The 2p -2h electromagnetic response in the quasielastic peak and beyond

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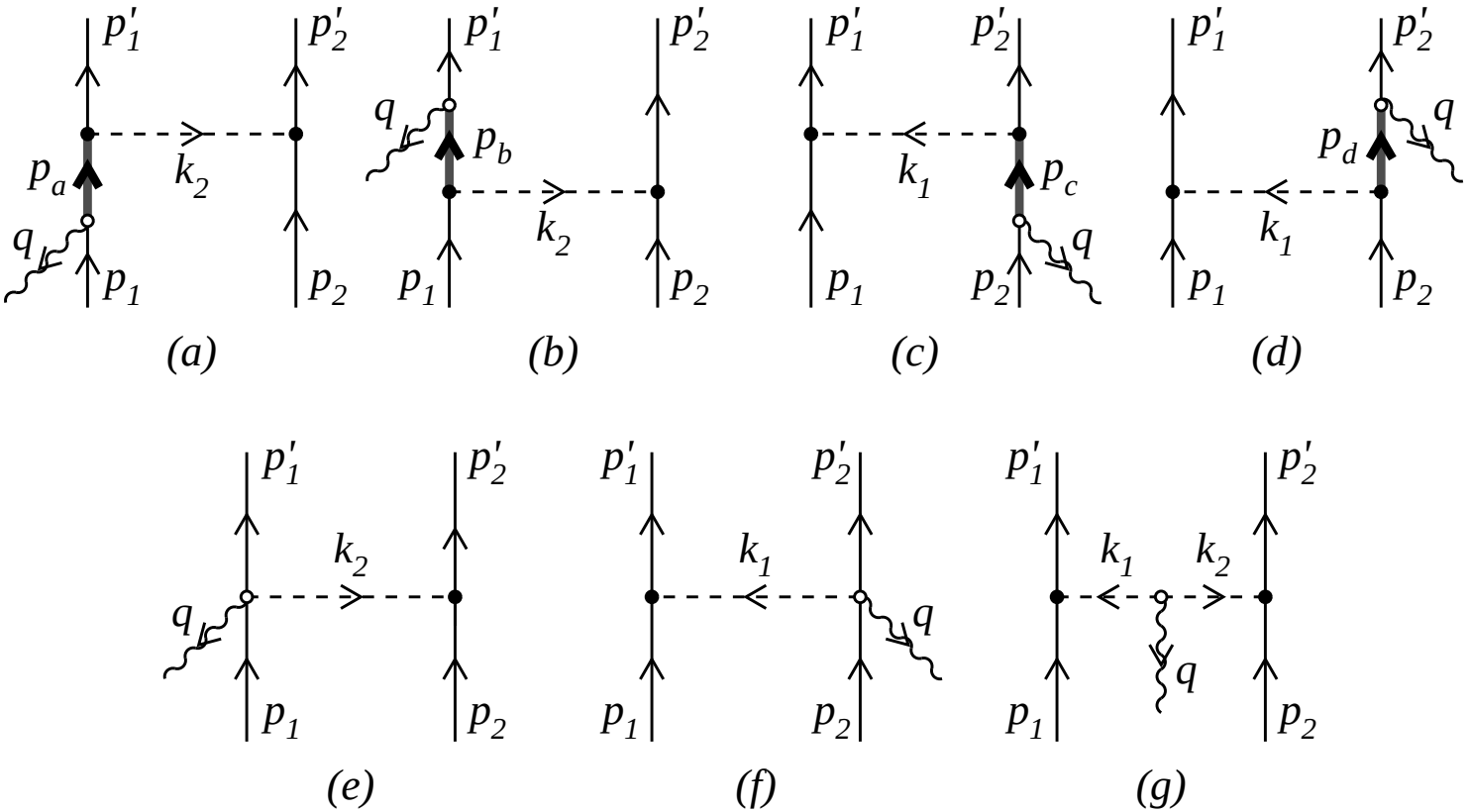
Overview

1. 2p-2h in electron scattering (so far)
   - 2p2h MEC
   - Currents
   - Transverse response
   - Non-relativistic response
   - Relativistic response

2. What else?
   - Correlations
   - and more

2p-2h MEC


p'_1
p'_2
p_a
k_2
q
p_1
p_2
(a)
p'_1
p'_2
q
p_b
k_2
p_1
p_2
(b)
p'_1
p'_2
k_1
p_c
q
p_1
p_2
(c)
p'_1
p'_2
p_d
q
k_1
p_1
p_2
(d)
p'_1
p'_2
k_2
q
p_1
p_2
(e)
p'_1
p'_2
k_1
q
p_1
p_2
(f)
p'_1
p'_2
k_1
k_2
q
p_1
p_2
(g)

Currents

pion-in-flight

$$\mathbf{J}^{\mu}_{f}(k_1,k_2) = -i\frac{1}{V^2}\frac{f^2_{\pi NN}f_{\gamma\pi\pi}}{\mu^2_{\pi}}(\boldsymbol{\tau}^{(1)}\times\boldsymbol{\tau}^{(2)})_3\Pi(k_1)_{(1)}\Pi(k_2)_{(2)}(k_2-k_1)^{\mu} \qquad \Pi(k)_{(i)} = \frac{(\not{k}\gamma^5)_{(i)}}{k^2-\mu^2_{\pi}}$$

contact

$$\mathbf{J}^{\mu}_{s}(k_1,k_2) = -i\frac{1}{V^2}\frac{f_{\pi NN}f_{\gamma\pi NN}}{\mu^2_{\pi}}(\boldsymbol{\tau}^{(1)}\times\boldsymbol{\tau}^{(2)})_3\left[\Pi(k_2)_{(2)}(\gamma^{\mu}\gamma^5)_{(1)}-\Pi(k_1)_{(1)}(\gamma^{\mu}\gamma^5)_{(2)}\right]$$

Δ

$$\begin{aligned}\mathbf{J}^{\mu}_{\Delta}(k_1,k_2) \quad = \quad & -\frac{1}{V^2}\frac{f_{\pi NN}f_{\pi N\Delta}f_{\gamma N\Delta}}{2M\mu^2_{\pi}}\left\{\left[\left(\frac{2}{3}\tau^{(2)}_3-\frac{i}{3}(\boldsymbol{\tau}^{(1)}\times\boldsymbol{\tau}^{(2)})_3\right)\left(j^{\mu}_{(a)}(p_a,k_2,q)\gamma_5\right)_{(1)}\right.\right.\\ & \left.\left.+\left(\frac{2}{3}\tau^{(2)}_3+\frac{i}{3}(\boldsymbol{\tau}^{(1)}\times\boldsymbol{\tau}^{(2)})_3\right)\left(\gamma_5 j^{\mu}_{(b)}(p_b,k_2,q)\right)_{(1)}\right]\Pi(k_2)_{(2)}+(1\leftrightarrow 2)\right\}.\end{aligned}$$

$$j_{(a)\mu}(p,k,q) = (4k_{\beta}-\not{k}\gamma_{\beta})S^{\beta\gamma}(p,M_{\Delta})\frac{1}{2}\left(-\gamma_{\mu}\not{q}\gamma_{\gamma}+q_{\mu}\gamma_{\gamma}\right)$$

$$j_{(b)\mu}(p,k,q) = \frac{1}{2}\left(-\gamma_{\beta}\not{q}\gamma_{\mu}+q_{\mu}\gamma_{\beta}\right)S^{\beta\gamma}(p,M_{\Delta})(4k_{\gamma}-\gamma_{\gamma}\not{k});$$

$$S^{\beta\gamma}(p,M_{\Delta}) = \frac{\gamma\cdot p+M_{\Delta}}{p^2-{M_{\Delta}}^2}\left(g^{\beta\gamma}-\frac{\gamma^{\beta}\gamma^{\gamma}}{3}-\frac{2p^{\beta}p^{\gamma}}{3{M_{\Delta}}^2}-\frac{\gamma^{\beta}p^{\gamma}-\gamma^{\gamma}p^{\beta}}{3M_{\Delta}}\right)$$

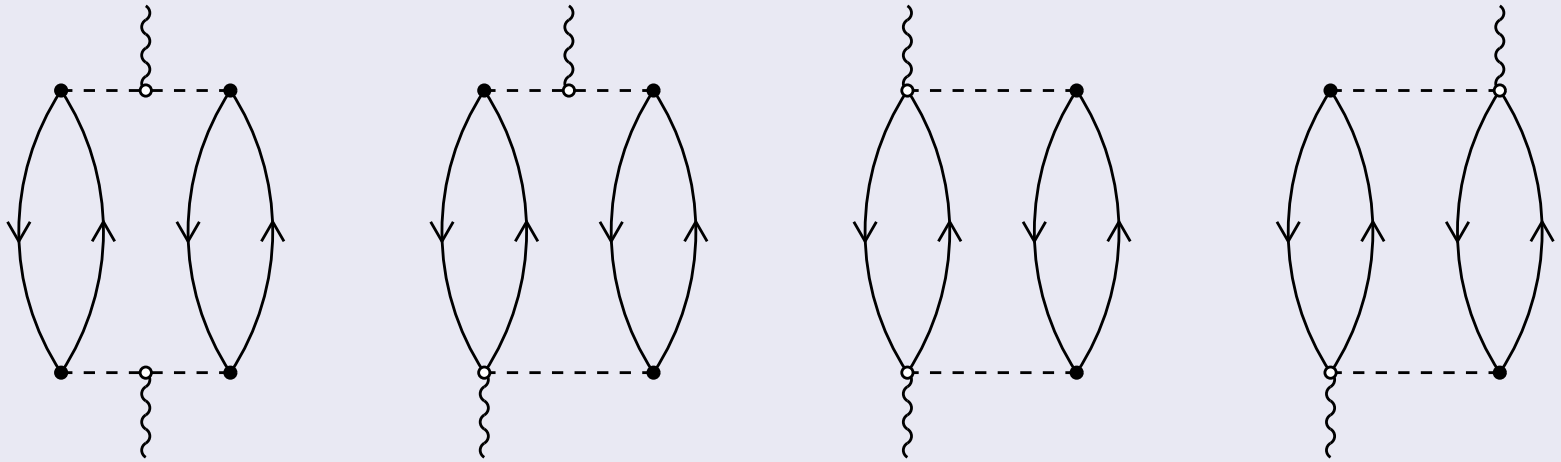
Response

Transverse response

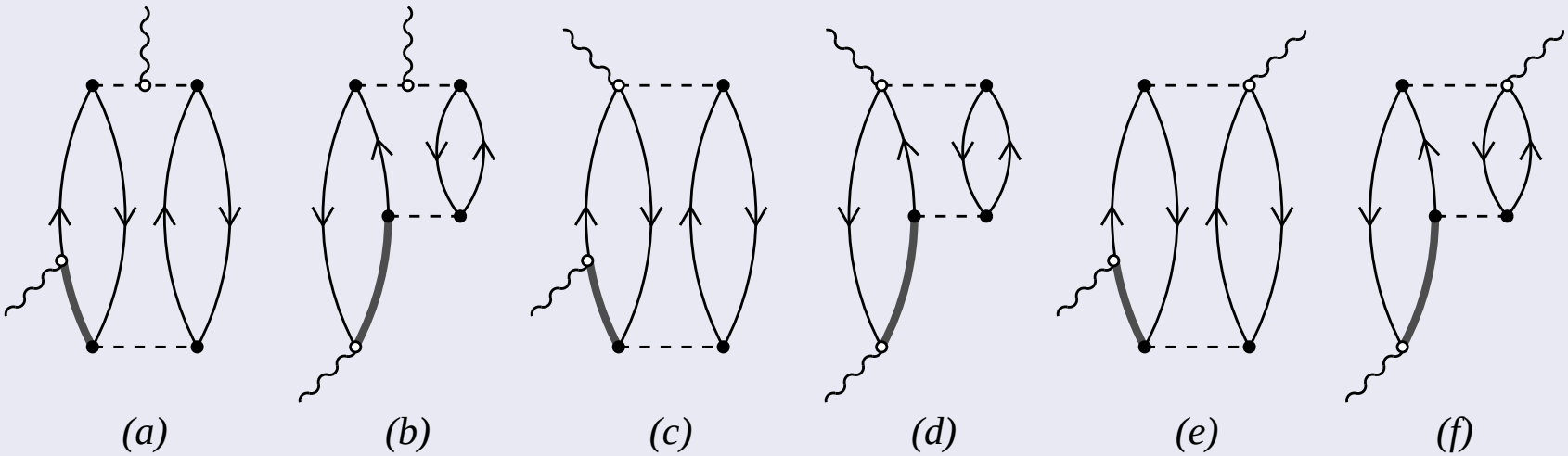
$$
\begin{aligned}
R_T(\mathbf{q},\omega) \quad = \quad & \frac{(2\pi)^3 V}{4}\frac{V^4}{(2\pi)^{12}}\int \frac{d\mathbf{p}_1'\, d\mathbf{p}_2'\, d\mathbf{p}_1\, d\mathbf{p}_2}{16 E_{\mathbf{p}_1'} E_{\mathbf{p}_2'} E_{\mathbf{p}_1} E_{\mathbf{p}_2}}\theta(|\mathbf{p}_1'|-k_F)\theta(|\mathbf{p}_2'|-k_F)\theta(k_F-|\mathbf{p}_1|) \\
& \times\theta(k_F-|\mathbf{p}_2|)\delta[\omega-(E_{\mathbf{p}_1'}+E_{\mathbf{p}_2'}-E_{\mathbf{p}_1}-E_{\mathbf{p}_2})]\delta^{(3)}(\mathbf{q}+\mathbf{p}_1'+\mathbf{p}_2'-\mathbf{p}_1-\mathbf{p}_2) \\
& \times 2\sum_{\sigma\tau}\sum_{i,j=1}^{3}\left(\delta_{ij}-\frac{q_i q_j}{\mathbf{q}^2}\right)\Big[J_i^\dagger(\mathbf{p}_1'-\mathbf{p}_1,\mathbf{p}_2'-\mathbf{p}_2)J_j(\mathbf{p}_1'-\mathbf{p}_1,\mathbf{p}_2'-\mathbf{p}_2) \\
& \qquad -J_i^\dagger(\mathbf{p}_1'-\mathbf{p}_1,\mathbf{p}_2'-\mathbf{p}_2)J_j(\mathbf{p}_1'-\mathbf{p}_2,\mathbf{p}_2'-\mathbf{p}_1)\Big]
\end{aligned}
$$

Response

direct pionic contributions

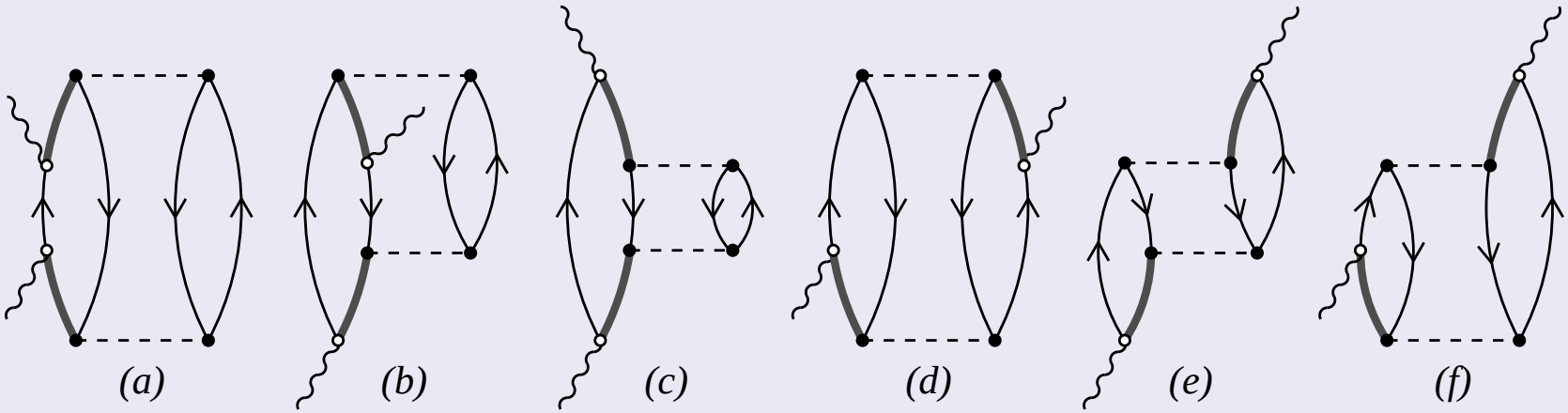


direct pionic-Δ interference contributions



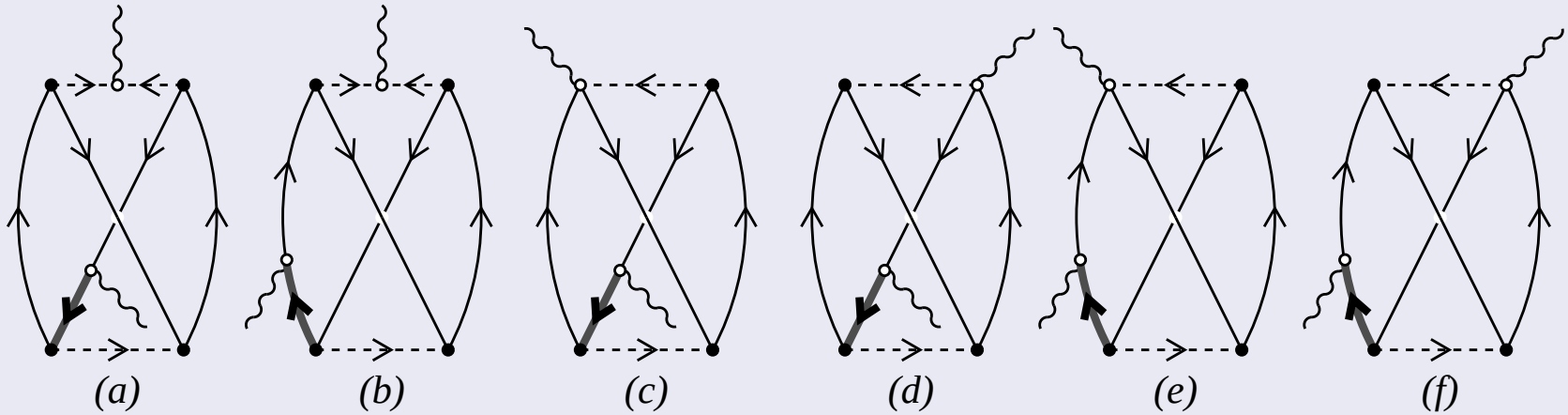
Response

direct Δ contributions

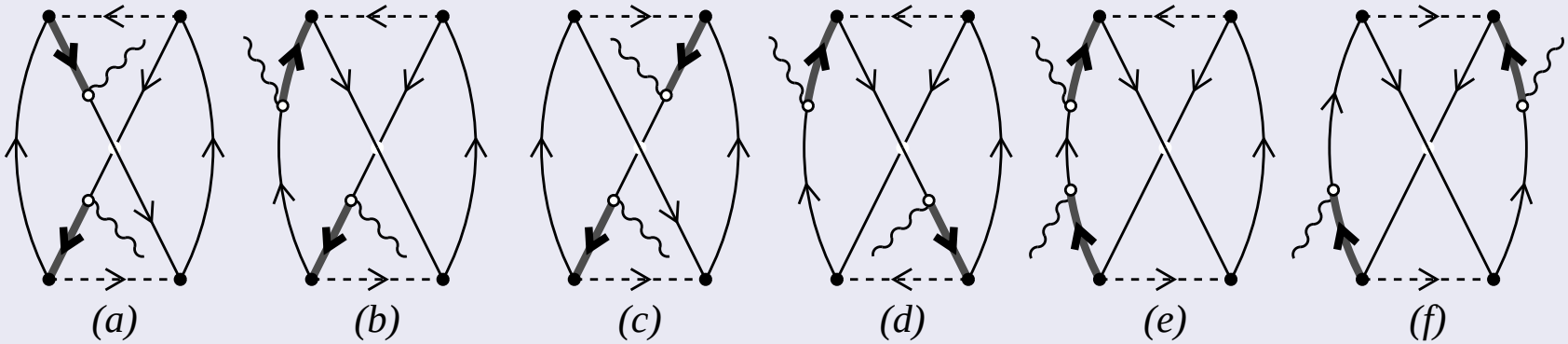


Response

exchange pionic-Δ interference contributions

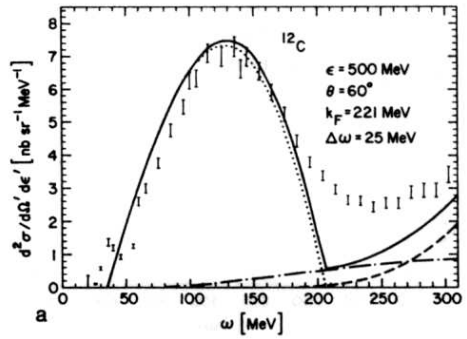


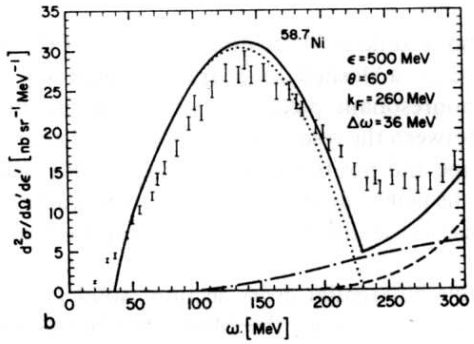
exchange Δ contributions

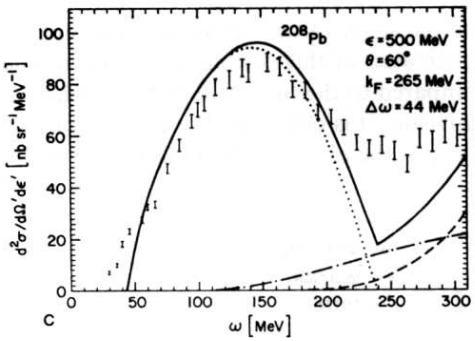


Non-relativistic response

J.W. Van Orden and T.W. Donnelly, Ann. Phys. 131 (1981) 451

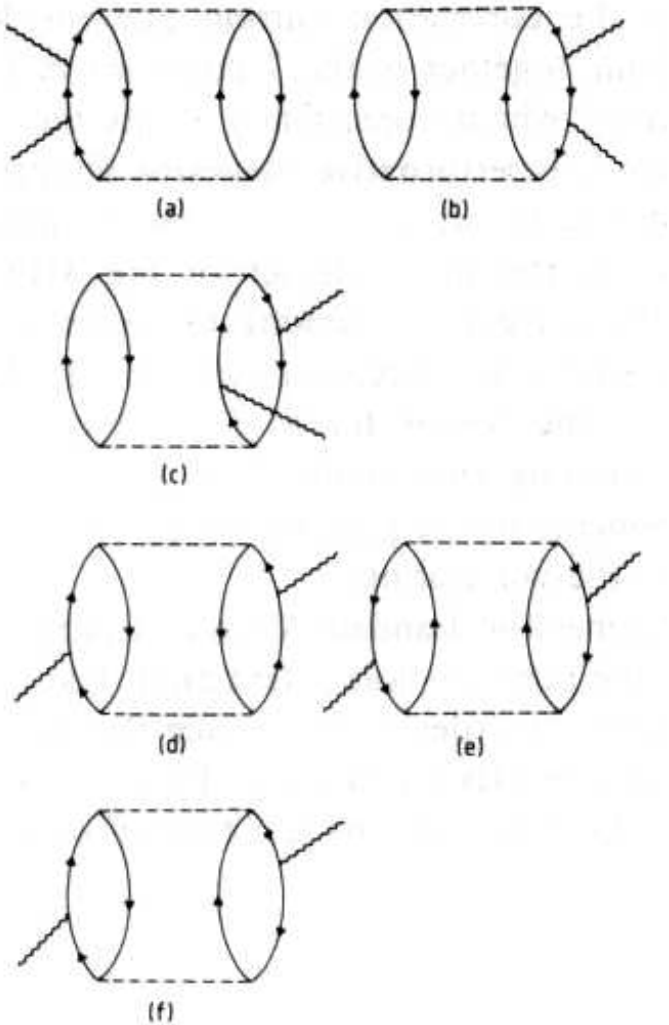






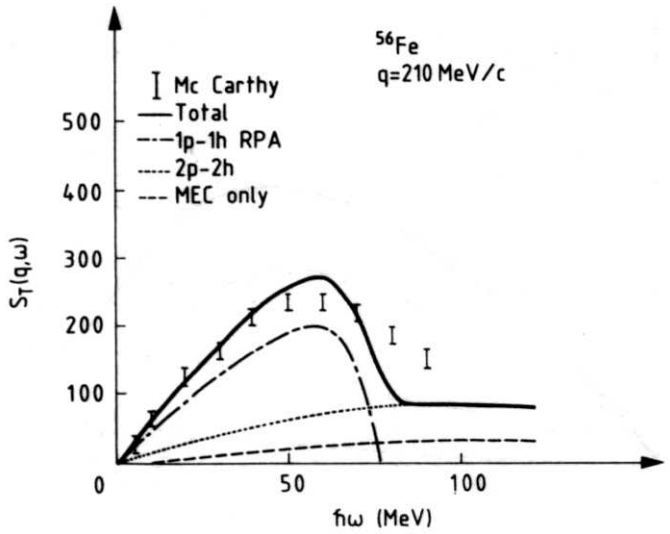
Non-relativistic response (correlations)

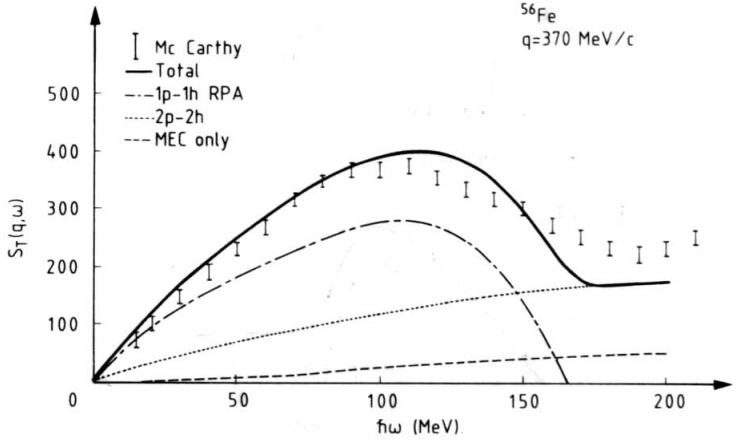
W.M. Alberico, M. Ericson and A. Molinari, Ann. Phys. 154 (1984) 356

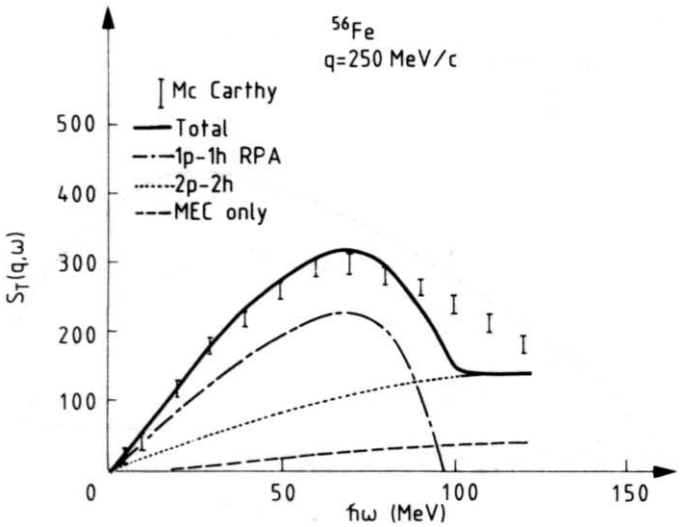


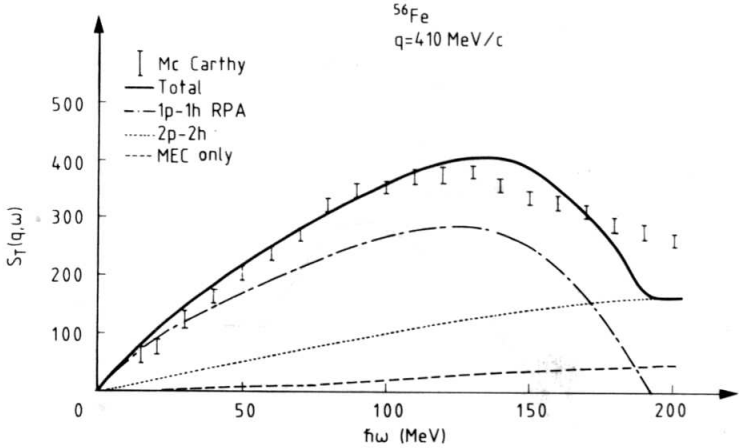
Non-relativistic response

W.M. Alberico, M. Ericson and A. Molinari, Ann. Phys. 154 (1984) 356





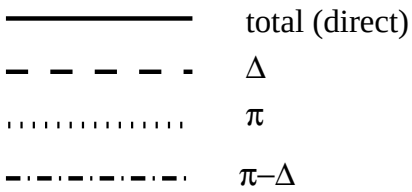


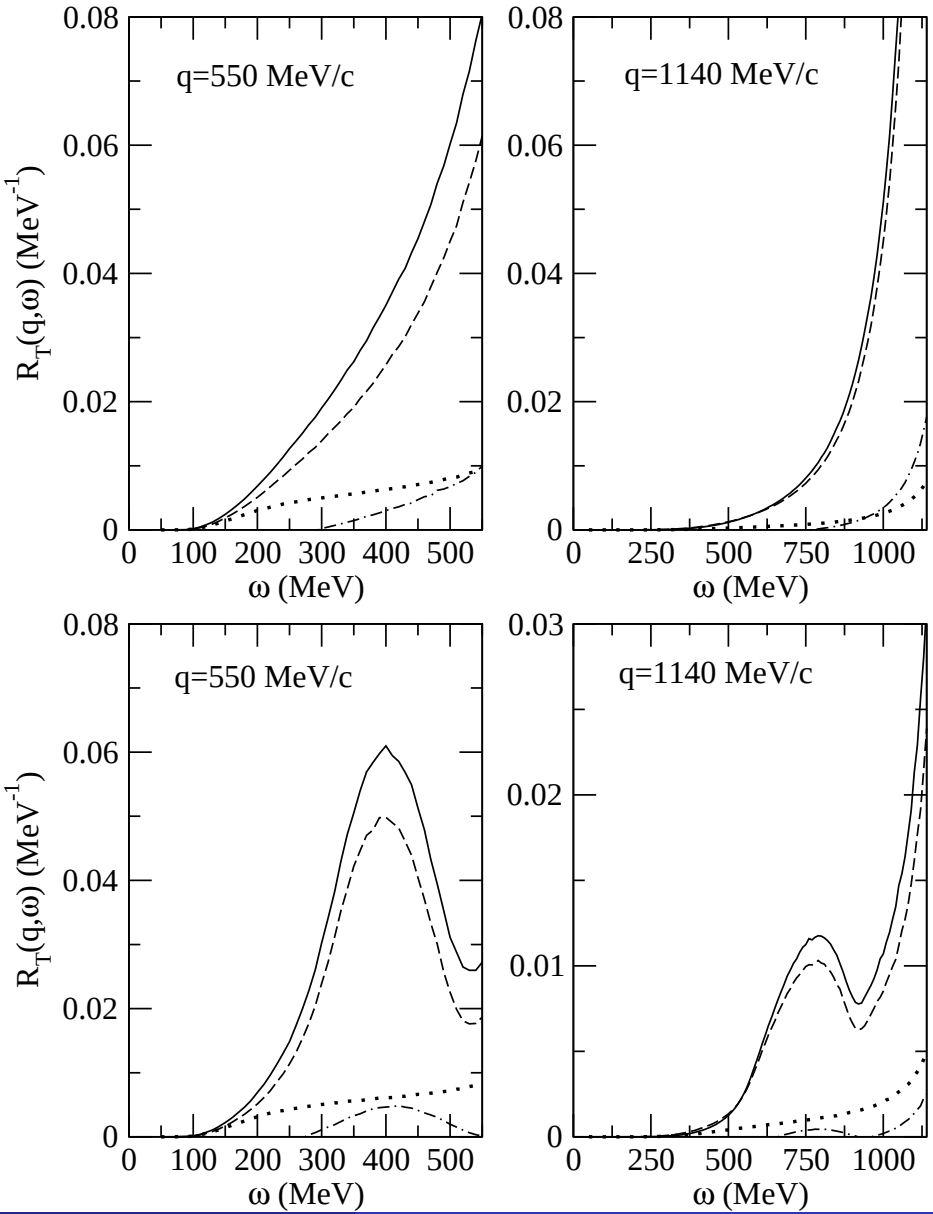


Response (relativistic vs non-relativistic)

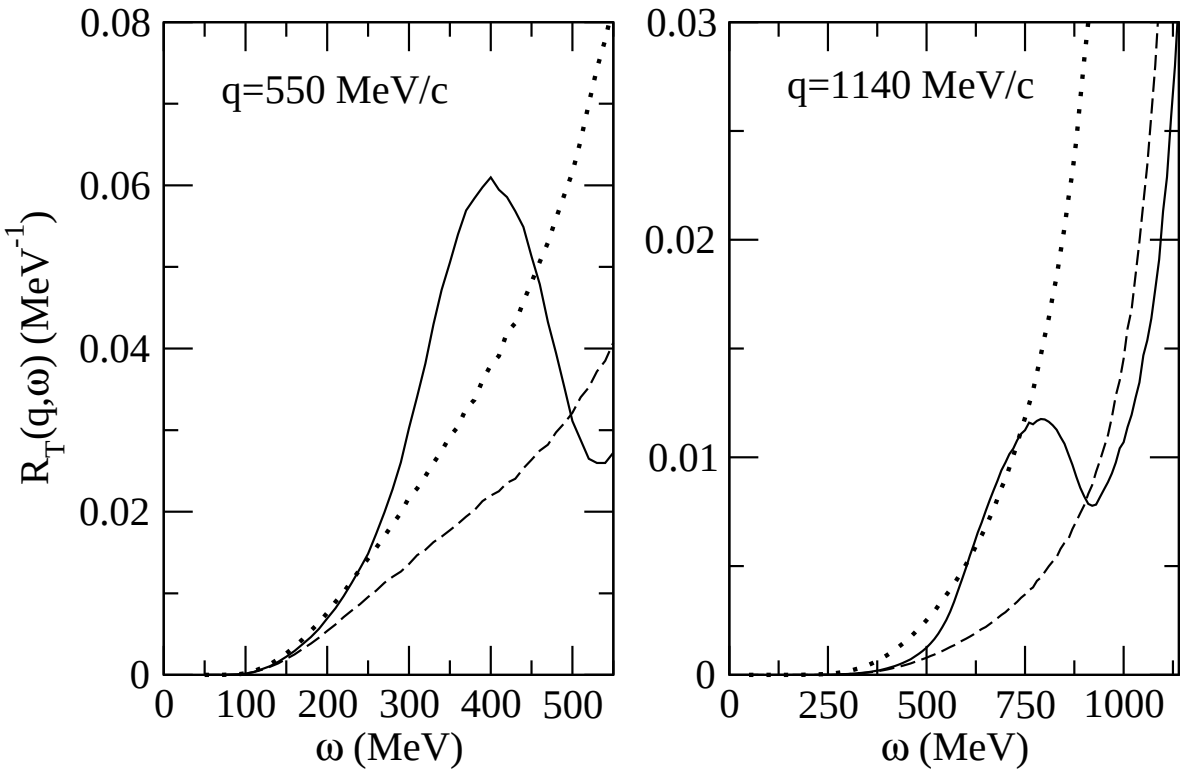
non-relativistic →

relativistic →





Response (Δ propagator)

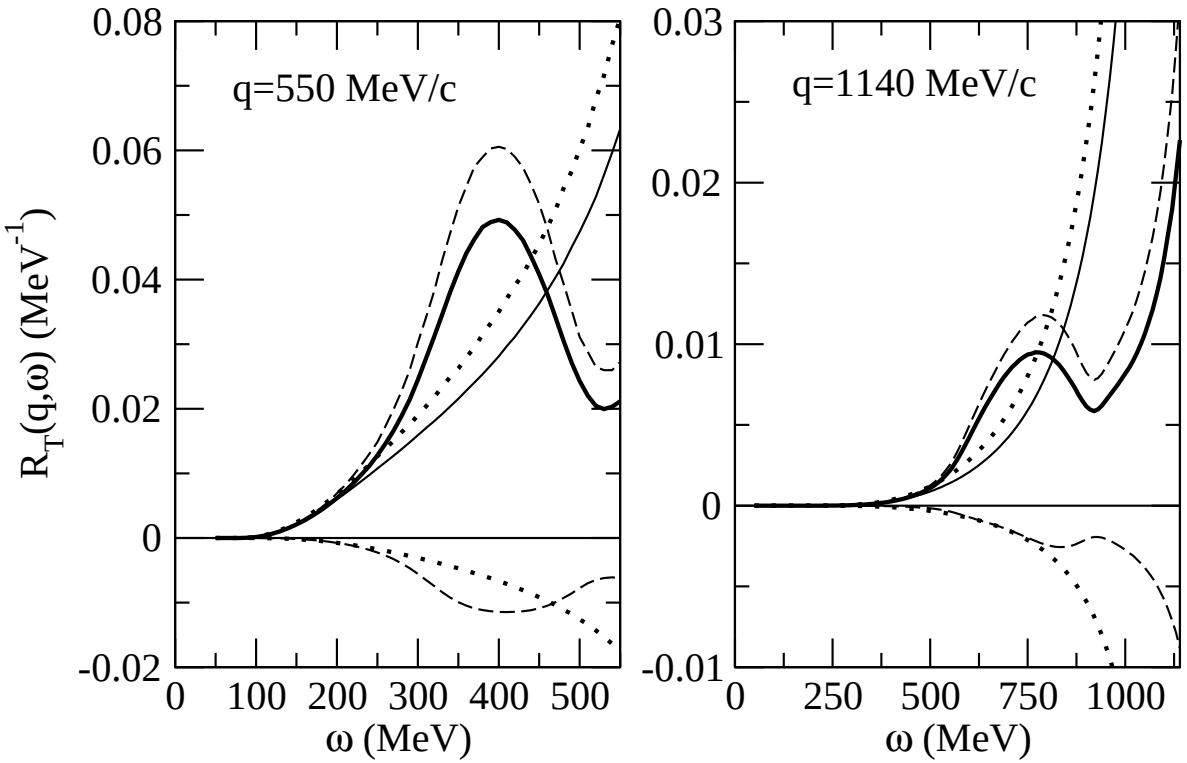


full Δ propagator

static Δ propagator

constant Δ propagator

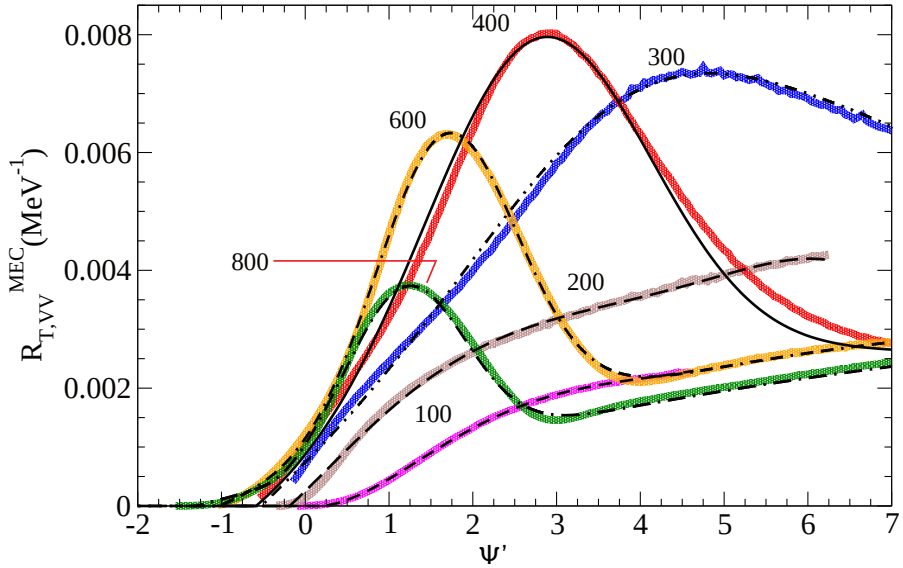
Response (exchange)

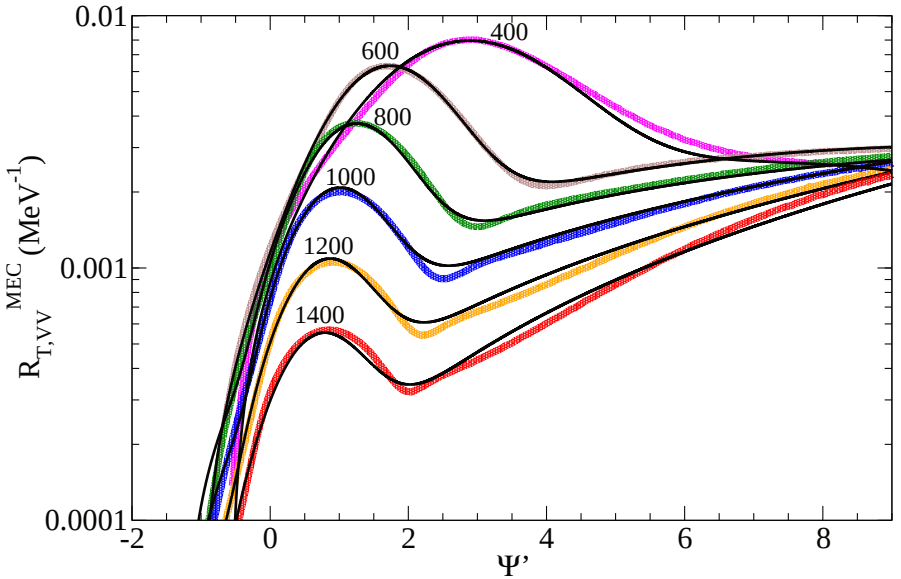


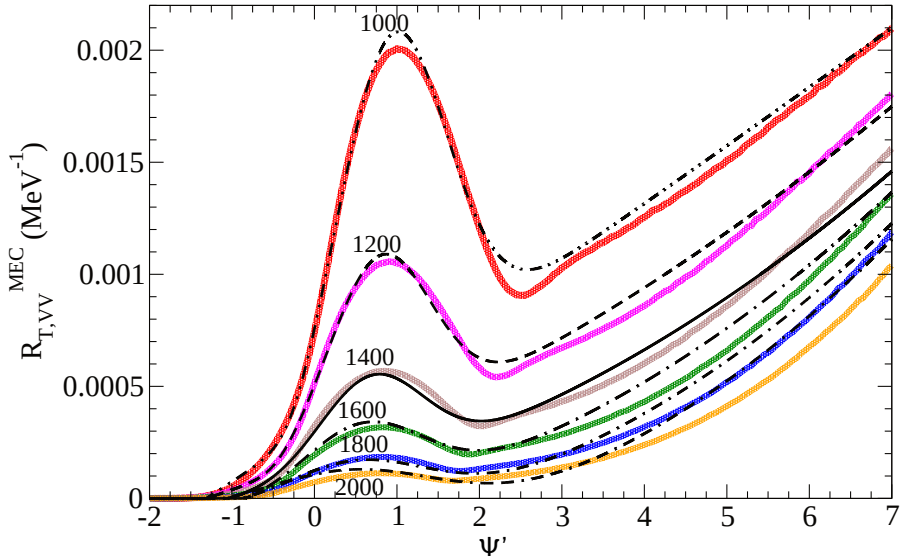
total (relativistic)
total (non−relativistic)
relativistic
non−relativistic

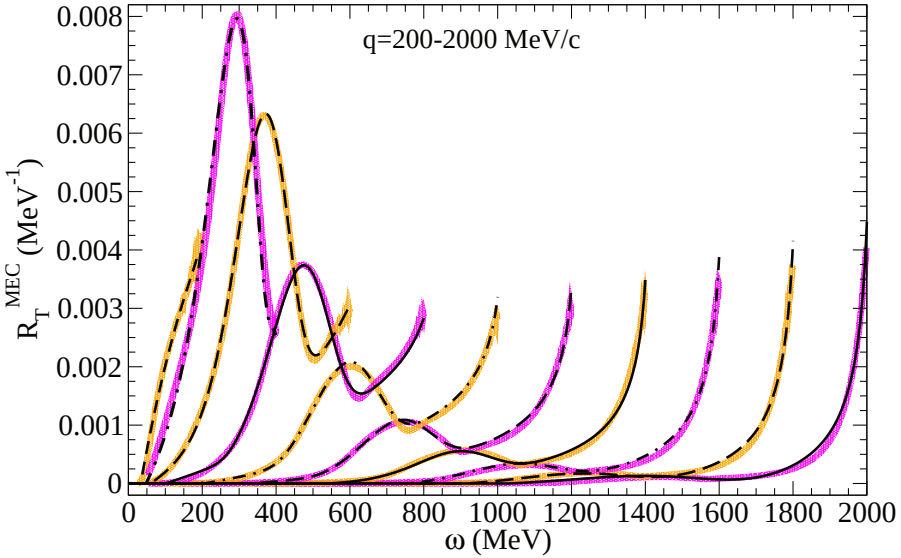
Response

G.D. Megias et al., Phys. Rev. D**91**, 073004 (2015)

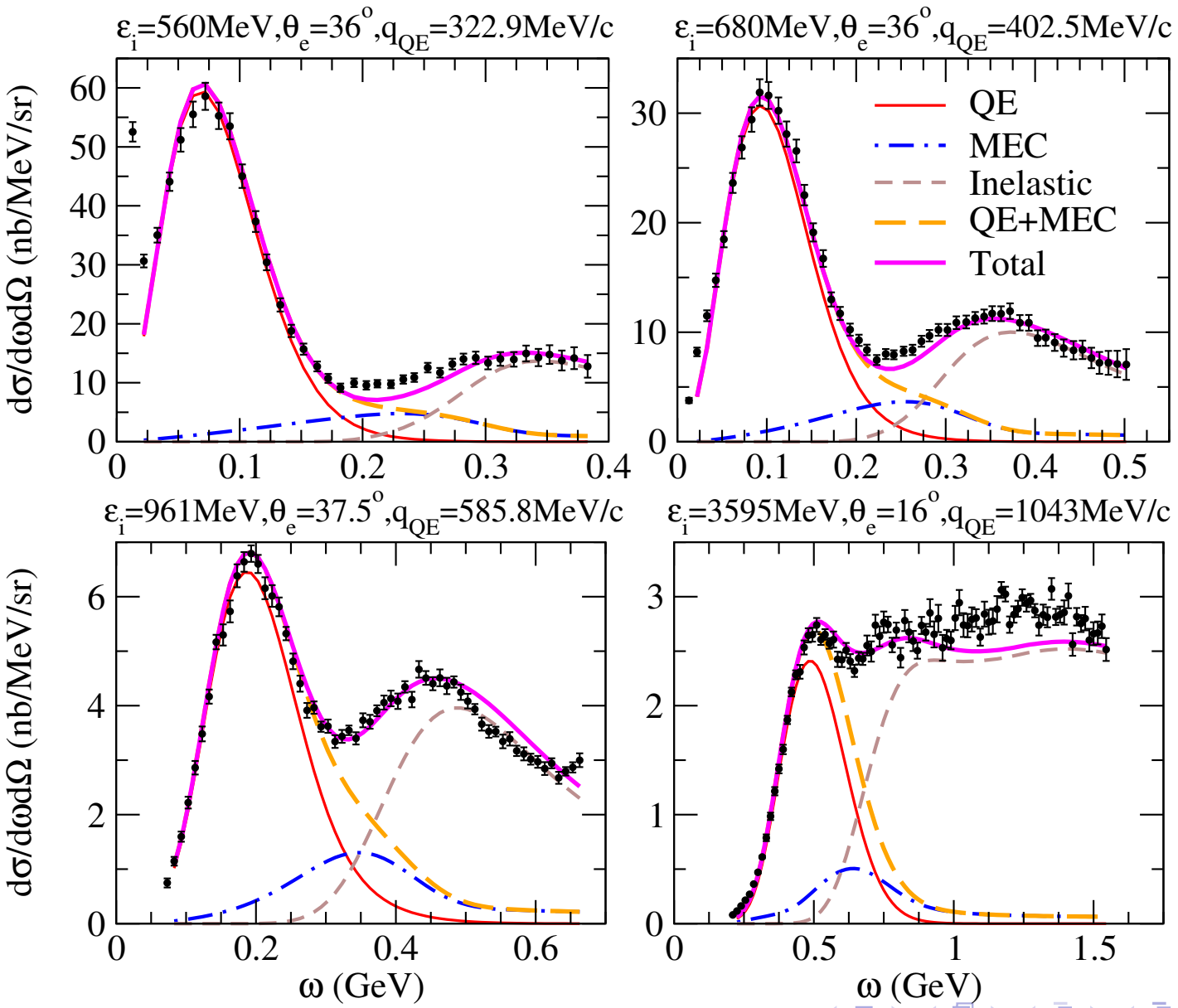








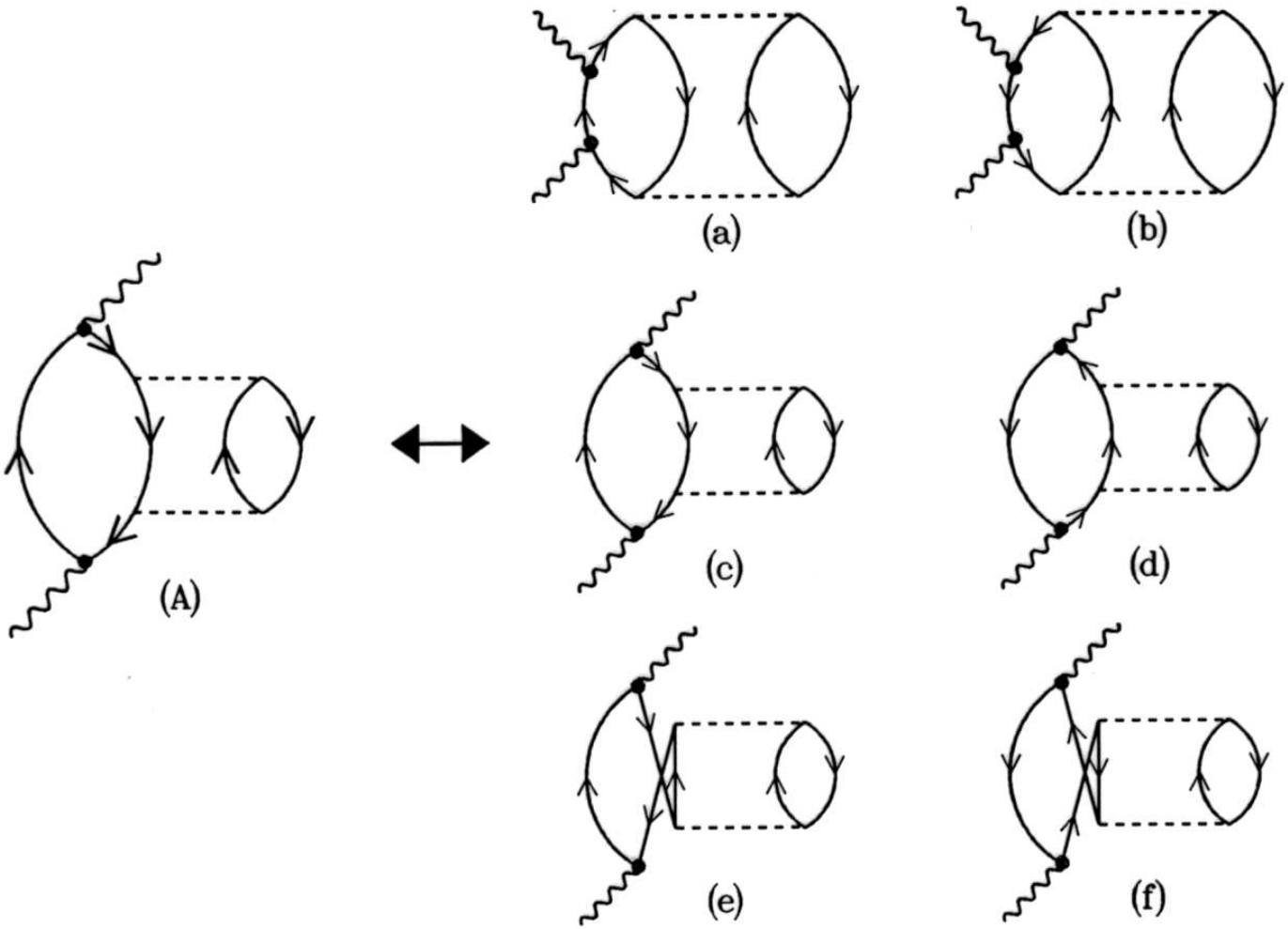
Response


εi=560MeV,θe=36°,qQE=322.9MeV/c
εi=680MeV,θe=36°,qQE=402.5MeV/c
εi=961MeV,θe=37.5°,qQE=585.8MeV/c
εi=3595MeV,θe=16°,qQE=1043MeV/c
dσ/dωdΩ (nb/MeV/sr)
ω (GeV)
QE
MEC
Inelastic
QE+MEC
Total

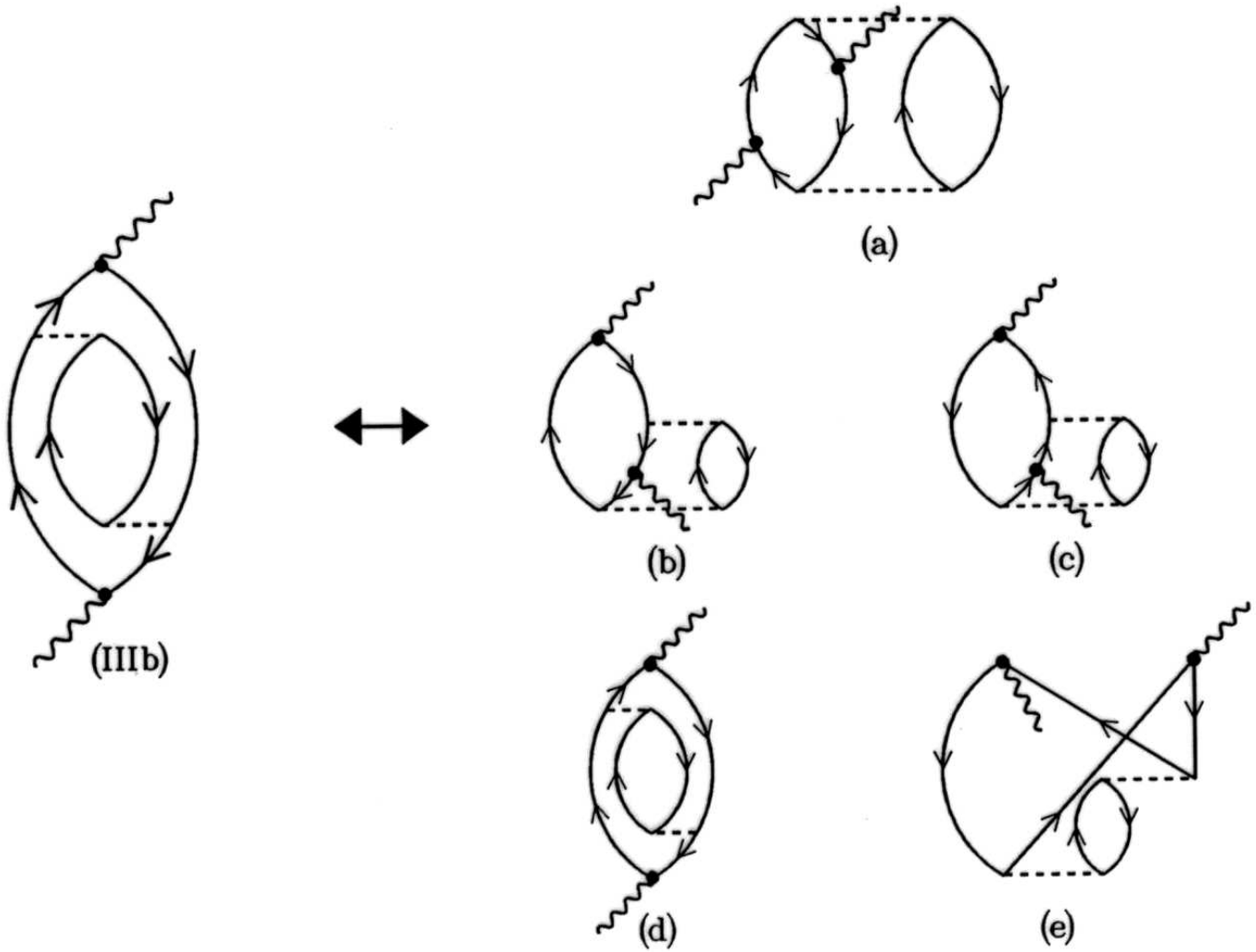
What else?

?

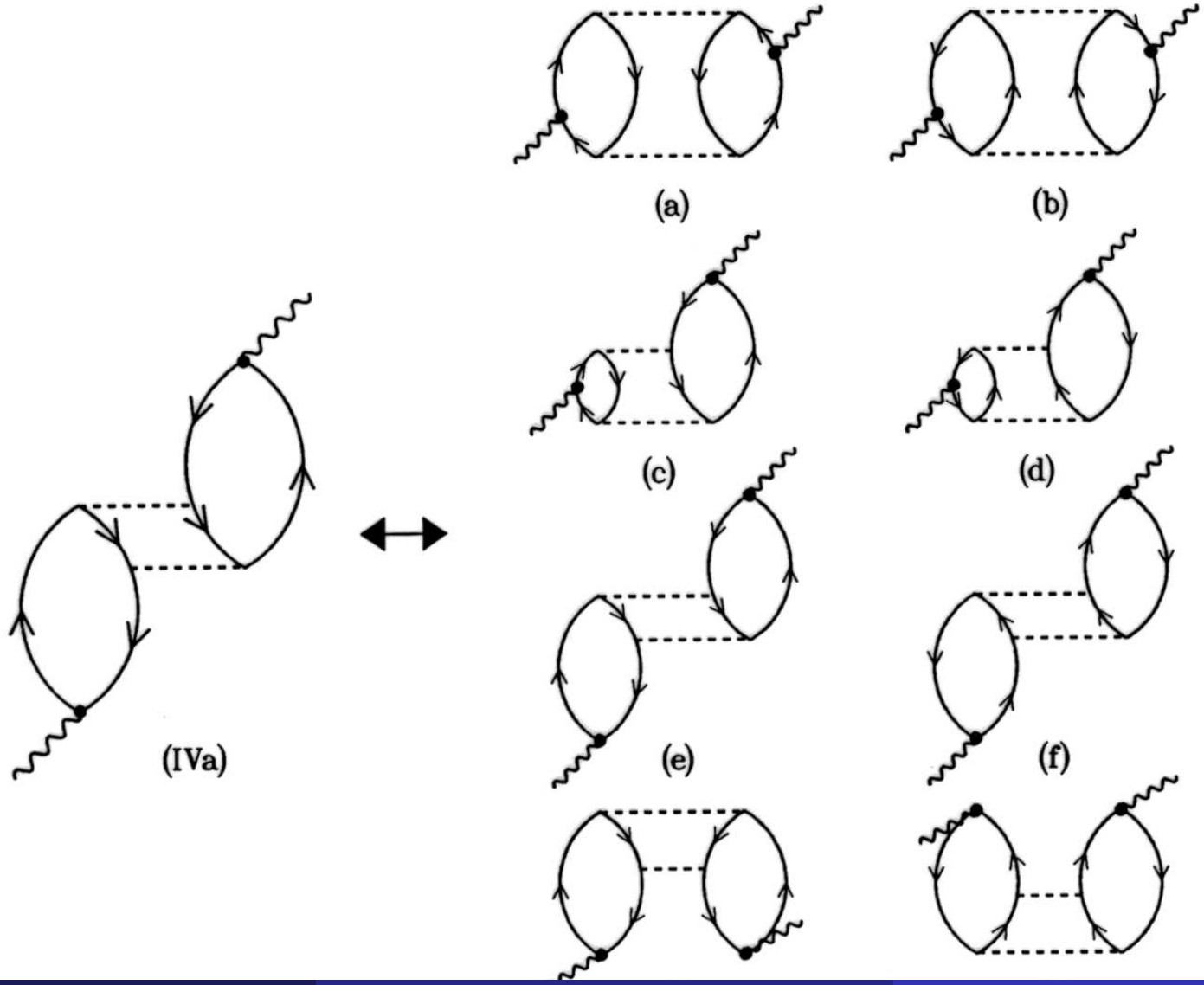
Correlations: one-body terms



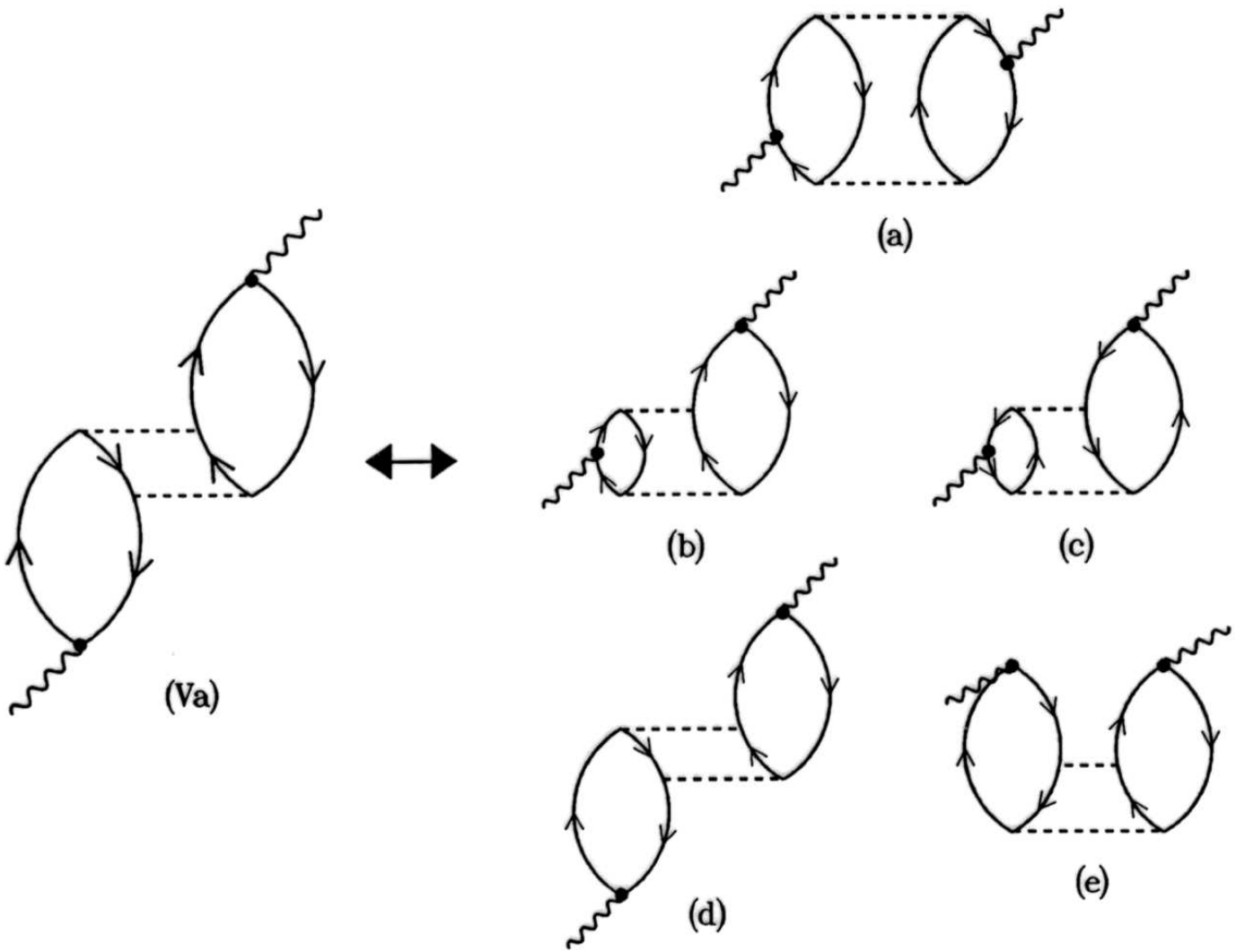
Correlations: irriducible two-body terms



Correlations: irriducible two-body terms



Correlations: irriducible two-body terms



and more...

- other mesons
- short range correlations
- ...