Yale 40609-1150

High Rate Multiplicity Detector for Relativistic Heavy-Ion Collisions

D. Beavis[1], M.J. Bennett[2], J.B. Carroll[3], J. Chiba[4], A. Chikanian[2], H.J. Crawford[5], M. Cronqvist[5], Y. Dardenne[5], R. Debbe[1], T. Doke[6], J. Engelage[5], I. Flores[5], L. Greiner[5], R.S. Hayano[7], T.J. Hallman[3], H.H. Heckman[8], T. Kashiwagi[6], J. Kikuchi[6], B.S. Kumar[2], C. Kuo[5], P.J. Lindstrom[8], J.W. Mitchell[9], S. Nagamiya[10], J.L. Nagle[2], J.K. Pope[2], P. Stankus[10], K.H. Tanaka[4], R.C. Welsh[11], and W. Zhan[10].

(The E878 Collaboration)

1. Brookhaven National Laboratory, Upton, NY

2. Yale University, A.W. Wright Nuclear Structure Laboratory, New Haven, CT 06511

3. University of California at Los Angeles, Los Angeles, CA

4. KEK, Tsukuba, Japan

5. University of California Space Sciences Laboratory, Berkeley, CA

6. Waseda University, Science and Engineering Research Institute, Waseda, Japan

7. University of Tokyo, Tokyo, Japan

8. Lawrence Berkeley Laboratory, Berkeley, CA

9. Universities Space Research Asoociation/Goddard Space Flight Center, Greenbelt, MD

10. Columbia University, Nevis Laboratory, Irvington, NY

11. Johns Hopkins University, Baltimore, MD

(November 9, 1994)

Abstract

We have constructed and operated a detector to measure the multiplicity of secondary particles produced in nucleus-nucleus collisions in the E878 experiment at the Brookhaven National Laboratory AGS facility. We describe the operation and performance of the detector in a high rate Au beam environment, and interpret the multiplicity data in terms of the impact parameters of the nucleus-nucleus collisions.

PACS numbers:29.40.Ym

Typeset using REVTEX

I. INTRODUCTION

Relativistic nucleus-nucleus collisions provide a means of creating states of hot and dense hadronic matter [1]. To understand in detail the evolution of the hot collision environment, it is imperative that simple dependencies on the geometry of the colliding partners be understood. Several techniques have been developed to understand the *global variables* of nucleus-nucleus collisions [2]. These techniques include measurements of transverse energy E_t [3,5], charged particle multiplicity N_c [4], and zero degree energy E_{ZD} [6]. Compelling qualitative arguments indicate that these variables are well correlated with impact parameter. Although one can not measure impact parameters directly, the global variables are demonstrably correlated with one another [7,8]. This latter fact supports the idea that these variables all measure effects of the collision geometry, and that one can obtain indirect information on the geometry by measuring one or more of these global variables.

We describe a detector that we have constructed to sample the multiplicity of relativistic particles produced in nucleus-nucleus collisions. The detector was operated in Experiment 878 at the Brookhaven National Laboratory AGS facility, and used to extract information on the impact parameters of collisions between nuclei. Experiment 878 is designed to operate at high interaction rates to search for rare particles like antinuclei and strangelets [9,10]. In addition, we wish to perform concurrent studies of the kinematic distributions and centrality dependences of the production rates of more abundant particles like antiprotons and light nuclei. Thus, our multiplicity detector must be capable of providing a reliable measure of the centrality of a given nucleus-nucleus collision without sacrificing the high rate capability necessary for the rare particle search. The data were measured in the fall of 1993 using 10.8 A GeV/c ^{197}Au beams at intensities in excess of 2×10^7 particles per spill. Each nucleus-nucleus collision results in the production of up to several hundred particles. The multiplicity array samples the total multiplicity of particles produced by measuring up to 28 of them in a fixed region of phase space. Below, we will describe the construction and operation of the detector. We will compare our data with Monte Carlo predictions of what we should expect to see, and then describe how we can use the detector to select on ranges of collision centralities.

II. THE APPARATUS

Figure 1 is a schematic view of the E878 apparatus [11]. The beam enters the figure from the left, and passes through a few beam monitoring detectors before striking the target. A multi-wire proportional chamber and a fiber Čerenkov hodoscope located near the target measure the position of the beam particles that strike the target. Ion chambers (IC 1 and IC 2) located upstream of the target are used to monitor the flux of the primary beam, and are complemented by single particle telescopes (SPTs) which monitor beam flux by counting secondary particles emitted at backward angles. The multiplicity of secondary particles produced in interactions between the projectile and target is measured by the multiplicity array.

Secondary particles that are emitted within a rectangular aperture of solid angle $\Delta\Omega = 200\mu sr$ centered on the beam axis, with the selected rigidity (ratio of momentum to charge) are transported through the beamline spectrometer. These particles are identified by their times of flight, and by the responses of the gas (Čk 1 and Čk 2) and Aerogel (Čk 3 and Čk 4) threshold Čerenkov detectors. This system allows us to identify particles in a kinematic range up to and beyond the momentum of the beam.

The E878 acceptance is sufficiently small that, for nearly all events, no more than one particle traverses the spectrometer. Triggers are generated by a particle in the spectrometer via a coincidence between two of the time-of-flight detectors (TOF 1 and TOF 3). Triggers from copiously produced particles (such as pions) are scaled down to enrich the rare particle fraction of the data. This particle-based trigger complicates the analysis of the multiplicity data somewhat, as will be discussed in the section on detector performance.

III. THE MULTIPLICITY DETECTOR

In keeping with the needs of E878, the multiplicity detector must be fast, simple, and generate as few data words as possible. We have chosen to measure multiplicity using an array of threshhold Čerenkov counters. The short time scale of the Čerenkov process, the small size of the individual counters, and the use of fast photomultiplier tubes (PMTs), combine to enable the detector to operate at high rates. In addition, we have simplified the readout by keeping the number of channels small. The design of the individual counters is also simple, as detailed below.

A. Design

The multiplicity detector consists of 28 counters, arranged in two rings oriented at 40 and 60 degrees relative to the beam direction, as shown in figure 2. The 40° ring covers laboratory pseudorapidities $0.46 < \eta < 0.64$ ($\eta = -\ln\tan(\theta/2)$), while the 60° ring covers $0.90 < \eta < 1.13$. Each counter is mounted on a card that also serves as a board for the PMT base electronics. These cards are positioned in slots in a Plexiglas ring on an aluminum mounting plate, so that the 28 individual counters form a single integrated detector. This plate is then mounted downstream of the target, such that the front face of each counter is roughly 10 cm from the front face of the target.

Each counter has a square cross section of side 3/4 in., determined by the dimensions of the square photomultiplier tube (Hamamatsu R2248SX). Mounted on the window of the PMT is a 1/4-in. thick quartz plate. On top of the quartz there is a 1/4-in. (approximately one radiation length) thick lead plate. The lead serves the dual purpose of converting photons into e^+ e^- pairs and ranging out low-energy δ rays, which are associated with electromagnetic rather than hadronic interactions of the projectile and target.

The array is designed to detect photons from the decays of neutral pions. These pions decay a short distance ($c\tau \approx 25$ nm) from the positions at which they are produced. We detect the photons by converting them to $e^+ e^-$ pairs in the lead plate. Those photons which do not convert within the target and which strike the front face of a counter are converted with $30-50\%$ efficiency in the lead plate. The e^+ and e^- then pass through the quartz plate and stimulate the emission of Čerenkov light. The Čerenkov photons are detected by the photomultiplier tube. The number of tubes which register a signal above threshhold should exhibit a good correlation with the number of neutral pions produced in the nucleus-nucleus interaction.

Since the active piece of each counter is a Čerenkov radiator with refractive index ≈ 1.46, the array is also sensitive to the detection of other charged particles that pass through the lead sheet and then propagate through the quartz plate with a speed $v > 0.7c$. Although our detector was not explicitly designed to detect these charged particles, they are products of the nucleus-nucleus interaction, and thus are part of the multiplicity signal that we wish to sample.

B. Electronics

The key to the high rate capability of these counters is the combination of the R2248SX PMT with a high rate base. The anode pulses from these units have characteristic rise times of less than 1 ns, and are approximately 4 ns wide at one tenth their maximum height, as shown in figure 3. The PMT is coupled to a transistorized base which maintains the dynode potential differences (and thus the anode pulse heights) at very high rates. Results from laboratory tests of the rate dependence of the pulse heights are shown in figure 4. These results demonstrate that the active bases maintain good linearity up to rates of 10^7.

Figure 5 illustrates the electronics chain. The anode signal from each PMT is discriminated (LeCroy 4413) at a level of 25 mV (the pulse amplitudes are approximately 100 mV). The discriminated signal is received by a LeCroy 2277 pipeline TDC. The TDC runs in common stop mode, with the event trigger providing the stop pulses using the signals of downstream detectors.

Each counter is limited to rates of less than 5×10^7 particles per second, because the TDC units can not resolve pulses closer in time than 20 ns. (It is possible to increase the rate capability by using a switching mechanism to reduce the effective peak separation time, as will be discussed below.) The maximum dispersion in the times of flight of secondaries to the multiplicity counter is approximately 0.2 ns, and thus each counter can only register one particle per event.

For each counter that detects a particle, the E878 data acquisition system (DA) reads out a leading edge time from the 2277 TDC. To reduce the number of words of output for the event, the DA applies a software cut so that it records only hits preceding the trigger in time by less than 1 μs (full scale for the LRS2277 is 64 μs). The non-beam related firing rate for the phototubes is very low (less than 100Hz); however, during the time required for the trigger to be formed, and in the time preceding the passage of the beam particle of interest, additional beam particles may pass through the target and fire some of the multiplicity counters. In a typical event, the entire detector produces approximately 100 TDC digitizations during the 1 μs window. However, for the heaviest targets and highest beam fluxes, the multiplicity detector is very active, so that, even with the software cuts applied, the detector can produce as many as 400 digitizations. The DA writes some of the events from each one-second beam spill (roughly 150 in a typical spill) to a buffering system, which is then read out and transferred to disk during the time between spills. The present capability of the data acquisition system to deal with large events, and, in particular, the space available for buffering events, becomes a limiting factor in the rate capabilities of the detector.

C. Detector Performance

Figure 6 is a raw TDC spectrum, taken at a moderate beam flux rate of 5×10^7 per second incident on a 22% Au target (22% of the beam particles suffer hadronic interactions in the target), for a sample of approximately 30,000 pion events. The peak in the spectrum corresponds to hits associated with a nucleus-nucleus interaction which produced a secondary particle, which in turn eventually created the trigger. The RMS width of the peak is 2.6 ns, a value which does not vary greatly from run to run. The peak is well above (a factor of 20-30 above) the background level. Here the primary source of background is from beam particles which did not create a trigger producing secondary particle. The inefficiency seen on the high time side of this peak is the result of the 20-ns double pulse resolution of the TDC, mentioned in the description of the detector electronics.

In order to determine the multiplicity of the nucleus-nucleus collision which created the trigger particle, one must first calculate when the hits should have occurred relative to the trigger. This is done by using the time of flight of the particle through the spectrometer to calculate the time at which the particle was at the target. This information, when properly calibrated, gives the time at which the multiplicity detector should have recorded hits from the nucleus-nucleus collision. The hit times from the multiplicity detector are searched for times corresponding to 3 ns before or after this collision time, and the number of hits satisfying this criterion are summed to give the multiplicity of the event. This 6 ns event window was chosen so as to be better than 90% efficient in including all event related multiplicity counter hits, yet narrow enough to minimize the chance of corruption by beam particles closely preceding or following the beam particle of interest.

In addition to multiplicities for produced particles, it was necessary to obtain minimum bias multiplicity distributions for calibration purposes. These data were recorded using a "good beam" trigger, which was set by any beam particle that fired the fiber hodoscope detector near its axial center. (The determination of multiplicity from this beam trigger was analogous to that described for particle triggers above.) Distributions of the multiplicities measured using this trigger are shown in Figure 7. Au targets of thickness equal to 22% of the Au beam hadronic interaction length result in full occupancy of the detector (28 hits) in $\approx 0.01\%$ of the events. Note that these distributions are for a beam trigger and a 22% interaction target. Hence, 78% of the events correspond to beam particles which did not suffer a hadronic interaction in the target. A Monte Carlo simulation was used to correct these distributions to give a minimum bias multiplicity distribution for interacting beam, as described in the next section.

Another avenue for investigation is detector performance under conditions of high beam flux. As stated earlier, the 20 ns double pulse resolution of the TDC fixes the nominal maximum efficient counting rate for any given tube to be 5×10^7 per second. However, the average detector occupancy for a beam particle (averaged over both interacting or non-interacting beam) is roughly 20%, so that the detector should be able to accomodate overall fluxes on the order of 2×10^8 per second without sacrificing the quality of the data. During this run of the experiment, the detector was operated at fluxes up to 8×10^7 per second, which should be safely within the operating range. One way to check the performance is to compare the measured multiplicity spectra for a given produced secondary particle over various ranges of beam flux. Such a comparison is made in figure 8 for π^- at a momentum of 5.1 GeV/c. There is no discernible flux dependent effect on the multiplicity spectra up to the highest flux seen in this run.

IV. ANALYSIS

A. Monte Carlo Simulations

To interpret our measured multiplicities, we must ensure that the multiplicity actually yields some information on the collision geometry. We have performed a Monte Carlo simulation of the response of the detector to secondary particles produced in nucleus-nucleus interactions.

We begin by using the RQMD [12] event generator (version 1.07) to model Au+Au (Au+Cu, or Au+Al) interactions at a beam momentum of 11 A GeV/c. The output of RQMD is a list of the particles produced in the interactions, and their momentum four-vectors. This list is used as an input to the detector Monte Carlo, which uses the GEANT [13] simulation framework. The detector simulation includes all of the relevant information on the geometry of the E878 apparatus. The simulation mimics the beam profile on the target by locating the interaction vertices (r,ϕ,z) for the nucleus-nucleus collisions using the distribution function

$$f(r,z) = \exp(-z/\lambda)\ \exp(-r^2/2\,\xi^2). \tag{1}$$

In this equation, λ is the interaction length for a Au nucleus in the target material, calculated from the geometric interaction cross section, and ξ is the RMS transverse size of the beam at the target. (We use $\xi = 0.5mm$, as measured in our MWPC.)

The particles generated by RQMD are tracked using GEANT through the target and detector geometries. In doing this, GEANT considers the effects of scattering and secondary interactions in the target, air, and lead. The simulation counts charged particles that propagate through the quartz plate with a speed $v > 0.7c$. The simulation does not count the number of photoelectrons from the particle in order to determine whether the phototube would have actually "seen" the light generated by the particle. This correction is not a significant one, because particles that are produced in the target generate Čerenkov light in the quartz at angles such that almost all of the light reaches the photocathode. In each event, only the first "hit" in each counter is considered, since the time difference between the arrival of the first and last particle in the event is less than the 20-ns double pulse resolution of the TDC. The simulated multiplicity is the sum of "first hits" in the event.

Table I shows the contributions of various particles to the measured multiplicity predicted by this simulation, as a function of impact parameter. Pions dominate the signal for the most central collisions; the π^o contribute slightly more than do the π^+ and π^- combined. In the most peripheral events, a large fraction of the multiplicity results from the the interactions of spectator nucleons in the bulk target material. This contribution is negligible in more central events.

Figure 9 shows the correlation of impact parameter with the multiplicity of detected particles, as modeled in this Monte Carlo. The correlation is good, although it exhibits significant dispersion. Shown in the same figure is the correlation of impact parameter with the total multiplicity predicted by RQMD. The two distributions are similar in shape. While a larger solid angle detector would have resulted in a better multiplicity measurement, it would have been much more expensive to implement, and would have impacted the high rate capability of our experiment.

The detector Monte Carlo was also used to predict the background multiplicity distribution for δ-rays from the gold ions propagating through the target. The same procedure described above was applied to this case: a fully ionized ^{197}Au projectile was allowed to propagate completely through the target, and GEANT was used to simulate its electromagnetic interactions. We also considered background from non-target sources; instead of simulating this contribution, we used our measurements of spectra using only the target frame (empty target). We convoluted the three contributions to the multiplicity μ (nucleus-nucleus interactions μ_{int}, target background μ_{target}, and non-target background $\mu_{notarget}$) to arrive at a prediction:

$$\mu = p_{int}\mu_{int} + (1 - p_{int})(\mu_{target} + \mu_{notarget}), \tag{2}$$

where p_{int} is the expected probability of nucleus-nucleus interactions in the event sample (approximately 22% for our gold target). Shown in Figure 10, along with the measured multiplicity spectra, are the spectra predicted using this method. The prediction agrees well with the measured "good beam" distributions.

Encouraged by the success with which we are able to describe the multiplicity spectra, we proceed to use the Monte Carlo calculations to correct for the background contribution to the measured spectra.

B. Interpretation of multiplicity spectra.

To extract a "true" multiplicity spectrum, we must correct the measured spectrum for events in which a nucleus-nucleus interaction did not occur. We scale the spectrum obtained from the Monte Carlo simulation of nucleus-nucleus interactions so that its integral equals the expected number of interactions in the event sample. In order to get the "true" multiplicity, we subtract the scaled Monte Carlo distribution from the experimentally measured beam trigger distribution. The remaining distribution is the multiplicity spectrum for non-strongly interacting beam, the majority of which is the result of δ-ray production in the target, as described previously. We truncate this distribution at the point where the Monte Carlo "crosses over" the beam triggered data, and then subtract it from the beam triggered data. The remaining distribution is then the "true" multiplicity (in essence, this is the Monte Carlo for the low multiplicity portion and the beam triggered data for the high multiplicity portion of the distribution). We integrate this corrected multiplicity spectrum to determine the fraction of events P that pass our multiplicity cuts. For example,

$$P = \sum_{k=\mu}^{28} P_k \tag{3}$$

is the fraction of events with multiplicity greater than or equal to μ, where P_k is the corrected fraction of events with multiplicity k.

Table II shows the multiplicity cuts for the three target materials, and the fraction of the events that pass these cuts. The application of the defined cuts to real particle data allows us to investigate the physics involved in particle production as a function of the multiplicity of the event.

V. UPGRADE STUDIES

Finally, we discuss briefly an attempt to increase the rate capability of this detector by using a multiplexing module, developed in conjunction with LeCroy and designated LRS2277/EXP. Input to this module was the logic signal from a LRS4413 discriminator operating in updating mode. In this mode, the time duration of the output signal is either some minimum width or the total time over threshold, whichever is greater. For each of the 28 counters, the LRS2277/EXP split the discriminator signal into leading and trailing edges. Each edge was then switched by the module between 4 channels of the LRS2277 TDC, with a switching time of 2 ns. Thus, instead of a single TDC channel with a 20 ns double peak resolution time, we effectively had 4 TDC channels with 2 ns double peak resolution time (assuming that not more that 4 signals arrive within a 20 ns period). In addition, we also had added some time over threshold information, with the aim of obtaining some rough idea of the energy deposited in the detector in addition to the simple particle count.

We operated the detector in this mode during the Spring 1992 heavy ion run at the BNL AGS, in the 14.6A GeV/c ^{28}Si beam (intensity of order 10^{11} per second) and the 10.8A GeV/c ^{197}Au beam (intensity of order 10^{7} per second). Analysis of this data showed that the LRS2277/EXP modules worked as expected. The time over threshold information proved to be only modestly useful, since for the majority of the events, the discriminator output was of the minimum width. While this is somewhat disappointing from the upgrade point of view, it does reassure us that when the LRS2277/EXP modules are not in use, we are not losing a lot of information from multiple hits in the same counter. The effect of the switching mechanism on the rate capability of the detector was a little more difficult to evaluate. The switching mechanism itself seemed to work well. However, the addition of information about both edges increased the number of data words by a factor of two; in addition, the reduced double peak resolution time also added some hits that would otherwise have been missed. This increase in the number of data words exacerbated the buffering problem mentioned in the description of the electronics. It should be noted that, while software cuts reduced the number of data words actually written to disk, all of the data words must be read out by the data acquisition system. Thus, the addition of a factor of two in data words resulted not only in some problems in fitting all the data for the spill into the buffer, it also significantly reduced the live time of the system. Thus, for the LRS2277/EXP system to work optimally, one would need a faster data acquisition system, with more buffer space available. For the second run of E878 in the fall of 1993, we chose not to use the LRS2277/EXP modules, since only Au beam was available, with a maximum flux of a few 10^{7} per second, so that the additional rate capability was not necessary.

VI. CONCLUSION

We have constructed and operated a multiplicity detector in Experiment 878 at the Brookhaven National Laboratory, in a high rate Au beam environment. We have demonstrated that the detector can be used to sample the multiplicity of secondary particles produced in nucleus-nucleus collisions, and hence provide information on the impact parameters of these interactions. We intend to use this detector to study, as functions of centrality, the kinematic distributions of antiprotons and light nuclei produced in nucleus-nucleus collisions.

VII. ACKNOWLEDGEMENTS

We are grateful to the Brookhaven AGS and Tandem staffs for providing the Au and Si beams. This work was supported in part by grant DE-FG02-91ER-40609 with the U.S. Department of Energy.

REFERENCES

[1] B. Shiva Kumar in proceedings of the 5th International Conference on the Intersections of Nuclear and Particle Physics, American Institute of Physics, 1994 and references therein.

[2] M.J. Tannenbaum, Int. J. Mod. Phy. **A4**, 3377 (1989).

[3] E814 Collaboration, J. Barrette *et al.*, Phys. Rev. Lett. **64**, 1220 (1990).

[4] E814 Collaboration, J. Barrette *et al.*, Phys. Rev. C **46**, 312 (1992).

[5] M.L.Tincknell, in *Hadronic Matter in Collision 1988*, P. Carruthers and J. Rafelski, eds., (World Scientific, Singapore, 1989), p. 378.

[6] WA80 Collaboration, R. Albrecht *et al.*, Phys. Rev. C **44**, 2736 (1991).

[7] T. Abbott *et al.*, Phys. Lett. B **332**, 258 (1994), and Phys. Rev. C **44** (1991) 1611.

[8] C. Pruneau, Proc. Heavy-Ion Physics at the AGS, BNL, January 1993, MITLNS-2158, p. 12.

[9] H. Crawford in [1].

[10] M. Aoki *et al.*, Phys. Rev. Lett. **69**, 2345 (1992).

[11] J. Engelage *et al.*, manuscript in preparation.

[12] H. Sorge, H. Stöcker, W. Greiner, Nucl. Phys. A, **498** (1989) 266.

[13] R. Brun *et al.*, GEANT User's Guide, Program Library W5013, CERN, 1993.

TABLES

TABLE I. Prediction of the Monte Carlo simulation for the contributions of various particles to the measured multiplicity for a 22% Au target. The category of “Secondaries from NN interactions” refers to products of nucleon interactions in the bulk target material. Relatively minor sources which are not tabulated include protons, $K^{\pm}$, and decay products from the η^{o}, K^{o}_{S}, and K^{o}_{L}.

Impact parameter	Average number of hits from				
range	direct	decays of	Secondaries	target	Total
(fm)	$\pi^{\pm}$	π^{o}	NN interactions	δ-rays	Monte Carlo
0-3	7.7	10.7	0.6	2.7	23.3 ± 4.8
3-6	6.8	7.9	1.0	2.7	20.3 ± 4.5
6-9	4.6	4.9	1.9	2.7	15.7 ± 4.0
9-12	2.0	2.5	3.4	2.7	11.4 ± 3.4
12-15	0.3	0.4	4.3	2.7	7.8 ± 2.8

TABLE II. The ranges in charge particle multiplicity corresponding to cuts defining the geometries (impact parameters) of the nucleus nucleus collisions.

		Defined multiplicity cuts		
Cut type	Percent of interactions	Au target	Cu target	Al target
Most central	10%	19-28	11-28	7-28
High midrange	20%	14-18	-	-
Low midrange	40%	6-13	-	-
Most peripheral	30%	0-5	-	-

FIGURES

FIG. 1. Schematic diagram of the E878 apparatus. The inset is a schematic diagram detailing the target and the detectors surrounding it.

FIG. 2. A. Schematic diagram of the E878 multiplicity array, showing in addition, the target, and the direction of the incident beam. B. Schematic diagram of one detector in the array, showing its components.

FIG. 3. The shapes of pulses produced by the Hamamatsu R2248SX photomultiplier tube.

FIG. 4. The rate dependence of pulse heights produced by the R2248SX photomultiplier tube shown for both resisitive and transistorized bases.

FIG. 5. A schematic diagram of the electronics used with the E878 multiplicity detector.

FIG. 6. Raw TDC spectrum from one counter in the multiplicity array. Time increases to the left; the least-significant bit on the TDC corresponds to 1 ns.

FIG. 7. Experimental multiplicity distributions for Al, Cu and Au targets. These spectra were recorded using a "good beam" trigger, described in the text. The thickness of each target is approximately 25% of a nucleus-nucleus interaction length.

FIG. 8. Flux dependence of multiplicity spectra for a 22% Au target. See text for details.

FIG. 9. The prediction of Monte Carlo simulations for the correlation of impact parameter with measured multiplicities. The histogram shows the probability of accepting various impact parameters for the "most central" cut in our detector (see table II). The first scatter plot shows the predicted correlation between impact parameter and multiplicity for our detector. The bottom scatter plot shows the predicted correlation in the case of an ideal detector covering 4π in solid angle.

FIG. 10. Experimental "good beam" multiplicity distributions for gold projectiles on Al, Cu, and Au targets. The predictions of the detector Monte Carlo are shown as solid lines.