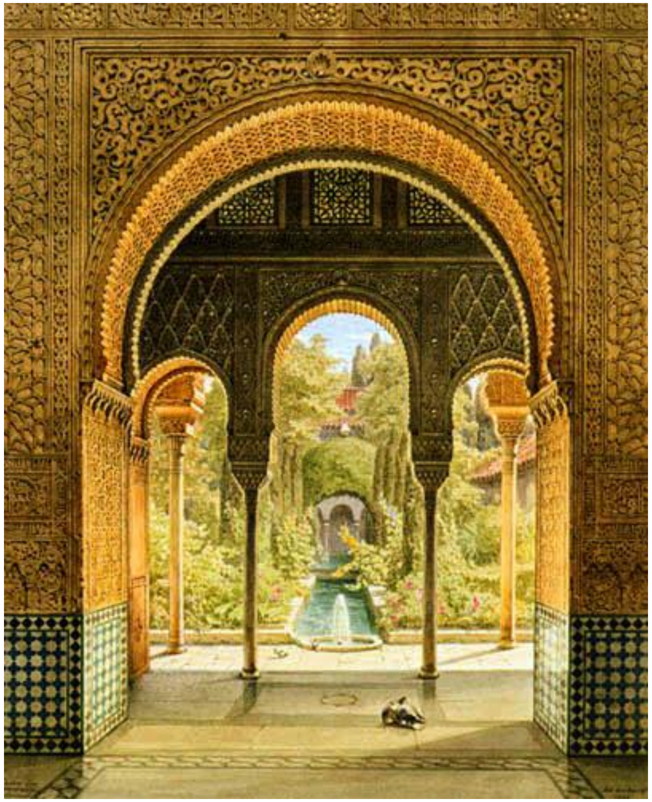
The CERN Accelerator School

# Introduction to Accelerator Physics
# Superconducting Magnets



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28 October - 9 November, 2012

# Overview

- Why superconductors ? A motivation
- A superconductor physics primer
- Superconducting magnet design
  - Superconducting cables
  - Superconducting magnets
- The making of a superconducting magnet
- A closing word

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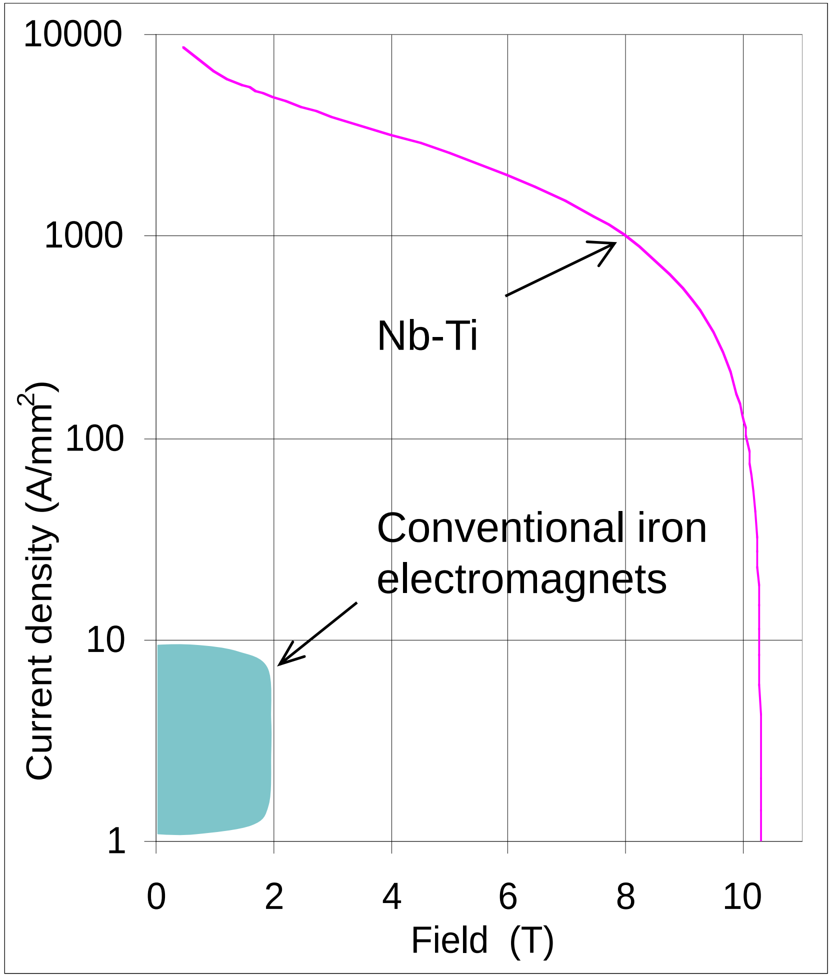
*Graphics by courtesy of M.N. Wilson*

# Why superconductivity anyhow ?

- **Abolish Ohm's law !**
  - no power consumption (although need refrigeration power)
  - high current density
  - ampere turns are cheap, so don't need iron (although often use it for shielding)
- Consequences
  - lower running cost ⇒ new commercial possibilities
  - energy savings
  - high current density ⇒ smaller, lighter, cheaper magnets ⇒ reduced capital cost
  - higher magnetic fields economically feasible ⇒ new research possibilities



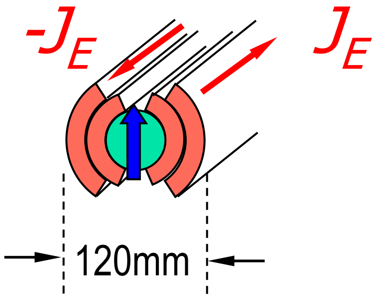
*Graphics by courtesy of M.N. Wilson*

# High current density - dipoles

- The field produced by an ideal dipole (see later) is:

$$B = \mu_o J_e \frac{t}{2}$$

**$J_E$ = 375 Amm$^{-2}$**

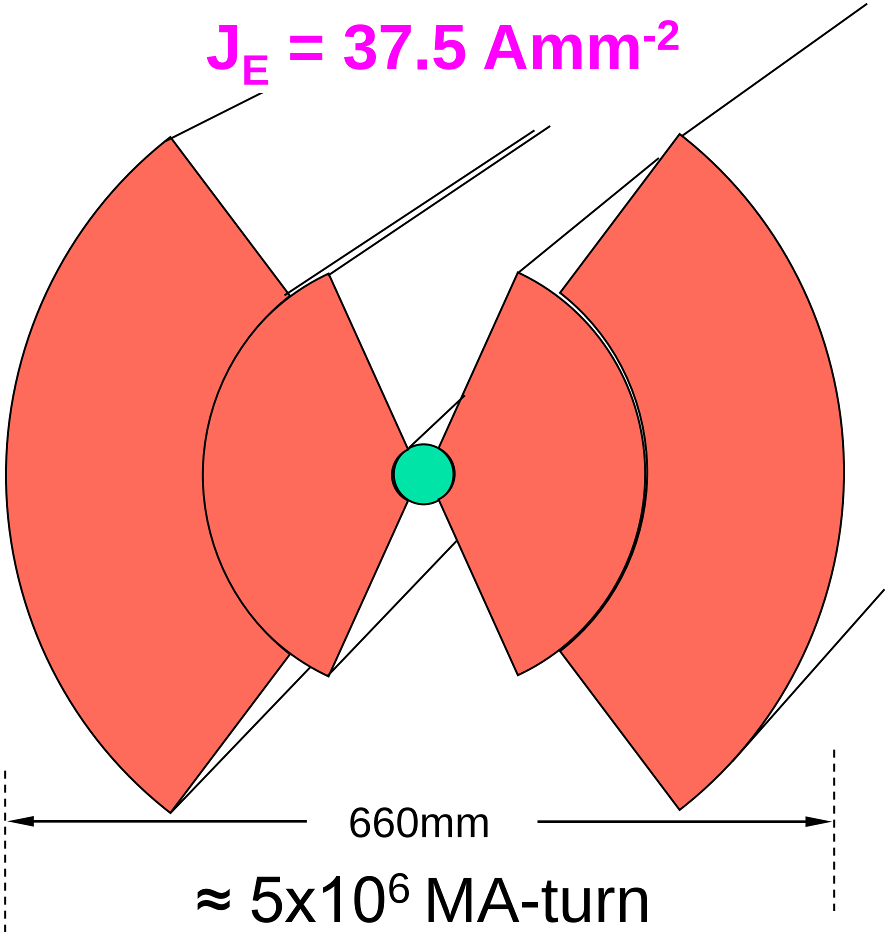


LHC dipole

≈ 1x10$^6$ MA-turn

**all-SC dipole record field: 16 T (LBNL, 2003)**

**$J_E$ = 37.5 Amm$^{-2}$**



≈ 5x10$^6$ MA-turn
≈ 6 MW/m

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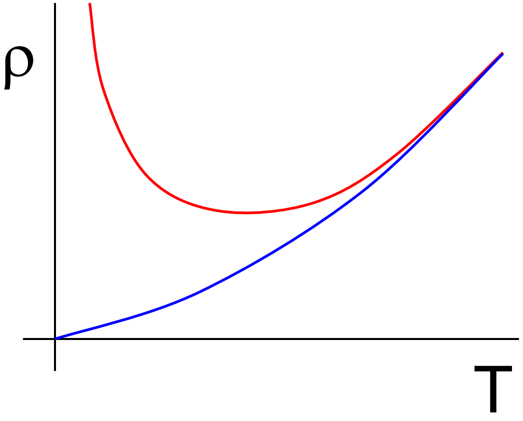
# A great physics problem in 1900

- What is the limit of electrical resistivity at the absolute zero ?



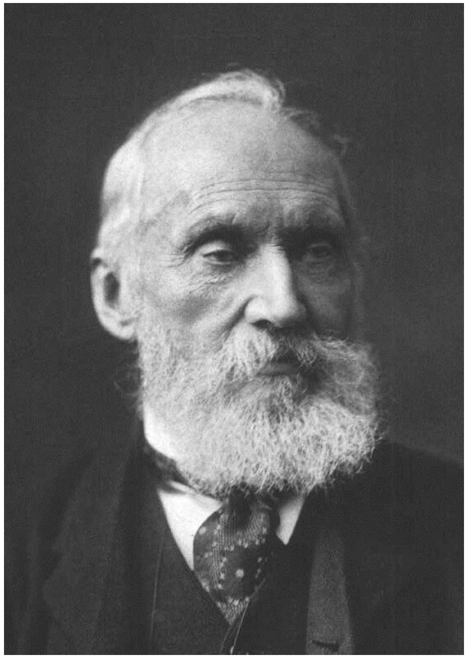
… electrons flowing through a conductor would come to a complete halt or, in other words, metal resistivity will become infinity at absolute zero.

"*X-rays are an hoax*"

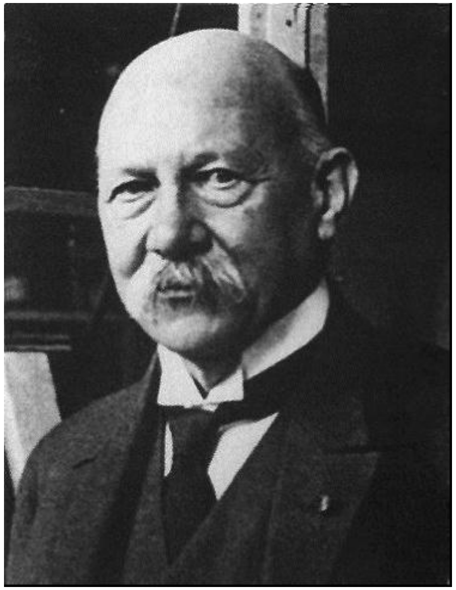
"*I have not the smallest molecule of faith in aerial navigation other than ballooning or of expectation of good results from any of the trials we hear of*"

*"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement*"

W. Thomson (Lord Kelvin)

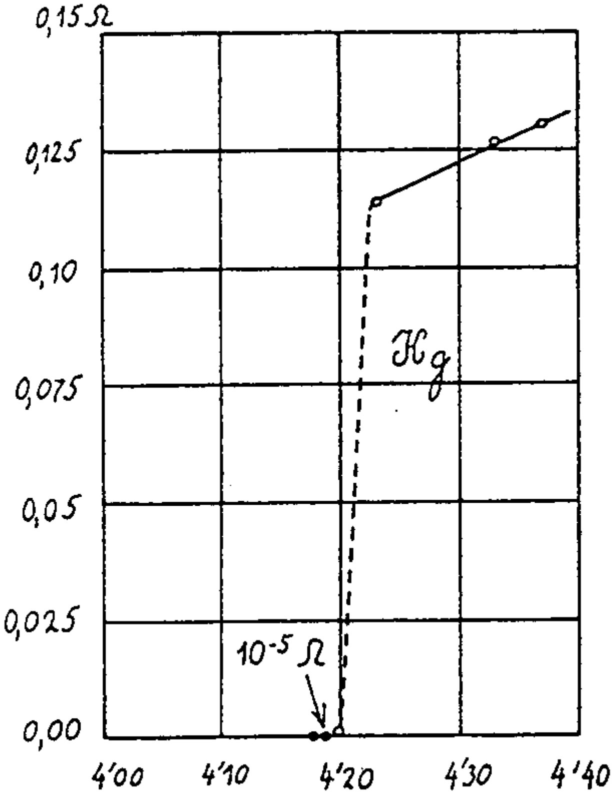


# Superconductors Pre-history



… thus the mercury at 4.2 K has entered a new state, which, owing to its particular electrical properties, can be called the state of *superconductivity*…

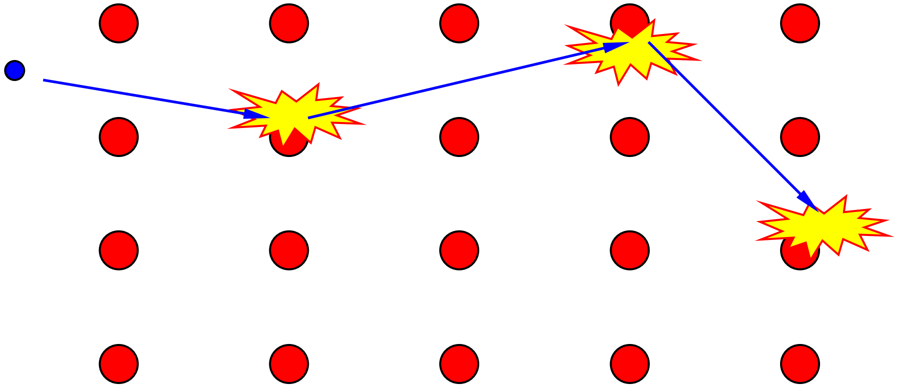
H. Kamerlingh-Onnes (1911)



# *Cooper* Pairs

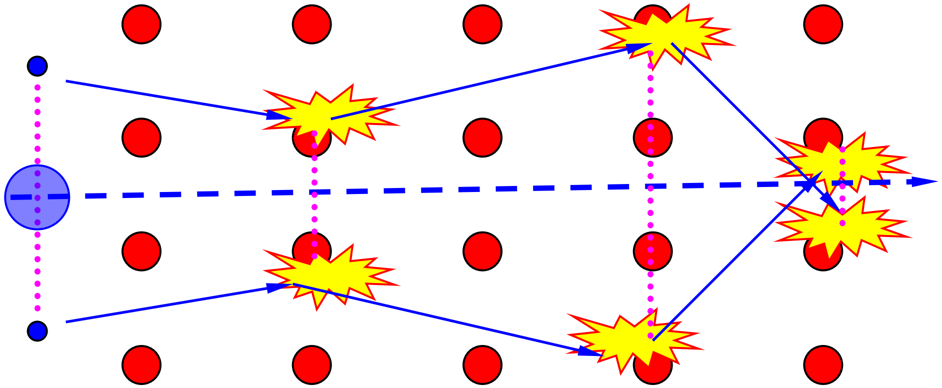
Bardeen, Cooper and Schrieffer

- Normal conductor
  - scattering of e$^-$
  - finite resistance due to energy dissipation



*Proper physics*: a gas of Fermions. The conduction electrons at the Fermi surface have large energy (few eV) and interact with lattice defects, displacements or thermal excitations (hence $\rho(T)$)

- Superconductor
  - paired electrons forming a quasi particle in *condensed* state
  - zero resistance because the scattering does not excite the quasi-particle



*Proper physics*: paired electrons in the vicinity of the Fermi surface, with opposite momentum and spin (bosons with zero spin). The binding energy introduces a small energy gap between paired and unpaired state. An external electric field makes the pair drift.

# Pairing mechanism

Lattice displacement

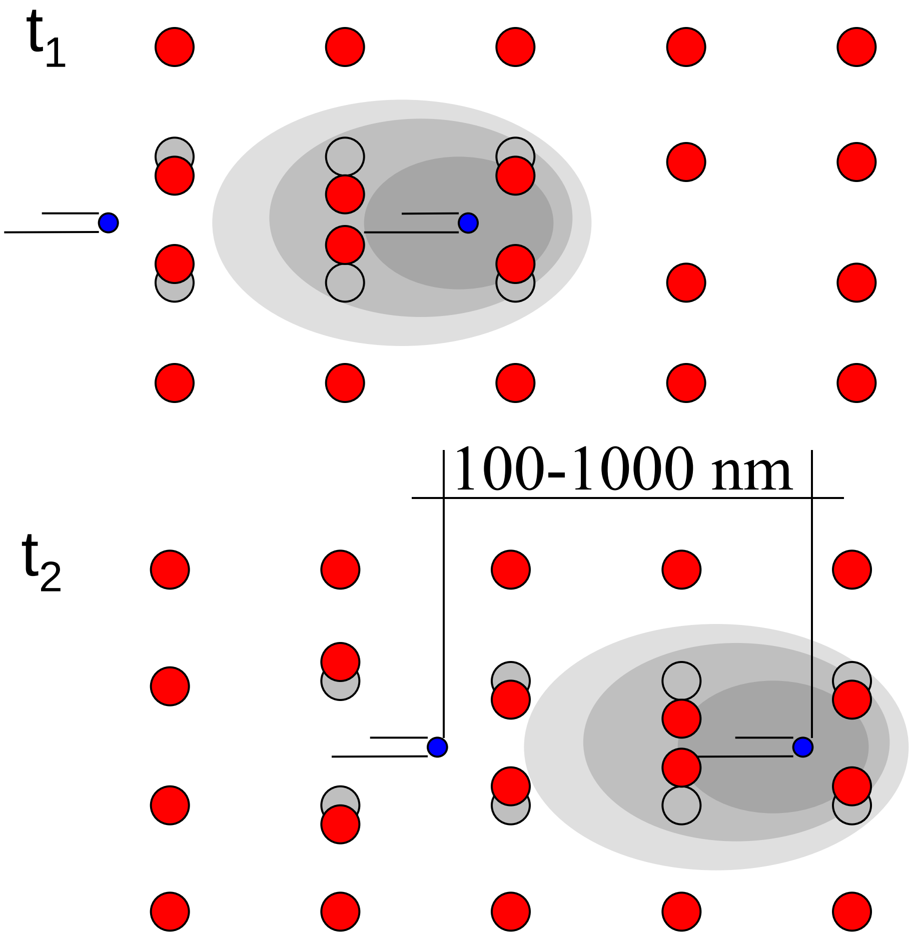
⇓

phonons (sound)

⇓

coupling of charge carriers

**Only works at low temperature**



Bardeen, Cooper, Schrieffer (BCS) - 1957

*Proper physics*: the binding energy is small, of the order of $10^{-3}$ eV. Pairs can be broken easily by thermal energy. The interaction is long range, and Cooper pairs overlap and can exchange electrons

# First (not last) superconducting magnet project cancelled

A 100 kGauss magnet ! (H. K. Onnes)

Third International Congress of Refrigeration, Chicago (1913)

Solvay conference (1914)

The 10 T magnet project was stopped when it was observed that superconductivity in Hg and Pb was destroyed by the presence of an external magnetic field as small as 500 Gauss (0.05 T)

*Superconductivity languished for 40 years…*

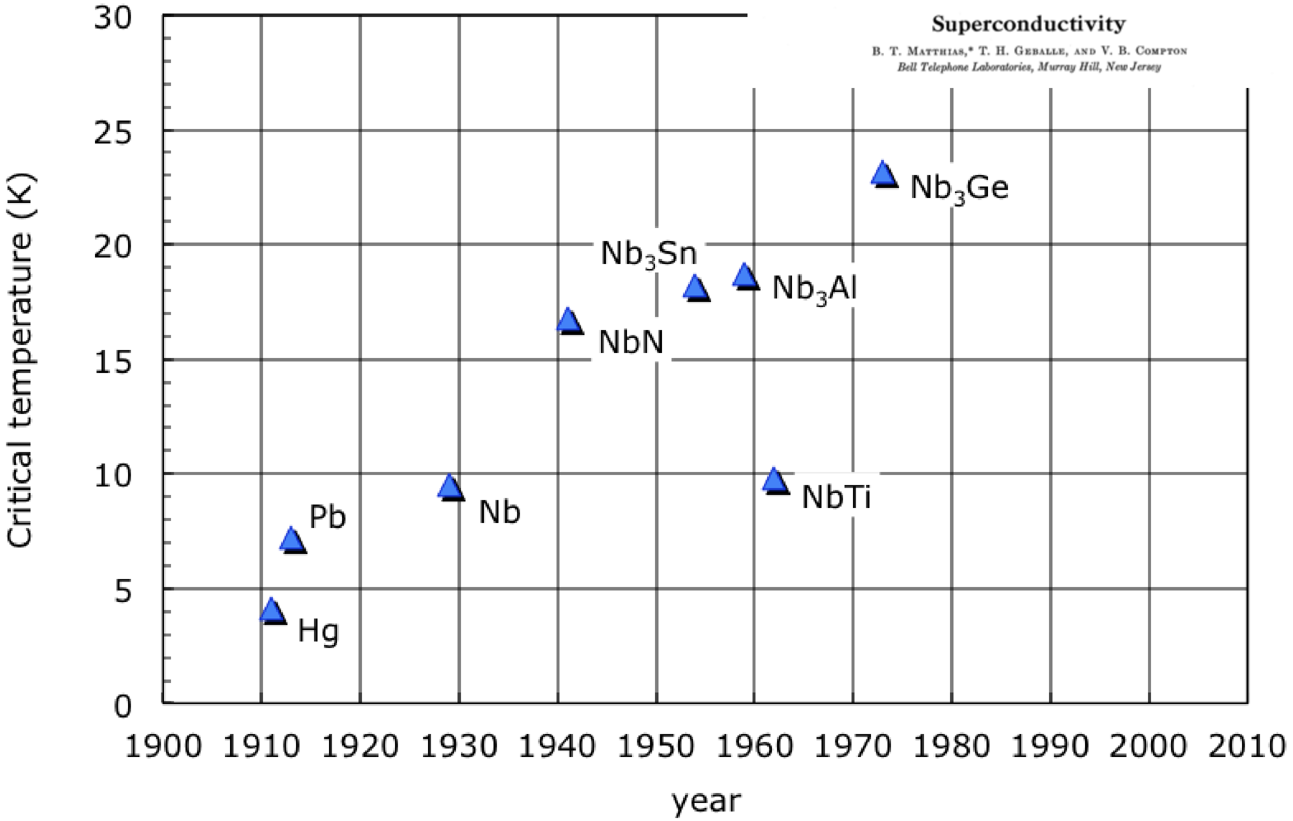
# Flourishing of materials, but depressing Tc…

*Theoretical* limit
around **30 K**

REVIEWS OF
MODERN PHYSICS
VOLUME 35, NUMBER 1 JANUARY 1963

**Superconductivity**

B. T. MATTHIAS,* T. H. GEBALLE, AND V. B. COMPTON
*Bell Telephone Laboratories, Murray Hill, New Jersey*

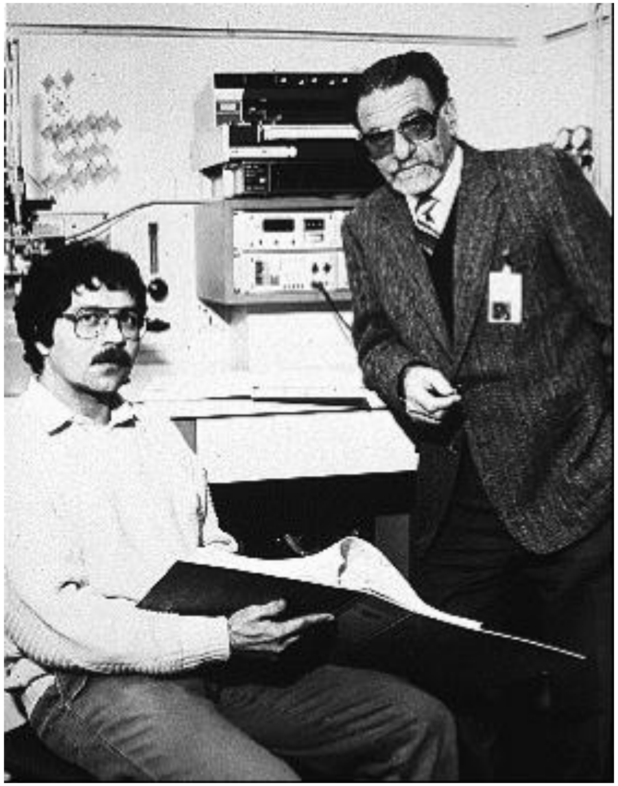


*One Thousand and One Superconductors*
B. Matthias (1918-1980)

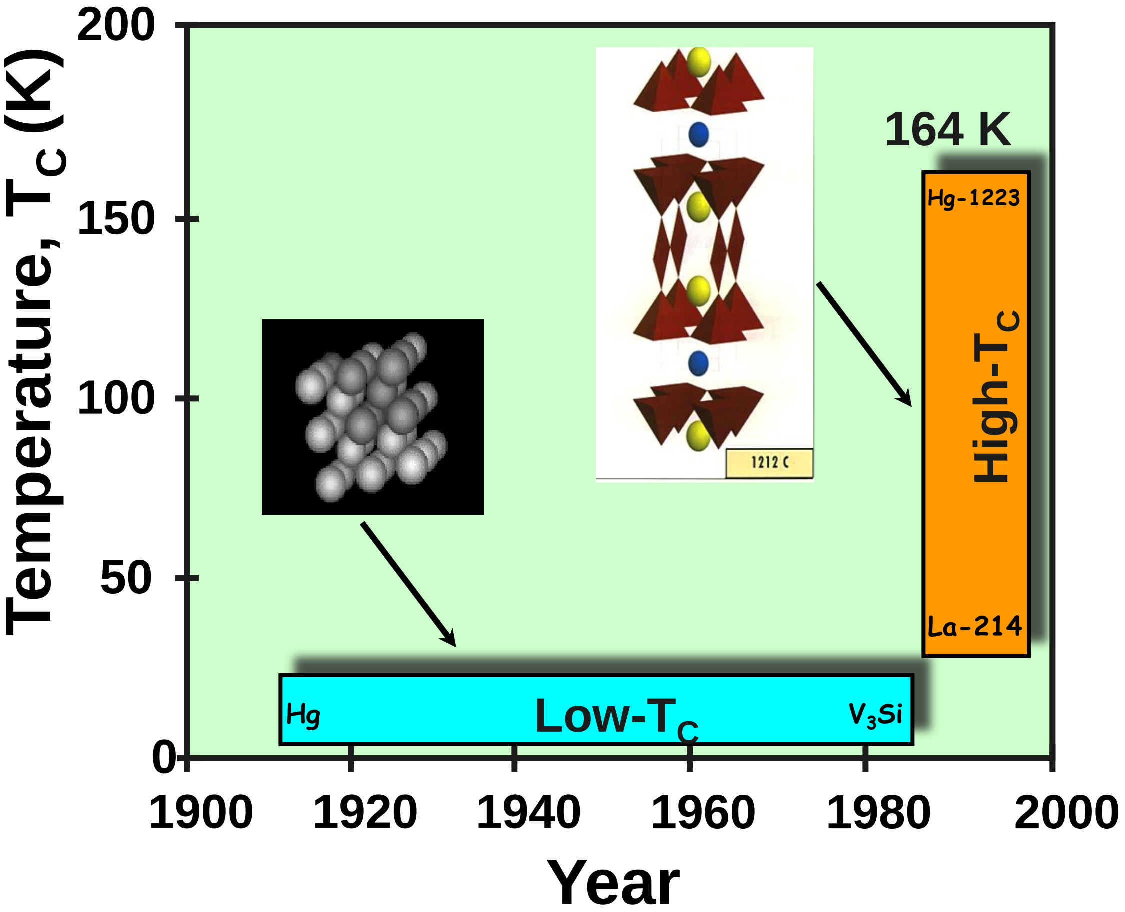
Superconductivity was a *physicist playground* till the late 1950's

*Graphics by courtesy of P. Grant*

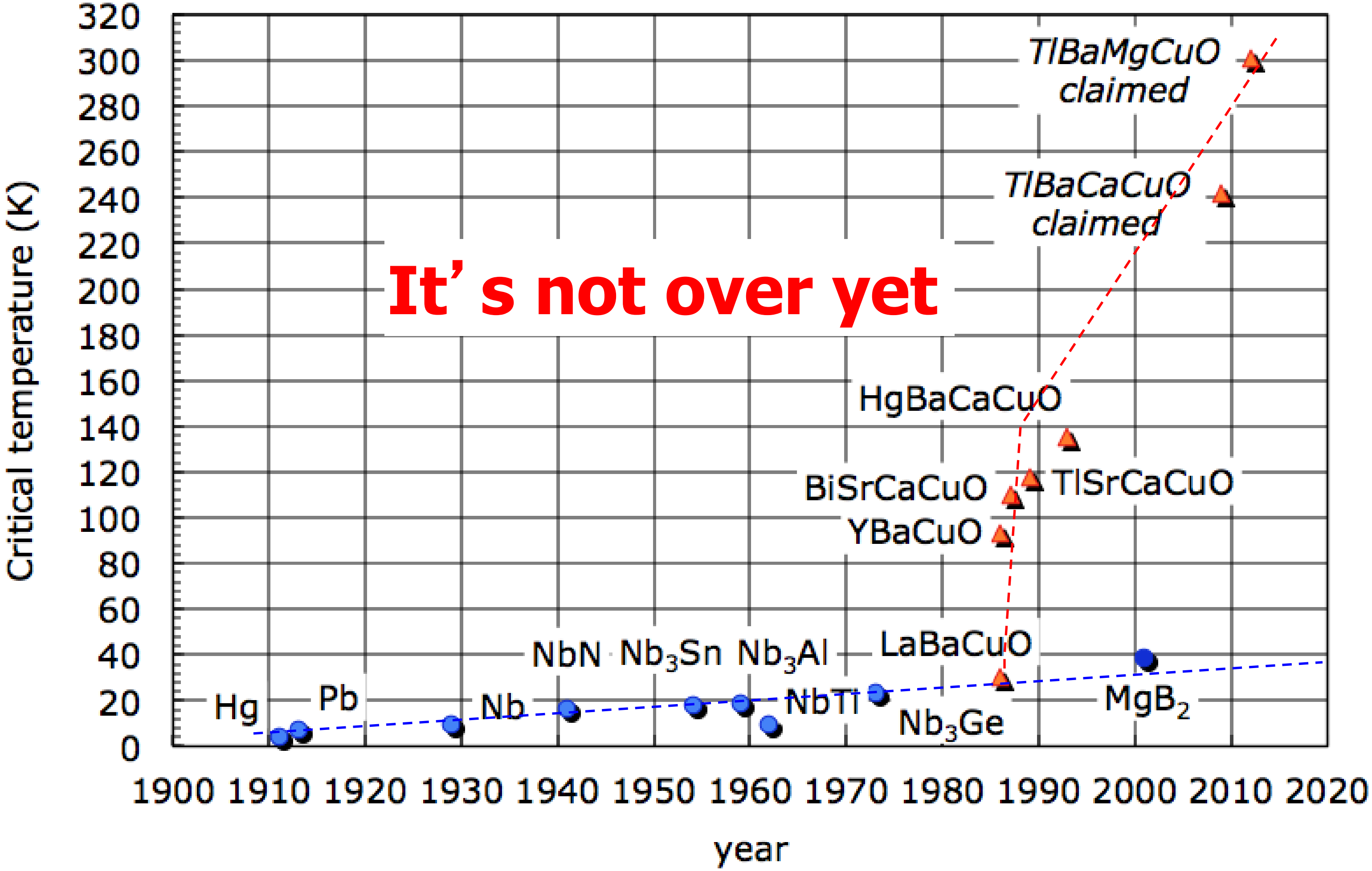
# 1986 - A Big Surprise



Bednorz and Mueller
IBM Zuerich, 1986

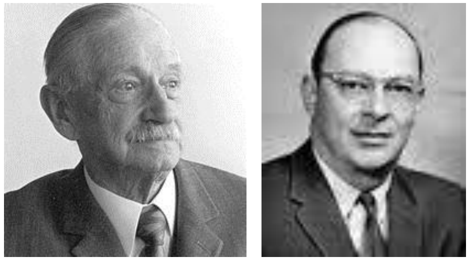


# High-Tc timeline - impressive !!!

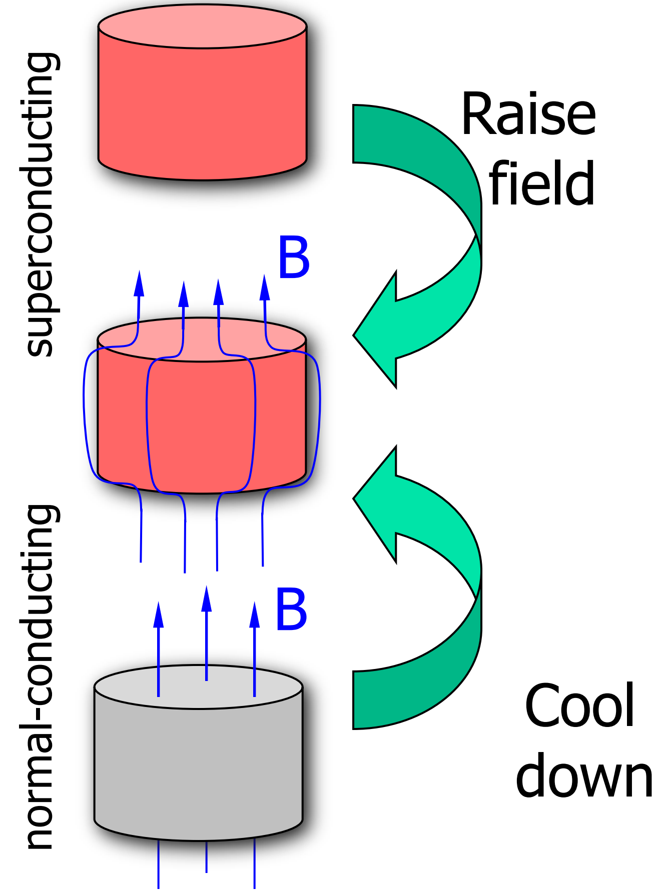


**It’s not over yet**

# Hey, what about field ?



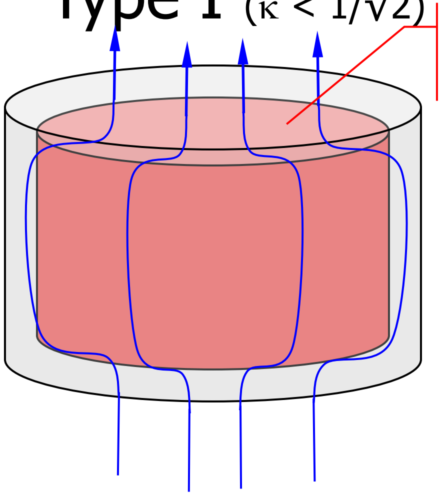
W. Meissner, R. Ochsenfeld



Raise field

Cool down

Type I ($\kappa < 1/\sqrt{2}$)



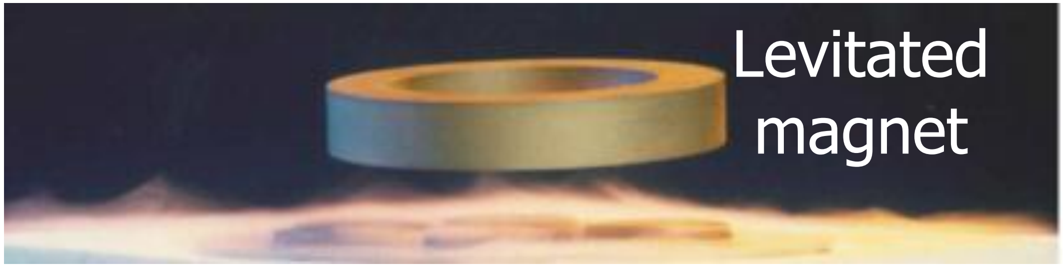
*Complete field exclusion*

Pure metals

$B_C \approx 10^{-3} \ldots 10^{-2}$ T

Meissner & Ochsenfeld, 1933

Example of magnetic levitation

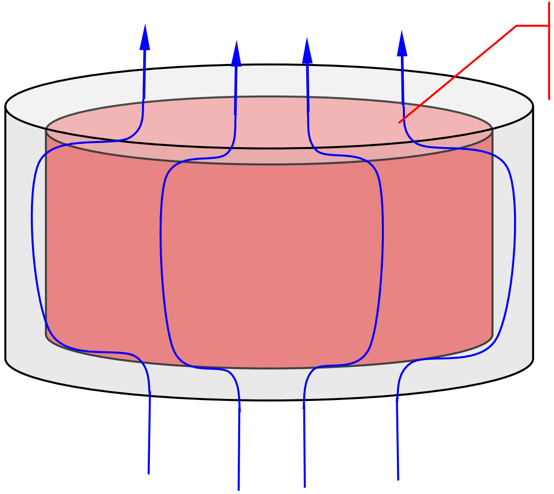


Superconducting disk

# Energy efficient fluxons

Landau, Ginzburg and Abrikosov

## Type I $(\kappa < 1/\sqrt{2})$



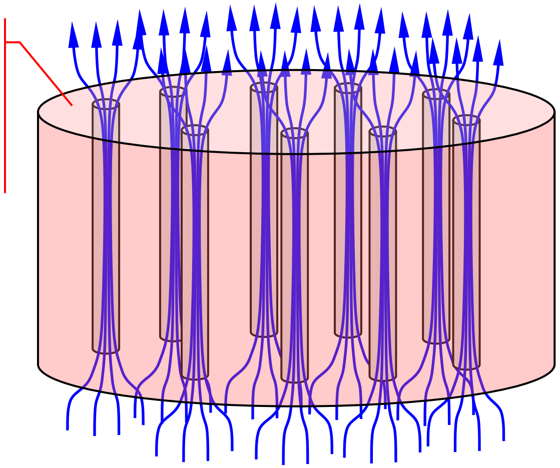
*Complete field exclusion*

Pure metals

$B_C \approx 10^{-3}…10^{-2}$ T

Meissner & Ochsenfeld, 1933

## Type II $(\kappa > 1/\sqrt{2})$



*Partial field exclusion*

*Lattice of fluxons*

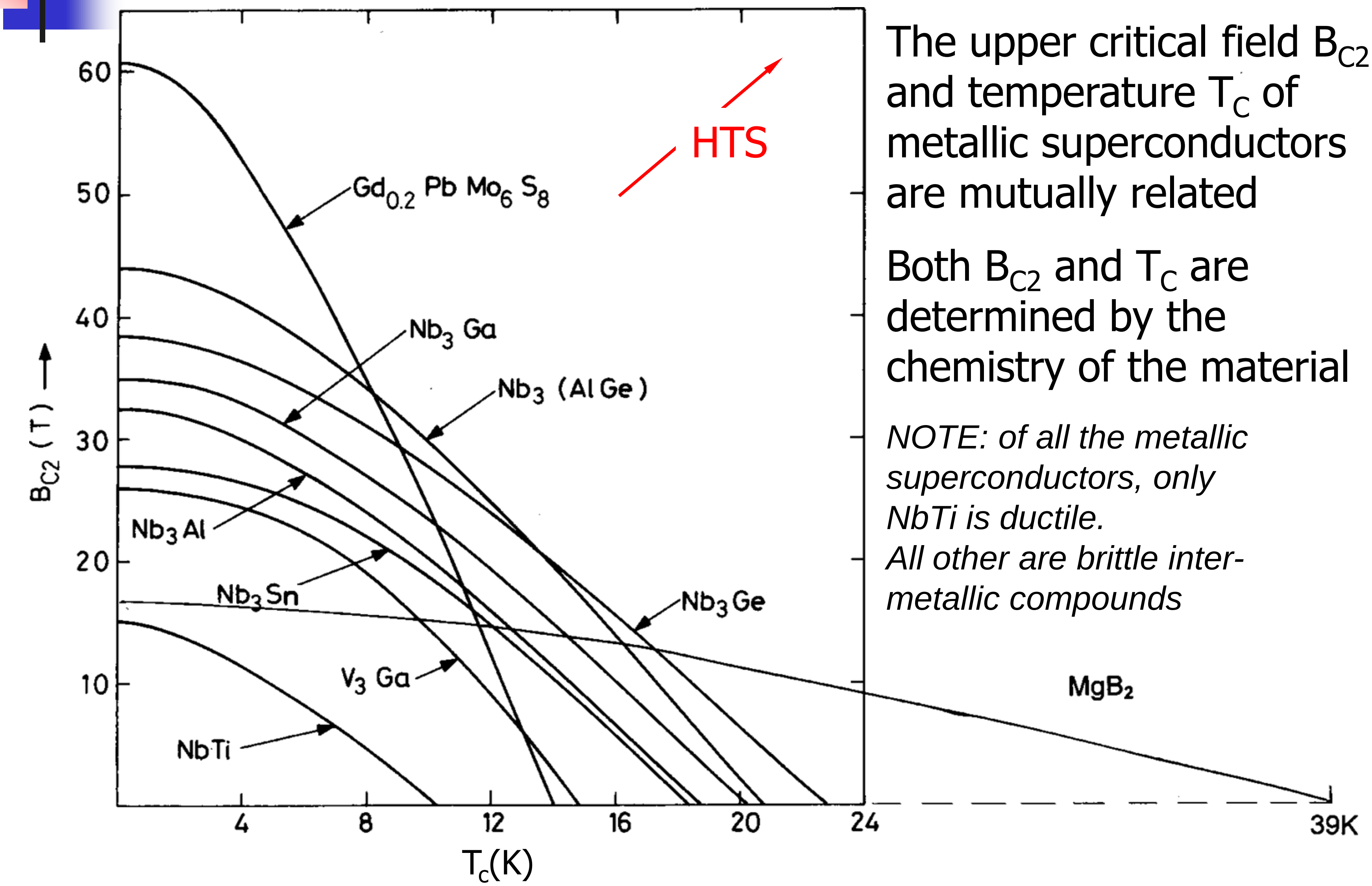
Dirty materials: alloys intermetallic, ceramic

$B_C \approx 10…10^{2}$ T

Ginsburg, Landau, Abrikosov, Gor' kov, 1950…1957

*Graphics by courtesy of M.N. Wilson*

# Type II – critical field



The upper critical field $B_{C2}$ and temperature $T_C$ of metallic superconductors are mutually related

Both $B_{C2}$ and $T_C$ are determined by the chemistry of the material

*NOTE: of all the metallic superconductors, only NbTi is ductile.*
*All other are brittle inter-metallic compounds*

# Hey, what about current ?

- A current flowing in a magnetic field is subject to the Lorentz force that deviates the charge carriers:

$$\mathbf{F} = \mathbf{J} \times \mathbf{B}$$

- This translates into a *motion of the fluxoids* across the superconductor ⇒ energy dissipation ⇒ loss of superconductivity
- To carry a significant current we need to *lock the fluxoids* so to resist the Lorentz force. For this we mess-up the material and create **pinning centers** that exert a pinning force $F_P$

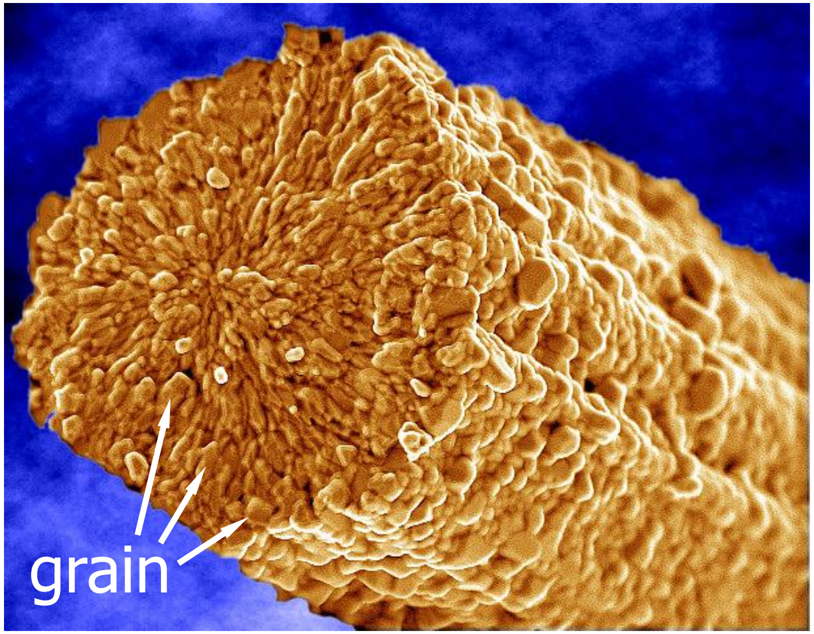
*Graphics by courtesy of Applied Superconductivity Center at NHMFL*

# Pinning centers

Precipitates in alloys

Microstructure of Nb-Ti

Grain boundaries in inter-metallic compounds



Microstructure of $Nb_3Sn$

# Jc(B,T,…)

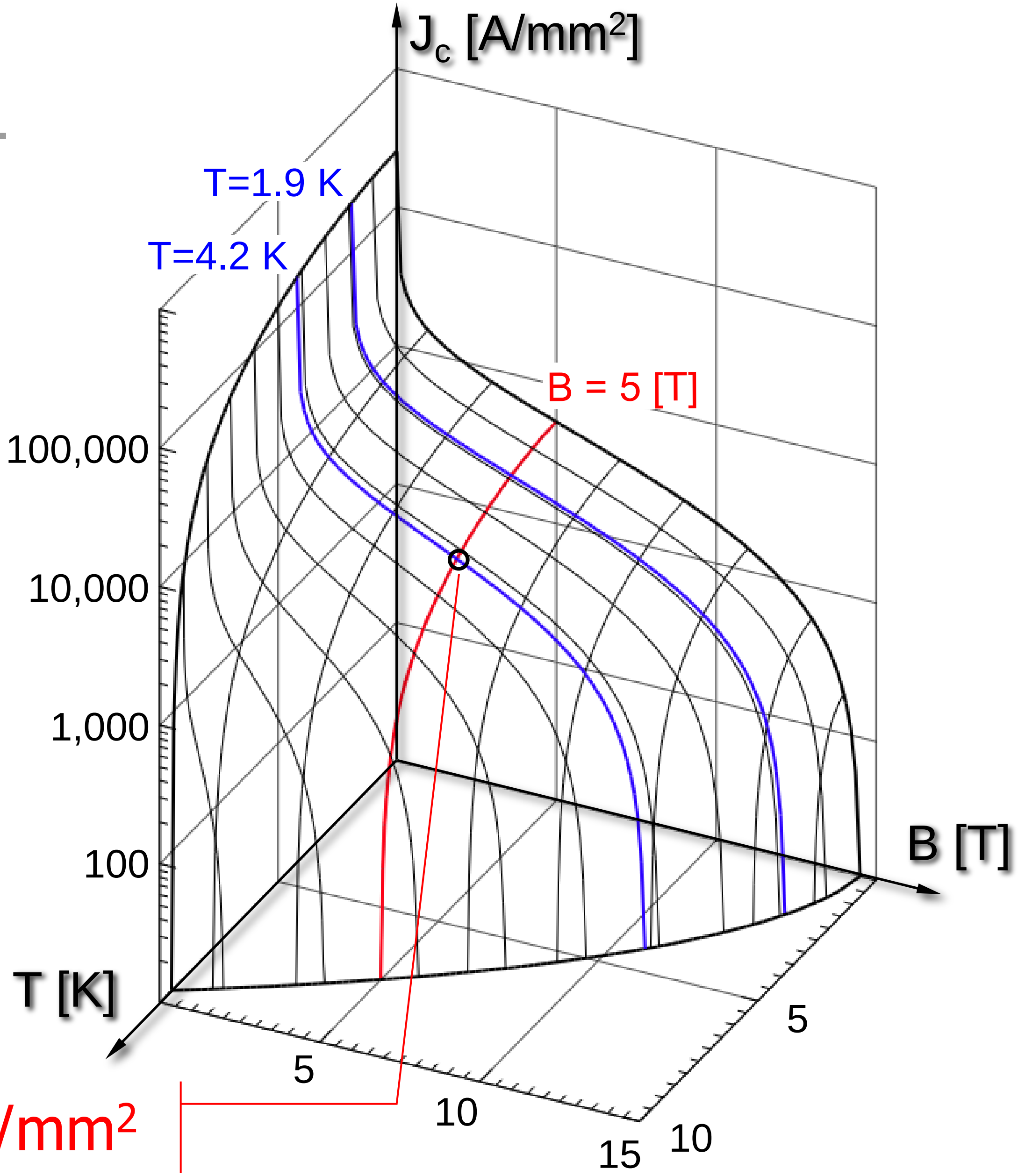
- The maximum current that can be carried by the superconductor is the current at which:

$$|\mathbf{J} \times \mathbf{B}| = F_P$$

- The above expression defines a **critical surface**:

$$J_C(B,T,\ldots) = F_P / B$$

Critical surface of a LHC NbTi wire



Jc (5 T, 4.2 K) ≈ 3000 A/mm$^2$

# Superconductors – the bottom line

- Superconducting materials are only useful if they are ***dirty*** (type II - high critical field) and ***messy*** (strong pinning centers)
- A superconductor is such only in conditions of temperature, field and current density within the critical surface, and it is a normal-conductor above these conditions. The transition is defined by a critical current density $J_C(B,T,\ldots)$
- The maximum current that can be carried is the $I_C = A_{SC} \times J_C$

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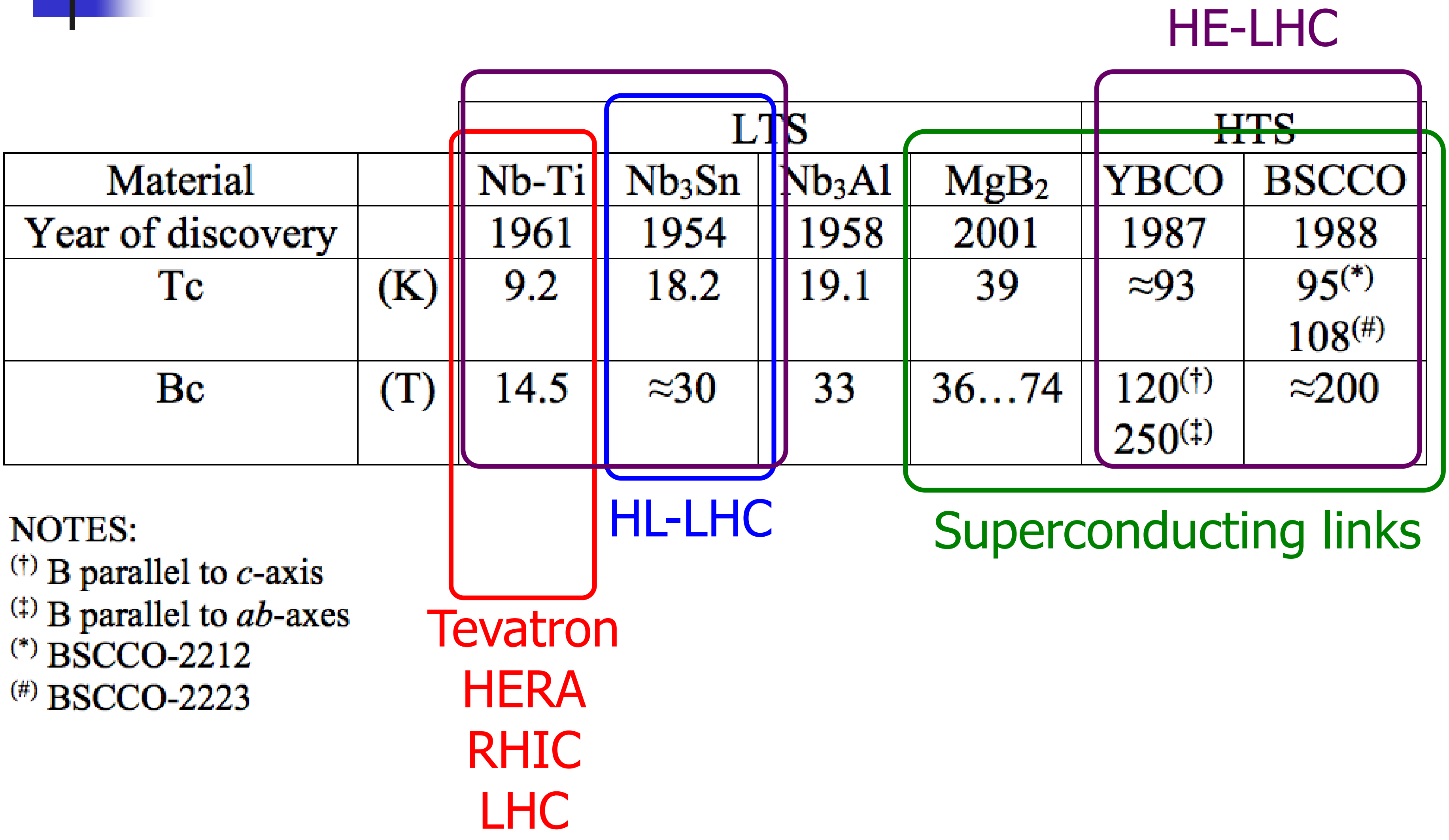
# From materials to magnets

- Materials must be made in high-current wires, tapes and cables for use in magnets
- The manufacturing route depends, among others on:
  - The material (e.g. alloy or chemical compound),
  - The material synthesis (e.g. reaction conditions or a crystal growth method)
  - The material mechanical properties (e.g. ductile or fragile)
  - The compatibility with other materials involved (e.g. precursors or mechanical supports)

# A summary of technical materials



HE-LHC

|  |  | LTS |  |  |  | HTS |  |
|---|---|---|---|---|---|---|---|
| Material |  | Nb-Ti | $Nb_3Sn$ | $Nb_3Al$ | $MgB_2$ | YBCO | BSCCO |
| Year of discovery |  | 1961 | 1954 | 1958 | 2001 | 1987 | 1988 |
| Tc | (K) | 9.2 | 18.2 | 19.1 | 39 | ≈93 | $95^{(*)}$<br>$108^{(\#)}$ |
| Bc | (T) | 14.5 | ≈30 | 33 | 36…74 | $120^{(\dagger)}$<br>$250^{(\ddagger)}$ | ≈200 |

NOTES:
(†) B parallel to *c*-axis
(‡) B parallel to *ab*-axes
(*) BSCCO-2212
(#) BSCCO-2223

HL-LHC

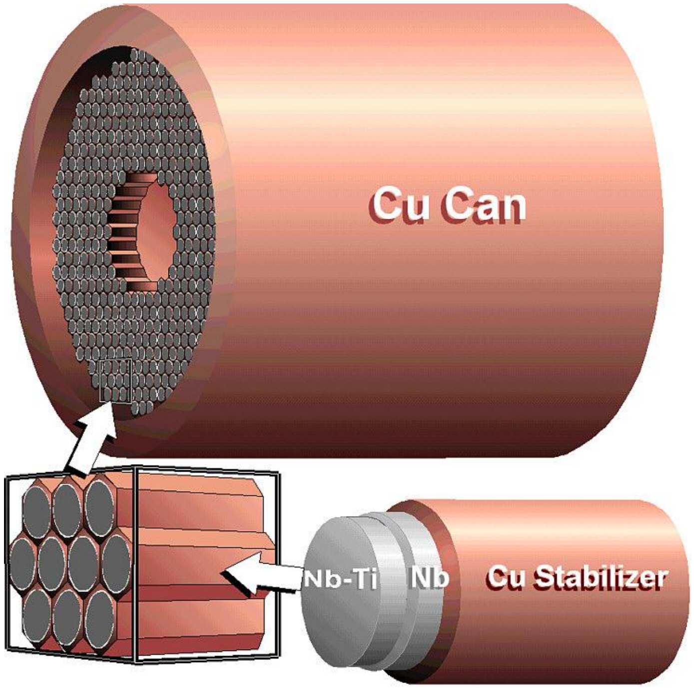
Superconducting links

Tevatron
HERA
RHIC
LHC

*Graphics by courtesy of Applied Superconductivity Center at NHMFL*

# Nb-Ti manufacturing route

NbTi billet



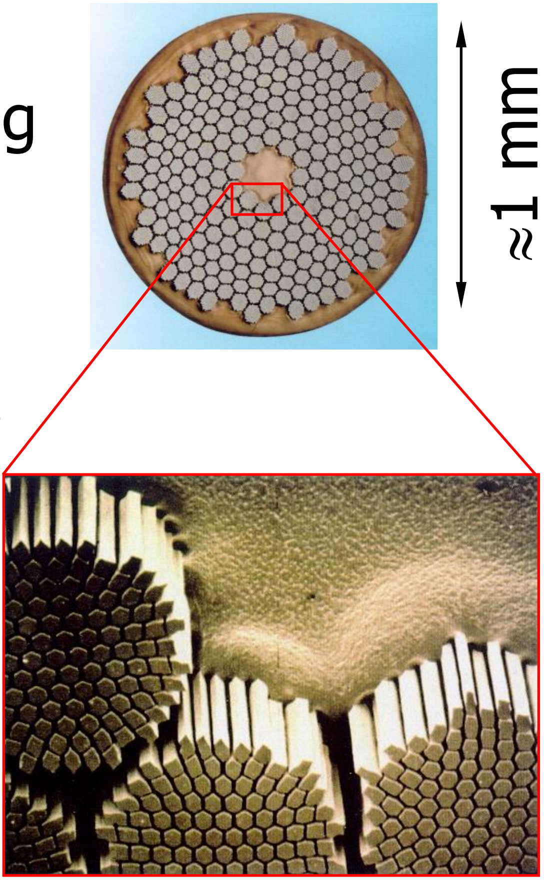
NbTi is a ductile alloy that can sustain large deformations

$I_C(5\ T, 4.2\ K) \approx 1\ kA$

extrusion
cold drawing

⇒

heat
treatments

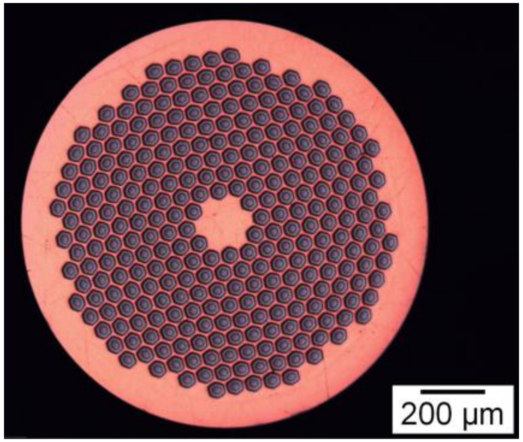


LHC wire

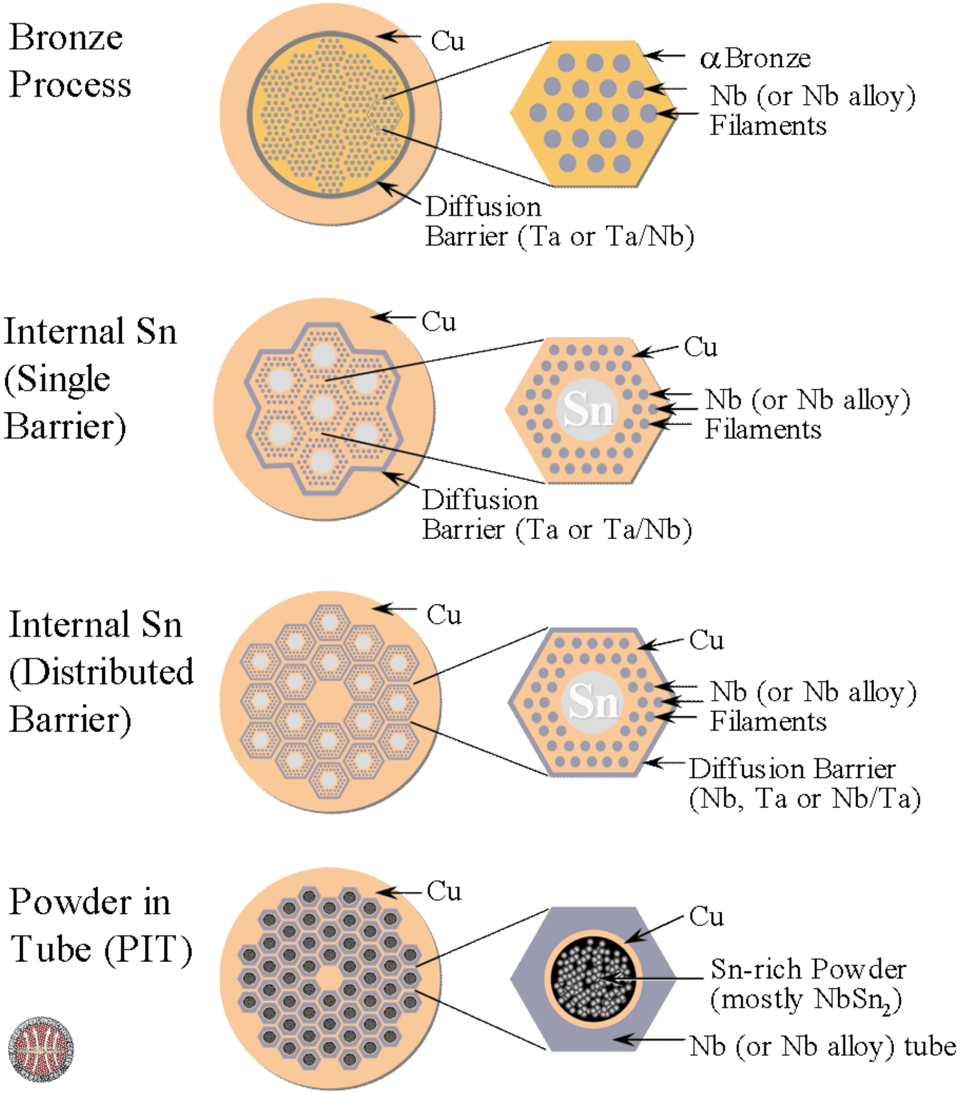
*Graphics by courtesy of Applied Superconductivity Center at NHMFL*

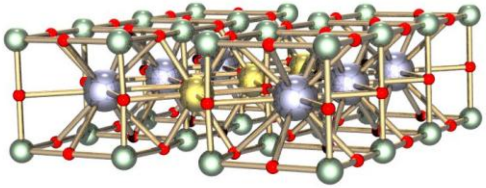
# Nb$_3$Sn manufacturing routes

Nb$_3$Sn is brittle and cannot be drawn in final form. The precursors are drawn and only later the wire is heat-treated to ≈650 C for several hrs, to form the Nb$_3$Sn phase



$I_C(12\ T,\ 4.2\ K) \approx 1.5\ kA$



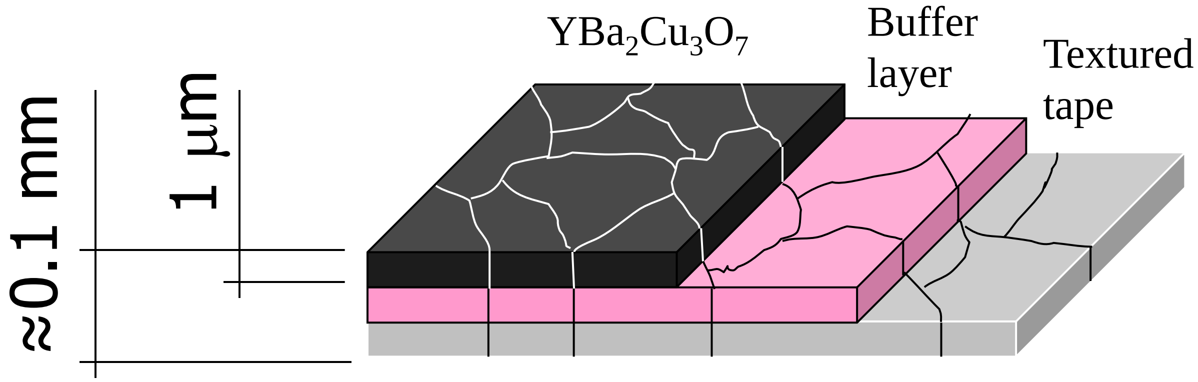


# YBCO tape (developmental)

YBCO has excellent critical properties, but grains do not align during processing. If grains are not aligned the supercurrent cannot jump between the grains. All manufacturing processes force a certain degree of alignment in the microstructure

- produce a tape with an aligned texture
- coat the tape with a buffer layer
- coat the buffer with a layer $YBa_2Cu_3O_7$ such that the texture of the YBCO follows that of the buffer and substrate

All routes use ion deposition techniques (laser, plasma) in vacuum (cost, length)

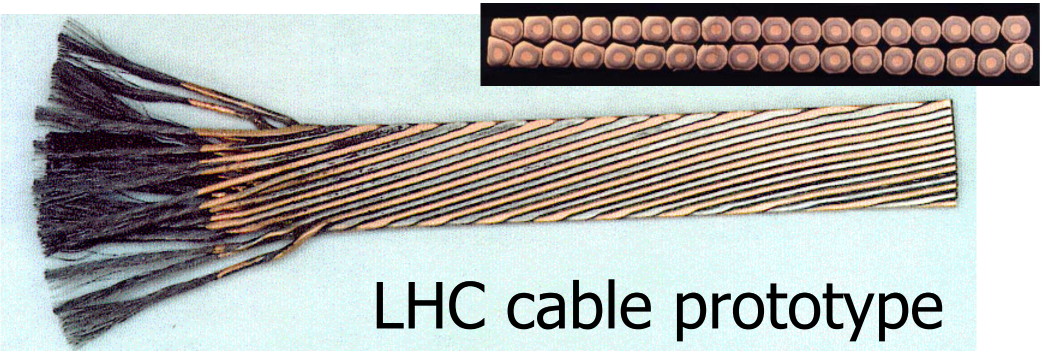


**$J_E \approx 500\ \mathrm{A/mm^2}$**

# Practical conductors: high $J_E$

- Multifilamentary wires have current carrying capability of 100… 1000 A
- Insulated with varnish or glass-braids they can be used to make all kind of small size magnets

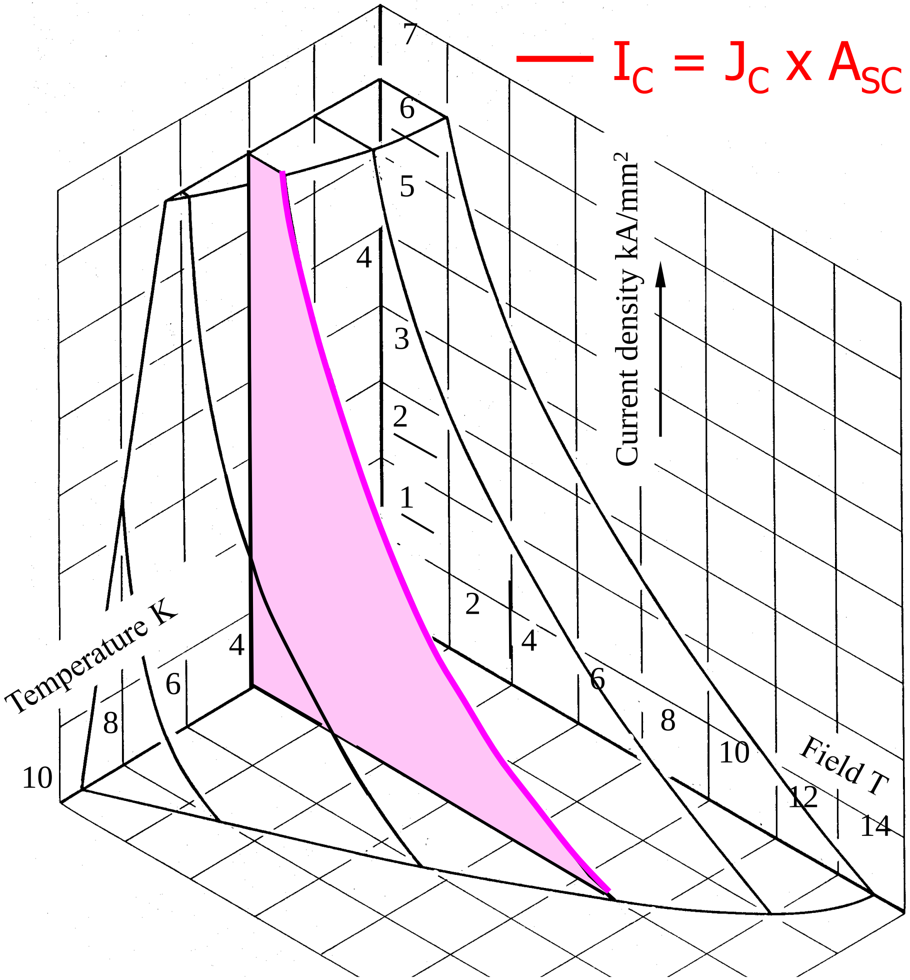
- Large size magnets (e.g. LHC dipoles) require invariably large operating currents (10 to 100 kA) to:
  - Decrease inductance,
  - Lower the operating voltage,
  - Ease magnet protection
- Rutherford cables are ideally suited for this task



LHC cable prototype

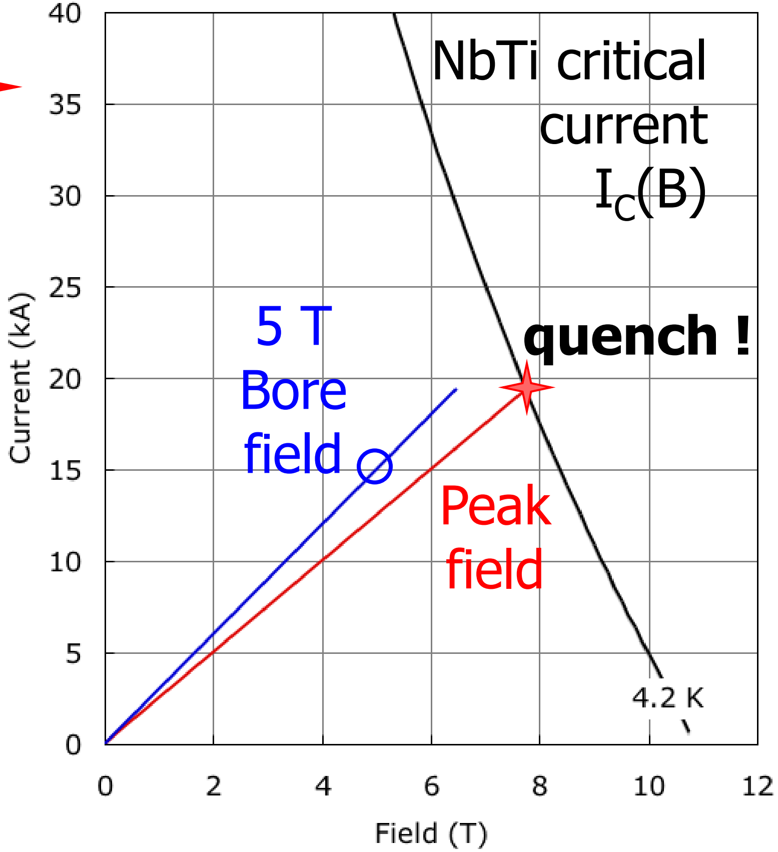
# Critical line and magnet load lines

NbTi critical surface



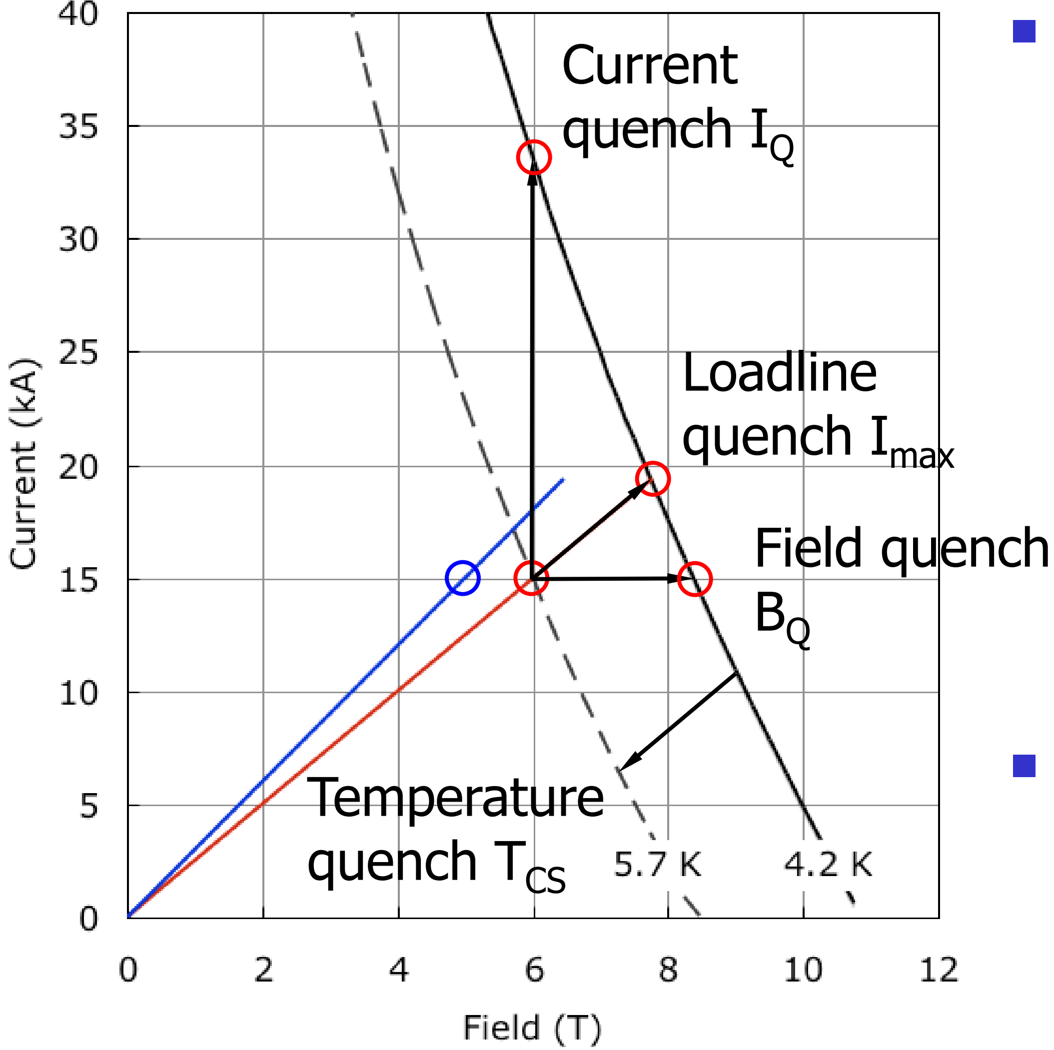
$I_C = J_C \times A_{SC}$ →

e.g. a 5 T magnet design



we expect the magnet to go resistive i.e. to **'quench',** where the peak field load line crosses the critical current line

# Operating margins



- Practical operation always requires margins:
  - Critical current margin: $I_{op}/I_Q \approx 50$ %
  - Critical field margin: $B_{op/}B_Q \approx 75$ %
  - Margin along the loadline: $I_{op}/I_{max} \approx 85$ %
  - Temperature margin: $T_{CS}$ - $T_{op} \approx$ 1…2 K
- The margin needed depends on the design and operating conditions

# Engineering current density

- All wires, tapes and cables contain additional components:
  - Left-overs from the precursors of the SC formation
  - Barriers, texturing and buffering layers
  - Low resistance matrices
- The SC *material fraction* is hence always < 1:

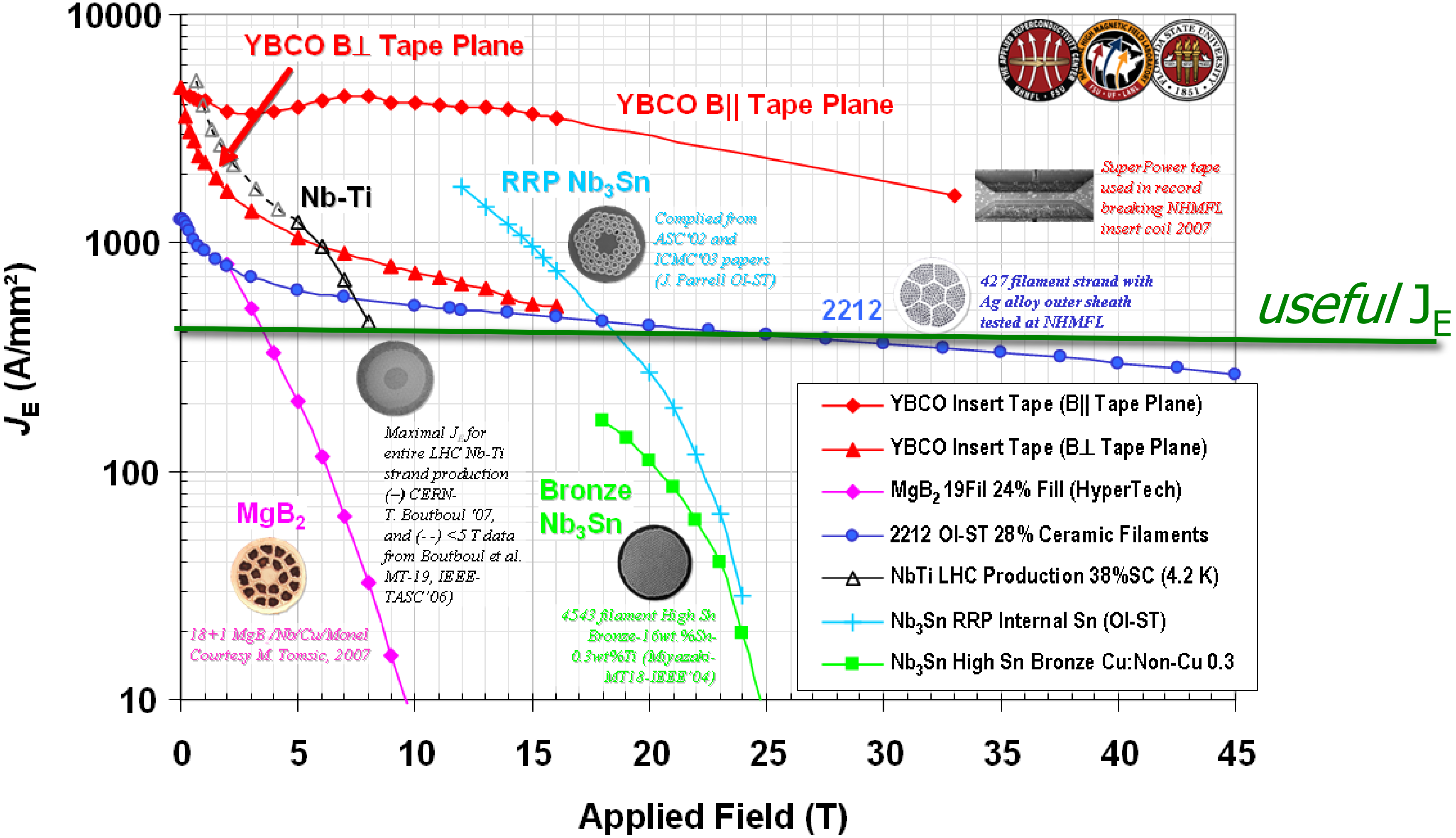
$$\lambda = A_{SC} / A_{total}$$

- To compare materials on the same basis, we use an *engineering current density*:

$$J_E = J_C \times \lambda$$

*Graphics by courtesy of Applied Superconductivity Center at NHMFL*

# *Best of* Superconductors $J_E$



*SuperPower tape used in record breaking NHMFL insert coil 2007*

*Complied from ASC'02 and ICMC'03 papers (J. Parrell OI-ST)*

*427 filament strand with Ag alloy outer sheath tested at NHMFL*

*Maximal $J_E$ for entire LHC Nb-Ti strand production (–) CERN-T. Boutboul '07, and (- -) <5 T data from Boutboul et al. MT-19, IEEE-TASC'06)*

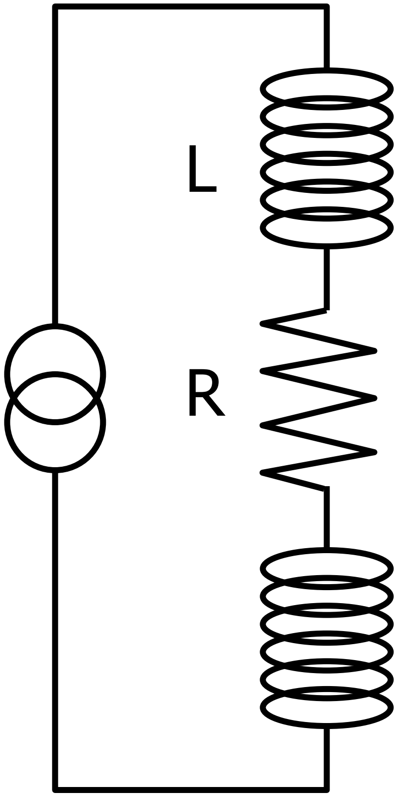
*4543 filament High Sn Bronze-16wt.%Sn-0.3wt%Ti (Miyazaki-MT18-IEEE'04)*

*18+1 MgB /Nb/Cu/Monel Courtesy M. Tomsic, 2007*

# What if we exceed the limits ? Quench

- the magnetic energy stored in the field:

$$E_m = \int_V \frac{B^2}{2\mu_0} dv = \frac{1}{2} L I^2$$



is converted to heat through Joule heating $RI^2$.
*If this process happened uniformly* in the winding pack:

  - Cu melting temperature 1356 K
  - corresponding $E_m$=5.2 $10^9$ J/$m^3$

limit would be $B_{max} \leq$ 115 T: NO PROBLEM !

BUT

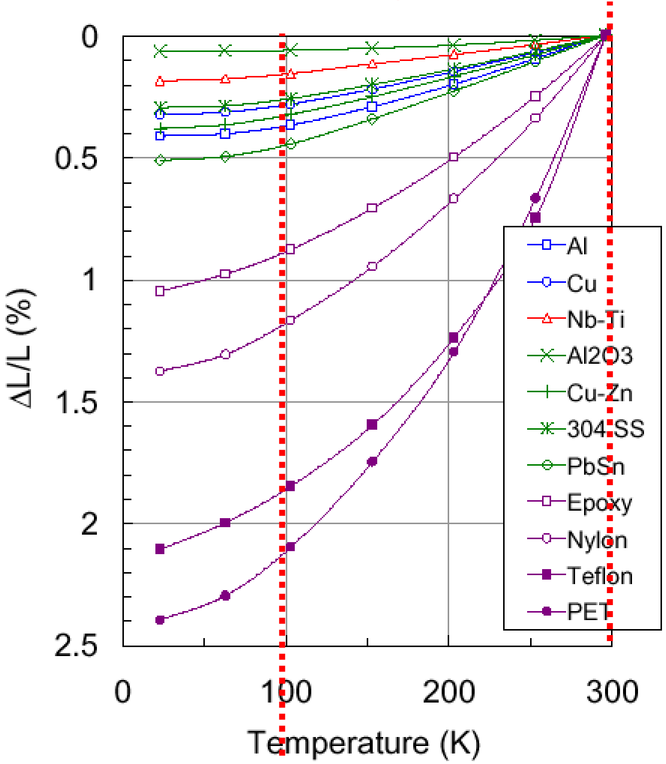
*the process does not happen uniformly* (as little as 1 % of mass can absorb total energy)

# Quench and protection basics

- A good conducting material (Ag, Al, Cu: large $Z(T_{max})$) must be added in parallel to the superconductor to limit the maximum temperature during a quench
- The effect of a quench can be mitigated by
  - Adding stabilizer (⇔ operating margin, stability)
  - Reducing operating current density (⇔ economics of the system)
  - Reducing the magnet inductance (large cable current), increasing the discharge voltage and subdividing (strings) to discharge the magnet as quickly as practical

# *Hot-spot* limits

$T_{max}$ < 300 K for highly supported coils (e.g. accelerator magnets)

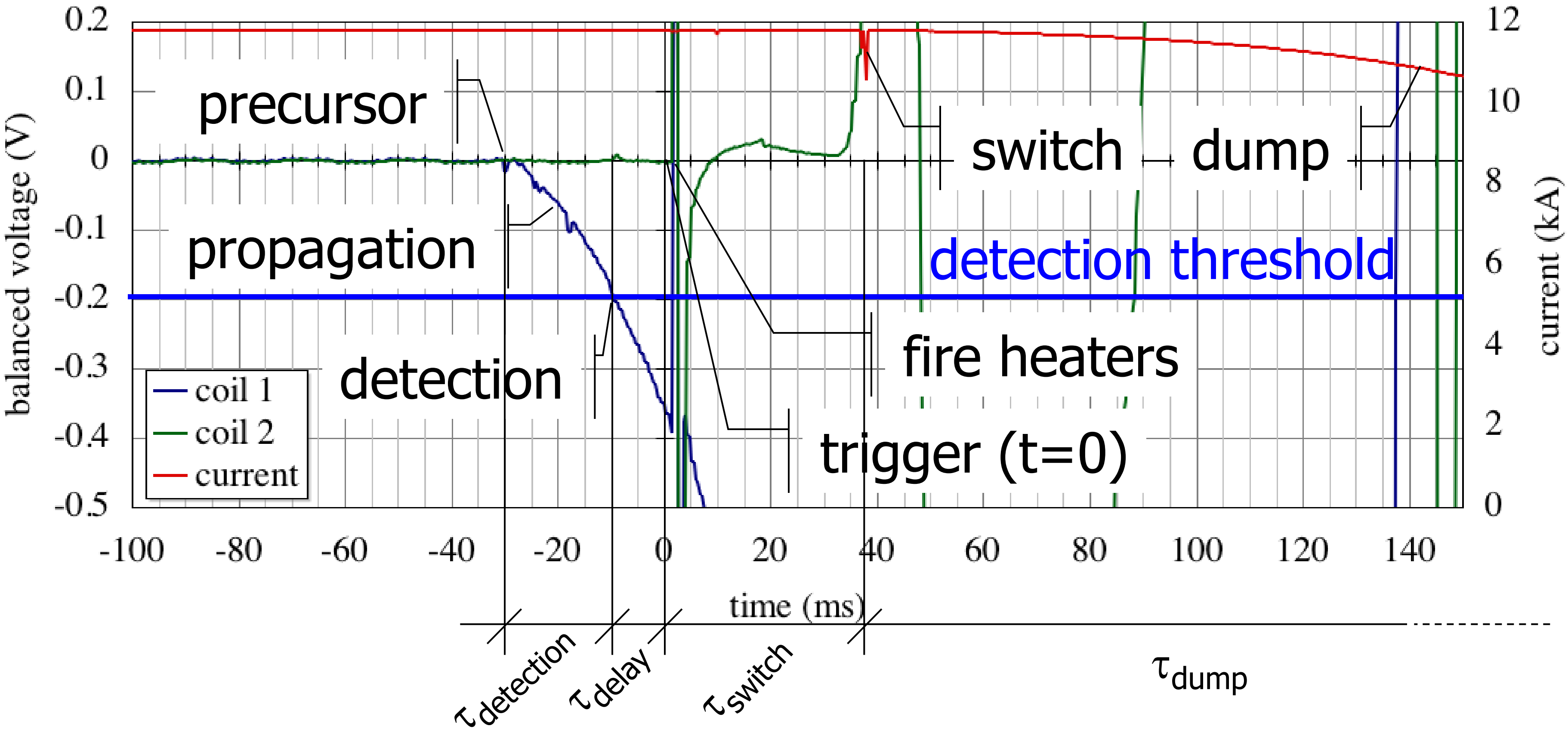


$T_{max}$ < 100 K for negligible effect

- the quench starts in a point and propagates with a *quench propagation velocity*
- the initial point will be the *hot spot* at temperature $T_{max}$
- $T_{max}$ must be limited to:
  - limit thermal stresses (see graph)
  - avoid material damage (e.g. resins have typical $T_{cure}$ 100…200 ° C)

By courtesy of M. Di Castro, CERN AT-MTM, 2007.

# Detection, switch and dump



$$\tau_{discharge} \approx \tau_{detection} + \tau_{delay} + \tau_{switch} + \tau_{dump}$$

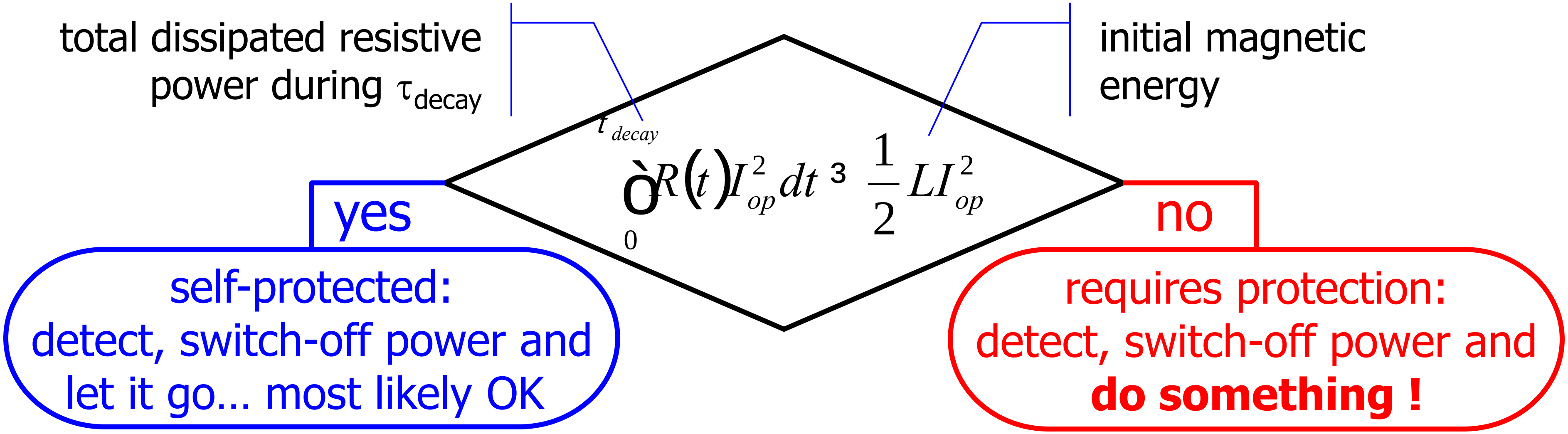
# Quench resistance

- the quench propagates in the coil at speed $v_{quench}$ longitudinally ($v_{longitudinal}$) and transversely ($v_{transverse}$)…
- …the total resistance of the normal zone $R_{quench}(t)$ grows in time following
  - the temperature increase, and
  - the normal zone evolution…
- …a resistive voltage $V_{quench}(t)$ appears along the normal zone…
- …that dissipates the magnetic energy stored in the field, thus leading to a discharge of the system in a time $\tau_{discharge}$.

the knowledge of $R_{quench}(t)$ is mandatory to verify the protection of the magnetic system !

# Quench protection

- The magnet stores a magnetic energy 1/2 L $I^2$
- During a quench it dissipates a power R $I^2$ for a duration $\tau_{decay}$ characteristic of the powering circuit



total dissipated resistive power during $\tau_{decay}$

initial magnetic energy

$$\int_0^{\tau_{decay}} R(t) I_{op}^2 \, dt \geq \frac{1}{2} L I_{op}^2$$

yes

self-protected:
detect, switch-off power and
let it go… most likely OK

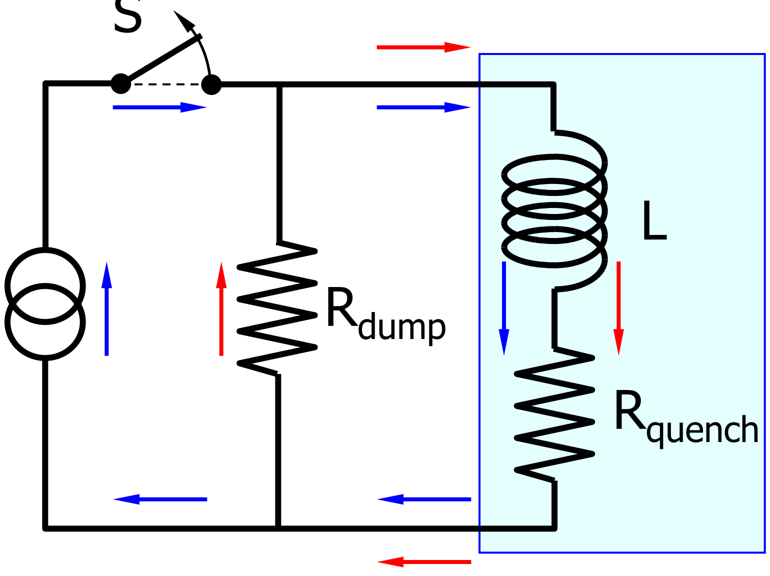
no

requires protection:
detect, switch-off power and
**do something !**

WARNING: the reasoning here is qualitative, conclusions require in any case detailed checking

B.J. Maddock, G.B. James, Proc. Inst. Electr. Eng., **115**, 543, 1968

# Energy dump



$$R_{dump} >> R_{quench}$$

← normal operation

← quench

- the magnetic energy is extracted from the magnet and dissipated in an external resistor:

$$I = I_{op} e^{-\frac{(t - t_{detection})}{\tau_{dump}}} \qquad \tau_{dump} = \frac{L}{R_{dump}}$$

- the integral of the current:

$$\int_0^\infty J^2 dt \approx J_{op}^2 \left( t_{detection} + \frac{\tau_{dump}}{2} \right)$$

- can be made small by:
  - fast detection
  - fast dump (large R$_{dump}$)

# Dump time constant

- magnetic energy:

$$E_m = \frac{1}{2} L I_{op}^2$$

- maximum terminal voltage:

$$V_{\max} = R_{dump} I_{op}$$

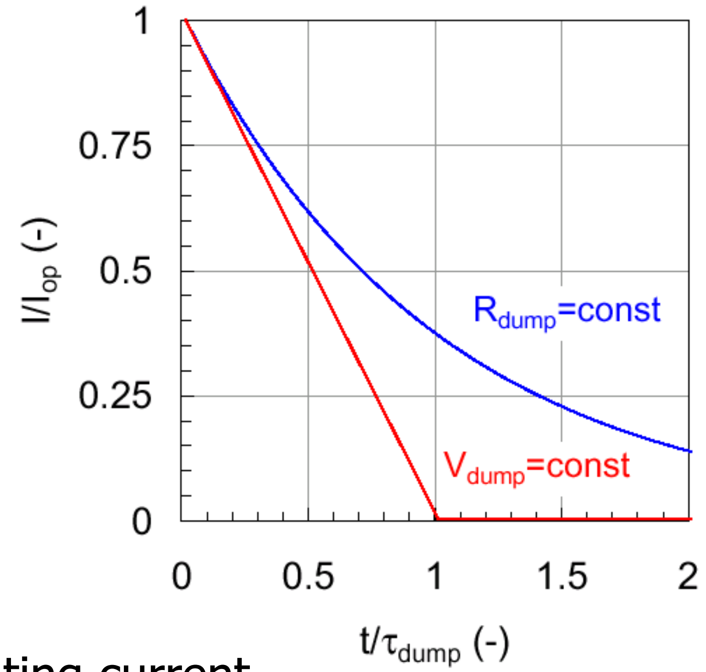
- dump time constant:

$$t_{dump} = \frac{L}{R_{dump}} = \frac{2E_m}{V_{\max} I_{op}}$$

maximum terminal voltage

operating current

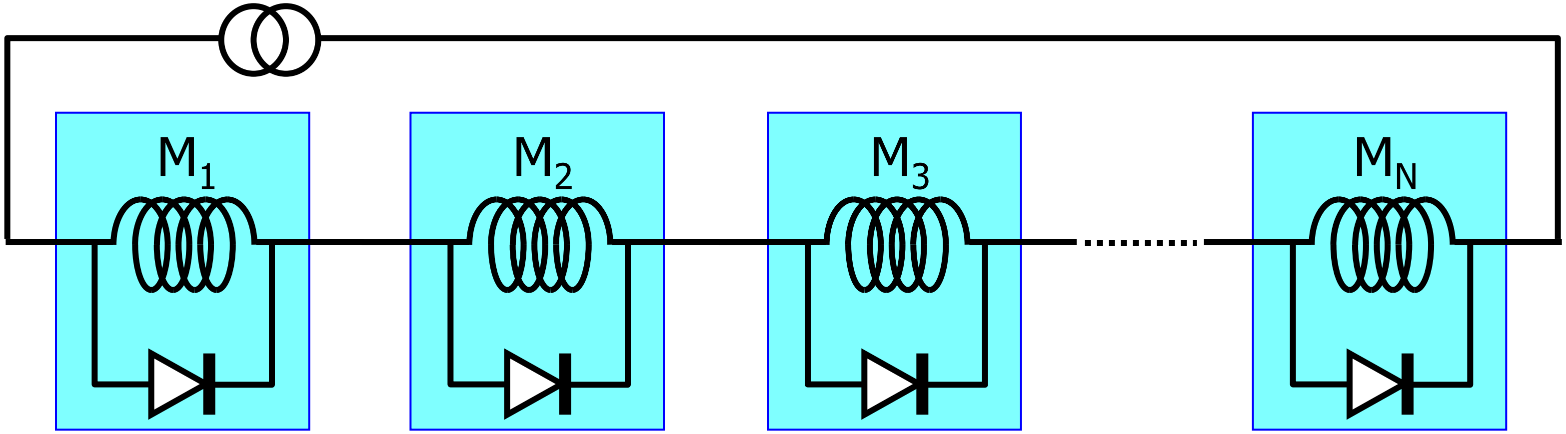
interesting alternative:
non-linear $R_{dump}$ or voltage source



increase $V_{max}$ and $I_{op}$ to achieve fast dump time

# Magnet strings

- magnet strings (e.g. accelerator magnets, fusion magnetic systems) have exceedingly large stored energy (10's of GJ):
  - energy dump takes very long time (10…100 s)
  - the magnet string is *subdivided* and each magnet is by-passed by a diode (or thyristor)
  - the diode acts as a shunt during the discharge

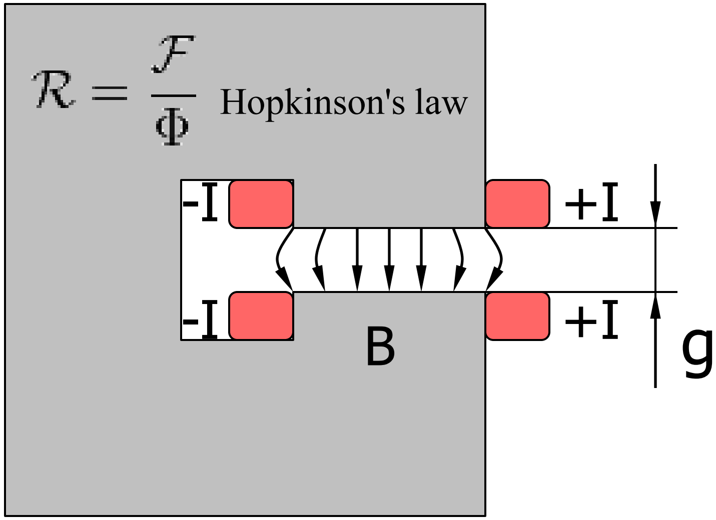


# Overview

- Why superconductors ? A motivation
- A superconductor physics primer
- Superconducting magnet design
    - Superconducting cables
    - Superconducting magnets
- The making of a superconducting magnet
- A closing word
- Examples of superconducting magnet systems
- A brief history of superconducting HEP magnets

# Magnetic design - basics

- NC: magneto motive force, reluctance and pole shapes



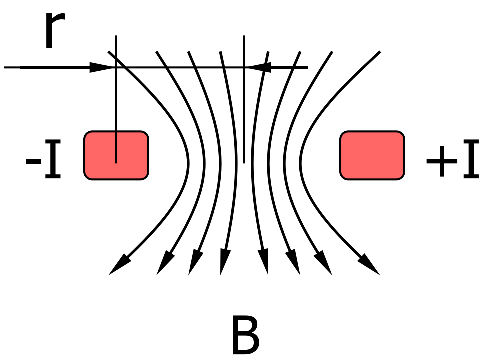
$$\mathcal{R} = \frac{\mathcal{F}}{\Phi}$$ Hopkinson's law

$B \approx \mu_0$ NI / g

g =100 mm
NI =100 kAturn
B =1.25 T

- SC: Biot-Savart law and coil shapes

$$\mathbf{B} = \int \frac{\mu_0}{4\pi} \frac{I d\mathbf{l} \times \mathbf{r}}{|r|^3}$$ Biot-Savart law

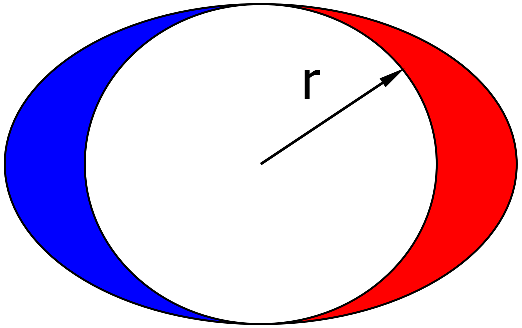


$B \approx \mu_0$ NI / $\pi$ r

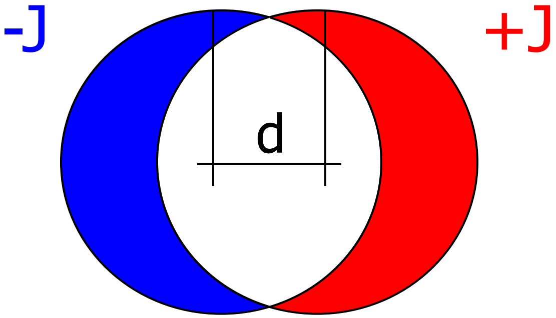
r =45 mm
NI =1 MAturn
B =8.84 T

# Design of an ideal dipole magnet

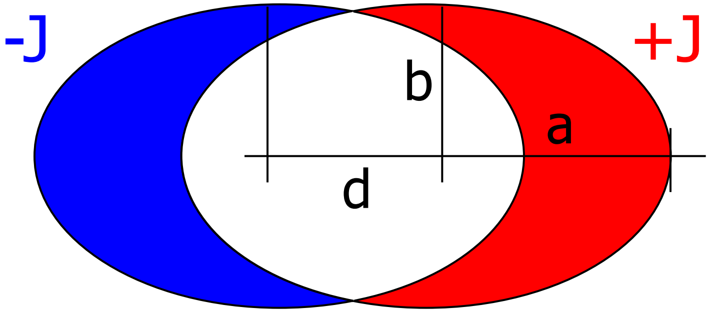
$I=I_0\cos(\theta)$ ⇨ $B_1=-\mu_0 I_0/2r$



Intersecting circles ⇨ $B_1=-\mu_0 J d/2$



Intersecting ellipses ⇨ $B_1=-\mu_0 J d\, b/(a+b)$

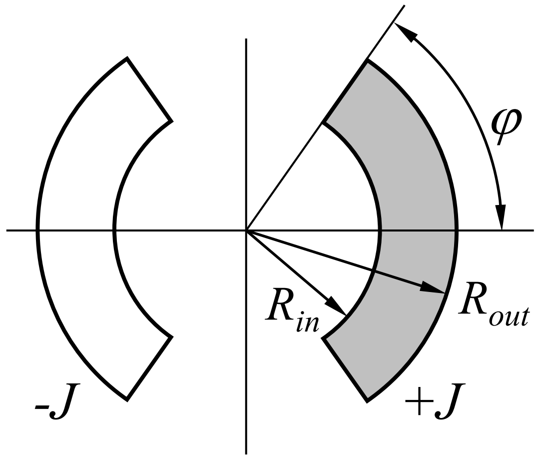


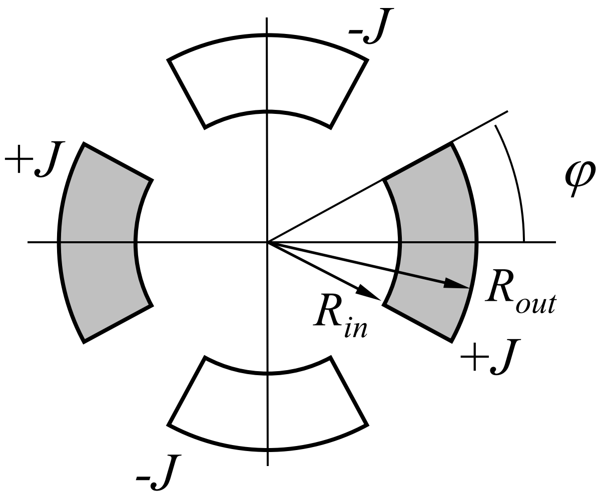
Several solutions are possible and can be extended to higher order multi-pole magnets

**None of them is practical !**

# Magnetic design - sector coils

- Dipole coil
- Quadrupole coil





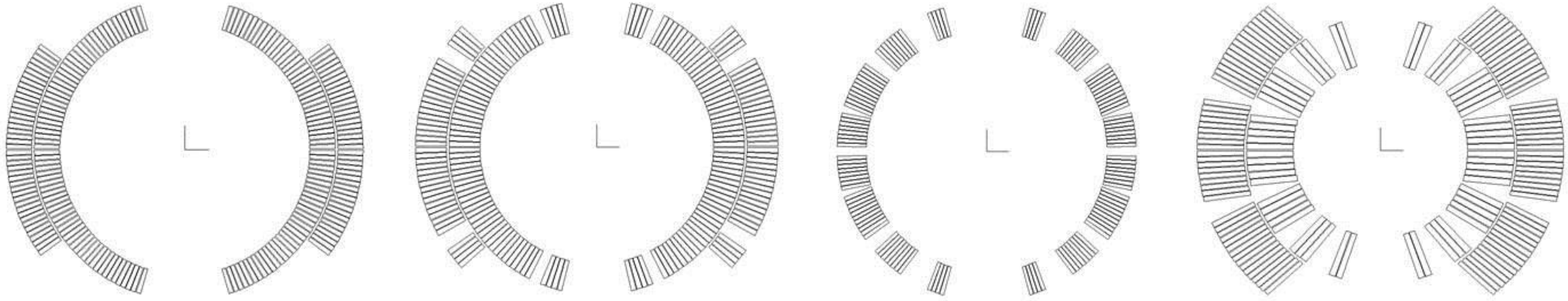
$B_1 = -2\mu_0/\pi\, J\, (r_2 - r_1)\, \sin(\varphi)$

$G = -2\mu_0/\pi\, J\, \ln(r_2/r_1)\, \sin(2\varphi)$

**This is getting much more practical for the construction of superconducting coils !**

# Evolution of coil cross sections

- Coil cross sections (to scale) of the four superconducting colliders

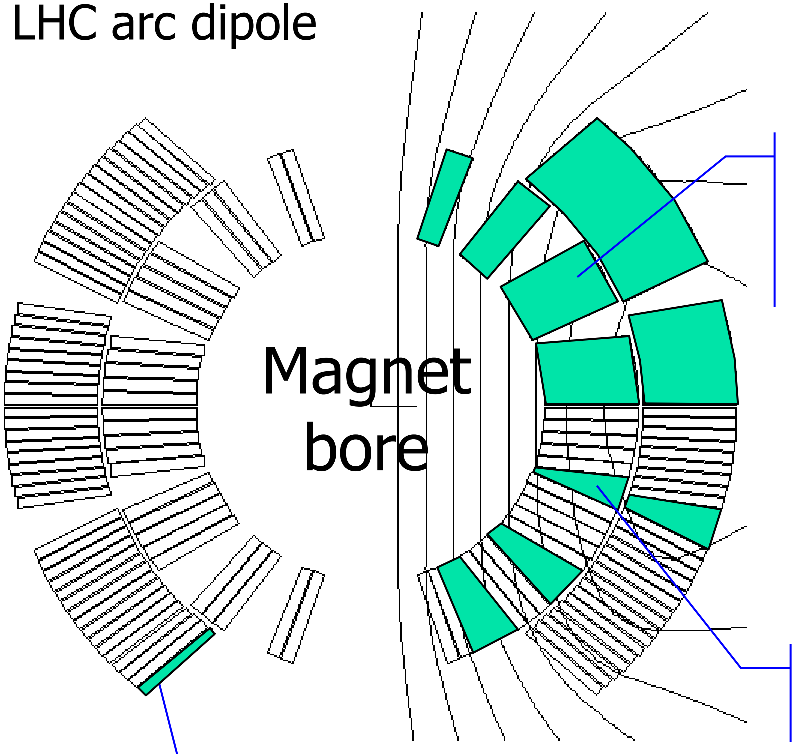


**Tevatron** **HERA** **RHIC** **LHC**

- Increased coil complexity (neted layers, wedges and coil blocks) to achieve higher efficiency and improved field homogeneity

# *Technical* coil windings

LHC arc dipole



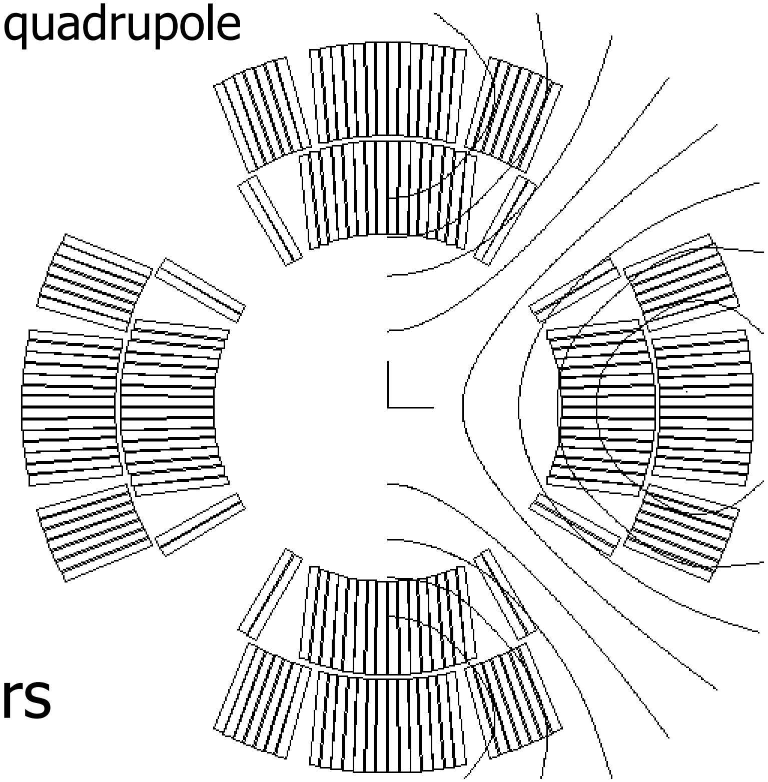
Magnet bore

Coil blocks

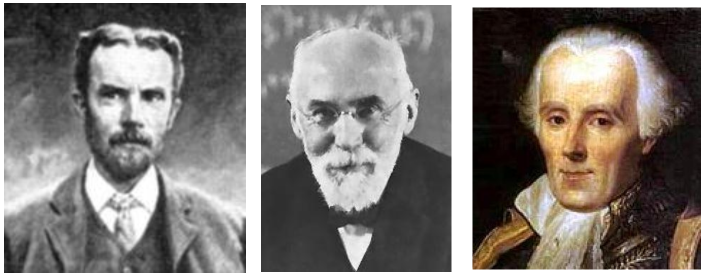
Spacers

Superconducting cable

LHC arc quadrupole



# Electromagnetic force



(O. Heaviside) E.A. Lorentz, P.S. Laplace

- An electric charged particle $q$ moving with a velocity $v$ in a field $B$ experiences a force $F_L$ called electromagnetic (Lorentz) force (N):

$$\vec{F}_L = q\vec{v} \times \vec{B}$$

- A conductor carrying current density $J$ (A/mm$^2$) experiences a (Laplace) force density $f_L$ (N/m$^3$):

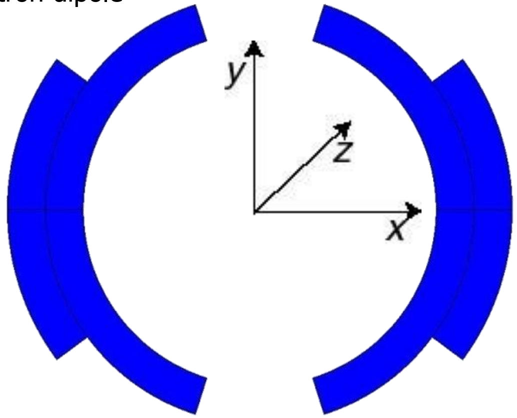
$$\vec{f}_L = \vec{J} \times \vec{B}$$

*Graphics by courtesy of P. Ferracin, S. Prestemon, E. Todesco*

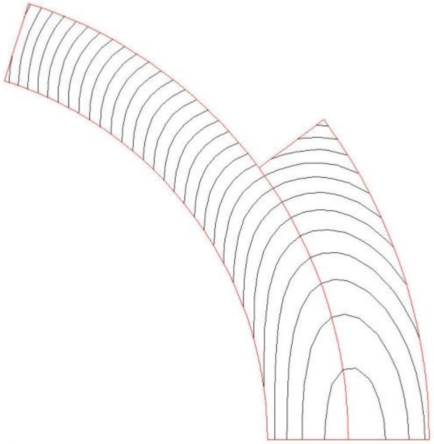
# Electromagnetic forces - dipole

- The electromagnetic forces in a dipole magnet tend to push the coil:
  - Vertically, towards the mid plane (Fy < 0)
  - Horizontally, outwards (Fx > 0)

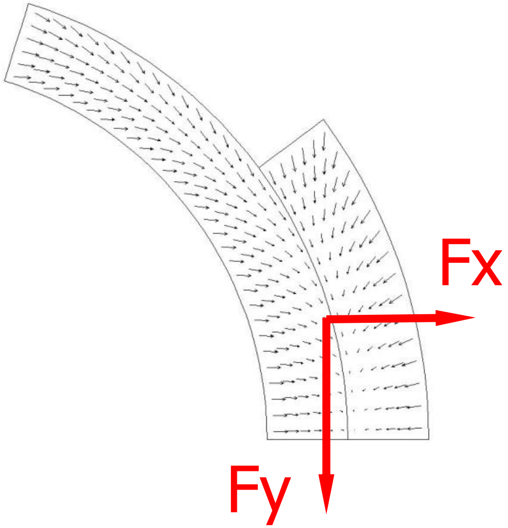
Tevatron dipole



Field



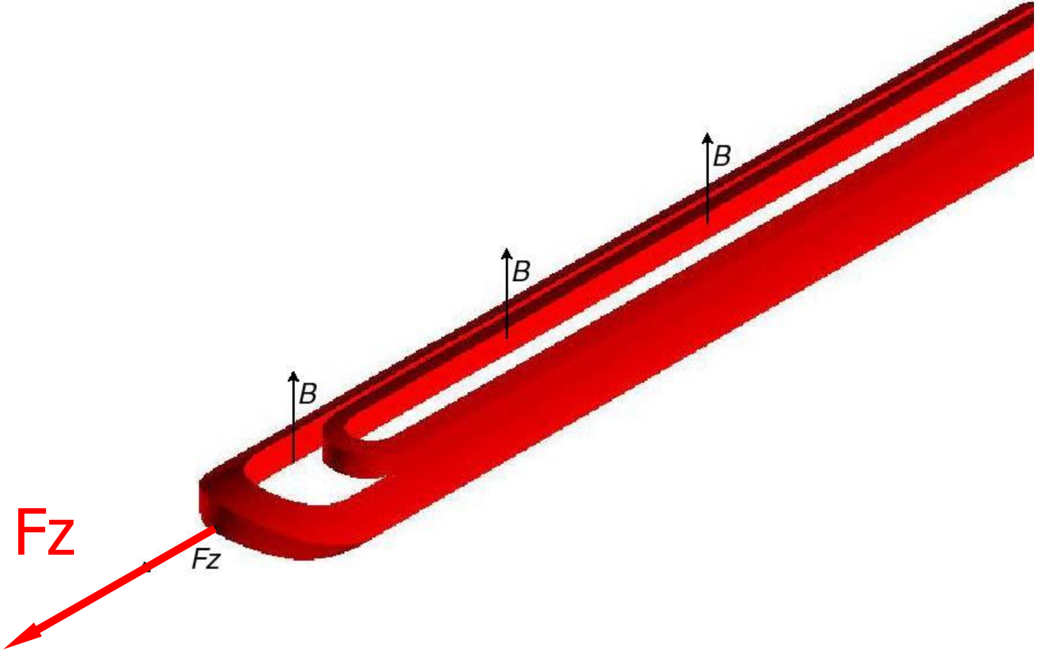
Force



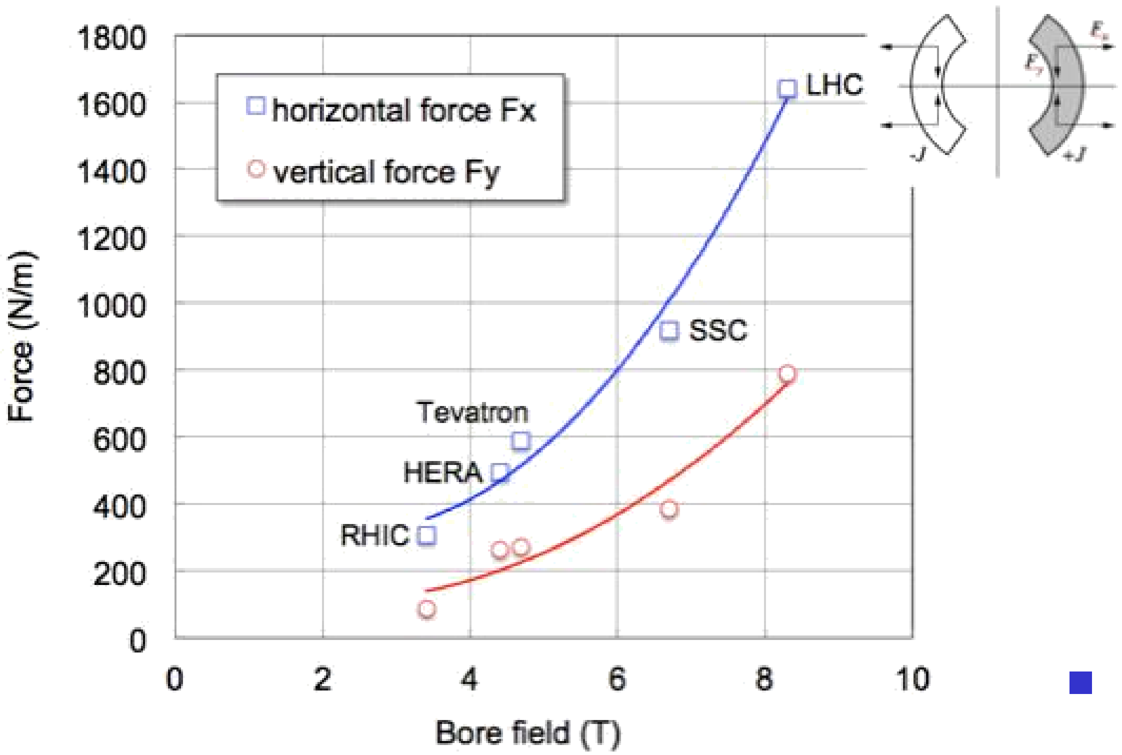
*Graphics by courtesy of P. Ferracin, S. Prestemon, E. Todesco*

# Electromagnetic forces - ends

- In the coil ends the Lorentz forces tend to push the coil:
    - Outwards in the longitudinal direction (Fz > 0), and, similar to solenoids, the coil straight section is in tension



# The real challenge of very high fields



- Force increases with the square of the field
  - Massive structure
    - High-strength materials
    - Weight, volume
  - Stress limit in the superconducting coil
    - Superconductor and insulation
    - Not as bad as for the forces because $J_e \approx 1/B$
- In practice the design is **limited by mechanics**

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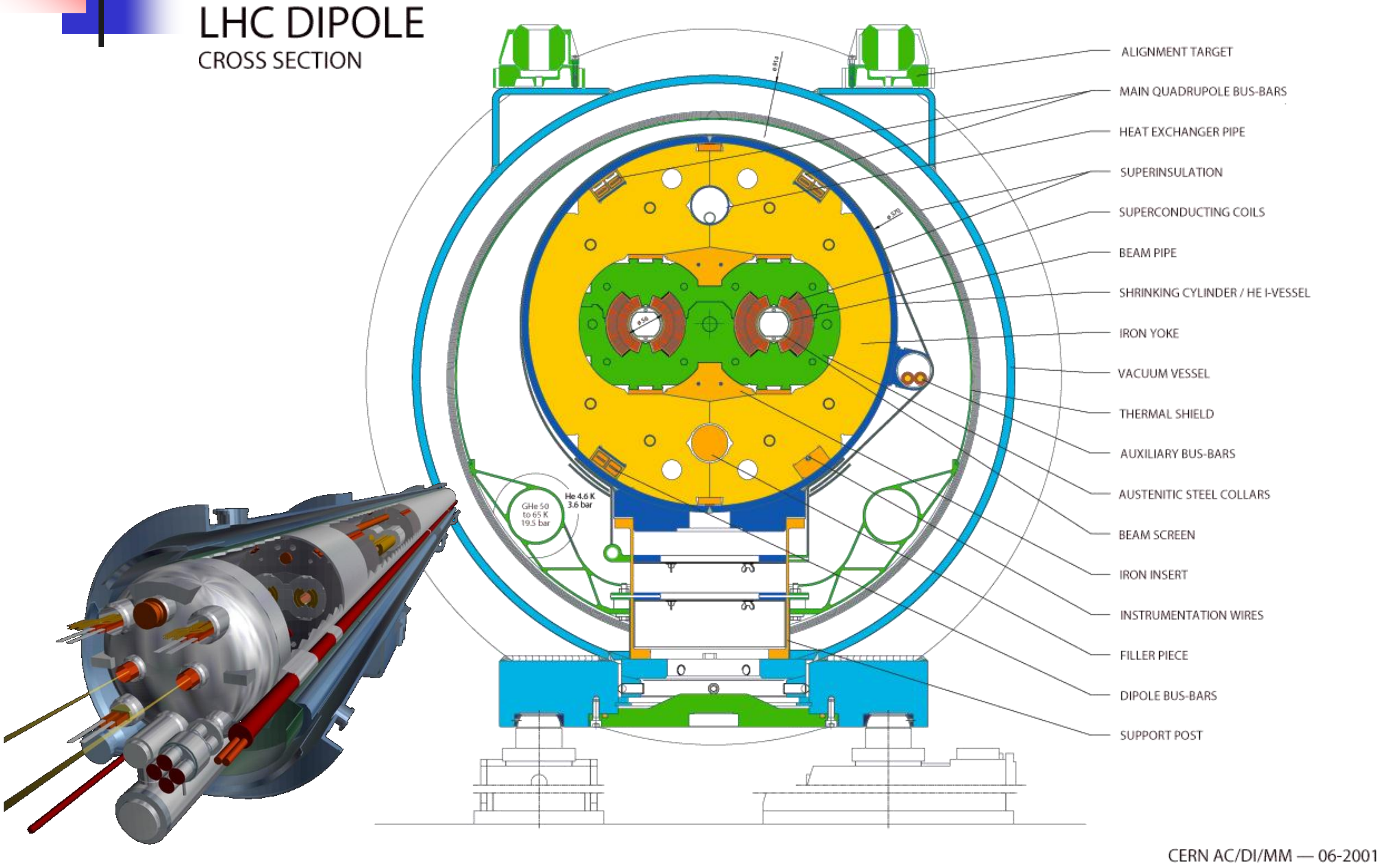
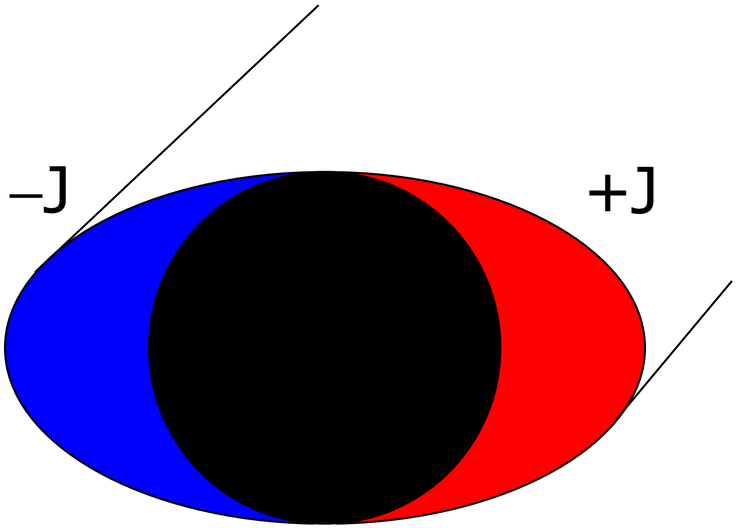
# LHC dipole

| | | |
|---|---|---|
| $B_{nominal}$ | 8.3 | (T) |
| current | 11850 | (A) |
| stored energy | ≈ 10 | (MJ) |
| cold mass | ≈ 35 | (tonnes) |

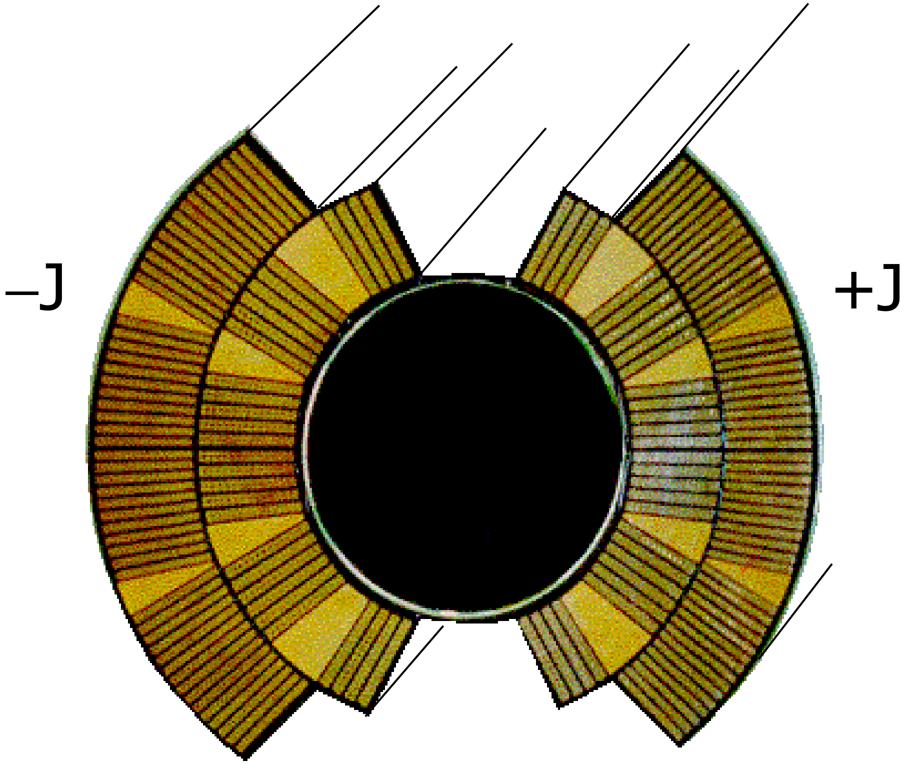


CERN AC/DI/MM — 06-2001

# Superconducting dipole magnet coil

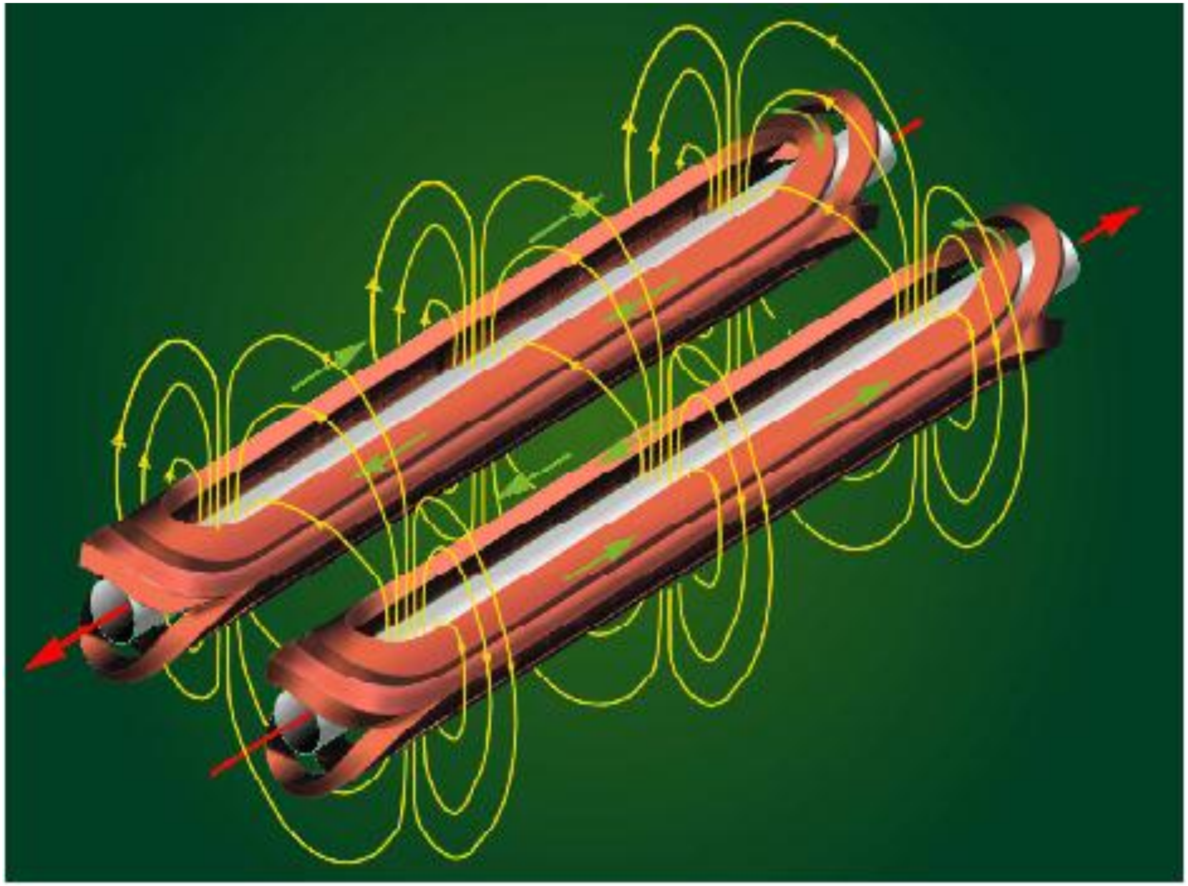


Ideal current distribution that generates a perfect dipole



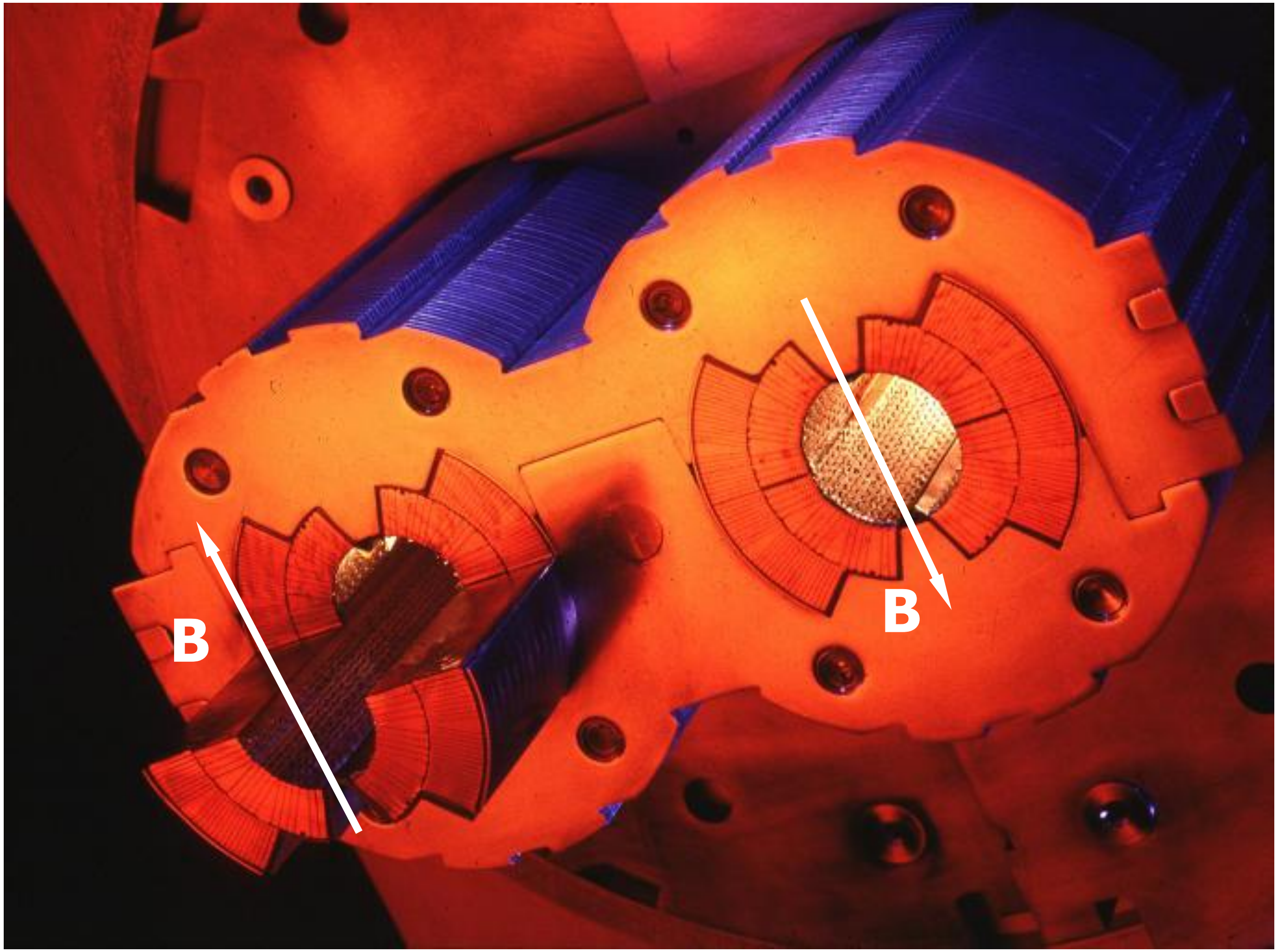
Practical approximation of the ideal distribution using Rutherford cables

# Twin coil principle

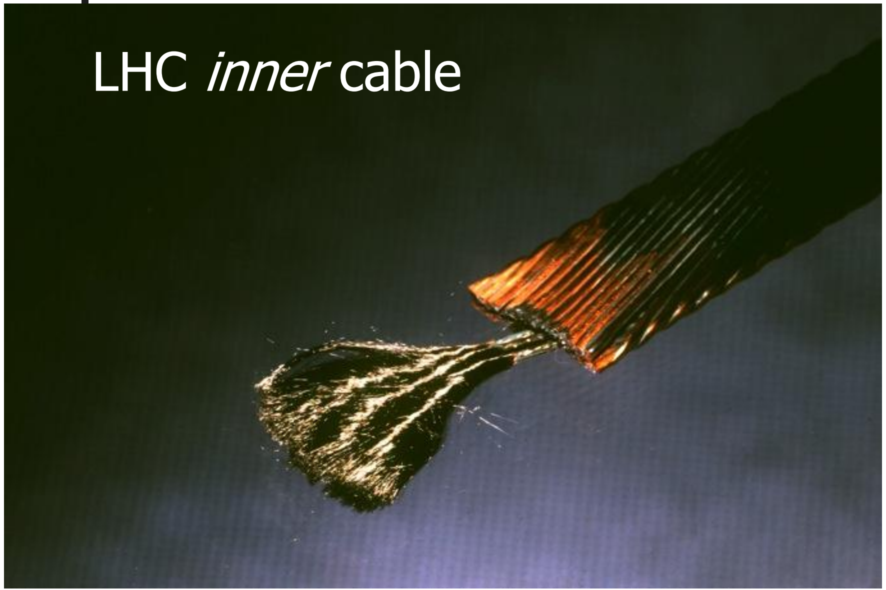


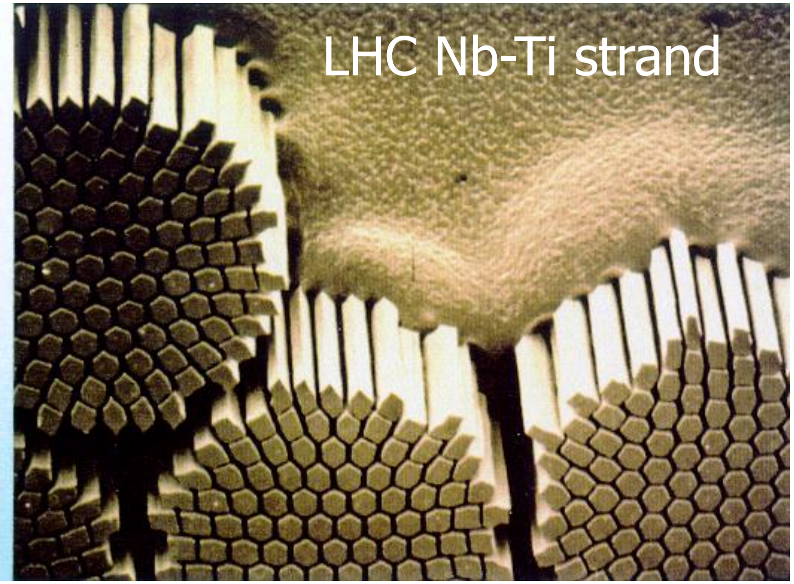
Combine two magnets in one
Save volume, material, cost

# LHC dipole coils



# Rutherford cables

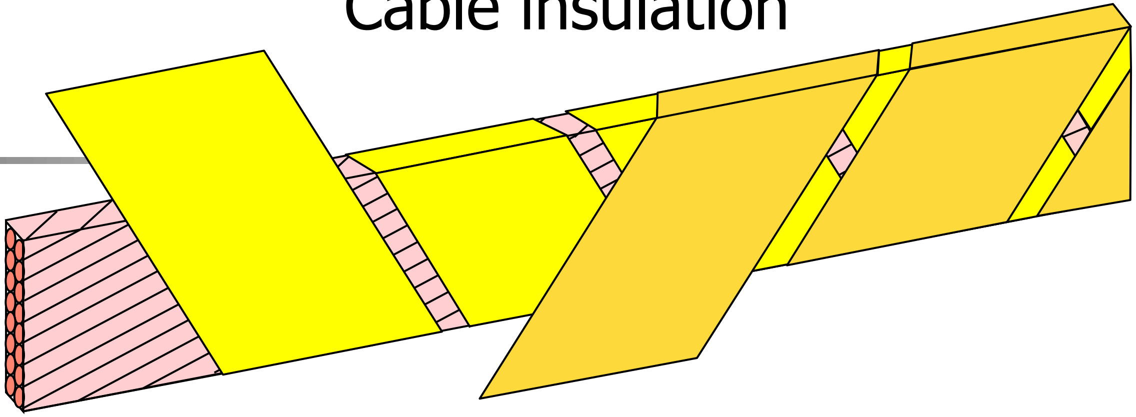

LHC *inner* cable


LHC Nb-Ti strand


LHC outer cable cross section

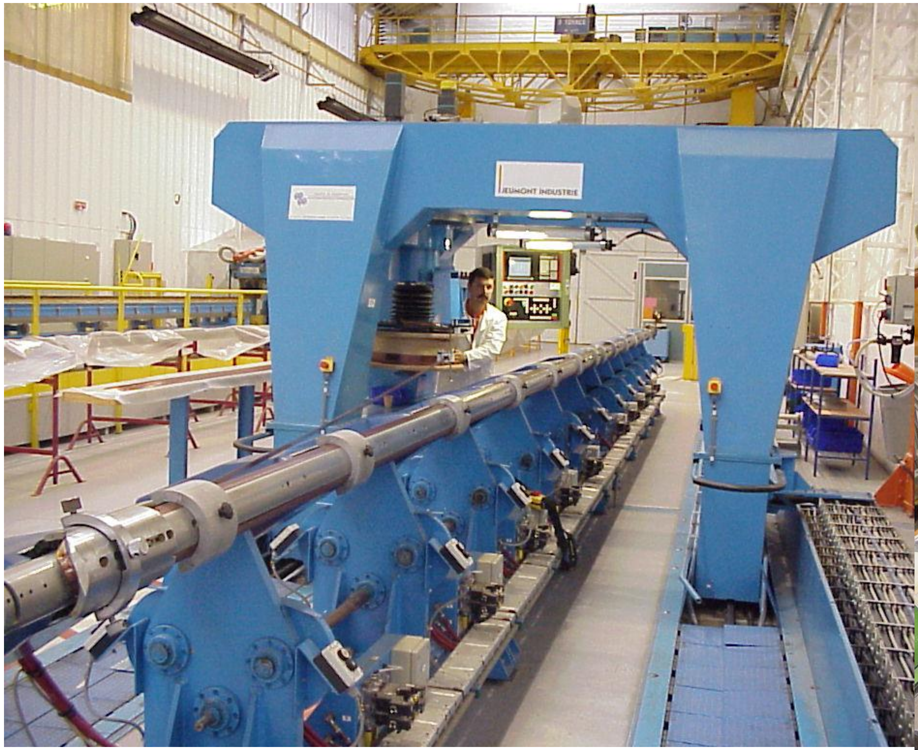
7500 km of superconducting cables with tightly controlled properties (state-of-the-art production)

# Coil winding



Cable insulation

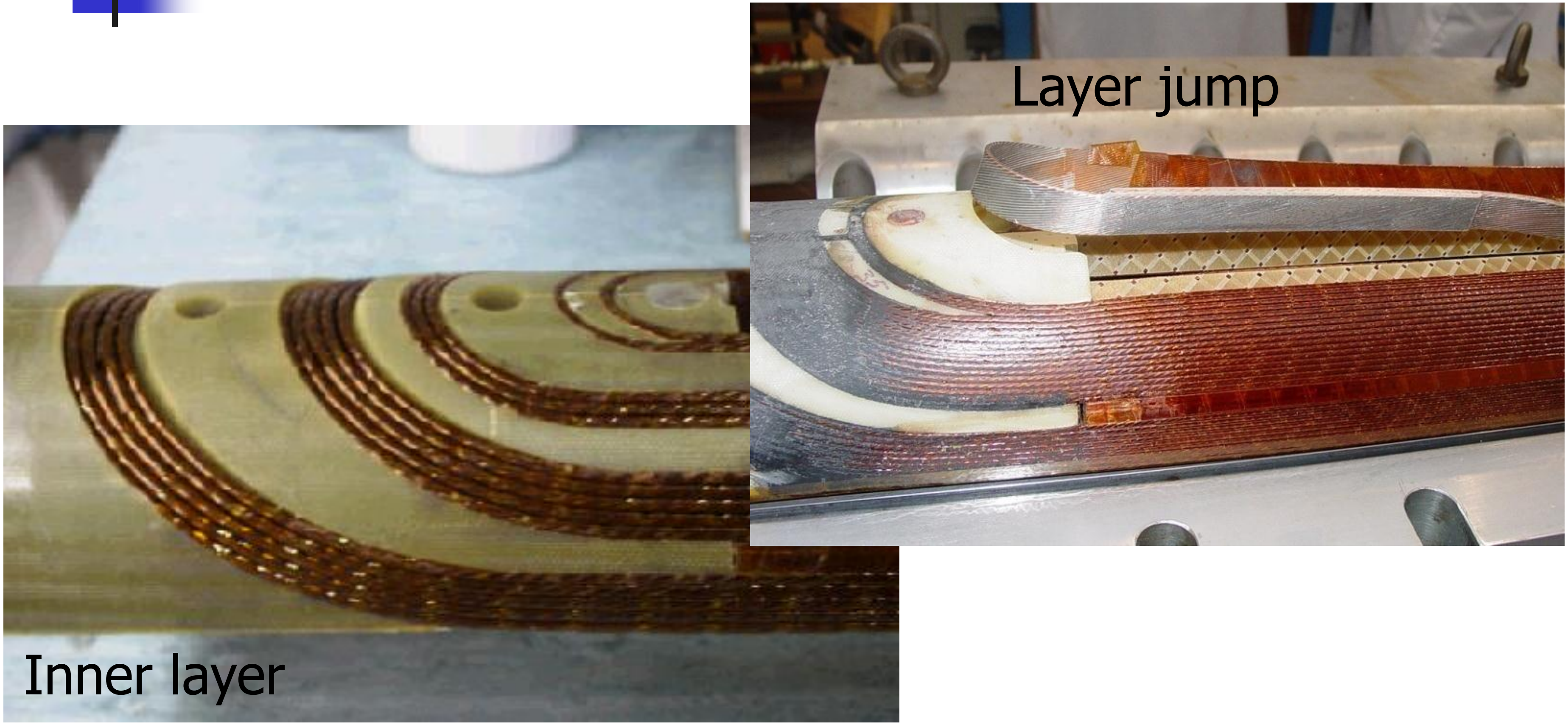
10 $\mu$m precision !



Coil winding machine

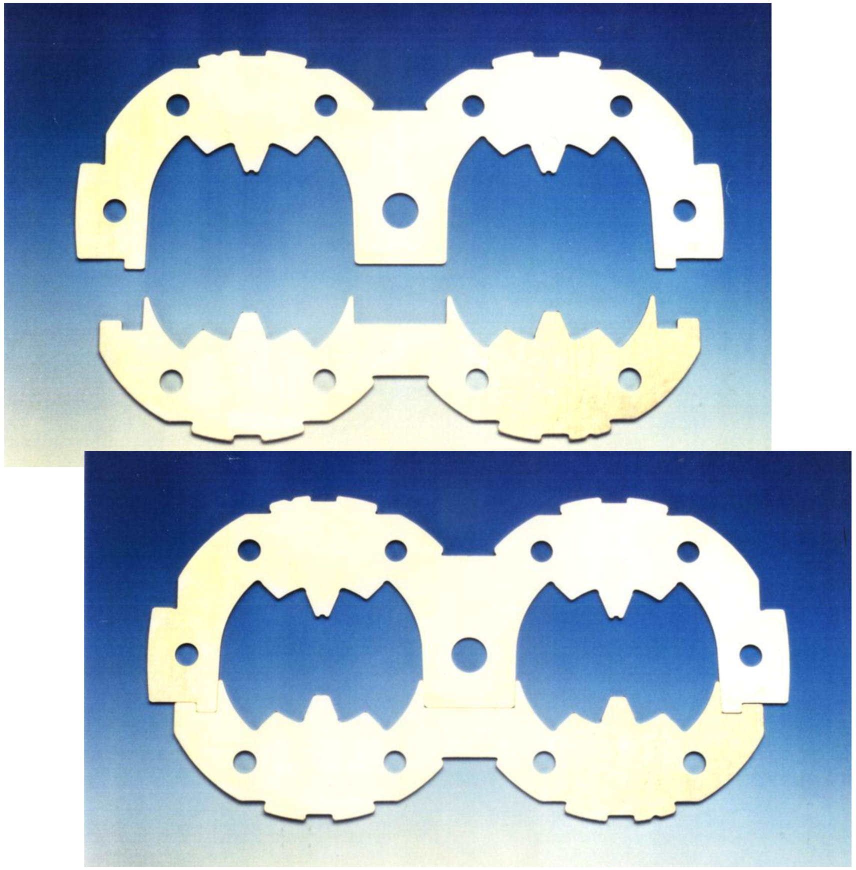
Stored coils

# Ends

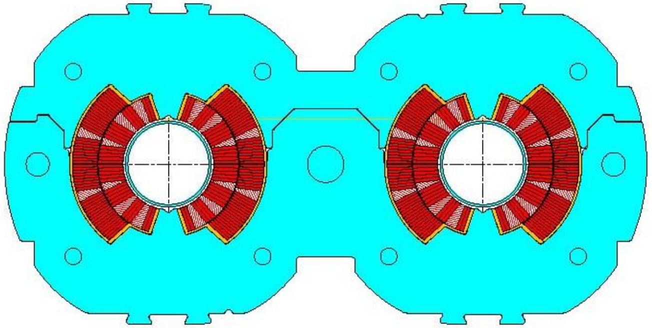


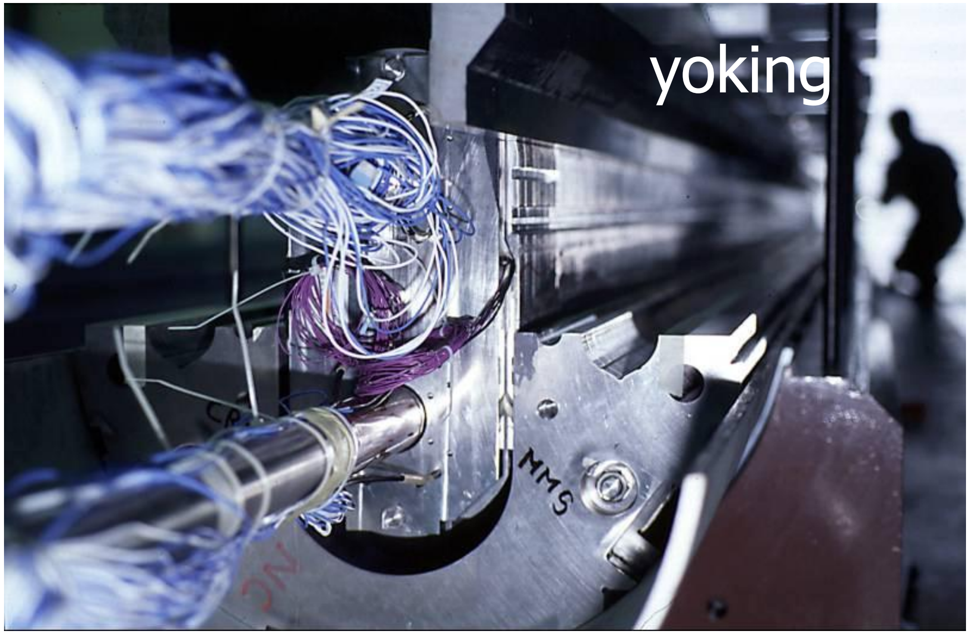
Ends, transitions, and any deviation from the regular structure are the most delicate part of the magnet

# Collaring and yoking



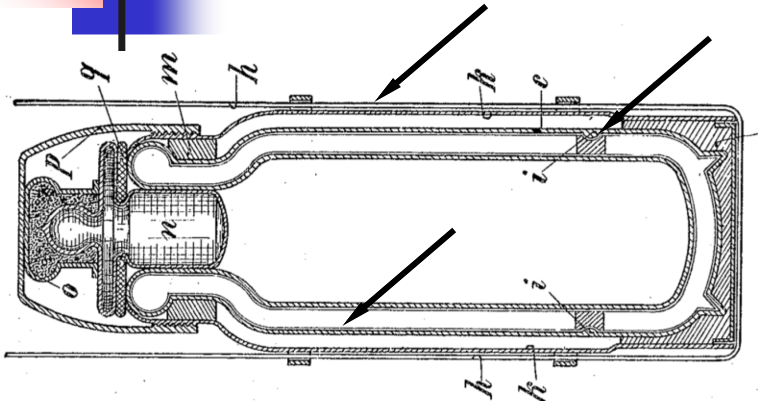
collaring





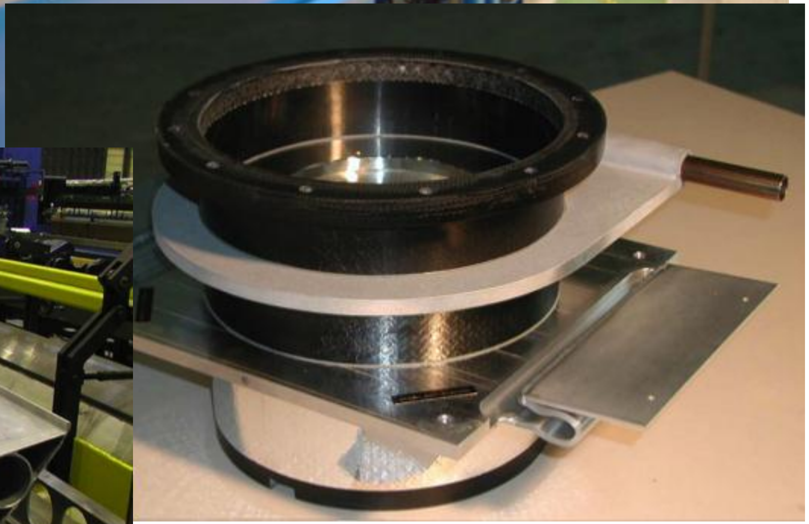
# Cold mass

# Cryostat

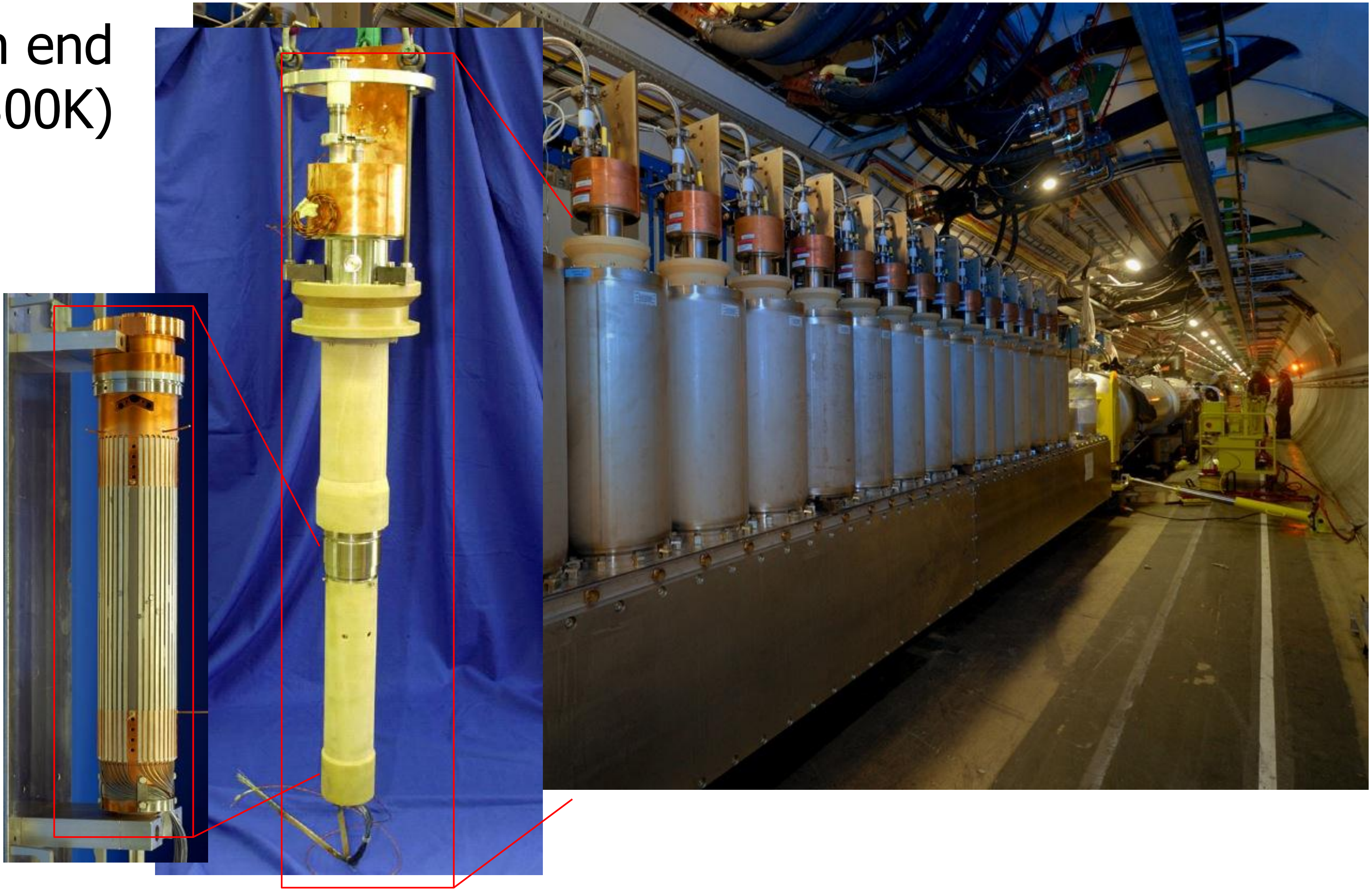



Vacuum enclosure


Thermal screens


Low conduction foot

# Large scale use of HTS



Warm end
(300K)

50 K

BSCCO
2223

4.2 K

# Finally, in the tunnel !

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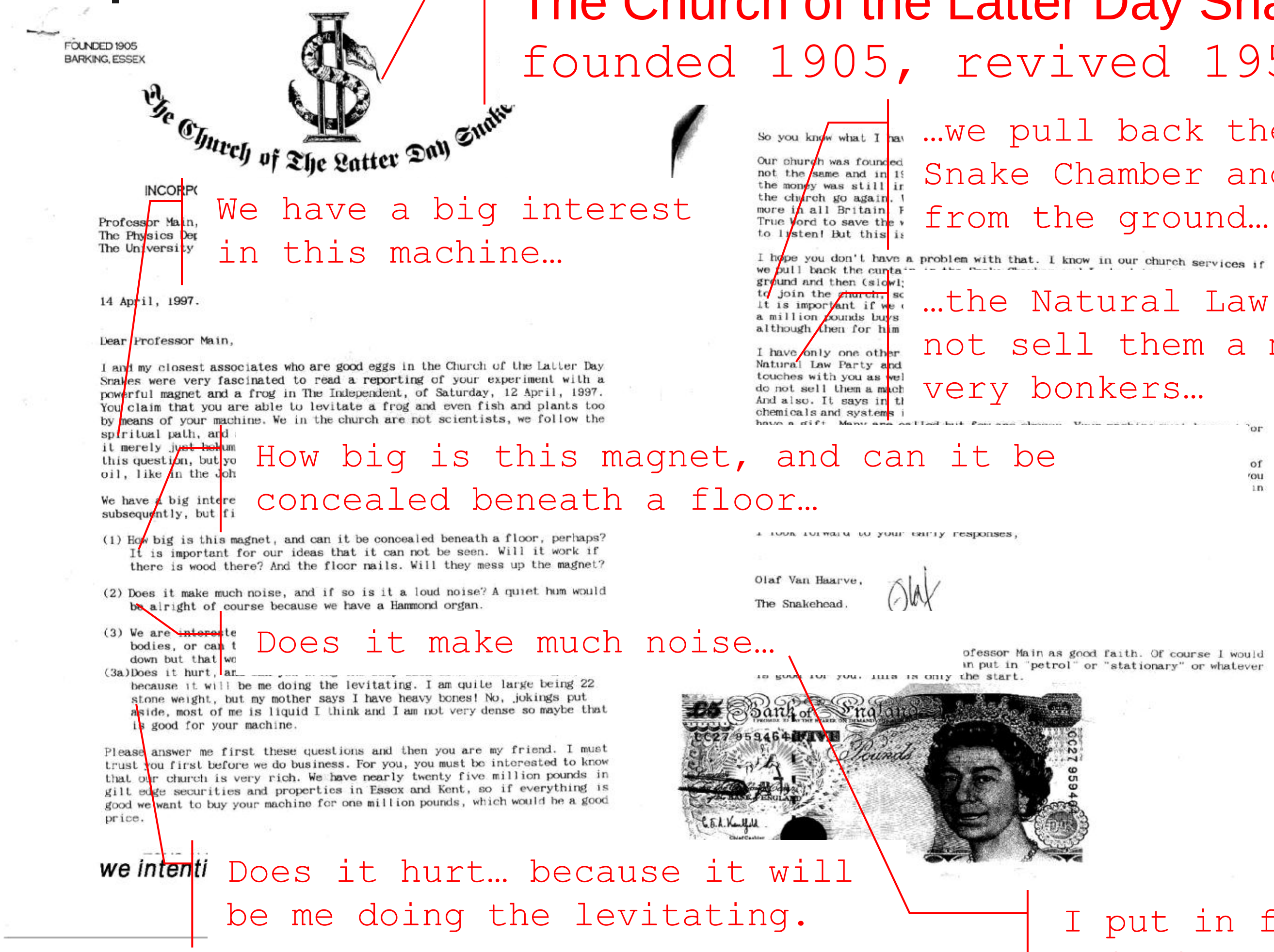
# A word of closing

- Superconducting magnet design is a lot about superconductors (materials, wires, cables, and their electric and thermal properties)…
- … but not only !
  - High field & forces bear mechanical problems that are tough to solve (B=10 T ⇒ $p_{mag}$=400 bar !)
  - Materials at low temperature are not what we are used to (mechanical and magnetic properties, thermal expansion, electrical insulation)
  - Cooling is an applied science by itself

# Other uses of superconductivity

The Church of the Latter Day Snakes
founded 1905, revived 1950



FOUNDED 1905
BARKING, ESSEX

The Church of The Latter Day Snakes

INCORP

Professor Main,
The Physics Dep
The University

14 April, 1997.

Dear Professor Main,

I and my closest associates who are good eggs in the Church of the Latter Day Snakes were very fascinated to read a reporting of your experiment with a powerful magnet and a frog in The Independent, of Saturday, 12 April, 1997. You claim that you are able to levitate a frog and even fish and plants too by means of your machine. We in the church are not scientists, we follow the spiritual path, and
it merely just hokum
this question, but yo
oil, like in the Joh

We have a big intere
subsequently, but fi

(1) How big is this magnet, and can it be concealed beneath a floor, perhaps? It is important for our ideas that it can not be seen. Will it work if there is wood there? And the floor nails. Will they mess up the magnet?

(2) Does it make much noise, and if so is it a loud noise? A quiet hum would be alright of course because we have a Hammond organ.

(3) We are intereste
bodies, or can t
down but that wo

(3a) Does it hurt, an
because it will be me doing the levitating. I am quite large being 22 stone weight, but my mother says I have heavy bones! No, jokings put aside, most of me is liquid I think and I am not very dense so maybe that is good for your machine.

Please answer me first these questions and then you are my friend. I must trust you first before we do business. For you, you must be interested to know that our church is very rich. We have nearly twenty five million pounds in gilt edge securities and properties in Essex and Kent, so if everything is good we want to buy your machine for one million pounds, which would be a good price.

we intenti

So you know what I hav

Our church was founded
not the same and in 19
the money was still in
the church go again.
more in all Britain.
True Word to save the
to listen! But this is

I hope you don't have a problem with that. I know in our church services if we pull back the curta
ground and then (slowl
to join the church, so
it is important if we
a million pounds buys
although then for him

I have only one other
Natural Law Party and
touches with you as wel
do not sell them a mach
And also. It says in th
chemicals and systems i

or

of
you
in

I look forward to your early responses,

Olaf Van Haarve,

The Snakehead.

ofessor Main as good faith. Of course I would
in put in "petrol" or "stationary" or whatever
is good for you. This is only the start.

We have a big interest in this machine…

…we pull back the curtain in the Snake Chamber and I start to rise up from the ground…

…the Natural Law Party… please do not sell them a machine… **they** are very bonkers…

How big is this magnet, and can it be concealed beneath a floor…

Does it make much noise…

Does it hurt… because it will be me doing the levitating.

I put in five pounds for you…
This is only the start.

Letter to Prof. Main, University of Nottingham, 14 April 1997