PART 6

SPECIAL EXPERIMENTAL CONFIGURATIONS

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A Lepton Detector Facility for ISABELLE*

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We propose a lepton detector facility based around a 4 tesla superconducting solenoid magnet. The large field permits accurate momentum measurements in a small volume, and also suppresses high particle fluxes by trapping low momentum particles near the beam. For muon detection, hadron filters are added at the axis of, and outside the magnet. A resolution of 1.5% at 50 GeV/c momentum can be attained. With the addition of calorimeter modules the detector would be a powerful tool for the study of hadron jets.

INTRODUCTION

One of the most exciting prospects at ISABELLE is the search for the very massive particles expected in our current views of the fundamental interactions. Although undiscovered, these particles have well established names: for instance $W^{\pm}$, the intermediate vector boson,[1] and Z^0, the weak neutral current mediator,[2] and Φ^0, the Higgs scalar particle.[3] Other exotic possibilities include heavy leptons,[4] and hadrons containing new flavors of quarks (tastefully called top and bottom).[5]

At a machine where the search can be made only by examining the products of proton-proton collisions the best chance of detecting heavy particles is via their leptonic decays. This is, of course, because prompt leptons are rarely produced in p-p collisions, so the detection of one is a good indication of an unusual event. The $W^{\pm}$ particles would decay into one charged lepton and a neutrino, the Z^0, Φ^0 and heavy $q\bar{q}$ hadrons decay into lepton pairs, while pairs of heavy leptons would decay to pairs of ordinary leptons, or even quartets in the case of recently predicted doubly charged heavy leptons (heptons).[6]

The signal of leptons in p-p collisions is not free from backgrounds. Mesons may decay to leptons, and electromagnetic processes such as the Drell-Yan mechanism yield lepton pairs. These effects generate a smooth spectrum of transverse momenta for single leptons, and also of invariant mass in the case of lepton pairs. Hence the ability of an experiment to detect the exotic lepton signal will depend not only on its sensitivity to minute cross sections but also on the resolution of signal from background. This is illustrated in Figure 1.

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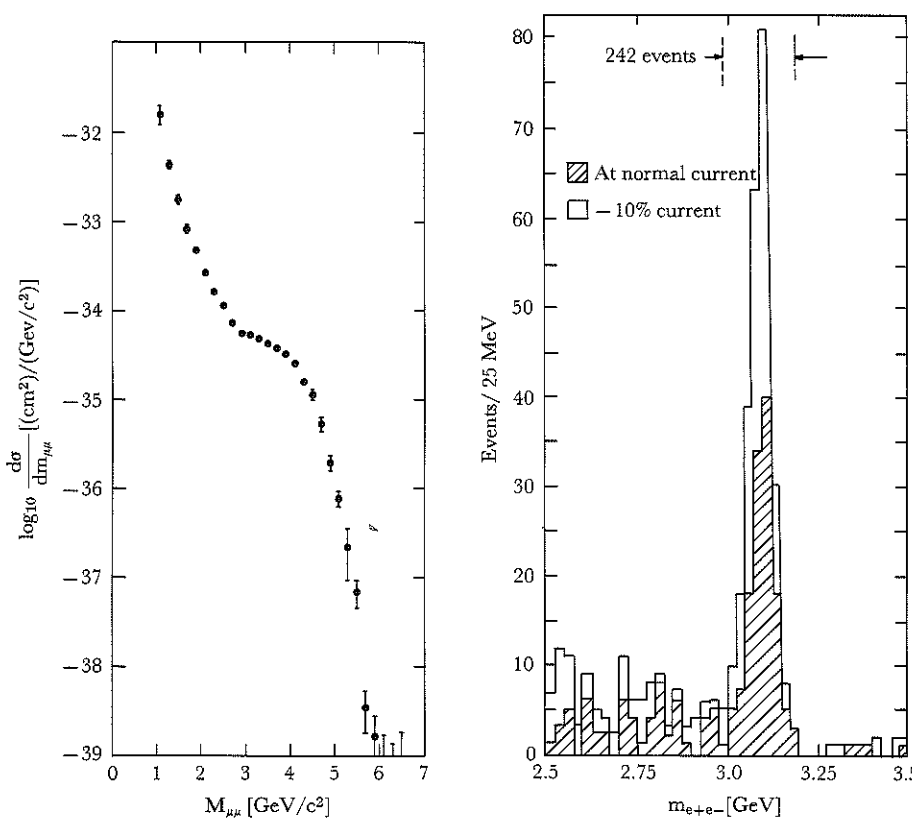


Figure 1. The effect of good resolution. Left: $pU \to \mu\mu X$, Right: $pBe \to eeX$ [7,8]

At intersecting storage rings, where the same luminosity is available to all experiments, sensitivity is achieved with a detector of large solid angle. Good signal/noise characteristics are obtained primarily through precise measurement of the particles' momenta. Less precision is required in measurement of the production angle, as even a rough determination suffices for single leptons; for pairs the opening angles are between 90° and 180° since the laboratory is also the center-of-mass frame.

This note sketches a large detector which attempts to combine maximum solid angle coverage with good momentum resolution and would be able to operate at the highest beam intensities forseen at ISABELLE. The central feature of the detector is a 40 kG superconducting solenoid magnet with axis along the beam direction (see Figure 2). The field is so large that low transverse momentum particles (the vast majority) are trapped inside cylinders of small radii. Only high transverse momentum (P_T) particles reach the outer region of the detector. This allows the momentum of the high P_T particles to be measured in an air core magnet rather than in an iron magnet, yielding much superior momentum resolution. The scale of the magnet is

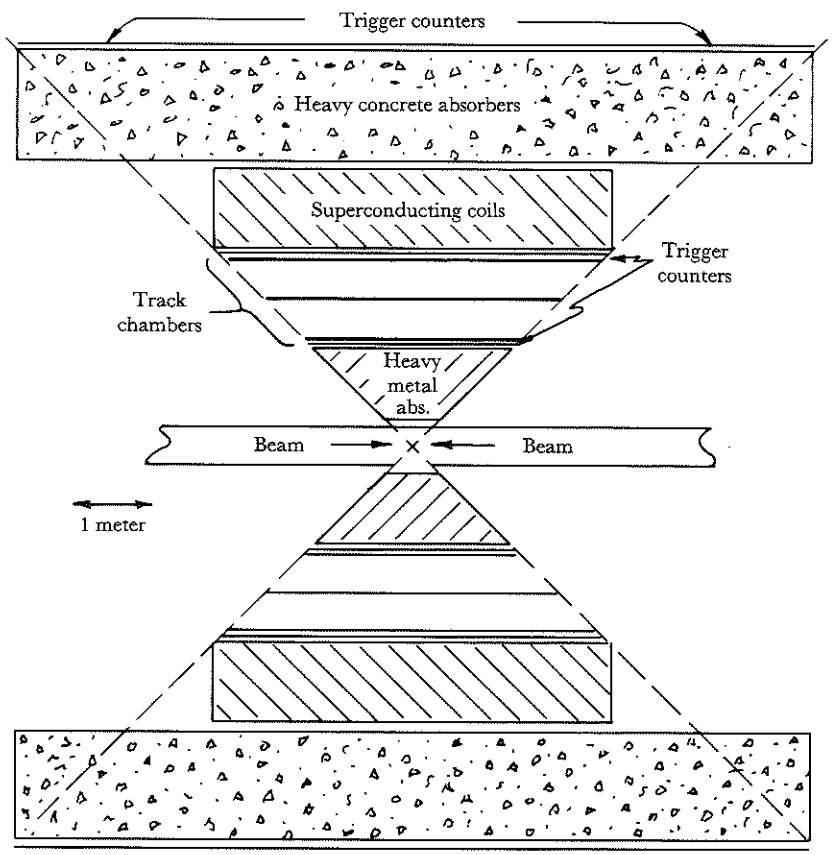


Figure 2. A cross section of the lepton detector.

very similar to that of the large bubble chamber magnets at Fermilab (15′) and CERN (BEBC).

Details of the detector indicated in Figure 2 include an optional heavy metal hadron filter close to the beam pipe, track chambers and trigger counters at larger radii inside the field, and a hadron filter and trigger counters surrounding the magnet.

This detector is principally designed to observe muons rather than electrons. Only for detecting pairs of heavy leptons, where $\mu^{\pm}e^{\mp}$ events would be the clearest signature, is this a significant restriction. If the hadron filter close to the beams were not used the detector would be an excellent analyzer of charged hadrons. Even without the filter the trapping of the low P_T hadrons allows the detector to be exposed to the highest available luminosity. With the addition of a suitable trigger it would have great capability for investigation of hadron jets, and hence quark-quark scattering. The simplicity and openness of the detector leave great flexibility for adding new elments as the physics interest evolves.

In the following sections we give more details on possible signals, the configuration of the detector, resolution, muon triggers, and suitability for other than muon physics. Finally, we present a rough cost estimate, and consider an option using the existing BNL 7 foot bubble chamber magnet.

PHYSICS OF THE SIGNAL AND BACKGROUNDS

Estimates of the $W^{\pm}$ and Z^0 Signals

In considering the possible cross sections for production of the weak interaction mediating particles, $W^{\pm}$ and Z^0, it is customary[9] to rely on the close relation between the weak and electromagnetic interactions. In particular, if the reaction $pp \rightarrow \mu^+\mu^- X$ proceeds via an intermediate virtual photon, such as the Drell-Yan[10] mechanism, then we suppose the weak production of a particle of mass M to be related to the electromagnetic production of a muon pair of mass M simply by replacing the electromagnetic coupling constant (α^2) and photon propagator by the weak coupling constant ($G/\sqrt{2}$)..Explicitly

$$\sigma_{W^{\pm}} \sim \frac{G}{\sqrt{2}} \cdot \frac{3M^3}{4\alpha^2} \frac{d\sigma}{dM} \sim 0.1\, M^3 \frac{d\sigma}{dM}\bigg|_{M=M_W} .$$

As the W^+ would be formed from a $u\bar{d}$ interaction while the W^- from $\bar{u}d$, we may expect about twice as many W^+ as W^- in pp collisions. For the case of the neutral weak particle, Z^0, the rates are expected[11] to be about at an order of magnitude smaller.

If we observe only muons, we must include an estimate of the branching ratio for $W^{\pm} \rightarrow \mu^{\pm}\nu$ and $Z^0 \rightarrow \mu^+\mu^-$. These will be of the order of $\sigma(e^+e^- \rightarrow \mu^+\mu^-)/\sigma(e^+e^- \rightarrow$ hadrons) at the appropriate energy. We shall use a conservative estimate of 10% for these branching ratios when $M \sim 100$ GeV$/c^2$. The discovery of additional quarks and leptons would reduce the branching ratio. In summary,

$$\sigma(W^{\pm} \rightarrow \mu^{\pm}\nu) \sim 0.01\, M^3 \frac{d\sigma}{dM}\bigg|_{M=M_W} , \qquad \sigma(Z^0 \rightarrow \mu^+\mu^-) \sim 0.001\, M^3 \frac{d\sigma}{dM}\bigg|_{M=M_Z} .$$

The other 90% of the decay modes will be hadronic, basically of the form $W^+ \rightarrow u\bar{d}$, etc. Each quark would carry energy $=M_W/2$, and should emerge with its own "dressing" as a hadron jet. Detection of these jet pairs will be considered in a later section.

In the Drell-Yan picture, the process $pp \rightarrow \mu^+\mu^- X$ obeys a scaling relation

$$M^3 \frac{d\sigma}{dM} = f\left(\frac{M^2}{S}\right)$$

where f is a function of the parton distributions of the proton. As we are concerned mainly with production of particles near 90° to the beams, and also to compare with existing data, we consider the cross section

$$\frac{d^2\sigma}{dM dy}\bigg|_{y=0}$$

where

$$y=\frac{1}{2}\ln\frac{E+P_L}{E-P_L}$$

is the usual rapidity variable. Then

$$M^3\frac{d^2\sigma}{dMdy}\bigg|_{y=0}=F(M^2/S)\,.$$

Figure 3 shows the scaling function, F, calculated using fits to the parton distributions,[12] and including the 1/3 factor due to color. Also shown are recent data[13,14] from the reactions $pA\to\mu^+\mu^-\,X$ at $\sqrt{s}=27$.

Figure 4 shows the cross section for Drell-Yan pairs evaluated at $\sqrt{s}=400$ GeV. Supposing the mass of the Z^0 to be 100 GeV/c^2, the cross section for $Z^0\to\mu^+\mu^-$ would be $\sim 10^{-36}$ cm^2 and might appear as shown.[15] The line width is based on an estimate of the mass resolution of the apparatus, to be discussed below.

If there is no other source of continuum muon pairs than the Drell-Yan mechanism, the Z^0 particle should be observable with a signal/noise ratio of 10^2-10^3 for $M_{Z^0}<200$ GeV.

An estimate of event rates can be obtained by noting that the aperture of the detector of 45°-135° to the beams corresponds roughly to $\pm 1/3$ unit of rapidity for masses of the order of 100 GeV/c^2. Then for a luminosity of 10^{33} cm^{-2}/sec, the event rates per GeV/c^2 mass interval are as shown in Figure 4. We might expect two $Z^0\to\mu\mu$ events per hour if its mass is 100 GeV/c.

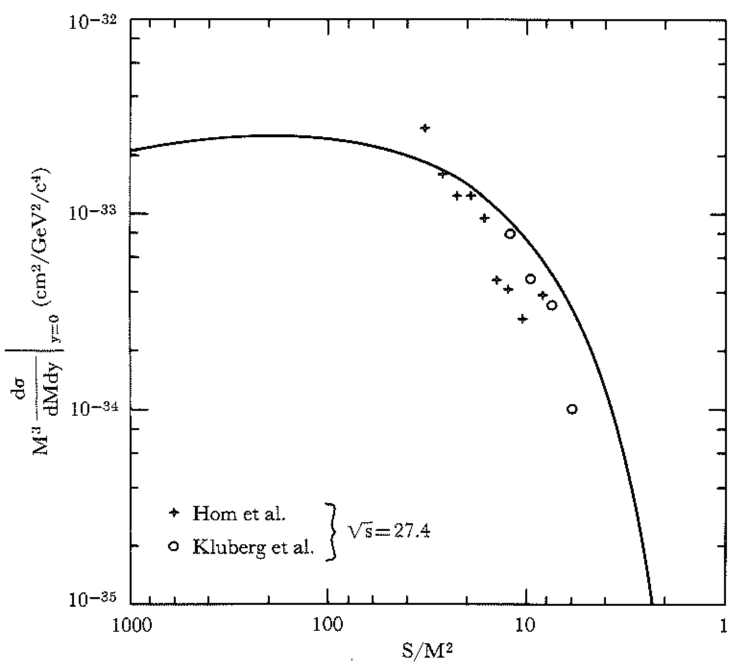


Figure 3. The Drell-Yan scaling function compared to recent experimental data.

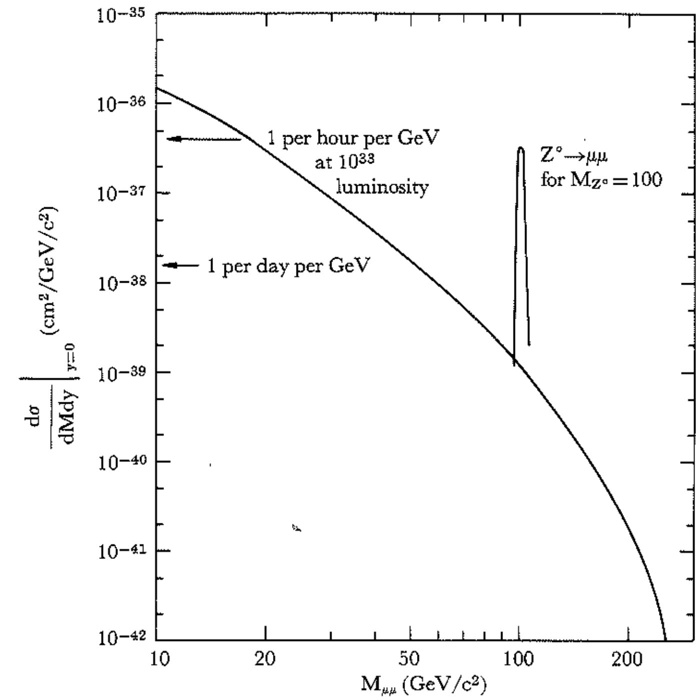


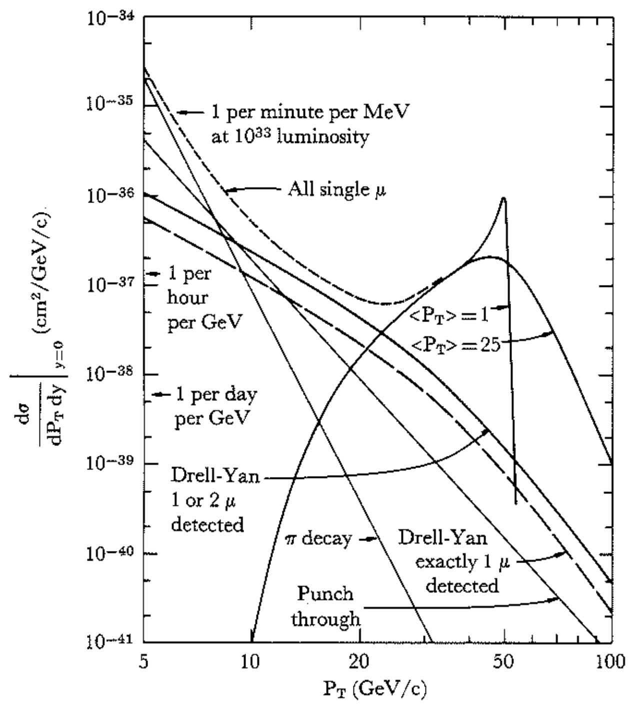
Figure 4. The cross section for Drell-Yan $\mu^+\mu^-$ pairs for $\sqrt{s}=400$ GeV. The cross section for production of a Z^0 with mass 100 GeV/c^2 includes the effect of experimental resolution. The rate estimates are per interval of 1 GeV/c^2 at 10^{33} cm^{-2}/sec luminosity.

For the $W^\pm$ particles we observe only a single muon. The $W^\pm$ should nonetheless be identifiable as a peak in the transverse momentum spectrum of muons near $M_W/2$. This is illustrated for $M_W=100$ GeV/c^2 in Figure 5, which also includes estimates of the inclusive muon spectrum from other sources.

The sharpness of the peak due to muons from the $W^\pm$ depends on the momentum resolution of the apparatus as well as on the transverse momentum spectrum of the $W^\pm$ itself. While low mass objects have low average transverse momentum, there is recent evidence[13,16,17] of a trend of the form $\langle P_T\rangle=0.25+M/4$. We illustrate two cases in Figure 5; if $\langle P_T\rangle=1$ GeV/c^2 the line shape is determined mainly by the momentum resolution (details given below); if $\langle P_T\rangle\sim M/4$, the line shape is quite broad and dominated by the P_T spectrum of the parent W. We have assumed

$$\frac{d\sigma}{dP_T}\sim P_T\exp(-2P_T/\langle P_T\rangle).$$

The inclusive spectrum of muons produced by the Drell-Yan mechanism is also shown in Figure 5. This is expected to be the principal source of "continuum" muons. If the $W^\pm$ are not accompanied by other muons from a correlated production process, we may increase the signal/noise by rejecting events in which both muons from a Drell-Yan pair are observed in the apparatus. For a detector of 45°-135°



e 5. The cross section for single muons from various sources. The contribution from a W of 100 GeV/c^2 is shown for two hypotheses: $\langle P_T \rangle = 1$ GeV/c, and $\langle P_T \rangle = 25$ GeV/c. The of momentum resolution is included. The tail to small P_T is due to production of Ws with ero rapidity which decay into a muon with $y=0$. The rate estimates are per interval of 1 at 10^{33} cm^{-2} luminosity.

ure, this would mean roughly a factor of 2 improvement. The $Z^0 \rightarrow \mu^+\mu^-$ de- vould also contribute to the single muon spectrum, causing a smaller spike at $M_Z/2$. Measurements of the $Z^0 \rightarrow \mu\mu$ mode would, however, allow a good sub- on of this "background."

Backgrounds from π and K decay, and hadron "punch through" are also illus- d in Figure 5, and will be discussed in detail later. For $P_T > 10$ GeV/c they are inly not important.

Although the $W^{\pm}$ may be produced with 10 times the cross section of the Z^0, ignal/noise in each case is comparable, being 10^2-10^3. This is because of the dening of the single muon peak due to kinematic effects of longitudinal and verse momentum of the $W^{\pm}$. At 10^{33} luminosity and for $M_W = 100$ GeV/c^2, we t expect 10-20 events/hour, spread over a 10-20 GeV/c interval of muon trans- momentum.

These estimates of W production are lower in both absolute rate and in signal/ to those given in the 1975 ISABELLE Summer Study.[18,19] The absolute rates ower because recent Drell-Yan parametrizations are almost a factor of 10 low-

er, and we use a branching ratio of $W \rightarrow \mu\nu$ of 1/10 instead of 1/3. The signal/noise ratio is lower because of the lower branching ratio, and broader estimate of the width of the transverse momentum spectrum of the daughter muons.

Background Muons From Hadrons

As mentioned above, the apparatus will experience backgrounds of muons from π and K decay and from hadrons misidentified as muons due to "punch

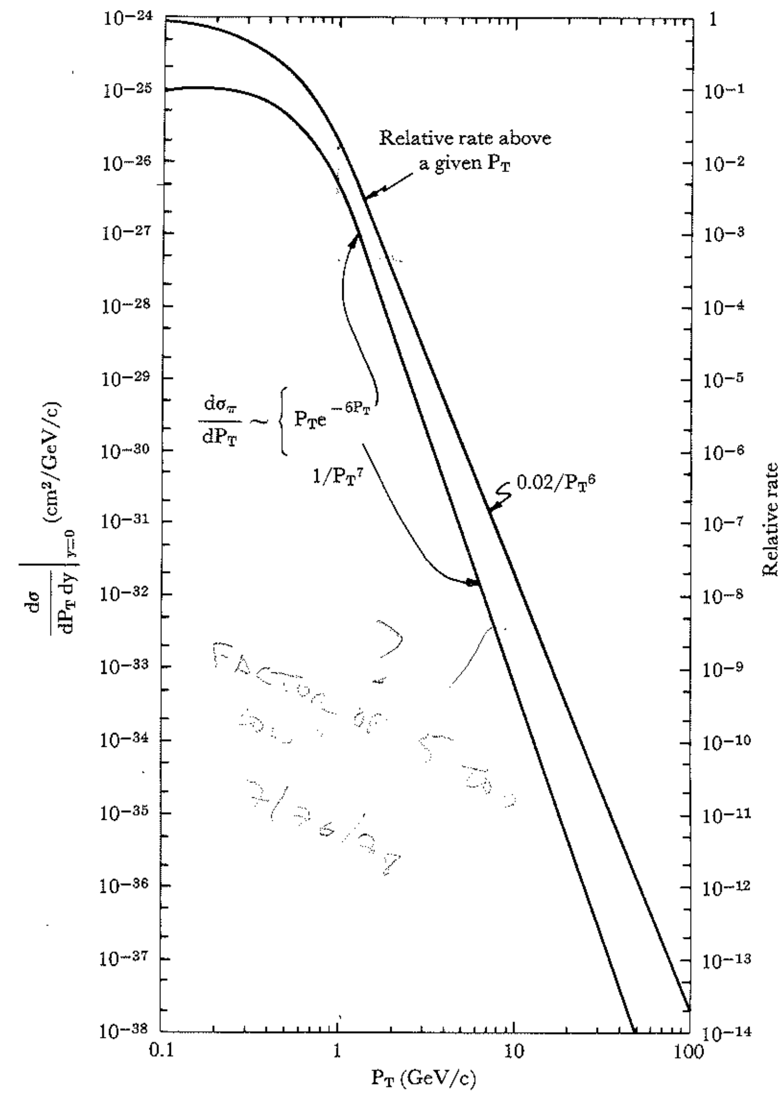


Figure 6. The inclusive cross section for hadrons (pions) at 90° as a function of P_T (left scale). The integral of the cross section above a given P_T is also shown (right scale).

through" of the hadronic cascade in the filter. In this section we set conservative upper limits for these effects.

The backgrounds are enhanced by the rise with beam energy of the cross section for high transverse momentum hadrons. We adopt a "worst case" fit to the cross section of

$$d\sigma/dP_T \sim P_T(\exp -6\,P_T) \qquad P_T < 4/3$$
$$\sim 1/P_T{}^7 \qquad P_T > 4/3$$

This corresponds to the infinite beam energy form of the CCR collaboration fit to their ISR data.[20]

The fit is illustrated in Figure 6 with normalization appropriate to

$$\left.\frac{d\sigma}{dP_T dy}\right|_{y=0}.$$

For pions the acceptance of the apparatus is ± 1 unit in y. For reference, Figure 6 also includes a curve indicating the fraction of all hadrons with transverse momentum larger than a given amount.

The probability of a pion decaying into a muon (and neutrino) is proportional to L (meters)/P_T (GeV/c) where L is the available decay path. Including the decay kinematics, and assuming a power law dependence of the pion P_T spectrum leads to a ratio of $\sigma_\mu/\sigma_\pi = 5\times10^{-3}$ (L/P_T) for σ_μ and σ_π evaluated at the same P_T. This is shown in Figure 7 for the cases $L=0.3$ meter and $L=3$ meters. The cross section for muons which have come from π decay is shown in Figure 5 for the case $L=0.3$ m, assuming all high P_T hadrons are pions.

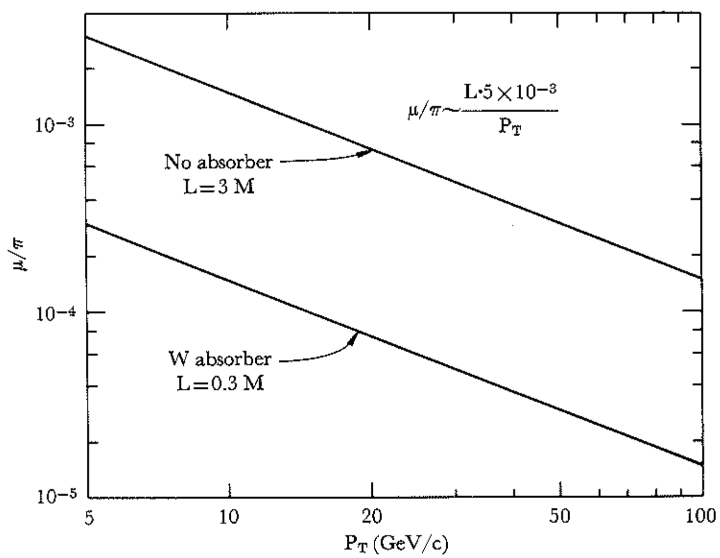


Figure 7. The cross section ratio for muons and pions at the same P_T, for muons from π decay. Curves are shown for two values of L, the mean free path of a pion.

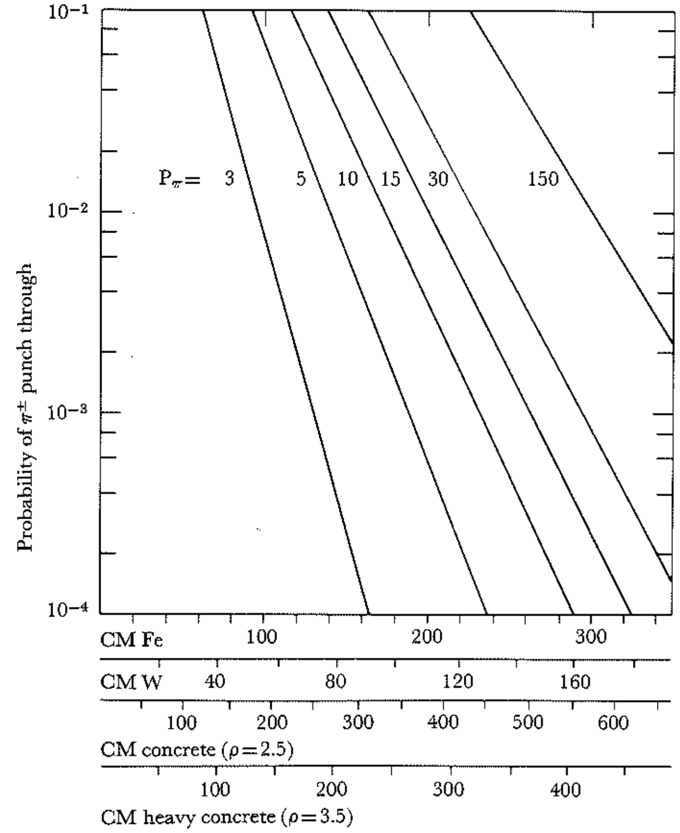


Figure 8. The probability of pion punch through as a function of absorber thickness for various pion momenta (no magnetic field).

A potentially more serious background is hadrons misidentified as muons due to "punch through" because this effect grows with increasing P_T. Figure 8 shows the probability of detecting a particle after various amounts of absorber for incident pions. The curves have been extracted from the work of Grant.[21] The punch through cross section for an absorber of 2.5 m iron (or equivalent) is shown in Figure 5. For momenta above 20 GeV/c, the punch through background is 10 times more serious than that of π decay. However, not all punch through will result in a misidentification as a muon, depending on the actual configuration of the absorber, and the presence of the analyzing magnet field. This suppression will be considered further below.

THE MUON DETECTOR

In this section we use the expectations of signal and background discussed above to determine the parameters of the detector.

As illustrated in Figure 2 and Figure 11, the main element of the detector is a 4 (or more) tesla superconducting solenoid with axis along the beams. Charged particle momenta are measured in drift chambers inside the solenoid. The primary goal is to trigger on, and analyze the events containing one or more high transverse momentum muons. We also wish to preserve the flexibility to study high P_T hadron jets, and high P_T electrons with only "minor" modifications to the apparatus.

The general criteria for detector performance are:

1. Good momentum and pair mass resolution;
2. Good rejection of π decay and punch through;
3. The ability to run at $10^{33} cm^{-2}/sec$ luminosity with a trigger rate on the order of 1/sec.

Resolution

The method of obtaining good momentum resolution is to analyze the muon tracks in an air core solenoid magnet spectrometer, as shown in Figure 2. In the spectrometer charged particle trajectories will be helices with axes parallel to the beam. As a measure of the transverse momentum resolution we use the track chamber resolution divided by the sagitta of the trajectory across the region of measurement. The sagitta in meters is approximately $L^2B/25\ P_T$ where L in meters is the maximum chamber separation, B is the magnetic field in tesla, and P_T is in GeV/c. This leads to a resolution, in percent, of $\Delta P_T/P_T = 2.5\ P_T\ \sigma/L^2B$ where σ is the chamber resolution in millimeters. This is illustrated in Figure 9 for the case of $B=4$ tesla, and $\sigma=0.1$ mm as can be obtained in drift chambers. We judge that the tracks should be observed over at least 1.5 meters to obtain adequate resolution.

Given the momentum resolution we may estimate the corresponding mass resolution for muon pairs with the additional assumption that a typical opening angle is 150°. This value is appropriate for high mass pairs with small P_T. Figure 10 shows the mass resolution as a function of mass. At low masses the resolution will be dominated by multiple scattering, which affects the opening angle measurement. This is only significant if the chambers are preceded by a hadron filter, such as the 80 cm of tungsten indicated in Figure 10.

Background Rejection

Hadron backgrounds will be rejected by an absorber consisting of 2 parts: A heavy metal absorber inside the solenoid close to the beam pipes, and a second absorber outside the solenoid coils. The inner absorber serves to suppress π decay by limiting the average flight path before interaction to 0.3 m. It also should reduce the rate of particles in the drift chambers, which otherwise may have difficulties functioning at 10^{33} cm^{-2}/sec luminosity. This absorber will be removable so that hadron and electron studies may be made. The outer absorber is needed to provide additional rejection of punch through of high P_T hadrons. Of course, if the inner absorber is thick enough, the outer absorber is unnecessary. If, however, it is desired to identify muons during the hadron or electron studies, the outer absorber must be very thick.

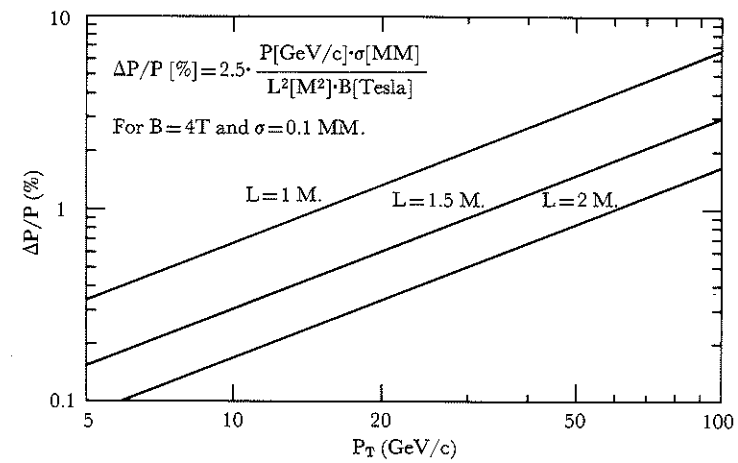


Figure 9. The momentum resolution (standard deviation) obtained in the spectrometer as a function of P_T. Curves are shown for 3 values of L, the distance between the first and last drift chambers.

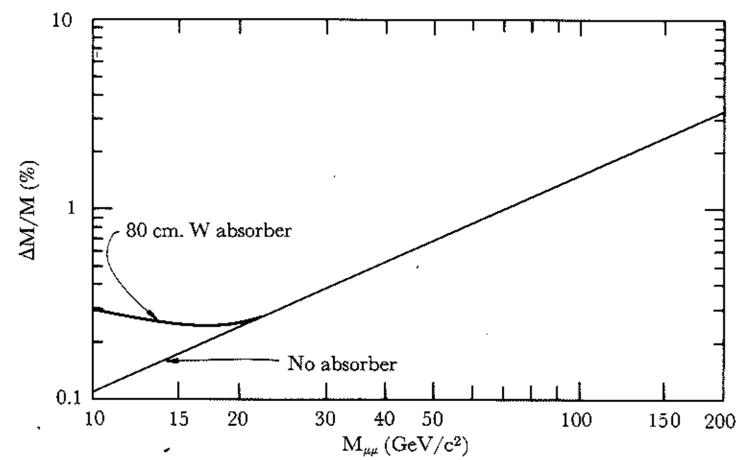


Figure 10. Mass resolution as a function of pair mass, assuming an average opening angle of 150°. The effect of multiple Coulomb scattering in the inner absorber appears at low masses.

Comparison of Figures 5 and 7 shows that the use of an inner absorber certainly suppresses π decay to a low enough level. Without the inner absorber, the π decay would be about 10 times more, which is still tolerable, especially at high P_T. Assuming only muons of more than 5 GeV/c can trigger the apparatus (lower P_T muons are bent back and/or stopped), a rate of single muon triggers of less than 10/sec is expected at 10^{33} cm^{-2}/sec luminosity, even without the inner absorber.

The rejection of punch through depends not only on the thickness of the absorber, but where it is placed. If the absorber is in the strong magnetic field, the hadron shower will be curled up, and will not penetrate so deeply. Hence, it is advantageous that the inner absorber be as thick as possible. Additionally, if the outer absorber were made as a multiplate hadron calorimeter, as considered below in the hadron jet option, the misidentification of punch through as a muon will be greatly reduced by requiring small energy deposition in the calorimeter.

As a first estimate of the danger of punch through, we neglect the two suppression factors mentioned, and use calculations for field-free, solid absorbers[21] (see Figure 8). We consider 2.5 m of iron (or equivalent) will provide sufficient rejection of punch through, as shown in Figure 5. If the inner absorber is 80 cm of tungsten, the outer absorber must be at least 1 m of iron or equivalent (for example 1.5m of heavy concrete). This thickness is quite appropriate for a calorimeter.

Trigger

The muon trigger would be(beam-beam interaction) $\cdot$ (penetrating particle). A pair trigger would clearly require two distinct penetrating particles.

A good beam-beam trigger can be made with scintillation counter planes perpendicular to the beams, and downstream of the detector far enough to provide time-of-flight rejection of beam-gas interactions. The principal need for a beam-beam interaction requirement is to suppress cosmic ray induced triggers. At 10^{33}

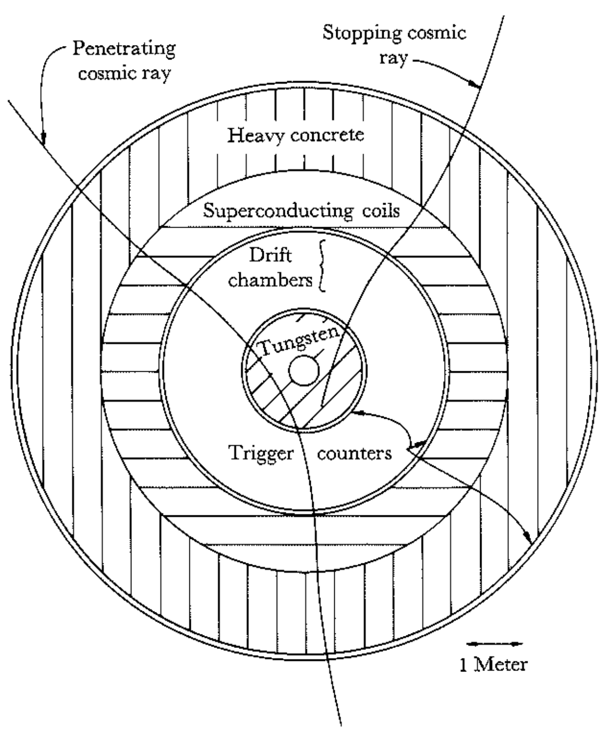


Figure 11. End view of the muon detector. Also shown are two kinds of cosmic rays which might simulate a single muon trigger.

cm^{-2}/sec luminosity, and 50 mb (extrapolated) cross-section, the average time between interactions is 20 nsec. The probability of accidental coincidence is considerable, so the beam-beam requirement will not be sufficient to reject cosmic rays, and the muon trigger must provide significant suppression. Therefore, the muon trigger will consist of hits in each of 3 concentric cylinders of scintillation counters (see Figure 11) at radii of 1m, just after the tungsten absorber, 2.5 m, just inside the magnet coil, and 5 m, after the hadron filter. The innermost cylinder presents 4 m^2 of area to the cosmic ray flux.

Two classes of cosmic rays present difficulties, as shown in Figure 11; those which completely penetrate the detector, and those which stop after passing through at least 3 counter banks. Assuming 5 m of earth shielding above the experiment, muons must have at least 3 GeV energy to enter the detector, 4 GeV to trigger 3 banks, and 9 GeV to penetrate completely. The cosmic ray flux above 4 GeV energy[22] is roughly $10^{-2}/E^2$ $cm^{-2}sec^{-1}sterad^{-1}$ GeV^{-1}. Allowing a full 2π solid angle acceptance, the rates are 400/sec stopping and 300/sec penetrating cosmic rays. The penetrating rays can be easily eliminatd by time-of-flight between the 2 hits in the outer ring of counters as the hits are 30 nsec apart, and hence 30 nsec out of time. The stopping muons can be fairly well eliminated by time-of-flight between the hits in the inner and outer rings which are 12 nsec apart, and hence 24 nsec out of time. This scheme will work only with the inner absorber in place, which cuts the singles rate in the inner counter ring from 10^8/sec to 10^6/sec (at $10^{33}cm^{-2}$/sec luminosity).

Rates and Sensitivity

We summarize the rates discussed in the preceding sections:

Single Muon Trigger:

1. ~1/sec from beam-beam interactions, dominated by $\pi^{\pm}$ decay; P_T min ~5 GeV/c.
2. $\lesssim$1/sec from cosmic rays.

Muon pair trigger:

1. ~1/min from Drell-Yan pairs with $M > 10$ GeV/c^2.
2. negligible from cosmic rays.

A run of 1000 hours at 10^{33} cm^{-2}/sec luminosity would reach a cross-section sensitivity of 3×10^{-40} cm^2/event. For $\sqrt{s}=400$, this corresponds to 1 event/GeV/c^2 at a mass of 125 GeV/c^2. For $W^{\pm}$ or Z^0 production with a signal of 10^3 above the Drell-Yan level, there would be 1 event at masses up to 250 GeV/c^2.

Muon Detector Parameters

We summarize the parameters of the detector discussed in the preceding sections, which are relevant for muon detection. (See also Figures 2 and 11.) Modifications for study of hadrons, jets, and electrons will be considered below.

Magnet: superconducting solenoid of 4 tesla field
inner radius = 2.5 m
outer radius = 3.5 m
length = 5 m
stored energy ~2×10^9 joule.

DRIFT CHAMBERS:	3 or more double planes at radii 1.0 to 2.5 m.
TRIGGER COUNTERS:	3 concentric rings at radii 1, 2.5 and 5 m.
HADRON FILTERS:	Inner heavy metal absorber radii 0.2 to 1.0 m. Weight ~80 tons. Outer heavy concrete absorber at radii 3.5 to 5 m. Weight ~1600 tons if density = 4. If iron, 1 m thick, then 2000 tons, and useful as a partial flux return.

HADRON JET PHYSICS

The interest in the physics of hadron jets is twofold: The majority of the decays of the $W^{\pm}$ and Z^0 particles should be into 2 hadron jets; and the "ordinary" hadron jets are the result of hard scattering of the proton constituents. In both cases the interest lies in the speculation that a hadron jet is the laboratory realization of a single energetic quark.

From studies at SPEAR and at the ISR, we can infer that the cross section for hadron jets from the strong interaction is ~100 times that of single hadrons,[23] as shown in Figure 12. Superimposed is an idealized jet spectrum from $W^{\pm}\rightarrow 2$ jets; perfect resolution of the jet momentum has been assumed. The signal/noise of the $W^{\pm}\rightarrow$jets is barely adequate. As mentioned before, our $W^{\pm}$ cross section estimate is on the low side, while the hadron estimate is maximal, so long as a $1/P_T{}^8$ behavior pertains at $P_T=50$ GeV/c. If the jet cross sections turn out to be like $1/P_T{}^4$ at high P_T, as expected in some models, it will probably be impossible to extract the weak interaction effects.

The experimental study of hadron jets requires a jet trigger, plus the measurement of the total jet energy, and ideally, separate measurement of the individual particles of the jet. As the energy is distributed over several particles, the trigger must rely on calorimetry. If the outer hadron filter (~1 m iron or equivalent) were made as a calorimeter, it would be an excellent triggering device. (It would also be useful in rejecting punch through in the muon trigger). It might consist of 1m of iron distributed over 1.5 m in 5 cm plates with 2.5 cm gaps filled with scintillator. Being next to the magnet coils, the iron would saturate at ~2 tesla, providing a flux return for about 2/3 of the 4 tesla solenoidal field. The concentrated field would be useful in case of a momentum selecting muon trigger. Such a calorimeter would not provide a good measurement of the jet energy, as a resolution of 10-15% might be expected at 50 GeV. Of course, the inner hadron absorber must be removed for the hadron studies. The solenoid magnet and drift chambers will provide excellent analysis of the charged component of the jet, provided the chambers can tolerate the particle rates. Chambers located at 1m radius will observe ~10% of all hadrons, or 10^7/sec into 12 m^2 surface area at 10^{33} cm^{-2}/sec luminosity. The component of the jet with transverse momenta below about 1 GeV/c will not be observed due to the strong magnetic field.

The neutral component of the jet may contain 25% of the jet energy. Of the neutral component, about 90% will be in the form of photons from π^0 decay. The photons are reasonably well measured in a lead plate shower counter. The liquid-argon ionization chamber[24] would be most appropriate for use in the solenoid mag-

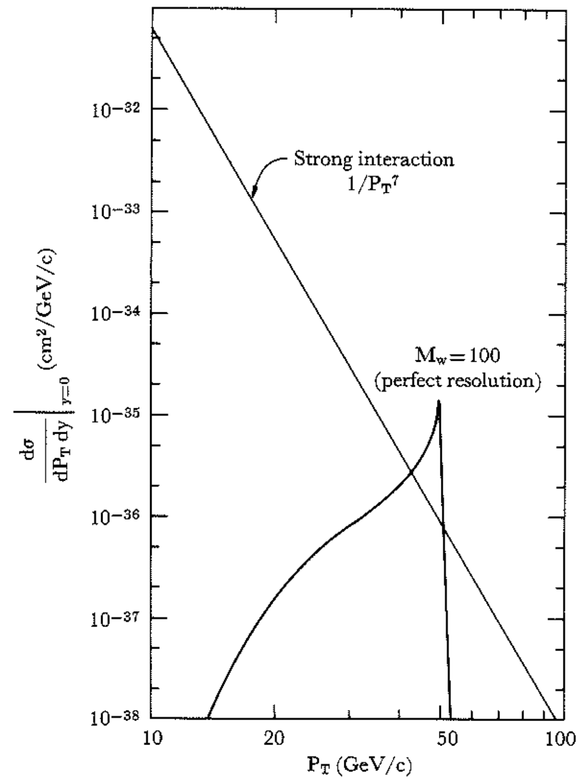


Figure 12. Cross sections for inclusive production of hadron jets at $\sqrt{s}=400$ GeV. We assume strong production at a level 100 times that of pions at a given P_T. The line shape of the jet spectrum from W decay assumes perfect momentum resolution.

net. (The magnetic field will not sweep away the neutrals, whose rate will be 10^8/sec at 10^{33}/sec luminosity. The sensitive time of 200-500 nsec then presents some problems.) A detector of 25 radiation lengths might occupy 0.5 m radially, and achieve a resolution of $9\%/\sqrt{E}$. It would be placed either just inside the magnet coils, or just outside them if the material in the coil amounts to only one radiation length or less. Better resolution would be obtained with the shower counter inside the magnet, but this adds 0.5 m to the radius of the (expensive) magnet.

A configuration of the apparatus for hadron, and electron, studies is shown in Figure 13. If the hadron jet cross section is as shown in Figure 12, a run of 1000 hours at 10^{33} cm^{-2}/sec luminosity would be sensitive to jets of energy up to the kinematic limit of $\sqrt{s}/2$.

We have not included the capability of identifying the charged hadrons as π, K, p, etc. Technically this is quite difficult to do over a large solid angle and range of momenta. The lack of particle identification is serious only in that it restricts the usefulness of the apparatus in searching for hadrons carrying new quantum numbers.

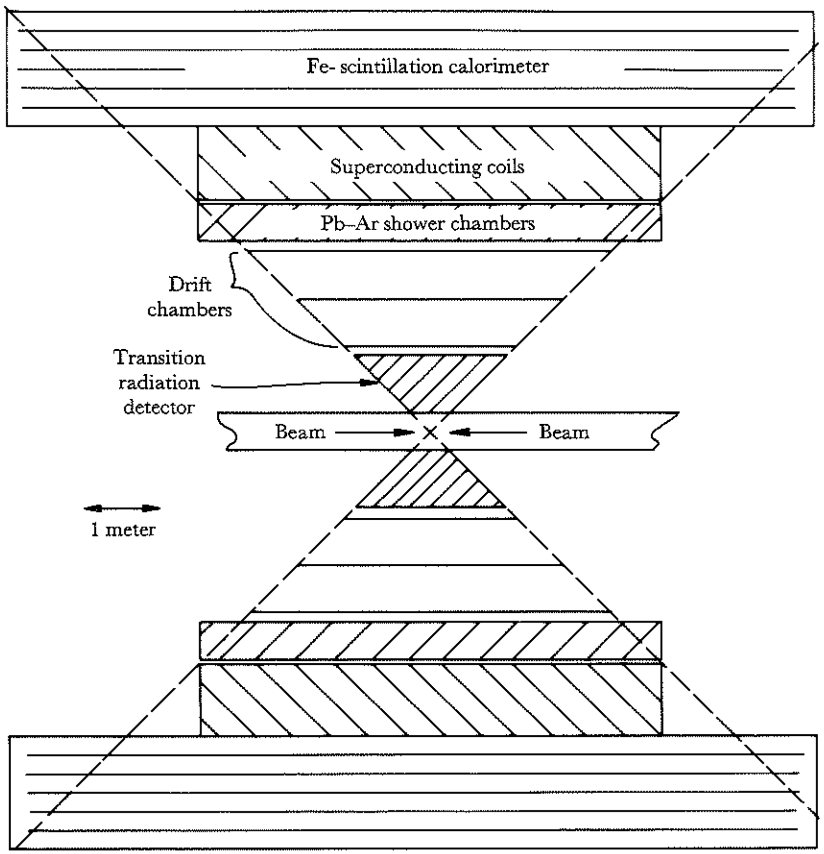


Figure 13. Cross section of the detector modified for the study of hadron jets. With the addition of a transition radiation detector electron studies may also be made.

ELECTRON DETECTION

As momenta are measured in air in this apparatus, the resolution for muons will be as good as for electrons. Hence, the only need for electron detection is to investigate processes for which an electron signature is crucial. For the weak boson, or new $q\bar{q}$ states, muons and electrons are equivalent. Only for heavy leptons are electrons advantageous. Here one looks for $\mu^{\pm}e^{\mp}$ events which have come from the leptonic decays of a pair of heavy leptons. Hence, the apparatus must have the ability to identify single electrons, not just pairs.

There are 2 difficulties in electron identification: separation of electrons from charged pions; and rejection of electrons from the Dalitz decays of the π^0, η, etc. The interesting electron signal may well be only 10^{-5} of that of pions of the same momentum. Hence, we need a rejection factor of $\sim 10^6$ against charged pions, and $\sim 10^4$ against Dalitz pairs. This will be very difficult to achieve, especially in the

case of Dalitz pairs where the strong magnetic field will curl up a soft electron from an asymmetric pair.

A possible solution to the problem of electron identification is to observe the electron's momentum, measure its energy in a shower counter, and observe the pulse height of transition radiation in a lithium foil detector.[25] The transition radiation detector might be placed in the space vacated by the removal of the hadron absorber (Figure 13). This exposes the device to rates of more than 10^7/sec at 10^{33} cm^{-2}/sec luminosity. Details of a possible detector have been given in the 1975 ISABELLE Summer Study.[18] With the transition radiation detector, rejection against charged pions of 3×10^{-3} might be achieved. Whether the energy versus momentum comparison can provide the additional 10^{-3} rejection factor needs study. Likewise, the rejection of the system against Dalitz pairs needs very thorough investigation.

COSTS

At this early stage of design, only crude estimates of costs can be made. We will rely on estimates made for similar configurations by the 1976 ISABELLE Lepton Detector Study Group.[26]

We give separate estimates for the basic muon detector, and for the hadron and electron options.

Muon detector	Costs in millions ($)
Superconducting Coil	4–5
Refrigerator	1
Drift Chambers (8000 wires)	0.7
Scintillation trigger counters (3 planes of 100 counters, 800 P.M.'s)	0.8
Heavy Metal Absorber (80 tons)	?
Concrete Absorber (1600 tons)	0.5
	7–8
Hadron and Electron Detectors	
Iron-Scintillator calorimeter	
iron (2000 tons)	1.2
scintillator, P.M.'s, etc.	0.4
Pb-Liquid Argon Calorimeter	0.9
Transition radiation detector	0.3
	2.8
Grand (!) Total	10–11

ADDENDUM: USE OF THE BNL 7 FOOT MAGNET

The BNL 7-foot bubble chamber magnet, considered as a solenoid, has the 45°-135° coverage appropriate for a lepton detector. Its inner radius is 1.14m, leaving only 1m useful space beyond the beam pipe. Its field is 3 tesla. With drift chambers throughout the available space a momentum resolution 3 times worse than proposed above could be obtained. With no absorber at small radii the trigger would suffer from π decay, and the chambers at small radii would suffer from rate. A luminosity of 10^{32}/sec might be the maximum tolerable.

For a first round experiment, when a luminosity of 10^{33} may not be available, a detector based on the 7-foot magnet could be very competitive.

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W^0 Detectors at ISABELLE

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Amongst the first experiments at ISABELLE will be the search for the W's. The expected cross sections for $W^{\pm}$ or W^0 at $\sqrt{s} = 400$ GeV are $\sigma_w \sim 10^{-34}$ cm^2 with $M_w{}^{\pm} \sim 70$ GeV, $M_w{}^0 \sim 80$ GeV. Thus, if the luminosity is $\sim 10^{33}$, even with 4π detection the production rates will only be $\sim 10^{-1}$/sec. This is to be compared with the total particle production rate $\sim 10^9$/sec. Clearly it will not be an easy task to find the W's in this sea of particles.

The W^0 is expected to have an $\sim 10\%$ branching ratio into $\mu^+\mu^-$, and through this decay mode has the greatest likelihood for early detection and study.

The muon detectors most frequently considered for W^0 detection (i.e., see Lepton Detector 1976 Workshop) have one feature in common: large volumes of magnetized iron surrounding the interaction region. Such systems have the advantage of good rejection of the large hadron background, near 4π acceptance and an ~ 20 kG magnetic field in a large magnetic volume for finite cost. Serious drawback: the momentum resolution is limited by multiple scattering to $\sim 10\%$. Thus the largest proposed systems have a $\Delta M \approx \pm 5$ GeV for a dimuon mass of 80 GeV. This may be adequate to detect the W^0, but seems to us a very poor resolution for a survey, in a new energy range, of particles decaying into $\mu^+\mu^-$. In particular the Z_0 is expected to have a width in the range 100-1000 MeV.

An alternative and in our opinion more desirable muon detection system is to surround the interaction region with first a hadron absorber, and then with an air core magnet. For example, a system of proportional chambers with 350 μm resolution inside a 30 kG magnetic field would give a $\delta p/p \sim \pm 10^{-2}$ leading to a ± 500 MeV