LC Physics and Detectors

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What am I Supposed to Cover?

Summarize "all physics groups", especially the "particular charge" to them; namely, "issues specifically related to informing detector and accelerator technology, and lay out choices that lie ahead of us over the next few years."

Apologies to speakers in parallel sessions (whose work is not summarized); and to those who know more about LC physics and/or detectors.

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A useful document on detector needs is the report on Linear Collider Detector R&D (by J. Brau, C. Damerell, G. Fisk, Y. Fujii, R.-D. Heuer, H. Park, K. Riles, R. Settles, and H. Yamamoto) at `http://blueox.uoregon.edu/~jimbrau/LC/LCrandd.ps`.

The Linear Collider Physics Program

We know that electroweak symmetry is broken, but we don't know what breaks it. Hierarachy + naturalness + triviality suggest new phenomena at the TeV scale.

If the scale of EWSB is unnaturally high (> 20 TeV) then fits to precisely measure electroweak observables imply

$$\begin{aligned} m_H &< 200 \text{ GeV @ at 95\% CL} \\ &< 2m_W + \varepsilon \text{ @ at 60–65\% CL} \end{aligned}$$

Aim of LC is to understand the light(er) Higgs boson(s) and non-Standard TeV-ish particles, in ways that go beyond LHC capabilities.

We know [Resource Book, TESLA TDR] that with $L \simeq 200\text{–}300 \text{ fb}^{-1}\text{yr}^{-1}$ that the LC event rate allows one elucidate different scenarios.

Consequently, the machine must work, and the detector must do its job.

What Are Your Final States?

b and c quarks: a key for light Higgs, top (b), and many non-Standard analyses

turn into jets with detached vertices

τ leptons: a key for light Higgs and many non-Standard analyses

decay to $l\bar{\nu}_l\nu_\tau$, $\pi\nu_\tau$, $\rho\nu_\tau$, $a_1\nu_\tau$, $\ldots$

W and Z: basic objects at TeV scale as signal and/or background

decays: $Z, W \to jj$, $Z \to l^+l^-$, $Z \to \nu\bar{\nu}$, $W \to l\nu_l$.

top quark: basic object at TeV scale *possibly special*

decays to bW

Notice that none of these "final" states ever makes it out of the beam pipe.

Your Final States Are

hadrons: basic objects in detector

sometimes as individuals, sometimes in jets

electrons, photons, and π^0s: basic "electromagnetic" objects in detector

for example, think about $\tau^\pm \to \rho^\pm \nu_\tau \to (\pi^\pm \pi^0)\nu_\tau$

muons: basic penetrating objects in detector

Will there be others?

missing E_T: in many classes of events

all MSSM, $Z \to \nu\bar{\nu}$, other exotic matter $\Gamma_H(\text{invisible})$

kaons: thought not to be interesting, but

can help tag charm: $c \to s \to KW^*$

Sources: Luminosity

$L = 200\text{–}300\ \mathrm{fb}^{-1}\mathrm{yr}^{-1}$ gives an interesting event rate

Last factor of two in L_{peak} is less important than

reliability

flexibility (energies, polarization)

future energy upgradability

Sources: Polarization

At the TeV scale e_L and e_R are different fields.

Therefore, e^- polarization (a proven technique) is a must.

It can help with background suppression.

It is key in susy for disentangling mixings of scalar partners.

Expect similar utility in similarly rich scenarios, but I don't know of demo.

Helpful for the general-purpose search for deviations in $e^+_{\P} e^-_{\P} \to \bar{f} f$.

Positron polarization helps also, for same physics reasons. Tradeoff with luminosity.

At the IR: dL/dE

The primordial energy spread, initial-state radiation, and beamstrahlung lead to a luminosity spectrum, dL/dE.

For Sitges, David Cinabro did a study of $t\bar{t}$ threshold, focusing not only on how the shmear affects m_t, but also how knowledge of dL/dE matters

Measure spectrum during experiment. bunch-to-bunch variations?

An issue $e^+e^- \to f\bar{f}$ measurements (Strom's talk).

Another obvious example is susy threshold scans.

Vertex Detector

Need to identify b and c quarks through detachment.

Essential part of light Higgs program. BR($c\bar{c}$) tests whether H gives mass to up-type quarks.

b is also key to identify top.

Part of precision studies of $e^+e^- \to q\bar{q}$ to look for deviations from SM (Strom).

b-c separation requires Si close to collision (~ 1 cm). Hence large magnetic field (to protect jewels from junk), with implications for tracking.

Physics Interlude: the τ

The τ is a relatively common "final" state, although not as easy to detect as e or μ.

On the other hand, a better polarimeter. τ_L and τ_R are different fields.

For example (G. Bower's talk): $H \to \tau\tau$ followed by $\tau \to \rho\nu_\tau$ (or $a_1\nu_\tau$, etc).

Acoplanarity of $\rho^\pm \to \pi^\pm\pi^0$ decay planes diagnoses parity of H.

This τ ID requires track and em calorimetry. Stressed by Brient, Videau, et al.

Tracking Detectors

In some case (τ ID) measure isolated tracks.

More usual job is to work with calorimeters on jets energy flow techniques.

The goal—to do the physics—is to separate Z from W.

A two-headed dragon.

Also, must be made of as little material as possible.

Electromagnetic Calorimetry

$e^{\pm}$, photons, and $\pi^0 = 2\gamma$ cause showers here.

Electron detection is a key in susy and also in study of contact interactions. Photons, e.g., in Higgs decay.

Good energy resolution for those famous box spectra in susy cascades.

Important down to very small angles. To reject background from $\gamma\gamma$ events, instrument mask (Colorado group).

Also some interest in measurement-quality detectors at small angles. $e^-e^- \to \tilde{e}^-\tilde{e}^- \to e^-e^-\tilde{\chi}_0\tilde{\chi}_0$ and any other t-channel exchange.

In central region, distinguish $2\gamma = \pi^0$ from 1γ.

Hadronic Calorimetry

Work with tracking to separate Z and W through energy flow.

Many interesting "final" states, like $t\bar{t}H$ and ZHH have lots of jets.

Fisk's theorem: $1\ \mathrm{TeV} > 10m_Z$ so high-energy LC optimization is not LEP I optimization (cf. talk by T. Junk). energy flow task force?!

Unless your calorimeter is cheap, it better separate Z and W up to $1\ \mathrm{TeV}$.

Tracker might change (cf. CDF and DØ).

Muon System

Muons appear is decays of Z and W.

Interesting in susy $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\chi}_0\tilde{\chi}_0$, and the more general-purpose search for deviations in $e^+e^- \to \mu^+\mu^-$.

Muon system is your last chance to detect anything.

For example, is susy breaking is gauge-mediated, the NLSP could have $c\tau\gamma \sim 1$ m, and decay to a standard particle (“non-pointing photon”) and a gravitino.

Hence, tail-catching calorimetry in muon system.

Missing Energy

By definition the particles you do not detect: ν, $\tilde{\chi}_0$, $\tilde{G}$.

Observed by process of elimination.

Calorimeters have to catch everything, also down to small angles.

Conclusions

Putting this all together, it's most important to identify the particles of the TeV scale.

But not necessarily "particle ID" detectors. (PID and $\not{R}$ susy both orphans).

distinguish Z from W, b from c, τ from e or μ or π, susy from $\gamma\gamma$, left from right.

Mind-boggling problems everywhere: use no material to track precisely; make energy flow work at $1\ \mathrm{TeV}$; put silicon in close; instrument small angles for veto, for physics, for L, for dL/dE.

But, the LC is a precision machine (and we assume the luminosity will come). The detector must meet the challenge, . . .

Assuming the Theory is Precise

Much of the anticipated LC physics is predicated on having precise calculations of background and signal processes. $e^+e^- \to f\bar{f}, 4f, 6f, 8f.$

Certainly starting with L_{SM}; probably starting with L_{TeV}.

So, greater investment in the craftsman's side of theoretical physics is needed.

Some of it is computing, but a smaller computing problem than LHC triggers, detector simulation, lattice QCD, ...

The main shortfall is the human resource: American physics departments tend to favor abstract theory and model building over the craft of difficult calculation.