LBL-38304
UC-414

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Presented at the Fourth Rio de Janeiro International Workshop on Relativistic Aspects of Nuclear Physics, Rio de Janeiro, Brazil, August 28–30, 1995, and to be published in the Proceedings

A First Look at Pb on Pb Collisions at 160 GeV/c at CERN SPS

G.J. Odyniec

February 1996

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-38304
UC-414

A First Look at Pb on Pb Collisions at 160 GeV/c at CERN SPS

G.J. Odyniec

Nuclear Science Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

February 1996

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

A First Look at Pb on Pb Collisions at 160 GeV/c at CERN SPS

Grazyna J. Odyniec
Lawrence Berkeley Laboratory
Nuclear Science Division
Berkeley, Ca 94720, USA.

1. Introduction

Last year marked a major milestone in the field of relativistic nuclear collisions. Lead beams were successfully accelerated at CERN SPS to an energy of about 160 GeV per nucleon in the projectile (i.e. to about 32 TeV total energy) and the first preliminary results of the analysis of Pb on Pb interactions are already available and discussed. Before going on to the discussion of these results, it would be helpful to stand back for a moment and try to recapitulate what we have learned from light "heavy" ion experiments at CERN SPS with oxygen and sulphur beams.

In the first part of this overview we shall shortly summarize the results of the experimental program with ^{16}O and ^{32}S beams at CERN SPS[1]. Next, we shall describe the concept of an event-by-event (e-b-e) analysis proposed for study of individual Pb+Pb collisions with several thousand identified hadrons in the final state. The main section of this paper will be focused on the results (very preliminary !) of the analysis of the first run (fall 1994) with the lead projectiles. To conclude, we will present plans for the future (as we understand them now).

2. What we learned from the light "heavy" ion era at CERN SPS

In the laboratory the only possible way of creating a volume of hot, high energy density strongly interacting nuclear matter is to bombard heavy nuclei head-on at

[1] I presented the broad overview of this topic, here in Rio in 1991, during the 2-nd Rio Workshop, see proceedings edited by T.Kodama et al., World Scientific (1992) .

ultrarelativistic energy. With luck, we might be able to reach sufficiently large volumes and energy densities to create the quark-gluon plasma where partonic degrees of freedom will play a dominant role in the interaction dynamics.

Up until 1994, the only available relativistic ions at SPS energies were ^{16}O and ^{32}S. A pilot program to investigate the properties of such nucleus-projectile collisions with different targets was begun in 1986 with ^{16}O beams at 60 and 200 GeV/c, and next with 200 GeV/c ^{32}S beams. Despite expectations that these runs would provide mainly a first look at the phenomenology of high energy nucleus-nucleus collisions and a great deal of useful experience (both theoretical and experimental) that would be of value in a later phase with heavier projectiles and/or higher beam energies, a number of surprises have emerged, including the observations of possible quark-gluon plasma signatures. During the six year sulphur beam era at CERN SPS we gathered and analyzed a tremendous amount of data, the results of which are by now in their final form.

What did we learn? First, we learned that a significant fraction of the individual longitudinal energy becomes degraded during interaction (due to elastic and inelastic collisions at the microscopic level) and deposited into reaction volume. Fig.1 shows the rapidity distribution of net baryon density measured in S+S, S+Ag and S+Au collisions from the NA35 experiment [2]. Clearly, there is significant net baryon density at midrapidity. With increasing target mass an increasing number of projectile and target nucleons is shifted to midrapidity. However, a considerable amount of non-thermal motion is still observed in the longitudinal direction. We conclude that at 200 GeV/c heavy ions neither are transparent nor appear to come to a full stop. This observation should be confirmed by the shape of the rapidity distribution of the produced particles. And, indeed, it is. Fig.2 shows rapidity distribution for negatively charged hadrons calculated assuming the pion mass (more than 90 % of them are π^- mesons) for central S+S, S+Ag and S+Au collisions. The solid line indicates the rapidity distribution of relativistic pions emitted isotropically in the nucleon-nucleon (N+N) c.m. system (arbitrary units). This distribution is significantly narrower (by about a factor of 2) than the measured distributions of negatively charged hadrons, indicating a strong angular anisotropy of the negative hadrons.

Naturally, the energy deposited into an initial reaction volume (midrapidity in Fig.1 and Fig.2) increases the energy density there. We can estimate it qualitatively using the Bjorken formula [1] to be of the order of 2-3 GeV/fm^3 for S+Au collisions if τ_0=1 fm/c is used for the thermalization time[2]. We can conclude that this should be

[2] At present, τ_0 must be consider as an arbitrary parameter.

sufficient to match the goal set by the lattice QCD results even allowing for uncertainty related to the τ_0 parameter of the Bjorken approach.

The next question is whether a high enough temperature is reached in the interaction volume to create a quark-gluon plasma. This is not an easy question because any equilibrium reached is at best transient, and because the system is expected to expand[3] and cool down before emitting the particles which are observed. The observed inverse slope parameters ("temperatures") of all hadrons, except pions where contribution from the resonance decays is substantial, are surprisingly high. See for example Table 1 where "temperatures" of strange particles measured by the NA35 experiment are presented. All values are of the order of 200 MeV.

The conclusion of observations, that the initial conditions reached in the collisions are suitable for production of a quark-gluon plasma, is not a surprise: the experiments were designed for such a study. However, observation of a signature for plasma production would be a surprise, since it was expected that the size of interaction volume for light projectiles like ^{32}S would be too small for an equilibrium to be established. I will mention here only two of the major surprises. The most striking one in the CERN light "heavy" ion program was obtained by the NA38 experiment in which J/ψ production was observed to have all the properties previously predicted for quark-gluon plasma formation (see C. Gerschel paper in this proceedings). Various post hoc explanations have been proposed to avoid the necessity of such a conclusion. The next major surprise was encountered by NA35, NA36 and WA85 experiments: the observation of a substantial enhancement of strange particle production, which finds its most natural explanations in terms of quark-gluon plasma formation [2-4]. The enhancement is seen in many channels from K and Λ to Ξ and Ω. Enhancement of singly strange particles is quite successfully described by hadronic cascade models [5-6], whereas the same models can not explain multistrange and strange antybaryon yields without introducing completely new, non-intuitively obvious mechanisms (e.g. "colour ropes" in RQMD [7].

Fig.3 shows a summary of the word data on various particle ratios involving Λ, $\overline{\Lambda}$, Ξ and $\overline{\Xi}$ (from WA85 and WA95 experiments). The comparison with the previously published p+p data [8] (solid symbols) indicates that the enhancement in the $\overline{\Xi}/\overline{\Lambda}$ in S+W and S+S is a factor two over the p+p results. These data are of great importance since the information on singly strange particles alone is not conclusive and does not

[3] The expansion may also be complicated by hydrodynamical flow, of interest in itself.

allow us to distinguish unambiguously between the hadronic gas and quark-gluon plasma scenarios.

The scope of this overview does not allow us to continue with further S+A results [4]. Let us shortly summarize the many new things we learned:

The ^{32}S beams experiments at CERN SPS

- have broken new ground in the characterization of ultrarelativistic nucleus-nucleus collisions,
- have provided a broad survey of the properties of these collisions,

and

- have also provided suggestive evidence of new phenomena which may be related to quark - gluon plasma formation.

3. Event by Event Analysis

At CERN SPS and, later on, at heavy ion collider experiments (RHIC and LHC), we will analyze in a single nucleus-nucleus collision several thousands of final state identified particles. The 'interesting' events which might lead to the discovery of plasma formation are expected to be rare and then only as a limit of the fluctuation in the reaction dynamics trajectory. Moreover, they may differ only very little from the 'ordinary' events. Event-by-event (e-b-e) analysis may thus be the only viable approach which will allow us to recognize and separate these events one by one for further study.

The concept of e-b-e analysis is not new in heavy ion physics. It was successfully used before at lower energies, e.g. at Bevalac experiments (1-2 GeV/c per nucleon) the phenomenological pattern, resolving non-trivial rare candidate events from a predominant background of lesser informational value allowed extraction and quantifying of the collective flow of nuclear matter [9-10].

The e-b-e analysis strategy can be briefly described in two steps:

I. *Separation of extreme events from the bulk of average events:*

The individual event does not reveal the features that become visible in an ensemble of events (e.g. temperatures, K/π ratio etc.). A first round of analysis would determine the event characteristics (energy density, baryon density, $\bar{p}/p$, K^-/K^+ ratios, 'temperatures' etc.) which will allow to define sub-ensembles (probably on the few percent level) that contain the extreme tail events corresponding to each of the

[4] you will find more informations in the previous Rio Workshop Proceedings.

investigated variables i.e. we will select extremely strange events or extremely dense events or extremely hot or large or etc.

II. *Separation of a class of events exhibiting simultaneous fluctuations:*

If a transient partonic state near equilibrium causes these fluctuations ('tails' discussed in I) they must occur simultaneously in the candidate events. We need to look for a class of events where fluctuations of relevant observables are correlated. Our final sub-ensemble will consist of events which are extremely strange and extremely hot and extremely dense etc.

It is very important to realize that this final ensemble of 'interesting' events (comprising of ~ 10^7 - 10^8 analyzed hadrons at the CERN SPS Pb-experiment) will still allow detailed study of shapes of the hadronic distributions, the yield ratios, HBT, etc.

If hadronic signals bear any memory at all of the plasma phase - it will be identified here.

4. Pb on Pb Experiments at 160 GeV per nucleon at CERN SPS

All predicted plasma formation signatures require highly specialized experimental setups with state of the art dedicated detectors. Usually the experimental requirements are orthogonal to each other and therefore the optimization of the layout for one observable limits drastically its capability for detection of another one. This is the reason that instead of one or two major universal experiments we see a rather substantial number of large fixed target experiments in the Pb program at CERN SPS.

Fig.4 taken from [11] lists large and small experiments at CERN SPS. The blocks show the family history of each experiment and a summary of the beams provided to the experiments. Seven of the large experiments (see "^{208}Pb" symbol in the right lower corner) carry a program with Pb beams: NA44[5] (magnetic spectrometer for study inclusive spectra and interferometry [12]), NA45 (Ring Imaging Čerencov detector system for e^+e^- pairs measurements [13]), NA49 (Time Projection Chambers system for charged hadron and neutral strange particle study [14]), NA50 (magnetic spectrometer to measure $\mu^+\mu^-$ pairs [15]), NA52 (high resolution magnetic/time of flight spectrometer aimed for strangelet search [16]), WA97 (silicon telescope for strange (anty)baryons study [17]) and WA98 (photon-hadron calorimeter/ spectrometer for direct photons, π^o, and η's [18]).

[5] We list experiments in the order of increasing numbers :44->45->49->50->etc ...

While all the major experiments are focused on different observables, they still cover a significant region of overlapping phase space allowing for comparison and cross-checks of the results.

The lower part of Fig.4 shows a family of small experiments based mainly on emulsion techniques. Four of them (EMU12, EMU13, WA101 and NA53) participate in the Pb program.

A massive amount of data was accumulated during the first run (Fall'94) and the first, highly preliminary results were presented in an exceptionally short time (two months after completion of data taking) during the Quark Matter'95 Conference in Monterey, California [19].

At the present time, while the results are more stable and understood, they still remain preliminary. In the next sections we will follow up on the most intriguing ones.

5.Energy density and stopping

In this chapter we will come back, with more detail, to the discussion of the energy density reached in the nuclear collision.

Energy density cannot be measured directly. However, we can estimate its value using the Bjorken formula (as we did in chapter 2) and measured the related quantity, dE_T/dy.

dE_T/dy is usually measured by calorimetry. Fig.5 shows the transverse energy (E_T) spectrum at mid-rapidity from Pb+Pb and S+Au collisions as recorded by the electromagnetic/hadronic shower calorimeter of the NA49 experiment. The spectrum reflects the collision geometry: large values of cross section for large impact parameters, followed by a plateau for a large range of impact parameters, where the two nuclei partially overlap, and rapidly vanishing cross sections for high E_T values. In the same figures, the predictions of Fritiof and Venus models are shown. Results of calculations of both models differ significantly from each other, especially at the tails of the distribution. Venus, which includes explicitly secondary interactions of the produced particles, describes the data much better. The triangle symbol denotes the mean E_T value in near head-on collisions, calculated in a geometrical manner, and corresponds to $dE_T/d\eta$=388 GeV. This leads, via the Bjorken formula, to the energy density $\varepsilon \sim 3$ GeV/fm^3, which is about 15 times higher than the ground state energy density (0.16 GeV/fm^3) of nuclear matter and it is in the range where deconfinement is expected.

This value is similar to the corresponding result in S+Au collisions at the slightly higher projectile energy of 200 GeV/nucleon. We observe that the energy density of an average central collision does not increase with increasing projectile mass whereas the reaction volume increases by a factor of about 3.5.

Extrapolation to a full phase space leads to the results that Pb+Pb collisions create a total transverse energy of about 1 TeV.

We will use this number to estimate nuclear stopping, which we define here as a ratio R of transverse energy of produced particles, E_T to E_{T-MAX}, energy corresponding to "full stopping" of all incoming energy in a single fireball, isotropic in momentum space ($R=E_T/E_{T-MAX}$). In Pb on Pb collisions it was found that R_{PbPb} =~60 % [14] what demonstrates that Pb on Pb collisions at CERN energies are fairly intransparent. The remaining fraction of the c.m. energy of about 2.5 TeV in Pb+Pb , should be seen in the longitudinal direction. And, indeed, it is. Fig.6 shows the rapidity distribution of negative hadrons (mostly π-) observed in the same events. The measured distribution (full symbols) is reflected (open symbols) with respect to the c.m. rapidity. The solid line indicates the shape of the rapidity distribution (arbitrary normalization) of relativistic pions emitted isotropically in the N+N c.m. system. The dark line indicates the gaussian fit to the data. The distribution for central S+S collisions at 200 GeV/nucleon is indicated by stars. The shapes of the distributions of central Pb+Pb and central S+S collisions [20] are similar[6] and about two times broader than the distribution for isotropic emission, which is consistent with the picture of the partial stopping emerging from the previous considerations.

Fig.7 shows the proton rapidity distribution observed in central Pb+Pb (NA49 experiment) and in S+Au collisions (NA35 experiment). Both spectra are rather similar in shape and peak at mid-rapidity as expected for "participant" protons. Both are far too broad for a scenario of "full stopping", however both demonstrate the presence of a significant degree of stopping.

The same observation was made by the NA44 experiment. It was a very important cross-check of the analysis, since NA44, being a focusing spectrometer experiment, has excellent direct particle identification capabilities, which limits contamination to the 1 % level, whereas the NA49 does not identify protons directly[7].

Fig.8 shows protons from S+S and Pb+Pb interactions, measured (directly) in the NA44 spectrometer. Solid squares represent data, open squares - reflection around c.m. rapidity. Trends observed in S+S and Pb+Pb are significantly different: protons in Pb+Pb pile up in mid-rapidity, whereas it is not the case in S+S collisions. We observe a

[6] which suggest s that the rescattering has very little, if any, influence on π- spectra.

[7] NA49 uses so called (+)-(-) -technique which allowed to deduce the net proton distribution from the measurement of the charge excess, for details see [2].

higher degree of stopping in heavier system, similarly like in case of NA49 data. Open circles represent results of RQMD model calculations. The model follows the data rather well.

Summarizing stopping and energy density studies, we conclude that, at Pb+Pb collisions at CERN SPS we observe a sufficient amount of energy deposited into the interaction volume (stopping at mid-rapidity estimated to be ~ 60%) to reach the energy density of ~ 3GeV/fm^3 necessary for plasma formation[8].

6. Transverse energy spectra and flow

In the previous section we saw the increasing nuclear stopping with the mass and the size of the system. In S+S we observed about 1.5 units of rapidity shift whereas in Pb+Pb it is above 2 units. Naturally, one should expect to see an increase in production of the particles (mainly pions) proportionally to the increase of the energy deposited into interaction volume. However, this is not the case. The number of pions per participating nucleon is roughly constant in all analyzed reactions (S+S, S+Au and Pb+Pb)[9], while the missing stopped energy appears in the transverse energy of the final state hadrons. Already in S+Pb collisions at 200 GeV/c we observed inverse slopes of transverse energy distributions of the order of 250 MeV for protons and 340 MeV for deuterons - see Fig.9 (NA44 experiment). In Pb+Pb those 'temperatures' are even higher - see Fig.10 (NA49 experiment) - and reach values of the order of 280 MeV. The data points are well reproduced by thermal fits (single component fit), but the values of derived 'temperatures' far exceed the Hagedorn limit of any kind of hadron gas (T_H~170 MeV). This effect was observed neither in p+p nor in p+A collisions, where all 'temperatures' stayed below 200 MeV. Fig.11 shows the complete systematics of inverse slopes of transverse energy distributions in pp, pA and AA reactions at CERN energies. We are led to the conclusion that the hadrons in A+A reactions carry much more transverse energy than expected from a thermal Hagedorn model and that this effect is enhanced with the increasing mass of nuclear projectiles, whereas it is absent in pp and pA collisions. This implies the presence of an additional mechanism, beyond simple thermal emission. The most natural candidate appears to be radial collective flow, derived from a hydrodynamics.

---

[8] according to QCD calculations, see e.g. J.B.Kogut, Nucl.Phys.A418 (1984) 381c or H.Satz, Nucl.Phys. A418 (1984) 447c.

[9] however it increases from p+p to A+A

Let us discuss this interpretation a little further. The shapes of the proton (and other hadrons) m_T spectra are well described by a single exponent fit, so the direct observation of flow must come from somewhere else. We base our argument for the existence of flow solely on the fact that the spectra reveal an initial E_T density that exceeds any conceivable hadron gas temperature value. Such a high value of E_T could only survive into the late hadron freeze-out stage if the system went through isentropic (constant entropy) expansion preserving memory of the phase from which it emerged. These findings suggest that, perhaps, we see the very first hints of an early formation phase.

7. Strangeness and strange matter

Having in mind the intriguing results on enhanced strangeness production in S+A experiments, we are awaiting with great interest the results on strangeness production from Pb+Pb interactions. At the time of this Workshop, two experiments, WA97 and NA49, have already presented clear signals of Λ, $\bar{\Lambda}$ and K^0. The data are not fully corrected yet, so we look at it rather as a promise of interesting physics. Fig.12 shows the preliminary invariant mass distributions of ($\pi^+\pi^-$) and ($p\pi^-$)with clear peaks seen at the correct rest masses of K and Λ, obtained with the WA97 silicon telescope.

Another very interesting (and experimentally challenging) topic related to strange flavor is the question of possible existence of strange matter, where two light flavor quarks combine with the strange quark to form stable entities.

Strangelets, nuggets of strange matter, are considered to be an ultimate signature of quark gluon plasma formation [21-23]. Their discovery would have dramatic implications far beyond the QGP issues. If discovered - and if strange matter turns out to be stable - it would establish in nature a new, not yet observed, ground state of matter [24-26].

The key to detecting strangelets is to take advantage of their small charge-to-mass ratio (strange matter should have a ratio as small as 1:10 or 1:20, whereas in normal nuclear matter it is 1:3). Therefore the most promising instrument for strange matter search appears to be a magnetic spectrometer.

Several experiments are currently under way. At CERN, the NA52 experiment began a program to look for new forms of matter with the first Pb-ion run. NA52 uses a relatively complex, about 0.5 km long spectrometer for secondary charged particles [27]. Besides strangelets, they are addressing production yields and rapidity distributions of particles near 0^0 production angle. While there is no report on evidence of strangelets yet, the first rapidity and centrality dependencies for the yields of π, K, p, $\bar{p}$, d and $\bar{d}$ are presented - e.g. see Fig.13.

8. Interferometry

Kaons and pions are emitted rather late in the evolution of a heavy ion collision, at the time of "freeze-out" when the hadrons cease to interact. Their correlations reflect the space-time evolution of the later part of the collision. In addition to characterizing the collision, correlations can signal a phase transition as they measure the duration of hadronization and particle emission, which should be long in both a first- or second-order phase transition [12].

The first, and of course very preliminary, results from Pb on Pb analysis are already available. Compared to S+Au there is an increase of about 40% in the transverse and somewhat less in the longitudinal correlation length (NA44 and NA49 experiments) [12, 28].

9. 'Small' Pb-beam experiments at CERN SPS

There is a number of very interesting results emerging from so called "small" experiments in CERN Pb-beams program. As an example, we will show some results from the WA101 experiment. WA101 uses the newly developed technique of the BP-1 phosphate glass detector [29] to characterize various processes like nuclear fragmentation, electromagnetic dissociation, nuclear capture and stripping, nuclear pickup, nuclear and electromagnetic spallation etc.

Fig.14 shows [30] a charge histogram of projectile and projectile fragments produced in collisions of Pb ions. We see that the charge resolution is very good.

Small experiments, using different techniques and apparatus are able to address issues left out by major experiments. Therefore, their outcome may contribute important, complementary information to the 'big' picture of Pb on Pb collisions at 160 GeV/c.

10. Conclusions

There is a lot of data gathered during the first Pb run at CERN SPS. Only a small part of it has, so far, been analyzed, but results, though still preliminary, already reveal new physics. There is a number of new data taking runs planned for the coming years

(~ one per year), so much more data will be collected. The large systems are clearly much more amenable to a thermal description and are also expected to show signals more clearly, but they are far more complex and CPU intensive than anything we have ever analyzed before. Therefore, it might be quite some time before we will be able to draw definite conclusions on issues of QGP formation, but they are coming ...

References:

1. J.D.Bjorken, Phys.Rev. D27, 140 (19983).
2. D.Rohrich, et al., Nucl.Phys. A566 (1994) 35c,
   M.Gazdzicki, et al., Nucl.Phys. A566 (1994) 503c.
3. S.Abatzius, et al., Phys.Lett. B316, 615 (1993); Nucl.Phys. A566,225c (1994).
4. E.Andersen et al., Phys.Lett. B327, 433 (1994); Phys.Lett. B294, 127 (1992).
5. R.Mattiello, H.Sorge, H.Stocker, W.Greiner, Phys.Rev.Lett.63,1459(1989).
6. K.Werner, J.Aichelin, Phys.Lett.B 308 (1993)372.
7. H.Sorge et al., Phys.Lett. B 289 (1992).
8. S.Abatzis et al., Phys.Lett. B 270, 123 (1991).
9. H.A.Gustafsson et al.,Phys.Rev.Lett. 52 (1984) 1590.
10. P.Danielewicz and G.Odyniec, Phys.Lett. 157B (1985)146.
11. J.Thomas and P.Jacobs - A Guide to the High Energy Heavy Ion Experiments, QM'95,1995.
12. B.Jacak et al., Nucl.Phys. A590 (1995) 215c.
13. P.Wurm et al., Nucl.Phys. A590 (1995) 103c.
14. S.Margetis et al., Nucl.Phys. A590 (1995) 355c.
15. S.Ramos et al., Nucl.Phys. A590 (1995) 117c.
16. G. Appelquist et al., Nucl. Phys. A590 (1995) 347c.
17. F. Antinori et al., Nucl.Phys. A590 (1995) 139c.
18. T.C.Awes et al., Nucl.Phys. A590 (1995) 81c.
19. Quark Mattert' 95, Proceedings of the Eleventh International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, Monterey, California, January 9-13, 1995, Nucl.Phys. A590 (1995).
20. J.Bachler et al., Zeit f.Phys. C58, 367 (1993).
21. S.A.Chin and A.K.Kerman, Phys.Rev.Lett. 43, 1292 (1979).
22. H.C.Liu and G.Shaw, Phys.Rev. D30, 1137 (1984).
23. C.Greiner et al., Phys.Rev.Lett. 58, 1825 (1987).

24. E.Witten, Phys.Rev. D30, 2379 (1984).
25. E.Farhi and R.L.Jaffe, Phys.Rev.D30, 2379 (1984).
26. M.S. Berger and R.L.Jaffe, Phys.Rev. C35, 213 (1987).
27. F.Dittus at al., Nucl.Phys. A590 (1995) 347c.
28. T.Alber at al., Nucl.Phys. A590 (1995) 435c.
29. M.Drndic et al., NIM B 93 (1994) 52,
Y.D.He et al.,NIM B 84 (1994)67.
30. Private communication.

Tables

Table 1. Temperature parameters of the transverse mass distributions of strange particles (NA35)

Figures

Figure 1: Rapidity distributions of net protons in central S+S, S+Ag and S+Au (NA35) at 200 GeV/c per nucleon.

Figure 2: Rapidity distributions for negatively charged hadrons in central S+S, S+Ag and S+Au collisions (NA35) at 200 GeV/c per nucleon. See text for the solid line description.

Figure 3: Ξ/Λ and Ξ/Λ ratios for different experiments.

Figure 4: Large and small experiments at the CERN SPS.

Figure 5: Transverse energy spectrum for Pb+Pb collisions at 160 GeV/c per nucleon (NA49).

Figure 6: Rapidity distribution for negative hadrons in Pb+Pb collisions at 160 GeV/c per nucleon (NA49).

Figure 7: Proton rapidity distribution in Pb+Pb (NA49) and S+Au (NA35) collisions at 160 GeV/c and 200 GeV/c per nucleon, respectively.

Figure 8: Rapidity distributions of protons from S+S (200 GeV/c) and Pb+Pb (160 GeV/c) collisions measured by NA44.

Figure 9: M_T spectra from S+Pb collisions at 200 GeV/c per nucleon (NA44).

Figure 10: Proton m_T spectra from Pb+Pb collisions at 160 GeV/c per nucleon (NA49).

Figure 11: Systematics of inverse slopes of transverse energy distributions in pp, pA and AA reactions at CERN energies.

Figure 12: Invariant mass distributions of ($\pi^+\pi^-$) and ($p\pi^-$) systems with clear peaks seen at the correct masses of K^0 and Λ (WA97).

Figure 13: Particle ratios in minimum bias Pb+Pb collisions at 160 GeV/c per nucleon at p_t=~0 (NA52).

Figure 14: Charge histogram of projectile and projectile fragments produced in collisions of Pb ions at 160 GeV/c per nucleon (WA101).

Table 1.

system	Λ	$\bar{\Lambda}$	K_s^0	K^+, K^-
SS ($y < 3$)	194 ± 15 MeV	200 ± 20 MeV	193 ± 15 MeV	240 ± 40 MeV
SAg ($y < 3$)	200 ± 10 MeV		213 ± 20 MeV	211 ± 20 MeV
SAu ($y > 3$)	235 ± 40 MeV	–	209 ± 20 MeV	–

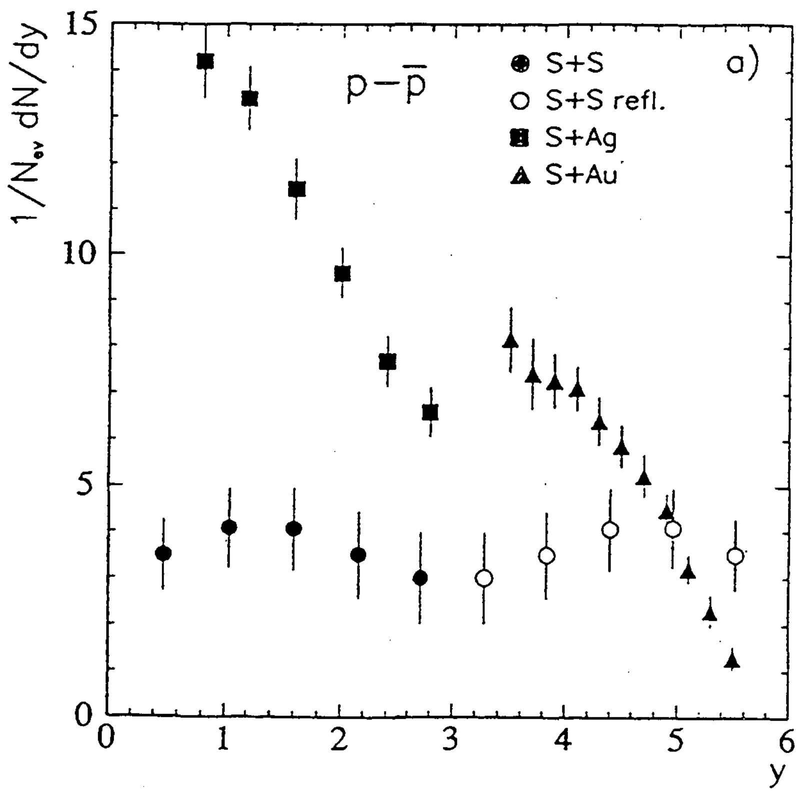

Figure 1.

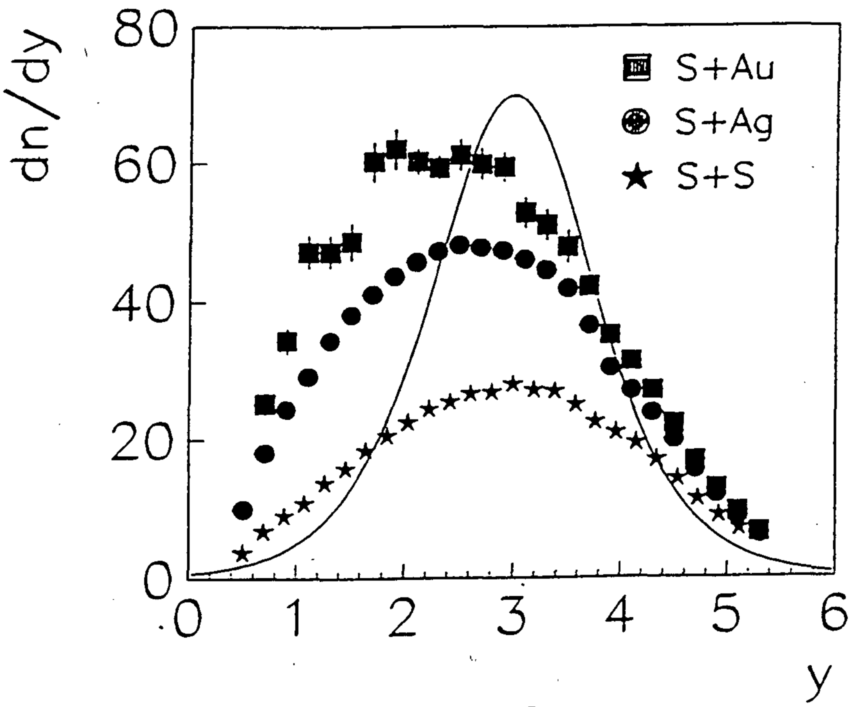

Figure 2.

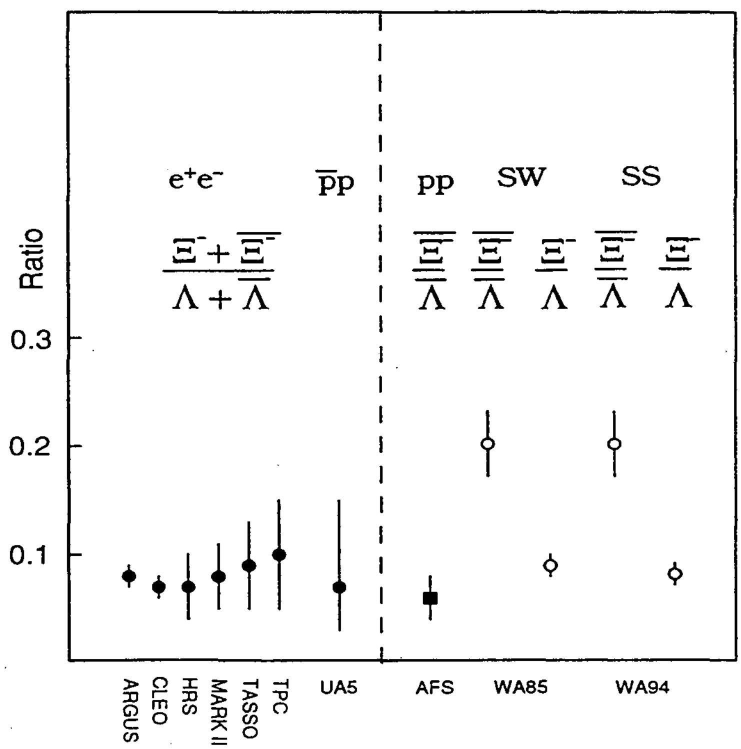

Figure 3.

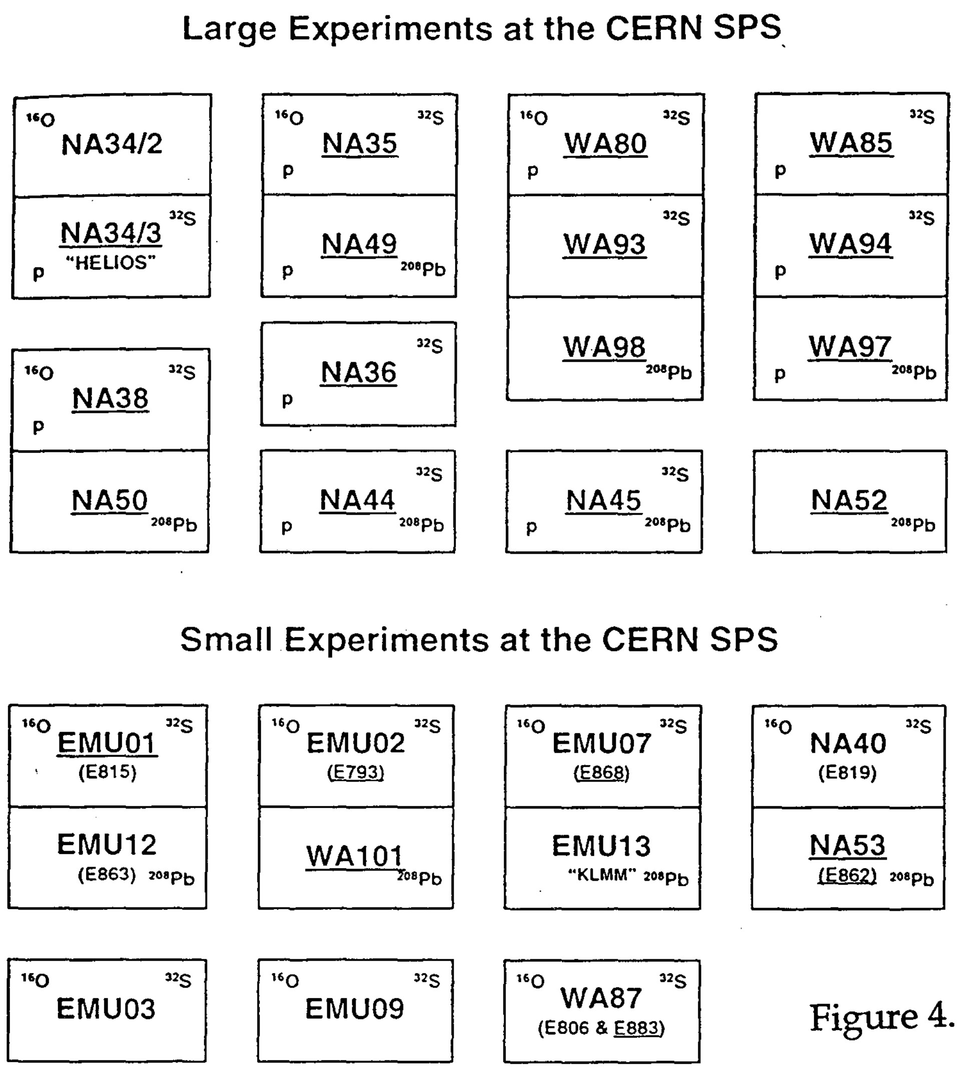

Figure 4.

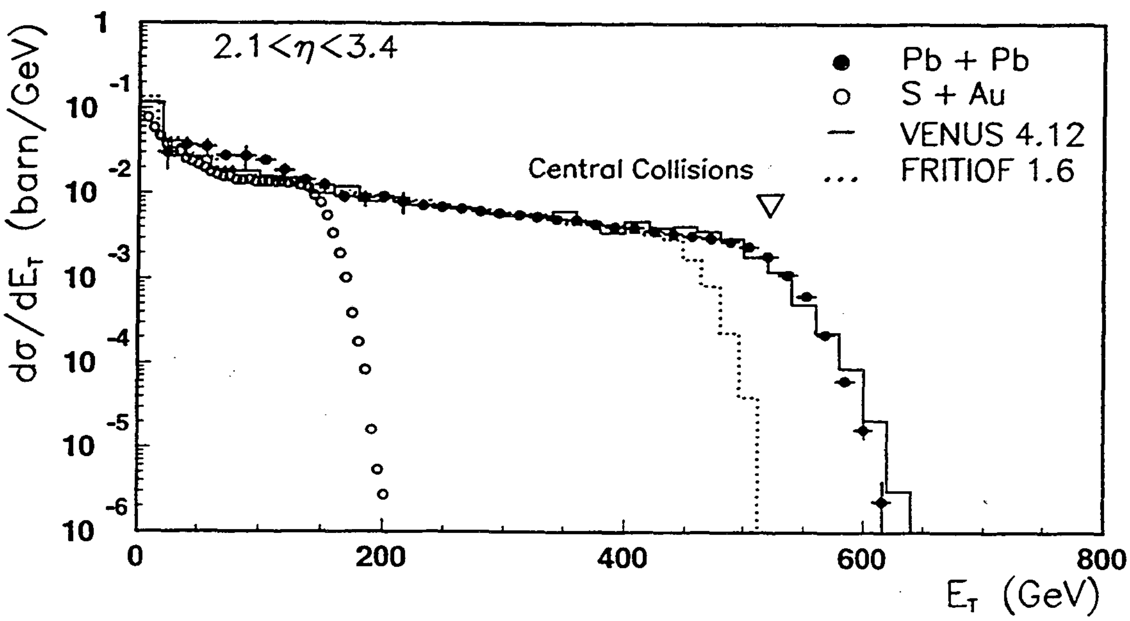

Figure 5.

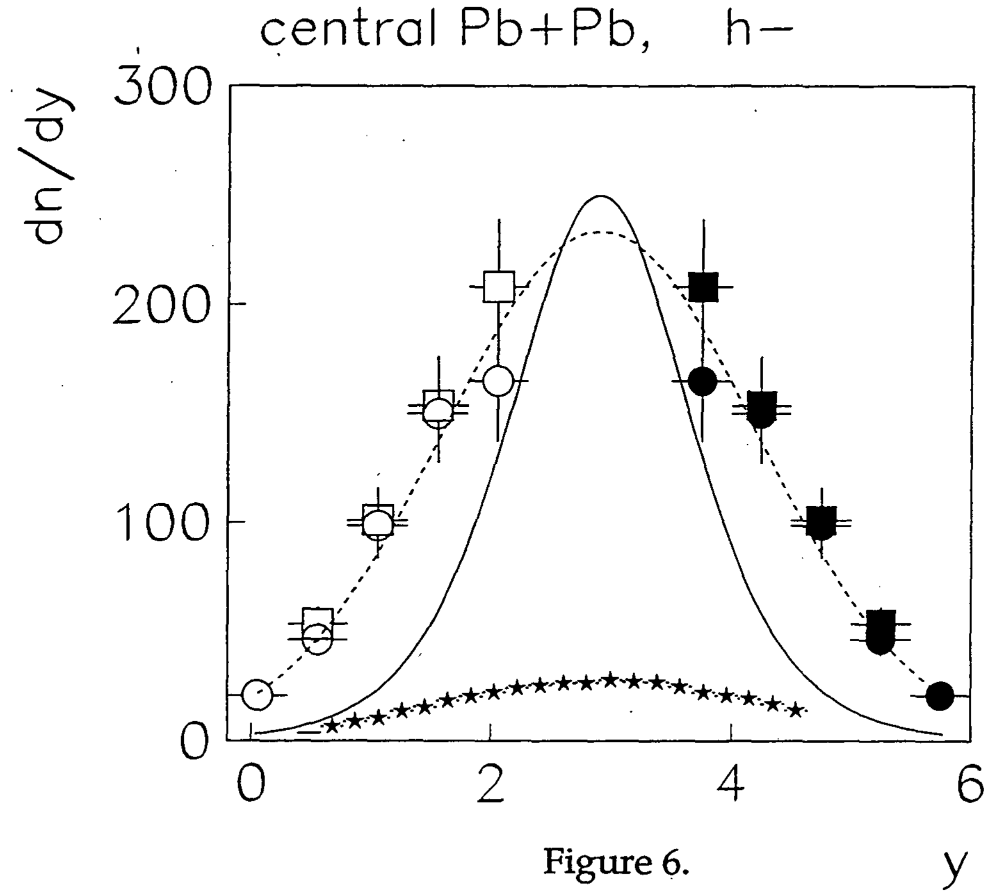

Figure 6.

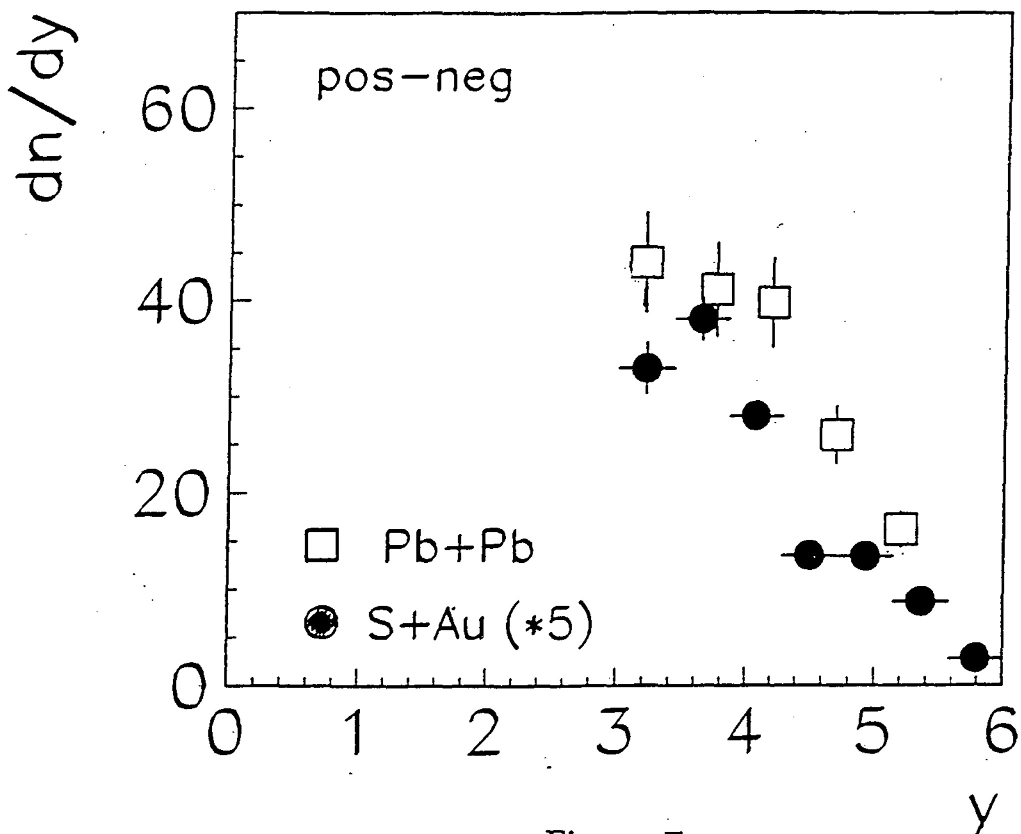

Figure 7.

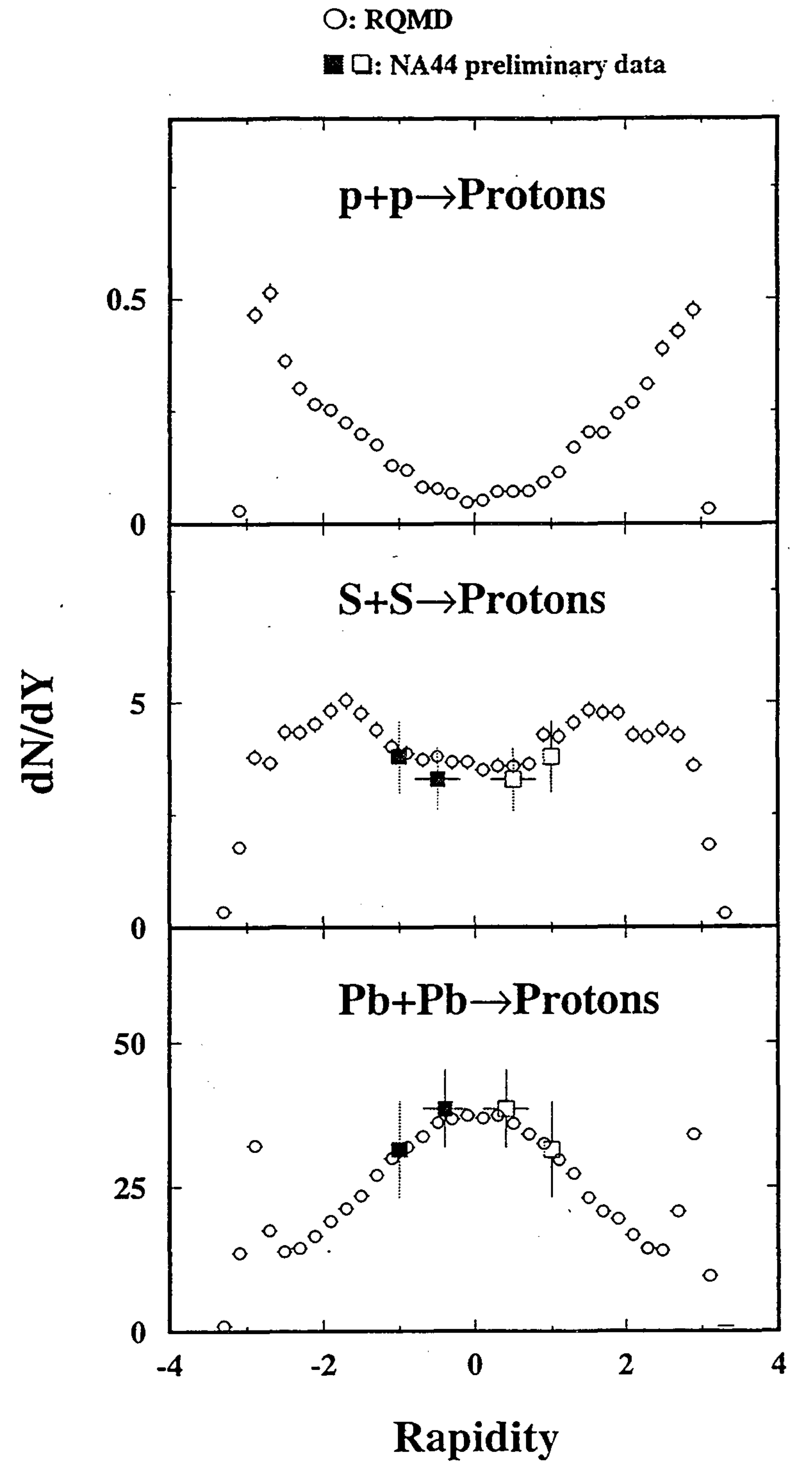
O: RQMD
■ □: NA44 preliminary data
p+p→Protons
S+S→Protons
Pb+Pb→Protons
dN/dY
0.5
0
5
0
50
25
0
-4
-2
0
2
4
Rapidity

Figure 8.

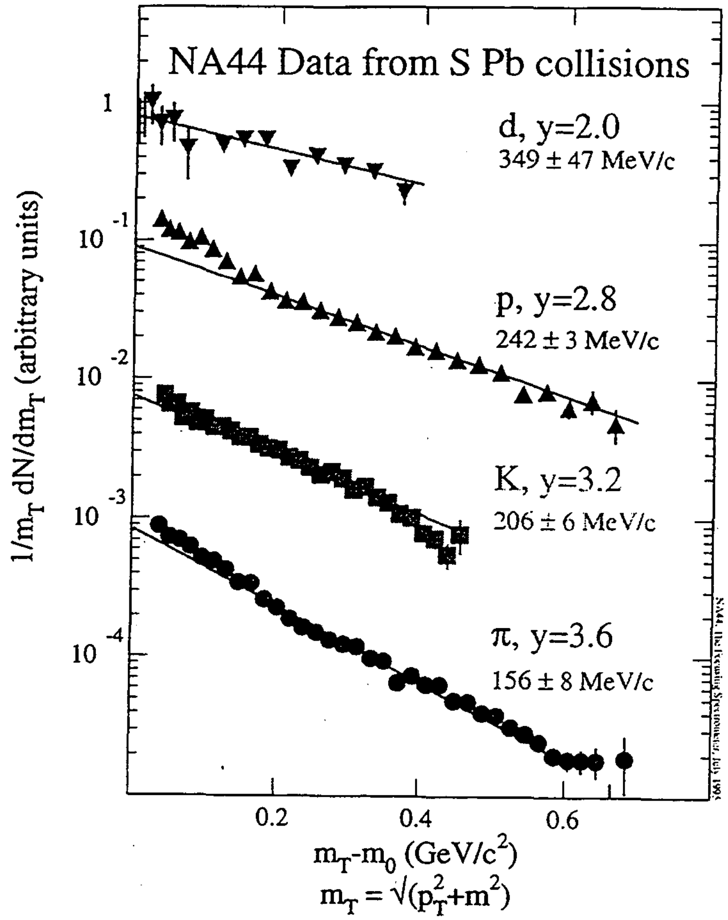

Figure 9.

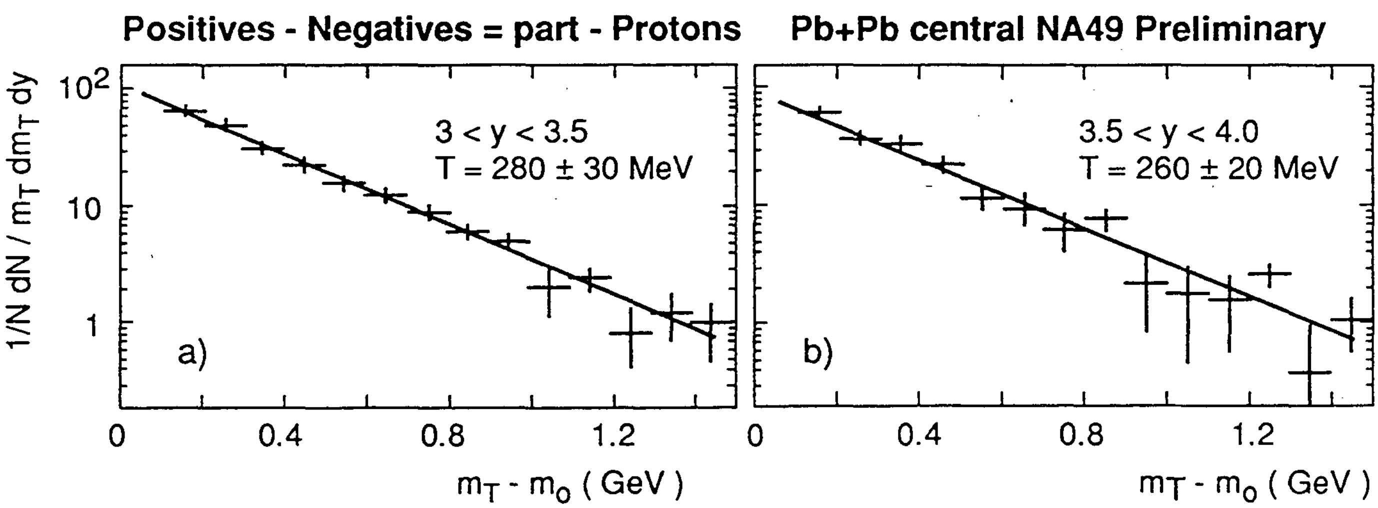

Figure 10.

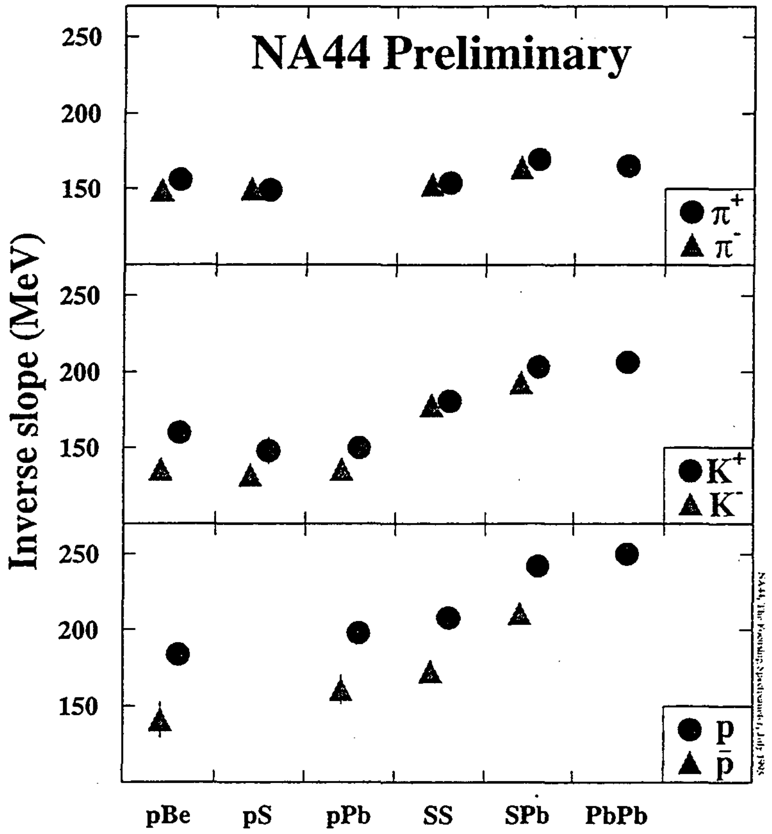

Figure 11.

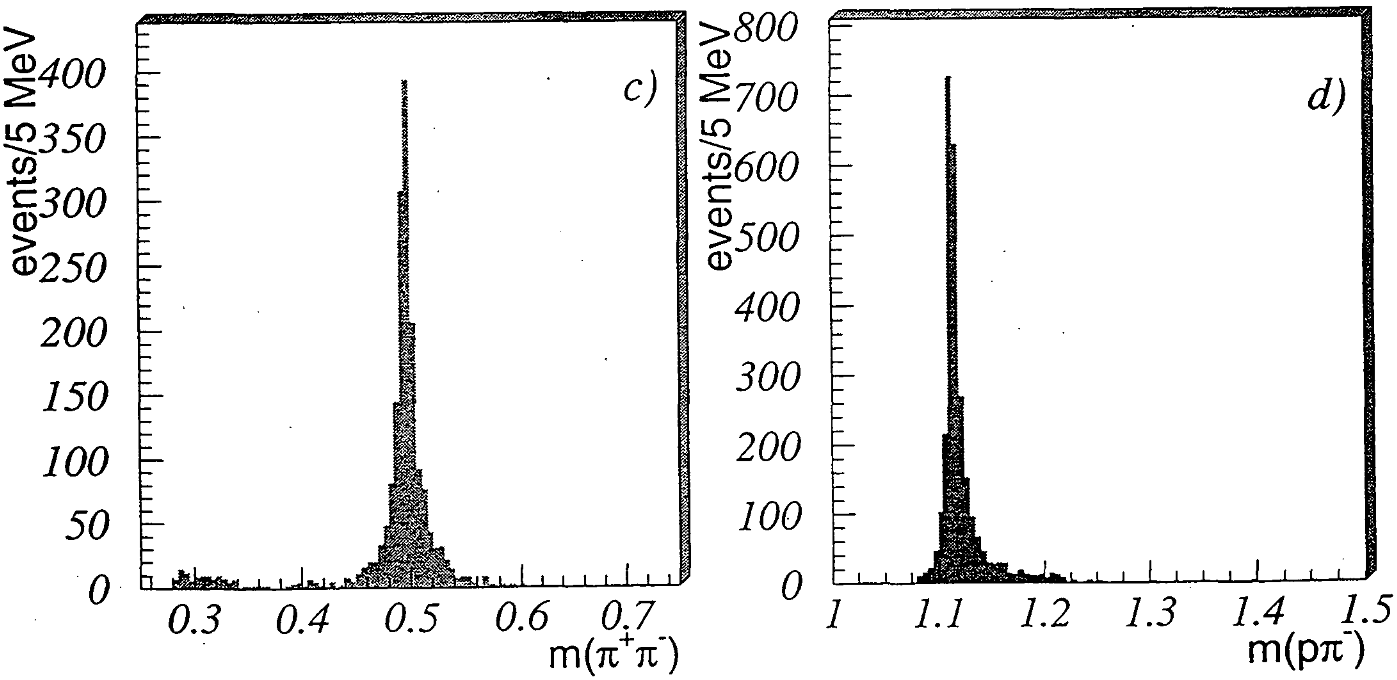

Figure 12.

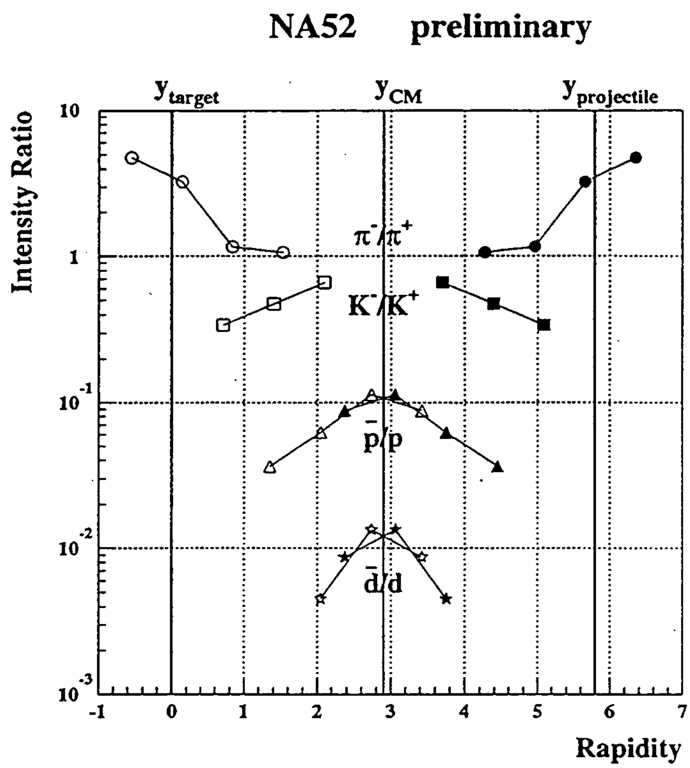

Figure 13.

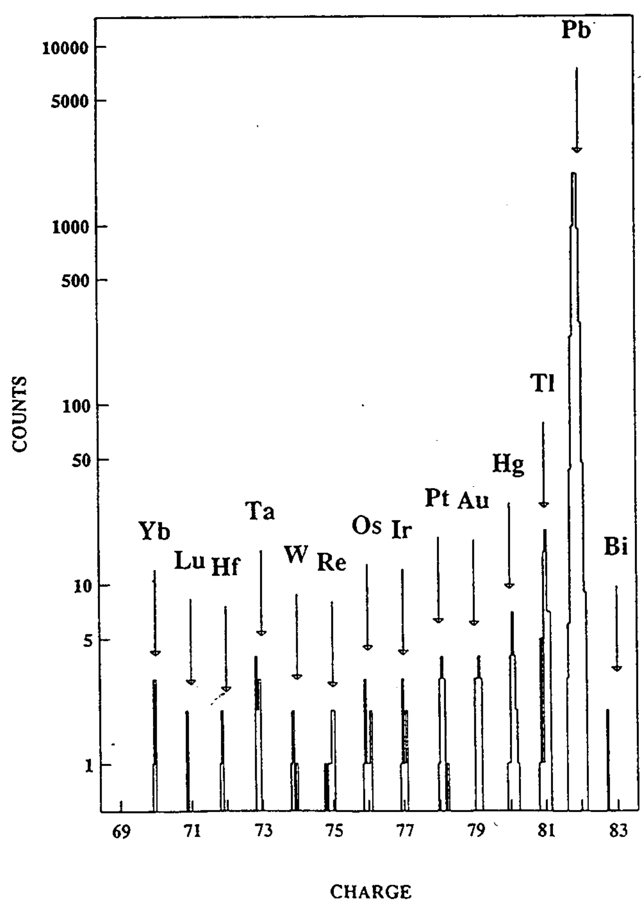

Figure 14.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL AND ELECTRONIC
INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720