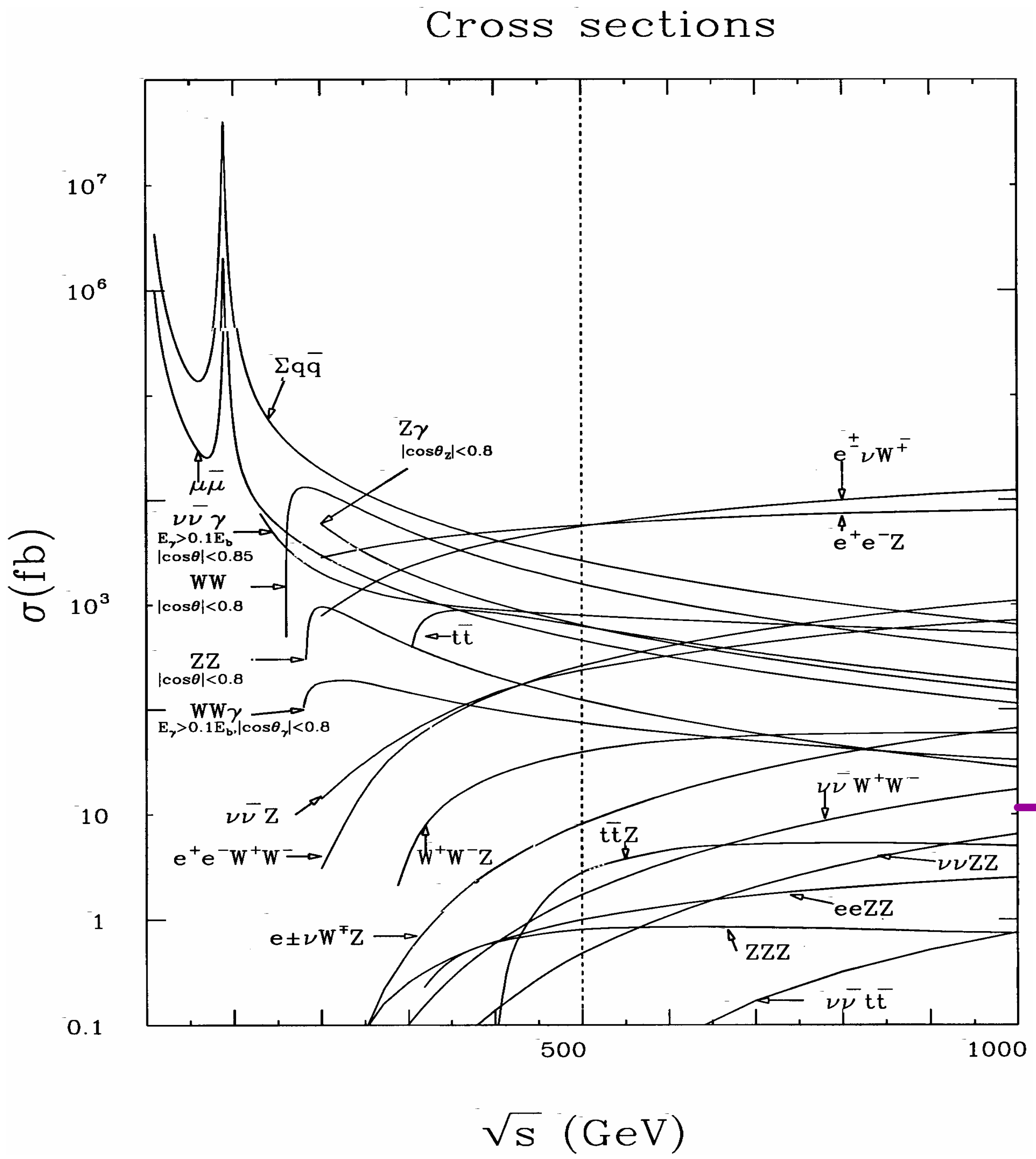
Linear Collider Physics Measurements

- Introduction
- Tevatron/LHC
- LC Detector
- Higgs Measurements
- SUSY
- Smuons/Selectrons
- WW Scattering
- Summary



Linear Collider

L ~ $1*10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

For one year = 10^7 s

? **Ldt =** $10^{41}\mathrm{cm}^{-2}$

= $100\ \mathrm{fb}^{-1}$

1000 events/yr

$\bar{p}p$ SM Higgs Production

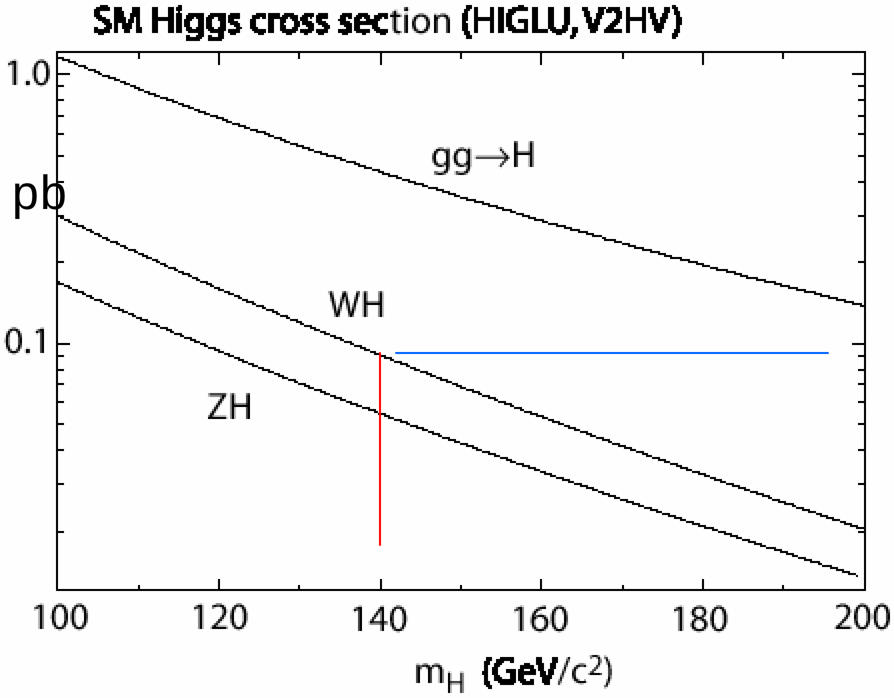


Figure 2: The production cross section in picobarns for the standard model Higgs boson in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. These cross sections are based on a calculation by T. Han and S. Willenbrock[3].

σ_{WH} (140) = 0.09 pb.

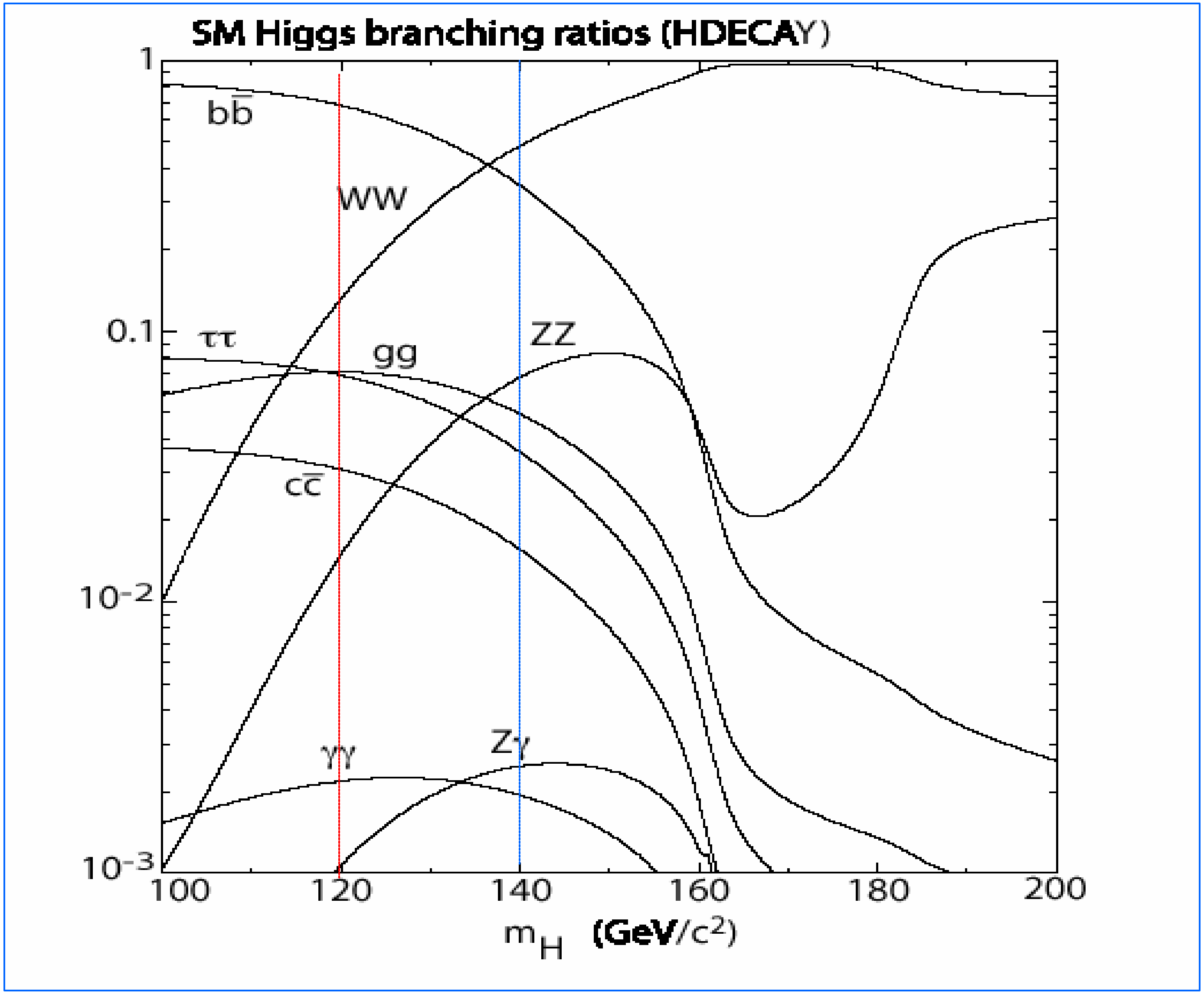
σ_{WH} x BR(e, μ, τ) x 1 fb^{-1} x ε

~ 0.8 events

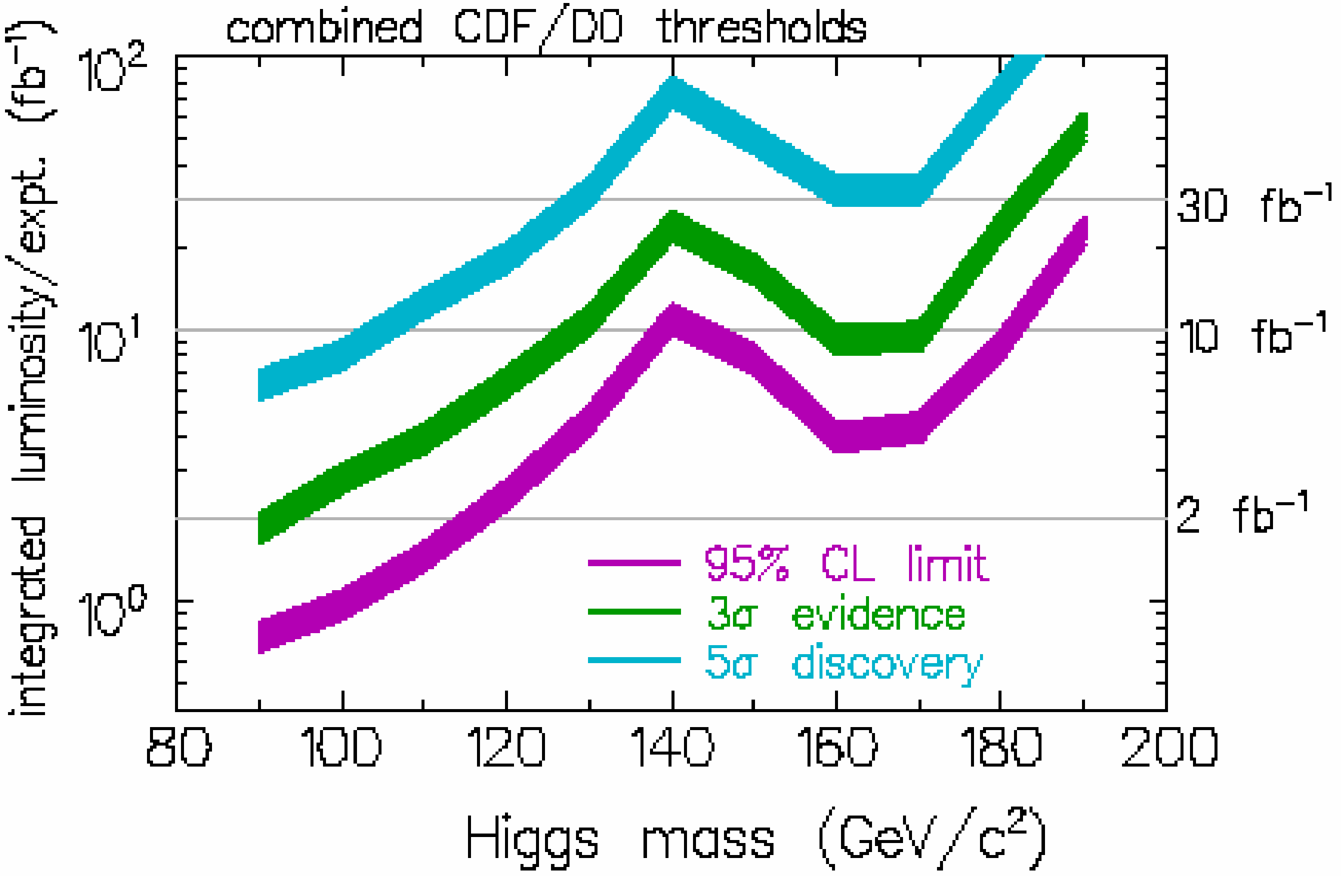
Efficiencies: (%)

e, μ, τ	43	7.8%
missing Et	89	
jet sel.	80	
kine. sel.	82	
2 b-tags	31	

SM Higgs Branching Ratios



Tevatron Higgs Search Sensitivity '99



SM Higgs Exclusion, Evidence,Discovery 2003 CDF/D0 Collaboration

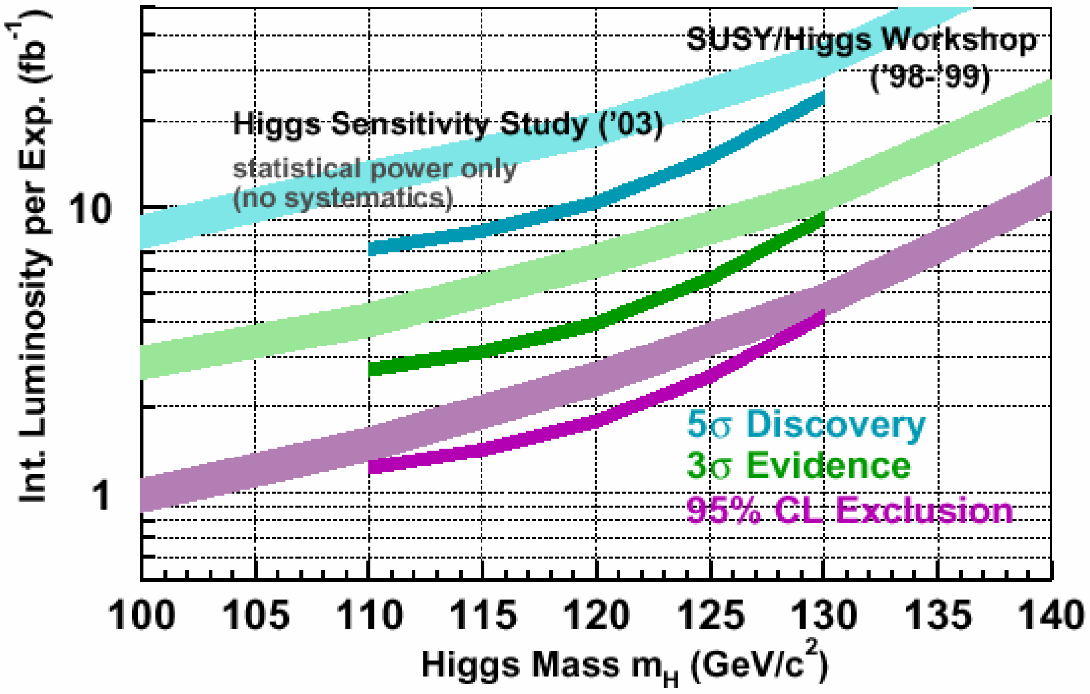
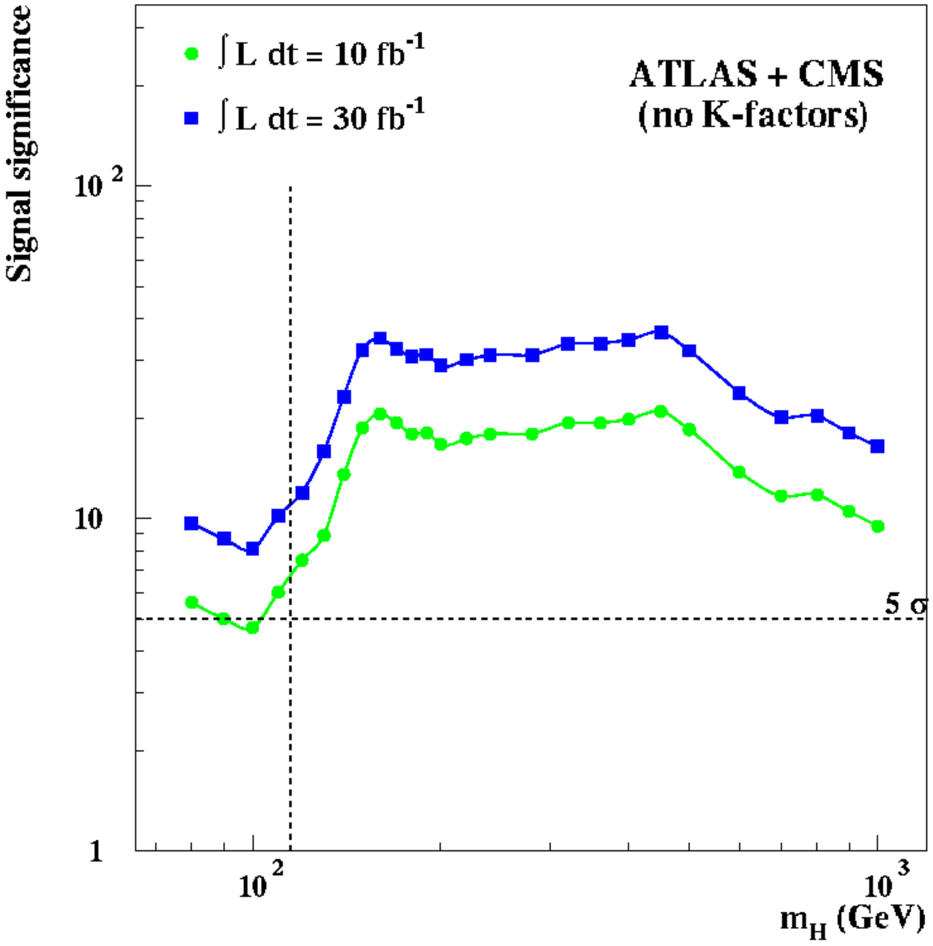


Figure 24: Integrated luminosities per experiment corresponding to the median expectations for 95% confidence level exclusion, 3σ evidence and 5σ discovery for $m_H = 110-130$ GeV/c^2. The narrow curves are the updated analysis from this study (2003) and the thicker curves are the results from the previous SHWG Study (1999).

LHC and the SM Higgs

Discovery in full mass range with 10 fb^{-1}



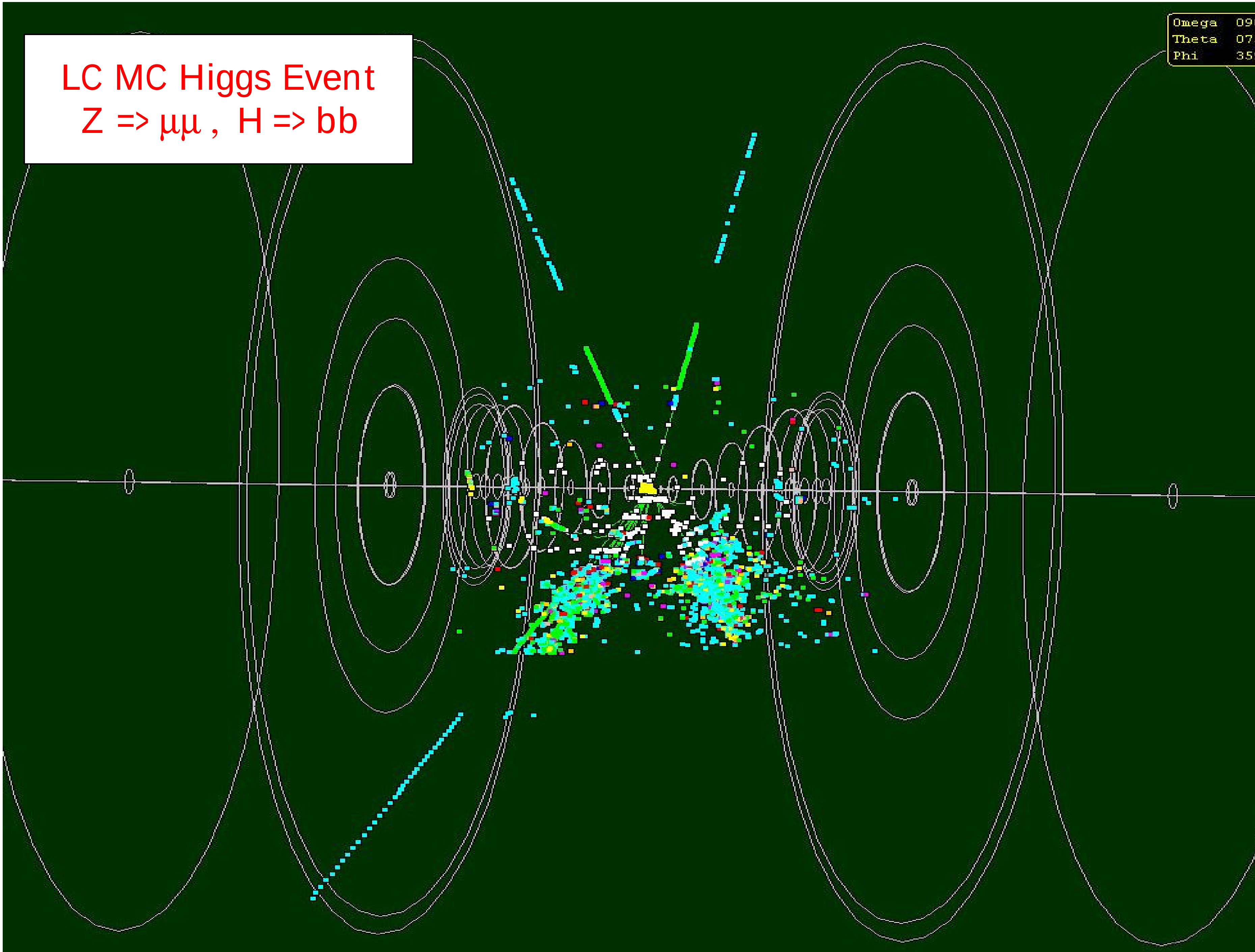
LHC

- $\Delta M/M$ = 0.1-1% large region
- $\Delta\Gamma/\Gamma$ = 5-8% ($M_H > 2M_Z$)
  = ~20% ($M_H < 2M_Z$)
- Ratios of couplings: 10-20%

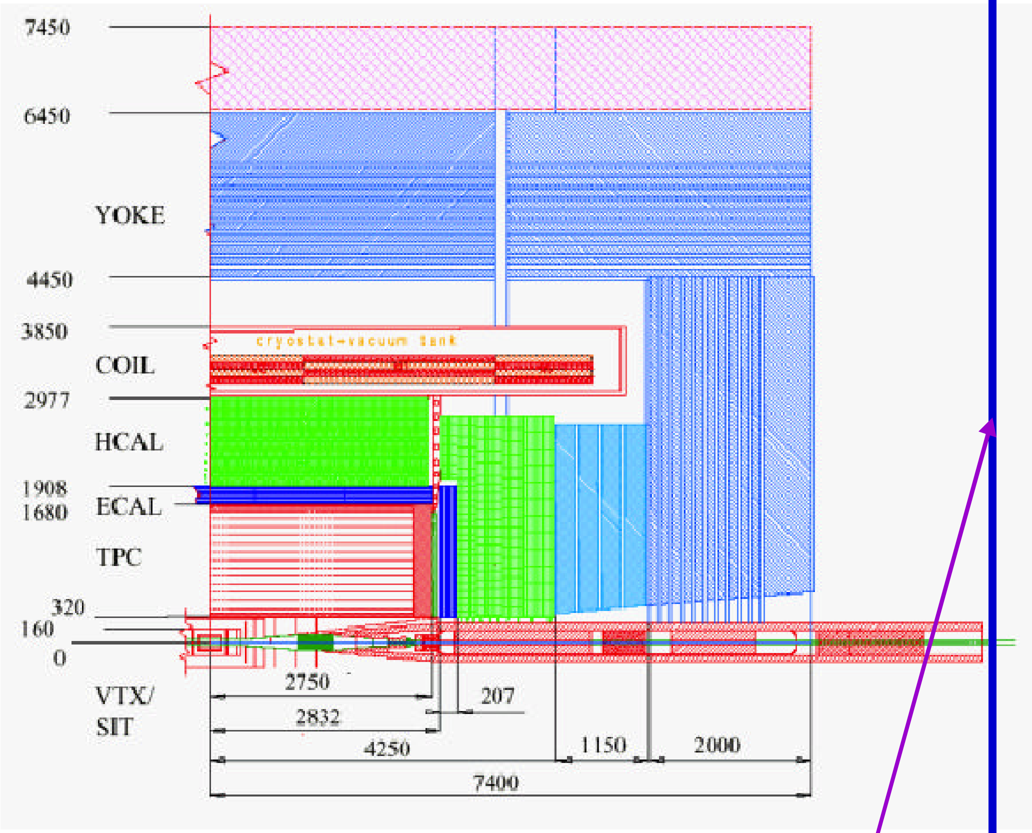
Albert de Roeck

Fermilab Talk October ‘03

LC MC Higgs Event
Z => μμ , H => bb



TESLA Detector



Dimensions in mm

Big R&D program w/ significant sci. personnel needs.

DETECTOR TECHNOLOGY OPTIONS:

VTX Detector

Charged Coupled Devices: 800Mpix

Monolithic Active Pixels (CMOS) ...

Barrel Tracking

Time Projection Chamber; Si Drift Det.

Jet chamber; Si Strip Det.; Read-out

EM Calorimeter

Si-W, Crystals

Pb-Scintillator: Strips/Tiles w fiber r.o.

Hadron Calorimeter

SS/w Scintillator strips/ tilees/ fiber;

SS/w RPC r.o.; SS/w GEM r.o.

Superconducting Solenoid

4 or 5 T

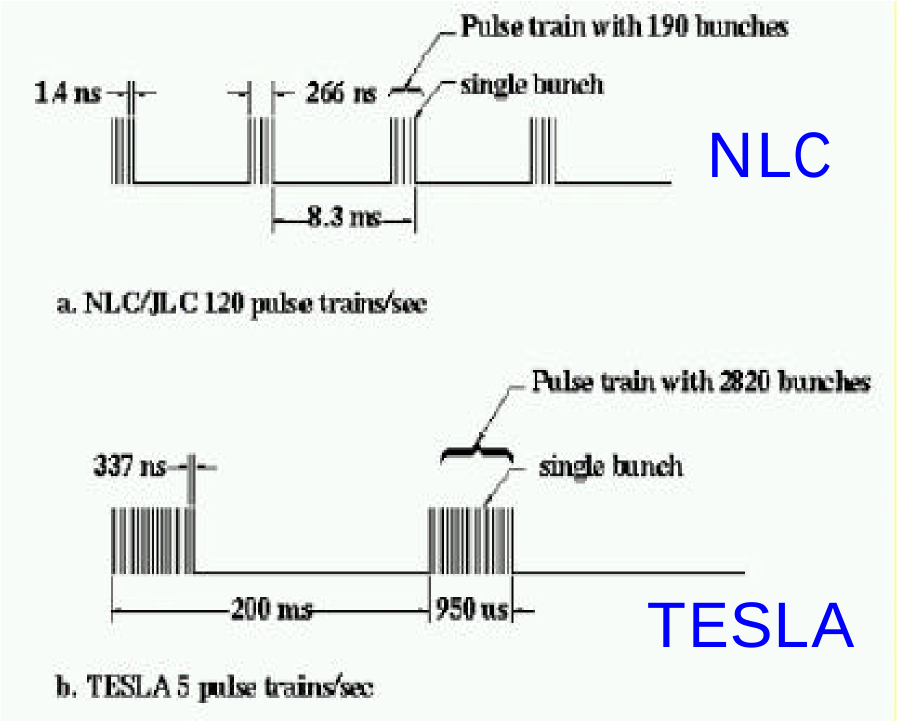
Muon Detectors/Fe Return Yoke

Resistive Plate Chambers;

Scintillator strips w/fiber r.o.

Simulation Software

Beam: Time Structure



- NLC 11.4 GHz; JLC 5.7 GHz

  1.4 ns between single bunches;

  ~ 16 empty RF buckets

  190 bunches = 266 ns = pulse train.

  8.3 ms = 1st bunch of ea train Δt

  0.75 X 10^{10} e's/bunch implies about 6 MW per beam.

- TESLA 1.3 GHz

  337ns between single bunches;

  ~ 440 empty RF buckets

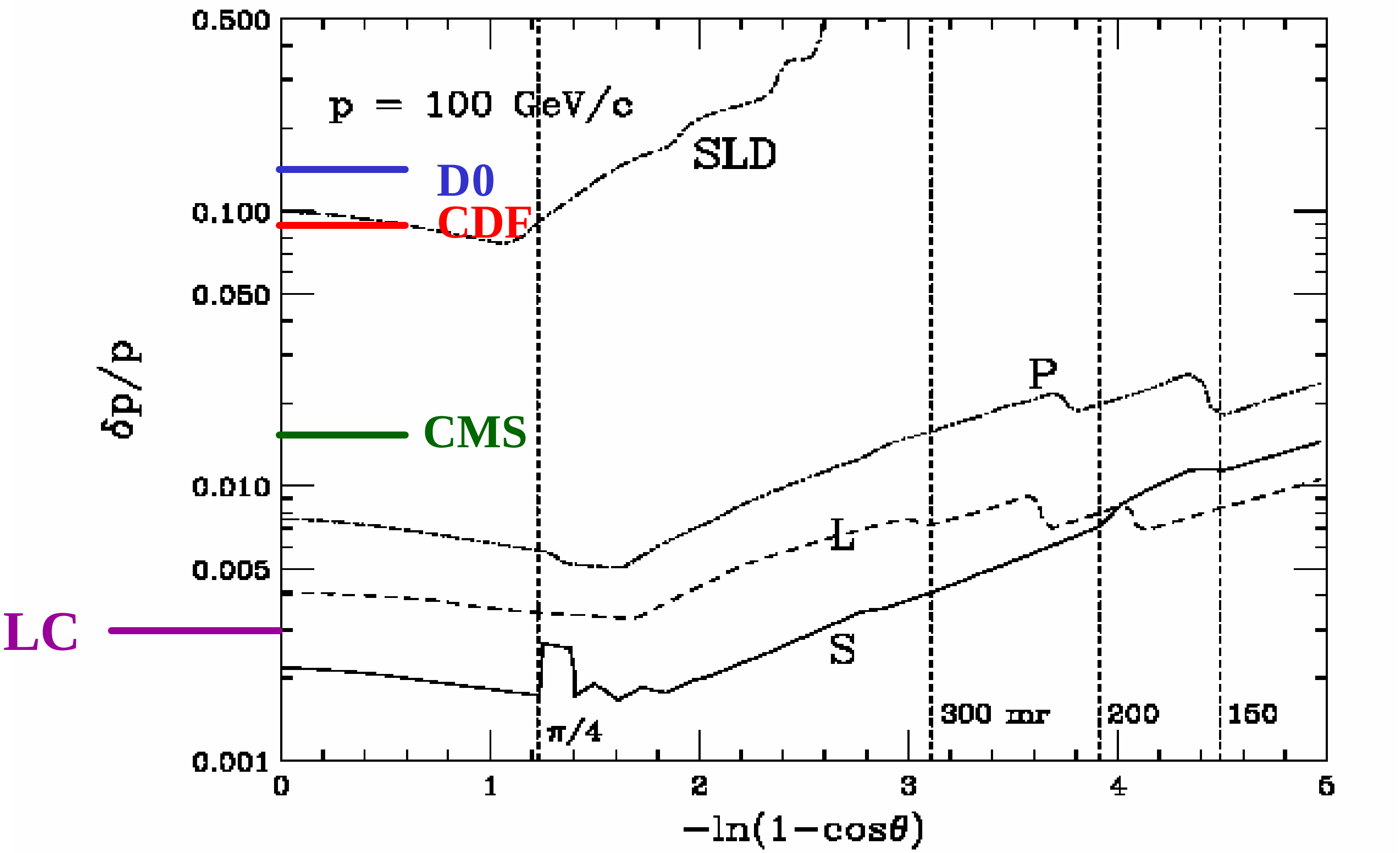
  2820 bunches = 950 μs = pulse train

  200 ms = 1st bunch of ea train Δt

  2 X 10^{10} e's/bunch implies about 10 MW per beam.

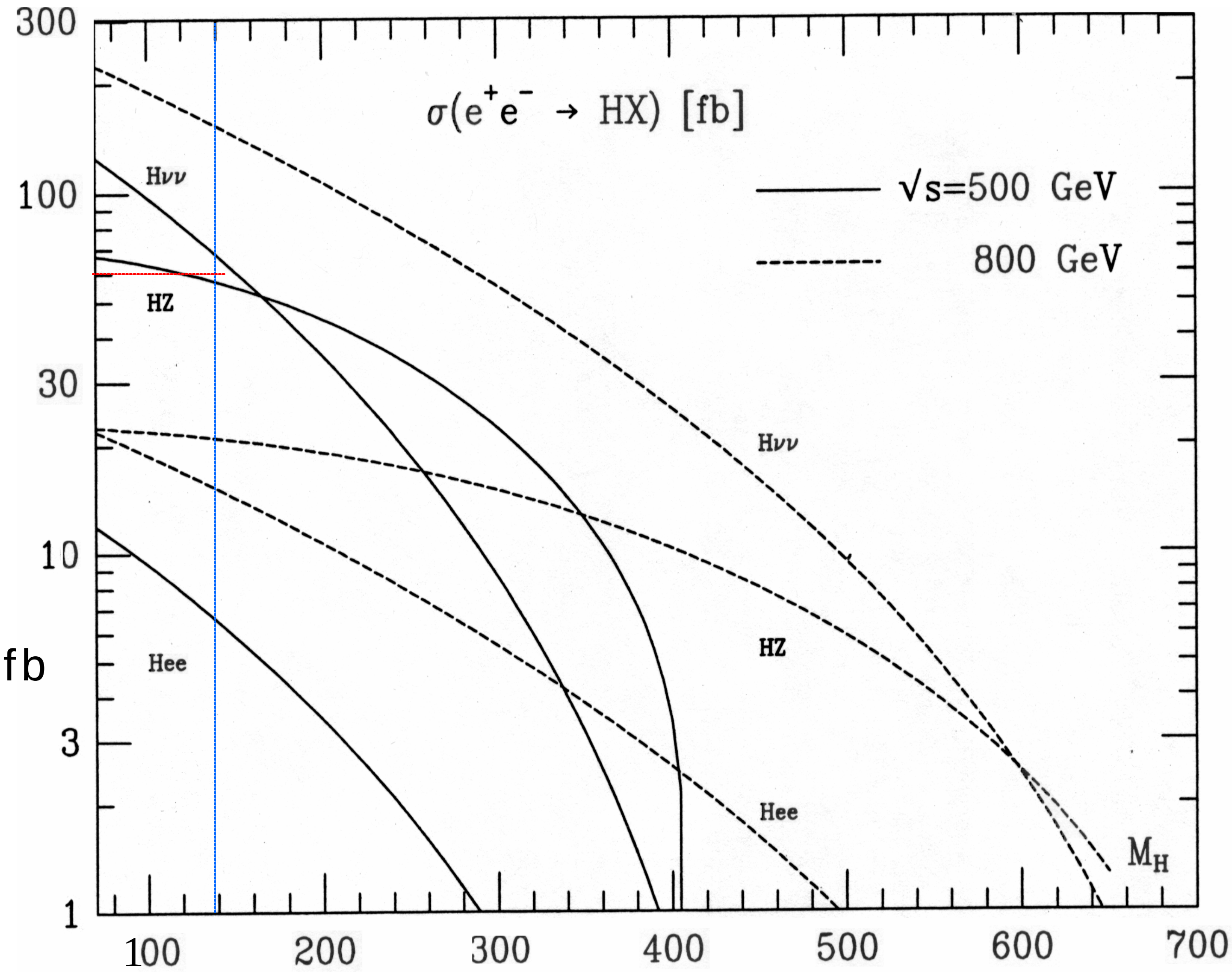
Momentum Resolution (NLC design)

p = 100 GeV/c

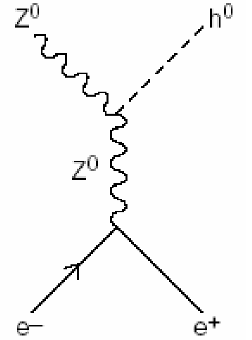


e^+ e^- SM Higgs Production

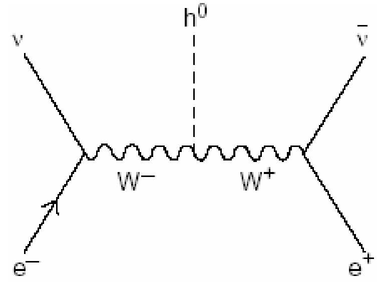
From J. Bagger et al, The Case for a Linear Collider ..



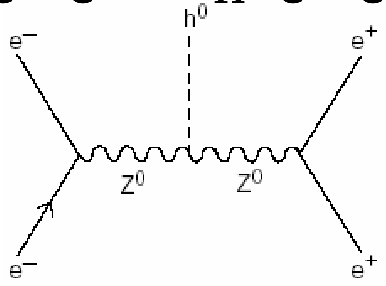
e+ e^- => Z h^o



e+ e^- => h^o ν ν



e+ e^- => h^o e+ e^-



For M_H = 140 GeV:
100 fb^{-1}/yr * 120 fb
12,000 evts x e x BR

LC Higgs

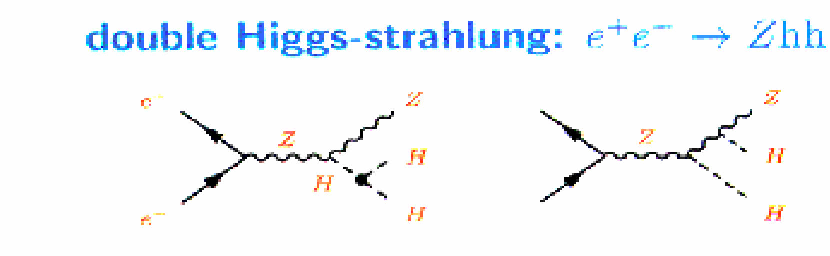
Three requirements to claim a Higgs:

1. Observe a neutral scalar particle: $h^0 \Rightarrow f + \bar{f}$ (LHC) and measure its mass well (LHC and LC). In LC one can use the recoil against the Z as a constraint. $\Delta M_h / M_h$ = 0.1 – 1%, 0.03%

2. Show that its branching ratios are proportional to mass.

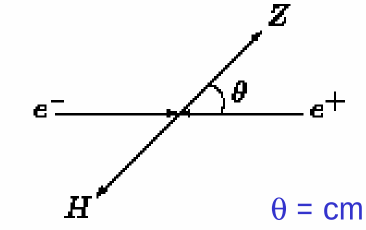
e.g. in the SM relative rates for $h^0(120) \Rightarrow$ b, c, τ pairs should be 72% : 3% : 7%. Done to ~ 20% at LHC ; few % at LC. LC can also measure the rate of H Z($\nu\nu$).

3. Measure the Higgs self coupling:


double Higgs-strahlung: $e^+e^- \to Zhh$

Castanier et al hep-ex/0101028

Beam Pol.



θ = cm production angle;

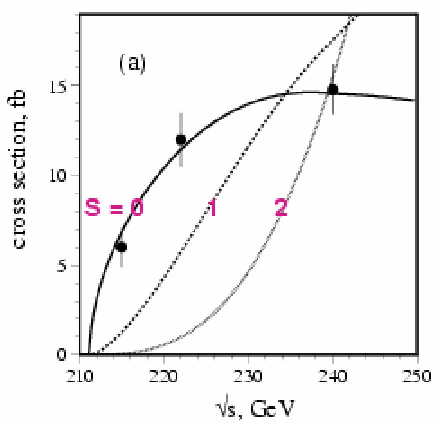
f = fermion decay angle in Z frame

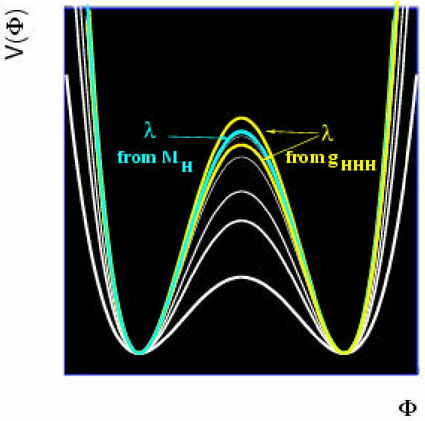
	$J^P = 0^+$	$J^P = 0^-$
dσ/dcosq	$\sin^2 q$	$(1 - \sin^2 q)$
dσ/dcosf	$\sin^2 f$	$(1 +/- \cos f)^2$

Threshold behavior of the cross section is sensitive to spin.

(Dova, Garcia-Abia, Lohmann Jeju Proc. 2002)

m_H = 120 GeV →





Use 6 jets; requires excellent jet energy resolution; can enhance σ's with positron polarization. Determine: Δλ/λ to ~20 – 30% in 1000 fb^{-1}

$M_H^2 = 4 l v^2$; $g_{HHH} = 6 l v/\sqrt{2}$

Making these measurements requires …

a. Superb vertex detection: 5μ space pts., secondary vertex definition. Si detector R&D

b. Momentum resolution:

$\Delta p/p = 0.5\%$ mass resolution @ 100 GeV/c. Low mass Si

c. b, c separation w/high purity and high eff.: e.g. BR meas. Requires a. & b. Particle ID?

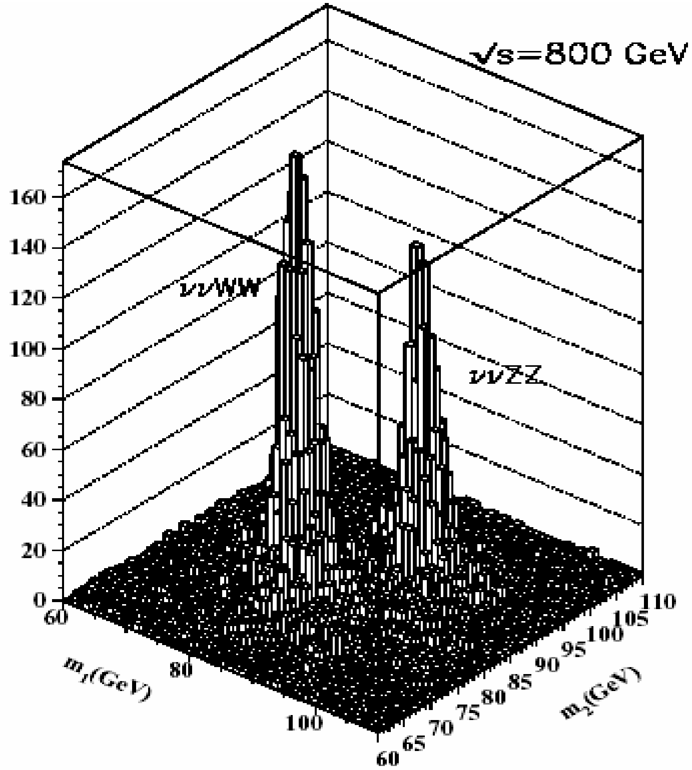
d. Calorimetry with the ability to separate W/Z → j_1 j_2:

E-flow algorithm, Simul. &TB

B = 5T, Small R_m. 5T = R&D

e. Elimination of backgrounds.

R. Chierici, S. Rosati, M. Kobel



TESLA LC-PHSM-2001-038

Higgs: low mass meas. simulation

Battaglia & Desch hep-ph/0101165

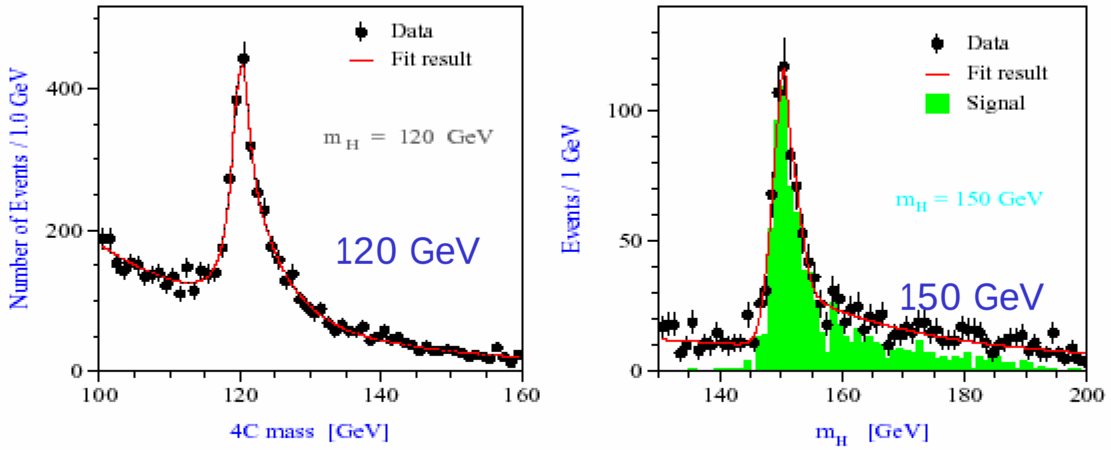


FIGURE 2. The Higgs boson mass reconstructed in the $H^0 \to b\bar{b}$, $Z^0 \to \ell^+\ell^-$ channel for M_H=120 GeV (left) and in the $H^0 \to WW^*$, $Z^0 \to \ell^+\ell^-$ channel for M_H=150 GeV

$$e^+ + e^- \rightarrow Z + H^o\ ;\ Z \rightarrow l^+ + l^-\ ;\ H^o \rightarrow b + \bar{b}$$

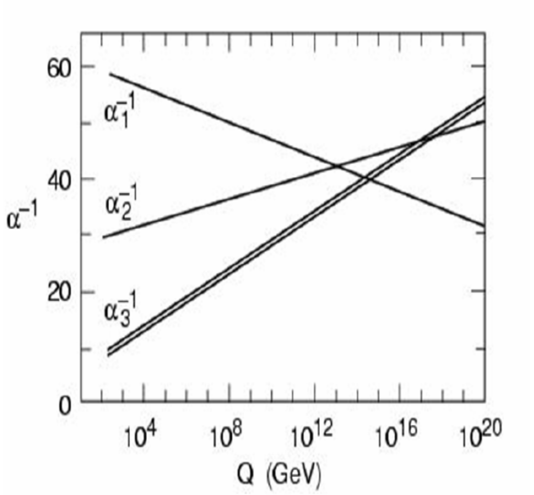
The analysis of Higgs mass and BR's depends heavily on tagging b's and the determination of jet energies. The jet energy resolution depends on detector design and whether the energy-flow algorithm works. This requires prototype detector tests with beams and a thorough understanding of how the beam tests couple jet energy resolution. R&D: Tracking, Calorimetry, Simulation, Test beam meas.

Not the only worry: Theory

The single Higgs SM is consistent with the present data, but the theory is not complete:

1. Calculations of M_H are unstable to quantum corrections. Radiative corrections at the Planck scale require phenomenal cancellation – to something like 30 decimal places (the hierarchy problem).

Gauge interaction unification doesn't occur.



2. The EW symmetry breaking could be induced by fundamental scalar fields (Higgs) or composite objects (not a Higgs).

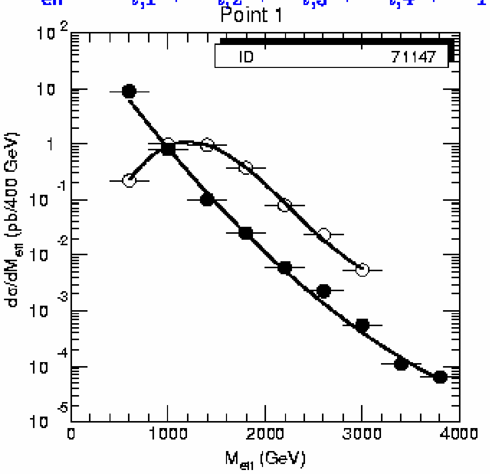
A plausible extension, that can embed the SM is Supersymmetry; all particles have a super-partner with complementary spin. There are two complex Higgs doublets f_1, f_2 to give mass separately to up- and down-type fermions. EWSB gives the W/Z masses and there are 5 Higgs states: **h^0**, **H^0** (scalars), **A^0** (pseudoscalar) and **$H^\pm$** (charged Higgs). The ratio $\langle f_1 \rangle / \langle f_2 \rangle$ = tanb is an unknown parameter, along with masses of fundamental scalars, spin ½ states, etc.

SUSY at the LHC

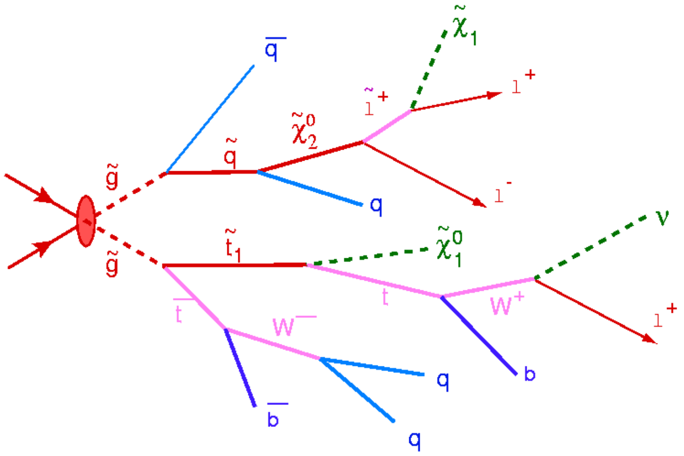
Particle	**SUSY Partner**
electron e	selectron e (J=0)
muon m	smuon m ”
quarks q	squarks q ”
gluons g	gluinos g (J= ½)
etc.	

CERN will find SUSY cascade decays as an excess of events at large M_{eff} or large missing Et.

$$M_{\rm eff} = P_{t,1} + P_{t,2} + P_{t,3} + P_{t,4} + E_T$$



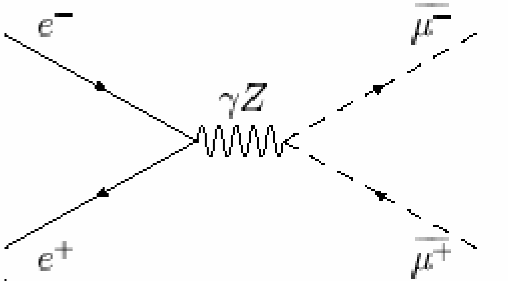
Untangling SUSY states w/H.C. can be tough.



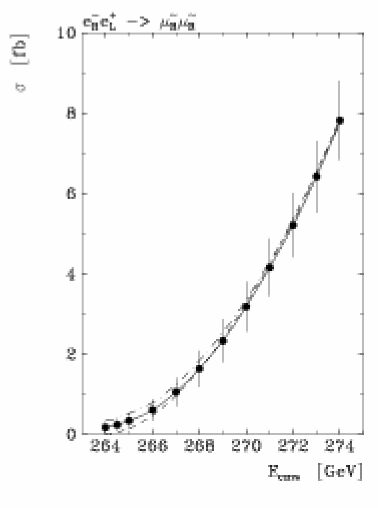
3 isolated leptons
+ 2 b-jets
+ 4 jets
+ E_t^{miss}

photon g	photino g (J= ½)
Z	zino Z ”
Higgs f_1	Higgsino f_1 ”
Higgs f_2	Higgsino f_2 ”
W	Wino W ”
H	Higgsino H ”

SUSY: Smuons



Production of m_R **, partner of the right-handed muon, via** $e^+e^-?\ \tilde{m}_R^+\tilde{m}_R^-$.
Production of scalar smuon pairs is p-wave which leads to a b³ threshold cross section that can be measured once the mass is known.



H. Marten, G. Blair hep-ph/9910416

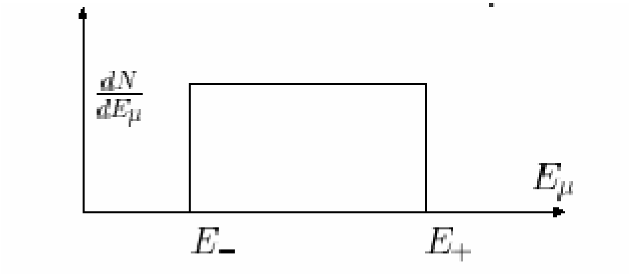
Because the spin of the smuon is 0 its decay to a μ and neutralino χ is isotropic in the rest frame of the smuon and because the smuon's momentum is fixed in the lab, the energy distribution of the μ is uniform with E± given by:

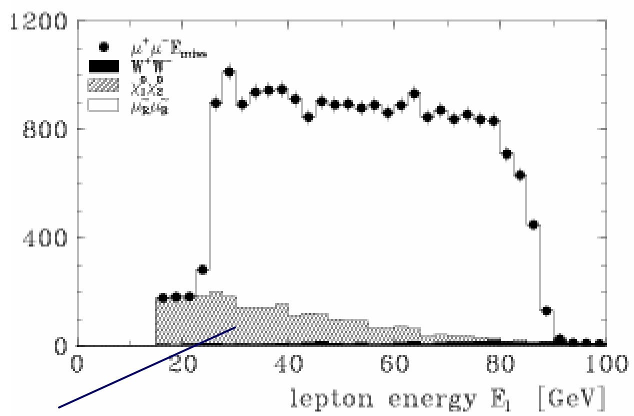
$E\pm = (vs/4)\ (1 \pm \beta)\ (1 - m_{\tilde{m}}^2/m_c^2)$;

$\beta = (1 - 4m_{\tilde{m}}^2/s)^{1/2}$

Such measurements depend on:

1. Polarization of the e^+ and e^- beams.
2. Clean environment.
3. 4π coverage.





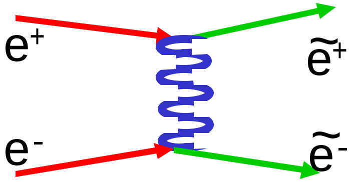
Neutralino bkgd.

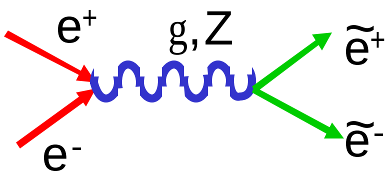
SUSY: Selectrons

Production of selectron pairs involves two diagrams:

(1) t-channel c^0 exchange dominates and allows measurement of neutralino couplings (gaugino vs. higgsino) to lepton/slepton.

(2) s-channel g/Z process only for $e_L^+ e_L^-$ and $e_R^+ e_R^-$. Bkgnd WW suppressed for beam e_R^- .

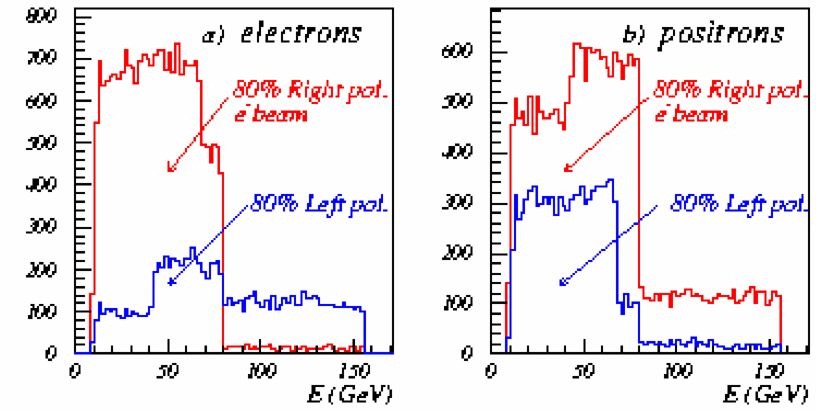




End point measurements for selectrons are complicated since $\tilde{e}_R^+\tilde{e}_R^-$, $\tilde{e}_R^+\tilde{e}_L^-$, $\tilde{e}_L^+\tilde{e}_R^-$, & $\tilde{e}_L^+\tilde{e}_L^-$ states appear simultaneously.

Upper and lower end points of the decay dN/dE from: $e_{L,R}$ ®˜ $e\,\tilde{\mp}\,c_1^0$ gives masses for the L, R selectrons and neutralino. Angular distribution of decay electrons with polarized beams give quantum numbers and coupling of exchanged $c_1^0$and give information on neutralino mixing.

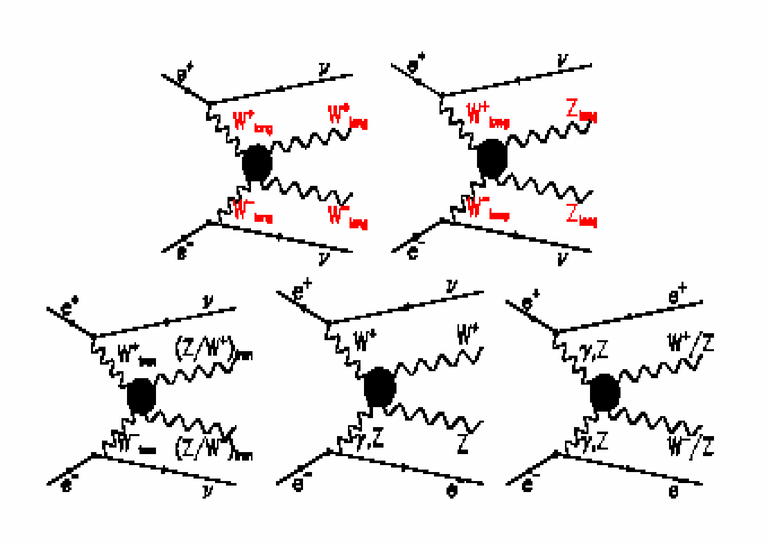
e distributions for both beam e^- polarizations

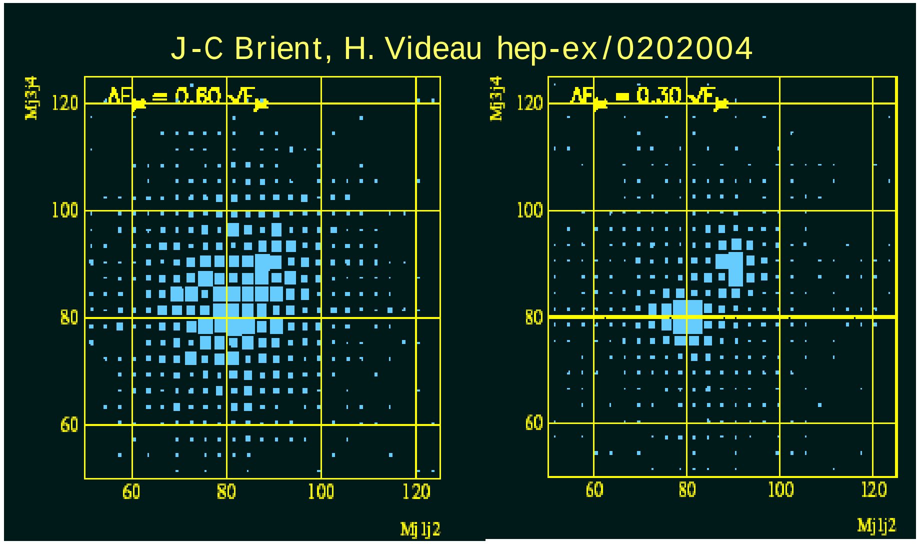


R&D Issues: Polarized e+ beam; bkgd control.

M. Dima LCWS_2000 Proc. P. 461

WW Scattering/Strong Coupling

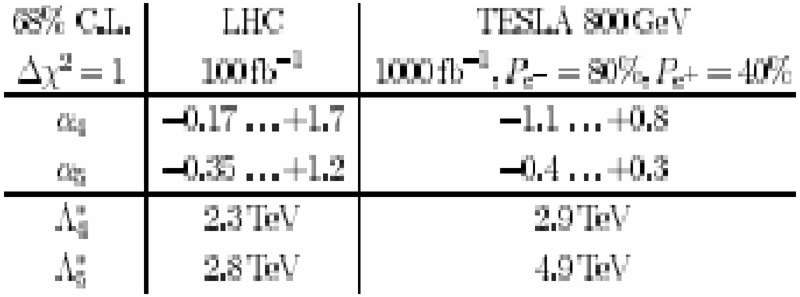



J-C Brient, H. Videau hep-ex/0202004

See articles by C. Burgard ( ); T. Barklow, Dawson, Haber & Siegrist in Snowmass 1996 Proc. also T. Barklow LCWS_2000 Proc., p 568

If there is Strong Coupling we expect to see modifications to SM cross sections through longitudinally polarized WW and ZZ scattering. Two 4-dimensional interactions can be introduced in the Lagrangian that respect SU(2) and describe the longitudinal boson scattering. These anomalous couplings, α_4 and α_5 = 0 in the SM. For new physics at Λ_i the values of α_i are determined from:

$\alpha_i/(16\pi^2) = (v/\Lambda_i^*)^2$, for $\Lambda_i \sim 1$TeV, $\alpha_i = 9.6$



68% C.L. $\Delta\chi^2 = 1$	LHC $100\,\mathrm{fb}^{-1}$	TESLA 800GeV $1000\,\mathrm{fb}^{-1}$, $P_{e^-} = 80\%$, $P_{e^+} = 40\%$
α_4	$-0.17 \ldots +1.7$	$-1.1 \ldots +0.8$
α_5	$-0.35 \ldots +1.2$	$-0.4 \ldots +0.3$
Λ_4^*	2.3 TeV	2.9 TeV
Λ_5^*	2.8 TeV	4.9 TeV

R. Chierici, et al. ibid.

WW Scattering/Strong Coupling - II

For the anomalous magnetic moment of the W ($\Delta\kappa_{\gamma,Z}$), the LC at 500 GeV with 1000 fb^{-1} has 10-20 times better precision than the LHC for various Strong Coupling models.

$\gamma\gamma \to$ WW gives orthogonal information of comparable precision.

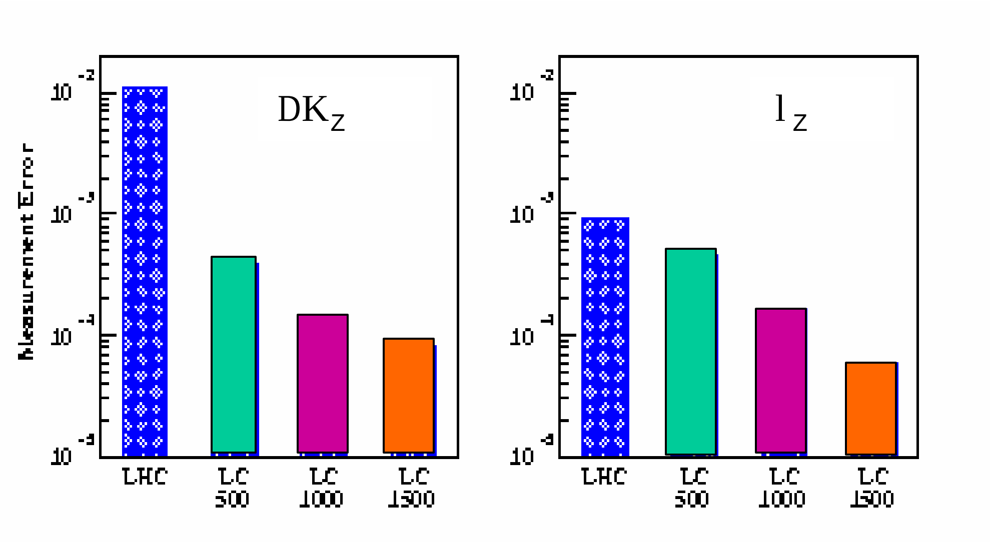
Requires:

? Ldt = 1000 fb^{-1}

Excellent calorimetry

Tracking

Elimination of Backgrounds



Summary

- Many precise measurements can be done with a linear collider to understand:

  Electroweak Symmetry Breaking

  Higgs discovery – what kind of Higgs? BRs, masses,

  b,c tagging, top, etc. R&D implications

  If SUSY, then untangling observations requires:

  polarization, understanding backgrounds, ….

  Strong coupling.
- R&D Areas: Accelerator and detector instrumentation, accelerator components, detector development for all systems: vertex detector, tracking, calorimetry, muons, SC solenoid, simulation and analysis software, beam tests, etc.
- We must continue to forge international collaboration on the R&D, proposal development and construction of accelerator and detector components.
- We understand our scientific goals and what the LC will be able to do. We must convince our scientific colleagues and government officials to support this science.