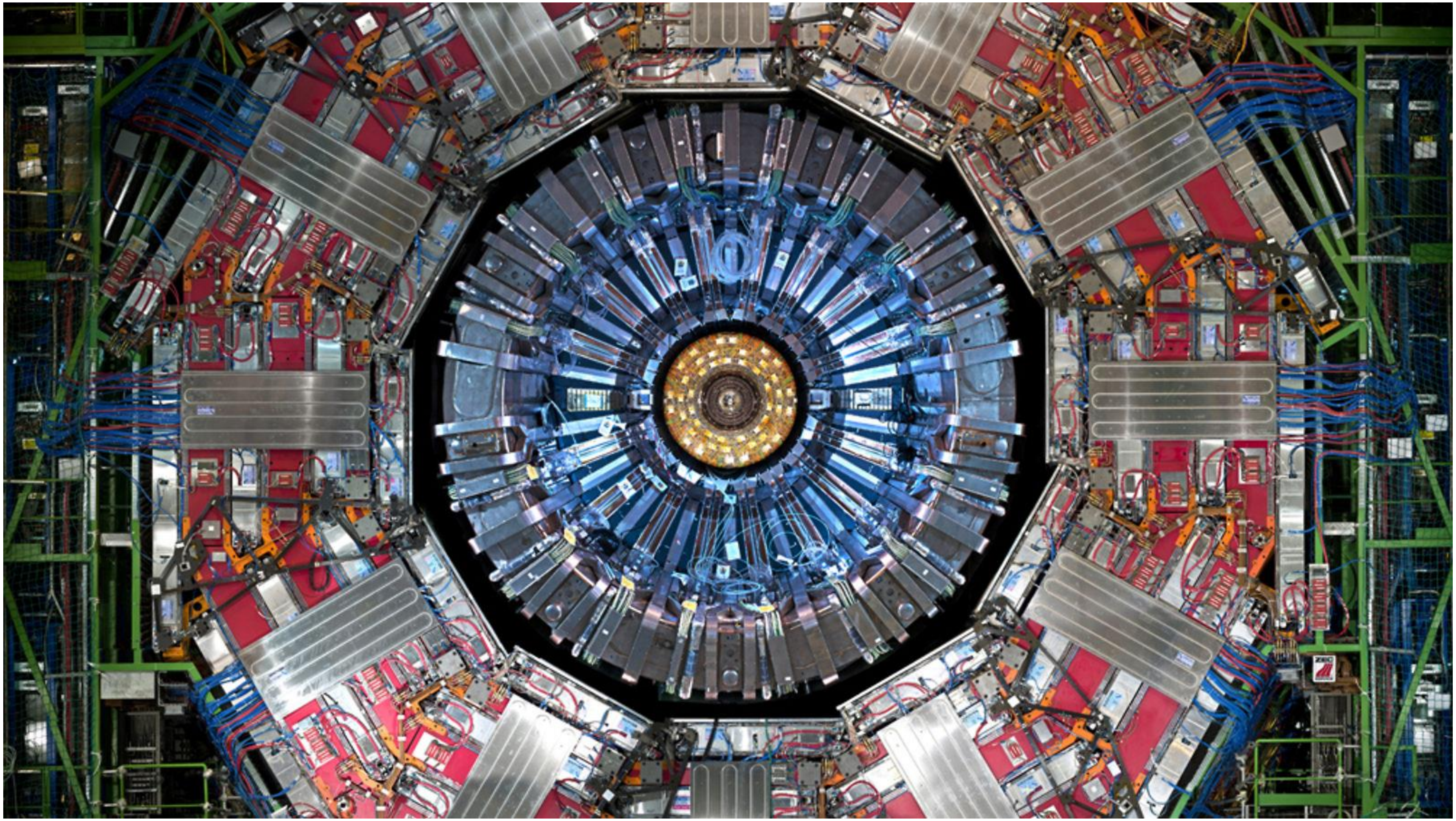
The CMS Detector

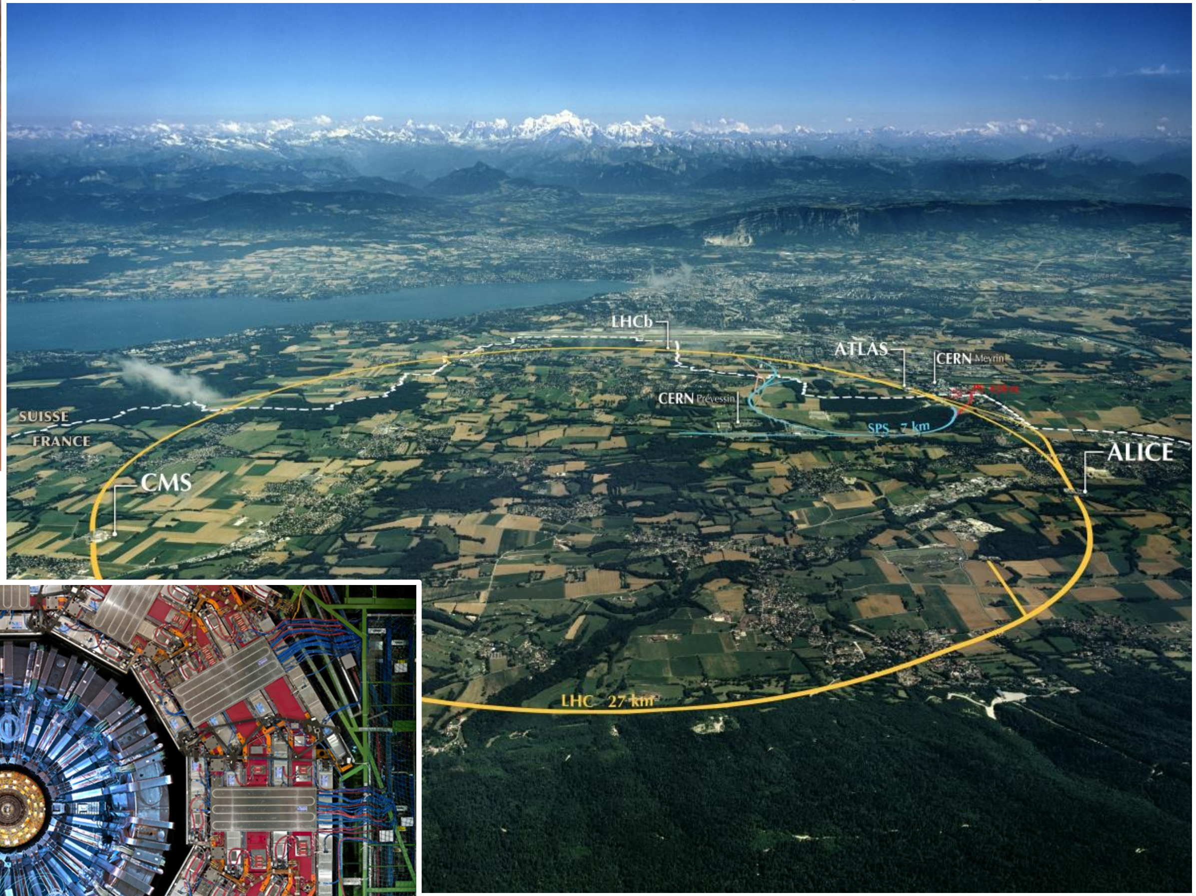


Hallie Trauger
Teaching Assistant Professor
NC A&T State University

The Large Hadron Collider at CERN

The most powerful particle accelerator in the world!

Beam line circumference 26.7 km (16.6 miles)

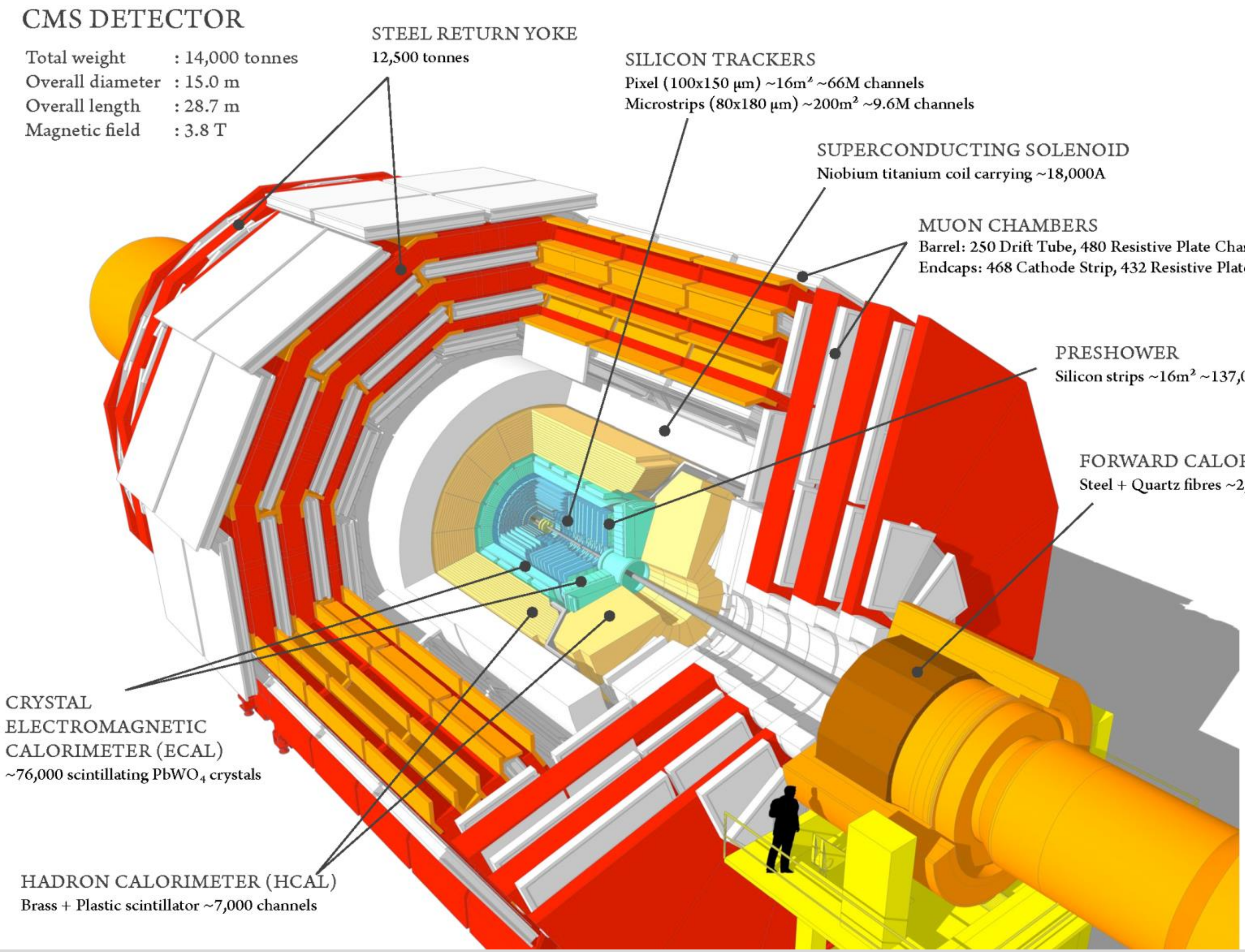


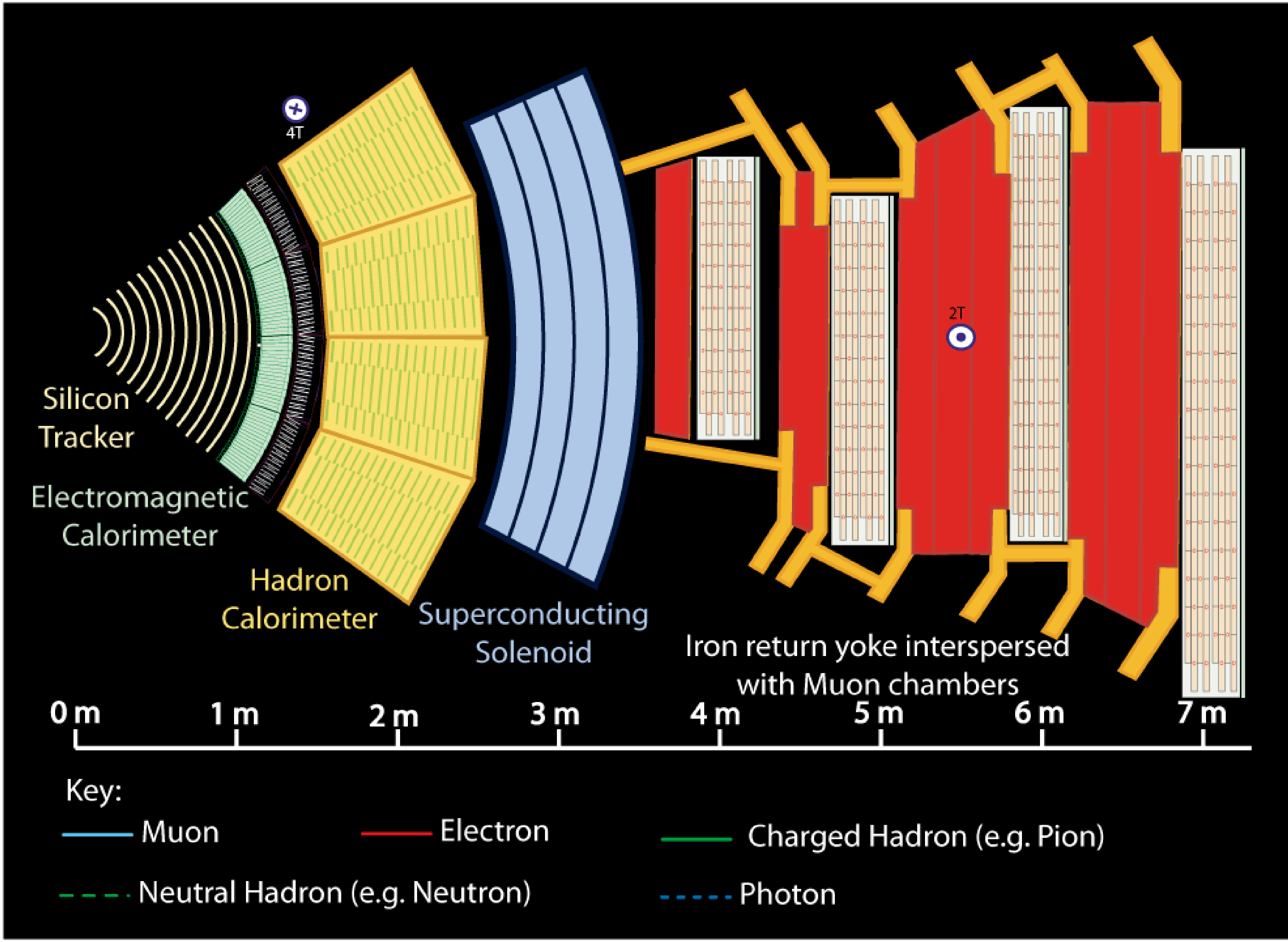
CMS Detector

Compact Muon Solenoid Detector

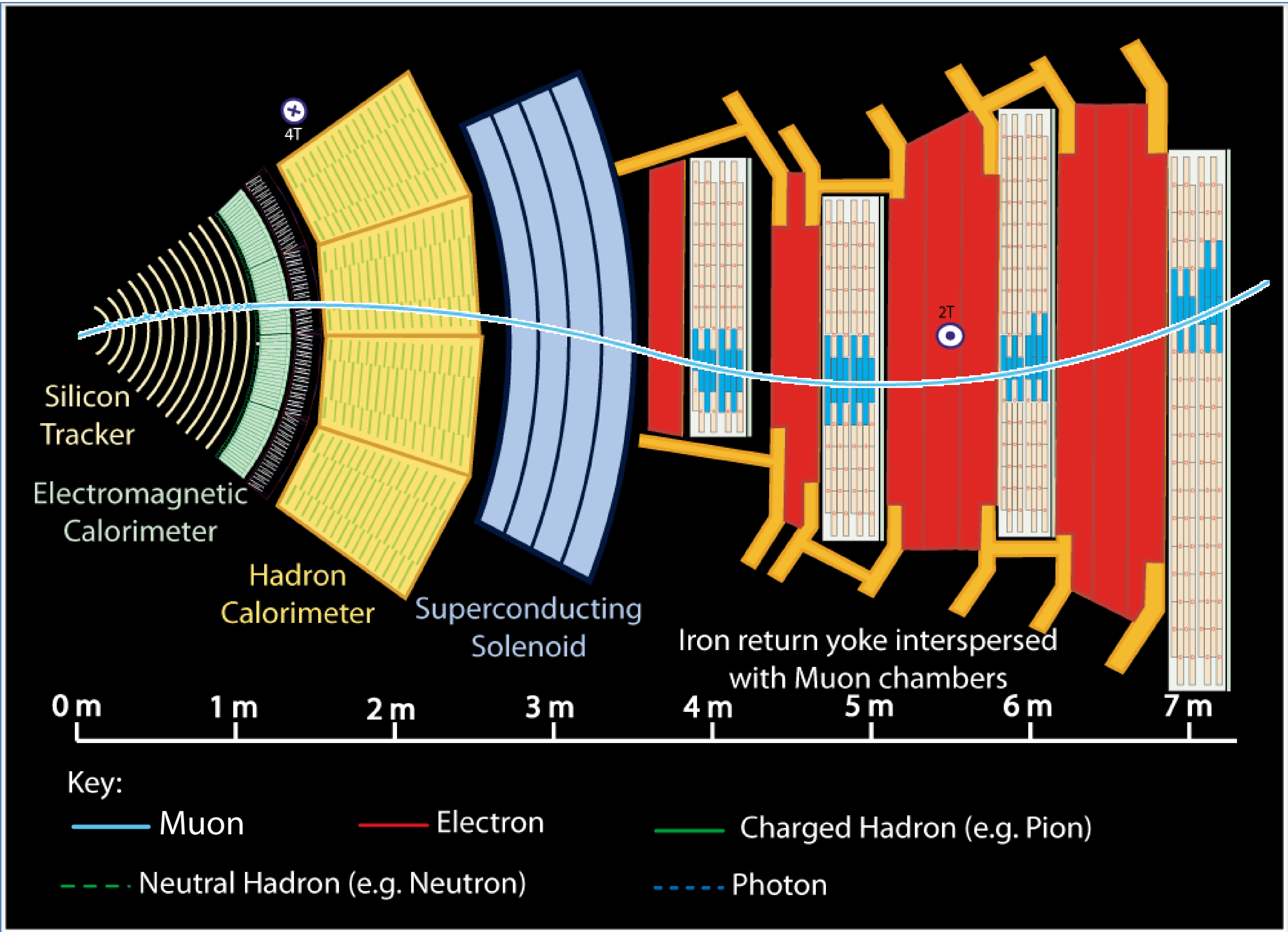
- **Compact** – Diameter is about 15 m (nearly 50 feet) across).
- **Muon** – Highly efficient muon tracking system outside the magnet.
- **Solenoid** – 4T superconducting magnet. Provides the magnetic field for tracking!

Compact Muon Solenoid 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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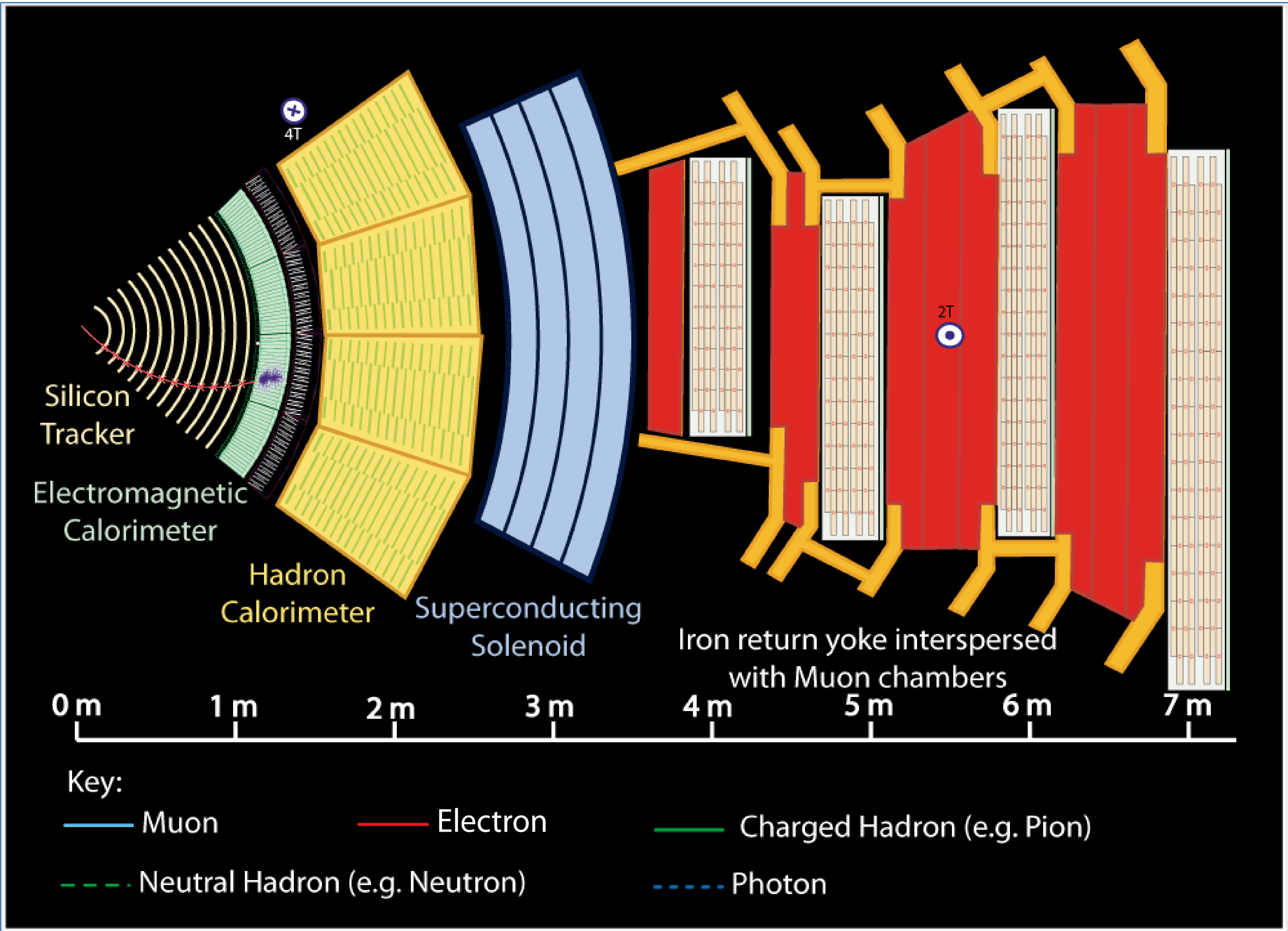
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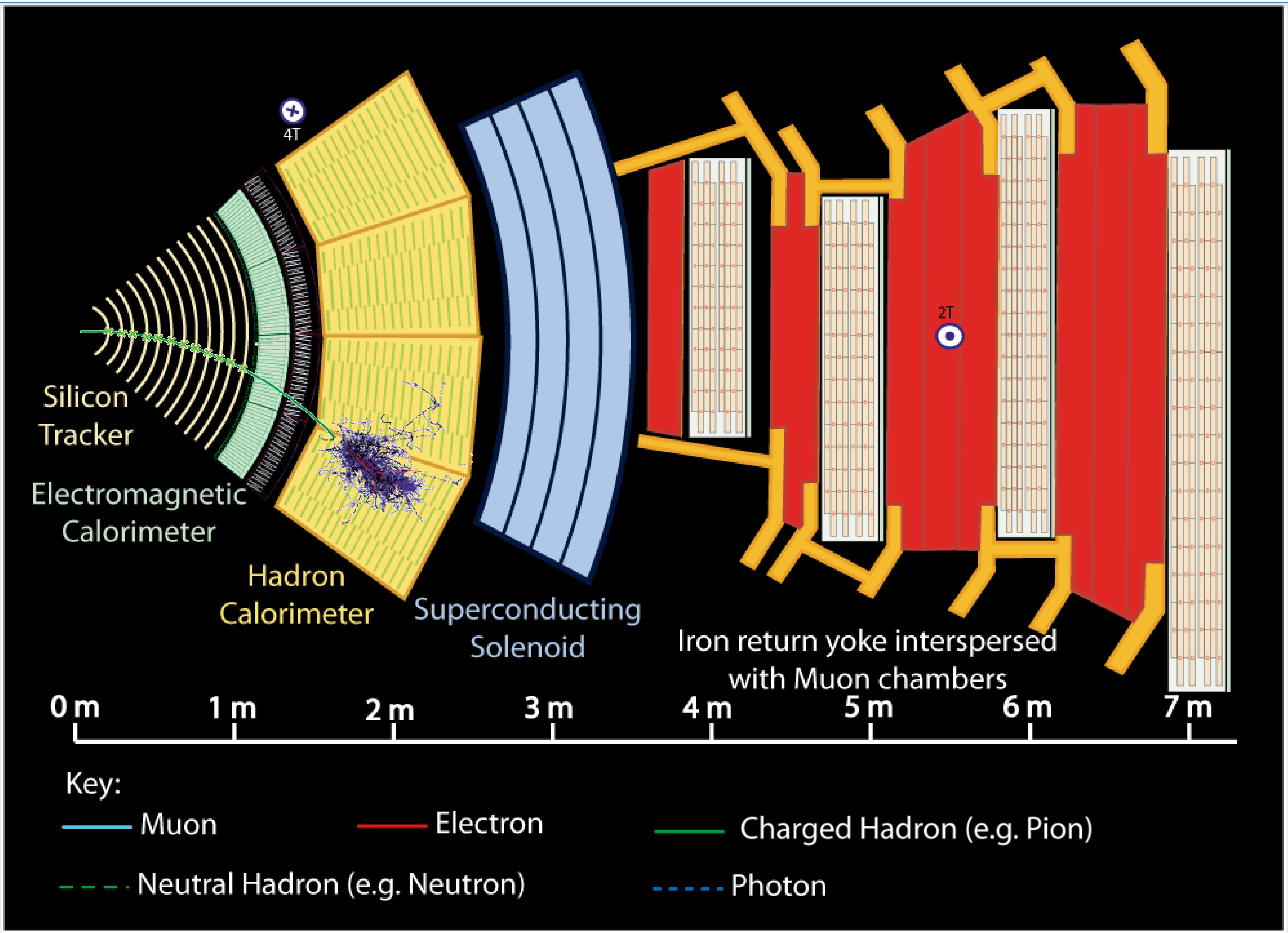
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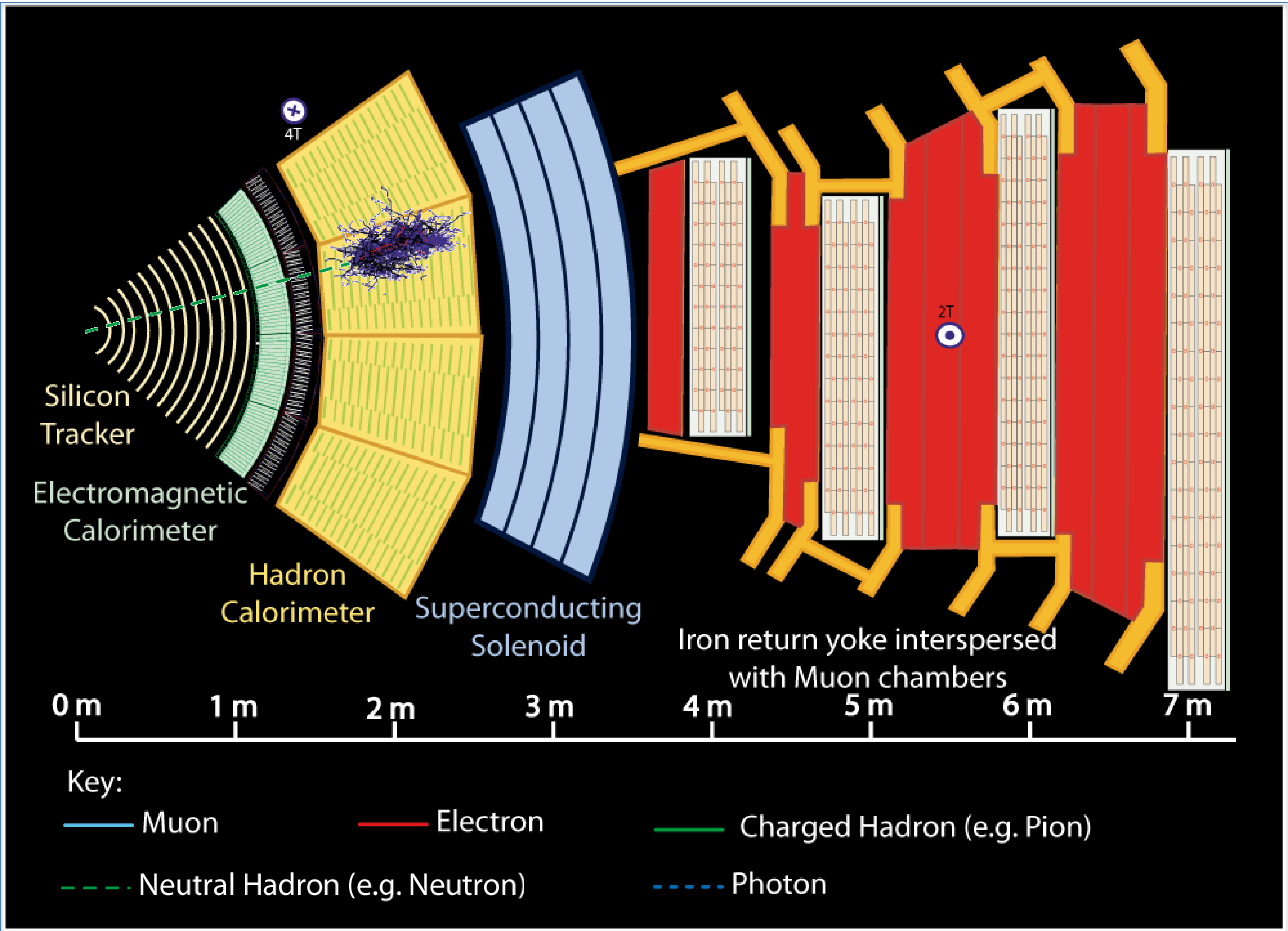

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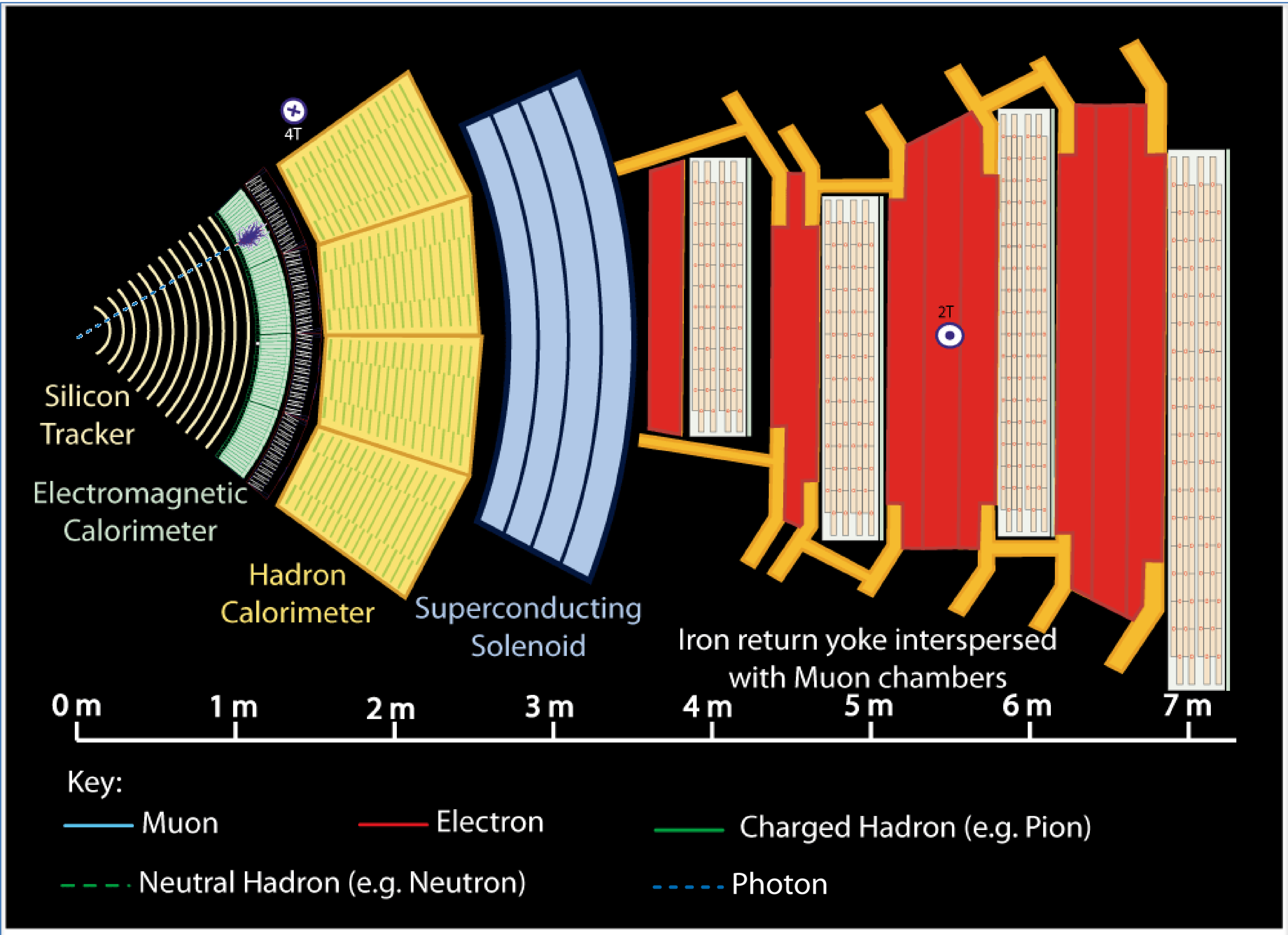
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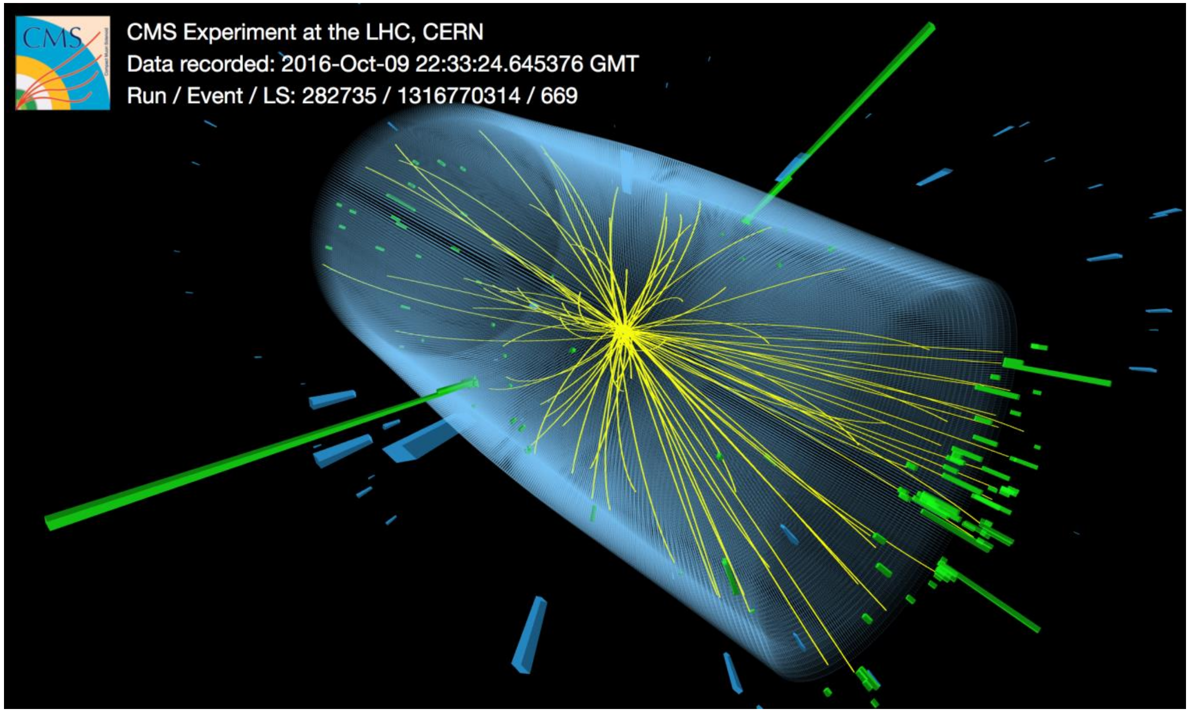
Most of the time: proton-proton collisions

Proton-proton collisions at 7 TeV (Run 1), 13 TeV (Run 2) and beyond

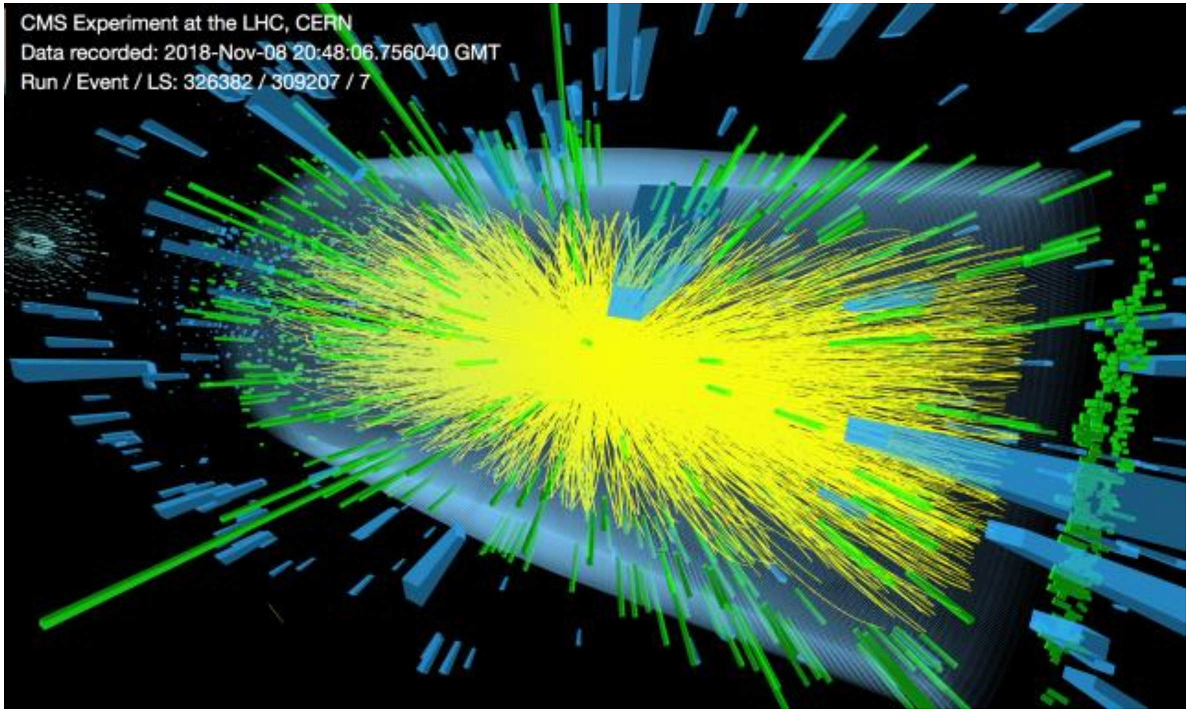
- Colliding two protons at high enough energies to study other kinds of particles (or even find new ones)
- This is how to do particle physics!
- Also how to win a Nobel Prize for observing the Higgs Boson (at right).



Occasionally: lead-lead (Pb-Pb) collisions

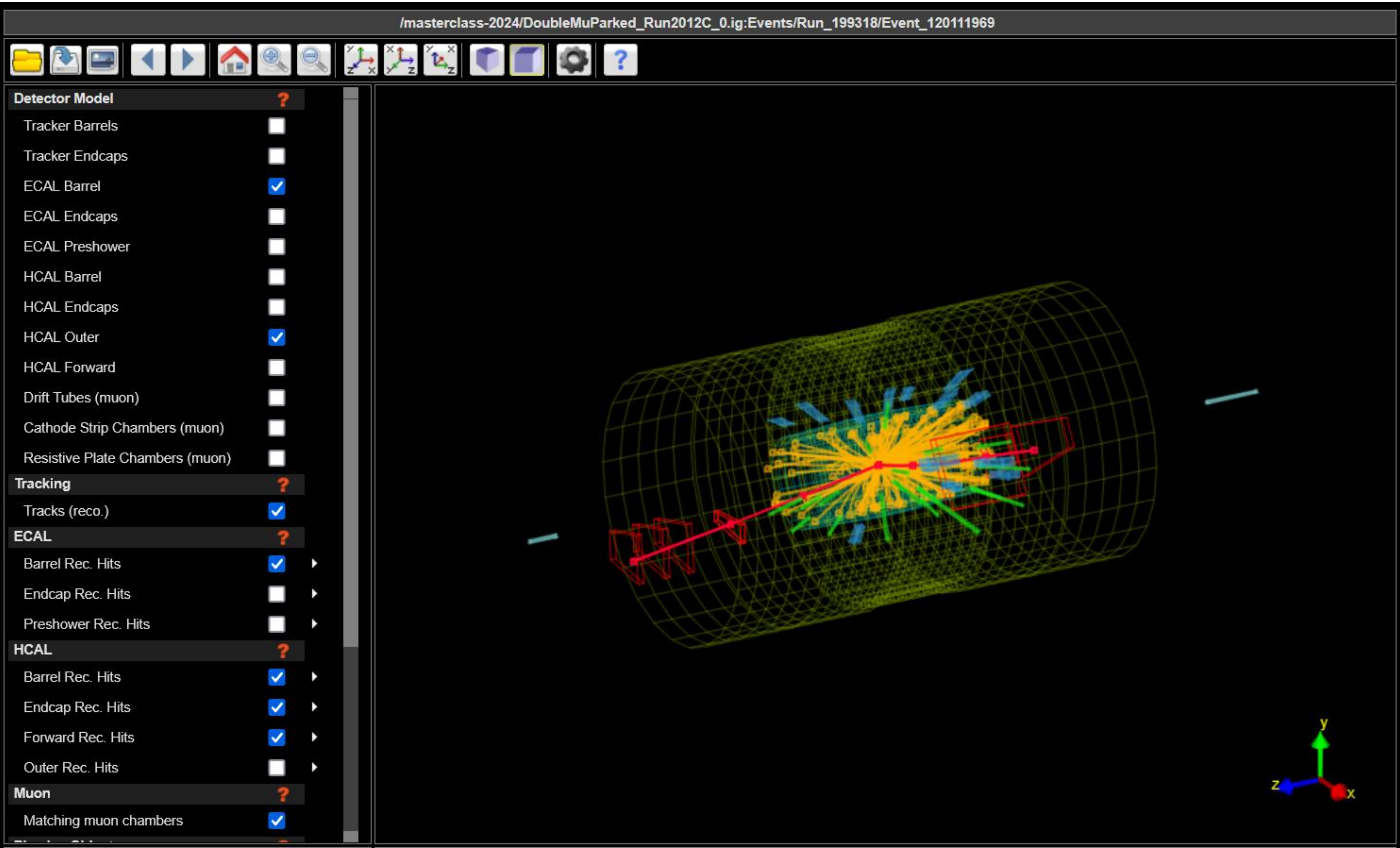
PbPb collisions at 2.76 TeV (Run 1) and 5 TeV (Run 2)

- Collide lead nuclei at close to the speed of light
- Produces sufficient density and temperature to generate a QGP
- Briefly produces a thermalized medium
- Detect final-state particles in tracker, calorimeters, etc.



Interactive Event Display: iSpy

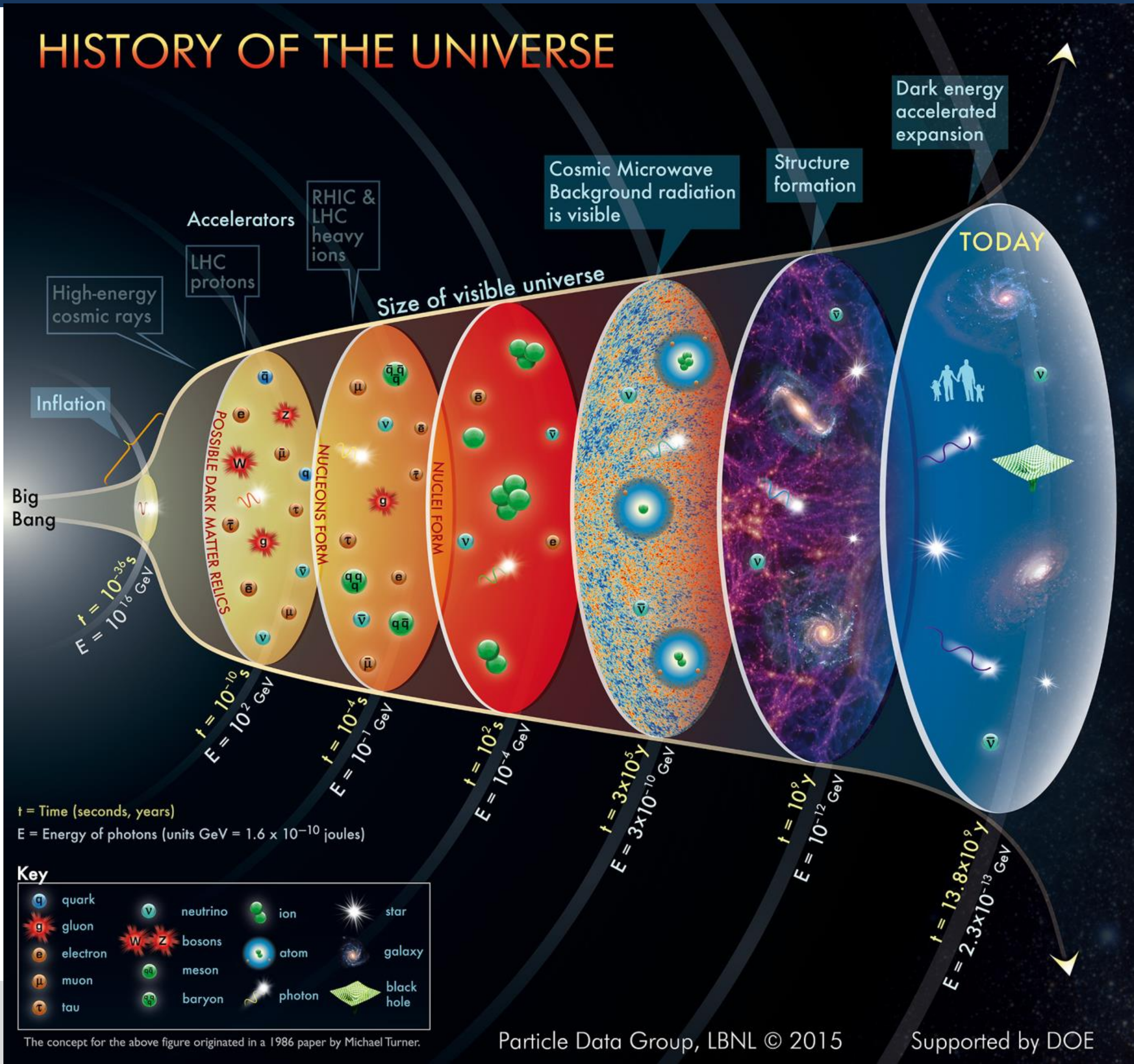
https://www.i2u2.org/elab/cms/event-display/



Bonus: High Energy Nuclear Physics

Let’s start at the very beginning …

…one microsecond after the Big Bang!



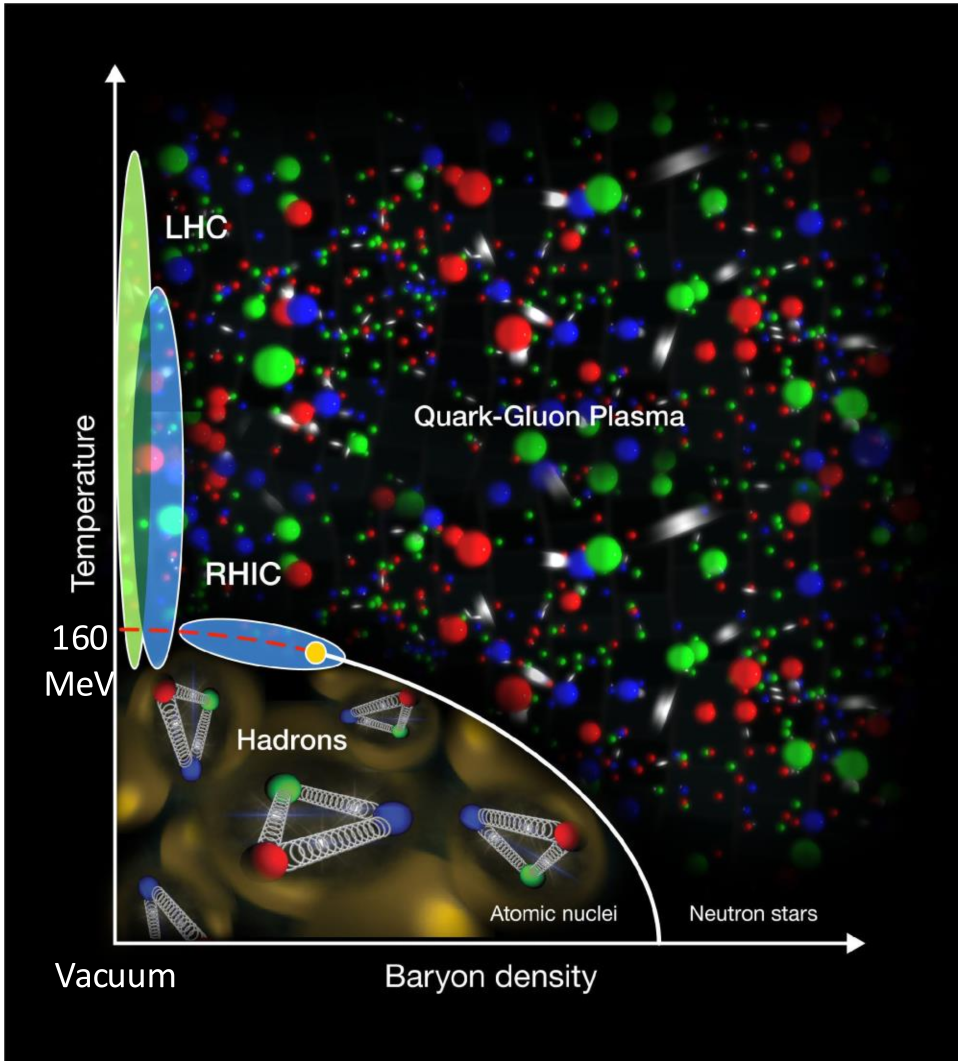
QCD Phase Diagram

Ordinary matter

- **Quarks** (up or down) held together by **gluons**
- **Protons** = 2 up quarks and one down quark
- **Neutrons** = 2 down quarks and 1 up quark

Quark Gluon Plasma

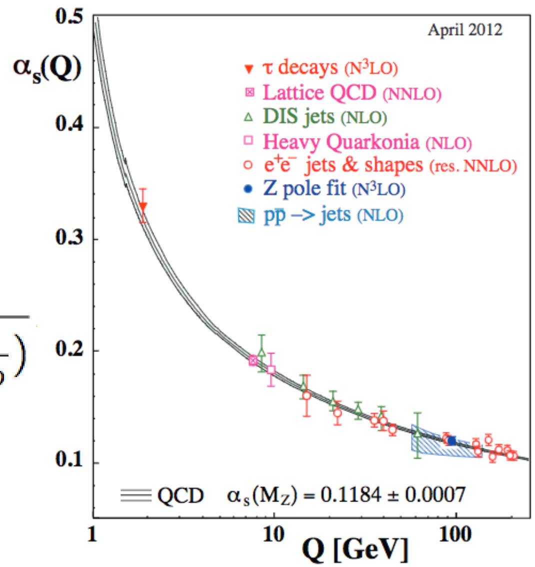
- Deconfined phase of quarks and gluons
- Predicted by quantum chromodynamics at sufficiently hot and dense conditions

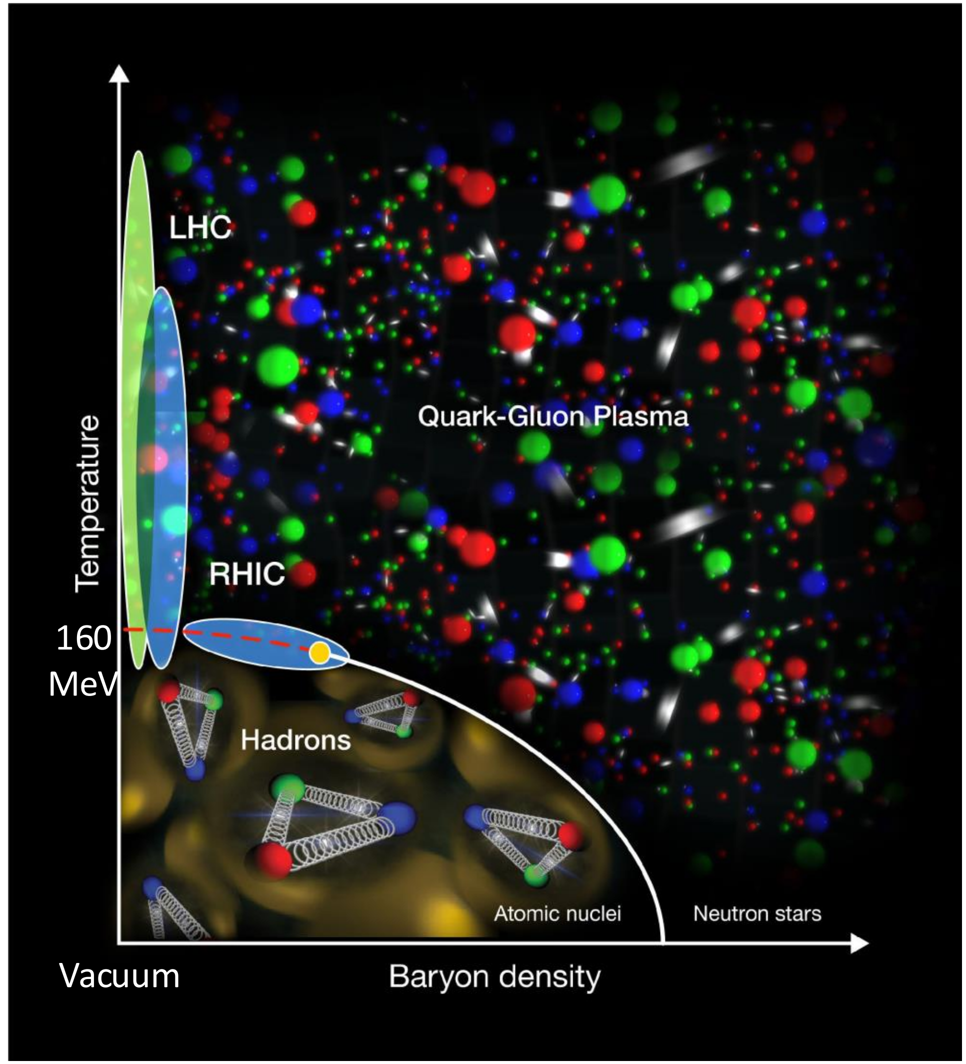


QCD Phase Diagram – Why a Quark Gluon Plasma?

$$\alpha_s(Q) \propto \frac{1}{\ln(\frac{Q^2}{\Lambda_{QCD}})}$$

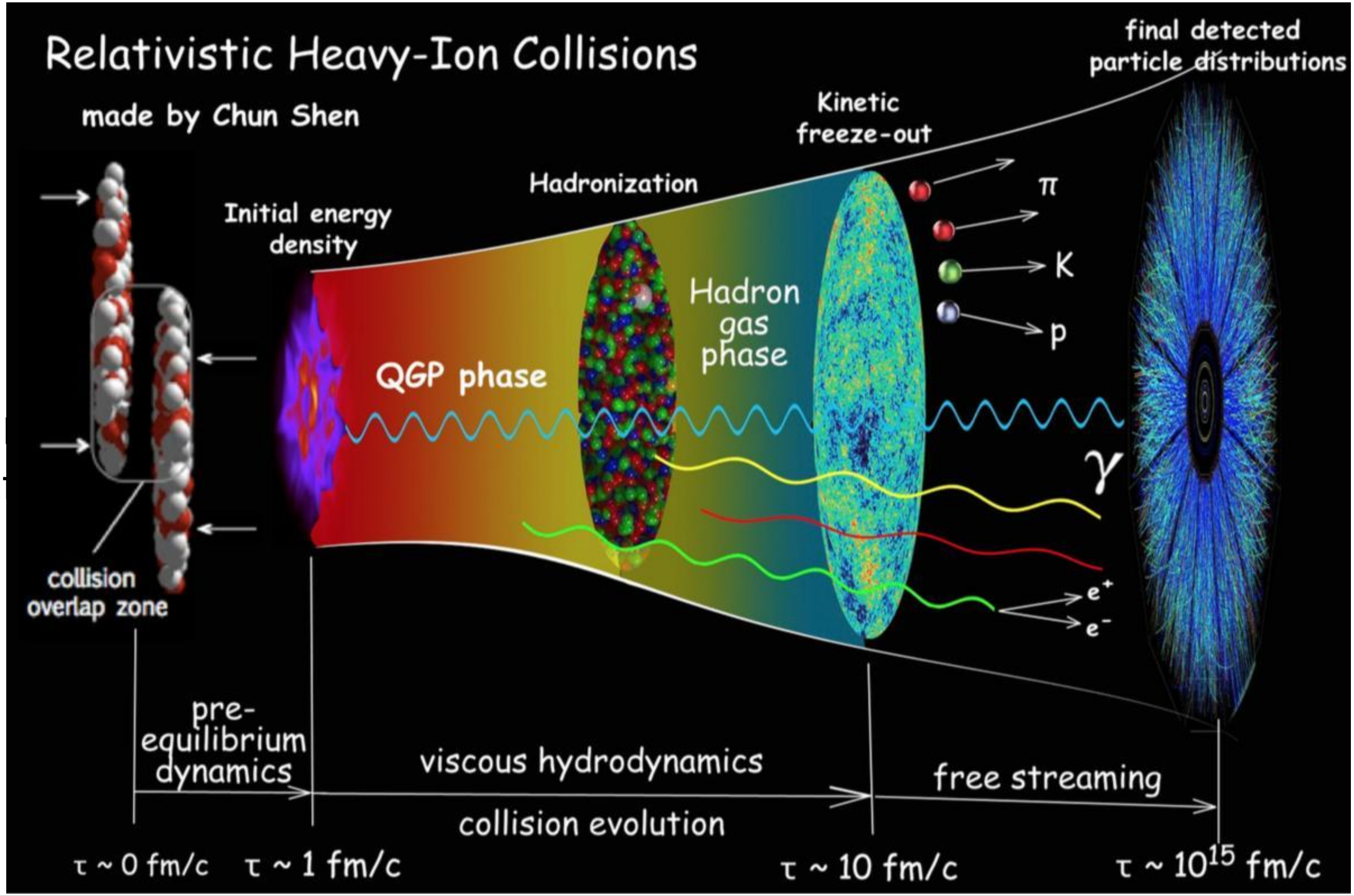
$$\Lambda_{QCD} \approx 0.2\ \mathrm{GeV}$$





- We are used to electrodynamics: coupling strength <u>increases</u> at small distances
- The quantum chromodynamics coupling constant works the opposite way: the coupling constant is <u>smallest</u> at high densities = "asymptotic freedom"

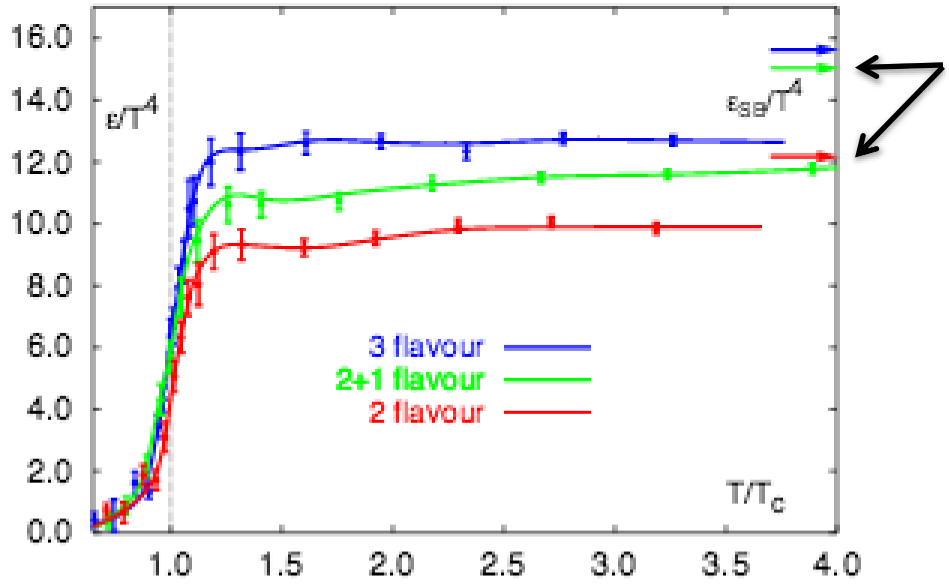
QGP Recreated in the Laboratory



Thermodynamics of the QGP

- Simple considerations of density of mass states and finite hadron size suggests phase transition in range $T_C \approx 150 - 200$ MeV
- Lattice QCD: sign of phase transition in sharp rise in energy density ε at $T_C \approx 175$, with $\varepsilon(T_C) \approx 0.5 - 1$ GeV/fm^3

Lattice QCD simulations of energy density



QGP differs from ideal bose gas limits due to thermal mass corrections

$$\epsilon = 3cT^4 + B$$

Elementary Particles, Baryons, and Mesons