LEPTON DETECTOR WORKSHOP SUMMARY

MASTER

R. Imlay

Rutgers University

S. Iwata

Nagoya University

S. Jacobs

Brandeis University

R. Kraemer

Carnegie-Mellon University

M. Kreisler

University of Massachusetts, Amherst

K. McDonald

University of Chicago

P. McIntyre

Harvard University

J. Thompson

University of Pittsburgh

A. Walenta

University of Heidelberg

and

I.H. Chiang, M. Sakitt, A. Thorndike, C. Wang, L.L. Wang

Brookhaven National Laboratory

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, warrants, expresses or implied, or assumes any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

I. INTRODUCTION

The study group met from June 7 to 11, 1976, with the dual purpose of reviewing the earlier Lepton Detector report¹ in order to resolve some of the remaining design problems and of considering possible alternatives. Since the role of this group was primarily that of providing a critique of the earlier work, the reader is referred to that earlier paper¹ for the general motivation and design of the detector, and we will here only describe problems that were studied at this

1. R. Burnstein, W.C. Carithers, M. Duong-van, R. Imlay, M. Kreisler, U. Nauenberg, C. Rubbia, L. Sulak, G. Snow, H.H. Williams, E. Paschos, M. Sakitt, C.L. Wang, and L.L. Wang, Proc. 1975 ISABELLE Summer Study, Brookhaven, BNL 20550, p. 9.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

session. The general configuration of the detector is shown in Fig. 1.

During the first day of the study we discussed the old design, which led us to focusing our efforts on the cost estimates and on a more careful look at the inner detector modules. In the original paper there was a fair amount of uncertainty in some of the cost estimates, and we felt an effort should be made to pinpoint where cost seems firm and where a rough guess was made. With regard to inner modules we wanted to examine the rate problem for the closest elements more carefully and to discuss the question whether one should use argon or lead-liquid scintillator calorimeters. As is usually the case, in discussion of these major topics many smaller problems were considered and some of them are also discussed below.

We planned to spend the last day or two on new designs which involved major modifications to the lepton detector. The major motivations for alternative designs were twofold. One was that the original detector looked quite expensive, and a study of the tradeoff of money versus physics had not really been done yet. The second point was that, since the physics region to be explored was totally new ground, one would like to leave as many options open as possible and build a detector that was as flexible as possible. While at times these two points were in conflict, the real question that was asked was whether it would be possible to build a cheaper, more modular structure which could be reassembled in different configurations. Three main alternatives were discussed. The first is a scaled-down version (Section III A) of the original design, which was strongly favored by this study. It appears that one can save an appreciable amount of money with a small decrease in the initial physics scope. The more modular designs (Sections III B, III C) seem quite attractive but not enough time was spent to demonstrate feasibility. They are more in the spirit of a conjecture than a design.

II. COMMENTS ON THE 1975 PLAN

A. Data Collection and Counting Rates in the Liquid Argon Calorimeters

A fundamental limit on the liquid argon calorimeter data collection is the electron mobility ($\sim 5 \text{ mm}/\mu\text{sec}$ at 1 kV/mm). If steel electrodes are rounded, the breakdown voltage is $\geq 10 \text{ kV}$ for a 2 mm gap. Working chambers have been used at $2 \text{ kV}/2 \text{ mm}$ gap with a drift time of 180 nsec/mm or $\sim 0.4 \mu\text{sec}$ time to collect all charge across the gap. The resolving time of the associated circuitry is $\sim 0.6 \mu\text{sec}$, well matched to the collection time.

Based on the acceptance of the calorimeter and scaling from ISR energies and luminosities, we estimated ~ 3 particles/event and ~ 1 event/25 nsec, or an average rate of 1 particle in the detector array/8 nsec (at 10^{33} luminosity). Whether this is a problem for the liquid argon calorimeter depends on the size of the individual elements.

There are six units, each about 1 meter wide by 2 meters long, so the area is about $6 \times 1 \text{ m} \times 2 \text{ m} \sim 12 \text{ m}^2$.

Originally $5 \text{ cm} \times 5 \text{ cm}$ Pb collection plates were proposed. In this case:

$$\begin{array}{lcl} \text{Average counting} & & \\ \text{rate in 1 collec-} & = & \frac{\text{Area of 1 collection plate}}{\text{Area of electron detector}} \times \text{counting rate} \\ \text{tion plate} & & \text{in total detec-} \\ & & \text{tor (all sex-} \\ & & \text{tants)} \end{array}$$

$$= \frac{25 \times 10^{-4} \text{ m}^2}{12 \text{ m}^2} \times \frac{3 \text{ particles/event}}{25 \text{ nsec/sec}}$$

$$= 0.25 \times 10^5 \text{ particles/sec.}$$

Thus the accidental rate in one plate, using a time window of $0.6 \mu\text{sec}$, is 1.5%. However, for complexity and cost reasons (see next section), a configuration of 5 cm by 1 m strips was proposed as an alternative.

The average counting rate in these strips would be 0.5×10^6 particles/sec leading to an accidental rate of $\sim 30\%$.

These accidental rates are quite high. By adding CH_4 to the argon one can reduce, by roughly $1/4$, the collection time in the calorimeter. Then, if one speeds up the associated electronics, which seems feasible, the accidental rate can be significantly reduced. Since one is interested only in high $P_{\perp}$ particles, one should note that most of the rates are from very low momentum particles and can be excluded by raising the electron calorimeter threshold and introducing a $P_{\perp}$ cut-off on the electrons accepted in the trigger. For example, one expects only ~ 2000 π 's with momentum > 5 GeV, even at 10^{33} luminosity in the entire detector, compared with a 10^8 estimated total counting rate. Thus one may wish to raise the electron calorimeter threshold but to protect the calorimeter circuitry against "pile-up" (a number of small pulses faking a large one) by monitoring the pulse shape.

3. Electron Calorimeter: Spatial Resolution vs Cost

Originally collection plates of $5 \text{ cm} \times 5 \text{ cm}$ were proposed for the electron calorimeter. However, collection plates of $5 \text{ cm} \times 5 \text{ cm}$ throughout the electron calorimeter volume would imply

$$\begin{aligned} \frac{\# \text{ channels}}{\text{sampling plane}} &= \frac{\text{Area of total detector presented to particles}}{\text{Area of plate}} \\ &= \frac{12 \text{ m}^2}{25 \times 10^{-4} \text{ m}^2} = 5 \text{ K channels/sampling plane} \end{aligned}$$

If one includes 20-100 sampling planes as was done in the CERN device, the $5 \text{ cm} \times 5 \text{ cm}$ plates quickly give an intolerably large number of channels, both in terms of cost and in terms of the number of words read into a computer record.

Thus a decision was made to consider a system of 5 cm crossed strips rather than 5 cm squares, (60 channels/sextant/sampling plane, or 360 channels/sampling plane) and to gang several sampling planes together so that one would only require electronics readouts for

~ 5 groups of sampling planes. Using such a configuration would reduce the number of channels to ~1800 and the cost for electronics to 1800 channels x \$250/channel or ~ \$450 K.

The number of channels may be reduced still further by careful study of the design of the CERN experiment. In that experiment, a rejection of 200:1 with 85% electron efficiency for 4 GeV electrons was achieved by looking only at the first 6 interaction lengths (separately at the first three and the second three interaction lengths) and, in fact, the entire calorimeter in the CERN experiment (comparable to our proposed electron calorimeter) had only 112 channels. High anticipated counting rates may dictate a higher number of channels in our case, but this point should be reviewed with reference to the CERN design.

G. Other Questions Raised but Not Settled, with Respect to Calorimeters

1. Magnetization of calorimeter plates: This has been suggested either advertently, to get more bending for the muon detector, or inadvertently, as a by-product of placing a magnet in the inner electron-hadron detector space. The question here is: how will the operation of the calorimeter be affected? Have calorimeters actually been operated in magnetic fields?

2. How will the stability and performance of the liquid argon compare in an experimental running situation with the known radiation damage problems of Pb-glass or with a possible BaF₂ - Decalin solution?

3. The original design allocated 30 cm in the radial direction for the electron calorimeter. One needs 30 cm for the lead and argon in order to get the necessary 20 radiation lengths. In the CERN design 20 cm was used for insulation which would lead to a total length of 50 cm. Some compression might be accomplished by more careful study but clearly a little more room is necessary.

D. An Alternative Steel-Liquid Scintillator Hadron Calorimeter

A steel scintillator hadron calorimeter was discussed as a possible alternate to the liquid argon calorimeter previously proposed. The calorimeter is assumed to be 1.4 m thick and to start 1.3 m from the beam line. It has 64 steel plates 1.5 cm thick separated by 0.66 cm gaps filled with liquid scintillator. It weighs 500 to 600 tons (the same as the argon calorimeter). The calorimeter is made up of 336 optical units parallel to the beam line with a phototube at each end of an optical unit. Each phototube observes an area of approximately 32 cm by 17 cm (8 gaps). The lengths of the optical units (from 2.75 m to 5.25 m) are chosen to cover the angular region $\pm 45^\circ$. The units are assumed to be constructed in a fashion similar to existing calorimeters. The only significant difference is that some of the proposed units are very long (5.25 m). It is felt to be better to use these long units rather than introduce phototubes and substantial dead space in the center of the detector.

The position of the energy deposited in an optical unit can be located to a few centimeters using the ratio of the pulse height on the phototubes at the two ends. The sum of the pulse heights at the two ends will give a measurement of the energy deposited after a correction for the position of the energy deposit. For the longest units (5.25 m) it would probably be necessary to make changes to obtain a more uniform response of the summed pulse height to the position of the energy deposited.

Approximate costs are (a) steel (500 tons) \$300 K, (b) scintillator (50 tons) \$100 K, (c) containers, Teflon, assembly \$250 K, (d) 700 phototubes and bases \$70 K.

E. Cost Estimate for 1975 Plan

The largest single element in the detector cost is the muon detector magnet, which has a weight of 5000 tons and a copper coil of 20 tons. We used \$0.30 per pound for cost of magnet iron (with a

minimum of machining) and \$3.00 per pound for the copper coil. This leads to \$3000 K for iron and \$120 K for coil. An estimate of \$100 K was made for the cost of installation, assembly, welding, etc., leading to a total cost of \$3220 K.

In addition, the magnet needs to have dc power and cooling water for a maximum level of 4 MW. If all costs of providing this are included the cost might be as great as \$1000 K, but some fraction of what is needed is included in the general facilities planned for ISABELLE. The incremental cost of the lepton detector may be considerably less, but the \$1000 K sum is included to be conservative.

The cost of the transition radiation unit was taken to be \$215 K as estimated in the summer study.

The cost of hadron and electron calorimeters were estimated on the basis of \$1.25 per pound to include machining plates, supports, providing vacuum systems, etc., for a unit consisting primarily of steel plates, made with moderate precision. The total weight of the hadron calorimeter was taken to be 550 tons and the electron calorimeter 35 tons. The corresponding costs (exclusive of electronics) are then \$1400 K and \$87 K. In addition, a refrigerator would be needed for liquid argon calorimeters. Its cost was estimated (very roughly) at \$40 K. To move these heavy calorimeter units in and out of the magnet structure will require a well-engineered mounting and support system, which has not been designed. To give some rough estimate of its cost, 10% of the calorimeter cost was used, an additional \$150 K.

Electronics for this large calorimeter system add a substantial cost. As described previously, approximately 2600 analog channels were envisaged in order to provide adequate space resolution, 1800 for the electron calorimeter, 800 for the hadron. Estimated cost per channel of \$250 led to a total electronics cost of \$650 K.

Drift chamber costs were taken at \$30 per wire for construction and \$50 per wire for electronics, based on current experience with large drift chambers. About 50 chambers would be required, each 4 m x 4 m in size with 160 wires, for a total of 8000 wires. This leads to a drift chamber construction cost of \$240 K and an electronics cost of \$400 K.

A data-acquisition computer will certainly be needed. It might be possible to use a central facility, but since data rates may be quite high it was thought wise to provide \$200 K for data handling dedicated to the lepton detector.

Cost Summary 1975 Design
(\$ in thousands)

Magnet	3 220
Magnet power supply and cooling system	1 000 (max)
Transition radiation unit	215
Hadron calorimeter units	1 400
Electron calorimeter units	87
Refrigerator for calorimeters	40
Calorimeter supports	150
Calorimeter electronics	650
Drift chamber construction	240
Drift chamber electronics	400
Data handling computer	<u>200</u>
TOTAL	7 600

These estimates are quite rough, but the intention was to put in all major items and to put in amounts that ought to be adequate. No large additional contingency should be needed. The incremental cost for the magnet power supply and cooling, estimated at \$1000 K, due to the lepton detector may be much lower, if these needs are met by general ISABELLE facilities. The overall estimate might be rounded off to \$8 000 000. This does not include any cost escalation to some future time at which it might be built. It does not include the experimental hall and supporting space to house electronics, which are assumed to be provided as ISABELLE facilities.

F. Construction Schedule for 1975 Summer Study Design

The schedule outlined below is aimed at having a useful lepton detector in June 1983, the time scheduled for ISABELLE turn-on in the May 1976 ISABELLE proposal.

<u>Fiscal Years</u>	<u>Activities</u>
1977-78	Prepare proposal for funding with general design and costs.
1979	Design magnet in detail.
1980-81	Finish detector design. Procure main components of magnet. Build first detector elements.
1982	Install magnet, power supply, etc. Test detectors at AGS. Build additional detectors.
1983	Install initial detectors in magnet. Tests with first ISA beam.
1984	Begin research program. Take initial data. Install more complete detectors.

In the ISABELLE proposal all buildings are scheduled to be completed by 1981. This provides adequate time for the magnet to be assembled in its building before ISABELLE operation begins, as in the above schedule. There is not time for much delay, however, and consequently such a plan requires funding for the lepton detector soon after funding for ISABELLE.

G. Space Requirements for 1975 Summer Study Design

The space requirements are set by the needs to get calorimeter modules in and out of the magnet structure. The magnet is hexagonal, so that there would be 12 hadron calorimeter modules if they are divided at the middle and installed through the open end. If the

total weight is 550 tons this gives 47 tons per module. A strong support system will be needed for sliding modules in and out. Outside they can be lifted by crane. A 40-ton crane would limit the module to a smaller size, so a 60-ton crane is preferable.

The magnet extends 5 meters from the central line, and the calorimeter module is about three meters long. For a high-luminosity insertion the free space is ≈ 13 meters, which provides a reasonable amount of extra space except for the need to provide for future "end caps". The consensus was to postpone the design of the end cap till after the initial detector is working since the early physics results may strongly influence the final design.

H. Possibility of Measuring the Di-Muon Continuum -- A Rough Rate Calculation

As part of the 1976 Workshop on the Lepton Detector, we considered the possible experimental program for the detector in addition to discovering the W. This note considers the rough rates for a measurement of the cross section $p + p \rightarrow \ell^+ + \ell^- + X$ as a function of $m_{\ell\ell}$ using the present design of the lepton detector.

We use as a starting point the scaling function $m_{\ell\ell}^3 d\sigma/dm_{\ell\ell}$ vs $s/m_{\ell\ell}^2$ as shown in Fig. 2 (originally Fig. 4, of Ref. 1).

We consider the case of ISABELLE running at $200 \text{ GeV} \times 200 \text{ GeV}$ with a luminosity of 10^{32} . The lepton detector has a minimum muon momentum cutoff of $\approx 8 \text{ GeV}/c$. For practical considerations, this implies a minimum di-muon mass of 20 GeV , corresponding to $s/m^2 = 400$. From Fig. 2, $m^3 d\sigma/dm$ is roughly flat down to $s/m^2 = 40$ and then falls off rapidly. (Since $d\sigma/dm$ decreases as the cube of the mass, we will not consider s/m^2 smaller than 40 in much detail.) $s/m^2 = 40$ implies $m_{\mu\mu} = 65 \text{ GeV}$.

The counting rates assuming $\Delta\phi/4\pi = \frac{1}{2}$ are shown in Fig. 3. We note with some distress that measurements above $m_{\ell\ell} \sim 70 \text{ GeV}$ become

extremely difficult -- even with a detector as massive as the lepton detector.

In order to have 10 events in the highest mass bin ($60 \rightarrow 70$ GeV), how long a run is required? Since the momentum resolution is $\sim 12\%$, $\Delta m/m \sim 15\%$. Thus, the bin size is ~ 10 GeV in mass. The counting rate in this bin is therefore

$$\frac{d\sigma}{dm} \times 10 \text{ GeV} \times \frac{\Delta\Omega}{4\pi} \times \mathcal{L} = 5 \times 10^{-5} . \quad (\text{at } 65 \text{ GeV})$$

Therefore in 2 days, one would expect 10 events. A one-week run would produce ample statistics. We note that at 20 GeV, $\Delta m = 3$ GeV,

$$\frac{d\sigma}{dm} \times 3 \text{ GeV} \times \frac{\Delta\Omega}{4\pi} \times \mathcal{L} = 3 \times 10^{-4} .$$

or approximately 60 events in a 3 GeV bin. This level of statistics would be sufficient to differentiate between the various quark predictions -- we note that the introduction of color reduces the estimate by a factor of 3. Newer data on the scaling function leads one to expect the lower curve, with the reduction of 3 to be more realistic. The possible results of a 2-day run are shown in Fig. 4. It therefore appears quite reasonable to measure the di-muon continuum with the lepton detector.

III. OPTIONS AND NEW IDEAS

A. Reduced Scale Option

1. General Concept

Since the magnet represents a large fraction of the total cost of the initial detector, we considered reducing the size of the inner detector modules so that the magnet could be smaller. In the reduced scale option we propose that the inner detector elements no longer have the capability, in each sector, to identify electrons

and have the full electron and hadron calorimeters. There would be two different types of modules. One would contain the transition radiators and the electron calorimeter and the other would contain only the electron and hadron calorimeters. We can consider an initial experiment comprised of alternating types of modules. In detecting the muonic decay of the W, there is no loss of solid angle in this reduced version compared to the original design, while for the electronic decay we lose a factor of 2. Clearly any μe correlations are also reduced by a factor of 2 in this initial configuration. Depending on the early performance of the detector and the early physics results, one always has the option of changing the modular configuration.

If we were optimistic we could believe the calculations for W production and then ask if we could do physics without any transition radiation modules. Filling all the sectors with an electromagnetic calorimeter followed by the hadronic calorimeter would still give us hadron rejection against electrons of at least 10^2 . Taking the W cross sections literally, we would have a π background of less than 10% in our electron sample, which still allows us to clearly see the W, without any loss of solid angle in comparison to the large-scale detector. Clearly one can fill half the sectors first with calorimeters and make the final decision concerning what goes in the other half after the initial run. Since this is more speculative than our general approach, we will do the cost estimate assuming two different type modules as described previously. The cost estimate using all calorimeters would be about \$400 K more than the estimates that follow.

2. Cost and Space Requirements

The cost of the magnet scales approximately as the volume of the iron, which is estimated to be 62% of the original in the reduced scale design. There is a saving of 38% in both magnet and power

supply, etc. This is $0.38 \times 4220 = \$1600$ K.

Since the transition radiation unit would only occupy three sectors instead of six, a reduction of \$100 K is estimated.

The number of hadron calorimeter modules would also be reduced by a factor of two and the size of each would be reduced. There is a saving in construction, supports, and electronics, totalling \$1300 K. There is, however, no significant reduction in the cost of electron calorimeters.

The drift chambers will be smaller in size, with fewer wires. This will lead to a reduction in cost of about \$200 K, including electronics. These reductions are summarized below:

Cost Reduction with Reduced Scale (\$ in thousands)	
Magnet and power supply	1 600
Transition radiation unit	100
Hadron calorimeter total	1 300
Drift chambers	<u>200</u>
Total Reduction	3 200
Resulting Cost Estimate	4 552

The overall result is to reduce the cost estimate from \$7 752 000 to \$4 552 000. This alternative might, therefore, prove to be an attractive one since it does not rule out any of the kinds of experiments for which the lepton detector would be built.

No detailed consideration was given to the schedule for implementation of a reduced scale design, but it was thought that there would not be any significant change in times required from those of the larger version.

The space requirements would, on the other hand, clearly be less for the reduced scale version. The difference is small enough to be within the uncertainties of the discussions held. There was some feeling that the experimental hall dimensions in the 1976 Proposal would be adequate for the reduced scale design but not for the full scale. If so, the reduced scale would be advantageous for that reason also.

An extra option that was briefly considered for the scaled-down version was an inner toroid magnet creating a field concentration around the beam. This would allow one to determine the sign of the electrons. It would however cut down on the acceptance and raise the cost of the detector. More design work would be necessary before one could decide if this was a feasible option.

B. Alternative Modular Magnet Assembly

The inner detectors were designed in a modular fashion to allow some flexibility for future innovation resulting from both technology advances and the early physics results. An attempt was made with a similar motive to see if one could conceive of the large magnet as being composed of module sections.

1. Hexagonal Configuration

A scheme was envisaged for assembling a hexagonal magnet in two layers with the outside edge 4.2 m from the beam line with blocks of iron with individual windings built into each of the blocks. A sketch of the individual blocks is shown in Fig. 5 and the assembly is shown in Fig. 6. The magnetic circuit goes around the hexagon as in the original design. The unit construction means that it could be enlarged by adding blocks, and additional iron shells could be added with a similar construction.

The outer hexagon has 54 rectangular blocks and 6 corner fillers, while the inner one has 24 and 6. For simplicity in assembly the

END
VIEW

CENTER
SECTION

CORNER
FILLER
END
VIEW

0 0.5 1.0 1.5 2.0 METERS

(a)

top and bottom blocks have no coils. The magnet blocks weigh about 30 tons, so a 40-ton crane should be adequate. Each hexagon is supported by an end frame which is a heavy channel to which the magnet blocks are bolted. The end frame is 8.4 m high, so it would have to be welded together in the building. The supporting framework is shown cross-hatched. The outer hexagon is supported from the floor and the inner hexagon is supported from the outer hexagon. For the bottom half, the outer hexagon is assembled first, then the inner, while for the top half the inner is done first, then the outer.

Bus bar and cooling manifolds mount to the supporting frame in the areas that have magnet windings.

It would seem appropriate to have a pit extending the full width of the building somewhat longer than the detector, but the rest of the building floor could be higher, at a level permitting the drift chambers between magnets to slide in from the ends. This would keep the height of supports and scaffolding reasonable. Trucks could drive in at this level, so no separate loading platform would be needed. The lowest drift chambers would slide under the magnet from the side, in the pit. They come in pieces about 4×4 m, presumably. Probably the total building width should be about 20 m, since the hexagon is about 10 m. The 16-m width in the '76 proposal seems a bit skimpy.

In some cases it might be useful to remove upper magnet blocks to get at the inner detector assembly, which would not be impossible to do.

2. Free Form Magnet Assembly

An alternative way of energizing the iron that avoids the necessity of constructing the full iron magnet at the beginning and also allows new arrangements of the iron at a later time is presented. The iron hexagon is made up of square blocks with a thickness

suitable for lifting with the crane. Blocks stacked together to give the desired thickness, say 1 m, would then be energized as a single toroid, with the magnetic field perpendicular to tracks at large angle to the beam. For example, a 5 m x 5 m block would have a 30-cm hole cut in the center. Each corner would be cut off (0.6 m x 0.6 m x 0.5 area) so as to provide a reasonable approximation to a circle. A coil would run from the center to each corner. The loss of area due to the missing corners and the hole in the center is approximately 3% of the total area. The width of a toroid would be chosen to correspond to one side of the iron hexagon, and thus two toroids side by side would be necessary to give the desired length along the beam. Thus the iron hexagon in the original proposal or any fraction of it could be constructed out of these iron toroids with a loss of coverage of only 3%.

C. Comments on the Central Solenoid Option

The merits of the solenoid magnet have been considered in the 1975 ISABELLE Summer Study.¹ This note concerns 3 potential drawbacks of the solenoid:

- Inferior on-line hadron rejection in the single electron trigger.
- High rates in the magnet chambers at $L = 10^{33}$.
- What to do with the flux return?

1. Hadron Rejection

We consider an on-line hadron rejection of $\sim 10^{-4}$ as a very desirable feature. The lepton detector with no solenoid has hadron rejection factors of 1/400 from the transition radiator sections and at least 1/10 from the calorimeter section. The overall factor of 1/4000 makes an excellent trigger.

As discussed in the 1975 Summer Study, the electron trigger with the solenoid option would rely on the longitudinal shower

development criterion alone, which is a rather loose trigger. Using the CCR formula, and an $e/\pi \sim 10^{-4}$, we have at $L = 10^{33}$ roughly 0.2 direct electrons per sec. A trigger with only 1/100 hadron rejection would give a rate of 20/sec, which is high, although not completely prohibitive. Additional off-line rejection is available by comparing the energy measured in the shower with the momentum measured in the magnet. For example, a requirement that the $E_{\text{shower}}/P_{\text{magnet}}$ be larger than 0.9 provides a hadron rejection of at least 1/60 at 5 GeV.²⁻⁴ While the solenoid's momentum resolution deteriorates with increasing energy, the shower counter improves. A more detailed calculation of the hadron rejection vs energy should be made.

However, the combined on-line and off-line hadron rejection is still not at the 10^{-4} level. Therefore, we consider the possibility of putting transition radiator modules inside the solenoid magnet along with the position measuring drift chambers. Suppose there are only 3 pairs of drift chamber planes, each requiring ~ 5 cm radially. To leave maximum space for transition radiators, we contemplate curved drift chambers, as well as curved TR modules. Then of the ~ 60 cm available inside the magnet, 15 cm are allotted to the drift chambers leaving 45 cm, perhaps 2 short modules, or one long module interrupted by the central drift chamber planes. Further study is clearly needed. Hopefully a hadron rejection of 1/50 to 1/100 could be obtained which would provide a fairly good trigger (10^{-3}) and should certainly give a final rejection of better than 10^{-4} in the off-line analysis.

2. J.S. Beale, F.W. Büsser, L. Camilleri, L. DiLella, G. Gladding, A. Placchi, B.G. Pope, A.M. Smith, B. Smith, J.K. Yoh, E. Zavattini, B.J. Blumenfeld, L.M. Lederman, R.L. Cool, L. Litt, and S.L. Segler, Nucl. Instrum. Methods 117, 501 (1974).
3. W.J. Willis and V. Radeka, Nucl. Instrum. Methods 120, 221 (1974).
4. J.A. Appel, M.H. Bourquin, J. Gaines, D.C. Hom, L.M. Lederman, H.P. Paar, J.-P. Repellin, D.H. Saxon, H.D. Snyder, J.M. Weiss, J.K. Yoh, B.C. Brown, C.N. Brown, J.-M. Gaillard, J.R. Sauer, and T. Yamanouchi, Nucl. Instrum. Methods 127, 495 (1975).

An important feature of an electron trigger is a pulse height measurement directly after the beam pipe to guard against electrons from γ conversions and π^0 Dalitz decays. Presumably this would be achieved with a barrel of narrow scintillators. With a solenoid, these would have long light guides and P.M.'s mounted outside the solenoid end cap. If the bake-out restrictions are met by leaving a gap between the pipe and the innermost detectors, the barrel might be at $R \sim 10$ cm, and so might have ~ 60 1-cm staves.

2. Rates

It is somewhat questionable whether data collected at luminosity 10^{33} in a central track detector can be analyzed. At $L = 10^{33}$ the interaction rate is

$$10^{33} \times 40 \text{ mb} = 4 \times 10^7 \text{ (25 nsec/event)}$$

assuming no rise in total cross section from ISR energies. Supposing the multiplicity on the central rapidity plateau is $dN/dy \sim 1.5$, there will be ~ 3 particles/event in the lepton detector ($\Delta y = 2$ for $\pm 45^\circ$). We consider the innermost drift chamber, located at $R = 10$ cm. Suppose we use 100 cells, so that the cell length is only ± 3 mm. The drift time is then ~ 75 nsec (assuming 200 nsec/cm). During this 75 nsec, on the average 3 additional beam-beam interactions occur, yielding 9 additional tracks in the detector.

These background tracks can be largely eliminated if the pairs of drift chambers are offset $\frac{1}{2}$ cell (needed for left-right ambiguity resolution in any case) by noting the sum of the transit times for a track in the 2 struck cells. For in-time events the sum is 75 nsec, while for out-of-time events it is less. Timing accuracies of ± 5 nsec could then eliminate $\sim 90\%$ of the background events. This rejection is somewhat less for low-momentum tracks which strike the chambers at an angle.

However, if a cell contains two tracks, the timing trick of background rejection fails, and the data is lost. With 9 background tracks, the probability of any cell containing one is 9/100. The failure probability is actually 3 times this probability, so the chance of failure is $\sim 27\%$ per real track. Thus a system of ± 3 mm cells, requiring 1500 cells in all, would still be subject to a 30% reconstruction failure. This conclusion may be a bit gloomy, but undoubtedly merits further thought.

Note that the transition radiator MWPC's, with 1 mm spacing, are not subject to so much trouble as extra hadron tracks do not destroy the electron signal unless they fall within one pulse-height-analyzed subunit. This should be only a few percent at $L = 10^{33}$, due to overlaps in the scintillator barrel.

3. Flux Return

The flux return scheme presented in the 1975 Summer Study may be the best.

Assuming a solenoid radius of 0.75 m, the total area of the field is 1.8 m^2 . If the field is 10 kG, and the flux in the iron is also taken to be 10 kG, the iron must have a cross section of 1.8 m^2 everywhere. For example, if the return path is a hexagonal shell at $R = 2.5$ m (after the hadron calorimeter) its thickness must be 10 cm. If the flux is carried from the solenoid to the shell at $R = 2.5$ by a disc end cap, the cap must be thicker at the center to maintain constant 1.8 m^2 cross section. In particular, at $R = 0.75$, $1.8 = 2\pi (0.75) T$ or $T = 38$ cm. Each end cap would weigh approximately 32 tons which would have to be easily movable to obtain access to the inner detector elements -- an interesting engineering problem. A view of this configuration is shown in Fig. 7.

Recall that the direction of the magnetic field in the flux return is perpendicular to that in the outer muon magnet. If the hadron calorimeter is to have magnetized iron (same direction as the

muon magnet), it may be best to have the flux return entirely separate from the calorimeter, a loss of 10 cm for active elements of the detector.

We consider some alternative configurations that might allow the end cap to remain in place except for access inside the solenoid itself. This might be obtained by dedicating a certain fraction of the azimuth of the outer detector to the flux return.

In the region of the electron calorimeter R goes from 0.8 to 1.3 meters. The azimuth needed is given by:

$$A = \phi \frac{(R_{\max}^2 - R_{\min}^2)}{2} = 1.8 \text{ m}^2$$

$$\phi = 3.6 \text{ radians} = 200^\circ .$$

This seems excessive, corresponding to an end view shown in Fig. 8a.

In the region of the hadron calorimeter R goes from 1.3 to 2.7 m. This time $\phi = 40^\circ$ which is not too implausible. One can contemplate the two configurations shown in Figs. 8b and 8c. However, the thin flux return in one dimension must be compensated by a large other dimension to keep the total cross section 1.8 m^2 . So instead of 38 cm, the end cap must be $38 \cdot 360^\circ / 40^\circ = \underline{3.4 \text{ m}}$, and a side view is shown in Fig. 8d.

IV. CONCLUSIONS AND FUTURE PLANS

A. Size of Detector

The smaller version of the lepton detector system was preferred because it would be significantly lower in cost and easier to build and its capabilities for muon detection were the same as those of the larger size. Electron and hadron energies can be measured as well as with the larger detector, the only sacrifice being in the solid angle for electron

(a)

(b)

(c)

and hadron detection when they are to be done at the same time. The solid angle is still a large one and seemed satisfactory for an extensive program of experiments.

For the present, therefore, further work on the design of the detector and experiments using it should be done with the smaller version.

B. End Caps

The detection of small-angle particles by means of end caps should be left to a later phase of the experimental program. Initially, the lepton detector would concentrate on particles of high $P_{\perp}$ and relatively large angle, without attempting to observe all secondary particles or achieve overall energy or momentum balance. Design of end caps to accomplish this might eventually be undertaken, but only after a first round of experiments in which the lepton detector would cover angles within $\pm 45^{\circ}$ of the 90° direction, and initial information on small-angle particles would come from experiments at other insertions with equipment designed for that purpose.

C. Cost Estimates

The cost estimates made during the workshop are very rough ones and may be substantially different from the final cost of an operational system. To arrive at more accurate cost estimates a conceptual design for the major components needs to be worked out in engineering terms and costs derived from it. A definite estimate should be possible for the magnet, which is the most expensive item, since it is of conventional construction though unusual configuration. For the detector modules the uncertainties would be somewhat larger, but estimates could be prepared that would be adequate for a proposal for funding. This should be done in the near future.

D. Feasibility of New Ideas

Two ideas were put forward that involve qualitative changes in design: the self-contained magnet blocks for the muon analyzing magnet, and the toroidal interior magnet for analysis of electrons and hadrons. The duration of the workshop was not adequate for a careful evaluation

of these ideas, so this needs to be done from two viewpoints. In the first place, do these ideas have real advantages from the high energy physics viewpoint; do they make better measurements or better experiments possible? In the second place, are they practical from an engineering viewpoint; would they be cost-effective to build and operate, and reliable and convenient in operation?

E. Need for a Working Design Group

A working design group is needed to prepare a proposal for the construction of a lepton detector system during the next 18 months. If a definite design and proposal are needed by the spring of 1978, this could be done in two phases, with an evaluation of the new ideas for magnet construction and design of the detector system carried out by summer of 1977, including reliable cost estimates. At that time a further workshop or summer study could review this information, and arrive at a decision concerning which ideas, if any, to incorporate, and resolve further questions concerning the conceptual design. Using this further input, the working group would determine further details and prepare a proposal for submission the following spring.

To do this would require a major fraction of the time of a mechanical engineer with design and drafting support, and part-time participation of physicists familiar with the types of detectors used (drift chambers, Li transition detectors, liquid argon calorimeters) and also superconducting magnets. In addition, the design must be compatible with the details of ISABELLE insertion and experimental hall, and members of the high energy physics community interested in lepton physics at ISABELLE should be kept informed of the progress of the working group.

In conclusion, there is a substantial amount of work that still has to be done on the preliminary design. Considering the various options and alternatives that have been discussed, a possible artist's conception of the detector is shown in Fig. 9.

FIGURE CAPTIONS

- Fig. 1. A schematic drawing of the ISA Summer Study 1975 Design for a Lepton Detector.
- Fig. 2. The scaling function integrated over the entire range of Y.
(From ISA Summer Study 1975.)
- Fig. 3. Counting rates as a function of mass.
- Fig. 4. Results for a two-day run.
- Fig. 5. Sketch of an individual block used in the hexagonal assembly.
- Fig. 6. Assembly for hexagonal magnet using module blocks.
- Fig. 7. Return flux for central solenoid option.
- Fig. 8. Some alternative approaches to the return flux problem for the central solenoid option.
- Fig. 9. This could be considered an artist's conception of our Lepton Detector. We thank the Escher Foundation, Haags Gemeentemuseum, The Hague, for permission to copy the work "Verbum" by M.C. Escher.