Detecting the Elusive Δ^+ Baryon in an Electron-Proton Inelastic Scattering Through its Decay-Products

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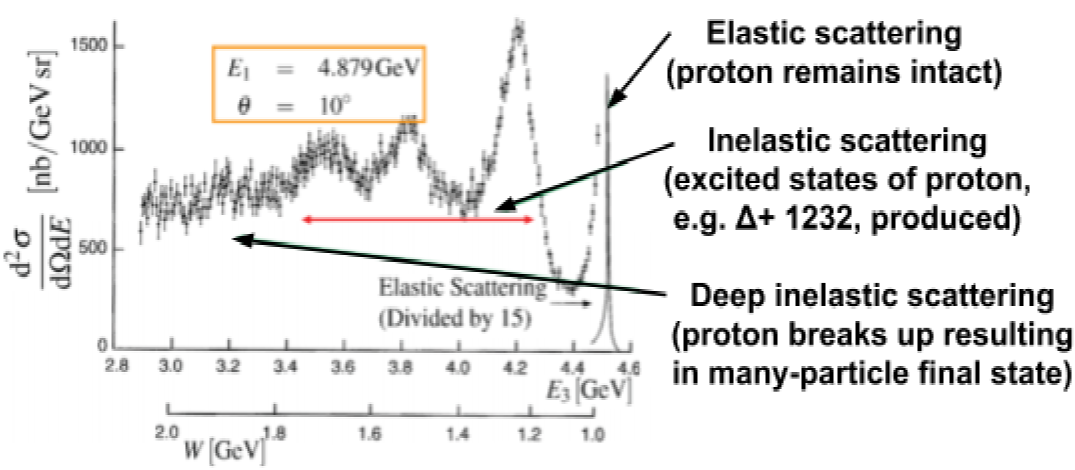
Introduction:

Just as scattering visible light off of a cell using a microscope allows us to examine a cell, a collision between resting **protons** and an **electron beam** produced by a particle accelerator could allow us to "see" subatomic particles and its miscellaneous interactions otherwise unobservable. Such a collision could result in interesting scattering effects, creation of elusive particles whose decay products can be detected and analyzed to trace back the event, which potentially enables us to further identify properties of the particles.

A histogram depicting the collision of a 4.9GeV electron beam with a static source of protons can be seen on Fig 1. The x-axis represents the energy/momentum of the scattered electrons, while the y-axis indicates the number of times an interaction of a specific energy/momentum occurred. The approximate peaks in the band of 3.5~4.2 GeV electrons suggest an inelastic scattering, which we are interested in to investigate.

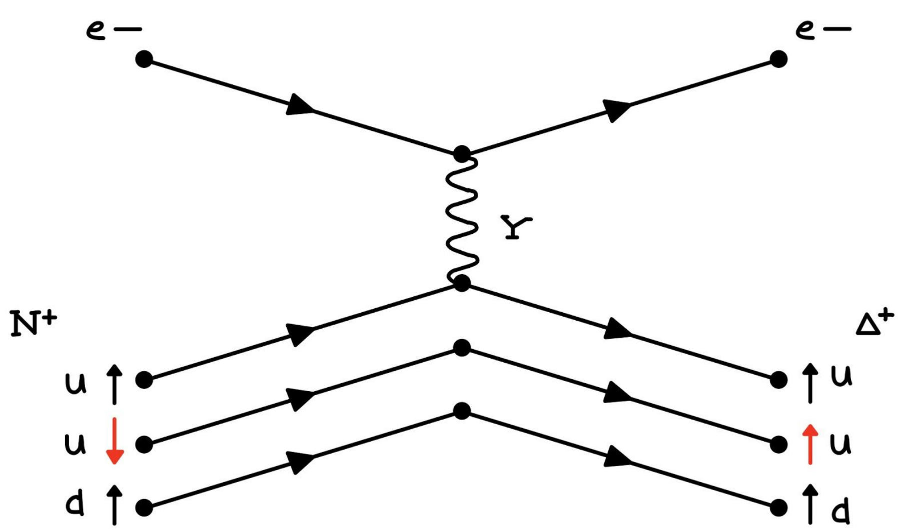


(Fig.1) // Source - W. BARTEL, B. DUDELZAKI, H. KREHBIEL, J. MCELROY. U. MEYER-BERKHOUT, W. SCHMIDT, V. WALTHER ttt and G. WEBER , *ELECTROPRODUCTION OF PIONS NEAR THE A(1236) ISOBAR AND THE FORM FACTOR C*M(q2) OF THE (yNA)-VERTEX - Deutsches Elektronen-Synchrotron DESY, Hamburg. Germany and II. Institut für Experimentalphysik der Universität Hamburg, Germany*

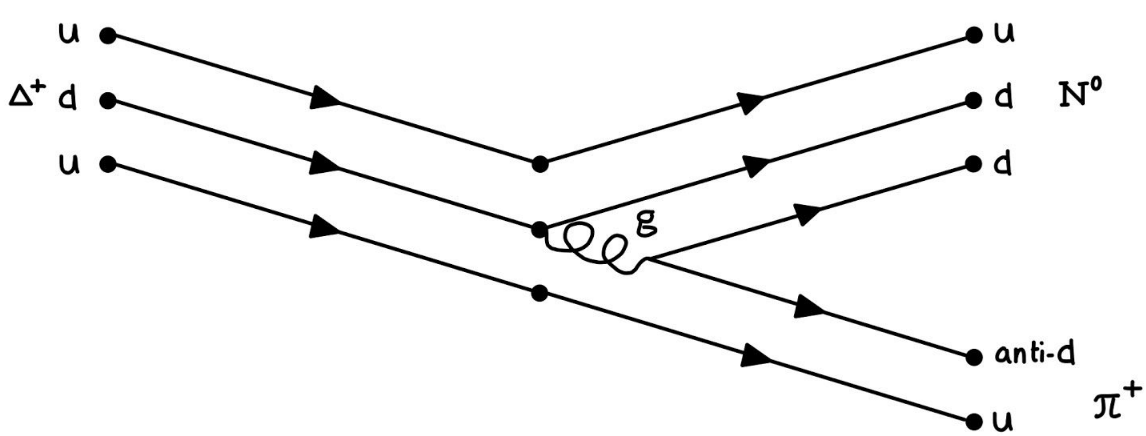
(Fig.1) Thomson, Mark. Particle Physics Handout 6: Deep Inelastic Scattering. The University of Cambridge, Department of Physics, Cavendish Laboratory, 2011, www.hep.phy.cam.ac.uk/~thomson/partIIIparticles/handouts/Handout_6_2011.pdf.

Based on the results of Thomson's experiment, we hypothesize that during inelastic scattering of protons with electrons, **Δ^+ (1232)** is synthesized, due to the inversion of spin on one of the quarks, as shown on Fig. 2. The **Δ^+** would subsequently decay into either a pair of π^0 and proton, or π^+ and neutron. Thereafter, a gluon will be emitted from the d quark in Δ^+ and decay into a pair of d and anti-d quarks resulting in the creation of a π^+ and a neutron as shown in Fig.3. By detecting the π^+, we want to verify that the inelastic scattering of a proton and an electron produces Δ^+, a virtual particle that cannot be detected directly. Consequently, this experiment would enable us to explore the decay mode of Δ^+ and furthermore the fundamental nature of the proton.

(Fig.2) Inelastic scattering of a Proton with an Electron



(Fig.3) Synthesis of a Neutron and a Pion Plus from a decaying Delta plus



Our investigation aims to detect π^+ and match its energy to the final energy of electrons indicated in Fig.1 such that their sum becomes the initial energy of the electrons. Thereby determining that the Δ^+ that is produced in the inelastic scatterings.

Hypothesis:

The sum of the energy and momenta of the particles must be equal before and after the inelastic scattering. As the proton and the neutron will have no KE and momentum, the electron's mass is negligible, and the proton's mass is approximately equal to the neutron's mass, the following must be true:

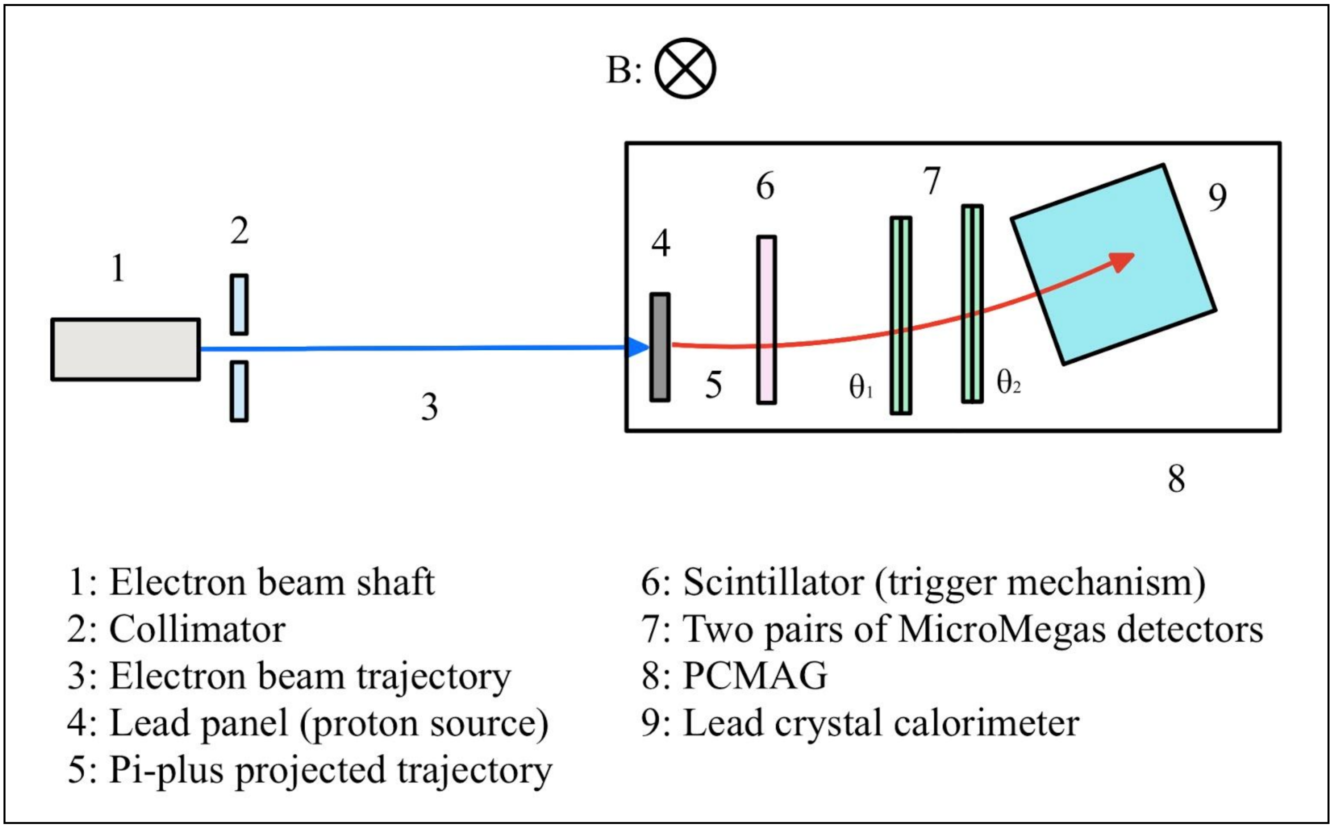
$Equation\ 1:\ m_0(N^+) + KE(e^-initial) = m_0(\Delta^+) + KE(e^-final) = m_0(N^0) + m_0(\pi^+) + KE(\pi^+) + KE(e^-final)$
$\Rightarrow m_0(\Delta^+) = m_0(N^+) + KE(e^-initial) - KE(e^-final)$,
$\Rightarrow m_0(\Delta^+) = m_0(N^0) + m_0(\pi^+) + KE(\pi^+)$, where $m_0(\pi^+) + KE(\pi^+)$ gives the total energy of π^+.
$Equation\ 2:\ p(e^-initial) = p(\pi^+) + p(e^-final)$

Assuming that the electrons travel at nearly the speed of light, the initial velocity of the electrons is equivalent to 1 (C=1). Here, the unknowns are the KE $(= \gamma m_0 - m_0)$ and momentum $(= \gamma m_0 v)$ of π^+ and e^- where $\gamma = \frac{1}{\sqrt{1-v^2}}$. As the KE and momentum are interrelated, we are essentially left with 2 unknowns. Solving these simultaneous equations would give a unique solution for these two unknown variables.

Experimental Setup:

1. First, a **collimator** will be placed in front of the beam shaft to select **4.9 GeV** electrons for the first trial and **6.3GeV** for the second trial.
2. A **PCMAG** will be placed along the beam axis, which will bend the trajectories of the π^+ and separate them from the scattered electrons with a negative charge. According to Flemming's rule, the π^+ will curve to the left when facing the lead panel from the electron beam shaft, and thus the detectors will be placed behind and to the left of the lead panel. The proton source and the detectors (mentioned in step 3-6) will be placed inside the PCMAG to enable direct π^+ detection.
3. A **lead panel** (dimension 200*200*1mm) will be placed first thing in PCMAG as a target. It will serve as the proton source for the electron-proton scattering.
4. Next, a **scintillator** will be placed behind the lead panel such that it covers the predicted trajectories of the π^+. Upon detecting the incident charged particles, the scintillator will transmit electrical signals to the succeeding detectors and initiate the measurement of the particle's momentum and energy.
5. Behind the scintillator, **2 pairs of MicroMegas detectors** will be placed to measure the angles (θ_1 and θ_2 in the diagram) by which the π^+ are deflected in a magnetic field to determine their momentum.
6. Finally, a **Lead crystal calorimeter** will measure the energy of the π^+.

Experimental Set-up Diagram:



The obtained values of charge, momentum, and energy will enable us to determine whether the particles we have detected are indeed π^+.

The mean lifetime of π^+ at rest is approximately $2.6 \cdot 10^{-8}$ seconds (M. Tanabashi et al, PDG, 2019). Considering the effects of length contraction and time dilation, we predict that the π^+ produced could travel a range of distances from **38.4m to 77.7m** before decaying. Therefore. we do not need to worry about π^+ decaying before its direct detection. The calculations to reach this conclusion are shown below.

$Energy\ range\ of\ \pi^+ = Initial\ energy\ of\ e^- - final\ energy\ of\ e^-$

$= 4.9GeV - (4.2\ to\ 3.5GeV)$

$= 0.7Gev\ to\ 1.4Gev$

$KE\ of\ \pi^+ = total\ energy\ - rest\ mass$

$= (700MeV\ \ to\ 1400MeV) - 139.6MeV$

$= 560.4\ to\ 1260.4MeV$

$KE = m_0(\gamma - 1),\ where\ c = 1$

$KE = m_0(\frac{1}{\sqrt{1-v^2}} - 1)$

$Rearranging\ this\ gives:\ v\ of\ \pi^+ = \sqrt{1 - (\frac{m_0}{KE+m_0})^2}$

$Using\ the\ above\ values,\ range\ of\ v\ of\ \pi^+ =$ **<u>0.980C to 0.995C</u>**

Using the equation for length contraction, the actual length covered by π^+ from the observer's perspective can be calculated:

$d = \frac{d'}{\sqrt{1-v^2}}$, $d' = vt$, *where* t = *average lifetime of pion and* d' = *distance travelled from* π^+ *perspective*,

$d' = 7.64m$ *to* $7.76m$, *and* d = **38.4m to 77.7m.**

Motivation:

With each member of our team coming from different corners of the world, we are invested in the values of cultural diversity in international collaboration - qualities that lie at the heart of the groundbreaking work of CERN and DESY. Furthermore, our team demonstrates an academic interest in various disciplines, chief among them Particle Physics. To indulge our curiosity, we created a Beamline-club at our school, passing on to younger students the opportunity to study beyond the scope of a classroom. At the same time, many of us conducted internships at CERN, where, among other things, we reflected upon implications of the confirmation of the existence of the Higgs Boson with distinguished particle physicist John Ellis. As a team, we visited CERN twice, discussing our proposal with editor-in-chief of the *CERN Courier* Mark Rayner. These formative experiences allowed us to gain insight into the work ethic, curiosity and creativity that drive cutting-edge research at CERN and DESY. We admire the skills of Particle Physicists and aspire to follow in their footsteps, using our creativity and problem-solving skills.

Given these experiences, backgrounds, levels of skill, and overarching passion for particle physics, we feel that DESY/BL4S would act as a catalyst through which we may grow as aspiring scientists and individuals through the culmination of a long-term collaborative and scientific endeavour.

Work Cited:

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