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Addendum

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CHARMED PHYSICS AT THE TAGGED PHOTON LAB

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I. INTRODUCTION

The recent discoveries of heavy narrow resonances at masses of 3.1[1,2,3] and 3.7 GeV[4] came at the same time as the successful testing by our group of the electron beam in the Fermilab Tagged Photon Facility.[10] The timing is perfect, as this facility with its clean environment and relatively high photon fluxes and energies will be the ideal location for several important experiments suggested by the new results. We outline below the new significance of our experiment to measure the photon total cross section (Experiment 25A), as well as six other experiments to study the new phenomena we can perform with little increase in running time and with the apparatus already being prepared for Experiment 25. This apparatus is particularly well suited for these experiments which include a definitive check on whether the new resonances are photo produced, a search for a pseudoscaler particle made of charmed quarks and a study of neutral decay modes (which may well be dominant) of new particles. Several of these experiments can most likely be performed nowhere else but the Tagged Photon Lab. We propose to spend some time during testing of the tagging system and the Experiment 25 apparatus to determine the feasibility of these new experiments.

The tests of the electron beam demonstrated that tagged photons with fluxes and backgrounds with ± 30% of predictions will be a reality by May, 1975. An informal report on these tests is included as an appendix. These tests and our consideration of

these new experiments lead us to conclude that both the study of σ_{tot} (γP) and σ_{tot} (γA) and the new measurements we here propose will make substantial contributions to the understanding of these new phenomena. We, therefore, request that the Laboratory continue to give as high a priority as possible to the completion of the tagged photon beam.

II. NEW SIGNIFICANCE OF σ_{tot} MEASUREMENTS

The discovery of the ψ (3105) and ψ' (3695) suggests that there may be higher mass strongly interacting vector particles coupled to the photon. Higher mass resonances of this type will be extremely difficult to detect because of the high multiplicity of their decay rates. If these particles interact strongly with the nucleon, it is to be expected that such states would contribute to the nuclear shadowing already observed at SLAC energies in the σ_{tot} (γ,A) measurements and attributed to the contribution of the well known vector mesons ρ ω and ϕ.[5,6] The energy and A dependence of the photo production total cross section may provide the only handle on the existance of such high mass states.

The onset of shadowing between E_γ = 2 GeV and E_γ = 4 GeV results from the quantity $\frac{2\,E_\gamma}{m_v^2}$ becoming large compared to the nuclear size for $m_\rho^2 \sim .5$ GeV^2.

For strongly interacting vector particles above the ψ mass, we can expect a corresponding increase in nuclear shadowing as E_γ is increased above 100 GeV.

III. Photoproduction of the ϕ_c and η_c

One possible explanation of the ψ (3105) is that it is ϕ_c, $c\bar{c}$ analogue of the ϕ (1015).

With the Experiment 25 apparatus and the tagged photon beam we can:

1. Determine whether the ψ is photoproduced, a critical question in determining whether the new particle is an intermediate boson or not. The tagged photon beam with fluxes similar to those of the other Fermilab photon beam, a well defined energy and a far cleaner environment is the ideal tool for a definitive resolution of this question.
2. Study the photoproduction of the ψ (3105) and ψ' (3695) from H and heavier nuclei.
3. Measure the energy t dependence of these cross sections.
4. If the ψ and ψ' are copiously produced, we can measure the σ ($\psi(\psi')$,N) by observing the A dependence of σ ($\gamma A \rightarrow \psi(\psi')A$).
5. Search for neutral decay modes of the ψ and ψ' into 3γ, $\gamma\pi^0$, $\gamma\eta$, or $\gamma\eta_c$ where η_c is the 0^-, $c\bar{c}$ boson predicted by Gaillard, Lee and Rosner.[7]
6. Search for the direct production of the η_c by Primakoff effect.

We propose to demonstrate the feasibility of these experiments during the installation and test phase of Experiment 25. Thiw will require no new equipment other than that already in preparation for E-25. To be specific, we ask for 100 hours of additional test time.

If the ψ (3105) is a 1^- state of $c\bar{c}$ quarks then the 0^- state, the η_c, should also exist with a similar mass and with even charge conjugation. Since the strong interaction of charmed with non-charmed quarks is unknown and could be small, we believe that it is advantageous to search for η_c by an electromagnetic process. The Primakoff production of such a particle of mass m depends on only one unknown quality, namely the $\gamma\gamma$ width $\Gamma_{\gamma\gamma}$. This width has been estimated to be 100 - 200 KeV.[8] We would look for the $\gamma\gamma$ final state with our proportional chamber - lead glass array shown in Figure 1. The branching to this state $\Gamma_{\gamma\gamma}/\Gamma_{tot}$ depends upon the rates for competing decay modes and could be as high as 50%, if we can take the width of the ψ as a guide. We note that the Primakoff cross section is proportional to the square of the nucleon or nucleus form factor. Since the minimum momentum transfer to the target is $\frac{m^2_{\eta_c}}{2E}$ the process is strongly inhibited, even on the nucleon, at energies lower than those available at Fermilab. The Fermilab tagged photon beam and the lead glass arrays of Experiment 25 are ideally suited to this process.

A crucial experiment at the present time is the photoproduction of the ψ. If it is a normal vector meson, like the ϕ, it will be photoproduced with a large and nearly energy independent cross section. SPEAR results indicate that the coupling to the photon $\frac{4\pi}{\gamma_\psi^2}$ is similar to that of the ϕ. The total

Elastic diffractive cross section is:

$$\sigma_{eL}^{T}(\gamma p \to \psi p) = \frac{\alpha}{4} \frac{4\pi}{\gamma_\psi^2} \frac{e^{a t_{min}}}{a} \frac{(\sigma_{\psi p}^{T})^2}{16\pi}$$

where a is the slope of the diffraction peak, $\sigma_{\psi p}^{T}$ is the total ψnucleon cross section and $t_{min} \simeq -\frac{m_\psi^4}{4E^2}$ is the minimum momentum transfer squared. The latest upper limit on is about 30 μb[9]. A smaller value of would imply that the ψ nucleon cross section is anamalously small (the φ nucleon cross section is ∿ 12 μbarns). Any measurable value would indicate that the ψ is not the weak intermediate boson.

We can detect the ψ most clearly by observing its e^+e^- final state, which apparently has about 5% branching ratio. We can also search for $\psi \to \gamma\pi^0$, $\gamma\eta$ and $\gamma\eta_c$ and ψ' (3.695) decays to the same channels by observing 3γ final states.

Experimental Apparatus

The detection apparatus, predicted counting rates and estimated backgrounds are as follows (See Figure 1).

We will use our 7 x 7 stack of 23" long x $(2.5")^2$ lead glass blocks as a multi element shower hodoscope. Electron track positions and gamma ray positions will be measured by a 3 radiation length lead converter followed by 6 planes of multiwire proportional chambers immediately in front of the lead glass stack.

The mass resolution depends upon the Pb glass resolution, the position resolution as determined by the wires and the thickness of the target. For this calculation, we assume a pessimistic ± 2% energy resolution for the Pb glass. Then the mass resolution is not markedly improved by

being further from the target than 8 feet. At this position, we have a geometrical acceptance for $\psi \to e^+e^-$ assuming a t slope of 5.5 GeV^{-2} of 42%. The weighted acceptance for $\eta_c \to \gamma\gamma$ and $\psi \to \pi^o\gamma$ including conversion efficiencies are about 48% and 42% respectively. The mass resolution is about ± 2.3%.

Acceptance vs E

ACCEPTANCE (E)

E	$\psi \to e^+e^-$	$\eta_c \to \gamma\gamma$	$\psi \to \gamma\pi^o$
50	.07	.064	.056
75	.34	.35	.27
100	.57	.52	.46
125	.67	.59	.54
60 - 115 (aver)	.42	.48	.42

Rates

The details of the Primakoff rate calculations are given in Appendix I. Since the rates may be quite low, we have assumed the use of a .2 r.l. radiator, a .3 r.l. Be target and 3 10^{12} 300 protons/pulse. Primakoff rates are then: 7 (MeV) $BR_{\gamma\gamma}$ events/hour. This is based on measurements of beam yeilds made during the recent tests.[10]

For the ψ photoproduction, we have assumed 1/3 the upper limit on the ψ cross section of 30 nbarns, energy independence, and a 5% branching to e^+e^-. With the same target and beam we then expect 5 events/hour at 50 GeV. For 3_γ final states, the rate would be 100 x $BR_{3\gamma}$ events/hour.

These rate predictions are conservative in that 400 GeV protons would give a factor of 3 increase and running at 6 10^{12} protons/pulse another factor of 2. It is expected that the target and dump can handle 10^{13} p/pulse at 400 GeV. If the machine intensities are high enough to provide this many protons, a factor of 10 higher experimental fluxes than predicted above can be anticipated.

Backgrounds

The Tagged Photon Lab will be an extremely clean environment in which to measure these low cross sections. The electron beam has been measured to have less than a few tenths of a percent pion contamination, and the tagging system reduces the rate of hadrons in the photon beam by many more orders of magnitude. The total photon interaction rate (neglecting small angle electron pairs) is only 600/pulse. The probability that a low energy electron from a pair scatters into the

chambers is about .15 per incident beam electron, or about 10^6/pulse. This should cause a negligible problem in identifying the charge of the shower.

Since the photon energy is known, we require that the detected energy in the lead glass array be consistent with the tagging energy within the resolution of the system, which is $\sim \pm 5\%$ with a thick radiator. Since the mass of the objects is so high, we require two electromagnetic particles each with a large P_T. An event with two π^0's carrying all of the incident energy and each having a large P_T would cause a background. We have not seen any data that is relevant to estimating this background. Consequently, the lower limits in the measurable cross sections can probably not be determined without making experimental tests. Of course, this two particle correlated high P_- "background" is of physics interest itself.

Acknowledgement

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FOOTNOTES

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APPENDIX I.

Rate Calculations

The Primakoff differential cross section on the nucleus Z is:

$$\frac{d\sigma}{d\Omega} = 8\alpha\, Z^2\, \Gamma_{\gamma\gamma} \left(\frac{\beta}{m}\right)^3 \left(\frac{E^2}{-t}\right)^2 \sin^2\theta\, F_Z(E,\theta)$$

where the 4 momentum transfer squared is:

$$-t = \frac{m^4}{4E^2} + E^2\theta^2$$

and β = the velocity of the particle.

The total cross section involves an integration over angles with a convergence at large angles due to the form factor fall off.

$$\sigma_{tot}(E) = \frac{8\alpha Z^2 \Gamma_{\gamma\gamma}}{m^3}\, 2\pi \int_0^{\theta_{max}} \frac{\theta^3 d\theta\, F^2(E,\theta)}{(\theta_0^2+\theta^2)^2}, \quad \theta_0^2 = \frac{m^4}{4E^4}$$

The value of $\sigma^{tot}(E)$ increases with energy due to the effect of the form factor. Using the Be form factor [11] $f(-t) = \left(1 + \frac{(-t)}{.078\ \mathrm{GeV}^2}\right)^{-3}$, we have evaluated this integral for a mass of 3.1 GeV. The result is shown in Figure 2 and is labelled $\sigma^{coh}_{(Z=4)}$

For high masses $\sim$ 3 GeV even at Fermilab energies σ_Z^{coh} is not dominant.

We also have an incoherent contribution from the individual nucleons.

$$\sigma_Z^{incoh}(E) = \frac{8\alpha Z \Gamma_{\gamma\gamma}}{m^3}\, 2\pi \int_0^{\theta_{max}} \frac{\theta^3 d\theta}{(\theta_0^2+\theta^2)^2} \left(1 + \frac{-t}{.71}\right)^{-2}$$

This integrand has a significant value out to $-t \sim .11\ (\mathrm{GeV}/c)^2$.

The data rate is then given by

$$\text{Yield} = N_e\, t_r N_Z\, A(N_Z) \int_{E_{min}}^{E_{max}} \frac{dE}{E} \left(\sigma_Z^{incoh}(E) + \sigma_Z^{coh}(E)\right) Acc(E)$$

where Ne is the number of incident electrons, t_r is the radiator thickness (thin target approximation), N_Z is the number of target nuclei/cm^2, A (N_Z) is the average correction due to beam attenuation in the target, and Acc(E)

Appendix I. (cont'd.)

is the acceptance of the detector for η_c.

We have evaluated this yeild for the following conditions:

$E_o = E^{max} = 115$ GeV

$N_e = 6 \cdot 10^6$/pulse corresponding to $3 \cdot 10^{12}$ protons/pulse at 300 GeV.

tr = .2 r.l.

$N_{(Z=4)} = 1.3 \cdot 10^{24}$ nuclei/cm^2 = .3 r.l. Be.

We then obtain a yield/hour = 12 $\Gamma_{\gamma\gamma}$ (MeV) $BR_{\gamma\gamma}$.

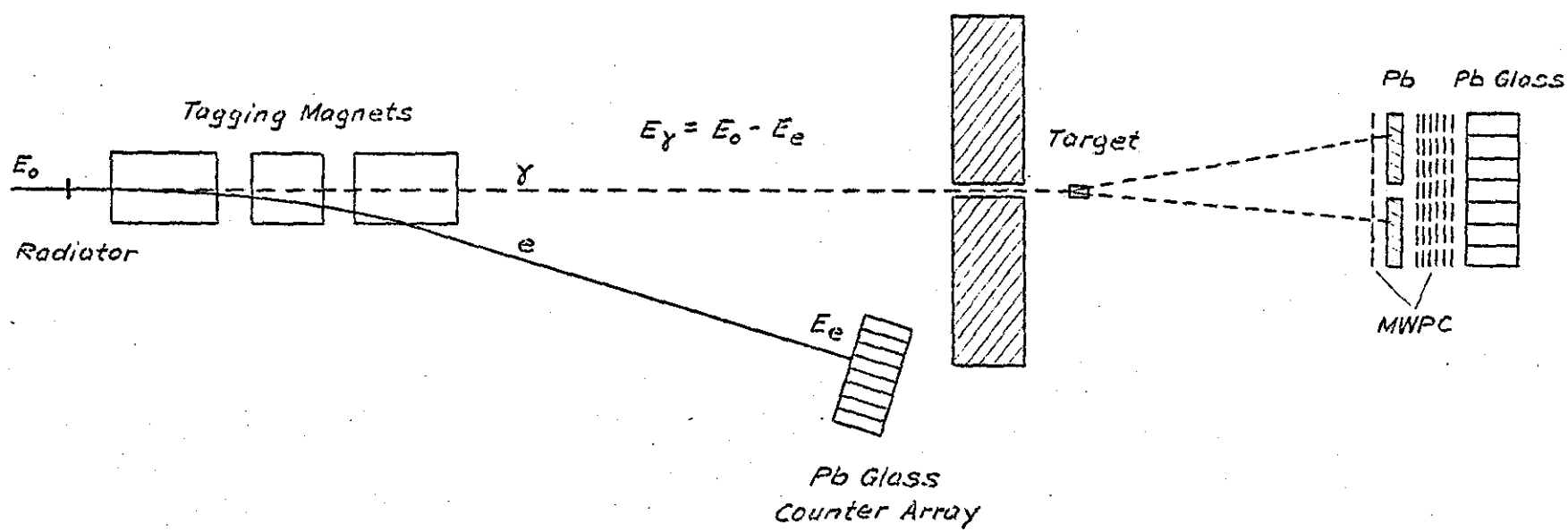
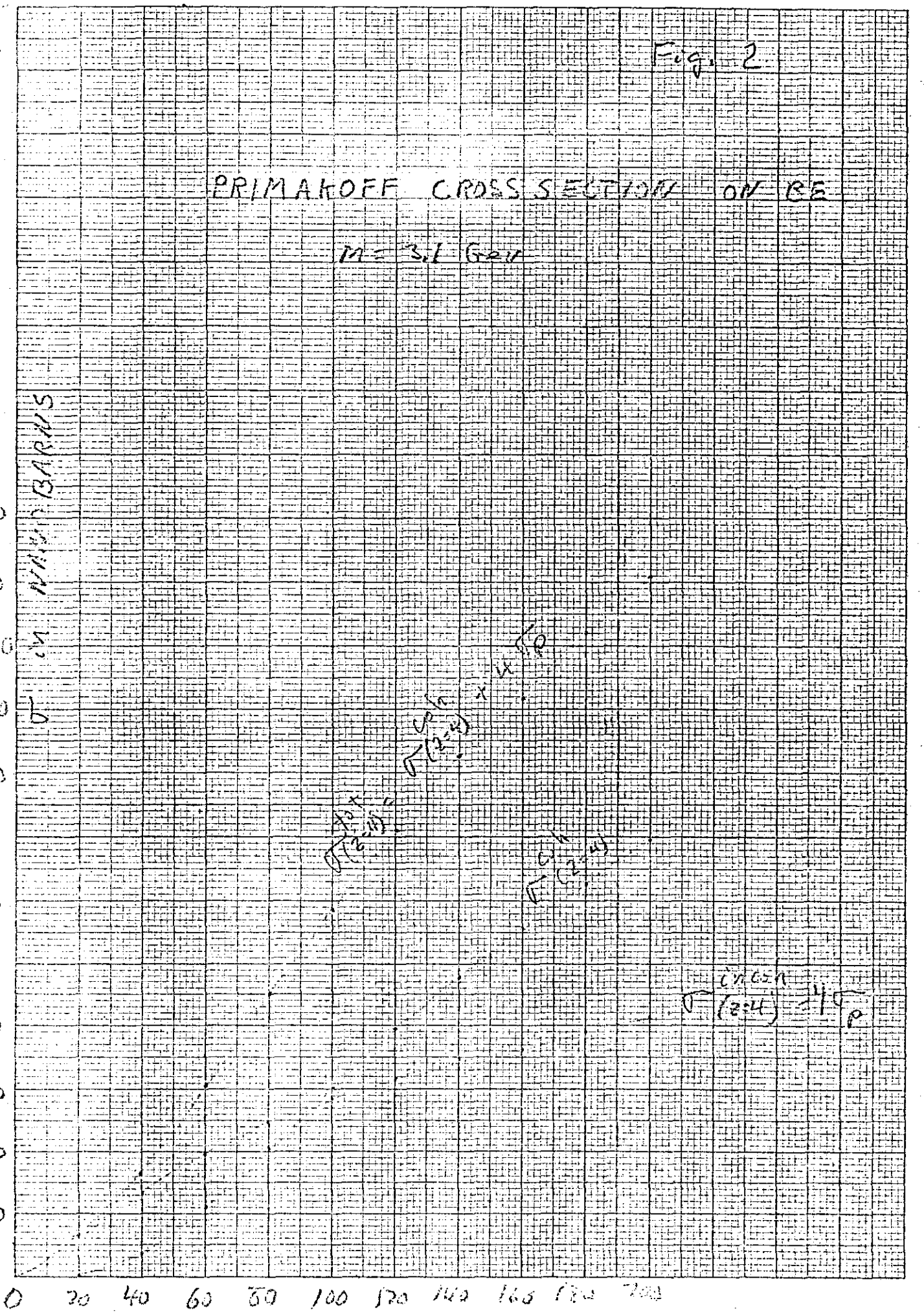


Figure 1
Schematic of Experimental Setup



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K&E 10 X 10 TO 1/2 INCH, 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.