Summary of Experimental Results and Future Opportunities

Samuel C.C. Ting
CERN and MIT

Abstract
This article is based on the summary talk presented at the XVII International Symposium on Lepton-Photon Interactions in Beijing, China, on 15 August 1995. It includes a selection of highlights of experimental results and future plans of different laboratories, as seen by each Laboratory Management. It also presents some particle physics experiments underground and in space.
Introduction

It is a pleasure for me to give this summary talk. I am impressed by the tremendous amount of important experimental results presented in this Conference.

Thirty years ago, when I first started working in this field, I was invited to present a ten minutes' talk on our results of tests of QED at the Lepton-Photon Conference in Berkeley. There was then a clear separation between results from traditional proton accelerators and results from electronsynchrotrons. At that time, experimental groups consisted of few people. Typically, an experiment was performed in one or two years - our DESY QED experiment was done by J. Asbury, U.J. Becker, M. Rhode, A.J.S. Smith and myself in eight months' time.

Today, most of the experimental groups have $10^2 - 10^3$ physicists and it takes an order of 10 years to perform an experiment. This situation makes it more and more difficult for young physicists to plan their career in our field.

In order to identify the future of our field, during the preparation of this talk, I have written to Laboratory Directors to ask them to select some of the highlights from their laboratory, the future plans of their laboratory as well as their personal observations of the future of our field.

My presentation consists of three chapters : highlights of recent experimental results, future plans of different laboratories and particle physics without accelerators.
Chapter One : Highlights of Recent Experimental Results

1.1 Tests of CPT

To begin with, as presented by Professor E.A. Paschos and Professor Paolo Franzini, we now have a very accurate test of CPT in the equality of masses of particles and antiparticles, equality of phases of $\eta^{+-}$ and $\eta_{00}$, and the measurement of the phase $\phi^{+-}$. These results are summarized in Table 1 and in Figures 1 and 2.

1. Equality of Masses for Particles and Antiparticles

\[
\frac{m_{K^0} - m_{\bar{K}^0}}{m_K} < 3.5 \times 10^{-18} \quad \text{NA31}
\]
\[
< 1.3 \times 10^{-18} \quad \text{E773}
\]
\[
< 1.8 \times 10^{-18} \quad \text{CP LEAR}
\]

2. The Phases of $\eta^{+-}$ and $\eta_{00}$ Equal

\[
\phi_{00} = \phi^{+-} \rightarrow \Delta \phi = \phi_{00} - \phi^{+-} = 0
\]
\[
\Delta \phi = 0.2° \pm 2.6° \pm 1.2° \quad \text{Carosi ('90) NA31}
\]
\[
\Delta \phi = 0.62° \pm 0.71° \pm 0.75° \quad \text{(st.) Schwingerheuer et al. E773 PRL 74, 4376 ('95)}
\]

3. The Phase test $\phi^{+-} = \phi_{SW} = \tan^{-1} (-2 \frac{\Delta M}{\Gamma})$

\[
\phi_{SW} = 43.37° \pm 0.17°
\]
\[
\phi^{+-} = 46.0° \pm 2.2° \pm 1.1° \quad \text{NA31}
\]
\[
\phi^{+-} = 43.53° \pm 0.58° \pm 0.49° \quad \text{(st.) E773}
\]
\[
\phi^{+-} = 43.2° \pm 0.9° \text{stat} \pm 0.6° \text{syst} \pm 0.7° \Delta m \quad \text{CP LEAR}
\]

Table 1: Tests of CPT symmetry

**Figure 1**: The measurement of $\phi^{+-}$

**Figure 2**: Measurement of $\Delta m = m_{K^0_L} - m_{K^0_S}$
Therefore CPT is tested to an accuracy of $1/10^{18}$.

1.2 From IHEP

Table 2 is a summary of recent results from our host Laboratory. They have provided the most accurate measurement of the mass of tau, a good measurement of the pseudo scalar decay constant $f_{D_S}$ and confirmed the existence of $\xi(2230)$ and shown that this resonance has a very narrow width and is flavor symmetric, thus it is very likely a glueball candidate. Professor Hesheng Chen has shown (in Figure 3) a very accurate $\mu$-$\tau$ universality test providing $G_\tau/G_\mu = 1.0026 \pm 0.0044$.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_\tau$ Measurement (1994)</td>
<td>$M_\tau = 1776.96^{+0.18+0.25}_{-0.21-0.17}$ MeV (1)</td>
</tr>
<tr>
<td></td>
<td>$G_\tau/G_\mu = 0.999 \pm 0.003$ (2)</td>
</tr>
<tr>
<td>Measurement of $f_{D_S}$</td>
<td>$f_{D_S} = (4.3^{+1.5+0.4}_{-1.3-0.4}) \times 10^2$ MeV (3)</td>
</tr>
<tr>
<td>$B(D_S \rightarrow eX) = (10.0^{+6.5+1.3}_{-4.6-1.2})$ % (4)</td>
<td></td>
</tr>
<tr>
<td>Confirm the existence of $\xi(2230)$ &amp;</td>
<td>Found two new decay modes:</td>
</tr>
<tr>
<td></td>
<td>$\xi(2230) \rightarrow \pi^+\pi^-$ (5)</td>
</tr>
<tr>
<td></td>
<td>$\xi(2230) \rightarrow \bar{p}p$ (6)</td>
</tr>
<tr>
<td>(likely to be a glueball candidate)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(likely to be a glueball candidate)</td>
</tr>
<tr>
<td>Find new anomalous suppression in vectortensor decays of $\psi'$:</td>
<td></td>
</tr>
<tr>
<td>$Br(\psi' \rightarrow \rho\pi) &lt; 3.6 \times 10^{-5}$ (7)</td>
<td></td>
</tr>
<tr>
<td>$Br(\psi' \rightarrow K^*K) &lt; 2.4 \times 10^{-5}$ (8)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Recent BES Results
1.3 From CESR

There are very interesting results from CESR on the study of B-decays. Figure 4 is an event picture of $\bar{B}^0 \to K^{-}\pi^+$. Table 3 summarizes some results from charmless B-decays. Measurements should soon be able to differentiate contributing processes between $W$ emission (which dominates in $B \to \pi\pi$) and gluonic penguin (which dominates in $B \to K\pi$).

<table>
<thead>
<tr>
<th>Collaboration</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO</td>
<td>$Br(B^0 \to h^-\pi^+) = 1.8 , ^{+0.6}_{-0.5} \times 10^{-5}$</td>
</tr>
<tr>
<td>ALEPH</td>
<td>$Br(B^0 \to \pi^+\pi^-) &lt; 4.6 \times 10^{-5}$ 90% C.L.</td>
</tr>
<tr>
<td>DELPHI</td>
<td>$Br(\Lambda_b \to pK) &lt; 3.0 \times 10^{-4}$ 90% C.L.</td>
</tr>
<tr>
<td>L3</td>
<td>$Br(B^0_d \to \pi^0\pi^0) &lt; 7.6 \times 10^{-5}$ 90% C.L.</td>
</tr>
</tbody>
</table>

Table 3: Charmless B-decays
Cleo has also provided a clear observation of electromagnetic "penguin" process with results summarized in Table 4:

**Exclusive Decay Channel:**

\[ \text{Br} (B^0 \rightarrow K^0 \gamma) = (4.3^{+1.1}_{-1.0} \pm 0.6) \times 10^{-5} \]

**Combined with inclusive result:**

\[ \frac{\Gamma(B \rightarrow K^* \gamma)}{\Gamma(b \rightarrow s \gamma)} = 0.19 \pm 0.07 \pm 0.04 \]

**Table 4:** CLEO Observation of Electromagnetic "Penguin" Process
1.4 From TRISTAN:

We have very interesting results from TRISTAN $e^+e^-$ collider, particularly in $\gamma+\gamma \rightarrow$ charm production, baryon production and jet production, as shown in Figure 5.

![Diagram](image)

Figure 5: $\gamma + \gamma \rightarrow$ charm production, baryon production and jet production

The TRISTAN results established "resolved-Photon" processes and selected "Gluon-Density" parametrizations. Another very interesting and important result from TRISTAN is the high-$Q^2$ measurement of the photon structure function $F_2^\gamma$ by the AMY collaboration as shown in Figure 6. The $Q^2$ dependence clearly shows the scale-breaking behaviour predicted by QCD.
Figure 6: High-\(Q^2\) measurement of the photon structure function \(F_2^{\gamma}\) by the AMY collaboration.

At the TRISTAN 12 GeV Proton Synchrotron, there is a very precise \(\mu\)SR study of mono-energetic \(\mu\)'s from \(K^+ \rightarrow \mu\nu\) at rest, as shown in Figure 7. This experiment provides a very accurate measurement of: \(\xi_{P\mu} = -0.9996 \pm 0.0030 \pm 0.0048\) this sets new limit on the "right-handed" current.

Figure 7: \(\mu\)SR study of mono-energetic \(\mu\)'s from \(K^+ \rightarrow \mu\nu\) at rest.
1.5 From BNL

At Brookhaven National Laboratory in Long Island, there is continued impressive progress in the study of rare K decays. Professor S. Wojcicki presented the recent progress on the study of $K^0_L$ to lepton pairs. This is shown in Table 5. It is important to note that in a very short time, the electron channel will reach the limit of $\sim 10^{-12}$ and there are already 4000 events on the pure muon channel.

<table>
<thead>
<tr>
<th>BNL Rare K decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^0_L \rightarrow \mu^\pm e^\pm$</td>
</tr>
<tr>
<td>$K^0_L \rightarrow e^+ e^-$</td>
</tr>
<tr>
<td>$K^0_L \rightarrow \mu^+ \mu^-$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>S. Wojcicki</td>
</tr>
</tbody>
</table>

**Table 5**: Recent progress at BNL on $K^0_L$ to lepton pairs

Table 6 summarizes the recent progresses in rare $K^+$ decays both at rest and in flight.

<table>
<thead>
<tr>
<th><strong>E791 [Littenberg] Rare $K^+$ decays at rest</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- first observation of $K^+ \rightarrow \pi^+\mu^+\mu^-$, $K^+ \rightarrow \pi^+ \gamma\gamma$</td>
</tr>
<tr>
<td>- new lower limits on $K^+ \rightarrow \pi^+\nu\nu$ [measures $</td>
</tr>
<tr>
<td>- other exotic decay searches, eg. $K^+ \rightarrow \pi^+ X^0$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>E865 [Zeller] Rare $K^+$ decays in flight</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- search for $K^+ \rightarrow \pi^+\mu e$ [lepton flavor violation]</td>
</tr>
<tr>
<td>- first observation of $K^+ \rightarrow \pi^+e^+e^-$</td>
</tr>
<tr>
<td>- other exotic decay searches, eg. $K^+ \rightarrow \pi^+ X^0$</td>
</tr>
</tbody>
</table>

**Table 6**: Recent progresses in rare $K^+$ decays at BNL
1.6 From S.L.A.C.

At the SLAC linear collider, there is a great achievement in the polarization of electron beam from the original value of 20% to almost the theoretical limit of 80% as shown in Figure 8.

![Figure 8: Beam Polarization, SLD 1992 - 1995 data](image)

Figure 9 shows the measurement of left-right asymmetry at Z° pole which is typically 15% as compared to no asymmetry in Bhabha scattering.

![Figure 9: $A_{LR}$ and luminosity bhabha asymmetries in data blocks](image)
Figure 10 shows the polarized $Z \rightarrow b\bar{b}$ asymmetry using jet charge to define the charge of $b$-quark. The angle $\theta_T$ is between the thrust axis of $b$-jet and the polarized incident electron beam.

![Figure 10: Polarized Z → b\bar{b} asymmetry](image)

Table 7 summarizes the impressive SLD results which provided a $\sin^2\theta_W = 0.2305 \pm 0.0005$

<table>
<thead>
<tr>
<th>1- Measurement of $A_{LR}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992, 93, 94/95 Data combined</td>
</tr>
<tr>
<td>$A_{LR} = 0.1551 \pm 0.0040$</td>
</tr>
<tr>
<td>$\downarrow$</td>
</tr>
<tr>
<td>$\sin^2\theta_W = 0.2305 \pm 0.0005$</td>
</tr>
<tr>
<td>2- Polarized Forward-Backward asymmetry for $b$ and $c$ quarks</td>
</tr>
<tr>
<td>$A_c = 0.57 \pm 0.10$</td>
</tr>
<tr>
<td>$A_b = 0.861 \pm 0.053$</td>
</tr>
</tbody>
</table>

**Table 7:** Summary of SLD results on measurements of electroweak parameters
In addition to the SLD results, SLAC also provided important information from the study of scattering of polarized muons from polarized protons to measure the spin-dependent structure function $g_1^p$. Professor Vernon Hughes who originated this study from the original Yale-SLAC collaboration in 1983, has presented impressive results shown in Figure 11.

![Figure 11: $g_1^p$ as function of $X$ measured over the last 10 years](image)

1.7 From LEP

At LEP-I, the four experimental groups (ALEPH, DELPHI, L3 and OPAL) have collected a total of $20 \times 10^6 Z^0$ providing a variety of precision tests of electroweak theory. Typical results from the four groups are the following:
1.7.1 From the ALEPH Collaboration:

Figure 12 shows the precise measurement of b lifetimes. The exclusive measurements show that the b-baryon decays faster than b-meson, as expected. The inclusive measurement yields an average b lifetime of 1.533 ± 0.026 ps.

![Figure 12: b-lifetimes measured by the ALEPH Collaboration](image)

Figure 13 shows the quality of the data in the measurement of b-baryon lifetime by the ALEPH collaboration showing a clear signal with very small combinatorial background.

![Figure 13: Measurement of b-baryon lifetime](image)
Professor S.L. Wu showed the important ALEPH study of $B^0-\bar{B}^0$ oscillation by measuring the rate of same sign dileptons normalized to the total dilepton rate. As seen from Figure 14, this provides a clear measurement of $B_d$ oscillation with small contribution from $B_s$, $b \rightarrow c$ and other backgrounds. The ALEPH measurements yield $\Delta m_d = 0.430 \pm 0.032 \pm 0.071 \text{ ps}^{-1}$.

![Figure 14](image)

**Figure 14:** ALEPH measurement of $B^0-\bar{B}^0$ oscillation as a function of proper time

1.7.2 From the DELPHI Collaboration:

DELPHI group has a very good particle identification capability. Figure 15 shows the clear separation of various particles by the gas RICH, the liquid RICH and the dE/dX of the central drift chamber.
The DELPHI collaboration provided a very interesting study of fragmentation function for b-hadrons, B*-mesons and B**-mesons, as shown in Figure 16.
1.7.3 From the OPAL Collaboration:

OPAL has also provided important results on the electroweak physics with heavy flavours. Figure 17 shows the measurement of the forward-backward asymmetry of b. The results are summarized in Table 8. As seen from Table 8, Opal obtained an $R_b = 0.2197 \pm 0.0014 \pm 0.0022$.

![Figure 17: OPAL measurement of forward-backward asymmetry of b](image)

**Table 8:** Summary of electroweak results from OPAL

<table>
<thead>
<tr>
<th>OPAL jet charge $A_{FB}^b$</th>
<th>$\sin^2 \theta^e_w = 0.2313 \pm 0.0012 \pm 0.0006$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_b = \Gamma (Z^0 \rightarrow b\bar{b}) / \Gamma (Z^0 \rightarrow \text{hadrons})$</td>
<td>$0.2197 \pm 0.0014 \pm 0.0022$</td>
</tr>
</tbody>
</table>

Average of 3 OPAL measurements
Figure 18 summarizes the OPAL measurement of $b$ hadron lifetimes, again indicating that $b$-baryon decays faster than $b$-meson.

![Figure 18: Summary of $b$ hadron lifetimes from OPAL](image)

Figure 19 is another important OPAL result, showing the evidence of $B$ decays to $D^{**}$ ($D_j$). Two states were observed: $D_j^0$ and $D_j^+$. 

![Figure 19: Evidence for semileptonic $B$ decays to $D^{**}$ ($D_j$)](image)
1.7.4 From the L3 Collaboration:

Professor Hesheng Chen showed the L3 measurement of tau polarization asymmetry (Figure 20), giving a $\sin^2 \theta_W = 0.2308 \pm 0.0013$.

The L3 collaboration also studied the production of tensor mesons from 2-photon processes, via the reaction $e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^- K^0_s K^0_s$ (see Figure 21).

Figure 20: Tau polarization asymmetry measurement by the L3 Collaboration

Figure 21: Production of tensor mesons by the L3 Collaboration from the reaction: $e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^- K^0_s K^0_s$
The mixing angle of the tensor nonet is determined to be $\theta = (29.4^{+1.4}_{-1.6})^\circ$. As seen from Figure 21, in addition to the $f_2'(1525)$, there is an indication of another $K_S^0 K_S^0$ state at a mass of $\sim 1800$ MeV.

The L3 Collaboration also studied the difference between $\eta$ production in quark jet and in gluon jets. Historically, gluon jets were first observed in 1979 by the MARK-J experiment with major contributions from H. Newman, M. Chen, J. Branson and from Chinese physicists (H.W. Tang, Z.P. Zheng, Z. Q. Yu, H.S. Chen and others). Figure 22 is a reproduction of the first statistically significant evidence that the 3-jet events cannot only come from fluctuations in fragmentation from heavy quark decays. The MARK-J experiment showed that a) the 3-jet rate agreed with QCD. b) the shape agreed with QCD.

![Diagram showing the distribution of events](image)

**Figure 22:** Discovery of gluon jets by the MARK-J experiment in 1979 as reproduced in the proceedings of the 1979 International Symposium on lepton and photon interactions at high energies (August 23-29, 1979). *See also H. Schopper New Results in $e^+e^-$ annihilation from PETRA, DESY 79/79, Dec. 1979.*

At LEP energies, the jets are much more collimated, as shown in Figure 23. Also shown are the $\gamma\gamma$ spectra from the two highest energy jets (jet 1 and jet 2), as well as from the gluon jet, jet 3.
Figure 23: Measurement of \( \eta \) production in quark jet and gluon jet

Figure 24 shows that for \( \pi^0 \) production, the momentum distribution for all 3 jets are well explained by QCD and fragmentation implemented in Monte-Carlo programs. But for \( \eta \) production, the momentum distribution of the third jet, at large \( X_p \), cannot be explained by Monte-Carlo. This may indicate a possible existence of glueball effects which are not included in the current \( \eta \) production Monte-Carlo.

Figure 24: Momentum distribution of \( \pi^0 \) and \( \eta \) production in jets
1.7.5 Summary of LEP-I Results

i) $M_Z$ : the mass of $Z^0$

Figure 25 summarizes the LEP measurements of the mass of $Z$ from the four LEP groups. The average mass from the four groups is $M_Z = 91188.4 \pm 2.2$ MeV. The 2.2 MeV error includes a common error of 1.5 MeV and the combined statistical error of 1.6 MeV from the four groups.

\[
\begin{array}{ccc}
\text{ALEPH} & 91192.4 \pm 3.7 \text{ MeV} \\
\text{DELPHI} & 91184.9 \pm 3.4 \text{ MeV} \\
\text{L3} & 91193.8 \pm 3.6 \text{ MeV} \\
\text{OPAL} & 91184.6 \pm 3.5 \text{ MeV} \\
\text{LEP} & 91188.4 \pm 2.2 \text{ MeV} \\
\end{array}
\]

\[\text{common 1.5 MeV} \quad \text{not com 1.6 MeV} \quad \chi^2/\text{dof} = 6.9/3\]

**Figure 25**: The measurement of $Z^0$ mass from four LEP groups

ii) $\Gamma_Z$ : the total width of $Z^0$

Figure 26 summarizes the LEP measurements of the total width of $Z$ from the four LEP groups, providing an average width of $\Gamma_Z = 2496.3 \pm 3.2$ MeV. Also shown in Figure 26 is the Standard Model calculation of $\Gamma_Z$ as function of the mass of the top quark, $M_t$, the mass of the Higgs, $M_H$, and $\alpha_s$, and the constraint on $M_t$ from the measurement of $M_Z$. 
**Figure 26**: The measurement of $\Gamma_Z$, the total width of $Z^+$, from the four LEP groups

### iii) $\Gamma_{\text{inv}}$: the invisible width and $N_V$: the number of neutrino species

Figure 27 summarizes the LEP measurements of the invisible width of $Z$ from the four LEP groups, providing an average $\Gamma_{\text{inv}} = 499.9 \pm 2.5$ MeV. In the framework of the Standard Model, this value of $\Gamma_{\text{inv}}$ determines the number of neutrino species $N_V = 2.990 \pm 0.016$. Also shown in Figure 27 is the Standard Model calculation of $\Gamma_{\text{inv}}$. 
iv) The direct measurement of the number of neutrino species $N_V$

The number of neutrino species can also be directly determined by measuring the single photon reaction $e^+ + e^- \rightarrow \nu \bar{\nu} \gamma$. Figure 28 shows the results from the L3 Collaboration giving an $N_V = 3.01 \pm 0.09 \pm 0.08$. Table 9 summarizes the results from Aleph, L3 and OPAL experiments.
Figure 28: Direct measurement of the number of neutrino species $N_{\nu}$ from the L3 Collaboration. Also shown is the energy and angular region of $\gamma$ measurement for this experiment.

Table 9: Summary of direct determination of $N_{\nu}$ from Aleph, OPAL and L3

<table>
<thead>
<tr>
<th></th>
<th>$\int \mathcal{L} dt$ (pb$^{-1}$)</th>
<th>$\Gamma_{\text{inv}}$ (MeV)</th>
<th>$N_{\nu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3</td>
<td>57.3</td>
<td>503 $\pm$ 15 $\pm$ 13</td>
<td>3.01 $\pm$ 0.09 $\pm$ 0.08</td>
</tr>
<tr>
<td>ALEPH</td>
<td>15.7</td>
<td>450 $\pm$ 34 $\pm$ 34</td>
<td>2.68 $\pm$ 0.20 $\pm$ 0.20</td>
</tr>
<tr>
<td>OPAL</td>
<td>40.5</td>
<td>539 $\pm$ 26 $\pm$ 17</td>
<td>3.23 $\pm$ 0.16 $\pm$ 0.10</td>
</tr>
<tr>
<td>Combined</td>
<td>507 $\pm$ 16</td>
<td>3.03 $\pm$ 0.10</td>
<td></td>
</tr>
</tbody>
</table>

v) The determination of $\sin^2\theta_W$

Figure 29 summarizes the LEP determination of $\sin^2\theta_W$ from forward-backward asymmetry of leptons, $A_{FB}$ lepton, from average tau polarization and forward-backward polarization asymmetry, $A_T$, $A_e$, from forward-backward asymmetry of b- and c-quarks, $A_{FB}$ b-quark, $A_{FB}$ c-quark. These measurements yield an average LEP value of $\sin^2\theta_W = 0.2318 \pm 0.0004$. Combined with the SLAC value of $\sin^2\theta_W = 0.2305 \pm 0.0005$, the average
value is $0.2314 \pm 0.0003$. Also shown in Figure 29 is the Standard Model calculation of $\sin^2 \theta_W$ and the constraint on $M_t$ from these measurements.

![Figure 29](image_url)

**Figure 29**: The determination of $\sin^2 \theta_W$ from the four LEP collaborations and SLD

### 1.7.6 Comments on LEP-I Results

i) **Determination of the top mass, $M_t$**

In addition to the measurements at LEP and SLD, the beautiful measurements of $\nu$ scattering on electrons by CHARM II provide an accurate determination of $g_A^e = -0.503 \pm 0.006$ (st) as shown in Figure 30.
CHARM II determination of $g_A^e$ and $g_V^e$. The measurement of the forward-backward asymmetry $A_{FB} (e^+e^- \rightarrow e^+e^-)$ at $Z^0$ is also shown.

Table 10 summarizes the determination of $M_t$, $\alpha_s$ from LEP data alone, from LEP data plus SLD and finally from all information including $\nu N$ data and the direct measurement of $M_W$. As seen, the fitted value of $M_t$ shown in the first row of Table 10 agrees with the direct measurements by CDF and D0 of $M_t = 180 \pm 12$ GeV.

<table>
<thead>
<tr>
<th></th>
<th>LEP</th>
<th>LEP + SLD</th>
<th>LEP + SLD + $M_W$ and $\nu N$ data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_t$ (GeV)</td>
<td>170 ± 10$^{+17}_{-19}$</td>
<td>180$^{+8}<em>{-9}$$^{+17}</em>{-20}$</td>
<td>178 ± 8$^{+17}_{-20}$</td>
</tr>
<tr>
<td>$\alpha_s (M_Z^2)$</td>
<td>0.125 ± 0.004 ± 0.002</td>
<td>0.123 ± 0.004 ± 0.002</td>
<td>0.123 ± 0.004 ± 0.002</td>
</tr>
<tr>
<td>$\chi^2$/d.o.f.</td>
<td>18/9</td>
<td>28/12</td>
<td>28/14</td>
</tr>
<tr>
<td>$\sin^2\theta_{lept}^{eff}$</td>
<td>0.23206 ± 0.00028$^{+0.00008}_{-0.00017}$</td>
<td>0.23166 ± 0.00025$^{+0.00006}_{-0.00013}$</td>
<td>0.23172 ± 0.00024$^{+0.00007}_{-0.00013}$</td>
</tr>
<tr>
<td>$1 - M_W^2/M_Z^2$</td>
<td>0.2247 ± 0.0010$^{+0.0004}_{-0.0002}$</td>
<td>0.2234 ± 0.0009$^{+0.0005}_{-0.0002}$</td>
<td>0.2237 ± 0.0009$^{+0.0004}_{-0.0002}$</td>
</tr>
<tr>
<td>$M_W$ (GeV)</td>
<td>80.295 ± 0.057$^{+0.011}_{-0.019}$</td>
<td>80.359 ± 0.051$^{+0.013}_{-0.024}$</td>
<td>80.346 ± 0.046$^{+0.012}_{-0.021}$</td>
</tr>
</tbody>
</table>

Table 10: Summary of fitted results of $M_t$ and $\alpha_s$ from LEP data and from LEP + SLD and finally from all available data. The last three rows are the consequence of the fitted $M_t$ and $\alpha_s$. 
ii) Consistency of Electroweak Theory:

The Standard Model seems to be able to explain all available data over a wide energy region. As an example, Figure 31 shows the comparison of $e^+ + e^- \rightarrow \mu^+ + \mu^- + \gamma$ from PEP, PETRA, TRISTAN and LEP showing excellent agreement between data and the Standard Model.

![Figure 31](image)

**Figure 31:** Comparison of the measured forward-backward asymmetry $A_{FB}$ and total cross-section, $\sigma$, to the lowest order Born predictions.

iii) The measurement of $R_b$ and $R_c$

The only possible deviation between data and the Standard Model arises from the measurement of $R_b = \frac{\Gamma_b}{\Gamma_{had}}$ and $R_c = \frac{\Gamma_c}{\Gamma_{had}}$. Figure 32 shows the comparison with the Standard Model predictions and the LEP average values of $R_b$ and $R_c$. As seen, the LEP average values of $R_b$ and $R_c$ deviate from the Standard Model prediction by three standard deviations. Obviously, more measurements are necessary to ascertain the origin of this deviation.

![Figure 32](image)

**Figure 32:** Comparison of the Standard Model prediction (SM) of $R_b$ and $R_c$ with the LEP average value.
1.7.7 Comments on the LEP-II Program

In November of this year, LEP will reach a center mass energy of 140 GeV. It is intended to have a data sample of 5 pb$^{-1}$ total luminosity. The machine energy will gradually increase to a final energy of ~ 193 GeV. Table 11 summarizes the current plan of LEP-II up to 1999. LEP-II will provide an important opportunity to search for new particles and additional tests of the Standard Model.

Table 11: LEP-II Program

<table>
<thead>
<tr>
<th>Date</th>
<th>Energy (GeV)</th>
<th>Luminosity (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 1995</td>
<td>140</td>
<td>5</td>
</tr>
<tr>
<td>May 1996</td>
<td>161</td>
<td>50</td>
</tr>
<tr>
<td>October 1996</td>
<td>175</td>
<td>30</td>
</tr>
<tr>
<td>1997 - 1999</td>
<td>183 - 193</td>
<td>150/yr</td>
</tr>
</tbody>
</table>

- Test of machine and detectors;
- Search for new particles up to $M = 70$ GeV.
- $W$ mass measurement at threshold $\Delta M_W \approx 100$ MeV
- Search for new particles up to $M = 80$ GeV.
- Search for Higgs Boson up to $M_H = 80$ GeV.
- Search for new particles up to $M = 87$ GeV.
- $W$ mass measurement $\Delta M_W = 80$ MeV
- Study of the three gauge boson couplings;
- Search for Higgs Boson up to $M_H = 100$ GeV.
- Search for new particles up to $M = 95$ GeV.

Figure 33 shows the sensitivity in the tests of the Standard Model characterized by the measurement of the deviation of the magnetic moment of $W^\pm$ ($\mu_W$)

$$\mu_W = \frac{e}{2M_W}(1 + K\gamma + \lambda\gamma)$$

Note: In the Standard Model $K\gamma = 1$; $\lambda\gamma = 0$; $X\gamma = K\gamma - 1$; $X\gamma = 0$.

Figure 33: Limits on anomalous couplings with $\int L dt = 500$ pb$^{-1}$ in reaction $e^+e^- \rightarrow W^+W^-$.
As seen from Figure 33, in the reaction $e^+e^- \rightarrow W^+W^-$, the measurement of the $W^\pm$ direction $\cos \theta$, the leptonic decay direction, $\theta_\ell$ and hadronic jet direction, $|\theta_j|$, provide very accurate constraints on the deviation of magnetic moment. Figure 34 provides an example of sensitivities for the $5\sigma$ discovery limit and the 95 % CL exclusion zone for the Standard Model Higgs as function of center mass energy and luminosity. As seen from Figure 34, near the end of 1999, one should be able to provide information on the existence of Higgs up to a mass of 100 GeV.

Figure 34: Standard Model Higgs Search
1.8 From Fermi National Laboratory

The most important physics results over the last two years are the discovery of the top, the measurement of the mass of top $M_t$ and the measurement of $M_W$. Figure 35 summarizes the CDF top results from leptonic decay channels.

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Obs.</th>
<th>Bkg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\mu, e\mu, e\mu$</td>
<td>8</td>
<td>$1.9 \pm 0.4$</td>
</tr>
<tr>
<td>$e\mu + \text{Jets w/ 2nd Vtx}$</td>
<td>40</td>
<td>$9.9 \pm 2.8$</td>
</tr>
<tr>
<td>$e\mu + \text{Jets w/ b\rightarrow e,}\mu$</td>
<td>40</td>
<td>$23.8 \pm 3.6$</td>
</tr>
</tbody>
</table>

**Figure 35**: CDF top results based on leptonic decay channels

CDF determined the mass of top quark $M_t = 176 \pm 8\text{(stat)} \pm 10\text{(sys)} \text{GeV/c}^2$ and the production cross-section $\sigma_{t\bar{t}} (M_t = 176 \text{ GeV/c}^2) = 7.6^{+2.4}_{-2.0} \text{ pb}$. The D0 Collaboration also found the top quark signal. They determined $M_t = 199^{+19}_{-21} \pm 14 \text{ GeV}$ and $\sigma_{t\bar{t}} (M_t = 199 \text{ GeV/c}^2) = 6.4\pm2.2\text{pb}$.

Figure 36 shows the CDF top results from pure hadronic decay channels. It is important to note that the leptonic and hadronic channels yield a consistent result.
Figure 36: CDF top results based on pure hadronic decay channels

Figure 37 is the determination of W mass by the CDF Collaboration from both W → eν and W → μν. These two measurements yield a determination of M_W = 80.41 ± 0.18 GeV. The data is based on a total luminosity of 19 pb⁻¹.
In the framework of the Standard Model, the determination of $M_W$ and $M_t$ provide a constraint of the mass of Higgs as shown in Figure 38.

Figure 38: Limits on Higgs mass from measurement of $M_W$ and $M_{top}$ as determined by the CDF Collaboration.
The width of $W$ was measured in two ways:

i) Indirect measurement from $\sigma_W \text{Br}(\nu) / \sigma_Z \text{Br}(\ell\ell)$: this yields
   \[ \Gamma_W = 2.06 \pm 0.09 \text{ GeV (ev) } \]
   \[ \Gamma_W = 1.80 \pm 0.11 \text{ GeV (} \mu \nu \text{) preliminary} \]

ii) Direct measurement from fitting $MT^W$ distribution, this yields
   \[ \Gamma_W = 2.11 \pm 0.32 \text{ GeV (ev) } \]

These numbers are in good agreement with the Standard Model prediction of $\Gamma_W = 2.07 \pm 0.02 \text{ GeV }$.

Both CDF and D0 Collaborations have provided good tests of the Standard Model, by studying $WW\gamma / WWZ$ couplings. Figure 39 is the observation of asymmetry in $\gamma$ rapidity by the CDF Collaboration. The measured asymmetry of $0.77 \pm 0.07$ is in good agreement with the Standard Model prediction of $0.76 \pm 0.04$.

**Figure 39:** Observation of asymmetry in $\eta_\gamma$ from $p + \bar{p} \rightarrow W\gamma + X$

Figure 40 is the combined limit by CDF and D0 on the anomalous magnetic moment of $W$ showing excellent agreement with the Standard Model.

**Figure 40:** Limits on anomalous magnetic moment of $W$
Finally, the available high center of mass energy provides an excellent opportunity to search for new particles. Table 12 summarizes the results of CDF exotic particle searches as well as their future prospects.

### CDF Exotic Particle Searches: Results and Run II Prospects

<table>
<thead>
<tr>
<th>Searches</th>
<th>Current CDF limit (GeV)</th>
<th>data set</th>
<th>run II (GeV)</th>
<th>with 2 fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W' \rightarrow e \nu$ (SM)</td>
<td>$&lt; 652$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 990$</td>
</tr>
<tr>
<td>$W' \rightarrow WZ$</td>
<td>$205 &lt; M &lt; 400$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 900$</td>
</tr>
<tr>
<td>$Z' \rightarrow \ell \ell$ (SM)</td>
<td>$&lt; 650$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 800$</td>
</tr>
<tr>
<td>$Z'<em>W, Z'</em>\eta, Z'_X, Z'_I$</td>
<td>$&lt; 415, 440, 425, 400$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 800$</td>
</tr>
<tr>
<td>$Z'<em>{LR}, Z'</em>{ALRM}$</td>
<td>$&lt; 445, 420$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 800$</td>
</tr>
<tr>
<td>Axigluon $\rightarrow qq$</td>
<td>$200 &lt; M &lt; 1000$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 1160$</td>
</tr>
<tr>
<td>Techniro $\rightarrow$ dijet</td>
<td>$270 &lt; M &lt; 510$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 770$</td>
</tr>
<tr>
<td>$W' \rightarrow qq$ (SM)</td>
<td>$380 &lt; M &lt; 470$</td>
<td>+</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 720$</td>
</tr>
<tr>
<td>$Z' \rightarrow qq$ (SM)</td>
<td>$410 &lt; M &lt; 460$</td>
<td>+</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 720$</td>
</tr>
<tr>
<td>$E_6$ Diquark $\rightarrow qq$</td>
<td>$370 &lt; M &lt; 460$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 570$</td>
</tr>
<tr>
<td>topgluon $\Gamma = .1M$</td>
<td>$200 &lt; M &lt; 550$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 300$</td>
</tr>
<tr>
<td>topgluon $\Gamma = .3M$</td>
<td>$210 &lt; M &lt; 450$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 300$</td>
</tr>
<tr>
<td>topgluon $\Gamma = .5M$</td>
<td>$200 &lt; M &lt; 370$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 300$</td>
</tr>
<tr>
<td>Leptoquark ($\mu\tau$)</td>
<td>$&lt; 180, (\beta = 1)$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 300$</td>
</tr>
<tr>
<td>Composit.Scale (qqqq)</td>
<td>$&lt; 1800$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 2200$</td>
</tr>
<tr>
<td>Composit.Scale (qqq\ell)</td>
<td>$2200, 1700 (ee)$</td>
<td>*</td>
<td>'88-89 (4pb⁻¹)</td>
<td>$&lt; 5000$</td>
</tr>
<tr>
<td>q$^\ast$ (W + jet, $\gamma +$ jet)</td>
<td>$&lt; 540$</td>
<td>*</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 820$</td>
</tr>
<tr>
<td>q$^\ast$ $\rightarrow$ dijet</td>
<td>$200 &lt; M &lt; 600$</td>
<td>*</td>
<td>1a + 1b (70pb⁻¹)</td>
<td>$&lt; 820$</td>
</tr>
<tr>
<td>massive stable ptl.,</td>
<td>$&lt; 140 to &lt; 255$</td>
<td>*</td>
<td>'88-89 (4pb⁻¹)</td>
<td>$&lt; 350/ &lt; 520$</td>
</tr>
<tr>
<td>gluino</td>
<td>$&lt; 160(\text{any } m_q), &lt; 225(\text{mg=mq})$</td>
<td>#</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 350/ &lt; 520$</td>
</tr>
<tr>
<td>squark</td>
<td>$&lt; 168$ (for $m_g &lt; 500$)</td>
<td>#</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 350/ &lt; 520$</td>
</tr>
<tr>
<td>gaugino</td>
<td>$\chi^\pm_1 &lt; 46, \chi^0_2 &lt; 46$</td>
<td>#</td>
<td>1a (20pb⁻¹)</td>
<td>$&lt; 350/ &lt; 520$</td>
</tr>
</tbody>
</table>

* Current world best limit in direct search mode for the model.
+ CDF has the world best limit in another decay mode.
# Same as *, but D0 also has comparable limits.

**Table 12** CDF exotic particle searches: results and run II prospects
1.9 From HERA

The luminosity at HERA has increased rapidly over the years as shown in Figure 41. The two experiments, ZEUS and H1 each expect 10 - 15 pb\(^{-1}\) in 1995 and 20 - 40 pb\(^{-1}\) in 1996.

**Figure 41**: HERA luminosity from 1992 to 1995

Figure 42 shows the measured total \(\gamma p\) cross section as a function of the center of mass energy squared \(W\). The data for \(Q^2 = 0\) show a moderate rise with increasing \(W\), while data with \(Q^2 > 1\) GeV\(^2\) (~ deep inelastic scattering) show a strong rise with increasing \(W\).
Figure 42: Measured total $\gamma p$ cross section as a function of the center of mass energy squared $W$. The curves, connecting points of the same $Q^2$ value, are given to guide the eye.

Both HERA groups have provided direct measurement of the gluon structure function. The results agree with each other and with the muon fixed target experiment NMC (results of indirect methods). This is shown in Figure 43.
Figure 43: Comparison of various methods to measure the gluon density at leading order. A novelty (in DIS) is the measurement of Boson Gluon Fusion events, from a sample of 2-jet events. This result is given at an average $Q^2$ of 30 GeV$^2$. Furthermore, indirect measurements (from scaling violations of $F_2$) are shown at $Q^2 = 20$ GeV$^2$ as well as with a determination from $J/\psi$ production by NMC evolved to $Q^2 = 30$ GeV$^2$.

The HERA groups have also studied photoproduction of vector mesons $\rho$ and $\phi$ by virtual photons. This is shown in Figure 44. A fit of the $\rho$ and $\phi$ production cross sections to a power law $W^n$ shows that:

a) For $Q^2 = 0$, $\rho$ and $\phi$ production vary slowly with increasing $W$. The production of $\phi$ agrees with vector dominance model (VDM) predictions, with the power law $n$ in the range of 0.2-0.3.

b) For $Q^2 >$ few GeV$^2$, both $\rho$ and $\phi$ production follow the curve $W^{0.8}$. This steep rise is in clear disagreement with VDM predictions.
Figure 44: Cross sections for exclusive $\rho$ and $\phi$ production in deep inelastic scattering: $\gamma^* p \to \rho p$, $\gamma^* p \to \phi p$, as function of $W$, the $\gamma^* p$ center of mass energy, for several values of $Q^2$. The low energy data ($W < 20$ GeV) come from fixed target experiments. The high energy data ($W > 50$ GeV) come from the ZEUS and H1 experiment. The ZEUS data on $\rho$ production have for $Q^2 > 5$ GeV an additional 31% systematic normalization uncertainty (not shown).

The HERA groups also provided a very important measurement of $\alpha_s$. This is shown in Figure 45. The HERA measurements of $\alpha_s$, when evolved to the scale $Q^2 = M_Z^2$, agree well with the world average of $\alpha_s(M_Z) = 0.117$, as well as the LEP average, within errors.

Figure 45: The measured value of $\alpha_s$ from the rate of 2-jet events as a function of $Q^2$. The line presents the combined result of H1 and ZEUS with the $1\sigma$ band.
As was presented in this conference, HERA has also presented very large amounts of data at very low $X$ down to $4 \times 10^{-5}$ and high $Q^2$ (to 5000 GeV$^2$). It is the ideal place for studying interplay between soft and hard processes. As seen from Figure 41, with increase in luminosity, we expect a tremendous amount of physics from HERA.
Chapter two: Future plans

In this chapter I summarize the Future Plans at High Energy Physics Laboratories and some observations on the future of our field from Laboratory directors.

2.1 In Italy:

INFN Frascati Laboratory

The Frascati Laboratory is presently engaged in the construction of the DAΦNE $e^+e^-$ Phi-Factory ($L = 10^{33}/cm^2/sec$) with two detectors, one of which is KLOE under Paolo Franzini’s leadership, as shown in Figure 46.

![Figure 46: The Frascati φ-Factory](image-url)
2.2 In China:
The Tau Charm Factory

Our host IHEP in Beijing is planning a Tau-Charm factory as a logical extension of their successful BEPC project. A Tau-Charm factory with a luminosity of $10^{33}$$/cm^2$ sec and energy range of 3 to 6 GeV will offer a unique opportunity for precision measurements in the Tau-charm energy range. Its physics cannot be replaced by other facilities and complements B-Factory physics. Table 13 summarizes some of the physics potential of a Tau-Charm factory.

**Unique experimental environment:**
- High statistics: 30-50 M $\tau/c$ /year
- Low backgrounds:
  - $\tau$ production below c/b threshold
  - Tagged charm hadrons
- Bgds. exp. measured < threshold
- High rate calibration sources: $J/\psi, \psi'$

**Physics highlights:**
- Direct $m(\nu_\tau)$ limit $\sim$ 1 MeV
- V-A in $\tau$ decays $\equiv$ precn. in $\mu$ decay
- CP violation in $\tau$ decays to $\sim$ 0.1%
- $D/\bar{D}s \rightarrow \mu\nu/\tau\nu$; $f_D/f_{Ds} \sim$ 2% precision
- $D^0/D^0$ mixing $\sim$ 10$^{-5}$, at SM level
- CP violation in D decays at SM level
- Systematic study of gluonic matter

**Table 13:** Tau-Charm Factory Physics

As pointed out by Professor T.D. Lee, the Tau-Charm factory offers a unique opportunity to study CP and T violation in the lepton systems.

2.3 In the US

a) At Cornell University

At Cornell, there is a vigorous plan (as shown in Figure 47) to upgrade the highly successful CESR to a much higher luminosity. The goal of CESR is to reach the luminosity much above $10^{33}$/cm$^2$/sec. This will offer a unique opportunity to study B-physics.
b) At Brookhaven National Laboratory

Professor Nicholas Samios shares with us the future plans of Brookhaven National Laboratory. Table 14 is the near term future plans of BNL both at AGS and at RHIC. Of great interest are: i) the continued study of rare kaon decay, ii) the definitive gluon exotics search iii) the search for strangelets iv) the precision measurement of muons (g-2) to 0.3 ppm.

**Alternating Gradient Synchrotron (AGS)**
- seek full utilization of the AGS facility (25 wks/yr for p’s + 12 wks/ye for Au ions)
- continue upgrades of intensity (now 6x10^6 ppp)
- develop beam injection for RHIC (Au & pol. p’s)
- run µ prod. & cooling studies for a µµ collider

**RHIC Project**
- complete & commission the RHIC collider
- complete 4 baseline heavy-ion detectors STAR, PHENIX, PHOBOS, BRAHMS
- complete the RHIC Computing Facility at BNL
- commence work on the AEE items for detectors

**Physics Goals**
- continue accumulating rare kaon decay events
- complete a definitive gluon/exotics search
- confirm or deny the existence of strangelets
- measure muon (g-2) to 0.3 ppm
- map the transparency of nuclei for elastic scatt.

**Table 14**: Near-term future plans for Brookhaven National Laboratory

---

**Figure 47**: CESR luminosity upgrade plan
Table 15 presents the long-term plans of Brookhaven National Laboratory.

<table>
<thead>
<tr>
<th>Program Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>– RHIC heavy ion physics program - 37 weeks/yr</td>
</tr>
<tr>
<td>– RHIC pol. proton exps. - up to 10 weeks/yr</td>
</tr>
<tr>
<td>– other AGS exps. as approved</td>
</tr>
<tr>
<td>– pursue relevant $\mu\mu$ collider (if approved)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physics Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>– explore the heavy ion physics of RHIC</td>
</tr>
<tr>
<td>quark-gluon plasma</td>
</tr>
<tr>
<td>disordered chiral condensate</td>
</tr>
<tr>
<td>boson correlation functions</td>
</tr>
<tr>
<td>meson mass and width shifts</td>
</tr>
<tr>
<td>new phenomena...</td>
</tr>
<tr>
<td>– explore the physics of pol. protons in RHIC</td>
</tr>
<tr>
<td>gluon structure functions $\Delta G (x)$</td>
</tr>
<tr>
<td>quark spin structure functions $\Delta q (x)$</td>
</tr>
<tr>
<td>transversity structure functions $h_l (x)$</td>
</tr>
<tr>
<td>search for quark substructure via jet $p_T$ shape other spin physics ...</td>
</tr>
<tr>
<td>– continue AGS physics as the field develops</td>
</tr>
<tr>
<td>neutrino oscillation parameters</td>
</tr>
<tr>
<td>exotic meson states</td>
</tr>
<tr>
<td>strangelet physics ?</td>
</tr>
<tr>
<td>gluino related states $S^0$ ?</td>
</tr>
<tr>
<td>other physics not yet identified ...</td>
</tr>
</tbody>
</table>

**Table 15**: Brookhaven National Laboratory long-term plans

Of particular interest is the plan to construct a $\mu^+\mu^-$ collider up to a maximum energy of 2 TeV x 2 TeV and with a luminosity larger $10^{34}$/cm$^2$/sec.

Professor Samios offered his views on the future of high energy physics, reproduced in Table 16, pointing out the need to continue vigorous research with present facilities as well as the need for higher energy and higher intensities complementary colliders.
Physics: Standard Model ? 17 parameters
Questions: Mass Fermions, W's, Z's (Higgs Supersymmetry)
Other States of Matter:
Quark Gluon Plasma
Glueballs, Exotics, Strangelets
Symmetries:
CP Violation
Chiral Sym.
SU(5) ?

Strategies:
1) Continued probing and search for deviations from
   Standard Model with present facilities.
   W, Z, t masses, sin^2θ_w, α_s ...
   Rare decays K, B, g-2
2) Accelerators: Higher energies, higher intensities and
   complementivity (hh, ℓℓ)
   Ideal: First high energy hh followed by specific ℓℓ
   \[ E \geq \frac{1}{2} \text{TeV} \]
   \[ \mathcal{L} \geq 10^{33} \]
   Few new machines
High intensity: Upgrade present facilities and possibly
   few new unique ones.
   \[ h > 10^{14} / \text{pulse} \]
   \[ \mathcal{L} = 10^{33} - 10^{34} \]

Table 16: View of a future of High Energy Physics by N. Samios

c) At Fermi National Laboratory

Fermi National Laboratory currently has the highest energy hadron collider and
has provided us with truly exciting new results. Dr. John Peoples has presented us his
very interesting plans on the future of Fermi National Laboratory, as reproduced in Tables
17 and 18.

- February 1996:
  complete the current collider run
- May 1996 - February 1998:
  operate the Tevatron in fixed-target mode for:
  - NuTeV, measure \( \sin^2θ_W \) using ν and \( \bar{ν} \) beams
  - KTeV, measure \( ε/ε' \) and branching ratios of rate decays of \( K^0_L \)
  - Continue the measurement of the properties of charm decays
    (FOCUS and SELEX) and charmonium (E-835)
  - Observe the interaction of tau ν's in matter (E-872)

Table 17: Near-term plans of Fermi National Laboratory
- Complete the Main Injector Project and related improvements to the Tevatron complex and resume colliding beams operation (1999).
- Upgrade the CDF and DO detector to handle a peak luminosity of $2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$ (1999).
- Increase the peak luminosity from greater than $5 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$ (1999) to $2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$ with a new storage ring, the Recycler (2001).
- Construct a neutrino beam from the Main Injector suitable for neutrino oscillation experiments (2001) and mount a short baseline and a long baseline experiment.
- Concurrent fixed-target operation with Main Injector and colliding beam operation (2001).
- Develop a plan to increase the peak luminosity of the Tevatron to $10^{33} \text{cm}^{-2} \text{s}^{-1}$.

**Table 18: Long-term plans of Fermi National Laboratory**

d) At SLAC

Professor Burton Richter has provided us with SLAC’s long-range program as summarized in Table 19.

**Near Term:**
- SLC / SLD with polarized electrons (500K more $Z^0$).
- 50 GeV polarized electron on polarized proton, neutron and deuteron targets.
- B-Factory and BaBar construction.
- NLC R&D.

**Mid Term:**
- Exploiting the B-Factory.
- Expanded NLC R&D.

**Long Term:**
- Continued exploitation of the B-Factory.
- Participation in an international NLC construction project.

**Table 19: Main elements of SLAC long-range program**
Of great importance is the construction at SLAC of the B-factory with physics scheduled to begin in 1999. The BABAR physics collaboration has an excellent detector with major contributions from the United States, from CERN member states and other countries.

SLAC is also vigorously planning to realize the Next Linear Collider (NLC) with initial energy of 500 GeV and luminosity of $5 \times 10^{33}$/cm$^2$/sec, with expansion capability to 1.5 TeV. Table 20 summarizes these plans and Figure 48 shows a schematic of the SLAC version of NLC.

- **International consensus that goal should be**
  - $E^* = 500$ GeV, $L = 5 \times 10^{33}$ cm$^2$/s
  - with expansion capability to 1 - 1.5 TeV.
- **Well coordinated worldwide program exists.**
- **300/1 beam demagnification demonstrated at SLAC by a collaboration including DESY, Orsay, Max Plank, Munich, Novosibirsk, KEK, FNAL, SLAC. Beam size of 70 nm demonstrated.**
- **A technically possible schedule:**
  - 1997 — choose best technology.
  - 1997 - 2000 — engineering design, international agreement to construct, site choice.

**Table 20:** Next Linear Collider Project

![Next Linear Collider Project](image)

**Figure 48:** Schematic of the Next Linear Collider
Professor Richter also has penetrating views on the future of High Energy physics, as reproduced in Table 21.

- Great concern exists everywhere about levels of future funding and opportunities for research as facilities grow larger and the number of major detectors shrinks.
- The next ten years are packed with scientific opportunities:
  - LEP II,
  - Tevatron,
  - HERA,
  - SLC,
  - B-Factories,
  - Tau/Charm Factory,
  - Non-accelerator experiments.
- In 2005:
  - LHC will be new,
  - B-Factories will be middle-aged,
  - HERA and the Tevatron will be old,
  - LEP II and SLC will be gone.
- It takes more than ten years from an accelerator concept to the first experiment. Are we investing enough in thinking about the future?
- If all of the regions are to continue in high energy physics, our future big facilities will have to be built, run, and funded inter-regionally.
- On the electron physics side, a large international R&D program is providing the basis for a future machine. Muon colliders are beginning to be studied for collision energies of beyond 10 - 20 TeV.
- On the proton side, there is no significant work on the high $T_c$ systems that will be required to build affordable machines much beyond LHC. It should begin.
- Non-accelerator experiments underground, on the surface, and in space should be better supported. They are very interesting and cost a lot less than a new machine.
- Since it is very unlikely that budgets will continue to increase, it will not be possible to keep increasing the number of people working in the field. How will we keep our field intellectually young?
- Finally:
  - If you are less than 40, you should be doing physics.
  - If you are older than 55, you should be spending most of your time creating opportunities for the next generation.
  - Those in the middle should see to it that the best young people stay in the field.

| Table 21: Professor B. Richter's views on the future of High Energy physics |

I share his view that "non-accelerator experiments underground, on the surface and in space should be better supported. They are very interesting and cost a lot less than a new machine".
2.4 In Japan

At the National Laboratory for High Energy Physics, KEK

Professor Hirotaka Sugawara has kindly provided me with the long-term scenario of High Energy physics in his laboratory, shown in Table 22, which centers on the commissioning of KEK B-factory by the end of 1998 and on the construction of the Linear Collider with international collaboration. The Japanese long-term scenario of high energy physics is the result of intensive studies of two committees, the first one chaired by Y. Nagashima, and the second one chaired by S. Komamiya. Professor Sugawara has summarized the future of our field as reproduced in Table 23.

<table>
<thead>
<tr>
<th>Long term scenario of High Energy Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction of LC (e^+e^- collider) through</td>
</tr>
<tr>
<td>International Cooperation</td>
</tr>
<tr>
<td><strong>Japan will be willing to host</strong></td>
</tr>
<tr>
<td><strong>International research institute</strong></td>
</tr>
<tr>
<td><strong>Time Schedule</strong></td>
</tr>
<tr>
<td>KEKB ; commissioning is scheduled in end of JFY 1998</td>
</tr>
<tr>
<td>JHP ; commissioning is expected in 2003 ?</td>
</tr>
<tr>
<td>LC ; HEP Subcommittee recommends an early construction of the Phase-1 LC such that experiments at the LHC and the LC can be conducted concurrently.</td>
</tr>
</tbody>
</table>

**Table 22 :** KEK long-term scenario on High Energy Physics, as provided by Professor Hirotaka Sugawara
The Future of our Field

Europe
Authorization of LHC

U.S.A.
60 TeV Hadron Collider ?,
μ+ μ− collider ?

Japan
LC (e+e− collider)

The first Subcommittee on Future Projects in Japan
(chaired by Y. Nagashima), Report in March 1986

1. To immediately launch an accelerator R&D program,
aiming at e+e− linear collider (LC) in the TeV range to
be built in Japan.

2. To participate in the research program at the SCC through
an international collaboration.

The second Subcommittee (chaired by Y. Nagashima),
Interim Report in July 1995

1. Physics program at e+e− linear collider
   SUSY scenario, Light Higgs boson,
   Colorless supersymmetric particles,
   Balanced strategy when combined with Hadron collider programs.

2. LHC Project
   Phase-1: E_{CM} = 250 - 500 GEV
   Phase-2: E_{CM} ~ 1 TeV or more

3. Early construction of an e+e− linear collider through International
   Cooperation.

4. Mission of KEK
   Center for Japanese efforts

Reorganization of the Laboratory to serve
research requirements of other fields

Nuclear and Material Science
JHP (Japan Hadron Project)
   3 GeV rapid cycle Proton Synchrotron for neutron source
   (beam power: 0.6 MW) and 50 GeV Proton Synchrotron (4x10^{14} PPP)

Synchrotron Radiation Science
   2.5 GeV Photon Factory ring and 6.5 GeV TRISTAN AR ring

High Energy Physics
KEKB Project, high-current asymmetric e+e− storage rings with
E_{CM} = 10.6 GEV for studies of CP-violation.

Table 23: Future of High Energy Physics as viewed by Professor Sugawara
2.5 In Germany

At DESY

Professor Bjorn Wiik has provided us with some fascinating progresses in the construction of a large electron-positron linear collider shown in Figure 49.

**Figure 49:** Research based on the exploitation of an electron-positron linear collider facility

The developing program of the 1 GeV Tesla Test Facility Free Electron Laser is progressing well.

Figure 50 shows the set-up of the Tesla Test Facility and a schematic of the Free Electron Laser with the following schedule:

- Electron acceleration by first Tesla module: end of 1995
- Start operation of Tesla Test Facility at 500 MeV: end of 1995
- SASE FEL tests at the Tesla Test Facility with $E \leq 500$ MeV: during 1998 (TTF FEL phase 1)
- Installation of Tesla Modules No. 5-8 and of full size undulator: 1998 - 1999
- Start commissioning of TTF FEL at 1 GeV: 2000
Figure 50: Schematic of Tesla Test Facility and VUV Free Laser Facility

Figure 51(a) shows the prototype cavities for Tesla and Figure 51(b) is the first results which have reached an impressive grading of 25 MeV/m.

Figure 51 (a) : Prototype Cavities for Tesla
The physics of the high energy $e^+e^-$ linear collider is compelling. The vigorous research plans at SLAC, KEK and at DESY will ensure that it becomes a reality.

### 2.6 At CERN

The Director General of CERN, Professor Chris Llewellyn Smith shares with us his future plans at CERN, as shown in Table 24. In addition to the vigorous physics program at LEP, CERN will provide a unique opportunity for heavy ion physics, for kaon physics and neutrino oscillations from SPS. From year 2004 onwards, CERN will host the Large Hadron Collider project with at least four detectors: ATLAS, CMS, ALICE and LHCB (see the LHC layout shown in Figure 52).

#### Table 24: Future Plans at CERN

1990s
- Successfully upgrade and exploit LEP (140 GeV in October 1995; $E > 2 M_W$ end 1996) → search for Higgs (to beyond $M_Z$) and SUSY, study $WWZ/\gamma$ vertex, $M_W$ ...
- Heavy ion physics with Pb beams from SPS, $\varepsilon'/\varepsilon$ (NA48), neutrino oscillations (CHORUS / NOMAD) ...
- Closure of facilities (Ω and LEAR at end 1996) to free resources and manpower →
- Get construction of LHC well underway

2000 - 2003
- Install LHC and LHC experiments
- ISOLDE + select / small fixed target program

2004 + ...
- LHC - (ATLAS, CMS, ALICE, LHCB + ?): hope to have 14 (+) TeV from the start
Figure 52: Layout of the CERN Large Hadron Collider

Professor Chris Llewellyn Smith has outlined his strategy and plans for the LHC and this is shown in Figure 53.

Figure 53: The development of the LHC project
LHC detectors are rather large and complex. Figure 54 shows a schematic of the general purpose ATLAS detector which features strong toroidal fields and Figure 55 presents the CMS detector which features a unique and precise electromagnetic calorimeter.

**Figure 54:** The ATLAS detector at LHC
In addition to LEP and LHC, as pointed out by Professor Chris Llewellyn Smith, CERN also has a very active neutrino physics program, CHORUS, shown in Figure 56 and NOMAD, shown in Figure 57. These detectors will provide a most sensitive study of neutrino oscillations. Indeed, the measurement of the mass of neutrino (see Figure 58) has raised more questions than answers over the last 15 years. Hopefully, this situation will soon be clarified by the CHORUS and NOMAD experiments.

**Figure 55**: The CMS detector at LHC

**Figure 56**: CHORUS detector
Figure 57: NOMAD detector

Figure 58: Measurement of the electron neutrino mass $M_\nu$
Professor Llewellyn Smith who guides the entire CERN research program shares with us his views of the future of particle physics (as presented in Table 25) and expresses his strong conviction that searches at LEP-2, Tevatron and LHC for supersymmetric particles and Higgs boson should be of top priority.

**Physics**

- Nature is (probably) supersymmetric (but not necessarily minimal) and there is (probably) an elementary Higgs boson - searches (LEP2, Tevatron, LHC) should be top priority.

- Hints of new physics in neutrino physics should be vigorously pursued - eagerly await results from CHORUS, NOMAD, SNO, S-Kamiokande ...

- CP violation is potentially the Achilles heel of the Standard Model, and must be sought in different systems (KTeV; NA48; HERAB; PEP II; TRISTAN II; LHC ...), but I will not be surprised if the results are standard.

- Searches for proton decay (must occur ?), dark matter (seems to exist !) are important and necessary in parallel with experiments at the high energy frontier.

**Politics / Funding**

Interregional Collaboration is a sina qua non: major facilities are now at the limit that can be funded by one region alone, and we must optimise the use of limited resources (and demonstrate - to scientists in other fields, as well as politicians - that we are responsible).

---

**Table 25**: Views of the Future of Particle Physics by Professor Chris Llewellyn Smith
Professor Stan Wojcicki, Chairman of HEPAP, which advises the U.S. Department of Energy on the future of High Energy physics, expresses his views in a similar manner as shown in Table 26.

<table>
<thead>
<tr>
<th>Whither HEP in the Future?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S. Wojcicki</strong></td>
</tr>
</tbody>
</table>

### a) First 10 years (t < 2005)

- Further probes of SM based on new/upgraded facilities e.g.
  - Searches for "light" new particles - Higgs, SUSY, Leptoquarks, etc. (LEPII, Tevatron, HERA)
  - Detailed study of CP violation (KEK, SLAC, HERAB, ...)
  - \( \nu \) oscillations and masses (CERN, Fermilab, KEK/Super K)
  - Baryon and lepton number violation (Super K, BNL, ...)
  - Continuation of precision studies in b and K decays, e-w parameters (LEP I, Tevatron, CESR, Frascati, BNL, B factories)
  - Non-accelerator experiments (Super K, SNO, Gran Sasso, ...)

- Negative (SM-consistent) results → more frustration
- Positive (SM-violating) results → definite focus for the future

### b) Following decade (2005 - 2015)

- Study of mass scale up to 1 TeV based on LHC and initial \( e^+e^- \) linear collider (\( E_{cm} \leq 1 \text{ TeV} \))
- Follow-ups on any positive results from previous decade
- Large scale astrophysics / cosmology efforts
- Departure from SM have to be seen by this time

### c) The decade beyond (2015 - 2025)

- Exploitation of next generation accelerator
  - Could be: 2nd generation \( e^+e^- \) linear collider (\( \geq 2 \text{ TeV} \))
  - Super Hadron collider (\( \geq 50 \text{ TeV} \))
  - \( \mu^+\mu^- \) collider (few TeV)

### d) Next decade and beyond (t > 2025)

- HEP based on new acceleration principles
  - or
- End of HEP

**Table 26**: View of High Energy Physics in the Future, by Professor S. Wojcicki, Chairman of HEPAP
Chapter Three: Particle Physics without Accelerators

In recent years, particularly after the construction of the Laboratory of Gran Sasso and the success of Kamiokande, there has been tremendous progress in the study of particle physics without accelerator. I will list three examples:

3.1 The MACRO Experiment

Figure 59 shows the MACRO experiment at Gran Sasso underground by a minimum of 3200 meters of water equivalent so as to have a minimum muon energy of 1.2 TeV. The detector is 77 meters x 9.5 meters x 12 meters. It uses streamer tubes for tracking (0.2° resolution) and scintillator for timing (0.5 ns resolution). MACRO provides high statistics unambiguous measurements of upgoing muons from neutrinos penetrating the earth as shown in Figure 60.
The Zenith distribution of Macro upgoing muons is shown in Figure 61. The data slightly favour neutrino oscillations with $\Delta m^2 = 8 \times 10^{-3} \text{ eV}^2$ and $\sin^2 (2\theta) = 0.87$. Clearly, more data are necessary.

**Figure 60:** Signals of upgoing muons observed at MACRO

**Figure 61:** Zenith distribution for MACRO upgoing muons
MACRO also put constraints on the magnetic monopole flux, as seen in Figure 62. In five years' time, the MACRO results will be below the important Parker limit over a wide range of monopole mass.

![Figure 62: Astrophysical constraints on Monopole flux and Macro flux limits](image)

3.2 The Super-Kamiokande Experiment

The Super-Kamiokande detector is a factor 10 more massive than Kamiokande II with a better energy and spacial resolution, as shown in Table 27.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Superkamiokande</th>
<th>Kamiokande</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total size</td>
<td>41 mh x 39 m φ</td>
<td>16 mh x 19 mh</td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>50,000 t</td>
<td>4,500 t</td>
<td></td>
</tr>
<tr>
<td>Fiducial mass</td>
<td>32,000 t</td>
<td>2,140 t</td>
<td>Supernova</td>
</tr>
<tr>
<td></td>
<td>22,000 t</td>
<td>1,040 t</td>
<td>Proton decay</td>
</tr>
<tr>
<td></td>
<td>22,000 t</td>
<td>680 t</td>
<td>Solar neutrino</td>
</tr>
<tr>
<td>Thickness of anti-counters</td>
<td>2 m</td>
<td>1.2 - 1.5 m</td>
<td></td>
</tr>
<tr>
<td>Number of PMT</td>
<td>11,200</td>
<td>948</td>
<td></td>
</tr>
<tr>
<td>PMT coverage</td>
<td>40 %</td>
<td>20 %</td>
<td></td>
</tr>
<tr>
<td>Energy resolution</td>
<td>2.6 % / √E</td>
<td>3.6 % / √E</td>
<td>Electrons (GeV)</td>
</tr>
<tr>
<td></td>
<td>2.5 %</td>
<td>4 %</td>
<td>µ with E_µ&lt; 1 GeV</td>
</tr>
<tr>
<td></td>
<td>14 % / √E/10 MeV</td>
<td>20 % / √E/10 MeV</td>
<td>Electrons(&lt; 50 MeV)</td>
</tr>
<tr>
<td>Position resolution</td>
<td>50 cm</td>
<td>110 cm</td>
<td>10 MeV electron</td>
</tr>
<tr>
<td></td>
<td>~ 10 cm</td>
<td>~ 50 cm</td>
<td>p → e⁺ π⁰</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>27 deg</td>
<td>27 deg</td>
<td>10 MeV electron</td>
</tr>
<tr>
<td></td>
<td>~ 1 deg</td>
<td>2.7 deg</td>
<td>through going µ</td>
</tr>
<tr>
<td>Trigger energy</td>
<td>4 ~ 5 MeV</td>
<td>5.0 MeV</td>
<td></td>
</tr>
<tr>
<td>Analysis threshold</td>
<td>5 MeV</td>
<td>7.5 MeV</td>
<td>Solar neutrino</td>
</tr>
<tr>
<td>e / µ separation</td>
<td>~ 99 %</td>
<td>98 ± 1 %</td>
<td></td>
</tr>
<tr>
<td>µ⁺ decay detection</td>
<td>95 %</td>
<td>87 ± 1 %</td>
<td>µ⁺ not included</td>
</tr>
</tbody>
</table>

Table 27: Parameters for Super-Kamiokande and for Kamiokande II
Super-Kamiokande will provide nearly two orders of magnitude improvement in sensitivity in search for proton decays as shown in Figure 63.

![Diagram](image)

The 90% C.L. lower limits of the nucleon partial lifetime for various nucleon decay modes obtained by the IMB ( ), Kamiokande ( ), and Frejus ( ) experiments. The expected limits to be reached after 5 years of the Superkamiokande operation are also shown ( ).

**Figure 63**: Sensitivity of Super-Kamiokande for different proton decay channels as compared with current experimental results

### 3.3 The AMS Experiment

Finally, let me present an experiment, the Alpha Magnetic Spectrometer (AMS) for extraterrestrial study of antimatter, matter and missing matter on the international space station Alpha. This experiment is an international collaboration from Switzerland (M. Bourquin, H. Hofer), Germany (K. Lübelsmeyer), Italy (R. Battiston, F. Palmonari,
In the past forty years, there have been many fundamental discoveries in astrophysics measuring micro waves, X-rays and gamma ray photons. There has never been a sensitive magnetic spectrometer in space, due to the extreme difficulty and very high cost of putting a superconducting magnet in orbit. However, recent advancements in permanent magnet material and technology (as shown in Figure 64) make it possible to use very high grade Nd-Fe-B to construct a permanent magnet with a $BL^2 = 0.15 \text{Tm}^2$ and with acceptance of $\sim 1 \text{m}^2\text{Sr}$ weighing about 2 tons.

![Figure 64: Advancement of permanent magnet material since 1960](image)

The physics objectives of this experiment are:

- To search for Antimatter ($\text{He, } \bar{\text{C}}$) in space with a sensitivity of $10^4$ to $10^5$ better than current limits.
- To search for dark matter by high statistics precision measurements of the $e^+$, $\gamma$, and $\bar{p}$ spectra.
- To study astrophysics by high statistics precision measurements of D, $^3\text{He}$, B, C, Be$^9$, Be$^{10}$ spectra.
The design principles of the AMS detector are (see Figure 65) the determinations of:

- Charge $|Q|$ by measuring energy loss $\frac{dE}{dX}$ in silicon tracker and in scintillation counters S1 to S4.
- Momentum and sign of charge ($P/Q$) by measuring the trajectory with 6 layers of silicon tracker. The magnet (M) provides a bending power of $BL^2 = 0.1 \text{Tm}^2$. The six layers of silicon tracker provide $x,y,z$ coordinate measurements to $10 \mu\text{m}$, providing typically: $\Delta P/P = \sim 7\%$ at 10 GeV/N.
- Velocity (V): by measuring the time of flight $t_1$ and $t_2$. This is to reject backgrounds.

**Figure 65:** Schematic of the AMS detector

In addition, there are:

i) Two directional Cerenkov counters $C_1$ and $C_2$ used to measure velocity, to reject background further and provide identification of various nuclei.

ii) Transition radiation detectors $S_{t1}, S_{t2}, S_{t3}, S_{t4}$ used to identify high energy positrons.

The physics objectives of AMS are closely related to CP violation and supersymmetry.

In the case of the search for antimatter, the Big Bang origin of the universe requires matter and antimatter to be equally abundant at the very hot beginning. Since there are very little experimental results on the abundance of antimatter in space, there are two classes of theories:

a) the theories predicting the total absence of antimatter and

b) the theories predicting the existence of antimatter
Theories predicting the total absence of antimatter are:

i) Grand Unified Theories: they can explain the absence of antimatter if there is a very strong breakdown of CP. These theories require the existence of heavy neutrinos and the abundance of monopoles. Neither have been found.

ii) Electroweak theories: they can explain the absence of antimatter if there is a very strong breakdown of CP. They require the mass of Higgs ($M_H$) to be $\sim 40$ GeV (the measurement is $M_H > 60$ GeV).

To ensure that there is indeed a total absence of antimatter, the AMS detector is designed to improve the existing sensitivity by $10^4$ to $10^5$ in the search of antimatter, as shown in Figure 66.

![Figure 66](image)

Figure 66: Sensitivity of AMS (3 years on ISSA) in a search for He and $Z > 2$ antinuclei (95% CL)

Theories predicting the existence of antimatter:

The breakdown of the Time-Reversal symmetry in the early universe might have set different signs for the production of matter and antimatter in different regions of space. Since there are $10^8$ clusters of galaxies and the observational constraints are limited to the scale of the clusters, the universe can be symmetric on a large scale. The observed matter-antimatter asymmetry is then a local phenomenon. Figure 67 shows the sensitivity of AMS in detecting antihelium as compared to the prediction of antihelium yield predicted by a symmetric universe. As seen from Figure 67, the current limit is not sensitive enough to test the existence of clusters of galaxies of antimatter and AMS is $10^3$ times more sensitive than predictions based on matter-antimatter symmetric universe.
Figure 67: AMS Antihelium-helium sensitivity as a function of energy as compared to the prediction of a symmetric universe.

The second physics objective of AMS is to search for dark matter. Ninety percent of the universe is made of dark matter. Most of the physicists (see for examples, J. Ellis et al., Phys. Lett. B214, 403 (1988b), Michael S. Turner, Frank Wilzek, Physical Review D42, 4, 1001 (15 August 1990)) believe that Weakly Interacting Massive Particles (WIMP’s) comprise dark matter. This can be tested by direct searches for various annihilation products of WIMP’s in the galactic halo, i.e. $\bar{p}$, $\gamma$, $e^+$.

$$\chi + \chi \rightarrow \bar{p} + ...$$
$$\gamma + ...$$
$$e^+ + ...$$

The large acceptance of AMS with the Cerenkov counters $C_1$ and $C_2$ and transition radiators, $St_1 - St_4$, will enable us to measure very accurately the energy spectrum of $\bar{p}$ and $e^+$.

The third objective of AMS is to study astrophysics. A high statistic measurement of isotopes can address many important issues in astrophysics, for example:

i) The ratio of $B/C$ will enable us to understand Cosmic Ray propagation in the Galaxy.

ii) The ratio of $Be^9/Be^{10}$ will enable us to determine Cosmic Ray confinement time in the Galaxy.
This experiment is scheduled to have a first measurement for ten days on the Space Shuttle DISCOVERY which is to be launched on 2 April 1998. Figure 68 shows the arrangement of AMS on the shuttle.

![Figure 68](image)

**Figure 68**: AMS on Shuttle "Discovery". The Shuttle will fly at an altitude of 200 nautical miles at an inclination angle of 51.6° with a crew of 5.

This one hundred hours’ flight will enable us to obtain a rather accurate \( \bar{p} \) spectrum below 1.3 GeV. as seen from Figure 69. The \( \bar{p} \) spectrum will provide a sensitive search of supersymmetric particles such as neutralinos.

![Figure 69](image)

**Figure 69**: Simulated 100 hour shuttle flight \( \bar{p} \) measurement. \( \bar{p} \) spectrum from \( M_\chi = 30 \) GeV and 60 GeV are from G. Jungman and M. Kamionkowski (Physical Review D49, 2316 (1994)).
This experiment is currently scheduled to be installed on the international Space Station at the beginning of year 2001. Figure 70 shows the location of AMS on the space station.

Figure 70: Location of AMS on the International Space Station Alpha.
Conclusion

Dr. John Peoples, Director of Fermi National Laboratory, has concisely expressed (Table 28) the trend and the future of High Energy physics, which I would like to share with you as the conclusion.

View of the Future

The extension of the energy frontier of elementary particle physics will require global collaboration in the construction and operation of the highest energy particle accelerators. Because it is likely that only one major new facility will be built in the world at one time, it will be necessary to more fully exploit the capabilities of existing facilities than has been the custom in the past. The boundary between the fields of elementary particle physics and astrophysics will provide a great opportunity to understand the early universe and particle physics not accessible to the next generation of accelerators.

Table 28: View of the Future by Professor John Peoples

Acknowledgements

I want to particularly thank Professor Chris Llewellyn Smith, Professor John Peoples, Professor Burton Richter, Professor Hirotaka Sugawara, Professor Björn Wiik, Professor Karl Berkelman, Professor Zheng Zhipeng, Professor Klaus Winter and Professor Stan Wojcicki for providing me with most valuable information. I also want to thank the speakers of the Conference for their help and support as well as Professor Guy Coignet, Dr. David Stickland, Dr. Martin Pohl, Dr. Joachim Mnich, Dr. Robert Clare, Dr. Yi Fang Wang, Dr. Jasper Kirkby, Professor Wolfgang Lohmann and Professor Hesheng Chen for their help and the discussions I had with them. I specially want to thank Ms. Laurence Barrin and Ms. Yvette Bernard for their technical support.