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REPORT ON THE OAK RIDGE WORKSHOP ON MONTE CARLO CODES FOR RELATIVISTIC HEAVY-ION COLLISIONS

Terry C. Awes
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

Soren P. Sorensen
University of Tennessee, Knoxville, Tennessee 37996 and
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

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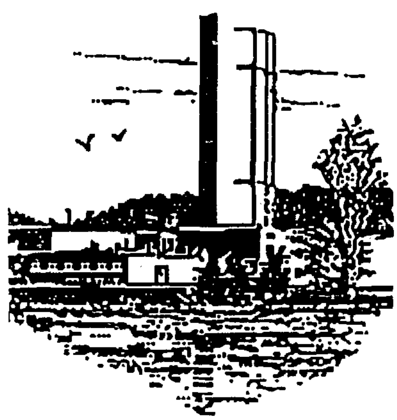

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REPORT ON THE OAK RIDGE WORKSHOP ON MONTE CARLO CODES
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Terry C. AWES

Oak Ridge National Laboratory,* Oak Ridge, Tennessee 37831, U.S.A.

Soren P. SORENSEN

University of Tennessee, Knoxville, Tennessee 37996, U.S.A., and
Oak Ridge National Laboratory,* Oak Ridge, Tennessee 37831, U.S.A.

It is widely believed that when nuclear matter is heated or compressed to sufficiently high energy density it will undergo a phase transition to a new state of matter in which the constituent quarks and gluons become deconfined over a large volume to form a so-called quark-gluon plasma (QGP). To produce, identify, and study the properties of such a plasma state is the primary goal of the field of relativistic heavy-ion collisions. Unfortunately, QGP identification is complicated by the complex nature of the heavy-ion reaction mechanism, its short expected lifetime, and the fact that it ultimately must return to the hadronic state upon cooling. The theoretical predictions for the QGP state and the experimental progress toward its observation and study are chronicled in the Quark Matter Conferences. It has become apparent that an unambiguous identification of the QGP state, as might be formed during a heavy-ion collision, will not be possible without a thorough understanding of what would be expected in the absence of plasma formation.

In order to make detailed predictions for the case of purely hadronic matter, several Monte Carlo codes have been developed to describe relativistic nucleus-nucleus collisions. Although these various models build upon models of hadron-hadron interactions and have been fitted to reproduce hadron-hadron collision data, they have rather different pictures of the underlying hadron collision process and of subsequent particle production. Until now, the different Monte Carlo codes have, in general, been compared to different sets of experimental data, according to which results were readily available to the model builder or which Monte Carlo code was readily available to an experimental group. As a result, it has been difficult to draw firm conclusions about whether the observed deviations between experiments and calculations were due

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to deficiencies in the particular model, experimental discrepancies, or interesting effects beyond a simple superposition of nucleon-nucleon collisions. For this reason, it was decided that it would be productive to have a structured confrontation between the available experimental data and the many models of high-energy nuclear collisions in a manner in which it could be ensured that the computer codes were run correctly and the experimental acceptances were properly taken into account. With this purpose in mind, a Workshop on Monte Carlo Codes for Relativistic Heavy-Ion Collisions was organized at the Joint Institute for Heavy Ion Research at Oak Ridge National Laboratory from September 12-23, 1988.

The format of the workshop was to invite representatives of most of the major experiments with results relevant to an understanding of nucleus-nucleus collisions and representatives of several of the nuclear collision models, and then to provide a framework within which cross-comparisons could easily be made between model and experiment or between the different models. To facilitate this comparison, a Monte Carlo (MC) framework was created, prior to the workshop, which acted as an interface between the various experiments and models. The structure of the framework is shown schematically in Fig. 1.

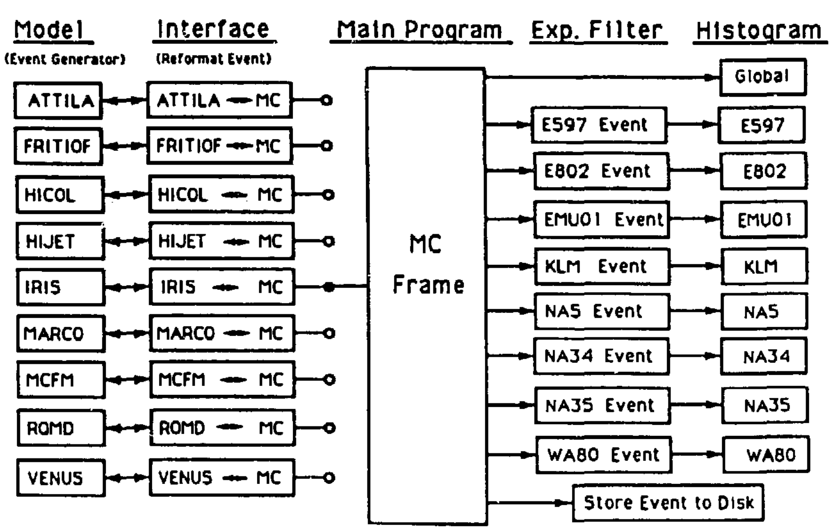

FIGURE 1
Schematic layout of the Monte Carlo code framework.

Within this framework, a standardized event format was adopted which used the ISAJET particle label convention based on quark content. Once a standardized event format is adopted, it is possible to create an acceptance routine for a given experiment which is independent of the particular model which creates the events. Thus, a clear separation of the tasks of the experimentalist and the theorist is obtained, with the theorist not having to know anything of the experimental acceptances and the experimentalist being spared the details of each of the Monte Carlo codes. The representative of each experiment was required to write only a single filter routine, based on the standardized event format, which accepted events as would be accepted in the experiment and which created histograms (using the CERN HBOOK4 routines) corresponding to the measured results. In addition, provision was made within the MC framework to histogram events without regard to any particular experimental acceptance in order to provide a global comparison between the models. It was also possible to write all events to disk for later analysis. The representative of each of the Monte Carlo codes was required to restructure the code into an initialization routine and an event-generating routine and to provide an interface routine to convert from the internal event format of the code to the standardized event format. The benefit of the standardized event format is obvious from Fig. 1. Once it is adopted, any model may be linked with the MC framework and immediately compared with a broad range of experimental results. Alternatively, a given experimental result may be immediately compared with many different models simply by linking with the various models.

At the workshop, results from proton-nucleus collisions were represented by results from experiment E597 at Fermilab and NA5 at CERN. Nucleus-nucleus collision results at AGS energies of 14.5 A GeV were represented by experiment E802 at Brookhaven. At the CERN-SPS energies of 60 and 200 A GeV, results were represented by those of experiments NA34/2, NA35, and WA80. In addition, representative emulsion results were included from experiment EMU01 at CERN and from the KLM collaboration at CERN and the AGS.

Nine different Monte Carlo codes for relativistic nucleus-nucleus collisions were represented at the workshop. These included ATTILA[1] and FRITIOF[2] based on the LUND string picture of hadron-hadron interactions. In this picture, each nucleon-nucleon collision results in excitation of the nucleon by the stretching of a string between the valence quark and diquark. A phenomenological excitation function determines the mass and momentum of the string after each interaction. After the last interaction the string decays to produce particles. Three other models based on a string picture of hadron-hadron interactions were also represented at the workshop. These were IRIS,[3] MCFM,[4] and VENUS,[5] all of which are "color exchange models" based on the Dual Parton Model (DPM) of Capella et al.[6] Here the basic mechanism of string formation is color exchange between the quarks of the colliding nucleons. In these models the string properties can be calculated from structure functions. The similarities and differences between the LUND model and the various DPM models have been discussed by Werner.[7] Other models represented at the workshop included HIJET,[8] which is an extension of the ISAJET model of hadron interactions, and MARCO,[9] which is based upon a phenomenological parameterization of nucleon-nucleon collisions and which emphasizes the problem of nuclear stopping. The above models are simple linear superpositions of nucleon-nucleon collisions, with the exception of ATTILA, which has the possibility of rope formation from overlapping strings, and MCFM and HIJET, which allow cascading of the produced particles when the assumed particle formation time is short. Two other models represented at the workshop with quite different approaches were the HICOL[10] and RQMD[11] models. HICOL is based on the Coherent Tube Model in which all of the projectile or target nucleons lying within a given tube are presumed to act coherently. RQMD is an extension to relativistic energies of the Quantum Molecular Dynamics which has been applied to nucleus-nucleus collisions at much lower energies.

During the period of the workshop, all nine models were incorporated into the MC framework and filter routines were created to produce a limited set of histograms for each of the experiments of Fig. 1. During the last week of the workshop, either 500 or 1000 events were produced for seven of the nine models for each of about 15 different reactions, yielding a total of nearly 20,000 produced spectra. Although it has not yet been possible to fully digest these results, it became immediately apparent that several of the models will need further development before final meaningful comparisons can be made. In particular, at the time of the workshop, only FRITIOF, HIJET, and VENUS were found to produce results which were not obviously incorrect and which conserved energy to a high degree. Although energy nonconservation, which arises in the treatment of particle production, has an effect which is perhaps minor at CERN energies, it resulted in entirely unreasonable results for several of the codes at AGS energies. Furthermore, the nucleus-nucleus collision geometry should be the same for all of the Monte Carlo codes since nuclear density distributions are well-known from nuclear physics and should not be treated as free parameters. However, when the calculated number of target participants for reactions of 200 A GeV $^{16}O + ^{197}Au$ were compared for the different models, significant differences were observed. This is shown in Fig. 2, where the number of target participants as a function of reaction impact parameter is compared for seven of the models. Here the result of FRITIOF, shown by the dashed histograms, has been used as a reference for all comparisons. Although the different models are in reasonable agreement (with the exception of HIJET, for which the number of target participants was apparently extracted incorrectly), it should be

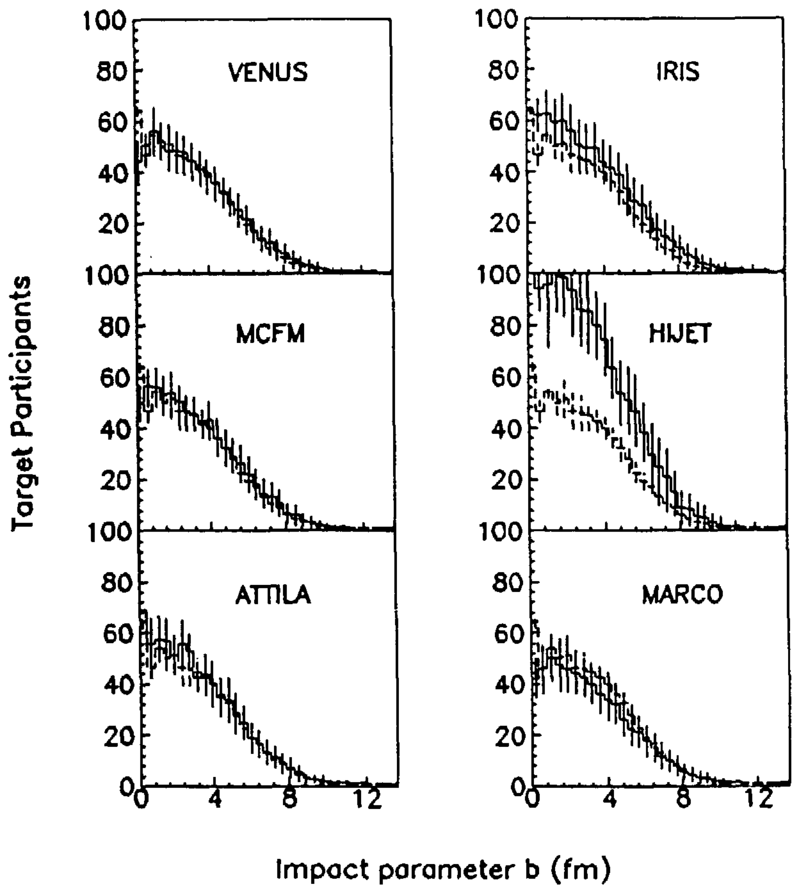

FIGURE 2
Number of participant target nucleons as a function of impact parameter for reactions of ^{16}O + ^{197}Au at 200 A GeV. The solid line histograms show the results from the six models which are compared to FRITIOF as shown by the dashed histogram in each case.

noted that deviations as small as 5-10% in the treatment of the nuclear geometry are significant since one hopes to draw conclusions about deviations from the measurements which are of a similar magnitude. A more sensitive indication of how the nuclear geometry and basic nucleon-nucleon interaction are treated is to compare the number of binary nucleon-nucleon collisions as a function of impact parameter, as shown in Fig. 3. Larger deviations between the models are apparent in this case, with FRITIOF giving more collisions than all other models, except HIJET. It is clear that before firm conclusions can be drawn upon the significance of the differences in the physics of the models at the nucleon-nucleon level, or on whether there exists experimental evidence for rescattering of the produced particles, or even for QGP formation, it will be necessary to ensure that the various models treat the nuclear geometry correctly and consistently.

Nevertheless, it is interesting to make some direct comparisons between the predictions of the different models to investigate the differences between them. Rather than compare the predictions of the models for a particular experimental measurement with limited acceptance, one can compare them in the

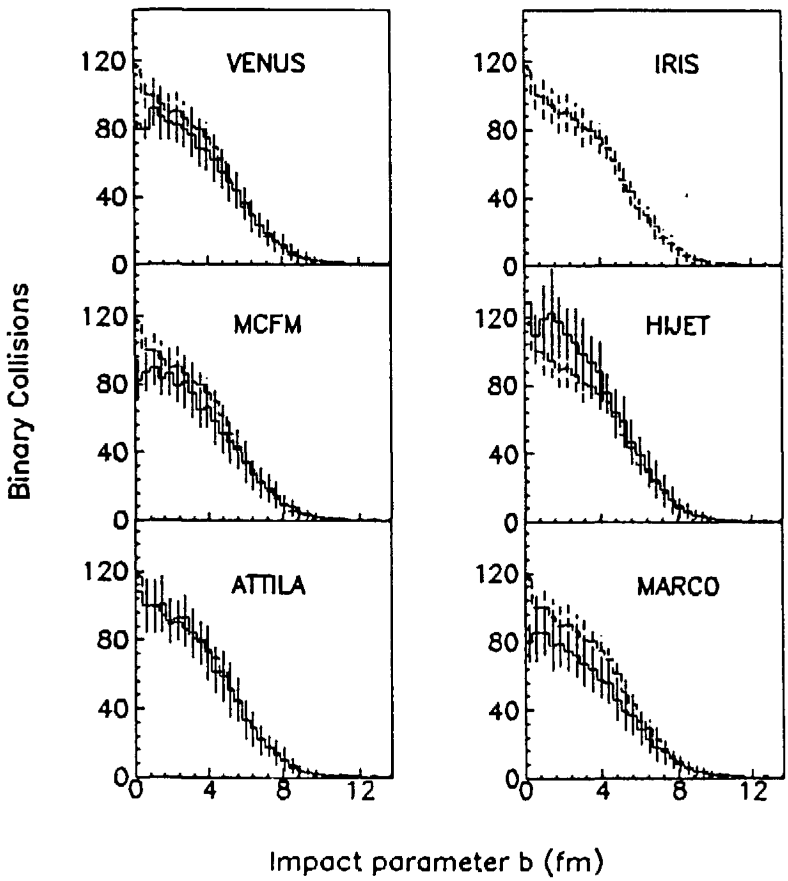

FIGURE 3
Number of binary nucleon-nucleon collisions as a function of impact parameter for reactions of $^{16}O + ^{197}Au$ at 200 A GeV. The solid line histograms show the results from the six models which are compared to FRITIOF as shown by the dashed histogram in each case.

case of a hypothetical global measurement with complete acceptance. The global E_T distribution for reactions of 200-A-GeV $^{16}O + ^{197}Au$ predicted by VENUS, IRIS, MCFM, and HIJET are compared to that predicted by FRITIOF in Fig. 4. For these comparisons MCFM has been run using a formation time of 1 fm/c, while HIJET has been run without secondary interactions. It is seen that although FRITIOF, VENUS, and HIJET have rather different pictures of the underlying nucleon-nucleon collision process, their predicted E_T distributions appear quite similar. On the other hand, VENUS, IRIS, and MCFM predict quite different distributions, although they are all based on the DPM picture of color exchange. In particular, the high-E_T slope predicted by IRIS is considerably flatter

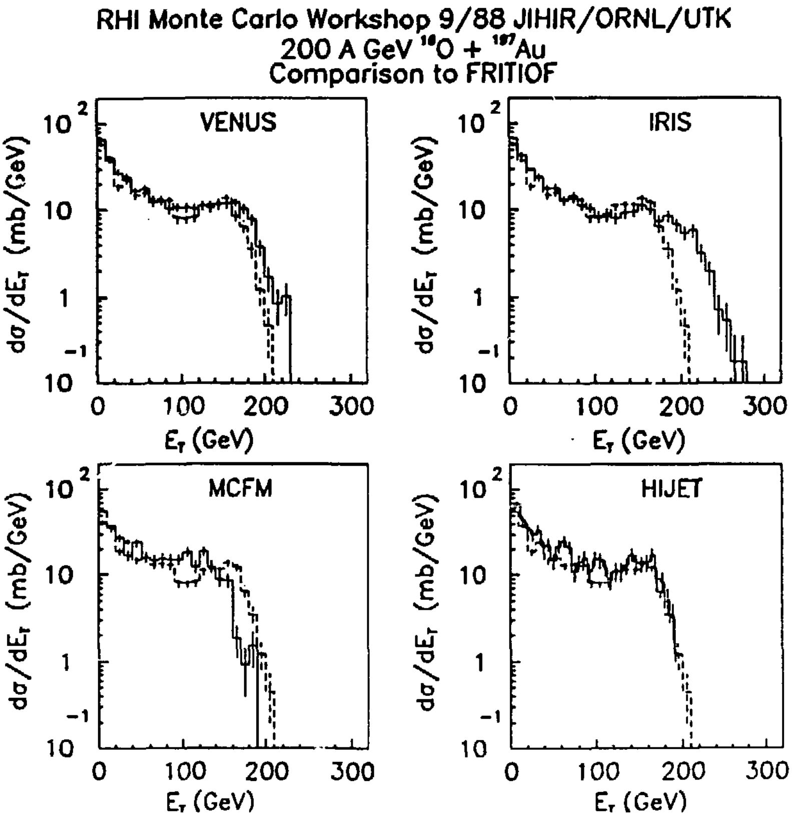

FIGURE 4
Total transverse energy for a complete acceptance measurement for reactions of $^{16}O + ^{197}Au$ at 200 A GeV. The solid line histograms show the results from the four models which are compared to FRITIOF as shown by the dashed histogram in each case.

than that predicted by the other models. Similar conclusions are obtained by comparing the charged-particle multiplicity distributions shown in Fig. 5. Here it is seen that the multiplicity distributions predicted by VENUS and IRIS both have a larger and flatter high multiplicity tail than predicted by the other models. It should be kept in mind that the E_T and multiplicity distributions are known to be sensitive to the collision geometry. Therefore, it is difficult to draw clear conclusions based on the results of Figs. 4 and 5, given the observed differences in nuclear geometry indicated in Figs. 2 and 3.

A result which is less sensitive to nuclear geometry but more sensitive to the nuclear stopping is the rapidity distribution of the participant protons.

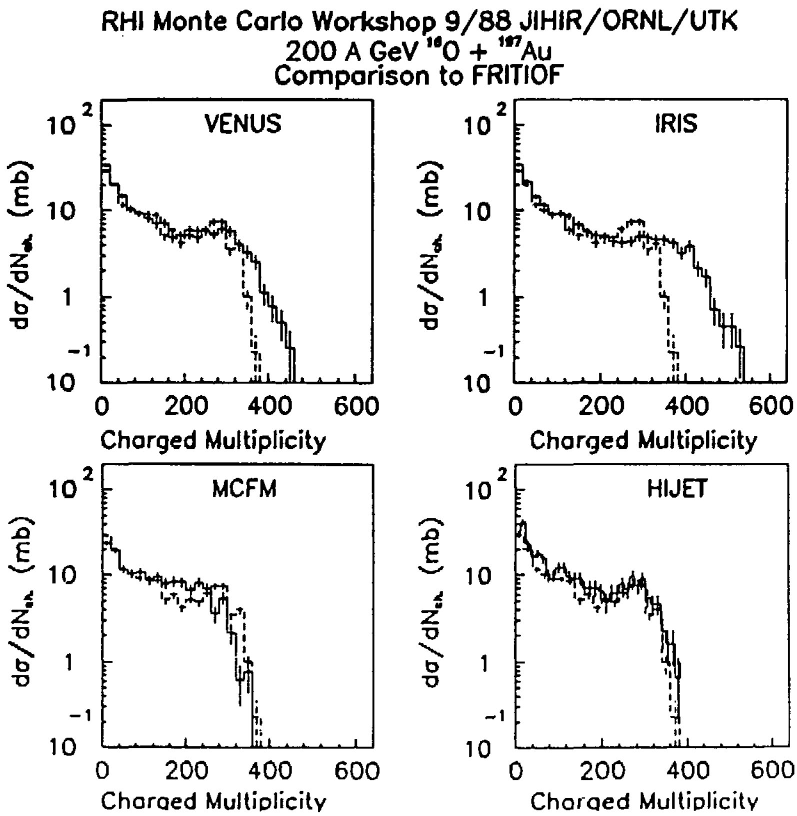

FIGURE 5
Total charged-particle multiplicity for a complete acceptance measurement for reactions of ^{16}O + ^{197}Au at 200 A GeV. The solid line histograms show the results from the four models which are compared to FRITIOF as shown by the dashed histogram in each case.

This is shown in Fig. 6, where the global participant proton rapidity distribution has been obtained by subtracting the distribution of all antiprotons from that of all protons, again for reactions of 200-A-GeV $^{16}O + ^{197}Au$. It is seen that VENUS, FRITIOF, and HIJET predict quite different participant proton distributions; whereas, they had predicted very similar E_T distributions (Fig.4), while the distributions of IRIS, MCFM, and FRITIOF are quite similar. Clearly, a comparison of such results with experiment will be useful to illuminate the underlying physics of the nucleon-nucleon collision process.

In conclusion, the workshop in Oak Ridge was extremely productive, simply from the viewpoint that it was possible to get many of the Monte Carlo codes to

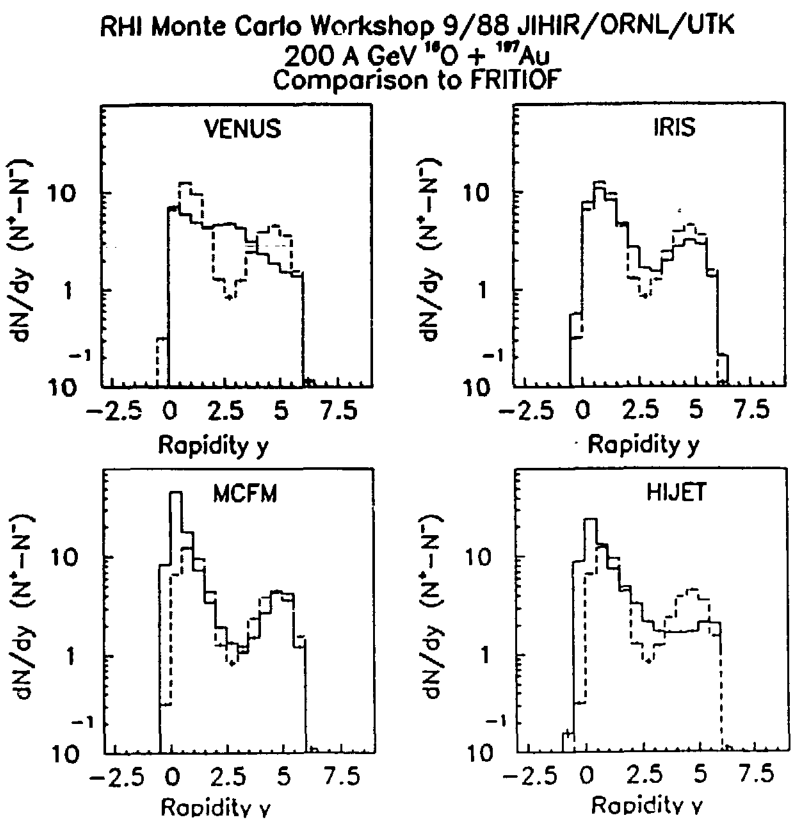

FIGURE 6
Rapidity distribution of protons minus antiprotons for a complete acceptance measurement for reactions of $^{16}O + ^{197}Au$ at 200 A GeV. The solid line histograms show the results from the four models which are compared to FRITIOF as shown by the dashed histogram in each case.

"speak the same language" by producing events with a standardized event format. The benefits to both theorists and experimentalists are obvious in that this allows an easy comparison between different models and a broad range of experimental data. It is strongly urged that the MC event format, or some similarly adopted convention, be adhered to in the future. During the short period of the workshop, deficiencies in several of the models and differences in how they handle the nuclear geometry became obvious, due to the ease with which the models could be compared. At present, it is planned to correct some of these deficiencies and then to make a more complete comparison between the models and experiment to attempt to obtain a clearer picture of the underlying physics and perhaps determine information on questions such as the degree of nuclear stopping, the particle formation time, and the importance of rescattering. These more complete comparisons are planned for a forthcoming Physics Reports.

REFERENCES

1) M. Gyulassy, preprint CERN-Th 4794/87.

2) B. Anderson, G. Gustafson, and B. Nilsson-Almqvist, Nucl. Phys. B281 (1987) 289; B. Nilsson-Almqvist and E. Stenlund, Comput. Phys. Commun. 43 (1987) 387.

3) J. P. Pansart, Nucl. Phys. A461 (1987) 521c.

4) J. Ranft, Phys. Rev. D 37 (1988) 1842.

5) K. Werner, Phys. Lett. 208B (1988) 520.

6) A. Capella and J. Tran Than Van, Z. Phys. C 10 (1981) 249; A. Capella, T. A. Casado, C. Pajares, A. V. Ramello, and J. Tran Thanh Van, Z. Phys. C 33, (1987) 541.

7) K. Werner, BNL Report 41502.

8) T. W. Ludlam, BNL Report 51921 (1985) p. 373; Asher Shor and Ronald S. Longacre, submitted to Physics Letters B; "ISAJET: A Monte Carlo Event Generator for pp and $\bar{p}p$ Interactions," F. E. Paige and S. D. Protopopescu.

9) C. Y. Wong, Phys. Rev. D 32 (1985) 94; C. Y. Wong, Proceedings of the International Conference on Medium and High Energy Nuclear Physics, Taipei, Taiwan, May 23-27, 1988 (Ed. W. Y. Pauchy Hwang), published by World Scientific Publishing.

10) N. Sarma, private communication.

11) J. Aichelin, G. Peilert, A. Bohnet, A. Rosenhauer, H. Stöcker, and W. Greiner, Phys. Rev. C 37 (1988) 2451; H. Sorge, private communication.