PHYS 3313
Lecture #1

Wednesday January 20, 2010
Dr. Andrew Brandt

1. Syllabus and Introduction
2. HEP Infomercial
3. Special Relativity

Please turn off your cell-phones, pagers, ipods, walkmans (walkmen?), laptops, etc. in class

http://www-hep.uta.edu/~brandta/teaching/sp2010/teaching.html
My Background+Research

B.S. Physics and Economics College of William & Mary 1985
PH.D. UCLA/CERN High Energy Physics 1992
(UA8 Experiment-discovered hard diffraction)

1992-1999 Post-doc and Wilson Fellow at Fermilab
- Discovered hard color singlet exchange
- 1997 PECASE Award for contributions to diffraction
- Proposed and built (with collaborators from Brazil) DØ Forward Proton Detector
- QCD and Run I Physics Convenor
- Trigger Meister, QCD Trigger Board Rep., Designed Run II Trigger List

1999-2004 UTA Assistant Prof; 2004-present Assoc. Prof
- DOE OJI, NSF MRI, Texas ARP awards for DØ FPD
- 2005 started fast timing work (ARP, DOE ADR)
- 2007 Grant on WMD detection
- 2008 sabbatical on ATLAS
Course Logistics

- Physics 3313 Fall 2009, SH129 MW 1:00-2:20
- Instructor: Andrew Brandt 817 272-2706, brandta@uta.edu
- Office Hours: MW 2:30 – 3:30, Tues. 2:00-3:00, and by appointment (344 Physics CPB)
- [http://www-hep.uta.edu/~brandta/teaching//teaching.html](http://www-hep.uta.edu/~brandta/teaching//teaching.html)
- Textbook: “Modern Physics for Scientists and Engineers” by Thornton & Rex (3rd Ed.)
Grading

1. Grades will be weighted as follows:
   - Homework+quizzes 25%
   - 2 Midterms (Mar. 10, April 19) 50%
   - Final (Monday May 10, 11:00) 25%

2. Drop lowest HW and lowest Quiz, final is comprehensive, NO Makeup tests, quizzes, late HW

3. Physics Clinic SH 224 (may be moving) is useful free resource for problem sets, but get as far as you can on your own, copying=cheating
Attendance and Class Style

• Attendance:
  – is **STRONGLY** encouraged; to aid your motivation I give pop quizzes

• Class style:
  – Lectures will be primarily on electronic media
    • The lecture notes will be posted ~**AFTER** each class
  – Will be mixed with traditional methods (blackboard) and non-traditional (youtube)
  – Active participation through questions and discussion are **STRONGLY** encouraged
Secrets to doing well in Modern Physics

• Come to class (and pay attention when you get there)
• Read text book, ideally read ahead (does anyone really do that?)
• Start homework problem sets early, and turn them in on time
• Put in the time that it takes (this is an upper division physics class), review lecture notes, go over HW solutions, test solutions
• It doesn’t hurt to be smart
Modern Physics Course Material

Survey class:
• Special Relativity
• Wave-Particle Duality
• Bohr Atom
• Quantum Mechanics
• Statistical Mechanics

Modern Physics deals with the fast and/or small where different rules apply from classical physics. Modern Physics is not current physics!
High Energy Physics at UTA

UTA faculty Andrew Brandt, Kaushik De, Amir Farbin, Andrew White, Jae Yu along with many post-docs, graduate and undergraduate students investigate the basic forces of nature through particle physics studies at the world’s highest energy accelerators.

In the background is a photo of a sub-detector of the 5000 ton DØ detector. This sub-detector was designed and built at UTA and is currently operating at Fermi National Accelerator Laboratory near Chicago.
Structure of Matter

Matter

Molecule

Atom

Nucleus

Baryon (Hadron)

Quark

Nano-Science/Chemistry

10^{-9}m

10^{-10}m

10^{-14}m

10^{-15}m

<10^{-19}m

protons, neutrons, mesons, etc.

\pi, \Omega, \Lambda...

top, bottom, charm, strange, up, down

Electron (Lepton)

<10^{-18}m

High Energy Physics

Atomic Physics

Nuclear Physics

High energy means small distances
All atoms are made of protons, neutrons and electrons.

Protons and neutrons made of quarks; different species of quarks and leptons; photons mediate EM interactions, gluons mediate strong interactions.
What is High Energy Physics?

- Matter/Forces at the most fundamental level.
- Great progress! The “STANDARD MODEL”
- BUT… many mysteries

=> Why so many quarks/leptons??
=> Why four forces?? Unification?
=> Where does mass come from??
=> Are there hidden symmetries??

⇒ What is the “dark matter”??
⇒ Will the LHC create a black hole that destroys the Earth?

Role of Particle Accelerators

• Smash particles together
• Act as microscopes and time machines
  – The higher the energy, the smaller object to be seen
  – Particles that only existed at a time just after the Big Bang can be made
• Two method of accelerator based experiments:
  – Collider Experiments: $p \bar{p}$, $pp$, $e^+e^-$, $ep$
  – Fixed Target Experiments: Particles on a target
  – Type of accelerator depends on research goals
Fermilab Tevatron and CERN LHC

- Formerly Highest Energy Collider (proton-anti-proton)
  \[ E_{cm} = 1.96 \text{ TeV} \]  
  \[ (=6.3 \times 10^{-7} \text{J/p}) \]  
  \[ 13 \text{M Joules on 10}^{-4}\text{m}^2 \]  
  \[ \Rightarrow \text{Equivalent to the K.E. of a 20 ton truck at a speed 81 mi/hr} \]

1500 physicists  
130 institutions  
30 countries

- Highest Energy collider as of Dec. 2009 (2.36 TeV) (p-p)
  \[ E_{cm} = 14 \text{ TeV} \]  
  \[ (=44 \times 10^{-7} \text{J/p}) \]  
  \[ 1000 \text{M Joules on 10}^{-4}\text{m}^2 \]  
  \[ \Rightarrow \text{Equivalent to the K.E. of a 20 ton truck at a speed 711 mi/hr} \]

5000 physicists  
250 institutions  
60 countries


LHC Diversion

- http://www.youtube.com/watch?v=BXzugu39pKM

LHC: http://www.youtube.com/watch?v=_6uKZWNJLCM
Particle Identification

Interaction Point

Charged Particle Tracks
Scintillating Fiber
Silicon Tracking

Energy
Calorimeter (dense)

Muon Tracks
Magnet
Wire Chambers

neutrino -- or any non-interacting particle missing transverse momentum

We know $x,y$ starting momenta is zero, but along the $z$ axis it may be non-zero, so many of our measurements are in the $xy$ plane, or transverse
DØ Detector

- Weighs **5000 tons**
- As tall as a **5 story building**
- Can inspect **3,000,000** collisions/second
- Record 100 collisions/second
- Records 10 Mega-bytes/second
- Recording $0.5 \times 10^{15}$ (500,000,000,000,000) bytes per year (0.5 PetaBytes).

ATLAS Detector

- Weighs **10,000 tons**
- As tall as a **10 story building**
- Can inspect **1,000,000,000** collisions/second
- Will record 200 collisions/second
- Records 300 Mega-bytes/second
- Will record $2.0 \times 10^{15}$ (2,000,000,000,000,000) bytes each year (2 PetaByte).
Building Detectors at UTA
High Energy Physics Training + Jobs

EXPERIENCE:
1) Problem solving
2) Data analysis
3) Detector construction
4) State-of-the-art high speed electronics
5) Computing (C++, Python, Linux, etc.)
6) Presentation
7) Travel

JOBS:
1) Post-docs/faculty positions
2) High-tech industry
3) Computer programming and development
4) Financial
My Main Research Interests

• Physics with Forward Proton Detectors
• Fast timing detectors
• Triggering (selecting the events to write to tape): at ATLAS 200/40,000,000 events/sec
One of the DØ Forward Proton Detectors built at UTA and installed in the Tevatron tunnel
ATLAS Forward Protons: A (10) Picosecond Window on the Higgs Boson

Andrew Brandt, University of Texas at Arlington

A picosecond is a trillionth of a second. This door opens ~once a second, if it opened every 10 picoseconds it would open a hundred billion times in one second (100,000,000).

Light can travel 7 times around the earth in one second but can only travel 3 mm in 10 psec.

Yes, I know it’s a door, not a window!
Central Exclusive Higgs

AFP concept: adds new ATLAS sub-detectors at 220 and 420 m upstream and downstream of central detector to precisely measure the scattered protons to complement ATLAS discovery program. These detectors are designed to run at a luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$ and operate with standard optics (need high luminosity for discovery physics).

You might ask: “Why build a 14 TeV collider and have 99% of your energy taken away by the protons, are you guys crazy or what??”

The answer is “or what”!—ATLAS is always (or at least for a few weeks last December) losing energy down the beam pipe, we just measure it accurately!!!

Note: the quest for optimal S/B can take you to interesting places:

Ex. The leading discovery channel for light SM Higgs, $H \rightarrow \gamma \gamma$, has a branching ratio of 0.002!
Cerenkov Effect

Use this property of prompt radiation to develop a fast timing counter.
**Fast Timing Detectors for ATLAS**

**WHO?** UTA (Brandt), Alberta, Louvain, FNAL

**WHY?** Background Rejection

Ex, Two protons from one interaction and two b-jets from another

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**How?** Use timing to measure vertex and compare to central tracking vertex

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**How Fast?** 10 picoseconds gives x20 background rejection

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Pedro Duarte (M.S.)
Shane Spivey, Arnab Pal, Ian Howley (GRA’s), Many UG’s
Fused Silica Bars

- 9 cm bars
- Some converted to mini-bars

Simulation by Joaquin Noyola (UG, now GRA) other studies by several UG’s

Spread in timing as $f(\lambda)$ since $n(\lambda)$
Micro-Channel Plate Photomultiplier Tube (MCP-PMT)

- Photocathode
- Dual MCP
- Anode
- Gain ~ $10^6$
- $\Delta V \sim 200\text{V}$
- $\Delta V \sim 2000\text{V}$
Ultra-fast Timing Issues

Time resolution for the full detector system:
1. Intrinsic detector time resolution
2. Jitter in PMT's
3. Electronics (AMP/CFD/TDC)
4. Reference Timing

• 3 mm = 10 ps
• Radiation hardness of all components of system
• Lifetime and recovery time of tube
• Backgrounds
• Multiple proton timing
Note: prior to June 2008 test beam, results marginal for QUARTIC 15mm bar: 80 ps/bar 80% efficient; allows you to reach close to 20 ps, but not 10 ps

Testing long bars 90 mm (HE to HH) and mini bars 15 mm (HA to HD)
Long bars more light from total internal reflection vs. losses from reflection in air light guide, but more time dispersion due to $n(\lambda)$
56.6/1.4 = 40 ps/bar using Burle 64 channel 10 µm pore tube including CFD!

\[ N_{pe} = \left( \frac{\text{area}}{\text{rms}} \right)^2 \]

\[ \delta t = \sqrt{(\delta t_1)^2 + (\delta t_2)^2} = \sqrt{2}\delta t_1 \]

so if \( \delta t = 2 \) then \( \delta t_1 = \delta t / \sqrt{2} \)

Time difference between two 9 cm quartz bars after Louvain constant fraction implies a single bar resolution of 40 ps for about 10 pe’s (expected 10 pe’s from simulations). Need to demonstrate \( \sqrt{N} \) (more later)
Rate and Current Limits

• The baseline QUARTIC detector could see rates of up to 15 MHz in the hottest 6mm x 6mm pixel of the MCP-PMT. If the current:

\[ I = R \cdot N_{pe} \cdot e \cdot G \]

is too high (~10% of strip current) the tube saturates (gain is reduced)

• To keep the current at tolerable levels, lower gain and less pe’s are desirable, but precise timing requires as many pe’s as possible (and conventional wisdom also indicated that high gain was necessary*). Smaller pores both reduces the current in any one pore and improves the timing

*Stay tuned for laser test results!
Lifetime Issues

Lifetime due to positive ions damaging the photocathode is believed to be proportional to extracted charge:

\[ Q/\text{year} = I \times 10^7 \text{ sec/year} \]

Q at maximum luminosity is up to 35 C/cm²/yr!
(assuming $5 \times 10^4$ gain instead of the typical $10^6$!)

Without a factor of 20 reduction in gain, the current and lifetime issues would make MCP-PMT’s unusable, with it the rate is borderline, but lifetime off by a factor of 50—tube dies every week!

Solution: Graduate student camps out in tunnel to exchange tubes as needed. (Sorry Ian)
Study properties of MCP-PMT’s:

1) How does timing depend on gain and number of pe’s

2) What is maximum rate? How does this depend on various quantities?

3) Establish minimum gain to achieve timing goals of our detector given expected number of pe’s (~10). Evaluate different electronics choices at the working point of our detector

4) Eventually lifetime tests

***Ongoing laser tests very useful in developing the fastest time of flight detector ever deployed in a collider experiment
Picosecond Test Facility featuring Undergraduate Laser Gang (UGLG) Undergraduate Laser Youths? (UGLY)

LeCroy Wavemaster 6 GHz Oscilloscope

Hamamatsu PLP-10 Laser Power Supply

Laser Box

LeCroy

MCP-PMT

mirror

beam splitter

filter

lenses

laser

January 12, 2010

Andrew Brandt, SLAC Seminar
More pe’s implies higher current, so tube saturates at lower laser frequency.

For fixed gain, study how relative pulse height varies with rate/current for different numbers of photoelectrons.
Timing vs Gain for 10 μm Tube

Measured with reference tube using CFD’s and x100 mini-circuits amps, with 10 pe’s can operate at ~5E4 Gain (critical for reducing rate and lifetime issues). With further optimization have obtained <25 ps resolution for 10 pe’s.
Timing vs. Number of PE’s

No dependence of timing on gain if sufficient amplification!
Aside: Measuring Speed of EM Waves

- We noted that ground plane oscillations on reference tube were picked up by second tube
- Used this to do a 3% measurement of speed of light (Kelly Kjornes)

Moving 2nd tube 2 feet from reference tube shifts pick-up oscillation pattern by 2.05 ns
New Multi-Channel Laser Setup
Prelecture Conclusions

• Modern Physics is a pre-cursor to current physics, will cover a lot of “new” material
• One of the current frontiers of physics is high energy or particle physics: very interesting (I think!)
• Nobel Prize possibilities
• Other interesting areas of physics at UTA include nano-bio physics, astrophysics, nano-magnetism, etc.