The Large Hadron Collider

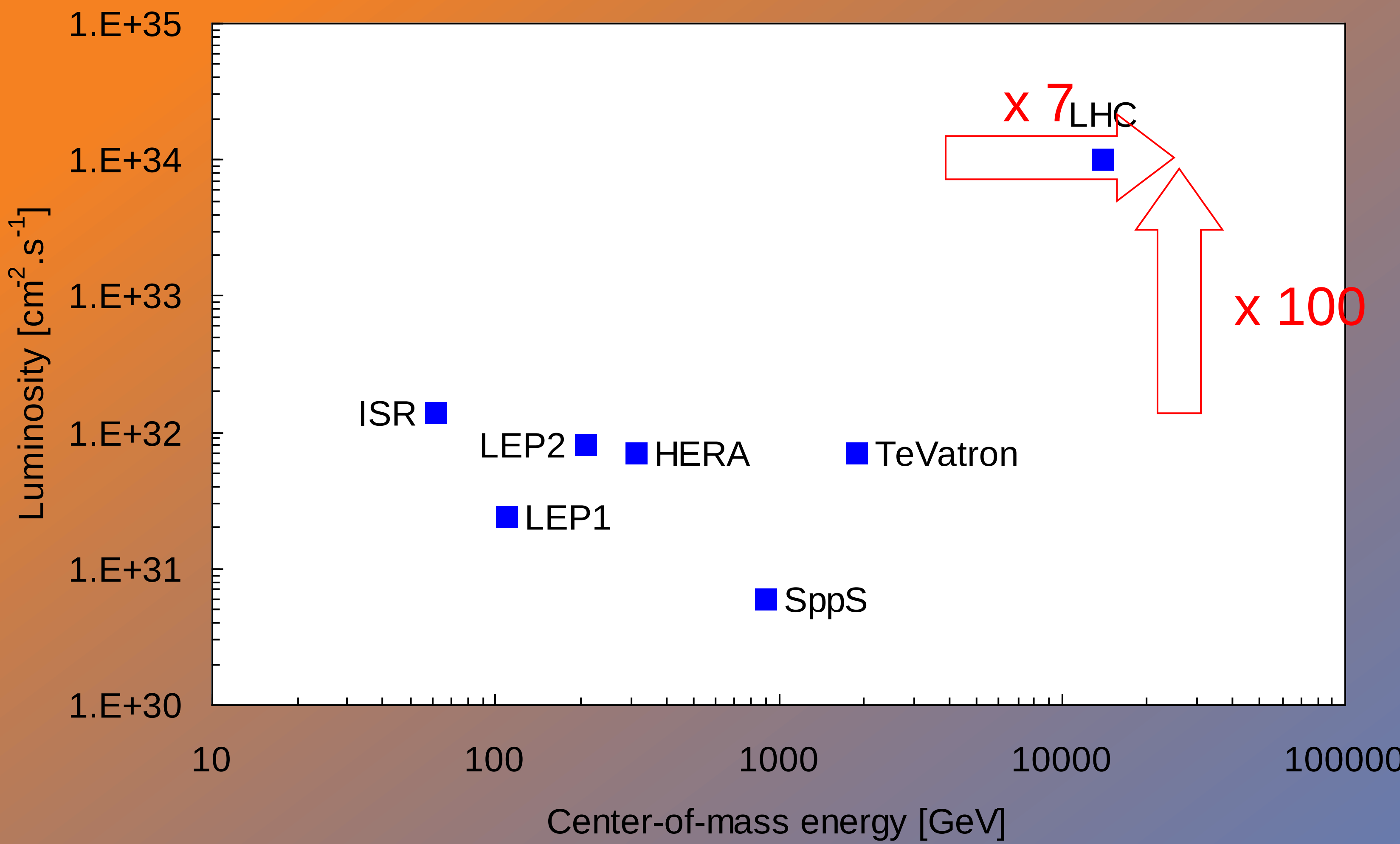
Lyn Evans – CERN/*IC*

ASP2012 Kumasi Ghana 30th July 2012

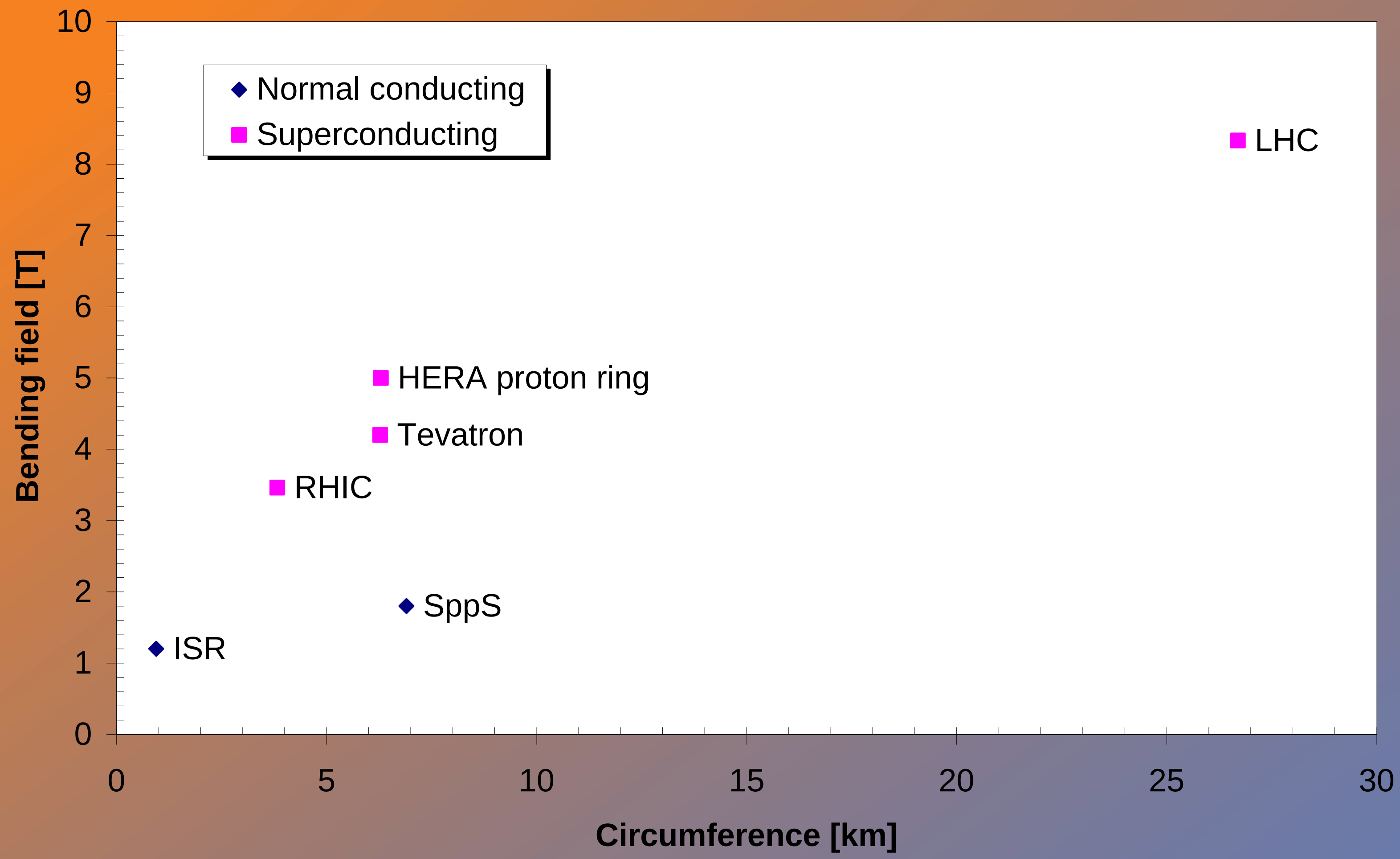
Advanced technology at work

23 km of superconducting magnets cooled in superfluid helium at 1.9 K

A new territory in energy and luminosity



Circumference & bending field of hadron colliders



Electrical power consumption

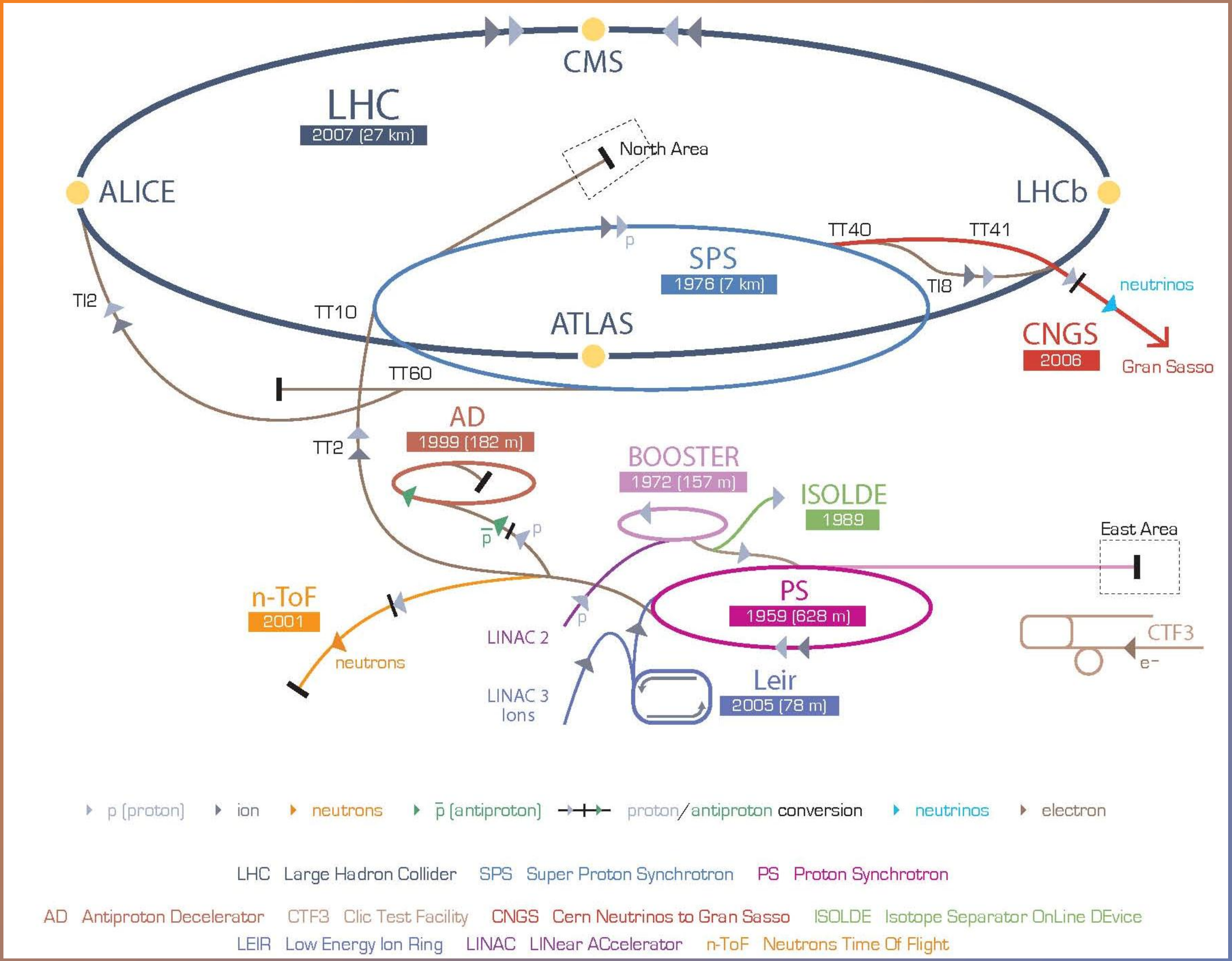
Superconducting magnets enable to contain electrical power consumption through two independent effects:

- **Higher magnetic field ⇒ smaller circumference**
- **No dissipation ⇒ lower power (refrigeration) per unit length**

	Normal conducting	**Superconducting (LHC)**
Magnetic field	1.8 T (iron saturation)	8.3 T (NbTi critical surface)
Field geometry	Defined by magnetic circuit	Defined by coils
Current density in windings	10 A/mm^2	400 A/mm^2
Electromagnetic forces	20 kN/m	3400 kN/m
Electrical consumption	10 kW/m	2 kW/m

Joule heating (→ 10 kW/m)   Refrigeration (→ 2 kW/m)

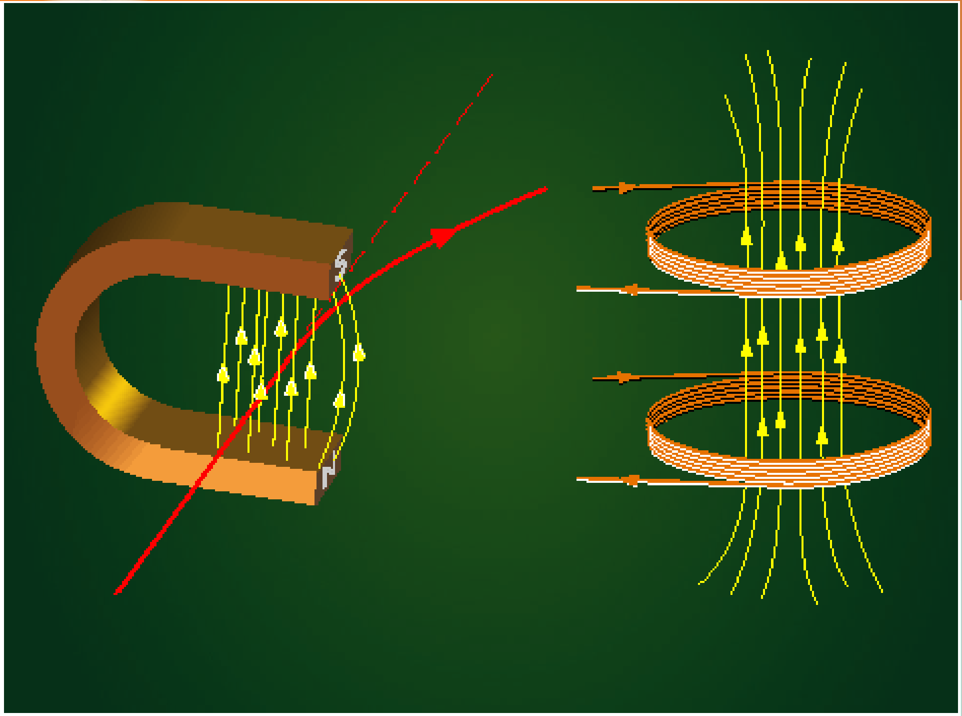
Making best use of CERN's infrastructure



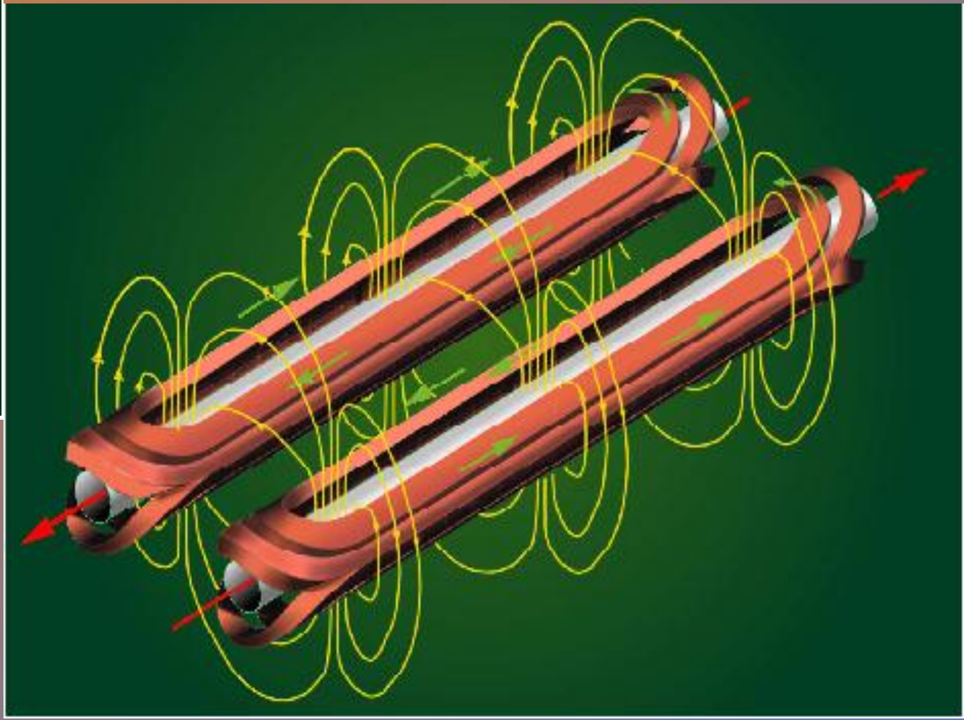
Main parameters of LHC (p-p)

Circumference	26.7	km
Beam energy at collision	7	TeV
Beam energy at injection	0.45	TeV
Dipole field at 7 TeV	8.33	T
Luminosity	10^{34}	$cm^{-2}.s^{-1}$
Beam current	0.58	A
Protons per bunch	1.15×10^{11}	
Number of bunches	2808	
Nominal bunch spacing	24.95	ns
Normalized emittance	3.75	μm.rad
Total crossing angle	285	μrad
Energy loss per turn	6.7	keV
Critical synchrotron energy	44.1	eV
Radiated power per beam	3.6	kW
Stored energy per beam	362	MJ
Stored energy in magnets	11	GJ
Operating temperature	1.9	K

Superconducting accelerator magnets



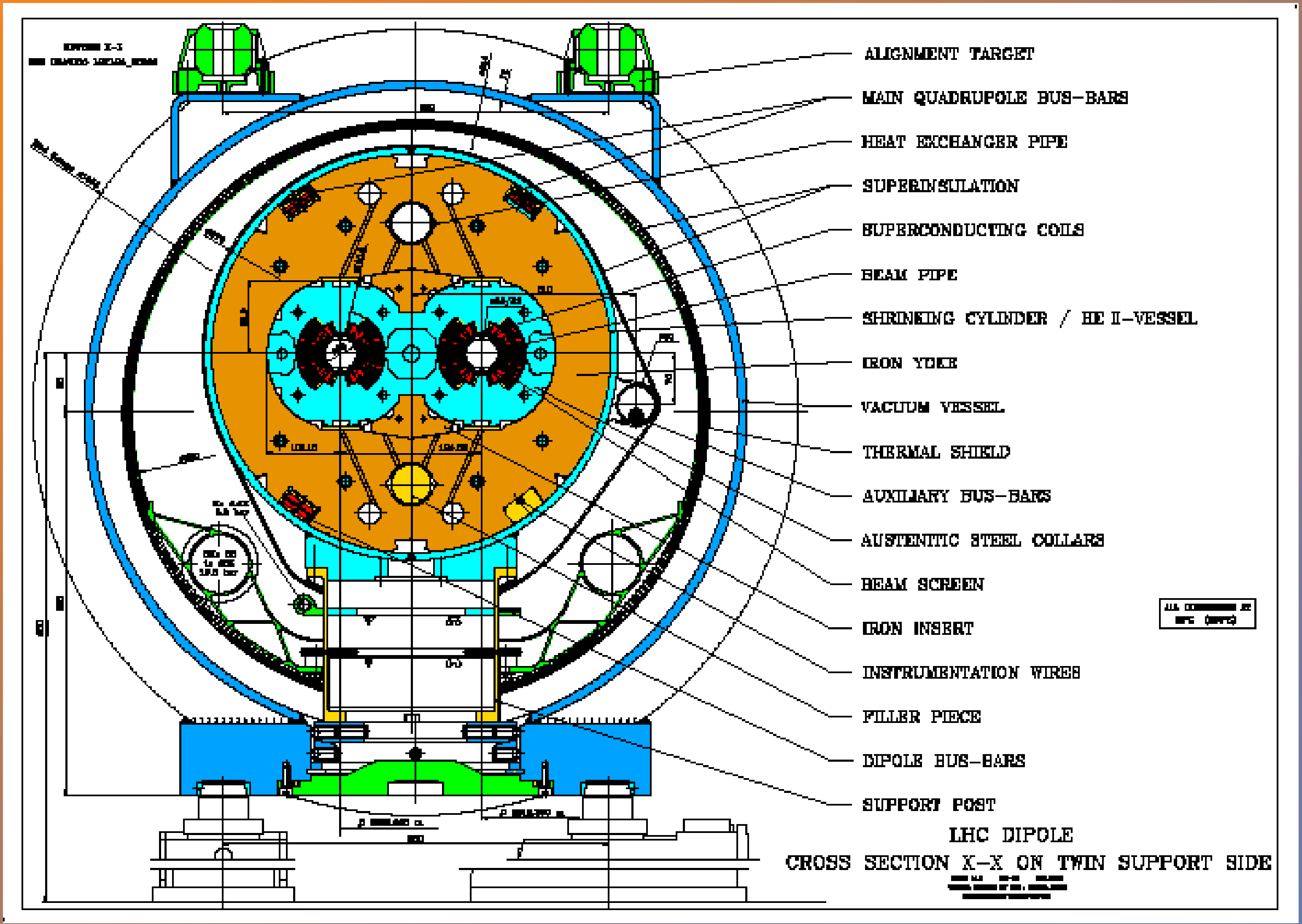
In a superconducting magnet, the field level and geometry is basically given by the current distribution in the coils.



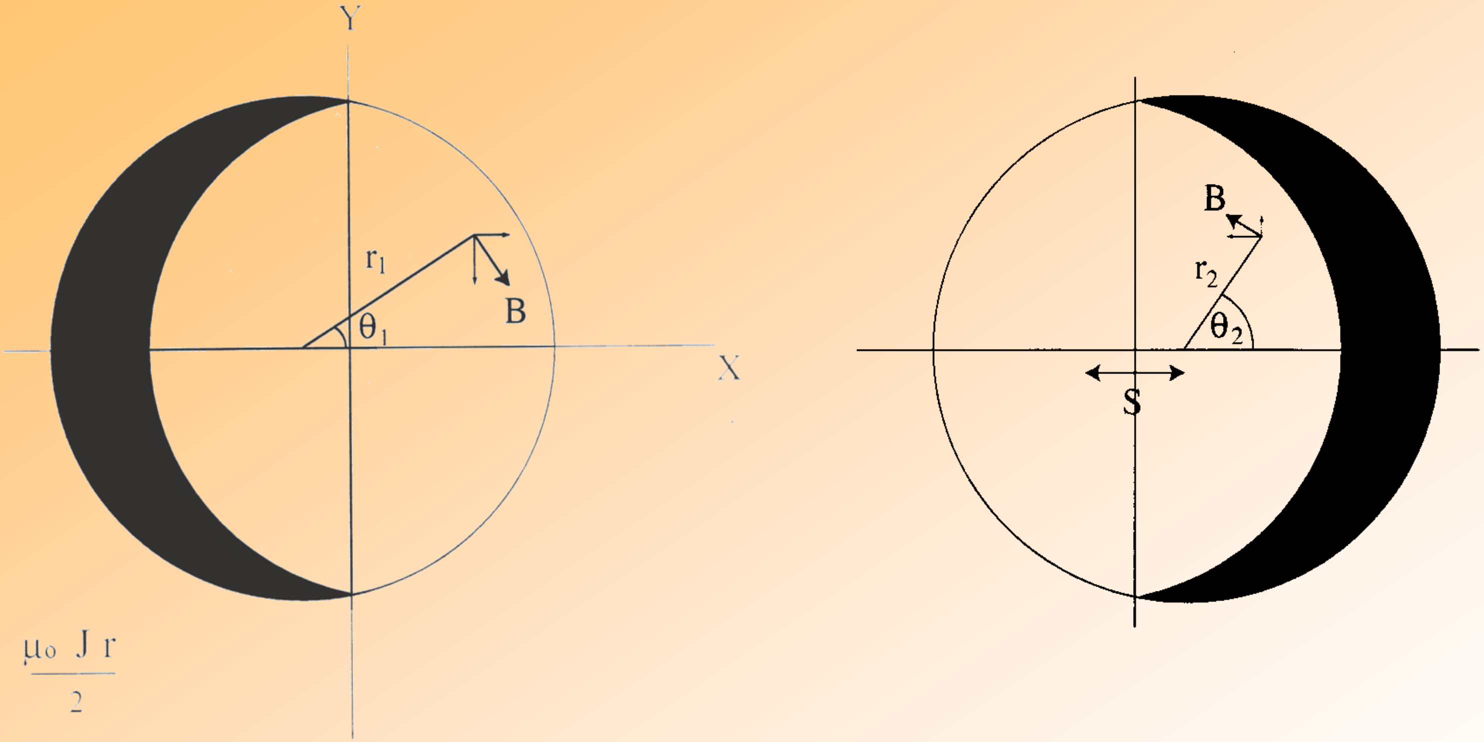
To match the geometry of the beam tubes, the coils are saddle-shaped & elongated.

In the LHC, two sets of coils create opposite fields in the neighbouring apertures.

Cryodipole cross-section



Current distribution for producing dipole field

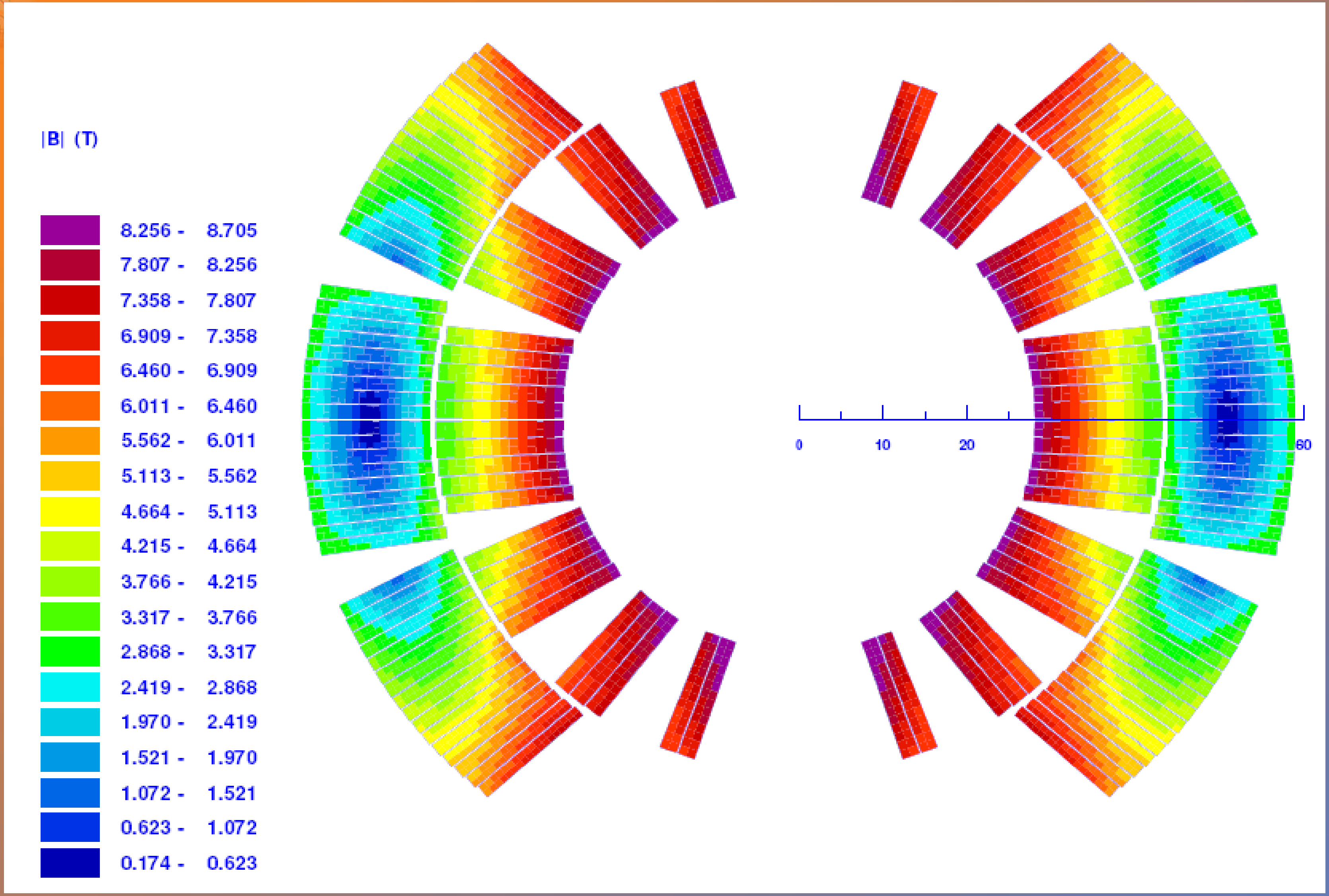


$$B = \frac{\mu_0 J r}{2}$$

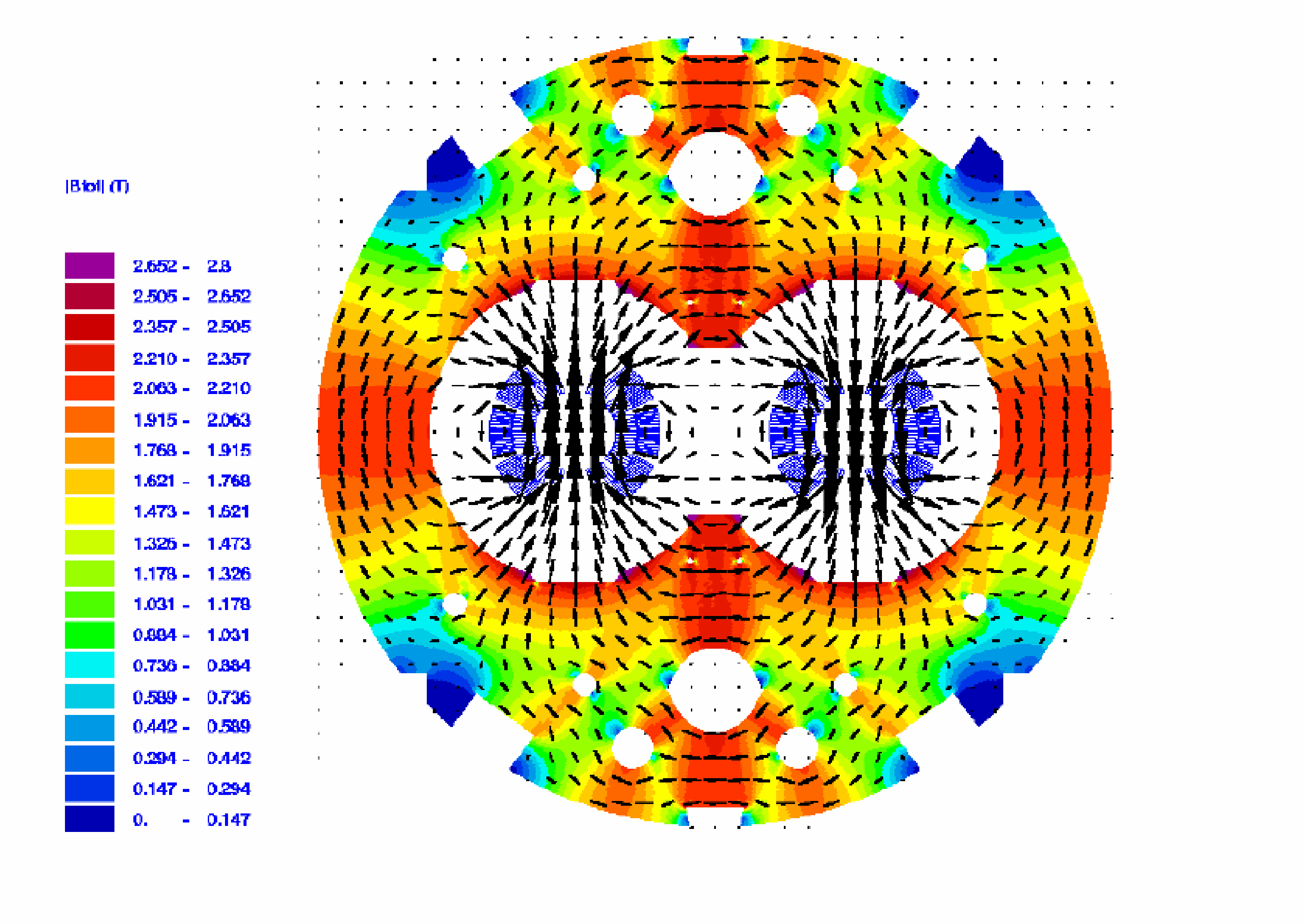
$$B_Y = \frac{\mu_0 J}{2}\left\{-r_1 \cos\theta_1 + r_2 \cos\theta_2\right\} = -\frac{\mu_0 J s}{2}$$

$$B_X = \frac{\mu_0 J}{2}\left\{r_1 \sin\theta_1 - r_2 \sin\theta_2\right\} = 0$$

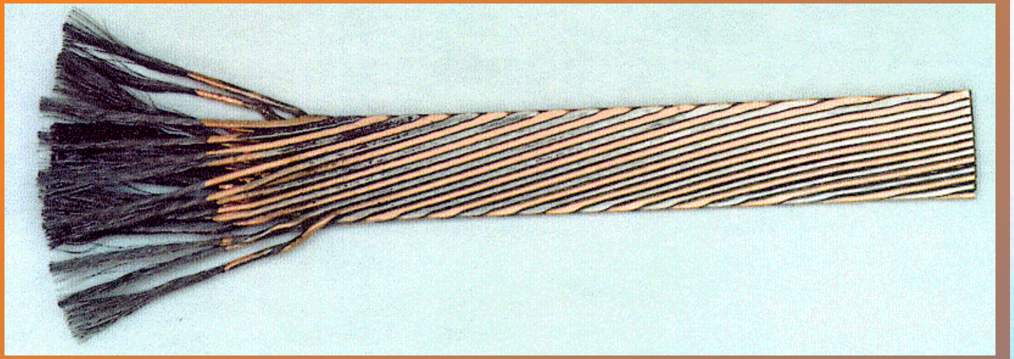
Distribution of conductors in dipole coil

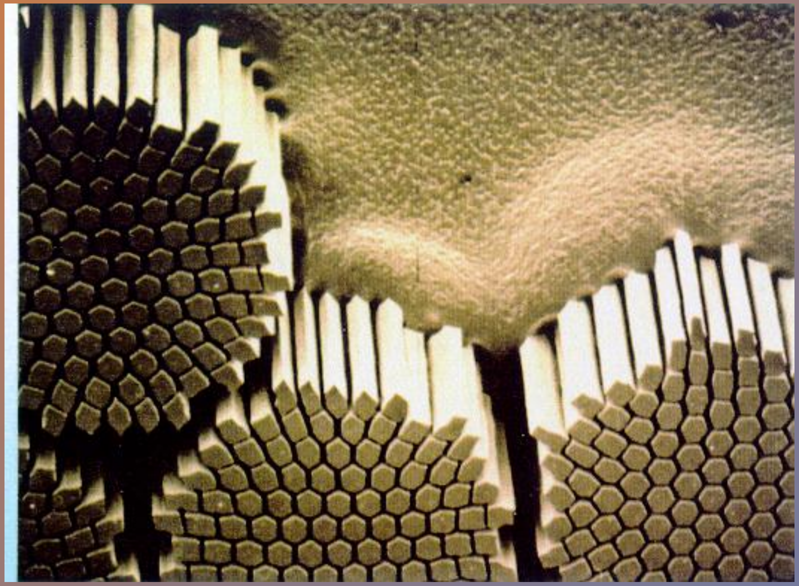


Dipole magnetic flux plot



7000 km of superconducting cable Nb-Ti



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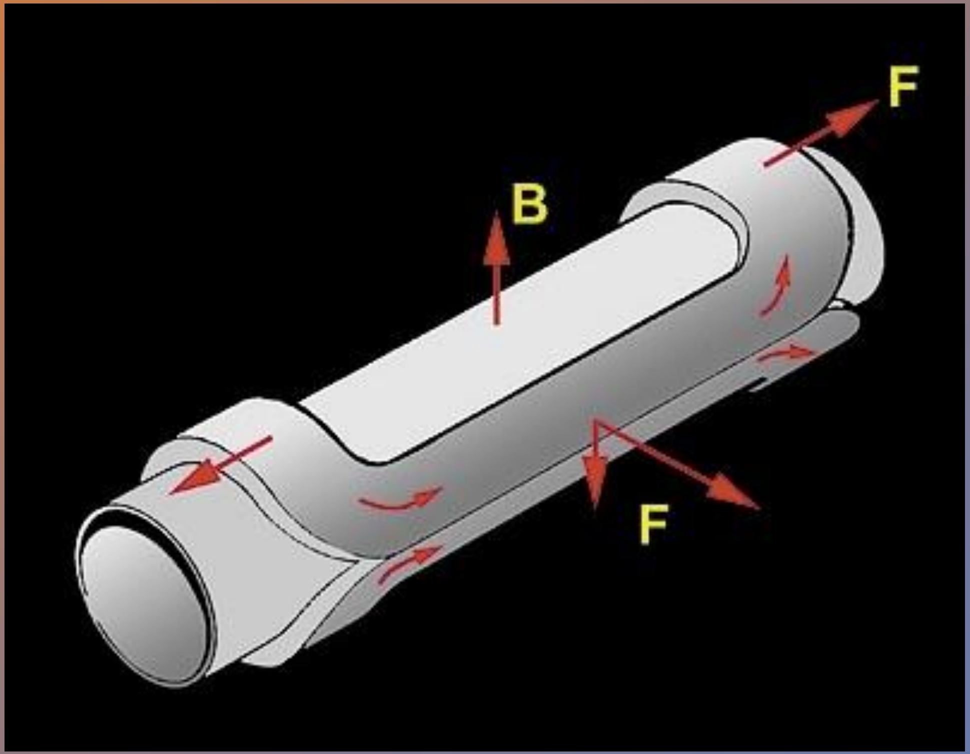
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Superconducting magnets in the LHC

Type	Number	Function
MB	1232	Main dipoles
MQ	392	Arc quadrupoles
MBX/MBR	16	Separation & recombination dipoles
MSCB	376	Combined chromaticity & closed orbit correctors
MCS	2464	Sextupole correctors for persistent currents at injection
MCDO	1232	Octupole/decapole correctors for persistent currents at injection
MO	336	Landau damping octupoles
MQT/MQTL	248	Tuning quadrupoles
MCB	190	Orbit correction dipoles
MQM	86	Dispersion suppressor & matching section quadrupoles
MQY	24	Enlarged-aperture quadrupoles in insertions
MQX	32	Low-beta insertion quadrupoles

Advanced technology at work

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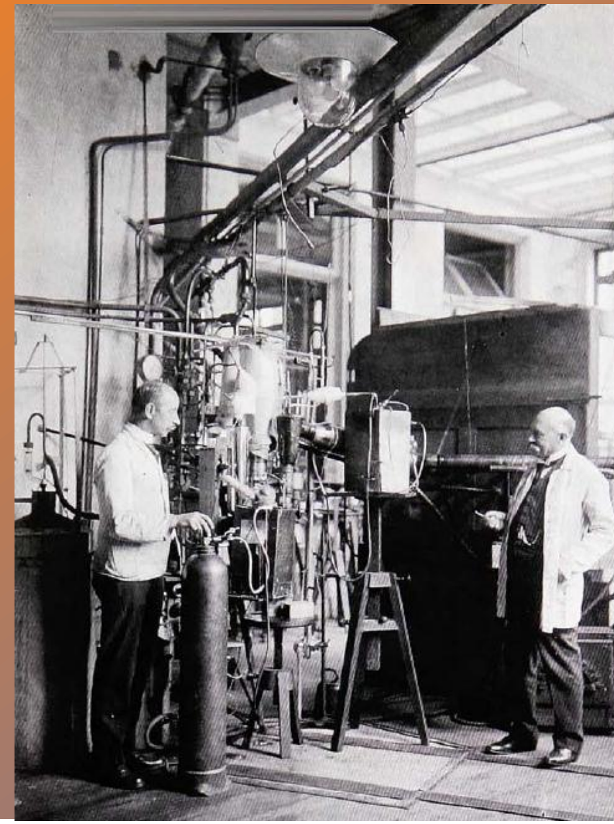
cooled in superfluid helium at 1.9 K

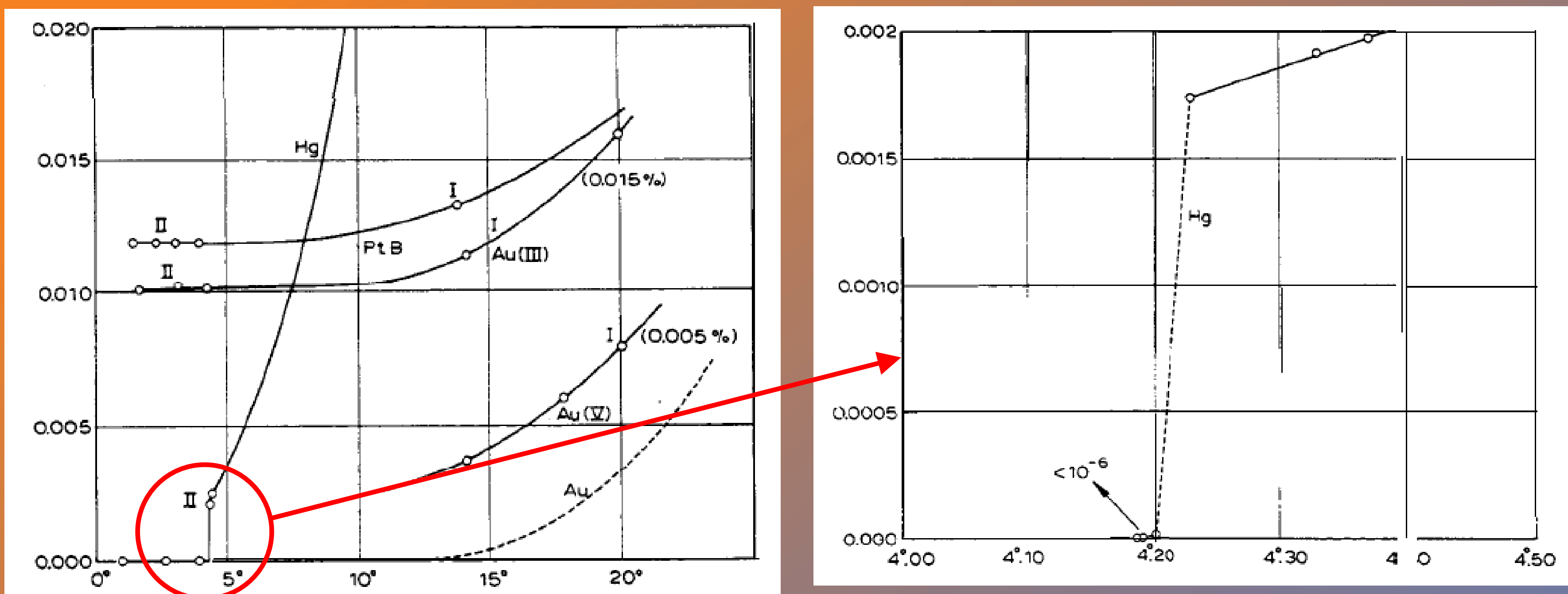


HEIKE KAMERLINGH ONNES

Investigations into the properties of substances at low temperatures, which have led, amongst other things, to the preparation of liquid helium

Nobel Lecture, December 11, 1913

Discovery of superconductivity (1911)



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.

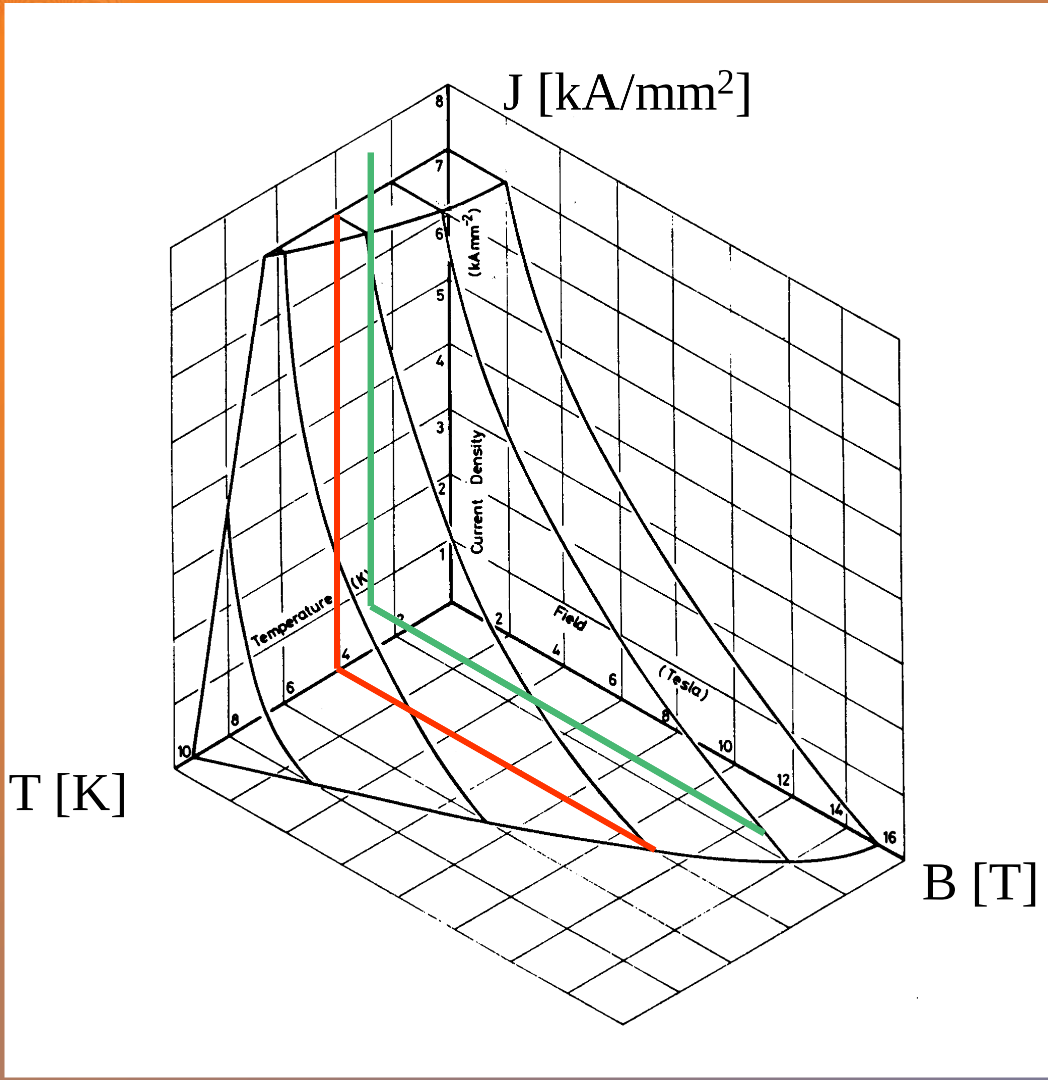
First idea of superconducting magnets (H. K. Onnes 1913)

dendum 2.) There is also the question as to whether the absence of Joule heat makes feasible the production of strong magnetic fields using coils without iron,* for a current of very great density can be sent through very fine, closely wound wire spirals. Thus we were successful in sending a current of 0.8 amperes, i.e. of 56 amperes per square millimetre, through a coil, which contained 1,000 turns of a diameter of 1/70 square mm per square centimetre at right angles to the turns.

critical field of superconductors!

after this lecture was given and produced surprising results. In fields below a threshold value (for lead at the boiling point of helium 600 Gauss), which was not reached during the experiment with the small coil mentioned in the text, there is no magnetic resistance at all. In fields above this threshold value a relatively large resistance arises at once, and grows considerably with the field. Thus in an unexpected way a difficulty in the production of intensive magnetic fields with coils without iron faced us. The discovery of the

Operating temperature of superconductors

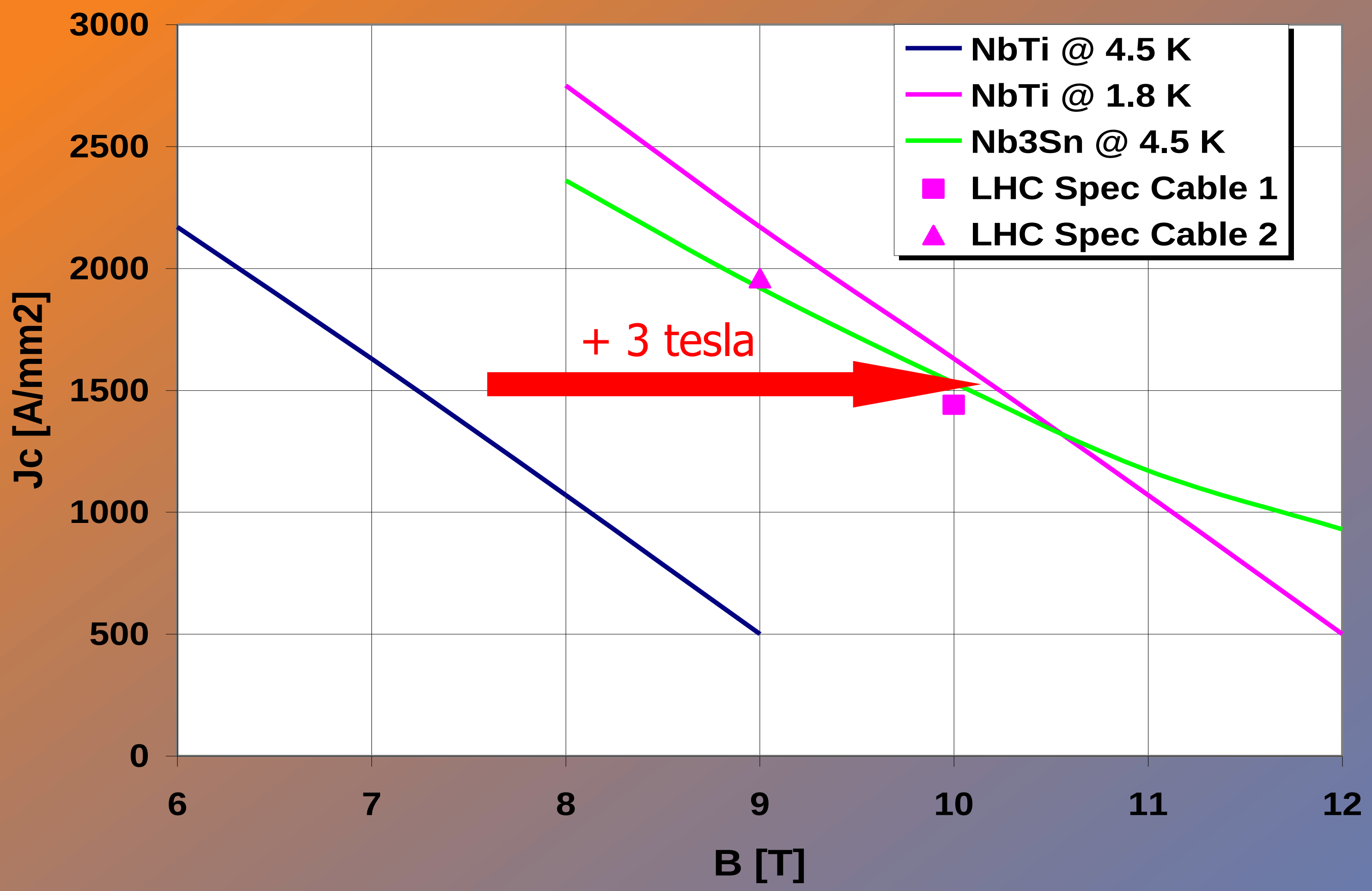


The superconducting state only occurs in a limited domain of temperature, magnetic field and transport current density

Superconducting magnets produce high field with high current density

Lowering the temperature enables better usage of the superconductor, by broadening its working range

Critical current density of technical superconductors



Unsuccessful attempt to solidify helium

Naturally the question arose as to whether helium can also be converted into the solid state. An experiment aimed at lowering the temperature of helium sufficiently by evaporating it without supply of heat was not successful, and only served to reach the lowest temperature recorded up to that time.

The evaporation of even a very small quantity, when the pressure of the vapour is small, demands the continuous carrying away of colossal volumes of vapour. With vacuum pumps of very large capacity we succeeded in lowering the pressure to 0.2 millimetre. The temperature then reached was 1.15°K according to the law of vapour pressure found. (Of course we can only make an estimate here. The working out of the thermometry of these low temperatures with, amongst other things, the aid of the Knudsen hot wire manometer is still in its initial stages.) Since it would have needed new equipment, I deferred the question as to whether helium can be made to freeze in favour of other, more urgent problems, which could be tackled with the equipment available.

Hint of a quantum effect…?

It is very noticeable that the experiments indicate that the density of the helium, which at first quickly drops with the temperature, reaches a maximum at 2.2°K approximately, and if one goes down further even drops again. Such an extreme could possibly be connected with the quantum theory.

Superfluid helium

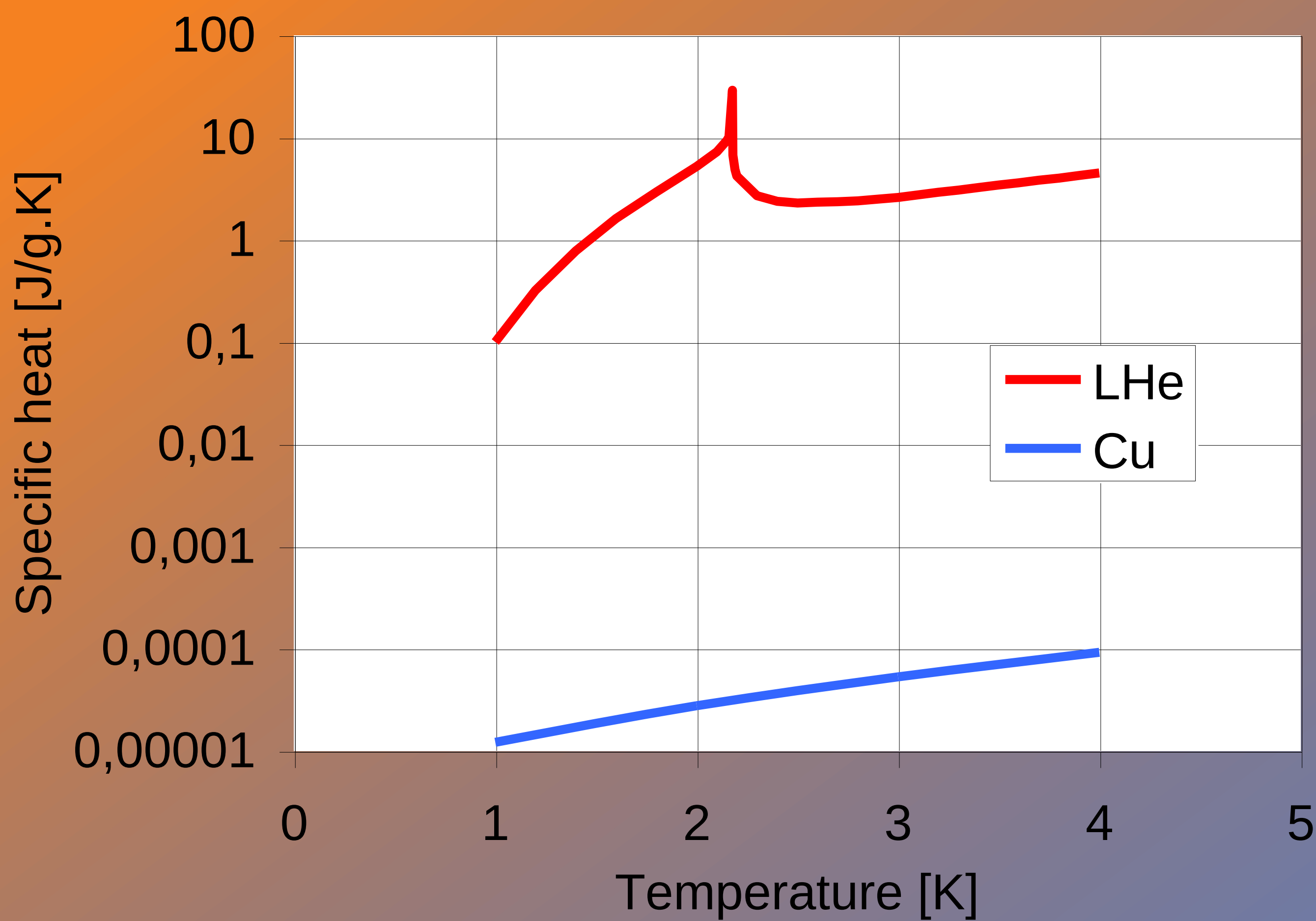
J. F. Allen

« In my PhD work in Toronto on superconductivity, I had often seen the sudden cessation of boiling at the lambda temperature T_λ but had paid it no particular attention. It never occured to me that it was of fundamental significance. »

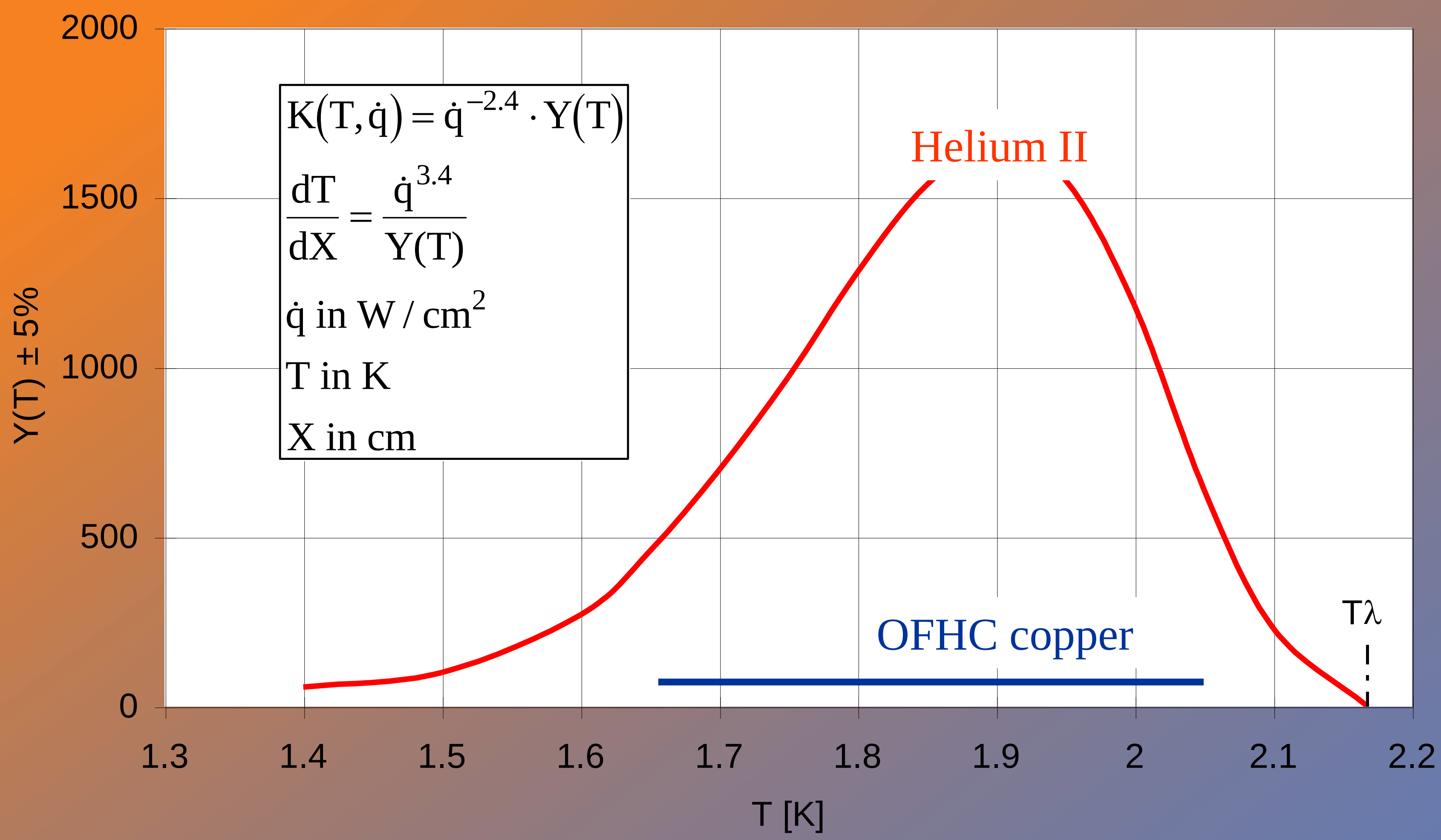
J. Allen, Physics World, November 1988, p 29.

Superfluid Helium

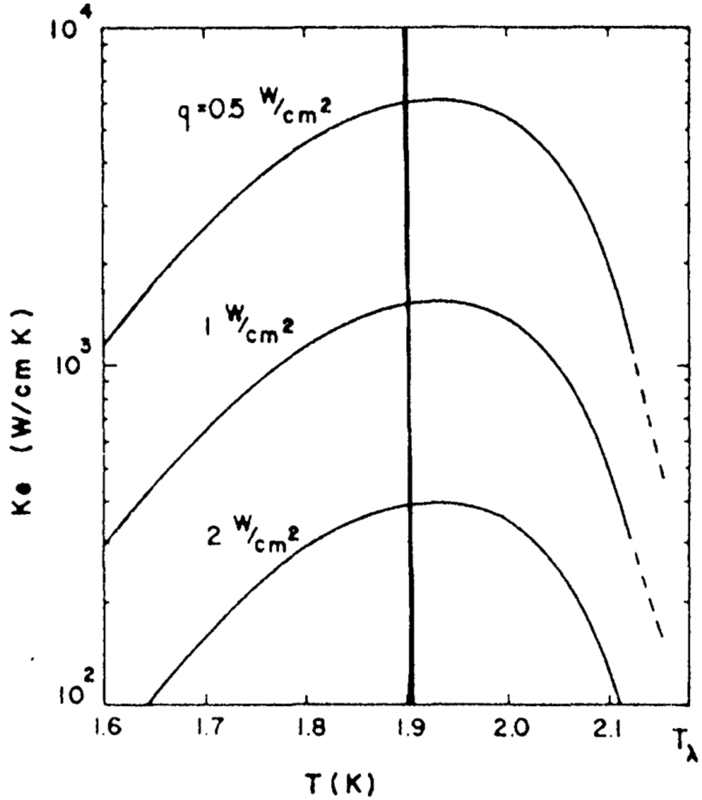
Specific heat of LHe and Cu



Equivalent thermal conductivity of He II

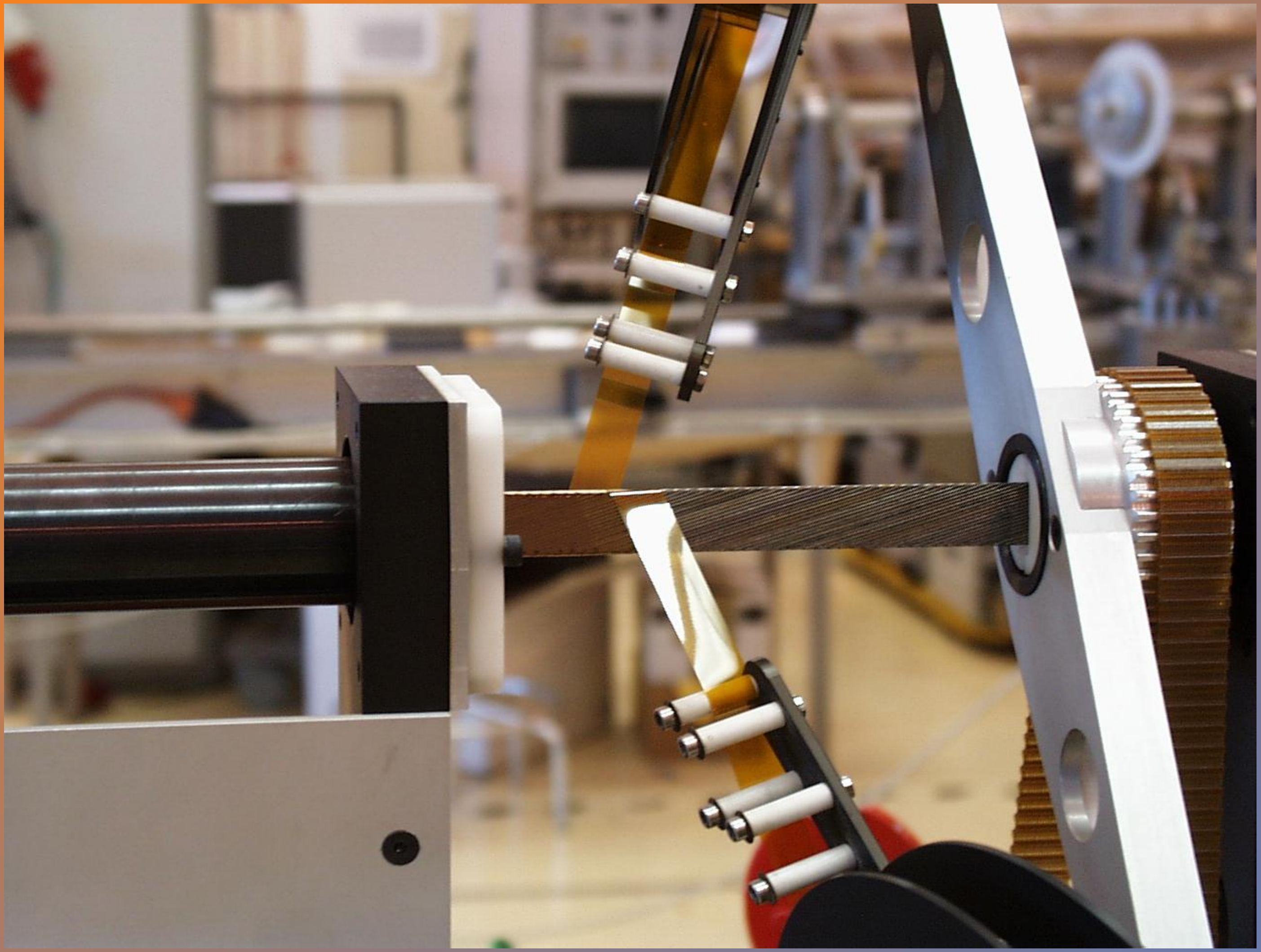


Equivalent thermal conductivity of He II

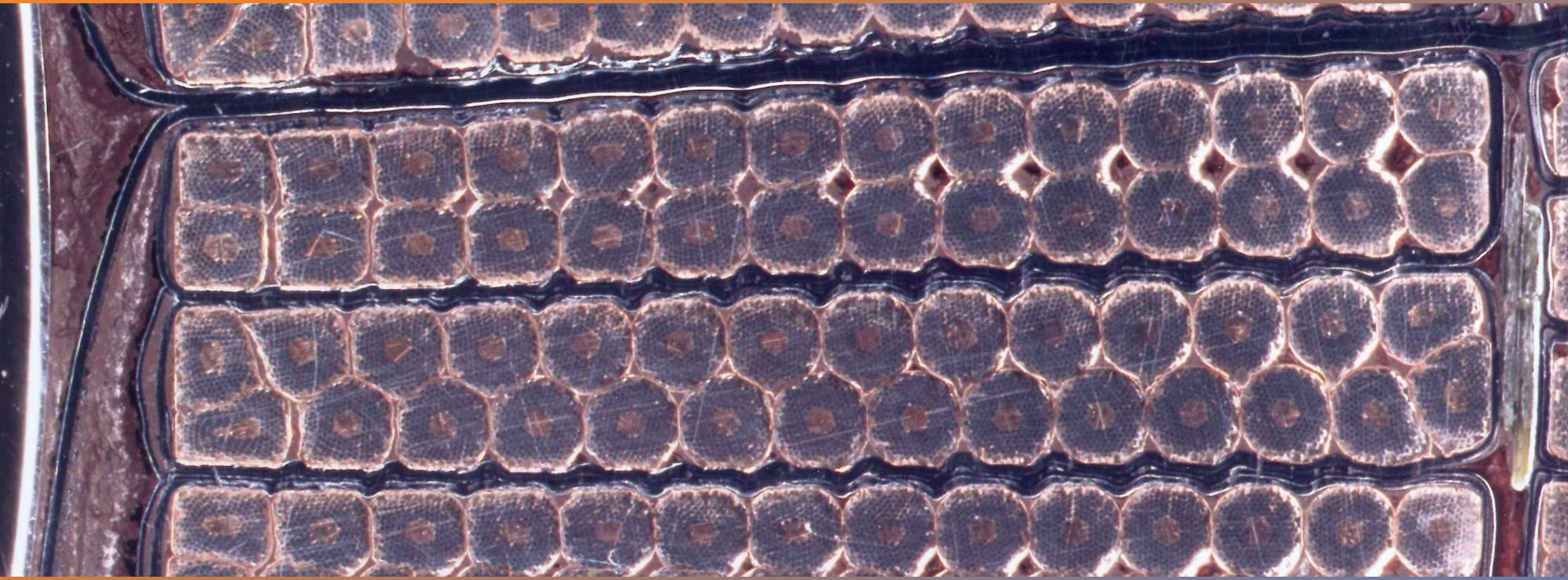


Effective thermal conductivity of He II.

Cable insulation by double polyimide wrap



Coil cross-section showing inter-turn and ground insulation

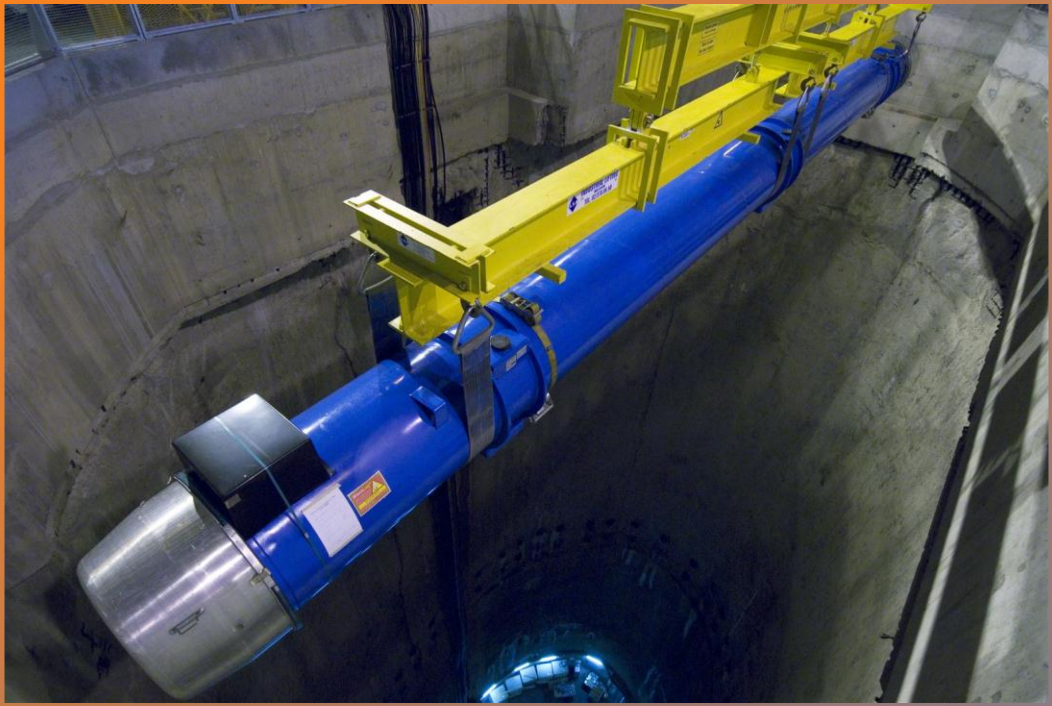


Manufacturing of superconducting coils

Assembly of dipole cold masses

Cryogenic Test Benches

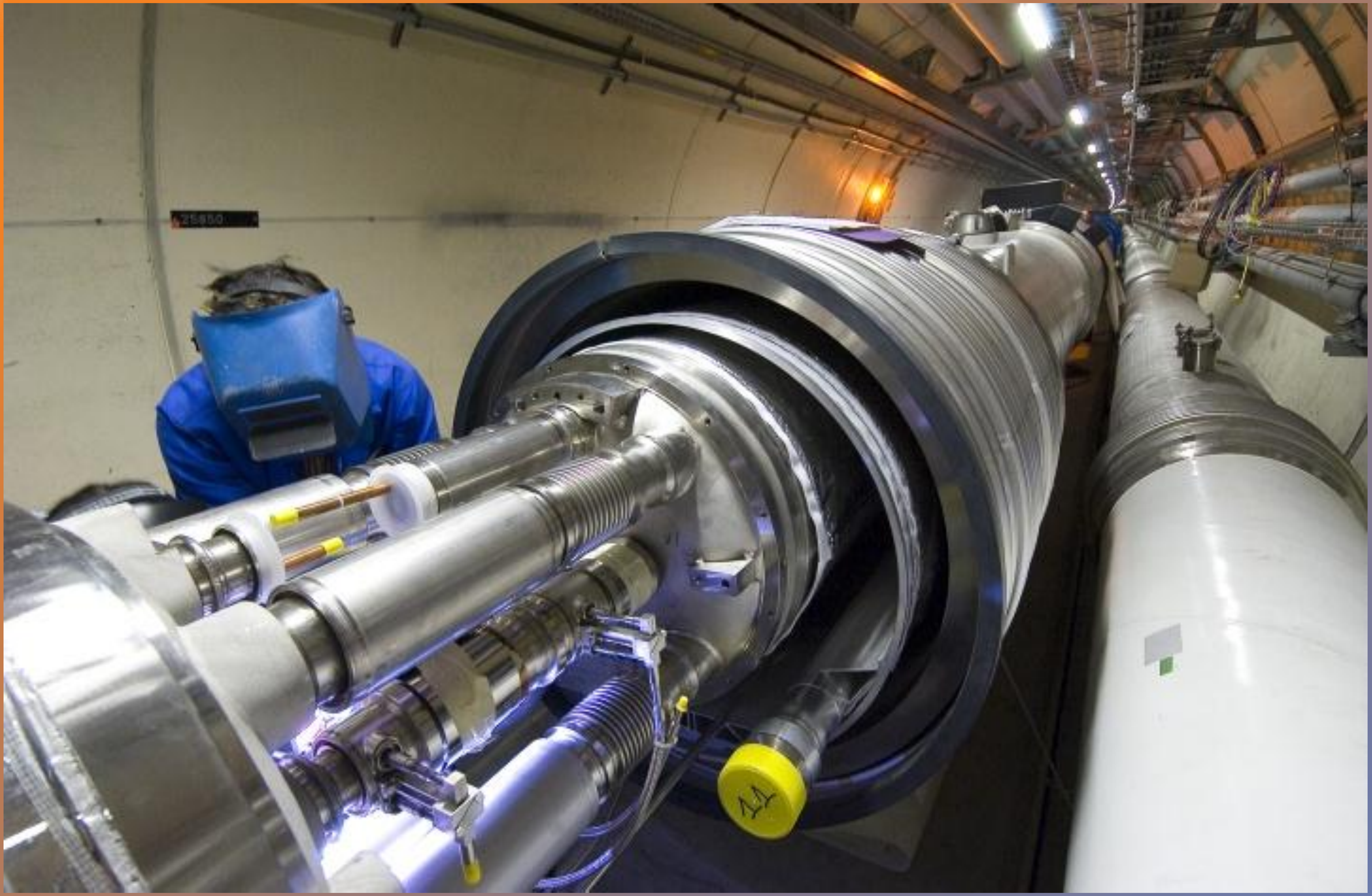
Magnet Descent into the Tunnel



Transport in the tunnel with an optical guided vehicle

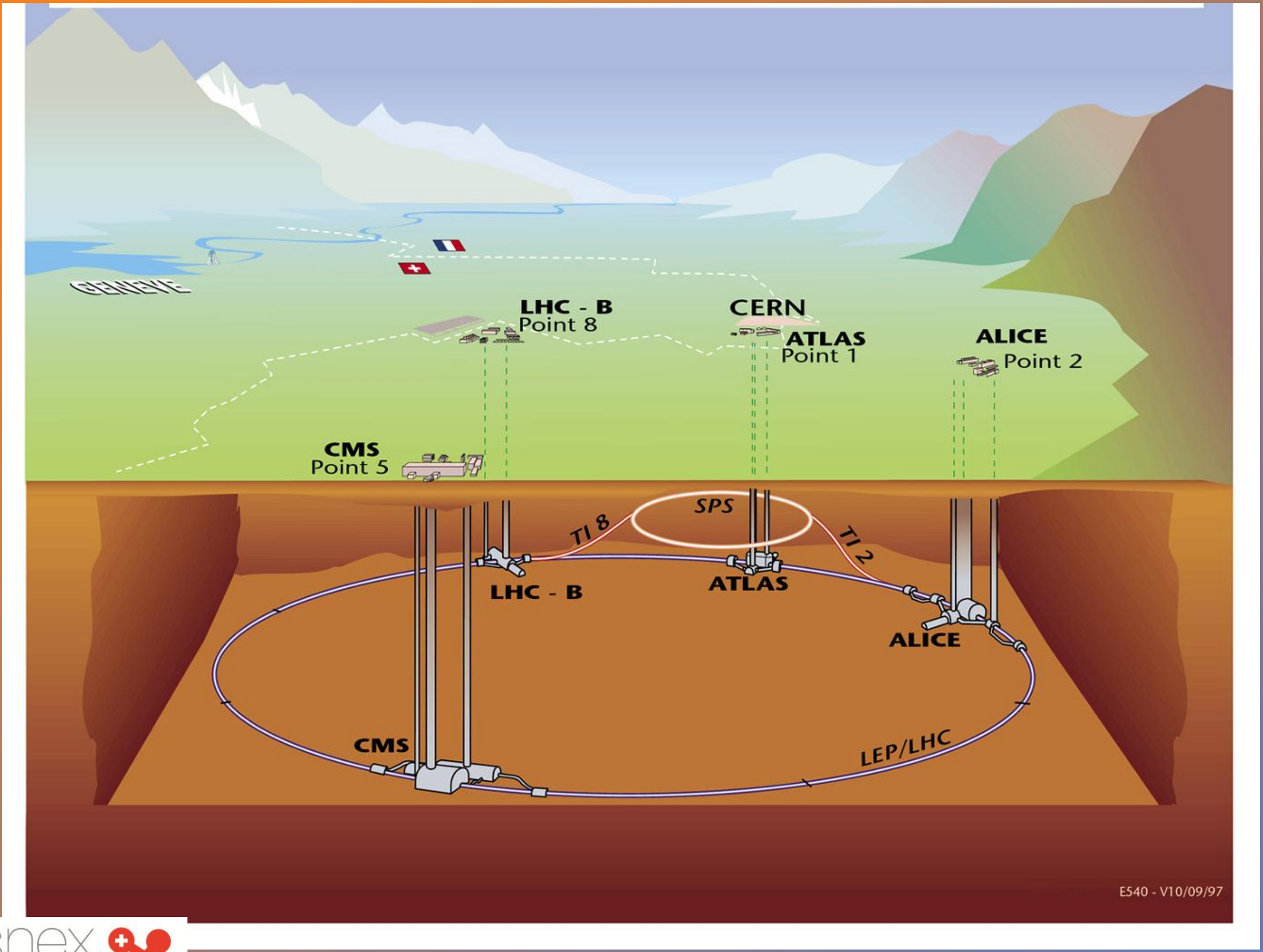
Transfer on Jacks

Dipole Dipole Interconnect



Electrical Splice

The LHC and its Detectors

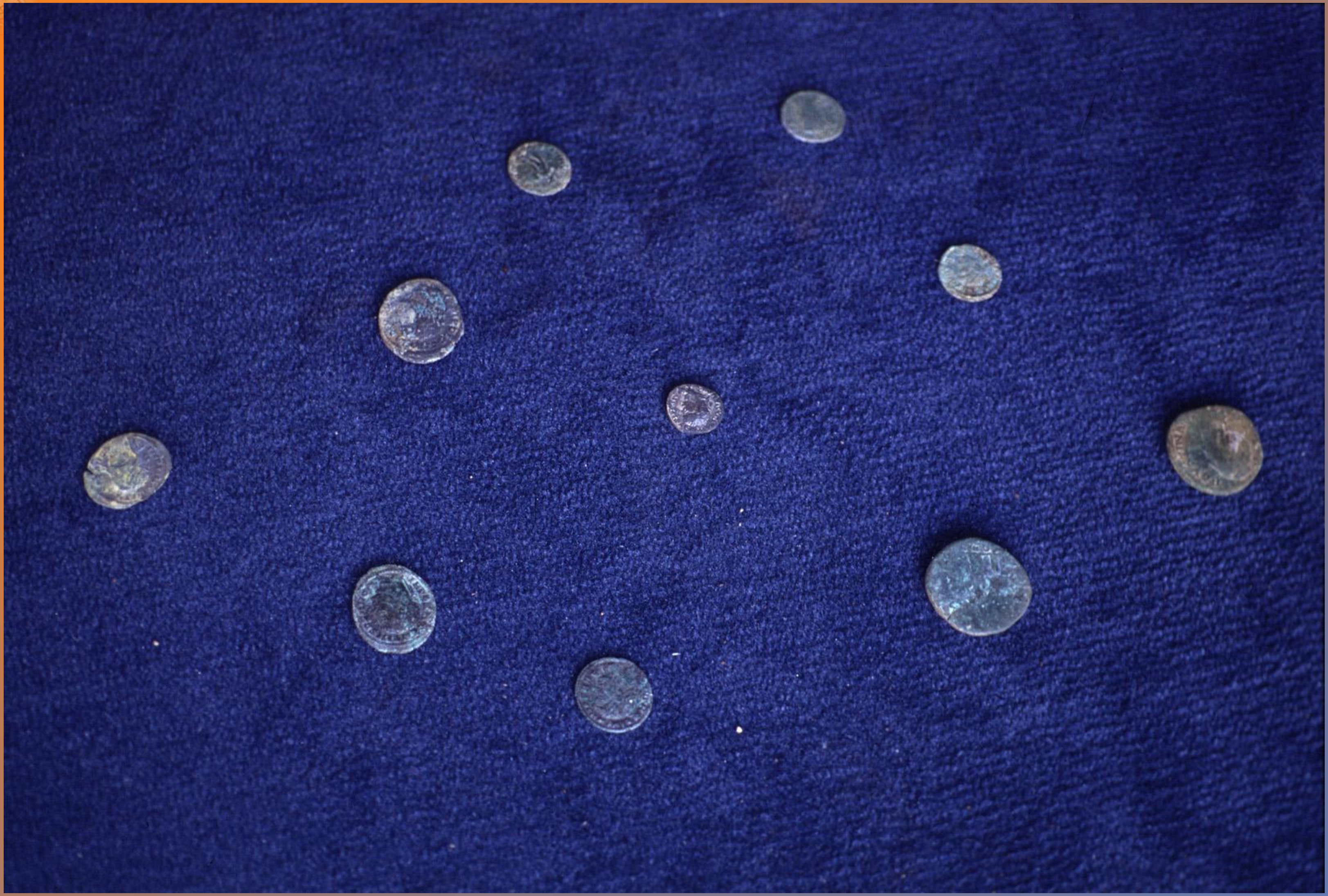


Point 1 - UX15 cavern - Concreting of vault panel n°2 - April 10, 2001 - CERN ST-CE

LHC Point 1 - UX 15 Cavern - Concrete walls 6th lift - 20-02-2003 - CERN ST-CE

Aerial view of Point 5
Gallo-roman vestiges 1998

Roman coins found during archeological excavations at Point 5

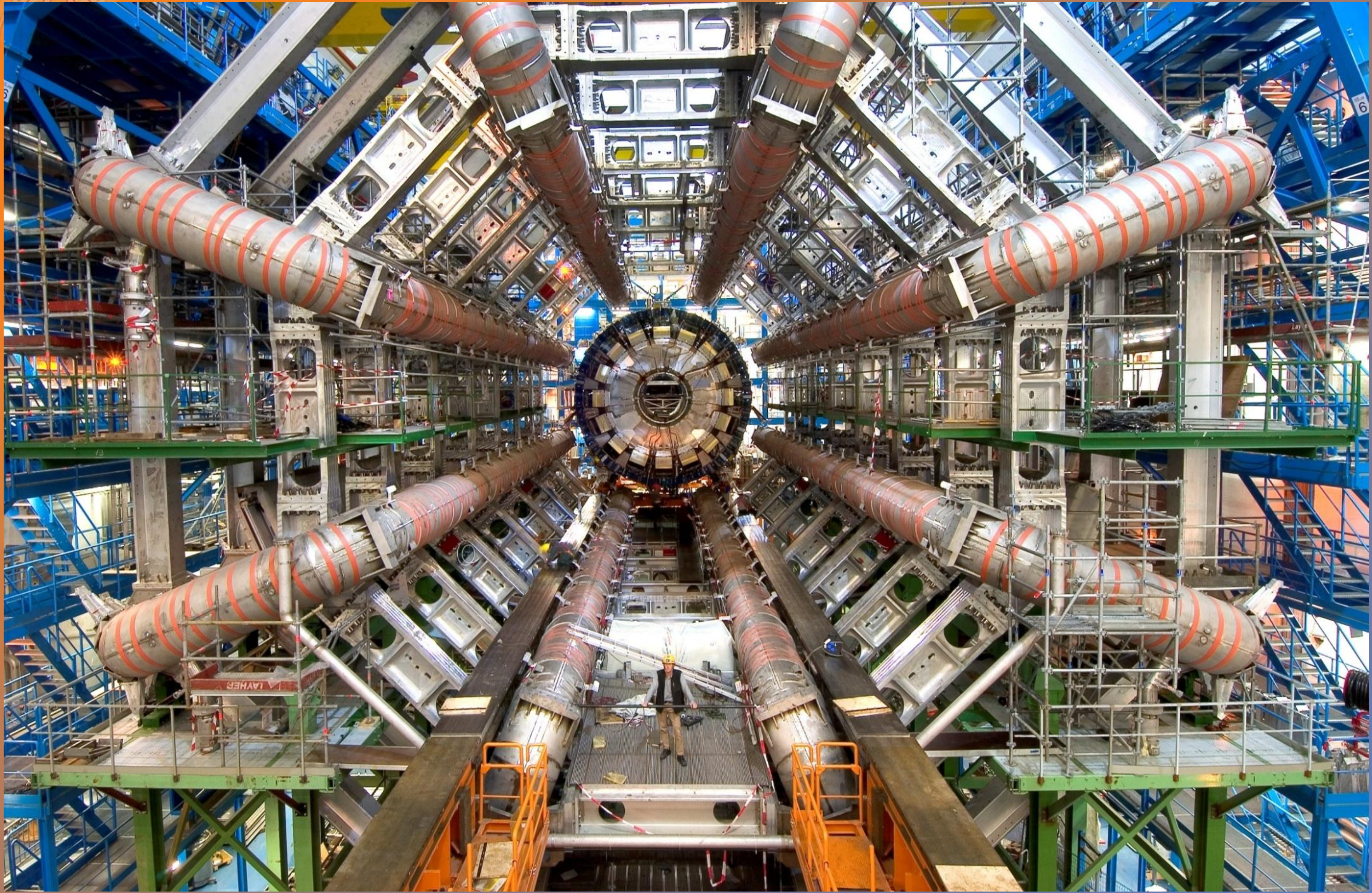


Point 5 -Excavation commencement of PM54 shaft - July 09, 1999 - CERN ST-CE

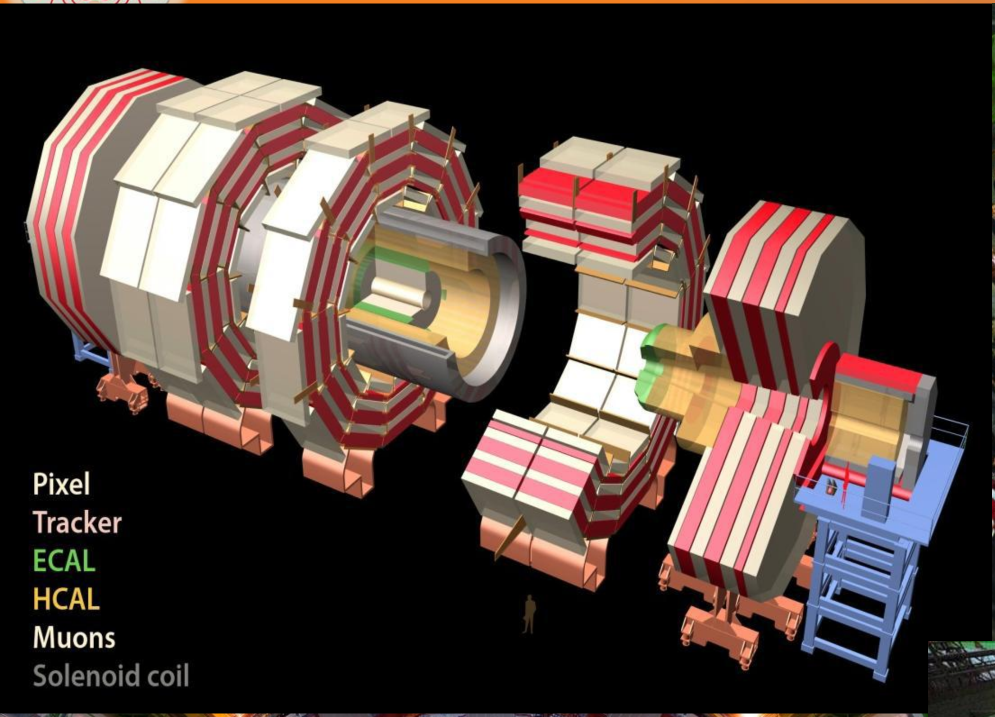
Point 1 - UX15 vault demolition of central pillar - September 20, 2000 - CERN ST-CE

Point 5 - UXC55 cavern excavation - LEP demolition - January 23, 2002 - CERN ST-CE

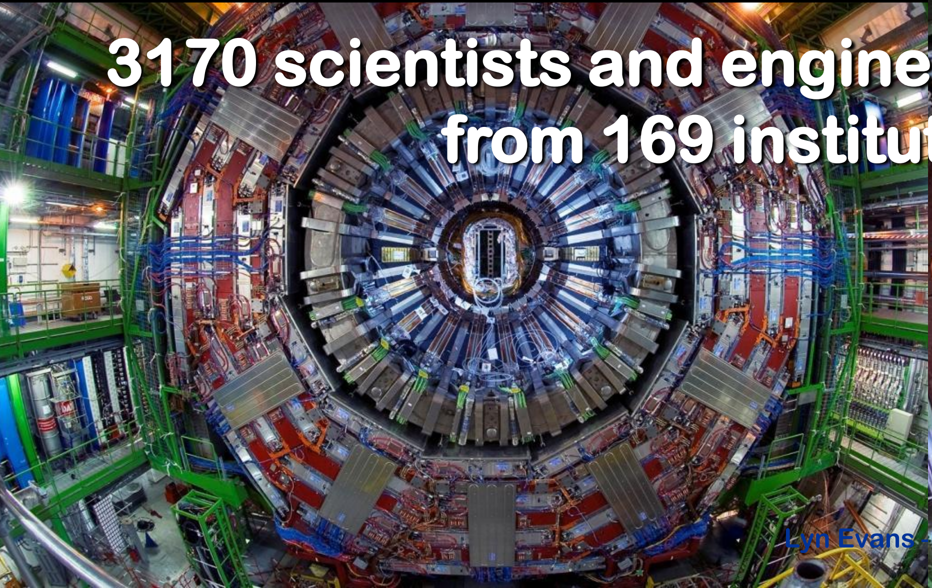
4th November 2005, the World-famous Picture of the Completed Barrel Toroid…



The CMS Collaboration

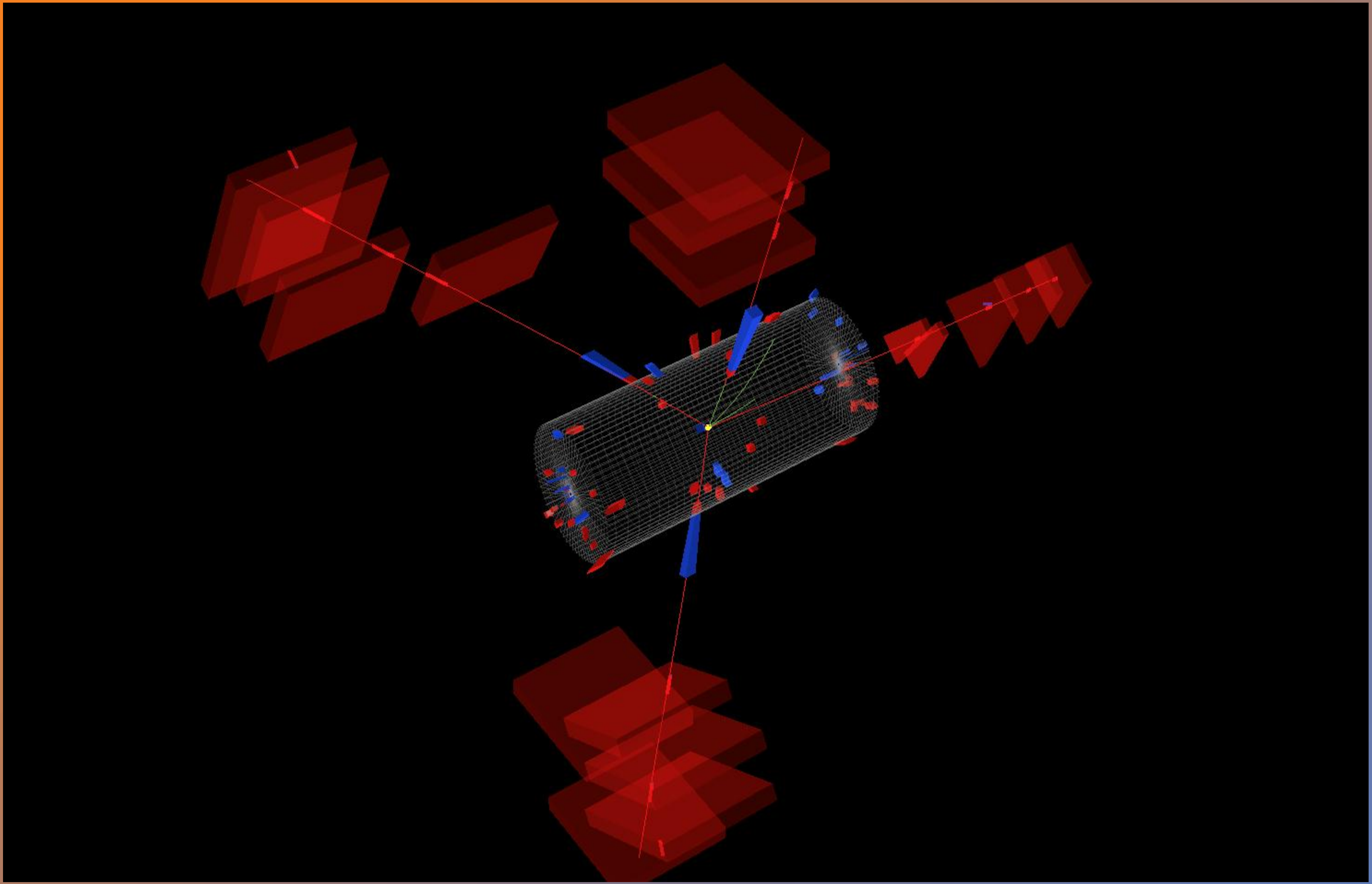


~ ¼ of the people who made CMS possible

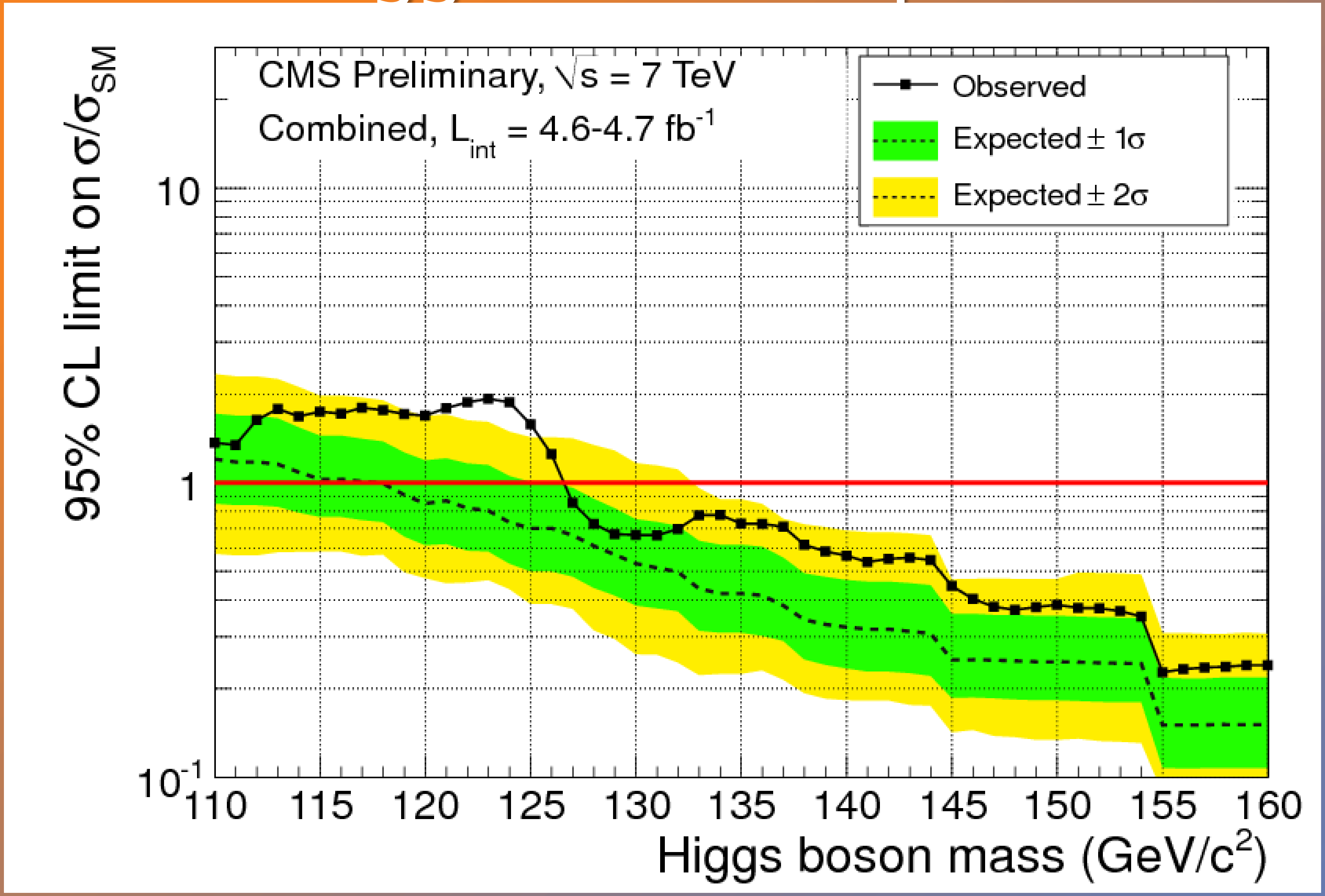


3170 scientists and engineers (including ~800 students) from 169 institutes in 39 countries

An Interesting 4-muon Event I



Higgs exclusion plot



CMS integrated luminosity 2012