Chocolate, Fondue, and Particle Physics

Life at the Large Hadron Collider

AJ Johnson
PhD Student, University of Colorado

Overview

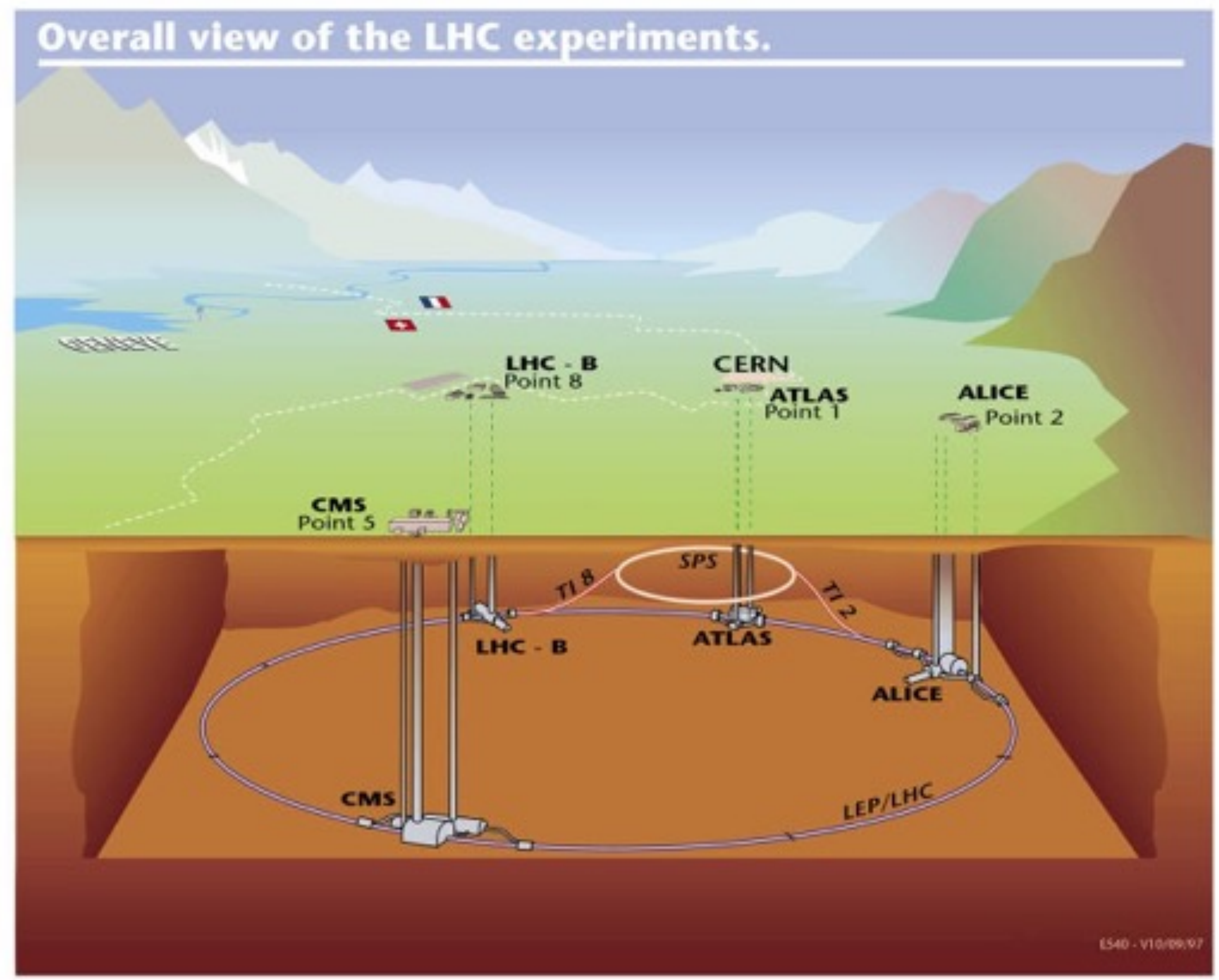
- CERN and the LHC
- Physics motivation - why collide protons?
- From collisions to papers
- The grad student experience @ CERN

CERN

- Largest particle physics laboratory in the world
- Employs over 10^4 staff, engineers, scientists, and research personnel + thousands of graduate students (from over 80 countries)
- Located in Geneva, Switzerland
- Main function: constructing and operating particle accelerators, particle physics research

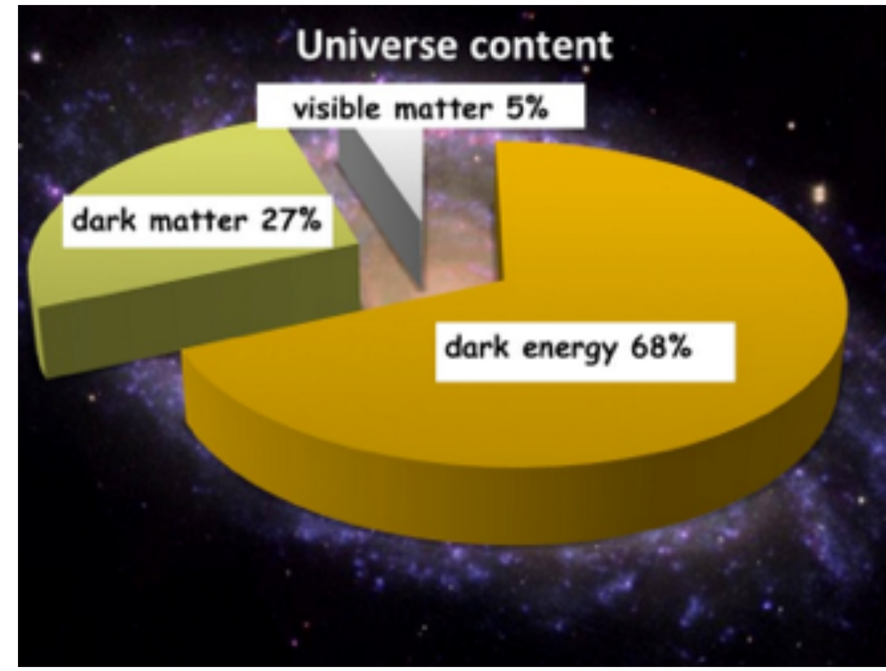
Large Hadron Collider

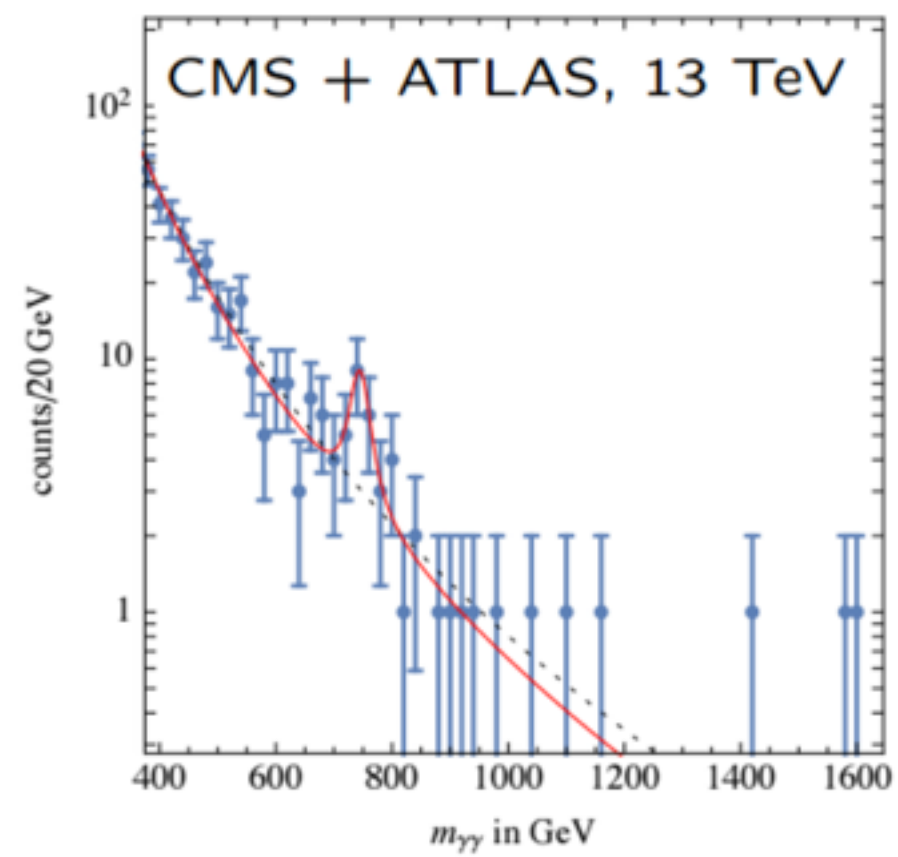
- World's largest particle accelerator
- Collides protons (and sometimes lead ions) together at near-light speed
- Four detectors take "snapshots" of collisions
- I work on the Compact Muon Solenoid (CMS) Experiment



Why collide protons?

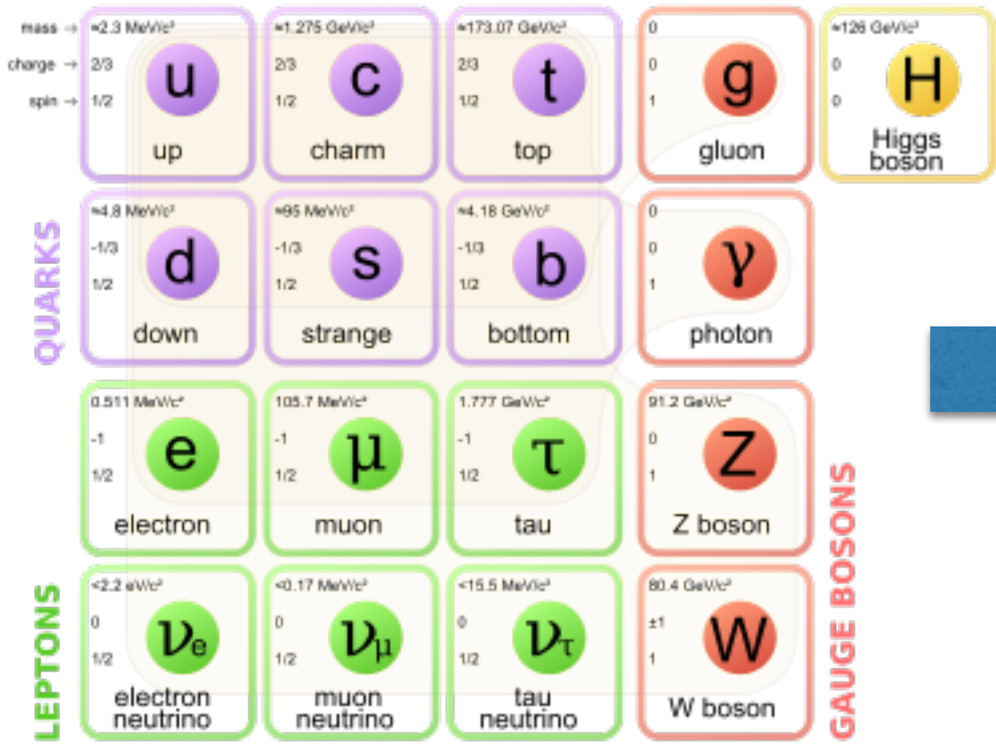
- Particle physics describes the most fundamental interactions in the universe
- There are many unsolved mysteries in the field:
    - Dark matter/dark energy
    - Hierarchy problem (why is gravity so weak/what's up with the Higgs mass?)
    - Is there only one type of Higgs boson?
- The LHC is a really expensive microscope
    - The higher the energy, the more particles we can create (can look "deeper")

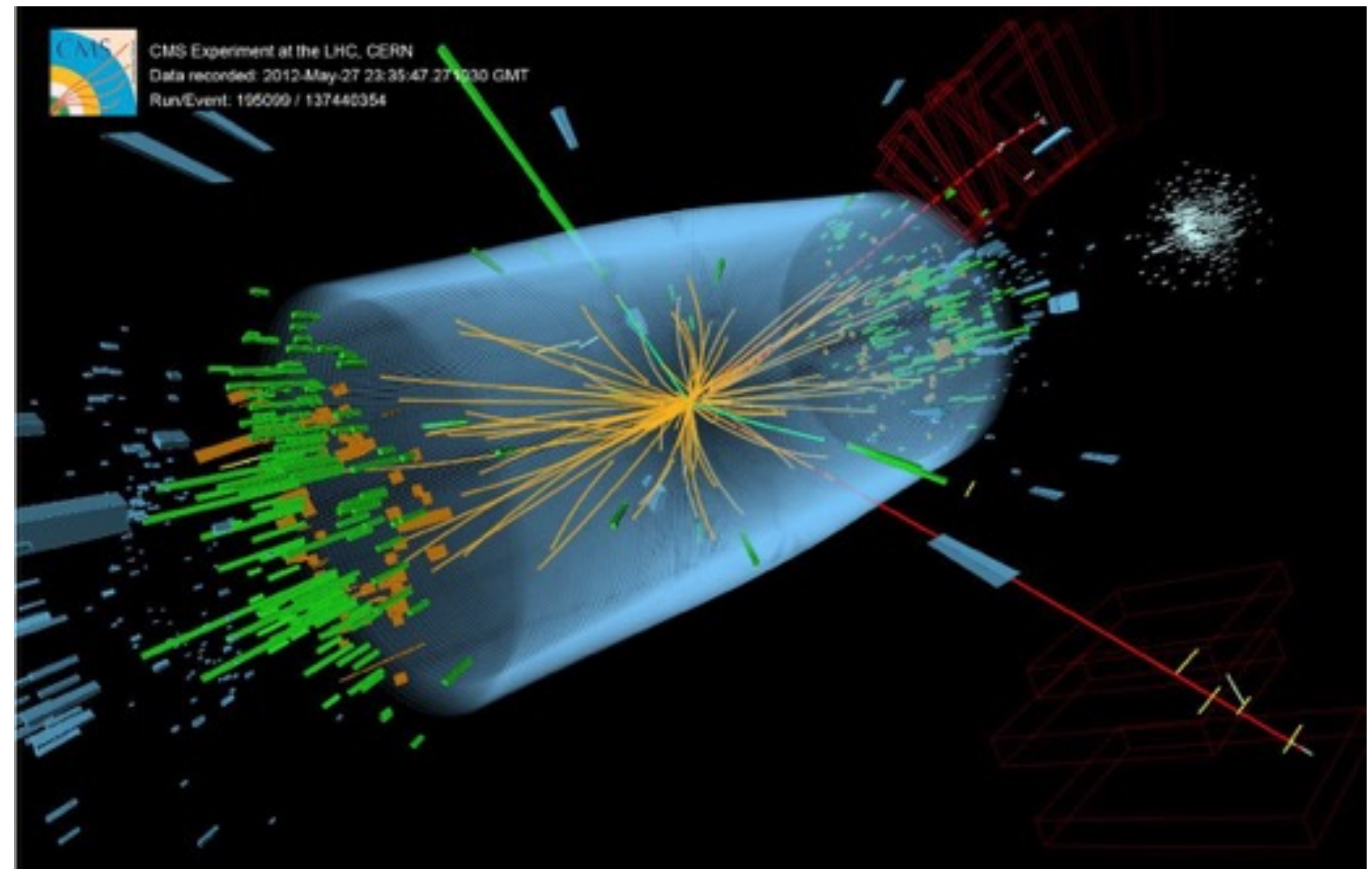




Physics at the LHC

Standard Model





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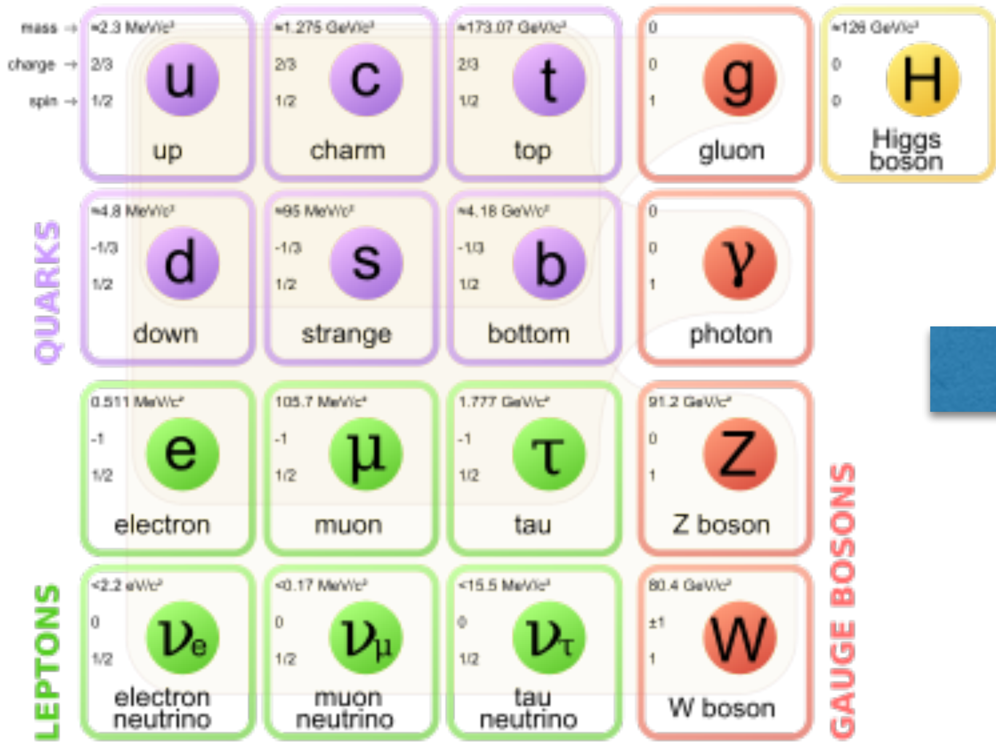
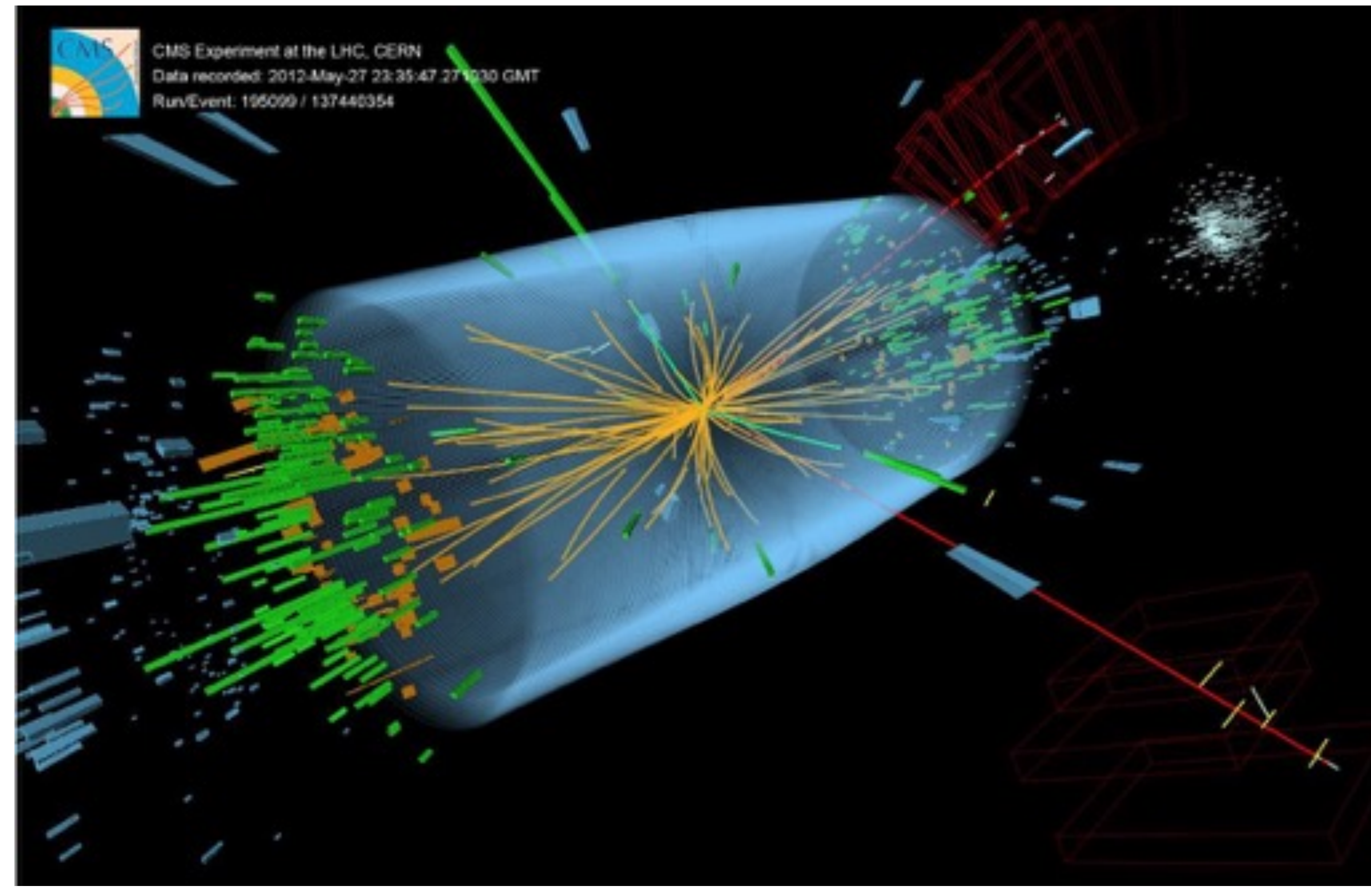
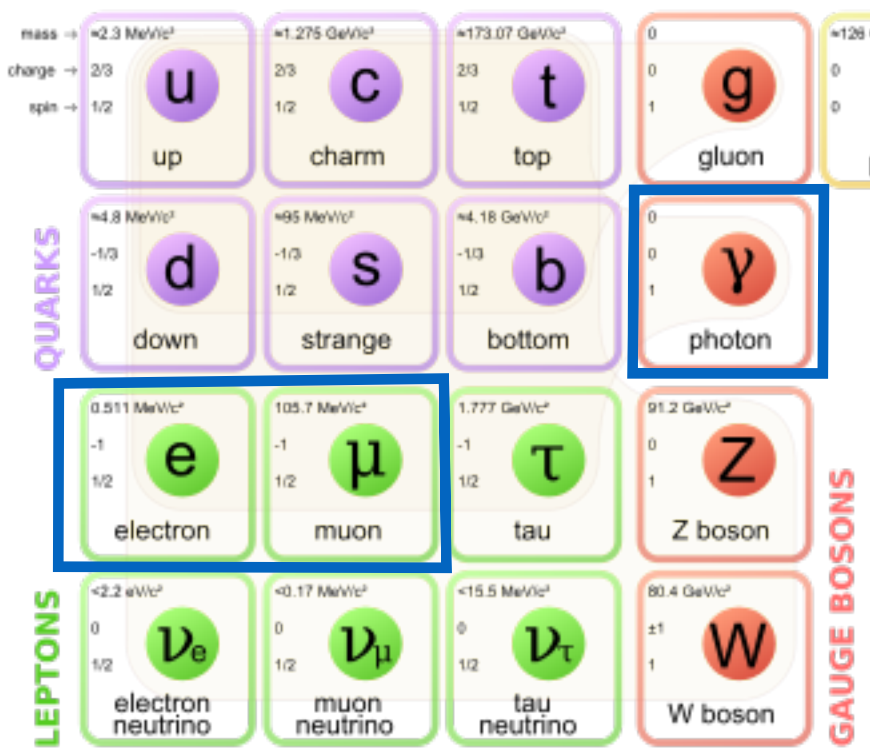


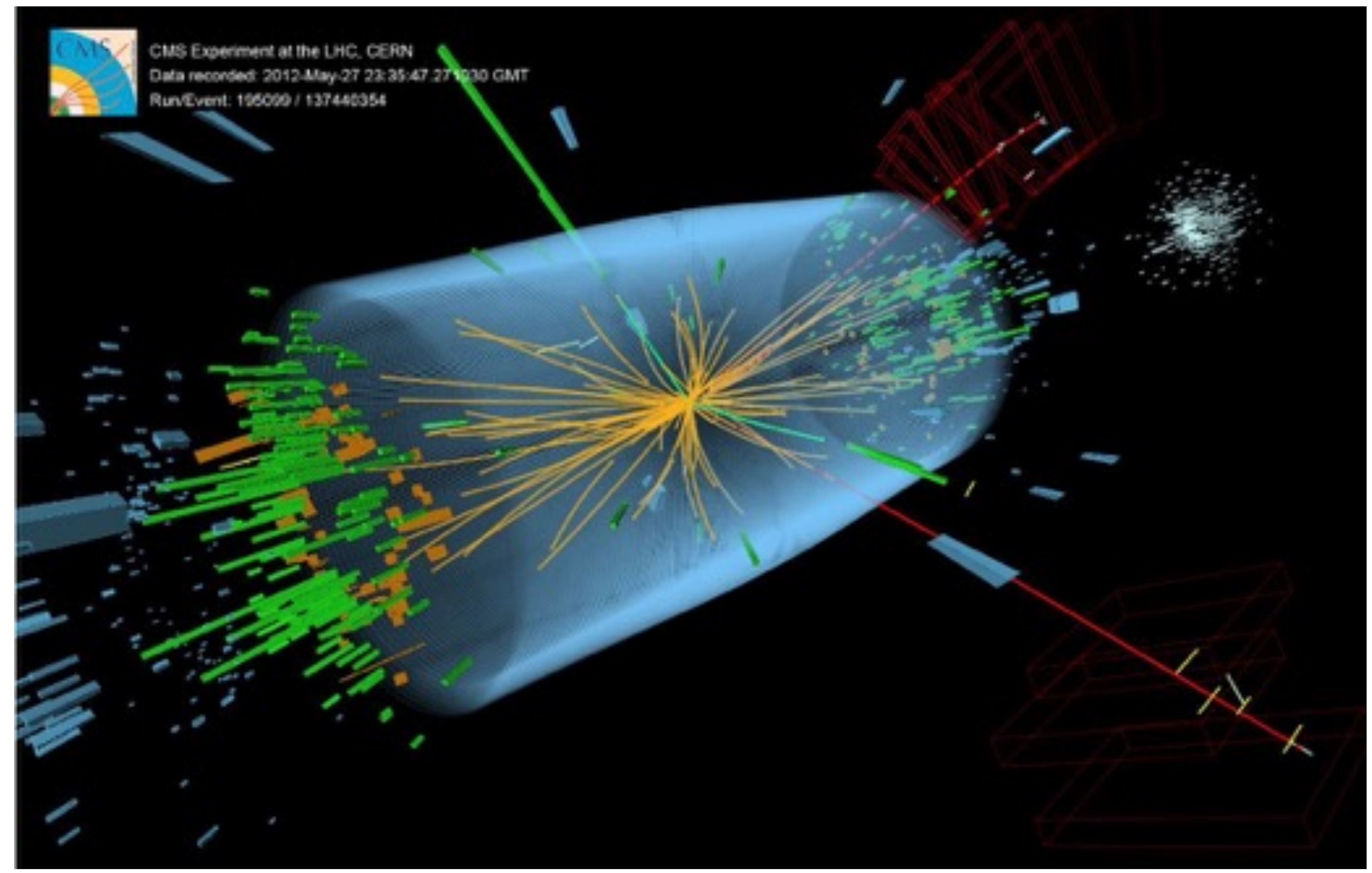


Discuss with your neighbor: which (fundamental) Standard Model particles can we directly detect? (Hint: there are three listed here)

Physics at the LHC

Standard Model





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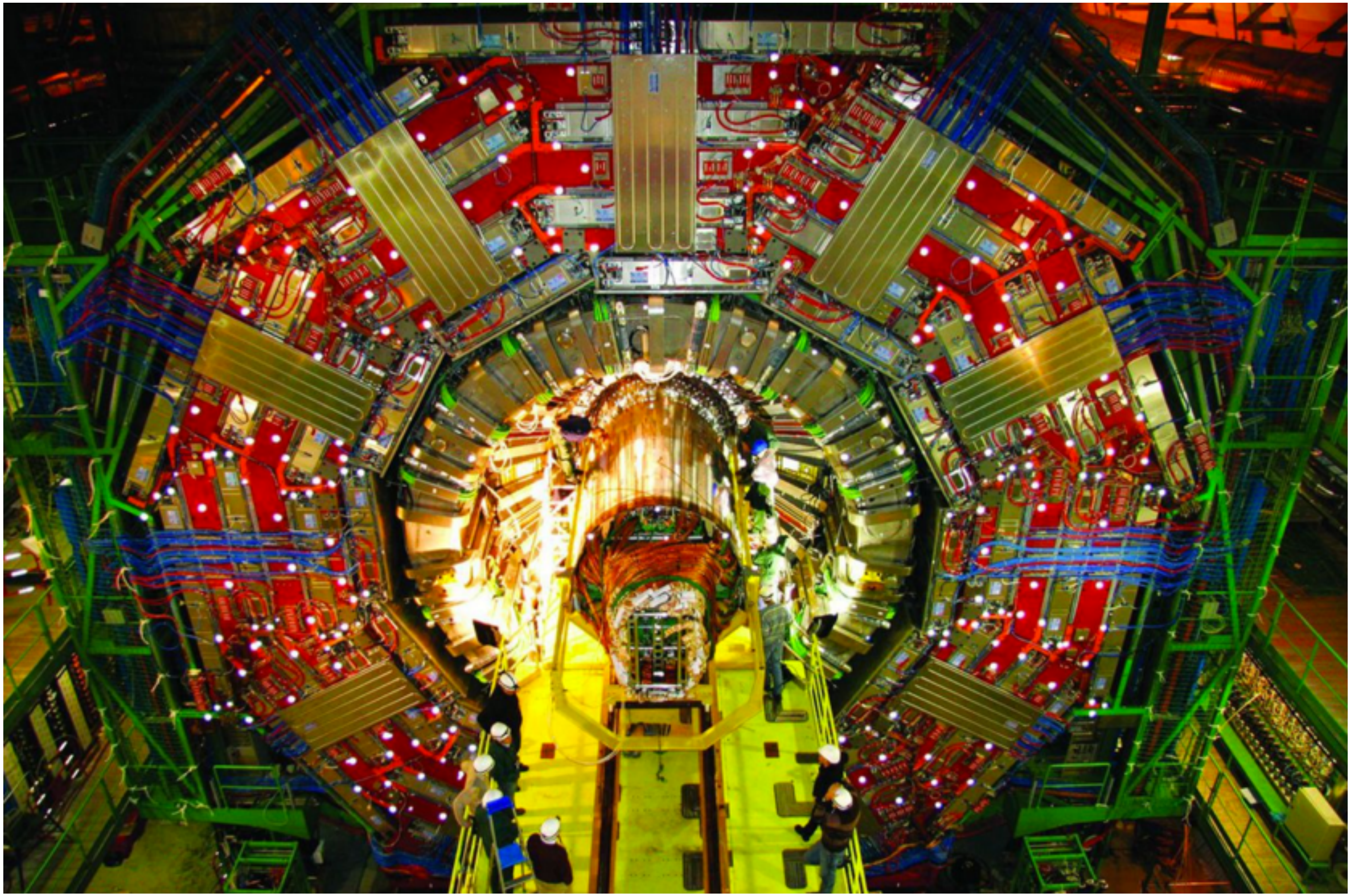
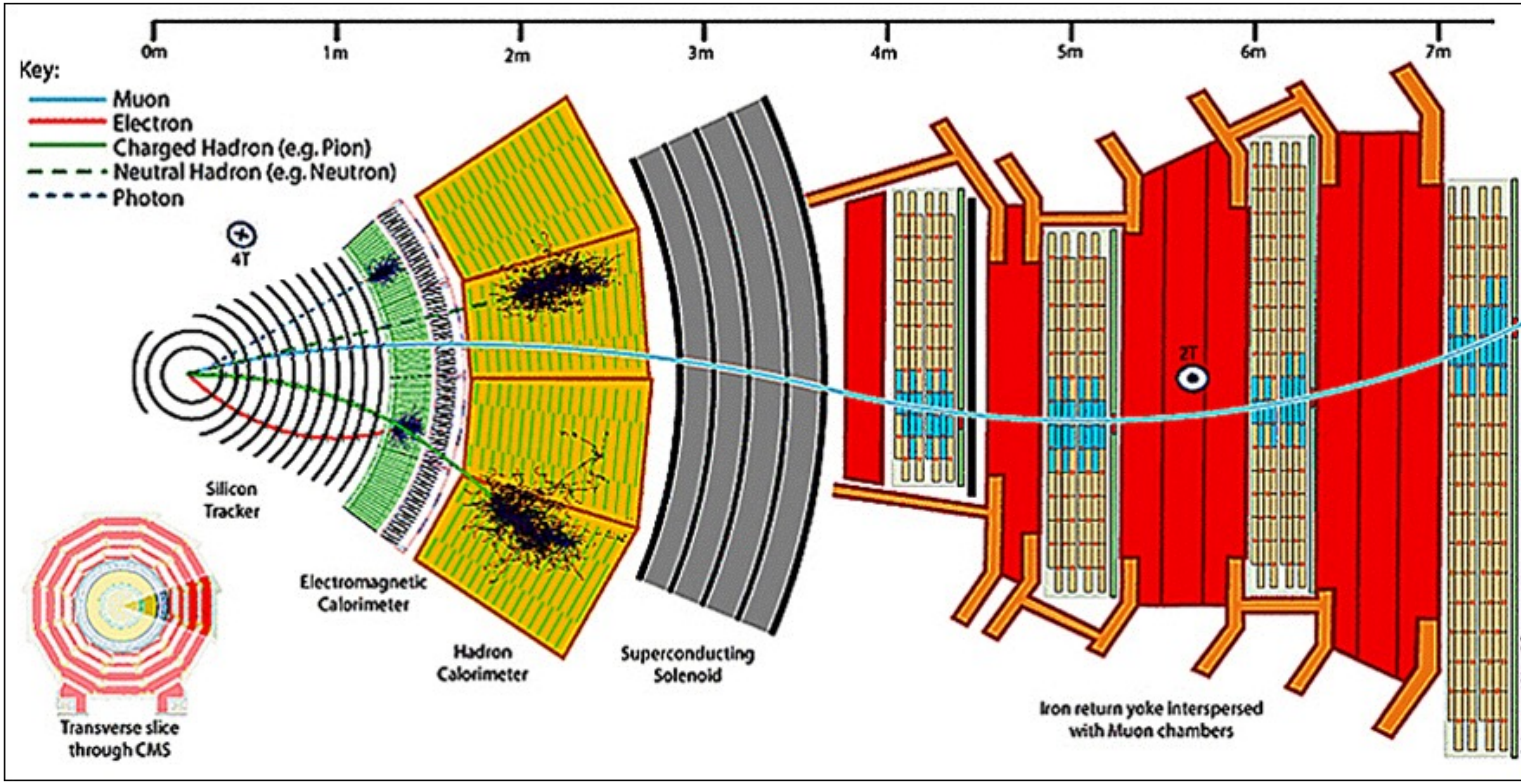
Can also detect hadrons: stable(ish) particles made up of quarks (e.g. protons, neutrons, pions)

Detecting Particles



The CMS Experiment

Detecting Particles



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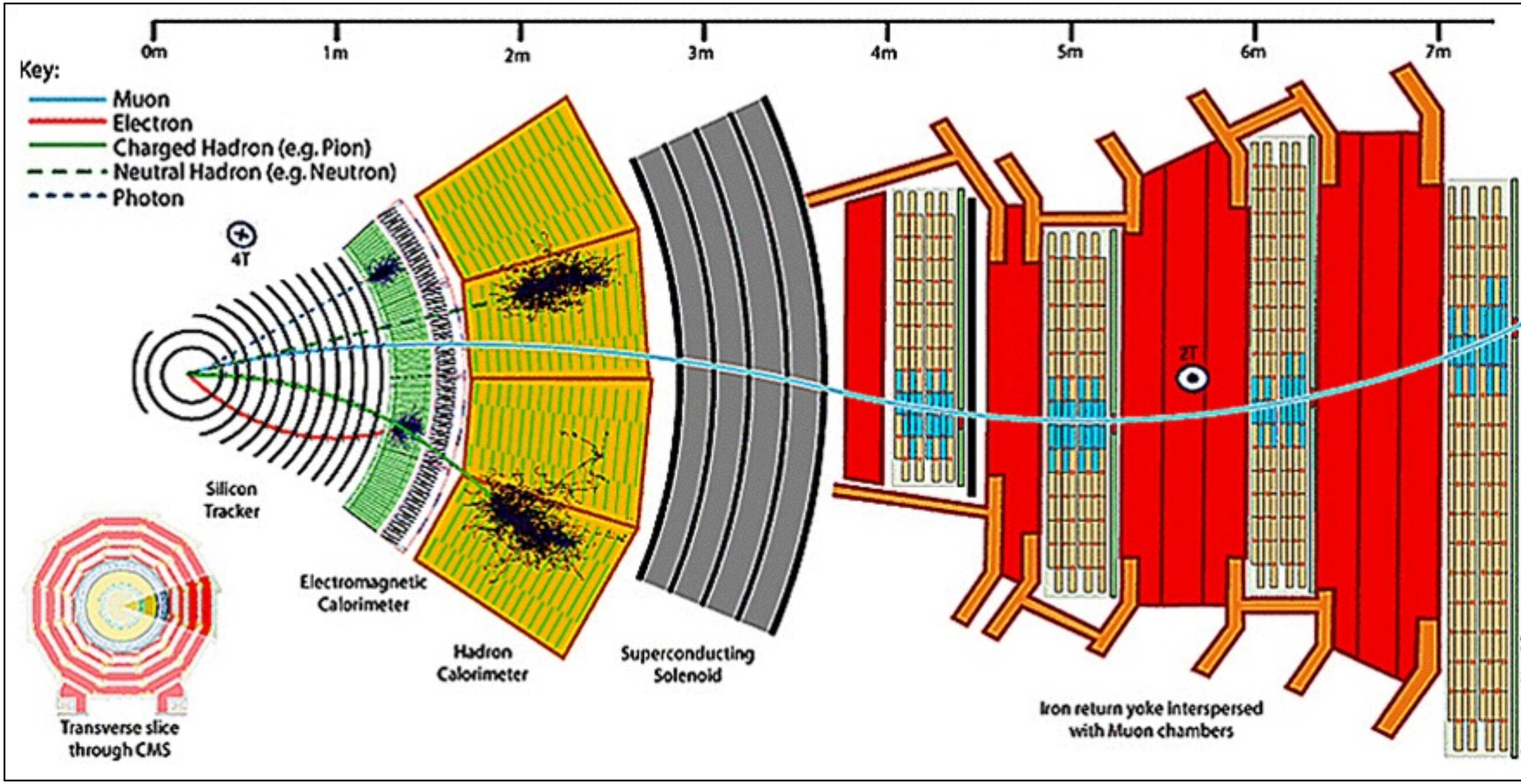
Detecting Particles



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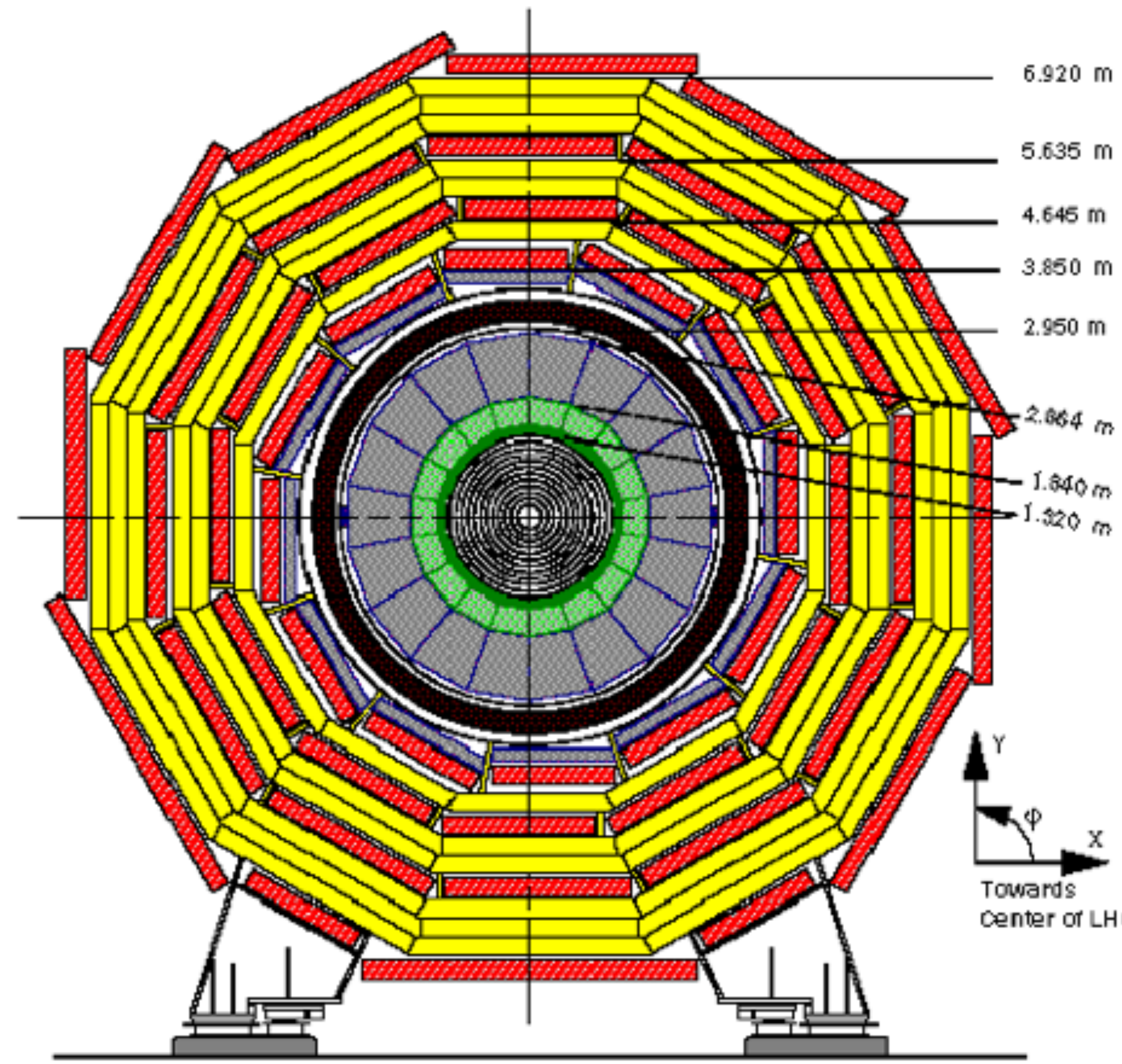
Discuss with your neighbor: what about neutrinos? How can we infer their presence?

Hint: CONSERVATION!

Measuring neutrinos

- Neutrinos go right through everything
- protons start with zero “transverse” momentum (all along beam line)
- What if we see net visible momentum in the transverse direction?

CMS Transverse View



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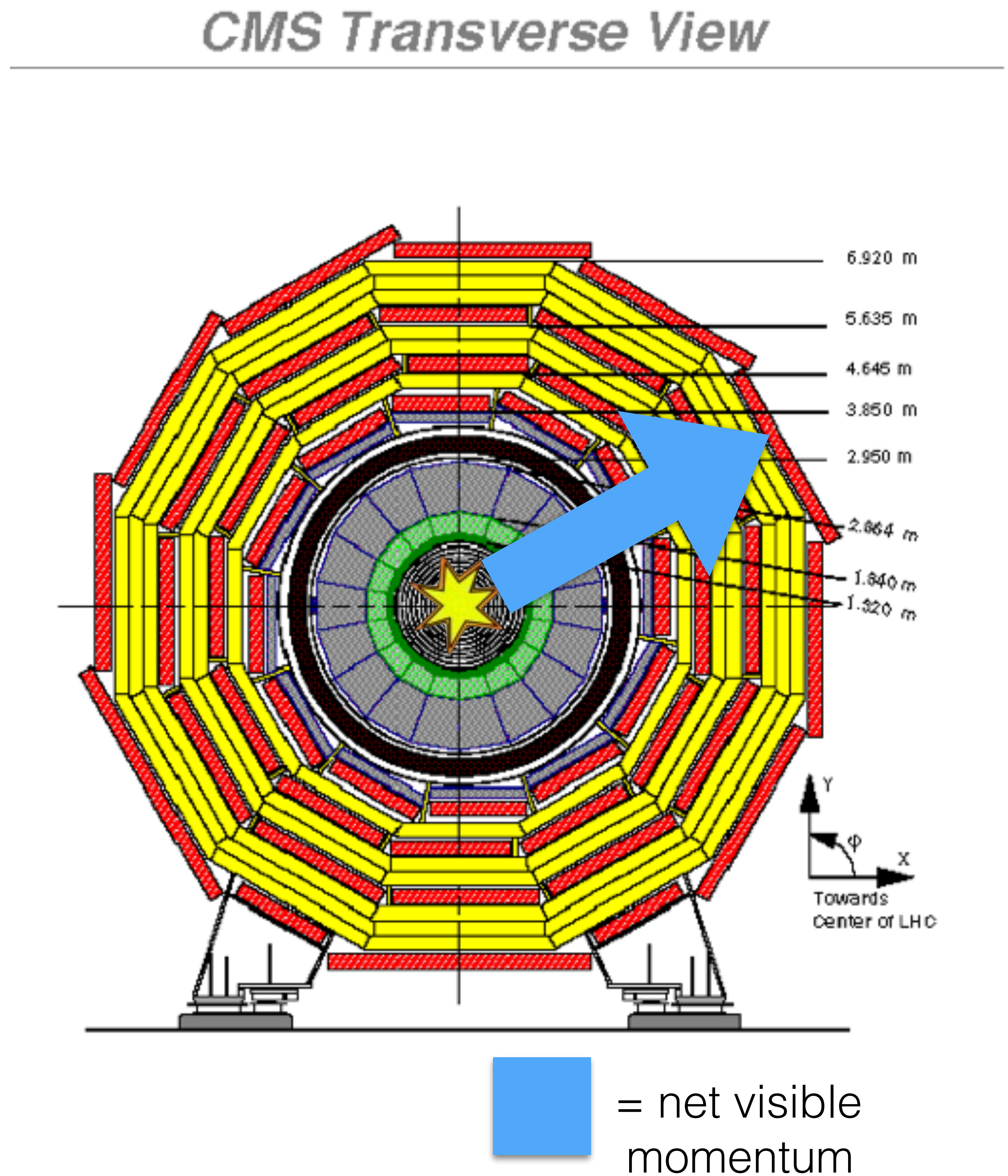
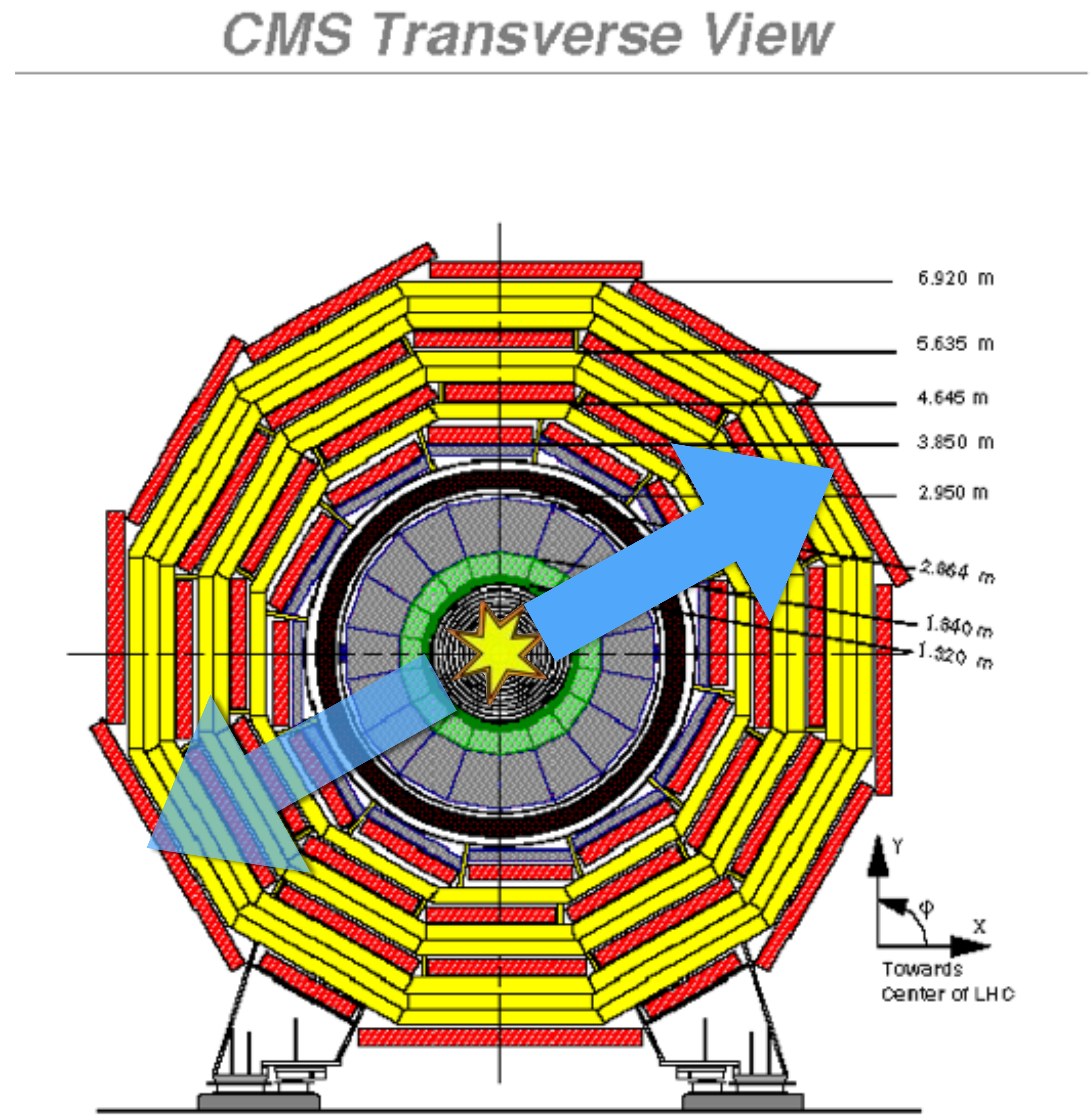


Measuring neutrinos

- Neutrinos go right through everything
- protons start with zero “transverse” momentum (all along beam line)
- What if we see net visible momentum in the transverse direction?
- There must have been neutrinos with net “invisible”momentum to cancel it out
- We call this “missing energy” (although it’s really momentum!)



= net invisible momentum

= net visible momentum

What do we do with our data?

- The LHC experiments provide us with petabytes of raw collision data - 4×10^7 “collision snapshots” every second, each ~10 MB.

- Our job as physicists: search for new physics behavior in a sea of Standard Model background

- How do we do this?

The CMS pipeline: turning protons into papers

pp collisions

detector operations

triggering

object reconstruction

monte carlo simulation

physics-based object selection

background estimation

validation & sanity checks

statistical analysis

approval from CMS higher-ups

PAPER!

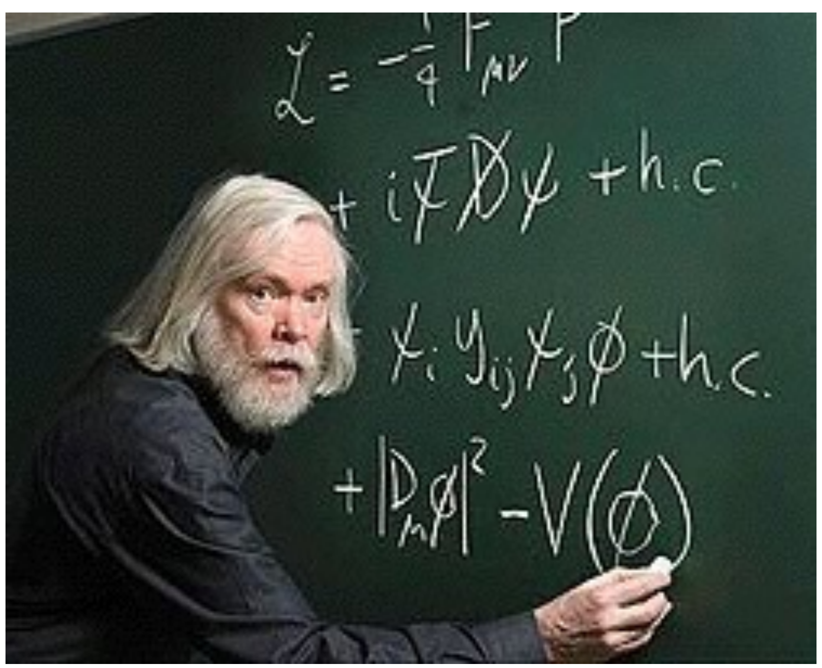
Computing @ CERN

- Work on an LHC experiment is overwhelmingly centered around software development
- CMSSW is one of the largest codebases in the world
- Every step of the “pipeline” from detector operations through physics analysis involves thousands of lines of code

Working as a grad student at CERN

What my family thinks I do

What my friends think I do



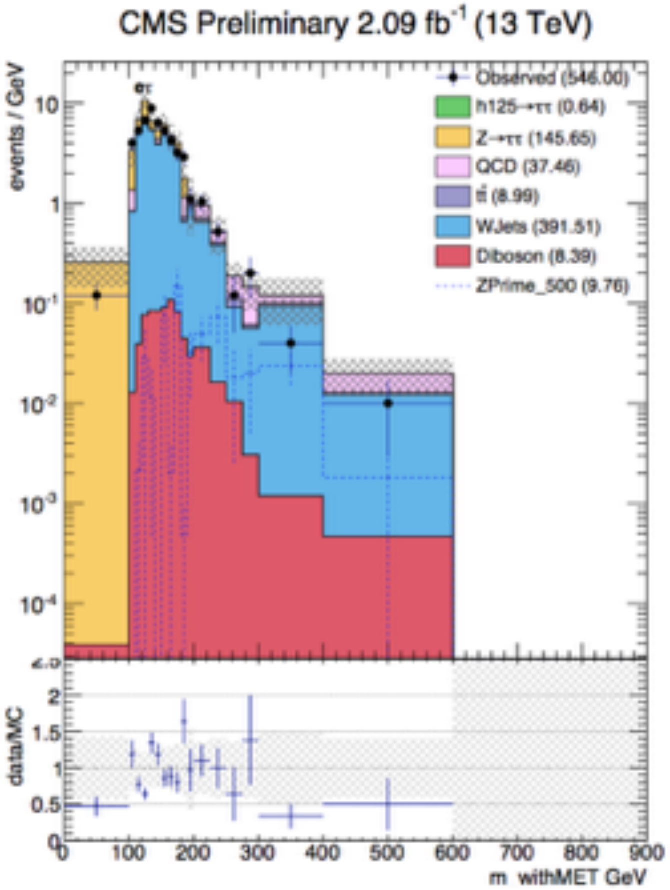
What I think I do

What I really do

Grad student responsibilities

- 50% analysis, 50% “service work”
- Running control room shifts
- Active involvement in software development for EVERY STEP of the pipeline
- C++ and Python (but plenty of other languages used)
- Meetings meetings meetings
- Collaboration with several research/operations groups

Day in the life of a CERN grad student



- 7:00: wake up in St. Genis (France)
- 7:30 - 8:00: walk across border into CERN
- 8:00 - 8:30: breakfast in R1
- 8:30 - 10:00: try to fix bugs in tau reconstruction code
- 10:00 - 11:30: work on pixel operations tool
- 11:30 - 12:15: lunch in R1
- 12:15 - 15:00: make plots for analysis
- 15:00 - 15:30: sanity coffee
- 15:30 - 19:00: afternoon meetings, more coding
- 19:00 - 21:00: dinner in Geneva (fondue!)
- 21:00 - 22:00: work out in CERN “gym”
- 22:00: bus back to St. Genis, sleep

Working at CERN vs. working in a lab

- Much more programming
- Much less “hands-on” hardware work
- Gigantic collaborations
- More red tape, but also more help
- Very different approach to papers
- You get to live in Switzerland!

Switzerland is AWESOME

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About me

- 5th year graduate student @ CU
- Advisor: John Cumalat
- Undergrad: Carnegie Mellon University
- REU @ CERN summer after Junior year
- Interests outside physics:
  - ski racing
  - wine
  - chocolate
- Come see me in Gamow F329!