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ILC IN 2008*

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The status of the ILC global effort is reviewed starting from the physics motivations and describing the present strategy to build such a machine and its associated detectors. Then assuming that the first significant results from LHC will soon become available, this presentation assumes four different scenarios and discuss the implications for ILC.

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1. Introduction

This paper will start by an introduction on our expectations on physics issues and why one expects an ILC to provide crucial answers. Then I will indicate what are the properties of ILC, what has been done so far to make progress towards building this machine and its associated detectors and what remains in front of us to achieve this task. Finally, I will describe a few scenarios which we may encounter at the start of LHC and how they can be dealt with by ILC.

1.1. The Higgs sector

There is a common view concerning the relevance of the Terascale energy for providing a decisive insight on fundamental mechanisms governing our universe. From what has been learned at present and past colliders (LEP/SLC and Tevatron) one expects that there should be a least a light Higgs detectable at LHC. This discovery will be a first and essential step to confirm our views on the origin of mass. Higgs discovery at LHC will be great but only a first step in our understanding of an entirely new sector. The Standard Model (SM) is an *ad hoc* phenomenology where the Higgs mechanism is "put by hand" but does not provide any understanding of the origin of this essential mechanism. Many questions need to be answered:

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- Is this a scalar?
- Is it SM or minimal supersymmetric SM (MSSM)?
- Or a Pseudo Goldstone boson residual of some broken hidden symmetry (Little Higgs)?
- Or a composite particle as in several extensions of the SM (*e.g.* AdS/CFT holographic model)?
- Does it mix with other scalars predicted in extra-dimensions (radion)?
- Does it conserve CP?
- Is it consistent with the theory at the quantum level ($M_h^{\mathrm{direct}} = M_h^{\mathrm{indirect}}$)?
- ...

One could establish the origin of the Higgs by directly discovering new particles at LHC or by indirectly observing significant deviations in the various very precise observations allowed by the clean environment provided by ILC. In particular by measuring very precisely the decay modes of the Higgs bosons at ILC it should be possible to establish its true nature and the underlying mechanisms, SUSY or extra-dimensions, at work. A fascinating possibility, even challenging at ILC, will be to observe matter–antimatter asymmetry in the Higgs decays which would open an entirely new domain. Therefore discovering the Higgs could be as opening a Pandora box and revealing obscure secrets of Nature. Therefore measuring precisely the Higgs properties with ILC may turn out as being the most exciting part of the Terascale explorations ...

1.2. The top sector

Generally speaking the top quark is likely to play a very specific role as being the heaviest fermion of the theory with a mass apparently related to the electroweak (EW) scale. Hierarchy of fermion masses, comparable in range to the EW/Planck hierarchy, remains a mystery. In the Randall Sundrum (RS) scheme one can find a common explanation for these hierarchies implying important effects in the top EW couplings. At ILC one will be able to produce about 10^6 top pairs which, statistically speaking, means reaching the per mill level on the cross-section and the polarization asymmetry A_{LR}. This is only true if systematical effects can be handled at this level (background subtraction, control on beam polarisation). This allows to test new physics with extremely good sensitivity as will be shown on some specific example (RS). LHC will certainly produce a much larger sample of top quarks but the production mechanism is dominated by the QCD processes while ILC will do it through EW currents (γ/Z). One may argue that top decays happen through EW process and could also reveal the same type of effects but recall that top decays dominantly through charged currents and also at an energy scale well below ILC energy. Single top production at LHC will be abundant (several 100 pb) and will also allow testing the W exchange process. Complementarity between the two colliders is therefore rather obvious.

1.3. What about SUSY?

There are good hints in favour of SUSY:

- It predicts $M_h \sim 100$ GeV, unification of forces at GUT, interprets the $(g-2)_\mu$ experimental discrepancy.
- It provides candidates for dark matter (DM).
- It is calculable, aesthetically attractive.

On this last point, scientific scepticism should be maintained. We are used to the SM but recall that it took quite some time to reach this "funny" $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ but successful structure. We do not yet understand the EW symmetry breaking (EWSB) aspect (as we do not yet really understand the supersymmetry breaking aspect). Quoting (in short) G. 't Hooft: Salam's picture of the natural world was that it should be described by physical laws that are aesthetically pleasing. He was enchanted by supersymmetry, supergravity, superspace and superstring theory. These theories had to be true just because they are beautiful. Indeed, correct theories are beautiful theories, in general. But turning this around very often does not work. It would have been perceived as "beautiful" when matter was made of just four elements, "water", "air", "earth" and "fire". This was the beauty that was searched for by the primitive scientists, yet the real truth would turn out to be more beautiful in its own, more complicated ways. This is a lesson that one should always keep in mind.

2. The ILC project

2.1. Energy and luminosity of ILC

- The energy scale, 500 GeV in the first phase, is set by Zhh production which, like Zh, is maximal near threshold.

- The need for high luminosity $\mathcal{L}$ (>100 LEP2) is set by the low cross-sections for these channels (~ 500 fb^{-1} collected in the first 4 years) and also allows to produce $\sim 10^5$ hZ or 10^6 top pairs.
- It also allows to cope with "difficult" Higgs scenarios (NMSSM, CPV, compositeness) where final states are complex and/or couplings are reduced.
- ILC is very robust ($\gg$ LEP2) in that respect.
- The detector properties are also determined by these challenging channels: resolution on jets, $b/\tau/c$ tagging.
- More speculative are the new physics scales which will be revealed by LHC but we know that ILC with high $\mathcal{L}$ and with electron polarisation $P_{e^-} > 80\%$ can explore indirectly physics well beyond LHC (Z', KK excitations).
- This is only true if errors from $\mathcal{L}$, P and E, and from theory are kept under control.
- Therefore although providing a clean environment ILC has to face very challenging goals to fully take advantage of its potential.

Options and their timing will be determined by our findings:

- An upgrade to 1 TeV.
- Polarized positrons $P_{e^+} \sim 60\%$.
- GigaZ ($10^9 Z$) which needs polarized positrons (Blondel scheme).
- e^-e^- easy.
- $\gamma\gamma$ and γe not easy.

2.2. International context

High-Energy Physics (HEP) resources are insufficient to afford independent regional initiatives on colliders even at the level of R&D. For the first time in our history the big labs through ICFA agreed to converge on one technology, the cold technology developed in Europe for the TESLA project. CLIC technology was not retained as not mature but goes on pushing for its R&D and intends to present a CDR in 2010. An XFEL will be built in DESY which highly comforts this choice with multiple synergies which can be anticipated, *e.g.* benefits from industrialisation studies for the main components of the LINAC. Two international organisations were set up:

- The World-Wide-Study (1 co-chair/region) for Physics+Detectors.
- The Global Design Effort for the Machine under B. Barish with oversight by ILCSC and ICFA which are international bodies including the major lab directors. The financial support and follow up by funding bodies goes through FALC (representatives of funding agencies).

An international recognition of the worldwide consensus on ILC happened in 2004 through OECD. Cf. the Science, Technology and Innovation for the 21st Century Meeting of the OECD Committee for Scientific and Technological Policy at Ministerial Level, 29–30 January 2004 — Final Communique. They noted the worldwide consensus of the scientific community, which has chosen an electron–positron linear collider as the next accelerator-based facility to complement and expand on the discoveries that are likely to emerge from the LHC currently being built at CERN. They agreed that the planning and implementation of such a large, multi-year project should be carried out on a global basis, and should involve consultations among not just scientists, but also representatives of science funding agencies from interested countries. Accordingly, Ministers endorsed the statement prepared by the OECD Global Science Forum Consultative Group on High-Energy Physics: A roadmap that identifies four interdependent priorities for global HEP:

- The exploitation of current frontier facilities until contribution of these machines is surpassed.
- Completion and full exploitation of the Large Hadron Collider at CERN.
- Preparing for the development of a next-generation e^+e^- collider.

2.3. The machine

The key aspects are low emittance provided by the damping ring and which needs to be conserved during acceleration in the supraconductive (SC) LINAC (80% of the cost). Accelerating cavities need to reach 35 MV/m with loss low to minimize power requirements. Beam delivery is also a delicate part given the very small tolerances allowed by a nanometric (vertically) beam. A major challenge is to reach $\mathcal{L} = 2 \times 10^{34}$ cm^{-2}/s which is 4 orders of magnitude better than with SLC, the first prototype for such a collider. The following formula can be given for the effective luminosity:

$$\mathcal{L} \sim \eta \frac{P_{\text{electrical}}}{E_{\text{CM}}} \sqrt{\frac{\delta_E}{\epsilon_{n,y}}} H_D \,, \tag{1}$$

where $P_{\text{electrical}}$ is the total electrical power, η is the conversion factor (optimal with supraconductivity), ϵ the emittance, δ is the beam energy spread and H is a factor close to 1 with ILC.

Note that $\mathcal{L}$ must grows like E^2 cm to compensate for the drop of cross-sections with energy meaning that a factor 100 is to be found on δ/ϵ to operate at 3 TeV. CLIC allows for an increase ~ 10 on δ and assumes a decrease of 2 on ϵ which remains to be proven. The table shows a comparison of parameters between the two machines. Experimental conditions are more difficult for CLIC which has 0.5 ns between bunch crossing instead of 300 ns for ILC and since coherent pair background increases fast with E cm.

		CLIC	ILC	NLC
E_{cms}	[TeV]	3.0	0.5	0.5
f_{rep}	[Hz]	50	5	120
N	$[10^9]$	3.7	20	7.5
ϵ_y	[nrn]	20	40	40
$\mathcal{L}_{\text{total}}$	10^{34} cm^{2}s^{-1}	5.9	2.0	2.0
$\mathcal{L}_{0.01}$	10^{34} cm^{2}s^{-1}	2.0	1.45	1.28
n_γ		2.2	1.30	1.26
$\Delta E/E$		0.29	0.024	0.046

ILC is an advanced project given that it uses the technology developed in industry for the free electron laser linac built at DESY. This project benefits from the experience of SLC at SLAC and from test facilities, TTF at DESY and ATF at KEK. There are very active ongoing R&D, the main challenge being on the uniformity of the gradient performances which needs to be improved with respect to the XFEL project. SC test stations are under construction at KeK, FNAL. ATF2 is an international project to study nanometric beams (stability, metrology).

For economical reasons ILC has only one interaction region. For scientific reasons there will be two detectors with a "push pull" scheme under investigation. Another important question is: how to raise the energy up to 1 TeV. The arrangement of the machine (bending magnets, DR) is conceived to minimize disruption. The 'empty tunnel' scenario has not been retained and therefore civil engineering is required to install the additional cavities needed. A cost evaluation has been released in 2007 which is expressed in ILC units (= 1 in 2007):

$$\begin{aligned} & 4.8 \text{ B ILC Units Shared}\,, \\ + \quad & 1.82 \text{ B ILC Units Site Specific}\,, \\ + \quad & 14.1 \text{ K person-years}\,. \end{aligned}$$

Regionally there are various ways to translate this amount taking into account inflation and contingencies. This evaluation has been recognized as realistic and conservative by an international panel chaired by L. Evans. Note finally, as will be discussed, that the two detectors come in addition for a total of about 1 B with the same convention. There is obviously room for savings, *e.g.*, on tunnels (site dependent), cooling power, *etc.* This is under vigorous study.

3. Experimental program at ILC

3.1. The detectors

Why are ILC detectors non trivial given the clean experimental environment (as compared to LHC) and why cannot we simply design a LEP/SLC type detector? Going from LEP/SLC to ILC the momentum resolution dp/p^2 needs to be improved by 10, jet resolution by 2, multijet topologies (6 for top pairs and Zhh) require full angular coverage to keep enough efficiency, hermeticity is needed down to very small angles to search for SUSY particles, *etc.* Fortunately one benefits from the existing CMS magnet which allows operating at high field. Recent R&D on tracking give great improvements on tracking accuracy (a factor 5 for the TPC with respect to LEP detectors), high granularity calorimetry becomes feasible with integrated electronics. Thin vertex detectors can be used at ILC with however some challenges due to backgrounds near the beam pipe which illustrates the need to watch carefully for Machine Detector Interface (MDI) aspects very specific to ILC. A vast R&D worldwide effort has been launched using test beams all over the world. International and regional review panels monitor this effort. One can illustrate the advantages of an improved detector with a few examples. The WW/ZZ separation needed to analyse the important process $ee \to WW\nu\nu$ is improved at ILC compared to the LEP type jet resolution. The gain in momentum resolution for the recoil mass reconstruction in Zh with Z decaying into muons is shown in Fig. 1. Note also that the recoil mass method allows observing the Higgs boson without any hypothesis on its decay mode. Last plot corresponds to a LEP type momentum resolution. Similarly one can tremendously improve on LEP and even on SLC for flavour tagging using a reduced radius and very thin detectors with $\sim 0.1\%$ X/plane. This allows for efficient charm and tau lepton tagging (see Fig. 2).

No hardware trigger is needed at ILC. All events are recorded and selected by software between bunch trains (1 ms duration every 200 ms). This time structure allows power pulsing of the read out electronics reducing heat dissipation problems.

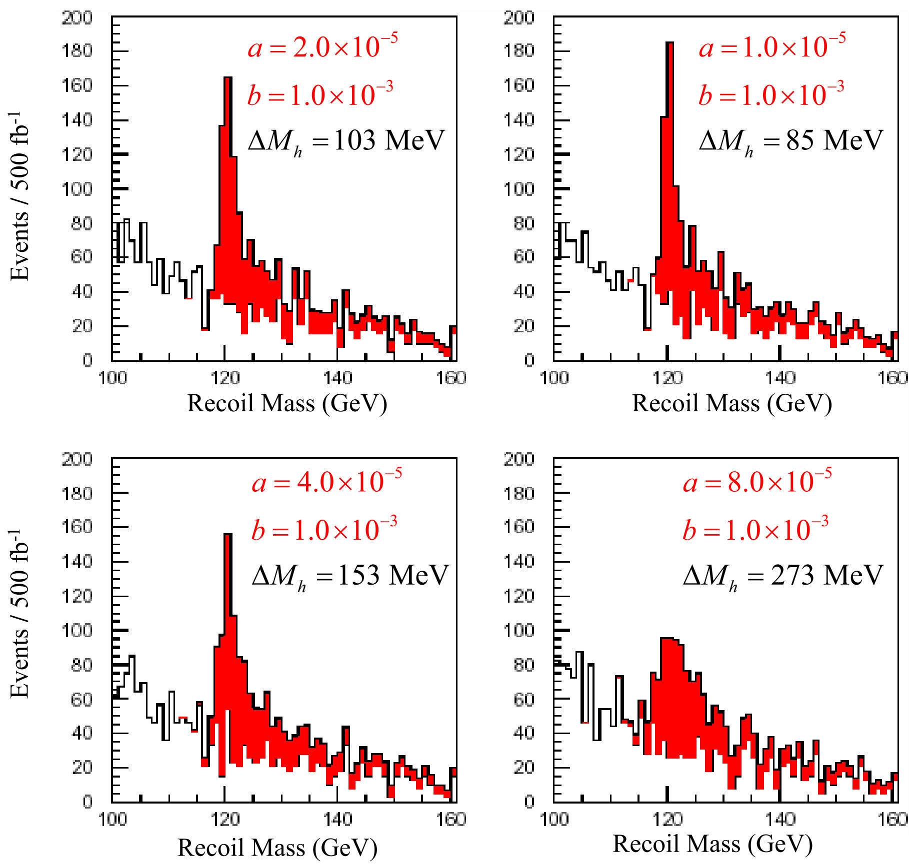

Fig. 1. Recoil mass reconstruction.

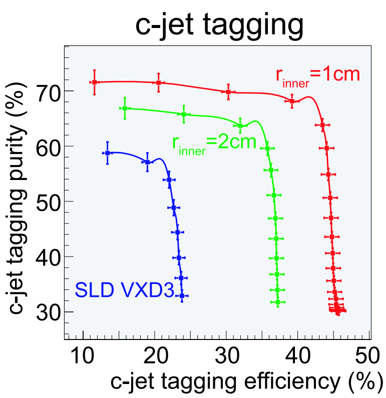

Fig. 2. c-jet tagging efficiencies.

3.2. The concepts

To fully understand the physics performances and to start a realistic study of an ILC detector, four concepts were proposed: GLD, LDC, SiD and the 4th concept. The first three follow the paradigm developed for LEP/SD which uses the so called PFLOW philosophy to reconstruct the jets by separating individually the charged and neutral particles. This approach needs very high granularity to avoid overlaps between particles in the calorimeter. To visualize the issue one can just look the Zh event in four jets. Another approach, proposed by the so-called 4th concept, reconstructs the jets (with the exception of the soft charged tracks swept away by the magnetic field) by a calorimetric approach. The trick is to read out the calorimeter deposits from different fibres which react differently to the electromagnetic and to the hadronic component of this deposit. Present results indicate that the PFLOW method provides adequate energy resolution, $\Delta E \sim 3$ GeV, for jet energies up to 250 GeV which seems sufficient for multijet physics at an ILC. The concepts are presently trying to optimize their parameters to reach the required performances at reasonable cost (typically 0.5 B ILC unit/detector). The driving costs come from the solenoid and from the calorimeters. Final realistic proof of this preliminary estimate will await for the results of the various ongoing R&D for the detector components under consideration. International collaborations (CALICE, LC-TPC, SILC, *etc.*) are operating on CERN, DESY, FNAL and KeK test beams with relatively large set ups. CALICE, for instance, is a collaboration of ~ 50 labs with 200 physicists and engineers.

3.3. The ILC roadmap

The first phase of the Machine and Detector+Physics efforts has culminated with the publication in 2007 of a Reference Design Report in 4 volumes which contained a detailed discussion of the various design issues concerning ILC with preliminary costing and a thorough discussion about the physics goals. This report has 1800 signatures from contributors in Asia (476), Europe (777) and North America (544), see Ref. [1]. The next step is to move from a conceptual design to a technical design and to start investigating governance and site aspects which would allow ILC to be ready for a decision of approval by 2010. This roadmap implies ambitious R&D goals and solid financial support. The recent financial crisis affecting the US and UK forced some revision on this planning which now will slip till 2012 with, however a first milestone in 2010 where one expects an improved costing estimate and results on the most critical R&D. It is also fair to add that in Japan ILC is part of the KeK roadmap at the horizon 2012 while in Europe ILC is supported by EU as one of the 35 major projects for the European roadmap and is already receiving large support in FP7. For the Detectors a new organization has been started under a Research Director, Sakue Yamada. A call for Letter of Intentions has been issued by ILCSC due by end of March 2009 to validate detector concepts and their associated teams in view of producing a full technical document in 2012. A peer review committee has been appointed to examine these letters. Three teams have expressed their intention to participate to this effort.

In conclusion, in spite of some serious setbacks in US and UK, the worldwide determination to move on towards a full project remains solid and there is a strong determination both on the Machine and Detector side to get ready for the decisions which should follow from a successful LHC start. From now on, I will attempt some guesswork on what type of scenario we could encounter when a significant luminosity has been collected and analysed at LHC and the consequences for ILC.

4. Possible scenarios in 2010's

After LHC first results, those from Tevatron and non-accelerator various searches, we can expect, at the beginning of the next decade, the following scenarios:

A: No signal with ~ 30 fb^{-1} analyzed at LHC.

B: A Higgs found with a mass compatible with SM.

C: A Higgs found with a mass incompatible with SM and MSSM.

D: A Higgs has been found with non SM signals.

In the following we will ask ourselves how can ILC at 500 GeV contribute to scenarios A, B, C, D?

4.1. Scenario A

Recall that in this scenario there is no signal observed at LHC with ~ 30 fb^{-1}. We know that, within the SM, LHC should have observed a Higgs signal. Higgs particles may elude LHC searches in non minimal scenarios where SM cross-sections are reduced by a factor 3–5. ILC then provides the best possible detection for Higgs particles which can accommodate any non minimal scenario (NMSSM, CPV *etc.*) with reduced ZZh couplings. Recall also that LEP2 has not excluded such scenarios for $M_h < 100$ GeV. On the other hand, one cannot arbitrarily reduce the ZZh coupling since we need this coupling to regulate $W_{\rm L}W_{\rm L}$ in an EW theory. Non-minimal scenarios can decouple certain Higgs states but there are so-called sum rules which guarantee that some states should be visible. Therefore a Higgs discovery cannot escape to ILC. The excellent ratio signal/background, S/B, allows a reduction in cross-section by two orders of magnitude for discovery in the hZ channel with h dominantly decaying into b quarks, illustrating the robustness of ILC searches. One can also start from the hZ final state but this time make no assumption on the decay mode of h but instead use the leptonic decay of Z to observe a Higgs signal by reconstructing the recoil mass to Z. Although leading to a reduced cross-section this method also leads to an excellent S/B, by operating at a centre of mass energy near threshold [2].

If the absence of Higgs signal is confirmed one can envisage two possible scenarios:

- With extra dimensions there is a family of Kaluza–Klein, KK, gauge bosons which replace the Higgs boson to cancel the $W_{\rm L}W_{\rm L}$ divergences.
- In the absence of a Higgs boson $W_{\rm L}W_{\rm L}$ final states become strongly interacting (SI).

In the first scenario ILC sensitivity to Z'/KK particles [3] covers 5–20 TeV depending on the scenario as shown in Fig. 3. Below 5 TeV LHC provides the mass as an input and ILC allows to understand the origin by measuring V and A couplings precisely. In the second scenario there should be deviations due to strong interactions in $W_{\rm L}W_{\rm L}$ final states. These deviations are in general observable on quartic couplings with $WW\nu\nu$ or ZWW final states. This type of analysis requires W/Z separation which can be achieved with detectors [4] considered in ILC. It is also true that for the quartic couplings are best measured at 1 TeV which gives the needed sensitivity [5] to insure visibility. LHC can also observe these effects but this requires luminosities which will not be achieved at an early stage. If there is a ρ-type resonance then it can be observed in the reaction $e^+e^- \to WW$ and already at a 500 GeV can ILC provide a sufficient sensitivity to observe significant deviations [6] as shown on Fig. 4.

In conclusion, scenario A although very difficult politically for ILC can well be defended scientifically. In the strongly interacting scenario ILC at 1 TeV would, in some cases, be clearly superior but it will take quite some time to get the first significant answers from LHC. In the Higgsless scenarios with ρ-type resonances or KK recurrences elastically coupled to e^+e^-, ILC at 500 GeV goes beyond the mass sensitivity of LHC and with a polarized beam provides the tools to measure the vector and axial parts of these new couplings and therefore the origin of the effect. One should finally recall that precision measurements (PM) do not favour such a scenario but rather SM or MSSM.

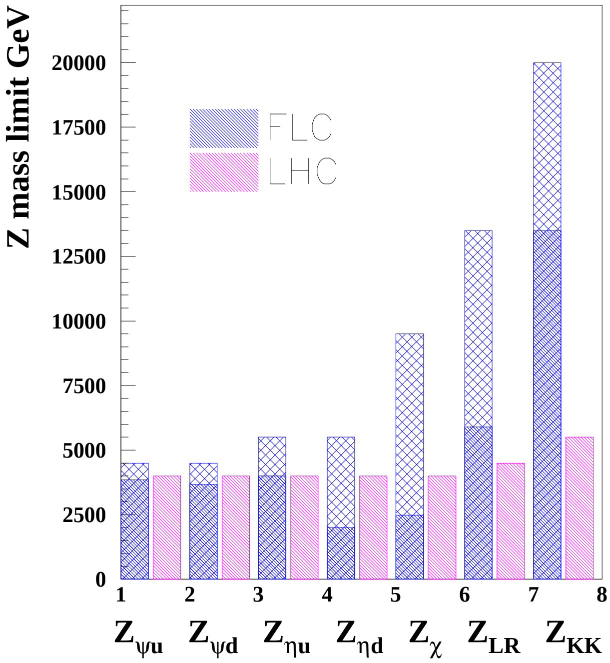

Fig. 3. Z' mass limits at ILC. Dark blue limits are from GigaZ with Z–Z' mixing.

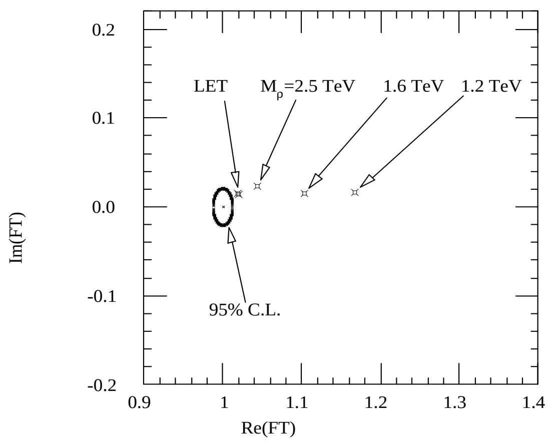

Fig. 4. ILC sensitivity on ρ-like resonances with 500 fb^{-1} at 500 GeV.

4.2. Scenario B

This scenario is sometimes called the "theorist nightmare": Nature would provide a Higgs and nothing else up to the GUT scale. There are of course many reasons to think that this will not happen some of them purely theoretical (the mass hierarchy problem, the requirement of unification between strong and electroweak forces not achieved within the SM), others based on cosmological observations. How about PM from LEP/SLC and Tevatron? If the SM remains valid up to the GUT scale, theory predicts that 140 GeV $< M_h <$ 175 GeV which is not favoured by data as can be seen in Fig. 5 (left) which combines the top mass measurements from Tevatron with the W mass measured at LEP and Tevatron. Without assuming the

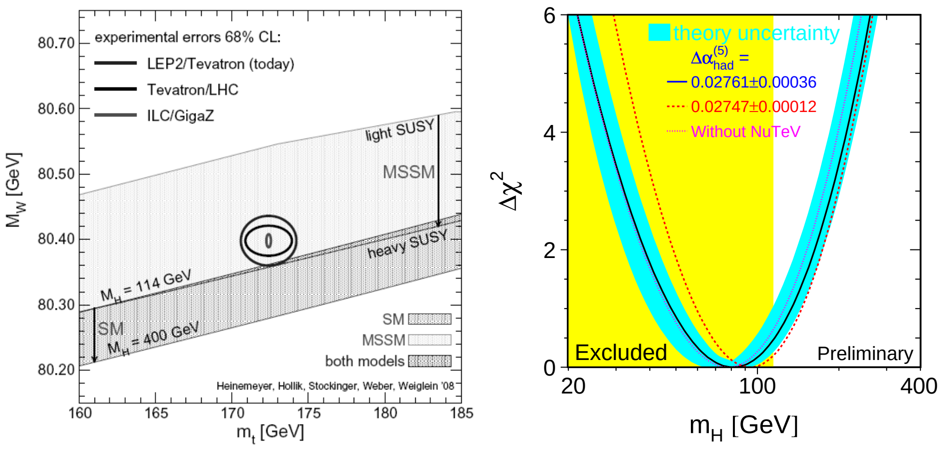

Fig. 5. Left: Higgs mass predictions *versus* top and W mass. The lighter (green) part is for MSSM and the darker (red) one for the SM [7]. Right: χ^2 dependence of the overall EW fit [8].

GUT prediction, LEP2 excludes at the 68% level the SM since from direct searches $M_h >$ 114.5 GeV, while the most probable value prefers a value of $\sim$ 60 GeV, Fig. 5 (left). While not yet significant, this effect suggests that there are extra contributions which could, within MSSM, be provided by a moderately light stop component. The Higgs mass can also be predicted by measuring $\sin^2\theta_W$ and we will discuss in scenario C the resulting predictions. LHC can discover such a SM Higgs particle with mass above 114 GeV. With limited accuracy however LHC may be unable to rule out the purely SM interpretation in the absence of new other signals. ILC has ten times more precision and a wider number of measurable channels, in particular Zhh, tth very difficult if not impossible at LHC. Fig. 6 recalls this impressive set of measurements achievable [5] at ILC.

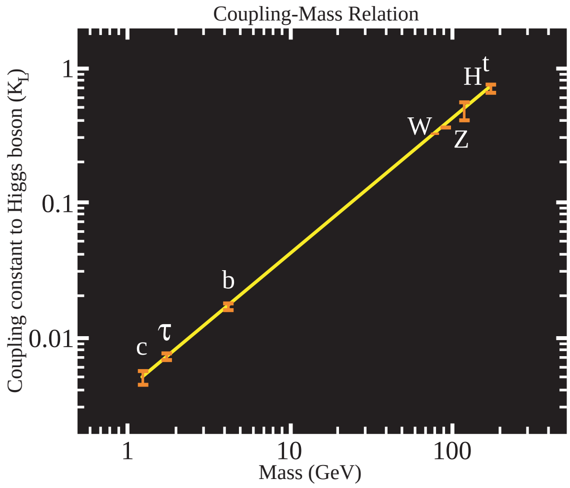

Fig. 6. Higgs couplings accuracies at ILC.

The GigaZ option, ILC running at the Z pole, would allow improving by more than one order of magnitude the accuracies reached at LEP1. It would then be possible to narrow down the indirect prediction on the Higgs mass within the SM and therefore check, at the quantum level, the overall consistency of the SM. One should establish whether:

$$M_h^{\text{direct}} = M_h^{\text{indirect}} \pm 5 \text{ GeV?}$$

Further important tests of the Higgs SM are possible with ILC:

- Test of CPV (CP violation).
- Search for invisible decays at the % level.

$\tau\tau$ decays provide the necessary observables to detect CPV violation. At LEP1 it was shown that polarisation of a τ can be efficiently measured from the hadronic decay modes. Here we need to correlate the polarisations of the two τ leptons which may cause certain problems given that the Higgs boson does not decay in its rest frame but preliminary studies indicate that these problems can be overcome [9]. Since a light Higgs boson, say below 150 GeV, couples very weakly to standard fermions it can easily receive a measurable branching ratio from any of the non standard extensions of the SM which predict light particles coupled to Higgs bosons. In several of these extensions one predicts significant, if not dominant, couplings to invisible particles (Majorons, sterile neutrinos, *etc.*). It is therefore essential to provide the highest sensitivity on the measurement on the Higgs invisible branching ratio $\mathrm{BR}_{\mathrm{inv}}$, as it carries a large discovery potential. Hence ILC extends very significantly the reach which could be achieved at LHC. In conclusion, LHC with limited accuracies on a limited set of measurements could be inconclusive for scenario B. Only ILC can ultimately tell if Higgs properties are consistent with a SM and "nothing else".

4.3. Scenario C

In this scenario a heavy Higgs would be observed and nothing else. This Higgs boson would decay into ZZ and therefore be soon discovered at LHC. Furthermore, if $M_h > 180$ GeV, SUSY would seem excluded while one would need indirect contributions from new physics to explain PM from LEP/SLC and Tevatron. In such a scenario ILC would play a very different role than for scenario B since fermionic branching ratios become negligible. The emphasis would therefore not be anymore on measuring Higgs decays but rather on measuring electroweak couplings Zff, ZWW and ZZh to detect indirectly the new physics at work. To illustrate this scenario let us assume that the underlying model has extra dimensions and more specifically let us assume a RS scheme with so-called warped extra dimension. This model allows accommodating the hierarchy problem by assuming that there is exponential damping between a Planck brane and a TeV brane. It further allows explaining the mass hierarchy observed for fermions, from neutrino masses to the top mass, by assuming different localisations of the fermions in the 5th dimension between these two branes. One assumes that the Higgs boson sits on the TeV brane, hence it's decoupling from the Planck scale. The top quark would be localized near the TeV brane while lighter fermions would come near the Planck brane. These different localisations would have some observable consequences due to the KK bosons which would interact differently with the various fermions. In particular one could expect different electroweak couplings for the heaviest quarks. In this respect it is worth recalling the intriguing discrepancy observed in the most precise determinations of $\sin^2\theta_W$ at LEP1 and SLC. For the latter one uses, with polarized electrons, the left–right asymmetry while LEP1 has the most precise determination through the forward–backward asymmetry using b quarks and there is a $\sim 3.5\sigma$ discrepancy between these two measurements. The consequences of this discrepancy are shown in Fig. 7 where one can see that the leptonic asymmetry (dominated by the SLC result) predicts a very light Higgs (comparable to the W result of Fig. 5) which is inconsistent with the b measurement [10]. The final puzzle comes from the absence of deviation observed on $R_b = \Gamma_b/\Gamma_{\mathrm{had}}$.

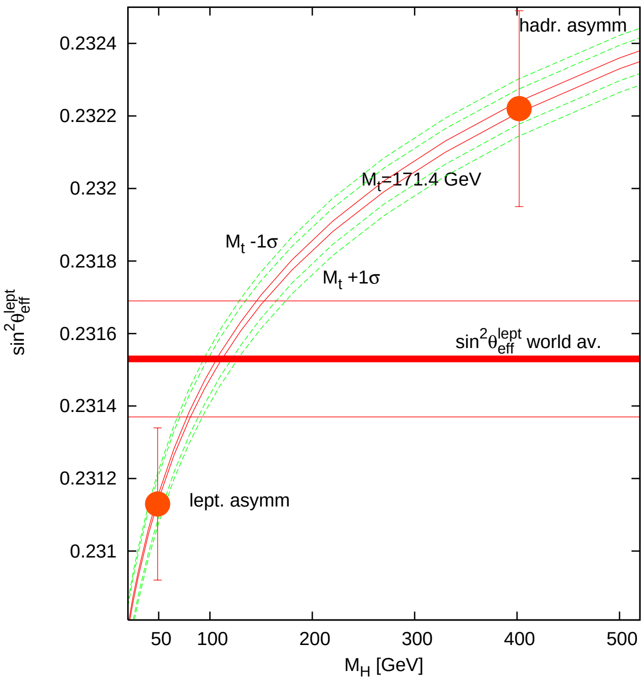

Fig. 7. $\sin^2\theta_W$ dependence with the Higgs mass. The first point comes from lepton and the second from FB asymmetry with bb.

One can reproduce [11] such features within the RS scheme assuming that there is a KK boson, Z', with mass $\sim$ 3 TeV and by adjusting the respective "positions" of the $b_{\rm R}$ and $b_{\rm L}$ quarks with respect to the TeV brane as shown in Fig. 8. Within this type of solution, very large deviations [11] are expected for top physics as shown in Fig. 9. Finally since the left right accuracy can be measured at better than a %, ILC is precise enough to detect a Z' boson with a mass up to 20 TeV, therefore covering the whole "reasonable" range of parameters for this model.

After reconciling the b asymmetry result on $\sin^2\theta_W$ with the leptonic results and M_W one still needs to explain the low Higgs mass prediction in apparent contradiction with the LEP2 limit. This in fact can be easily achieved since the RS model contains the needed ingredients to create the necessary inputs on the T and S variables to be consistent with a heavy Higgs [12].

This type of model also provides an EWSB mechanism where the Higgs boson appears as a Goldstone boson from a SI hidden sector. This is the so called strongly interacting light Higgs discussed in [13]. This scheme allows passing PM constraints but leaves significant imprints visible at LHC

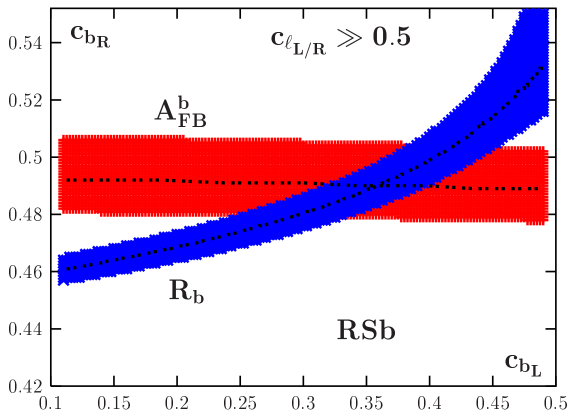

Fig. 8. Contour plots giving $b_{\rm R}$ and $b_{\rm L}$ RS parameters consistent with R_b and the FB asymmetry.

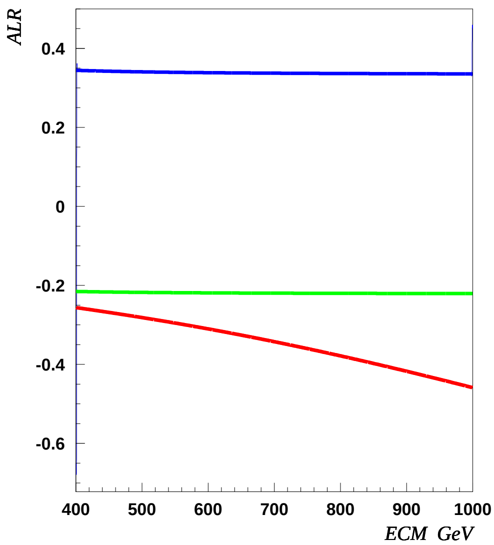

Fig. 9. $A_{\rm LR}$ for top quarks for SM (top) and RS (bottom). The middle curve is due to Z–Z' mixing.

(through KK resonances) and/or ILC through deviations of the various Higgs couplings. LHC can directly discover such resonances up to 3 TeV while the indirect reach of ILC is ~ 8 TeV.

In conclusion, above examples amply illustrate the high potential of ILC for scenario C.

4.4. Scenario D

In this scenario at least one Higgs boson would be observed with extra signals incompatible with SM interpretations. Our favourite choice at the present conference is SUSY and there are indeed several indications of light SUSY which are mainly coming from the W mass measurement combined with the top mass (see Fig. 5) and with the deviation observed on $(g-2)_\mu$ at the 3.5 σ level. In [14] a fit was performed which predicts, in particular, light staus observable at ILC as shown in Fig. 10. Although not overwhelming these indications predict a wealth of exciting results which should come out quite soon from LHC giving further informations on the reach of ILC.

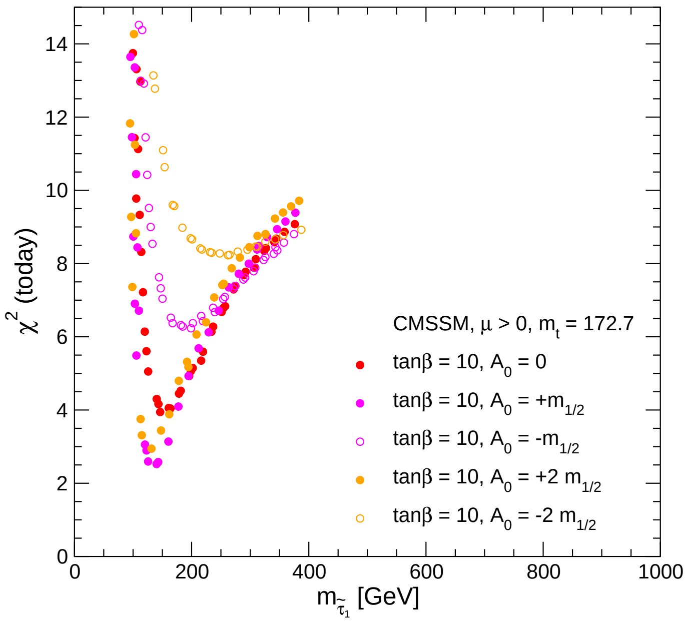

Fig. 10. χ^2 dependence of the EW fit with the stau mass for various SUSY sets.

There are, however, a few caveats which need to be recalled. The limit from LEP2 $M_h > 114.5$ GeV excludes a large fraction of SUSY parameters provoking some concerns at the theoretical level about fine tuning. Recall however that within MSSM the true mass limit is $M_h > 90$ GeV (and even much lower with CPV). There is even a slight indication [15] at LEP2 below 100 GeV as shown in Fig. 11. This indication would be consistent with MSSM if $h/A/H$ have similar masses. A complex situation may occur if $h/A/H$ are mass degenerate [16] and can mix with CPV as shown in Fig. 12. It will take ILC mass resolution and purity to disentangle this complicated scenario.

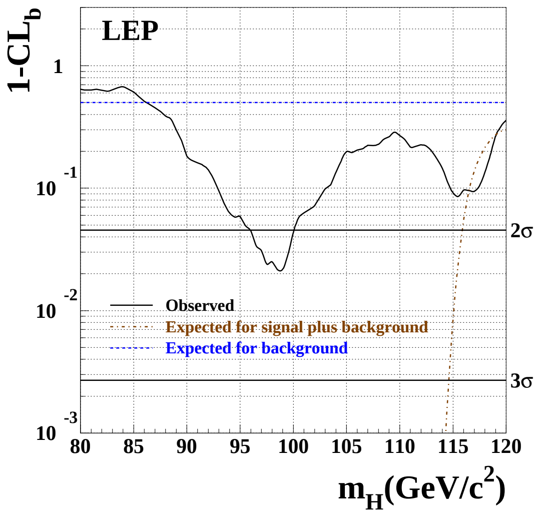

Fig. 11. Background CL dependence *versus* the Higgs mass observed at LEP2.

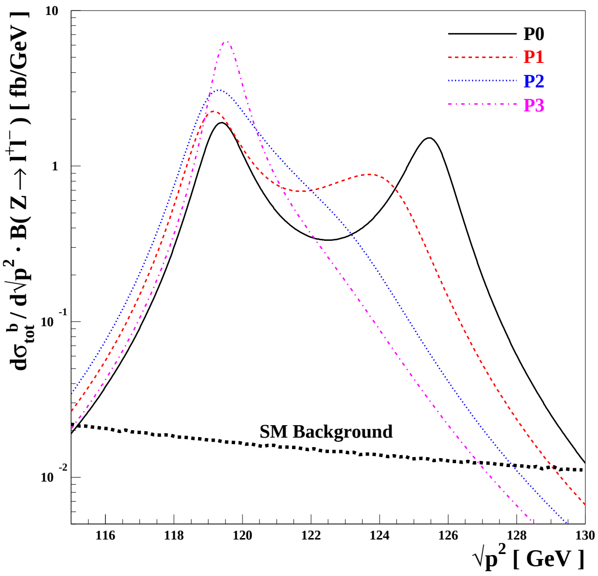

Fig. 12. $\mu\mu$ recoil mass expected at ILC with a CPV scenario where $h/A/H$ are quasi degenerate in mass.

Since ILC has excellent S/B for sleptons and gauginos it can provide, as well known, excellent and precise inputs to extract the fundamental SUSY parameters in conjunction with LHC. In particular while LHC can measure mass differences it has limited capabilities to determine absolute masses. ILC with polarization and threshold scans will offer dramatic improvements in the slepton and gaugino sectors in particular in determining the LSP mass. These features will allow reaching the accuracies needed to test the theory at the GUT scale. This could have dramatic consequences in the neutrino sector [17] within SUSY with SO(10) as displayed in Fig. 13. From light slepton masses ILC could accurately predict the mass of the Majorana neutrino conveying the see-saw mechanism and also predict the absolute mass of the neutrino.

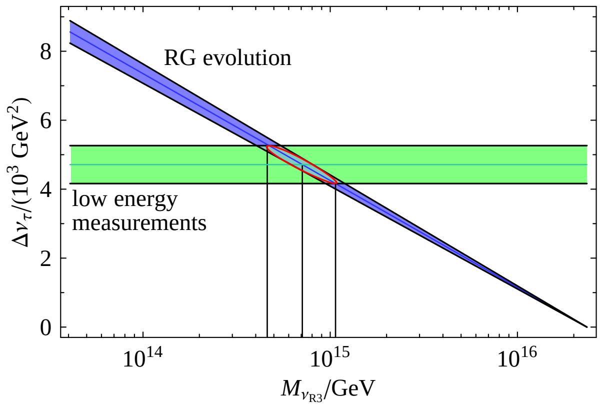

Fig. 13. Heavy (and light) neutrino mass determination using slepton accuracy measurements at ILC.

As pointed out in [18] there are some blind regions in the SUSY mass spectrum which may compromise elucidation of the so-called LHC-1 problem. This occurs primarily in mass degenerate scenarios which may occur in certain DM as discussed below. Recall also that the meaning of "mass degenerate" at LHC covers quite a large range. If one considers for instance a scenario, not unlikely, for which the lightest squark is a stop quark which would decay into $c\chi$, it would require a mass difference larger than 50 GeV between the stop mass and the neutralino mass to observe this signal. At ILC the limitation comes from the $\gamma\gamma$ background can be handled if the mass difference $\Delta m > 3$ GeV as was shown for stau decaying into $\tau\chi$ for the co-annihilation DM scenario analysed in [19]. Needless to say that such analysis relies on efficient vetoing in the forward region of the detector which has received great attention.

To illustrate these features of ILC Fig. 14 shows the quality of the S/B separation for a DM solution given in [17] (so called point D where $m_{\rm stau} =$ 217 GeV, $\Delta m = 5$ GeV). This result comes from an update [20] shown at LCWS07 and demonstrates that an accuracy of ~ 0.1 GeV is achievable on Δm which is sufficient to predict the DM content of the universe at the WMAP/Planck accuracy level (see Fig. 15).

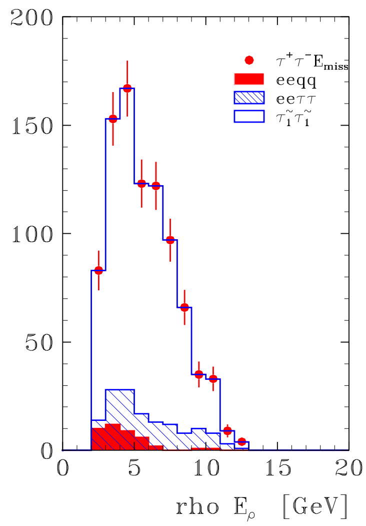

Fig. 14. ρ mass reconstruction in $\tau\tau$ events with missing energy.

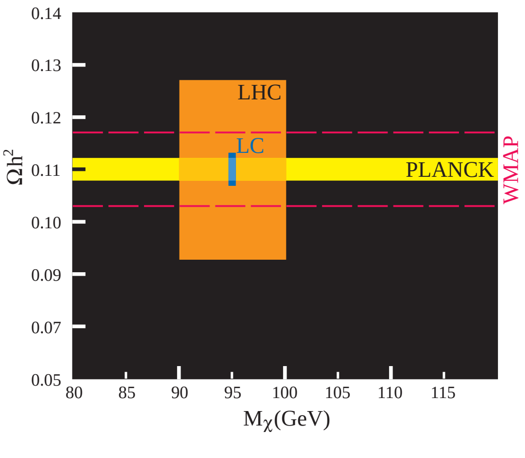

Fig. 15. ILC predictions for DM in co-annihilation scenarios compared to satellite determinations.

5. Summary

- ILC should, in some cases, complete LHC exploration of the Terascale and, in other cases, uniquely extend this exploration.
- For the Higgs sector, SM or SUSY, ILC provides a superior reach for fundamental measurements and allows a full coverage of scenarios.
- Measuring the top EW couplings at the per mille offers full exploration in several extensions of the SM.
- ILC together with LHC can fully reconstruct the underlying parameters of SUSY, allowing GUT extrapolations very promising in the leptonic sector.
- ILC allows to cover SUSY "mass degenerate" cases which are likely to occur in some DM scenarios.

It is a pleasure to thank the organizers of the Baeza meeting and in particular Paco del Aguila for inviting me to this nice meeting.

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