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Scenario for a worldwide e^+e^- collider

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Summary. — This presentation is meant to give a snapshot of the main physics arguments in favor of the construction of a TeV e^+e^- collider and to describe a possible scenario leading to a worldwide machine. Simple arguments are given concerning the machine parameters and the criteria guiding the R&D on detectors.

PACS `13.66.-a` – Lepton-lepton interactions.
PACS `14.80.-j` – Other particles (including hypothetical.

Introduction

- There is a consensus that to get adequate accuracies, *e.g.*, on the Higgs sector, we need a leptonic collider beyond LHC.
- By far the most advanced project is the TeV SC collider, called ILC, which is developed by a worldwide collaboration.
- It aims at a TDR for the end of 2012.
- CLIC for a multi-TeV collider is in an R&D phase and intends to prove its feasibility (CDR) by 2010.
- These machines are very challenging projects in comparison to LEP2/SLC.
- A muon collider is studied at FNAL.
- Even more futuristic R&D is actively performed with laser-plasma and beam-plasma acceleration.

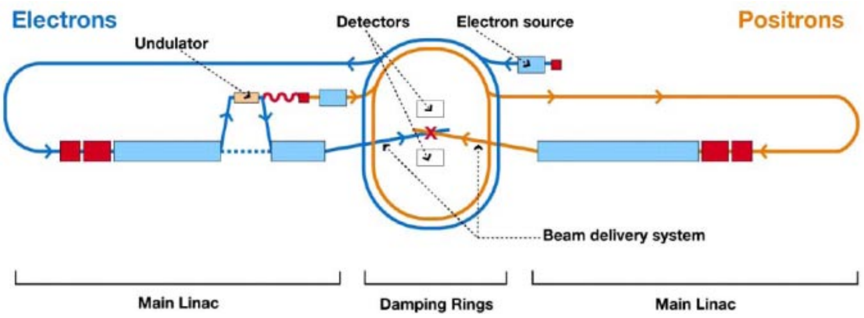

Fig. 1. – Simplified set-up of ILC (30 km long for 500 GeV).

The ILC project

- ILC has a large 5% "prototype" under construction, the DESY XFEL, and intense R&D on critical aspects in Asia, Europe and NA.
- Italy (+other Europeans like FR, Ge, SP, UK, CERN) is actively contributing to ILC through XFEL and studies in DAFNE (e-cloud, kickers).
- GDE, under B. Barish, is an international organization set by ICFA, recognized by the 3 regions which is about to produce an "almost" ready for construction project to be proposed to governments in 2012.
- ILC works with a large community $\sim$ 1000 physicists and engineers preparing detectors and furbishing solid physics arguments in favor of such a project.
- ILC and CLIC intend to start at 500 GeV.
- ILC is upgradable, with present technology, at 1 TeV.
- CLIC could reach 3 TeV but with $\sim$ constant luminosity assuming an improved emittance, $P_{\text{electric}} = 400$ MW (for the same beam energy dispersion δ).

Table I. – *Table illustrates the key parameters of ILC & CLIC compared to previous colliders. The formula* $L \sim \eta \frac{P_{\text{electric}}}{E_{CM}} \sqrt{\frac{\delta_E}{\varepsilon_{n,y}}} H_D$ *gives the luminosity* (HD $\sim$ 1) *vs. vertical emittance* ε *and energy spread* δ_E*.*

Type	LEP200	SLC100	ILC500	CLIC500
Vertical size nm	4000	700	5.7	2.3
Total P MW	65	50	216	129.4
Wall plug transf $\%\eta$			9.4	7.4
Luminosity $10^{31}\,\text{cm}^{-2}\,\text{s}^{-1}$	5	0.2	1500	1400
Interval between bunches ns	$\ggg$	$\ggg$	300	0.5
Polarisation %	No	80	> 80	> 80
Gradient MV/m	8	17	31.5	100

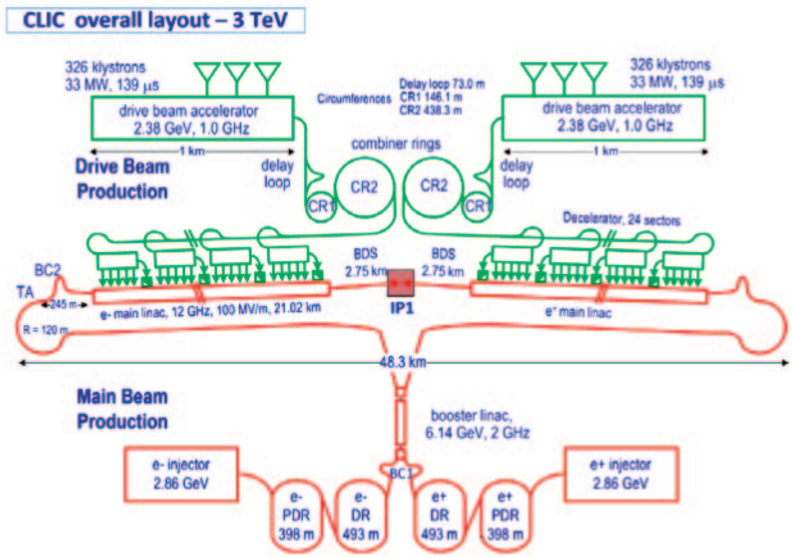

Fig. 2. – (Colour on-line) Set-up of CLIC with the auxiliary beam in green and the main beam part in red.

Physics at ILC

- Physics arguments in favor of ILC are solid.
- Precise measurements with a light Higgs as predicted within SUSY and the SM interpretation of LEP/SLC/TeVatron precision measurements (PM).
- Energy 0.5–1 TeV optimal to cover Higgs physics and presumably lightest SUSY particles.

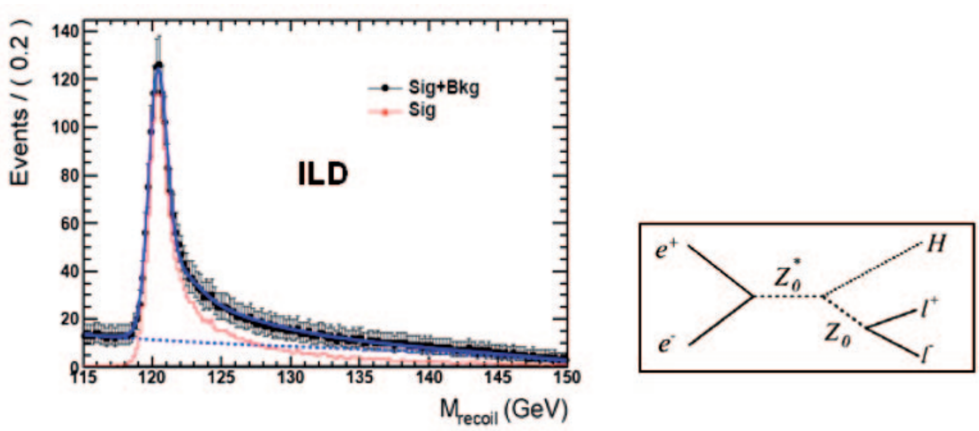

Fig. 3. – Recoil mass spectrum to muon pairs for a 120 GeV Higgs produced at 250 GeV center of mass with full simulation and reconstruction with the ILD detector.

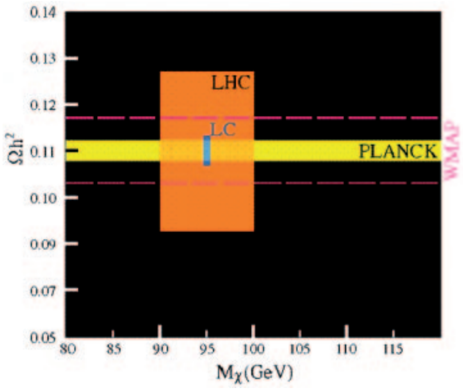

Fig. 4. – (Colour on-line) The yellow band represents the accuracy on DM expected from Planck surveyor compared to the typical outcomes of LHC and LC.

– ILC accuracy needed for the Higgs and SUSY sectors (as illustrated below).

– SC technology is well suited for this energy range but, while not strictly limited to 1 TeV cannot, with present SC materials, go well beyond.

$ee \to ZH$

– The recoil mass technique with $Z \to \mu^+\mu^-$ gives a very clean signal at $\sqrt{s} = M_H + 110\,\text{GeV}$.

– Works even if H decays into invisible or complex modes.

– ZZH coupling constant determined to 1%.

– In the SM case most BR ratios known 10 times more precisely than at LHC.

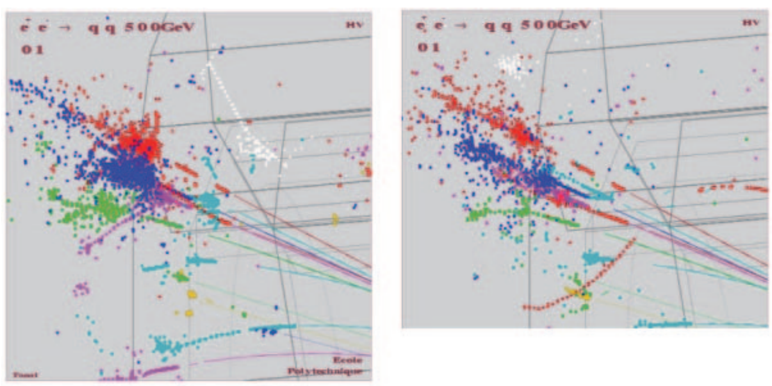

Fig. 5. – Examples of jets as seen in an Si-Fe calorimeter (left) and in a Si-W calorimeter (right).

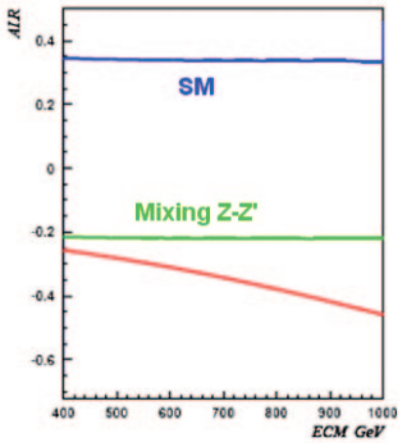

Fig. 6. – Effect on the left-right polarization asymmetry of Z-Z' mixing (green) + exchange (red) within the RS model by A. Djouadi *et al.*, *Nucl. Phys. B*, **773** (2007) 43.

Dark matter & SUSY

– With LHC + LC it is possible to reach sufficient accuracy on the predicted dark matter to match cosmological observations.

– Do they coincide?

Challenges and hopes

– Why is this simple and convincing vision facing several challenges?

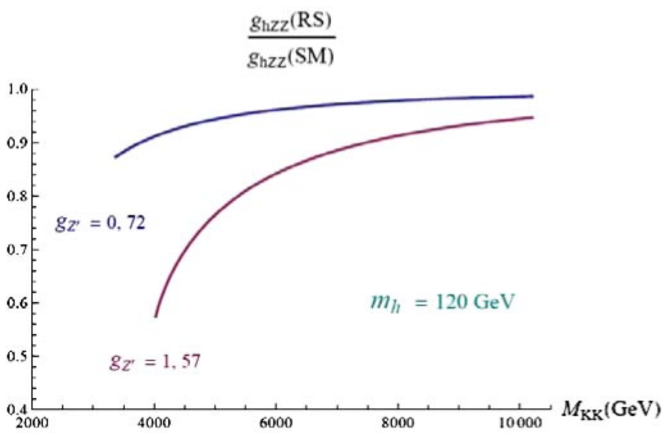

Fig. 7. – Effect on the ZH cross-section of a Z' exchange within the RS model by G. Moreau and C. Bouchart, arXiv:0909.4812.

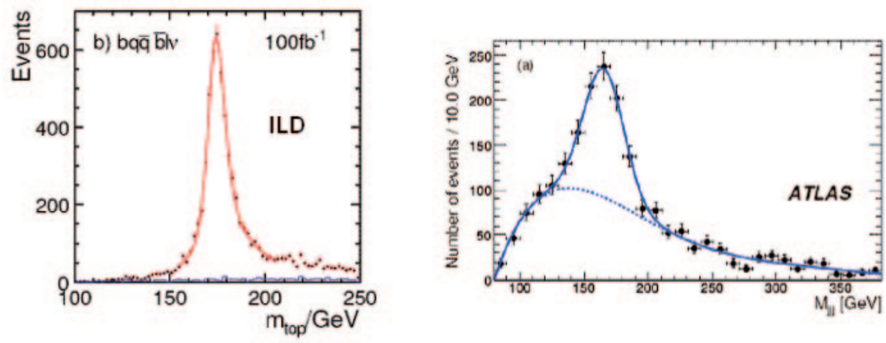

Fig. 8.

– In the US, using its own costing approach (×3–4 ∼6 B\$), DOE is judging the project too expensive and is no more proposing to build it in the US, it is however contributing substantially ∼ 35 M\$ (FNAL, JLAB, Cornell) and achieving good progress.

– In Europe CERN is heavily committed on LHC but there is an initiative to allow a “Scientific and geographical enlargement of CERN” which would facilitate an organized participation to an international project (not necessarily at CERN). CLIC-ILC Collaboration helps.

– Japan is highly committed on JPARC and super-Belle but after the Nobel shows increased motivation (lobbying at parliament, contacts with industry) to house ILC.

– *CERN boss wants to bid for linear collider* `http://www.physorg.com/news172317407.html`.

– September 16th, 2009 *CERN’s director general Rolf-Dieter Heuer will push for the linear collider, the next big experiment in particle physics after the Large Hadron*

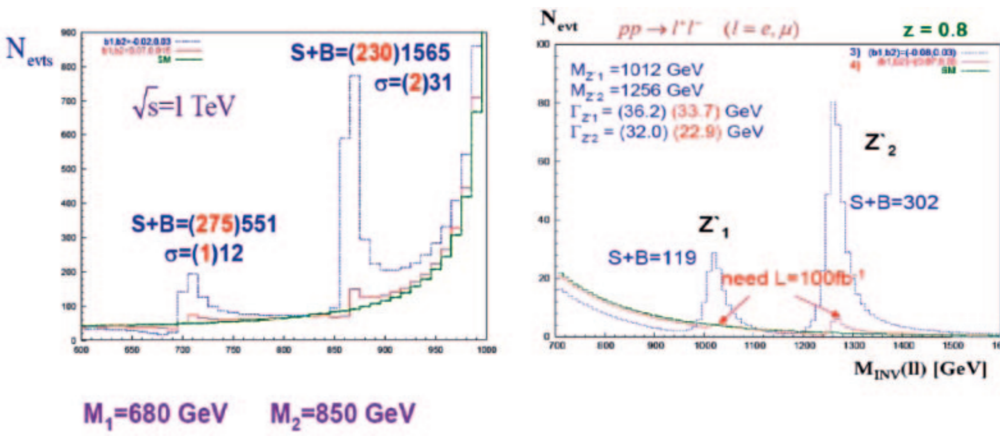

Fig. 9. – De Curtis *et al.*, shown at the CERN WS “From LHC to a future collider”, Feb. 2009.

Collider (LHC), to be built at the Geneva lab. Heuer made his call to situate the linear collider at CERN in an exclusive video interview with Physicsworld, which is being relaunched today, Wednesday 16 September.

Physics?

- Physics arguments have also been challenged.
- So far there is no compelling evidence for SUSY.
- There is no unique prediction for SUSY masses (could even escape LHC).
- There are competing scenarios without necessarily a light Higgs and even Higgsless.

Present view

- Get ready technically to propose a construction of ILC by the end of 2012.
- See what comes out from LHC (and Tevatron).
- See if there are convincing indications from these results to trigger a decision on ILC.
- If not, wait and prepare for alternate scenarios: CLIC (or μ colliders?).
- In this view, advocated by CERN DG, ILC and CLIC projects have decided to share efforts.
- Also true for Detectors where CERN has signed the 3 proposed ILC concepts.

Detectors

- They need also to be ready by the end of 2012 and well integrated to the machine (push pull issue).
- 3 Letters of Intent (1000 P+I) have been examined for validation by peer review (IDAG) during summer.
- *SiD ILD* have been validated based on PFLOW ideas.
- Important to pursue R&D on the dual readout technology proposed by the *Fourth* concept.
- Challenging detectors quite different from LEP.
- CERN has joined this effort and intends to use the same detector concepts for CLIC.
- Does it work for CLIC? Seems OK for WW/ZZ separation but watch for duty cycle effects.
- High granularity+high density (SiW).
- μ electronics integrated inside calorimeters.
- Possible with new technology+power pulsing.
- Requires R&D.

Alternate physics scenarios

- What are the alternate physics scenarios, and how can they influence our choices?
- Most of these scenarios have a hard time to pass PM.
- It seems however possible to accommodate a heavy Higgs and even an absence of Higgs.
- Examples: strongly coupled field theory (TC) dual to extra dimensions (RS), 4th generation, BESS, etc. . .
- These models provide S, T extra contributions and therefore alter the light Higgs prediction ("conspiracy").
- What could a LC observe in such scenarios?
- The Randall-Sundrum model provides an interpretation for Planck/EW and fermion masses hierarchies with *no new scale*.
- S, T constraints require extended groups and hence not only KK states but also Z' and "custodians".
- KK bosons couple preferentially to b and even more to t, most likely tR.
- AFBb at LEP1 could be interpreted within RS by Z-Z' mixing in RS.
- AFBt indication at Tevatron could be interpreted as Gkk exchange.
- Reduced ZZH coupling.
- Not a problem at ILC (but severe for LEP2).
- Could be the only signal if KK are heavy in which case ILC could be sensitive to this new physics well beyond LHC (up to $\sim 10\,\text{TeV}$).
- Plays a very peculiar role in most of these models.
- In RS tR couples preferentially to Z' through Z-Z' mixing.
- Large effect on ALRt expected from the AFBb (M'_Z up to $\sim 10\,\text{TeV}$).

Top at ILC

- LC 1 pb, LHC 1nb but with larger uncertainties.
- Very good s/b at ILC and energy conservation allows to reconstruct modes with a neutrino (cleaner signal, AFBt).
- M_t and Γ_t with $50\,\text{MeV}$ error, 0.4% on cross-section.
- Polarisation allows to separate tR and tL (extra dimensions).

Higgsless models

- Hyp: SM Higgs excluded by TeVatron+LHC.
- Truly Higgsless?
- There is the distinct possibility that a light Higgs was missed even at LEP2 if it cascades to 2 light CP-odd Higgs NMSSM.
- Would be covered by ILC irrespective of its decay modes (if narrow resonance) and with reduced cross-section.
- Without Higgs (RS, TC, BESS) several deviations expected in $ee \to WW$, ZWW, $WW\nu\nu$ better observed at CLIC.
- Very demanding in luminosity at LHC which would delay any decision to build a LC.
- Instead one could observe $\sim$ TeV resonances which could be accessible earlier.

Bess model

- In extra dimensions (and "deconstructed" versions) they require additional Z to control unitarity violation in WLWL.
- ILC could see a signal but it will require CLIC to see the whole picture.
- In some cases very large luminosity is needed both at LC and LHC.

How soon will LHC provide answers?

- Will start with reduced lumi & energy (≤ 5 TeV/beam) and with few 100 pb^{-1} not enough to discover the Higgs boson (shut down end 2011 for $\sim$ 1 year to reach 7 TeV).
- CMSSM could be explored with 200 pb^{-1} at $5+5$ TeV.
- AFBt not easy to confirm since at LHC $\bar{q}q \ll gg$.
- Heavy quarks < 500 GeV either from 4th generation of from RS are accessible.
- BESS needs $> 1\,\mathrm{fb}^{-1}$?

Summary on the HEP strategy

- Connect CLIC and ILC efforts to avoid duplication and potentially damaging competition.
- Prepare for major challenges: technical (industrialisation 16000 SC cavities), financial ($\sim$ 6 B\$), political with a worldwide machine (LHC different, $\sim$ ITER?) OCDE, ESFRI.
- ILC and CLIC projects intend to address these problems.
- Present uncertainties justify an open scenario.
- However ILC is ready to go while it will take longer to complete the CLIC project.

Conclusions

- The HEP community has developed a consistent and worldwide strategy to construct an e^+e^- LC.
- A viable project, ILC, can be presented to the governments at the end of 2012.
- A final decision (ILC/CLIC) will depend on the physics results from LHC (or Tevatron).

For references see `http://www.desy.de/conference/ecfa-lc-study.html` and related links.