

# The CMS Detector



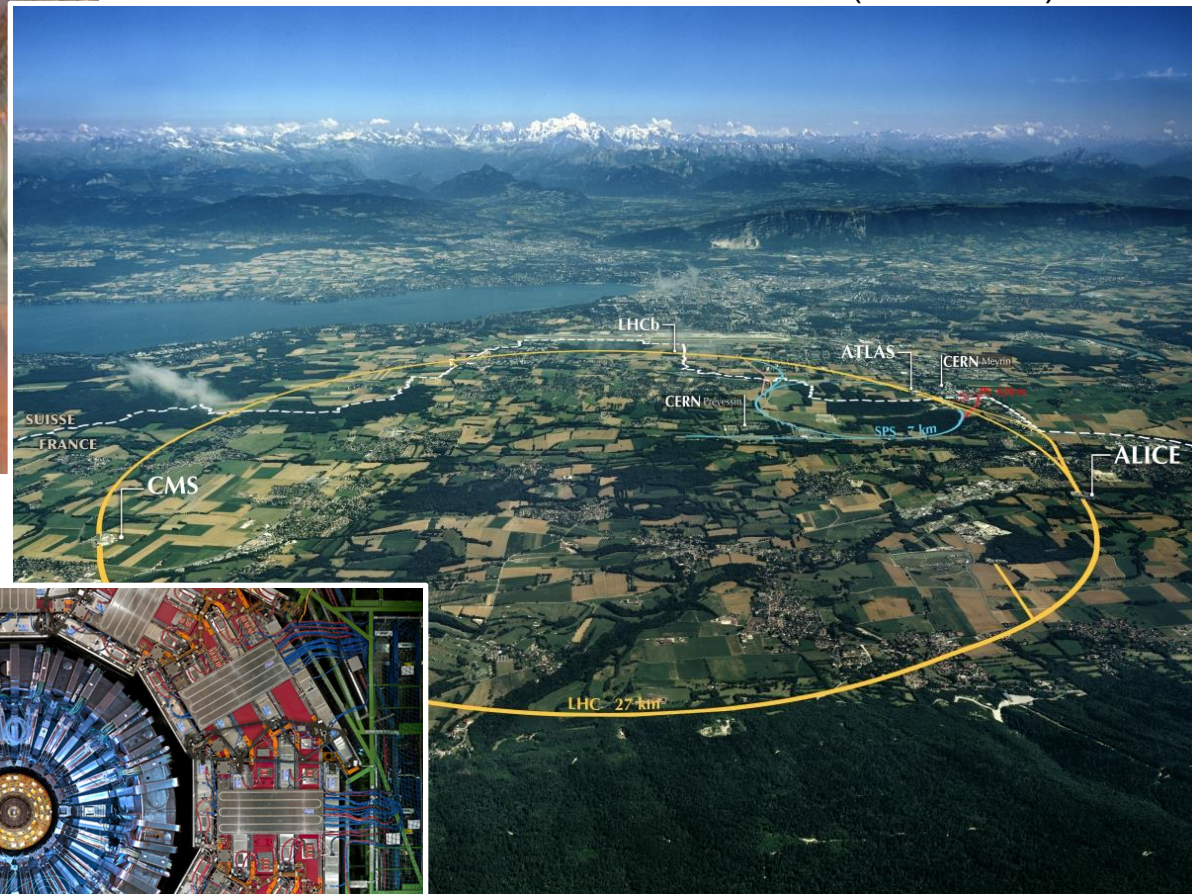
Hallie Trauger  
Teaching Assistant Professor  
NC A&T State University

# 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

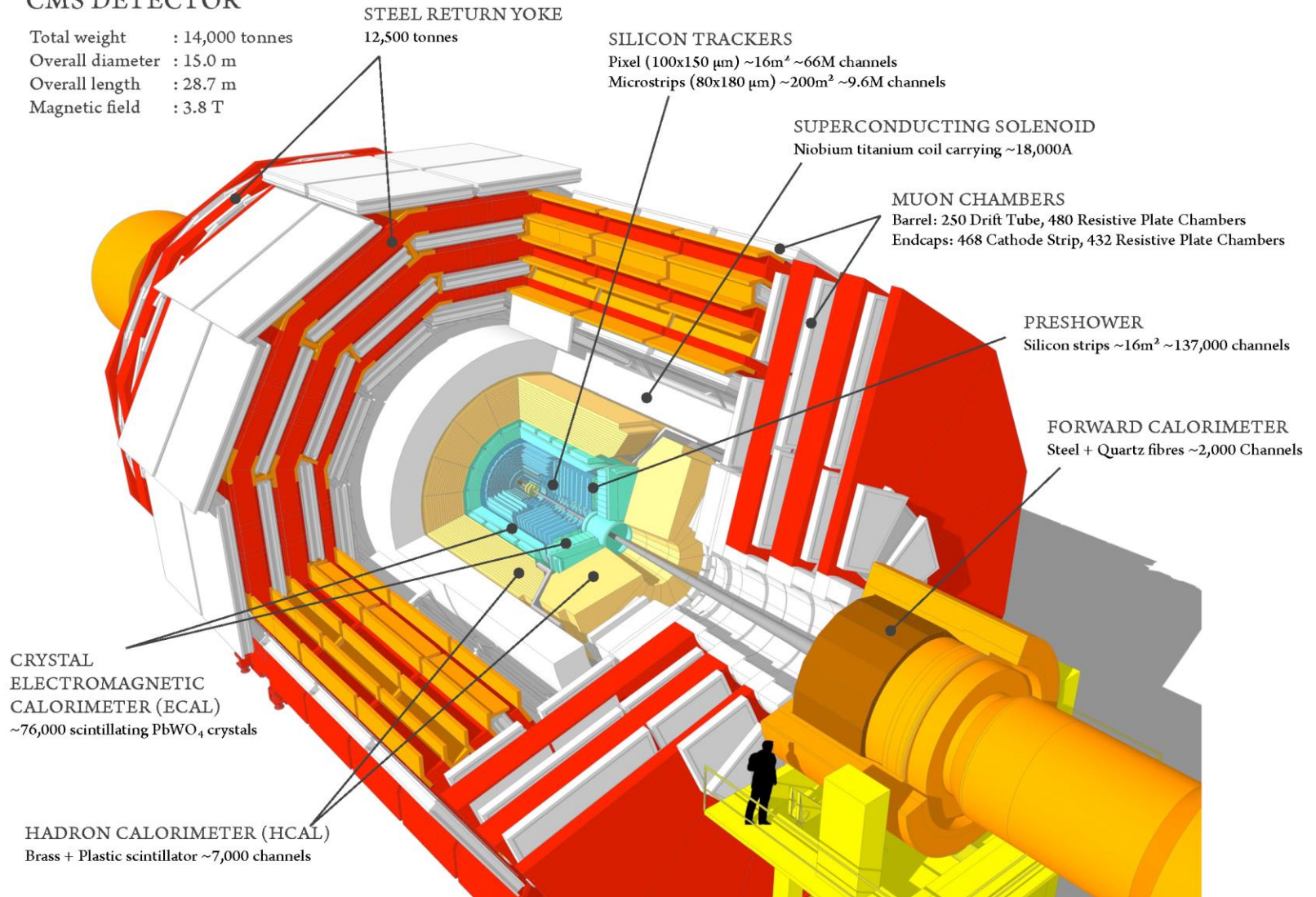
- **Compact** – Diameter is about 15 m (nearly 50 feet) across).
- **Muon** – Highly efficient muon tracking system outside the magnet.
- **Solenoid** – 4T superconducting magnet. Provides the magnetic field for tracking!

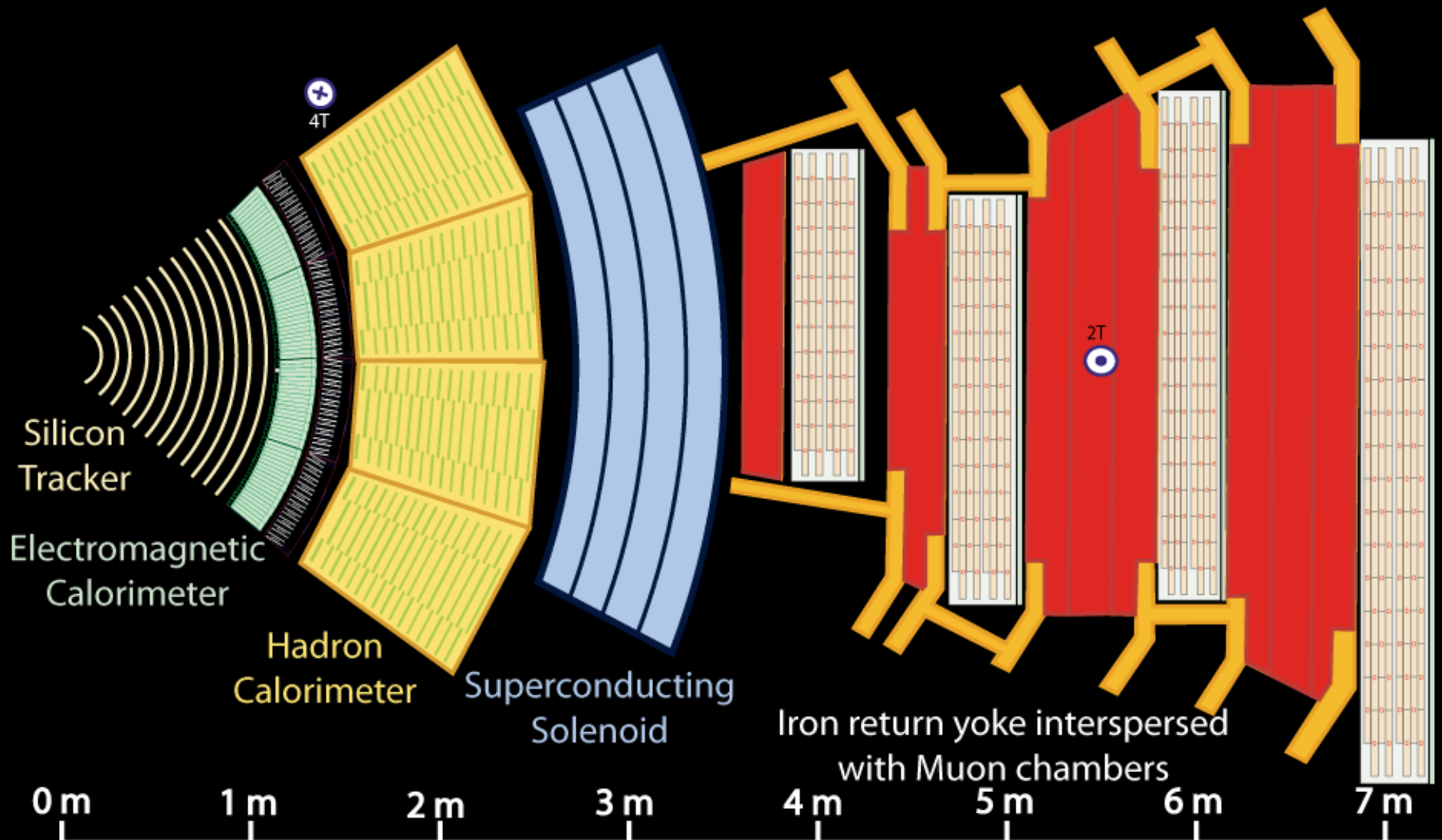


# Compact Muon Solenoid Detector

## CMS DETECTOR

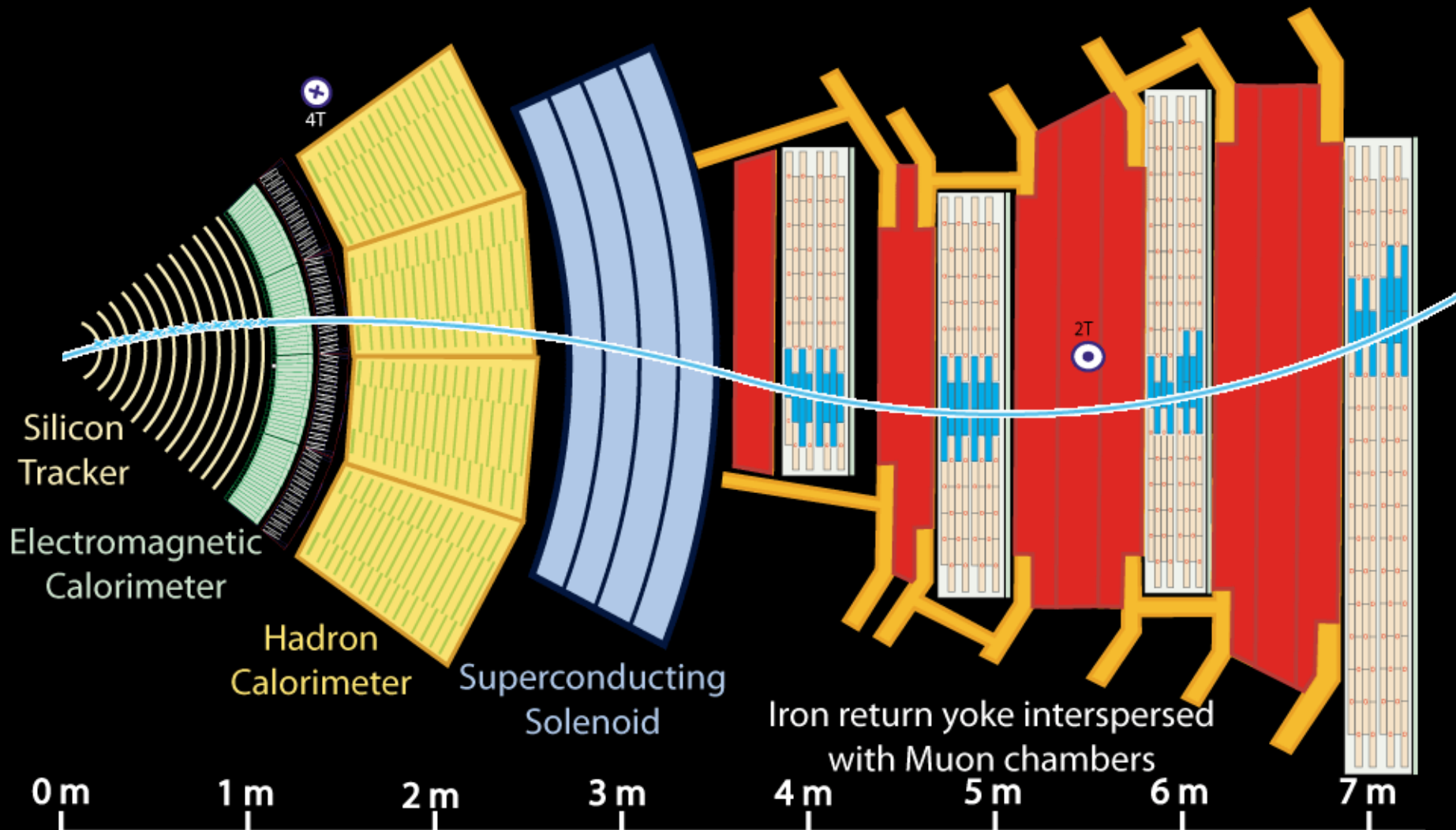
Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T





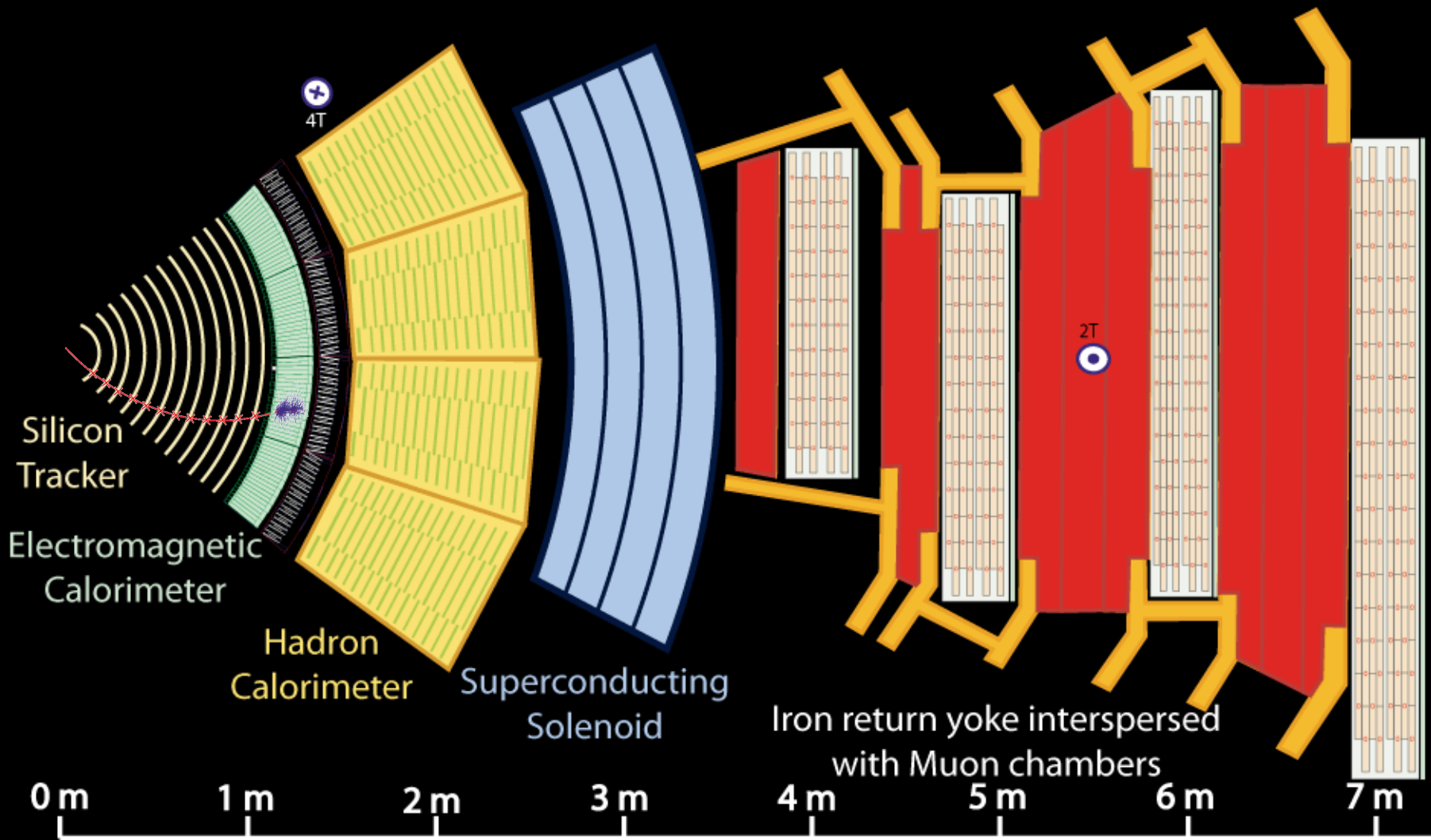
Key:

- Muon
- Electron
- Charged Hadron (e.g. Pion)
- - - Neutral Hadron (e.g. Neutron)
- - - Photon



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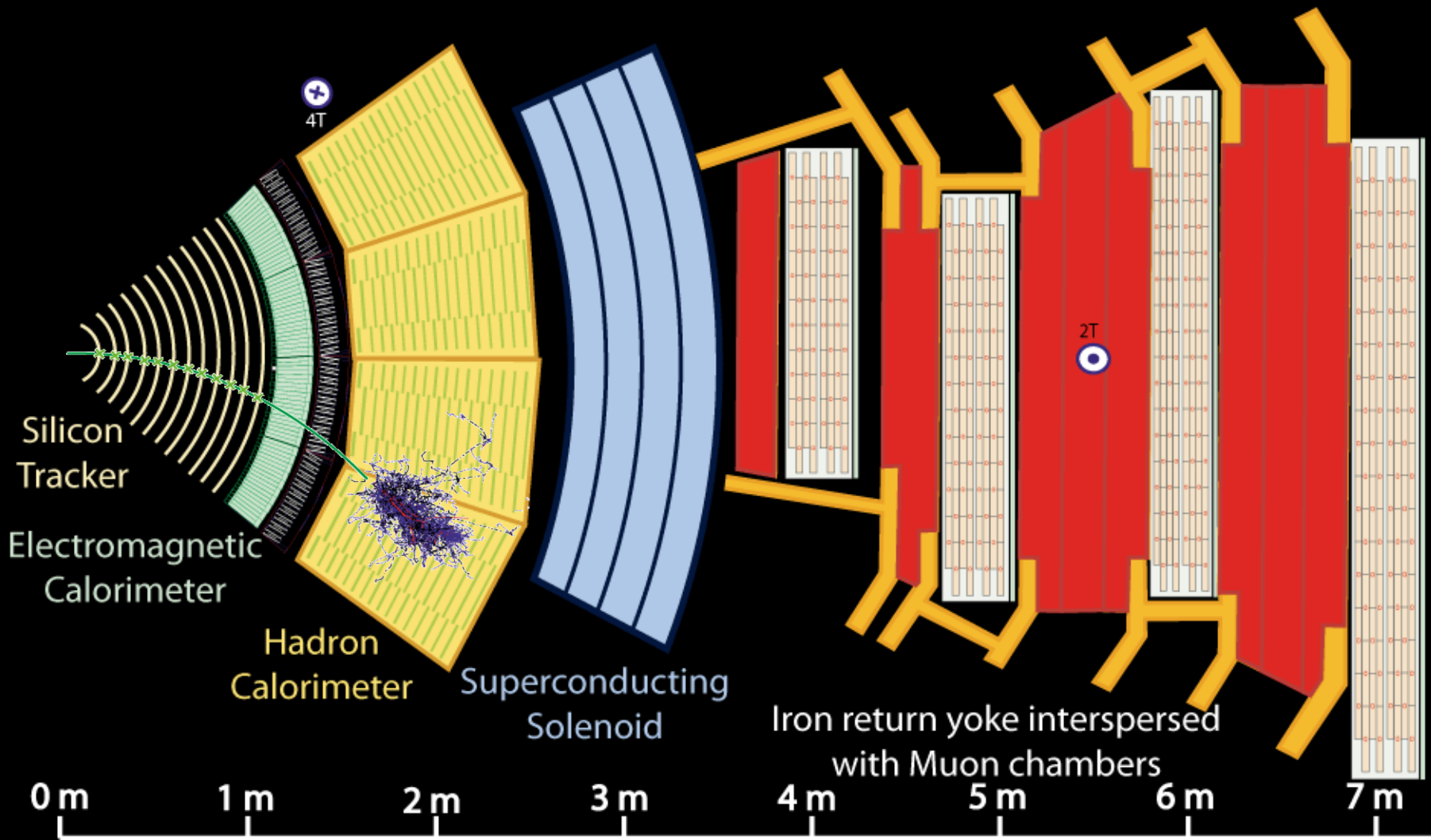
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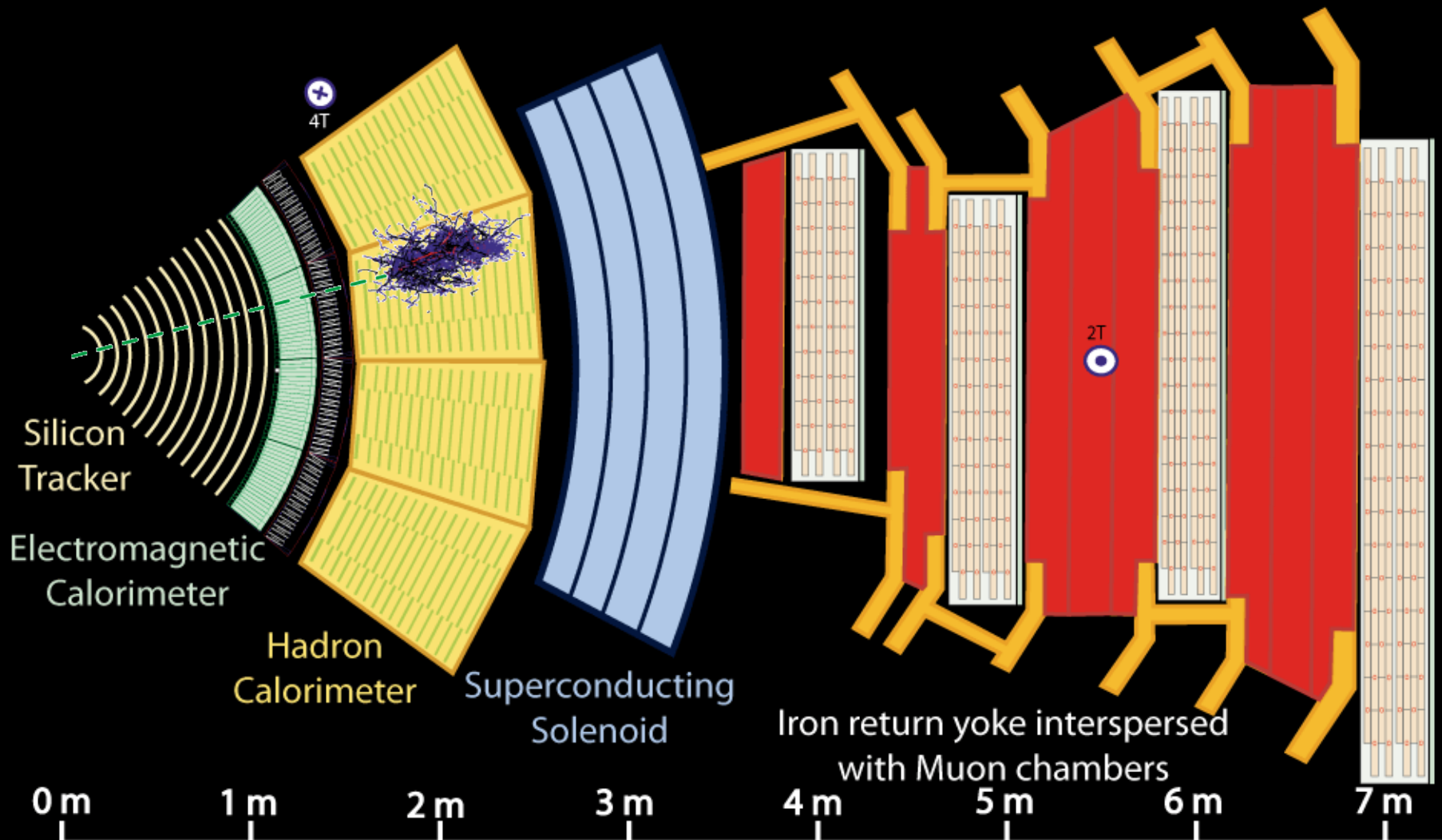
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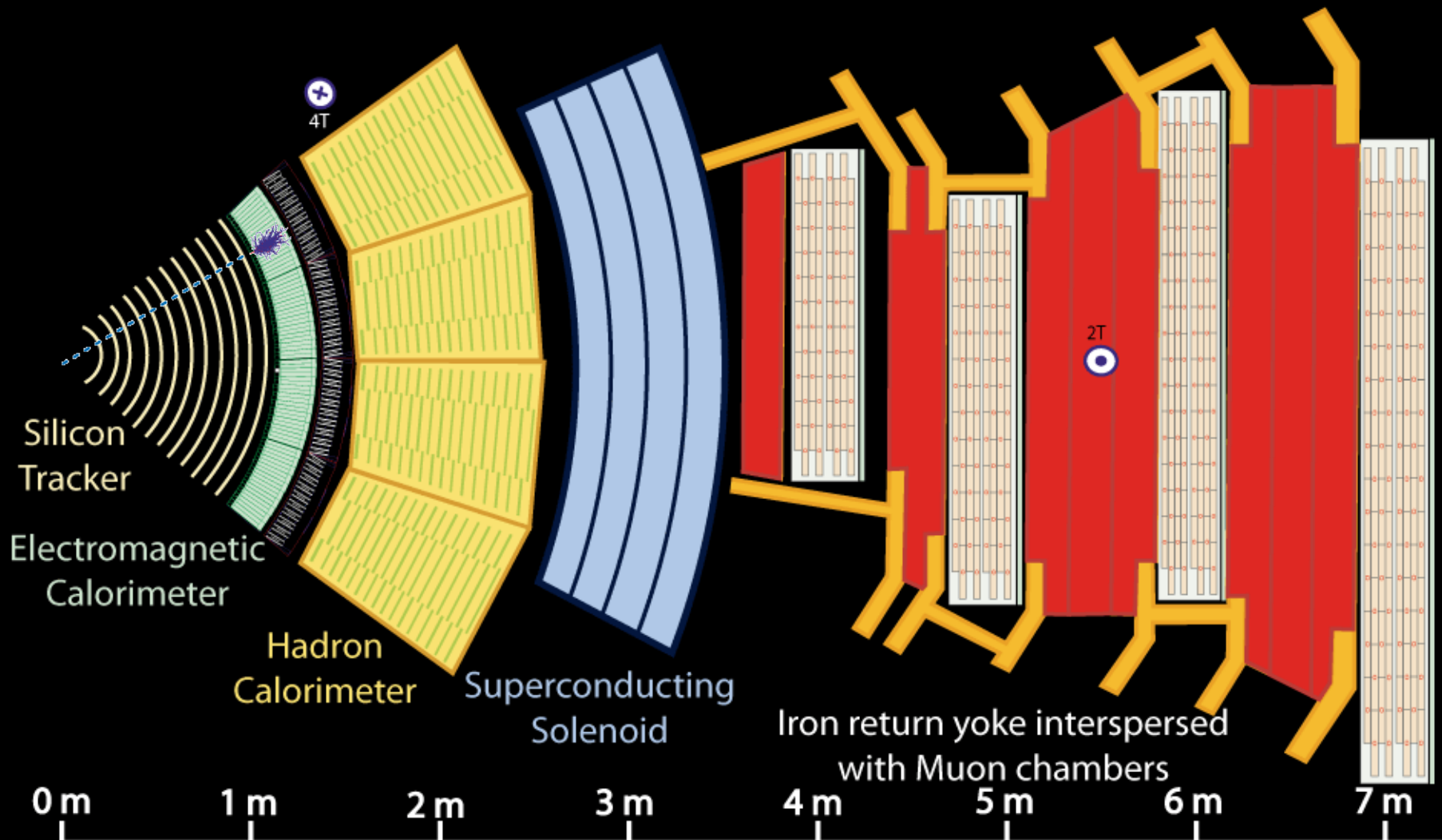
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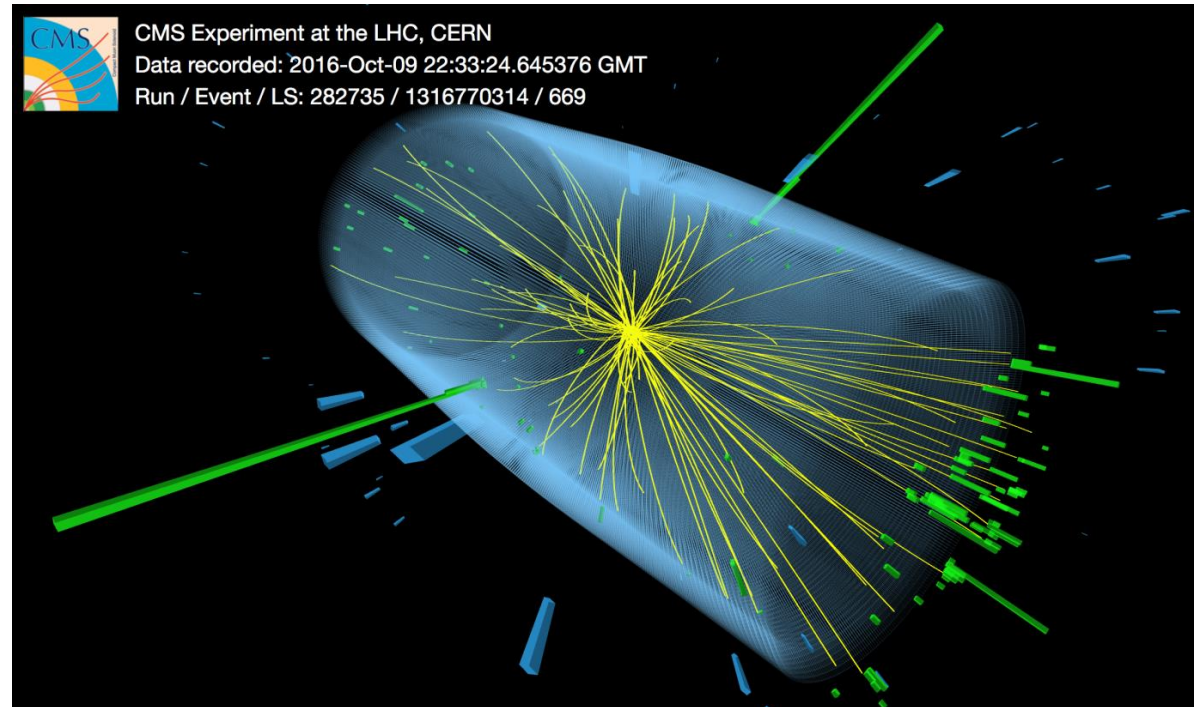
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# Most of the time: proton-proton collisions

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

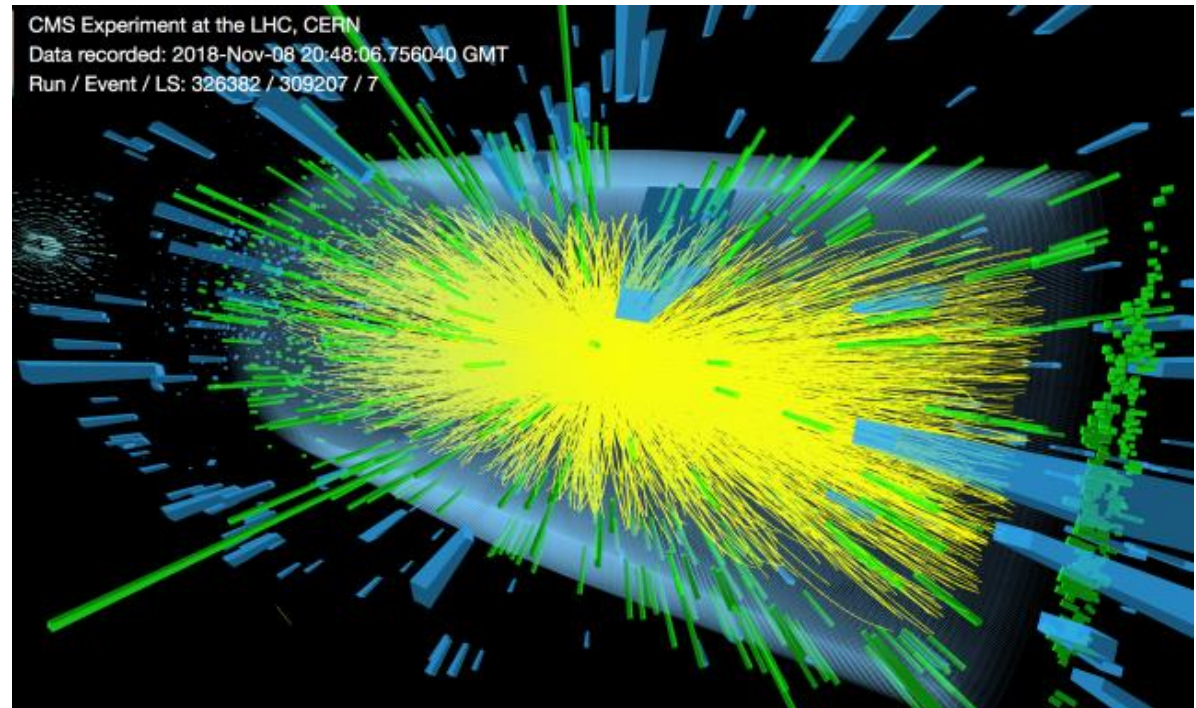
- Colliding two protons at high enough energies to study other kinds of particles (or even find new ones)
- This is how to do particle physics!
- Also how to win a Nobel Prize for observing the Higgs Boson (at right).



# Occasionally: lead-lead (Pb-Pb) collisions

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

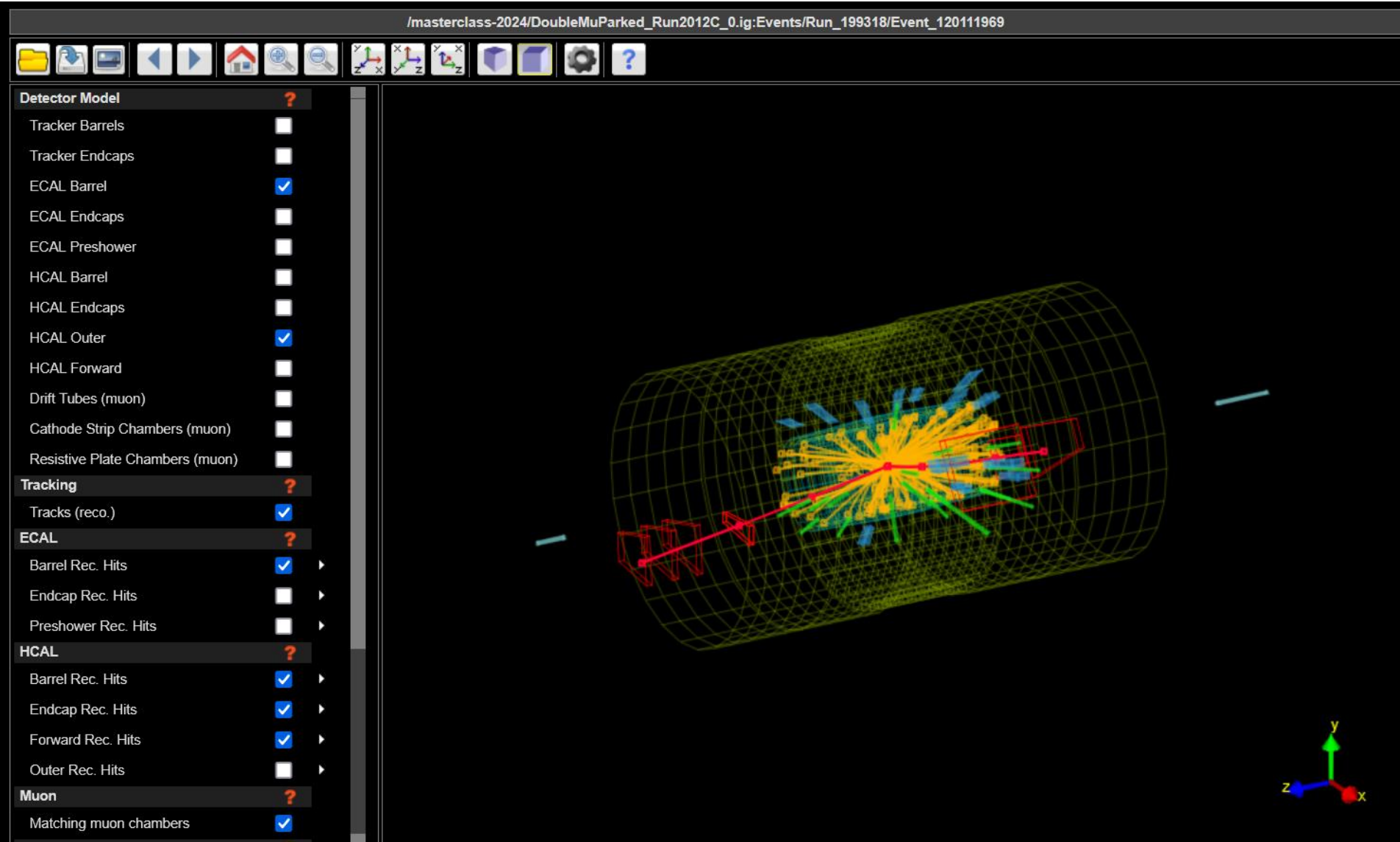
- Collide lead nuclei at close to the speed of light
- Produces sufficient density and temperature to generate a QGP
- Briefly produces a thermalized medium
- Detect final-state particles in tracker, calorimeters, etc.



# Interactive Event Display: iSpy

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

/masterclass-2024/DoubleMuParked\_Run2012C\_0.ig:Events/Run\_199318/Event\_120111969



**Detector Model** ?

- Tracker Barrels
- Tracker Endcaps
- ECAL Barrel
- ECAL Endcaps
- ECAL Preshower
- HCAL Barrel
- HCAL Endcaps
- HCAL Outer
- HCAL Forward
- Drift Tubes (muon)
- Cathode Strip Chambers (muon)
- Resistive Plate Chambers (muon)

**Tracking** ?

- Tracks (reco.)

**ECAL** ?

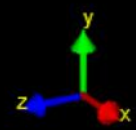
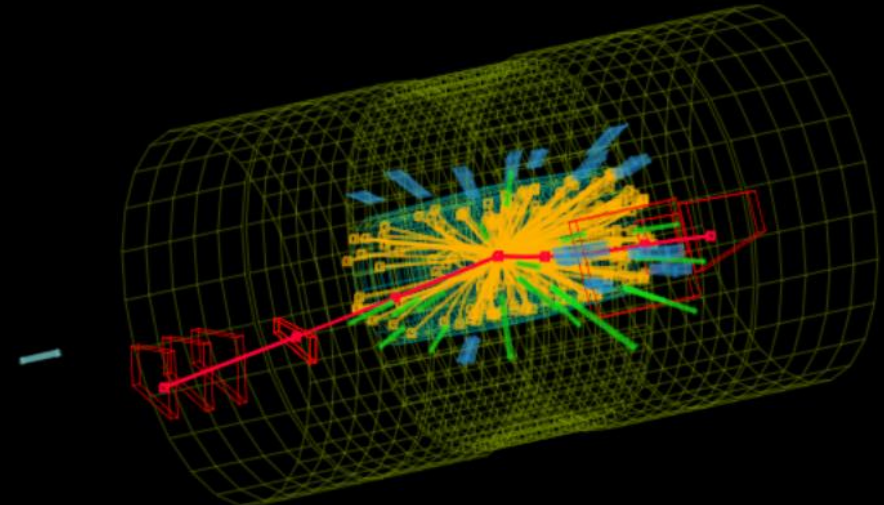
- Barrel Rec. Hits  ▶
- Endcap Rec. Hits  ▶
- Preshower Rec. Hits  ▶

**HCAL** ?

- Barrel Rec. Hits  ▶
- Endcap Rec. Hits  ▶
- Forward Rec. Hits  ▶
- Outer Rec. Hits  ▶

**Muon** ?

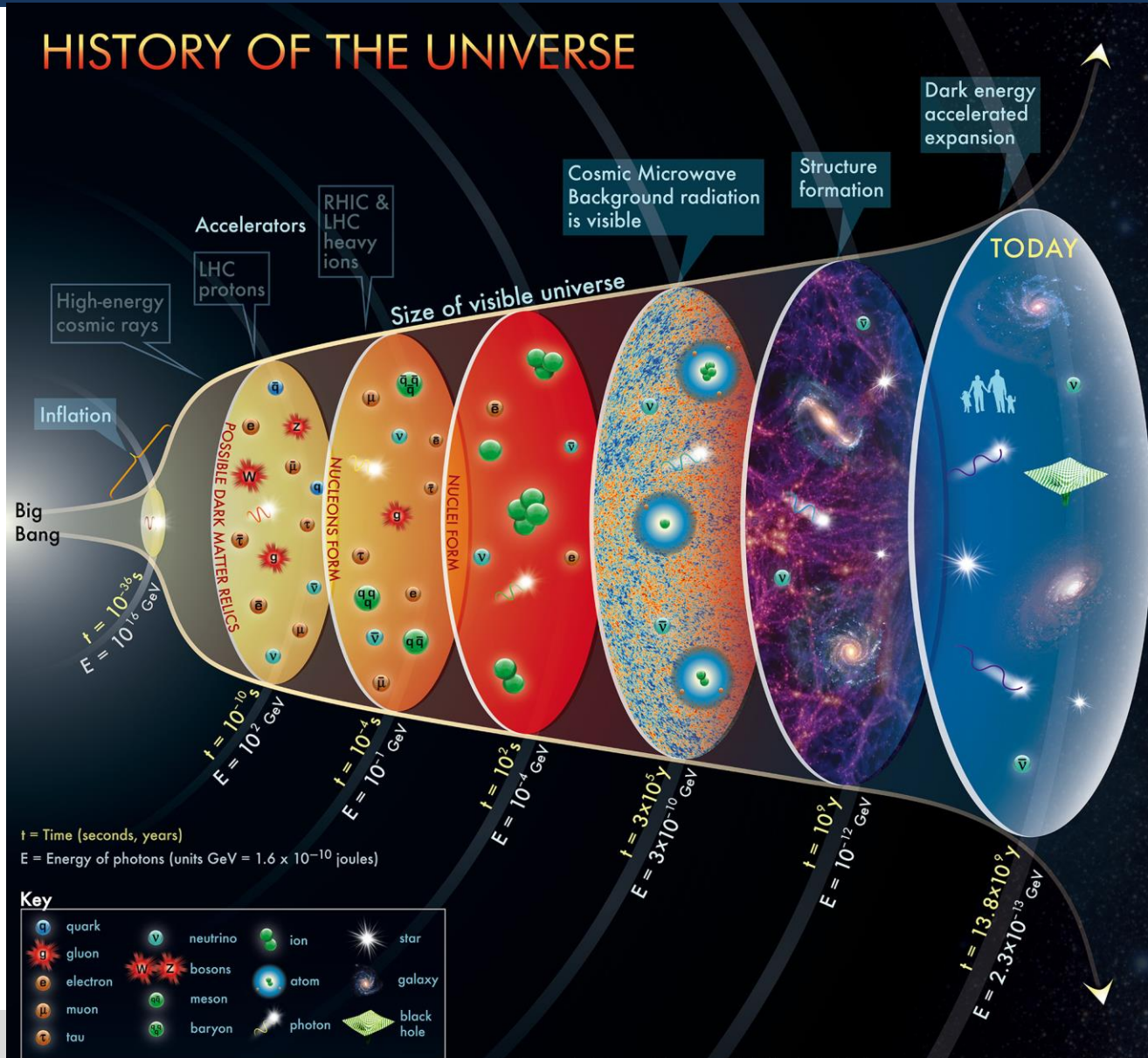
- Matching muon chambers



# Bonus: High Energy Nuclear Physics

# Let's start at the very beginning ...

...one  
microsecond  
after the  
Big Bang!



The concept for the above figure originated in a 1986 paper by Michael Turner.

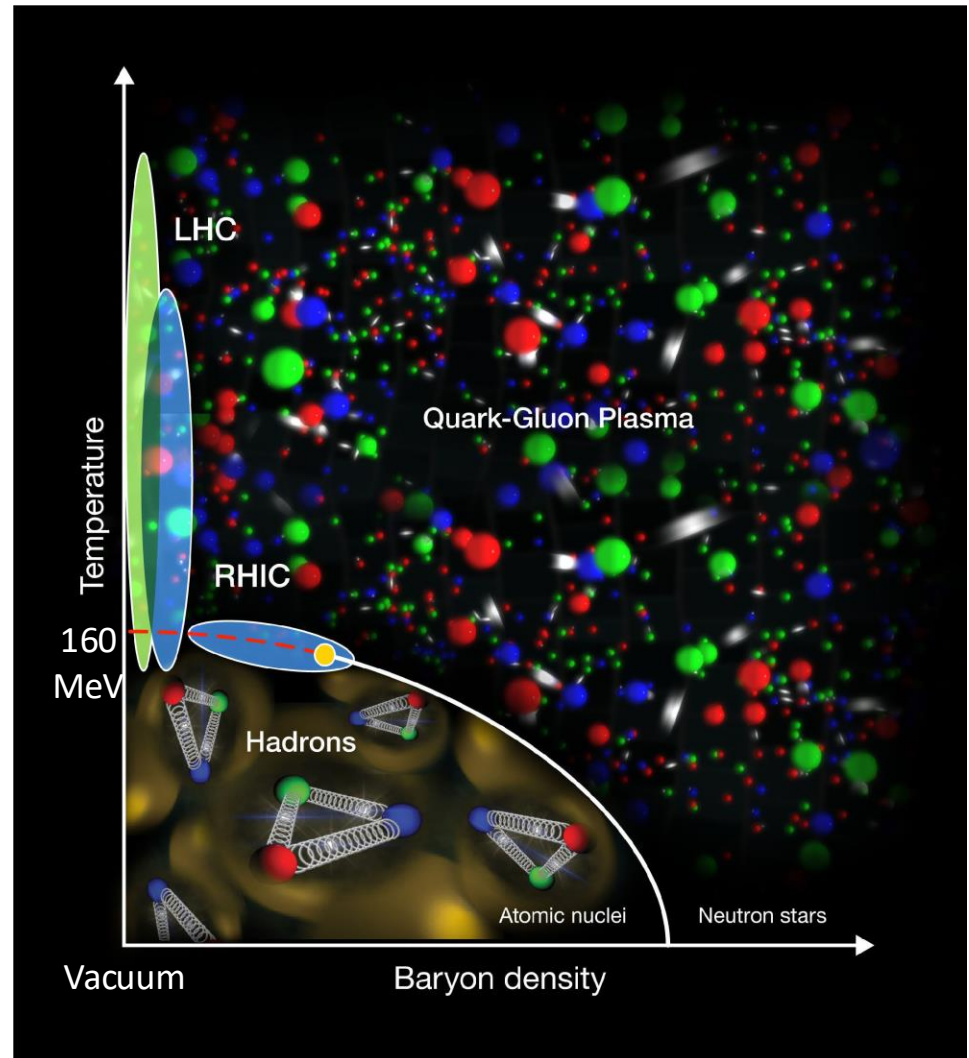
# QCD Phase Diagram

## 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

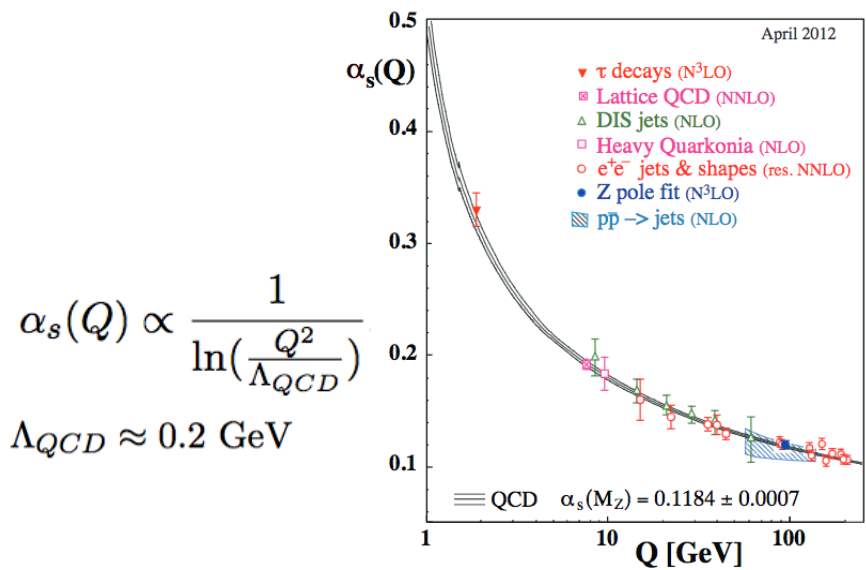
## Quark Gluon Plasma

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

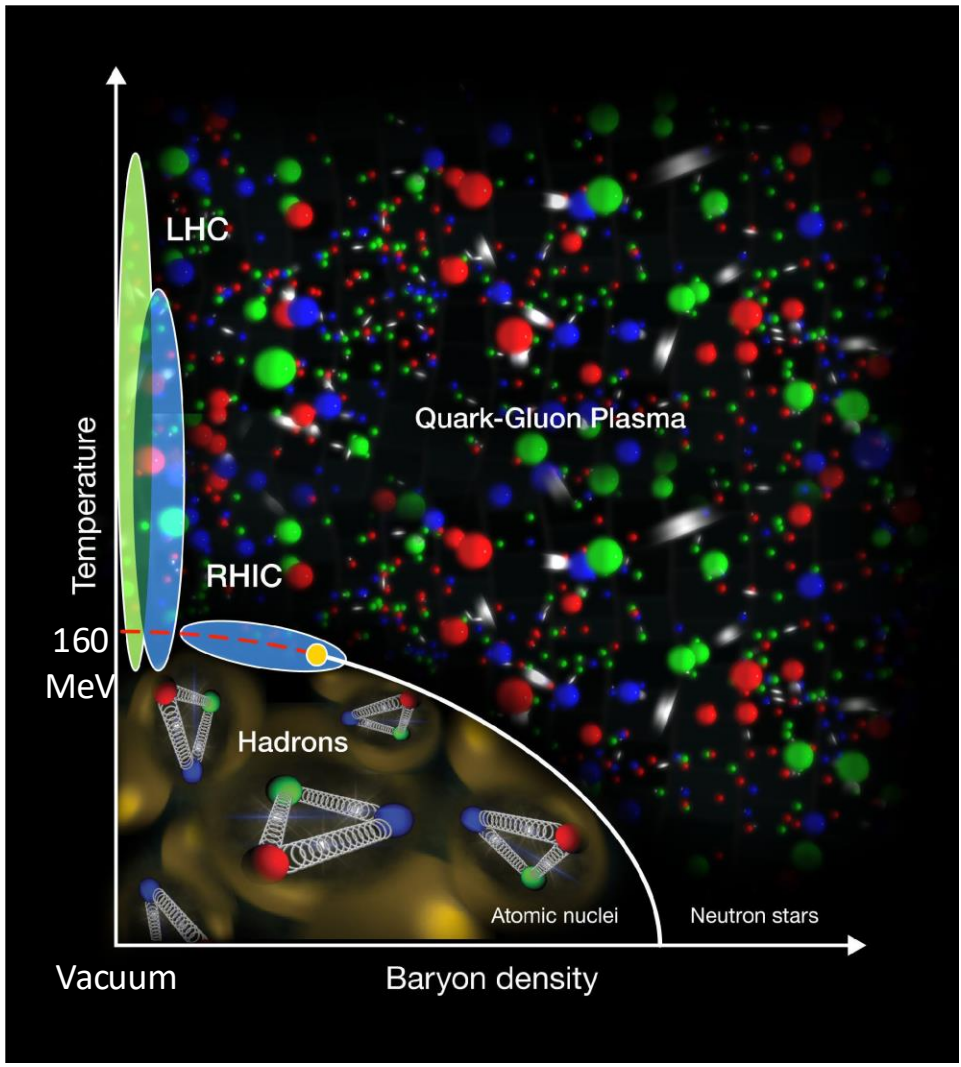




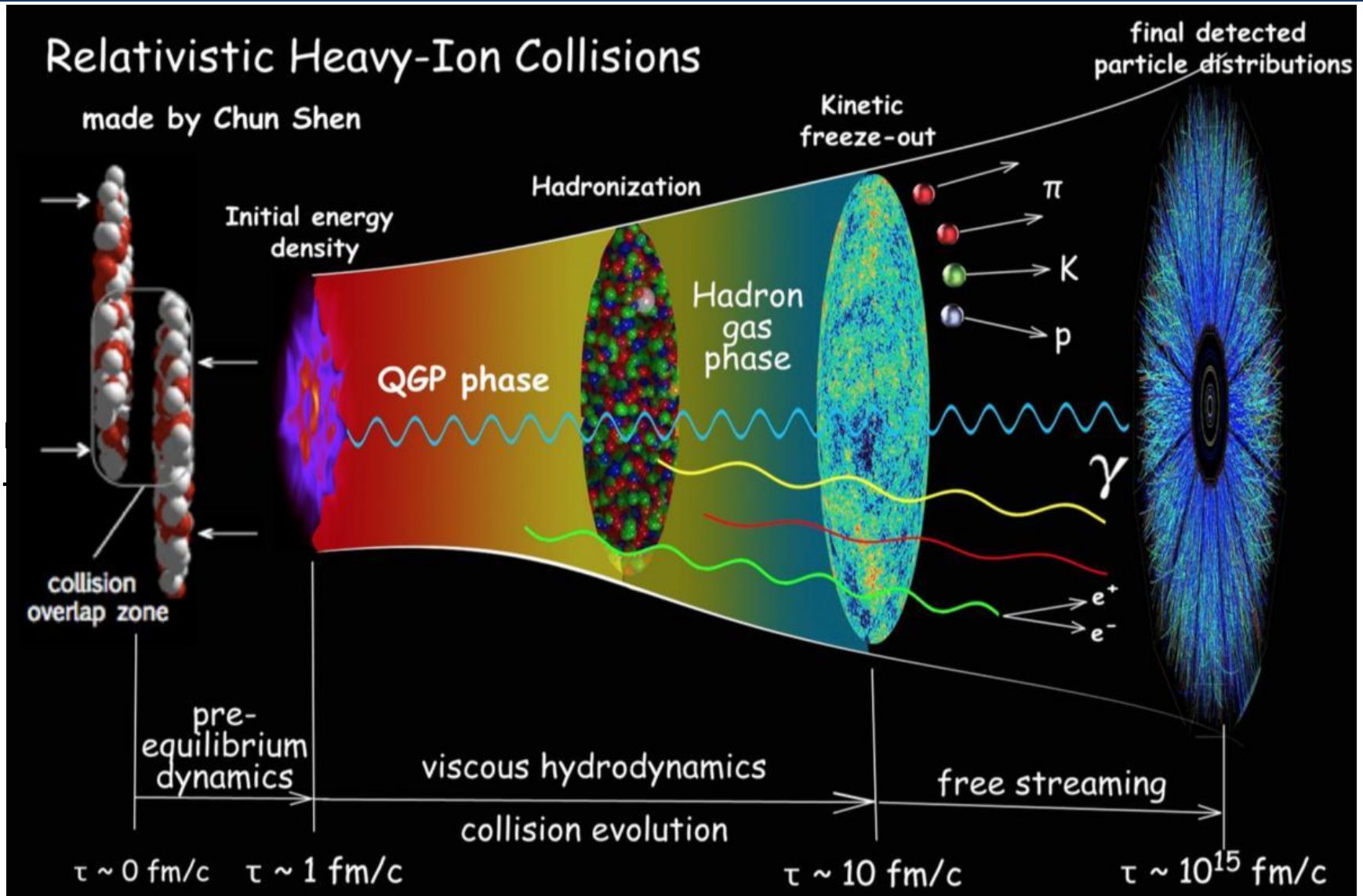
# QCD Phase Diagram – Why a Quark Gluon Plasma?



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



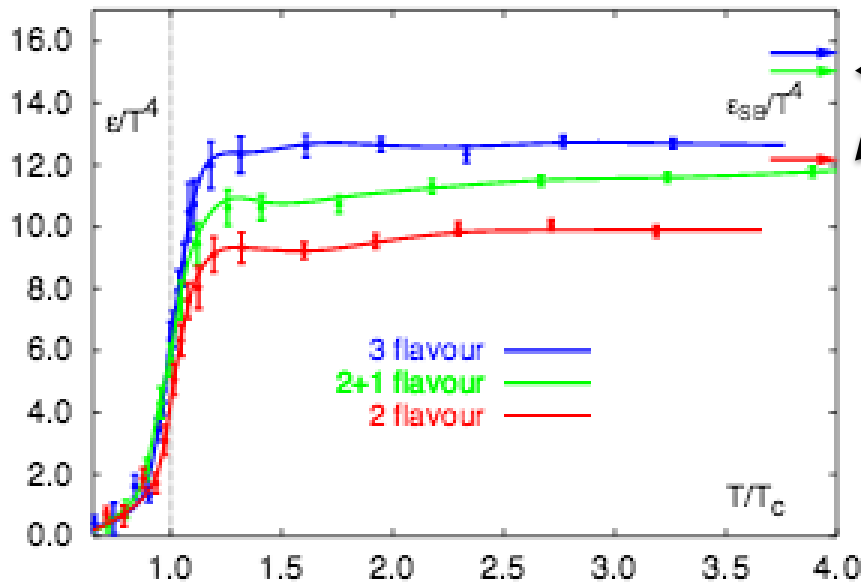
# QGP Recreated in the Laboratory



# 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  $\epsilon$  at  $T_C \approx 175$ , with  $\epsilon(T_C) \approx 0.5 - 1$  GeV/fm<sup>3</sup>

## 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

## Fermions

### Leptons (spin 1/2)

Electron  
(Charge -1)

$e^-$

Electron  
Neutrino  
(Charge 0)

$\nu_e$

Tau  
(Charge -1)

$T$

Tau  
Neutrino  
(Charge 0)

$\nu_e$

Muon  
(Charge -1)

$\mu$

Muon  
Neutrino  
(Charge 0)

$\nu_\mu$

### Quarks (spin 1/2)

Bottom  
Quark  
(Charge -1/3)

$b$

Up Quark  
(Charge 2/3)

$U$

Down  
Quark  
(Charge -1/3)

$d$

Top Quark  
(Charge 2/3)

$t$

Strange  
Quark  
(Charge -1/3)

$s$

Charm  
Quark  
(Charge 2/3)

$C$

### Baryons (spin 1/2 2/3)

Proton  
(Charge +1)

$P^+$

Anti  
Proton  
(Charge -1)

$\bar{P}^-$

Neutron  
(Charge 0)

$N^0$

Lamda  
(Charge 0)

$\Lambda^0$

Omega  
(Charge -1)

$\Omega^-$

### Mesons (spin 0,1)

Pion  
(Charge +1)

$\pi^+$

Kaon  
(Charge -1)

$K^-$

Rho  
(Charge +1)

$\rho^+$

B-zero  
(Charge 0)

$B^0$

Eta-c  
(Charge 0)

$\eta_c$

- ❖ Any member of a group of subatomic particles having odd half-integral angular momentum (spin 1/2, 3/2).
- ❖ Fermions obey the Pauli exclusion principle, which forbids more than one particle of this type from occupying a single quantum state.
- ❖ Fermions include nuclei of odd mass number.

## Bosons (spin 1)

Photon  
(Charge 0)

$\gamma$

$W^-$  Boson  
(Charge -1)

$W^-$

$W^+$  Boson  
(Charge 1)

$W^+$

$Z^0$  Boson  
(Charge 0)

$Z^0$

Gluon?  
(Charge 0)

$g$

- ❖ Subatomic particle with integral spin (i.e., angular momentum in quantum-mechanical units of 0, 1, etc.)
- ❖ Bosons (force carriers) differ significantly from fermions in that there is no limit to the number that can occupy the same quantum state.