Physics Syllabi for INO Ph.D Program

- **Particle Physics IPHY 201**
  - Symmetries in particle physics: charge conjugation, parity, time reversal, isospin and SU(2), motivation for the quark model and SU(3).
  - Introduction to relativistic kinematics: Mandelstam variables, phase space, calculation of cross-sections and decay widths.
  - The Dirac equation and its solutions,
  - Basics of quantum electrodynamics: electron-positron annihilation, electron-muon scattering, Bhabha scattering, Compton scattering.
  - Deep inelastic scattering: Bjorken scaling, parton model, scaling violation, introduction to quantum chromodynamics.
  - Introduction to weak interactions: parity violation, (V-A) theory, pion and muon decay, neutrino scattering and cross-sections.
  - The gauge theory of electroweak interactions: Glashow-Salam-Weinberg model, applications of the model, neutral current phenomena, The physics of W-and Z-bosons, physics of the Higgs boson.

- **Experimental Methods I IPHY 203**
  - Vacuum generation and measurement - rough, high, UHV.
  - Cryogenics - low and ultra low temperatures.
  - Generation and measurement of voltage, current, time, frequency and examples of measuring resistance, temperature, pressure, magnetic field.
  - Basic semiconductor device physics: p-n junction, diodes, I-V curve, rectifiers. Transistor (NPN, PNP), JFET, MOSFET.
  - Principle of Negative feedback.
  - Differential amplifier + OPAMP, applications-differentiator, integrator, summing, inverting amplifier.
  - Sensors for specific gases, light etc.
  - Particle accelerators - DC, RF, storage rings, colliders. Secondary beams using high current electron, proton and heavy ion accelerators. Beam transport - dipole magnets including fast kickers, quadrupoles, higher order correction magnets. Beam measurement - energy, current, X-Y-time intensity distribution, beam emittance.
  - Keeping track of dimensions, dimensional arguments, order of magnitude estimation - cross section, efficiency, count rates.

- **Numerical Methods and Error Analysis, IPHY 205**
  - Introduction to programming languages: F77, F90 or C
  - Errors in numerical calculations.
  - Chi-Squared Analysis, Solutions of Linear Equations, Eigenvalue problems
  - Stochastic processes, Gaussian, Binomial and Poisson distributions, central limit theorem
  - Interpolation techniques, Generation and use of random numbers.
  - Differentiation and Integration Algorithms; Monte Carlo techniques, Direct Sampling, Metropolis Algorithm,
  - Optimisation, extrema of many variable functions.
  - ODE's and PDE's: including FFT and finite difference methods, integral equations.

- **Experimental Project I, IPHY 207**

- **Neutrino Physics, IPHY 202**
  - Neutrino Interactions in the Standard Model, neutrino and anti-neutrino scattering with electrons, protons and nucleons.
  - Neutrino cross-sections, quasi and deep inelastic cross-sections, neutrino scattering with nucleons and electrons at low, intermediate and high energies.
  - Dirac and Majorana masses for neutrinos, see-saw mechanism and the link between neutrino parameters and unified theories at high energies.
  - Experimental techniques for direct mass measurements via beta decay, Double beta decay physics and experiments.
  - Neutrino Oscillations in vacuum and matter, MSW effect, neutrino mixing parameters.
  - Solar, Atmospheric, Supernova and UHE Neutrinos; Neutrinos from accelerators and reactors, Fluxes and Detection techniques for neutrinos from these sources, Beta-beam and Neutrino factory basics.
  - Present neutrino detectors and knowlwedge/status of mixing parameters as obtained via global analyses, future and planned experiments.

- **Experimental Methods II, IPHY 204**
  - **A. Matter Particle interaction**
  - Interaction of high energy particles with matter: heavy charged particles, electrons, photons, neutrons, hadrons, neutrinos.

- Gas detectors, physical processes. Examples of types of gas detectors - ionization, drift chamber, proportional, MWPC, TPC, avalanche, RPC, GEM.
- Scintillator, photomultiplier, light guides, wavelength shifting fibres -Time of flight method, trigger.
- Semiconductor detectors, silicon and Si(Li), high purity germanium, mixed semiconductors (e.g. Si telescopes, vertex detector, HPGe array).
- Neutron detectors - slow and fast neutron detectors, BF_3, ^3He, plastic & liquid scintillators, pulse shape discrimination, neutron shielding.
- Cerenkov emission, transition radiation -Threshold counter, Differential counter.
- Assorted detectors used in Nuclear & High Energy Physics : Electromagnetic Calorimeter, Hadronic calorimeter
- Design of High Energy Physics detectors - CMS, INO
- **B. Pulse processing electronics and data acquisition**
- Basic detector characteristics and output (charge/current/voltage signal :pulse/DC).
- Noise in detector & electronics and its reduction.
- Digital circuits, PF, JKPF, RSPF
- Co-axial cables, signal transmission/loss, impedance matching, noise/distortion.
- Commonly used front end electronics - preamplifier, amplifier (slow and fast), pulse stretcher, fast and slow concidence, logic and linear gates, logic & linear fan-in/fan-out, delay line, timing discriminators (incl. constant fraction), single channel analyser, multi-channel analyser, Voltage ADC (Wilkinson, successive approximation, flash), Time to Digital Converter, DAC, scalar, precision pulse generator. Digital signal processing.
- PC interfacing/protocol - RS-232, CAMAC, VME
- Labview

- **Numerical Simulation and Track Reconstruction Techniques, IPHY 206**
  - Basic Geant4 simulation - INO detector simulation
  - Reconstruction algorithms: cluster (photon and hadron), track, Cerenkov photon
  - Kalman fitting technique - INO track reconstruction
- **Experimental Project II, IPHY 208**