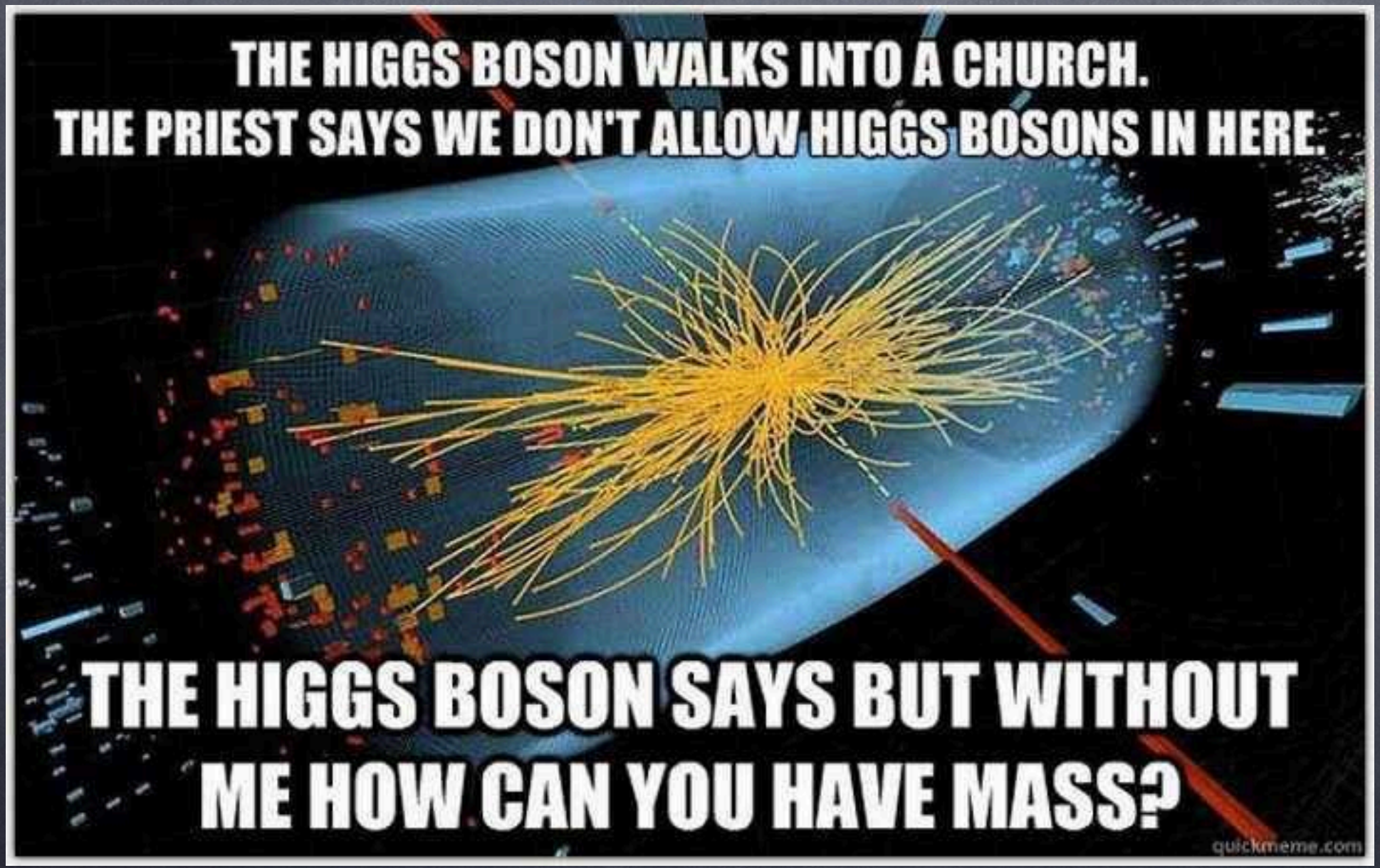
Hunting the Higgs

What is a Higgs boson?

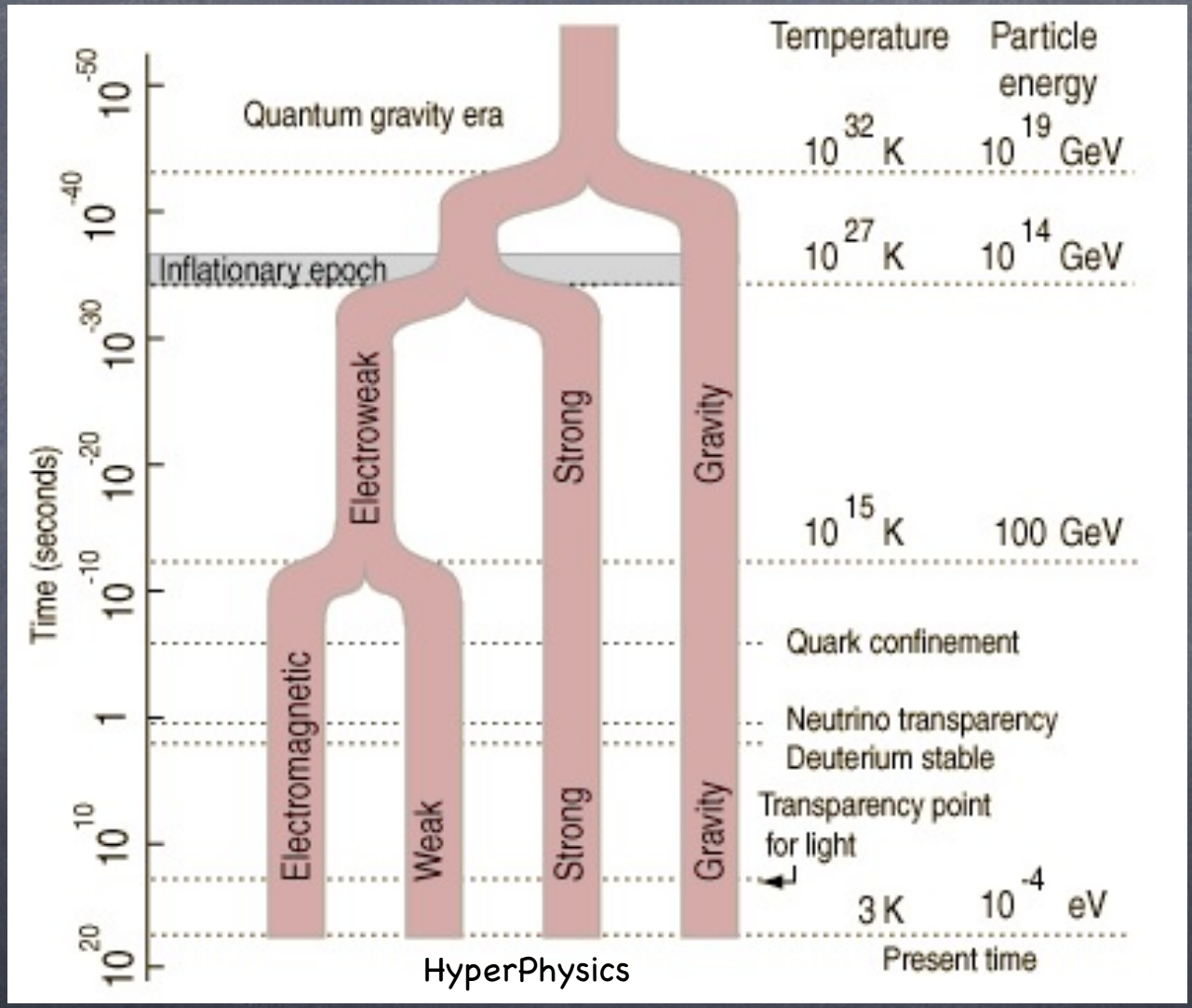


Examples of Symmetries

- Continuous: Translational, Temporal, Rotational.
  - Conservation of Momentum, Energy, and Angular Momentum.
- Discrete: C, P, and T.
- Internal: Gauge transformations
  - Conservation of electric charge, lepton number, baryon number, isospin, hypercharge, ...

We can learn things from broken symmetries, too.

Symmetry Breaking



in the Standard Model interactions

The Standard Model

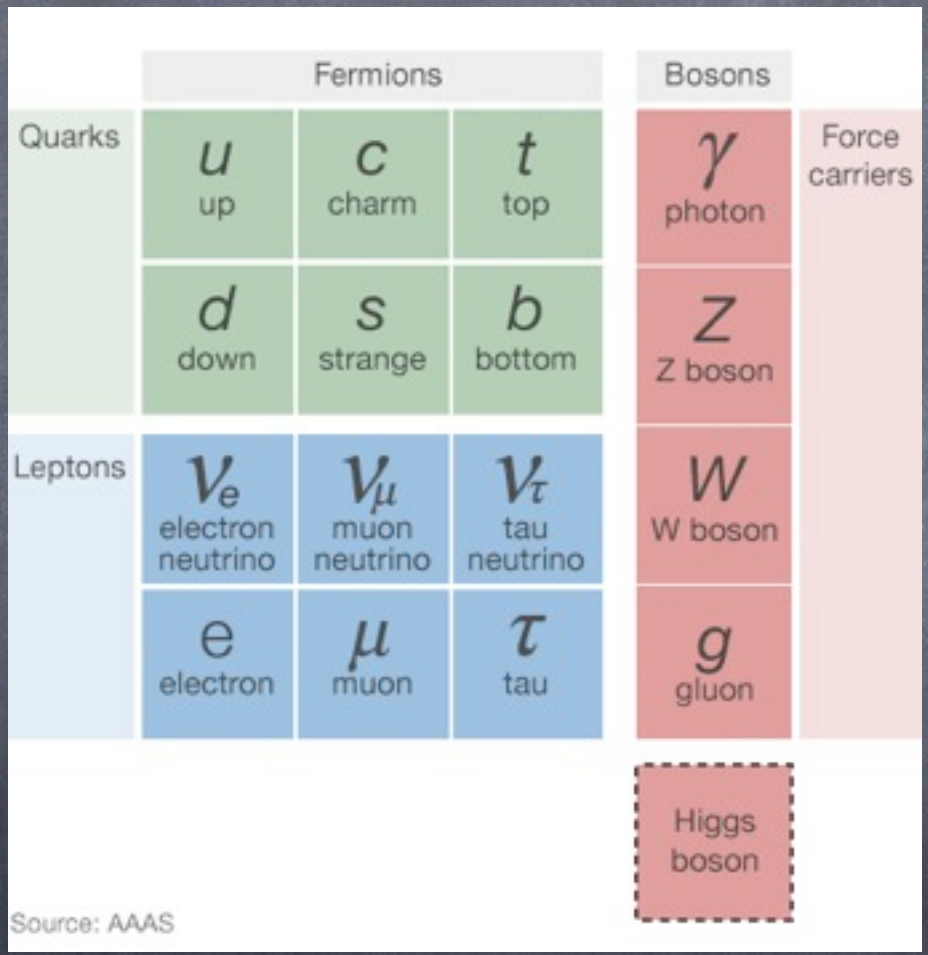
players

$q = 2e/3$

$q = -e/3$

$q = 0$

$q = -e$



$m_\gamma c^2 = 0$

$m_Z c^2 = 92$ GeV

$m_W c^2 = 80$ GeV

$m_g c^2 = 0$

Remarkably successful, but 20 free parameters

The Higgs Mechanism

qualitatively, in four bullets

- In quantum theory, the vacuum contains a sea of virtual particle-antiparticle pairs produced out of nothing, constrained by the Heisenberg Uncertainty Principle.
- The vacuum is filled with a condensate of Higgs particles.
- Quarks, leptons, Ws and Zs interact with the condensate as they travel, and get slowed down. The stronger the interactions, the heavier the particles become.
- The coupling to the Higgs boson is proportional to mass.

SM Higgs properties

Zero electrical charge

decay products must have zero net charge

Lifetime 1.56×10^{-22} s

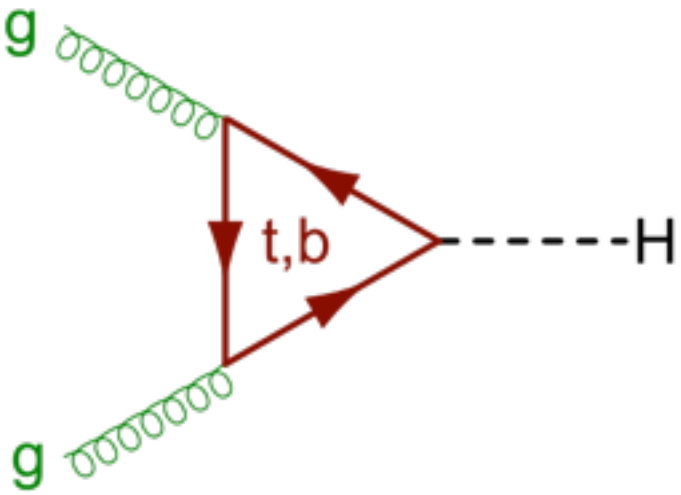
natural line width of 0.004 GeV

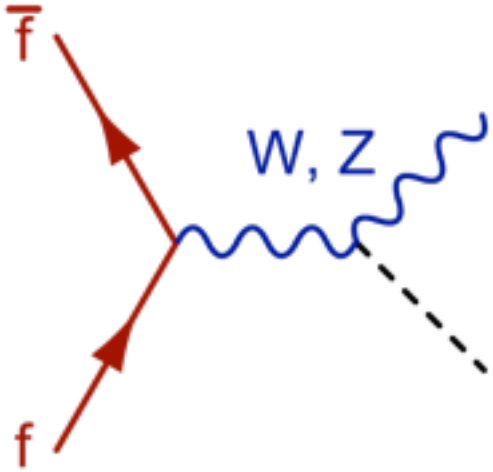
Boson with spin 0

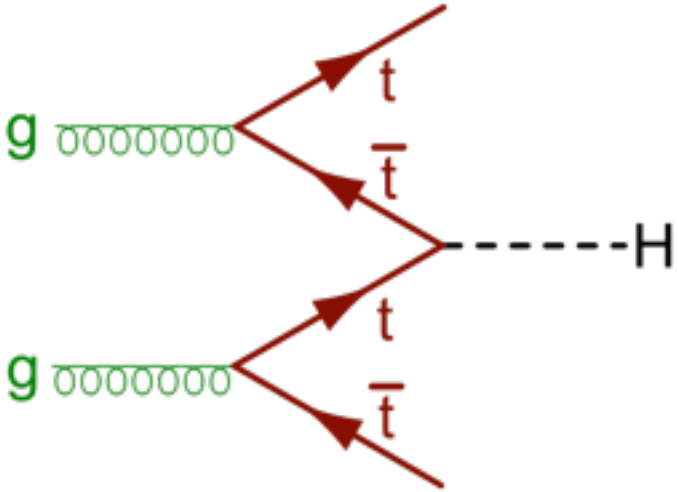
cannot decay into an odd number of fermions

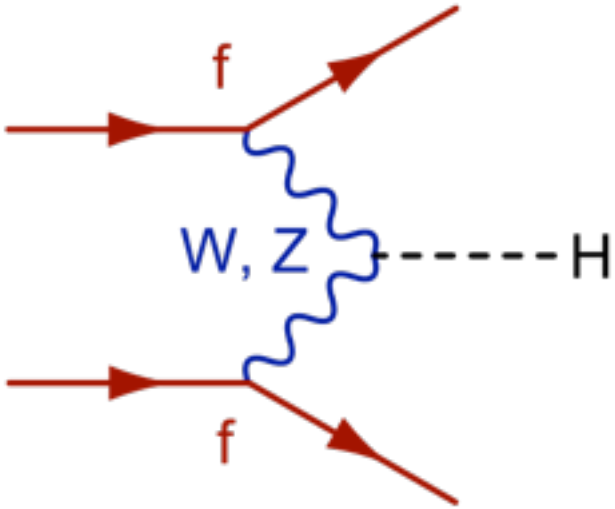
The theory does not predict the mass of the H^0, but it does predict its production rate and decay modes for each possible mass.

Higgs Production Channels



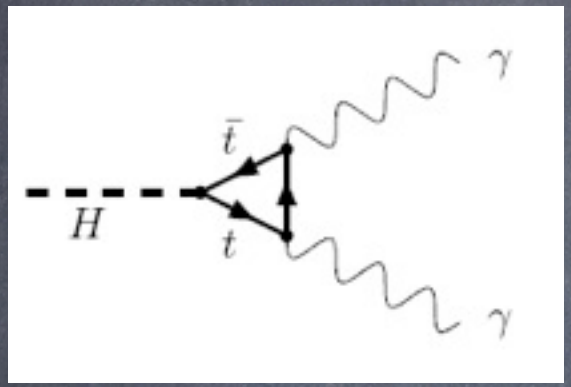


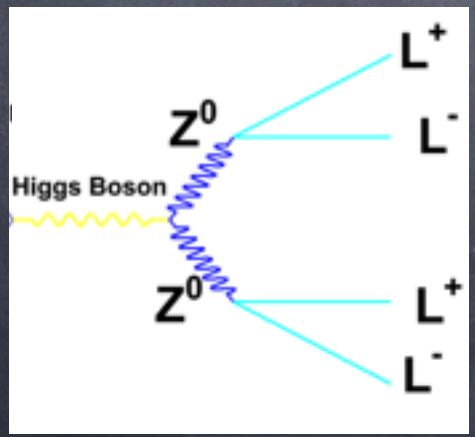


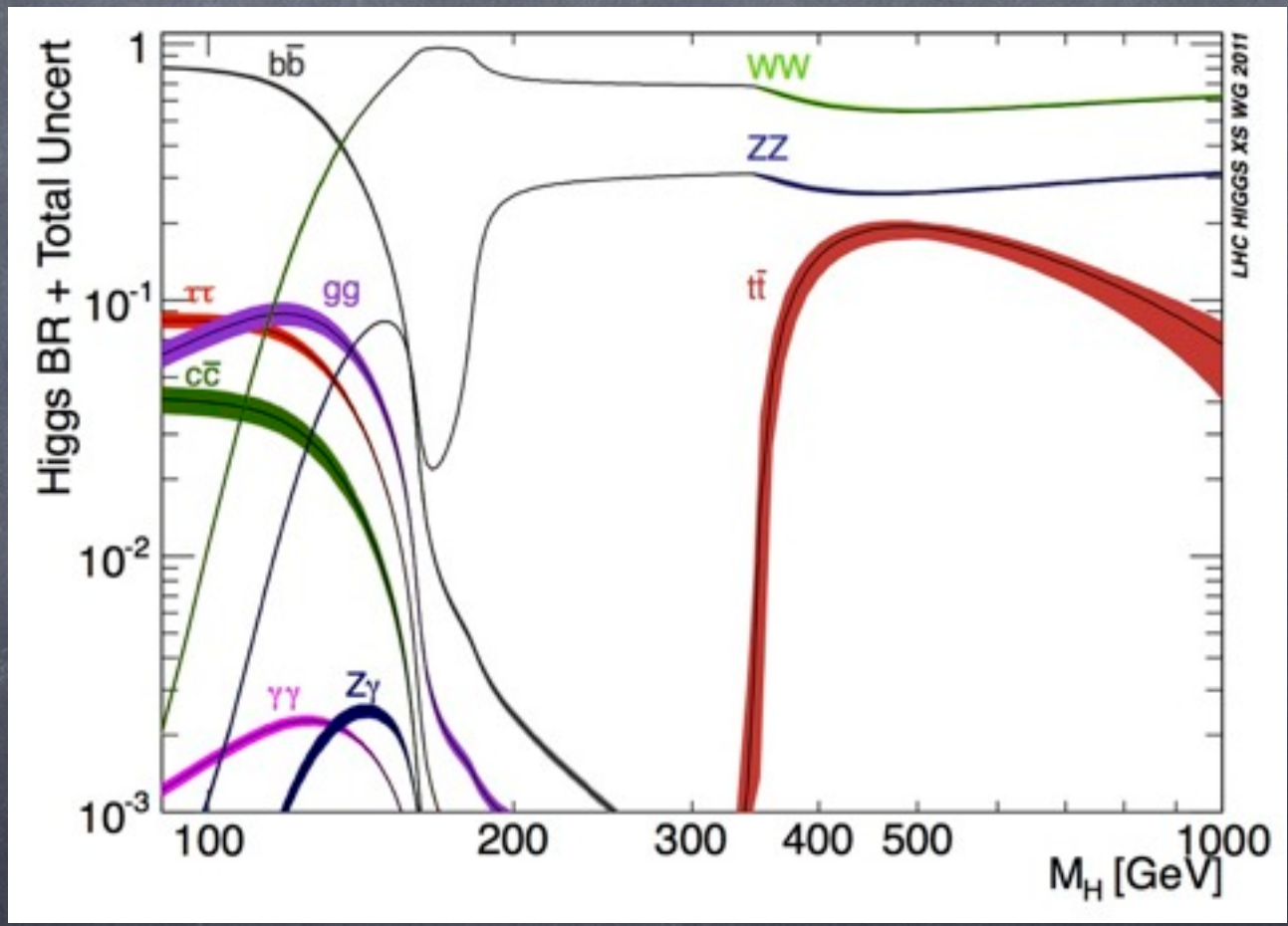


Wikipedia

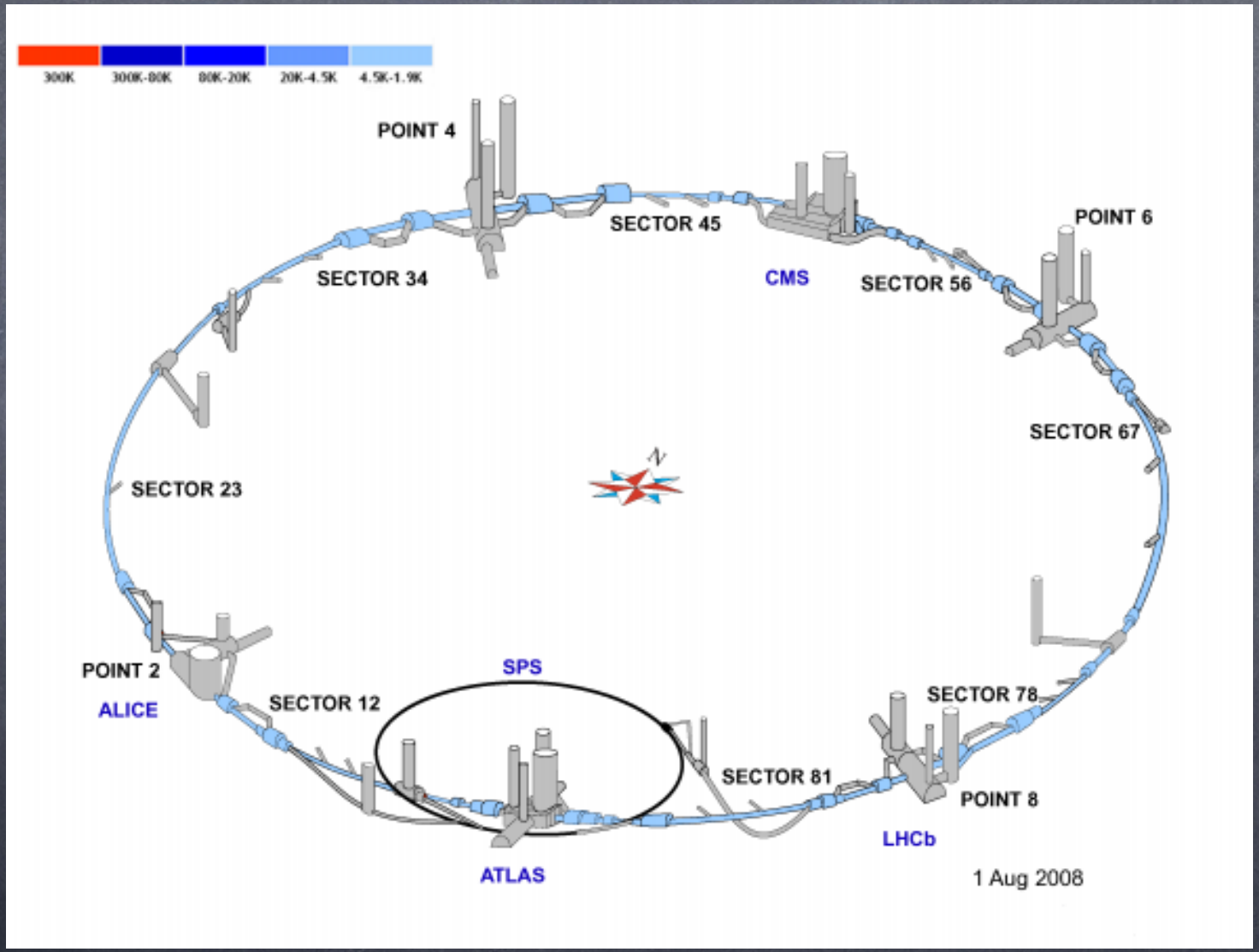
Higgs Decay Channels







The Large Hadron Collider



LHC Numbers

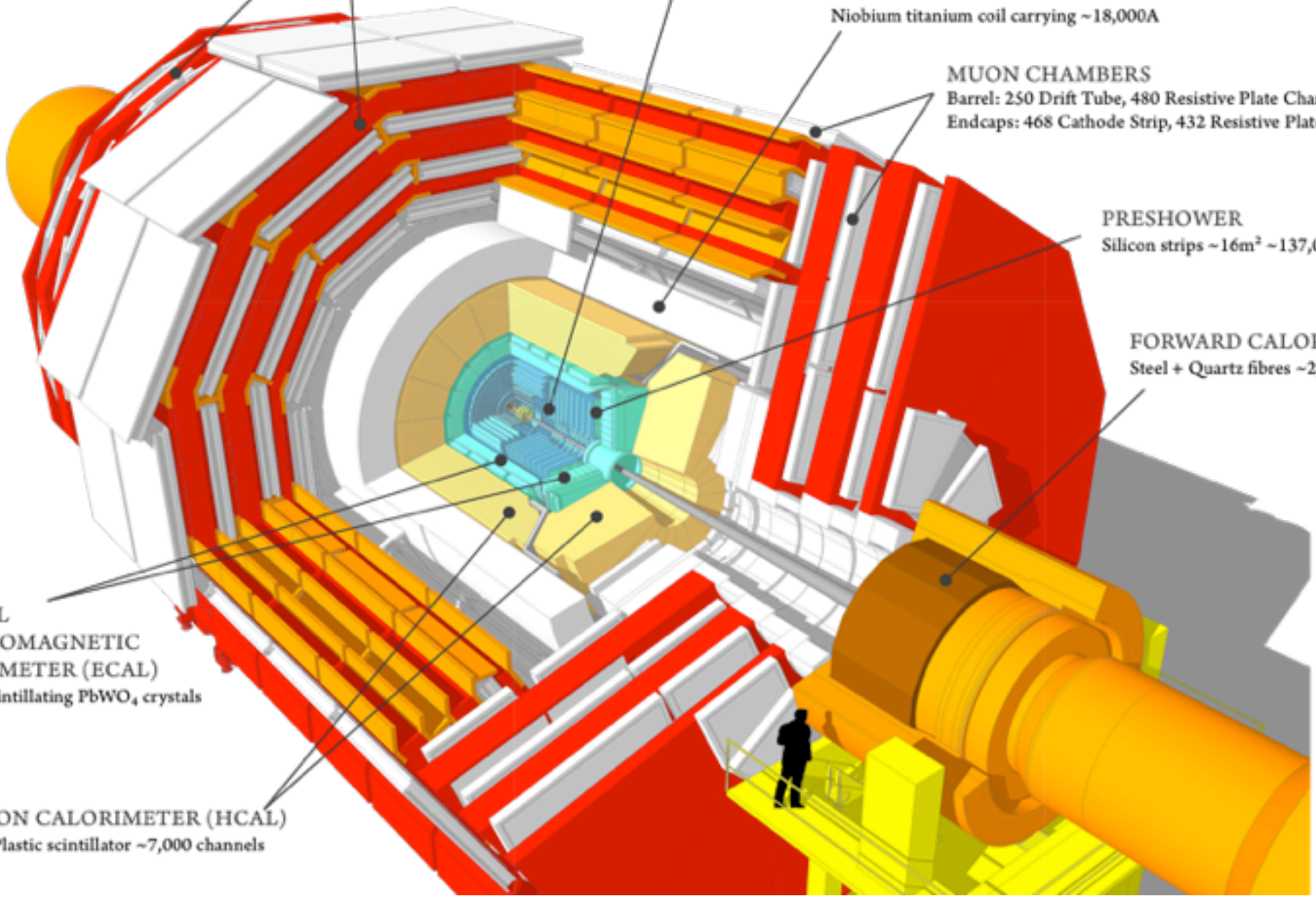
- 100 m underground, 27 km in circumference.
- Opposing proton beams: 10^{34} cm^{-2} s^{-1} at 4 TeV/p and an rms beam spot size of 17 μm.
- 2800 bunches per beam: each with 10^{11} protons, 11 cm long, and 10 m between them.
- Circulating beam current 0.6 A and total energy 200 MJ.
- Higgs experiments: 2
  - ATLAS: A Toroidal LHC ApparatuS
  - CMS: Compact Muon Solenoid

CMS Numbers

- > 2500 scientists, including 600 students
- 14,000 tons, 15 m in diameter and 21.5 m long
- 10^9 Hz p+p collisions: 100 Hz triggered as "interesting", and 1 Higgs expected per 10^{13} collisions.
- 50,000 data channels provide 10^{12} bit/s.
- Main Physics goals: 4
  - Higgs, TeV physics, beyond SM, and heavy-ion physics

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T



STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

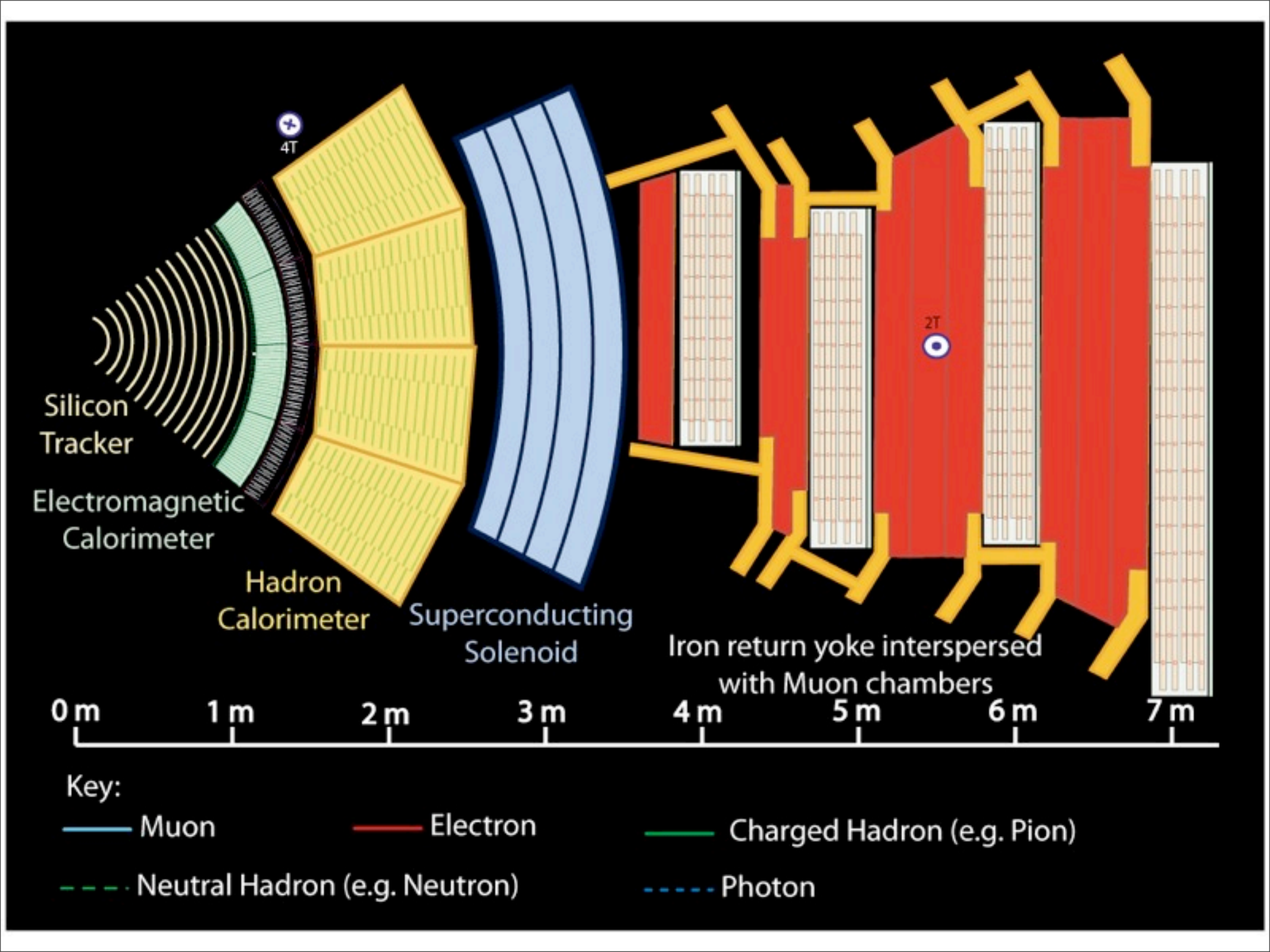
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

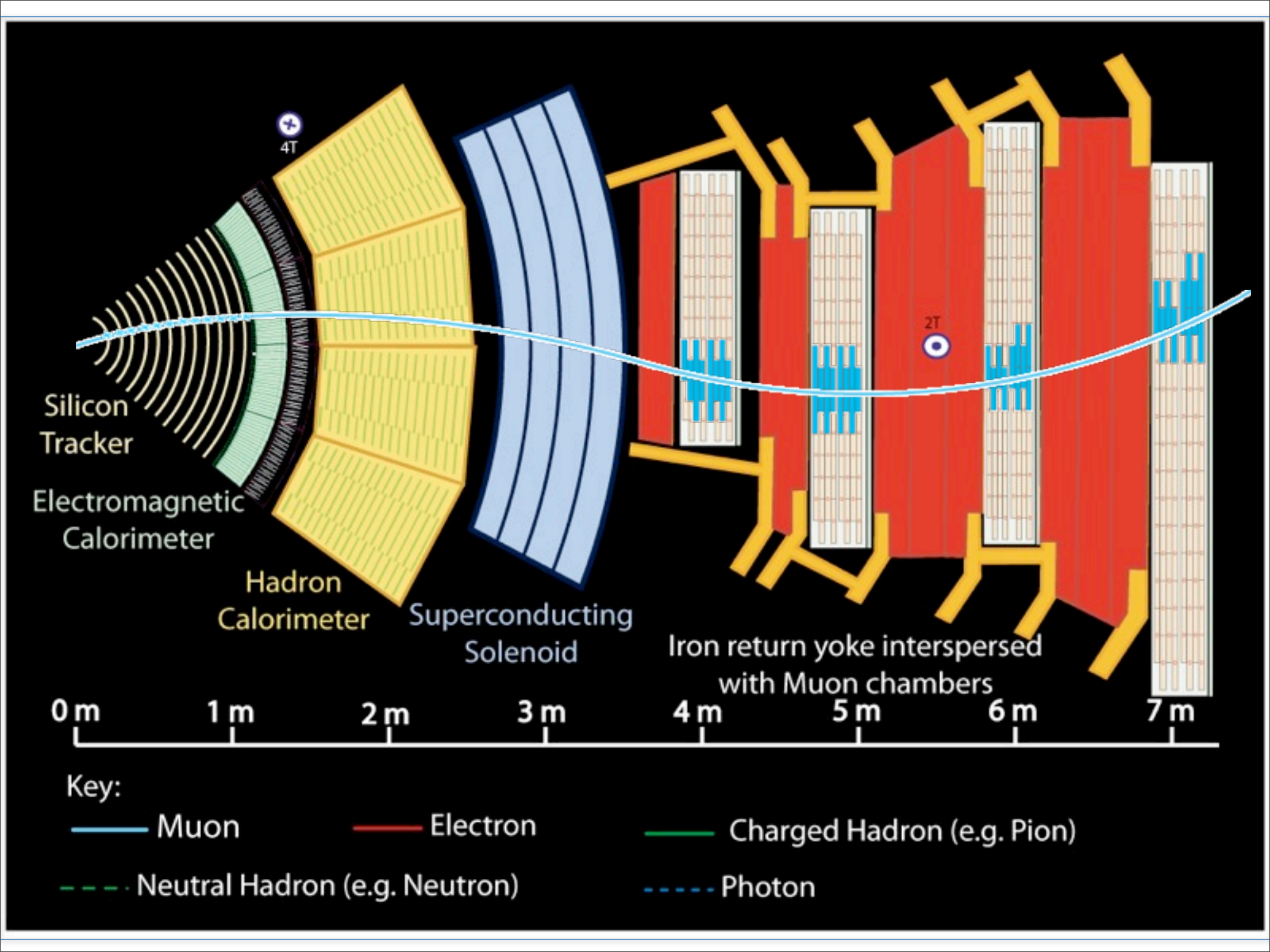
PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels


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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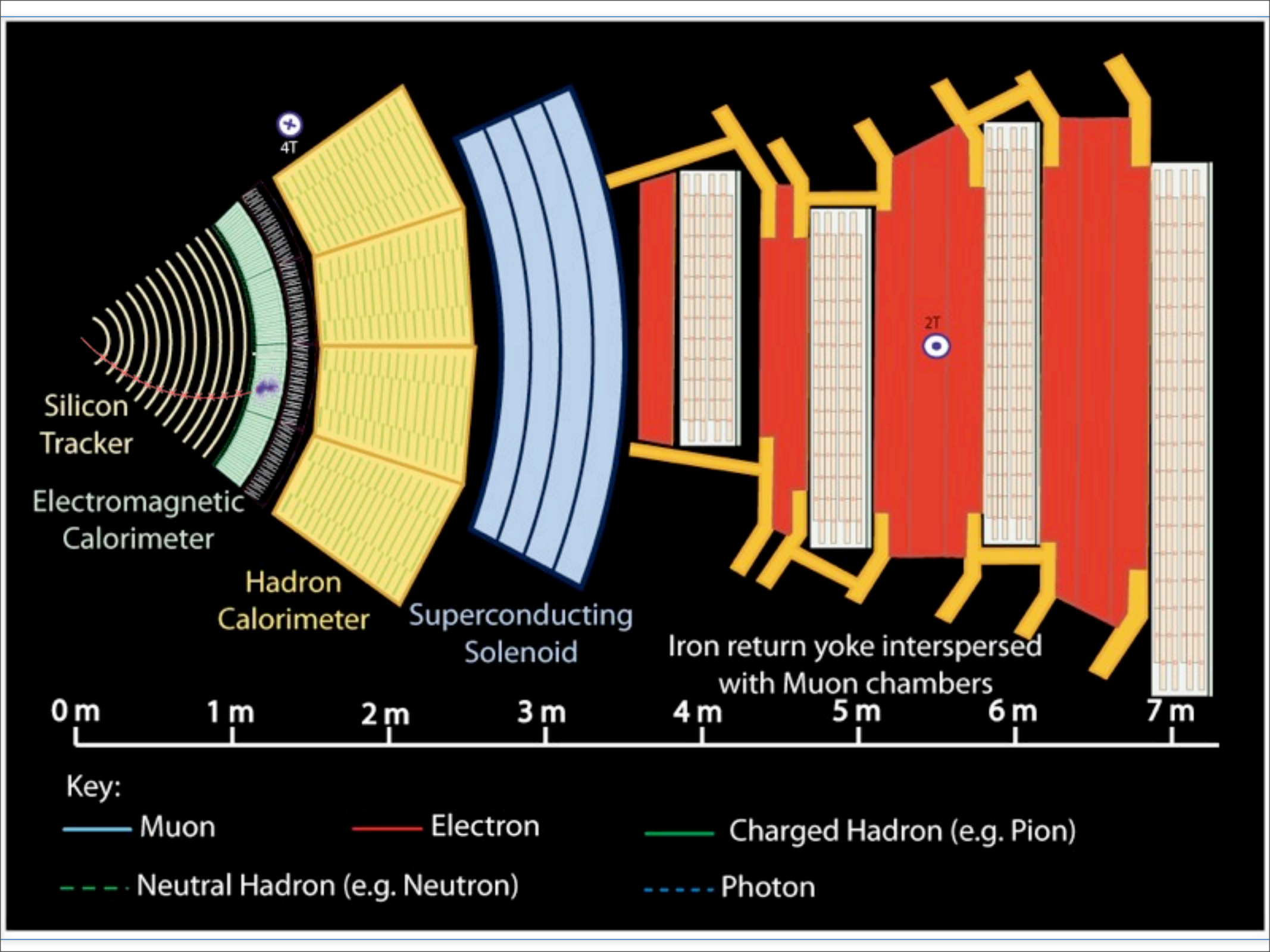
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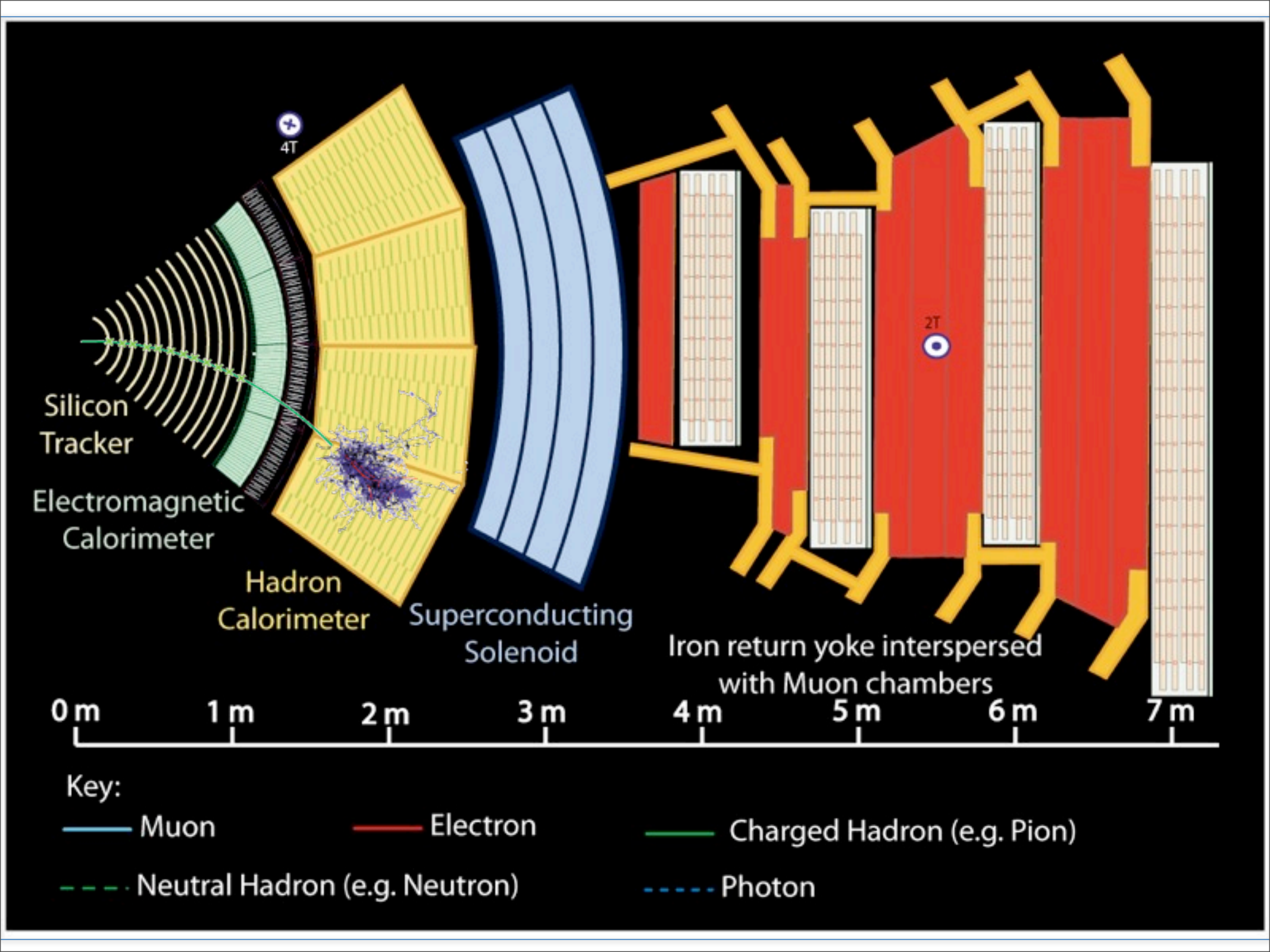
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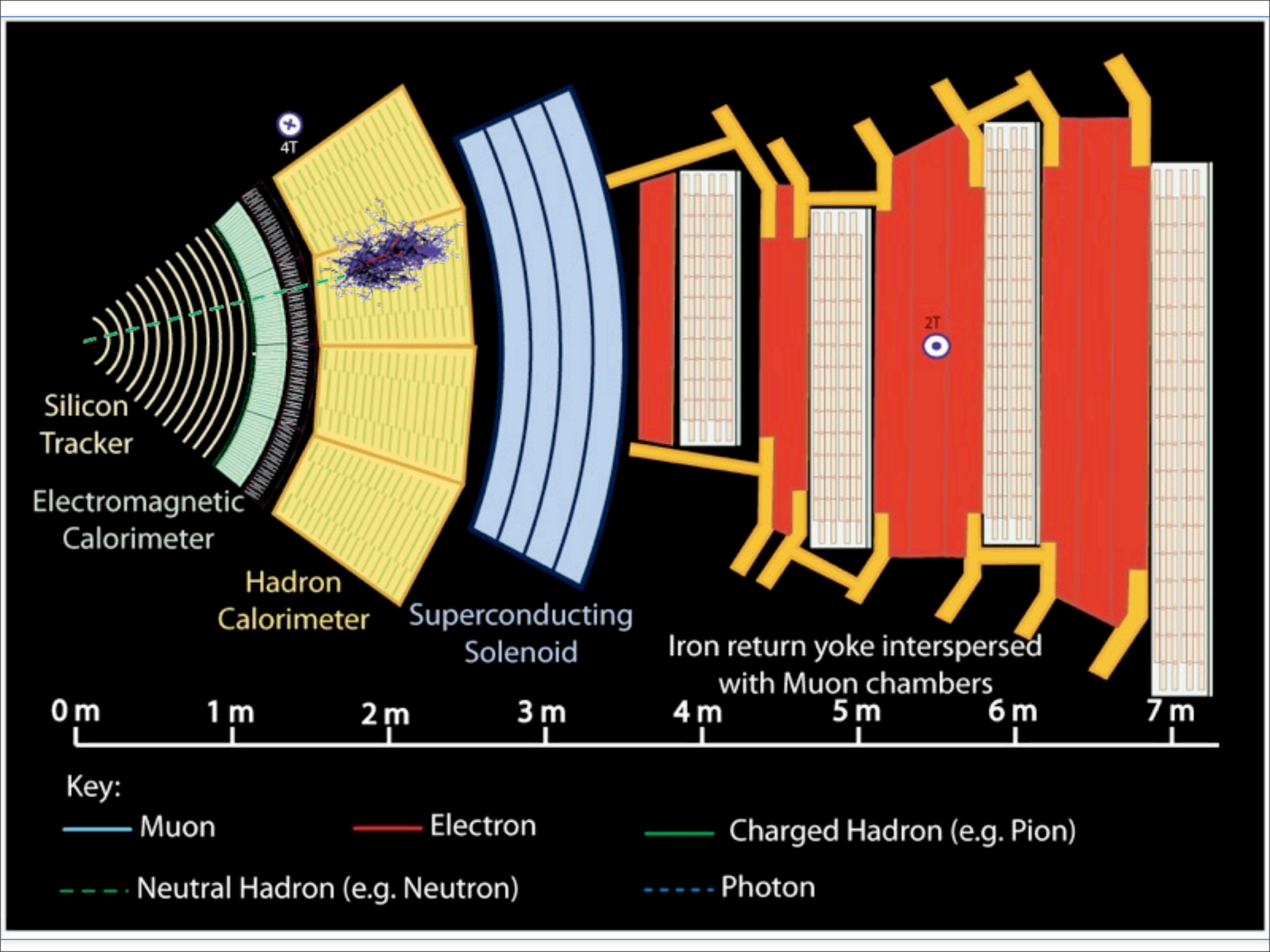
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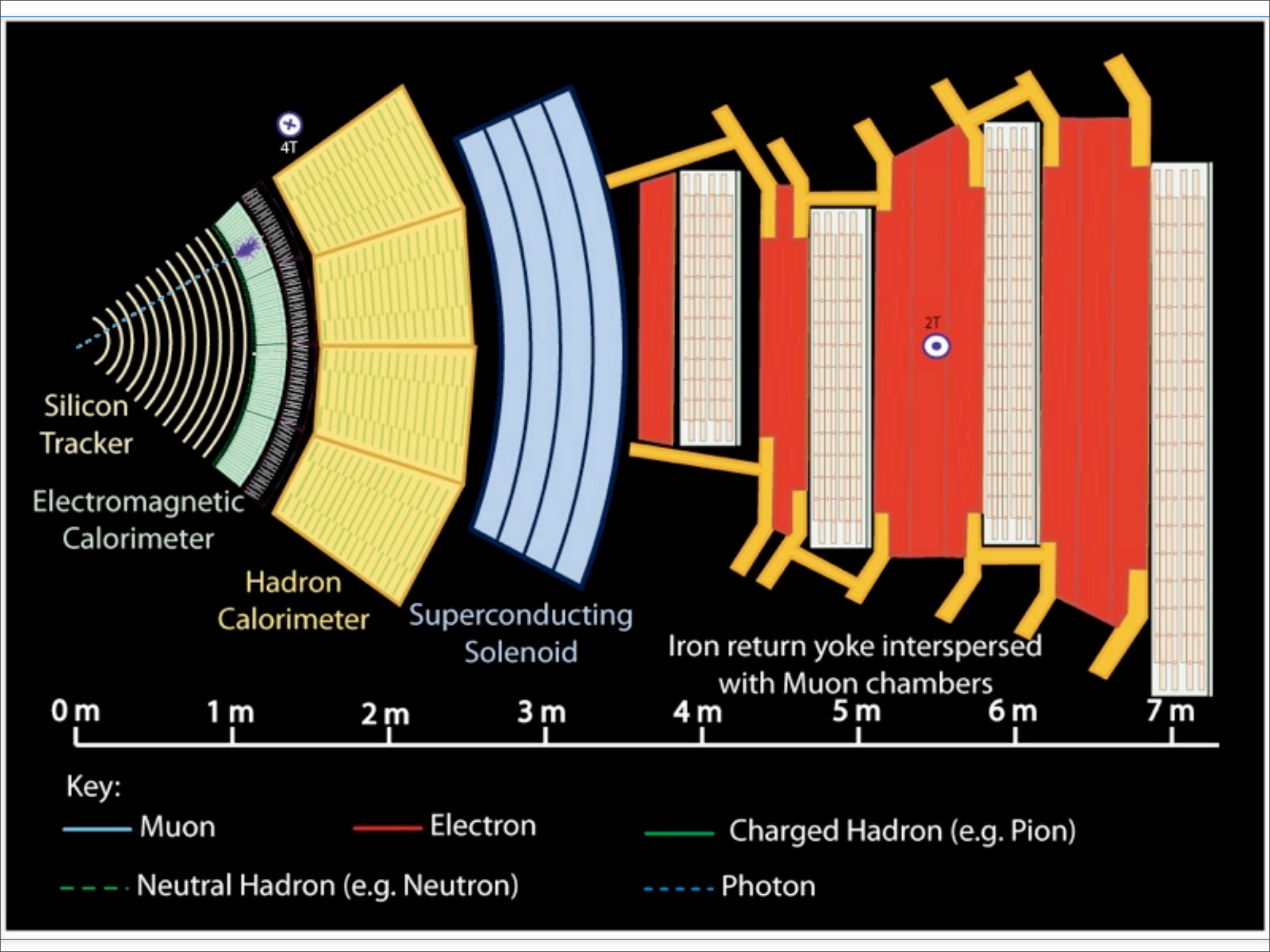
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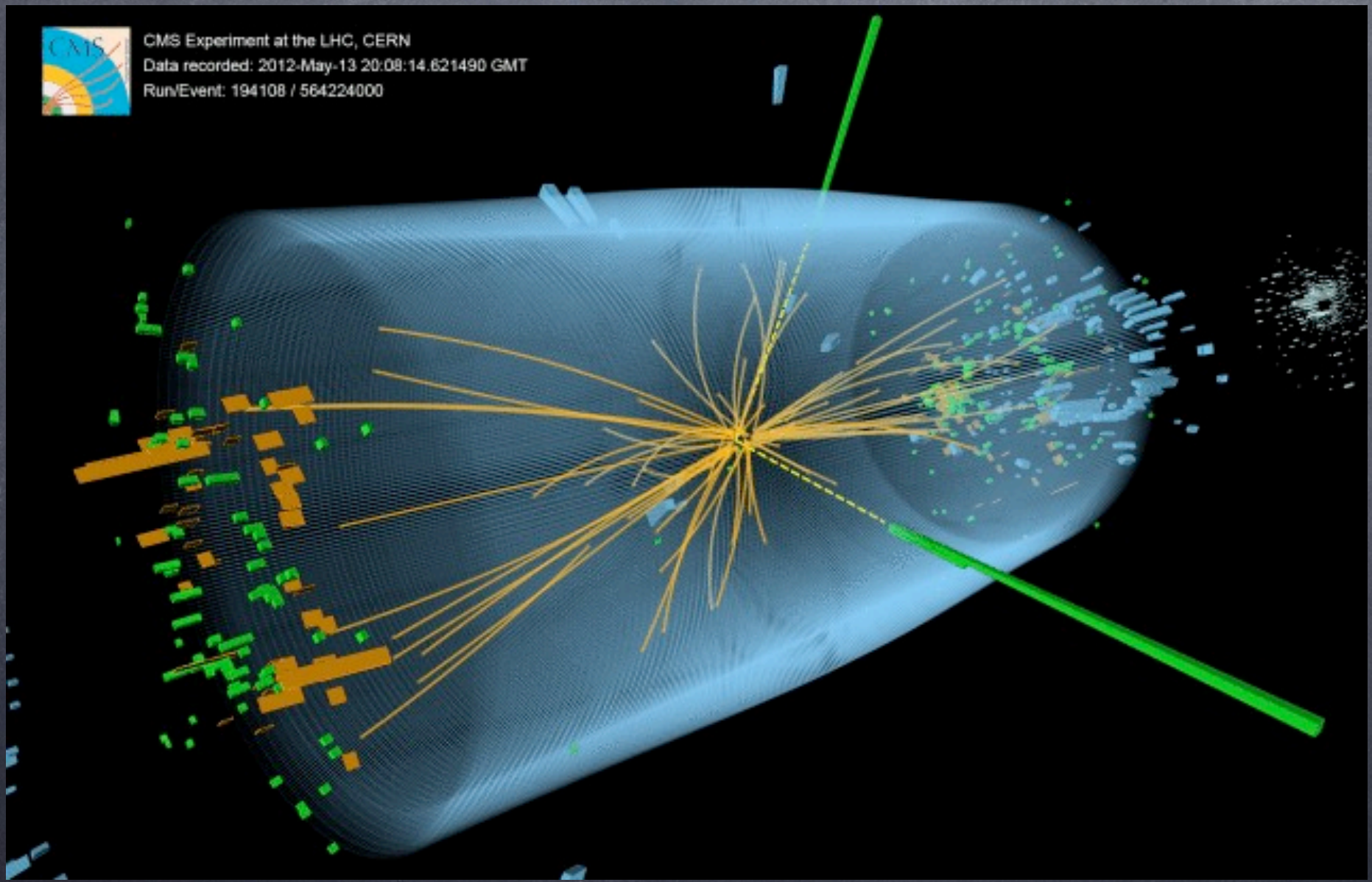
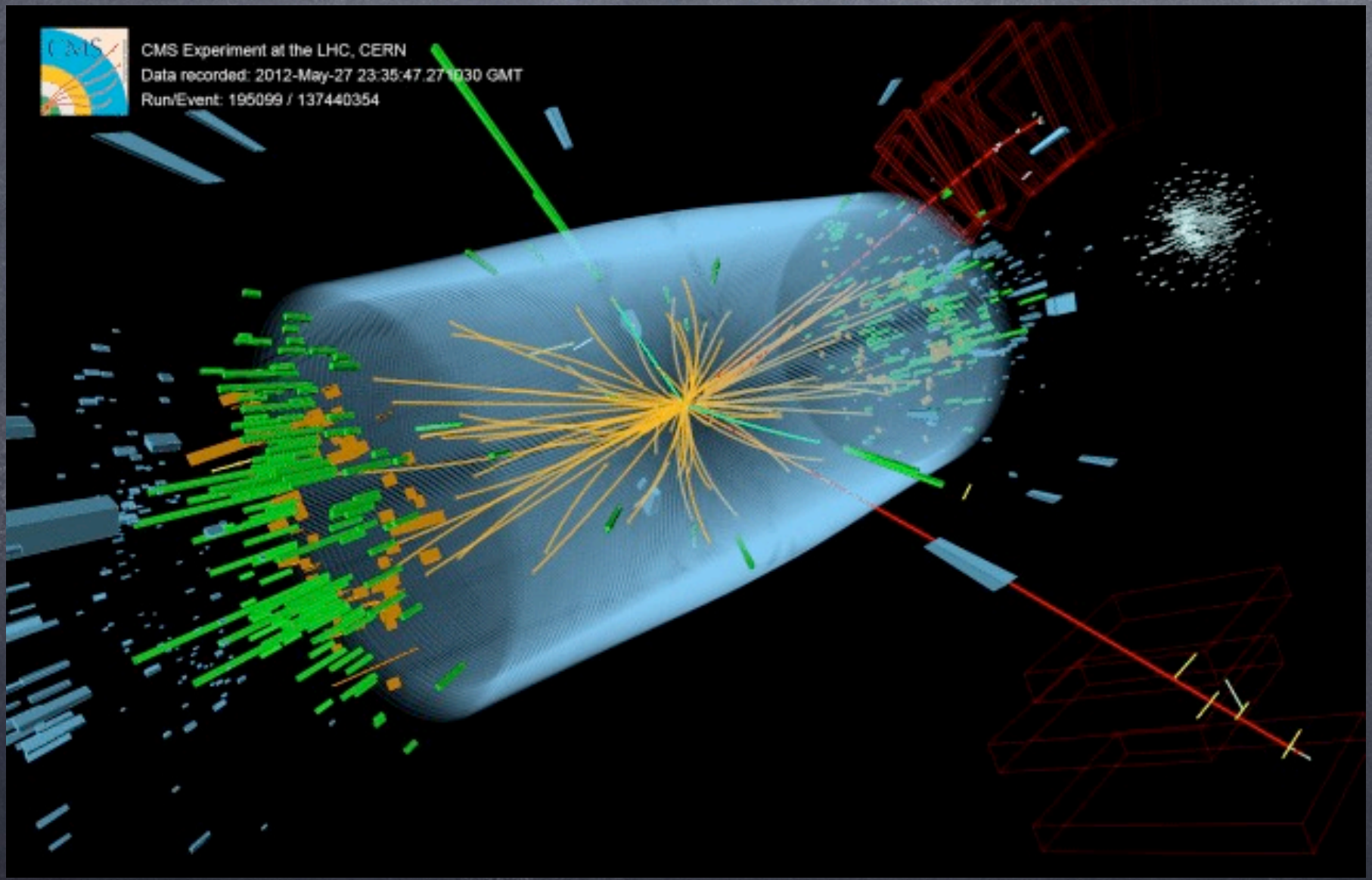
$H \rightarrow \gamma + \gamma$?

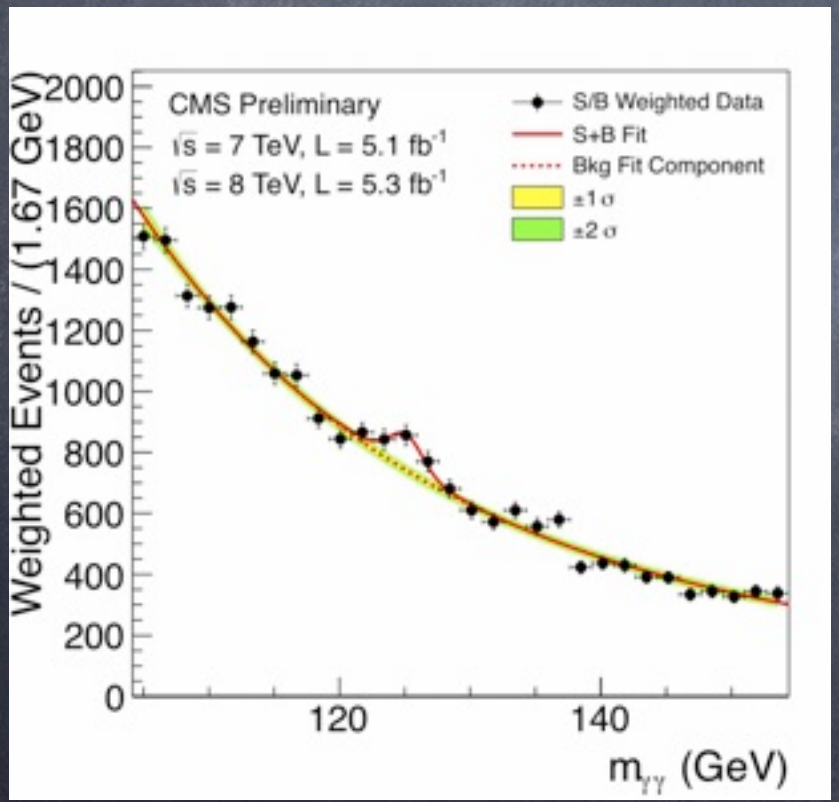


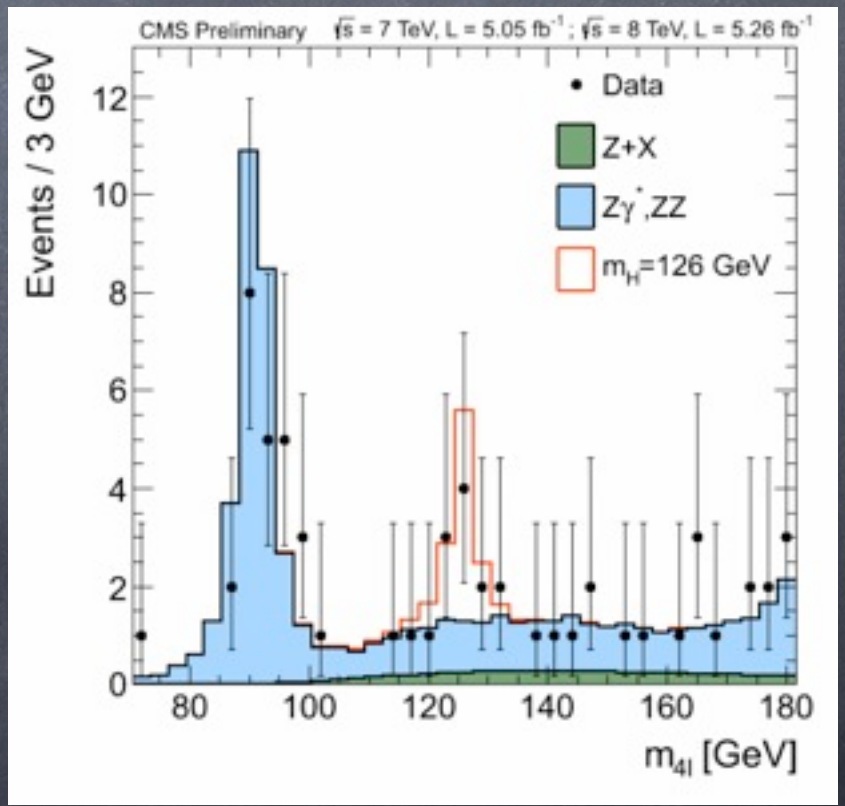
$$H \rightarrow Z^{o} + Z^{o} \rightarrow e^{+} + e^{-} + \mu^{+} + \mu^{-}$$



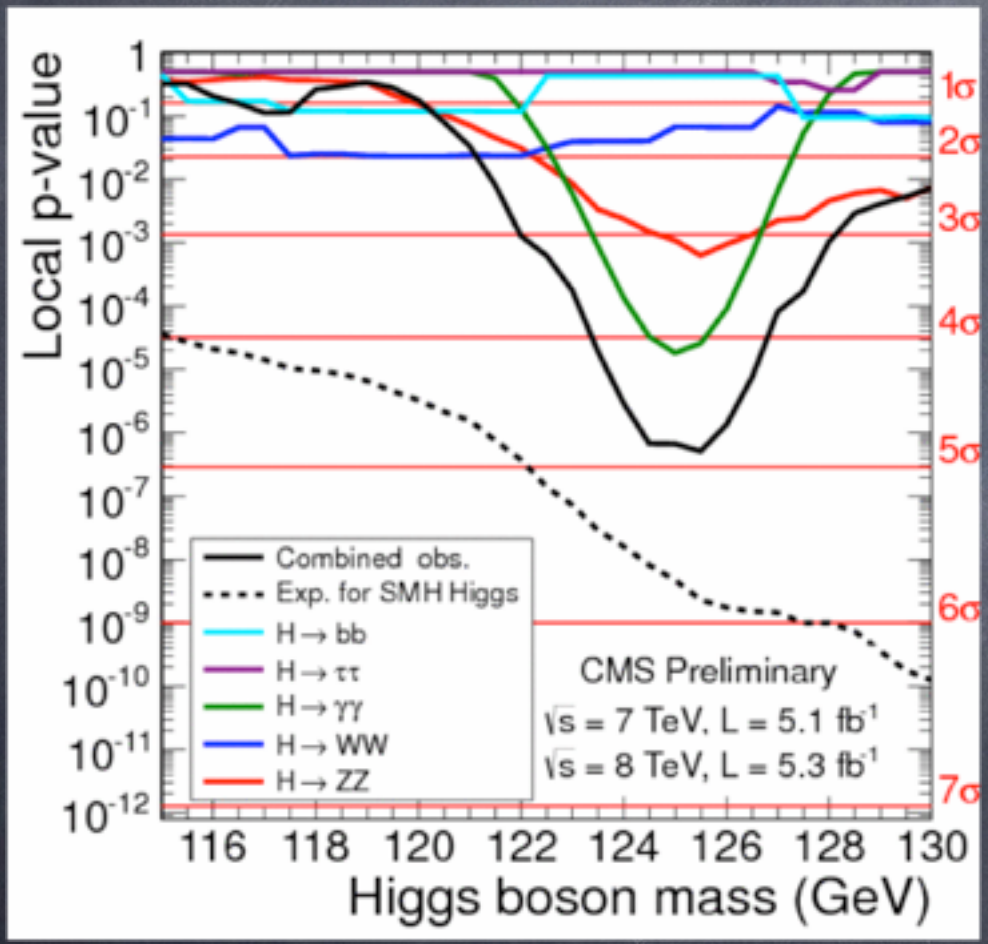
Invariant Mass Reconstructions

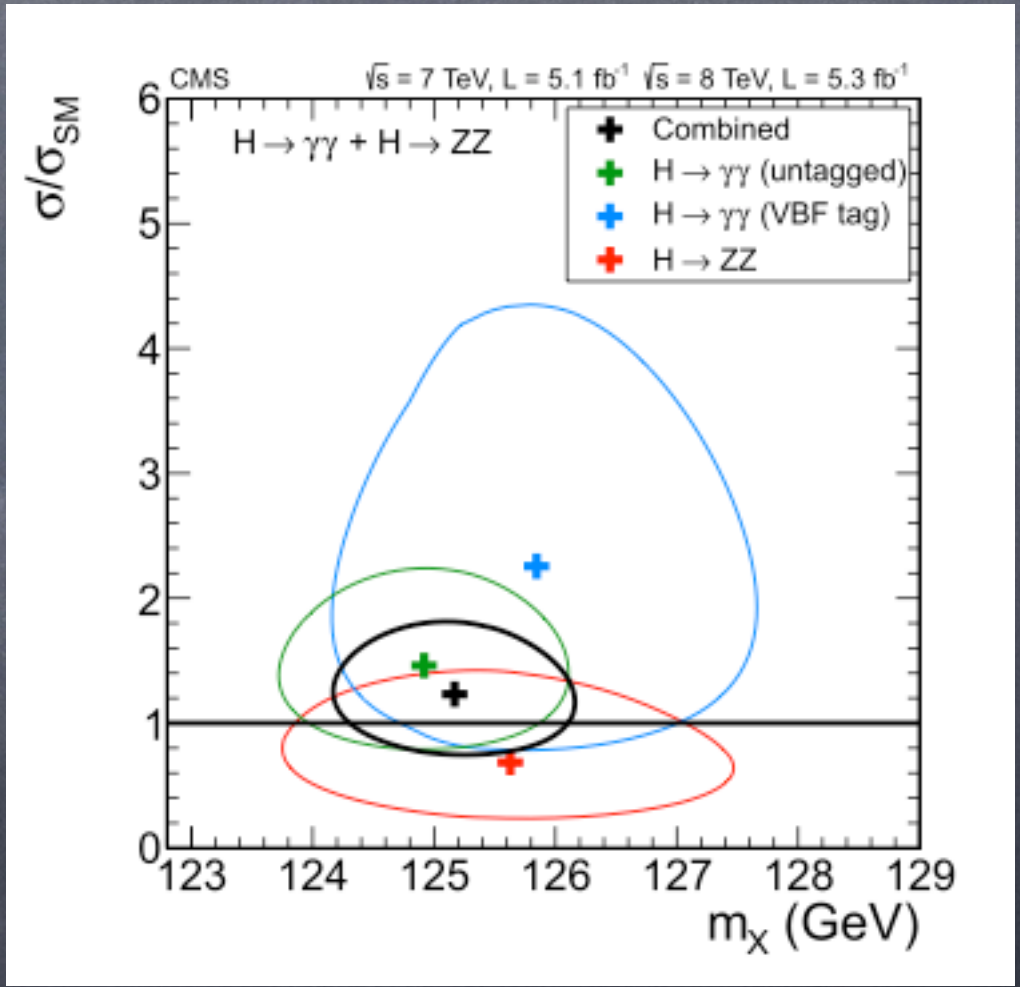
$$mc^2 = \sqrt{E_{\mathrm{tot}}^2 - p_{\mathrm{tot}}^2 c^2}$$





Confidence Levels





What next?

More data!

Summary

- The Higgs boson is one important manifestation of the mechanism by which elementary particles acquire mass. Not finding it would throw the entire SM into disarray.
- Its large mass requires powerful accelerators to make it, and enormous detectors to find it.
- A large mass particle has been identified with the right qualitative behavior. Is it the Higgs?

All images and data are publicly available thanks to the LHC and CMS.