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HEAVY-ION COLLISIONS AND THE NUCLEAR EQUATION OF STATE

PROGRESS REPORT TO THE US DEPARTMENT OF ENERGY

FOR THE PERIOD

AUGUST 15, 1992 — APRIL 1993

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Abstract

The overall goal of this project is to study nucleus-nucleus collisions experimentally at intermediate and relativistic energies, with emphasis on measurement and interpretation of correlation effects that provide insight into the nuclear phase diagram and the nuclear equation of state. During the course of this reporting period, the PI returned to Kent from a 15-month leave at Lawrence Berkeley Lab, which had been devoted 100% to work on this research project. The EOS Time Projection Chamber at LBL's Bevalac accelerator has continued to be the major focus of research for all of the supported personnel; about a year ago, this detector successfully took data in production mode for the first time, and accumulated in excess of 1000 hours of beam time before the termination of the Bevalac in February 1993. Reduction and analysis of these data is currently our first priority. Effort has also been devoted to the STAR detector at the Relativistic Heavy Ion Collider, in the form of contributions to the Conceptual Design Report, work on HV control hardware and software for use with the STAR Time Projection Chamber, and tracking software development. Since May 1992, 11 journal papers have been published or submitted for publication; 1 conference proceedings, 3 technical reports, and 16 abstracts have also been published during the past 12 months. One paper in Phys. Rev. Lett. and a review article are based on the thesis project of one of the PI's students who graduated earlier this year, and is now employed in private industry in the area of nuclear medical physics.

1. High-Order Flow Correlations

My interest in high-order effects in the context of Hanbury-Brown-Twiss (HBT) correlations dates back to the mid-1980s, when I was a Research Associate at U.C. Riverside. More recently, the progress we have made in using a correlation function to study sideward flow (discussed in last year's report) has led us to an investigation of the corresponding idea in the context of flow correlations. This work has been carried out by my graduate advisee, Jinghua Jiang. Initial findings were published early in the current reporting period (publication [i], section 6).

The underlying idea has important implications for our understanding of the equation of state, as demonstrated by the fact that our paper was published in Phys. Rev. Lett. despite being based on previously-reported decade-old streamer chamber data. Our paper points out that no previous study of the sideward flow effect has ruled out the possibility that the effect is dominated by a small number of correlated fragments in each event, as opposed to being a true collective motion to which most or all fragments contribute. We introduce two separate methods of characterizing "collectivity" — the percentage of fragments that carry a component of the ordered sideward motion. Collectivity is a new degree of freedom that is independent of the magnitude of the flow correlation (the quantity normally measured in studies of sideward flow). In our Phys. Rev. Letter, we infer that more than 70% of the forward-going fragments from collisions of Ar on Pb at 0.44 GeV carry a component of the collective motion, and in Jinghua Jiang's Ph.D. dissertation, the effect has been confirmed in another system with better statistical significance, and the above-mentioned lower limit increases to 80%.

As a result of this work, we have been invited to write a review article for the International Journal of Modern Physics E (publication [xi]). The scope includes triplet and higher multiparticle effects in the context of HBT correlations in addition to flow; drawing on details contained in Jinghua Jiang's dissertation, we demonstrate that the high-order effects in these two contexts are qualitatively rather different, with "pure" high-order effects (as measured by quantities termed cumulant moments) being present in the former case, but not in the latter. We have completed a draft of this article, and plan to submit our final version within the next month.

Jinghua Jiang has based her dissertation in part on the above analyses, although her hardware and experimental running experience came from her participation in more recent experiments at LBL. She was resident at LBL during 1991 – 1992 while I was there on leave. In January of this year, she was awarded a David B. Smith Fellowship, a distinction given annually to about 4 students in recognition of outstanding scholarship and research, and open to any of the 5,000 graduate students here at Kent State. She defended her dissertation earlier this semester, and

since March, has been employed by Trionix Research Laboratory, a Cleveland-area company that designs and manufactures CT medical diagnostic equipment, optimized for 140 keV γ s from ^{99}Tc . Dr. Jiang is expected soon to become a permanent resident of the US, and it is gratifying to view her case as an example where a modest educational investment by the DOE and the State of Ohio promises to generate an impressive return for the local and national economy assuming she continues to pursue her career in the private sector.

The work described in this section opens the way for a wide-ranging systematic investigation of the collectivity of the sideward flow phenomenon using the EOS TPC (see section 3), and this is one of the topics currently being pursued by my graduate advisee Yiping Shao.

2. Influence of Higher Orders on Pion-Pair Interferometry

As discussed in the previous section, the motivation to study high-order flow correlations arose from earlier work on high-order HBT correlations. In 1986, we demonstrated for the first time that analyses of pure pion triplet interference effects can provide important additional information [Y.M. Liu *et al.*, Phys. Rev. C 34, 1667 (1986)] beyond what can be obtained from the conventional studies of pion pair interference. In the same paper, we also described a correction term for the Coulomb repulsion between triplets, correct to lowest order. Finally, we cast light on the possible distortion of source parameters extracted from conventional particle-pair HBT analyses as a result of triplet interference, and identified the combinations of source radius and effective temperature where this distortion is appreciable. Since then, Zajc [Phys. Rev. D 35, 3396 (1987)] and Cramer [Phys. Rev. C 43, 2798 (1991)] have made valuable contributions to our understanding of multiparticle HBT correlations.

Our latest work on this topic (publications [vii] and [ix]) revisits an idea first explored in our 1986 paper: the effect that triplet HBT interference has on the interpretation of conventional pair HBT analyses, a potentially important source of distortion that has been ignored in all such analyses to date. We have now developed a procedure for correcting the distortion from all orders of multiparticle interference, not just triplets. Moreover, the multiparticle interference is not merely an unwanted source of distortion, but is itself a phenomenon of great intrinsic interest; our new formalism has allowed us to investigate the multipion interference in two experimental samples. Comparing 2.1A GeV Ne + Pb and 1.8A GeV Ar + Pb, we find a larger multipion effect for the Ne beam than for the Ar beam — a consequence of a smaller pion source radius with the lighter projectile.

3. The EOS Time Projection Chamber

The EOS project continues to be the major focus of the personnel supported by this grant. Although the EOS detector had completed some test running at the time of last year's report, the main running period, amounting to more than a thousand hours, took place during summer and fall 1992.

Since June 1990, my graduate advisee Yiping Shao has been resident continuously at LBL to work on EOS; in June 1991, another advisee, Alan Scott, took up residence at LBL to work full-time on EOS. Also in June 1991, my own one-year leave at LBL began, with EOS as a major focus of effort. In April 1992, Marvin Justice was hired into a postdoc position currently supported 50% by this grant and 50% by Kent State U.; over the past year, most of his effort has been devoted to EOS (see below). In Fall 1992, Alan Scott and I returned to Kent, while Yiping Shao and Marvin Justice have remained stationed at LBL.

Yiping Shao has implemented further improvements over the past year in the EOS Pad Monitor software (described in last year's report), but his major effort has been directed towards data-taking and analysis. One of the topics under investigation is high-order effects and collectivity, as discussed in section 1; another relates to the distribution of flow in the $p^\perp$ plane. More specifically, the observed transverse momenta can be visualized as the vector sum of random momenta and a collective momentum contribution, but based on the usual observables like $\langle p^x \rangle$ and cross sections relative to the reaction plane $d\sigma/d(\phi - \phi_R)$, it is not possible to uniquely constrain the variation of the angle and magnitude of the collective contribution as a function of $\phi - \phi_R$. Our new study can extract this information, and does so without the need to explicitly estimate the orientation of the reaction plane for each event. Apart from the new information obtained, this analysis offers several advantages, including relatively low sensitivity to azimuthal asymmetry in the detector response (a problem we expect will diminish in the future as we improve our software for TPC track finding and reconstruction). Yiping Shao presented his findings at APS meetings last Fall in Santa Fe and this Spring in Washington, DC. In late April of this year, the EOS Collaboration met and selected his analysis as one of two candidates for early publication.

Alan Scott has worked on a number of EOS hardware projects, including installation, testing and repair of fiber optic cabling, thermal switch testing in high magnetic fields, and assisted in redesign and testing of the TPC gated grid power supply. His major software project has been in the area of particle identification, and his contribution to the upcoming Annual Report of LBL's Nuclear Science Division is attached as Appendix 1. His familiarity with the dE/dx response of

the EOS TPC and particle id has led naturally into a physics analysis of entropy, where particle abundances are the primary observables.

Marvin Justice began work last year by testing the feasibility of Miklos Gyulassy's Elastic Tracking (ET) algorithms in the context of a simplified EOS geometry. Within a couple of months, he reached the conclusion (detailed in Appendix 2) that ET is not a practical alternative to the conventional Road Finding (RF) algorithm, although less radical departures from RF looked promising. By this time, the EOS analysis effort was getting under way, and it became clear that the existing EOS hitfinding and tracking codes had serious limitations and were significant impediments to progress towards our physics goals. In particular, the existing RF tracking code becomes easily confused for events with higher track densities. Marvin took on the task of troubleshooting and upgrading both codes. Hitfinding and tracking had previously been the responsibility of different people (Gulshan Rai and Howard Matis of LBL) and an integrated approach offers many advantages. Marvin has already implemented many improvements to the hitfinder, including deconvolution of partially overlapping tracks along the pad rows (previously, deconvolution was implemented only in the time direction), and has implemented spatial reconstruction of heavily ionizing tracks which saturate the dynamic range of the electronics.

Marvin's most crucial contribution to EOS has been in the area of tracking. He has developed a new track finding code based on the Progressive Fit (PF) method [R.K. Bock *et al.*, *Data Analysis Techniques for High-Energy Physics Experiments* Cambridge University Press, 1990]. The initial steps of the PF algorithm are identical to the RF algorithm (see Appendix 2 for a description of RF). Track reconstruction begins at the downstream end of the TPC where the track density is lowest. Chains are initiated by searching for three points that line up within some small tolerance. A line is then projected from the points on rows N-1 and N-2 to row N-3. If a hit is found on row N-3 within the search 'road' it is added to the chain. Unlike the RF method, where this simple two-point linear extrapolation is continued all the way inward to the pad row nearest the target, the PF algorithm stops after a 'sufficient' number of hits have been added. The five parameters necessary to define a trajectory and their corresponding covariance matrix are then determined by fitting the chain with a helix. From here on inward the algorithm proceeds by using the track model and the five track parameters to extrapolate to subsequent rows. As each row is crossed new points that lie within statistical limits of the extrapolation are added to the chain. When a new point is added, the track parameters are updated to include this new information.

A production version of a Progressive Fit code is nearing completion. Early test results are very encouraging and a substantial improvement over the simple Road Finding approach is expected. Novel refinements such as 'parallel' PF in which all chains are followed simultaneously from the downstream end of the detector are also a possibility.

4. The STAR Detector

A major milestone for STAR during the past year has been the completion of the Conceptual Design Report, and STAR's approval as a construction project. I contributed two sections to the CDR: one on neutral kaon interferometry, which simulations indicate to be feasible using a combination of information from the central TPC and the Silicon Vertex Tracker, and the second on dE/dx resolution and particle identification in the central TPC. Among the questions addressed in the latter section is the feasibility of using dE/dx information to identify HBT-correlated particle pairs in cases where the two tracks are too close in momentum to be resolved over most of their track length in the TPC. Such pairs, once identified, would be candidates for measurement of relative momentum using global tracking algorithms that would be impractical to apply to more than a select subset of the data.

We have undertaken to develop an integrated monitor and control system for the STAR TPC anode voltage supplies. On the hardware level, we are using the LeCroy 1440 HV system, which offers all of the required functions except nanoamp current sensitivity. For EOS, an external analog nA current monitor with 16 channels was used; for STAR, we eventually need 256 channels, with the current monitoring integrated into the overall slow control system. The simplest solution is to modify standard LeCroy 1444 modules to increase their current sensitivity to the desired level. This has been tried for one 1444 module (8 channels), and our tests at Kent so far have not uncovered any problems with this approach. The next step is to modify a second module and evaluate these two modules in conjunction with TPC endcap prototype tests at LBL later this summer. Al Baldwin is a very experienced electronics engineer supported 100% by the university, and his services are available to this project free of charge for design and construction of new current monitoring hardware if it later appears that our present solution is inadequate; otherwise, his services could be redirected to another STAR-related task. On the software level, this project involves development of a Graphic User Interface to run on a UNIX workstation, with provision for voltage switching and ramping, setting of limits on various parameters, voltage and current display and logging, and automatic trip recovery. A decision has been made to write this GUI in the framework of the EPICS (Experimental Physics and Industrial Control System)

STAR Memorandum of Understanding (exerpt)

Name	Position	% time in year					
		'93	'94	'95	'96	'97	
Al Baldwin	Electronic Eng.	15	15	-	-	-	4.2.4.2.4 hardware
Marvin Justice	Postdoc	30	50	-	-	-	4.8.2.3.2.2
Declan Keane	Assoc. Prof.	15	15	15	20	25	contact
Yiping Shao	Grad. Student	8	8	-	-	-	4.2.4.2.4 software
To be named	Postdoc	40	20	20	25	50	4.2.4.2.4 software thru 95
To be named	Postdoc	-	-	50	75	100	TPC software (4.8.2.3.2.2)
To be named	Grad. Student	-	-	50	100	100	4.8.2.3.2.2 & 4.2.4.2.4
To be named	Grad. Student	-	-	50	100	100	4.8.2.3.2.2 & 4.2.4.2.4

The percentages listed ABOVE are those already assigned and needed for the indicated tasks, or (in the case of the later years) definitely committed to a mix of the indicated STAR task with another STAR task.

The percentages listed BELOW are those either committed to a STAR task to be specified later, or available to STAR if requested. In addition, undergraduate student help is available on-campus.

Bryon Anderson	Physicist	10	15	15	15	15	will participate
Al Baldwin	Electronic Eng.	-	-	15	15	15	available
Brechtelsbauer	Mech. Tech.	15	15	15	15	15	available
John Watson	Physicist	10	10	10	10	10	

Baldwin and Brechtelsbauer are supported solely by Kent State U; Anderson, Keane and Watson are 9/12 supported by Kent State U and 2/12 by non-RHIC funding; other personnel are currently supported on average about 20% by Kent State University and 80% by non-RHIC federal funding. All time profiles have latitude for adjustment to match project requirements.

TABLE I

package, which has been adopted as the software standard in STAR for slow control functions. Negotiations are currently in progress between LBL and a software vendor for a collaboration-wide license to facilitate development of this software structure at a variety of locations. Dr. Weiming Zhang, a Senior Research Fellow supported in part by Kent State University and in part by the NSF grant of Profs. Anderson, Madey and Watson, is initially taking responsibility for the software aspects of this project.

Table I is an excerpt from the Memorandum of Understanding between STAR and Kent State University, and outlines the anticipated overall contribution of our group through 1997. The first "to be named" postdoc position represents a composite of the above-mentioned contribution by Dr. Weiming Zhang plus (in later years) a share of the new postdoc position supported in part by this grant. The second "to be named" postdoc position is the continuation of the Marvin Justice position. The current work by Marvin Justice on hitfinding and tracking in the context of EOS (see section 3) is largely generic to TPCs, and we expect that later this year, he will be in a position to adapt his EOS-tested codes to the specific environment of the STAR TPC. It is anticipated that a gradually increasing fraction of our postdoc effort will continue to go towards STAR TPC software. It is worth noting that all of our current effort relates to the "baseline detector", and is increasingly weighted towards software, which has been identified as being in particular need of manpower.

5. Intermediate-Term Project

Just over a year ago, it became known that the Bevalac would cease operation early in 1993, and the need for an intermediate-term project to bridge the time interval between data-taking at EOS and at STAR became clear. Within the past few weeks, it has become apparent that RHIC will be delayed more than a year, making the argument for a new project even more compelling. At the time of last year's report, I indicated my intention to join the NA49 collaboration at CERN, effective this year, and DOE supported this initiative through an additional \$12k towards a new 0.5 FTE postdoc to be hired this calendar year. This postdoc position is jointly funded with Prof. Mark Manley. Mark Manley's research, funded by NSF, is mainly in the area of experimental electron scattering at Bates and CEBAF, and his immediate need is for a postdoc to help construct a gas target for Bates. This position was filled last month with the hiring of Dr. Dhammika Weerasundara, who has just graduated from the University of Pittsburgh.

Over the past year, there has been increasing interest among the EOS collaboration in a project informally called EOS II (or more fancifully STAR minus 1) — moving the EOS TPC to the AGS (probably inside the MPS magnet), where we would be able to continue our systematic

investigation of 4π physics with Au beams at energies of, say, 2.5A GeV, 5A GeV, and maximum AGS energy. LBL's Gulshan Rai is spearheading this initiative. There are many indications of interesting physics at these energies. To mention just one example: the latest implementation of the Quantum Molecular Dynamics model [J. Jaenicke and J. Aichelin, Nucl. Phys. A547, 542 (1992)] and a Relativistic Cascade (ARC) model [S. Kahana, Y. Pang and T. Schlagel, Proc. HIPAGS '93] suggest that maximum Bevalac energy is too low to obtain good sensitivity to the nuclear equation of state, while maximum AGS energy is too high if the goal is to maximize effective nuclear compression through high baryon rapidity density. Even at maximum AGS energy, Au beam rapidity is less than twice maximum beam rapidity at the Bevalac. Thus, we expect that the EOS TPC will perform quite well between target rapidity and mid-rapidity. Last month, LBL management expressed its support for the project, and initial reaction from BNL management has also been encouraging.

Viewed as an alternative to NA49, EOS II offers a number of advantages in the particular context of our group. First, a continuation of work with the EOS TPC involves less dilution of effort, given that it is less like a new and distinct project than NA49; second, the timing is more favorable, because EOS data reduction and analysis deserves maximum priority over the next several months in conflict with the needs of NA49; furthermore, a new student who plans to join our group to replace Jinghua Jiang would have conflicts between completion of coursework and the running schedule of NA49; third, a program based at BNL has the obvious advantages of geographical proximity and easier overlap with STAR. Of course, there is an element of risk in that the status of EOS II is more uncertain than NA49, but all things considered, I have reluctantly decided not to pursue my original intention to join NA49. In this scenario, Dr. Weerasundara's initial work in the heavy ion area will be on simulations for the EOS II beam time proposal.

6. Publications for 12-Month Period Ending April 1993

This section lists all work coauthored by the PI having a publication date within the 12-month interval since last year's report; in the case of refereed journal publications, papers in press or submitted for publication are also listed.

6.1 Papers in Refereed Journals

- [i] J. Jiang, D. Beavis, S.Y. Chu, G. Fai, S.Y. Fung, Y.Z. Jiang, D. Keane, Q.J. Liu, Y.M. Liu, Y. Shao, M. Vient, and S. Wang,
"High-order Collective Flow Correlations in Heavy-Ion Collisions",
Phys. Rev. Lett. **68**, 2739 (1992).
- [ii] W.B. Christie, W.F.J. Mueller, D.L. Olson, T.J.M. Symons, H.H. Wieman, D. Beavis, F.P. Brady, J. Romero, C.E. Tull, T. Abbott, S.Y. Fung, D. Keane, and Y. Liu,
"Pion Correlations in 1.8 A GeV Ar on KCl and on La and 1.2 A GeV Xe on La",
Phys. Rev. C **45**, 2836 (1992).
- [iii] Q.J. Liu, Y.Z. Jiang, S. Wang, Y.M. Liu, D. Keane, S.Y. Fung, and S.Y. Chu,
"Multi-particle Azimuthal Correlations and the Nuclear Equation of State",
High Ener. & Nucl. Phys. **16**, 801 (1992).
- [iv] L. Huo, Y.Z. Jiang, S. Wang, Y.M. Liu, D. Keane, S.Y. Fung, and S.Y. Chu,
"Spatial Parameter from Two-pion Interferometry",
High Ener. & Nucl. Phys. **16**, 816 (1992).
- [v] A.R. Baldwin, R. Madey, W.-M. Zhang, B.D. Anderson, D. Keane, J. Varga, J.W. Watson, G.D. Westfall, K. Frankel, and C. Gale,
"Inclusive Neutron Cross Sections from Ne-Pb Collisions at 790 MeV/nucleon",
Phys. Rev. C **46**, 258 (1992).
- [vi] W.B. Christie, D.L. Olson, C.E. Tull, F.P. Brady, G.P. Grim, J.H. Osborne, M.L. Partlan, J.L. Romero, J. Chang, S.Y. Fung, J. Kang, S. Zhang, D. Keane, and Y. Dardenne,
"Pion Correlations for 1.2A GeV Lanthanum on Lanthanum",
Phys. Rev. C **47**, 779 (1993).
- [vii] W.N. Zhang, Y.M. Liu, S. Wang, Q.J. Liu, J. Jiang, D. Keane, Y. Shao, S.Y. Chu, and S.Y. Fung,
"Distortion of Two-Pion Interferometry by Multipion Correlations",
Phys. Rev. C **47**, 795 (1993).
- [viii] P. Markowitz, J.M. Finn, B.D. Anderson, H. Arenhövel, A.R. Baldwin, D. Barkhuff, K.B. Beard, W. Bertozzi, J.M. Cameron, C.C. Chang, G.W. Dodson, K. Dow, T. Eden, M. Farkhondeh, B. Flanders, C. Hyde-Wright, W.-D. Jiang, D. Keane, J.J. Kelly, W. Korsch, S. Kowalski, R. Lourie, R. Madey, D.M. Manley, J. Mougey, B. Ni, T. Payerle, P. Pella, T. Reichelt, P.M. Rutt, M. Spraker, D. Tieger, W. Turchinets, P.E. Uimer, S. Van Verst, J.W. Watson, L. Weinstein, R.R. Whitney, and W.M. Zhang,
"Measurement of the Magnetic Form Factor of the Neutron",
Phys. Rev. C **47**, (in press).
- [iz] W.N. Zhang, Y.Z. Jiang, S. Wang, Y.M. Liu, D. Keane, J. Jiang, Y. Shao, S.Y. Fung, and S.Y. Chu,
"Multi-pion Correlations in Two-pion Interferometry",
High Ener. & Nucl. Phys. **17**, (in press).

- [z] M. Elaasar, R. Madey, W.M. Zhang, J. Schambach, D. Keane, B.D. Anderson, A.R. Baldwin, J.W. Watson, G.D. Westfall, G. Krebs, H. Wieman, C. Gale, and K. Haglin
"Maximum Neutron Azimuthal Anisotropy in Nb - Nb Collisions at 400A MeV and the Nuclear Equation of State",
 submitted to Phys. Rev. Lett.
- [zi] Jinghua Jiang, Declan Keane and Yiming Liu,
"Triplet and Higher-Multiplet Correlations in Heavy-Ion Collisions",
 Invited review article to appear in Int. J. Mod. Phys. E.

6.2 Conference Proceedings

- [a] R. Madey, M. Elaasar, W.M. Zhang, J. Schambach, D. Keane, B.D. Anderson, A.R. Baldwin, J.W. Watson, G. Krebs, H. Wieman, G.D. Westfall, C. Gale, and K. Haglin
"Probing the Nuclear Matter Equation of State with Neutrons from Nucleus-Nucleus Collisions",
 Nucl. Phys. A553, 779c (1993).

6.3 Technical Reports

- [a] M.E. Beddo *et al.* (STAR Collaboration), *"Conceptual Design Report for the Solenoidal Tracker at RHIC (STAR)"*, PUB-5347 (1992).
- [b] W. Christie, D. Olson, P. Brady, J. Chang, Y. Dardenne, S. Fung, G. Grim, J. Kang, D. Keane, J. Osbourne, M. Partlan, J. Romero, C. Tull, and S. Zhang, *"Pion Correlations in Relativistic Heavy Ion Collisions at HISS"*, 1991 Annual Report of Nuclear Science Division, Lawrence Berkeley Laboratory, LBL-31855.
- [c] F. Bieser, F.P. Brady, D. Cebra, A.D. Chacon, J. Chance, Y. Choi, S. Costa, J. Elliott, M. Gilkes, A. Hirsch, E. Hjort, D. Keane, U. Lynen, H.S. Matis, M. McMahan, C. McParland, W. Mueller, G. Odyniec, D.L. Olson, M.D. Partlan, N. Porile, R. Potenza, G. Rai, J. Rasmussen, H.G. Ritter, J.L. Romero, H. Sann, R. Scharenberg, A. Scott, Y. Shao, B. Srivastava, T.J.M. Symons, M. Tincknell, C. Tuve, P. Warren, H.H. Wieman, and K. Wolf, *"Performance of the EOS TPC"*, 1991 Annual Report of Nuclear Science Division, Lawrence Berkeley Laboratory, LBL-31855.

6.4 Abstracts

- [1] M. Elaasar, R. Madey, W.M. Zhang, J. Schambach, D. Keane, B.D. Anderson, A.R. Baldwin, J.W. Watson, G. Westfall, G. Krebs, and H. Wieman, C. Gale, and K. Haglin, *"Probing the Nuclear Matter Equation of State with Neutrons from Nucleus-Nucleus Collisions"*, 101st Annual Meeting of the Ohio Academy of Science, Akron, Ohio, May 1992, [The Ohio Journal of Science 92, 29 (1992)].
- [2] E. Hjort, N. Albergo, F. Bieser, F.P. Brady, Z. Caccia, D. Cebra, A.D. Chacon, J. Chance, S. Costa, J. Elliott, R. Fonte, M. Gilkes, A. Hirsch, D. Keane, V. Lindenstruth, H.S. Matis, C. McParland, W.F.J. Müller, D.L. Olson, M.D. Partlan, N. Porile, R. Potenza, G. Rai, J. Rasmussen, H.G. Ritter, J.L. Romero, H. Sann, R. Scharenberg, A. Scott, Y. Shao, B. Srivastava, T.J.M. Symons, M. Tincknell, C. Tuve, P. Warren, H.H. Wieman, and K. Wolf, *"Performance of the EOS TPC"*, Bull. Amer. Phys. Soc. 37, 1265 (1992).
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