

# **THE FUTURE OF PARTICLE PHYSICS: THE CASE FOR BUILDING ANOTHER HUGE PARTICLE ACCELERATOR**

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One might ask why we are spending so much effort designing and laying the groundwork for building yet another ambitious particle accelerator, especially considering that the Large Hadron Collider at CERN will soon produce collisions in the same energy regime.

To put my answer into perspective, we need to appreciate where the field of particle physics has come over the past few decades and what the future holds. I like to characterize particle physics as a field that has grown out of what in earlier days might have been thought of as an “observational science.” That is, we would build a new particle accelerator every few years in a new energy regime and then be more or less guaranteed that it would lead to new exciting and important discoveries.

As the field has matured, we now understand much more about the underlying physics of elementary particles and our questions have become much better focussed. You might say the field has now become an “inquiry based science.” We no longer build new instruments just to open a new frontier for observations, but rather, we articulate the key scientific questions we want to answer and then build instruments that are directed toward answering those questions.

Some of types of questions that are now driving our investigations, both theoretically and experimentally, include the following:

- Are there undiscovered principles of nature, like new symmetries or, new physical laws?
- How can we solve the mystery of dark energy?
- Are there extra dimensions of space?
- Do all the forces become one?
- Why are there so many kinds of particles?
- What is dark matter and how can we make it in the laboratory?
- What are neutrinos telling us?
- How did the universe come to be?
- What happened to the antimatter?

This particular set of questions comes from a nice little popularization of particle physics called “the Quantum Universe.” Although this is not a unique set of questions, and some of my colleagues might make a slightly different list, it represents pretty well the types of questions we must answer to move our field forward. Interestingly, having

such a list of questions helps us to focus on just what experimental tools we should develop.

To really understand the answers to such difficult and fundamental questions requires both developing theories to test and making complementary experimental measurements. Most of these questions probably won't have simple answers, but instead will require new ideas and further experiments to understand them. What we learn by probing such questions often leads us to new sets of questions and that is how physics and our understanding of nature evolve. In an inquiry based approach to science, the questions guide and open up new directions for our research.

In order to experimentally address the particular questions I have posed, we are led in three complementary directions: In addition, there also are special experiments aimed at one or more particular issue and these can be as or even more important. But, today I am concentrating on the main directions of our research, those that require large investments in experimental facilities..

The three key areas of research that broadly define our field are the following:

- **Neutrinos.** Neutrinos enable us to study a variety of questions through using a probe that interacts by the weak interactions. This science is bringing particle physics and astrophysics closer together. For example, one of the most fundamental questions in astrophysics is what is the dark matter? That question may well have its answer in new particle physics, in fact the leading candidate is supersymmetry.
- **High Energy Proton-Proton Colliders:** The LHC at CERN is our next large particle accelerator, and it promises to open up a new frontier at the TeV scale. We expect many of the phenomena on our list will reveal themselves in this energy regime. The LHC should immediately shed light on the question of the origin of mass and can very likely unveil supersymmetric particles, if they exist.
- **High Energy Electron-Positron Collider:** The International Linear Collider, a proposed global project, is the third probe and it will enable doing precision measurements at this new energy frontier. It could make discoveries not uncovered by the LHC because of the extra features and cleanliness of an electron-positron collisions. At the same time, it will be able to do precision measurements to follow-up and reveal the underlying physics for the phenomena that is seen at the LHC.

In this short presentation, I will only discuss the last of these probes, by briefly motivating the parameters of the machine, and briefly introducing our present concept for such a machine.

## ELECTRON POSITRON COLLISIONS

Protons are complex objects made up of quarks and “gluons” (the strong forces that hold it together), while electrons and positrons are simple point-like particles. As a consequence, these two probes present very different issues, in terms of technically building such a particle accelerator and in what they bring to the science. A proton can

more easily be accelerated to high energy, but they are more complex objects when they make collisions. The combination of the two probes provides a complementary way of approaching the science. The combination of results from proton-proton and electron-positron collisions has been at the core of the advances of particle physics over the past forty years.

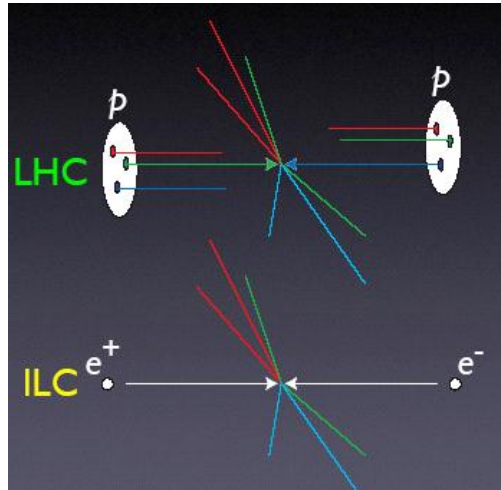


Figure 1: The figure illustrates the characteristic differences between  $e^+e^-$  and  $pp$  collisions.

For the case of a proton, e.g. at LHC, a collision occurs when a quark (or gluon) from one proton collides with a quark (or gluon) from the other proton. The colliding particles, or constituents, carry an unknown fraction of the total momentum carried by the proton and only a fraction of the center-of-mass energy of the protons goes into the collision. Experiments measure the outgoing products from the collisions and study the physics statistically, since the kinematics or even the colliding particles are not known for each collision. In addition, most collisions are diffractive, while the interesting physics usually involves collisions having large transverse momentum. In general, while studying proton-proton collisions can be a very effective way of exploring a new energy regime, it is difficult to isolate new phenomena or to make precision measurements.

In contrast, for electrons and positrons the collisions are between elementary point-like objects, having well-defined energy and angular momentum. In each collision, the full center-of-mass energy is used, and particles are more or less produced democratically, meaning that the interesting physics is not buried as rare events in a large background. Finally, depending on the capabilities of the detectors, the events can be fully reconstructed for every collision.

## THE INTERNATIONAL LINEAR COLLIDER

The international high energy physics community has studied the range of physics goals for a linear collider and have agreed on the key parameters.

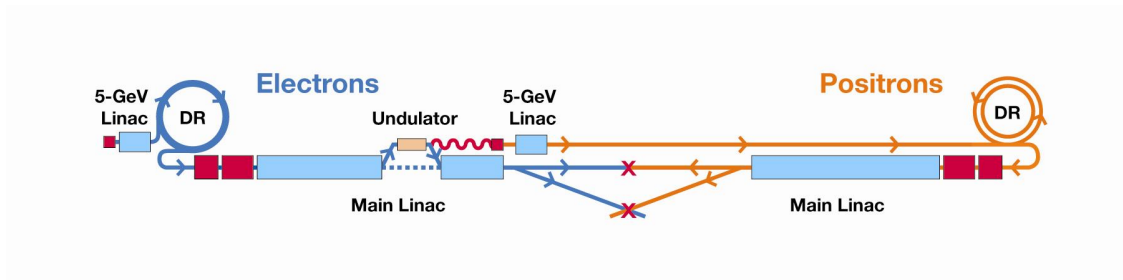


Figure 3: Conceptual Layout of the International Linear Collider.

Some of the main parameters include:

- Ecm adjustable from 200 – 500 GeV
- Luminosity  $\rightarrow \int L dt = 500 \text{ fb}^{-1}$  in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

and

- The machine must be upgradeable to 1 TeV

To reach these goals, vigorous R&D was pursued during the 1990s on two different technical approaches, one based on a room temperature copper structures and the other on superconducting niobium cavities. A couple of years ago, the crucial decision to pursue the design for the linear collider based on superconducting rf technology was agreed upon.

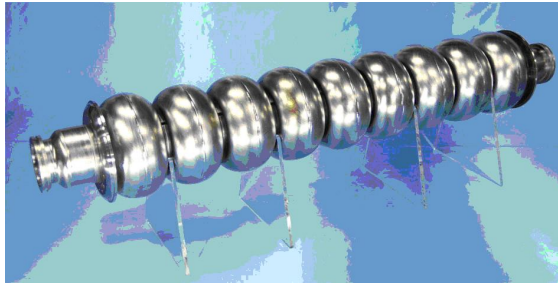


Figure 2: Niobium 9 cell 1 meter long superconducting cavity

An international team of accelerator physicists is now engaged in doing a detailed design of such a machine, which will be about 40 km in length, be mounted deep underground and will be built by a global collaboration. A general configuration for such a machine has now been agreed upon and documented, and we are in the midst of the process of doing a reference or conceptual design to be completed early next year. Once that is complete, we will be ready to do a detailed engineering design, with a goal to be ready for approval and construction in about 2010, when first results from LHC should be available. Assuming the science is as exciting as we expect, we then will go to our governments world-wide to garner the financial support to construct such a machine with a time-scale for realizing such a machine of about 2020.

One interesting aspect of this initiative is that it is not being developed under the auspices of any existing laboratory or country. Rather, it is a creature of the international physics community and the present organization is totally international. All design concepts and decisions are being decided internationally with the idea that all partners will take ownership of the engineering design and of the R&D program needed to support the design.

What will be the next step? Clearly international governance will have to be setup and the first steps have been taken. The major funding agencies internationally have come together as an informal group, Funding Agencies for the Linear Collider (FALC), chaired by Roberto Petronzio (INFN President). FALC is dealing with questions like how to develop an international governance, how to determine the siting, and finally, how the International Linear Collider will fit into the broader program in particle physics.

I would like to end by remarking that this whole futuristic and ambitious endeavour I have been speaking about had its origins here in Italy. Bruno Touschek built the first successful electron-positron collider at Frascati, Italy (1960) and his machines eventually went all the way up to 3 GeV. Unfortunately he was very unlucky, because that is barely below the energy where great discoveries were made at SLAC a few years later..

I am very happy and honoured to be here today with my beautiful wife, as well as with my colleague and good friend Shelly Glashow and his wife Joan to receive a "Laurea ad Honorem in Physics," especially from this very famous and historic University.