Fermilab Directorate

MEMORANDUM OF UNDERSTANDING
FOR THE 2007-2010 TEST BEAM PROGRAM

T991

Chameleon Afterglow Search (CHASE)

August 5, 2009

INTRODUCTION

This is a Memorandum of Understanding (MOU) between the Fermi National Accelerator Laboratory and experimenters of the CHASE (Chameleon Afterglow Search) experiment who have committed to participate in this test experiment to be carried out during the 2009 laboratory program.

This memorandum is intended solely for the purpose of providing a work allocation for Fermi National Accelerator Laboratory and participating universities and institutions. It reflects an arrangement that is currently satisfactory to the parties involved. It is recognized, however, that changing circumstances of the evolving research program may necessitate revisions. The parties agree to negotiate amendments to this memorandum to reflect such revisions.

The CHASE experiment is a photon to milli-eV mass chameleon particle search that looks for a photon afterglow signature from chameleons that are effectively trapped in a jar.

MOTIVATION

The greatest unsolved problem in cosmology is the origin of the cosmic acceleration. A cosmological constant, the simplest modification to known physics that can account for such an acceleration, requires a great deal of fine tuning, so the search is on for alternative explanations. For example, the cosmic acceleration could be caused by a scalar field slowly rolling down its potential, by a modification to gravity, or by extra spatial dimensions.

Now that the existence of the cosmic acceleration has been confirmed, the next major goal is to determine whether it is caused by a cosmological constant or by some alternative dark energy model. Couplings between dark energy and Standard Model fields give rise to local differences between a cosmological constant and alternative theories, such as equivalence principle violations, variations in the fine structure constant, and new interactions between known particles, which can be probed at laboratory or solar system scales. Two classes of tests, cosmological and laboratory, probe distinctly different types of dark energy. This fact motivates a multi-pronged approach, in which laboratory tests search for dark energies coupled to Standard Model fields, while cosmological probes seek dark energies without such couplings. The proposed CHASE experiment falls in the former category.

It is well known that self interactions allow scalar fields to hide their couplings to Standard Model particles [Khoury and Weltman 2003]. Nonlinear self interactions cause the mass of such a scalar to vary with the local matter density or gauge field strengths. Known as the chameleon mechanism, this variation in mass shortens the range and decreases the effective strength of scalar couplings to other particles, making such couplings difficult to detect in laboratory experiments. Since a scalar dark energy cannot be a free particle, and must have some self interaction, experiments which can probe self interacting (chameleon) dark energy models are crucial.

The CHASE experiment is a dedicated search for chameleon particles that improves upon the original GammeV chameleon search in several ways (outlined below). These experiments use a novel approach to detect precisely those chameleon fields which would be hidden to previous laboratory experiments. The chameleon mechanism ensures that the scalar will be more massive inside a dense material than in a vacuum, allowing chameleons of sufficiently low energy to be trapped inside a chamber made out of that dense material. A chameleon that couples to photons allows photons to oscillate into chameleons in a background magnetic field inside a vacuum chamber. These chameleons are then trapped by the very mechanism that let them hide from fifth force experiments. Over time the chameleon particles will oscillate back into photons which can be observed as an exponentially decaying afterglow once the original photon source is extinguished.

The afterglow effect is remarkable in that it allows us to probe non-cosmological consequences of dark energy in a laboratory setting. Scalar field models dominate dark energy theory, and yet it is difficult to distinguish among them using cosmological observations. By searching for afterglow, CHASE can probe a region of dark energy parameter space that is complementary to cosmological constraints.

PROJECT DESCRIPTION

The experimenters will perform an optical conversion experiment whereby photons from a laser will scatter off of ambient photons in a magnetic field, converting into chameleon particles which, due to their strong matter interactions, remain trapped inside the vacuum chamber. As chameleon particles are a candidate for the observed dark energy, this experiment will be the first to broadly test chameleon dark energy models in a laboratory setting. This experiment is also sensitive to a large class of power-law chameleon models.

The experiment is conducted in two phases, a filling phase and an observation phase. The filling phase is accomplished as mentioned above with an existing, pulsed, Nd:YAG laser shining through a vacuum chamber that contains an external magnetic field supplied by a Tevatron dipole magnet. The population of chameleon particles will grow over the approximately five-hour filling procedure. Once the chamber is filled, the laser is turned off and an existing Hamamatsu PMT is exposed to optically transparent windows of the chamber. Trapped chameleons will reconvert into photons which escape the chamber and impinge upon the detector. The population of chameleons will decay with an exponential profile and with a lifetime that depends upon the chameleon-photon coupling.

The previous GammeV experiment was the first to search for such particles, but had certain limitations because it was initially designed for a different experiment. The sensitivity of the previous experiment was bounded in four primary areas: 1) it was not sensitive to large couplings because such couplings would cause the chamber to empty before the detector was exposed, 2) it was not sensitive to very low couplings because of systematic uncertainty in the PMT background rate, 3) it was not sensitive to masses larger than about 1 meV because the fixed length of the magnetic field region causes a decrease in sensitivity once the mass of a chameleon exceeds sqrt(E/L) where E is the photon energy and L is the length of the magnetic field region (a similar decrease in sensitivity occurs with axion searches and neutrino oscillations), and 4) it was only sensitive to a narrow range of chameleon models due to the use of a positive displacement vacuum pumping system (chameleons could be pumped out of the chamber) and due to a relatively poor vacuum quality (~1e-7 torr).

These four limitations are remedied in CHASE in the following ways: 1) large couplings are probed by conducting runs at lower magnetic fields where the chameleon to photon conversion is slowed and by implementing a fast (~1 second), electronically driven transition to the data acquisition phase, 2) small couplings are probed by using a shutter system to monitor the PMT dark current in real time and by employing more sophisticated model of the signal, 3) larger masses are probed by partitioning the magnetic field region into chambers of different length, approximately 5 meters and 1 meter, which give overlapping and simultaneous sensitivity to a broader range of chameleon masses and 4) a wider range of chameleon models are probed by improving the vacuum system, using ion pumping and cryo-pumping to forbid the chameleons from escaping the chamber through some exhaust mechanism and also by using metal gaskets instead of rubber o-ring seals to improve the vacuum quality to approximately 1e-10 torr (3 orders of magnitude).

The figures below shows the schematic of the experiment. and the expected improvements in the sensitivity.

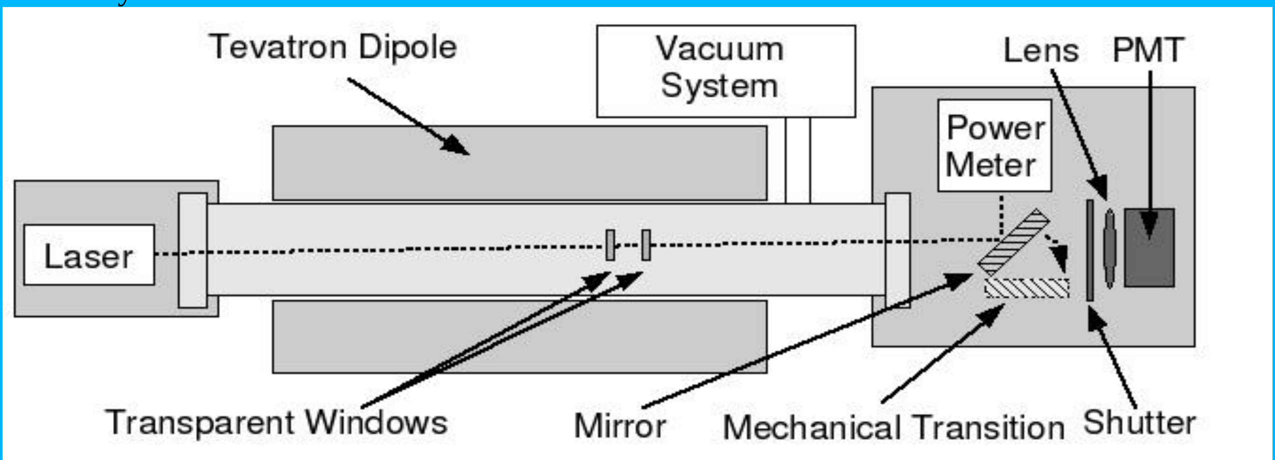

Illustration 1: Schematic overview of the CHASE experimental apparatus.

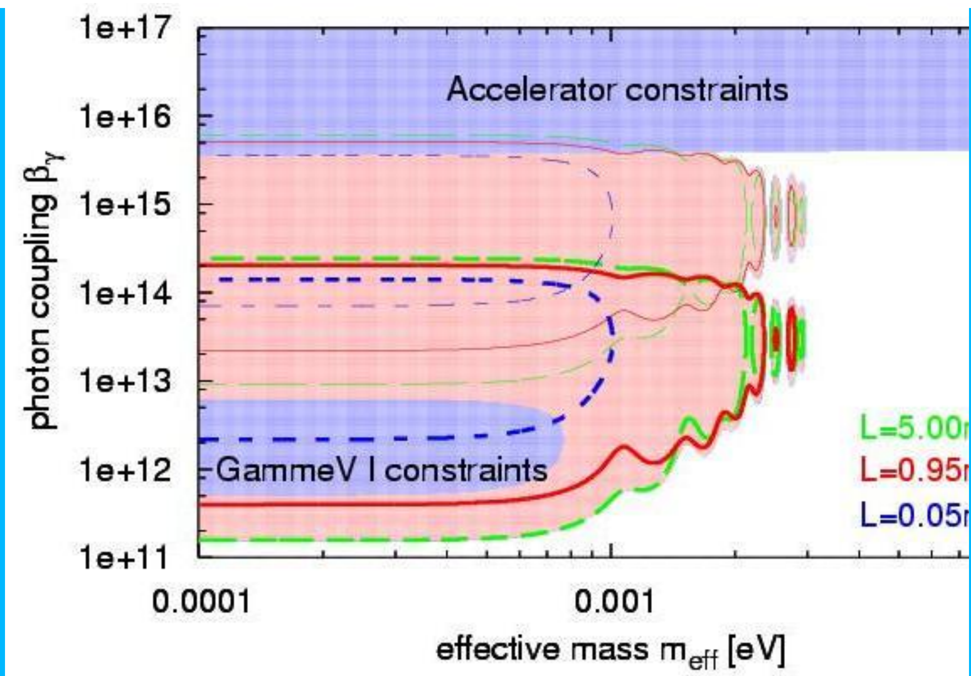

Illustration 2: Sensitivity Sensitivity of the CHASE experiment to chameleon/photon coupling as a function of the chameleon mass in the chamber. Also

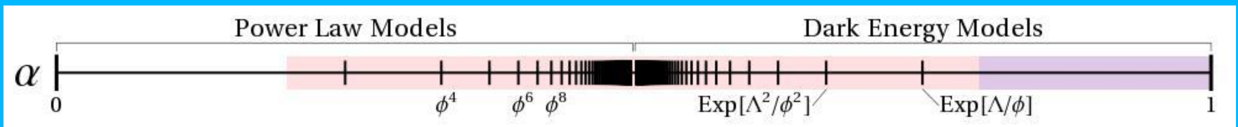

Illustration 3: Model sensitivity (parameterized by the quantity alpha) of the CHASE experiment. Alpha can be any real number between zero and unity. The original GammeV experiment was sensitive to alpha larger than approximately 0.8 (shown in violet). CHASE will be sensitive to alpha larger than approximately 0.2 and will include all chameleon dark energy models and a wide range of power-law models.

PERSONNEL AND INSTITUTIONS:

Scientific spokesperson: J. Steffen, Fermilab

The group members at present are:

1.1 FNAL: A. Baumbaugh, A. Chou, W. Wester, P. Mazur, J. Steffen, R. Tomlin
Kavli Institute for Cosmological Physics (U. Chicago): A. Upadhye
University of Cape Town: A. Weltman

Other commitments:
Pierre Auger: P. Mazur
CDF, DES, SNAP: W. Wester
PPD Elec. Engineering: A. Baumbaugh
Acc Div.: R. Tomlin

II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS

2.1 LOCATION

2.1.1 The CHASE experiment will be conducted at the Magnet Test Facility (MTF) located in Industrial Building 1 (IB1) at Fermilab. Test Stand 2 in MFT will be used to support the magnet. The laser box will be supported near the feed can which services the magnet for cryogenic operation. A 36 in. x 36 in. optical bench that is incorporated into the laser box will be supported on a large cement block on the floor of MTF or in a similar way in a manner that allows for access to nearby existing equipment. The PMT box will be supported approximately 1 meter beyond the cryogenic return can on the test stand. A small area adjacent to the PMT box will be used for the computer and DAQ system. This location is operated by the Technical Division.

2.1.2 The refurbishing of the Laser box and the construction of the PMT box, as well as some components of the vacuum system will take place at Lab 8 facility in the Fermilab Village, which is operated by the Particle Physics Division.

2.1.3 The optical prototype will be assembled and operated in the Linac Laser lab in the Linac building. This room is configured with an interlock as a safety measure for the operation of a Class IV laser. This area is operated by the Accelerator Division.

2.1.4 The data acquisition electronics and software will be assembled on the 14th floor of Wilson Hall at Fermilab in space used by the electrical engineering department of the Particle Physics Division.

2.1.5 Various other areas are expected for short term tests such as the laboratory space in the cross connect at SiDet operated by the Particle Physics Division, which has various test stand dark boxes that can be used for bench testing of the photomultiplier tube.

2.2 BEAMS (LASER only)

2.2.1 The CHASE experiment will use a photon beam generated by a Class-IV Nd:YAG laser at 1064nm capable of 420mJ pulses at 20Hz. When the light is frequency doubled to 532nm, the energy per pulse is 160mJ which is approximately 4.3×10^{17} photons per pulse or an average power of approximately 3.2W.

2.3 SETUP

2.3.1 The CHASE experiment and support systems will be installed and operated at the MTF in Industrial Building 1.

2.3.2 Crane operators will be needed to mount the chosen Tevatron dipole magnet on Test Stand No 6 (possibly Test Stand 2, depending upon the needs of the MTF) – this is part of normal operations in the facility. The experimenters also anticipate the need to move a large cement block or other structure to be used for supporting the laser box near the feed can.

2.3.3 Additional equipment including the laser box and the PMT box can be transported on a cart. PPD technical personnel will be responsible for the setup of these items with minimal consultation with MFT technical personnel.

2.3.4 A small number of cables will interface various components of the experiment to the data acquisition system. No extra-ordinary cabling effort is required.

2.4 SCHEDULE

2.4.1 The set-up of the experiment will occur during the early Fall of 2009. This will involve the movement of most of the materials (laser box, PMT box, etc.) into the magnet test facility.

2.4.2 The vacuum system must be "baked-out" in order to prepare the components for the ultra high vacuum conditions required by the experiment. This task, and the assembly and verification of the vacuum system, will be performed by Scott McCormick and the technicians from the Accelerator Division.

2.4.3 October 2009 will involve the integration of the equipment onto the Test Stand including various alignment and laser tests, vacuum tests, and measurements. The end step of this activity will be the installation of the photomultiplier tube.

2.4.4 Data taking will begin in the last part of October or the first part of November 2009. This schedule will depend upon the completion of the construction project that is expected to occur at the end of summer 2009.

2.4.5 Additional data taking may be required into December 2009 in order to verify initial results of the experiment. In addition, since CHASE will have to operate with minimal disturbance to the activities at the MTF, the data taking running period may be adjusted from this schedule.

III. RESPONSIBILITIES BY INSTITUTION - NON FERMILAB

3.1 Amol Upadhye (KICP) and Amanda Weltman (U. Cape Town) are both theorists who have expertise in chameleon models. Their contributions will be in the design of the experiment as well as the analysis and interpretation of the experimental results.[$0k]

IV. RESPONSIBILITIES BY INSTITUTION - FERMILAB

4.1 Fermilab Accelerator Division

4.1.1 The experimenters require Accelerator Division support in the assembly, instrumentation, and commissioning of the vacuum system, allowing for the use of residual gas analyzers (RGA), vacuum gauges, and vacuum fittings and valves (including at least four gate valves), and supporting Alex Chen and Scott McCormick (1 week each) to work/consult on the experiment and two vacuum techs for approximately 1 month to prepare, install, and prove the vacuum system.

4.1.2 The Accelerator Division vacuum experts will conduct any preparation of the vacuum materials (e.g. cleaning, baking, etc.) for operation at or below 1e-10 torr.

4.1.3 The experimenters require Accelerator Division support in approving of the use of the particular Tevatron magnet, allowing for use of the Laser lab in the Linac area, and supporting Ray Tomlin (8 weeks) to work/consult on the experiment.

4.1.4 The Accelerator division will provide use of the Continuum Surelite Laser as well as an HeNe alignment laser and other optical components under Ray Tomlin’s care.

4.1.S Summary of Accelerator Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	18.0

4.2 Fermilab Particle Physics Division

4.2.1 The Particle Physics Division will be the source of M&S funds for the experiment. The costs include approximately $5K for vacuum components, $7K for other mechanical hardware, $7K for optical components, and $1K for electronics for a total of $20K. In addition, a 50% contingency fund is to be made available after prompt notification to the division that such funds will be needed and such need is justified.

4.2.2 The PPD Mechanical team of John Korienek and Carl Lindenmeyer will be responsible for the design, fabrication, and installation of the laser box, PMT box, and interfaces between these items and the vacuum system. Some of the pieces, including some vacuum components, will require machine shop and welding workmanship.

4.2.3 The PPD Electrical Engineering Department will be responsible for providing engineering and technical support of the data acquisition system. This will include the design and fabrication of a new data acquisition card. This effort will be led by Sten Hansen with technical assistance. The department will also provide support for software engineering by Al Baumbaugh who will write the graphical user interface and underlying software for the control of the experiment. Additional support will be provided for electrical parts of the safety system.

4.2.4 The PPD shall provide access to a Continuum Surelite Laser (currently under Hogan Nguyen's care) as a back-up to the accelerator division laser.

4.2.5 The PPD ES&H Department will assist in all of the necessary safety reviews.

4.2.6 The PPD will provide administrative support through the Experiment Physics Projects office.

4.2.S Summary of Particle Physics Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Mechanical design and fabrication			10.0 tech
Electrical engineering support			8.0 engineer
Machine shop fabrication			1.0 tech
Administrative Support			1.0
Mechanical pieces	$7K		
Optical components	$7K		
Vacuum components	$5K		
Electronics	$1K		
Total new items	$20K		20.0

4.3 Fermilab Technical Division

4.3.1 The Technical Division will be responsible for the operation of the Tevatron dipole magnet on the test stand at MTF. This includes the installation of the magnet onto the test stand and the connections to the feed and return cans for cryogenic operation. Technical Division personnel will operate and monitor the magnet. These activities will be considered as MFT Test Stand operations and will not be directly charged towards the CHASE effort. This document is written with the assumption that the stand will be Test Stand 6, however, Test Stand 2 is also an acceptable stand. The Technical Division will make the space on Test Stand 6 available to the project for the duration of the effort. It is understood that there may be circumstances for which higher priority activities may take precedence over CHASE and the schedule and even the experiment's priority on Test Stand 6 may be adjusted in order to take into account these priorities.

4.3.2 The Technical Division will supply power and cryogens necessary for the operation of the magnet throughout the duration of the project. This includes time needed by the vacuum experts from the Accelerator Division while the vacuum system is being assembled and tested as cryogenic pumping is the major component of the vacuum system and of the experiment as a whole.

4.3.3 The Technical Division will provide limited technical assistance to PPD personnel who have the responsibility for the installation of the experiment and interfacing it with the magnet. The experimenters estimate the total involvement of CHASE specific technical support to total 2 person weeks.

4.3.4 The TD ES&H Department will assist in all of the necessary safety reviews.

4.3.5 The Technical Division will provide a nominal 5T (5100 amps) field with normal stability controls in place and will provide current and other routine monitoring data to the experimenters. The Technical Division will also provide magnet time with the field at a value of 0.2T (204 amps). The Technical Division will provide 20 hours of magnetic field to the experimenters usually in continuous duration of either 5 hours (at 5T) or 0.5 hours (at 0.2T). The nature of this experiment is such that short interruptions are not acceptable and would require restarting the run. Because of priorities, the Technical Division can choose these hours during weekend or swing shift times if necessary. The Technical Division will consider a possible request for additional hours beyond 20 hours within the context of this MOU in the event that the experimenters require further investigations of a possible signal.

4.3.S Summary of Technical Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	2.0

4.4 Fermilab ES&H Section

4.4.1 The ES&H Section will provide assistance with safety reviews and safety approvals in order to help ensure the experiment will be conducted in a safe manner.

V. SUMMARY OF COSTS

Source of Funds [$K]	Equipment	Operating	Personnel (person-weeks)
Particle Physics Division	$20K	$0.0K	20
Accelerator Division	0	0	18
Computing Division	0	0	0
Technical Division	0	0	2
Workplace Development Section	0	0	0
ES&H Section	0	0	0
Totals Fermilab	$20.0K	$0.0K	41
Totals Non-Fermilab	$0K		

VI. SPECIAL CONSIDERATIONS

6.1 The responsibilities of the CHASE Spokespersons and procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Experimenters" (PFX) (http://www.fnal.gov/directorate/documents/index.html). The Physicists in charge agree to those responsibilities and to follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ES&H) reviews are necessary. This includes creating a Partial Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The CHASE Spokespersons will follow those procedures in a timely manner, as well as any other requirements put forth by the division's safety officer.

6.3 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ES&H section.

6.4 All items in the Fermilab Policy on Computing (http://computing.fnal.gov/cd/policy/cpolicy.pdf) will be followed by experimenters.

6.5 The CHASE Spokespersons will undertake to ensure that no PREP and computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Computing Division management. They also undertake to ensure that no modifications of PREP equipment take place without the knowledge and consent of the Computing Division management.

6.6 Each institution will be responsible for maintaining and repairing both the electronics and the computing hardware supplied by them for the experiment. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

6.8 At the completion of the experiment:

6.8.1 The CHASE Spokespersons are responsible for the return of all PREP equipment, Computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the CHASE Spokespersons will be required to furnish, in writing, an explanation for any non-return.

6.8.2 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ES&H requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters.

6.8.3 The experimenters will assist the Fermilab Divisions and Sections with the disposition of any articles left in the offices they occupied, including computer printout and magnetic tapes.

6.8.4 An experimenter will report on the test effort at a Fermilab All Experimenters Meeting.

SIGNATURES:

______________________________ / / 2009
Jason Steffen (PI), Fermilab

____________________________________ / / 2009
Mike Lindgren, Particle Physics Division

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Roger Dixon, Accelerator Division

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Georgio Apollinari, Technical Division

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Nancy Grossman, ES&H Section

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Greg Bock, Associate Director, Fermilab

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Stephen Holmes, Associate Director, Fermilab

APPENDIX I - Hazard Identification Checklist

Items for which there is anticipated need have been checked

Cryogenics		Electrical Equipment		Hazardous/Toxic Materials	
X	Beam line magnets	X	Cryo/Electrical devices		List hazardous/toxic materials
	Analysis magnets		capacitor banks		planned for use in a beam line or experimental enclosure:
	Target	X	high voltage		
	Liquid Argon TPC		exposed equipment over 50 V		
Pressure Vessels		**Flammable Gases or Liquids**			
	inside diameter	Type:			
	operating pressure	Flow rate:			
	window material	Capacity:			
	window thickness	**Radioactive Sources**			
Vacuum Vessels			permanent installation	**Target Materials**	
1 ½" - 2"	inside diameter		temporary use		Beryllium (Be)
Atm–10-10 torr	operating pressure	Type:			Lithium (Li)
Glass: BK7 + HPFS 7980 Fused Silica	window material	Strength:			Mercury (Hg)
1/2"	window thickness	**Hazardous Chemicals**			Lead (Pb)
Lasers			Cyanide plating materials		Tungsten (W)
	Permanent installation		Scintillation Oil		Uranium (U)
X	Temporary installation		PCBs		Other :
	Calibration		Methane	**Mechanical Structures**	
X	Alignment		TMAE	X	Lifting devices
Type:	Continuum Surelite Nd:Yag		TEA		Motion controllers
Wattage:	9W, 420mJ/5ns @ 20 Hz		photographic developers		scaffolding/elevated platforms
class:	IV		Other:		Others

APPENDIX II Laser Hazard Requirements

All personnel on the project who deal with the laser will be required to go through safety training suitable for the Class IV status of the laser.

Further information from Ray Tomlin follows:
The people that oversee safety in Accelerator Division laser labs are listed here.
Ray Lewis, John Anderson. Also, Tim Miller has a nice web page:
http://www-esh.fnal.gov/CourseHandout_Mat/laser_safety_20081028.ppt

Lab laser safety guidelines are here:
http://www-esh.fnal.gov/FESHM/5000/5062.1.pdf

Ray Tomlin operates the LINAC laser labs in AD and has been even more conservative than the ES&H folks striving for zero exposure if possible.
Rich Ruthe (TD, SSO) has attended the class 4 laser committee meetings sponsored by Tim Miller so he has had at least indirect input on the operation of this laser and all the class 4 lasers on site.

The laser to be used for the CHASE experiment is a Continuum SureLite I-20. It fires a 420 milli joule, 5nsec pulse at 20 Hz. Wave length is 1064 nm, in the near IR, and invisible. Average power is 9 to 10 watts of photons. The laser outputs 160 mJ at 20 Hz when frequency doubled to 532nm.

This laser has been in two laser labs run by Ray Tomlin. It has been in service in the pre-accelerator. While in the pre-accelerator, it was enclosed in a metal box. Passers-by could reach out and touch the box. The box was light tight and covers were interlocked. Since the IR beam was fired into the H- beam line, interlocks included vacuum valve status, vacuum level status, PREAC HV status, in addition to the microswitches on the laser box covers. The laser was successfully employed for the original GammeV experiments where the interlocked laser box was also accessible.

APPENDIX III Cryogenic and Electronics Hazard Requirements

CHASE will use cryogens (liquid N_2 and He) as they are used for magnet operations by the Magnet Test Facility within the Technical Division. TD specified safety procedures will be followed. The electronics equipment is modest with no exposed high voltages. Circuitry will be appropriately fused and protected as required by safety concerns.

APPENDIX IV APPROXIMATE RUN PLAN

1)	Rigging, installation, setup	September, 2009
2)	Alignment and Calibration at MFT	October 1 – October 15, 2009
3)	Vacuum system and PMT commissioning	October 15 – October 31, 2009
4)	Data taking	November 1 – November 15, 2009
5)	Optional running time if needed	November 15 – December 15, 2009