LBL-14561 c.2

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY

AUG 16 1982

LIBRARY AND
DOCUMENTS SECTION

Presented at the Workshop on Quark Matter Formation and Heavy Ion Collisions, Bielefeld, W. Germany, May 10-14, 1982

ACCELERATOR PROSPECTS FOR HIGH ENERGY HEAVY ION COLLISIONS

Howel G. Pugh

June 1982

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 6782.

NUCLEAR SCIENCE DIVISION

LBL-14561 c.2

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

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-14561

ACCELERATOR PROSPECTS FOR HIGH ENERGY HEAVY ION COLLISIONS

Howel G. Pugh

Nuclear Science Division, Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

Summary remarks at the Workshop on Quark Matter
Formation and Heavy Ion Collisions,
Bielefeld, W. Germany, 10-14 May, 1982

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

LBL-14561

ACCELERATOR PROSPECTS FOR HIGH ENERGY HEAVY ION COLLISIONS

Howel G. Pugh
Nuclear Science Division, Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

"Between the idea
And the reality ...
Falls the Shadow"
T.S. Eliot: The Hollow Men

1. Objectives

What accelerators are necessary to study the transition from hadronic matter to the quark-gluon plasma? What accelerators exist? What accelerators are being proposed? What is a reasonable next step?

2. High Energy Density and its Achievement

Estimates of the energy density required to produce a quark-gluon plasma range from 0.5 to 4.0 GeV/fm^3 (see elsewhere at this workshop). It seems reasonable to consider the internal energy density of the proton, 0.44 GeV/fm^3, as a threshold at which the whole of a nucleus might consider turning into a single quark bag.

To achieve such energy densities we can consider three regimes. At Bevalac energies, both the interacting nuclei overlap, so we start from twice nuclear density, i.e., 0.34 GeV/fm^3. Extensive intranuclear cascade calculations have shown that the overlapping nuclei also pile up and provide a further increase, yielding energy densities in the region of 1.0-1.5 GeV/fm^3. As the energy is increased, a further increase in density may occur, but eventually the nature of the interaction changes. By 15 GeV/amu in the laboratory, even a uranium nucleus is contracted to the thickness of a single proton. It is then difficult for the incident nuclei to transfer all their momentum into the mid-rapidity region and "transparency" sets in. In the very high energy regime the energy

density in the mid-rapidity region is made up of created particles. Kajantie at this workshop made some estimates, which depend on the A dependence of pion multiplicity in the central region. I have assumed that the A dependence will lie between $A^{2/3}$ and A, leading to the schematic outline in Figure 1.

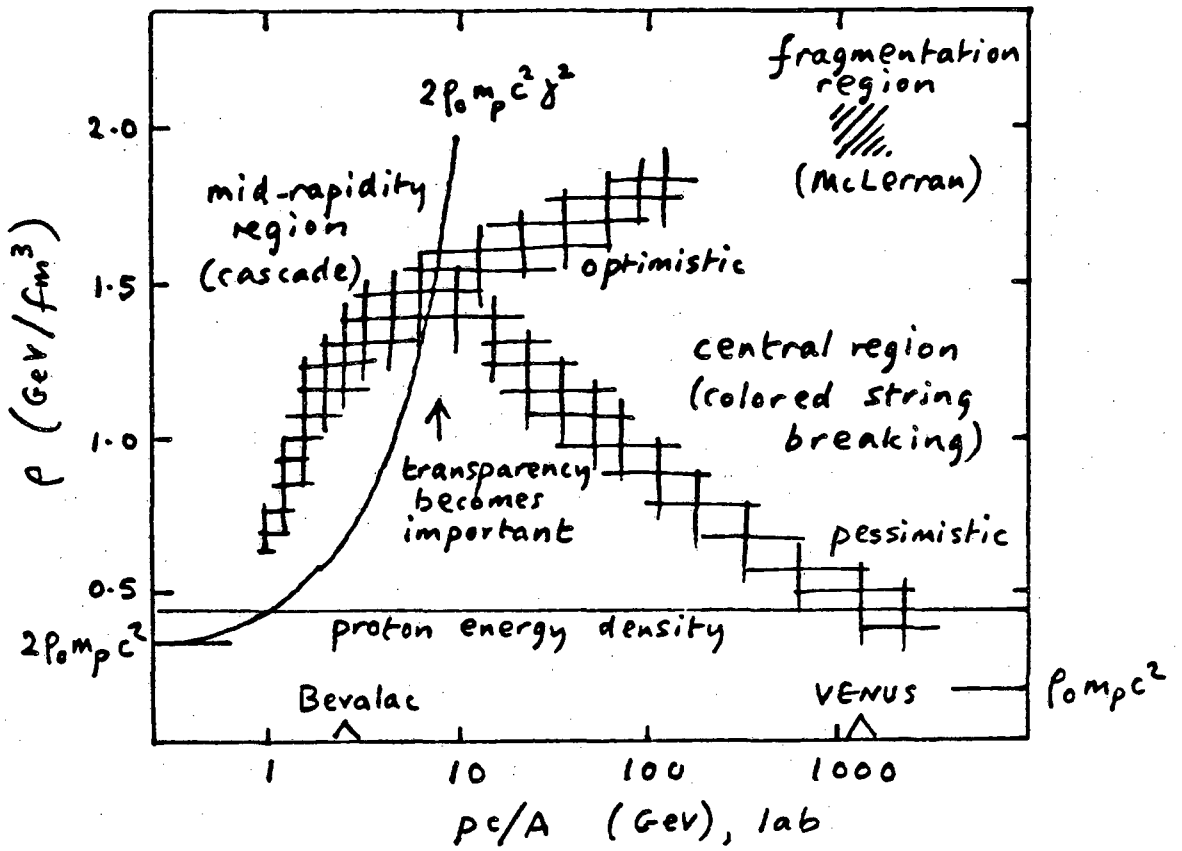

Fig. 1. Tentative scheme for energy density reached in U-U collisions as a function of beam momentum.

McLerran and others have considered also the fragmentation regions at very high energies. Here, starting from the normal nuclear density of 0.17 GeV/fm^3, they find energy densities in the region of 2.0 GeV/fm^3 in the comoving frame of the excited nucleus. Gyulassy at this workshop attached some uncertainties to this estimate. Figure 1 serves as an outline to begin to correlate the various estimates; at present it is very schematic and needs much refinement.

Projectile and target masses must be high for several reasons: to reach a high energy density, to reach it over sufficient volume to reach equilibrium, and to avoid having the interesting physics in the high density region obscured by uninteresting surface effects. As a partial illustration of the advantage of heavy nuclei, Figure 2 shows a comparison of Ca-Ca and Pb-Pb interactions at 1 GeV/amu, obtained from a cascade calculation. It shows, for the optimum situation--zero impact parameter, the number of incident nucleons that make N or fewer binary nucleon-nucleon collisions during the interaction. The median number of collisions is four for Ca-Ca and nine for Pb-Pb. In the Ca-Ca system, 25% of all the nucleons undergo only zero, one, or two collisions. For non-zero impact parameters the situation would clearly be much worse.

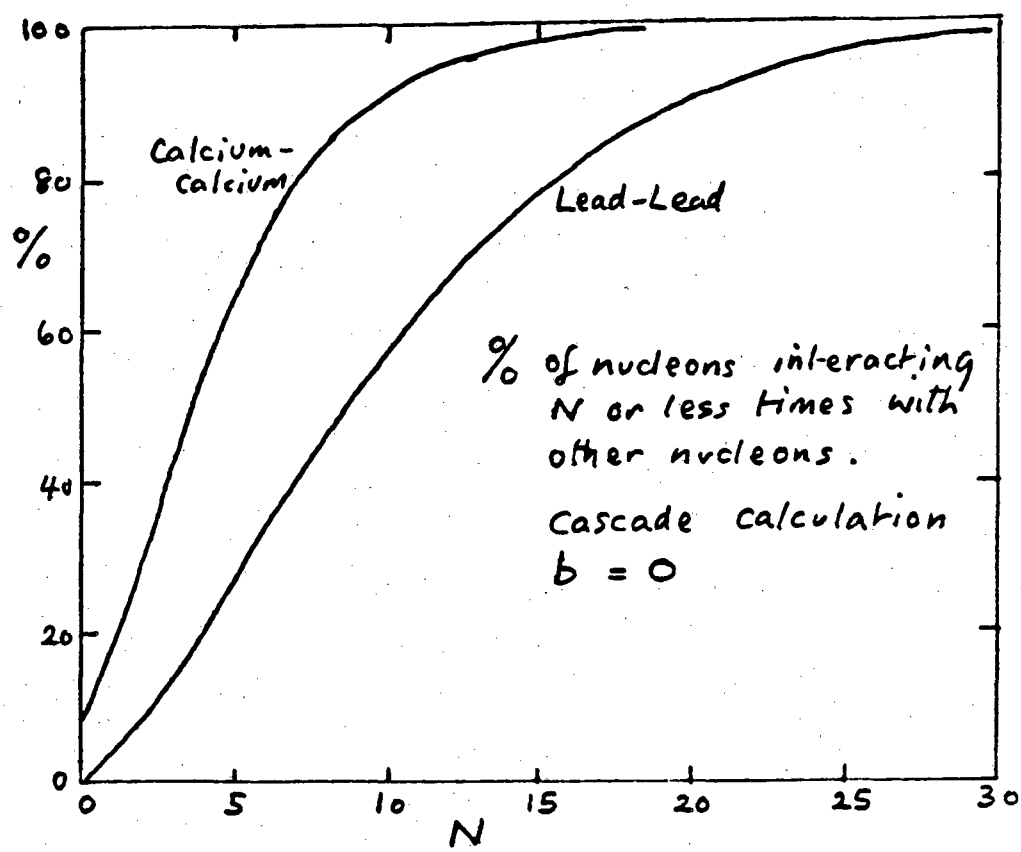

Fig. 2. Results of a cascade calculation of Ca-Ca and Pb-Pb head-on collisions. Courtesy J.W. Harris.

3. Existing Heavy Ion Accelerators

The only existing capabilities for heavy ion research at these energies are shown in Table I.

Table I

Existing Heavy Ion Accelerators

Name	pc/A GeV/amu	Maximum Ion	Intensity of Maximum Ion
Bevalac*	2.9	U	$\sim 10^7$/sec
Synchrophasotron	4.5	Ne	$\sim$100/sec
Cosmic Rays	2.10^4-2.10^5	Fe	$\sim$1-2/day

*The first uranium beams, at 1000/pulse, were extracted during the workshop.

In addition there are some projects under construction. At the Saturne II facility in Saclay, an EBIS ion source is expected to operate in 1983 and provide light ions up to pc/A = 1.8 GeV/amu. The Synchrophasotron is being upgraded by means of a new injector to provide heavier ions. A new facility, SIS 12/18, is expected to be completed at GSI, Darmstadt, in 1987 and provide ions and energies comparable to those at the Bevalac.

4. Desired Parameters for New Facilities

Any new facility should clearly have very heavy ions at energies substantially greater than those available at the Bevalac. The VENUS facility, proposed for LBL, is one possibility. Its parameters are shown in Table II.

This facility permits study of all three high density regimes discussed in Section 2. The fixed target capability will permit study of the region where both target and projectile nuclei are brought to rest in the cm frame. At the upper end of the fixed target energy range we may expect that the target and projectile fragmentation regions are just becoming separated for very heavy nuclei. The colliding beam capability has a sufficient rapidity interval between projectile and target ($\Delta y = 8$) that we may expect to observe separated fragmentation regions and also a clear central region.

Table II

VENUS (Variable Energy Nuclear Synchrotron)

Fixed Target:	50 Z GeV/c $y_{proj.} - y_{targ.} = 4$ for Z/A = 1/2	
Collider:	50 Z GeV/c on 50 Z GeV/c $y_{proj.} - y_{targ.} = 8$ for Z/A = 1/2	
Intensity:	10^{11} particles per sec	A ∿ 40
	10^{10} particles per sec	A ∿ 200
Luminosity:	10^{30} cm^{-2} sec^{-1}	A ∿ 40
	10^{29} cm^{-2} sec^{-1}	A ∿ 200

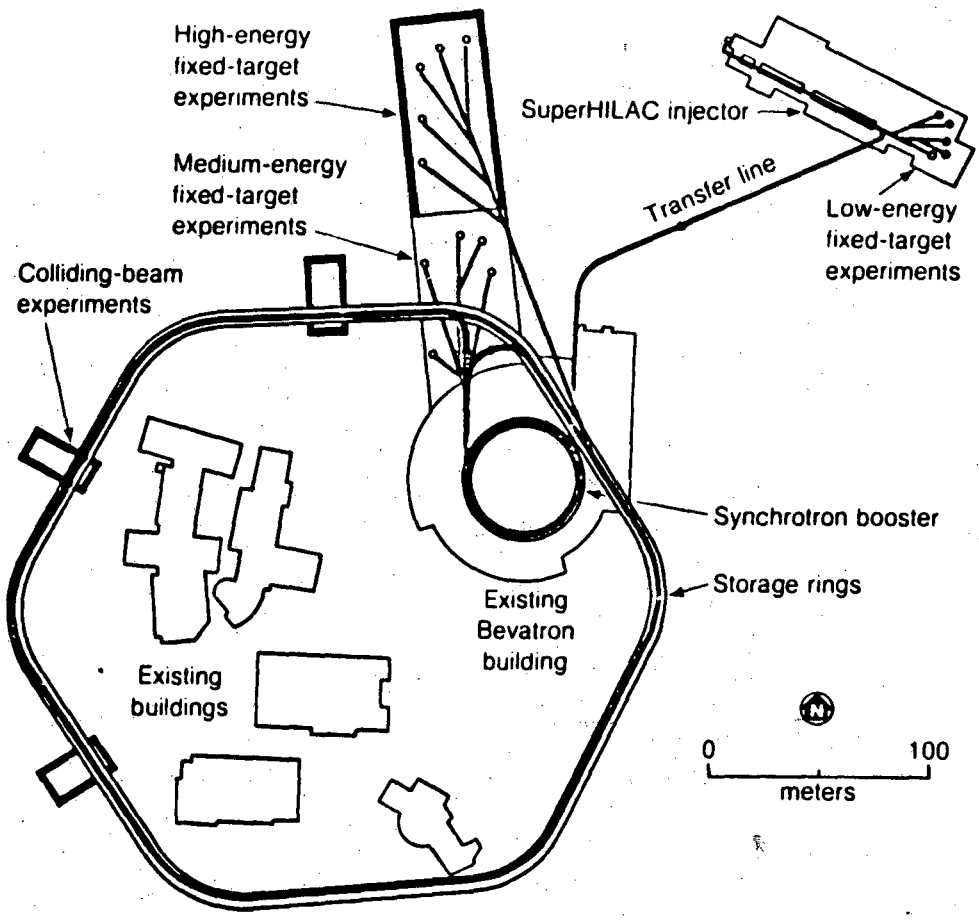

Fig. 3. Layout of proposed VENUS facility.

The maximum energy of VENUS, about 60% higher than the ISR, was chosen to put the nucleon-nucleon cm energy for U-U collisions at 20 GeV/amu, just in the middle of the well-studied ISR range for proton-proton collisions, which seems to be about ideal. No demonstrable advantage can be identified in going to higher energy. Already at this energy strange particle production, very important for diagnostics, is more or less asymptotic. Any change in the K-π ratio as A increases will be hard to explain at this energy. As the energy is increased further, the energy density increases only marginally. Charm production would increase, but it is never expected to be significant. However, going to lower energies, clearly different regimes remain to be explored, and major surprises like the anomalon may occur. For this reason, the VENUS plan, shown in Figure 3, includes a 4 GeV/amu (uranium) injector at which a research program is also expected to be mounted. The entire energy range up to about 1 TeV/amu is thus available for experimentation.

Finally, now that the ISR is not to be made available, a major advantage of building a new facility should be stressed. The beams and detectors can be designed explicitly for heavy ion physics. The detectors in existence at the ISR (and SPS) could be used, with difficulty, only for some of the lighter ion experiments.

5. SPS, ISR, VENUS, Isabelle

It is interesting to compare the relative merits of colliding beam and fixed target facilities at the same cm energy. For a new facility the much smaller cost associated with the colliding beam option is most important. The comparison between SPS and ISR was much discussed at the workshop and is instructive.

The SPS provides easy accessibility to experiments for set-up purposes; extreme forward kinematics, a serious nuisance; on the other hand a large Lorentz factor that permits hyperon beams; a very difficult detector situation at 200 GeV, in which it is "almost impossible" to distinguish π, K, p.

The ISR provides an easier detector situation; a better match of detectors to reaction kinematics; worse background problems.

VENUS would be similar to the ISR but with the advantage of a design specific for heavy ions. Isabelle, at a much higher energy, would have many of the particle identification problems associated with the SPS.

To make a concrete comparison of currently active proposals, Table III shows some performance figures.

Table III

Comparison of SPS, VENUS, Isabelle

Facility Proposed	Beam	Injector Intensity	Luminosity
SPS	^{16}O	10^7/sec	$\sim 10^{29}$ (assuming one radiation length target)
VENUS	$A < 40$	10^{11}/sec	$\sim 10^{30}$
	$A \sim 200$	10^{10}/sec	$\sim 10^{29}$
Isabelle	$A \sim 100$	10^9/sec	$\sim 10^{28}$

With only the low intensity available from the proposed ion source, the SPS loses the usual advantage of a fixed target facility in terms of luminosity.

6. Comments on SPS Program

Since this workshop has been focused on the SPS, I mention a few special points of relevance that came up during the meeting.

1) $\bar{p}A$, αA, and AA studies would be desirable, not just AA.
2) pA could be done in the collider and might be interesting to diagnose quark dynamics.
3) ^{16}O-Pb studies, though restricted in the volume to be heated, would provide important tests of nuclear stopping power.
4) Existing detectors can be used, but they will have serious difficulty with the high vertex multiplicities, even for ^{16}O.
5) There is an energy gap between PS and SPS but this could be closed using an internal target at the SPS.
6) α particles could be available in the SPS next year but ^{16}O not before late 1984.

The most serious difficulty is that there is no crucial experiment, which means a systematic program is necessary and a great deal of beam time. The experimental designs of the working groups were made much more difficult by the requirement that all the experiments should be completed in one or two weeks!

7. Proposals

Table IV shows a summary of known proposals in addition to the existing facilities of Table I. The percentage availability for heavy ion physics is included as an important parameter for coherent program development. Unless beam time is to be available, it will not be considered worthwhile to make investment in ion sources, injectors, specialized detectors, etc., and the field may develop so slowly that a concentrated level of critical attention may never be achieved.

Table IV

Projects and Proposals (for existing facilities see Table I)

Facility	Availability	Comments
+ Saturne II (Saclay)	∿50%	EBIS (1983)
SIS 12/18 (GSI)	100%	SIS 100 proposed
Numatron (INS)	100%	location to be resolved
+ MARIA (Edmonton)	25%	comparable to Saturne II
+ KEK 6 GeV/amu	25%	needs new ion source
+ PS/SPS 200 GeV/amu	10% ?	^{16}O with new ion source
VENUS		
25x25 GeV/amu	100%	$L = 10^{29}$ $A \sim 200$
AGS/ISABELLE		
200x200 GeV/amu	10% ?	$L = 10^{28}$ $A \sim 100$

+ Light ions only

At this time, Isabelle has only been discussed as a possible future option, after the facility itself has been brought into operation. At this workshop, R.M. deVries also mentioned that Los Alamos is considering a colliding beam facility for heavy ions.

Addition information on some of these facilities is given in reference 1.

8. Conclusions

(a) U-beams at the Bevalac are very exciting. The densities achievable are not ruled out for a transition to the quark-gluon plasma and studies in this direction should be pursued. The anomalous nuclear fragments could be the first sign that something interesting in this direction is going on.

(b) Cosmic-ray studies are extremely important, and research should be supported as strongly as possible.

(c) Research with light ions at the PS and SPS should be pursued since it is the only game in town, but availability of beam time is unsatisfactory. If a firm commitment of SPS time were made, a high intensity linac might be justified for improved luminosity and ions up to A $\sim$ 40.

(d) A dedicated U-U facility is needed, having a wide energy range and newly optimized detectors. VENUS is the only option addressing all the needs. If we think the field is interesting, the VENUS proposal should be pushed as hard as possible. Figure 4 shows the region of parameter space covered by this facility.

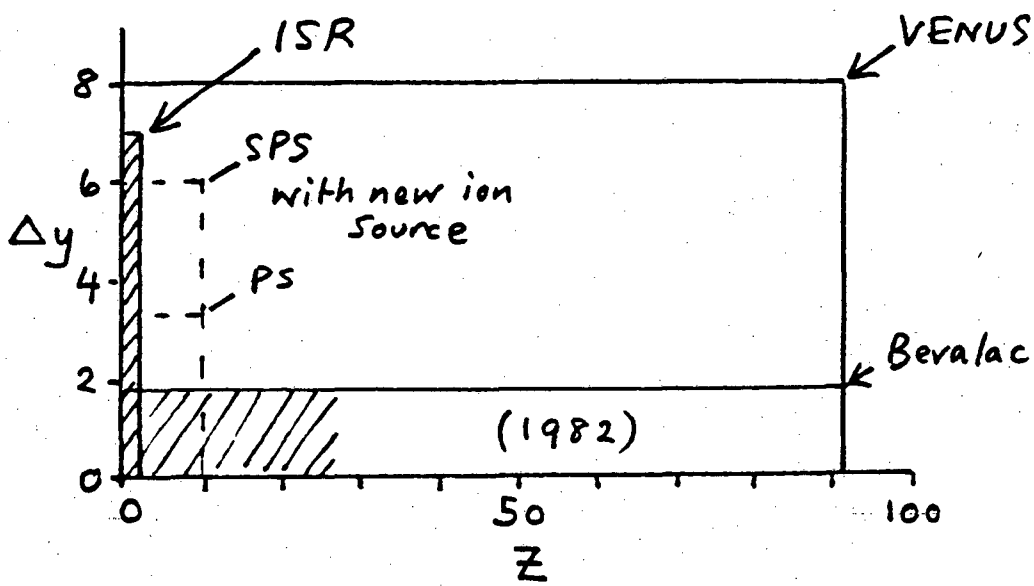

Fig. 4 Parameter space covered by principal facilities and proposals (schematic).

Acknowledgments

I thank the many participants at the workshop from whom I gleaned new information for this summary. This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

References

1. H.G. Pugh, LBL-12835 (1981) and LBL-13029 (1981).

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

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