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

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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)

Related work:
- P. Lebiedowicz, O. Nachtmann, A. Szczurek, arXiv:1309.3913, Annals Phys. 344 (2014) 301
- P. Lebiedowicz, talk at DIS 2014
Examples for soft reactions:

- elastic scattering:
  - $p + p \rightarrow p + p$
  - $\bar{p} + p \rightarrow \bar{p} + p$
  - $\pi + p \rightarrow \pi + p$

- photoproduction:
  - $\gamma + p \rightarrow \rho^0 + p$
  - $\gamma + \gamma \rightarrow \rho^0 + \rho^0$

- central production:
  - $p + p \rightarrow p + \text{meson} + p$

- For $\sqrt{s} \rightarrow \infty$, but $|t| \lesssim 1 \text{ GeV}^2$ 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

$$
\begin{align*}
\langle p(p'_1), p(p'_2) | T | p(p_1), p(p_2) \rangle |_p & = i \left[ 3 \beta_{NN} F_1(t) \right]^2 (\gamma_\mu)^{\alpha_p} (t)^{-1} \\
& \times \bar{u}(p'_1) \gamma_\mu u(p_1) \bar{u}(p'_2) \gamma_\mu u(p_2), \\
\langle \bar{p}(p'_1), p(p'_2) | T | \bar{p}(p_1), p(p_2) \rangle |_p & = i \left[ 3 \beta_{NN} F_1(t) \right]^2 (\gamma_\mu)^{\alpha_p} (t)^{-1} \\
& \times \bar{u}(p_1) \gamma_\mu u(p'_1) \bar{u}(p'_2) \gamma_\mu u(p_2),
\end{align*}
$$

- (Donnachie-Landshoff pomeron ansatz)

- 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 $\bar{p}$. 

• A way out of 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:

\[
- i 3 \beta_{PNFN} F_1((p' - p)^2) \\
\times \left\{ \frac{1}{2} \left[ \gamma_\mu (p' + p)_\nu + \gamma_\nu (p' + p)_\mu \right] - \frac{1}{4} g_{\mu\nu}(p' + p) \right\}
\]

• 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 ($\text{IP}, f_{2R}, a_{2R}$) formulated as rank-two-tensor exchanges.
  - $C=-1$ exchanges ($\omega_R, \rho_R$, Odderon(?)) as vector exchanges.

- Huge set of vertices respecting QFT rules
  - $\text{IP}_{\rho\rho}, \gamma\rho, \text{IPNN}, \rho\pi^+\pi^-$, …
  - 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.

 ömething is given to apply the model to a concrete calculation of amplitudes.
Aim is to construct a Monte Carlo event generator for the reaction

\[ \gamma(q) + p(p) \rightarrow \pi^+(k_1) + \pi^-(k_2) + p(p') \]

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

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

\[
\frac{d\sigma}{dp} = \frac{1}{4(2\pi)^2} \left( \frac{1}{s-m_p^2} \right) \left( -1 \sum_{s', s} M_{s' s}^s M_{s' s}^\mu \right) \left( \frac{1}{(2\pi)^5} \frac{d^3k_1}{2k_1^0} \frac{d^3k_2}{2k_2^0} \frac{d^3p'}{2p'^0} \delta^{(4)}(k_1 + k_2 + p' - p - q) \right) = d\phi_3, \text{ Phase Space}
\]

- Find / write computer programs
  - to calculate the spin sum.
  - to integrate the phase-space 2 \( \rightarrow \) 3 phase space.
  - to obtain differential cross sections.
- Resonant $\rho$, $\omega$, $\rho'$ production via exchanges of pomeron (IP) and reggeons ($f_{2R}$, $a_{2R}$).
Included processes

- Resonant $f_2$ production via exchanges of
  - reggeons ($\rho_R^*, \omega_R$)
  - photons (Primakoff-Effect)
  - Odderon (?)

\[ \begin{align*}
\text{b)} & \quad \gamma(q) \\
\text{c)} & \quad \gamma(q) \\
\text{d)} & \quad \gamma(q)
\end{align*} \]
Included processes

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

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{diagram.png}
\end{figure}

- photons, $\rho_R$

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{diagram.png}
\end{figure}

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 $\rho$ production (1\textsuperscript{st} diagram) $\rightarrow$ skewing of $\rho$-line shape.
• Results
σ(γp → π⁺π⁻) compared to data

Data: DESY 97-237

No agreement expected at very low W_{γp} values
Model for photoproduction of $\pi^+\pi^-$ pairs, skewing (Drell-Söding) & $\omega$-$\rho$ interference

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

$W_{\gamma p} = 30\,\text{GeV}$

Data figure: taken from DESY 97-237
Model for photoproduction of $\pi^+\pi^-$ pairs

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

$W_{\gamma p} = 30 \text{ GeV}$
Model for photoproduction of $\pi^+\pi^-$ pairs 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 $\text{IP, } f_{2R}, a_{2R}$ represented as tensors.
  - $C=-1$ exchanges $\omega_R, \rho_R$, 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, $\omega$-$\rho$ interference)
  - Different $m_{\pi\pi}$ and $t$ behavior for different included processes.
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 $2 \rightarrow 3$ phase space and integration.
   - $2 \rightarrow 3$ 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 $d\sigma$ 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 ($\rightarrow$ Matrix elements, Parameters, etc.)

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