BNL--40999

APR 0 5 1988

DE88 007666

CONF-880260--1

The multistring model VENUS for ultrarelativistic heavy ion collisions

K. Werner

Physics Department
Brookhaven National Laboratory
Upton NY 11973

ABSTRACT

The event generator VENUS is based on a multistring model for heavy ion collisions at ultrarelativistic energies. The model is a straightforward extension of a successful model for soft proton–proton scattering, the latter one being consistent with e^+e^- annihilation and deep inelastic lepton scattering. Comparisons of VENUS results with pA and recent AA data allow some statements about intranuclear cascading.

Invited talk

Winter Workshop on Nuclear Dynamics V

Sun Valley, Idaho

22–26 February 1988

Die Arbeit wurde mit Unterstützung eines Stipendiums des Wissenschaftsausschusses der NATO über den DAAD ermöglicht.

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the U. S. Department of Energy. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution or allow others to do so, for U. S. Government purposes.

The multistring model VENUS for ultrarelativistic heavy ion collisions

K. Werner
Physics Department
Brookhaven National Laboratory
Upton NY 11973

The event generator VENUS is based on a multistring model for heavy ion collisions at ultrarelativistic energies. The model is a straightforward extension of a successful model for soft proton–proton scattering, the latter one being consistent with e^+e^- annihilation and deep inelastic lepton scattering. Comparisons of VENUS results with pA and recent AA data allow some statements about intranuclear cascading.

1. Introduction

The main purpose of the heavy ion experiments at Brookhaven and CERN[1,2] is to produce a new kind of matter: quark gluon plasma, a gas of free quarks and gluons. One way to detect such a phenomenon is to understand "ordinary" heavy ion collisions, collisions without any collective state involved, just pp extrapolation.

In this paper we construct a model for "ordinary" ultrarelativistic heavy ion collisons, which incorporates all the knowledge we gained in the past twenty years about deep inelastic lepton scattering and soft pp interactions. Considering a hierarchy of models from e^+e^- annihilation toward the very complex heavy ion collision should provide confidence into the nucleus–nucleus model, since model assumptions can be tested step by step: e^+e^- annihilation (at least in zero order approximation) is just quark–antiquark ($q - \bar{q}$) string fragmentation. Somewhat more complicated is deep inelastic lepton nucleon scattering: one has to deal with diquark–quark ($qq - q$) strings and also with the quark structure of the proton. Whereas in these leptonic collisions at least the basic boson–quark coupling can be calculated (in perturbation theory due to the large momentum transfer), the situation is more ambiguous when we proceed to proton–proton collisions: the majority of the pp events is soft (low momentum transfer), so we can't apply perturbation expansions; we have to rely on phenomenological models for string formation in pp collisions. Since, however, the string fragmentation in pp scattering should be treated as in the leptonic collisions, the only new ingredient — string formation — can be easily tested by comparing with a huge variety of pp data. Once we have derived a reliable model for proton–proton collisions, being able to reproduce (more or less) all available data in a certain energy range, it is nearly straightforward to extrapolate toward proton–nucleus and nucleus–nucleus collisions just by taking into account the (well known) nuclear geometry. No additional parameters should occur (apart from parameters characterizing the nuclear shape and the elementary pp cross section).

Several models have been constructed along these lines: LUND models[3,4] assume that every pp collision results in excited baryons. A phenomenological excitation function determines excitation energy and momentum of the baryon, which is further on treated as a particle-producing string. Another class of models are motivated by Regge phenomenology like Dual Parton Models[5–7] and VENUS,[8] which will be described in this paper. Here the basic mechanism to form strings is color exchange between the quarks of colliding nucleons. An advantage over LUND is that string properties can be calculated from structure functions (though an extrapolation toward low momentum transfer is necessary).

2. Multistring model for heavy ion collisions

In the following we give a short summary of the multistring model underlying the computer code VENUS. Before extrapolating toward pA and AA, let us consider proton–proton scattering. Color exchange

---

Die Arbeit wurde mit Unterstützung eines Stipendiums des Wissenschaftsausschusses der NATO über den DAAD ermöglicht.

is assumed to cause the formation of color strings: i exchanges of color between quarks of the projectile and target proton result in $2i$ strings. The relative weight of a i color exchange contribution is named w_i, thus cross sections can be written as a superposition $\sigma = \sum w_i \sigma_i$, where σ_i is the contribution consisting of $2i$ strings. We first describe the dominant $i = 1$ contribution, i.e. the formation of two strings: color exchange between a quark of the projectile and a quark of the target rearranges the color structure of the pp system: instead of two protons in singlet states we find two singlets each consisting of a diquark and a quark of the other nucleon (see fig. 1a). We explicitly treat the case in which one (or both) of the quarks participating in the color exchange is accompanied by an antiquark such that the $q\bar{q}$ pair is color neutral, because in this case the diquark quark ($qq-q$) string is replaced by a $q-\bar{q}$ string and a baryon. In figs. 1b,c,d we show this for the case when the projectile quark (b), the target quark (c), of both quarks (d) are part of colorless $q\bar{q}$ pairs. We generate quarks with and without $\bar{q}$ partners with probabilities w and $1-w$, so the relative weights of the contributions 1a,b,c,d can be expressed in terms of the parameter w (in a complicated way because certain events have to be discarded as unphysical). Higher order contributions ($i > 1$ color exchanges) are obtained by applying contributions a-d several times.

We try to make a straightforward extrapolation of the pp model described above toward nucleus–nucleus collisions. Since we introduced already the concept of multicolor exchange, it is very easy to generalize to collisions involving several projectile and target nucleons. First of all, the nucleons in each nucleus are distributed according to a Woods–Saxon density distribution. A projection of the nucleon positions (including the displacement due to the impact parameter) on the plane perpendicular to the beam axis defines nucleon–nucleon collisions whenever a projectile and target nucleon come closer than $\sqrt{\sigma_{\rm pp}/\pi}$. The nucleon–nucleon interaction is then treated as described above: one or more color exchanges occur (according to Fig. 1a-d) resulting in the formation of color strings. A heavy ion collision with two participating nucleons per nucleus might look as demonstrated in Fig. 2. In this example the third collision (= third color exchange, occurs between nucleons which suffered already a collision (wounded nucleons!), which does not pose any conceptual difference. However, as seen in this example, collision between "wounded nucleons" wouldn't increase the number of baryonic strings, showing thus a similarity to wounded nucleon models.[18]

To calculate string properties like virtual mass or rapidity of strings, we use the knowledge about the quark structure of the nucleon, as investigated in deep inelastic lepton nucleon scattering. We consider a system where projectile and target nucleon are fast (i.e. the cm system). Longitudinal momenta of quarks involved in color exchange are generated according to quark structure functions, the measured momentum distributions of quarks in nucleons. The transverse momentum is assumed to be exponentially distributed with an adjustable parameter $< p_t >$. The assumption of massless partons allows the calculation of string properties. To determine the particle production of strings, we use a Feynman–Field type of fragmentation algorithm,[9,10] with all parameters being fixed by comparing with e^+e^- annihilation and lepton proton scattering. Since in this way the fragmentation is used like a black box for hadronic collisions it should not matter which fragmentation procedure is used (provided the same parameters apply for leptonic and hadronic collisions).

3. Results

Before showing results we want to discuss the parameters. The momentum transfer Q^2 entering the structure function is taken to be $Q^2 = 4$ GeV^2. The probability w, that in a pp collisions an interacting quark is accompanied by anantiquark, is fixed such that the fraction of events with one surviving proton matches the ratio $\sigma_{\rm diffr}/\sigma_{\rm inel}$, which has over a wide energy range the value 0.2. For the mean transverse momentum $< p_t >$ of quarks in the proton, we use $< p_t >= 0.40$ GeV. For the multicolor exchange probabilities w_i we use an exponential distribution with a slightly energy–dependent mean value $< i > \approx 1.85$. It is obvious from this discussion of parameters that pp and also AA collisions are essentially (with very few additional parameters) expressed in terms of string fragmentation.

As (partly) shown in earlier publications,[8,10,11] VENUS can reproduce a wide variety of pp data (rapidity–, momentum–, transverse momentum, multiplicity–, transverse energy distributions and more at ISR energies) which provides much more a test of the model rather than just a fit. So, we have a reliable proton–proton model available and can proceed to investigate the consequences of extrapolating toward pA and AA collisions. As mentioned already, the extrapolation does not involve additional parameters other than the nucleons' mean free path through nuclear matter, and nuclear shape parameters, yet there are some difficulties like lack of knowledge about multiquark distribution functicns requiring assumptions (factorization).[8,13]

Before comparing pA results we should mention a qualitative difference of pA compared to pp collisions: a certain number of particles (with small rapidities) from string fragmentation were produced inside the target nucleus, thus having the possibility to perform collisions with target nucleons (cascading). This effect can be seen from NA5 data[12] showing an abundance of slow positive particles. To avoid "contamination" with slow spectator nucleons (= not from string fragmentation) we compare in Fig. 3 negative particle rapidity distributions for 200 GeV pp, pAr, and pXe reactions. The VENUS results show the same trend as the data[12] to have more and more particles produced at negative rapidities (y is the rapidity in the pp cm system), because for heavier targets more and more "target-like" strings contribute. A "target-like" string is a string with a baryon flavor content, moving in target direction. We have always ν "target-like" and one "projectile-like" string in an event with ν collisions. A noticable result is that even in the backward rapidity tails the VENUS results for pAr and pXe are pretty close to the data: there is not much room for additional production of negatives due to cascading. This is confirmed by Fig. 4, where the negative particle multiplicity distributions are in excellent agreement with NA5 data, whereas charged particle distributions are much flatter than VENUS predicts (missing spectator protons, probably). Since cascading occurs only in a certain rapidity range (< 0), we investigate in Figs. 5 and 6 multiplicity distributions for given rapidity bins in forward ($0 < y < y_b$ with $y_b = 0.5,\ 1.0\ \ldots 3.5$) and in backward ($-y_b < y < 0$) intervals. First of all, we observe both for charged and negative particles much broader backward than forward distributions, simply because more "target-like" than "projectile-like" strings contribute (for pAr on the average twice as many; therefore the distribution is approximately twice as broad). More remarkable is the following statement: the negative particle distributions are perfectly reproduced both in forward and backward rapidity bins, whereas VENUS underpredicts charged particle distributions in the two largest backward bins ($-3.5 < y < 0$ and $-3 < y < 0$). This effect is even slightly stronger for pXe. This again means that cascading essentially just knocks out some spectator nucleons, which are detected aroung $y = -3$ ($\hat{=} y_{\rm lab} = 0$), whereas the effect on pion production should be small.

Cascading is usually blamed for disagreement in E_t distributions between data and models, especially in the target, but also in the projectile fragmentation region. Fortunately three CERN experiments investigate different rapidity regions: NA34[14] ($-0.1 < \eta < 2.9$) covers the target fragmentation region, where cascading in the target should play a role; NA35[15] ($2.2 < y < 3.8$) covers the central region, which should not be affected by rescattering; WA80[16] ($2.4 < \eta < 5.5$) includes the projectile fragmentation region, which is thought to be affected by projectile cascading. To be consistent with the pA results, which indicate a moderate cascading effect, the VENUS results should not be too far off the data, even for NA34 and WA80. Figure 7 shows the results: agreement for NA35 (central region => no rescattering); slight underprediction for WA80, and somewhat more underprediction for NA35, especially for the heavier targets.

4. Conclusions

We conclude, even without considering cascading, that VENUS gives a fairly good description of pA multiplicity distribution and AA E_t distributions, both for a variety of rapidity regions. The effect of cascading might be smaller than expected[17] for the following reason: inelastic rescattering occurs in a certain rapidity interval $y_{\rm min} < y < y_{\rm max}$ where the upper limit guarantees that the particle materializes inside the nucleus. The fastest pions in this region are still pretty much forward peaked, so they travel a considerable portion of their way through a tube of "string matter" rather than nuclear matter. This means that interactions occur with forward-moving baryons (from string fragmentation) rather than with nucleons at rest, which results in a smaller collision energy.

Acknowledgements

I gratefully acknowledge discussions with S. Kahana, T. Ludlam, R. Longacre, F. Paige, A. Shor, and M. Tannenbaum.

References

1. Proceedings of the Fifth International Conference on Ultrarelativistic Nucleus–Nucleus Collisions, Asilomar, California, 1987, edited by L. Schroeder and M. Gyulassy, Nucl. Phys. A461 (1987).

2. Proceedings of the Sixth International Conference on Ultrarelativistic Nucleus–Nucleus Collisions, Quark Matter 1987, Schloss Nordkirchen, Z. Phys. C.
3. B. Anderson, G. Gustafson, and B. Nielsson-Almqvist, Nucl. Phys. B281, 289 (1987).
4. M. Gyulassy, preprint CERN–TH 4794/87.
5. A. Capella and J. Tran Thanh Van, Z. Phys. C10, 249 (1981);
   A. Capella, T. A. Casado, C. Pajares, A. V. Ramello, and J. Tran Thanh Van, Z. Phys. C33, 541 (1987).
6. J. Ranft and S. Ritter, Z. Phys. C27, 413 (1985);
   P. Aurenche, F. W. Bopp, and J. Ranft, Z. Phys. C23, 67 (1984).
7. T. P. Pansart, in (1).
8. K. Werner, in (2).
9. R. D. Field and R. P. Feynman, Nucl. Phys. B136, 1 (1978).
10. K. Werner, to appear in Acta Physica Polonica.
11. K. Werner, Phys. Lett. 197B, 225 (1987).
12. C. DeMarzo et al, Phys. Rev. D26, 1019 (1982);
    F. Dengler et al, Z. Phys. C33, 187 (1986).
13. K. Werner, J. Hüfner, M. Kutschera, and O. Nachtmann, Z. Phys. C37, 57 (1987).
14. HELIOS collaboration, T. Akeson et al, preprint CERN-EP/87–176.
15. A. Bamberger et al, Phys. Lett. 184B, 271 (1987).
16. R. Albrecht et al, preprint GSI–87–60.
17. G. Baym, P. Braun–Munzinger, and V. Ruuskanen, Phys. Lett. 190B, 29 (1987).
18. B. Bialas, A. Bleszynski, W. Czyz, Nucl. Phys. B111, 461 (1976).

Figure Captions

Fig. 1. The four basic (one color exchange) contributions to pp collisions. Color exchange (arrow) is the basic mechanism to rearrange color singlets (closed lines) and thus to produce strings. The contributions (a) to (d) differ in the number N of quarks being part of a white $q\bar{q}$ pair: $N = 0$ for (a), $N = 1$ for (b),(c), and $N = 2$ for (d). Contributions (b) and (c) may be referred to as "diffractive excitation," (d) corresponds to "double Pomeron exchange."

Fig. 2. A possible diagram for nucleus–nucleus collisions.

Fig. 3. Rapidity distributions of negative particles for pp, pAr, and pXe at 200 GeV.

Fig. 4. Multiplicity distributions of charged particles (left) and negative particles (right) for 200 GeV pp, pAr, and pXe. The Argon results are multiplied by 10; the Xenon results by 100.

Fig. 5. Multiplicity distributions for negative particles for forward and backward rapidity intervals: $0 < y < y_i$ and $-y_i < y < 0$ respectively (y is the rapidity in the pp cm system) with $y_i = 3.5,\ 3.0,\ 2.5,\ 2.0,\ 1.5,$ 1.0, 0.5 (from top to bottom). The curves are displaced by a factor of 10. The points represent negative binomial fits to data.

Fig. 6. Same as Fig. 6, but for charged particles (including slow protons!).

Fig. 7. Transverse energy distributions for 0 + Nucleus collisions for different rapidity coverage: target fragmentation region (left), central region (middle), and projectile fragmentation region (right).

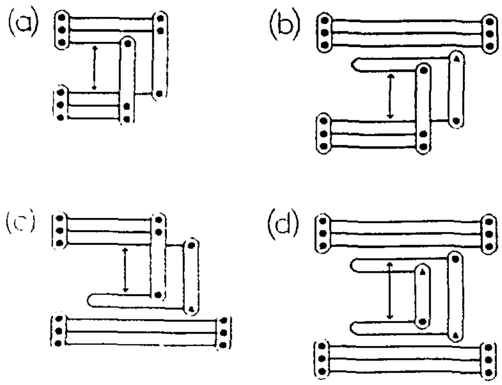

fig. 1

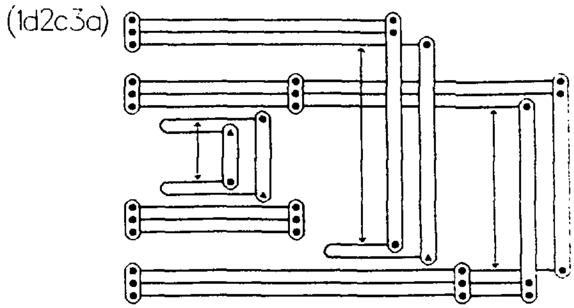

fig. 2

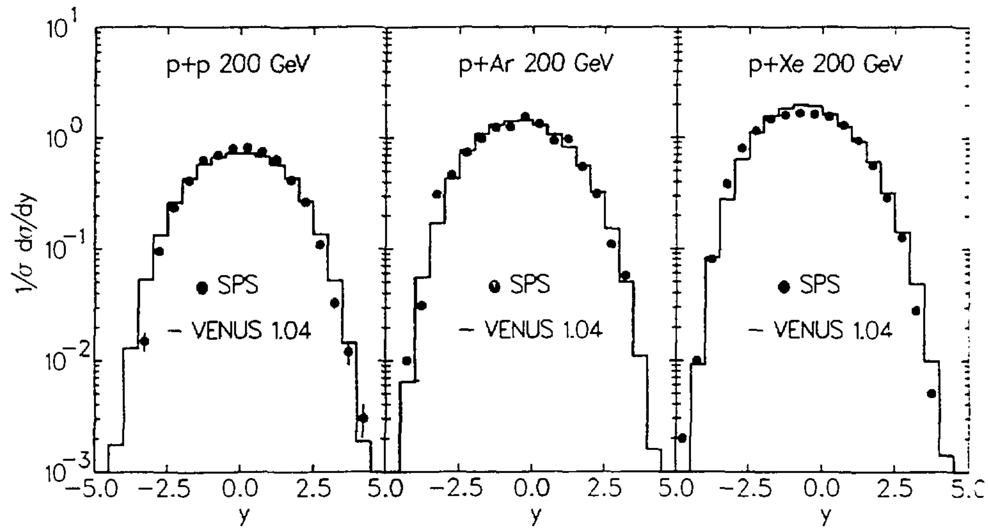

fig. 3

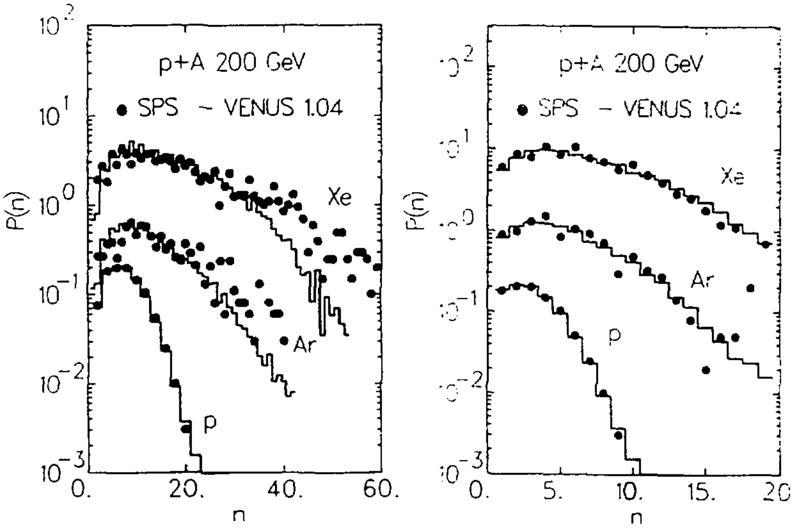

fig. 4

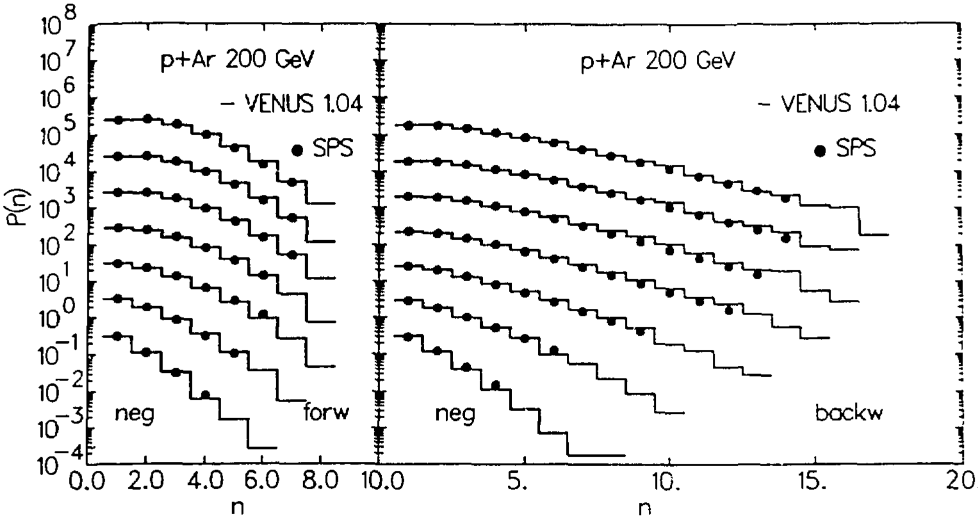

fig. 5

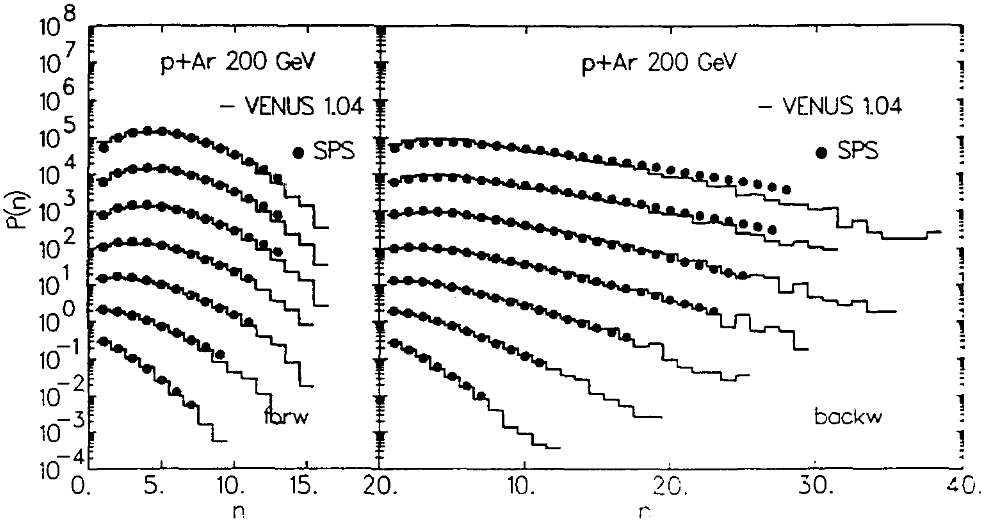

fig. 6

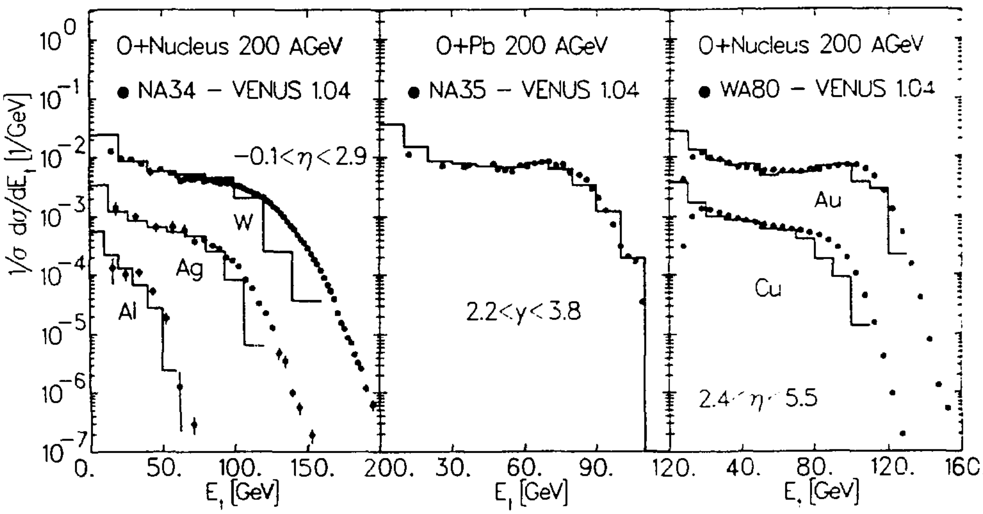

fig. 7