2016 International Neutrino Summer School Schedule

Week 1	Mon 18 July	Tues 19 July	Wed 20 July	Thurs 21 July	Fri 22 July	Sat 23 July
8:00-9:15	Welcome session Neutrino Phenomenology 1 (BK)	Neutrino Phenomenology 2 (BK)	Neutrino Phenomenology 3 (BK)	Neutrino Phenomenology 4 (BK)	Solar & Atmospheric 1 (JR)	Solar & Atmospheric 2 (JR)
9:15-9:45	Tea/Coffee	Tea/Coffee	Tea/Coffee	Tea/Coffee	Tea/Coffee	Tea/Coffee
9:45-11:00	Neutrino Mass Models 1 (ZX)	Neutrino Mass Models 2 (ZX)	Neutrino Mass Models 3 (ZX)	Cosmology and Astrophysics 1 (MHR)	Cosmology and Astrophysics 2 (MHR)	Neutrino Mass Models 4 (ZX)
11:00-12:30	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch
12:30-2:45	Group Tutorials	Talk by J.M.Frere Group Tutorials	Excursion	Group Tutorials	Group Tutorials	Group Tutorials
2:45-3:15	Tea/Coffee	Tea/Coffee		Tea/Coffee	Tea/Coffee	Tea/Coffee
3:15-4:30	Neutrino Detection 1 (MY)	Neutrino Detection 2 (MY)		Neutrino Detection 3 (MY)	Neutrino Cross Section 1 (KM)	Neutrino Cross Section 2 (KM)

Sunday July 24 is a free day to relax (and to prepare for the second week!).

Week 2	Mon 25 July	Tue 26 July	Wed 27 July	Thurs 28 July	Fri 29 July
8:00-9:15	Direct Mass and 0nubb 1 (SM)	Excursion	Accelerator Neutrinos 1 (JH)	Accelerator Neutrinos 2 (JH)	Accelerator Neutrinos 3 (JH)
9:15-9:45	Tea/Coffee		Tea/Coffee	Tea/Coffee	Tea/Coffee
9:45-11:00	Direct Mass and 0nubb 2 (SM)		Direct Mass and 0nubb 4 (SM)	Reactor 1 (SS)	Reactor 2 (SS)
11:00-12:30	Lunch	Lunch	Lunch	Lunch	Lunch
12:30-2:45	Group Tutorials	Group Tutorials	Group Presentations	Future Efforts 1 (SC)	Future Efforts 2 (SC)
2:45-3:15	Tea/Coffee	Tea/Coffee	Tea/Coffee		
3:15-4:30	Neutrino Cross Section 3 (KM)	Direct Mass and 0nubb 3 (SM)	Group Presentations		

The school banquet will be held on Wednesday July 27.

Course Outlines

- **Neutrino Mass Models:** ZhiZhong Xing (IHEP, Chinese Academy of Science, Beijing, P.R. China)
  Lecture (1): neutrinos----special flavors in the standard model
  ----The standard model in a nutshell
  ----Neutrino flavors and lepton number
  ----Examples of neutrino interactions
  Lecture (2): Dirac and Majorana neutrino mass terms
  ----The Dirac mass term and lepton number conservation
  ----The Majorana mass term and lepton number violation
  ----Comments on electromagnetic properties of neutrinos
  Lecture (3): Lepton flavor mixing and CP violation
  ----Diagnosis of quark/lepton flavor mixing and CP violation
  ----Salient features of the PMNS neutrino mixing matrix
  ----What is behind: the mu-tau flavor symmetry and more?
  Lecture (4): Seesaw mechanisms and their portals
  ----Three typical seesaw mechanisms and their variations
  ----Possible lepton-number (flavor)-violating signatures
  ----Model-building strategies and related flavor issues

- **Neutrino Phenomenology:** Boris Kayser (Fermilab, Batavia, Illinois, USA)

  - Leptonic mixing and its role in leptonic weak interactions
  - The physics of neutrino oscillation
  - Important special cases of oscillation
  - A summary, all in one place, of what we have learned from the oscillation (and other) data
  - Major open questions about neutrinos and their roles in physics and astrophysics
  - The nature of Majorana neutrinos, and what the observation of neutrinoless double beta decay would tell us
  - CP violation in neutrino physics, and leptogenesis as the origin of the matter-antimatter asymmetry of the universe
  - The possible existence of light sterile neutrinos, non-standard neutrino interactions, and really wild neutrino behavior
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- **Neutrino Detectors:** Masashi Yokoyama (The University of Tokyo, Tokyo, Japan)

  1. Basics of neutrino interaction and detection
     1.1 Introduction of neutrino detection
     1.2 Neutrino interaction primer
     1.3 Overview of particle detection techniques
  2. Neutrino detectors (I)
     2.1 Low energy nue and anti-nue detectors
     2.2 Accelerator nu detectors
  3. Neutrino detectors (II)

3.1 Large water/ice Cherenkov detectors
3.2 Liquid Ar detectors
3.3 Other detectors

- **Accelerator Neutrino Experiments:** Jeff Hartnell (Sussex University, Brighton, United Kingdom)

  Conventional accelerator neutrino beams: design of conventional beams, magnetic horns, decay pipe, target. Energy spectrum, flavour composition. Ideas for future beams: muon storage and decay, radioisotope decay. Pros and cons.

  The physics we want to measure and how we do that: neutrino disappearance experiments, appearance measurements, NC rate. Signatures of sterile neutrinos. Past, present and future accelerator neutrino experiments.

- **Neutrino Interactions:** Kevin McFarland (University of Rochester, Rochester, NewYork, USA)

  Topic 1: Weak Interactions of Neutrinos with other Fermions

  * Motivation for studying neutrino interactions
  * Calculation of neutrino-electron elastic scattering cross section
  * Application: measuring flux at MINERvA and DUNE
  * Inverse muon decay and lepton mass effects
  * Generalization to other targets: what can we learn from neutrino-electron scattering? What must change when target has structure?
  * Neutrino-quark scattering and deep inelastic scattering
  * Parton distributions and calculation of cross-sections
  * Phenomenology of high energy cross-sections
  * BACKUP MATERIAL IF TIME: Massive final state leptons and hadrons in DIS

  Topic 2: Elastic and Inelastic Scattering on Nucleons

  * CC and NC elastic scattering on free nucleons
  * Nucleon form-factors
  * Kinematics of CC and NC nucleon elastic scattering
  * Experimental measurements of elastic and *quasi*elastic scattering and observed "puzzles"
  * Barely inelastic processes

* Baryon resonance production, in brief
* Transition to deep inelastic scattering and quark-hadron duality

Topic 3: Nuclear Effects

* Nucleon kinematics inside the nucleus
* Final state interactions
* Multi-nucleon processes
* Application to quasi-elastic scattering and recent measurements. [A return to the "puzzles" of the previous lecture]
* Impacts on oscillation experiments
* Coherent elastic and inelastic neutrino-nucleus scattering
* Developments in recent data
    * Precision CC0pi and CC1pi cross sections on nuclei
    * Identification of multinucleon kinematics in nearly elastic events
    * Muon and electron neutrino cross sections
    * Coherent and diffractive pion production
    * Neutrinoproduction of kaons
    * Identification of multinucleon kinematics
* Comments on neutrino interaction generators for oscillation experiments
* Low energy processes
* Inverse (neutron) beta decay
* BACKUP MATERIAL IF TIME: Neutrino-electron elastic scattering on bound electrons
* BACKUP MATERIAL IF TIME: Ultra-high energy scattering and modifications to DIS phenomenology at ultra-high energies
* Where are the theory and data lacking? What will we learn soon? What may remain a puzzle?
* Summary

- **Direct Neutrino Mass and Neutrino-less Double Beta Decay Measurements:** Susanne Mertens (LBNL, Berkeley, California USA)

- Introduction:
    - Discovery of Neutrino
    - Discovery of Neutrino Mass
    - Open Questions
- Neutrinoless double beta decay
    - Dirac vs Majorana
    - Helicity vs Chirality
    - Experimental challenges
    - 0nbb and neutrino mass
    - Experiments: CUORE, MAJORANA, EXO
- Single beta decay

Tritium beta decay, Fermi Theory
Single beta vs double beta
Experimental Challenges
Experiments: KATRIN, ECHO, PROJECT8

- Other physics with beta decays
  Search for sterile neutrinos
  Search for relic neutrinos

- **Solar and Atmospheric Neutrino Experiments:** Jen Raaf (Fermilab, Batavia, Illinois, USA)
  — Natural Sources of Neutrinos
  — Atmospheric neutrinos
  * The starting point: nucleon decay
  * Atmospheric neutrino deficit
  * Zenith angle & L/E
  * Tau neutrino appearance
  * Atmospheric neutrino properties
  * Future prospects
  — Solar neutrinos
  * How the sun burns/Solar nu spectrum
  * Early solar neutrino experiments
  * Solar neutrino problem
  * Solving the solar neutrino problem
  * Solar neutrino properties
  * What next

- **Reactor Neutrino Experiments:** Seon-Hee Seo (Seoul National University, Seoul, Korea):

Nuclear reactors produce vast numbers of electron anti-neutrinos (nu_e_bar): ~2×10^{20} anti-ν_e/sec per GW_{th}. Only disappearance experiments are possible since the energy of the reactor anti-neutrinos is less than 10 MeV. Folding in the detection cross section, which has a threshold of 1.8 MeV, the mean anti-neutrino energy is 3.6 MeV.

Reactor neutrinos have been playing very important roles in the history of neutrino physics. The discovery of the neutrino was made in Reines and Cowan's reactor neutrino experiment in 1956. In 2002, the KAMLAND reactor experiment in Japan confirmed the LMA (Large Mixing Angle) solution to the solar neutrino puzzle discovered by SNO in 2001 and has since made the most precise measurement of solar mass splitting. Daya Bay and RENO reactor experiments discovered the last remaining neutrino mixing angle, θ_{13}, in 2012.

Thanks to the relatively large value of θ_{13} (~9 degrees), it is possible to explore more challenging but very important questions on neutrinos: leptonic CP violation phase (δ_{CP}) and the neutrino mass ordering. Future detectors like JUNO and RENO-50 will use reactor neutrinos to determine neutrino mass ordering as well as very precise measurements of neutrino oscillation parameters.

The 1st lecture focuses on "introduction to reactor neutrinos" and " θ_{13} measurements from the three reactor neutrino experiments: Daya Bay, RENO, and Double Chooz". The 2nd lecture focuses on "neutrino mass ordering determination with reactor neutrinos".

- **Cosmology / High Energy Neutrino Astrophysics:** Mary Hall Reno (The University of Iowa, Iowa City, Iowa, USA)

  - Neutrinos in cosmology
    * Expanding universe and limits from Omega
    * Big bang nucleosynthesis constraints
    * CMB and matter power spectrum constraints
    * Limitations of constraints - wiggle room

  - Neutrinos in astrophysics
    * GZK neutrinos - cosmogenic flux
    * Diffuse flux - Waxman-Bahcall bound and IceCube
    * HE neutrino production in astrophysical sources
    * Neutrino oscillations and flavor content
    * Supernova neutrinos

- **Future Efforts of the Field:** Sandhya Choubey (Harish-Chandra Research Institute, Allahabad, India)

Measuring the neutrino mass hierarchy, the octant of theta23 and the CP phase delta are among the main goals in neutrino physics for the immediate future. A large number of experiments are being planned to measure these parameters. These experiments will be observing neutrinos produced in earth's atmosphere, in accelerators and in reactors. In these lectures we will look at the sensitivity of these experiments to measure all or some of these parameters.

While the three-generation paradigm appears to be working fine to explain the data from solar, atmospheric and reactor/accelerator experiments, there still remains the hint of oscillations of a fourth neutrino observed in the LSND experiment. Hint for sterile neutrinos come also from the reactor sector and the Gallium experiments. This extra neutrino has to be sterile and hence beyond the standard model. A large number of experiments are being planned to test this. Beyond standard model physics could also affect neutrino oscillations through the existence of additional contribution to the charge-current-like and neutral-current-like couplings of the neutrinos. These are known as Non-Standard Interactions (NSIs). The physics reach of the long baseline experiments could change in the presence of sterile neutrinos and NSIs and we will study this.