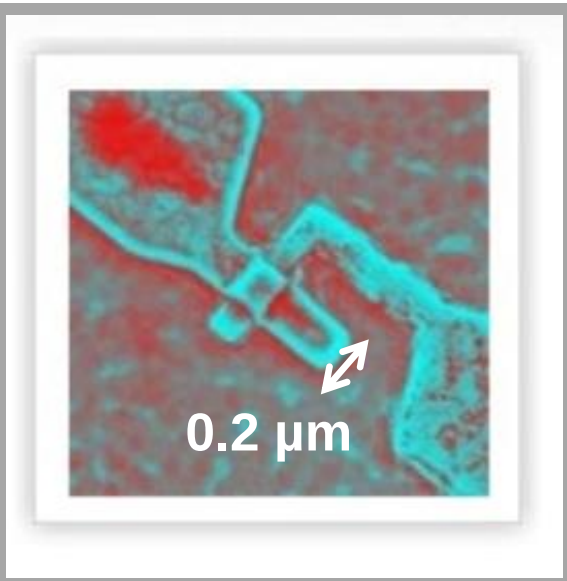
Materials and Fabrication for Superconducting Quantum Hardware

Spring School on Superconducting Qubit Technology

2025, May 21 - May 30

Organizers:

David López-Núñez (Qilimanjaro Quantum Tech / IFAE, Barcelona, Spain), Fabian Zwiehoff (ParTec AG, Munich, Germany), Pol Forn-Díaz (Qilimanjaro Quantum Tech / IFAE, Barcelona, Spain)



Ioan M. Pop

KIT

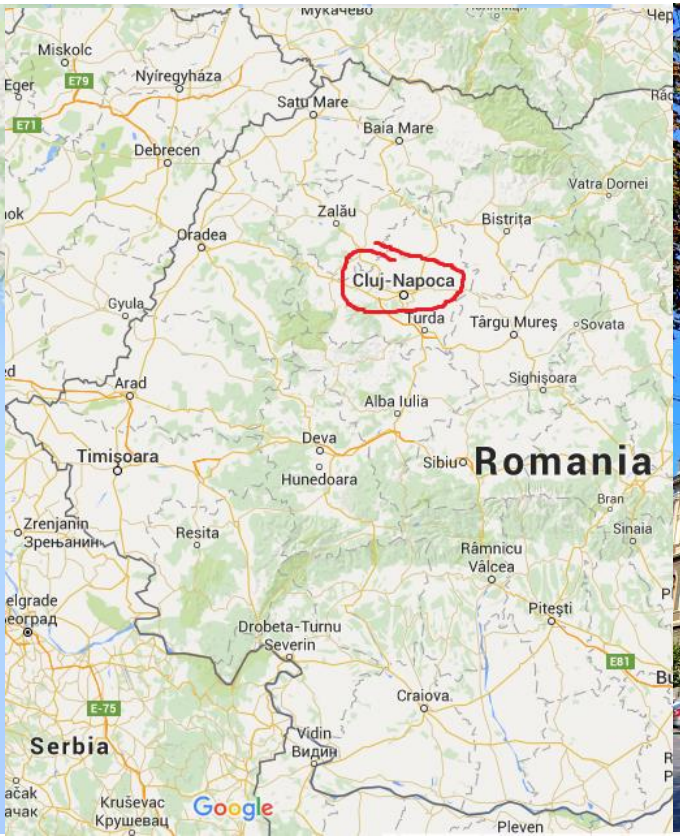
An older example: post-apprentice in the baker's guild

MUSEUM DER BROTKULTUR ULM *1955

By the rules of the guild, before settling down and opening a shop, a young baker had to travel for several years to learn new recipes and techniques.

My initiation journey

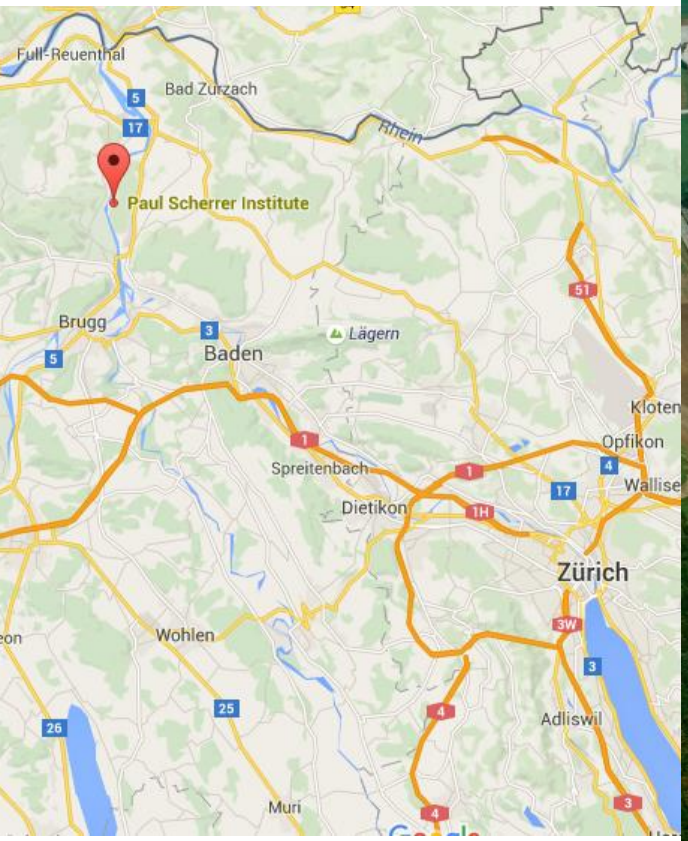
My initiation journey



Undergraduate at Babes-Bolyai University, Bachelor in Physics

(2002-2006)

My initiation journey



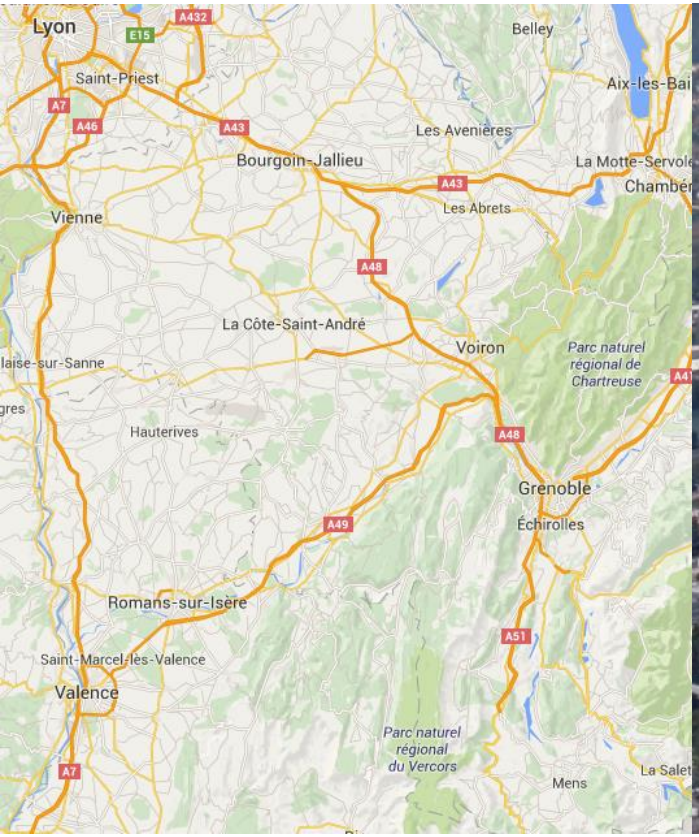
PAUL SCHERRER INSTITUT

PSI

Research Internships at Paul Scherer Institute (PSI)

(2005 and 2006)

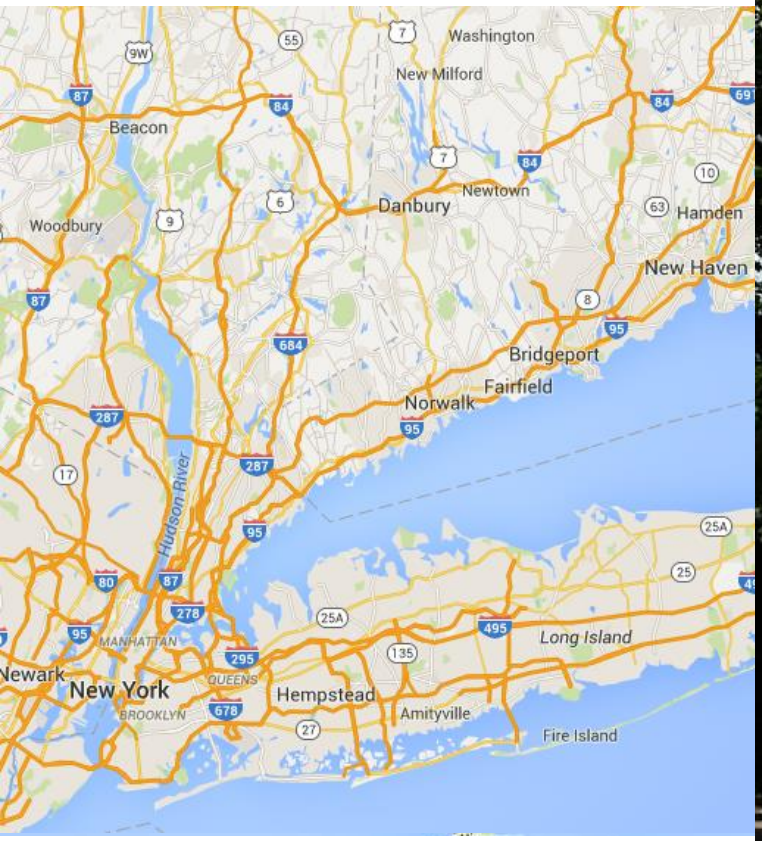
My initiation journey

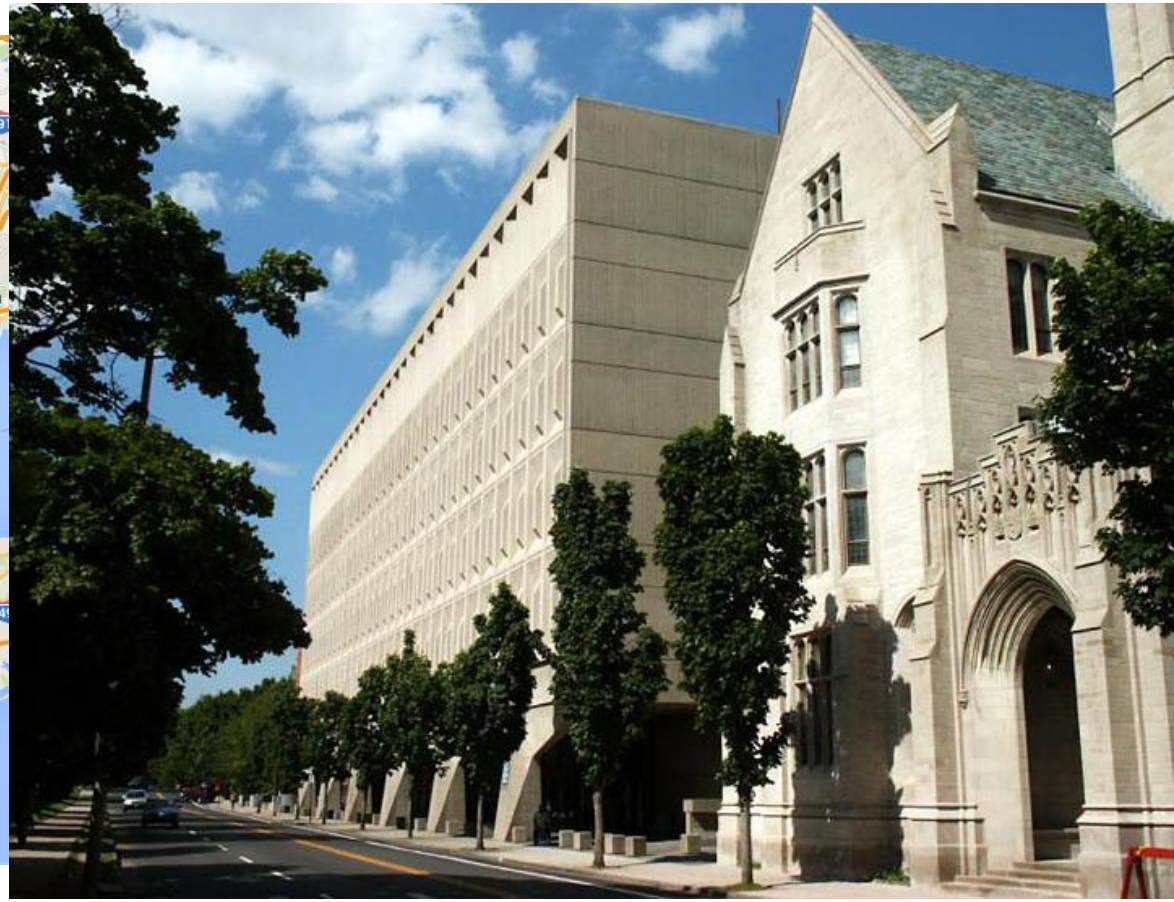


Master and PhD, in CNRS and University of Grenoble

(2006-2011)

My initiation journey

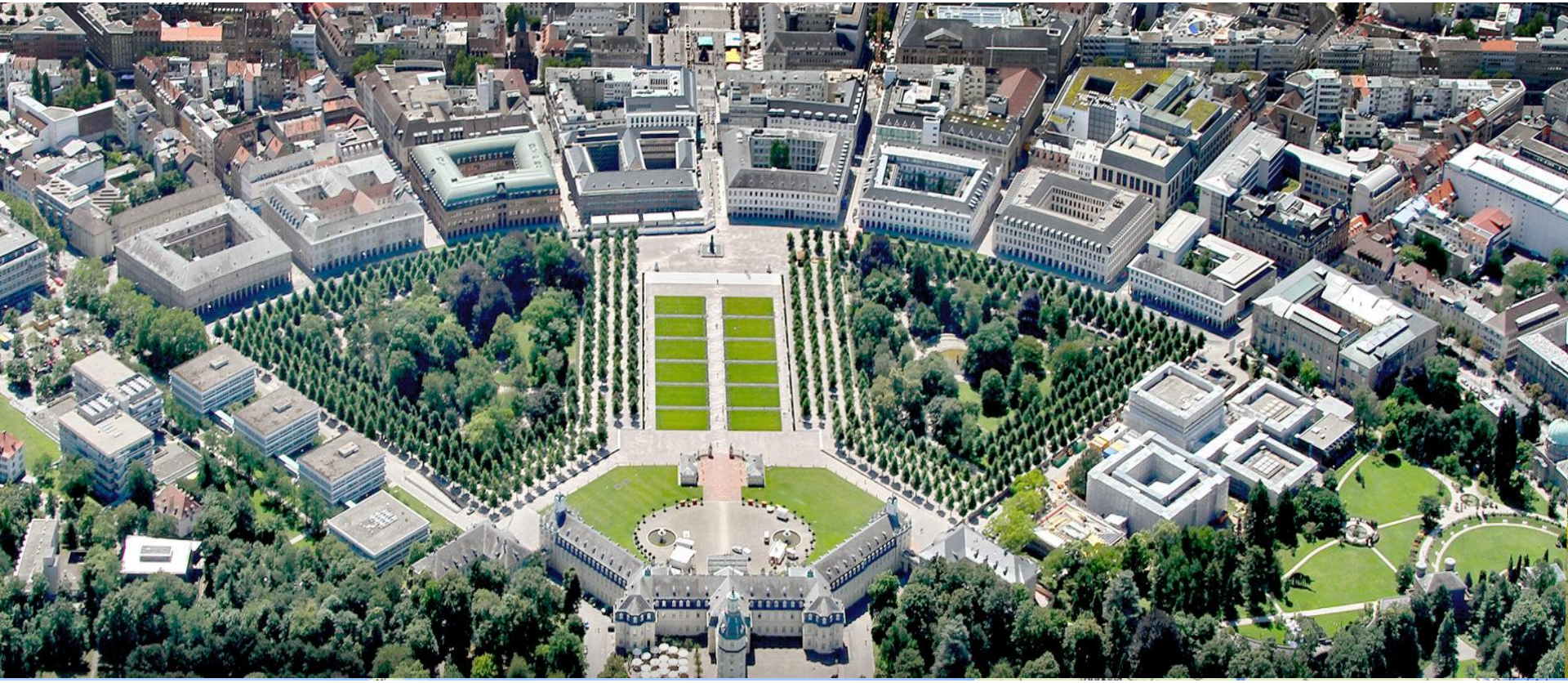




Postdoctoral research in Yale University

(2011-2015)

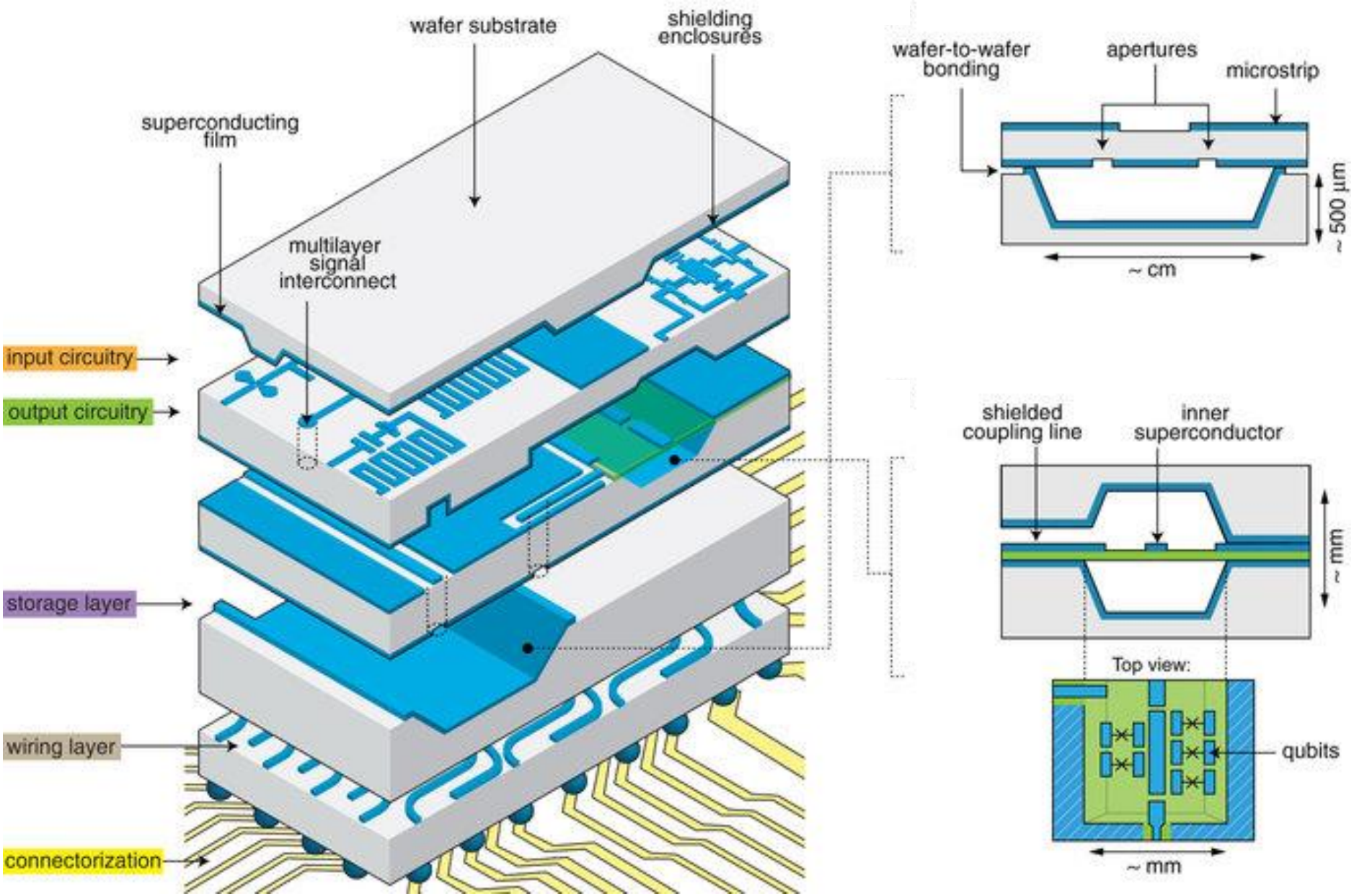
My initiation journey



Back in Europe!

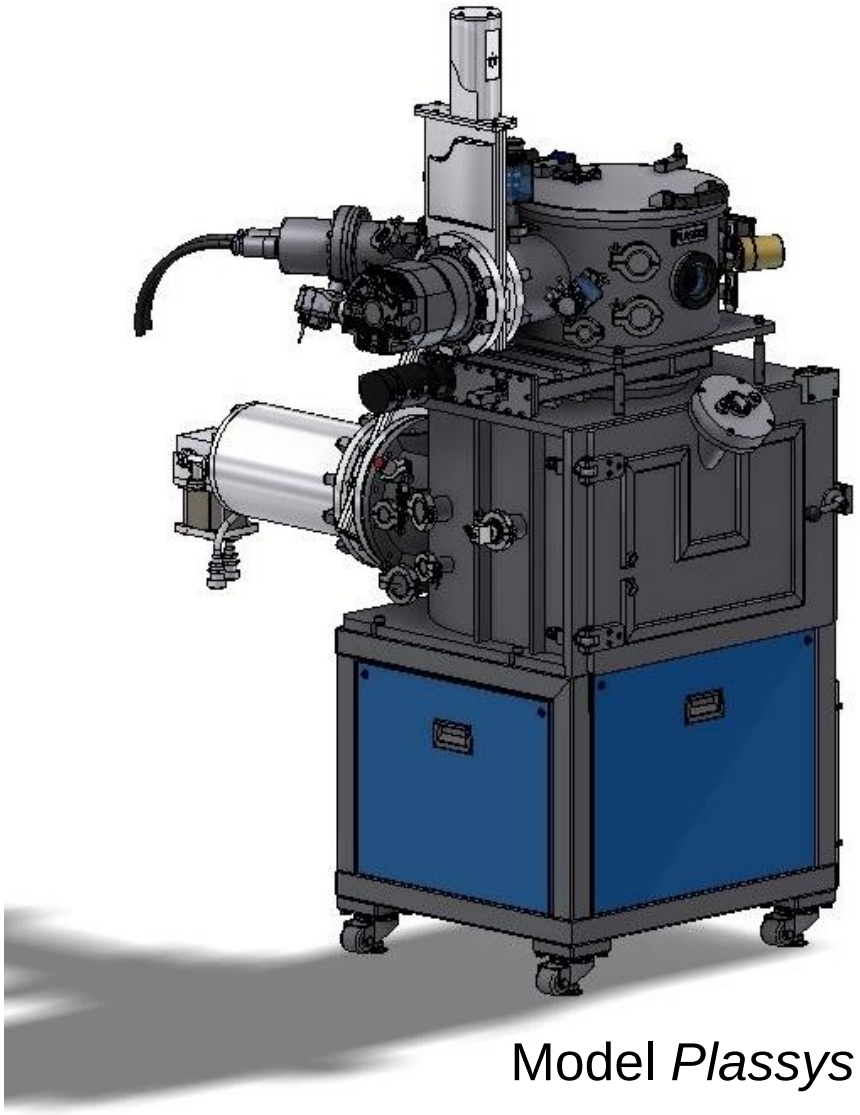
Thanks to the Humboldt Foundation


BLACK FOREST
QUANTUM



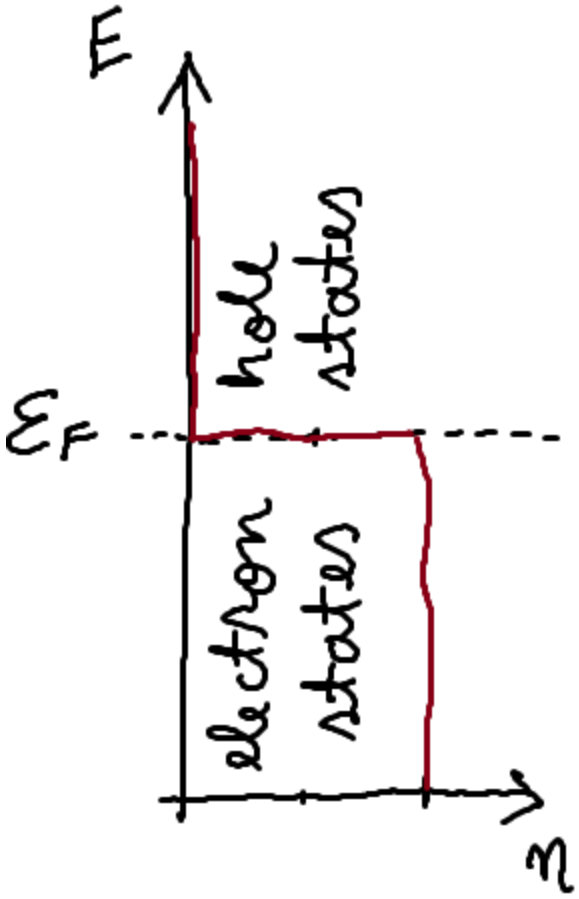
Brecht et al. , *Multilayer Microwave Integrated Quantum Circuits for Scalable Quantum Computing,* NPJ Quantum Information (2016)

Metal evaporator



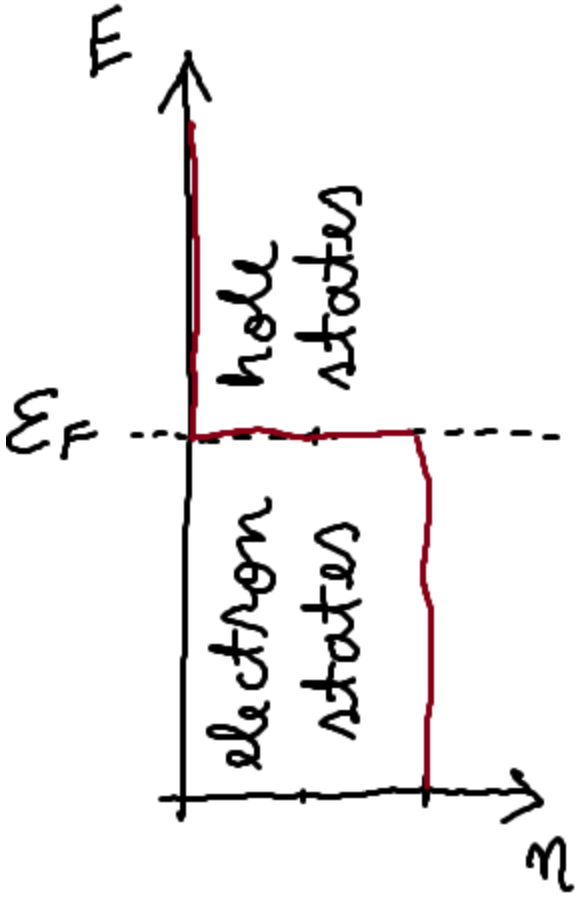
Model *Plassys MEB550*

Why Superconductors?



T=0

Why Superconductors?



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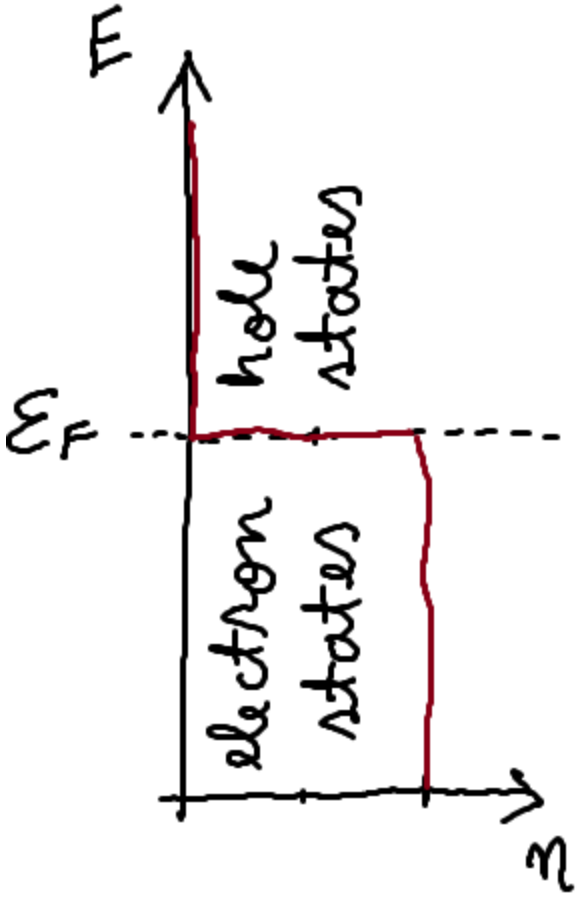

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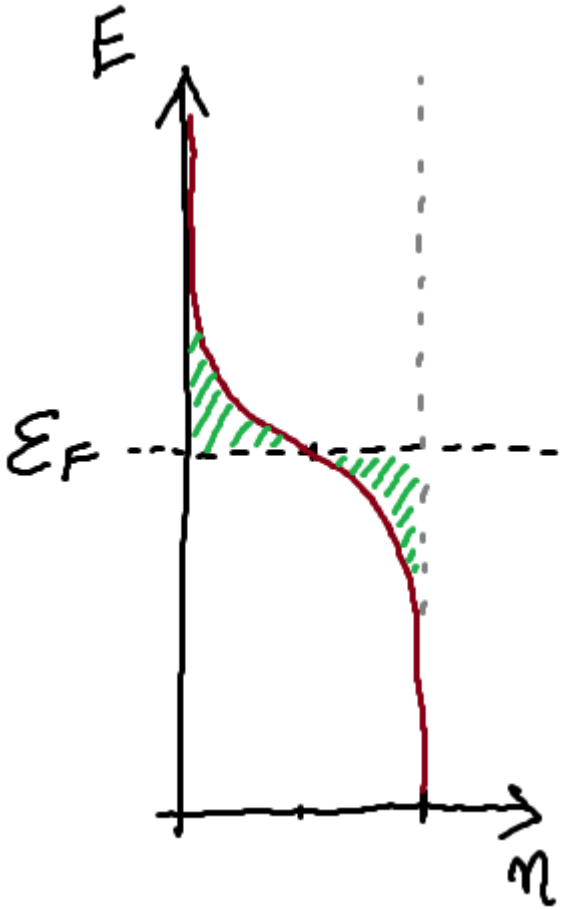

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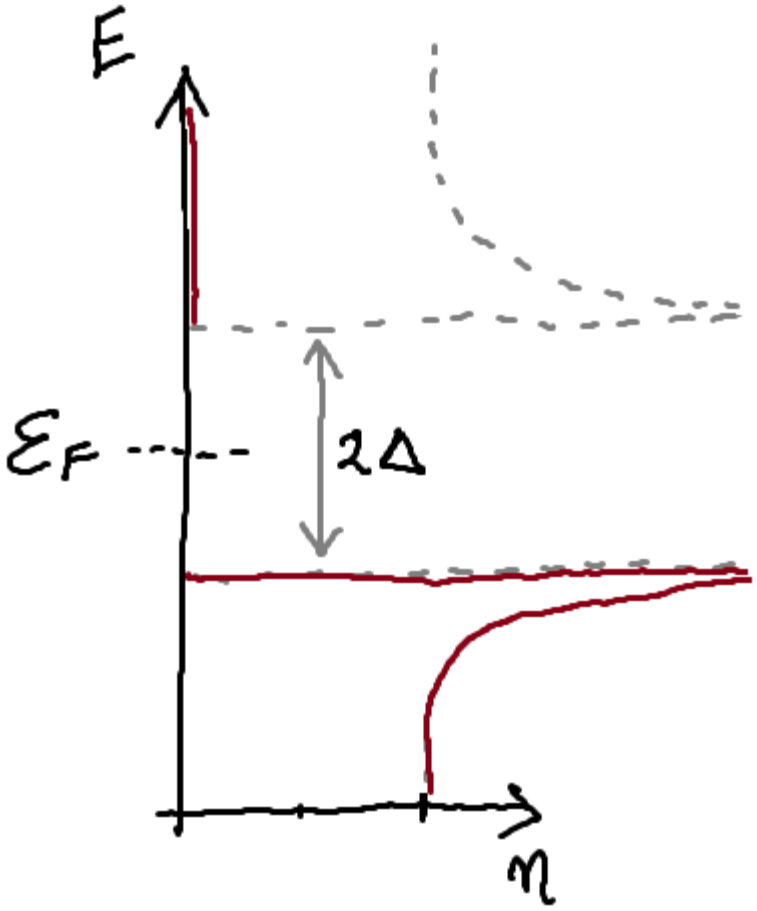

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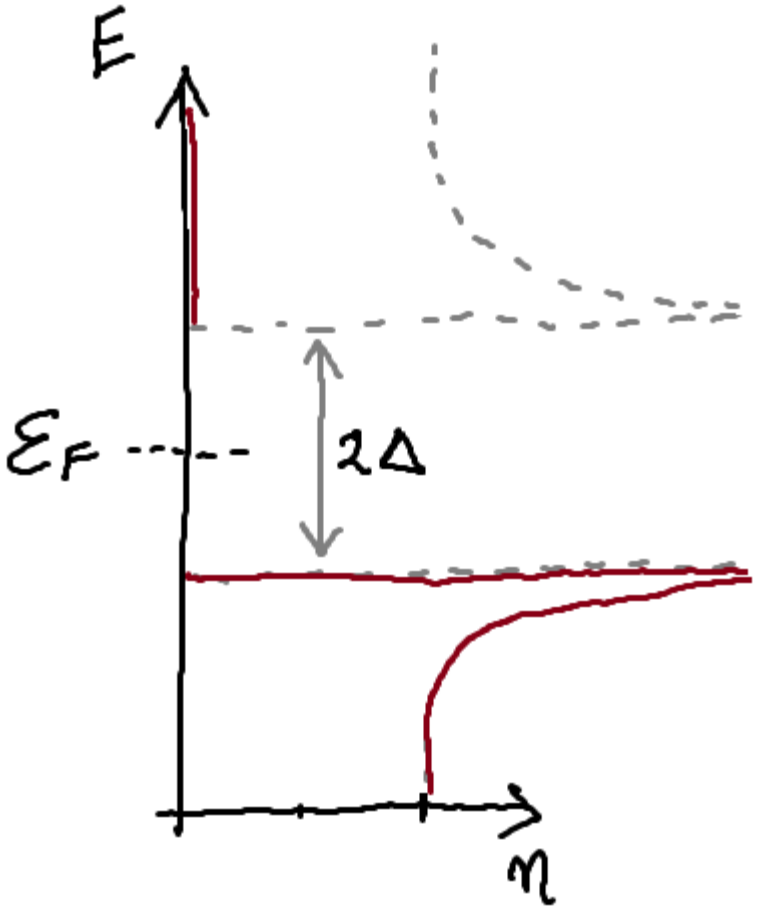
Why Superconductors?



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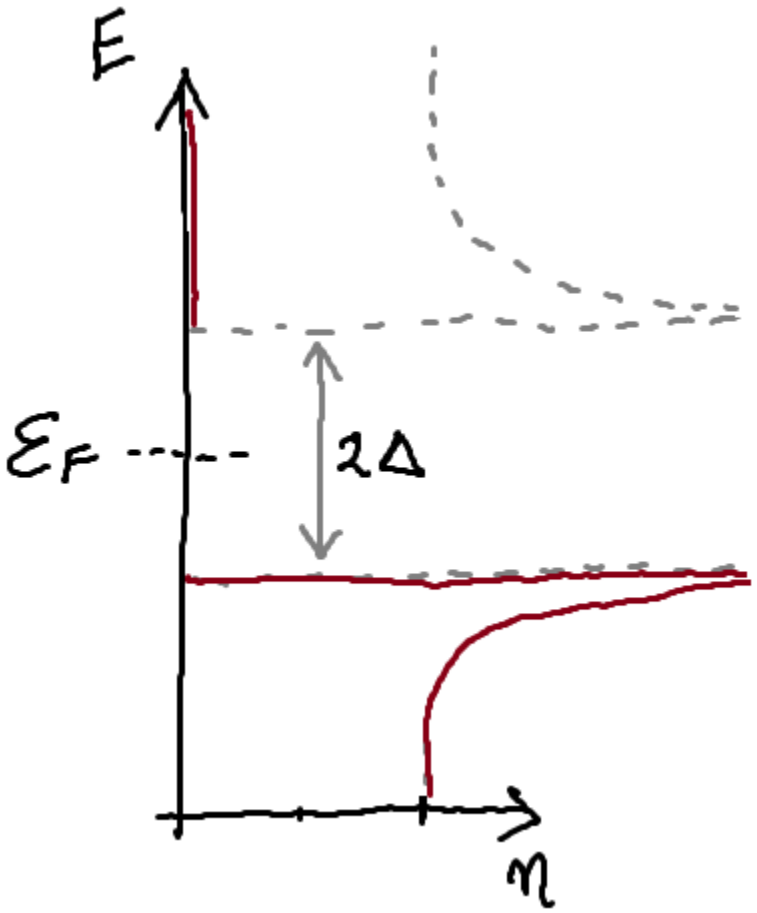

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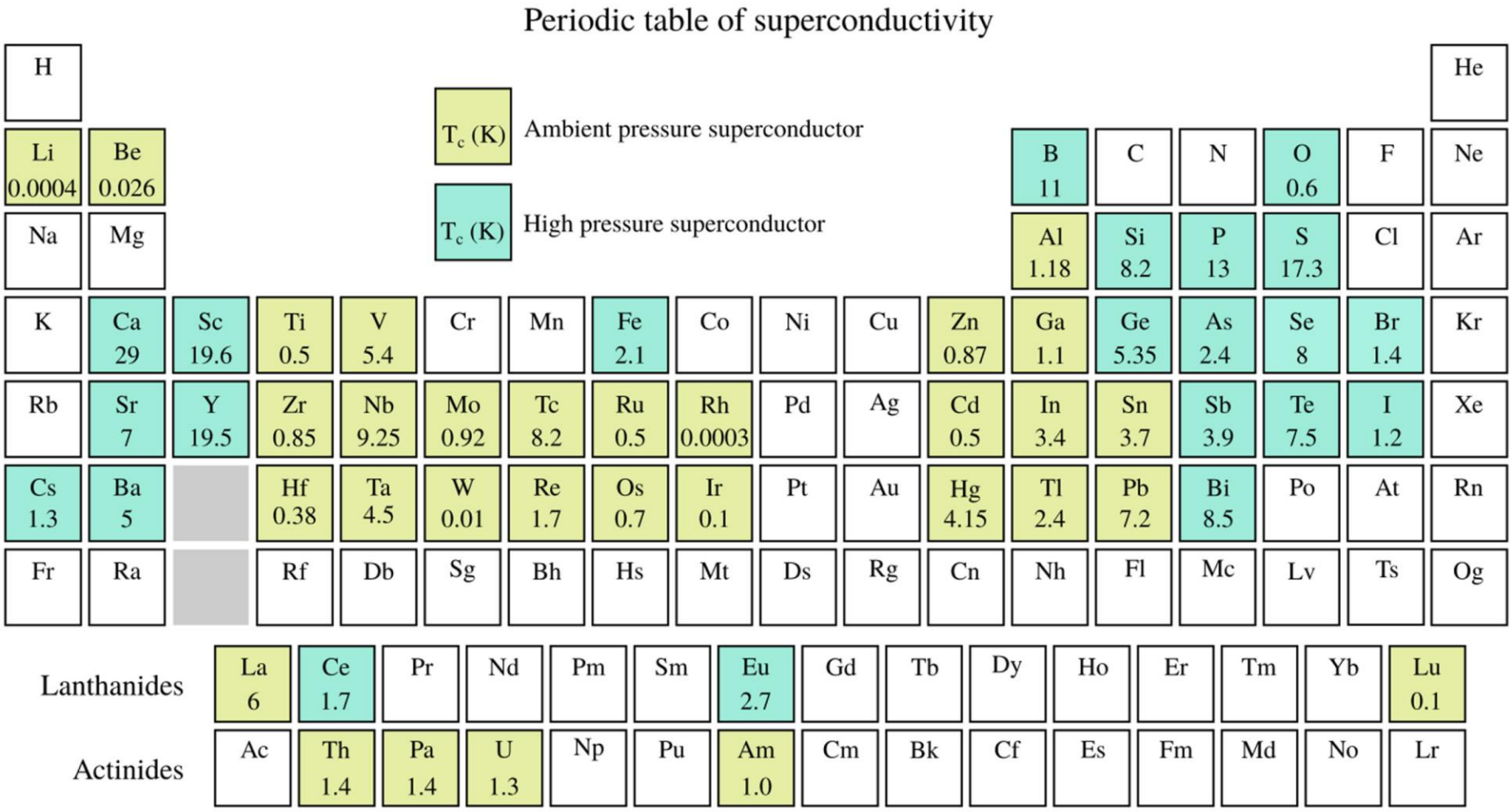
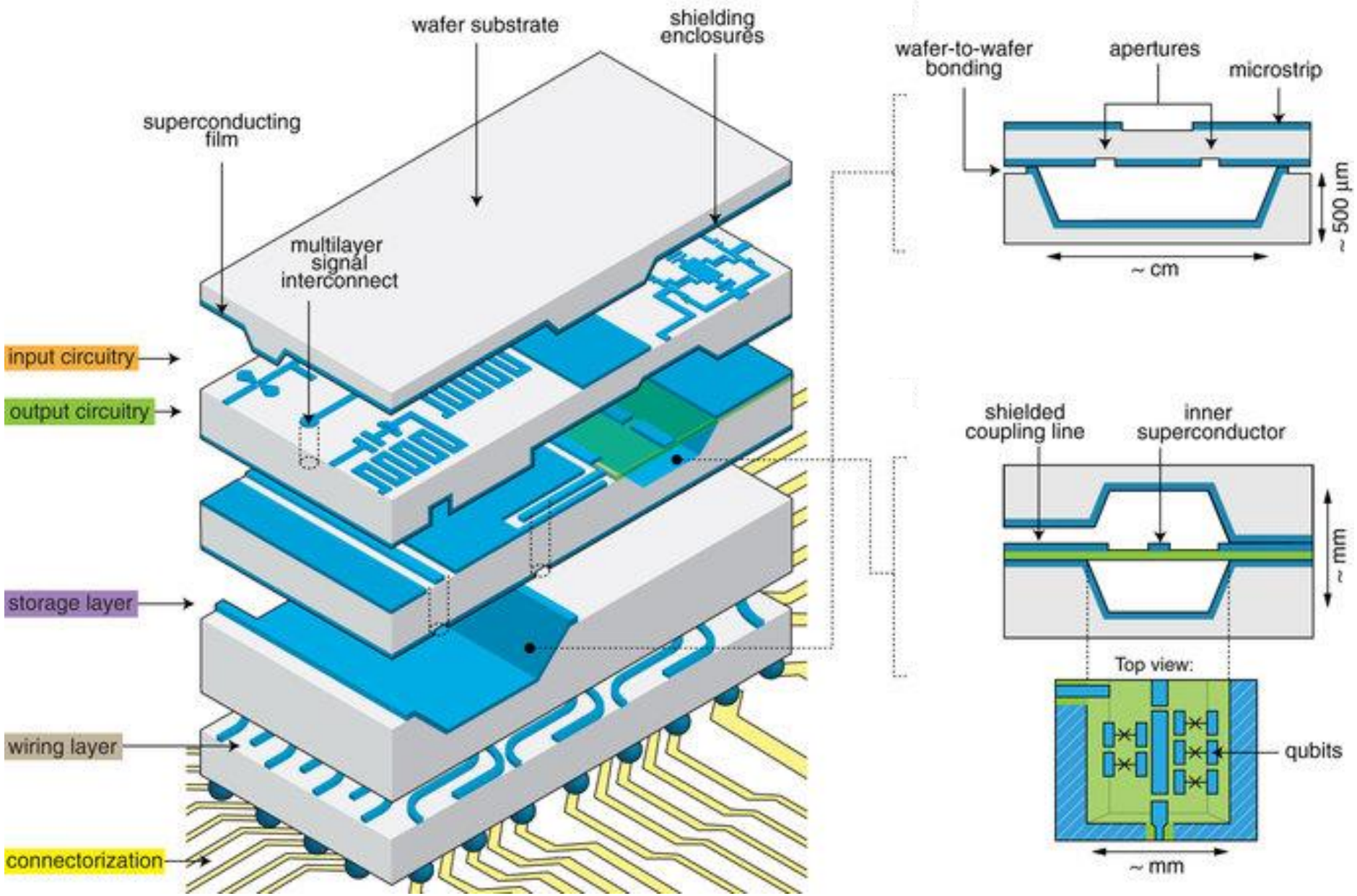
Which Superconductors?



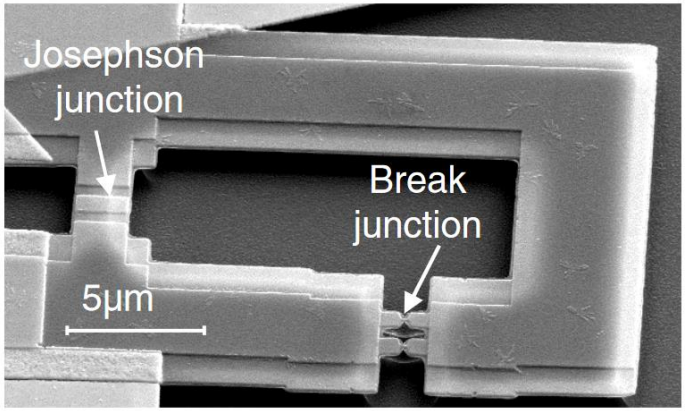
Flores-Livas et al. Phys. Rep. 856 (2020)

How about the junctions?

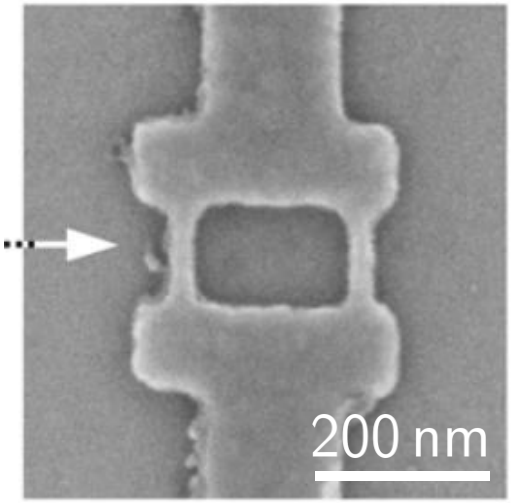


What should we chose?

Point Contact



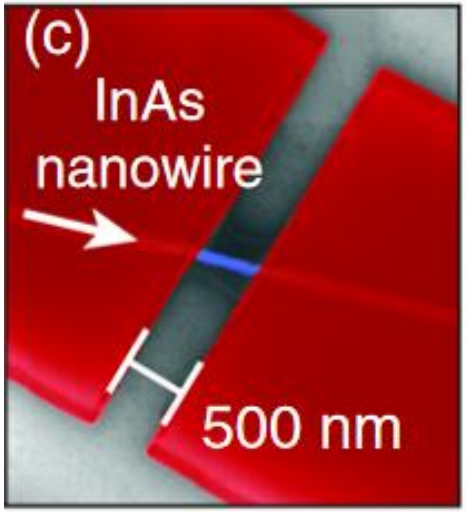
Rocca et al., PRL **99** (2007)



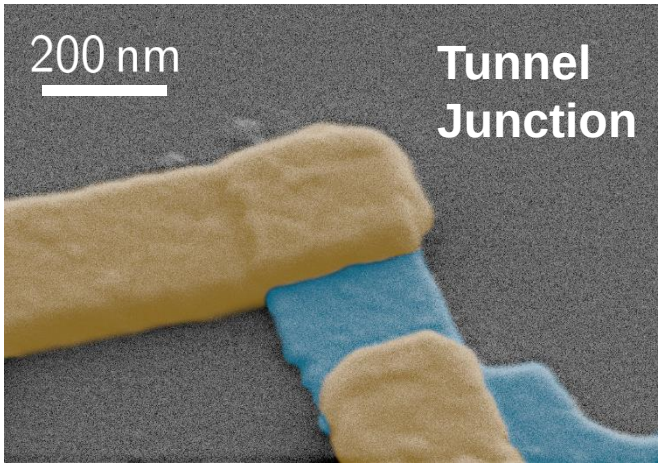
Constriction

Wernsdorfer, Supercond. Sci. Technol. 22 (2009)

Semiconductor Junction

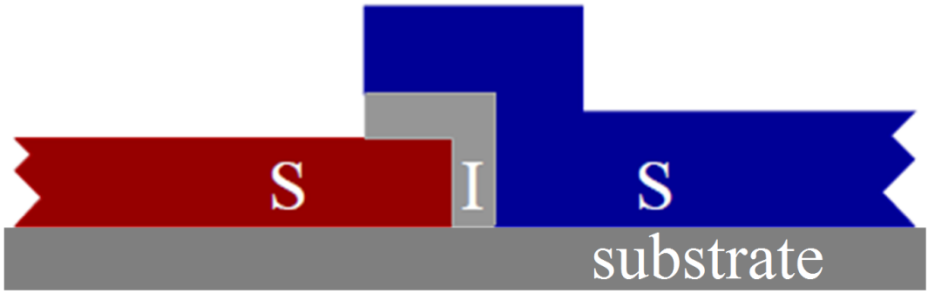


Lange et al., PRL **115** (2015)



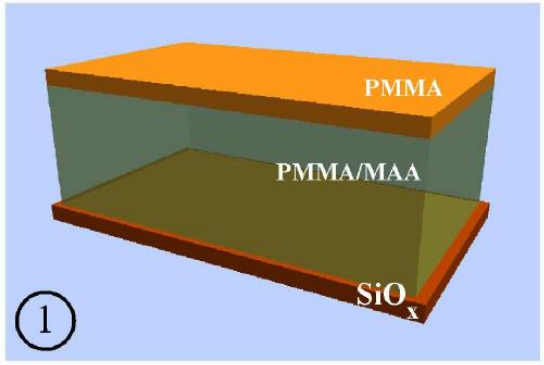
The building blocks of superconducting circuits: SIS Josephson junctions

Side view



Qubit Fabrication : Dolan bridge technique

Spin the
PMMA resist



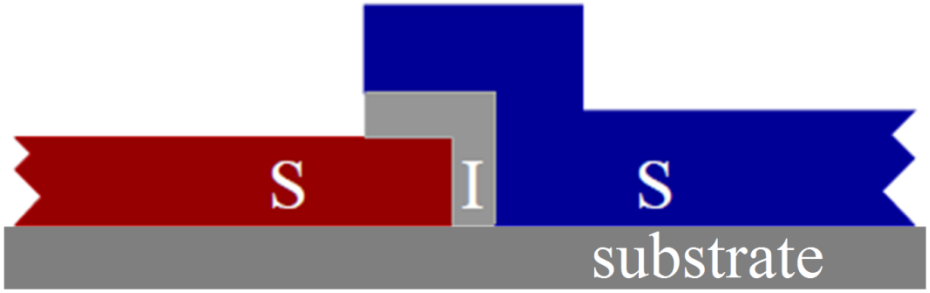
Death Valley

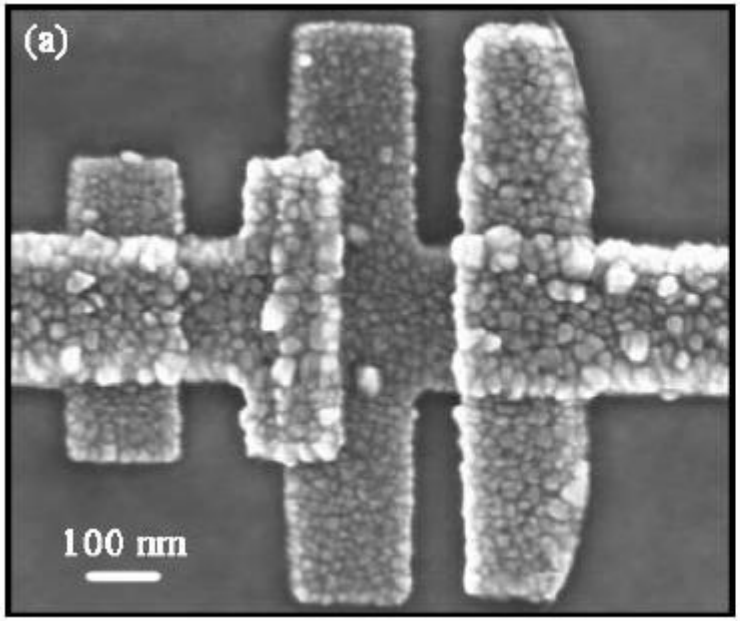
An intuition about our junctions with AlO_x

Red Rock Canyon

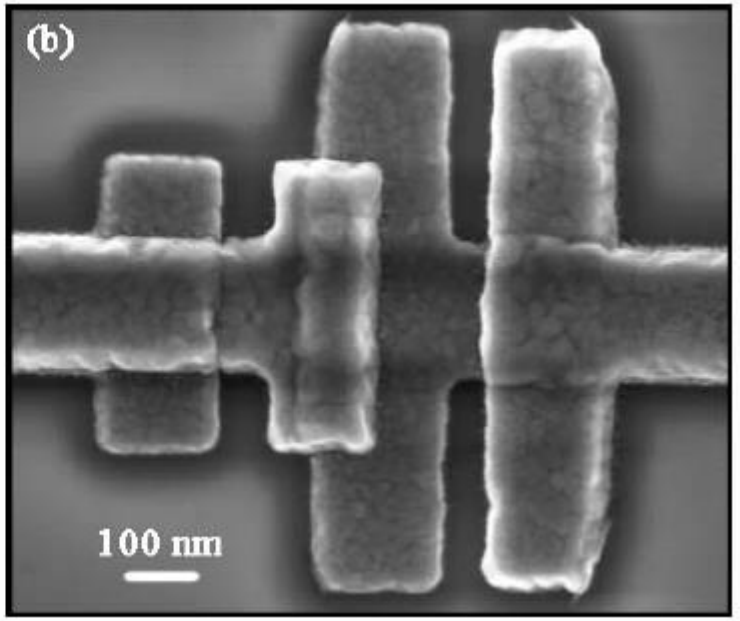
The building blocks of superconducting circuits: SIS Josephson junctions

Side view



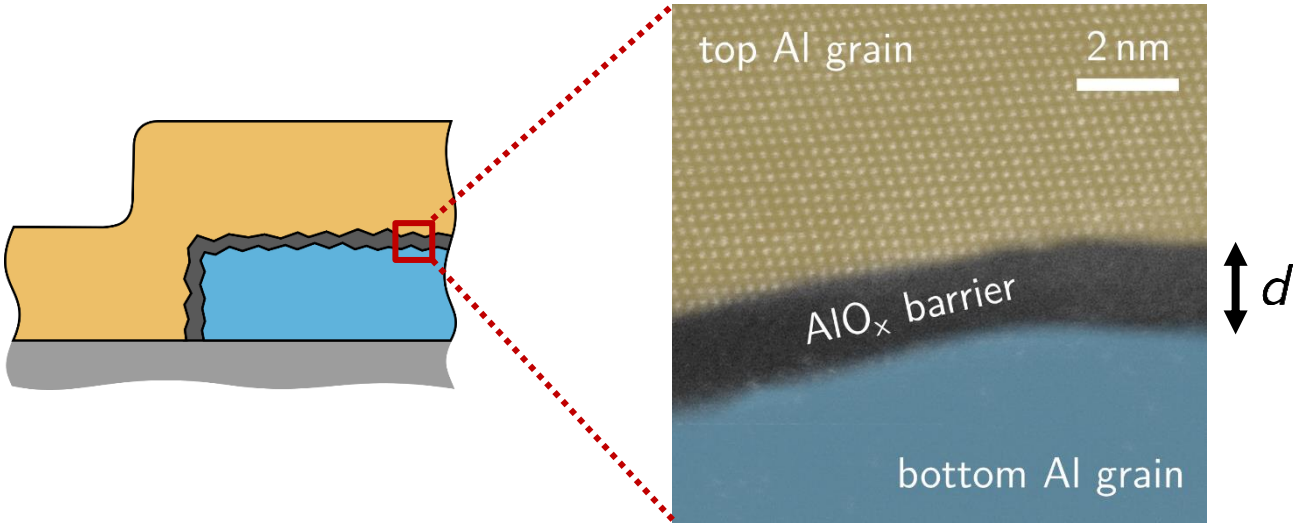


Slow deposition: 0.1 nm/s

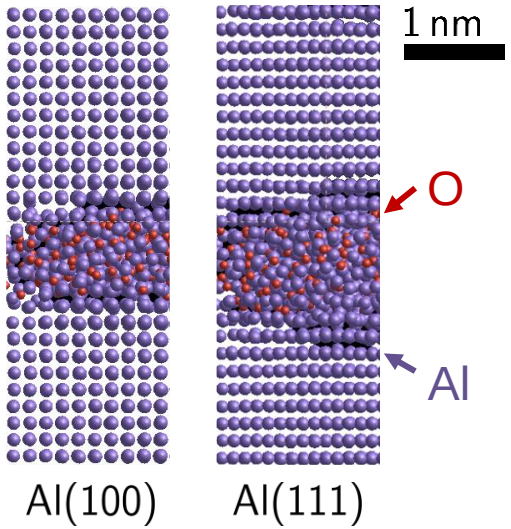


Fast deposition: 1 nm/s

Transmission Electron Microscopy and Molecular Dynamics reveal AlO_x barrier inhomogeneity



Schüffelgen Group, FZ Jülich



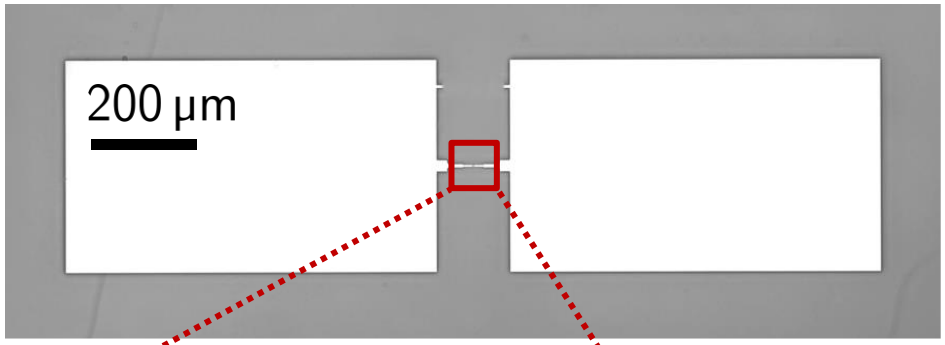
ITIM Group, Cluj, Romania

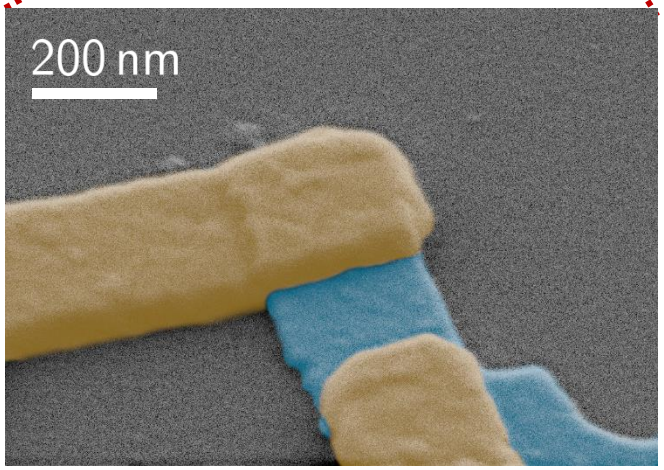
Gaussian thickness distribution → few % of $\sin 2\varphi$

Gianluigi Catelani, FZ Jülich

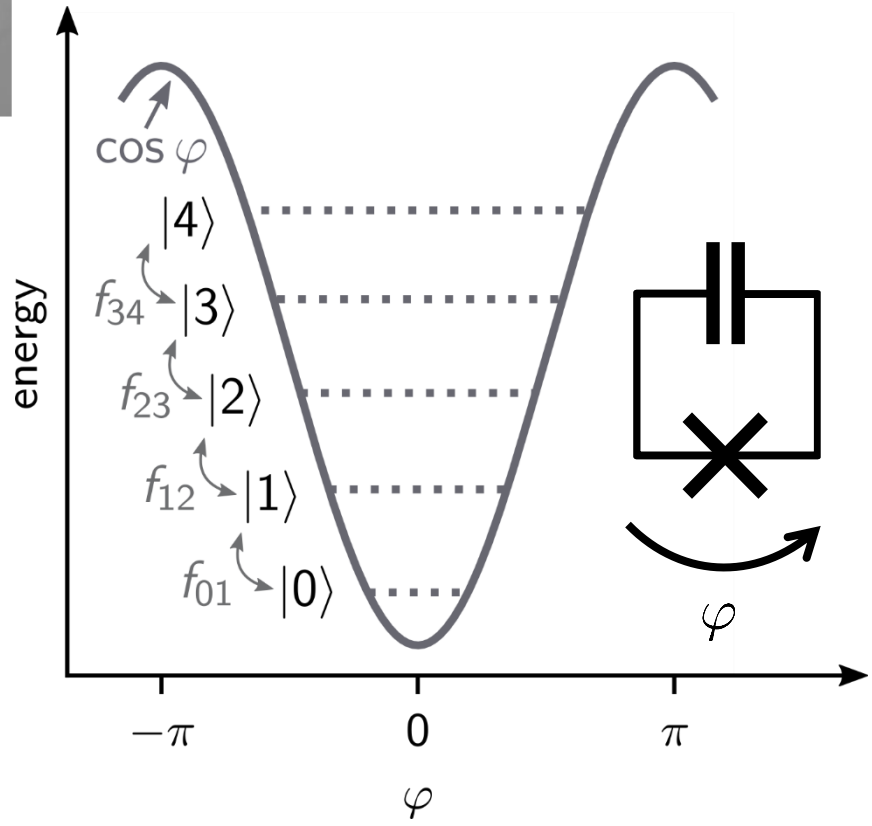
Willsch & Rieger et al. Nature Phys. 2024

Example of a “transmon” qubit



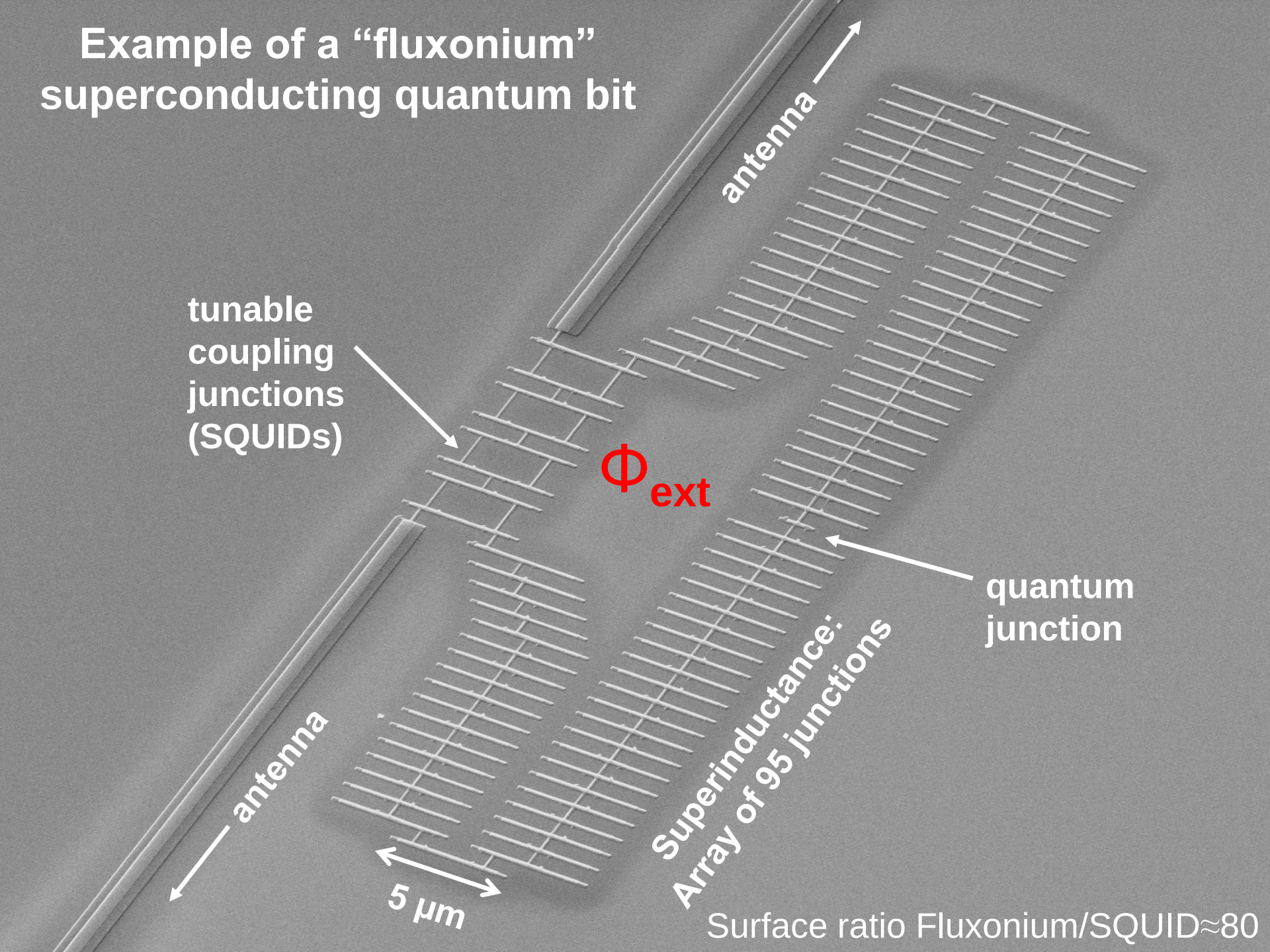


$$H = 4E_c n^2 - E_J \cos\varphi$$



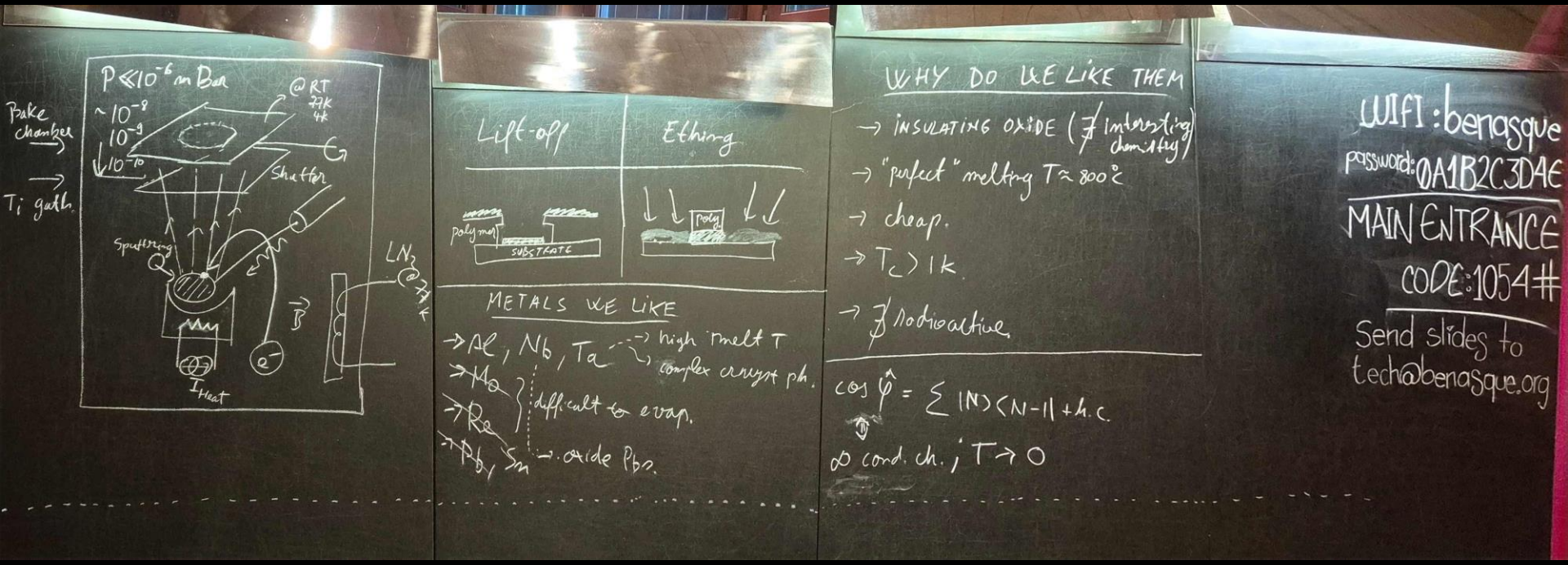
Willsch & Rieger et al. Nature Phys. 2024

Example of a “fluxonium” superconducting quantum bit



Surface ratio Fluxonium/SQUID≈80

The Board


P ≪ 10⁻⁶ mBar
@ RT 77K 4K
~ 10⁻⁸
10⁻⁹
↓ 10⁻¹⁰
Bake chamber
Ti getth.
Shutter
Sputtering
LN₂ @ 77 K
e⁻
I Heat
Lift-off
Etching
poly mask
SUBSTRATE
poly
METALS WE LIKE
→ Al, Nb, Ta → high melt T
→ complex cryst ph.
→ Mo
→ Re
→ difficult to evap.
→ Pb, Sn → oxide Pb?
WHY DO WE LIKE THEM
→ INSULATING OXIDE (≠ interesting chemistry)
→ "perfect" melting T ≈ 800°C
→ cheap.
→ T_c > 1K
→ ≠ radioactive
cos φ̂ = Σ |N⟩⟨N−1| + h.c.
∞ cond. ch.; T → 0
WIFI: benasque
password: 0A1B2C3DAE
MAIN ENTRANCE
CODE: 1054#
Send slides to
tech@benasque.org