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BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
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ACCELERATOR DEPARTMENT
Informal Report

FORWARD MUONS AND MUON PAIRS AT ISABELLE

A. J. S. Smith and Mark Strovink*

June 16, 1972

*Princeton University

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INTERSECTING STORAGE ACCELERATOR NOTES

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ABSTRACT

In this note we mention some of the processes possibly giving rise to muons and muon pairs produced at ISABELLE along the beam directions, and consider the problems associated with their detection.

To be specific, our attention is focussed on muons which intersect the spectrometer shown in Fig. 1. At one end of the 20 m "west" straight section, five magnetized iron toroids of 4 m diameter and 1 m thickness are distributed along the beam. Detectors in the 0.5 m interstices measure both position and angle of the muon trajectory. Nearly the full azimuthal range is accepted between polar angles of 50 and 400 mrad. Additional details appear in section C below.

From a scheduling viewpoint, there are several attractive features. First, the forward muon spectrometer is physically compatible with a 90° lepton detector of the type described by Lederman[1]. In addition, successful operation of the 90° spectrometer will require suppression of forward hadrons produced by beam-gas interactions near the ends of the straight sections. The necessary shielding at one end is provided by these iron toroids. We emphasize that magnetic field containment within the iron toroids effectively removes the possibility of interference with synchrotron tuning.

A. Experiments at Low Luminosity -- The Keuffel Effect

Five years ago the Utah group[2] reported evidence for an anomalous zenith-angle distribution of cosmic-ray muons in the TeV range. Clarification of the experimental situation has been impeded by the absence of independent data of comparable apparent sensitivity, and by major quantitative (though not qualitative) changes in subsequent Utah results. One continues to hope that ongoing surface experiments[3,4] can achieve a sensitivity sufficient to provide the necessary confirmation or disproof.

In the event that the Keuffel effect is still "alive" or in dispute, one could decisively resolve the pertinent experimental questions in the infancy of the ISABELLE facility. The effect is speculatively interpreted by Bjorken et al.[5] as evidence for the reaction

$$p + p \rightarrow X + \bar{X} + \ldots$$
$$X\ (\bar{X}) \rightarrow \mu^{\pm} + \text{another light particle.}$$

Associated production of the $\bar{X}$ is necessary in order to prevent X from decaying rapidly via the inverse production process, rather than into muons. The size of the observed cosmic ray effect implies that X is produced strongly; its threshold suggests that X weighs several tens of GeV. Following the analogy with $p\bar{p}$ production made by Adair and Price[6], the authors of Ref. (5) suppose the X - production cross section to rise quadratically with primary proton energy up to 4 times threshold, becoming flat thereafter. If X is produced with a flat distribution of longitudinal momenta, and with the small transverse momenta characteristic of strong interactions, this model reproduces the observed energy threshold for anomalous muon production if $M_X \approx 20$ GeV, with a production corss section of ≈ 0.3 mb. These estimates put the effect at the edge of detectability at the ISR.

For observation of Keuffel muons at ISABELLE, two facts are important. One is that the very steep ($p^{-2.7}dp$) momentum spectrum of the primary cosmic-ray protons makes the X production cross section, as inferred from the cosmic ray data, a very strong function of the average efficiency with which X carries off the available momentum. The the extent that a 0.3-mb cross section is already startlingly large, the momentum spectrum of X should be at least flat and may show additional enhancement in the fragmentation regions. The daughter muon is thereby Lorentz-transformed forward and detected efficiently in the proposed spectrometer. Figure 2 exhibits the angular distribution of these muons at ISABELLE, following the aforementioned model of Ref. (5). For an X mass of 20 GeV, the proposed muon spectrometer detects 1/4 of the Keuffel muons, as opposed to 5% in the 90° detector. The second important fact is that there is as yet no direct experimental evidence that large transverse muon momenta are associated with the Keuffel effect, although an experiment is planned[7] to test that possibility. To be prudent, one should also be able to detect efficiently muons with transverse momenta of 1 -2 GeV/c. Again, this fact argues in favor of muon detection near the beam direction.

If $\Gamma(X\rightarrow\mu+..) >> \Gamma(\pi\rightarrow\mu\nu)$, as would be implied by phase-space arguments, the effective production cross section for Keuffel muons (including detection efficiency) would approach $10^{-28}cm^2$! This corresponds to a miniscule (10^{26}) minimum luminosity requirement. So stupendous a muon and (by universality) electron production cross section, especially at high transverse momenta, would present a ≈ 1 MHz lepton background to the electromagnetic and weak interaction experiments operating at full ISABELLE luminosity. If the muonic decay rate of X is ≈ 10^7/sec (the lower limit set by cosmic ray data), luminosities of 10^{28} would be required to see the effect.

B. Higher Luminosity Experiments -- Forward Muon Pairs

Drell and Yan(8) have proposed a model for muon-pair production in which the lepton pairs are created in p-p collisions by parton-antiparton annihilation. Qualitative agreement with the AGS experiment of Christenson et al. has been obtained(9). Berman, Bjorken, and Kogut(10) have used this model to give the cross section for the inclusive process

$$p + p \rightarrow \ell + \ldots$$

as follows:

$$\frac{d^2\sigma}{dx_1\,dx_2} = \frac{4\pi\alpha^2}{s x_1^2 x_2^2}\,\mathcal{F}(x_1, x_2) ,$$

where x_1 and x_2 are related to the usual Mandelstam variables by

$$x_1 = -t/s \quad ; \quad x_2 = -u/s .$$

In terms of the lepton's transverse momentum $p_\perp$ and polar angle θ with respect to the beam,

$$x_1 x_2 = p_\perp^2/s ,$$
$$x_1/x_2 = \cot^2\theta/2 ,$$

and

$$\frac{d^2\sigma}{d(\ln_{\sqrt{s}} p_\perp)\,d(\cos\theta)} = \frac{4\pi\alpha^2}{p_\perp^2 \sin^2\theta}\,\mathcal{F}(x_1, x_2) .$$

This cross section is plotted vs Θ for $p_\perp = 10$ GeV/c and $s = (400)^2$ in Fig. 3. Both spectacular enhancement and dramatic suppression take place as Θ moves from 90° toward 0°. Although far outside the 90° lepton detector, this structure falls squarely in the accepted range of the spectrometer proposed here. It is expected that the essential symmetry of the $\gamma_V \rightarrow \mu^+\mu^-$ decay will make almost automatic the detection of the second muon.

Although this bizarre prediction is strongly model-dependent, it gives a glimpse of the richness of the physics. Basically, one is probing the longitudinal momentum distribution of virtual photons with $q^2 \approx 4p_\perp^2$. Within the context of the parton-annihilation model, this quantity is intimately related to the momentum distribution of individual partons. The forward direction requires a large asymmetry in parton momenta, corresponding to the parton's carrying a large fraction of the proton momentum. This appears to be the time-like analogue of lepton-proton scattering as $Q^2/2m\nu \rightarrow 1$, for Q^2 far above the SLAC range. More generally, the forward muon pairs test a variety of concepts ("light-cone" analysis model(11), "parton-bremsstrahlung" model(12)) of virtual photon emission by hadronic systems. For example, the conclusion by Berman, Levy, and Neff(12) that timelike proton form factors in parton bremsstrahlung scale except for the factor s^{-1}, would be critically tested at these high center-of-mass energies. We expect that further theoretical progress will make possible a precise definition of the areas of greatest interest in the study of these muon pairs.

The muon spectrometer described here accepts 1-2 "parton-annihilation" muon pairs/hour per logarithmic (base $\sqrt{e}$) interval in $p_\perp$, for $p_\perp = 10$ GeV/c, at a luminosity of only 10^{32}. However, estimates in the next section suggest that the spectrometer can withstand a luminosity of at least 10^{33} without unmanageable background rates.

C. Muon Spectrometer Design

The muon spectrometer is shown schematically in Fig. 1. Its main elements are five (5) magnetized iron toroids, each 1 m thick, 4 m in diameter, and ten (10) drift-chamber modules in the 0.5 m interstices. The set of magnets, similar to those long used in cosmic-ray experiments, costs <\$100 K. Each drift-chamber module, giving track projections in x,y,u, and v coordinates, has spatial resolution of 0.2 mm rms. This allows both position and angle measurement in each interstice, with an uncertainty dominated by multiple scattering in the iron. The muon track is required to traverse at least two magnets, giving 9 -14 % momentum resolution, and 6 - 10 % resolution in the mass of the dimuon. For unit detector efficiency, each track has a minimum of 8 independent geometrical constraints. The spectrometer is triggered by scintillation-counter hodoscopes (not shown) which impose a simple transverse-range requirement on one or two muon tracks, using the iron in the magnets and in 60-cm-diameter iron collars in the interstices.

Our first look at backgrounds has been reassuring. The average probability of a pion's decaying into a muon, or penetrating the iron as though it were a muon, is estimated as $\approx 3 \times 10^{-2}$. The transverse-range requirement, that $p_\perp$ (muon) $>$ 1.5 GeV/c, results in an extra suppression of $\approx 10^{-3}$. An ISABELLE luminosity of 10^{33} will produce $\approx 10^{9}$ particles/ second, which give rise to a summed singles rate of $\approx 3\times10^{4}$ /sec in all detectors. With a 3-nsec resolving time for the scintillation counters, accidental coincidences are below 10/sec. Subtraction of accidental dimuons, by the delayed-time-slice method, will be necessary only for those events with lowest $p_\perp$.

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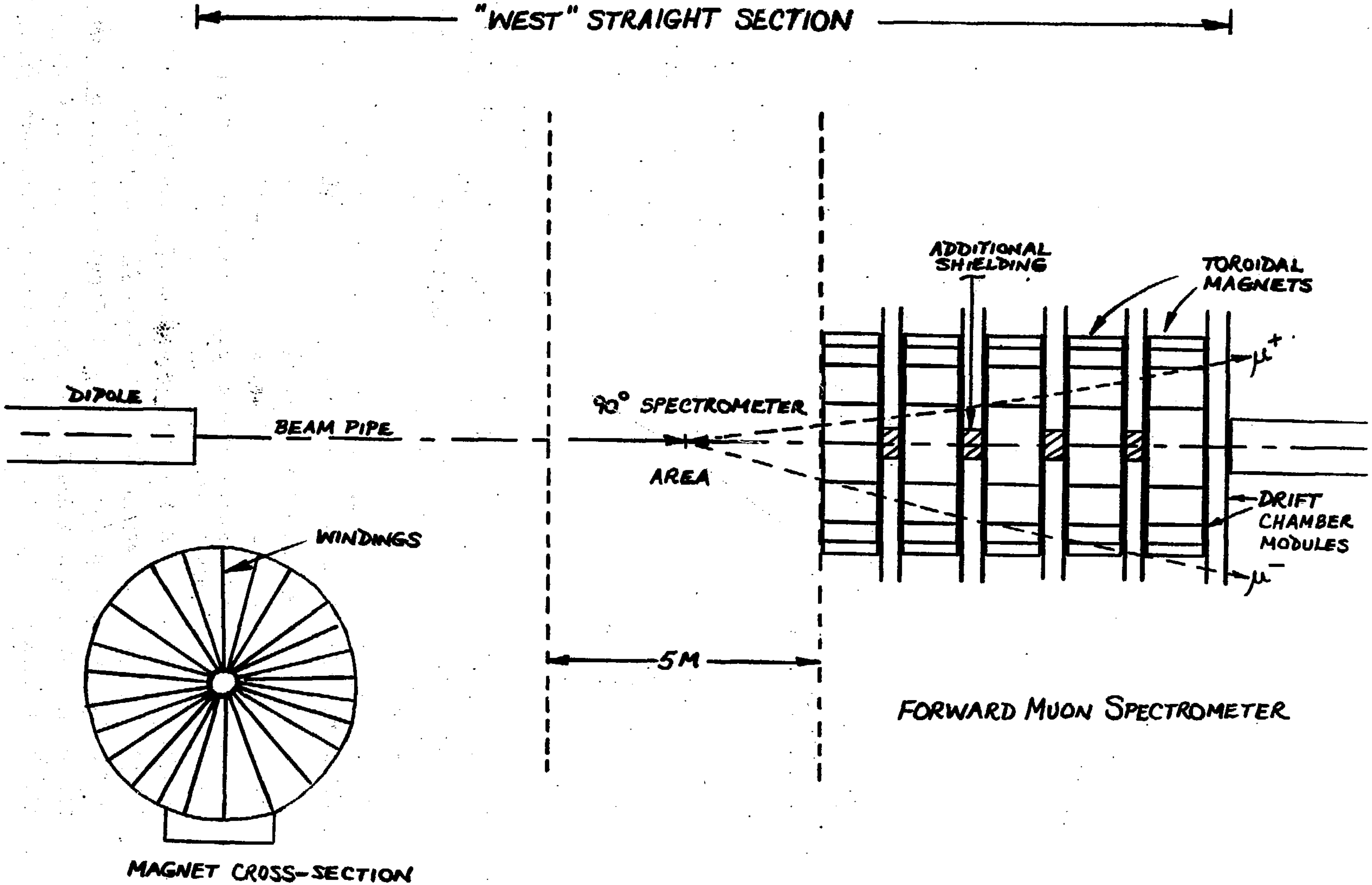
"WEST" STRAIGHT SECTION
DIPOLE
BEAM PIPE
90° SPECTROMETER
AREA
ADDITIONAL SHIELDING
TOROIDAL MAGNETS
DRIFT CHAMBER MODULES
μ+
μ−
WINDINGS
5M
MAGNET CROSS-SECTION
FORWARD MUON SPECTROMETER

Figure 1

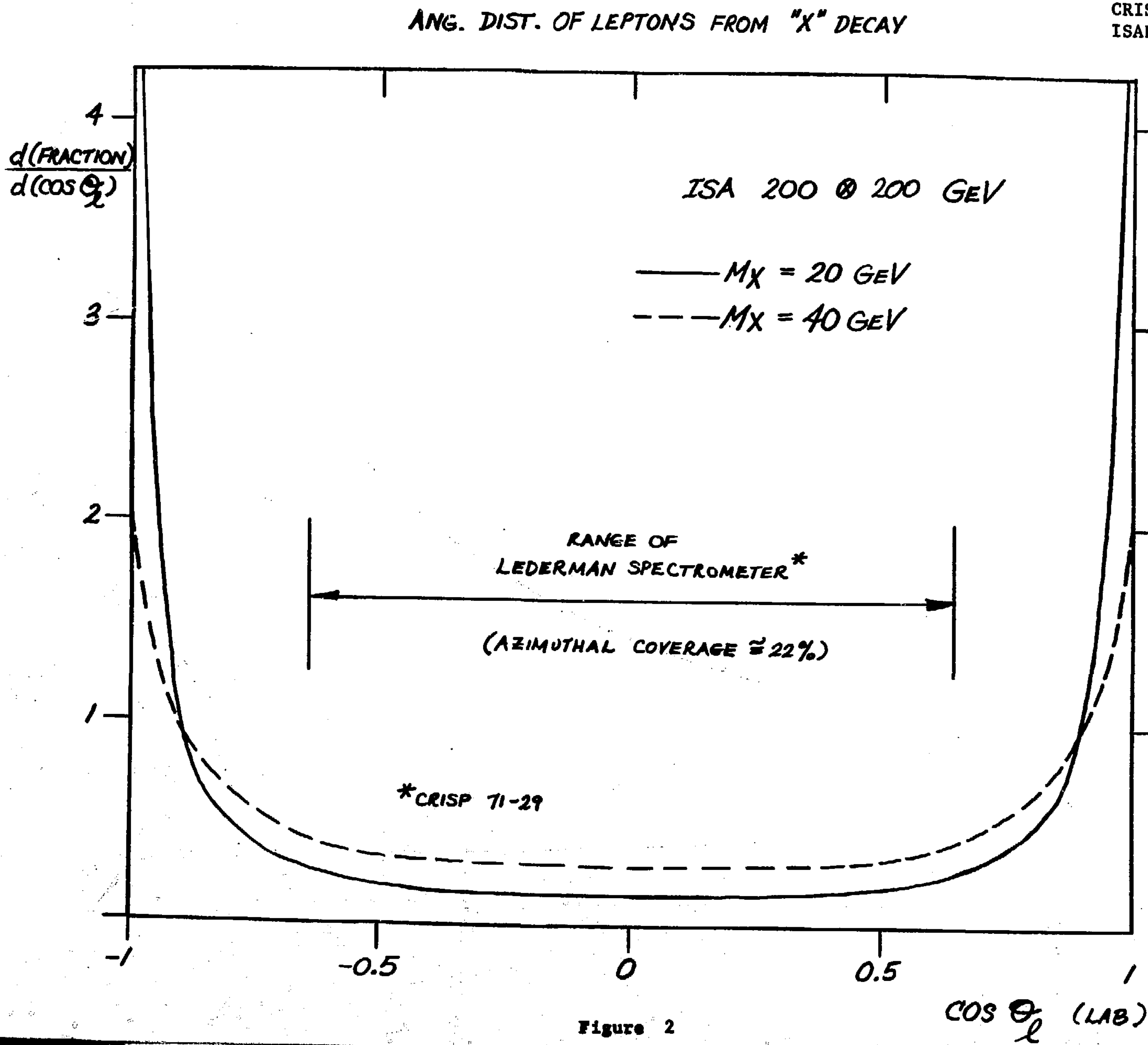
ANG. DIST. OF LEPTONS FROM "X" DECAY
4
3
2
1
d(FRACTION) / d(COS Θℓ)
ISA 200 ⊗ 200 GEV
Mx = 20 GEV
Mx = 40 GEV
RANGE OF LEDERMAN SPECTROMETER*
(AZIMUTHAL COVERAGE ≅ 22%)
*CRISP 71-29
-1
-0.5
0
0.5
1
COS Θℓ (LAB)

Figure 2

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ISABELLE PROJECT

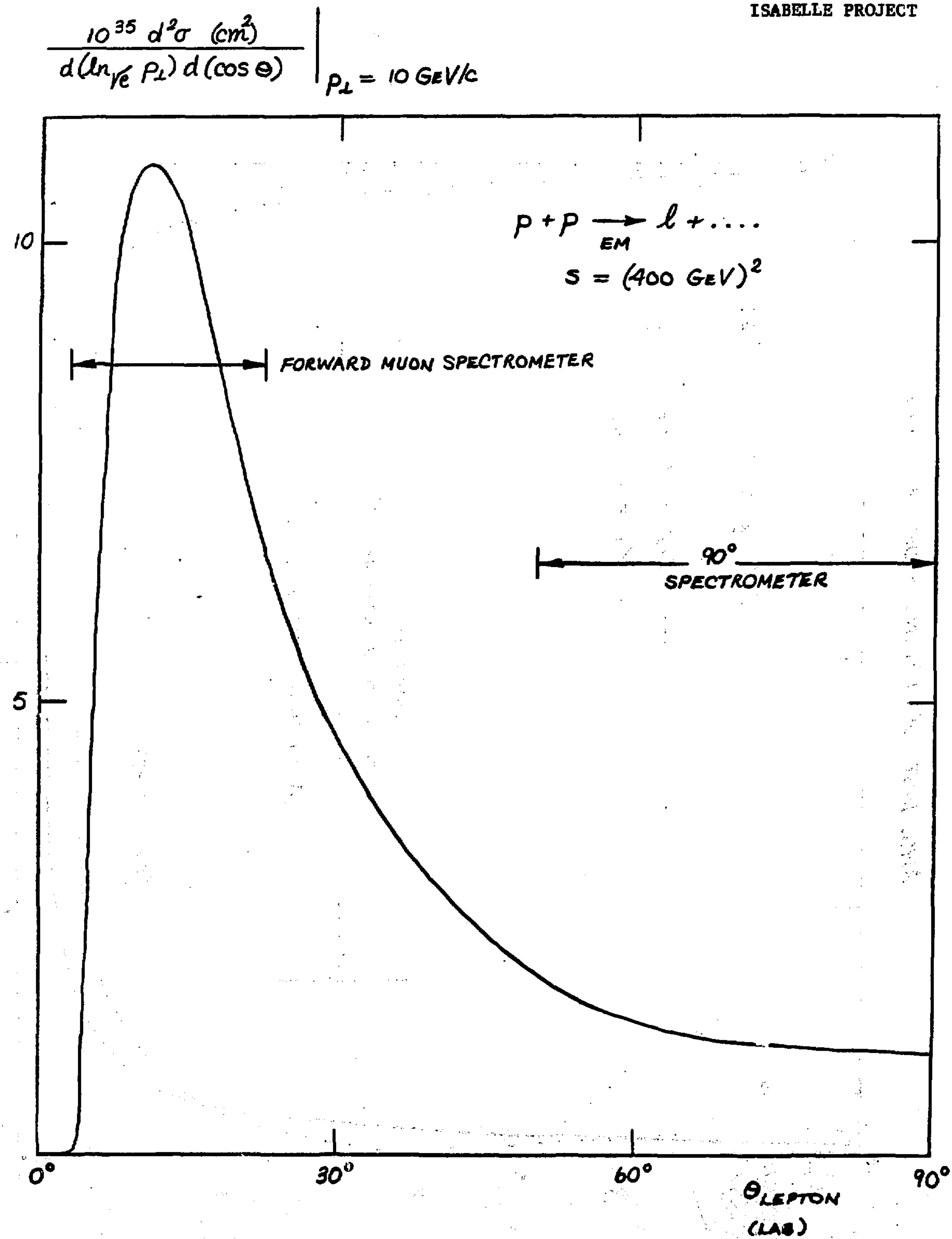

Figure 3