Measurement of OZI rule violation and spin alignments in Φ(1020) and ω(782) production at COMPASS

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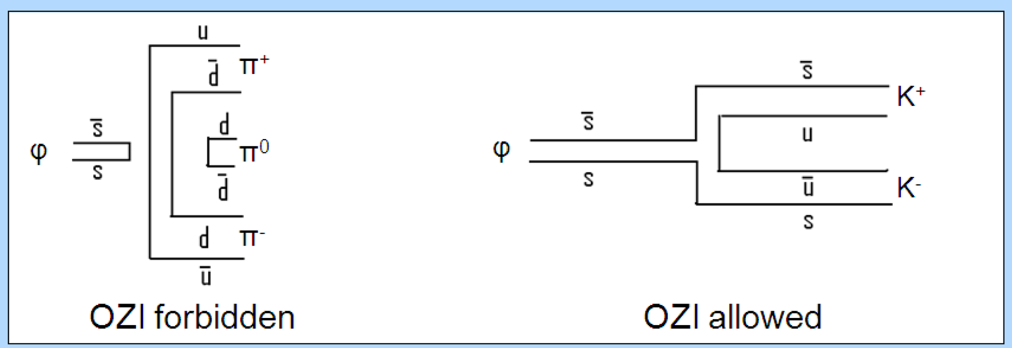
on behalf of the COMPASS Collaboration

1. The Okubo-Zweig-Iizuka (OZI) rule:

- states that processes with disconnected quark lines are forbidden[1].
- explains suppressed decay modes and production of vector mesons.



- allows production of ϕ mesons thanks to deviation from ideal mixing
- predicts the cross section ratio of ϕ / ω production[2]:

$$R(\phi/\omega) = \sigma(AB \to X\phi) / \sigma(AB \to X\omega) = 4.2 \cdot 10^{-3}$$

where A, B are hadrons without strangeness.

The OZI prediction is fulfilled in pion-induced reactions and in proton-antiproton annihilations in flight.

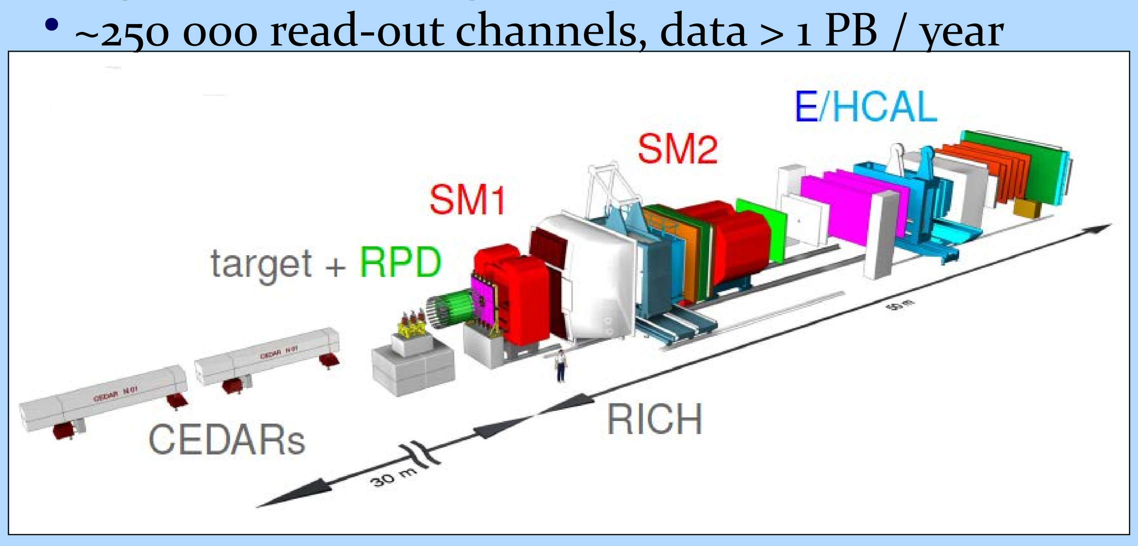
Apparent violations have been found in proton-induced reactions, proton-antiproton annihilations at rest and in reactions near the kinematic threshold[3]. Possible explanations:

- gluonic intermediate states[4].
- polarised hidden strangeness in the nucleon[5].

[1] S. Okubo, Phys. Lett. 5 (1963) 165, G. Zweig, CERN report TH-401 (1964), J. Iizuka, Prog. Theor. Suppl. 38 (1966) 21f
[2] H.J. Lipkin, Phys. Lett. B 60 (1976) 371
[3] V.P. Nomokonov and M.G. Sapozhnikov, Physics of Particles and Nuclei 24 (2003).
[4] S. J. Lindenbaum, Nouvo Cim. 65 A (1981) 222
[5] J. Ellis et al. Phys. Lett. B 353 (1995) 319, J. Ellis et al. Nucl. Phys. A 67 3 (2000) 256

2. The COMPASS experiment[6]

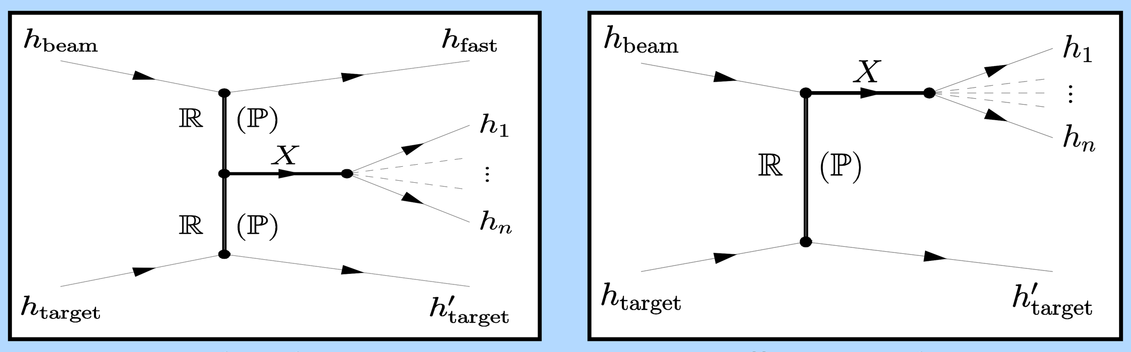
- two stage spectrometer
- high resolution, large acceptance
- ~250 000 read-out channels, data > 1 PB / year



Experimental setup 2008/09[7]:

- 190 GeV/c beam ($p^\pm$, $K^\pm$, p), liquid H_2 target
- new pixelised tracking detectors
- new recoil proton detector RPD (exclusive trigger)
- 2 CEDARs (beam particle PID)
- Calorimetry in both stages – upgraded 2008/09
- RICH in 1st stage – upgraded in 2006 [8]

Production mechanisms at COMPASS



Central production — Diffractive production

[6] The COMPASS collaboration, NIM A 577 (2007) 455
[7] Hadron set-up 08/09, NIM A, in preparation (2012)
[8] NIM A 587 (2008) 371., NIM A 616 (2010) 21.

3. Analysis

Event selection, common cuts for ϕ / ω:

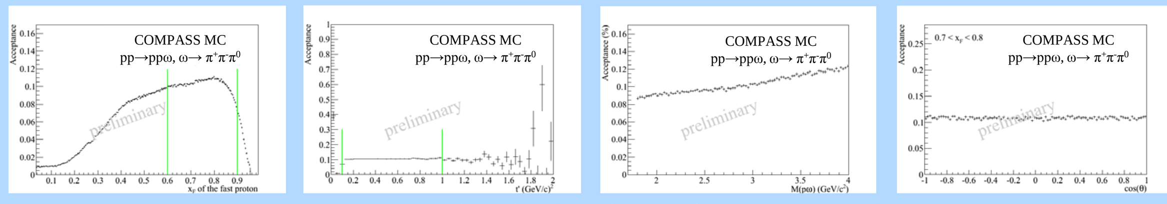
- primary vertex in target volume
- three charged tracks, charge conservation
- beam proton (tagged with CEDARs)
- recoil proton (tagged by RPD)
- exclusivity and coplanarity
- $0.6 < x_F(p_{fast}) < 0.9$
- $0.1 < t' < 1.0\ (GeV/c)^2$

Specific cuts for ω:

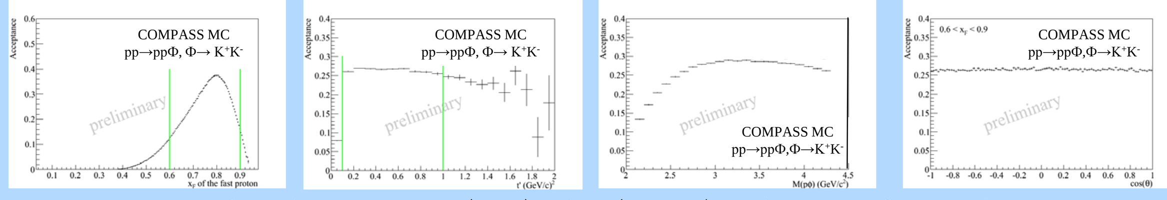
- > 1 photon in any of the ECALs
- exactly one π^0 candidate
- one π^+ identified in the RICH
- $1.8 < M(p_{fast}\,\omega) < 4.0\ GeV/c^2$

Specific cuts for ϕ :

- one K^+ identified in the RICH
- $2.1 < M(p_{fast}\,\phi) < 4.3\ GeV/c^2$



Acceptance distributions in $x_F(p_{fast})$, t', $M(p_{fast}\,\omega)$ and $\cos\theta_{Hel}$ for $pp \to p_{recoil}\,p_{fast}\,\omega$

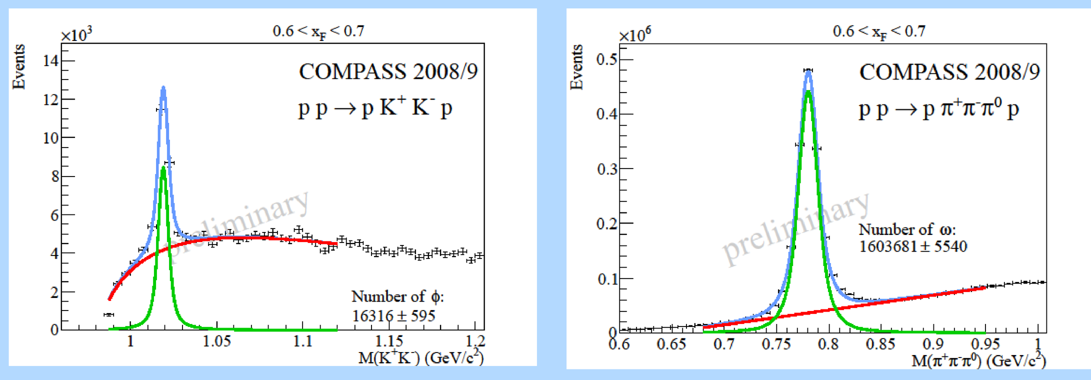


Acceptance distributions in $x_F(p_{fast})$, t', $M(p_{fast}\,\phi)$ and $\cos\theta_{Hel}$ for $pp \to p_{recoil}\,p_{fast}\,\phi$

Acceptance correction:

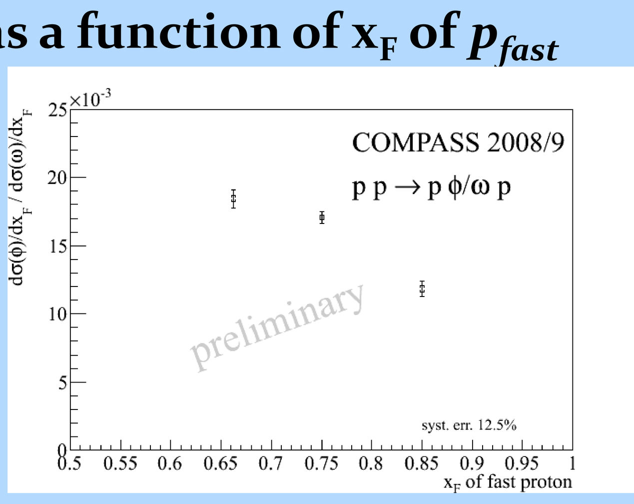
Two 3D-acceptance matrices for each reaction have been constructed; one in $x_F(p_{fast})$, t', $M(p_{fast}\,\phi)$ and one in t', $M(p_{fast}\,\phi)$ and $\cos\theta_{Hel}$. The acceptance correction of the real data is then performed on an event-by-event basis.

Background subtraction:



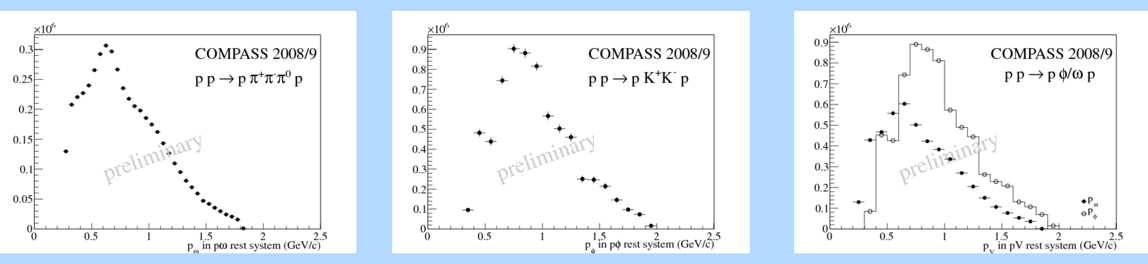
A Breit-Wigner function, convoluted with a single (ϕ) or a double (ω) gaussian and a polynomial background was fitted to the data in order to extract the ϕ and ω yields (examples for $0.6 < x_F < 0.7$).

4. R(ϕ /ω) as a function of x_F of p_{fast}



The ratio R(ϕ /ω)= σ(pp →ppϕ) / σ(AB →ppω) was calculated from the background subtracted, acceptance corrected and branching ratio corrected ϕ and ω yield in 3 x_F bins: 0.6-0.7, 0.7-0.8 and 0.8-0.9. The statistical errors are shown in the error bars and the systematical errors, mainly from the ECAL and RICH efficiencies, add up quadratically to 12.5 %. The OZI rule is violated with a factor of 2.9 – 4.4.

5. R(ϕ /ω) as a function of x_F with $p_V > 1.0$ GeV/c

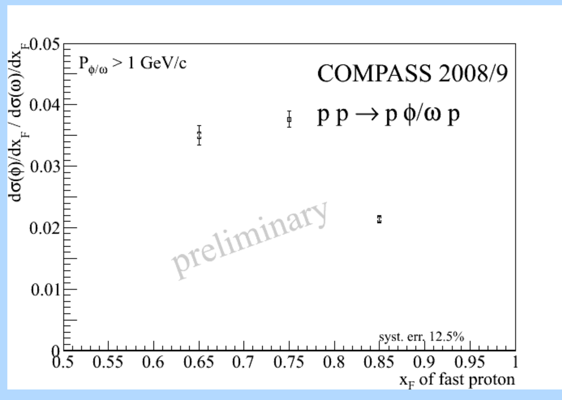


The quantity p_V for side-band subtracted, acceptance and BR corrected ω (left) and ϕ (middle) data. To the right is the combined plot, with the ϕ yield multiplied with a factor of 100.

In order to obtain R(ϕ /ω) in a region without prominent pV resonances, an additional cut was applied on the momentum of the vector meson, p_V, in the rest system of the $p_{fast}V$ (V = ϕ or ω).

We required $p_V > 1$ GeV/c as in the work by SPHINX[9].

The OZI rule is then violated by a factor of 4.5 – 9.1, in agreement with SPHINX.



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

6. Spin alignment measurements

- Sensitive to the production mechanism,[10] but also to the structure of the initial system.[5,11]
- Low energy *pd* experiments show that ω is produced unpolarised [12] whereas ϕ is produced polarised[13].
- The differential cross section of a 3-body decay is given by

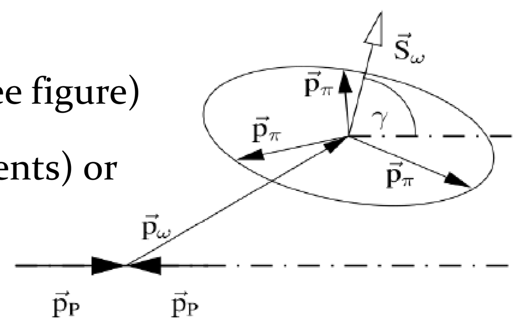
$$W_{3body}(\cos\theta) = N(2\rho_{00} - (3\rho_{00} - 1)\cos^2\theta)$$

and for a 2-body decay

$$W_{2body}(\cos\theta) = N(1 - \rho_{00} + (3\rho_{00} - 1)\cos^2\theta)$$

where ρ_{00} is the zeroth element of the spin-density matrix and N a proportionality constant. [14]

- Unpolarised when $\rho_{00} = 1/3$
- In this work, we study the helicity angle, *i.e.* As reference axis we take the direction of the $p_{fast}V$ system in the rest frame of the vector meson *V*.
- Analyser in the ω case: $\hat{e}_{\pi+} \times \hat{e}_{\pi-}$ (see figure)
- Analyser in the ϕ case: $\hat{e}_{K+}$ (odd events) or $\hat{e}_{K-}$ (even events).

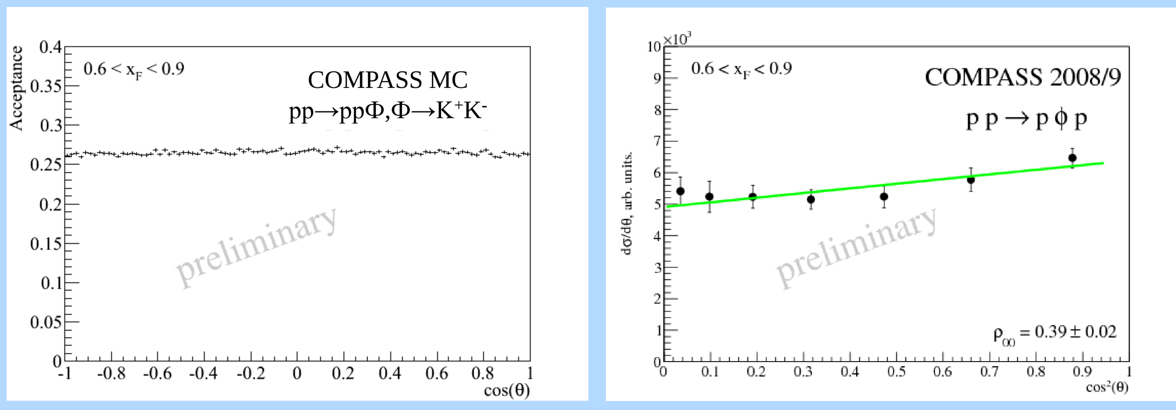


[10] K. Gottfried & J.D. Jackson, Nuovo Cim. 33 (1964) 302.
[11] X. Quing-hua & L. Zuo-Tang, Phys. Rev. D 68 (2003) 034023
[12] K. Schönning *et al.*, Phys. Lett. B 668 (2008) 258.
[13] F. Belleman *et al.*, Phys. Rev. C 75 (2007) 015204
[14] M. Abdel-Bary *et.al.* Eur. Phys. J. A. 44 (2010) 7

7. Results: spin alignment and $M(p_{fast}V)$ of ϕ

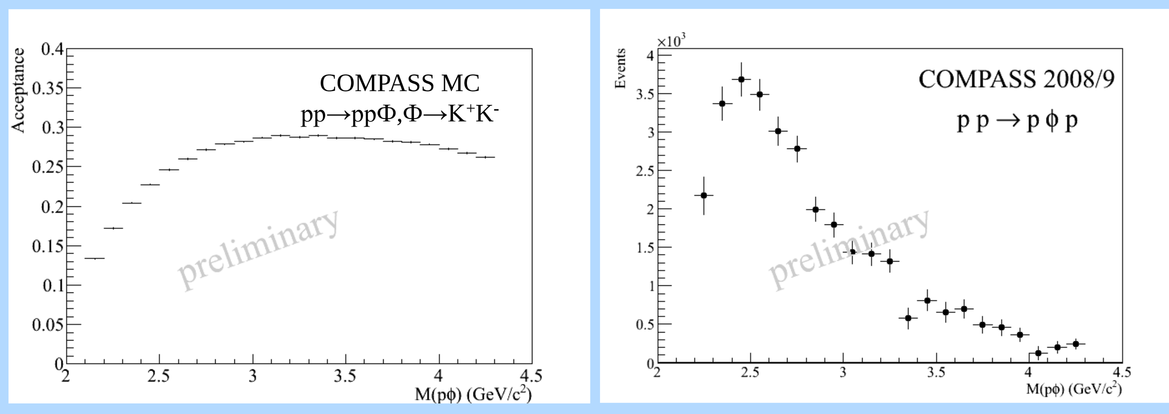
If diffractive production (*i.e.* there are intermediate baryon resonances) we expect high sensitivity to the helicity angle.

The acceptance as a function of the cosine of the helicity angle is flat (left plot below). The $\cos^2\theta$ distribution is consistent with a positive slope but the deviation from flatness is small (right plot below).



The invariant mass distribution of the $p_{fast}V$ system can also give hints about intermediate processes in the production.

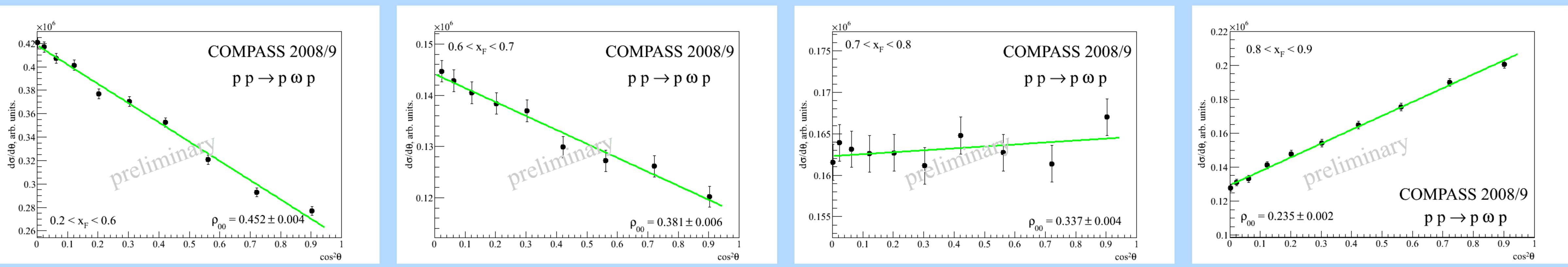
No obvious structures are observed in the $M(p_{fast}\phi)$ distribution.



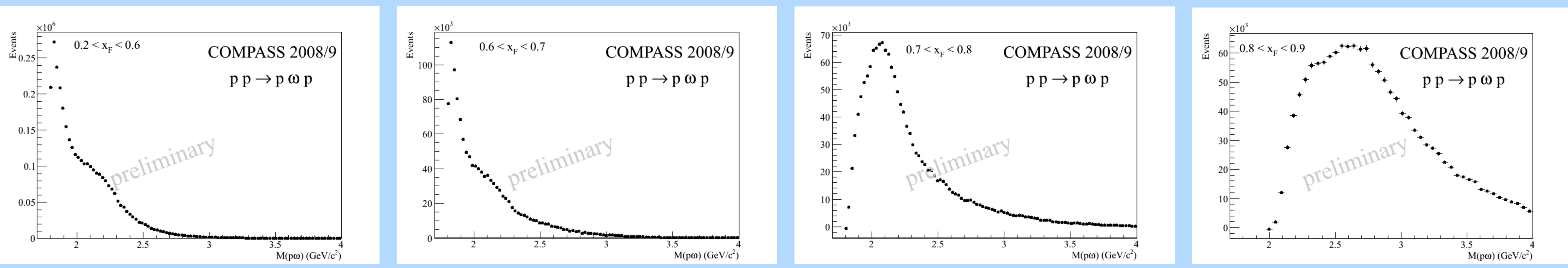
The acceptance as a function of the $M(p_{fast}\phi)$ (left) and the sideband subtracted and acceptance corrected distribution observed in the data (right).

8. Results: spin alignment and $M(p_{fast}\,V)$ of ω in $x_F(p_{fast})$ bins

High statistics and signal-to-background ratio allows for extraction of ρ_{00} and $M(p_{fast}\,\omega)$ subregions of $x_F(p_{fast})$. The results reveal how strongly the physical processes depend on x_F.



The $\cos^2\theta$ of the helicity angle in different $x_F(p_{fast})$ subregions, indicated in the figures. The ω mesons are significantly aligned at low $x_F(p_{fast})$, whereas the alignment is weaker in the $0.6 < x_F(p_{fast}) < 0.7$ region and completely arbitrary (unpolarised) within $0.7 < x_F(p_{fast}) < 0.8$. At higher $x_F(p_{fast})$, the ω mesons are again aligned but in the opposite direction.



The $M(p_{fast}\,\omega)$ distribution in different $x_F(p_{fast})$ subregions, indicated in the figures. Different structures appear in different $x_F(p_{fast})$ regions. For a reliable identification of the observed structures, Partial Wave Analysis would be needed.

9. Summary and Outlook

- The cross section ratio R(ϕ/ω) has been measured as a function of $x_F(p_{fast})$. The OZI rule was found to be violated with a factor of 2.9-4.4.
- For $p_V > 1.0$ GeV/c, the OZI violation is 4.5-9.1.
- The ϕ mesons are very weakly aligned.
- No obvious structures were found in the $M(p_{fast}\phi)$ spectrum.
- The alignment of the ω mesons depends significantly on $x_F(p_{fast})$.
- Clear structures were observed in the $M(p_{fast}\omega)$ spectrum, but PWA is needed for identification of any baryon resonances. The character of the $M(p_{fast}\omega)$ distribution depends strongly on $x_F(p_{fast})$.

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bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

12th International Workshop on Meson Production, Properties and Interaction
31 May - 5 June 2012