High Energy Particle Physics

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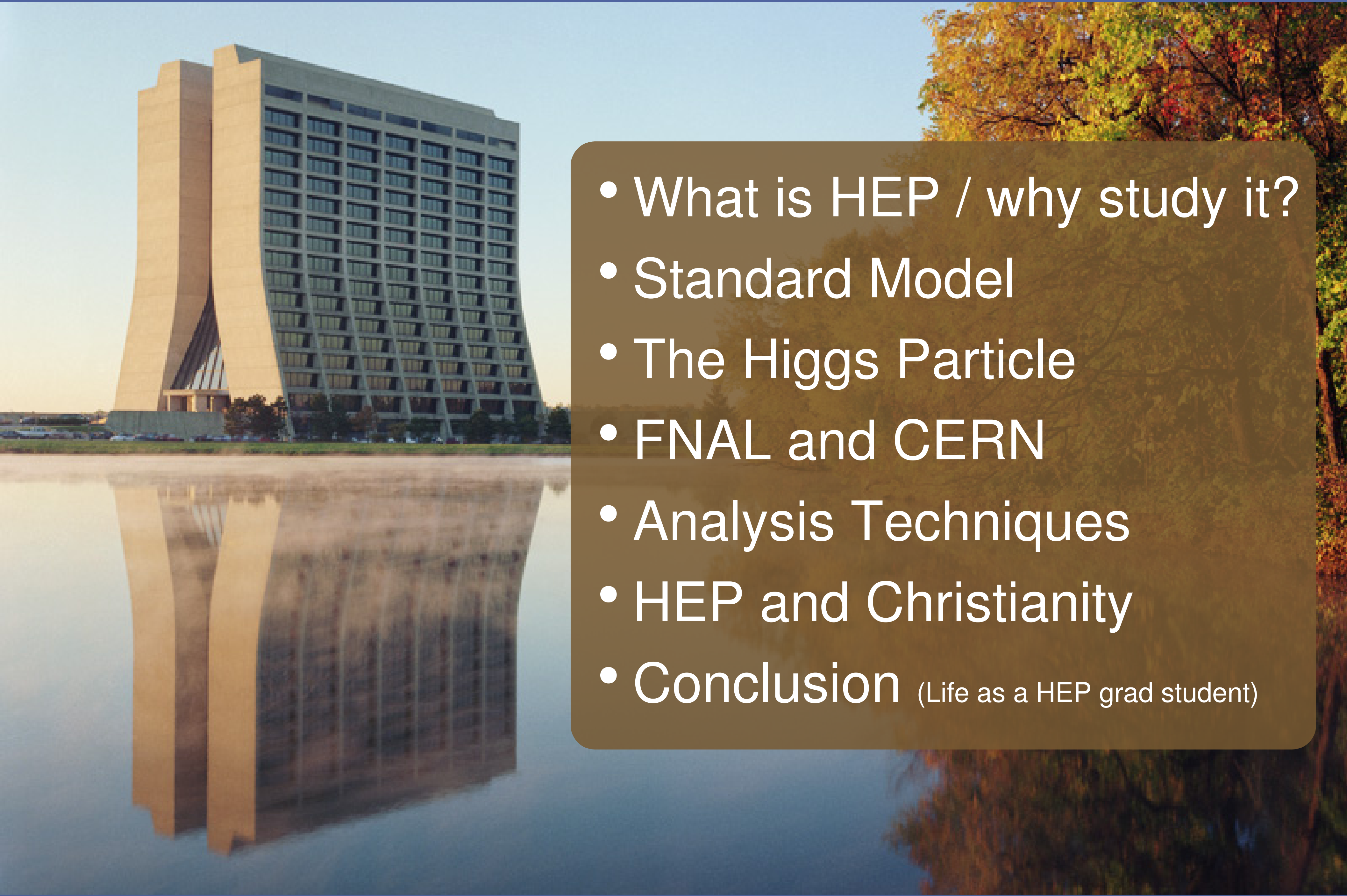
University of Michigan
CDF Experiment, FNAL



- What is HEP / why study it?
- Standard Model
- The Higgs Particle
- FNAL and CERN
- Analysis Techniques
- HEP and Christianity
- Conclusion (Life as a HEP grad student)

What is HEP?

High Energy Physics (HEP) is the study of the

- *Very* Small
- *Very* Light
- *Very* Fast

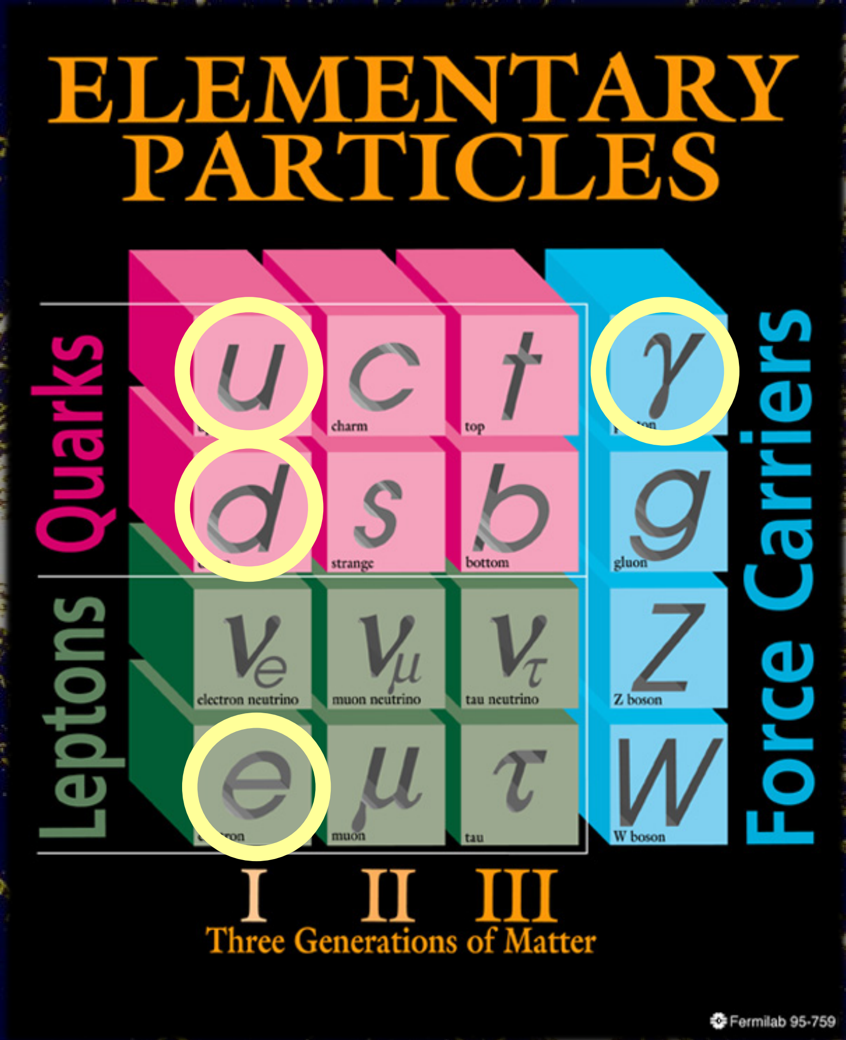
- Search for undiscovered particles
- Study particle properties

Despite our name, we don't investigate new energy sources for your car! Rather, we study the smallest particles that make up matter

Why Study HEP?

- Study *fundamentals* of physics
- What particles make up our universe?
- What interactions occur?
- Matter asymmetry (baryogenesis)
- Dark Matter? Dark Energy?
- How many dimensions are there?
- Force-carrying particles, neutrino mass, gravitons?
- Difficult cosmological questions can be studied in the lab, not just through astronomy!

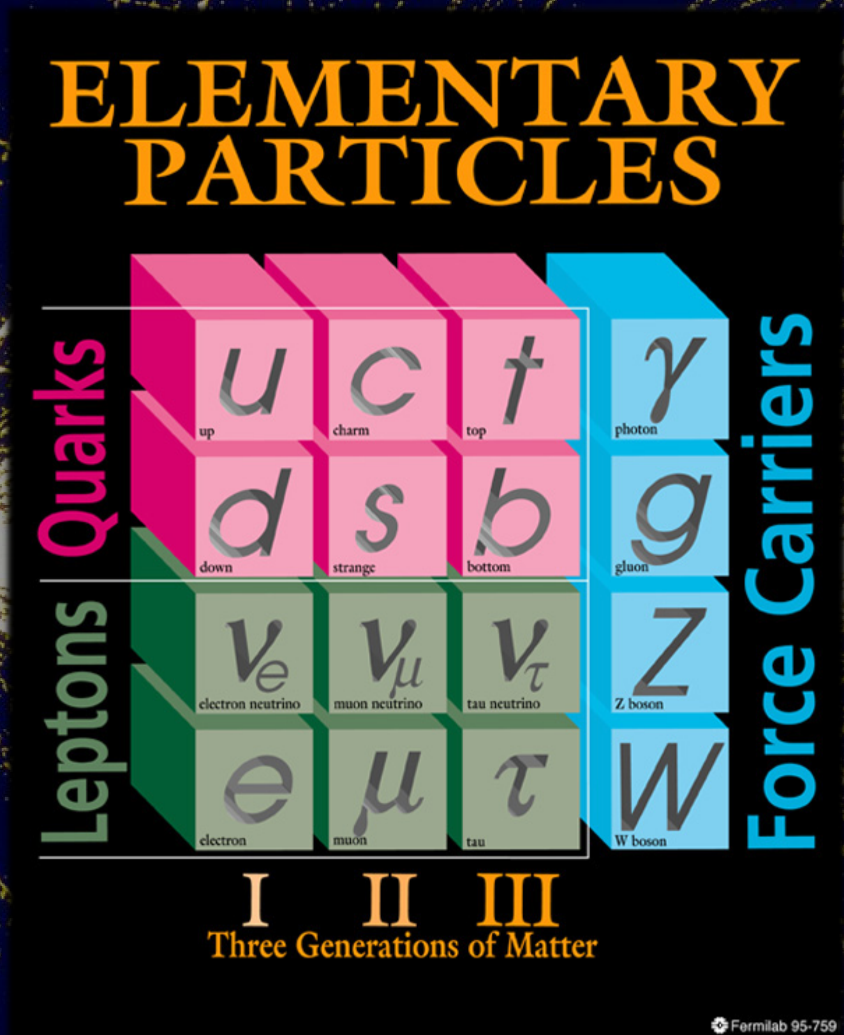
The Standard Model



The Standard Model is our current best description of the particles that make up our universe.

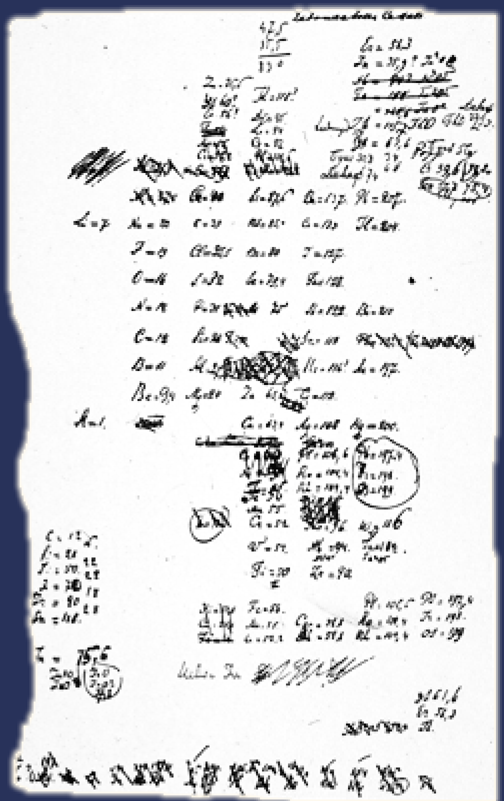
Everything you see is made up of only a few particles in this box, but the other are involved in forces or existed in the early Universe (more on that later)

The Standard Model

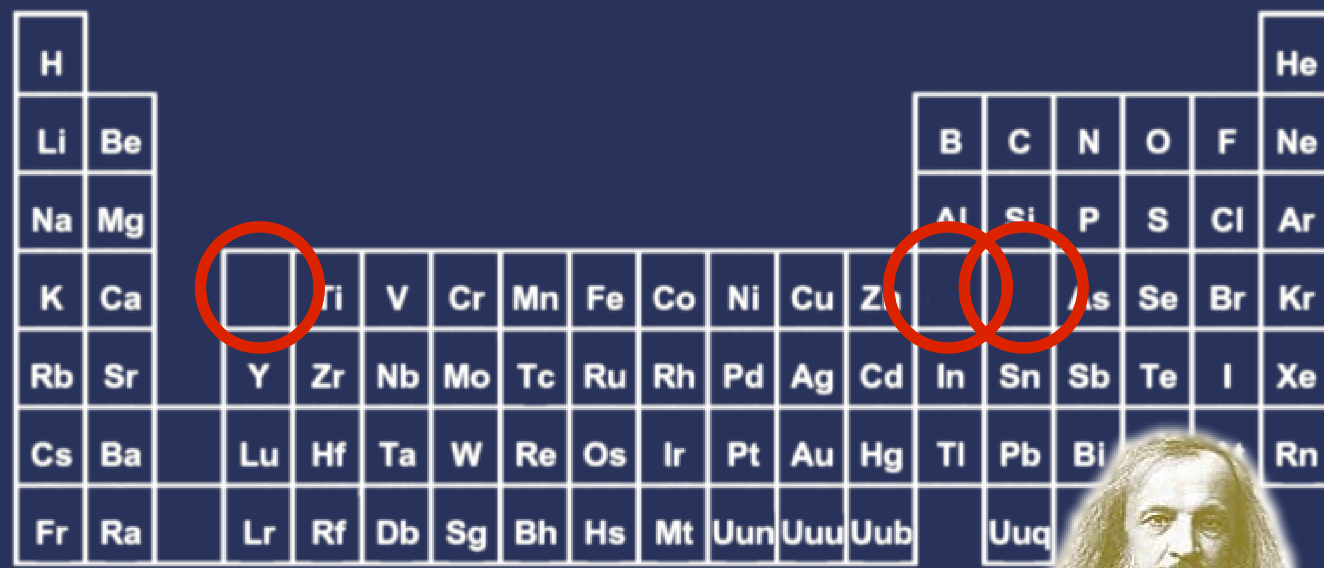


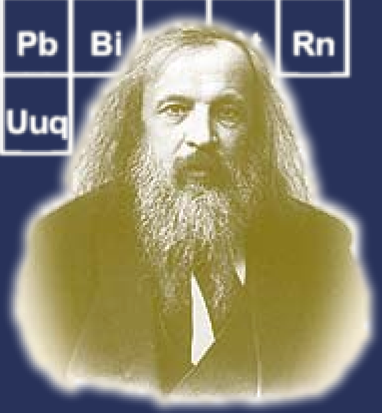
Everything here is predicted to have zero mass! We need another interaction...

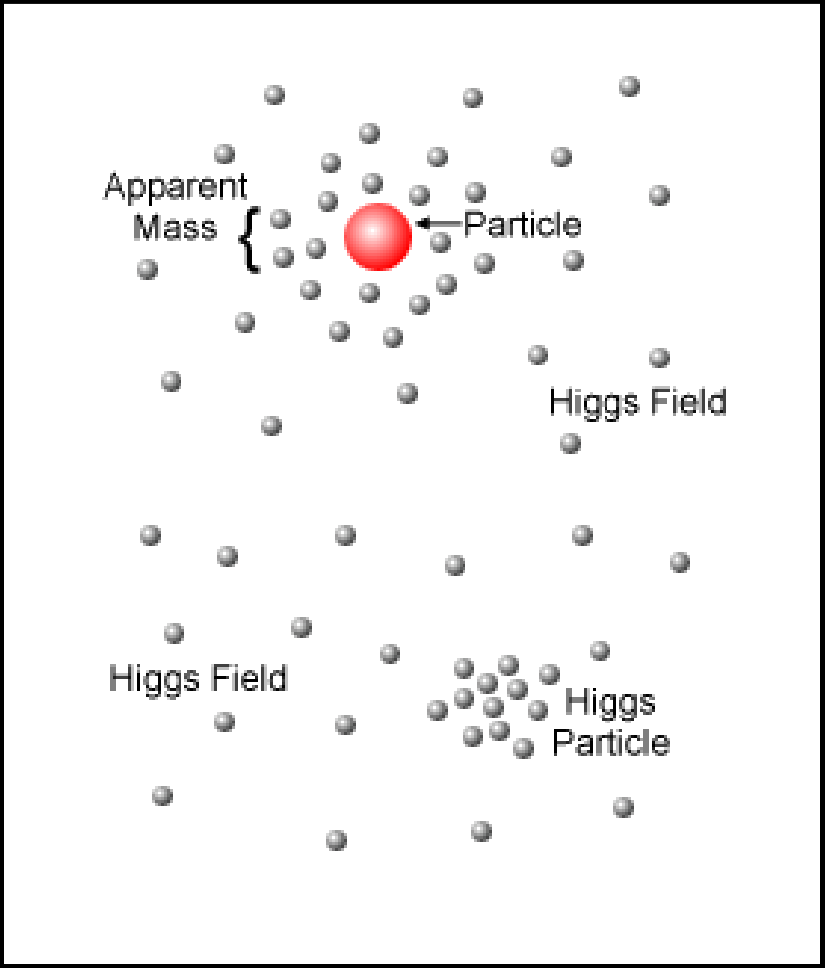
THE HIGG'S BOSON

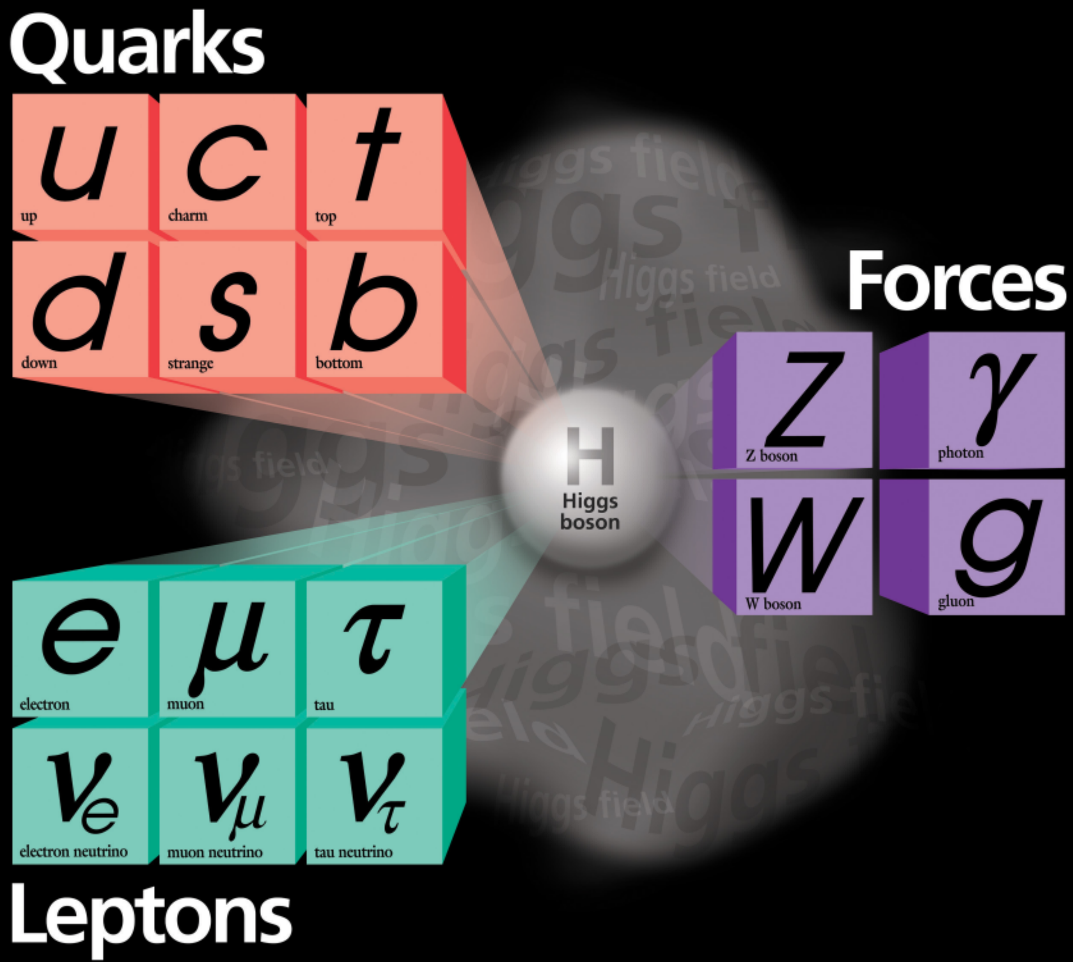


Can you tell what is missing from this table?









We need to have a Higg's field.

The Basic Method

The basic experimental method of particle physics:

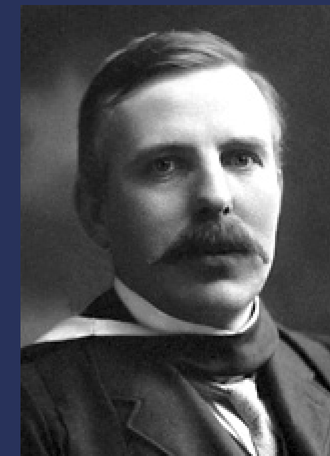
- Obtain high-speed particles
- Fire them into a target (or beam)
- Create new, exotic particle to study
- Observe outgoing particles
- Pay attention to outgoing particle types, energies, and angles.
- Compare observations with theory

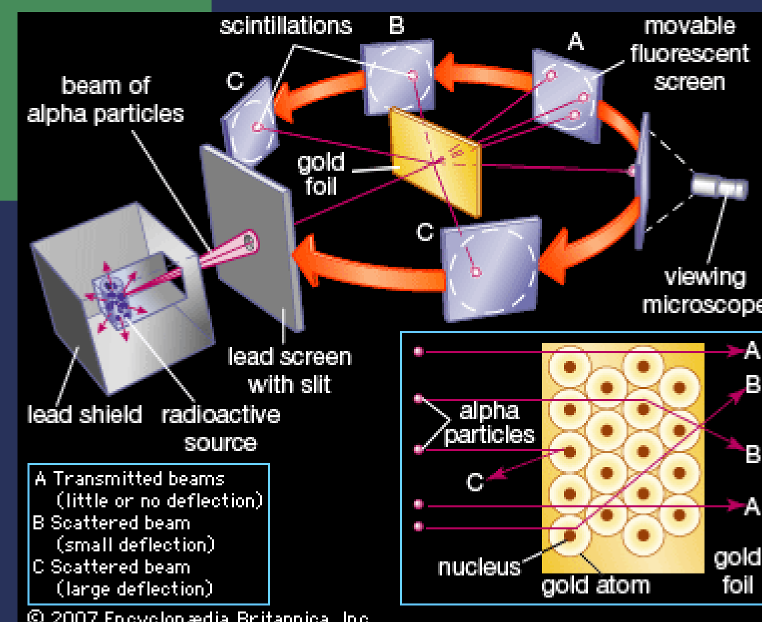
$E=MC^2$

High Energy Particles

To obtain high-speed particles...

- Early experiments used particles emitted from radioactive sources
- Cosmic rays also used
- Cathode rays (electrons)
- and...





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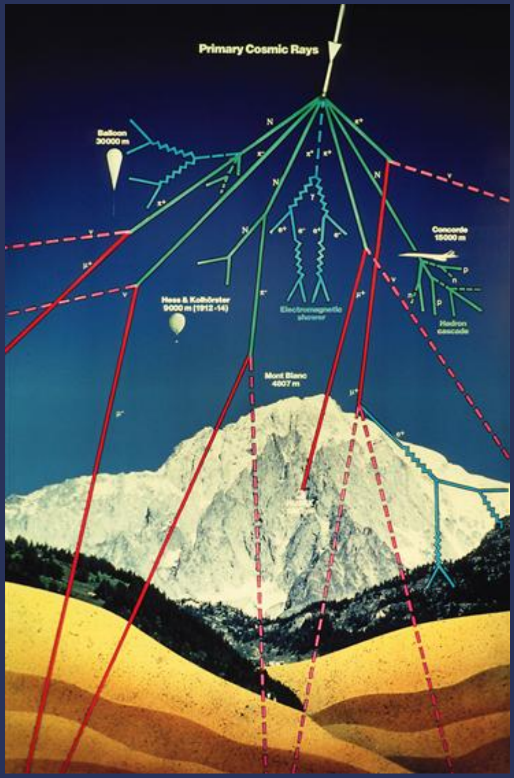

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High Energy Particles

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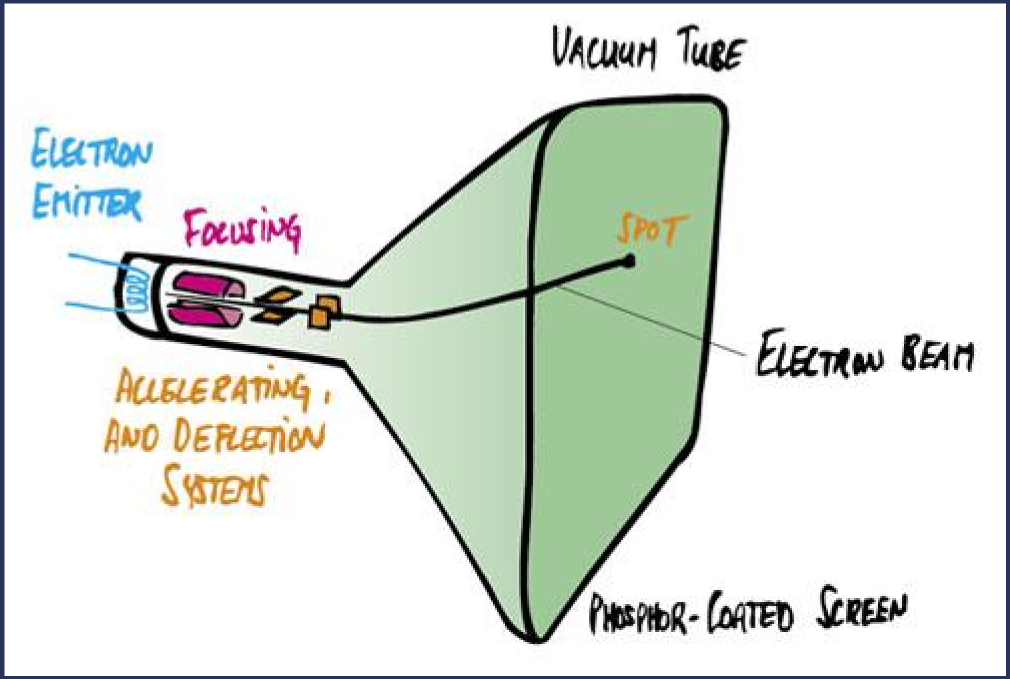
it all starts here...

Your (old) television is a particle accelerator...



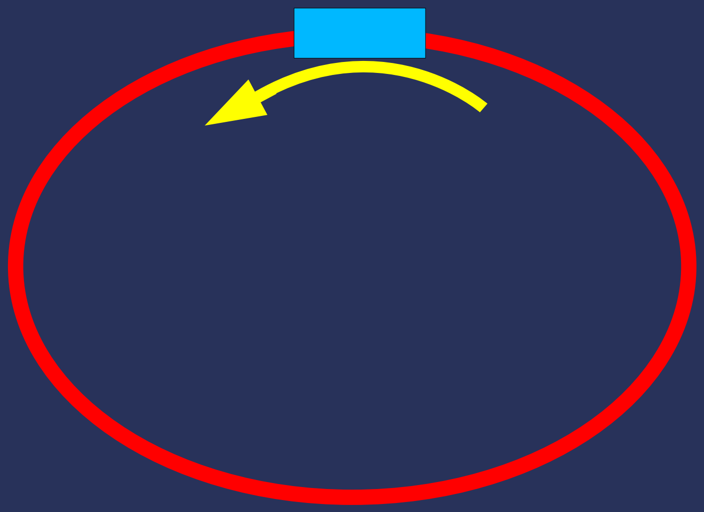
Capacitors are used to accelerate and steer an electron beam

Question: What are the rings for?

Answer: We can use the same length of accelerator to boost the particles each time they go around!

Higher energies, more efficiency, recycle particles.

The top speed of the Tevatron is 0.999999999c, so particles are going around the 4 mile loop 40,000 times a second!

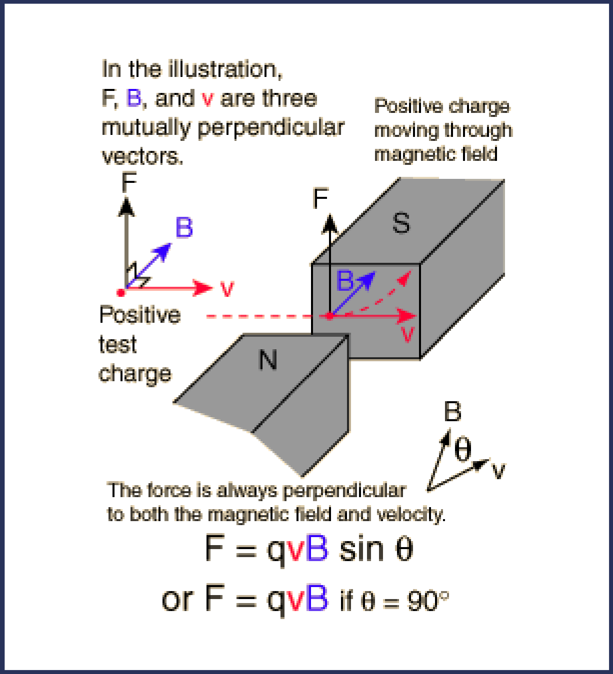


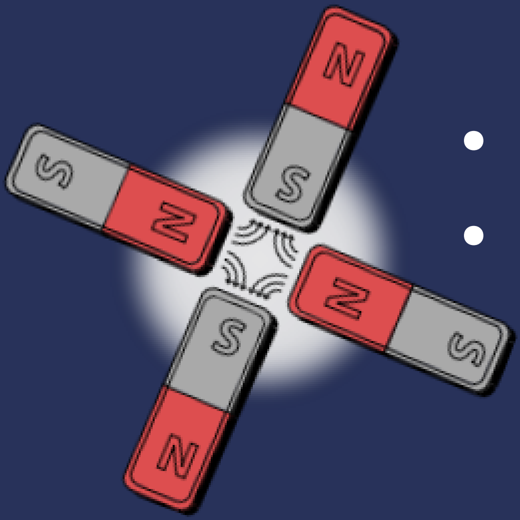
0.98 TeV = 980,000,000,000 eV

The total beam energy in the Tevatron is

≈ calories in 2 jelly donuts!

...at the LHC, the energy is much larger!





Magnetic fields cause charged beams to curve

- Dipole fields steer the beams
- Quadrupole fields focus

Question: So why does the ring need to be so big?

Answer: More energetic particles have more momentum, so we'll need either stronger bending magnets or a larger radius of curvature for the beam path.

Bigger Ring = Higher Energy Possible!

Antimatter

At the Tevatron, we use protons and anti-protons for our beams.

Anti-matter really exists – it's not science fiction!

- Most properties are same as matter (mass, spin, etc.)
- Opposite charge as matter
- Annihilate with matter – into radiation or other particle pairs

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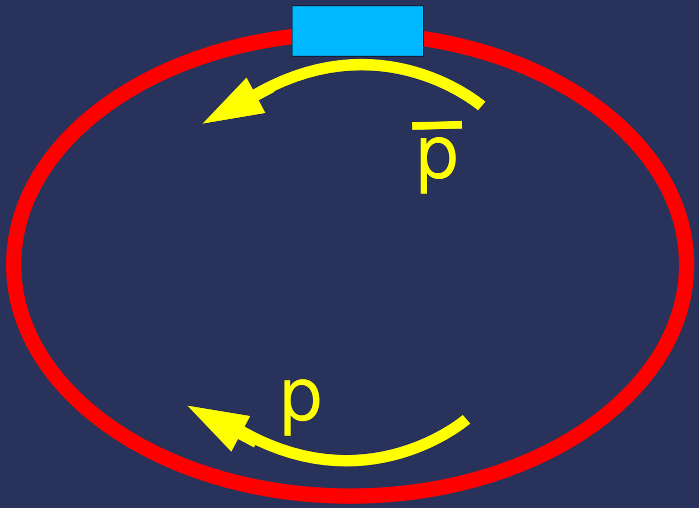
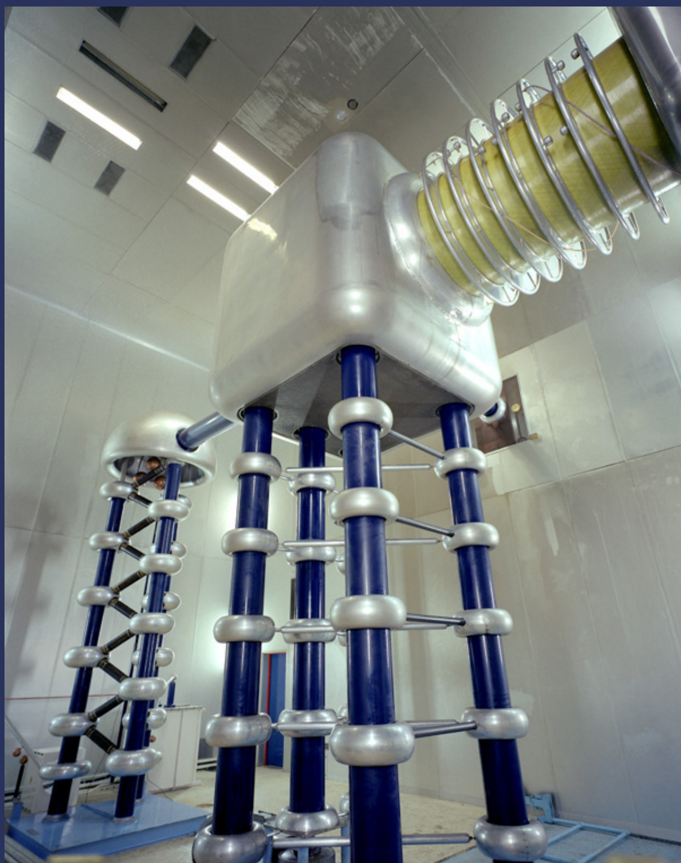
Since particles and anti-particles are oppositely charged, we can use the same magnetic field and beam pipe and have them travel in opposite directions.

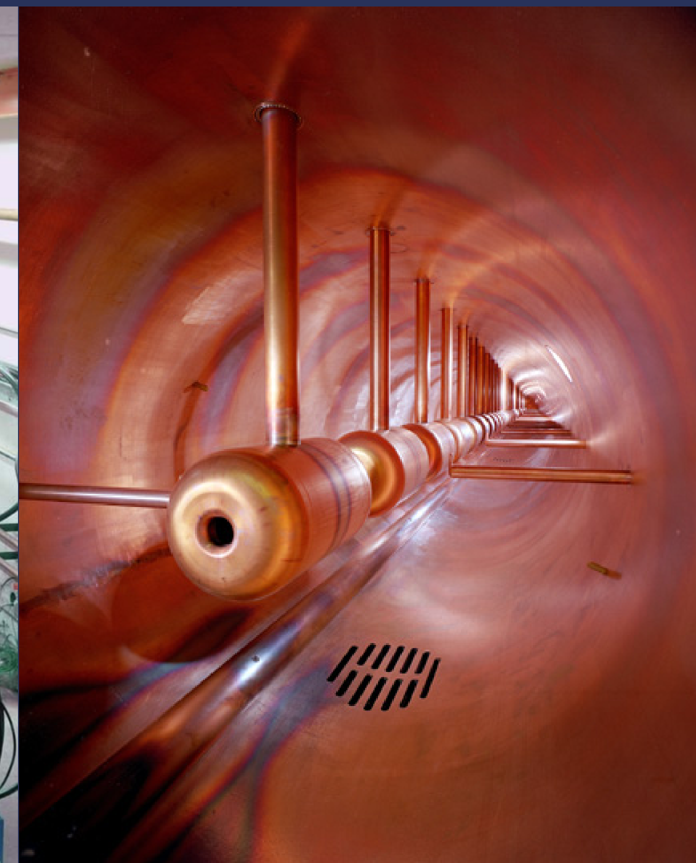


Accelerators

0 – 750 KeV

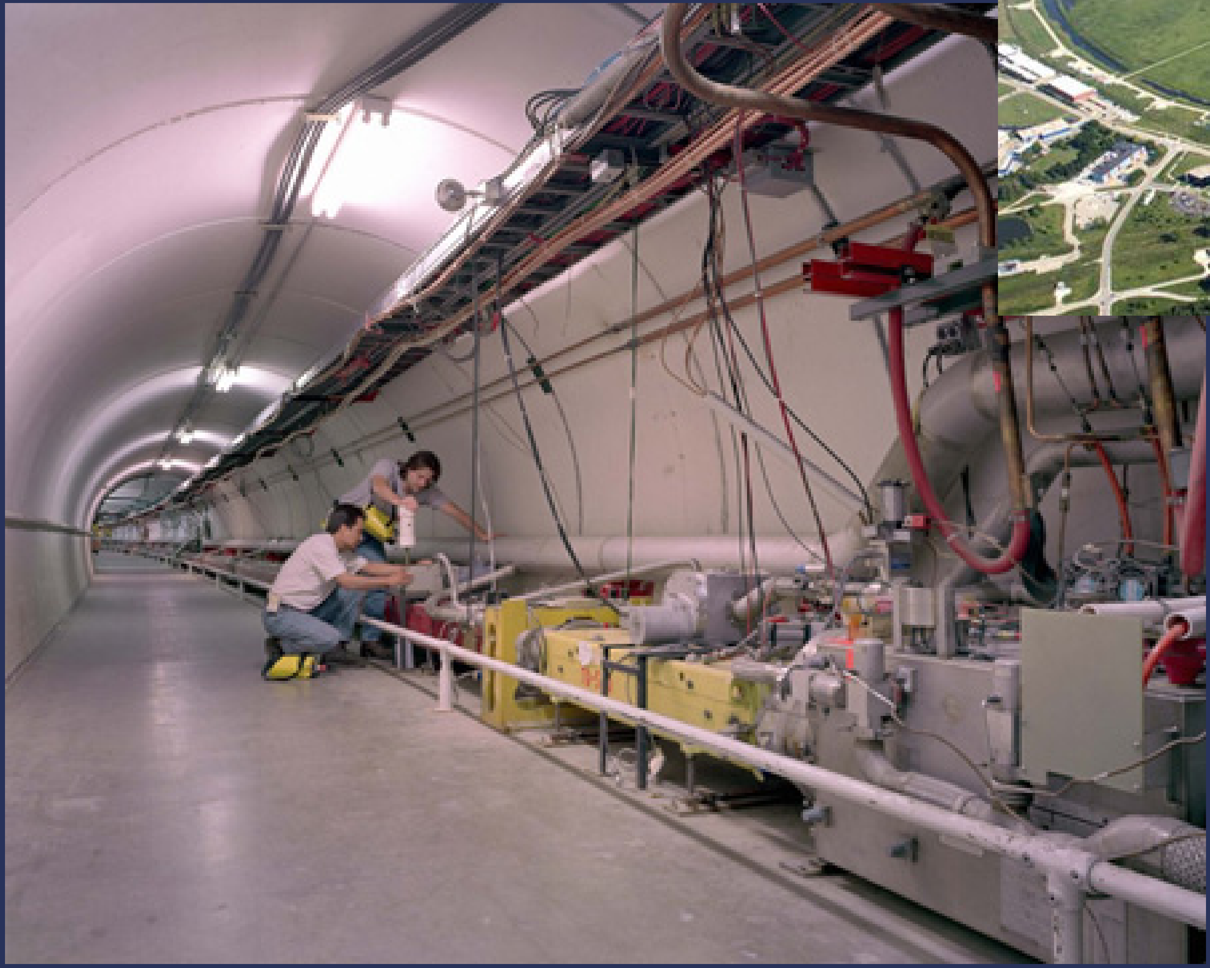


750 KeV – 400 MeV



We begin our journey with electric (RF) fields and linear acceleration...

The Tevatron



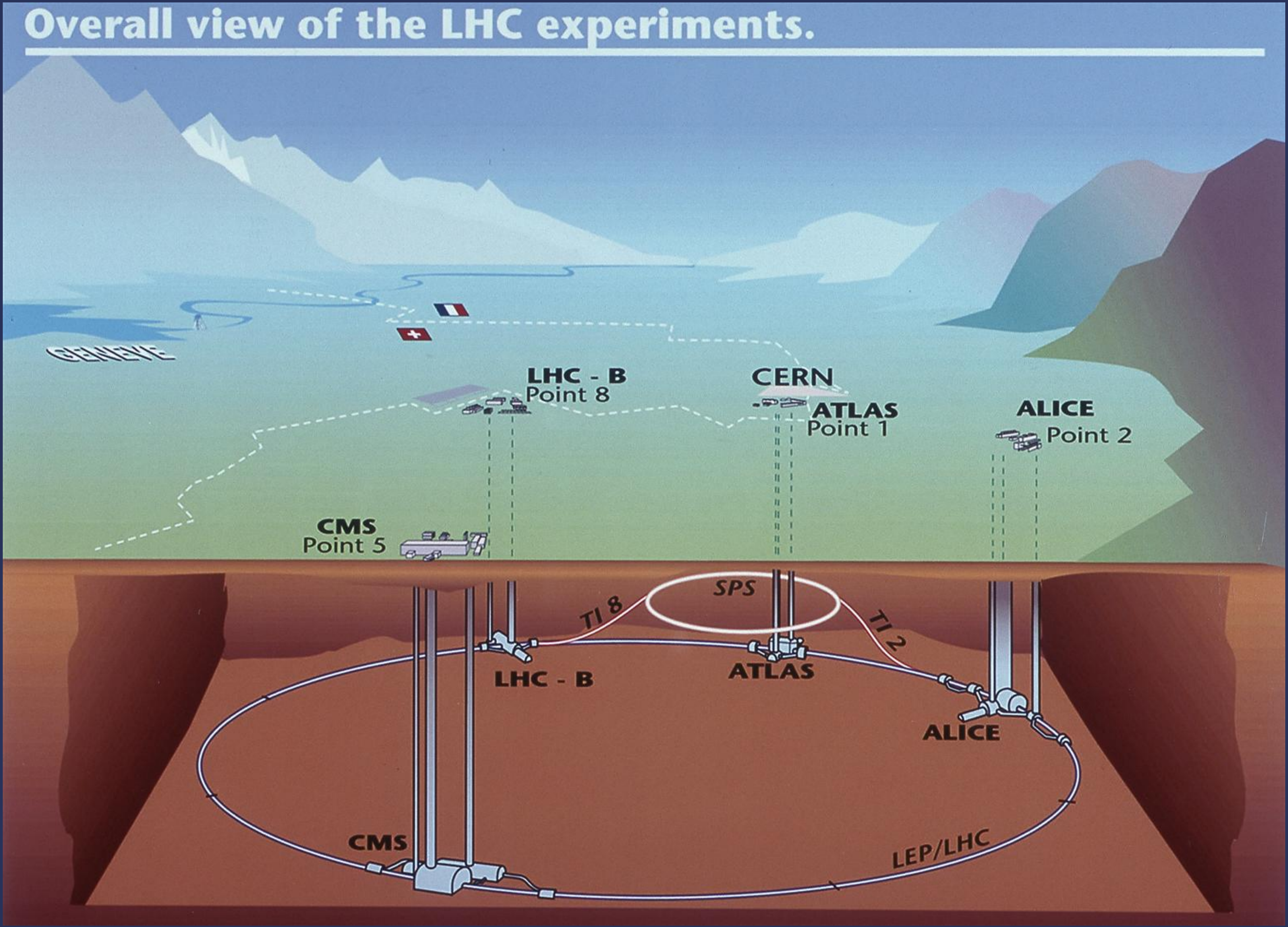
4 miles around

30 feet underground

The Tevatron

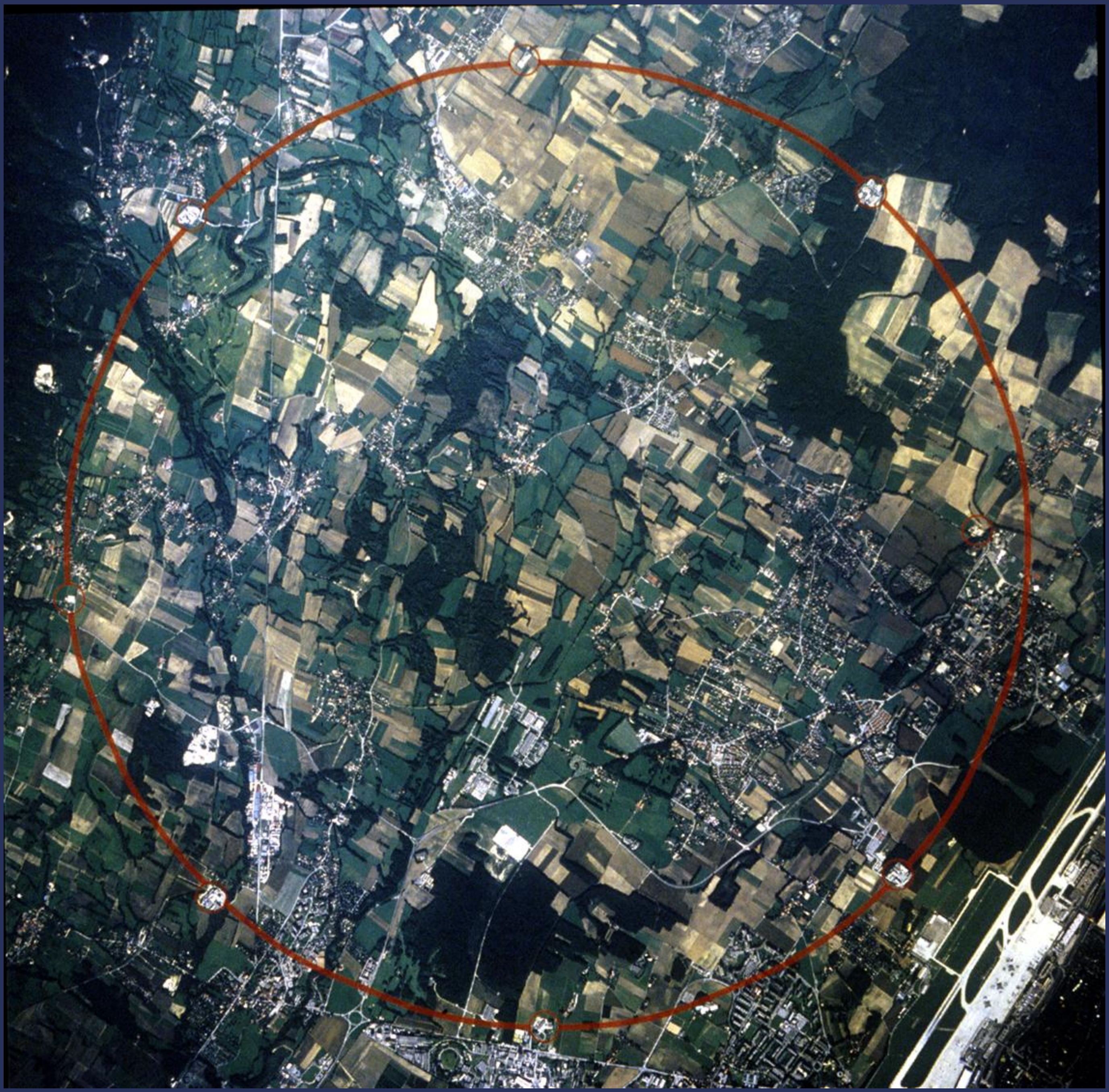
Scientists in the main control room manage the high energy beams of protons and anti-protons.

CERN / LHC



Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

CERN / LHC



17 miles around – over 4 times larger than the Tevatron

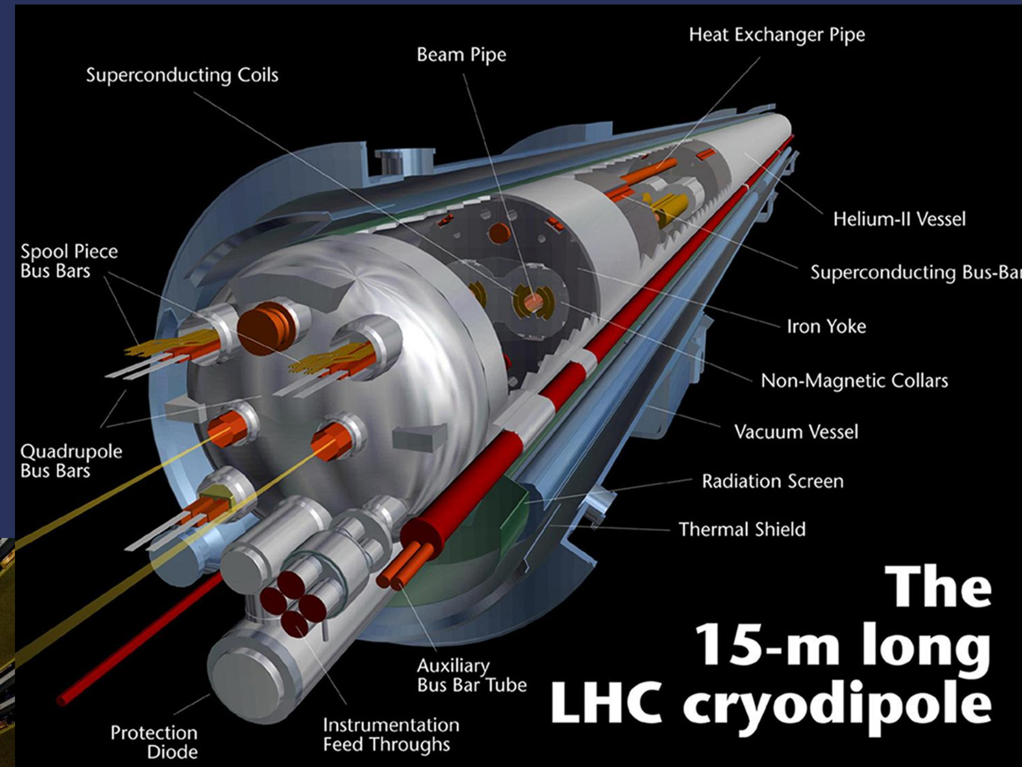
Proton-on-proton, so no anti-matter like at Fermilab

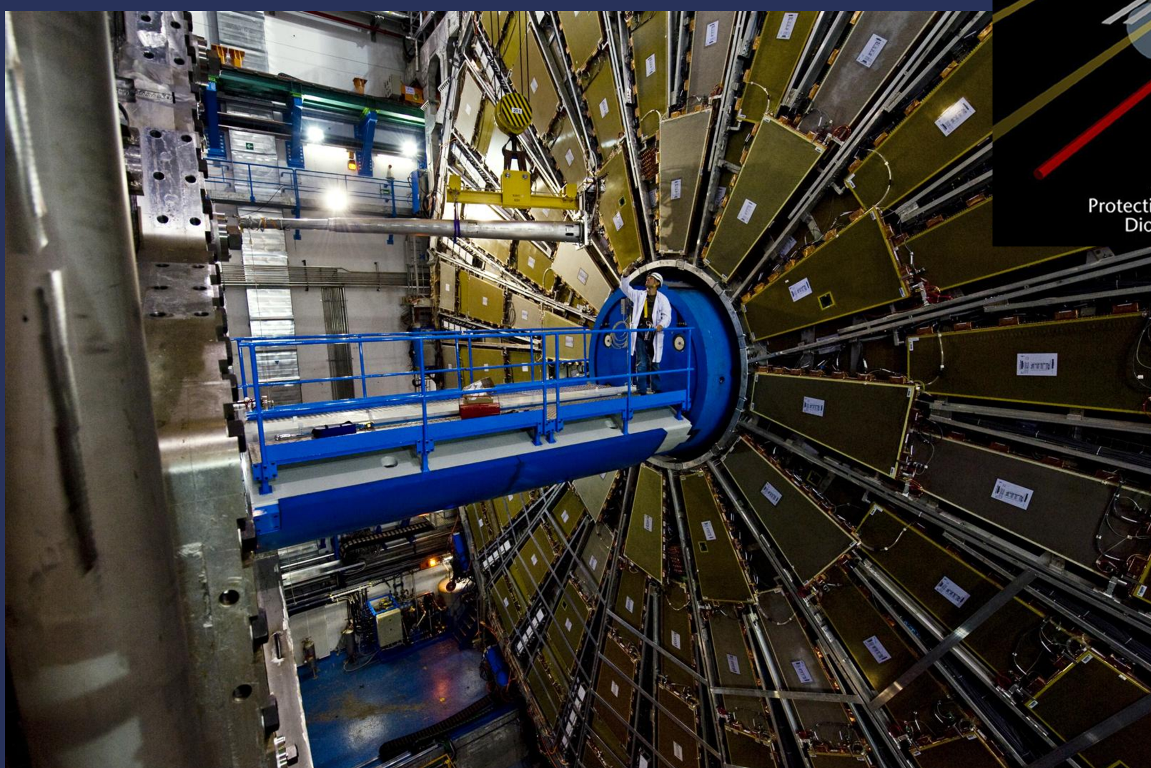
Beam energy will be a 14TeV interaction, over 7 times the energy of the Tevatron.

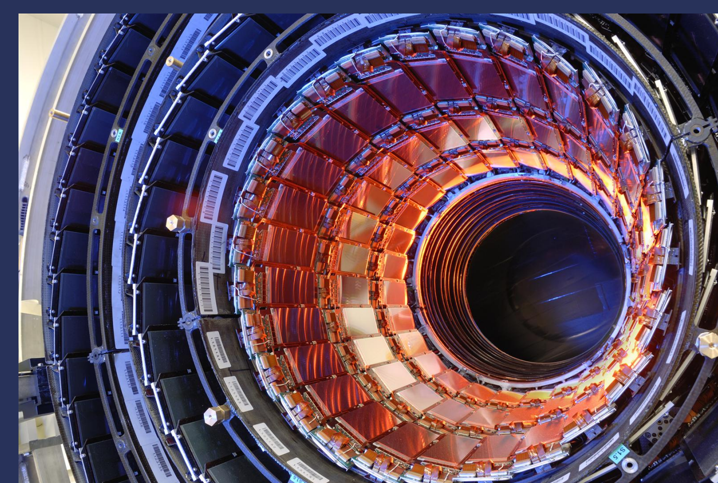
CERN / LHC

Bigger energies require larger magnetic fields and careful planning to avoid accidents.

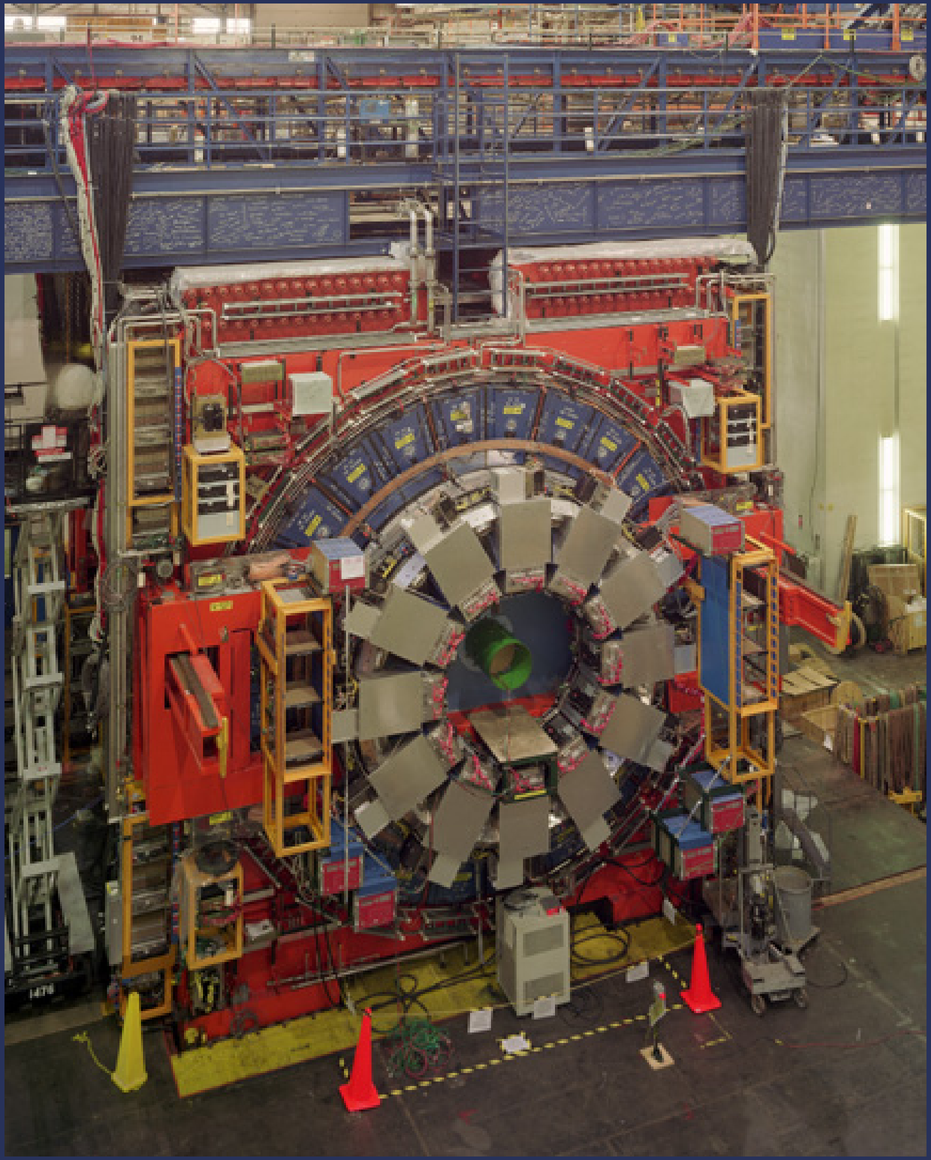
The detectors are bigger-and-better, too, and designed to carefully track muons for Higgs searches.

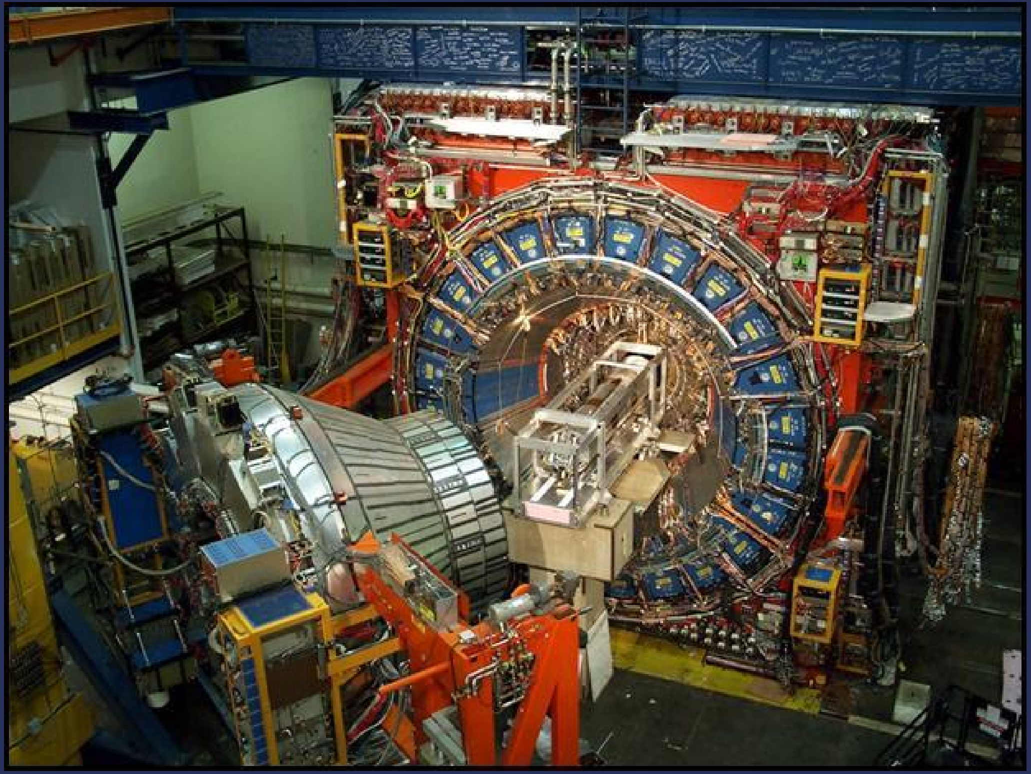




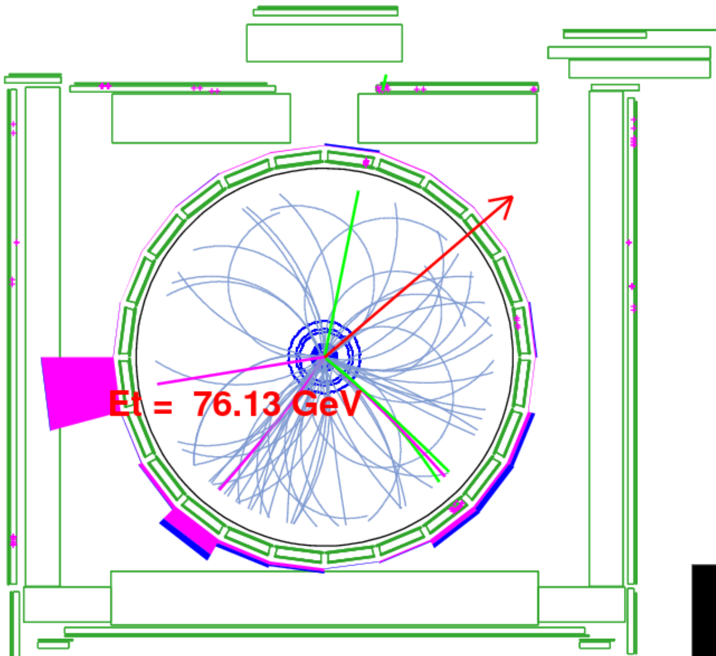


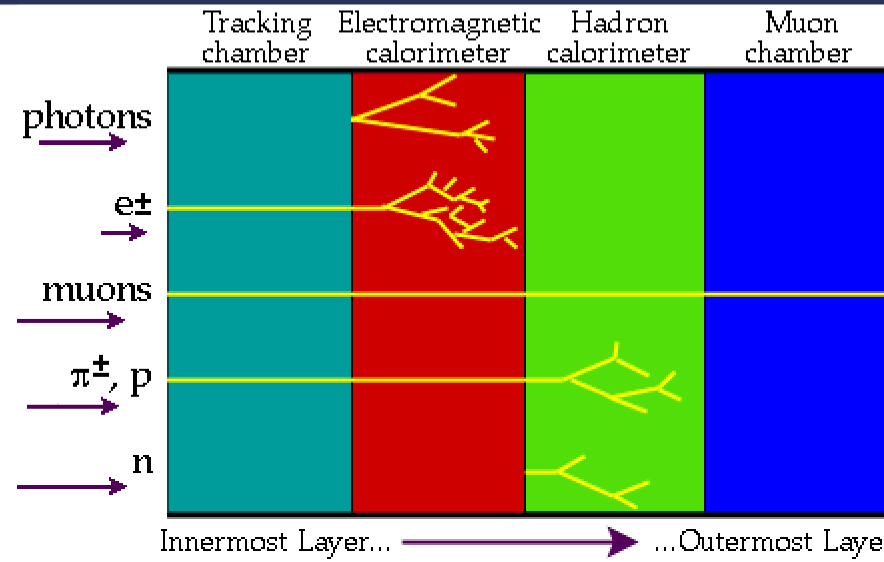
Detecting Particles

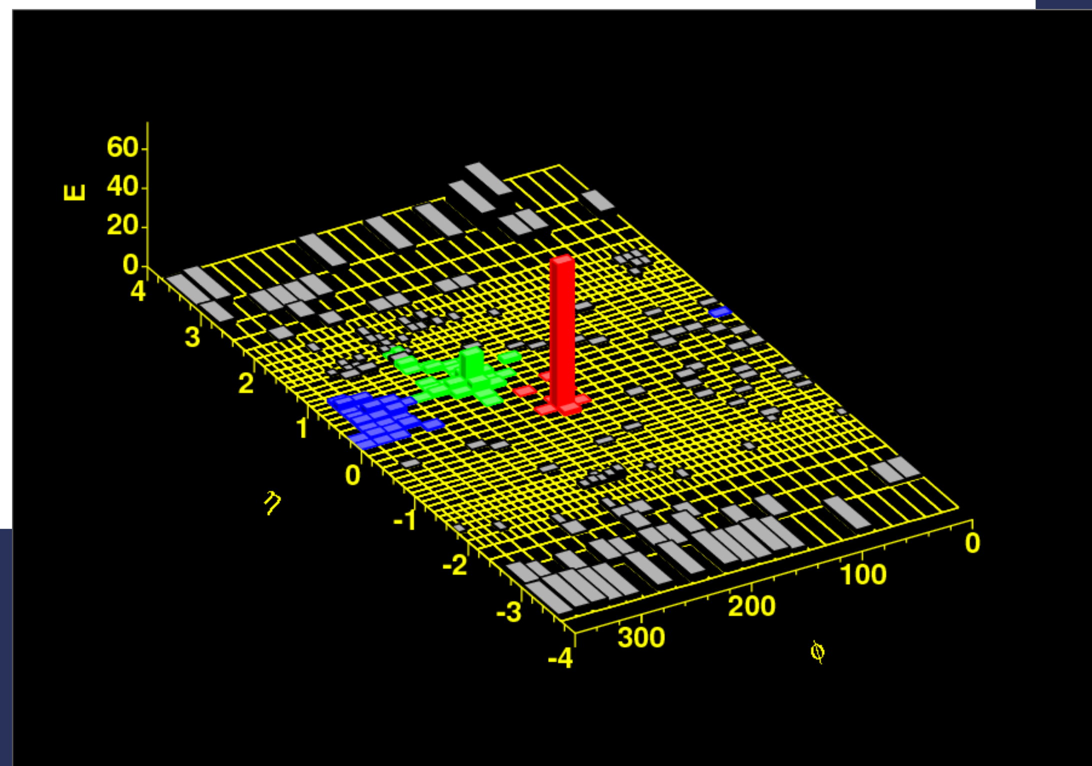




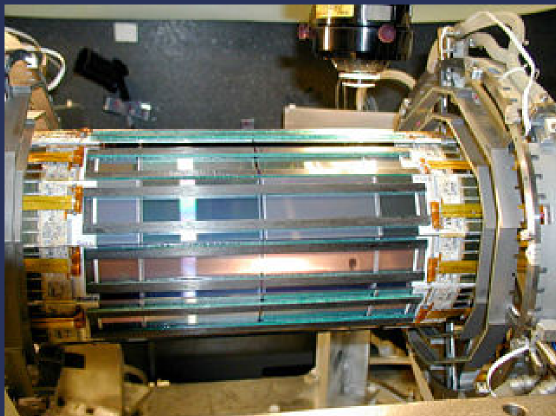
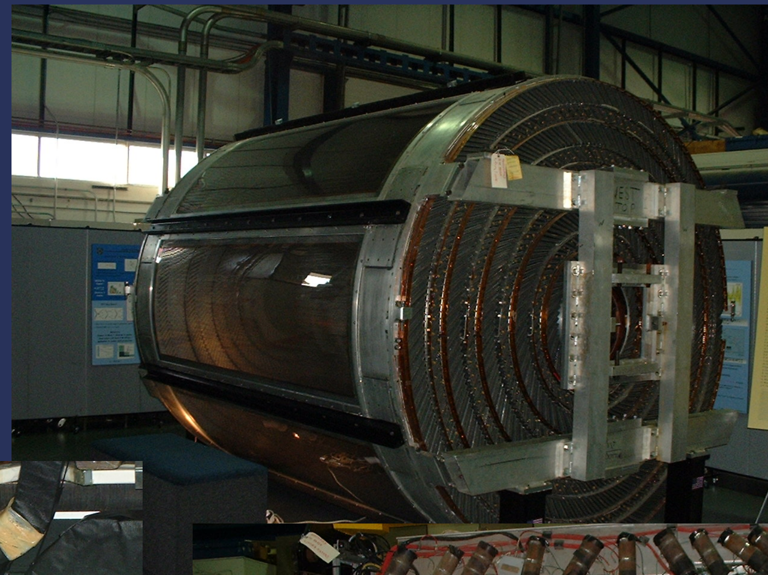
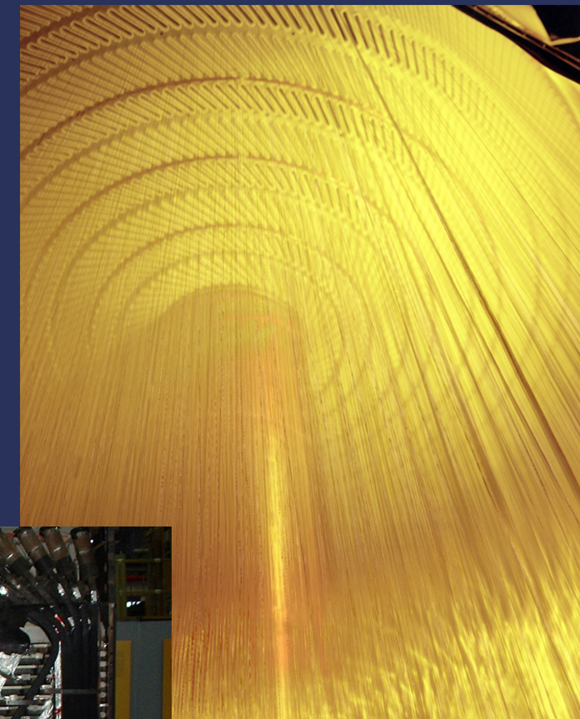
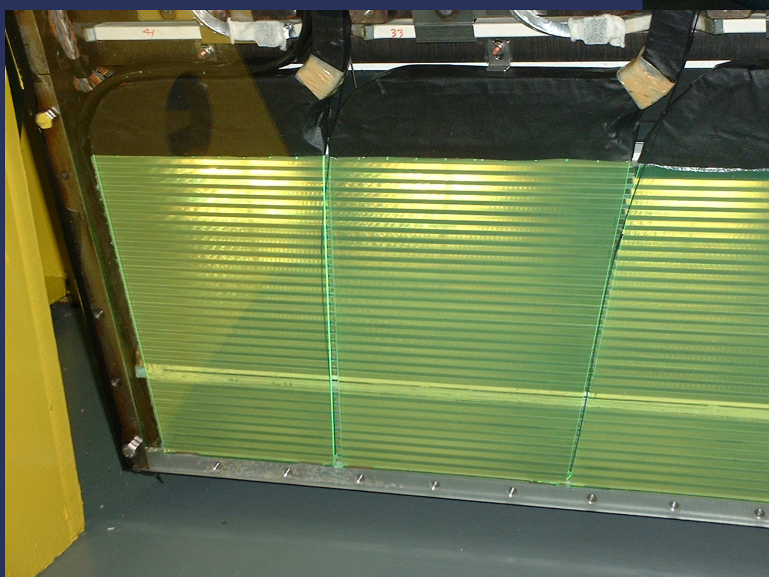
CDF


Et = 76.13 GeV


Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer


E
60
40
20
0
4
3
2
1
0
-1
-2
-3
-4
η
0
100
200
300
φ

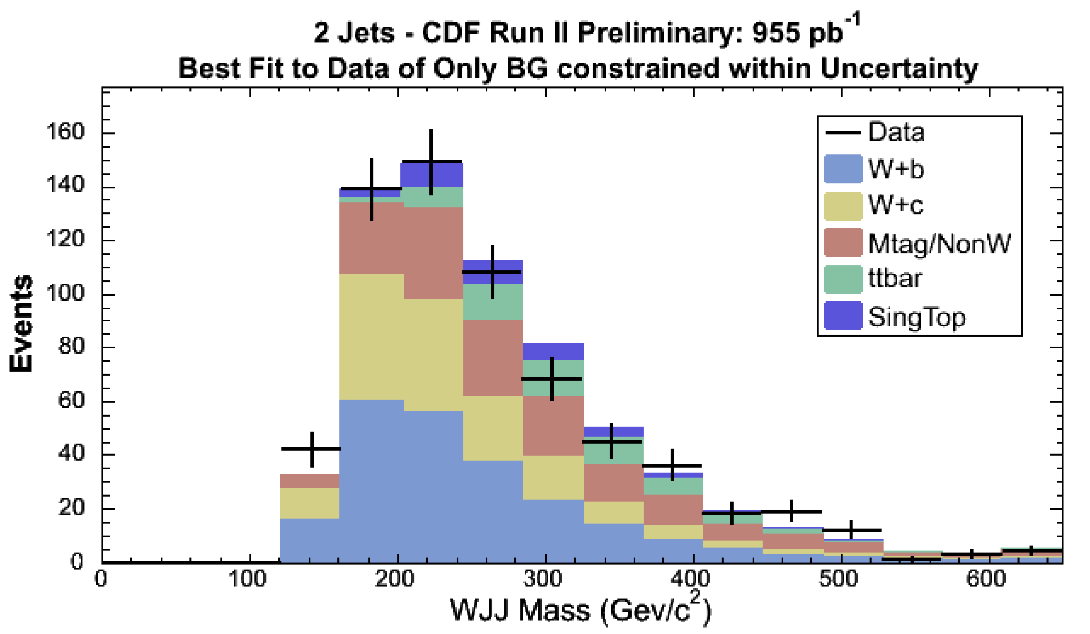
CDF

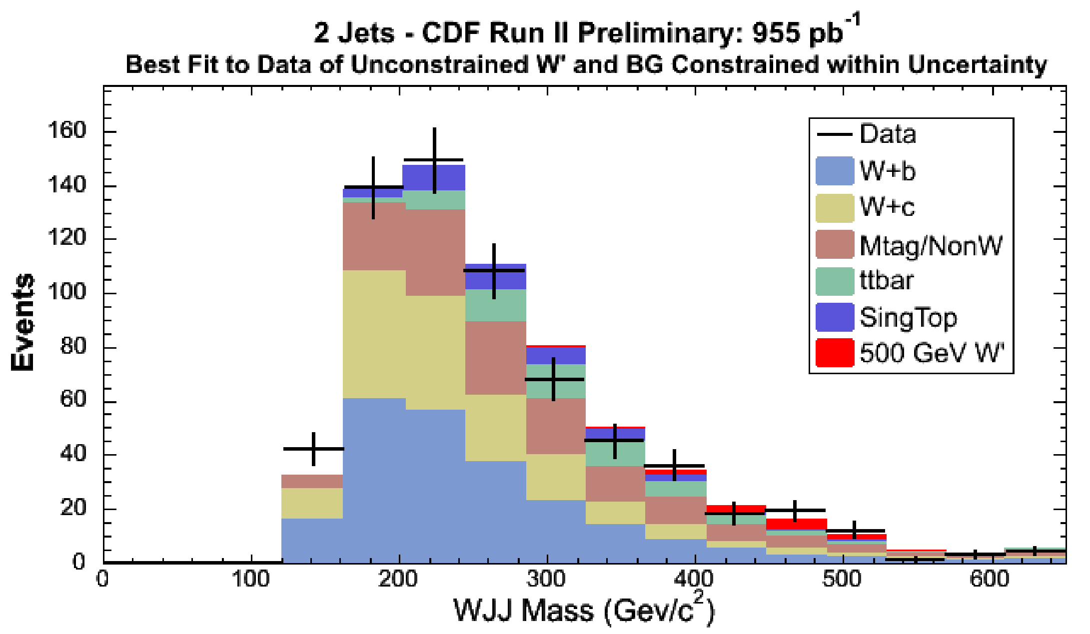






Here are several parts of the CDF detector

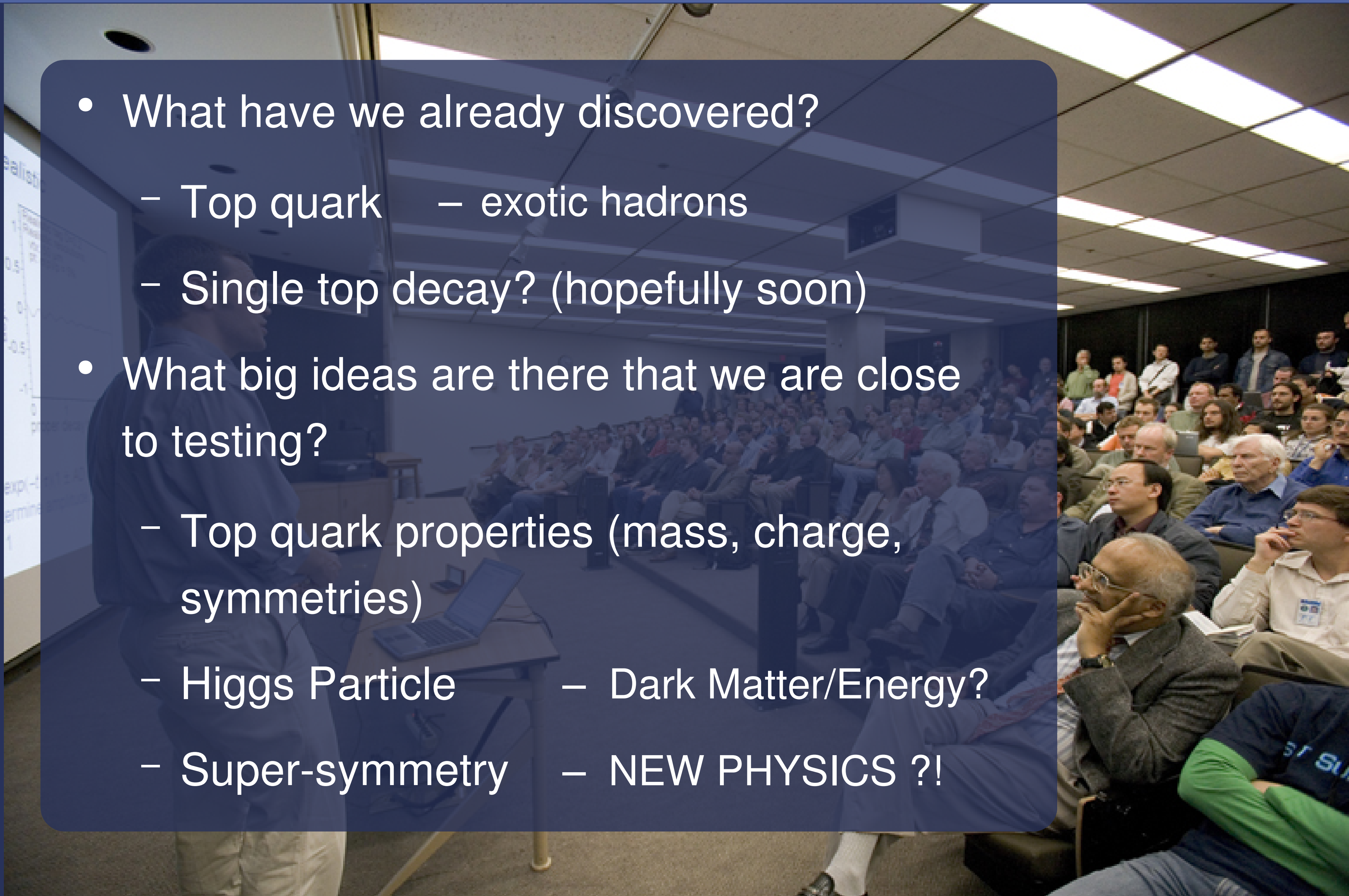
Analysis Techniques

- Analysis is like doing a Google search for events meeting certain criteria
- Plot variables relevant to our study
- Understand backgrounds!
- Model what we already know.
- Look for differences between data and simulation
- Requires LOTS of STATISTICS



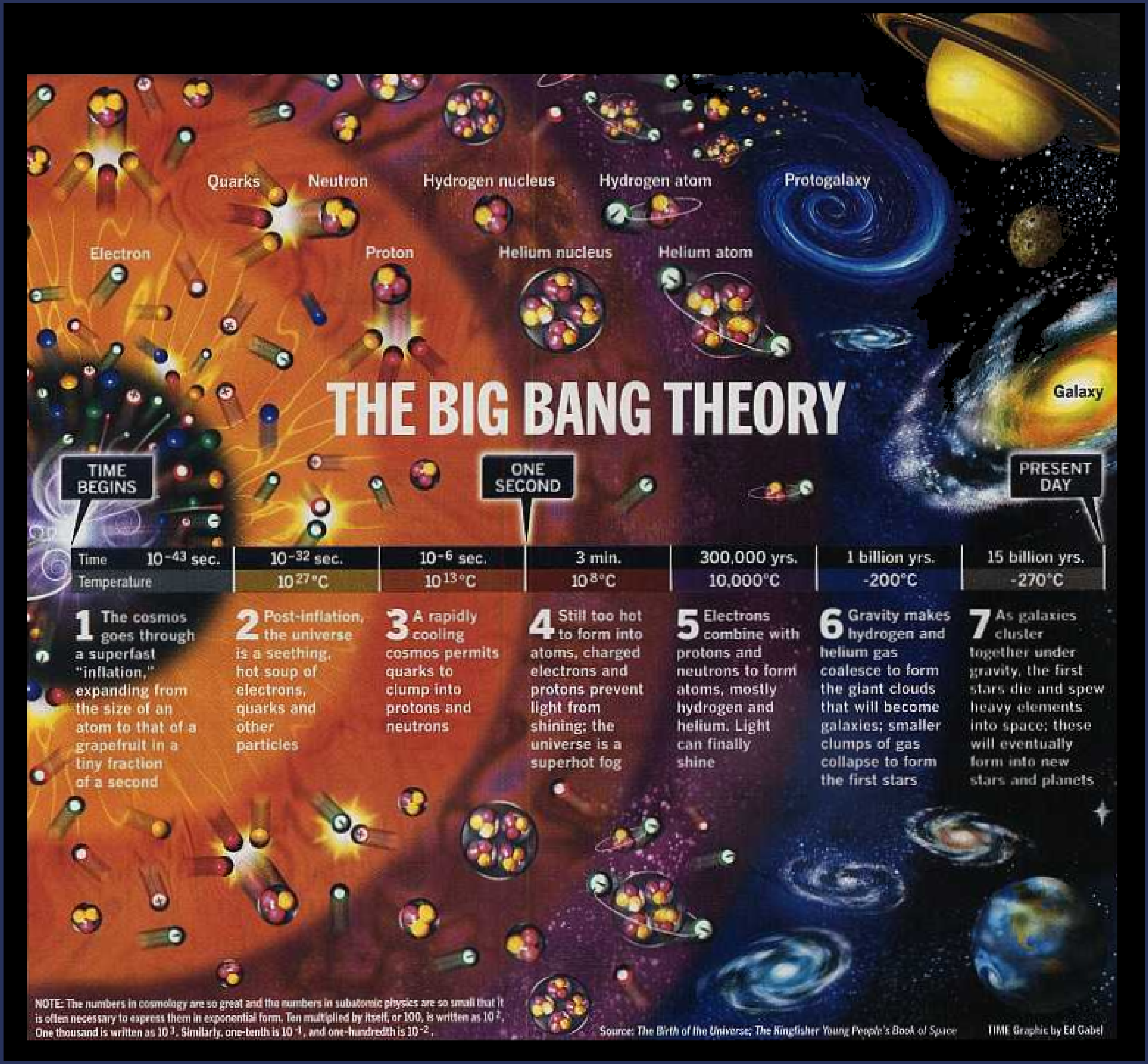


New Discoveries on the Horizon



- What have we already discovered?
  - Top quark
  - exotic hadrons
  - Single top decay? (hopefully soon)
- What big ideas are there that we are close to testing?
  - Top quark properties (mass, charge, symmetries)
  - Higgs Particle
  - Dark Matter/Energy?
  - Super-symmetry
  - NEW PHYSICS ?!

HEP and Christianity



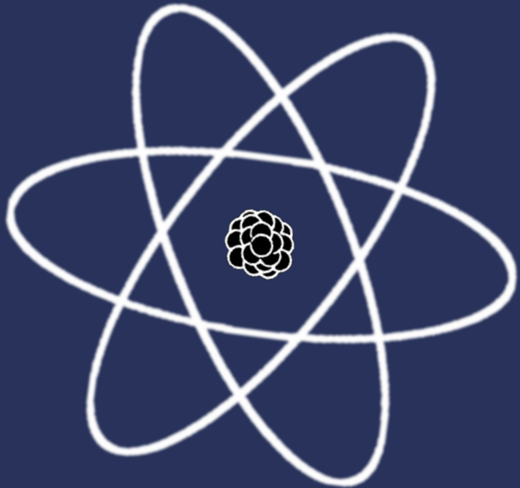
Hmm. . .

is this a problem?

HEP and Christianity

What kinds of issues could one face as a Christian in HEP?

- Big Bang Cosmology / Age of Universe
- Antimatter, dark matter, extra dimensions???



The biggest challenge is just being a Christian around atheist friends, demonstrating that it is possible to be a Christian and do good physics. Many of my coworkers are foreign, and our field offers unique missionary opportunities.

Conclusion

So, do you think you might be interested in studying experimental particle physics in graduate school? Here are a few negatives and positives my friends and I have found:

- the physics can be difficult
- involves a lot of computer programming
- language barriers can be frustrating
- collaborations are very large
- funding / politics / the future

- it's easy when you have the tools, people, and resources
- involves a lot of computer programming!
- great diversity!
- Collaborations are tight knit communities and are enjoyable!
- CERN is almost ready for the LHC – new discoveries on the horizon!

The End