The 4th Concept Detector for the International Linear Collider

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The International Particle Physics community has reached a consensus on the importance of a lepton collider for a full understanding of Physics at the Terascale.
The *International Linear Collider* (ILC) is being proposed as a particle accelerator that could answer fundamental questions, complementing and enhancing the scientific results and the discovery of new Physics expected from the *Large Hadron Collider* (LHC). Consisting of two linear accelerators of approximately 31 kilometres in length facing each other, in the ILC electrons and positrons will collide $14,000$ times per second at 500 GeV center-of-mass energy. The current baseline design allows for an upgrade to a 50-kilometre, 1 TeV machine during the second phase of the project. In the next few years, results from the LHC will set the required energy for a lepton collider.

Three detector Concepts, *ILD*, *SiD* and the *4th Concept*, have been developed complete designs for the ILC detectors. All the three concepts will attempt an innovative whole-detector approach for calorimetry and tracking devices.

The *4th Concept* is a general purpose detector designed for a high-energy e^+e^- collider that can measure with high precision all the fundamental fermions and bosons of the standard model, and thereby access all known physics processes. The *4th Concept* consists of four basic subsystems: a pixel vertex detector for high precision vertex definitions, impact parameter tagging and near-beam occupancy reduction; a cluster-counting low-mass drift chamber for robust pattern recognition with over one hundred three-dimensional space-points each with about 55μm resolution, 3.5% specific ionization measurement; a high precision dual-readout fiber calorimeter, complemented with an EM dual-readout crystal calorimeter, both with time-history readout, for the energy measurement of hadrons, jets, electrons, photons, missing momentum, and the tagging of muons; and, an iron-free dual-solenoid to return the flux and provide a second field region for the inverse direction bending of muons in a gas volume to achieve high acceptance and good muon momentum resolution. The pixel vertex chamber, tracking and calorimeter are inside the solenoidal magnetic field.

All four subsystems separately achieve the important scientific goal to be 2-to-10 times better than the already excellent LEP detectors, ALEPH, DELPHI, L3 and OPAL.

All four basic subsystems contribute to the identification of standard model partons, some in unique ways, such that consequent physics ensembles are identified with high efficiency and high purity. We achieve a jet energy Gaussian resolution of $\sigma/E \approx 29\%/\sqrt{E} \oplus 1.2\%$ on complete ensembles without prior selection and a consequent $2\sigma_M$ separation in the two-jet invariant mass of W and Z hadronic decays.

Our experimental group is part of the *4th Concept* Collaboration and it is involved in many important tasks related to performance and the optimization of the detector. The two most important activities being pursued in Lecce are:

- the development of the software framework and the algorithms to simulate and reconstruct events
- the simulation of the *4th Concept* subdetectors
- the developement of new algorythms for the analysis of jets

Finally, there is an intense optimization activity, with the goal of proposing the best solutions for a set of Physics measurements.

1. The Off-line framework for simulation, reconstruction and analysis: ILCRoot[1][2]

ILCRoot derives from AliRoot [3], the offline framework of `Alice` [4] experiment based on the C++, Object Oriented framework, ROOT [5]. The reasons for such a choice are several. First of all it is a single framework for all the steps, from the simulation to the reconstruction phase. Furtools of ROOT, which is the standard environment adopted today as HEP software.

The detectors are implemented as independent modules that contain functionalities for the simulation and reconstruction of the events while the analysis code is progressively added. A STEER module provides steering, run management, interface classes, and base classes to the entire framework.

The detector response simulation can be also performed via different transport codes like GEANT3, GEANT4, and FLUKA. The user can decide which one to load at runtime and, thanks to the Virtual Monte Carlo abstract interface[6], no user code has to be changed.

Figure 1 shows an event display of $e^+e^- \rightarrow ZH \rightarrow \nu\overline{\nu}c\overline{c}$ at $E_{CM} = 250$ GeV in ILCRoot framework.

Figure 1. *Display of a* $e^+e^- \rightarrow ZH \rightarrow \nu\overline{\nu}c\overline{c}$ *event at* $E_{CM} = 250$ GeV.

2. Detectors and Physics Performance

The Physics goals of the International Linear Collider project range over a variety of processes in a wide energy region of $\sqrt{s}$ from M_Z to 1 TeV. In the experiments at the ILC it is essential to reconstruct events down to fundamental particle (leptons, quarks, and gauge bosons). Most of the interesting Physics processes include gauge bosons, W or Z, heavy flavour quarks, b and c), and/or leptons, *electrons*, *muons* and *taus*, as direct products of e^+e^- collisions or as decay daughters of heavy particles like *SUSY particles*, *Higgs boson*, *top quark*, etc. To fully exploit the Physics opportunities presented at the ILC, the detector must have capabilities well beyond the detectors at LEP or LHC. The requirements can be summarized as follows:

- Efficient quark-flavor and charge identification capability.
- Excellent charged-particle momentum resolution.
- Good jet-energy resolution.
- Hermetic coverage.

The performance goal for the detector system corresponding to the requirements listed above are then:

- Impact parameter resolution

$$\sigma(IP) = 5 \oplus 10/p\beta sin^{3/2}\theta \, \mu\text{m} \quad (1)$$

- Transverse momentum resolution

$$\sigma(p_t)/{p_t}^2 = 5 \times 10^{-5} (\text{ GeV}/c)^{-1} \quad (2)$$

- Jet energy resolution

$$\sigma(E_j)/E_j = 30\%/\sqrt{E_j(\text{ GeV})} \quad (3)$$

- Hermeticity

$$\theta_{min} = 5(\text{ mrad}) \quad (4)$$

All of the above requirements have been studied in details and the simulations performed by the *4th Concept* group in Lecce have proven that the detector either meets or exceeds such goals. A clear example stems from the analysis of the reaction $e^+e^- \rightarrow H^0Z^0 \rightarrow jj\nu\nu$ that we have presented at the LCWS08 Conference in Chicago. Fig. 2 shows the distribution of 2-jet invariant mass for such process, including the background from the Standard Model. The two peeks of the Z and Higgs boson are clearly separated, a result that can be achieved only with a detector that meets the requirements listed above.

Figure 2. *Distribution of 2-jet masses for the signal process* $e^+e^- \rightarrow H^0Z^0 \rightarrow jj\nu\nu$ *and a background process* $e^+e^- \rightarrow Z^0Z^0 \rightarrow jj\nu\nu$.

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