Superconductors to jump in the future

Andrea Bersani

INFN Sezione di Genova
Istituto Nazionale di Fisica Nucleare

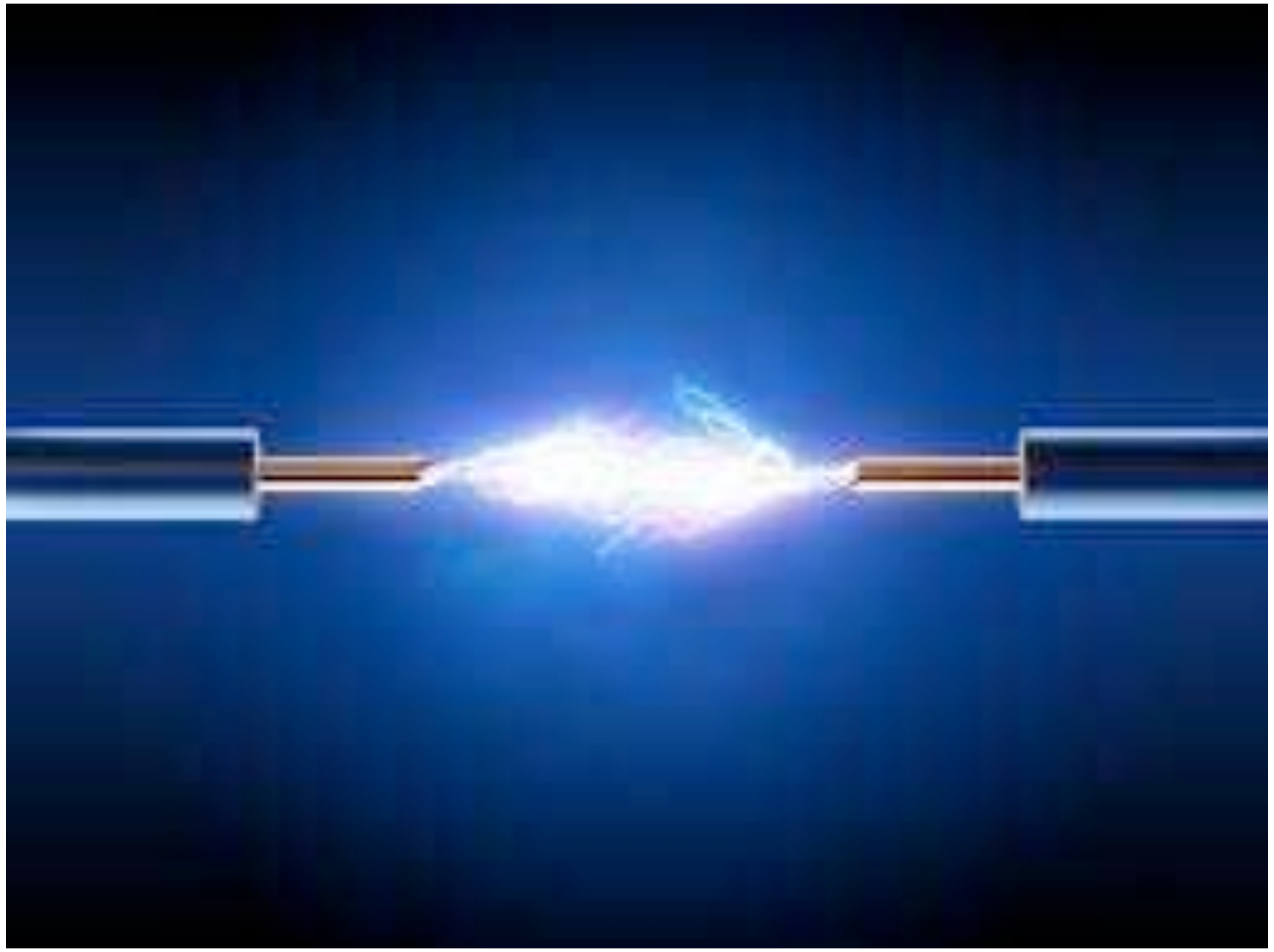
Dedication

We would like to dedicate
this talk ~~this book~~ to the memory of
Benjamin Franklin
whose arbitrary selection of polarity
has confounded myriads of physics students.

- from Conte-Mackay, An Introduction to the Physics of Particle Accelerators

Normal conductivity

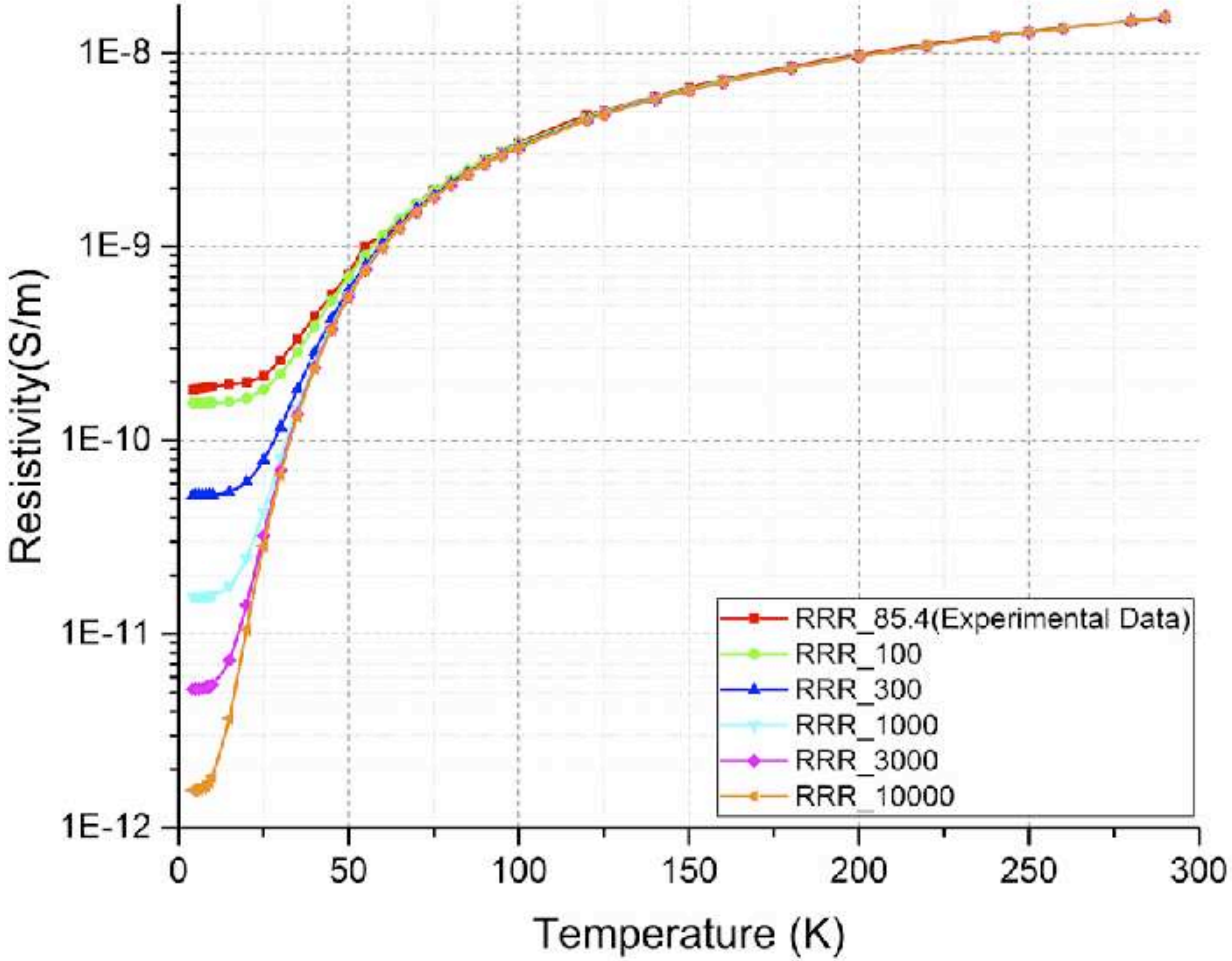
- Some materials are conductors
  - metals in particular
- Some are excellent conductors
  - copper, aluminium, gold, silver...
- Some are insulating
  - oxygen, nitrogen, rare gases
- ... at room conditions



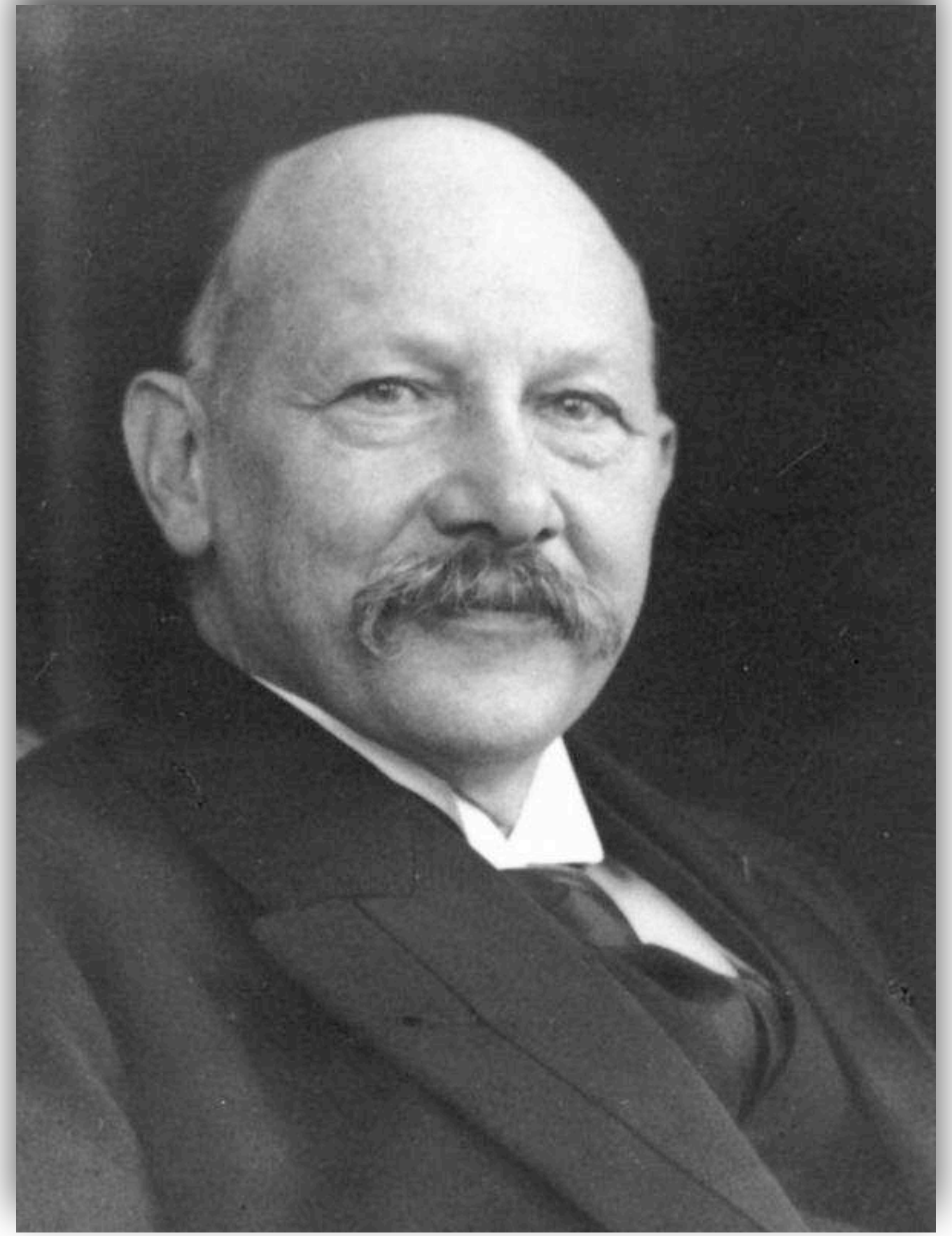
- Conductivity is due to electrons that travel in a material
- Also the "best" conductors have some non vanishing resistivity

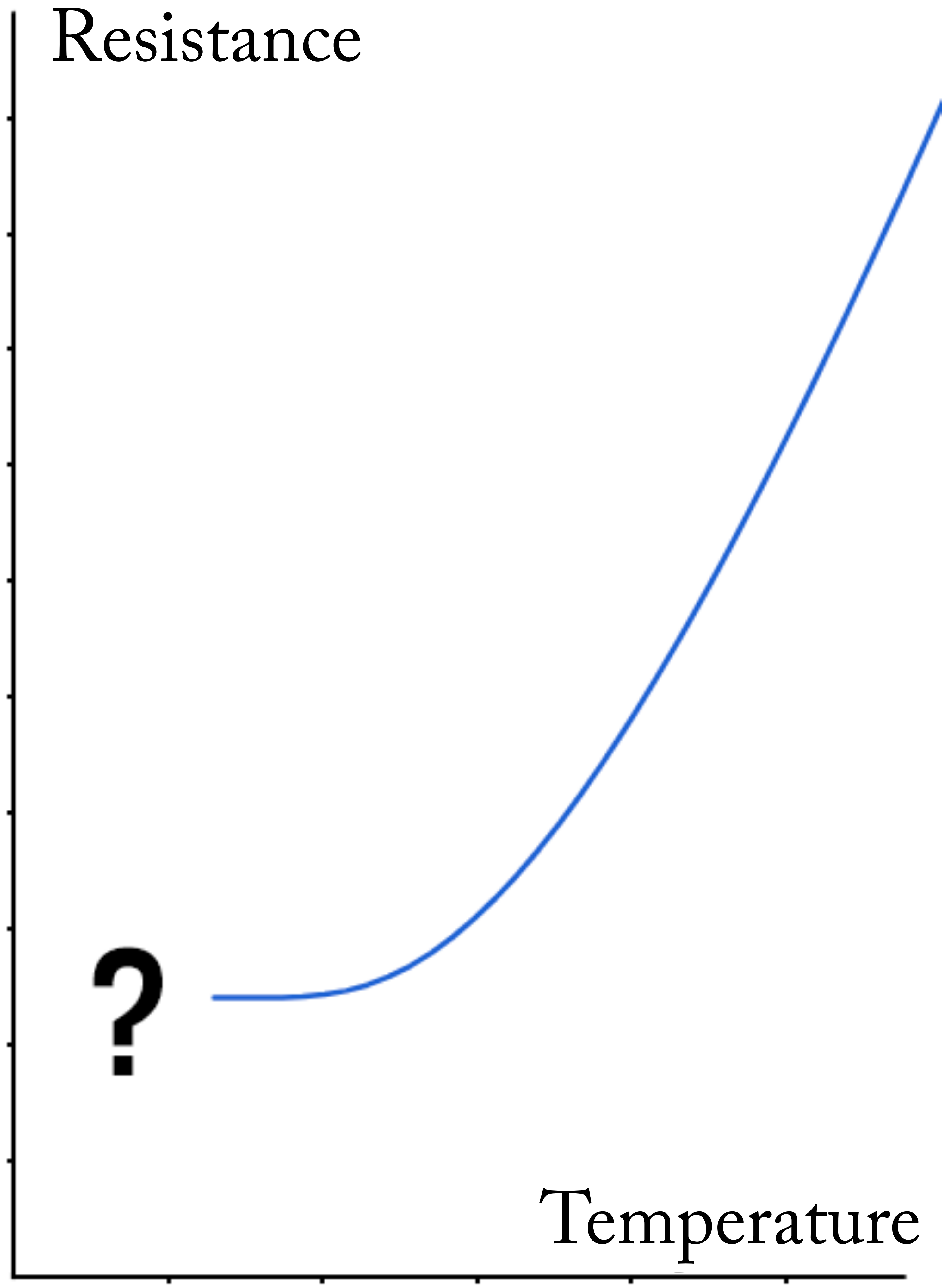
Resistivity vs. temperature

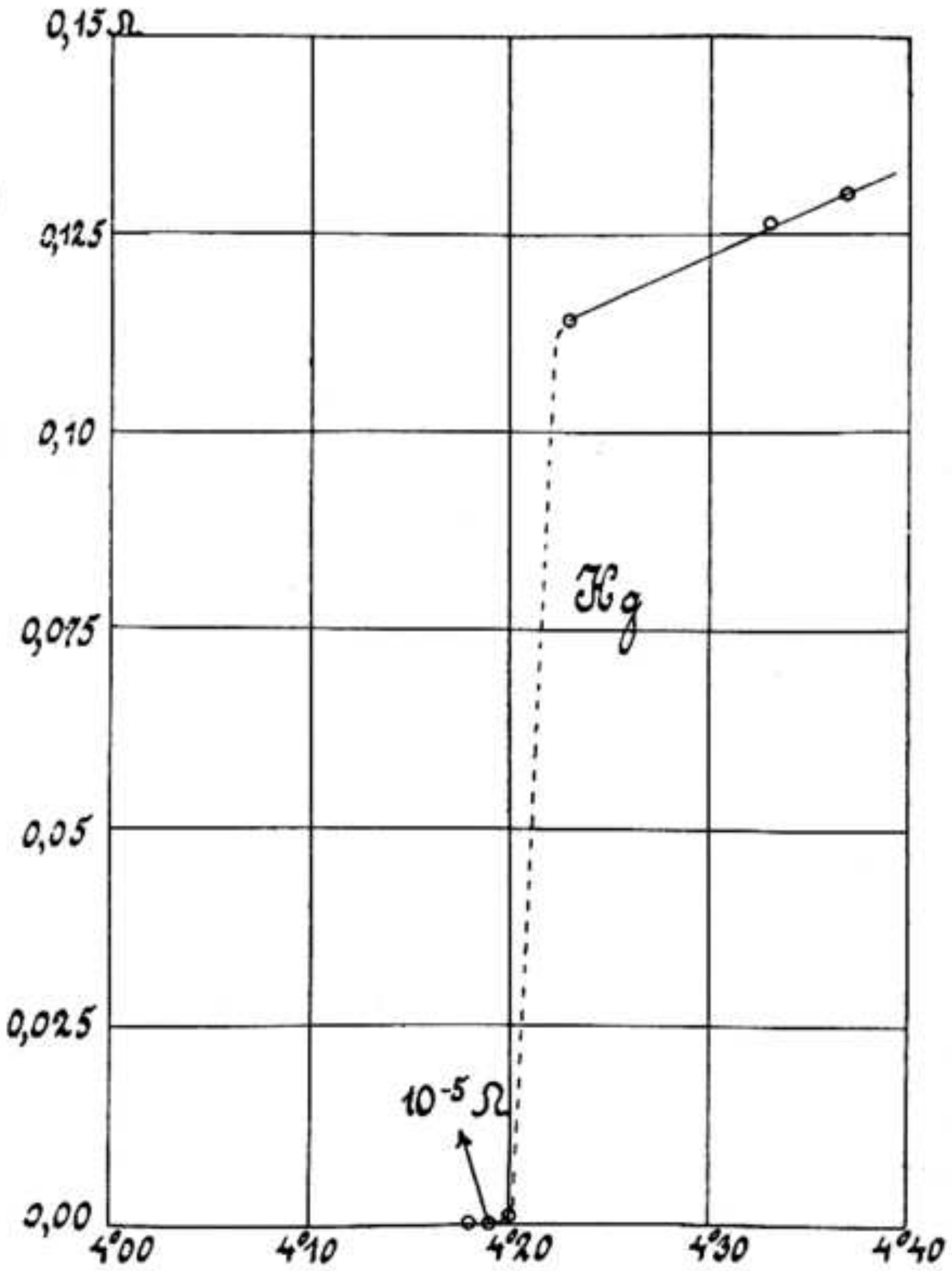
- In general, resistivity decreases
- At a certain T, it stabilises
- We got RRR
- Why it stabilises
- What happens if we go colder?
- At 0 K everything "freezes"
- Should the electrons stop?



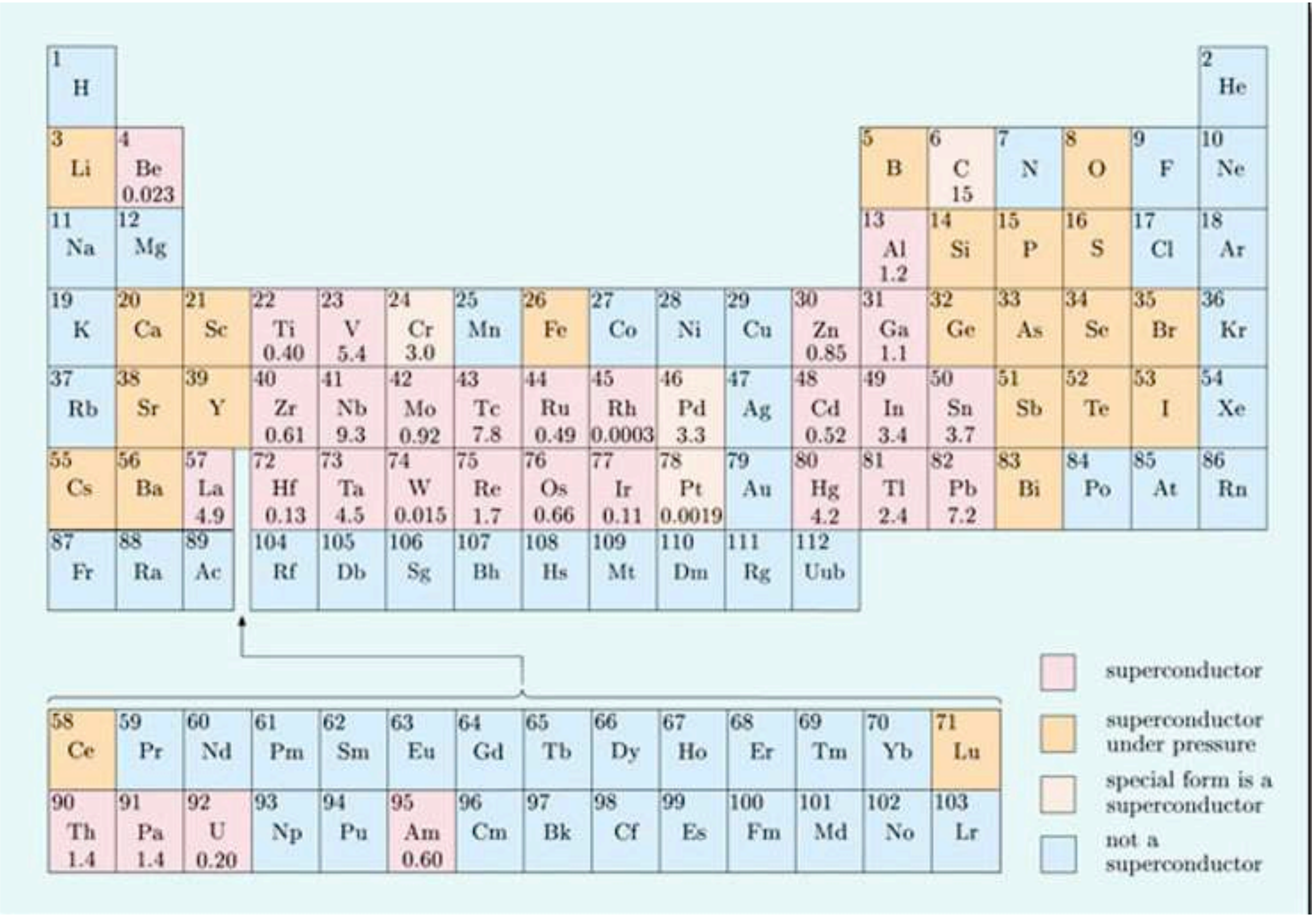
A "reversed" discovery



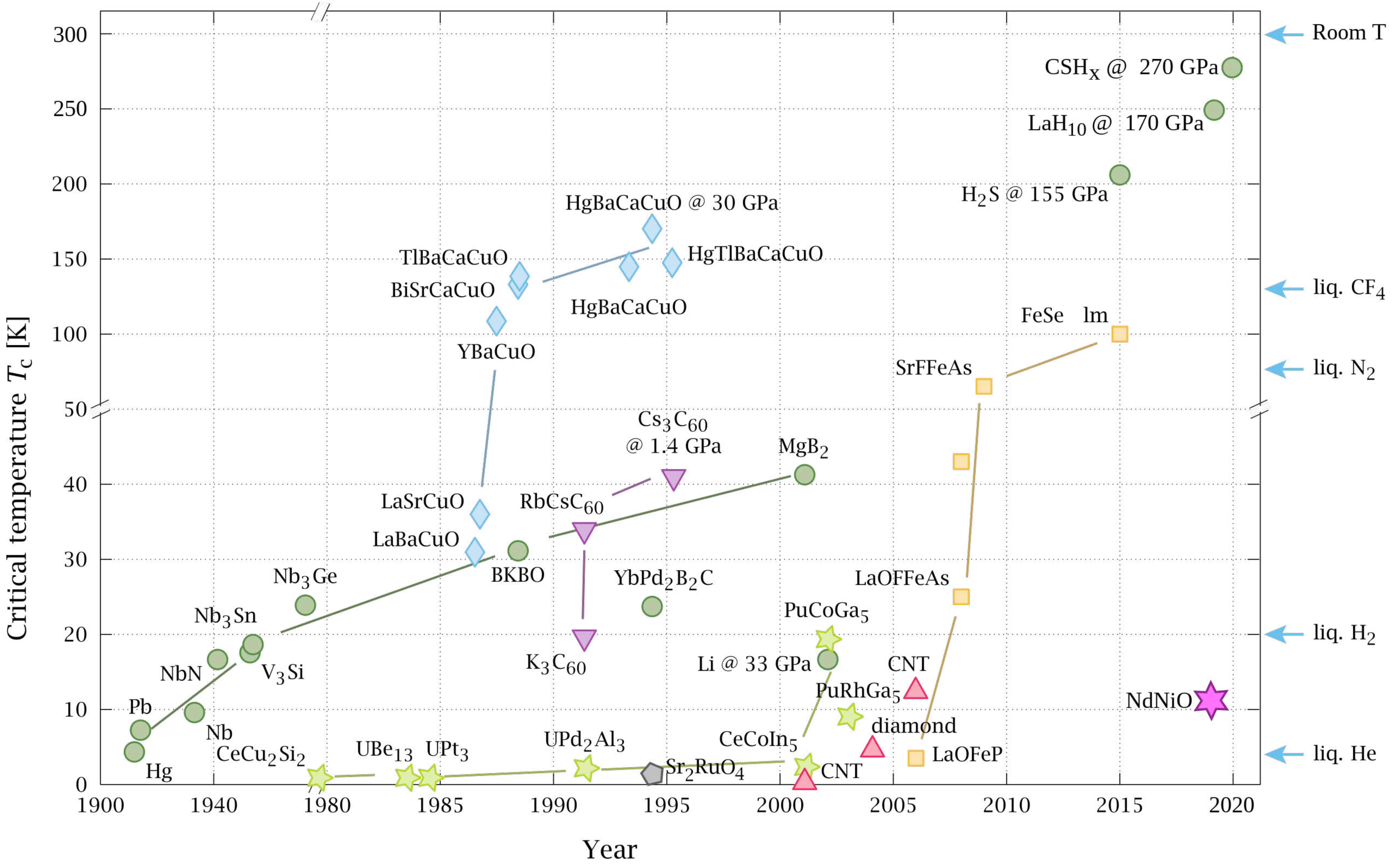




Superconducting elements



Superconducting materials



How this works

- It's not so clear

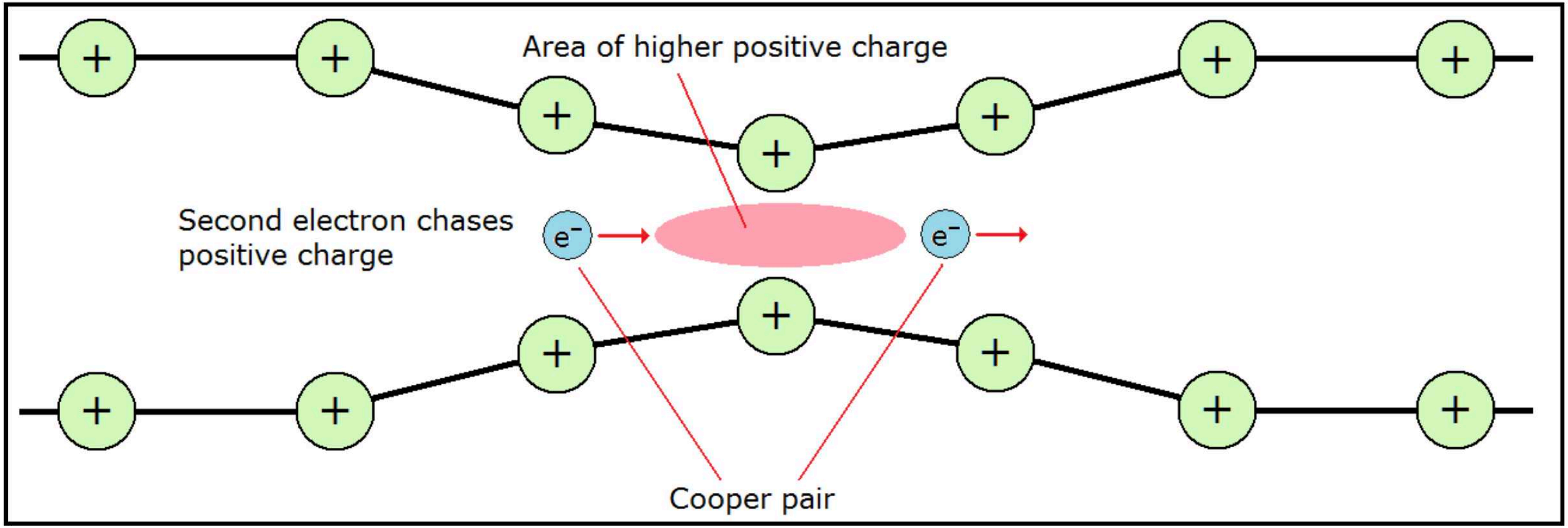
- For pure metals, some quantum mechanical effect
  - Cooper pairs
  - crystal lattice is too coherent
  - electrons travel untouched

- For alloys and intermetallic compounds... fairly clear
  - almost the same scenario, actually not everyone is convinced, but they works fine

- For non metallic crystals... not clear at all
  - resistivity at room temperature is some 5 orders of magnitude worse than conductors one
  - indeed, some 20 orders of magnitude better than insulators

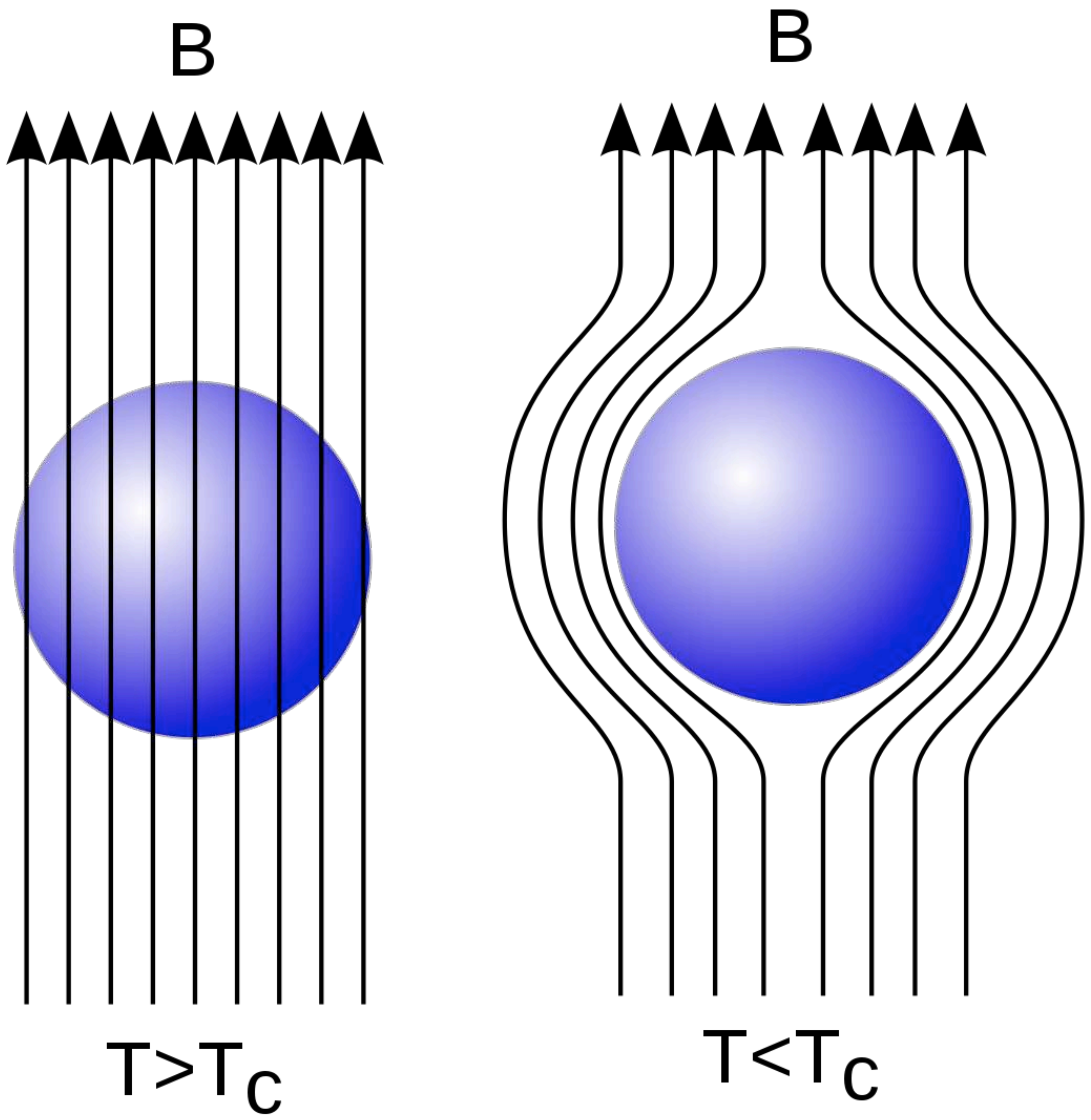
Cooper pairs

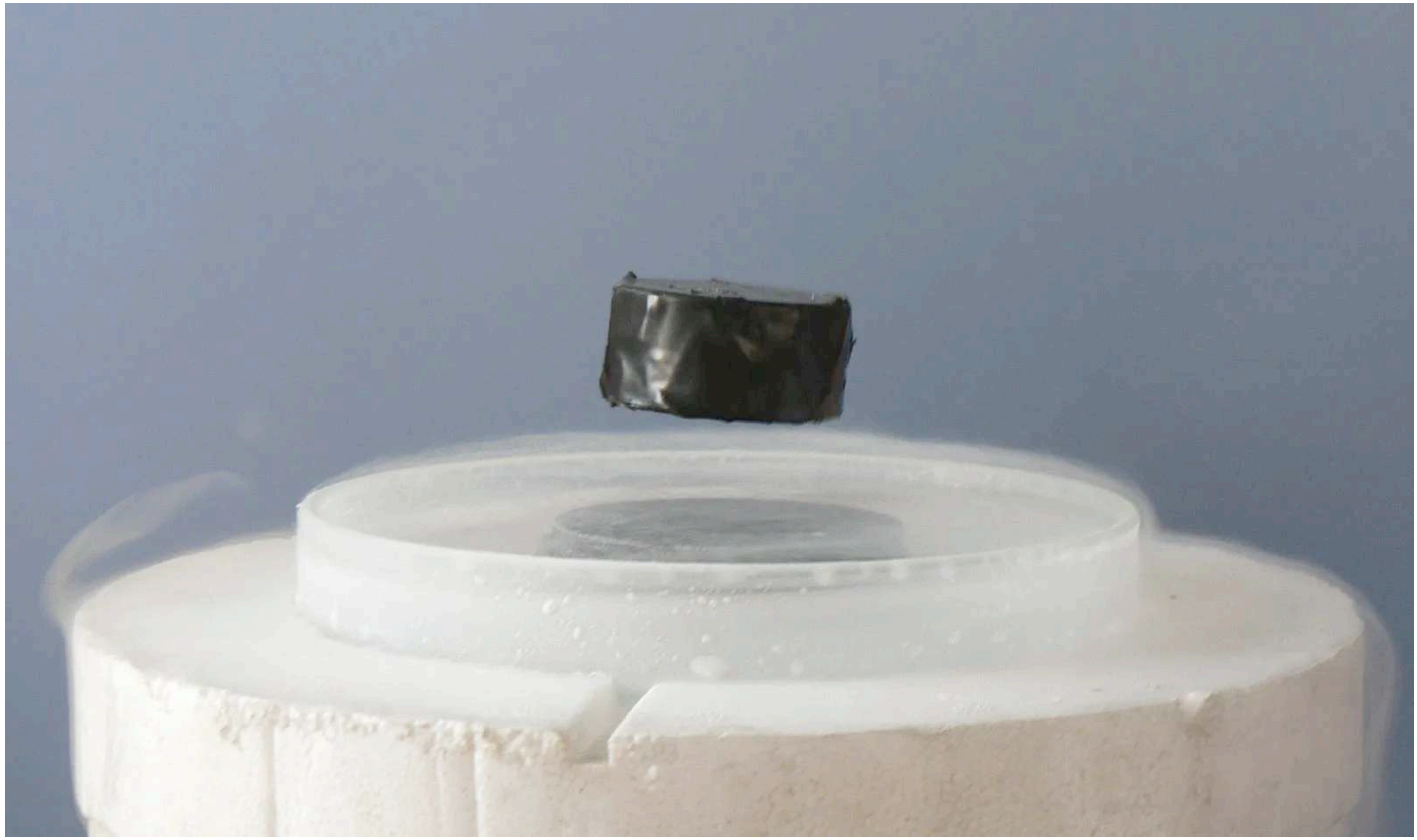
- Theory from Bardeen, Cooper and Schrieffer (out in 1957, BCS, Nobel in 1972)
- In a superconductors, electrons "pair" and exchange energy only among themselves



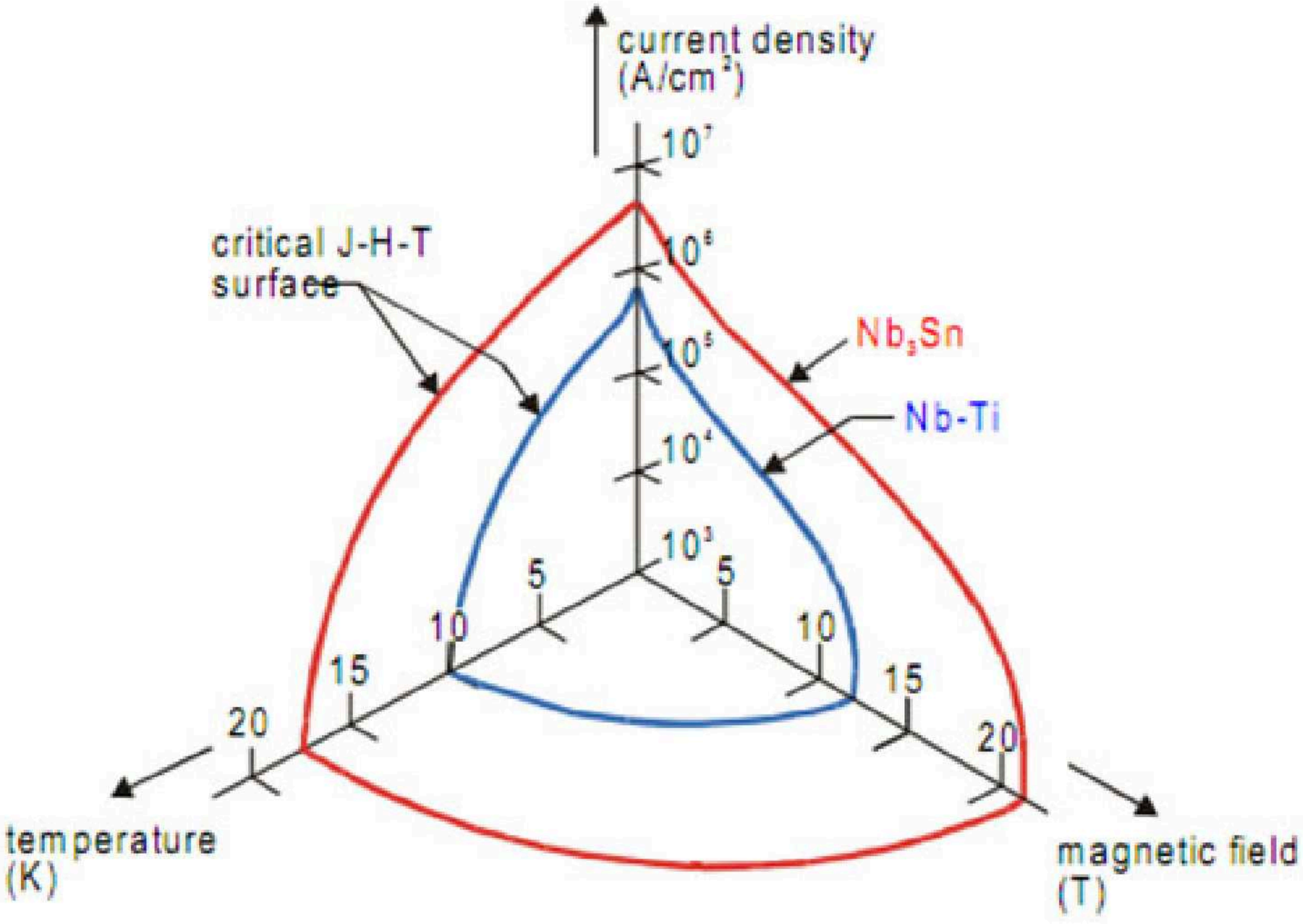
https://dc.edu.au/wp-content/uploads/cooper-pair-phonon.png

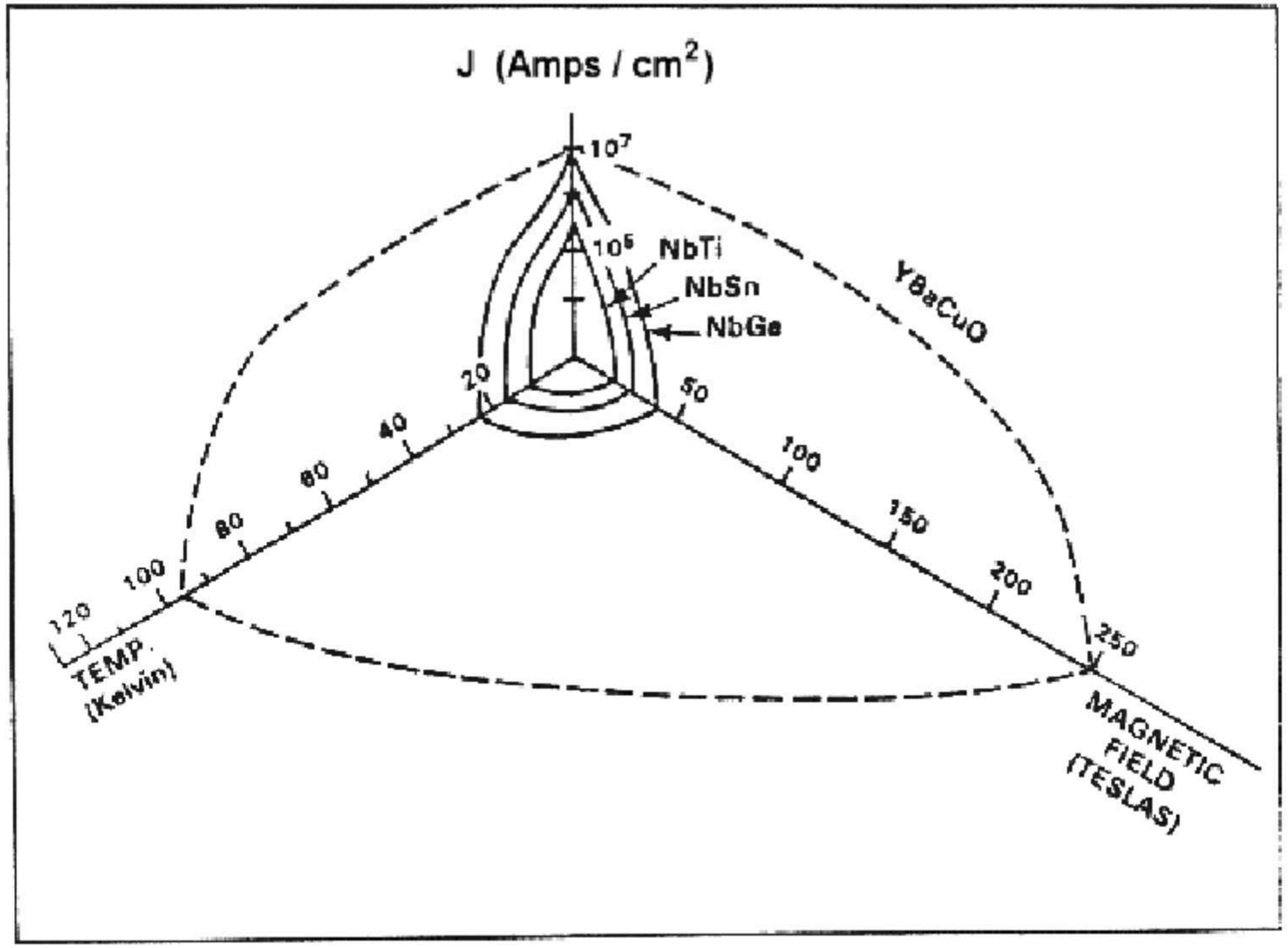
Other cool features of S/C





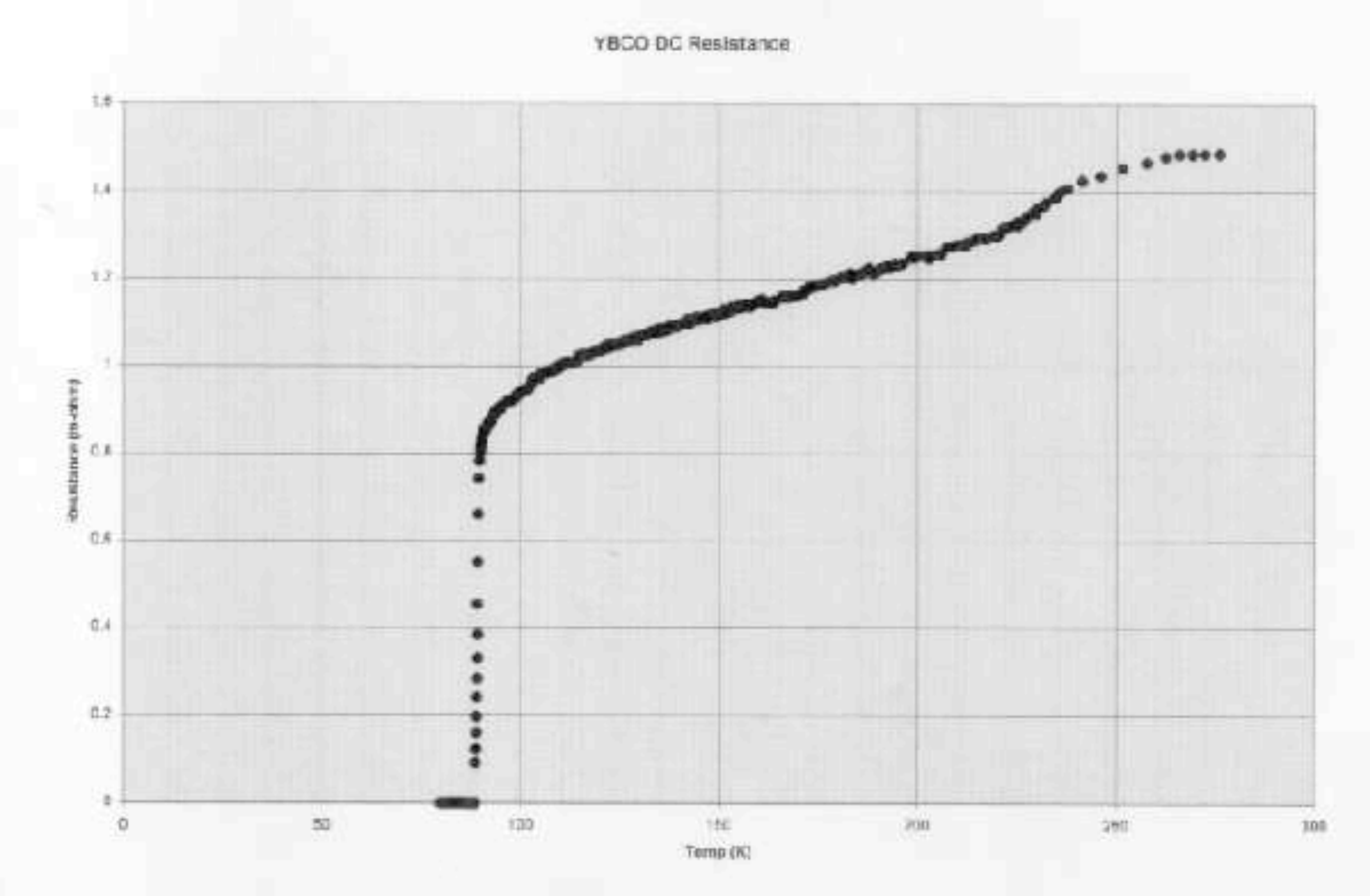
Superconductivity vs. not only T





Why S/C depends on T

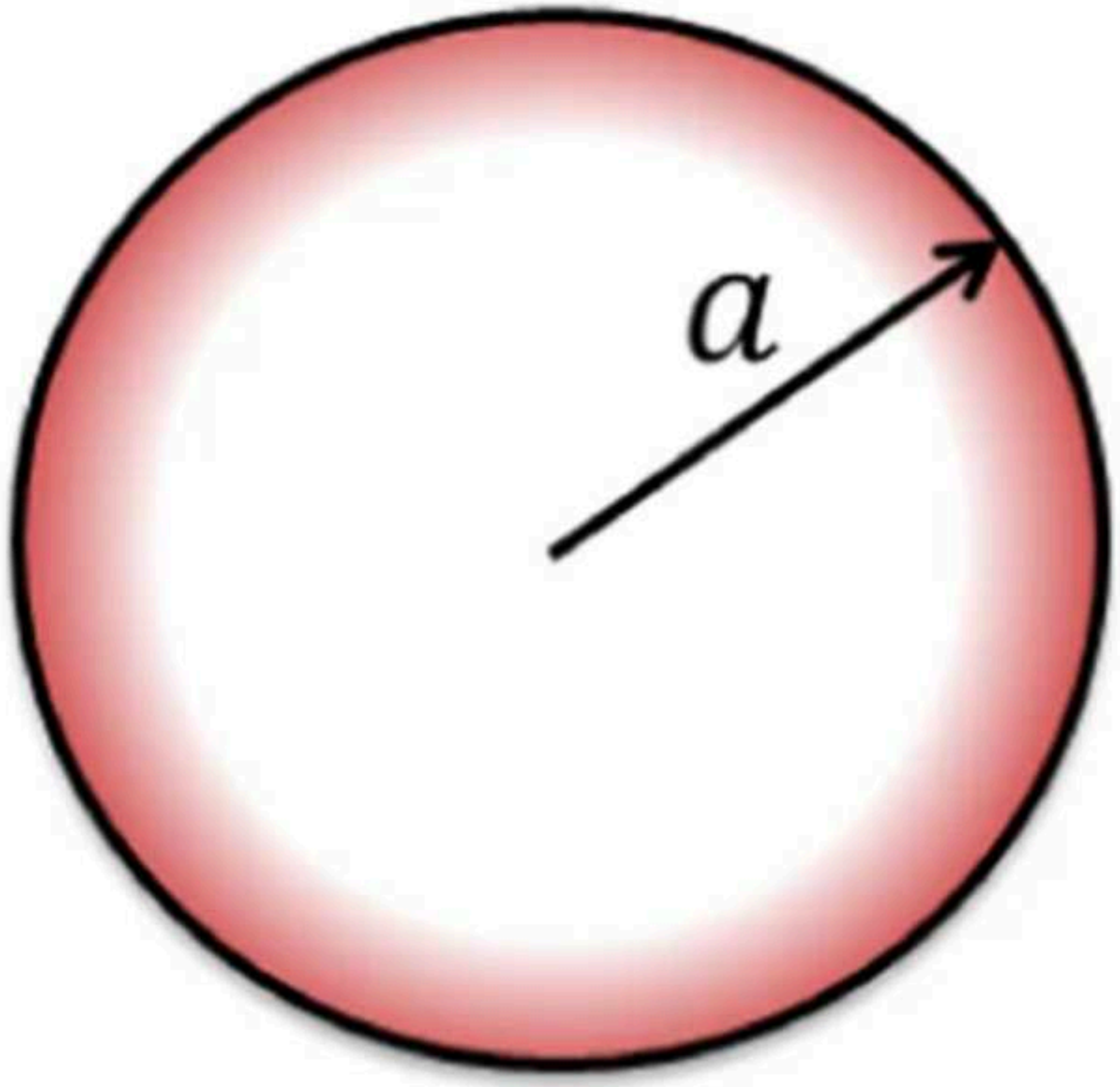
- Essentially increasing T you make the lattice less "monolithic"
- Electrons can release energy in the bulk



Why S/C depends on current

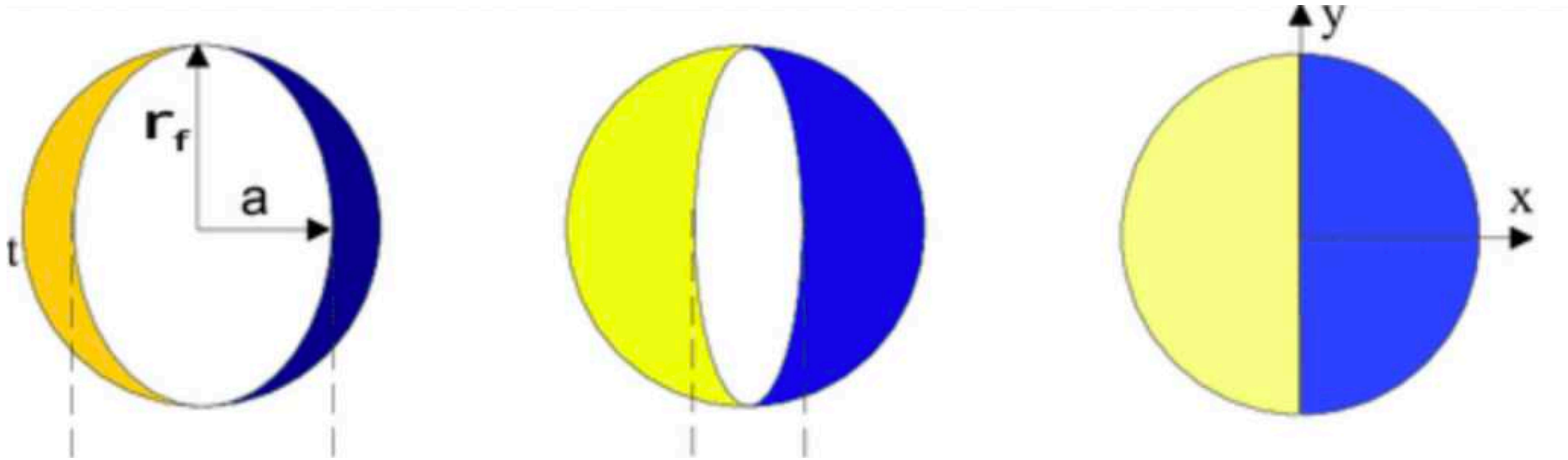
- Current is carried by electrons
- In a S/C, electrons try to run along the surface
- They have a finite density in the material
- Current density is electron volume density multiplied by drift speed
- If current increases too much, speed must increase
- At a certain point, they have sufficient energy to release a part of it to the lattice

$a \gg \lambda$



Why S/C suffers external magnetic field

- To expel external field, currents arise in the S/C
- They decrease the available density of "free" electrons
- At the limit, the screening currents reach the critical current

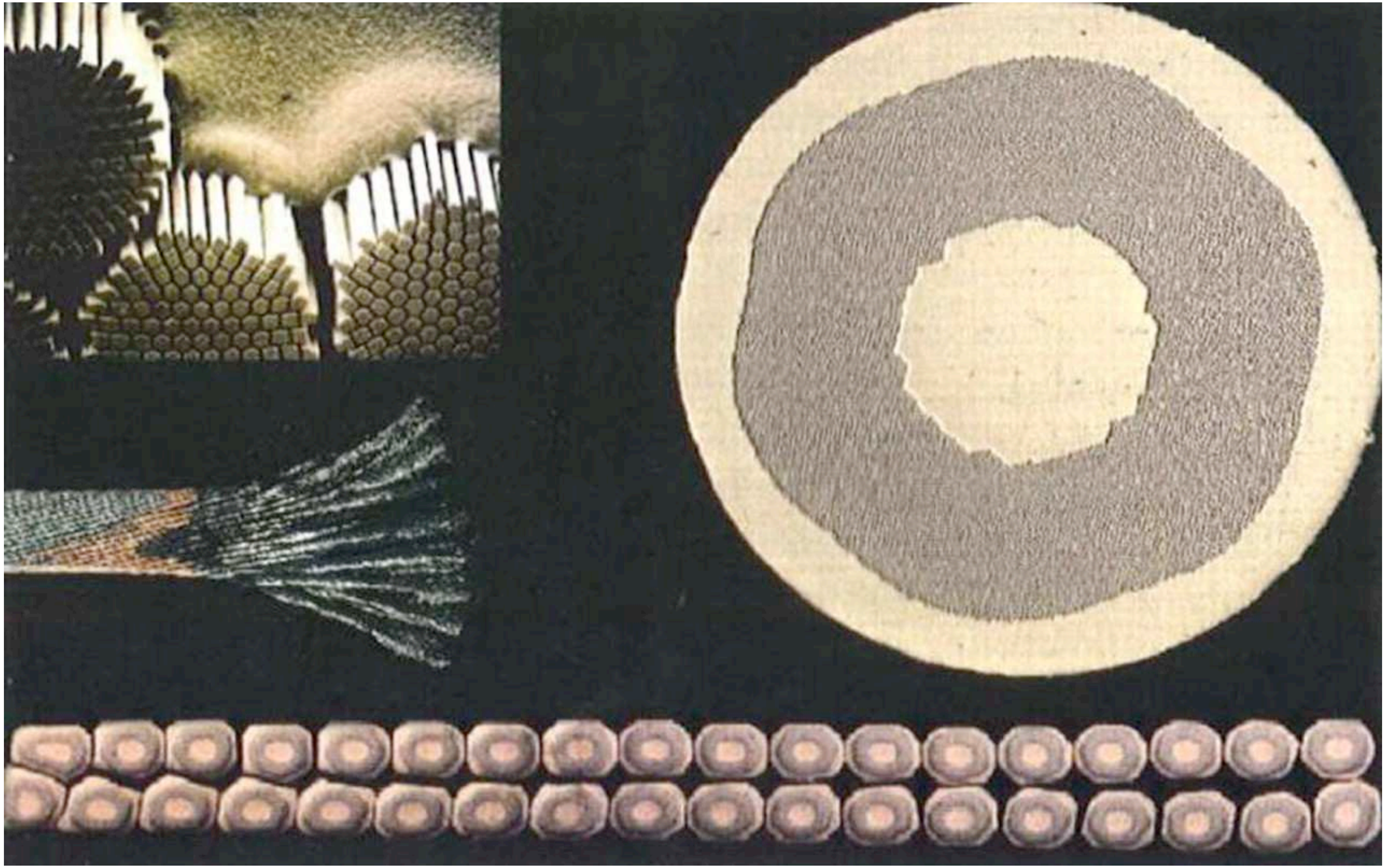


(almost) Room temperature S/C

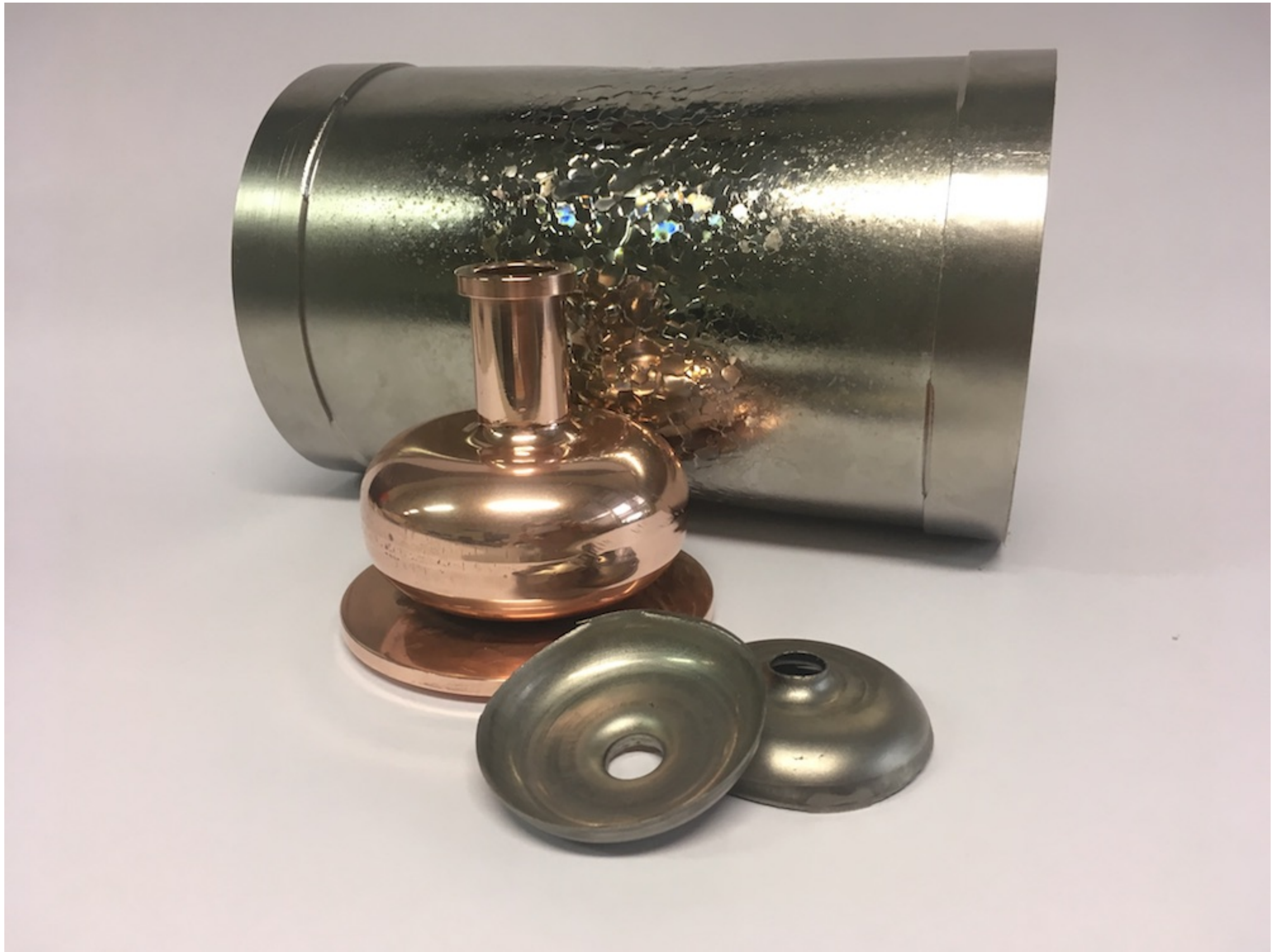
- Some materials show S/C at "room" temperature
- They are BCS compliant
- They only work under HUGE pressure
- Hundreds of gigaPascal
  - millions of atmospheres
- Fairly unpractical
- Recent claim for RT S/C is "controversial"
- "Carbonaceous sulfur hydride" at +15°C
  - presently the paper has been retracted

Superconducting cables stack

Superconducting strands and filaments



Where you can find them

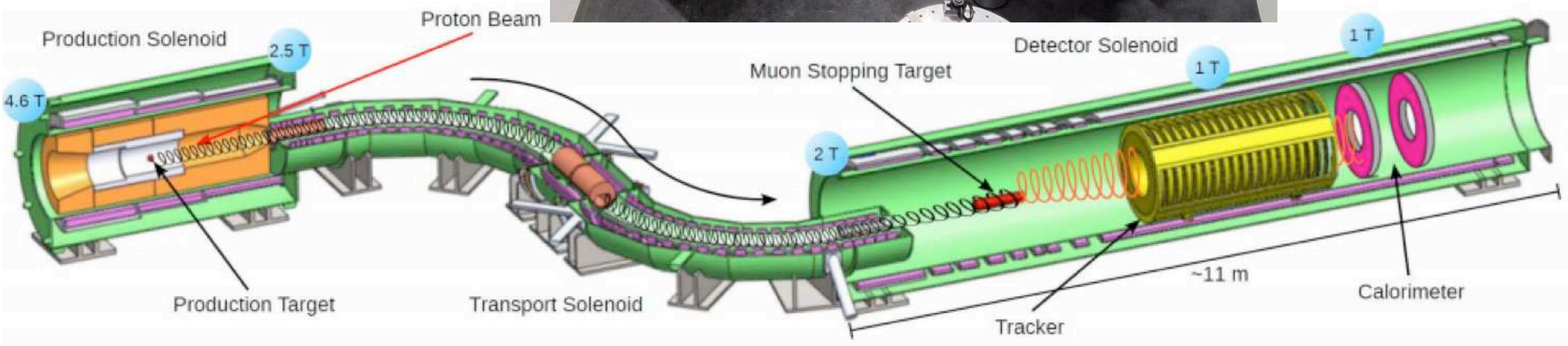


Where you can find them

Where you can find them

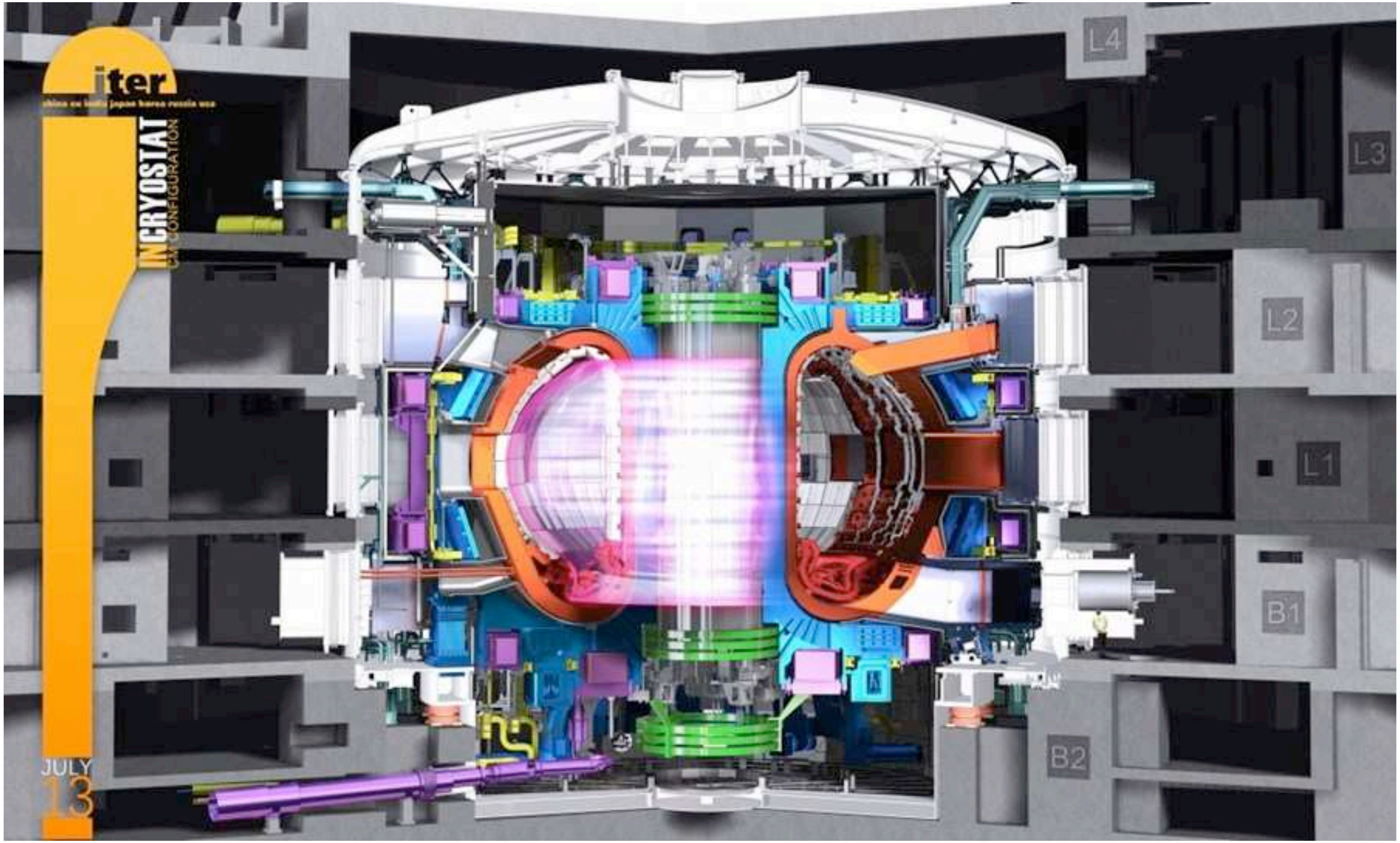
What we do today

Mu2e @ FermiLab



What we do today

ITER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IN CRYOSTAT
CAT CONFIGURATION
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L4
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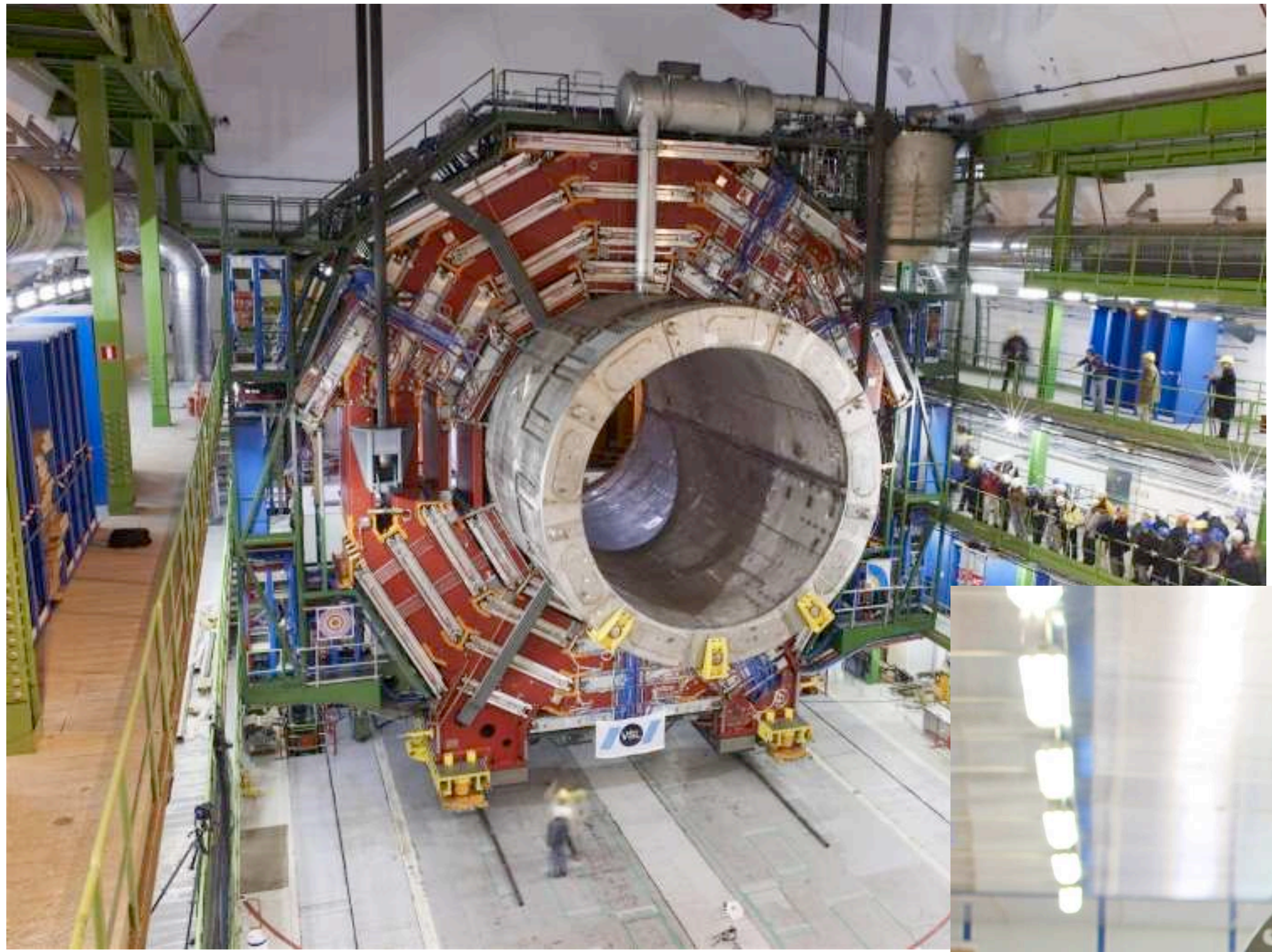
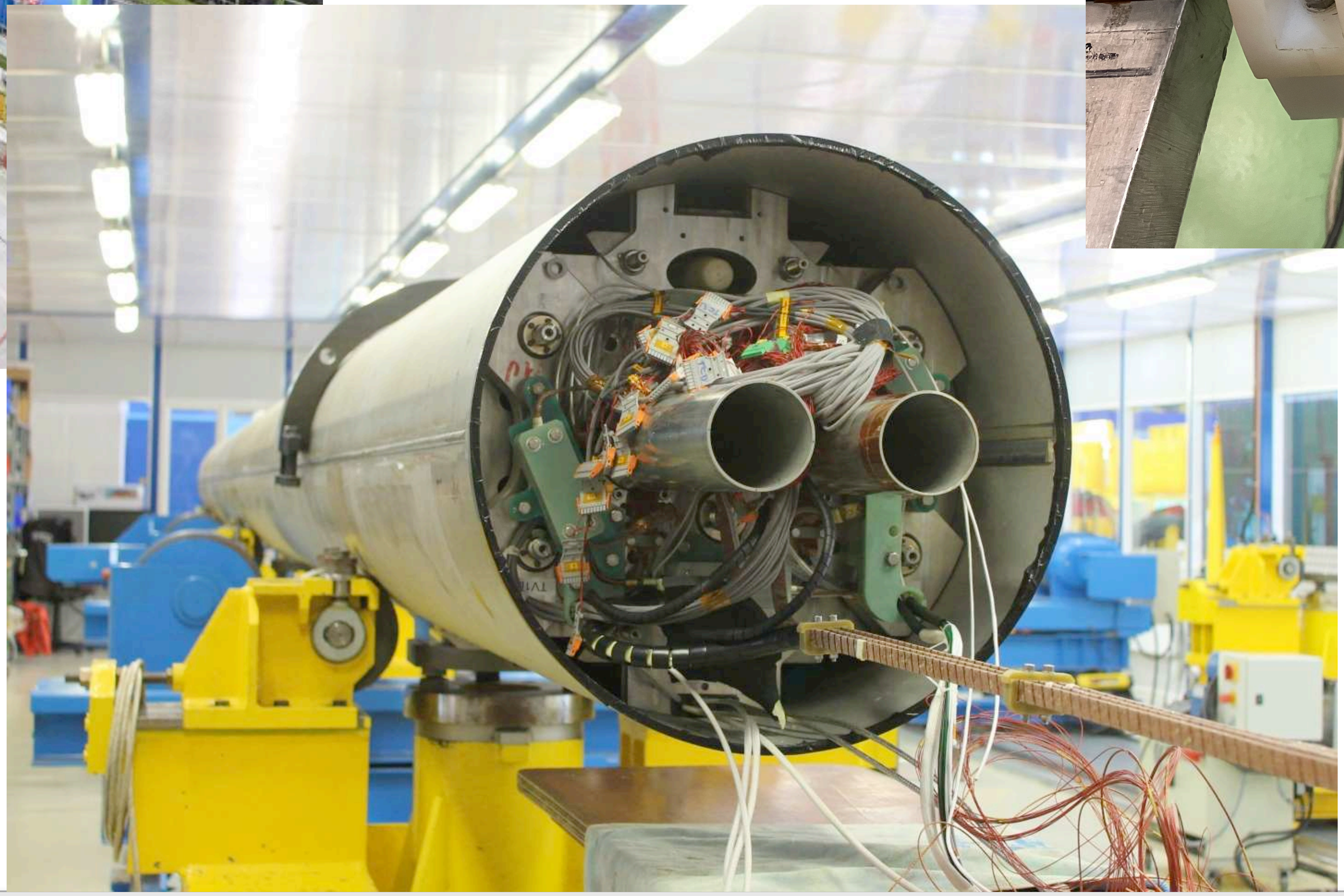
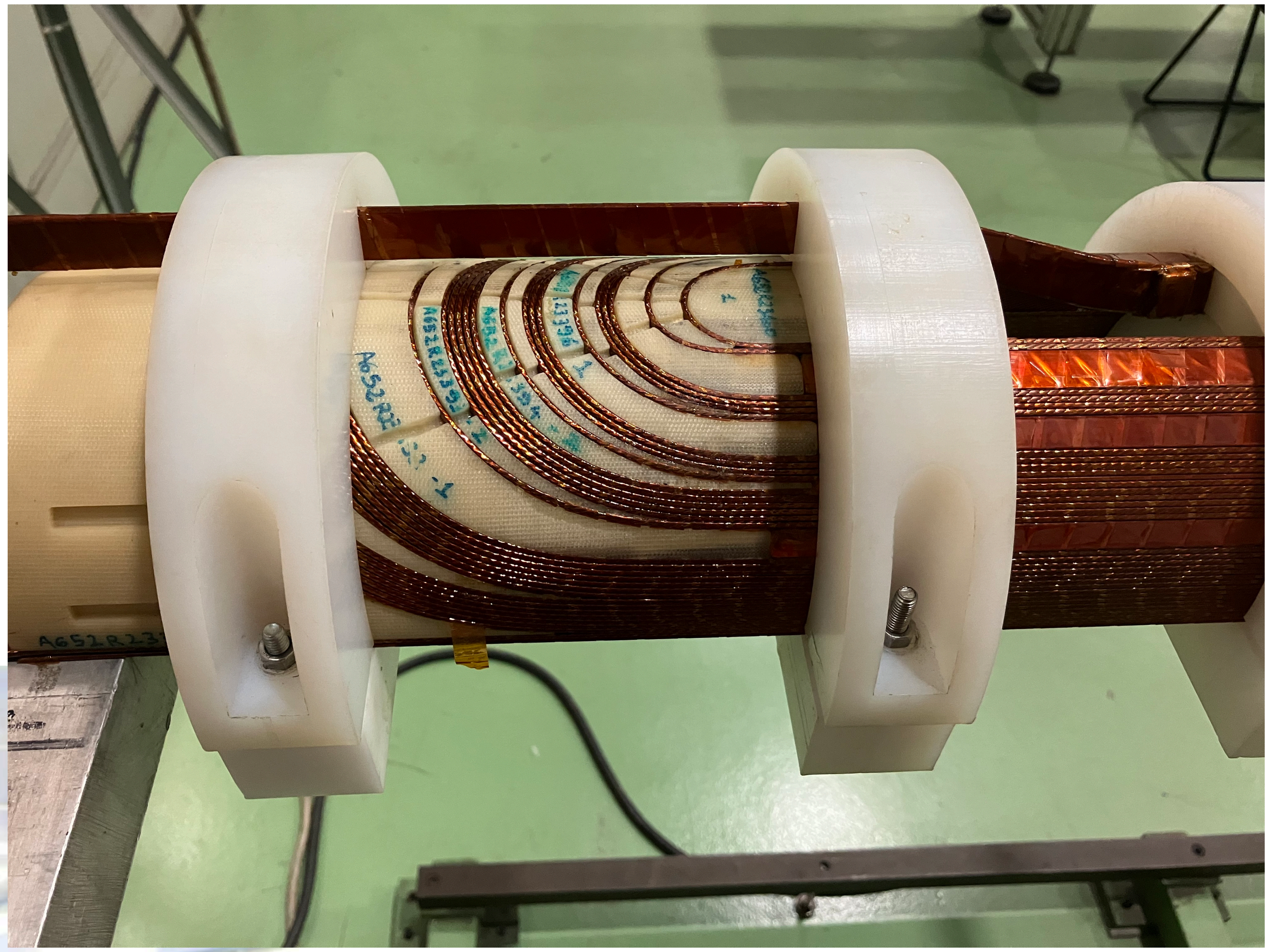
What we do today

Shortly, BIG and STRONG magnets

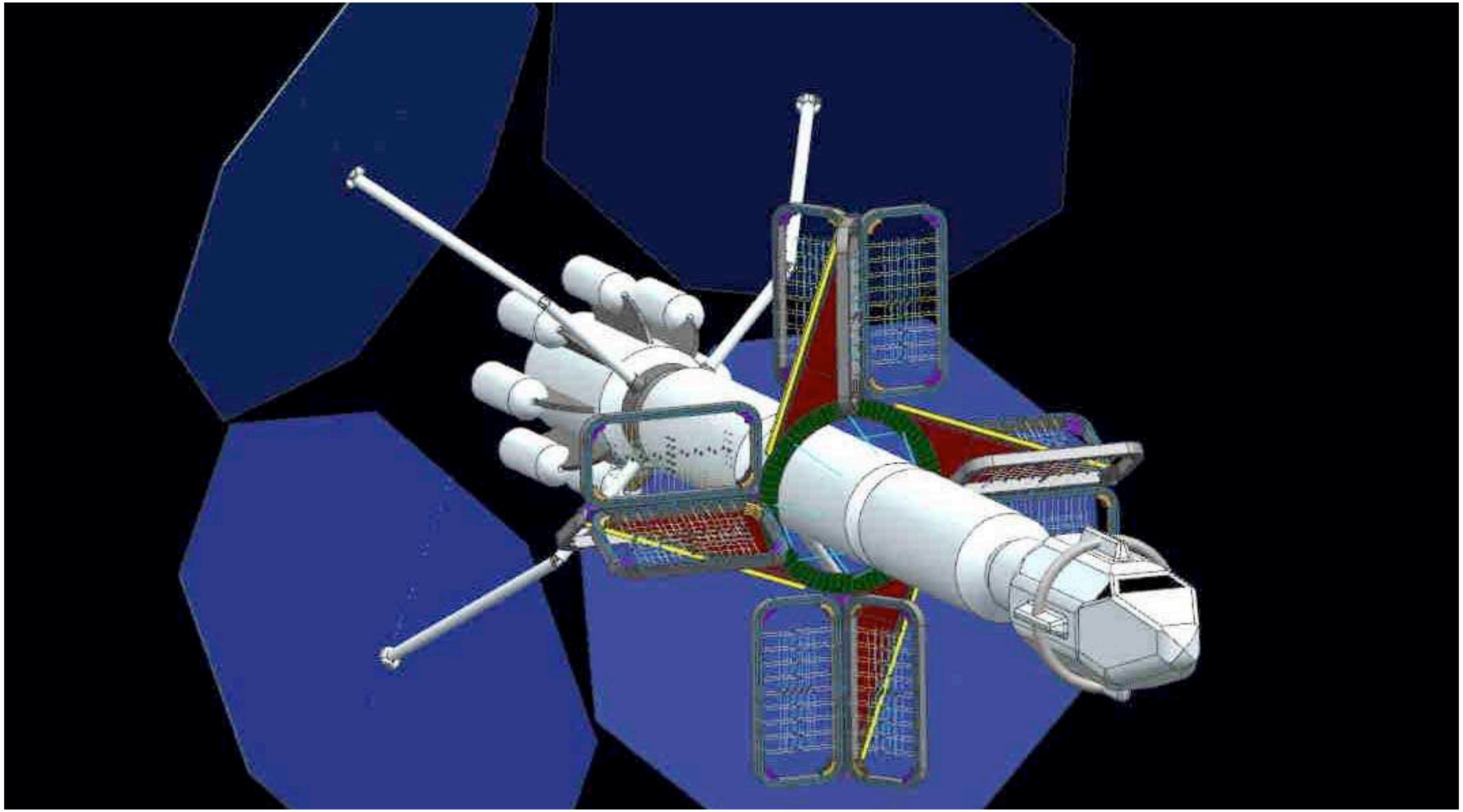






What we could do tomorrow

What we could do tomorrow



What we could do tomorrow

Just in my city

Waiting for 2061...

- 1911: LTS
- 1986: HTS
- 2061: ???