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Search for cavities in the Teotihuacan Pyramid of the Sun using cosmic muons: preliminary results

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Over the last three years the Pyramid of the Sun, at Teotihuacan, Mexico, has been searched for possible hidden chambers by means of muon attenuation measurements inside the monument's volume. The experimental method is based on the use of a muon tracker which is placed in a tunnel, running below the base and ending close to the symmetry axis of the pyramid. The accumulated experimental data, when compared to physics simulations using GEANT4, already show identifiable known features of the external shape of the pyramid. Experimental results of the relative density distribution inside the pyramid are presented.

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1. Introduction

Teotihuacan, located some 40 Km north of Mexico City, is one of the most emblematic archaeological sites in Mexico. With an estimated population of 150,000, twenty centuries ago this city must have ranked among the largest world-wide. Yet, little is known about this extraordinary civilization because of the lack a written language. In particular, the motivation to build there one of the largest pre-Hispanic monuments in Mesoamerica, remains a mystery. Was it meant to be a mausoleum? or just a ceremonial monument? Excavation of tunnels, by M. Gamio and E. Noguera, in the lowest body, and by S. Smith on its 5th body, showed this pyramid to be built of soil, while the investigated volume (1 % of its 1 million tons) showed no significant internal structure The existence of a pre-Colombian, man-made tunnel running 8 m below the floor level, roughly centred along the pyramid's base and reaching near its symmetry axis, allowed us to reproduce the classical experiment by Alvarez et al. [1] who searched for cavities in Chephren, one of the famous Egyptian pyramids. The project, and its first results, have been reported elsewhere [2, 3, 4]. Here we present a preliminary report, based on 3 years of data taking, aided by comparisons with GEANT4 [5] Monte Carlo simulations to reveal emerging interesting aspects of the data.

2. Pyramid description

When compared to an Egyptian pyramid, the Mexican monument (see Fig. 1) is characterized by having a flatter aspect ratio, half the heigh but, roughly, a similar size square base as Chephren. More important, it differs by having a 5-level external corridor structure, irregularly distributed in height. The Pyramid of the Sun also has a well defined front-face, having an extra pyramid body in its lower part, as well as (less pronounced) external climbing-stairs. As already mentioned, the Mexican pyramid also has a system of man-made tunnels. Our detector is installed in a 4-leafed clover-shaped cave, located some 36 m west of the (vertical) symmetry axis of the pyramid, at the end of the pre Hispanic tunnel. Because of the displacement from the symmetry axis, only the 5th-body tunnel lies within the field of view of our detector, in its vertical orientation. Thus, besides the pyramidÂt's top, the more noticeable external structures within the detector's observation solid angle are the upper-most 4 corridors.

3. Experimental setup

As described in [3] and shown in Fig. 2, our instrumental array consists of four 1m x 1m scintillators used to generate the muon trigger, and six Multiwire Preoportiona Chambers (WMPC), also having 1m x 1m sensitive area, for muon-tracking purposes. The measured singles sintillator counter efficiency range between 80-90%. They are arranged by pairs to form two planes, separated 75 cm apart. To enlarge the trigger solid angle, these planes are located as follows: one at the bottom of the detection system, and one below the top-most two MWPC's. The scintillators in each plane are operated in a logic OR mode. This way, the individual scintillator efficiencies, ranging between 70% and 90%, results in a 94%-97% efficiency for each plane. A logic AND between the two scintillator planes constitute the trigger, yielding a mean 92% efficiency. The efficiency of each MWPC's is measured using the trigger. This method requires a geometrical correction

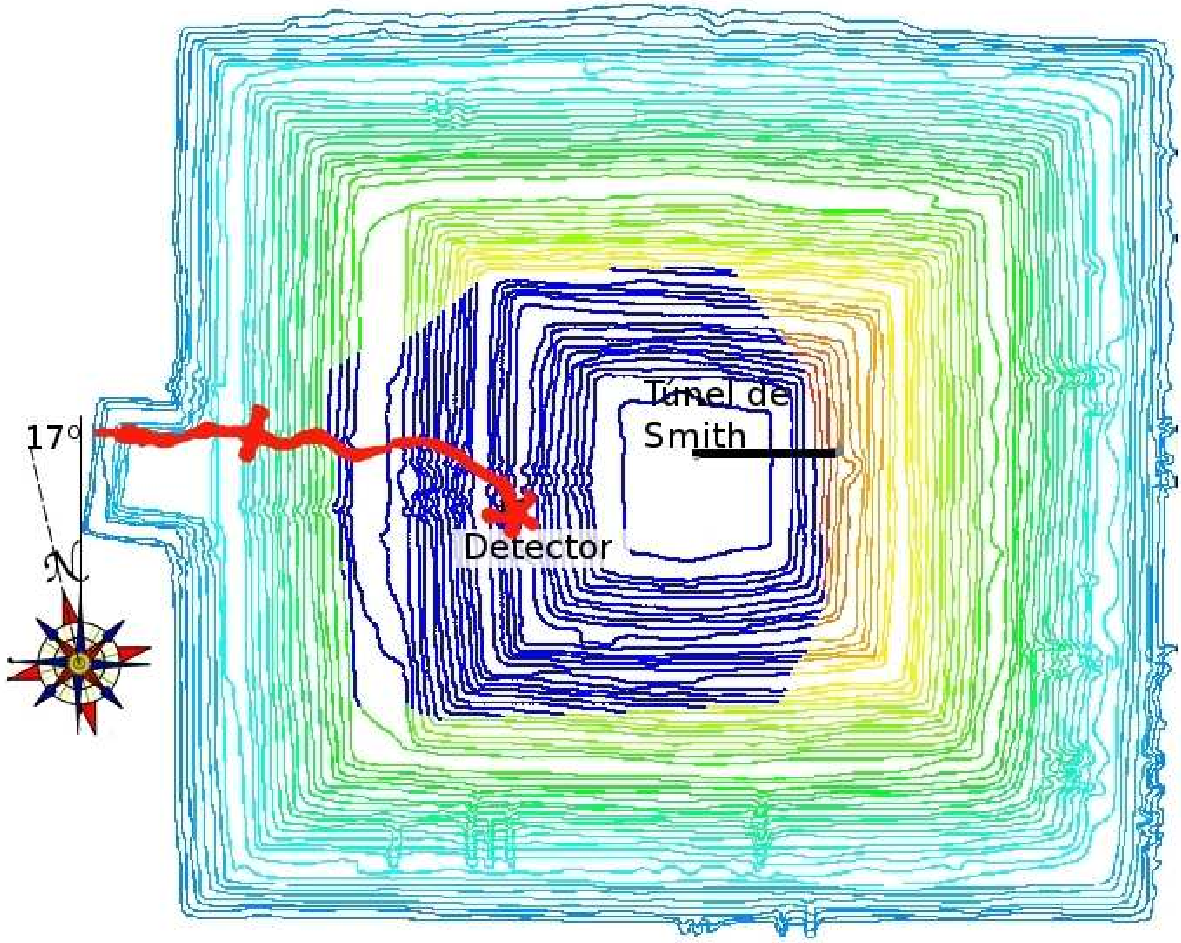

Figure 1: Pyramid of the Sun external shape. Outlined in dark blue is the projected detector field of view. The prehispanic tunnel location is shown in red.

for the two top-most MWPC's.The resulting full 3-point track reconstruction efficiency turned out to be below 10%. Data taking has also been impacted by external factors, such as data-network connectivity and electric-power failures, as well as MWPC gas-mix quality fluctuations, which at times introduced up to a 50% efficiency reduction. In spite of all this, the trigger rate has been sufficiently stable during the data-taking time. An approximatly 20 % contribution from accidentals has been estimated using the time-of-flight (TOF) spectrum between two scintillator planes within a 80ns time window. So the estimated count rate is about 2.7 $\pm$0.05 Hz, which is close to the Monte-Carlo simulation predictions of 2.62, reflecting that the detector position, pyramid average-thickness and average density used in the simulations are consistent with the observation. The muon-track coordinate corresponding to each chamber has been estimated by means of a Flash ADC (FADC) signal shape analysis technique[6]. The tracks have been reconstructed using three chambers for each coordinate. More details about the track reconstruction, coordinate and angular resolutions can be found in [3].

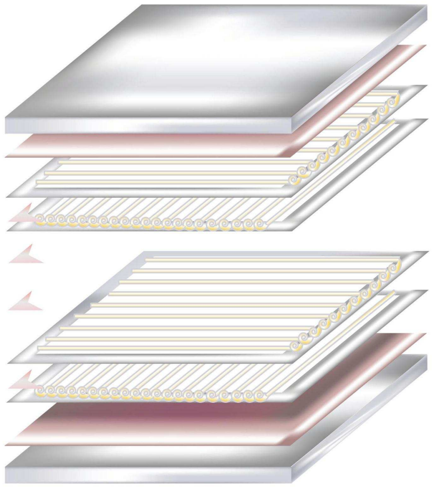

Figure 2: Schematic representation of the detector system. The top and bottom gray-shaded boxes represent the scintillators. The mid volume is occupied by 6 MWPC (although only 4 are shown, to allow an inside view), having their wires on alternating, mutually perpendicular, positions

4. MC-simulation

Muon transport through the detector, as well as through the body of pyramid, has been simulated using the GEANT4 Monte Carlo package [4]. This allowed us to estimate both, the detector geometrical efficiencies, as well as the expected muon-flow distribution inside the pyramids cave, where the detector is located. Details about the pyramid geometry construction, precision, and detector position may be found in [3, 8]. The simulation indicates that only muons having > 200MeV kinetic energies can cross the detector's volume. Above that threshold, the detector geometrical efficiency has been estimated assuming a (muon) power-law spectrum. As reported in [4], using first momentum distributions, the topology of the data already shows the expected anti-correlation with the detector-pyramid-surface distance distribution. That is: more matter implies reduced count rates, and vice versa.

5. Simulation vs data

Simulation predictions for the muon rates, corrected by the detector geometrical efficiency, have also been generated and subtracted from the data equating the statistics, in order to search for significant differences. As example of the results obtained, Fig. 3 shows one such comparison based on published[3] data. In it, corresponding to 10 % of the data, the bin by bin difference of these distributions is presented in significance units, defined as bin difference divided by the error of that difference. Here one can appreciate a clear top-bottom asymmetry suggesting that within the detector acceptance, the Pyramid of the Sun seems to be significantly less dense on its south side (corresponding to the bottom part of Fig. 3) than on its north side (top of Fig. 3). The current analysis (not shown) which now includes 60 % of the data indicates that the density difference is $\approx 20\%$.

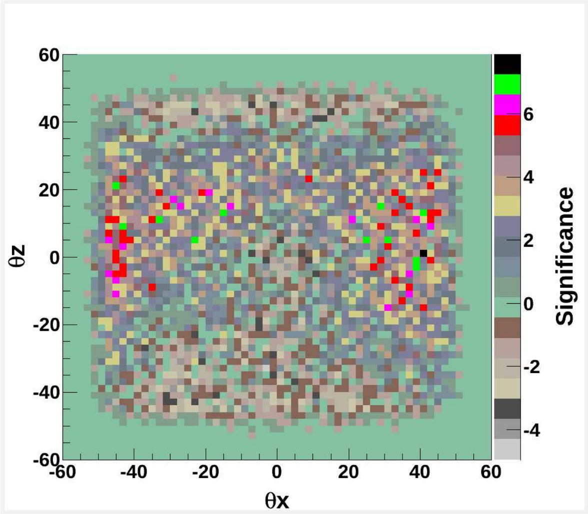

Figure 3: Significance of a preliminary Data-Simulation difference distributions.

6. Conclusions

Progress in the muon attenuation experiment carried out at the Pyramid of the Sun, in Teotihuacan, Mexico, is reported, including experimental and simulation details. After three years-worth of data the experiment-simulation comparisons show an intriguing north-south density asymmetry. The complete data analysis, together with plausible interpretations shall be presented in a later publication.

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