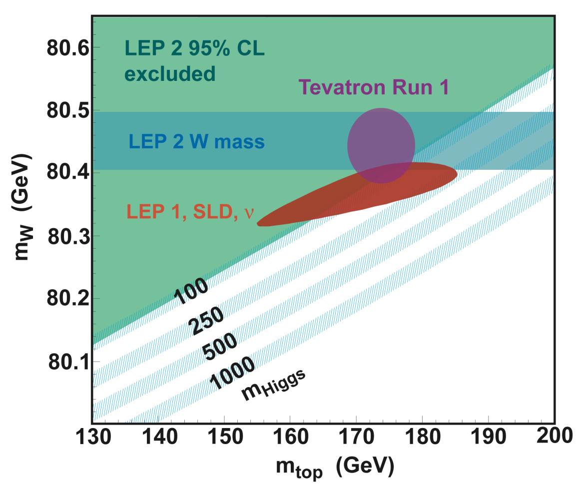
The EPP Questions

Response from the LHC/ILC Study Group

Ground-breaking discoveries are expected from the experiments under construction at the Large Hadron Collider (LHC) and those planned for the International Linear Collider (ILC). These high-energy particle accelerators will open up a new energy domain that will allow us to examine the very fabric of matter, energy, space and time. The experimental results should reveal how particles obtain the property of mass, whether the different forces that we experience in nature are in fact different manifestations of only one fundamental force, whether space and time are embedded into a wider framework of "supersymmetric" coordinates, and whether dark matter can be produced on Earth.

The LHC and ILC will probe this new TeV energy regime (roughly equivalent to 1000 proton masses) in very different ways, as a consequence of the distinct features of the two machines. Due to its high collision energy and luminosity, the LHC has a large mass reach for the discovery of new heavy particles. The striking advantages of the ILC are its clean experimental environment, polarized beams, and tunable collision energy. The ILC can thus perform precision measurements and detailed studies of directly accessible new particles, and also has exquisite sensitivity to quantum effects of unknown physics. Indeed, the fingerprints of very high-scale new physics (e.g. very high mass particles) will often only be manifest in small effects whose measurement requires the greatest possible precision.

The need for instruments that are optimized in different ways is typical in all branches of natural sciences, for example earth- and space-based telescopes in astronomy. In high-energy physics there has historically been a great synergy between hadron colliders, which can reach the highest energies, and lepton colliders, at which high-precision measurements are possible. As an example, the precise knowledge of the Z boson mass from LEP and precise measurement of its decay properties led to the prediction of a heavy top quark. Its mass was well beyond the energy reach of LEP but accessible to the Tevatron. Following the Tevatron's discovery of the top quark, its mass was determined. Subsequently the Tevatron and LEP measured the W boson mass with high precision. In combination, these measurements point tantalizingly toward a light Higgs boson.

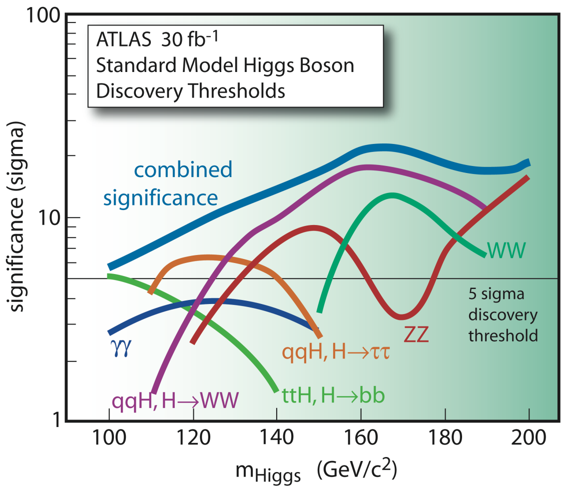


Precise measurements from concurrent running of LEP and the Tevatron experiments have brought us to the threshold of discovering the Higgs boson.

We expect an even greater synergy between the LHC and ILC. Discoveries made at the LHC will guide the operation of the ILC, and the precision ILC measurements can make it possible for the LHC to extract subtle signals for new physics and particles that may have escaped detection. Ultimately both machines will be needed to definitively connect TeV-scale measurements with the underlying theoretical structure.

Discoveries at the LHC

We eagerly anticipate the discovery of dramatic new phenomena at the LHC. In fact, what is most exciting is that we do not know exactly what to expect. Whatever we find in the new energy domain, it is certain to greatly enhance our understanding of the origin of mass, and could open up a new realm to explore. Detecting the Higgs boson would be a groundbreaking discovery. If in addition (or instead) new particles such as those predicted by supersymmetry are observed, or if the effects of hidden dimensions of space are found, the implications would be profound. For example these results would have deep implications for our understanding of the nature of dark matter and dark energy in the cosmos.



The LHC can discover a light Standard Model Higgs boson in the initial period of operation in a number of modes.

The elementary quark and gluon constituents of the proton beams of the LHC are strongly interacting particles, and collide with a fraction of the total available energy; this fraction varies from collision to collision. Typically, evidence for new phenomena has to be extracted from a plethora of conventional processes. Furthermore, very different kinds of hypothetical new physics can lead to similar experimental signals. Consequently, the LHC alone may not be sufficient to achieve a full theoretical understanding of the new phenomena observed.

Discoveries at the ILC

The ILC will provide very precise measurements of the attributes of all accessible particles, and these in turn can better define the properties of new heavier particles. This is made possible by its very clean initial state from colliding electrons and positrons, by its tunable collision energy and by the possibility of polarizing the incoming particles. Indeed, the machine running conditions can be tailored to the specific physics processes or particles under investigation. Furthermore, the sensitivity to quantum effects of new physics achievable at the ILC can in fact often exceed that in the direct search reach for new particles at either machine.

What physics would a Linear Collider address that would be impossible to probe at the LHC?

The high-precision information obtainable at the ILC will be crucial for identifying the nature of new physics, and in this way new fundamental laws of nature can be discovered. For instance, once one or more Higgs particles are detected at the LHC, a comprehensive program of precision Higgs measurements at the ILC will be necessary to reveal their properties and the underlying physical laws. Indeed, only the ILC may be able to discern whether the Higgs observed at the LHC is that of the Standard Model or a Higgs-like (possibly composite) scalar tied to a more complex mechanism of mass generation.

Should no fundamental Higgs boson be discovered at the LHC or ILC, the best way to probe the underlying dynamics responsible for particle masses will be through a combination of very high energy LHC measurements and very precise ILC measurements.

For supersymmetric particles, new states arising from extra dimensions of space, and other kinds of hypothetical new physics, the ILC can provide the precision that will allow an unambiguous discrimination among competing theoretical models. For example, understanding whether and how the forces unify at very high energy scales will require a level of precision that only the ILC can provide. In addition, the ILC can definitively relate elementary particle properties and interactions with cosmology. In particular, properties of dark matter candidates and the nature of their interactions can be studied in detail and confronted with cosmological observations and constraints.

Impact of LHC on the ILC Running

The ILC will come into operation following a period of LHC running. The great flexibility of the ILC in terms of the tunability of its energy and beam polarization will be brought immediately into play to focus on the properties of any new particles and phenomena observed at the LHC.

How will results from the LHC influence the running of the Linear Collider?

In the case of a light Higgs boson, for example, the LHC could indicate that top priority should be assigned to a precise measurement of the Higgs mass, branching ratios and self-coupling. The best precision would be achieved by adjusting the energy and configuration of the ILC appropriately. Deviations of Higgs properties from those expected in the Standard Model would then have important implications for future LHC running and upgrades. In general, new phenomena observed at the LHC will be interpreted in scenarios of new physics, so that the expected phenomenology at the ILC can be explored in model-independent ways. If a weakly interacting stable particle is discovered at the LHC, the ILC can be configured to determine if it can account for the dark matter of the universe. If supersymmetric particles are observed at the LHC, the ILC can be tuned to perform more complete and precise measurements of the mass spectrum than at the LHC, and to determine the properties needed to reveal deeper aspects of the nature of supersymmetry breaking.

Physics Gains from Concurrent Running of the LHC and ILC

The synergy between the LHC and ILC works both ways: there will be a profound interplay between the LHC and ILC during concurrent running that will enhance the capabilities of both machines. Upon a discovery at the LHC, the ILC conditions can then be adjusted so that the exploration of the new phenomena can be optimized. The ILC results will then suggest important new confirming searches and strategies for the LHC.

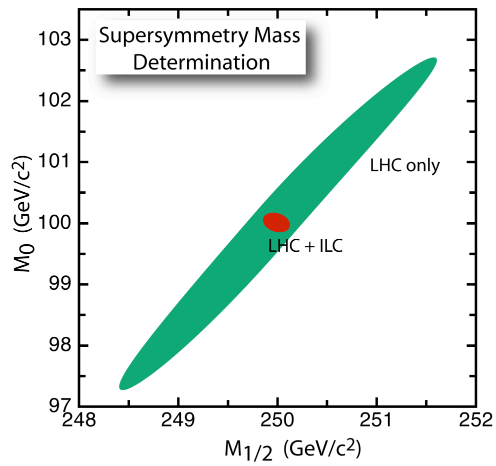
What are the physics arguments for operating a Linear Collider in the same time frame as the LHC?

Ultimately both machines will be necessary in order to disentangle the underlying structure of the new physics that lies ahead of us. The combined interpretation of the LHC and ILC data will lead to a much clearer picture of the underlying physics than the results of both colliders taken separately, allowing the new laws of nature to be identified.

In general, the LHC can most readily discover the heavy states of new physics that are "strongly coupled" (that is, produced via the strong interaction). These strongly coupled states typically decay via complicated cascades into new “weakly coupled” particles. The ILC is ideal for directly producing and detecting these weakly coupled particles. Precision ILC measurement of the properties of these particles are essential in understanding the strongly coupled ones and their decay patterns. Moreover, ILC measurements of quantum effects can be combined with direct LHC and ILC measurements to infer the existence and properties of additional heavy states at first missed by the LHC and too massive to be directly produced at the ILC. In many cases, these could then be directly discovered using modified LHC procedures.

How would the combination of the LHC and a Linear Collider answer questions that could not be addressed by either machine alone?

As an example, the existence and properties of heavy Higgs bosons and/or difficult-to-detect scalar Higgs-like particles associated with extra dimensions can be inferred from precision ILC Higgs measurements. A dedicated LHC search can then confirm their existence. In supersymmetry and extra-dimension theories, the LHC and the ILC will typically access different parts of the spectrum of new states.



Together the ILC and LHC can measure the unified supersymmetry masses much more precisely than either machine alone.

Summary

There will be a profound synergy between the physics results from the LHC and those from the ILC. The two machines complement and supplement one another in many ways, and concurrent operation will maximize the impact of both. Understanding the physics of the TeV scale will have an important impact on cosmology and other fields, as well as give timely guidance regarding future facilities. The sooner the ILC can be brought into operation, the sooner these benefits can be exploited. Optimal use of the capabilities of both machines will greatly improve our knowledge of the fundamental nature of matter, energy, space and time.

We urge the international high energy physics community and the governments of all the countries involved to strive to make the ILC a reality in the coming decade.

See the full report of the LHC/ILC Study Group at http://arxiv.org/abs/hep-ph/0410364

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May 16, 2005