

## Outline

- Relativistic Kinematics
  - ▶ (4-momentum)<sup>2</sup> 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  $e^-$ 

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

$$\Delta E(\text{GeV}) / \text{turn} = \frac{4\pi}{3} \frac{r_e(m)}{m_e^3(\text{GeV})} \frac{E^4(\text{GeV})}{\rho(m)}$$
- More useful version is lower
- $\rho$ =bending radius
- $r_e$  is classical  $e^-$  radius ( $2.8 \times 10^{-15}\text{m}$ )
- $m_e$  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  $e^-e^-$  collider of radius 4.3km (~LEP2) radiates ~32 GeV ( $e^-/\text{turn}$ ).

## Decay Length

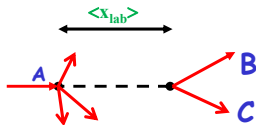
- Time  $\tau$  in decay  
 $e^{-\tau/\tau}$

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

- Time dilation

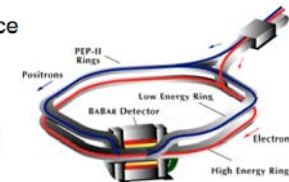
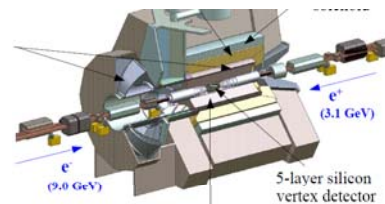
- ▶ Particles moving at  $\gamma > 1$  live longer (to us)
- ▶  $\tau_{\text{lab}} = \gamma \tau$
- ▶  $\langle x_{\text{lab}} \rangle = \beta \gamma c \tau$
- ▶ Particle mass  $m$ , energy  $E$ , momentum  $p$ 
  - $\Rightarrow \gamma = E/m$
  - $\Rightarrow \beta = p/E$
  - $\Rightarrow \beta\gamma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

- Examples... asymmetric colliders PEP-II, 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

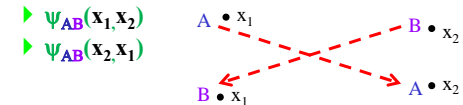
### 3. Classification of Particles

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



- Then 2-particle system is indistinguishable under exchange  $A \leftrightarrow B$

- ▶  $|\Psi_{AB}|^2 = |\Psi_{BA}|^2$
- ▶ Therefore,
  - ⇒  $\Psi_{AB} = \Psi_{BA}$  (symmetric). Case if **identical bosons**
  - ⇒  $\Psi_{AB} = -\Psi_{BA}$  (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)