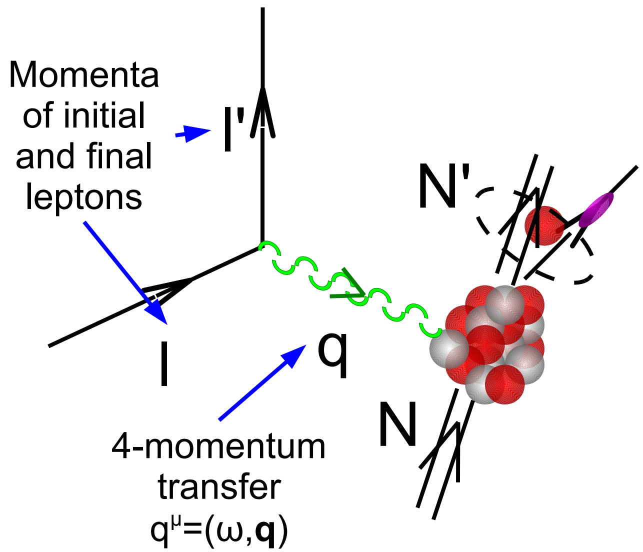
Multi-particle excitations in the lepton- nucleus scattering process at energy transfers below 1 [GeV]

WNG seminar 22.11.2010

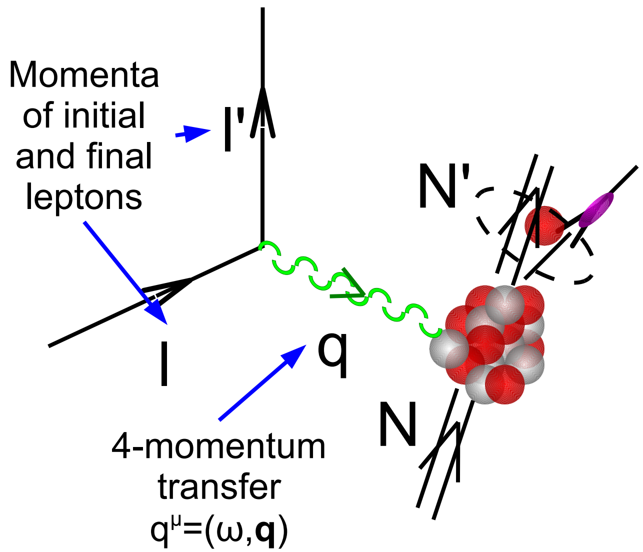
Jakub Żmuda

jazmuda@ift.uni.wroc.pl

Lepton- nucleus scattering process



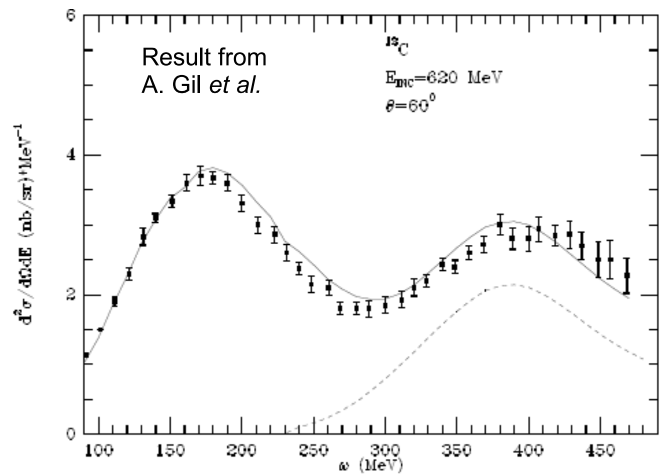
Lepton- nucleus scattering process



- Observables: coincidence cross- sections for N, π, γ etc. emissions
- Inclusive cross-section= total
- Lack of precise data for neutrinos. Electron- precision probe. Nuclear model good for e should be good for ν

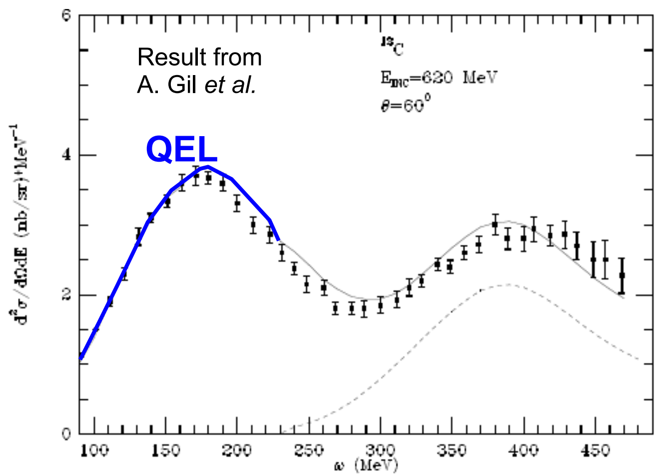
Overview of main dynamics under 1 [GeV]

- (e,e') process for ^{12}C, $E = 620[MeV], \Theta = 60^o$.



Overview of main dynamics under 1 [GeV]

- (e,e') process for ^{12}C, $E = 620[MeV], \Theta = 60^o$.

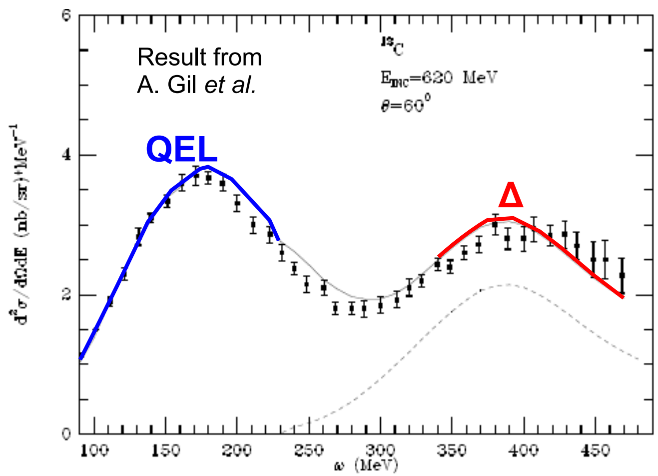


1. **Q**uasi**EL**astic: interaction with a single nucleon, nucleon emission. Base: Fermi Gas

i-particle excitations in the lepton- nucleus scattering process at energy transfers below

Overview of main dynamics under 1 [GeV]

- (e,e') process for ^{12}C, $E = 620[MeV], \Theta = 60^o$.

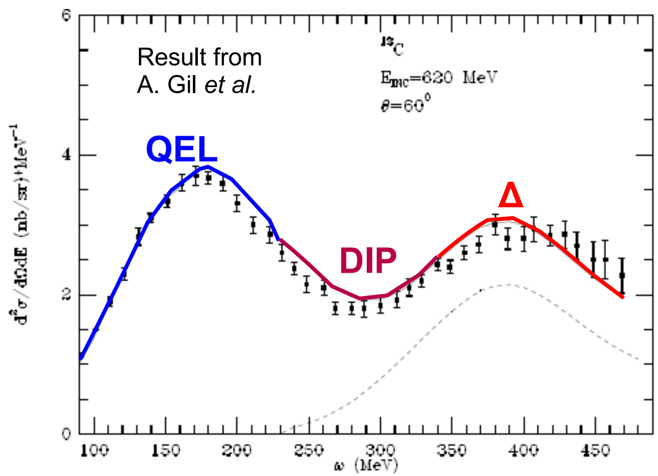


1. **Q**uasi**EL**astic: interaction with a single nucleon, nucleon emission. Base: Fermi Gas
2. **Δ**-peak: dominant $\Delta \to \pi N$ process

i-particle excitations in the lepton- nucleus scattering process at energy transfers below

Overview of main dynamics under 1 [GeV]

- (e,e') process for ^{12}C, $E = 620[MeV], \Theta = 60^o$.

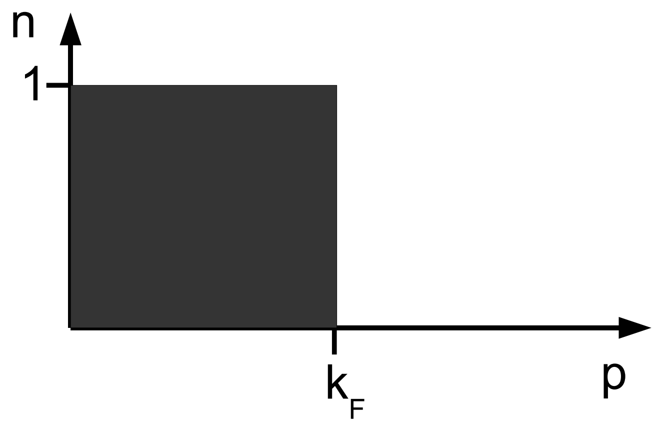


1. **Q**uasi**EL**astic: interaction with a single nucleon, nucleon emission. Base: Fermi Gas
2. **Δ**-peak: dominant $\Delta \to \pi N$ process
3. **DIP**: dominant $npnh$ processes; **M**eson **E**xchange **C**urrents: intermediate pion exchange between nucleons. +tails of QEL and Δ

i-particle excitations in the lepton- nucleus scattering process at energy transfers below

Philosophy of nuclear interactions: $1p1h$, IA

Fermi Gas

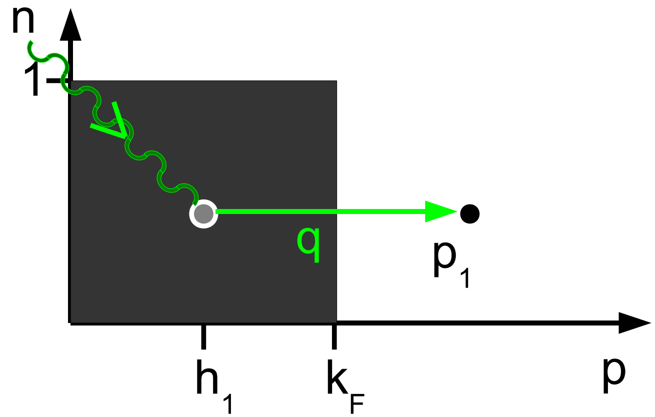


- All levels filled up to k_f + (iso)spin degrees of freedom

i-particle excitations in the lepton- nucleus scattering process at energy transfers below

Philosophy of nuclear interactions: $1p1h$, IA

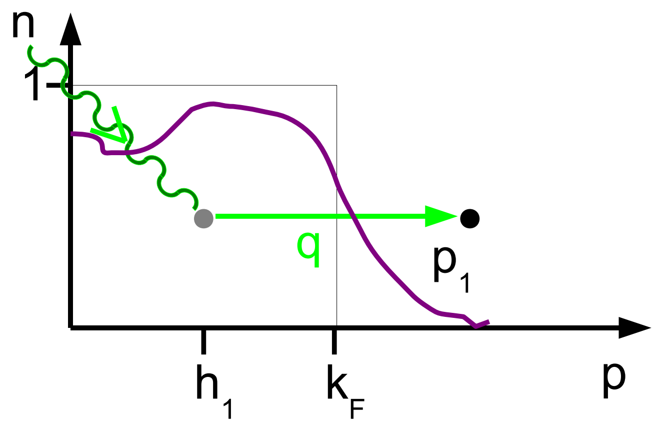
Fermi Gas



- All levels filled up to k_f + (iso)spin degrees of freedom
- IA: whole momentum transfer for one nucleon

Philosophy of nuclear interactions: $1p1h$, IA

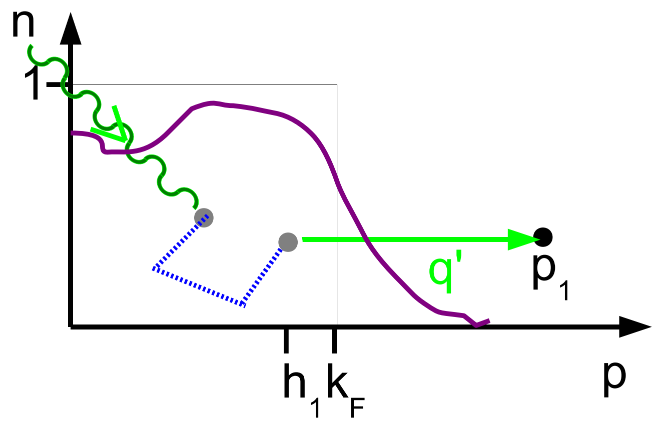
Fermi Gas + LDA



- All levels filled up to k_f + (iso)spin degrees of freedom
- IA: whole momentum transfer for one nucleon
- LDA: more realistic momentum distribution

Philosophy of nuclear interactions: $1p1h$, IA

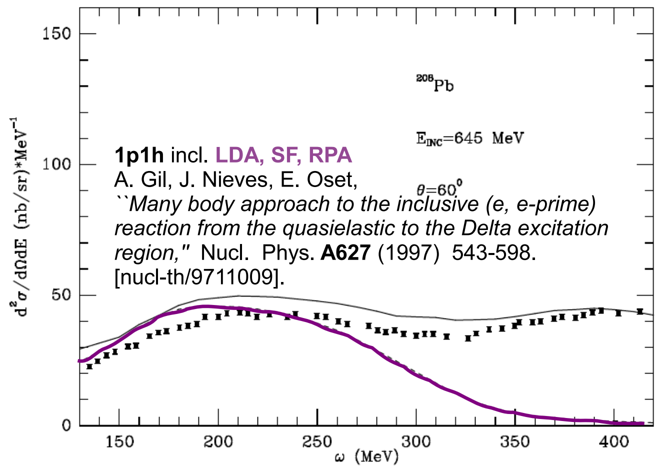
Fermi Gas + LDA +NN correlations to 1p1h



- All levels filled up to k_f + (iso)spin degrees of freedom
- IA: whole momentum transfer for one nucleon
- LDA: more realistic momentum distribution
- self-energy or/and medium polarisation correction

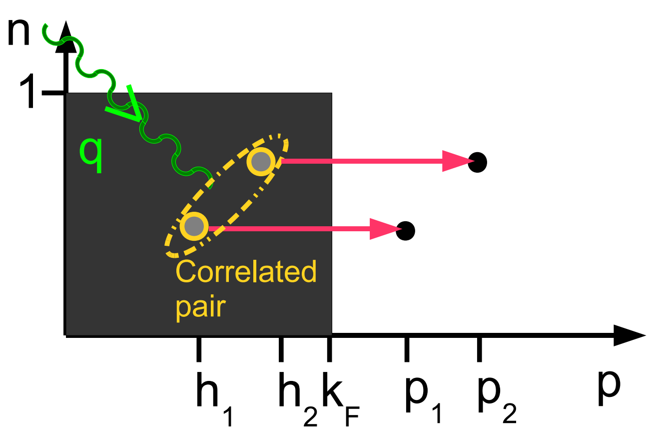
Philosophy of nuclear interactions: $1p1h$, IA

Fermi Gas + LDA +NN correlations to 1p1h



- All levels filled up to k_f + (iso)spin degrees of freedom
- IA: whole momentum transfer for one nucleon
- LDA: more realistic momentum distribution
- self-energy or/and medium polarisation correction
- not enough if only one ph pair in final state

Philosophy of nuclear interactions: 2p2h



- Add more complicated final states
- For example $2p2h$ excitations

Nuclear 1 and 2-body currents

- Typical one-photon-exchange momentum representation S-matrix element:

$$S_{fi} \propto \frac{\alpha}{q^2} l^\mu \mathcal{J}_\mu \delta^{(4)}(\mathbf{l} - \mathbf{l}' + \mathbf{P_N} - \mathbf{P}'_\mathbf{N})$$

- For QEL 1p1h process:

$$\mathcal{J}^\mu = \left\langle f_{1p1h} \left| \hat{J}^{\mu(1)}(0) \right| i \right\rangle$$

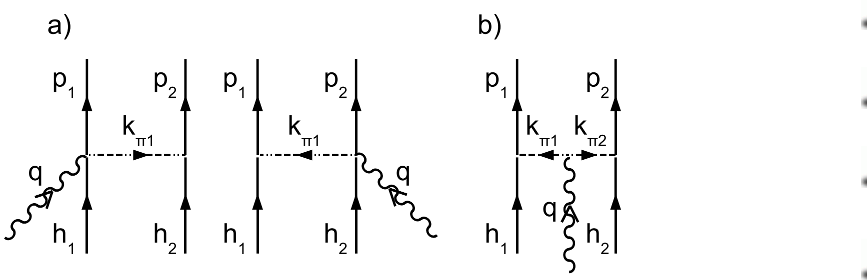
- Typical model for vector+ axial currents:

$$\begin{aligned} \hat{J}^\mu(0) &= \overline{\psi_n}(0)\hat{\Gamma}^\mu \psi_{n'}(0) \\ \Gamma^\mu(q) &= \gamma^\mu F_1 + i\sigma^{\mu\alpha} q_\alpha \frac{F_2}{2M} + \gamma^5\gamma^\mu F_A + \gamma^5 q^\mu \frac{F_P}{M} \ (particle\ only) \end{aligned}$$

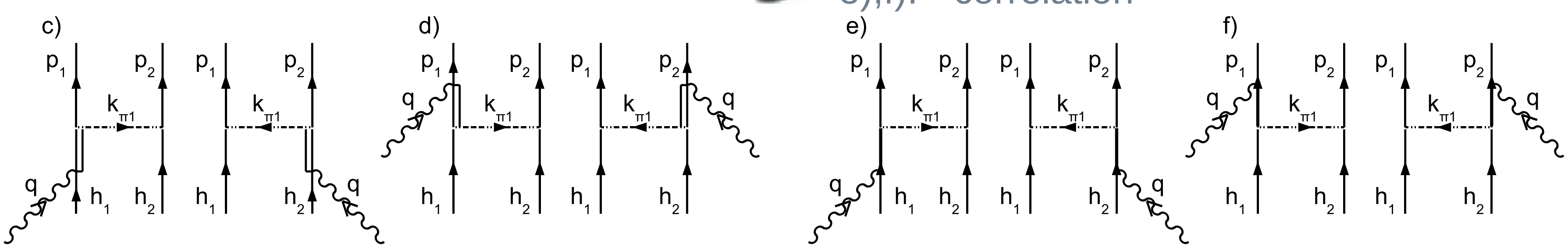
- Problematic construction of 2-body currents

Nuclear 1 and 2-body currents

- First approach: T.W. Donnelly and Van Orden (1981): dominant NN correlation from the π meson exchange and/or intermediade ${}^{1232}\Delta$ production.



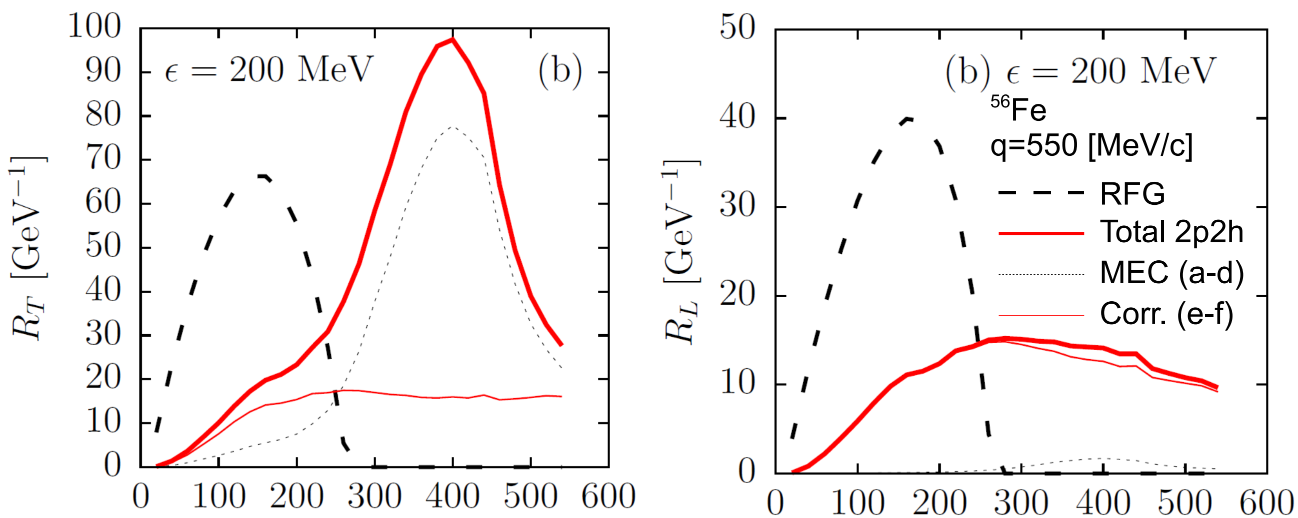
- a): seagull (contact)
- b): pion-in-flight
- c),d): Δ-excitation
- e),f): "‘correlation"’



- Definition of the 2-body curent matrix elements from FG ground-state

$$\left\langle p_1 p_2 h_1 h_2 \left| J^{\mu(2)} \right| FG \right\rangle = \left\langle p_1 p_2 \left| J^{\mu(2)} \right| h_1 h_2 \right\rangle - \left\langle p_1 p_2 \left| J^{\mu(2)} \right| h_2 h_1 \right\rangle$$

Recent result of this model



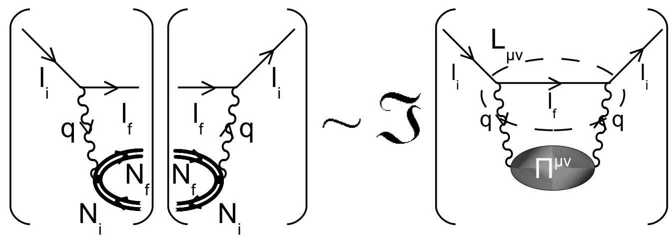
J.E. Amaro, C. Maieron, M.B. Barbaro, J.B. Caballero T.W. Donnelly
Phys. Rev. **C82** (2010) 044601. [arXiv:1008.0753 [nucl-th]].

- 2p2h excitatons are crucial to understand the inclusive cross-section.

Approach by E. Oset

- The cross-section $\rightarrow$ gauge boson self-enegy in nuclear matter

$$\overline{\sum_{N_i,s_i}}\sum_{N_f,s_f}\int \Pi_{N_f}$$

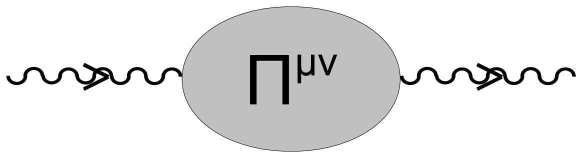


- Model introduced by E. Oset in Phys. Lett. **B165** (1985) originally for pions, later for electrons and neutrinos
- Main idea adapted by M. Martini and J. Marteau (Eur. Phys. J. **A5** (1999)) for neutrinos
- Standard QFT/MBT expasion:

$$\begin{aligned}
\Pi^{\mu\nu}(q) &= \Omega M_T \int d^4x e^{iqx} \left\langle i \left| T\left\{ J^{\nu\dagger}(x) J^{\mu}(0) \right\} \right| i \right\rangle = \\
&= \Omega M_T \int d^4x e^{iqx} \left\langle i \left| T\left\{ J_I^{\nu\dagger}(x) J_I^{\mu}(0) exp^{i\int d^4x \mathcal{L}_{int}(x)} \right\} \right| i \right\rangle
\end{aligned}$$

- $\Pi^{\mu\nu}$: Feynman graph level analysis capable

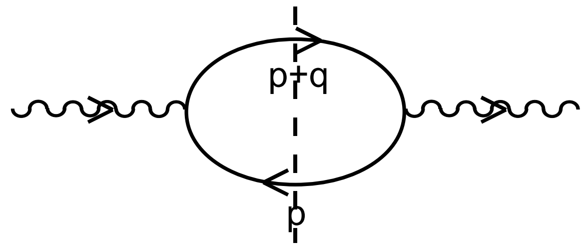
How does it work?: polarisation propagator



- The polarisation propagator represents particle self-energy in medium

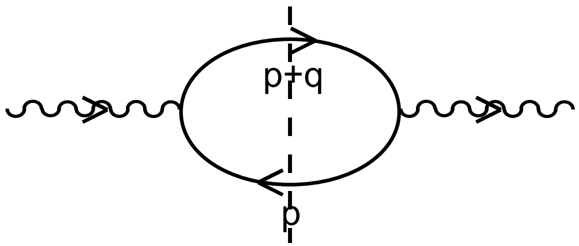
i-particle excitations in the lepton- nucleus scattering process at energy transfers below

How does it work?: polarisation propagator



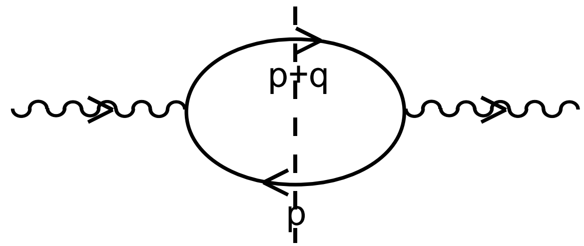
- The polarisation propagator represents particle self-energy in medium
- No interactions- Fermi Gas.(vertical cut: propagator on-shell). Nonrelativistic limit with only positive energy baryons

How does it work?: polarisation propagator

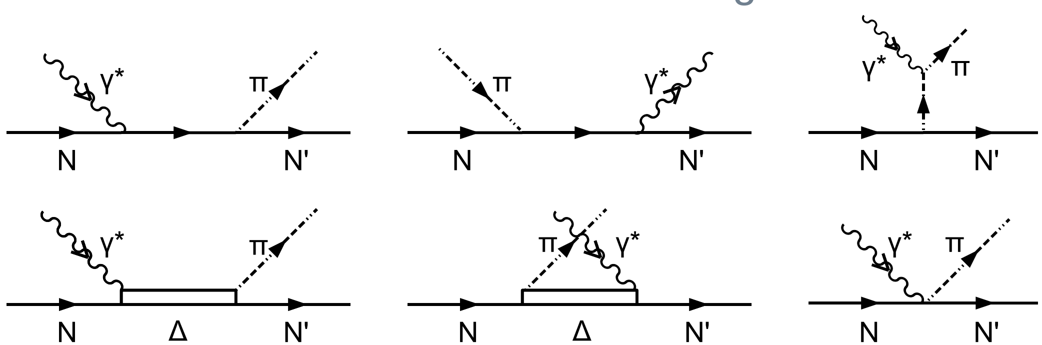


- The polarisation propagator represents particle self-energy in medium
- No interactions- Fermi Gas.(vertical cut: propagator on-shell). Nonrelativistic limit with only positive energy baryons
- Application of LDA.

How does it work?: polarisation propagator

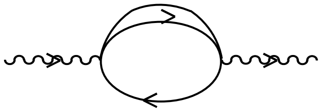


- The polarisation propagator represents particle self-energy in medium
- No interactions- Fermi Gas.(vertical cut: propagator on-shell). Nonrelativistic limit with only positive energy baryons
- Application of LDA.
- Interactions: nonrelativistic version of the following vertices:

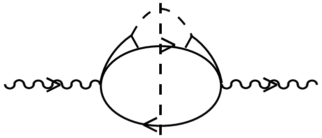


How does it work?: Δh excitation

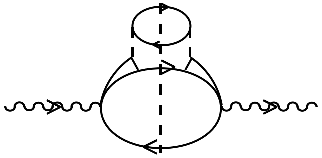
- First: excitation of Δ through $\gamma N \Delta$ vertex:



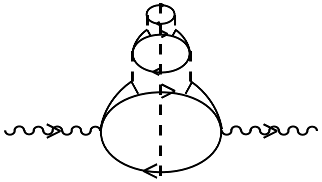
- Δ unstable, decay to pion:

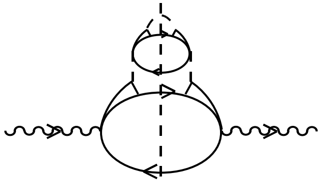


- pion excites another ph pair ($2p2h$):



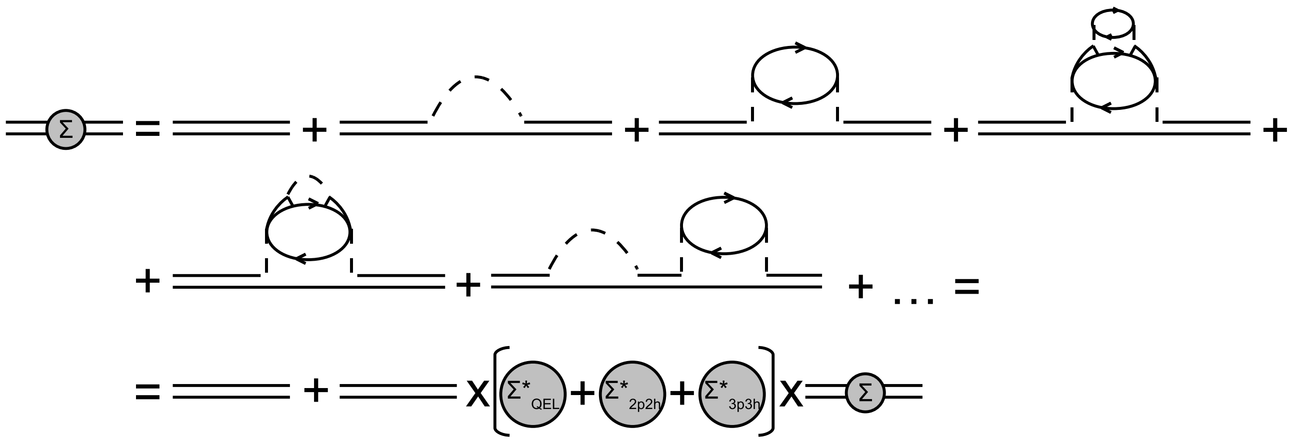
- ... or another Δh ($3p3h$, $2p2h1\pi$):



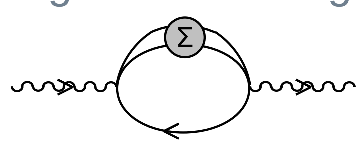


How does it work?: $\triangle$ self-energy

- All these graphs $\rightarrow$ Δ self- energy (through Dyson equation)



- Many orocesses included through the following diagram:

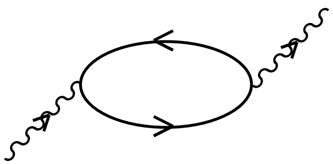


- E. Oset in Nucl. Phys. **A468** (1987):analytical parametrisation of Δ self energy for e and π scattering:

$$-\Im\Sigma_{\Delta}(\omega,\rho) = C_Q(\omega)(\rho/\rho_0)^{\alpha(\omega)} + C_{A2}(\omega)(\rho/\rho_0)^{\beta(\omega)} + C_{3A}(\omega)(\rho/\rho_0)^{\gamma(\omega)}$$

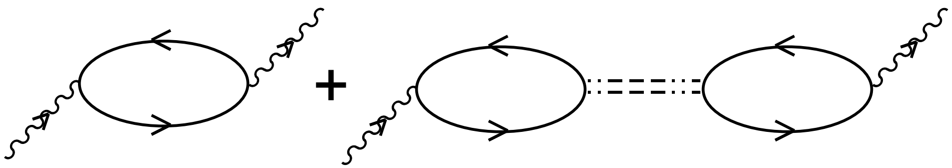
How does it work?: RPA

- Starting point: Fermi Gas



How does it work?: RPA

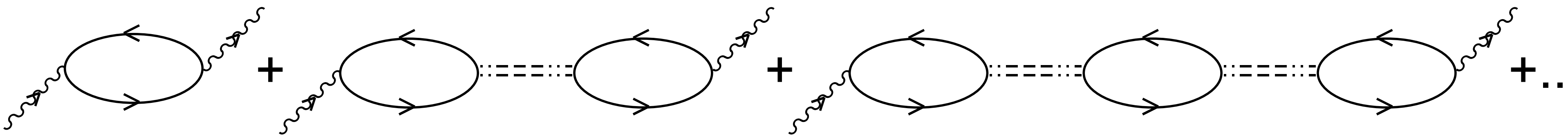
- Starting point: Fermi Gas



- ph pair propagation through nuclear medium

How does it work?: RPA

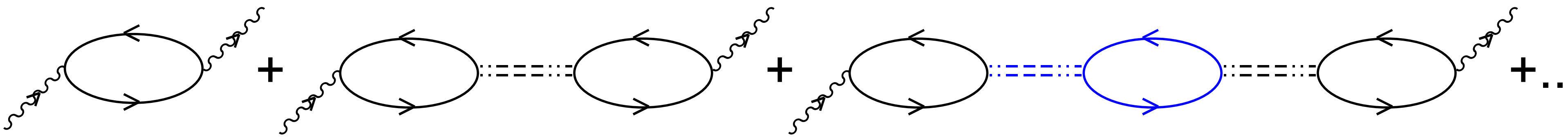
- Starting point: Fermi Gas



- ph pair propagation through nuclear medium

How does it work?: RPA

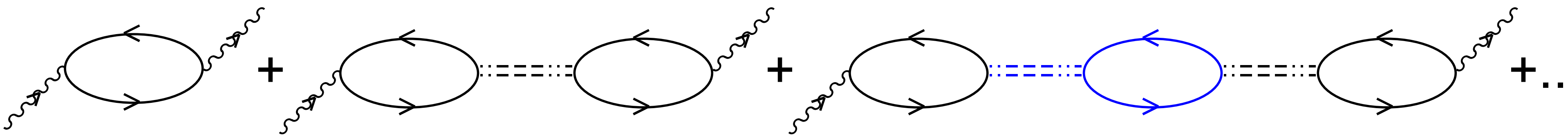
- Starting point: Fermi Gas

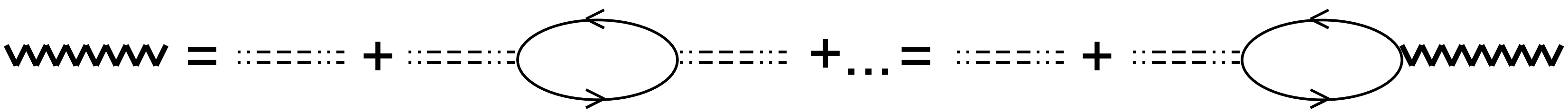


- ph pair propagation through nuclear medium

How does it work?: RPA

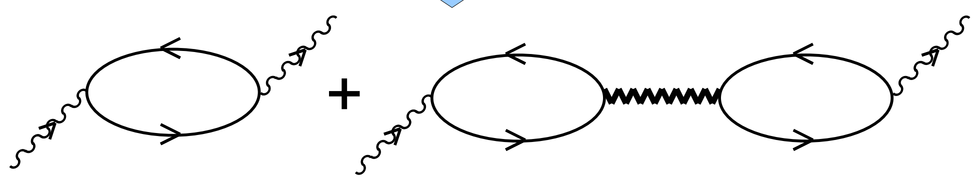
- Starting point: Fermi Gas





- ph pair propagation through nuclear medium

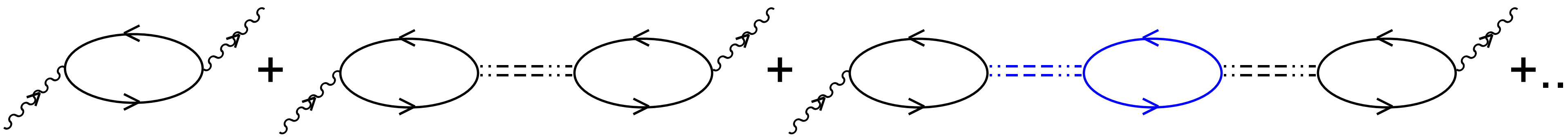
(Ring Approximation)

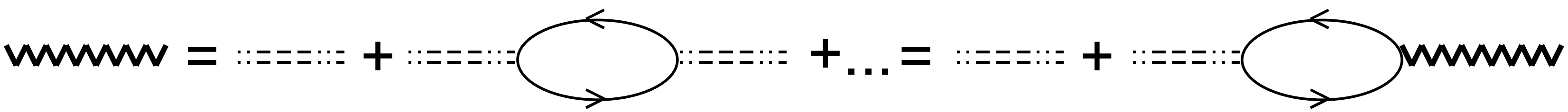


"medium polarisation" $\leftrightarrow$ creation of virtual ph pairs during propagation

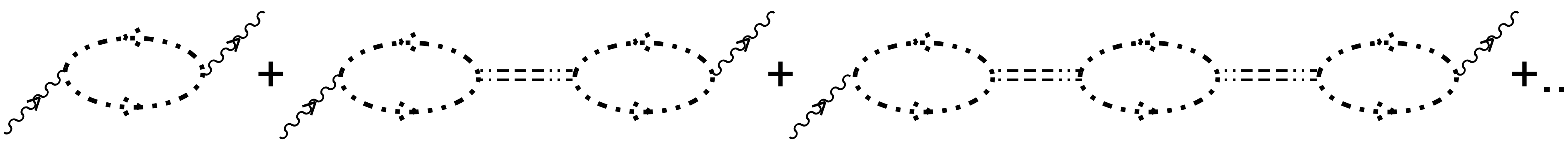
How does it work?: RPA

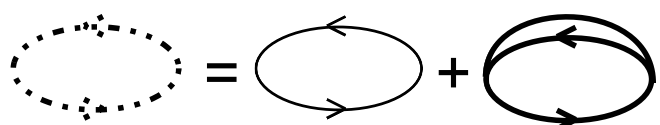
- Starting point: Fermi Gas





- ph pair propagation through nuclear medium

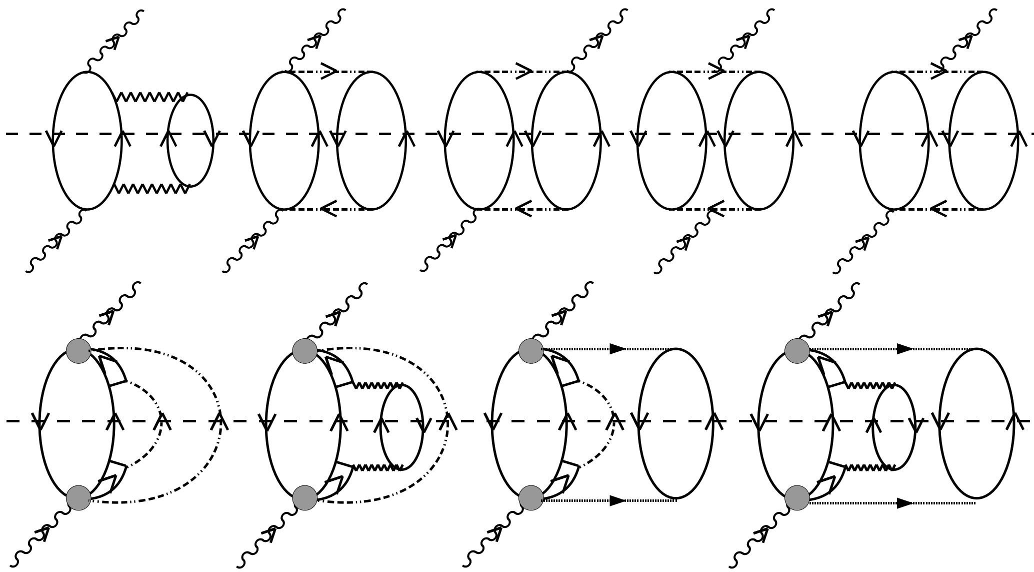




Δh excitations too + RA for pionic propagator

How does it work?: whet else has been included

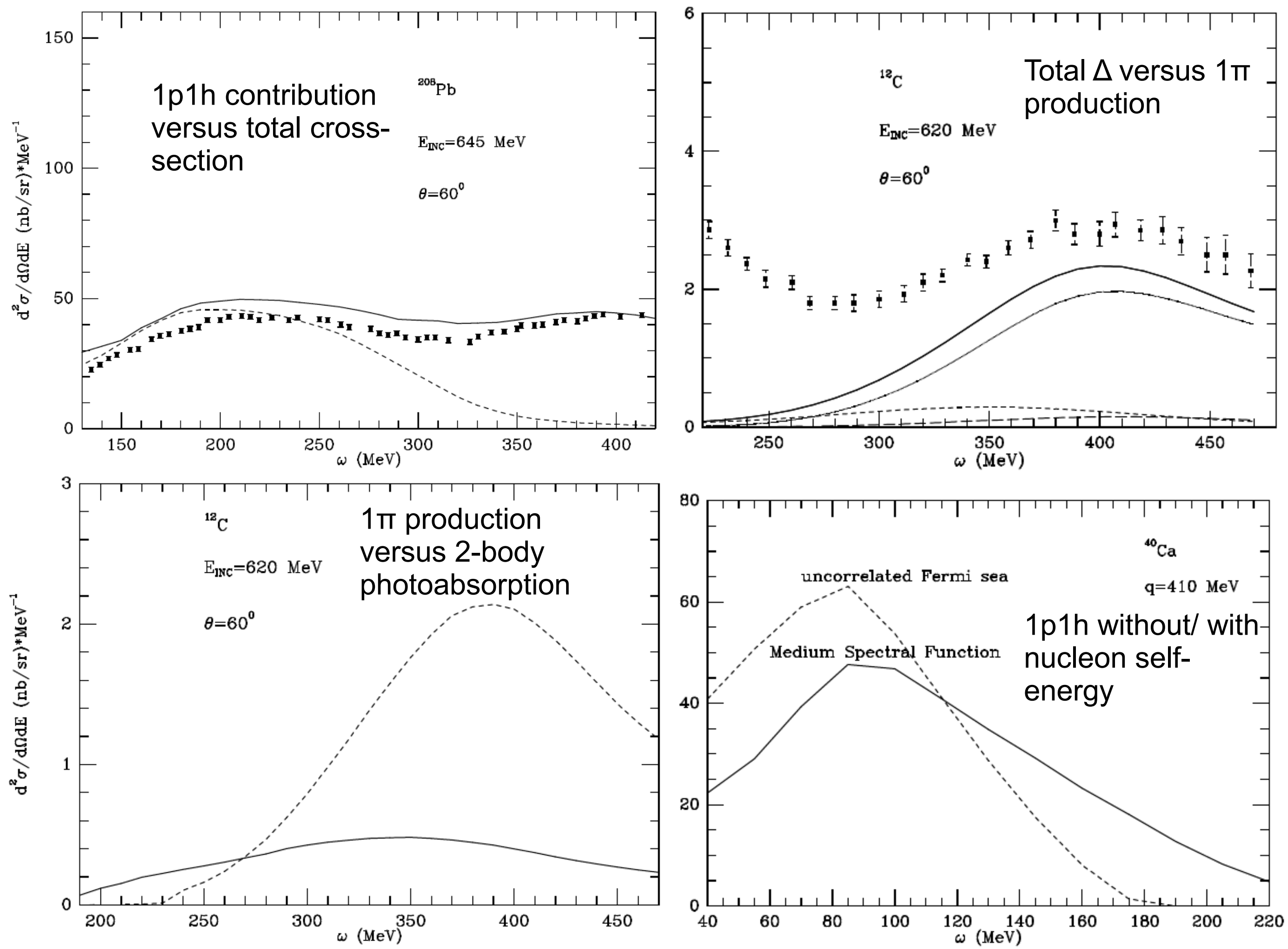
- Some more diagrams connected with MEC and $2p2h$,$2p2h1\pi$, $3p3h$ excitations:



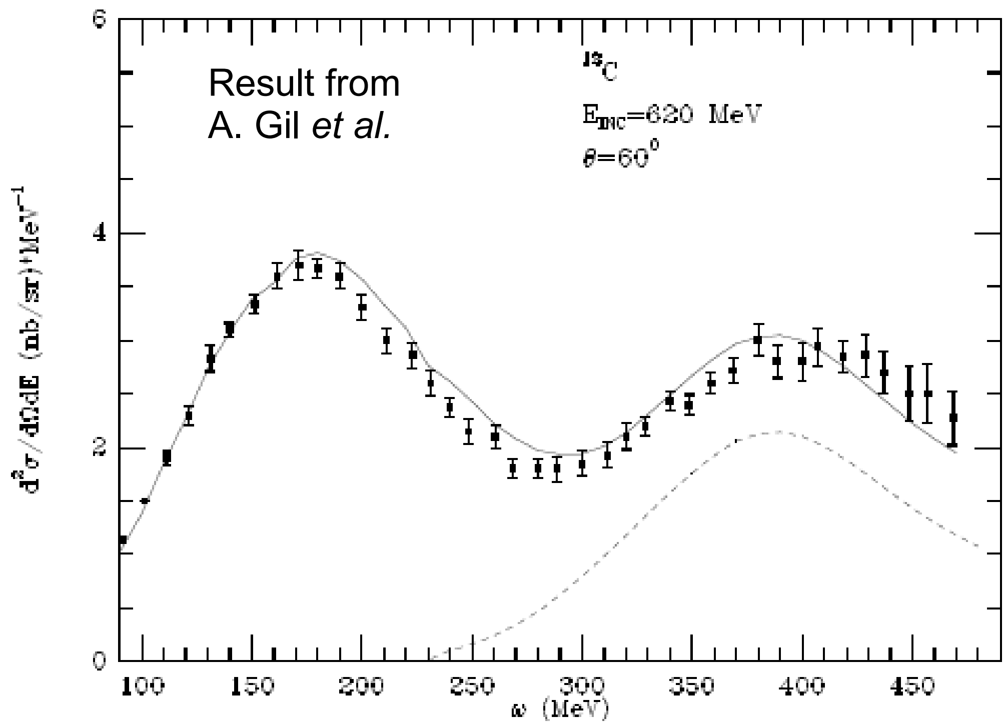
- Medium Spectral Function: nucleon self-energy (like for Δ but using Landau-Migdal effective point interaction)

- Self- consistent model, consequent use of the quantum many-body theory and field theory

Results of A. Gil, J. Nieves, E. Oset, Nucl. Phys. A627 (1997)



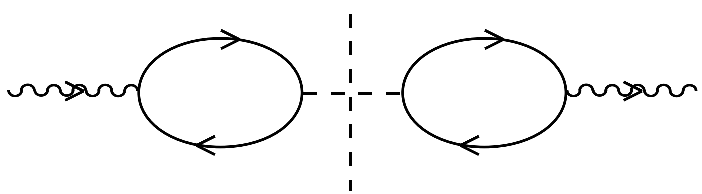
Results of A. Gil, J. Nieves, E. Oset, Nucl. Phys. A627 (1997)



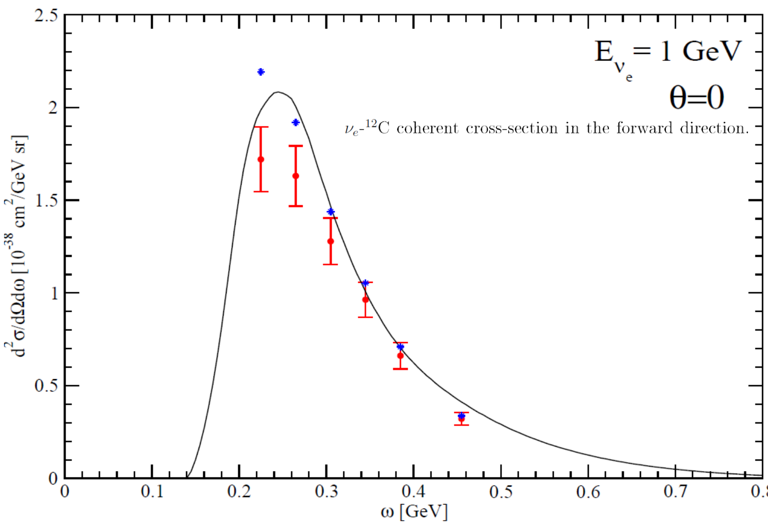
- The cross- section is incredibly accurate
- The model, although complicated, arises from a consistent many-body theory

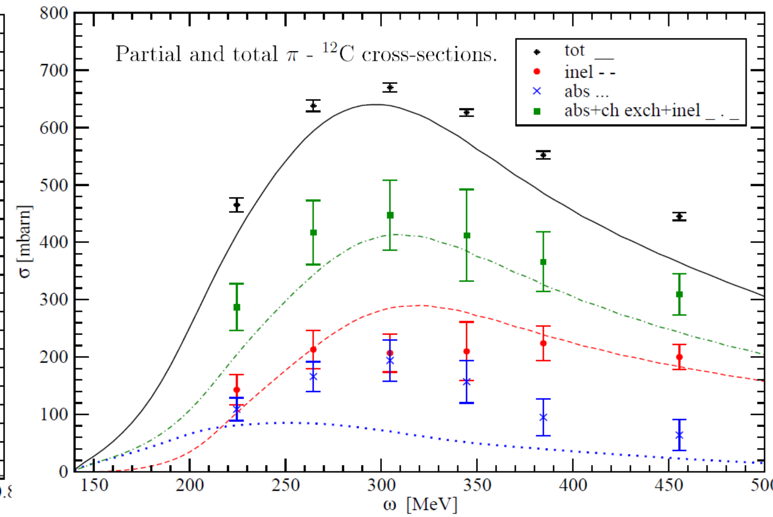
Marteau and Martini approach

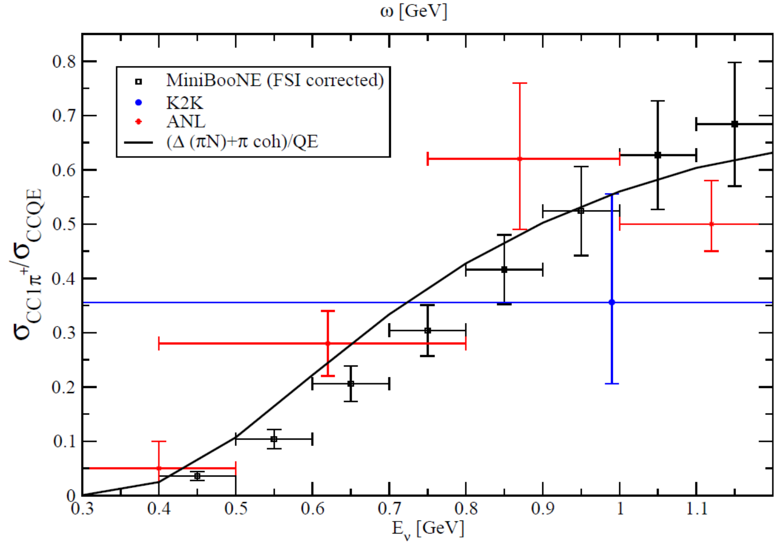
- According to J. Marteau, Eur. Phys. J. **A5** (1999) 183-190. [hep-ph/9902210] the model is almost the same as the one used by E. Oset.
- The main difference is lack of pionic seagull (Kroll-Ruderman) terms
- The model has been used to evaluate the nucleon knock -out coherent and incoherent pion production
- "‘coherent"’ :intermediate pion on-shell (new w.r.t. E. Oset):

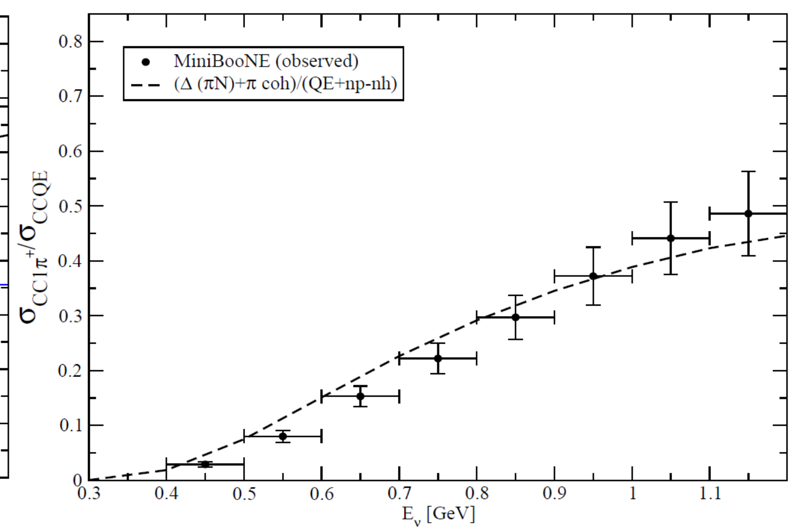


Results from M. Martini, M. Ericson, G. Chanfray *et al.*, Phys. Rev. C80 (2009) 065501.









i-particle excitations in the lepton- nucleus scattering process at energy transfers below

Conclusions

- In order to understand ν and e inclusive cross-sections one has to go beyond the $1p1h$ excitation region
- Models based on impulse approximation fail for a wide kinematical range under $1[GeV]$.
- 2-body excitations and beyond have to be incorporated
- Models based on the consistent field-theoretical approach seem to work very well
- It would be interesting to see what are the effects of relativistic treatment of

  Oset's/Marteau models compared to the one introduced by T.W. Donnelly

Bibliography

- J. W. Van Orden, T. W. Donnelly, Annals Phys. **131** (1981) 451-493.
- J. E. Amaro, C. Maieron, M. B. Barbaro *et al.*, Phys. Rev. **C82** (2010) 044601. [arXiv:1008.0753 [nucl-th]].
- A. Gil, J. Nieves, E. Oset, Nucl. Phys. **A627** (1997) 543-598. [nucl-th/9711009].
- E. Oset, L. L. Salcedo, D. Strottman, Phys. Lett. **B165** (1985) 13-18.
- E. Oset, L. L. Salcedo, Nucl. Phys. **A468** (1987) 631-652.
- J. Marteau, Eur. Phys. J. **A5** (1999) 183-190. [hep-ph/9902210].
- M. Martini, M. Ericson, G. Chanfray *et al.*,Phys. Rev. **C80** (2009) 065501. [arXiv:0910.2622 [nucl-th]].
- D. Ashery, I. Navon, G. Azuelos *et al.*, Phys. Rev. **C23** (1981) 2173-2185.