MEASUREMENT OF THE $\Sigma^-$ CHARGE RADIUS AT SELEX

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ON BEHALF OF THE SELEX COLLABORATION

The charge radii of $\Sigma^-$ and $\pi^-$ have been determined by direct elastic scattering on shell electrons. The measurement was performed in the framework of the SELEX (E781) charm hadroproduction experiment at Fermilab which employs a 600 GeV/$c$ high-intensity $\Sigma^-$/$\pi^-$ beam and a three-stage magnetic spectrometer covering $0.1 \leq x_F \leq 1.0$. Scattering angles and momenta of both hadron and electron were measured with high precision using silicon microstrip detectors, thus allowing for a segmented solid target. Two TRDs provided full particle identification. A preliminary result for the $\Sigma^-$ charge radius for a four-momentum transfer squared of $0.03 \text{ GeV}^2/c^2 \leq Q^2 \leq 0.16 \text{ GeV}^2/c^2$ will be reported. In a parallel analysis the $\pi^-$ charge radius has been determined for $0.03 \text{ GeV}^2/c^2 \leq Q^2 \leq 0.2 \text{ GeV}^2/c^2$, and is found to be consistent with previous experiments.

1 Introduction

We report here on first results of a measurement of the $\Sigma^-$ and $\pi^-$ charge radii by direct elastic scattering off atomic shell electrons.

Hadrons as we understand them today are composite systems which we characterize by their static properties. One static property which reflects the phenomenon unique to hadrons – quark confinement – is the size of the particle.

The definition of the radius of a hadron depends on the probe used to measure it. A strong-interaction mean squared radius can be extracted from hadron-proton collisions. The hadron-electron interaction, on the other hand, yields the mean squared charge radius: Elastic scattering of an electron off a charged hadron is modified from a point interaction by the form factor $F(Q^2)$ where $Q^2$ is the four-momentum transfer squared. At zero momentum transfer
the mean squared charge radius is related to the slope of the form factor by
\[
\langle r^2 \rangle = -6h^2 \frac{dF(Q^2)}{dQ^2} \bigg|_{Q^2=0}.
\]

Unfortunately, charge radii are known only for five different hadrons so far. The fact that the \( K^- \) radius has been found to be smaller than that of the \( \pi^- \) by \( \sim 0.1 \text{ fm}^2 \) suggests that the size of a hadron is related to the flavor composition of its constituent quarks. There is supporting evidence from a study of strong interaction radii which finds that replacing an \( u \) or \( d \) quark by a \( s \) quark in a baryon decreases its radius by approximately \( 0.08 \text{ fm}^2 \). Consequently the \( \Sigma^- \) radius should be smaller than the proton radius, and larger than the \( \Xi^- \). The definition of a strong-interaction radius, however, is model-dependent. The significance of the above observation is therefore limited unless validated by a systematic study of hyperon charge radii.

2 Experimental setup

The 800 GeV/c proton beam from the Fermilab Tevatron was used to produce a beam consisting to approximately equal parts of \( \Sigma^- \) and \( \pi^- \) at 600 GeV/c with a momentum spread of \( \pm 8 \% \). The primary objective of the experiment being the hadroproduction and spectroscopy of charm baryons in the forward hemisphere, \textsc{Selex} was laid out as a 3-stage magnetic spectrometer as shown in Fig. 1. Beam particles were identified by a transition radiation detector (BTRD). Interactions took place in a target stack of two Cu and three C
foils adding up to 5% of an interaction length for protons. Downstream of
the targets 20 silicon planes of 20-25 μm strip pitch provided good vertex
resolution.

The M1 and M2 magnets implemented momentum deflections of
2.5 GeV/c and 15 GeV/c, respectively. Each stage of the spectrometer was
equipped with proportional and drift chambers for tracking and a lead glass
calorimeter (ECAL). In addition, 50 μm pitch silicon detectors were used
close to the beam axis downstream of the M1 and M2 magnets to improve the
resolution for high momenta. A second transition radiation detector (ETRD)
provided electron identification. SELEX was also equipped with a ring-imaging
Čerenkov counter (RICH) for separation of p, K, and π. A third spectrometer
stage aided in the reconstruction of large-momentum Λ. A hadronic calorimeter
(NCAL) concluded the setup.

For hadron-electron elastic scattering, two hits in the negative and none
in the positive half of a hodoscope downstream of the second magnet in co-
incidence with a multiplicity of two in a set of scintillation counters 3 cm
downstream of the target constituted a valid trigger condition. The typical
trigger rate at this level was 3000 per 20-second spill at a beam rate of 10^7
particles per spill. An online filter performed a preliminary track recon-
struction in the M2 spectrometer. Requiring at least one track with negative and
none with positive slope together with other conditions crucial to a com-
plete reconstruction reduced this sample by a factor of 1:1.7

3 Data Analysis

In the 1997 run SELEX has recorded 215 million candidates for hadron-electron
scattering with Σ^-/π^- -beam. In preparation for a first analysis with the
software tools available at that time the negative-beam sample was stripped
to 10 % of its original size by cutting on an electron signature in the ETRD,
unambiguous identification of the beam particle by the BTRD, and a two-
negative-track event topology in the M2 spectrometer. A second-stage strip
required a two-prong vertex, again reducing the sample by a factor of 10.

Out of the stripped data sample described above, 12,000 Σ^- - electron and
26,000 π^- - electron elastic scattering events were extracted. For each event,
the incoming and outgoing tracks in the vertex were required to be coplanar.
Particle identification for the two outgoing tracks was performed by combin-
ing ETRD information with kinematic constraints. Events with ambiguous
particle identification were discarded. For Σ^- , decays upstream of the M2
chambers were rejected by requiring the scattered beam particle to have at
least 60% of the incoming beam particle’s momentum. Finally, electron mo-
The charge radii were determined by fitting the differential cross section with an assumed radius as single parameter to the observed distribution of the four-momentum transfer squared $Q^2$ (Fig. 2). Since the shape of the $Q^2$-distribution yields the radius no absolute normalization is needed. In this first analysis, $Q^2$ was calculated from the beam momentum and the scattering angle of the electron. From Monte Carlo studies the $Q^2$ resolution was estimated to be 1.5%. Preliminary acceptance studies were performed using generated elastic scattering events embedded in real data. The geometrical and reconstruction-dependent acceptance was modeled and a preliminary evaluation of the trigger efficiency performed.

For the $\Sigma^-$ data, a $Q^2$ region with flat acceptance was chosen for fitting the radius. For the $\pi^-$ data, an acceptance correction was applied. Each event was normalized to its individual beam momentum to eliminate effects of the beam momentum spread. An unbinned maximum likelihood fit using dipole electric and magnetic form factors for the $\Sigma^-$ yields a mean squared charge radius of

$$\langle r^2 \rangle_{\Sigma^-} = 0.60 \pm 0.08 \text{ (stat.)} \pm 0.08 \text{ (syst.)} \text{ fm}^2$$
in the $Q^2$ region of $0.03 \leq Q^2 \leq 0.16$ GeV$^2$/c$^2$ (7,800 events). This result is well inside the limits determined by the WA89 collaboration, $0.4$ fm$^2 \leq \langle r^2 \rangle_{\Sigma^-} \leq 1.4$ fm$^2$ (Fig. 3).

For the negative pion, a monopole electric form factor is used. We find

$$\langle r^2 \rangle_\pi = 0.45 \pm 0.03 \text{ (stat.)} \pm 0.07 \text{ (syst.)} \text{ fm}^2,$$

where $0.03 \leq Q^2 \leq 0.20$ GeV$^2$/c$^2$. (12,000 events). This result is in excellent agreement with the so far best direct measurement of $\langle r^2 \rangle_\pi = 0.44 \pm 0.01$ fm$^2$ as well as a recent calculation which takes into account form factor measurements in both space-like and time-like regions.

Major contributions to the systematic error come from the $Q^2$ resolution,
uncertainties in the corrections for trigger efficiency, and beam contamination by other particles, particularly \( \Xi^- \). Significant improvement is expected for all of these when advanced reconstruction and simulation software is used to refine the data sample. \( Q^2 \) will be determined from all kinematic variables and events with identified \( \Sigma^- \) decays accepted as well. We anticipate a statistical error of less than 10\% in the final analysis of the \( \Sigma^- \) radius.

4 Summary

A measurement of the \( \Sigma^- \) and \( \pi^- \) mean squared charge radii has been performed by elastic hadron-electron scattering. A preliminary analysis yields a \( \Sigma^- \) radius which is within 2\( \sigma \) of the proton radius. The \( \pi^- \) radius is in excellent agreement with previous experiments.

References

1. B. Povh and J. H"ufner, Phys. Lett. B 245, 653 (1990).
2. I. Eschrich, Measurement of the \( \Sigma^- \) Charge Radius at the Fermilab Hyperon Beam, MPIH–V22–1998, Dissertation, MPI f. Kernphysik / Univ. Heidelberg, 1998.
3. S. Paul, these proceedings.
4. K. Vorwalter, Determination of the Pion Charge Radius with a Silicon Microstrip Detector System, MPIH–V23–1998, Dissertation, MPI f. Kernphysik / Univ. Heidelberg, 1998.
5. S. Amendolia et al., Nucl. Phys. B 277, 186 (1986)
6. B. V. Geshkenbein, [hep-ph/9806413](1998).
7. G. Simon, C. Schmitt, F. Borkowski, and V. Walther, Nucl. Phys. A 333, 381 (1980)
8. L. Hand, D. Miller, and R. Wilson, Rev Mod Phys 35, 335 (1963)
9. J. Murphy, Y. Shin, and D. Skopik, Phys. Rev. C 9, 2125 (1974)
10. P. Mergell, U. Meissner, and D. Drechsel, Nucl. Phys. A 596, 367 (1996)
11. T. Udem et al., Phys. Rev. Lett. 79, 2646 (1997)
12. J. Kunz, P. Mulders, and G. Miller, Phys. Lett. B 255, 11 (1991)
13. N. Park and H. Weigel, Nucl. Phys. A 541, 453 (1992)
14. S. Sahu, Mod. Phys. Lett. A 10, 2103 (1995)
15. H. Kim, A. Blotz, M. Polyakov, and K. Goeke, Phys. Rev. D 53, 4013 (1996)
16. G. Wagner, these proceedings.