Muon Capture on the Proton

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January 12, 2006

1 Summary of Proposed Research

This is a request for a new *Medium Resource Allocation* for data analysis and simulation of the μCap experiment[1, 2]. The measurements are carried out by an international collaboration at the proton accelerator of the Paul Scherrer Institute (Switzerland), which produces the highest muon fluxes worldwide. After an extended R&D phase the experiment has now reached full production stage. While the limited data of the engineering and first physics run could be analyzed with smaller Linux farms, the present and future data volume, coupled with high precision analysis techniques, requires supercomputer resources. Such computing power is not available to the moderately sized, university based collaboration, but is indispensable for a successful analysis of the experiment which is primarily carried out by the US University groups at Illinois, Kentucky and Berkeley. The experiment is funded by National Science Foundation contracts NSF 02-44889 including a special equipment supplement for μCap, and a UIUC Research Board grant (Illinois), NSF 02-44816 (Kentucky) and the US DOE (Berkeley). The project has also received attention as an example for a sustained US-Russian research collaboration, to provide alternatives to emigration for Russian scientists, and to employ former weapon scientists in civilian research. It received two consecutive US Civilian Research and Development Foundation grants (2002 and 2006), which is rare, as the grant is highly competitive. This international aspect of the experiment is covered in media reports[3].

The goal of the *μCap* experiment is a precision measurement of the muon capture reaction on the free proton. This determines directly the pseudoscalar form factor g_P, which is the least well known of the nucleon form factors characterizing the structure of its charged electro-weak current. We can now precisely calculate g_P based on the chiral symmetry of QCD and its breaking. Thus, its experimental determination sensitively probes our understanding of QCD at low energies. Despite efforts spanning the last 30 years, experimental results are still controversial and subject to uncertainties in their interpretation.

The *μCap* experiment is designed to overcome the uncertainties that plagued earlier efforts and to measure g_P with about tenfold improved precision. The method requires a combination of novel and challenging detector techniques. A TPC operating with 10-bar hydrogen gas determines the incoming muon stop position. Electrons from muon decay are reconstructed using a nearly deadtime-free electron tracking system. A sophisticated gas system maintains and monitors the ultra-high purity of the deuterium-depleted H_2 gas used as an active target. During the last 3 years the hardware was built and commissioned. In fall 2004, a first physics run achieved 20 percent of our final statistics goal for negative muons. These data surpass all previous experiments, both in statistics and in reduction of systematic uncertainties and are currently being analyzed by two graduate students. Final major upgrades were successfully commissioned in 2005, including a pulsed muon kicker, which allowed tripling the data acquisition rate. The experiment is slated for 10 weeks of high statistics data taking in spring 2006 to increase our total statistics with both muon polarities by about an order of magnitude.

A key feature of the experimental method is the recording of the *dominant* muon decay process instead of the *rare* capture process. While dramatically reducing the systematic uncertainties, the data volumes generated by this technique are large, challenging both the data acquisition as well as the data analysis. The DAQ is based on custom built hardware combined with high bandwidth networking and has worked reliably at its specification. For the analysis of production datasets supercomputing resources are needed. In summer 2005 we applied and received a *Development Allocation* at NCSA and used it to develop, install and test the μCap analysis procedure on the tungsten cluster. Based on this very successful experience we request the present *Medium Resource Allocation*. The current application is for one year. After reassessing our requirements in a year, we are planning to request a renewal grant for several years to perform the analysis of μCap and analyze a follow-up experiment presently under preparation.

2 Experimental Goal and Approach

The *μCap* experiment is a measurement of the rate λ_S for the semi-leptonic electroweak process (ordinary muon capture OMC),

$$\mu^- + p \rightarrow n + \nu_\mu \qquad (BR \cong 10^{-3})$$

to 1-percent precision. Although this reaction is of a similar fundamental nature as neutron beta decay, it has been measured with only 6–10 percent precision. In particular, this experiment will determine the least-well-known of the charged weak form factors of the nucleon, the pseudoscalar g_p, to 7 percent, providing a stringent test of theoretical predictions based on the chiral symmetries of QCD. The importance of such measurements is underscored by the recent progress in effective theories (heavy baryon chiral perturbation theory) that are capable of predicting g_p within better than 3 percent. Existing experiments are unable to meet this challenge, but rather lead to a controversial experimental situation. The origin of the problem lies in the imprecise knowledge of λ_{OP}, the rate of conversion between the ortho- and para-$pp\mu$ states formed after muons are stopped in hydrogen. Because of the strong spin dependence of the *V–A* interaction, the knowledge of the initial molecular state for the capture reaction is essential for the extraction of g_P. As ppμ molecules are formed quickly at higher hydrogen density, the sensitivity to λ_{op} is most critical for experiments using liquid targets. Because of the advantages of a larger stopping mass, the most precise capture experiments have been performed under these unfavorable conditions. At the time of our experimental proposal, the basic QCD predictions disagreed by more than 4 σ with a recent experiment on the related radiative muon capture (RMC) process.[4] The advancements of theory, combined with this unexplained discrepancy, have stimulated a flurry of theoretical papers and discussion on this topic.[5,6] During 2005, the situation has become even more confused (see Fig. 1). A new measurement[7] of λ_{OP} dramatically disagrees with earlier results. The large uncertainty in $\lambda_{OP,}$ as well as inconsistencies between the experimental results, suggest that g_P is currently constrained to only a precision of no better than 50 percent. Due to the daunting experimental challenges, the μCap experiment is the only prospect to solve the g_P puzzle with precision muon capture experiments in the foreseeable future

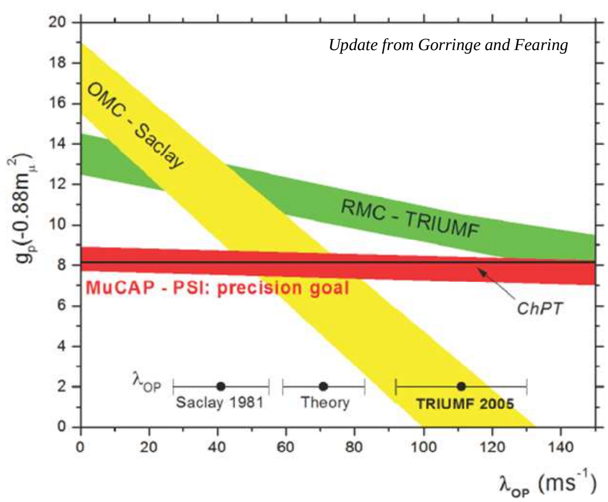

Figure 1. Experimental constraints on g_P. The uncertainty of λ_{OP} implies a large uncertainty in the extraction of g_P. The *μCap* experiment will be more accurate and nearly independent of λ_{OP}.

and was enthusiastically endorsed and accepted as a high-priority experiment by the international Program Committee at the Paul Scherrer Institute in 2001.

The *μCap* experiment is based on a new method that avoids the key uncertainties of earlier efforts. Thus, we expect to improve the determination of g_p by about an order of magnitude. The experiment is a muon lifetime measurement in ultra-pure and deuterium-depleted hydrogen gas. The measured decay lifetime of the negative muon in hydrogen is shorter, compared with that of the positive muon, because of the additional capture reaction. Therefore, λ_S can be determined to 1 percent from $\tau_{\mu^+} - \tau_{\mu^-}$, if both lifetimes are measured to 10 ppm. This implies the collection of a huge statistics of at least 10^{10} fully reconstructed muon decay events. Muons of both polarities are stopped in an active target and a specially developed TPC contained in a 10-atm hydrogen pressure vessel. Two cylindrical wire-chambers and a large scintillator hodoscope surround the pressure chamber. This detector system tracks the electrons back to the muon stop location. Several unique features will allow a significant improvement in precision:

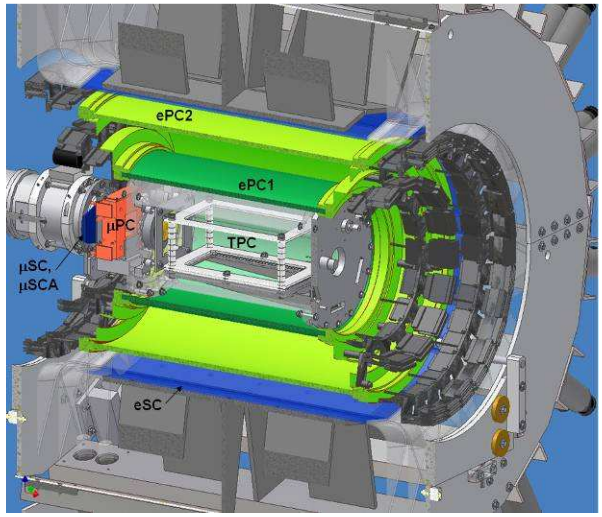

Figure 2. CAD model of completed μCap detector during physics run fall 2004.

- ***Unambiguous interpretation.*** The target density is 100 times lower than in LH_2. At these conditions, muon capture proceeds predominantly from the singlet hyperfine state of the $p\mu^-$ atom and the sensitivity to λ_{op} is reduced to a minor correction.
- ***Clean muon stop definition***. With 3D tracking, the TPC selects only μ^- stops in the hydrogen gas, eliminating otherwise overwhelming background from stops in higher-*Z* materials.
- ***Clean muon electron tracking.*** Cuts on the muon-electron vertex can be systematically applied using the reconstructed electron vector. This leads to strong background suppression, essential consistency checks and a diagnostic method for monitoring the isotopic purity of the hydrogen.
- ***Gas impurity control.*** Because *μCap* is an active target experiment, very low levels of impurities can be monitored *in situ* with the TPC. A sophisticated purification system has been commissioned.
- ***High statistics.*** The detector can operate with high muon stop rates as the data acquisition runs in a continuous deadtime free mode.

3 Project Status

μCap

The overall status of the experiment is described in the Progress Reports posted on the experiment's web page[1] and in recent publications[8]. Achieved and planned milestones of the project include

2004	Completion and commissioning of the basic μCap detector. Commissioning of continuous gas purification system[9].
	First high statistics physics run.
2005	Upgrades to the detector: TPC reaches design specifications. New in-situ gas diagnostics. Neutron detectors installed. New Muon-on-Request[10] scheme allows to triple data taking

	rate. New wave form digitizer (WFD) system for electron scintillators installed.
	All components commissioned with beam.
2006	New CRDF grant approved to build on-site H/D separation system. New Flash ADC (FADC) system for all TPC wires developed.
	Main long data run to increase statistics 10 fold to achieve the proposal goal.
2007	Additional experimental run to study systematic issues.

Several main trends in this production phase can be noticed. The basic data volume will increase dramatically. New electronics is being installed to record additional detailed information from the main detector components. Sophisticated support systems (purification etc) are installed. These upgrades aim at the final optimization of the experiment with emphasis of reduction of systematic correction and redundancy in their estimation. The final result for g_p should be dominated by statistics, not systematics.

These developments have to be matched by significantly increased power in the data processing CPU farm. An order of magnitude more data with additional information have to be analyzed. Higher sophistication in the analysis methods as well as a variety of complementary analysis methods are required to demonstrate consistent and systematically stable results of the final precision experiment.

Follow-up experiment

Let us briefly mention that the collaboration is actively exploring the feasibility of a precision measurement of the $\mu + d \rightarrow n + n + \nu$ capture process as a follow-up experiment to *μCap*. In recent years, the response of the two-nucleon system to electroweak probes has been studied[11] intensively in the framework of potential models and effective field theories (EFTs) (pion-less as well as hybrid EFT), culminating in estimated theoretical uncertainties of better than 1 percent. This progress has also been fueled by astrophysics interests, in particular in the $\nu+d$ reactions observed by the SNO experiment and the solar *pp* fusion process. The systematic EFT expansion demonstrated that exactly the same combination of low-energy constants, which parameterizes contributions from short-range axial two-body currents, appears in all these fundamental reactions.

Kammel[12] and Chen[13] suggested that a 1-percent measurement of *μd* capture would provide the most accurate experimental information on the axial current interacting with the 2*N* system, and it could determine the low-energy constant common to these processes. Two immediate questions arose in this context: Can the capture process with energy transfer of the order of the muon mass be directly related to the lower-energy solar reactions? Two recent theoretical studies[13, 14] gave an affirmative answer, because the kinematic region having small energy transfer to the 2*N* system dominates $\mu+d$ capture. Moreover, the calculations achieved the required precision of 1–2 percent.

As past experiments had 10–15-percent errors, the second question is whether a high-precision measurement is feasible. Fortunately, *μCap* has developed several key techniques that promise to enable a tenfold reduction in experimental uncertainties. In addition we have to optimize the target conditions—temperature and pressure, to eliminate uncertainties due to the μ*d* hyperfine state population at the moment of capture and due to background coming from μ^3He formation rate. Our studies indicate promising conditions at densities of 5–10 percent of LD_2 and reduced temperatures of $T < 80$ K.

4 Justification of Resources Requested

4.1 Data Analysis

Computing Methodology

There are several computational stages in going from the raw data produced in μCap to the final lifetime spectra:

1. **Data storage.** The data must be transferred from the experiment to NCSA. Presently we have stored 8 TBs of the 2004 run at the NCSA Mass Storage System, and another 10 TB from the 2005 run (finished on 12/22/05) are presently being shipped from Switzerland. We estimate that the full data set will about 50 TB. We have experimented with different methods of data transfer to NCSA. At this point, the storage of data on LTO tapes and transfer from the tape robot at our NPL computer center at Loomis appears the most robust solution. The planned new 10Gig uplink from physics will accommodate large transfer of data without saturating the total bandwidth.
2. **"Skimming" of the raw data.** This removes raw data outside of certain time-windows of interest. For the μCap data of 2004, this step reduces the raw data file size from typically 1.6 GB to about 350 MB, a reduction of nearly a factor of 5. While this skimmed data is complete as far as the physics analysis of the data, the original 1.6 GB raw data files are required for systematic cross-checks of the data. (With the installation of the new Muon-On-Request scheme in 2005, nearly all data is clean and contributes to the total useful statistics. Thus, the skimming step will be unnecessary.)
3. **Particle tracking, formation into Tree data structure.** This step finds correlations in the single detector hits and forms these into particle track objects. These objects are then stored in a Tree data object and written to file. For the 2004 data, the size of the output file containing the Tree is typically 170 MB, with an additional 20 MB of miscellaneous histograms in a separate output file. Typical computation time (single-CPU) for one 350 MB "skimmed" input file is about 10 minutes. On the raw data, this step takes 45 minutes per 1.6 GB input file.
4. **Formation of histograms from Tree data.** This analysis takes the difference of electron and muon track times and accumulates these (decay) times into many histograms according to different cuts. The input file, the output of step 3 above, is typically 170 MB. The output file size will tend to increase as more histogram cuts are added; currently, with over 500 different histogram cuts, the file size is about 4 MB. Computation time (single-CPU) is less than 1 minute per 170 MB input file.
5. **Merging of lifetime histograms from different files.** The purpose of this step is to combine lifetime spectra across files according to the conditions in which the data were taken (e.g., μ^- in pure protium, μ^+ or μ^- in impurity doped protium). The total single-CPU time for this step is less than 1 hour for the 2004 data set.

	Analysis Step	Avg. File Size (MB)	# of files	CPU time (min)	total size (GB)	total SUs per pass
1	raw data	1430	3576	N/A	5114	N/A
2	skimmed data	324	3576	N/A	1126	N/A
3	tree data	160	3576	10	559	596
4	lifetime spectra	3.8	3576	1	14	59.6

Table 1: Summary of run 2004 main data (Total data including systematic studies is 8 GB).

For a complete analysis we expect that at least 10 passes over the data are required, i.e. about 6000 SUs for the 2004 skimmed data set. An additional 3000 SUs will be needed for one complete pass over the raw 2004 data set, necessary for cross-checks of the data.

Status and Results

The μCap analysis software was installed on the cluster beginning in early September. The raw data in skimmed form had already been transferred to UniTree. Following recommendations of NCSA consultants, skimmed raw data was transferred to the global scratch disk prior to running the analysis Step 2, and 1 TB space on the project disk to write subsequent output data (Trees, histograms) was requested and received.

Since the analysis had been written as a single-CPU job, some effort was made to better utilize the dual-processor Xeon nodes. Since the automatic parallelization switches of the Intel C++ compiler did not improve the execution speed of the main analysis Step 3, perl scripts were developed to asynchronously maintain two, separate single-CPU analysis processes running per node, until all the input files specified for a given job were processed.

So far, two passes over a particular subset of the (skimmed) raw data, representing about half of the total data, were completed. A list of 20 runs (files) were designated for each batch job such that it takes about 20/2*10 min = 100 min per batch job. A wall clock limit of 2 hours was imposed in case of some lockup of the job. The first pass indicated some problems that were not obvious from the earlier, smaller test batches: many of the analyses, about 25%, were failing due to memory overutilization. Further investigation showed that this was a consequence of the way one part of the code, which was formerly regarded as a library to be linked into the user part of the analysis, was handling the output file. Basically, the Tree was written to a logical file in memory during execution and only written to disk at the end. Thus, memory usage would increase throughout execution until, roughly 25% of the time; it perhaps hit the 2 GB limit, apparently causing a crash when the data would be written to disk. This was worked around simply by having the user part of the code create a separate file for the Tree structure, and therefore allowed the data to be streamed to file rather than memory throughout execution. With this change, 100% of the analyses completed successfully in the second pass. All batch jobs in both passes completed well before the wall clock limit, and the total wall time to run over the data (half total) was less than 24 hours.

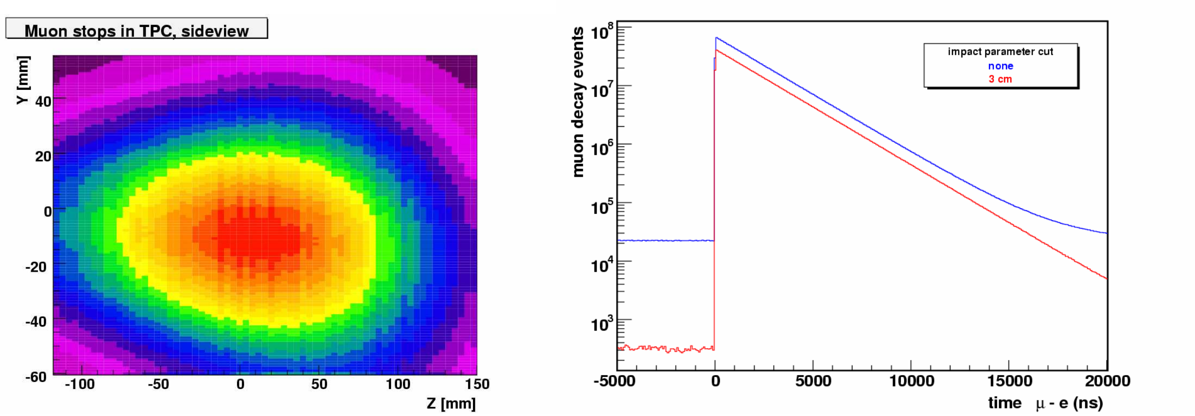

Figure 3. Left: Time projection chamber side view, which images the μ^- stop distribution (beam enters from left). Right: Decay spectra showing dramatic accidental suppression improvements due to *μ-e* impact parameter cut.

Further processing of the Tree data into lifetime spectra were successful, and finally lifetime spectra files were merged into a few data sets of interest. These merged files were transferred to the NPL computing cluster for fitting. The total SU's used of our initial 10000 allocation is 616 as of today (Jan. 12, 2005). It results from two passes over half of the skimmed data, three histogramming passes over the Tree data, plus many small test jobs, and is basically consistent with the estimates in Table 1. Thus far we have avoided a pass over the full raw data, as it would cost one quarter of our development allocation which is our main computing resource until we receive the allocation requested in this proposal.

4.2 Monte Carlo simulation

Monte Carlo simulation has been and will be an integral part of the μCap experiment. It has been extensively used for apparatus design and improvement, and the understanding of the obtained data. Currently the emphasis is on studies concerning the correct interpretation of our data and several systematic effects.

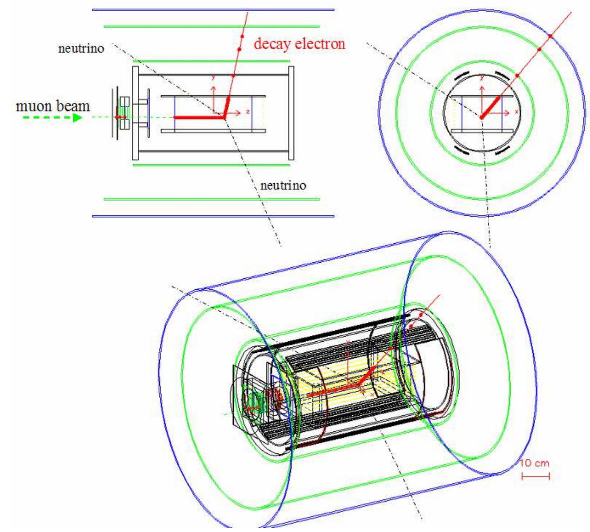

Figure 4: View of a typical event in the simulated experiment. A muon enters the setup and stops in the central TPC detector. The subsequent decay into an electron and two neutrinos shows the respective tracks and detector hits from the charged particle in the surrounding electron counters.

Computing Methodology

Our approach towards the simulation is twofold: We have an overall GEANT based Monte Carlo including full physics processes and detector geometry and we have several simulations for specific effects.

For the purpose of full simulation and interpretation of the data from the μCap apparatus we have developed a 3 staged approach:

1. The simulation of the physics processes in our setup using the GEANT 3.11 package;
2. The modification of the Monte Carlo data to reflect our full experimental setup and add specific detector effects like experimental resolutions, or energy and time offsets;
3. Transformation of the simulated data into the format of real data coming form the DAQ, which allows us to analyze simulated data with the absolutely identical analysis routines as are employed for the real data.

This concept has proven to be very fruitful. It is still under development to incorporate more sophisticated processes. The final goal is to have a simulation which is comparable to the experimental statistics, at least of the order of several times 10^9 analyzed μ-e events.

At the present stage the generation of 300k fully tracked muons, which stop in the target detector, diffuse and then decay, with the decay electron tracked through the setup, needs typically 1 hour of CPU time on a 1.5 GHz Pentium IV for stage 1 and additional 40 minutes for stage 2 and 3 of processing. 2 GB storage is required for the intermediate data files. The final data file for 300k events amounts to 100 MB. The full analysis of such a file using our typical sets of histograms typically takes 15 minutes on the same machine.

Besides this general Monte Carlo framework, we have also developed code for very specific tasks such as the understanding specific effects of time dependent and time independent random background effects on the TPC drift time distribution. Times for calculation are typically much shorter for the same number of events as with the full GEANT simulation.

	Simulation step	File size MB	CPU time min	Total file size GB	Total CPU time hours
		$3x10^5$ mu events		$2x10^9$ mu events	
1	GEANT data	1300	60	8580	6600
2	modified data	600	30	3960	3300
3	real data structure	100	10	660	1100
4	analysis step 1	12	12	79	1320
5	analysis step 2	2	3	13	330
	total	2014	115	13292	12650

Table 2: Summary of complete μCap Monte Carlo study for $3x10^5$ and $2x10^9$ simulated muons.

Results

The μCap technical notes web-page[1] gives a good summary of all the results from our Monte Carlo. Specific design issues studied included the μSR magnet, the exact shape and material of the window of the hydrogen pressure volume, and the influence of various materials and setup items on decay electron scattering. Studies of energy deposits in our detector served to understand the signal behavior in the TPC detector. The study of effects due to the combination of the detector geometry resolution together with the physical diffusion of muonic atoms is ongoing and has already yielded valuable insight that, though the effect is small (on the mm scale), μp diffusion can affect our decay time measurement. This study was originally initiated to determine effects from the much larger diffusion of muonic deuterium atoms. For the latter we have developed a specific Monte Carlo to simulate all the complicated physics involved in μd diffusion. This yielded results which are parameterized and then incorporated in the full GEANT simulation.

4.3 Projected Computing Requirements

The 2004 data analysis provides the basis for our computing request for 2006. Most of the data structure is the same, with a few key differences: an electrostatic kicker, additional waveform digitizer data and a larger data set.

Kicker. Prior to the 2005 run, the μCap experiment installed an electrostatic kicker which selects only events with a single muon in our detector. During 2004, this device was not available and a software skimmer was implemented to remove the multi-muon events, which require large systematic corrections and are not used in the main physics analysis (see point 2 in section 4.1). The installation of this device tripled the good data rate and density on tape. Prior to the 2006 run, beginning in April, it is imperative to analyze the 2005 data to understand any potential systematic effects produced by this promising new device. Thus, a preliminary pass over the 2005 data is needed in the next two months. During 2004, each 1.6 GB data file contained approximately 350 MB of usable data. With the implementation of the kicker, each file contains about 800 MB of usable data. Using the 2004 analysis rate of 35 MB/min, we compute that for each file, this portion of the data will require about 25 minutes to analyze.

WFDs. During the 2005 run, waveform digitizers (WFDs) were implemented to provide analog information of electron detector signals in addition to the digital information recorded as in 2004. Approximately one half of each data file is composed of WFD data in the 2005-2006 data set. Although the analysis for the WFD portion of the data is not fully developed yet, it is reasonable to assume that a robust analysis will take an amount of time comparable to the time needed to analyze the digital data. Since there is approximately 800 MB of each type of data in each file, each 1.6 GB file in the 2005-2006 data set will take approximately 47-60 minutes.

Data Set. During 2005, 10 TB of data were collected. During the data production phase of the run, the data rate was 2.5 TB per calendar week. With 8-10 calendar weeks planned for the 2006 run, an additional 20 to 25 TB of data will be accumulated. This results in roughly 30 to 40 TB of data for the combined 2005-2006 data set. Using 40 TB and 60 minutes per 1.6 GB file, we calculate 25,000 SU per production pass. With 10 passes, 250,000 SU are required for the complete analysis of the 2005-2006 combined data.

Based on the experience of the 2004 analysis, the tree data requires roughly one half of the space of the good data. This step of the analysis will then produce an additional 20.5 TB of data that will need to be stored.

	Analysis Step	Avg. File Size (MB)	# of files	CPU time per file(min)	total size (TB)	total SUs per pass
1	raw data	1638	25000	N/A	41	N/A
2	tree data	819	25000	60	20	25000

Table 3: Expected data and computing requirement for the 2006 data

There are several software/analysis projects that are critical to the success of the μCap experiment. During the coming months, the analysis of the 2004 data set will be completed. During this time, it is also critical to prove the legitimacy of using the kicker in 2006. After the 2006 run, the attention will move to the main analysis which will require the bulk of our computing needs. In addition simulations to fully understand the systematic effects accompanying the high precision phase of the experiment will be required. For a full understanding of small systematic effects we intend to simulate of the order of 10^{10} muon events and subsequently analyze these data with our analysis routines developed with physics μCap data.

	Project	Time Frame	SUs
1	2004 data	1/06 - 6/06	9000
2	2005 data preliminary	1/06 - 3/06	3000
3	2005 -2006 data final	4/06 - 4/09	250000
4	Monte Carlo	4/06 - 4/09	50000

Table 4: Outlook on data and computing requirements

In the current one-year proposal we ask for 100000 SUs and a project disk of 2-5 TB. After the first year we will adjust the request in a renewal proposal, according to the requirements established by the operating experience during the first year.

5 Local Computing Environment

The Nuclear Physics Lab (NPL) cluster is comprised of ~17 dual processor machines. The computing cluster is upgraded about once per year. For data analysis and Monte Carlo needs, the nuclear physics cluster has 7 dual 1.9 GHz Athlon nodes, 6 dual 2.4 GHz Xeon nodes and 4 dual 3.2 GHz Xeon nodes. The nodes are connected by two different networks: a shared 100 Megabit network for process control and user interaction and a Gigabit network for data transfer. For data storage needs, there are LTO tape robots and a few TB of buffer space intended for data staging, but the principle data for each experiment is stored on tape. This computing facility supports the research needs of half a dozen experiments and is administered by two graduate students. Due to resource sharing and regular maintenance, it has been our experience that we have access to roughly 5 processors at any given time.

The computing resources in Berkeley are presently limited to a small local PC cluster running under Linux with four Pentium IV CPUs (1MHz, 1.2 MHz, 2 x 1.5 MHz) and a total of ~700 GB storage capacity. One of the 1.5 MHz PCs is presently fully dedicated to Monte Carlo. The ongoing developments are done on this local cluster. Test runs up to 10^7 events are routinely performed. NCSA will be necessary to perform a final full statistics simulation once all necessary physics processes are incorporated and tested in the code.

6 Other Computer Support

In order to keep the result of this precision experiment unbiased, the frequency of the precision clock providing the time base is blinded to the collaboration. Moreover, two independent analysis frameworks have been developed at UCB and UIUC. UCB has been using the Merlin cluster at PSI. It consists of 56 computational nodes: 32 nodes with dual Athlon 1600MP, 8 nodes with dual Athlon 2200MP, and 16 nodes with dual 500-700MHz PentiumIII running a customized version of Red Hat Linux. This has been very helpful in the past and we continue to use this farm. However, because of the limited processing nodes as well as load sharing with many other users, it will be too slow for the main data set. For that reason the UIUC group has initially developed its software on the local NPL cluster and then started the migration to NCSA, as this seems the only promising option to obtain a final precision result with the upcoming large data volume.

7 Project Team Qualifications

Peter Kammel and Tim Gorringe have more than 25 years of experience in Nuclear/Particle physics, in particular precision physics with muons, as documented by more than 100 publications.

Kammel proposed the μCap experiment and is the co-spokesman of the collaboration. He leads the experiment in scientific, technical and organizational aspects. He has proposed the custom hardware for high-rate readout of the TPC and extensively used the NERSC computing facilities in the development of the experiment during his tenure at UC Berkeley. Currently he has two graduate students working for their Ph.D. theses on the μCap experiment.

Tim Gorringe participated in and proposed several important experiments in this field, e.g. the RMC experiment[4] at TRIUMF and the recent measurement of the ortho-para rate[7]. He is also coauthor of an authoritative review[5] on the pseudoscalar coupling constant g_P. In the experiment his group is responsible for the readout of one of the main data sources, a state of the art 500 MHZ WFDs developed by our collaborators at Boston University. His group will concentrate on analyses based on the new WFD data.

Members: S. Clayton, P. Kammel, B. Kiburg (University of Illinois at Urbana-Champaign), T. Gorringe, Vladimir Tischenko (University of Kentucky), T. Banks, F. Gray, B.Lauss (University of California, Berkeley).

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