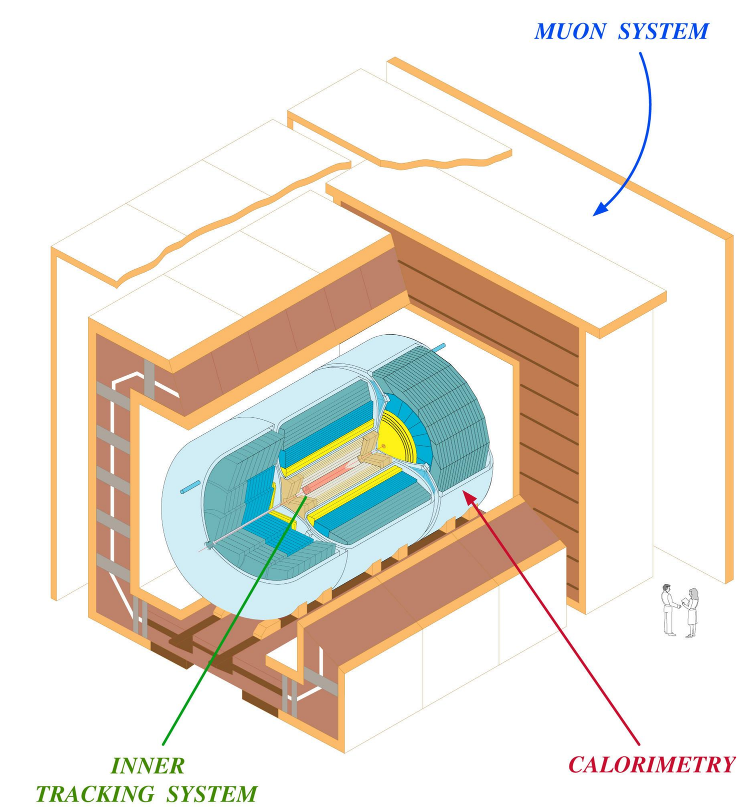
The DØ experiment is one of two large collider experiments based at the Fermilab Tevatron. It commenced operations in 1992 and its first data taking period went until 1996. During that time, DØ and its sister experiment CDF jointly discovered the top quark. In 1996, the accelerator stopped operations for a significant upgrade. The Tevatron began again in 2001 and will run semi-continuously until 2010.



The DØ Detector

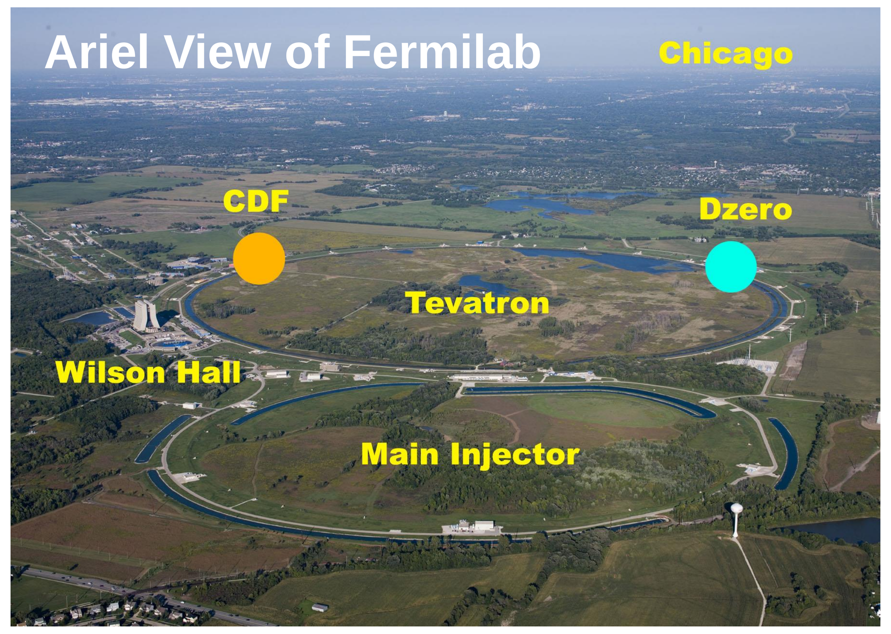
The DØ experiment is made of several technologies, ranging from a silicon and optical fiber tracker, surrounded by a calorimeter that includes uranium (not the kind that goes "boom!") and liquid argon and finally a system designed to measure muons.

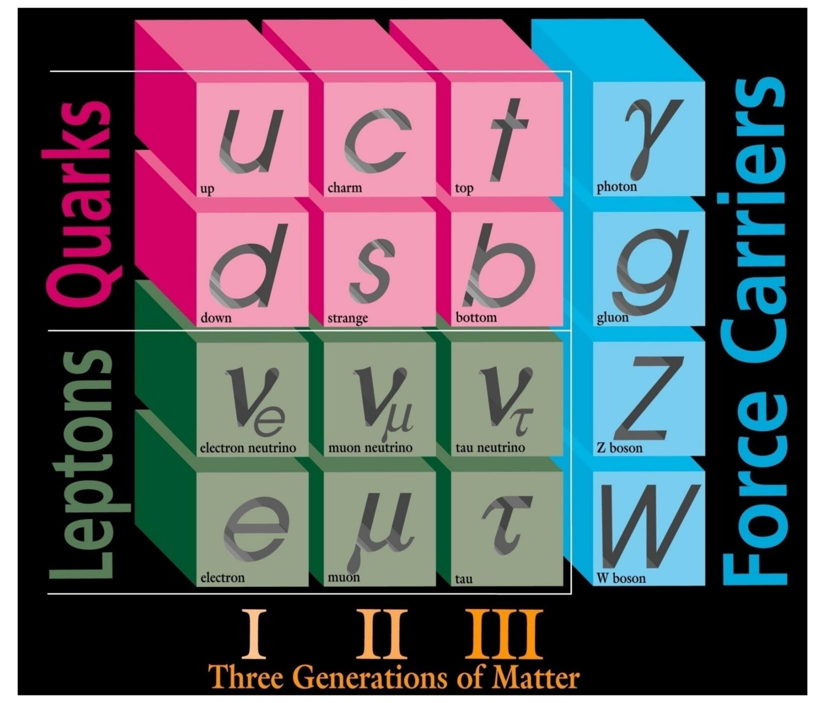
The DØ detector is about 30' × 30' × 50' and weighs about 5,000 tons. You can see examples and artifacts of the detector technologies in this museum area.

The DØ collaboration is formed by about 600 physicists, 25% of which are graduate students working on their Ph.D. degree. Our collaboration is very international in flavor, including physicists from all over the world.

The two collider experiments are situated at two separate spots on the Tevatron accelerator, a ring four miles in circumference.

The laboratory is located about forty miles west of Chicago. It comprises some 5,800 acres of undeveloped land and provides a home to many plant and animal species in a natural environment.



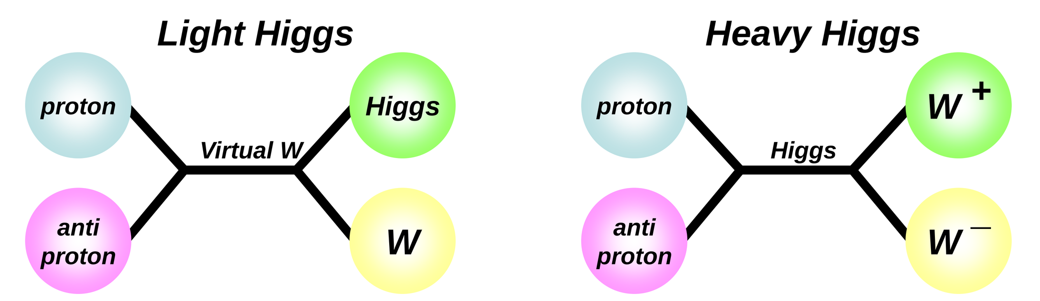


Experiments at Fermilab investigate the fundamental constituents of matter, the quarks and leptons from which everything is comprised. Of the particles shown above, three of them were discovered at Fermilab, the bottom quark (1977), the top quark (1995) and the tau neutrino (2003). The other particles were all discovered at other laboratories.

In these posters, you will find a tiny sampling of the physics results we have measured. Research at DØ has yielded hundreds of Ph.D. theses and hundreds of publications.

Higgs Boson: *The Last Piece of the Standard Model Puzzle*

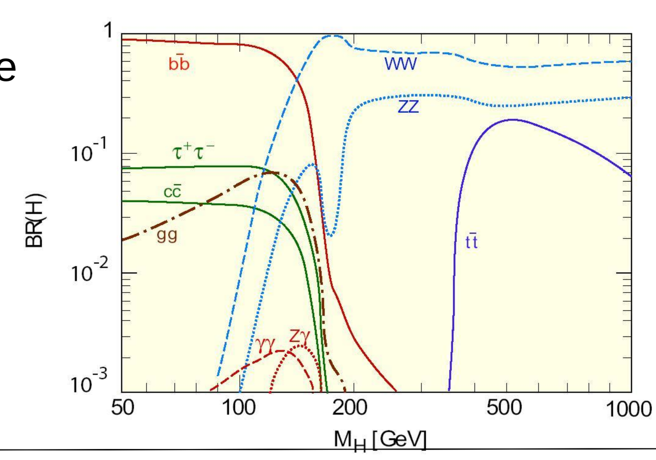
The Standard Model cannot explain why the particles have the masses they do. In fact, in unifying the weak and the electromagnetic theories, physicists needed to make a simplifying assumption…that all particles were massless.



This obviously-incorrect assumption demanded explanation. In 1964, Peter Higgs suggested that perhaps there was a field in the universe that gave the subatomic particles their mass. Particles that interacted a lot with the field would have a lot of mass. Those that interacted very little with the field would have no mass at all.

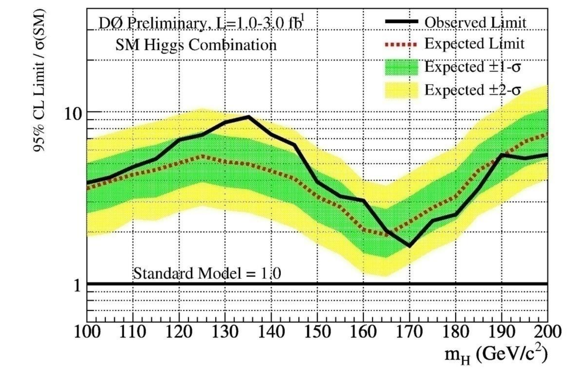
If this idea were true, physicists could unify electromagnetism and the weak force *and* explain the disparity of particle masses. Higgs realized that if his idea were true, there would necessarily be a particle not yet discovered, called the Higgs Boson and made popular in Leon Lederman's book *The God Particle.*

There was only one little problem. The Higgs Boson has never been observed. Physicists do not know whether it exists or, if it exists, its mass. However if the Higgs idea is correct, we can calculate how it will decay. We know that if the Higgs Boson is very massive, it will decay into pairs of W bosons. If it is lighter, it will decay into a pair of bottom quarks. There are other possibilities, but these are of lesser interest.

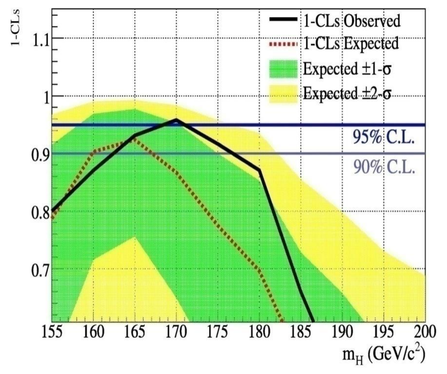


Further, if the Higgs Boson is light, for technical reasons, we only look for it in conjunction with a W or Z boson.

Since the Higgs Boson's mass is unknown, DØ has searched for all possible decays. We have not found it yet, although we have been able to set limits on the mass. To the right we show our results.



The horizontal black line shows the Standard Model prediction, while the wiggly one shows our results. We know that region above the wiggly black line is excluded. As we accumulate more data, the wiggly line will approach the straight line. If the wiggly line goes below the straight line, we will rule out that mass.



When we combine our results with our sister experiment (CDF), we effectively double the amount of data we have recorded. The combined data of both experiments have excluded a Higgs Boson mass of 170 GeV. This achievement shows that the Fermilab Tevatron may be the place where the Higgs boson is discovered!

It Won't Make You Zzzzzzzzzzzzzzzz

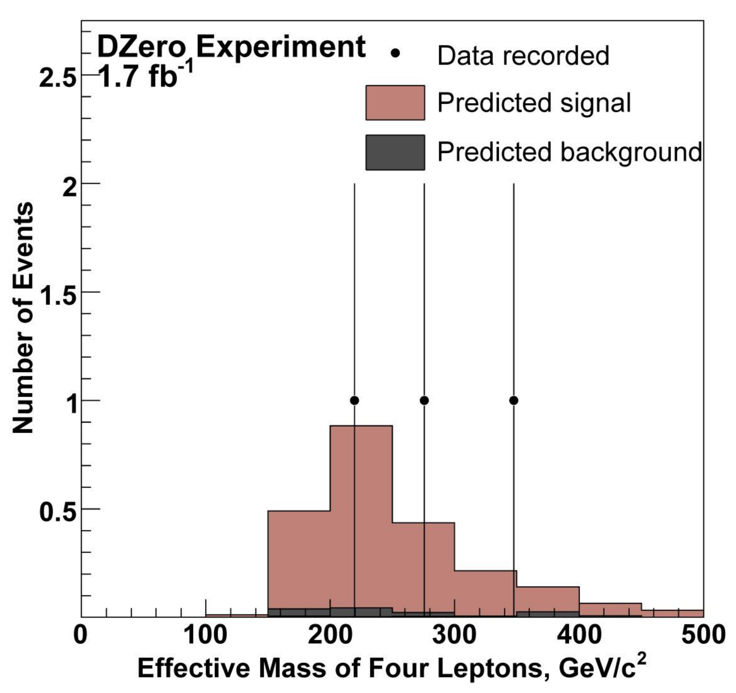
The electroweak bosons (the W & Z bosons) mediate the weak force, which governs some kinds of radioactive decay. Unlike their purely-electromagnetic cousin (the photon or γ), they are very heavy, weighing about 100 times as much as a proton. They were discovered in Europe in 1983-1984. Because these bosons are so heavy and because they mediate the weak force, they are rarely made.

While the study of the weak force is important in its own right, we now exploit the rarity of observing electroweak bosons while looking for Higgs bosons. The easiest way to observe the Higgs boson is either through its decay into pairs of electroweak bosons, or its production at the same time as a W or Z boson.

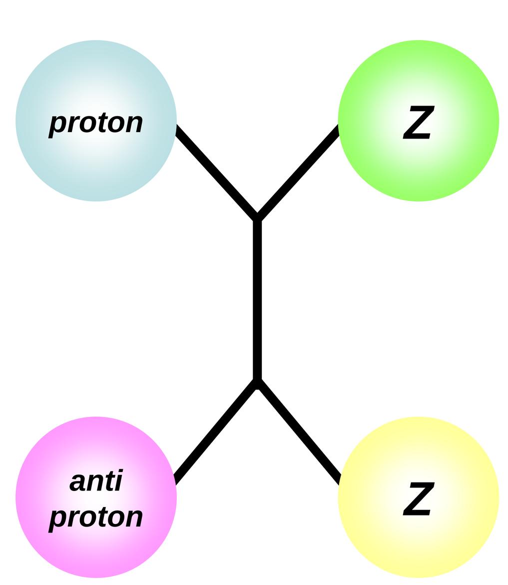
DØ recently observed the production of pairs of Z bosons, the last such unobserved combination except for the Higgs boson itself.

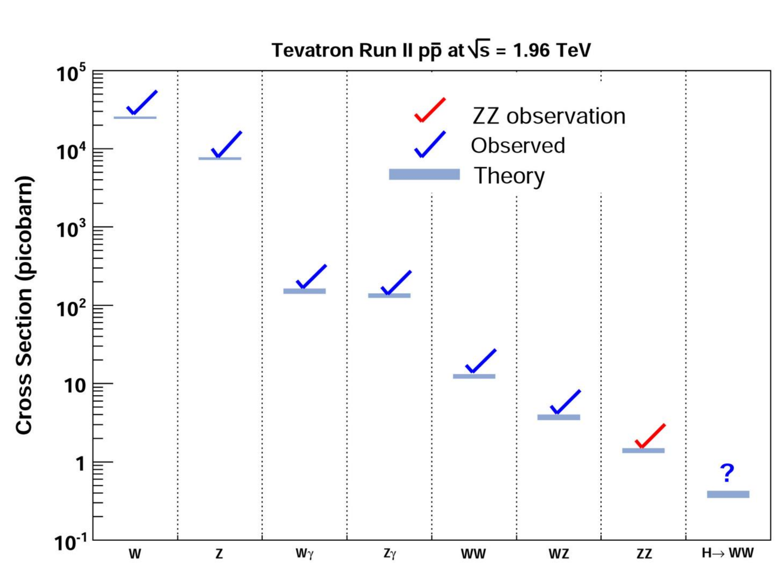
In this analysis, countless collisions and billions of recorded collisions were inspected. In the end, precisely three such collisions were observed, with an expected "background" (i.e. events that looked like what we wanted but were fake) of 0.01 fake events.

Observation of ZZ Production

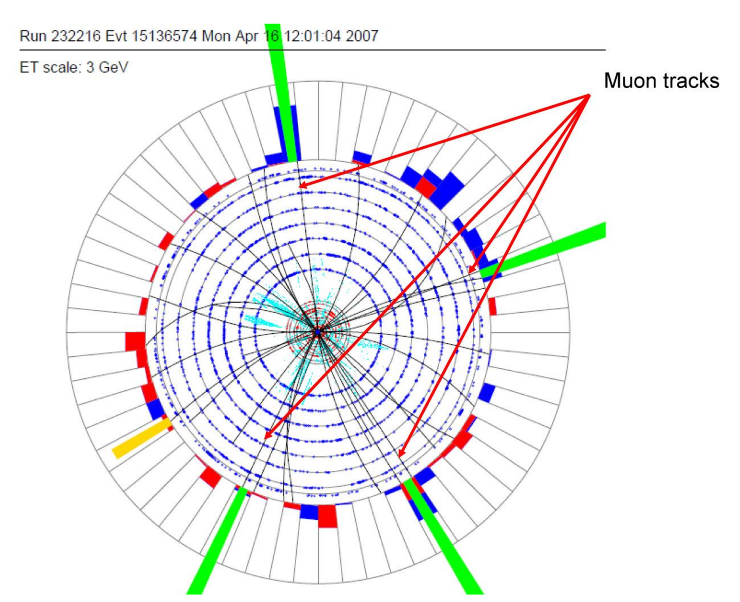


ZZ Production

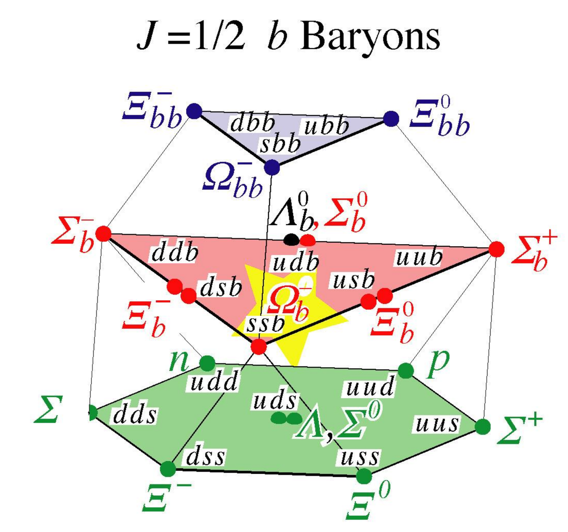




A Collision in Which Two Z Bosons Were Created



Hitting Rock Bottom

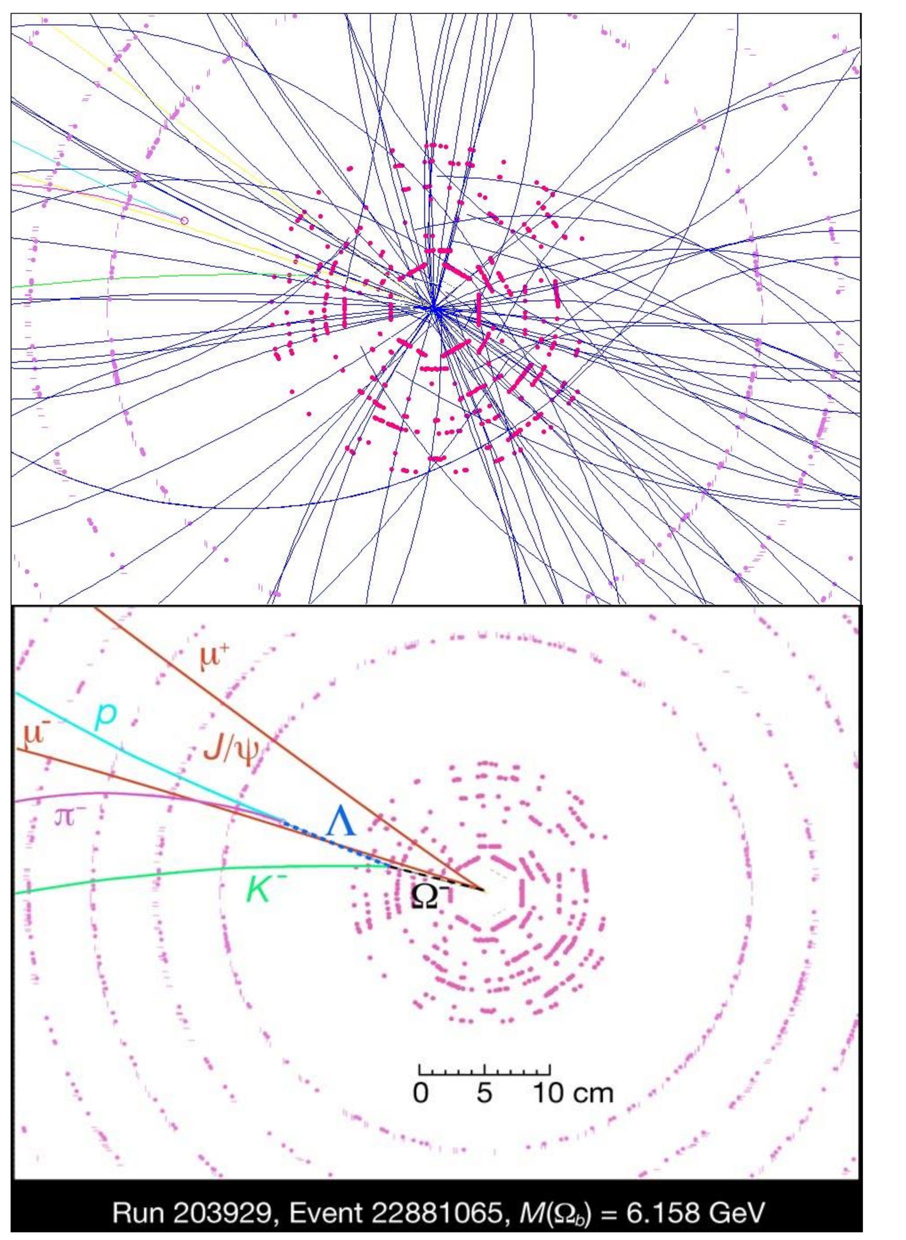


There are two kinds of subatomic particles, called *mesons* and *baryons.* Mesons contain a quark and antimatter quark, while baryons contain three quarks.

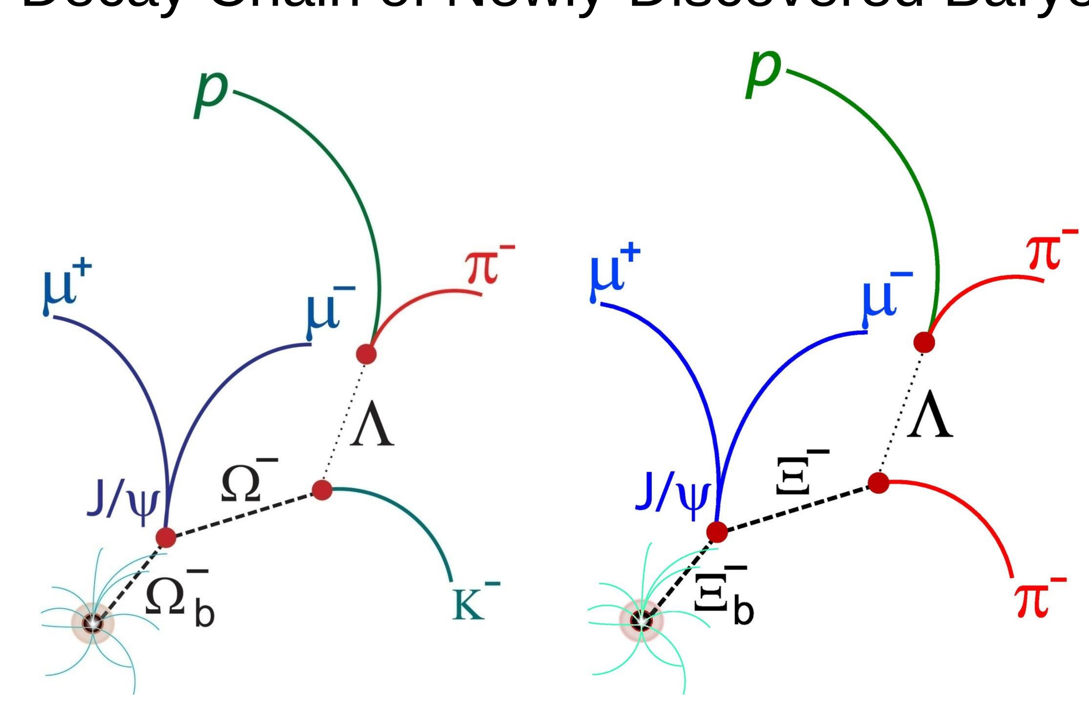
Two rare kinds of baryons were observed for the first time in DØ, the Ξ^-_b (containing a down, strange and bottom quark) and the Ω^-_b (containing two strange quarks and a bottom quark.)

We see here in these plots the difficulty in observing these particles. Below you can see a diagram of what is going on. To the right, you see the same collision two different times. The top figure is the entire collision, with both detectors and tracks overlaid. On the bottom, only tracks relevant to observing the Ω^-_b are displayed.

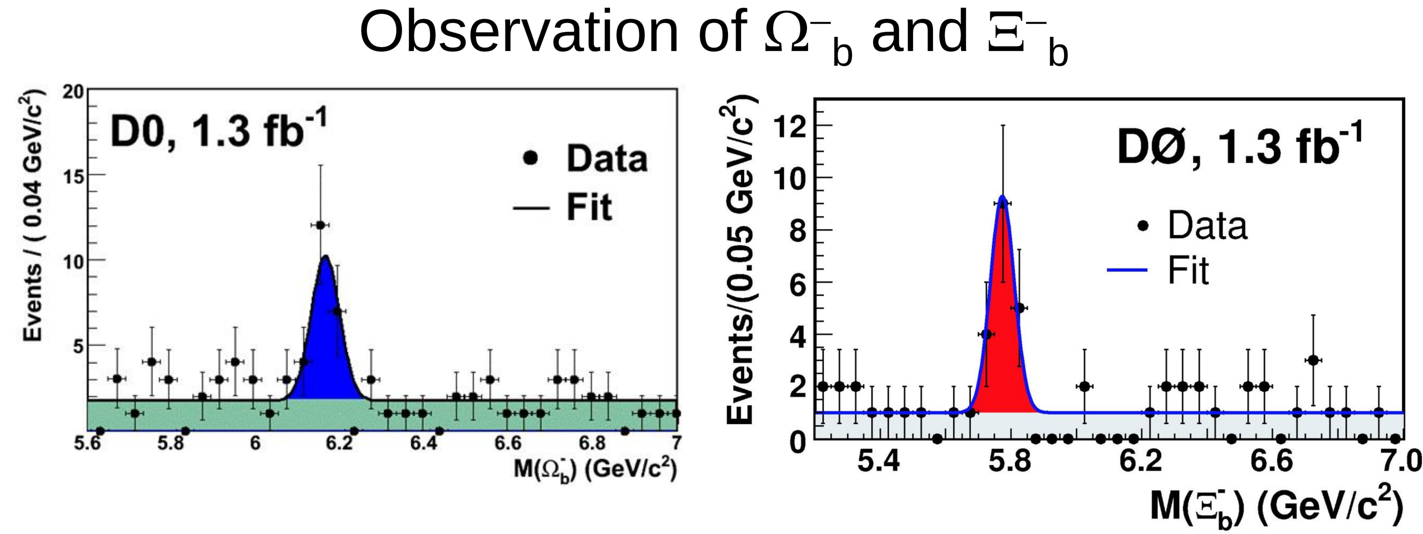
Event containing an Ω^-_b



Decay Chain of Newly-Discovered Baryons

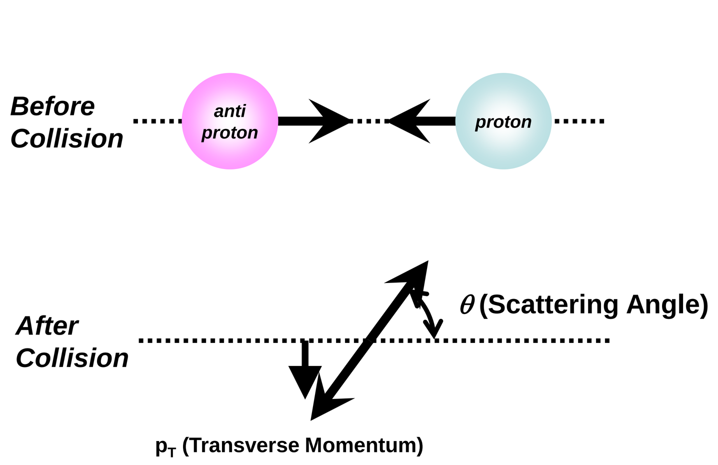


Observation of Ω^-_b and Ξ^-_b



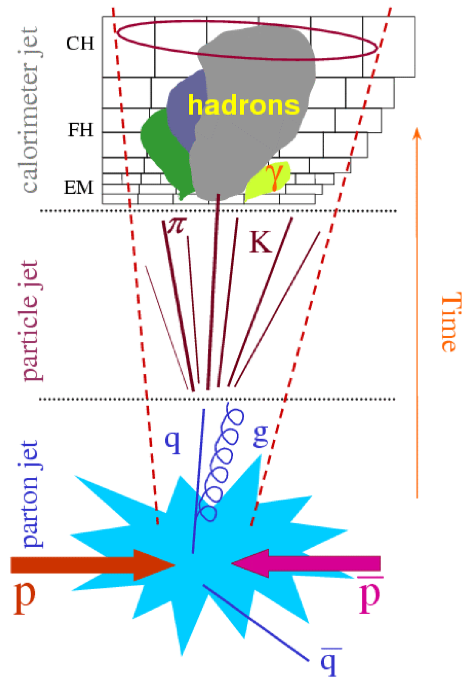
Quark Scattering

Of the known forces, the strongest force is called the *strong force.* This force is responsible for holding the nuclei of atoms together and the quarks inside nucleons.



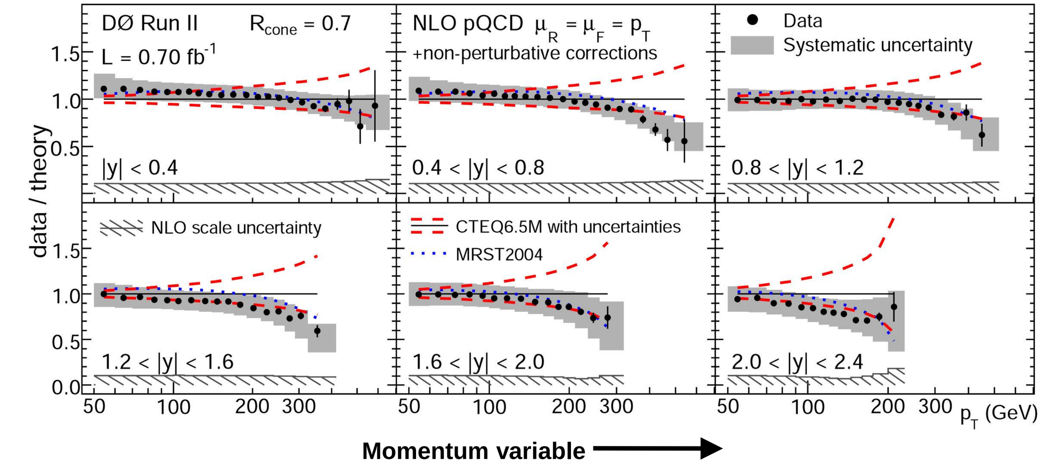
Quarks were postulated in 1964 and observed in the 1970s. We now have a theory that describes how the strong force affects quarks. This theory is called *Quantum ChromoDynamics* or QCD. The name stems from the fact that the strong charge (analogous to the familiar electric charge) is called *color*, although this name is unrelated to actual color.

Because this force is so strong, simple quark scattering is the most common phenomenon observed in DØ. A quark from a proton and an antimatter quark from the antiproton collide and scatter.

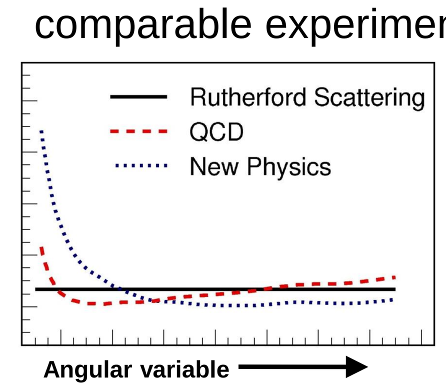


A quark becomes a jet

Because of the nature of the strong force, we are unable to observe quarks directly. When they are knocked out of a proton, they undergo additional interactions and end up as a spray of particles all moving in about the same direction. These sprays of particles are called *jets.* We are able to add up the energy in these sprays of particles and relate them to the original parent quark. Translating a measurement in our experiment to the original quark scattering is difficult and one of DØ's most noteworthy strengths.



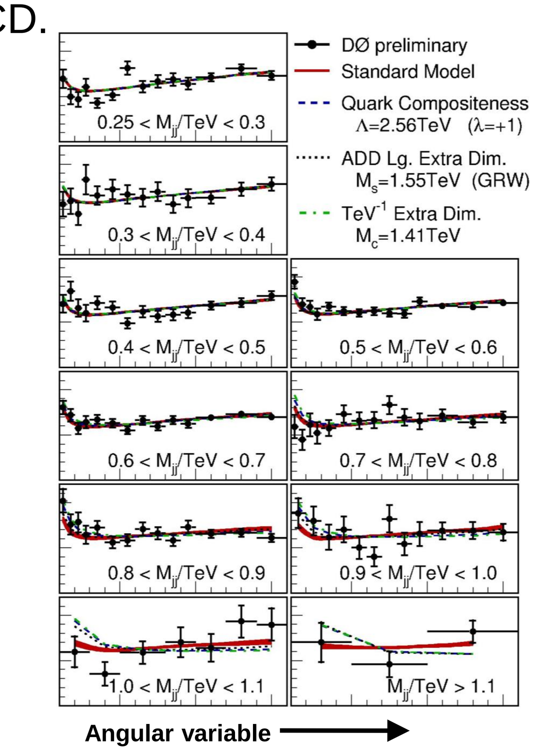
In the plot above, we compare our measurements of the "violence" of the collisions to theoretical predictions in many angular regions. If the theory correctly predicted the data, these would be flat lines at 1. Of special note is the width of the grey bands. These bands indicate the precision of our measurement. These uncertainties are as low as 10%, which is the best achieved by any comparable experiment by about a factor of two.



In addition to the violence of the collisions, we measure the angles at which quarks are scattered. It is possible that new phenomena may exhibit a different pattern than QCD.

In the plot to the right, we compare our measurements of the angle at which quarks are scattered to both predictions of QCD and various theories that predict new physical phenomena.

Our measurements favor the traditional QCD model and seriously constrain any future speculation that new phenomena may exist.



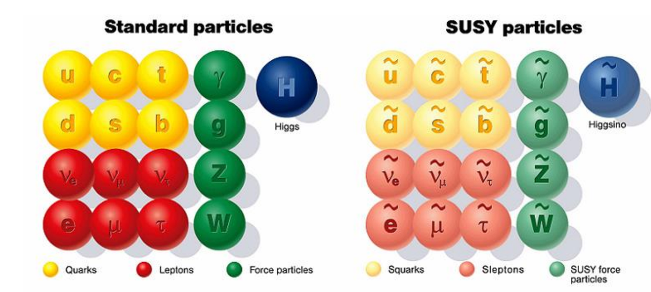
New Phenomena: *Searching for something never seen before*

Summarizing the broad research program searching for new phenomena is extremely difficult. By its very definition, we don't know what we'll find. However, we can offer a laundry list of some of the interesting topics. We are looking for:

- Extra dimensions of space and time
- Leptoquarks, particles that are part lepton & part quark
- Compositeness, searching for something inside quarks and leptons
- Supersymmetry, an idea that there should exist another series of particles, similar to those we know but with different quantum mechanical spin.
- Gravitons, the particle that mediates the gravitational force.
- And on and on and on and…

Here is a smattering of our research topics.

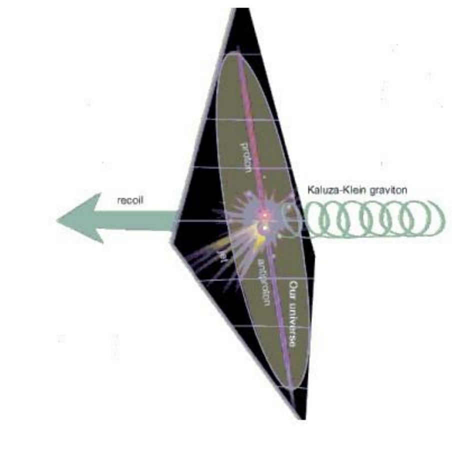
Supersymmetry (aka SUSY)



If SUSY turns out to be real, it predicts new particles, called squarks, sleptons and gauginos. No such particles have been observed, but there are compelling theoretical reasons to expect SUSY exists. For instance, theories containing SUSY provide natural candidates for dark matter and SUSY can provide a natural explanation for why the gravitational force is so much lower than the others.

There have been thousands of theoretical and experimental papers written on the subject of SUSY.

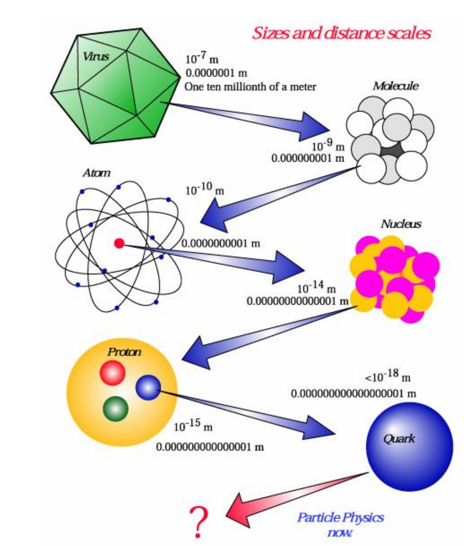
Extra dimensions



The idea of extra dimensions is attractive because it could explain why gravity is so much weaker than the other forces. If gravitons, hypothetical carriers of the gravity force, can enter additional dimensions, then this would explain the weakness of gravity. Experimentally, we would observe gravitons by not seeing them! Gravitons would escape unseen into additional dimensions.

Compositeness

The history of particle physics is full of a continuous stream of discoveries of particles that were thought to be fundamental (i.e. contain nothing in them) only to find out that they themselves turned out to contain smaller objects. Atoms turned out to contain protons, neutrons and electrons. Protons and neutrons themselves were made up of quarks, although the leptons (most familiarly the electron) still appear to be fundamental. Along with the leptons, quarks too seem to be structureless and can be represented by a mathematical point. Naturally, we have reasons to suspect that this situation could well change with additional research. We do not have a favorite theory that might describe what goes on inside quarks and leptons and so we simply keep our eyes open and see what we can.



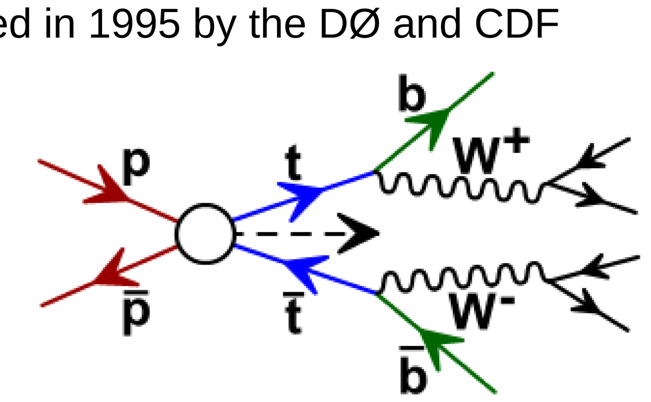
These are only a few of the interesting topics under investigation.

Heading for the Top

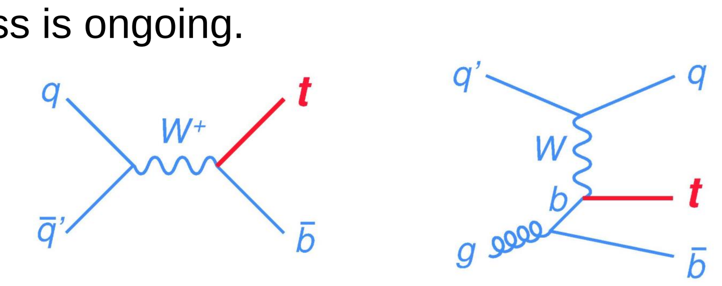
In 1964, the idea of quarks was proposed. In the first proposal, there were only three types: up, down and strange. Down and strange quarks were similar and it was a mystery why there should not be one equivalent to the up quark. This new quark type was called charm and was discovered in 1974.

In 1977, another "down-like" quark (bottom) was discovered and with that, the race was on to find the up-like equivalent. With much effort and a few false steps along the way, the top quark was discovered in 1995 by the DØ and CDF experiments.

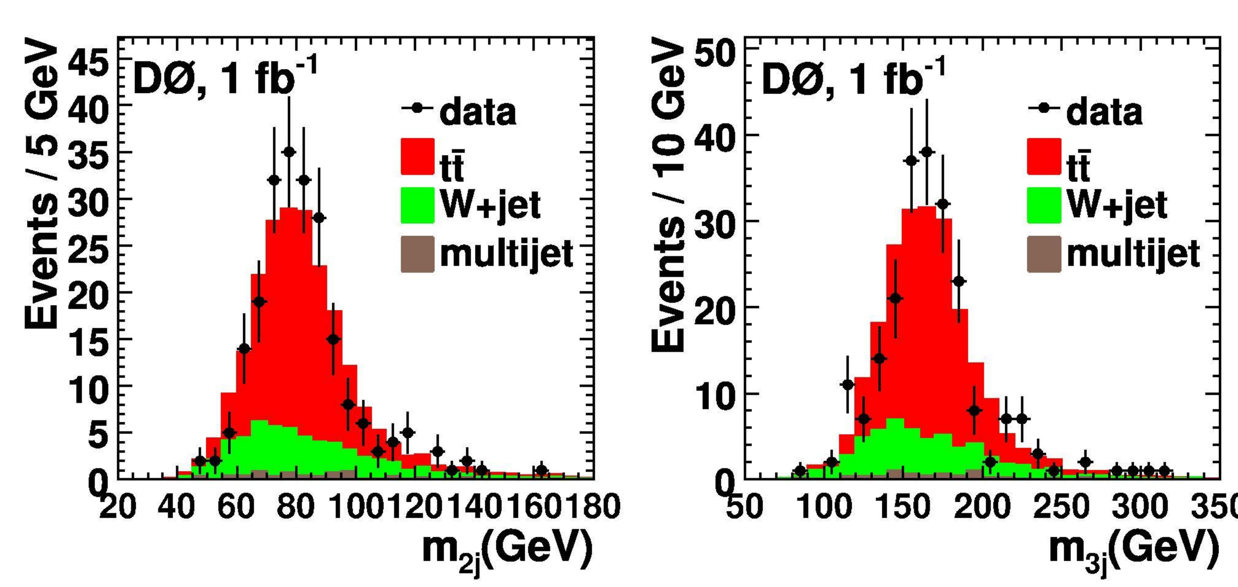
Top quarks are almost always produced in pairs. They decay rapidly into a bottom quark and a W boson.



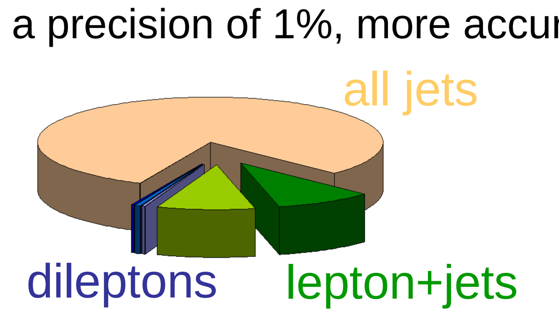
The W bosons themselves decay in turn. Thus an event in which top quarks are created typically contain six distinct objects. It is possible in very rare cases for a single top quark to be observed in an event. The search for this rare process is ongoing.



Top quarks are very heavy, about 170 times heavier than a proton and weigh as much as an entire atom of the element osmium. Further, they exist for a very brief period of time, on the order of 10^{-24} seconds.

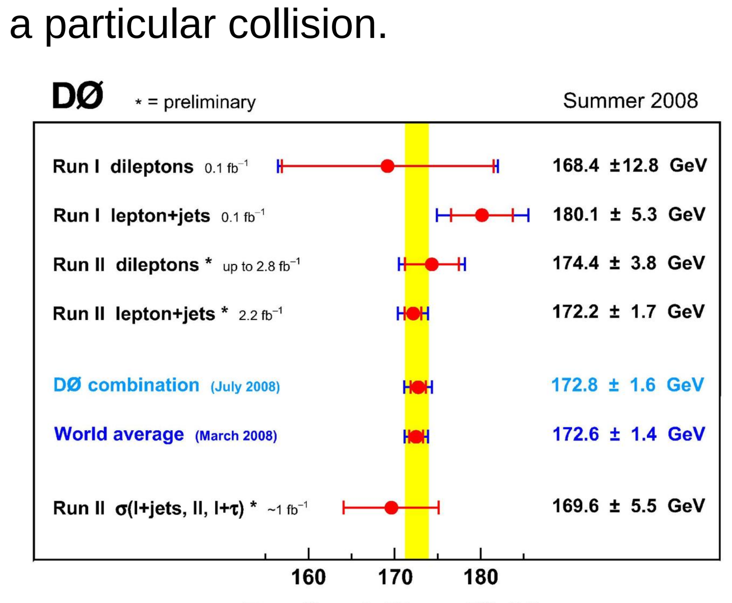


Even though the top quark exists for a very short period of time, we now have recorded a few thousand events in which they are produced. Ironically, we have measured the mass of the top quark to a precision of 1%, more accurately than any of the others.

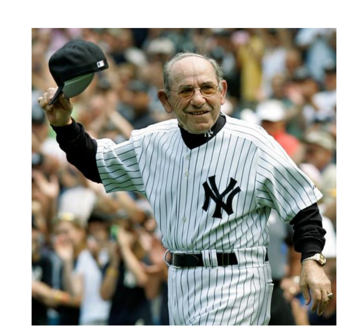


We categorize top quark events by the manner in which the W boson decays. The W boson decays predominantly into quarks, but these events are hard to measure precisely. Thus much of our efforts are put towards those events in which the W bosons decay into electrons or muons. In such events, we are able to very accurately measure the mass of the top quark as well as the probability that we will manufacture top quarks in a particular collision.

Since the top quark is the heaviest of all known subatomic particles, it interacts the most with the Higgs boson. Thus studying the top quark is expected to help guide us to decide where to look for the all elusive Higgs boson.



DØ and the Future

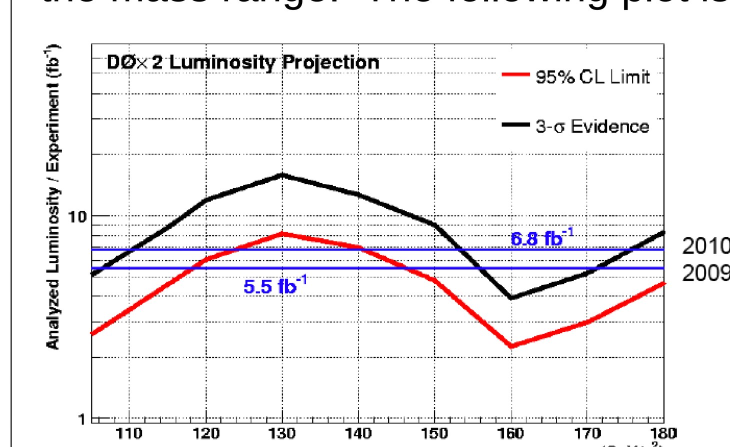


Prediction is very hard, especially when it's about the future.

— Yogi Berra

DØ will be running through the end of 2010. During this time, we expect to record double the data currently in hand.

We expect to either observe the Higgs boson or exclude a lot of the mass range. The following plot is a little complicated, but it shows Fermilab's expected performance while searching for Higgs bosons. The horizontal lines show us how much data we will have available in 2009 and 2010. The red curve shows the possible Higgs boson masses that the Fermilab Tevatron can rule out. When the red line dips below the horizontal line, we will be able to rule out that mass. The black line is a higher standard. It is the curve that tells us what we might see. If the Higgs boson exists, wherever the black curve dips below the horizontal line, we will likely see it. We see that in 2010, we will be able to rule out all possible Higgs boson masses except for the region of 120-140 GeV (if the Higgs boson does not exist) and we will be able to show very interesting evidence at least if the mass is in the region of 155-170 GeV. If we take more data, we will be able to explore or rule out a larger range.

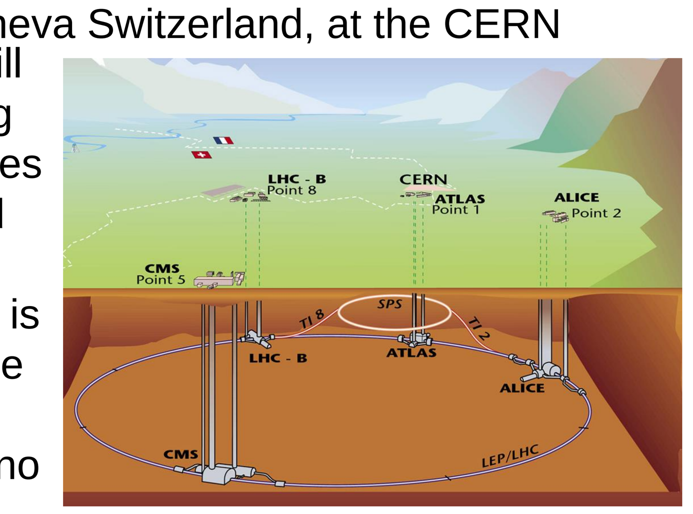


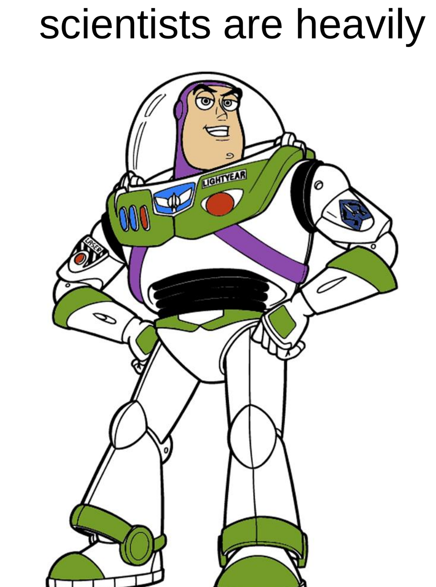
Note that a Higgs mass of 170 GeV is already ruled out and that region is already heavily disfavored.

While the Higgs boson is the most pressing discovery still to be made, it is by no means the only. Studies into the nature of top and bottom quarks, the electroweak sector and QCD are all ongoing.

The Competition: The Large Hadron Collider

While the Fermilab Tevatron has reigned supreme as the highest energy accelerator in the world, this is a position it will not hold for much longer. The Large Hadron Collider, or LHC, is a new accelerator based outside Geneva Switzerland, at the CERN laboratory. This accelerator will accelerate two counter-rotating beams of protons to seven times the energy of the Tevatron and about fifty times as many collisions per second. While it is expected that it will take a while for the LHC to be operating as well as it is designed, there is no doubt that Fermilab scientists await its official startup in the spring of 2009 with great anticipation and yet a twinge of sadness. By 2010 or 2011, the torch will have passed to another generation of accelerators and the venerable Tevatron will be turned off for the last time. Luckily Fermilab scientists are heavily involved in both the LHC accelerator and in experiments based there. The excitement continues!





To the Quantum Frontier and Beyond!