Pion induced dilepton production

TORIC, Crete

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Gy. Wolf

together with M. Zétényi

KFKI RMKI, Budapest

- Motivation
- Effective Lagrangian
- Preliminary results
- Summary

Introduction

Dileptons are good probe for the hot/dense medium

Experiment: HADES, DLS, CBM?

Theory

- We need a good knowledge of elementary processes
- The description of elementary NN data is not settled
- lot of freedom in the models, parameters are not well constrained
- we need predictions for πN

Dilepton production in NN collisions

Strategy 1: put the measured $NN \to NNe^+e^-$, $\pi^+\pi^- \to e^+e^-$ and the estimated cross secton for the secondaries to a transport and obtain the HIC result.

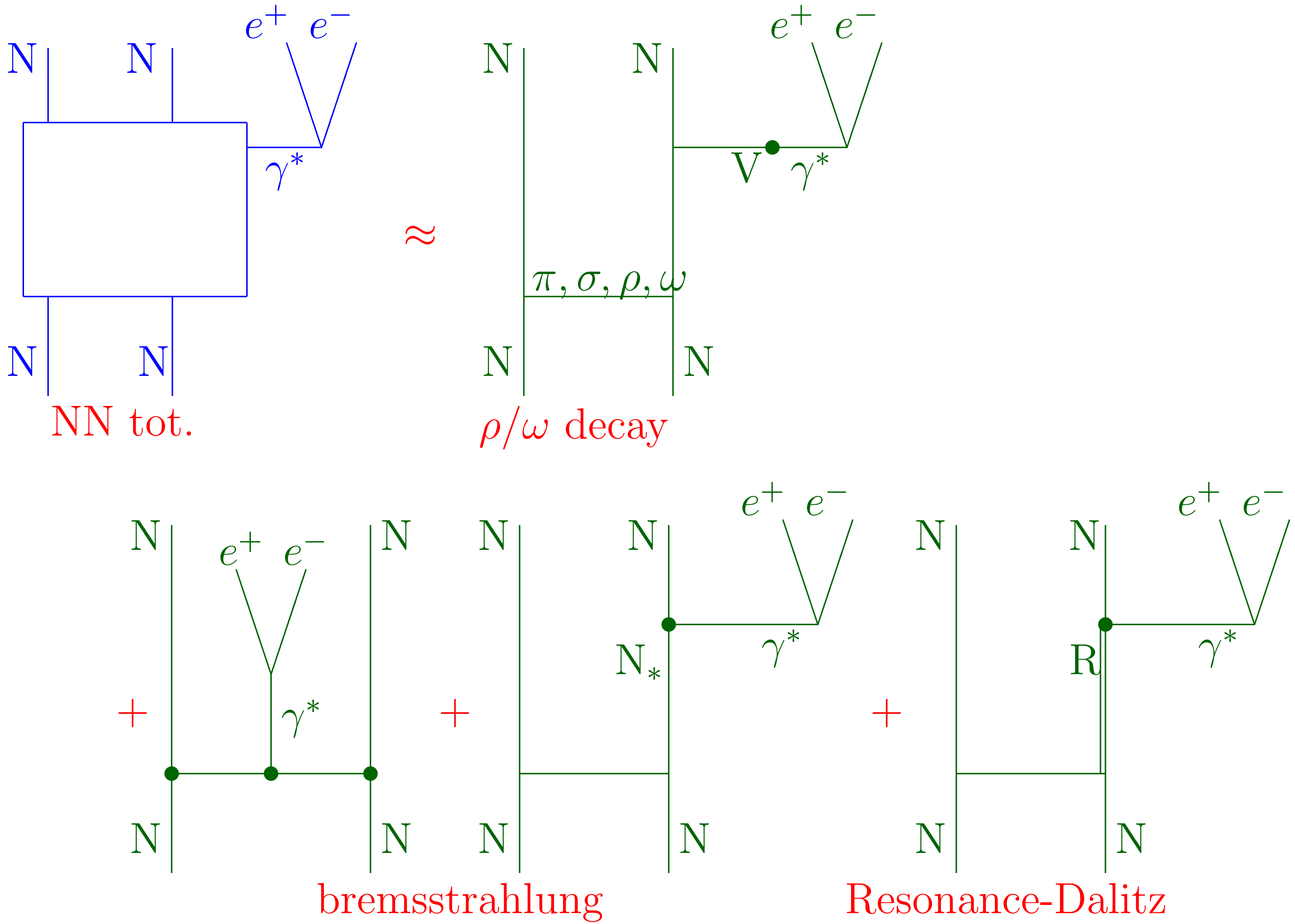
Problem: Hunted in-medium effects are buried in the $NN \to NNe^+e^-$ cross section

Strategy 2: microscopic understanding of channels contributing to $NN \to NNe^+e^-$

OBE: meson-nucleon couplings determined from elastic NN scat. energy dependent couplings

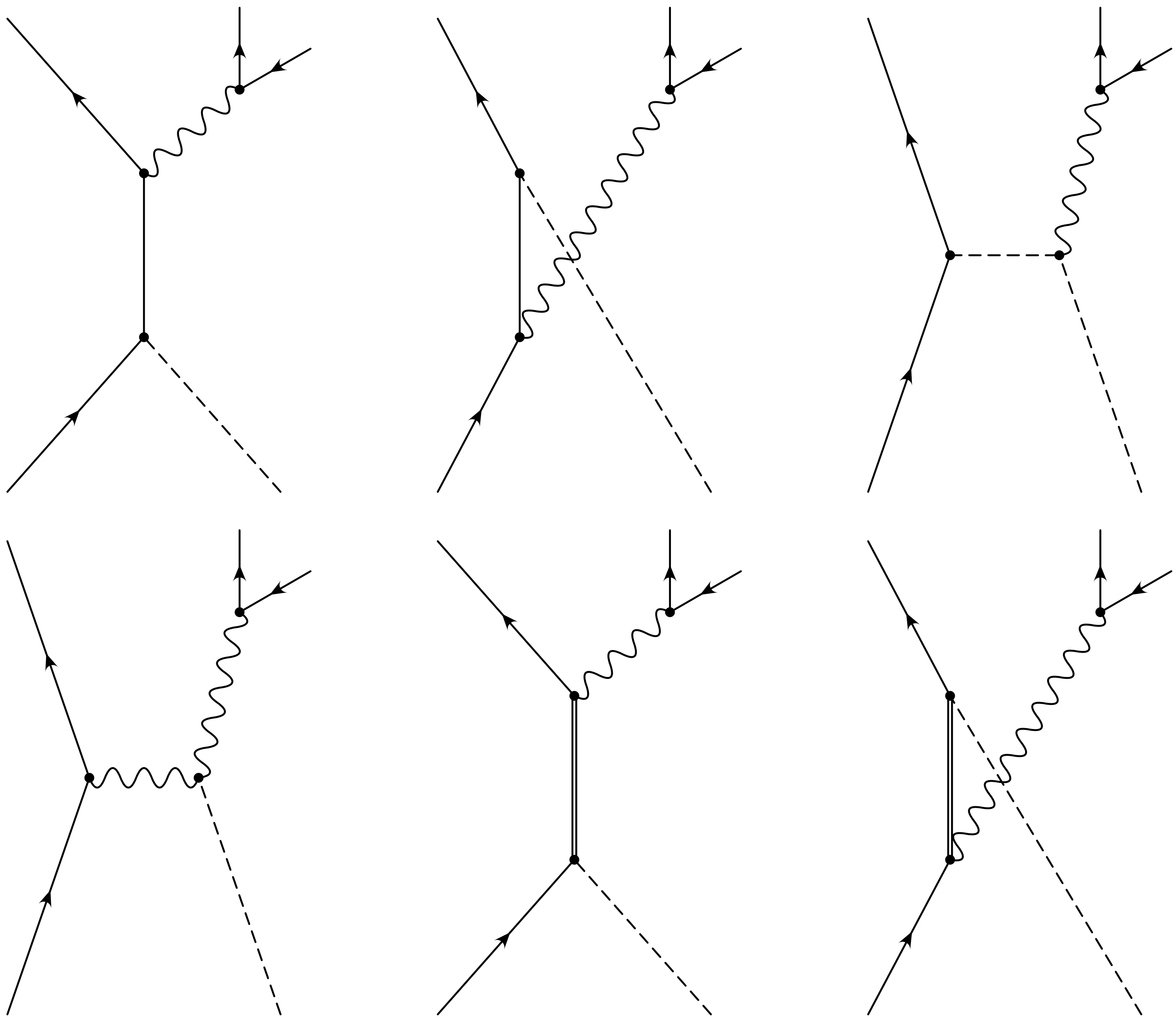
- L.P. Kaptari, B. Kämpfer, Nucl. Phys. A **764** (2006) 338.
- R. Shyam, U. Mosel, Phys. Rev. C**67** (2003) 065202, C**79** (2009) 035203, nucl-th:1006.3873

Dilepton production in OBE

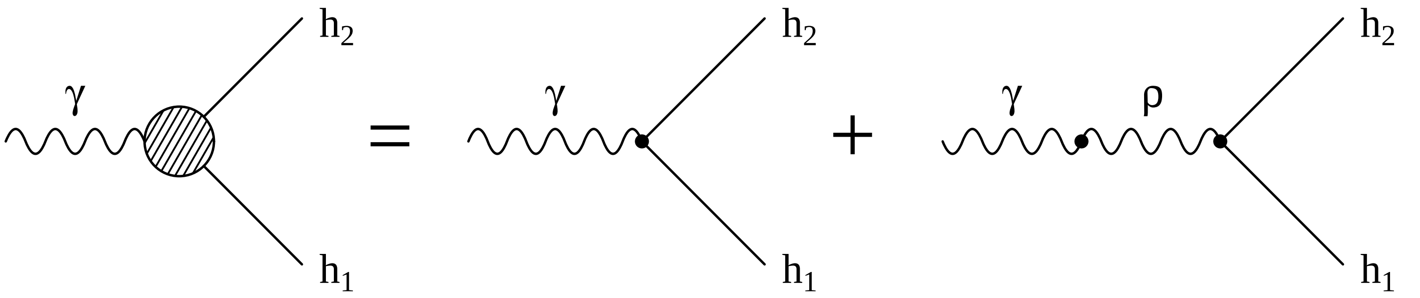


Feynman diagrams contributing to the process

$$\pi + N \rightarrow N + e^+e^-$$



Vector meson dominance



- $\mathcal{L}_{VDM1} = -\frac{em_\rho^2}{g_\rho}\rho_\mu^0 A^\mu$
  The width of $R \to N\gamma$ and $R \to N\rho$ are not independent photons from ρ (ρ-width taken from PDG) already overestimate the γ-width

- $\mathcal{L}_{VMD2} = -\frac{e}{2g_\rho}F^{\mu\nu}\rho_{\mu\nu}^0$
  From ρ-width the contribution to the photonic decay can be obtained by multiplying it with $\frac{e}{g_\rho}\frac{k^2}{m_\rho^2 - k^2 - iq\Gamma_\rho(k^2)}$
  Decay through ρ does not contribute to the real photonic width.
  We use VMD2. The final result depend on the choice, the ratio: M_{dil}^2/m_ρ^2

Dalitz-decay of baryon resonances

$$\frac{d\Gamma_{R\to Ne^+e^-}}{dM^2} = \frac{\alpha}{3\pi}\frac{1}{M^2}\Gamma_{R\to N\gamma}(M).$$

$$\Gamma_{R\to N\gamma}(M) = \frac{\sqrt{\lambda(m_*^2, m^2, M^2)}}{16\pi m_*^3}\frac{1}{n_{pol,R}}\sum_{pol}|\langle N\gamma|T|R\rangle|^2,$$

- spin-J fermion, $J \geq 3/2$: Rarita-Schwinger spinor-tensor field

$$\begin{aligned} u^{\cdots\rho_i\cdots\rho_k\cdots}(p_*, \lambda_*) &= u^{\cdots\rho_k\cdots\rho_i\cdots}(p_*, \lambda_*), \\ u^{\cdots\sigma\cdots}{}_{\sigma}{}^{\cdots}(p_*, \lambda_*) &= u^{\cdots\sigma\cdots}(p_*, \lambda_*)p_{*\sigma} = u^{\cdots\sigma\cdots}(p_*, \lambda_*)\gamma_\sigma = 0, \end{aligned}$$

Zétényi, Wolf, Phys. Rev. C67 (2003) 044002; Heavy Ion Phys. 17 (2003) 27.

EM coupling of baryon resonances

- There are 3 independent tensor structures (for S$\geq 3/2$) for coupling of nucleon and Rarita-Schwinger spinors ($G = 1$ or γ_5):

$$\Gamma_{\mu\rho_1\cdots\rho_n} = \sum_{i=1}^{3} f_i(q^2 = M^2)\chi^i_{\mu\rho_1} p_{\rho_2}\cdots p_{\rho_n} G,$$

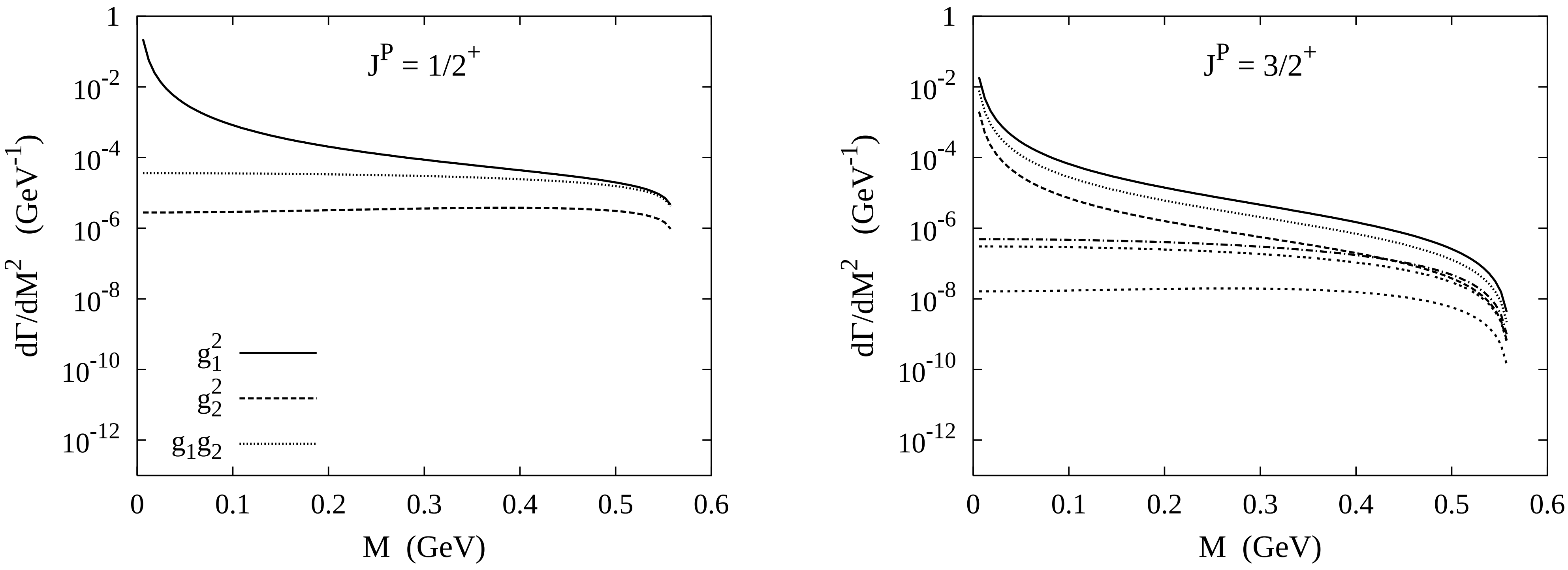
with

$$\chi^1_{\mu\rho} = \gamma_\mu q_\rho - \not{q} g_{\mu\rho},$$

$$\chi^2_{\mu\rho} = P_\mu q_\rho - (P\cdot q) g_{\mu\rho},$$

$$\chi^3_{\mu\rho} = q_\mu q_\rho - q^2 g_{\mu\rho},$$

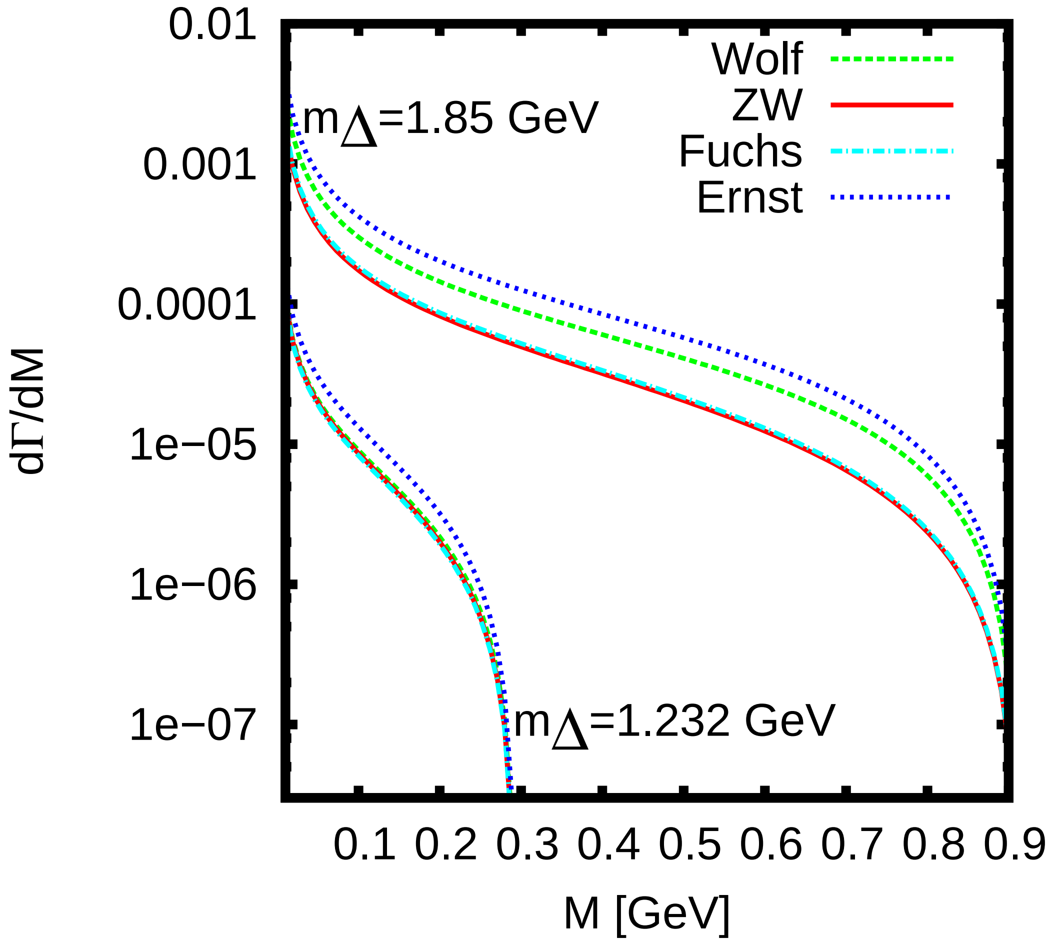
Dalitz-decay contributions



$m_* = 1.5$ GeV. Dimensionless coupling constants are set to 1.

In the S$= 1/2$ case g_2 and in the S$\geq 3/2$ case g_3 cannot be fixed at M=0, since their contributions there are identically 0.

$\Delta(1232)$



The Zétényi-Wolf results agree with the Tübingen ones (Fuchs).

Electromagnetic interaction of hadrons

For nucleons

$$\mathcal{L}_{NN\gamma} = -e\bar{\psi}_N \left[\frac{1+\tau_3}{2}\{\not{A} - (\kappa^s + \kappa^v\tau_3)\frac{\sigma_{\mu\nu}}{4m_N}F^{\mu\nu}\right]\psi_N$$

$$\mathcal{L}_{NN\rho} = -g_{NN\rho}\bar{\psi}_N\vec{\tau}\cdot\left(\vec{\not{\rho}} - \kappa_\rho\frac{\sigma_{\mu\nu}}{4m_N}\vec{\rho}^{\mu\nu}\right)\psi_N$$

For spin-1/2 nucleon resonances we use the Lagrangians

$$\mathcal{L}_{R_{1/2}N\gamma} = \frac{g_{RN\gamma}}{2m_\rho}\bar{\psi}_R\sigma^{\mu\nu}\Gamma\psi_N F_{\mu\nu} + \text{h.c.}$$

$$\mathcal{L}_{R_{1/2}N\rho} = \frac{g_{RN\rho}}{2m_\rho}\bar{\psi}_R\vec{\tau}\sigma^{\mu\nu}\Gamma\psi_N\cdot\vec{\rho}_{\mu\nu} + \text{h.c.}$$

For spin-3/2 nucleon resonances the corresponding Lagrangians are

$$\mathcal{L}_{R_{3/2}N\gamma} = -\frac{ig_{RN\gamma}}{m_\rho}\bar{\psi}^\mu_R\gamma^\nu\Gamma\psi_N F_{\mu\nu} + \text{h.c.}$$

$$\mathcal{L}_{R_{3/2}N\rho} = -\frac{ig_{RN\rho}}{m_\rho}\bar{\psi}^\mu_R\vec{\tau}\gamma^\nu\Gamma\psi_N\cdot\vec{\rho}_{\mu\nu} + \text{h.c.}$$

and for spin-5/2 nucleon resonances we use

$$\mathcal{L}_{R_{5/2}N\gamma} = -\frac{ig_{RN\gamma}}{m_\rho}\bar{\psi}^{\mu\rho}_R\gamma^\nu\Gamma(\partial_\rho\psi_N)F_{\mu\nu} + \text{h.c.}$$

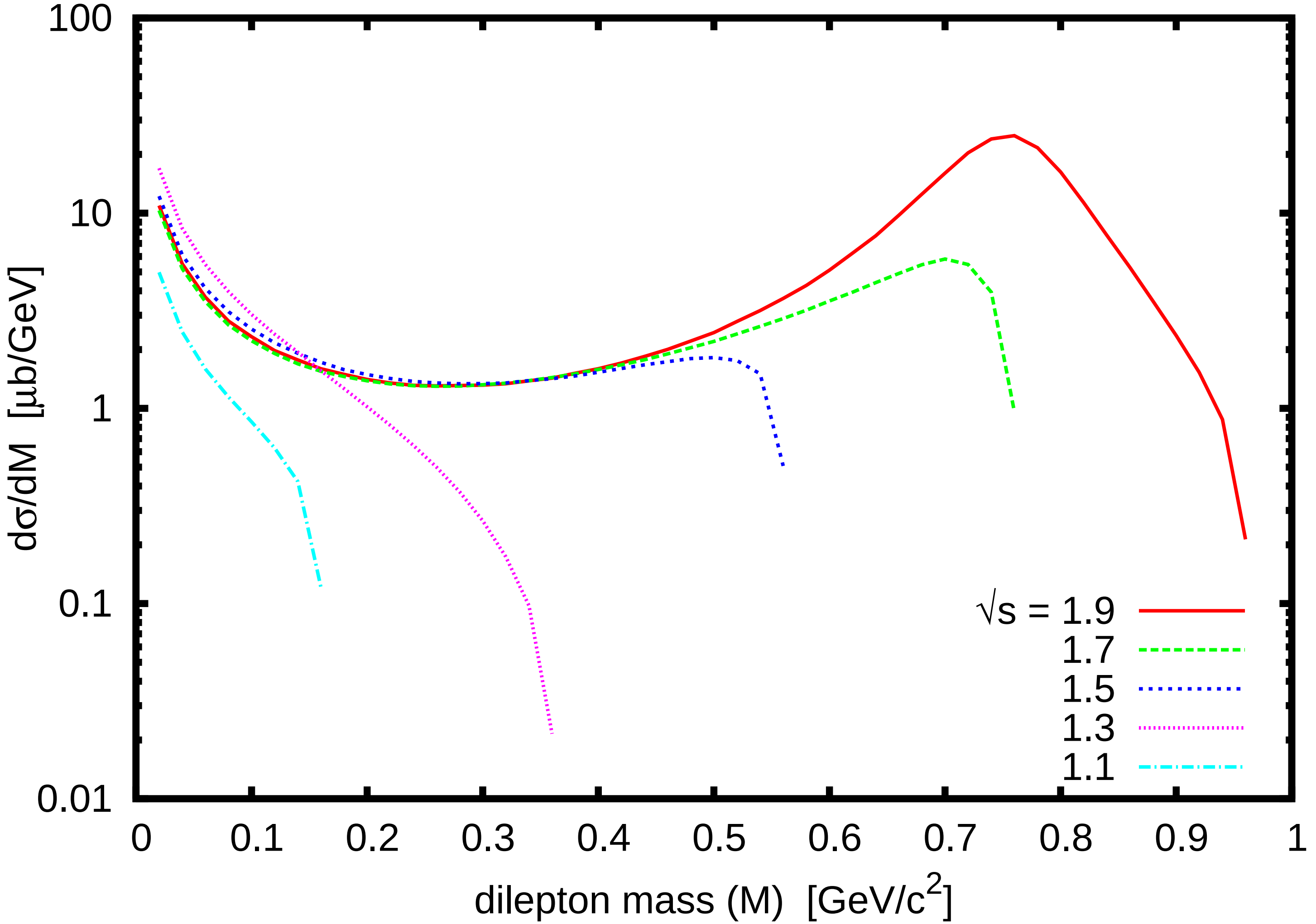
$$\mathcal{L}_{R_{5/2}N\rho} = -\frac{ig_{RN\rho}}{m_\rho}\bar{\psi}^{\mu\rho}_R\vec{\tau}\gamma^\nu\Gamma(\partial_\rho\psi_N)\cdot\vec{\rho}_{\mu\nu} + \text{h.c.}$$

For pions

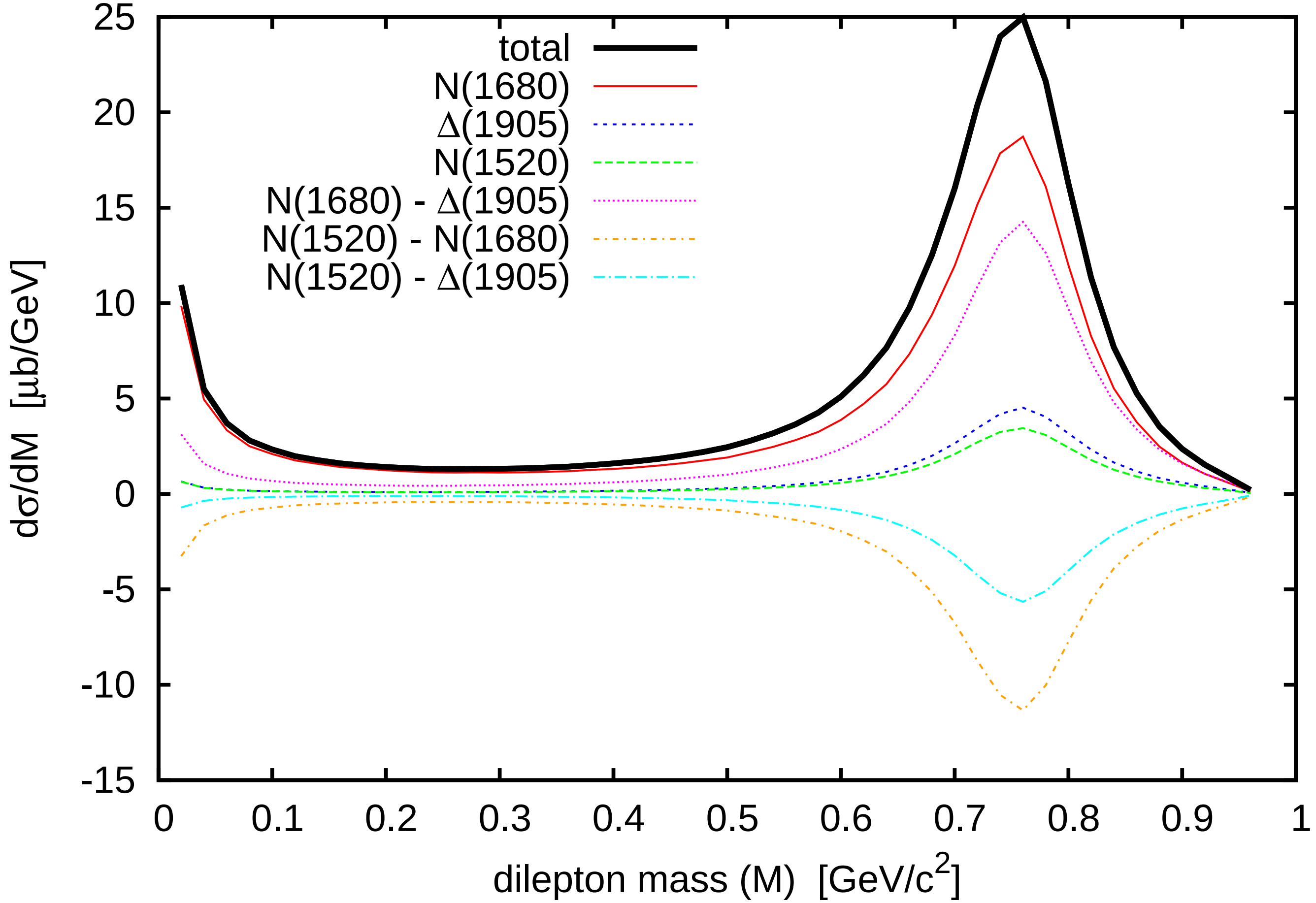
$$\mathcal{L}_{\gamma\pi\pi} = -eA_\mu J^\mu_\pi \qquad \mathcal{L}_{\rho\pi\pi} = -g_{\rho\pi\pi}\left[(\partial^\mu\vec{\pi})\times\vec{\pi}\right]\cdot\vec{\rho}_\mu$$

Results

Dilepton yield at different (1.1-1.9 GeV) pion energies

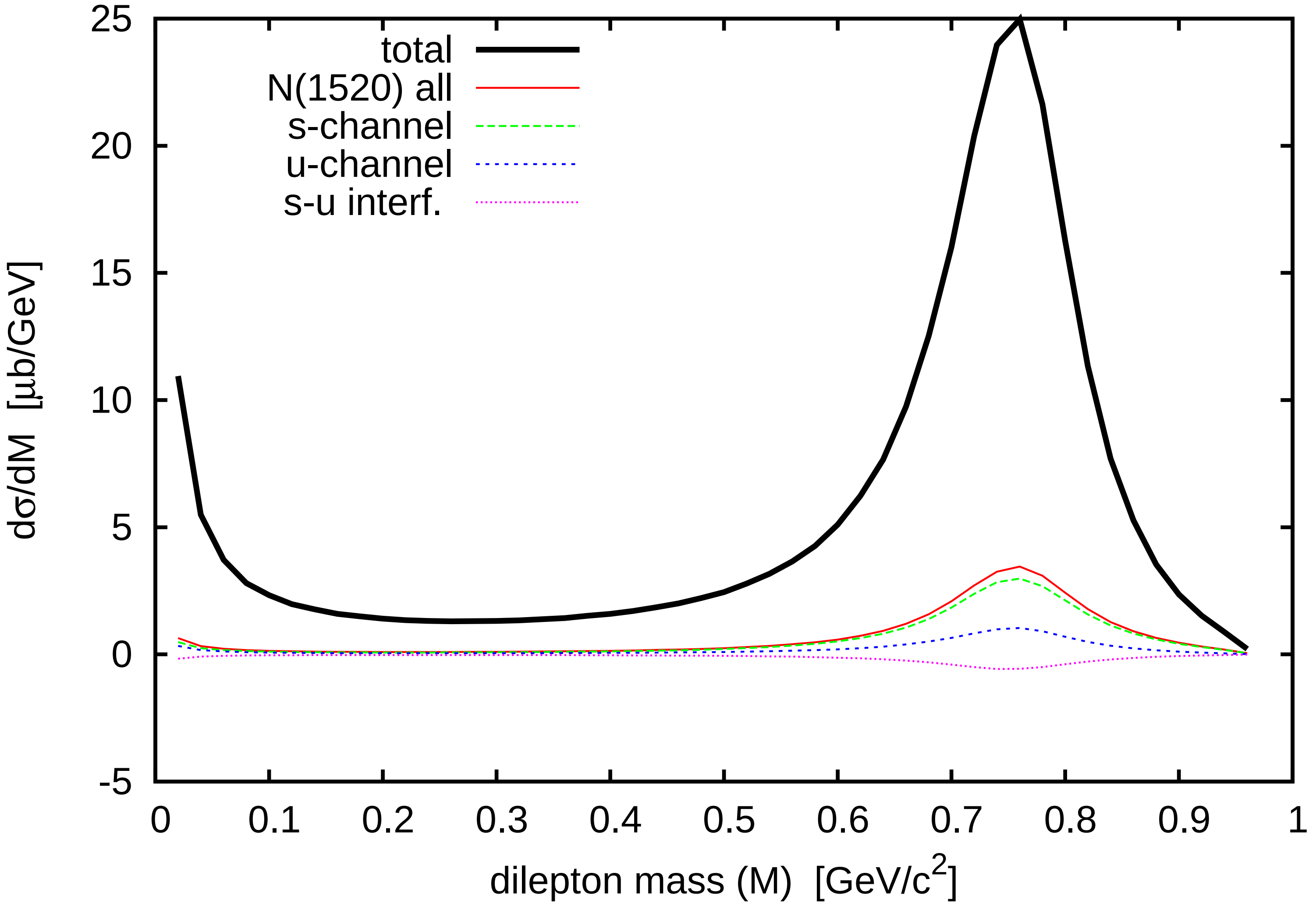


Interference between resonances



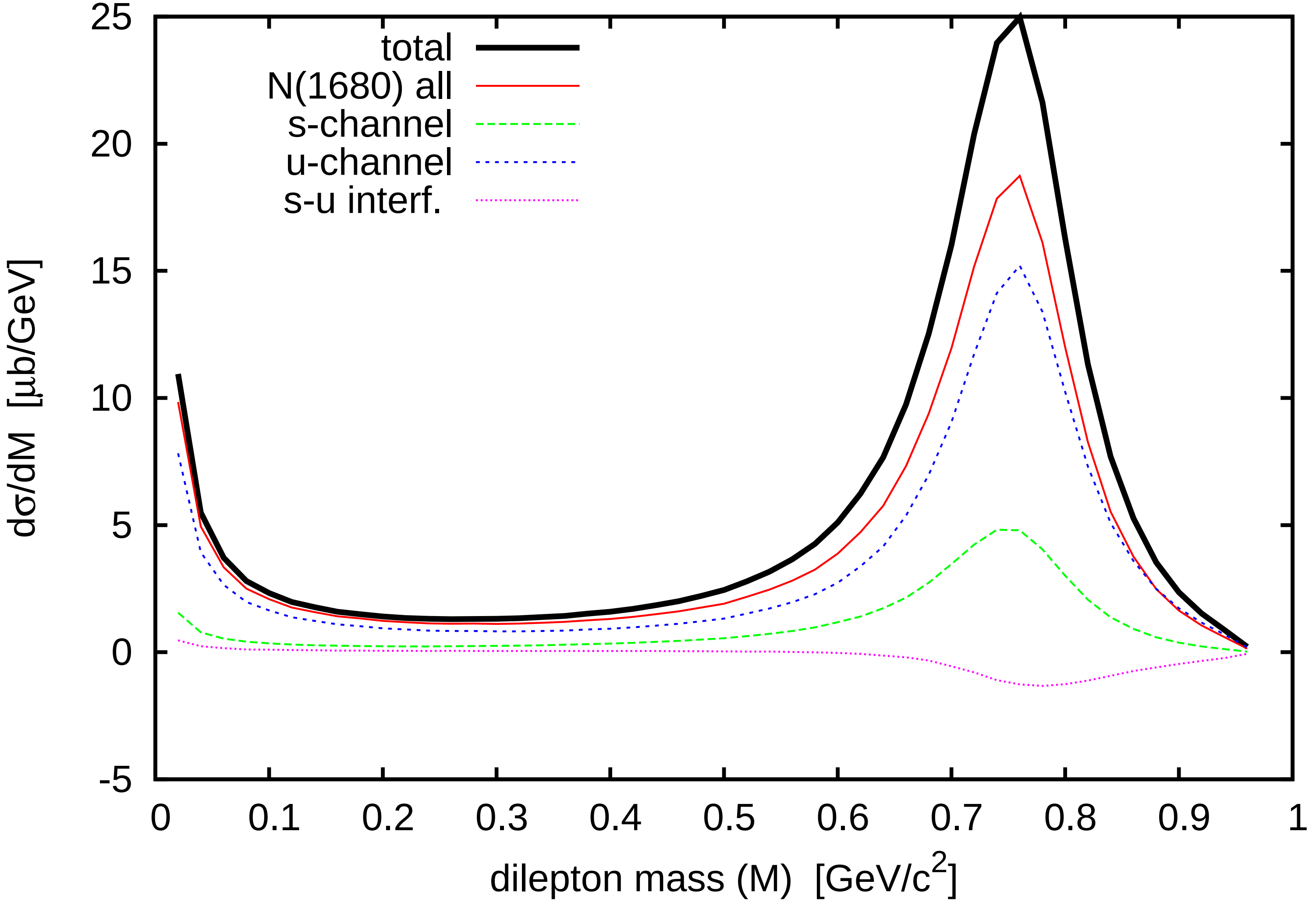
The main contributions come from N(1680),Δ(1905) 5/2 spin resonances and from the N(1520) 3/2 spin resonance.

Contribution of N(1520)
interference between u and s channels



cut-off is introduced to suppress u-graphs for $\gamma N \rightarrow N\pi$.

Contribution of N(1680)
interference between u and s channels



same cut-off is used as for lower spins to suppress u-graphs.

It seems for 5/2 states this suppression should be larger.

Summary

- Lot of uncertainties even on the level of the model
- interference effects are important
- u-diagrams cannot be neglected (as was shown in photon induced reactions, too)
- global fit to gamma induced pion production is needed (sign problem, u channel problem)

Effective interactions

$$\mathcal{L}_{NN\pi} = ig_{NN\pi}\bar{\psi}\gamma_5\vec{\tau}\psi \cdot \vec{\pi}.$$

$$\mathcal{L}_{\rho\pi\gamma} = e\frac{g_{\rho\pi\gamma}}{4m_\pi}\tilde{F}_{\mu\nu}\vec{\rho}^{\mu\nu} \cdot \vec{\pi}.$$

we employ ps couplings in the case of spin-1/2 nucleon resonances,

$$\mathcal{L}_{R_{1/2}N\pi} = ig_{RN\pi}\bar{\psi}_R\tilde{\Gamma}\vec{\tau}\psi_N \cdot \vec{\pi} + \text{h.c.}.$$

In the spin-3/2 case we use the Lagrangian

$$\mathcal{L}_{R_{3/2}N\pi} = \frac{g_{RN\pi}}{m_\pi}\bar{\psi}^\mu_R\tilde{\Gamma}\vec{\tau}\psi_N \cdot \partial_\mu\vec{\pi} + \text{h.c.},$$

while in the spin-5/2 case the Lagrangian

$$\mathcal{L}_{R_{5/2}N\pi} = \frac{g_{RN\pi}}{m_\pi}\bar{\psi}^{\mu\nu}_R\tilde{\Gamma}\vec{\tau}\psi_N \cdot \partial_\mu\partial_\nu\vec{\pi} + \text{h.c.}.$$

$\vec{\tau}$ is replaced by $\vec{T}$ in the case of Δ resonances.

Propagators

$$G^{\mu\nu}_{R_{3/2}}(p) = \frac{i}{p^2 - (m_R - i\Gamma_R(p^2)/2)^2} P^{\mu\nu}_{3/2}(p, m_R)$$

$$P^{\mu\nu}_{3/2}(p, m_R) = -(\not{p} + m_R)\left(g^{\mu\nu} - \frac{\gamma^\mu\gamma^\nu}{3} - \frac{2}{3}\frac{p^\mu p^\nu}{m_R^2} + \frac{p^\mu\gamma^\nu - p^\nu\gamma^\mu}{3m_R}\right).$$

On the mass-shell $P^{\mu\nu}_{3/2}(p, m_R)$ coincides with the spin-3/2 projector operator.

$$G^{\mu\nu,\rho\sigma}_{R_{5/2}}(p) = \frac{i}{p^2 - (m_R - i\Gamma_R(p^2)/2)^2} P^{\mu\nu,\rho\sigma}_{5/2}(p, m_R),$$

$$\begin{aligned} P^{\mu\nu,\rho\sigma}_{5/2}(p, m_R) &= (\not{p} + m_R)\left[\frac{3}{10}\left(G^{\mu\rho}G^{\nu\sigma} + G^{\mu\sigma}G^{\nu\rho}\right) - \frac{1}{5}G^{\mu\nu}G^{\rho\sigma}\right. \\ &\left. -\frac{1}{10}\left(T^{\mu\rho}G^{\nu\sigma} + T^{\nu\sigma}G^{\mu\rho} + T^{\mu\sigma}G^{\nu\rho} + T^{\nu\rho}G^{\mu\sigma}\right)\right], \end{aligned}$$

$$G^{\mu\nu} = -g^{\mu\nu} + \frac{p^\mu p^\nu}{m_R^2},$$

$$T^{\mu\nu} = -\frac{1}{2}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu) + \frac{p^\mu\left(\not{p}\gamma^\nu - \gamma^\nu\not{p}\right)}{2m_R^2} - \frac{p^\nu\left(\not{p}\gamma^\mu - \gamma^\mu\not{p}\right)}{2m_R^2}.$$