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

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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)
   paper in preparation

3) First results of 2)

<u>Related work:</u>

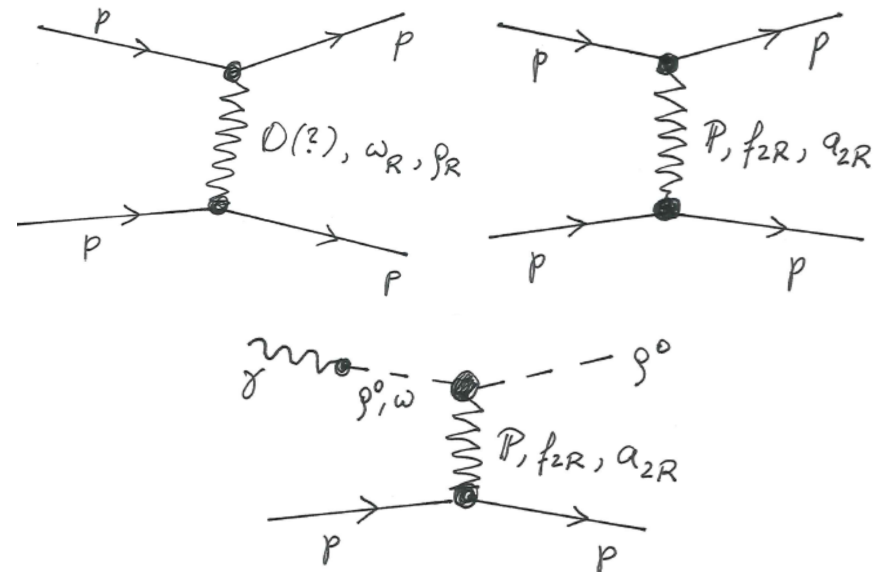
- P. Lebiedowicz, O. Nachtmann, A. Szczurek, arXiv:1309.3913, Annals Phys. 344 (2014) 301
- P. Lebiedowicz, talk at DIS 2014

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:
  - $p + p \to p + meson + p$

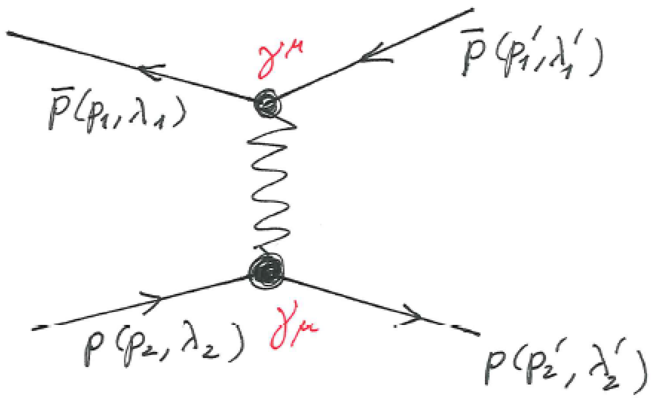
Examples of Feynman-diagrams

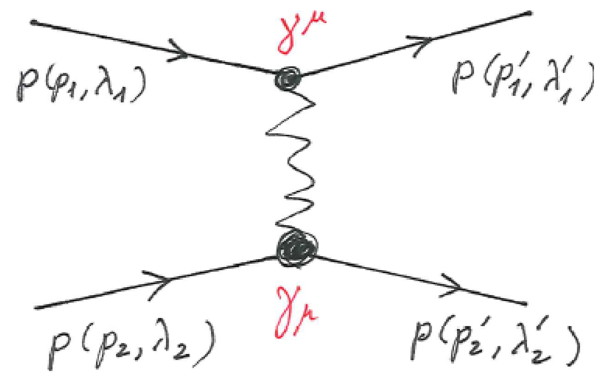


- For $\sqrt{s} \to \infty$, but $|t| \lesssim 1$ GeV^2 this is neither a pure short distance regime nor a pure long distance phenomenon. → difficult to treat in QCD.
- ➢ Physics of exchanges, Regge regime.

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

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





- (Donnachie-Landshoff pomeron ansatz)

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

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

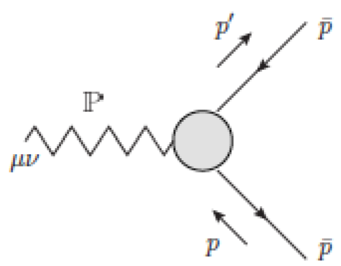
- The $\gamma^\mu \otimes \gamma_\mu$ structure suggests to consider the pomeron as an effective vector exchange.

- 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

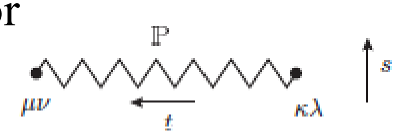
- A way out off the dilemma:
  - Write pomeron exchange as an effective tensor exchange.
  - A tensor – like for gravity – gives the same sign for the coupling of particles and antiparticles.
- Example:

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 $s \rightarrow \infty$ 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:

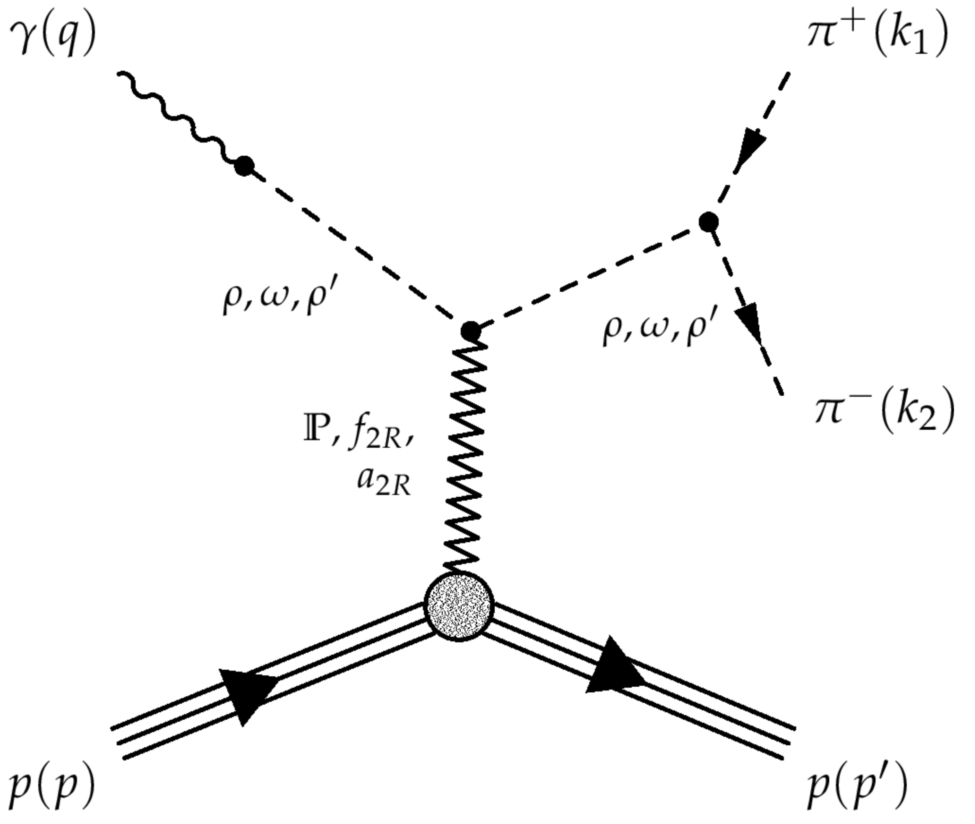
$$\mathrm{d}\sigma^{\gamma p} = \underbrace{\left(\frac{1}{4}\frac{1}{2(s-m_p^2)}(\hbar c)^2\right)}_{\text{Norm}} \underbrace{\left((-1)\sum_{\mathfrak{s}',\,\mathfrak{s}} \mathcal{M}^*_{\mu,\,\mathfrak{s}',\,\mathfrak{s}} \mathcal{M}^{\mu}_{\mathfrak{s}',\,\mathfrak{s}}\right)}_{\text{Sum over matrix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

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

Included processes

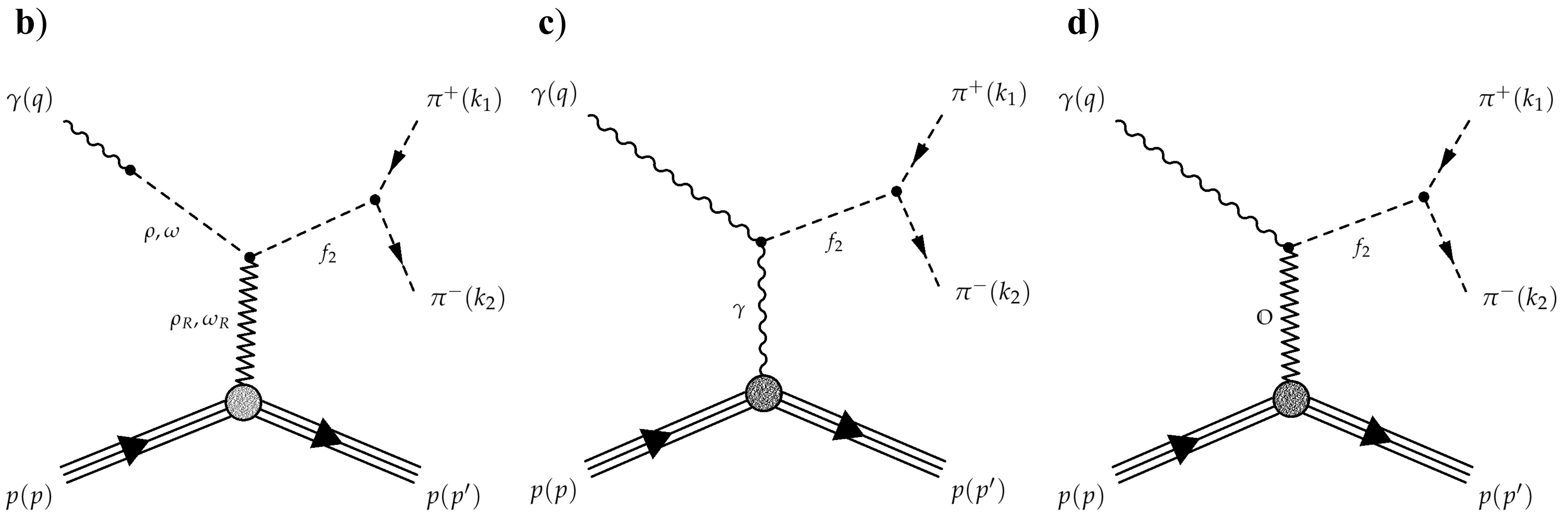
- Resonant ρ, ω, ρ' production via exchanges of pomeron (IP) and reggeons (f_{2R}, a_{2R}).

a)



Included processes

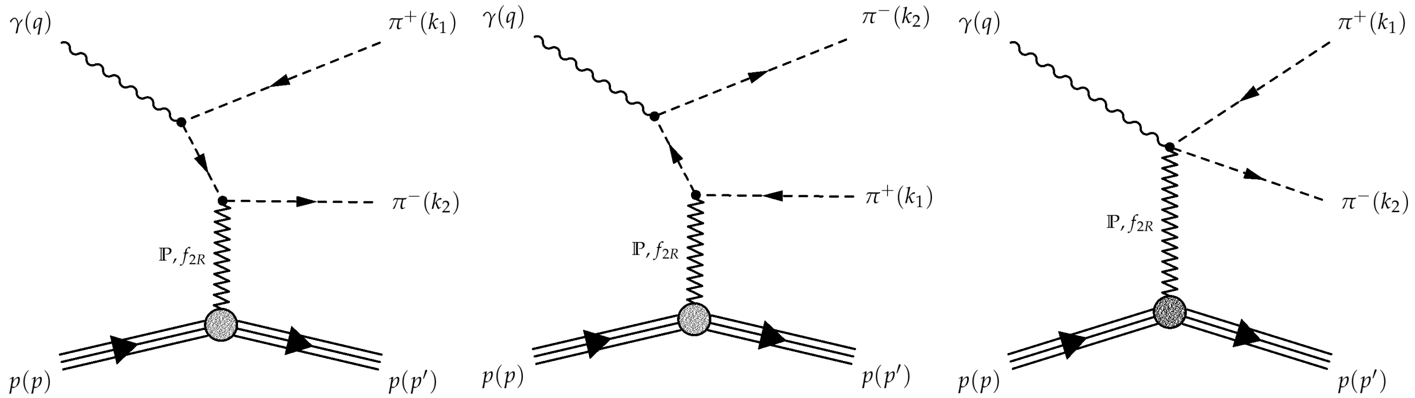
- Resonant f_2 production via exchanges of
  - reggeons (ρ_R, ω_R)
  - photons (Primakoff-Effect)
  - Odderon (?)



Included processes

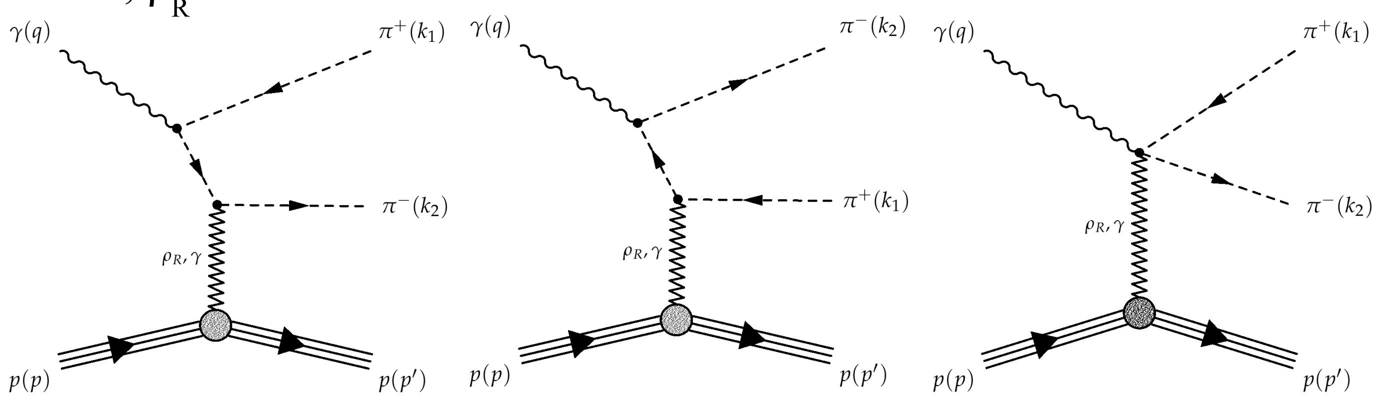
- Non-resonant $\pi^+\pi^-$ production via exchanges of
  - pomeron (IP) and reggeon (f_{2R})

e)



  - photons, ρ_R

f)

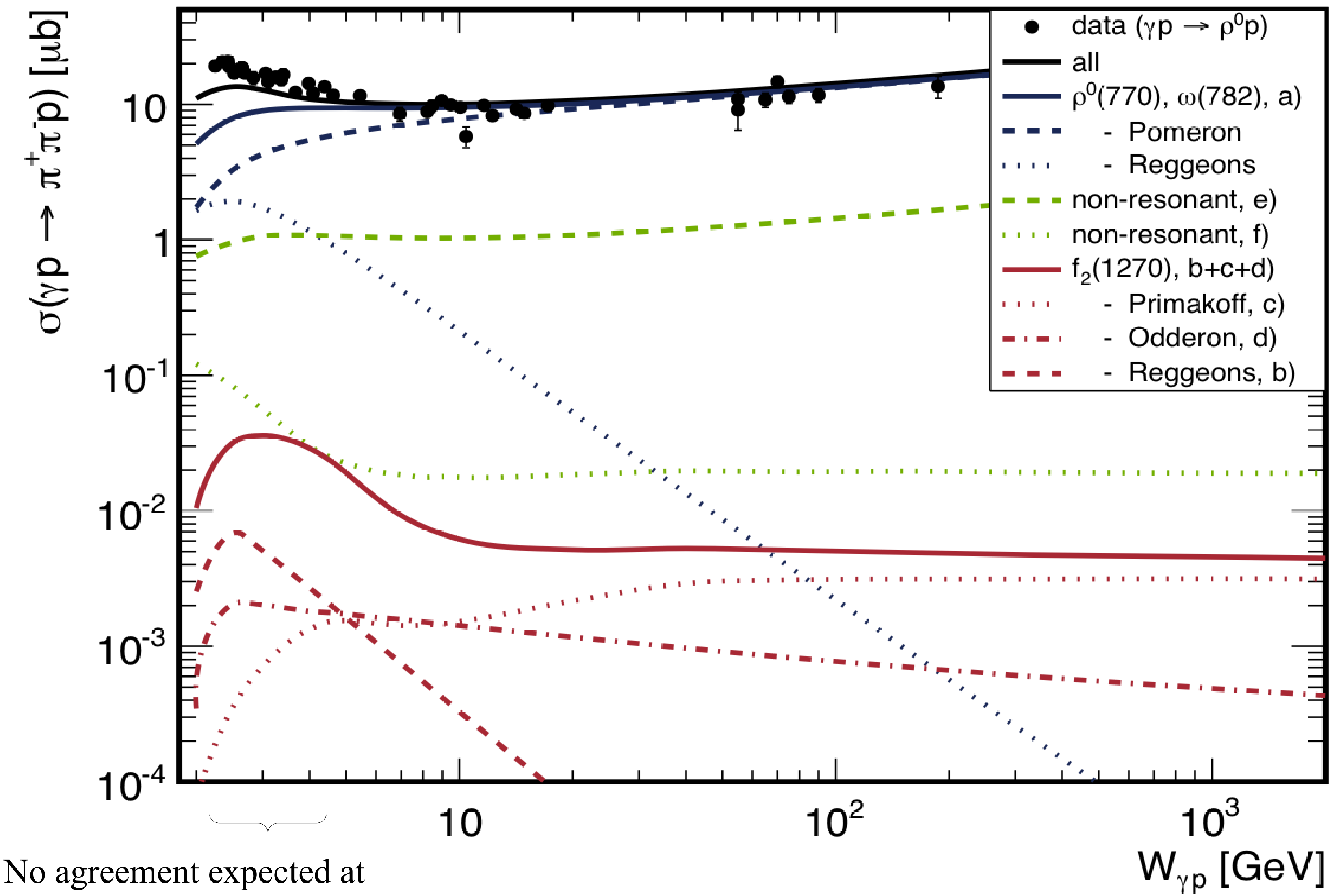


<u>Remark:</u> The inclusion of these diagrams is a gauge invariant version of the Drell-Söding mechanism. The non-resonant pomeron and reggeons interfere with resonant ρ production (1st diagram) → skewing of ρ-line shape.

- Results

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

Data: DESY 97-237

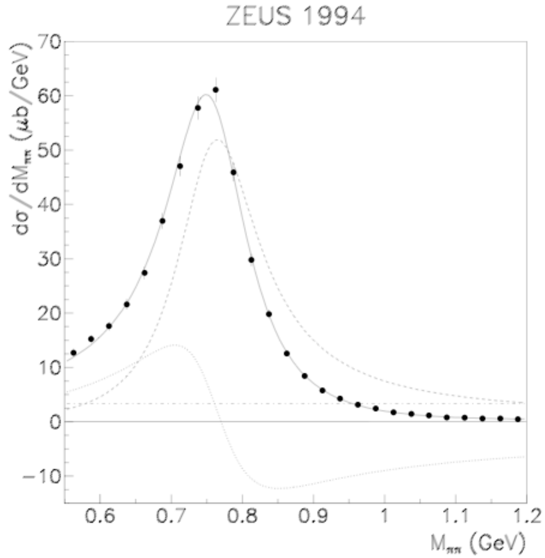


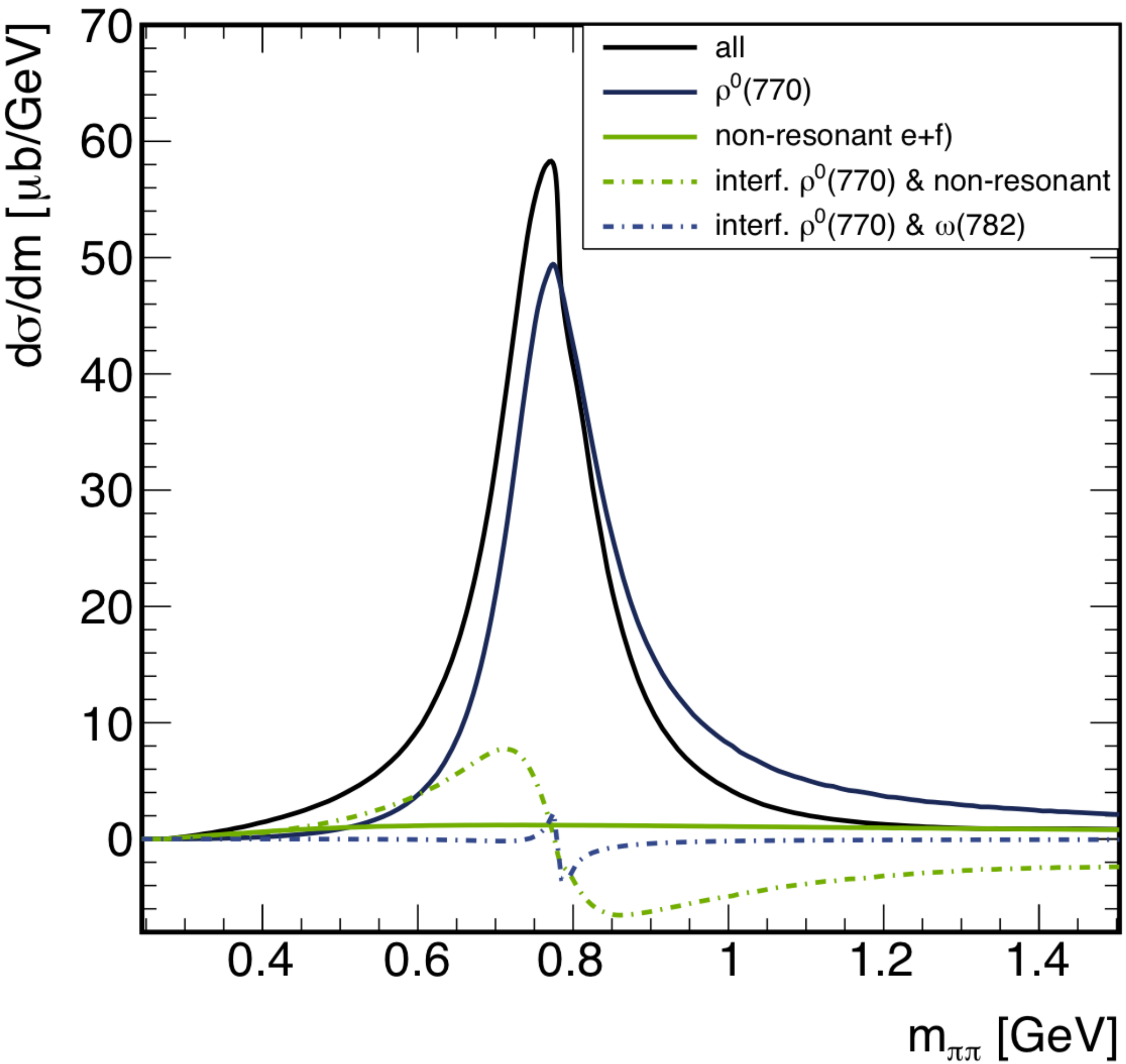
No agreement expected at very low $W_{\gamma p}$ values

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

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

$W_{\gamma p}$ =30 GeV

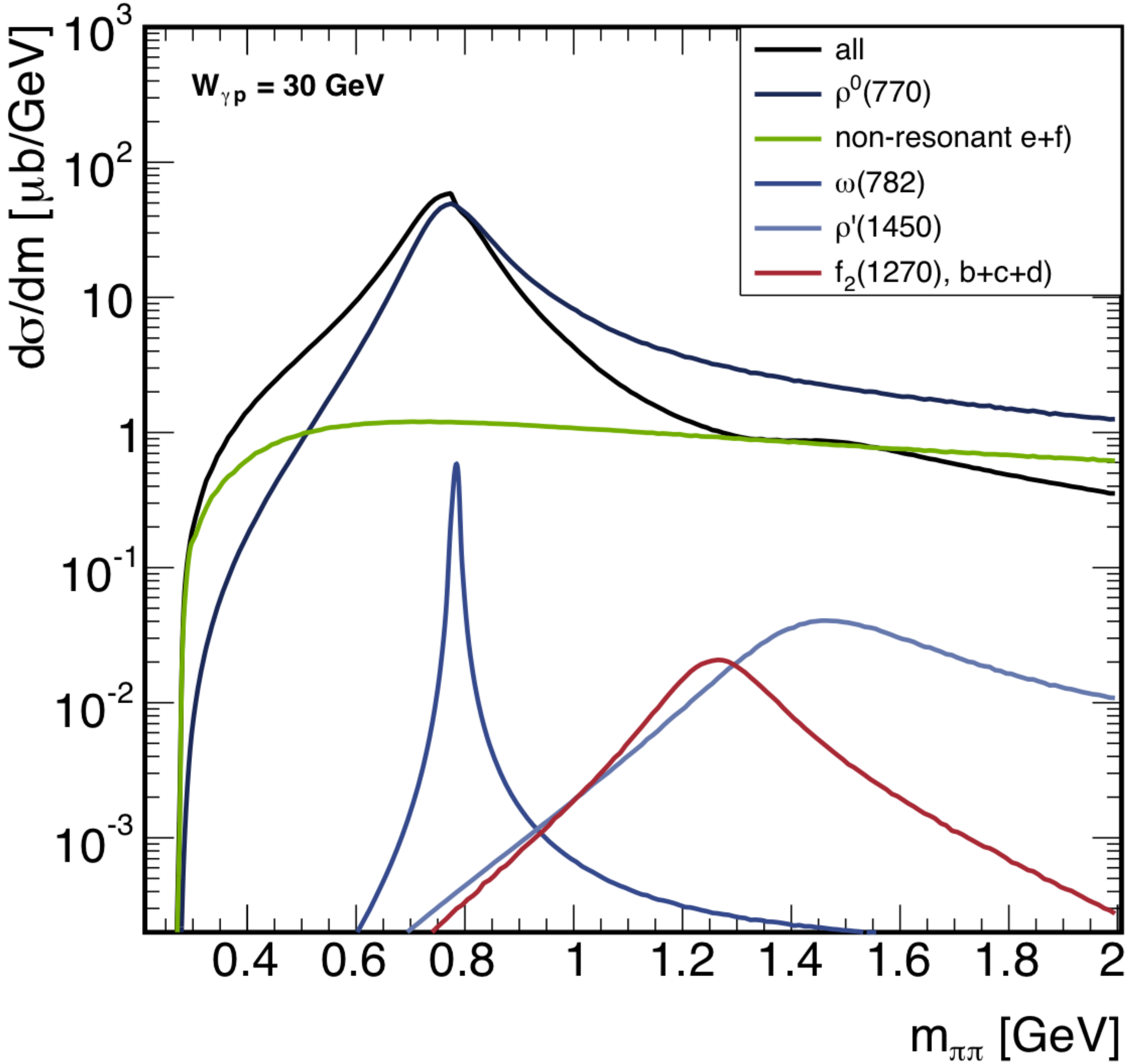




Data figure: taken from DESY 97-237

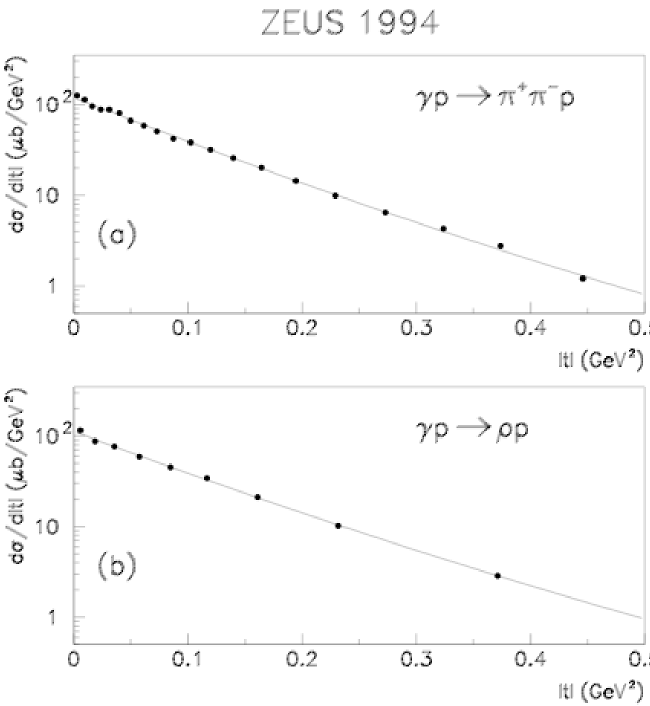
$d\sigma(\gamma p \rightarrow \pi^+\pi^-) / dm_{\pi\pi}$, different contributions

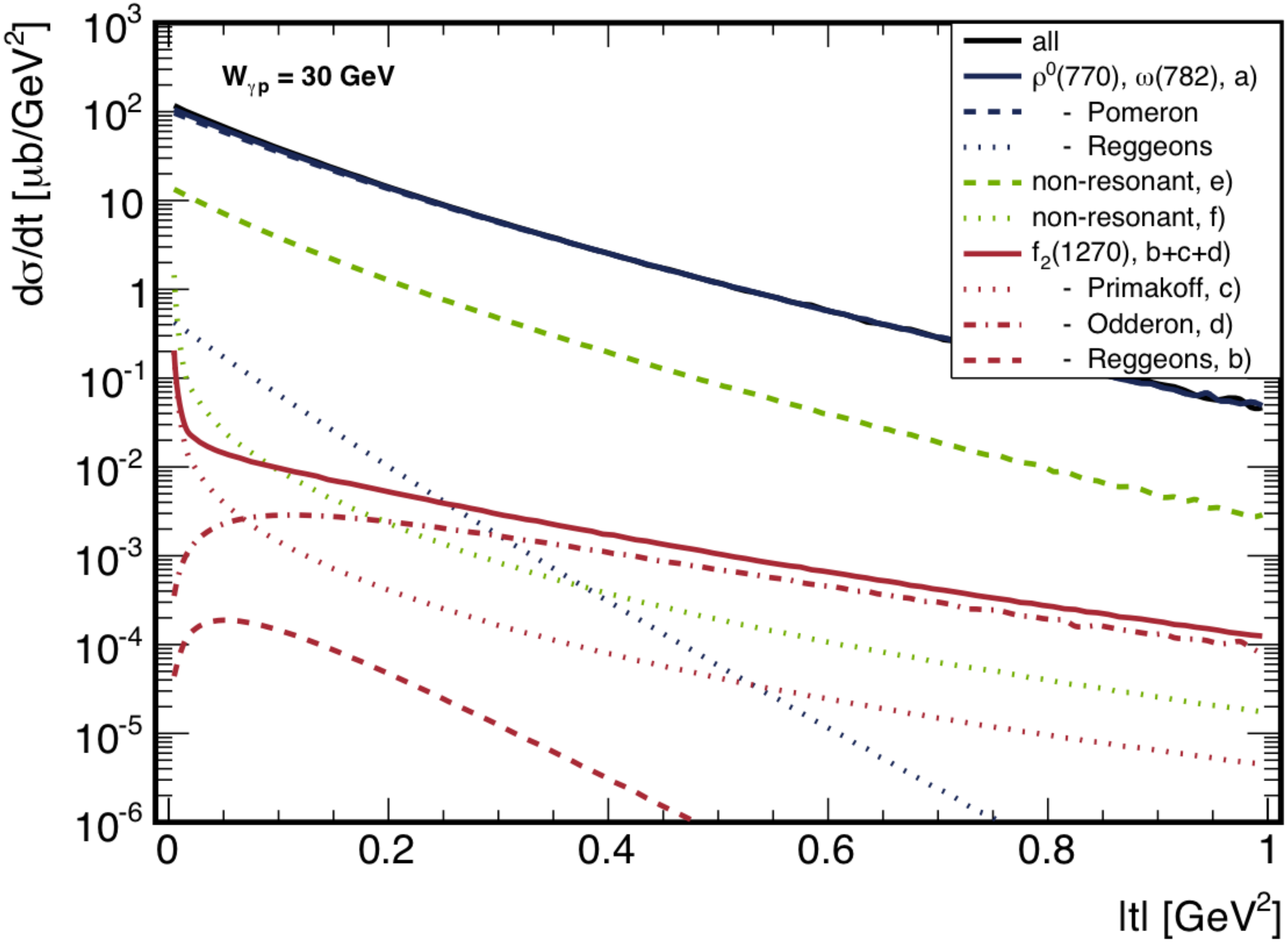
$W_{\gamma p}$ =30 GeV



$d\sigma(\gamma p \to \pi^+\pi^-) / d|t|$ compared to data, different contributions

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





Data figure: taken from DESY 97-237

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. More work is needed to see if the model describes the data in detail, and to optimize the model parameters.
  - Includes interference effects (Drell-Söding mechanism, ω-ρ interference)
  - Different $m_{\pi\pi}$ and t behavior for different included processes.

backup

A few technical remarks:

1) Calculation of the spin sum:
   - We have two (partially) independent implementations (convenient for debugging):
     i. Algebraic calculations with mathematica package feyncalc (http://feyncalc.org/). Compact result as a function of Mandelstam-variables and 2 decay-angles, exported to fast C++ code.
     ii. Direct calculation of algebraic expressions in C++ program, using ltensor package (code.google.com/p/ltensor/). Allows to use Einstein's sum-convention in C++.

2) Phase-space 2 → 3 phase space and integration.
   - 2 → 3 phase space written as a function of t, $m_{\pi\pi}$, 3 angles. Comment: RAMBO turned out to be inefficient for this purpose.
   - Efficient MC-integration of dσ using dedicated pre-sampling functions in t and $m_{\pi\pi}$.

3) Combination of 1) and 2) with some more functions (related to the form-factors and propagators) to one C++ program. Result:
   - weighted events (4-vectors of all particles) saved in a RooT-tree
   - Full control over program behavior via steerings (→ Matrix elements, Parameters, etc.)

4) Differential cross sections (eventually in a complicated phase-space) can be obtained from that using RooT.