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A NEW 0^-S MESON AND NEW RESULTS ON THE 1^+S STATE IN THE COHERENTLY PRODUCED 3π SYSTEM

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ABSTRACT

Partial wave analysis has been performed on $\pi^-\pi^-\pi^+$ events coherently produced on nine nuclear targets in a π^- beam of 40 GeV/c. Evidence has been found for a $I^GJ^PL = 1^-0^-S$ resonance at 1.2 GeV with a $\Gamma \simeq 0.330$ GeV and a phase variation of $\sim 80°$. This new state can be interpreted as the first radial excitation of the pion (π').

In the A_1 region the 1^+S state shows a strong phase motion which increases systematically with increasing atomic weight of the target. For the heavy nuclei the relative phase varies by $\sim 120°$.

The 0^- waves are definitely more absorbed by the nuclear matter than are the 1^+ amplitudes.

The behaviour of the hadronic matter immediately after it has been produced can be studied in principle if the production takes place inside the nucleus. The new-born hadronic system can interact with the nucleons before it reaches asymptotic conditions.

A systematic study of the hadronic states going into 3π and 5π channels has been carried out by our Collaboration. The channel

$$\pi^- A \to \pi^- \pi^- \pi^+ A \ , \qquad (1)$$

with A = Be, C, Al, Si, Ti, Cu, Ag, Ta, and Pb, has been studied at 40 GeV at the Serpukhov accelerator (5th Joint CERN-IHEP experiment), with statistics of $\sim$ 120,000 good events. In addition $\sim$ 15,000 events of the channel

$$\pi^- A \to \pi^- \pi^- \pi^- \pi^+ \pi^+ A \qquad (2)$$

on the same targets have been analysed. Details of the experimental set-up can be found elsewhere[1]).

The coherence mechanism is strongly present in the data in the full mass range, as shown by the $t' = |t - t_{min}|$ distributions (see as an example in Fig. 1 the t' distributions of the 3π system in the low-mass region). Coherent samples are defined for every target by selecting the events with t' smaller than the first diffractive minimum. Total cross-sections for the coherent production in the full t' range were also measured by subtracting the incoherent background.

The data of the channel (1) were analysed using the program PWA (partial wave analysis)[2]). The set of important waves in the coherent sample consists of eight contributions: 1^+S, 1^+P, 1^+D, 0^-S, 0^-P, 2^-S, 2^-P, 2^+D. The spin-flip amplitudes have been found negligible. The behaviour of the contributions and of the phase differences for the more important waves has been investigated as a function of $M_{3\pi}$ of the atomic weight (A) of the nuclear target, and of t'.

First of all we have performed the 3π mass-dependent PWA in the sample of the events for all targets together (Fig. 2). The mass shapes and the phase variations show not only for 1^+S, but also for 0^-S amplitudes, a resonance behaviour in the A_1 region.

The parameters of the 0^-S resonance have the following values: $M_{3\pi} \simeq 1.20 \pm 0.03$ GeV and $\Gamma \simeq 0.330 \pm 0.040$ GeV; its phase variation is $\sim 80°$ (Fig. 2).

The quantum numbers, the mass, and the strong decay of this state correspond, in terms of the quark model, to the first radial excitation of the pion[3] (π').

The contribution and the phase variations of the amplitudes have been studied in samples of events from different targets, grouped together as follows: Be + C, Al + Si, Ti + Cu, Ag + Ta + Pb. The 1^+S state shows a striking dependence on the nuclear target: the motion of the 1^+S-0^-P relative phase across the A_1 region increases systematically with increasing A, passing from $\sim 70°$ for the light nuclei to $\sim 120°$ for the heavy ones (Fig. 3).

In any case, for both states it is clear that the nucleus enhances drastically the relative phase motion compared with the interactions on the proton. In Figs. 4 and 5 the relative phases 1^+S-0^-P and 0^-S-0^-P are compared with the data on protons[4] and with the results of a previous experiment on nuclear targets carried out at 15 GeV[5]. The phase motions of 1^+S and 0^-S seem to increase somewhat with the incident energy in the coherent interactions on nuclei.

A different contribution of 1^+S and 0^-S amplitudes as a function of the target atomic weight has been found by analysing the samples on the different targets. In the coherent region and in the full mass range the percentages of the 1^+ state increase with increasing A, while the 0^- state percentages definitely decrease. The increase of the 1^+ state is due mostly to the 1^+S wave; the decrease of the 0^- to the 0^-S wave. These effects are clearly shown by Figs. 6a and 6b. While in the light nuclei the 1^+ and 0^- waves exhibit a flat dependence on t', in the heavy targets the 1^+ waves have a clear enhancement and the 0^- waves a strong depression in the coherent region.

A different dependence on t' for the different nuclear targets is shown also by the relative phase 1^+S-0^-P, which is nearly constant in the light nuclei, whilst it changes rapidly at small t' in the heavy targets (Fig. 7).

From the previous results two sound conclusions can be drawn:

i) The nucleus is a powerful means of selecting and enhancing resonances, as 1^+S and 0^-S.

ii) The characteristics of the 0^-S resonance do not change with the nuclear target, while the 1^+S moves; this is more pronounced the larger the nuclear atomic weight.

We do not have a clear explanation of the 1^+S dependence on the nuclear target. We can only mention some mechanisms which could be responsible for this behaviour:

i) The coherent mechanism selects and enhances the production at very small t'.

ii) The nucleus can absorb in different ways the different states or contributions, and the absorption effects increase with the atomic weight; in such a frame the nuclear absorption could clean up some states, cutting the contribution of mechanisms which normally interfere in a negative way with the resonant states.

iii) An intermediate or transition state, after the hadron-hadron collision but before fixed final states have been reached, probably exists; during this transition time the new-born hadronic matter could interact with the nucleons and its characteristics can be changed, as is found for 1^+S.

A more detailed analysis of the nuclear effects on the contribution of the different waves can be carried out using a specific model. For this purpose the Kölbig-Margolis-Glauber model has been used, even if in its approach the interaction is assumed to be instantaneous and point-like. As is well known, the nuclear absorption is measured by the parameter σ_2, which in the frame of this model is interpreted as the collision cross-section between the state under investigation and the bound nucleons.

The best fit values obtained for σ_2 from the 3π and 5π total samples are of the order of 15 and 8 mb, respectively, with small fluctuations for the different mass regions. For the 3π channel, σ_2 has been evaluated also for the different partial waves. 0^- and 1^+ waves give for σ_2 the following ranges: 21-30 and 11-16 mb, respectively, which reflects the different contributions of these waves in the coherent region as shown in Figs. 6a and 6b.

REFERENCES

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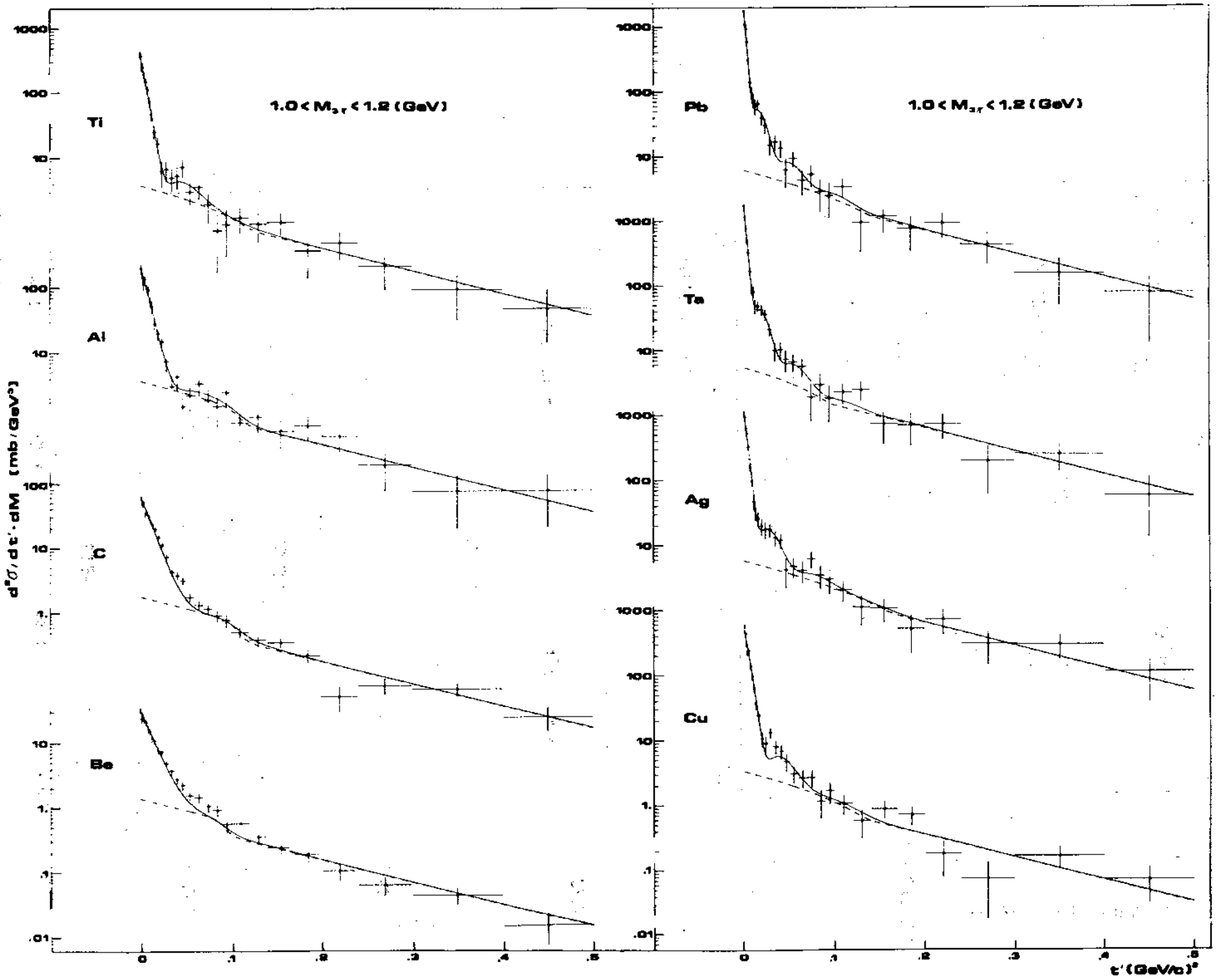
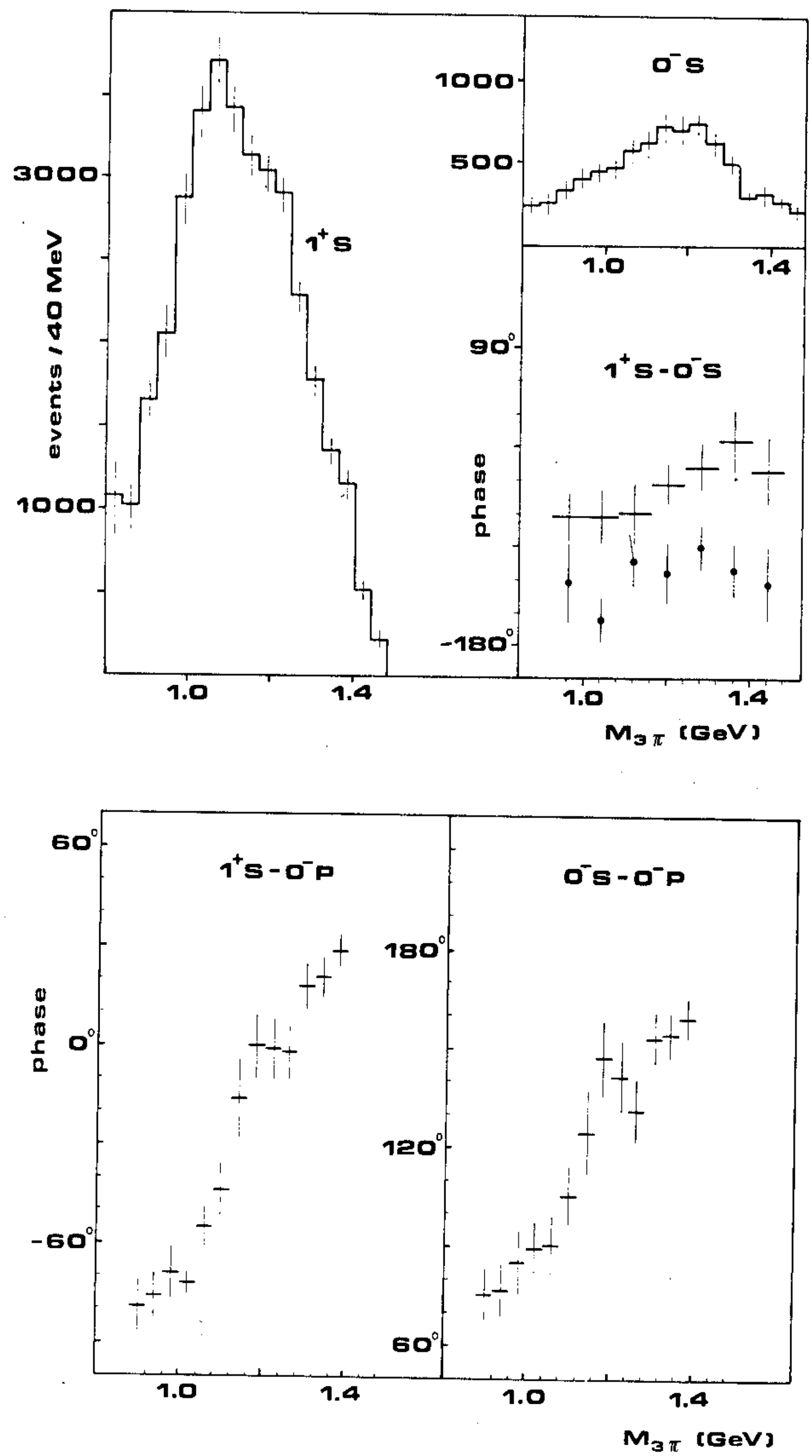
4) C. Daum et al., Diffractive production of 3π states at 63 and 94 GeV, preprint CERN-EP/80-219 (1980).

5) J. Pernegr et al., Nucl. Phys. B134, 436 (1978),



1.0 < M3π < 1.2 (GeV)
1.0 < M3π < 1.2 (GeV)
Ti
Al
C
Be
Pb
Ta
Ag
Cu
d²σ/dt'·dM (mb/GeV³)
t' (GeV/c)²

Fig. 1



1⁺S
3000
1000
events / 40 MeV
1.0
1.4
0⁻S
1000
500
1⁺S-0⁻S
90°
-180°
phase
M₃π (GeV)
1⁺S-0⁻P
60°
0°
-60°
phase
0⁻S-0⁻P
180°
120°
60°
M₃π (GeV)

Fig. 2

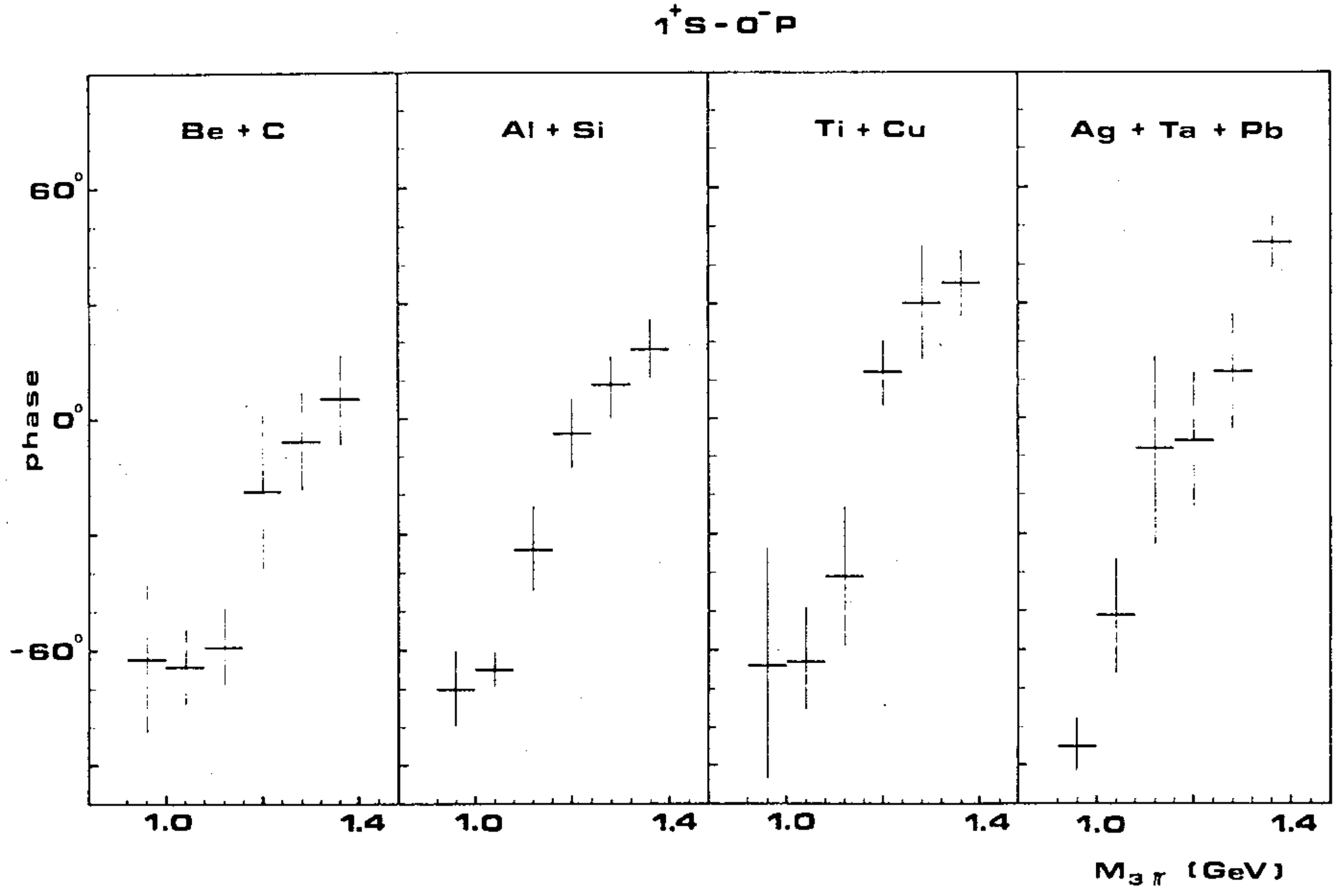
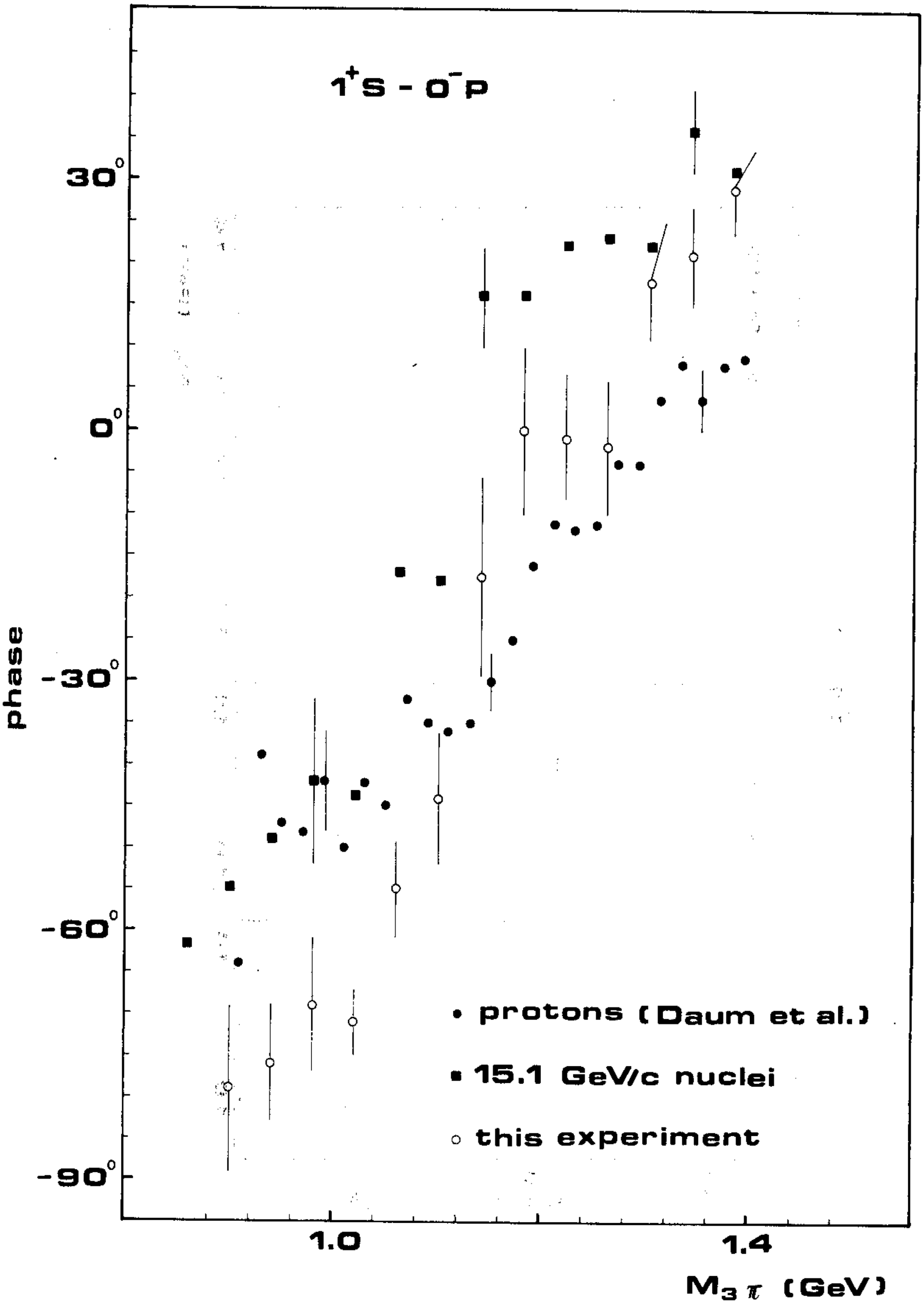


Fig. 3



1⁺S - 0⁻P
30°
0°
-30°
-60°
-90°
phase
1.0
1.4
$M_{3\pi}$ (GeV)
• protons (Daum et al.)
▪ 15.1 GeV/c nuclei
○ this experiment

Fig. 4

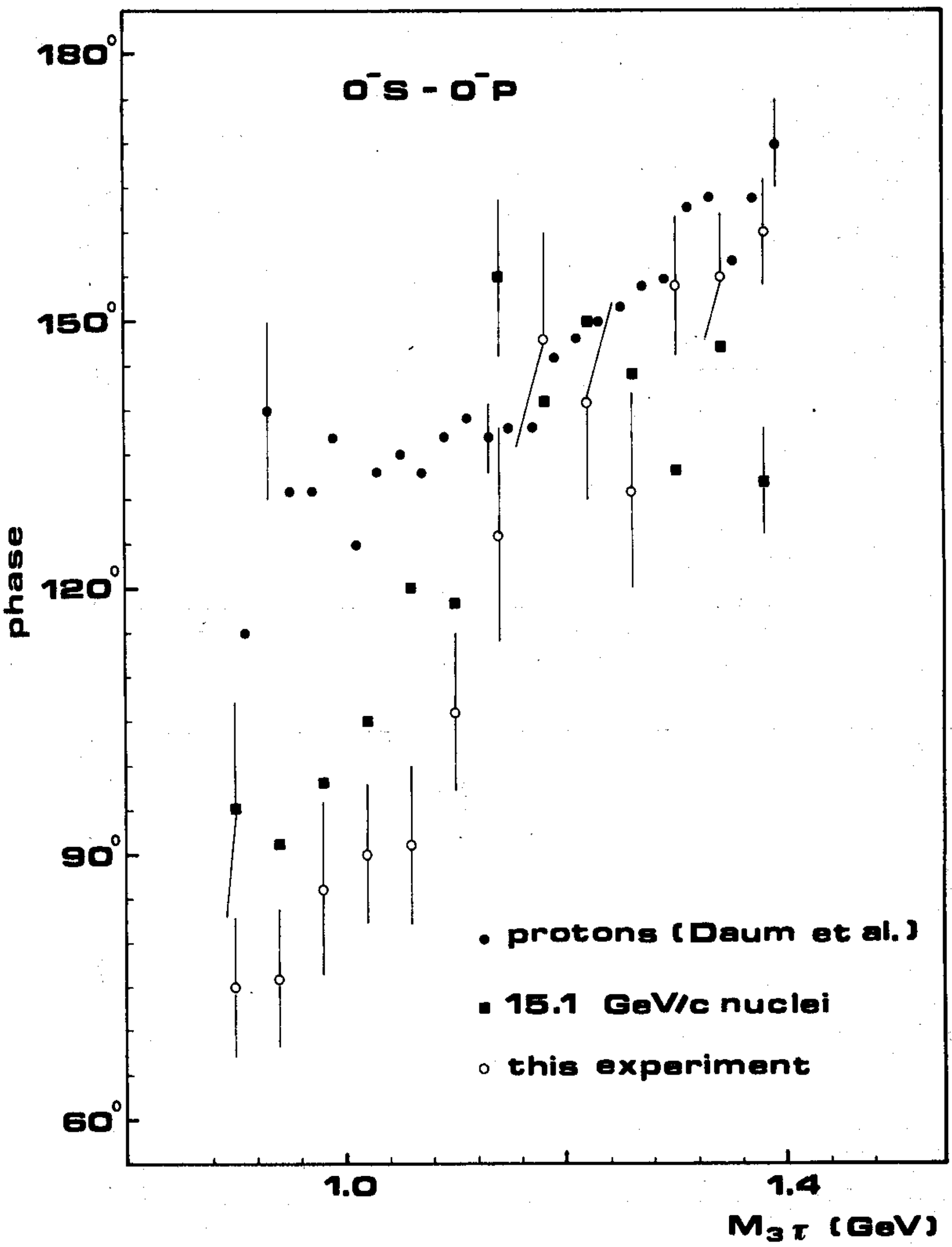

0⁻S - 0⁻P
180°
150°
120°
90°
60°
phase
1.0
1.4
M3π (GeV)
protons (Daum et al.)
15.1 GeV/c nuclei
this experiment

Fig. 5

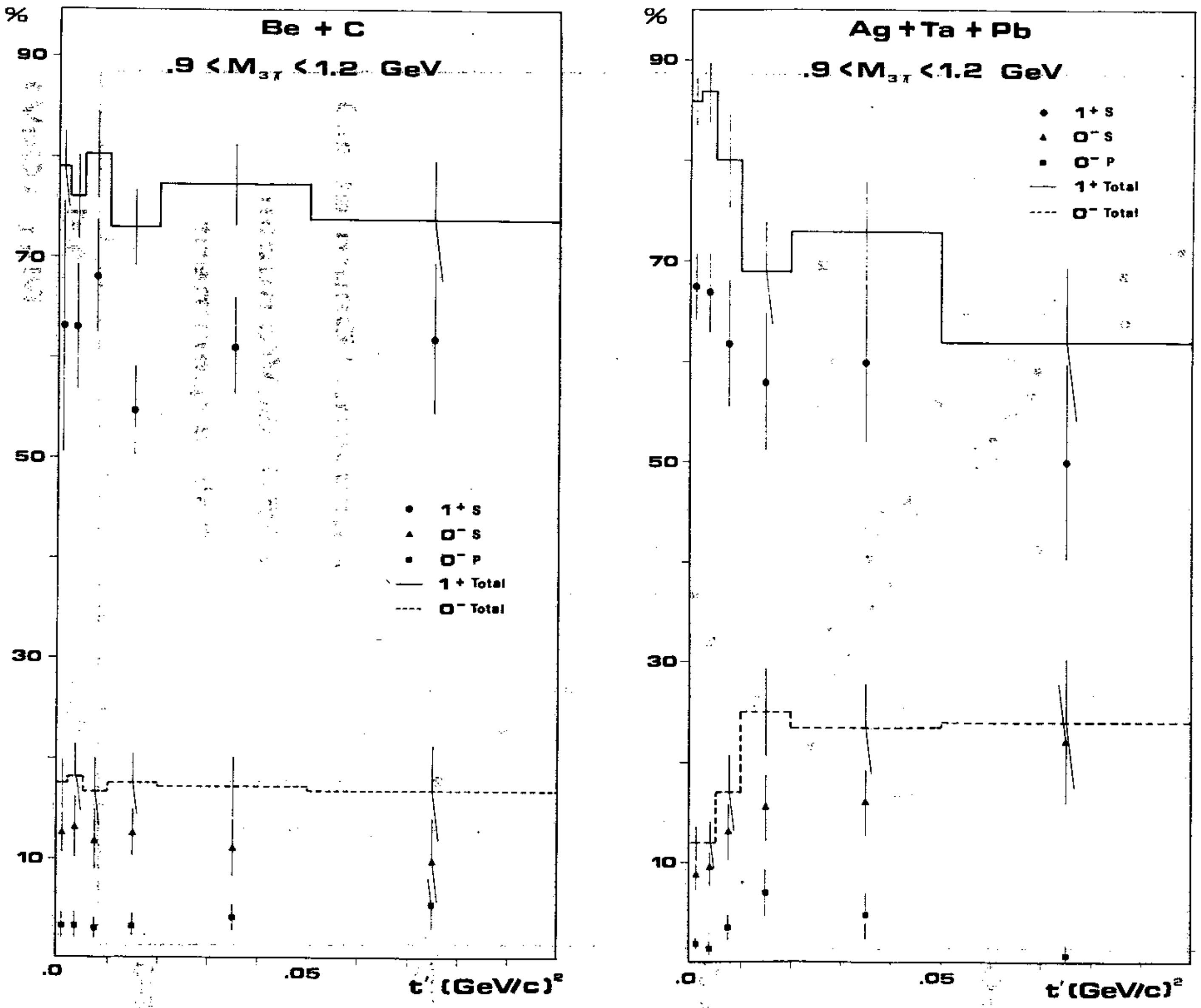

Be + C
.9 < $M_{3\pi}$ < 1.2 GeV
Ag + Ta + Pb
.9 < $M_{3\pi}$ < 1.2 GeV
%
90
70
50
30
10
.0
.05
t' (GeV/c)²
1⁺ S
0⁻ S
0⁻ P
1⁺ Total
0⁻ Total

Fig. 6a

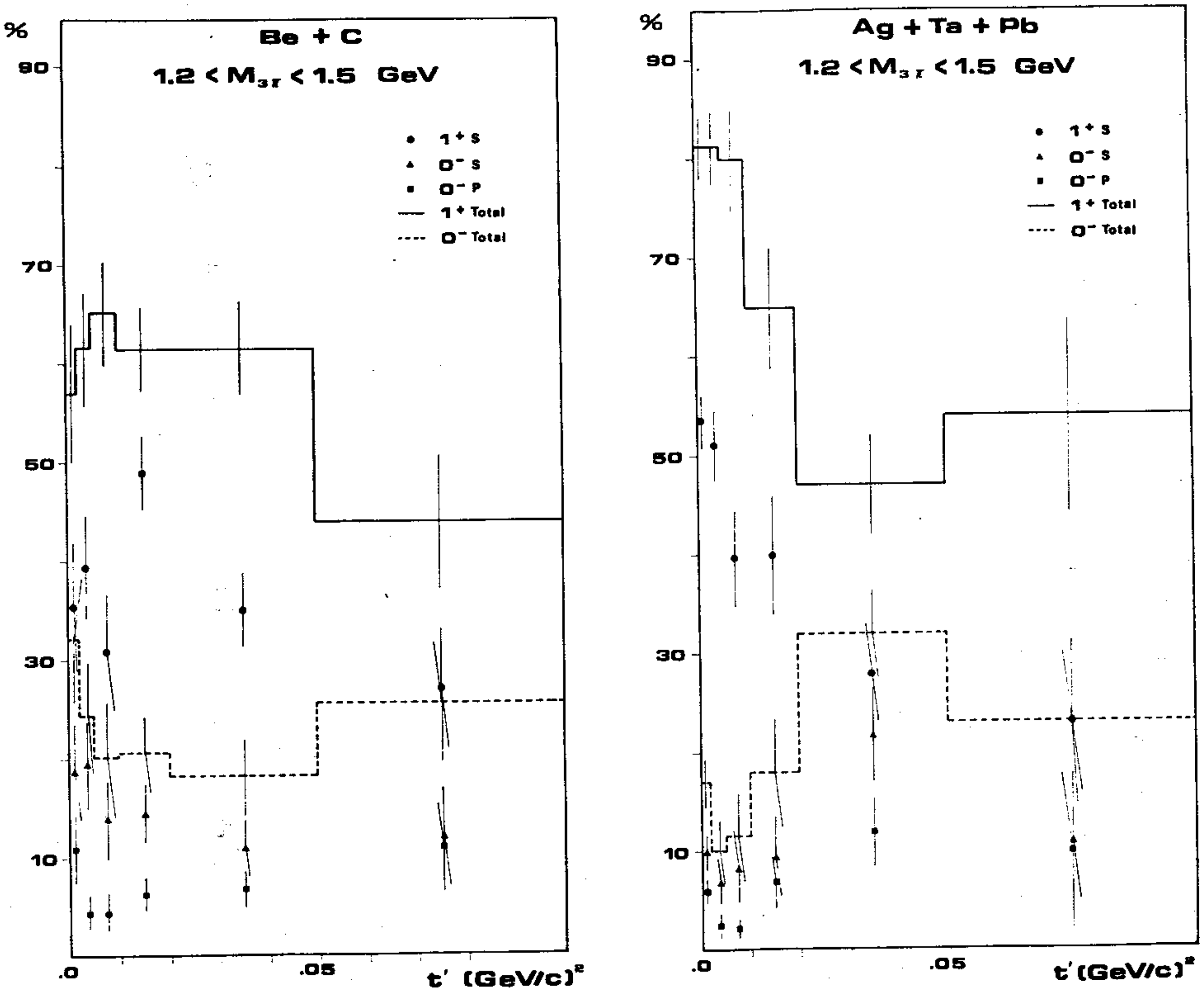

%
Be + C
1.2 < $M_{3\pi}$ < 1.5 GeV
1+ S
0− S
0− P
1+ Total
0− Total
90
70
50
30
10
.0
.05
t' (GeV/c)²
%
Ag + Ta + Pb
1.2 < $M_{3\pi}$ < 1.5 GeV
1+ S
0− S
0− P
1+ Total
0− Total
90
70
50
30
10
.0
.05
t' (GeV/c)²

Fig. 6b

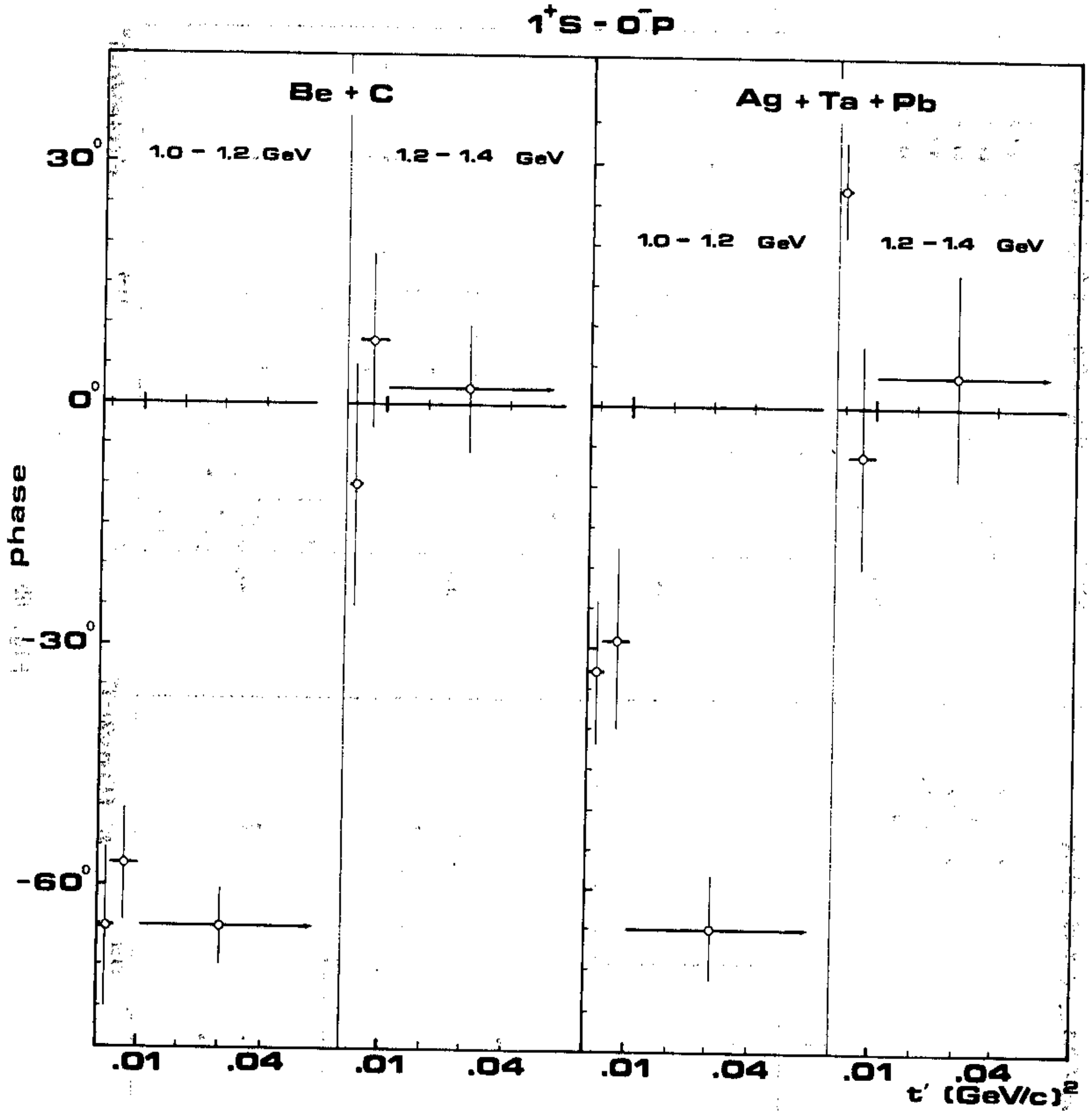

1⁺S - 0⁻P
Be + C
Ag + Ta + Pb
1.0 - 1.2 GeV
1.2 - 1.4 GeV
1.0 - 1.2 GeV
1.2 - 1.4 GeV
30°
0°
-30°
-60°
phase
.01
.04
.01
.04
.01
.04
.01
.04
t' (GeV/c)²

Fig. 7