Partial wave analyses of the $\pi^+\pi^-\pi^-$ system at upgraded VES setup

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Preface

Purpose of the report

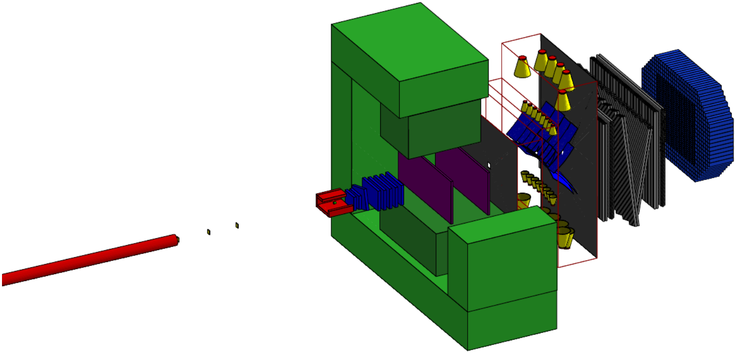
- present first results of mass-independent PWA of the $\pi^+\pi^-\pi^-$ system on the data, obtained after VES upgrade.
- compare them with data before upgrade.
- discuss structures which can be considered resonant
- currently we do not claim any numerical results

VES setup

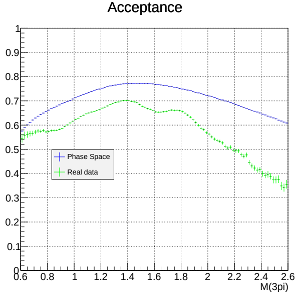
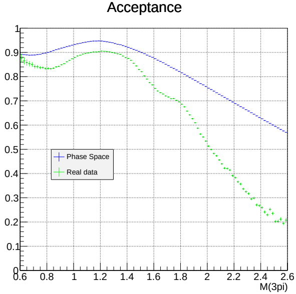
- Negative beam (98% π^-) with Cherenkov ID, Be target
- Magnetic spectrometer with 38 planes of PCs and DCs
- EM – calorimeter, 1500 cells
- Multicell Cherenkov Counter for particle ID
- Minimum bias trigger
- Fast DAQ, $40 \cdot 10^3$ events per 9 sec cycle

VES setup.

VES setup upgrade (concerning $\pi^+\pi^-\pi^-$ system) — taking out of trigger hodoscope and use of non-trigger drift tubes.



VES before and after upgrade.

	Before upgrade	After upgrade
Beam	π^- 37 GeV/c	π^- 29 GeV/c
Target	Be	Be
Trigger	Interaction$*$Hodoscope	Interaction
Events	$12 \cdot 10^6$	$30 \cdot 10^6$
Acceptance		

Event selection for $\pi^+\pi^-\pi^-$ final state

The final state $\pi^+\pi^-\pi^-$ dominates for π^- beam at VES energies, so its selection is simple and background is negligible.
Requirements are:

- beam particle identified as π^-
- 3 tracks with charges $+--$
- tracks are identified as $\pi^+\pi^-\pi^-$ by MCH (not done for new data yet)
- total energy for charged tracks 27–31 (36–38) GeV
- free energy in EM calorimeter less than 0.5 GeV
- vertex of interaction is inside the target

Analysis is done for $M(3\pi) = 0.6$–$2.6\ GeV/c$ and $|t'|$ intervals 0–0.03–0.15–0.30–0.80 GeV^2/c^2

Partial wave analysis method

Event by event extended max. LK with unlimited rank density matrix as parameters. Likelihood function to be optimized is

$$\ln \mathcal{L} = \sum_{e=1}^{N_{ev}} \ln \sum_{i,j=1}^{N_w} C_{k(i)} R_{m(i)n(j)} C^*_{l(j)} \mathcal{M}_i(\tau_e) \mathcal{M}^*_j(\tau_e)$$

$$- \quad N_{ev} \sum_{i,j=1}^{N_w} C_{k(i)} R_{m(i)n(j)} C^*_{l(j)} \int \varepsilon(\tau) \mathcal{M}_i(\tau) \mathcal{M}^*_j(\tau)\, d\tau$$

where

- N_{ev} — number of events, N_w — number of waves
- $\mathcal{M}(\tau_e)$ — amplitudes for e-th event (data)
- R — positive definite density matrix (parameters)
- C — coupling coefficients (parameters)
- $m(i)$, $k(i)$ — describes wave to C and R correspondence
- τ — phase space variables
- $\varepsilon(\tau)$ — acceptance of the setup (geometric model is used)

PWA method — continued

Partial waves

For 3-particle PWA amplitudes (partial waves) are constructed using isobar model, sequential decay via $\pi\pi$ subsystem. Wave has quantum numbers $J^P L M^\eta$ R where J^P is spin-parity for 3π system, M^η is projection of spin-exchange naturality, R is the known resonance in $\pi\pi$ system and L is orbital momentum in Rπ decay. $I^G = 1^-$ is implicit for 3π charged states.

$R = f_0(975), f_0(1500), \rho(770), f_2(1270), \rho_3(1690), \ldots$

For $\pi\pi$ S-wave we use also ε — broad structure, modified AMP M-solution. In this notation

$a_1(1260)$ — $1^+S0^+\rho(770)$, $a_2(1320)$ — $2^+D1^+\rho(770)$,
$\pi_2(1670)$ — $2^-S0^+f_2(1270)$, $\pi(1800)$ — $0^-S0^+f_0(975)$

Coherent part of density matrix

Coherent part of the density matrix ρ is the largest part of the matrix which has rank 1 and behaves like vector of amplitudes. Let

$$\rho = \sum_{k=1}^{d} e_k * V_k * V_k^+ \quad \text{where} \quad \begin{cases} e_k \text{ is k-th eigenvalue} \\ V_k \text{ is k-th eigenvector} \end{cases}$$

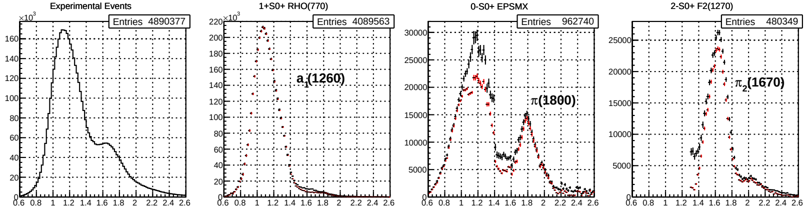
Let $e_1 \gg e_2 > \ldots > e_d > 0$. Leading term ρ_L is coherent part of density matrix and ρ_S is the rest (incoherent part). This decomposition is stable w.r.t. variations of ρ matrix elements.

$$\rho = \rho_L + \rho_S, \quad \rho_L = e_1 * V_1 * V_1^+, \quad \rho_S = \sum_{k=2}^{d} e_k * V_k * V_k^+$$

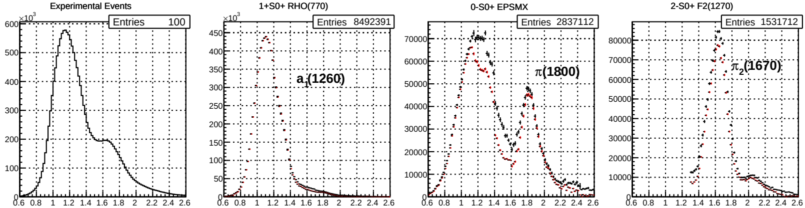
Experience shows that resonances tend to concentrate in ρ_L. ρ_S can contain non-leading exchanges, albeit it often contains garbage. Results for ρ_L are draw as red points, for full ρ as **black**.

Largest waves, $|t'| < 0.03\ \mathrm{GeV}^2/c^2$

Before upgrade — 37 GeV

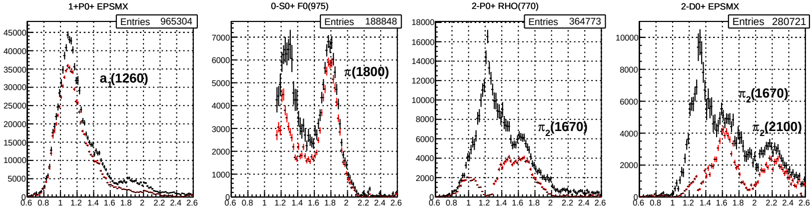


After upgrade — 29 GeV

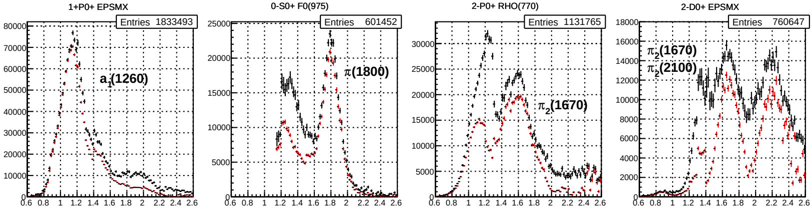


Largest waves 2, $|t'| < 0.03$ GeV$^2/c^2$

Before upgrade — 37 GeV



After upgrade — 29 GeV

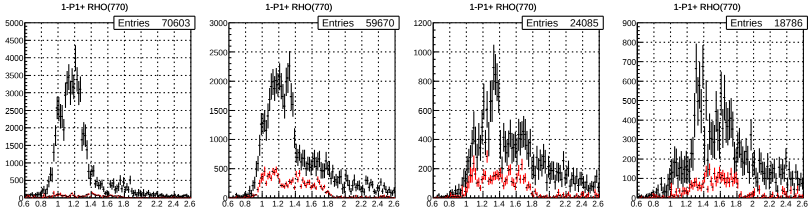


Exotic (non $q\bar{q}$) wave $J^{PC} = 1^{-+}$

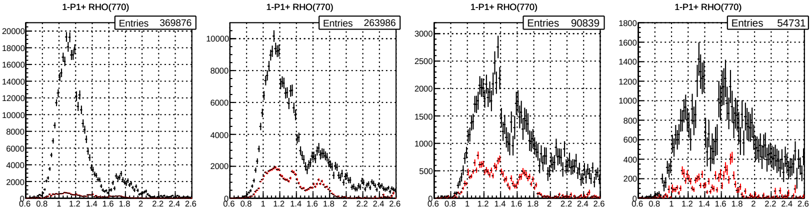
Results for $|t'| = 0$–0.03–0.15–0.30–$0.80\ \mathrm{GeV}^2/c^2$

Object $a_1(1600)$ can be drawn here, but... waves are small and smooth

Before upgrade — 37 GeV

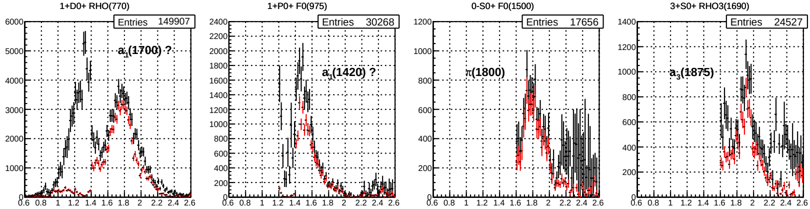


After upgrade — 29 GeV

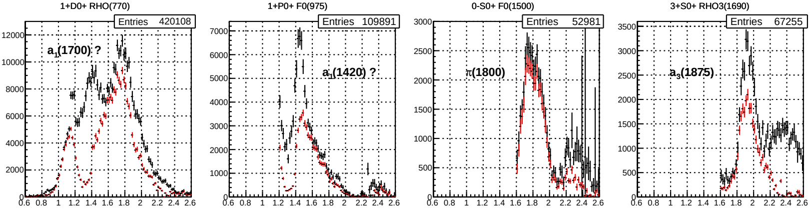


Possibly resonant waves, $|t'| < 0.03\ \text{GeV}^2/c^2$

Before upgrade — 37 GeV

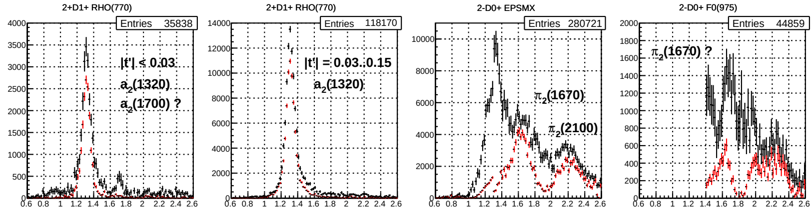


After upgrade — 29 GeV

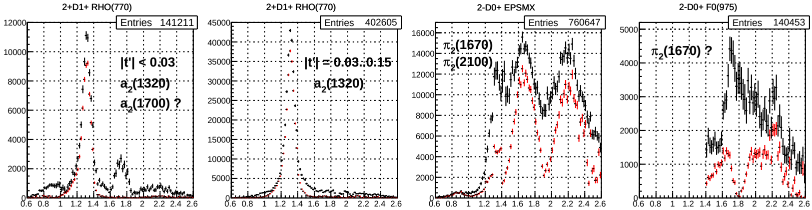


Possibly resonant waves — 2, $|t'| < 0.03\ GeV^2/c^2$

Before upgrade — 37 GeV



After upgrade — 29 GeV



Conclusions

- Mass-independent PWA is done for old 37 GeV and new 29 GeV $\pi^+\pi^-\pi^-$ data.
- Large waves look alike for 37 GeV and 29 GeV data.
- Some small waves are seen much better in new data.
- Decay modes $\pi(1800) \to f_0(1500)\pi$, $a_3(1875) \to \rho_3(1690)\pi$ are seen in $0^-\mathtt{S}$, $3^+\mathtt{S}$ waves. State $a_2(1700)$ is not seen in $2^+\mathtt{D}1^+$ $\rho\pi$.
- Interpretation of $f_0(975)\pi$ in $1^+\mathtt{S}$ wave at $M = 1.4$ GeV$/c^2$, $a_1(1420)$, and in $2^-\mathtt{D}$ wave at $M = 1.7$ GeV$/c^2$ is controversial. Same for $a_1(1700)$ in $1^+\mathtt{D}$ wave.
- Waves with $J^{PC} = 1^{-+}$ are 1.5 times large in new data w.r.t. statistic for $|t'| < 0.15$ GeV$^2/c^2$ region. Probably acceptance is not polished enough for new data.