Production of the ω-Meson at Threshold
in the reaction pp $\rightarrow$ pp ω at COSY-11

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Abstract

In various meson exchange models the heavier mesons like the ω(783)-, the σ-, the correlated 2 π, and the ρ-meson are important as exchange mesons in short range baryon-baryon interaction. The on shell production of these heavier mesons will yield valuable information concerning the coupling constants. Apart from the σ which is not a genuine particle the ω and the ρ are accessible in p p interactions. Due to the small solid angle at the COSY-11 installation only the width of the ω (from these two mesons) is sufficiently small to perform successfully threshold production measurements at the COSY-11 installation. The production rate of both, the ω(783) and the ϕ(1020)-meson are important to probe the - perhaps OZI-violating - ratio of the ϕ to ω production.
Measurements close to the production threshold allow the examination of the reaction mechanism and the meson-nucleon final state interaction to determine for instance the meson-nucleon coupling constant.
It is proposed to measure the ω production via the $pp \rightarrow pp\omega$ reaction at a beam momentum of 2.74 GeV/c, sufficiently above the ω mass to cover the whole ω width.

Motivation

Exchange mesons

In the concept of Yukawa the baryon-baryon interaction can be described by exchange mesons. The π exchange dertermines the long range part of the interaction whereas heavier mesons contribute significantly to interactions at shorter distances. These virtual exchange-mesons can be produced as real particles on the mass shell using sufficient total energies $\sqrt{s}$. The exchange of mesons heavier then the π plays a significant role in different calculations of production cross sections in various reactions. Horowitz [3] [7] incorporated heavy meson exchange into the threshold $NN \rightarrow d\pi$ calculations to enhance the grossly underestimated cross section. With the inclusion of heavy meson exchange Lee and Riska [8] gave the first quantitativ description of high precission IUCF data of the reaction $pp \rightarrow pp\pi^0$ [5] [6]. The resulting contribution enhance the cross section near threshold by a factor of 3-5 [8] [4]. Drescribing the data both the σ and the ω exchange are very significant [4] [6].
In the threshold production of the ω-meson, with the outgoing particles in a relative S-wave, we have a clean system to investigate the meson-nucleon final state interaction.

ϕ/ω production rate

According to the quark line or OZI-rule [10] [11], assuming the absence of strange quarks in the incoming nucleons, the ϕ-meson can only be produced due to their non strange quark content, which is proportional to $sin\vartheta$, with ϑ beeing the deviation from the ideal mixing angle. For both the vector mesons ϕ and ω holds

$$\phi = \phi_0 sin\theta - \phi_8 cos\theta \ , \tag{1}$$

$$\omega = \ \phi_8 sin\theta + \phi_0 cos\theta \ , \tag{2}$$

with ω and ϕ beeing the physical vector mesons and ϕ_8, ϕ_0 the singlet-, respectively, the octet-states with $I = S = 0$. Since

$$\phi_0 = (d\bar{d} + u\bar{u} + s\bar{s})/\sqrt{3} \quad and \tag{3}$$

$$\phi_8 = (d\bar{d} + u\bar{u} - 2s\bar{s})/\sqrt{6} \tag{4}$$

the quark content for the special mixing angle $\theta \approx 35°$ calculates as

$$\phi = s\bar{s}\,, \tag{5}$$

$$\omega = (u\bar{u} + d\bar{d})/\sqrt{2}\,. \tag{6}$$

This ideal mixing is given in nature, so that the ϕ is almost a pure $s\bar{s}$ state whereas the ω is built out of u and d quarks. Thus the ϕ versus the ω production is expected to be suppressed in the nucleon-nucleon collision by a factor of $tan^2(\theta - \theta_{ideal}) \approx (1-3) \times 10^{-3}$ under the same conditions when a mixing angle of $\theta = 37.1° - 38.5°$ is used [14]. To probe this violation the ratio of the branching ratios $R_x = \frac{BR(p\bar{p} \to \phi X)}{BR(p\bar{p} \to \omega X)}$, where X represents one or more acompanying particles, should be determined. In various measurements of branching ratios in the $p\bar{p}$ annihilation the OZI-rule is evaded by a factor of 100 and more, for instant the ratio $R_x = \frac{BR(p\bar{p} \to \phi\gamma)}{BR(p\bar{p} \to \omega\gamma)} = 0.33 \pm 0.15$ (see also tab. 2 in [12]). Attempts to describe the data are intermediate resonances [13], final state interactions [17] or an enhanced $s\bar{s}$ content in the proton wave function [16], [15]. Also in nucleon-deuteron interactions the violation was observed [9]. In the reaction $pd \to ^3HeX$ measured at SATURNE Wurzinger et al. extracted the ratio of the total cross sections $R(\frac{\phi}{\omega}) \approx (6.3 \pm 0.5)\%$.
Therefore it is of principle interest to measure this ratio also in the p p channel at threshold.

Experimental Status

The proposed measurements can be performed with the standard COSY-11 setup [2], see fig.1. Since the detector system is limited by the gap of a regular COSY-C-typ dipole a 100 % acceptance will only be observed up to an excess energy of ≈ 0.5 MeV for the reaction $pp \to pp\omega$. The produced ω-meson will be identified via the missing mass technique.

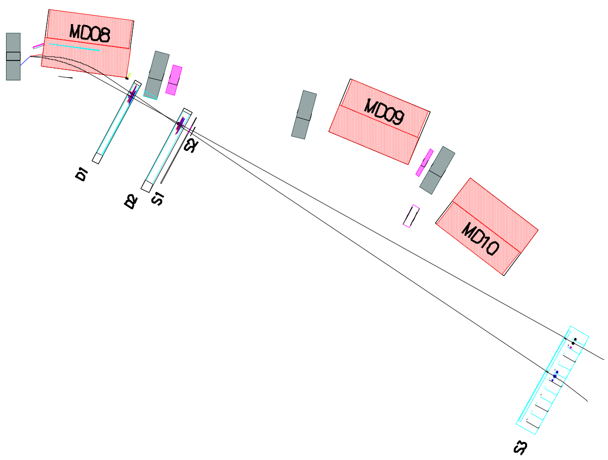

Figure 1: One monte carlo generated ω-event in the established COSY-11 setup at a beam momentum of 2740 MeV/c.

We expect to get $\approx 2 \times 10^{10}$-beam particles circulating with a frequency of about 1.5 MHz. Typical density values for the cluster target are 1×10^{14} atomes/cm^2 [1]. With the target beam diameter of 9 mm in connection with the COSY-11 beam optics [2] we get almost a 100 % overlap of both beams. Thus the expected luminosity is: L= $2 \times 10^{10} \times 1.5 \times 10^6 \times 1 \times 10^{14} = 3 \times 10^{30} cm^{-2}s^{-1}$.
The differential cross section for the ω production in the reaction $pp \to pp\omega$ was measured by the CRN collaboration at SATURNE and described in the Annual Report [18]. With the magnetic spectrometer

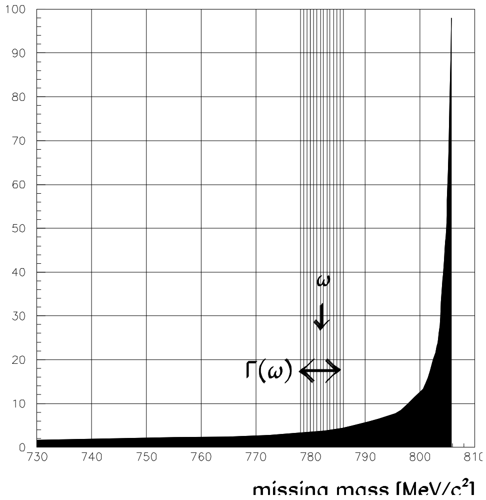

Figure 2: The geometrical acceptance off the COSY-11 setup for registering two protons at the ω production threshold.

SPES3 the ω production under $0°$ at nominal machine energies of 1905, 1920 and 1935 MeV was detected. The ω was reconstructed by the missing mass method. The total cross section was calculated by extrapolating the differential cross section with respect to Monte Carlo phase space simulations.
Facing that we would expect for our intended energy of 1958 MeV a total cross section of $\approx 1 - 1.5\mu b$.

At COSY-11 we propose to measure the ω production at $\approx$ 2.74 Gev/c beam momentum, i.e. 72 MeV/c above threshold.
The acceptance is drastically reduced for momenta a few MeV/c above threshold but it decreases smoothly to a level of $\approx$ 3% which can be seen from fig. 2. Here the acceptance from Monte Carlo events is plotted as a function of the produced mass X in $pp \to ppX$ reactions for a beam momentum of 2740 MeV/c. The whole ω range (FWHM=8.43 MeV) emphazised by the shadowed area with the center mass of 781.95 MeV is covered in such a measurement with a mean acceptance of 4.1%.
The Dalitz plot for 50000 simulated ω events, reconstructed within the conditions of the COSY-11 installation, is shown in fig. 3. Although the acceptance is reduced no holes in the Dalitz plot are visible.

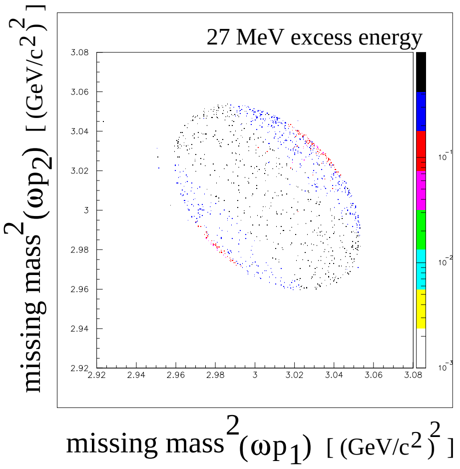

Figure 3: The Dalitz plot of the monte carlo generated data $pp \to pp\omega$.

At 2.75 GeV/c the kinematical limit is 26 MeV above the ω mass which corresponds to ≈ 3 times the full width of the ω. Therefore the missing mass plot includes the complete ω distribution with the background contribution above and below the ω. The background from the multi pion production and other reaction channels is expected to result in a structureless behaviour in the missing mass plot. The most important background channels are listed in tab. 1. The cross sections were extrapolated from data at beam momenta in the range of 2.8 GeV/c, respectively 5.5 GeV/c for the 5 pion and the ρ reaction.

channel X	σ_X [mb] *
$\pi^+\pi^0\pi^-$	0.2
$\pi^+\pi^0\pi^0\pi^-$	0.005
$\pi^+\pi^-$	2.3
$\pi^+\pi^+\pi^0\pi^-\pi^-$	0.01
$\pi^+\pi^+\pi^-\pi^-$	0.0005
$\pi^0\pi^0$	0.88
ρ	0.0024

Table 1: Relevant background channels pp $\rightarrow$ pp X with *estimated cross sections at P_{beam}=2740 MeV/c (E_{CM}=2682 MeV).

Geant Monte Carlo calculations have been done for all the relevant channels in order to check the acceptances at COSY-11. Then the three dominant channels, i. e. ($\pi^+\pi^-$), the ($\pi^0\pi^0$) and the ρ production have been simulated with high statistics. For the production a phase space distribution was assumed. The Monte Carlo events were generated within the COSY-11 setup and the detected protons in this events were analyzed by the standard analysis program which is also used for the real data. In fig. 4 the missing mass plots are shown for this three separate channels, weighted with the estimated cross sections.

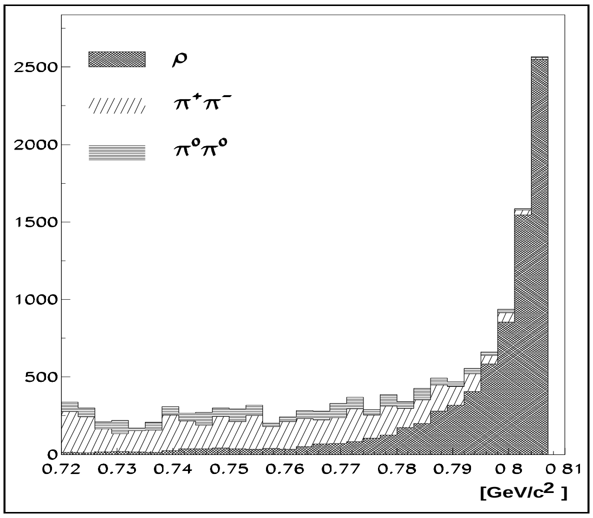

Figure 4: Missing mass plot of the relevant background channel for the ω production.

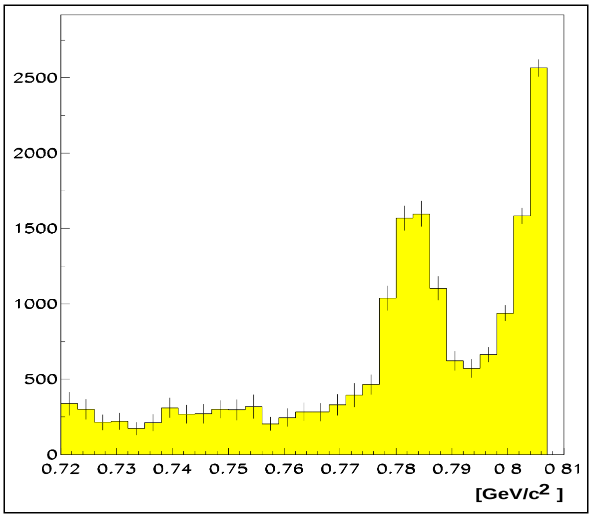

Figure 5: The ω channel added to the simulated background.

The beam momentum of 2.74 GeV/c is in the same order of the SATURNE measurements [18]. Therefore a total cross section of ≈ 1 μb for the ω production was assumed for the further simulations. In fig. 5 the addition of all three dominant background channels including the ω production with $\sigma_{tot.} = 1\mu$b is shown. A clear ω peak is visible in the missing mass plot.
In a short test run the background situation was examined at a beam momentum of 2.74 GeV/c. Fig. 6 shows the preliminary result of this test. Here the missing mass plot for the analyzed events is shown. An enhancement at the ω mass region is seen but compared to the Monte Carlo studies the ω/background ratio is much lower. From the count rate in this enhancement the cross section for ω production is a factor of 2-3 lower than reported by the SATURNE experiment.

Furthermore the increase at the upper end due to ρ events is not seen which means that the estimated cross section in the Monte Carlo for the ρ production was to high. The analysis of our test data is still in progress.

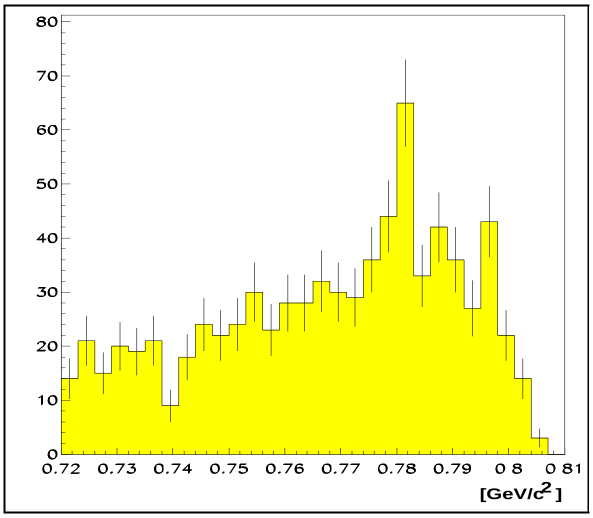

Figure 6: Missing mass plot.

Apart from the background of other reaction channels which can not be separated from the ω production the experimental background is very low. The trigger rate for a run without target is in the order of 2 events/s compared to 220 events/s for the run with target. Also the discrimination of pions is sufficient which is shown by fig. 7. A clear separation of the three event types $\pi\pi$, πp and pp is seen.

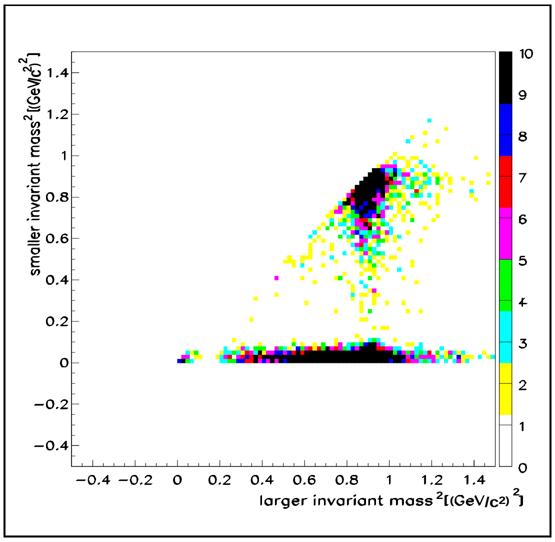

Figure 7: . Invariant mass of the recontructed particles from two track events.

Beam Request

It is proposed to measure the ω production at two beam momenta in the range of 2.75 GeV/c shifted by a few MeV/c. By comparison of both measurements a check of the background subtraction is possible. On the basis of the SATURNE measurement [18] ≈260000 events per day will be produced for a luminosity of L=3 × $10^{30} cm^{-2} s^{-1}$. Including the mean acceptance of 4.2% ≈ 11000 events/day could be detected.

beam request for ω						
P_{beam} [MeV/c]	exess energy [MeV]	acceptance [%]	counts [1/day]	required counts	required time[days]	requested time[days]
2740	23.96	4.1	5000	25000	5	5
2736	22.64	4.3	5000	25000	5	5
for ϕ						
3481	23.99	≈4.0	300	1200	4	4
						$\Sigma = 14$

Table 2: Beam request.

In view of our preliminary test results a rate is expected which is down by a factor of 2-3, therefore we expect to observe ≈5000 ω events/day.
For the corresponding ϕ production a number of 300 ϕ events/day can be assumed taking into account the OZI-rule violation determined in the reaction $pd \rightarrow ^3HeX$ by Wurzinger et al. of $R(\frac{\phi}{\omega}) \approx 6\%$.
It is asked for a two week block for this measurements (tab. 2). The statistics for the ω production will be sufficient to establish or to correct the assumed total cross section and to fill a Dalitz plot for more detailed analysis. In case of the ϕ production the statistics will be sufficient for a check of the OZI-rule violation in the p p channel.

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