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Author
Pugh, H.G.

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H.G. Pugh

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Howel G. Pugh

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

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Abstract

The CERN-GSI-LBL plan to install an injector for light ions at the CERN SPS is reviewed, and an outline is given of the experiments so far approved by CERN for 50 A GeV and 225 A GeV running in 1986-87.

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.
**Introduction**

A topic of great current interest is the behavior of nucleus-nucleus collisions at very high energies. It is believed that a phase transition may occur in which the quarks bound within individual nucleons become deconfined and part or all of the interacting nuclear volume becomes a "quark-gluon plasma." Such a phase transition might be recognized by study of dilepton pairs, of increased strange particle production, or of multiparticle variables which reveal the thermodynamic properties of the interacting system and its behavior during deconfinement and reconfinement.¹ Such experiments are presently possible only at the Bevalac and Synchrophasotron, which probably have too low a bombarding energy, or in rare cosmic ray events. Thus a variety of accelerators have been proposed for new construction, with nuclear beams up to uranium. For exploratory work another possibility is to modify existing high energy facilities such as at Brookhaven, CERN, or Fermilab.

CERN is unique among high energy laboratories in that the LINAC 1 injecting the Proton Synchrotron (PS) has already the capability of accelerating ions with charge-to-mass ratio of less than unity. In March 1981 the GSI-LBL collaboration working at the Bevalac submitted a letter of intent to CERN to install a source for light ions (¹⁶O, ²⁰Ne) at the LINAC 1 and to perform experiments at the PS at energies up to 13 A GeV. With CERN encouragement a proposal followed in February 1982. It was approved in 1983 as experiment PS 190, and a formal agreement was executed between CERN, GSI, and LBL for construction of the source and for its use in experiments. The CERN-GSI-LBL agreement was for construction of a preinjector consisting of an electron cyclotron resonance (ECR) ion source followed by a radio-frequency
quadrupole (RFQ) pre-accelerator section. This preinjector would be constructed by GSI and LBL, assembled and tested at GSI, then moved to CERN for installation at the LINAC 1. It would be operated by GSI and LBL, but the beams would be made available to other users in addition to GSI and LBL.

The proposal led to wide interest and an extensive discussion of the possibilities for using light ion beams at the CERN Super Proton Synchrotron (SPS) occurred at the Bielefeld meeting in May, 1982. Eventually in September-November 1984 several additional proposals were approved, for energies of 50 A GeV and 225 A GeV, while the previously approved PS 190 was also modified for the higher energies.

The Injector

The layout of the accelerators at CERN is shown in Figure 1. Any ion

![Figure 1. Layout of the accelerators at CERN](image-url)
that can be produced by LINAC 1 and then fully stripped of its electrons by means of a foil can be accelerated by the PS Booster (PSB) and eventually by the PS and SPS. The Intersecting Storage Rings (ISR) are no longer available.

Figure 2 shows the layout of the preinjector under construction.

The projectile $^{16}O^{6+}$ is chosen as a compromise between the limitations of the ion source for producing ions with a large value of $q/A$ and the limitations of the LINAC 1 for accelerating ions with a small value of $q/A$. The ECR ion source is being purchased from CENG, Grenoble. It is identical to one which has already been delivered to GANIL and which has operated with the
required performance. The RFQ pre-accelerator is very similar to one which has been constructed at LBL for use at the Bevatron, and machining of the vanes has already begun. CERN will provide the necessary radio-frequency power supplies. The entire preinjector is to be assembled and tested at GSI in the latter half of 1985, moved to CERN in November, 1985, and operational in February, 1986. Experiments are scheduled for December, 1986 and March, 1987.

Possibility of Heavier Beams than $^{16}O$

The ECR source can produce heavier ions than $^{16}O^{6+}$ and also $^{16}O$ ions in higher charge states, but the intensities available are not sufficient for the CERN accelerator complex which relies on a feedback control mechanism that requires sensing of the beam during acceleration. However, it has recently been suggested that it might be possible to accelerate other beams simultaneously with the $^{16}O$ beam. The $^{16}O$ beam would have sufficient intensity for the accelerator control system to operate, while the other ions, if they have identical q/m, would be carried through under the same accelerator settings. The ions which satisfy this condition (within small binding-energy mass differences) are $^{16}O^{6+}$, $^{24}Mg^{9+}$, $^{32}S^{12+}$ and $^{40}Ca^{15+}$ in the ECR, RFQ and LINAC 1. After stripping they become $^{16}O^{8+}$, $^{24}Mg^{12+}$, $^{32}S^{16+}$ and $^{40}Ca^{20+}$ in the PSB, PS and SPS.

The possibility of such a mode of operation is at present being investigated by CERN. If it turns out to be practical it will open up experiments with heavier ions. Tests of the ECR source have demonstrated $^{16}O^{6+}$ and $^{40}Ca^{20+}$ produced simultaneously in the ratio $1:10^{-4}$ and $^{16}O^{6+}$ and $^{24}Mg^{9+}$ in the ratio $1:10^{-3}$. While these tests have not yet been
made under conditions corresponding to the desired $10^8 16\text{O}^{6+}$ per pulse it seems likely that $32\text{S}^{12+}$ beams in the proportion of $1 : 10^{-3}$ will eventually be obtained.

The use of such mixed beams in experiments will be straightforward. All the experiments approved so far use an intensity of $10^5$ to $10^6$ particles per second to the beam. At these rates Cerenkov detectors can be used in the beam to count individually and identify the $16\text{O}$ and $32\text{S}$ ions, using the fact that the detector response is proportional to $Z^2$. The $32\text{S}$ intensity will be very useful for general exploratory studies.

The Experiments

The original experiment, for which the program was established, has two parts, referred to as PS 190(1) and PS 190(2). Subsequently approved experiments are described in order of proposal number: P.196, P.198, P.201, P.203. Official CERN numbers have not yet been assigned to all these experiments but it is expected that they will be NA35, WA80, NA36, EMU01, EMU02 and NA34-2 respectively. Several other proposals are in the process of evaluation by the SPS Committee, or in preparation for submission. These will not be discussed here.

PS 190(1): NA35

This is a GSI-LBL-Heidelberg-Marburg-Frankfurt-Warsaw-Athens collaboration centered on use of a streamer chamber in a superconducting magnet. The use of a visual detector has an immediacy appropriate for a first generation experiment. While relatively few events will be recorded ($\sim 10^5$) a great deal of information will be obtained on each event. The streamer
chamber is supplemented by extensive fine-grain calorimetry covering the forward hemisphere in the nucleon-nucleon c.m. system, and by a charged multiplicity detector. The layout, shown in Figure 3, is very similar to that for SPS experiment NA5, which used a similar streamer chamber and the same calorimetry.

![Diagram of the PS 190(1): NA35 experiment](image)

Figure 3. Layout of the PS 190(1): NA35 experiment

Quantities to be extracted include multiplicities for positive and negative charged particles, rapidity distributions for pions and protons, and transverse momentum distributions. $K^0$ and $\Lambda^0$ will be detected in the forward hemisphere with about 10% efficiency, and $K^\pm$ will be detected with about 1% efficiency via their decay into three charged pions.

Because the detector provides complete coverage for charged particles, it will be possible to study fluctuations in rapidity and correlations between variables, including total transverse energy $E_T$ and the mean transverse momentum $<p_T>$ on an event-by-event basis. Complete reconstruction of the charged particles in each event will permit a search for collective phenomena such as hydrodynamic flow.
PS 190(2): WA80

This is a GSI-LBL-Lund-Muenster-Oak Ridge collaboration using the Plastic Ball detector from the Bevalac. The Plastic Ball has a geometry similar to the Crystal Ball from Stanford, with 815 $\Delta E - E$ particle identifying modules where the $\Delta E$ is a $\text{CaF}_2(\text{Eu})$ crystal and the $E$ counter is a plastic scintillator. A solid angle of 96% of $4\pi$ is covered. In addition to the Plastic Ball, forward fine-grain calorimetry will be used, as well as a multiplicity detector and a $\pi^0/\gamma$ spectrometer at mid-rapidity. The layout is shown in Figure 4.

![Diagram of the PS 190(2): WA80 experiment](image)

Figure 4. Layout of the PS 190(2): WA80 experiment

The Plastic Ball provides for identification of protons, deuterons, tritons, $^3\text{He}$ and $^4\text{He}$ at rapidity $y < 2$. Following Bevalac experience, studies of energy spectra, particle ratios, particle correlations and multiplicities will give information about temperatures, entropy and collective flow in the target fragmentation regime. The $\pi^0/\gamma$ spectrometer
consists of 1000 3.5 x 3.5 x 46 cm lead glass blocks. The calorimetry is of the Fabian-Willis design and consists of 300 20 cm x 20 cm towers of lead-scintillator and steel-scintillator sandwiches. A uranium-scintillator sandwich calorimeter will be used at zero degrees to measure the energy remaining in the projectile. Note that there is no magnetic field in this experiment.

P.196: NA36

This is an Athens-Bergen-Berkeley-Birmingham-Brookhaven-Carnegie-Mellon-Serpukhov-Vienna collaboration which will use a time projection chamber (TPC) in the European Hybrid Spectrometer (EHS) to study the production of strange baryons and antibaryons (Λ, Λ̅, Π± and Ω±).

A layout of the experiment is shown in Figure 5. The TPC is located such that the beam avoids it and such that most of the produced pions are swept away from it by the magnetic field. Its 1800 channels provide unambiguous space-point tracking for the recognition of decay vertices of K_S^0 and strange (anti) baryons with |S| = 1,2,3 in the kinematical range 1 ≤ y ≤ 4. Figure
9

6 shows a typical decay pattern to be observed in the TPC. Proportional wire chambers and drift chambers enhance the tracking capability, and a variety of existing fine-grain electromagnetic and hadronic calorimeters will provide information on \( \frac{d\varepsilon_t}{dy} \) for \( y \geq 2.3 \).

![Diagram of decay pattern](image)

**Figure 6.** Decay pattern for a typical \( \Xi^- \rightarrow \pi^- \Lambda; \Lambda \rightarrow p\pi^- \) cascade. The kink at the first decay and the Vee at the second are recognized by the TPC.

A feature of the experiment is the planned high data-acquisition rate of \( 10^3 \) events per second using a buffer memory in Fastbus and data storage on optical laser disks. Even if no enhancement of strange particle production is produced due to quark-gluon plasma formation it is anticipated that good statistical accuracy will be obtained for \( K_S^0, \Lambda, \bar{\Lambda}, \Xi^\pm \) and \( \Omega^\pm \) production. Similar information will be obtained for p-p and p-A collisions.

P.198: EMU01

This Jaipur-Jammu-LBL-LUND-Ottawa-Washington experiment uses emulsion chambers and conventional emulsion stacks to study pseudorapidity distributions and correlations of charged particles. The chief advantage of this technique is that the excellent spatial resolution of emulsion detectors will handle easily the highest multiplicities of particles anticipated. After
classifying events according to multiplicity of singly-charged relativistic particles, of target fragments, or projectile fragments with \( Z \geq 2 \), and of recoil protons, a subset of highly central events produced in heavy target nuclei (Ag, Br) will be selected for special study. It is planned to make detailed measurements on \( 10^2-10^3 \) of such events, with special emphasis on "spikes" in the pseudorapidity distribution and on correlations between particles associated with those spikes.

P.201: EMU02

This U.C. Berkeley-CERN experiment is to search for fractionally charged particles by means of CR-39 plastic track detectors. While this is not one of the signatures of the quark-gluon plasma predicted by QCD (in which quarks are always confined in the final state) it is obviously of fundamental interest for this field of study. The oxygen ions will strike a 3 cm lead target preceded and followed by plastic detector sheets. Measurements will be concentrated on projectile fragments in the charge regime 6-7. The first 8 sheets of detectors after the target will (with 16 etch-pit diameter measurements) identify whether a particle is fractionally charged. The remaining 92 sheets will permit studies of subsequent interactions of any such particle. It is planned to study approximately 15,000 projectile fragments.

P.203 (NA34 extension request): NA34-2

This Brookhaven CERN Heidelberg-Los Alamos-Lund-McGill-Moscow-Novosibirsk-Pittsburgh-Saclay-Syracuse-Tel Aviv experiment combines 4\( \pi \) calorimeter coverage with measurements of low- and high-mass lepton pairs and photons. A spectrometer in the region \( 0.8 < y < 2.0 \) also provides
information on $\pi^+K^+p^-$ spectra and pair correlations. The layout of the main part of the experiment is shown in Figure 7. There are two active targets in use simultaneously for independent measurements in a complex arrangement serving several different purposes.

The first part of the experiment consists of a "box calorimeter" made of uranium-scintillator modules at angles greater than $15^\circ$, a magnetic calorimeter for angles between $6^\circ$ and $15^\circ$ and a uranium-liquid argon forward calorimeter segmented in 20 mm towers and strips. The forward calorimeter is further backed by uranium-scintillator modules. A variety of triggering possibilities is foreseen based on properties of the distribution of $E_T$ versus $y$ and $\phi$.

An external "few-particle spectrometer" looks in through a 10 cm crack in the box calorimeter at $15^\circ < \theta_L < 45^\circ$ corresponding to $0.8 < y < 2.0$. 

Figure 7. Layout of the P.203: NA34-2 experiment
The existence of the crack causes loss of less than 0.1% of the energy in the reaction, while it is estimated that an average of 1 charged particle per central \(^{16}\text{O}-\text{Au}\) event at 225 A GeV will enter the spectrometer (10\% probability of 2 charged particles). The spectrometer will allow identification of \(\pi^\pm K^\pm p^\pm\) up to about 3.5 GeV/c, as well as the study of two particle correlations.

Inside the box calorimeter, not shown in the figure, a low-energy photon detector is planned using BiO, NaI and converters followed by wire chambers. It is planned to explore the photon energy regime down to 1 MeV. A dielectron spectrometer based on BiO crystals and a ring imaging Cerenkov detector (RICH) has also been considered for this region.

Behind the forward uranium calorimeter will be the magnet, wire chambers and scintillator hodoscopes of the NA3 dimuon spectrometer. This will permit a resolution of about 160 MeV/c\(^2\) to be obtained for \(\mu\mu\) pairs and an extensive study to be made of \(\mu\mu\) effective masses from below the \(\rho\) to above the \(\psi\). Several thousand \(\psi\) events are expected.

**Future Projects**

By mid-1987 we can expect from the CERN program and from the Brookhaven AGS program a major qualitative jump in our knowledge of high energy nucleus-nucleus collisions. Assuming that the trick of accelerating two beams simultaneously at the SPS works, we will have information on \(^{32}\text{S}-\text{nucleus}\) collisions at 15 A GeV, 50 A GeV and 225 A GeV. The results will test our present ideas on how the reactions should proceed and it will indeed be surprising if some of those ideas were not proved incorrect.
A variety of further possibilities exists. If the energy of the SPS proves optimal, the range of projectiles available could be extended by further modifications to the injectors. Another possibility in this energy regime is the "minicollider" that has been discussed for injection by the Bevalac. This would have the advantage that uranium ions are already available. If the energy regime below 15 A GeV is optimal, the AGS booster proposed at Brookhaven would provide heavier ions, e.g. gold. Finally, on the reasonable assumption that it will be desirable to use even higher energies than are available at the SPS, the RHIC facility proposed for 100 A GeV colliding beams at Brookhaven will provide the needed capability.

In conclusion, experiments to be carried out at CERN in 1986-7 will, in conjunction with those planned for Brookhaven, map out the general features of heavy ion collisions between the present Bevalac-Synchrophasotron regime and 225 A GeV. Depending on those results a variety of attractive options exists for future development.

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References

1) The scientific justification for this field of research is reviewed elsewhere in these Proceedings by B. Muller.

2) The proceedings of the Bielefeld Workshop are to be found in: Quark Matter Formation and Heavy Ion Collisions, M. Jacob and H. Satz (Eds.), World Scientific, Singapore (1982). This also includes a description of the GSI-LBL proposal (p. 557). However, note that the ion source technology has been completely changed since that time, and additional detectors have been added to the experiment.

3) Copies of the individual experiment proposals can be obtained from the SPSC Secretary, CERN, or from the spokesmen (listed under "Acknowledgments"). Supplementary documentation is also often available.


5) Brookhaven's plans for the AGS are described by O. Hansen elsewhere in these Proceedings.

6) The RHIC proposal is described by T. Ludlam elsewhere in these Proceedings.
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