Collider Particle Physics Program
Prof. C. Luci - AA 2025-26

- **Accelerators**
  Basic principle of electrostatic accelerators and Linac; Cyclotron; Synchrotron. Strong focusing. Basic points of beam dynamics: beta function, emittance, particle oscillation in the transverse plane. Acceleration system, phase stability. Colliders: energy and luminosity.

- **Reminder of a few basic concepts of Particle Physics**
  Cross-section definition at fixed target experiment and at a collider. Formation and production resonances. Invariant mass. Breit-Wigner formula. Definition of elastic scattering. S-channel and t-channel scattering.

- **Reminder of a few key points of the Standard Model**
  Gauge theories. Covariant derivatives for $U(1)$, $SU(2)$ and $SU(2)_L \times U(1)_Y$. $\lambda\phi^4$ lagrangian for a scalar field and a complex field. Spontaneous symmetry breaking. Goldstone theorem. Brout-Englert-Higgs mechanism. Higgs boson. Higgs mechanism for Yang-Mills field and for GWS lagrangian. Gauge bosons mass and weak mixing angle (Weimberg angle). Z boson and photon masses. Fermion masses. W coupling. Weak charged and neutral currents. Z interaction: Vector and Axial couplings, Left-handed and Right-handed couplings. Basic points of QCD and the Standard Model. Hints on the running of α_{em}, asymptotic freedom in QCD and running of α_s.

- **ISR Collider at CERN**
  The first proton-proton collider. Proton-proton elastic scattering: Pomeron exchange. Total cross section determination. Optical theorem. Luminosity determination through the Van der Meer scan. Roman Pots. Soft physics at LHC.

- Sp$\bar{\text{p}}$S **Collider at CERN and W and Z discovery**
  W and Z mass prediction. The proton-antiproton collider idea. Basic principle of the stochastic cooling. Sp$\bar{\text{p}}$S main parameters. The Sp$\bar{\text{p}}$S detectors: UA1 and UA2. W and Z production mechanism at the Sp$\bar{\text{p}}$S. W and Z decay channels. Kinematics at the hadron collider: rapidity and pseudorapidity. W and Z mass measurement methods. W mass measurement with the lepton p_T. Gluon radiation from the initial state. W transverse p_T. Detection of neutrino through missing p_T. Missing transverse energy E_T. Invariant transverse mass. Effect of the recoil on the invariant transverse mass. Determination of the W spin. Z boson mass measurement. Invariant mass resolution. Determination of $\sin^2\theta_W$.

- **LEP Collider at CERN and Z boson Physics**
  Main parameters of the LEP collider: center of mass energies of LEP1 and LEP2. Methods to measure the beam energy. The collider competitor: SLC. Main characteristics of LEP detectors: Aleph, Delphi, L3 and Opal. Signature of the different particles in the detectors, b-jet tagging. Analysis strategies: event selection, background subtraction, trigger and selection efficiencies. Luminosity measurement. Cross-section as a function of the center of mass energy. The Z lineshape parameters: peak position, partial widths and peak cross-section. Measurement of Z mass. Differential cross-section with respect to $\cos\theta$. Forward-backward asymmetry A_{FB}. Helicity cross-section of the Z-pole. Final state polarization asymmetry A_{pol} and initial state polarization asymmetry A_{LR}. Radiative correction. Improved Born approximation and redefinition of the coupling constants. Dependence on the top and Higgs masses. Renormalization of α_{em}. Initial state radiation, radiator function. Global fit strategy at LEP. Line shape observables: Z mass, Z total and partial widths, cross-section at the peak. Z couplings: g_V, g_A, g_L and g_R. Determination of $\sin^2\theta_W$. Measurement of the number of neutrino families with the indirect method. Measurement of the neutrino families with the single photon method.

- **LEP2 Physics**
  LEP2 final states: first order diagrams. Two fermion final state and radiative return to the Z, effective center of mass energy. W decay channels and WW final state categories, event selection. W pair production cross-section; triple gauge boson coupling. Effect of W width and ISR on the cross-section. W mass measurement at threshold. W mass direct reconstruction method, colour reconnection and Bose Einstein condensation. ZZ final state. LEP global fit: prediction of the top and Higgs masses. Reminder of Higgs coupling to gauge bosons and to fermions. Higgs production mechanism at LEP. Event selection for the HZ final states. Higgs searches at LEP1 and LEP2.

- **Tevatron Collider at Fermilab and top Physics**
  The Tevatron collider. W mass measurement at the Tevatron. Top quark discovery. Top properties. $t\bar{t}$ production diagrams at Tevatron and at LHC. Top pair final states signature. Method to measure the top mass at LHC: direct measurement and indirect method through the cross-section. Comparison of the two methods.

- **HERA Collider at DESY and PDF determination**
  The Hera collider. H1 and Zeus experiments. Reminder of kinematics of lepton-hadron scattering. Lepton-hadron collision on fixed target experiments. Reminder of the cross-section in terms of structure functions. Parton model cross-sections: meaning of x. Parton Density Functions (PDF). Scaling violation. Parton model: meaning of y. Relationship between helicity and inelasticity factor y. Neutral current deep inelastic scattering (DIS) events at HERA. Neutral current cross section versus Q^2. Deep Inelastic Scattering with charged current: W exchange. Charged current with polarized beams. QCD corrections to parton model. Gluon emission diagrams and cross sections. Collinear approximation. QCD factorisation and PDF dependence on Q^2. Hints on DGLAP equation. Hera measurement of DIS cross-section. Extracting the PDF from the cross-sections. How to distinguish different quarks. How to measure the gluon PDF.

- **LHC Collider at CERN and a few selected physics topics**
  Reminder of the CERN accelerator complex. LHC operation parameters. LHC cycle. LHC luminosity dependence on proton-per-bunch (ppb) and number of bunches. Integrated luminosity and pile up. Main characteristics of the LHC detectors ATLAS and CMS and comparison between them. Proton-proton collisions and PDF distributions. Total cross-section at LHC. Drell-Yan processes and SM cross-sections overview. W mass measurement at LHC. Hints of $\sin^2\theta_W$ measurement through forward-backward asymmetry. Z invisible width measurement with monojet. Gauge boson coupling at LHC, an example: vector boson scattering, with same sign WW and two jets final state. Hints on Dark Matter and susy particle searches at LHC.

- **Higgs discovery at LHC**
  Higgs boson production mechanisms at LHC and Higgs boson decay modes. Discussion of the two most sensitive decay channels used in the Higgs search: four lepton channels and two photons final state. Muon, electron, photon identification and energy/momentum calibration. Four lepton irreducible background. Reducible background. Higgs mass measurement in the two channels. Width measurement strategy. Spin and parity measurement. Higgs coupling to fermions, bosons and self couplings. Identification of the production modes. Signal strength and k-framework. Main Run-2 results: two photons, WW, four leptons, tau-tau and bb channels. Two muon channel limits. Combined fits in the k-framework. Hints on simplified template cross-sections. Fiducial and differential cross-sections. Unfolding matrices. Differential fiducial cross-sections in the four leptons and two photon channels. Effective field theory. Double Higgs production. Di-Higgs analyses. Self and quartic coupling modifiers.