Fabrication and Characterization of Graphene-Superconductor Devices

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FH Fellow Meeting 2021: 25-26 Mar 2021

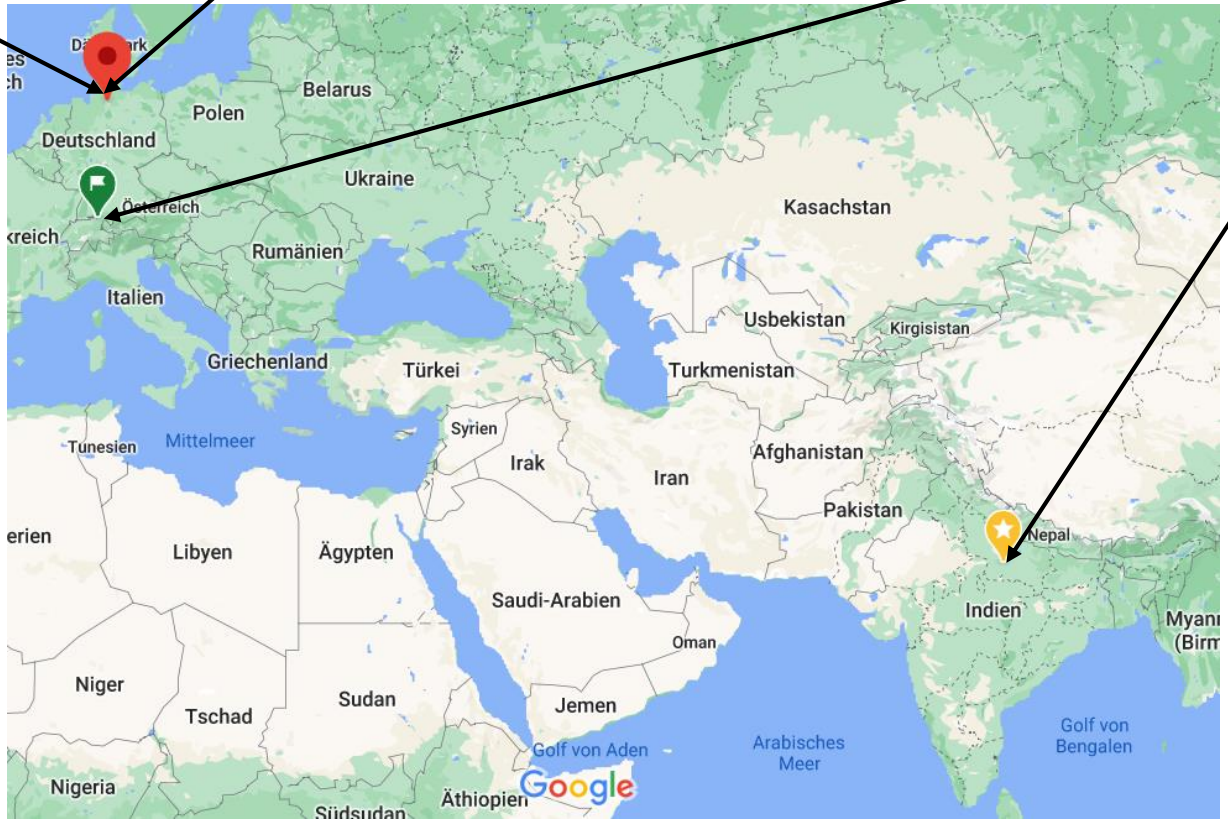
Personal Introduction

Scientist @ DESY (Jan 2020-present)

Research Associate (2014-2020) @ UHH

Postdoc (2009-2014) @ MPI Stuttgart

PHD (2004-2010) @ IITK, Kanpur



Timeline of superconductivity

~1000 years
300 K

High-T_C SC

Fe-pnictides

2008: iron-based SC

Fe-chalcogenides

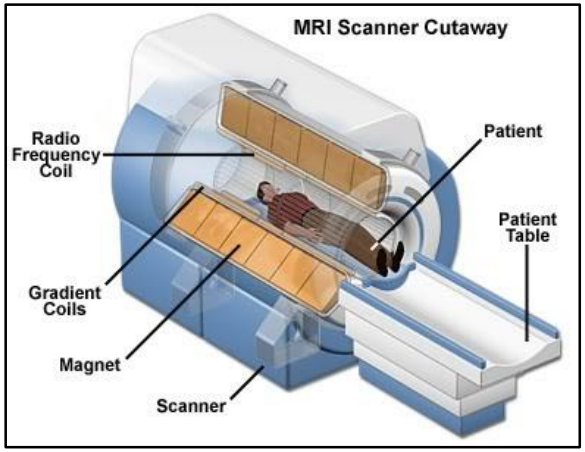
1911: Discovery of SC

wikipedia.org

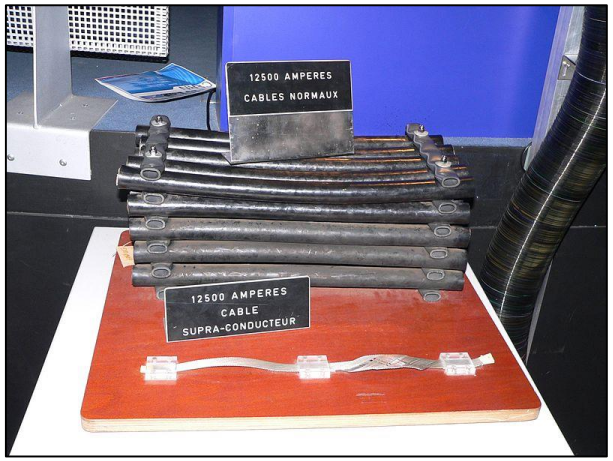
Applications of superconductors

Maglev trains-400 Km/hr

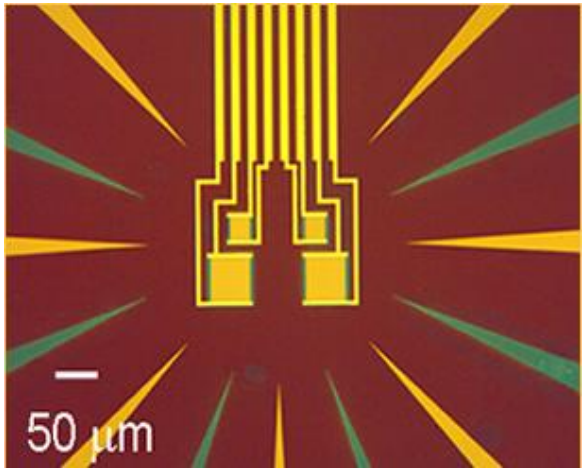
Superconducting magnet in MRI machine



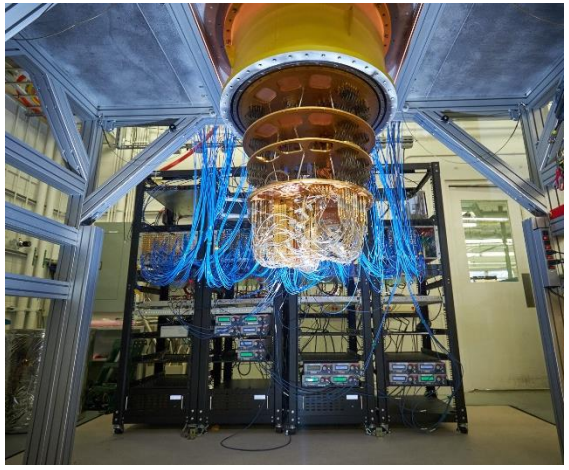
Superconductor-based cables



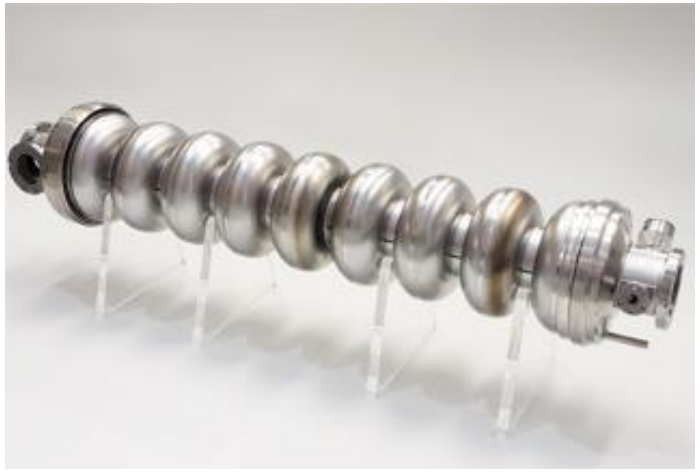
Superconducting detector



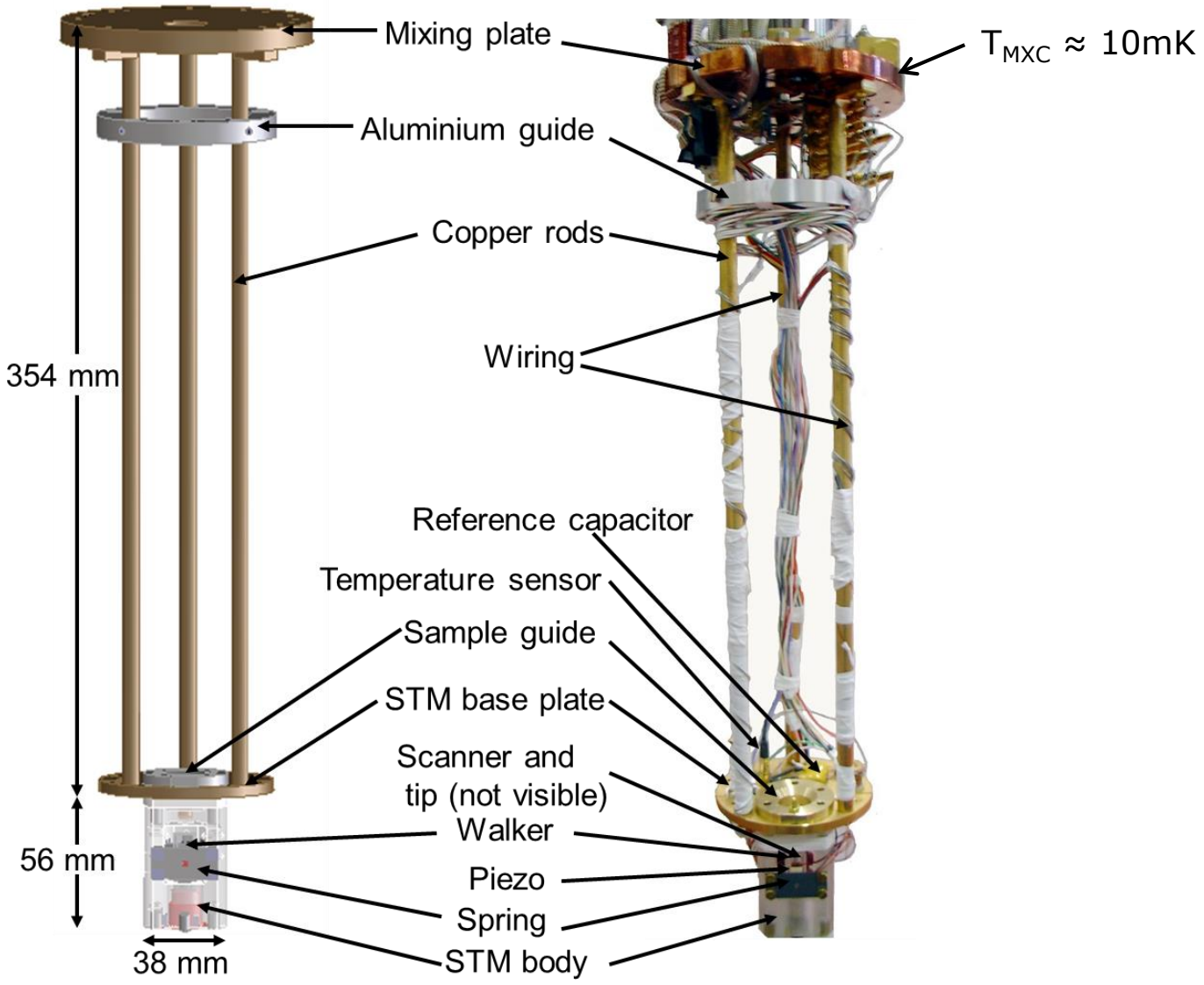
Quantum computers



Superconducting cavities

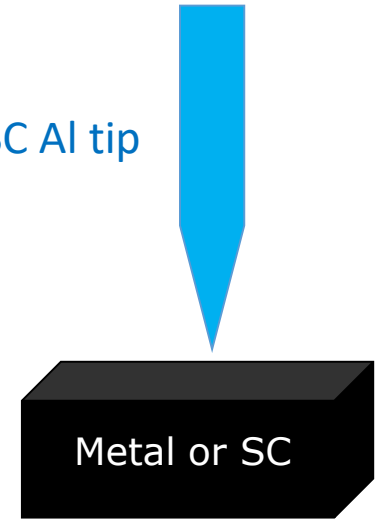


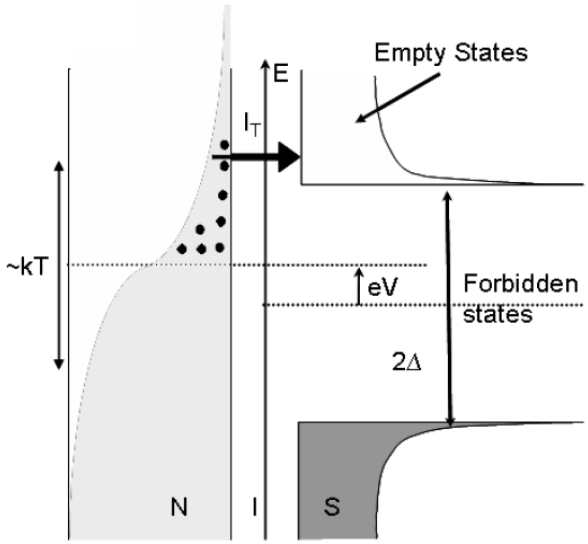
Dilution-Refrigerator based mK-STM (T_{MXC} = 10mK and B = 14T)



Singh et al., RSI 84, 013708 (2013)

Metal - Al and Al- Al superconductor junctions





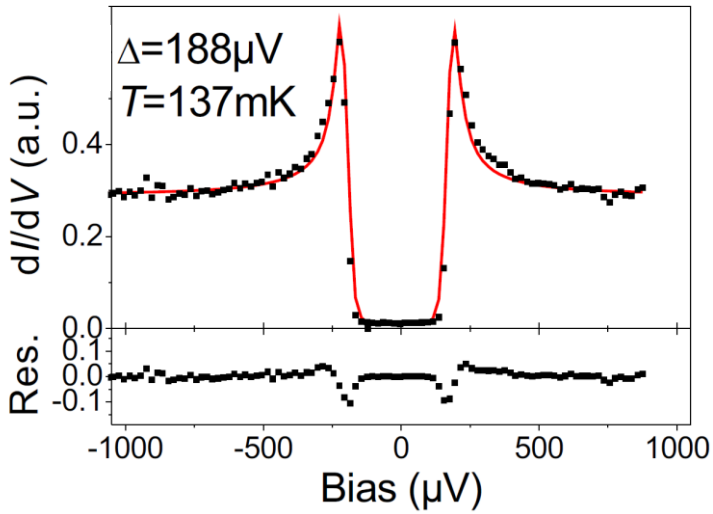
$$\frac{dI}{dV} \propto N_{sample}(eV)e^{-\kappa z}$$

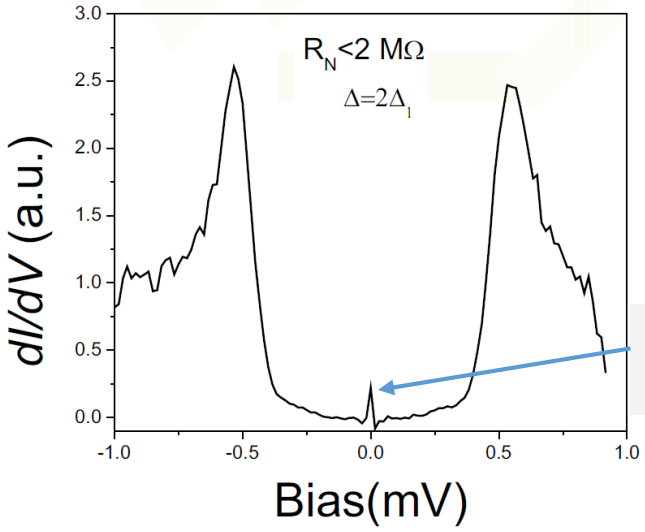
Dynes function

$$\frac{dI}{dV}(E) = \frac{E - i\Gamma}{\sqrt{(E - i\Gamma)^2 - \Delta^2}}$$

Γ: quasiparticle-lifetime broadening

SC gap of Aluminum



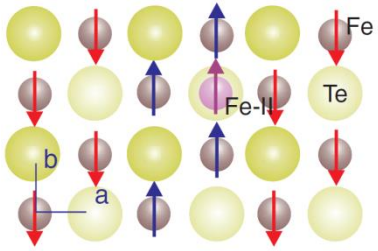


Josephson supercurrent

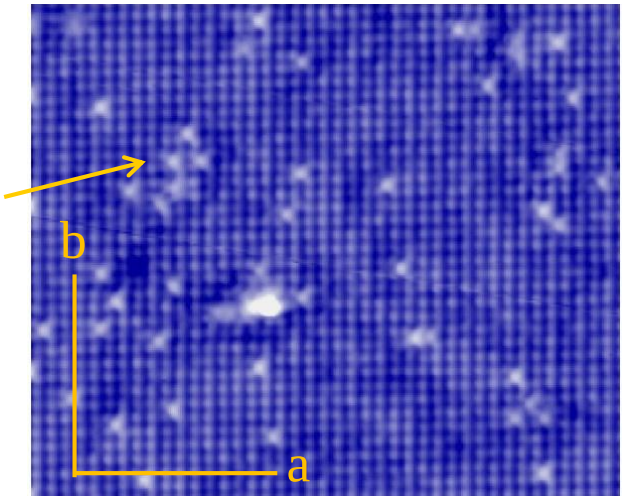
Singh et al., RSI 84, 013708 (2013)

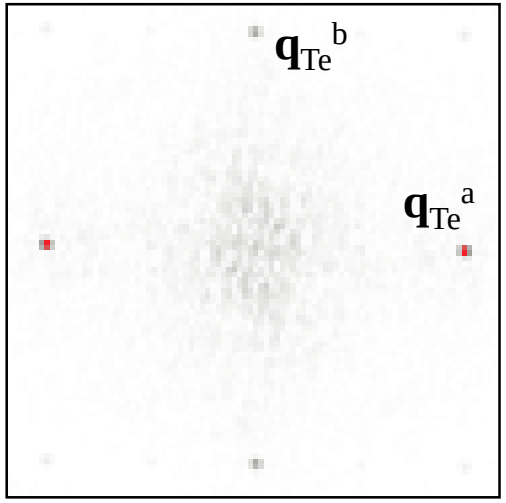
Detection of magnetic order in $Fe_{1.08}Te$ by STM

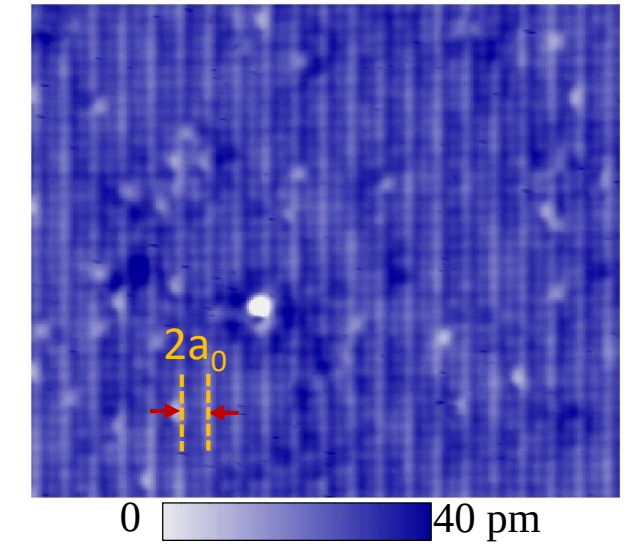
- Topographic image without magnetic contrast
- Excess iron atoms (bright spots) clearly visible in between Te atomic rows



- Topographic image after picking up a magnetic cluster showing the magnetic contrast of unidirectional commensurate modulation at $\mathbf{q}_{AFM}(\pm 1/2, 0)$







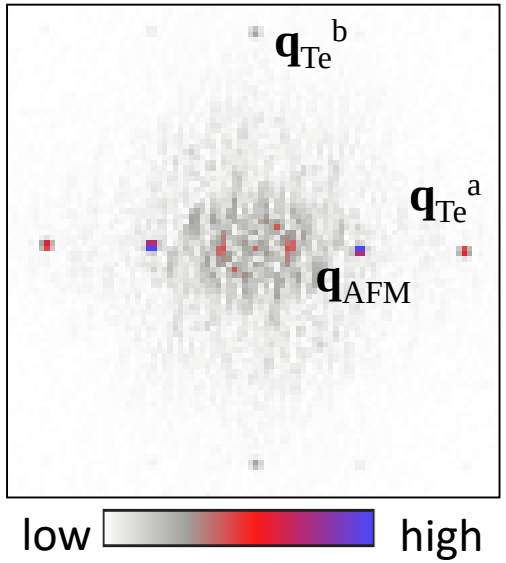


Image size = 14.7x12.2 nm^2, V_b = 60 mV, I_t = 0.2 nA, and T= 3.8 K

Enayat, Zhang, Singh et al., Science 345, 653 (2014)

UHV-Variable Temperature STM (22K-300K)

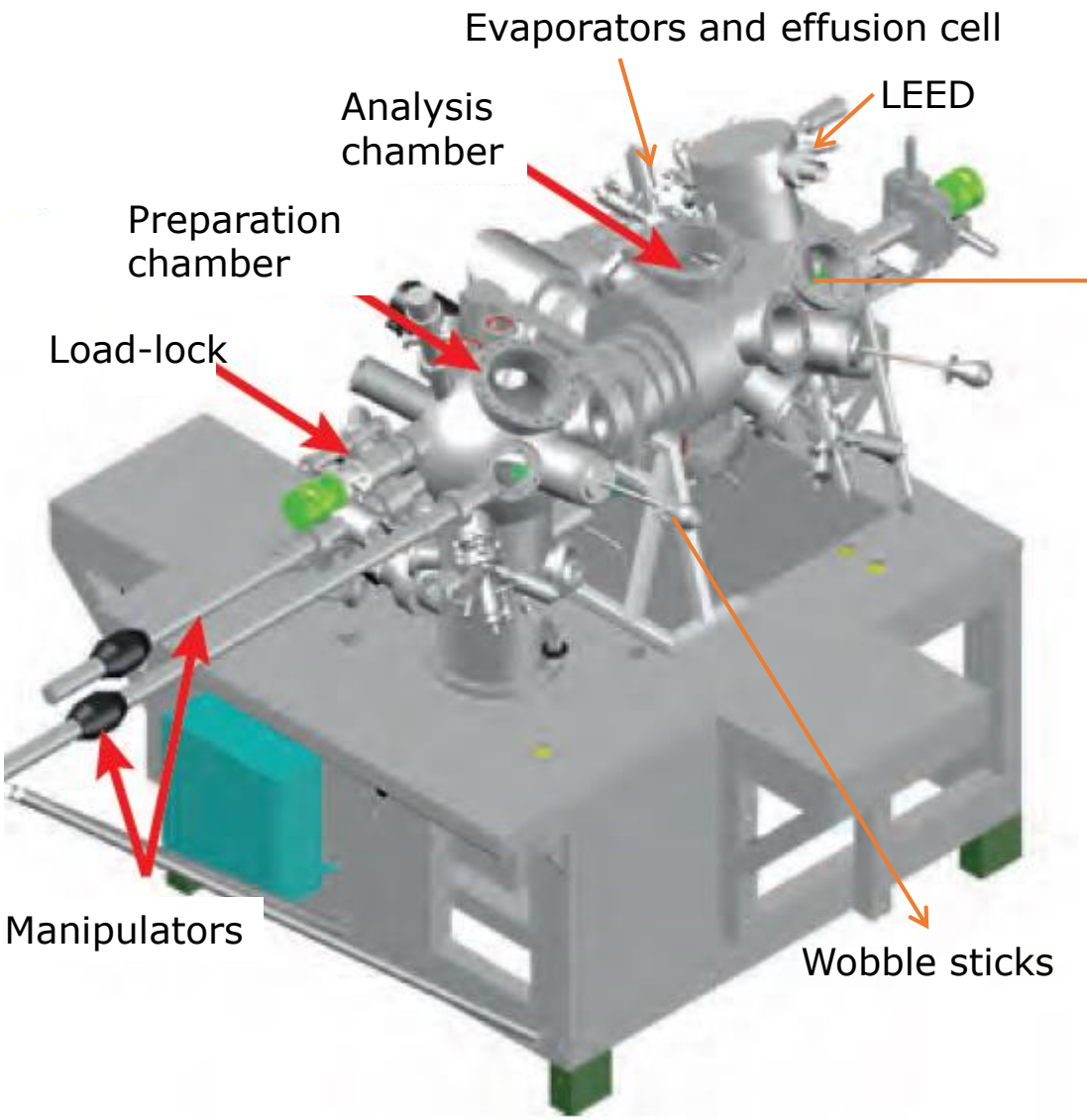
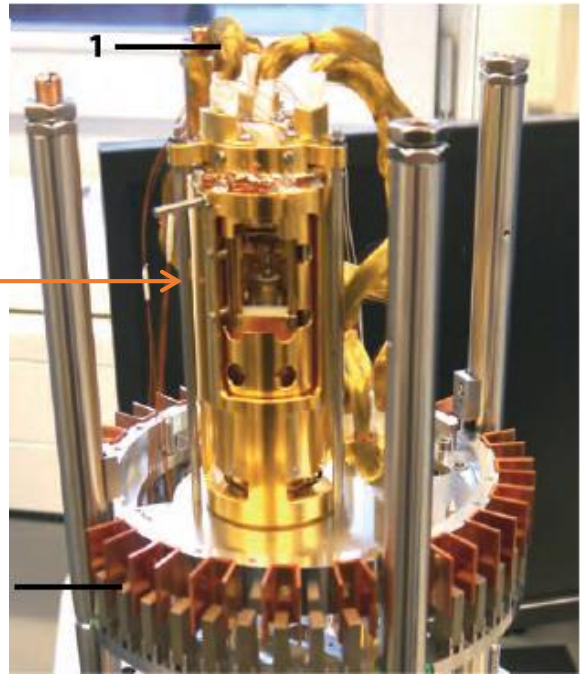


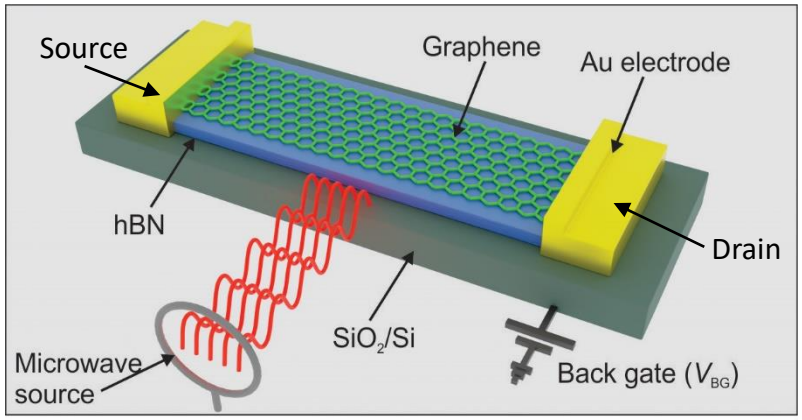
Photo of the VT-STM



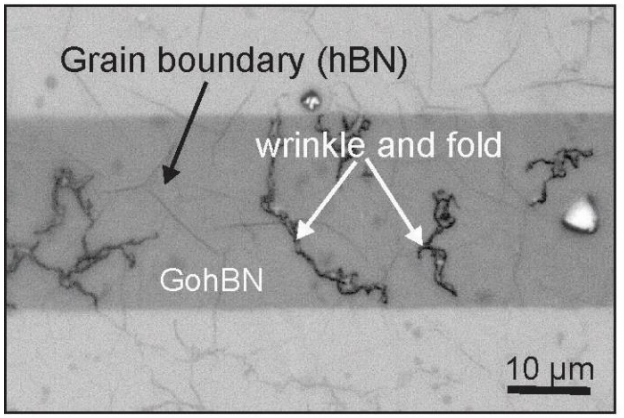
Preparation of sample

Andreas Eich, Thesis (2014)

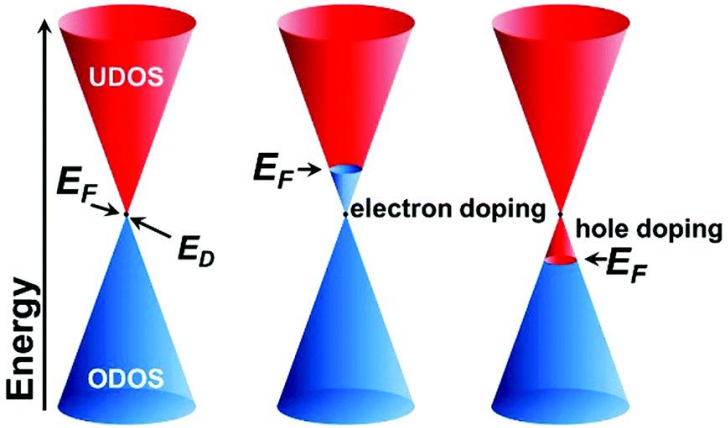
CVD graphene/hBN based field effect transistor



Sketch of graphene on hBN (GohBN) and microwaves (red wiggled lines) are coupled to the device.

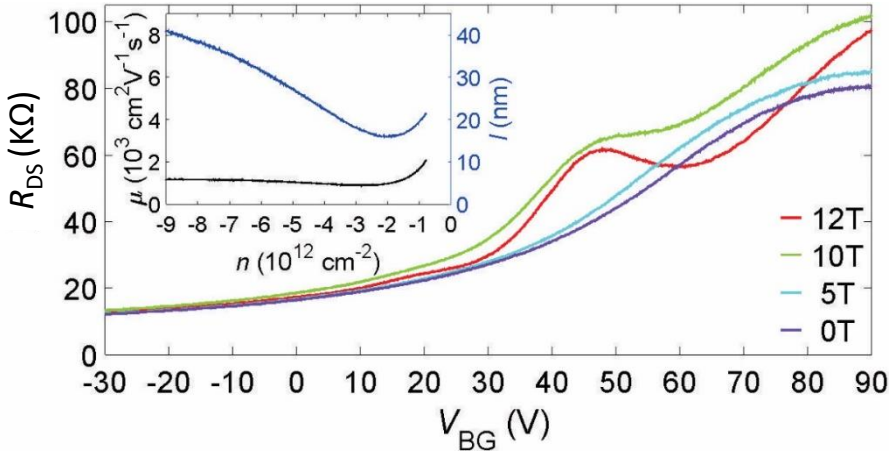


Optical micrograph of GohBN Hall bar



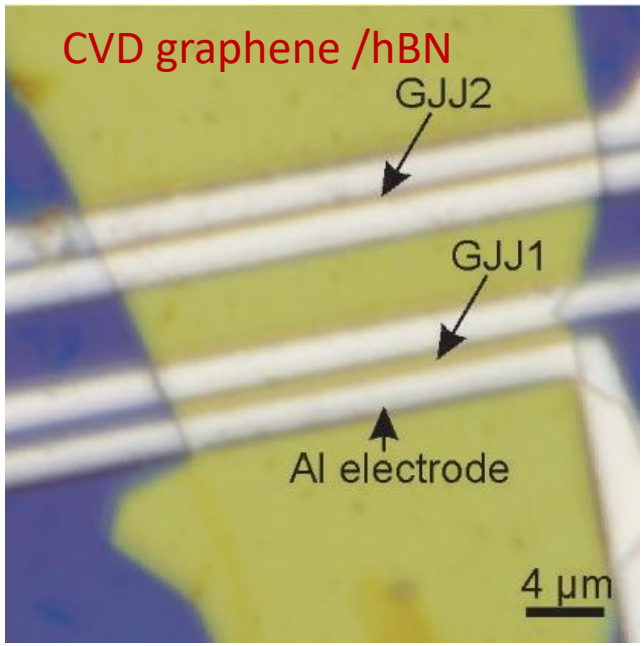
- Charge Neutrality Point
- Massless Dirac charge carriers
- Very high mobility (100,000 $cm^2/V.s$)

Singh et al., PRB 102, 245134 (2020)

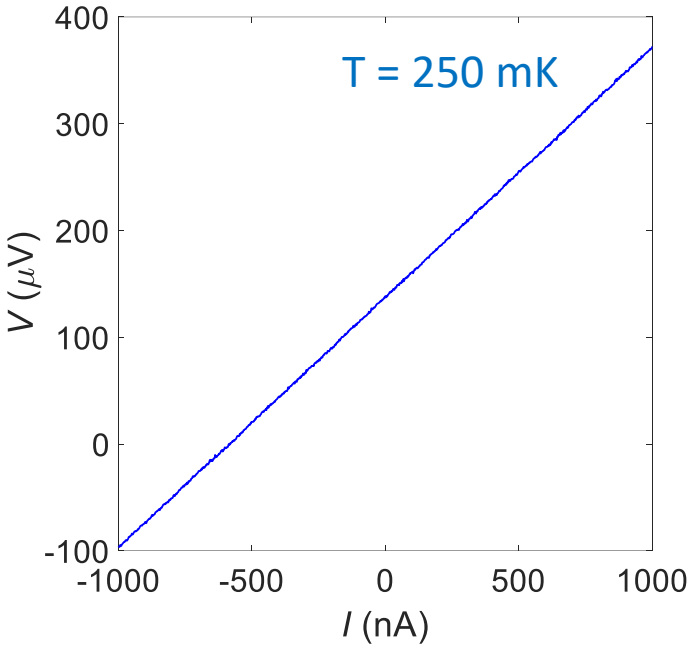


- Landau levels at finite magnetic fields (parameters: T = 1.32 K and I_{DS} = 5 nA)
- Inset: poor mobility (1150 to 1200 cm^2V^{-1} s^{-1}) due to scattering of charge carriers from wrinkles and folds

Graphene-based Josephson junctions (GJJ)



Two GJJ with different weak link lengths (GJJ1: 1000 nm and GJJ2: 500 nm).



Linear curve indicating for ohmic JJ

For $V = V_0$

$$I = I_0 \sin\left(\frac{2eV_0}{\hbar}t\right)$$

$$f = \frac{2eV_0}{h}$$

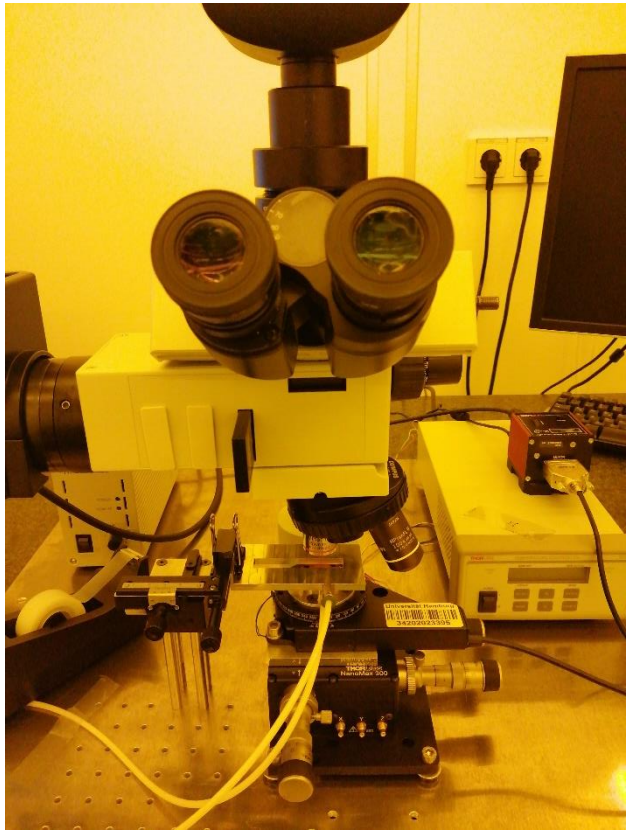
microwave range

where $2e/h = 483.6$ GHz/mV.

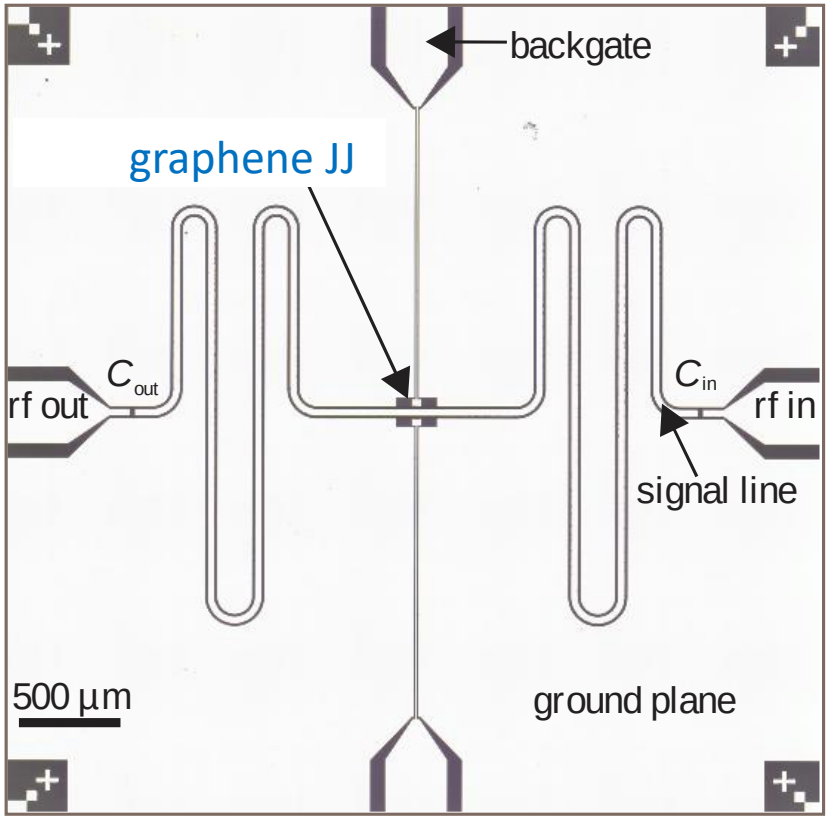
- GJJ can work as a single photon detector in the GHz frequency range due to very small heat capacity of graphene at the Dirac point.
- It can play a pivotal role in detecting ultra-low energy particles in dark matters such as axions.
- GJJ can provide more frequency-stable superconducting qubit in qunatum computing.

Unpublished data

Integration of graphene JJ into CPW circuits



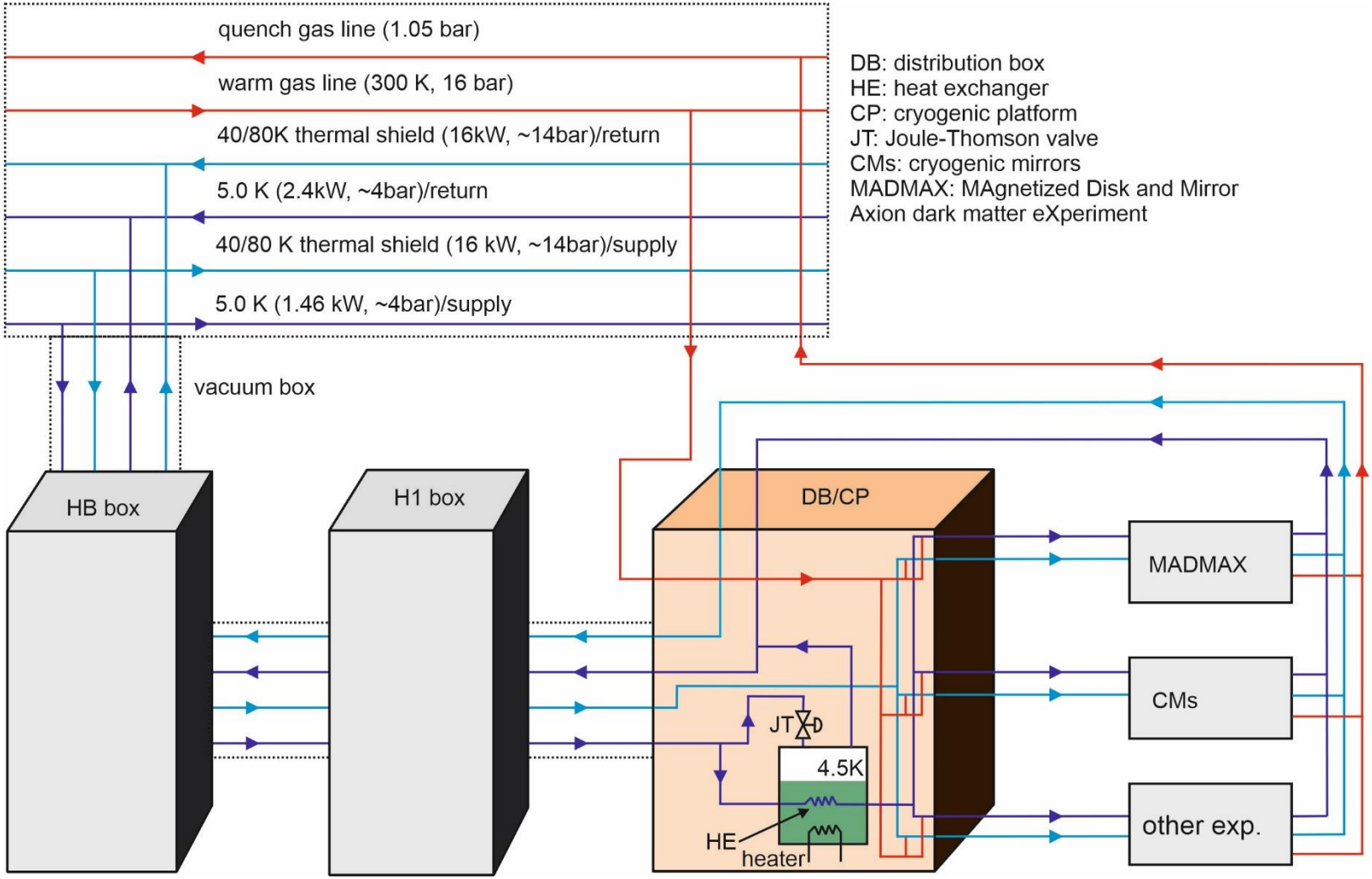
A transfer system of graphene and other van der Waals materials (Constructed by Chithra)



Integration of JJ into superconducting CPW circuits and trying to investigate them under microwave irradiations at low temperatures

High-quality-biomass-graphene-kn95-mask

Schematic representation of a cryoplatform in Hera North Hall



Jörn Schaffran, Christoph Reinhardt, and Axel Lindner

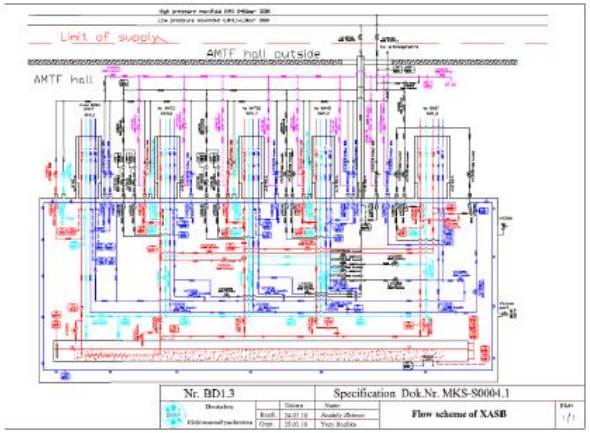
Jörn et al. heal load document

Accelerator Module Test Facility (AMTF)

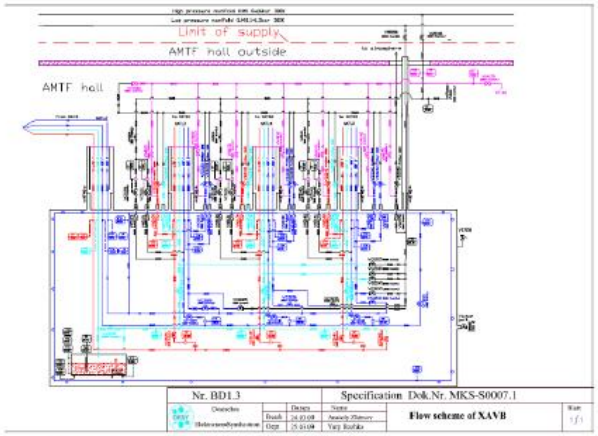
DESY is acting for XFEL company

Manufacturer: DeMaCO

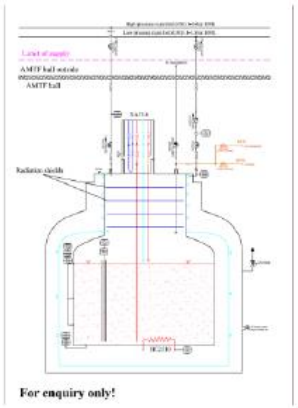
Wessington Cryogenics Ltd, UK



Sub-Cooler Box XASB



Valve Box XAVB



L Helium Dewar XAST

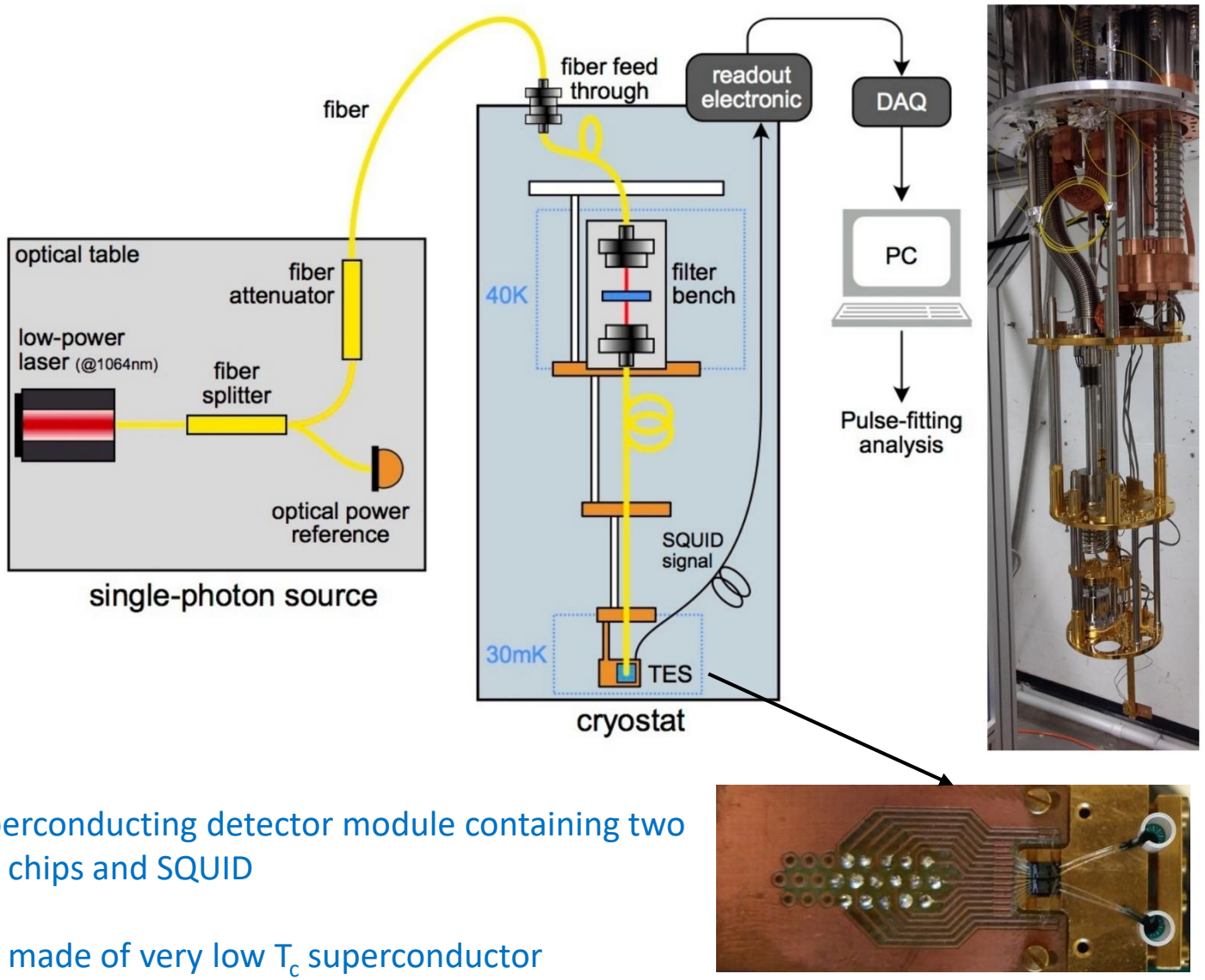
Courtesy: Dr. S. Putselyk, DESY

MADMAX (Magnetized Disc and Mirror Axion Experiment)

Jörn Schaffran and Dr. Axel Lindner

https://alps.desy.de/our_activities/axion_wisp_experiments/madmax/

Transition-edge sensor (TES)

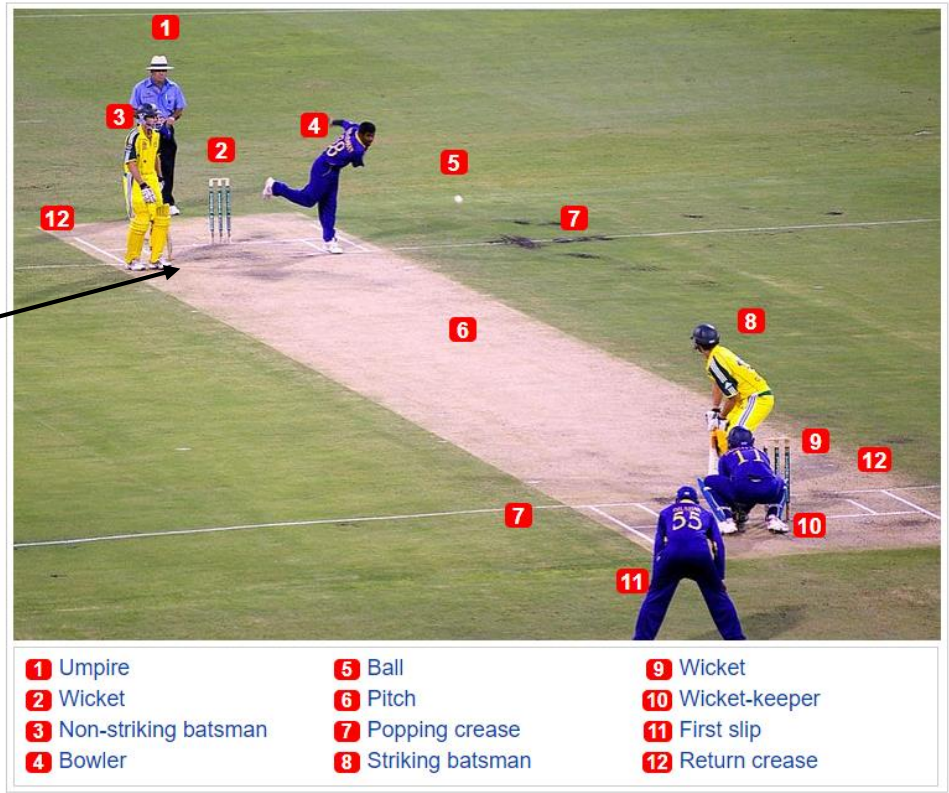


- Superconducting detector module containing two TES chips and SQUID
- TES made of very low T_c superconductor

https://alps.desy.de/our_activities/axion_wisp_experiments/alps_ii/detector/

Other activities

- Cricket
- Running
- reading books
- exploring new places and cultures
- Learning German language B2 level



Thank you very much for your attention!!!