Exclusive two-pion photoproduction

Antoni Szczurek

INSTITUTE OF NUCLEAR PHYSICS

POLISH ACADEMY OF SCIENCES

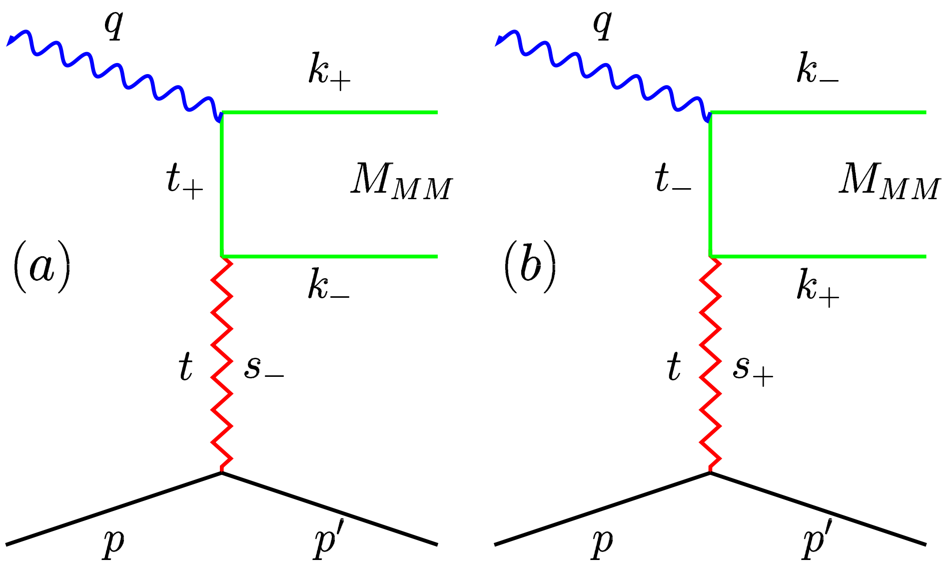
IFJ PAN

AND

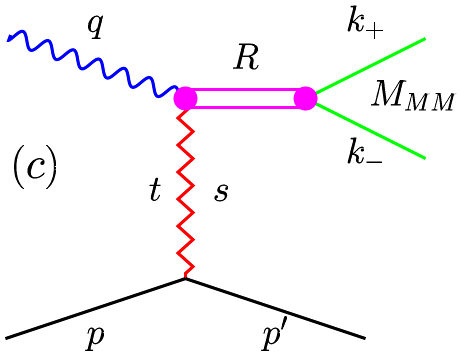
UNIVERSITY OF RZESZOW

Processes included

Continuum contribution



Resonance contribution



Model of the continuum

$$d\sigma = (2\pi)^4\delta^4(q+p-p_+-p_--p')\frac{d^3p_+}{2\omega_+(2\pi)^3}\frac{d^3p_-}{2\omega_-(2\pi)^3}\frac{d^3p'}{2\omega'(2\pi)^3}$$

$$\times\frac{1}{flux}\overline{|\mathcal{M}^{\gamma p\to M^+M^-p}|^2}$$

$$\frac{d\sigma(M^2_{MM},t,\theta,\phi)}{dM^2_{MM}dtd\Omega} = \frac{\beta}{16\pi^4}\frac{1}{s^2}\overline{|\mathcal{M}^{\gamma p\to M^+M^-p}|^2}\,,$$

Regge factorized form:

$$\mathcal{M}^{\gamma p\to M^+M^-p}_{\lambda_\gamma\lambda\to\lambda'}(s,t,s_+,t_+,s_-,t_-) =$$

$$= V_{\gamma M^+}(\lambda_\gamma)\frac{F_{os}(t_+)}{t_+-m_M^2}\mathcal{M}^{M^-p}_{\lambda\lambda'}(s_-,t) + V_{\gamma M^-}(\lambda_\gamma)\frac{F_{os}(t_-)}{t_--m_M^2}\mathcal{M}^{M^+p}_{\lambda\lambda'}(s_+,t)$$

In the Gottfried-Jackson frame,

$$\epsilon(\lambda_\gamma = \pm 1) \cdot k_+ = \mp \frac{k}{\sqrt{2}} \sin(\theta_{GJ}) \exp(\pm i\phi_{GJ})$$
$$\epsilon(\lambda_\gamma = \pm 1) \cdot k_- = \pm \frac{k}{\sqrt{2}} \sin(\theta_{GJ}) \exp(\pm i\phi_{GJ})$$

$$t_\pm - m_M^2 = -2qk_\pm = -\frac{1}{2}(M_{MM}^2 - t)(1 \mp \beta cos\theta) \ .$$

Small $M_{M^+M^-}$ and large s
$\Rightarrow$ s_+ and s_- are also large.

The factor $F_{os}(t_\pm)$ takes into account the extended nature of the exchanged particle.
There are two vertices with an off-shell pseudoscalar meson. Let us take the factorized ansatz:

$$F_{os}(t_\pm) = F_{em}^{hos}(Q^2, t_\pm, m_M) \cdot F_{corr}(t_\pm) \ ,$$

At high energies $2 \longrightarrow 2$ quasielastic amplitude:

$$\mathcal{M}^{M^{\pm}p}_{\lambda\lambda'}(s_{\pm},t) = i s_{\pm}\, \sigma^{tot}_{M^{\pm}p}(s_{\pm}) \exp\left(\frac{B}{2}t\right) \delta_{\lambda\lambda'} \; .$$

- The Kronecker $\delta_{\lambda\lambda'}$ reflects explicit imposition of the nucleon helicity conservation.
- The total cross sections for $\pi^{\pm}p$ or $K^{\pm}p$ are well-known experimentally. We use Regge-inspired parametrization of the world data for the total cross sections by Donnachie and Landshoff.
- Slope parameter B should be taken as a slope of the elastic scattering data for $\pi^{\pm}p$ or $K^{\pm}p$

Current conservation ?

The amplitude is not yet complete – it does not satisfy EM current conservation. The current is given by

$$J^\mu = 2e\left[k_+^\mu \frac{F_{os}(t_+)}{t_+ - m_M^2}\mathcal{M}_{\lambda\lambda'}^{M^-p}(s_-,t) - k_-^\mu \frac{F_{os}(t_-)}{t_- - m_M^2}\mathcal{M}_{\lambda\lambda'}^{M^+p}(s_+,t)\right]$$

so that the amplitude can be written as

$$\mathcal{M}_{\lambda_\gamma\lambda\to\lambda'}^{\gamma p\to M^+M^-p} = \epsilon_\mu(\lambda_\gamma)J^\mu(s,t,s_+,t_+,s_-,t_-)$$

Current conservation implies $q_\mu J^\mu = 0$, while we find

$$q_\mu J^\mu = -4e\left[F_{os}(t_+)\mathcal{M}_{\lambda\lambda'}^{M^-p}(s_-,t) - F_{os}(t_-)\mathcal{M}_{\lambda\lambda'}^{M^+p}(s_+,t)\right].$$

The origin of current nonconservation is two-fold:

- non-pointlike nature of exchanged particles ($F_{os} \neq 1$)
- difference in M^+p and M^-p scattering

The latter implies that EM charge flows differently in $M^+p \to M^+p$ and $M^-p \to M^-p$.
Since photon couples to all charge currents, there has to be a correction which reflects this difference.
Let us separate the corrections to the current from the upper (meson) and lower (baryon) vertices. We define:

$$F_\pm \equiv \frac{1}{2}\left[F_{os}(t_+) \pm F_{os}(t_-)\right]$$

and

$$M_\pm \equiv \frac{1}{2}\left[\mathcal{M}_{\lambda\lambda'}^{M^-p}(s_-,t) \pm \mathcal{M}_{\lambda\lambda'}^{M^+p}(s_+,t)\right]$$

The total current can be written as

$$J^\mu = J_C^\mu + J_N^\mu + J_M^\mu \;, \quad \text{where}$$

$$J_C^\mu = 2e\left[\frac{k_+^\mu}{t_+ - m_M^2} - \frac{k_-^\mu}{t_- - m_M^2}\right](F_+M_+ + F_-M_-)$$

is a conserved current,

$$J_N^\mu = 2e\left[\frac{k_+^\mu}{t_+ - m_M^2} + \frac{k_-^\mu}{t_- - m_M^2}\right]F_+M_-$$

is non-conserved ($M^+p \neq M^-p$) and

$$J_M^\mu = 2e\left[\frac{k_+^\mu}{t_+ - m_M^2} + \frac{k_-^\mu}{t_- - m_M^2}\right]F_-M_+$$

is non-conserved due to the dynamics in the meson vertex.

The additional contribution to the current required by current conservation will depend on meson variables for J^μ_M and nucleon variables for J^μ_N,

$$J^\mu_N \to J^\mu_N + \delta J^\mu_N \ ,$$

$$\delta J^\mu_N = 2e\,\frac{(p+p')^\mu}{q(p+p')} F_+ M_-$$

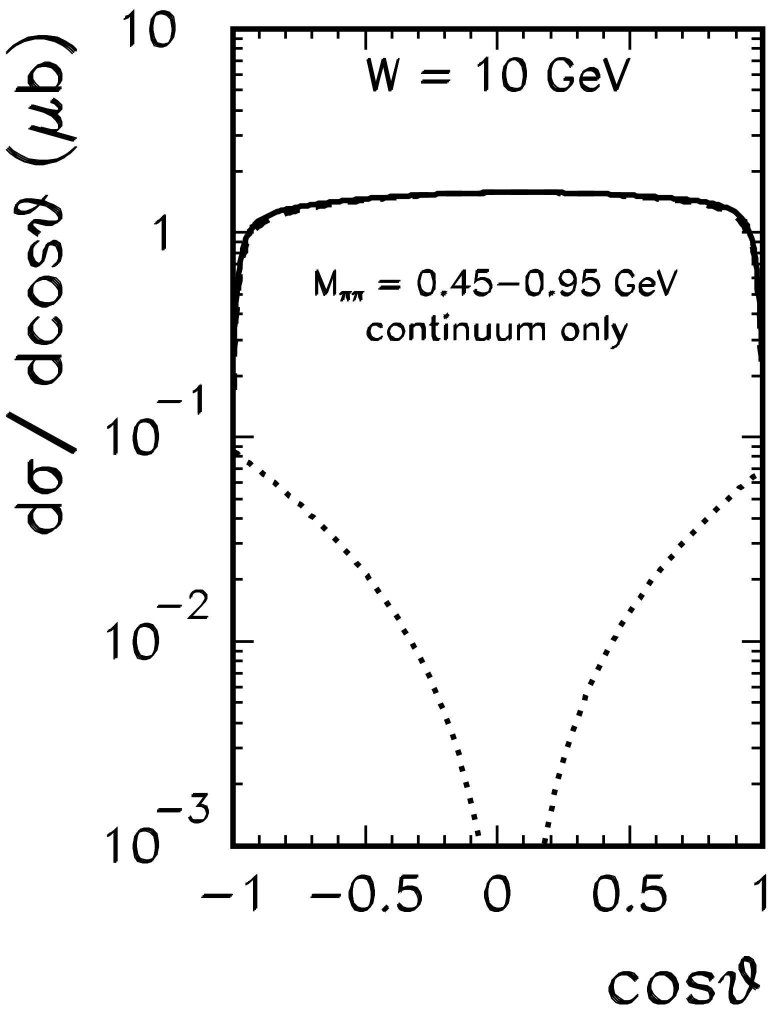
and

$$J^\mu_M \to J^\mu_M + \delta J^\mu_M$$

$$\delta J^\mu_M = 2e\,\frac{(k_+ + k_-)^\mu}{q(k_+ + k_-)} F_- M_+ = -4e\,\frac{(k_+ + k_-)^\mu}{t - M^2_{MM}} F_- M_+$$

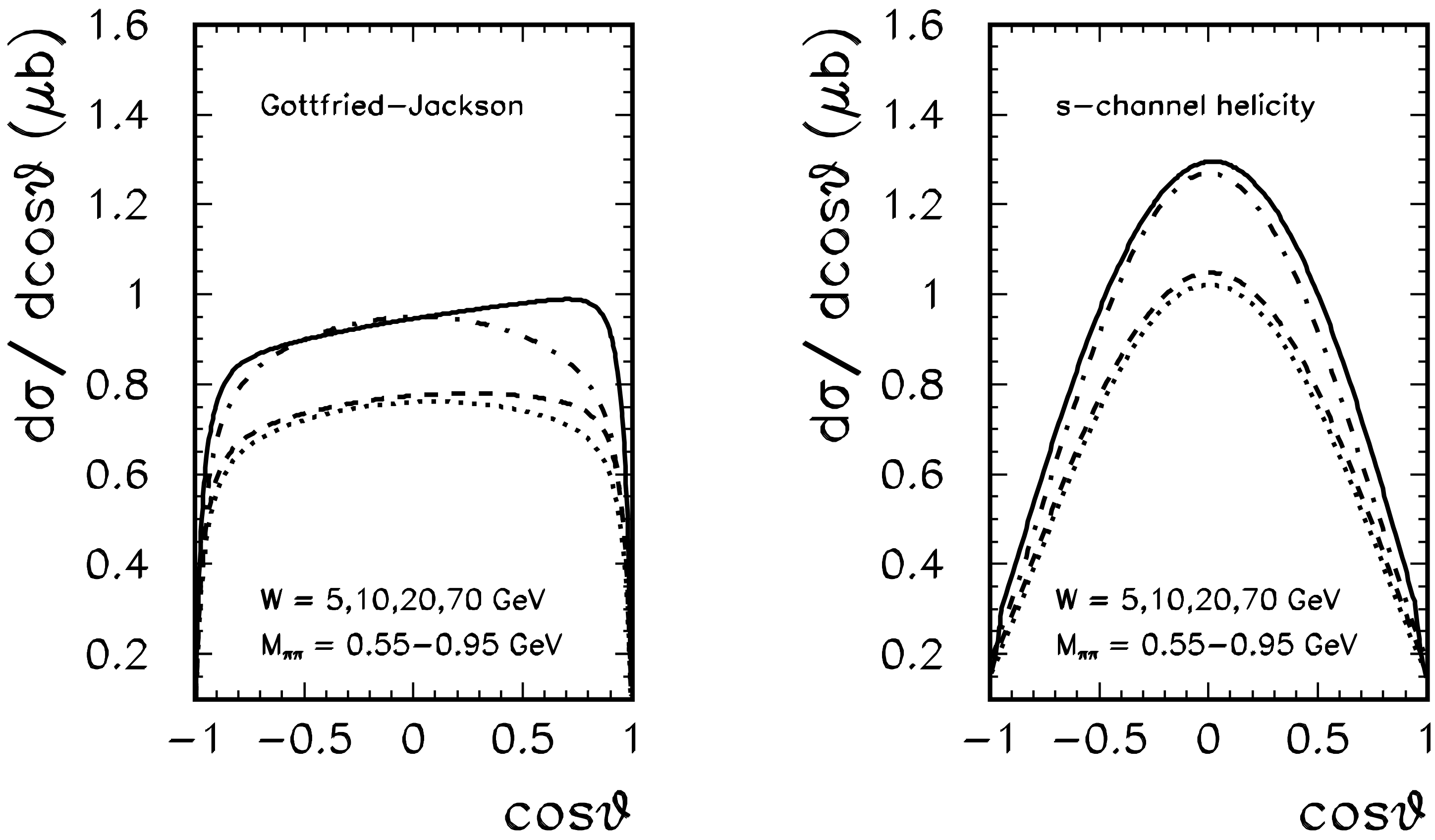
To avoid an unphysical pole at $t = M^2_{MM}$, this equation implies that $F_-(t = M^2_{MM}) = 0$.

Corrections restoring current conservation



Monopole off-shell form factor with M_{os} = 1 GeV

GJ versus SCH



W = 5 GeV (solid), W = 10 GeV (dashed),
W = 20 GeV (dotted) and W = 70 GeV (dash-dotted).

monopole off-shell form factor with M_{os} = 1 GeV

Resonance contribution

$$\mathcal{M}^{\gamma\to\rho^0\to\pi^+\pi^-}_{\lambda_\gamma\lambda\to\lambda'}(s,t,M_{\pi\pi},\theta,\phi) = C_{conv}\,\frac{e}{\gamma_\rho}\,\mathcal{M}^{\rho^0 p}_{\lambda\lambda'}(s,t)\; f_{BW}(M_{\pi\pi})Y_{1,\lambda_\gamma}(\theta,\phi$$

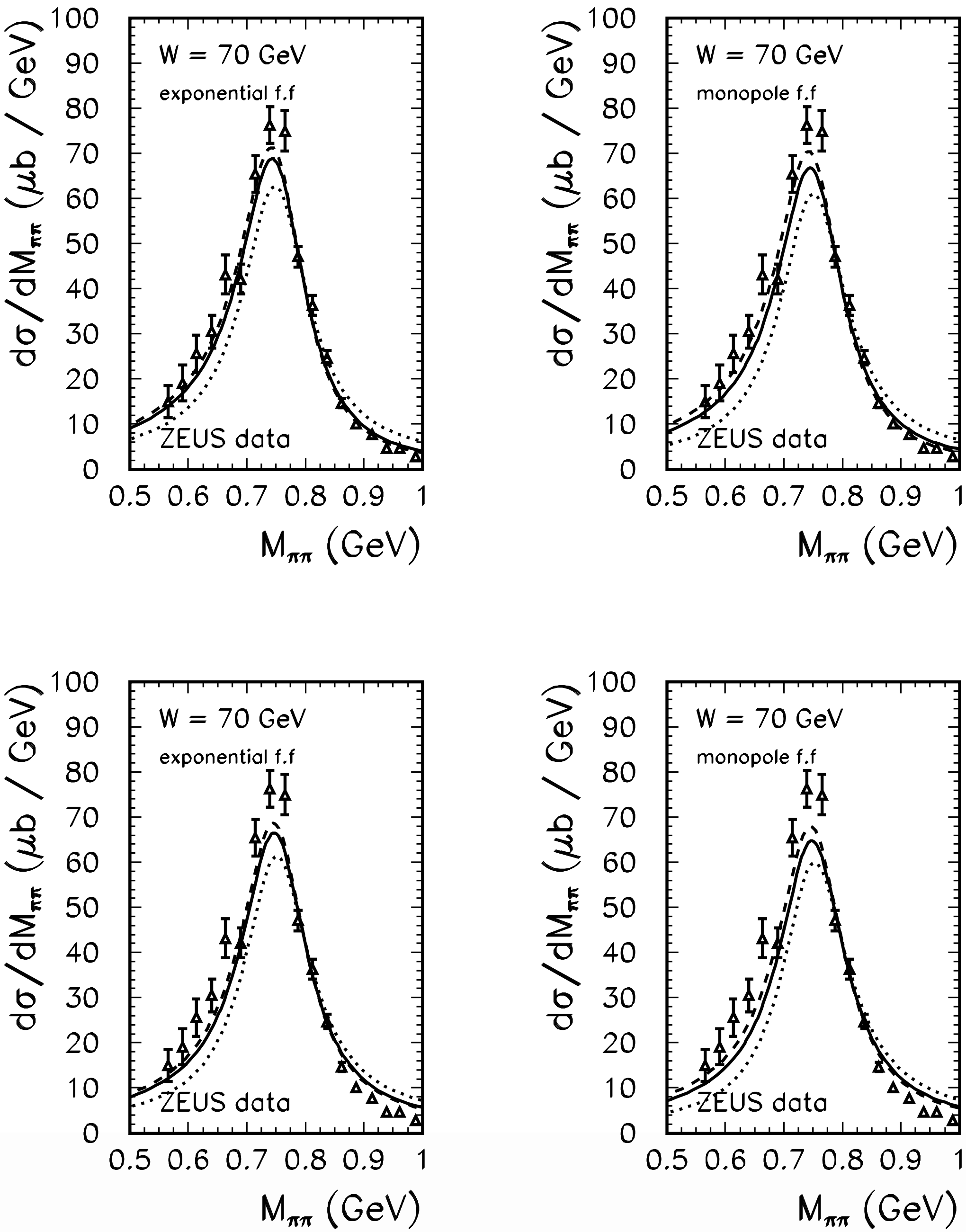
$$\mathcal{M}^{\rho^0 p}_{\lambda\lambda'}(s,t) = is\,\sigma^{tot}_{\rho^0 p}(s)\exp\left(\frac{B_{\rho p}t}{2}\right)\;\delta_{\lambda\lambda'}\;.$$

$$f_{BW}(M_{\pi\pi}) = \frac{\sqrt{M_0\Gamma(M_{\pi\pi})/\pi}}{M_0^2 - M_{\pi\pi}^2 - iM_0\Gamma(M_{\pi\pi})}\;,$$

where $$\Gamma(M_{\pi\pi}) = \Gamma_0\left(\frac{M_{\pi\pi}^2-4m_\pi^2}{M_0^2-4m_\pi^2}\right)^{3/2}\;.$$

$$\sigma^{tot}_{\rho^0 p}(s) = \tfrac{1}{2}\left[\sigma^{tot}_{\pi^+ p}(s)+\sigma^{tot}_{\pi^- p}(s)\right]\;.$$

$\pi\pi$ invariant mass

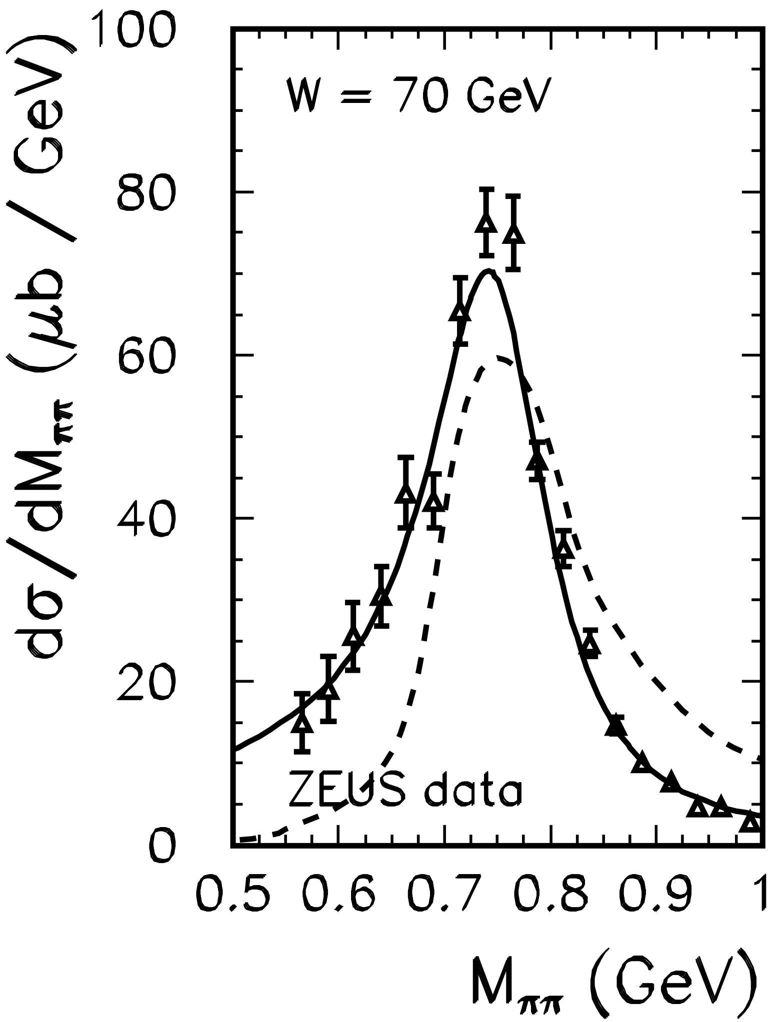


without rotation

$B = 8$ GeV^{-1}

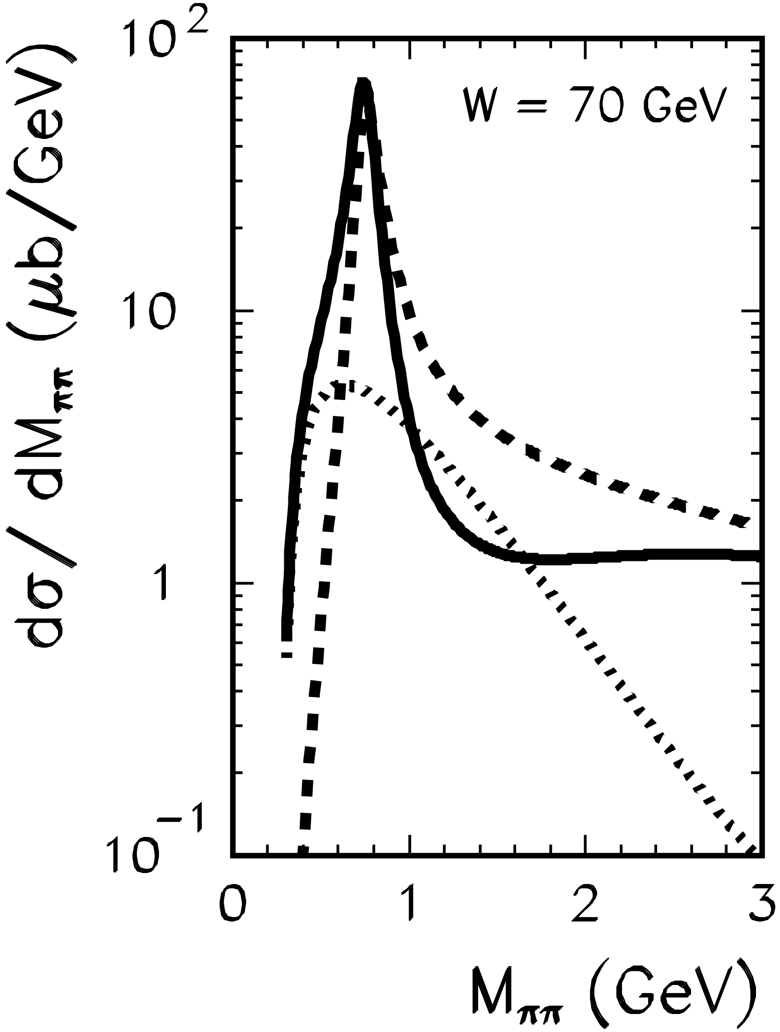
with rotation

Resonance-shape modification



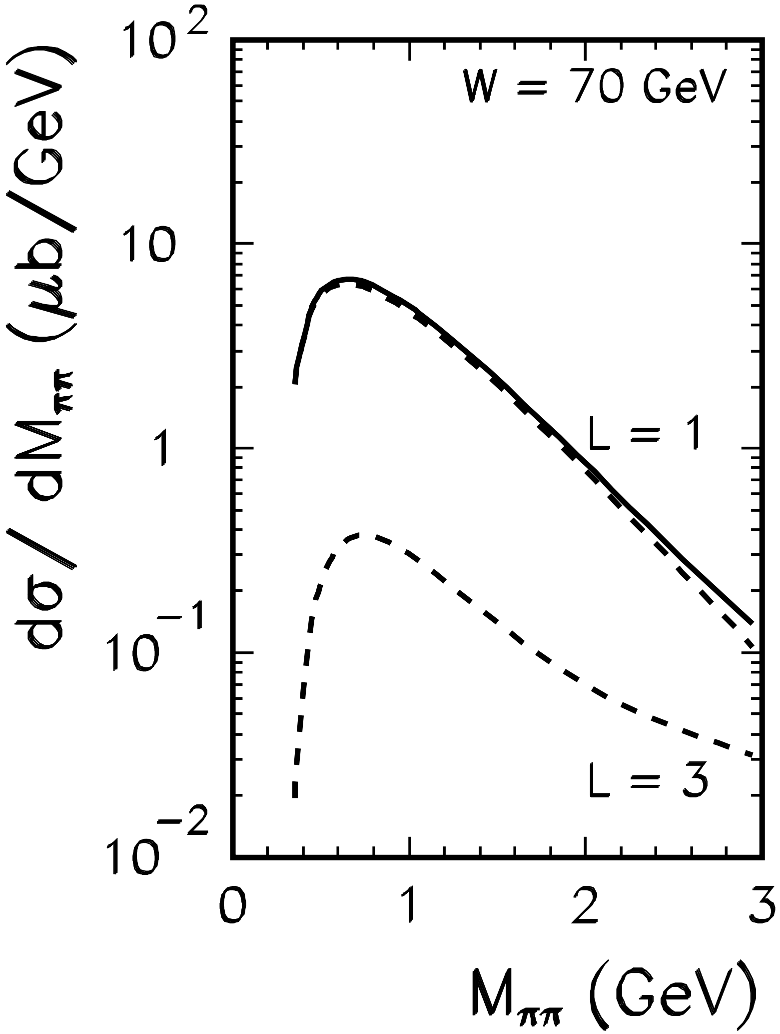
W = 70 GeV, ZEUS collaboration, B = 8 GeV^{-2}

Spectrum decomposition



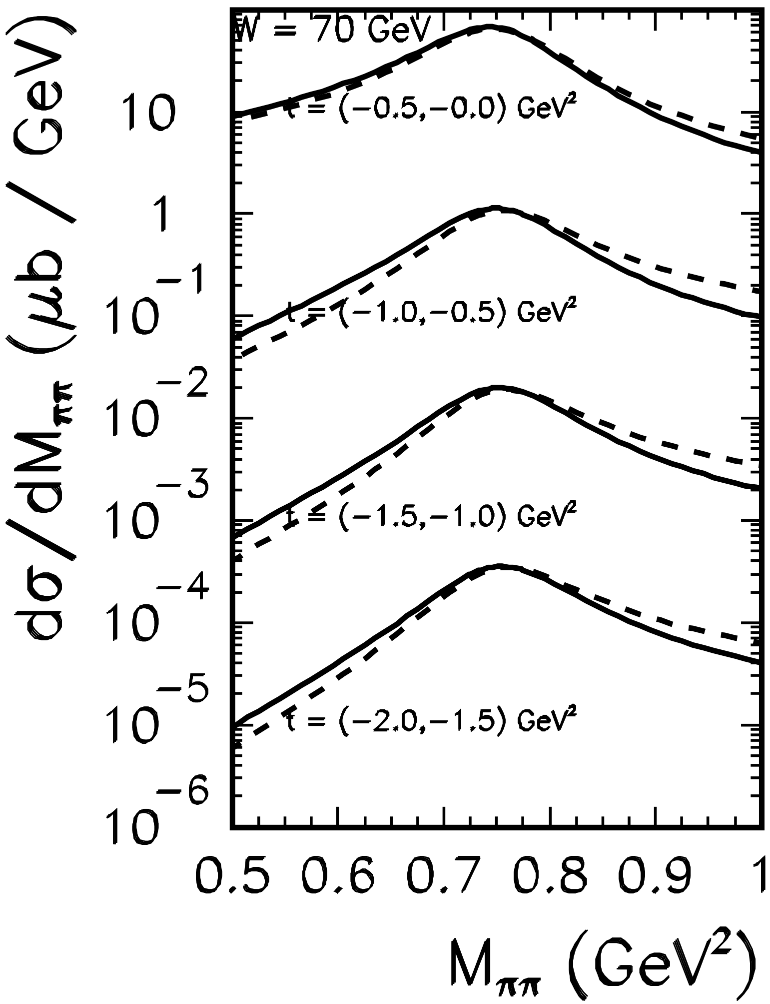
W = 70 GeV , B = 8 GeV^{-2}

Partial wave decomposition



$$\mathcal{M}^{\gamma p \to M^+ M^- p}_{\lambda_\gamma, \lambda \to \lambda'}(t, M_{\pi\pi}, \theta, \phi) = \sum_{l,m} a^{\lambda_\gamma, \lambda, \lambda'}_{lm}(t, M_{\pi\pi})\, Y_{lm}(\theta, \phi)\ .$$

t-binning

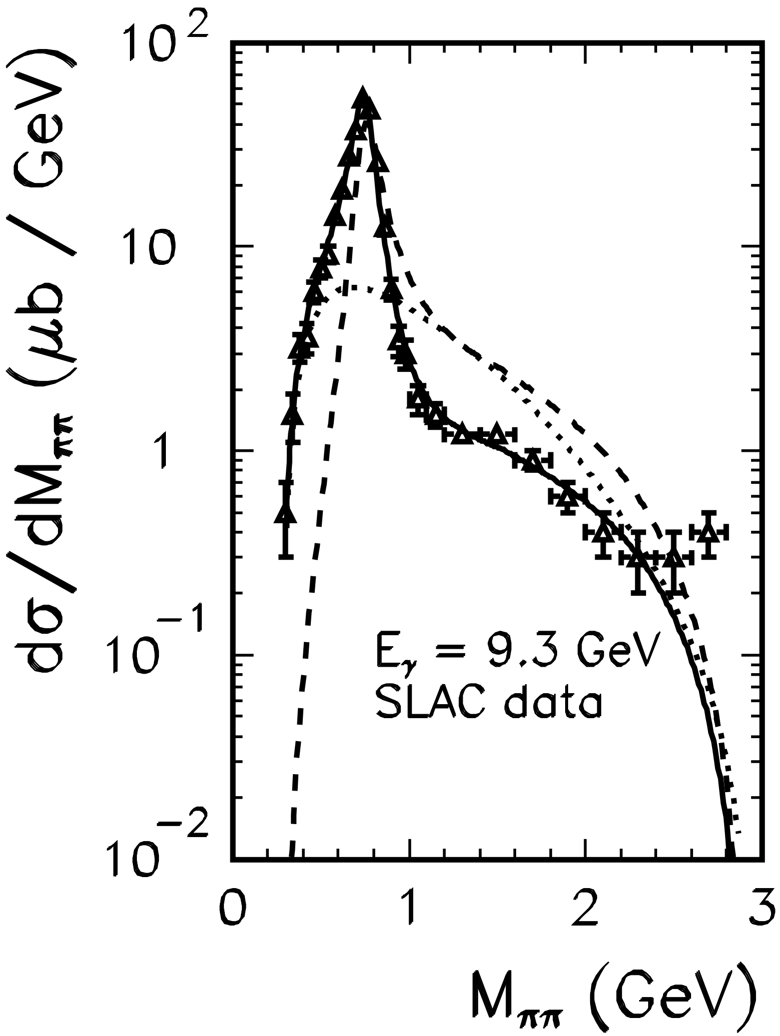


solid – without rotation

dashed – with rotation

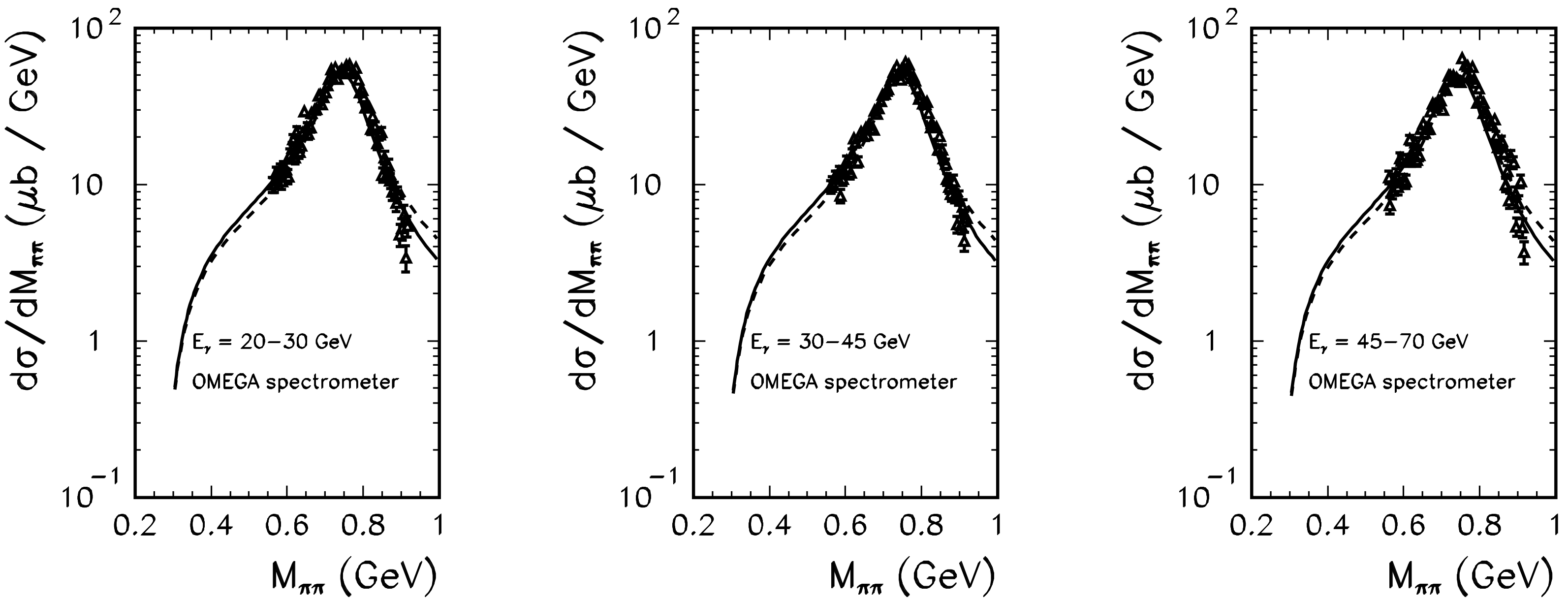
W = 70 GeV

Low energies



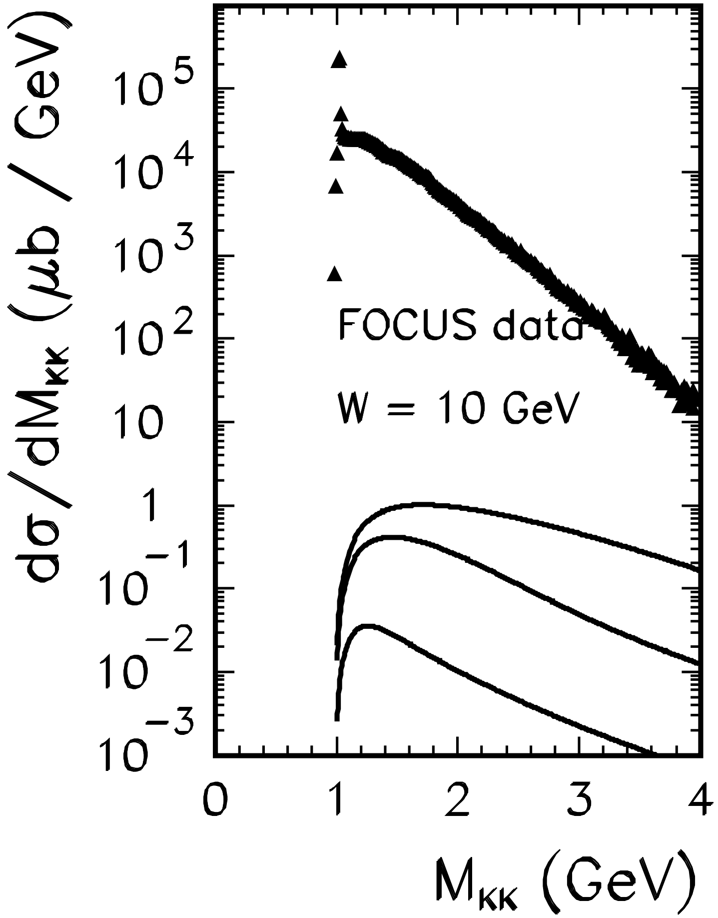
SLAC bubble-chamber experiment

Intermediate energies



OMEGA-spectrometer collaboration at CERN

KK production

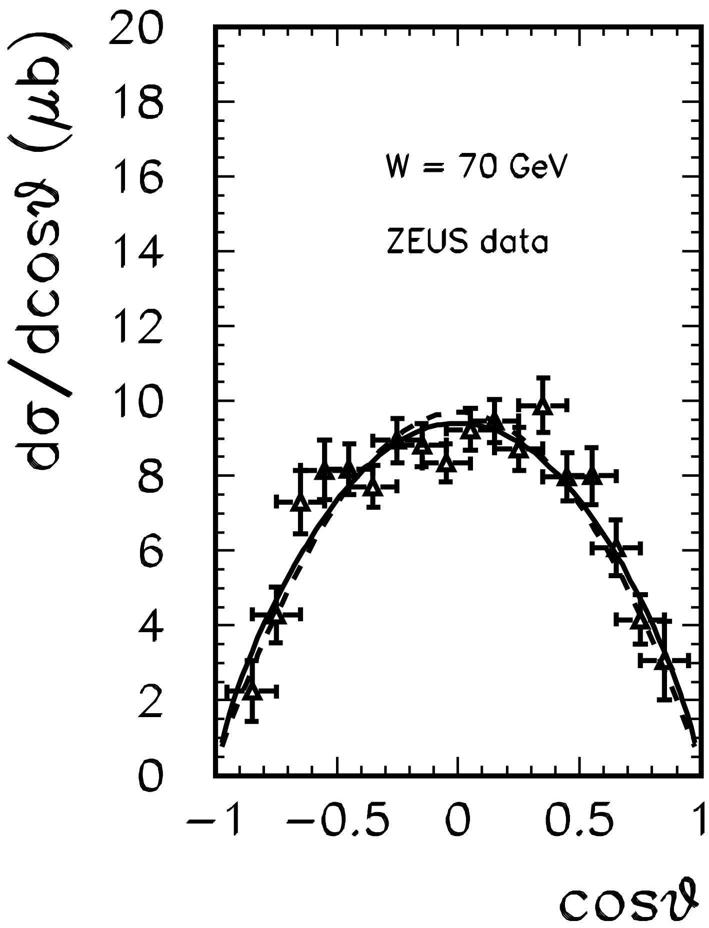


FOCUS collaboration (without acceptance corrections !!!)

$B = 6\ \mathrm{GeV}^{-2}$

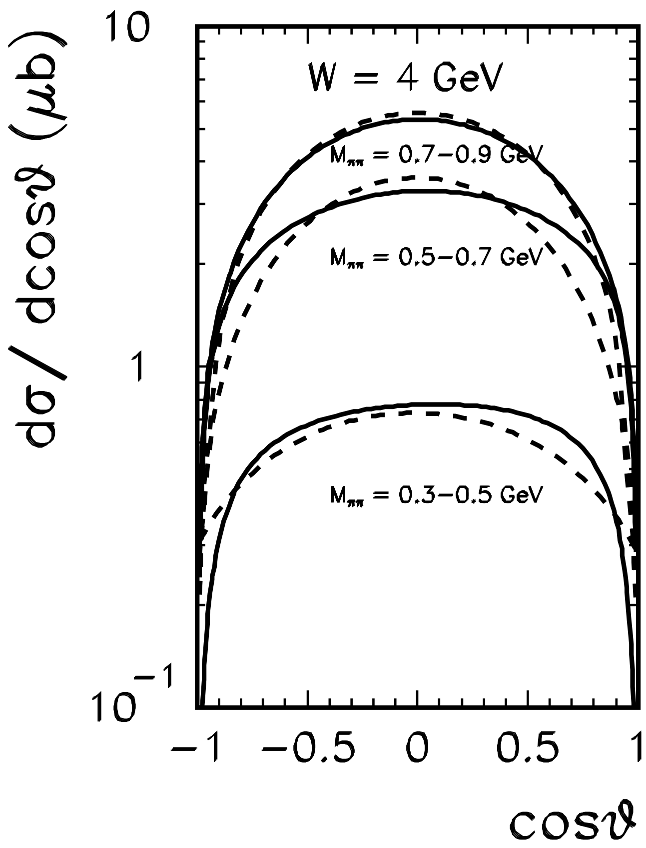
exponential off-shell form factor with Λ = 0.5, 1.0, 2.0 GeV

Angular distribution of pion in SCH frame



W = 70 GeV
$M_{\pi\pi}$ in the measured range
exponential form factor with Λ = 1 GeV

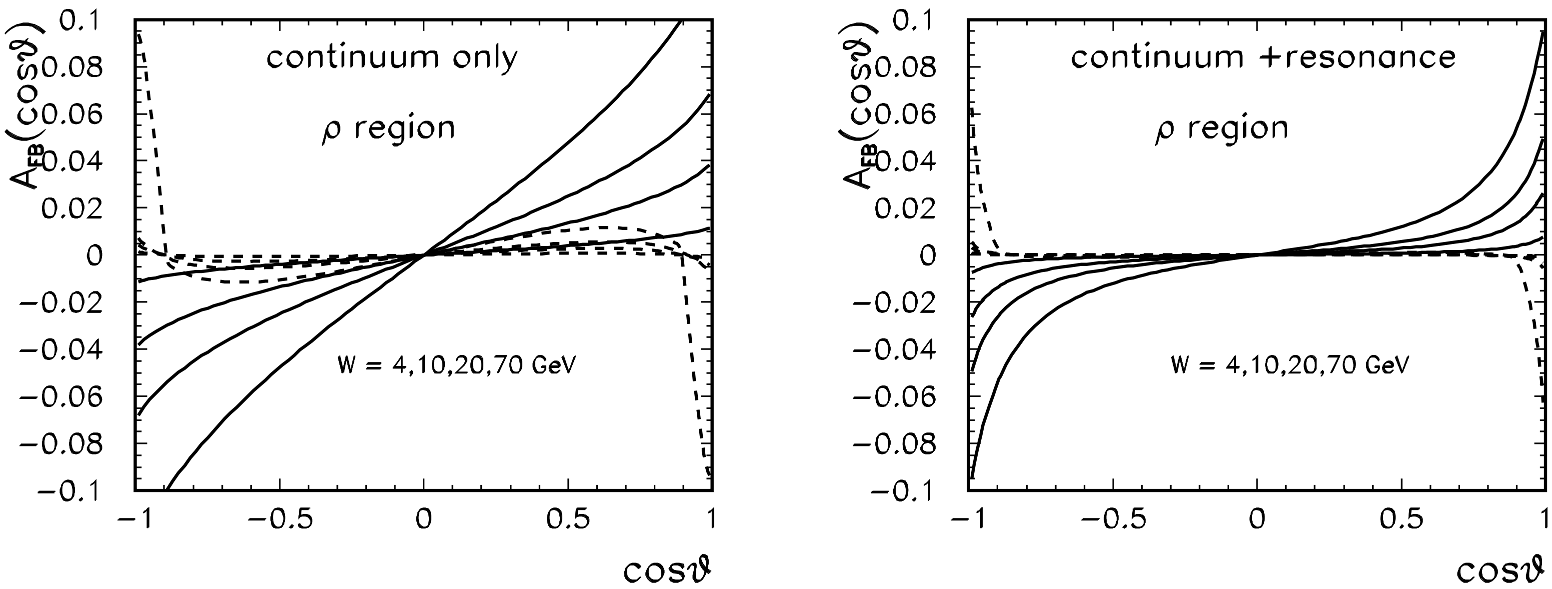
Predictions for GlueX at TJLAB



W = 4 GeV
B = 6 GeV^{-2}
exponential off-shell form factor with Λ = 1 GeV
solid line – no extra rotation
dashed line – extra rotation

Forward-backward asymmetry

$$A_{FB}^{\pi^\pm}(\theta) \equiv \frac{\frac{d\sigma^{\pi^\pm}}{dz}(\theta) - \frac{d\sigma^{\pi^\mp}}{dz}(\theta)}{\frac{d\sigma^{\pi^\pm}}{dz}(\theta) + \frac{d\sigma^{\pi^\mp}}{dz}(\theta)} .$$

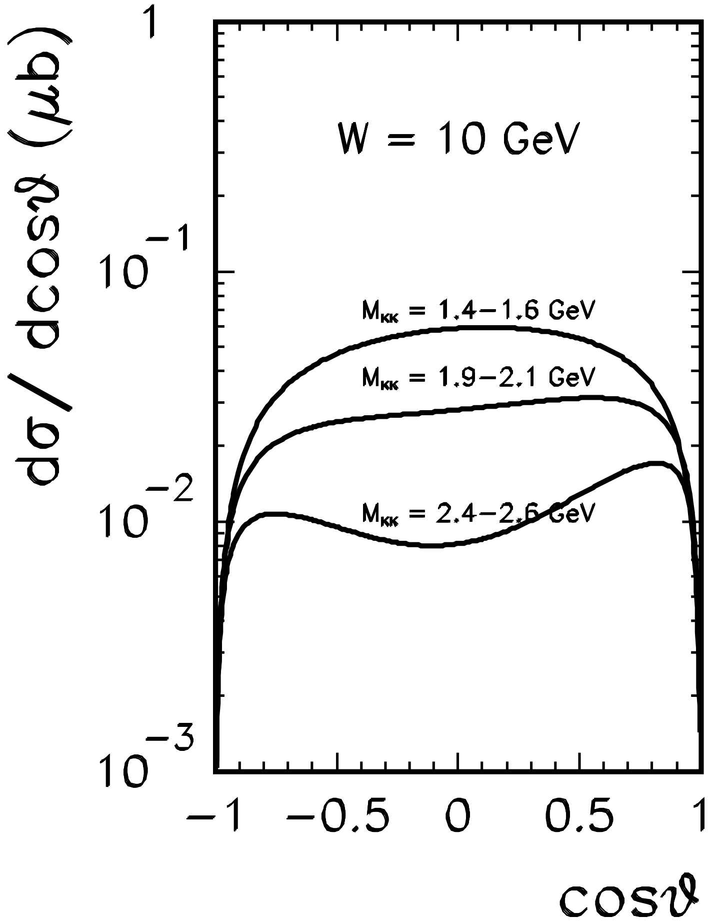


W = 4, 10, 20, 70 GeV

solid line – continuum in the GJ frame

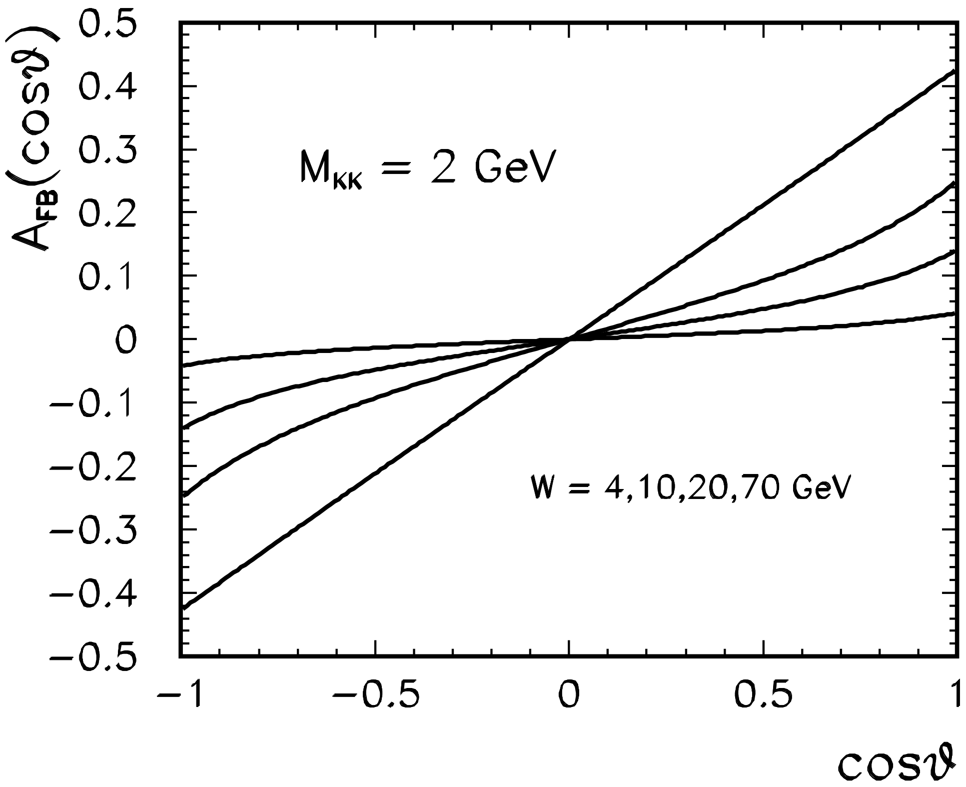
dashed line – continuum in the SCH frame

Kaon angular distribution



FOCUS energy W = 10 GeV
B = 6 GeV^{-2}

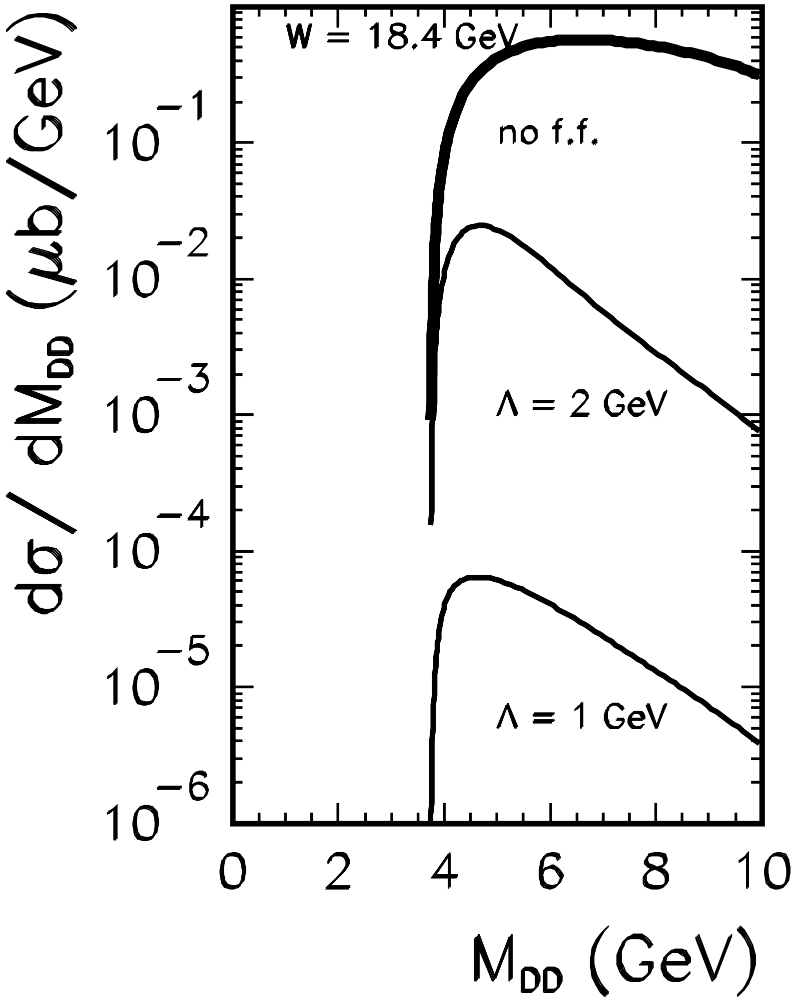
Kaon forward-backward asymmetry



GJ frame

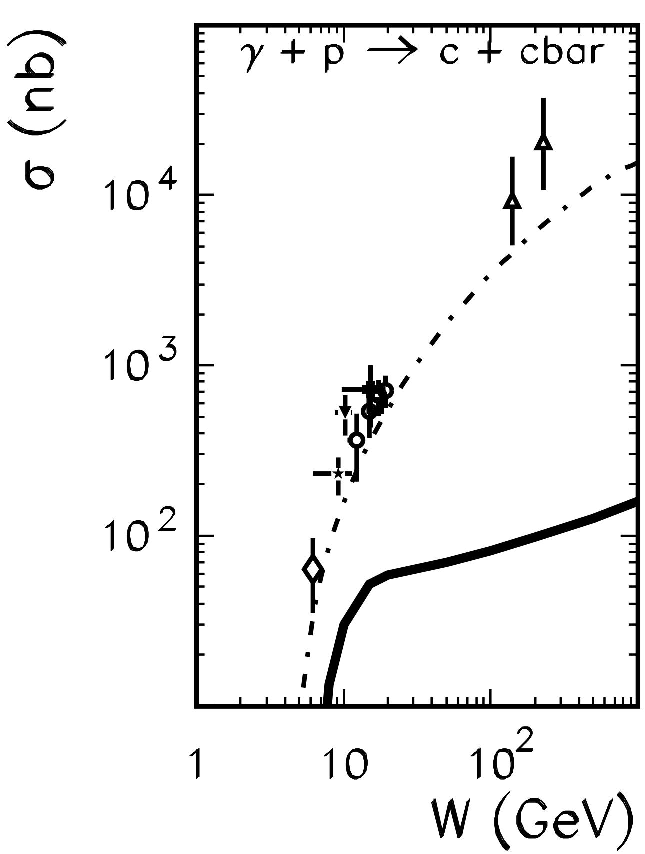
W = 4, 10, 20, 70 GeV

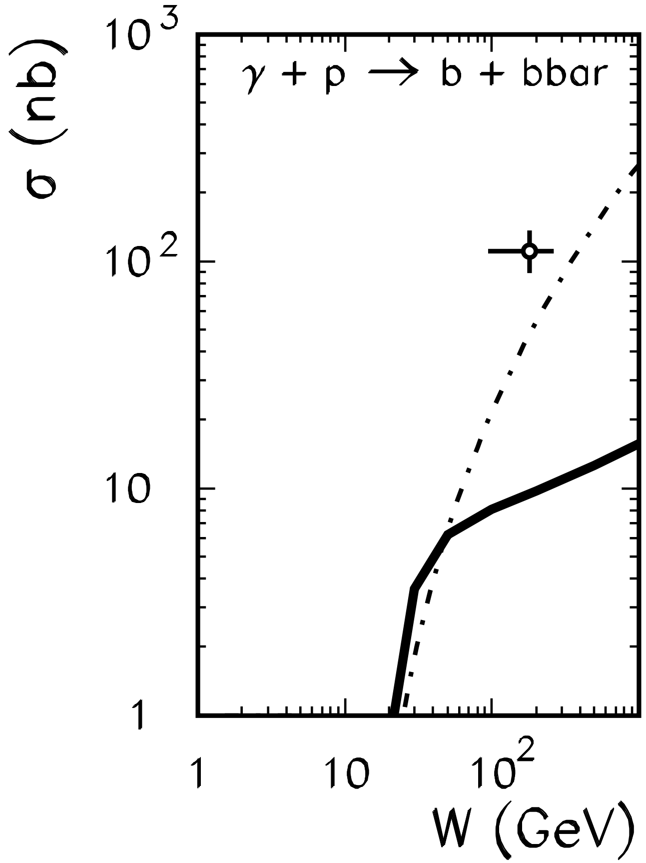
DD invariant mass



$B = 6\ \mathrm{GeV}^{-2}$

Integrated cross sections





D^+D^- and B^+B^- (solid line), Λ_{os} = 2, 4 GeV
open charm and bottom production (dash-dotted line)

Conclusions

Three-body (Deck) continuum:

- Modifies line shape of the ρ^0 resonance.
- Leads to a specific dependence on Mendelstam t
- Leads to forward-backward asymmetry for positive and negative mesons in GJ frame
- Explains the size and shape of the continuum for K^+K^- channel

WARNING !!!

The Deck-like continua may be important in interpretation of the so-called mesonic exotic states;
to be analyzed in future