Elastic Neutrino-Nucleus Scattering

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and Coherent Neutrino Scattering
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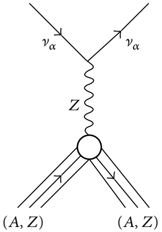
ELASTIC ν-A SCATTERING

$$\nu + A(N, Z) \to \nu + A(N, Z)$$



Why should we care about this process?

- As a signal
  - Neutron density distributions
  - Detection of supernova neutrinos
  - Astrophysical processes
  - Nuclear reactor monitoring
- As a background
  - Dark matter searches

SM Cross Section for Spin-Zero Targets

- Differential cross section ($T \approx q^2/2M_A$, with $q = |\mathbf{q}|$, is the nuclear recoil kinetic energy)

$$\frac{d\sigma}{dT} = M_A \frac{G_F^2}{4\pi} \left(1 - \frac{q^2}{4E_\nu^2}\right) \left[(1 - 4\sin^2\theta_W) Z F_Z(q^2) - N F_N(q^2)\right]^2$$

- The charge and neutron form factors are the Fourier transform of the corresponding densities

$$F_{Z(N)}(q^2) = \frac{1}{Z(N)} \int d^3r \, \mathrm{e}^{i\mathbf{q}\cdot\mathbf{r}} \, \rho_{Z(N)}(r) \Rightarrow F_{Z(N)}(0) = 1$$

- Total cross section

$$\sigma = \int_{T_{\min}}^{T_{\max}} \left(\frac{d\sigma}{dT}\right) dT$$

- $T_{\min}$ is the detection threshold, $T_{\max} \approx 2E_\nu^2/M_A$

Energy range of elastic scattering

- Elastic scattering requires momentum transfer such that

$$\frac{1}{q} \gg R_A \approx r_0 A^{1/3}\ ,\ r_0 = 1.25\ \text{fm}$$

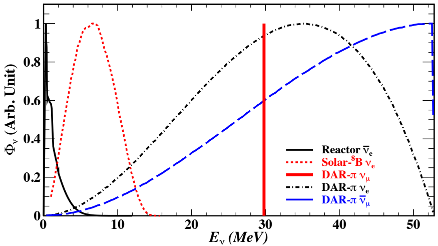
- Combining the above relation with the kinematical limit $q < q_{\text{max}} = 2E_\nu$ yields

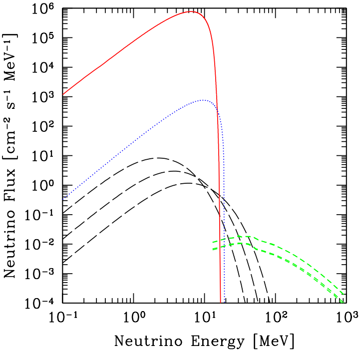
$$E_\nu \ll \frac{1}{2R_A}$$

- For nuclear targets with mass number in the range $12 \lesssim A \lesssim 132$, including C, Ar, Ge, and Xe

$$10 \lesssim E_\nu \lesssim 30\ \text{MeV}$$

RELEVANT NEUTRINO SOURCES





- ⋆ Left: fluxes of reactor, solar (^{8}Be), and spallation neutron source (SNS) neutrinos, normalized to their maxima.
- ⋆ Right: fluxes of solar (^{8}Be and hep), diffuse supernova background (DSNB) at three different temperatures, and atmospheric neutrinos.

The Nuclear Form Factors

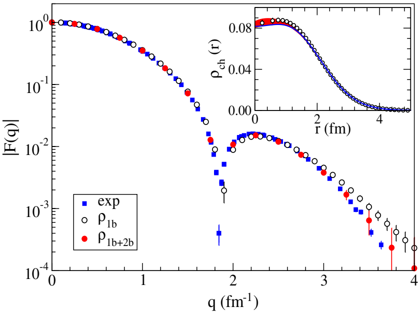
- The charge form factor of nuclei with $A \leq 12$, can be carried out studied measurung elastic electron-nucleus scattering cross sections

$$\left(\frac{d\sigma}{d\Omega}\right)_A = |F_Z(q^2)|^2 \left(\frac{d\sigma}{d\Omega}\right)_{\rm point}$$

- Owing to the factor $(1 - 4\sin^2\theta_W)$, the contribution of the charge form factor is strongly suppressed, and the elastic ν-A cross section is dominated by the neutron contribution $F_N(q^2)$
- Need theoretical models capable to explain measure $F_Z(q^2)$ data and predict $F_N(q^2)$
- Most calculations of the elastic ν-A cross section are carried out assuming $F_N(q^2) = F_Z(q^2)$, and using the nuclear shell model to obtain the charge form factors

$$\rho_Z(r) = \sum_\alpha |\phi_\alpha(r)|^2$$

- ⋆ The charge form factor $F_Z(q^2)$ can be computed exactly using realistic uclear hamiltonian and Quantum Monte Carlo techniques

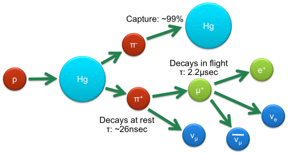


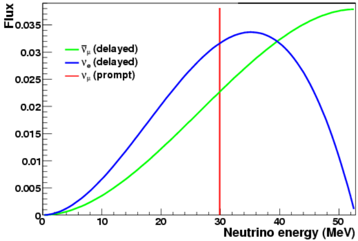
- ⋆ The extension to heavier and non isospin-symmetric nuclei, while not implying severe conceptual difficulties, involve non trivial computaional problems

THE COHERENT EXPERIMENT

⋆ Measuring the elastic *ν-A* cross section using SNS neutrinos

Stopped-Pion (πDAR) Neutrinos





$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

$$\downarrow$$

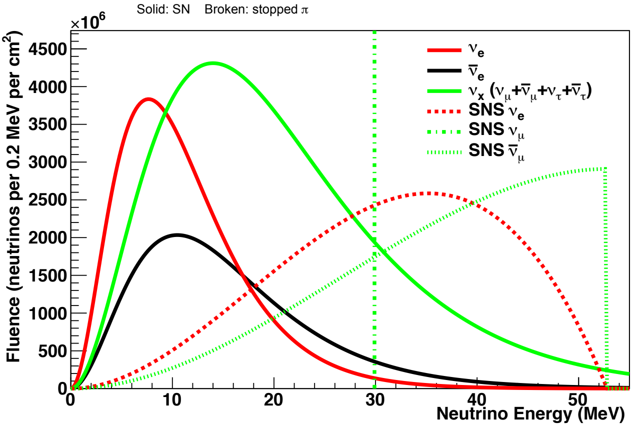
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies
between 0 and $m_\mu/2$
DELAYED (2.2 μs)

THE COHERENT EXPERIMENT

⋆ Measuring the elastic ν-A cross section using SNS neutrinos

Good overlap w/ SN spectrum



Summary & Outlook

- ⋆ Knowledge of the elastic ν-A scattering is relevant to the understanding of a variety of open issues
- ⋆ Theoretical calculations within *ab initio* approaches feasible for isospin-symmetric targets with $A \leq 12$
- ⋆ The extension to heavier nuclei with $A \neq Z$ is needed to take into acount the effects of short-range nuclear dynamics, not included in the nuclear shell model
- ⋆ Measurements carried out with monoenergetic SNS neutrinos will be most vaulable