The OZI Rule and Spin Alignment of Vector Mesons at COMPASS

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The reaction $pp \to pVp$ ($V = \omega$, ϕ) has been studied with the COMPASS spectrometer in 2008 and 2009, using a 190 GeV/c proton beam impinging on a liquid hydrogen target. The measured cross section ratio ratio violates the OZI prediction by a factor of ≈4. Its kinematic dependence of the Feynman x_F and the M_{pV} mass is discussed in terms of diffractive production of baryon resonances in competition with central production. The $M_{p\omega}$ spectrum has a rich structure, indicating the importance of baryon resonances decaying into $p\omega$, in sharp contrast to the structureless $M_{p\phi}$ spectrum. Outside the resonant region, the OZI violation factor is about 8, independently of x_F. The spin density matrix element ρ_{00} of the vector mesons is studied in selected reference frames. Dependences of the vector meson spin alignment on x_F and M_{pV} are found.

The Okubo-Zweig-Iizuka (OZI) rule [1] states that all hadronic processes with disconnected quark lines are suppressed. As a consequence, the production of ϕ mesons from non-strange hadrons would only be allowed due to its deviation from ideal mixing with the ω meson. Using the known deviation of the mixing angle, $\delta_{\rm V} = 3.7^{\rm o}$, the cross section ratio for ϕ and ω production is predicted to be $\sigma(AB \to X\phi)/\sigma(AB \to X\omega) = \tan^2 \delta_{\rm V} = 0.0042$, where A, B and X are non-strange hadrons [2]. At low energies, the ratio can be expressed in terms of meson-meson or meson-nucleon couplings: $g^2_{\phi\rho\pi}/g^2_{\omega\rho\pi} = g^2_{\phi NN}/g^2_{\omega NN} = \tan^2 \delta_{\rm V} = 0.0042$, assuming the coupling ratios $g_{\phi\rho\pi}/g_{\omega\rho\pi}$ and $g_{\phi NN}/g_{\omega NN}$ are equal [3].

The OZI rule has been tested in several experiments and has been found to be remarkably well fulfilled [4, 5]. Apparent violations of the OZI rule – observed in $p\bar{p}$ annihilations at rest and in nucleon-nucleon collisions – can be interpreted either as a true violation due to gluonic intermediate states [6] or as an evasion from the OZI rule because of a hidden strangeness component in the nucleon [7].

The COMPASS collaboration here presents a study of the OZI violation in $p_{\rm beam}\, p_{\rm target} \to p_{\rm fast}\, V\, p_{\rm recoil}$ at a beam momentum of 190 GeV/c. For simplicity, this will from now on be denoted $p\,p \to p\,V\,p$. Unless otherwise stated explicitly, p without subscript and the Feynman variable $x_{\rm F} = p_L/p_{L\max}$, p_L denoting the longitudinal momentum, will refer to the fast proton. The reduced 4-momentum transfer squared is $t' = |t| - |t|_{\min}$, where $t = (p_{p\rm beam} - (p_{p\rm fast} + p_V))^2$. In the region where the COMPASS data are collected, *i.e.* $t' > 0.1$ (GeV/c)^2, production of vector mesons occur either by resonant production, where the beam proton dissociates diffractively to an intermediate baryon resonance, or non-resonant production, which can be either central Pomeron-Reggeon fusion or a shake-out of a $q\bar{q}$ pair [7] from the sea of the beam nucleon when interacting with a Pomeron or a Reggeon emitted from the target. In resonant production, the dynamics of the vector meson depends on the intermediate baryon resonance whereas in non-resonant production it depends on the exchange object(s).

The production mechanism is reflected in the decay angular distributions which can be expressed in terms of the spin density matrix [8]. When the inital state is unpolarised, symmetries leave one independent element of the spin density matrix, ρ_{00}, which is a measure for spin alignment (tensor polarisation). It can be extracted from distributions of the angle between the decay plane (3-body decay) or decay axis (2-body decay) of the vector meson and a well-chosen reference axis [9].

The COMPASS spectrometer set-up [10] is suitable for this kind of measurements due to the large angular acceptance and high momentum resolution. COMPASS is a two-stage fixed-target magnetic spectrometer at the CERN SPS. The analysis is based on the 2008 and 2009 data taking with a positively charged hadron beam impinging on a liquid hydrogen target. The hadron beam contains 75% protons which are tagged by CEDARs (differential Cherenkov detectors). Pions, protons and kaons in the final state are identified with a RICH detector in the first stage and electromagnetic (ECAL) and hadronic calorimeters in both stages of the set-up. The trigger system selects events with a recoiling proton in a cylindrical time-of-flight detector surrounding the target (RPD) which results in a minimum bias on the forward kinematics. Since the ω and ϕ mesons are measured simultaneously with the same set-up and triggers, many systematic uncertainties cancel.

For the analysis, events from the reactions $pp \to p\,\omega\,p$, $\omega \to \pi^+\pi^-\pi^0$ and $pp \to p\,\phi\,p$, $\phi \to K^+K^-$ are selected. The recoil proton is detected in the RPD, whereas charged pions, kaons and fast protons are detected in the spectrometer. RICH identification is required for the π^+ from the ω decay and the K^+ from the ϕ decay. The π^0 mesons from the ω decays are identified from the invariant mass distribution of two photons detected in the ECAL's. The ω mesons are identified from the $\pi^+\pi^-\pi^0$ invariant mass distribution and the ϕ mesons from the K^+K^- mass distribution. Additional cuts on exclusivity and coplanarity are applied. The x_F is required to lie within the interval 0.6-0.9 and t' within 0.1-1.0 (GeV/c)^2 to assure that the ϕ and the ω samples belong to the same phase space region. To separate signal from background, a Breit-Wigner function folded by a gaussian on top of a polynomial background has been fitted to the data. The acceptance is corrected for event-by-event using a 3-dimensional acceptance matrix in t', $M_{p\mathrm{V}}$ and x_{F}. The systematic uncertainties are estimated to 12%, where the largest contributions come from the RICH and ECAL efficiencies. More details on the analysis is given in Refs. [11, 12].

The invariant mass of the pV system, M_{pV}, has been studied for ω and ϕ. In the case of the ω, the data are divided into four different ranges in x_F (0.2-0.6, 0.6-0.7, 0.7-0.8 and 0.8-0.9). Several structures are then discernible in the $M_{p\omega}$ spectrum, located at about 1800 MeV/c^2, 2200 MeV/c^2 and 2600 MeV/c^2. These can be interpreted as N^* resonances that have been observed in other experiments, mainly in $N\pi$ final states [13]. The $M_{p\phi}$ spectrum appears structureless.

The cross section ratio $R_{\phi/\omega} = \frac{d\sigma(p\,p \to p\,\phi\,p)/dx_{\mathrm{F}}}{d\sigma(p\,p \to p\,\omega\,p)/dx_{\mathrm{F}}}$ has been measured in three x_F intervals: 0.6-0.7, 0.7-0.8 and 0.8-0.9. The OZI violation factor is defined as the cross section ratio divided by the value predicted by the OZI rule: $F_{\mathrm{OZI}} = R_{\phi/\omega}/\tan^2\delta_{\mathrm{V}}$, with $\tan^2\delta_{\mathrm{V}} = 0.0042$. The results are shown in Figure 1. The ratio is between 2.9 and 4.5 and depends on x_F. The abundance of intermediate baryon resonances in ω production, observed in the $p\omega$ mass spectrum, suggests that resonant production is dominant in the case of ω but not for ϕ. In order to compare ω and ϕ samples produced with the similar mechanisms, the resonant region was removed by imposing a cut in the momentum of the vector meson in the rest frame of the proton - vector meson system, p_V. This is shown in the left panel of Fig. 1. Since no structures are observed in the $M_{p\omega}$ spectrum above $M_{p\omega} = 3.3$ GeV/c^2, which corresponds to $p_V = 1.4$ GeV/c, the $F_{\rm OZI}$ factor was measured for $p_V > 1.4$ GeV/c. In this region, the value of $F_{\rm OZI}$ converges to about 8, independent of x_F. The SPHINX collaboration used $p_V > 1.0$ GeV/c [14] and we therefore carried out the same measurement for comparison. The COMPASS result is consistent with SPHINX [11].

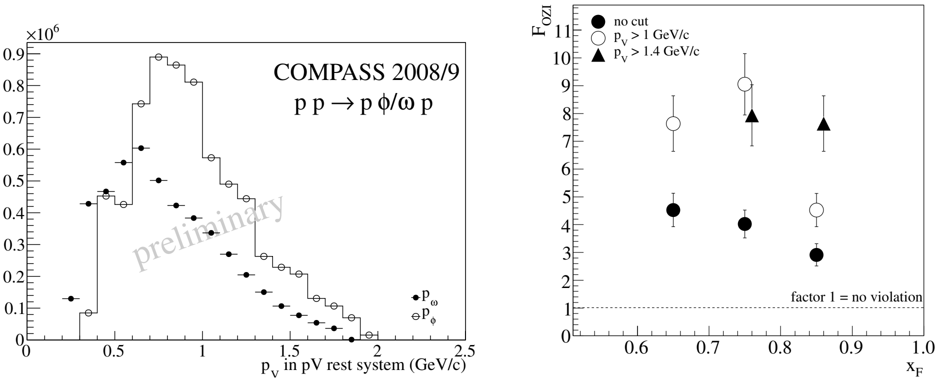

Figure 1: Left: The vector meson momentum p_V in the rest frame of the pV system, where V refers to ϕ (white dots) or ω (black dots. The ϕ histogram has been scaled by a factor of 100. Right: OZI violation factor $F_{\rm OZI}$ as a function of $x_{\rm F}$ for different p_V cuts.

The spin alignment, quantified by the first element of the spin denisty matrix, ρ_{00}, has also been measured. The differential cross section can be parameterised in terms of ρ_{00} and the angle between the analyser (the normal of the decay plane in the case of the $\omega \to \pi^+\pi^-\pi^0$ decay and the direction of one of the decay kaons in the case of the $\phi \to K^+K^-$ decay) and some reference axis. Two different reference axes have been tested: the direction of the pV system in the rest system of V (the helicity frame) and the direction of the transferred momentum from the beam proton to the fast proton, $\Delta\vec{P}$ (the transferred momentum frame). The ω meson is significantly aligned in the helicity frame and the value of ρ_{00} depends strongly on $M_{p\omega}$, as shown in the left panel of Figure 2. This is in line with the abundance of structures in the $M_{p\omega}$ spectrum and emphasises the importance of intermediate baryon resonances in the production of ω mesons. Above the resonant region, ρ_{00} approaches 1/3 which corresponds to an unaligned ω spin. The ϕ meson spin is unaligned in the helicity frame in the two measured $M_{p\phi}$ intervals, consistent with the absence of resonances in the $M_{p\phi}$ spectrum [11]. In non-resonant production, the helicty frame becomes irrelevant since the pV system does not correspond to a resonant state. In such cases, the transferred momentum frame should be a more natural choice. The results, presented in the right panel of Figure 2, show that this is indeed the case for both ω and ϕ. The ϕ meson spin is strongly aligned in this frame and the alignment becomes stronger with increasing x_F, *i.e.* when the contribution from central production increases. The results for the ω meson spin show the same behavious though the alignment is weaker than for ϕ. After removing the resonant region in the ω data, the results are consistent with those of the ϕ meson.

To summarise, this study shows that intermediate baryon resonances play a very important role in the production of ω mesons. This is supported by structures in the $M_{p\omega}$ spectrum, the p_V dependence of the OZI violation factor and the strong $M_{p\omega}$ dependence of the ω meson spin alignment in the helicity frame. The corresponding measurement for ϕ indicates an absence

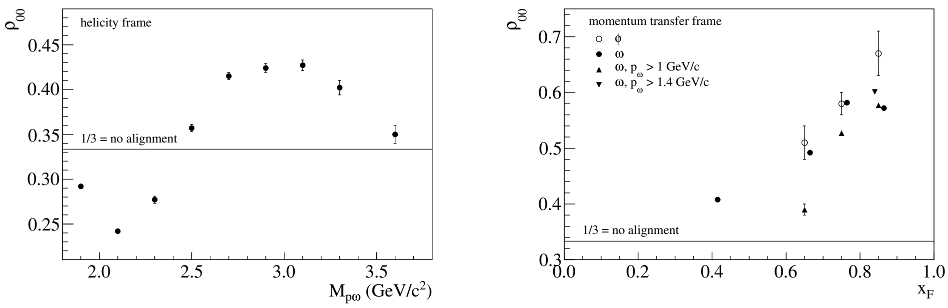

Figure 2: Left: Spin alignment ρ_{00} as a function of $M_{p\omega}$. Right: Spin alignment ρ_{00} extracted using $\Delta\vec{P}$ as reference axis as a function of $x_{\rm F}$ for different $p_{\rm V}$ cuts.

of baryon resonances in ϕ production. Other processes, *e.g.* central Reggeon-Pomeron fusion or the shake-out of a $q\bar{q}$ state in the nucleon sea may instead contribute here. The strong x_F dependence of the spin alignment with respect to the transferred momentum from the beam proton to the fast proton speaks in favour of the former. The latter could be investigated by comparing the results presented here, obtained with a proton beam, to results obtained with a pion beam. With a pion beam, no contribution from a $q\bar{q}$ shake-out can occur.

Another interesting finding is that outside the $p\omega$ resonant region, the OZI violation factor converges to a value of about 8, independently of $x_{\rm F}$. This is in remarkable agreement not only with the SPHINX analysis [14] after removal of the low-$M_{p\omega}$ region, but surprisingly also with data close to threshold from ANKE [15], DISTO [16] and COSY-TOF [17, 18].

References

[1] S. Okubo, Phys. Lett. **5** (1963) 165; G. Zweig, Developments in the Quark Theory of Hadrons, Volume 1. Edited by D. Lichtenberg and S. Rosen. pp. 22-101; J. Iizuka, Prog. Theor. Phys. Suppl. **37** (1966) 21.

[2] H. J. Lipkin, Int. J. Mod. Phys. E **1** (1992) 603.

[3] H. J. Lipkin, Phys. Lett. B **60** (1976) 371.

[4] V. P. Nomokonov and M. G. Sapozhnikov, Phys. Part. Nucl. **34** (2003) 94 [Fiz. Elem. Chast. Atom. Yadra **34** (2003) 189].

[5] A. Sibirtsev and W. Cassing, Eur. Phys. J. A **7** (2000) 407.

[6] S. J. Lindenbaum, Nuovo Cim. A **65** (1981) 222.

[7] J. R. Ellis, M. Karliner, D. E. Kharzeev and M. G. Sapozhnikov, Phys. Lett. B **353** (1995) 319; J. R. Ellis, M. Karliner, D. E. Kharzeev and M. G. Sapozhnikov, Nucl. Phys. A **673** (2000) 256.

[8] K. Gottfried and J. D. Jackson, Nuovo Cim. **33** (1964) 309.

[9] K. Schilling, P. Seyboth and G. E. Wolf, Nucl. Phys. B **15** (1970) 397 [Erratum:ibid. B **18** (1970) 332].

[10] P. Abbon *et al.* [COMPASS Collaboration], Nucl. Instrum. Meth. A **577** (2007) 455.

[11] C. Adolph *et al.* [COMPASS Collaboration], Nucl. Phys. B **886** (2014) 1078.

[12] J. Bernhard, Ph.D. thesis, Mainz University (2014).

[13] J. Beringer *et al.* [Particle Data Group Collaboration], Phys. Rev. D **86** (2012) 010001.

[14] S. V. Golovkin *et al.*, Z. Phys. A **359** (1997) 435.

[15] M. Hartmann *et al.* [ANKE Collaboration] Phys. Rev. Lett. **96** (2006) 242301

[16] F. Balestra *et al.* [DISTO Collaboration], Phys. Rev. C **63** (2001) 024004

[17] S. Abd El-Samad *et al.* [COSY-TOF Collaboration], Phys. Lett. B **522** (2001) 16

[18] M. Abdel-Bary *et al.* [COSY-TOF Collaboration], Phys. Lett. B **647** (2007) 351