The High Energy Physics group consists of four faculty experimentalists and four faculty theoreticians, as well as several postdoctoral research fellows, and other personnel supporting research including a research scientist, an IT specialist, and an engineer.

The goals of the experimental high energy physics group are to search for new physics and to explore the predictions of the Standard Model to unprecedented accuracy. In order to perform this research, we are involved in the DØ experiment at Fermilab (near Chicago) and the ATLAS experiment at the Large Hadron Collider (LHC) at CERN. While DØ continues taking data as a mature experiment, the ATLAS experiment is in the early stages of data taking at the LHC.

The DØ experiment is situated at the Fermilab Tevatron, which produces the highest energy proton antiproton collisions in the world. The collisions allow us to study the strong (QCD) and electroweak interactions through the decays of the produced particles and through their measured angular distributions. Some of the recent results from the DØ experiment include the discovery of the top quark, a precision measurement of the W mass, and gluon radiation interference effects. In addition, numerous searches for new particles, new forces and discrepancies with the Standard Model are all being carried out. An upgrade was completed a few years ago which greatly enhanced the detector’s ability. For the next few years new physics discoveries will continue to be pursued at one of the premier detectors in the world.

The LHC is the highest energy proton-proton collider ever constructed, eventually with a collision energy of 14 TeV. These energetic collisions are expected to probe some of the most fundamental questions in the universe. Questions regarding the origin of mass, the dark matter in the universe, and the abundance of matter over anti-matter may be answered at the LHC. We will look for more fundamental structure within the quarks and leptons that make up our universe and probe fundamental questions about supersymmetry, string theory, and extra dimensions. Though definitive answers to these questions are far from certain, the energy and collision rate of the LHC should make it one of the most exciting scientific tools ever built by humans.

Besides the direct physics research, we have also been involved in state-of-the-art detector development for the DØ and the ATLAS experiment. This program, which uses our own facilities at OU, focuses on advanced silicon micro-strip detectors. The excellent position resolution of silicon allows identification of short-lived particles and allows us to measure their properties.

The theoretical group is studying non-perturbative aspects of quantum field theory (QFT) and gauge theories. QFT is the basic framework for the description of particle physics, as well as for many other areas of physics. The calculations required today to solve field theories cannot be done by considering relatively small corrections (perturbations) to non-interacting theories of quarks and gluons, for example. In particular, non-perturbative methods are essential to understand the phenomena of strong interactions. Thus new mathematical methods are required, some of which are being developed in our group. In addition to developing new types of perturbative expansions and approximation methods, as well as studying new types of quantum field theories, analytical calculations are being applied to a number of important particle physics topics: quantum chromodynamics, quantum electrodynamics, the Casimir effect (vacuum fluctuations).

Another major focus of our theoretical research is phenomenology of electroweak symmetry breaking, supersymmetric grand unification, CP violation, dark matter, cosmology and theories with extra dimensions. We investigate direct and indirect signatures of new physics beyond the Standard Model in present and future experiments, particularly at the LHC. We are especially excited by potential early signatures of supersymmetry that may be detected there. In addition, we are employing particle physics to explain interesting astrophysical and cosmological phenomena as well as applying astrophysical and cosmological observations to test and constrain particle theories.
My research in experimental particle physics has recently been in heavy flavor physics, which includes both the bottom and the top quark. I am a member of the DØ collaboration at the Fermi National Accelerator Laboratory, which is located near Chicago Illinois. At DØ, I have been primarily studying the bottom quark. In particular Bs mixing, which involves a Bs meson oscillating into its anti-matter partner. I have also been involved in a number of searches and measurements for new particles. Measurements of the newly discovered X(3872) particle may shed light on its nature. The $\Xi_b^-$ baryon was recently discovered at DØ. This baryon is interesting in that it contains a quark from all three generations (down, strange, bottom). The latest particle discovered at DØ is the doubly strange $\Omega_b$ baryon. This is currently the heaviest b-baryon discovered.

I am also a member of the ATLAS collaboration at the Large Hadron Collider located near Geneva Switzerland. I have been primarily studying the top quark on ATLAS. The ATLAS detector is in its early stages of collecting data and it is hoped that the LHC will discover the elusive Higgs particle and perhaps answer questions such as, what gives mass to particles, are their as yet undiscovered fundamental symmetries in nature, are there additional dimensions, and what exactly is dark matter.
My research interests lie at the interface of theoretical and experimental High Energy Physics, basically matching the predictions of theory against experimental data. I am especially interested in physics beyond the Standard Model, as given by theories with weak scale supersymmetry (SUSY). These theories predict a symmetry between bosons and fermions, and so each particle of the Standard Model is expected to have a superpartner particle differing in spin, and with mass of order the TeV scale.

My collaborators and I have developed the first computer code to reliably predict what supersymmetric matter states would look like in colliding beam machines such as the LHC. The LHC should have enough energy to either discover SUSY or rule out many of its manifestations.

I also work on the cosmology/particle physics interface, and have developed code to estimate the relic abundance of dark matter from the Big Bang in SUSY theories. We have also calculated rates for direct and indirect detection of WIMP (weakly interacting massive particles) dark matter. Recently, we are most interested in the consequences of mixed axion/axino cold dark matter.

Lately, I am especially interested in SUSY grand unified theories based on the gauge group SO(10), and their associated predictions for LHC superpartner searches and cosmological consequences.

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SUSY event with 3 lepton + 2 Jets signature

\[
\begin{align*}
    m_0 &= 100 \text{ GeV}, \quad m_{1/2} = 300 \text{ GeV}, \quad \tan \beta = 2, \quad A_0 = 0, \quad \mu < 0, \\
    m(\tilde{q}) &= 686 \text{ GeV}, \quad m(\tilde{g}) = 766 \text{ GeV}, \quad m(\tilde{F}^0_{1}) = 257 \text{ GeV}, \\
    m(\tilde{F}^0_{2}) &= 128 \text{ GeV}.
\end{align*}
\]

Leptons:

\[
\begin{align*}
    p_t(\mu^+) &= 55.2 \text{ GeV} \\
    p_t(\mu^-) &= 44.3 \text{ GeV} \\
    p_t(e^-) &= 43.9 \text{ GeV}
\end{align*}
\]

Jets:

\[
\begin{align*}
    E_t(\text{Jet1}) &= 237 \text{ GeV} \\
    E_t(\text{Jet2}) &= 339 \text{ GeV}
\end{align*}
\]

Sparticles:

\[
\begin{align*}
    p_t(\tilde{\chi}^0_1) &= 95.1 \text{ GeV} \\
    p_t(\tilde{\chi}^0_{1/2}) &= 190 \text{ GeV}
\end{align*}
\]

Charged particles with \( p_t > 2 \text{ GeV} \), \( |\eta| < 3 \) are shown; neutrons are not shown; no pile up events superimposed.


Over the past 20 plus years, I have carried out research in experimental high energy physics. The research has been performed at two of the premier high energy physics laboratories in the world, Fermilab near Chicago and the CERN laboratory near Geneva, Switzerland. Currently I am a member of the DØ collaboration, one of two research groups that use the Fermilab Tevatron, currently the world’s highest energy particle collider. The goal of the research is to study all aspects of proton/anti-proton collisions. This includes studying particles that are produced in these collisions, such as the top-quark, and refining previous measurements to set limits on how well the standard model of particle physics agrees with data. These measurements will ultimately lead to extensions of the standard model, which should help answer such questions as the origin of mass and the asymmetry between matter and anti-matter in the universe, among many others.

At the present time, I am participating in measurements of top-quark production and using these measurements to set limits on the existence of Higgs particles that may exist in extensions to the standard model of particle physics. In the past I have carried out physics analyses that involve QCD (strong interactions) and electroweak interactions.

With the start up of the Large Hadron Collider at the CERN laboratory, I have begun to move my research effort to exploring the data that will be made available in the near future using the ATLAS detector. For the moment my plan is to extend the research that I am currently carrying out at Fermilab using the top-quark as a probe of the standard model of particle physics.


My current interests are in cosmology. With colleagues we are looking at nonlinear gravitational lensing corrections caused by embedding inhomogeneities (galaxies, clusters, etc.) in otherwise homogeneous models of the universe. To find nonlinear effects such as the cosmological constant’s alteration of Einstein’s bending angle, we found it necessary to use the exact GR solution called Swiss cheese. In other projects we have managed to incorporate absorption into Gordon’s optical metric on space time and are revisiting time delays in gravitational lensing, hoping to find new observational opportunities.


In the figure, the gold sample of observed supernova distance moduli vs redshifts (green points) are compared to the accelerating concordance model (green) and two non-accelerating index of refraction models (red and blue). See Figure 1 of *PRD* 78, 044040 (2008), *PRD* 79, 104007 (2009), and *PRD* 80, 044019 (2009) for details.

A sketch of a radiation beam of cross-section “A” propagating through a “Swiss-cheese” universe from a distant source to an observer. Understanding how local inhomogeneities affect the propagation of light is important in determining cosmological parameters from data.
My research interests are in theoretical high energy physics, astrophysics and cosmology, especially Electroweak Symmetry Breaking (EWSB), supersymmetry, unification of fundamental interactions, CP Violation, dark matter, and theories with extra dimensions. One of the most important goals of future colliders is to discover the Higgs bosons or to prove their nonexistence. In the Standard Model of electroweak interactions, the Higgs field condenses (disappears into the vacuum), spontaneously breaking the electroweak symmetry and generating masses for the elementary particles. Weak scale supersymmetry is the most compelling extension of the Standard Model to preserve the elementary nature of the Higgs bosons. In most supersymmetric models, the lightest neutralino can be a good cold dark matter candidate if R-parity is conserved. Recently, I have been investigating direct and indirect signatures of new physics in present and future experiments to pursue interesting physics of electroweak symmetry breaking, supersymmetry, CP violation and astrophysics.


The interactions that give rise to the structure of atoms, nuclei, and elementary particles are described by quantum gauge field theories. These gauge theories are Abelian in the case of electrodynamics (photons do not interact with each other), and are non-Abelian in the case of weak and strong nuclear interactions (gluons, for example, couple directly with each other). These theories are mostly understood in the weak-coupling regime, where perturbation theory may be applied, which contradicts the essentially strong interaction of the subnuclear force.

I am primarily interested in developing nonperturbative methods for use in quantum field theories and gauge theories. During the past decade I have worked on the quantum finite-element lattice method, variational perturbation theory, the delta or logarithmic expansion, and analytic perturbation theory. At present I am developing a new alternative to conventional Hermitian quantum theories, where symmetry under the combination of space and time reflection is used in place of mathematical Hermiticity to define a unitary theory. These ideas are being applied to quantum electrodynamics and quantum chromodynamics. Quantum vacuum energy phenomena (Casimir effects) are also nonperturbative in that the background reflects nontrivial topological configurations of the underlying fields. Applications range from subnuclear through nanontechnological to cosmological phenomena. Finally, I continue to have interest in developing the theory of magnetic monopoles.


Non-contact gears. Quantum electrodynamics implies a vacuum energy between dielectric bodies. In particular, there is a lateral force between corrugated surfaces. Moving one body parallel to the other will transmit a sideways force on the second, without contact between the bodies which would result in stiction. Such a device could be used in nanomachinery.

New calculational techniques in quantum field theory allow us to compute the quantum vacuum forces between arbitrarily shaped bodies. Shown here is a hyperboloid of revolution above a plane, for which the Casimir force can be computed exactly. Previously only forces between parallel planes could be exactly evaluated.
My area of research is experimental elementary particle physics. My present interest in this field is in experiments which produce particles containing the heavy “bottom” or “beauty” quark (“bottom-flavored” particles). I also have a strong interest in the development of semiconductor detectors for use in high-energy physics experiments, and I am currently involved in several major efforts in the continued development of these detectors.

I am currently involved in an electron-positron colliding beam experiment at the Cornell Electron Storage Ring (CESR). This experiment has been collecting data since 1979 and has produced the world’s first direct evidence for the existence of “bottom-flavored” particles. The experiment uses a large multi-purpose detector called CLEO. One goal of the experiment is to investigate symmetry (CP) violation by B mesons as a probe of the fundamental nature of the nuclear force. We have recently observed rare decays of the B meson in which such symmetry violations could occur.

I have also worked within the department’s high-energy group on the development of semiconductor pixel detectors for a future experiment called ATLAS. This experiment is under construction at the European particle physics laboratory CERN located in Geneva, Switzerland. It is a multipurpose detector to study collisions between protons. A major goal of ATLAS is to discover the Higgs particle, which is thought to be responsible for the generation of the masses of other particles according to current theory. One possible decay mode of the Higgs particle is to two b quarks so our experience with bottom physics may prove useful in detecting the Higgs. If the Higgs particle is discovered, this will open up whole new areas of study. The pixel detectors we are developing will be the detector elements closest to the collision point and will provide the best position measurement for charged particles produced in collisions.
My research is in Experimental Particle Physics. I am currently doing research with both the DØ detector using the Tevatron collider at the Fermi National Accelerator Laboratory near Chicago and with the ATLAS detector using the Large Hadron Collider (LHC) at CERN laboratory near Geneva, Switzerland. Both these machine are excellent instruments for testing the predictions of the Standard Model of elementary particles and fields and to look for experimental deviations from those predictions. I will continue to work at both experiments until the LHC is running efficiently and then exclusively do research at CERN.

At the Tevatron my recent research has focused on testing various properties of Quantum Chromodynamics (QCD), particularly the properties of the gluons within the proton. I am also studying various properties of the b quark, including B meson decay rates.

Because the LHC will have the highest energy collisions of any machine ever built, it has the potential of discovering new phenomena which may extend or supersede the Standard Model. Studies indicate that answers to fundamental questions about the nature of mass, the asymmetry between matter and antimatter, and even the particles that make up the dark matter in the universe may be discovered in the near future at the LHC.

With the Tevatron running smoothly and the LHC starting up, the future potential for the discovery and observation of new and interesting phenomena in the field of elementary particles and fields looks extremely promising. It is an exciting time to be doing experimental physics in this field.


