REDTOP: Rare Eta Decays with a TPC for Optical Photons

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Abstract: The REDTOP experiment is primarily intended to look for new violations of the basic symmetries. It aims to improve the sensitivity level of key physics conservation laws by several orders of magnitude beyond those of previous experiments. In doing so, it will open doorways for possible Physics Beyond the Standard Model including dark matter and energy, and/or new forces. The REDTOP measurements will focus on rare decays of the η and η' mesons produced by proton beams of a few GeV energy and high intensity. Physics BSM is searched mainly in the decay products of the η and η' mesons.

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I. SCIENTIFIC CONTEXT AND OBJECTIVES

Physics is built on principles of symmetry for which evidence is developed over many years or decades. The symmetries lead to conservation laws. Sometimes, a symmetry principle or conservation law is found to be violated, and new physics is discovered.

It is now generally accepted that the Standard Model (SM) is not a complete description of nature. The exact nature of dark energy, dark matter, neutrino mass, and the baryon asymmetry of the universe (BAU) are among the major questions that must find answers Beyond the Standard Model (BSM). These and similar issues provide strong hints that BSM physics could contain new particles and/or forces that may violate some of the discrete symmetries of the universe. For example, the baryon asymmetry can arise only through C, CP, and baryon number violations outside of thermal equilibrium.

To date, the LHC has found few if any hints of New Physics at high energy, indicating that new physics is more elusive than expected and that it more likely lies at low energies. As a consequence, multiple new theoretical models are flourishing, trying to accommodate observed discrepancies with the SM by postulating new physics in the 1-GeV energy regime and with coupling constants of the order of 10^{-8} or lower.

In such a scenario, fixed target and low energy experiments with intense beams could play an important role in the discovery of new physics. Such experiments would require integrated luminosities of 10^{45} cm^{-2}, a level not reachable in the foreseeable future by high energy colliders. After allowing for different production scenarios the production rates for neutral GeV-scale states from fixed targets can be enhanced by several order of magnitude compared to searches at colliders. Consequently, these experiments are capable of producing a large number of events, opening the door to the exploration of very rare processes.

However, the design of such experiments is often very constrained by the limitations of current detector technologies that are not well suited for coping with very high event rates, and have poor particle identification properties needed to reject the expected large background. The improvements necessary for the next generation of detectors, especially when employed with proton beams, are:

- Timing resolutions of $\leq$ 100 psec, to cope with event production rates of few nsec;
- low sensitivity to neutrons;
- Particle-Identification and, in particular, the capability to disentangle photons from neutrons;
- Radiation hardness.

The REDTOP experiment [REDTOP] is primarily intended to look for new violations of the basic symmetries. It has two preeminent goals. First, it aims to improve the sensitivity level of key physics conservation laws by several orders of magnitude beyond those of previous experiments. In doing so, it will open doorways for possible Physics Beyond the Standard Model including dark matter and energy, and/or new forces.

Second, to meet the challenge, REDTOP will extend and develop new and innovative detector technology. Precision timing capabilities will be implemented for the dual-readout calorimeter design from the T1015 (ADRIANO) project at Fermilab [T1015-1,T1015-2,T1015-3]. The features will provide many new opportunities for future experiments in Particle and Nuclear Physics, and possibly other fields as well.

The REDTOP measurements will focus on decays of the η and η' mesons produced by proton beams of a few GeV energy. The additive quantum numbers for these particles are all zero, the same as for the vacuum, with the exception of their negative parity, leading to the suppression of SM decays. Extensions to kaon and muon beams will also be possible. Early measurements will be aimed at testing C, CP, and T conservation laws to many orders of magnitude below current levels.

II. PHYSICS MEASUREMENTS

We have compiled an extensive list of possible measurements that can be made with REDTOP. They can be grouped into 6 categories, as outlined in Table I. Although the scope of the experiment is large, we shall showcase here only a few of the most interesting and potentially influential ones, presenting those with both a high degree of physics interest and real practical prospects for a meaningful result.

An attractive feature of the η meson is that it is flavor neutral, so its SM C- and CP-violating interactions are known to be very small. Thus, rare η decays are a promising place to look for BSM effects. From the Standard Model and various BSMs, such decays can provide distinct insights into the limits of conservation laws, and open unique doors to new ones at branching ratio sensitivity levels typically below 10^{-9}. Notably, however, current experimental upper limits for η decays are many orders of magnitude larger, so η decays have not been competitive with rare decays of flavored mesons. The sensitivity goal of REDTOP is better than 10^{-11} for the branching ratio of most decay modes, based on an estimated yield of about than 10^{13} η mesons. Production cross sections for the η' are about 1/100 those for the η. Numerous and unprecedented opportunities for constraining new physics will thus become available.

Dedicated attention will be given to several “Golden Channels" of great interest:

- Certain definitive asymmetries that might be found in the Dalitz plot of the decay $\eta \to \pi^+\pi^-\pi^0$ would be evidence of C and/or CP violation. Existing data are far from definitive, and a REDTOP-sized sample will be needed.
- The decay $\eta \to \pi^+\pi^- l^+ l^-$, with $l = e,\ \mu$, can test CP violation by measuring the angular asymmetry between the (e^+, e^-) and pion pair decay planes. Again, recent measurements are statistics limited, and REDTOP will provide an enhancement of at least 100 with improved systematics.
- The decay $\eta \to \gamma A'$, with $A' \to e^+e^-$ or $\mu^+\mu^-$, provides two opportunities for new physics. They include vector dark photons A' from e^+e^- pairs, such as a possible one near 17 MeV. In addition, searches for scalar e^+e^- pairs could support a postulated light gauge boson as a mediator of a fifth, milli-weak force.
- The decay $\eta \to \pi^0 H$, where $H \to e^+e^-$ or $\mu^+\mu^-$, is a Higgs-like scalar. A 2-photon intermediate state ($\eta \to \pi^0\gamma\gamma$) conserves C, while a 1-photon mechanism ($\eta \to \pi^0\gamma \to \pi^0 e^+e^-$) violates C. Significant enhancement of the branching ratio above 2-photon models will indicate both C violation and the presence of two mechanisms.
- Due to its low energy scale, REDTOP will provide outstanding opportunities to explore the possibility that axion-like particles (ALPs) [Holdom] can be discovered as signatures of BSM physics. Some ALPs can be produced from $\eta \to \pi^0\pi^0 a$ or $\eta' \to \pi^+\pi^- a$ decays, where a is an ALP that decays into e^+e^- [O'Connell]. For other portals, the ALP can decay to $\gamma\gamma$, 3π, or $\pi\pi\eta$ without an initial η or η' [Batell,Pospelov].

The physics program will require a CW proton beam with an energy range of 1.8–3.5 GeV, and a minimum intensity of 10^{10} POT/sec (or an annual integrated flux of 10^{17} POT). The CERN PS

Table I. Summary of REDTOP physics program

C, T, CP-violation
CP Violation via Dalitz plot mirror asymmetry: $\eta \to \pi^+\pi^-\pi^0$
CP Violation (Type I – P and T odd , C even): $\eta \to 4\pi^0$
CP Violation (Type II - C and T odd , P even): $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \gamma\gamma\gamma$
Test of CP invariance via μ longitudinal polarization: $\eta \to \mu^+\mu^-$
Test of CP invariance via γ^* polarization studies: $\eta \to \pi^+\pi^-e^+e^-$ – and : $\eta \to \pi^+\pi^-\mu^+\mu^-$
Test of CP invariance in angular correlation studies: $\eta \to \mu^+\mu^-e^+e^-$
Test of T invariance via m transverse polarization: $\eta \to \pi^o\mu^+\mu^-$ and $\eta \to \gamma\mu^+\mu^-$
CPT violation: μ polariz. in $\eta \to \pi^+\mu^-\nu$ vs $\eta \to \pi^-\mu^+\nu$ and γ polarization in $\eta \to \gamma\gamma$
Searches for new particles and forces
Scalar meson searches (charged channel): $\eta \to \pi^0 H$, with $H \to e^+e^-$, $\mu^+\mu^-$
Dark photon searches: $\eta \to \gamma A'$ with $A' \to l^+l^-$
Protophobic fifth force searches : $\eta \to \gamma X_{17}$ with $X_{17} \to e^+e^-$
New leptophobic baryonic force searches : : $\eta \to \gamma B$, with $B \to e^+e^-$, $\pi^o\gamma$
Indirect searches for dark photons new gauge bosons and leptoquark: $\eta \to \mu^+\mu^-$ and $\eta \to e^+e^-$
Search for true muonium: $\eta \to \gamma\ (\mu^+\mu^-)_{2M_\mu} \to \eta \to \gamma\ e^+e^-$
Other discrete symmetry violations
Lepton Flavor Violation: $\eta \to \mu^+e^-\ +c.c.$
Double lepton Flavor Violation: $\eta \to \mu^+\mu^+e^-e^-\ +c.c.$
Other Precision Physics measurements
Proton radius anomaly: $\eta \to \gamma\mu^+\mu^-$ vs $\eta \to \gamma e^+e^-$
All unseen leptonic decay mode of η/η' (SM predicts $10^{-6} - 10^{-9}$)
Non-η/η'' based BSM Physics
Dark photon and ALP searches in Drell-Yan processes: $q\bar{q} \to A'/a \to l^+l^-$
ALP's searches in Primakoff processes: $pZ \to pZa \to l^+l^-$ (F. Kahlhoefer)
Charged pion and kaon decays: $\pi^+ \to \mu^+\nu A' \to \mu^-\nu l^+l^-$ and $K^+ \to \mu^+\nu A' \to \mu^-\nu l^+l^-$
Neutral pion decay:$\pi^o \to \gamma A' \to \gamma e^+e^-$
High precision studies on medium energy physics
Nuclear models
Chiral perturbation theory
Non-perturbative QCD
Isospin breaking due to the u-d quark mass difference
Octet-singlet mixing angle
Electromagnetic transition form-factors (important input for g-2)

is capable of providing a suitable beam. We estimate that 10^{17} POT will yield about 8×10^{12} η mesons and $\sim 5 \times 10^{11}$ η' mesons, allowing us to address the physics issues in Sec. II.

In addition to their key intrinsic merit regarding electromagnetic conservation laws, studies of neutral η decays will also be critical to the development of the detector and techniques used by REDTOP.

III. THE REDTOP DETECTOR

The experimental technique proposed for REDTOP presents three major challenges to the detector: a) The rate of inelastic hadronic interactions between the beam and the target systems is of the order of 1 GHz, requiring fast response times and high granularity; b) The rate of production of baryons (mostly slow protons and neutrons) is, also, of the order of 1 GHz, requiring a tracker mostly blind to them; c) the new physics is almost always accompanied by leptons and/or gammas, requiring a calorimeter with excellent particle identification.

The detector contains several critical components that must work together to achieve the goals of the experiment. Three major components of the detector, the Optical TPC (O-TPC), the ADRIANO2 calorimeter, and the active Muon Polarimeter, are novel technologies under active development. Thus, REDTOP will not only challenge fundamental physics limits, but also represents a step-up in detector technologies, paving the way for more challenging experiments in the future. A schematic of the detector is shown in Fig. 1. A brief description of its main components follows.

III.A. The Target System

The target system (corresponding to the blue disks along the beam axis in Fig. 1) is composed of ten round low-Z foils (lithium or beryllium), each about 240-300 μm thick and about 1 cm in diameter. The target system is held in the center of a beryllium or carbon-fiber beam pipe by thin AlBeMet wires. The pipe will also help in maintaining a vacuum and in supporting an aerogel radiator attached to its external wall. A proton with 1.8 GeV of kinetic energy has about 1-2% probability to make an inelastic scattering in any of the foils. The probability that one such scattering would produce an η meson is about 0.4%. Assuming an integrated flux of 10^{17} POT, the number of η mesons produced is expected to be about 8×10^{12}. The physics goals are intended to be reached in a 1-year (10^7 seconds) period.

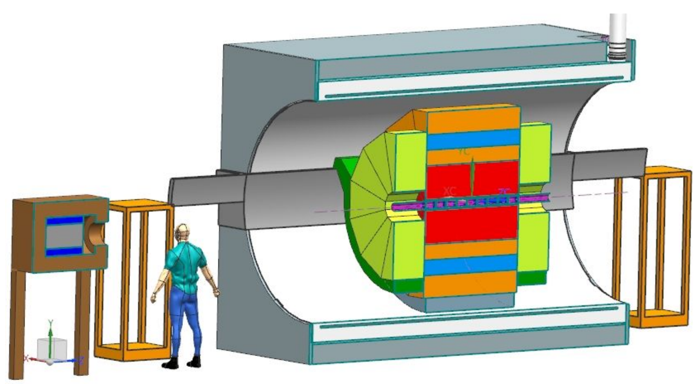

Figure 1. The REDTOP experimental apparatus.

In contrast to the use of a gaseous target (*e.g.* [WASA14]), the distributed targets will help to disentangle the η events from backgrounds, the latter being mostly constituted by inelastically scattered protons from the target matter. The distance between foils is sufficient to identify the location of the primary vertex without ambiguities, while the tracking systems will provide $r\varphi$ coordinates. Finally, preliminary Monte Carlo simulations have indicated that the decay products of the η meson are minimally affected when traversing a very thin beryllium foil. The fraction of the beam absorbed by the target system is about 2%. Consequently, each beryllium foil will need to dissipate only 1.5 mW, easily achievable by thermal radiation and by conduction through the supporting metal wires.

III.B. The Fiber Tracker

The main purposes of the Fiber Tracker (marked in blue in Fig. 1) are to complement the pointing capabilities and vertexing of the O-TPC and to reject the background from photon conversion in the aerogel. A baseline design of such tracker is based on the technology developed by the LHCb Collaboration [LHCb] for their tracker upgrade. The proposed layout consists of three dodecagonal 1-m-long cylinders (super-layers), positioned between the beam pipe and the aerogel. Each super-layer is composed by four mats of scintillating fibers with 250 μm diameter, read-out at each end by multi-channel Silicon Photomultipliers. Extensive studies by LHCb collaboration [Aachen] have demonstrated that a spatial resolution in the x-y plane of about 60 μm is achievable. Measurement of the z-coordinate is possible using stereo layers of with light-division methods.

III.C. The Optical TPC

As with a conventional TPC, the O-TPC (marked in red in Fig. 1) will measure the momentum and trajectory of a charged track through its deflection in a solenoidal magnetic field. However, rather than detecting the tracks via an ionization process in the gas, the Čerenkov effect is employed. The momentum of that particle is then reconstructed from the detection of the photons radiated from an aerogel layer along the inner radius of the O-TPC, as well as from the gas, by using an array of photo-sensors mounted inside the vessel. About 175 Large Area Picosecond Photodetectors (LAPPD) or 280,000 SiPMs are needed to cover the entire outer surfaces. The pattern of detected photons will also provide the position in space of the initial particle (along with the hits from the Fiber Tracker). The advantage of an O-TPC over a conventional TPC is that it will be sensitive only to the fast particles (leptons and fast pions) entering the volume of the detector. In particular, hadrons and slower pions will be below the Čerenkov threshold and, therefore, will not be detected.

III.D. The ADRIANO2 Calorimeter

Dual-readout calorimetry is a novel detector technique that has received considerable attention in the past few years. An implementation, named ADRIANO (A Dual-Readout Integrally Active Non-segmented Option), has been under development for several years at Fermilab [T1015-1, T1015-2, T1015-3]. It is based on the simultaneous measurements of the energy deposited by a hadronic or electromagnetic shower into two media with different properties. The first medium is usually a plastic scintillator. Consequently, any charged particle depositing energy in that medium will produce scintillation. The second medium is usually a heavy glass with high refractive index ($n_D \geq 1.8$) and high density ($\rho > 5.5$ g/cm^3). The latter medium will be sensitive only to charged particles above the Čerenkov threshold, which usually happens for the electromagnetic components of the shower (electrons and positrons or photons producing pairs). Furthermore, the high density of the medium will make it an ideal integrally active absorber for all particles impinging on the detector. Summing the Čerenkov (C) and the scintillation (S) signals will provide the total energy of the particle. Comparisons of the scintillation vs. the Čerenkov signals provides information about the ID of the particle that generated the shower. Furthermore, the different behavior in terms of S vs. C for muons and pions will complement the double aerogel systems for identifying the two species. The rationale for employing such a calorimeter is that the large backgrounds from the vast majority of neutrons entering the detector can be easily rejected.

The calorimeter is indicated in orange in Fig. 1. An implementation with finer granularity than ADRIANO is being considered for REDTOP (ADRIANO2). It consists of small, alternating Pb-glass and plastic scintillating tiles, each read-out by a SiPM. In addition to the improved pattern recognition and overlapping shower separation, a timing precision of about 50 ps or better can be achieved from the prompt Čerenkov signal. The latter will greatly enhance the trigger capability of the detector and the disentangling of overlapping events. The implementation of Particle Flow Analysis (PFA) algorithms [PFA-2009] will further improve the performance of the detector.

III.E. The Active Muon Polarimeter

The Active Muon Polarimeter (the blue bars in Fig. 1) is an array of plastic scintillators and wire chambers inserted between the inner and the outer layers of the Calorimeter. They will detect the electrons and positrons emitted when a muon is stopped inside the Calorimeter, which occurs within a short range after the muon has lost all of its energy. The initial polarization of the muon is not lost in this process because the lead-glass used in ADRIANO2 is a homogeneous and isoscalar medium. Ongoing detector simulations are determining whether the muon polarization can effectively be measured with the highly granular ADRIANO2 calorimeter. Consequently, the use of a Muon polarimeter is, for the moment, considered optional.

III.F. The Solenoid

The REDTOP detector will be inserted inside a large superconducting solenoid (the white cylinder in Fig. 1) where a 0.6-T solenoidal field will be generated. The magnetic field will allow the O-TPC to measure the transverse momentum of charged particles, and the Muon Polarimeter to measure the polarization of muons. The Finuda magnet [Bert99] from the Frascati Phi factory (DAPHNE) is being considered for that application.

IV. EVENT TRIGGER SYSTEM

The number of η and η' mesons produced by 10^{17} POT, as noted in Sec. II, is of the order of 10^{-3} of the yields from other mesons and baryons coming from nuclear fragmentation of the target, and other background events. Taking into account the total p–Be(Li) inelastic collision rate, we estimate a total event rate up to $\sim 2 \times 10^8$ Hz while the beam is on target. The task of the REDTOP trigger is to reduce this event rate from 2×10^8 Hz down to about 1×10^2 Hz for events that will be permanently recorded. Assuming an average final event size of 5×10^3 bytes, this yield will produce an output data rate of 500 KB/s or about 5 PB/year, which we consider manageable.

The needed $\sim 10^6$ reduction in event rate is achieved by two trigger stages, Level 0 (L0) and Level 1 (L1), each one resulting in a rate reduction of about 100. These two stages are preceded by a digitization and compression (DAC) stage that is directly attached to the front-end of the detector. Level 0 and Level 1 sit off the detector. A fiber optics network delivers data from the DAC to Level 0 and from Level 0 to Level 1. The events filtered by Level 1 are delivered to Level 2, a processor farm that performs event building, reconstruction, formatting, and classification. A further rate reduction of 200 is implemented at Level 2, based on the analysis of the event topology and particle identification. Only events compatible with final states from new physics (mostly with leptons) are kept for permanent storage. Table II summarizes data and event rates into and out of the different stages.

Table II. Data and event rates for different stages. **Update the numbers as needed.**

Trigger stage	*Input event rate Hz*	*Event size bits*	*Input data rate bits/s*	*Event rejection*
Level 0	$2. \times 10^8$	1×10^4	2×10^{12}	100
Level 1	$2. \times 10^6$	$5. \times 10^4$	$1. \times 10^{11}$	100
Level 2	$2. \times 10^4$	$5. \times 10^4$	$1. \times 10^9$	200
Storage	$1. \times 10^2$	$5. \times 10^2$	$1. \times 10^7$	

The DAC hardware continuously digitizes all data coming from the detector in real time, performs zero suppression, and data compression to reduce the amount of data to be transmitted to the following stages. No event selection is performed at this stage. Based on preliminary Monte Carlo simulations, each p–Be(Li) collision produces an average of about 10 Kb of data from the DAQ, corresponding to 2 Tb/s for a 200 MHz collision rate. Such a data rate can be comfortably transmitted by a network of a few hundred optical fiber links. Trigger latency is not a problem, at least to first order. Therefore the Level-0 logic can be heavily pipelined. Although a new event will arrive, on average, every 5 ns, the time taken to make a decision on a specific event can be much longer, possibly microseconds.

Level 0: The selection performed by Level 0 is based on simple global features of the events produced by p–Be(Li) inelastic collisions. Preliminary simulations suggest that, by setting thresholds on the occupancy of the O-TPC and on the total energy deposited in the calorimeter, we can achieve the needed rejection factor of 100 while preserving a satisfactory efficiency on interesting physics processes.

Level 1: Level-1 rejection will be based on thetopology of the event. Specialized hardware, likely based on massive use of FPGAs, will need to be designed to handle the $\sim$ 2-MHz event rate. Features will include reconstructing Čerenkov rings from muons and electrons in the O-TPC, and discriminating photon conversions in the Čerenkov radiator and beam pipe with high efficiency.

Level 2: The Level-2 processor farm will receive an average 20 kHz of events which need to be reconstructed and formatted for permanent storage. We assume that this task can be completed by using less than 100 ms of CPU time and, consequently, a farm of 2000 CPUs should be adequate. This same processor farm can be used for "data analysis" when the experiment is not taking data.

V. PHYSICS AND DETECTOR STUDIES

V.A. Simulation frameworks

REDTOP has a collection of simulation codes that are specially adapted to the needs of the project. The two software framework used by the Collaboration: *ilcroot* and *slic-lcsim* have been developed by the ilc community for the past twelve years. They are mature and robust and more than adequate for the preparation of a full proposal. The reconstruction packages include all aspects of digitization and reconstruction, including fitting of charged tracks in a magnetic field (either with a Kalman or a circle algorithm). The only two missing pieces are a realistic pattern recognition and the reconstruction of the tracks in the O-TPC: at present, those two packages require some information from the Montecarlo truth. At this stage of the project, we do not believe that will affect the results of our studies in any relevant manner.

V.B. Detector Performance Studies

Detector studies are currently ongoing to optimize the granularity of the detector and to lower construction costs. Sensitivity to new physics, and in particular to the golden channels listed in Sec. II are used for guidance in the optimization of the detector parameters. No optimization studies are foreseen for the fiber tracker, whose performance has been extensively explored by LHCb Collaboration. A summary of the planned studies is given below.

ADRIANO2: Three parameters need to be optimized: a) SiPM dimensions for the glass tiles; b) thickness of the glass tiles; c) ganging (either active and/or passive) of multiple channels. The dimensions of the of the SiPM affect the light collection and, consequently, the energy resolution and reconstruction efficiency of showers. The thickness of the glass tiles affects the C/S ratio and, consequently, the performance in terms of particle identification. Ganging of multiple channels affects the effective granularity of the detector and, consequently, the performance in terms of two-shower separation and event pile-up.

O-TPC: Two parameters need to be optimized: a) SiPM dimensions; b) refractive index of the aerogel. The dimensions of the of the SiPM affect the momentum resolution of charged tracks and, in order to be cost-effective, needs to match the uncertainty due to the multiple scattering occurring in the aerogel. The refractive index of the aerogel affects the threshold of detection efficiency for muons and pions and, consequently, the $\pi - \mu$ separation.

Trigger: The optimization of the algorithms used in the three levels of the trigger affects directly the amount of data that require permanent storage and the reconstruction efficiency of final states associated to new physics.

V.C. Physics studies

The primary source impacting sensitivity for any rare process comes from the amount of background feeding through the reconstruction and analysis. Therefore, the most critical aspect of physics studies for REDTOP is the simulation of primary interactions between the proton beam and the nuclear matter. No experimental data are currently available that reproduce the scattering of 1.8 and 3.5 GeV protons on either Lithium or Beryllium. Consequently, our simulations rely heavily on computerized nuclear models, which, however, are known to have important uncertainties at the energy of interest to REDTOP. In order to have partially mitigated this limitation, we have implemented the GenieHad [GenieHad] event generator framework with several interfaces to the many nuclear scattering models (see Sec. VI below). Studies are ongoing to estimate the uncertainties related to the primary scattering by comparing simulations with different nuclear models.

VI. STATUS OF THE PROJECT AND CHALLENGES

The REDTOP Collaboration began forming in 2015 and, currently, it counts 67 members from 23 institutions (see Addendum). Several groups are actively participating in physics and detector simulations and detector R&D. A preliminary analysis of the beam delivery systems and of the experiment hall for an implementation at Fermilab and CERN has been made by study groups at their respective laboratories.

Beam delivery and experimental hall: A scenario for REDTOP at Fermilab envisions a single 15-Hz pulse from the Booster to be extracted to the Recycler Ring in the Main Injector tunnel and appropriately re-bunched. The existing 2.4-MHz RF system (slightly upgraded with the addition of an extra RF-cavity) will be used to decelerated the beam from 8 GeV to 1.8 GeV ($\eta\, factory$) or to 3.5 GeV ($\eta'\, factory$) and, finally, extracted to the AP50 experimental hall with a slow resonant extraction system. The detector will be located in AP50 where no other experiments are present for the foreseeable future. The technique is capable of delivering in excess of 10^{18} POT/yr with almost no impact to the existing experimental program (the pulse extracted for REDTOP is currently dumped for beam stability reasons). A Expression of Intent of the Collaboration [EOIFNAL] was sent to Fermilab's PAC in Fall 2017. In spite of a good physics review, the PAC decided not to pursue the project at this time because of potential interference between the upgrade of the Recycler Ring (needed by REDTOP)and the running of the Mu2e experiment.

Several options for a scenario of REDTOP at CERN have been considered, the most realistic being that of extracting a 1.8/3.5 GeV beam to the PS which could then deliver it to the East Hall, where the detector could be located. Although no blocking issue have been identified, more machine studies would be required. The initial structure of the beam, with a relatively short top-off, could allow about 10^{17} POT/yr, an order of magnitude lower than at Fermilab. REDTOP would probably have to be installed in place of the CHARM facility.

In both scenarios, more studies are needed to complete a design of the beam delivery for REDTOP. We expect to receive support by the hosting laboratory for this activity once the experiment receive the go-ahead.

Physics and detector simulations: Numerous studies of the response of the detector to η and η' decays have been made. In collaboration with the Physics Beyond Colliders studies [PBC-studies], emphasis is being given to the Golden Channels, especially the ones for dark photons and ALPs. Currently, the following Geniehad models have been implemented: Incl++, Urqmd, PHSD, Gibuu, Exclusive η decays (via Gibuu LUT), Intranuke and two more are being planned (jas and LAQGSM). Clusterization, de-exicitation-evaporation of the secondary nuclear remnants are, also, taken into account with state of the art models (Abla++, Abla7, Gemini).

Detector R&D: We estimated that about two years of detector R&D are necessary to finalize the design of the detector. The effort will be mostly concentrated on the O-TPC, since a multi-year R&D has been in place for ADRIANO (T1015 Collaboration) and for the fiber tracker (LHCb Collaboration). A new prototype ADRIANO2 detector is currently under construction at Northern Illinois University and it is expected to run at the FTBF in 2019. The solenoid and the lead-glass required for the Čerenkov component of ADRIANO are readily available from INFN, while the fibers for Tracker and for the Scintillating component of ADRIANO are commercially available with short lead times. We do not expect surprises from the R&D on the O-TPC, since the detector is, ultimately, a gas-filled vessel surrounded by photo-sensors. The low cost, large area photo-detectors required for the O-TPC are becoming commercially available at Incom, and the production of few hundred units for REDTOP seems not to represent a problem for the company [INCOM]. Alternative photo-sensors are also being considered (SiPM's). The target systems does not present particular challenges, considering its dimensions and the low-power dissipated [TARGET].

Expected challanges: We do not expect major surprises regarding the design and the performance of the detector: ADRIANO2's R&D is currently funded by INFN and Northern Illinois University, and the construction of a prototype is well advanced. The Fiber Tracker requires no R&D. Activities on the O-TPC will start once appropriate funding is established.

The biggest concern we have at this time is potential radiation damage to the detector and/or electronics due to the high neutron flux expected in the areas near the beam pipe. Detailed simulation studies indicate that the most critical part of the apparatus is the region occupied by the plastic fibers of the tracker, were we expect an integrated absorbed dose of about 6 kGy during the full experiment. LHCb studies indicate that the light attenuation length in the fibers is reduced by about 70% after that level of irradiation, with a consequent loss of detector efficiency. However, major effects on the physics program are not expected, due to the much shorter length of the fibers in of REDTOP. Radiation damage of the SiPMs used for the O-TPC or in ADRIANO2 are also of concern due to high neutron flux, especially on the endcap regions closest to the beam pipe. The well documented effect of the yellowing of Pb-glass due to absorption of the radiation has almost no effect on REDTOP, given the small dimensoins of the tiles.

Another concern is the power to be dissipated by ∼600,000 pre-amplifiers embedded in the ADRIANO2 calorimeter. We conservatively estimate a power consumption of 2 mW/channel for the (slower) plastic tiles [Power-2mW] and of 7 mW for the (<100 psec fast) glass tiles [Power-7mW]. Overall, up to 2.7 kW of heat needs to be removed from the 9 m^3 of the ADRIANO2 volume. The Collaboration is addressing the issue and looking at efficient ways to remove the heat from the calorimeter.

VII. FUTURE PLANS

The Collaboration is actively working at the preparation of a full proposal, which will be presented to the SPSC immediately after the conclusion of the ESPP process (mid-2020).

[4th-concept] http://www.linearcollider.org/ILC/physics-detectors/Detectors/Detector-LOIs

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