Invariant mass reconstruction of the η meson in the decay channel $\pi^+\pi^-\pi^0$ with the REDTOP experiment

Sofía Escobar Martínez[1,2], Isabel Pedraza Morales[2], Brenda Fabela Enríquez[2,3] on behalf of the REDTOP collaboration[*]

[1] Universidad Nacional Autónoma de Honduras, [2]Benemérita Universidad Autónoma de Puebla, [3] Universidad Autónoma de Zacatecas

Abstract: REDTOP is a novel experiment being proposed at the Delivery Ring of Fermilab with the intent of producing more than 10^{13} η mesons per year in order to detect possible rare η decays which can be a clear evidence of the existence of Physics Beyond the Standard Model. Such statistics are sufficient for investigating several discrete symmetry violations, searching for new particles and interactions and precision studies. One of the golden processes to study is the $\eta \rightarrow \pi^+\pi^-\pi^0$ decay, where π^0 decays promptly into two photons. In the context of the Standard Model, the dynamics of the charged pions is symmetric in this process, implying that any mirror-asymmetry in the Dalitz plot would be an irrefutable indication of C and CP violation. We present the study on the performance of the REDTOP detector by reconstructing the invariant mass of the final state $\pi^+\pi^-$ $\gamma\gamma$ using Monte Carlo samples.

Introduction

The *Rare Eta Decays with a TPC for Optical Photons* (**REDTOP**) experiment is a new Fermilab project in its proposal stage. It intends to produce about 10^{13} η mesons in one year of running. One of the processes to study is the $\eta \rightarrow \pi^+\pi^-\pi^0$ decay channel in order to test CP and C invariance using Dalitz plot analysis. Since this technique is based on the reconstruction of the invariant mass of the particles in the final state, it is important to study on the performance of the detector. The study is based on the smearing of the energy response of the calorimeter.

$\eta \rightarrow \pi^+\pi^-\pi^0$ process

- The three body decays into pseudoscalar mesons constitute the majority of all η decays ($\eta \rightarrow \pi\pi\pi$) [1].
- The $\eta \rightarrow 3\pi$ decays do not conserve isospin and the partial widths are similar to the second order electromagnetic processes. However, the contributions from electromagnetic processes are apparently suppressed and the decays are driven by an isospin violating term of the QCD Lagrangian proportional to m_d - m_u.
- This process is an ideal laboratory for testing chiral perturbation theroy (ChPT) as well as the *CP* and *C* invariance [2].
- For the latter, the dynamics of the charged pions are totally symmetric in the context of the Standard Model. Consequently, the Dalitz plot of that decay should show no signs of asymmetries. Any mirror-asymmetry in the Dalitz plot would be an indication of *CP and C* violation [3].

Invariant mass reconstruction of the η meson

The $\eta \rightarrow \pi^+\pi^-\pi^0 \rightarrow \pi^+\pi^-\gamma\gamma$ decay is generated with GenieHad and is processed in the REDTOP experimental configuration using Geant4. The corresponding process is:

$$p + Be \rightarrow \eta \, X \text{ with } \eta \rightarrow \pi^+\pi^-\pi^0$$

where the proton beam energy is of 1800 MeV and the URQMD scattering model is used. In total, 4390 events were processed. Using the Monte Carlo truth, the π^0 is reconstructed by summing up pairs of photons; likewise the η is reconstructed summing the π^+ $\pi^-\pi^0$ 4-vectors and its invariant mass is calculated. To test the performance of the REDTOP detector, a smearing in the energy resolution of the ADRIANO calorimeter is done, using values obtained from simulations for the hadronic resolution. which is given by:

$$\sigma_E \, / \, E = \alpha \, / \sqrt{E} \oplus \beta$$

After obtaining the invariant mass distribution, a Gaussian fit is done and the values of the η mass and the σ is calculated using the Java Analysis Studio 3 framework. In this poster, we show the changes on the invariant mass of the η meson when the α and β parameters are varied.

The REDTOP experiment

Figure 1. Schematics of the REDTOP detector.

- **REDTOP** is a fixed target experiment which will use a continuous proton beam of 1.8 GeV [4].

- η meson production via the hadronic production from inelastic scattering of protons in beryllium targets composed of ten round foils of about ⅓ mm thick each.
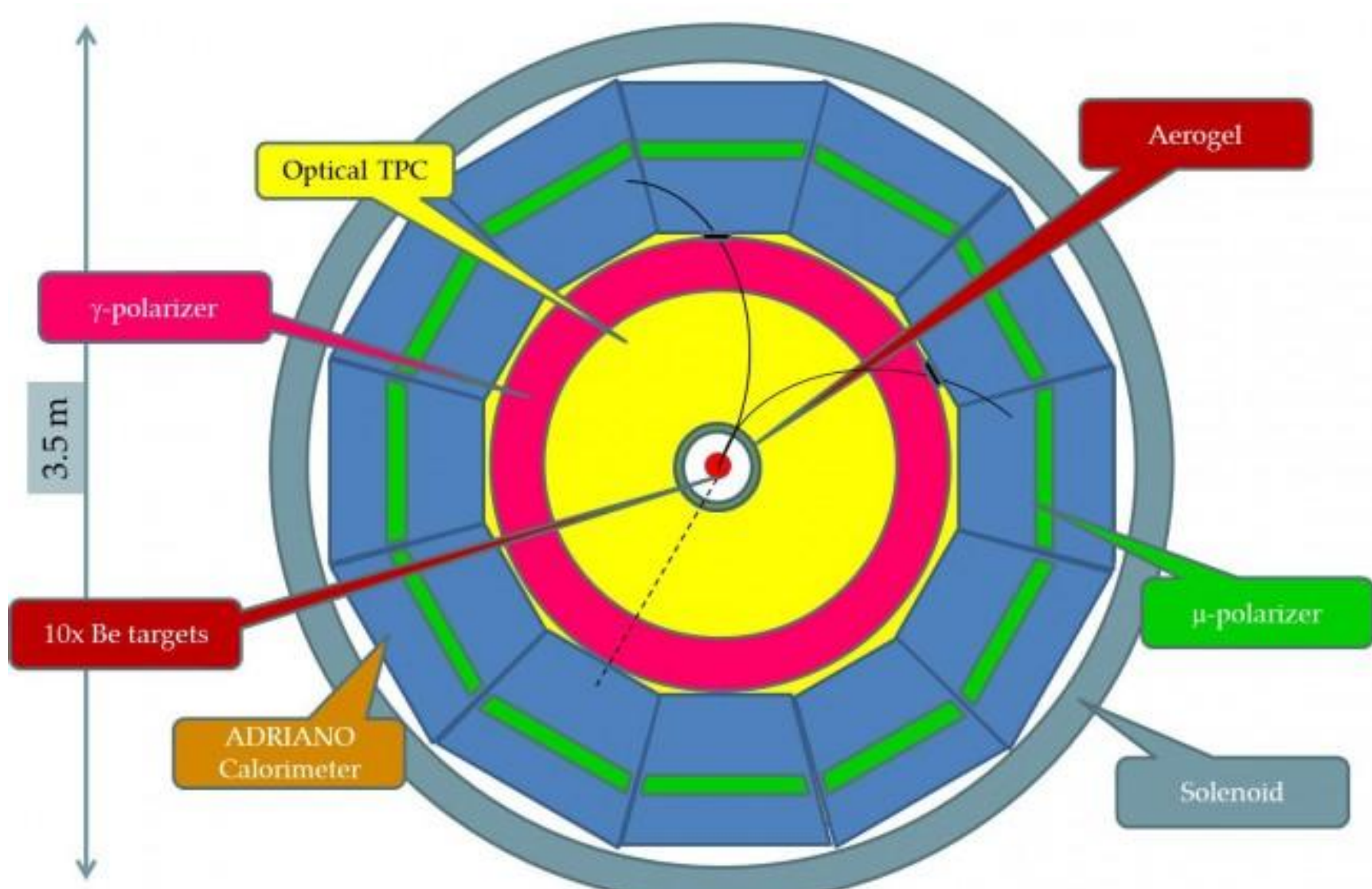
- It has a 3.5 m diameter detector consisting of:
  - The **Optical TPC**: it will measure the momentum and position in space by using a deflecting solenoidal field of 0.6 T. The OTPC is based on the Cerenkov effect instead of the gas ionization as a conventional TPC.
  - The **ADRIANO Calorimeter**: it is a dual readout calorimeter, based on the two simultaneous measurements of energy deposited by a hadronic or electromagnetic shower into two media with different properties.
  - The **Muon and Photon (optional) Polarimeters** are made from an array of plastic scintillators that count the number of electron and positrons emitted when a muon is stopped inside the calorimeter or when a photon is converted into a e⁺e⁻ pair. The difference in the counting performed inside the solenoidal magnetic field will provide an estimate of the polarization of the particle.
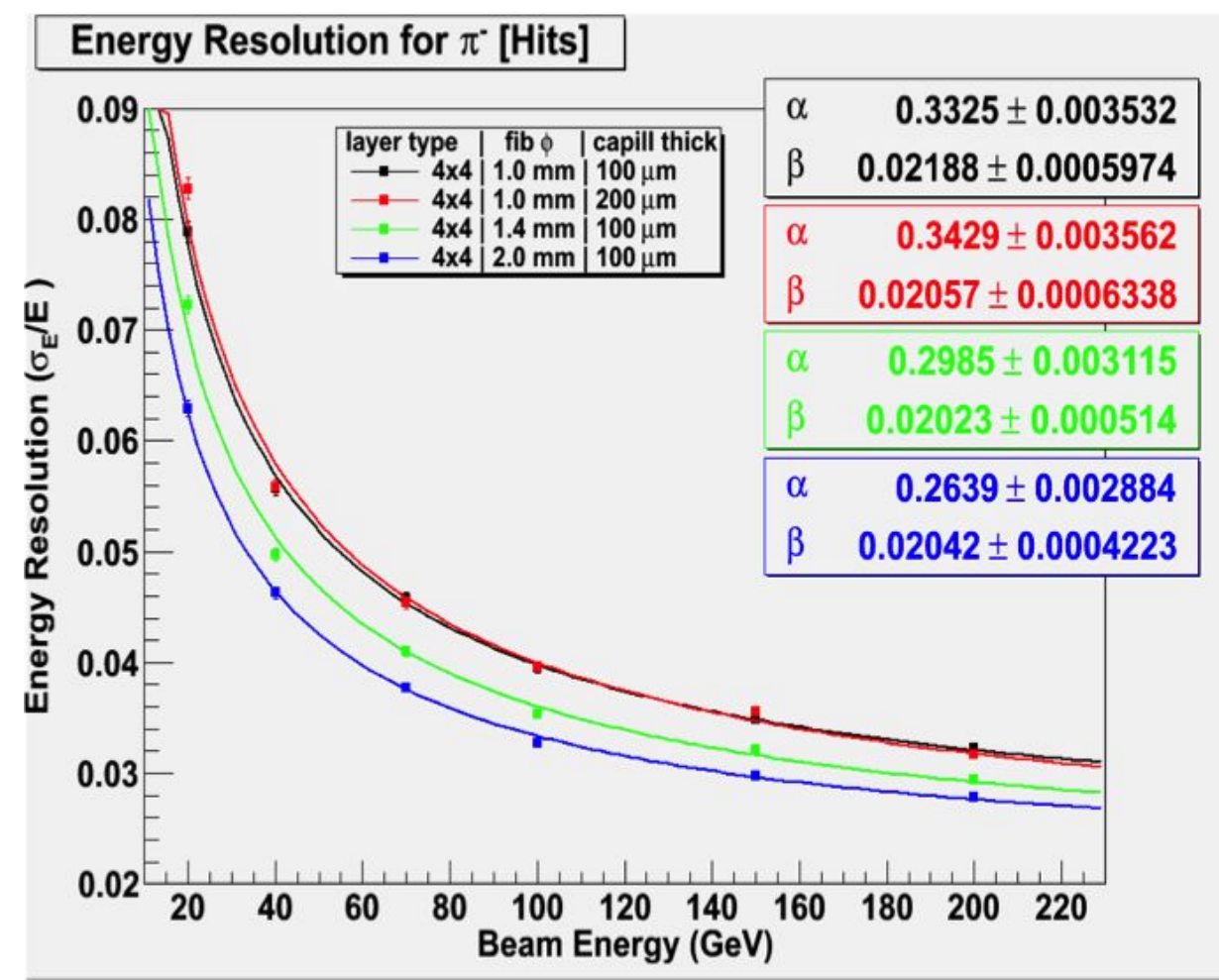
Results

Figure 2. Hadronic resolution of the ADRIANO calorimeter in dual readout mode [5].

α (GeV$^{1/2}$)	β	m(η) (GeV)	$\sigma_{m(\eta)}$ (GeV)	$\sigma_{m(\eta)}$/m(η) (%)
0.050	0.030	0.556 ± 0.003	0.028 ± 0.005	4.99 ± 0.932
0.100	0.000	0.560 ± 0.005	0.044 ± 0.008	7.83 ± 1.44
0.150	0.000	0.574 ± 0.006	0.057 ± 0.006	9.93 ± 1.00
0.191	0.04	0.579 ± 0.009	0.081 ± 0.012	14.0 ± 1.92
0.264	0.020	0.580 ± 0.013	0.117 ± 0.014	20.2 ± 1.96
0.298	0.020	0.590 ± 0.014	0.126 ± 0.014	21.4 ± 1.82
0.333	0.022	0.572 ± 0.028	0.179 ± 0.031	31.3 ± 3.90
0.343	0.021	0.564 ± 0.033	0.194 ± 0.038	34.4 ± 4.72

Table 1. Values of the invariant mass of the η meson and its resolution for each value of the energy resolution for the calorimeter considered.
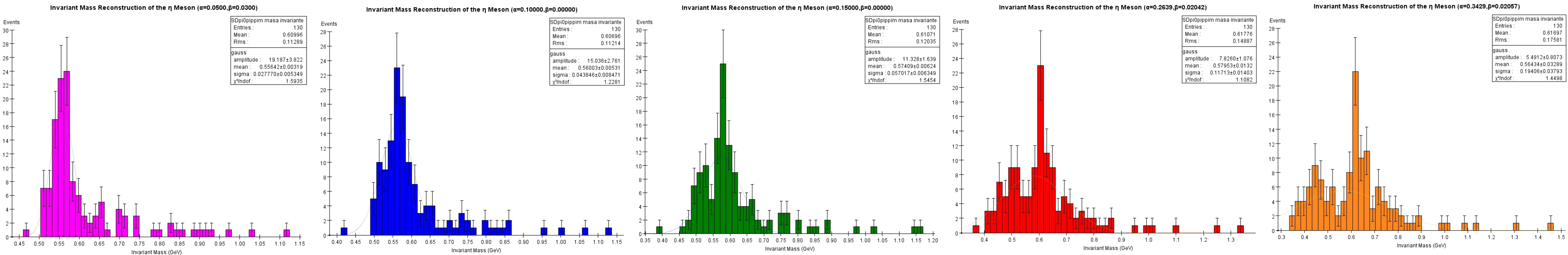

Figure 3. Reconstructed invariant mass distributions for the η meson.

Conclusions and future work

- The invariant mass of the η meson was reconstructed, smearing on the energy resolution of the ADRIANO calorimeter and it agrees with the expected value m(η) = 547.862 ± 0.017 MeV [6].
- The best energy is achieved for values of α < 0.15.
- Only signal samples were considered.
- For the future it is planned to use more statistics to refine and confirm the results presented here and to smear on the size of the calorimeter cells and the parameters of the particle trajectories in the OTPC.

References

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