INFORMATION ABOUT HIGH-ENERGY HADRONIC INTERACTION PROCESSES FROM EXTENSIVE AIR SHOWER OBSERVATIONS

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Extensive air showers (EAS) induced by collisions of primary cosmic particles with atoms of the Earth’s atmosphere are a playground for studies of the high-energy hadronic interaction. The hadronic interaction is subject of various uncertainties and debates, in particular in energy regimes which exceed the energies of man-made accelerators and the knowledge from collider experiments. The EAS development is dominantly governed by soft processes which are not accessible to perturbative QCD. Thus one has to rely on QCD inspired phenomenological interaction models like string models, based on the Gribov-Regge theory. In the present paper the role of EAS observations is illustrated with respect of their information about salient features and tests of various high-energy interaction models, being en vogue as generators for Monte Carlo EAS simulations. The constraints expected from data of the Large Hadron Collider are briefly commented.

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“Observations always involve theory.”
\textit{Edwin Powel Hubble}

1. INTRODUCTION

Cosmic rays are a radiation from the outer space, a feature of our environment like the starlight. Since their discovery a century ago by the Austrian physicist Victor Hess this phenomenon of nature has gained a lot of interesting and fascinating aspects relevant to astro- and particle physics.

There is now a general consensus that the bulk of primary cosmic rays is accelerated at discrete sites, e.g. in supernova explosions in our Galaxy, and the particles roam around for ten millions years before incidentally hitting the Earth. Since they are overwhelmingly charged particles (protons, helium, carbon, nitrogen up to iron ions), they are deflected by the interstellar magnetic fields and they have lost all memory of their origin when they accidentally arrive. This circumstance implies that their direction of incidence is no more related to the location of the sources. This remains true, except of the highest energies whose features are currently of frontier interest. However, in general, the only observable quantities which may give us some information about the origin of cosmic rays are the energy distribution and the elemental composition of the primary particle radiation. Their experimental determinations are current topics of contemporary experimental research, especially in energy regions which exceed the energies provided by artificial accelerators installed by man on our Earth [1, 2].

Fig. 1 – Primary energy spectrum of cosmic rays. The flux is multiplied by $E^{2.5}$ in order to emphasize the discontinuities in the slope. The axis at the top indicates the equivalent c.m. energy if the cosmic rays were protons (for references see [1,2]).

The investigation of the detailed spectral shape and of conjectured variations of the mass composition in the region of the so-called knee around $3 \cdot 10^{15}$ eV (see Fig. 1), have been the objectives of a number of large scale experiments like the KASCADE experiment [3], set up in Karlsruhe (Germany), later extended to KASCADE-Grande [4], covering the energy range up to $10^{18}$ eV (i.e. EeV).
The shape of spectrum in the EeV region and above is an issue of great astrophysical and cosmological relevance. A cut-off of the spectrum had been predicted [5] at $6 \cdot 10^{19}$ eV due to the photo-interaction of the protons with the universal 2.7 K background radiation. The fact that some experiments seem to have observed a few events above the cut-off, though with low statistical accuracy and with controversial features (see Ref. 1), was considered as a mystery of science and has prompted large scale experiments like the Pierre - Auger Observatory [6].

Let us realize the span on the energy scale of the cosmic ray spectrum! Till recent times the largest artificial accelerators provided proton beams in the TeV region. Operated as colliders the centre – of - mass energies ($\sqrt{s}$), reached by head-on-collisions correspond for protons - for the TeV Collider in the Fermi laboratory - to $1.8 \cdot 10^{15}$ eV. The Large Hadron Collider (LHC) in CERN [7] which was put very recently into operation extends the range of man made accelerator energies to $3 \cdot 10^{17}$ eV.

In addition to the astrophysical aspects of origin, acceleration and propagation of the primary cosmic rays there is a historically well developed and complementary aspect: the interaction of high-energy particles with matter. Cosmic rays interacting with the atmosphere as target (on sea level it is equivalent to a lead bloc of 1m thickness) produce the full zoo of elementary particles and induce by cascading interactions extensive air showers (EAS), which we do observe with large extended detector arrays distributed in the landscapes, recording the features of different EAS components [1].

The development of such air showers carries information about the hadronic interaction (though it must be disentangled from the unknown nature and quality of the primary beam). When realizing the limits of man made accelerators, it is immediately obvious, why there appeared a renaissance of interest in cosmic ray studies, also from the point of view of particle physics. EAS observations of energies $> 10^{15}$ eV represent an unique chance to test theoretical achievements of very high - energy nuclear physics. Such studies experienced in recent years a new playground as with $\sqrt{s} = 7$ TeV, the LHC is the first collider reaching an energy higher than the knee in the spectrum of cosmic rays.

This paper reviews some relevant aspects of hadronic interactions affecting the EAS development, prevailingly illustrated with recent results of EAS investigations of various large scale experiments like KASCADE – Grande [4] and of the Pierre Auger Observatory (PAO) [6]. It updates and details some aspects of previous articles [8, 9]. The actual conclusions from the first LHC data on inclusive hadron production which seem grossly supporting a conventional extrapolation of the known features of multiparticle production, are briefly commented.

2. EAS DEVELOPMENT AND HADRONE INTERACTIONS

Let us first briefly recall what has to be specified for understanding when a primary nucleus from the cosmos interacts with air nuclei of the high-altitude
atmosphere. After an average of an interaction length, the nucleus is interacting, but typically only few nucleons participate. The spectator part breaks up in some fragments, which will in turn interact with producing further spectator fragments. This process is iterated until finally all nucleons eventually interact.

Strictly here enters the fragmentation pattern which may be described in detailed nuclear models, but mostly, in particular at high energies, it is common praxis to rely on a simple superposition model: a nucleus of mass number $A$ and the total energy $E_0$ behaves after the first collisions like a swarm of $A$ independent nucleons of the energy $E_0/A$.

Each nucleon interacting with the nuclei of the atmosphere produces many hadrons. Each hadronic particle (i) will continue by interacting again or decaying, say after a travelling distance $X$ (measured in grammage) with the probability:

$$P_i(X) = 1 - \exp\left\{ -X \left( \frac{1}{\lambda_i} + \frac{1}{c\tau_i\gamma_i} \right) \right\}$$

(1)

$\lambda_i =$ mean free path length (in grammage); $\tau_i =$ mean life time; $\gamma_i =$ Lorentz factor; $c\tau_i\gamma_i =$ geometric path length; $\rho(h) =$ density.

Fig. 2 – Schematic view of the EAS development.

At very high energy the typical interaction length of a nucleon is $\lambda_N = 80$ g/cm$^2$, while a heavy nucleus can interact after only few g/cm$^2$. We have then the evolution of hadronic cascades, which develop completely to an extensive air shower after ca.
12 interaction lengths for protons. At each step in the shower process the number of particles will grow while the average energy will decrease. Thus the number of particles (“shower size”) and the energy transferred to secondaries will reach a maximum at a particular atmospheric depth ($X_{\text{max}}$), which depends on the primary energy, on the nature of the primary particle and the details of the interactions (Fig. 2).

Most of the produced particles in the hadronic interactions are pions and kaons, which can decay into muons and neutrinos before interacting, thus producing the most penetrating component of atmospheric showers. The most intensive component – electrons and photons – originates from the fast decay of neutral pions into photons, which initiate electromagnetic showers, distributing the originally high energy to millions of charged particles of lower energies. The backbone of an air shower is the hadronic component of nucleons, pions and more exotic hadronic particles (Fig. 3).

![Fig. 3 – Particle components of an extensive air shower.](image)

For the case of $10^{19}$ eV proton induced showers, Fig. 4 shows the average lateral and longitudinal development of the particle density of various EAS components: the sizes of the electromagnetic, the muon and the hadron components. In the case of high energy gamma rays, whose observation is the subject of gamma ray astronomy, the development of the shower is much less fluctuating and the shower is “muon poor” (the muon content is decreased) due to the small cross section of photo production of muons.

The electromagnetic component is accompanied by additional EAS phenomena, the production of atmospheric Cerenkov light and at higher energies...
nitrogen fluorescence light which carry important information about the longitudinal shower development, in particular about the atmospheric height ($X_{\text{max}}$) of the shower maximum [1].

Fig. 4 – Average lateral (a) and longitudinal (b) development of different components of proton induced EAS of vertical incidence at $10^{19}$ eV (Monte Carlo simulations). The lateral distributions are simulated for the atmospheric height of 870 g/cm² (PAO).

Fig. 5 – Extensive air shower observations.
In general, however, ground-based detector arrays are not in the situation to observe the longitudinal development. Only the laterally developed status of the air shower cascade at a certain observation level is observed. From the observables there, that means from the total number of particles, the lateral and eventually the energy distributions of the different EAS components and their mutual correlations, the properties of the primary particle, starting the cascade are deduced. The inherent fluctuations of the stochastic cascade processes are largely obscuring discriminating features. This is the greatest problem: the superposition of many fluctuating interaction processes at different energies makes an air shower rather insensitive to the initiating conditions. It turns out that the fluctuations are dominated by the scatter of the first interaction point.

3. INTERACTION INGREDIENTS

From the point of view of the hadronic interactions, the basic ingredients for the understanding of EAS are the total cross sections of hadron - air collisions and the differential cross sections for multiparticle production specifying:

- The number of secondary particles: Multiplicity distributions.
  The multiplicity increases with, but less than in linear proportion to, primary particle energy.
- The average fraction of energy converted into multiparticle production: Inelasticity $K$.
  This quantity is about 50-60% and almost independent of energy. As a consequence the average energy of the secondary particles increases faster than the primary energy.
- The longitudinal and transverse momenta: Rapidity and $P_T$- distributions.
  The transverse momenta increase slowly with the energy and consequently the longitudinal momenta faster.

Actually our interest in the total cross section is specified to the inelastic part, since the elastic part does not drive the EAS development.

Usually with ignoring coherence effects, the nucleon – nucleon cross section is considered to be more fundamental than the nucleus – nucleus cross section, which is believed to be obtained in terms of the first. Due to the short range of hadron interactions the proton will interact with only some, the so-called wounded nucleons of the target. The number could be estimated on basis of geometrical consideration, in which size and shape of the colliding nuclei enter. All this is mathematically formulated in the Glauber multiple scattering formalism [10] ending up with nucleon – nucleus cross sections. Actually it is not definitively clarified to which extent the Glauber model must be refined in some details for the application at very high energies.
It is useful to remind that cosmic ray observations of particle phenomena are strongly weighted to sample the production in forward direction. The energy flow is peaking near the kinematical limit. That means, most of the energy is carried away longitudinally. In cosmic ray studies we regard kinematical regions complementary to collider experiments!

Fig. 6 – Knowledge from accelerator experiments [11]. Distribution of the longitudinal momentum (expressed by the Feynman $x_F$) of secondary particles. The bulk of the secondary particle is produced with small momentum (a). There is one leading particle that carries many quantum numbers with the incoming particle (b). The peak at large $x_F$ results from diffractive interactions (from [9]).

Fig. 7 – Knowledge from accelerator data: (a) total and elastic cross sections in proton – proton and proton – antiproton collisions (from [9]); (b) Charged particle multiplicity in $p+p$ cross section compared with current models (from [9]).
Fig. 8 – Knowledge from accelerator experiments: charge particle multiplicity (a) and energy density, (b) as function of the pseudorapidity η (from [9]).

Looking for the cross features of the particle production, the experiments show that the bulk of it consists of hadrons emitted with limited transverse momenta ($<P_t> \sim 0.3$ GeV/c) with respect to the direction of the incident nucleon. In these „soft“ processes the momentum transfer is small. More rarely, but existing, are hard scattering processes with large $P_t$ - production.

4. HADRONE INTERACTION MODELS AS GENERATORS OF MONTE-CARLO SIMULATIONS

Microscopic hadronic interaction models, i.e. models based on parton-parton interactions are approaches, inspired by the QCD and considering the lowest order Feynman graphs involving the elementary constituents of hadrons (quarks and gluons). However, there are not yet exact ways to calculate the bulk of soft processes within first-principles (QCD) since due to the small momentum transfer the coupling constant $\alpha_s$ of the strong interaction is so large so that perturbative QCD fails. Thus we have to resort to phenomenological models which incorporate the fundamental concepts of quantum field and scattering theory.

A class of successful models are based on the Gribov - Regge theory [12] which finally leads to descriptions of colour exchange and re-arrangements of the quarks by string formation.

In the language of this theory the interaction is mediated by exchange particles so-called Reggeons. At high energies, when the non-resonant exchange is dominating, a special Reggeon without colour, charge and angular momentum, the Pomeron, gets importance. In a parton model the Pomeron can be identified as a
complex gluon network or generalised ladders i.e. a colourless, flavourless multiple (two and more) gluon exchange. For inelastic interactions such a Pomeron cylinder of gluon and quark loops is cut, thus enabling colour exchange ("cut cylinder") and a re-arrangement of the quarks by a string formation.

In order to recall the principles of the construction of such cut cylinders, we consider some basic diagrams (Fig. 9).

The interacting valence quarks of projectile and target rearrange by gluon exchange the colour structure of the system (the arrow indicates the colour exchange by opening the cylinder). As a consequence, constituents of the projectile

Fig. 9 – Parton interaction diagrams.
and target (a fast quark and slow di-quark e.g.) form a colour singlet string with partons of large relative momenta. Due to the confinement the stretched chains start to fragment (i.e. a spontaneous \( q \bar{q} \) - production) in order to consume the energy within the string. We recognize a target string (T) and a projectile string (P), which are the only chains in pp collisions. In multiple collision processes in a nucleus, sea quarks are additionally excited and may mediate nucleon-A interactions. While in the intermediate step the projectile di-quark remains inert, chains with the sea quark of the projectile are formed.

Most important are diffractive processes, signaled in the longitudinal momentum \((x_F = 2p_{\text{par}} / \sqrt{s})\) distribution by the diffractive peak in forward directions. Here the interacting nucleon looks like a spectator, in some kind of polarisation being slowed down a little bit due to a soft excitation of another nucleon by a colour exchange with sea quarks (quark-antiquark pairs spontaneously created in the sea).

There are a number of such quark lines, representing nondiffractive, diffractive and double diffractive processes, with single and multiple colour exchange.

The various string models differ by the types of quark lines included. For a given diagram the strings are determined by Monte Carlo procedures. The momenta of the participating partons are generated along the structure functions. The models are also different in the technical procedures, how they incorporate hard processes, which can be calculated by perturbative QCD. With increasing energy hard and semihard parton collisions get important, in particular minijets induced by gluon-gluon scattering.

In summary, the string models like SYBILL [13], QGSJET [14, 15], VENUS [16], NEXUS [17], DPMJET [18], and EPOS [19] which we specifically use as generators in Monte-Carlo simulations of air showers, are based on the Gribov-Regge theory. They describe soft particle interactions by exchange of single or multiple Pomerons. Inelastic reactions are simulated by cutting Pomerons, finally producing two color strings per Pomerons which subsequently fragment into color-neutral hadrons. The differences between the models are in some technical details in the treatment and fragmentation of strings and in procedures how to guarantee the conservation laws. An important difference is that QGSJET and DPMJET are both able to treat hard processes. SYBILL (2.1) contains a minimum of assumptions and is optimized to describe the features needed for air shower simulations. It cannot be used for simulating heavy ion collisions.

In EAS simulations the high energy models have to be complemented by low energy models for the interaction energies \( \lesssim 200 \) GeV. Used models of this kind are GEISHA [20], FLUKA[21] and UrQMD[22].

All these models which are implemented in the Karlsruhe Monte Carlo simulation program CORSIKA [23] – now worldwide used – and to which we refer in the analyses of data, are based on similar concepts, but differ in detail.

In Figs. 6-8 the predictions of such models are compared with the present knowledge from accelerator experiments. The models are considered as attempts to calculate the hadronic multiparticle production in a way able to allow consistently
an extrapolation to the *terra incognita* of hadronic interactions. On this way many ambiguities do appear, and there is no surprise that model predictions do significantly diverge at high energy. This stresses the importance of collider data as Fig. 8b demonstrates, showing the model predictions of the variation of density with the pseudo rapidity \( \eta = -\ln[\tan(\theta/2)] \), where \( \theta \) is denoting the emission angle relative to the beam axis. Already the first results of LHC provide strong constraints [24].

5. ANALYSIS OF EAS OBSERVABLES

The general procedure of the analysis of EAS observations (Fig. 10) is comparing the model predictions with observed EAS observables. Using Monte Carlo simulations pseudo-experimental data are constructed which can be considered in the light of the real data. The first attempt is just to compare simple
single observables (in a parameterized or non-parameterized form) with the MC predictions. Sometimes, for studying particular features unusual observables like the muon charge ratio in EAS are of interest [25]. This observable which may inform about details of the multiplicity distribution of secondary particles is currently under investigation in NIPNE Bucharest [26]. The king-way of the comparison is the application of advanced statistical techniques of nonparametric multivariate analyses of distributions of observables correlations [27] (Bayes decision making and neural networks). Nonparametric techniques account also for the influence of the fluctuations of the cascading interaction processes. But these techniques require a good statistical accuracy, also what concerns the simulations.

5.1. THE $N_e - N_\mu$ CORRELATION

A classic procedure in EAS investigations is the measurement of the number of electrons (electron size $N_e$) and of the number of muons (muon size $N_\mu$). These observables carry a lot of information on the energy and nature of the primary cosmic particle as well as of its hadronic interaction. Actually since the lateral distribution of the EAS muons is widely extended, a pure experimental determination of $N_\mu$ is difficult. Usually a standard lateral distribution function is invoked to extrapolate the muon distribution to the unobserved region. The KASCADE collaboration used the truncated muon number $N_{\mu}^{tr}$, which is the number of muons obtained from an integration of the lateral distribution adjusted in the radial range from 40 to 200 m. It has been shown that this quantity is approximately a mass independent energy estimator for the KASCADE layout, conveniently used for a first energy classification of the showers.

Experiments like KASCADE – Grande observe only the number of charged particles $N_{ch}$, from which $N_\mu$ has to be subtracted.

Fig. 11 – The correlation between the number of electrons and muons at sea level, simulated by the Monte Carlo program CORSIKA [23].
A powerful method involves studies of the \( N_e - N_\mu \) correlation. Fig. 11 displays some predictions for Fe and p induced showers for the EPOS model (with the largest \( N_\mu \)) and the SIBYLL model (with the smallest \( N_\mu \)). The difference in the muon numbers are related to the difference in the secondary particle multiplicity predicted by the models. Applying a correlation analysis to the experimentally observed correlation, though with difficulties due the uncertainties in the interaction model, has given evidence for the change of the mass composition of cosmic rays in the knee range from a mixed to a more heavy composition [29].

5.2. THE LONGITUDINAL SHOWER PROFILE

A further quantity of interest is the mean depth \( X_{\text{max}} \) of the maximum in the longitudinal shower development. This experimental quantity is accessible by observing the Cherenkov light produced by the electrons in air, or at higher energies by the nitrogen fluorescence light of the EAS. For such observations various installations are equipped for [see ref. 1].

Fig. 12 displays the longitudinal profiles of 10 proton, iron and photon induced showers as simulated with the SIBYLL model. As expected from the larger interaction length, protons exhibit larger fluctuations than Fe showers, photons penetrate deepest. Both the mean depth of the shower maximum \( X_{\text{max}} \) as well as the fluctuations of \( X_{\text{max}} \) from shower-to-shower are sensitive to the composition of cosmic rays.

![Fig. 12a – Longitudinal shower profile for 10 iron- proton - and photon - induced EAS of \( 10^{19} \) eV as simulated with SIBYLL. The experimental data correspond to one shower of approximately the same energy as observed with the PAO [30].](image)
Fig. 12b – Shower-to-shower fluctuations of $X_{\text{max}}$ from different models and data of PAO [31].

Fig. 12b compares model predictions of the fluctuations (RMS $X_{\text{max}}$) with data from the PAO displaying the trend from a predominantly light or mixed composition (at ca. $10^{18}$ eV) to a heavier composition at higher energies.

Fig. 13 – Mean depth of shower maximum: experimental results ([31 – 35]), compared with different model predictions.

The merit of the $X_{\text{max}}$ variation studies stems from control of various a priori reasonable extrapolations of the hadronic interaction models to the highest energies. For example a larger increase of the minijet production in the SYBILL
model would bend the proton curve as if the composition would be "proton like" at highest energies. Simultaneously the model would imply and constrain the extrapolation of the total cross section to the highest energies [36].

6. CONSISTENCY TESTS BY MULTIVARIATE DISTRIBUTIONS ANALYSES

There exists not only the possibility to compare the predictions of different models, there is also a test possibility of the internal consistency of one single model.

When attempting to reconstruct simultaneously the variation of the mass composition of cosmic rays, we express the mass composition by the value of the mean logarithm of A.

In ref. [28] results of the variation of the mass composition are given as deduced from the analysis of the correlations of different sets of EAS observables. Different combinations, though showing the same tendencies, lead to different results. The result teaches that the underlying model does not reproduce the internal correlations, as required by the nature. Such an information should influence the work of the model builders and is thanks to the multi detector character of the experiment.

7. EMULSION CHAMBER EXPERIMENTS AT HIGH MOUNTAIN ALTITUDES

The feature that the most energetic particles are concentrated in the core of the extensive air showers in their initial stages is the basis of the traditional emulsion chamber experiments on high altitudes, on Mt. Chacaltaya or Pamir e.g., which collect with a special technique continuously strong interaction data and registrate also peculiar events.

![Fig.15 – Schematic view of a typical emulsion chamber experiment [37].](image)
Fig. 15 shows a typical set up which provided a data set for testing different interaction features by the observation of hadron distributions. It is a particular type of chambers being in operation in the Pamir experiments: The PAMIR thick lead chambers [37]. They are characterized by a large thickness of the absorbers: 60 cm lead as compared to 3.3 cm mean free path of inelastic nucleon collisions. This assures almost 100% collision probability of the hadrons and allows the detection of electromagnetic showers all over the depth of the chambers.

A hadron incident upon the chamber undergoes a nuclear collision with multiple particle production and the surviving and produced hadrons experience further nuclear collisions, the collisions are indicated by electromagnetic showers following the decay of neutral pions, while minimum ionising particles (muons) are not registered by the emulsions. From the analysis of darkness of the spots the energy released at a single shower event could be estimated. The ratio $z$ of the first shower event (assumed to be proportional to the energy loss by the first collision) to some of the subsequent subshower energies is an estimate to the inelasticity $K$, the fraction of the primary energy converted into the secondary particles. Thus a Japanese group [37] has analysed events exceeding the energy of 30 TeV (more than any accelerator may provide in future) and has found as average value $<K> = 0.60 \pm 0.02/0.05$ for hadron-lead collisions.

This is only an example, how such experiments could contribute to the debate about energy variation of the inelasticity, which is an important quantity in controlling the interaction models.

8. PROTON – AIR CROSS SECTION

A classical problem relating cosmic ray physics to particle physics studies is the measurement of the proton - air production cross section beyond energies reached by fixed target and collider experiments. Early analyses of measurements were based on the assumption that unaccompanied hadrons have not interacted (attenuation of the primary flux). An improved approach considers the distribution of the depth $X_1$ of the first interaction point of air showers

$$\frac{dN}{dX_1} = \frac{1}{\lambda_{int}} \exp(-X_1 / \lambda_{int})$$

where $\lambda_{int}$ is the interaction mean free path of protons in air and related to the cross section by $24160 \text{ mb/g/cm}^2 / \lambda_{int}$. A recent review about this topic and improved methodical features are given in ref. [3].

As the first interaction point cannot be directly observed, various procedures have been developed to estimate the depth of the first interaction from correlations with air shower variables. As these correlations are dependent of the hadronic interaction, the simulation results unavoidably depend on the used interaction model, and the derived cross sections are affected by significant systematic
uncertainties. Fig. 14 shows a compilation of proton-air cross section results and predictions of hadronic interaction models. The cross section refers to the particle production cross section i.e. the inelastic part of the total cross section. All data above $10^{14}$ eV stem from EAS analyses while the results at lower energies originate from unaccompanied hadron studies.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure14.png}
\caption{Comparison of the p-air cross section predicted by interaction models with data of cosmic ray measurements [39 – 41].}
\end{figure}

The trend of the more recent results to yield systematically lower cross sections than predicted by the current interaction model is not understood. However most recently a determination of the p – air cross section has been reported by the Pierre Auger collaboration [42] for an energy of $10^{18.2}$ eV averaged over results from the use of various interaction models:

$$\sigma_{p-\text{air}} = \left( 505 \pm 22^{\text{stat}} \left( +23 \right)_{-15}^{\text{sys}} \right) \text{mb}$$

(3)

being perfectly in agreement with the EPOS prediction, e.g. A considerable contribution to the systematic uncertainty results from the uncertainty about the composition of the primary flux.

9. CONCLUDING REMARKS

This paper focuses the attention to the unique possibility to use observations of phenomena driving high-energy giant air showers as a source of information
about current problems in understanding the structure of high energy hadronic interactions [36], in particular in kinematically unknown regions. This view is illustrated by various, methodically slightly different examples of EAS observations by Earth bound detector arrays in particular like KASCADE (-Grande) and the Pierre Auger Observatory.

In addition of direct comparisons of average EAS observables with predictions of the constraints arising from different hadronic interaction models via Monte Carlo simulations, an interesting variant is provided by analyses of EAS observations by scrutinizing (preferentially by non parametric procedures) a single particular model, looking on the internal consistency of the results about primary energy and mass in multidimensional analyses of successively different sets of EAS observables. Such studies are enabled by multi detector experiments observing simultaneously a larger number of EAS variables: the sizes of different shower components in event-by-event mode, or when one observable of a particular EAS component could be measured simultaneously under different conditions. In experiments at high mountain altitude we do meet not only the chance to study the EAS components in a very early status of development. Moreover we can observe rather directly hadrons of ultrahigh energy and study their interaction by calorimetric devices. These calorimetric devices like large emulsion chambers, though worked out with very refined techniques, do still deserve our further technical attention. They may need some methodical modernisations, but they should not be ignored, in order to exploit more efficiently the information potential.

From the investigation of a series EAS observables and comparisons with different hadronic interaction models, presently en vogue for ultrahigh energy collisions, we do conclude that the QGSJET, SYBILL and EPOS models seem to reproduce the data in the best way. All current models are in a continuous process of refinements and modifications.

Any approach to understand the astrophysical origin of cosmic ray particles, whatever the energy range under consideration may be, has to be accompanied by serious studies of the hadronic interaction governing the energy regime. Otherwise the results remain stuck in model-dependence, and even the determination of the energy of the primary particles stays affected by this type of uncertainties. This is a current experience of various experimental approaches by large scale experiments, and it is the basic origin of actual controversial debates of the shape of the spectrum of the highest energies (see [1, 2]).

The uncertainties of the high-energy interaction models arise from the necessity to extrapolate over a large energy range, experimentally inaccessible. An additional complication is that the relevant phase space regions of particle production are not experimentally studied in current collider experiments. Hence there are serious discussions, how dedicated accelerator experiments may help in understanding cosmic ray data, and this question establishes a specific research line.
First LHC data at $\sqrt{s} = 7$ TeV have already put severe constraints on existing models [24]. Further progress is promised by future experiments measuring the cross sections and forward particle production at LHC: LHCf [43], TOTEM [44] and the forward detector CASTOR [45].

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