Relativity

(A) Boost corrections

(B) QFT + RMF approximation

(A) $v_{ij} \rightarrow v_{ij}(\vec{P}) = v_{ij} + \delta v(\vec{P})$, with $\vec{P} = \vec{p}_i + \vec{p}_j$

$$\delta v_{ij}(\vec{P}) = \frac{\vec{P}^2}{8m} v_{ij}$$

$$+ \frac{1}{2}\left[(\vec{P}\cdot\vec{r}_{ij})(\vec{P}\cdot\nabla_{ij}), v_{ij}\right]$$

$$+ \frac{1}{2}\left[(\vec{\sigma}_i - \vec{\sigma}_j)\times\vec{P}\cdot\nabla_{ij}, v_{ij}\right]$$

QFT? needed when number of particles is <u>not</u> conserved

replace wave function with field

starting point is a lagrangian density (similar to Yukawa's) simplest implementation: Walecka model (mid 1970s)

degrees of freedom

- nucleon $\quad \psi_N = \begin{pmatrix} p \\ n \end{pmatrix}$

- vector-isoscalar field
  $\omega^\mu \quad m_\omega \sim 780$ MeV short range repulsion

- scalar-isoscalar field
  $\sigma \quad m_\sigma \sim 550$ MeV (not a phisical, that is, observed particle)

$$\mathcal{L}_0 = \bar{\psi}(i\partial\!\!\!/ - m)\psi + \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m^2\sigma^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega$$

$$F_{\mu\nu} = \partial_\nu\omega_\mu - \partial_\mu\omega_\nu$$

$$\mathcal{L}_{int} = g_\sigma\bar{\psi}\psi\sigma - g_\omega\bar{\psi}\gamma^\mu\psi\omega_\mu$$

Eq. of motion cannot be solved using perturbation theory

$$(\Box + m_\sigma^2)\sigma = g_\sigma\bar{\psi}\psi$$

$$(\Box + m_\omega^2)\omega_\mu - \partial_\mu(\partial_\nu\omega^\nu) = g_\omega\bar{\psi}\gamma_\mu\psi$$

$$[\gamma_\mu(i\partial^\mu - g_\omega\omega^\mu) - (m - g_\sigma\sigma)]\psi = 0$$

$$[i\gamma_\mu(\partial^\mu - g_\omega\omega^\mu) - (m - g_\sigma\sigma)]\psi = 0$$

MFA $\quad \sigma \to \langle\sigma\rangle$

$$\omega_\mu \to \langle\omega_\mu\rangle \to \langle\omega_0\rangle$$

$$(\langle\omega_i\rangle = 0)$$

for example

$$m_\sigma^2\langle\sigma\rangle = g_\sigma\langle\bar{\psi}\psi\rangle$$

$\langle\ \rangle$ = sum over all states belonging to the Fermi sea

$$[(i\partial\!\!\!/ - g_\omega\gamma_0\langle\omega_0\rangle) - (m - g_\sigma\langle\sigma\rangle)]\psi = 0$$

$$\mathcal{L}_{MFA} = \bar{\psi}[\quad]\psi - \frac{1}{2}m_\sigma^2\langle\sigma\rangle^2 + \frac{1}{2}m_\omega^2\langle\omega_0\rangle^2$$

Eq. of motion from energy-momentum tensor

$$T^{\mu\nu} = \frac{\partial\mathcal{L}}{\partial\,\partial_\mu\psi}\partial^\nu\psi + \frac{\partial\mathcal{L}}{\partial\,\partial_\mu\bar{\psi}}\partial^\nu\bar{\psi} - g^{\mu\nu}\mathcal{L}$$

$$\Rightarrow \quad i\bar{\Psi}\gamma^{\mu}\gamma^{\nu}\Psi - g^{\mu\nu}\mathcal{L}$$

EOS from

$$\epsilon = T^{00}$$

$$P = \frac{1}{3}T^{ii}$$

at fixed baryon density $\langle\bar{\Psi}\gamma^{0}\Psi\rangle$

$$\Rightarrow \quad P = P(\epsilon)$$