OLYMPUS

8.276 Final Poster — Daniel Guetta — guetta@cantab.net

1 Introduction

G_E G_M

- The **electric** and **magnetic form factors**, G_E and G_M describe the **distribution** of "**stuff**" in the **proton**.
- There are a **number of ways** to measure these, which, to date, have led to **inconsistent results**.
- The current theory is that **cross-section measurements** are **contaminated** by **two-photon processes**.
- **OLYMPUS** will attempt to ascertain **to what extent** this is true.

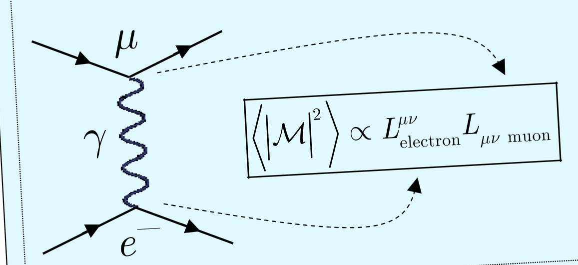
2 Theory

- In theory, if we **know** everything about the **proton**, we should be able to obtain an **analytic expression** for the **form factors**.
- Advances in **lattice QCD techniques** are getting us **closer** and closer to this goal, and results are expected in the **foreseeable future**…
- In the meantime, however, theorists can't help much.

3 Scattering Cross-Sections

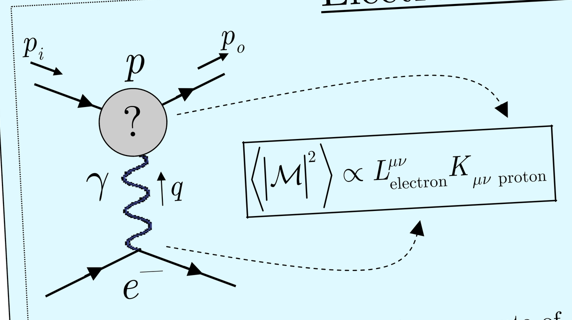
~ Spin Averaged Amplitudes ~

Electron-Muon Scattering



The L are **symmetric tensors** determined using **QED** — one describing the **behaviour** of **each particle** (vertex)

Electron-Proton Scattering



p_i, p_o are the incoming and outgoing momenta of the proton, and q is the momentum transferred by the virtual photon

For **elastic scattering**, L_{electron} remains as before. K_{proton} encodes the (unknown) way the **proton behaves**. This depends on the **form factors**.

~ Form Factors ~

- K is not completely unknown:
  - It must be **symmetric** (since $L^{\mu\nu}$ is symmetric)
  - It can only depend on q, p_i and p_o, and $q = p_o - p_i$.
- **Mathematically**, there are only so many ways of obtaining a **symmetric tensor** from **only two four-vectors**. $K_{\mu\nu}$ can only contain **two independent numbers** — say K_1 and K_2.
- We then obtain the famous **Rosenbluth Formula**:

Fine structure const. — Incident energy of electron — Scattering angle

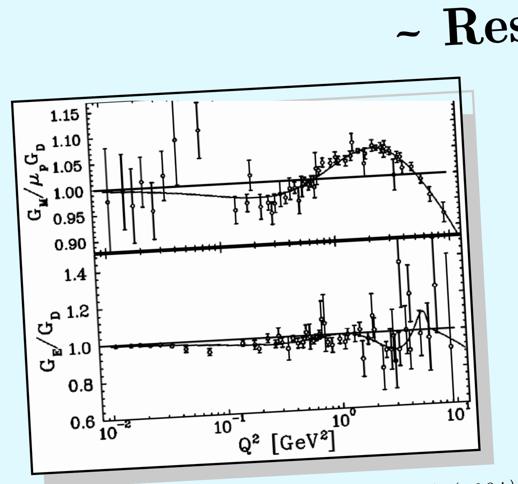
$$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha}{4m_p E\sin^2(\theta/2)}\right)^2 \frac{E'}{E}\left[2K_1\sin^2(\theta/2) + K_2\cos^2(\theta/2)\right]$$

Proton mass — Outgoing energy of electron

- By **experimentally measuring cross sections** at **fixed q** for **a range of angles** and **energies**, we can determine K_1 and K_2. By carrying out these measurements at a **range of q**, we find the functions $K_1(q)$ and $K_2(q)$.
- These are sufficient to determine the **form factors**

$$K_1 = -q^2 G_M^2 \qquad K_2 = (2m_p)^2 \frac{(2m_p)^2 G_E^2 - q^2 G_M^2}{(2m_p)^2 - q^2}$$

~ Results ~



J. Arrington, Phys. Rev. C 69, 022201(R) (2004).

Current data indicates that both **electric** and **magnetic form factors** have the **same dipole distributions** G_D:

$$\frac{G_E}{G_D} = \frac{G_M}{\mu G_D} = 1$$

Such **form factors** indicate that **charge** is **concentrated** in the **centre** of the **proton**, and **decreases exponentially**.

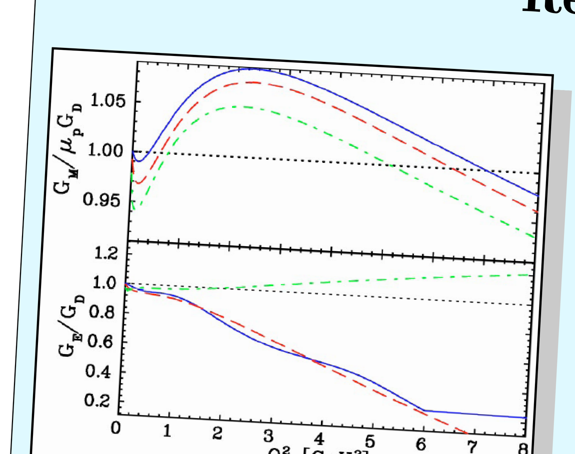
4 Polarised Scattering

- The factors G_E and G_M can also be determined by performing **scattering experiments** using **polarised particles**.
- For example when **polarised electrons** are scattered off **unpolarised protons**, **polarisation transfer** occurs to the proton with **two components** — **parallel** ($P_\parallel$) and **perpendicular** ($P_\perp$) to the **proton momentum** in the **scattering plane**. In fact:

$$\frac{G_E}{G_M} = -\frac{P_\perp}{P_\parallel}\frac{(E+E')}{2m_p}\tan\left(\frac{\theta}{2}\right)$$

- Similarly, carrying out e^-p scattering with spins aligned and anti-aligned and measuring the **difference in cross sections** (the **scattering asymmetry**) allows us to determine the **form factors**.
- A **crucial aspect** of these experiments is that they **only occur** when a **single photon** is **transferred** in the **interaction**.

~ Results ~



J. Arrington, Phys. Rev. C 69, 022201(R) (2004).
Green: cross section measurements
Red/blue: polarisation measurements

Measurements using these method produce **roughly similar results** for G_M but **completely different results** for G_E. Something has gone awry. The measurements even predicts a **node** in G_E near 8 (GeV/c)^2.

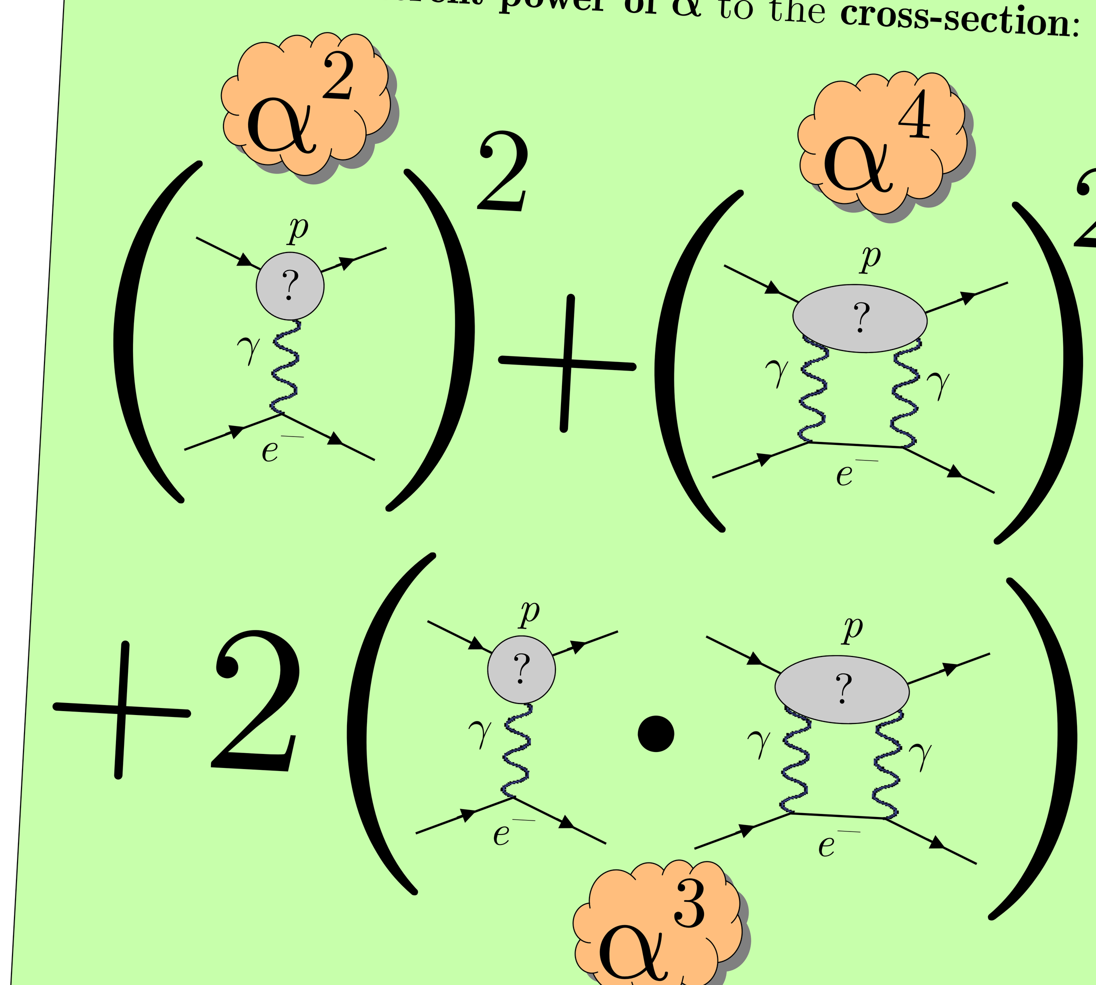
These form factors predict a much **richer inner structure**.

5 Explanation

- A **crucial assumption** in deriving the **Rosenbluth Formula** was that the **Born approximation** applied (ie: only **one photon** was involved in the interaction).
- **Polarisation transfer** only occurs in **one-photon processes**, and does **not** rely on this **approximation**.
- The idea is that the **cross-section measurements** are **polluted** by **second-order interactions**. These render the resulting form-factors **meaningless**, because the entire (already doubtful) **interpretation** of these **measurements** as **fourier transforms** of the **charge distribution** relies heavily on the **assumptions** that **only single-photon processes** are **involved**.

6 Proving it!

- Assuming **second-order processes occur**, **three terms** will appear in the ***ep* scattering cross-section**: one arising **purely from single-photon processes**, one from **purely multi-photon processes** and one from the **interference** of these **two processes**.
- Each **vertex** adds **one power** of the **fine-structure constant** to the cross section. Thus, each term contributes a **different power of α** to the **cross-section**:



- Using a **positron** is effectively equivalent to **time reversal** in the **electron vertices**, and **QED** tells us that **this reverses the sign of the coupling constant α**.
- This makes the **third term flip sign**.
- We can therefore measure the **importance** of **second-order interactions** by measuring the **difference in cross-section** between e^-/p and e^+/p scattering.

7 Practical Details

- Measurements of this kind have **already been made**, but at **low energy** (~ **500 MeV**) and with **poor precision**. The aim of **OLYMPUS** is to make measurements in the **2 GeV range** with **1% precision**.

~ Getting the Particles ~

DESY Website

The experiment will use the **DORIS** storage ring at **DESY** in **Hamburg, Germany**. Because (1) it can be used to **store both** e^- and e^+ at **high energies** *and* (2) the **beams** can be **switched** from e^+ to e^- in **under an hour**. The experiment would involve **installing** an **unpolarised hydrogen gas target** at the **storage ring**.

~ Detecting the results ~

The experiment will use the **BLAST** (Bates Large Acceptance Spectrometer Toroid) **detector** from the **MIT-Bates accelerator**. It is **optimally designed for 1-2 GeV elastic *ep* scattering** because of its **toroidal shape** (the beam can be located in the **centre** of the detector) and its **drift chambers**. Only problem — it's **over 3500 miles away!**

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