STANFORD LINEAR ACCELERATOR CENTER • 1967–1973

Deep Inelastic Scattering

Probing the Inner Structure of the Proton with High-Energy Electrons

The landmark MIT-SLAC experiment that provided direct experimental evidence for quarks.

SCIENTIFIC CONTEXT

Rutherford Scattering at the Subatomic Scale

The Nucleon Puzzle

By the 1960s, protons and neutrons were known to possess measurable magnetic moments, indicating they were not point particles, but their internal composition remained unknown.

Quark Hypothesis

Gell-Mann and Zweig proposed constituent "quarks" in 1964, but many physicists viewed them merely as convenient mathematical placeholders rather than real physical objects.

Inelastic Probe Strategy

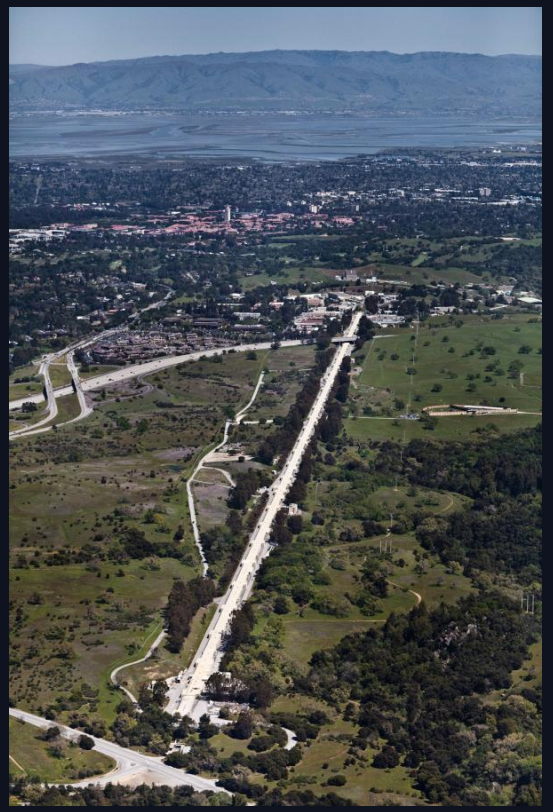
High-energy electron beams fired into protons transfer energy and momentum, breaking the proton apart ("inelastic") and resolving tiny sub-structures inside.

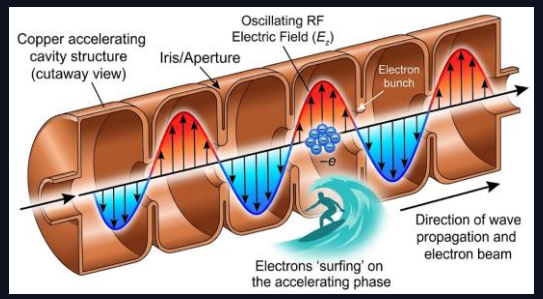
Goal: Measure the energy and deflection angles of scattered electrons to see if hard core scattering occurs.

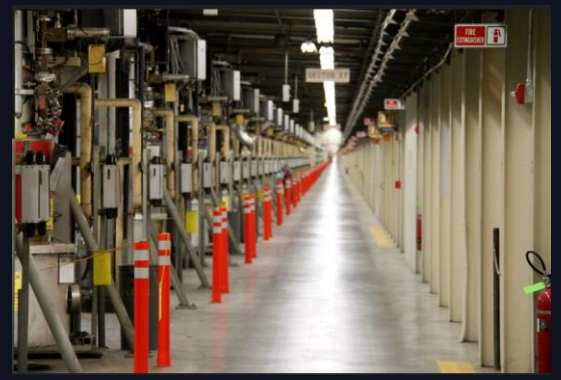
PARTICLE ACCELERATOR

The Two-Mile SLAC Linear Accelerator

- **2-Mile Length: World's longest linear accelerator, delivering high-intensity electron beams in a straight line without synchrotron radiation losses.**
- **20 GeV Energy Beam: Driven by 240 high-power klystrons operating at S-band microwave frequencies (2.856 GHz).**
- **Ultra-Short Wavelength: High-momentum electrons provided a spatial resolution under 10^{-15} meters—fine enough to resolve point-like constituents.**







TARGET & FACILITY

End Station A & Target Architecture

Liquid Target

20-cm long target cell containing liquid hydrogen (protons) and liquid deuterium (bound neutrons) maintained at 20 Kelvin.

Beam Delivery

Bending and focusing magnets steered the 20 GeV electron beam with precise energy resolution directly onto the target cell.

Angular Freedom

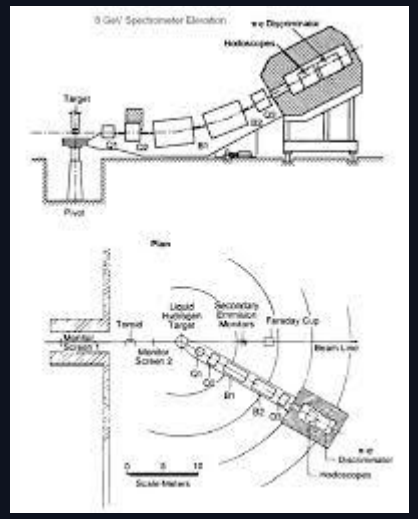
Massive spectrometer arms rested on circular railway tracks to sweep horizontally across scattering angles from 4° to 34°.

DETECTION HARDWARE

The Magnetic Spectrometer Detectors

SLAC Magnetic Spectrometer





- 8 GeV & 20 GeV Spectrometers: Multi-ton dipoles and quadrupoles bent scattered electron trajectories to measure momentum accurately.
- Gas Cherenkov Counters: Discriminated fast electrons from a heavy background of unwanted pions created in collisions.
- Lead-Glass Shower Counters: Absorbed electrons to measure total energy deposition through electromagnetic cascades.

HISTORICAL DISCOVERY

Observation of Point-Like Partons (Quarks)

$$F_2(x) = 2xF_1(x) = \Sigma_{i=1}^{N_q}(z_i e)^2 f_i(x)$$

Bjorken Scaling Observed

Cross sections depend only on the dimensionless scaling variable x, not momentum transfer Q^2.

Scattering point-like particles behave as spin ½ fermions: evidence for the existence of quarks within the nucleons

- **Unexpectedly Large Scattering: Electrons scattered at large angles far more frequently than predicted for a smooth, continuous charge distribution.**
- **Feynman's Parton Model: The results proved electrons were bouncing elastically off point-like, fractionally-charged constituents (quarks).**
- **1990 Nobel Prize: Awarded to Jerome Friedman, Henry Kendall, and Richard Taylor for confirming the reality of quarks.**

Image Sources



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