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BRANCHING RATIOS OF THE A_2^+ MESON OBSERVED IN 7 GeV/c $\pi^+ p$ INTERACTIONS*

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ABSTRACT

The observed branching fractions of the A_2^+ produced in the reaction $\pi^+ p \rightarrow A_2^+ p$ at 7 GeV/c and decaying to $\rho\pi$, $\eta\pi$, $K\bar{K}$, and $\eta'\pi$ are presented. The data show no convincing evidence for the decay $A_2^+ \rightarrow \eta' \pi^+$, the branching fraction being less than 3%. For the other decay modes the values obtained for $\rho\pi$, $\eta\pi$, and $K\bar{K}$ are 0.744 ± 0.029, 0.183 ± 0.026, and 0.072 ± 0.012 respectively.

The A_2 meson has been an object of intense interest because structure has been reported in its mass distribution [1], suggesting the possibility that the A_2 region may contain more than one resonance. If this is the case the observed branching ratios into various decay modes may depend upon the production mechanisms of the resonances. Measurements of the apparent branching ratios of the A_2 produced under different experimental conditions may therefore help in understanding the nature of the observed structure.

Using the SLAC 82-inch bubble chamber, we have studied the production of the A_2^+ in $\pi^+ p$ interactions at 7.1 GeV/c and its decay into all reported decay modes ($K^+\bar{K}^0$, 3π or $\rho\pi$, $\eta\pi^+$, and $\eta'\pi^+$). The mass spectra obtained in this experiment [2] do not show the particular structure reported in previous experiments. The A_2^+ was produced in the reaction $\pi^+ p \to A_2^+ p$, followed by the decays:

$$A_2^+ \to K^+ K_1^0 \qquad (1)$$
$$\hookrightarrow \pi^+\pi^-$$

$$A_2^+ \to \pi^+ \rho \quad \text{or} \quad A_2^+ \to \pi^+\pi^+\pi^- \qquad (2)$$
$$\hookrightarrow \pi^+\pi^-$$

$$A_2^+ \to \pi^+ \eta \qquad (3)$$
$$\hookrightarrow \pi^+\pi^-\pi^0$$

$$A_2^+ \to \pi^+ \eta' \qquad (4)$$
$$\hookrightarrow \pi^+\pi^-\eta$$
$$\hookrightarrow \text{neutrals}$$

Events of reaction (1) appear in the chamber as V-2 prongs; reactions (2)-(4) are 4-prongs.

The acceptance criteria for the reactions (1)-(3) are described in reference [2]. For reaction (4) we tried the two-constraint hypothesis $\pi^+ p \to \pi^+ p\eta'$ followed by $\eta' \to \pi^+\pi^-\eta$ and used acceptance criteria [3] similar to those for reaction (3). Fig. 1a shows $M(\pi^+\pi^-\eta)$ obtained from the one-constraint fit $\pi^+ p \to \pi^+ p \pi^+\pi^- \eta$ with the events accepted into the $\eta' \to \pi^+\pi^-\eta$ sample shaded.

We improved the A_2 signal-to-noise ratio in reactions (2) to (4) by making two cuts on the data from the 4-prongs: 1) we removed events with $M(\pi^+ p) < 1.38$ GeV to remove potential Δ^{++}; 2) for reaction (2) we removed all events with four-momentum transfer to the proton, $|t_{pp}|$ less than 0.2 $(\text{GeV}/c)^2$; this cut removes most of the A_1 signal.

In addition, in all decay channels we have removed events with $|t_{pp}|$ greater than 0.8 $(\text{GeV}/c)^2$. This cut was made because we only measured 4-prongs in which the scanner had recorded a dark track [4].

After these cuts were made we obtained the mass distributions shown in fig. 2. A clear A_2^+ signal is seen in the first three decay modes but not in the $\eta'\pi^+$ mass distribution.

To obtain the number of events in each A_2^+ decay channel we fit a Breit-Wigner with a linear background to our mass distributions. See table 1 and fig. 2. If more than one resonance contributes to the A_2 region, this procedure would be open to question. However, the Breit-Wigner gives an adequate fit to our data [2]. We estimated the errors by hand-drawing various backgrounds and counting the variation of the number of events in the A_2^+ signal. For the $K^+\bar{K}^0$ and $\eta\pi^+$ channels the background is quite small whereas it is large for the 3π decay mode. In addition, the shape of the background is complicated by the presence of

some A_1 signal in the 3π mode and by a peak between 1.6 and 1.7 GeV in the 3π and $K\bar{K}$ channels. Both these effects increase the uncertainty in the measurement of the A_2^+ signal. Since there is no peak at the A_2 mass in the $\eta'\pi$ mass distribution, we give only an upper limit in this channel.

Corrections were made for the following detection efficiencies and losses caused by the selections made on the data (see table 2).

1) A correction was made for scanning efficiency.

2) We made a correction for the efficiency of the measurement and analysis system. We find that the slightly different acceptance criteria used for different topologies has negligible effect on the branching ratios.

3) From the measurements of 4-prongs with no dark track we find that the loss from our dark track 4-prongs due to the scanning error in identifying dark tracks is $6 \pm 1\%$ for the $\eta\pi$ and $\eta'\pi$ and $8 \pm 1\%$ for the 3π sample.

4) A correction is required for the lower $|t_{pp}|$ cut in the 3π events. To estimate this loss we plotted the $|t_{pp}|$ distributions from the $\eta\pi$ (no Δ^{++}) and $K\bar{K}$ events (fig. 1b and 1c). We find that they are the same within statistics so we combine them. Using this distribution, we find 111 events below $|t_{pp}| = 0.2$ and 193 events above, giving a fraction of $64 \pm 3\%$ above $|t_{pp}| = 0.2$ $(\text{GeV}/c)^2$. If more than one resonance contributes to the A_2 region, then the t-distribution in the three channels may be different. In that case, our branching ratios involving the 3π mode should be interpreted as being valid only for the momentum transfer region $0.2 < |t_{pp}| < 0.8$ $\text{GeV}/c)^2$.

5) By examining the Dalitz plots and mass plots for events with and without Δ^{++} we find that the Δ^{++} cut has removed $8 \pm 2\%$, $12 \pm 3\%$

and $13 \pm 6\%$ from the 3π, $\eta\pi$, and $\eta'\pi$ samples respectively.

6) The events in the $\eta\pi^+$ channel contain η events which decay via $\eta \to \pi^+\pi^-\gamma$ but fit $\eta \to \pi^+\pi^-\pi^0$ within our acceptance criteria. We generated events by using the computer code PHONY [5] for $A_2^+ \to \eta\pi^+$, followed by $\eta \to \pi^+\pi^-\pi^0$ or $\eta \to \pi^+\pi^-\gamma$. We find that 8% of the generated $\eta \to \pi^+\pi^-\gamma$ events are accepted as $\eta \to \pi^+\pi^-\pi^0$, giving a 2% contamination in our $\eta \to \pi^+\pi^-\pi^0$ sample.

7) The $K^+K_1^0$ events were corrected for the K_1^0 decaying very close to the production vertex or outside the fiducial volume. The K_1^0 proper time distribution was consistent with that expected from the known K_1^0 lifetime [6]. The average detection efficiency in the A_2 region was $95.3 \pm 0.5\%$.

Using the detection efficiencies in table 2, we obtain the "corrected" number of A_2^+ events in table 1. A further correction is made for the unseen decay modes of the η, η', and K^0 by using the branching ratios and errors given in reference [6].

We cannot observe the decay $A_2^+ \to \pi^+\pi^0\pi^0$. If we <u>assume</u> that all A_2's decaying into the 3π channel contain a ρ then the number of $\pi^+\pi^0\pi^0$ decays is equal to the number of $\pi^+\pi^+\pi^-$ [7]. Then we obtain branching fractions for the $\rho\pi$, $\eta\pi$, and $K\bar{K}$ channels of 0.744 ± 0.029, 0.183 ± 0.026, and 0.072 ± 0.012 respectively. For $\eta'\pi$ we obtain an upper limit of 3%.

The branching ratios that we obtain for $K\bar{K}/\rho\pi$ and $\eta\pi/\rho\pi$ agree with those reported by some previous experiments, but are significantly larger than values reported by other experiments [8]. Since the experiments were performed under various conditions (for example, identity, charge or momentum of the incident particle, momentum transfer region,

or decay mode studied) these disagreements could be interpreted as evidence that the A_2 mass region contains more than one resonance. It is also possible that they are the result of systematic errors in estimating backgrounds.

We thank Joseph J. Murray for his work in beam design and construction. We gratefully acknowledge the assistance of the staff of the Stanford Linear Accelerator and the 82-inch bubble chamber in obtaining the data for this experiment. We also thank Lawrence Radiation Laboratory Group A Scanning and Measuring Group for their help in data reduction.

Footnotes and References

*Work done under the auspices of the U. S. Atomic Energy Commission.

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3. The criteria for η and η' selection differ only in that a missing π^0 is replaced by a missing η. (See reference [2].)

4. To estimate the detection efficiency for our 4-prong sample we measured about 20% of the 4-prong events which the scanner had recorded as having no dark track. From these measurements we find that the correction to our sample should be 10% at $|t_{pp}| = 0.5$, 25% at $|t_{pp}| = 0.7$, and 40% $|t_{pp}| = 0.8$. In our $\eta\pi^+$ sample with Δ^{++} removed (fig. 1c) for $|t_{pp}| > 0.8$ $(\text{GeV}/c)^2$ the correction is large, the number of events small, and the estimation of this correction is inaccurate.

5. E. Burns and D. Drijard, Trilling-Goldhaber Lawrence Radiation Laboratory Technical Note No. 143, 1968 (unpublished).

6. Particle Data Group, Review of Particle Properties, Phys. Letters 33B (1970) 1.

7. From a preliminary analysis of the Dalitz plot of 3π events in the A_2 mass region (1200 to 1400 MeV) we find that our data are consistent with this assumption.

8. The values of all reported branching ratios are tabulated in reference [6]. The experiments contributing are:

F. Conte et al. Reaction $\pi^- p$ at 11 GeV/c (Genoa-DESY-Milano-Saclay collaboration), Nuovo Cimento 51A (1967) 175.

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Table 1. A_2^+ Branching ratios

Decay mode	$\pi^+\pi^+\pi^-$	$\rho\pi$	$\eta\pi^+$	$K^+\bar{K}^0$	$\eta'\pi^+$
All events observed 1.0 - 1.6 GeV	4084[a]		288	183	66
A_2 events in B-W[b] 1.0 - 1.6 GeV	945± 90[a]		167±20	113±16	<30
A_2 events corrected for experimental detection efficiency. See table 2	2023±231		230±30	131±19	<43
A_2 events corrected for unseen decays	2023±231	4046±462[c]	996±137	393±57	<136
Branching fraction (%)		74.4±2.9[c]	18.3±2.6	7.2±1.2	< 3

a) $|t_{pp}| > 0.2$ (GeV/c)^2.

b) The errors on these numbers obtained from the fit of a B-W resonance above a linear background are ±48, ±14, and ±12 for the $\pi^+\pi^+\pi^-$, $\eta\pi^+$, and $K^+\bar{K}^0$ channels. These errors were increased because of the uncertainty in estimating the shape of the background.

c) Assuming that in the $A_2^+ \to 3\pi$ decay mode all events contain a ρ. Branching ratios are:

$$K\bar{K}/\rho\pi = 9.7\pm1.8\%\,, \quad \eta\pi/\rho\pi = 24.6\pm4.2\%\,, \quad \eta'\pi/\rho\pi < 4\%\,, \quad K\bar{K}/\eta\pi = 39.5\pm7.9\%$$

Table 2. Detection efficiencies, in percent

Decay mode	$\pi^+\pi^+\pi^-$	$\eta\pi^+$	$K^+\bar{K}^0$	$\eta'\pi^+$
Scanning	98±1	98±1	94±3	98±1
Measuring	88±3	88±3	96±3	88±3
Dark proton	92±1	94±1	100	94±1
$\|t_{pp}\|$ cut	64±3	100	100	100
Δ^{++} cut	92±2	88±3	--	87±6
$\eta \to \pi^+\pi^-\gamma$ contamination	--	102±0.5	--	--
K_1^0 escape	--	--	95.3±0.5	--

Figure Legends

Fig. 1. a) $M(\eta\pi^+\pi^-)$ in the η' region for events fitting $\pi^+p \to \pi^+p\pi^+\pi^-\eta$ and with $M(\eta\pi^+\pi^-\pi^+) < 1.75$ GeV. The shaded events were accepted into the η' sample. When events containing a $\Delta^{++}[M(\pi^+p) < 1.38$ GeV] were removed, a similar η' signal-to-background ratio was found for the remaining events.

b) Momentum transfer $|t_{pp}|$ for reaction (1).

c) $|t_{pp}|$ for reaction (3). The shaded areas show the correction for dark track scanning efficiency (see text).

Fig. 2. Mass distributions for the decay modes a) $A_2^+ \to K^+\bar{K}^0$, b) $A_2^+ \to \pi^+\pi^+\pi^-$, c) $A_2^+ \to \eta\pi^+$, d) $A_2^+ \to \eta'\pi^+$. For the $K^+\bar{K}^0$, $\eta\pi^+$, and $\eta'\pi^+$ samples $|t_{pp}| < 0.8$ $(\text{GeV}/c)^2$; for the 3π sample, $0.2 < |t_{pp}| < 0.8$ $(\text{GeV}/c)^2$. The dashed lines indicate the fitted background. The arrow on the $M(\eta'\pi^+)$ histogram is at M = 1307 MeV, the central value of the A_2 obtained from the other decay channels [2].

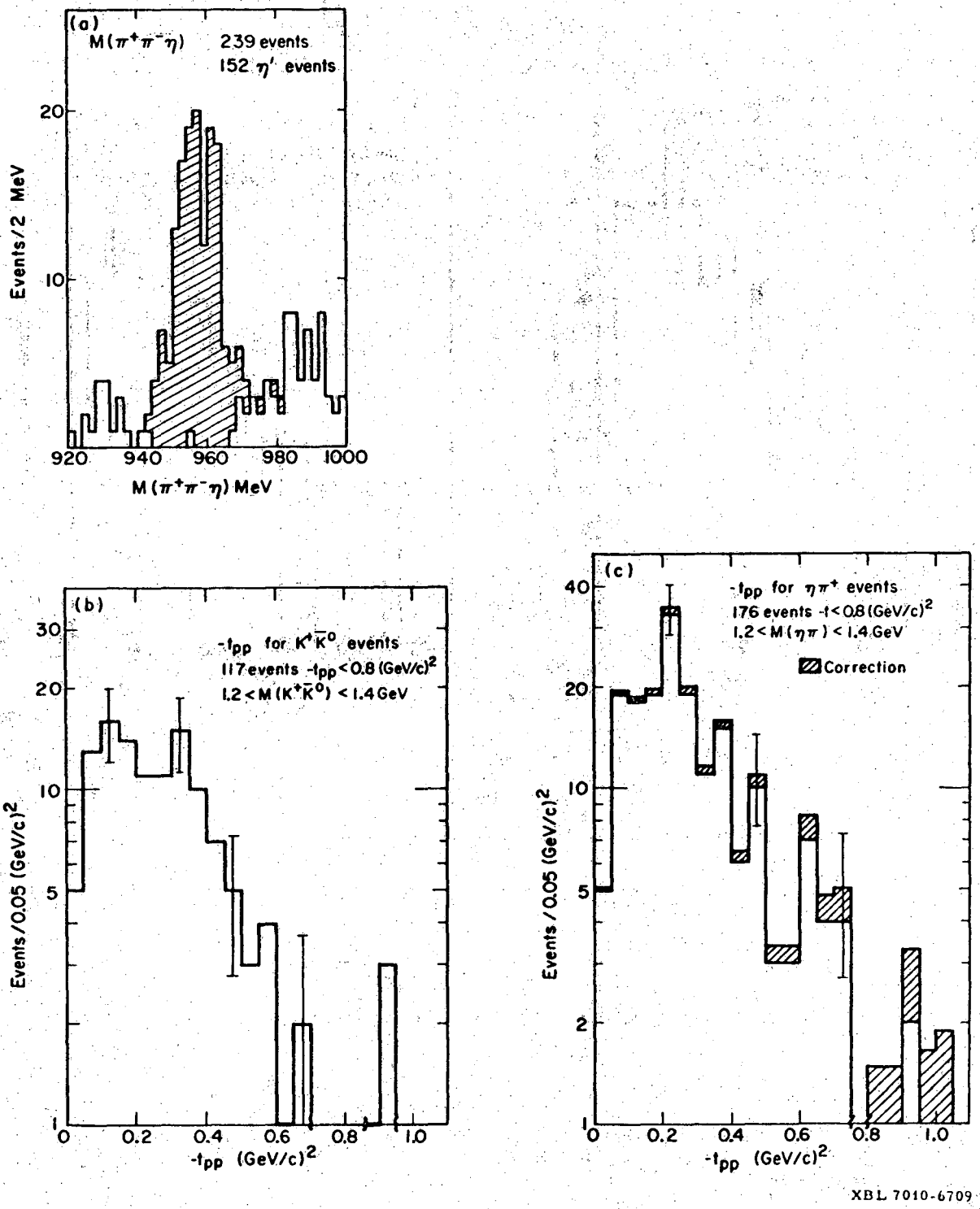
(a)
M(π⁺π⁻η)
239 events
152 η′ events
Events/2 MeV
M(π⁺π⁻η) MeV
(b)
-t_pp for K⁺K̄⁰ events
117 events -t_pp<0.8 (GeV/c)²
1.2<M(K⁺K̄⁰)<1.4 GeV
Events/0.05 (GeV/c)²
-t_pp (GeV/c)²
(c)
-t_pp for ηπ⁺ events
176 events -t<0.8 (GeV/c)²
1.2<M(ηπ)<1.4 GeV
Correction
Events/0.05 (GeV/c)²
-t_pp (GeV/c)²
XBL 7010-6709

Fig. 1

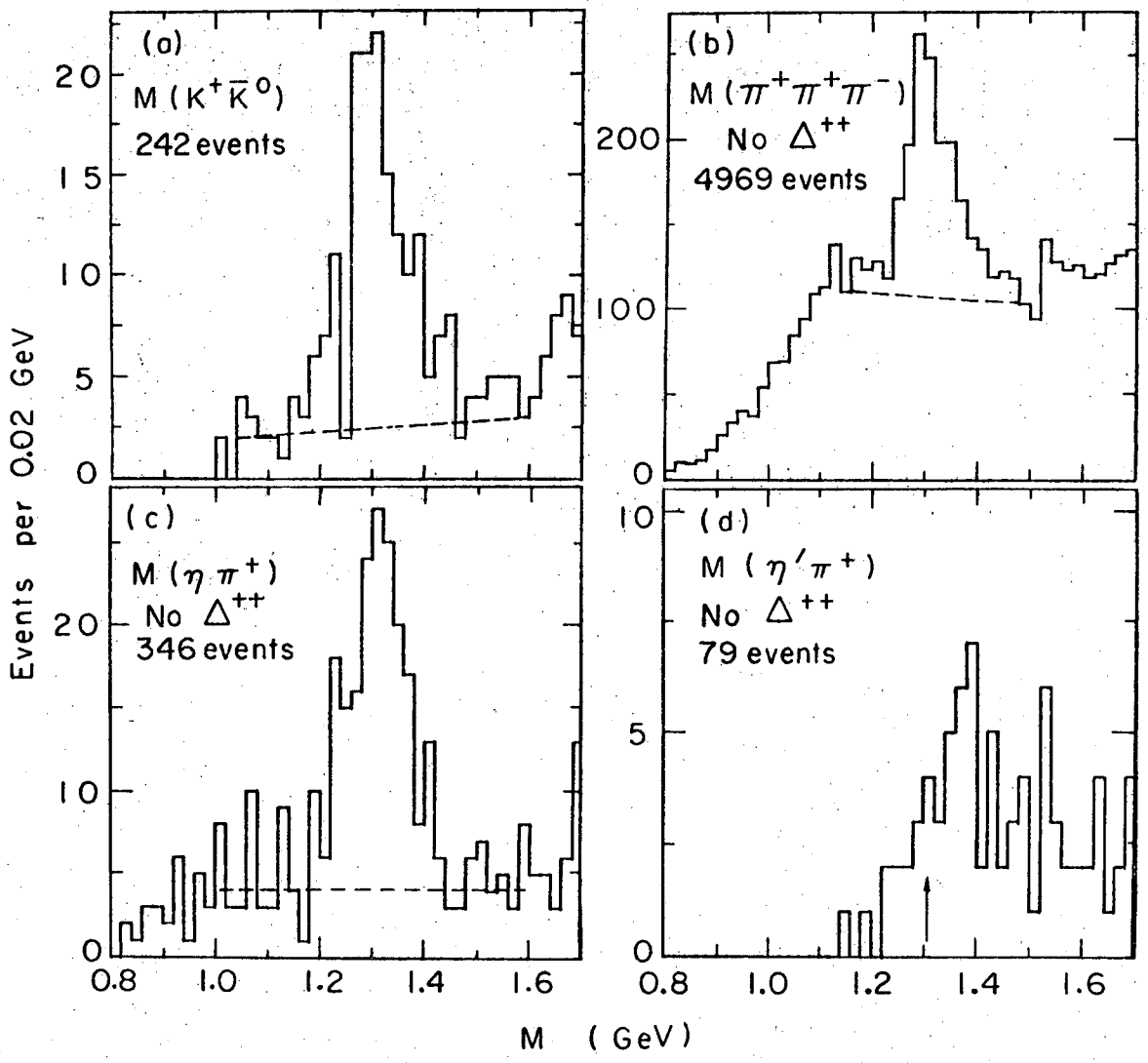
(a)
M (K⁺K̄⁰)
242 events
(b)
M (π⁺π⁺π⁻)
No Δ⁺⁺
4969 events
(c)
M (η π⁺)
No Δ⁺⁺
346 events
(d)
M (η′π⁺)
No Δ⁺⁺
79 events
Events per 0.02 GeV
M (GeV)
0.8
1.0
1.2
1.4
1.6
X BL7010-3983

Fig. 2

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