NuFact08 Course Descriptions

Introduction to Accelerator Physics (3 lectures) Elena Wildner

1. Introduction to Accelerators, general overview
    a. Different parts in an accelerator complex
    b. Picture gallery
    c. Simple Basic Mathematical recall

2. Transverse motion
    a. Magnets
    b. Lattices
    c. Hills Equation
    d. Twiss Parameters

3. Longitudinal Motion and Instabilities
    a. General RF parameters
    b. Rf cavities
    c. Acceleration
    d. Dispersion
    e. Chromaticity
    f. Phase space
    g. Instabilities

Introduction to Future Facilities: Beta Beams (1 lecture) Elena Wildner

High Power Targets (2 lectures) Jacques Lettry

The options discussed since the start of neutrino factory workshops in Lyon in 1999 will be reviewed in the introduction. The choice of target material will be discussed and the global layout of a pion production target station will be described. The HARP experiment will be used as an illustrative example. The main features of Horns and Solenoids will be discussed.

In High power targets, the Heat removal of high power densities and pulsed energy depositions will be discussed on the base of Solid and liquid targets. Experimental evidence of shocks and vibrations will lead to the investigation of fatigue effects and properties of irradiated materials. In Liquid targets, the shocks Hg-trough, thimble and jet experiments at CERN and BNL will be presented, compared to simulations and illustrated via laser induced cavitation in a water jet. Magneto-hydro dynamics basics will be defined and the MHD of Hg jets in a 20 Tesla solenoid test at GHMFL Grenoble will be described. Eventually, the MERIT experiment results will be presented.

The Beam dump of a 4 MW proton beam will be mentioned as well as activation and radioactive waste, target handling issues.

Production, transport and ionization of beta beam light short lived radioisotopes.

Introduction to Future Factilities : Super Beams (3 lectures) Sacha Kopp

Conventional neutrino beams are derived from the decays of high energy mesons produced by a proton beam incident upon thick nuclear targets. Focusing systems are often used to reduce the divergence of the meson, and hence neurtino, beam. These lectures will discuss the relativistic kinematics of meson decay, the proper description of meson trajectories through magnetic focusing elements, and rudimentary techniques in calculating the resulting neutrino flux. These topics are selected from S. Kopp, "Accelerator Neutrino Beams," Phys.Rept.439:101-159, 2007.

Lecture I: Kinematic Relations for Neutrino Beams
Lecture II: Meson Production in Targets
Lecture III: Focusing Systems

Introduction to Future Facilities: Neutrino Factories: (1 lecture) Juergen Pozimiski

The layout of a Neutrino factory will be presented in general together with a discussion of the interdependence and performance of the individual sections. The key challenges of a Neutrino Factory will be introduced and discussed together with optimisation strategies.

Overview of Neutrino factory layout

Proton driver

- Energy & material dependence of meson production
- Time structure of pulse on target
- Different driver options and challenges

Meson production target

- Optimisation of target for meson production
- Energy density in the target and shock
- Meson collection and proton beam handling

Muon front end

- Phase rotation
- Ionisation cooling

Fast acceleration

- Accelerator options for fast acceleration
- Recirculating linacs (dogbone)
- FFAG

Decay rings

- Options for decay rings (race track, triangle and tie bow)
- Choice of site for Neutrino Factory and detector

Accelerator Physics for Neutrino Factories and Muon Colliders- 4 lectures): David Neuffer

Key problems in the design and implementation of beam collection, cooling, acceleration and storage rings are presented. Muons from the production target must be captured, and cooled in order to fit within the acceleration and storage ring systems of neutrino factories and muon colliders. For a neutrino factory beam the critical parameter is obtaining the largest number of muons, while for a collider the muons must also be cooled to beam sizes small enough to obtain high luminosity collisions, and both signs must be captured. Muon acceleration is discussed. The critical difficulty is that the muons must be accelerated before decay. High gradient acceleration is required. Several approaches to acceleration are being developed, and further studies are needed to find an optimal scenario. For colliders and ν-factories the beams are stored for ~1000 turns in a high-energy storage ring. The neutrino factory ring needs long straight sections for muon decay, and the beams. The collider needs focusing of the colliding beams to very small spot sizes at interaction region points.

Lecture 1 and 2 – Beam Collection and Cooling
- Muon Capture
- Bunch Formation
- Ionization cooling for Neutrino Factories and Muon Colliders
- Demonstration Experiments (MICE/MuCOOL)
- Ionization cooling for beta-beam and neutron sources

Lecture 3 - Acceleration
- Linac,
- Recirculating linac (RLA)
- Fixed-field alternating gradient (FFAG)
- Rapid cycling synchrotron (RCS)
- FFAG approach (in detail)
- Other applications for FFAG's

Lecture 4 – Storage/collider rings
- The storage rings for colliders
- Storage Rings for ν-factories
- Ring activation
- Detector considerations
- Beta-beam storage ring

Introduction to Neutrino Oscillation Physics (5 lectures) Carlo Giunti

The general theory of neutrino masses and mixing is introduced. We start with the extension of the Standard Model by the introduction of right-handed neutrino fields which lead to Dirac neutrino masses through the standard Higgs mechanism. The theory and physical meaning of Majorana masses are explained. The most general Dirac-Majorana mass term is discussed,with emphasis on the see-saw mechanism. We review the theory of neutrino oscillations in vacuum and in matter, with discussion of the most important general phenomenological aspects.

-Lecture 1: Dirac Neutrino Masses
- Dirac Mass
- Higgs Mechanism in the Standard Model
- Dirac Lepton Masses
- Three-Generations Dirac Neutrino Masses
- Massive Chiral Lepton Fields
- Massive Dirac Lepton Fields
- Quantization
- Mixing
- Flavor Lepton Numbers
- Total Lepton Number
- Mixing Matrix
- CP Violation
- Jarlskog Invariant
- Maximal CP Violation
- GIM Mechanism
- Lepton Numbers Violating Processes

-Lecture 2: Majorana Neutrino Masses
- Two-Component Theory of a Massless Neutrino
- Majorana Equation
- Majorana Lagrangian
- Lepton Number
- CP Symmetry
- Effective Majorana Mass
- Mixing of Three Majorana Neutrinos
- CP Violation

-Lecture 3: Dirac-Majorana Mass Term
- One Generation
- CP Invariance
- Maximal Mixing
- Dirac Limit
- Pseudo-Dirac Neutrinos
- See-Saw Mechanism
- Right-Handed Neutrino Mass Term
- Singlet Majoron Model
- Three-Generation Mixing
- Number of Massive Neutrinos?

-Lecture 4: Neutrino Oscillations in Vacuum
- Ultrarelativistic Approximation
- Easy Example of Neutrino Production
- Neutrino Oscillations in Vacuum

Neutrinos and Antineutrinos
CPT, CP and T Symmetries
Two-Neutrino Mixing and Oscillations
Types of Experiments
Average over Energy Resolution of the Detector

- Lecture 5: Neutrino Oscillations in Matter
Matter Effects
Effective Potentials in Matter
Evolution of Neutrino Flavors in Matter
MSW Effect (Resonant Transitions in Matter)
Averaged Survival Probability
Crossing Probability
Solar Neutrinos
Electron Neutrino Regeneration in the Earth
Phenomenology of Solar Neutrinos

Neutrinos and Astrophysics: (3 lectures) Teresa Montaruli

Abstract: I will describe the motivations of neutrino astronomy and the additional information it can provide respect to gamma astronomy. Neutrino candidate sources and expected fluxes will be illustrated together with the connection between measured gamma fluxes and expected neutrino ones. I will describe the detection technique of Cherenkov neutrino telescopes and the main parameter that describe their performance. I will then illustrate what is going on in the field and focus on point-like source results and on the measurement of atmospheric neutrinos.

Lecture 1:

Introduction on neutrino astronomy

detection principle and candidate sources,

connection with gamma astronomy,

calculation of neutrino flux from gamma one

example of sources and expected rates of neutrinos

Lecture 2:

Detection Technique

Main parameters of Detection Techniques (PSF, eff area, energy resolution).

Lecture 3:

Point-source analysis strategy.

Atmospheric neutrinos.

Experiments at work now

Introduction to Neutrino Interaction Physics (3 lectures): Paul Soler

Abstract: A crucial problem in performing neutrino oscillation experiments is to understand in detail the physics of neutrino interactions. In these lectures I will describe our current knowledge of neutrino interaction cross-sections. I will start by giving a historical overview, describing Fermi's original 4-point interaction theory, the V-A theory and Weinberg-Salam Standard Model. In the next section I will use neutrino-electron scattering to develop the tools to calculate charged current, neutral current and the interference between charged and neutral current neutrino interactions. I will then describe neutrino-nucleon deep inelastic scattering, including charged and neutral current interactions, sum rules, determination of $\sin^2 \theta_W$ from neutrino interactions and finally, charm production from deep inelastic neutrino scattering. In the next section I will describe the transition region in which Quasi-elastic, resonance, coherent and diffractive scattering co-exist. This region, around the 1 GeV energy, is extremely important for future neutrino oscillation experiments. I will end with a short discussion on nuclear effects necessary to understand neutrino interactions.

Part 1: History and introduction

- 1.1 Fermi Theory
- 1.2 Neutrino discovery
- 1.3 Parity violation and V-A theory
- 1.4 Neutral currents
- 1.5 Standard model introduction

Part 2: Neutrino-electron Scattering

- 2.1 Charged current
- 2.2 Neutral current
- 2.3 Interference charged and neutral current
- 2.4 Number of neutrinos

Part 3 Neutrino-nucleon Deep Inelastic Scattering

- 3.1 Variables
- 3.2 Charged current
- 3.3 Quark content of nucleons
- 3.4 Neutral current
- 3.5 Sum rules
- 3.6 A case study: $\sin^2 \theta_W$ from neutrino interactions
- 3.7 Charm production in neutrino interactions

Part 4: Neutrino-nucleon Quasi-Elastic, Resonance, Coherent and Diffractive Scattering

- 4.1 Charged Current Quasi-elastic scattering

4.2 Neutral Current Elastic Scattering

4.3 Resonant Charged and Neutral Current single and multi-pion production

4.4 Coherent and Diffractive production of mesons

Part 5: Nuclear effects

5.1 Fermi smearing and Pauli blocking

5.2 Nuclear Reinteractions

Extracting Oscillation Parameters from Neutrino Data (4 lectures): Andrea Donini

The measurement of the neutrino fluxes produced by nuclear reactions in the Sun and by cosmic rays hitting the outer layers of the Earth atmosphere have been pointing out that neutrinos do have non-vanishing mass for long. It is only recently, however, that the discrepancy between expected and observed neutrino fluxes have been interpreted as neutrino mixing (at least dominantly) beyond any doubt. The experimental data are now understood in the framework of a leptonic mixing matrix, U_{PMNS} equivalent to the hadronic mixing matrix $\$V_{CKM}$. The parameters of the leptonic mixing matrix must be now measured with a precision similar to those in the hadronic sector, if we want to build a model for the fermion masses and the Yukawa couplings of the Standard Model. The measurement of these parameters with a high precision, moreover, is mandatory if we are to look for new physics (i.e., beyond the neutrino masses and three-flavor mixing) in the leptonic sector.

Lecture 1. Solar neutrinos: extracting θ_{12} and Δm_{12}^2

Lecture 2. Atmospheric neutrinos: extracting θ_{23} and $|\Delta m_{23}^2|$

Lecture 3. Looking for θ_{13} and Cp-violation: bounds on θ_{13} from reactor and long baseline experiments. Short review of proposed facilities (see courses on physics at SuperBeams, BetaBeams Reactors and Neutrino Factories)

Lecture 4. Sterile neutrinos: LSND, MiniBooNE and N x N mixing matrices

Detectors for Future Facilities (3 lectures): Mark Messier

This series of lectures will cover the basic techniques of neutrino detection. The series of lectures with begin by covering the relevant features of neutrino interactions and neutrino event topologies which generally inform all decisions regarding detector designs and optimization. Following this general introduction, the focus with switch to detectors optimized for electron neutrino detection in energy ranges relevant to future super-beam, beta-beam, and neutrino factory facilities. The lectures will conclude with a discussion of muon-neutrino detection with a focus on the $\nu_e \rightarrow \nu_\mu$ channel at a neutrino factory.

0. The basics
   a. What does a neutrino detector do?
   b. The need for mass
   c. The need for resolution
1. Neutrino event topologies
   a. Basics of neutrino interactions: (CC,NC)*(QE, 1-pi, DIS)*(nue,numu,nutau)
   c. Fundamentals of muon response
   d. Fundamentals of electron and gamma response
   e. Fundamentals of hadron response
   f. Historical examples
2. Overview of detector technologies
   a. Non-segmented detectors
   b. Segmented detectors
   c. "Hybrid" detectors
   d. Comparisons of major features
3. Electron neutrino detection
   a. Future measurements requiring electron neutrino detection
   b. Principles of electron neutrino signal and background identification
   c. Detectors
      i. Water cherenkov
      ii. TASD
      iii. LqAr
4. Muon neutrino detection
   a. Future measurements requiring muon neutrino detection
   b. Principles of muon neutrino signal and background identification
   c. Detectors
      i. Iron sandwich
      ii. "Magnetized caverns" (TASD/LqAr)
5. Summary and conclusion

Reactor Neutrinos (2 lectures): Ed Blucher

Nuclear reactors have played a critical role in exploring the properties of neutrinos, from the first direct observation of the neutrino in 1956 to current neutrino oscillation experiments. In these lectures, we will first review some properties of reactors as antineutrino sources and the techniques used to detect antineutrinos in experiments. Next, we will discuss the Reines-Cowan experiments, which illustrate many issues relevant for all reactor neutrino experiments. The major part of the lectures is devoted to the use of reactor neutrinos as a tool to investigate neutrino oscillations.

Lecture 1:
- Reactors as neutrino Sources

- Antineutrino Detection
- Reines Cowan Experiments
- Introduction to Oscillation Experiments

Lecture 2:
- Solar Delta m^2 (KAMLAND)
- Atmospheric Delta m^2 (Chooz, Double Chooz, Daya Bay)