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STAR Electromagnetic Calorimeter R&D Progress Report

(1 October 1992 - 31 August 1993)

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A lead-scintillator sampling electromagnetic calorimeter (EMC) is planned as an upgrade to the STAR detector for the RHIC Accelerator at Brookhaven National Laboratory (BNL). Considerable work on the conceptual design of the calorimeter, and related interfacing issues with the solenoidal magnet and the time projection chamber (TPC) subsystems of STAR occurred in the period 1 October 1992 to 31 August 1993 (FY 1993). This report documents and summarizes the conclusions and progress from this work.

A number of sources contributed financial support for this work. The mechanical engineering effort at Argonne National Laboratory (ANL) was supported by \$130K from RHIC/STAR R&D funds and \$130K from the ANL High Energy Physics Division budget from the U.S. Department of Energy (DOE). Support for physicists and all other effort was obtained from contracts at the respective institutions.

A large number of tasks have been accomplished this fiscal year. Some of the most important have been mechanical and electronic integration work, described in Sections A and B. Interactions of the designs for the EMC, TPC, and solenoidal magnet have been studied and many problems solved due to the availability of the RHIC/STAR R&D and ANL-HEP funds. More work remains. The similarity of photomultiplier base requirements for the charged trigger barrel (CTB), time-of-flight (TOF), and the EMC has led to considerable dialog between members of the EMC and CTB/TOF groups. Important interactions of the EMC electronics design and the STAR trigger have been discussed, but much more work is required in this area.

Progress on the design of the barrel electromagnetic calorimeter is described in Section C. It is believed that a viable conceptual design has been found, after a number of other designs appeared to have significant problems. A small prototype

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EMC for physics measurements, and an engineering model for a barrel EMC module are under construction. Connected with the work on the barrel EMC design is effort to adopt a design for the shower maximum detector, summarized in Section D. Several successful tests have been performed by the Protvino group. The conceptual design of the endcap EMC is presented in Section E, and a number of important simulations results are summarized in Section F. Conclusions are presented in Section G.

A) **Mechanical Integration**

The present STAR detector design has a conventional solenoidal magnet outside the electromagnetic calorimeter. The material in the magnet coils would very seriously degrade the EMC performance if the magnet were to be located inside the calorimeter. The EMC and some structural support is expected to be heavy (~ 180 tons), and could affect the size of the inside diameter of the solenoid, depending on the method of support for the EMC. Loading of the STAR detector support system from the EMC could conceivably cause considerable and undesirable deflections and/or stresses. Finally, the magnet location affects the method of transmitting the scintillation light to the calorimeter photomultipliers, which in turn affects the magnet design. Many of these integration issues were addressed the fiscal year of this report. This would have been impossible without the RHIC/STAR R&D funding.

An important consideration for the calorimeter design is the gap between adjacent modules. This gap should be minimized for optimum EMC performance, which leads to requirements of small deflections within calorimeter modules. On the other hand, large structural supports or many support points are needed to achieve these small deflections. The large structural supports would require a larger solenoidal magnet inner radius, and thus higher costs. Early in FY1993, a joint decision with the STAR magnet designers was made to support the calorimeter modules at nine, approximately equally spaced, locations along the beam direction (z). The supports would be in the form of rings between the magnet coil packages. With a 70 mm "strongback" and 30 mm thick aluminum or nonmagnetic stainless steel back plate for structural support on the modules, mechanical calculations indicated small module deflections. Furthermore, deflections of the magnet flux return steel bars, which are part of the STAR detector support system, were shown to be small by finite element calculations.

Intensive work on the calorimeter design was performed in response to a request to "freeze" the dimensions of the STAR magnet, which depended on the EMC thickness. The resulting calorimeter thickness estimate was based on a design of compressed lead plates, separated by aluminum I-beam spacers. A similar design with depleted uranium plates was used for the ZEUS detector at HERA (Ref. 1). A total of 20 lead plates of thickness 5 mm was assumed in order to contain electromagnetic showers with energies up to tens of GeV. The lead was assumed to be clad on both sides with 0.4 mm thick nonmagnetic stainless steel to distribute the compressional loads in the lead. The I-beam spacers were taken to have a height of 6.6 mm in order for the 4.0 ± 0.4 mm thick scintillator to fit next to the I-beam web. This minimizes the gap between adjacent scintillators. A small amount of extruded aluminum of the proper I-beam shape was ordered and found to be satisfactory. The number of scintillator layers is 21, and the lead and scintillator correspond to a total of approximately 18 radiation lengths ($18 X_0$). An aluminum front plate of thickness 20 mm, a shower maximum detector of 25 mm, a back plate of 30 mm, and the 70 mm thick strongback complete the module. The total thickness, including tolerances, was estimated to be 41 cm. This thickness, combined with dimensions of other STAR detector elements, gave an inner EMC radius of 2200 mm, and an inner magnet radius of 2620 mm. A more recent calorimeter design is expected to have approximately the same thickness; see Section C. A recent drawing by the STAR integration group, showing the space assigned for the EMC, is shown in Fig. 1.

Uncertainties in the calorimeter funding led to the need to be able to install the EMC modules after the TPC and other STAR subsystems are in place. The large number of electronics and cables for the TPC, and the relatively delicate construction of the TPC, make it undesirable to frequently remove and reinstall it. The solution adopted is to have the EMC modules supported on "ways", so that they can be installed from the ends of STAR without removing the TPC. Each module would extend from the center ($\eta = 0$) to the end of the magnet ($\eta \sim 1.0$). Finite element calculations in FY1993 for a variety of cross sectional shapes for the ways indicated that the stresses and deflections would be acceptably small. An example is given in Fig. 2. It is expected that only 8 of the total of 120 EMC modules would need to be installed with the TPC removed, because of interference with the TPC supports (see Fig. 3). A conceptual design of an inexpensive installation fixture is shown in Fig. 4. This design was requested by the integration group to see whether sufficient space would be available in the assembly building for EMC installation.

The EMC photomultipliers are assumed to be located outside the magnet flux return bars, so that they would be in a low field environment and could be easily shielded. Plastic optical fibers appear to be the only practical solution to bring the scintillation light to the photomultipliers. For example, plastic wave-shifter plates, similar to those used for ZEUS (Ref. 1), would be very hard to form to the proper dimensions in order to fit between the magnet coils, would require considerable space, and would be difficult to install after the magnet was assembled. The plastic fibers solve all these problems. However, geometrical constraints lead to sharp bending radii for the fibers of ~ 4 cm, which can only be met by fibers of diameter up to about 1 mm. Such fibers have relatively short attenuation lengths of approximately 6 m for 1 mm fibers. If the fibers are routed to the ends of the magnet, the loss of light in the long fibers would cause poorer energy resolution for the calorimeter. Thus, the fibers will be routed between the magnet coils, next to the EMC support rings, and between the magnet flux return bars. It has been demonstrated with 1 mm diameter fibers, bundled inside plastic shrink tubing, and with wood models, that this fiber routing can be accomplished during module installation. A 50 mm radius of curvature on the rings, where the fibers bend toward the outside of the barrel, has been shown to be adequate; see Figs. 5 and 6.

Details of stress and deflection calculations for the EMC support rings and magnet flux return bars are documented in Ref. 2 (STAR Note #115, attached). These calculations suggested that 76 mm thick aluminum rings, supported at several points around their circumference, would give acceptable deflections and stresses in both the rings and the magnet structural elements. (These calculations were later confirmed by a BNL engineer.) Note that another calculation showed that the sag in the EMC support rings must be less than 10 mm so as to keep the reduction in the gap between adjacent modules to less than 0.3 mm. A 70 mm thick ring has been adopted in the most recent design, as shown in Fig. 7. The work described in Ref. 2 was done at the request of the STAR magnet group before the STAR design review meeting (January 1993) at Lawrence Berkeley Laboratory (LBL).

A preliminary design of the EMC support rings has recently been in progress, again at the request of the STAR magnet group. Both the cost and the method of mounting the rings to the magnet flux return bars are of importance. Machining each ring from a large, solid aluminum plate was estimated to be prohibitively expensive. A solution that appears practical has each ring formed from 6 identical cast sections of 60° , machined and then pinned together; see Figs. 8 and 9. Cost

estimates to make the rings have been received from outside machine shops, indicating that the nine rings could be constructed for slightly less than \$200 K. Detailed design of the mounting brackets and alignment fixture(s), and estimates of the times to install and align the rings and ways are in progress. An alternate design with some rings made of smaller, non-connected pieces, is also under consideration. This other design would be cheaper to construct, but would probably take longer to align. It is hoped that a final decision on the design can be made soon, and final design of the rings, etc. completed in a few months.

The design of the endcap electromagnetic calorimeter had a small impact on the magnet design. In particular, the space was limited for this part of the EMC, and the support for the magnet pole tip must also carry the 30 ton load from this detector. A method of mounting the endcap EMC to the magnet pole tip was devised that did not distort the magnetic field; see Ref. 3 (STAR Note #120, attached) and Section E.

Finally, some of the RHIC/STAR R&D funding supported trips by ANL engineers and physicists to magnet design review meetings at BNL and LBL.

B) Electronics Integration

No special funds were allotted for electronics engineering for the EMC. Nevertheless, some important progress was made on a number of topics. One was the design of a photomultiplier base in common with the CTB/TOF subgroup. In order to save the expense and space needed for large numbers of high voltage cables, several designs are under consideration for a base where the high voltage is generated locally; see Fig. 10. The voltage would be set remotely via an ethernet connection which would also serve to adjust other EMC parameters, such as ADC offsets and gains. A report (Ref. 4 - attached) summarizes the work by the UCLA group on this subject.

A number of integration issues have been discussed concerning the EMC electronics. The location of low voltage D.C. power supplies for the photomultiplier bases and VME crates mounted nearby was discussed with LBL integration engineers. The supplies will probably be installed on a cart near the STAR detector, along with supplies for other subsystems. The front-end and some of the trigger electronics will probably be mounted near the EMC photomultipliers, on the outside of the magnet flux return bars and the magnet pole tip. It is desired to be able to look at raw signals from the EMC tower photomultipliers in the counting house, but a practical method to accomplish this is not yet available.

A prototype for the EMC front-end data acquisition electronics was built and tested at ANL. The input photomultiplier signals are first sent to a 1:64 current splitter in this prototype. Then the signals from the splitter go to two charge integrators with fast clear, two 10 bit flash ADC's, and a RAM. The information from the two ADC's will be combined to give a 16 bit dynamic range for the EMC signals. The prototype is presently in a CAMAC package for ease of testing, but eventually will reside in VME. Tests with both pulser and photomultiplier signals have been performed. Work is also in progress to study and test trigger algorithms with XYLINX chips. This is necessary now because of the special challenges associated with triggering for both heavy ion interactions with many low momentum particles and for high transverse momentum events. Continued research on both the front-end and trigger electronics is expected to occur next fiscal year.

There have been some discussions with members of the trigger and other subsystem groups about the implementation of the level-0 trigger. The problem is that only approximately 1 μ sec is available to make sums of pulse heights from all 1200 or from individual sets of 4 towers in order to make a trigger to gate the TPC. Various digital and analog concepts to accomplish the summing in the allowed time have been considered, but the help of an electrical engineer is needed to obtain a satisfactory solution. In fact, such help will be essential next fiscal year to address a range of integration issues.

C) Barrel EMC Design

A number of conceptual designs for the construction of the barrel electromagnetic calorimeter were seriously considered. The first design involved stacked lead plates with aluminum I-beam spacers under compression. The spacers were to prevent significant loading on the scintillator plates. Friction between the spacers and lead plates was used to provide structural integrity to the EMC modules. Initially, projective "towers" were assumed, so that the spacers were located in depth along a line pointing toward the center of the STAR detector. However, a finite element analysis of this design suggested stresses of $\geq 3,000$ psi in the lead, whereas negligible creep in the lead over a period of ~ 20 years would require the stresses to be $\leq 1,000$ psi. The calculated stresses are shown in Fig. 11. The deformation, due to the creep, could lead to a reduction in the compressive loads and a failure of the module assembly. Consideration of various lead alloys, nonprojective towers with spacers all located at fixed z , and cladding of the lead with 0.020" stainless steel sheet did not solve this creep problem. Therefore, this design was rejected.

A second design involved casting the lead with slots for the scintillator plates. Internal reinforcing plates and tubes were found necessary in the design of a similar calorimeter for the SDC detector planned for the SSC. An independent cost analysis by ANL engineers for this design option indicated that it was significantly more expensive than the stacked option above. A sizable cost was related to the molds. Construction costs were high because of the tight tolerances on many of the mold parts, especially for the plates used to make the scintillator slots. Large effort would be needed to remove, clean, and reinstall many of the mold parts after a casting. There was also concern that there might be expensive checks for warping of the plates needed after every casting. Tests of plate warpage with various aluminum and stainless steel plates heated to casting temperatures indicated that this might be a significant problem; see Ref. 5 (STAR Note #118, attached). The uncertainties of how often a mold could be reused, and the high costs noted above, ruled out this design option.

A third design also consisted of lead plates and scintillator in a stacked arrangement held together by compressive loads. In this instance, however, the size of the compressive load is the same, but the pressure is reduced by eliminating the I-beam spacers and stacking the lead and scintillator on top of one another. The effective surface area between sampling layers is greatly increased in this design, reducing the pressure required for module stability. Experience with similar designs at CDF and UA1 has been favorable. This option has not been eliminated, but concern over the long-term response of scintillator under pressure and the possibility that the success of this design might be specific to a particular batch or type of scintillator has prompted the investigation of other designs as well.

The adopted design utilizes the 20 mm front and 30 mm back plates described above, end plates of 3 mm stainless steel, a central 6 mm thick stainless steel bulkhead at $| \eta | \sim 0.5$, and 0.5 mm aluminum or stainless steel side sheets to support the gravitational load of the module. In this design (see Fig. 12), the lead absorber sheets are half the full module length and are captured by fixtures at the ends and middle of the module. This design eliminates the need for high compressive forces. Aluminum I-beam spacers may be used to prevent the lead from contacting the scintillator. Alternately, the 3-4 psi pressure from the gravitational load on the scintillator from the lead (without spacers) is not expected to cause significant long-term changes in the EMC response. Finite element calculations of this mechanical design gave acceptable deflections and stresses in all parts of the

module for all module orientations studied. The side sheets were found to be essential for structural integrity of the modules located near 12 o'clock.

More refined finite element models of the barrel calorimeter modules are planned, in order to look in detail at the loading at the ends and central bulkhead due to the lead. However, it is planned to construct a full size engineering model of a module to verify these calculations. Lead sheets with masonite plates instead of scintillator may be used to simulate the loads. Drawings are being prepared for machining the parts of the model. It should be completed early next fiscal year, after which testing will begin.

The design of the ways was studied with finite element calculations. A variety of cross sectional shapes were tried; stresses and module deflections were low in all cases studied (see Fig. 2). Recently commercial systems are being investigated for the ways. These systems may be much cheaper than the present conceptual design. However, the rods which form the ways and the bearings are constructed of magnetic stainless steel. The use of nonmagnetic materials is being discussed with the manufacturer.

Some preliminary work has been performed on the design of the magnetic shielding boxes for the barrel EMC photomultipliers. The arrangement of the photomultipliers, the routing of the fibers, and the location of the electronics were all studied. Interference is expected with supports at the bottom of the STAR detector, with water and power connections to the solenoidal magnet at the 3 and 9 o'clock positions, and with the door between the Wide Angle Hall and the assembly building at the top. The location of power supplies for the EMC electronics has also been discussed with the integration group. More work is clearly needed in these areas.

The method of coupling the light from the 4 mm thick scintillators to the wave length shifting (WLS) fibers was studied during FY1993. Machining a groove into the face of the scintillator, and inserting or gluing the fiber into the groove has been shown to work acceptably, but is labor intensive and expensive. The present conceptual design for the coupling involves constraining the WLS fibers to lie along the edge of the scintillator by wrapping them tightly in aluminized mylar, which acts as a concentrating reflector. Using this technique last fiscal year, the light output from a 3 mm thick piece of BC-408 PVT scintillator coupled to 50 cm of WLS fiber, which in turn was spliced onto 3 m of clear fiber, was measured to be 2 photoelectrons per minimum ionizing particle (mip). This result, obtained using a Hamamatsu R580 photomultiplier, is adequate to meet the design goal for the EMC energy resolution, and was the basis for adopting this conceptual design.

During FY1993, similar tests were performed with 4 mm thick SCSN-38 polystyrene scintillator; only 1.3 photoelectrons per mip were seen. While this is better than the ZEUS calorimeter, it is desired to do better. A number of different edge coupling techniques have been tried to get more light to the photomultipliers without having to resort to machining grooves. The tests done with no glue have not shown any real improvement, and the tests with glue are not yet complete. One basic problem is that polystyrene scintillator, though cheaper, puts out less light than PVT scintillator. There may also be different doping levels of wave shifter in different batches of scintillator.

For example, the measurement above used 1 mm diameter fibers. WLS fibers of 1, 1.5, and 2 mm diameter were tested with a 4 mm scintillator in the same manner as above. Some tests indicated little change in the number of photoelectrons ($\leq 20\%$), while others gave sizable changes; further study is needed. In other studies, there was only a modest increase in light collection with two 1 mm fibers placed side by side. A single 1 mm diameter fiber is assumed in the present conceptual design because of lower cost, and more importantly, better mechanical flexibility for routing.

Studies have been begun of the light coupling for the end cap scintillators with two straight grooves in the scintillator faces. The different geometry for the endcap requires such grooves in order to minimize the gap between adjacent towers.

The preparation of the scintillator edges is known to have a large influence on the light collection efficiency, and thus the EMC energy resolution. Traditional cut and polish techniques work well, but are very labor intensive. An alternate method using a milling machine equipped with a diamond cutting tool was tested and shown to give essentially the same light collection for far less fabrication time (see Ref. 4). It is presently envisioned that the diamond mill will be used for preparing the scintillator edges.

Some tests of the effects of heat on the clear fibers have been performed, since they must pass between the magnet coils. The tests were done in a temperature controlled oven, with the fibers coiled in a $1.5'' = 3.8$ cm radius. The light transmission for the clear fibers showed no change with heating to 120° F for two weeks. Such temperatures may occur in the magnet during summer runs if no chiller for the magnet cooling water is available. Similar tests with the WLS fibers were somewhat ambiguous, and a more controlled test is being performed.

A small prototype EMC test module is under construction. The goal is to test the performance for low energy hadrons, electrons, and photons for heavy ion mea-

surements with the electromagnetic calorimeter. Most of the parts have been purchased, but a support still needs to be built. This prototype has the full barrel EMC thickness, and is equivalent to $\Delta\eta = 0.2$ and $\Delta\phi = 0.2$ (two barrel EMC modules in width). Provision is being made to install both types of shower maximum detectors. Tests in accelerator beams are planned for next year.

D) Shower Maximum Detector Design

Though RHIC/STAR R&D funding was approved for the design of the shower maximum detector, it proved to be impossible to get these funds to the IHEP Protvino collaborators. Nevertheless, significant results were obtained. A test scintillator strip shower maximum detector was constructed and tested with radioactive sources and accelerator beams. The test results are described in Refs. 6-9 (enclosed). A serious concern had been whether sufficient numbers of photoelectrons would be observed in the photomultipliers from the passage of minimum ionizing particles through the thin scintillator strips. This concern arose because of the attenuation of the scintillator light in the small diameter optical fibers (1 mm) and the relatively low photoefficiency of the available photomultipliers. The tests indicated slightly less than 2.0 photoelectrons per mip, a value which should give reasonably good performance for the shower maximum detector constructed of scintillator strips.

Another concern had been whether adequate space was available on the outside of the magnet flux return bars for all the photomultipliers from the barrel EMC towers and shower maximum detector strips. A method for mounting all the photomultipliers was found that did not have excessive fiber lengths. However, a similar method will not work for the endcap EMC because of the smaller area available. Routing of the many fibers from the scintillator strips (see Fig. 13) was also solved with a minimum impact on the gap between adjacent modules.

An alternate design for the shower maximum detector consists of wire chambers with pad readout similar to the one built for CDF (Ref. 10); see Figs. 14 and 15. Advantages of this scheme include the possibility to use slightly modified TPC electronics for readout, saving a considerable amount of money and/or allowing more independent readout channels. A possible disadvantage is the longer pulse lengths from such counters, which could affect the detector response at the highest RHIC luminosities. It is planned to construct a test chamber with this alternate design next fiscal year. Both types of shower maximum detector are expected to be tested

in the small EMC prototype with accelerator beams at the BNL AGS, MSU cyclotron, and elsewhere.

Additional work is also required on modifying the TPC electronics, routing of readout cables or fibers, and performing cost estimates. A decision between the two types of shower maximum detector is expected next fiscal year.

E) Endcap EMC Design

Details of the conceptual design for the endcap EMC are presented in Ref. 3 (STAR Note #120, attached). Two 180° sections form each endcap calorimeter, as shown in Fig. 16. There are 25 layers of 5 mm thick lead sheets and 26 scintillator planes in depth. Extruded aluminum "Z" spacers are planned between lead layers. A front and back plate for structural strength, a shower maximum detector, plus additional structural elements near $|\eta| = 1.1$ and 2.0, complete each endcap section. These EMC sections are to be mounted to the magnet pole tips with non-magnetic stainless steel blocks bolted to the pole face. It was concluded that mechanical problems with the endcap EMC design were significantly less severe than for the barrel EMC. An improved cost estimate, a conceptual design for the location and shielding of the photomultipliers, and some additional optical tests remain to be done next fiscal year.

F) Simulations

A variety of physics simulations for both A + A and polarized p + p interactions in the STAR EMC have been performed during FY1993. The best summaries of some of these studies are given in the NSF proposal/ EMC conceptual design report and in the update to the RHIC spin proposal (R5) to the BNL Program Advisory Committee (PAC). A sample of these simulations is described below.

The sensitivity of the STAR EMC to events with unusual isospin abundances was estimated. Ten normal Au + Au events with 100 GeV/c per nucleon beams were generated and the response of the full STAR detector simulated with GEANT. The same events were then modified by changing 50% of the π^0 mesons to $\pi^\pm$ mesons, without changing momenta or energies, and the STAR response again computed. The results are displayed in Fig. 17, where a clear separation of the two types of events is observed. A similar sensitivity can be observed for events in which the mean transverse momentum per particle is substantially less than normal. These results demonstrate some of the capabilities of the EMC for triggering on interesting heavy ion events.

Simulations also assisted in the detailed EMC design. For example, projective towers have been assumed in the barrel EMC conceptual design. However, when it was concluded that the compressed, stacked lead and spacer option would not work, the behavior of the EMC with "z" or nonprojective towers in η was simulated. A small degradation of performance was found. The response of such a calorimeter with equal Δz and equal $\Delta \eta$ nonprojective towers was also studied, and little difference noted in performance.

Simulations of high transverse momentum processes in pp interactions for spin measurements have occurred. Earlier work on inclusive direct photon production has been extended to show that isolation cuts to remove Bremsstrahlung processes have little effect on the observed cross sections. Backgrounds for high dilepton mass inclusive Drell-Yan production have also been studied, and shown to be small for masses above about 10 GeV. Simulations of inclusive W and Z production have been begun and will continue for the Fall BNL PAC meeting, at which an update to the R5 proposal will be presented. These high momentum processes are all very important to study various spin distributions in the proton.

G) Conclusions

A wide range of issues in the design of an electromagnetic calorimeter for STAR have been addressed during FY1993. A viable method for constructing both the barrel and the endcap EMC has been found. There has been progress in designing a common photomultiplier base for the CTB, EMC, and TOF subsystems, and in developing a trigger for STAR using signals from the EMC. Much effort has been devoted to developing consistent designs for the solenoidal magnet and EMC supports that meet stringent criteria from both subsystems. Important first steps were taken for the design of a shower maximum detector needed for measurements of inclusive direct-photon production and of gluon distributions in nuclei and protons. Finally, simulations of detector performance and physics processes have been very helpful in guiding the EMC design.

The wide range of problems studied and issues addressed during this past fiscal year is partially the result of requests from other STAR subsystems and the integration group. For example, work on the EMC support rings, barrel module installation fixture, photomultiplier base, thermal calculations relating to heating from the magnet coils, decisions on space needed for the barrel EMC, etc. all fall in this category. These tasks all took priority over the barrel calorimeter design activities when they arose. Furthermore, there was considerable effort devoted to the

writing of the EMC conceptual design report, as part of a National Science Foundation (NSF) funding proposal for the construction of the EMC. Several other technical reports on the work of the STAR EMC collaborators have also been written and are attached to this progress report. The return on the investments from RHIC/STAR R&D and ANL-HEP Division funds has certainly been very high.

Much important integration and conceptual design work remains for the future. In particular, the electronics and mechanical engineering will be very important to have the EMC designs for the trigger, photomultiplier base, and shower maximum detector electronics and for the EMC supports and photomultiplier boxes consistent with the other STAR subsystems. Decisions on shower maximum detector technology and work to obtain funding for the EMC will also be very high priority.

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Figure Captions

- Figure 1 Space available in the STAR detector for the electromagnetic calorimeter and associated electronics. The barrel and endcap sections can be seen.
- Figure 2 Stresses computed in a finite element model of a possible design for a way and strongback to mount the EMC modules. These stresses are reasonably low for stainless steel.
- Figure 3 Sketches of the STAR detector showing the TPC support brackets and regions of the EMC that must be modified; a) side view, b) end view. Eight modules ($\Delta\eta = 1.0$, $\Delta\phi = 0.1$) plus the endcap sections are affected.
- Figure 4 A conceptual design for an installation fixture for the barrel EMC modules. This design was required in order to determine whether there would be adequate space in the assembly building for the installation and whether the planned crane coverage was sufficient.
- Figure 5 Photograph of 1 mm diameter plastic optical fibers in plastic "shrink tubing." The fiber had very poor optical quality from the manufacturer, and was obtained free from Fermilab.
- Figure 6 Photograph of a fixture to test the minimum bending radius required on the EMC support rings in order to route the fiber bundles to the outside of the STAR detector to the EMC photomultipliers.
- Figure 7 Diagram of the cross sectional view through the solenoidal magnet coils and the EMC support rings. The location of the magnet flux return (backleg) bars, the iron end ring, and the magnet pole tip are also shown.

- Figure 8 Sketch of a preliminary design for a 60° section of the EMC support ring. Six such sections will be machined and pinned into a complete ring.
- Figure 9
- a. Sketch of a section of the EMC support ring, ways, and magnet flux return bars near the 6 or 12 o'clock positions. A conceptual design for tie rods from the outside of the bars to the EMC support ring is also shown.
 - b. Sketch of the full EMC support ring, EMC modules, ways, and magnet flux return bars.
- Figure 10 A possible circuit design for a photomultiplier base which generates the required high voltages from a low D.C. voltage. No magnetic materials are present in this design, allowing its use for CTB and TOF, as well as EMC photomultipliers.
- Figure 11 Stresses computed in a finite element model of lead plates with stainless steel cladding and rectangular aluminum spacers in compression. The calculated maximum stress in the lead was > 3,000 psi, which would be expected to suffer significant creep during the lifetime of STAR.
- Figure 12 A simplified sketch of the structural elements in the present conceptual design for the barrel electromagnetic calorimeter. Thin side sheets are also necessary, but are shown removed so that the central bulkhead and one end are visible.
- Figure 13 Fiber routing scheme for the barrel EMC scintillator strip shower maximum detector. These strips are 1 cm wide, and are only half the width of an EMC module. A similar set, offset in depth, covers the other half of the module width.
- Figure 14 Conceptual design for a wire chamber/strip detector for shower maximum in the endcap EMC. For the barrel, the wires are parallel to the beam and the pads extend in ϕ over the full module width.

- Figure 15 Conceptual design for the aluminum extrusion and wire supports for a wire chamber shower maximum detector similar to CDF.
- Figure 16 Sketch of a conceptual design for a 180° section of the endcap EMC. Structural elements include a front plate (not shown), back plate, bulkheads and ends every 30° in ϕ , and inner and outer radial supports. Fibers and scintillators are shown in one 30° section.
- Figure 17 Results of a simulation using Au + Au interactions at RHIC. The energy deposited in the EMC and the multiplicity measured in the central trigger barrel can be used to identify events with unusual ratios of numbers of π^0 to $\pi^\pm$ mesons per event.

7271.54
6521.29
5771.04
5020.80
4270.55
3520.30
2770.05
2019.80
1269.55
519.302
-230.94
-981.19
-1731.4

SUIEWH (386) 3.18 File:hepmad4b 92/10/16 LC 1/ 1 Vu= 7 Lo= 45 La= 45 R= 0

Figure 3a

Figure 3b

STAR BARREL EMC INSTALLATION FIXTURE

6-4-93 E.B.

Figure 4

Figure 5

Figure 6

54 REQ'D.
MACHINE FROM ALUM. CASTING (SKETCH HEP0040)

Figure 8

Figure 9a

Figure 9b

Figure 10

GET VAL
Var out

[Esc]

Help Undo
Inp Snap
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Big Menu
Top Draw

Other method = Minimum Principal Stress

Click on node to get display value at that node.

NODE #5018: X=0, Y=95.3806, Z=-0.7565: Val=-17978.4

SVIEW 4.00 File:leadbm8 92/12/23 12:17 EC 1/ 1 Vu=5.1e+001a= 0.0

SIMPLIFIED PROJECTIVE TOWER CONCEPT FOR THE
BARREL ELECTROMAGNETIC CALORIMETER

-31-

VIEW WITH SIDE SHEETS REMOVED
NO LEAD OR SCINTILLATOR SHOWN

Figure 12

Figure 13

Figure 14

WIRE CHAMBER SECTION

Figure 15

Figure 16

1 of 1

STAR Electromagnetic Calorimeter R&D Progress Report

(1 October 1992 - 31 August 1993)

*Argonne National Laboratory
Johns Hopkins University
Michigan State University
University of Texas at Austin
University of California at Los Angeles,
and
Institute of High Energy Physics, Protvino, Russia*

OCT 01 1993

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A lead-scintillator sampling electromagnetic calorimeter (EMC) is planned as an upgrade to the STAR detector for the RHIC Accelerator at Brookhaven National Laboratory (BNL). Considerable work on the conceptual design of the calorimeter, and related interfacing issues with the solenoidal magnet and the time projection chamber (TPC) subsystems of STAR occurred in the period 1 October 1992 to 31 August 1993 (FY 1993). This report documents and summarizes the conclusions and progress from this work.

A number of sources contributed financial support for this work. The mechanical engineering effort at Argonne National Laboratory (ANL) was supported by \$130K from RHIC/STAR R&D funds and \$130K from the ANL High Energy Physics Division budget from the U.S. Department of Energy (DOE). Support for physicists and all other effort was obtained from contracts at the respective institutions.

A large number of tasks have been accomplished this fiscal year. Some of the most important have been mechanical and electronic integration work, described in Sections A and B. Interactions of the designs for the EMC, TPC, and solenoidal magnet have been studied and many problems solved due to the availability of the RHIC/STAR R&D and ANL-HEP funds. More work remains. The similarity of photomultiplier base requirements for the charged trigger barrel (CTB), time-of-flight (TOF), and the EMC has led to considerable dialog between members of the EMC and CTB/TOF groups. Important interactions of the EMC electronics design and the STAR trigger have been discussed, but much more work is required in this area.

Progress on the design of the barrel electromagnetic calorimeter is described in Section C. It is believed that a viable conceptual design has been found, after a number of other designs appeared to have significant problems. A small prototype

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EMC for physics measurements, and an engineering model for a barrel EMC module are under construction. Connected with the work on the barrel EMC design is effort to adopt a design for the shower maximum detector, summarized in Section D. Several successful tests have been performed by the Protvino group. The conceptual design of the endcap EMC is presented in Section E, and a number of important simulations results are summarized in Section F. Conclusions are presented in Section G.

A) **Mechanical Integration**

The present STAR detector design has a conventional solenoidal magnet outside the electromagnetic calorimeter. The material in the magnet coils would very seriously degrade the EMC performance if the magnet were to be located inside the calorimeter. The EMC and some structural support is expected to be heavy (~ 180 tons), and could affect the size of the inside diameter of the solenoid, depending on the method of support for the EMC. Loading of the STAR detector support system from the EMC could conceivably cause considerable and undesirable deflections and/or stresses. Finally, the magnet location affects the method of transmitting the scintillation light to the calorimeter photomultipliers, which in turn affects the magnet design. Many of these integration issues were addressed the fiscal year of this report. This would have been impossible without the RHIC/STAR R&D funding.

An important consideration for the calorimeter design is the gap between adjacent modules. This gap should be minimized for optimum EMC performance, which leads to requirements of small deflections within calorimeter modules. On the other hand, large structural supports or many support points are needed to achieve these small deflections. The large structural supports would require a larger solenoidal magnet inner radius, and thus higher costs. Early in FY1993, a joint decision with the STAR magnet designers was made to support the calorimeter modules at nine, approximately equally spaced, locations along the beam direction (z). The supports would be in the form of rings between the magnet coil packages. With a 70 mm "strongback" and 30 mm thick aluminum or nonmagnetic stainless steel back plate for structural support on the modules, mechanical calculations indicated small module deflections. Furthermore, deflections of the magnet flux return steel bars, which are part of the STAR detector support system, were shown to be small by finite element calculations.

Intensive work on the calorimeter design was performed in response to a request to "freeze" the dimensions of the STAR magnet, which depended on the EMC thickness. The resulting calorimeter thickness estimate was based on a design of compressed lead plates, separated by aluminum I-beam spacers. A similar design with depleted uranium plates was used for the ZEUS detector at HERA (Ref. 1). A total of 20 lead plates of thickness 5 mm was assumed in order to contain electromagnetic showers with energies up to tens of GeV. The lead was assumed to be clad on both sides with 0.4 mm thick nonmagnetic stainless steel to distribute the compressional loads in the lead. The I-beam spacers were taken to have a height of 6.6 mm in order for the 4.0 ± 0.4 mm thick scintillator to fit next to the I-beam web. This minimizes the gap between adjacent scintillators. A small amount of extruded aluminum of the proper I-beam shape was ordered and found to be satisfactory. The number of scintillator layers is 21, and the lead and scintillator correspond to a total of approximately 18 radiation lengths ($18 X_0$). An aluminum front plate of thickness 20 mm, a shower maximum detector of 25 mm, a back plate of 30 mm, and the 70 mm thick strongback complete the module. The total thickness, including tolerances, was estimated to be 41 cm. This thickness, combined with dimensions of other STAR detector elements, gave an inner EMC radius of 2200 mm, and an inner magnet radius of 2620 mm. A more recent calorimeter design is expected to have approximately the same thickness; see Section C. A recent drawing by the STAR integration group, showing the space assigned for the EMC, is shown in Fig. 1.

Uncertainties in the calorimeter funding led to the need to be able to install the EMC modules after the TPC and other STAR subsystems are in place. The large number of electronics and cables for the TPC, and the relatively delicate construction of the TPC, make it undesirable to frequently remove and reinstall it. The solution adopted is to have the EMC modules supported on "ways", so that they can be installed from the ends of STAR without removing the TPC. Each module would extend from the center ($\eta = 0$) to the end of the magnet ($\eta \sim 1.0$). Finite element calculations in FY1993 for a variety of cross sectional shapes for the ways indicated that the stresses and deflections would be acceptably small. An example is given in Fig. 2. It is expected that only 8 of the total of 120 EMC modules would need to be installed with the TPC removed, because of interference with the TPC supports (see Fig. 3). A conceptual design of an inexpensive installation fixture is shown in Fig. 4. This design was requested by the integration group to see whether sufficient space would be available in the assembly building for EMC installation.

The EMC photomultipliers are assumed to be located outside the magnet flux return bars, so that they would be in a low field environment and could be easily shielded. Plastic optical fibers appear to be the only practical solution to bring the scintillation light to the photomultipliers. For example, plastic wave-shifter plates, similar to those used for ZEUS (Ref. 1), would be very hard to form to the proper dimensions in order to fit between the magnet coils, would require considerable space, and would be difficult to install after the magnet was assembled. The plastic fibers solve all these problems. However, geometrical constraints lead to sharp bending radii for the fibers of ~ 4 cm, which can only be met by fibers of diameter up to about 1 mm. Such fibers have relatively short attenuation lengths of approximately 6 m for 1 mm fibers. If the fibers are routed to the ends of the magnet, the loss of light in the long fibers would cause poorer energy resolution for the calorimeter. Thus, the fibers will be routed between the magnet coils, next to the EMC support rings, and between the magnet flux return bars. It has been demonstrated with 1 mm diameter fibers, bundled inside plastic shrink tubing, and with wood models, that this fiber routing can be accomplished during module installation. A 50 mm radius of curvature on the rings, where the fibers bend toward the outside of the barrel, has been shown to be adequate; see Figs. 5 and 6.

Details of stress and deflection calculations for the EMC support rings and magnet flux return bars are documented in Ref. 2 (STAR Note #115, attached). These calculations suggested that 76 mm thick aluminum rings, supported at several points around their circumference, would give acceptable deflections and stresses in both the rings and the magnet structural elements. (These calculations were later confirmed by a BNL engineer.) Note that another calculation showed that the sag in the EMC support rings must be less than 10 mm so as to keep the reduction in the gap between adjacent modules to less than 0.3 mm. A 70 mm thick ring has been adopted in the most recent design, as shown in Fig. 7. The work described in Ref. 2 was done at the request of the STAR magnet group before the STAR design review meeting (January 1993) at Lawrence Berkeley Laboratory (LBL).

A preliminary design of the EMC support rings has recently been in progress, again at the request of the STAR magnet group. Both the cost and the method of mounting the rings to the magnet flux return bars are of importance. Machining each ring from a large, solid aluminum plate was estimated to be prohibitively expensive. A solution that appears practical has each ring formed from 6 identical cast sections of 60° , machined and then pinned together; see Figs. 8 and 9. Cost

estimates to make the rings have been received from outside machine shops, indicating that the nine rings could be constructed for slightly less than \$200 K. Detailed design of the mounting brackets and alignment fixture(s), and estimates of the times to install and align the rings and ways are in progress. An alternate design with some rings made of smaller, non-connected pieces, is also under consideration. This other design would be cheaper to construct, but would probably take longer to align. It is hoped that a final decision on the design can be made soon, and final design of the rings, etc. completed in a few months.

The design of the endcap electromagnetic calorimeter had a small impact on the magnet design. In particular, the space was limited for this part of the EMC, and the support for the magnet pole tip must also carry the 30 ton load from this detector. A method of mounting the endcap EMC to the magnet pole tip was devised that did not distort the magnetic field; see Ref. 3 (STAR Note #120, attached) and Section E.

Finally, some of the RHIC/STAR R&D funding supported trips by ANL engineers and physicists to magnet design review meetings at BNL and LBL.

B) Electronics Integration

No special funds were allotted for electronics engineering for the EMC. Nevertheless, some important progress was made on a number of topics. One was the design of a photomultiplier base in common with the CTB/TOF subgroup. In order to save the expense and space needed for large numbers of high voltage cables, several designs are under consideration for a base where the high voltage is generated locally; see Fig. 10. The voltage would be set remotely via an ethernet connection which would also serve to adjust other EMC parameters, such as ADC offsets and gains. A report (Ref. 4 - attached) summarizes the work by the UCLA group on this subject.

A number of integration issues have been discussed concerning the EMC electronics. The location of low voltage D.C. power supplies for the photomultiplier bases and VME crates mounted nearby was discussed with LBL integration engineers. The supplies will probably be installed on a cart near the STAR detector, along with supplies for other subsystems. The front-end and some of the trigger electronics will probably be mounted near the EMC photomultipliers, on the outside of the magnet flux return bars and the magnet pole tip. It is desired to be able to look at raw signals from the EMC tower photomultipliers in the counting house, but a practical method to accomplish this is not yet available.

A prototype for the EMC front-end data acquisition electronics was built and tested at ANL. The input photomultiplier signals are first sent to a 1:64 current splitter in this prototype. Then the signals from the splitter go to two charge integrators with fast clear, two 10 bit flash ADC's, and a RAM. The information from the two ADC's will be combined to give a 16 bit dynamic range for the EMC signals. The prototype is presently in a CAMAC package for ease of testing, but eventually will reside in VME. Tests with both pulser and photomultiplier signals have been performed. Work is also in progress to study and test trigger algorithms with XYLINX chips. This is necessary now because of the special challenges associated with triggering for both heavy ion interactions with many low momentum particles and for high transverse momentum events. Continued research on both the front-end and trigger electronics is expected to occur next fiscal year.

There have been some discussions with members of the trigger and other subsystem groups about the implementation of the level-0 trigger. The problem is that only approximately 1 μ sec is available to make sums of pulse heights from all 1200 or from individual sets of 4 towers in order to make a trigger to gate the TPC. Various digital and analog concepts to accomplish the summing in the allowed time have been considered, but the help of an electrical engineer is needed to obtain a satisfactory solution. In fact, such help will be essential next fiscal year to address a range of integration issues.

C) Barrel EMC Design

A number of conceptual designs for the construction of the barrel electromagnetic calorimeter were seriously considered. The first design involved stacked lead plates with aluminum I-beam spacers under compression. The spacers were to prevent significant loading on the scintillator plates. Friction between the spacers and lead plates was used to provide structural integrity to the EMC modules. Initially, projective "towers" were assumed, so that the spacers were located in depth along a line pointing toward the center of the STAR detector. However, a finite element analysis of this design suggested stresses of $\geq 3,000$ psi in the lead, whereas negligible creep in the lead over a period of ~ 20 years would require the stresses to be $\leq 1,000$ psi. The calculated stresses are shown in Fig. 11. The deformation, due to the creep, could lead to a reduction in the compressive loads and a failure of the module assembly. Consideration of various lead alloys, nonprojective towers with spacers all located at fixed z , and cladding of the lead with 0.020" stainless steel sheet did not solve this creep problem. Therefore, this design was rejected.

A second design involved casting the lead with slots for the scintillator plates. Internal reinforcing plates and tubes were found necessary in the design of a similar calorimeter for the SDC detector planned for the SSC. An independent cost analysis by ANL engineers for this design option indicated that it was significantly more expensive than the stacked option above. A sizable cost was related to the molds. Construction costs were high because of the tight tolerances on many of the mold parts, especially for the plates used to make the scintillator slots. Large effort would be needed to remove, clean, and reinstall many of the mold parts after a casting. There was also concern that there might be expensive checks for warping of the plates needed after every casting. Tests of plate warpage with various aluminum and stainless steel plates heated to casting temperatures indicated that this might be a significant problem; see Ref. 5 (STAR Note #118, attached). The uncertainties of how often a mold could be reused, and the high costs noted above, ruled out this design option.

A third design also consisted of lead plates and scintillator in a stacked arrangement held together by compressive loads. In this instance, however, the size of the compressive load is the same, but the pressure is reduced by eliminating the I-beam spacers and stacking the lead and scintillator on top of one another. The effective surface area between sampling layers is greatly increased in this design, reducing the pressure required for module stability. Experience with similar designs at CDF and UA1 has been favorable. This option has not been eliminated, but concern over the long-term response of scintillator under pressure and the possibility that the success of this design might be specific to a particular batch or type of scintillator has prompted the investigation of other designs as well.

The adopted design utilizes the 20 mm front and 30 mm back plates described above, end plates of 3 mm stainless steel, a central 6 mm thick stainless steel bulkhead at $| \eta | \sim 0.5$, and 0.5 mm aluminum or stainless steel side sheets to support the gravitational load of the module. In this design (see Fig. 12), the lead absorber sheets are half the full module length and are captured by fixtures at the ends and middle of the module. This design eliminates the need for high compressive forces. Aluminum I-beam spacers may be used to prevent the lead from contacting the scintillator. Alternately, the 3-4 psi pressure from the gravitational load on the scintillator from the lead (without spacers) is not expected to cause significant long-term changes in the EMC response. Finite element calculations of this mechanical design gave acceptable deflections and stresses in all parts of the

module for all module orientations studied. The side sheets were found to be essential for structural integrity of the modules located near 12 o'clock.

More refined finite element models of the barrel calorimeter modules are planned, in order to look in detail at the loading at the ends and central bulkhead due to the lead. However, it is planned to construct a full size engineering model of a module to verify these calculations. Lead sheets with masonite plates instead of scintillator may be used to simulate the loads. Drawings are being prepared for machining the parts of the model. It should be completed early next fiscal year, after which testing will begin.

The design of the ways was studied with finite element calculations. A variety of cross sectional shapes were tried; stresses and module deflections were low in all cases studied (see Fig. 2). Recently commercial systems are being investigated for the ways. These systems may be much cheaper than the present conceptual design. However, the rods which form the ways and the bearings are constructed of magnetic stainless steel. The use of nonmagnetic materials is being discussed with the manufacturer.

Some preliminary work has been performed on the design of the magnetic shielding boxes for the barrel EMC photomultipliers. The arrangement of the photomultipliers, the routing of the fibers, and the location of the electronics were all studied. Interference is expected with supports at the bottom of the STAR detector, with water and power connections to the solenoidal magnet at the 3 and 9 o'clock positions, and with the door between the Wide Angle Hall and the assembly building at the top. The location of power supplies for the EMC electronics has also been discussed with the integration group. More work is clearly needed in these areas.

The method of coupling the light from the 4 mm thick scintillators to the wave length shifting (WLS) fibers was studied during FY1993. Machining a groove into the face of the scintillator, and inserting or gluing the fiber into the groove has been shown to work acceptably, but is labor intensive and expensive. The present conceptual design for the coupling involves constraining the WLS fibers to lie along the edge of the scintillator by wrapping them tightly in aluminized mylar, which acts as a concentrating reflector. Using this technique last fiscal year, the light output from a 3 mm thick piece of BC-408 PVT scintillator coupled to 50 cm of WLS fiber, which in turn was spliced onto 3 m of clear fiber, was measured to be 2 photoelectrons per minimum ionizing particle (mip). This result, obtained using a Hamamatsu R580 photomultiplier, is adequate to meet the design goal for the EMC energy resolution, and was the basis for adopting this conceptual design.

During FY1993, similar tests were performed with 4 mm thick SCSN-38 polystyrene scintillator; only 1.3 photoelectrons per mip were seen. While this is better than the ZEUS calorimeter, it is desired to do better. A number of different edge coupling techniques have been tried to get more light to the photomultipliers without having to resort to machining grooves. The tests done with no glue have not shown any real improvement, and the tests with glue are not yet complete. One basic problem is that polystyrene scintillator, though cheaper, puts out less light than PVT scintillator. There may also be different doping levels of wave shifter in different batches of scintillator.

For example, the measurement above used 1 mm diameter fibers. WLS fibers of 1, 1.5, and 2 mm diameter were tested with a 4 mm scintillator in the same manner as above. Some tests indicated little change in the number of photoelectrons ($\leq 20\%$), while others gave sizable changes; further study is needed. In other studies, there was only a modest increase in light collection with two 1 mm fibers placed side by side. A single 1 mm diameter fiber is assumed in the present conceptual design because of lower cost, and more importantly, better mechanical flexibility for routing.

Studies have been begun of the light coupling for the end cap scintillators with two straight grooves in the scintillator faces. The different geometry for the endcap requires such grooves in order to minimize the gap between adjacent towers.

The preparation of the scintillator edges is known to have a large influence on the light collection efficiency, and thus the EMC energy resolution. Traditional cut and polish techniques work well, but are very labor intensive. An alternate method using a milling machine equipped with a diamond cutting tool was tested and shown to give essentially the same light collection for far less fabrication time (see Ref. 4). It is presently envisioned that the diamond mill will be used for preparing the scintillator edges.

Some tests of the effects of heat on the clear fibers have been performed, since they must pass between the magnet coils. The tests were done in a temperature controlled oven, with the fibers coiled in a $1.5'' = 3.8$ cm radius. The light transmission for the clear fibers showed no change with heating to 120° F for two weeks. Such temperatures may occur in the magnet during summer runs if no chiller for the magnet cooling water is available. Similar tests with the WLS fibers were somewhat ambiguous, and a more controlled test is being performed.

A small prototype EMC test module is under construction. The goal is to test the performance for low energy hadrons, electrons, and photons for heavy ion mea-

surements with the electromagnetic calorimeter. Most of the parts have been purchased, but a support still needs to be built. This prototype has the full barrel EMC thickness, and is equivalent to $\Delta\eta = 0.2$ and $\Delta\phi = 0.2$ (two barrel EMC modules in width). Provision is being made to install both types of shower maximum detectors. Tests in accelerator beams are planned for next year.

D) Shower Maximum Detector Design

Though RHIC/STAR R&D funding was approved for the design of the shower maximum detector, it proved to be impossible to get these funds to the IHEP Protvino collaborators. Nevertheless, significant results were obtained. A test scintillator strip shower maximum detector was constructed and tested with radioactive sources and accelerator beams. The test results are described in Refs. 6-9 (enclosed). A serious concern had been whether sufficient numbers of photoelectrons would be observed in the photomultipliers from the passage of minimum ionizing particles through the thin scintillator strips. This concern arose because of the attenuation of the scintillator light in the small diameter optical fibers (1 mm) and the relatively low photoefficiency of the available photomultipliers. The tests indicated slightly less than 2.0 photoelectrons per mip, a value which should give reasonably good performance for the shower maximum detector constructed of scintillator strips.

Another concern had been whether adequate space was available on the outside of the magnet flux return bars for all the photomultipliers from the barrel EMC towers and shower maximum detector strips. A method for mounting all the photomultipliers was found that did not have excessive fiber lengths. However, a similar method will not work for the endcap EMC because of the smaller area available. Routing of the many fibers from the scintillator strips (see Fig. 13) was also solved with a minimum impact on the gap between adjacent modules.

An alternate design for the shower maximum detector consists of wire chambers with pad readout similar to the one built for CDF (Ref. 10); see Figs. 14 and 15. Advantages of this scheme include the possibility to use slightly modified TPC electronics for readout, saving a considerable amount of money and/or allowing more independent readout channels. A possible disadvantage is the longer pulse lengths from such counters, which could affect the detector response at the highest RHIC luminosities. It is planned to construct a test chamber with this alternate design next fiscal year. Both types of shower maximum detector are expected to be tested

in the small EMC prototype with accelerator beams at the BNL AGS, MSU cyclotron, and elsewhere.

Additional work is also required on modifying the TPC electronics, routing of readout cables or fibers, and performing cost estimates. A decision between the two types of shower maximum detector is expected next fiscal year.

E) Endcap EMC Design

Details of the conceptual design for the endcap EMC are presented in Ref. 3 (STAR Note #120, attached). Two 180° sections form each endcap calorimeter, as shown in Fig. 16. There are 25 layers of 5 mm thick lead sheets and 26 scintillator planes in depth. Extruded aluminum "Z" spacers are planned between lead layers. A front and back plate for structural strength, a shower maximum detector, plus additional structural elements near $|\eta| = 1.1$ and 2.0, complete each endcap section. These EMC sections are to be mounted to the magnet pole tips with non-magnetic stainless steel blocks bolted to the pole face. It was concluded that mechanical problems with the endcap EMC design were significantly less severe than for the barrel EMC. An improved cost estimate, a conceptual design for the location and shielding of the photomultipliers, and some additional optical tests remain to be done next fiscal year.

F) Simulations

A variety of physics simulations for both A + A and polarized p + p interactions in the STAR EMC have been performed during FY1993. The best summaries of some of these studies are given in the NSF proposal/ EMC conceptual design report and in the update to the RHIC spin proposal (R5) to the BNL Program Advisory Committee (PAC). A sample of these simulations is described below.

The sensitivity of the STAR EMC to events with unusual isospin abundances was estimated. Ten normal Au + Au events with 100 GeV/c per nucleon beams were generated and the response of the full STAR detector simulated with GEANT. The same events were then modified by changing 50% of the π^0 mesons to $\pi^\pm$ mesons, without changing momenta or energies, and the STAR response again computed. The results are displayed in Fig. 17, where a clear separation of the two types of events is observed. A similar sensitivity can be observed for events in which the mean transverse momentum per particle is substantially less than normal. These results demonstrate some of the capabilities of the EMC for triggering on interesting heavy ion events.

Simulations also assisted in the detailed EMC design. For example, projective towers have been assumed in the barrel EMC conceptual design. However, when it was concluded that the compressed, stacked lead and spacer option would not work, the behavior of the EMC with "z" or nonprojective towers in η was simulated. A small degradation of performance was found. The response of such a calorimeter with equal Δz and equal $\Delta \eta$ nonprojective towers was also studied, and little difference noted in performance.

Simulations of high transverse momentum processes in pp interactions for spin measurements have occurred. Earlier work on inclusive direct photon production has been extended to show that isolation cuts to remove Bremsstrahlung processes have little effect on the observed cross sections. Backgrounds for high dilepton mass inclusive Drell-Yan production have also been studied, and shown to be small for masses above about 10 GeV. Simulations of inclusive W and Z production have been begun and will continue for the Fall BNL PAC meeting, at which an update to the R5 proposal will be presented. These high momentum processes are all very important to study various spin distributions in the proton.

G) Conclusions

A wide range of issues in the design of an electromagnetic calorimeter for STAR have been addressed during FY1993. A viable method for constructing both the barrel and the endcap EMC has been found. There has been progress in designing a common photomultiplier base for the CTB, EMC, and TOF subsystems, and in developing a trigger for STAR using signals from the EMC. Much effort has been devoted to developing consistent designs for the solenoidal magnet and EMC supports that meet stringent criteria from both subsystems. Important first steps were taken for the design of a shower maximum detector needed for measurements of inclusive direct-photon production and of gluon distributions in nuclei and protons. Finally, simulations of detector performance and physics processes have been very helpful in guiding the EMC design.

The wide range of problems studied and issues addressed during this past fiscal year is partially the result of requests from other STAR subsystems and the integration group. For example, work on the EMC support rings, barrel module installation fixture, photomultiplier base, thermal calculations relating to heating from the magnet coils, decisions on space needed for the barrel EMC, etc. all fall in this category. These tasks all took priority over the barrel calorimeter design activities when they arose. Furthermore, there was considerable effort devoted to the

writing of the EMC conceptual design report, as part of a National Science Foundation (NSF) funding proposal for the construction of the EMC. Several other technical reports on the work of the STAR EMC collaborators have also been written and are attached to this progress report. The return on the investments from RHIC/STAR R&D and ANL-HEP Division funds has certainly been very high.

Much important integration and conceptual design work remains for the future. In particular, the electronics and mechanical engineering will be very important to have the EMC designs for the trigger, photomultiplier base, and shower maximum detector electronics and for the EMC supports and photomultiplier boxes consistent with the other STAR subsystems. Decisions on shower maximum detector technology and work to obtain funding for the EMC will also be very high priority.

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Figure Captions

- Figure 1 Space available in the STAR detector for the electromagnetic calorimeter and associated electronics. The barrel and endcap sections can be seen.
- Figure 2 Stresses computed in a finite element model of a possible design for a way and strongback to mount the EMC modules. These stresses are reasonably low for stainless steel.
- Figure 3 Sketches of the STAR detector showing the TPC support brackets and regions of the EMC that must be modified; a) side view, b) end view. Eight modules ($\Delta\eta = 1.0$, $\Delta\phi = 0.1$) plus the endcap sections are affected.
- Figure 4 A conceptual design for an installation fixture for the barrel EMC modules. This design was required in order to determine whether there would be adequate space in the assembly building for the installation and whether the planned crane coverage was sufficient.
- Figure 5 Photograph of 1 mm diameter plastic optical fibers in plastic "shrink tubing." The fiber had very poor optical quality from the manufacturer, and was obtained free from Fermilab.
- Figure 6 Photograph of a fixture to test the minimum bending radius required on the EMC support rings in order to route the fiber bundles to the outside of the STAR detector to the EMC photomultipliers.
- Figure 7 Diagram of the cross sectional view through the solenoidal magnet coils and the EMC support rings. The location of the magnet flux return (backleg) bars, the iron end ring, and the magnet pole tip are also shown.

- Figure 8 Sketch of a preliminary design for a 60° section of the EMC support ring. Six such sections will be machined and pinned into a complete ring.
- Figure 9
- a. Sketch of a section of the EMC support ring, ways, and magnet flux return bars near the 6 or 12 o'clock positions. A conceptual design for tie rods from the outside of the bars to the EMC support ring is also shown.
 - b. Sketch of the full EMC support ring, EMC modules, ways, and magnet flux return bars.
- Figure 10 A possible circuit design for a photomultiplier base which generates the required high voltages from a low D.C. voltage. No magnetic materials are present in this design, allowing its use for CTB and TOF, as well as EMC photomultipliers.
- Figure 11 Stresses computed in a finite element model of lead plates with stainless steel cladding and rectangular aluminum spacers in compression. The calculated maximum stress in the lead was > 3,000 psi, which would be expected to suffer significant creep during the lifetime of STAR.
- Figure 12 A simplified sketch of the structural elements in the present conceptual design for the barrel electromagnetic calorimeter. Thin side sheets are also necessary, but are shown removed so that the central bulkhead and one end are visible.
- Figure 13 Fiber routing scheme for the barrel EMC scintillator strip shower maximum detector. These strips are 1 cm wide, and are only half the width of an EMC module. A similar set, offset in depth, covers the other half of the module width.
- Figure 14 Conceptual design for a wire chamber/strip detector for shower maximum in the endcap EMC. For the barrel, the wires are parallel to the beam and the pads extend in ϕ over the full module width.

- Figure 15 Conceptual design for the aluminum extrusion and wire supports for a wire chamber shower maximum detector similar to CDF.
- Figure 16 Sketch of a conceptual design for a 180° section of the endcap EMC. Structural elements include a front plate (not shown), back plate, bulkheads and ends every 30° in ϕ , and inner and outer radial supports. Fibers and scintillators are shown in one 30° section.
- Figure 17 Results of a simulation using Au + Au interactions at RHIC. The energy deposited in the EMC and the multiplicity measured in the central trigger barrel can be used to identify events with unusual ratios of numbers of π^0 to $\pi^\pm$ mesons per event.

(me7/caylor/STAR-env/EMC 20-July-93)

LAWRENCE BERKELEY LABORATORY									
PROJECT: STAR-ENV/EMC									
SUBJECT: MAGNET POLE TIP									
DRAWN: J. CAYLOR									
CHECKED: J. CAYLOR									
DATE: 20-JULY-93									
SCALE: 1/4" = 1'-0"									
SHEET: 23FXXX48									
REVISIONS:									
NO.	DATE	DESCRIPTION	BY	CHKD	APP'D	DATE	NO.	DATE	DESCRIPTION
1	20-JUL-93	INITIAL DESIGN	J. CAYLOR				1	20-JUL-93	INITIAL DESIGN
2	20-JUL-93	REVISION	J. CAYLOR				2	20-JUL-93	REVISION
3	20-JUL-93	REVISION	J. CAYLOR				3	20-JUL-93	REVISION
4	20-JUL-93	REVISION	J. CAYLOR				4	20-JUL-93	REVISION
5	20-JUL-93	REVISION	J. CAYLOR				5	20-JUL-93	REVISION
6	20-JUL-93	REVISION	J. CAYLOR				6	20-JUL-93	REVISION
7	20-JUL-93	REVISION	J. CAYLOR				7	20-JUL-93	REVISION
8	20-JUL-93	REVISION	J. CAYLOR				8	20-JUL-93	REVISION
9	20-JUL-93	REVISION	J. CAYLOR				9	20-JUL-93	REVISION
10	20-JUL-93	REVISION	J. CAYLOR				10	20-JUL-93	REVISION

Figure 1

7271.54
6521.29
5771.04
5020.80
4270.55
3520.30
2770.05
2019.80
1269.55
519.302
-230.94
-981.19
-1731.4

SUIEWH (386) 3.18 File:hepmad4b 92/10/16 LC 1/ 1 Vu= 7 Lo= 45 La= 45 R= 0

Figure 3a

Figure 3b

STAR BARREL EMC INSTALLATION FIXTURE

6-4-93 E.B.

Figure 4

Figure 5

Figure 6

54 REQ'D.
MACHINE FROM ALUM. CASTING (SKETCH HEP0040)

Figure 8

Figure 9a

Figure 9b

Figure 10

GET VAL
Var out

[Esc]

Help Undo
Inp Snap
Cur Swtc
Big Menu
Top Draw

Other method = Minimum Principal Stress

Click on node to get display value at that node.

NODE #5018: X=0, Y=95.3806, Z=-0.7565: Val=-17978.4

SVIEW 4.00 File:leadbm8 92/12/23 12:17 EC 1/ 1 Vu=5.1e+001a= 0.0

SIMPLIFIED PROJECTIVE TOWER CONCEPT FOR THE
BARREL ELECTROMAGNETIC CALORIMETER

-31-

VIEW WITH SIDE SHEETS REMOVED
NO LEAD OR SCINTILLATOR SHOWN

Figure 12

Figure 13

WIRE CHAMBER SECTION

Figure 15

Figure 16

Figure 17

**DATE
FILMED**

11 / 18 / 93

END