

# Report from Physics and Detector Studies

Andreas S. Kronfeld  
Theoretical Physics Department  
Fermilab

U.S. NLC Collaboration Meeting  
31 May 2000

thanks to ...

Sławek Tkaczyk,  
Paul Derwent,  
Bogdan Dobrescu,  
Konstantin Matchev,  
Adam Para,  
Dave Rainwater,  
Rick Van Kooten,  
William Wester,  
G.P. Yeh,  
Sekhar Chivukula,  
& Chris Quigg

# (North) American Study

Charlie Baltay and Paul Grannis

## Working groups for physics:

---

---

** Higgs boson(s)	Howie Haber, ASK, Rick Van Kooten
** Susy sparticles	Uriel Nauenberg, Frank Paige, Jim Wells
** Alternative NP	Joanne Hewett, Sławek Tkaczyk
* Strong EWSB	Tim Barklow, Bogdan Dobrescu
* Electroweak	Bill Marciano
Top quark	Uli Baur, David Gerdes
QCD	Lynne Orr, Bruce Schumm
Simulation	Norman Graf, Adam Para, Michael Peskin

---

---

## Working groups for detectors:

---

---

Vertex detectors	Jim Brau
Tracking	John Jaros, Keith Riles
Calorimetry	Ray Frey
Muon detectors	Gene Fisk, David Koltick
Infrastructure	Marty Breidenbach, Bob Kephart

---

---

# Fermilab Study

coordinators: ASK and Sławek Tkaczyk

<http://www-lc.fnal.gov/>

December 3, 1999

Dear Fermilab Colleague:

I would like to ask you to participate in a physics study of linear  $e^+e^-$  colliders at Fermilab. . . .

The charge for the group will be to deliver a report by September 18, 2000, which should explicitly include:

1. An analysis of the capability for Higgs physics as a function of energy and luminosity. This should include measurement of Higgs boson parameters including couplings and indirect measurements of virtual effects for very massive Higgs bosons.
2. A comparison with the physics capability of the LHC experiments in some well-defined scenarios for physics beyond the standard model.

As you know, SLAC and Fermilab have begun a collaboration on the NLC design. The experience gained from the accelerator collaboration and the physics study should make it possible for the Fermilab community to develop an informed opinion on the merits of proposed accelerators.

. . .

Sincerely,

Mike Shaevitz

# Physics Questions

What violates  $CP$  and baryon number?

$$\mathcal{L}_{\text{Yukawa}} = \bar{L}_L^i \Phi_E^{ij} E_R^j + \bar{Q}_L^i \Phi_D^{ij} D_R^j + \bar{Q}_L^i \Phi_U^{ij} U_R^j$$

Where do flavors come from?

$$\text{in SM: } \Phi_a^{ij} = y_a^{ij} \phi?!$$

What is the origin of neutrino mass?

???

How is electroweak symmetry broken?

$$\mathcal{L}_{\text{EWSB}} = \sum_A (D_\mu \Phi_A)^2 + V(\Phi_A)$$

All these questions are fundamental, but EWSB is the most central.

Scale of EWSB is known:  $\sim \text{TeV} \Rightarrow \text{SSC, LHC}$

What kind of LC will elucidate and extend discoveries made at LHC?

Energy, luminosity, flexibility.

# Scalar Field Theory

At high energies, scalar field theories behave poorly. In particular, the Standard Model with one Higgs doublet behaves poorly.

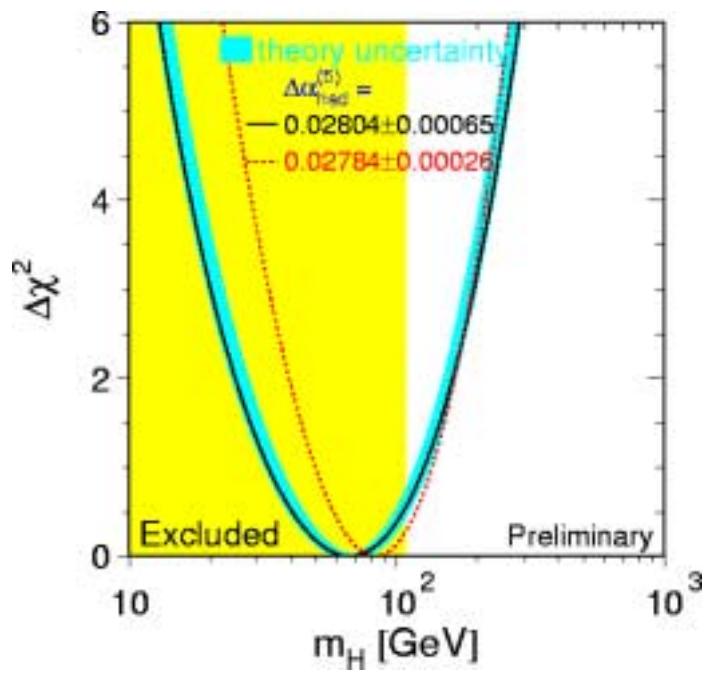
Something takes over at a scale  $\Lambda$ . What is it? quantum gravity? supersymmetry? extra dimensions? strong dynamics?

*Triviality* problem:  $\Lambda$  is tied up with the Higgs mass. If it's a few TeV

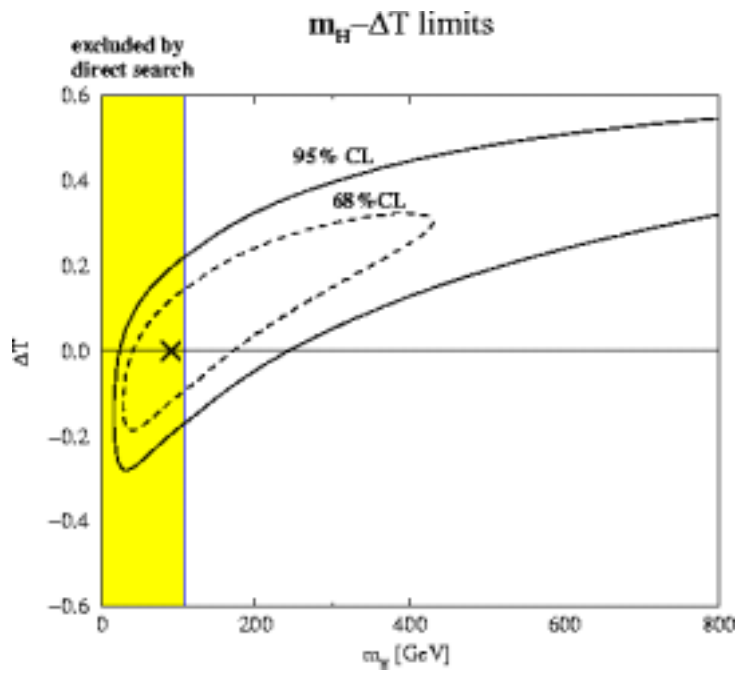
$$\begin{aligned} m_H &< 700 \text{ GeV, or see } \sim 3\% \text{ deviations} \\ &< 500 \text{ GeV, or } \sim 0.1\% \\ &< 1000 \text{ GeV, or } \sim 100\% \end{aligned}$$

New particles with mass  $m = c\Lambda$ , generically  $c > 1$ .

When the triviality problem is taken into account, the well-known fits to precision electroweak data are not informative.  $\leftrightarrow$  plots



LEPEWWG



Chivukula, Evans, Hölbling

If  $\Lambda$  is high, say  $10^{19}$  GeV, then Higgs is light. Then the hierarchy of scales induces a *fine-tuning* problem:

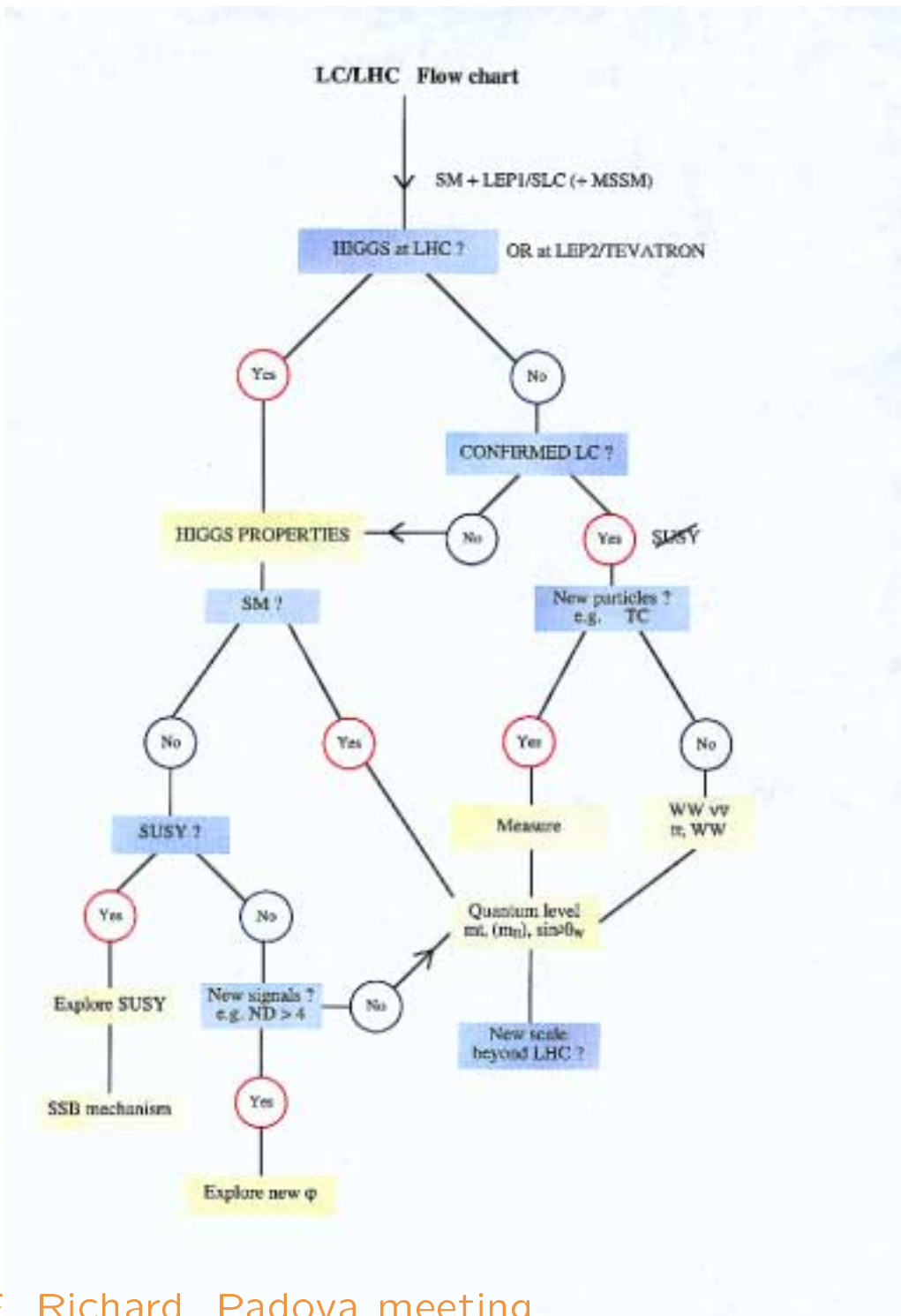
$$m_H^2(\text{TeV}) = m_H^2(\Lambda) - a\alpha\Lambda^2$$

The fine-tuning is alleviated in supersymmetry or extra dimensions:  $v \ll \Lambda \ll 10^{19}$  GeV.

Now the hierarchy of  $\Lambda$  and  $10^{19}$  GeV is decoupled from EWSB, and stems from supersymmetry breaking or from the geometry of extra dimensions.

In supersymmetry, the (lightest) Higgs boson must be light,  $m_H < 140$  GeV or so, is susy is relevant to EWSB.

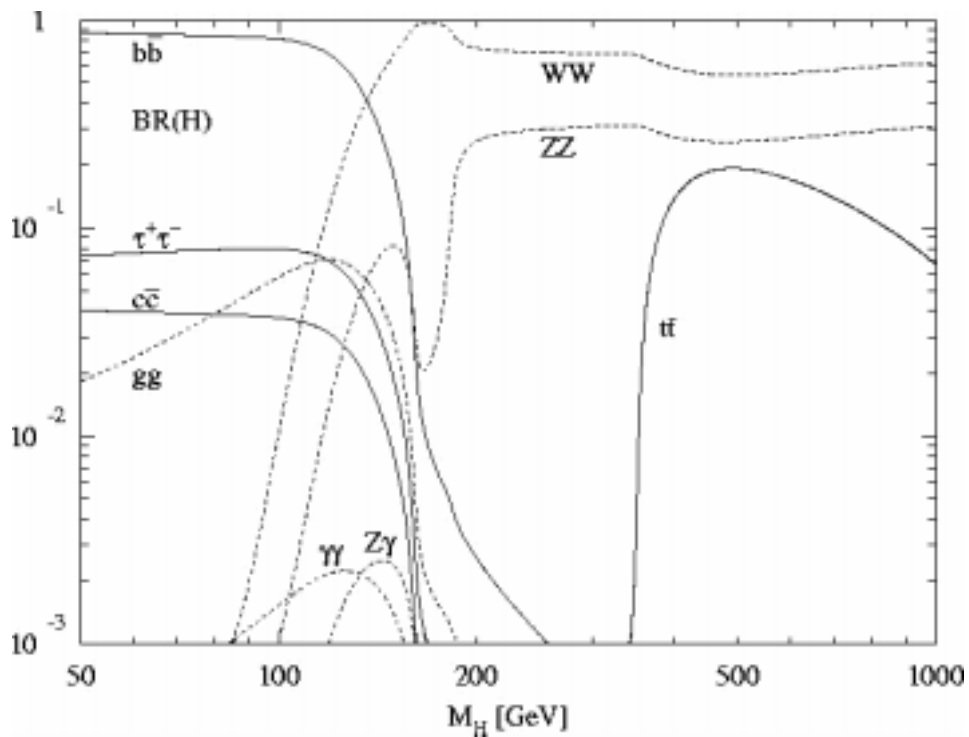
In models of (composite) Higgs from extra dimensions, all bets are off.



F. Richard, Padova meeting

# Higgs at LHC? Yes!

Does one field gives mass to vector bosons ( $W$ ,  $Z$ ), (charged) leptons ( $\tau$ ), down-like quarks ( $b$ ), and up-like quarks ( $c$ ,  $t$ )?

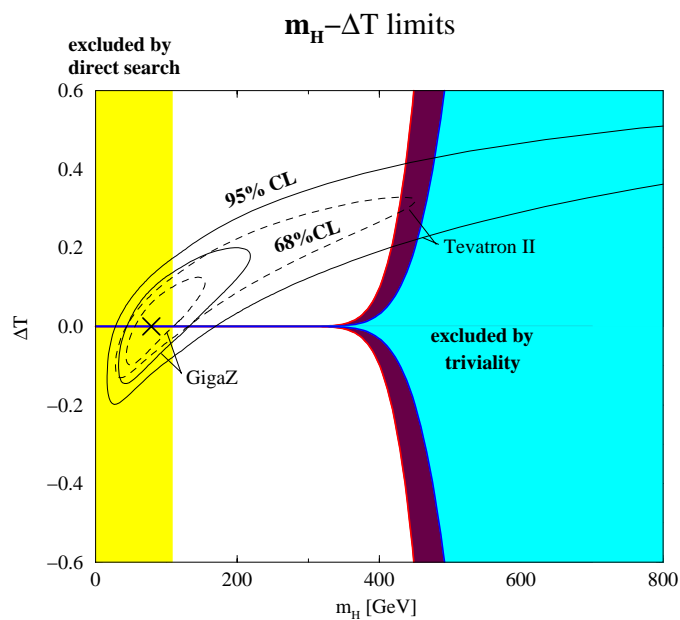


This is easiest if the (lightest) Higgs boson has mass  $m_H < 2m_W$ . Precision measurements of BRs become key: they are sensitive, through loops, to more massive states, such as the  $CP$ -odd Higgs boson of susy [Battaglia].

But what if  $m_H = 170$  GeV? Or 400 GeV?

Then, in SM-like scenarios, only the  $W$ ,  $Z$ , and  $t$  couplings are measurable.

What can be gained from precision measurements of  $H^0$ ,  $W^\pm$ , and  $Z^0$ ?



While trying to figure out the energy of the post-LHC  $pp$  collider, there is a role for a low energy LC with extremely high  $\int \mathcal{L} dt$  (GigaZ).

Here the case for the LC is thought by many to be weak. Our study group is grappling with “intermediate” and “heavy” Higgs.

# SUSY at LHC? Yes!

For those who believe that supersymmetry is the resolution of the electroweak hierarchy problem, the case for the LC is obvious.

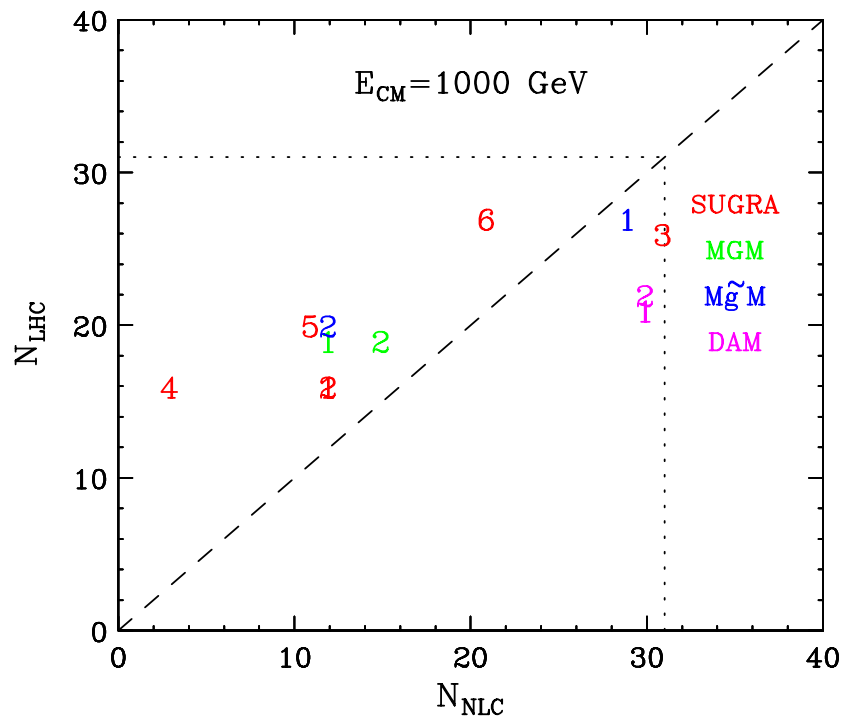
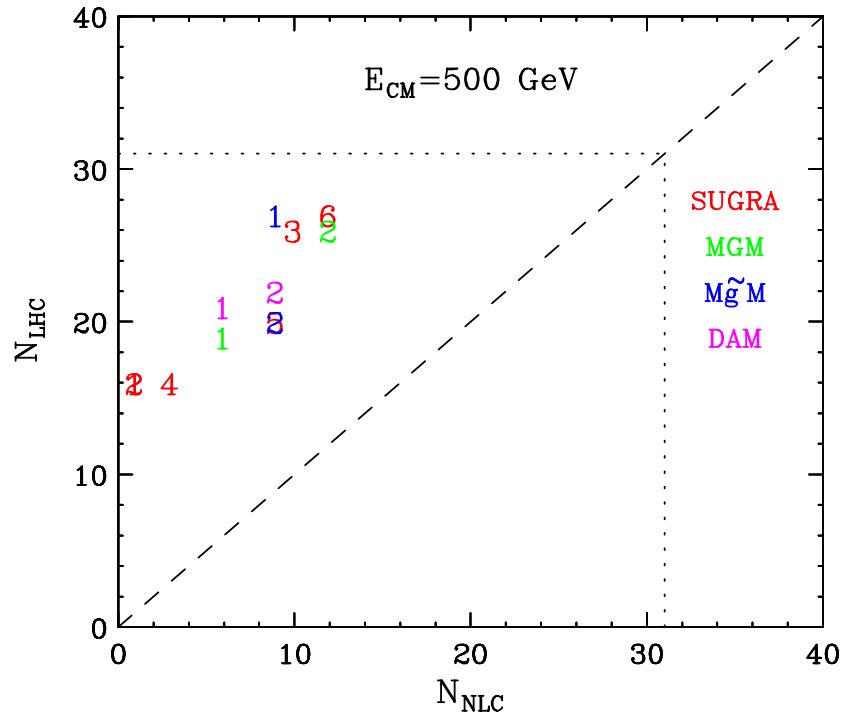
The (lightest) Higgs is in the richest region.

Focus will shift from origin of EWSB to origin of susySB. Precision of LC helpful [Blair, Porod, Zerwas].

Superpartners require detailed studies: LHC and LC complement each other. For example, LC will simplify determination of spin.

Zerwas estimates  $\int \mathcal{L} dt = 2000 \text{ fb}^{-1}$  for threshold scans of 25 (or so) superpartners.

Upgrade to higher energy will probably be needed.  $\hookrightarrow$  plots



K. Matchev

# SUSY at LHC? No!

The most fashionable ideas these days involve extra dimensions.

Principal signature are Kaluza-Klein excitations, with mass  $M^2(n) = m^2 + (2\pi n/L)^2$ .

With the known SM fields (i.e. all but Higgs doublet) in 6 dimensions, EWSB can arise. KK excitations of gluon bind  $t$  (and  $b$ ) to KK excitations of  $t$ , with TeV physics that looks like a one (two) doublet model, possibly with extra singlets [Cheng, Dobrescu, Hill].

In two-doublet version, phenomenology is rich. The usual Higgs may decay to a  $CP$  odd scalar with axion-like properties. May be seen at Run II [Dobrescu, Landsberg, Matchev].

Many aspects of these models are similar to non-minimal susy. Will need LC to tell the difference. Will also probably need an energy upgrade.

## Higgs at LHC? No!

The the physics of EWSB is beyond our imagination. Therefore, it is possible.

The LC has an important role here, because of the model-independent search for an object recoiling against a  $Z$ .

$\sqrt{s} = 0.8\text{--}1.0$  TeV should be enough, but need enough  $\int \mathcal{L} dt$  to see a (broad?) bump over background.

Then measure  $\Gamma_{\text{inv}}$ ,  $\Gamma_{WW}$ ,  $Z^*ZH$ ,  $t\bar{t}H$ , and any other branching ratios.

If no Higgs particle is found, the dynamics must be strong and there may be associated particles beyond reach of LHC: 2–3 TeV?

If not even that, a program of high precision  $WW$  scattering,  $m_W$ , and  $Z$  resonance properties may be warranted. (A program not unlike  $B$ ,  $K$  and  $\nu$  physics.)

# Conclusions

A linear collider will be a desirable complement to the LHC, if the price is affordable, if the luminosity is high enough, and if the energy is flexible.

The cost: taxpayers and the HEP community will want value for money (and have bought LHC already).

The luminosity: Zerwas estimates  $2000 \text{ fb}^{-1}$  for 25 threshold scans of  $\tilde{\chi}\tilde{\chi}$  and  $\tilde{\ell}\tilde{\ell}$ .

The energy: upgrades to 2–4 TeV will be essential; GigaZ may be essential.