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EXCLUSIVE $\omega\pi^0$ PRODUCTION WITH MUONS

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Abstract

Using 160 GeV muon scattering data collected with the COMPASS Experiment at CERN, the exclusive production of $\omega\pi^0$ via virtual photons was studied. Selective population of a peak around 1250 MeV is observed. Possible contributions from spin-parity 1^- are searched for, inspecting decay angular correlations. In particular, the orientation of the ω decay plane may allow a distinction from the 1^+ $b_1(1235)$ state. Our observation is compared with indications of a $\rho'(1250)$ in annihilation and in γp.

1 Motivation

Identification of the radially excited ρ meson is debated since a long time [1) 2)]. An early photoproduction experiment [3)], using photons with energy between 20 and 70 GeV, observed an enhancement in the $\omega\pi^0$ channel with mass around

1250 MeV and width of about 200 MeV. For spin-parity analysis it was assumed that the produced meson retains the helicity of the incoming photon (s-channel helicity conservation, SCHC). A dominant 1^- contribution was deduced.

However, subsequent investigations at the CERN SPS [4] and at SLAC [5] employing linearly polarized photons, revealed a dominance of the well known $J^{PC} = 1^{+-}$ state $b_1(1235)$, leaving only about 20% for a $\rho'(1^{--})$ contribution at the same mass. Angular distributions were found inconsistent with SCHC in these experiments where the mean photon energy was 20–30 GeV.

Supportive evidence for a ρ' state at this mass came from a Crystal Barrel study [6] of the annihilation reaction $\bar{p}n \to \omega\pi^-\pi^0$, suggesting ρ excitations at 1200, 1400 and 1700 MeV. The lowest lying state stands out by dominant $\omega\pi$ decay, in contrast to other non-ω related 4π decays.

The experimental situation has been reviewed by Donnachie and Kalashnikova [2], including results from e^+e^- annihilation and τ decay. In their interpretation, two 1^{--} states with mixed configurations are present between the ground state $\rho(770)$ and the first orbital excitation (1^3D_1) $\rho'(1700)$: the one at 1250 MeV with dominant $q\bar{q}$ configuration 2^3S_1 (the radial ρ' excitation), decaying preferably via $\omega\pi$, and the heavier one at $\sim$1450 MeV, with dominant hybrid or quartet configuration, preferring alternative decay channels like e.g. $a_1\pi$.

Concerning b_1 and ρ' competition in photoproduction, it was suggested [7] that helicity-flip Regge exchange, resulting in b_1, prevails at the mean photon energies of Ref. [4] [5], while helicity conserving Pomeron exchange, resulting in ρ', wins at higher energy.

We report on the first study of $\omega\pi^0$ production with virtual, quasi-real photons in inelastic muon scattering. According to the suggested systematics [7], b_1 and ρ' production should be of comparable size at the available γ^*p c.m. energy W≈13 GeV.

2 Experimental setup

COMPASS [8] is a two stage magnetic spectrometer installed at the end of the M2 beam extraction line at the CERN SPS machine. The extracted μ^+ beam of an intensity of about $2{\cdot}10^8$ per spill, with 5 s spill length and 16 s repetition, had an energy of 160 GeV and a polarisation of about 80%. It was directed on a two-cells polarized ^{6}LiD target, where the (longitudinal) polarisation was +

and − 56%.

Charged particle tracking involves silicon strip detectors, scintillation fibers, micromegas and GEMs at small angles and straw drift tubes and multiwire proportional chambers at large angles. In addition, muon-hadron separation is obtained with μ-filters.

For neutral particle detection in 2004 a lead glass detector, covering angles up to ±35 mrad as viewed from the target, served as electromagnetic calorimeter (ECAL2).

3 Event selection

A data sample collected in 8 weeks of the 2004 COMPASS run was analyzed. To select the exclusive process

$$\mu + N \to \mu' + \omega(\pi^+\pi^-\pi^0)\pi^0 + N, \quad (1)$$

with $\pi^0 \to \gamma\gamma$, the following criteria were applied:

— a primary reaction vertex with an identified incoming and scattered μ and (only) two additional particles of opposite charge is fully reconstructed;
— 4 and only 4 clusters not associated with a reconstructed charged track are found in ECAL2. To reduce background, only clusters with energy above 1 GeV are accepted.
— π^0's are selected cutting on the 2 photon invariant mass, 120 MeV $< m(\gamma\gamma) <$ 150 MeV, and on the decay opening angle, $\theta_{\gamma\gamma} < 0.025$ rad;
— a ω candidate is selected imposing the cut 750 MeV $< m(\pi^+\pi^-\pi^0) <$ 815 MeV;
— exclusivity is defined by means of the missing energy

$$E_{miss} = \frac{M_{miss}^2 - M_P^2}{2M_P}, \quad (2)$$

where M_P is the proton mass and M_{miss} is the missing mass. The exclusive $\omega\pi^0$ final sample is selected with the cut $-6 < E_{miss} < 4$ GeV.

Figure 1, left, shows the missing energy versus the 4π invariant mass for events with a uniquely identified $\omega\pi^0$ without the exclusivity cut: evident is the presence of an exclusive sample around $E_{miss} = 0$. The E_{miss} window

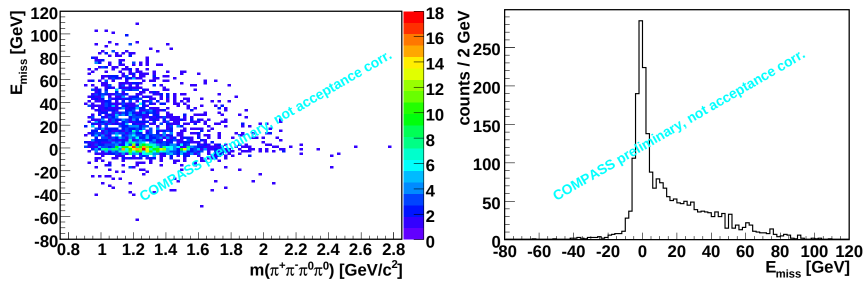

Figure 1: *Missing energy* E_{miss} *vs.* $\pi^+\pi^-\pi^0\pi^0$ *invariant mass for events with a single reconstructed* $\omega(\pi^+\pi^-\pi^0)\pi^0$ *(left) and projection on the* E_{miss} *axis (right).*

used for selection was adapted to the exclusivity peak visible in the projection (right).

4 Results

Figure 2 shows the $\omega\pi^0$ invariant mass spectrum. A peak with a mean value of about 1250 MeV and a width of about 300 MeV is observed. The acceptance variation over the peak range is estimated to be less than 20%. Our observation is consistent with the results of the quoted photoproduction experiments.

To access non-ω background, the $\pi^+\pi^-\pi^0$ invariant mass cut was somewhat relaxed. Figure 3 (left) shows the 3π versus the 4π invariant mass: events in the ω mass region correspond to the 4π invariant mass interval around 1250 MeV. The projection on the 3π mass axis (right), puts in evidence the ω contribution; the width is due to the experimental resolution.

For a quantitative determination of the non-ω background, we have considered the λ distribution, defined by

$$\lambda = \frac{|\vec{p_1} \times \vec{p_2}|^2}{|\vec{p_1} \times \vec{p_2}|^2_{max}}, \tag{3}$$

where $\vec{p_1}$ and $\vec{p_2}$ are the momenta of any two of the three pions. In this analysis, the two charged ones were chosen. The observed linear increase of the intensity with λ is a unique signature of $J^P = 1^-$, already applied in the original J^P

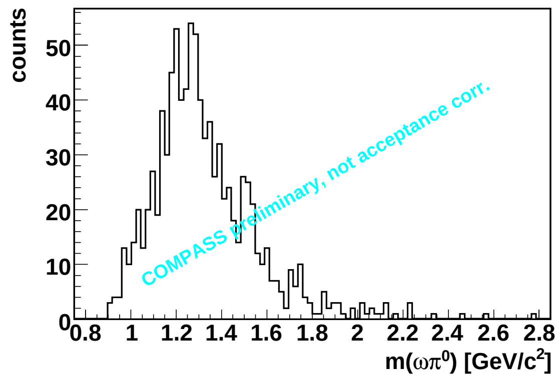

Figure 2: *Invariant mass spectrum of exclusively produced* $\omega\pi^0$.

assignment for the ω [9]. In contrast, the λ distribution for events outside the exclusivity window is flat. From the linear fit in figure 4, we deduce a background contribution of 12% in the final sample.

Figure 5 shows some important kinematic distributions for the final sample: the virtual photon mass squared $Q^2 = -q^2$, the Bjorken scale variable x_B, the $\gamma^* p$ center of mass energy W, and the $\omega\pi^0$ momentum in the laboratory system. The mean value of the latter corresponds to $E(\gamma^*) \approx 90$ GeV. The

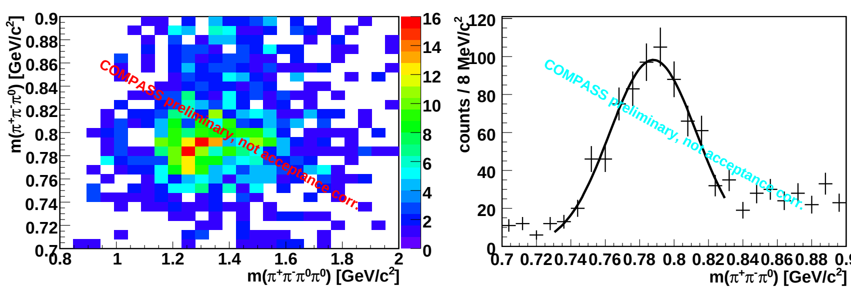

Figure 3: 3π *vs.* 4π *invariant mass for events in the exclusivity region (left) and corresponding* 3π *mass projection (right).*

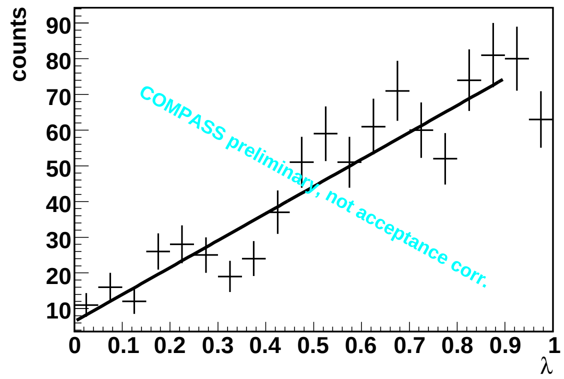

Figure 4: λ *distribution, eq. (3).*

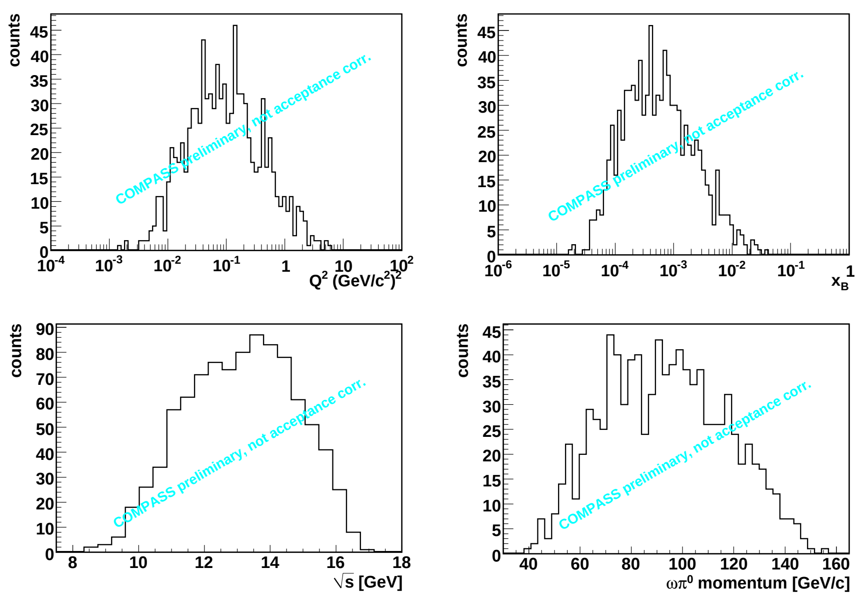

Figure 5: *Kinematic distributions for the exclusive* $\omega\pi^0$ *final sample. Top-left: Virtual photon mass squared* Q^2*; Top-right: Bjorken scale variable; Bottom-left:* $\gamma^* p$ *c.m. energy* W*; Bottom-right:* $\omega\pi^0$ *momentum in laboratory frame.*

4-momentum transfer squared $t = (q - v)^2$ (not shown) is characterized by an exponential shape, as is typical of diffractive processes.

5 Angular distributions

Three types of angular correlations are suited for spin-parity studies. The first two characterize the decay of the $\omega\pi^0$ resonance:

(i) the angle ψ of the ω momentum $\vec{p}_\omega$ relative to the $\omega\pi^0$ direction (reference axis z) in the overall $\gamma^* p$ c.m. system;
(ii) the angle θ between the vector $\vec{n}_\omega$ perpendicular to the ω decay plane (in the ω rest frame) and the z axis.

For electroproduction via quasi-real photons, one can assume linear polarization of the γ^* in the primary scattering plane and adopt the corresponding angular correlation formalism [10]. Following Ballam *et al.* [11], we define appropriate "spin analyzers" $\vec{a} = \vec{n}_\omega \times \vec{p}_\omega$ and $\vec{a} = \vec{n}_\omega$ for $J^P = 1^-$ and 1^+ states, respectively. Their direction with respect to the γ^* polarization is described by:

(iii) the azimuthal angle Ψ between μ scattering plane and $\vec{a}$.

Assuming SCHC, the two sets of angular distributions in table 1 are predicted [3] for the two different J^P assignments to $\omega\pi^0$. The quantity $x \approx 0.07$ is the known D/S-wave amplitude ratio squared of b_1.

Monte Carlo simulations for pure 1^+ and 1^- states reveal a strong acceptance dependance of the distribution (i), whereas (ii) is only weakly affected. As shown in figure 6, the characteristic shapes of $I(cos\theta)$ are roughly maintained after taking into account detector and selection acceptance. Our preliminary experimental results (not shown) are in favour of the 1^- case. However the de-

Table 1: *Decay angular distributions for $J^P = 1^\pm$ assignments to $\omega\pi^0$.*

J^P	$I(cos\psi)$	$I(cos\theta)$
1^+ $(b_1(1235))$	$\sim 1 + xcos^2\psi$	$\sim sin^2\theta$
1^- (ρ')	$\sim 1 + cos^2\psi$	$\sim 1 + cos^2\theta$

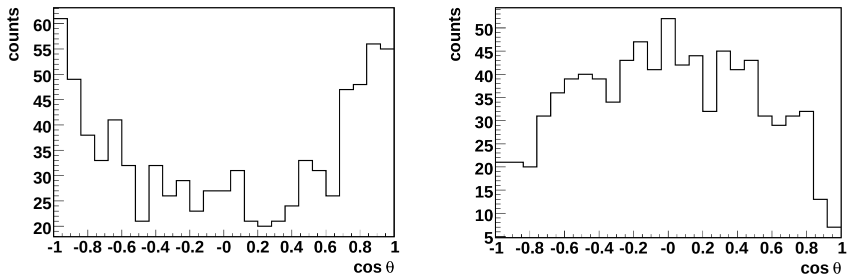

Figure 6: *Estimate of the* $cos\theta$ *distributions, based on Monte Carlo simulations of the detector and selection acceptance, for* $J^P(\omega\pi^0) = 1^-$ *(left) and* 1^+ *(right).*

pendence on the SCHC assumption should be kept in mind. This holds as well for the distribution (iii), which shows an indication of a $cos 2\Psi$ contribution, characteristic of $J^P = 1^-$. Interference between S- and P-wave, corresponding to 1^+ and 1^- decay in $\omega\pi^0$, would give rise to a forward-backward anisotropy in the distribution (i), irrespective of the SCHC assumption. Detailed acceptance studies are required for this analysis.

6 Conclusion

We have observed the exclusive production of $\omega\pi^0$ in muon scattering via virtual photons in the energy range around 90 GeV lab. energy. The mass spectrum is dominated by a peak at 1250 MeV and width 300 MeV, which is consistent with previous photoproduction experiments. Preliminary results on angular correlations are consistent with the presence of a 1^- contribution, if SCHC holds. An appreciable increase in statistics is expected with the 2006 and 2007 COMPASS data.

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