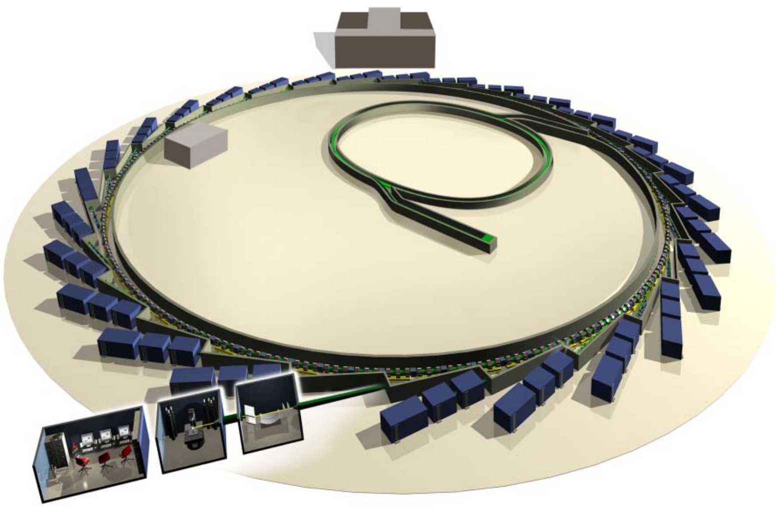
Outline

- Relativistic Kinematics
  - (4-momentum)2 invariance, invariant mass
  - Hypothesis testing, production thresholds
  - Cross-sections, flux and luminosity, accelerators
  - Particle lifetime, decay length, width
- Classification of particles
  - Fermions and bosons
  - Leptons, hadrons, quarks
  - Mesons, baryons
- Quark Model
  - Meson and baryon multiplets
  - Isospin, strangeness, c, b, t quarks
- Particle Interactions
  - Virtual particles and range of forces
  - Strong and weak decays, conservation rules
  - Parity, charge conjugation, CP
  - Weak decays of quarks
  - Colour charge, QCD, gluons
  - Charmonium and upsilon systems
- Electroweak Interactions
  - Charged and neutral currents
  - W, Z, LEP experiments
  - Higgs and the future
- LHC Experiments
- Future – introduction to accelerator physics

Please see web page for specific references to textbooks and brief reviews from PDG. (Particularly if you are taking PP Group Studies.)

Reminder**: no lecture on Monday 30 Jan.**
To be re-arranged later in term as required.

Synchrotron Radiation



- SR loss for e^-

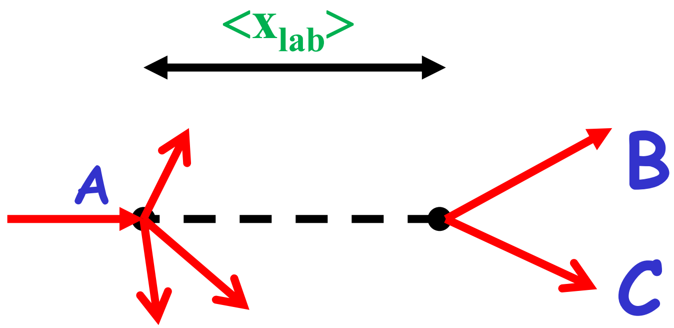
$$\Delta E/\text{turn} = \frac{4\pi}{3}\frac{e^2\beta^2\gamma^2}{\rho}$$

$$\Delta E(\text{GeV})/\text{turn} = \frac{4\pi}{3}\frac{r_e(\text{m})}{m_e^3(\text{GeV})}\frac{E^4(\text{GeV})}{\rho(\text{m})}$$

- More useful version is lower
- ρ=bending radius
- r_e is classical e^- radius (2.8×10^{16}m)
- m_e is electron mass (in energy units)

- Great if you want SR for experiments ("light sources", e.g. LCLS, Diamond, etc. ☺
- Disaster if you want high energy e^+e^- collisions ☹
- e.g. 200 GeV e^- collider of radius 4.3km (~LEP2) radiates ~32 GeV (/e^-/turn).

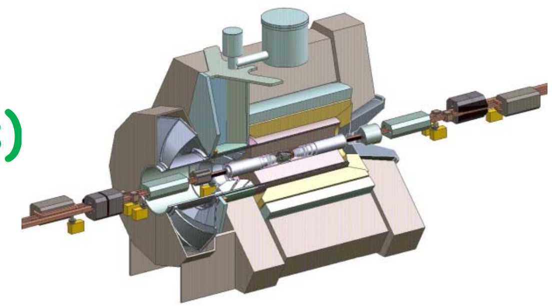
Decay Length



- Time t in decay
  $e^{-t/\tau}$

is <u>proper time</u> (measured in A's rest frame)

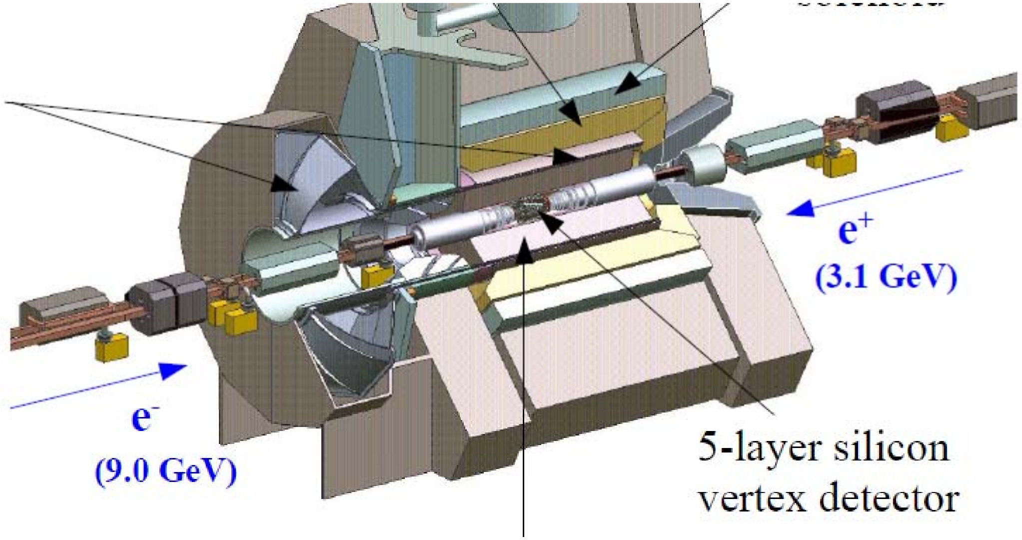
- Time dilation
  - Particles moving at $\gamma>1$ live longer (to us)
  - $t_{lab} = \gamma\, t$
  - $\langle x_{lab} \rangle = \beta\, \gamma\, c\, \tau$
  - Particle mass m, energy E, momentum p
    - $\Rightarrow \gamma = E/m$
    - $\Rightarrow \beta = p/E$
    - $\Rightarrow \beta\gamma = p/m$

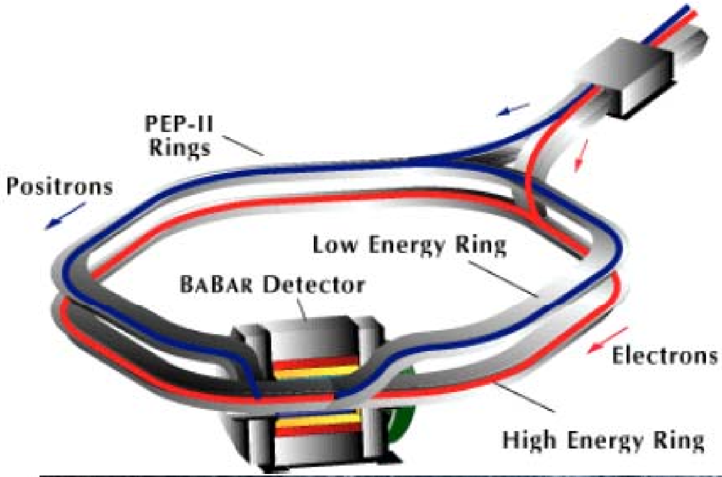


- Examples… asymmetric colliders PEPII, KEKB

Decay length example: BaBar

Asymmetric beam energies produce boost of $\beta\gamma=0.56$ in lab frame





- Makes decay vertex easier to measure because of time dilation

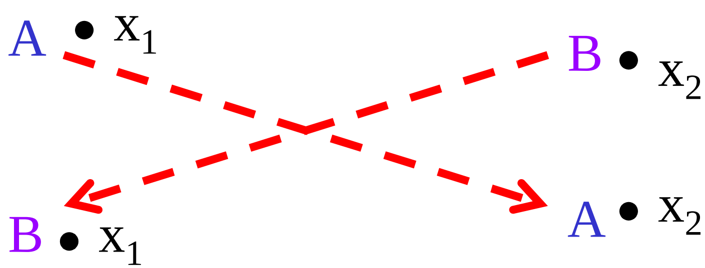
3. Classification of Particles

Historical names, but need to be familiar with definitions.

- Fermions Bosons
- Leptons Hadrons
- Quarks Flavours
- Mesons Baryons

3.1 Identical Particles

- If particles A and B identical
  - $\psi_{AB}(\mathbf{x}_1, \mathbf{x}_2)$
  - $\psi_{AB}(\mathbf{x}_2, \mathbf{x}_1)$



- Then 2-particle system is indistinguishable under exchange A←→ B
  - $|\psi_{AB}|^2 = |\psi_{BA}|^2$
  - Therefore,
    - $\Rightarrow \psi_{AB} = \psi_{BA}$ (symmetric). Case of identical bosons
    - $\Rightarrow \psi_{AB} = -\psi_{BA}$ (antisymmetric). Case if identical fermions

3.2 Fermions

- Particles of half-(odd) integer spin, 1/2,3/2
- QM wavefunction for pair of identical fermions, A, B, is antisymmetric under particle interchange
  - $\psi_{AB}(\mathbf{x}_1, \mathbf{x}_2) \equiv \psi_A(\mathbf{x}_1)\,\psi_B(\mathbf{x}_2) - \psi_B(\mathbf{x}_1)\,\psi_A(\mathbf{x}_2)$
  - Fermi-Dirac Statistics

Pauli Exclusion Principle: 2 identical fermions cannot occupy same quantum state

- Implication: atoms and nuclei stable
- "Fermion number" conserved in all reactions

3.3 Bosons

- Particles of integer spin, 0, 1, 2, …
- QM wavefunction for pair of identical bosons, A, B, is symmetric under particle interchange
  - $\psi_{AB}(\mathbf{x}_1, \mathbf{x}_2) \equiv \psi_A(\mathbf{x}_1)\,\psi_B(\mathbf{x}_2) + \psi_B(\mathbf{x}_1)\,\psi_A(\mathbf{x}_2)$
  - Bose-Einstein Statistics

2 or more identical bosons can occupy same quantum state

- Implication: atoms and nuclei stable
- "Boson number" not conserved (so not useful concept)