Electron Scattering Experiments

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Topics in High Energy Physics

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Electron Scattering?

- Send electron beam on various target
- Detect scattered electrons
- Depending on the detection of other particles
  - No more detection, only scattered electrons are detected - *inclusive* reaction

$$A(e, e')X \qquad \text{with unknown state } X$$

  - Complete detection of all the particles in the final state - *exclusive* reaction

$$A(e, e'B)C \qquad \text{rarely} \quad A(e, e'BC)D$$

  - Detection of one more particle other than the electron - *semi-inclusive* reaction

$$A(e, e'B)X$$

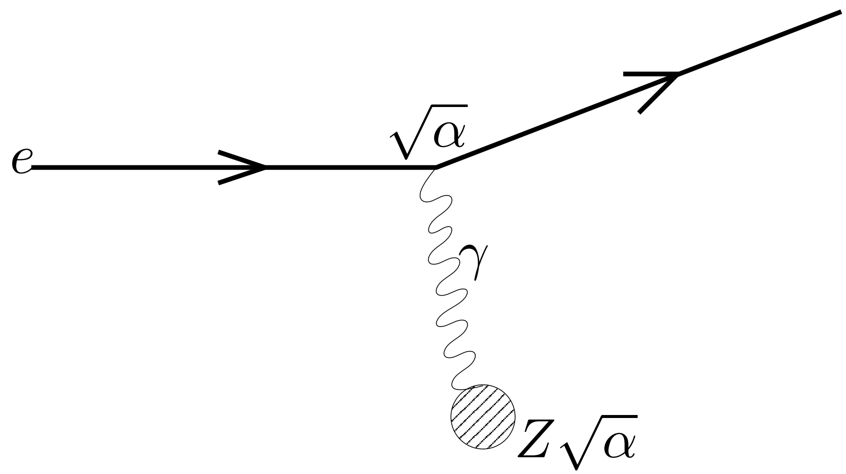
Why use electrons?

- One of *elementary* particles (so far)
  - point-like *without* internal structure
  - stable particle
  - well-known properties (mass, charge, spin *etc*)
  - well-known interaction with other elementary particles (*e.g.* quarks)
- Relatively easy to prepare (compare to other leptons or quarks)
- Easy to detect
- In general, experiments are quite *clean* compared to those with hadron beams (remember the photo of ^{197}Au + ^{197}Au)

Drawbacks

- Interaction limited to *electromagnetic*
  "couples only to charges"
- Too small mass - not *easy* to accelerate to very high energies - due to energy loss from the *radiation* (kind of synchrotron radiation)
- The results need to be corrected for radiative effects during the reaction - *radiative corrections*

Electron scattering from Coulomb potential

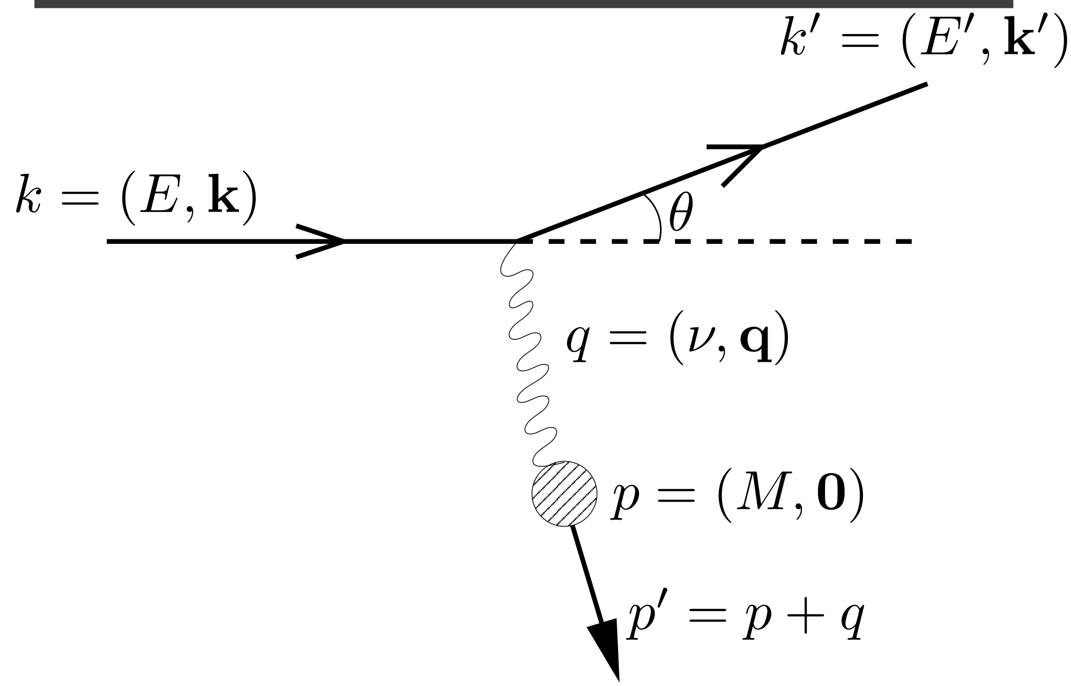


- Generally called *Rutherford* scattering
- Cross section is given by

$$\frac{d\sigma}{d\Omega} = \frac{Z^2\alpha^2}{4E^2}\frac{1}{\sin^4(\theta/2)}$$

- $1/[E^2\sin^4(\theta/2)]$ is a feature from Coulomb potential

Kinematics in the Lab frame



$$
\begin{aligned}
q &= k - k' \\
q^2 &= (k - k')^2 \\
&\simeq -2k \cdot k' = -2EE'(1 - \cos\theta) = -4EE' \sin^2 \frac{\theta}{2}
\end{aligned}
$$

Kinematics (Cont)

- *Elastic* scattering: $p'^2 = p^2 = M^2$

$$q^2 = -2p \cdot q = -2\nu M \qquad \text{so} \qquad \nu = E - E' = -\frac{q^2}{2M}$$

- *Inelastic* scattering: $p'^2 \neq M^2$

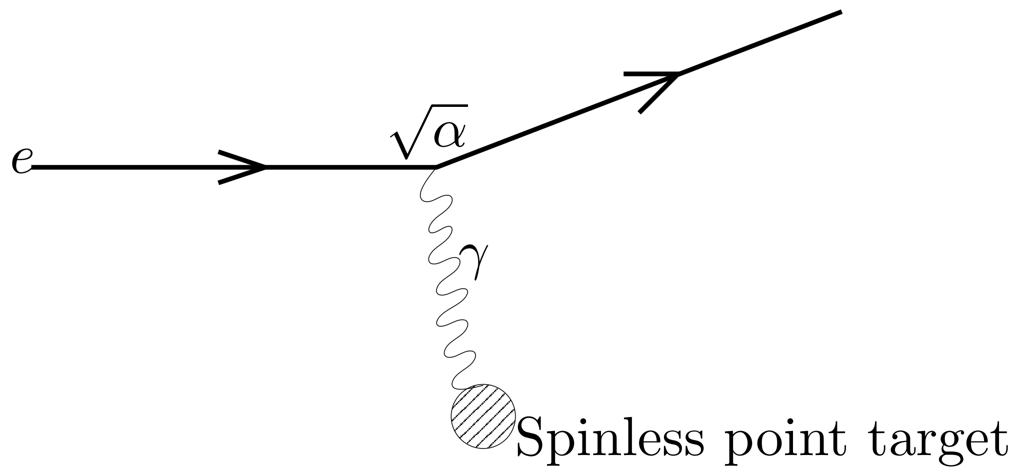
$$W \equiv p'^2 = (p+q)^2 = M^2 + 2M\nu - q^2$$

- Usually, define $Q^2 = -q^2$
- Then elastic scattering implies $Q^2 = 2M\nu$ or

$$1 = \frac{Q^2}{2M\nu} \equiv x$$

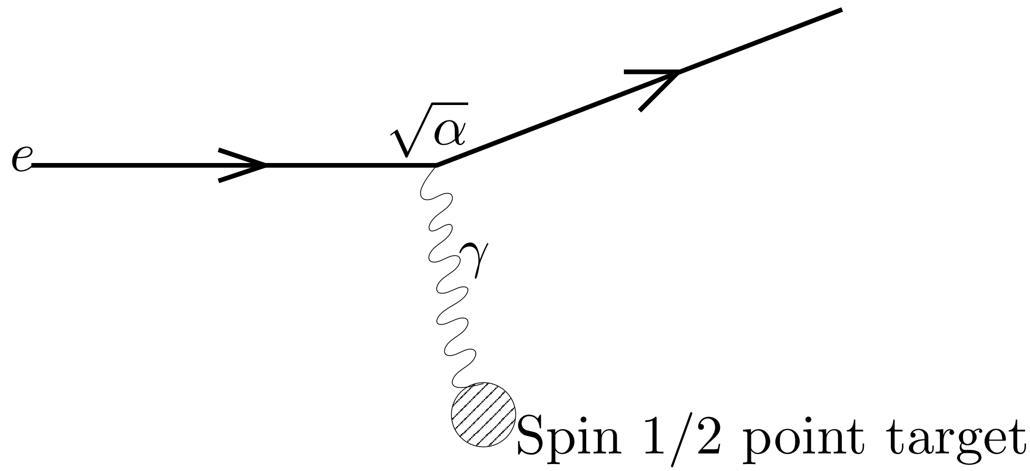
- $x \leq 1$

Electron scattering from spinless point particle



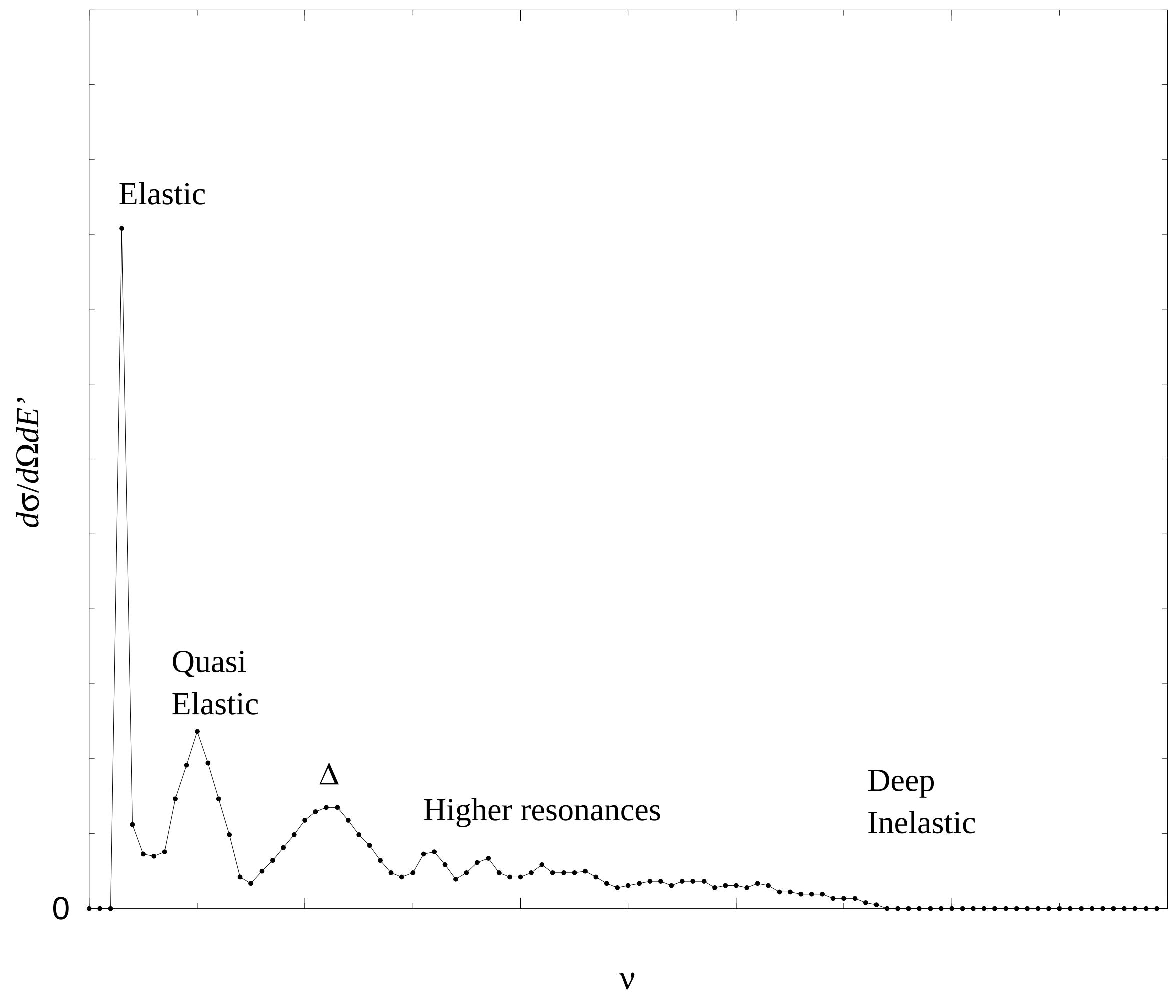
$$\frac{d\sigma}{d\Omega}_{\text{lab}} = \left(\frac{\alpha^2}{4E^2 \sin^4 \frac{\theta}{2}} \right) \frac{E'}{E} \cos^2 \frac{\theta}{2}$$

Electron scattering from spin 1/2 point particle



$$\frac{d\sigma}{d\Omega}_{\rm lab} = \left(\frac{\alpha^2}{4E^2 \sin^4 \dfrac{\theta}{2}} \right) \frac{E'}{E} \left\{ \cos^2 \frac{\theta}{2} - \frac{q^2}{2M^2} \sin^2 \frac{\theta}{2} \right\}$$

Inclusive Electron Scattering



Real and Virtual Photons

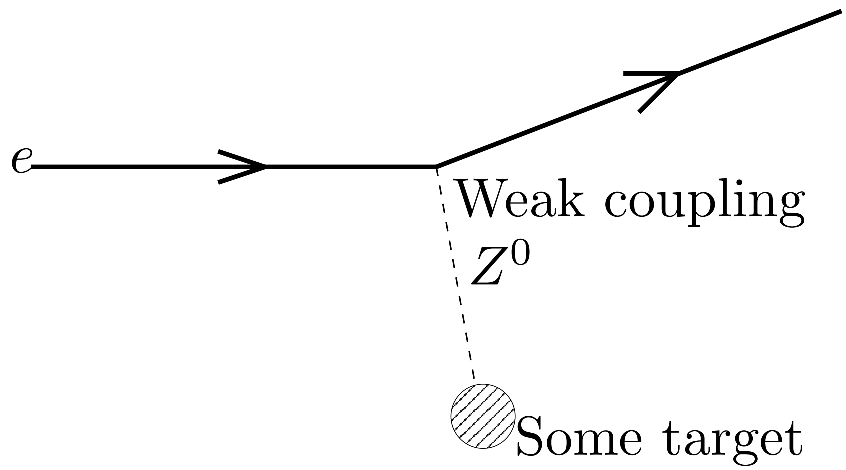
- Real photon has *zero* mass: $Q^2 = 0$
- Virtual photon is just a convenient *tool* to describe the scattering process
- Virtual photon has *non*-zero mass

$$Q^2 > 0 \quad : \quad \text{space-like}$$
$$Q^2 < 0 \quad : \quad \text{time-like}$$

- Real photon has only transverse polarization
- Virtual photon can have longitudinal polarization (due to non-zero mass)

transverse polarization	:	interaction with *magnetization*
longitudinal polarization	:	interaction with *charge*

Not Only Virtual Photon



- Weak interaction violates parity
- Cross sections are different for *left* - *right* scattering
- Experimentally measure $L - R$ *Asymmetry*

$$A = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

- Measure parameters of Standard Model - *particle* physics