Phi meson decay in pp collisions

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Outline

Okubo-Zweig-Iizuka rule and Lipkin.

- It is believed that dynamics of ω and ϕ mesons production in πN and NN collisions is very similar.

If it is so the ratio of the ϕ to ω production cross sections follows the simple rule proposed by Lipkin.

$$R_{\phi/\omega} = \frac{g^2_{\phi\rho\pi}}{g^2_{\omega\rho\pi}} = \frac{g^2_{\phi NN}}{g^2_{\omega NN}} = \frac{\sigma(\pi N \to \phi X)}{\sigma(\pi N \to \omega X)} = \frac{\sigma(NN \to \phi X)}{\sigma(NN \to \omega X)}$$
$$= \tan^2(\Delta\theta_V) = 4.2 \cdot 10^{-3}.$$

Concerning the last part of the above equation, this rule is known as Okubo-Zweig-Iizuka rule. $\Delta\theta_V$ is deviation from the ideal mixing angle between singlet and octet vector mesons. $SU(3)$ gives $\Delta\theta_V$=3.7^o or $R_{\phi/\omega}$=4.2$\cdot$10^{-3}.

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Actually this formalism is already violated on a level of the $\phi\rho\pi$ and $\omega\rho\pi$ coupling constants, namely

$$R_{\phi/\omega}=g^2_{\phi\rho\pi}/g^2_{\omega\rho\pi} = (12.5 \pm 3.4)\cdot 10^{-3} \neq 4.2\cdot 10^{-3} = SU(3).$$

These coupling constants can be extracted from $\phi\to\rho\pi$, $\omega\to 3\pi$, $\omega\to\pi\gamma$ and $\rho\to\pi\gamma$ decays. Note that is also established that the $\phi\to\rho\pi$ decay alone violates OZI rule.

A systematic analysis of experiments on ϕ and ω production in πN and NN reactions leads to an average ratio of $R_{\phi/\omega} = (13.4 \pm 3.2)\cdot 10^{-3}$. So seems to be no problem.

A. Sibirtsev and W. Cassing, Eur. Phys. J. A7 (2000) 407.

Let us inspect data that indicate even larger ratios!

Okubo-Zweig-Iizuka rule.

An analysis of ϕ and ω photoproduction from proton shows that the ratio $R_{\phi/\omega} = 0.8 \pm 0.2$.

This was interpreted in terms of quark–anti-quark fluctuations of the photon. Considering the $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, $b\bar{b}$ and $t\bar{t}$ photon structure one might expect that at high energies, i.e. in the perturbative QCD regime, the ratios of different vector mesons approach unity, up to corrections due to the hadronic wave functions.

The results are given in: A. Sibirtsev, U.-G. Meißner and A.W. Thomas, Phys. Rev. D 71 (2005) 094011.

Okubo-Zweig-Iizuka rule.

There are still some phenomena, which might be a signature of a $s\bar{s}$ component in the nucleon resulting in large ratio.

For example, proton–antiproton annihilation at rest results in $R_{\phi/\omega}$=0.294±0.097 for the $\phi\gamma$ and $\omega\gamma$ final states while a ratio $R_{\phi/\omega}$=0.106±0.012 was found for the $\phi\pi$ and $\omega\pi$ channels. At the same time the available data for the annihilation in flight yield a ratio $R_{\phi/\omega}$ = (14.55±1.92)·10^{-3}.

The DISTO measurement done in pp collisons at beam energy of 2.85 GeV results in the ratio $R_{\phi/\omega}$=(36±16)·10^{-3}.

F. Balestra et al., Phys. Rev. Lett. 81 (1998) 4572.

Most recent results.

Most recent results were obtained by ANKE Collaboration at COSY. The measurements were done using the proton beam at energies close to the reaction threshold.

M. Hartmann et al., Nucl. Phys. A 755 (2005) 459.

To analyse these data we need to consider the corrections due to the different phase space for ϕ and ω production at low proton beam energies, the interaction between the final protons and final width of the mesons, especially ω.

So we should analyse not the ratio of the measured cross section but the reaction amplitude squared.

Formalism.

The average reaction amplitude squared $|\mathcal{M}|^2$ can be extracted from the reaction cross section σ as

$$\sigma(\epsilon) = \frac{\sqrt{m_N^2 m_V}}{2^7\pi^2(2m_N+m_V)^{3/2}} \frac{\epsilon^2}{\sqrt{s^2-4sm_N^2}} \times \left[1+\frac{4\beta^2-4\alpha^2}{-\alpha+\sqrt{\alpha^2+m_N\epsilon}}\right]|\mathcal{M}|^2, \quad (1)$$

$\epsilon = \sqrt{s} - 2m_N - m_V$, $\sqrt{s}$ is the invariant collision energy and pp FSI is described by Jost function

$$|J(q)|^{-1} = \frac{q+i\beta}{q-i\alpha} = \left[\frac{r\beta^2}{2}+\frac{rq^2}{2}\right]\left[-\frac{1}{a}+\frac{rq^2}{2}-iq\right]^{-1}, \quad (2)$$

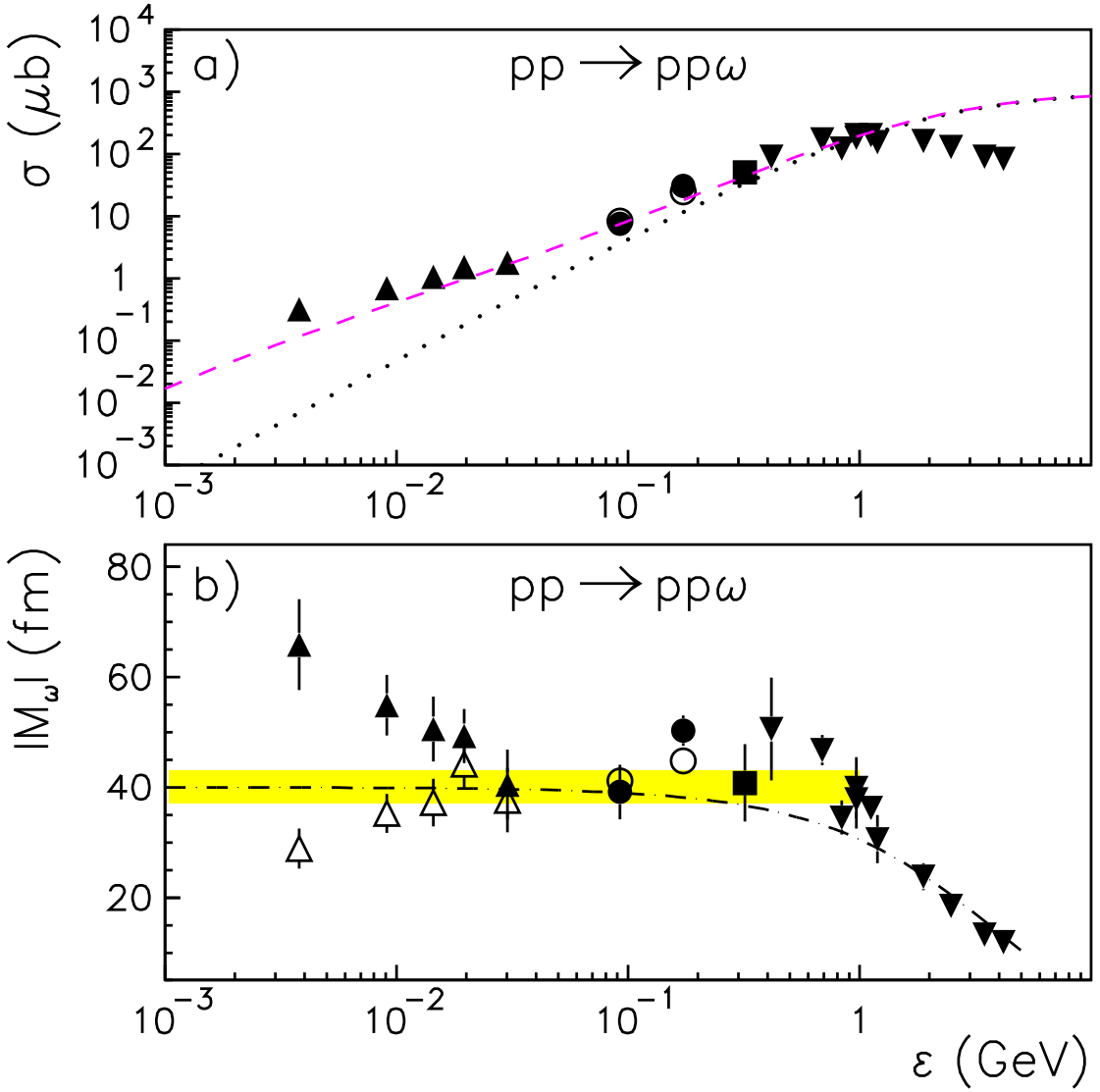
with $\alpha = -20.5$ MeV and $\beta = 166.7$ MeV.

ω-width.

Indeed one should account for the ω-meson width, Γ=8.49 MeV, when analyzing the data at low excess energies, *i.e.* at $\epsilon \simeq \Gamma$. In that case the relation between the $pp \to pp\omega$ cross section and reaction amplitude is given as

$$\sigma(\epsilon) = \frac{1}{2^8 \pi^3 s \sqrt{s^2 - 4sm_N^2}} \int_{2m_\pi}^{\sqrt{s}-2m_N} \frac{dx}{2\pi} \frac{\Gamma\ |\mathcal{M}|^2}{(x-m_\omega)^2 + \Gamma^2/4}$$
$$\int_{4m_N^2}^{(\sqrt{s}-x)^2} dy \frac{\sqrt{y^2 - 4ym_N^2}\sqrt{(s-y-x)^2 - 4yx^2}}{y} \frac{y^2 - 4m_N^2 + 4\beta^2}{y^2 - 4m_N^2 + 4\alpha^2}\,. \qquad (3)$$

Results.



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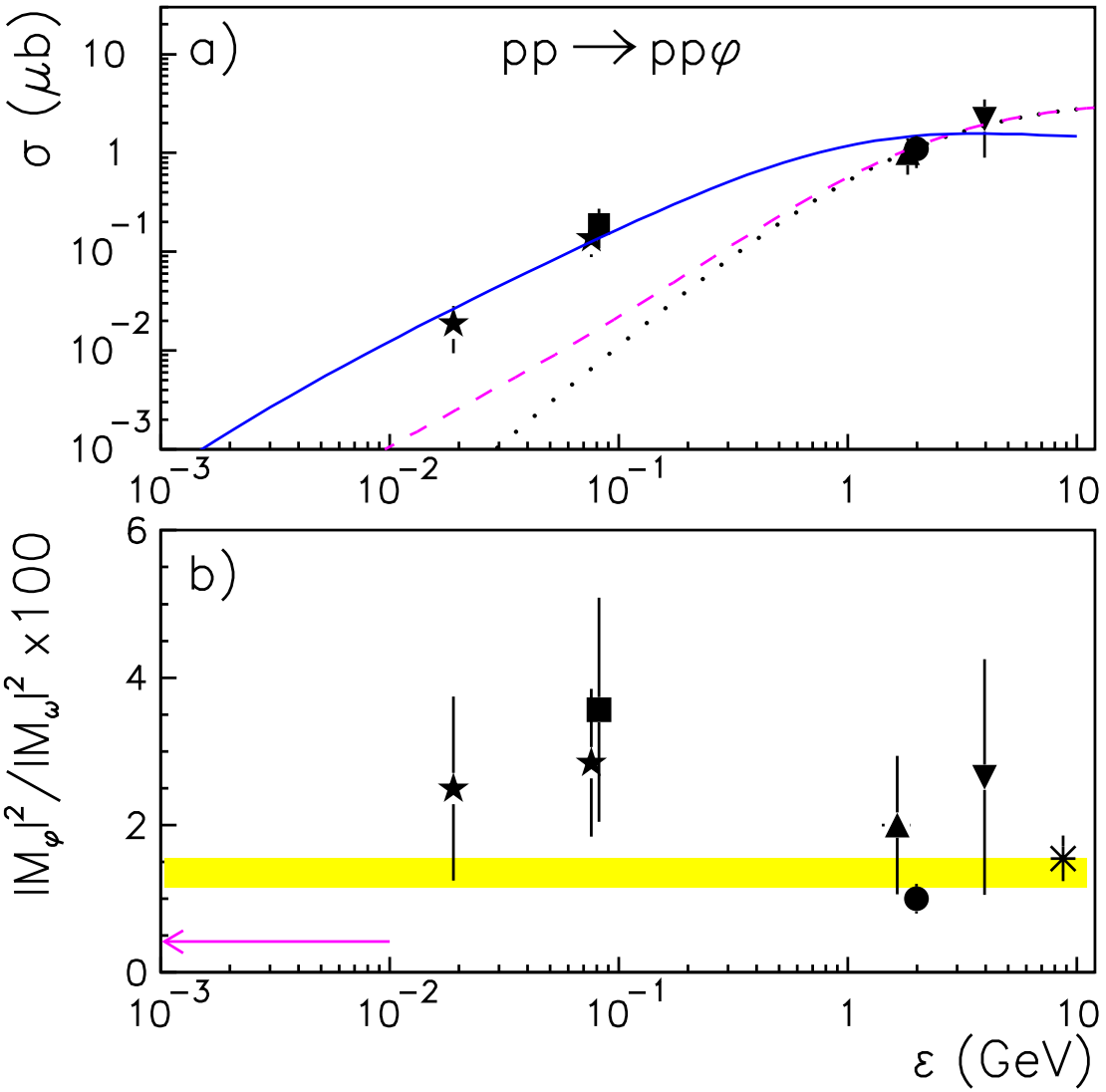
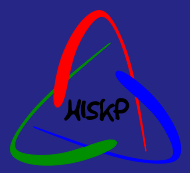


Speculations.

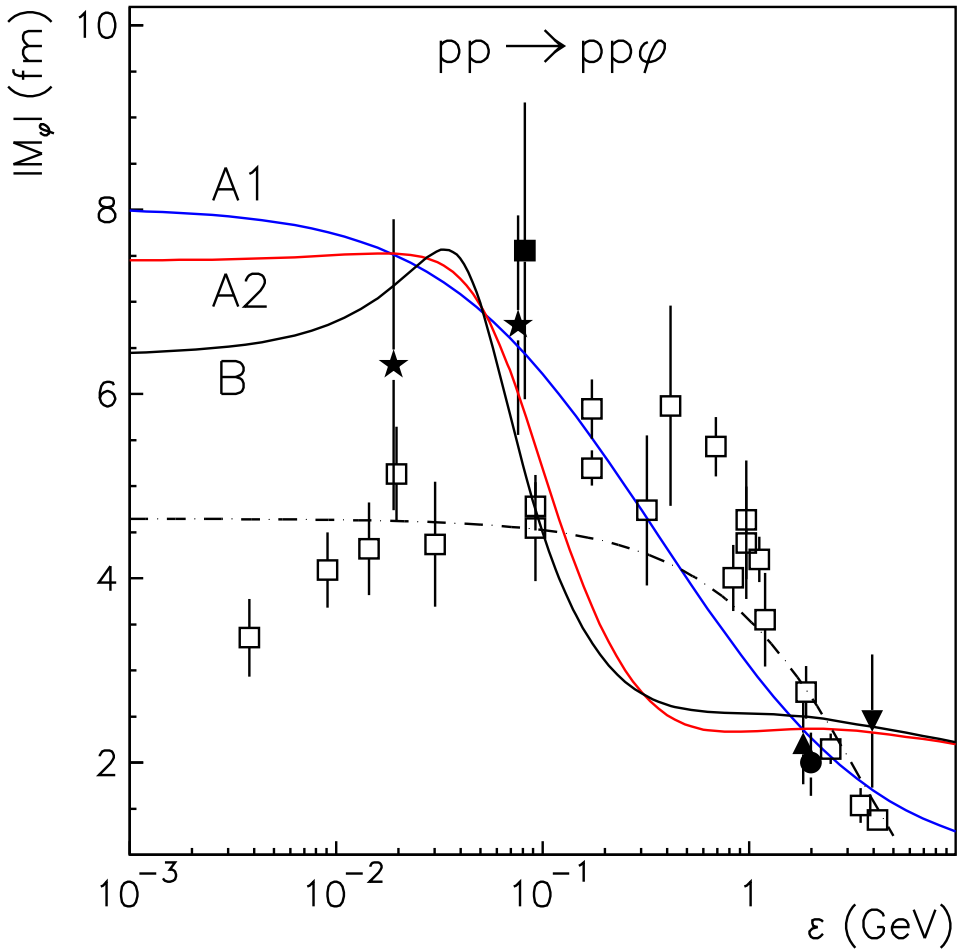
Landsberg proposed that ϕp production is well suited for the search of cryptoexotic baryons with hidden strangeness, $B_\phi{=}uudds\bar{s}$.

It is expected that these pentaquark baryons have a narrow width and decay preferentially into the ϕN, $K\bar{K}N$ or YK channels, where Y stands for ground-state or excited hyperons. Note that these decays are OZI allowed.

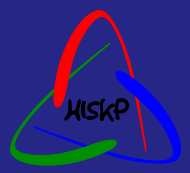
There are two independent observations of a narrow peak in the $\Sigma(1385)^0K^+$ spectra, the first one with a mass $M = 2050{\pm}6$ MeV and width $\Gamma \leq 50{\pm}19$ MeV and the second one with $M = 1956^{+8}_{-6}$ MeV and $\Gamma{=}27 \pm 15$ MeV. The high-statistics study of the Σ^0K^+ mass spectrum indicates two exotic states with $M = 1807{\pm}7$ MeV, $\Gamma = 62{\pm}19$ MeV and $M = 1986{\pm}6$ MeV, $\Gamma = 91{\pm}20$ MeV.



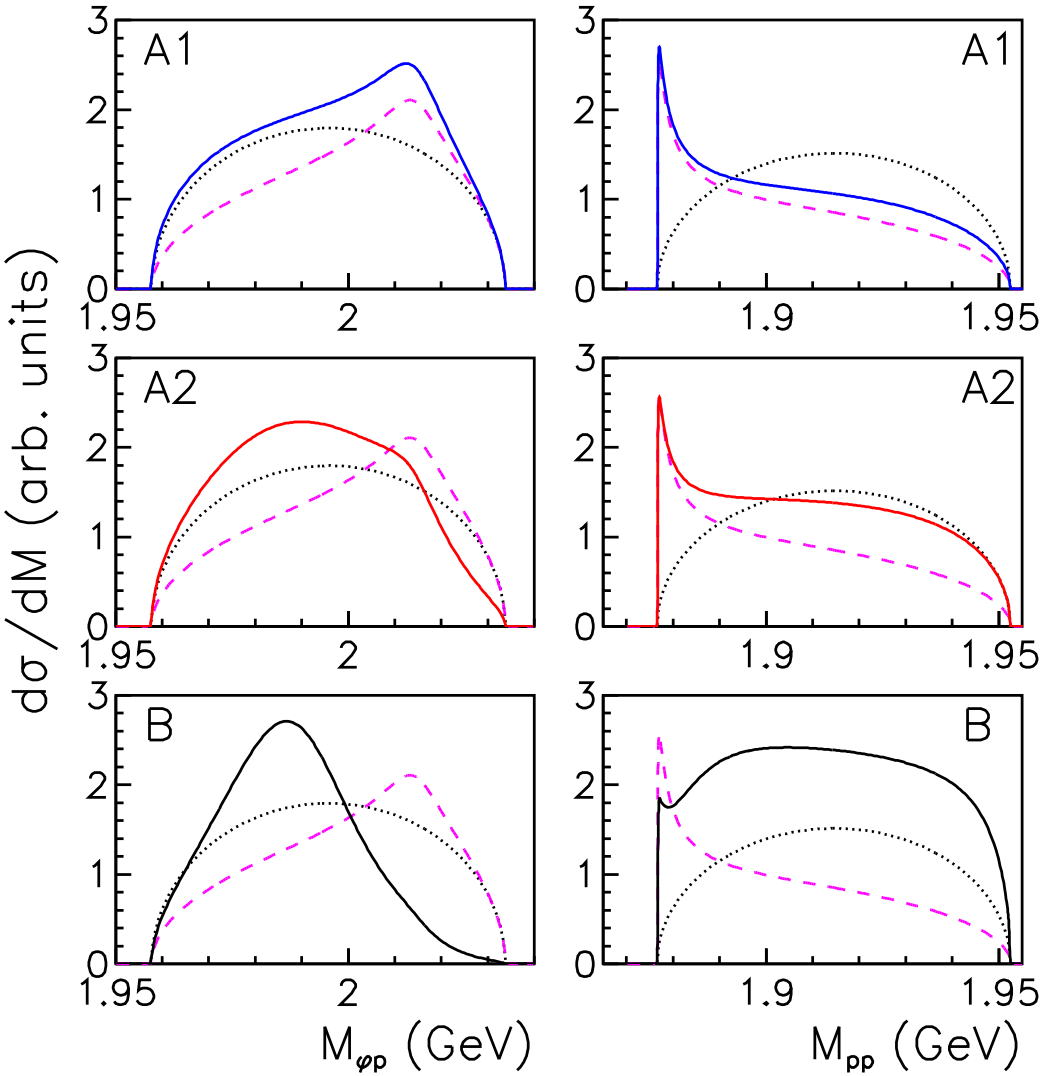
Exotic baryon.



Results in: A. Sibirtsev, J. Haidenbauer and U.G. Meißner, Eur. Phys. J. A27 (2006) 263.



Mass spectra at ϵ=76 MeV.



Further progress and conclusion.

Apparently the measurements of Dalitz plot and mass spectra will clarify the situation with possible existence of cryptoexotic baryon.

This experiment is underway at ANKE at COSY. One needs large statistics and good mass resolution.

Very recently ANKE reports results on ϕ-decay distribution from $pp \rightarrow pp\phi$ reaction.

It was proposed that while ϕ is a product of $B_\phi \rightarrow \phi + p$ decay, then the ϕ-decay spectrum is proportional to $\sin^2$.

And it was explicitely the result reported by ANKE.