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Hadron Spectroscopy Using Measurements with Spin

M.Svec
McGill University
Montreal, P.Q., Canada H3A 2T8

McGill U.

Abstract

Measurements of $\pi N_\uparrow \to \pi^+\pi^- N$ on polarized target enable hadron spectroscopy on the level of spin amplitudes. We find evidence for new scalar state $I = 00^{++}$ (750) and for unexpected spin-dependent structures within ρ^0 mass region.

Measurements of pion production on transversely polarized targets opened possibilities for new physics in hadron spectroscopy. First measurements of $\pi^+ p_\uparrow \to \pi^-\pi^+ n$ were made at 17.2 GeV/c at CERN-PS by CERN-Munich collaboration.[1] First measurements of $\pi^+ n_\uparrow \to \pi^+\pi^- p$ and $K^+ n_\uparrow \to K^+\pi^- p$ reactions were made at 6 and 12 GeV/c also at CERN-PS by Saclay group.[2,3] Experiments with polarized targets enable model independent construction of production amplitudes from data. Hadron spectroscopy studies can then be done on the level of individual amplitudes rather than spin-averaged cross-sections.

Such amplitude spectroscopy of $\pi N_\uparrow \to \pi^+\pi^- N$ reactions led to two important discoveries: (a) new scalar state $I = 0\ 0^{++}$ (750) and (b) spin dependent structures within the ρ^0 mass region.

The angular distribution of produced dimeson system is described in terms of spin density matrix elements (SDME). For dimeson masses below 1000 MeV spin states $J = 0$ (S-wave) and $J = 1$ (P-wave) dominate and the experiments measure 6 unpolarized and 9 polarized SDME. These spin observables are expressed in terms of nucleon transversity amplitudes.[4] There are two S-wave amplitudes (S and $\overline{S}$), and six P-wave amplitudes. The P-wave amplitudes L, $\overline{L}$ have dimeson helicity $\lambda = 0$ while U, $\overline{U}$ are combinations of $\lambda = \pm 1$. The amplitudes S, $\overline{S}$, L, $\overline{L}$ and U, $\overline{U}$ all describe π and A_1 unnatural exchanges. The P-wave amplitudes N, $\overline{N}$ are natural exchange (A_2) amplitudes. The amplitudes $\overline{S}$, $\overline{L}$, $\overline{U}$, $\overline{N}$ (S, L, U, N) have recoil nucleon spin up (down) relative to the scattering plane.

Amplitude analysis[4] expresses 8 normalized moduli and 6 cosines of relative phases in terms of SDME. There are two similar solutions. The unnormalized moduli are $|A|^2\Sigma$, $|\overline{A}|^2\Sigma$ where $A = S, L, U, N$ and $\Sigma = d^2\sigma/dmdt$.

The ρ^0 peak seen in Σ is resolved[5] into spin components (unnormalized moduli) in Fig. 1 for $\pi^- p \to \pi^-\pi^+ n$ at 17.2 GeV/c and $-t \leq 0.2$ (GeV/c).[2] Looking first at P-wave moduli, we see that there is large spin dependence of ρ^0 production. The amplitude $|\overline{L}|^2$ dominates $|L|^2$ and $|\overline{U}|^2$ is also larger than $|U|^2$. The reverse is true for the amplitudes $|N|^2$ and $|\overline{N}|^2$. There is no theoretical explanation for such a large dependence of ρ^0 on nucleon spin. Next we look at the S-wave moduli. They show resonant like bumps around 750 MeV. The relative phase between $\overline{S}$ and $\overline{L}$ is zero and the relative phase between S and L varies only slowly over the ρ^0 mass region. This behaviour indicates a resonant S-wave structure.

To examine further the S-wave resonance we look at partial wave intensities $I_A = (|A|^2 + |\overline{A}|^2)\Sigma$ for $A = S, L, U, N$. There are 4 solutions for each I_A corresponding to

the two independent solutions for moduli $|A|^2$ and $|\overline{A}|^2$. In Figure 2 we show I_L and I_S normalized to 1 at maximum value.[5] Both solutions (1,1) and (2,2) show resonant shape in I_S with mass 750 MeV. The solutions (1,2) and (2,1) are similar.[5] The evidence for 0^{++} (750) is solution independent. The width depends on solution and varies for 150 to 250 MeV.

In Fig. 3 we show t-evolution of mass dependence of normalized moduli based on Saclay data.[6] We notice unexpected structures in the moduli $|\overline{L}|^2$ and $|L|^2$ in ρ^0 mass region which depend on nucleon spin and t. These structures provide a new information on dynamics of ρ^0 production.

Future directions of hadron spectroscopy should include measurements with spin. We need new measurements of reactions $\pi N_\uparrow \to \pi^+\pi^- N$ and $KN_\uparrow \to K\pi N$ to investigate scalar states under ρ^0 and K^{0*} and the spin structure of resonance peaks. Measurements of polarization and recoil nucleon polarization will constrain phase shift analyses below 3 GeV/c. Complete measurements of spin observables in two-body reactions enable construction of amplitudes. These amplitudes show dip structures which look like absorption resonances. A systematic study of dip structures in two-body reactions is a natural extension of hadron spectroscopy into space-like region and should bring new insights into hadron dynamics. This new frontier will be best explored at the proposed Canadian KAON Factory.

References

[1] H. Becker et al., Nucl. Phys. B150 (1979) 301, B151 (1979) 46.
[2] A. de Lesquen et al., Phys. Rev. D32 (1985) 21.
[3] A. de Lesquen et al., Phys. Rev. D39 (1989) 21.
[4] M. Svec et al., Phys. Rev. D45 (1992) 55.
[5] M. Svec et al., Phys. Rev. D46 (1992) 949.
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Figure Captions

Fig. 1. The mass dependence of moduli squared of S-wave and P-wave nucleon transversity amplitudes and cosines of their relative phases in $\pi^- p \to \pi^-\pi^+ n$ (Ref. 5).

Fig. 2. The mass dependence of S-wave and P-wave partial wave intensities scaled to 1 at maximum value showing the spectral shapes for dimeson helicity $\lambda = 0$ in reaction $\pi^- p \to \pi^-\pi^+ n$ (Ref. 5).

Fig. 3. The t-evolution of mass dependence of moduli squared of t-channel normalized nucleon transversity amplitudes in $\pi^+ n \to \pi^+\pi^- p$ at 5.98 GeV/c together with results for $\pi^- p \to \pi^-\pi^+ n$ at 17.2 GeV/c for $t = -0.068$ (GeV/c)^2 (Ref. 6).

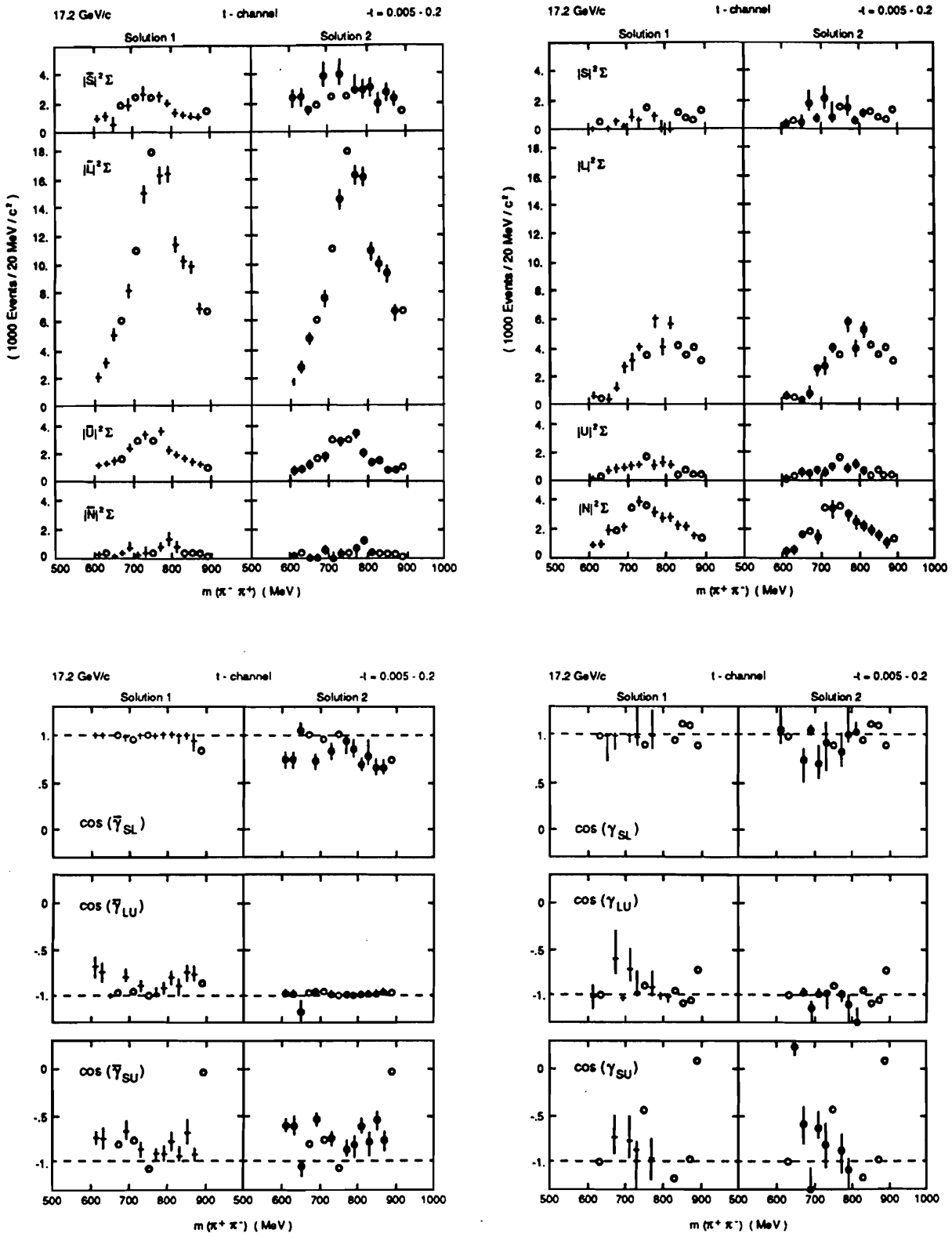
17.2 GeV/c
t - channel
-t = 0.005 - 0.2
Solution 1
Solution 2
|S̄|²Σ
|L̄|²Σ
|Ū|²Σ
|N̄|²Σ
|S|²Σ
|L|²Σ
|U|²Σ
|N|²Σ
(1000 Events / 20 MeV / c²)
m (π⁻ π⁺) (MeV)
m (π⁺ π⁻) (MeV)
cos (γ̄SL)
cos (γ̄LU)
cos (γ̄SU)
cos (γSL)
cos (γLU)
cos (γSU)

Fig. 1

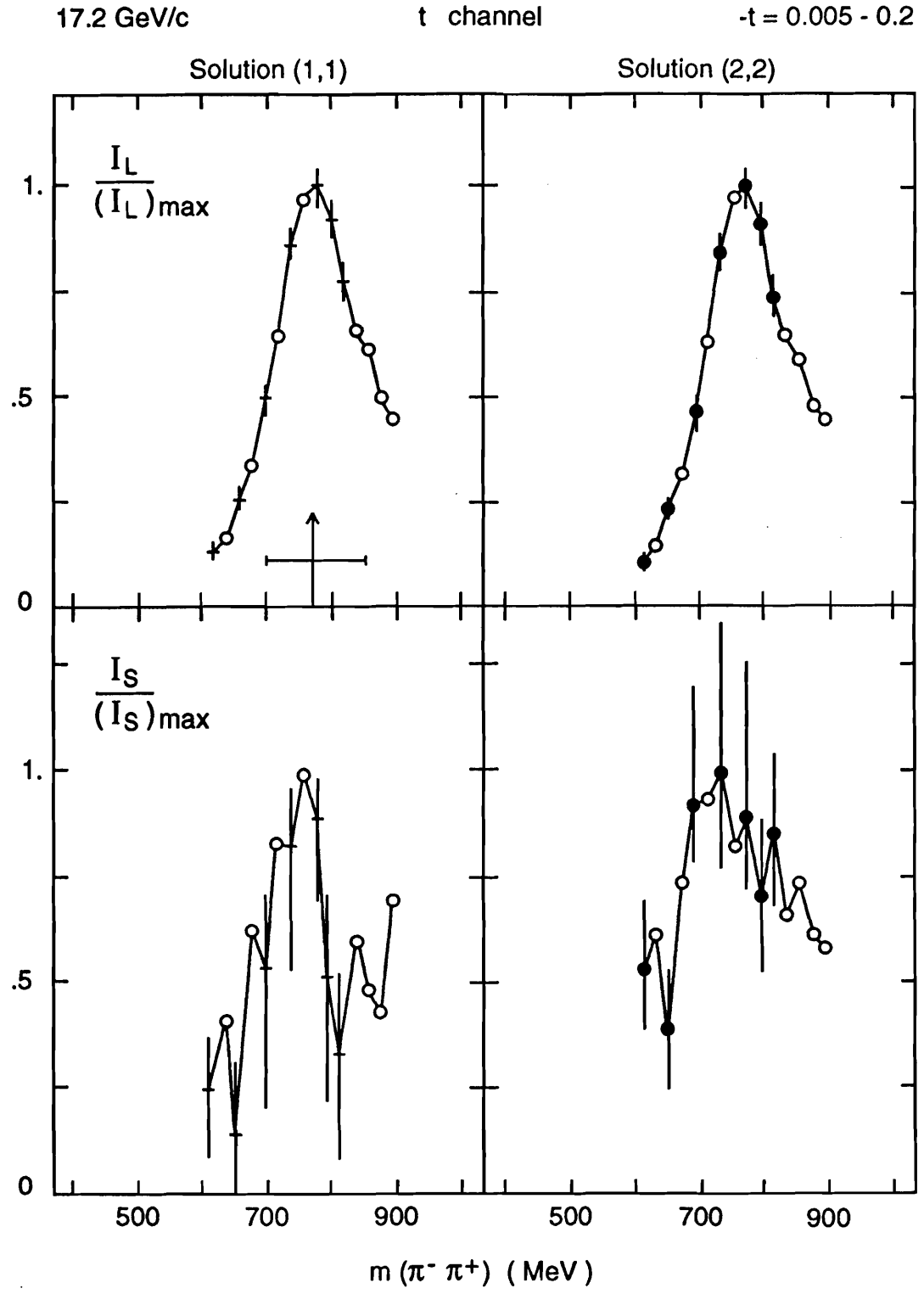
17.2 GeV/c
t channel
-t = 0.005 - 0.2
Solution (1,1)
Solution (2,2)
$\frac{I_L}{(I_L)max}$
$\frac{I_S}{(I_S)max}$
1.
.5
0
500
700
900
m (π^- π^+) (MeV)

Fig. 2

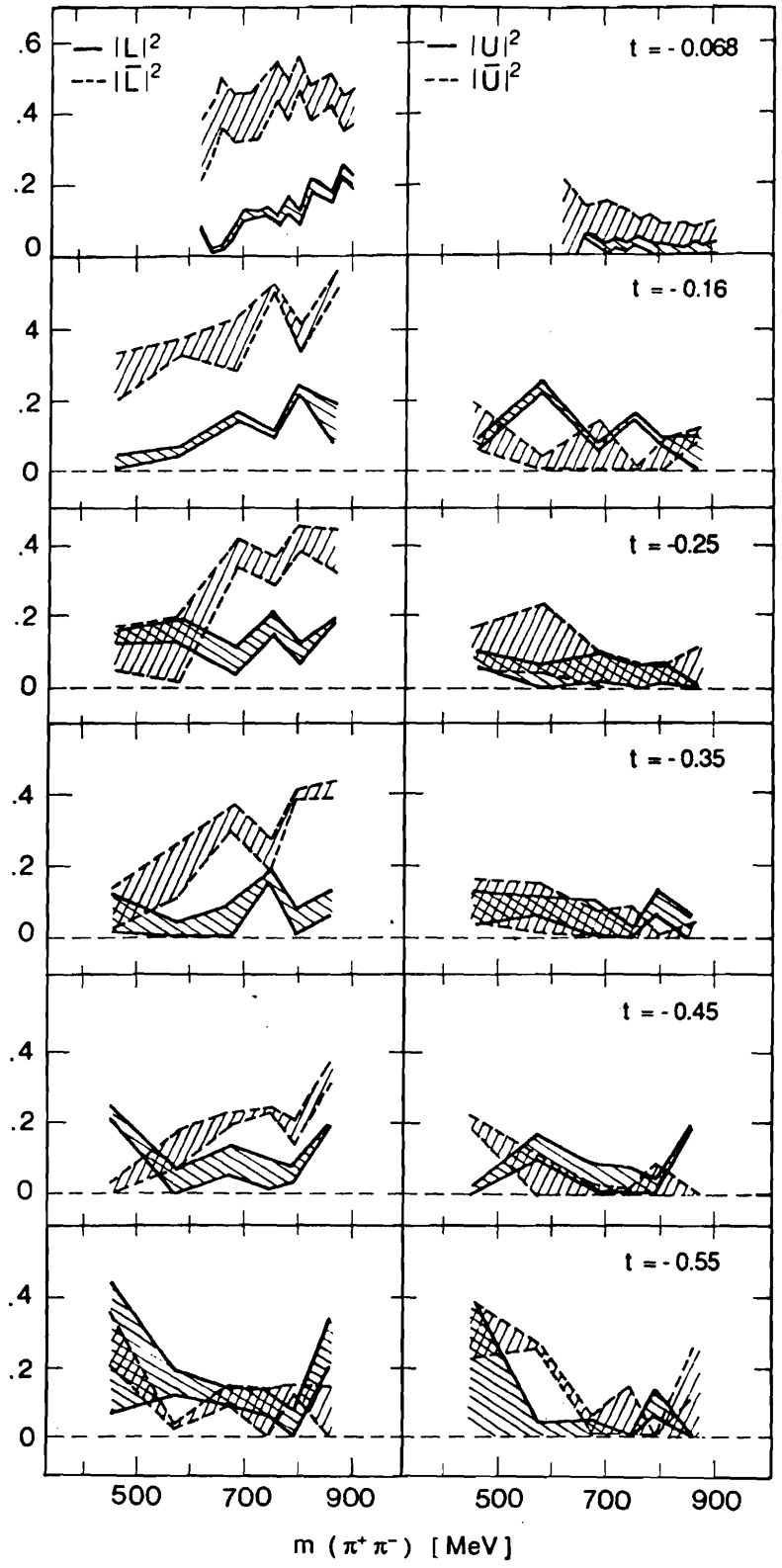
— |L|²
--- |L̄|²
— |U|²
--- |Ū|²
t = - 0.068
t = - 0.16
t = -0.25
t = - 0.35
t = - 0.45
t = - 0.55
.6
.4
.2
0
500
700
900
m (π⁺π⁻) [MeV]

Fig. 3