Particle accelerators: what is important?

- Particles for acceleration need charge *and* sufficient lifetime.
- Only electric fields can accelerate.
  - magnetic fields cannot change the *absolute* momentum of a particle.
- Magnetic fields are used for deflection (bending, focussing etc.)
  - for relativistic particles, magnetic fields are a 100× more efficient.
- Electrostatic acceleration is limited to approx. 10 MeV
- Acceleration by RF (radio-frequency) wave is basically unlimited.
- Phase focussing = capture and acceleration of a bunch of particles
  - bucket = interval of RF phase to capture particles → bunching of beam
    - Linac: ballistic bunching: higher energy → higher velocity → faster → stability and acceleration for 0º < phase < 90º
    - Synchrotron: magnetic bunching: higher energy → longer path → slower → stability and acceleration for 180º > phase > 90º
- Transverse beam dynamics: Hamiltonian → transfer matrix
- Magnetic rigidity $(B\rho)=p/q$
- Multipole expansion: dipole, quadrupole, sextupole etc.
- Dipole: bending, [focusing], generation of dispersion
- Quadrupole: focusing in one plane, defocusing in other plane
  - AG focusing (alternating gradient): focusing in both planes by quadrupole doublet.

- Phase space density is constant (Liouville theorem)
  - valid for Hamiltonian system: all forces are derived from potentials
  - beam emittance (2-dimensional phase space area) is invariant (if there is no coupling)
  - origin of deterministic chaos in non-linear optics
- A bunch of particles is described by moments
  - 0^{th} moment = charge, 1^{st} moment = orbit (center of mass)
  - 2^{nd} moment = sigma-matrix : beam sizes (diagonal) and correlations (off-diagonal)
  - Beta-function and emittance describe the beam completely (in linear case)
- Periodic solution in circular accelerators
  - requires $\cos 2\pi Q = |\frac{1}{2} \mathrm{Trace}(M)| < 1$. M = one-turn transfer matrix, Q = lattice tune
- Synchrotron radiation
  - high power, small opening angle, high photon energy
  - double violation of conditions for Liouville theorem: damping and quantum excitation
  - determines emittance in electron rings (radiation equilibrium) → damping rings for linacs
- Luminosity is given by space-time overlap of colliding bunches
  - limited by the space charge parameter (or linear tune shift)
  - highest luminosity in crossing collision with crab cavities or crab sextupoles
- Muon colliders and neutrino factories
  - components: high power (multi-MW) proton source, high power target, large acceptance capture, muon cooling channel, fast acceleration by linac, FFAG, fast cycling synchrotron.
  - common developments for spallation neutron sources and accelerator driven reactors.