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Meson Retardation in the Two-Body Problem

1. Introduction
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Collaborators:
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References:
Phys. Lett. B 420 (1998) 255
Nucl. Phys. A 631 (1998) 583c
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nucl-th/0105033

1. Introduction

- fundamental theory of strong interactions: QCD
- nonperturbative regime ($E \lesssim 1$ GeV): QCD cannot be solved at present

$\longrightarrow$ effective degrees of freedom: nucleons, mesons, isobars

- test object for effective theory: hadronic and electromagnetic reactions on few-nucleon systems
- two-nucleon system allows studies on
  - the structure of the NN- and NΔ-interaction
  - the role of medium effects via two-body operators
  - the change of single-particle properties in the nuclear medium (offshell effects)
- basic requirements on a model:
  - realistic NN-interaction
  - dynamical treatment of the Δ-resonance
  - incorporation of one- as well two-body currents
  - gauge invariance
  - unitarity

Note: different reactions are linked via unitarity:

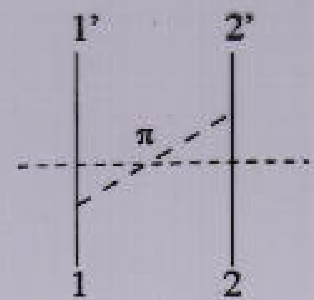
$$\mathrm{Im}\, T(NN \rightarrow NN; \theta = 0) \sim \sigma_{tot}(NN \rightarrow NN, \pi d, \pi NN)$$

$$\mathrm{Im}\, T(\gamma d \rightarrow \gamma d; \theta = 0) \sim \sigma_{tot}(\gamma d \rightarrow NN, \pi d, \pi NN)$$

$\longrightarrow$ reactions should be described within *one* consistent treatment

Realization:

Retarded coupled NN/NΔ-approach based on three body scattering theory with nucleon-, Δ- and meson-degrees of freedom.



retarded propagator:

$$G_0(z) = \left(z - E_N(1') - E_N(2) - E_\pi\right)^{-1}, \quad z = E + i\epsilon$$

characteristic features:

- nonlocal
- nonhermitean
- existence of singularities above pion-threshold
  → coupling of NN- to πNN-system

→ low energy approximation: static limit

$$G_0(z) \to G_0^{stat} := -E_\pi^{-1}$$

- advantage: feasability
- 1. disadvantage: violation of unitarity
- 2. disadvantage: failure in describing $\gamma d \to NN$

2. The Model

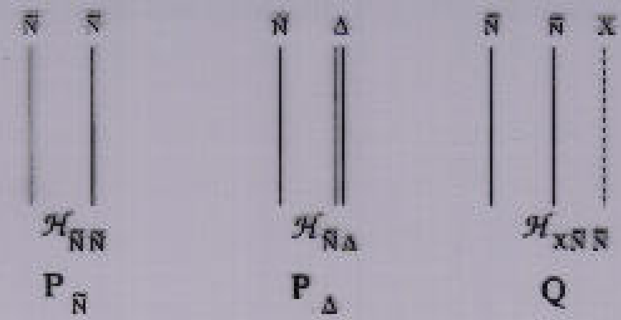


Illustration of general procedure:

- Introduction of **effective** operators with the help of projection operators $P_{\tilde{N}}, P_{\Delta}, Q$ and $P = P_{\tilde{N}} + P_{\Delta}$

$$\langle f|P\mathcal{O}_{eff}(z)P|i\rangle := \langle f|\mathcal{O}|i\rangle$$

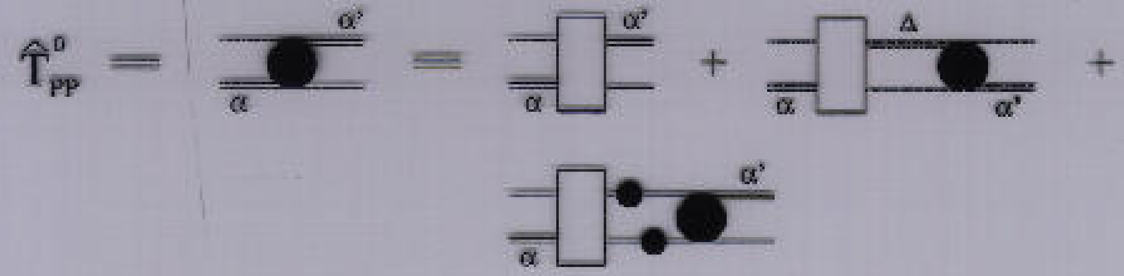
- first stage: potential V is solely given by pion nucleon vertices:

- Lippmann-Schwinger-equation: $\hat{T}(z) = V + V\hat{G}_0(z)\hat{T}(z)$
- result for effective NN-scattering amplitude:

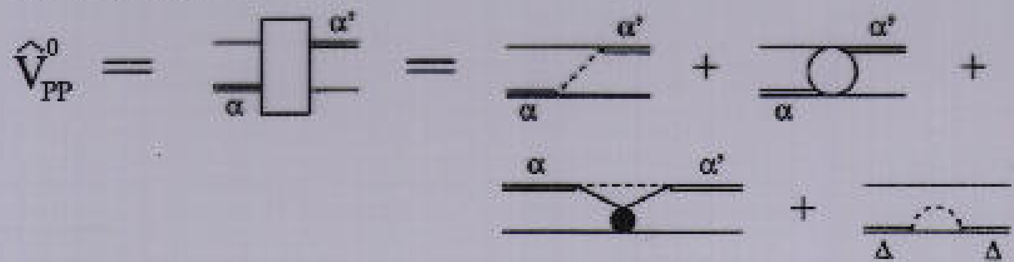
$$\hat{T}_{eff}(z) = \hat{V}_{eff}(z) + \hat{V}_{eff}(z)\hat{G}_0(z)\hat{T}_{eff}(z)$$

graphical illustration of $\hat{V}_{eff}(z)$:

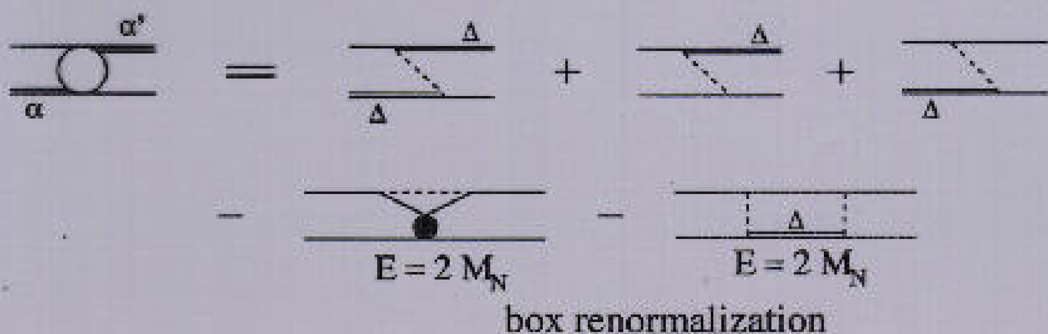
- second stage: Δ-resonance, heavier mesons and πd-channel are taken into account



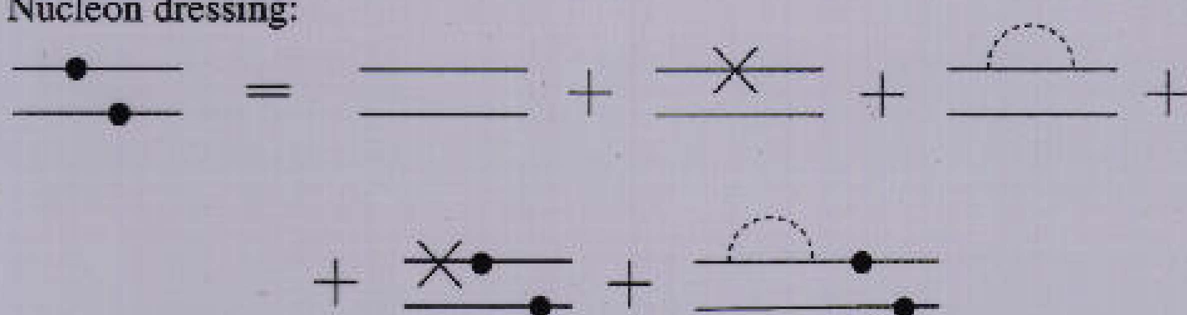
Driving term:



Exchange interaction:



Nucleon dressing:

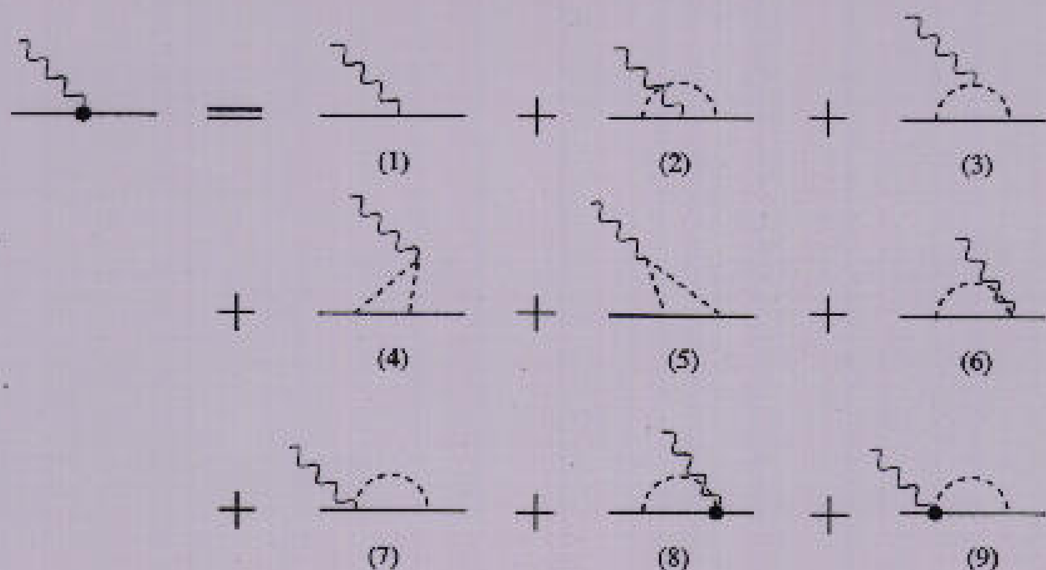


Effective Current Operators

(a) (b) (c) (d)

(a) nucleonic one-body current

- convection- and spin current
- spin-orbit-current
- offshell contributions



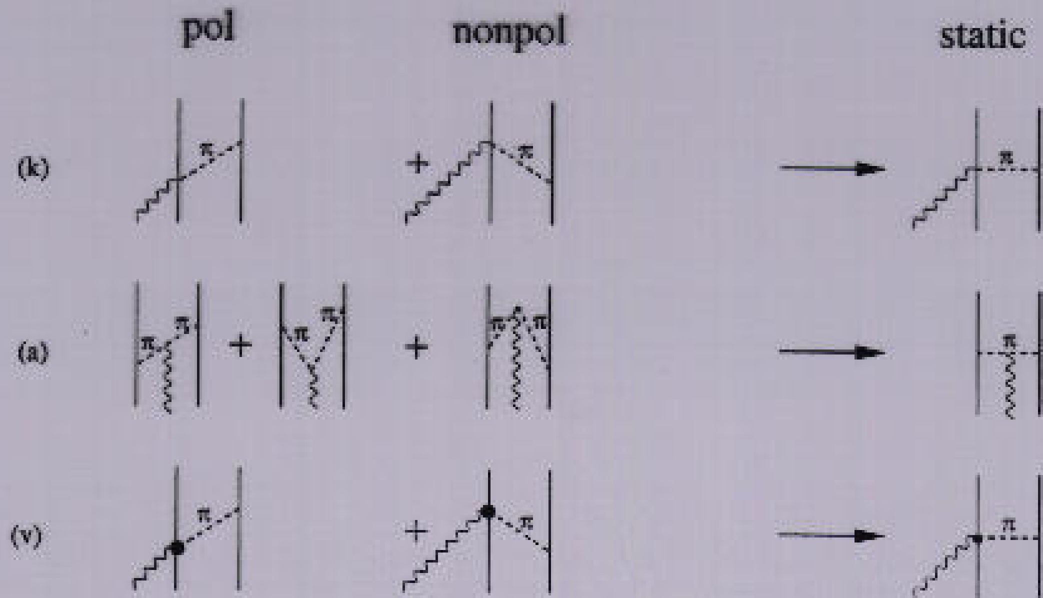
(b) Δ-excitation one-body-current

$$\mathbf{J}_{eff}(W,\mathbf{k}) = \frac{G_{M1}^{\Delta\tilde{N}}(z = W + i\epsilon, k)}{2M_{\tilde{N}}}\, \tau_{\Delta N,0}\; i\,\boldsymbol{\sigma}_{\Delta N} \times \mathbf{k}$$

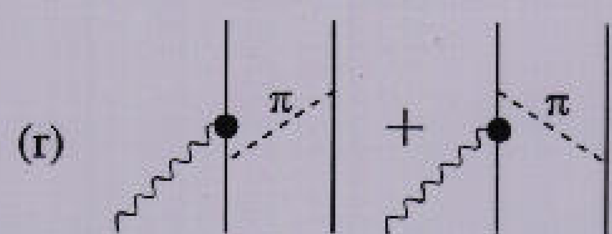
determination of $G_{\Delta\tilde{N}}^{M1}$ by fitting photopionproduction on the nucleon in the $M_{1+}(3/2)$-channel.

(c) nucleonic two-body current besides static ρ-MEC

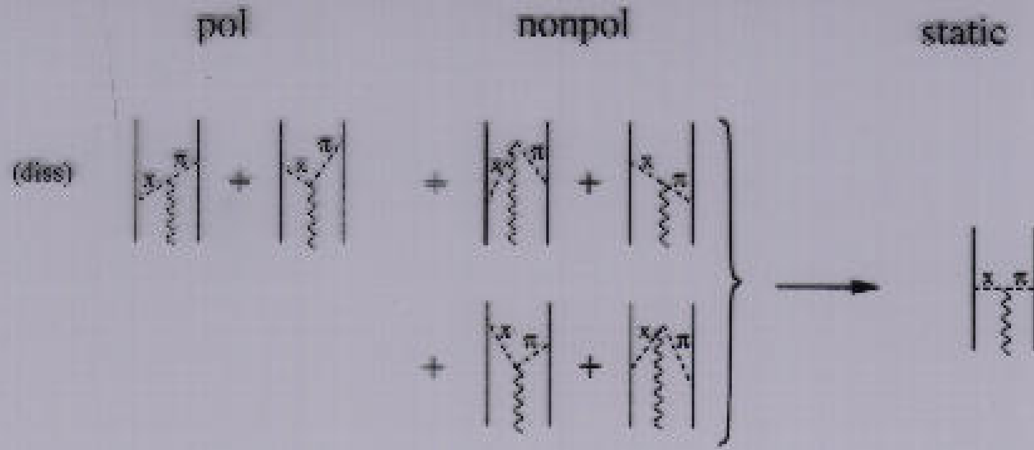
- **retarded** π-contact/flight/vertex-MEC



- **retarded** recoil-MEC (not present in static calculations)

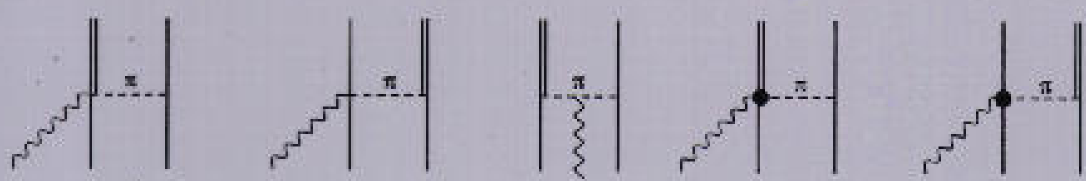


– **retarded** $\gamma\pi\rho/\gamma\pi\omega$-current (dissociation current)



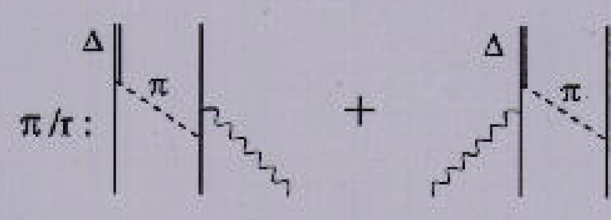
(d) two-body $NN \rightarrow N\Delta$-current

– static Δ-contact/flight/vertex-MEC



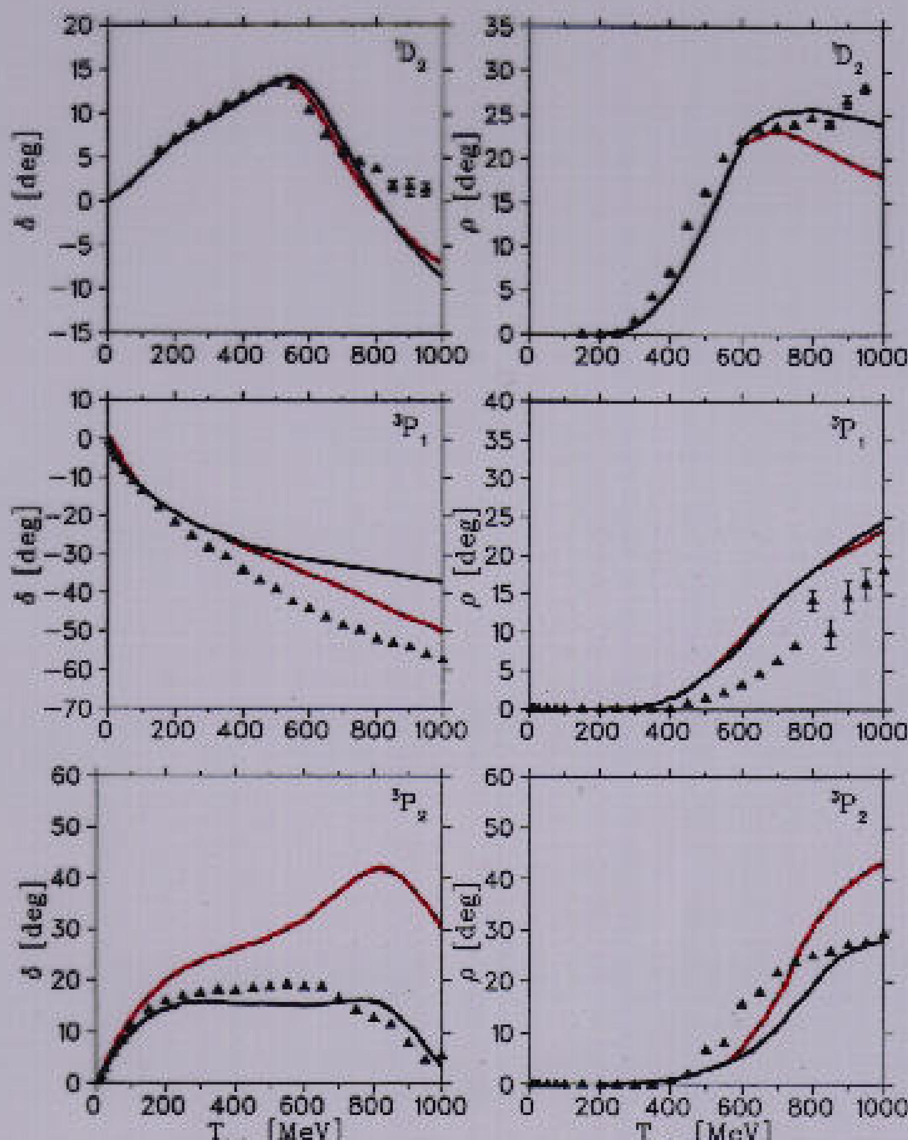
a) b) c) d) e)

– **retarded** recoil-MEC



3. Results

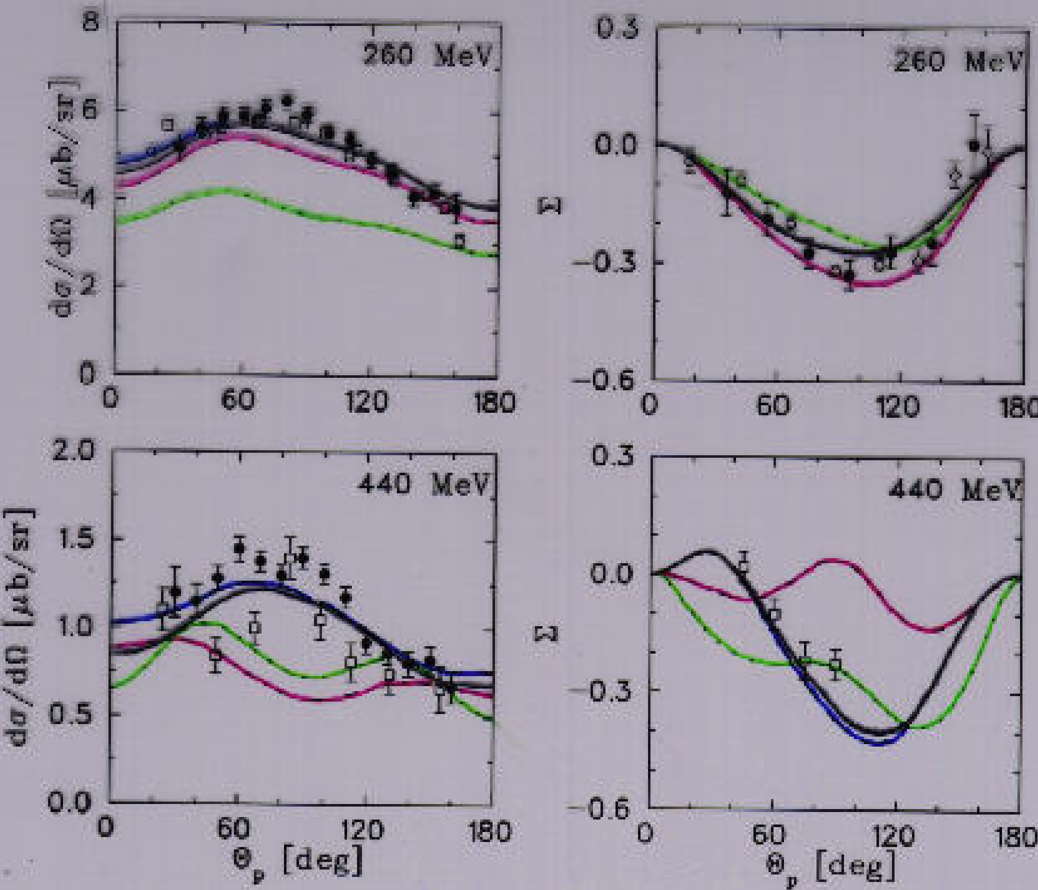
NN-SCATTERING



red: static calculation

black: full retarded calculation

Photodisintegration



green:	static calculation of Wilhelm et al. (1993)
red:	improved static calculation (including πd, ρ-exchange in $N\Delta$-interaction, improved $\gamma N\Delta$-coupling, dissociation currents)
blue:	retardation in hadronic interaction and MEC switched on, offshell effects neglected
black:	full retarded calculation

experimental data for cross section:
□ Bonn (1984), ∘ LEGS (1995), • Daphne (1996)
experimental data for photon asymmetry:
□ Adaminan et al. (1991), ∘ LEGS (1995), • Daphne (1999)

GDH-SUM RULE

The spin-asymmetry $\sigma^P(k) - \sigma^A(k)$ of the total photoabsorption cross section determines the **GDH** sum rule:

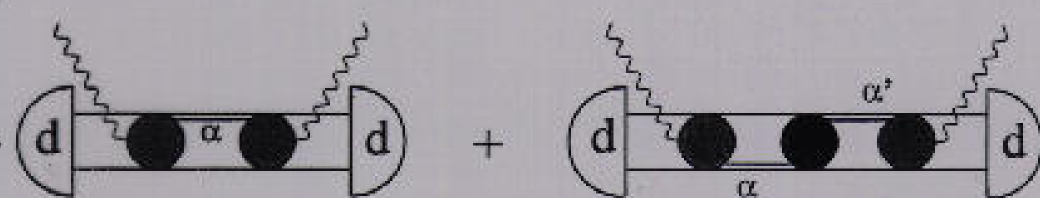
$$\int dk \frac{\sigma^P(k) - \sigma^A(k)}{k} = 4\pi\kappa^2 \frac{e^2}{M_d^2} S$$

For the neutron, in the absence of neutron targets it has been suggested to measure the spin asymmetry of the total photoabsorption cross section of the neutron using vector polarized deuteron targets.

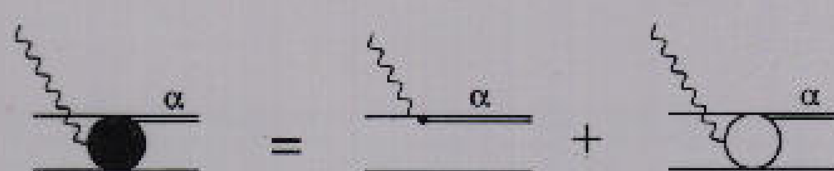
Important assumption:

> Spin asymmetry is dominated by the **quasifree process**, i.e. binding and final state effects can be neglected.

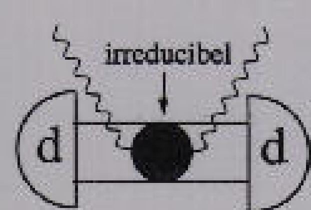
Diagrammatic representation of forward Compton scattering off deuteron:



with



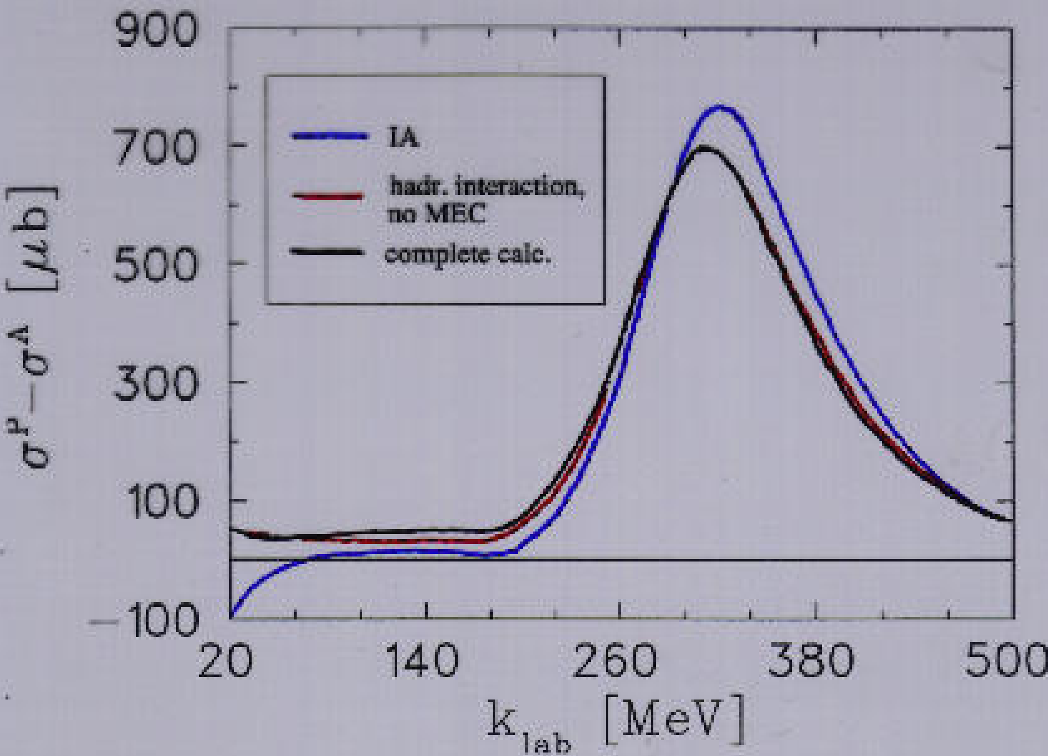
Neglected **diagram**:



Present calculation contains the contributions of photodisintegration and coherent and incoherent pion production as well.

Result

Preliminary, because most of the Born terms of pion photoproduction are neglected at the moment:



Future improvements:

- Inclusion of neglected diagram (→ Born terms),
- Comparison with sum of proton and neutron spin asymmetries within the same model.

4. Summary and Outlook

- construction of model for hadronic and electromagnetic interactions considering **full** retardation in πNN-propagators and dynamical treatment of $N\Delta$-final state interaction
- *for the first time:* good description of total and differential cross sections in photodisintegration (within 5-10 %)
- impulse approximation not sufficient for GDH on the deuteron
- in future:
  - extension to related reactions in the two-nucleon-system, especially $d(e,e'N)N$ and pion production
  - conceptual improvements:
    * improvement of hadronic interaction

      ...