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H.G. Pugh

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A NEW COLLIDER SCHEME AT LBL*

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Invited paper presented at the Fourth International Conference on Ultra-relativistic Nucleus-Nucleus Collisions, Helsinki, Finland, 17-21 June, 1984

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A NEW COLLIDER SCHEME AT LBL*

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This paper presents current ideas from Berkeley concerning a possible new facility for studying the phase transition from hadronic matter to quark matter. The physics ideas have evolved over a period of more than five years, the VENUS concept for a 25 GeV/nucleon colliding beam facility having been presented in 1979.[1] The concept for the Minicollider has been, like that of VENUS, the work of Hermann Grunder and Christoph Leemann.

1. Progress Since the Bielefeld Meeting

Our knowledge of heavy ion collisions has increased greatly since my summary talk at Quark Matter '82.[2]

During that meeting I was able to report that the first uranium beams had been extracted from the Bevalac.[3] As a result of experiments carried out with the new beams (previous experiments having been limited to projectiles up to the mass-40 region) the importance of using the heaviest nuclei has now been demonstrated. The recent work of Gustafsson et al.[4] is an excellent illustration. Using the Plastic Ball-Wall combination they studied collisions of equal mass nuclei and measured all the charged particles emitted. They constructed the flow tensor[5] for each event, and histogrammed the flow angle for various charged particle multiplicity bins. The results for $^{40}Ca + ^{40}Ca$ and $^{93}Nb + ^{93}Nb$ are shown in figure 1, together with an intranuclear cascade calculation for comparison. For $^{40}Ca + ^{40}Ca$, the flow angle (which represents the most probable direction of energy flow) is peaked in the beam direction, with just a hint of a deflection in the highest multiplicity bin. However, for $^{93}Nb + ^{93}Nb$ a well-defined deflection is seen. The intranuclear cascade calculation does not reproduce the data. This is clear evidence for relativistic hydrodynamical effects, as has been shown by Graebner et al.[6] These effects can be discerned in the $^{40}Ca + ^{40}Ca$ data, taken earlier, but it is only with the increased mass that they emerge

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clearly.

At Quark Matter '83, Busza and Goldhaber[7] forced a reconsideration of nuclear stopping power. So little has been known about this question that in my review of Bevalac research at Bielefeld[8] I was unable to provide proof that nuclei stop in each other at 2 GeV/nucleon incident laboratory energy. The fact that they do is now clear[5] but the results of Busza and Goldhaber on the degradation of high energy protons in nuclei suggest that nuclear stopping may continue to much higher energies. Whereas a few years ago it was believed that nuclear transparency should set in above about 10 AGeV in the laboratory, it now seems quite possible that stopping may occur up to energies of the order of 50 AGeV. This implies that much greater densities may be achieved in the baryon-rich regime than had previously been thought possible.

A major development on the technical side has been a careful study done at Brookhaven on the achievable luminosities in heavy ion colliders.[9] These have proved to be much lower than previously thought, and are determined primarily by intrabeam scattering. At Berkeley we therefore reexamined the possible use of the Bevalac as an injector. We found to our surprise that the luminosity is not limited by the Bevalac beam quality. We thus already have an operating injector already providing beams of fully stripped uranium at an energy suitable for injection into a collider.

In the two years since Bielefeld there has also been extensive examination and reexamination of possible experiments to look for the quark-gluon plasma. We have a much better appreciation of the conditions under which experiments with present-day techniques are possible, and a better appreciation of the difficulties involved in interpreting the various proposed "signatures" of the quark-gluon plasma.

2. Signatures of the Phase Transition

There has been extensive discussion of signatures of the quark gluon plasma, and none has been found which is free from difficulties of interpretation. The reason is that, because of confinement, there is no first order effect in which we could see the quarks and gluons directly after they have been liberated by the phase transition. We always have to look at re-condensed material (hadrons) in the final state. Experiments involving leptons are partially free from this criticism since they can sense the space- and time-integrated behavior of the collision process, including the period during which the system was in the plasma state. However, their interpretation will

require a rather complete understanding of the collision mechanism and will require many subsidiary experiments.

Under the circumstances it seems preferable to start with a number of simpler exploratory studies, and look for signatures of the phase transition. Here we can consider a standard experiment:

a) Choose a variable which is related to the energy density ε. Such a variable is the bombarding energy E, as can easily be checked by the first experiments, by measuring dn/dy (y = 0) as a function of E. Also, ε may be a monotonically increasing function of target and projectile mass A, though perhaps after a certain value of A has been reached only the duration of the quark-gluon phase may increase with A. Or, ε may be a monotonically increasing function of some other variable to be defined by the experimenter.

b) Choose an observable that may be sensitive to the internal properties of the system, such as $\langle p_T \rangle$, or the multiplicity of created particles, or the composition of products in terms of q, $\bar{q}$, s, $\bar{s}$. Many such observables can be imagined.

c) It may then be expected that with the properly chosen variable and observable, the phase transition will be manifested by a curve of the form shown in Fig. 2.

It seems likely that some experiment of such a nature will reveal the phase transition. However, it will be necessary to have a sufficiently wide energy range available for experiments and to be able to identify both regions A and B. An experiment that showed only the lower half of the curve would be unconvincing. Once the phase transition has been observed, the time will be ripe to proceed to study properties of the quark-gluon plasma in region B, perhaps by contrast with similar studies in region A.

3. The Berkeley Minicollider

As a result of the above considerations, we have concluded that a collider for uranium ions in the c.m. region up to about 4 AGeV (50 AGeV laboratory) would provide a wide range of opportunities to study the phase transition to the quark gluon plasma in the baryon-rich regime.

The Berkeley Minicollider would be injected by the Bevalac at 400 AMeV and would accelerate up to 4 AGeV (uranium) or 5.4 AGeV (calcium). Its parameters are shown in Table 1 together with a comparison with the AGS (including the proposed booster).

Table 1
Energies for uranium-uranium collisions

Berkeley Minicollider	AGS with Booster
0.2 - 4.0 AGeV c.m.	up to 1.56 AGeV c.m.
1.0 - 50.0 AGeV lab.	up to 11.4 AGeV lab.

The lower energy limit of the Minicollider is arbitrarily set as that which is presently achieved in fixed target experiments at the Bevalac. It is interesting for orientation purposes to look at estimates of the energy density obtained if the colliding nuclei were to stop exactly in each other,[10] i.e. $\epsilon_g = 2m_p c^2 \rho_o \gamma_{cm}^2$. At Bevalac energies this value is exceeded due to the formation of a shock front. At some energy the energy density will drop below this value. The energy at which the energy density exactly equals ϵ_g might be a suitable definition of the <u>onset of transparency</u>. Table 2 gives values for ϵ_g and the baryon component of it, ϵ_g (baryon) = $2m_p c^2 \rho_o \gamma_{cm}$ at the upper energies of the Minicollider and of the AGS (with Booster).

Table 2
Goldhaber estimates for energy density ϵ_g and the baryon fraction of it at Berkeley Minicollider and AGS (with Booster), for uranium-uranium collisions

	K.E.(lab)	K.E.(cm)	ϵ_g	ϵ_g (baryon)
AGS with Booster	11.4 AGeV	1.56 AGeV	2.03 GeV/fm^3	0.76 GeV/fm^3
Berkeley Minicollider	50.0 AGeV	4.0 AGeV	7.94 GeV/fm^3	1.50 GeV/fm^3

The values for the Minicollider encourage us to believe that it might be possible with that facility not only to reach the phase transition (end of region A in Figure 1) but to exceed it, map out the entire phase transition and reach the region B in Figure 1 where the bulk of the interacting nuclei have been converted into quark-gluon plasma.

The layout of the facility has been planned to have minimal interference with existing projects. The collider can be constructed while the Bevalac is running, and when complete it can operate simultaneously with the ongoing program of therapy, biomedical research, nuclear physics and atomic physics. A possible layout is shown in Figure 3. Here one of the intersection regions is placed conveniently in the high-bay area of Building 64. The opposite intersection area falls in a region of Blackberry Canyon which is already planned

to be filled by mid-1985. This layout is in the spirit of the project, which is to make maximum utilization of existing facilities, to use in-hand technology for the magnets, and to use stochastic cooling techniques which LBL has helped develop for Fermilab.

4. Some Details of Performance

The following are approximate numbers from the present stage of development of the planning:

-- There will be single-turn injection into and extraction from the Bevalac, and about 10^6 particles per Bevatron pulse will be accepted into each Minicollider ring;

-- Stochastic cooling will be applied continuously during filling to allow the storage of many injector pulses: approximately 100 pulses, over 10 minutes, will lead to 10^8 ions stored in each ring;

-- The beams will then be accelerated slowly (over a period of about 60 sec) to operating energy;

-- The Minicollider will have high luminosity intersection region design, and stochastic cooling will be applied continuously during experiments to counteract intrabeam scattering and the corresponding fall-off in luminosity and beam quality;

-- The beam lifetime is expected to be of the order of a day, so that the facility hardly takes up any significant fraction of Bevalac time;

-- Luminosity at 4 AGeV (scales as $\beta\gamma A^2/Z^4$)

U - U	$8 \cdot 10^{23}$	cm^{-2} sec^{-1}
Au - Au	10^{24}	"
Ca - U	$3 \cdot 10^{24}$	"
Ca - Ca	10^{25}	"
p - p	10^{27}	"

-- Beam size: <1 mm high, a few mm wide
crossing angle--a few mrad
length of diamond--1 m for stated luminosity

-- The duty factor will be 100%, since a coasting beam will be used; furthermore, the luminosity will remain near its peak value because of the continuous application of stochastic cooling.

5. Experiments with the Minicollider

With the design luminosities, most types of desired experiments can be carried out. For example, the U - U event rate would be ~7/sec. If one takes as a standard the statistics achieved for minimum bias data in recent Plastic Ball experiments[5)] demonstrating

collective flow, we find that 50,000 minimum bias events are extremely useful. These could be obtained in 2 hours. For central collisions, applying a selection procedure much more severe than any used to date, i.e. central collision cross section of 40 mb (equal to the p - p cross section), we find one extremely central collision every 25 seconds. Taking as a standard the statistics achieved by recent Streamer Chamber data on central collisions,[5] 1000 such events would be very valuable. These could be obtained in 7 hours.

Such data rates are excellent for central region production, stopping power studies, strange particle production, studies of temperature, entropy and flow, and photon production. They are inadequate for dilepton production as presently foreseen and for high transverse momentum studies.

A consideration of detector needs has been made at the recent Detector Workshop at Berkeley.[11] The salient points are:

-- Extrapolation of Bevalac experience with uranium at 1 AGeV to the Minicollider at 4 AGeV is not a big step. By comparison, extrapolation of experience with 50 GeV protons to uranium at 50 AGeV at an equivalent fixed target facility is a much bigger step;

-- Detectors at the Minicollider will be less sensitive to problems due to track density than the equivalent detectors at a 50 AGeV fixed target facility by a factor of about 25;

-- A variety of basic detectors is feasible, including a time projection chamber, a streamer chamber, and an improved Plastic Ball; however, because of expense a choice will have to be made, and this has not been done yet;

-- The central region detectors at the Minicollider will be similar in many ways to those eventually needed at the Brookhaven 100 AGeV collider.

6. Conclusion

The Minicollider is feasible, economical, and useful. It will be complementary to projects at Brookhaven and CERN.

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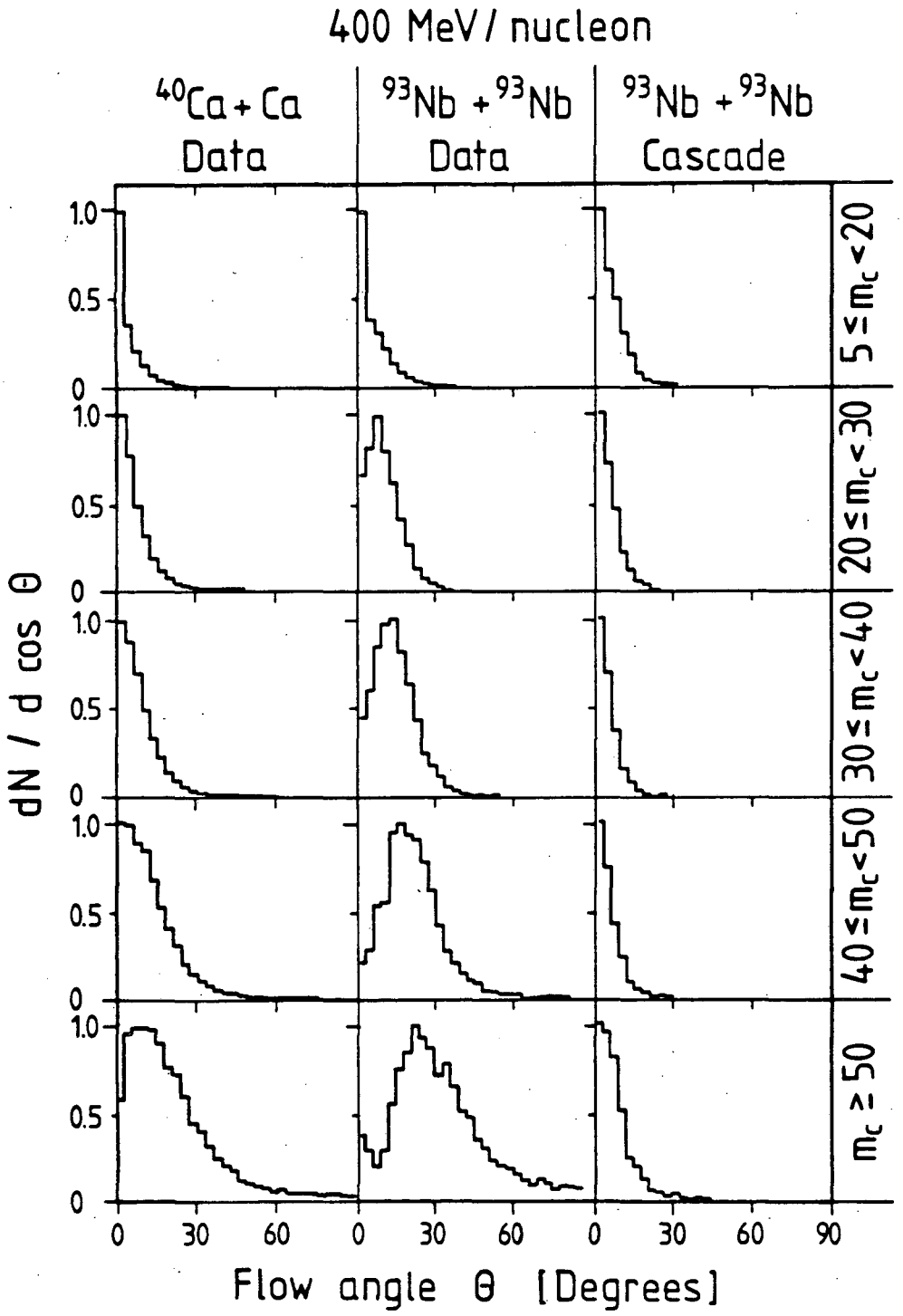

Figure 1

Flow distributions for the reactions Ca + Ca and Nb + Nb, and cascade model predictions for Nb + Nb. The peak in the flow angle (predicted by hydrodynamic calculations) is clearly visible for Nb + Nb but not well-defined for Ca + Ca.

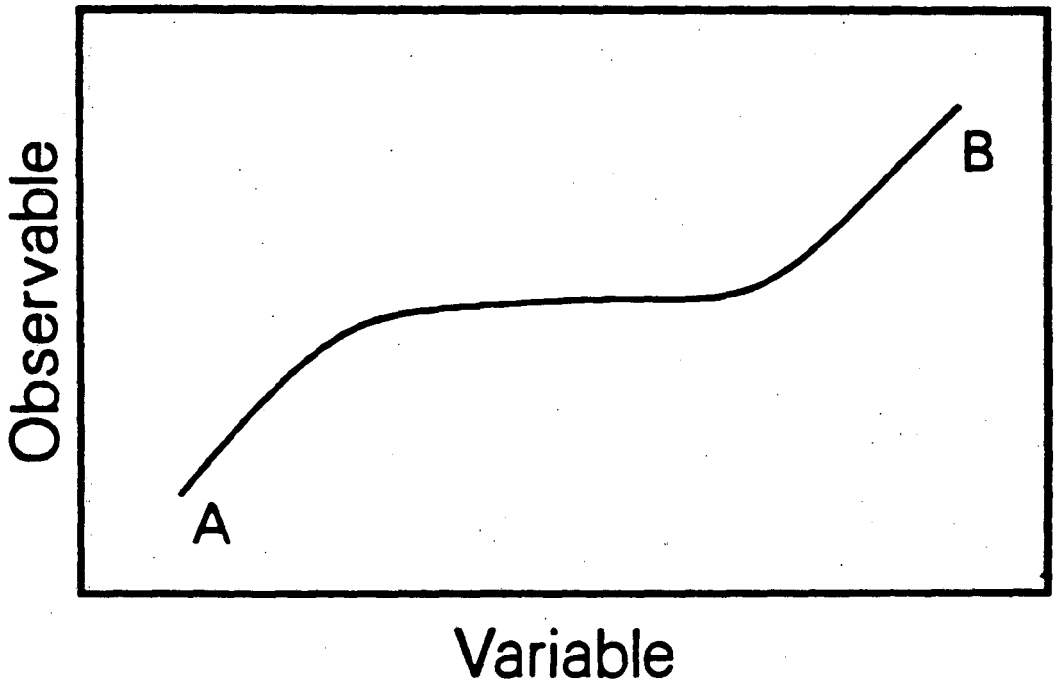

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Figure 2

Schematic experiment to observe the phase transition from a hadronic gas to the quark-gluon plasma.

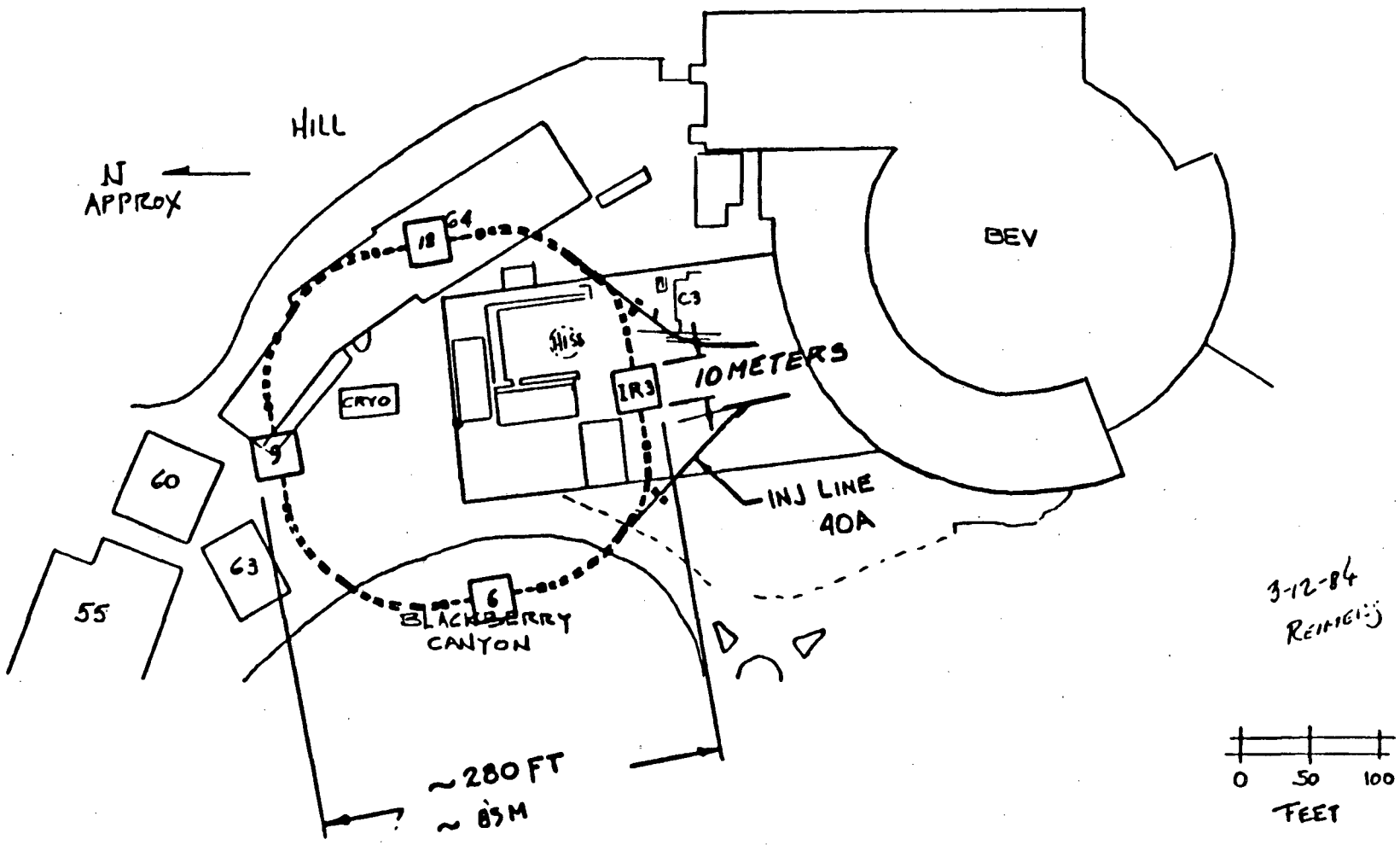

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Figure 3

One of the possible layouts for the LBL Minicollider. This makes maximum use of existing facilities and interferes minimally with the ongoing Bevalac program.

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