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ELEMENTARY PARTICLES AND FIELDS
Experiment

TRASGOS: Towards a New Standard for the Regular Measurement of Cosmic Rays

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Abstract—A new family of high accuracy multitracking detectors called TRASGOs, sensitive to both electrons and muons is proposed for multidisciplinary cosmic ray research. The corresponding tools for monitoring, tracking, event reconstruction and analysis are being developed. The present status of the project is presented and discussed.

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1. INTRODUCTION

Cosmic rays are mainly high energy protons and heavier atomic nuclei coming from the Sun and the outer space. When they hit the atmosphere they produce up to several billions of secondary particles, many of which could arrive at the Earth's surface where they can be detected and measured. The regular analysis of the cosmic rays either in satellites, balloons, on the ground or underground detectors provides us information about the composition and dynamics of the Universe, the solar activity and the Earth magnetic field, among other fields [1]. The energies of primary cosmic rays producing secondary particles reaching the Earth surface range between a few GeV up to more than 10^{11} GeV. The flux of primary cosmic rays decreases dramatically with the energy; for the highest-energy cosmic rays a flux of around one event per century and per square km is expected. Figure 1 summarizes most of the phenomena that influence the rate of secondary cosmic ray measured by ground detectors. It also shows some of the main techniques used for the regular measurement of cosmic rays as a function of the energy of the primary.

All the shown techniques have their own advantages. Neutron monitors are very efficient in the low energy region but they are bulky and only provide integrated fluxes. In order to get estimations of the arrival direction of the primary cosmic rays, a large amount of detectors is needed, covering different geomagnetic latitudes and offering different asymptotic direction cones [2]. Muon telescopes have a higher energy threshold but they are conveniently and highly directional allowing, for instance, a better forecasting of magnetic storms. Many muon detectors are also deployed around the world but they differ in design and only a some of them function as a real network [3]. However, muon telescopes are very sensitive to the temperature profile of the atmosphere on top of the detector which can not be measured in real time. Water Cherenkov Detectors are very useful because they are able to detect charged particles over a big volume at a low cost but they are not sensitive to the arrival directions. There exists an interesting initiative in Latinamerica for the creation of a network of such detectors for the regular study of cosmic rays over the whole continent [4].

As a complement to the above-mentioned techniques, the TRASGO Project aims to offer high resolution detectors with multi-tracking capability and, as a consequence, able to detect both single secondary cosmic particles as well as bundles of particles belonging to the same shower. Presently, three TRASGO detectors are already operational and two more are under construction.

2. THE TRASGO PROJECT

TRASGO is the acronym of TRAck reconStructinG bOx and all the operative detectors of the family take advantage of the stimulating performances offered by the tRPC (timing Resistive Plate Chamber) technology [5]. TRASGOs offer tracking capability, a high granularity, an outstanding time resolution (~0.3 ns) and the possibility of making particle identification between electron and muons using software algorithms. Most of these features will allow to

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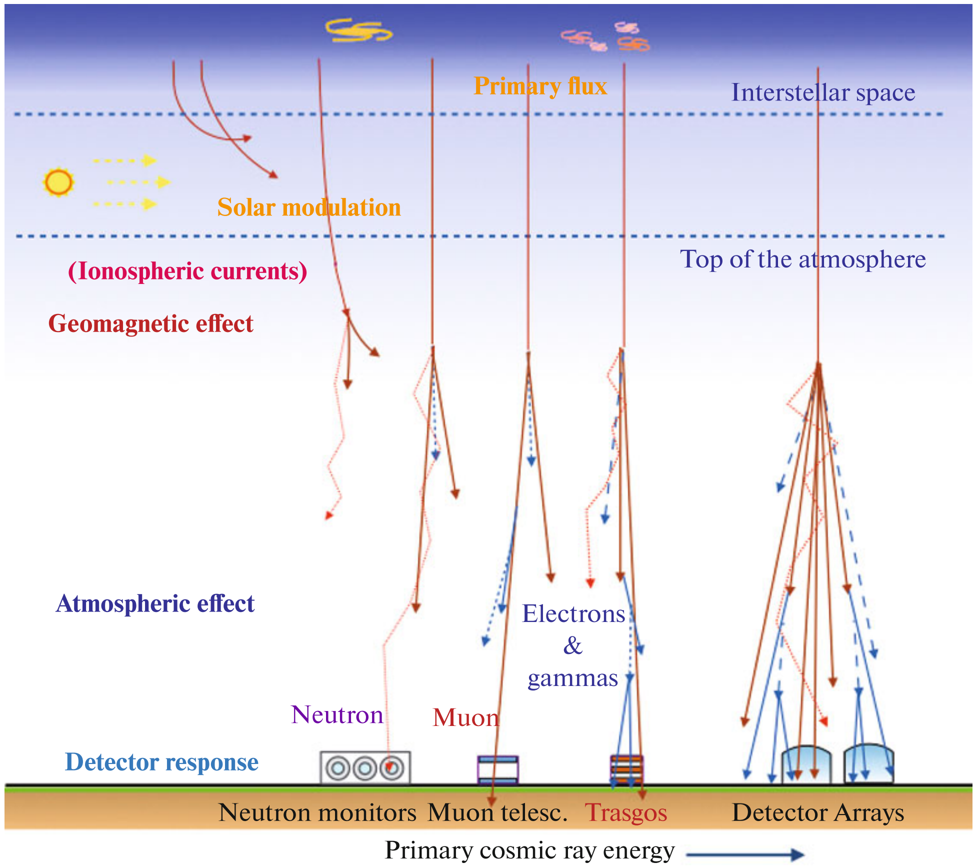

Fig. 1. (Color online) Cosmic rays. Main effects modulating the rate and distributions of cosmic rays measured at the Earth's surface with a few of their detection techniques. TRASGOs are sensitive to both muons and electrons.

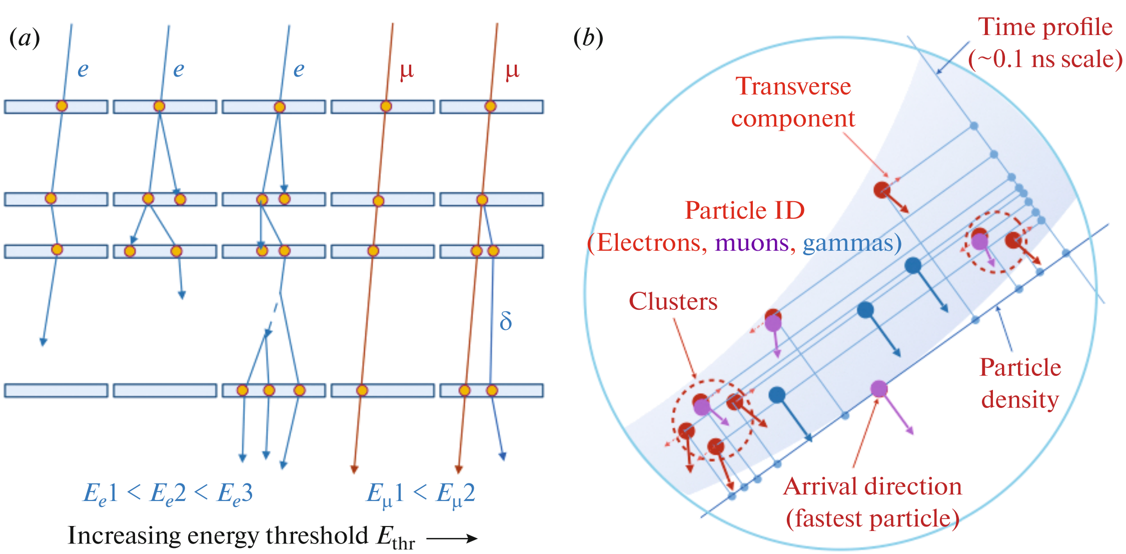

Fig. 2. (Color online) (*a*) Examples of particle identification abilities of a TRASGO detector. Electrons of higher energies might produce showers of higher multiplicities and large ranges. High energy muons might pool of delta electrons producing small and narrow showers. (*b*) Examples of cosmic ray signatures directly available to TRASGO detectors.

regularly access the cosmic ray information that are usually absent from other detectors. For instance, as a higher track multiplicity requires a primary cosmic ray with a higher energy, events with different densities of particles would correspond to arrival primaries with different energy thresholds; see Fig. 2.

The TRASGO family uses a novel concept on the construction of RPCs, the Sealed Glass Stack

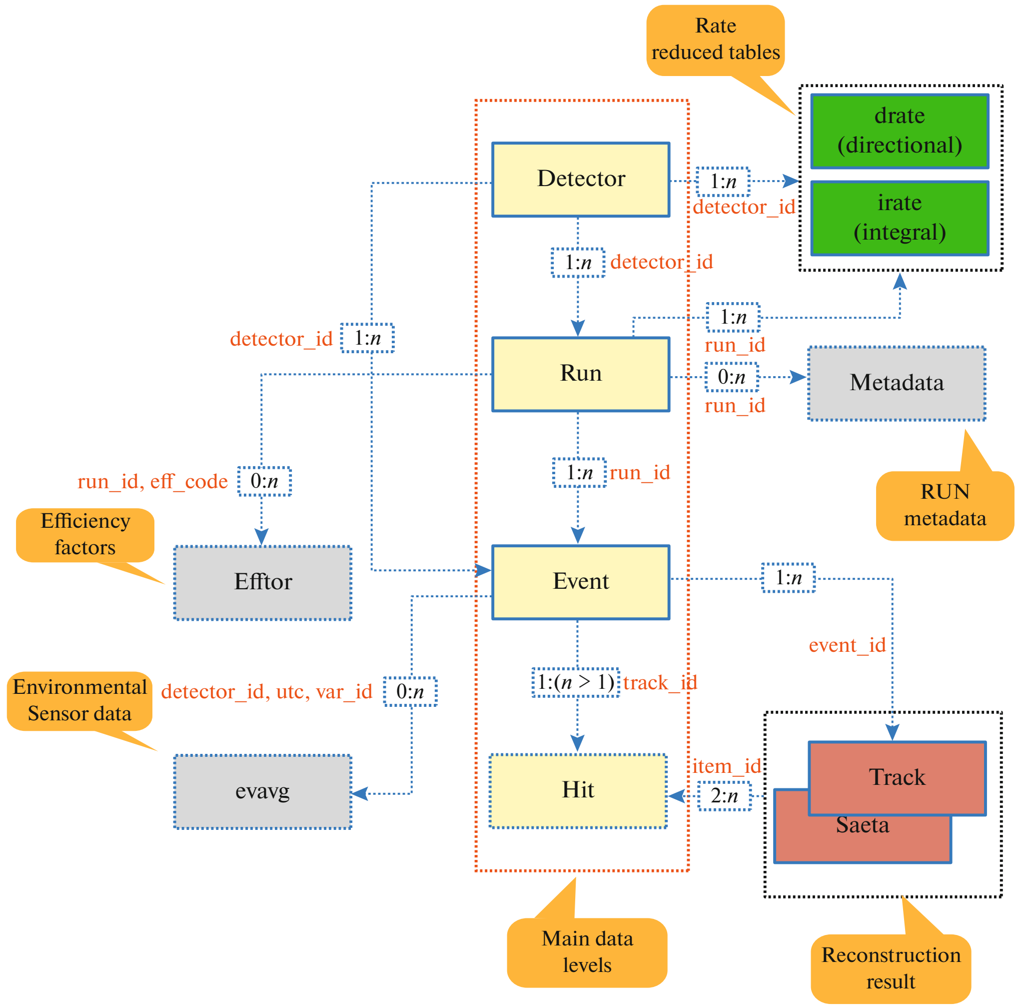

Fig. 3. (Color online) ERD (Entity relationship diagram) diagram, showing the relationship between all the data involved in the reconstruction of the events and in their storage for a fast and efficient retrieval.

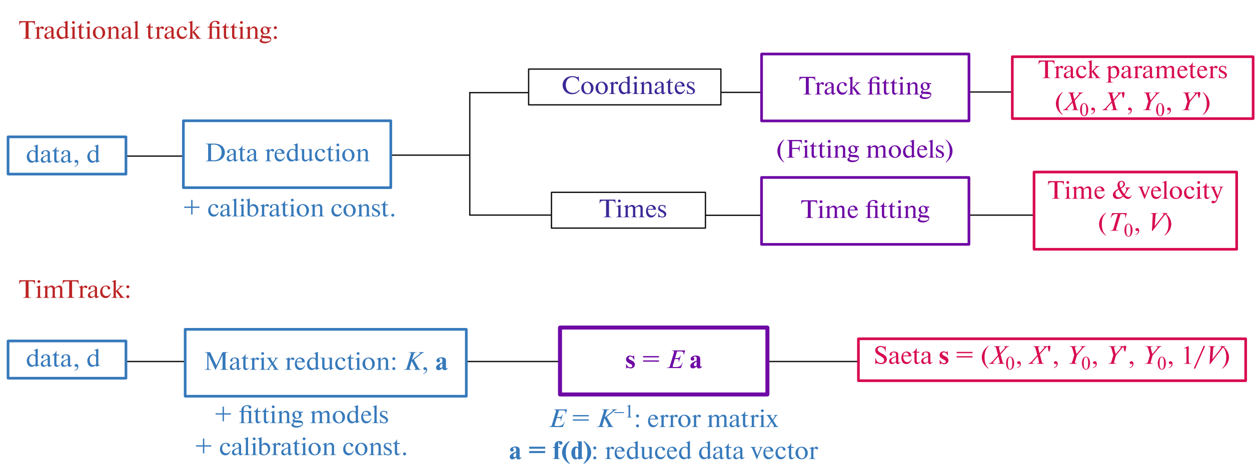

Fig. 4. (Color online) Comparison between a typical reconstructing method and the TimTrack formalism. TimTrack uses a powerful matrix formalism, needing any data reduction and might deal with calibration parameters in the same way as with the fitting parameters.

(SGS) [6] and [7]. With this approach, two delicate aspects of an RPC, the gas volume and the High Voltage (HV) insulation, are confined inside a permanent sealed plastic box, decoupling it from the rest of the device, namely, the pick up electrodes, located on top and bottom of the SGS. The main advantages of

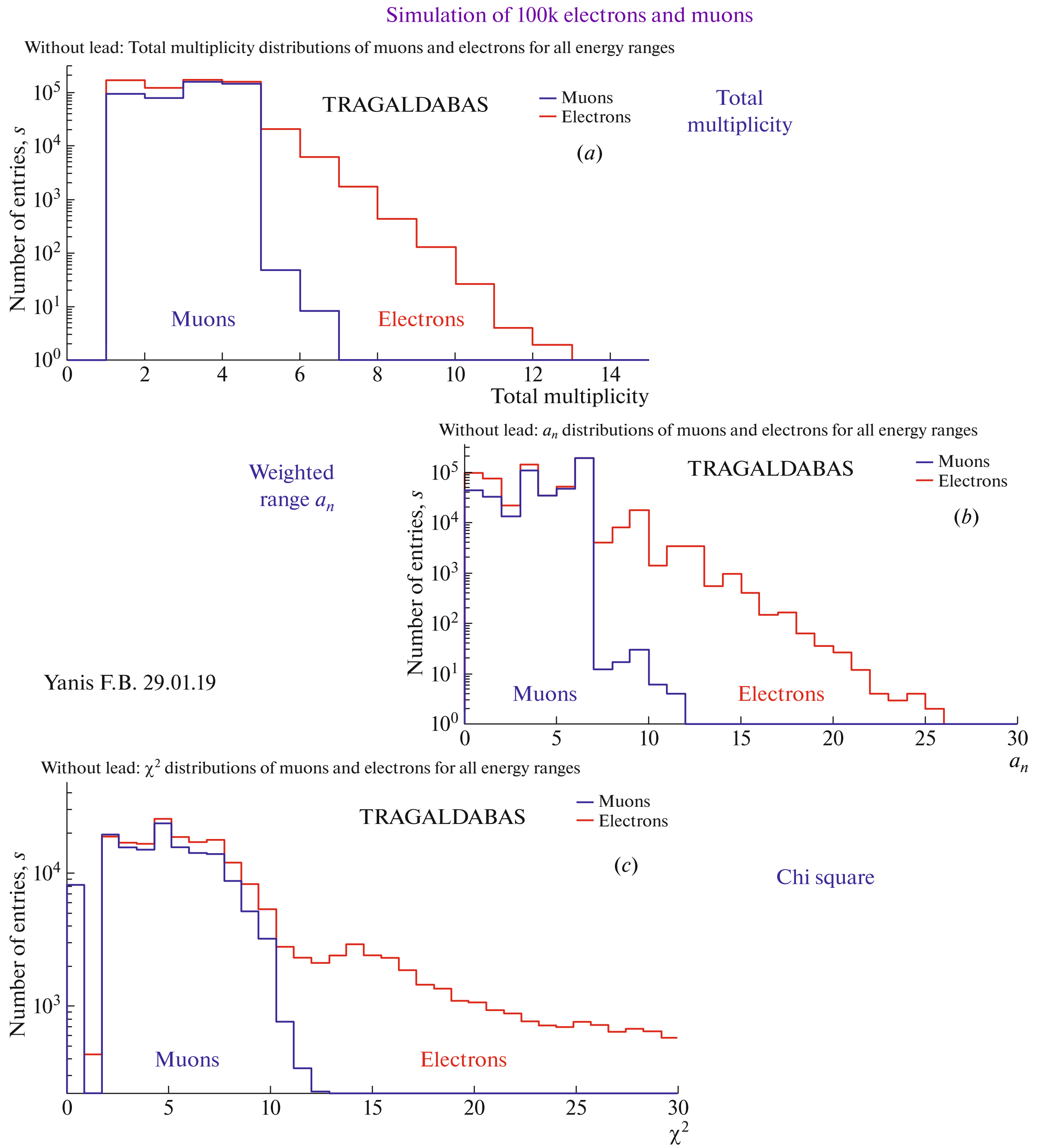

Fig. 5. (Color online) MIDAS. Distribution of several variables analized with a realistic simulation of muons and electrons in the kinetic energy range (10, 5600) MeV: (*a*) the total multiplicity of hits in the detector, (*b*) a weighted range a_n of the shower that takes into account both the number of hits and their distribution in the planes, (*c*) the χ^2 distributions of straight lines fitting.

the SGS are: versatility, the same SGS construction can be coupled to different readout electrodes; easiness of construction, can be constructed easily and at low cost in the scale of 1 to 2 m^2 and the complete gas tightness of the plastic box allows a low gas flux operation.

A very important baseline of the project is that all TRASGOs, independently of their particular design or purpose, share most of the operating tools (acquisition, monitoring, tracking, analysis, etc.) in order that any new development performed for any of the devices can be easily implemented to the other devices of the family. Handling large data volumes in the future is a challenge, so, a big effort is being done in

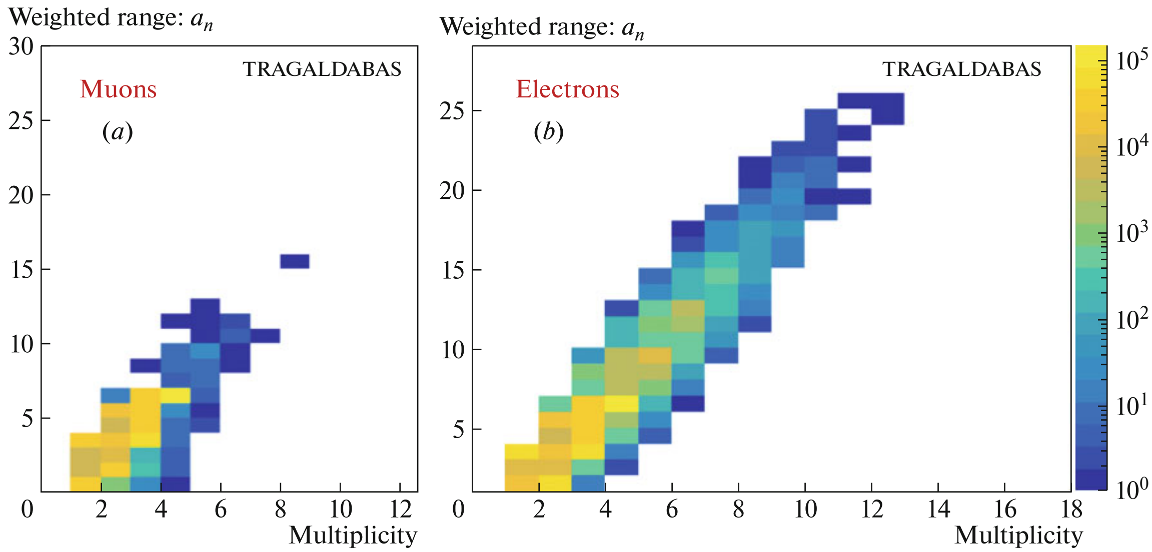

Fig. 6. (Color online) MIDAS. Weighted range a_n as a function of total hit multiplicity of the same event over the full detector, for (a) muons and (b) electrons.

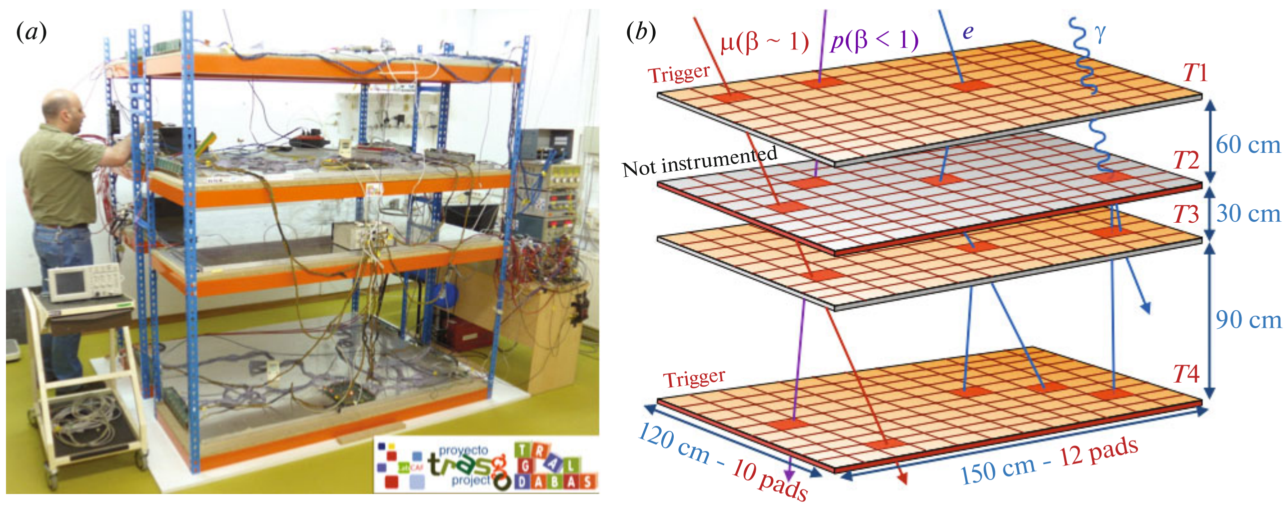

Fig. 7. (Color online) (a) The TRASGO TRAGALDABAS, at the Univ. of Santiago de Compostela. (b) Present layout of the detector and a few its PID posibilities. Protons, muons, electron and gammas might be separated according to several variables: velocity, hit multiplicity or fit quality, among others.

order to implement an efficient, structured and secure data storage/retrieve with different data levels. So, all the information might be easily accessible by means of well defined APIs (i.e.: RESTful web services), SQL and even Big Data tools. Figure 3 shows the ERD diagram displaying the relationships of all the variables involved in the reconstruction of an event and in their storage in the data base.

The track reconstruction algorithm used by the TRASGOs detectors is called TimTrack [8] and is being developed at the USC as a part of the project (Fig. 4). Its most interesting feature is it does not need an external trigger and it provides, together with the particle direction, the arrival time and the velocity. It also allows an easy estimation of the calibration and synchronization parameters and the fit of decaying particles. The set of parameters defining a reconstructed track is called saeta s and it has always the form $s = (X_0, X', Y_0, Y', T_0, S)$. The first four parameters represent the arrival point (X_0, Y_0) and the projected slopes (X', Y') of the particle to the horizontal x and y axes at a reference plane, T_0 is the arrival time and S, or slowness, is the inverse of the velocity of the particle. The algorithm also provides the error matrix of the six parameters.

3. PID CAPABILITY

A defining characteristic of TRASGO detectors is their capability of separating most muons from electrons. A novel and powerful algorithm called MIDAS

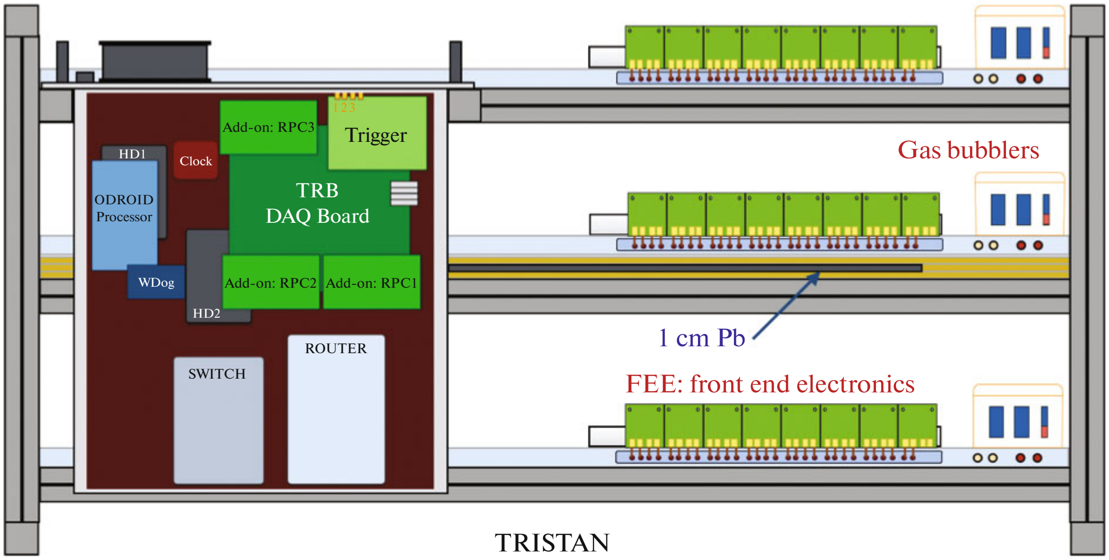

Fig. 8. (Color online) Layout of the TRISTAN detector. On the left side the main elements of the data acquisition system are shown. The front end electronics is an improved version of the one developed for the HADES spectrometer at GSI (Darmstadt) and used both by TRAGALDABAS and by the detectors of the STRATOS project.

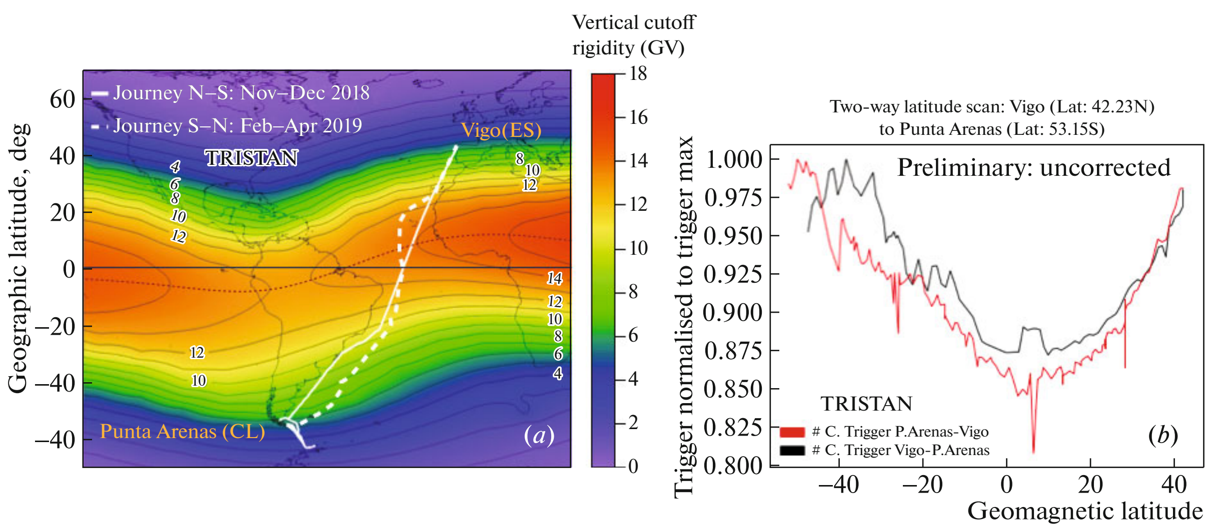

Fig. 9. (Color online) (*a*) Autumn (solid line) and Winter-Spring (dashed line) of the TRISTAN detector between Vigo (Spain) and P. Arenas (Chile) on board of the S. de Gamboa oceanographic vessel. (*b*) Uncorrected trigger rates of the TRISTAN detector as a function of the geomagnetic latitude for both journeys between Vigo (Spain) and Punta Arenas (Chile).

(Multisampling Identification Software) has been developed to identify the different particle species. Midas is based on the detailed analysis of several observables (such as hit multiplicity, chi square value, particle range, etc.) and the probability that a given topology is produced by a particle of a given mass or energy.

A very realistic simulation was made: initial secondary cosmic rays were produced with the CRY Cosmic Ray shower generator [9], and the TRAGALDABAS detector was placed in its nominal location inside the building, whose geometry and materials were simulated as well. Events were propagated and analyzed within the EnsarRoot framework [10]. The parametrized observables were the total hit multiplicity over the four detector planes, M, a weighted range a_n obtained multiplying the range of a track with the number of hits in each plane, and the χ^2 of the track fitting after the TimTrack reconstruction.

Figure 5 shows the different contributions of muons and electrons to the measured χ^2 of the track and to the a_n weighted range. The combination of the

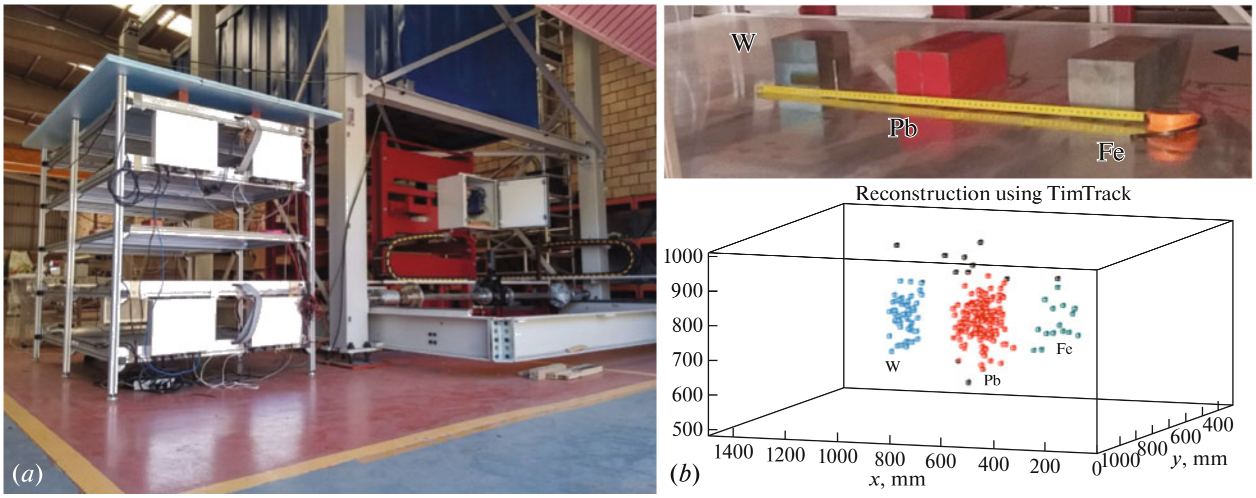

Fig. 10. (Color online) (*a*) The photo shows the MuTT detector in the foreground, with the Macroscanner facility behind; both are installed in an industrial hangar near Vigo (Spain). (*b*) Reconstruction of three bricks of tungsten, lead and iron using the MuTT detector. A photo of the three bricks is shown in the upper part of the figure. The tungsten brick was half the size of the other two bricks.

two measured observables in a dedicated algorithm allows to separate most of electrons from the majority of muons.

Figure 6 illustrates the behavior of the weighted range as a function of total multiplicity M. In addition to χ^2 and a_n, this total hit multiplicity of the same event over the full detector contributes to improve the separation between species.

The accuracy of the method with simulated data is higher than 90% and can be improved including a 1-cm or 1.5-cm wide lead plate behind the third plane to foster the development of higher multiplicity electromagnetic showers.

4. THE TRASGO FAMILY

To date, three TRASGOs have been already developed and have been taking data for different purposes in different locations.

TRAGALDABAS—The TRAGALDABAS detector was designed in order to study some of the effects related to the micro structure of the EAS, observed during the commissioning of the tRPC (timing Resistive Plate Chamber) detectors of the HADES ToF Wall [3] at the GSI laboratory although it is being used also for solar and atmospheric studies. The detailed layout of the detector and the distance between layers is shown in Fig. 7. Several features of the detector have been already published in [11, 12], and [13].

The TRAGALDABAS detector has four active RPC planes based on the design developed by the LIP of Coimbra for the MARTA extension of the Pierre Auger Observatory. Each plane has an active size of 1.2×1.5 m^2 and is read out by 120 rectangular pads instrumented with the fast HADES FEE electronics, [14] and [15]. The data acquisition system is based on the TRBV2 readout board developed at GSI [16]. The acquisition trigger is done by a coincidence between the second and the fourth planes (counting starts from above), hereafter T2 and T4 planes, respectively. The main expected performances of the detector for a charged straight track are: $\sigma X \sim \sigma Y \sim 3$ cm, $\sigma T \sim 300$ ps, $\sigma\theta \sim 2.5°$, where θ is the zenith angle.

TRISTAN—The TRISTAN detector (Fig. 8) has been designed as an element of the ORCA observatory, to be installed in the Spanish Antarctic Base Juan Carlos I, in the Livingston island. It consists of three RPC planes quite similar to those of the TRAGALDABAS detector. In TRISTAN each plane is read out by 30 rectangular pads and under the second layer there is a 1 cm-wide lead plate covering around 60% of the surface of the detector and enabling a better muon-electron separation.

Before installing the detector in the Antarctic base, the detector made a two-way journey on board of the Spanish Sarmiento de Gamboa oceanographic vessel between Vigo (Spain) and Punta Arenas (Chile) taking data in a thermalized room. The ship left the port of Vigo on November 17th 2018 and the trip to Chile lasts around 4 weeks. The journey back took place between February 24th and April 9th. Figure 9 shows the paths of both journeys and a relative comparison of the respective measured raw rates as a function of the geomagnetic latitude, showing the expected equatorial minimum.

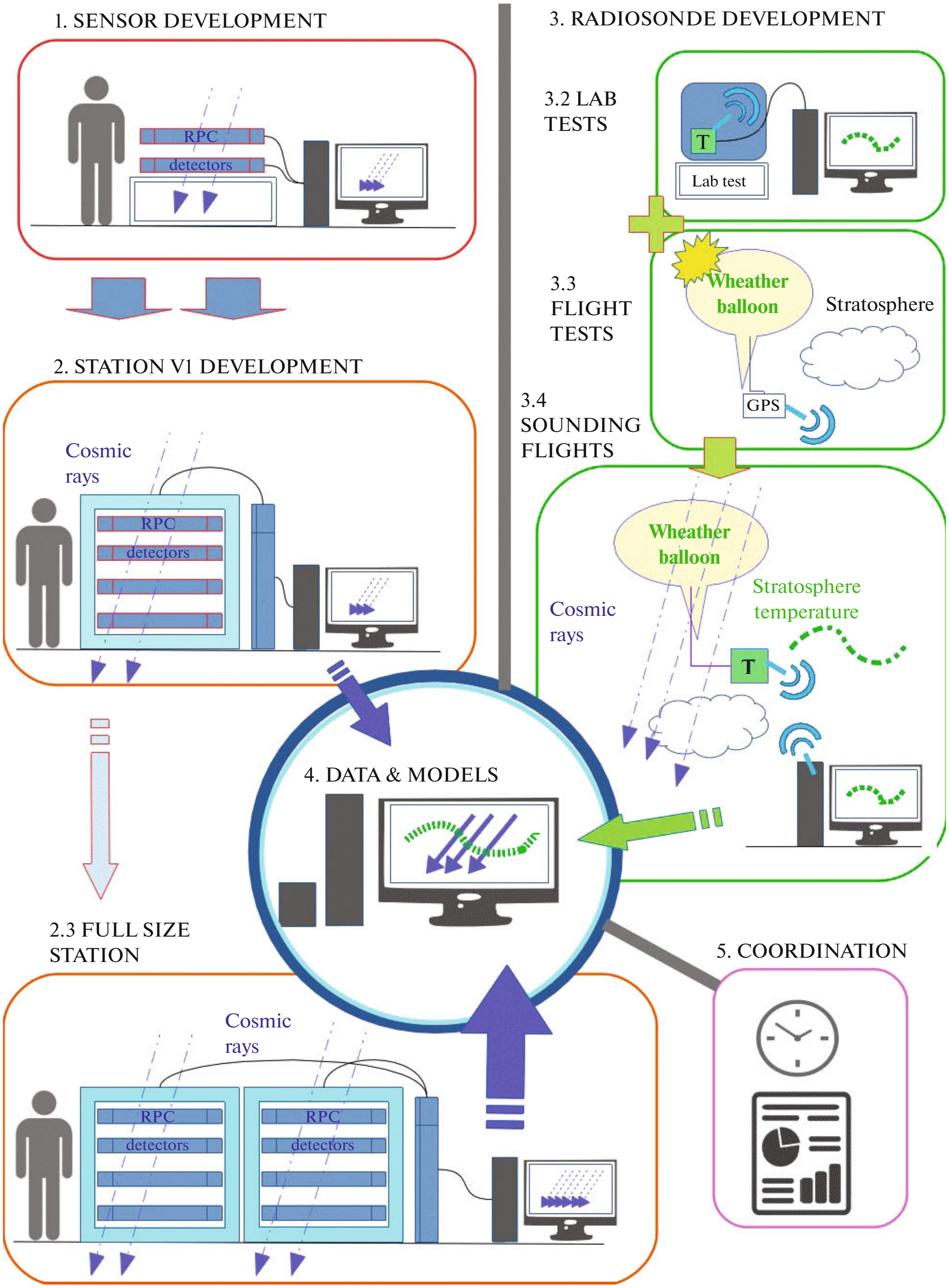

Fig. 11. (Color online) Main steps of the methodology of the STRATOS project. The project aims to obtain a correlation model between in-situ temperature measurements in the stratosphere and the cosmic rays radiation flow values measured at a relatively close point on the Earth's surface, using a couple of TRASGO detectors.

MuTT—The overall objective of the MuTT detector (Fig. 10) of the Macroescaner project was the development of an industrial scale Cosmic Ray tracking detector system for the inspection of cargo containers and vehicles, to identify the possible presence of hidden materials of high atomic number, as special nuclear materials and/or shielding, for the control of illegal traffic and contraband. The principle of operation is based on the detection of significant multiple-scatter effects of the muonic and electromagnetic components of the cosmic rays by their interaction with dense materials. For that purpose, a modular and scalable cosmic ray tracker has been built, based on four detection RPC planes of large area ($\sim$2 m^2) with high angular resolution ($\sim 1^\circ$) and sub-nanosecond time resolution ($\sim$500 ps). Two muon tomography prototypes have been developed: a rack scale size fixed geometry prototype and a cargo container scale size movable geometry prototype; they have been operated continuously in long term and realistic industrial environment conditions; and the Proof-of-Concept of high-Z material identification has been achieved.

The Stratos project—STRATOS is an ongoing program aiming to investigate the feasibility of remotely and continuously monitoring the stratospheric temperature by directional flow measurements of cosmic radiation incident on the Earth's surface (Fig. 11). For that purpose a pair of high sensitivity and stable response RPC-based Cosmic Ray hodoscopes are being built, with very high performances: angular resolution $\sim 1^\circ$ and a time resolution aim $\sim$100 ps. Cosmic ray directional flow variations will be correlated to in-situ temperature measurements at the stratosphere obtained from weather balloon radiosondes. Several detector optimization R&D activities are ongoing: RPC gas volume stabilization and sealing to contaminants (water vapor and oxygen), optimization of multichannel front-end electronics performance and cost, full system integration based on all-in-one detector modules, detector production process optimization for industrial mass-production, among others. Some of them may become standard features of other TRASGOs being built in the future.

5. SUMMARY

A new family of cosmic ray tracking detectors, called TRASGOs, offering multitrack capability together with outstanding performances in position, arrival time distribution and arrival direction, is being developed. TRASGOs are suitable for detecting either single cosmic particles or bundles of particles belonging to the same air shower; as a consequence, they are sensitive to changes in the rates of primary cosmic rays of different energies and also to the changes in the measured cosmic ray distribution as a consequence of variations in the atmospheric changes. A set of common tools that can be shared with any TRASGO detector is being developed, including programs and tools for monitoring, reconstruction of events and analysis of the data. Three TRASGOs have been already built and are operative, whereas two more are under construction. A final important goal is that all operative TRASGO detectors can function as a global network regardless of their location.

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