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HIGH ENERGY NUCLEAR BEAMS AT BERKELEY - PRESENT AND FUTURE POSSIBILITIES*

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Before presenting our plans for a future high energy machine capable of delivering nuclear beams for physics research at the Lawrence Berkeley Laboratory (LBL), I will first remind you of what our present capabilities in this area are.

THE BEVALAC

In 1974 the era of relativistic heavy-ion physics with moderately heavy ($A \lesssim 56$) projectiles began at LBL when the SuperHILAC was coupled via a transfer-line to the Bevatron. Figure 1 shows a layout of the combined complex which is called the Bevalac. The SuperHILAC serves as the heavy-ion injector (at 8.5 MeV/nucleon) for the Bevatron. After injection into the Bevatron, the beams are accelerated and extracted for physics research, as well as for a major bio-medical program. In this early period of operation the Bevalac provided beams up to Fe at energies of approximately 2.1 GeV/nucleon. In addition, protons at 4.9 GeV were available from the Bevatron's local 20 MeV linac. The primary goal of the research program was, and continues to be, the study of nuclear matter under extreme conditions of high temperature and baryon density. At the same time an active program addressing more conventional aspects of nuclear physics such as momentum distributions of fragmentation products and production of new neutron-rich isotopes was started.

It was clear from the beginning that one wanted to extend the range of available projectiles for research all the way up the periodic table to

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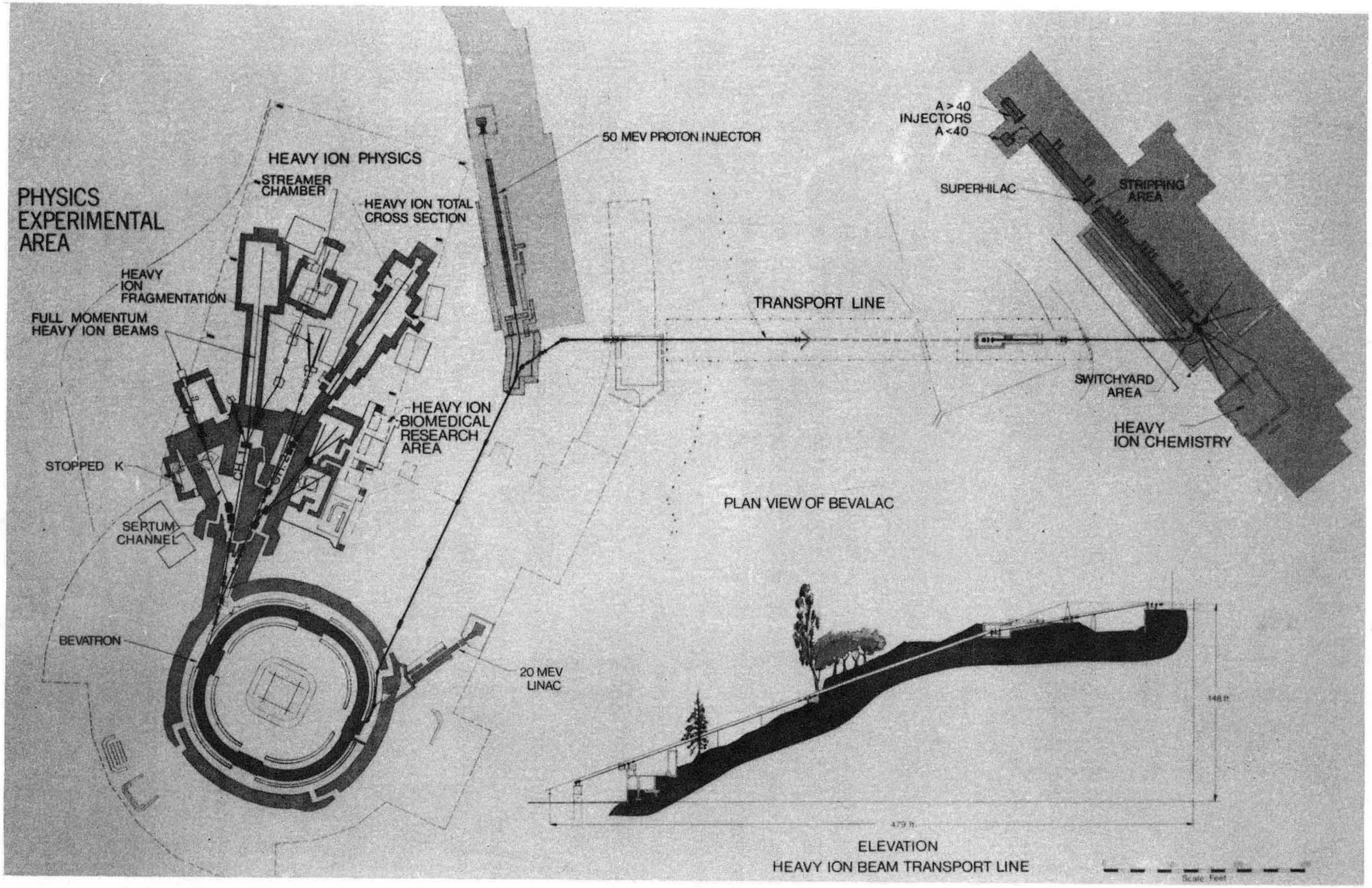

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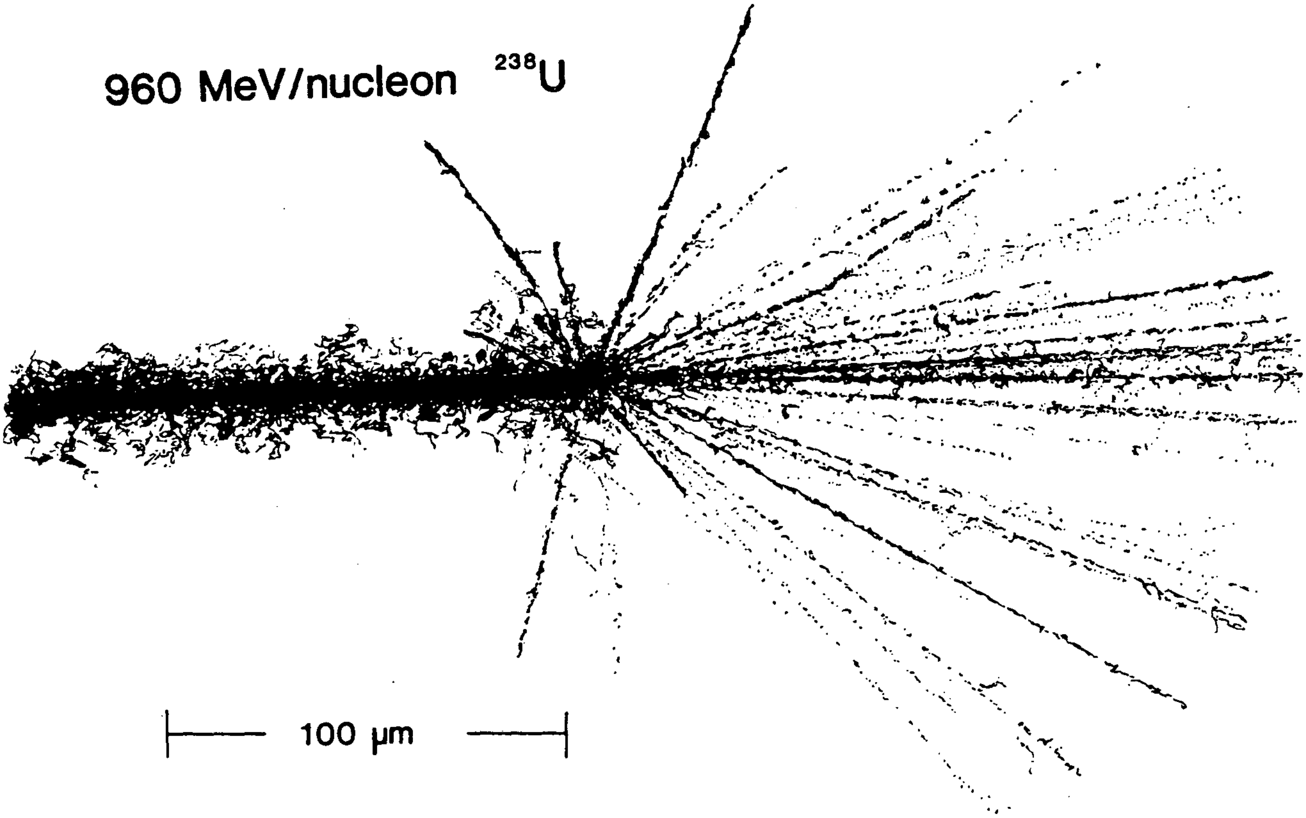
Figure 1: Layout of the Bevalac Facility at Berkeley.

uranium. This "uranium capability" was realized in 1982 after the addition of a third injector at the SuperHILAC (to provide the heaviest beams) and the improvement of the Bevatron's vacuum from the range of 10^{-7} torr to about 10^{-10} torr. The improved vacuum is necessary to allow partially stripped ions to survive acceleration in the Bevatron without suffering catastrophic losses through interactions with residual gas atoms. With this improvement the Bevalac became the first machine to provide beams of uranium ions at relativistic energies of about 1 GeV/nucleon. Figure 2 shows an example of a 960 MeV/nucleon uranium nucleus interacting violently (near central collision) with a heavy nucleus (either Ag or Br) in a nuclear emulsion[1]. With these much heavier beams one expects to create, in central nucleus-nucleus collisions, a much larger equilibrated volume of hot-dense nuclear matter.

RECENT PLANS FOR GOING BEYOND THE BEVALAC

As early as 1979, LBL was developing a concept for a machine capable of achieving nucleus-nucleus collisions in a colliding beam mode. It was called VENUS, which stood for -- Variable Energy NUclear Synchrotron[2,3]. The physics behind this was the possibility of producing quark matter (the term quark-gluon plasma was not generally in vogue at this time) in high energy heavy-ion collisions. The central feature of this concept involved two superconducting accelerating rings capable of operation at energies up to 20 GeV/nucleon in either a fixed target or colliding beam mode. This type of dual operation clearly called for high-field ($\sim$4.5 T), rapid-cycling ($\sim$ 1 T/sec) superconducting magnets.

In 1982, due to the relatively tight fiscal climate in the United States, we decided to step-back and investigate the possibilities of less expensive options. The basic idea was to look for a facility which would be a natural extension of the Bevalac to higher energies allowing us to provide a rich program of conventional nuclear physics; and at the same time having the capability to strike out and explore the domain of the quark-gluon plasma in the region of maximum baryon density. These studies resulted in the Tevalac concept[4], a facility which would be capable of delivering uranium beams at 10 GeV/nucleon for physics research. Again, high-field ($\sim$ 6 T), rapid-cycling ($\sim$ 1 T/sec) superconducting magnets were an essential feature.



XBL 829-11834

Figure 2: Example of a 960 MeV/nucleon uranium nucleus interacting nearly head-on with a heavy nucleus (Ag or Br) in a nuclear emulsion.

In 1983, two significant events occurred -- both associated with actions of the Nuclear Science Advisory Committee (NSAC), which help shape our plans at LBL. The first was the NSAC recommendation for the construction of a 4 GeV CW electron machine. One of the by-products of this recommendation is that it helps establish a new scale in nuclear science, allowing the community to think about more ambitious projects. The second event was the decision by NSAC, at the Wells College meeting called to up-date the Long-Range Plan for Nuclear Science in the United States, to recommend as the next major construction project (after the 4 GeV electron machine) a heavy-ion collider to produce and study the quark-gluon plasma. In a real sense this brings us full-circle, back to a device like VENUS.

FUTURE PLANS - RELATIVISTIC NUCLEAR COLLIDER (RNC)

Figure 3 shows our present concept for a relativistic nuclear collider (RNC) at LBL. It consists of the following elements:

- Improved SuperHILAC as the heavy-ion injector.
- An intermediate energy conventional synchrotron to serve as a booster for the final stage of the RNC. The energy for this stage is dictated by the need to strip off all the electrons on the heavy-ion being accelerated. Figure 4, taken from recent Bevalac results[5], shows that approximately 1 GeV/nucleon would be adequate for the energy of this booster. As shown it could also have a physics program of its own.
- The final stage contains two superconducting rings, operating for either fixed target (single ring only) or colliding beam (both rings) physics. As in earlier LBL concepts, high-field, rapid cycling magnets would be used.

The central theme of the physics to be studied at the RNC is shown in Figure 5. There are two regions of interest, both leading to quark-gluon plasma formation:

- At laboratory energies in the 10-20 GeV/nucleon range theoretical estimates(4) indicate that maximum baryon density will be achieved. In such a domain one would create a baryon-rich plasma. This regime would be accessed by single ring operation of the RNC, a natural extension to the present Bevalac program.

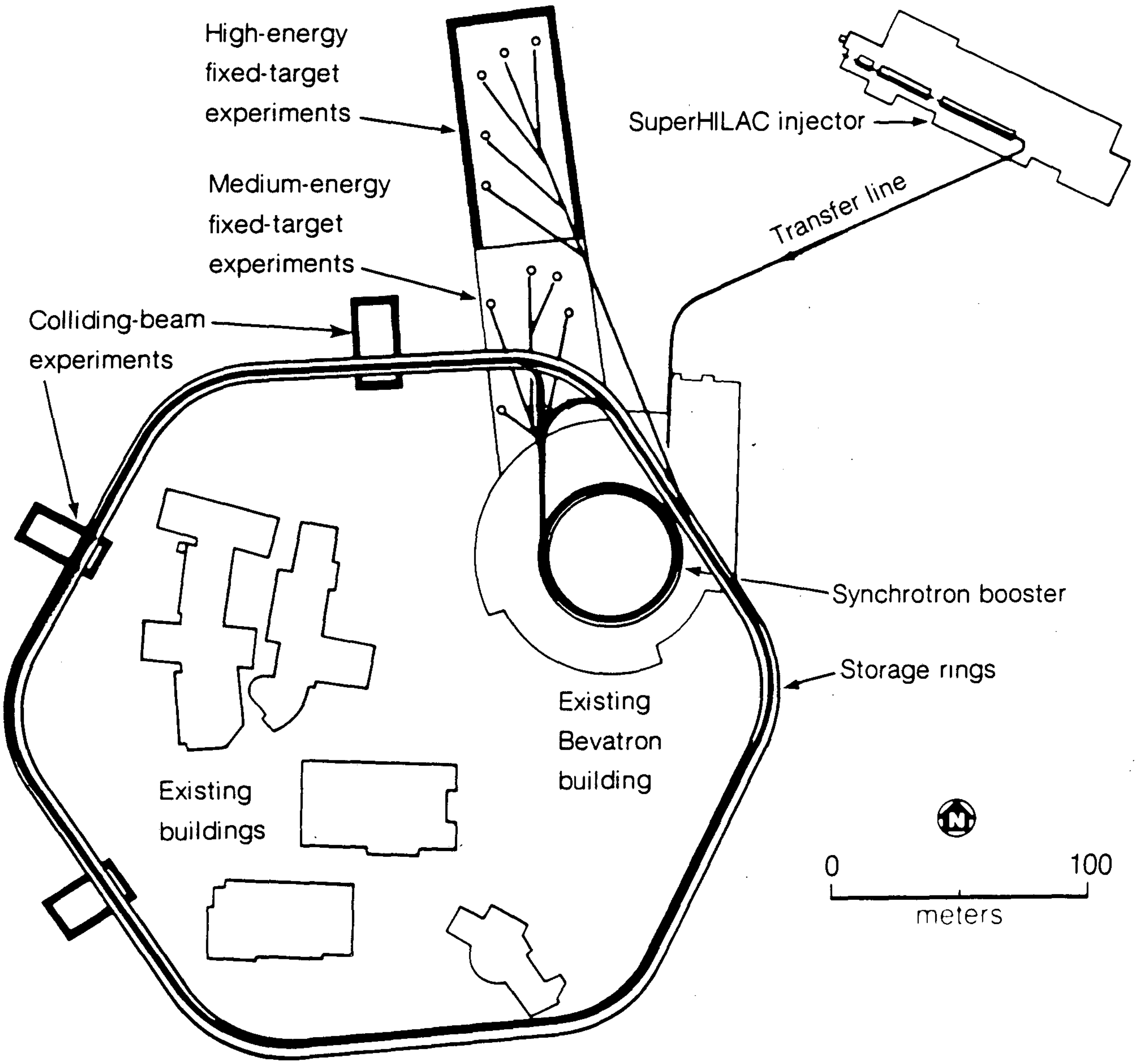


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Figure 3: Conceptual layout for a relativistic nuclear collider (RNC) at LBL. Various components of such an accelerator complex are indicated.

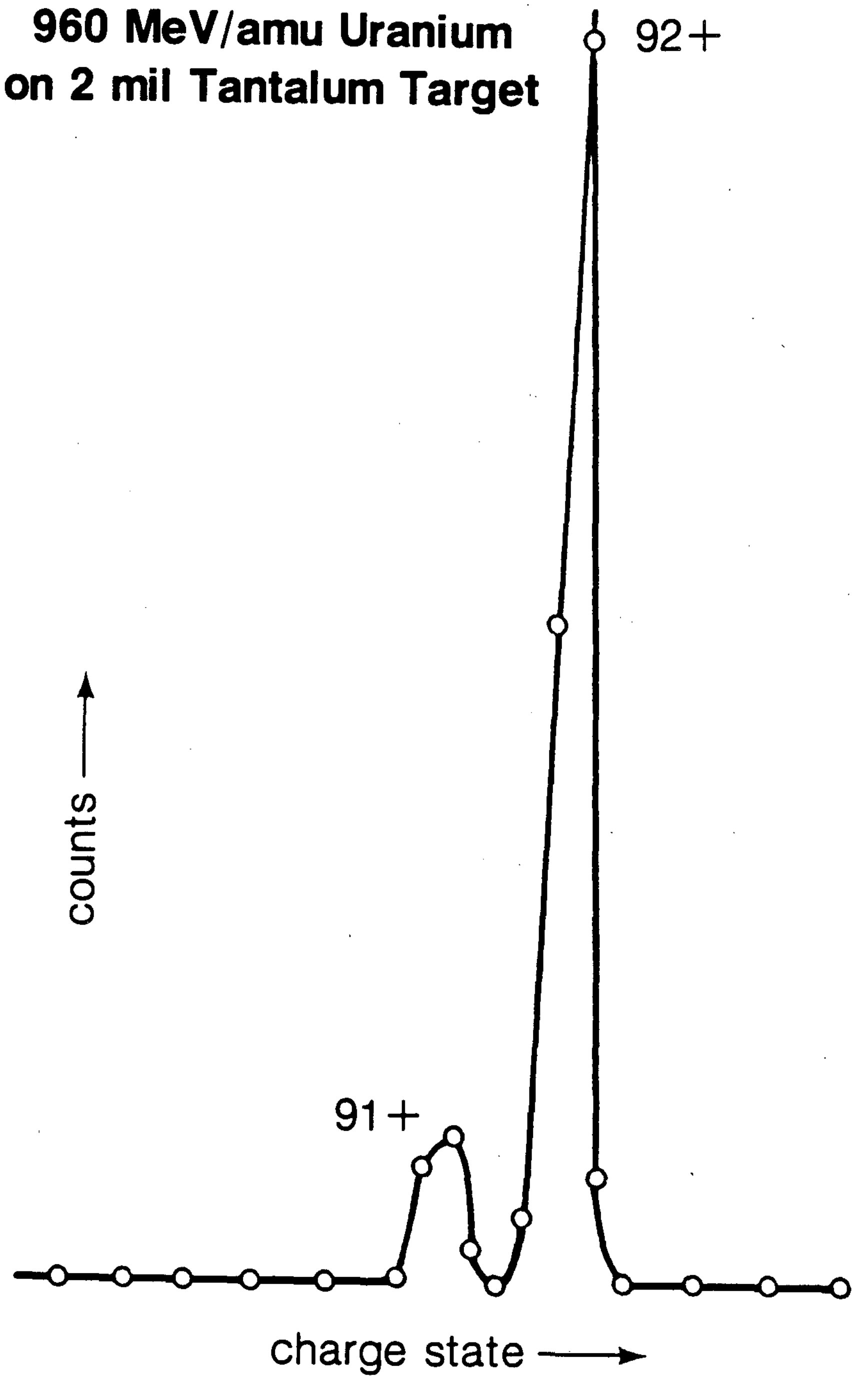

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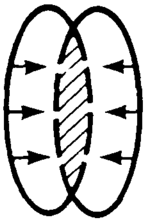
Figure 4: Charge states resulting from the stripping by a 2 mil Ta target of a 960 MeV/nucleon U^{68+} beam. Approximately 90% of this beam is fully stripped (92^+).

CENTRAL NUCLEAR COLLISIONS

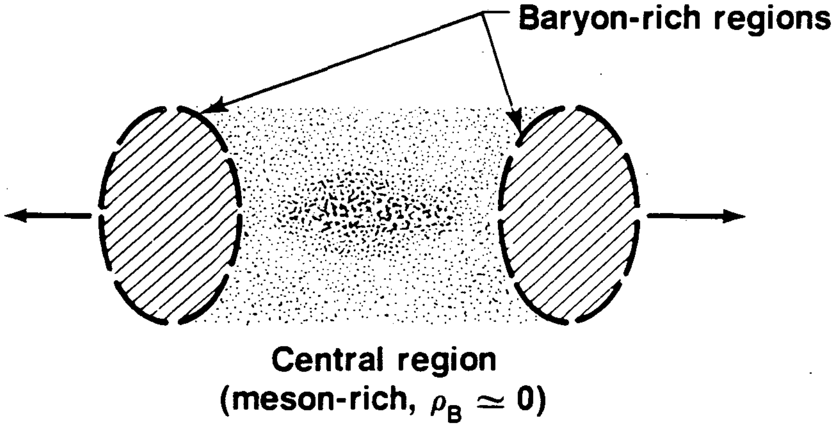
Before collision

Case 1: Nuclear STOPPING in system's center of mass



Expect maximum baryon density (ρ_B) to be achieved in stopped nuclei at $E_{lab} \simeq 10$ GeV/N for uranium.

Case 2: Nuclear "TRANSPARENCY"



Expect minimum baryon density in central region after nuclei pass through each other at $E_{c.m.} \simeq 30$ GeV/N (equivalent to $E_{lab} \simeq 2$ TeV/N).

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Figure 5: Characterization of the physics to be probed in fixed target (case 1) and in colliding beam (case 2) operation of the RNC.

- At the much higher energies available to a collider, the two nuclei interpenetrate and disassemble, but do not stop in the over-all center of mass. Instead, a hot plasma rich in mesons and low in baryons is left behind, with the net baryon number residing in the out-going target and projectile fragmentation regions. It has been suggested[6] that about 30 GeV/nucleon per beam is required to produce sufficient separation in rapidity for these conditions to be met.

GENERAL REQUIREMENTS FOR RNC

The final machine parameters required for formation of the quark-gluon plasma at an RNC will be clarified at workshops (like this present one at BNL) over the period of the next one to two years. Clearly, careful consideration will have to be given to the overall operating costs including the necessary instrumentation to address the challenge of this physics. In the meantime, there are, however, a number of conclusions that can be drawn at this point concerning general requirements for an RNC. These include:

- Research versatility -- such a facility must solve a wide range of problems in nuclear, particle, and atomic physics, astrophysics and cosmology.
- Full nuclear spectrum -- must deliver all elements (p to U) for physics research.
- Collider operation --
  - $E_{c.m.} \leq 30$ GeV/nucleon for each beam.
  - $\mathcal{L}_{min} \sim 10^{25} \mathrm{cm}^{-2} \mathrm{sec}^{-1}$ [based on using $\sim 1\%$ of the U-U interactions ($\sigma^{geom}_{U-U} \sim 10$ barns) this yields 1 central U-U collision/sec].
  - $\mathcal{L}_{max} \sim 10^{28}$-$10^{29} \mathrm{cm}^{-2} \mathrm{sec}^{-1}$ yields 10^3-10^4 central collisions/sec [there will always be some experimenters who are looking at either very rare processes or using small acceptance requiring large luminosity].
  - 2-3 will-instrumented interaction regions will be needed.
- Fixed-target capability -- must provide continuity of energy from existing fixed-target machines to collider energies.

A facility to meet the above requirements at LBL, would, of course, require superconducting magnets with high-field and rapid pulsing capabilities. One of the chief goals of the LBL program will be to further develop and refine such a magnet.

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5) H. Gould (LBL), private communication.

6) See for example the summary talk of G. Baym, this volume.

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