2011 Cross Strait Meeting on Particle Physics and Cosmology

Proton Compton Scattering In Unified Proton-Δ^+ Theory

ZHANG Yun
(Collaboration With Konstantin G. Savvidy)
Physics Department, Nanjing University

April 1, 2011

- Δ^+(1232MeV, $J^P = \frac{3}{2}^+$) freedom must be taken into account in proton Compton scattering

- $\Delta^+(1232\text{MeV}, J^P = \frac{3}{2}^+)$ freedom must be taken into account in proton Compton scattering
- Previously p is treated as spin 1/2 Dirac spinor and Δ^+ in a different theory

- Δ^+(1232MeV, $J^P = \frac{3}{2}^+$) freedom must be taken into account in proton Compton scattering
- Previously *p* is treated as spin 1/2 Dirac spinor and Δ^+ in a different theory

- Our innovation:
  We treat *p* and Δ^+ in a unified spin 3/2 field theory

- $\Delta^+(1232\text{MeV}, J^P = \frac{3}{2}^+)$ freedom must be taken into account in proton Compton scattering
- Previously p is treated as spin 1/2 Dirac spinor and Δ^+ in a different theory
- Our innovation:
  We treat p and Δ^+ in a unified spin 3/2 field theory

How Motivated

- $\Delta^+(1232\text{MeV}, J^P = \frac{3}{2}^+)$ freedom must be taken into account in proton Compton scattering
- Previously p is treated as spin 1/2 Dirac spinor and Δ^+ in a different theory
- Our innovation:
  We treat p and Δ^+ in a unified spin 3/2 field theory

How Motivated

Proton and Δ^+ are both comprised of the same quarks.

- Δ^+(1232MeV, $J^P = \frac{3}{2}^+$) freedom must be taken into account in proton Compton scattering
- Previously p is treated as spin 1/2 Dirac spinor and Δ^+ in a different theory

- Our innovation:
  We treat p and Δ^+ in a unified spin 3/2 field theory

How Motivated

Proton and Δ^+ are both comprised of the same quarks.

Three spin 1/2 particles results in 8 spin states, that for a spin 3/2 particle and two spin 1/2 particles.

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$

$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$

$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$

$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$

$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$

- $\mathcal{L}$ invariant under point transformation:
  $\psi^\mu \to \psi^\mu + \lambda\gamma^\mu\gamma_\nu\psi^\nu$
  $\xi' = \xi(1-4\lambda) - 2\lambda$

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$

$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$

$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$$

- $\mathcal{L}$ invariant under point transformation:
  $\psi^\mu \to \psi^\mu + \lambda\gamma^\mu\gamma_\nu\psi^\nu$
  $\xi' = \xi(1-4\lambda) - 2\lambda$
- $\xi = 2z - 1 \Longrightarrow$
  $p_\mu \psi^\mu(p) = 0.$

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$

$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$

$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$

- $\mathcal{L}$ invariant under point transformation:
  $\psi^\mu \rightarrow \psi^\mu + \lambda\gamma^\mu\gamma_\nu\psi^\nu$
  $\xi' = \xi(1-4\lambda) - 2\lambda$
- $\xi = 2z - 1 \Longrightarrow$
  $p_\mu \psi^\mu(p) = 0.$
- mass spectrum:
  $m_{3/2} = m, m_{1/2} = \frac{m}{6z-2}.$

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu$,

$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu$,

$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$

- $\mathcal{L}$ invariant under point transformation:
  $\psi^\mu \rightarrow \psi^\mu + \lambda\gamma^\mu\gamma_\nu\psi^\nu$
  $\xi' = \xi(1-4\lambda) - 2\lambda$
- $\xi = 2z - 1 \Longrightarrow p_\mu\psi^\mu(p) = 0.$
- mass spectrum: $m_{3/2} = m, m_{1/2} = \frac{m}{6z-2}$.

Original Rarita-Schwinger Theory:

- $z = \frac{(1+3\xi)^2+3(1+\xi)^2}{4}$.

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$

$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$

$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$$

- $\mathcal{L}$ invariant under point transformation:
  $\psi^\mu \to \psi^\mu + \lambda\gamma^\mu\gamma_\nu\psi^\nu$
  $\xi' = \xi(1-4\lambda) - 2\lambda$
- $\xi = 2z - 1 \Longrightarrow$
  $p_\mu \psi^\mu(p) = 0.$
- mass spectrum:
  $m_{3/2} = m, m_{1/2} = \frac{m}{6z-2}.$

Original Rarita-Schwinger Theory:

- $z = \frac{(1+3\xi)^2+3(1+\xi)^2}{4}.$
- no spin 1/2 on shell component.

The Lagrangian

Konstantin G. Savvidy, arXiv:1005.3455:

$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$

$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$

$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu, \zeta = \frac{3\xi^2+2\xi+1}{2}$

- $\mathcal{L}$ invariant under point transformation: $\psi^\mu \to \psi^\mu + \lambda\gamma^\mu\gamma_\nu\psi^\nu$ $\xi' = \xi(1-4\lambda) - 2\lambda$
- $\xi = 2z - 1 \Longrightarrow$ $p_\mu\psi^\mu(p) = 0.$
- mass spectrum: $m_{3/2} = m, m_{1/2} = \frac{m}{6z-2}.$

Original Rarita-Schwinger Theory:

- $z = \frac{(1+3\xi)^2+3(1+\xi)^2}{4}.$
- no spin 1/2 on shell component.
- superluminal propagation

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$
$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$
$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu$$

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$
$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$
$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu$$

Spin 1/2 component wave function:

$u_2(0, +\frac{1}{2}) =$
$\frac{1}{3z-1}(0, 0, 0, 0, 0, \frac{1}{2\sqrt{3}}, 0, -\frac{1}{2\sqrt{3}}, 0, \frac{i}{2\sqrt{3}}, 0, -\frac{i}{2\sqrt{3}}, \frac{1}{2\sqrt{3}}, 0, -\frac{1}{2\sqrt{3}}, 0)^T$

$u_2(0, -\frac{1}{2}) =$
$\frac{1}{3z-1}(0, 0, 0, 0, \frac{1}{2\sqrt{3}}, 0, -\frac{1}{2\sqrt{3}}, 0, -\frac{i}{2\sqrt{3}}, 0, \frac{i}{2\sqrt{3}}, 0, 0, -\frac{1}{2\sqrt{3}}, 0, \frac{1}{2\sqrt{3}})^T$

$u^\mu_{2\,\alpha}(k, \sigma) = L^\mu{}_{\nu\alpha\beta}(k, M) u^\nu_{2\,\beta}(0, \sigma)$
$L^\mu{}_{\nu\alpha\beta} = LV^\mu{}_\nu \otimes LS_{\alpha\beta}$
LV, LS: boost matrix for vector and dirac spinor fields respectively.

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$
$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$
$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu$$

$$LV = \begin{pmatrix} \frac{E}{M} & \frac{k_1}{M} & \frac{k_2}{M} & \frac{k_3}{M} \\ \frac{k_1}{M} & 1 + (\frac{E}{M} - 1)\frac{k_1^2}{|\vec{k}|^2} & (\frac{E}{M} - 1)\frac{k_1 k_2}{|\vec{k}|^2} & (\frac{E}{M} - 1)\frac{k_1 k_3}{|\vec{k}|^2} \\ \frac{k_2}{M} & (\frac{E}{M} - 1)\frac{k_2 k_1}{|\vec{k}|^2} & 1 + (\frac{E}{M} - 1)\frac{k_2^2}{|\vec{k}|^2} & (\frac{E}{M} - 1)\frac{k_2 k_3}{|\vec{k}|^2} \\ \frac{k_3}{M} & (\frac{E}{M} - 1)\frac{k_3 k_1}{|\vec{k}|^2} & (\frac{E}{M} - 1)\frac{k_3 k_2}{|\vec{k}|^2} & (\frac{E}{M} - 1)\frac{k_3^2}{|\vec{k}|^2} \end{pmatrix}$$

$$LS = \frac{1}{\sqrt{2M(E+M)}} \begin{pmatrix} E + M - \vec{k}\cdot\vec{\sigma} & 0 \\ 0 & E + M + \vec{k}\cdot\vec{\sigma} \end{pmatrix}$$

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$
$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$
$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu$$

Electrodynamic Interaction

$$p_\mu \to p_\mu - A_\mu \Rightarrow \mathcal{L}_I = A_\mu J^\mu = e\bar{\psi}_\nu \Gamma^{\mu\nu}{}_\rho \psi^\rho A_\mu,\ p_\mu J^\mu = 0$$
$$\Gamma^{\mu\nu}{}_\rho = \gamma^\mu \delta^\nu{}_\rho + \xi(\gamma^\nu \delta^\mu{}_\rho + \gamma_\rho \eta^{\nu\mu}) + \zeta\gamma^\nu\gamma^\mu\gamma_\rho$$

$$\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu,$$
$$D^\mu{}_\nu = \gamma^\rho p_\rho \delta^\mu{}_\nu + \xi(\gamma^\mu p_\nu + \gamma_\nu p^\mu) + \zeta\gamma^\mu\gamma^\rho p_\rho \gamma_\nu,$$
$$\Theta^\mu{}_\nu = \delta^\mu{}_\nu - z\gamma^\nu\gamma_\nu$$

Electrodynamic Interaction

$$p_\mu \to p_\mu - A_\mu \Rightarrow \mathcal{L}_I = A_\mu J^\mu = e\bar{\psi}_\nu \Gamma^{\mu\nu}{}_\rho \psi^\rho A_\mu, \; p_\mu J^\mu = 0$$
$$\Gamma^{\mu\nu}{}_\rho = \gamma^\mu \delta^\nu{}_\rho + \xi(\gamma^\nu \delta^\mu{}_\rho + \gamma_\rho \eta^{\nu\mu}) + \zeta\gamma^\nu\gamma^\mu\gamma_\rho$$

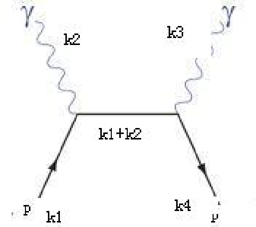
Comparison

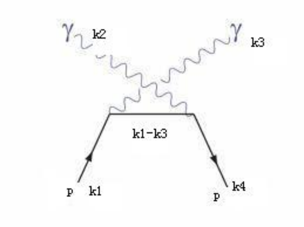
V. Pascalutsa and O. Scholten, Nucl. Phys. A591, 658 (1995)

$$\mathcal{L}_I^1 = \frac{iG_1}{2m}\bar{\psi}^\alpha \Theta_{\alpha\mu}(z_f)\gamma_\nu\gamma_5 T_3 N F^{\nu\mu} + h.c.$$
$$\mathcal{L}_I^2 = \frac{-G_2}{(2m)^2}\bar{\psi}^\alpha \Theta_{\alpha\mu}(z_f)\gamma_5 T_3 \partial_\mu N F^{\nu\mu} + h.c.$$
$$\mathcal{L}_I^3 = \frac{-G_3}{(2m)^2}\bar{\psi}^\alpha \Theta_{\alpha\mu}(z_f)\gamma_5 T_3 N \partial_\nu F^{\nu\mu} + h.c.$$

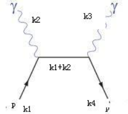
In $\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu$,we identify spin 3/2 component as Δ^+ and spin 1/2 component as proton.

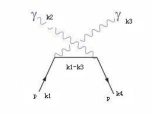
Proton Compton Scattering Feynman Diagrams





In $\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu$,we identify spin 3/2 component as Δ^+ and spin 1/2 component as proton.

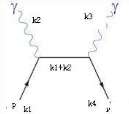


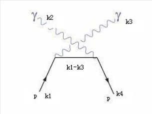


Feynman Rules

Out line: $u_2(k_1)$, $\bar{u}_2(k_4)$
Vertex: $\Gamma^{\mu\nu}{}_\rho = \gamma^\mu \delta^\nu{}_\rho + \xi(\gamma^\nu \delta^\mu{}_\rho + \gamma_\rho \eta^{\nu\mu}) + \zeta \gamma^\nu \gamma^\mu \gamma_\rho$
Propogator: $[D^\mu{}_\nu - m\Theta^\mu{}_\nu]^{-1}$

In $\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu$,we identify spin 3/2 component as Δ^+ and spin 1/2 component as proton.



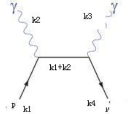


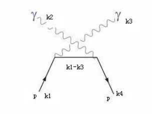
Feynman Rules

Out line: $u_2(k_1)$, $\bar{u}_2(k_4)$
Vertex: $\Gamma^{\mu\nu}{}_\rho = \gamma^\mu \delta^\nu{}_\rho + \xi(\gamma^\nu \delta^\mu{}_\rho + \gamma_\rho \eta^{\nu\mu}) + \zeta \gamma^\nu \gamma^\mu \gamma_\rho$
Propogator: $[D^\mu{}_\nu - m\Theta^\mu{}_\nu]^{-1}$

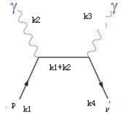
Two poles in propogator:
$p^2 = m^2$: Δ^+ pole
$p^2 = M^2$: proton pole($M = \frac{m}{6z-2}$)

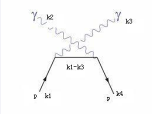
In $\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu$,we identify spin 3/2 component as Δ^+ and spin 1/2 component as proton.





In $\mathcal{L} = \bar{\psi}_\mu [D^\mu{}_\nu - m\Theta^\mu{}_\nu]\psi^\nu$,we identify spin 3/2 component as Δ^+ and spin 1/2 component as proton.





Amplitude and Differential Cross Section

$$\mathcal{M}_{\sigma_1,\sigma_4,\lambda_2,\lambda_3} = ie^2(\bar{u}_{2\eta}(k_4,\sigma_4)\Gamma^{\mu\eta}{}_\rho S^\rho{}_\gamma(k_1-k_3)\Gamma^{\nu\gamma}{}_\kappa u_2{}^\kappa(k_1,\sigma_1)$$
$$+\bar{u}_{2\eta}(k_4,\sigma_4)\Gamma^{\nu\eta}{}_\rho S^\rho{}_\gamma(k_1+k_2)\Gamma^{\mu\gamma}{}_\kappa u_2{}^\kappa(k_1,\sigma_1))$$
$$\epsilon_\mu(k_2,\lambda_2)\epsilon^*_\nu(k_3,\lambda_3)$$

$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2}\left(\frac{\omega'}{\omega}\right)^2 \sum_{\sigma_1,\sigma_4,\lambda_2,\lambda_3} |\mathcal{M}|^2$$

Low energy expansion agrees with F.E.Low,PR96,1428(1954):

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2(1+\cos^2\theta)}{2M^2} - \frac{\alpha^2(1-\cos\theta)(1+\cos^2\theta)}{M^3}\omega + O(\omega^2)$$

Low energy expansion agrees with F.E.Low,PR96,1428(1954):

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2(1+\cos^2\theta)}{2M^2} - \frac{\alpha^2(1-\cos\theta)(1+\cos^2\theta)}{M^3}\omega + O(\omega^2)$$

Difference at $O(\omega^2)$ from Dirac theory affects the extraction of polarizability parameters($\bar{\alpha}$,$\bar{\beta}$) from experiment($\delta\bar{\alpha}$,$\delta\bar{\beta} = O(1)$)

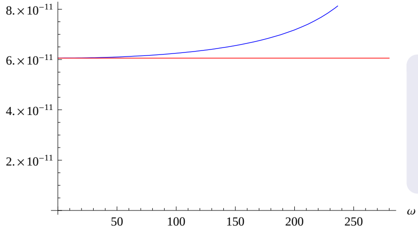
$$\frac{d\sigma}{d\Omega} = (\frac{d\sigma}{d\Omega})_{\text{Born}} - \frac{\alpha\omega^2}{M}(\frac{\bar{\alpha}+\bar{\beta}}{2}(1+\cos\theta)^2 + \frac{\bar{\alpha}-\bar{\beta}}{2}(1-\cos\theta)^2)$$

Low energy expansion agrees with F.E.Low,PR96,1428(1954):

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2(1+\cos^2\theta)}{2M^2} - \frac{\alpha^2(1-\cos\theta)(1+\cos^2\theta)}{M^3}\omega + O(\omega^2)$$

Difference at $O(\omega^2)$ from Dirac theory affects the extraction of polarizability parameters($\bar{\alpha}$,$\bar{\beta}$) from experiment($\delta\bar{\alpha}$,$\delta\bar{\beta} = O(1)$)

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} - \frac{\alpha\omega^2}{M}\left(\frac{\bar{\alpha}+\bar{\beta}}{2}(1+\cos\theta)^2 + \frac{\bar{\alpha}-\bar{\beta}}{2}(1-\cos\theta)^2\right)$$



$\theta = 0$

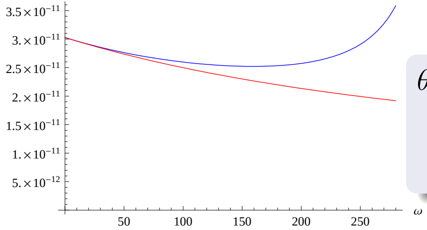
- Blue: current theory
- Red: Dirac theory

Low energy expansion agrees with F.E.Low,PR96,1428(1954):

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2(1+\cos^2\theta)}{2M^2} - \frac{\alpha^2(1-\cos\theta)(1+\cos^2\theta)}{M^3}\omega + O(\omega^2)$$

Difference at $O(\omega^2)$ from Dirac theory affects the extraction of polarizability parameters($\bar{\alpha}$,$\bar{\beta}$) from experiment($\delta\bar{\alpha}$,$\delta\bar{\beta} = O(1)$)

$$\frac{d\sigma}{d\Omega} = (\frac{d\sigma}{d\Omega})_{\rm Born} - \frac{\alpha\omega^2}{M}(\frac{\bar{\alpha}+\bar{\beta}}{2}(1+\cos\theta)^2 + \frac{\bar{\alpha}-\bar{\beta}}{2}(1-\cos\theta)^2)$$



$\theta = \frac{\pi}{2}$

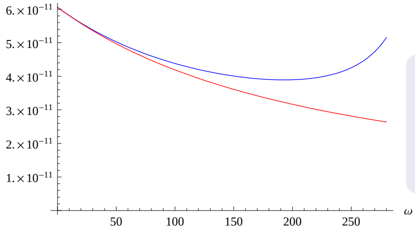
- Blue: current theory
- Red: Dirac theory

Low energy expansion agrees with F.E.Low,PR96,1428(1954):

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2(1+\cos^2\theta)}{2M^2} - \frac{\alpha^2(1-\cos\theta)(1+\cos^2\theta)}{M^3}\omega + O(\omega^2)$$

Difference at $O(\omega^2)$ from Dirac theory affects the extraction of polarizability parameters($\bar{\alpha}$,$\bar{\beta}$) from experiment($\delta\bar{\alpha}$,$\delta\bar{\beta} = O(1)$)

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} - \frac{\alpha\omega^2}{M}\left(\frac{\bar{\alpha}+\bar{\beta}}{2}(1+\cos\theta)^2 + \frac{\bar{\alpha}-\bar{\beta}}{2}(1-\cos\theta)^2\right)$$



$\theta = \pi$

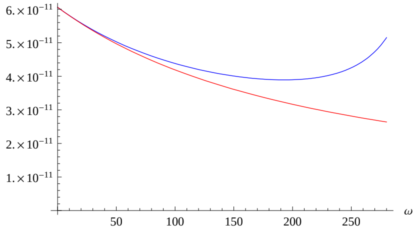
- Blue: current theory
- Red: Dirac theory

Low energy expansion agrees with F.E.Low,PR96,1428(1954):

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2(1+\cos^2\theta)}{2M^2} - \frac{\alpha^2(1-\cos\theta)(1+\cos^2\theta)}{M^3}\omega + O(\omega^2)$$

Difference at $O(\omega^2)$ from Dirac theory affects the extraction of polarizability parameters($\bar{\alpha}$,$\bar{\beta}$) from experiment($\delta\bar{\alpha}$,$\delta\bar{\beta} = O(1)$)

$$\frac{d\sigma}{d\Omega} = (\frac{d\sigma}{d\Omega})_{\text{Born}} - \frac{\alpha\omega^2}{M}(\frac{\bar{\alpha}+\bar{\beta}}{2}(1+\cos\theta)^2 + \frac{\bar{\alpha}-\bar{\beta}}{2}(1-\cos\theta)^2)$$



We are not ready to fit experimental data yet, since proton is not a fundamental particle.

Reminiscence

Dirac spinor electrodynamic interaction:

$$\bar{u}(p')[\frac{(p+p')^\mu}{2m}F_1(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2m}F_2(q^2)]u(p)A_\mu \qquad q = p' - p$$

F_1, F_2: form factors.

Reminiscence

Dirac spinor electrodynamic interaction:

$$\bar{u}(p')[\frac{(p+p')^\mu}{2m}F_1(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2m}F_2(q^2)]u(p)A_\mu \qquad q = p' - p$$

F_1, F_2: form factors.

Our Task

Find (all) possible ${\Gamma^{\mu\nu}}_\rho(p,p')$ in $\bar{\psi}_\nu(p'){\Gamma^{\mu\nu}}_\rho(p,p')\psi^\rho(p)A_\mu$

Gauge Invariance: $q_\mu\bar{\psi}_\nu(p'){\Gamma^{\mu\nu}}_\rho(p,p')\psi^\rho(p) = 0$

Our Task

Find (all) possible $\Gamma^{\mu\nu}{}_{\rho}(p,p')$ in $\bar{\psi}_{\nu}(p')\Gamma^{\mu\nu}{}_{\rho}(p,p')\psi^{\rho}(p)A_{\mu}$
Gauge Invariance: $q_{\mu}\bar{\psi}_{\nu}(p')\Gamma^{\mu\nu}{}_{\rho}(p,p')\psi^{\rho}(p) = 0$

Structures We Have Found

$\Gamma^{\mu\nu}{}_{\rho}(p,p') =$

Scalar Type

$\eta^{\nu}{}_{\rho}(p+p')^{\mu}$ $\times$ $\eta^{\nu}{}_{\rho}\gamma^{5}(p+p')^{\mu}$

$\gamma^{\nu}\gamma_{\rho}(p+p')^{\mu}$ $\times$ $\gamma^{\nu}\gamma_{\rho}\gamma^{5}(p+p')^{\mu}$

Our Task

Find (all) possible $\Gamma^{\mu\nu}{}_{\rho}(p,p')$ in $\bar{\psi}_{\nu}(p')\Gamma^{\mu\nu}{}_{\rho}(p,p')\psi^{\rho}(p)A_{\mu}$
Gauge Invariance: $q_{\mu}\bar{\psi}_{\nu}(p')\Gamma^{\mu\nu}{}_{\rho}(p,p')\psi^{\rho}(p) = 0$

Structures We Have Found

$\Gamma^{\mu\nu}{}_{\rho}(p,p') =$

Vector Type

$\eta^{\nu}{}_{\rho}\gamma^{\mu}$	$\times$	$\gamma^{\nu}\eta^{\mu}{}_{\rho} - \gamma_{\rho}\eta^{\mu\nu}$
$\gamma^{\nu}\gamma^{\mu}\gamma_{\rho}$	$\times$	$\gamma^{5}(\cdots)$
$\gamma^{\nu}\eta^{\mu}{}_{\rho} + \gamma_{\rho}\eta^{\mu\nu}$		

Our Task

Find (all) possible $\Gamma^{\mu\nu}{}_{\rho}(p, p')$ in $\bar{\psi}_{\nu}(p')\Gamma^{\mu\nu}{}_{\rho}(p, p')\psi^{\rho}(p)A_{\mu}$
Gauge Invariance: $q_{\mu}\bar{\psi}_{\nu}(p')\Gamma^{\mu\nu}{}_{\rho}(p, p')\psi^{\rho}(p) = 0$

Structures We Have Found

$\Gamma^{\mu\nu}{}_{\rho}(p, p') =$

Tensor Type

$\tau^{\mu\lambda\nu}{}_{\rho}q_{\lambda}$
$\sigma^{\mu\lambda}\eta^{\nu}{}_{\rho}q_{\lambda}$
$\sigma^{\mu\lambda}\sigma^{\nu}{}_{\rho}q_{\lambda}$
$\tau^{\mu\lambda\nu}{}_{\kappa}\sigma^{\kappa}{}_{\rho}q_{\lambda}$
$\tau^{\mu\lambda\kappa}{}_{\rho}\sigma^{\nu}{}_{\kappa}q_{\lambda}$

$\times \quad \gamma^5(\cdots)$

Structures We Have Found

Scalar Type:

$\eta^{\nu}{}_{\rho}(p+p')^{\mu}$

$\gamma^{\nu}\gamma_{\rho}(p+p')^{\mu}$

Vector Type:

$\eta^{\nu}{}_{\rho}\gamma^{\mu}$

$\gamma^{\nu}\gamma^{\mu}\gamma_{\rho}$

$\gamma^{\nu}\eta^{\mu}{}_{\rho}+\gamma_{\rho}\eta^{\mu\nu}$

Tensor Type:

$\tau^{\mu\lambda\nu}{}_{\rho}q_{\lambda}$

$\sigma^{\mu\lambda}\eta^{\nu}{}_{\rho}q_{\lambda}$

$\sigma^{\mu\lambda}\sigma^{\nu}{}_{\rho}q_{\lambda}$

$\tau^{\mu\lambda\nu}{}_{\kappa}\sigma^{\kappa}{}_{\rho}q_{\lambda}$

$\tau^{\mu\lambda\kappa}{}_{\rho}\sigma^{\nu}{}_{\kappa}q_{\lambda}$

Our Claim

The scalar, vector and tensor type vertexes we have found comprise the most general set of vertexes that are at most first order in q, and dominate the low energy Compton scattering amplitude.

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
    - * Lagrangian;

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - * Lagrangian;
  - * spin 1/2 solution;

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - * Lagrangian;
  - * spin 1/2 solution;
  - * electrodynamic interaction

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - Lagrangian;
  - spin 1/2 solution;
  - electrodynamic interaction
- Proton Compton scattering amplitude and cross section

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - Lagrangian;
  - spin 1/2 solution;
  - electrodynamic interaction
- Proton Compton scattering amplitude and cross section
  - Low energy limit;

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - Lagrangian;
  - spin 1/2 solution;
  - electrodynamic interaction
- Proton Compton scattering amplitude and cross section
  - Low energy limit;
  - comparison with Dirac theory calculation

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - * Lagrangian;
  - * spin 1/2 solution;
  - * electrodynamic interaction
- Proton Compton scattering amplitude and cross section
  - * Low energy limit;
  - * comparison with Dirac theory calculation
- Constructing general electrodynamic interaction vertexes

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  - * Lagrangian;
  - * spin 1/2 solution;
  - * electrodynamic interaction
- Proton Compton scattering amplitude and cross section
  - * Low energy limit;
  - * comparison with Dirac theory calculation
- Constructing general electrodynamic interaction vertexes
  - * Scalar, vector and tensor type vertexes;

Summary

- Motivation for unifying proton and Δ^+ in a generalized Rarita-Schwinger theory, and the model
  * Lagrangian;
  * spin 1/2 solution;
  * electrodynamic interaction
- Proton Compton scattering amplitude and cross section
  * Low energy limit;
  * comparison with Dirac theory calculation
- Constructing general electrodynamic interaction vertexes
  * Scalar, vector and tensor type vertexes;
  * claiming that other vertexes are higher order in q

Thank you all!