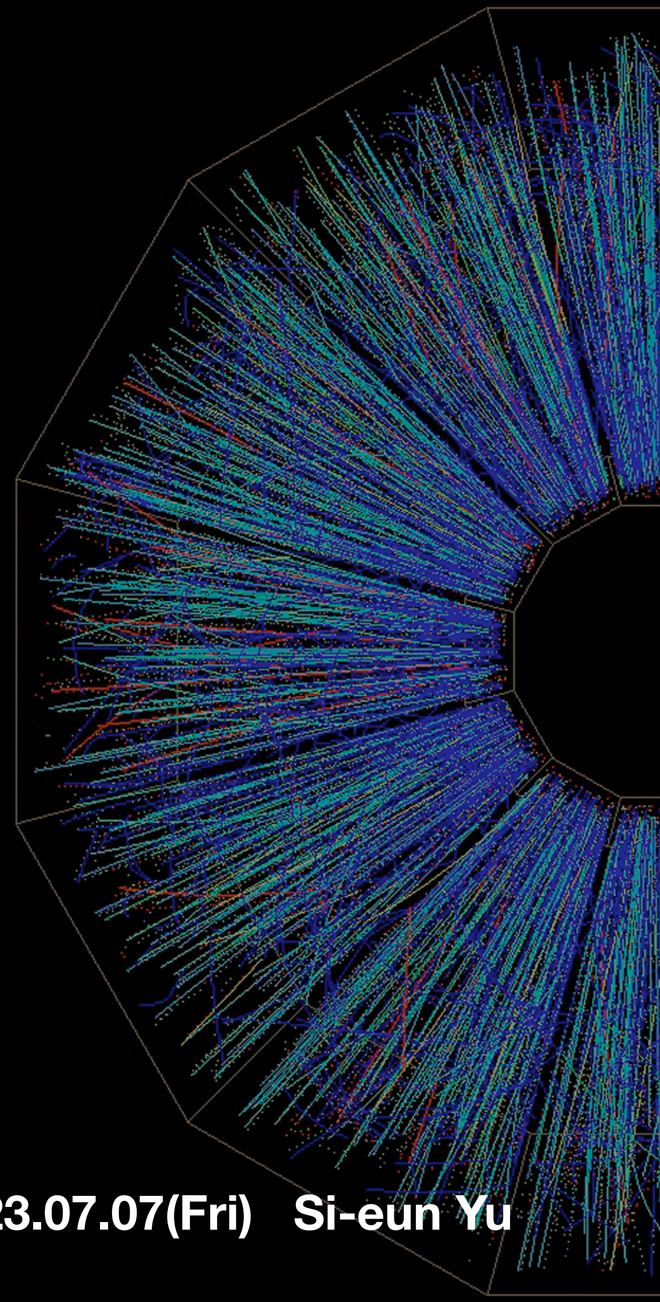
CERN-KOREA Summer Student Program

Particle Accelerator

- Synchrotron -



2023.07.07(Fri) Si-eun Yu

Particle Accelerator

What is it?

- Accelerates Particles by using the Electric fields

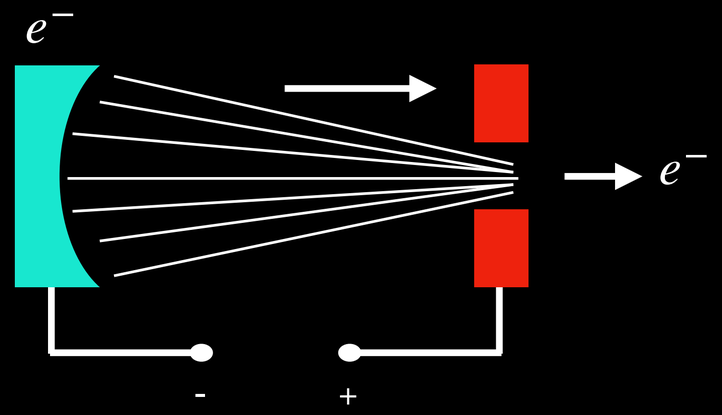
$$\vec{F} = e\vec{E}$$

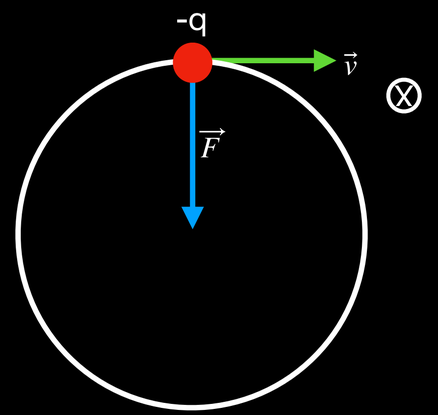
- Steer the beam by using Magnetic field

$$\vec{F} = e\vec{v} \times \vec{B}$$

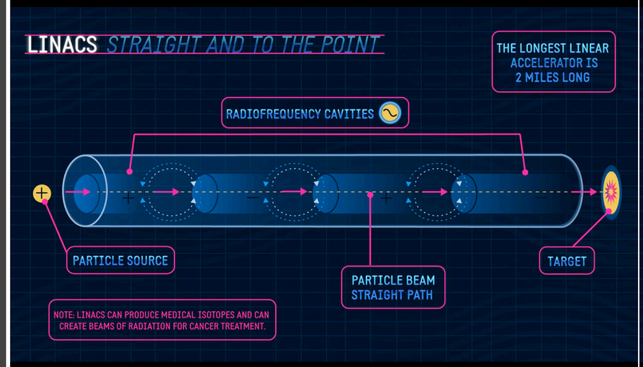
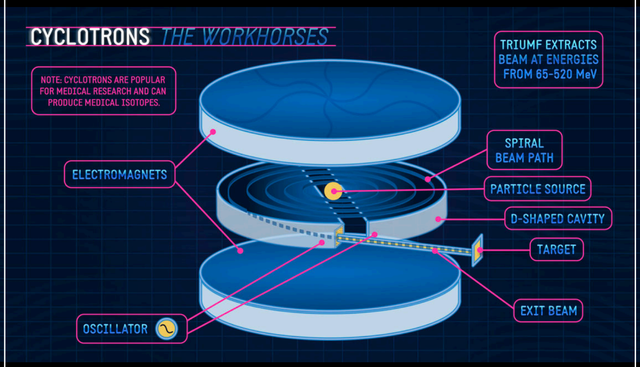
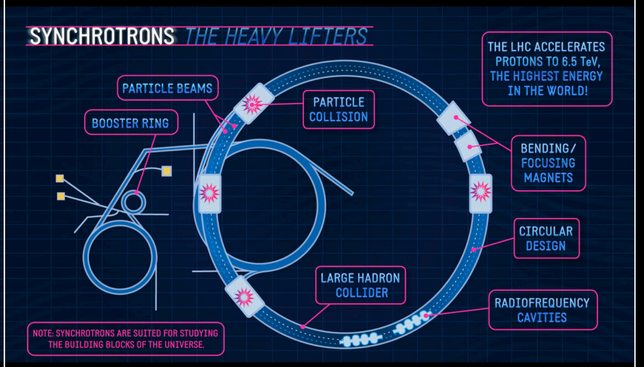
- For high energy(relativistic limit) : $u_z \approx c$ & $u_z B_y \gg E_x$

  → ***Magnetic fields*** much more efficient for steering

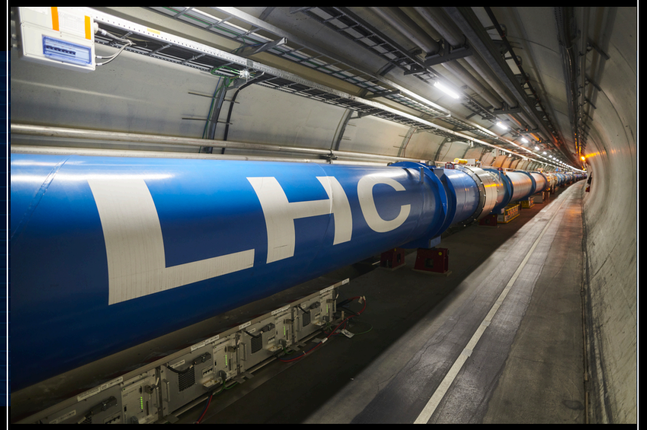




Types

	Linac(SLAC Linac)	Cyclotron(JULIC)	Synchrotron(LHC)
Particle	Electrons	Protons, deuteron	Protons, Heavy Ion
Accelerate Path	Linear path	Center ⇢ Outward Spiral	Closed-loop
Energy	50 GeV	45 MeV / 90 MeV	14 TeV (7 TeV)
Size	3.2 km	0.0157 km(Diameter)	27 km(Diameter)
Figure	 Artwork by Sandbox Studio, Chicago with Jill Preston	 Artwork by Sandbox Studio, Chicago with Jill Preston	 Artwork by Sandbox Studio, Chicago with Jill Preston

Types

	Linac(SLAC Linac)	Cyclotron(JULIC)	Synchrotron(LHC)
Particle	Electrons	Protons, deuteron	Protons, Heavy Ion
Accelerate Path	Linear path	Center ⇢ Outward Spiral	Closed-loop
Energy	50 GeV	45 MeV / 90 MeV	14 TeV (7 TeV)
Size	3.2 km	0.0157 km(Diameter)	27 km(Diameter)
Figure			

Synchrotron

Weak Focusing Synchrotron

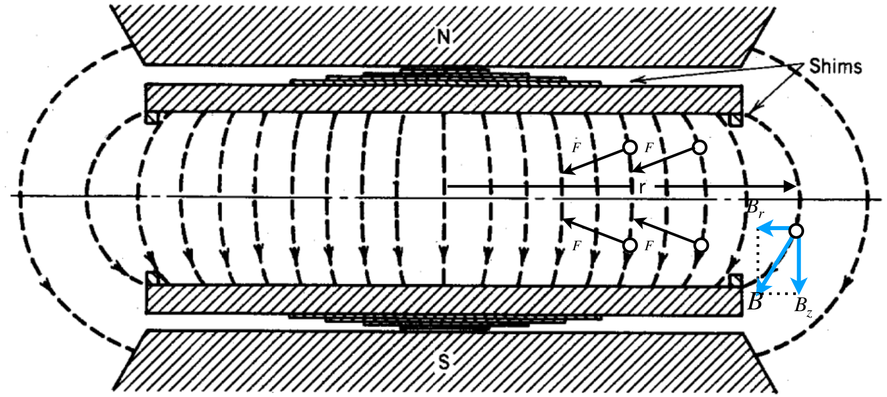
- Early synchrotron
- Bending magnets were shaped to produce a field with index in the range

  $0 < n \approx -\dfrac{\partial B_z}{\partial x} < 1$ (Steenbeck's condition)

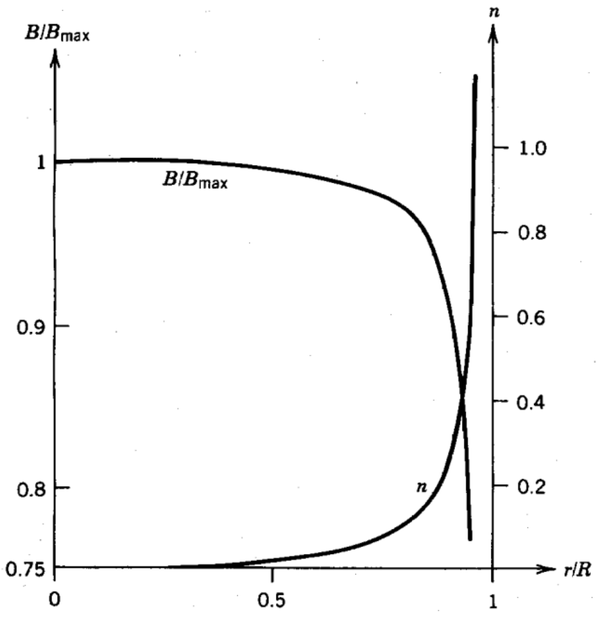
- Large cross section

  : the combined effects of transverse particle velocity & synchrotron oscillations

  → Costly, Large-bore magnet



(a)



(b)

Figure 15.2 Magnetic fields of uniform-field cyclotron. (*a*) Sectional view of cyclotron magnetic poles showing shims for optimizing field distribution. (*b*) Radial variation of vertical field magnitude and field index. (M. S. Livingston and J. P. Blewett, *Particle Accelerators*, used by permission, McGraw-Hill Book Co.)

Synchrotron

Strong Focusing Synchrotron

- Strong Focusing

  → Alternating diverging and focusing lenses separated by finite distance results in net focusing

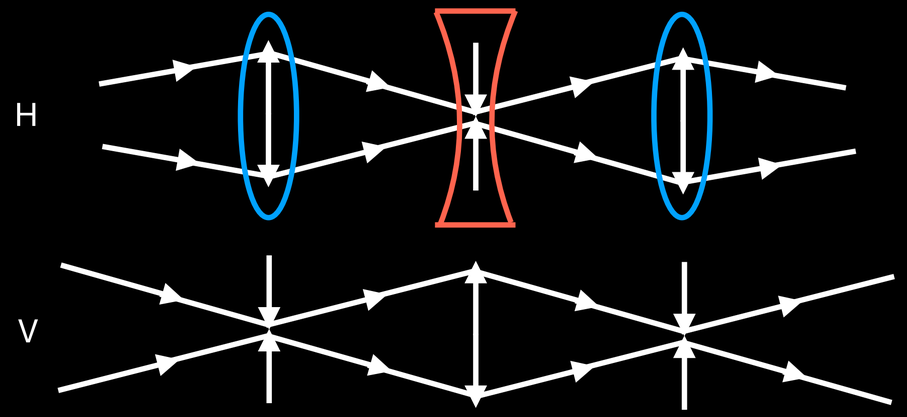
  → Magnetic quadrupole focuses in one plane and defocuses in orthogonal plane

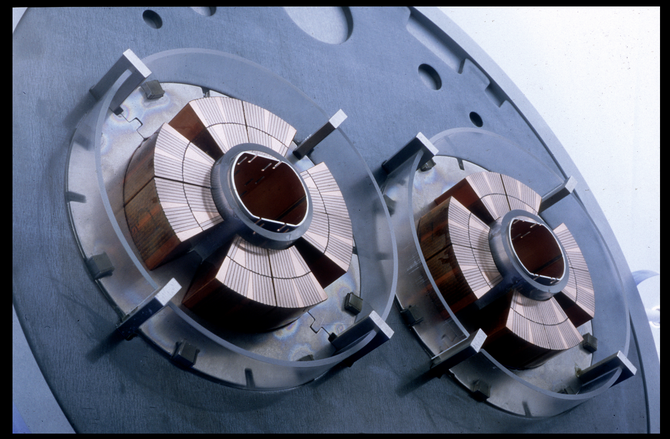
  → Alternating quadrupole focus in both planes

    - Much stronger than focusing of solenoids of radial magnetic gradients(dipoles)

    - Decreases aperture required for stability

    - Greatly extends energy range of acceleration





Model of an LHC superconducting quadrupole magnet - Laurent Guiraud - © 2000-2023 CERN

Synchrotron

Strong Focusing Synchrotron

- Alternating Gradient Synchrotron (AGS) - PS (CERN)

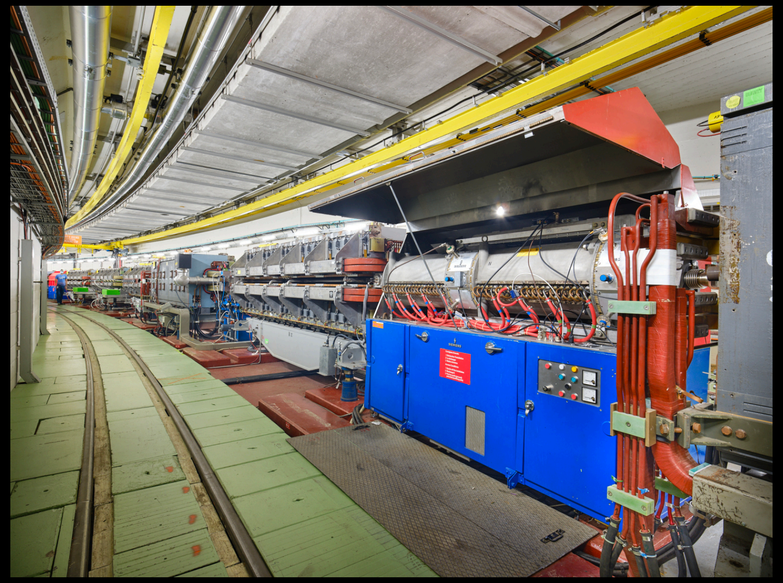
  1) Bending Field is produced by a ring of wedge-shape magnets.

  2) Combination of focusing and defocusing in the horizontal and vertical directions

- Separated Function Synchrotron

  1) Bending field is provided by sector magnets with uniform vertical field.

  2) Focusing is performed by quadrupole magnetic lens set between bending magnets.



Survey Operators in tunnel PS and picture of magnet with case open - Brice, Maximilien - © 2020 CERN

Synchrotron

Strong Focusing Synchrotron

- Alternating Gradient Synchrotron (AGS) - PS (CERN)

  1) Bending Field is produced by a ring of wedge-shape magnets.

  2) Combination of focusing and defocusing in the horizontal and vertical directions

- Separated Function Synchrotron

  1) Bending field is provided by sector magnets with uniform vertical field.

  2) Focusing is performed by quadrupole magnetic lens set between bending magnets.

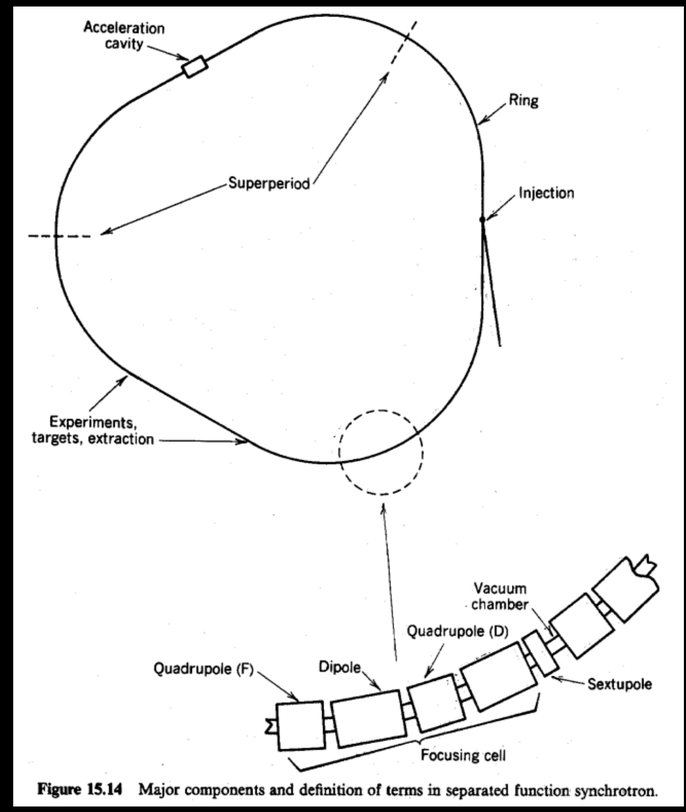


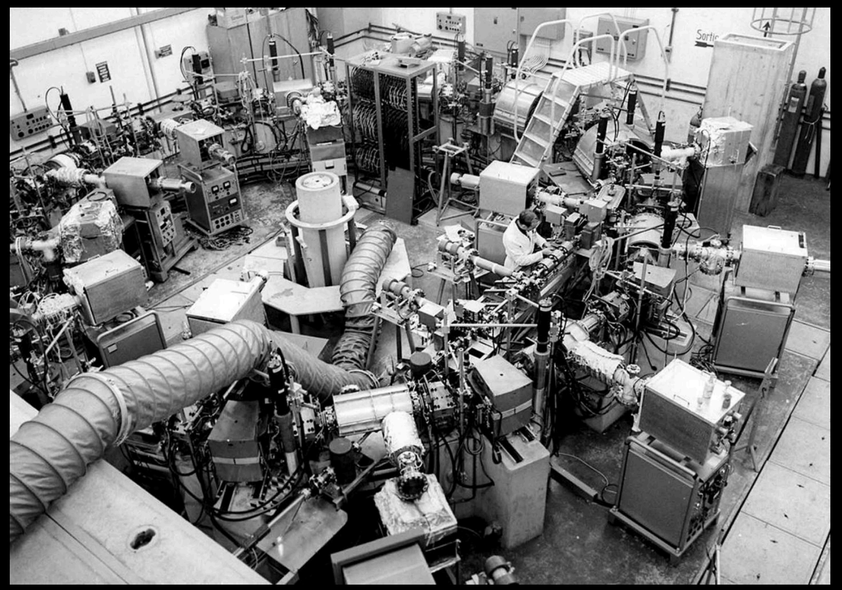
Figure 15.14 Major components and definition of terms in separated function synchrotron.

Synchrotron

Storage Ring

- Same focusing and bending field configuration as a separated function synchrotron, but provides ***no acceleration***.
- Contains energetic particles at ***constant energy*** for long periods of time.

  → Usefully used by experimental users.

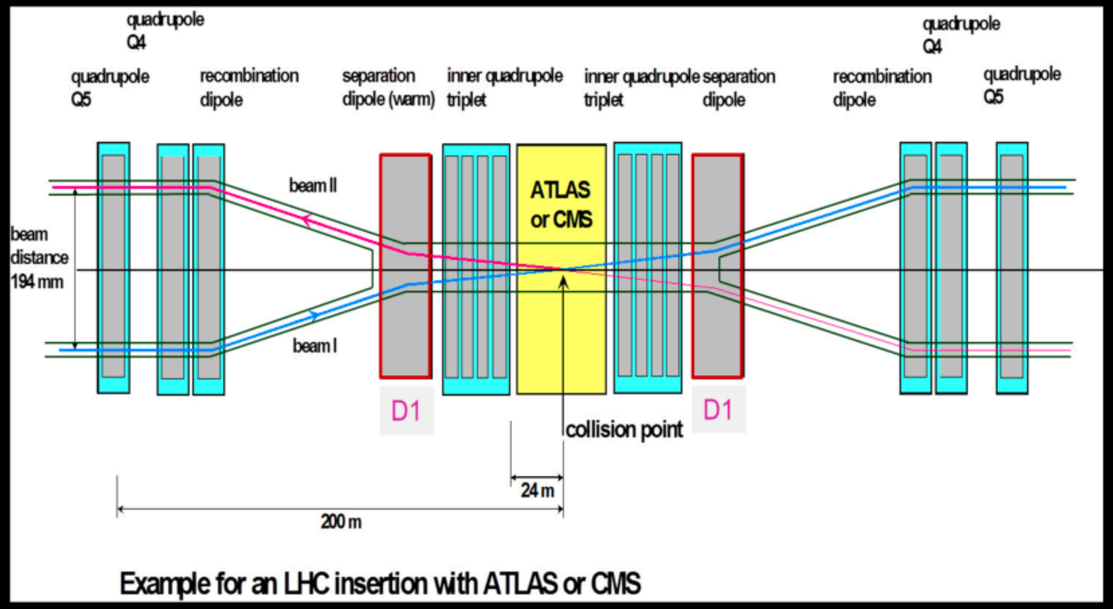


The CERN Electron Storage and Accumulation Ring (CESAR) in 1967 (Image: CERN)

Synchrotron

Collider

- Allow high-energy charged particles moving in opposite directions to collide head-on at a number of positions



Machine Protection and Interlock Systems for Circular Machines - Example for LHC - Schmidt, R. - arXiv:1608.03087

Illustration of a LHC insertion with the normal-conducting D1 magnets to separate the beam left and right from the collision points

Q & A

Thanks!

Reference

1. Susana Izquierdo Bermudez, “Accelerator Technology Challenges : Part 1 - Superconducting magnets” (CERN Summer Student Lecture program, CERN, 2023.07.03)

2. “The Large Hadron Collider”, Archived, 04 July, 2023, https://home.cern/science/accelerators/large-hadron-collider

3. “Nuclear Physics Institute (IKP)”, Archived, 04 July, 2023, https://www.fz-juelich.de/en/ikp/research/accelerators

4. “SLAC National Accelerator Laboratory”, Archived, 04 July, 2023, https://www6.slac.stanford.edu/

5. “LCLS Overview”, Archived, 06 July, 2023, https://lcls.slac.stanford.edu/overview

6. Archived, “ Large Hadron Collider restarts”, 22 April, 2022, https://home.web.cern.ch/news/news/accelerators/large-hadron-collider-restarts

7. *F. Chautard*. 2012. “Beam dynamics for cyclotrons”. CERN. https://cas.web.cern.ch/sites/default/files/lectures/zeegse-2005/chautard-final.pdf

8. Foteini Asvesta. 2023. “Particle Accelerators and Beam Dynamics”. CERN

9. Georg. Hoffstaetter. 2008. “Class Pays 488/688”. Cornell University. https://www.classe.cornell.edu/~hoff/LECTURES/08S_688/08S_688_080128.pdf

10. A. Bogacz, G. A. Krafft, and T. Zolkin. 2013. “Accelerator Physics - Weak Fouling”. Jefferson Lab, Colorado State University. https://casa.jlab.org/publications/viewgraphs/USPAS2013/L_2_WeakFocusing.pdf