Physics 417/517 Introduction to Particle Accelerator Physics

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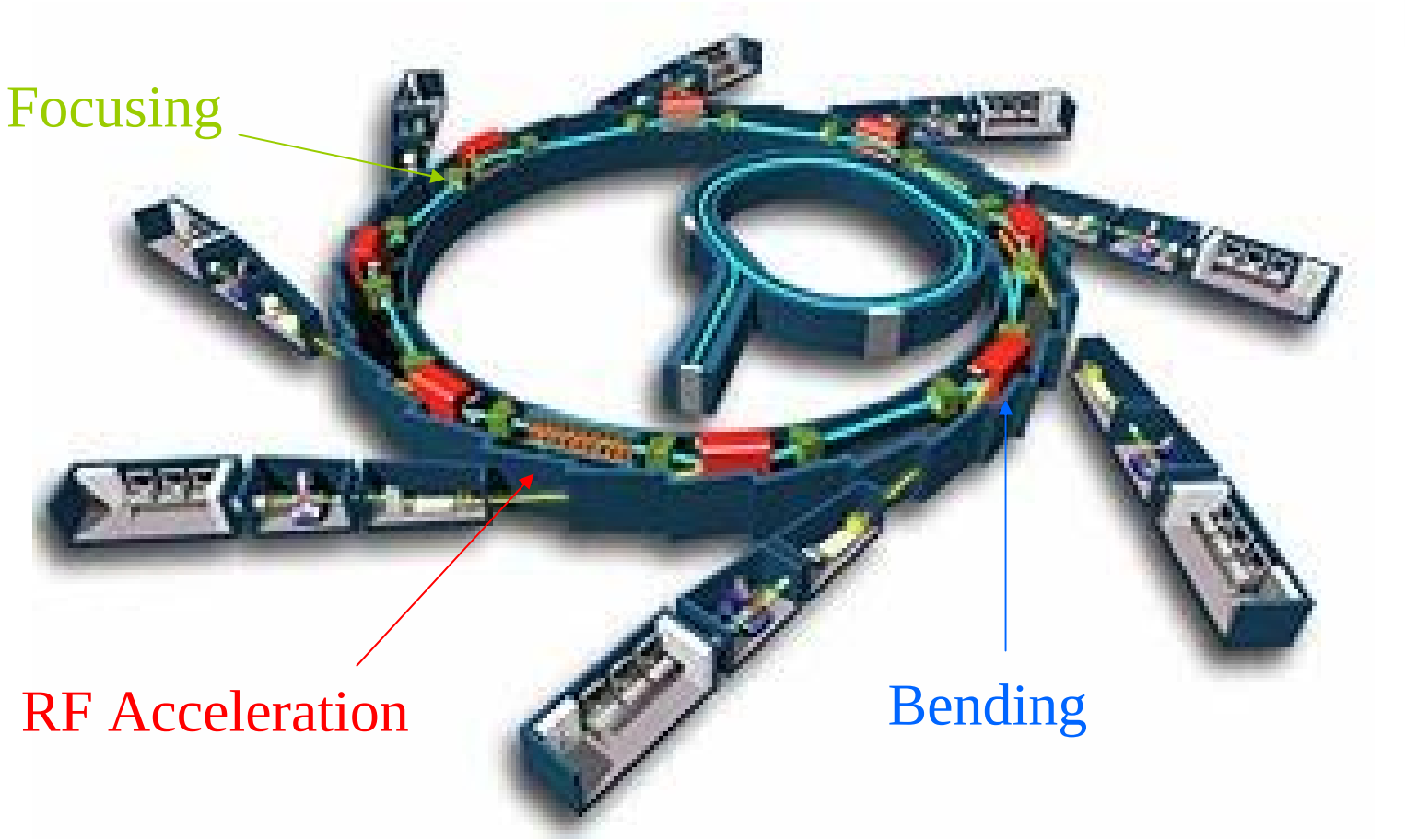
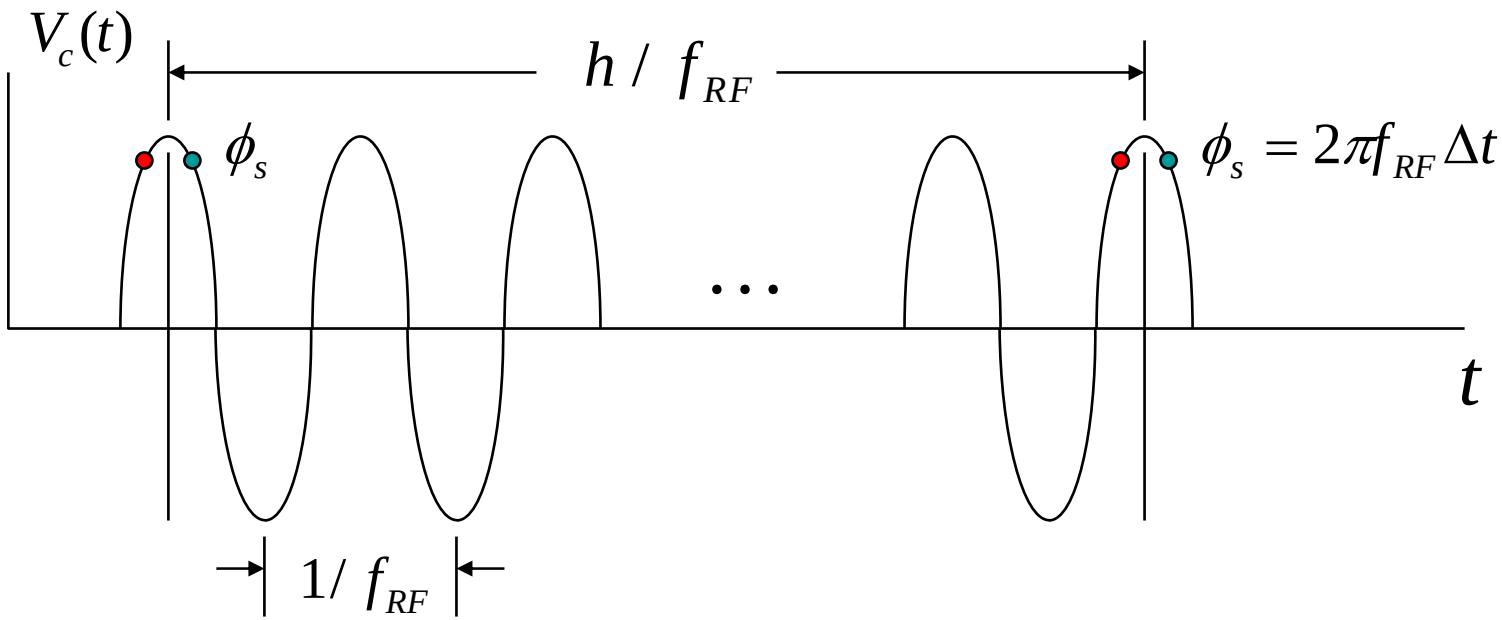
Generic Modern Synchrotron



Spokes are user stations for this X-ray ring source

Synchrotron Phase Stability

Edwin McMillan discovered phase stability independently of Veksler and used the idea to design first large electron synchrotron.



$$h = L f_{RF} / \beta c$$

Harmonic number: # of RF oscillations in a revolution

Transition Energy

Beam energy where speed increment effect balances path length change effect on accelerator revolution frequency. Revolution frequency independent of beam energy to linear order. We will calculate in a few weeks

- Below Transistion Energy: Particles arriving EARLY get less acceleration and speed increment, and arrive later, with repect to the center of the bunch, on the next pass. Applies to heavy particle synchrotrons during first part of acceleration when the beam is non-relativistic and accelerations still produce velocity changes.

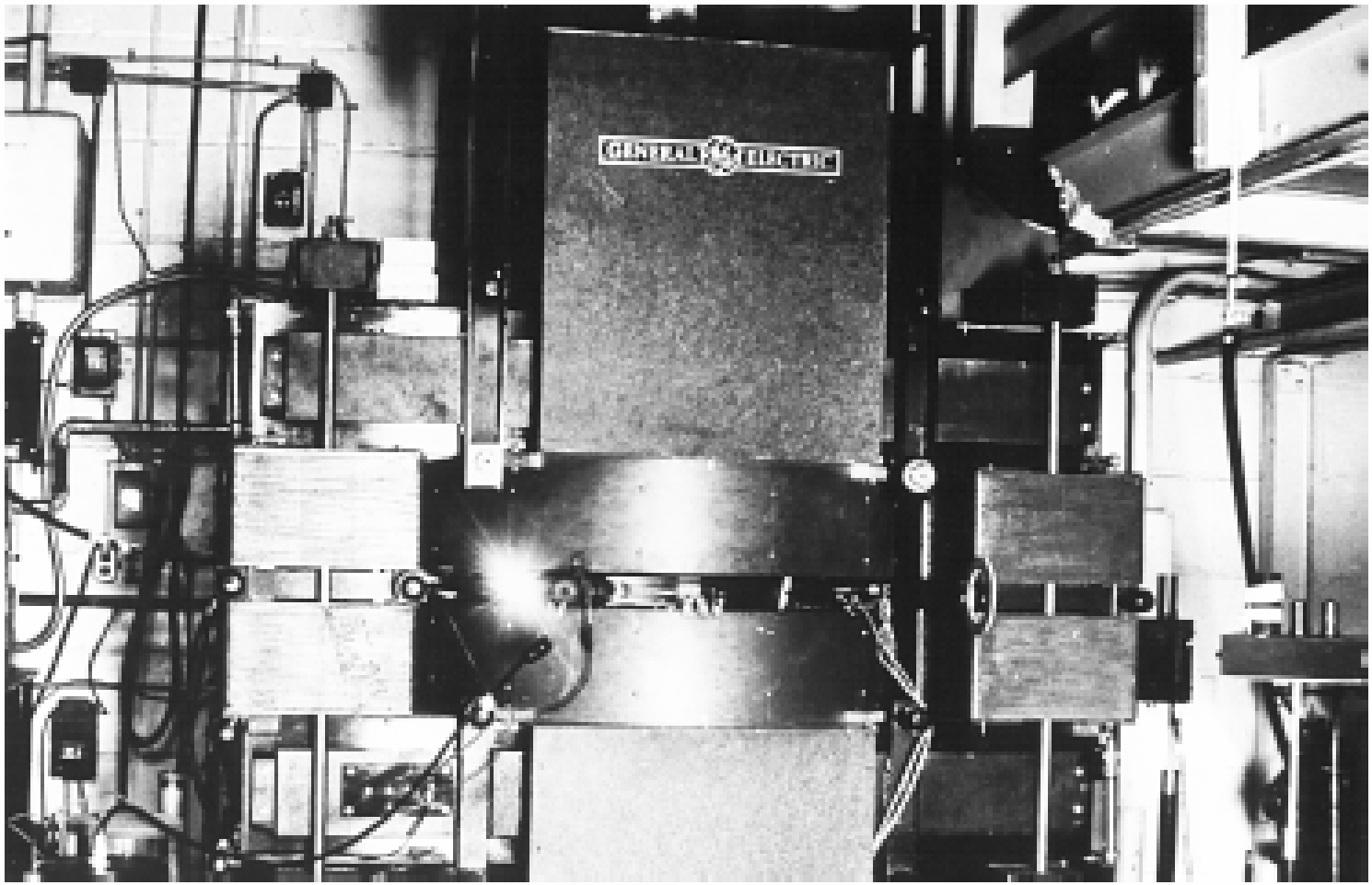
- Above Transistion Energy: Particles arriving EARLY get more energy, have a longer path, and arrive later on the next pass. Applies for electron synchrotrons and heavy particle synchrotrons when approach relativistic velocities. As seen before, Microtrons operate here.

Ed McMillan

Vacuum chamber for electron synchrotron being packed for shipment to Smithsonian

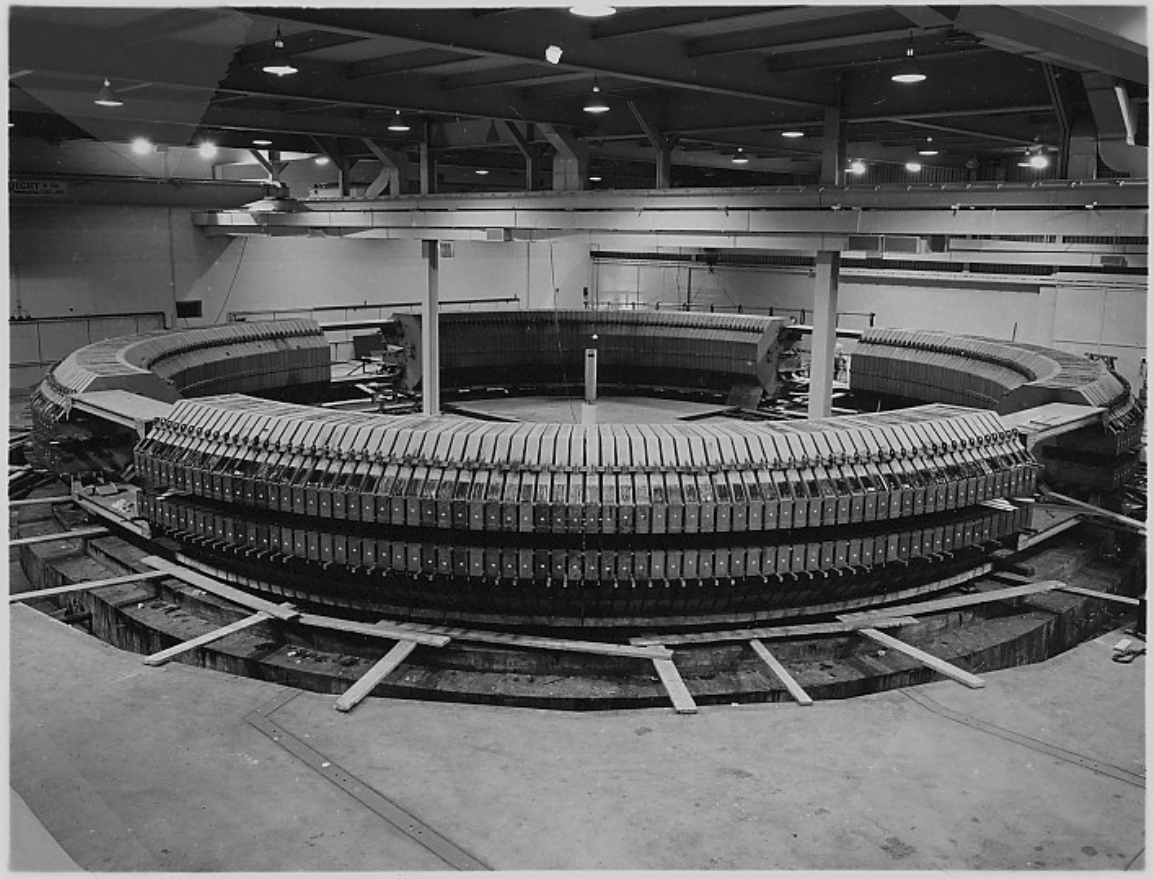
Full Electron Synchrotron

GE Electron Synchrotron



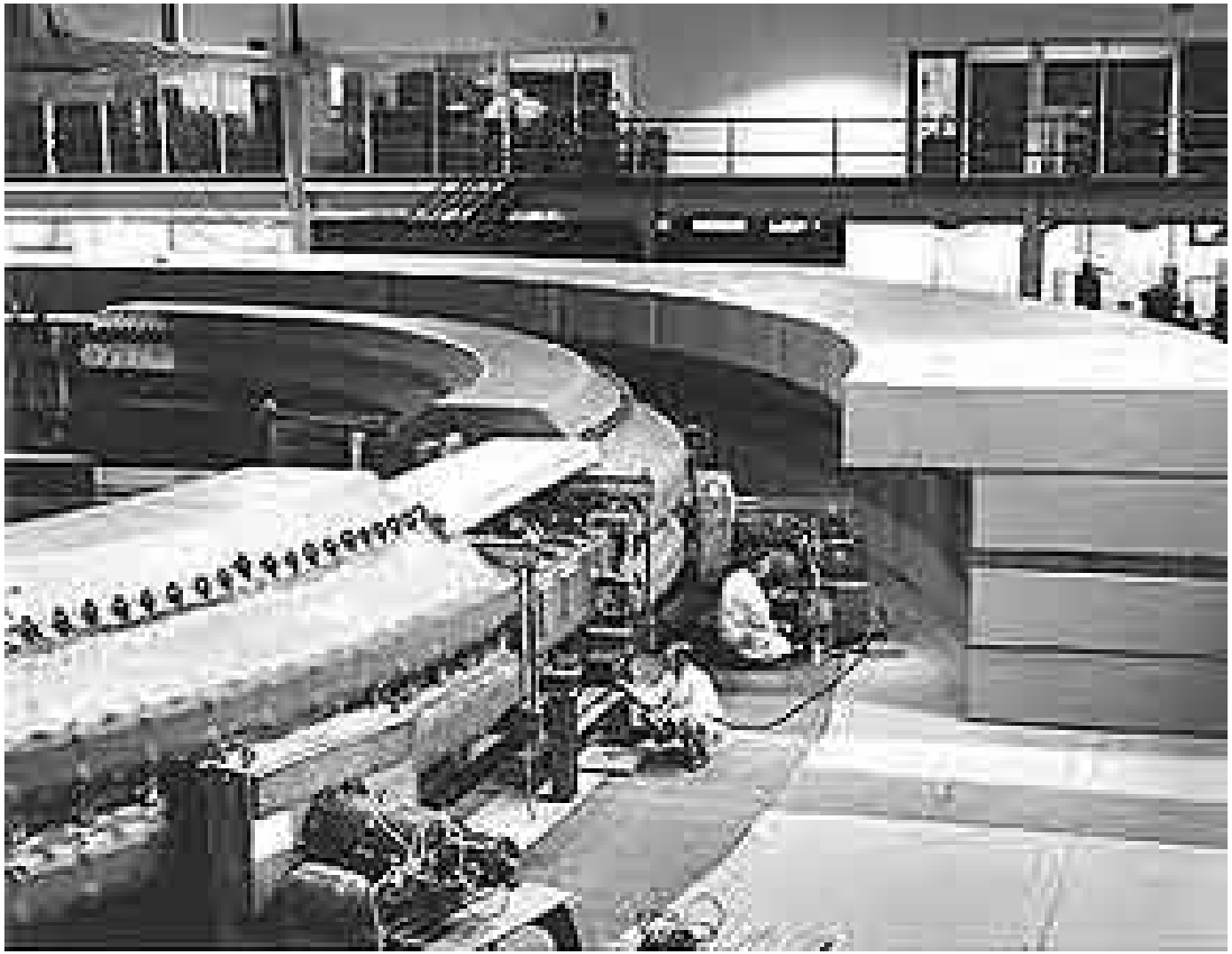
Elder, F. R.; Gurewitsch, A. M.; Langmuir, R. V.; Pollock, H. C., "Radiation from Electrons in a Synchrotron" (1947) *Physical Review*, vol. 71, Issue 11, pp. 829-830

Cosmotron (First GeV Accelerator)

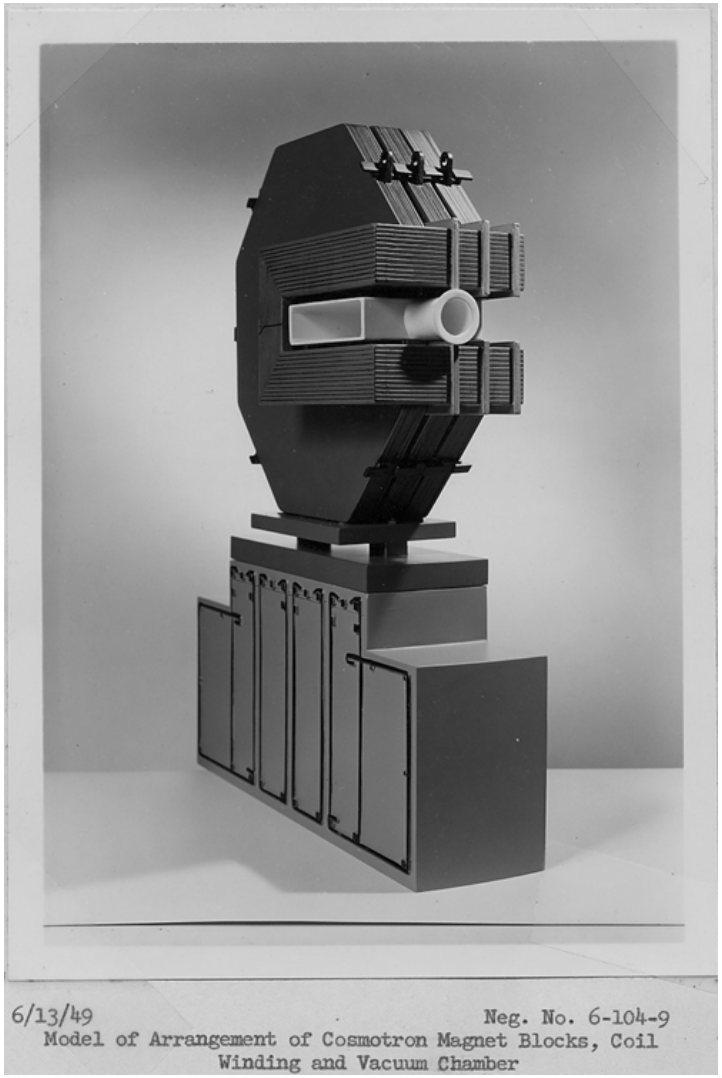


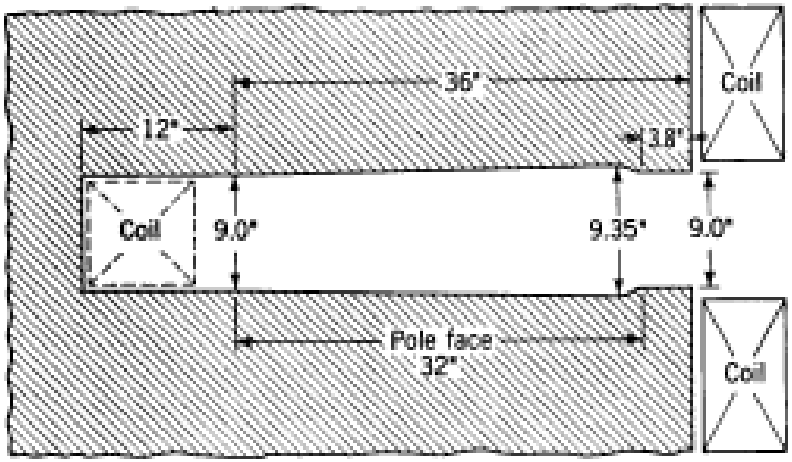
6/15/50 Neg. No. 6-151-0
View of Cosmotron Magnet Blocks after Leveling and Spacing

BNL Cosmotron and Shielding



Cosmotron Magnet





The Cosmotron magnet

Cosmotron People

E.Courant -Lattice Designer

Stan Livingston - Boss

Snyder -theorist

Christofilos - inventor

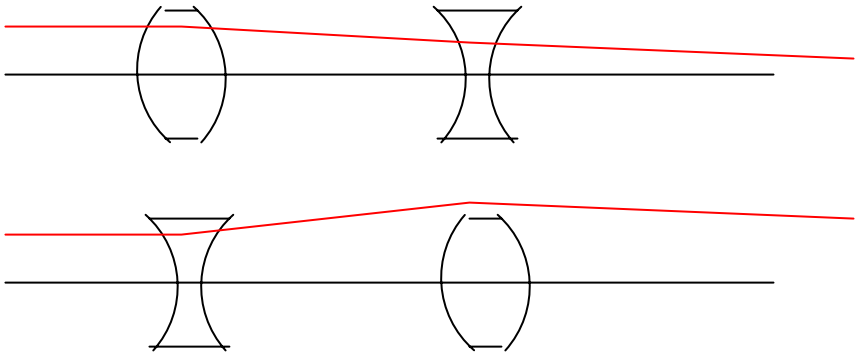
Bevatron

Designed to discover the antiproton; Largest Weak Focusing Synchrotron

Strong Focusing

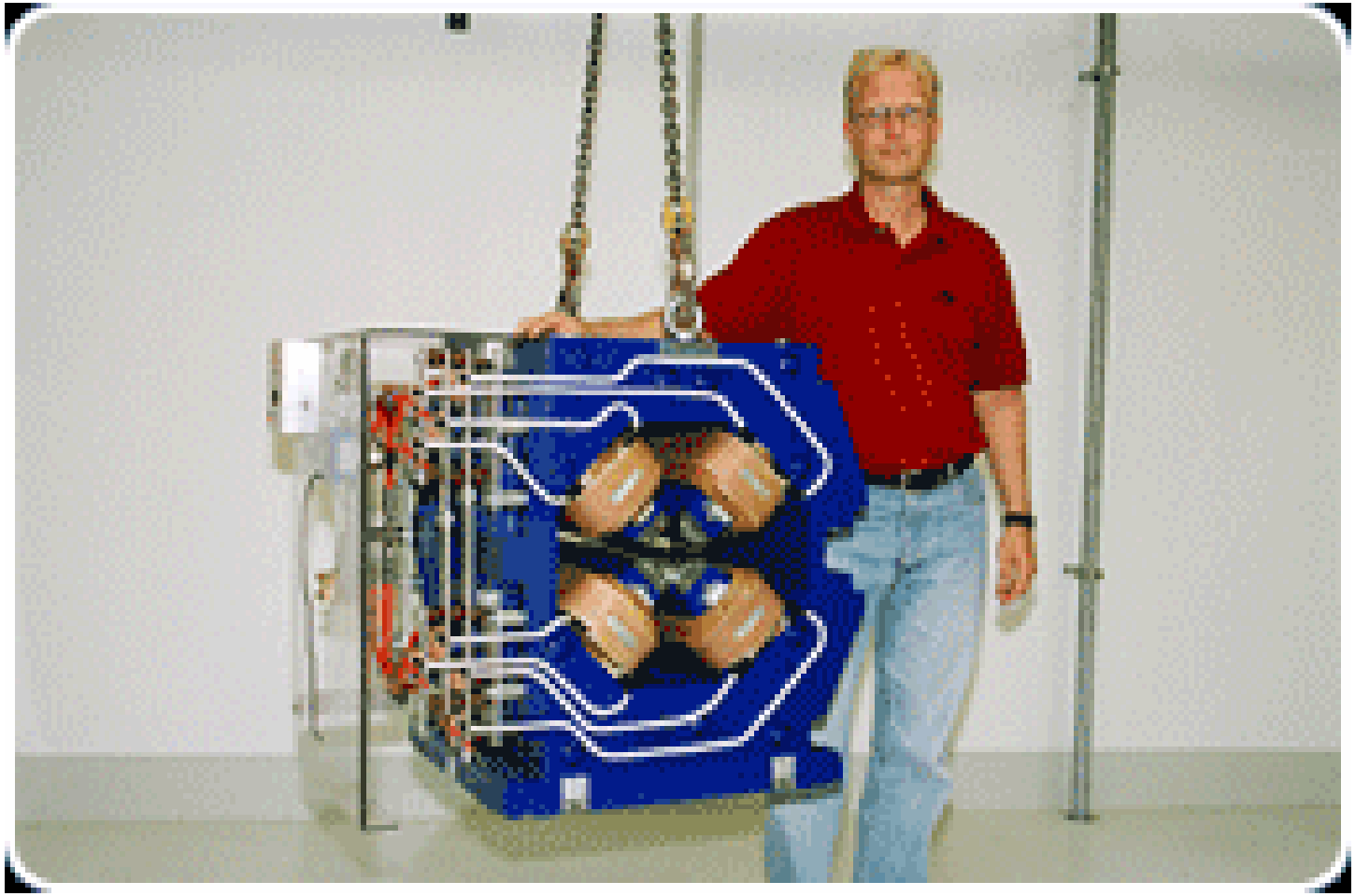
- Betatron oscillation work has showed us that, apart from bend plane focusing, a shaped field that focuses in one transverse direction, defocuses in the other
- Question: is it possible to develop a system that focuses in both directions simultaneously?

- Strong focusing: alternate the signs of focusing and defocusing: get net focusing!!



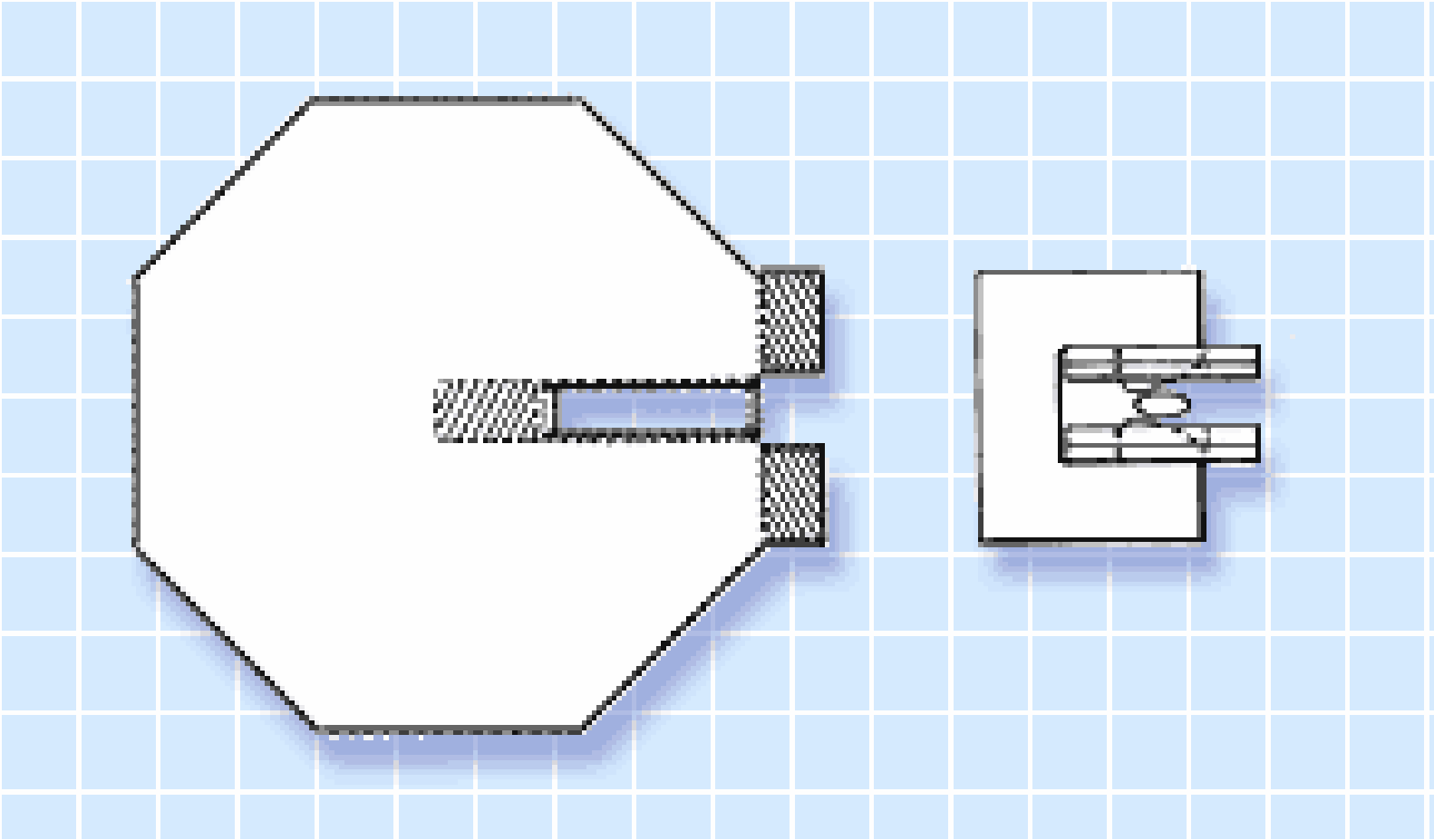
Order doesn't matter

Linear Magnetic Lenses: Quadrupoles



Source: Danfysik Web site

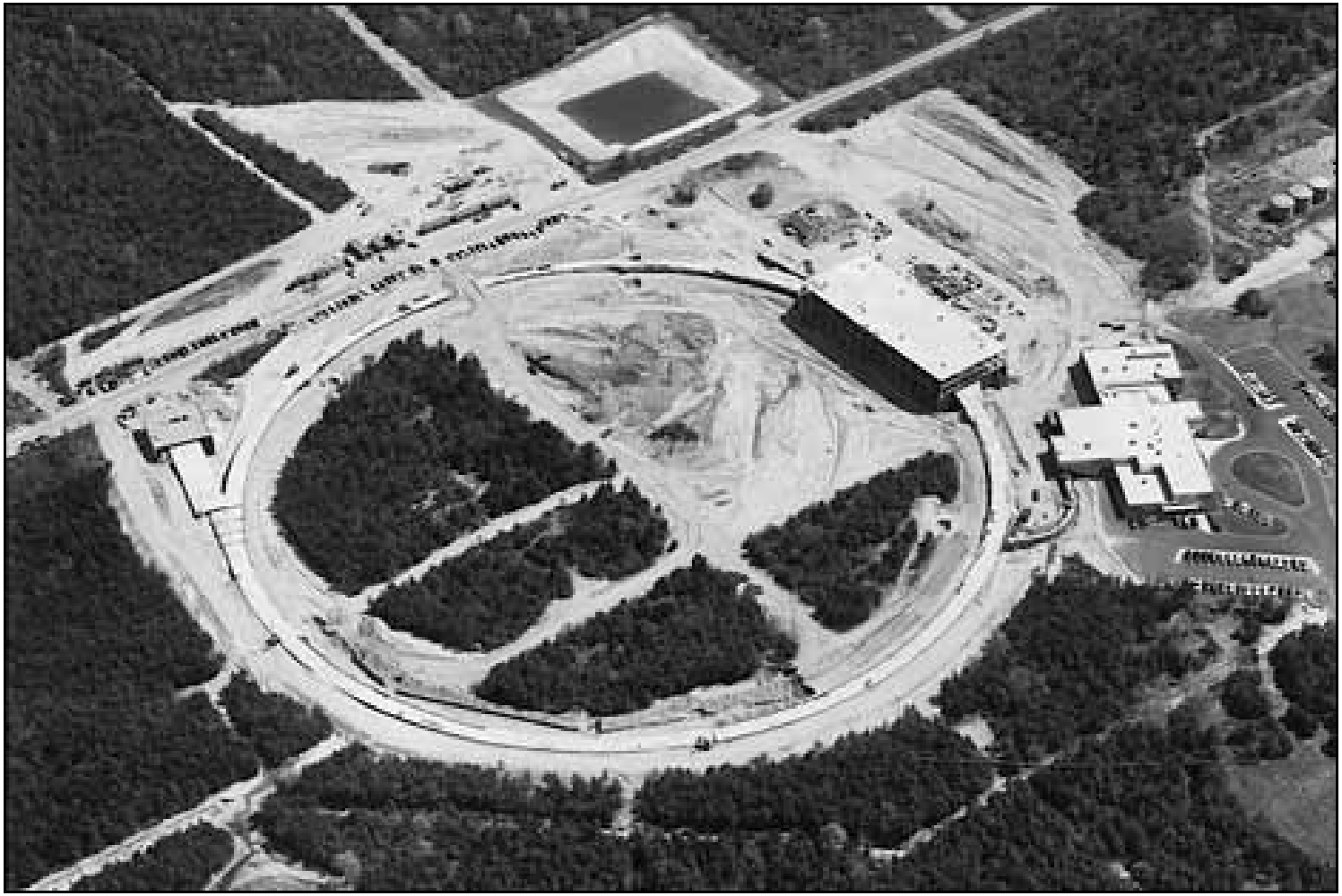
Weak vs. Strong Benders



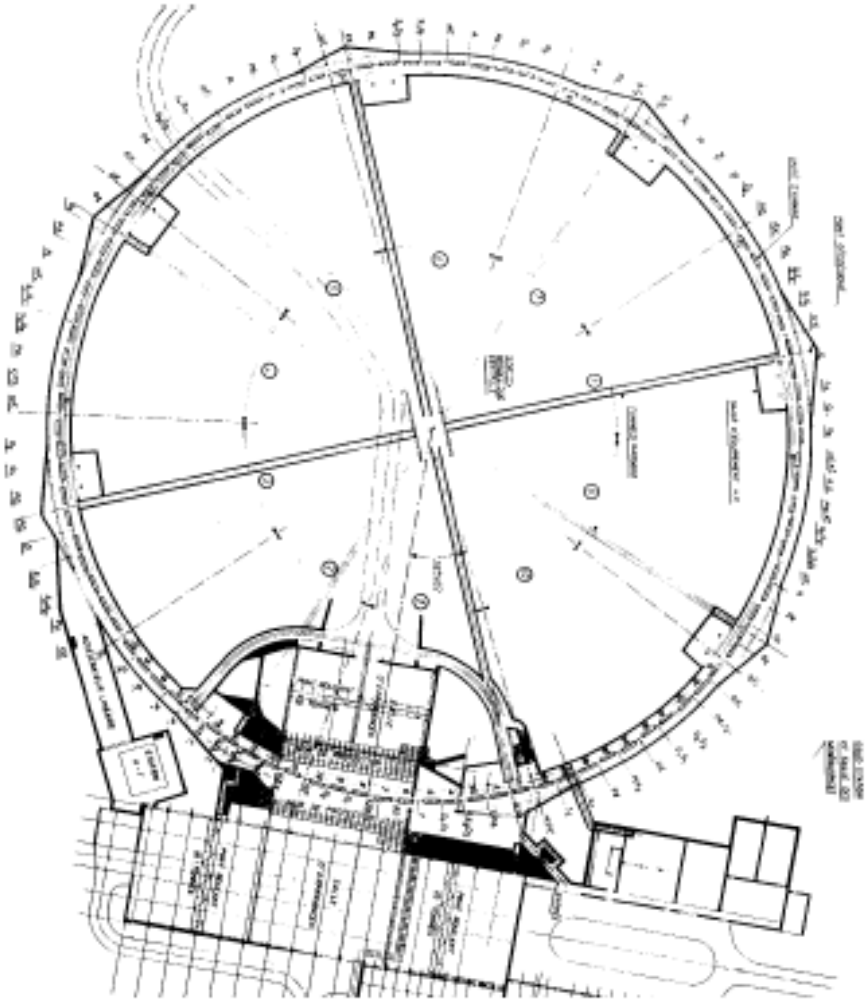
First Strong-Focusing Synchrotron

Cornell 1 GeV Electron Synchrotron (LEPP-AP Home Page)

Alternating Gradient Synchrotron (AGS)



CERN PS



25 GeV Proton Synchrotron

CERN SPS

Eventually 400 GeV protons and antiprotons

FNAL

First TeV-scale accelerator; Large Superconducting Benders

LEP Tunnel (Now LHC!)

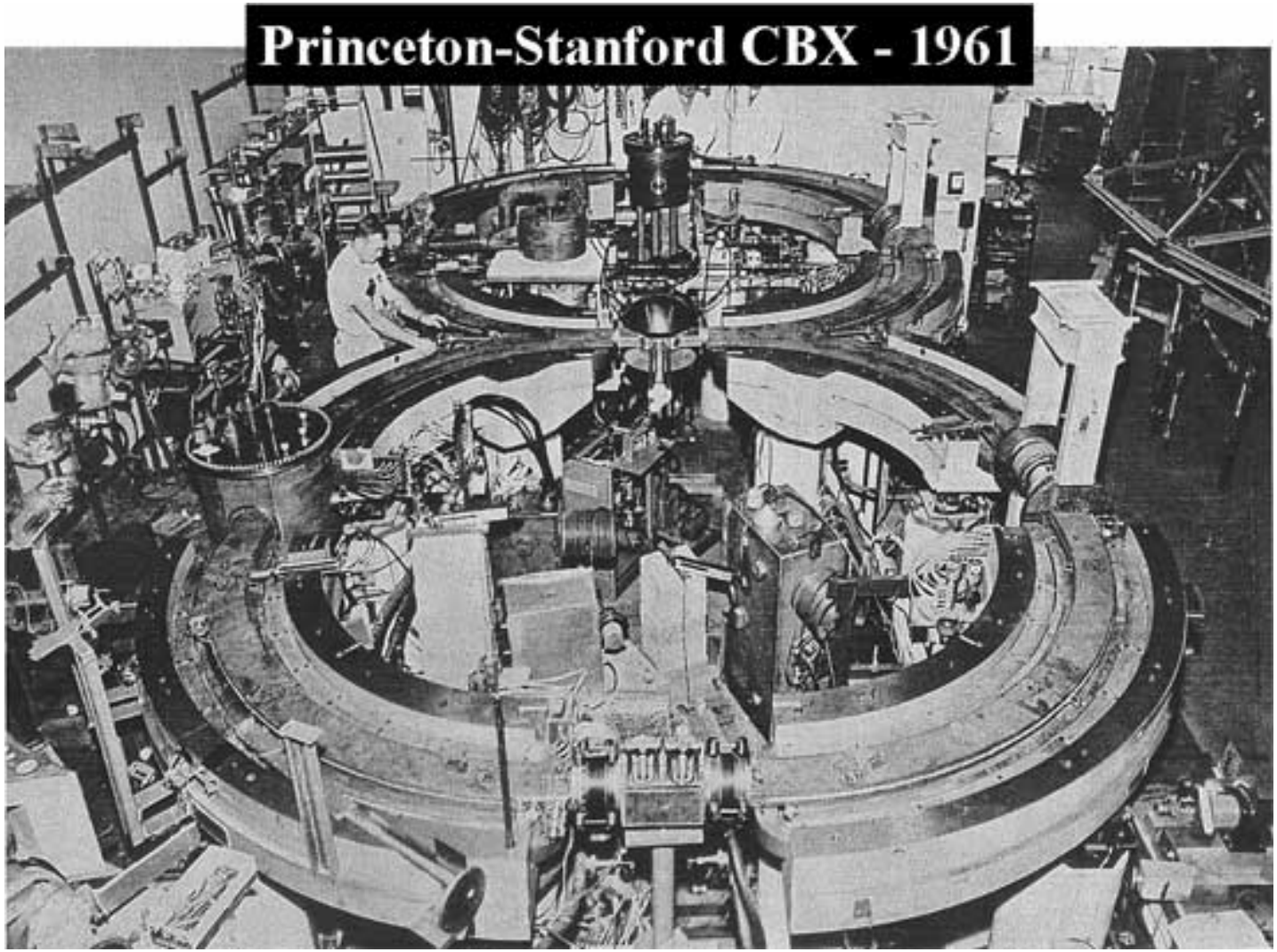
Empty

LHC

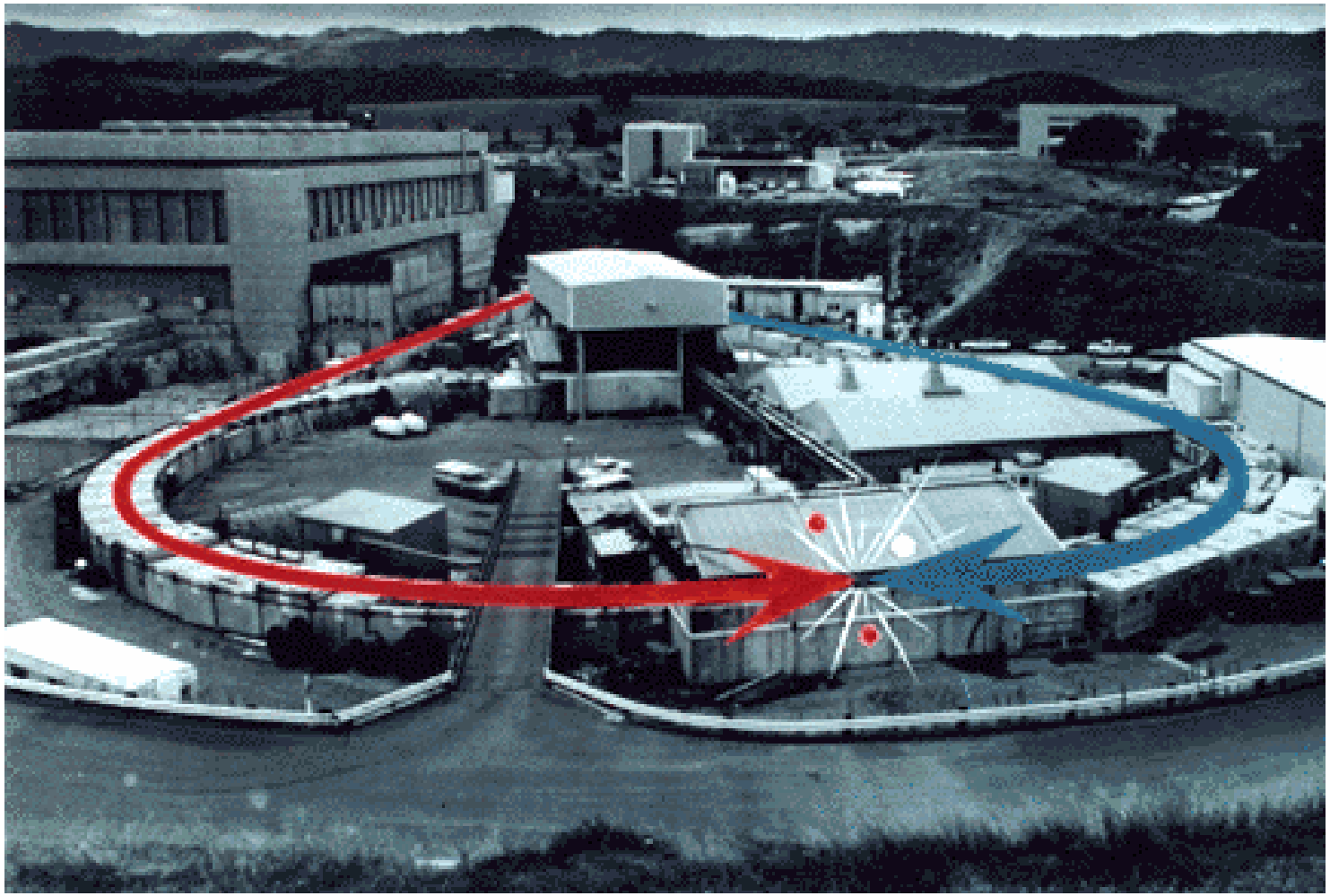
Storage Rings

- Some modern accelerators are designed not to “accelerate” much at all, but to “store” beams for long periods of time that can be usefully used by experimental users.
  - Colliders for High Energy Physics. Accelerated beam-accelerated beam collisions are much more energetic than accelerated beam-target collisions. To get to the highest beam energy for a given acceleration system design a collider
  - Electron storage rings for X-ray production: circulating electrons emit synchrotron radiation for a wide variety of experimental purposes.

Princeton-Stanford Collider



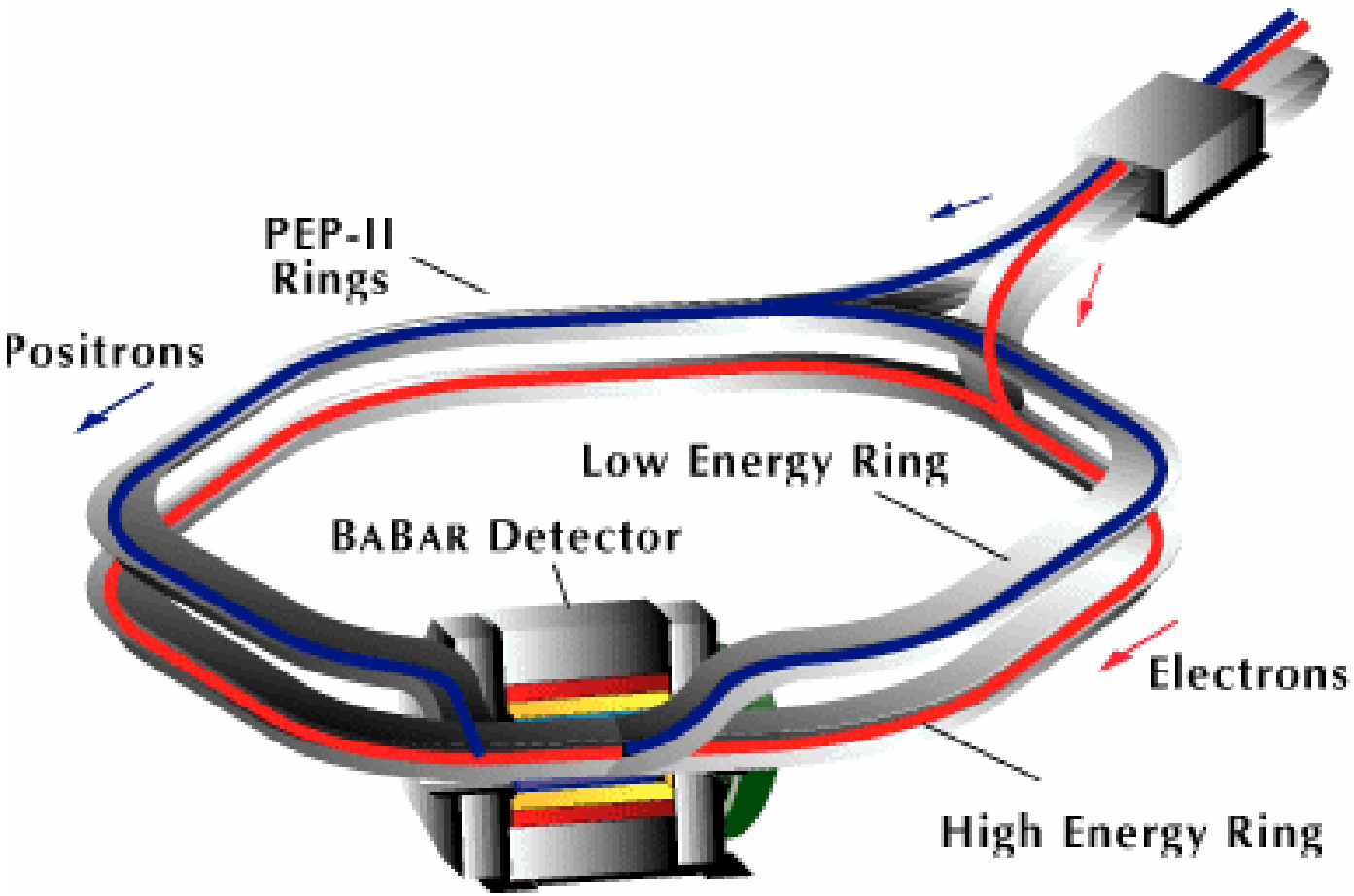
SPEAR



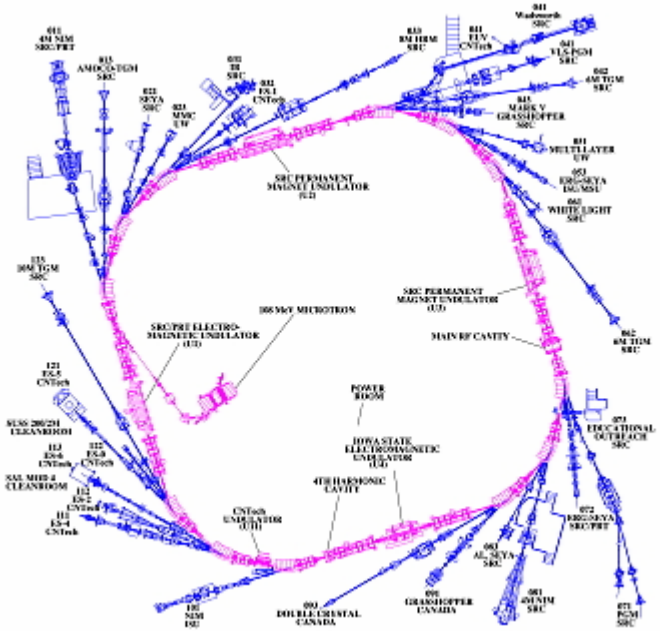
Eventually became leading synchrotron radiation machine

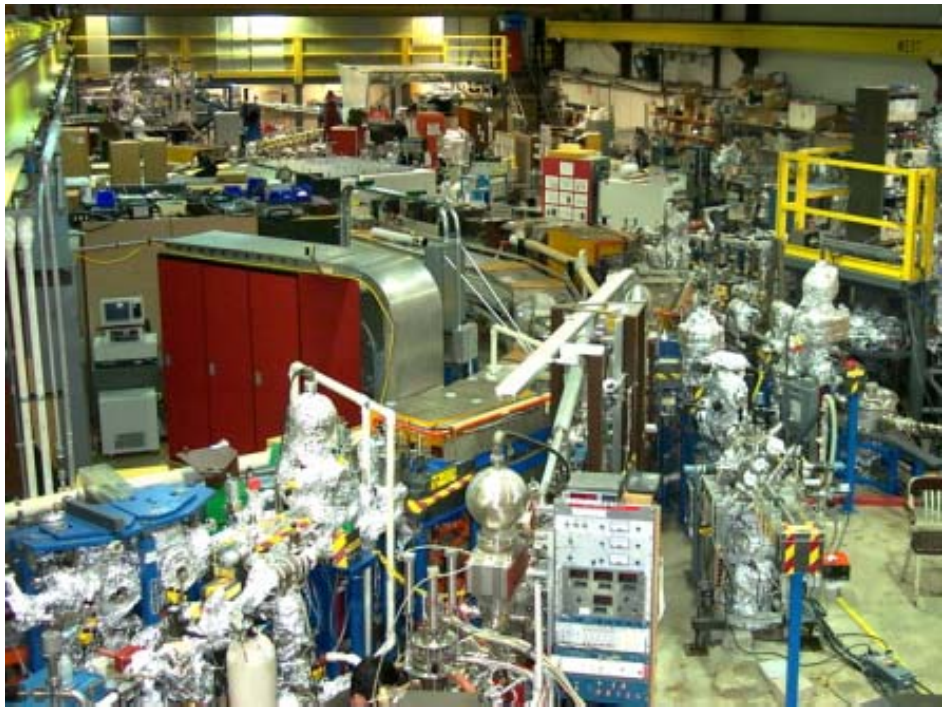
Cornell 10 GeV ES and CESR

SLAC's PEP II B-factory



ALADDIN at Univ. of Wisconsin

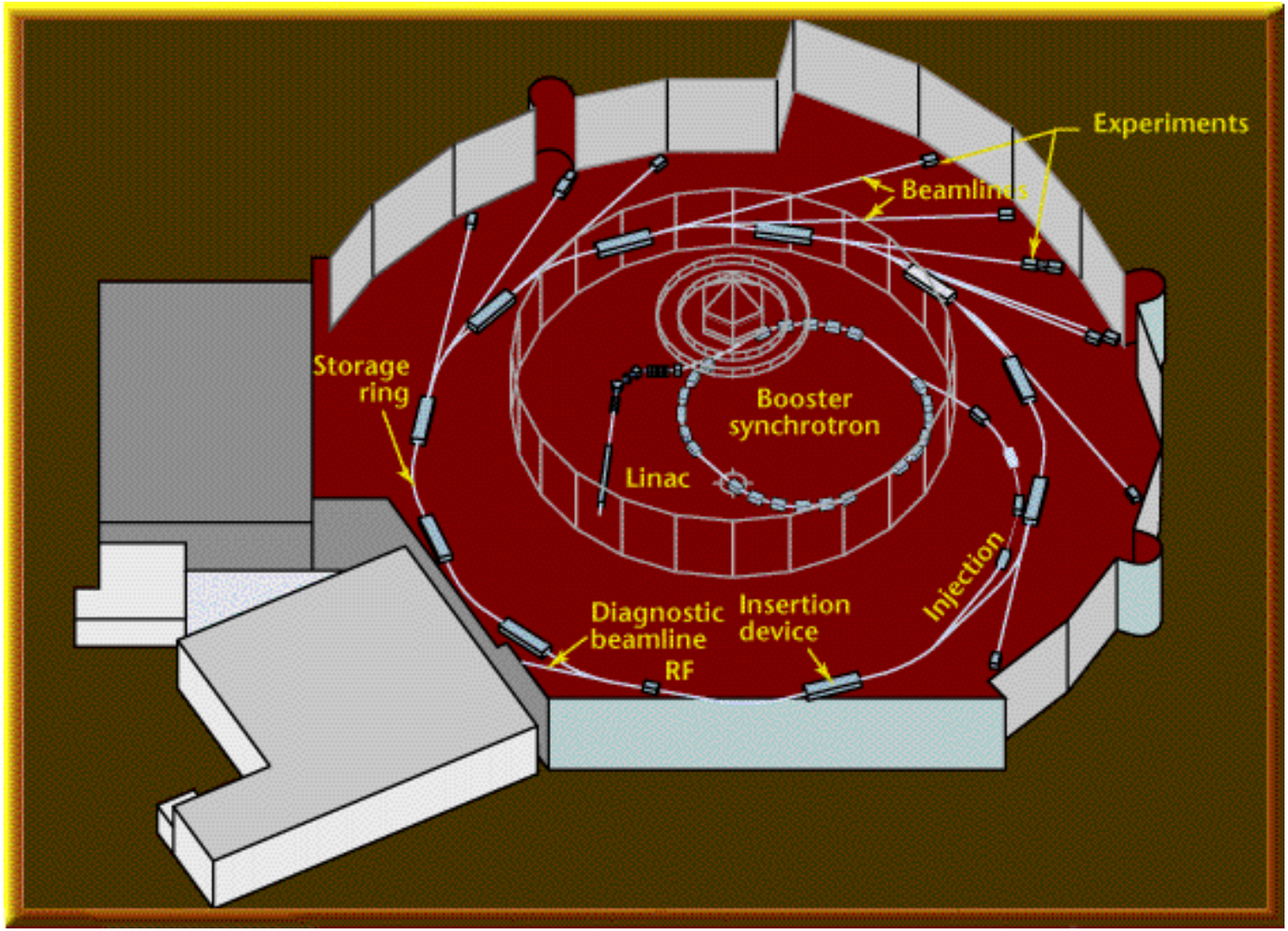




VUV Ring at NSLS

VUV ring “uncovered

Berkeley's ALS



Argonne APS

ESRF