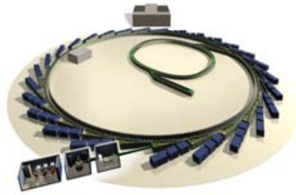
Outline

- 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⁻

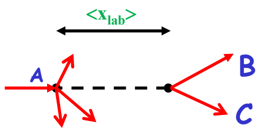
$$\Delta E\,/\,\text{turn} = \frac{4\pi}{3}\frac{e^2\beta^2\gamma^2}{\rho}$$

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

- 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



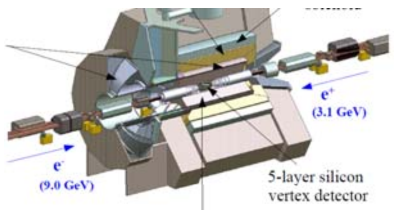
- Time t in decay $e^{-t/\tau}$

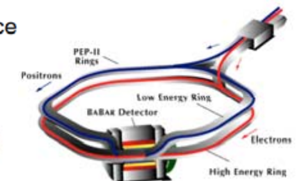
is proper time (measured in A's rest frame)

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

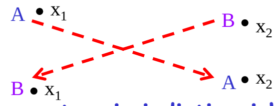
3. Classification of Particles

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



- 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
  - $\psi_{AB}(x_1, x_2) \equiv \psi_A(x_1)\,\psi_B(x_2) - \psi_B(x_1)\,\psi_A(x_2)$
  - 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

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