Massachusetts Institute of Technology

Department of Physics

Course: 8.882
Title: LHC Physics: Experimental Methods and Measurements
Term: Spring 2009

1 Introduction

In the 8.882 lecture series on *LHC Physics: Experimental Methods and Measurements* we will learn how to perform measurements in experimental high energy (HEP) and heavy ion (HI) physics with emphasize on the upcoming LHC experiments. The LHC is the Large Hadron Collider being built right now at CERN, the European Organization for Nuclear Research, the world's largest particle physics center.

There are a total of four experiments, Atlas, CMS, LHCb and Alice, which will record particle collisions from proton-proton interactions at 14 TeV and heavy ion collisions at 5.5 TeV. The community has the highest hopes for this machine and the potential to find something spectacular, which might revolutionize particle physics and our view of the matter and forces, is larger than it has been for many years.

We will after a brief overview of the physics goals concentrate on a set of representative experimental measurements which we will use to develop all important and most sophisticated analysis tools to date.

2 Description

In a total of 26 lectures in this semester we are going to focus on the one main goal: **how to perform a physics measurement in the typical high energy / heavy ion physics environment**. Basic understanding of

- particle accelerators
- particle detectors and their use
- computational techniques
- and statistics

are provided during the lecture. The goal is going to be achieved by performing a set of analyses with an increasing level of sophistication. Typical analysis tasks could be:

- charged track multiplicities,
- ratio of production cross sections of various Υ states,
- lifetime for longer lived particles like B^0, B^+ or B_s,
- mixing or asymmetry measurement for B^0 and B^+,
- cross section of processes like: $Z \rightarrow \mu^+\mu^-$
- Higgs search

- search for new or as of yet 'unknown' physics

During the course of the analysis we will discuss and perform some or all of the following tasks:

- design an analysis and the tools to use: histograms, ntuples *etc.*
- generate a Monte Carlo sample
- perform a sample selection
- determine acceptance and efficiency measurements
- perform a fit to maximize the analysis result
- determine statistical and systematic uncertainties (implies understanding of detector functioning)
- determine an upper or lower limit in a search
- prepare a detailed presentation for a conference
- write a paper
- participate in a mini conference

This is going to be a course where you will have the opportunity to see how research is done in particle or heavy ion physics. The course should enable you to apply all the tools, even the most advanced, which are today used in this field of research. I am looking forward to this opportunity.

3 Technical Contents

From the technical point of view the following points will be discussed to some extent:

Organization, Basic Programming and Graphical Presentation

- C++, root
- latex, open office, power point
- general styles: presentations, publications

Data Storage

- histograms
- ntuple design
- designing high level physics objects

Basic Particle Detectors

- trigger and data acquisition
- tracking
- calorimeters
- electron, photon, muon and other particle id devices

Monte Carlo Techniques

- generator level Monte Carlo (production and decay)
- simulating detector responses
- GEANT, full hit based simulations

Selection Techniques

- cut based approaches
- optimization techniques for your analysis
- likelihood techniques
- neural network selections

Fitting Techniques

- χ^2 formulation
- binned likelihood based
- unbinned likelihood based

4 Personnel

Lecturer	Christoph Paus	24-509	8-0314	paus@mit.edu
Recitation Instructor	TBA	—	—	—
Teaching Assistant	TBA	—	—	—

5 Structure

Lecture is twice a week, tentatively planned for Monday and Wednesday, from 1:00pm to 2:30pm in the Kolker Room 26-414. A good fraction of the lecture will be given over video, which the Kolker room is well equipped for. This is another example of how life is as an experimentalist in the HEP and HI communities, where many meetings happen over the phone and video systems.

In addition to the lecture which will cover the core material of the course there will be recitation sections. We will have to find an appropriate time for those sections, which will most likely involve sitting in front of a terminal and ask questions which will inevitably come up during your work, or tutorials on programming or high level analysis tools. Depending on your level of knowledge of C++, root, latex or similar tools these sections might be essential or just educative and interesting to you.

At the end of the term there will be a final project in form of a mini conference in which you will have to write a publication style article and prepare a corresponding 10-15 minutes presentation of a measurement you performed. We will have a conference style 2 hour session in which each student will present and the rest of the audience is invited to listen, ask questions and comment. We will invite people from the physics department to these presentations to make it like a real little conference.

6 Collaboration

It is common practise in the field that analyses are performed in collaboration of several people. The reason for this is that having two people do the same thing indepedently and come up with the same result constitutes a very valuable test of the analysis and helps to avoid publishing wrong results. Analyses can also be quite complex and sharing of the work helps to get it done quicker.

We will therefore form groups of two maybe three students to work on one topic. All work you hand in for 8.882 should be the work you have achieved together with the team you are working in. Talking with other teams on technical aspects is fine as long as the analysis is done truely independently. This means no talking about the result.

7 Text

There is no text which this course will really follow. There are a number of books about the basics of particle physics which I can recommend for reading but none of them is required material:

Quarks and Leptons	F.Halzen, A.Martin
Introduction to the Physics of Quarks and Leptons	P.Renton
Introduction to Elementary Particles	D.Griffith
Introduction to High Energy Physics	D.H.Perkins

The important pointers to more technical material and other more specific books will be mentioned throughout the course for further reading. There is going to be plenty of material on the Web page.

8 Course Work and Grading

The course work will consist of a four mini projects, which consist of one measurement each. The first three measurements will be documented in form of a short paper in a printable document which will be graded. The fourth measurement will be documented in form of a presentation at our mini conference. The projects have to be turned in to the recitation instructor in electronic format in form of a pdf file. The grade of the course will be a combination of your combined 4 mini projects.

9 Office Hours

Office hours are listed below. If you need further help outside of the office hours, please contact any of us by e-mail or phone.

Christoph Paus	8-0314 (CERN: +41/7648/72318)
TA	TBD

10 Course WEB Site

The course WEB site is:

http://web.mit.edu/8.882/www/

which will be operative on February 3. The web site will contain course announcements, course materials as the description of the projects *etc.* No paper copies will be handed out.

11 Syllabus

11.1 Organization by Unit

The lecture is subdivided into the following five big units: introduction, measurements of charged particle multiplicity, measurements of Υ production fractions, measurement of a B meson lifetime and a Standard Model Higgs search. The analysis are roughly ordered by increasing complexity. In the 5 units the following components are discussed.

Introduction

- lecture overview
- LHC program overview
- detector overview
- event recording and processing
- analysis overview

Charged Track Multiplicity

- tracking detectors
- tracking algorithms and tracking objects
- beamline, primary vertex and vertex reconstruction

Υ Production Fractions

- secondary vertex and vertex reconstruction
- muon reconstruction
- event selection (cut based)
- χ^2 fits

***B* Meson Lifetimes**

- muon reconstruction
- event selection (likelihood and neural network based)
- manipulating track parameter uncertainties
- binned and unbinned likelihood fits

Higgs Search

- lepton reconstruction
- b tagging
- jet reconstruction
- missing energy reconstruction
- setting limits

11.2 Organization by Lecture

Lecture	Unit	Date	Topic
-	-	02/02/2009	*First day of semester, Registration*
1	0	02/03/2009	Introductory Lecture
2	0	02/09/2009	Accelerators
3	0	02/11/2009	Particle Detectors Overview
-	-	02/16/2009	*President's Day*
4	1	02/17/2009	Heavy Ion Physics Overview
5	1	02/18/2009	Charge Multiplicity Measurements
6	1	02/20/2009	Data Analysis Strategies and Essentials
7	1	02/23/2009	Detectors: Tracking
8	1	03/25/2009	Track Reconstruction and Fitting
9	1	03/02/2009	Analysis Tips – Charge Multiplicity
10	2	03/04/2009	Onia as Probes in Heavy Ion Physics
11	2	03/09/2009	Secondary Particle Production
12	2	03/11/2009	Detectors: Electron/Muon Detection and Particle Id
13	2	03/16/2009	Analysis Tips – Bottomonia Cross Section
-	-	03/23/2009	*Student Holiday*
-	-	03/25/2009	*Student Holiday*
14	2	03/30/2009	Resonance Production, Decay and Reconstruction
15	2	04/01/2009	Search Strategies and Observations
16	2	04/06/2009	Efficiency and Acceptance
17	2	04/08/2009	High Energy Physics Overview
18	-	04/13/2009	b Hadron Lifetimes and Other Essentials
19	3	04/15/2009	B Physics Trigger Strategies
-	3	04/20/2009	*Patriots Day*
20	3	04/22/2009	Proper Time Reconstruction
21	3	04/27/2009	Sophisticated Selections: Likelihoods/Neural Networks
22	4	04/29/2009	Higgs Search and Other Essentials
23	4	05/04/2009	Detectors: Calorimetry
24	4	05/06/2009	Jets and Missing Energy
25	4	05/11/2009	B Tagging
26	4	05/13/2009	Review
-	-	05/14/2009	*Last day of class*

Final exam week will be 05/18-22/2009. Our mini conference will be scheduled during that week. Date to be determined.