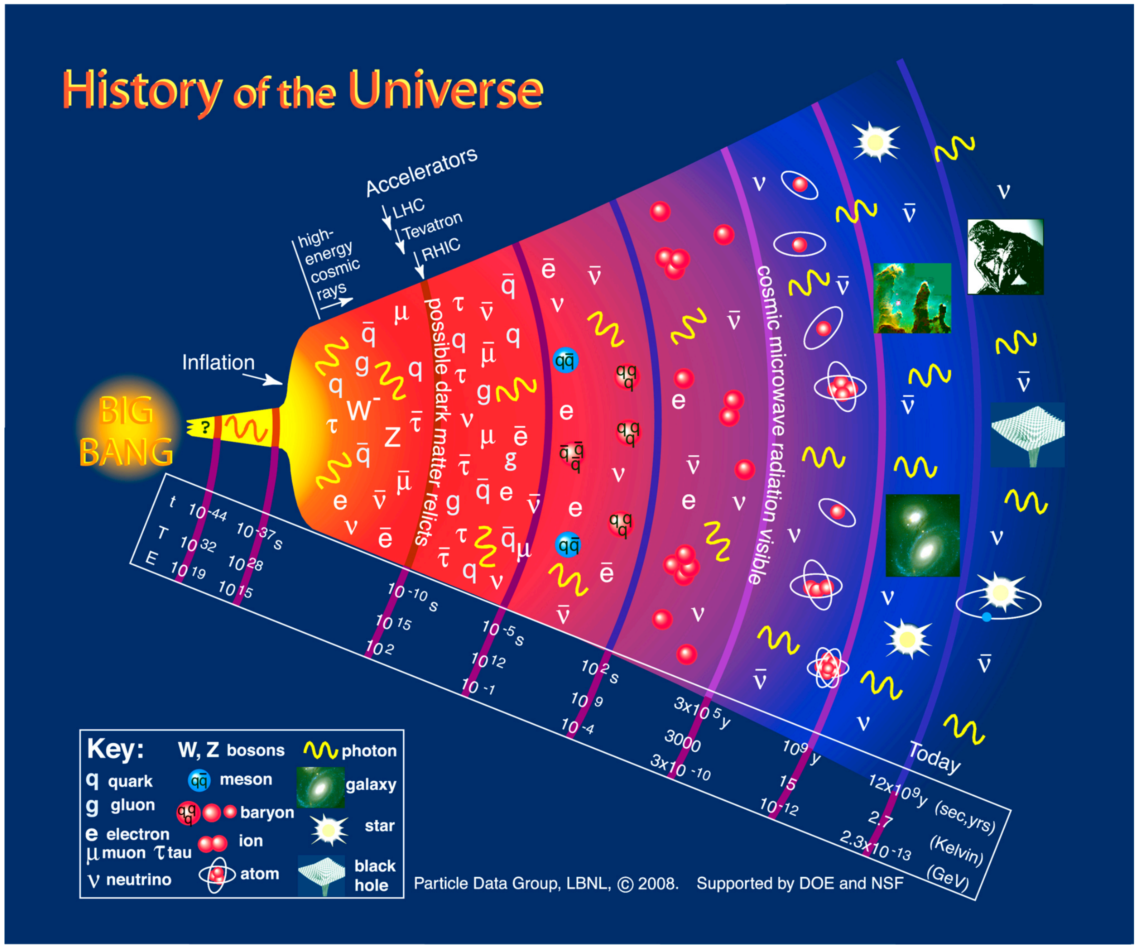
Particle Physics and Cosmology in the Age of the Large Hadron Collider (LHC)

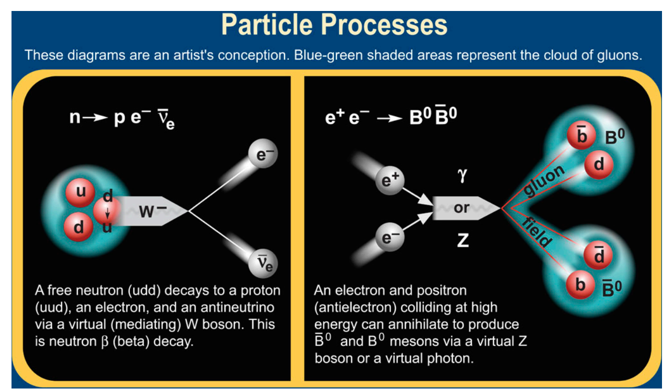


"The Universe is not made of Atoms it is made of Stories"
Muriel Rukeyser

Solved and Unsolved

The Standard Model answers many of the questions about the structure and stability of matter, but???

- **Are quarks and leptons actually fundamental, or are they made up of even more fundamental particles?**
- **Why can't the Standard Model predict a particle's mass?**
- **How does gravity fit into all of this?**
- **Why is there more matter than antimatter in the universe**
- **What is this "dark matter“?**

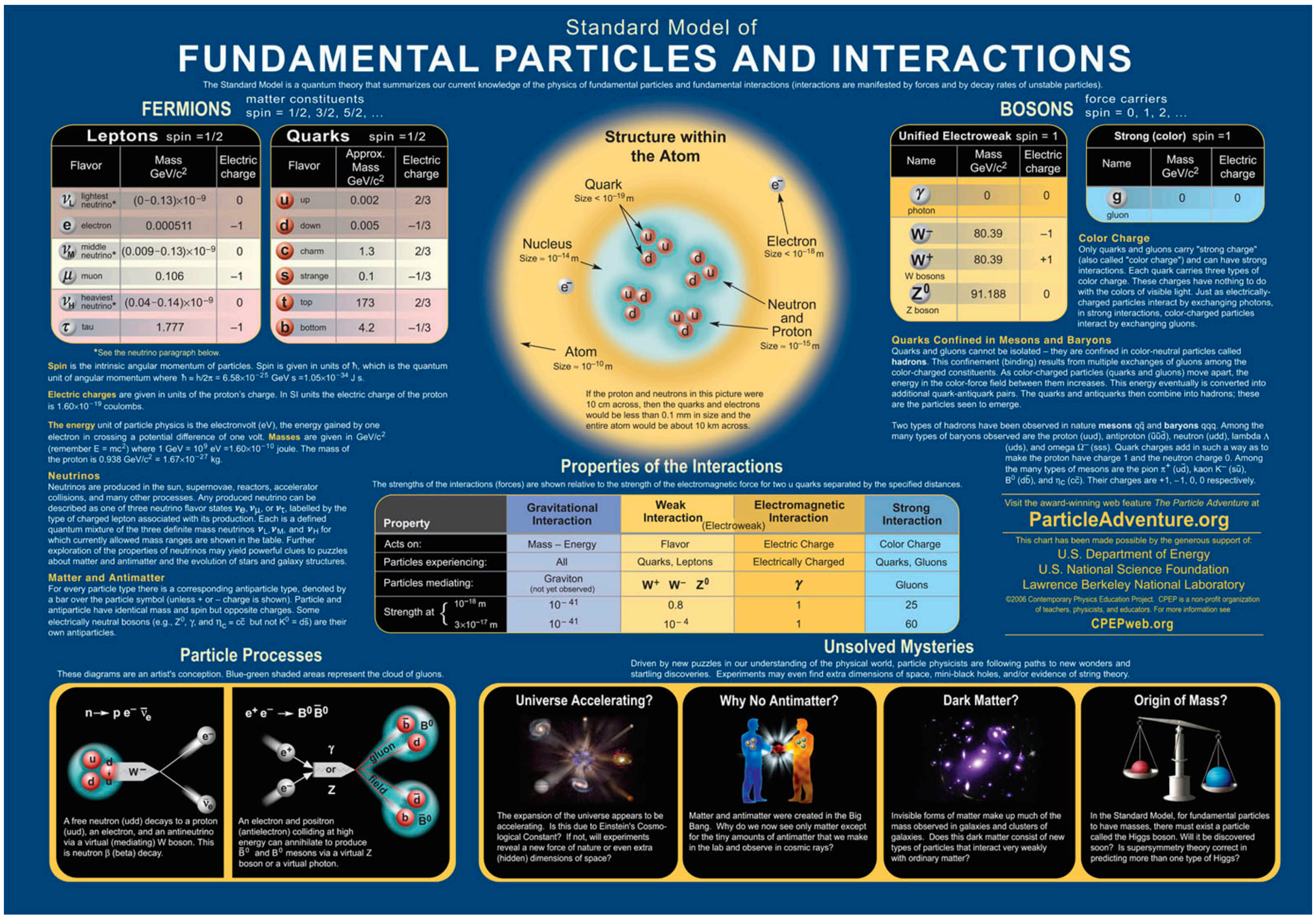


Standard Model
Particle Physics Review

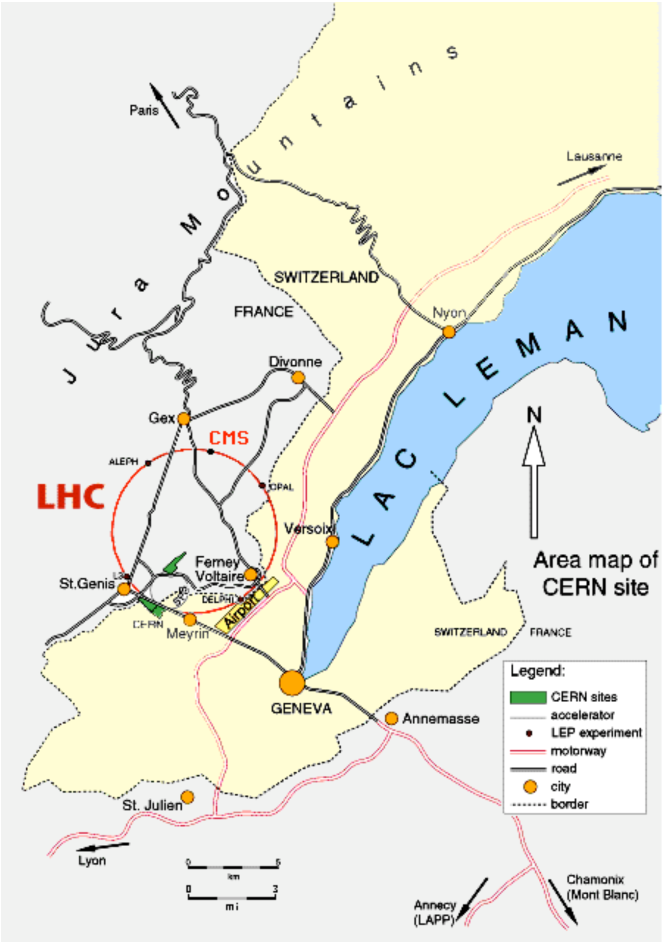
”If I could remember the names of all these particles... I'd be a botanist!” Enrico Fermi

- Fundamental particles
  - Quark
  - Electron
- Hadron-Two types, experience strong interaction
  - Baryon-made of three quark, *fermions*
    - Proton
    - Neutron
  - Meson-made of quark and antiquark, *bosons*
    - Pion
    - Kaon
- Lepton-Three flavors, spin ½ does, does not experience strong interaction
  - Electron
  - Muon
  - Tau
- Neutrino-Three flavors, lepton
- Fermion-Obey Pauli exclusion principle odd ½ integer spin
  - Lepton, quarks
  - Baryon
- Boson-Do not obey Pauli exclusion integer spin
  - Force carrier-Photon, W and Z particles, and Gluons
  - Meson

Standard Model

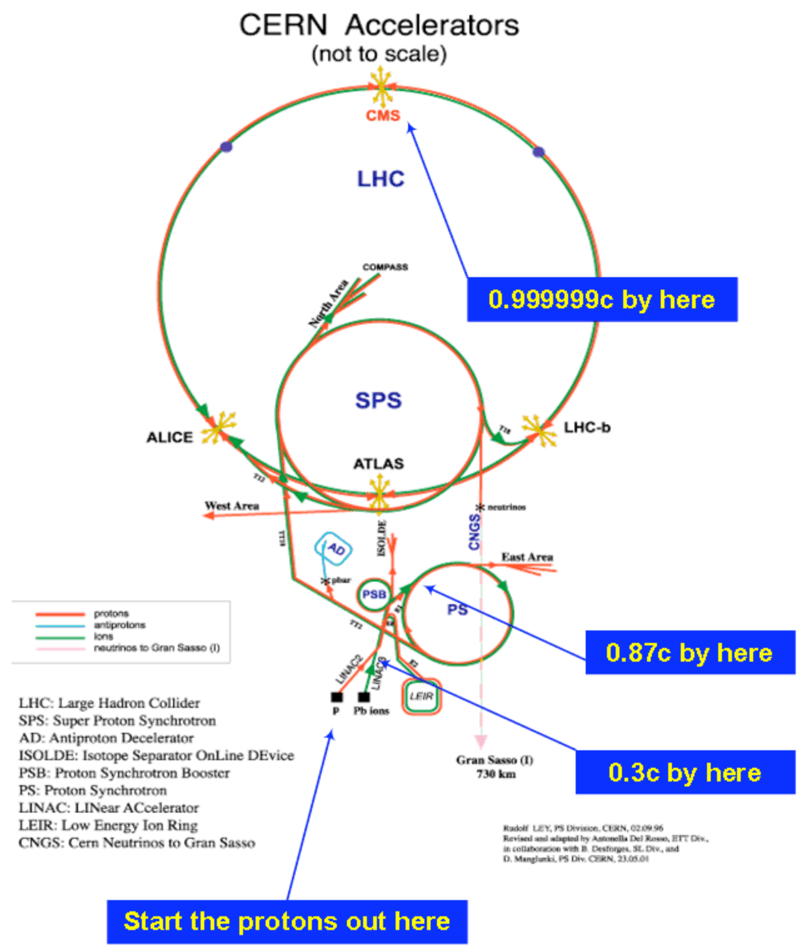


Large Hadron Collider (LHC)
Solving the Unsolved???



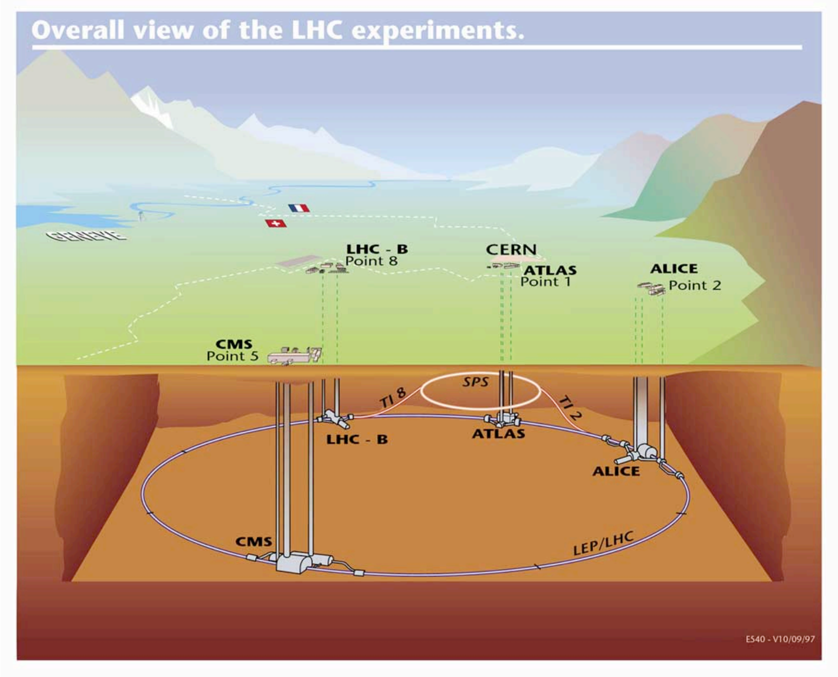
Overview of LHC

- Linear Accelerator-0.31c
- Booster-0.87c -0.92c
- Proton Synchrotron PS-.996c
- Super Proton Synchrotron SPS-450 GeV
- LHC-2, 7 TeV beams of protons

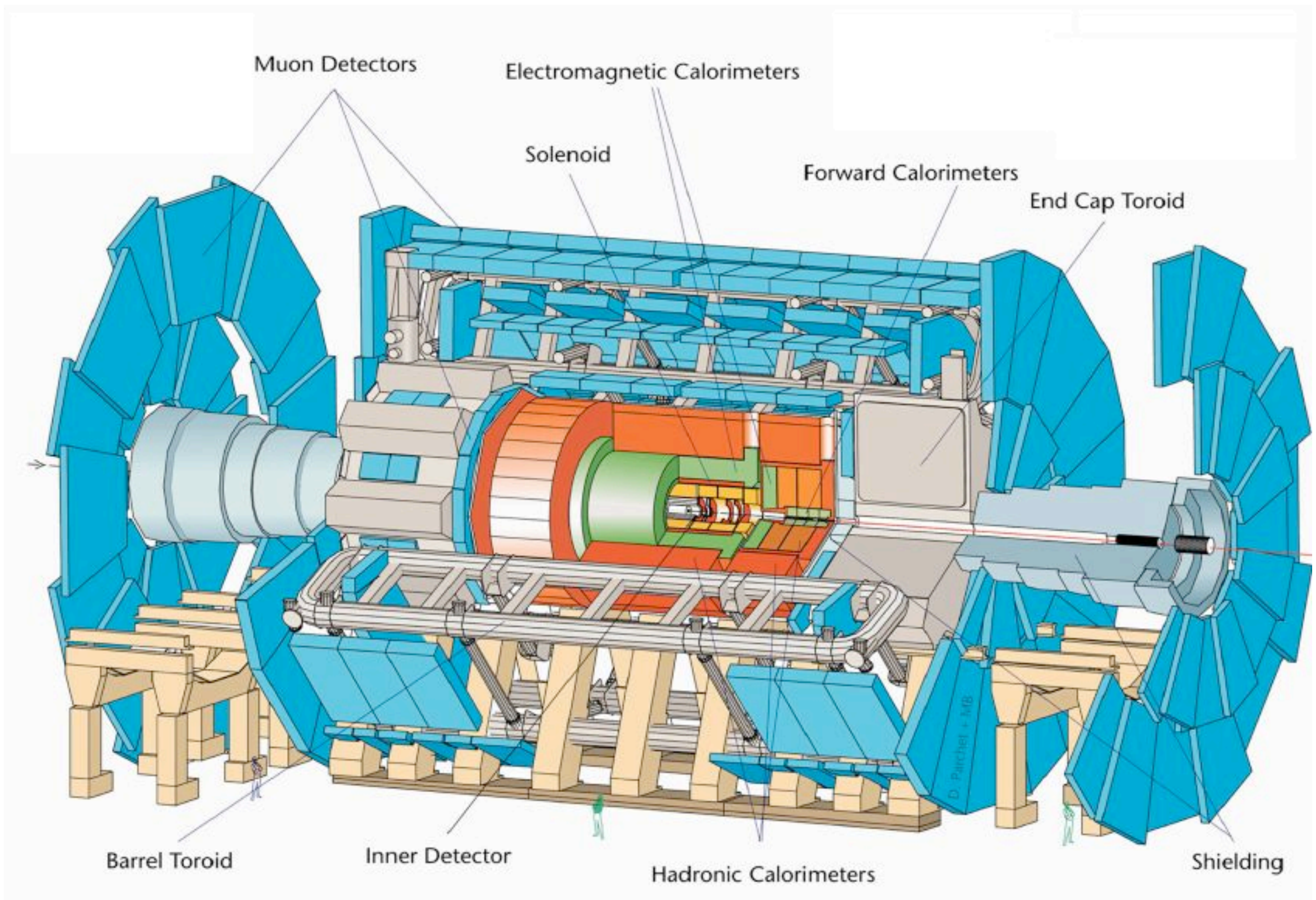


Four main detectors at LHC

- Four main experiments
  - LHCb-designed to measure CP violation of heavy particles containing bottom quarks (why is there more matter than antimatter)
  - Alice-Pb Pb collision study quark-gluon plasma
  - Atlas-general purpose detector
  - CMS-general purpose detector



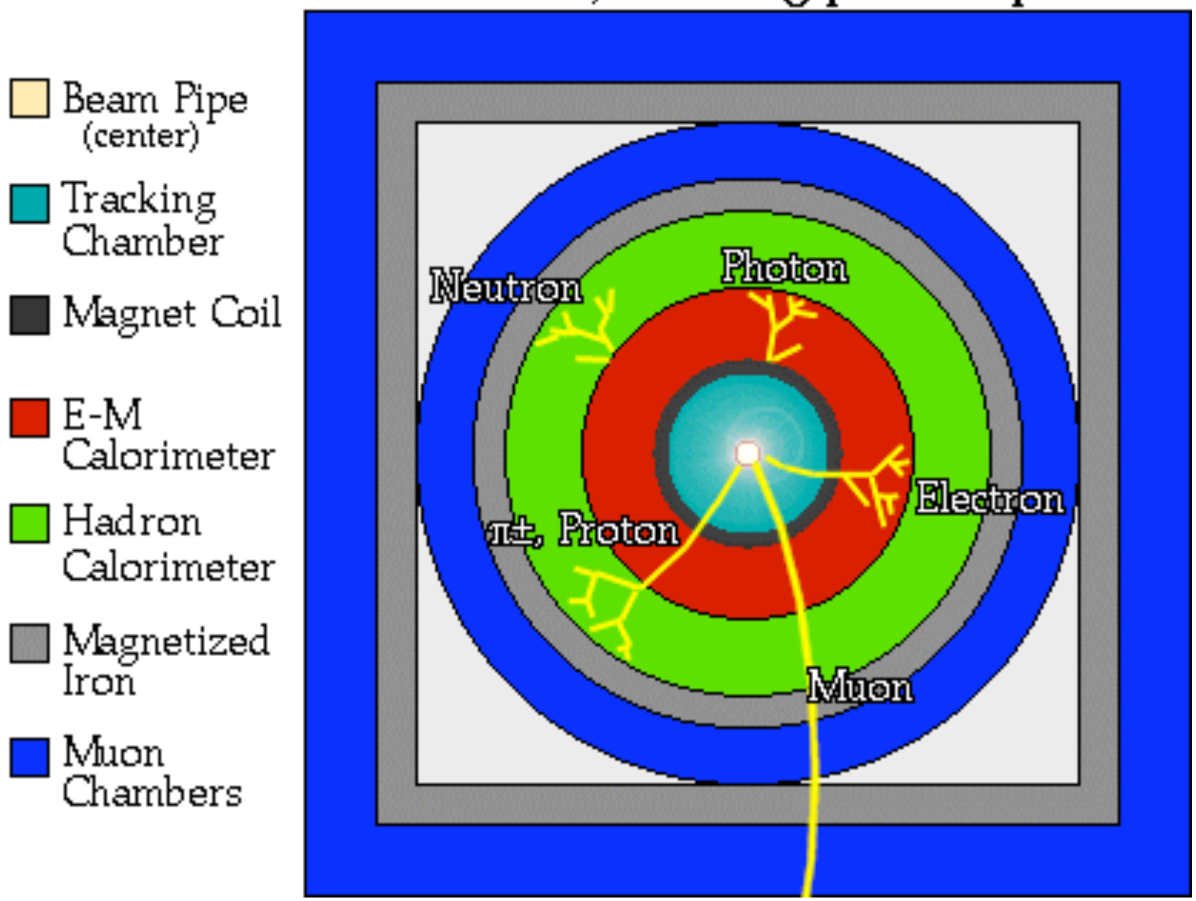
Atlas



Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

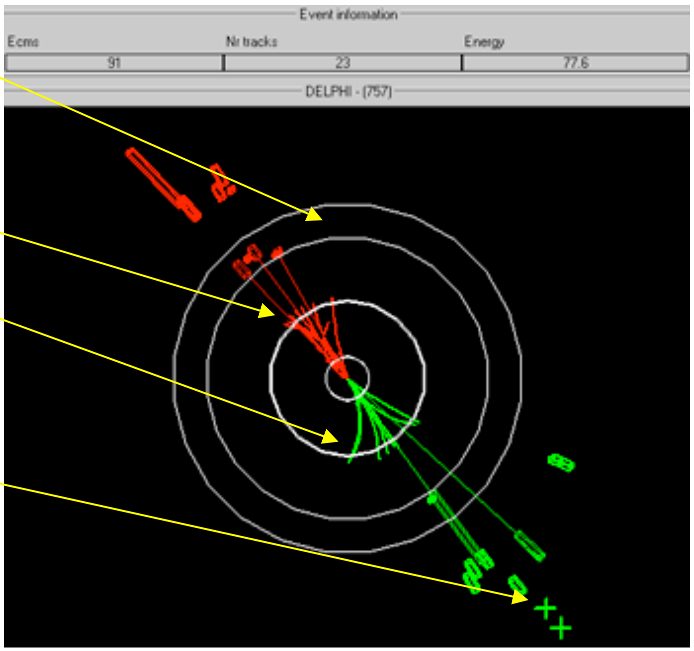
Detector

A detector cross-section, showing particle paths



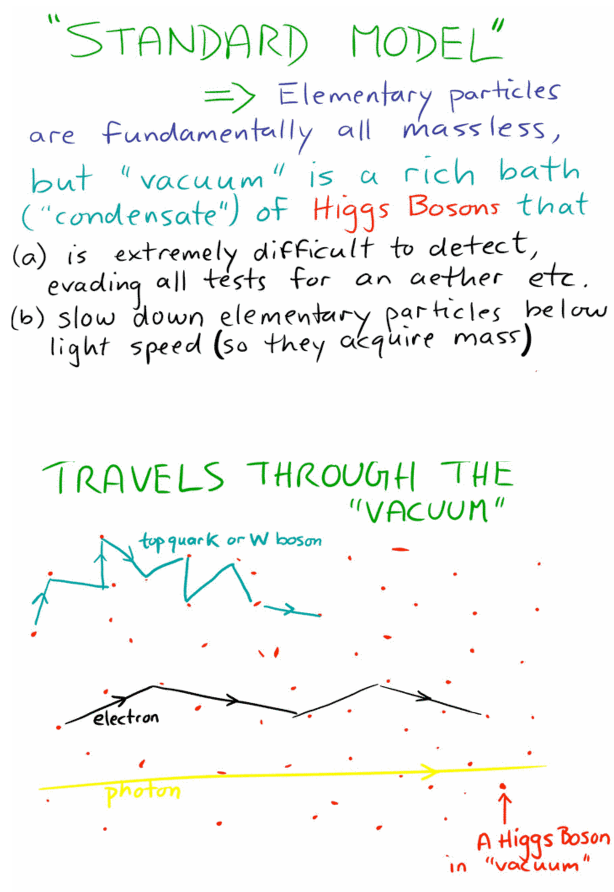
Delphi Detector at CERN
Z particle decay

- E & M detector
- Quark jets (red and green spaghetti lines)
- Muons (green ++)



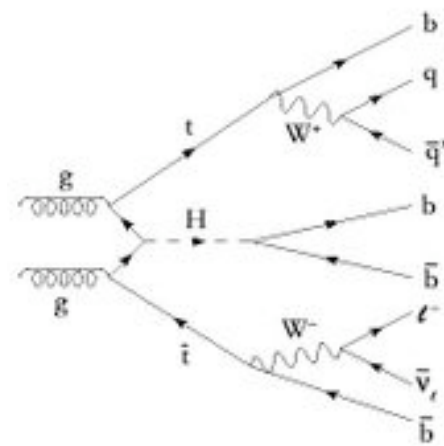
How particles acquire mass… Higgs Boson?

- Standard theory tells us all particles have a zero rest mass
- Particles interacting with the Higgs field gives mass to a particle!
- Particles moving through a Higgs field can be modeled like resistance in a conductor.
- What is the Higgs particle (first 8 min.)

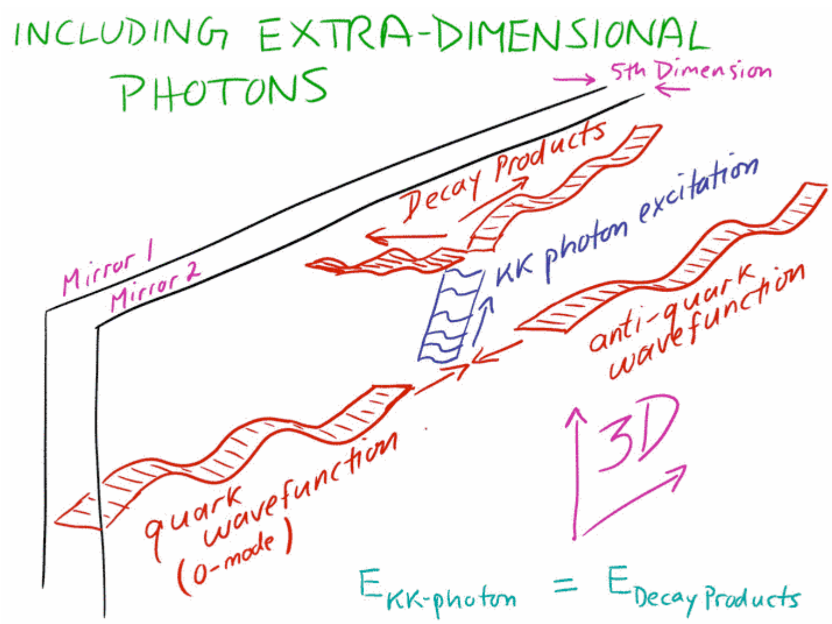


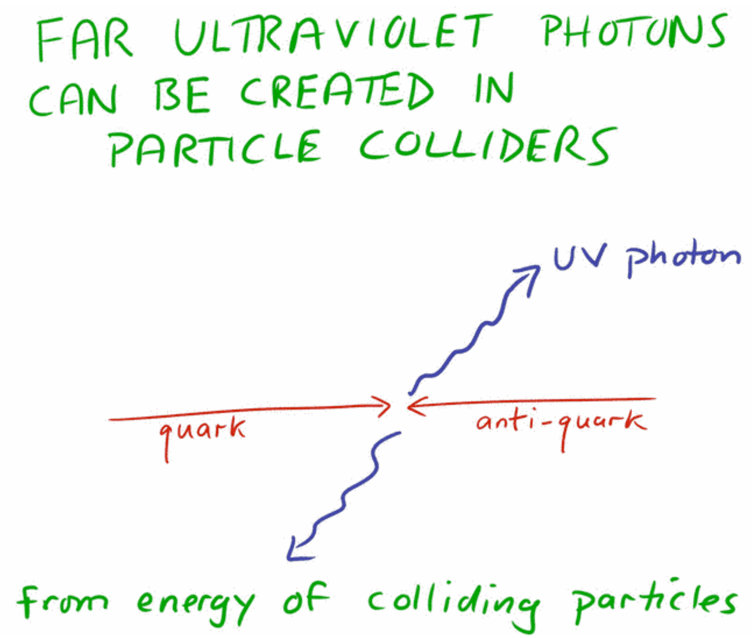
How to detect a Higgs particle at the LHC

- This point in history should see a merger of radioactivity and E&M. (symmetry breaking) which leads to the Higgs mechanism. The LHC is poised to see this.
- One way the **Higgs boson** may be produced at the LHC.
  - Two gluons decay into a top/anti-top quark pair
  - The quark pair then combine to make a neutral Higgs

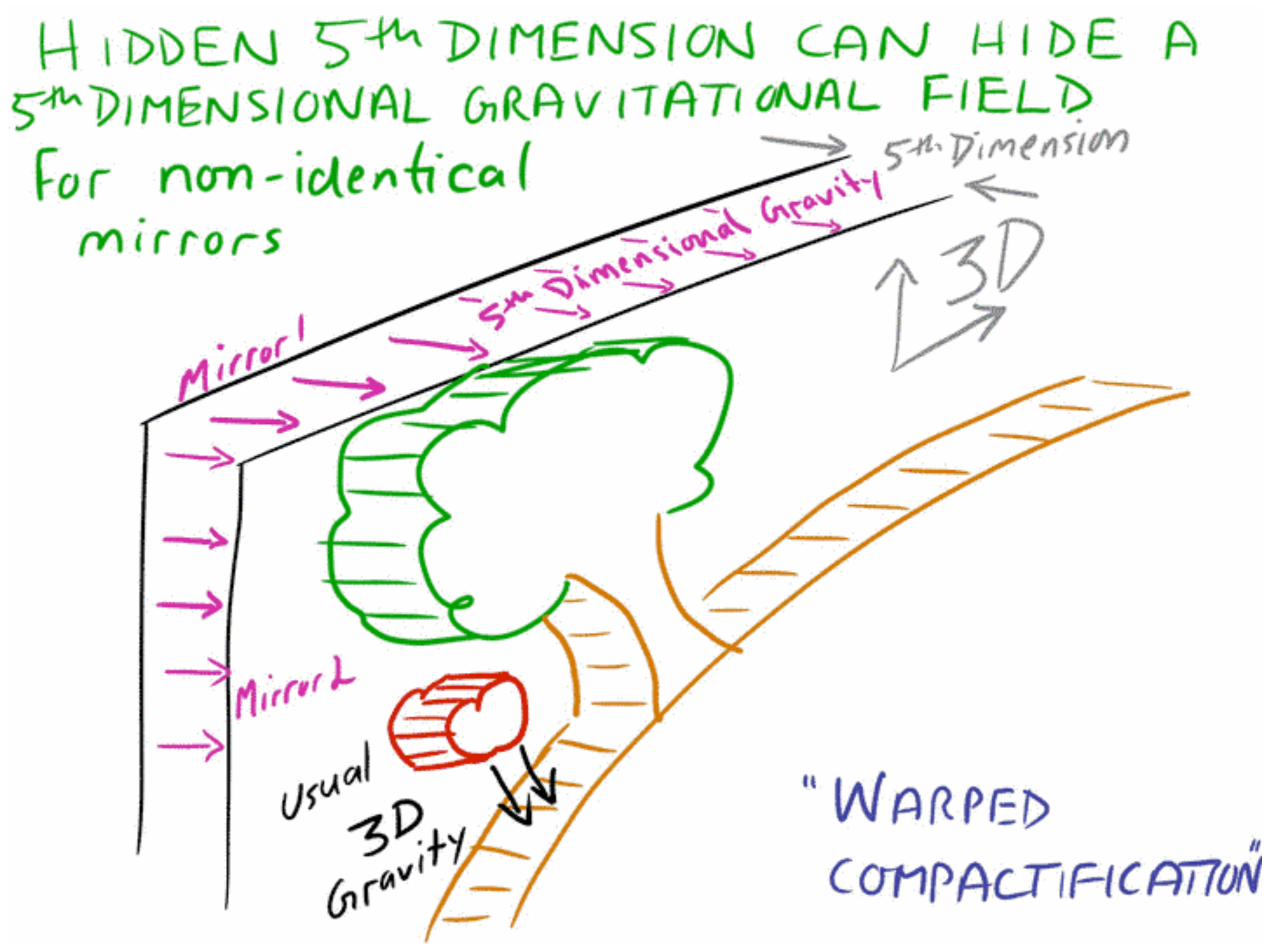


Could a hidden dimension be seen at LHC?

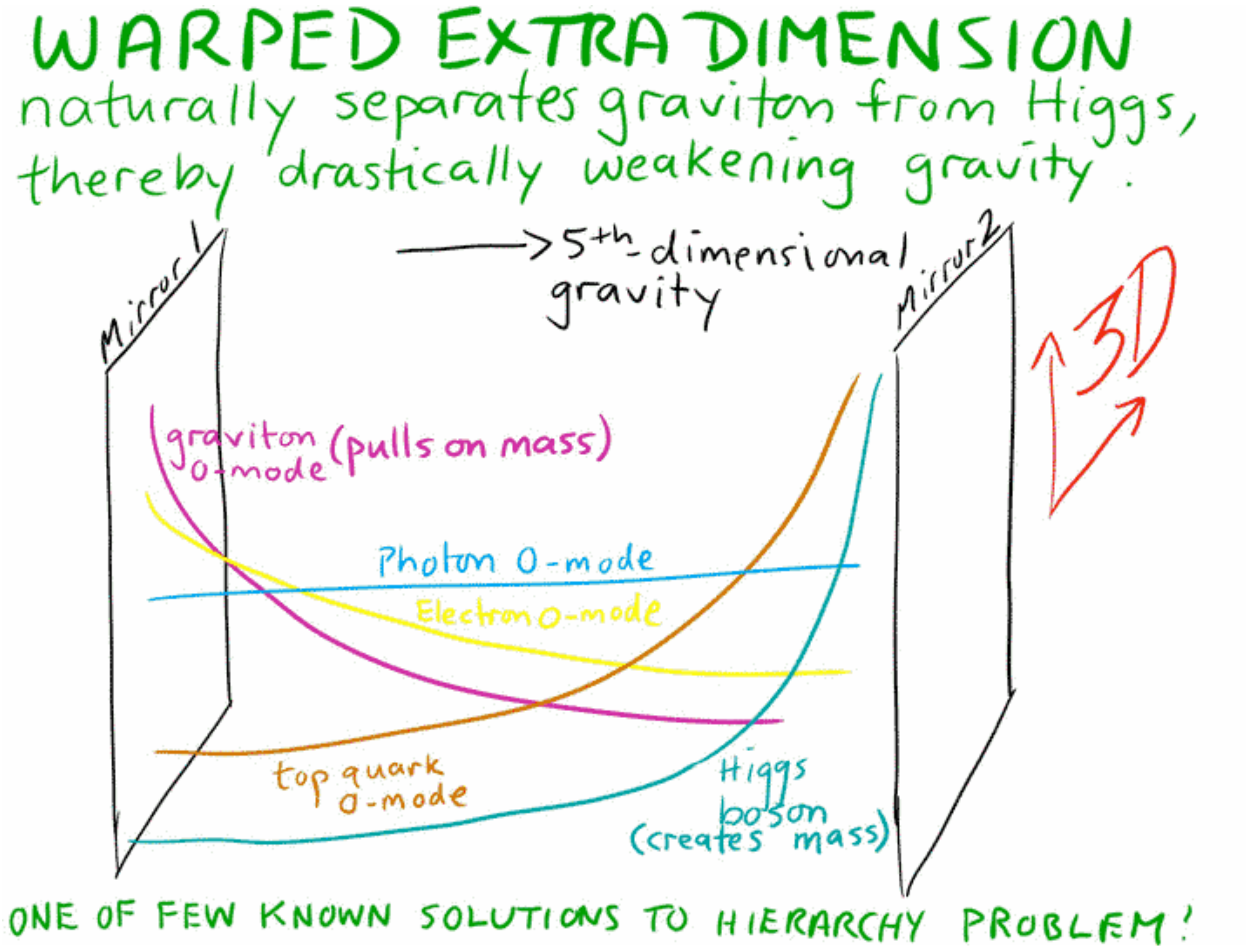




Warped compactification and the hierarchy problem…

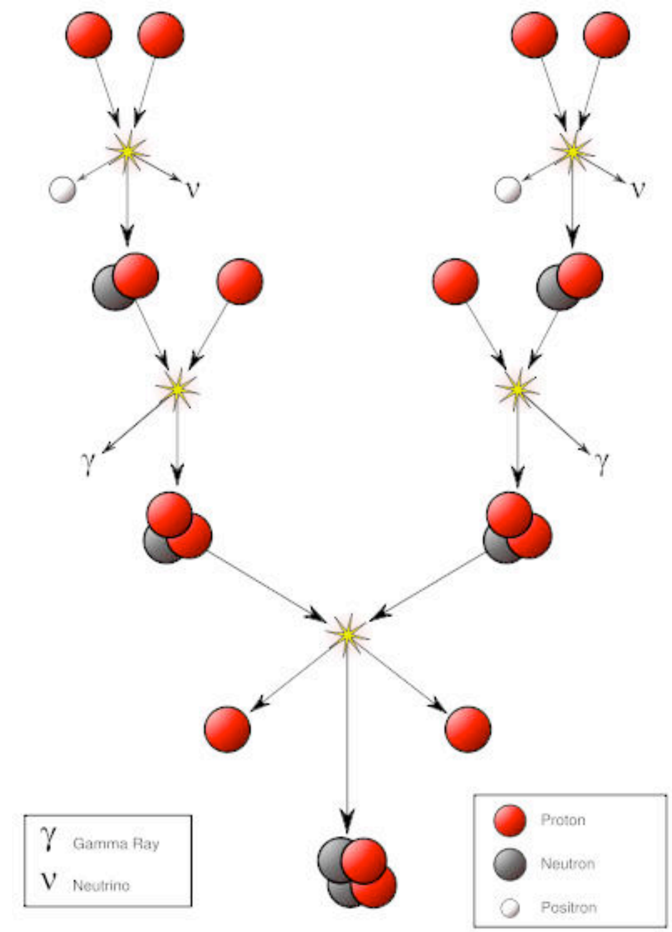


Hierarch Problem Solved?



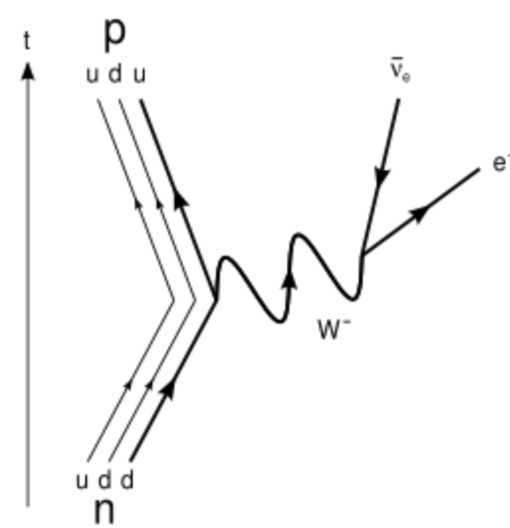
Neutrinos Physics
‘You don’t work at the LHC’?

- Produced in nuclear fusion (Sun)
- Product of radioactive decay (β decay)
- Produced by cosmic rays (protons) interacting with the atmosphere
- There are 3 flavors of neutrinos



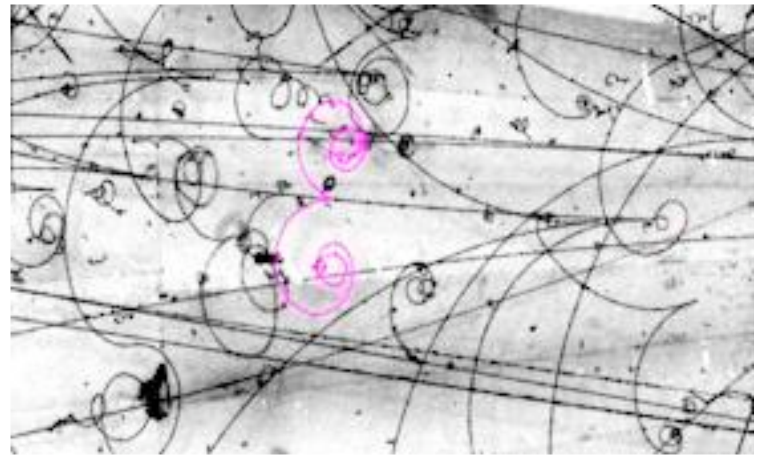
Weak Force Beta Decay and the Neutrino

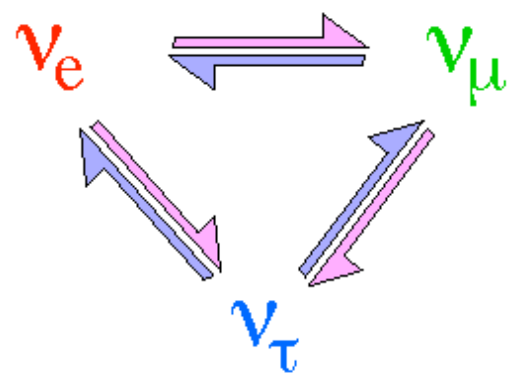
- Weak force
  - 10^{13} times less than strong force (hence name)
  - Range of weak interaction 10^{-18} m
  - Only weak force affects neutrinos (gravity has a very small affect)
  - Weak force is the only interaction capable changing flavors (up quark to down)



Why study neutrinos?
Matter Antimatter Asymmetry

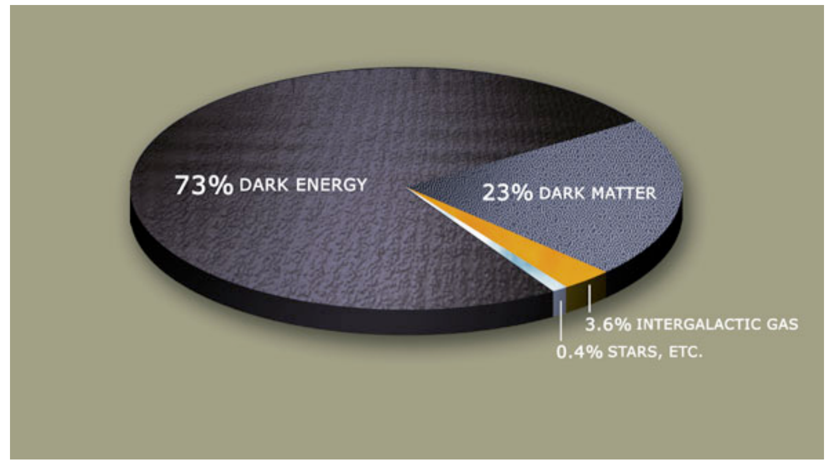
- Neutrinos may oscillate between the three flavors. Will this show why we see a large matter antimatter asymmetry in the universe?

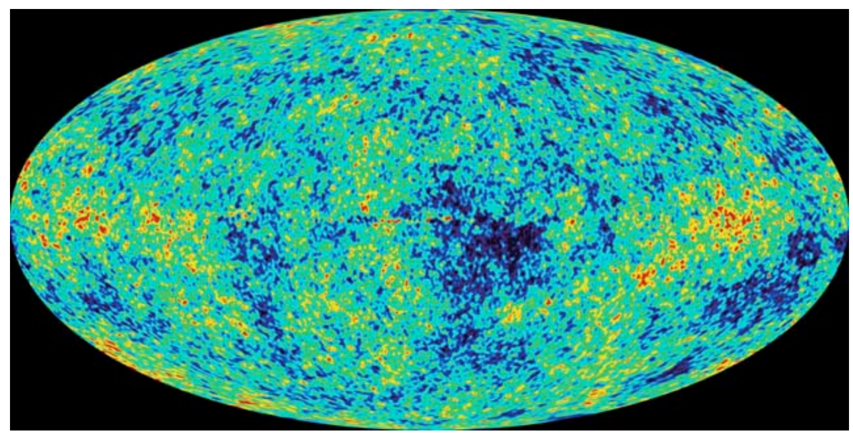




The search for Dark Matter

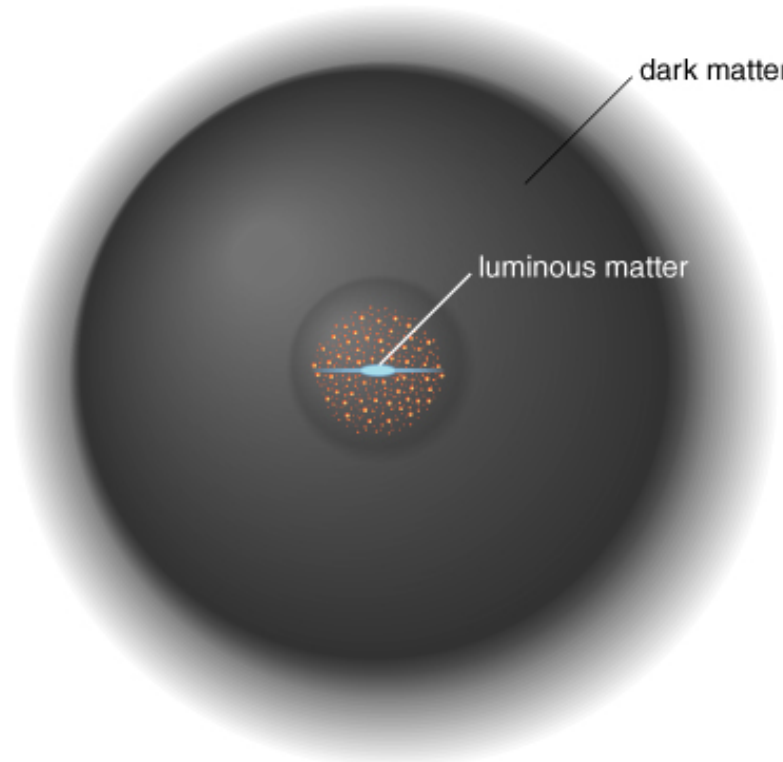
- Cosmology requires the existence of dark matter
- How do we know this?
  - Galactic rotation curves
  - Collision of cluster galaxies
  - Cosmic microwave background temperature fluctuations



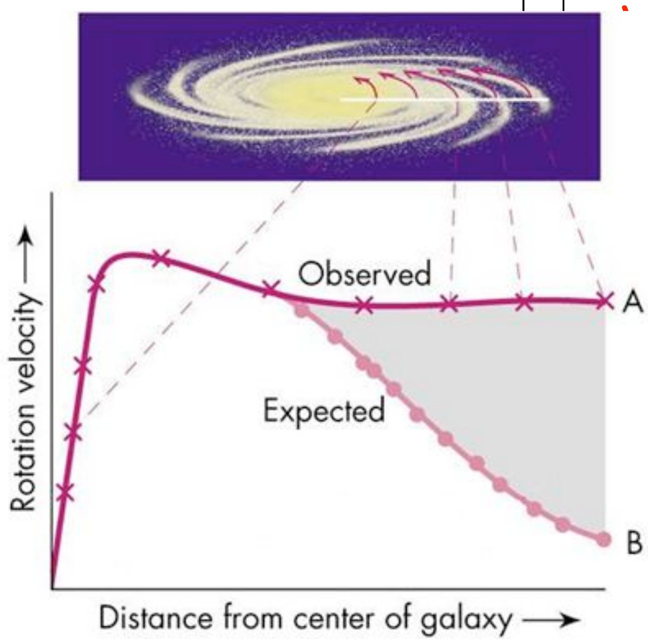


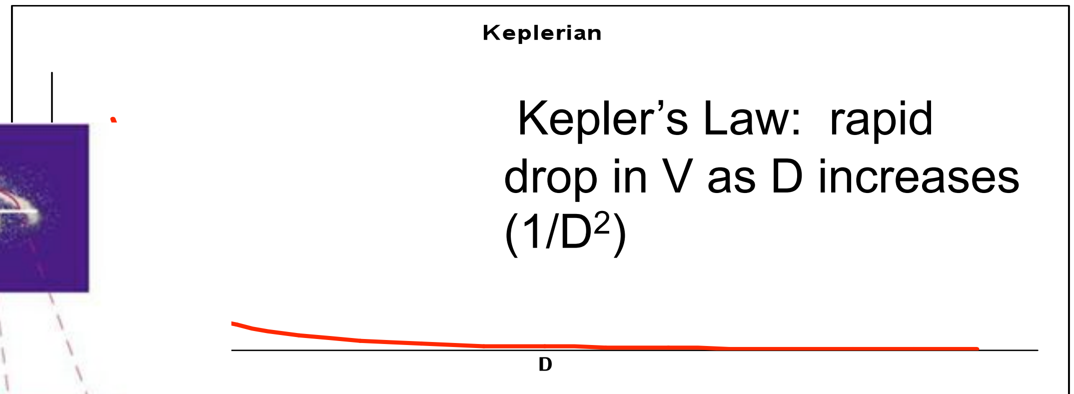
What is Dark Matter?

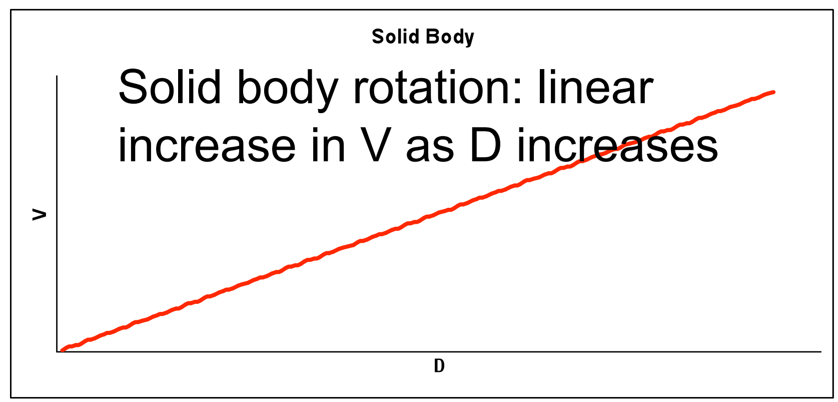
- Properties of simplest Dark Matter
  - Must be stable (have immutable qualities)
  - Density 1 particle per hand
  - Z_2 charge invariance with an odd charge
  - R-parity
- Possible Candidates
  - Lightest Supersymmetric Particle (LSP)
  - Lightest Kaluza-Klein
  - Technibaryons
  - Singlet Fermion
  - Gravitons
  - WIMP



Existence of Dark Matter
Galactic Rotation Curves

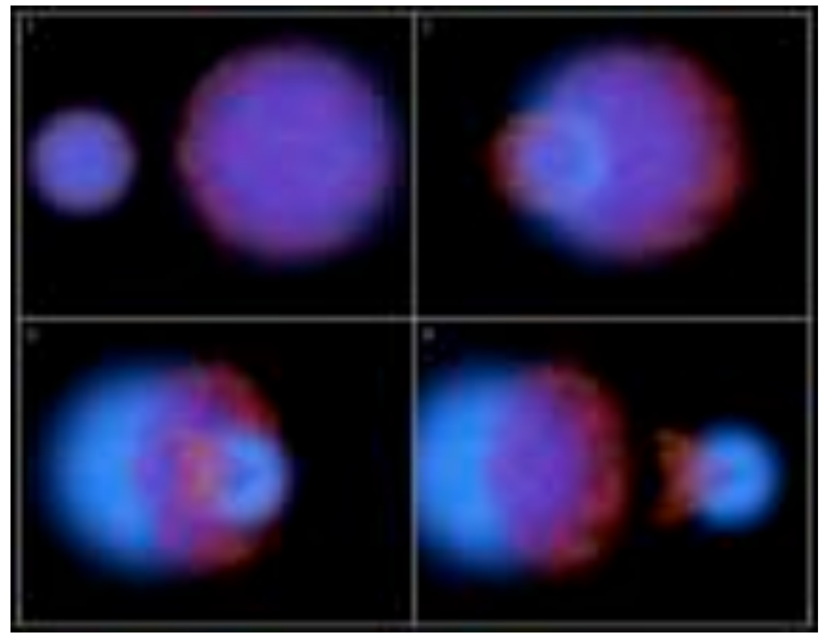






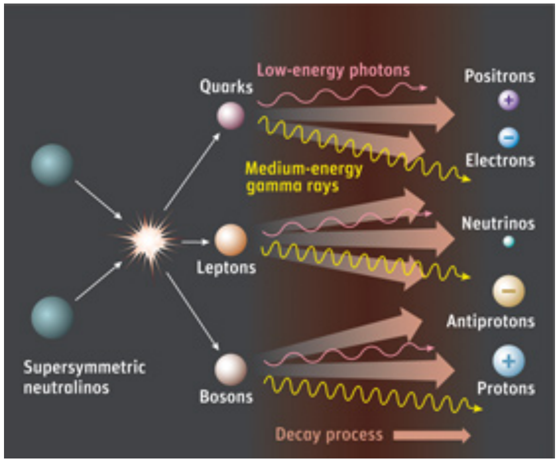
Existence of Dark Matter Collision of Galactic Clusters

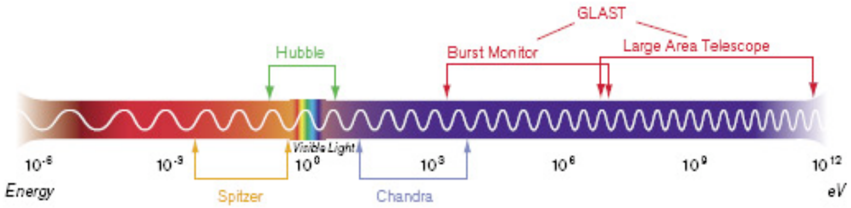
- Artist's representation of the collision between two clusters in the Bullet Cluster
- **Normal matter in the cluster, is shown in red** and **dark matter is shown in blue**.
- The last image is showing the hot gas seen with the Chandra X-ray Observatory (pink) and the cluster mass as inferred by gravitational lensing (blue), which is mostly dark matter.
- Best evidence for dark matter to date



Search for Dark Matter NASA GLAST

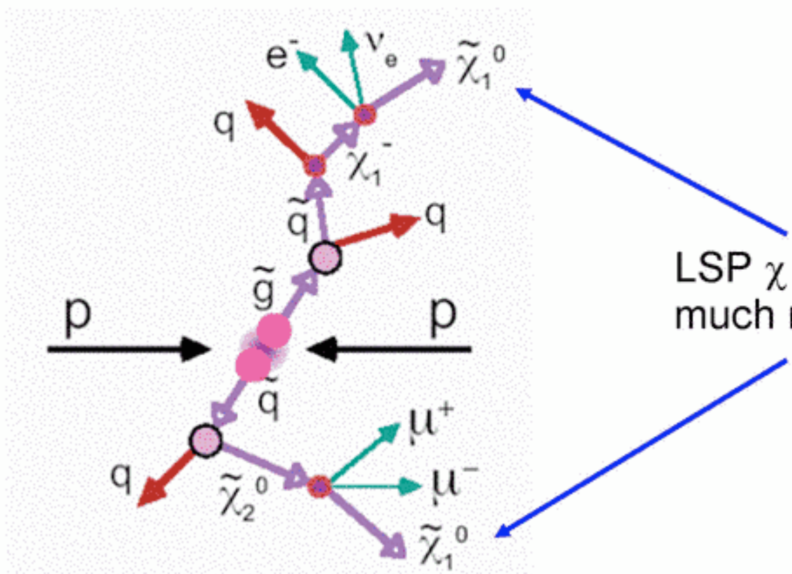
- Glast (NASA)Gamma-ray Large Area Space Telescope
- The GLAST space telescope, launched June 11, 2008, searching for gamma wave events, may also detect WIMPs.
- Supersymmetric particle and antiparticle collisions should release a pair of detectable gamma waves. The number of events detected will show to what extent WIMPs comprise dark matter.





Search for Dark Matter at the LHC

Example SUSY Event at LHC



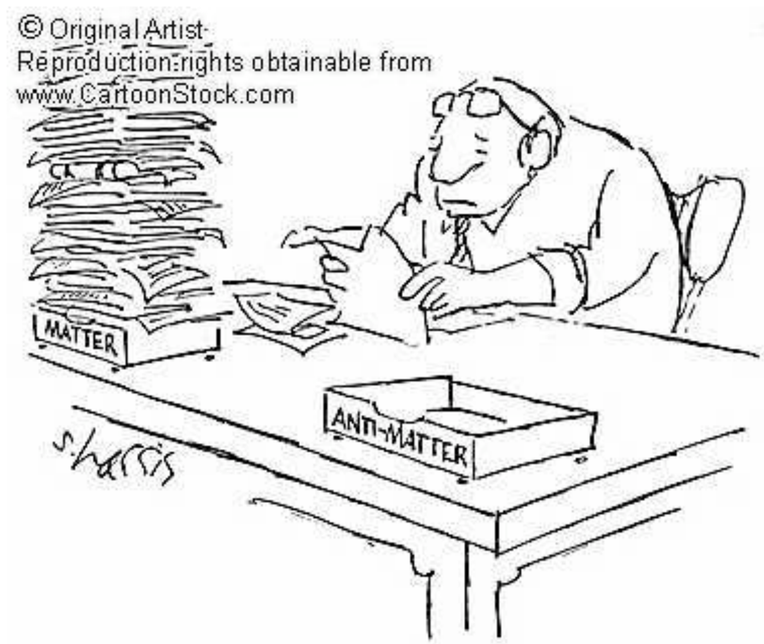
LSP χ is source of much missing energy.

http://www.icepp.s.u-tokyo.ac.jp/~kenta/analysis.html

Summary

- LHC looks at <10^{-10} s after the Big Bang
- LHC will produce energies near 14 TeV
- Atlas is one of the main detectors at the LHC
- Some unsolved physics problems that may be solved at the LHC
  - Why is gravity so much weaker than the 3 other forces? Can the hierarchy principle solve this?
  - What is mass? Will the Higgs particle be found?
  - Why is there more matter than antimatter? Does this have to do with neutrino oscillation?
  - What is dark matter and will we find any? GLAST and the LCH just might!

The next couple years in particle physics will be exciting!



Homework

- http://hands-on-cern.physto.se/ (If this doesn't work, try the link below)
- http://www.physicsmasterclasses.org/exercises/hands-on-cern/hoc_v21en/

(hands on CERN WIRED)

- http://www.haystack.mit.edu/edu/undergrad/srt/SRT%20Projects/rotation.html

Galactic Rotation Lab (Great experience!)

- http://www.particleadventure.org/

Particle Adventure

- http://www.particleadventure.org/other/education/index.html

Education material

References

- http://online.kitp.ucsb.edu/online/lhct_c08/

Lesson based on talks for 2008 Teachers Conference Kavli Institute UCSB

- http://www.youtube.com/watch?v=AM7SnUlw-DU&feature=related

Dr. David Gross's overview of the Future of particle physics and what can be expected from the LHC.

- http://www.youtube.com/watch?v=1sVPCT5qHM

(Start at 22min.) Richard Muller Quarks, exchange forces and confinement

- http://www.youtube.com/watch?v=Xcww72_6gCI&feature=related

You Tube video on quarks and leptons

- http://www.youtube.com/watch?v=AHT9RTICqjQ

Good collision You Tube video

- http://www.youtube.com/user/TheATLASExperiment

Good You Tube video of Atlas

- http://www.youtube.com/watch?v=FNCSIc9A-Vs

Physics for future Presidents Richard Muller talks about the Higgs particle
What is the Higgs particle? What first 8 min.

- http://www.youtube.com/watch?v=kw0iRW2hoC4

Peter Higgs-Interviewed (11 min.)

- http://www.pbs.org/wgbh/nova/sciencenow/3410/02.html

PBS 12 min video on CERN

- http://www.pbs.org/wgbh/nova/sciencenow/dispatches/080111.html

Science Now dark matter and the Bullet Cluster

References

- Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions (Paperback) by Lisa Randall **Paperback:** 512 pages **Publisher:** Harper Perennial (September 19, 2006) **ISBN-10:** 0060531096 **ISBN-13:** 978-0060531096
- Particle Physics A very short Introduction by Frank Close Oxford Press
- http://www.nasa.gov/mission_pages/chandra/main/index.html

Chandra x-ray telescope

- http://www.nasa.gov/multimedia/podcasting/index.html

Nasa Video/Audio podcast Dark Energy/Matter

- http://glast.gsfc.nasa.gov/

Search for composition of dark Matter

- http://www.pbs.org/wgbh/nova/sciencenow/3410/02.html

PBS show Dark Matter