NYT Journeys — Visit to CERN
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Physics at the LHC

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The Higgs boson

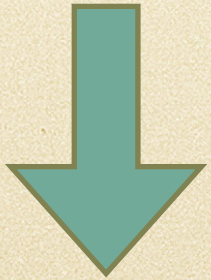
The depth of "Why?" questions is a measure of the maturity of the field. We can only approach "why" questions when we have a solid understanding of the "what"s and "how"s

Example: mass

$\mathbf{m=E/c^2}$ $\Rightarrow$ for a composite system the mass is obtained by solving the dynamics of the bound state

So m_p=938 MeV requires a "how" explanation, not a "why" one

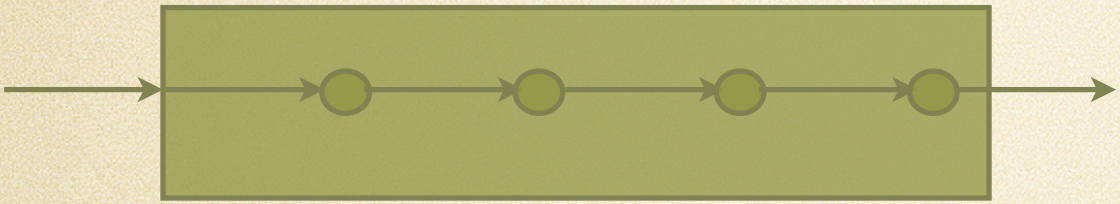
But what about elementary particles? Elementary
$\Rightarrow$ no internal dynamics



Need to develop a new framework within which to understand the value of the electron mass

The Higgs and particles' masses

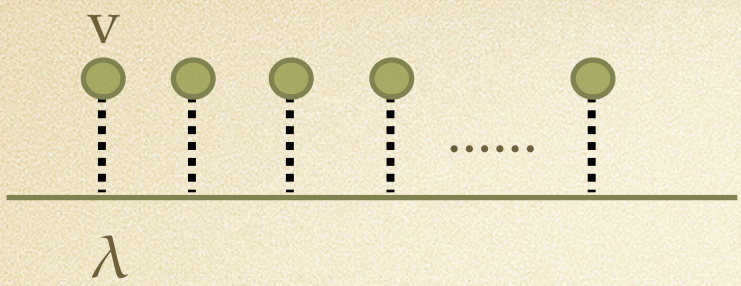
Light propagating in a medium is slowed down by its continuos interaction with the medium itself



The time it takes to move across the medium is longer than if light were propagating in the vacuum,

$\Rightarrow c_{medium} < c_{vaccum}$

Think of the Higgs field as being a continuum medium embedding the whole Universe. Particles interacting with it will undergo a similar "slow-down" phenomenon. Rather than "slowing down", however, the interaction with the Higgs medium gives them "inertia" => mass



$m \propto \lambda v$

The number "v" is a universal property of the Higgs field background. The quantity "λ" is characteristic of the particle moving in the Higgs field. Particles which have large λ will have large mass, with $m \propto \lambda v$

Now the question of "why does a given particle has mass **m**" is replaced by the question "why does a given particle couple with the Higgs field with strength $\lambda \propto m / v$"

However at least now we have a model to understand **how** particles acquire a mass.

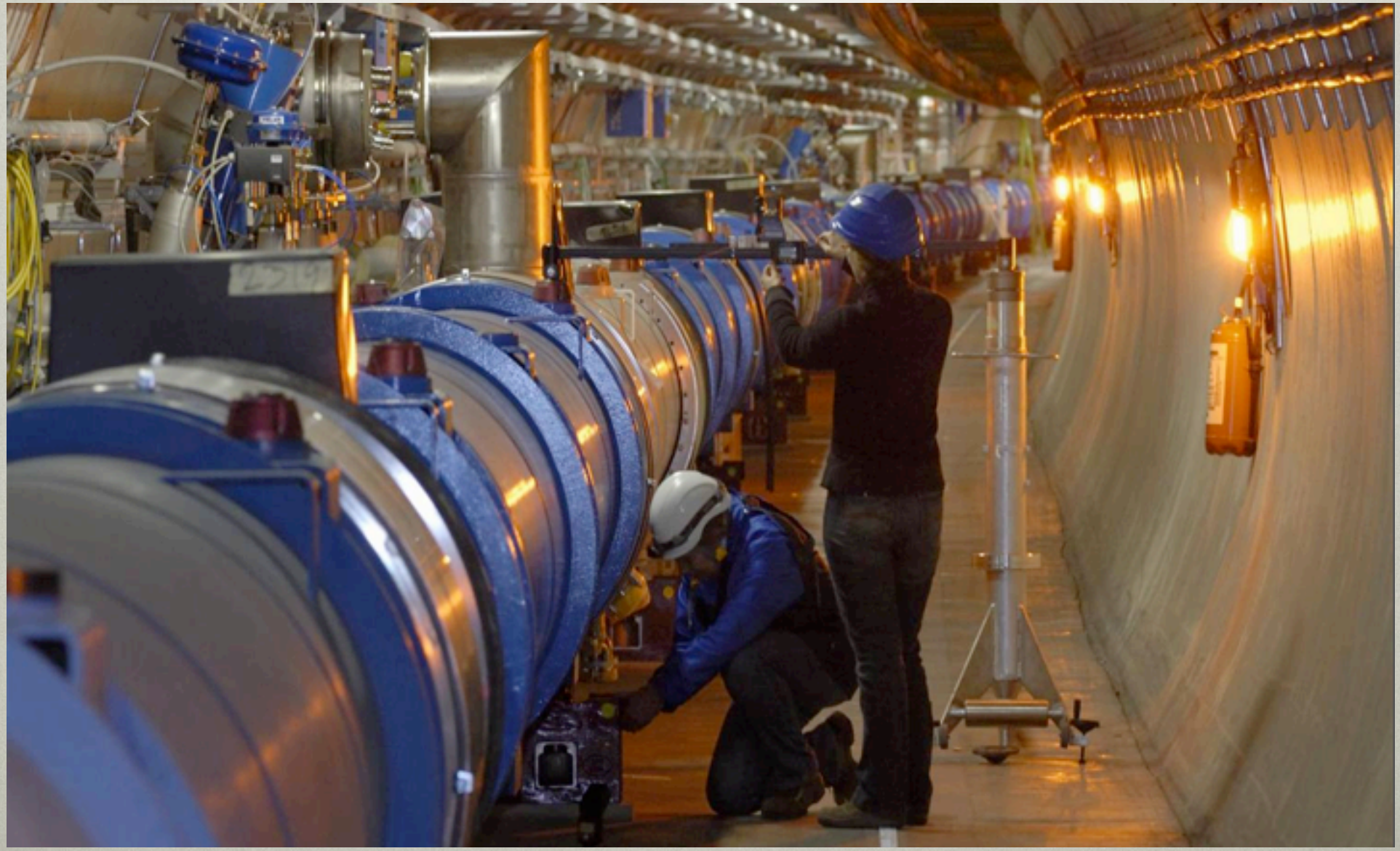
Detecting the Higgs boson

Like any other medium, the Higgs continuum background can be perturbed. Similarly to what happens if we bang on a table, creating sound waves, if we "bang" on the Higgs background (something achieved by concentrating a lot of energy in a small volume) we can stimulate "Higgs waves". These waves manifest themselves as particles* , the so-called Higgs bosons

What is required is that the energy available be larger than the Higgs mass ⇒ LHC !!!

* Even the sound waves in a solid are sometimes identified with "quasi-particles", called "phonons"

The LHC:
Energize the protons…

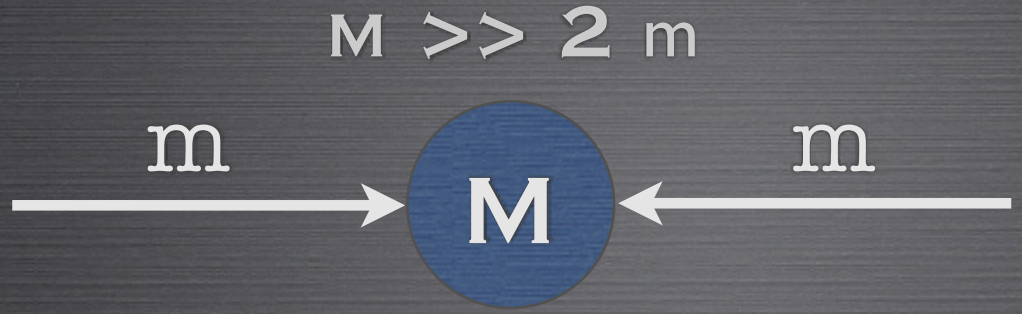


$E = mc^2$

E.g., in the Sun:

$4\,p \rightarrow He + 2\,e^{+} + 2\,\nu + 1.6 \times 10^{-13}\,J$

4×10^{-17} Kcalories



$$E = Mc^2$$

$$E = \frac{m c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

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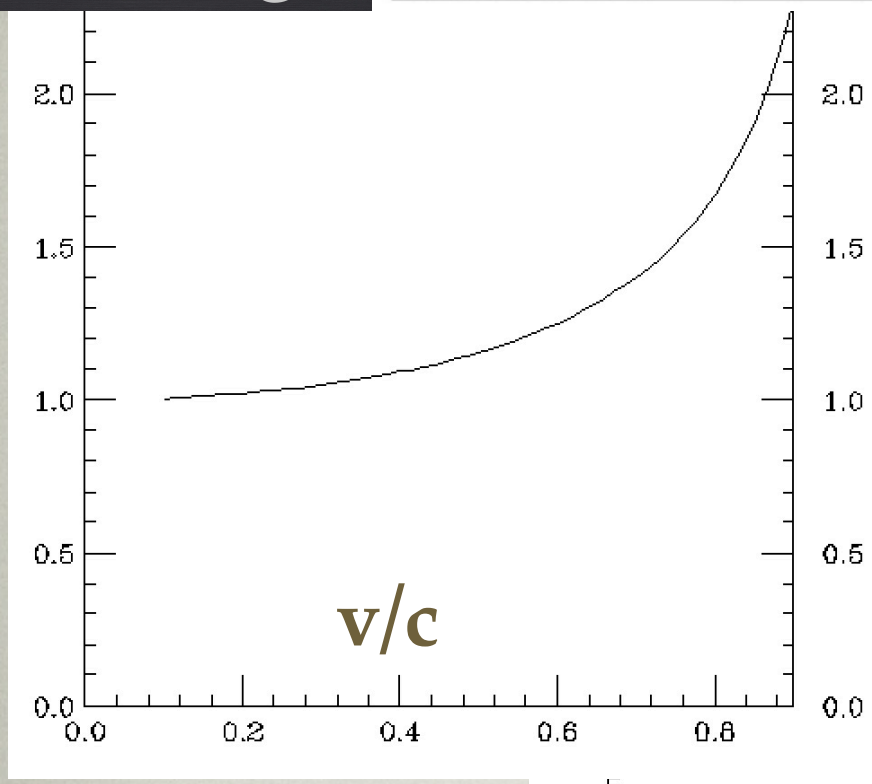
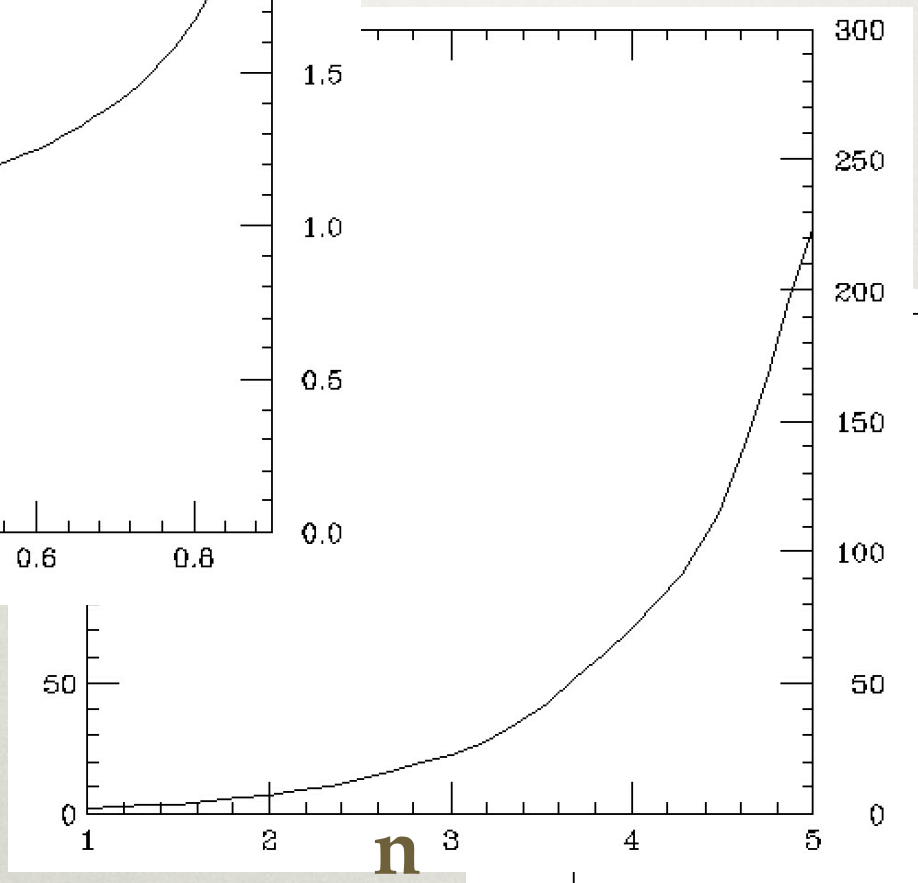
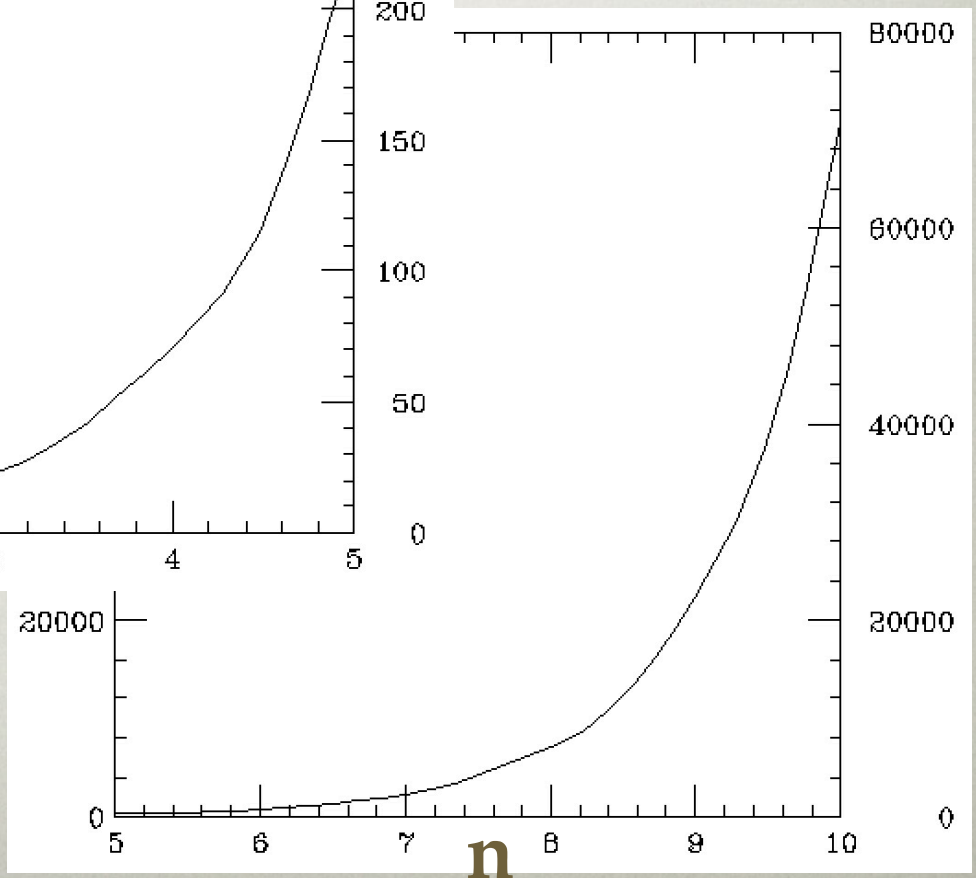
Number of 9's	1	2	3	4	5	6	7	8	9	10
v/c	0.9	0.99	0.999	0.9999	0.99999	0.999999	0.9999999	0.99999999	0.999999999	0.9999999999
Energy, in units of the proton mass (~GeV)	2.3	7.1	22.4	70.7	223.6	707.1	2236.1	7071.1	22360.7	70710.7

E=7000 GeV,
LHC energy



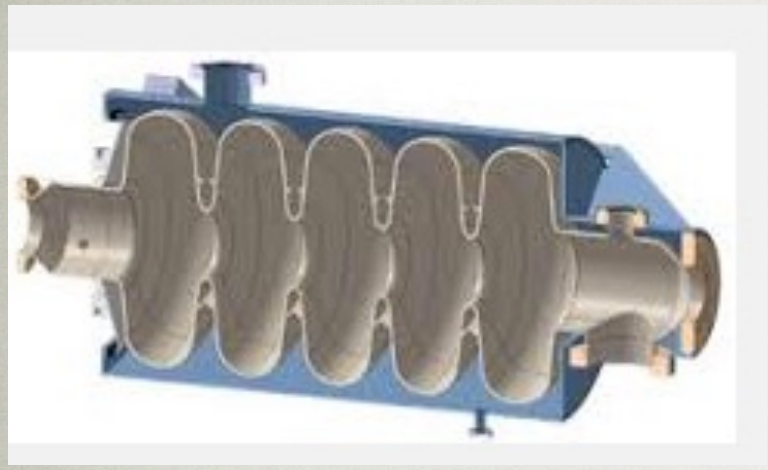


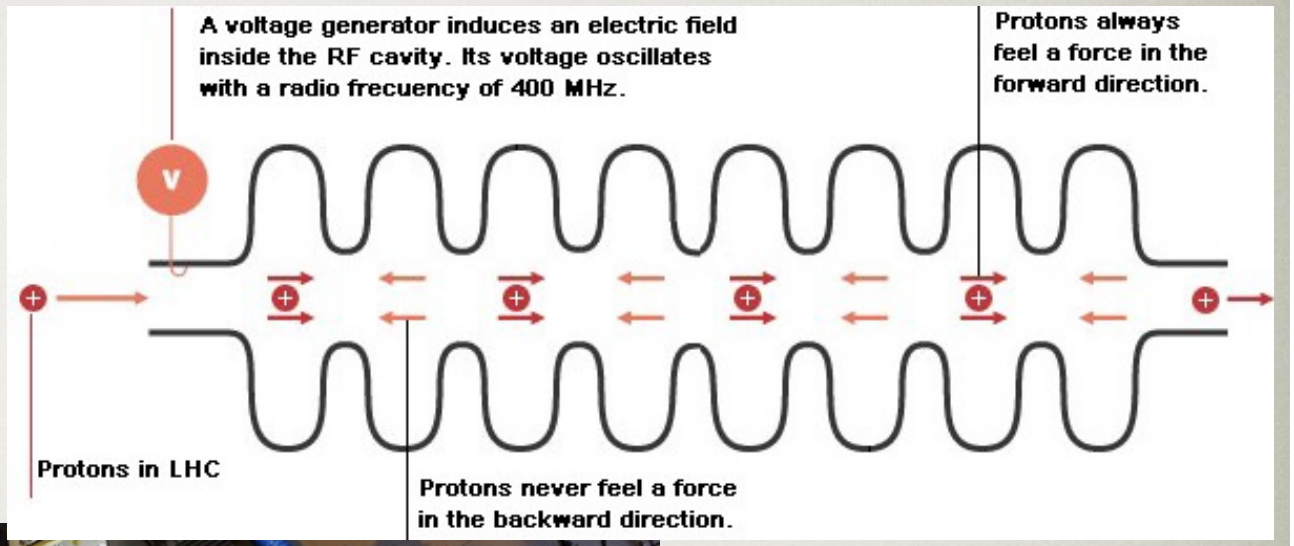


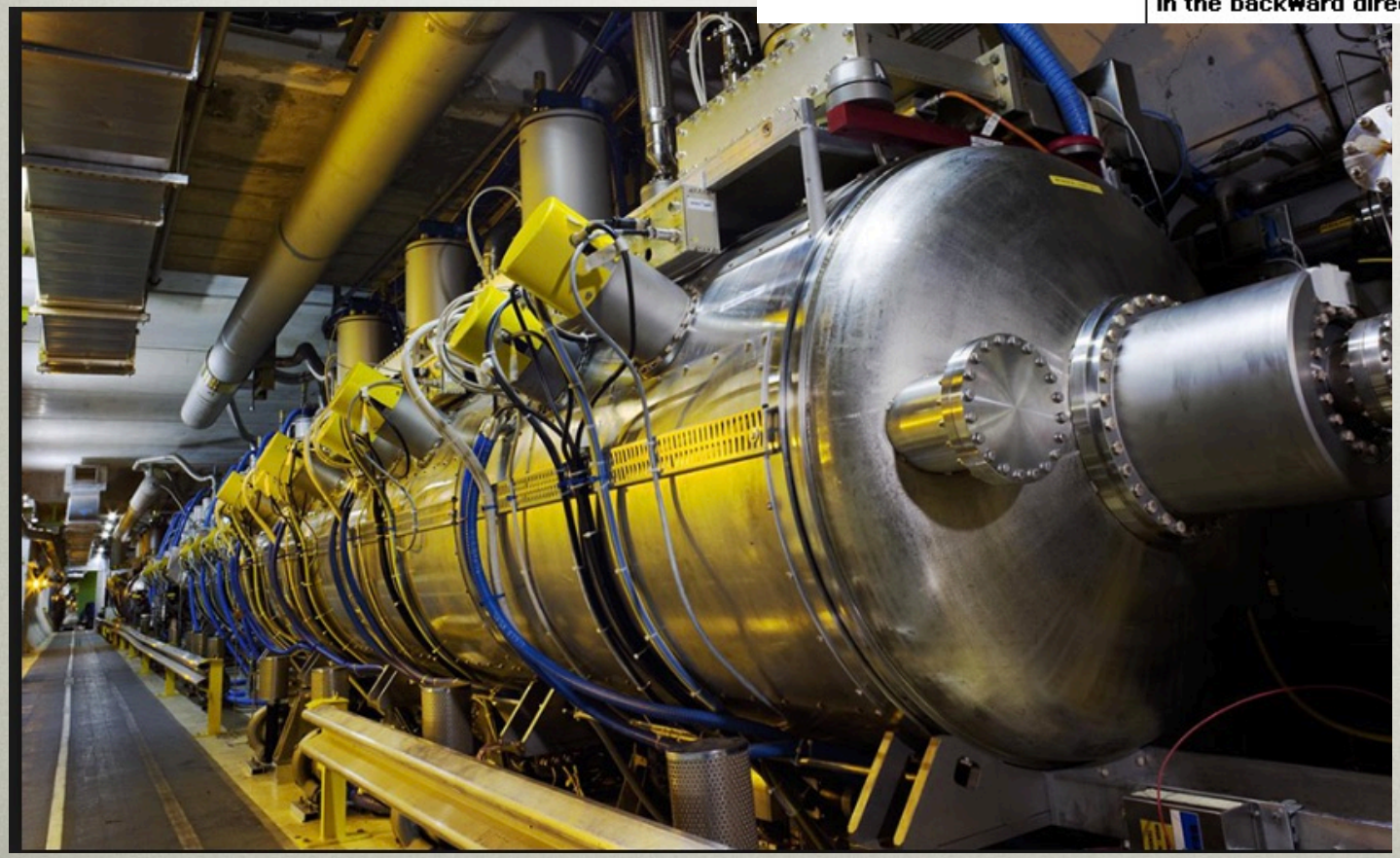
n=# of 9's

v = 0.99….999 c

LHC radiofrequency cavity (to increase beam energy)



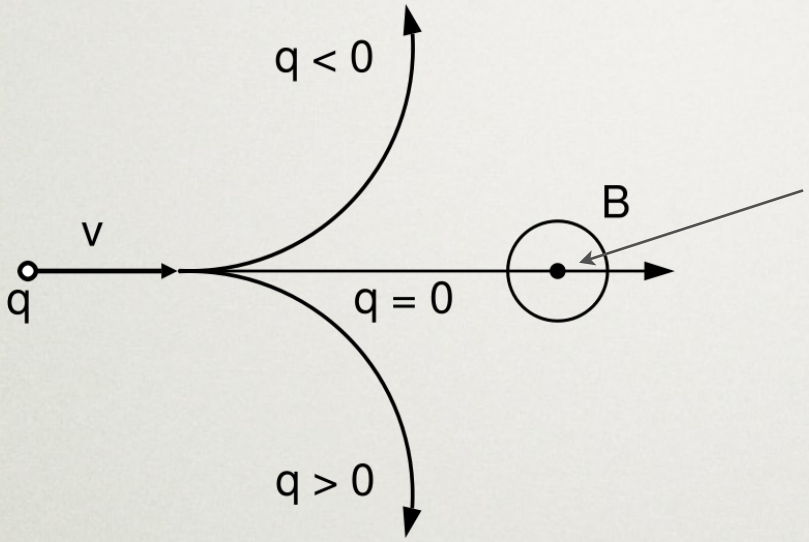




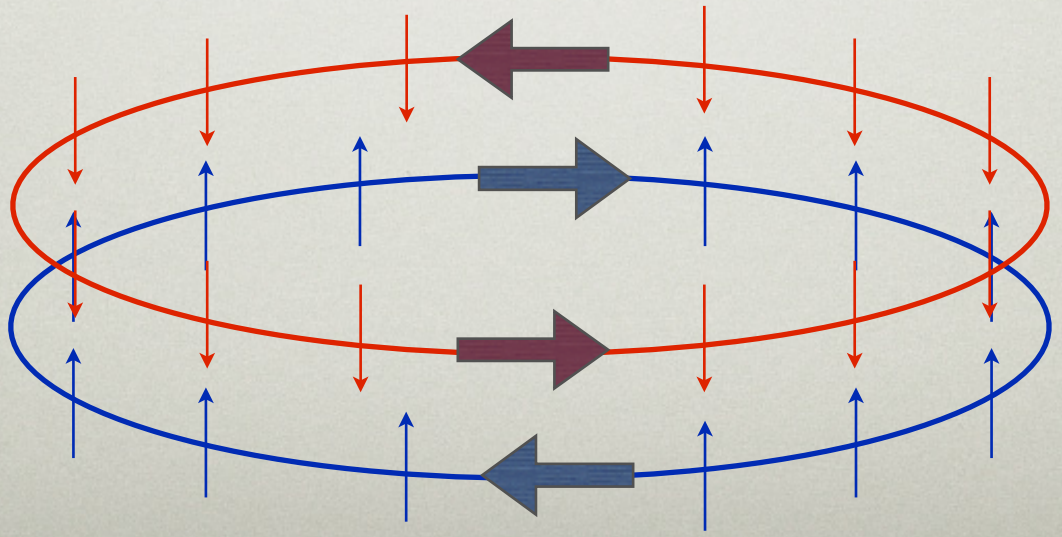
400 MHz =>
1 cycle/2.5×10^{-9}sec

2.5×10^{-9}sec at v=c =>
75cm (~30in ~ 2.5ft)

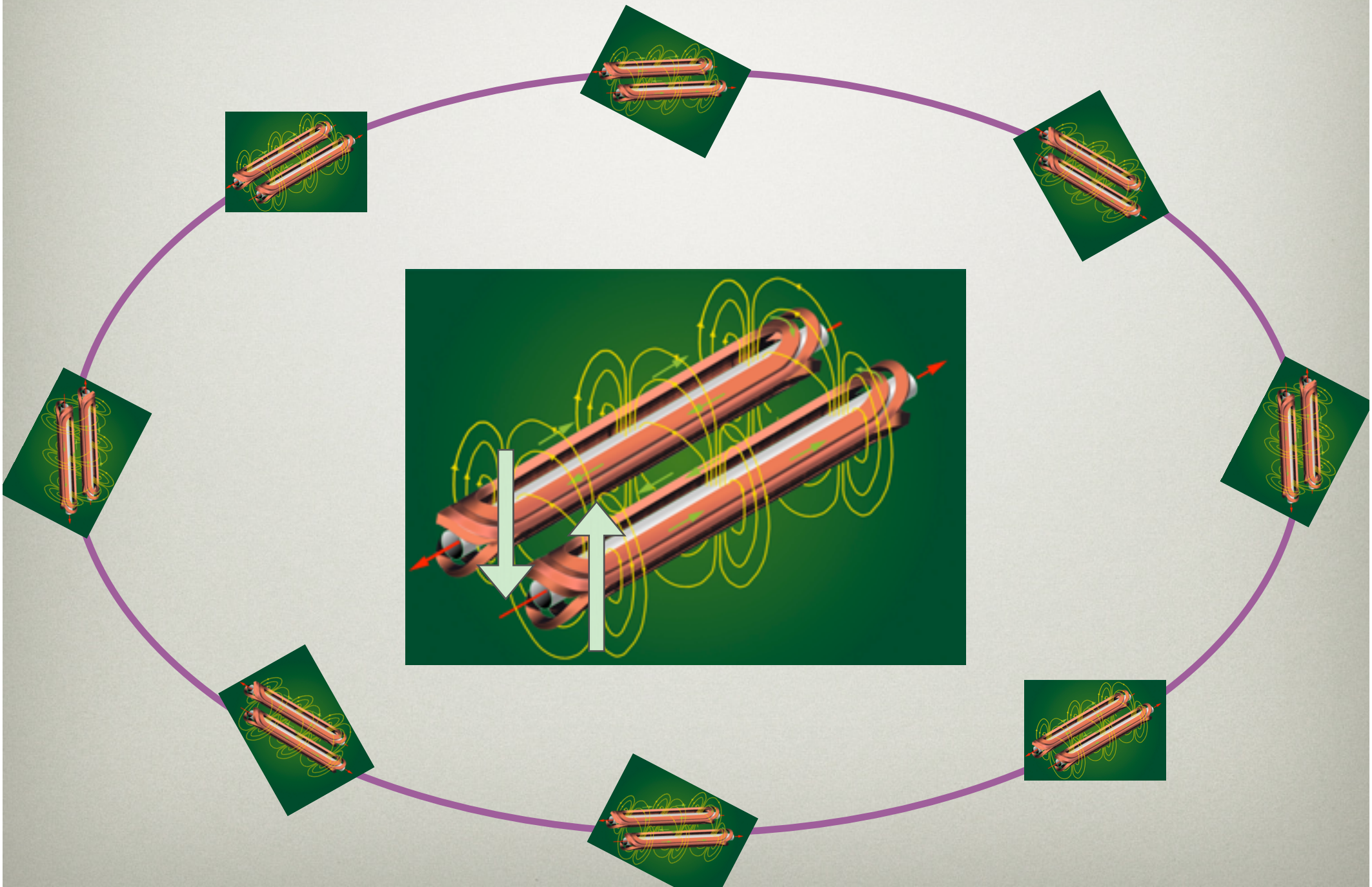
Steering protons

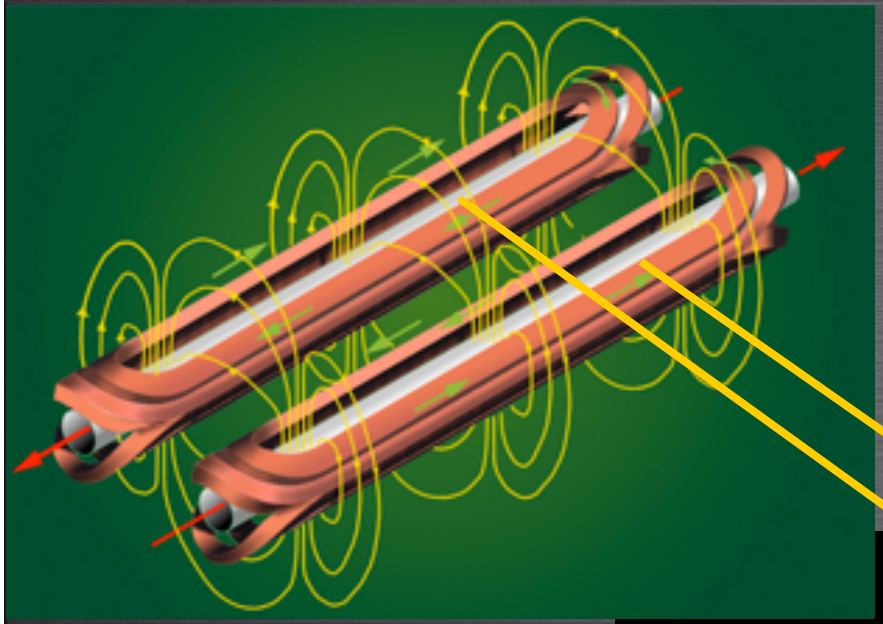


B: Magnetic field line perpendicular to the screen



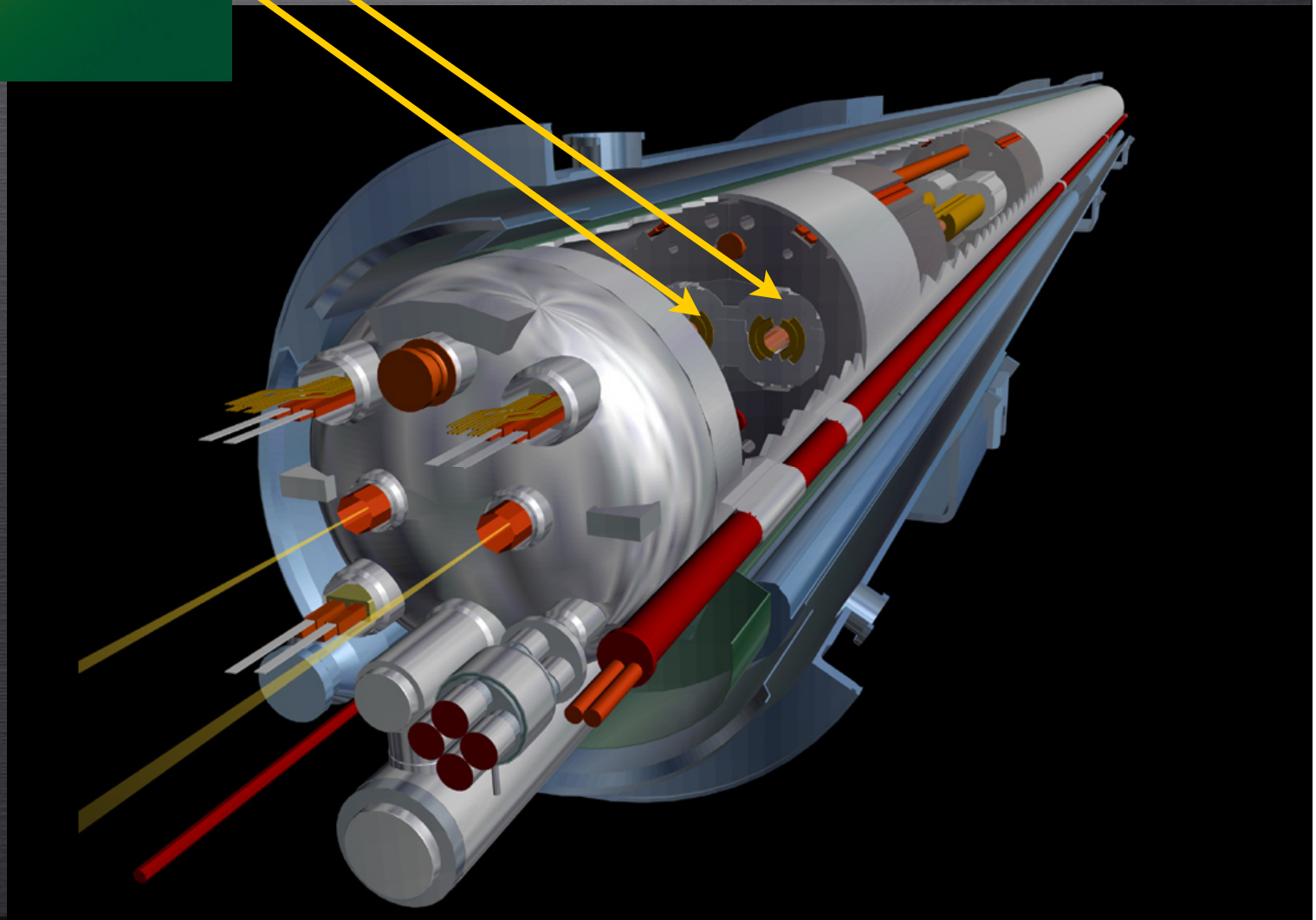
The LHC dipolar field





The LHC dipole magnet

http://cerncourier.com/cws/article/cern/29011

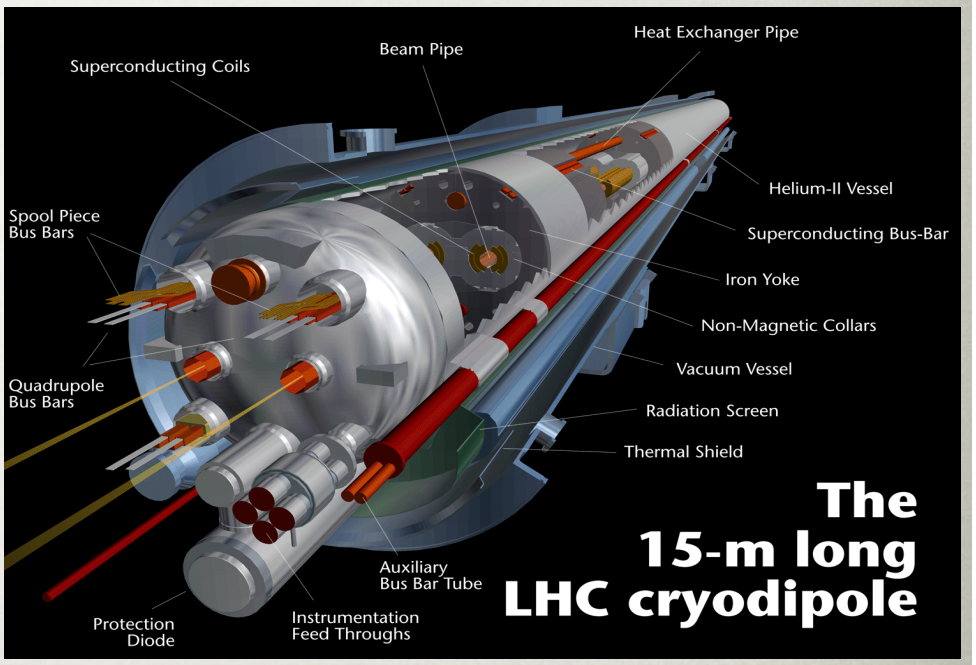


The LHC dipole

- B field = 83,000 Gauss
  - Ni Ti SC cable

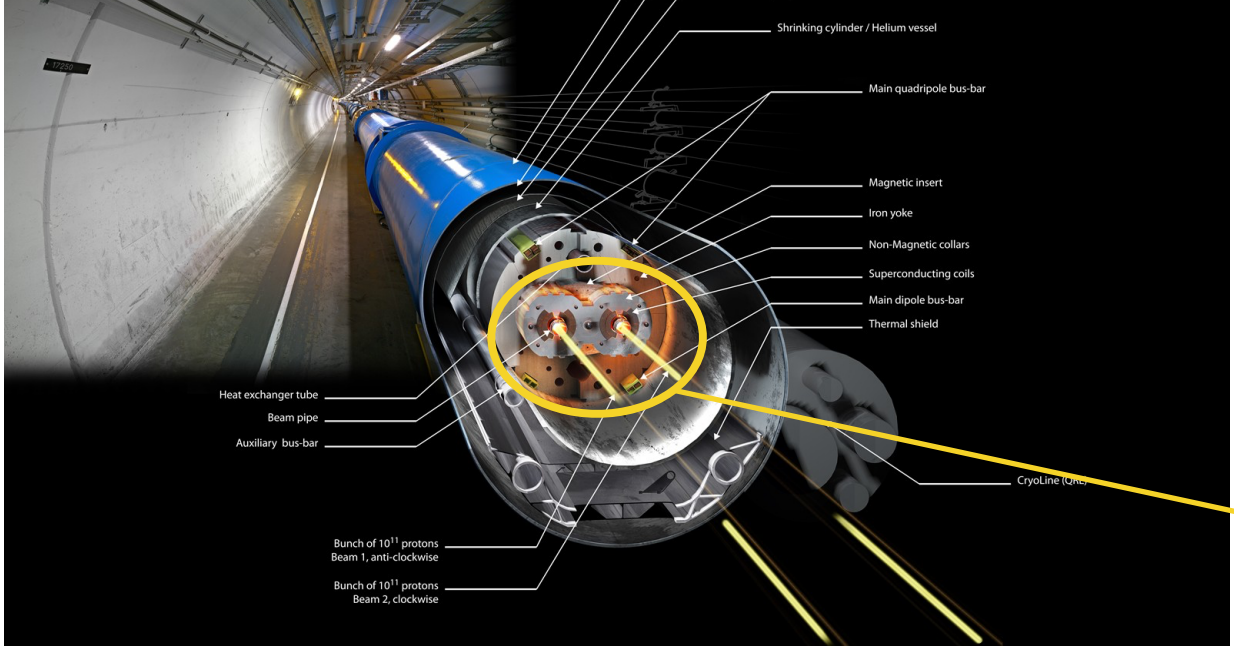
(Earth's field ~ 0.5 Gauss)

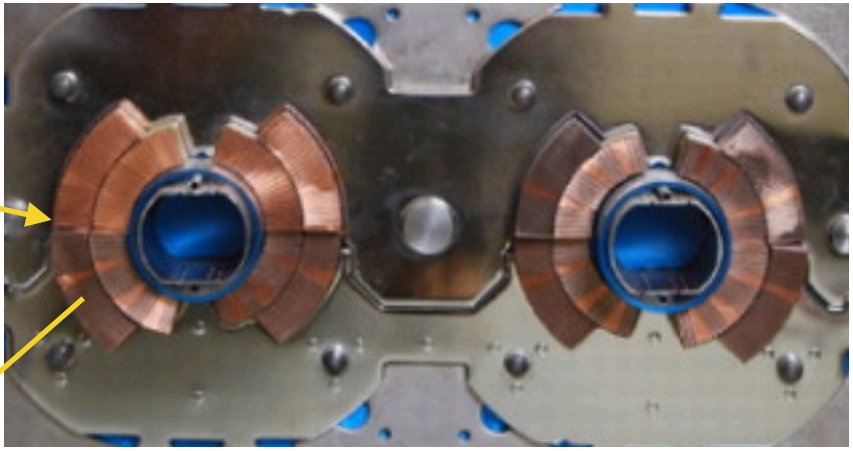
- T = 1.9K^0 = – 456 F
  - superfluid liquid Helium
- 35 tonnes
- 50 ft long
- Stress at the collar: 150 MPa
  - ~ 22,000 psi
  - ~ 1,500 kg/cm^2
- Stored energy: 7 MJoule

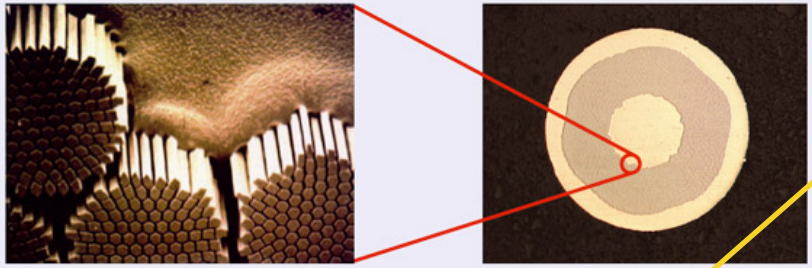


More, but simple, facts about LHC dipoles:

http://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.magnetic_dipoles







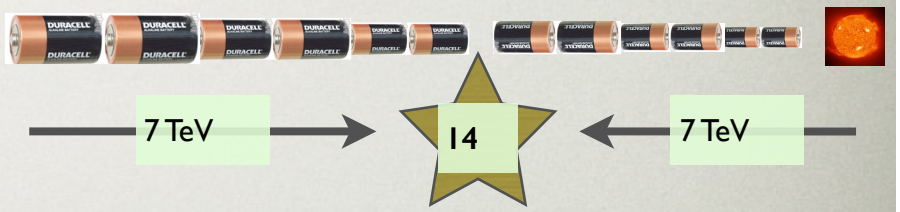
STRAND	**Type 01**	**Type 02**
Diameter (mm)	1.065	0.825
Cu/NbTi ratio	1.6-1.7 ± 0.03	1.9-2.0 ± 0.03
Filament diameter (μm)	7	6
Number of filaments	8800	6425
Ic (A) @1.9 K	515 (±4 %) @ 10 T	380 (±4 %) @ 7 T
Jc (A/mm^2) @1.9 K	1530 @ 10 T	2100 @ 7 T
μ_0M (mT) @1.9 K, 0.5 T	30 ±4.5	23 ±4.5
CABLE	**Type 01**	**Type 02**
Number of strands	28	36
Width (mm)	15.1	15.1
Mid-thickness (mm) @ MPa	1.900 ±0.006	1.480 ±0.006
Keystone angle (degrees)	1.25 ±0.05	0.90 ±0.05
Cable Ic (A) @ 1.9 K	13750 @ 10T	12960 @ 7T
Maximum Ic cabling degradation	5 %	5%
Interstrand resistance (μΩ)	10-50	20-80

The LHC accelerator

- 1232 LHC dipoles, plus ~600 other smaller magnets

- E_{beam} = 7000 GeV ~ 7×10^{12} eV ~ 5 trillions 1.5V batteries

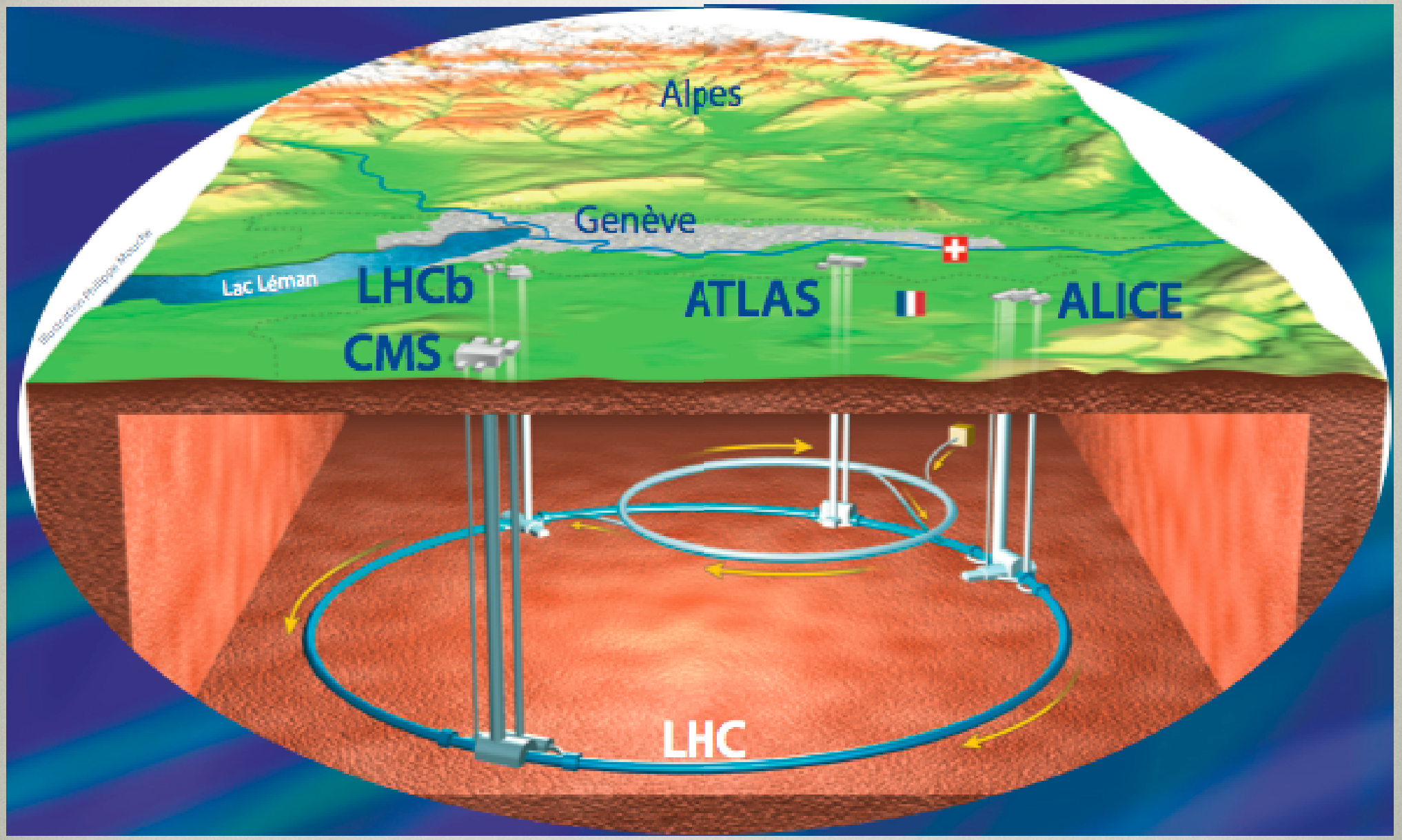
~ 100 M km of batteries, about d[Earth-Sun]

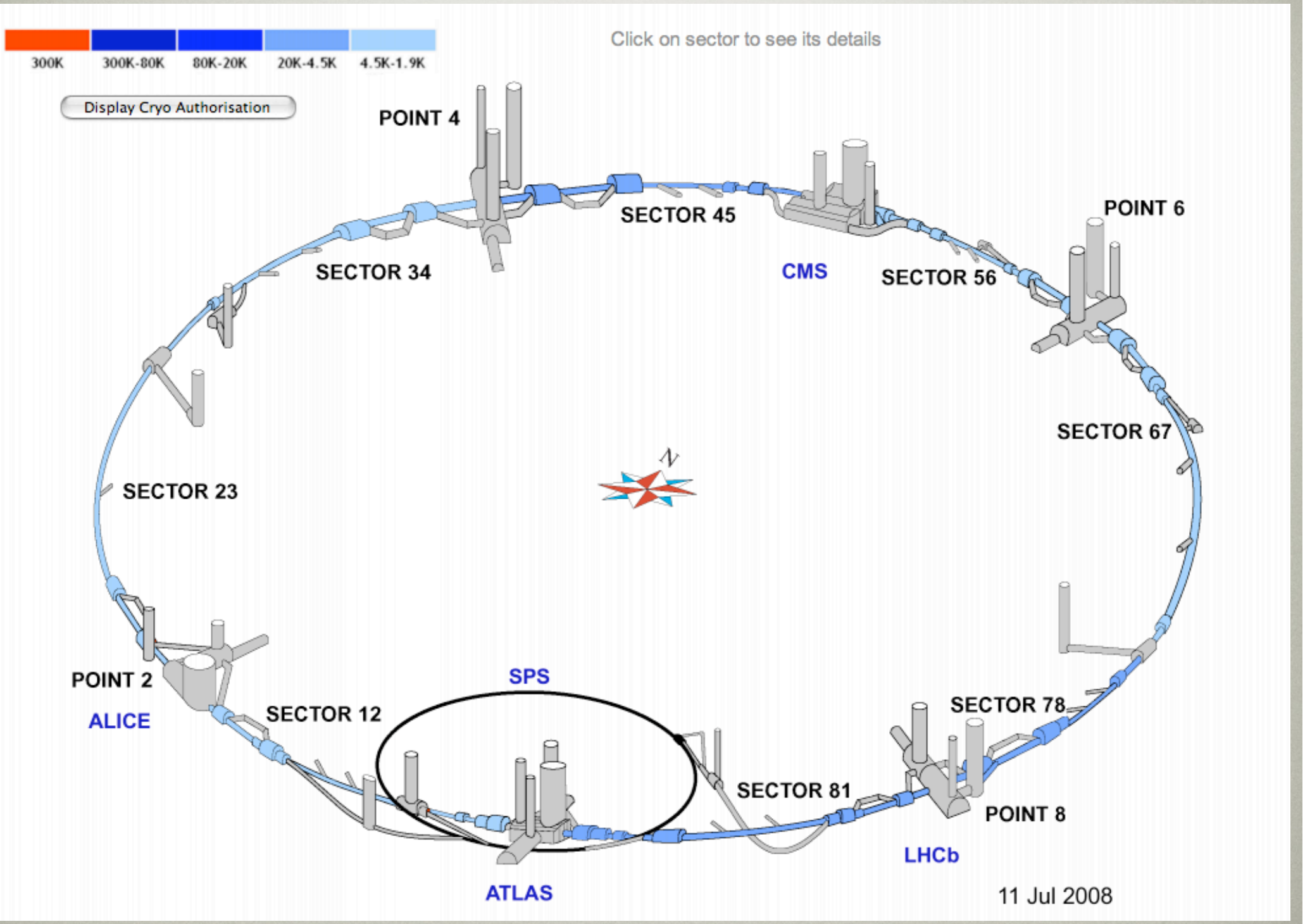


- E_{beam} = 7000 GeV ~ 7500 m_{proton} c^2
  - $E=mc^2 / \sqrt{[1-v^2/c^2]} \Rightarrow v = 0.999\ 999\ 99\ c$

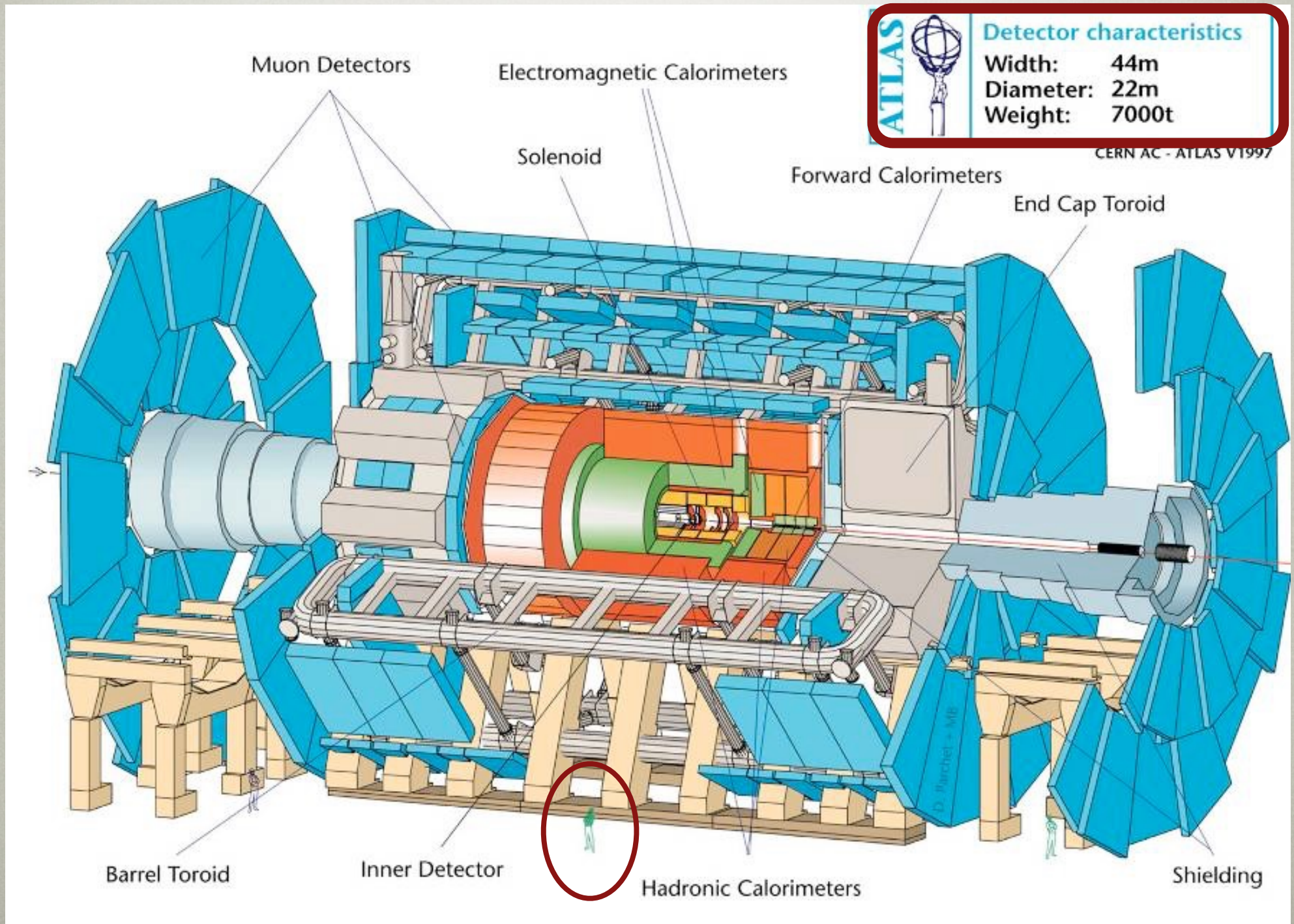
- N_{proton} ~ 10^{11}/bunch x 2800 bunches/beam x 2 beams ~ 10^{14}

- Energy stored ~ 350 MJ ~ 200 lb of TNT ~ Amtrak running full speed


Alpes
Genève
Lac Léman
LHCb
ATLAS
ALICE
CMS
LHC

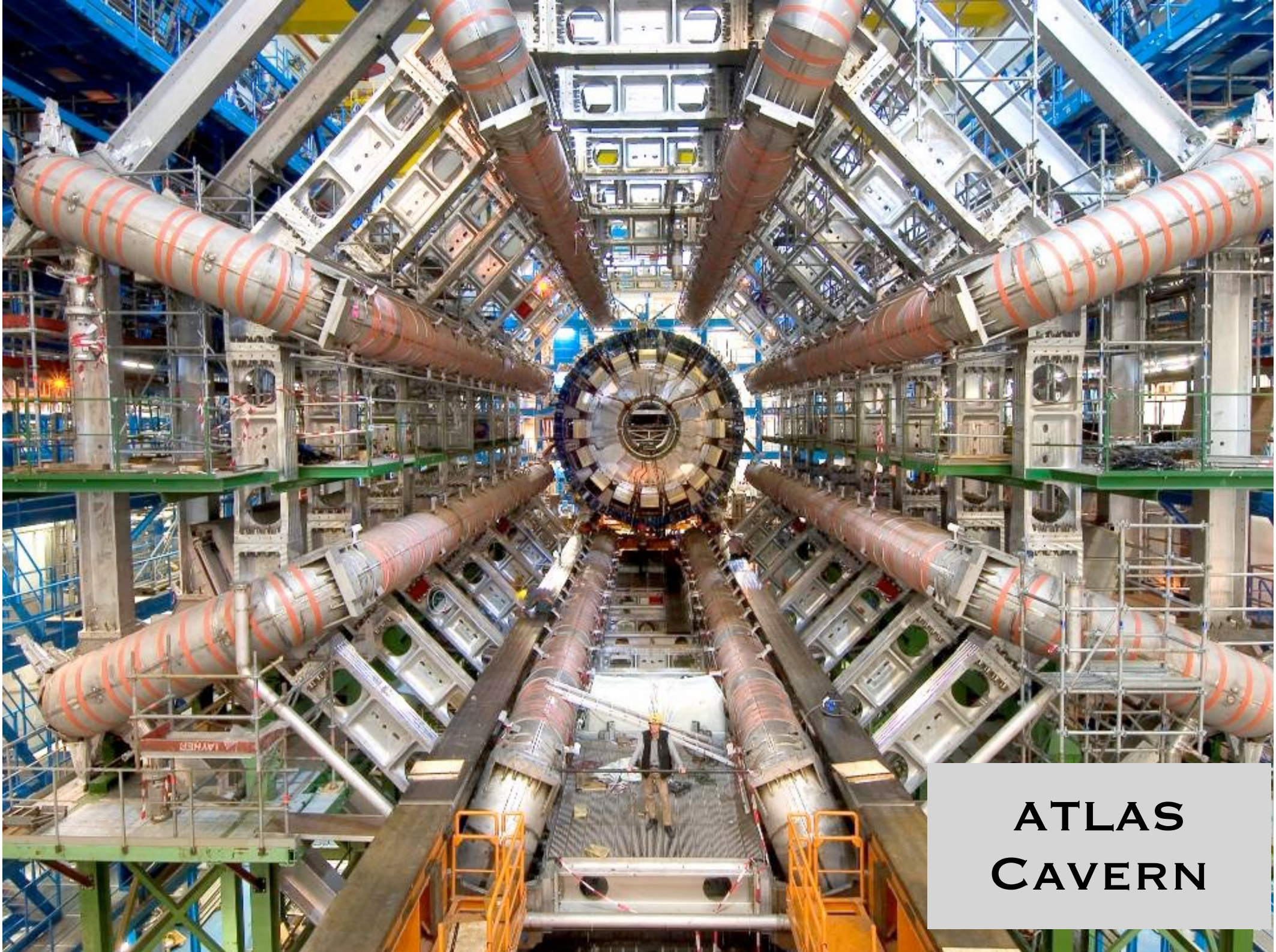

300K
300K-80K
80K-20K
20K-4.5K
4.5K-1.9K
Click on sector to see its details
Display Cryo Authorisation
POINT 4
SECTOR 45
SECTOR 34
CMS
SECTOR 56
POINT 6
SECTOR 67
SECTOR 23
N
POINT 2
ALICE
SECTOR 12
SPS
SECTOR 81
SECTOR 78
POINT 8
LHCb
ATLAS
11 Jul 2008

Atlas detector



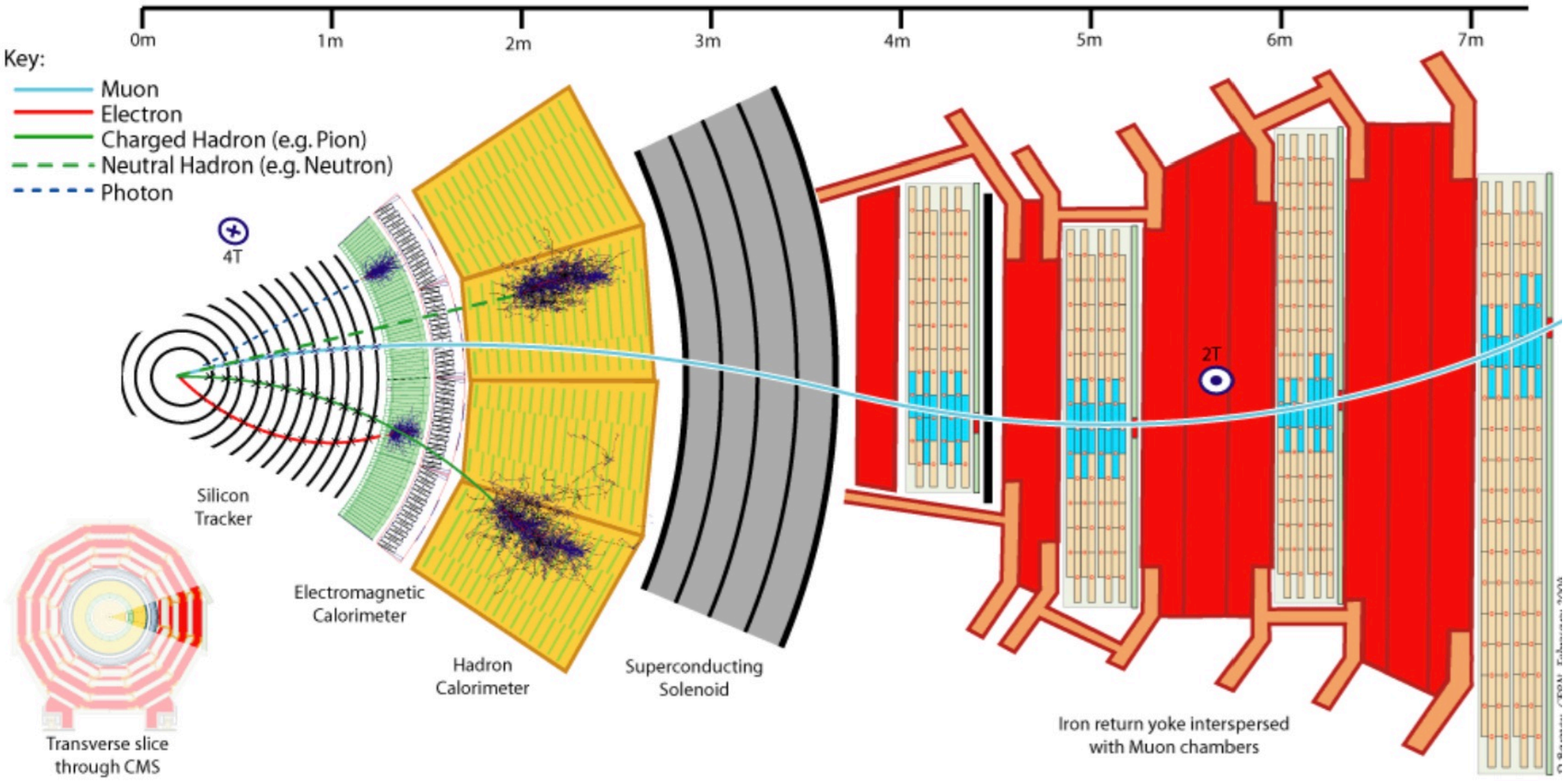
The experimental challenge

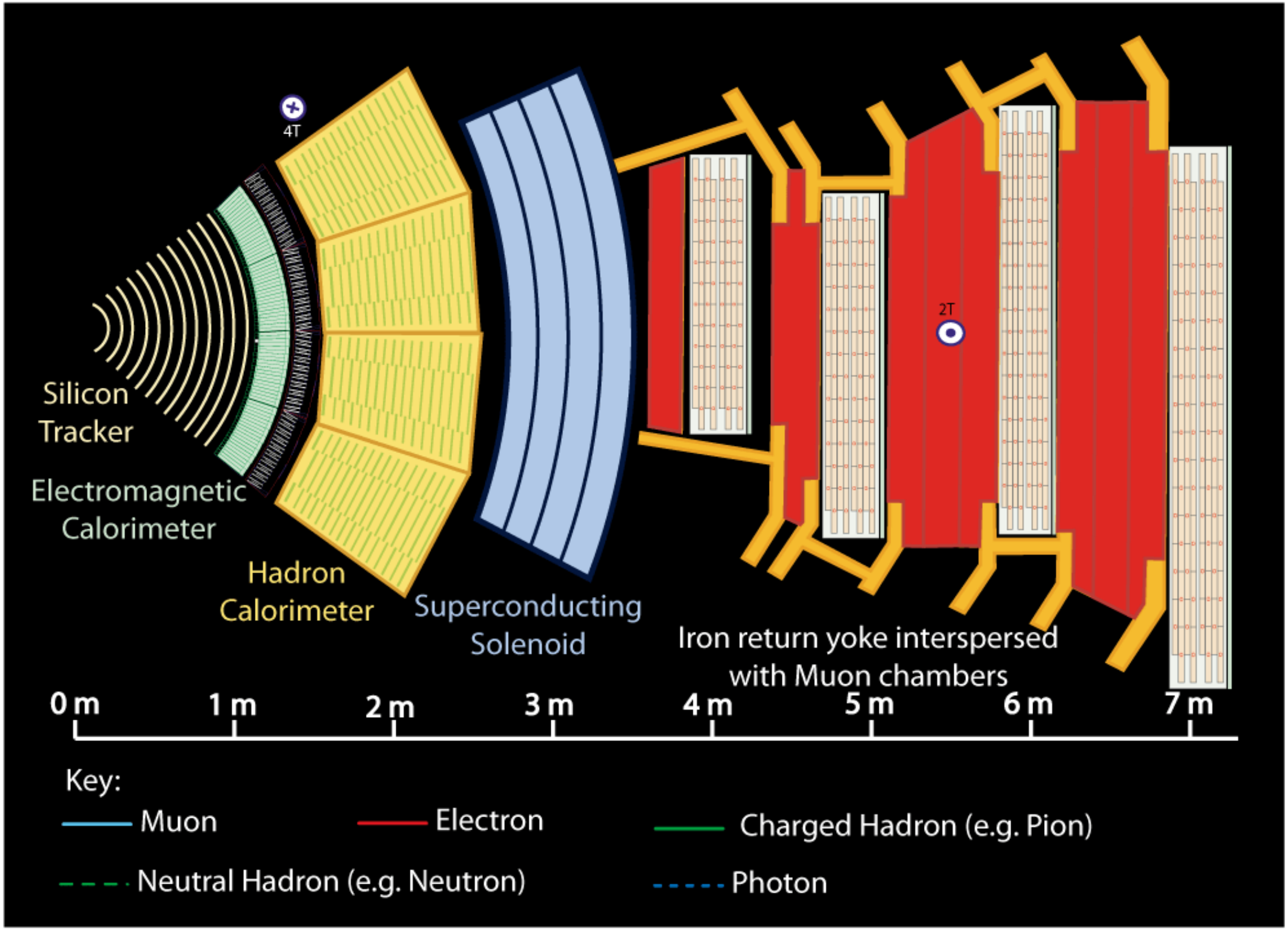
- Bunch crossing repetition rate: 40 MHz
  - 40 million beam collisions per second!
  - 1 top quark produced / sec
    - like finding 1 needle in a 10 tonnes stack of needles, with 1 second of time to do it
  - 1 Higgs boson produced / hr
    - like finding 1 needle in a 10,000 tonnes stack of needles

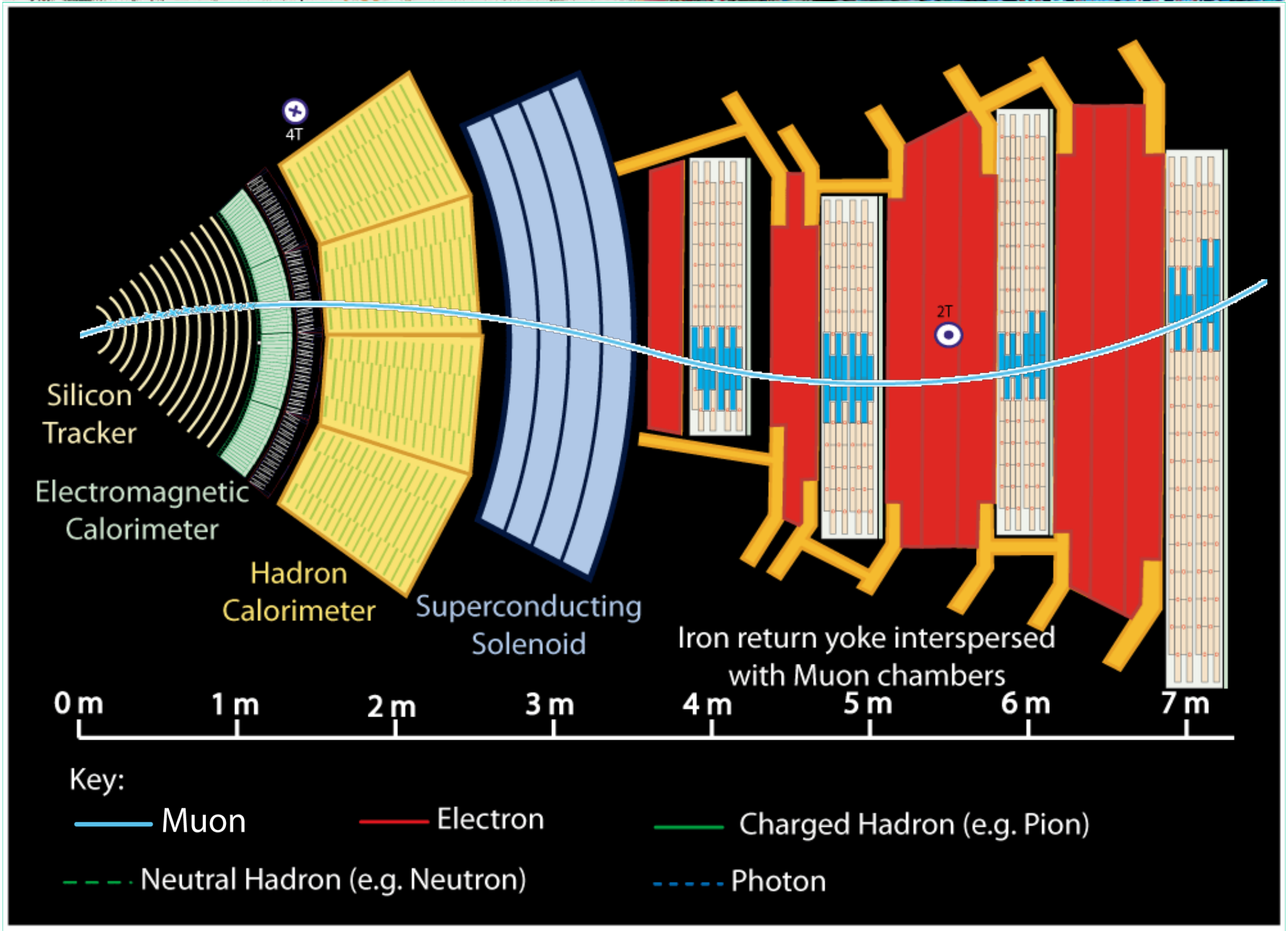


ATLAS Cavern

A slice of the CMS detector




4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon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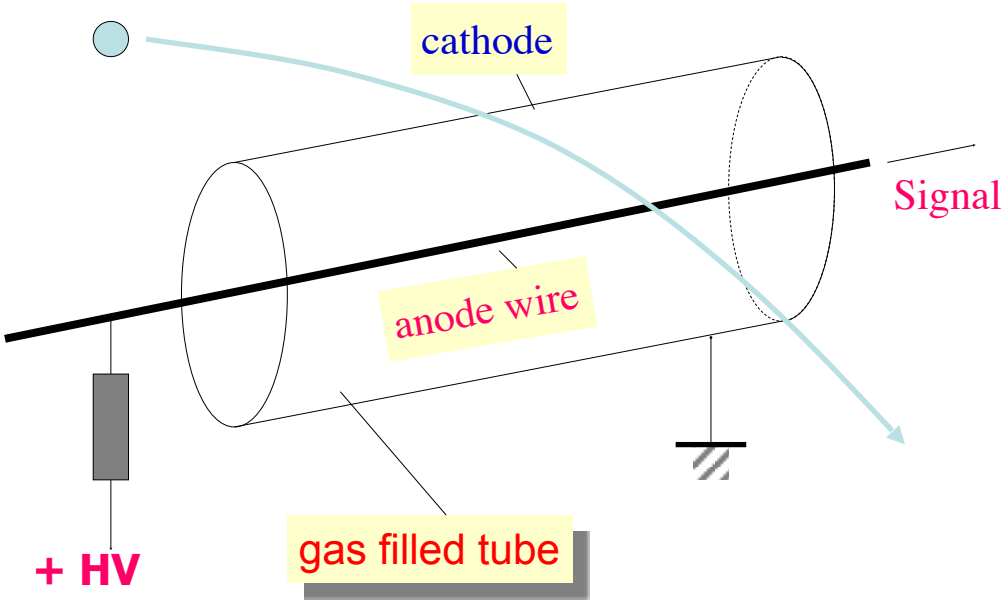
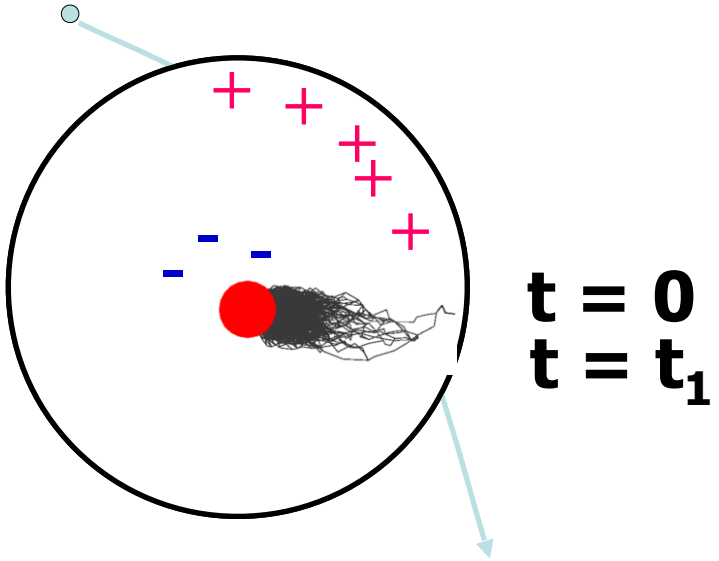
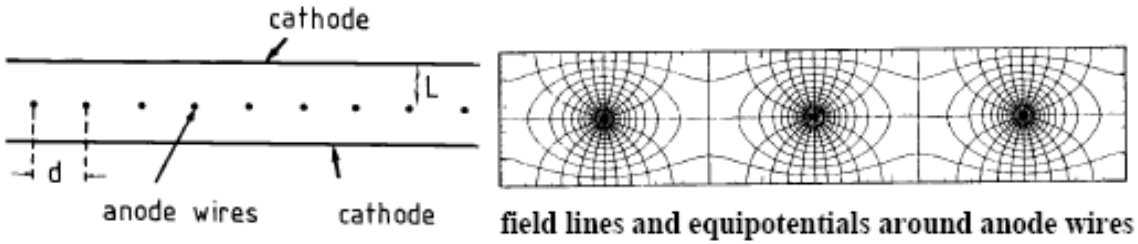
Detecting the path of a charged particle: Gas detectors





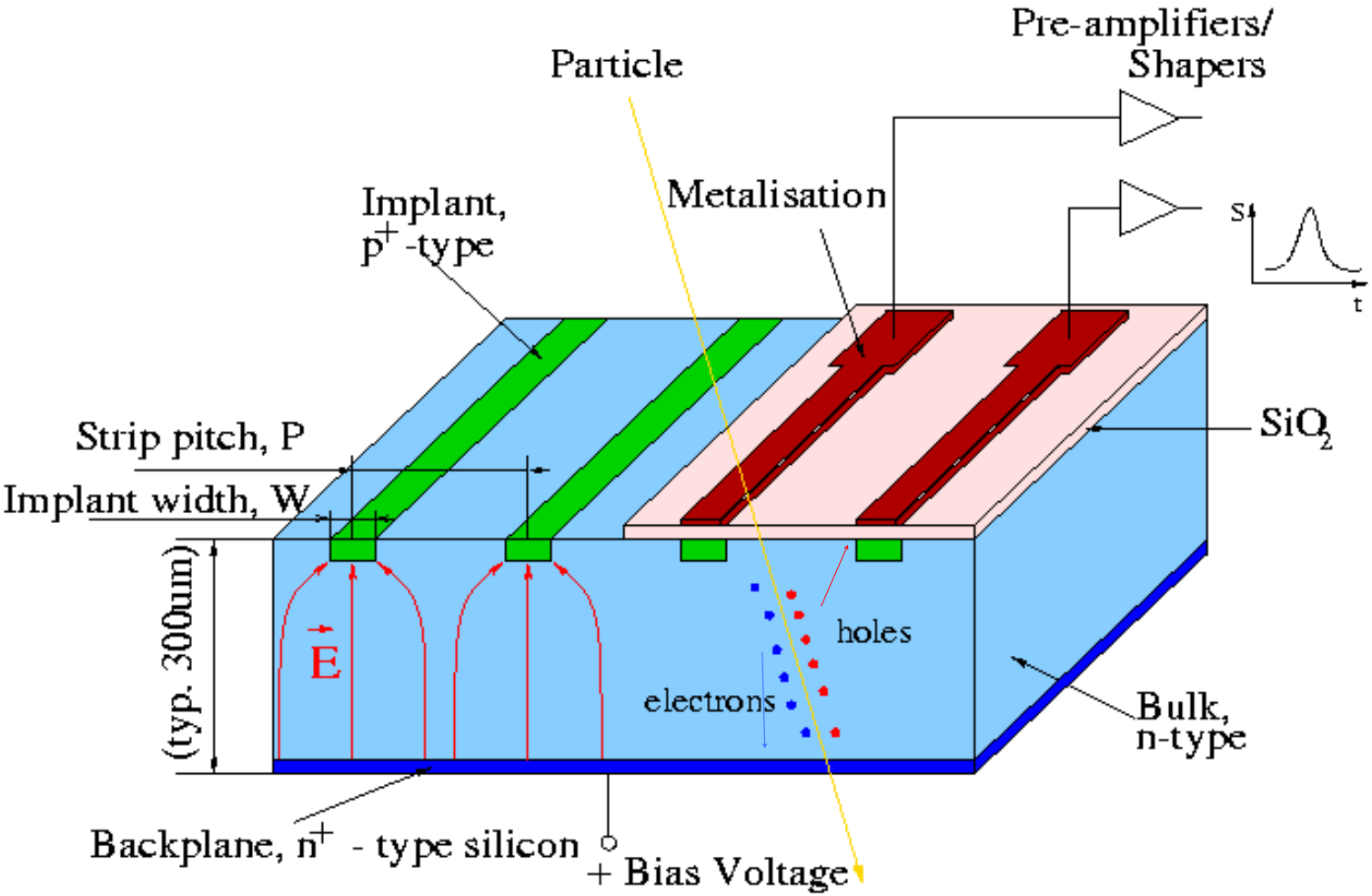
- Geiger-Counter: Binary response
- Proportional Counter:
- **MWPC:** Multi Wire Proportional Chamber
- ....

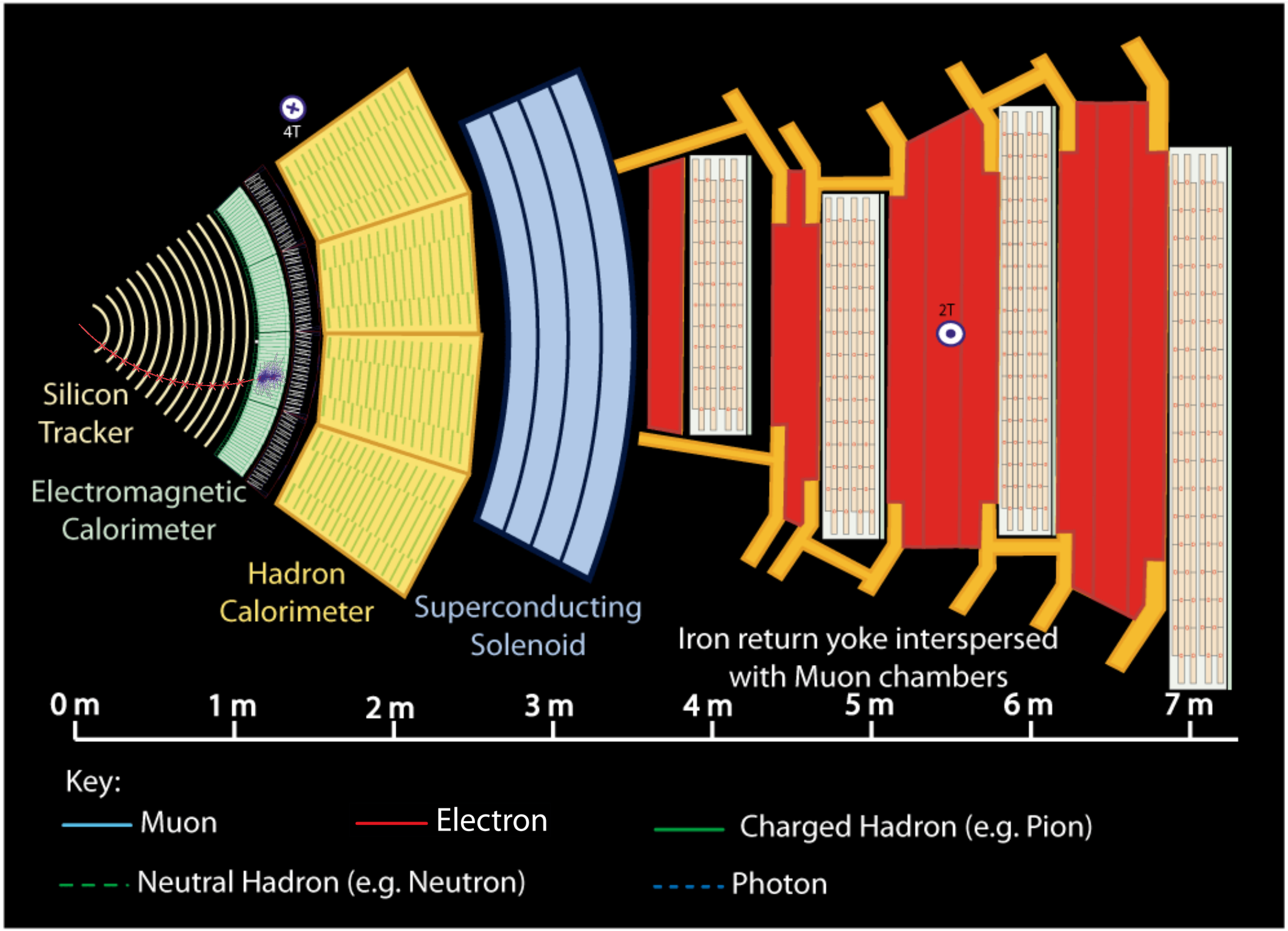


field lines and equipotentials around anode wires

Silicon detectors

Replace gas with properly doped silicon

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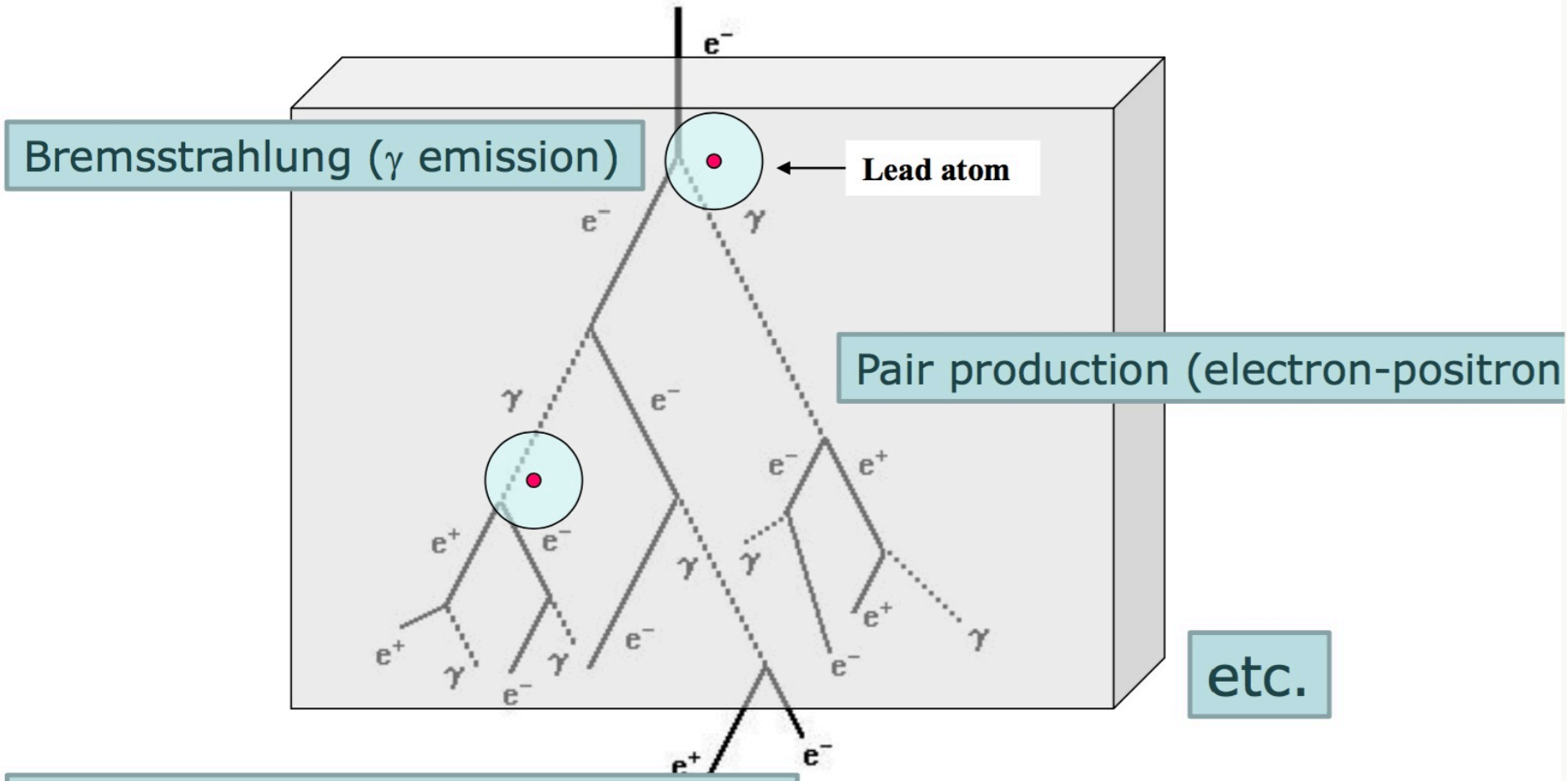
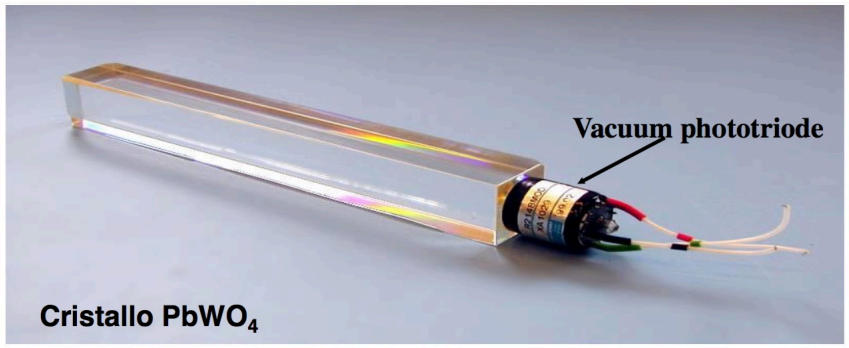
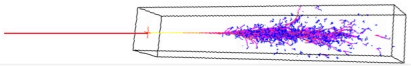
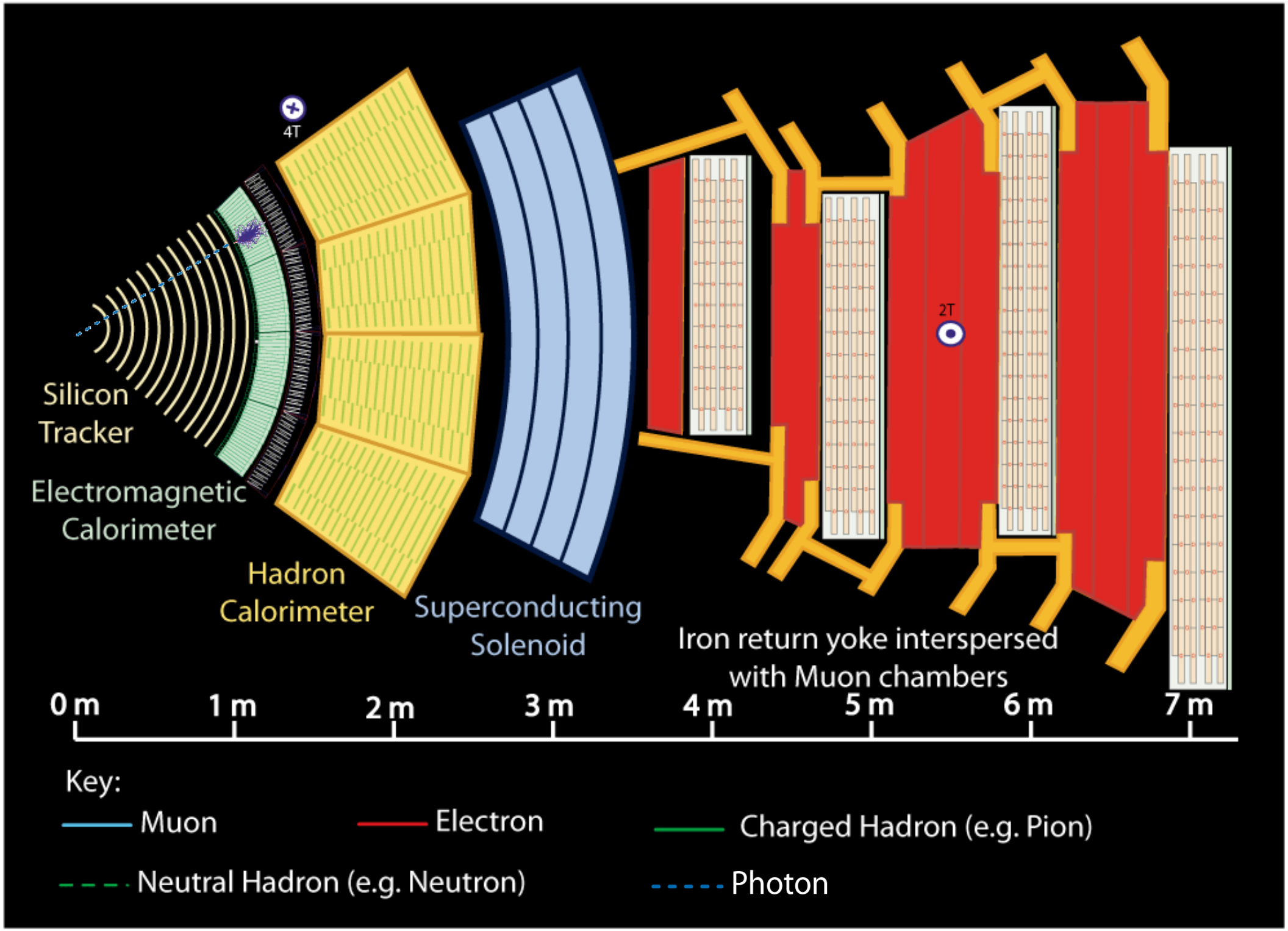
An electromagnetic shower



CMS EM calorimeter



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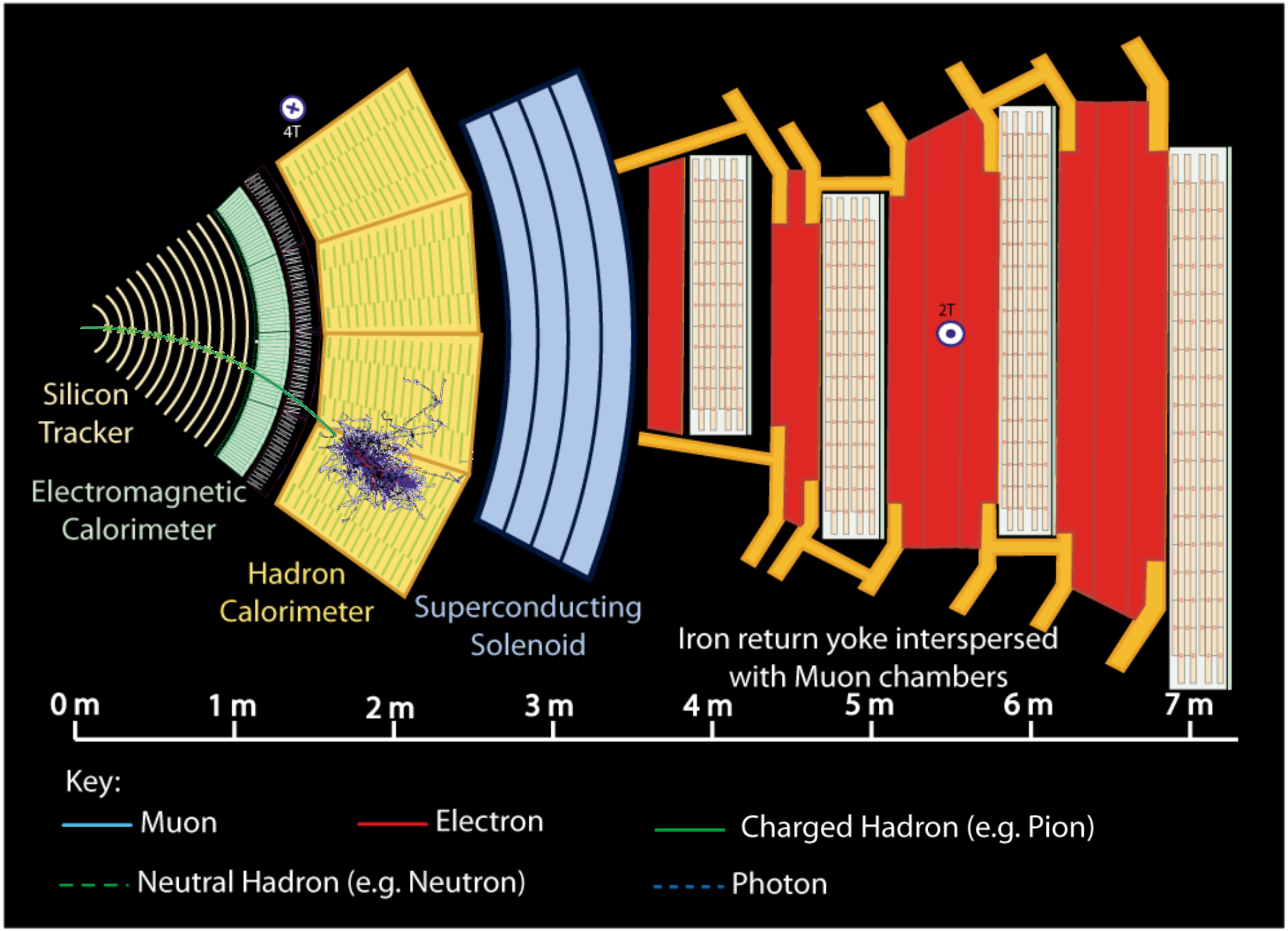
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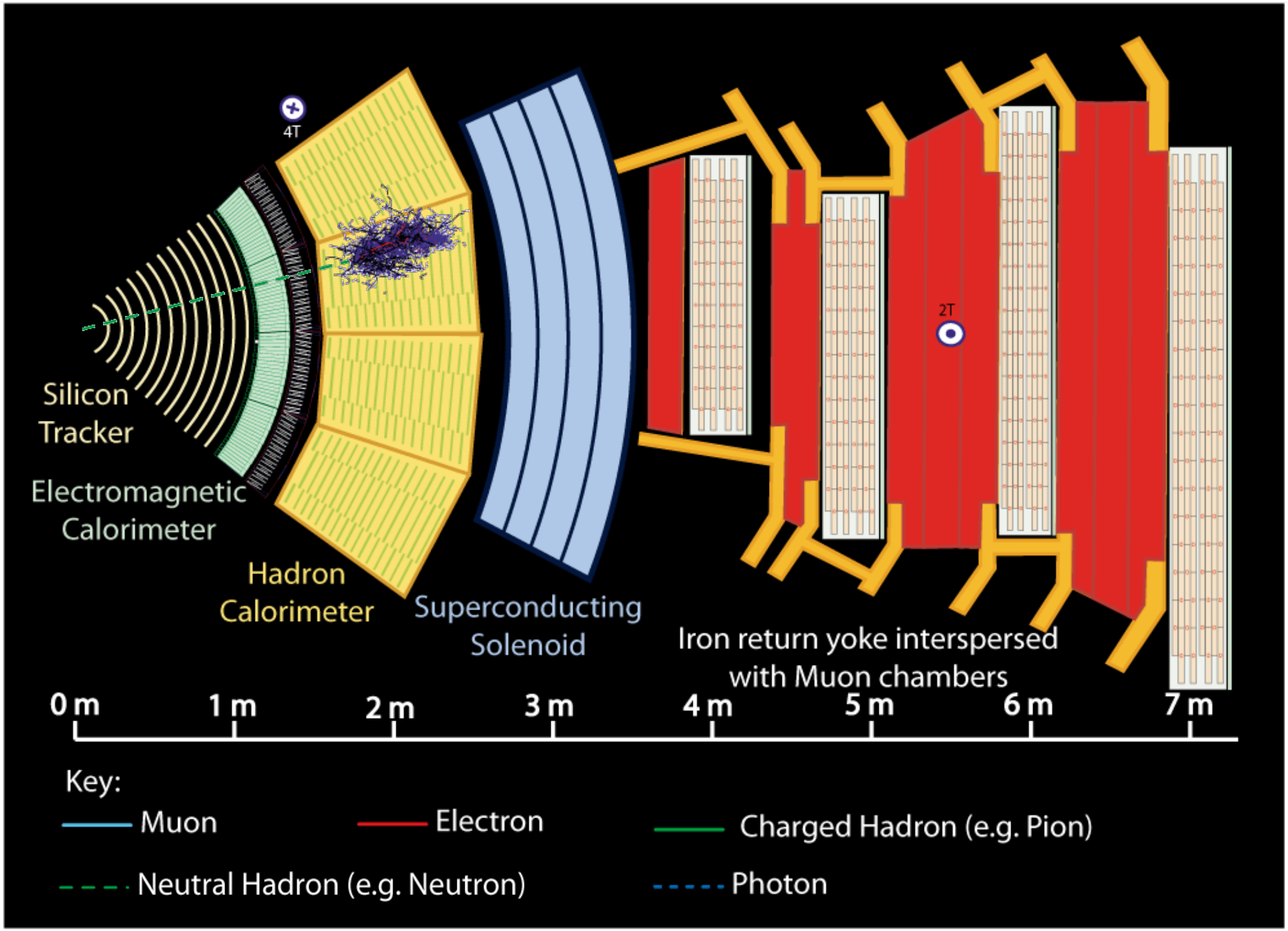
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