Most information about atomic nuclei and their constituents (nucleons/quarks) is obtained via accelerators. Consider a "beam" particle of rest mass \( m \), momentum \( \vec{p} \), and kinetic energy \( T \) hitting a "target" particle of size \( d \).

According to standard QM, the beam particles have wave properties, characterized by their de Broglie wavelength

\[ \lambda = \frac{h}{p}. \]

From wave optics, we know that the beam particles can "resolve" an object of diameter \( d \) provided that

\[ \lambda \ll d \quad (1) \]

Typically, one specifies the kinetic energy \( T \) of the beam particle. We use relativistic kinematics to compute \( p \):
From \( E^2 = \frac{p^2 c^2}{m c^2} \) we obtain \( pc = \sqrt{E^2 - (mc^2)^2} \).

\[
\lambda = \frac{\hbar}{p} = \frac{hc}{pc} = \frac{2\pi (\hbar c)}{\sqrt{E^2 - (mc^2)^2}}
\]

with \( \frac{\hbar c}{m} = 197.3 \text{ MeV} \cdot \text{fm} \) \( (2b) \)

Application: Compute \( \lambda \) for nucleon bound in nucleus.

From the Fermi gas model (see section 2.2, p.18) one obtains a max. kinetic energy,

\[
T_{\text{max}} = T_F = 37 \text{ MeV}.
\]

\[
\Rightarrow E_{\text{max}} = T_{\text{max}} + mc^2 = 37 + 939 = 976 \text{ MeV}.
\]

We obtain the \textit{minimum} de Broglie wavelength of a nucleon bound in an atomic nucleus.

\[
\lambda_{\text{min}} = \frac{2\pi (\hbar c)}{\sqrt{E_{\text{max}}^2 - (mc^2)^2}} = \frac{2\pi \times 197.3 \text{ MeV} \cdot \text{fm}}{\sqrt{976^2 - 939^2} \text{ MeV}} = 4.6 \text{ fm}
\]

From scattering with polarized \( e^- \) one obtains the charge distribution of \( p/n \). For the proton, one finds a root-mean square radius:

\[
\langle r^2 \rangle^{1/2} \approx 0.8 \text{ fm} \Rightarrow d = 2r \approx 1.6 \text{ fm}
\]

\[
\Rightarrow \frac{\lambda_{\text{min}}}{d} = \frac{4.6 \text{ fm}}{1.6 \text{ fm}} \approx 3
\]

We see that \( \lambda_{\text{min}} > d \), so the nucleons inside a nucleus "see" each other as point-like particles.