High Energy Cosmic Rays

This revised edition provides an up-to-date summary of the field of ultra-high energy cosmic rays, dealing with their origin, propagation, and composition, . The authors reflect the enormous strides made since the first edition in the realm of experimental work, in particular the use of vastly improved, more sensitive and precise detectors. The level remains introductory and pedagogical, suitable for students and researchers interested in moving into this exciting field. Throughout the text, the authors focus on giving an introductory overview of the key physics issues, followed by a clear and concise description of experimental approaches and current results. Key Features: Updates the most coherent summary of the field available, with new text that provides the reader with clear historical context. Brand new discussion of contemporary space-based experiments and ideas for extending ground-based detectors. Completely new discussion of radio detection methods. Includes a new chapter on small to intermediate-scale anisotropy. Offers new sections on modern hadronic models and software packages to simulate showers.

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"I have taught from and enjoyed the first edition of the book. The selection of topics is the best I've seen. Maurizio Spurio gives very clear presentations using a generous amount of observational data. " James Matthews (Louisiana State University) This is the second edition of an introduction to " multi-messenger " astrophysics. It covers the many different aspects connecting particle physics with astrophysics and cosmology and introduces high-energy astrophysics using different probes: the electromagnetic radiation, with techniques developed by traditional astronomy;

charged cosmic rays, gamma-rays and neutrinos, with methods developed in high-energy laboratories; and gravitational waves, recently observed using laser interferometers. The book offers a comprehensive and systematic approach to the theoretical background and the experimental aspects of the study of the high-energy universe. The breakthrough discovery of gravitational waves motivated this new edition of the book, to offer a more global and multimessenger vision of high-energy astrophysics. This second edition is updated and enriched with substantial new materials also deriving from the results obtained at the LIGO/Virgo observatories. For the first time it is now possible to draw the connection between gravitational waves, traditional astronomical observations and other probes (in particular, gamma-rays and neutrinos). The book draws on the extensive courses of Professor Maurizio Spurio at the University of Bologna and it is aimed at graduate students and post-graduate researchers with a basic understanding of particle and nuclear physics. It will also be of interest to particle physicists working in accelerator/collider physics who are keen to understand the mechanisms of the largest accelerators in the Universe.

Recounts the discovery of cosmic rays, extremely energetic atomic nuclei that bombard the earth from space, and describes recent developments in their study

Gamma Rays, Cosmic Rays, and Neutrinos

High Energy Radiation from Black Holes

Astroparticle Physics: Theory and Phenomenology

Astrophysical Aspects Of The Most Energetic Cosmic

Rays - Proceedings Of The Icrr International Symposium
Proceedings of two ISSI Workshops, 18–22 October 1999 and 15–19 May 2000, Bern, Switzerland

The Pierre Auger Observatory is the world's largest ultra-high energy cosmic ray detector. Its goals include answering basic questions about the origins and composition of cosmic rays at the highest energies. We outline the scientific motivation for constructing such an observatory and we highlight some of the significant results produced so far by this world-class instrument. We present the results of our own contributions toward calibrating the timing characteristics of the instrument followed by two alternative techniques for analyzing cosmic ray arrival direction data. The first technique is based on a Bayesian statistical framework and is presented as a solution to some of the difficulties in applying a standard analysis to identify anisotropy in the cosmic ray flux. The second analysis we present is based on a Markov Chain Monte Carlo method for identifying sources of cosmic rays in our arrival direction data. We are able to use our method to set an upper limit of 0.15 per square km per year on the flux from any potential sources producing ultra-high energy cosmic rays with energy E{u2265}3 EeV. We conclude with a proposal for enhancing the already successful observatory with an array of non-imaging Cherenkov detectors. According to our simulation work, such an array could serve as both an independent measure of the cosmic ray energy and, if the array is dense enough, it could also provide insight

into the composition of ultra-high energy cosmic rays on an event by event basis.

Gamma ray astronomy, the branch of high energy astrophysics that studies the sky in energetic ?-ray photons, is destined to play a crucial role in the exploration of nonthermal phenomena in the Universe in their most extreme and violent forms. The great potential of this discipline offers impressive coverage of many OC hot topicsOCO of modern astrophysics and cosmology, such as the origin of galactic and extragalactic cosmic rays, particle acceleration and radiation processes under extreme astrophysical conditions, and the search for dark matter."

The Pierre Auger Observatory (Auger) in Argentina studies Ultra High Energy Cosmic Rays (UHECRs) physics. The flux of cosmic rays at these energies (above 1018 eV) is very low (less than 100 particle/km2-year) and UHECR properties must be inferred from the measurements of the secondary particles that the cosmic ray primary produces in the atmosphere. These particles cascades are called Extensive Air Showers (EAS) and can be studied at ground by deploying detectors covering large areas. The EAS physics is complex, and the properties of secondary particles depend strongly on the first interaction, which takes place at an energy beyond the ones reached at accelerators. As a consequence, the analysis of UHECRs is subject to large uncertainties and hence many of their properties, in particular their composition, are still unclear. Two complementary *techniques are used at Auger to detect EAS initiated by UHE- CRs: a 3000 km2 surface detector (SD) array of water Cherenkov tanks which samples particles at ground level and fluorescence detectors (FD) which collect the ultraviolet light emitted by the de-excitation of nitrogen nuclei in the atmosphere, and can operate only in clear, moonless nights. Auger is the largest cosmic rays detector ever built and it provides high-quality data together with unprecedented statistics. The main goal of this thesis is the measurement of UHECR mass composition using data from the SD of the Pierre Auger Observatory. Measuring the cosmic ray composition at the highest energies is of fundamental importance from the astrophysical point of view, since it could discriminate between different scenarios of origin and propagation of cosmic rays. Moreover, mass composition studies are of utmost importance for particle physics. As a matter of fact, knowing the composition helps in exploring the hadronic interactions at ultra-high energies, inaccessible to present accelerator experiments.*

Offers an accessible text and reference (a cosmic-ray manual) for graduate students entering the field and high-energy astrophysicists will find this an accessible cosmic-ray manual Easy to read for the general astronomer, the first part describes the standard model of cosmic rays based on our understanding of modern particle physics. Presents the acceleration scenario in some detail in supernovae explosions as well as in the

passage of cosmic rays through the Galaxy. Compares experimental data in the atmosphere as well as underground are compared with theoretical models
Astrophysics at Ultra-High Energies

A Study of Ultra-high Energy Cosmic Ray Composition and Hadronic Interactions with Data from the Pierre Auger Observatory
Ultra High Energy Cosmic Rays and Monte Carlo Simulation
Very High Energy Cosmic-ray Interactions

Abstract: The Cosmic Ray Energetics And Mass (CREAM) experiment is a balloon-borne, high energy particle detector designed to measure cosmic ray nuclei from protons through Iron at energies up to 1015 eV. It has succeeded in measuring this broad range of charge and energy through multiple Antarctic flights, data from the first of which will be presented here, using complementary charge and energy detectors. These included a Timing Charge Detector (TCD), a Transition Radiation Detector (TRD), a Silicon Charge Detector (SCD), and a Calorimeter. The TRD and Calorimeter provide both tracking and an energy determination. The TCD and SCD provide excellent charge resolution, of order 0.2 e. Together, these have enabled us to construct absolute spectra for individual primary nuclei, Carbon, Oxygen, Neon, Magnesium, Silicon, and Iron, as well as the less abundant secondary, Nitrogen. Our spectra agree well with previous measurements, and for several nuclei extend to the highest energies yet measured. The well-resolved charge species have also permitted us to form the secondary to primary ratios of Boron to Carbon and Nitrogen to Oxygen, also up to the highest energies measured and in agreement with previous data. Since charged particles like cosmic rays bend in magnetic fields which permeate our galaxy, traditional pointing astronomy is not possible. Instead, we use the spectra and ratios to provide us with clues to cosmic rays' origins, acceleration mechanism, and propagation history. In particular, the CREAM I Boron to Carbon ratio fits a propagation model with index of [delta] = 0.5 - 0.6 while the CREAM II primary nuclei spectra all have an index of 2.66 " 0.04. This last suggests that they all have the same acceleration mechanism, and after accounting for propagation energy loss consistent with the Boron to Carbon ratio, that the mechanism is likely Fermi first order acceleration. Finally, Nitrogen serves as a particularly useful test bed for these findings. Its ratio with Oxygen is consistent with a small amount of Nitrogen existing in the cosmic ray source, ~ 10% with respect to the source's Oxygen content, given propagation conditions again based on the Boron to Carbon ratio. At the highest energies, this source flux is seen, as expected, to emerge over the secondary flux in the Nitrogen spectrum itself.

Many kinds of radiation exist in the universe, including photons and particles with a wide range of energies. Some of the radiation is produced in stars and galaxies, and some is cosmological background radiation, a relic from the history of cosmic evolution. Among all this radiation, the most energetic are cosmic ray particles:

nucleons, nuclei, and even extremely energetic gamma rays. There are some observational facts about cosmic rays to give suggestions on their origin. The most important one among them is that the energy spectrum of high energy cosmic rays above 10 GeV (where the magnetic field of the sun is no longer a concern) is well represented by a power law form. This indicates cosmic ray particles are products of non-thermal processes. Their energy extends over more than 13 decades from 107 eV up to 1020 eV. In terms of its structure, the spectrum can be divided into three regions: two 'knees' and one 'ankle'. The first 'knee' appears around 3×1015 eV where the spectral power law index changes from -2.7 to -3.0. The second 'knee' is somewhere between 1017 eV and 1018 eV where the spectral slope changes from -3.0 to around -3.3. The 'ankle' is seen at or after 3×1018 eV. Above that energy the spectral slope is around -2.7, but with a large uncertainty because of poor statistics and resolution. This book deals with the final and most energetic population, the Ultra High Energy Cosmic Rays (UHECRs).

Extensive air showers are a very unique phenomenon. In the more than six decades since their discovery by Auger and collaborators we have learned a lot about these extremely energetic events and gained deep insight into high-energy phenomena, particle physics and astrophysics. In this Tutorial, Reference Manual and Data Book Peter K. F. Grieder provides the reader with a comprehensive view of the phenomenology and facts of the various types of interactions and cascades, theoretical background, experimental methods, data

evaluation and interpretation and air shower simulation. He discusses astrophysical aspects of the primary radiation and addresses remaining puzzling questions that cannot yet be answered. They remain as a challenge for present and future research in the field. The book is split into two volumes. Volume I deals mainly with the basic theoretical framework of the processes that determine an air shower and ends with a summary of ways and means to extract information from air shower observations on the primary radiation. It also presents a compilation of data of our current knowledge of the high energy portion of the primary spectrum and composition. Volume II contains mainly compilations of data of experimental and theoretical nature as well as predictions from simulations of individual air shower constituents. Also included are chapters dedicated exclusively to special processes and detection methods. Extensive up-to-date reference lists appear at the end of each chapter. Researchers and students working in the field of cosmic ray detection and astroparticle physics will appreciate finding this book in their library.
Providing students with an in-depth account of the astrophysics of high energy phenomena in the Universe, the third edition of this well-established textbook is ideal for advanced undergraduate and beginning graduate courses in high energy astrophysics. Building on the concepts and techniques taught in standard undergraduate courses, this textbook provides the astronomical and astrophysical background for students to explore more advanced topics. Special emphasis is given to the underlying physical principles of high energy

astrophysics, helping students understand the essential physics. The third edition has been completely rewritten, consolidating the previous editions into one volume. It covers the most recent discoveries in areas such as gamma-ray bursts, ultra-high energy cosmic rays and ultra-high energy gamma rays. The topics have been rearranged and streamlined to make them more applicable to a wide range of different astrophysical problems.

Opening the Ultra High Energy Cosmic Ray Window from the Top

The Astrophysics of Galactic Cosmic Rays

On the Origin of Ultra High Energy Cosmic Rays II

High Energy Particles In Astrophysics

Upper Limits on the Ultra-high Energy Cosmic Ray Flux from Unresolved Sources

Measurements in present experiments have dramatically advanced our understanding of ultrahigh-energy cosmic rays. The suppression of the flux at the highest energies is now confirmed without any doubt, and strong limits have been placed on the photon and neutrino components. There are indications for a small, large-scale anisotropy both below and above the energy of the angle and for a correlation on smaller angular scales at E > 5.5*1019 eV. Around 3*1018 eV, there is a distinct change of slope with energy, and the shower-to-shower variance decreases. Interpreted with the leading LHC-tuned shower models, this implies a gradual shift to a heavier composition, and a number of

fundamentally different astrophysical model scenarios have been developed to describe this evolution.

The study of Ultra High Energy Cosmic Rays (UHECR) has attracted great attention in recent years. I will outline why there is such interest and review the existing experimental data that has led to an apparent enigma, as the cosmic rays of 1020 eV must be young but no sources are seen nearby. After a brief survey of proposals made to explain this enigma, I will give an overview of the prospects and promise of the Pierre Auger Observatory that has now been recording showers for over a year with its Engineering Array.

This book discusses various aspects of cosmic ray physics and astrophysics. Also discussed herein are answers to those astrophysical and cosmic ray questions which are essential for understanding of the subject, such as description of the Universe and of some astrophysical objects, a brief history of cosmic ray investigation, the peculiarities of detection of cosmic rays at various energy bands, a list of arrays for an ultra-high-energy-cosmic-ray investigation and GZK-effect.

The handbook centers on detection techniques in the field of particle physics, medical imaging and related subjects. It is structured into three parts. The first one is dealing with basic ideas of particle detectors, followed by applications of these *devices in high energy physics and other fields. In the last part the large field of medical imaging using similar detection techniques is described. The different chapters of the book are written by world experts in their field. Clear instructions on the detection techniques and principles in terms of relevant operation parameters for scientists and graduate students are given.Detailed tables and diagrams will make this a very useful handbook for the application of these techniques in many different fields like physics, medicine, biology and other areas of natural science.*

Charged cosmic rays, neutrinos, γ-rays and gravitational waves

On the Energy Estimation of Ultra High Energy Cosmic Rays Observed with the Surface Detector Array

Handbook of Particle Detection and Imaging

A Crucial Window on the Extreme Universe

Very High Energy Cosmic Gamma Radiation

This book, designed as a tool for young researchers and graduate students, reviews the main open problems and research lines in various fields of astroparticle physics: cosmic rays, gamma rays, neutrinos, cosmology, and gravitational physics. The opening section discusses cosmic rays of both galactic and extragalactic origin, examining experimental results, theoretical models, and possible future developments. The basics of gamma-ray astronomy are then described, including the detection methods and techniques. Galactic and extragalactic aspects of the field are addressed in the light of recent discoveries with space-borne and ground-based detectors. The review of neutrinos outlines the status of the investigations of neutrino radiation and brings together relevant formulae, estimations, and background information. Three complementary issues in cosmology are examined: observable predictions of inflation in the early universe, effects of dark energy/modified gravity in the large-scale structure of the universe, and neutrinos in cosmology and large-scale structures. The closing section on gravitational physics reviews issues relating to quantum gravity, atomic precision tests, space-based experiments, the strong field regime, gravitational waves, multi-messengers, and alternative theories of gravity.

Beginning with Einstein's special and general theories of relativity, the authors give a detailed mathematical description of fundamental astrophysical radiation processes, including Compton scattering of electrons and photons, synchrotron radiation of particles in magnetic fields, and much more.

The discovery and detection of ultra high energy cosmic rays (UHECRs) of energy up to 10 DEGREES20 eV have posed a serious challenge to the astrophysicists about their origin as well as the physical acceleration mechanisms. Some theoretical approaches in the past assuming elastic scatterings of cosmic charged particles with magnetic clouds then developed by assuming the presence of shock waves originated from supernova remnant succeeded to explain the existence of energies up to 10 DEGREES15 eV. The assumption of particle-electromagnetic field interaction with constant fields succeeded to interpret the possibility of finding cosmic particles of energies up to 10 DEGREES20 eV. From the astrophysical plasma aspects, the interaction of cosmic charged particles with the time varying magnetic field, like that present in the magnetosphere of pulsar and magnetar, as potent sources can lead to higher energies. Moreover, the coupling of the cosmic charged particle-spatially varying electromagnetic field interaction and the well-known Fermi

mechanisms furnish a reasonable theoretical approach to interpret the existence of UHECRs of ener
Stochastic descriptions of a harmonic oscillator can be obtained by adding additive noise, or/and three types of multiplicative noise: random frequency, random damping and random mass. The first three types of noise were intensively studied in many published articles. In this book the fourth case, that of random mass, is considered in the context of the harmonic oscillator and its immediate nonlinear generalization — the pendulum. To our knowledge it is the first book fully dedicated to this problem.Two interrelated methods, the Langevin equation and the Fokker-Planck equations, as well as the Lyapunov stability method are used for the mathematical analysis. After a short introduction, the two main parts of the book describe the different properties of the random harmonic oscillator and the random pendulum with random masses. As an example, the stochastic resonance is studied, where the noise plays an unusual role, increasing the applied weak periodic signal, and also the vibration resonance in dynamic systems, where the role of noise is played by the second high-frequency periodic signal.First and second averaged moments have been calculated for a system with different types of additive and multiplicative noises, which define the stability of a system. The calculations have been extended to two multiplicative noises and to quadratic noise. This book is useful for students and scientists working in different fields of statistical physics.
Cosmic Rays
Ultra High Energy Cosmic Rays
Multiple Messengers and Challenges in Astroparticle Physics
Mass Composition Studies of Ultra High Energy Cosmic Rays Through the Measurement of the Muon Production Depths at the Pierre Auger Observatory
On High Energy Cosmic Rays from the CREAM Instrument

This books aims at giving an overview over theoretical and phenomenological aspects of particle astrophysics and particle cosmology. To be of interest for both students and researchers in neighboring fields of physics, it keeps a balance between well established foundations that will not significantly change in the future and a more in-depth treatment of selected subfields in which significant new developments have been taking place recently. These include high energy particle astrophysics, such as cosmic high energy neutrinos, the interplay between detection techniques of dark matter in the laboratory and in high energy cosmic radiation, axion-like particles, and relics of the early Universe such as primordial magnetic fields and gravitational waves. It also contains exercises and thus will be suitable for both introductory and advanced courses in astroparticle physics.
It turned out to be really a rare and happy occasion that we know exact1y when and how a new branch of space physics was born, namely, a physics of solar cosmic rays. It happened on February 28 and March 7, 1942 when the fIrst "cosmic ray bursts" were recorded on the Earth, and the Sun was unambiguously identifIed for the fIrst time as the source of high-velocity 10 particles with energies up to > 10 eV. Just due to such a high energy these relativistic particles have been called "solar cosmic rays" (SCR), in distinction from the "true" cosmic

rays of galactic origin. Between 1942 and the beginning ofthe space era in 1957 only extremely high energy solar particle events could be occasionally recorded by cosmic ray ground-level detectors and balloon borne sensors. Since then the detection techniques varied considerably and the study of SCR turned into essential part of solar and solar-terrestrial physics.

This book introduces young researchers to the exciting field of ultra-high energy astrophysics including charged particles, gamma rays and neutrinos. At ultra-high energy the radiation is produced by interactions of cosmic ray particles accelerated in explosive events such as supernovae or hypernovae, black holes or, possibly, the big bang. Through direct contact with senior scientists, now actively planning the next generation of experiments/models, the excitement and motivation for research at ultra-high energy was conveyed. The underpinning of these fields is a synthesis of knowledge and techniques from nuclear and particle physics, astronomy and cosmology. Informing the participants of this background, how it was derived, and the new challenges for the future are the major goal. Further, the course has helped to foster new astrophysical research and promoted contacts, which have resulted in new collaborations. Sample Chapter(s). Chapter 1: Gamma-Ray Burst: Discoveries With Swift (352 KB). Contents: Powerful

Astrophysical Sources: Gamma Ray Bursts: Discoveries with Swift (A Wells); Gamma Ray Burst Phenomenology in the Swift Era (P M(r)sziros); The Nature of Dark Matter (P L Biermann & F Munyaneza); Cosmic Rays: Particle Acceleration and Propagation in the Galaxy (V S Ptuskin); GRB as Sources of Ultra-High Energy Particles (P M(r)sziros); The KASCADE-Grande Experiment (F Cossavela et al.); Gamma Ray and Neutrino Astronomy: Study of Galactic Gamma Ray Sources with Milagro (J Goodman); The GLAST Mission and Observability of Supernovae Remnants (O Tibolla); First Results from AMANDA using TWR System (A Silvestri); and other papers. Readership: Academics in astrophysics, high energy, cosmology and earth science."

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The Highest Energy Particles in Nature (Ultra High Energy Cosmic Rays).

Probes of Multimessenger Astrophysics

Introduction to Ultrahigh Energy Cosmic Ray Physics

Physics and Astrophysics of Ultra High Energy Cosmic Rays

High Energy Phenomena and Astrophysical Aspects

- A Tutorial, Reference Manual and Data Book

While several arguments can be proposed against the existence of particles with energy in excess of (3--5) x 1019 eV in the cosmic ray spectrum, these particles are actually observed and their origin seeks for an explanation. After a description of the problems encountered in explaining these ultra-high energy cosmic rays (UHECRs) in the context of astrophysical sources, the authors review the so-called Top-Down (TD) Models, in which UHECRs are the result of the decay of very massive unstable particles, possibly created in the Early Universe. Particular emphasis will be given to the signatures of the TD models, likely to be accessible to upcoming experiments like Auger.

Since the discovery of cosmic rays by Victor Hess in 1912, it has contributed immensely to understand many fundamental problems in physics. However the problems related with high energy cosmic rays sources and acceleration mechanisms are not solved yet. The source and acceleration mechanism of UHE cosmic rays is still a mystery. There is a glorious possibility that in the UHE cosmic ray interactions the Higgs bosons may produce by thermofield mechanism. It has been established that other heavy short lived particles like charmed hadrons are produced in the high energy cosmic rays interactions. So cosmic rays provide a useful mechanisms to study the high or ultra high energy particle interactions, that are beyond the capability of the human made accelerators. To study the high or ultra high energy cosmic rays in the different perspectives it is very much essential to use Monte Carlo simulation technique, which is a technique of doing virtual experiment based on probability distributions. In this work Monte Carlo simulation technique is used to study few ultra high energy cosmic ray phenomena and the primary particle detection by an unconventional method.

The International School on Physics and Astrophysics of Ultra High Energy Cosmic Rays (UHECR2000) was held at the

Observatoire de Paris–Meudon on June 26-29, 2000. This was the ?rst international school speci?cally dedicated to ultra high energy cosmic rays. Its aim was to familiarize with and attract students, physicists and astronomers into this quickly developing newresearch ?eld. The mysterious and currently unknown origin of the most energetic par- cles observed in Nature has triggered in recent years theoretical speculations ranging from electromagnetic acceleration to as yet undiscovered physics - yond the Standard Model. It has also lead to the development of several new detection concepts and experimental projects, some of which are currently - der construction. By its nature, the ?eld of ultra high energy cosmic rays is therefore highly interdisciplinary and borrows from astrophysics and cosmology, via particle physics, to experimental physics and observational astronomy. One main aspect of the school was to emphasize and take advantage of this interd- ciplinarity. The lectures were grouped into subtopics and are reproduced in this volume in the following order: After a general introductory lecture on cosmic rays follow two contributions on experimental detection techniques, followed by three lectures on acceleration in astrophysical objects. The next four contri- tions cover all major aspects of propagation and interactions of ultra high energy radiation, including speculative issues such as newinteractions.

In 1912 Victor Franz Hess made the revolutionary discovery that ionizing radiation is incident upon the Earth from outer space. He showed with ground-based and balloon-borne detectors that the intensity of the radiation did not change significantly between day and night. Consequently, the sun could not be regarded as the sources of this radiation and the question of its origin remained unanswered. Today, almost one hundred years later the question of the origin of the cosmic radiation still remains a mystery. Hess' discovery has given an enormous impetus to large areas of science, in particular to physics, and has played a major role in the formation of our current understanding of universal evolution. For example, the development of new fields of research such as elementary particle physics, modern astrophysics and cosmology are direct consequences of this discovery. Over the years the field of cosmic ray research has evolved in various directions: Firstly, the field of particle physics that was initiated by the discovery of many so-called elementary particles in the cosmic radiation. There is a strong trend from the accelerator physics community to reenter the field of cosmic ray physics, now under the name of astroparticle physics. Secondly, an important branch of cosmic ray physics that has rapidly evolved in conjunction with space exploration concerns the low energy portion of the cosmic ray spectrum. Thirdly, the branch of research that is concerned with the origin, acceleration and propagation of the cosmic radiation represents a great challenge for astrophysics, astronomy and cosmology. Presently very popular fields of research have rapidly evolved, such as high-energy gamma ray and neutrino astronomy. In addition, high-energy neutrino astronomy may soon initiate as a likely spin-off neutrino tomography of the Earth and thus open a unique new branch of geophysical research of the interior of the Earth. Finally, of considerable interest are the biological and medical aspects of the cosmic radiation because of it ionizing character and the inevitable irradiation to which we are exposed. This book is a reference manual for researchers and students of cosmic ray physics and associated fields and phenomena. It is not intended to be a tutorial. However, the book contains an adequate amount of background materials that its content should be useful to a broad community of scientists and professionals. The present book contains chiefly a data collection in compact form that covers the cosmic radiation in the vicinity of the Earth, in the Earth's atmosphere, at sea level and underground. Included are predominantly experimental but also theoretical data. In addition the book contains related data, definitions and important relations. The aim of this book is to offer the reader in a single volume a readily available comprehensive set of data that will save him the need of frequent time consuming literature searches.

Cosmic Rays at Earth

Proceedings of the NATO Advanced Study Institute held in Durham, England, August 26–September 6, 1974

Ultra-high Energy Particle Astrophysics

Cosmic Rays and Particle Physics

Extensive Air Showers

We show that accretion disks around Active Galactic Nuclei (AGNs) could account for the enormous power in observed ultra high energy cosmic rays ≈102° eV (UHEs). In our model, cosmic rays are produced by quasi-steady acceleration of ions in magnetic structures previously proposed to explain jets around Active Galactic Nuclei with supermassive black holes. Steady acceleration requires that an AGN accretion disk act as a dynamo, which we show to follow from a

modified Standard Model in which the magnetic torque of the dynamo replaces viscosity as the dominant mechanism accounting for angular momentum conservation during accretion. A black hole of mass M{sub BH} produces a steady dynamo voltage V ∝ √M{sub BH} giving V ≈ 102° volts for M{sub BH} ≈ 108 solar masses. The voltage V reappears as an inductive electric field at the advancing nose of a dynamo-driven jet, where plasma instability inherent in collisionless runaway acceleration allows ions to be steadily accelerated to energies ≈ V, finally ejected as cosmic rays. Transient events can produce much higher energies. The predicted disk radiation is similar to the Standard Model. Unique predictions concern the remarkable collimation of jets and emissions from the jet/radiolobe structure. Given MBH and the accretion rate, the model makes 7 predictions roughly consistent with data: (1) the jet length; (2) the jet radius; (3) the steady-state cosmic ray energy spectrum; (4) the maximum energy in this spectrum; (5) the UHE cosmic ray intensity on Earth; (6) electron synchrotron wavelengths; and (7) the power in synchrotron radiation. These qualitative successes motivate new computer simulations, experiments and data analysis to

provide a quantitative verification of the model.
The sources of ultra high energy cosmic rays detected by the Pierre Auger Observatory are yet unknown. It is natural to expect that cosmic-ray sources could produce high-energy neutrinos detectable by IceCube. In this work we discuss the potential utility and implementation of a correlation search between IceCube and Auger. Any such correlations would allow an unprecedented view of transient astrophysical events, such as a gamma-ray burst. Where previous studies have focused on thehighest energy events(ECR > 57 EeV), weanalyzethe subthreshold data available in the IceCube public dataset and overlapping Auger data down to ECR = 3 EeV. A likelihood estimator is constructed from spatial and temporal correlations based on Monte Carlo simulations of the data. Data is compared to a randomized (scrambled) data set, where any correlations are bound to be accidental, and shown to be consistent with the background hypothesis. We then discuss how this procedure can be used in a real time search, allowing for any coincidences with sufciently high likelihood to be followed up with near real time multiwavelength observations.

High Energy Cosmic RaysSpringer Science & Business Media
Proceedings of the NATO Advanced Study Institute, Durham, England, August 26-September 6, 1974
Anisotropy of Extremely High Energy Cosmic Rays
High Energy Cosmic Rays
Analysis of Correlations Between Ultra High Energy Cosmic Rays Detected by the Pierre Auger Observatory and High Energy Neutrinos Detected by the IceCube Experiment
Energy Budget in the High Energy Universe
Origin of Cosmic Rays

Ultra-high energy cosmic rays are particles of enormous energy -- greater than 1018 eV -- reaching Earth from still mysterious sources. In this thesis, we analyze data from the Pierre Auger Observatory, a giant cosmic ray detector located in Argentina, to derive information on the mass of ultra-high energy cosmic rays and on their hadronic interaction properties. The data show a change of cosmic ray mass composition as a function of energy. We perform a measurement of the proton-air inelastic cross section, yielding sinelp-air =501+24-23 stat+30 -35syst +30-32

composition mb, at an equivalent energy of 57 TeV in the center of mass of a proton-proton collision -- a range yet inaccessible to particle accelerators. The measured cross section is in good agreement with predictions from hadronic interaction models.

Solar Cosmic Rays

International School of Cosmic Ray Astrophysics, 15th Course, Erice, Italy, 20-27 June 2006

High Energy Astrophysics

Origin and Propagation of Extremely High-energy Cosmic Rays

Cosmic Bullets