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High Energy Physics @ PUC

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Eternal Questions

What the world is made of?

and…

What holds it together?

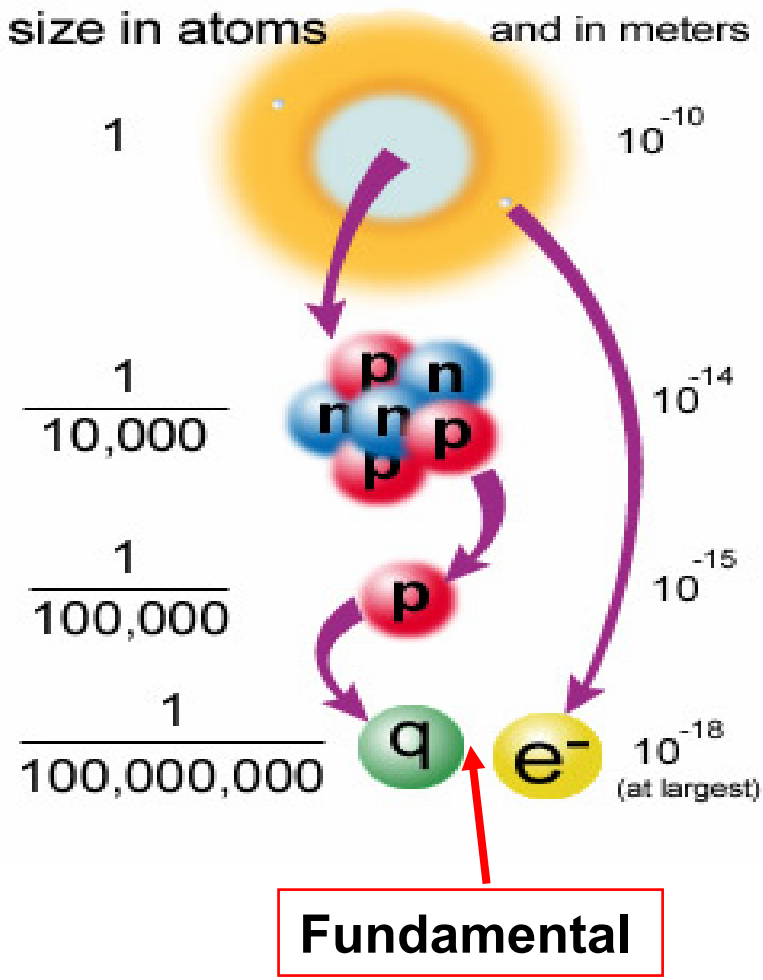
This is High Energy Physics – Pure Science

Historical Perspective

What is Fundamental?

- Objects that are simple and structureless
- Around 1900 A.D. “atom” was thought of as fundamental
- Found that the atom had a tiny, dense positive nucleus and a cloud of negative electrons
- Nucleus made of protons and neutrons discovered
- Protons and Neutrons composed of even smaller particles, called quarks

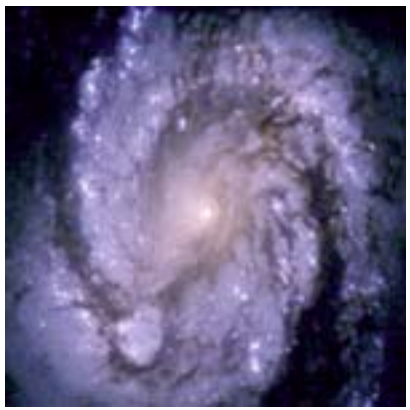
Modern Atom Model



Everything..

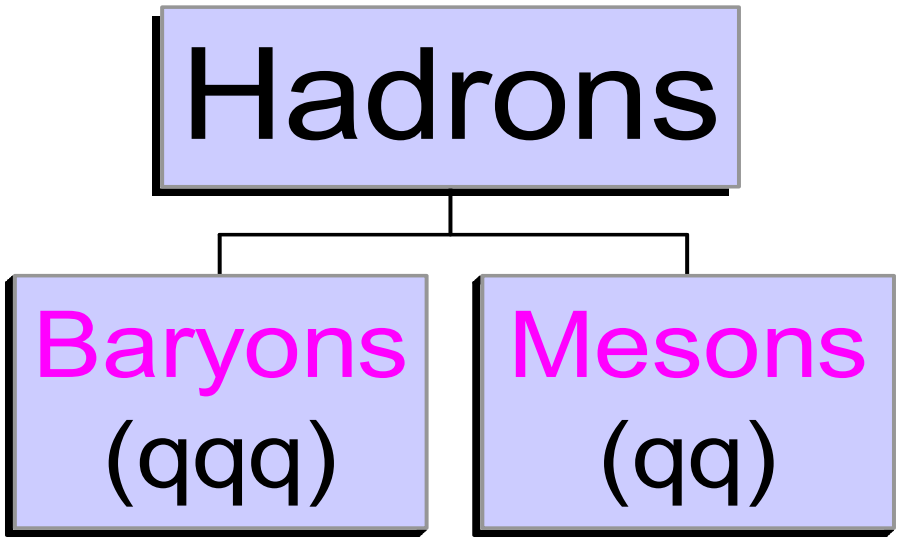
From galaxies to mountains to molecules made from

QUARKS and LEPTONS



- Quarks behave differently from Leptons
- Every particle has an anti-particle

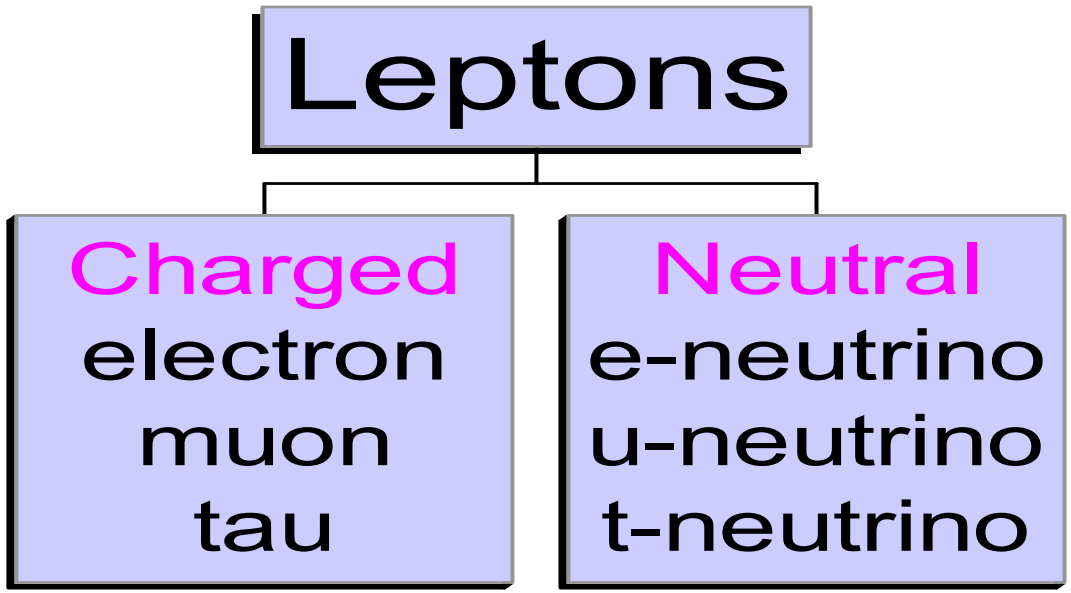
Quarks: point-like confined



Peculiar feature of hadrons

- A very small part of the mass is due to the quarks in it
- Most of the mass is due to the kinetic and potential energy ($E = mc^2$)

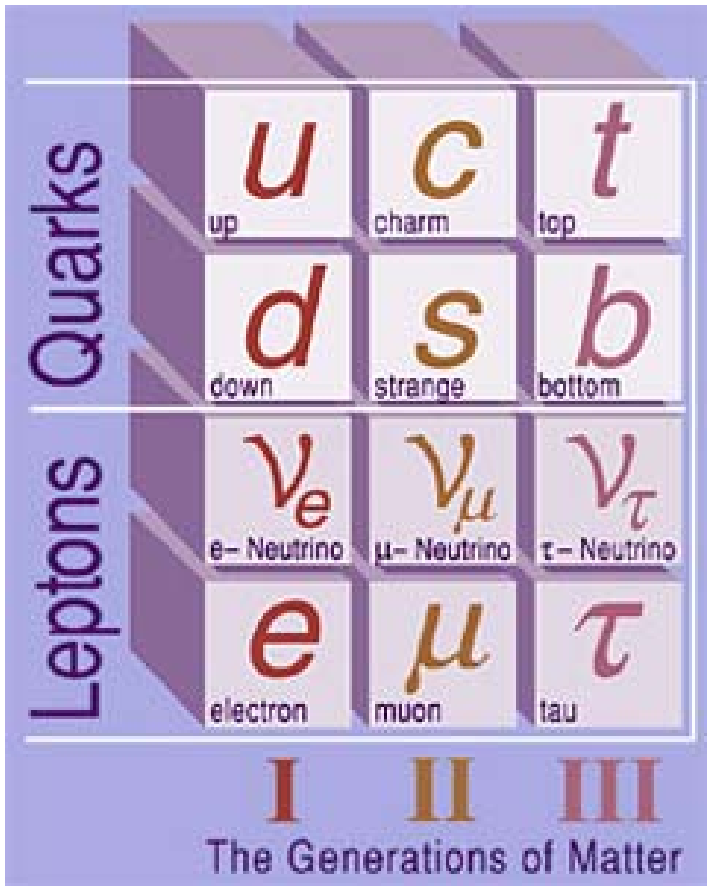
Leptons: point-like free



Peculiar feature of leptons

- **Lighter leptons:** e and the three neutrinos are stable, hence observed
- **Heavier leptons:** muon and tau will decay into lighter leptons and hence not directly observed

Fundamental Particles



Charge

+2/3

-1/3

0

-1

Mass →

What holds Quarks and Leptons ?

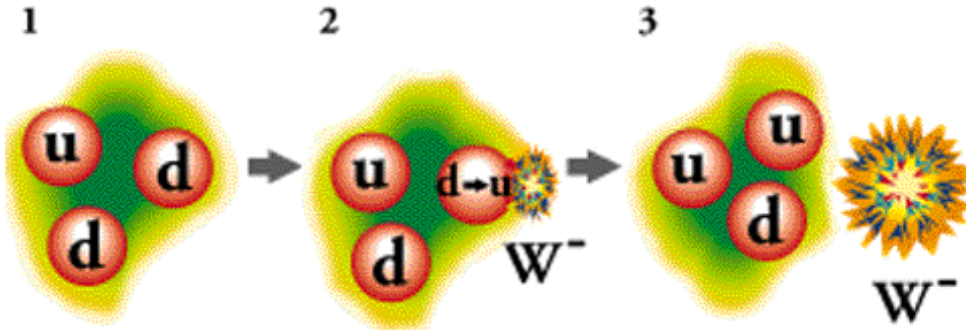
- **What holds the nucleus and electrons together in an atom?**
  - **ELECTROMAGNETISM**
    - **In the atom the electron and nucleus are held together by exchanging photons**
    - **Charged objects interact by exchanging photons-the carrier of electromagnetic force**
    - **Light is a manifestation of electromagnetic force**

Contd…

- Why doesn't the nucleus - full of positive protons that repel one another and neutral neutrons - blow itself apart?
  - STRONG FORCE
- Well it turns out quarks have another quantum number or charge called "color charge"
- The force between these color charges is extremely strong
- Two quarks interact by exchanging the strong carrier called "gluon"

The Weak Force

- Radioactivity is a manifestation of the weak force
- At the quark level, d quark in the neutron decays into an u quark, by emitting a W particle



- <u>The heavy W particle is the carrier of the weak force</u>

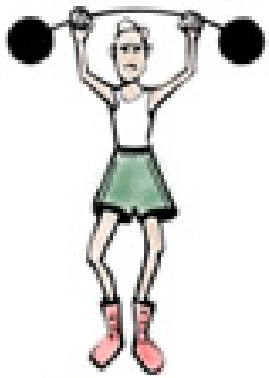
There are three weak carriers W^+,W^-, and Z^0
Discovered in 1983

Gravity

- Although a deep understanding of gravity has been around the longest it is not understood at the carrier level.

- The graviton, the carrier of gravitational force has not been discovered.

Summary of Forces

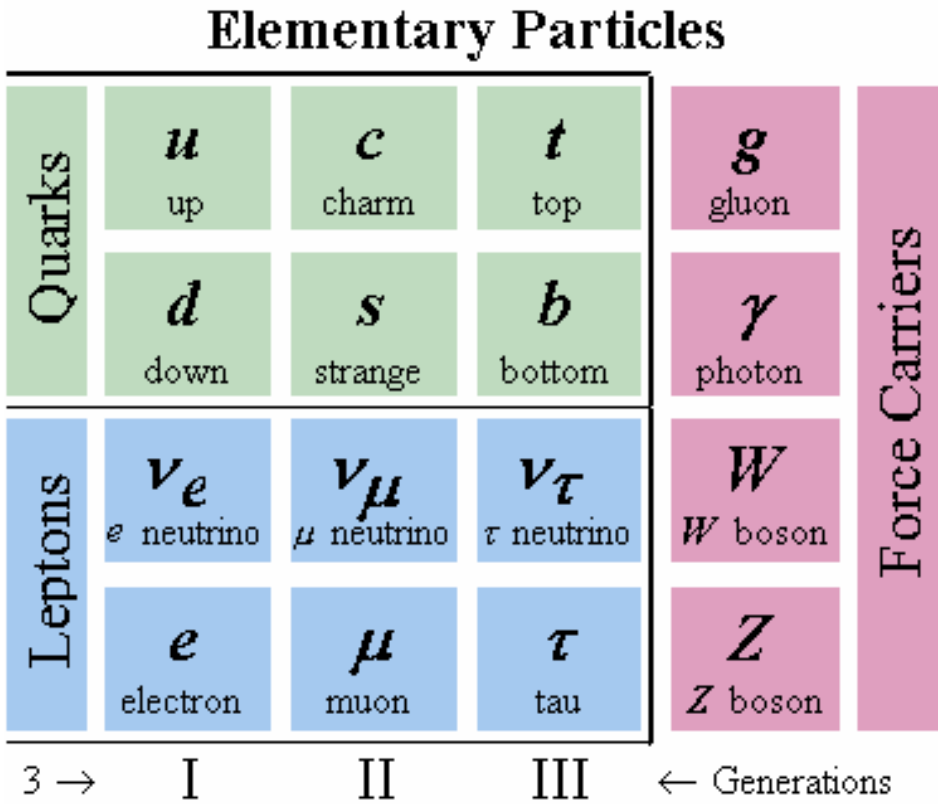
	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and W^+ W^-	Quarks and Gluons

10^{-37} weaker than EM

Explained by complete theory

The Standard Model

- Simple and comprehensive theory that explains all of the particles and interactions among them
  - 6 quarks
  - 6 leptons
  - Force carrier particles
- Four fundamental interactions
  - Strong: Gluon
  - Electromagnetic: Photon
  - Weak: W and Z bosons
  - Gravity (not included in the Standard Model)

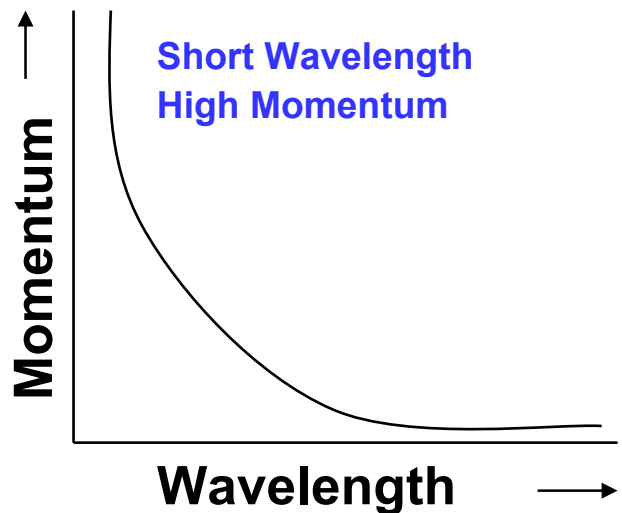


Need for experiments (colliders)

In order to test the Standard Model

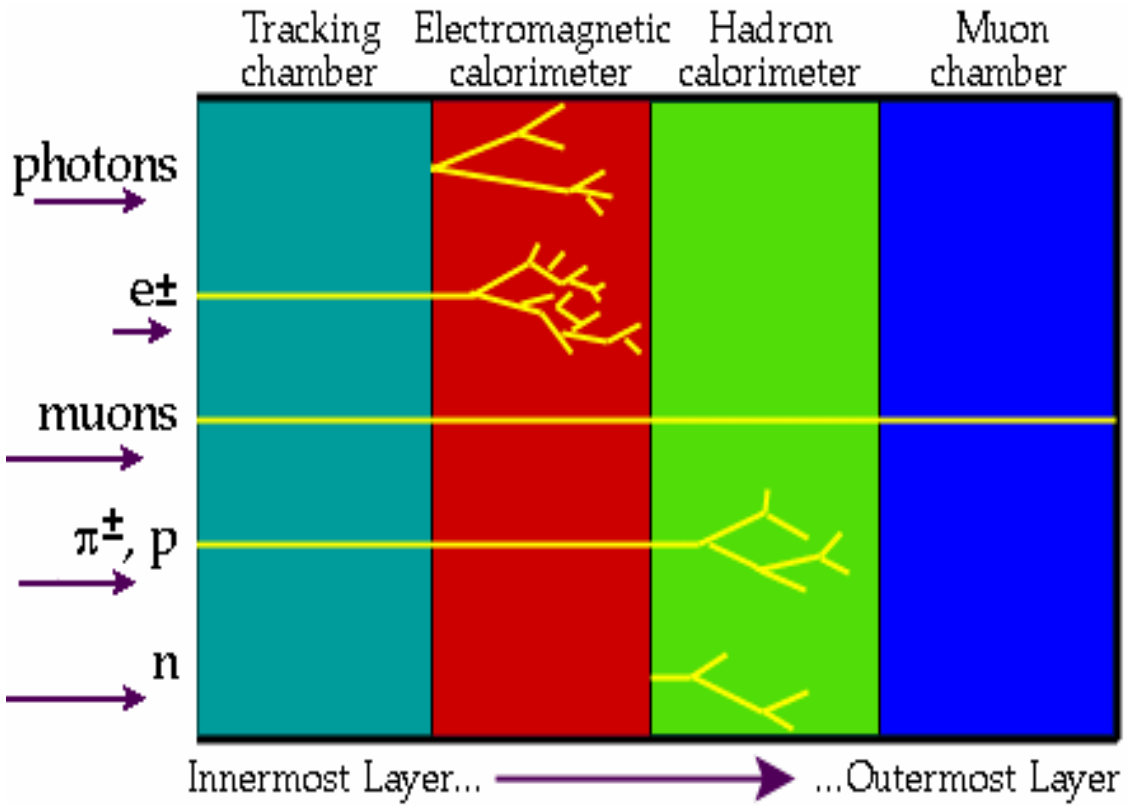
- The wavelength of visible light is too large to examine atomic structure
- Particles in nature have fairly long wavelengths
  - A particle's momentum and its wavelength are inversely related

$$\lambda = \frac{h}{p}$$



Features of a detector

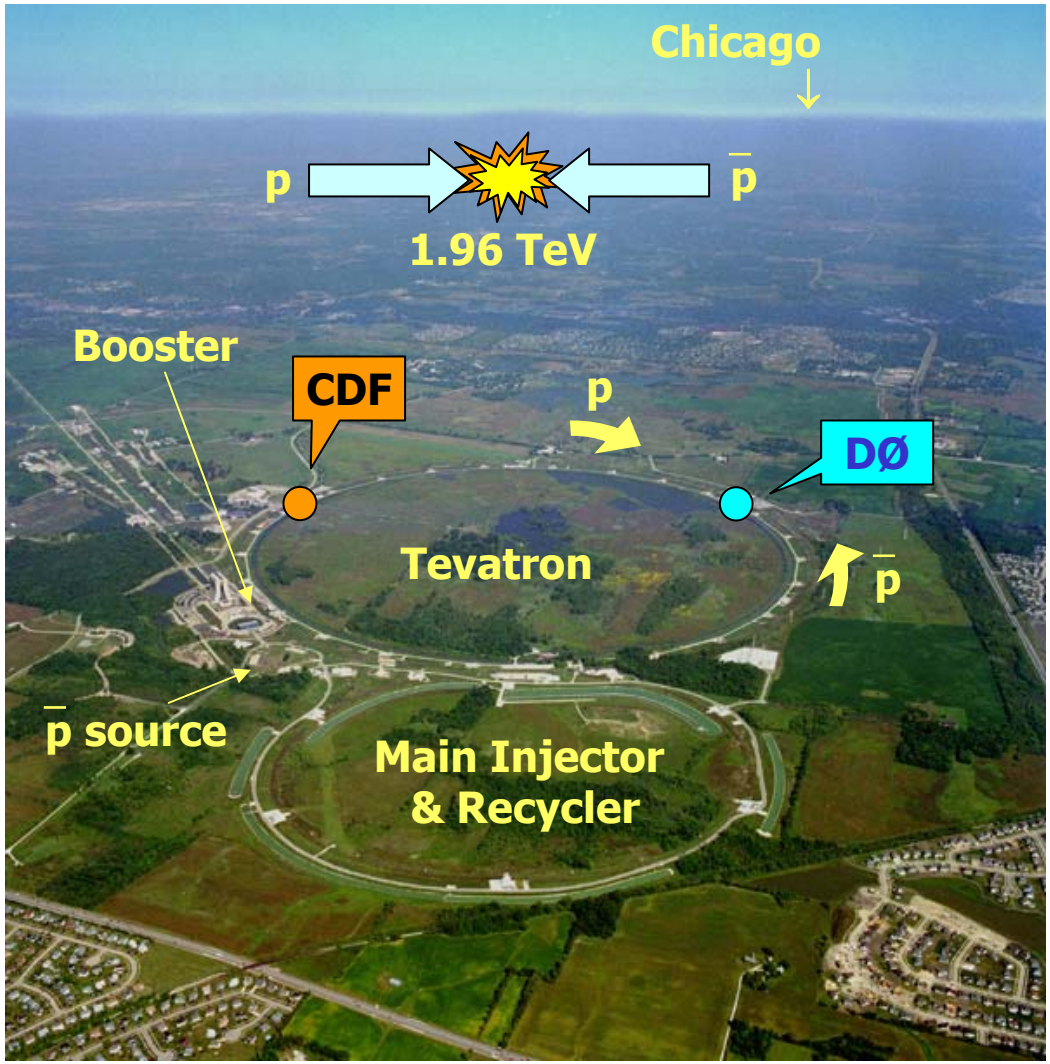
- Charged particles leave tracks in the detector
- Neutral particles do not leave tracks in the detector
- Measure charge and momentum of a particle
- To study different particles, the detector is designed to be multi-component

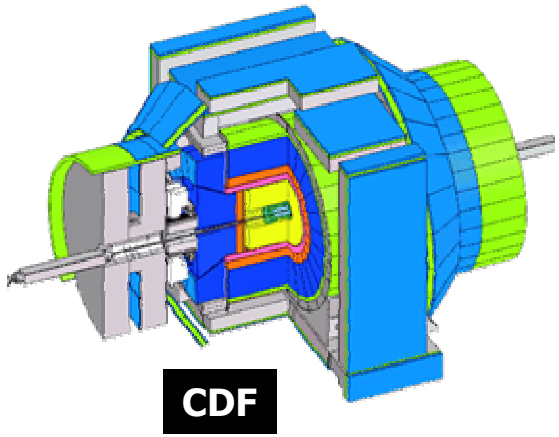


Experiments

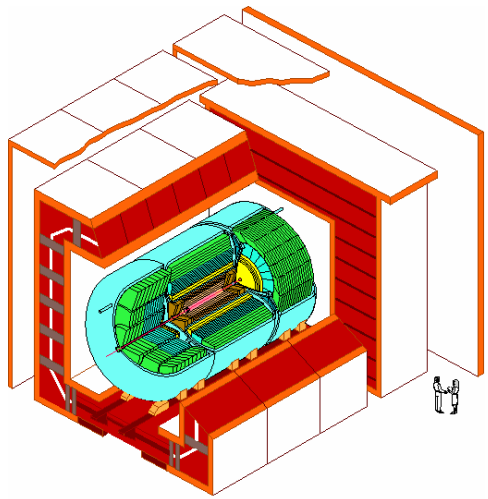
- **Typical Design**
  - Collider – initiates collisions between sub-atomic particles
  - Detector – detects these collisions
  - Computing farms – record these collisions for physics analysis
- **Collaboration**
  - Fermi National Accelerator Laboratory – FERMILAB
    - Batavia, Illinois (60 miles Northwest of Hammond)
  - European Center for Nuclear Research – CERN
    - Geneva, Switzerland

The Fermilab Tevatron Collider





CDF



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Fermilab

- Located 35 miles west of Chicago, Illinois
- Largest U.S. laboratory for research in high-energy physics
- Operated by Universities Research Association (URA) - a consortium of 90 research universities

High Rise

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Research at Fermilab

- **Accelerators:** High-energy instruments to reveal a new world
- **Collider experiments:** Discovery at the energy frontier
- **Neutrino Physics:** Do neutrinos have mass?
- **Technology:** Innovative tools to study matter, space and time
- **Computing:** Managing and analyzing vast amounts of data
- **Theory:** Powerful ideas point to new particles, new forces, hidden dimensions
- **Astrophysics:** From the smallest to the largest scales

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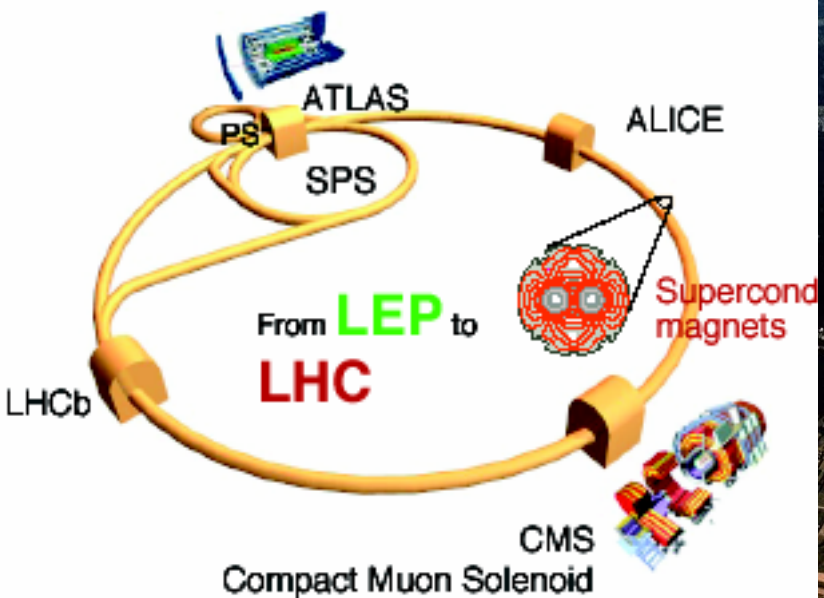
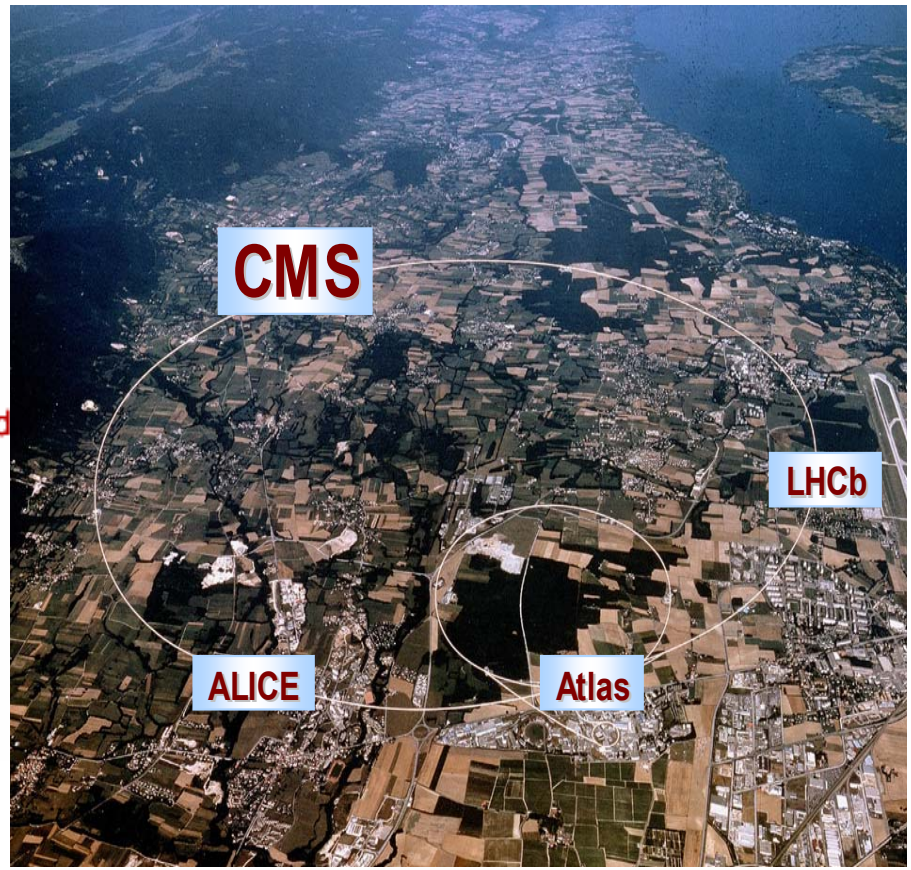
Education at Fermilab

- **Offers education to students at different levels**
  - K-Primary, Intermediate, Midlevel, High school, under-graduate, postgraduate, graduate
- **Subjects introduced**
  - Physical Science, Life Science, Earth and Space Science, Mathematics, Engineering, Technology
- **Wide range of programs**
  - Lederman Science Center, Quarknet, Linc Online, Teacher Resource Center etc...

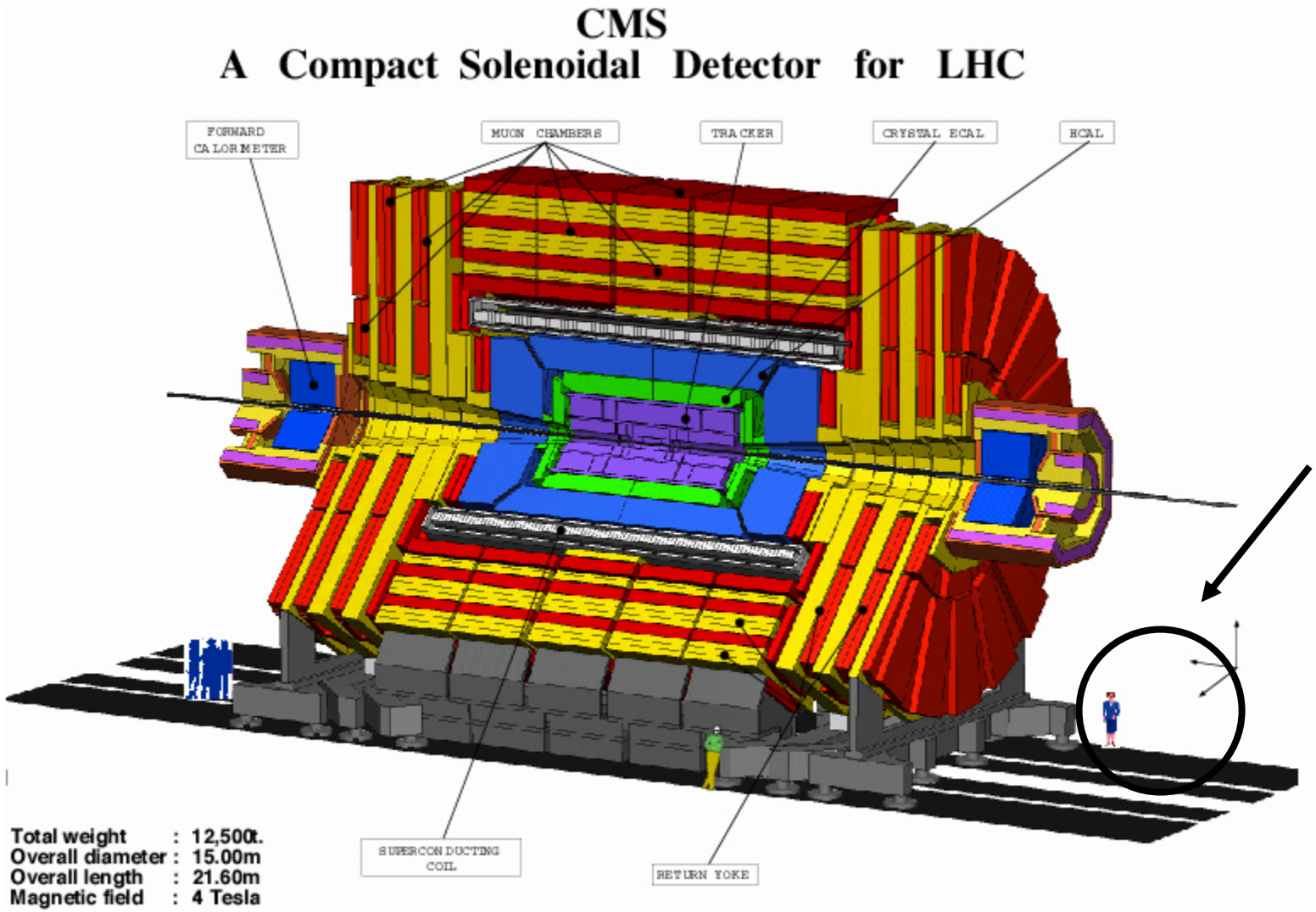
Large Hadron Collider

- **Energy frontier, high Luminosity *p*-*p*-collider at CERN, Geneva, Switzerland**





CMS at CERN


CMS
A Compact Solenoidal Detector for LHC
FORWARD CALORIMETER
MUON CHAMBERS
TRACKER
CRYSTAL ECAL
HCAL
SUPERCONDUCTING COIL
RETURN YOKE
Total weight : 12,500t.
Overall diameter : 15.00m
Overall length : 21.60m
Magnetic field : 4 Tesla

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CMS Assembly

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PUC & HEP

- PUC is an official member both at Fermilab and CERN
- HEP Effort at PUC is led by NP
  - Post-doctoral fellow- Dr. Vesna Cuplov
  - 1 undergraduate- Physics- Dayna Thompson
  - 1graduate- Math- Ana Momidik
- CMS and DZERO research activities at PUC are funded by National Science Foundation
- DZERO Detector – FERMILAB (750 physicists)
- CMS Detector– CERN (2800 physicists)

Both are INTERNATIONAL Collaborations

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PUC on the DZERO map

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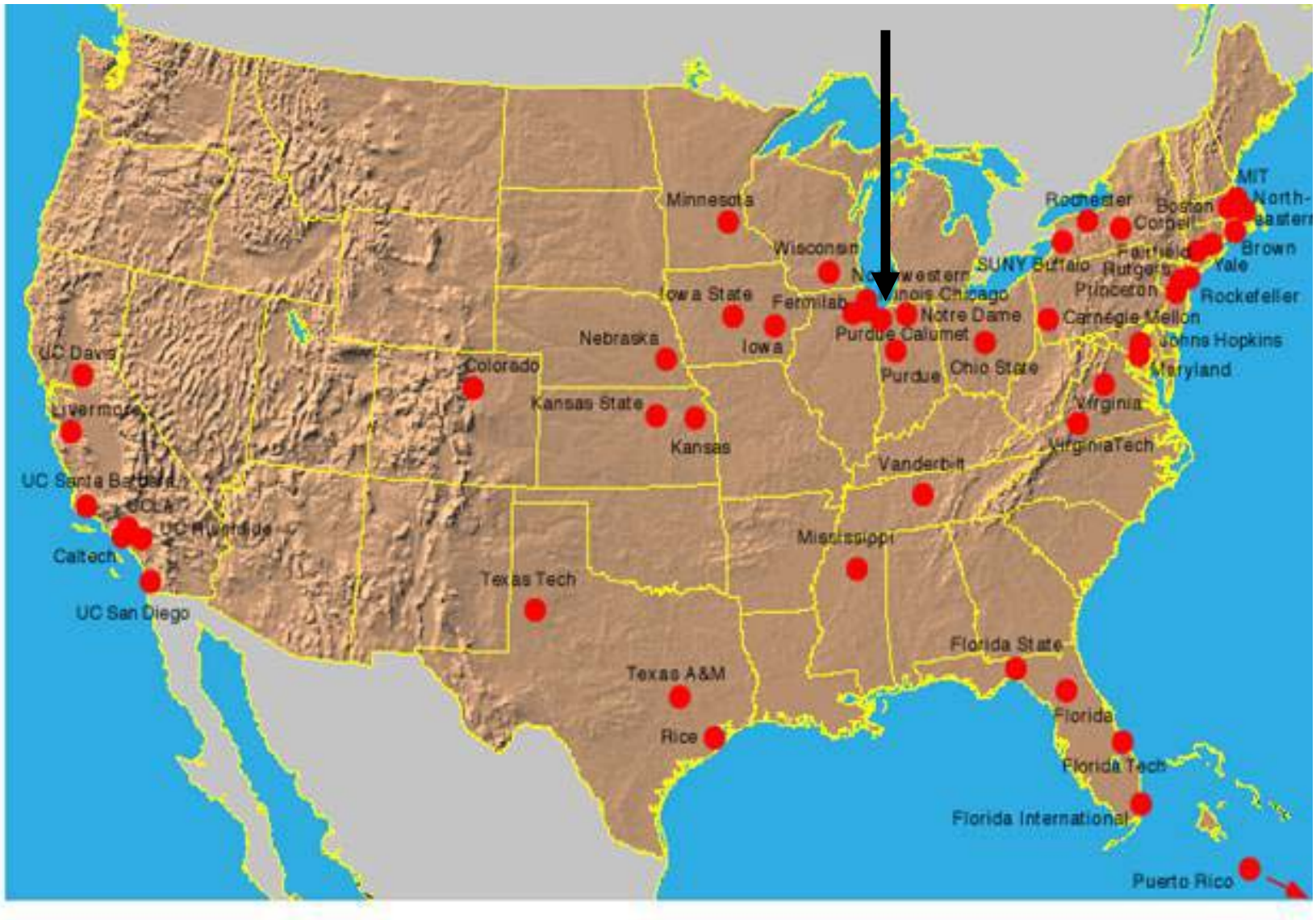
PUC on the US-CMS map



MORE

More info can be found at

http://www-d0.fnal.gov/~neeti/