Elastic Hadron Scattering & Alan Krisch
Cornell & Michigan
1963 - 1971

Carl W. Akerlof
University of Michigan
Elastic scattering cross sections

(all variables are in the C-M frame)

Kinematics:

\[ |q| = |p_f - p_i| = 2p_{CM} \sin \left( \frac{\theta}{2} \right) = \sqrt{-t} \]

\[ p_{\perp} = p_{CM} \sin (\theta_{CM}) = 2p_{CM} \sin \left( \frac{\theta_{CM}}{2} \right) \cos \left( \frac{\theta_{CM}}{2} \right) \]

\[ q \times r / \hbar c \approx 5 \left( q / 1 \text{ GeV/c} \right) \left( r / 1 \text{ Fm} \right) \]

Rutherford scattering:

\[ \frac{d\sigma}{dq} = 8\pi \left( \frac{Z_1Z_2\alpha\hbar c}{\beta} \right)^2 \frac{1}{|q|^3} \quad ; \quad \beta = \frac{p_{CM}}{E_{CM}} \]

Rigid sphere collisions:

\[ \frac{d\sigma}{dq} = \sigma_{tot} \frac{|q|}{2p^2} \]
Technical Background…

Bubble chamber invented by Don Glaser in 1952. Greater than $10^6$ exposures were extremely onerous → only channels with $\sigma > 0.1$ µbarn.

Higher energy accelerators and strong focusing magnets enabled smaller emittance particle beams.

Fast transistors developed in the early ’60s permitted compact 100 MHz electronic logic.
Early Significant Experiments

1963  p-p elastic scattering at large momentum transfers and

1965  large-angle π-p elastic scattering at high energies

1966  measurement of π⁻-p elastic scattering at 180°

1967  elastic p-p elastic scattering at 90° and proton structure

1967  π, K, and p̅ production in the C-M in high energy p-p collisions
Phys. Rev. 166, 1353-1364 (1968)
p – p scattering at the AGS
L-R telescopes coincidence logic

L-R time-of-flight correlation
Some parameters of the AGS p – p elastic scattering experiment

$10^{11}$ protons on internal target, $\sim 100$ multiple traversals permit $\sim 10$ cm path length in CH$_2$

$\mathcal{L} \sim 10^{35}$ cm$^{-2}$ s$^{-1}$ \hspace{1cm} (Tevatron $\sim 10^{32}$ cm$^{-2}$ s$^{-1}$)

$\int \mathcal{L} \, dt \sim 10^{40}$ cm$^{-2}$ \hspace{1cm} (one day)

Lowest cross section: $d\sigma/d\Omega_{cm} = 1.1 \times 10^{-36}$ cm$^2$ sr$^{-1}$

$d\Omega_{cm} \sim 3 \times 10^{-3}$ sr $\Rightarrow$ Lowest number of events $\sim 25$
normalized $d\sigma/d\Omega_{cm}$ vs. $t$

$d\sigma/d\Omega_{cm}$ vs. $p_\perp$
PROTON-PROTON SCATTERING AND STRONG INTERACTIONS

Alan D. Krisch
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
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There has recently been considerable interest in the high-energy differential cross section of strongly interacting particles. We will show that for proton-proton scattering the existing data can be fit by a simple function which can be understood in terms of a simple model.

We consider the differential cross section for elastic proton-proton scattering, which is normalized according to

\[ X(s, t) = \frac{d\sigma/dt}{d\sigma/dt|_{t=0}^{\text{opt}}} = \frac{d\sigma/d\Omega}{d\sigma/d\Omega|_{\theta=0}^{\text{opt}}}, \]

where \( d\sigma/d\Omega_{\theta=0}^{\text{opt}} = k^2 \sigma_{\text{tot}}^2 / 16 \pi^2 \).

**Exponential fit:**

\[ X(s, p_{\perp}^2) = A e^{-a p_{\perp}^2} + B e^{-\beta p_{\perp}^2} \]
π-p elastic scattering at high energies
(8 – 12 GeV/c)

**Fig. 3.** Layout for Geometry 1. Several different magnet positions were used to obtain different regions of scattering angle.

**Fig. 4.** Layout for Geometry 2 which was used for scattering angles up to 81° in the center-of-mass system.

**Fig. 5.** Layout for Geometry 3 which was used for scattering angles near 180°.
Fig. 6. Angular distributions for $\pi^-p$ elastic scattering at lab momenta of 3.63, 8, and 12 GeV/c. Curves are drawn only as a guide.

Fig. 7. Angular distributions for $\pi^+p$ elastic scattering at lab momenta of 4, 8, and 12 GeV/c. Curves are drawn only as a guide.
$\pi^\pm - p$ backward elastic scattering near 180°

\[ \frac{d\sigma}{d\theta} \text{ in } \mu b (\text{GeV}/c)^2 \]

$u$ in $(\text{GeV}/c)^2$

- $4 \text{ GeV/c}$
- $8 \text{ GeV/c}$

\[ \pi^+ \rightarrow n, p \]
\[ \pi^- \rightarrow \Delta^{++}, p \]
π⁻ - p backward elastic scattering

(1.6 – 5.3 GeV/c)
Fig. 3. Experimental layout; the incident protons come down the extracted beam and strike the target. The scattered protons pass out through the magnets and scintillation counters.

elastic p-p scattering at 90° and proton structure

(5.0 – 13.4 GeV/c)
**Fig. 8.** Plot of $d\sigma/d\Omega$ versus $P_{\text{c.m.}}$ for 90° proton-proton elastic scattering. Other data (Refs. 20, 22, 23) are also plotted. The line drawn is the straight line fit suggested by the statistical model.

**Fig. 10.** Plot of $d\sigma/dt$ versus $P_{\text{c.m.}}^2$ for proton-proton elastic scattering at 90°, comparing it to electron-proton elastic scattering at high momentum-transfer. The lines drawn are the straight line fits to the proton-proton data. The electron-proton data (Ref. 44) are plotted as the fourth power of the form factor, and are normalized to the proton-proton cross section.
π, K, and \( p \) production in the C-M in high energy p-p collisions

(12.5 GeV/c)
particle production experiment fast logic and controls
Fig. 11. Plot of $d^2\sigma/d\Omega dp$ against $P_t^2$ for $P_t^{c.m.}$ held fixed. The production cross sections for $\pi^+, \pi^-, K^+, K^-$, and antiprotons are shown. The lines are straight-line fits to the data.

Fig. 12. Plot of $d^2\sigma/d\Omega dp$ against $P_t$ for $P_t^2$ held fixed. The cross sections for $\pi^+, \pi^-, K^+, K^-$ production are shown. The lines are freehand fits to the data.
Alan Krisch’s Cornell transportation
All Best Wishes...