Photoproduction of $\pi^+\pi^-$ pairs in a model with tensor-pomeron and vector-odderon exchange

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Future Physics with HERA Data for Current and Planned Experiments
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Content

1) A Model for Soft High-Energy Scattering: Tensor Pomeron and Vector Odderon.
   C.Ewerz, M.Maniatis, O.Nachtmann, arXiv:1309.3478, Annals Phys. 342 (2014) 31-77

2) Photoproduction of $\pi+\pi-$ pairs: Development of a MC-generator based on 1)
   Arthur Bolz, Carlo Ewerz, Markos Maniatis, Otto Nachtmann, Michel Sauter, André Schöning
   arXiv:1409.8483, submitted to JHEP

3) Results of 2)

4) Some comments.

<u>Related work:</u>

- P. Lebiedowicz, O. Nachtmann, A. Szczurek, arXiv:1309.3913, Annals Phys. 344 (2014) 301
- P. Lebiedowicz, talk at DIS 2014

Photoproduction of $\pi^+\pi^-$ pairs in a model with tensor-pomeron and vector-odderon exchange

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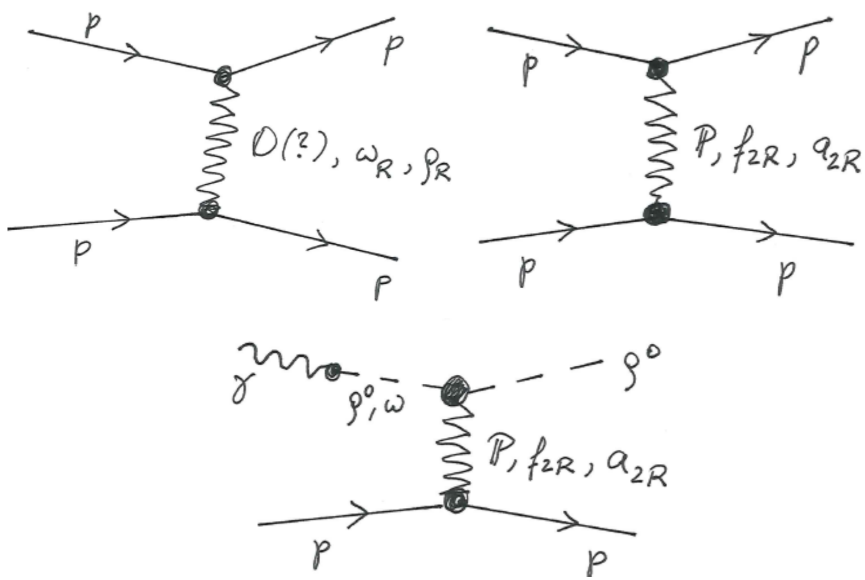
ABSTRACT: We consider the reaction $\gamma p \to \pi^+\pi^- p$ at high energies. Our description includes dipion production via the resonances ρ, ω, ρ' and f_2, and via non-resonant mechanisms. The calculation is based on a model of high energy scattering with the exchanges of photon, pomeron, odderon and reggeons. The pomeron and the $C = +1$ reggeons are described as effective tensor exchanges, the odderon and the $C = -1$ reggeons as effective vector exchanges. We obtain a gauge-invariant version of the Drell-Söding mechanism which produces the skewing of the ρ-meson shape. Starting from the explicit formulae for the matrix element for dipion production we construct an event generator which comprises all contributions mentioned above and includes all interference terms. We give examples of total and differential cross sections and discuss asymmetries which are due to interference of $C = +1$ and $C = -1$ exchange contributions. These asymmetries can be used to search for odderon effects. Our model is intended to provide all necessary theoretical tools for a detailed experimental analysis of elastic dipion production for which data exist from fixed target experiments, from HERA, and are now being collected by LHC experiments.

Introduction

<u>Examples for soft reactions:</u>

- elastic scattering:
  - $p + p \to p + p$
  - $\bar{p} + p \to \bar{p} + p$
  - $\pi + p \to \pi + p$
- photoproduction:
  - $\gamma + p \to \rho^0 + p$
  - $\gamma + \gamma \to \rho^0 + \rho^0$
- central production:
  - $p + p \to p + meson + p$

Examples of Feynman-diagrams

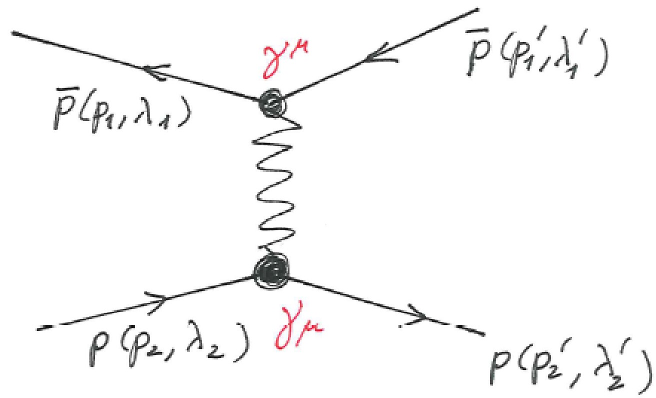


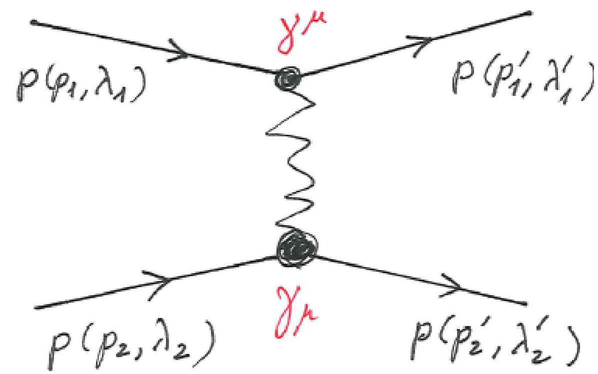
- For $\sqrt{s} \to \infty$, but $|t| \lesssim 1$ GeV^2 this is neither a pure short distance regime nor a pure long distance phenomenon. → difficult to treat in QCD.
- ➢ Physics of exchanges, Regge regime.

- Goal of 1): Formulate rules in terms of effective propagators and vertices for C=1 and C=-1 exchanges compatible with effective QFT.

Combination of QFT with Regge theory leads to a dilemma

Example: $p+p$ and $\bar{p}+p$ scattering in Regge approach





- (Donnachie-Landshoff pomeron ansatz)

$$\langle p(p_1'),p(p_2')|\mathcal{T}|p(p_1),p(p_2)\rangle\big|_{\mathbb{P}} = i\,[3\beta_{\mathbb{P}NN}F_1(t)]^2(-is\alpha'_{\mathbb{P}})^{\alpha_{\mathbb{P}}(t)-1} \times \bar{u}(p_1')\underline{\gamma^\mu u(p_1)\bar{u}(p_2')\gamma_\mu}u(p_2)\,,$$

$$\langle \bar{p}(p_1'),p(p_2')|\mathcal{T}|\bar{p}(p_1),p(p_2)\rangle\big|_{\mathbb{P}} = i\,[3\beta_{\mathbb{P}NN}F_1(t)]^2(-is\alpha'_{\mathbb{P}})^{\alpha_{\mathbb{P}}(t)-1} \times \bar{v}(p_1)\underline{\gamma^\mu v(p_1')\bar{u}(p_2')\gamma_\mu}u(p_2)\,,$$

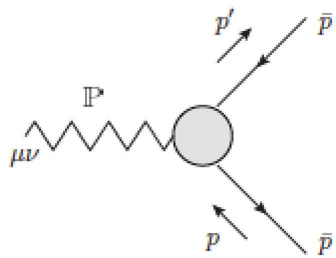
- The $\gamma^\mu \otimes \gamma_\mu$ structure suggests to consider the pomeron as an effective vector exchange.

- A QFT vector will couple to the proton and antiproton with opposite sign.
  - Dilemma IP couples equally to p and $\bar{p}$.

Pomeron as an effective tensor exchange

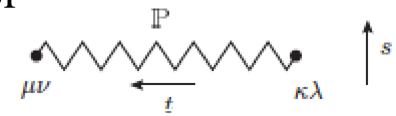
- A way out off the dilemma:
  - Write pomeron exchange as an effective tensor exchange.
  - A tensor – like for gravity – gives the same sign for the coupling of particles and antiparticles.
- Example:

IP$_{NN}$ vertex



$$-i\,3\beta_{\mathbb{P}NN}F_1[(p'-p)^2]$$
$$\times\left\{\frac{1}{2}\left[\gamma_\mu(p'+p)_\nu+\gamma_\nu(p'+p)_\mu\right]-\frac{1}{4}g_{\mu\nu}(\not{p}'+\not{p})\right\}$$

IP propagator



$$\frac{1}{4s}\left(g_{\mu\kappa}g_{\nu\lambda}+g_{\mu\lambda}g_{\nu\kappa}-\frac{1}{2}g_{\mu\nu}g_{\kappa\lambda}\right)(-is\alpha'_{\mathbb{P}})^{\alpha_{\mathbb{P}}(t)-1}$$

- Is this all in contradiction to Donnachie-Landshoff?
  - No! The amplitudes are for $s\to\infty$ exactly as for the DL-pomeron.

What else has the model to offer?

- Propagators for
  - C=+1 exchanges (IP, f_{2R}, a_{2R}) formulated as rank-two-tensor exchanges.
  - C=-1 exchanges (ω_R, ρ_R, odderon(?)) as vector exchanges.

- Huge set of vertices respecting QFT rules
  - IP$\rho\rho$, $\gamma\rho$, IPNN, $\rho\pi^+\pi^-$, …
  - Form factors are taken into account and are explicitly given for hadronic vertices (hadrons are extended objects).

- Inclusion of photons using the vector dominance model, VDM

- Set of all parameters with starting values; where possible estimated from data.

> Everything is given to apply the model to a concrete calculation of amplitudes.

Photoproduction of $\pi^+\pi^-$ pairs: Development of a MC-generator

- Aim is to construct a Monte Carlo event generator for the reaction

$$\gamma(q) + p(p) \longrightarrow \pi^+(k_1) + \pi^-(k_2) + p(p')$$

at typical HERA energies ($W_{\gamma p} \gtrsim 10$ GeV) or above.

- Draw all Feynman diagrams that should be included, and apply the model. One ends up with the standard formula:

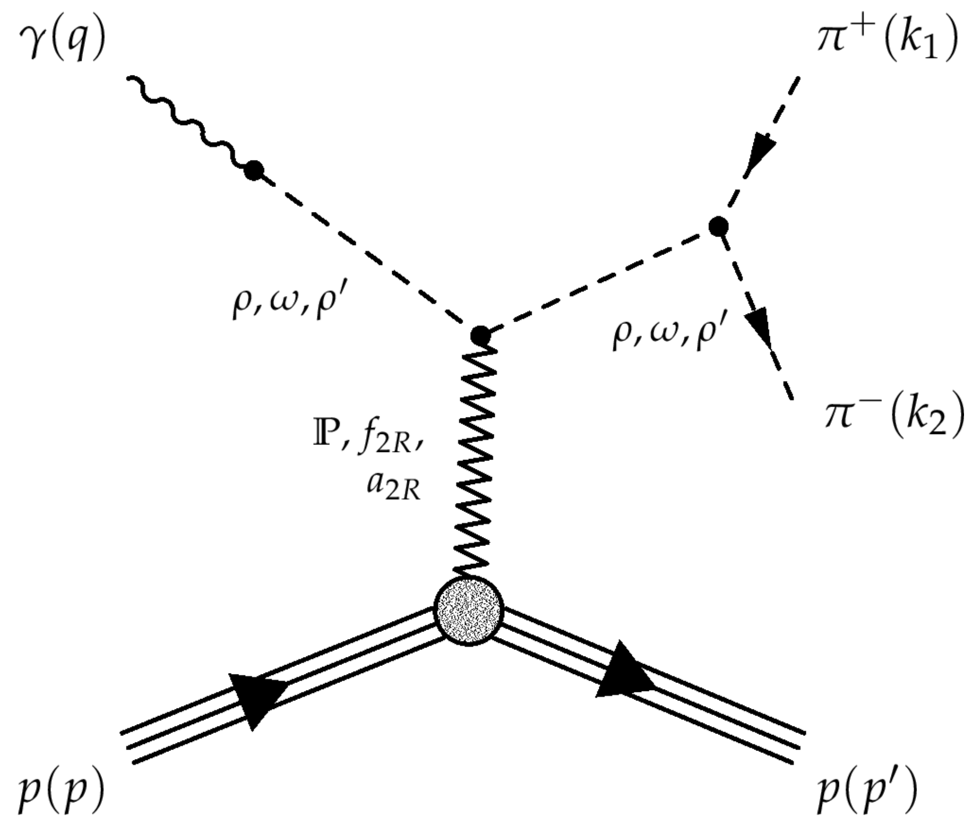
$$d\sigma^{\gamma p} = \underbrace{\left(\frac{1}{4}\frac{1}{2(s-m_p^2)}(\hbar c)^2\right)}_{\text{Norm}} \underbrace{\left((-1)\sum_{\mathfrak{s}',\,\mathfrak{s}} \mathcal{M}^*_{\mu,\,\mathfrak{s}',\,\mathfrak{s}} \mathcal{M}^{\mu}_{\mathfrak{s}',\,\mathfrak{s}}\right)}_{\text{Sum over matrix elements squared}} \underbrace{\left(\frac{1}{(2\pi)^5}\frac{d^3k_1}{2k_1^0}\frac{d^3k_2}{2k_2^0}\frac{d^3p'}{2p'^0}\delta^{(4)}(k_1+k_2+p'-p-q)\right)}_{=\,d\phi_3,\ \text{Phase Space}}$$

- Find / write computer programs
  - to calculate the spin sum.
  - to integrate the phase-space $2 \rightarrow 3$ phase space.
  - to obtain differential cross sections.

Included processes

- Resonant ρ, ω, ρ' production via exchanges of pomeron (IP) and reggeons (f_{2R}, a_{2R}).

a)

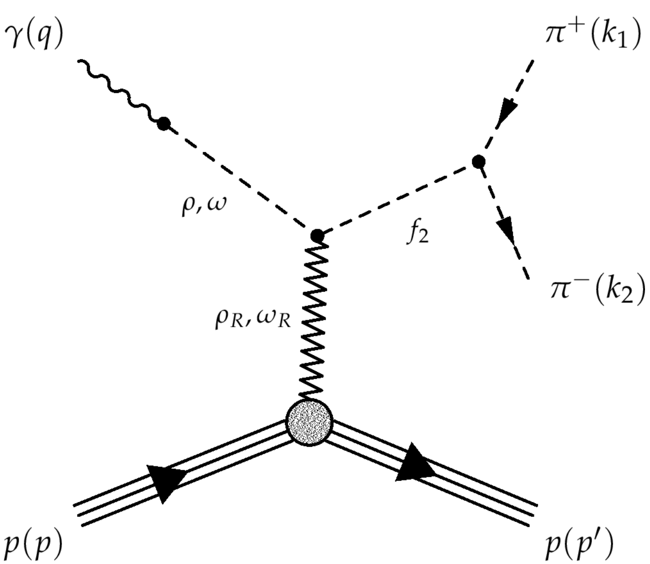


$\boxed{C = +1}$

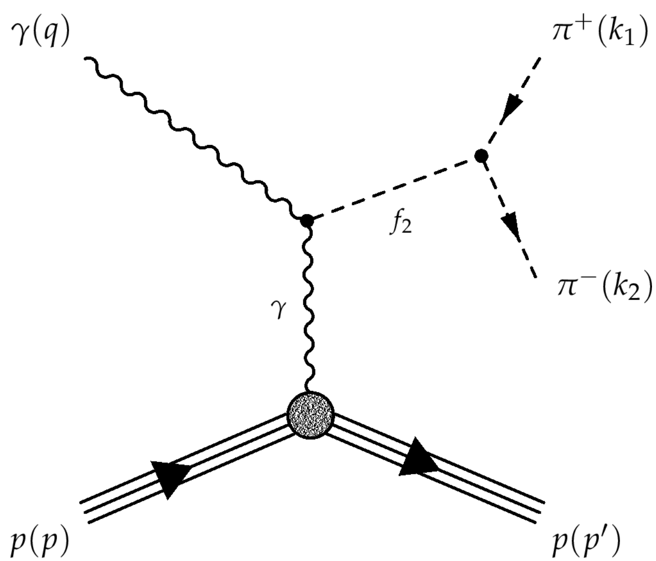
Included processes

- Resonant f_2 production via exchanges of
  - reggeons (ρ_R, ω_R)
  - photons (Primakoff-Effect)
  - odderon (?)

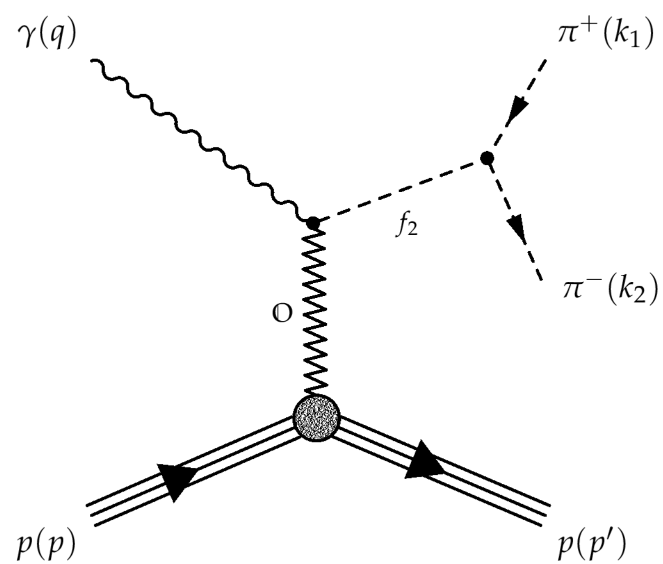
b)



c)



d)

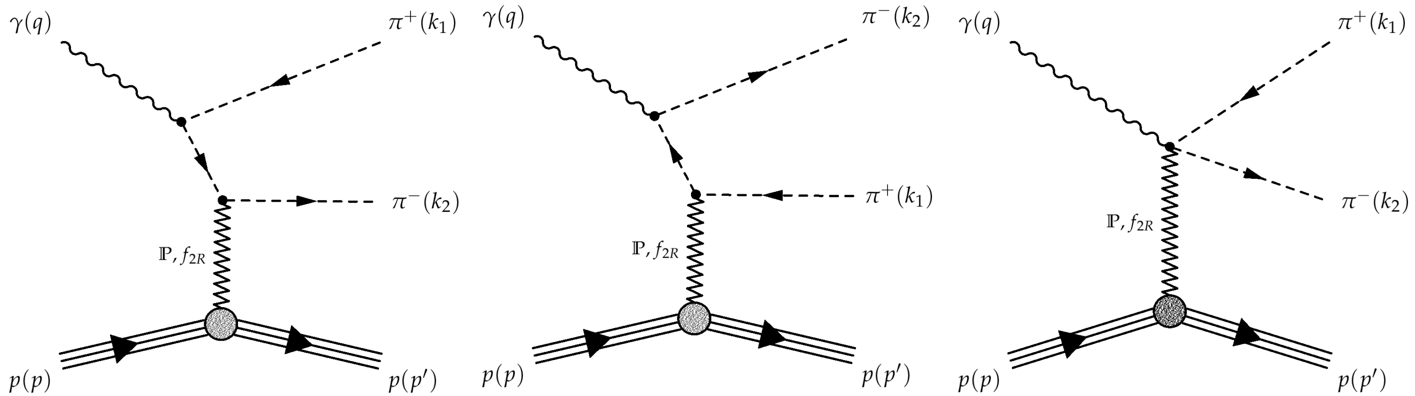


$\boxed{C = -1}$

Included processes

- Non-resonant $\pi^+\pi^-$ production via exchanges of
  - pomeron (IP) and reggeon (f_{2R})

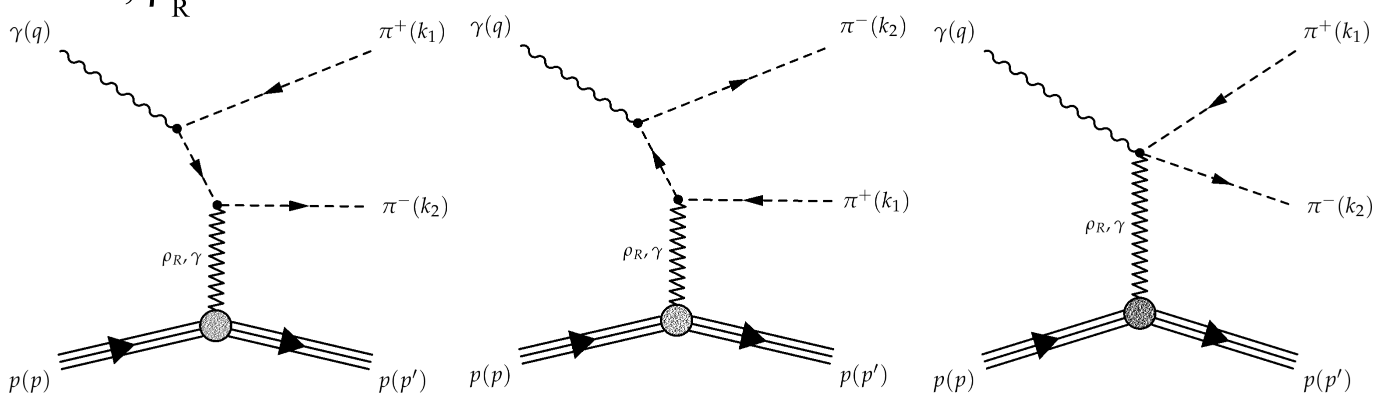
e)



C = +1

  - photons, ρ_R

f)



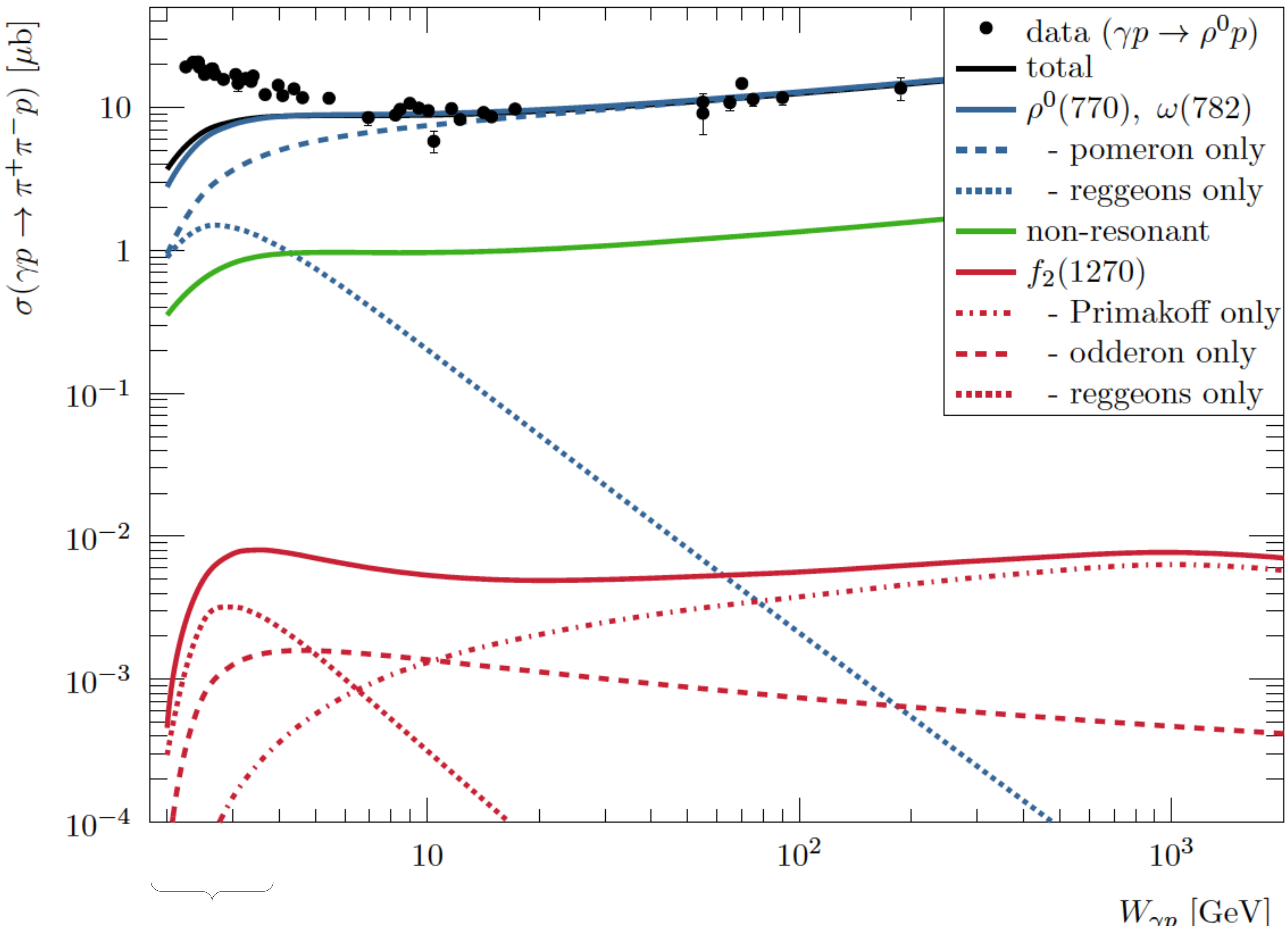
C = -1

Remark: The inclusion of these diagrams is a gauge invariant version of the Drell-Söding mechanism. The non-resonant pomeron and reggeons interfere with resonant ρ production (1st diagram) → skewing of ρ-line shape.

- Results

$\sigma(\gamma p \longrightarrow \pi^+\pi^-)$ compared to data

Data: DESY 97-237

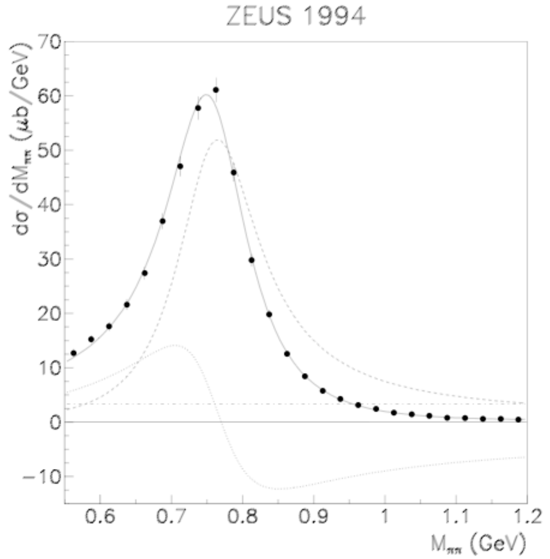


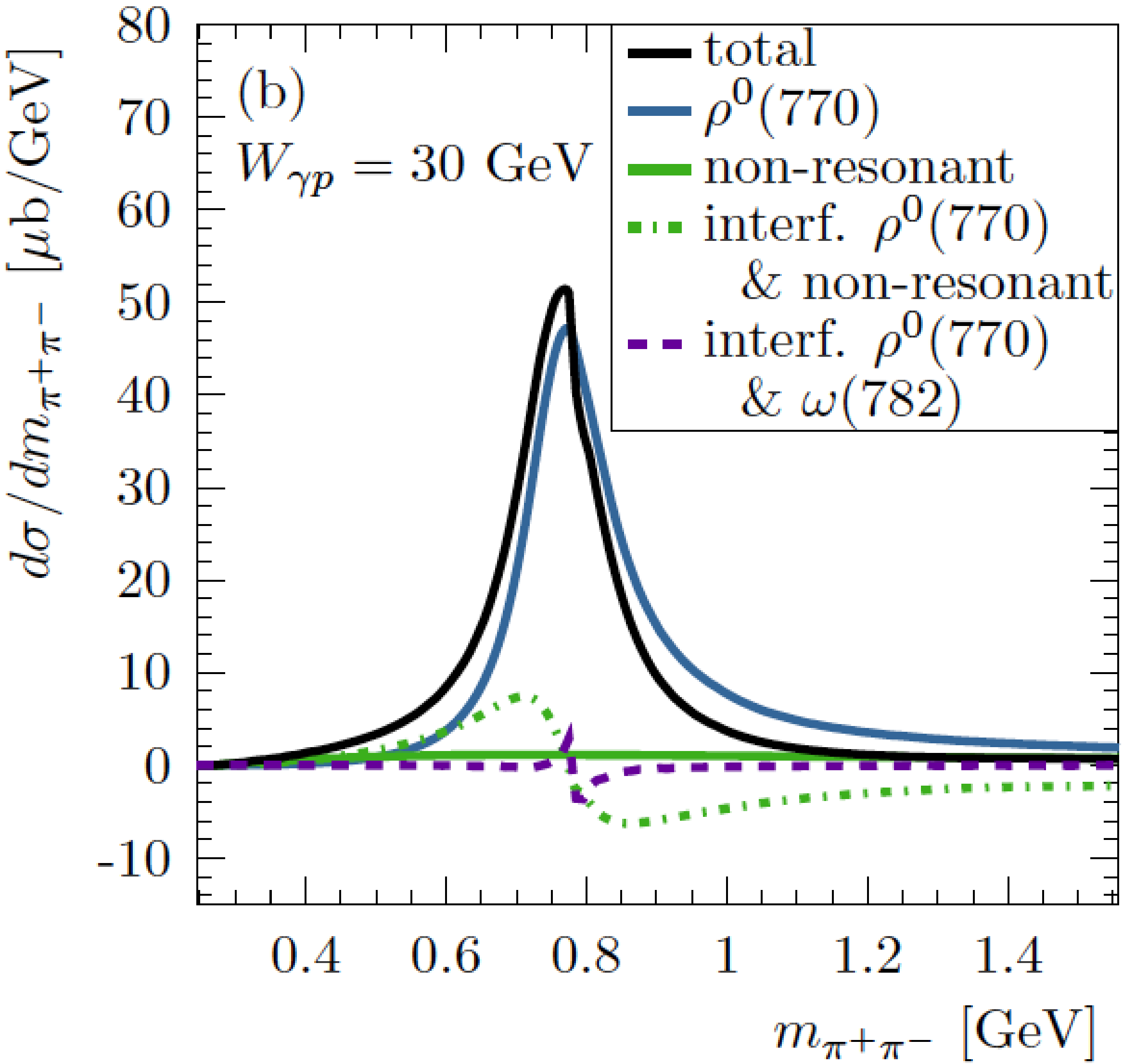
No agreement expected at very low $W_{\gamma p}$ values

$d\sigma(\gamma p \to \pi^+\pi^-) / dm_{\pi\pi}$, skewing (Drell-Söding) & ω-ρ interference

$W_{\gamma p}$ = 50-100 GeV

$W_{\gamma p}$ =30 GeV

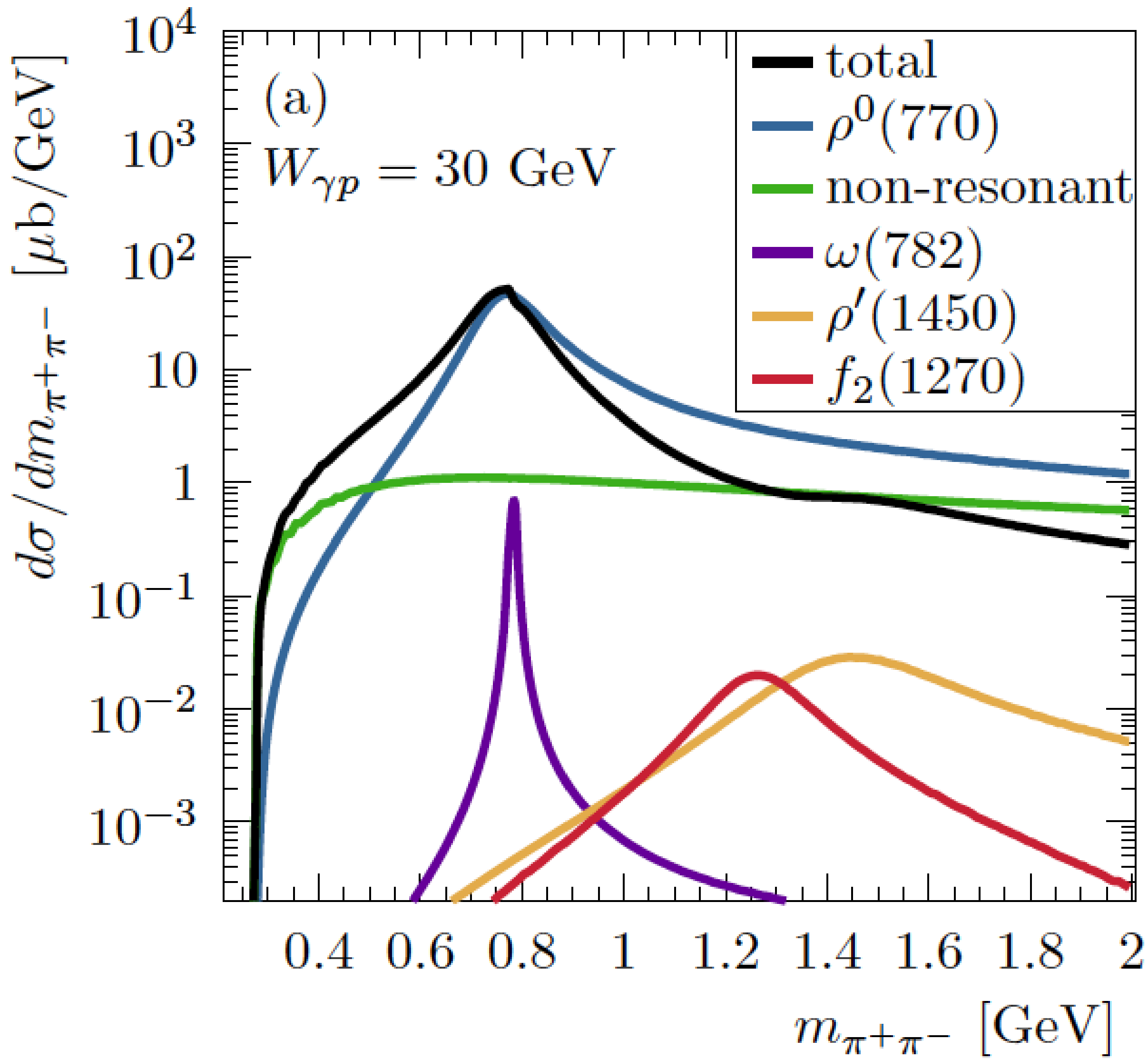




Data figure: taken from DESY 97-237

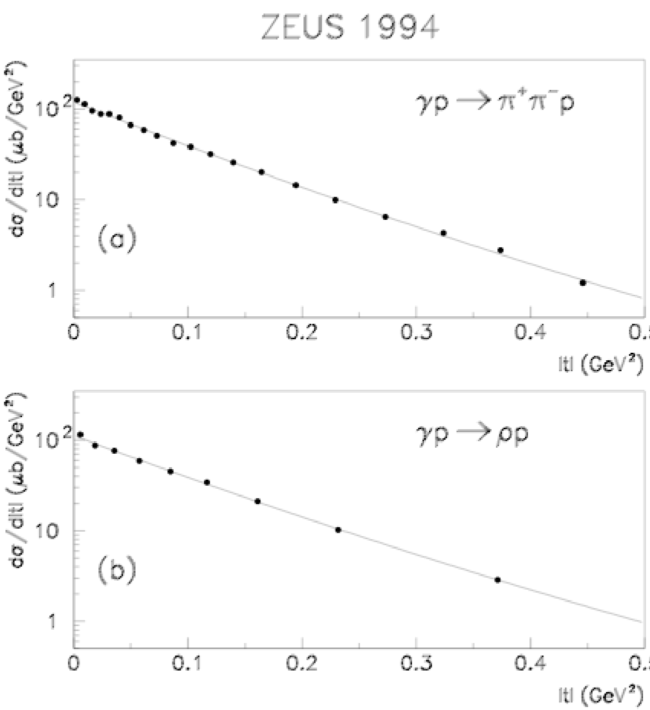
$d\sigma(\gamma p \rightarrow \pi^+\pi^-) / dm_{\pi\pi}$, different contributions

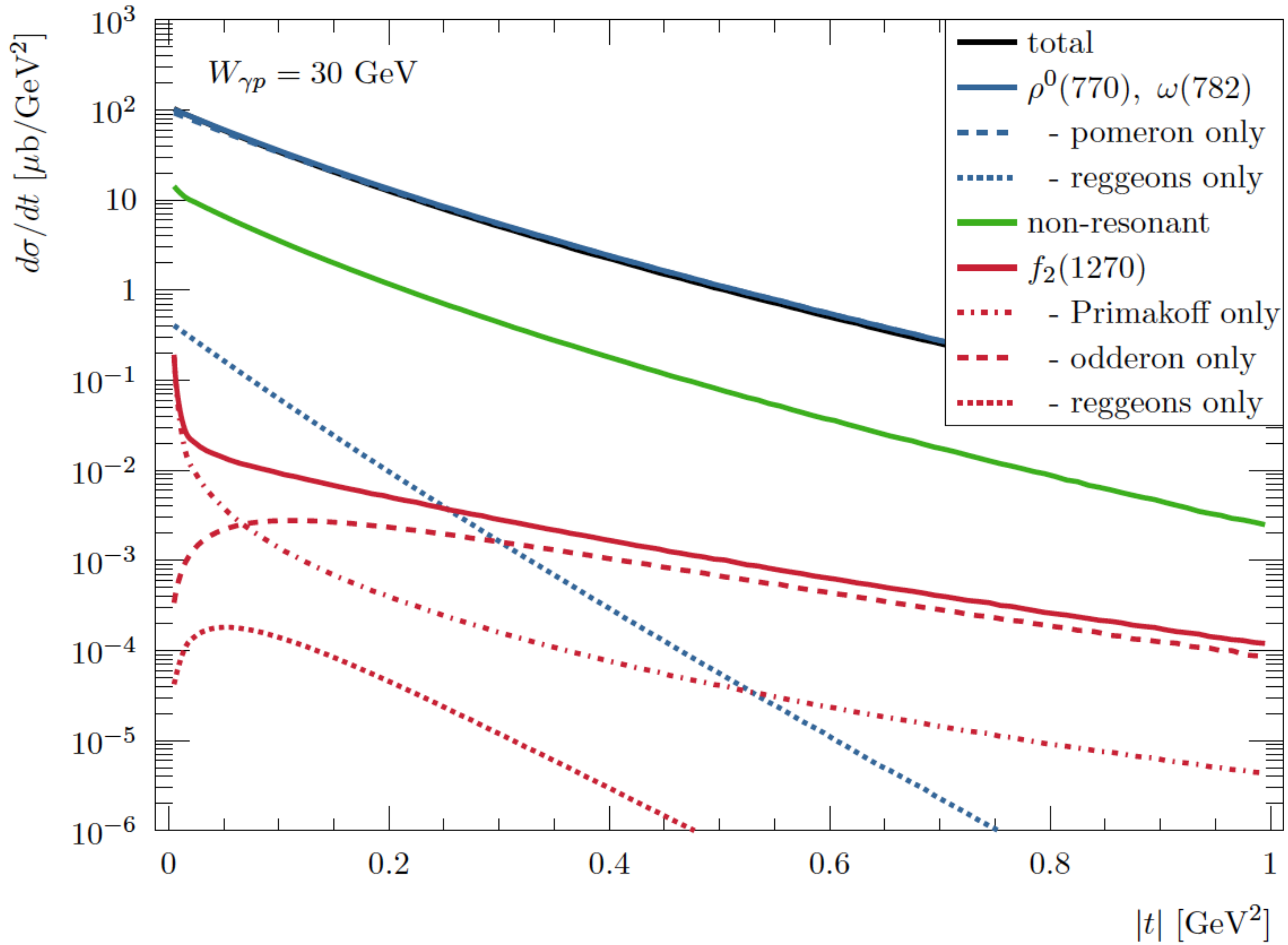
$W_{\gamma p}$ =30 GeV



dσ(γp ⟶ π⁺π⁻) / d|t| compared to data, different contributions

$W_{\gamma p}$ = 50-100 GeV

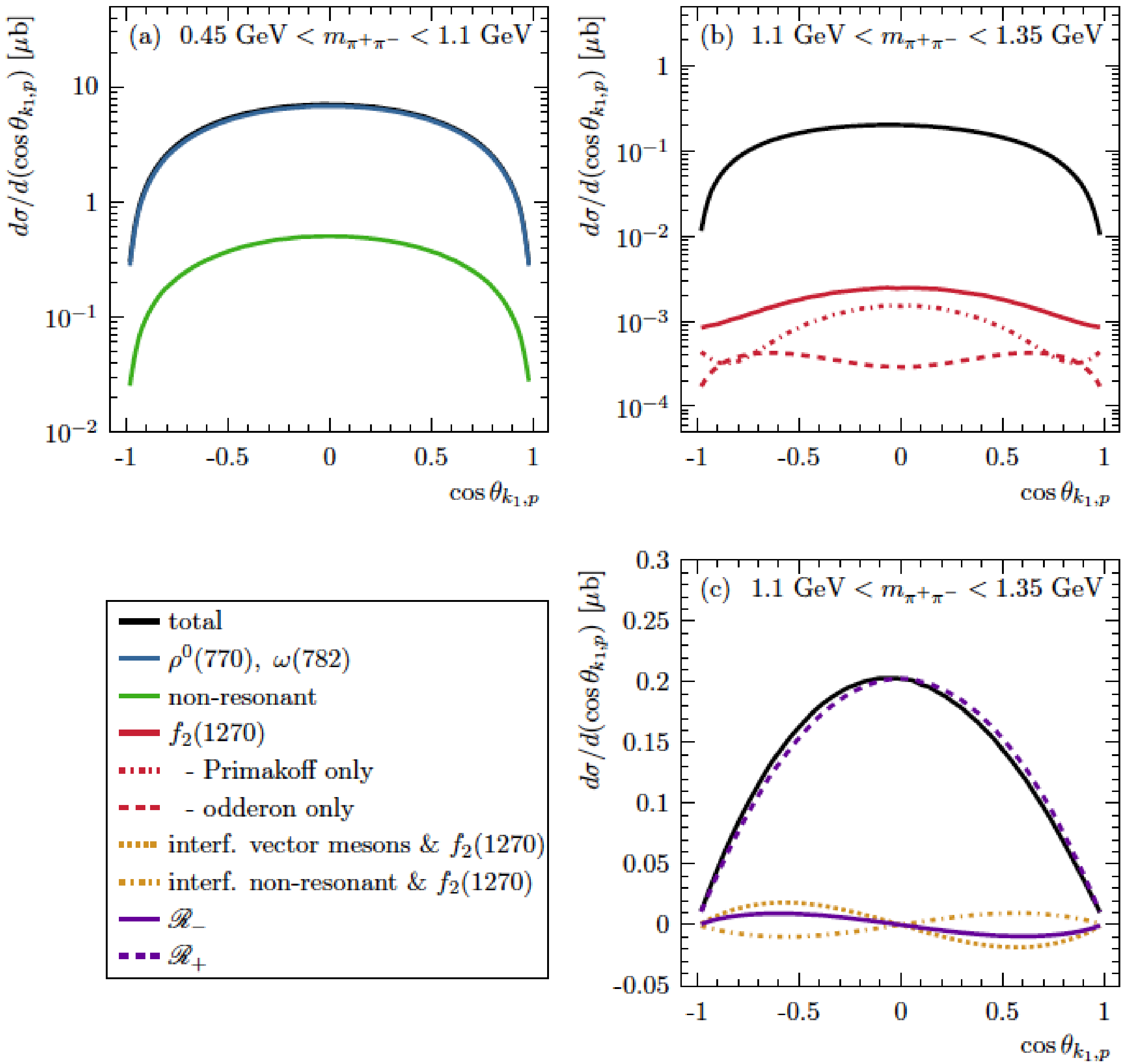




Data figure: taken from DESY 97-237

$d\sigma(\gamma p \longrightarrow \pi^+\pi^-) / d\cos\theta_{k1,p}$ compared to data, different contributions

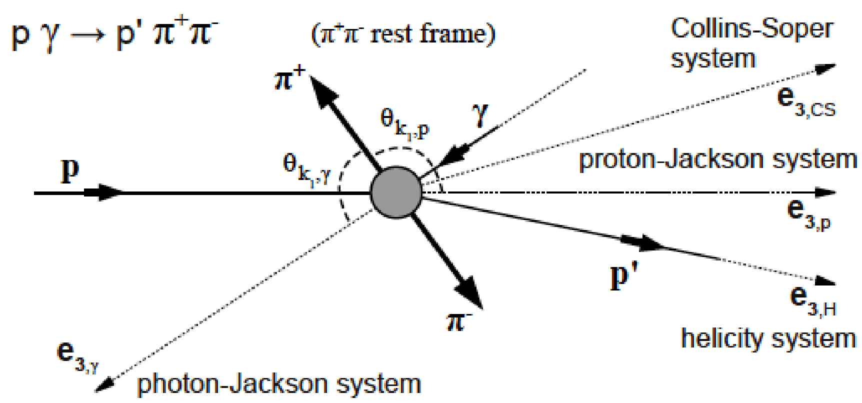
$\cos\theta_{k1,p}$ = angle between π^+ and outgoing p in $\pi\pi$-rest frame.

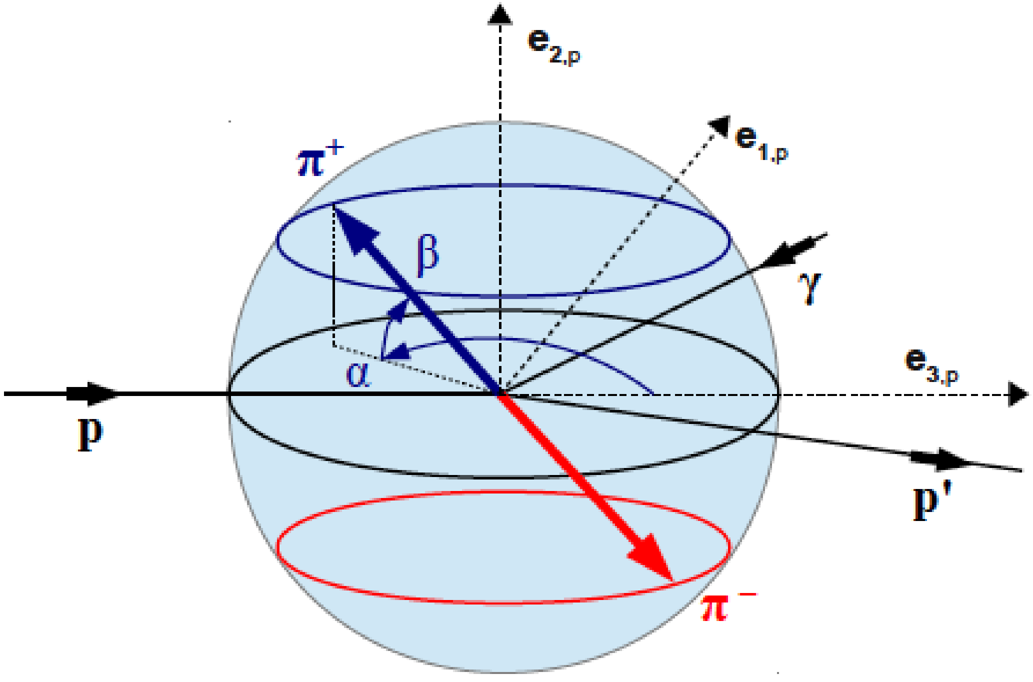


- Deviation from naïve $\sin^2\theta$ behavior around f2-mass, due to interference of C=+1 and C=-1 diagrams.

Charge asymmetries due to interference

- The interference of diagrams with exchange of C = +1 and C = -1 objects is signaled by an asymmetry under
$$k_1 \rightarrow -k_1$$
with k_1 = 3-vector of π^+ in $\pi\pi$ rest-frame.
- π^+ distribution symmetric under reflection on the reaction plane (given by incoming and outgoing proton) due to P-invariance.
- Define asymmetries with respect to specific direction in reaction plane.





Charge asymmetries due to interference

- Definition of charge asymmetry in proton-Jackson frame:

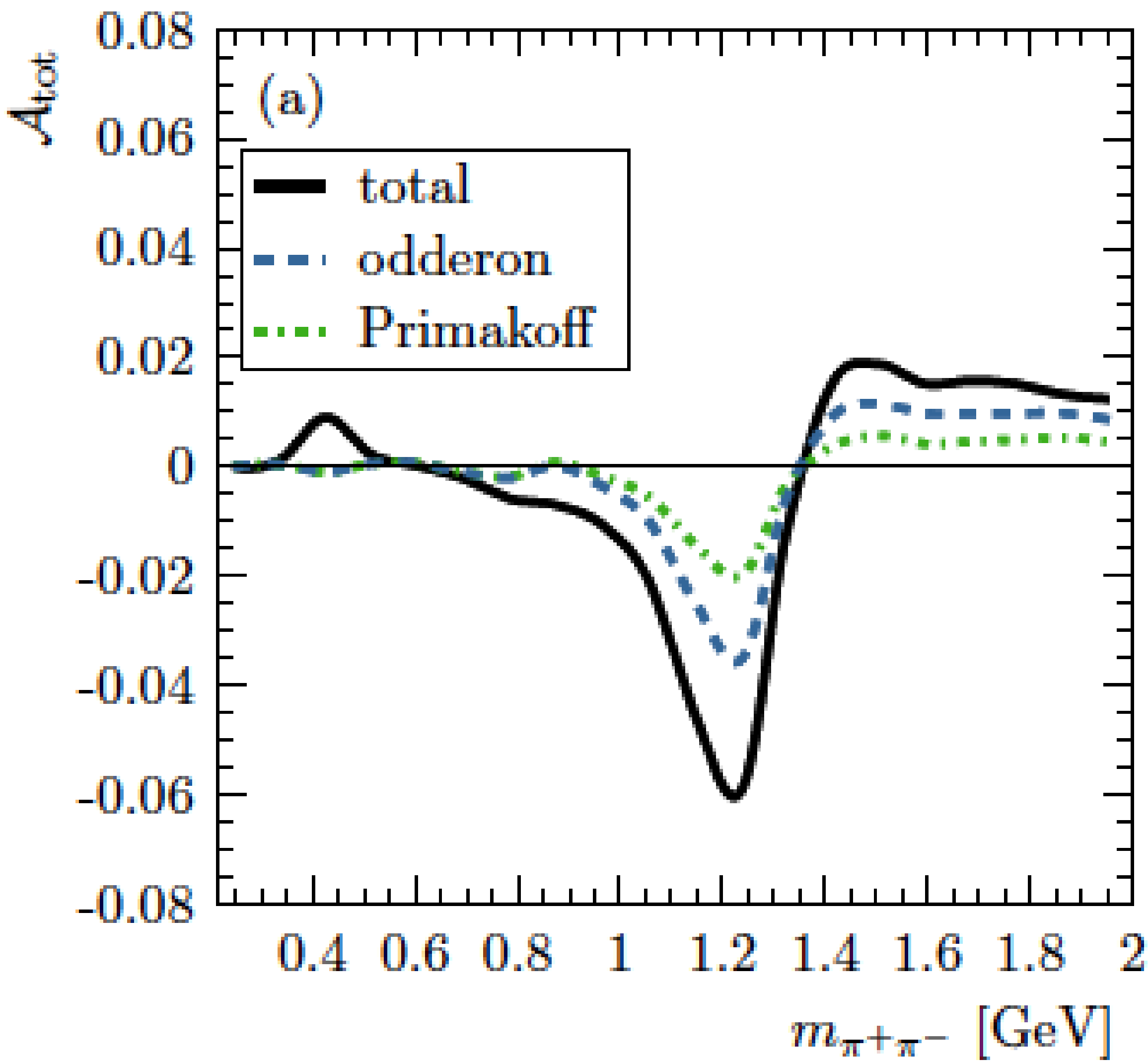
$$\widehat{\mathcal{A}}(\cos\theta_{k_1,p}) = \frac{\frac{d\sigma}{d\cos\theta_{k_1,p}}(\cos\theta_{k_1,p}) - \frac{d\sigma}{d\cos\theta_{k_1,p}}(-\cos\theta_{k_1,p})}{\frac{d\sigma}{d\cos\theta_{k_1,p}}(\cos\theta_{k_1,p}) + \frac{d\sigma}{d\cos\theta_{k_1,p}}(-\cos\theta_{k_1,p})} \qquad \text{for } \cos\theta_{k_1,p} > 0\,.$$

- Definition of total charge asymmetry:

$$\mathcal{A}_{\text{tot}} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}\,,$$

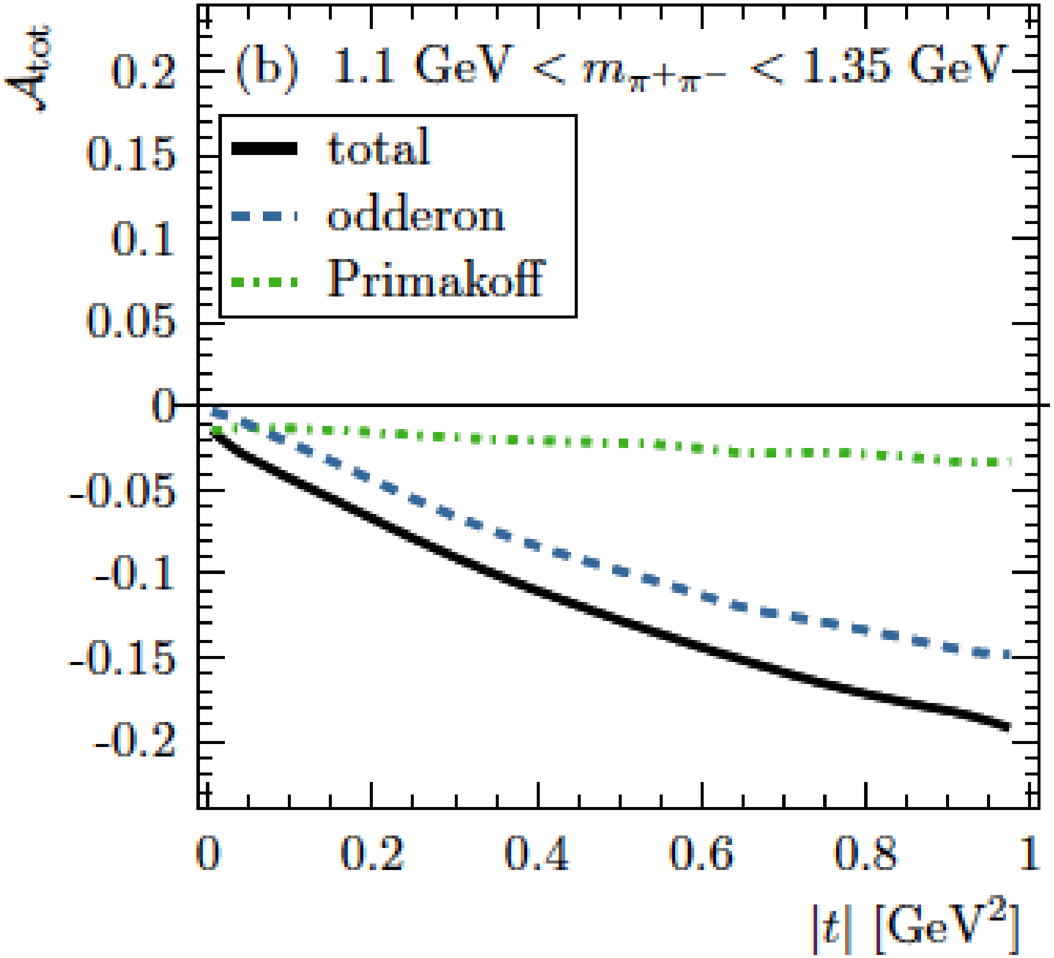
$$\sigma_\pm = \int_0^1 \frac{d\sigma}{d\cos\theta_{k_1,p}}(\pm\cos\theta_{k_1,p})\, d\cos\theta_{k_1,p}\,.$$

Total charge asymmetry as function of $m_{\pi\pi}$



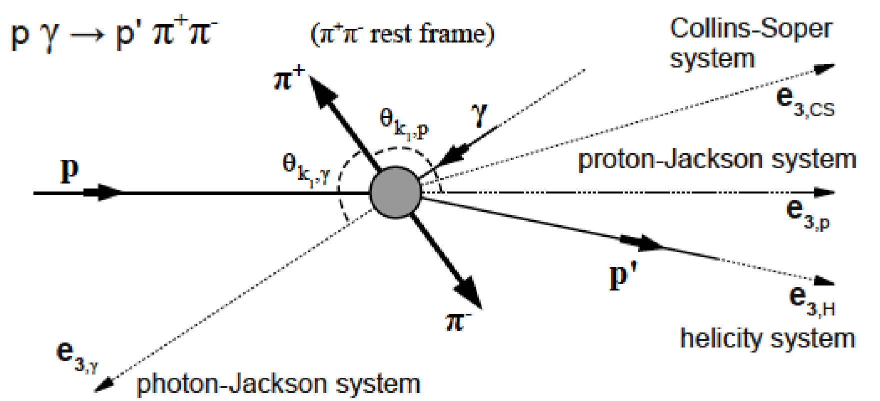
- Significant charge asymmetry predicted around f2-mass = 1.27GeV.
- Asymmetry driven by Primakoff effect (γγ) and odderon (?).
- Exact shape and sign of asymmetry depend on unknown model-parameters.

Total charge asymmetry as function of |t|



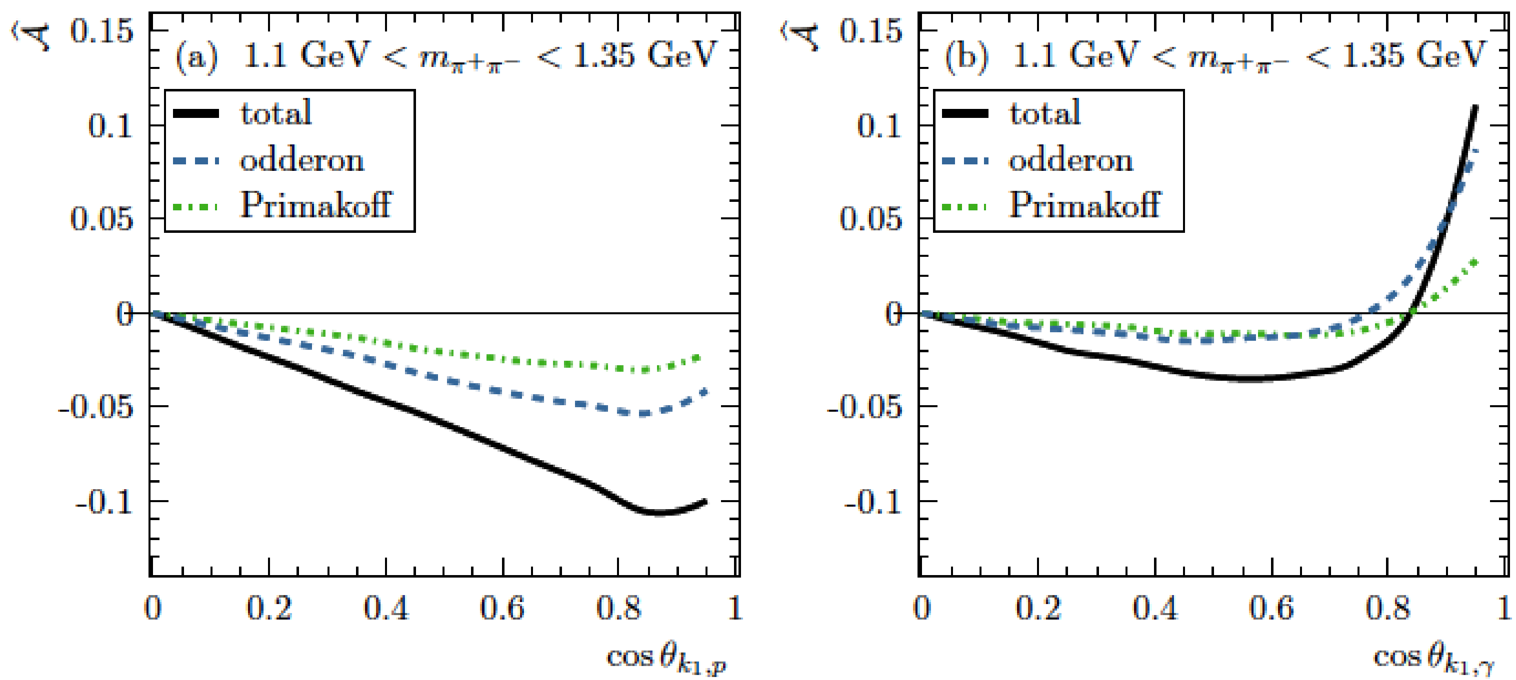
- If the asymmetry (around f2-mass = 1.27GeV) is increasing as a function of |t|, this is might indicate the observation of an odderon-effect.

Comment to the exact definition of θ



proton-Jackson system

photon-Jackson system



- All "common" frames to measure θ are in the limit $|t| \to 0$ identical.
- The used definition, however is for an asymmetry measurement crucial.

Comments to the model-parameters

- Our model comes with lots of parameters, which are partially unknown.
- All plots are for a default set of parameters, precise shape and even some features depend on parameters. I.e. reality might be different.
- Some characteristics are generic:
  - Asymmetry around f2-mass.
  - Increase of asymmetry as function of |t| driven by odderon.

parameters	see eqs.	default value	constraint	ref.	
m_ρ	(B.3)-(B.18)	$775.26\,\mathrm{MeV}$	$775.26 \pm 0.25\,\mathrm{MeV}$	[62]	
m_ω	(B.3)-(B.18)	$782.65\,\mathrm{MeV}$	$782.65 \pm 0.12\,\mathrm{MeV}$	[62]	
Γ_ω	(B.3)-(B.18)	$8.49\,\mathrm{MeV}$	$8.49 \pm 0.08\,\mathrm{MeV}$	[62]	
$b_{\rho\omega}$	(B.17)	3.5×10^{-3}	$(3.5 \pm 0.5) \times 10^{-3}$	[61]	
$g_{\rho\pi\pi}$	(B.17), (B.56)	11.51	11.51 ± 0.07	[61]	
$g_{\omega\pi\pi}$	(B.17), (B.57)	-0.35	-0.35 ± 0.10	[61]	
$m_{\rho'}$	(B.22)	$1465\,\mathrm{MeV}$	$1465 \pm 25\,\mathrm{MeV}$	[62]	
$\Gamma_{\rho'}$	(B.22)	$400\,\mathrm{MeV}$	$400 \pm 60\,\mathrm{MeV}$	[62]	
$g_{\rho'\pi\pi}$	(B.55)	0.5			*
m_{f_2}	(B.29)	$1275.1\,\mathrm{MeV}$	$1275.1 \pm 1.2\,\mathrm{MeV}$	[62]	
Γ_{f_2}	(B.29)	$185.1\,\mathrm{MeV}$	$185.1^{+2.9}_{-2.4}\,\mathrm{MeV}$	[62]	
$\frac{\Gamma(f_2\to\pi\pi)}{\Gamma_{f_2}}$	(B.30)	84.8%	$(84.8^{+2.4}_{-1.2})\%$	[62]	
$\epsilon_{\mathbb{P}}$	(B.32)	0.0808	0.0808	[24]	
$\alpha'_{\mathbb{P}}$	(B.32)	$0.25\,\mathrm{GeV}^{-2}$	$0.25\,\mathrm{GeV}^{-2}$	[24]	
$\alpha_{\mathbb{R}_+}(0)$	(B.34)	0.5475	0.5475	[24]	
$\alpha'_{\mathbb{R}_+}$	(B.34)	$0.9\,\mathrm{GeV}^{-2}$	$0.9\,\mathrm{GeV}^{-2}$	[24]	
$\alpha_{\mathbb{R}_-}(0)$	(B.36)	0.5475	0.5475	[24]	
$\alpha'_{\mathbb{R}_-}$	(B.36)	$0.9\,\mathrm{GeV}^{-2}$	$0.9\,\mathrm{GeV}^{-2}$	[24]	
M_-	(B.36)	$1.41\,\mathrm{GeV}$	$1.41\,\mathrm{GeV}$	[24]	
$\eta_{\mathbb{O}}$	(B.38)	-1	± 1	[24]	*
$\epsilon_{\mathbb{O}}$	(B.38)	0	$\epsilon_{\mathbb{O}} \le \epsilon_{\mathbb{P}}$	[24]	*
$\alpha'_{\mathbb{O}}$	(B.38)	0.25		[24]	*
γ_ρ	(B.46)	$[\frac{1}{4\pi}0.496]^{-1/2}$	$[\frac{1}{4\pi}(0.496 \pm 0.023)]^{-1/2}$	[24]	
γ_ω	(B.46)	$[\frac{1}{4\pi}0.042]^{-1/2}$	$[\frac{1}{4\pi}(0.042 \pm 0.0015)]^{-1/2}$	[24]	
γ_ϕ	(B.46)	$-[\frac{1}{4\pi}0.0716]^{-1/2}$	$-[\frac{1}{4\pi}(0.0716 \pm 0.0017)]^{-1/2}$	[24]	
$\gamma_{\rho'}$	(B.46)	γ_ρ			*
$\frac{\mu_p}{\mu_N}$	(B.52)	2.7928	2.7928	[24]	
m_D^2	(B.53)	$0.71\,\mathrm{GeV}^2$	$0.71\,\mathrm{GeV}^2$	[24]	
m_0^2	(B.54)	$0.50\,\mathrm{GeV}^2$	$0.50\,\mathrm{GeV}^2$	[24]	
$g_{f_2\pi\pi}$	(B.59)	9.26	9.26 ± 0.15	[24]	
Λ_{f_2}	(B.60)	$1.8\,\mathrm{GeV}$	$1 - 4\,\mathrm{GeV}$		*
$a_{f_2\gamma\gamma}$	(B.62)	$\frac{e^2}{4\pi}1.45\,\mathrm{GeV}^{-3}$	$\frac{e^2}{4\pi}1.45\,\mathrm{GeV}^{-3}$	[24]	
$b_{f_2\gamma\gamma}$	(B.62)	$\frac{e^2}{4\pi}2.49\,\mathrm{GeV}^{-1}$	$\frac{e^2}{4\pi}2.49\,\mathrm{GeV}^{-1}$	[24]	
$\beta_{\mathbb{P}NN}$	(B.65)	$1.87\,\mathrm{GeV}^{-1}$	$1.87\,\mathrm{GeV}^{-1}$	[24]	
$\beta_{\mathbb{P}\pi\pi}$	(B.70)	$1.76\,\mathrm{GeV}^{-1}$	$1.76\,\mathrm{GeV}^{-1}$	[24]	
$g_{f_{2R}pp}$	(B.73)	11.04	11.04	[24]	
$g_{a_{2R}pp}$	(B.75)	1.68	1.68	[24]	
$g_{f_{2R}\pi\pi}$	(B.77)	9.30	9.30	[24]	
$g_{\rho_R\pi\pi}$	(B.80)	15.63	15.63	[24]	

Summary and Conclusions

- Ewerz-Maniatis-Nachtmann model: formulation of a Regge-type model respecting the rules of QFT to describe high-energy soft reactions:
  - C=+1 exchanges IP, f_{2R}, a_{2R} represented as tensors.
  - C=-1 exchanges ω_R, ρ_R, odderon(?) represented as vectors.
  - List of vertices, propagators and parameters given.
- New MC generator for the reaction $\gamma p \rightarrow \pi^+\pi^- p$
  - Preliminary comparisons with data look fine.
  - Includes interference effects (Drell-Söding mechanism, ω-ρ interference, γ-ρ and odderon-ρ interference)
  - Different $m_{\pi\pi}$ and t behavior for different included processes.
  - Charge asymmetry around f2-mass: Increase as a function of |t| might indicate an odderon-effect.

backup

Charge Asymmetry in αβ-plane