The REDTOP Project

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ABSTRACT

The η/η' mesons are almost unique in the particle universe since they are Goldstone bosons, and the dynamics of their decays are strongly constrained. Because the η/η' have no charge, decays that violate conservation laws can occur without interfering with a corresponding current. The integrated eta meson samples collected in earlier experiments have been less than ~10^8 events, limiting considerably the search for such rare decays. The η' sample is even more scarce. A new experiment, REDTOP, is being proposed at the proton booster of Fermilab with the intent of collecting more than 10^{12} triggers/year for studies of rare η/η' decays. Such statistics are sufficient for investigating several symmetry violations and for searches for new particles beyond the Standard Model. The physics program, the accelerator systems and the detector for REDTOP are presented below.

Introduction

The *Rare Eta Decays with a TPC for Optical Photons* (**REDTOP**) experiment is a new Fermilab project in its proposal stage. It belongs to the High Intensity class of experiments. It would use a 1.9 GeV continuous proton beam impinging on a target composed by 10 foils of beryllium to produce about 10^{12} η mesons in one year of running. The detector will attempt to capture the decay products of the η mesons, in particular the ones that are either not expected or suppressed at the 10^{-11} level. The REDTOP detector is based on the detection of prompt Cherenkov light in order to be sensitive to leptons and fast pions only.

Physics program at REDTOP

η* meson**. Goldstone boson, therefore symmetry constrains its QCD dynamics. It is an eigenstate of the ***C, ***P***, ***CP*** and ***G*** operators. All its additive quantum numbers are zero. All the possible strong decays of the *η* meson are forbidden in lowest order by ***P*** and ***CP*** invariance, ***G***-parity conservation and isospin and charge symmetry invariance. Similarly, electromagnetic decays are forbidden in lowest order by ***C*** invariance and angular momentum conservation.

Consequently, the η is a very narrow state, helping considerably in the reconstruction of the final state since the invariant mass of the latter has to match the *η* mass; the contributions from higher-order processes are enhanced by a factor of ~100,000. Therefore *η* decays are mostly free of Standard Model backgrounds for new physics searches.

Among the physics processes that REDTOP intends to study are:

Symmetry violations
- CP Violation (Type I and Type II, via the polarization of the muons)
- CP and C Violation with Dalitz plot studies
- T Violation via the polarization of muons
- CPT Violation (with non-hermitian lagragians)
- Single and double lepton flavor violation

Searches for new particles and forces
- True muonium
- Dark photons
- Leptoquarks
- New scalar particles
- New baryonic forces

Further studies
- Proton radius anomaly
- High precision studies on physics BSM
- Nuclear and intermediate energy physics

The accelerator complex

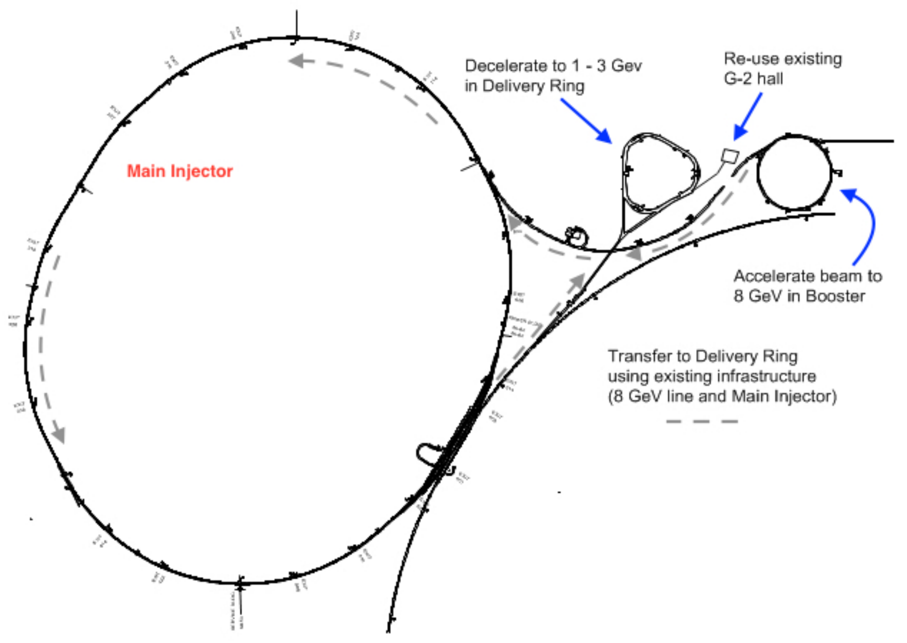

Figure 1. Beam from the Booster is sent through the Main Injector to the Delivery Ring at 8 GeV, before final deceleration to 2 GeV and subsequent slow spill.

Beam requirements for REDTOP
- Continuous Wave (CW) proton beam in the 1.9 – 4 GeV energy range,
- Average intensity: 10^{11} protons/sec,
- *η* production rate: 2×10^5 *η*/sec (or 2×10^{12} *η*/year).

Target systems. Ten round foils of beryllium, each about 1/3 mm thick and 1 cm diameter.

The detector

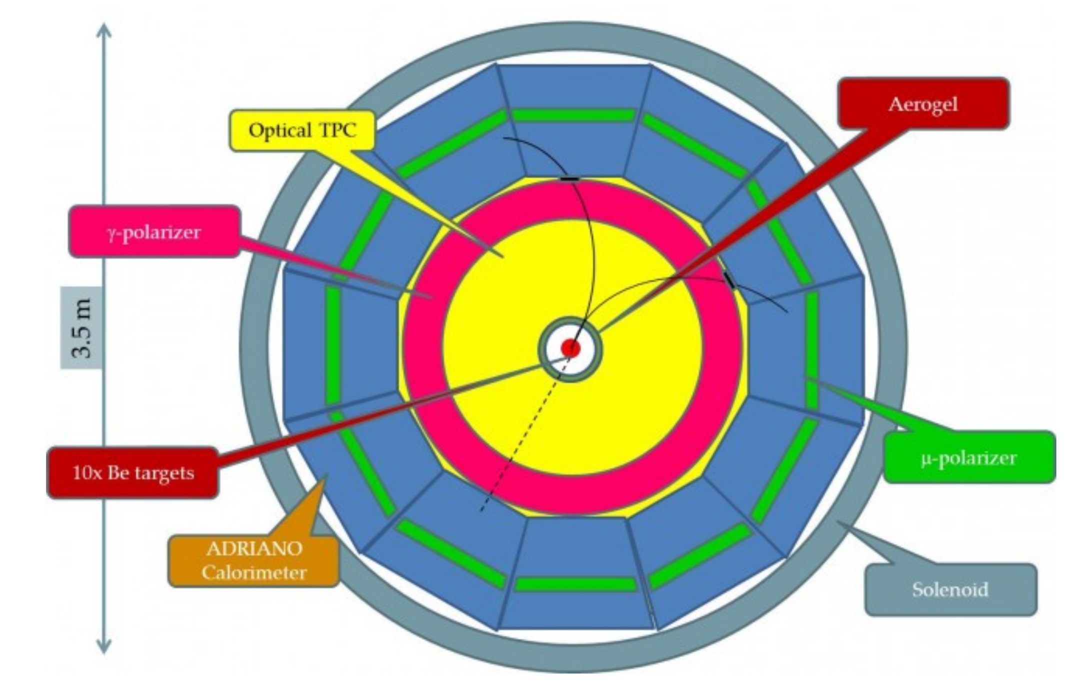

Figure 2. Schematics of the REDTOP detector.

The Optical TPC. The OTPC works on the same principles as a conventional TPC, but it uses the Cherenkov effect to detect the particles. Two Cherenkov radiators are present in the OTPC: A double aerogel cylinder, about 3 cm thick at the inner wall and low-pressure nitrogen gas filling the rest of the volume of the OTPC. Tracks are reconstructed by the photons emitted in the radiators. The momentum is determined with the help of a solenoidal magnetic field.

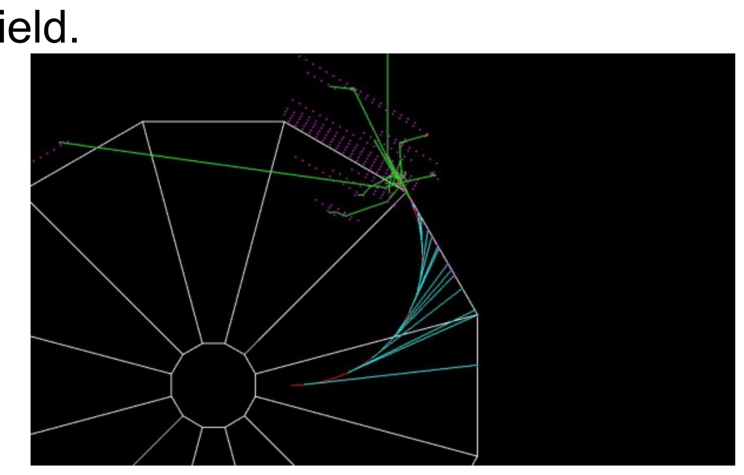

Figure 3. Representation of a 100 MeV electron (red track) traveling trough the gas in a 0.6 T magnetic field. Several Cherenkov photons (cyan tracks) are generated and detected by the optical sensors surrounding the gas.

The ADRIANO Dual-Readout Calorimeter. One version of the dual-readout calorimetric technique is named ADRIANO (A Dual-Readout Integrally Active Non-segmented Option). It is based on the two simultaneous measurements of the energy deposited by a hadronic or electromagnetic shower into two media with different properties. It will detect the photons generated from the *η*/*η'* decay while the large background from most hadrons entering the detector could be easily rejected. Particle identification is achieved by comparing the lights produced by the scintillation and the Cherenkov processes in two separated optical media.

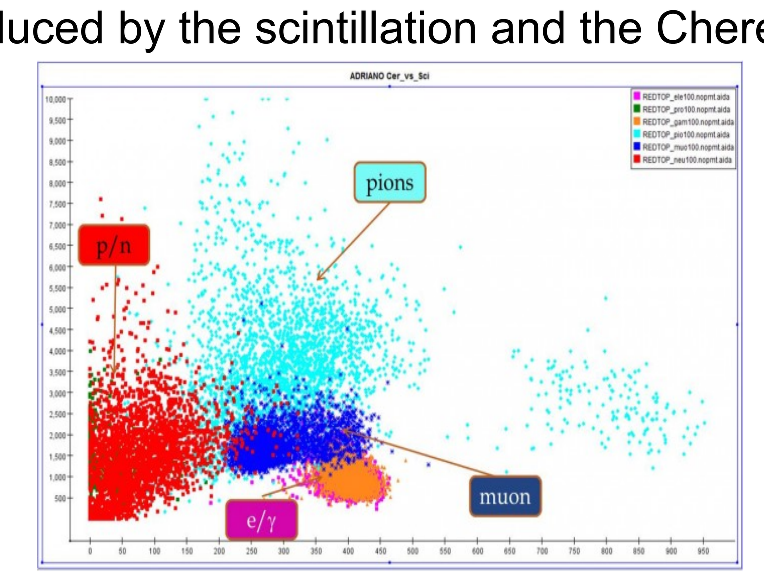

Figure 4. Particle identification from the comparison between the scintillation vs. Cherenkov signals in the ADRIANO calorimeter for simulated particles with E_{kin} = 100 MeV

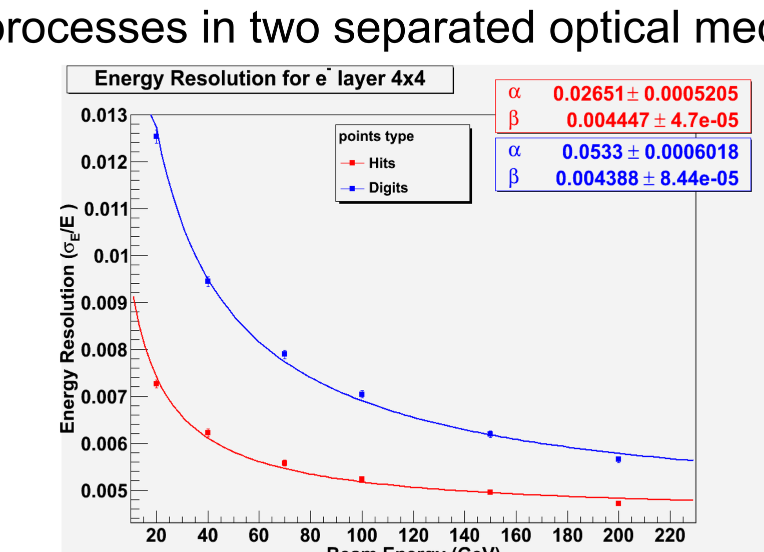

Figure 5. Energy resolution simulated with Ilcroot.

The Muon and Photon Polarimeter. They are made from an array of plastic scintillators inserted between the inner and the outer shells of ADRIANO calorimeter and a 5 mm thick scintillating plate inserted inside the volume of the OTPC respectively. They will count the number of electrons and positrons emitted when a muon is stopped inside the ADRIANO calorimeter or when a photon is converted into an e^+e^- pair. The asymmetry in the counting provides an estimate of the polarization of the decaying particle.

Expectations and Conclusions

The *η*/*η'* mesons are an excellent laboratory for searching for physics beyond the Standard Model, provided that an experiment could be designed to produce in excess of 10^{12} such particles. REDTOP is being designed to do exactly this, with a novel detector technique which is highly sensitive to processes from new physics, but mostly insensitive to background from old physics.