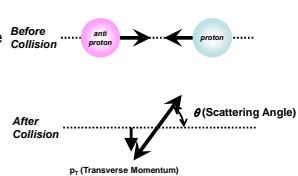




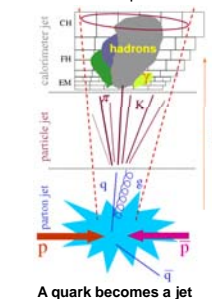
# Quark Scattering

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.

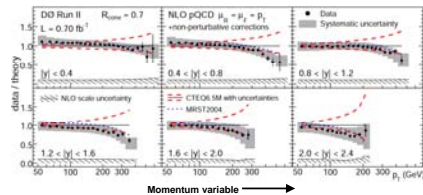


Quarks were postulated in 1964 and observed in the 1970s. We now have a theory that describes how the strong force affects quarks. This theory is called **Quantum Chromodynamics** or QCD. The name stems from the fact that the strong charge (analogous to the familiar electric charge) is called **color**,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

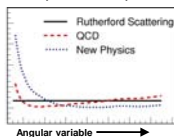
Because this force is so strong, simple quark scattering is the most common phenomenon observed in DØ. A quark from a proton and an antimatter quark from the antiproton collide and scatter.



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 many 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.



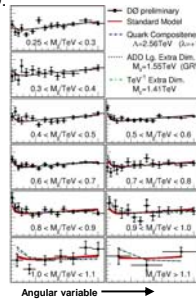
In the plot above, we compare our measurements of the "violence" of the collisions to theoretical predictions in many angular regions. If the theory correctly predicted the data, these would be flat lines at 1. Of special note is the width of the grey bands. These bands indicate the precision of our 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.



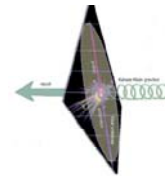
# New Phenomena: Searching for something never seen before

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...

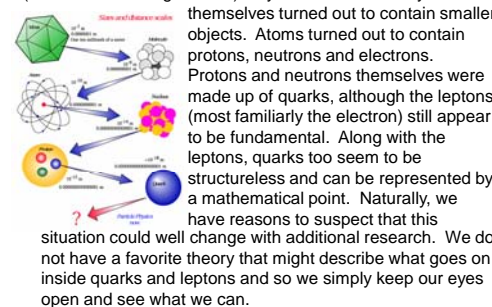
## Extra dimensions

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

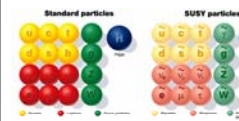
The history of particle physics is full of a continuous stream of discoveries of particles that were thought to be fundamental (i.e. contain nothing in them) only to find out that they



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.

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.

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

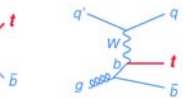
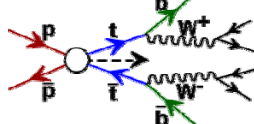
# Heading for the Top

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.

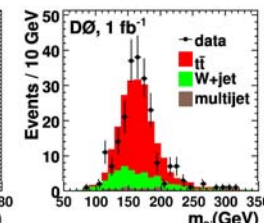
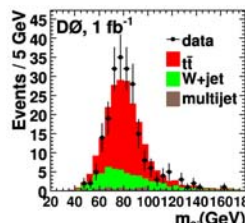
In 1977, another "down-like" quark (bottom) was discovered and with that, the race was on to find the up-like equivalent. With much effort and a few false steps along the way, the top quark was discovered in 1995 by the DØ and CDF experiments.

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

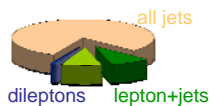
The W bosons themselves decay in turn. Thus an event in which top quarks are created typically contain six distinct objects. It is possible in very rare cases for a single top quark to be observed in an event. The search for this rare process is ongoing.



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.



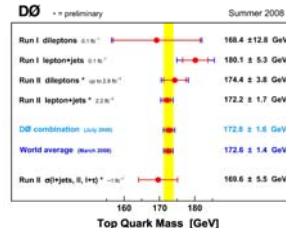
Even though the top quark exists for a very short period of time, we now have recorded a few thousand events in which they are produced. Ironically, we have measured the mass of the top quark to a precision of 1%, more accurately than any of the others.



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

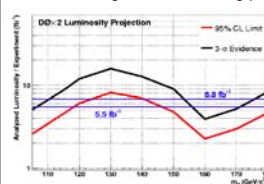


Prediction is very hard, especially when it's about the future.

— 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.

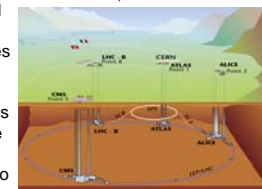
Note that a Higgs mass of 170 GeV is already ruled out and that region is already heavily disfavored.

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!