The Future of Fixed Target Physics: Snowmass E5 Working Group Summary

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Fixed target experimentation remains a vigorous and important tool. In many cases it provides the best technique to study elementary physics. Here we explore several areas, where, in the near future, fixed target experiments have the potential to alter our understanding of physics. These include, but are clearly not limited to, high precision tests of CP violation in the Kaon sector, ultra-precise determination of the weak mixing angle and its evolution, and lepton flavor violation.

Traditionally the study of elementary particles and fields uses a number of different techniques, each of which sharpens our basic understanding of the fundamental forces and building blocks of nature in some unique way. Many of these techniques can be divided into two broad categories: collider experimentation and fixed target experimentation. While the center-of-mass energy frontier clearly belongs to the colliders, there are still very significant contributions which can and are being made by fixed target experiments. Here, several of these areas in which the unique properties of the fixed target environment can be exploited are explored. It must be emphasized that this is a rich field, and that these are only some of the experiments which are particularly suited to fixed targets. Note that one very exciting application of fixed target techniques, neutrino physics, is covered by the E1: Neutrino Factories and Muon Colliders working group and is not discussed here.

I. FACILITIES

While physics should drive new proposals and not the availability of beams, it is useful to review what new or improved facilities will be available in the future. These facilities may be divided into those which provide hadron beams and those which provide lepton and photon beams. For each facility, the discussion here focuses on the facility itself, rather than the experimental programs of the facility, much of which is discussed later.

Two facilities within the United States will soon have upgraded proton beams for use in fixed target experiments. Fermilab plans to extract 120 GeV proton beams from the new Main Injector (MI). Slow resonant extraction from the MI has already been demonstrated. Several experiments have been approved using this beam. The CKM experiment will start collecting data around 2007 (see Sec. II). On this timescale, beams of 3×10^{13} protons/pulse at a rate of 0.3 Hz will be available (0.2 MW of power). Running at the same time as CKM, E906 [1] has been approved to explore the structure of the proton sea at high x (see Sec. V A). Lower intensity beams will be available sooner (2002) [2]. While both the collider and the neutrino programs are running, the total number of available accelerated proton becomes critical. To alleviate this problem, various proton stacking methods are being investigated which would allow more protons to be accelerated by the MI.

The Brookhaven AGS can deliver a 24 GeV proton beam with 0.14 MW of power. This beam is available only while RHIC is running, and during these periods, time is allocated from the AGS to refill RHIC (approximately 2 hrs every 10 hrs is allocated for RHIC). Currently, the AGS can supply up to 7×10^{13} protons per spill spaced 2 s apart. With the addition of a future upgrade including a 1.2 GeV injector linac, the total power would be 1 MW with 10^{14} protons per pulse at a rate of 2.5 Hz. A unique feature of this beam, required by the KOPIO experiment (see Sec. II) for background rejection, is the micro-bunching of the beam.

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TABLE I: Properties of future and upgraded fixed target accelerator facilities.

Hadron (Proton) Facilities

Facility	Beam Energy	Intensity	Notes
Japanese High Intensity Proton Accelerator (JHF)	50 GeV	1 MW (5 MW upgrade) 16 μA	Phase I funded; Completion in 2007; LOI's solicited soon.
Brookhaven AGS	24 GeV	0.14 MW (1 MW upgrade 10^{14} at 2.5 Hz)	Available while RHIC runs; Upgrade requires 1.2 GeV Linac
Fermilab Main Injector	120 GeV	0.2 MW 3×10^{13} at 0.3 Hz	Low intensity beams in 2002; CKM expt in 2007

Lepton and Photon Facilities

Facility	Beam Energy	Intensity	Notes
Jefferson Lab	12 GeV polarized e^-	50 μA CW	New Hall D; 11 GeV Halls A, B, C; Upgrade Physics 2008
SLAC End Station A	10-50 GeV polarized e^- polarized γ	10 μA, 120 Hz	Coherent Bremsstrahlung
TESLA-N	50-100 GeV polarized e^-	20 nA 5 Hz	Populate missing RF buckets
ELFE@DESY	20-30 GeV e^-	30 μA CW	TESLA injector; HERA stretcher
NLC	250 - 500 GeV polarized e^-	27 μA 120 Hz	Post-collision "disrupted beam"

The Japanese High Intensity Proton Accelerator (also known as the JHF) presents a new facility. Phase I of this facility is funded and is scheduled for completion in 2007. The Phase I facility will consist of a 400 MeV linac feeding a 3 GeV proton synchrotron (PS). This in turn will feed a 50 GeV PS, which will have up to 1 μA of current with an intensity of 1 MW. Possible upgrades could bring the intensity to 5 MW [3].

Both Jefferson Laboratory and SLAC have electron beam facilities. The accelerator facility at Jefferson Lab has been routinely producing beams with 80% polarization of currents up to 100 μA and energies up to 5.7 GeV. Beams may be simultaneously delivered to 3 experimental halls. Future plans at Jefferson Lab include increasing the maximum energy beam to 12 GeV, upgrading the existing experimental halls and the construction of a new experimental hall, Hall D, for meson spectroscopy (see Sec. III). These plans have been endorsed by the *NSAC Long Range Plan* [4]. Current plans call for Construction to begin in 2004 and be completed by 2010, with the physics programs of some of the experimental halls beginning by 2008.

At SLAC, End Station A has been used with a polarized electron beam in a number of successful experiments. The beam energies ranged from 7 to 48 GeV with typical polarizations of 80 to 90% and 0.3 MW of power. This beam can also be used for photoproduction experiments using a coherent bremsstrahlung beam produced on a near-perfect diamond radiator. E-158 [5] will collect data at End Station A to measure $\sin^2\theta_W$ (see Sec. VI A), and a number of other experiments have already been approved [6–8].

The proposed linear colliders represent excellent machines at which to stage fixed target experiments as well. At DESY, the TESLA-N proposal uses the unpopulated RF-buckets in the positron beamline to produce a polarized beam of 250 to 500 GeV electrons. This could deliver a 20 nA beam at a rate of 5 Hz to a fixed target experimental hall [9]. ELFE (Electron Laboratory for Europe) also makes use of TESLA. A portion of the linac (27 GeV) is used to accelerate electrons which are then injected into the HERA electron ring, which serves as a pulse stretcher. After the HERA ring is filled, it would be extracted to external experiments. The beam would have an energy range of 15 to 27 GeV with a maximum current of 30 μA. ELFE at TESLA could operate concurrently with TESLA collider operations by using empty beam pulses [10].

At a proposed Next Linear Collider (NLC) there are also plans for fixed target facilities. At the NLC, the beams collide at a very slight angle. This allows the uninteracted (or "disrupted" beam) to be extracted and used for fixed target experiments. When in operation, the post collision electrons would be directed toward a hole in the beam dump by a bending magnet. The beam dump hole would also act the first collimator for the beam. The energy spread of the disrupted beam is reduced through a series of additional collimators. This could make available a polarized (up to 90%) high-current (27 μA) beam for fixed target use at very little additional cost due to its parasitic nature.

II. CP VIOLATION

Studies of neutral kaons have provided essential insights into CP violation, the Standard Model and weak decay physics and illustrate the unique capabilities of fixed target experiments. Fixed target kaon experiments continue to illuminate fundamental physics issues and future experiments will provide precision tests of the Standard Model.

Since the first observation of $K_{\rm L} \to \pi^+\pi^-$ nearly 40 years ago, understanding CP violation has been one of the major goals of particle physics. Until recently, all observations of CP violation were consistent with a small asymmetry between $K^0 \to \overline{K}^0$ and $\overline{K}^0 \to K^0$ mixing. This asymmetry, referred to as indirect CP violation, renders the weak eigenstates $K_{\rm S}$ and $K_{\rm L}$ as mixtures of CP even ($K_{\rm even}$) and CP odd ($K_{\rm odd}$) states:

$$\begin{aligned} K_{\rm S} &\sim K_{\rm even} + \epsilon K_{\rm odd} \\ K_{\rm L} &\sim K_{\rm odd} + \epsilon K_{\rm even}, \end{aligned} \tag{1}$$

where $\epsilon \sim O(10^{-3})$ parameterizes the effect.

CP violation can also occur directly in the decay amplitude ($K_{\rm odd} \to \pi\pi$). This process is known as direct CP violation and is parameterized by ϵ'. The ratio $\mathrm{Re}(\epsilon'/\epsilon)$ can be determined from a measurement of the double ratio of the $K_{\rm S}$ and $K_{\rm L}$ decay rates (Γ) to 2 pions:

$$\mathrm{Re}(\epsilon'/\epsilon) \simeq \frac{1}{6}\left[\frac{\Gamma(\mathrm{K_L} \to \pi^+\pi^-)/\Gamma(\mathrm{K_S} \to \pi^+\pi^-)}{\Gamma(\mathrm{K_L} \to \pi^0\pi^0)/\Gamma(\mathrm{K_S} \to \pi^0\pi^0)} - 1\right]. \tag{2}$$

The Standard Model predicts both direct and indirect CP violation, though large uncertainties in hadronic matrix elements make precise calculations very difficult. Other models, such as Wolfenstein's Superweak Model [11], predict no direct CP violation. $\mathrm{Re}(\epsilon'/\epsilon) \neq 0$ is an unambiguous indication of direct CP violation.

NA48 at CERN and KTeV at Fermilab have recently announced results of the most precise measurements of $\mathrm{Re}(\epsilon'/\epsilon)$ yet made. The results are shown in Fig. 1 and indicate reasonable agreement, compared to the more confusing situation that existed previously. The KTeV and NA48 results definitively establish the existence of direct CP violation, consistent with the CKM formalism of the Standard Model.

The Standard model also predicts direct CP violating effects in hyperon decays with dynamics and matrix elements that are very different than in kaon decays. The HyperCP experiment at Fermilab is currently analyzing over 2.5 billion hyperon decays in search of CP violation. Λ's of known polarization were produced from unpolarized Ξ^- and $\overline{\Xi}^+$ hyperons. HyperCP measures the slope of the proton (antiproton) $\cos\theta$ distribution in the Λ rest frame where the Λ momentum direction in the Ξ rest frame defines the polar axis. CP is violated if the slopes of the proton and antiproton $\cos\theta$ distributions are not identical. HyperCP is sensitive to CP violation in both Ξ and Λ decays. A preliminary study of 1.7% of the data shows no asymmetry to the 10^{-3} level. The full data set should yield a sensitivity of $\sim 2\times10^{-4}$ which is at the high end of the range of theoretical predictions. CP violation in Λ and Ξ decays is manifestly direct CP violating.

Almost any extension to the Standard Model includes new possibilities for CP violation. To search for new physics, the Standard Model must be over-constrained and tested for consistency using processes with well controlled experimental <u>and</u> theoretical errors. The most promising processes which satisfy both criteria currently are $B \to \Psi K_{\rm S}$, B_s mixing, $K_{\rm L} \to \pi^0\nu\overline{\nu}$ and $K^+ \to \pi^+\nu\overline{\nu}$.

$K_{\rm L} \to \pi^0\nu\overline{\nu}$ is a second order weak decay that proceeds through loop diagrams dominated by the top quark. The decay is essentially pure direct CP violating. The hadronic matrix element for the decay can be extracted from the well-measured decay $K_{\rm L} \to \pi^\pm e^\mp \nu$. The branching ratio (BR), in terms of the Wolfenstein parameterization of the CKM matrix is

$$\begin{aligned} BR(K_{\rm L} \to \pi^0\nu\overline{\nu}) &= 4.08 \times 10^{-10} A^4 \eta^2 \\ &= (3.1 \pm 1.3) \times 10^{-11} \end{aligned} \tag{3}$$

where η is the parameter in the Standard Model responsible for all CP violating effects. The error of 1.3×10^{-11} is due almost entirely to the current measurement precision of the CKM elements that are input to the calculation, primarily V_{cb} and the top quark mass, m_t. The theoretical uncertainty in the calculation is only 1-2% making this a unique decay mode of great importance.

Similarly,

$$\begin{aligned} BR(K^+ \to \pi^+\nu\overline{\nu}) &\propto |V_{cb}|^4 |V_{td}|^2 \\ &= (0.77 \pm 0.21) \times 10^{-10}. \end{aligned} \tag{4}$$

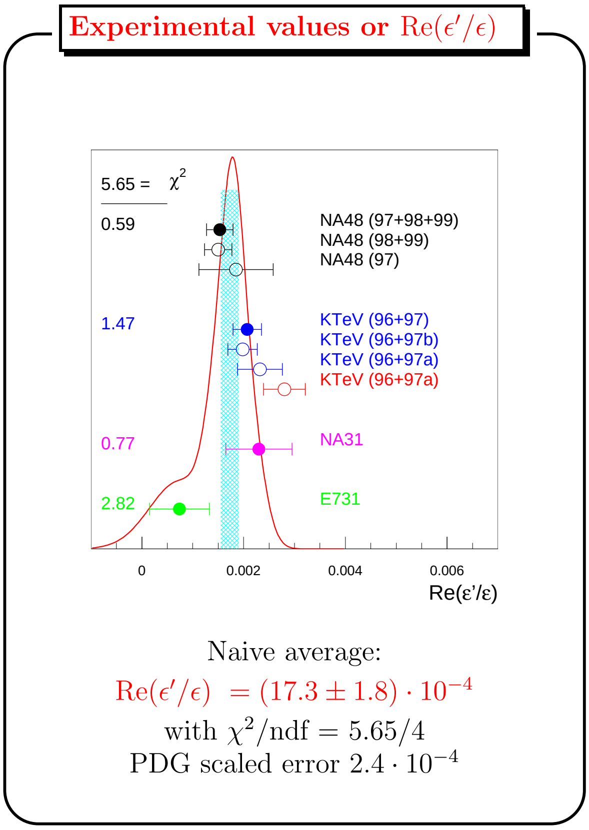

FIG. 1: Status of recent measurements of $\mathrm{Re}(\epsilon'/\epsilon)$ as well as previous results from NA31 at CERN and E731 from Fermilab. The results from the two groups are now in reasonable agreement and unambiguously indicate the presence of direct CP violation, in agreement with the Standard Model.

The error of 0.21×10^{-10} is dominated by the current measurement precision of $|V_{cb}|$ and the charm quark mass, m_c. The contribution to the uncertainty due to theory is ≈5% and is limited primarily by uncertainty of the c-quark contribution.

Together, the two $K \to \pi\nu\overline{\nu}$ measurements can determine $\sin(2\beta)$ without any uncertainty from $|V_{cb}|$. The measurement accuracy in the kaon system is, in principle, similar to anticipated $\sin(2\beta)$ measurements from $B_d^0, \bar{B}_d^0 \to J/\psi\, K_S^0$.

In the kaon system,

$$\sin 2\beta = \frac{2\overline{\eta}(1-\overline{\rho})}{(1-\overline{\rho})^2+\overline{\eta}^2} = \frac{2r_s}{1+r_s^2} \tag{5}$$

where

$$r_s = \frac{1-\overline{\rho}}{\overline{\eta}} = \sqrt{\sigma}\frac{\sqrt{\sigma(B_1-B_2)}-P_0}{\sqrt{B_2}} \tag{6}$$

$B_1 \sim \mathrm{BR}(K^+ \to \pi^+\nu\overline{\nu}\ )$, $B_2 \sim \mathrm{BR}(K_L \to \pi^0\nu\overline{\nu}\ )$ and P_0 is calculable from perturbation theory. The Standard Model definitively predicts that $\sin(2\beta)$ should be the same in both the kaon and B systems. Any deviation would be a significant signal of new physics.

$K \to \pi\nu\overline{\nu}$ and $B_d^0, \bar{B}_d^0 \to J/\psi\, K_S^0$ are distinctly different processes that could be impacted by new physics in different ways. $K \to \pi\nu\overline{\nu}$ proceed through second order loop processes where the $Zd\overline{s}$ vertex is particularly sensitive to new physics contributions. $B_d^0, \bar{B}_d^0 \to J/\psi\, K_S^0$ includes tree level processes $b \to c\overline{c}s$ and $\overline{b} \to \overline{c}c\overline{s}$.

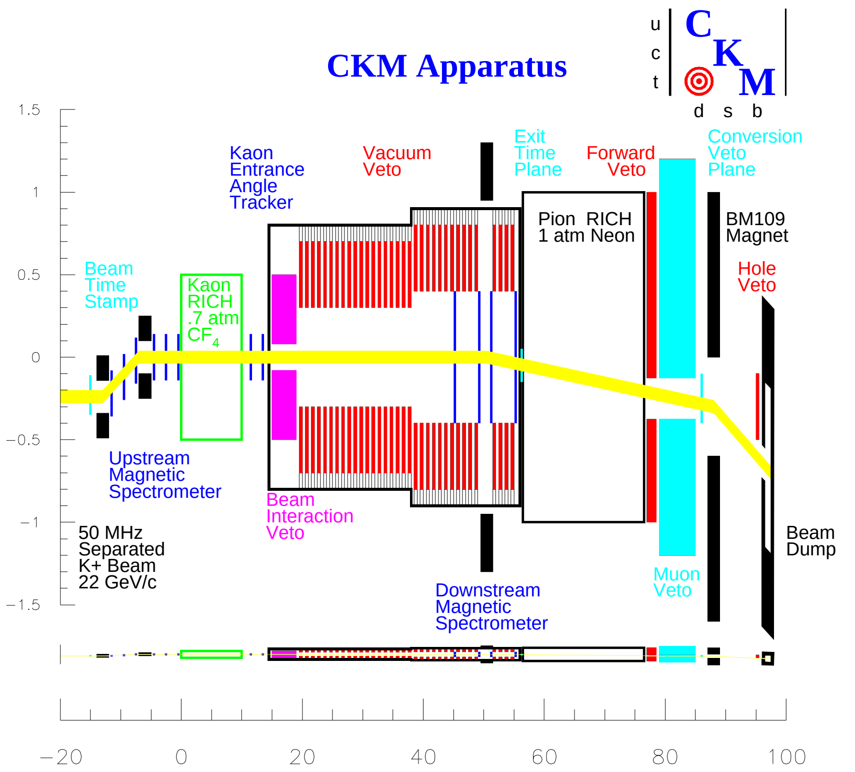

FIG. 2: Layout of the CKM detector. The lower section shows the true proportions of the apparatus.

New physics could be manifested in different $\sin(2\beta)$ measurements from the K and B systems; to explore fully the consistency of the Standard Model all four of the well-controlled processes must be measured.

E787 at Brookhaven is an attempt to observe $K^+ \to \pi^+\nu\overline{\nu}$ decays for the first time. It is a stopping experiment that observes the entire $K^+ - \mu^+ - e^+$ decay chain. The experiment has observed 1 clean event from a total of 3.2×10^{12} K^+ stops in their 1995-97 data sample. Data taken during 1998 is currently being analyzed. The total data sample from 1995-98 should result in a sensitivity of 0.8×10^{-10}. E949 is an upgrade to E787 that is currently taking data. E949 expects to observe 5-10 events, assuming the Standard Model branching ratio.

Observation of $K^+ \to \pi^+\nu\overline{\nu}$ decays is an impressive feat, but precision measurements of CKM parameters require greater statistics than can be accumulated using stopped kaons. The CKM experiment at Fermilab has been recently approved to accumulate 100 events at the Standard Model branching ratio with a 10% background. This would provide a theoretically clean measurement of V_{td} with a precision of 10%. CKM has developed a novel technique using a velocity spectrometer in conjunction with an RF separated beamline. The 50 MHz, 22 GeV/c K^+ beam has an estimated contamination of 30%. Decays in flight are redundantly measured using RICH detectors and a magnetic spectrometer while an extensive photon veto system rejects background from $K^+ \to \pi^+\pi^0$ decays. The CKM detector is shown in Fig. 2.

The best published limit for the decay $K_{\rm L} \to \pi^0\nu\overline{\nu}$ is 5.9×10^{-5} (90% C.L.) from KTeV [12]. A number of proposals have been made to extend this measurement. E791a at KEK expects to mount an experiment to run in 2003 to reach a single event sensitivity of 10^{-10}. This is an engineering run for an eventual JHF experiment to collect 1000 events. Backgrounds are still under evaluation.

The KAMI collaboration has proposed a significant upgrade to the KTeV detector at Fermilab to obtain 90 $K_{\rm L} \to \pi^0\nu\overline{\nu}$ decays per year at the Standard Model branching ratio. A signal-to-background of 4 is expected using a high energy kaon beam, the KTeV CsI detector and a state-of-the-art hermetic photon veto system. The KAMI proposal was rejected by Fermilab.

The KOPIO collaboration at Brookhaven has been approved to search for $K_{\rm L} \to \pi^0\nu\overline{\nu}$ decays using a low-energy, micro-bunched kaon beam ($\sigma_{\Delta t} = 200\ ps$). The low energy kaons make it possible to determine the momentum of decaying kaons by measuring time-of-flight. Together with a photon preshower detector with

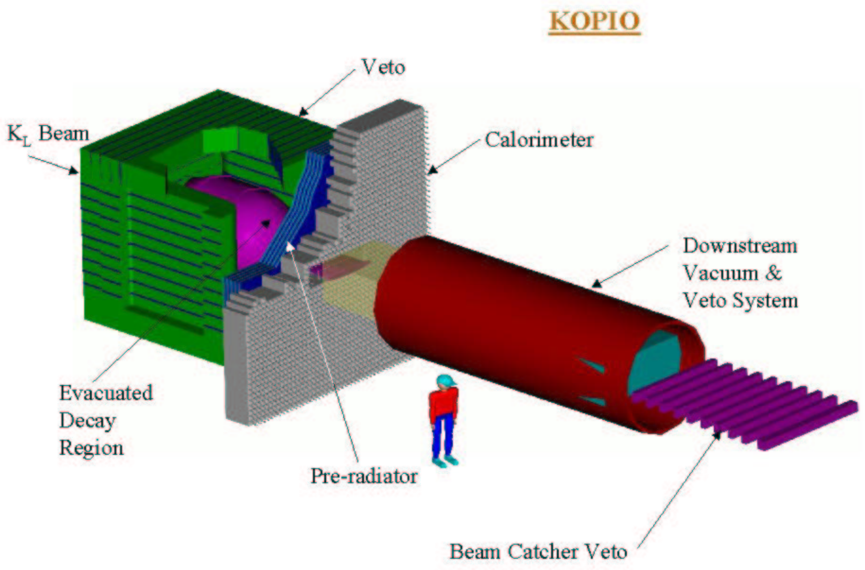

FIG. 3: Layout of the KOPIO detector.

pointing capabilities, this allows for full kinematic reconstruction of the event in the kaon center-of-mass frame. The resulting constraints provide significant rejection of the dominant $K_L \to 2\pi^0$ background. A hermetic photon veto system allows for redundant rejection of background as well as numerous cross checks. The KOPIO detector is shown in Fig. 3. KOPIO expects 40 events/year at the Standard Model branching ratio with a signal-to-background of 2. KOPIO is currently awaiting a final funding decision from the NSF.

III. MESON SPECTROSCOPY

A rich spectrum of meson states has emerged since the discovery of the π meson in the 1940's. Quantum Chromodynamics (QCD) requires that any observable state be color neutral, and the observed meson and baryon spectrums are well described in terms of color neutral quark-antiquark ($q\bar{q}$) and three quark (qqq) states, respectively. In addition to these states, other color neutral combinations of quarks, antiquarks and gluons (g) should exist, *e.g.* $q\bar{q}g$, $q\bar{q}qqq$ or ggg, where the g represents a "valence" gluon. Some, but not all, of these non-$q\bar{q}$ states possess quantum numbers not accessible to ordinary $q\bar{q}$ pairs, known as "exotic" quantum numbers. While predictions of these states have existed for many years, conclusive evidence of such states has yet to be seen clearly (for a review, see [13]); although, a hint of a state with $J^{PC} = 1^{-+}$ has been seen using pion beam in BNL E852 [14, 15]. Over the next decade, several experimental programs will explore the non-$q\bar{q}$ mesonic spectrum.

The Jefferson Laboratory Hall D collaboration will embark on a program to search for states with exotic quantum numbers below the $c\bar{c}$ threshold. Their approach uses linearly polarized photons produced by coherent bremsstrahlung from an upgraded 12 GeV electron beam. In photoproduction, these exotic states are expected to be enhanced, when compared with a pion beam of BNL E852, because of the spin alignment of the quarks in the photon probe. The polarization of the photon also greatly aids in the partial wave analysis needed to identify such states [16]. A diagram of the Hall D apparatus is shown in Fig. 4.

CLEO-c will be pursuing a complementary program in charm and bottom spectroscopy using e^+e^- collisions at the CESR ring. In addition to standard quark model states (*e.g.* η_c', h_c, η_b, h_b) CLEO-c will search for charmed hybrids ($c\bar{c}g$ states), which are not accessible to the lower-energy beam at Jefferson Laboratory Hall D. CLEO-c will also search for purely gluonic resonances, including the somewhat elusive $f_J(2220)$ which is possibly a tensor state made purely of gluons (*i.e.* a glueball) [17].

IV. COLD BARYONS

Over the past decade, major improvements in trapping of antiprotons have produced the best limits on CPT invariance in baryonic systems. Further improvements in experimental techniques have the potential to improve

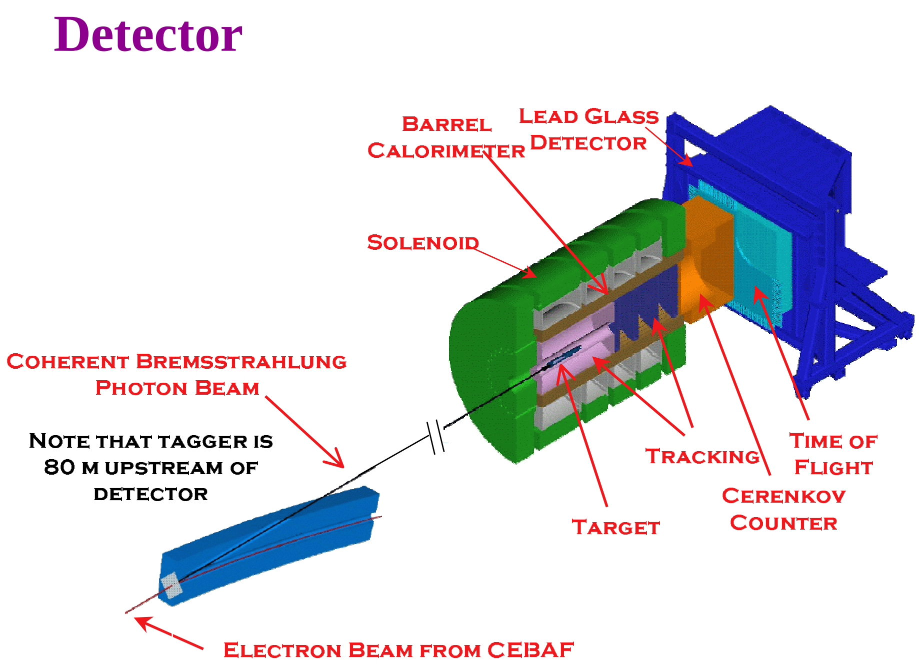

FIG. 4: Schematic diagram of the Jefferson Laboratory Hall D apparatus to be used in a search for exotic mesons.

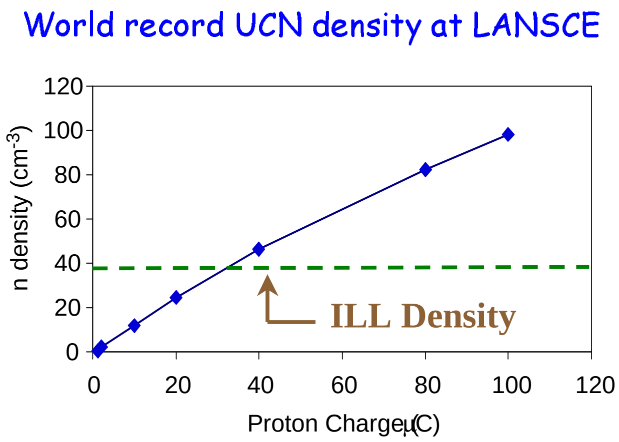

FIG. 5: Ultra-Cold Neutron density as a function of proton beam current obtained at LANSCE.

the sensitivity of such tests by several orders of magnitude. In parallel, recent developments in the production and trapping of ultra-cold neutrons (UCN) have spawned a new generation of experiments that could have a major impact on particle physics.

A. Cold and Ultra-Cold Neutrons

The recent improvement in stored ultra-cold neutron (UCN) density is demonstrated in Fig. 5, which shows the world record UCN density obtained at the Los Alamos Neutron Science Center (LANSCE). Other international facilities such as ILL in France, PSI in Switzerland and KEK in Japan are also in the process of building or upgrading their capabilities for neutron sources, demonstrating the world-wide interest in its physics potential for measurements of fundamental properties of the neutron.

Looking further into the future, new sources of neutrons for fundamental experiments are expected from spallation neutron beams, which primarily service the material science community that require cold neutron

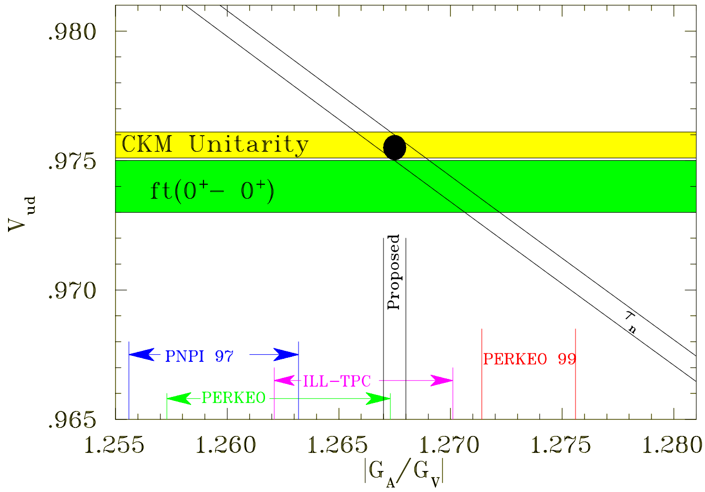

FIG. 6: Projected accuracy of neutron lifetime (diagonal band labeled τ_n) and beta asymmetry measurements in future LANSCE experiments (horizontal band labeled "Proposed"). Together, these measurements will provide a measurement of V_{ud}. Also shown are the experimental uncertainties on other measurements of $|G_A/G_V|$.

beams. However, these facilities have the potential to produce even higher neutron densities and could represent the next generation of neutron experiments. The Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory can have new beamlines ready for neutron experiments as early as 2007.

B. Neutron EDM

It is well known that a non-zero neutron permanent electric dipole moment is a sensitive probe of new sources of CP violation beyond the Standard Model. The current limit for a neutron electric dipole moment (EDM) is at the level of 10^{-25} e-cm. In the Standard Model, the expected size of the neutron EDM is at the level of 10^{-31}. However, many SUSY-GUT models predict EDM values ranging from $10^{-27} - 10^{-25}$ e-cm. It is thus important to push the neutron EDM limit further.

A new concept for an experiment at LANSCE using UCN seeks to reach a sensitivity of 10^{-28} e-cm. This is a challenging goal and requires a sustained program of feasibility experiments. These are currently underway and it is anticipated that the experiment could be launched in 2004.

C. Neutron Beta Decay

Another area where neutron physics can have significant impact is in the measurement of the CKM matrix element V_{ud}. Unitarity tests of the CKM matrix are an important way to probe for new physics; many SUSY and left-right symmetric models predict unitarity violations. Currently, the unitarity test of the CKM matrix involving the top row $(V_{ud}^2 + V_{us}^2 + V_{ub}^2)$ deviates from unity by 2 standard deviations.

The error on the test is dominated by the error on the dominant term: V_{ud}. The most precise measurement of V_{ud} comes from the measurement of the ft-value in $0^+ - 0^+$ super-allowed nuclear beta decays. An alternative approach using UCN promises to begin a new generation of precision measurements of neutron properties. In particular, much more precise measurements of the neutron lifetime as well as the beta-asymmetry appear feasible.

Experiments at LANSCE have been approved, which together will allow the measurement of V_{ud} to better precision than the current world average. The neutron lifetime measurement using UCN will circumvent the most dominant source of systematic errors from earlier experimental techniques. The UCNA collaboration is preparing the experimental apparatus that proposes to use UCN to measure the beta-asymmetry in neutron decay to an accuracy of 0.3%. Data taking is anticipated in 2003. The anticipated accuracy on V_{ud} from these measurements is shown in Fig. 6.

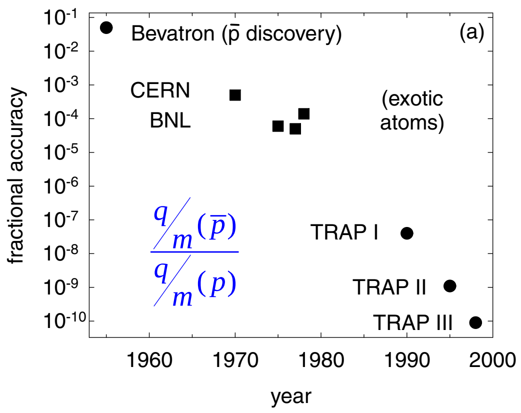

FIG. 7: CPT tests on antiprotons with the TRAP apparatus

D. CPT Test with Antihydrogen

Virtually all viable theories for physics beyond the standard model obey CPT symmetry. Nevertheless, it important to pursue searches for violations of CPT symmetry experimentally. The most recent measurement of the ratio of the charge to mass ratio of the antiproton to the proton has been found to be unity with an accuracy approaching 10^{-10} using the TRAP III apparatus at CERN's low energy antiproton facility (LEAR). A summary of recent measurements is shown in Fig. 7.

While the LEAR facility has since been decommissioned, the new antiproton decelerator (AD) facility has been approved for construction at CERN. The ATRAP collaboration has been formed to extend the sensitivity of the CPT test by several orders of magnitude by comparing the laser spectroscopy of hydrogen and antihydrogen. The experimental strategy is to trap single antiprotons and positrons in traps and then bring them in close vicinity to form antihydrogen. The ultimate goal is to improve lepton and baryon CPT tests to the same level of accuracy (10^{-18}) as the $K\bar{K}$ system.

V. STRUCTURE FUNCTIONS

Much of what is known about the parton level structure of the proton has been learned through fixed target inclusive and semi-inclusive deep inelastic scattering (DIS) experiments. These experiments have used electron, muon and neutrino beams to probe proton structure over many orders of magnitude in both struck quark momentum fraction (x) and energy scale (Q^2). From these data, using global fits which combine the data from many experiments, parton density functions (PDF's) of the proton can be extracted. In addition, the use of polarized beams and targets has allowed for measurements of the quark-level spin structure of the proton.

A. Unpolarized Proton Structure

Even though the global fits are performed on a wide body of experimental data and are quite sophisticated, there is still room to refine our picture of the proton. Additional measurements are still desired to help understand many details, including the effects of nuclear corrections on the global fits, large-x PDF behavior, origins of the light quark sea, and intrinsic heavy quarks.

Because of the relatively small neutrino cross section, much of the neutrino data are taken on heavy nuclear targets. In the global fits, these data provide the information on the large-x sea structure of the proton; however, clear measurement of effects of nuclear binding on neutrino scattering have never been made. With the possibility of very bright neutrino sources, these effects could be systematically studied and included in our understanding of the parton structure by making measurements on light targets.

As $x \to 1$ even the size effects of deuterium play an important role. Attempts to extract the ratio of F_2^p/F_2^n and hence the d/u quark ratio from deuterium and hydrogen data are dominated by the uncertainties in the treatment of deuterium, with the ratio at $x = 0.85$ ranging from 0.25 to 0.65 [18]. Using the post-upgrade Jefferson Laboratory, this particular problem may be solved by comparing ^{3}He and ^{3}H. Here, presumably, the nuclear effects will be the same in the proton and neutron measurements and will cancel out when extracting the ratio of d/u in the proton.

While the PDF's in the $x \to 1$ region are arguably quite small, they are still very important. Through QCD evolution, the parton distributions in this high-x region determine the PDF's at more moderate x but much higher Q^2. These are precisely those PDF's which are used in background calculations needed to establish possible indications of new physics phenomena at very high Q^2.

Mapping the x structure of the sea of the proton provides insight into the non-perturbative nature of QCD. In particular, an asymmetry has been observed between the proton's $\bar{d}(x)$ and $\bar{u}(x)$ distributions. While the perturbative sea, generated through gluon splitting ($g \to \bar{u}u$ and $g \to \bar{d}d$), may generate much of the strength of the sea, it cannot produce the observed asymmetries which have been extracted from the Drell-Yan $p +^1 H$ and $p +^2 H$ cross sections [19]. Plans are underway to extend these measurements to larger x to better understand the interplay between perturbative and non-perturbative QCD in producing the proton's sea [1, 3].

B. Polarized Structure Functions

One of the goals of an extensive program of nucleon spin structure function measurements has been to elucidate the contribution of quarks and gluons to the spin of the nucleon. Over the past fifteen years, precision measurements of the spin dependence of lepton-nucleon deep inelastic scattering have shown that, while the data are consistent with the predicted behavior from perturbative QCD, the contribution to the total spin of the nucleon from the quarks within the nucleon is approximately 25%, which is significantly smaller than the naive predictions of the relativistic quark model.

The data thus indicate that the nucleon sea, the gluons in particular, might carry a significant portion of the nucleon spin. The first direct measurements of the contribution of polarized gluons to the nucleon spin will be measured in approved programs at CERN, SLAC and RHIC over the next five years. However, to cleanly establish the presence of gluon polarization in the nucleon and quantitatively establish a further spin deficit, measurements at new facilities will be required.

1. Proton Spin Structure

The TESLA-N proposal at DESY would be a dedicated fixed target facility that would run parasitically with the proposed TESLA linear collider [9]. With a 250 GeV longitudinally polarized electron beam, ultra-precise measurements of the proton spin structure function g_{1p} will be possible, down to $x \sim 0.003$. This is demonstrated in Fig. 8. It should be pointed out that similar or more precise measurements could be carried out at a future electron-proton collider.

2. Neutron Spin Structure

While the luminosity of the proposed TESLA-N facility is adequate to make measurements of the spin structure function of the proton, corresponding measurements on the neutron (g_{1n}) are more difficult. This is because reasonably dense solid polarized proton targets are technically feasible while the best polarized neutron targets are made from gaseous ^{3}He. Figure 9 shows the world data at low x for g_{1n}. It can be seen that currently, a divergent behavior cannot be ruled out at lower x.

At a future e^+e^- linear collider, it is possible to provide very high beam intensity to parasitic fixed target experiments, provided accommodation is made for the collimation and delivery of the full ("spent") beam to a fixed target experimental area. One could then measure g_{1n} to great accuracy down to $x \sim 10^{-3}$, which would establish whether the function is divergent or convergent. Figure 10 shows a schematic layout of facility that would effectively transport the spent beam of a linear collider through a couple of fixed target areas on to a beam dump [20].

VI. THE ELECTROWEAK MIXING ANGLE

Precision measurements of weak neutral current interactions have played a central role in establishing the validity of the Standard Model at the quantum loop level. Using the measurements of α_{QED}, G_μ and M_Z as inputs, measurements of the $\sin^2\theta_W$ and M_W serve to check the consistency of the Standard Model, provide indirect measurements of the m_t and provide indirect constraints on new physics.

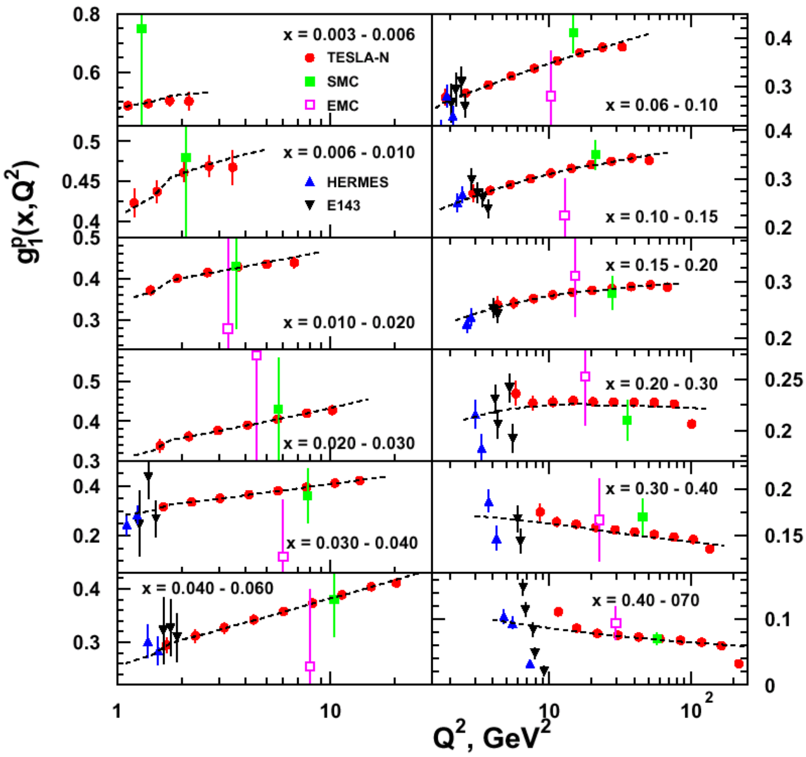

FIG. 8: Projected errors on g_{1p} from a TESLA-N polarized lepton-nucleon deep inelastic scattering experiment (red circles). Also shown are the existing SMC, EMC, HERMES and SLAC-E143 data.

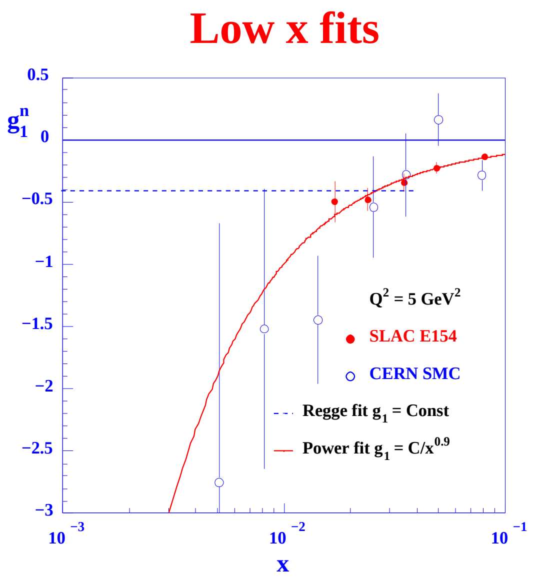

FIG. 9: Current data on the spin structure function g_{1n}.

While the gauge sector of the theory has been clearly established at the quantum loop level from the analysis of world data, very little is known about fundamental scalars. For example, assuming that the gauge boson masses are generated by its interactions with a single elementary scalar, an improvement of the world average on $\sin^2\theta_W$ by a factor of 5 would be required to provide an indirect measurement of the scalar mass with a fractional error of 15%.

It is also important to obtain multiple measurements of the most precise electroweak observables, with

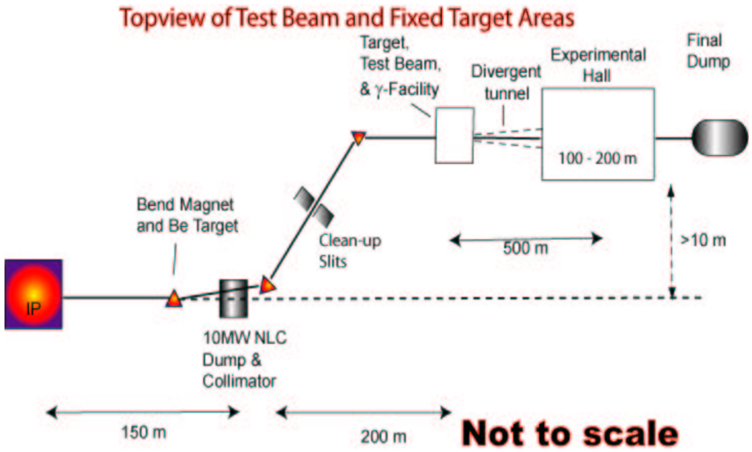

FIG. 10: Schematic diagram of a fixed target facility using the exhaust beam at a Linear Collider

different initial and final states as well as various energy scales. Taken together, such measurements probe for new physics beyond the standard model at the TeV scale from sources such as extra dimensions, new gauge bosons, compositeness etc.

Several possibilities have been investigated to measure $\sin^2\theta_W$ to an accuracy better than 0.00008: the left-right asymmetry at a giga-Z factory, the left-right asymmetry at a new high energy e^+e^- collider and the left-right asymmetry with very high luminosity of a longitudinally polarized high energy e^-e^- collider. At a beam energy of 250 GeV or above, it is also possible to achieve comparable precision via a measurement of the left-right asymmetry in fixed target Moller scattering, which we discuss below [21].

A. E158 at SLAC

At the E158 experiment [5], the 48 GeV longitudinally polarized electron beam will impinge on a 150 cm long liquid hydrogen target. Electrons that are scattered within the range of 5 to 8 mrad are selected by a fiducial annular collimator and focused by quadrupoles upon a total absorption calorimeter. The quadrupoles focus the Moller electron scatters while spatially separating the e-p scatters.

The physics asymmetry, which is 0.18 parts per million (ppm) in the standard model, would be measured to a precision of 8% in a 5 month long production run. The experiment recently had a successful engineering run. Commissioning of the experiment will be completed in Feb. '02 and physics data taking is planned to begin in Apr. '02. It is anticipated that the final statistics will be collected in a run in early 2003.

This measurement is uniquely sensitive to parity-violating contact electron contact interactions at the level of 15 TeV. Such interactions could be caused by new Z bosons in the mass range of 1-2 TeV. Such bosons are predicted by various GUT models as well as models involving extra dimensions. The contact interactions could also be caused by dilepton gauge bosons that couple to electrons. Such contact interaction couplings would be probed at a level of $0.01G_F$ [22].

B. Fixed Target Polarized Moller Scattering at the Linear Collider

The figure of merit for the Moller scattering experiment increases dramatically with increased incident beam energy. The asymmetry rises linearly with beam energy while the cross-section drops only linearly with beam energy, resulting in the analyzing power rising linearly with beam energy. This experiment requires the full "spent" beam at a linear collider, as was briefly discussed in section V B 2.

Assuming the default parameters of the NLC design (6×10^{11} electrons per pulse at a repetition rate of 120 Hz and 90% beam polarization), it is possible to achieve an accuracy of $\delta(\sin^2\theta_W) \sim 0.00007$ with a run lasting 10^7 seconds at each of two energies: 250 GeV and 500 GeV. The predicted asymmetry is 1.8 ppm for an incident beam energy of 500 GeV. Figure 11 shows the projected errors from such a measurement, compared to the projected errors from the E158 run as well as from possible high energy collider asymmetry measurements.

One challenging aspect of this measurement is that the asymmetry would have to be measured with a fractional accuracy of 0.7%. One dominant source of normalization error is the measurement of the longitudinal beam

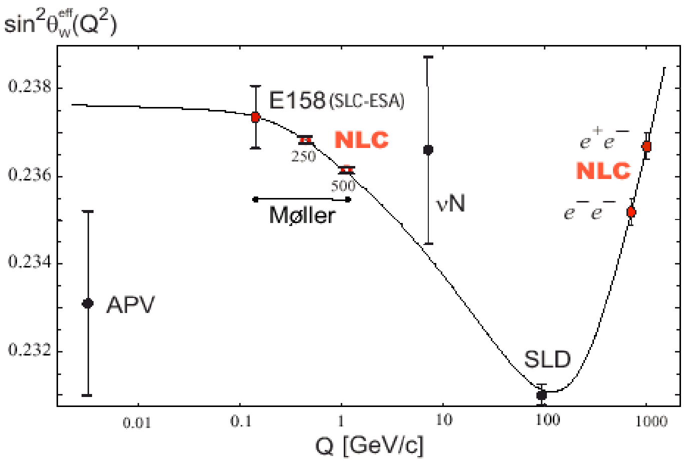

FIG. 11: Projected error on $\sin^2\theta_W$ from future asymmetry measurements. Note: the figure does not include the most recent NuTeV result, which deviates from the Standard Model prediction by 3σ [23].

polarization. Compton polarimetry is the method of choice and a systematic error of 0.5% has been achieved by the SLD collaboration. It is expected that modest improvements in the polarimeter design will allow the beam polarization at 250 GeV and higher to be measured with an accuracy of 0.25%. This translates into $\delta(\sin^2\theta_W) \sim 0.00003$. One important feature of this measurement is that the weak neutral current vector coupling of the electron is 43% smaller than the corresponding coupling at the Z pole due to radiative corrections, leading to a less stringent requirement on the absolute normalization systematic error.

VII. LEPTON FLAVOR VIOLATION

Since the discovery of multiple families of particles, physicists have searched for the violation of the additive quantum number associated with each type of lepton species, known as lepton flavor violation. While it is observed that lepton flavor is nearly exactly conserved, there is no gauge symmetry that requires this to be the case. Recent observations of neutrino oscillations can be accommodated within the Standard Model by postulating that neutrinos have mass and they they mix. However, the implications for charged lepton flavor violation is that the effects are well below a level that can be accessed by current experimental techniques. Thus, experiments for probing charge lepton flavor violation are sensitive probes of new physics at very high energies.

Searches for lepton flavor violation have been carried out with increasing sensitivity and current limits have probed the ≈ 100 TeV scale. A new round of experiments involving the processes $\mu \to e\gamma$ and $\mu + N \to e + X$ plan to probe the several PeV scale[24, 25].

The MECO experiment is designed to search for coherent conversion of muons to electrons in a field of nucleus and plans to reach a single event sensitivity of about 2×10^{-17}[26]. At this level, the measurement is sensitive to various SUSY models. The experiment proposes to use a novel set of superconducting magnets to achieve a graded solenoidal field that would channel muons, produced by protons impinging on a production target, on to a stopping target with high efficiency coupled with tremendous background rejection. The experiment is approved to run at BNL and is awaiting construction funds from the NSF. If funded, the experiment would start data collection in late 2006.

VIII. CONCLUSIONS AND ACKNOWLEDGMENTS

Fixed target experimentation remains a vigorous and important tool. In many case it provides the best technique to study particular aspects of elementary physics. Here we have explored several areas, where, in the near future, fixed target experiments has the potential to alter our understanding of physics. These include high precision tests of CP violation in the Kaon sector, ultra-precise determination of the weak mixing angle and its evolution, and lepton flavor violation. To continue to reap the benefits provided by the unique fixed target environment, the ability to provide fixed target beams must be clearly included in the design and construction of new facilities.

The many people who participated in the Fixed Target Working Group at Snowmass 2001 made it a very rich experience. In particular, this working group owes its very existence to the those who made the presentations on which this summary is based:

Structure Functions I

E. Kinney	*HERMES, Future Plans*
Y. Kolomensky	*Probing Gluon Polarization through Inclusive Deep Inelastic Scattering*
A. Deshpande	*A Review of ΔG Measurements: Present & Future*

Intense Muon Sources I (joint with E1)

W. Marciano	*Theoretical overview*
Y. Kuno	*Experimental Overview*
F. DeJongh	*Possibility of Fermilab Muon Experiments*
A. Sato	*PRISM project at JHF*
K. Yoshimura	*μ–e Conversion Experiment with PRISM at JHF*
M. Aoki	*Muonium to Anti-Muonium Conversion and (μ^-, μ^-)*

Spectroscopy (joint with P5)

A. Lednev	*Meson Spectroscopy at IHEP*
A. Dzierba	*The Hall D Project: Gluonic Excitations*
S. Dytman	*Projected Non-Perturbative QCD Studies with CLEO-c*
W. Kilgore	*$pp \to H + X$ at Next-to-Leading Order*
C. Balazs	*Higgs Transverse Momentum at the LHC*
L. Reina	*$t\bar{t}$ H Production*
D. Zeppenfeld	*QCD Requirements for Precision Higgs Studies at the LHC*

Intense Muon Sources II (joint with E1)

L. Roberts	*Muon $g-2$*
W. Morse	*Muon EDM*
W. Molzon	*μ–e Conversion Experiment at BNL (MECO)*
K. Nagamine	*Muon Science Application*

Facilities: Near Term New/Upgraded Fixed Target

D. von Harrach	*Fixed Target Physics at TESLA*
S. Sawada	*KEK-JAERI Joint Project on High Intensity Proton Accelerators*
T. Roser	*AGS Fixed Target Program and Plans*
C. Moore	*Fixed Target Physics at Fermilab*
K. de Jager	*JLab Research Program with the 12 GeV Upgrade*
D. Walz	*The SLAC Fixed Target Program in End Station A*

CP Violation / Beyond the Standard Model I

K. Nelson	*Status of the HyperCP Experiment at Fermilab: The Search for Direct CP Violation in Hyperon Decays*
M. Sozzi	*A New Measurement of Direct CP Violation by the NA48 Experiment at CERN*
E. Blucher	*A New Measurement of ϵ'/ϵ from KTeV*
R. Gupta	*Prospects for Calculating ϵ'/ϵ from the Lattice*

Charm, Hyperons and Antiprotons

M. Sozzi	*Hyperon Physics at the NA48 Experiment at CERN*
D. Kaplan	*$\bar{p}p \to$ Hyperons (and Other Physics Opportunities)*
S. Pordes	*$\bar{p}p$ Studies of Charmonium*
R. Harr	*Status and Plans for HERA-B*
G. Jackson	*Commercial Applications for Antiprotons*

CP Violation/Beyond the Standard Model II

J. Mildenberger	*Measuring $K^+ \to \pi^+ \nu\bar{\nu}$ at BNL*
A. Kushnirenko	*Measurement of $K^+ \to \pi^+ \nu\bar{\nu}$ at CKM*
M. Hebert	*Searching for Lepton Flavor Violation with the MECO Experiment at BNL*

Structure functions II

F. Olness — *PDF's: What Do We Need to Know?*
P. Reimer — *Drell-Yan Measurement of Nucleon and Nuclear Structure with the FNAL Main Injector*
S. Sawada — *High-Mass Dimuon Experiment at the New 50-GeV Proton Synchrotron*
P. Hoodbhoy — *Large-x Physics: A Brief Overview*
G. Cates — *New Developments in Polarized Targets*

CP violation/Beyond the SM III
G.Y. Lim — *Search for $K_{\rm L} \to \pi^0 \nu\bar{\nu}$ Decay (KEK-PS E391a Collaboration*
J. Mildenberger — *An Experiment to measure $K^0_{\rm L} \to \pi^0 \nu\bar{\nu}$ at BNL: KOPIO*
S Ledovskoy — *$K_{\rm L} \to \pi^0 \nu\bar{\nu}$ at Fermilab Main Injector*

Electroweak Standard Model
P. Souder — *E158 and Its Extension to Higher Energy*
W. Marciano — *Precision Measurement of the Weak Mixing Angle*
R. Pitthan — *Fixed Target e^- Physics at NLC*
M. Woods — *(Some) Aspects of Polarimetry at a Future Linear Collider*

Physics with low-energy nucleons
P. Herczeg — *Physics Beyond the Standard Model with Neutrons: Theory Overview*
T. Bowles — *LANCE Facilities*
A. Young — *Electroweak Physics with Neutrons*
G. Greene — *Neutron Physics at SNS*
M. Cooper — *Electric Dipole Moment of the Neutron*
G. Gabrielse — *Progress on Antimatter Experiments: Quest for Cold Antihydrogen*

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