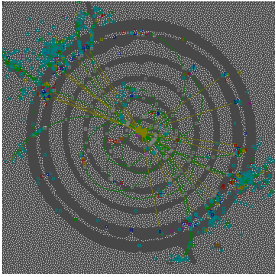


Electroweak Physics and the International Linear Collider



Jim Brau

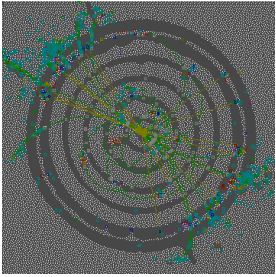
April 18, 2007



Electroweak Physics and The International Linear Collider



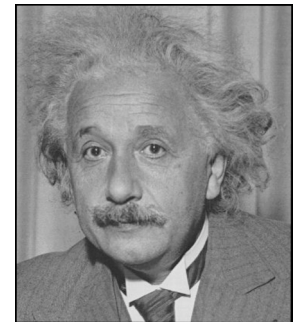
- **Electroweak Physics**
 - ✚ **Development of theory**
 - ❖ unification of E&M with beta decay (weak interaction)
 - ✚ **Predictions**
 - ❖ eg. M_W , M_Z , asymmetries....
 - ✚ **Missing components**
 - ❖ origin of symmetry breaking (Higgs Mechanism)
- **The Hunt for the Higgs Boson**
 - ✚ **Limits, indirect constraints and on-going search at TeVatron and LHC**
- **The International Linear Collider**
- **ILC physics program**

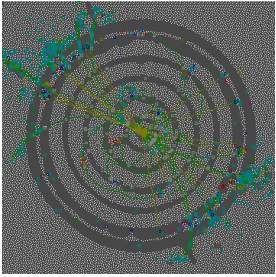


Electroweak Symmetry Breaking



- A central focus of particle physics research today is the origin of Electroweak Symmetry Breaking
 - ⇒ The weak nuclear force and the electromagnetic force have been unified into a single description $SU(2) \times U(1)_Y$
 - ⇒ Why is this symmetry hidden?
 - ⇒ The answer to this appears to promise deep understanding of fundamental physics
 - ❖ the origin of mass
 - ❖ supersymmetry and possibly the elements of dark matter
 - ❖ additional unification (strong force, gravity) and possibly hidden space-time dimensions

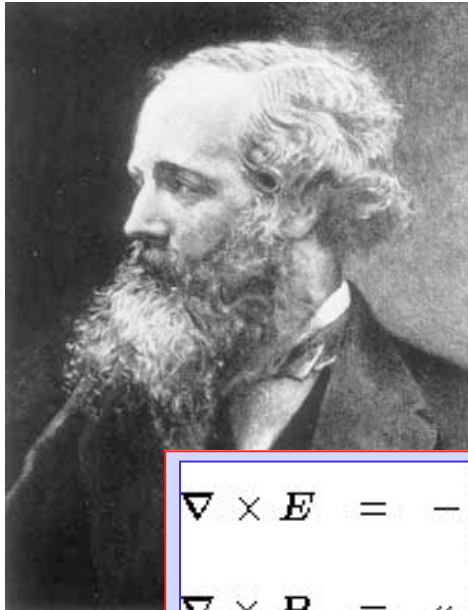




Electromagnetism and Radioactivity



- Maxwell unified Electricity and Magnetism with his famous equations (1873)

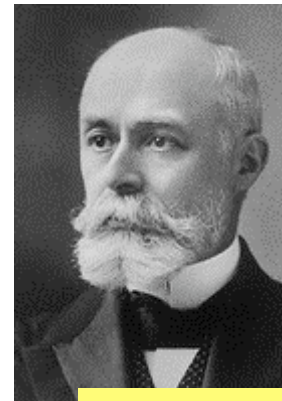
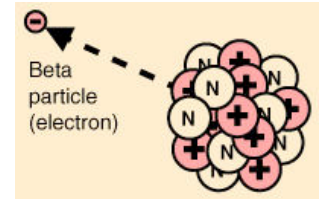


$$\begin{aligned}\nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{B} &= \mu_0 \mathbf{J} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t} \\ \nabla \cdot \mathbf{E} &= \rho / \epsilon_0 \\ \nabla \cdot \mathbf{B} &= 0\end{aligned}$$

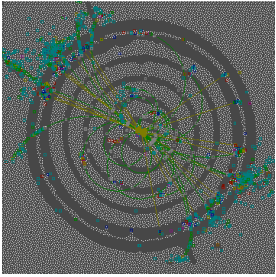
- Matter spontaneously emits penetrating radiation

↳ Becquerel uranium emissions in 1896

↳ The Curies find radium emissions by 1898



**This new interaction
(the weak force)
is related to E&M**

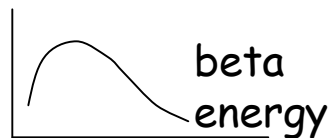


Advancing understanding of Beta Decay

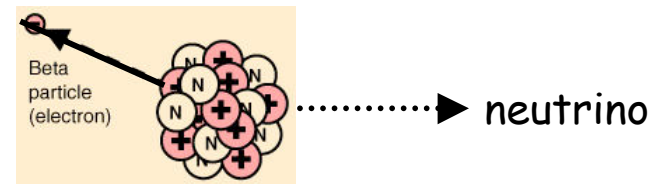


- Pauli realizes there must be a neutral invisible particle accompanying the beta particle:

↪ the neutrino

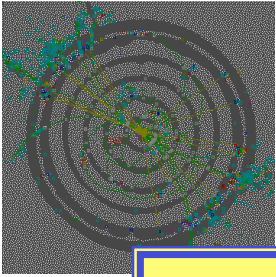


- Fermi develops a theory of beta decay (1934)



- 1956 - Neutrino discovered
Reines and Cowan
- Savannah River Reactor, SC



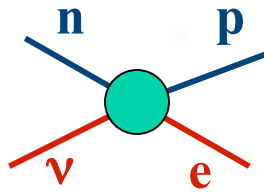


EM and Weak Theory in 1960



Weak Interaction Theory

- Fermi's 1934 pointlike, four-fermion interaction theory

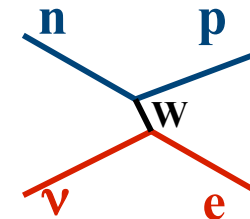

$$M = G J_{\text{baryon}}^{\text{weak}} J_{\text{lepton}}^{\text{weak}} = G (\bar{\psi}_p O \psi_n) (\bar{\psi}_e O \psi_\nu)$$
$$W = \frac{2\pi}{\hbar} G^2 |M|^2 \frac{dN}{dE_0}$$

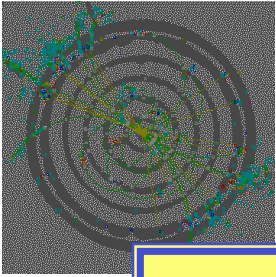
V-A



- Theory fails at higher energy, since rate increases with energy, and therefore will violate the “unitarity limit”

⇒ Speculation on heavy mediating bosons
but no theoretical guidance on what to expect





EM and Weak Theory in 1960



Quantum Electrodynamics (QED)

- Dirac introduced theory of electron - 1926
- Through the pioneering theoretical work of Feynman, Schwinger, Tomonga, and others, a theory of electrons and photons was worked out with precise predictive power
- example: magnetic dipole of the electron

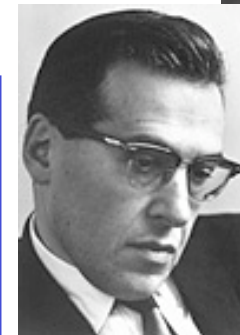
$$[(g-2)/2] \quad \mu = g (e\hbar/2mc) S$$

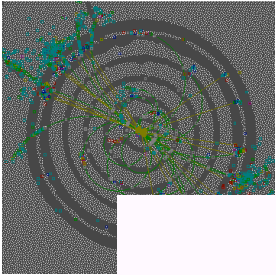
- current values of electron $(g-2)/2$

$$\text{theory: } 0.5 (\alpha/\pi) - 0.32848 (\alpha/\pi)^2 + 1.19 (\alpha/\pi)^3 + ..$$

$$= (115965230 \pm 10) \times 10^{-11}$$

$$\text{experiment} = (115965218.6 \pm 0.4) \times 10^{-11}$$





The New Symmetry Emerges



VOLUME 19, NUMBER 21

PHYSICAL REVIEW LETTERS

20 NOVEMBER 1967

¹¹ In obtaining the expression (11) the mass difference between the charged and neutral has been ignored.

¹² M. Ademollo and R. Gatto, *Nuovo Cimento* **44A**, 282 (1966); see also J. Pasupathy and R. E. Marshak, *Phys. Rev. Letters* **17**, 888 (1966).

bra is slightly larger than that (0.23%) obtained from the ρ -dominance model of Ref. 2. This seems to be true also in the other case of the ratio $\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma) / \Gamma(\gamma \gamma)$ calculated in Refs. 12 and 14.

¹⁴ L. M. Brown and P. Singer, *Phys. Rev. Letters* **8**, 202 (1967).

A MODEL OF LEPTONS*

Steven Weinberg†

Laboratory for Nuclear Science and Physics Department,
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

Leptons interact only with photons, and with the intermediate bosons that presumably mediate weak interactions. What could be more natural than to unite¹ these spin-one bosons into a multiplet of gauge fields? Standing in the way of this synthesis are the obvious differences in the masses of the photon and intermediate meson, and in their couplings. We might hope to understand these differences

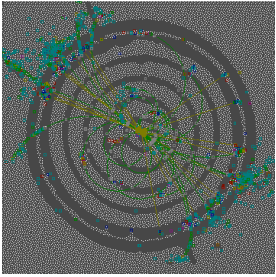
3*

67)

a right-handed singlet

$$R = [\frac{1}{2}(1 - \gamma_5)]e.$$





Enter Electroweak Unification



- Weinberg realized that the vector field responsible for the EM force
 - ↪ the photon
- and the vector fields responsible for the Weak force
 - ↪ yet undiscovered W^+ and W^-
- could be unified if another vector field, mediated by a heavy neutral boson (Z^0), were to exist
- This same notion occurred to Salam



$$L = g \mathbf{J}_\mu \cdot \mathbf{W}_\mu + g' J_\mu^Y B_\mu$$

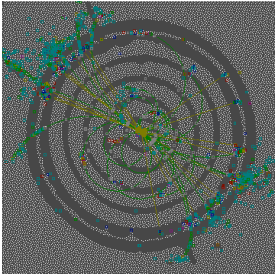
$$W_\mu^{(3)} = \frac{g Z_\mu + g' A_\mu}{\sqrt{g^2 + g'^2}} \quad B_\mu = \frac{-g' Z_\mu + g A_\mu}{\sqrt{g^2 + g'^2}} \rightarrow e J_\mu^{(em)} A_\mu$$

$$g'/g \equiv \tan \theta_W$$

$$\sin^2 \theta_W = g'^2 / (g'^2 + g^2)$$

$$e = g \sin \theta_W = g' \cos \theta_W$$

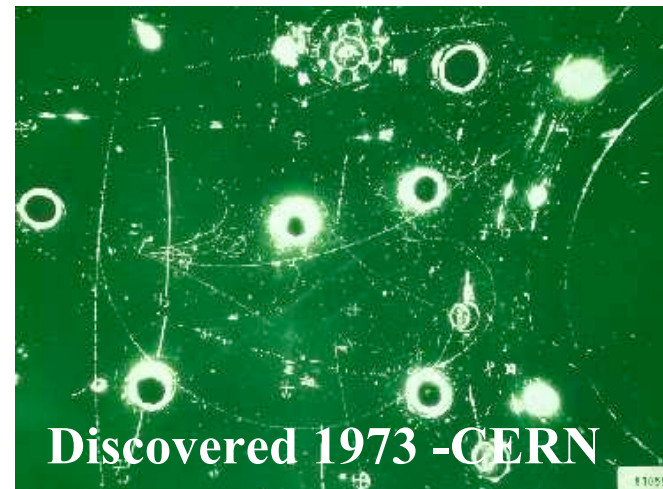
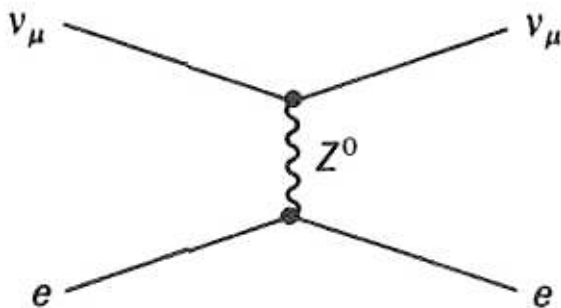


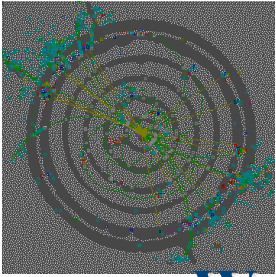


Electroweak Unification



- There remained a phenomenological problem:
 - ↪ where were the effects of the Z^0
- These do not appear so clearly in Nature
 - ↪ they are small effects in the atomic electron energy level
- One has to look for them in high energy experiments



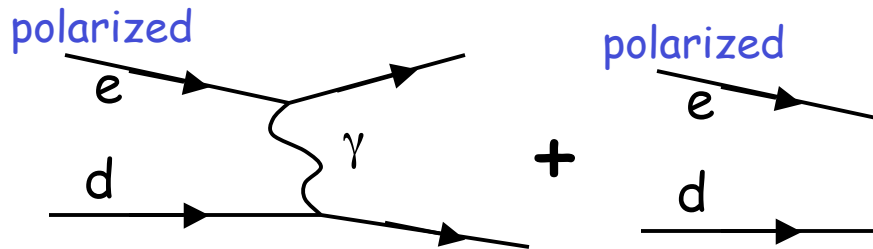


Confirmation of Neutral Currents

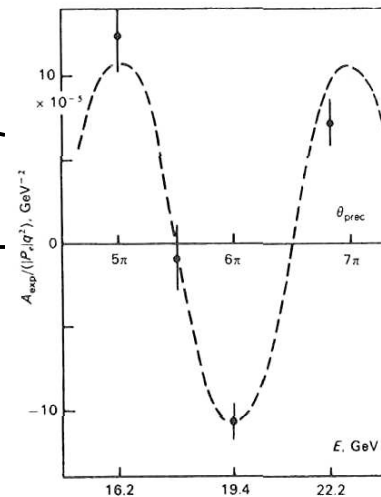


○ Weinberg-Salam Model predicts there should be some parity violation in polarized electron scattering

- ↪ The dominant exchange is the photon (L/R symmetric)
- ↪ A small addition of the weak neutral current exchange leads to an expected asymmetry of $\sim 10^{-4}$ between the scattering of left and right-handed electrons



- ↪ Prescott et al. (SLAC) 1978
- ↪ confirms theory
- ↪ first accurate measurement of weak mixing angle



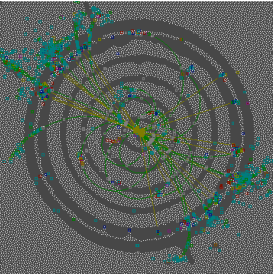
70 exchange violates parity

$$g_R \neq g_L$$

asymmetry of 10^{-4}



$$\sin^2 \theta_W = 0.22 \pm 0.02$$



W and Z Masses



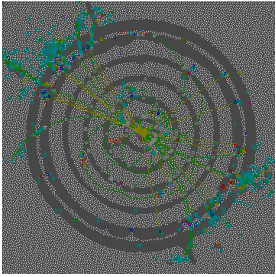
- Knowing $\sin^2\theta_W$ allows one to predict the W and Z boson masses in the Weinberg-Salam Model

$$M_{W^\pm} = \left(\frac{e^2 \sqrt{2}}{8G \sin^2 \theta_W} \right)^{1/2} = \frac{37.4}{\sin \theta_W} \text{ GeV} \quad \sim 80 \text{ GeV}/c^2$$

$$M_{Z^0} = \frac{M_{W^\pm}}{\cos \theta_W} = \frac{75}{\sin 2\theta_W} \text{ GeV} \quad \sim 90 \text{ GeV}/c^2$$

TREE LEVEL EXPRESSIONS

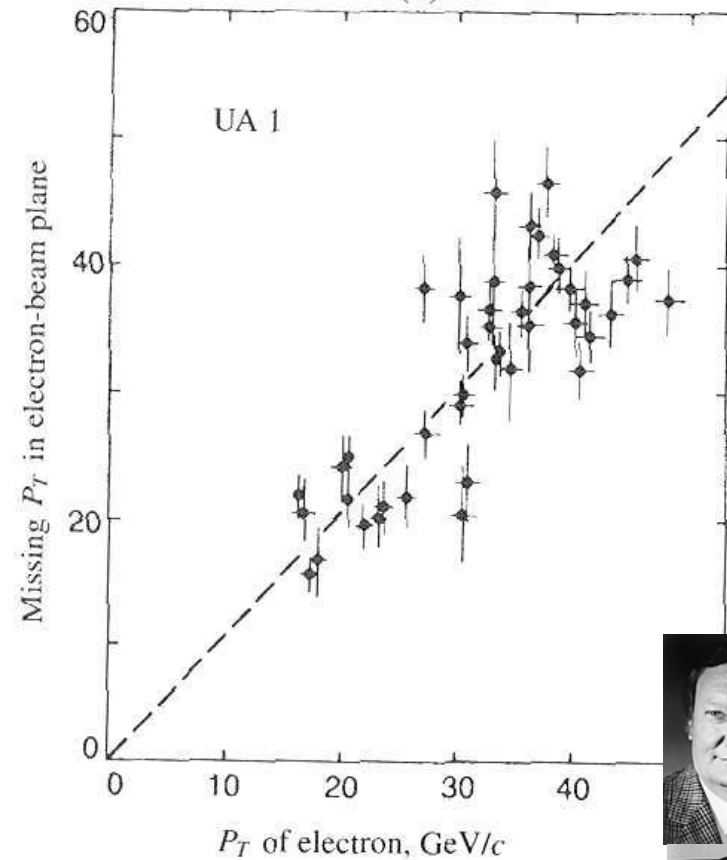
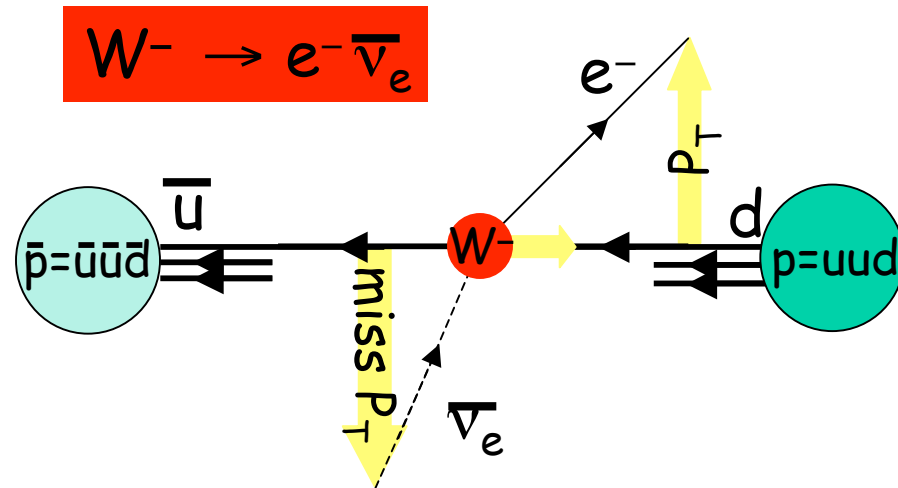
- Motivated by these predictions, experiments at CERN were mounted to find the W and Z



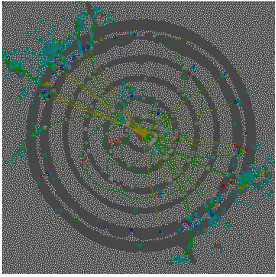
Antiprotons stored
at CERN in 1981



Discovery of the W and Z



UA1 and UA2 discovered the W and the Z bosons



Discovery of the W and Z

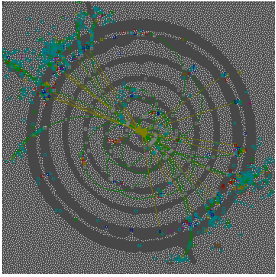


- That was over 20 years ago
- Since then:
 - ⇒ precision studies at Z^0 Factories
 - ❖ LEP and SLC
 - ⇒ precision W measurements at colliders
 - ❖ LEP2 and TeVatron

$$M_Z = 91187.6 \pm 2.1 \text{ MeV}$$

$$M_W = 80403 \pm 29 \text{ MeV}/c^2$$

- These precise measurements (along with other precision measurements) test the Standard Model with keen sensitivity
 - ⇒ eg. are all observables consistent with the same value of $\sin^2\theta_W$

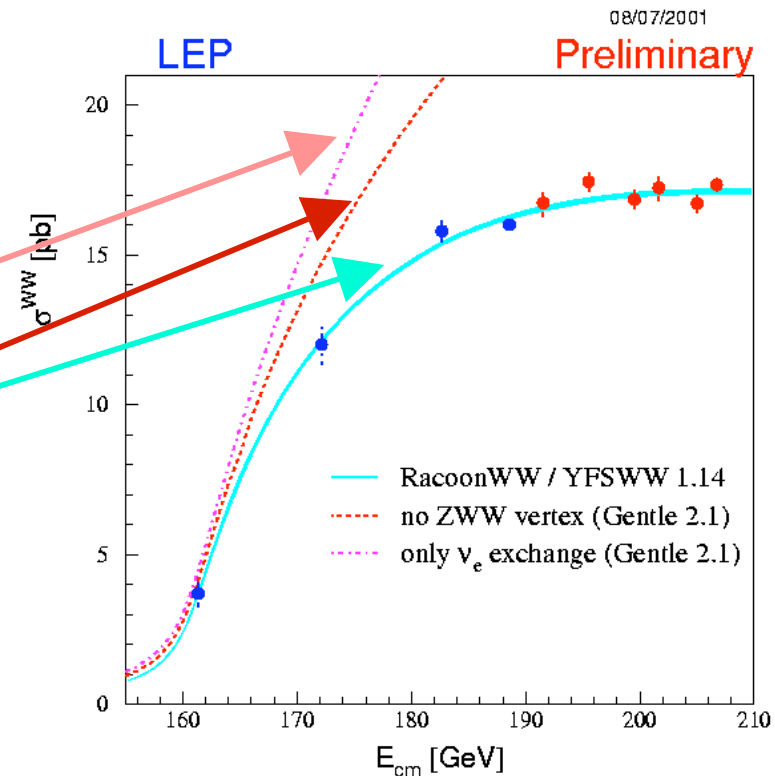
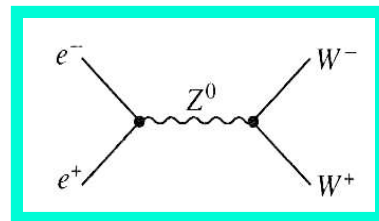
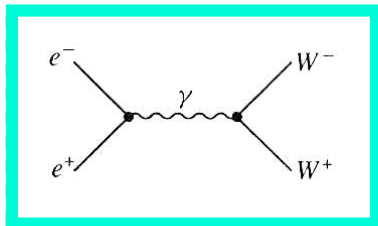
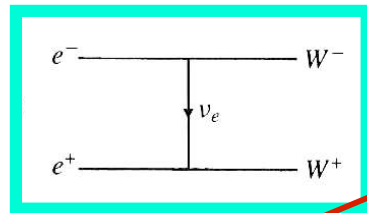


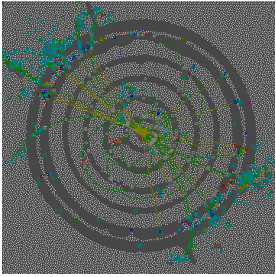
Electroweak Symmetry Breaking



Confirmation of the completeness of the Standard Model

$e^+e^- \rightarrow W^+W^-$ (LEP2)





The Higgs Boson

- Why is the underlying SU(2)xU(1) symmetry

$$L = g \mathbf{J}_\mu \cdot \mathbf{W}_\mu + g' J_\mu^Y B_\mu$$

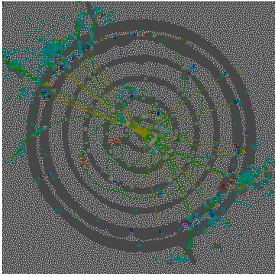
broken

$$= -\frac{g}{2\sqrt{2}} \sum_i \bar{\psi}_i \gamma^\mu (1 - \gamma^5) (T^+ W_\mu^+ + T^- W_\mu^-) \psi_i$$

$$- e \sum_i q_i \bar{\psi}_i \gamma^\mu \psi_i A_\mu$$

$$- \frac{g}{2 \cos \theta_W} \sum_i \bar{\psi}_i \gamma^\mu (g_V^i - g_A^i \gamma^5) \psi_i Z_\mu .$$

- Theoretical conjecture is the Higgs Mechanism:
a non-zero vacuum expectation value of a scalar field,
gives mass to W and Z and leaves photon massless

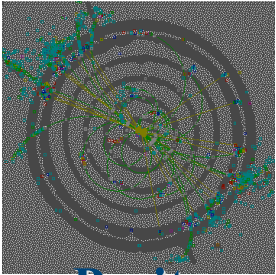


The Higgs Boson



- **This scalar field, like any field, has quanta, the Higgs Boson or Bosons**
 - ↪ **Minimal model - one complex doublet $\Rightarrow$ 4 fields**
 - 3 “eaten” by W^+ , W^- , Z to give mass
 - 1 left as physical Higgs
- **This spontaneously broken local gauge theory is renormalizable - t’Hooft (1971)**
- **The Higgs boson properties**
 - ↪ **Mass $< \sim 800 \text{ GeV}/c^2$ (unitarity arguments)**
 - ↪ **Strength of Higgs coupling increases with mass**
 - ❖ fermions: $g_{ffh} = m_f / v$ $v = 246 \text{ GeV}$
 - ❖ gauge boson: $g_{wwh} = 2 m_Z^2 / v$





Positron

Neutrino

Pi meson

Quark

Charmed quark

Bottom quark

W boson

Z boson

Top quark

Higgs boson

ELEMENTARY PARTICLES

Anticipated Particles

Dirac theory of the electron

missing energy in beta decay

Yukawa's theory of strong interaction

patterns of observed particles

absence of flavor changing neutral currents

Kobayashi-Maskawa theory of CP violation

Weinberg-Salam electroweak theory

“ “ “

Mass predicted by precision Z^0 measurements

Electroweak theory and experiments

I II III

Three Generations of Matter

Quarks

Leptons

Force Carriers

up charm top photon

down strange bottom gluon

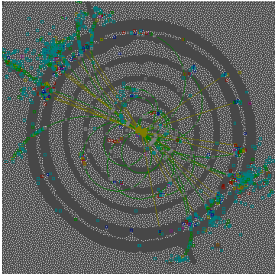
electron neutrino muon neutrino tau neutrino

electron muon tau

Z boson

W boson

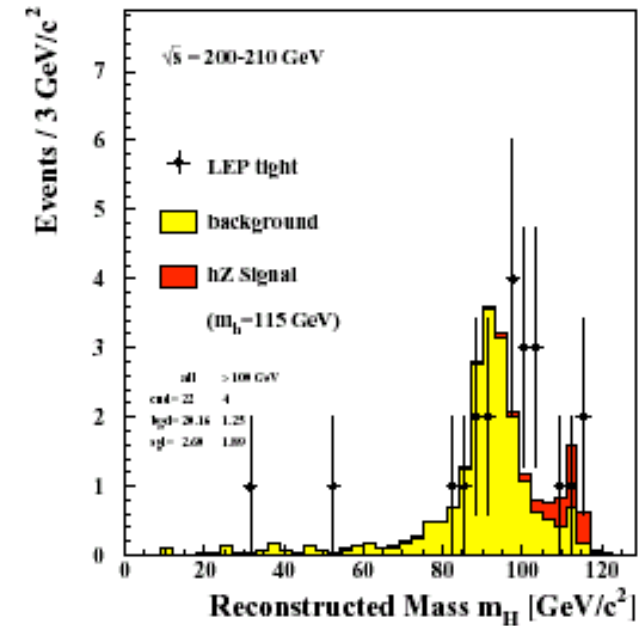
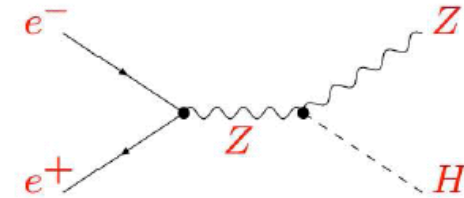




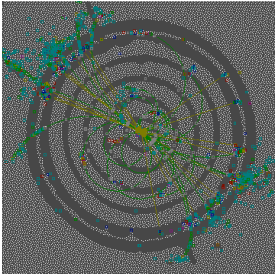
The Search for the Higgs Boson



○ LEP II (1996-2000)



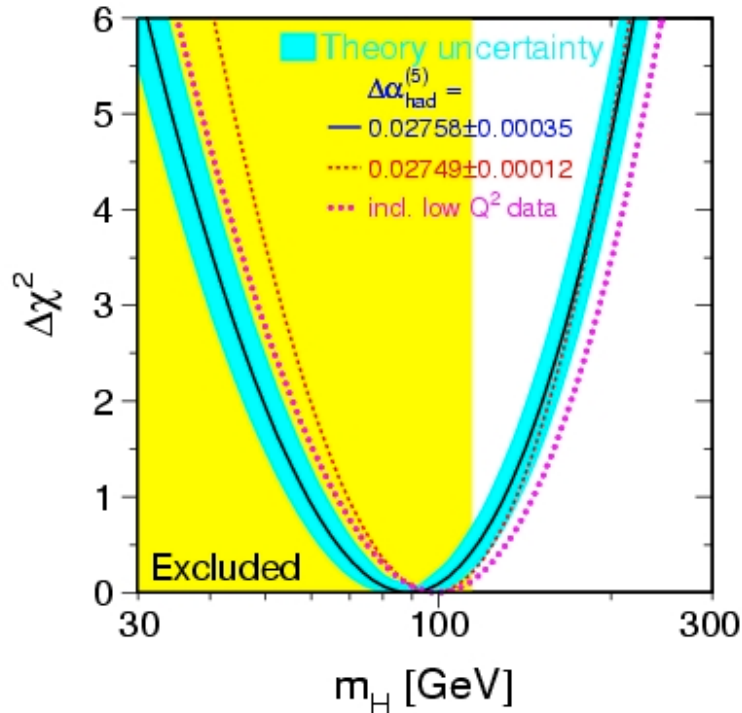
$M_H > 114 \text{ GeV}/c^2$ (95% conf.)



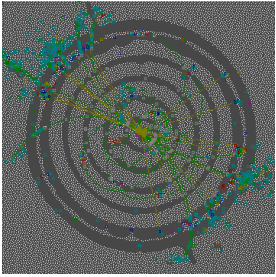
Standard Model Fit



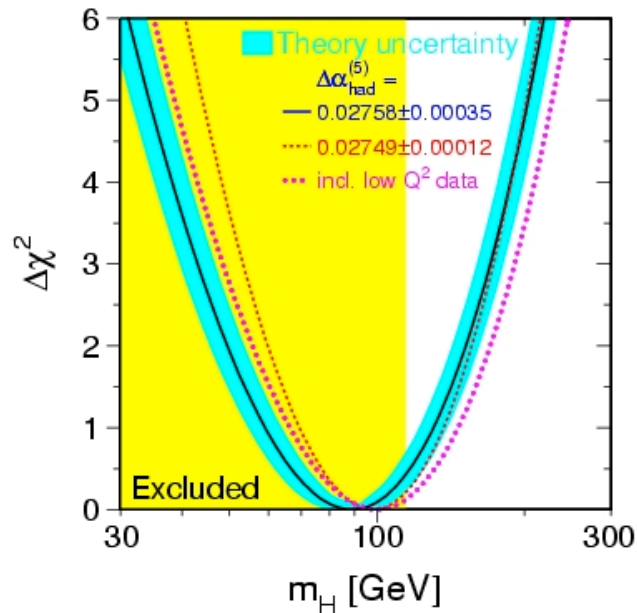
○ $M_H = 89^{+42}_{-30} \text{ GeV}/c^2$



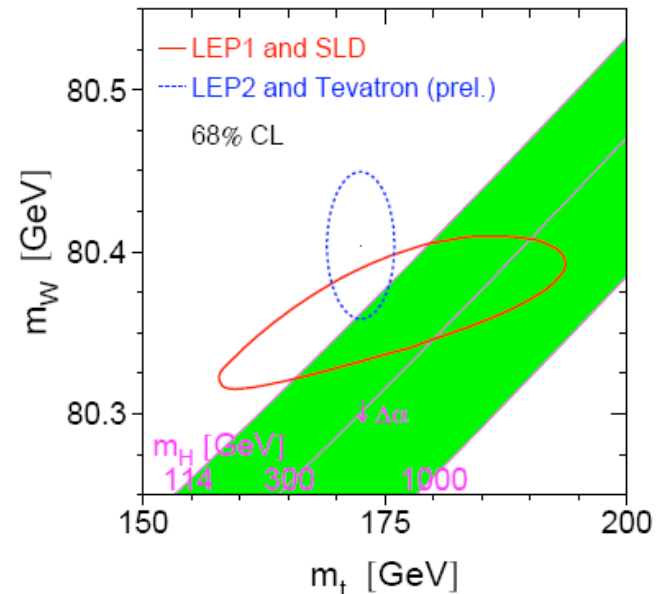
	Measurement	Fit	$\frac{O^{\text{meas}} - O^{\text{fit}}}{\sigma^{\text{meas}}}$
$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ_{had}^0 [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.743	
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01643	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480	
R_b	0.21629 ± 0.00066	0.21581	
R_c	0.1721 ± 0.0030	0.1722	
$A_{\text{fb}}^{0,b}$	0.0992 ± 0.0016	0.1037	
$A_{\text{fb}}^{0,c}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
$A_l(\text{SLD})$	0.1513 ± 0.0021	0.1480	
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.404 ± 0.030	80.376	
Γ_W [GeV]	2.115 ± 0.058	2.092	
m_t [GeV]	172.5 ± 2.3	172.9	



Light Standard Model-like Higgs

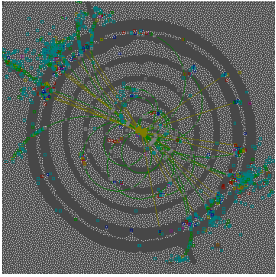


(SM) $M_{\text{higgs}} < 175 \text{ GeV}$ at 95% CL.
LEP2 direct limit $M_{\text{higgs}} > 114.4 \text{ GeV}$.



W mass ($\pm 30 \text{ MeV}$)
and top mass ($\pm 3 \text{ GeV}$)
consistent with precision measures
and indicate low SM Higgs mass

LEP Higgs search – Maximum Likelihood for Higgs signal at
 $m_H = 115.6 \text{ GeV}$ with overall significance (4 experiments) $\sim 2\sigma$



The Search for the Higgs Boson



○ Tevatron at Fermilab

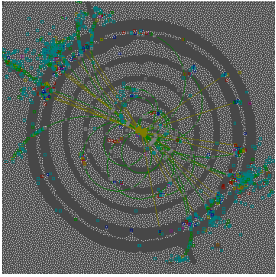
- ↗ Proton/anti-proton collisions at $E_{\text{cm}} = 2000 \text{ GeV}$
- ↗ Now through 2009



○ LHC at CERN

- ↗ Proton/proton collisions at $E_{\text{cm}} = 14,000 \text{ GeV}$
- ↗ First collisions later this year/early next year





Models of Electroweak Symmetry Breaking



Standard Model Higgs

excellent agreement with EW precision measurements

implies $M_H < 175 \text{ GeV}$ (but theoretically ugly - h'archy prob.- M_h unstable)

MSSM Higgs

expect $M_h < \sim 135 \text{ GeV}$

light Higgs boson (h) may be very “SM Higgs-like”
(de-coupling limit)

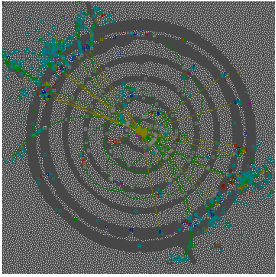
Non-exotic extended Higgs sector

eg. 2HDM

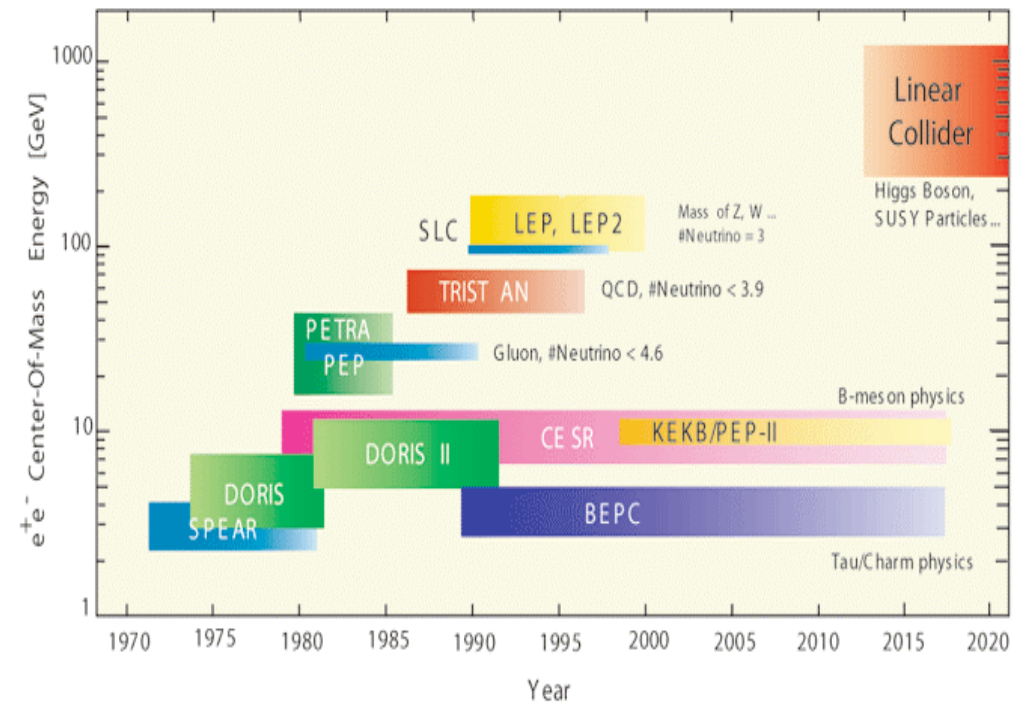
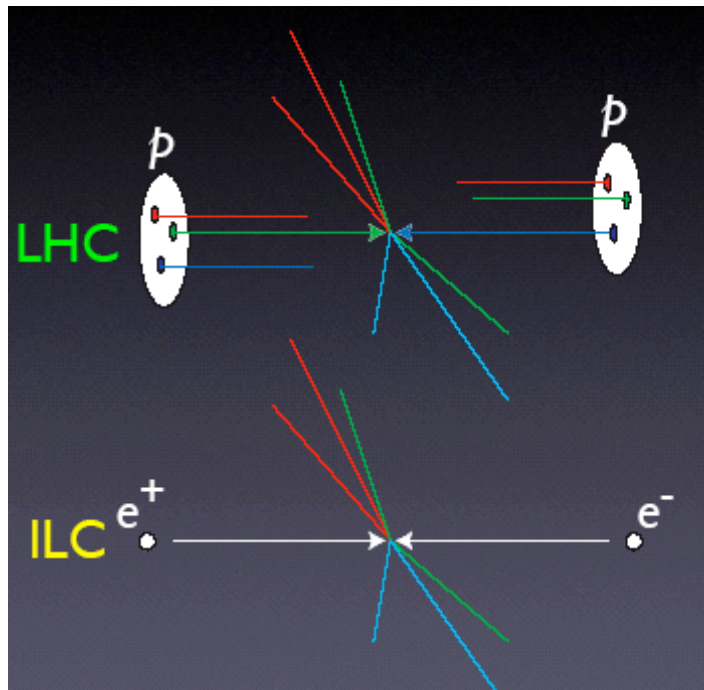
Strong Coupling Models

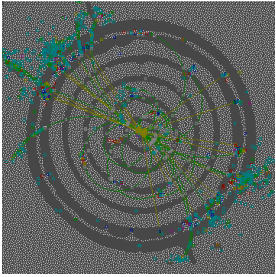
New strong interaction

The ILC will provide critical data to assess these possibilities



Complementarity of Electron Colliders





The Large Hadron Collider and the ILC



- LHC at CERN, colliding protons
first collisions – late this year/next year
- History demonstrates the
complementarity of
hadron and **electron** experiments



discovery

facility of
discovery

facility of
detailed study

charm

BNL + SPEAR

SPEAR at SLAC

tau

SPEAR

SPEAR at SLAC

bottom

Fermilab

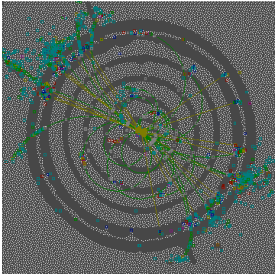
Cornell/DESY $\Rightarrow$ B Factories

Z^0

SPPS/CERN

LEP and SLC

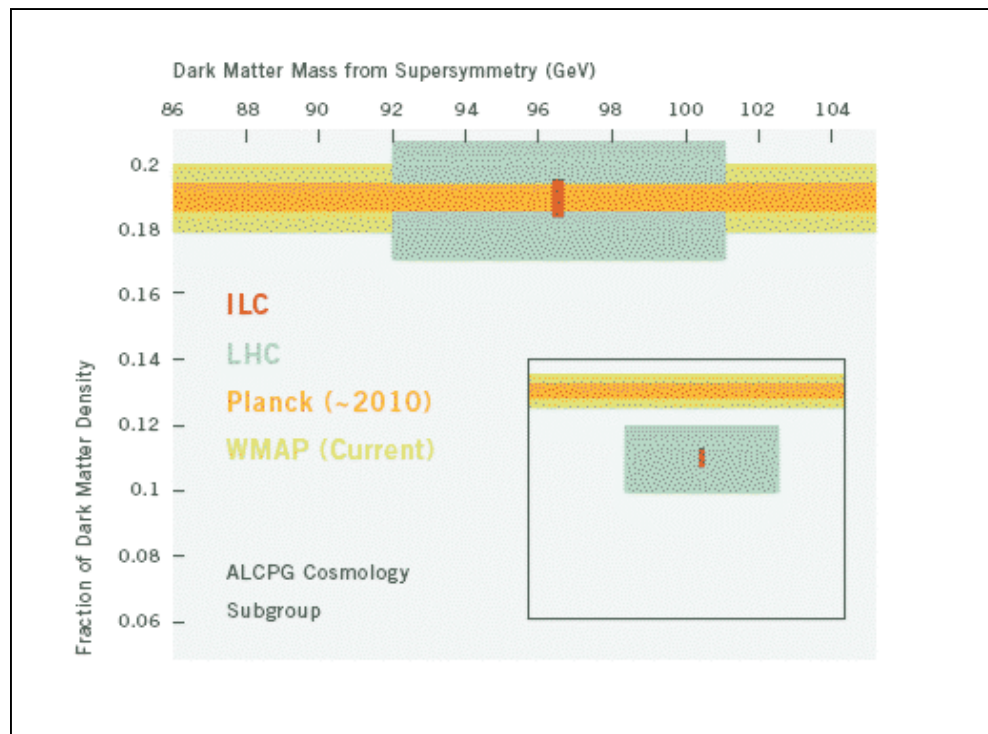
- Electron experiments have frequently provided most precision



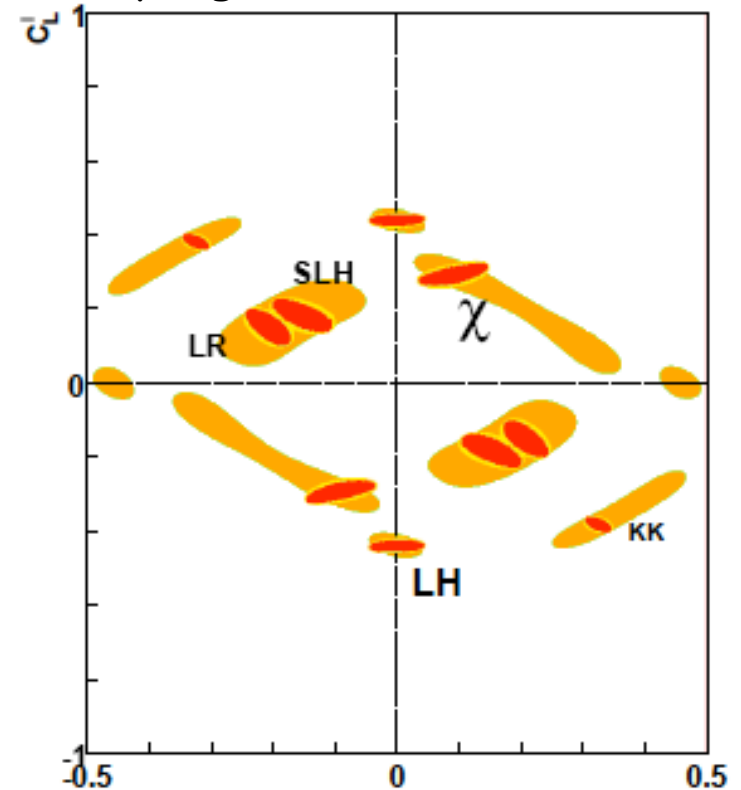
Complementarity with LHC



SUSY mass and coupling measurements
=> Identification of dark matter

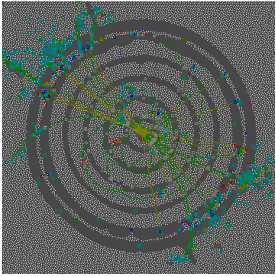


Z' discovered at LHC
Couplings determined at ILC



$m_{Z'} = 2\text{TeV}, E_{\text{cm}} = 500\text{ GeV}, L = 1\text{ab}^{-1} \mathcal{L}_R^I$
with and w/o beam polarization

S.Godfrey, P.Kalyniak, A.Tomkins

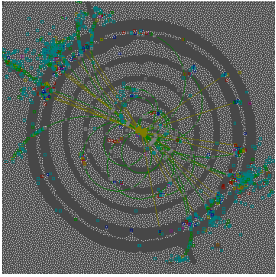


Colliders (Circular and Linear)



- **Storage rings have been the optimal facilities for colliding beam experiments for several decades**
 - ✚ **Developed in 1960's to achieve highest possible center of mass collision energy**
 - ✚ **Particle beams stored for many hours**
 - ✚ **Efficient transfer of beam energy to interactions**
- **Electron storage rings have a limited useful energy**
LEP ~ 100 GeV beam energy



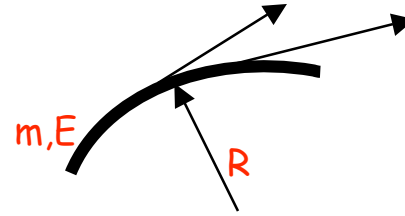


Linear Colliders



- **Synchrotron radiation**

↪ $\Delta E \sim (E^4 / m^4 R)$

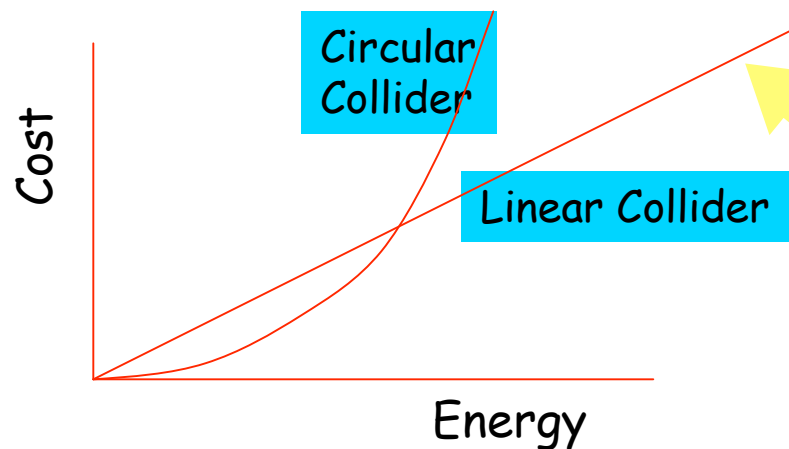


- **Therefore**

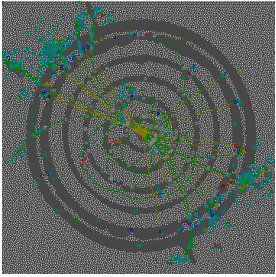
↪ **Cost (circular) $\sim a R + b \Delta E \sim a R + b (E^4 / m^4 R)$**

❖ Optimization $R \sim E^2 \Rightarrow \text{Cost} \sim c E^2$

↪ **Cost (linear) $\sim a' L$, where $L \sim E$**



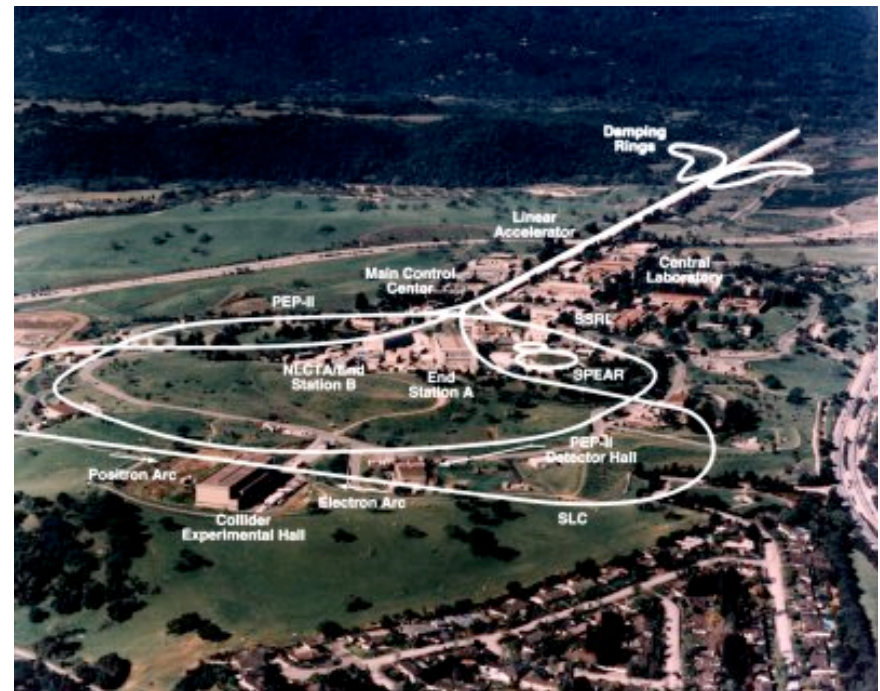
○ **At high energy,
linear collider is
more cost effective**

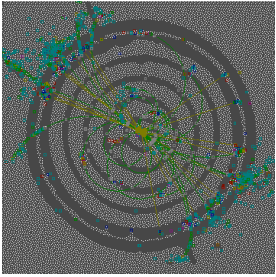


The First Linear Collider



- This concept was demonstrated at SLAC in a linear collider prototype operating at ~ 91 GeV (the SLC)
- SLC was built in the 80's within the existing SLAC linear accelerator
- Operated 1989-98
 - ⇒ precision Z^0 measurements
 - ❖ Suggests Light Higgs Boson
 - ⇒ established ILC concepts

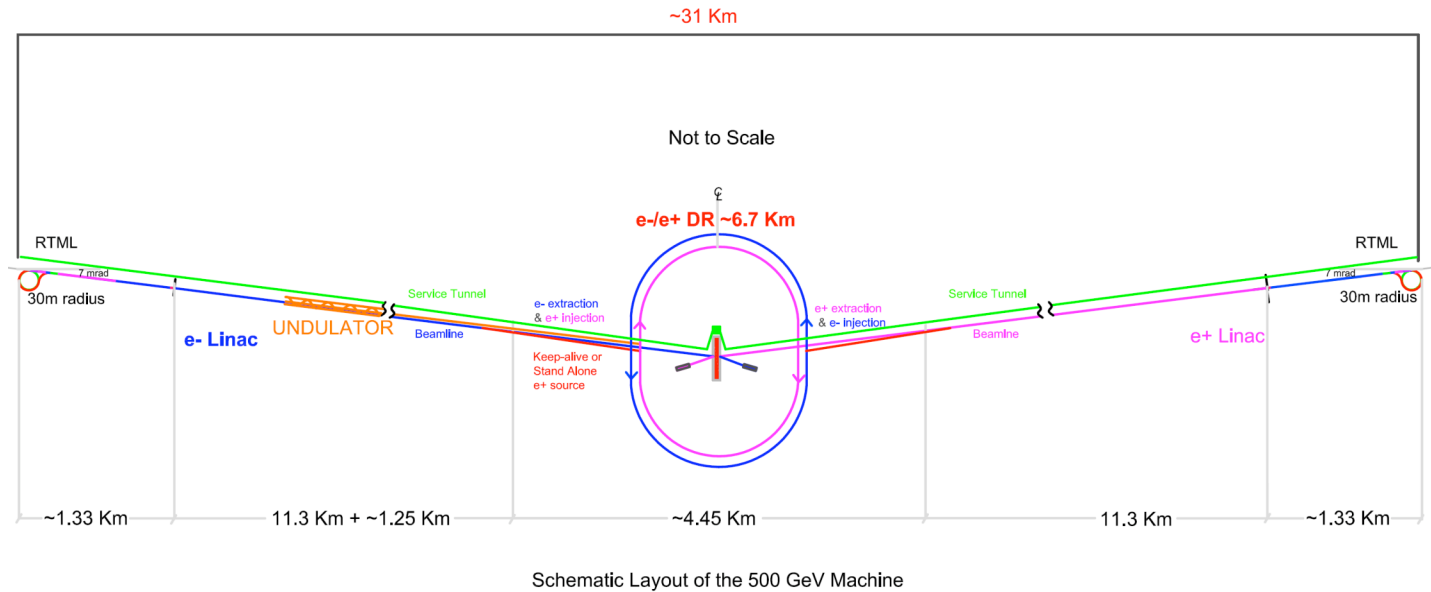




The International Linear Collider



$E_{\text{cm}} = 500 \text{ GeV}$
 - 1000 GeV
 Polarized e^-
 (~80% and e^+)
 Length (500 GeV)
 ~30 km
 ~20 miles



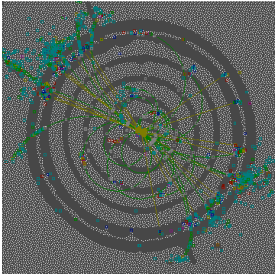
Elucidate Electroweak Interaction

- ⇒ precision meas. symmetry breaking
 - ❖ Higgs bosons
 - ❖ supersymmetric particles
 - ❖ extra dimensions

Construction could begin soon after 2010 (perhaps 2012)
 and operation in 2018-2020

- ⇒ Intense R&D needed by 2010





ILC Experimental Advantages



Elementary interactions at known E_{cm}^*
 eg. $e^+e^- \rightarrow ZH$ * beamstrahlung manageable

Democratic Cross sections
 eg. $\sigma(e^+e^- \rightarrow ZH) \sim 1/2 \sigma(e^+e^- \rightarrow d\bar{d})$

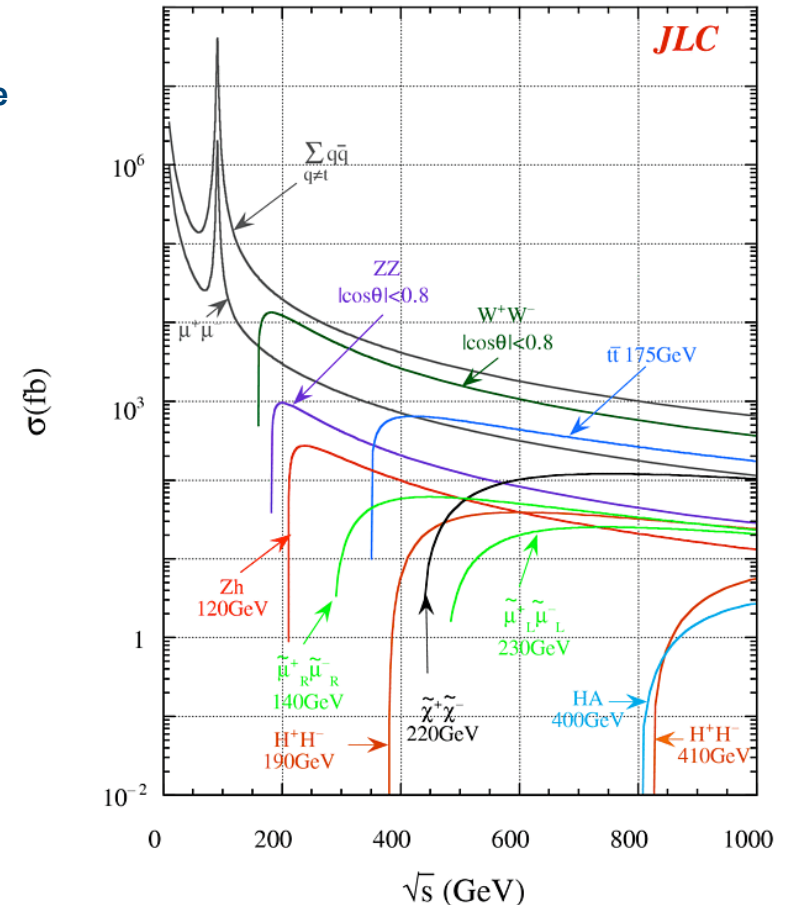
Inclusive Trigger
 total cross-section

Highly Polarized Electron Beam
 $\sim 80\%$ (positron polarization? – R&D)

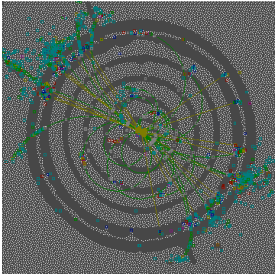
Exquisite vertex detection
 eg. $R_{\text{beampipe}} \sim 1 \text{ cm}$ and $\sigma_{\text{hit}} \sim 3 \mu\text{m}$

Calorimetry with Particle Flow Precision
 $\sigma_E/E \sim 30\text{-}40\%/\sqrt{E}$

Advantage over hadron collider on precision meas.
 eg. $H \rightarrow c\bar{c}$



Detector performance translates directly into effective luminosity

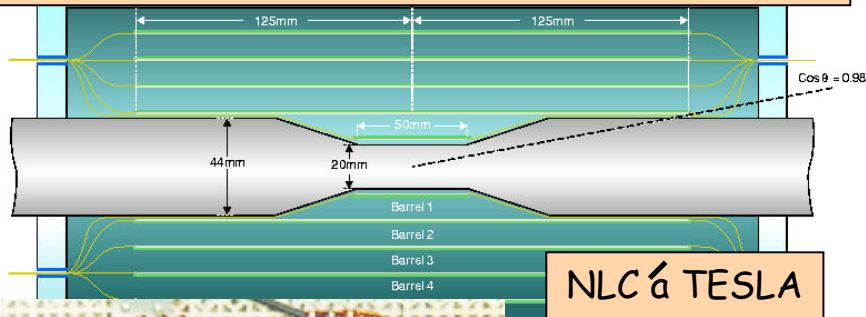


Linear Collider Detectors

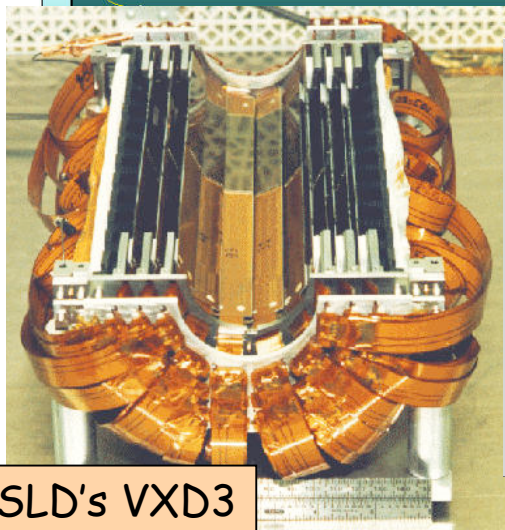


The Linear Collider provides very special experimental conditions (eg. superb vertexing and jet calorimetry)

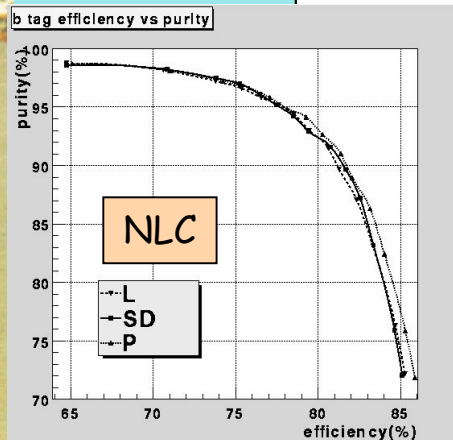
Giga-pixel Vertex Detector



NLC @ TESLA



SLD's VXD3

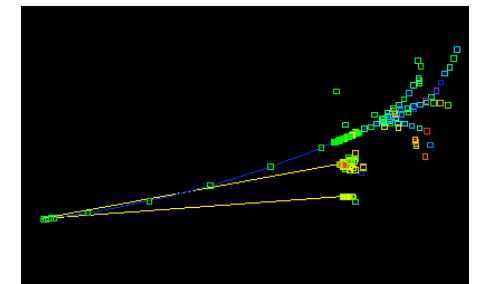
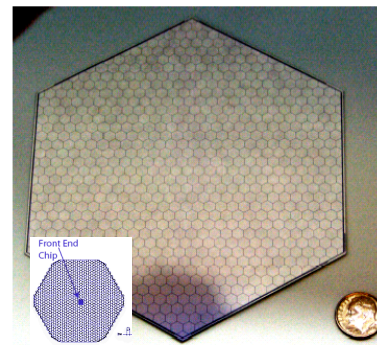


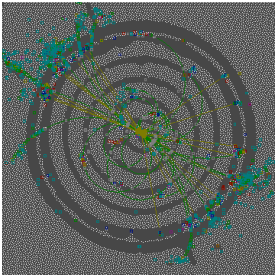
NLC

Silicon-Tungsten EM Calorimetry

SLD Lum (1990)
Aleph Lum (1993)
Opal Lum (1993)

90 Mcell Si/W EM calorimeter
central element in
particle flow measurement



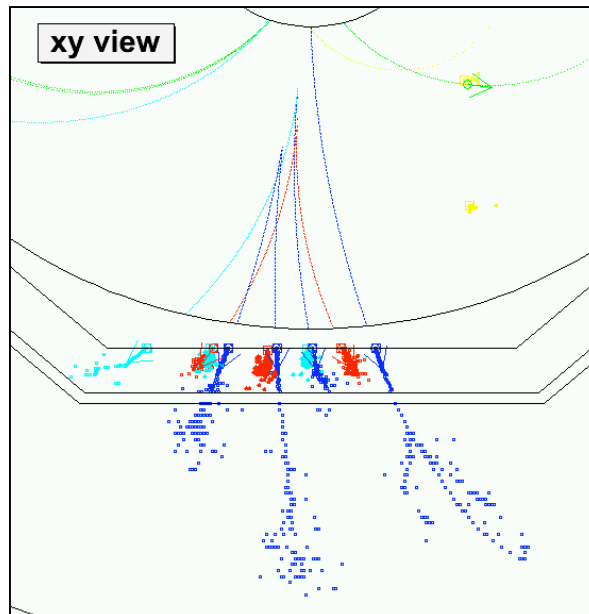


Linear Collider Detectors

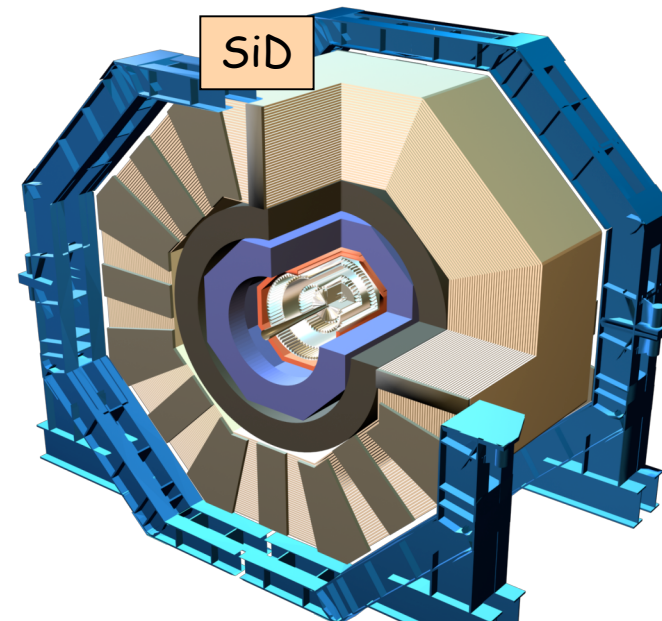


Digital Hadron Calorimeter

40 Mcell hadron calorimeter
jet resolution $\sim 30\% / \sqrt{E}$
relies on tracker for charged particles

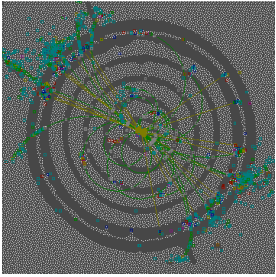


Integrated Detector Designs



Also,
GLD,
LDC,
4th

Silicon Tracking
5 Tesla Solenoid



Higgs Physics Program of the ILC



**ELECTROWEAK PRECISION MEASUREMENTS SUGGEST
THERE SHOULD BE A RELATIVELY LIGHT HIGGS BOSON:**

When it's discovered, its nature must be studied.
The ILC is essential to this program.

MASS MEASUREMENT (~ 50 MeV at 120 GeV)

TOTAL WIDTH

PARTICLE COUPLINGS

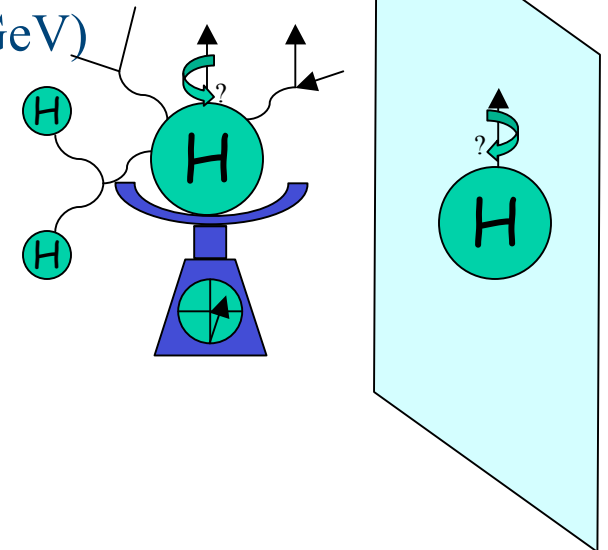
VECTOR BOSONS

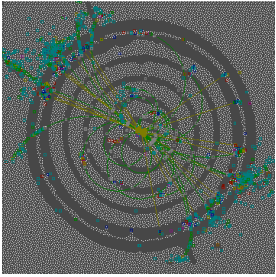
FERMIONS (INCLUDING TOP)

SPIN-PARITY-CHARGE CONJUGATION

SELF-COUPLING

The ILC makes precise measurements

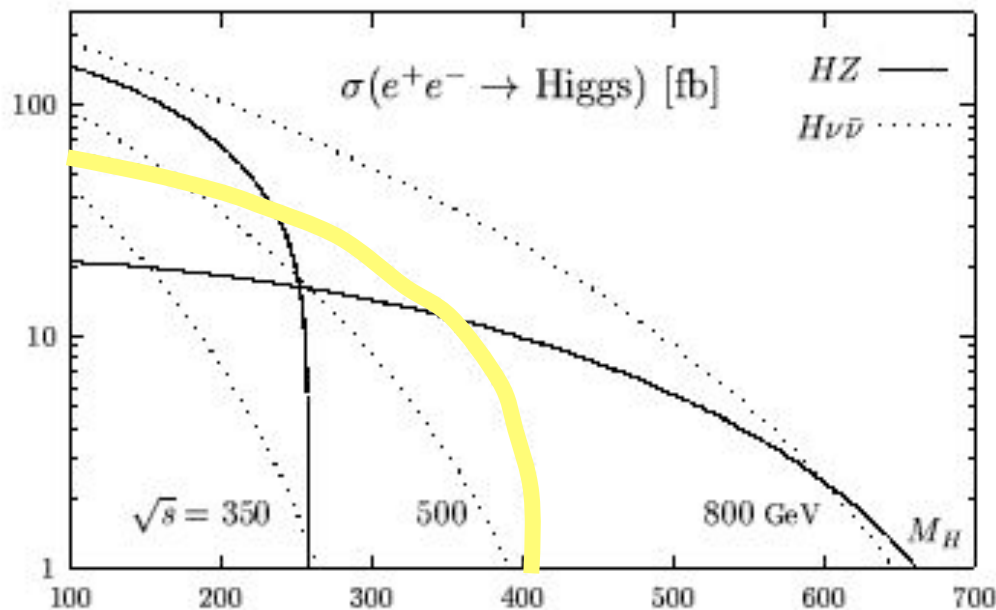




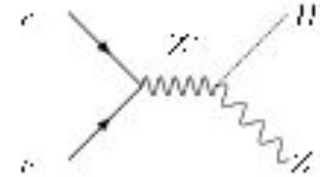
Higgs Production Cross-section



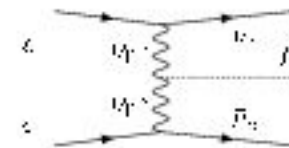
ILC program ~ 500 events / fb



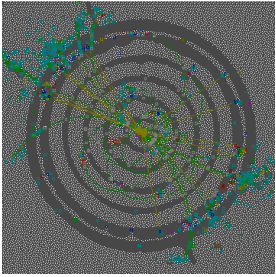
Higgs-strahlung



WW fusion



$$\sigma_{\text{PT}} = 87 \text{ nb} / (E_{\text{cm}})^2 \sim 350 \text{ fb} @ 500 \text{ GeV}$$



Higgs Studies - the Power of Simple Reactions

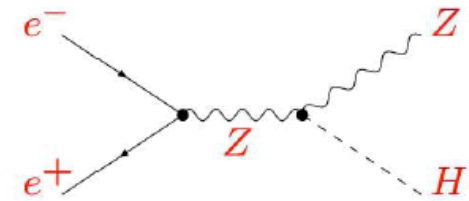
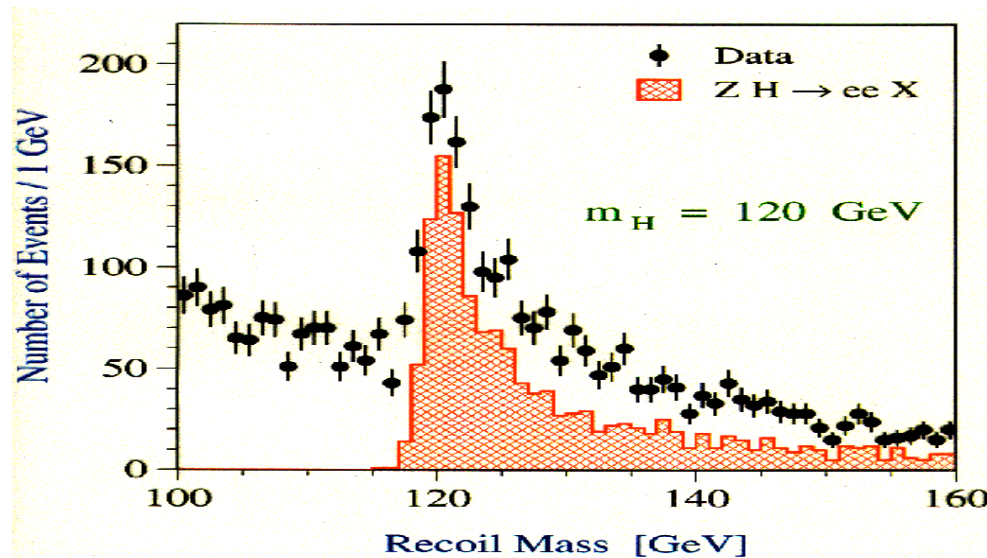


ILC observes Higgs recoiling from a Z, with known CM energy↓

- powerful channel for unbiased tagging of Higgs events
- measurement of even invisible decays

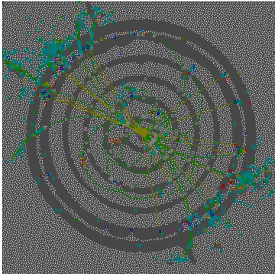
(↓ - some beamstrahlung)

- Tag $Z \rightarrow l^+ l^-$
- Select $M_{\text{recoil}} = M_{\text{Higgs}}$



Invisible decays are included

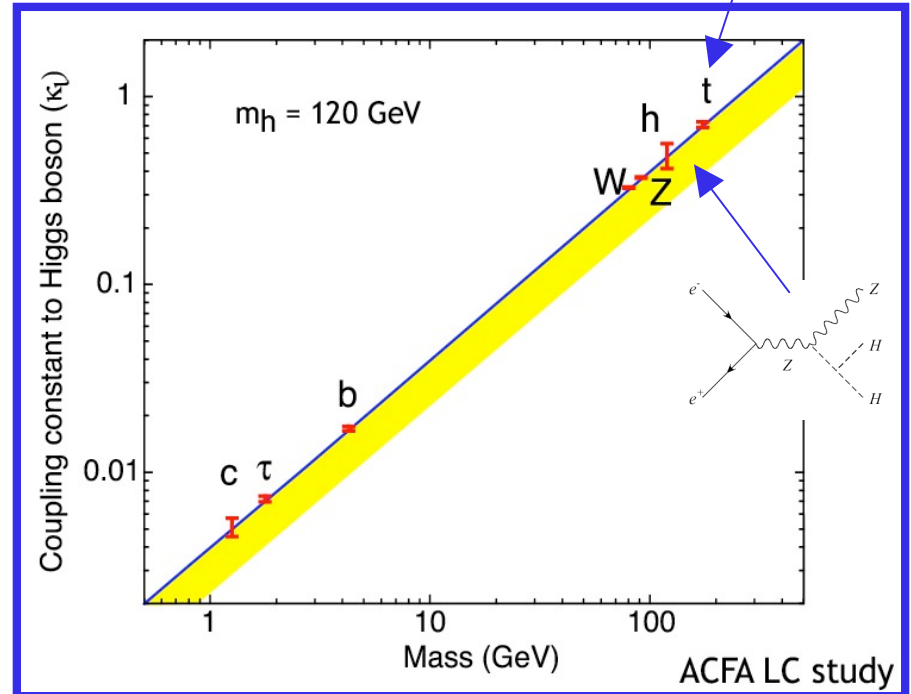
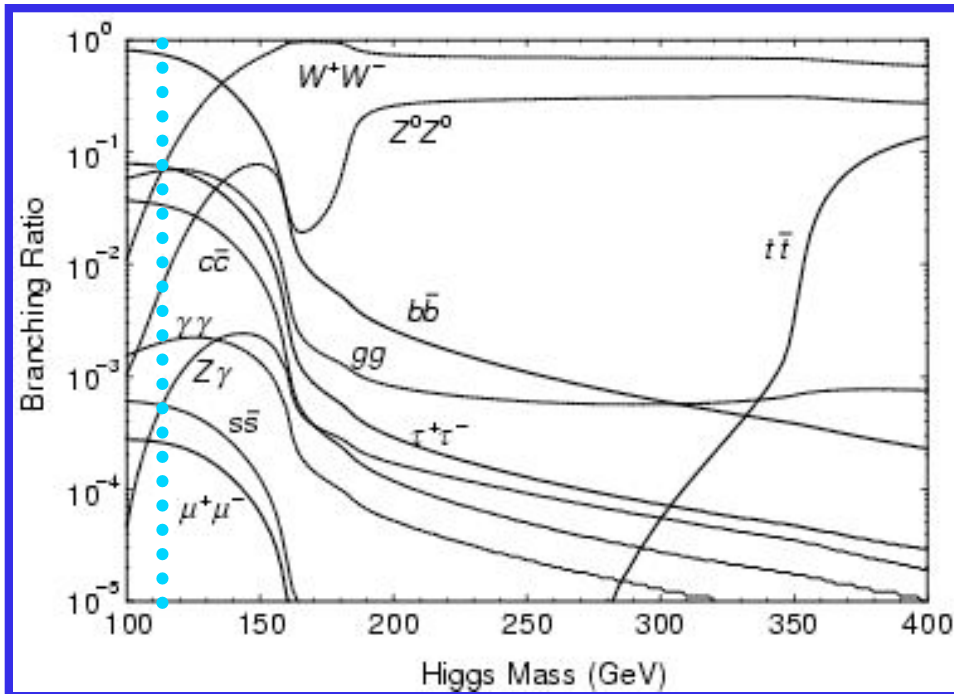
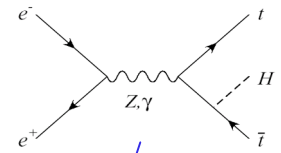
500 fb⁻¹ @ 500 GeV, TESLA TDR, Fig 2.1.4



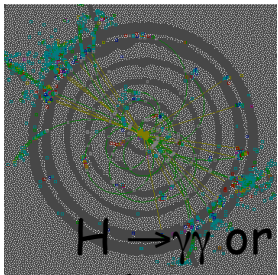
Higgs Couplings the Branching Ratios



$$g_{ffh} = m_f / v \quad v = 246 \text{ GeV}$$



Measurement of BR's is powerful indicator of new physics
e.g. in MSSM, these differ from the SM in a characteristic way.
Higgs BR must agree with MSSM parameters from many other measurements.

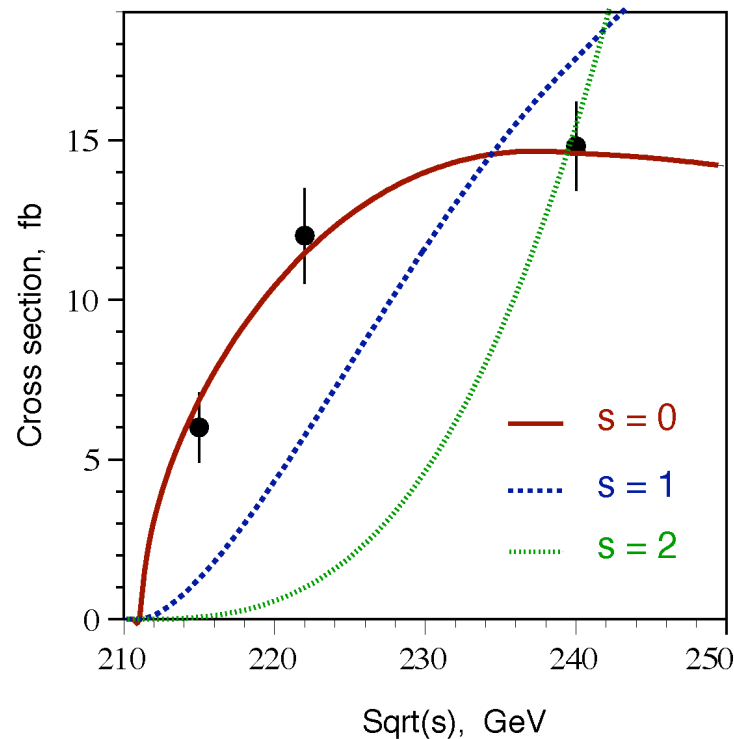


Higgs Spin Parity and Charge Conjugation (J^{PC})

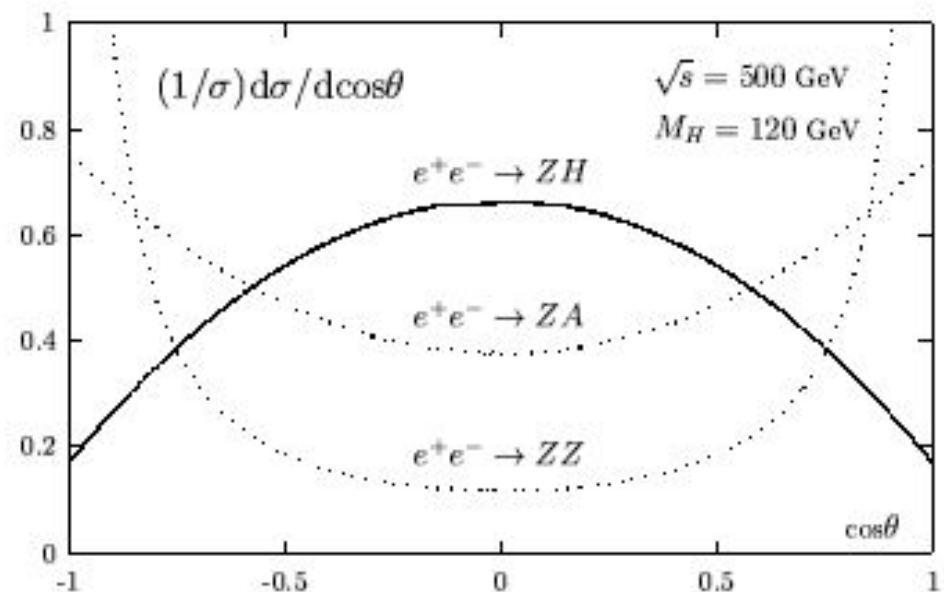


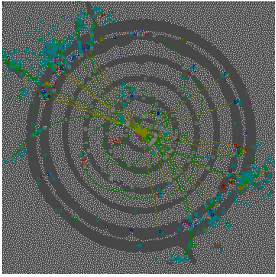
$H \rightarrow \gamma\gamma$ or $\gamma\gamma \rightarrow H$
rules out $J=1$ and indicates $C=+1$

Production angle (θ) and Z
decay angle in Higgs-strahlung
reveals J^P ($e^+ e^- \rightarrow Z H \rightarrow f\bar{f}H$)



LC Physics Resource Book,
Fig 3.23(a)





Is This the Standard Model Higgs?



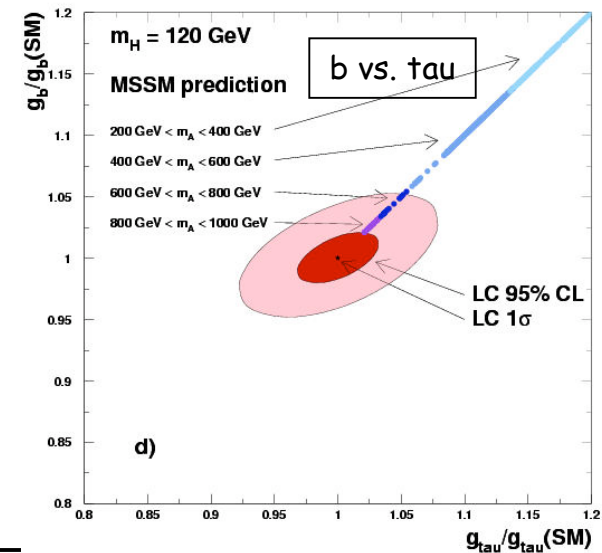
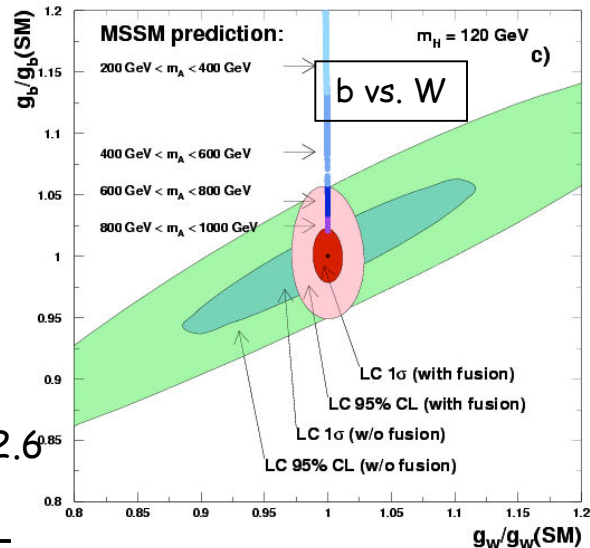
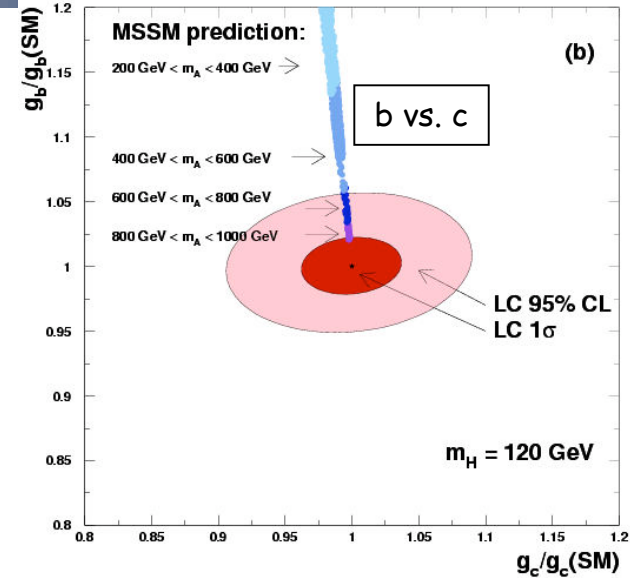
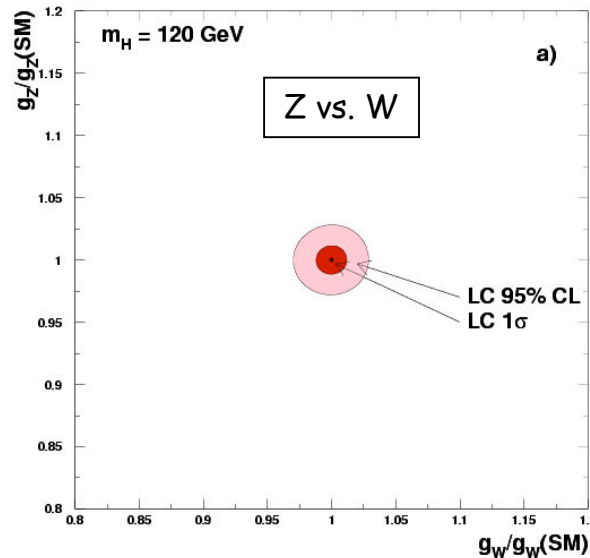
Arrows at:

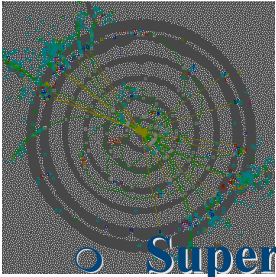
- $M_A = 200-400$
- $M_A = 400-600$
- $M_A = 600-800$
- $M_A = 800-1000$

HFITTER output

conclusion:
for $M_A < 600$,
good sensitivity

TESLA TDR, Fig 2.2.6





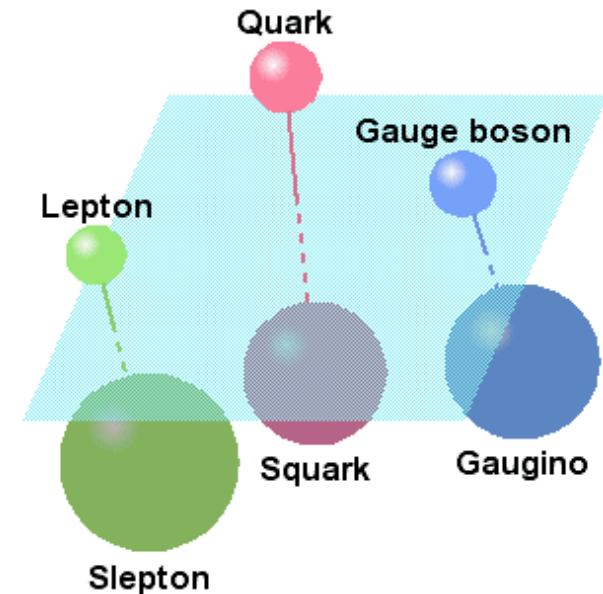
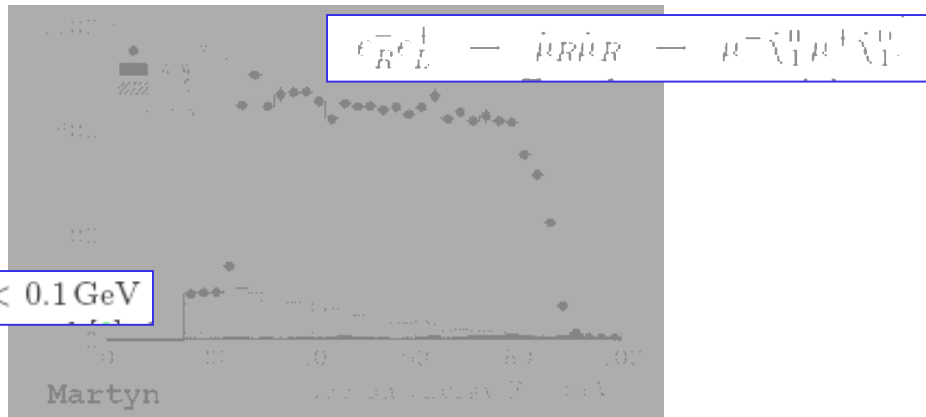
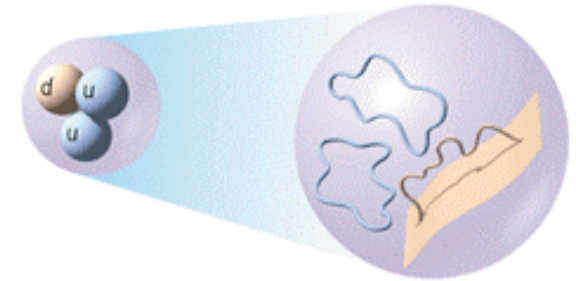
Supersymmetry

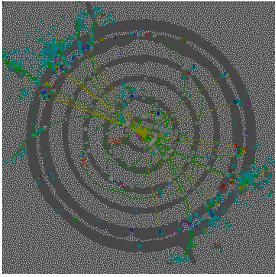


Supersymmetry

- ↗ particles matched by super-partners
 - ❖ super-partners of fermions are bosons
 - ❖ super-partners of bosons are fermions
- ↗ inspired by string theory
- ↗ cancellation of divergences
- ↗ dark matter?
- ↗ many new particles
 - ❖ ILC could detail properties

c



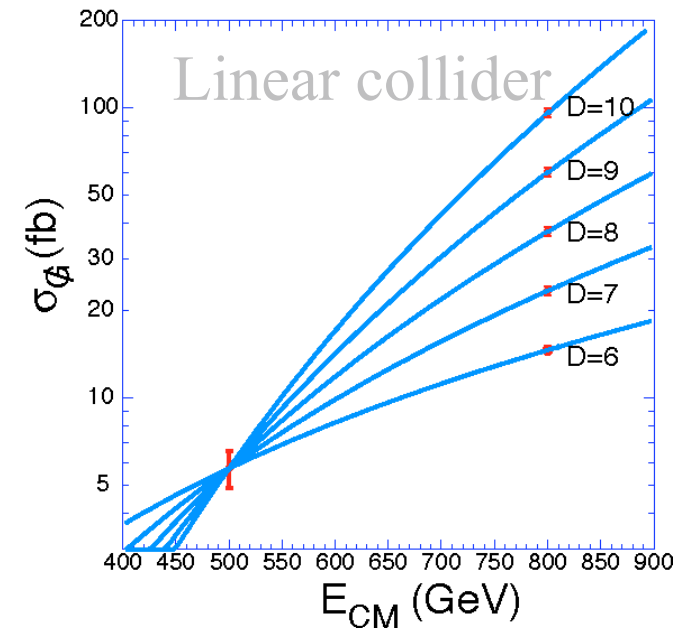
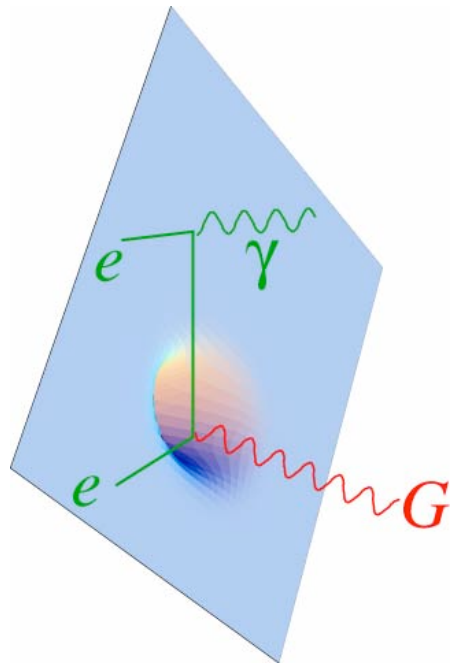


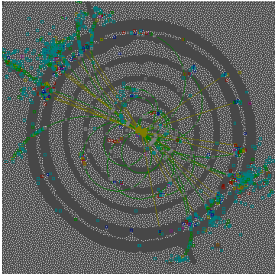
Extra Dimensions



○ Extra Dimensions

- ↪ string theory inspired
- ↪ solves hierarchy problem ($M_{\text{planck}} \gg M_{\text{EW}}$)
 - ❖ if extra dimensions are large
- ↪ large extra dimensions observable at ILC

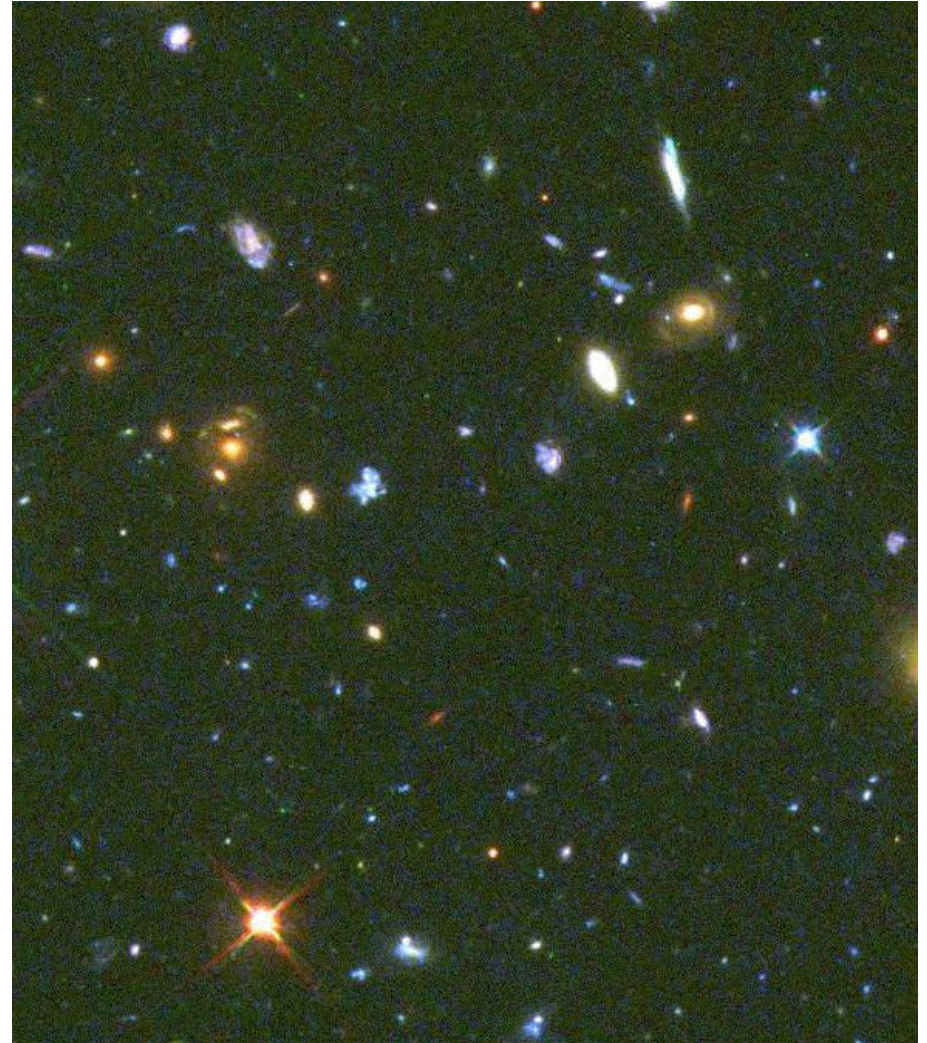


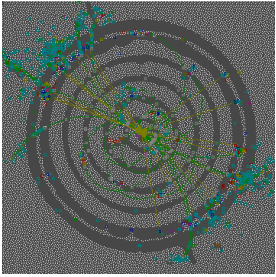


Cosmic connections



- **Early universe**
- **GUT motivated inflation**
- **Dark matter**
- **Accelerating universe**
- **Dark energy**





Some Steps Toward the ILC



- **2002- DOE/NSF High Energy Physics Advisory Panel**
 - ⇒ Subpanel on Long Range Planning for U.S. High Energy Physics
 - ⇒ A high-energy, high-luminosity electron-positron linear collider should be the highest priority of the US HEP community, preferably one sited in the US
 - ⇒ Similar statements in other regions ⇒ global consensus on next collider
- **2003- DOE Office of Science Future Facilities Plan**
 - ⇒ Linear Collider is ranked first among mid-term projects
- **2004 – Technology choice by ICFA (Superconducting RF)**
- **2005 – Global Design Effort formed**
 - ⇒ Baseline Configuration Document
- **Apr. 26, 2006 – NRC Report on the Future of Particle Physics**
- **Feb. 2007 – GDE Reference Design Report (w/ cost)**



The GDE Plan and Schedule

2005

2006

2007

2008

2009

2010

CLIC

Global Design Effort

Project

→ **Baseline configuration**

→ **Reference Design**

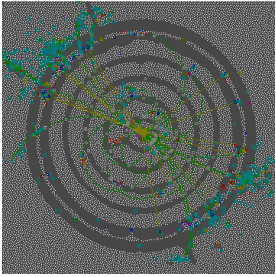
→ **Technical Design**

→ **ILC R&D Program**

→ **Expression of Interest to Host**

→ **International Mgmt**

**LHC
Physics**



Americas Sample Site



B. Barish

○ Design to “sample sites” from each region

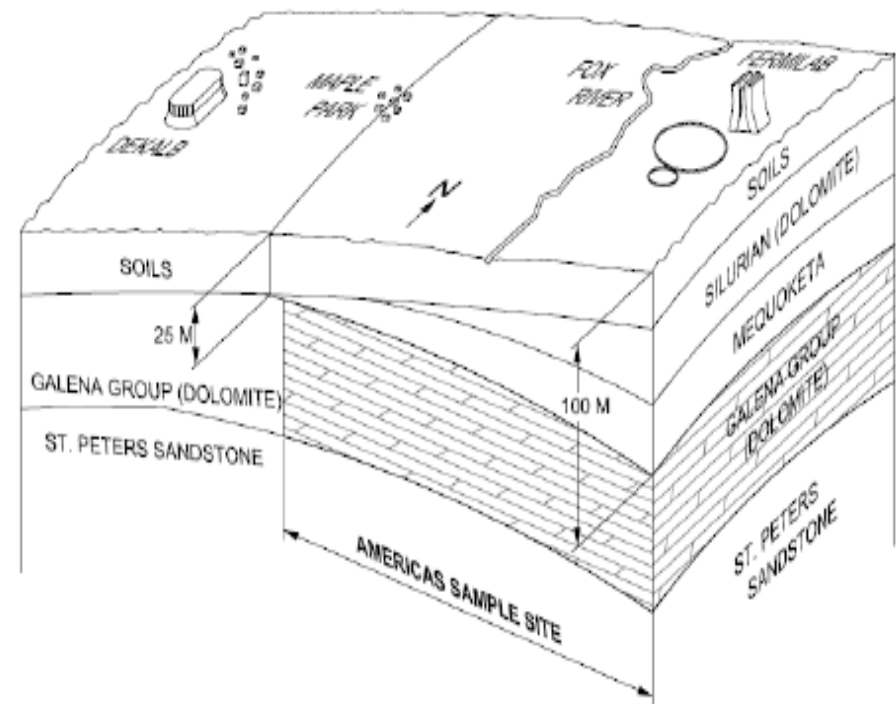
- ↗ Americas – near Fermilab
- ↗ Japan – west of Tokyo
- ↗ Europe – CERN & DESY

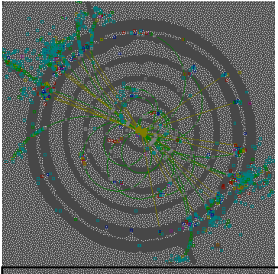
○ Illinois Site

– depth 135m

- ↗ Glacially derived deposits overlaying Bedrock.
- ↗ The concerned rock layers are from top to bottom
 - ❖ the Silurian dolomite,
 - ❖ Maquoketa dolomitic shale,
 - ❖ the Galena-Platteville dolomites.

Americas Sample Plan / Section





March 26, 2006

Revealing the Hidden Nature of Space and Time

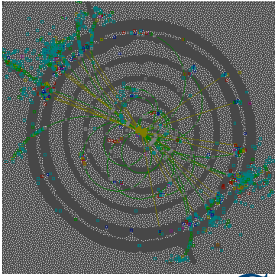
THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine



Charting the Course for Elementary Particle Physics

**EPP 2010: Elementary
Particle Physics in the
21st Century**

- Given the excitement of the scientific opportunities in particle physics, and in keeping with the nation's broader commitment to research in the physical sciences, the committee believes that the United States should continue to support a competitive program in this key scientific field.
- **Action Item 1: The highest priority for the U.S. national effort in elementary particle physics should be to continue to be an active partner in realizing the physics potential of the LHC experimental program.**
- **Action Item 2: The United States should launch a major program of R&D, design, industrialization, and management and financing studies of the ILC accelerator and detectors.**
- **Action Item 3: The United States should announce its strong intent to become the host country for the ILC and should undertake the necessary work to provide a viable site and mount a compelling bid.**



Conclusion



- **Current status of Electroweak Precision measurements indicates the physics at the LHC and ILC will be rich**
- **The International Linear Collider will be a powerful tool**
 - Electroweak Symmetry Breaking**
 - origin of mass**
 - other fundamental physics**
 - advance understanding of LHC discoveries**
- **This physics follows a century of unraveling the mystery of the electroweak interaction**
- **Future discoveries may advance our knowledge of fundamental physics in unanticipated ways**