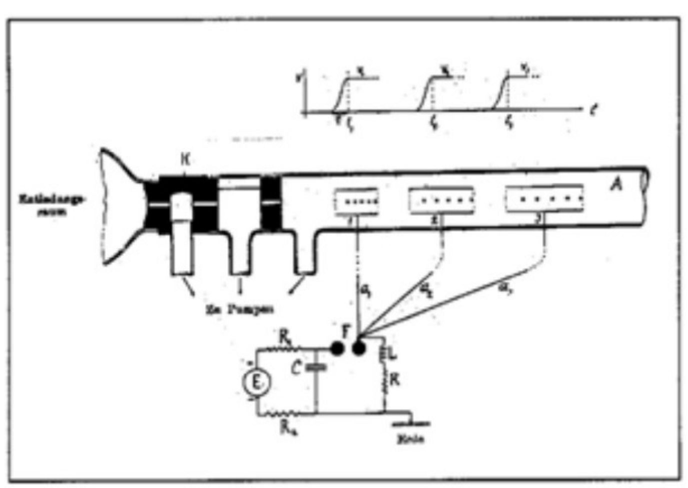
Particle beams, accelerators, and colliders

Rolf Wideroe (Ising)

- Ising and Wideroe suggested the repeated application of a much smaller voltage in a linear accelerator by using time-varying fields
- In this way, a high particle beam energy could be attained by repeatedly applying voltage “kicks”



Ising's idea

R. Wideroe

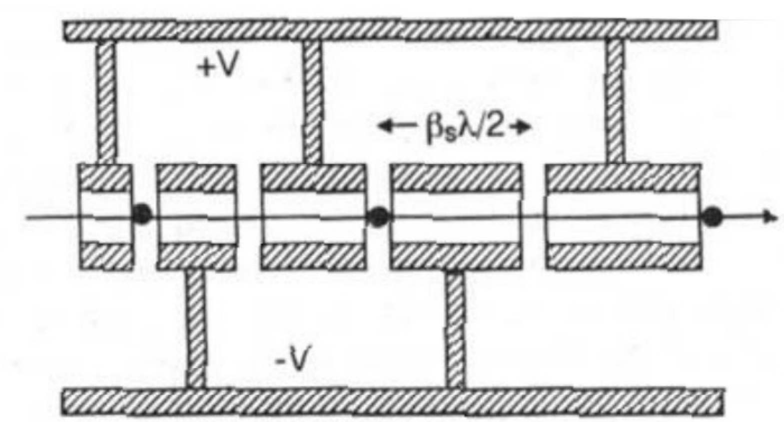
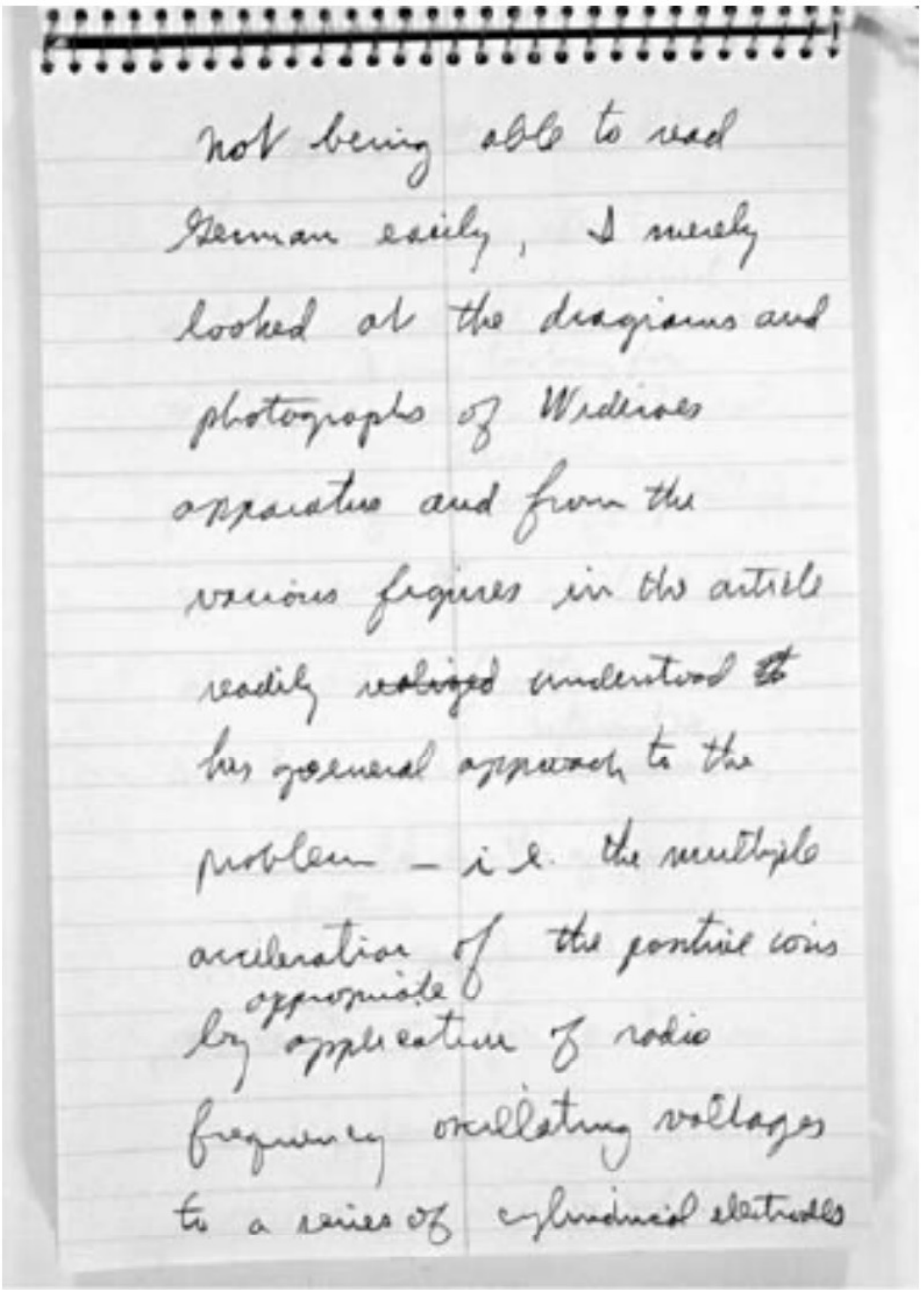
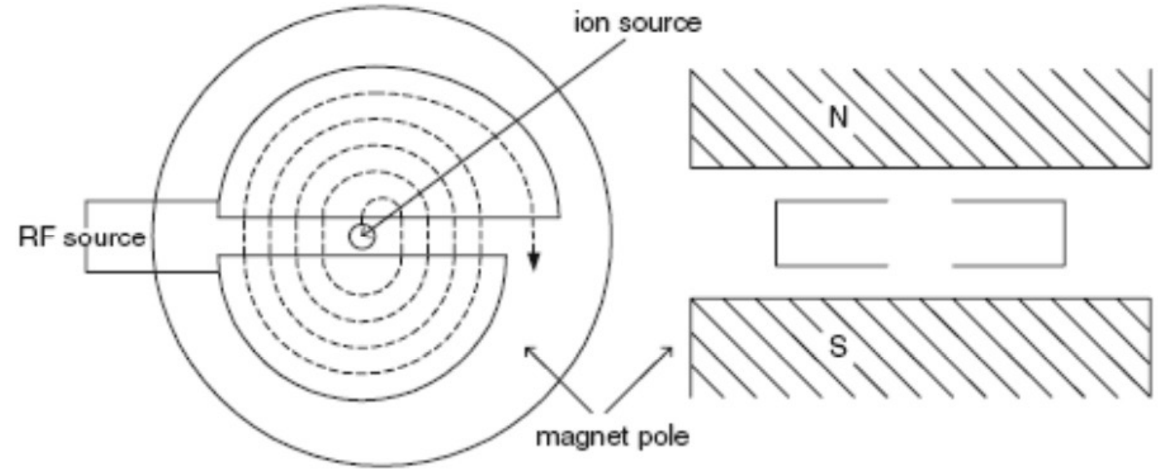


Figure 4.4 Wideröe or Sloan–Lawrence or interdigital structure.


not being able to read German easily, I merely looked at the diagrams and photographs of Wideroes apparatus and from the various figures in the article readily ~~realized~~ understood ~~th~~ his general approach to the problem – i.e. the multiple acceleration of the positive ions by appropriate application of radio frequency oscillating voltages to a series of cylindrical electrodes

Lawrence's notes on Wideroes idea



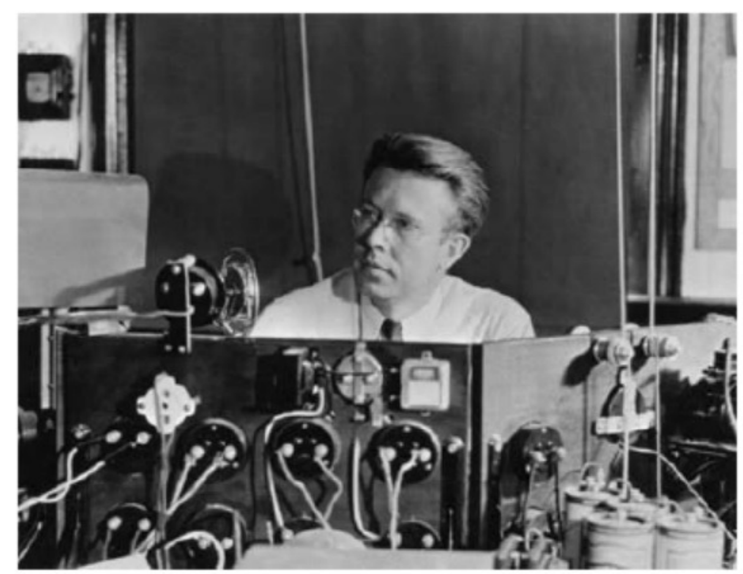
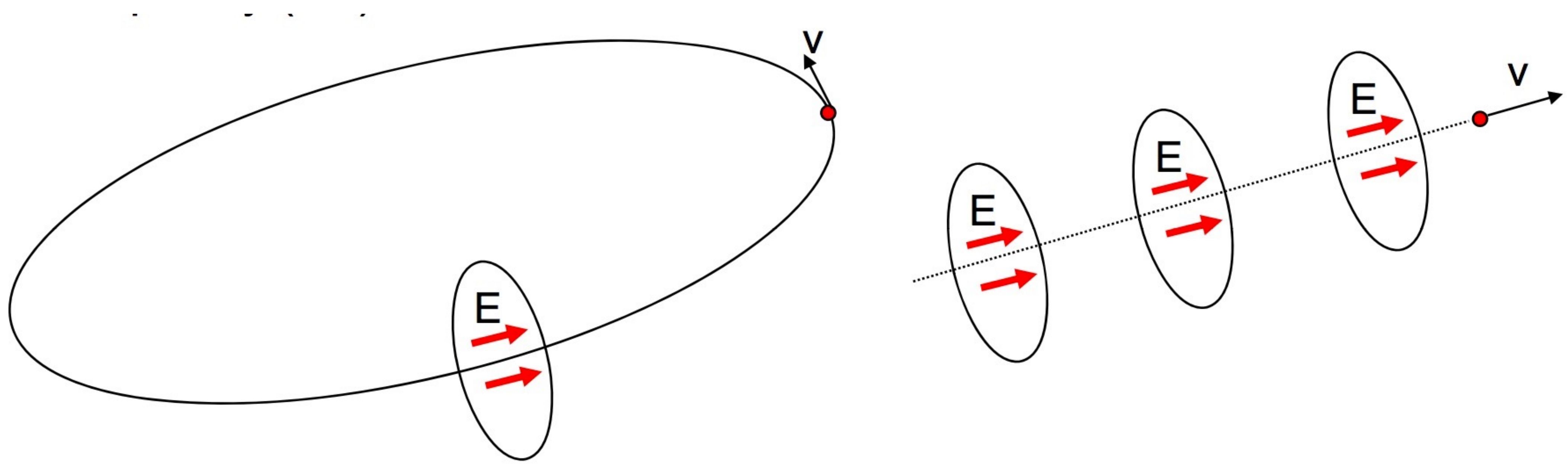


Fig. 1.10. Ernest Lawrence at the controls of the 37 inch cyclotron in about 1938 (Reprinted with permission from LBL)

E. O. Lawrence: Nobel Prize, 1939

From linear to circular and back to linear



Wideroe —> Lawrence —> Richter —-> ILC/CLIC

- Uniform circular motion is maintained via centripetal acceleration:

$$\frac{mv^2}{r} = qvB$$


The first cyclotron 4.5" diameter (1929).

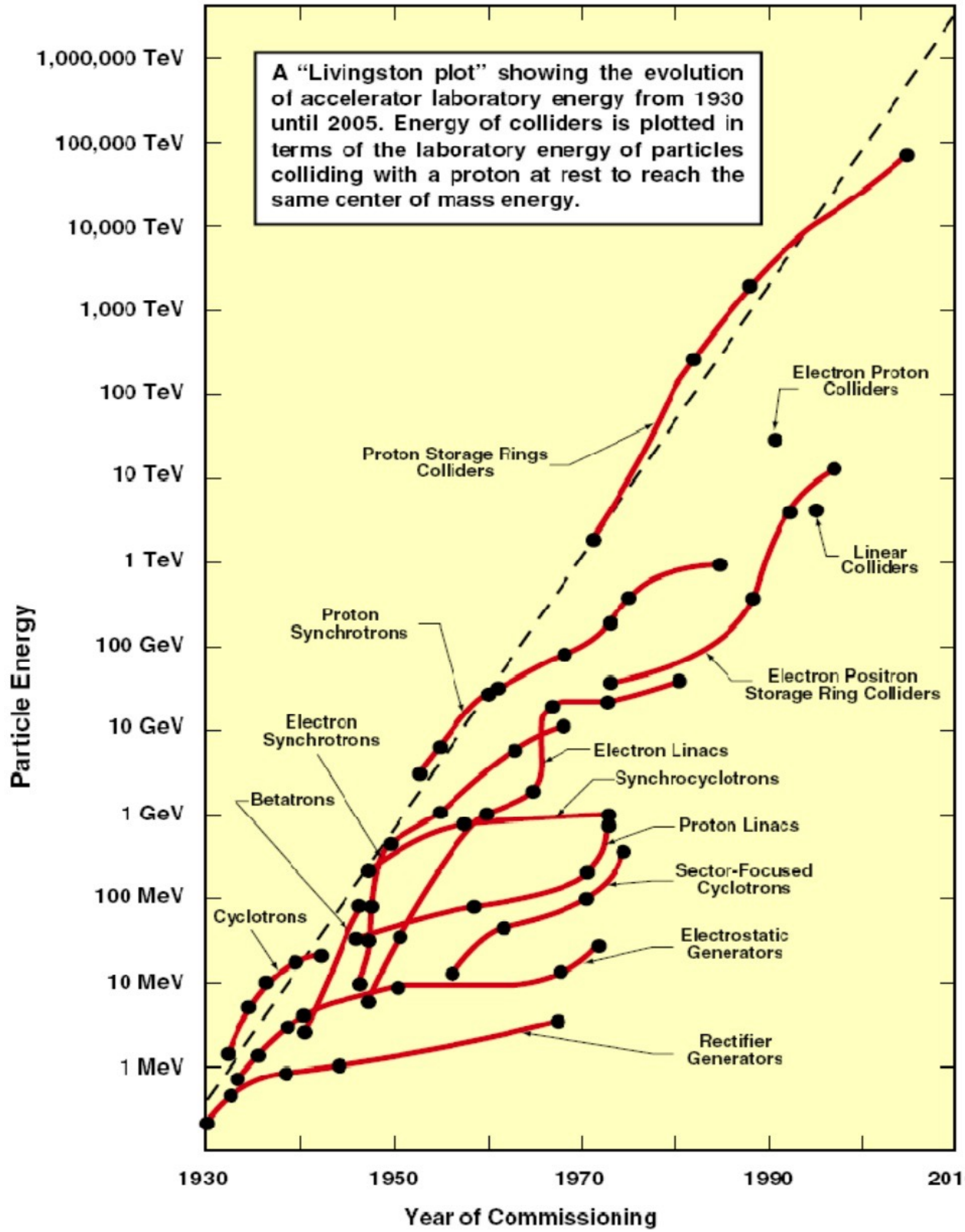
- The radius is

$$r = \frac{mv}{qB}$$

- The revolution period and frequency are independent of particle velocity:

$$T = \frac{2\pi m}{qB} \qquad \omega = \frac{qB}{m}$$

- Therefore, a particle in resonance with a time varying field applied to the Dees with frequency given as above will be accelerated. The particle is in *synchronism* with the time-varying field.
- Such cylcotrons can accelerate proton energies up to 20-30 MeV
- The situation becomes more complicated at higher energies due to the increase in relativistic mass
  - The frequency decreases and particles get out of synchronism


A "Livingston plot" showing the evolution of accelerator laboratory energy from 1930 until 2005. Energy of colliders is plotted in terms of the laboratory energy of particles colliding with a proton at rest to reach the same center of mass energy.
Particle Energy
1,000,000 TeV
100,000 TeV
10,000 TeV
1,000 TeV
100 TeV
10 TeV
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
Year of Commissioning
1930
1950
1970
1990
2010
Electron Proton Colliders
Proton Storage Rings Colliders
Linear Colliders
Proton Synchrotrons
Electron Positron Storage Ring Colliders
Electron Synchrotrons
Electron Linacs
Synchrocyclotrons
Betatrons
Proton Linacs
Sector-Focused Cyclotrons
Cyclotrons
Electrostatic Generators
Rectifier Generators

Energy	Physical system
20 TeV	SUSY, ... ?
1 TeV	Higgs, W , Z , top
1 GeV	p,n masses
	quark mass, μ mass
1 MeV	transitions between nuclear states
	e^- mass
1 keV	transitions between inner atomic shells
1 eV	transitions between atomic elections
1 meV	phonons, lattice vibrations
	ν masses
1 μeV	?

History

1895 Roentgen discover x-rays
1897 J.J.Thomson discovers electron
1905 Einstein pe effect, special relativity
1907 Schott theory of synchrotron radiation
1911 Rutherford uses alpha particles to discover nucleus
1920 Greinacher builds first cascade generator 100 kV
1924 Ising proposes linac
1927 Wider builds first linac and accelerates Na and K ions
1928 Dirac predicts anti-matter
1931 Van de Graaff builds first high-voltage generator
1932 Cockroft and Walton build first accelerator, p+Li —> He+He
1932 Lawrence and Livingston build cyclotron, 1.2 MeV protons
1932 positron (Anderson) and neutron (Chadwick) are discovered
1939 Klystron invented (Hansen, Varian)
1941 Betatron (Kerst, Serber)
1941 concept of particle storage ring (Touschek, Wideroe)
1943 concept of synchrotron (Oliphant)
1947 proton linac (Alvarez)
1947 electron linac (Ginzton)
1950-52 concept of strong focussing
1954 R.R. Wilson builds first strong focussing synchrotron (Cornell)
1956 first use of synchrotron radiation for spectroscopy
1960 first e+e- collider, ADA at Frascati
1972 first pp collider, ISR at CERN
1981 first p-pbar collider, SPS at CERN

Weak focussing: cyclotron, betatron

Strong focussing: proton synchrotron

Beam stability
RF: kV/m —> MV/m —> 40MV/m —> 150MV/m
Tevatron ILC CLIC (2-beam)
e: radiates and cools; “hot” —“cold”
p: does not radiate: “hot” stays hot
6d phase space.
machine backgrounds: dB —> out of stability —> scrape
beam-gas —> muon “halo”
p+p+ machine “pumps” the vacuum
beamstrahlung: 3 TeV at ILC
beam optics: transfer matrices.
e+e-: LEP, SPEAR,PEP,PETRA
SLC, ILC (337 ns), CLIC (0.4 ns)
Synch. radiation: γ^4/R^2
Asylum machines: e+e- —> BB~