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Comparison of the Differential Cross-sections for $\pi^- p \rightarrow \eta' n$ and $\pi^- p \rightarrow \eta n$ at 8.4 GeV/c*

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ABSTRACT

We present preliminary data, based on 45% of our sample, from a simultaneous study of $\pi^- p \rightarrow \eta' n$, $\eta' \rightarrow \eta\pi^+\pi^-$, $\eta \rightarrow \gamma\gamma$ (1770 events) and $\pi^- p \rightarrow \eta n$, $\eta \rightarrow \pi^0\pi^+\pi^-$, $\pi^0 \rightarrow \gamma\gamma$ (3250 events) at 8.4 GeV/c, covering a range of momentum transfer t' from 0 to 1.7 $(GeV/c)^2$. Both charged pions and both γ's from each reaction were measured in the Charged and Neutral Spectometer at the Argonne ZGS. Backgrounds are 2 - 5%. We find the shapes of $d\sigma/dt$ for the two reactions are significantly different, the η' having considerably less forward turnover. The ratio of $d\sigma/dt$ at t'=0 is (within our present understanding of the systematics) consistent with a simple quark model and a quadratic mixing angle $\sim -10^o$.

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DISCLAIMER

It is widely held that the ψ particles are nearly pure "hidden charm" $c\bar{c}$ states with very small admixtures of other kinds of $q\bar{q}$ pairs, and that their long lifetimes may be explained by Zweig's rule. Much recent attention has therefore recently been given to understanding the mixing of the old "charmless" mesons. The pseudoscalar I=0 mesons η,η' differ from the vectors (ω,ϕ) and tensors (f,f') in that ϕ and f' apparently have nearly pure $s\bar{s}$ (strange quark) composition, while the η' is more nearly an SU(3) singlet. This is inferred both from the quadratic mass formula and from the strong Zweig's rule suppression of ϕ and f' production from pion beams.

The relative cross-sections for the reactions

$$\pi^- p \rightarrow \eta n \tag{1}$$

$$\pi^- p \rightarrow \eta' n \tag{2}$$

contain information about the η,η' mixing angle, as was pointed out long ago[1]; larger strange quark content for the η' leads to a suppression of reaction (2). In the simplest model[1] the relative matrix elements for the two reactions should be given by the relative nonstrange quark content of the η and η', or

$$R \equiv |M_\eta|^2 / |M_{\eta'}|^2 = \tan^2(\alpha-\beta) \approx 1.04,$$

where α = magic mixing angle for pure $s\bar{s}$, = 35.3°

β = η,η' mixing angle, = -10.3° from quadratic mass formula.

A small correction ($\sim$10% at 8.4 GeV) is needed to account for the slightly different available phase space. In addition, form factor effects may make it advisable to do the comparison in the forward direction ($t'=0$).

Previous experimental measurements[2,3,4] of R have been severly limited by statistics and/or by the uncertainty in the $\eta' \to \gamma\gamma$ branching ratio. Typically $R \sim 2$-4, the highest-statistics reported measurement[4] (at 40 GeV) giving $1/R = 0.52 \pm .07$ at $t = 0$. Such a large value of R implies a mixing angle $\beta \simeq -20^{o}$, inconsistent with the quadratic mass formula (but much more consistent with a linear mass formula).

We report here preliminary results of a high-statistics comparison of reactions (1) and (2) at 8.4 GeV/c in which the decays $\eta \to \pi^{o}\pi^{+}\pi^{-}$ (with $\pi^{o} \to \gamma\gamma$) and $\eta' \to \eta\pi^{+}\pi^{-}$ (with $\eta \to \gamma\gamma$) were observed in the Charged and Neutral Spectrometer at the Argonne ZGS. The present data sample, about 45% of the total, contains 3250 ηn and 1770 $\eta' n$ events in the momentum transfer range $0.0 < |t'| < 1.7$ $(GeV/c)^2$. Data were collected simultaneously for both reactions. We have previously published results[5] at 6.0 GeV/c on reaction (1) which agree very well with older data at 5.9 GeV/c.

The apparatus, shown in Figure 1, is described in detail elsewhere.[5] It measure the vector momenta of both charged pions and both γ's in the $\pi^{+}\pi^{-}\pi^{o}$ and $\pi^{+}\pi^{-}\eta$ final states; the recoil neutron is not detected. Momentum analysis of the π^{+} and π^{-} is performed in a large aperture magnetic spectrometer using conventional magnetostrictive spark chambers. Immediately downstream is a thin ($1\frac{1}{2}$ radiation length) lead converter followed by three magnetostrictive spark chambers to record the shower conversion points. An array of 56 lead glass Cerenkov counters measures the shower energies. The whole apparatus is made as short and wide as possible to maximize the acceptance for multiparticle final states; the magnet is less than a meter deep, and the 1.52×1.52 m^2 lead glass array is only 3.8 m from the hydrogen target. Scintillator hodoscopes allow approximate selection of charged and shower multiplicities, and scintillator-lead sandwiches surrounding the target reject most recoils other than neutrons.

Histograms of $\gamma\gamma$ and $\pi^+\pi^-\gamma\gamma$ effective masses, and of nucleon missing mass, are shown in Figures 2 and 3 for the η and η' reactions respectively. The arrows indicate the cuts which define the accepted events. The regions of $\pi^+\pi^-\pi^o$ and $\pi^+\pi^-\eta$ mass labeled BG are used to make a background subtraction (typically 2.7% and 5.2% for reactions (1) and (2) respectively) in each t' bin. We have applied corrections of 20% (11%) for good events chopped off in the tails of the distributions in Figure 2 (Figure 3). We believe that missing masses above the neutron contribute negligible background with the cuts as shown.

Corrections to the data are very similar to those described in Reference 5, and are generally the same for reactions (1) and (2), since both are seen as $\pi^- p \rightarrow \pi^+\pi^-\gamma\gamma$. The most important source of relative systematic error is the Monte Carlo acceptance calculation, which should eventually be accurate to 5-10%. However, we are not fully satisfied with the preliminary version used here and believe it may introduce t-dependent systematic errors $\sim$25% due to inadequate treatment of counter holes around the beam.

In order to compare reactions (1) and (2) we must correct for unobserved decay modes. We have used the following branching ratios[6]: $(\eta \rightarrow \pi^+\pi^-\pi^o)/\mathrm{all} = .239 \pm .006$, $(\eta' \rightarrow \pi^+\pi^-\eta)/\mathrm{all} = 2/3\ (.706 \pm .025)$, $(\eta \rightarrow \gamma\gamma)/\mathrm{all} = .380 \pm .010$.

Preliminary differential cross-sections for reactions (1) and (2) at 8.4 GeV/c, corrected for unseen decay modes, are shown in Figure 4.

The curve through the η data is an interpolation between fits to our 6 GeV/c data[5] and those of others[7] at energies up to 100 GeV. Significant deviations from this curve are likely to reflect inadequacies in the present acceptance calculation.

It is clear from Figure 4 that the η and η' differential cross sections do not have the same shape. The η data turns over sharply in the forward direction, falling a factor ∿2 inside $|t'| = 0.1$; similar behavior was seen in our 6 GeV/c data, and also in recent results from Fermilab[7,8] at energies of 20 to 200 GeV. The η' cross section does not turn over to any comparable extent, but remains roughly constant as t' approaches zero. No previous experiment has had sufficient statistics at small $|t'|$ to see this effect. The η' differential cross section also exhibits a steeper slope between $0.25 < |t'| < 0.8\ (\text{GeV}/c)^2$.

As a result of the different shapes, comparisons of the total cross-sections, or of dσ/dt outside $|t'| = 0.1\ (\text{GeV}/c)^2$, gives a ratio $R \sim 2$, in agreement with previous results and implying a mixing angle $\simeq -20^\circ$, roughly consistent with a linear mass formula. At $|t'| = 0$, however, dσ/dt for the two processes is (within our present understanding of the systematics) nearly equal, as a mixing angle $\simeq -10^\circ$ consistent with the quadratic mass formula would imply.

We note in conclusion that it is certainly plausible to interpret the difference in shapes as arising from different contributions to reactions (1) and (2) from nucleon helicity flip and nonflip amplitudes, with the nonflip cross-sections approximately equal for η and η', but the η' flip cross section conspicuously smaller than that for η. The question then becomes, which of these amplitudes is better described by the quark model?

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FIGURE CAPTIONS

Figure 1. Layout of the experiment. The scale along the beam direction has been slightly expanded for clarity, and the spark chambers which measure the beam direction are not shown.

Figure 2. (a) $\pi^+\pi^-\pi^o$ effective mass. (b) $\gamma\gamma$ effective mass. (c) Nucleon missing mass. The arrows indicate the cuts for selecting good events. Events in the regions labeled BG are used for the background subtraction.

Figure 3. (a) $\pi^+\pi^-\eta$ effective mass. (b) $\gamma\gamma$ effective mass, (c) Nucleon missing mass. The arrows indicate the cuts for selecting good events. Events in the regions labeled BG are used for the background subtraction.

Figure 4. Differential cross sections for $\pi^-p \to \eta n$ and $\pi^-p \to \eta' n$, corrected for unseen decay modes. The curve through the data is discussed in the text.

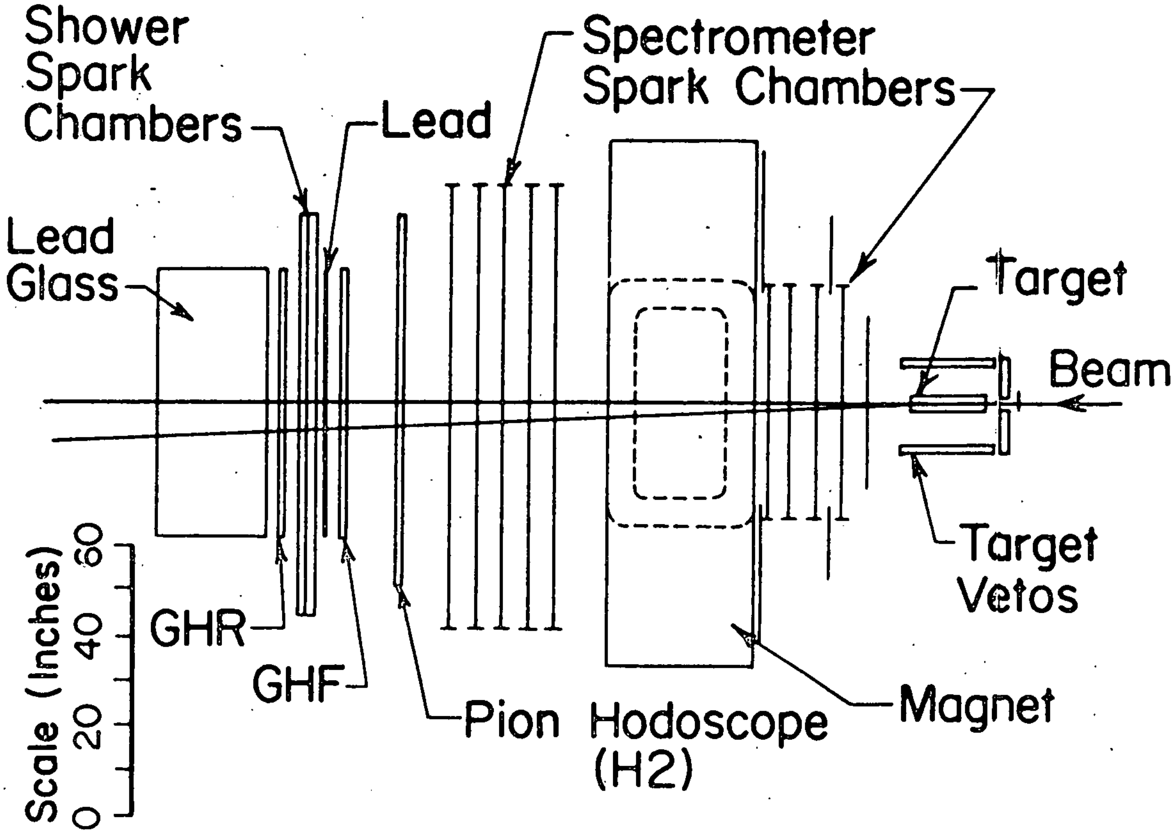
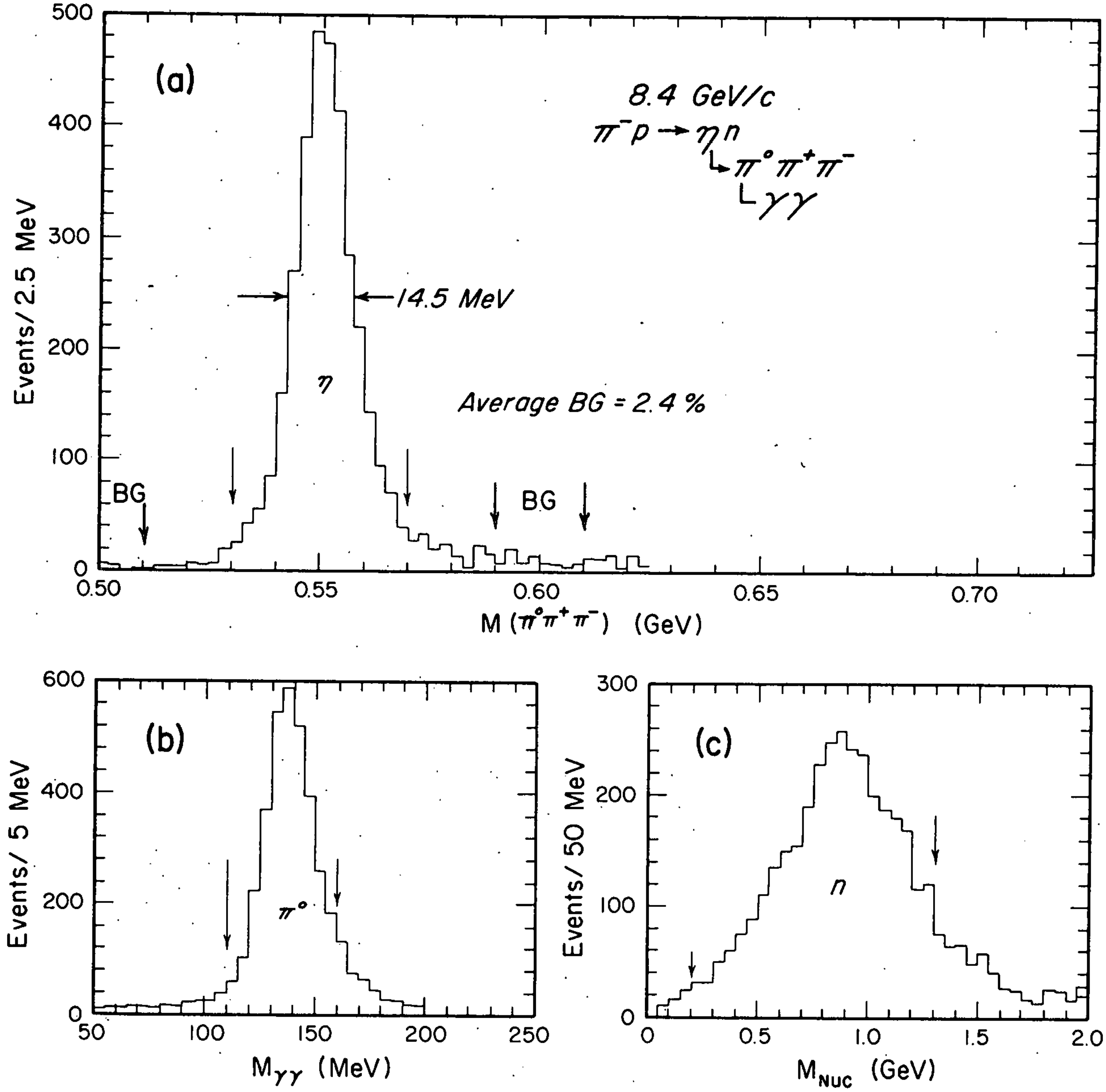
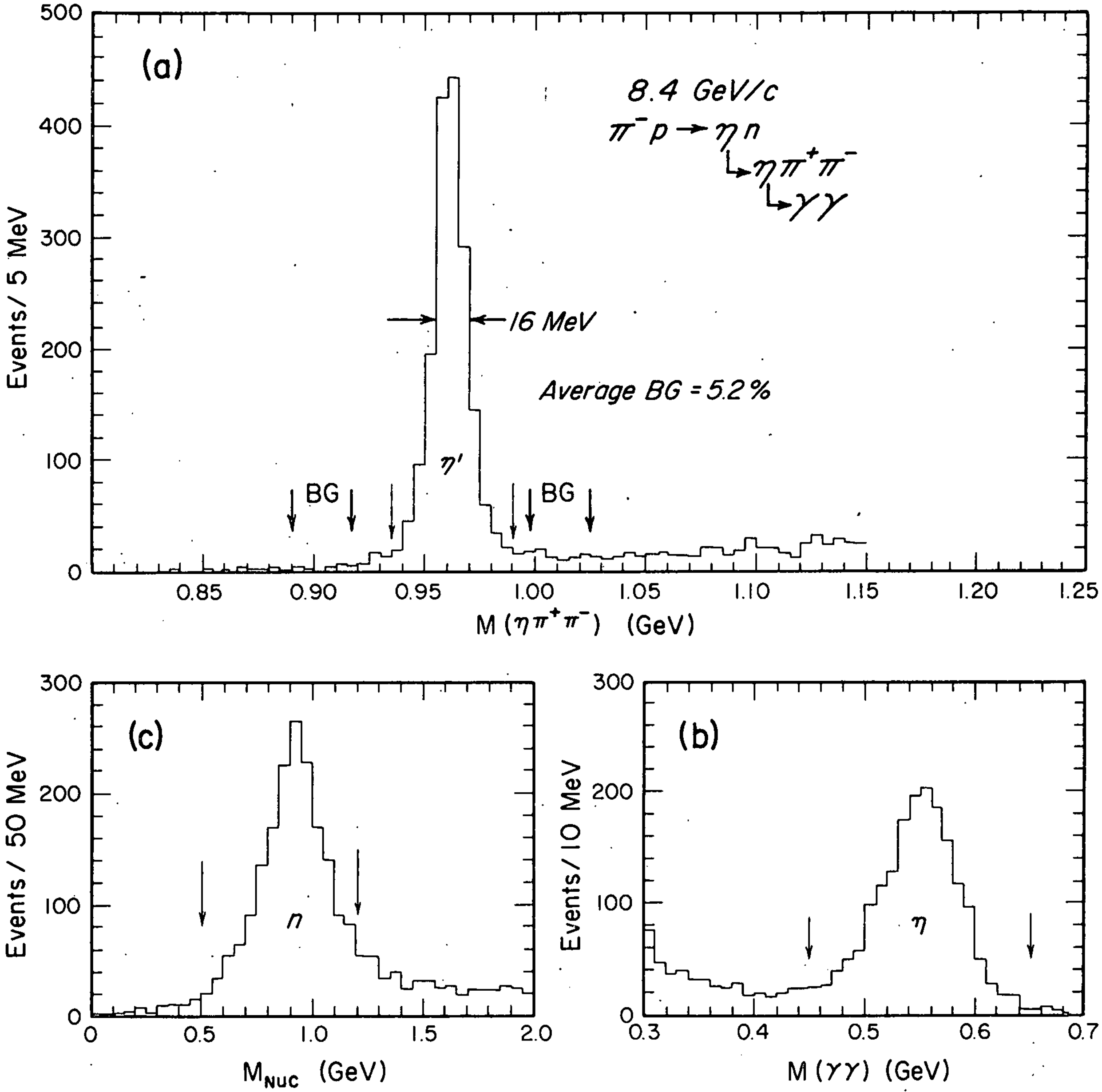

Shower Spark Chambers
Lead
Spectrometer Spark Chambers
Lead Glass
Target
Beam
Target Vetos
Magnet
GHR
GHF
Pion Hodoscope (H2)
Scale (Inches)
0
20
40
60

Figure 1.



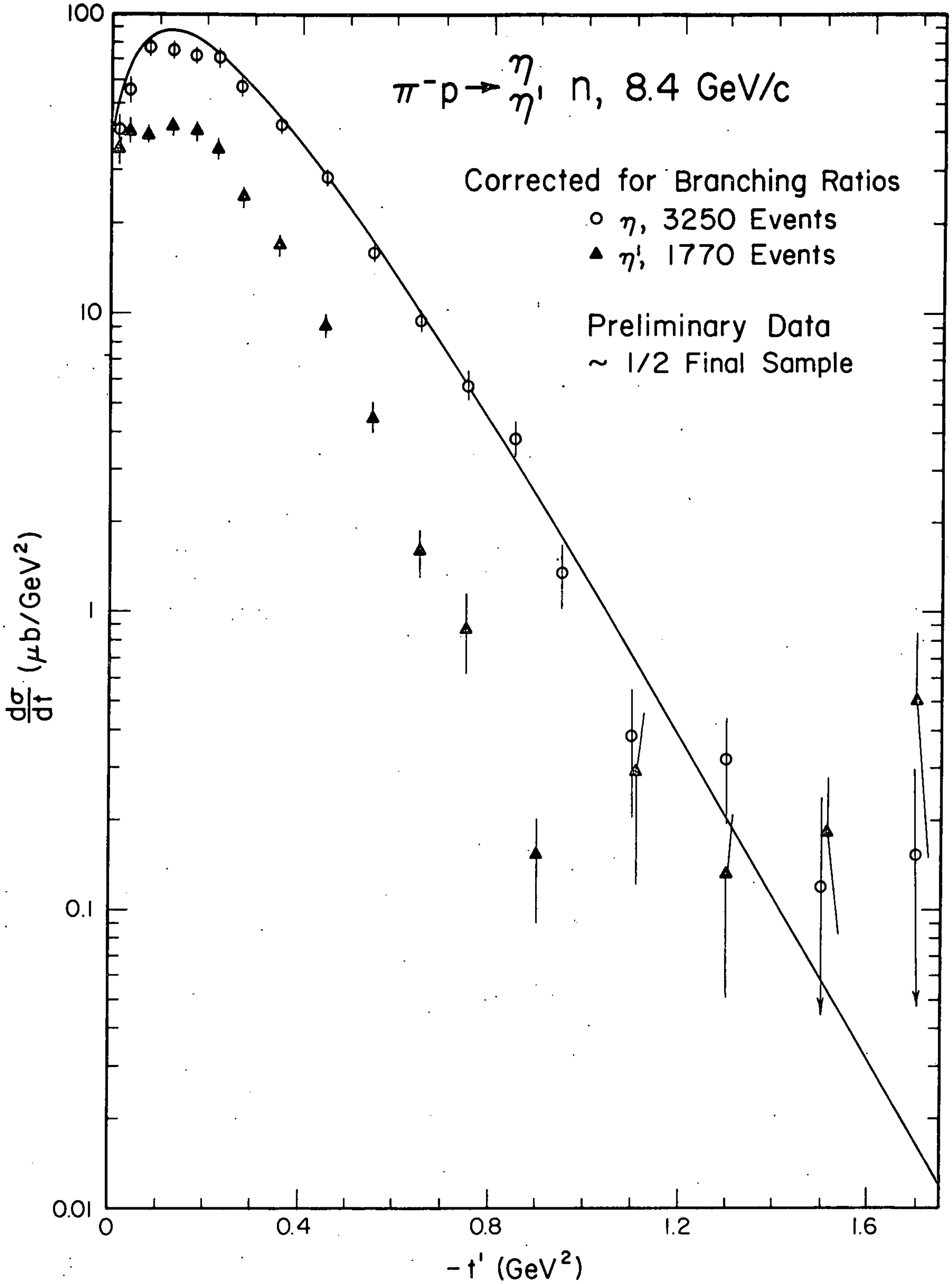
(a)
8.4 GeV/c
π⁻p → ηn
↳ π°π⁺π⁻
↳ γγ
14.5 MeV
η
Average BG = 2.4 %
BG
BG
Events/ 2.5 MeV
M (π°π⁺π⁻) (GeV)
(b)
π°
Events/ 5 MeV
Mγγ (MeV)
(c)
n
Events/ 50 MeV
MNUC (GeV)

Figure 2.



(a)
8.4 GeV/c
π⁻p → η′n
↳ηπ⁺π⁻
↳γγ
16 MeV
Average BG = 5.2 %
η′
BG
BG
Events/ 5 MeV
M (ηπ⁺π⁻) (GeV)
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
1.25
(c)
n
Events / 50 MeV
M_NUC (GeV)
(b)
η
Events/ 10 MeV
M (γγ) (GeV)

Figure 3.



$\pi^- p \to \eta, \eta'$ n, 8.4 GeV/c
Corrected for Branching Ratios
○ η, 3250 Events
▲ η', 1770 Events
Preliminary Data
~ 1/2 Final Sample
100
10
1
0.1
0.01
0
0.4
0.8
1.2
1.6
$\frac{d\sigma}{dt}$ (μb/GeV^2)
$-t'$ (GeV^2)

Figure 4.