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ELECTROMAGNETIC AND WEAK INTERACTIONS

MEASUREMENT OF THE BRANCHING RATIO FOR THE DECAY $\eta \rightarrow \mu^+ \mu^-$

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Two of us from IUCF have contributed, primarily while on sabbatical leave, to the construction and testing of an η "tagging facility" and the study of η leptonic decay. We report here preliminary results from experimental efforts to measure the $\eta \rightarrow \mu^+ \mu^-$ branching ratio.

The leptonic decay of a neutral pseudoscalar meson of the type $P^0 \rightarrow l^+ l^-$ is a fourth-order electromagnetic process that transforms quarks into leptons. While permitted within the "standard model" (SM), such decays are strongly suppressed and tightly constrained.

Hence their study has the potential of providing unique SM tests. To date, however, the only two leptonic decays which have been definitively observed are the decay^{1,2} $\eta \rightarrow \mu^+ \mu^-$ and the quark-flavor-changing neutral current process^{3,4} $K_L \rightarrow \mu^+ \mu^-$.

Theoretically, a lower limit (the so-called unitary bound) can be obtained by evaluating the imaginary part of the decay amplitude via an intermediate state of two virtual photons, $P^0 \rightarrow \gamma\gamma \rightarrow l^+ l^-$. For the case $\eta \rightarrow \mu^+ \mu^-$, this gives a lower limit to the branching ratio^{5,6,7} $\text{BR}(\eta \rightarrow \mu^+ \mu^-) \geq 4.3 \times 10^{-6}$, independent of η substructure. The *real* part of the amplitude depends on the $\eta\gamma\gamma$ vertex and its calculation is somewhat model dependent. Nevertheless, various estimates using quark and vector meson dominance (VMD) models suggest the total decay width to be less than 1.5 times the unitary bound.⁸ A precision measurement of $\text{BR}(\eta \rightarrow \mu^+ \mu^-)$ can thus constrain models of the $\eta\gamma\gamma$ formfactor. A result significantly different from the above expectations (or below unitarity) might be a signal for new physics.⁹

An η -tagging facility was installed at the Laboratoire National Saturne (LNS), located in Saclay, soon after the discovery¹⁰ of an unexpectedly large cross-section for η meson production at the $p\,d \rightarrow {}^3\text{He}\,\eta$ reaction threshold. As a first generation experiment, the measurement of the decay channel $\eta \rightarrow \mu^+ \mu^-$ was initiated. The near-threshold kinematics of such a tagging facility are particularly advantageous for the design of both the tagging and decay product detector systems. Since the η total-production cross section happens to be maximal [$\sigma(p\,d \rightarrow {}^3\text{He}\,\eta) \approx 0.4\,\mu\text{b}$] at only a few MeV above threshold, the η 's are produced in a narrow cone around 0° (lab) and are nearly monochromatic. The resulting small phase space allows essentially 100% acceptance of the tagging ${}^3\text{He}$ reaction products from $p\,d \rightarrow {}^3\text{He}\,\eta$ on the focal plane of a spectrometer (SPES II) located at 0° . The ${}^3\text{He}$ were identified by time-of-flight vs. " ΔE " pulse height in two scintillator planes located behind the spectrometer focal plane. A hardware threshold on ΔE included in the trigger was in fact sufficient to obtain reasonable on-line tagging conditions. Three wire chambers with x and y readout were used for trajectory reconstruction with high (97%) efficiency. The two dipole arrangement of the SPES II allowed a clean separation between the momentum-analyzed ${}^3\text{He}$ and the proton beam exiting from the target, with the latter deflected by the first dipole into a beam dump located between the two magnets. Under normal running conditions, a beam of 10^{11} protons/second incident on a 7 mm LD₂ target yielded $\sim 10^8$ η 's a day. (This yield could be in principle increased by about a factor of 50 if the associated hadronic background in the decay product detectors could be tolerated.)¹¹

The muon detectors for this initial experiment consisted of relatively simple range telescopes without magnetic analysis. The telescopes were used to measure the opening angle of the η decay products, as well as to identify and determine the range of the muons. One arm of the left-right symmetric array is shown schematically in Fig. 1. The active parts of the detector closest to the target, the horizontal and vertical position hodoscope planes, were made of narrow scintillator elements for an accurate angle determination (30 mrad resolution in the opening angle for μ pairs) providing kinematical background suppression. These detectors could also tolerate relatively high counting rates (several MHz per plane). A wedge-shaped iron absorber in front of the position hodoscope was used to eliminate much of the large hadronic flux from the target. Additional iron and lead absorbers behind the position hodoscope, and in front of a muon trigger hodoscope, further slowed the muons

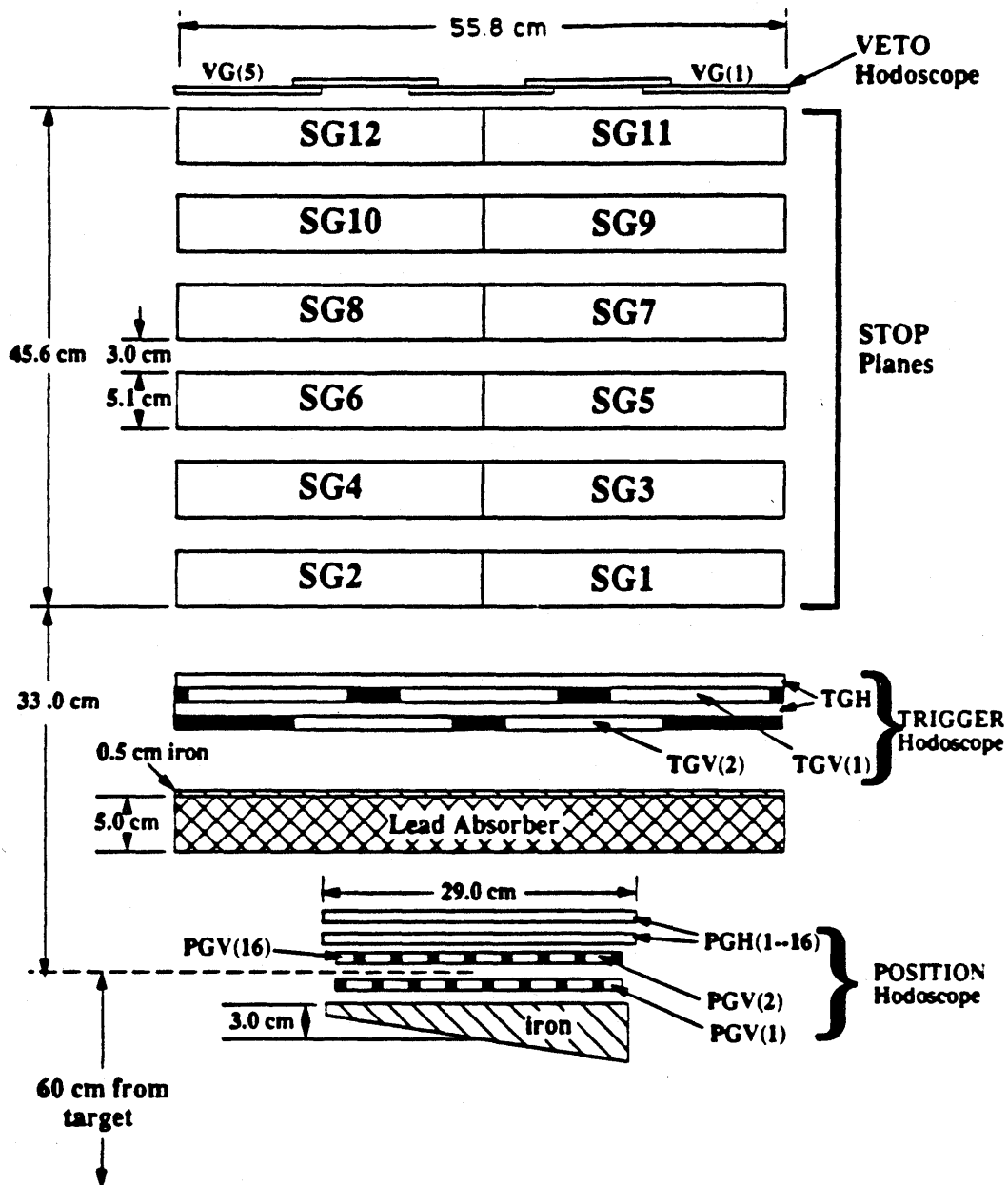


Figure 1. Schematic of the beam left (Gauche) range telescope for detecting muons from $\eta \rightarrow \mu^+ \mu^-$. The basic detector elements of the array are indicated: (i) position hodoscopes PGH, PGV to determine muon trajectories, (ii) trigger hodoscopes TGH, TGV to detect the penetrating particles that traverse the various absorbers, and (iii) stop counters that identify the muons and measure their range.

and attenuated electromagnetic showers. Finally, the array of stop counters was used to identify the muons via their energy loss and range. Muon identification was crucial in rejecting remaining correlated background from photon conversion in the wedge absorber, arising from the sizable decay branches $\eta \rightarrow \gamma\gamma$ ($BR \approx 0.4$) and $\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$ ($BR \approx 0.3$). Details of the experimental setup are given in Ref. 12.

The concept of the measurement is quite simple. Two data streams were recorded simultaneously: (i) ${}^3\text{He}$ singles (actually prescaled) detected by the SPES II spectrometer gave the $p\,d \rightarrow {}^3\text{He}\,\eta$ event rate, while (ii) triple coincidences between ${}^3\text{He}$ and the two muon detectors registered the rate at which we detected η 's that decayed into a $\mu^+\mu^-$ pair. The $\eta \rightarrow \mu^+\mu^-$ branching ratio is then obtained, independent from systematic uncertainties in beam intensity, target thickness, tagging efficiency, ${}^3\text{He}$ acceptance, production cross section, computer dead time, etc., by the relation:

$$BR(\eta \rightarrow \mu^+\mu^-) = \frac{N(\eta \rightarrow \mu^+\mu^-)}{N(p\,d \rightarrow {}^3\text{He}\,\eta)} \times \frac{1}{A_{\eta \rightarrow \mu^+\mu^-} \times \epsilon_{\mu^+\mu^-}^{\text{analysis}} \times \epsilon_{\mu^+\mu^-}^{\text{electronic}}}, \quad (1)$$

where $N(\eta \rightarrow \mu^+\mu^-)$ is the number of observed $\eta \rightarrow \mu^+\mu^-$ events, $N(p\,d \rightarrow {}^3\text{He}\,\eta)$ is the number of tagged η 's, $A_{\eta \rightarrow \mu^+\mu^-}$ is the geometric acceptance for the decay $\eta \rightarrow \mu^+\mu^-$, $\epsilon_{\mu^+\mu^-}^{\text{analysis}}$ is the analysis efficiency, and $\epsilon_{\mu^+\mu^-}^{\text{electronic}}$ is the electronic efficiency for recording the true three-arm coincidences. The most severe limitation of the experiment came from accidental coincidences (TOF resolution ~ 0.7 ns FWHM) and pulse height pile-up due to the high (about 1 MHz per counter) singles rates in the muon detectors. A third data stream utilizing a random pulser, triggered at a rate proportional to instantaneous beam intensity, was used to record *in situ* "random" spectra for all detectors. Events from the latter stream were combined with those generated in a detailed Monte Carlo simulation of $\eta \rightarrow \mu^+\mu^-$ (using the code GEANT), in order to determine the acceptance and analysis efficiency in the presence of the accidental coincidences and pileup.

Data were obtained in two running periods: during a test run in the fall of 1990, and during a much longer production run in spring, 1991. In the initial analysis leading to the present preliminary result¹³ only those prompt triple coincidences consistent with a single track through both position hodoscope planes on each arm were analyzed. This resulted in $\sim 99\%$ background rejection, with a loss of $\sim 23\%$ $\eta \rightarrow \mu^+\mu^-$ events to various accidental hit configurations. After timing cuts were applied, the signal/background ratio was $\sim 10^{-2}$. Subsequent cuts and kinematic constraints provided by observables from the remaining counters (as discussed above) led to a very clean identification of $\eta \rightarrow \mu^+\mu^-$ events. The data is perhaps best displayed by use of an angle correlation function $\Delta\Theta_{LR} \equiv \Theta_{LR}^{\text{calc}} - \Theta_{LR}^{\text{measured}}$, where $\Theta_{LR}^{\text{calc}}$ is the $\mu^+\mu^-$ opening angle calculated for the η momentum inferred from the tagged ${}^3\text{He}$, and $\Theta_{LR}^{\text{measured}}$ is the measured $\mu^+ - \mu^-$ opening angle. Data for this correlation function are shown in Fig. 2 after all cuts have been applied. From this plot, the preliminary number of events consistent with η production and decay is 75 ± 10 . This number and its uncertainty include the results of a separate analysis, made to determine the continuum background from $p\,d \rightarrow {}^3\text{He}\,\rho$ followed by $\rho \rightarrow \mu^+\mu^-$. This was accomplished by extrapolating (with the aid of a simulation for $\rho \rightarrow \mu^+\mu^-$) the measured (very small) continuum background for ${}^3\text{He}$ momenta lying *outside* the allowed kinematic

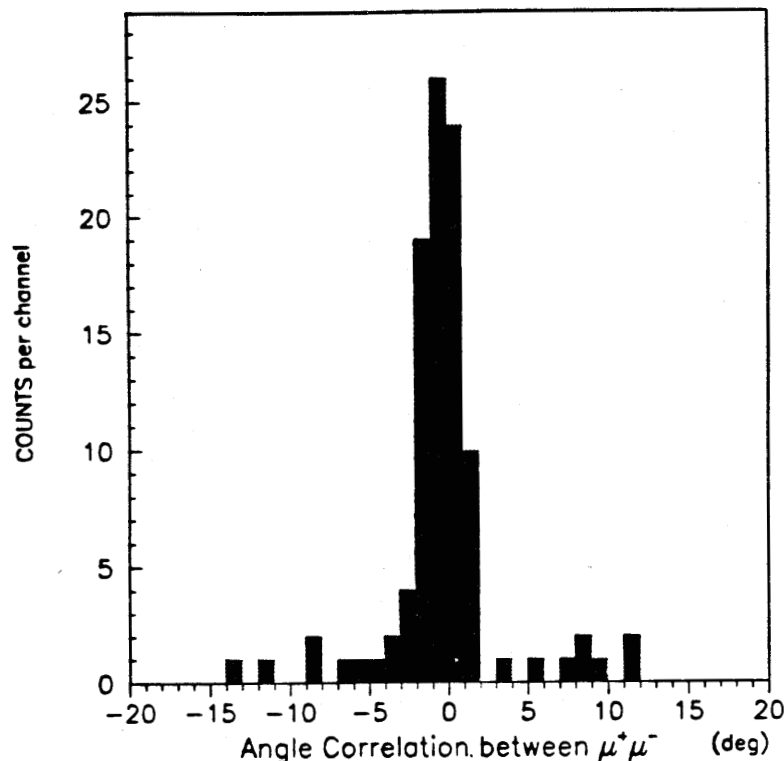


Figure 2. Signal for $\eta \rightarrow \mu^+ \mu^-$ from a preliminary analysis with all software cuts applied. The number of counts is displayed as a function of the angular correlation between μ^+ and μ^- , as described in the text.

region for $p d \rightarrow {}^3\text{He } \eta$, into the region under the η production peak. The resulting estimate is that less than 7% of the $\eta \rightarrow \mu^+ \mu^-$ peak signal arises from $\rho \rightarrow \mu^+ \mu^-$. For comparison, in the previous experiment¹ at Serpukhov, the background from $\rho \rightarrow \mu^+ \mu^-$ was 1.5 times larger than the signal from $\eta \rightarrow \mu^+ \mu^-$.

The systematic error in the measured BR is dominated by uncertainties in the efficiency and acceptance factors appearing in eq. (1). The $\mu^+ \mu^-$ geometric acceptance was determined from the Monte Carlo simulation to be $(2.9 \pm 0.1)\%$. More important are the systematics of the various losses incorporated in the analysis efficiency. These losses, due to various effects of the accidentals, to muons multiple scattering out of the detector stack before they stop, and to otherwise good events being discarded by software cuts, lead to an overall analysis efficiency of about 45%. While several of these losses are fairly large, they are well understood within the framework of the simulation, and thus the overall uncertainty in the analysis efficiency is $\simeq 7\%$. The electronic efficiency factor in eq. (1) is the fraction of $\eta \rightarrow \mu^+ \mu^-$ events (triple coincidences) that were recorded on magnetic tape. The losses here ($\sim 8\%$) were monitored by observing the recording efficiency for coincidences generated by a system of light emitting diodes attached to a several of the muon and SPES II scintillators.

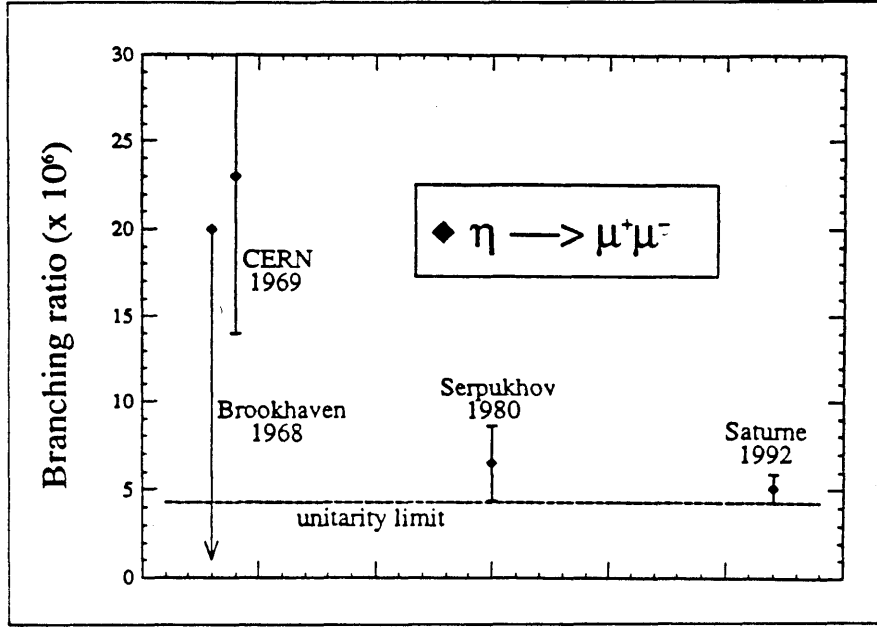


Figure 3. Preliminary result for $BR(\eta \rightarrow \mu^+\mu^-)$ in units of 10^{-6} for this experiment (labeled “Saturne”), with error bar reflecting a first estimate of the statistical and systematic uncertainties combined in quadrature. Published results of several previous measurements^{1,2,14} are also displayed. The horizontal dashed line indicates the lower limit imposed by the unitarity bound.

Putting the results of the analyses so far¹² into eq. (1) yields

$$BR(\eta \rightarrow \mu^+\mu^-) = (5.1 \pm 0.7^{stat} \pm 0.4^{syst}) \times 10^{-6}. \quad (2)$$

Ongoing analysis aims to understand systematic effects more fully and to recover events with more complicated hit patterns in the muon detectors. The preliminary result is compared with previous measurements in Fig. 3. Adding the statistical and systematic errors in quadrature, the branching ratio with respect to its unitary bound is $R \equiv BR(\eta \rightarrow \mu^+\mu^-)/BR_{unit} = 1.2 \pm 0.2$. Viewed in this way, our new result improves upon the previous Serpukhov¹ measurement of $R = 1.5 \pm 0.5$, and does not support the earlier CERN² value of $R = 5.3 \pm 2.1$.

Thus, at present, we can say that the decay mechanism for $\eta \rightarrow \mu^+\mu^-$ appears dominated by the on-shell two-photon intermediate state $P^0 \rightarrow \gamma\gamma \rightarrow \mu^+\mu^-$. The contribution from the real part of the decay amplitude is evidently consistent with most SM calculations using quark and VMD models. There is no indication, and in fact little remaining leeway, for any exotic contribution to the $\eta \rightarrow \mu^+\mu^-$ decay rate.

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A SEARCH FOR THE H PARTICLE (BNL EXPTS. E813/836)

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The goal of this experiment is to search for a strangeness=-2 dibaryon called the H particle. This state was predicted by Jaffe to have a mass 80 MeV less than the $\Lambda\Lambda$ mass of 2232 MeV.¹ The experimental observation of this state would provide much needed data to help understand the confinement mechanism of quarks. The apparatus and experimental technique were presented in a previous progress report and will not be repeated here.

The IUCF contribution to this project is the second-level trigger system. The second-level trigger is designed to fast clear events before they are read into the main data acquisition computers. The events we wish to fast clear are background events such as $K^- + p \rightarrow K^- + p$ and $K^- + p \rightarrow K\pi p$, where the proton is detected in the K^+ magnetic spectrometer. We are using time-of-flight to differentiate protons from kaons.

The experiment was setup and debugged and took data in spring, 1991. During this run and subsequent analysis, we have now verified that all major detector systems are working. Analysis codes are being developed for the in-beam (kaon) detectors, silicon