Long range correlations in ν - nucleus interactions

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Outlines

Neutrino-nucleus interactions

When Neutrinos encounter Nuclei

Events measured by current neutrino experiments depend on

- Neutrino Flux
- Neutrino cross section
- Neutrino nuclear effects

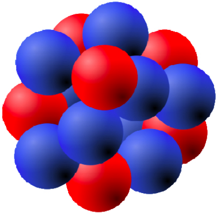
Nuclear effects in neutrino nucleus interaction

- target nucleon in motion $\rightarrow$ Modeling the nucleus
- certain reactions prohibited $\rightarrow$ Pauli suppression
- physical quantities ares modified within nuclear environment $\neq$ in an isolated nucleon
- produced topologies are modified by final-state interactions
- nucleon-nucleon correlations: Meson-exchange currents (MEC), Short-range correlations (SRC), Long-range correlations (LRC) $\sim$ RPA - Random Phase Approximation

Nuclear Models

Modeling the nucleus - Thanks to lecturers in NuSTEC2017

- The nucleus is a mesocopic system
  →usually too big for few-body techniques
  →usually too small for statistical methods

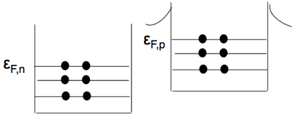


- Nuclear physics is hard work !

Nuclear Models

No correlation models

- very approximate: liquid drop liquid model
- slightly less approximate: the Fermi gas model



correlation models

- not too approximate: already quite some correlations: the mean field model (or shell model)
- the Hartree-Fock mean field

The static mean field

- the mean field approximation is realized in a self-consistent way solving the Hartree-Fock (HF) equations.
- predict ground state properties of nuclei with increasing accuracy as the system becomes larger.
- nucleons are moving independent from each other in a mean field
- How to obtain a reliable and consistent mean field ?

$$
\begin{aligned}
H &= \sum_i T_i + \frac{1}{2}\sum_{i,j} V_{i,j} && (1)\\
&= \sum_i (T_i + U(r_i)) + \left(\frac{1}{2}\sum_{i,j} V_{i,j} - \sum_i U(r_i) \right) && (2)\\
&= \sum_i H_0(i) + H_{res}(i,j) && (3)
\end{aligned}
$$

The static mean field

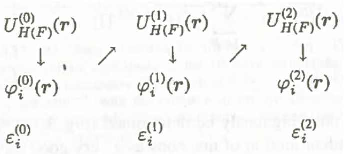
- The HF equation

$$-\frac{\hbar^2}{2m}\nabla^2\varphi_i(x) + V_H(x)\varphi_i(r) - \int d^3x' v_F(x',x)\varphi_i(x') = \varepsilon_i\varphi_i(x) \quad (4)$$

$$V_H(x) = \sum_{\beta,\varepsilon_\beta<\varepsilon_F}\int d^3r'\varphi^+_\beta(x')V(x',x)\varphi_\beta(x') \quad (5)$$

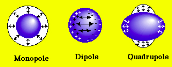
$$V_F = \sum_{\beta,\varepsilon_\beta<\varepsilon_F}\varphi^+_\beta(x')V(x',x)\varphi_\beta(x) \quad (6)$$

- Numerical calculation recipe



The time-dependent mean field

- the static mean field describes systems in equilibrium
- there are many excited states with features that cannot be understood in terms of shell model excitations
- a coherent participation by many nucleons takes place in the nucleus, resulting in a collective excitation of the system as a whole.



- The Random Phase Approximation (RPA): ground state of the system is not purely Hatree-Fock but may contains correlations.

RPA and neutrino-nucleus cross-section

from arXiv:0909.0642v1, Martini2009

- total neutrino-nucleus cross-section

$$\begin{aligned}\frac{\partial^2\sigma}{\partial\Omega\,\partial k'} &= \frac{G_F^2\cos^2\theta_c\,(\vec{k}')^2}{2\pi^2}\cos^2\frac{\theta}{2}\Bigg[G_E^2\,(\frac{q_\mu^2}{\vec{q}^2})^2 R_\tau^{NN} + G_A^2\,\frac{(M_\Delta - M)^2}{2\vec{q}^2}R_{\sigma\tau(L)}^{N\Delta} + G_A^2\,\frac{(M_\Delta - M)^2}{\vec{q}^2}R_{\sigma\tau(L)}^{\Delta\Delta} \\ &+ \left(G_M^2\,\frac{\omega^2}{\vec{q}^2} + G_A^2\right)\left(-\frac{q_\mu^2}{\vec{q}^2} + 2\tan^2\frac{\theta}{2}\right)\left(R_{\sigma\tau(T)}^{NN} + 2R_{\sigma\tau(T)}^{N\Delta} + R_{\sigma\tau(T)}^{\Delta\Delta}\right) \\ &\pm 2G_A G_M\,\frac{k+k'}{M}\tan^2\frac{\theta}{2}\left(R_{\sigma\tau(T)}^{NN} + 2R_{\sigma\tau(T)}^{N\Delta} + R_{\sigma\tau(T)}^{\Delta\Delta}\right)\Bigg].\end{aligned}$$

$$R(q,\omega) = -\frac{1}{\pi} Im\Pi(q,q,\omega)$$

- $\Pi = \Pi^0 + \Pi^0 V \Pi$, V denotes the effective interaction between particle-hole excitations