Chronology of Particle Physics

1895	**Discovery of X-rays (W. Roentgen)**
1896	**Discovery of radioactivity (H. Becquerel)**
1897	**Discovery of electron (J.J. Thomson)**
1898	**Isolation of radium (M. Curie and P. Curie)**
1905	**Special theory of relativity (A. Einstein)**
1909	**Alpha particle shown to be helium nucleus (Rutherford and Royds)**
1911	**Discovery of nucleus (E. Rutherford)**
1912	**Discovery of cosmic radiation (Victor Hess)**
1913	**Planetary atomic model (N. Bohr)**
1915	**General theory of relativity (final form) (A. Einstein)**
1919	**Eddington observes deflection of light by Sun in total eclipse**
1926	**Quantum mechanics (E. Schrodinger)**
1927	**Dirac equation and prediction of antiparticles (P. Dirac)**

Chronology of Particle Physics

1928	**Theory of α- radioactivity (Gamow, Gurney, Condon)**
1930	**Hubble discovers expansion of universe**
1930	**Neutrino hypothesis (W. Pauli)**
1930	**Invention of cyclotron (E.O. Lawrence)**
1932	**Discovery of positron in cosmic rays (Anderson)**
1932	**Discovery of neutron (Chadwick)**
1934	**Theory of β-radioactivity (E. Fermi)**
1935	**Meson hypothesis (Yukawa)**
1937	**Discovery of muon in cosmic rays (Neddermeyer, Anderson)**
1947	**Discovery of pion in cosmic rays (Powell)**
1947	**Discovery of V-particles in cosmic rays (strange meson - kaon) (Rochester and Butler)**
1950	**Discovery of more V-particles (strange baryon - Λ) (Anderson)**

Chronology of Particle Physics

1952	More strange particles (Ξ, Σ) discovered in cosmic rays.
1955	Discovery of antiproton at Berkeley Bevatron (Chamberlain and Segre)
1956	Discovery of antineutron at Berkeley Bevatron
1956	Experimental detection of neutrino (Reines and Cowan)
1974	Discovery of J/ψ resonance (Charm quark) (Richter and Ting)
1975	Discovery of τ-lepton (Perl)
1977	Discovery of Bottom quark
1983	Discovery of W and Z bosons (Rubbia and Van der Meer)
1995	Discovery of Top quark (D0 and CDF)
2000	Discovery of tau-neutrino (DONUT)
1995-2001	Discovery of neutrino mass and oscillations (solar and atmospheric neutrino) (Homestake, GALLEX, SAGE, Super-K, SNO)

Structure of the atom

Thomson's model:
Electron is a universal constituent of matter.
Atom consists of many electrons with balancing positive charge.

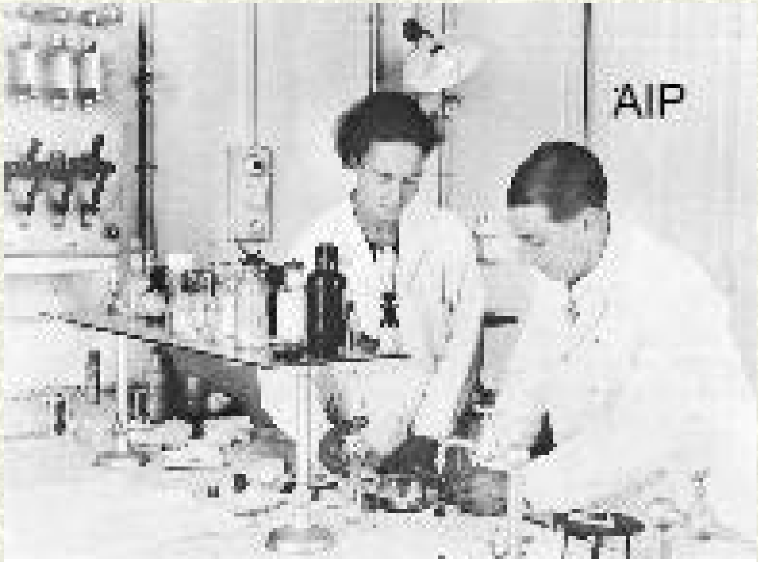
1909 - **Geiger, Marsden and Rutherford**: scattering of alpha particles off thin metal foil. Many of the alpha particles were scattered through large angles, in disagreement with Thomson model of atom.
1911 - **Rutherford** published his analysis of the experiment showing that the atom had a small, charged nucleus.
1919 - **Rutherford** found the first evidence for proton by radiating nitrogen with alpha-particles.
1920 - **Rutherford** proposed the existence of neutron, although physicists continued to speak of the nucleus as having *A* protons and *A-Z* electrons.

Discovery of the neutron

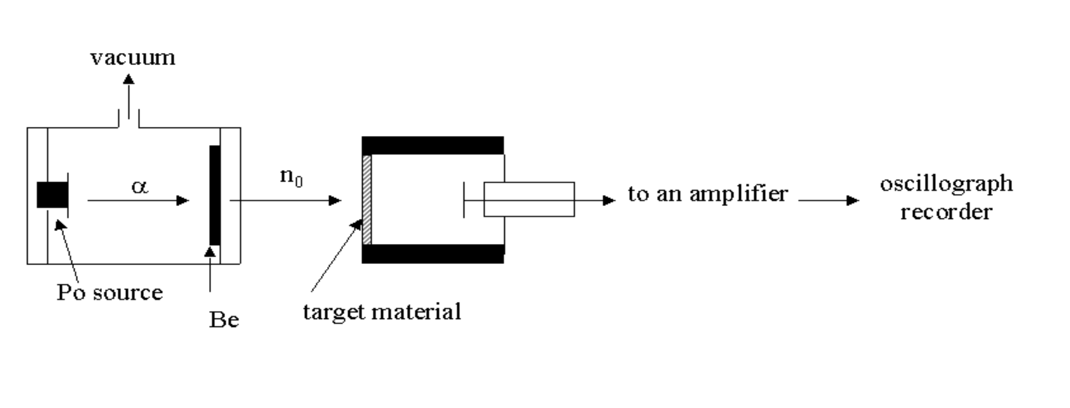
Bothe and Becker, and Curie and Joliot (1931) - experiment which involves irradiation of beryllium by alpha particles from polonium source. At that time alpha particles were already known (Rutherford) to be doubly ionised helium atoms. They observed neutral penetrating radiation that they thought was *X*-rays. In fact, they observed the reaction:

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

Curie and Joliot showed that this radiation was able to knock protons out of paraffin. But they misinterpreted the phenomenon as scattering of gamma rays on protons (a process similar to the Compton effect - scattering of gamma rays on electrons).



Discovery of the neutron: Chadwick's experiment

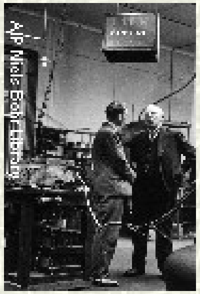


- **James Chadwick** reported to **Lord Rutherford** on Joliot-Curies' result.
- **Lord Rutherford** "*I do not believe it*!"

- **Chadwick** used ionisation chamber in which he could measure ionisation (number of ions) produced by a charged particle and the length of the track. He also used alpha particles from polonium source and beryllium as a target for alpha particles. He put several additional target materials (hydrogen, helium, lithium, beryllium, carbon, air and argon) on the way of neutral radiation from beryllium.
- Particles ejected from hydrogen behaved like protons (what else can we expect to be ejected from hydrogen?) with speeds up to 3.2×10^9 cm/s. The particles ejected from heavier targets had larger ionising power and were in each case recoil ions of the element.

Discovery of the neutron

- If the ejection of a proton is due to the scattering of photon on nucleus, then to speed up proton up to 3.2×10^9 cm/s, a 52 MeV photon is needed. This exceeded all known energies of photons, emitted by nuclei.
- Similar process on nitrogen with 52 MeV photons would produce 400 keV nitrogen recoils with ionisation yield and track length much less than observed in **Chadwick's** experiment.
- All difficulties disappear if we assume that incident particles are neutral particles with the mass equal to that of proton.
- **Chadwick** called it the **neutron** in a letter to Nature in **February 17, 1932.**
- **1935 - Chadwick** received **the Nobel Prize.**

Discovery of the positron

- Search for new fundamental particles by **C. D. Anderson** (since 1933).
- X-rays and radioactive sources have limited energies (up to a few MeV).
- Higher energies were reachable using cosmic rays.
- Pioneering measurements of cosmic rays were done by **Victor Hess and Dmitry Skobeltzyn.**
- A cloud chamber (Wilson chamber) was normally used at that time to detect tracks of charged particles. It contained a supersaturated vapour. When a charged particle enters the chamber, it collides with air or alcohol vapour atoms, producing free ions (ionisation process). Vapour in the chamber condenses around these free ions, forming droplets. The droplets are what form the trail.

Expansion type cloud chamber

Original Wilson chamber

Discovery of the positron

- Anderson used cloud chamber in a 1.5 T magnetic field.
- The chamber was divided into two parts by a 6 mm lead plate.

- Greater curvature of the track in the upper part of the chamber indicates that the particle entered the chamber from below. This determines the positive charge of the particle.
- Anderson concluded that the positive charge of the particle is less than twice (or is probably exactly equal to) that of proton (electron) and the mass is less than twenty times the electron mass.

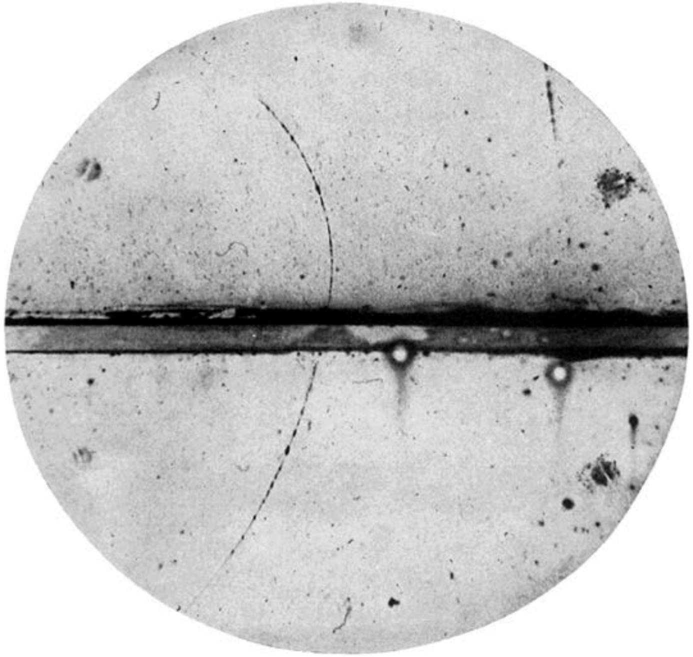
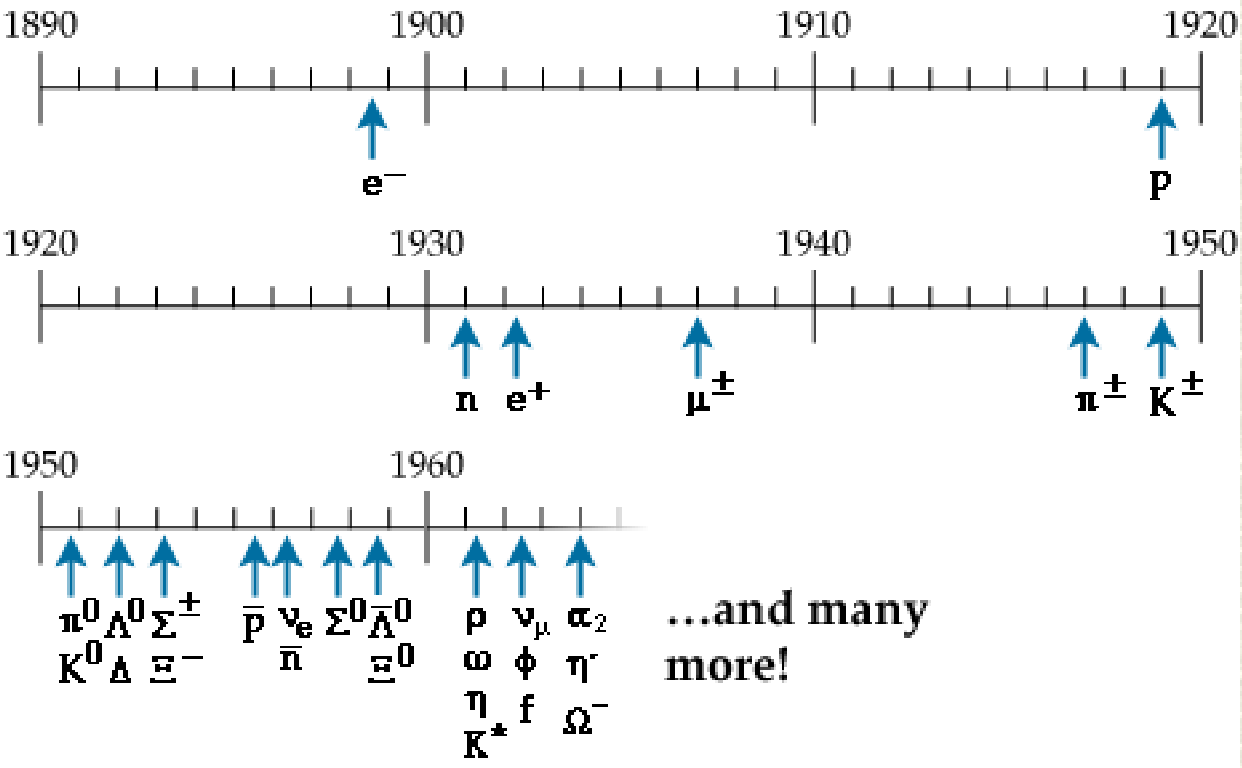
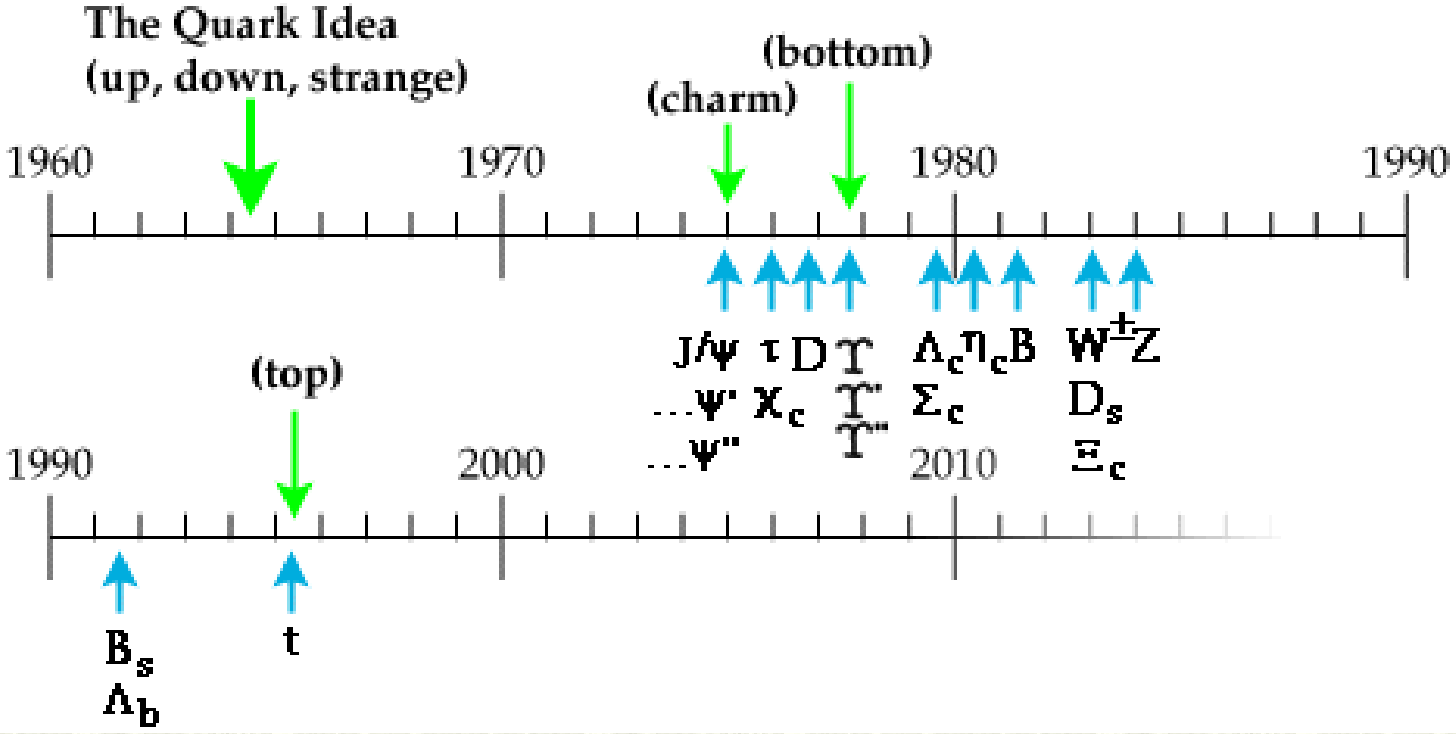


FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

Particles discovered 1898 - 1964:



Particles discovered since 1964:



Summary

- The atom was completed in **1932** with the discovery of neutron.
- The positron, discovered in **1933,** was just the first known particle created in an interaction of other particle with matter (not emitted from atom or nucleus).