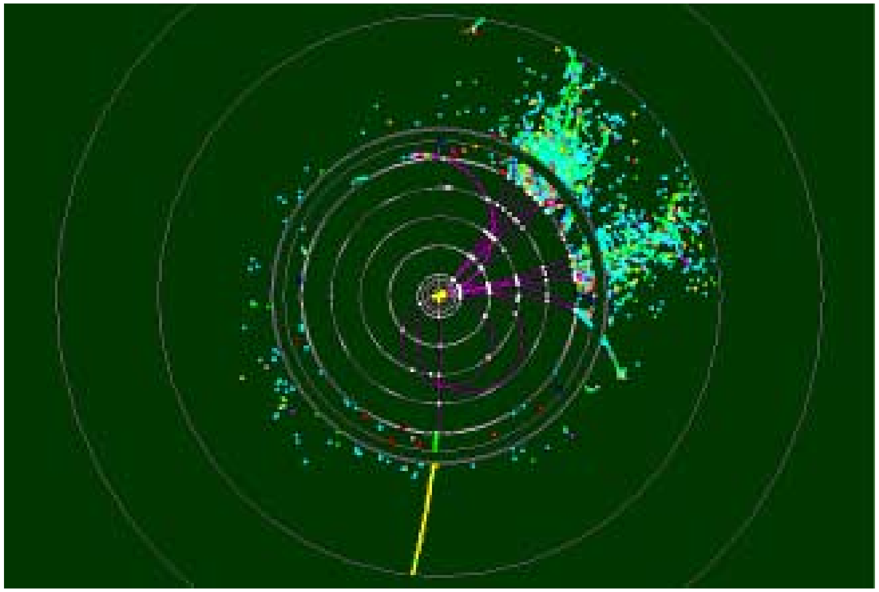
Experimental Approaches at Linear Colliders

E3 Working Group Plenary Report

M. Battaglia, I. Hinchliffe, J. Jaros, and J. Wells



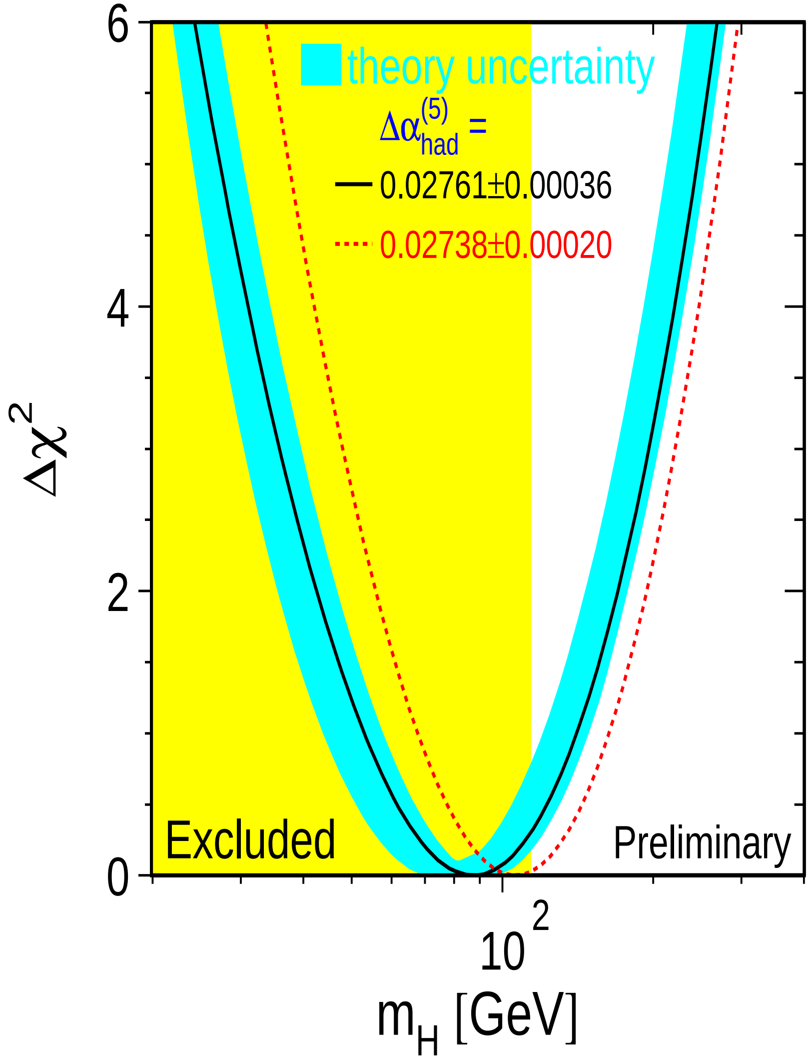
The Next Physics Threshold

✧ Precision tests remarkably confirmed electro-weak SM predictions

✧ Radiative corrections to precision EW observables sensitive to full particle content of the theory. They indicate a low mass Higgs boson:

$$M_H < 200 \text{ GeV}$$

✧ The data indicates **new physics** below 500 GeV



✧ 500 GeV LC provides precision tests of electro-weak symmetry breaking, mass generation, New Physics

✧ Tevatron and LHC explore this region first.

✧ Precise LC data is essential for complete elucidation of physics

✧ As a result of extensive world-wide studies we now believe that

- **There is a compelling physics program for a TeV-class LC**
- **The technology to construct a 500 GeV collider is ready to be implemented shortly**

The E3 Working Group Activity

E3 Group was structured to meet our charge:

- Review and refine the physics case for a TeV-class LC
- LC performance requirements and readiness
- The case for special options of LC operations:
  Polarization, $\gamma\gamma$, e^-e^-, $e^-\gamma$
- Detector R&D to guarantee full LC productivity
- New physics landmarks that come into view with energy upgrades

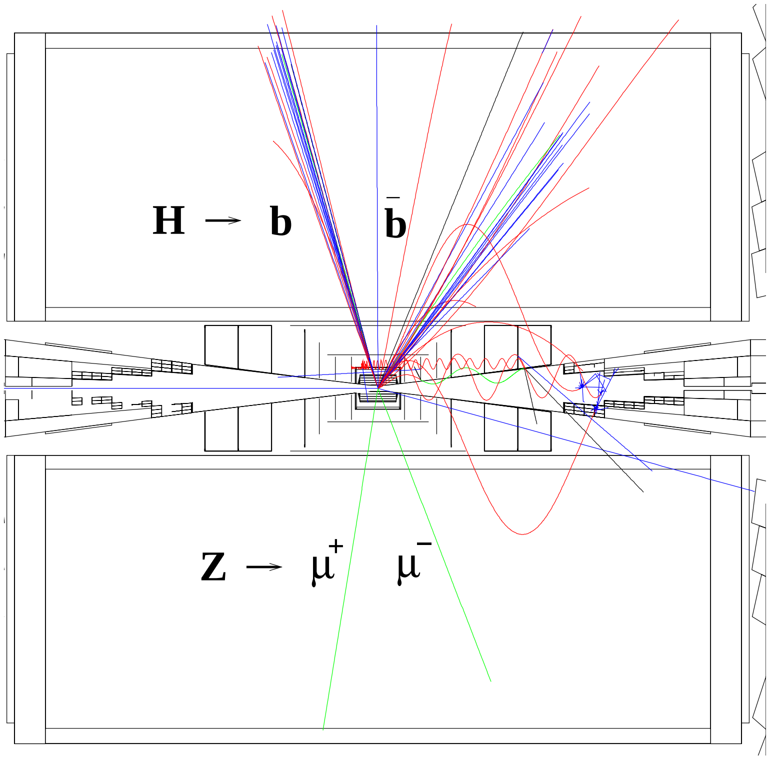
Sub-Group Leaders and Physics Contacts

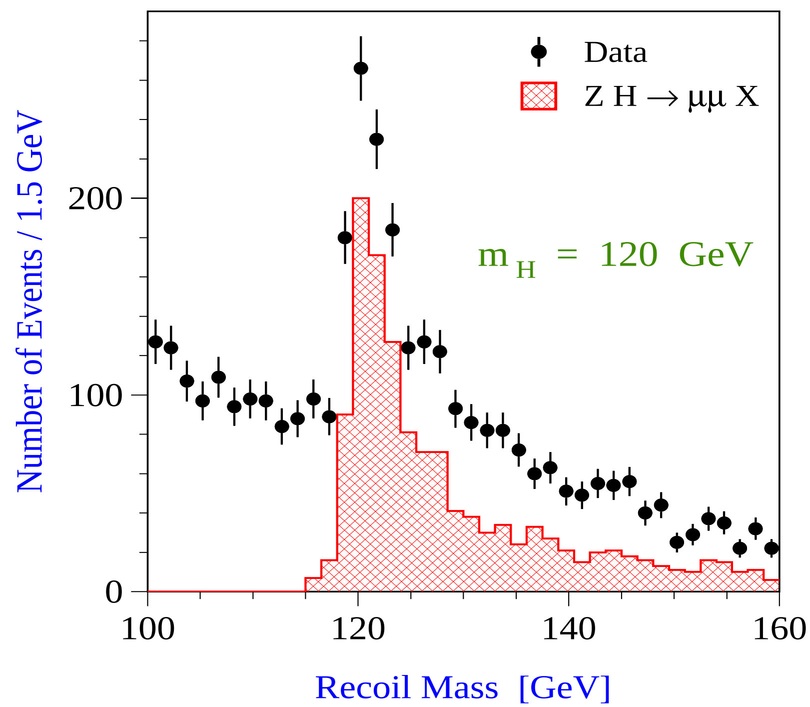
M. Breidenbach, T. Tauchi, C. Damerell; A. De Roeck, T. Barklow; P. Grannis, R. Cahn, H. Montgomery; P. Burrows, R. Patterson; M. Velasco, K. Moenig, C. Heusch, J. Gronberg, P. Rowson, E. Torrence; R. van Kooten, M. Perelstein, G. Blair, G. Wilson, S. Mrenna, J. Conway.

Studying the Higgs Boson at LC

✧ Associated HZ production gives model-independent Higgs boson tag and measurement of HZZ coupling

P.G. Abia et al.





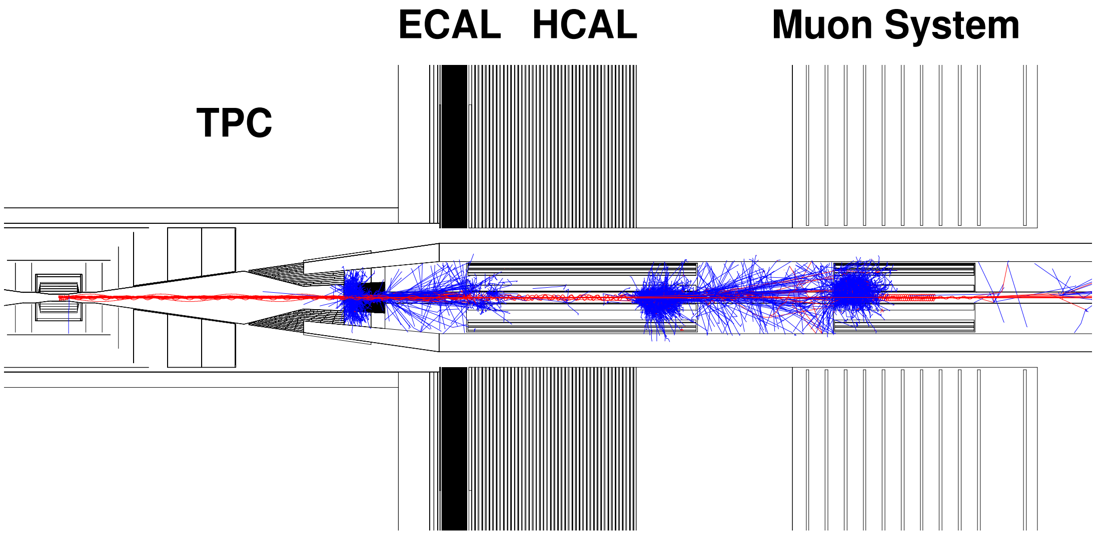
High $\mathcal{L}$ is crucial:

$\mathcal{L} = 2 \times 10^{34}$ cm^{-2}s^{-1} at 350 GeV $\rightarrow$ 24000 HZ evts./year

e^+e^- Experimental Environment

✧ Known initial state energy, partons and helicities

Note:
Magnified
Vertical
Scale



✧ Radiation from interaction of intense beams produces beamstrahlung and e^+e^- pairs

✧ Multi-Tesla solenoidal field confines pairs inside beam-pipe.
Forward masks needed to avoid back-scattering

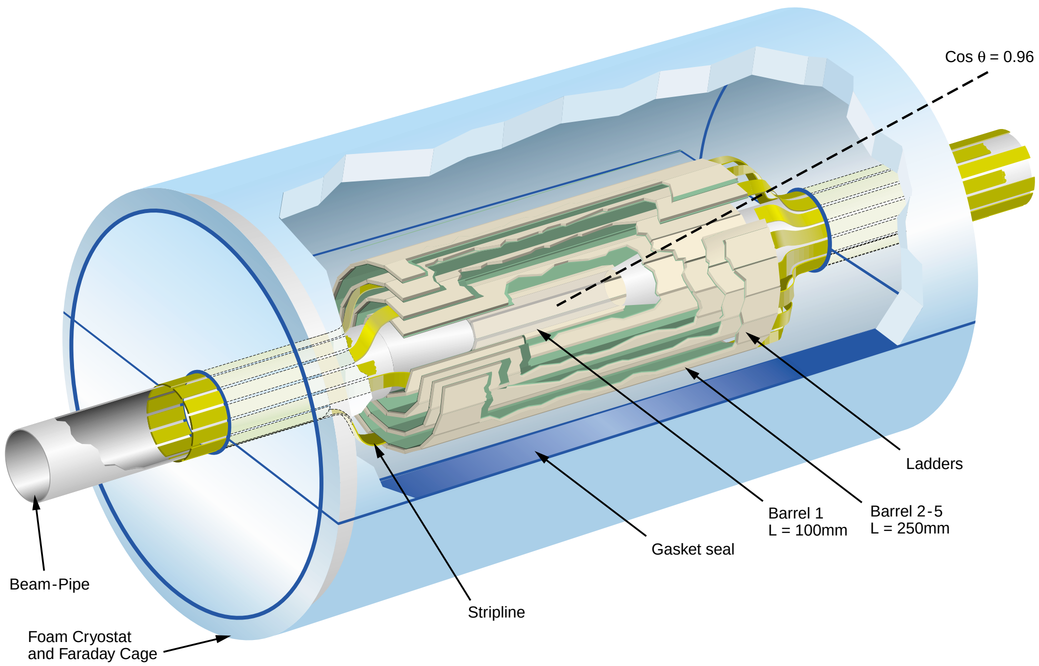
✧ Radiation induced energy spread small at 500 GeV and moderate at 1 TeV, comparable to ISR

✧ Beamstrahlung remains manageable at multi-TeV

Vertex Detector

✧ Detector performance must be significantly enhanced over present experiments to capitalize on LC physics potential. More R&D is needed.

Vertex Detector essential for fermion flavor identification



b Efficiency	b Purity
0.60	**0.98**
c Efficiency	**c Purity**
0.60	**0.65**

✧ Vigorous pixel sensor technology R&D is under way

✧ LC environment allows superb vertexing and physics program requires it

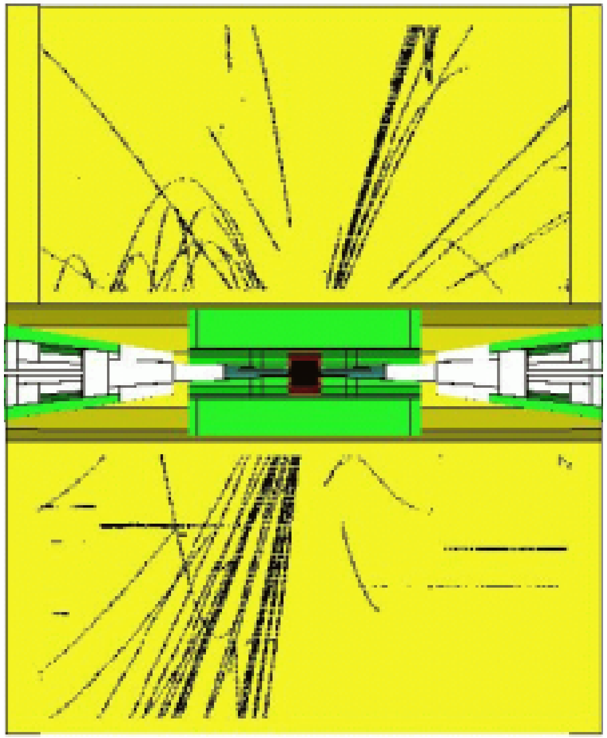
Goal: Impact Parameter Resolution $\simeq 5\ \mu m \oplus 5\ \mu m/p_t$

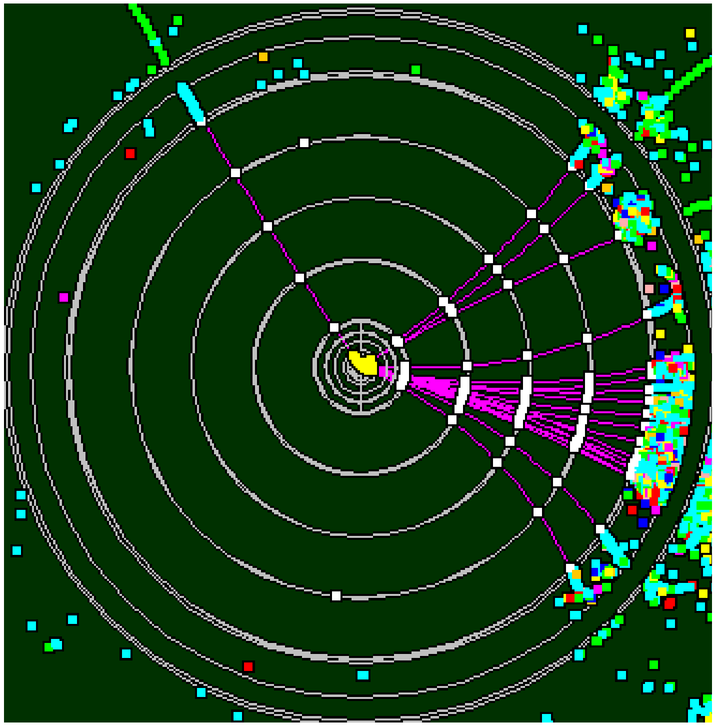
Outer Tracking

✧ Recoil mass measurements push track momentum resolution to

$$\Delta p/p \leq 5 \times 10^{-5} p \text{ (GeV/c)}$$

TPC Continuous Tracker **Discrete Si Tracker**





✧ Present R&D is addressing TPC, Drift Jet Chamber and All-Si Tracker solutions

Calorimetry and Energy Flow

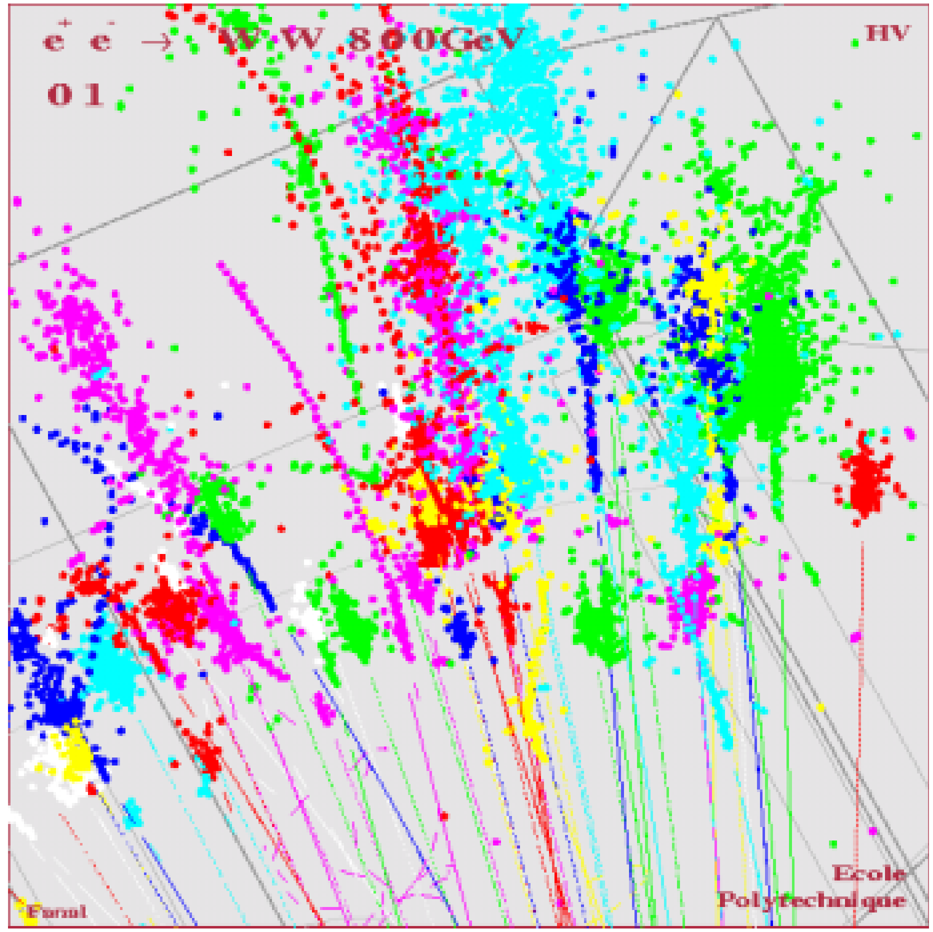
✧ Studies at LC benefit from clean separation of $W^{\pm}$, Z^{0} and H^{0} by di-jet mass determination

✧ 3D calorimetric reconstruction is important

✧ Several techniques are being studied for ECAL and HCAL

Si-W
Shashlik
Scintillator Tiles
Digital HCAL

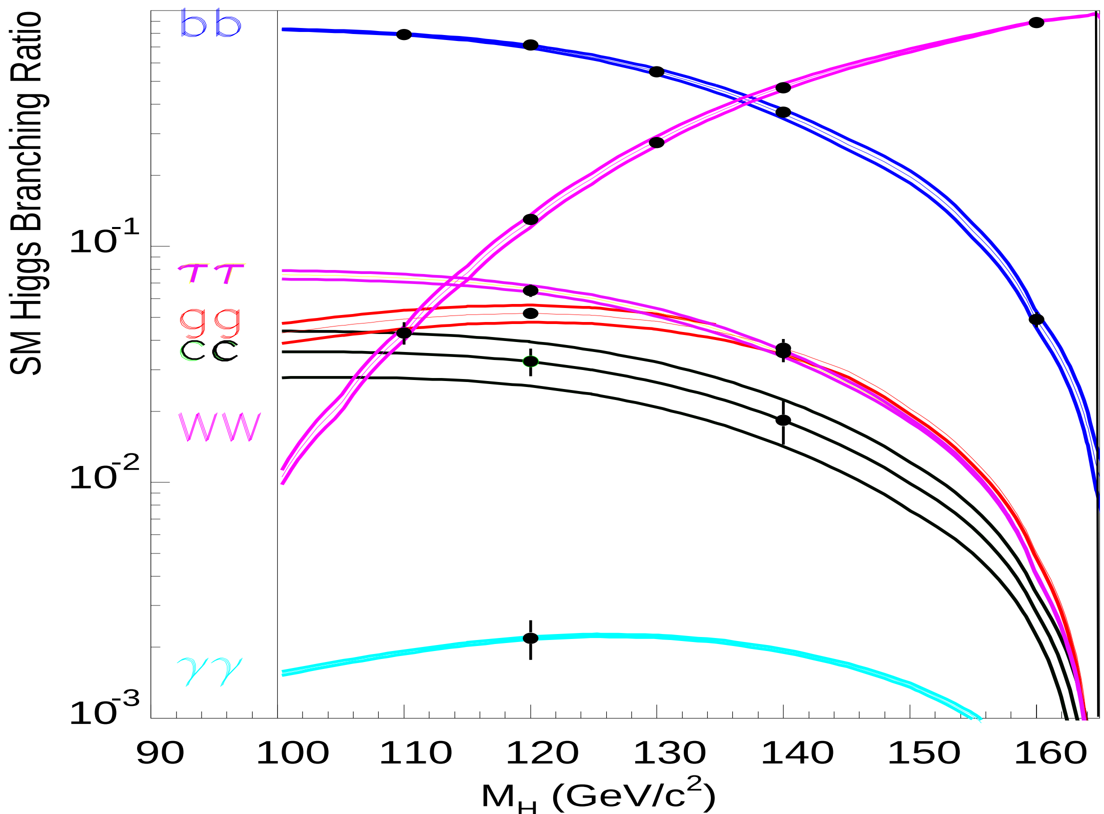
✧ Ongoing R&D programs aimed at development of energy flow reconstruction



✧ Energy flow techniques combine charge particle tracking and neutral energy calorimetry, need to be validated in the multi-jet environment

Studying the Higgs Boson at LC

✧ Higgs boson couplings must be measured with great precision to demonstrate that Higgs mechanism is responsible for mass generation:



M. Battaglia

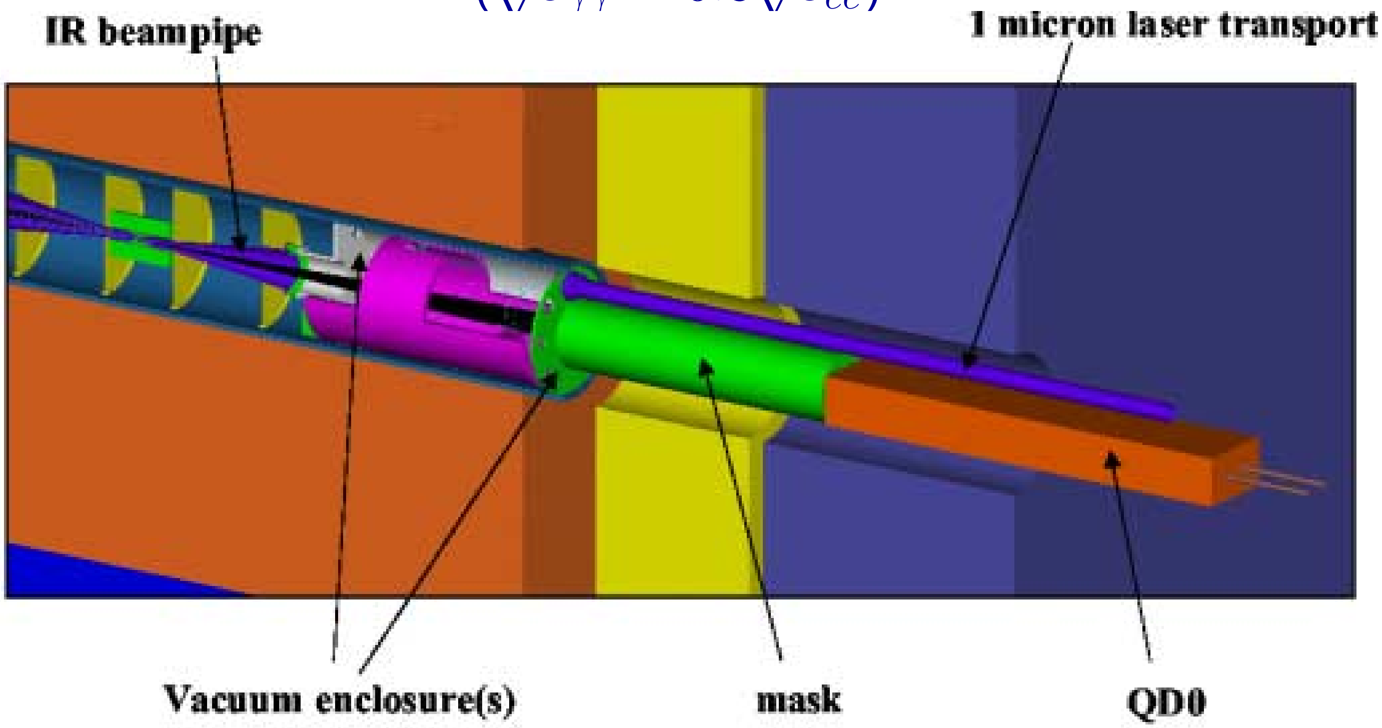
✧ Measure the Higgs self-coupling to $\sim 20\%$

✧ 500 GeV LC adds the precision which establishes the key elements of the Higgs mechanism.

$\gamma\gamma$ Collisions

✧ LC program can be enriched with the study of $\gamma\gamma$ collisions

$$(\sqrt{s_{\gamma\gamma}} \sim 0.8\sqrt{s_{ee}})$$



✧ Realistic design exists. Laser R&D expected to deliver proof of principle within one year.

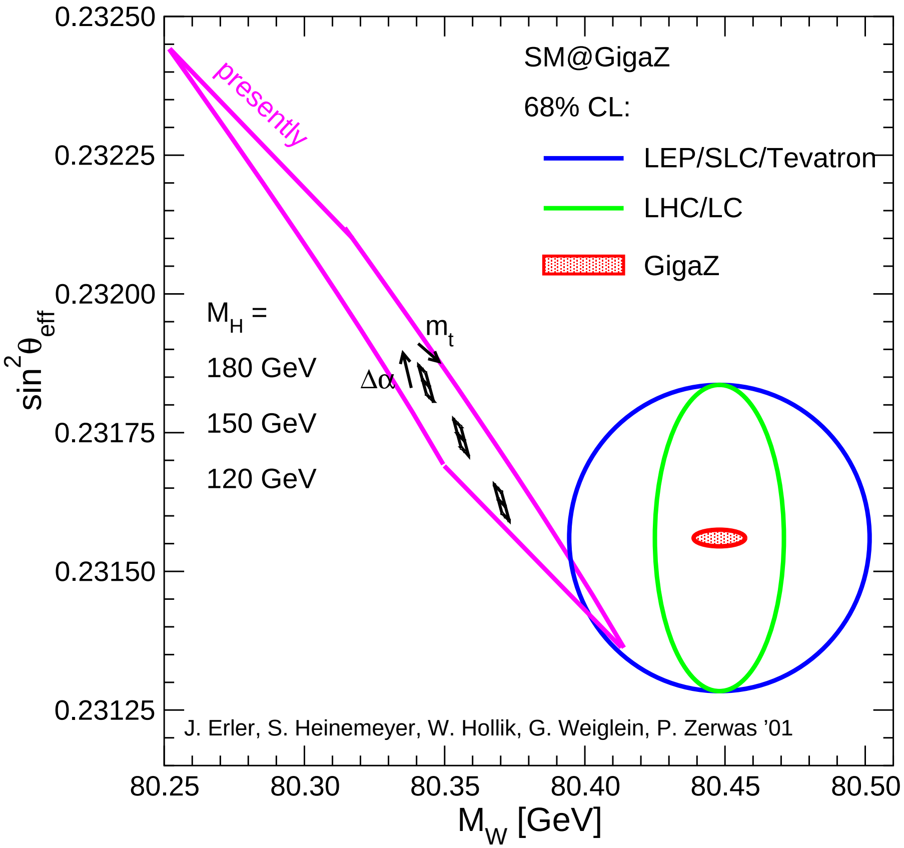
✧ Precision $\Gamma(H \to \gamma\gamma)$ measurement sensitive to new physics

✧ $\gamma\gamma$ produces and distinguishes H^0 and A^0 with significant rate even if $e^+e^- \to H^0A^0$ is not accessible

Impact of GigaZ on Precision Measurements

✧ If the Higgs is heavy, electro-weak constraints imply new physics to compensate ⇒ observable either directly or indirectly

✧ GigaZ option and W mass measurement dramatically improve precision on electroweak observables:



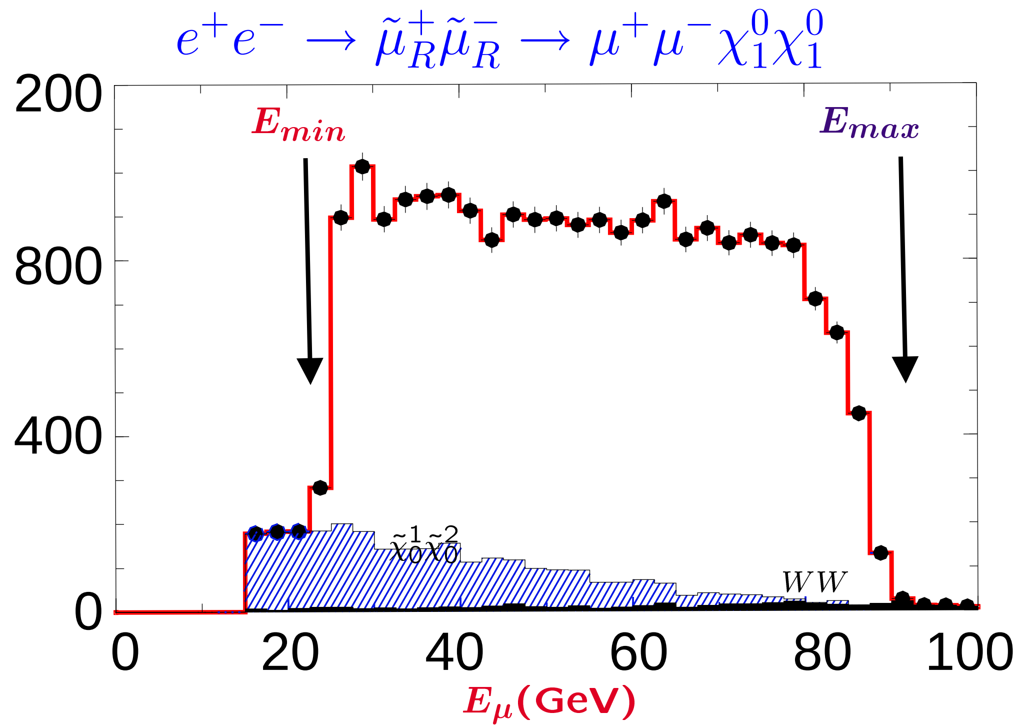
$\Delta \sin^2\theta_W$	.00017	$\longrightarrow$	.00002
ΔM_W	35 MeV	$\longrightarrow$	6 MeV
ΔA_b	.015	$\longrightarrow$	.001

G. Weiglein et al.

Studying Supersymmetry at LC

✧ Naturalness considerations prefer SUSY near weak scale $\longrightarrow$ expectation of sparticles at 500 GeV LC

✧ Masses and couplings measured with high accuracy:



U. Martyn

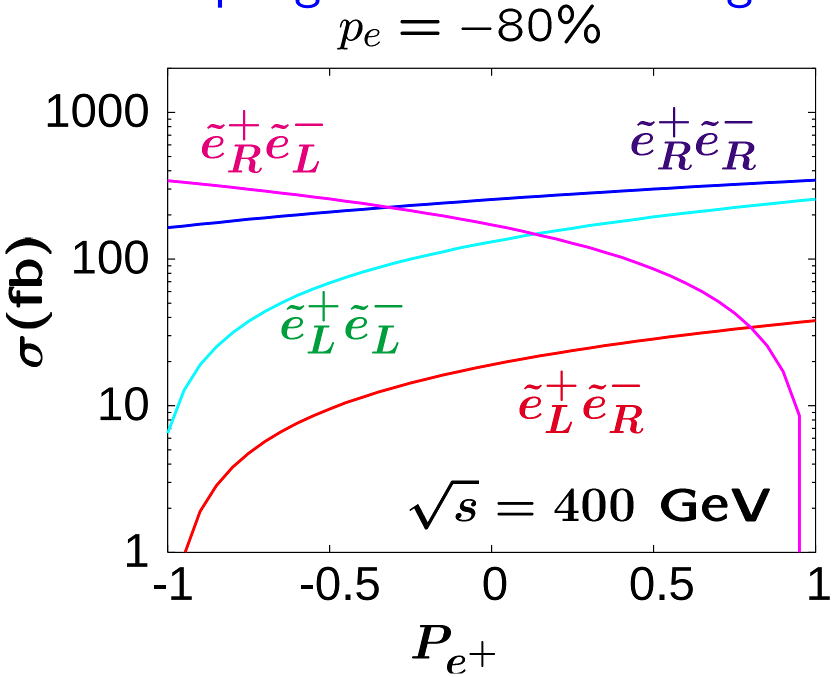
E_{min}, E_{max} $\rightarrow$ $M(\tilde{\mu}_R)$ and $M(\chi_1^0)$ $\quad \frac{\Delta M}{M} = 0.2\%$

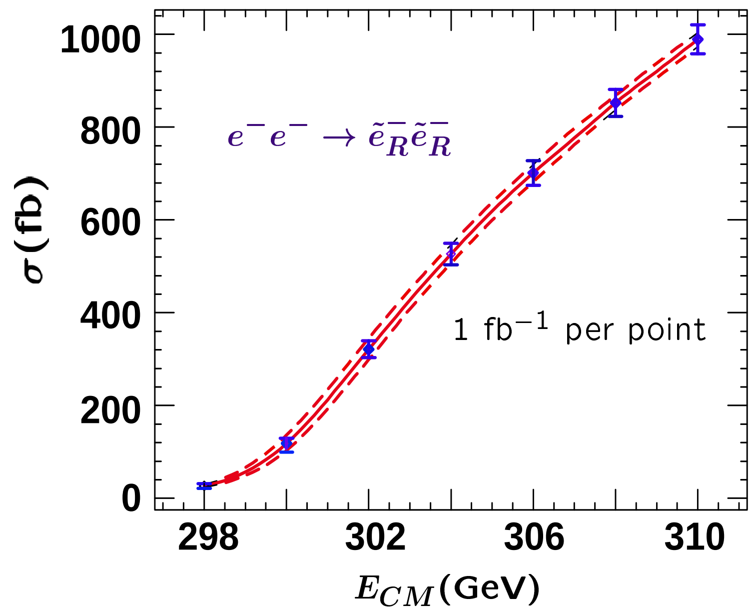
$\tilde{\mu}_R$ angular distribution $\frac{d\sigma}{d\Omega} = \sin^2\theta \Rightarrow J^P = 0^+$

✧ LC complements LHC SUSY measurements by adding precision determinations of electro-weak sparticles

SUSY with Polarization, e^-e^-, $\gamma\gamma$

- ✧ Polarization necessary to select sparticle production modes, precisely extract couplings and reduce backgrounds





G. Moortgat-Pick M. Peskin et al.

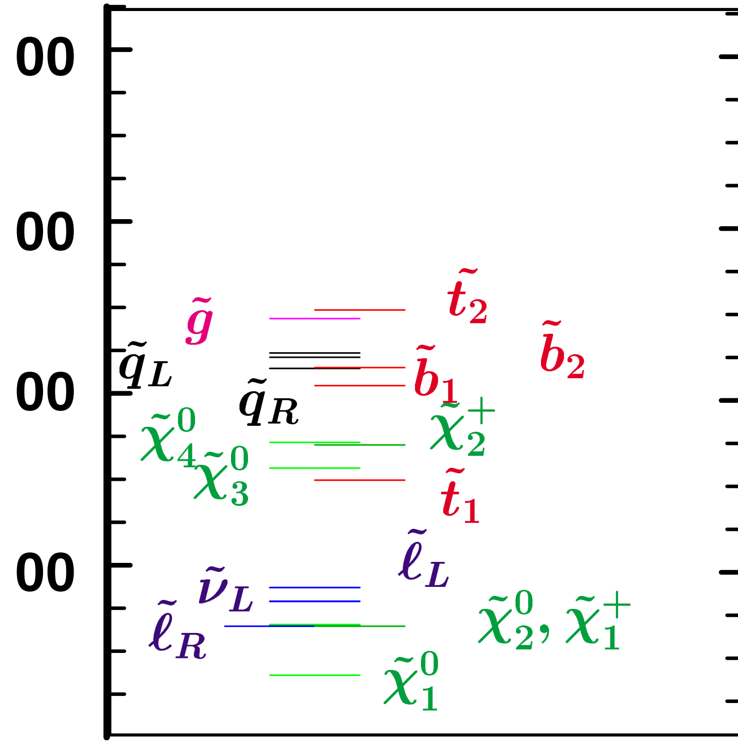
- ✧ e^- Polarization crucial and straightforward to accomplish
- ✧ e^+ Polarization increases effectiveness
- ✧ e^-e^- threshold scan determines $\Delta M_{\tilde{e}} \leq 100$ MeV
- ✧ $\gamma\gamma \to \tilde{f}\tilde{f}$ advantageous due to unambiguous couplings

Run-time Scenarios with SUSY

Can LC explore low mass SUSY in a reasonable amount of time ?

Approach: consider light SUSY scenario
Assume no positron polarization

Measure spectral end-points and scan



Luminosity Assumptions:

Year	1	2	3	4	5	6	7
$\int \mathcal{L}_{500}$ (fb^{-1})	10	40	100	150	200	250	250

Run Plan for $\mathcal{L}_{500} = 1000\ \mathrm{fb}^{-1}$

Strategy	$\sqrt{s}$	$\mathcal{L}$	$\int \mathcal{L}_{500}$	$P(e^-)$
Sit	500	245	245	L/R
3 Point Scan $\tilde{\nu}$	320	160	250	L/R
Scan $\chi_1^\pm$	256	20	40	L/R
Scan $\tilde{\mu_R}$, $\tilde{\tau}_1$	264	50	95	R
$e^- e^-$ Scan $\tilde{e_R}$	264	10	95	RR
Scan $\tilde{\ell}_L$	308	20	30	L
Scan t and $\tilde{\tau}_2$	350	20	30	L/R
Scan χ_2^0, χ_3^0	450	100	110	L
Scan $\chi_1^\pm$, $\chi_2^\pm$	470	100	105	L/R

✧ SUSY masses measured precisely $\Delta M \sim .2 - .5$ GeV

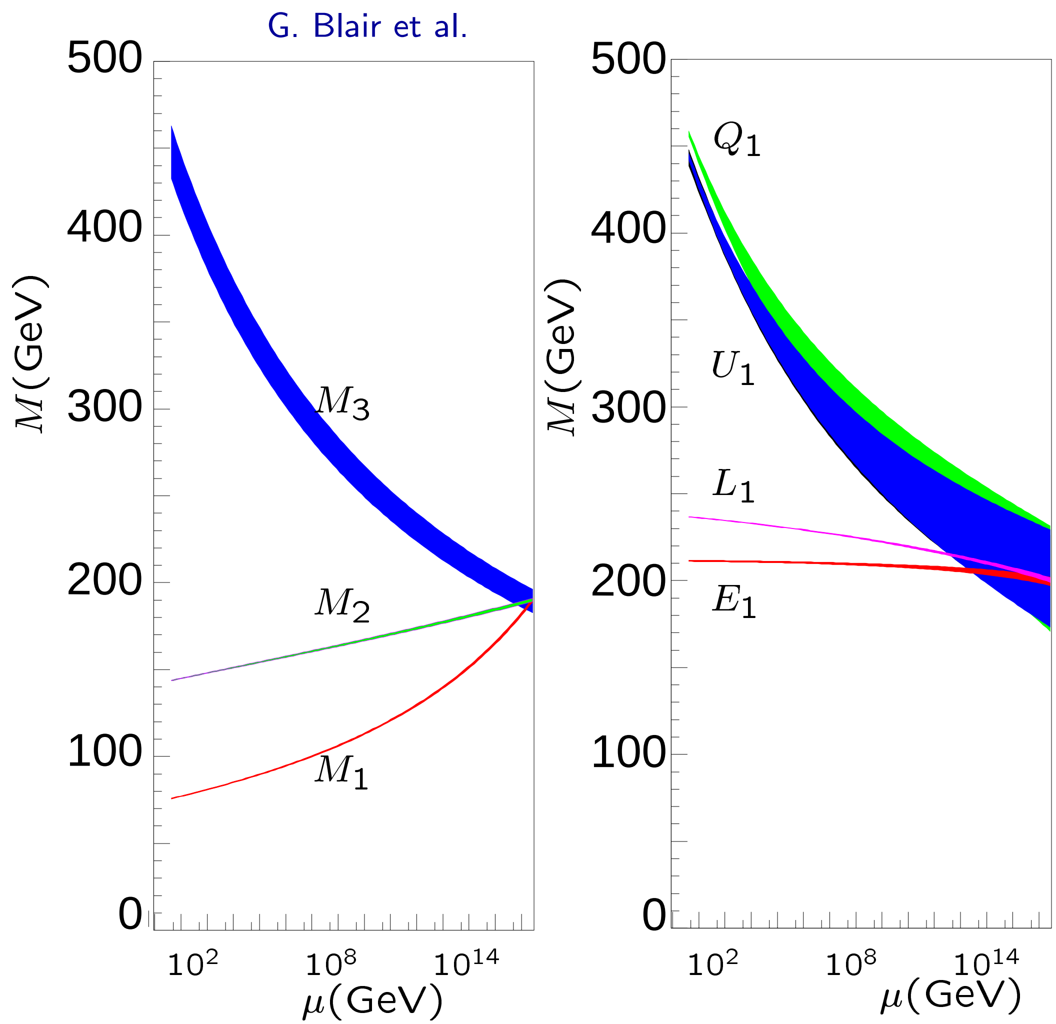
✧ Higgs mass and couplings measured $\Delta g_{Hbb} = 1.5\%$

✧ Top mass and width measured $\Delta M = 150$ MeV

Precision SUSY Measurements

✧ The pattern of sparticle masses gives information about the SUSY breaking mechanism

✧ High precision is needed to test evolution of masses to possible unification scale



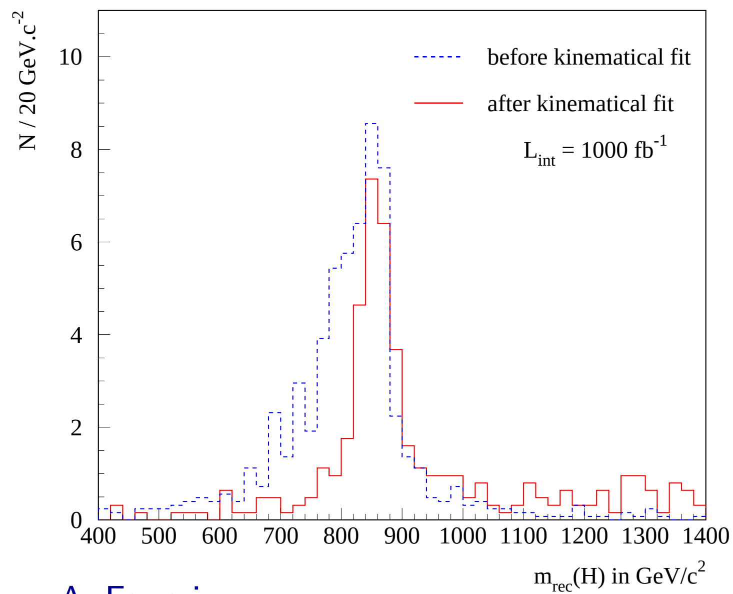
Gauginos **Sparticles**

Multi-TeV Landscape

✧ Results from LC and LHC will point us towards new physics scales

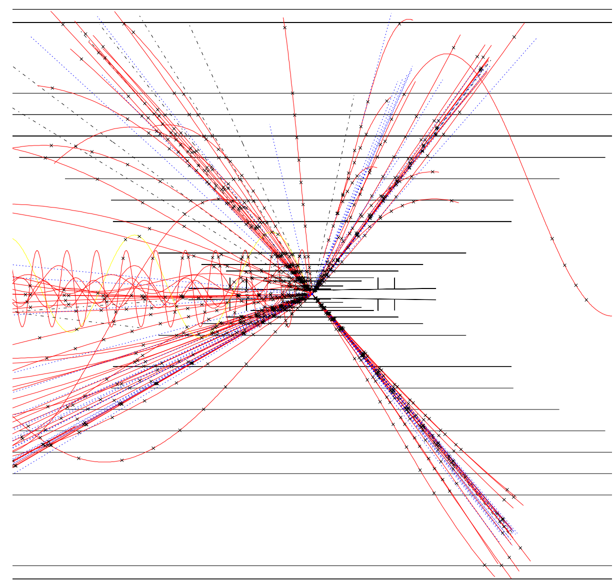
✧ Very high energy e^+e^- collisions will: improve Higgs potential and heavy Higgs bosons, capture the full SUSY spectrum and break new ground

Charged Higgs Mass



A. Ferrari

$G_3 \rightarrow G_1 G_1$



✧ 3-5 TeV collisions may be realized using the two-beam acceleration technique under development by the CLIC Study at CERN.

LC Energy and Upgradability:

✧ **$\sqrt{s}$=500 GeV motivated by:**

1. **Compelling physics program**
2. **Feasible step from LEP-2 and SLC**

✧ **Upgradability to $\simeq$ 1 TeV must be built in**

✧ **Both TESLA and NLC/JLC have upgrade capabilities:**

1. Capability to reach $\sqrt{s}$=600-750 GeV by trading luminosity/energy
2. Cost of 1 TeV upgrade = 20-25% of initial cost
3. Both must demonstrate gradient for $\sim$ 1 TeV operation

✧ Upgrade significantly beyond 1 TeV requires new technology.

Conclusion

There is a strong physics argument for proceeding as expeditiously as possible with a 500 GeV LC upgradable to $\sim$ 1 TeV

In all physics scenarios examined 500 GeV LC makes important measurements

Large scale of project, wide user community and world-wide expertise require an international approach

A managed international detector R&D program is needed

We must be open to collaboration with other fields of science which can profit from unique LC beams.

Worldwide Study for e^+e^- Collider

Worldwide Study of
the Physics and Detectors
for Future Linear
e^+e^- Colliders

http://lcwws.physics.yale.edu/lc/

Forthcoming Meetings:

ECFA-DESY Workshop
Krakow, September 14-18, 2001

ACFA Workshop
Bejing, October 31 - November 2, 2001

US-LC Workshop
November - December, 2001

International Linear Collider Workshop LCWS
Korea, August 26-30, 2002