

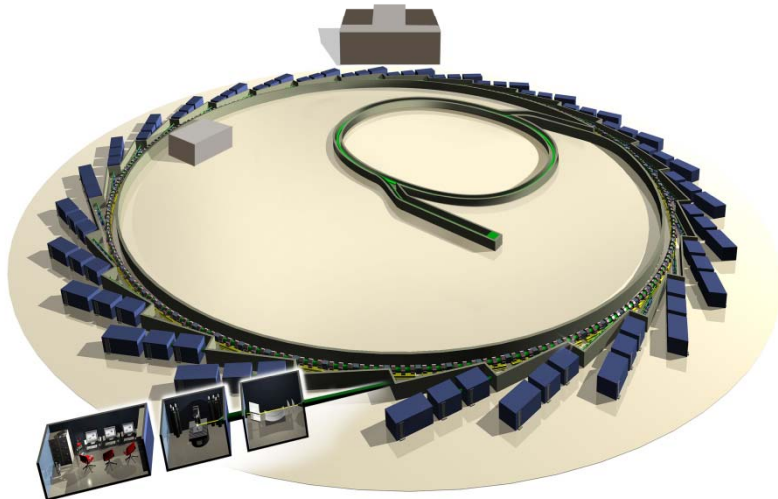
Outline

- 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^-

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

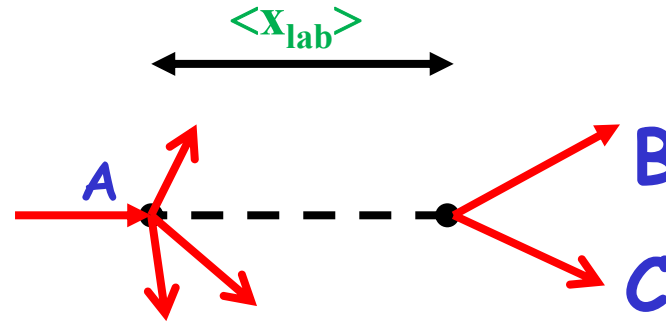
$$\Delta E(\text{GeV}) / \text{turn} = \frac{4\pi}{3} \frac{r_e(\text{m})}{m_e^3(\text{GeV})} \frac{E^4(\text{GeV})}{\rho(\text{m})}$$

- More useful version is lower
- ρ =bending radius
- r_e is classical e^- radius ($2.8 \times 10^{-16}\text{m}$)
- 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^- collider of radius 4.3km (\sim LEP2) radiates ~ 32 GeV ($/e^-/\text{turn}$).

Decay Length

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



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

- Time dilation

- ▶ Particles moving at $\gamma > 1$ live longer (to us)

- ▶ $t_{lab} = \gamma t$

- ▶ $\langle X_{lab} \rangle = \beta \gamma c \tau$

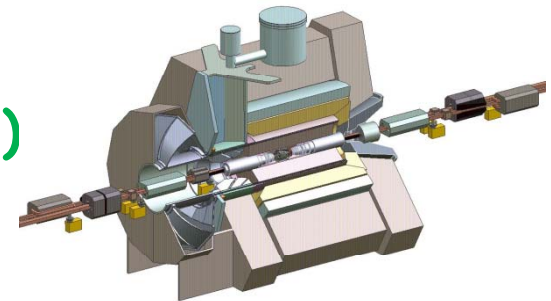
- ▶ Particle mass m , energy E , momentum p

$$\Rightarrow \gamma = E/m$$

$$\Rightarrow \beta = p/E$$

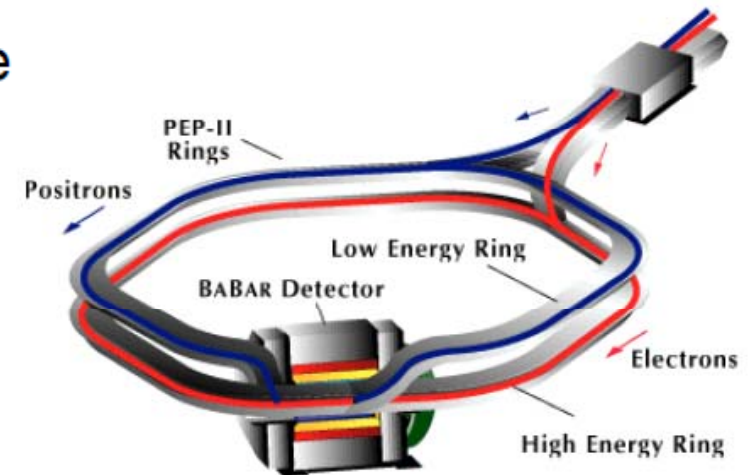
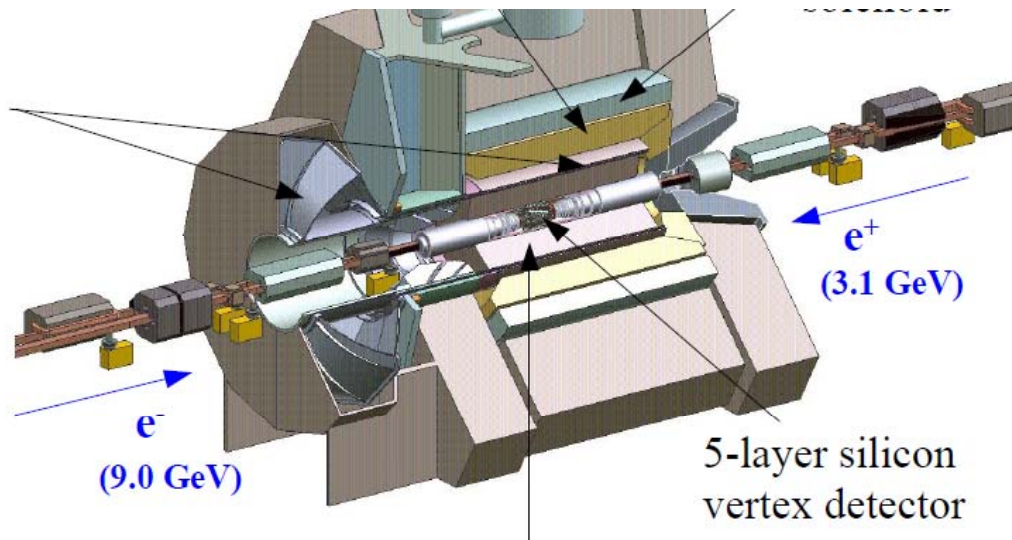
$$\Rightarrow \beta\gamma = p/m$$

- 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.

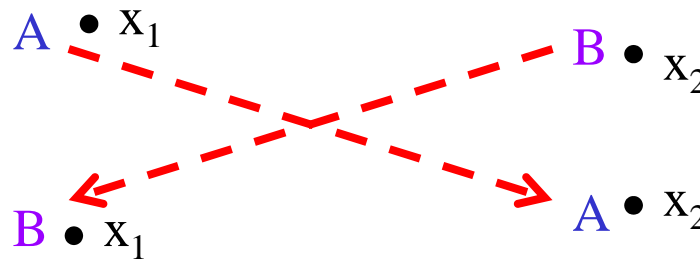
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|------------|----------|
| ■ Fermions | Bosons |
| ■ Leptons | Hadrons |
| ■ Quarks | Flavours |
| ■ Mesons | Baryons |

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 $A \leftrightarrow B$

- ▶ $|\Psi_{AB}|^2 = |\Psi_{BA}|^2$

- ▶ 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
 - ▶ $\Psi_{AB}(\mathbf{x}_1, \mathbf{x}_2) \equiv \Psi_A(\mathbf{x}_1) \Psi_B(\mathbf{x}_2) - \Psi_B(\mathbf{x}_1) \Psi_A(\mathbf{x}_2)$
 - ▶ 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

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