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"Spectra, Composition, and Interactions of Nuclei above 10 TeV using Magnet-Interferometric Chambers"

Final Report

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ABSTRACT

Although the SCIN-MAGIC experiment has, like all ASTROMAG and most other Attached Payload experiments, been "de-selected" from Space Station, we expect that ultimately such emulsion chambers will be flown on the Station. This report describes some brief studies made in support of the design efforts for such a program being conducted at MSFC.

INTRODUCTION

This report constitutes the first year effort by the UAH in support of the SCIN-MAGIC Experiment to fly on the US Space Station ASTROMAG facility in, or around, the year 2000.

We proposed to fly an experiment in the Astromag Facility to measure the composition and spectra of the cosmic ray nuclei above 10^{14} electron volts and to study with the magnetic field the characteristics of particles produced in nucleus-nucleus interactions above 10^{12} eV/amu. The proposed interaction studies are intimately connected with high energy cosmic ray studies since analysis of data from air showers and "ionization calorimeters" depend upon the behavior of the interactions.

The chemical composition will be measured for all elements from hydrogen to iron with sufficient statistics to deduce spectra for the abundant primaries (H, He, CNO, NeMgSi, and the Fe group) in the energy region where the principal models of cosmic ray acceleration and propagation predict major composition and spectra changes. A measurement of the electron spectrum above 1 TeV will also be made.

The experiment will also measure the transverse momenta of charged particles and photons from a number (>100) of heavy ion central collisions that are expected to exceed 2×10^{45} GeV/m^3 energy density in the interacting complex. At those densities calculations based on quantum-chromo-dynamics (QCD) predict a phase change in nuclear matter from bound nucleons to a quark-gluon plasma (QGP) and a chiral symmetry phase. This experiment is designed to use the Astromag field to measure exceptional characteristics of the produced particles that are predicted to signal these phase changes. A larger sample of data will be available in which the produced particle number distribution, rapidity distributions, angular correlations, charged/neutral ratio, etc., will be measured.

The experiment will be carried out with passive detector instruments (emulsion chambers) very similar to those flown on balloons and used recently with heavy ion beams at CERN. The emulsion chambers will be in two configurations. One (EMCAL) will be similar to those frequently used in balloon borne composition studies. The other (MAGIC) contains a low density target section designed so that the high field of Astromag can be used to measure the signs and transverse momenta of charged particles produced in the interactions.

The proposed apparatus contains eight blocks (chambers) which contain nuclear track emulsions, CR39 plastic, X-ray film, lead or tungsten plates, and other inert materials. The apparatus is in two pallets of four chambers (two each of EMCAL and MAGIC); each pallet weighing ~ 1200 kg. Thermal control is achieved with coatings, insulation blankets, and electrical heaters. Two 90 day exposures of the two-pallet configuration are proposed, the first as soon as practical in the Astromag high field region.

Essentially all the techniques required for this investigation have had extensive exercise in balloon and accelerator experiments which have been carried out by the UAH Co-Investigators.

The dynamic range and position-resolution of emulsion chambers make them particularly appropriate as the detector system for the first systematic direct measurements in the 10^{14} - 10^{15} eV per particle regime. The same emulsion system is used to measure protons and Fe and to measure the characteristics of interactions with secondary multiples of 1000 or more. The capacity of emulsions to record the passage of all ionizing particles, with exceptionally high spatial resolution, is a distinct asset in an investigation in a new realm of high energy nuclear physics.

Design Studies for SCIN-MAGIC

1) The scientific design effort of the SCIN-MAGIC was supported by the UAH science team (JCG, YT and TH) at several science reviews held at MSFC. Some specific studies were undertaken.

a) Direct Tracking of Primary and Secondary Particles in a Magnetic Field

We have been conducting a series of interaction studies with highly relativistic nuclei at CERN, Geneva, using emulsion techniques for particle tracking. A recent run in August 1990 with sulphur-32 at 300 GeV/c used an electromagnet with a 1.8 Tesla field. A significant finding from these studies is a demonstration of the capability for tracking nuclei in an emulsion chamber system in a magnet field. Precision tracking of singly-charged particles in emulsion chambers has been achieved using accelerator nuclear beams (Figs. 1a and 1b).

The momentum resolution for secondary tracks with the latest design of MAGIC telescope (Magnetic-Interactive-Emulsion-Chamber) is

$$\Delta p/p\ (\%) = 5 + 0.25\ (p/\mathrm{GeV}/c),$$

for a magnet field of 1.8 Tesla. This was confirmed by a MAGIC experiment performed at CERN in August, 1990. A suppression of multiple scattering was achieved by reducing a number of emulsion plates in the telescope.

For the purpose of a momentum measurements of primary (beam) nuclei, we designed a BEAM TELESCOPE (BT). Figure 2 shows a new emulsion chamber system with a BT in a planned solenoid magnet; Magnetic bending of primary nuclei is also illustrated. Table 1 gives magnetic displacements of a nucleus track in the coordinate (x) perpendicular to the magnetic fields (z). A unique identification of a heavy nucleus track is much easier than that of singly-ionizing tracks that are often too many. Therefore, a large spacing (5 cm) between tracking layers can be used for BT, which improves momentum resolution and measurable upper-end of momentum. Electromagnetic scattering is drastically reduced by using only several layers of thin (30 microns) emulsions and thin (300 micron) CR39 plates. The BT has an integrated field length of 1.2T X 0.2m = 0.24 Tesla.m for a vertical path length, and the maximum detectable momentum should be 2 TeV/n for a 1.2 micron resolution of relative coordinates measured from reference tracks.

The provision of straight-line fiducial marks is crucial to the application of this technique in cosmic ray experiments.

Our existing effort produced effective tracking software, and we have built an automatic microscope, CAVIA (Computer-Assisted-Visual-Image-Analysis). By using them, we realized that the system and software allowed precision tracking of CR39 etch-pits as well. Reconstruction of nuclear tracks in CR39 plates was made with a precision of 1.5 microns. A BT telescope with the emulsion calorimeter will allow such direct rigidity measurements of nuclei with a similar precision, because very high energy nucleus events (above 2 TeV/n) give a perfect set of straight lines (in-flight fiducial) for reconstruction of coordinates. It is a unique virtue of an emulsion chamber with EMCAL (Emulsion Calorimeter). No telescopes can maintain microscopic precision without independent detection of these high energy tracks.

The expected accuracy of momentum measurements is a function of the primary momentum,

$$\Delta\ p/p\ (\%) = 0.1 + 0.05\ (p/GeV/c),$$

Consequently, the maximum detectable momentum (MDM) is about 2 TeV/c/n for a field strength of 1.2 Tesla.

These new findings indicate that an emulsion chamber method in a magnet field is more versatile than initially considered, allowing observation of cosmic ray nuclei in an unprecedentedly wide energy band, 1 GeV/n - 1,000 TeV/n. This bandwidth observable by the same detector system is nearly ideal for a detailed study of cosmic ray composition and energy spectra.

ENERGY (GeV/N) (A/Z =1)	1	10	100	1000	2000
(A/Z =2)	0.5	5	50	500	1000
DELTA X (microns)	7199	719	72	7.3	3.6

(FOR B= 1.2 T, L= 20 CM)

TABLE 1

Magnetic deflection (microns) of x-axis for 20 cm-long BT in a 1.2 Tesla magnet field.

b) Upgrading of the Automatic Microscope for Large-Area Experiments

Further work on beam tracking of nuclei in a large area Beam telescope can be accomplished within a few years by upgrading auto-scan equipment. A small-stage (6" x 6") automatic microscope (CAVIA) is in operation, and upgrading of it to a larger (16" x 20") version can be accomplished with commercially available equipment. A digitized and motorized large stage microscope will be assembled in less three years using existing software for automatic scanning and analysis. We plan to replace a desk-top IBM PC 386 with a Workstation (SUN SPARC 1+ GX) to handle large object data from a large-area scanning. Until its completion, an examination of beam tracking accuracies in automatic scanning will be made with small-size (4" x 5") emulsion and CR39 plates exposed to oxygen and sulfur beams in a magnet field at 200 GeV/n. Assuming the availability of a track analysis system, a test balloon flight experiment can begin in 1993 or 1994 with a 1.2 Tesla superconducting solenoid magnet. Construction of a superconducting solenoid magnet (1.2 Tesla field), suitable for emulsion chambers and a 10 day flight, has just started at National Laboratory for High Energy Physics (KEK) in Japan (Fig. 4a and 4b). We have obtained a permission to use it for balloon flight experiments for about ten years. We are anticipating a delivery of a complete solenoid magnet and cryogenics system from Japanese collaborators by early 1993.

Design Studies in Support of SCIN-MAGIC

The UAH team has been concurrently involved in the detailed thermal and mechanical design and analysis of the Emulsion Chamber Technology Experiment (ECT). This OAET-sponsored technology development project will place a full size emulsion chamber weighing approximately 500 lbs. on the STS for a 7 to 10 day evaluation. The project is seen as an ideal precursor to the much larger exposure of SCIN-MAGIC or similar arrays on the Space Station.

The UAH engineering team including Dr. Francis Wessling (Chief engineer), Reinhold Freiseis (stress analysis), Ron Eakes (mechanical design), Lisa Hughes (thermal analysis) and the PI attended several engineering reviews at MSFC where the SCIN-MAGIC requirements were discussed and the findings of the ECT analysis presented and discussed. Copies of the ECT engineering analyses both from the PRR and the PDR have been delivered to MSFC and are not reproduced here.

As a result of a development shake test of a full scale model of ECT at Marshall several improvements have been made to the final design. These are included in the CDR report package which has also now been delivered.

FIGURES:

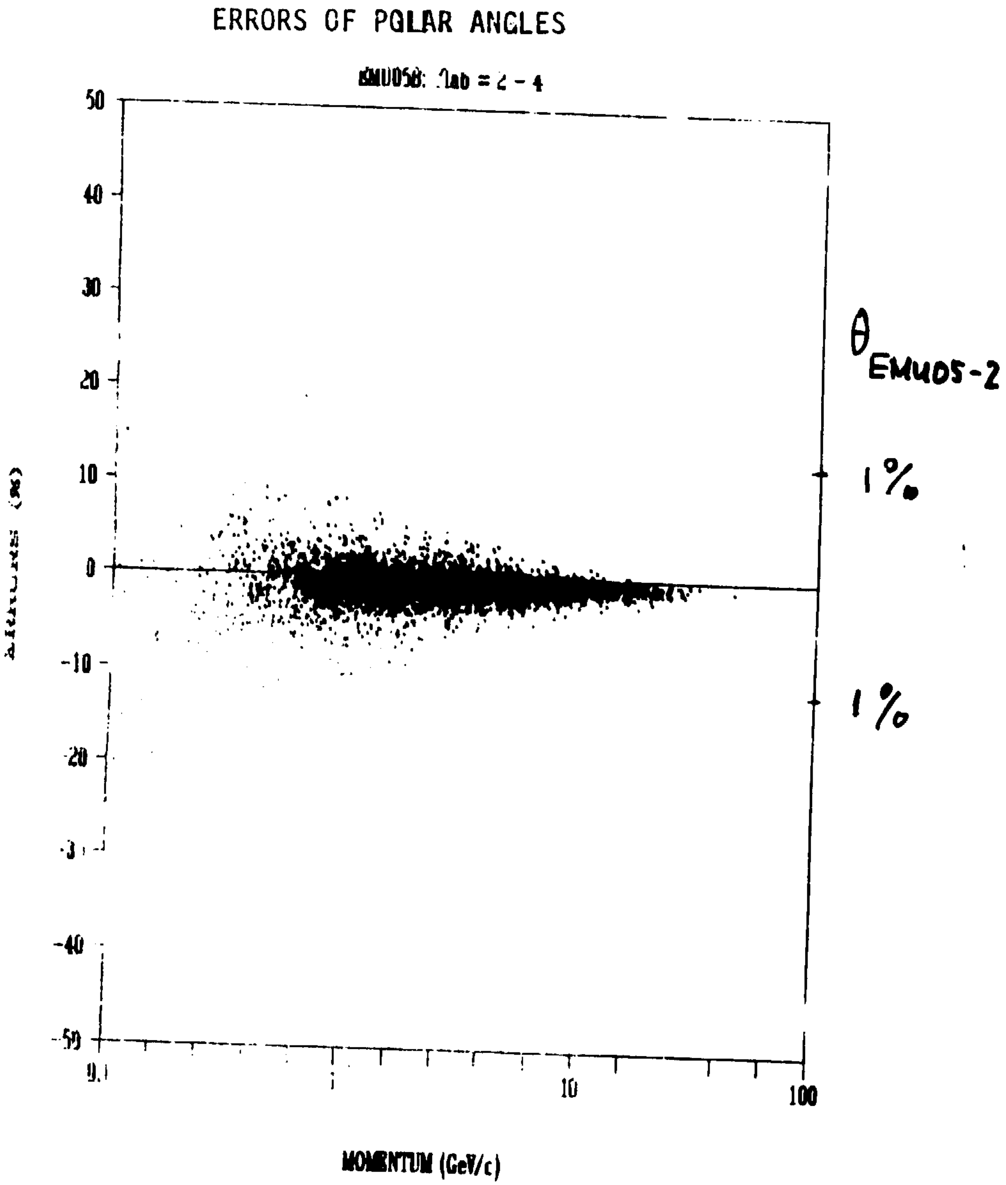


Figure 1(a)

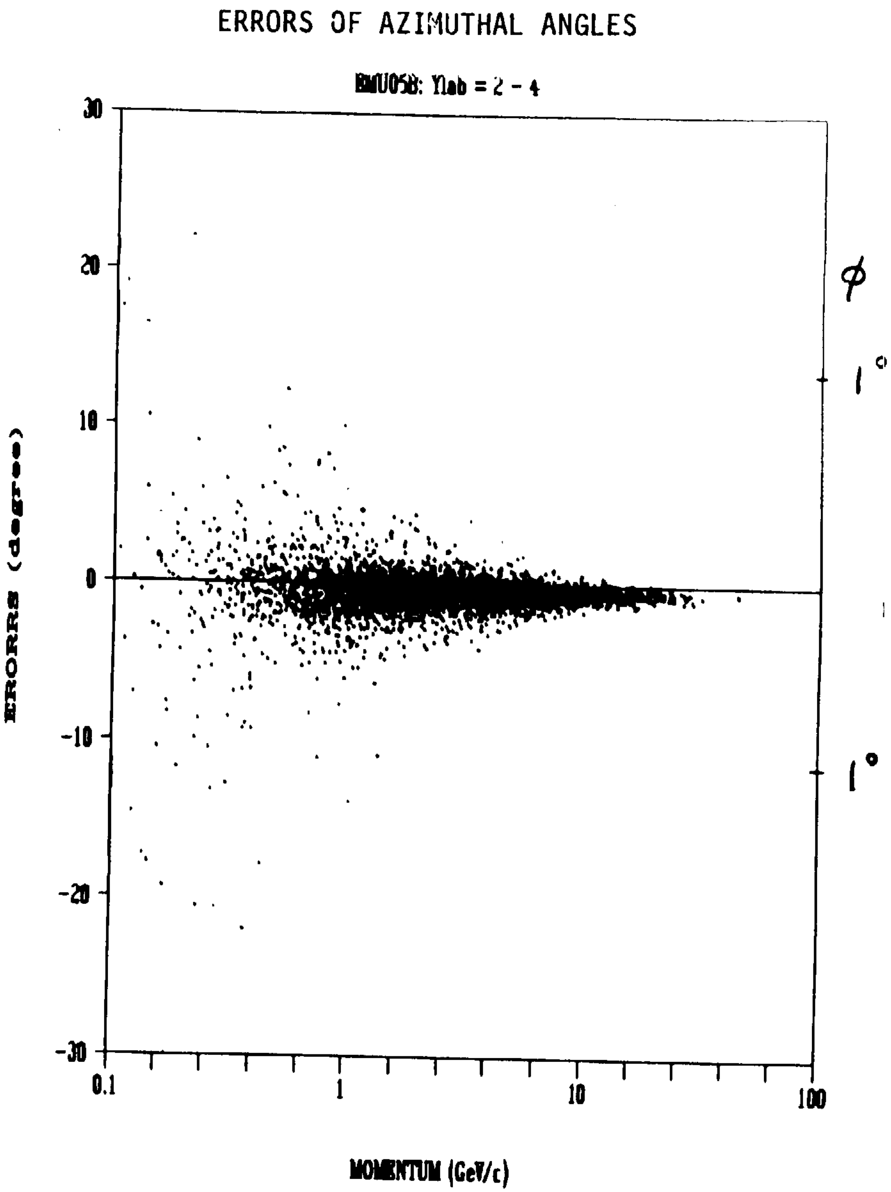
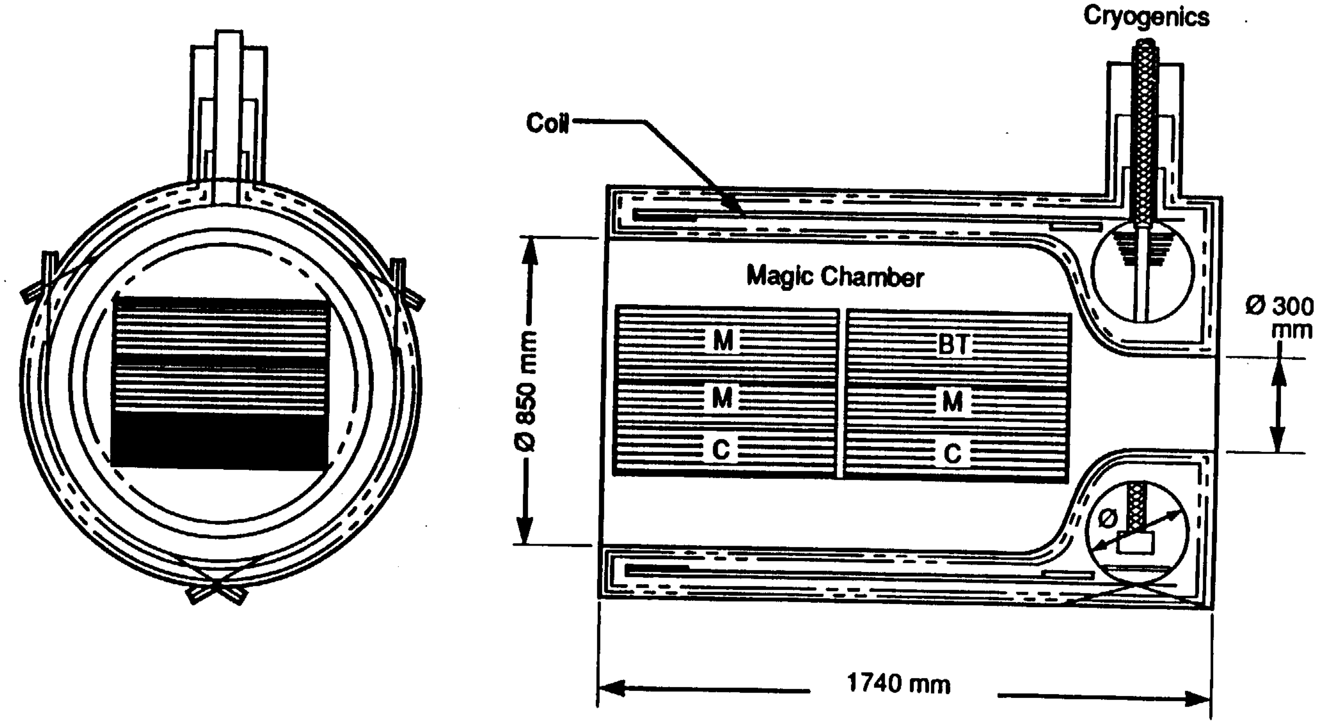


Figure 1(b)

MAGIC Chambers in a Super-conducting Magnet Solenoid



B = 1.2 TESLA

Emulsion Chambers 2×$(0.5m)^2$

M - Magic Target and Emulsion Tracking Plates
BT - CR39 Primary Beam Tracking Plates
C - Ionization Calorimeter

Figure 2

MAGIC - MOMENTUM RESOLUTION

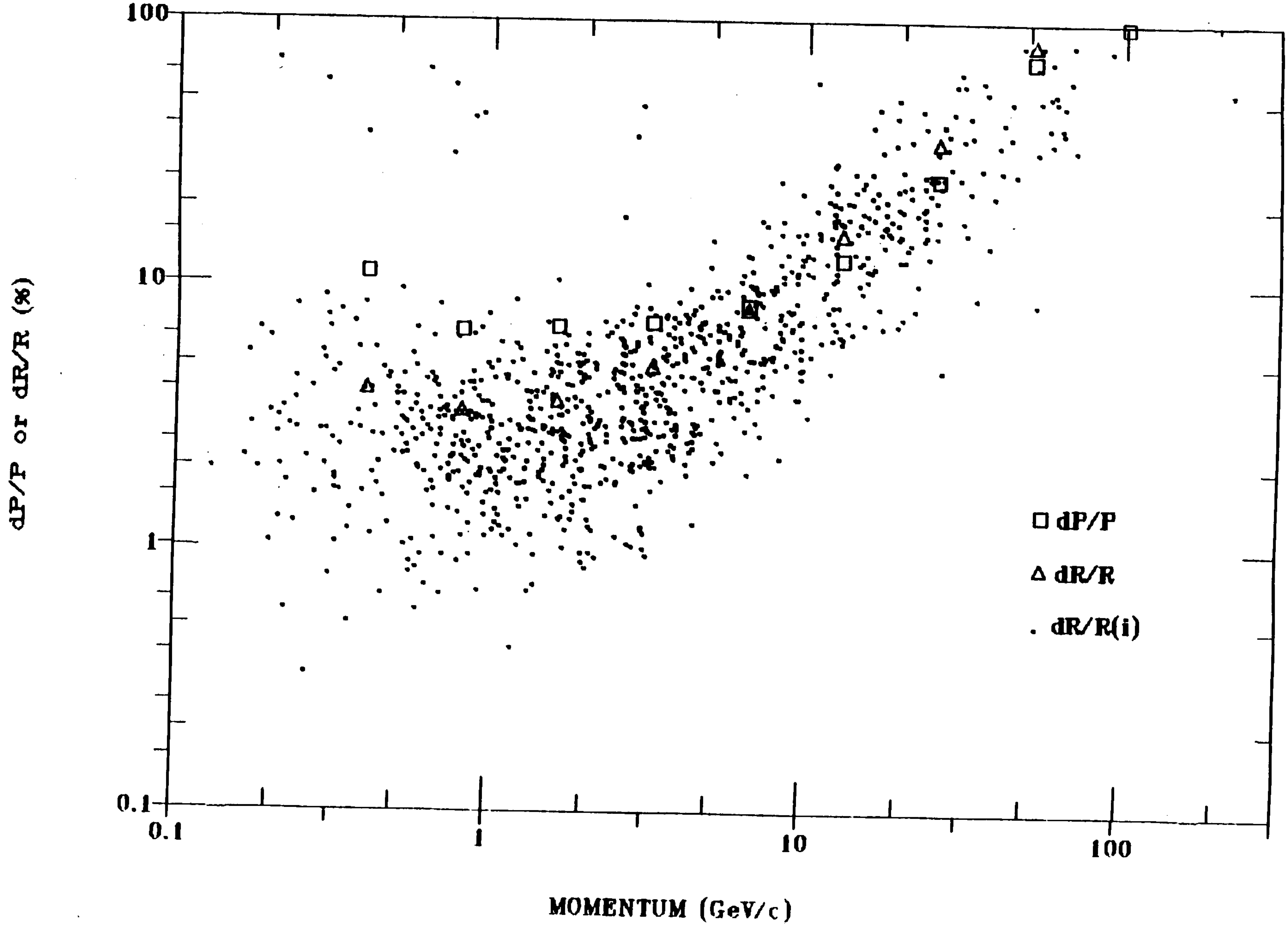


Figure 3

Super-conducting Solenoid Magnet Being Built at KEK

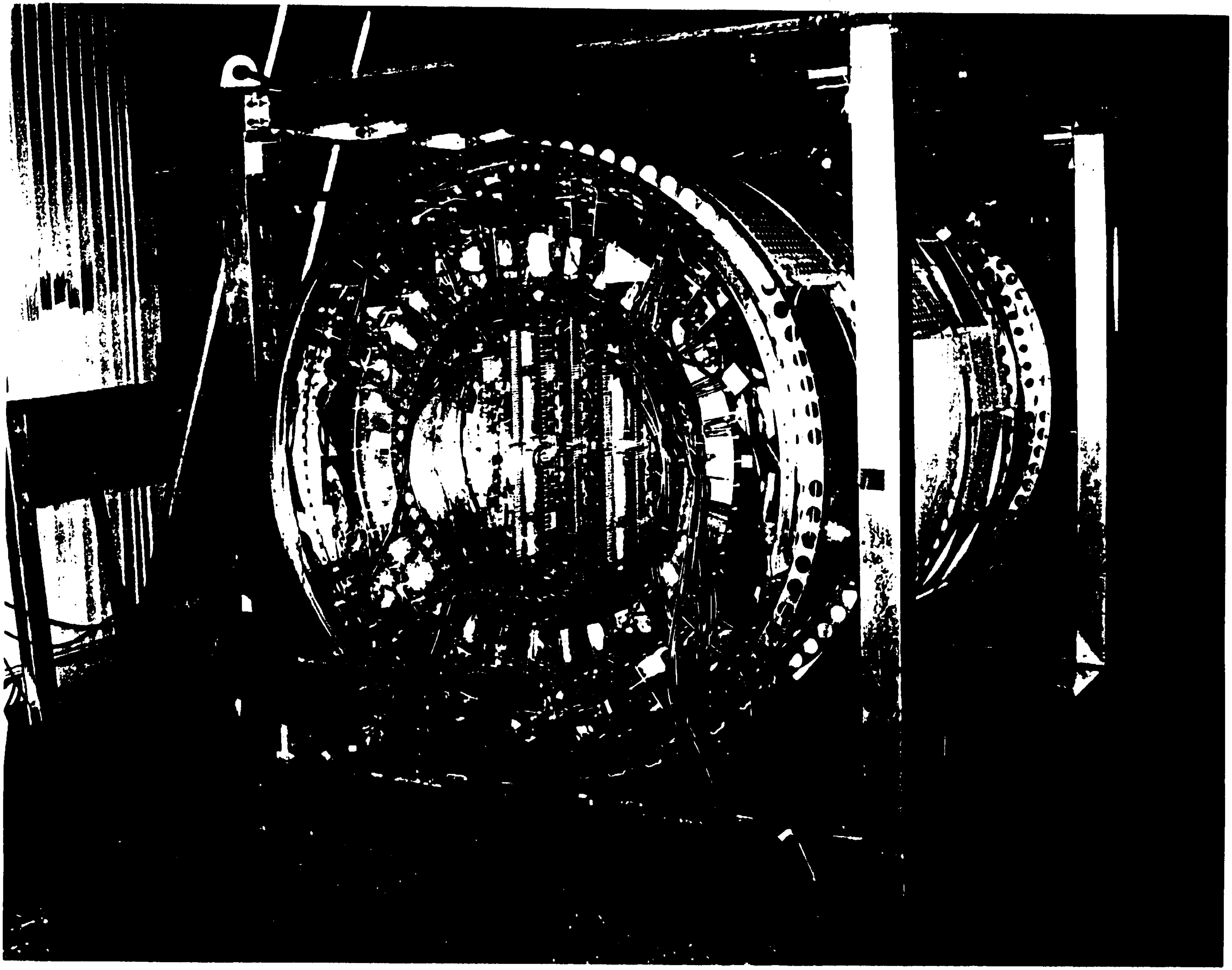


Figure 4(a)

Cross Sectional views of the solenoid

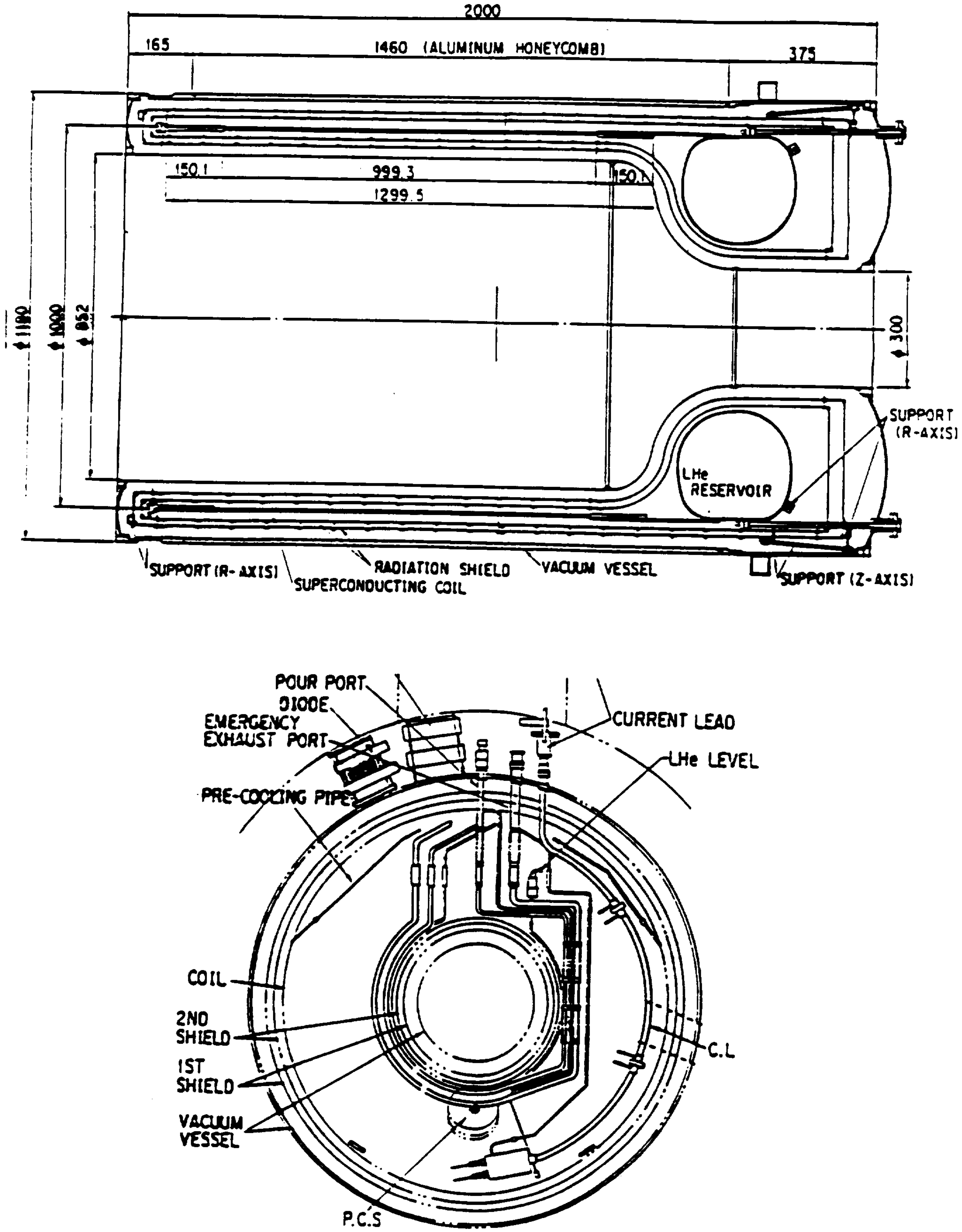


Figure 4(b)

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ABA:   Author
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