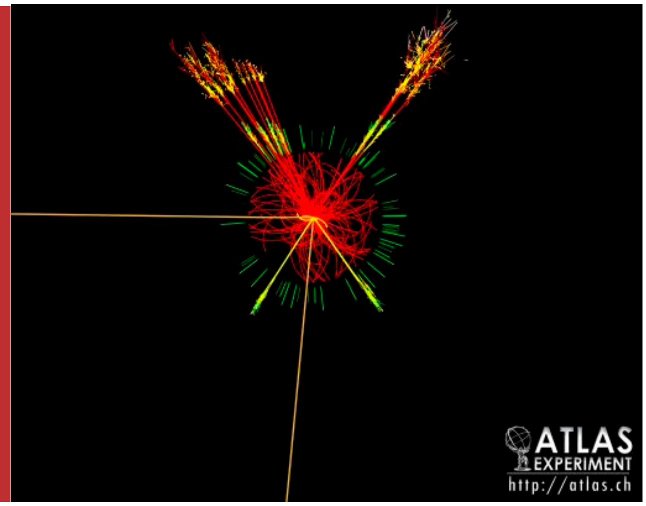
QUARKS, SPACETIME, and the BIG BANG

spring term 2012



A simulated Higgs Boson event as it might appear inside of the ATLAS detector at the Large Hadron Collider.

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http://pa.msu.edu/~brock/

A Big Questions Course – studying the of the Origins of the Universe

This is a course about the most fundamental aspects of our Universe: How it came to be, how it evolved, and why we think we understand these things.

Goals of the Course

There are three broad goals to ISP220:

1. **To Learn Stuff.** You'll learn the contemporary theories of fundamental physics and cosmology and to be aware of open questions.
    - You will learn abstract ways of thinking about Nature.
    - You will learn how current research tells us about the nature of space, time, and our origins.
    - You'll learn about current and future experiments aimed at tackling some of the Big Questions and how Michigan State is involved.
2. **To Do Stuff.** To apply basic physics tools of reasoning and mathematics to understand experimental and theoretical techniques.
3. **To Meet People.** To meet some historical and contemporary physicists and learn their personal stories of discovery and practice.

What's in the syllabus:

10^{-14} seconds = time after the beginning of the Universe reproduced in a laboratory

Details

Course Numbers......	ISP220a, ISP220b
Location....................	BPS1415

Cyberspace

Course Blog.............	go there first: http://www.chipbrock.org/
Course Wiki..............	http://isp220.wikispaces.com/
Facebook Group.......	search on “QS&BB” and request to join.
Twitter.......................	@isp220

Texts

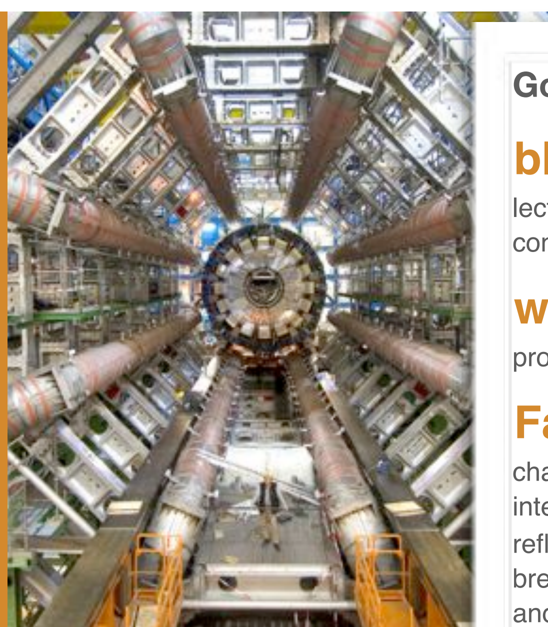
Required...................	Hobson, Physics, *Concepts & Connections* & Ford, *The Quantum World*
Recommended.........	Gordon Kane, *The Particle Garden*

Staff

Professor...................	Prof Raymond Brock http://pa.msu.edu/~brock/ 3210 BPS, 3-1693, brock@pa.msu.edu, http://pa.msu.edu/~brock/, Skype: chipbrock In-person office hours: Wed 10-noon, or by appointment Skype office hours: Thursday evenings, 8-10pm EST
CERN guide..............	Dr Barbara Alvarez-Gonzalez at CERN, 32 2-B03, barbara.alvarez.gonzalez@cern.ch
TA.............................	Ms. Kendra Lyons; Office hours: TBA

(Easter Egg #1) If you read this sentence, keep track of them. This is one.

right: The enormous air-core, superconducting magnets of the **ATLAS detector** will pick out important remnants of the p-p collisions at the **Large Hadron Collider**



Go to the

blog for:

lecture notes
content “memos”

wiki for:

projects

Facebook Group for:

chat
interactive questions/answers/
reflections
breaking news in the particle physics and cosmology worlds

1.25×10^{11} = estimated number of galaxies in the Universe

The deep essence of Nature doesn't fit our brains so you'll struggle to grasp the meanings, just as we do. Will it be challenging? Will you succeed? Yes and Yes! Come to class. Do the work. Talk to me. You'll do fine.

The Management

A message to you from your instructor:

This an unusual physics course – decidedly *not* dead white guy science. I hope that you'll come away with a sophisticated appreciation for some of the most intriguing and baffling ideas about the Universe, most of which have come about only in the last few decades. This understanding didn't come easily and it's still incomplete. So we at MSU are hard at work pushing deeper working in international labs around - and above and below(?) - the Earth. And I want to tell you about it!

These topics are alive. The work is ongoing. I can't tell you the all of the answers, because in some important cases we're still trying to figure out the questions!

And *that's* one of the things I hope you will find interesting about this course: it's current.

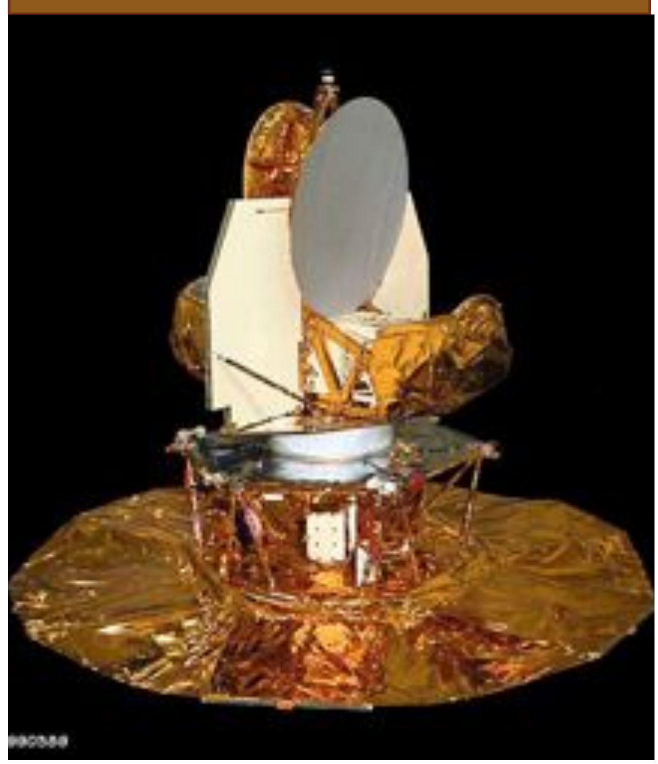
In order to get to the neat stuff, we'll pass through some basic physics and I'll try to do that in a gentle and engaging way, emphasizing what we need. I promise not to get bogged down in the mathematics. In fact, you'll be surprised how simple the math will be.

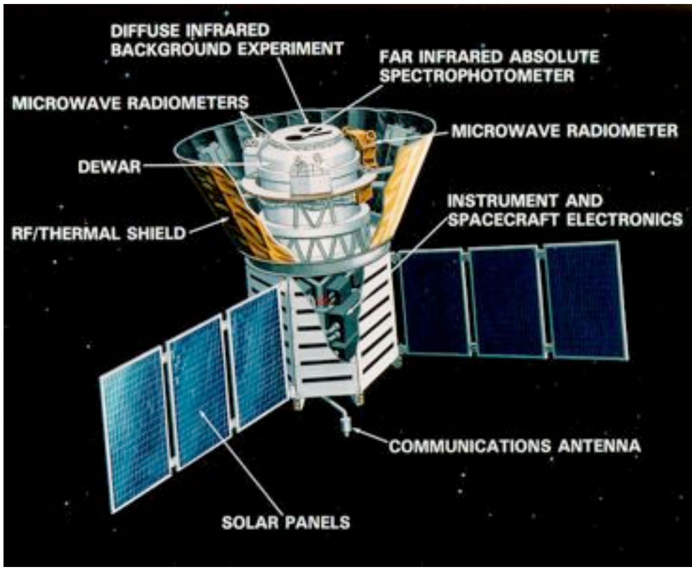
Nope. Mathematics isn't where this course will be challenging. It's *the abstract ideas* that emerge from the mathematics that will cause you to scratch your heads. We're going to find that simple questions asked by imaginative people – Einstein, Bohr, Fermi, Dirac, Feynman, Gamow, Hubble, Weinberg, Guth, and others – led to unusual answers.

Homework & extra credit

There will be extra credit offered for those who complete the Honors Options. Homework will sometimes be problems and sometimes concepts.

below:
The Wilkinson Microwave Anisotropy Probe (WMAP) currently in orbit around the Earth measuring the Cosmic Microwave Background - the echoes of the Big Bang.





left:
The Cosmic Background Explorer scientific satellite, aka COBE. After its 4 year mission: incredible precision in the temperature distribution of the primordial microwave radiation from the Big Bang and 2 quickly awarded Nobel Prizes.

Yes, Twitter!

It's the perfect way to communicate with a class. I'll announce due-dates and extra material from the @isp220 twitter account. I'll retweet from labs and experiments. It will migrate to the Facebook group, but you'll see it first if you get an account and follow the course account.

95% =
fraction of the stuff of the Universe that's unaccounted for

Social Media and ISP220

1. Please get a twitter account.

Twitter is how I'll communicate with you. Follow @isp220. You post with " #isp220 ". See the wiki for how-to. With Twitter I can communication with everyone, all at once. With Twitter you can ask me a question (relatively anonymously) and I can answer it...and everyone can see the exchange. I can do it from my phone and so can you.

2. Please join the facebook group as on page 3.

But we all use Facebook, including many scientists and laboratories. So it's a familiar resource that we can use to chat and share science postings and news.

Ask me anything! Post a message to the QS&BB Group and I'll answer.

To get started, you need to request to be made a member. Please do so.

About friending...I know that being friends with a professor can be creepy. So I won't friend you (Groups no longer require this) and I won't accept a friend request from you during the semester. If – when the semester is over – you would (still!) like to friend me, that's great! I enjoy keeping up with students as we both move on with our lives.

3. Skype hours.

As noted on page 3 I will hold Skype-open virtual office-hours no matter where I am in the world. We can audio, video, and/or IM connect for questions and maybe even answers.

Rules. There've Gotta be Rules.

My requests of you are simple and reasonable:

- I'd like you to attend lecture and I'd appreciate your attention!
- Better yet, I'd like your participation...
- Your open computer in lecture makes me think you're trolling in Facebook!
- Notes in ISP220 are best done with paper and pen...you'll see.
- Phones off, please. Seriously.
- Project and homework due-dates matter.
- Smile.

(Easter Egg #2) If you read this sentence, keep track of them. This is two!

1 = the number of LHC references in the Muppet Movie

Grades and points:

There are lots of ways to gain points:

14 homework sets (ave 12 pts each)	**168**	**42%**
take-home midterm	**50**	**13%**
projects	**70**	**18%**
on-line activity	**20**	**5%**
take-home final exam	**50**	**13%**
in-class final exam project	**25**	**6%**
discretionary	**17**	**4%**
total	**400**	**100%**

Collaboration on homework or projects is encouraged - just tell me each time who you worked with.

Projects

There are two out-of-class projects and one in-class project. The first two you'll create on the wiki.

Content Module Creation Project

Teams of 5 (2 researchers, 2 writers, and an editor) will build "wikipedia-like" discussions of topics that expand on content in the lectures. You should write them so that your classmates can learn from them. In fact, you will create 2 questions based on your topic which might be on the midterm or the final. I'll create wiki pages for each topic and detailed instructions will follow in ***early February***.

Fake Facebook Page Project

Each of you will choose a scientist for whom you will create a Fake Facebook info page. Detailed instructions will follow in ***early March***.

Other Work

Homework

Quantitative and qualitative questions from the lectures, Hobson, and readings nearly every week.

Take-home Midterm and Final Exams

Take-home midterm & final exams: like the homework.

On-line activity

Active participation in the Facebook group and twitter is encouraged and rewarded. Read and report on at least one science blogger and blogs.

In-class Final Exam Project

During the final exam period, teams of 2 or 3 students will be assigned an elementary particle collision reaction to describe from prediction through to how it would manifest itself in a generic particle detector. Detailed instructions will follow in ***early April***.

Many ways to get points!

It looks confusing, but it will be clear as we roll out the projects and the instructions.

right: The inside of the ATLAS detector while under construction.

10^{-22} meters = the smallest dimension ever measured

BIG Questions:

What is the nature of Space?
What is the nature of Time?
Did the Universe have a beginning?
What is nothing?
What was the nature of the Early Universe?
What is the nature of Gravity?
How many fundamental forces are there?
How many dimensions of space are there?
How many fundamental particles are there?
How did the early universe evolve?
Is Nature basically granular or continuous?
Is the Universe stable or stationary?
How did the first stars and galaxies form?
What is Dark Matter?
Are we alone in the Universe?
Where is all of the antimatter?
Can the proton decay?

One of the outcomes of the course will be to appreciate the status of some of the most fundamental questions asked by humans. Some are well understood, some are about to be studied, some are still pure speculation still without experimental evidence. You'll appreciate them all.

How You'll Get the Information

Material will be presented in three ways:

Lectures

These will be as entertaining as possible and sometimes interactive with your white boards (you'll see). Everything presented in class will be uploaded and accessible from the "WEEKS" link on the blog.

"Memos" on the Blog

Sometimes I'll write detailed articles for you on topics that you'll need to work on by yourself.

Reverse Lectures

Sometimes I'll record a lecture on video for you to watch before class and then in class we'll work problems together.

Readings

I'll assign readings and the occasional on-line source.

At CERN

One of our postdocs will periodically meet with us over video from various places at the CERN site in Geneva, Switzerland. You'll get to know Barbara as the semester progresses.

All material is fair-game for the Homework.

Many Topics!

We will cover many topics, but not all of them at the same level of detail. The list on the next page shows you the panorama: from quantum mechanics to the big bang and everything in between.

right:
Deep underground in Northern Minnesota, the MINOS neutrino detector awaits beam to be sent through the earth from the Fermilab neutrino facility in Illinois

6 mph =
how much slower than the speed of light are the protons at the Large Hadron Collider

above:
The Fermi National Accelerator in Batavia, Illinois (Fermilab), with the WIlson "High Rise" in the background.

What you need to know: The blog

The homepage of the blog will be updated constantly with posts of interest. http://www.chipbrock.org/ A Tweet will announce each post.

- "Memos" will appear as blog posts. These will be short write-ups of material not covered in the readings and not covered in depth in the lectures.
- The "CALENDAR" link is...well...a calendar.
- The "WEEKS" link: Go here to find out what topics will be covered, what to read, and where to find lecture slides.
- The "GLOSSARY" link will accumulate the jargon that is inevitable in a specialized subject like ours.
- The "IN THE KNOW" link will have a bulleted lists of what I think was important from each lecture – things that you'll need for the future material.
- The "BANNERS" link will summarize detectors, particles, labs, and accelerators as they appear in the lectures.
- The "HOMEWORK/PROJECTS" link is where instructions, due dates, handouts, etc for weekly homework and the big projects can be found.
- The WIKI link just points to the wiki, where you'll do some projects.

Topics Covered

We will cover the following topics in order spread over the whole semester. Go to WEEKS to see how they approximately distribute on the calendar.

Basic Physics

Speed, Velocity and Acceleration
Vectors
Momentum, force, and collisions
Feynman Diagrams 1
Energy
Gravitation of Newton - Cosmology 1
Dark Matter
18th Century Electricity and Magnetism
Faraday, Maxwell, and Fields
Charged Particles in Fields
Electron Discovery

Tools of the Trade

Particle Accelerators
Particle Detectors
Telescopes and Satellites

Relativity

Relativity Background
Frames of Reference
Time Dilation, Length Contraction, Simultaneity, and Gamma
Relativistic Momentum and Energy
Equivalence Principle

Cosmology

Cosmology 2: General Relativity Solutions
Stellar Evolution and Black Holes
Hubble's Law and the Lemaitre Universe

Quantum Mechanics

Black Body radiation and Photons

6 =
the number of known quarks

Rutherford-Bohr Atom
deBroglie: Waves and Particles
Schroedinger Wavefunction and Quantum Probability
Uncertainty Principle
Feynman Diagrams 2: Compton Scattering
Feynman Diagrams 3: Spacetime
Dirac Equation and Antimatter
Elements and Spin
Relativistic Quantum Field Theory
Spacetime frame, Lab frame, and reactions
Feynman Diagrams 4: Creation and Annihilation

Forces of Nature

Nuclear Decay and Radioactivity
Beta Decay, the Yukawa Idea, and the Muon
Charge Independence and Messenger Particles
Feynman Diagrams 5: Primitive Diagrams and the IVBs
Neutrino Beams
Neutrino Properties

Quarks

The Hadronic Zoo
Quarks
Feynman Diagrams 6: Fat Collisions
Quantum Chromodynamics

Standard Models of Particle Physics & Cosmology

Phase Transitions
Higgs Mechanism
The Standard Model of Particle Physics
Standard Model Reactions
Standard Model of Cosmology
Hubble's Law
Cosmology 3: Big Bang and the CMB
Cosmology 4: The Standard Model of Cosmology
Beyond the Standard Models
Beyond the Standard Model of Particle Physics
Beyond the Standard Model of Cosmology
Cosmology 5: Inflationary Cosmology

Famous Past Discoveries

The answers to some of these questions came from famous, historical experiments. We'll talk about them and the people who designed them.

Future Discoveries?

Who knows? Now you'll understand them when they happen...!
(Easter Egg #3) If you read this sentence, keep track of them. This is three. I'll ask how many you found.

Current QS&BB Experiments

We are working on experiments right now around the world (green are MSU experiments):

The Large Hadron Collider
The Tevatron at Fermilab
The Neutrino Program at Fermilab
Direct Dark Matter searches
The Hubble Telescope
The WMAP Observatory
Infrared land-based astronomy
Ground-based cosmic ray experiments
Antihydrogen experiments
Gravitational wave searches
The Dark Energy Survey

Some Future QS&BB Experiments

The International Linear Collider
The James Webb Observatory
Dark Matter Searches in mines
Very long baseline neutrino experiments
Project X
Sensitive proton decay experiments
Xenon 1 ton

top
A view of the Large Hadron Collider looking towards the Swiss Alps. The red circle marks the location of the 300 foot deep ring.

1.25×10^{11}= estimated number of galaxies in the Universe

Web Sites and Resources

Physics Periodicals

Symmetry Magazine: http://www.symmetrymagazine.org/cms/?pid=1000886
Interactions.org: http://www.interactions.org/

Physics Laboratory Websites and Blogs

Fermi National Accelerator Laboratory: http://www.fnal.gov/
Stanford Linear Accelerator Center: http://www.slac.stanford.edu/
Argonne National Laboratory: http://www.anl.gov/
Lawrence Berkeley National Laboratory: http://www.lbl.gov/
Brookhaven National Laboratory: http://www.bnl.gov/world/
Laboratory for Elementary Particle Physics at Cornell: http://www.lns.cornell.edu/
Thomas Jefferson National Laboratory: https://www.jlab.org/
CERN: http://public.web.cern.ch/Public/
Rutherford-Appleton Laboratory: http://www.stfc.ac.uk/About+STFC/51.aspx
HIgh Energy Accelerator Research Organization: http://www.kek.jp/intra-e/

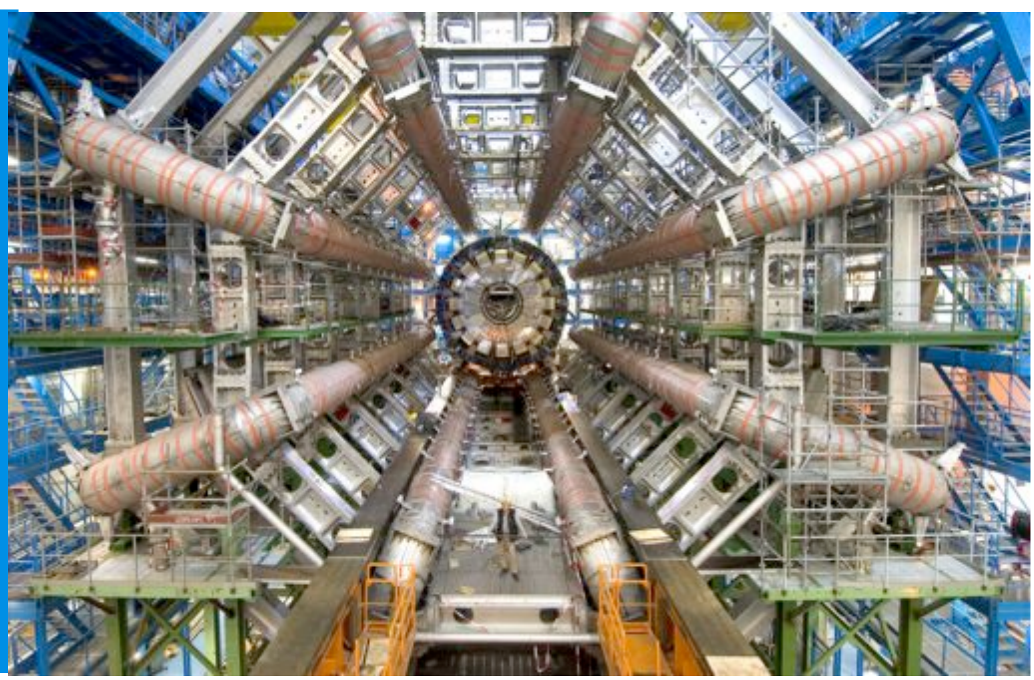
Individual Scientists' Websites and Blogs

Of Particular Significance (Matt Strassler) http://profmattstrassler.com/2011/12/14/a-trly-spectacular-year/
Quantum Diaries (a crew): http://www.quantumdiaries.org/
Asymptopia (Clifford V. Johnson): http://asymptotia.com/
Antimatter (Cormac O'Rafferty): http://coraifeartaigh.wordpress.com/
Cocktail Party Physics (Jennifer Ouellette): http://twistedphysics.typepad.com/cocktail_party_physics/
Cosmic Diary (a crew): http://www.cosmicdiary.org/
Cosmic Log (Alan Boyle): http://cosmiclog.msnbc.msn.com/

Blogs

I'll ask you to read blogs for content as well as enrichment.

right:
The enormous air-core, superconducting magnets of the **ATLAS detector** will pick out important remnants of the p-p collisions at the **Large Hadron Collider**



$>10^{34}$ years = minimum lifetime of the proton

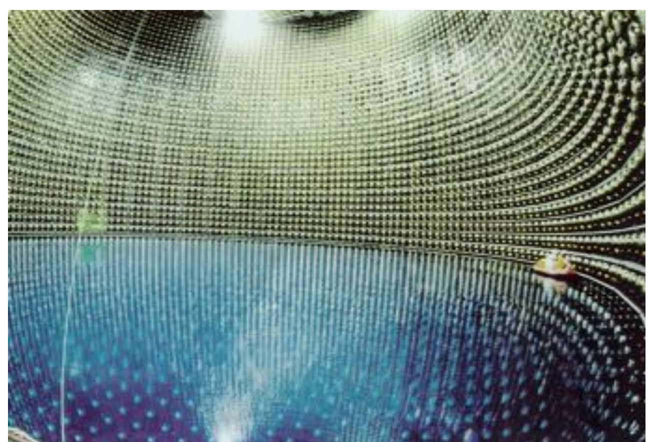
Cosmic Variance (often Sean Carroll): http://blogs.discovermagazine.com/cosmicvariance/
Life As a Physicist (Gordon Watts): http://gordonwatts.wordpress.com/
Physics and Physicists (ZapperZ, Fermilab) : http://physicsandphysicists.blogspot.com/
Resonances (Jester, Paris): http://resonaances.blogspot.com/
Stephanie Majewski: http://stephatcern.blogspot.com/
Symmetry*breaking*: http://www.symmetrymagazine.org/breaking/
Not Even Wrong (Peter Woit): http://www.math.columbia.edu/~woit/wordpress/
FIND OTHERS!

Projects' and Experiments' Websites and Blogs

DZero experiment: http://www-d0.fnal.gov/
CDF experiment: http://www-cdf.fnal.gov/
ATLAS experiment: http://atlas.ch/
CMS experiment: http://cmsinfo.web.cern.ch/cmsinfo/
LHCb experiment: http://lhcb.web.cern.ch/lhcb/
ALICE experiment: http://aliceinfo.cern.ch/
Super-Kamiokand: http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html
MINOS experiment: http://www-numi.fnal.gov/
NOvA experiment: http://www-nova.fnal.gov/
BaBar experiment: http://www.slac.stanford.edu/BFROOT/
Belle experiment: http://belle.kek.jp/
HAWC experiment: http://hawc.umd.edu/
BooNE experiment: http://www-boone.fnal.gov/
International Linear Collider: http://www.linearcollider.org/
Hubble Telescope: http://hubblesite.org/
Ice Cube South Pole Observatory: http://icecube.wisc.edu/
WMAP: http://map.gsfc.nasa.gov/
Hubble Space Telescope: http://hubblesite.org/
James Webb Telescope: http://www.jwst.nasa.gov/
Planck Observatory: http://www.esa.int/esaMI/Planck/SEMWN20YUFF_0.html
FIND OTHERS!

Agencies, Science Societies' Websites and Blogs.

NASA: http://www.nasa.gov/
DOE physics: http://energy.gov/physics
DOE High Energy Physics: http://science.energy.gov/hep/
National Science Foundation: http://www.nsf.gov/
NSF Mathematics and Physical Sciences: http://www.nsf.gov/dir/index.jsp?org=MPS
European Space Agency: http://www.esa.int/esaCP/index.html
American Physical Society: http://www.aps.org/
APS Division of Particles and Fields: http://dpfnewsletter.org/
European Physical Society: http://www.eps.org/
EPS High Energy Particle Physics Board: http://eps-hepp.web.cern.ch/eps-hepp/
Physical Society of Japan: http://www.soc.nii.ac.jp/jps/english/president_messagenagamiya.html
Association of Asia Pacific Physical Societies: http://www.aapps.org/main/



above:
A partially full Super Kamiokande proton decay experiment 1,000m underground in Kamioka-mine in Hida-city, Gifu, Japan. The detector is 50,000 tons of very pure water which senses when charged particles traverse the volume: either possibly decaying protons or neutrinos from the sun or supernova explosions. See the boat on the right with scientists repairing one of the 11,000 phototubes. The cylinder is 120 feet tall.

What about the Honors College?

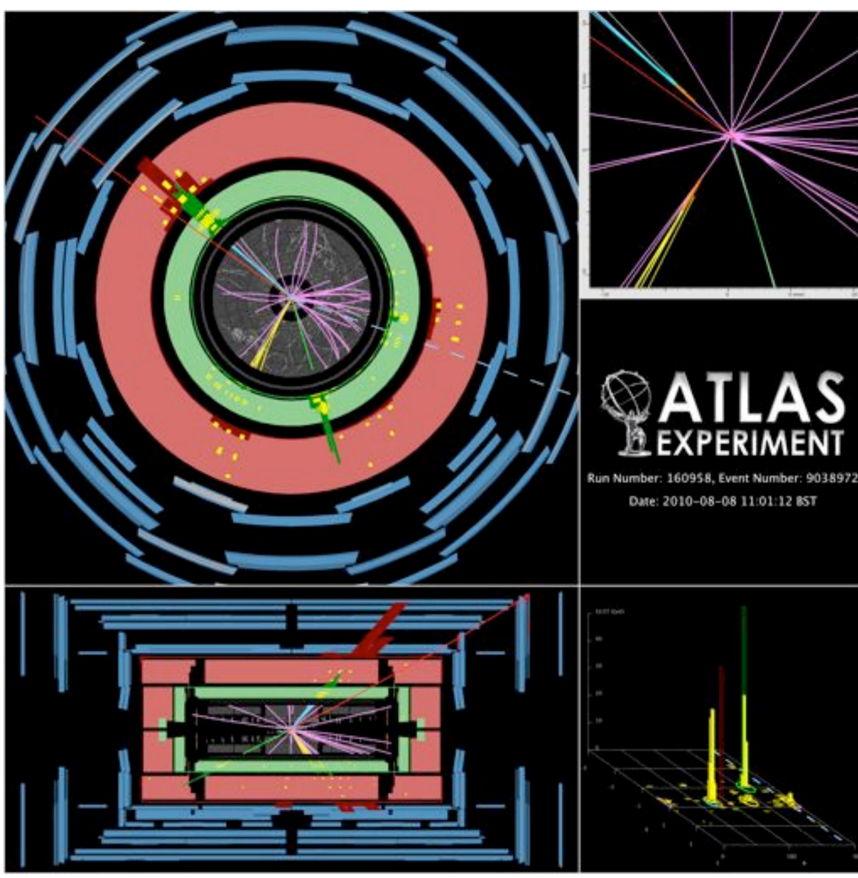
Honors credit will be offered to enrolled Honors College students and Academic Scholars. (40 points of extra credit is offered to non-Honors/AS students.) The Honors portion of the course will consist of two projects designed to dig deeper into more of the practical aspects of working in a modern collider physics experiment. They include:

Analysis of real data. The ATLAS experiment at CERN has created a Java-based version of its event-viewer and is collecting real as well as simulated collider physics collisions. A student can scan events and classify them for their physics interest according to characteristics that we use in the real experiment. The image below is an example of the ATLAS experiment event display. This particular event is a candidate production and decay of a top quark pair, the 6th and most (puzzlingly) massive of the set of quarks that we know about.

One of the primary tools that physicists use to calculate the probabilities of different reactions was invented by Richard Feynman who created a graphical step in the complicated calculation chain using relativistic quantum field theory (a mouthful!). While "Feynman Diagrams" have a sophisticated role, they are also great visual images of the reactions independent of their professional use. The second project for Honors credit will involve taking a few reactions of interest, creating the Feynman spacetime diagrams to represent them and then overlaying them onto schematics of the ATLAS detector to predict the observables that we'll be using to search for these reactions.

Both of these projects can be done individually, or with groups of two students. Detailed instructions for the computer work and the background will be provided, along with tutorial sessions if necessary.

This should be fun!



left:
A top quark candidate event from the 2010 running of the ATLAS experiment at CERN. The upper left picture is a computer reconstruction looking from a beam's-eye-view at a side projection of the whole detector. The bottom left is a side view with beams coming from the left and right, while the upper right isolates the precision tracking detectors in the center.