The Accelerator Data - Cosmic Ray Monte Carlo Interface; an Update

Lawrence W. Jones
University of Michigan, Ann Arbor, Michigan, 48109-1120, U.S.A.

Abstract

At the Hamburg ICRC 2001, the need for accelerator data at equivalent cosmic ray energies of a PeV and greater for the verification and refinement of Monte Carlo models of primary cosmic ray interactions was discussed. This presentation is an update on subsequent interactions and discussions of this important topic over the past two years. In 2002, the NEEDS Workshop in Karlsruhe and sessions at the XII International Symposium on Very High Energy Cosmic Ray Interactions at CERN focused on these issues. While no single, comprehensive experiment is scheduled which would answer all questions raised in these discussions, there are relevant initiatives and activities at each of the major hadron collider laboratories which merit recognition and support by the cosmic ray community.

1. Introduction

The discussion at the Hamburg ICRC in 2001 [1] summarized the need for accelerator data needed to improve the interaction models used in the Monte Carlo simulations required to interpret ground-based data - from air shower arrays, etc. - in terms of primary composition and interaction dynamics. As frequently discussed, the primary cosmic ray flux at and above a PeV (10^{15} eV) is too low to permit direct observation from balloon and/or satellite detectors, so that the understanding of the primary composition through the "knee" region of the spectrum is totally dependant on the indirect ground-based observations. And the different publications of primary mass composition through these energy regions reveal a complete chaos of disagreement. While the c.m. energies available in present and near-future hadron colliders reach the equivalent cosmic ray energies which are of interest, the coverage of the major 4π detectors misses the very forward region (of large pseudorapidity, η) wherein most of the final-state energy flows, and which therefore dominates the air shower observables.

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2. The NEEDS Workshop and Subsequent Discussions

In April 2002 the Karlsruhe group convened a "Workshop on the Needs from Accelerator Experiments for the Understanding of High-Energy Extensive Air Showers". The presentations at this NEEDS Workshop are on the Karlsruhe web site [2], and a summary report of the Workshop was carried in the CERN Courier [3]. At the XII International Symposium on Very High Energy Cosmic Ray Interactions, held at CERN in July 2002, a session was devoted to summarizing and discussing the reports from the NEEDS Workshop and related matters. These issues were also discussed in a seminar at Fermilab in August 2002 [4].

3. A Priority List

An objective and result of the NEEDS Workshop was a "Priority List" (shopping list) of desired data to be obtained from hadron collider experiments. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven accelerates protons or nuclei to energies of $250Z/A$ GeV in each beam; for proton-proton collisions this corresponds to a cosmic ray proton of 133 TeV on a stationary proton target. The Tevatron Collider at the Fermi National Accelerator Laboratory is operating at 950 GeV, producing proton-antiproton collisions at energies equivalent to a 2 PeV cosmic ray proton. The CERN Large Hadron Collider (LHC), scheduled to commence operation in 2007, will collide 7 TeV protons, equivalent to cosmic ray energies of over 100 PeV. The LHC program also includes nucleus-nucleus collisions.

A first priority is a measurement of the inclusive differential cross sections for the reaction products of proton - proton (or antiproton - proton) interactions vs. Feynman x, over the range $0.1 < x < 1$. Note that integration over transverse momenta is assumed. It is appropriate to recall also that final-state neutrons must also be included; at sub-TeV fixed-target energies, the final state forward baryon in a $p - p$ collision is a neutron about a quarter of the time. Forward gammas from neutral pion decays should also be included. These data are very relevant to the determination of the inelasticity distribution in the cosmic ray interactions, which is an important component of the interaction Monte Carlos and has been a perennial source of uncertainty and confusion.

The final state inclusive distributions of pion-nucleon interactions over the same ranges of parameters would also be of interest, although of course limited to more modest energies, as colliding beam experiments with pions are impractical. But even at fixed-target energies, more complete inclusive data would be welcomed. Inclusive distributions from $p - A$ and $A - A$ collisions are also of interest, in particular for A=14 (e.g. air nuclei). Theorists place the greatest emphasis on the $p - p$ interactions; they are reasonably confident of their handling of intra-nuclear cascading, although nuclear data would indeed be welcome.

Total cross section and inelastic cross section data, for $p-p$ interactions in particular, but also $p-A$, $\pi-A$, and $A-A$ are also important. Other measurements could be added to the list as lower priorities, such as 'centrality dependent' spectra, for example. The priority list agreed to at the NEEDS Workshop is indeed that outlined in earlier correspondence from the Karlsruhe group and summarized in the discussions two years ago [1]. One pragmatic measurement, useful for the Flys Eye group, would be a good determination of the fraction of the final-state energy which is 'invisible' to detectors such as theirs; i.e. what fraction of energy is carried away by neutrinos, energetic muons, and nuclear dissociation which do not contribute to the atmospheric scintillation signal. They have assumed an upper limit of 10% for this invisible energy but would like to confirm their assumptions from direct accelerator data.

4. Scheduled Relevant Accelerator Measurements and Experiments

During the late 1990s accelerator experiments were proposed which would have contributed significant data to these priorities, but were rejected in the face of higher priorities and the limited resources at Fermilab and CERN. At Fermilab, a modest experiment was proposed which would move the beam-beam interaction point back into a bending magnet near a straight section, permitting observation of neutral secondaries produced at or near zero degrees and of forward charged secondaries of both signs over a range of x [5]. With a specially designed vacuum chamber in the interaction region and with the flexibility of moving the interaction point to various azimuths in the accelerator magnets, a significant range of the forward pseudorapidity phase space could have been covered.

A more ambitious proposal was made at CERN to develop an LHC detector in the ALEPH experimental area with particular emphasis on the forward region. With forward magnets and associated detectors, it would have been possible to cover forward production over virtually the full range of Feynman x for charged particles, and a zero degree calorimeter would have provided measurements of neutrons and gammas. However this FELIX proposal [6] was also not accepted.

Of the operating collider experiments at RHIC, BRAHMS appears to have the greatest relevance to the priorities noted above. It has a forward magnetic spectrometer, and also a zero degree hadron calorimeter. Small angle coverage at the Fermilab collider, where the beam-beam collision point is at the center of the straight sections, is difficult because of the relatively short straight sections in the Tevatron. In this respect, the CERN LHC has an advantage because it employs the tunnel constructed for LEP (the electron positron collider) where 500 m straight sections were required for the radio frequency accelerator cavities.

At the CERN LHC, the CMS detector and related sub-systems appear to have the best potential for providing the information discussed above. The CASTOR detector is integrated into the CMS complex. It employs a hadron

and electromagnetic calorimeter system designed to cover $5.5 < \eta < 7.0$. The TOTEM experiment is also located in the CMS domain. This experiment, originally designed to study elastic scattering, has been elaborated by its CERN spokesman Karsten Eggert (the CERN spokesman for the FELIX proposal) to also collect data over a broad range of forward pseudorapidities. For the study of elastic scattering, it will employ "Roman Pots". However it will also employ special counter telescopes to study charged secondaries with pseudorapidies over the range $3 < \eta < 7$ [7]. There will also very probably be a zero degree calorimeter (ZDC) for the study of forward neutrons and gammas [8].

5. Conclusions

It thus appears that measurements will be possible at the LHC which will be valuable for the cosmic ray Monte Carlo interaction simulations, although admittedly not covering the complete "priority list" of desired data. And, with the LHC startup still four years in the future, the cosmic ray community will have to work with what relevant data will be produced at RHIC and the Tevatron Collider until then. Meanwhile the many air shower experiments probing the "knee" region of the primary cosmic ray spectrum will continue to study parameters and variables in an attempt to find an agreed upon combination of interaction models, detailed spectral shape, and primary composition vs. energy to which the different data sets can agree.

6. References

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