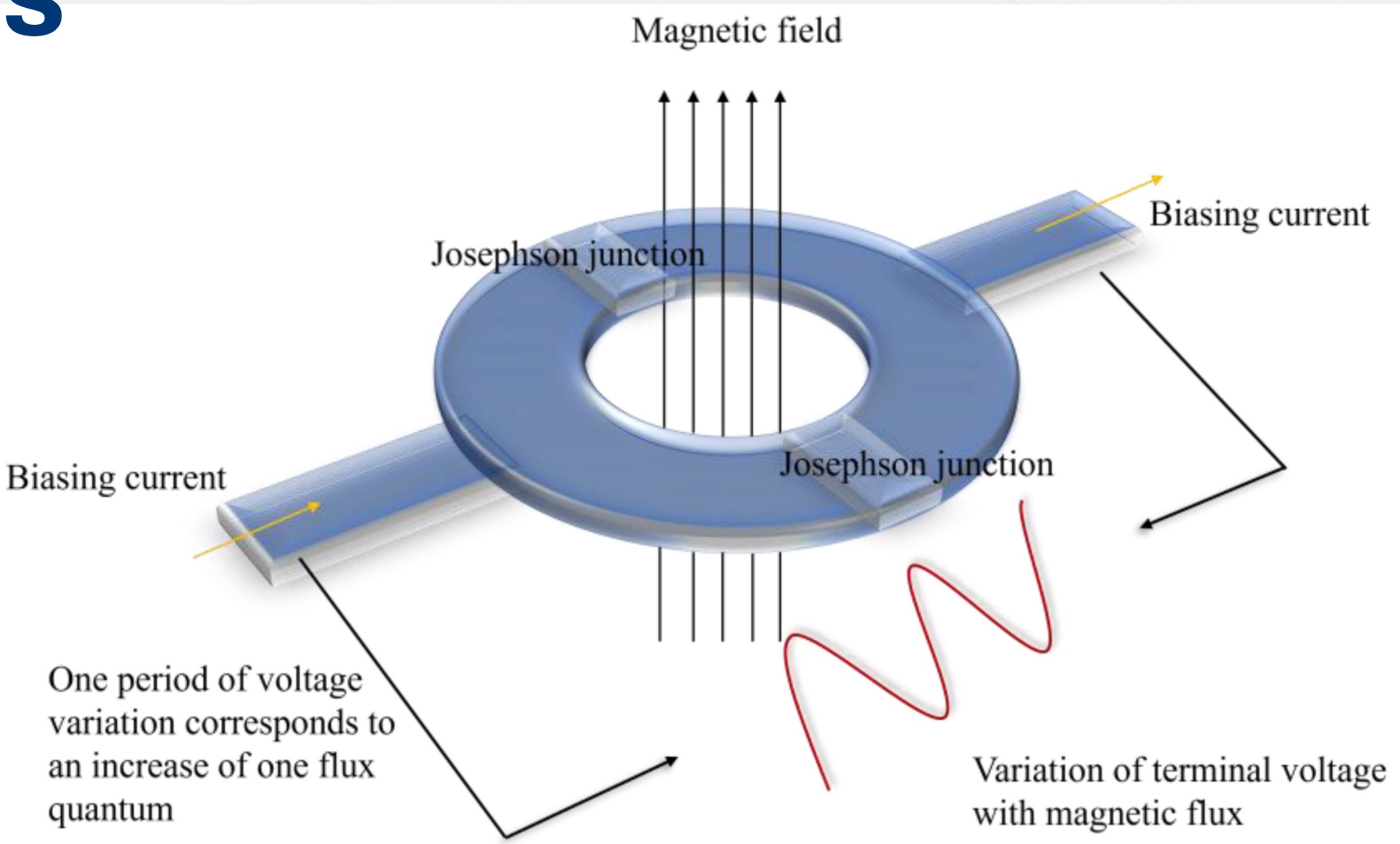
BRIEF FUNCTIONAL OVERVIEW

He-4 gas provides multi-stage pre-cooling to ~1K. In the mixing chamber (final dilution stage), pure liquid He-3 is dissolved into a He-4 rich superfluid phase. This heat-absorbing process drives the system to millikelvin temperatures.

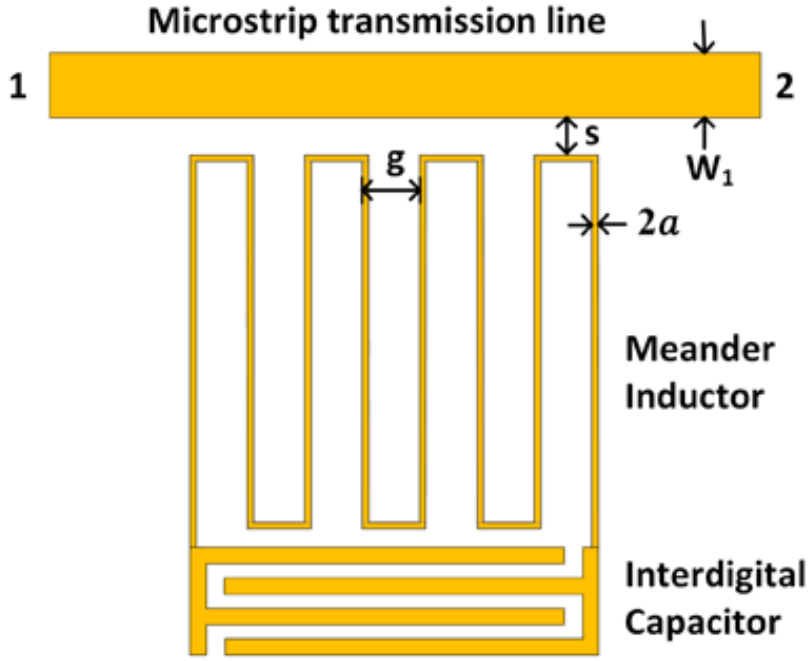


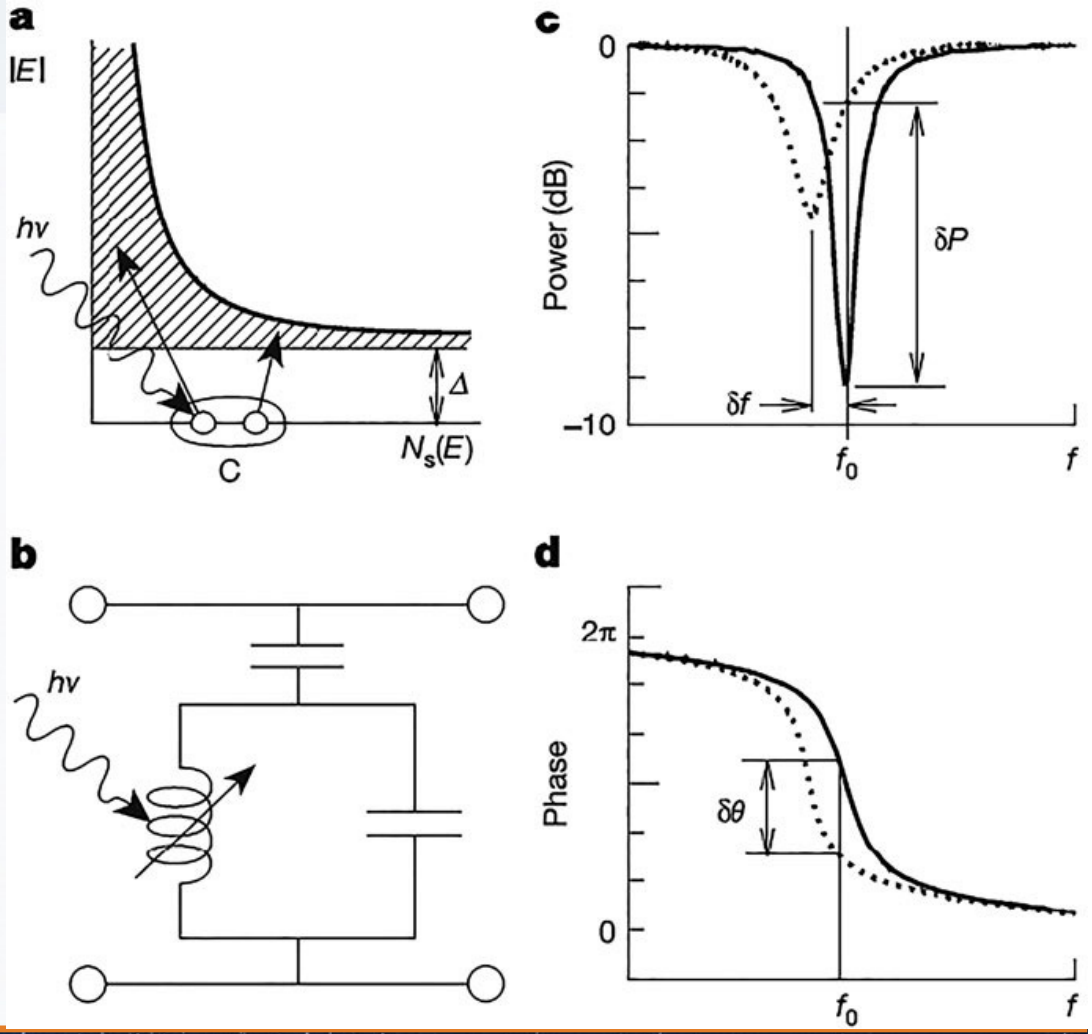

Muon flux [cm^{-2} s^{-1}]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
1000
2000
3000
4000
5000
6000
7000
8000
Vertical depth [m w.e.]
Overburden
Flat
Mountain
CallioLab 400
LSC
CallioLab 660
Kamioka
Soudan
CallioLab 990
LNGS
Boulby 1100
CallioLab 1390
Boulby 1400
LSM
SURF
CJPL
SNOLAB

SQUIDs


Magnetic field
Biasing current
Josephson junction
Josephson junction
Biasing current
One period of voltage variation corresponds to an increase of one flux quantum
Variation of terminal voltage with magnetic flux

KIDs


Microstrip transmission line
1
2
s
g
W_1
2a
Meander
Inductor
Interdigital
Capacitor


a
|E|
hν
Δ
C
$N_s(E)$
b
hν
c
0
−10
Power (dB)
δP
δf
f_0
f
d
2π
0
Phase
δθ
f_0
f