CESR

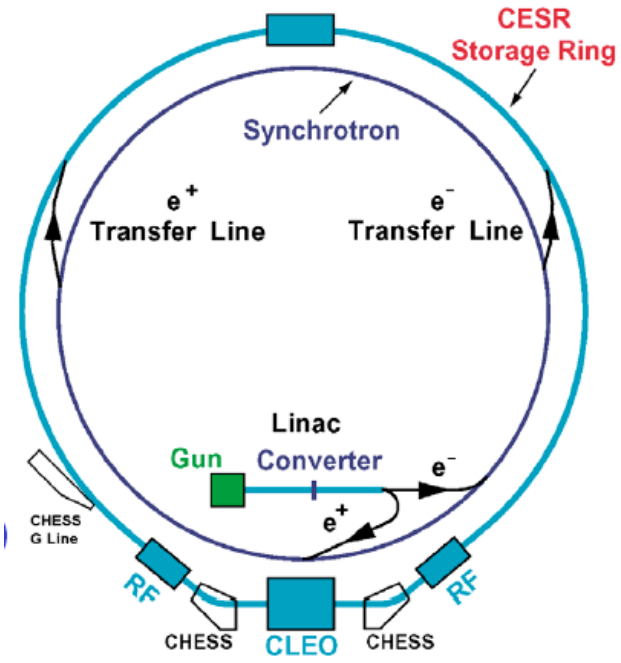
Donna
Kubik
Spring 2005

CESR

- With thanks to many at CESR for technical guidance (and friendship!):

  Dave Rice, Stu Peck, Jerry Codner, Gerry Dugan, and my mentor, Mario Giannella…

CESR


CESR
Storage Ring
Synchrotron
e+
Transfer Line
e-
Transfer Line
Linac
Gun
Converter
e-
e+
CHESS
G Line
RF
RF
CHESS
CLEO
CHESS

CESR Control Room

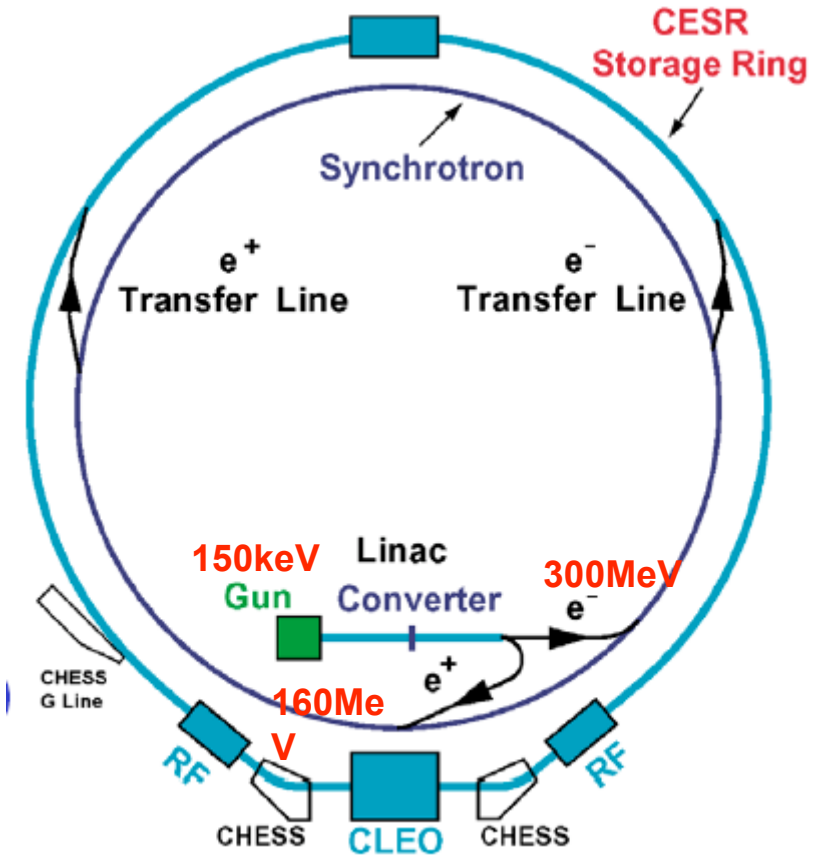
Names

- The names used to refer to the colliding beam facilities and the rings that comprise the facilities can be confusing
- “CESR” and “Tevatron” technically refer only to the storage ring
- But often “CESR” and “Tevatron” are used to refer to the entire accelerator complex

Names

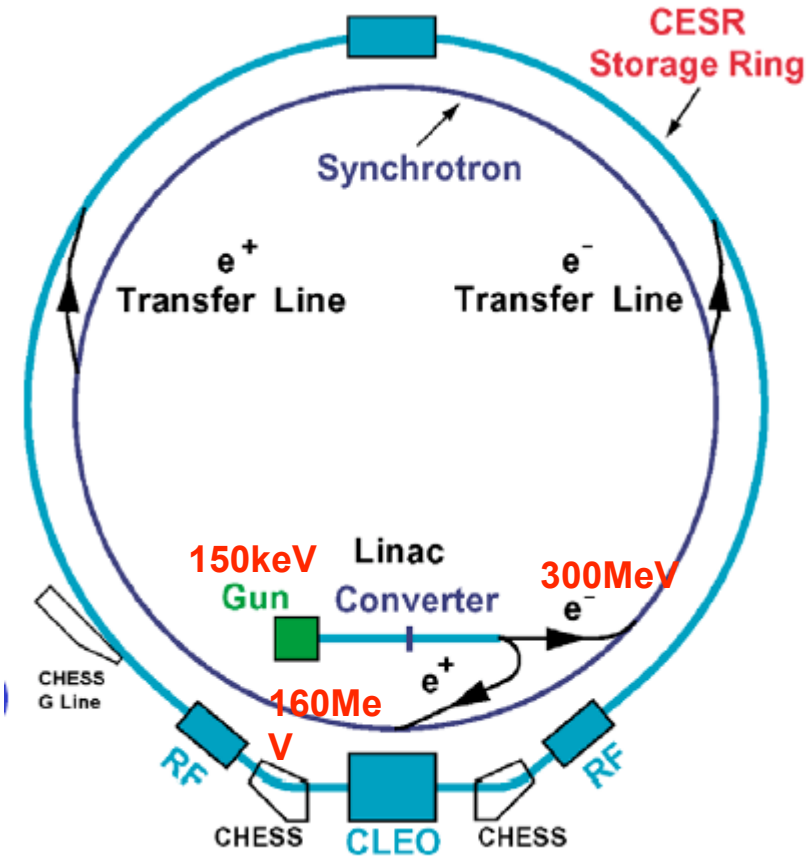
- Wilson Lab accelerator
  - Linac
  - Synchrotron
  - Storage ring (CESR)
- Fermilab accelerator
  - Linac
  - Booster
  - Main injector
  - Antiproton source
  - Storage ring (Tevatron)

Linac

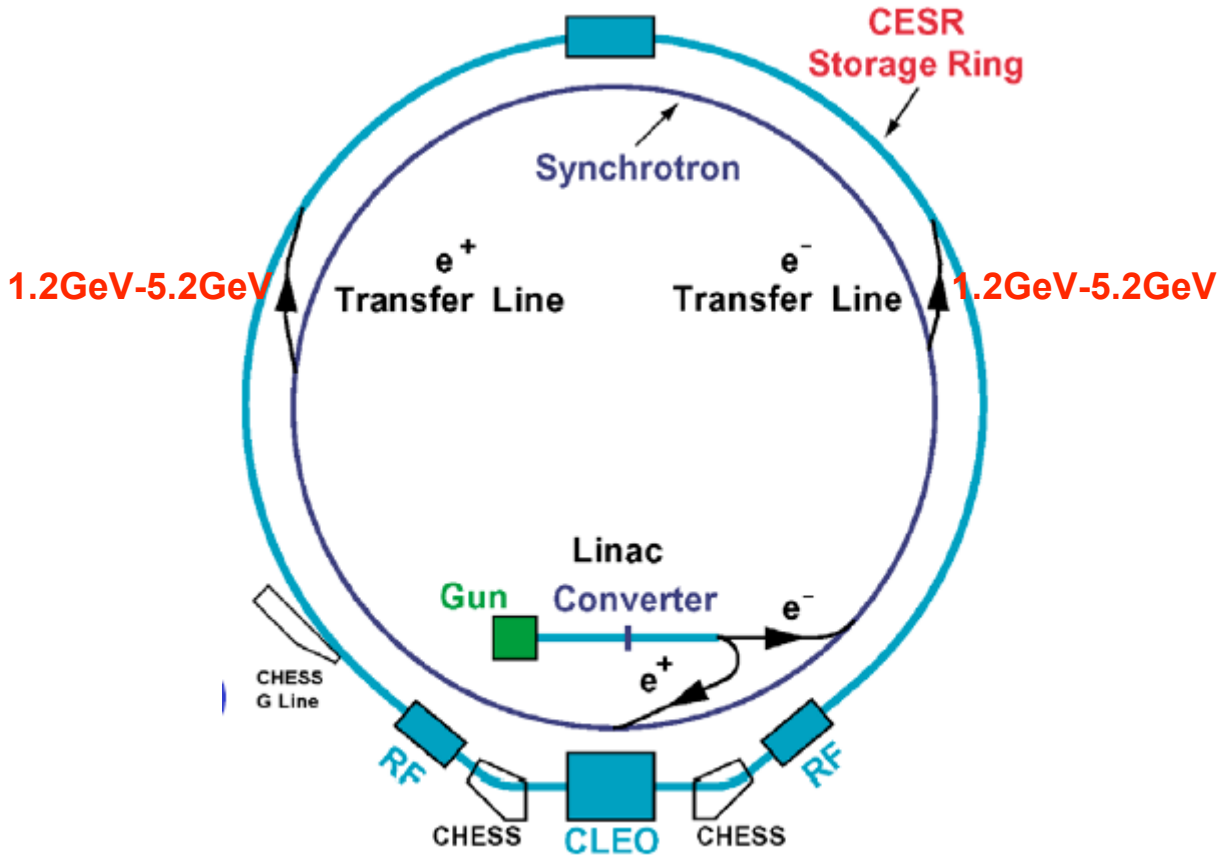

CESR
Storage Ring
Synchrotron
e+
Transfer Line
e-
Transfer Line
150keV
Gun
Linac
Converter
300MeV
e-
e+
160Me
V
CHESS
G Line
RF
RF
CHESS
CLEO
CHESS

Converter

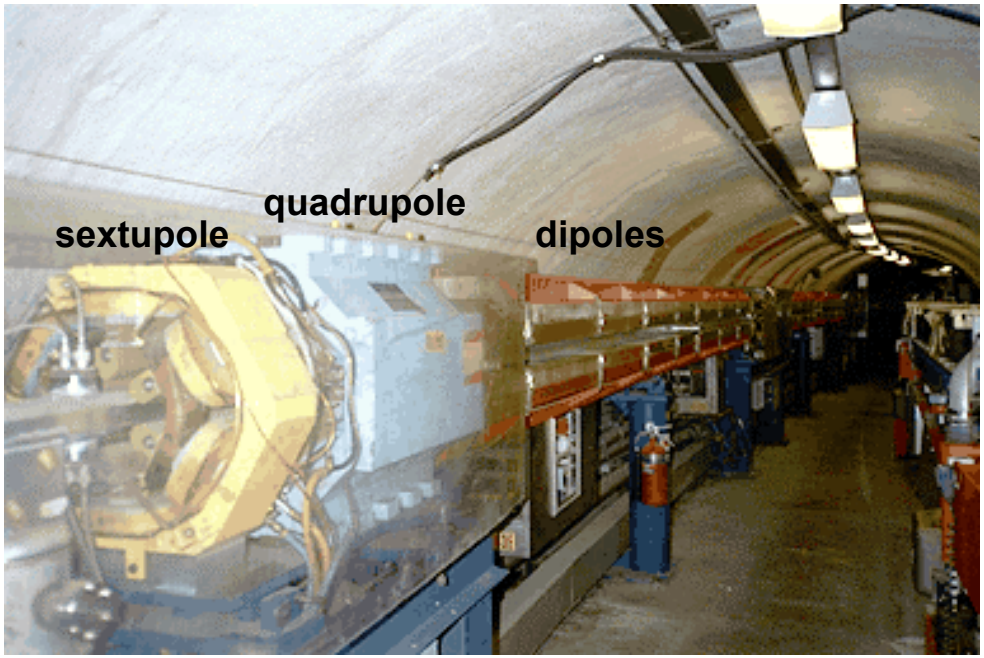
- "Converts" electrons to positrons
- Positrons are produced by accelerating electrons up to 150 MeV at an intermediate point of the linac where they strike a tungsten plate
- A spray of electrons, positrons, and X-rays emerges from the plate
- The positrons are selected, focused, accelerated in the remaining length of the Linac up to the 160 MeV final energy and injected into the synchrotron.



Synchrotron and storage ring

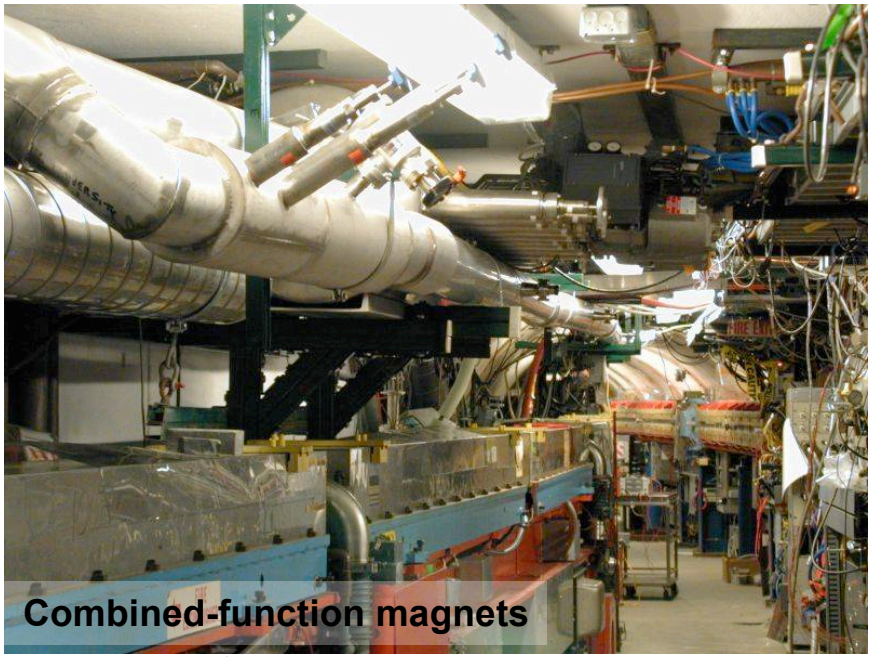


Synchrotron and storage ring



Storage ring

Synchrotron

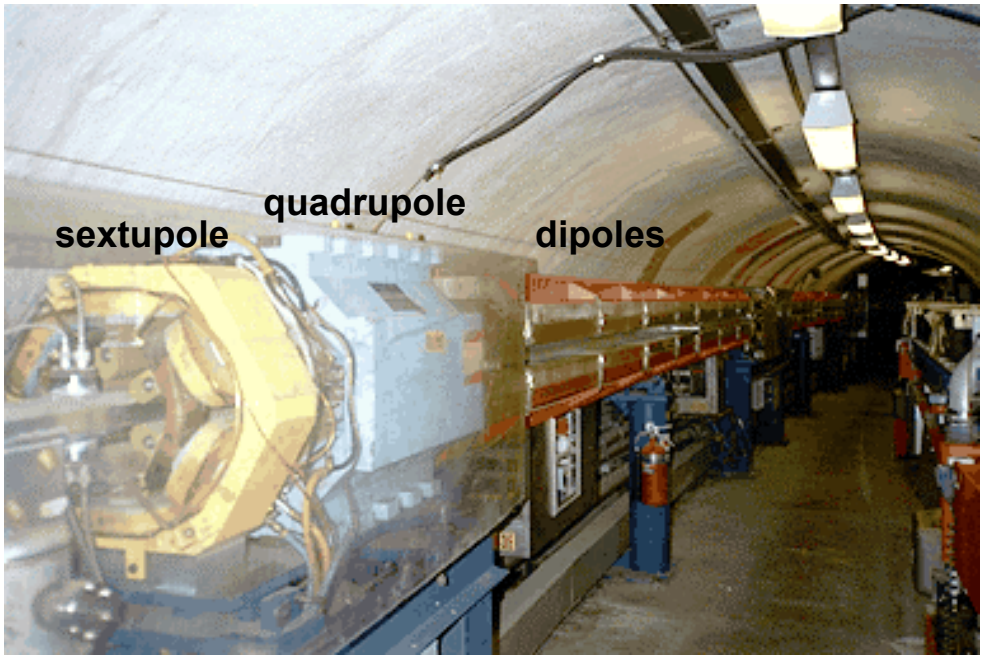


magnets

Synchrotron

Storage ring

Synchrotron and storage ring

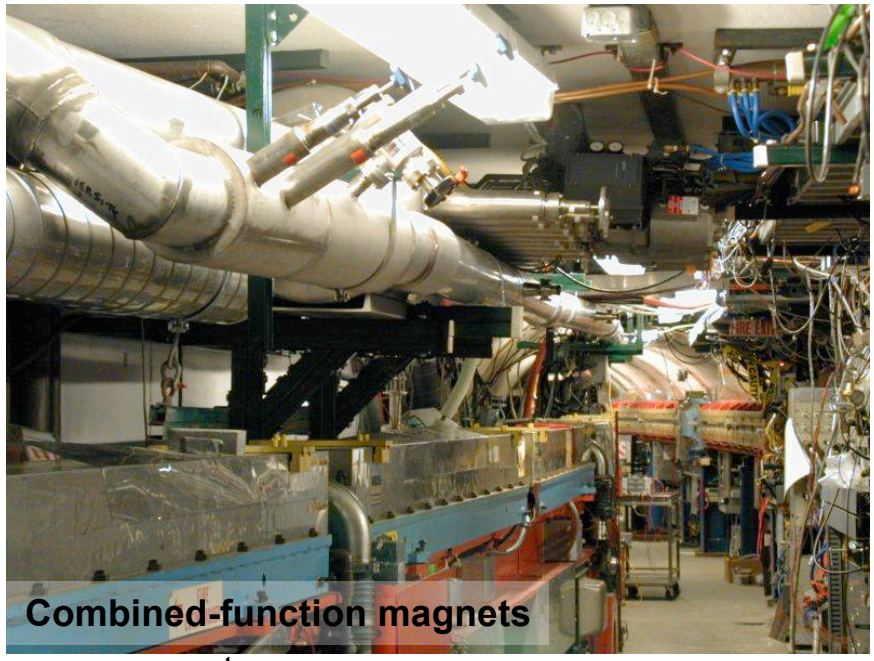


- There are either e^+ or e^- in the synchrotron
- Each species is accelerated and injected into the storage ring separately
- On the contrary, both e^+ and e^- are in the storage ring.

Combined function magnets

- The synchrotron magnets (in contrast to those in the storage ring) are combined function magnets (aka gradient magnets).

- Each magnet bends the beam (a dipole function) and focuses the beam (a quadrupole function)



Combined function magnets

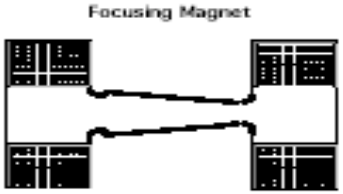
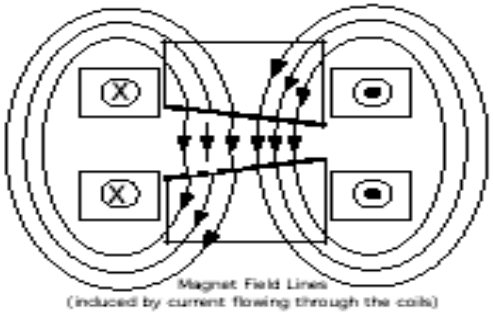
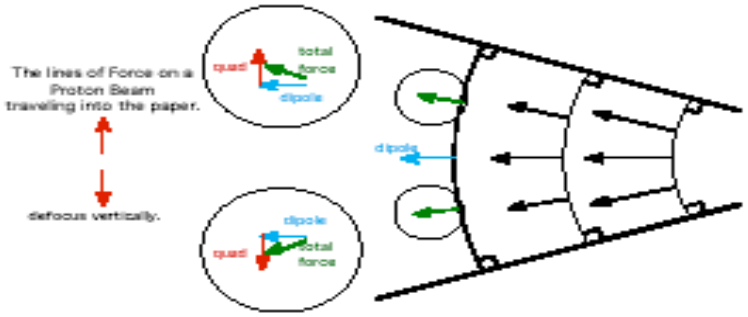


figure 2.2.2





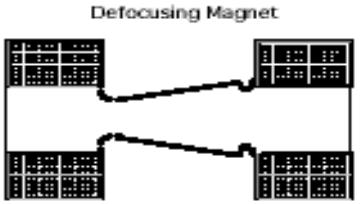
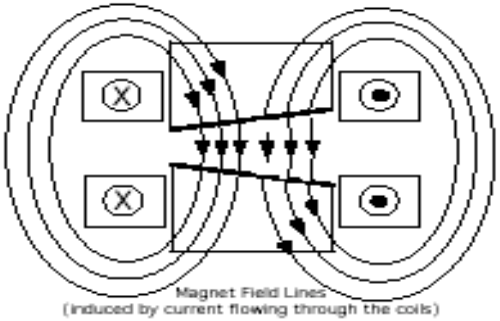
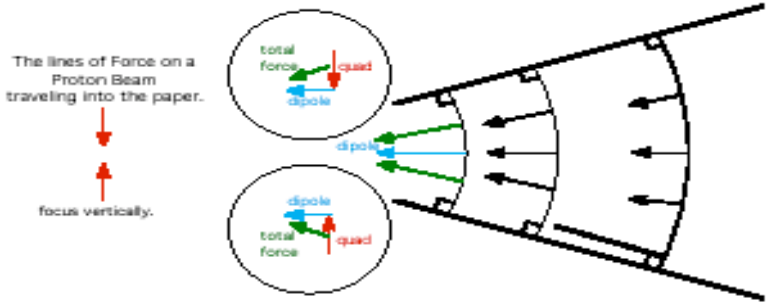


figure 2.2.3





Rapid cycling

- The synchrotron magnets are part of a 60 Hz resonant circuit
- Energy is exchanged between the magnets and the capacitor banks with the power supply making up the losses

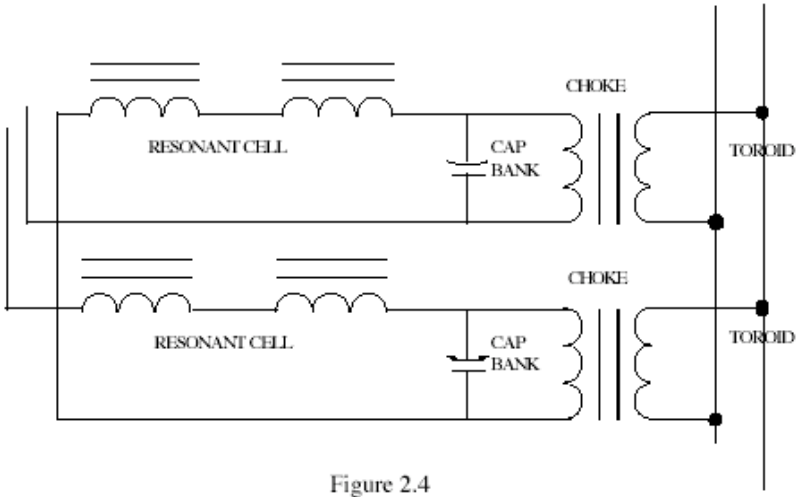
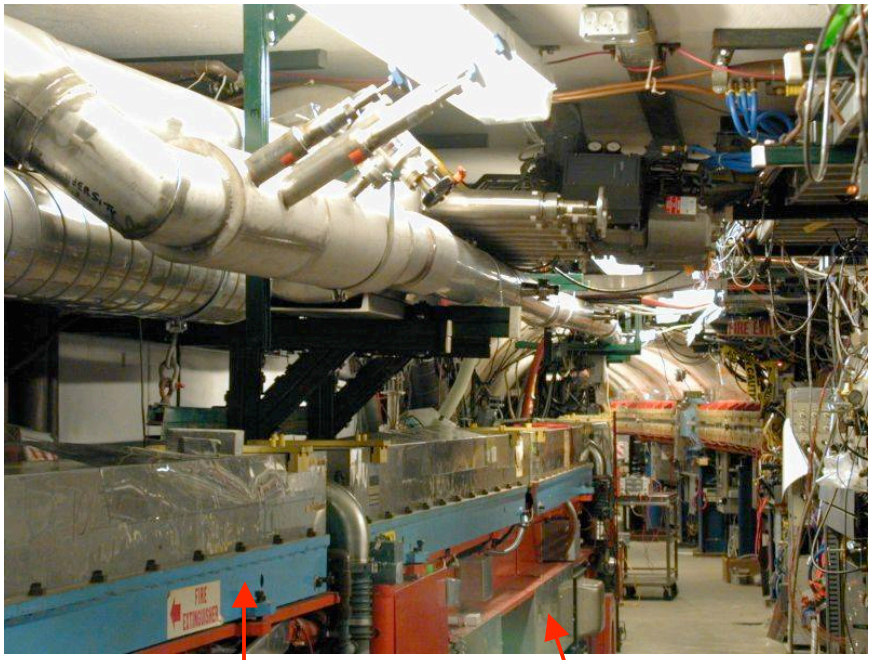


Figure 2.4
Resonant Cell

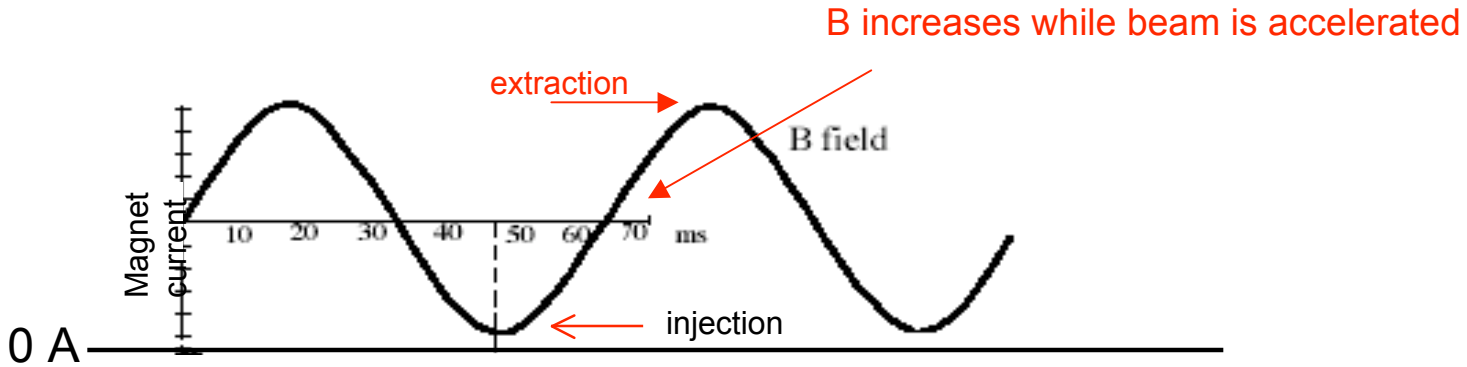


Inductors
(the magnet coils)

Capacitor bank

Acceleration

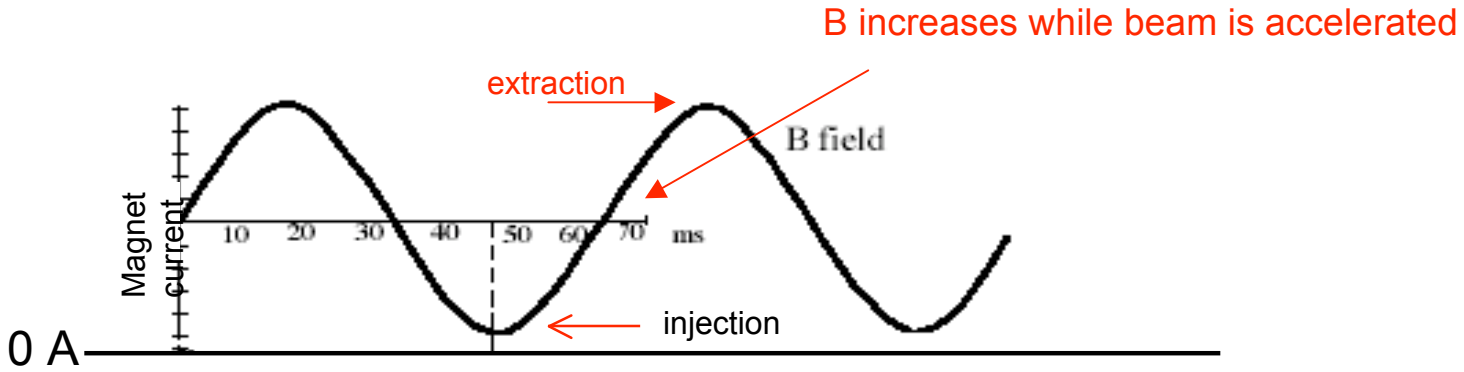
- Acceleration cycles occur at 60 Hz
- As particles are accelerated and gain energy in the synchrotron, the magnetic field must also increase



Note: The period shown is for a 15 Hz rep rate (which is the rep rate of FNAL's rapid cycling synchrotron)

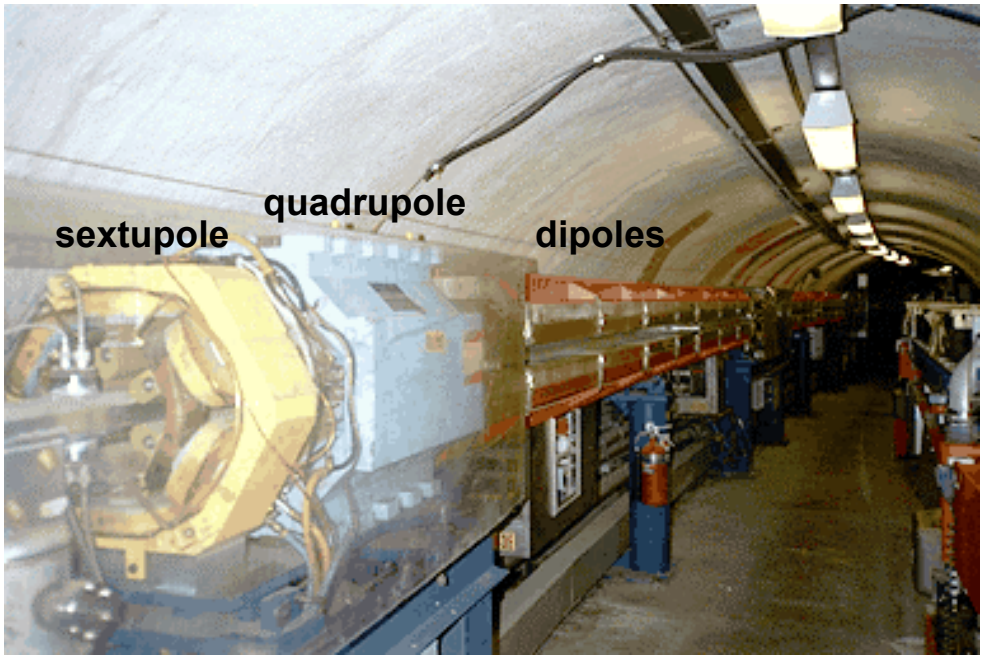
Acceleration

- The magnet current waveform has a DC offset; the whole sinusoidal waveform is raised so the current is always positive.
- The electrons/positrons are injected just after the current reaches its lowest point.
- As particles are accelerated and gain energy in the synchrotron, the magnetic field also increases



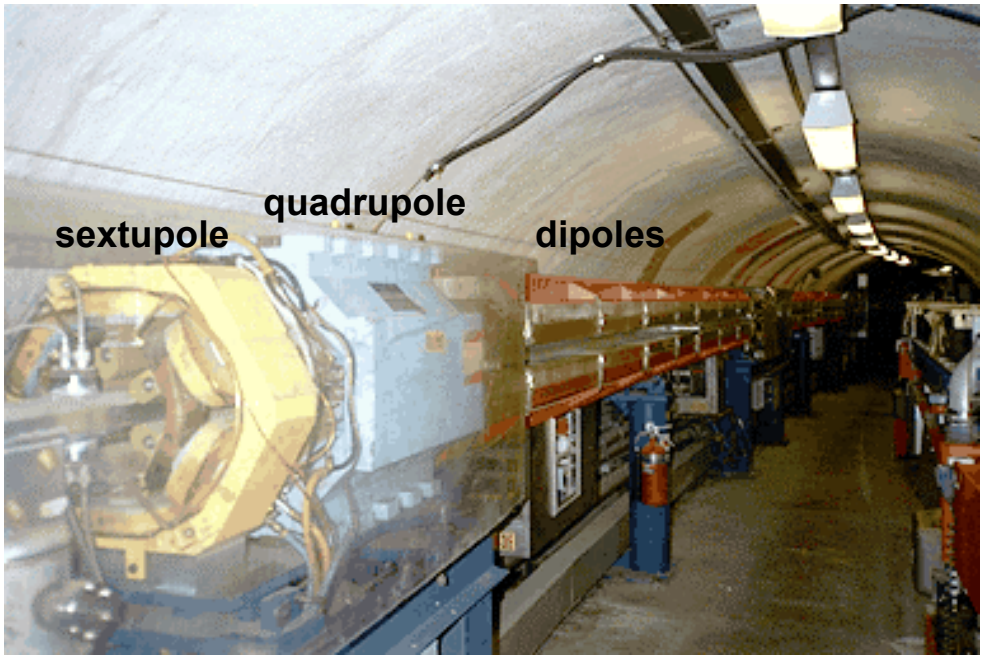
Note: The period shown is for a 15 Hz rep rate (which is the rep rate of FNAL's rapid cycling synchrotron)

Storage ring



- The storage ring has separated function magnets
- Dipoles, quadrupoles, sextupoles, octupoles
- Dipoles operate DC and are wired in series
- All higher order magnets are individually tunable

Storage ring



- Note, no acceleration occurs in the storage ring, so no magnet ramps are required (this is not true of Fermilab's storage ring)
- But, as will be shown later, the storage ring requires lots of RF to restore energy lost to synchrotron radiation

Lorentz force law

- The e^+ and e^- move in the opposite directions around the ring
- Therefore, depending on their function, some devices in the storage ring use E fields and some are based on B fields

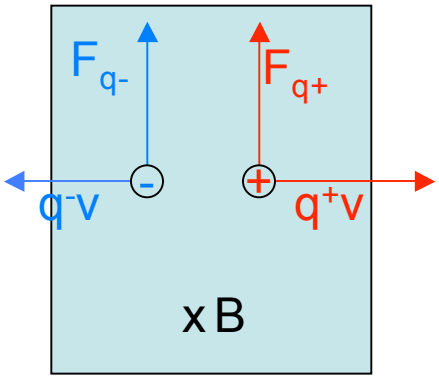
$$\overline{F} = q[\overline{E} + (\overline{v} \times \overline{B})]$$

$$\overline{F} = \underbrace{q\overline{E}}_{\text{Use this to separate the e+ and e- beams}} + \underbrace{q(\overline{v} \times \overline{B})]}_{\text{Use this to make the particles travel in a circular orbit}}$$

Lorentz force law

- Magnetic fields
  - Used when you want both charges to be deflected in the same direction
  - They will follow the same orbit with opposite velocity

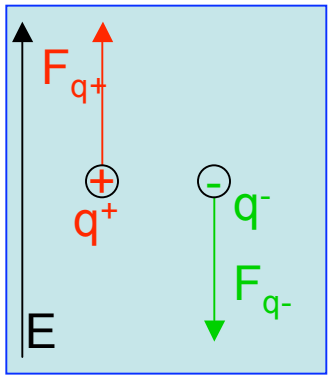
$$\overline{F} = q(\overline{v} \times \overline{B})$$



Bird's eye view of dipole

- Electric fields
  - Used when you want both charges to be deflected in the opposite direction
  - They will follow the different orbits

$$\overline{F} = q\overline{E}$$

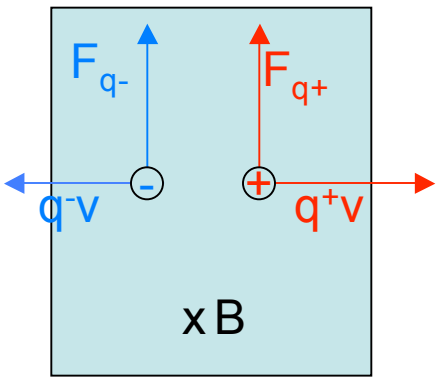


Bird's eye view of accelerator

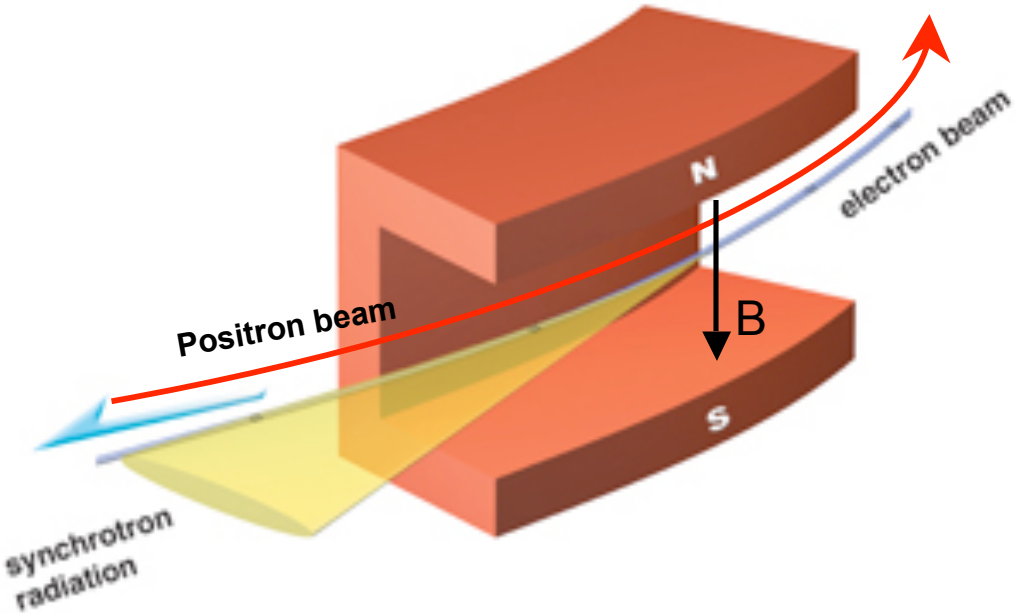
Lorentz force law

- Magnetic fields
  - e+ and e- follow the same orbit

$$\overline{F} = q(\overline{v} \times \overline{B})$$



Bird's eye view of dipole

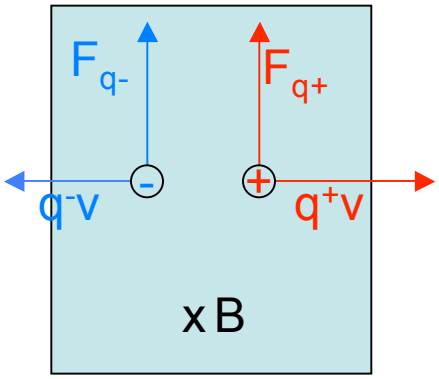


Dipole magnet

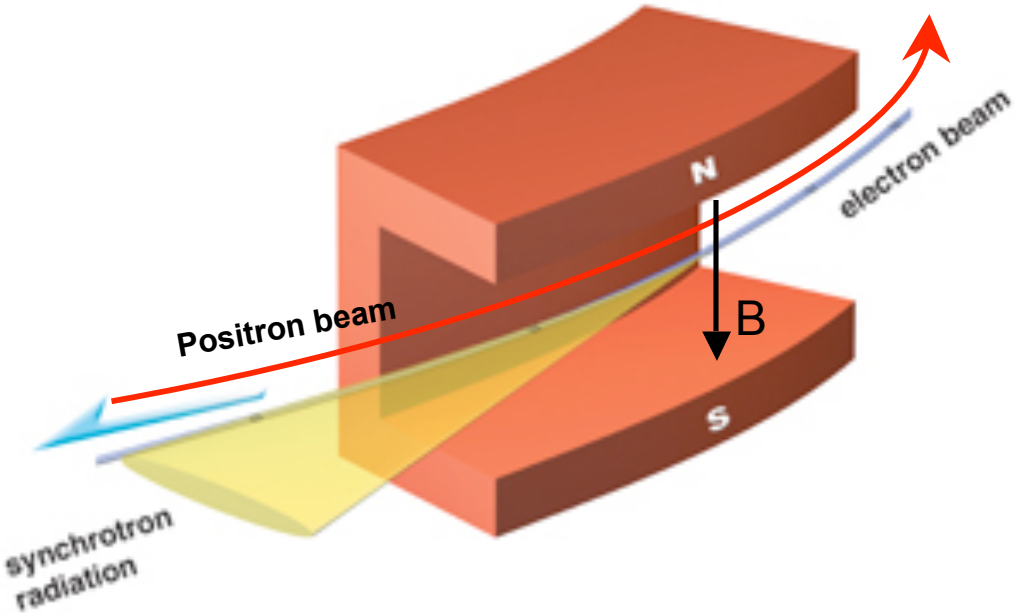
Lorentz force law

- Magnetic fields
  - Allows the e+ and e- to be deflected by the same magnets and share the same vacuum chamber (beam tube)

$$\overline{F} = q(\overline{v} \times \overline{B})$$



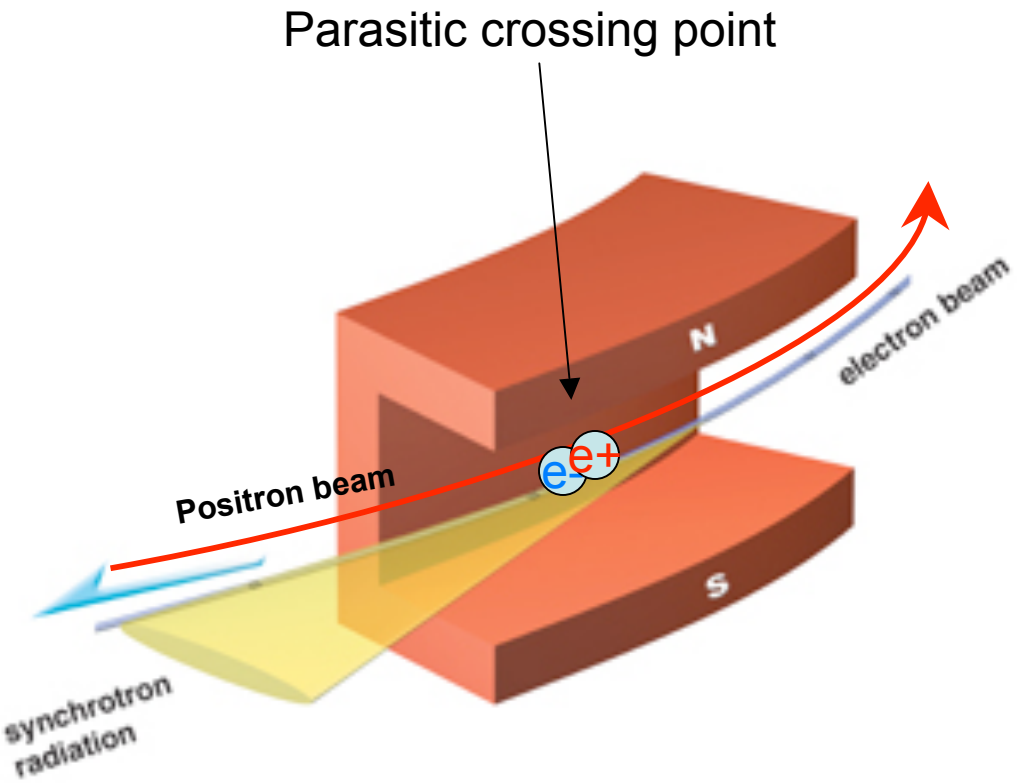
Bird's eye view of dipole



Dipole magnet

Parasitic crossings

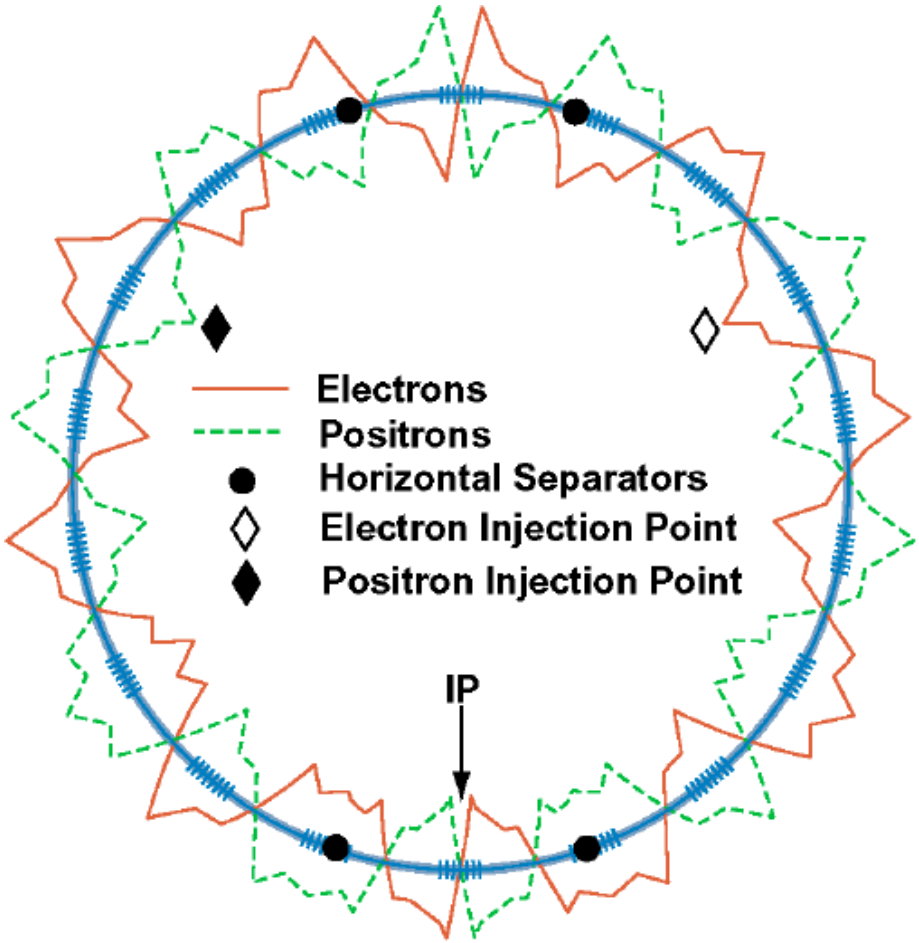
- But, if the electrons and positrons follow exactly the same orbit, the bunches will collide at many places around the ring, not only at the detector.
- 45 bunches/beam
  (9 trains x 5 bunches)
- 89 parasitic crossings
- This will unduly disturb the beam



Want this to happen only at the interaction point!

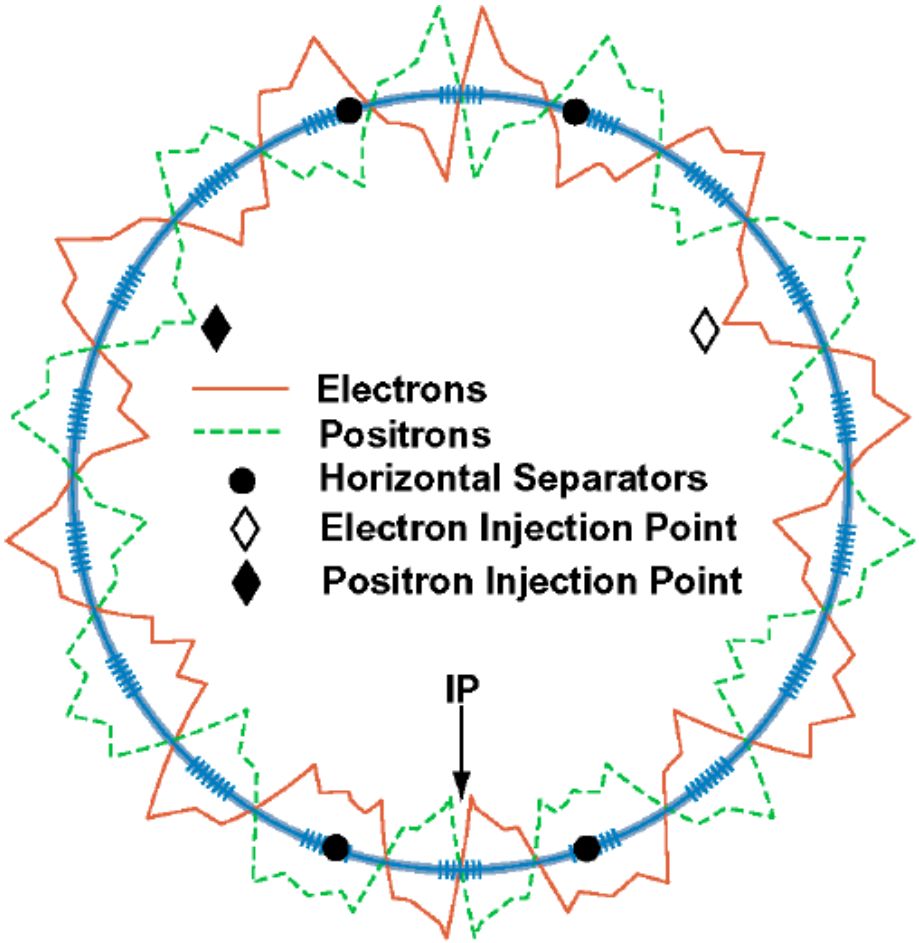
Electrostatic separators

- Beams are separated at the parasitic crossing points by separating the closed orbits of the e+ and e- with electrostatic deflectors (separators)



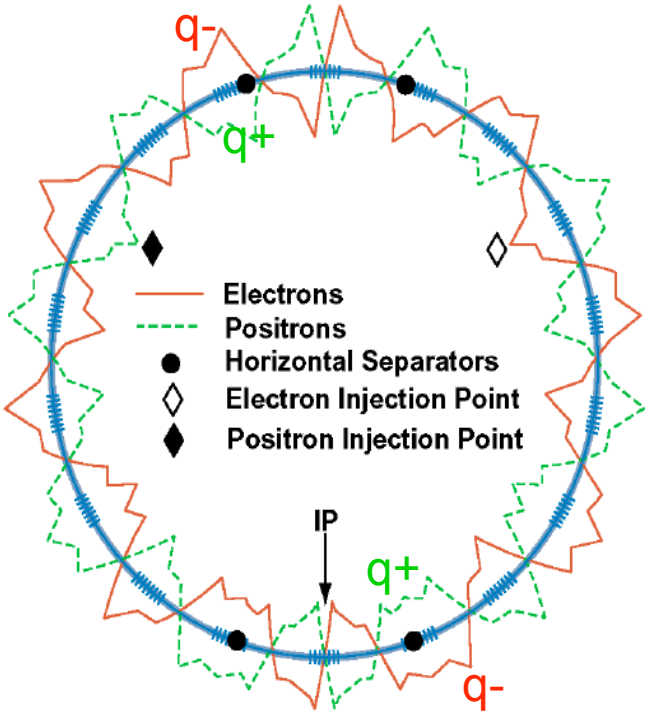
Separators

- 4 horizontal (H) separators create a “pretzel” orbit
- The pretzel is only in H plane
- +-20 mm maximum separation
- 2 vertical (V) separators in north create semi-closed separation bump at north IP, where H pretzel has a node
- Mismatch of beta at e/w V separators is used to adjust V separation at south IP.

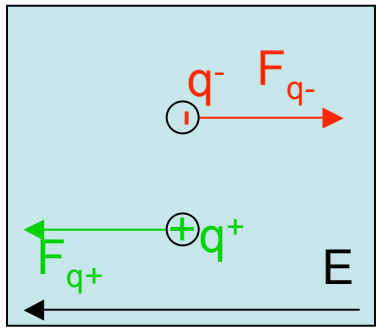


Separator design

- Must use electric field to cause opposite defection of e+ and e-



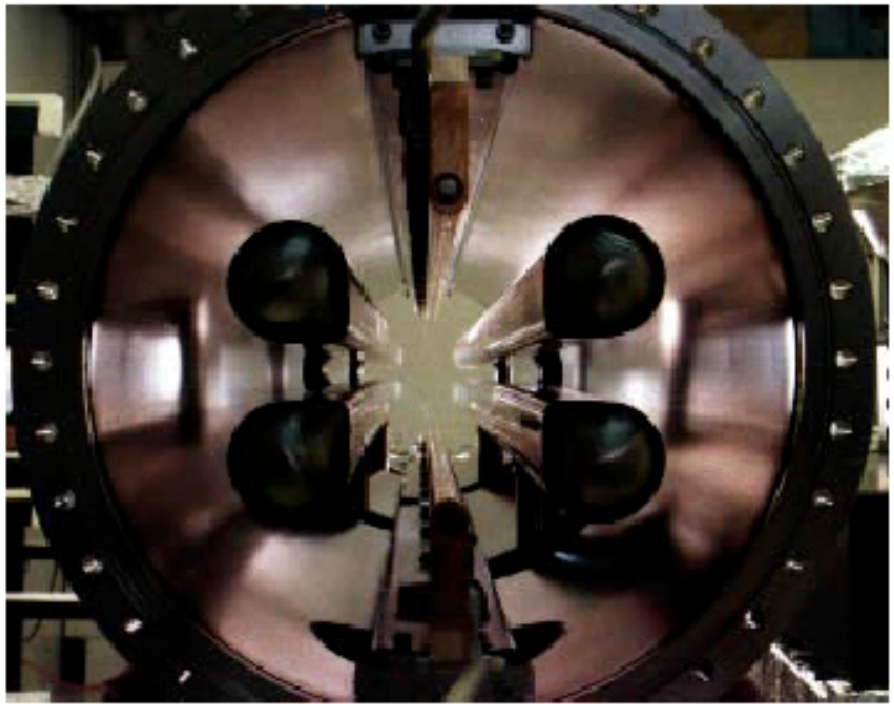
$$\overline{F} = q\overline{E}$$



Viewed in beam direction

Separator design

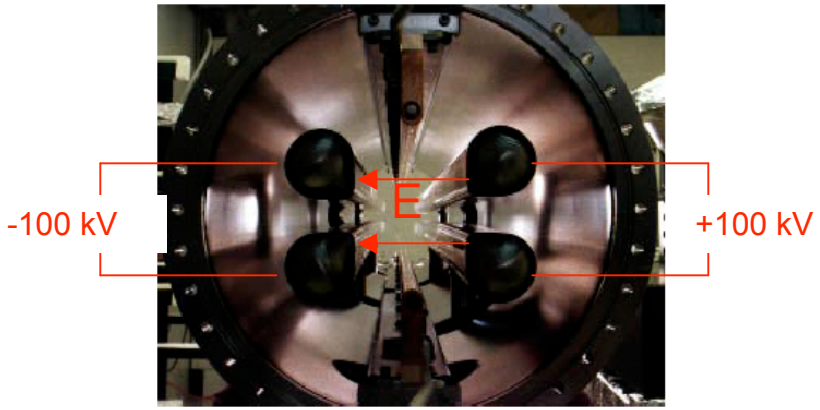
- Use of two electrodes per side with a gap in the middle avoids bombarding the electrodes with direct synchrotron radiation which would generate huge photo currents.

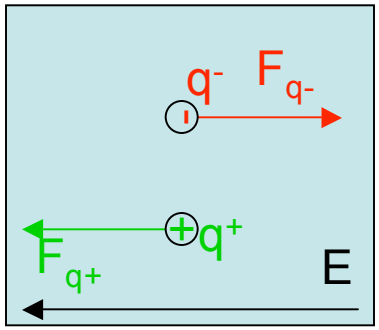


Separator
Viewed in beam direction

Separator design

- +V and -V are from two separate DC 0-100 kV power supplies.

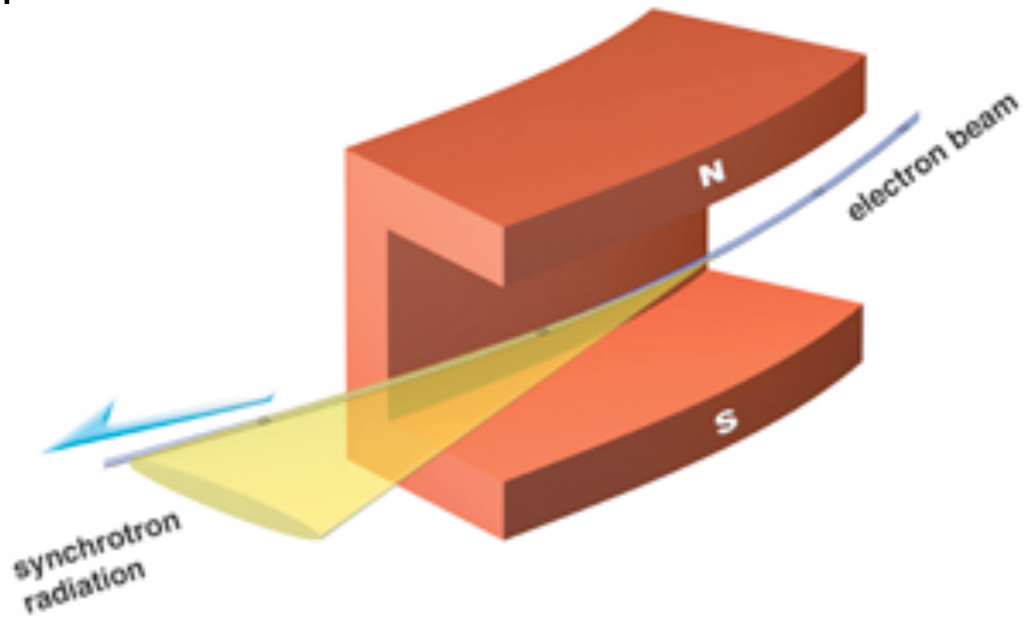




Viewed in beam direction

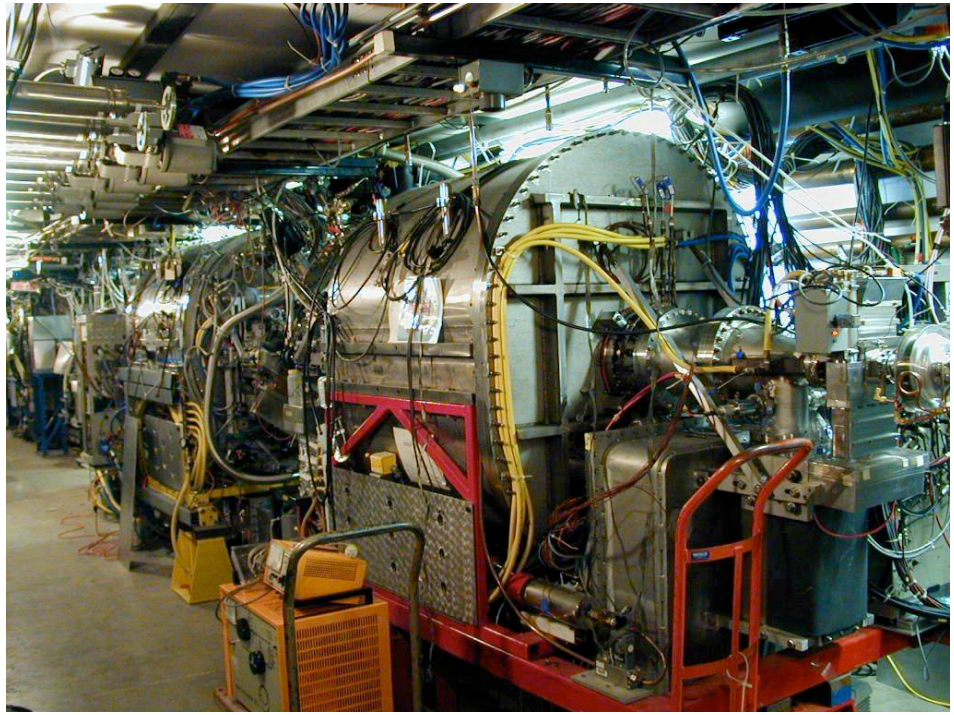
Synchrotron radiation

- The acceleration due to the field within the bending magnet or a separator is perpendicular to the particle trajectory
- The resultant energy loss by synchrotron radiation is a significant fraction of the particle energy.



Synchrotron radiation

- Power of this synchrotron radiation is about half a megawatt
- 4 SRF cavities restore lost energy to the beam
- Sync radiation strikes the vacuum chamber in a narrow stripe, depositing energy on the vacuum chamber wall
- The heat generated must be carried away by water circulating through a channel in the vacuum chamber wall



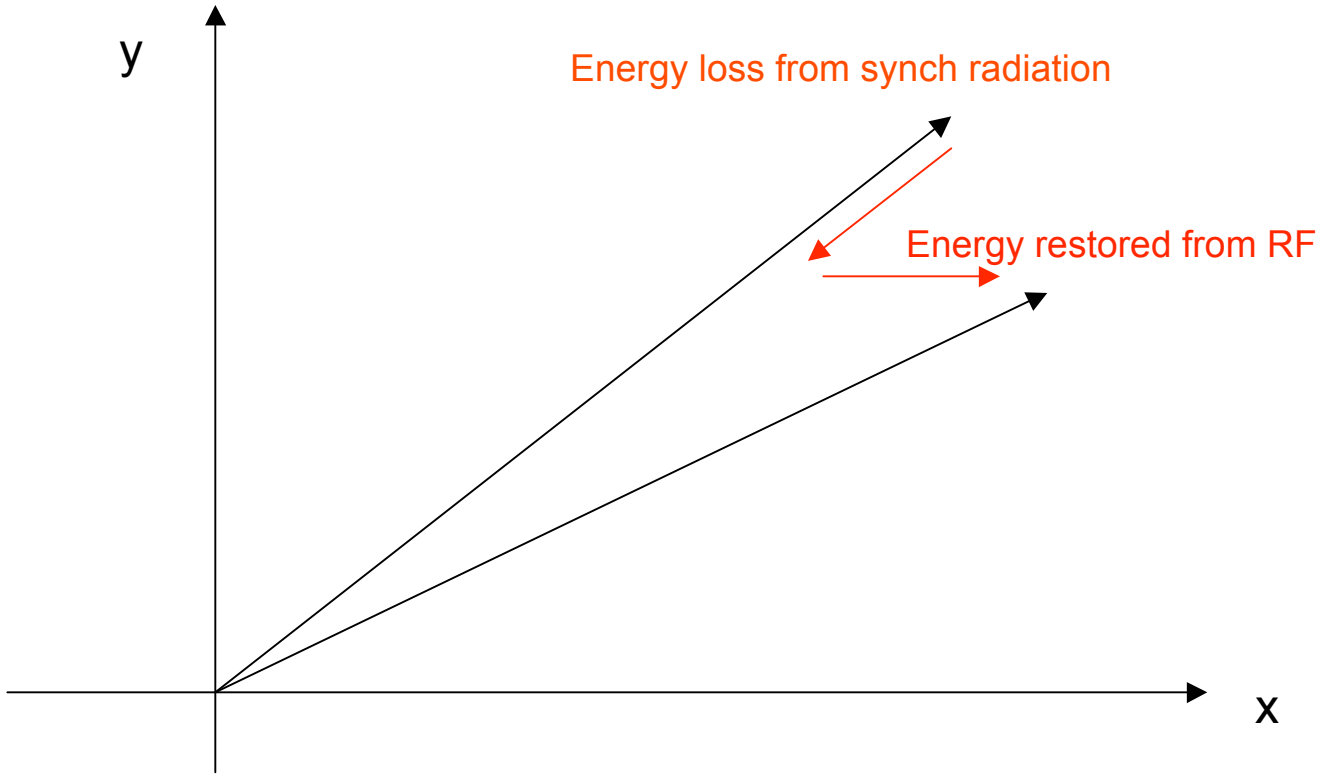
One of the 4 CESR SRF cryostats

Synchrotron radiation

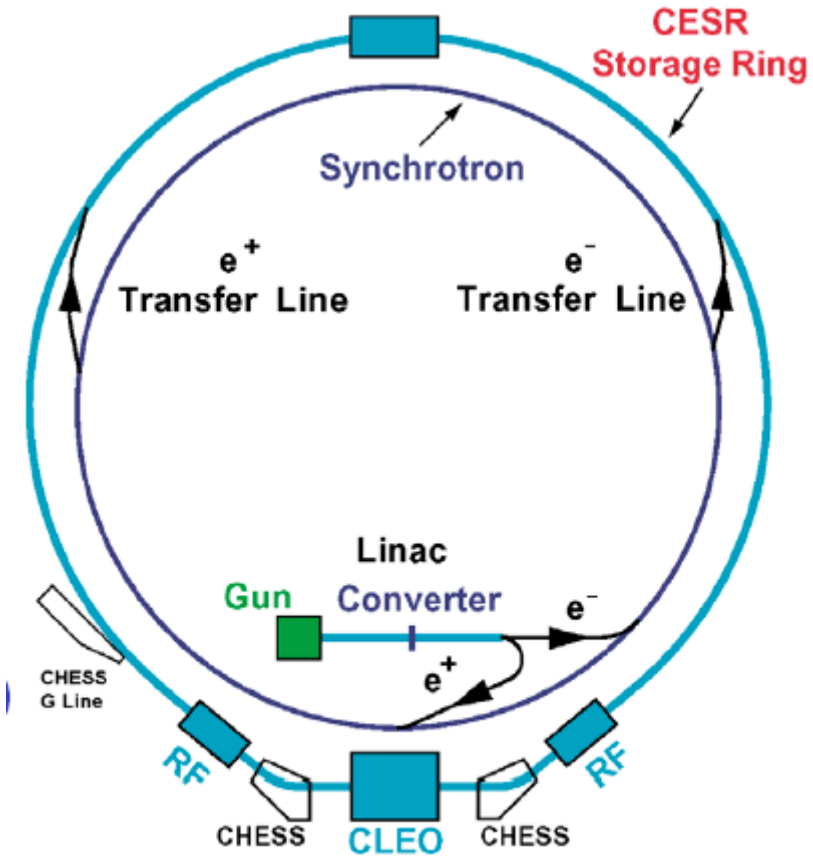
- But the synchrotron radiation is not all bad
  - It provides radiation-damping for the beams
  - CESR doubles as a light source
    - CHESS is the Cornell High Energy Synchrotron Source

Radiation damping

- Synchrotron radiation reduces the momentum of the particle in the direction of its motion while the acceleration system restored momentum parallel to the central orbit



CHESS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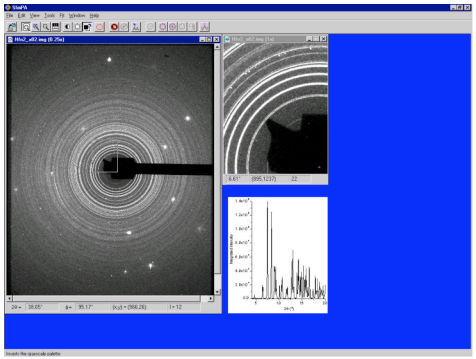
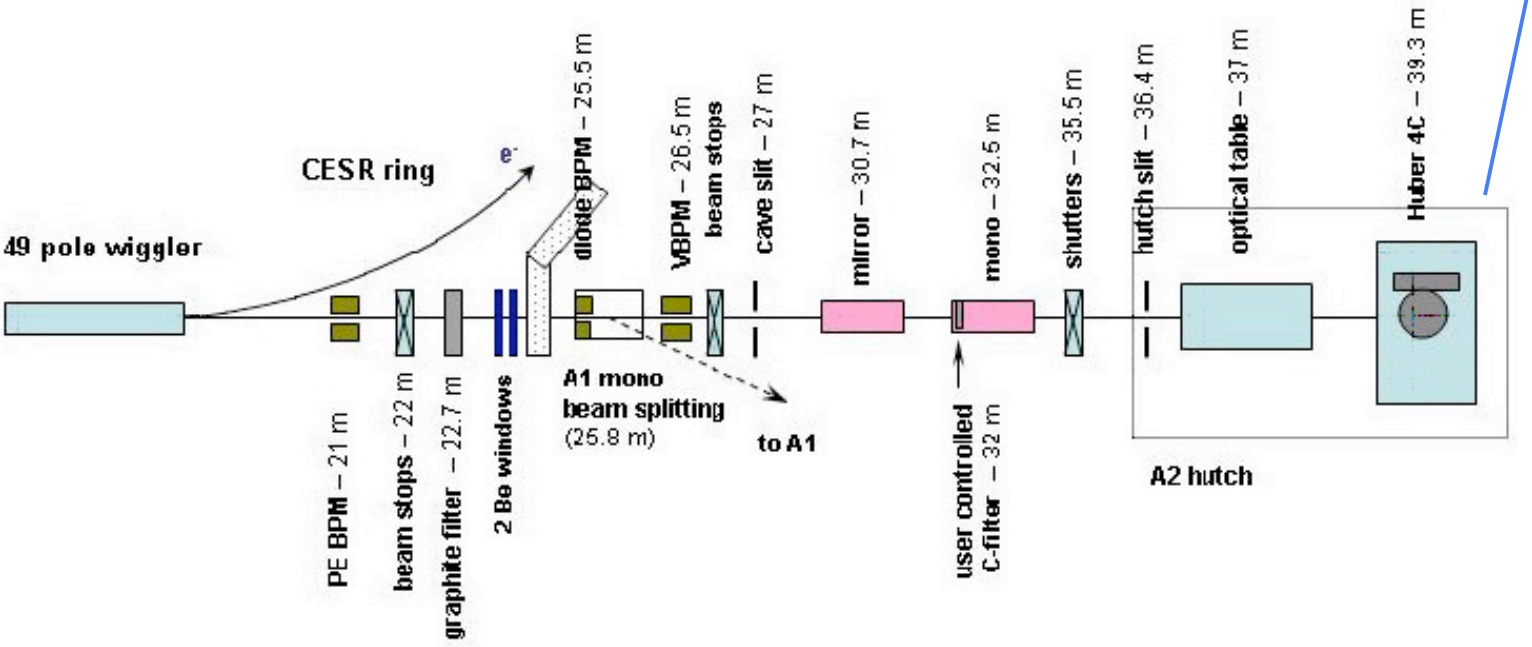
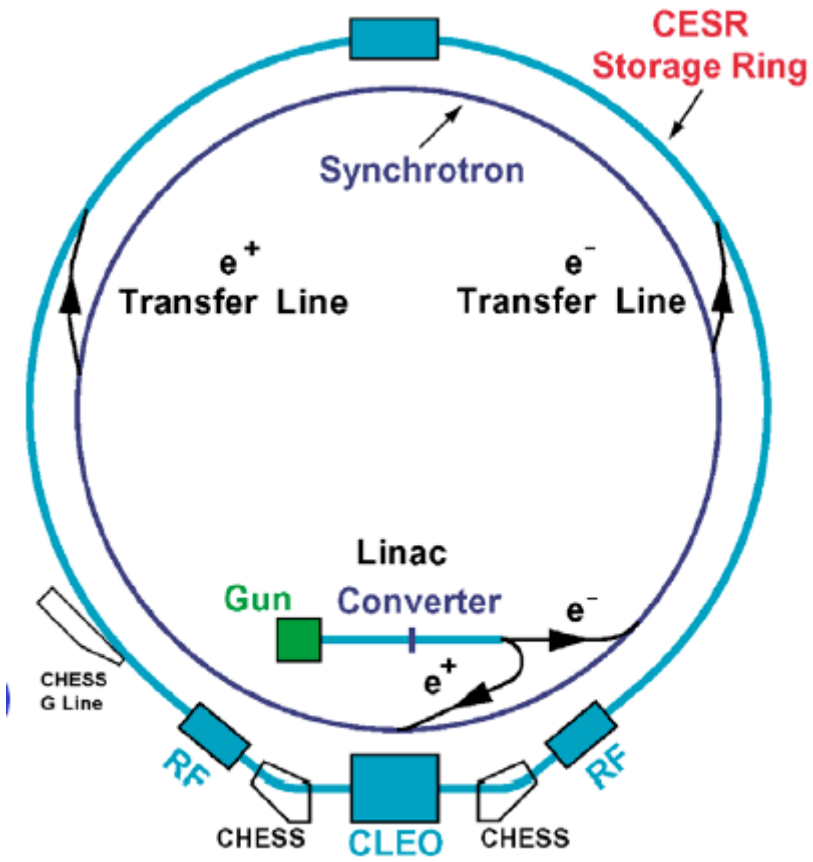


CHESS experimenter's display



CLEO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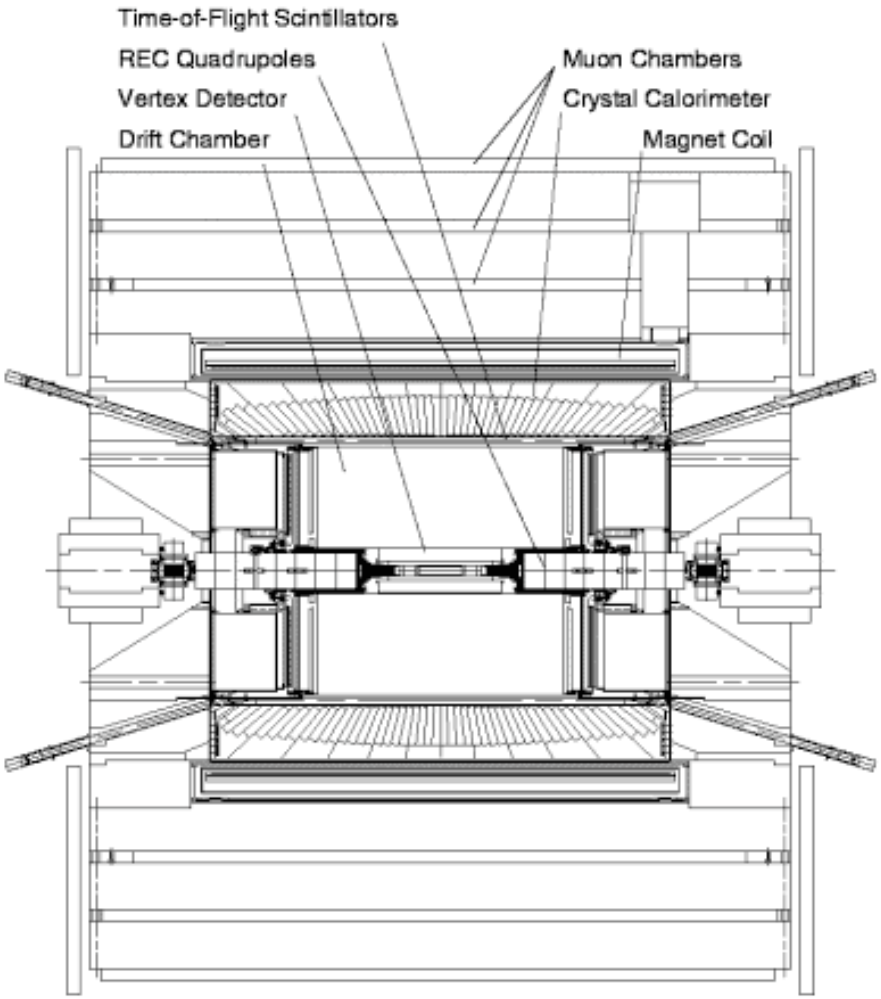
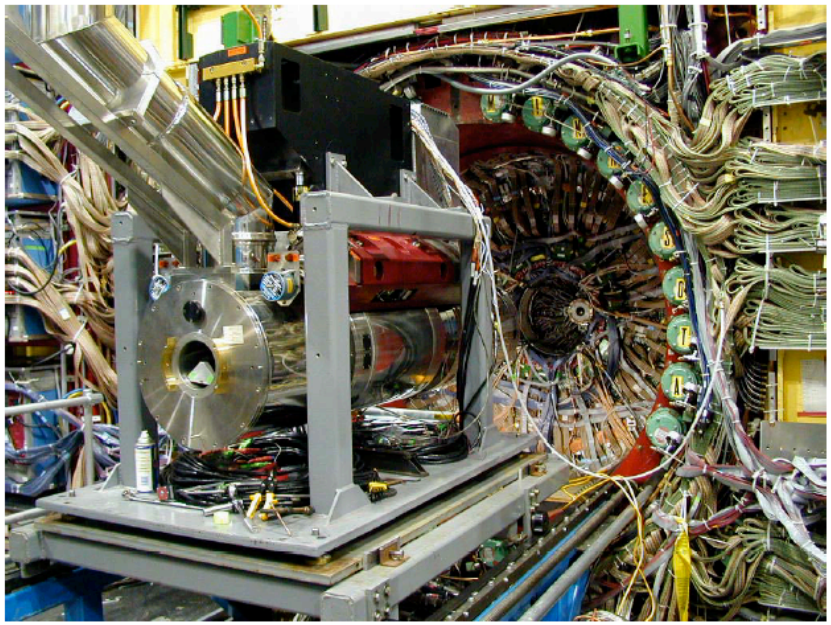
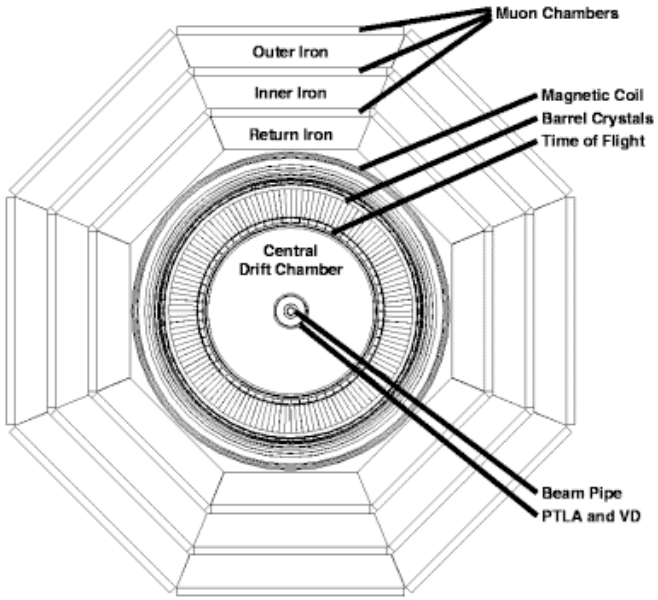


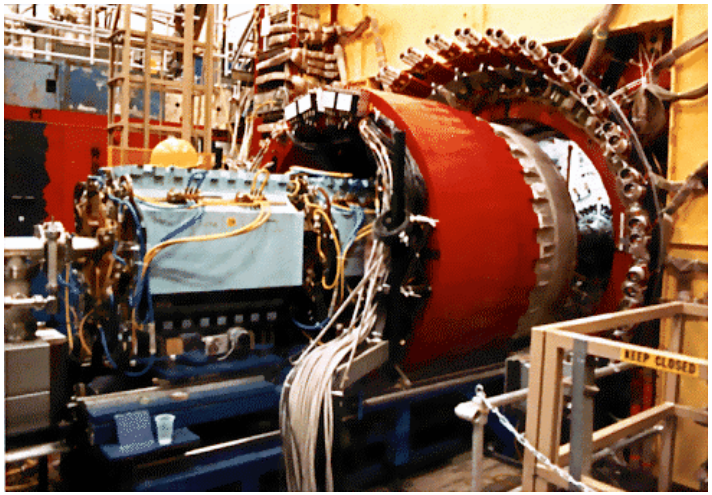
- Nine trains
- 5 bunches/train
- 14-ns bunch spacing



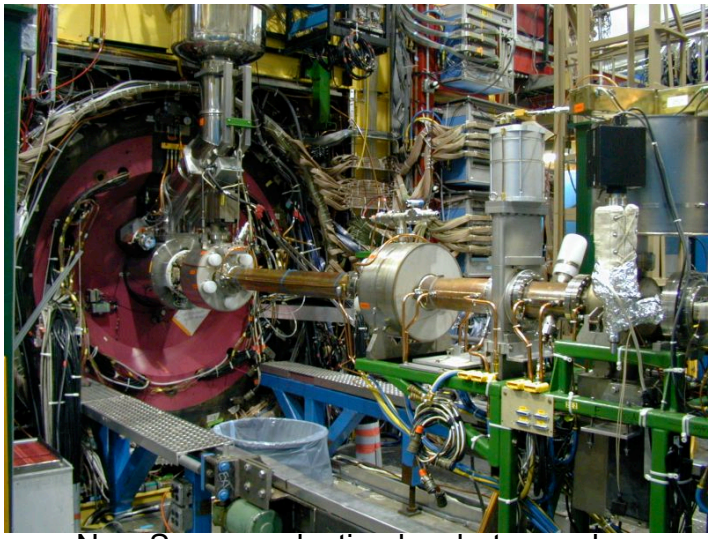
CLEO

- CLEO has a 1.5 Tesla superconducting solenoid
- All quads rotated 4.5 degrees (solenoid compensation)





Old Normal-conducting quads



New Superconducting low-beta quads

Beam energy

- For CESR-b the beam energy in the storage ring had to be maintained within 1 MeV of the $\Psi(4S)$ resonance peak (the peak width is 10 MeV)
- Note: CESR has changed from B physics to J/psi and Charm physics which require running CESR between 1.5 and 2.4 GeV
- The resonance peak is traditionally found by performing lengthy beam energy scans.
- Following such a scan, the beam energy is determined on a run-by-run basis by calculation based upon the machine parameters (rf frequency, measure dipole field, corrector strengths, electrostatic separator voltages, etc) while taking into account magnetic history.

Beam energy

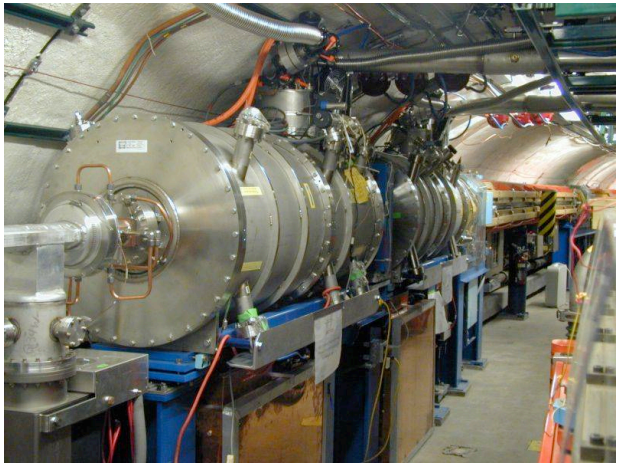
- The traditional method of beam energy measurement at electron storage rings in resonant depolarization which is accurate with relative precision of 10^{-5}
- This measurement takes a long time and cannot be part of routine or daily operations
- Another class of measurements has been investigated using synchrotron radiation

Beam energy

- CESR has investigated exploiting the very steep energy dependence of SR spectrum at xray energies.
- Able to measure energy changes consistent with expectations
- However, limited reproducibility and count rate
  - For example, may clip beam on apertures differently run to run, day to day

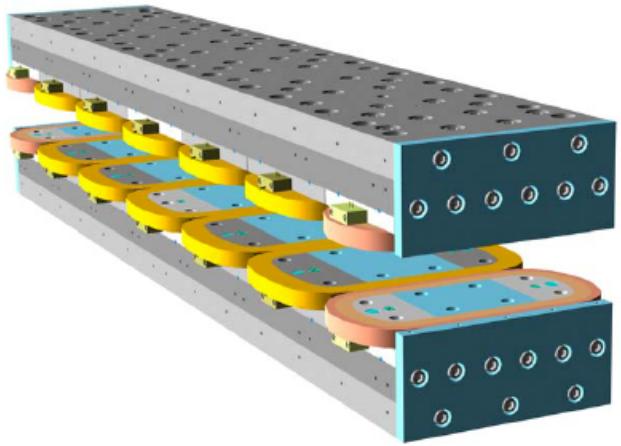
Beam energy

- CESR has changed from B physics to J/psi and Charm physics which require running CESR between 1.5 and 2.4 Gev



- There is less energy loss due to synchrotron radiation at these lower energies

- However, there is also less beneficial beam damping by the synchrotron radiation



Beam energy

- 12 superconducting wigglers have been installed in CESR to restore the beam damping lost by operating at lower energies