Outline
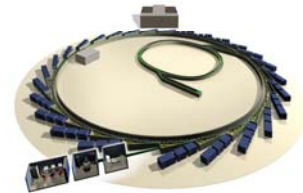
- **Relativistic Kinematics**
  - (4-momentum)2 invariance, invariant mass
  - Hypothesis testing, production thresholds
  - Cross-sections, flux and luminosity, accelerators
  - Particle lifetime, decay length, width
- **Classification of particles**
  - Fermions and bosons
  - Leptons, hadrons, quarks
  - 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 (2.8x10^{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).**
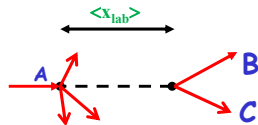
Decay Length

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

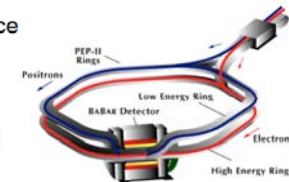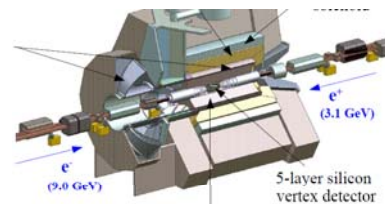 is proper time (measured in A's rest frame)

- **Time dilation**
  - Particles moving at γ>1 live longer (to us)
  - $t_{lab} = \gamma\, t$
  - $<x_{lab}> = \beta\, \gamma\, c\, \tau$
  - 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

e+ (3.1 GeV)

e- (9.0 GeV)

5-layer silicon vertex detector

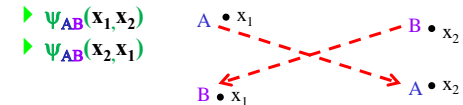- **Makes decay vertex easier to measure because of time dilation**

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**
  - ▸ $\psi_{AB}(x_1, x_2)$
  - ▸ $\psi_{AB}(x_2, x_1)$

  A • x_1 B • x_2
  B • x_1 A • x_2

- **Then 2-particle system is indistinguishable under exchange A ⟷ B**
  - ▸ $|\psi_{AB}|^2 = |\psi_{BA}|^2$
  - ▸ **Therefore,**
    - $\Rightarrow \psi_{AB} = \psi_{BA}$ (symmetric).   *Case if **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
  - ▸ $\psi_{AB}(x_1, x_2) \equiv \psi_A(x_1)\,\psi_B(x_2) - \psi_B(x_1)\,\psi_A(x_2)$
  - ▸ 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
  - ▸ $\psi_{AB}(x_1, x_2) \equiv \psi_A(x_1)\,\psi_B(x_2) + \psi_B(x_1)\,\psi_A(x_2)$
  - ▸ Bose-Einstein Statistics

  > 2 or more identical bosons can occupy same quantum state

- Examples?
- "Boson number" not conserved (so not useful concept)