Outline

- Relativistic Kinematics
  - (4-momentum)2 invariance, invariant mass
  - Hypothesis testing, production thresholds
  - Cross-sections, flux and luminosity, accelerators
  - Particle lifetime, decay length, width
- Class
  -
  -
  -
- Quar
  -
  -
- Parti
  -
  - Strong and weak decays, conservation rules
  - Virtual particles and range of forces
  - Parity, charge conjugation, CP
  - Weak decays of quarks
  - 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

Today

- Lecture 17 (4 slides/page) - Parity, Charge conjugation, Time reversal symmetries
  - Griffiths, pp. 136-144, 149-151, 161.
  - Perkins, pp. 71-76, 83-86,
  - Some experimental studies of T/CPT invariance
    - CERN Press Release, 7 Mar 2012 NEW 1st resonant transitions measured in antihydrogen
    - Phys. Rep. : 374 (2003) , pp.165-270, *Physics at CPLEAR*, A. Angelopoulos et al. (CPLEAR Collaboration), pg ~171.
    - preprint CERN-EP-2001-060, *T-violation and CPT-invariance measurements in the CPLEAR experiment: a detailed description of the analysis of neutral-kaon decays to e pi nu* , Angelopoulos et al.
    - Phys. Rev. D 83, 092001 (2011), *Precise Measurements of Direct CP Violation, CPT Symmetry, and Other Parameters in the Neutral Kaon System*

Previous lecture

- Lecture 16 (4 slides/page) Charmonium, upsilon systems and parity
  - Griffiths Sect. 5.4
  - Williams Sect. 10.8

Conservation Rules

Interaction	Symbol	SI	EM	WI
Energy	E	✓	✓	✓
Momentum	P	✓	✓	✓
Angular Mom$^{n.}$	J	✓	✓	✓
Charge (e.m, colour)	Q	✓	✓	✓
Fermion number		✓	✓	✓
Quark number		✓	✓	✓
Baryon number	B	✓	✓	✓
Lepton number	L	✓	✓	✓
Electron number	L_e	✓	✓	✓
Muon number	L_m	✓	✓	✓
Tau number	L_t	✓	✓	✓
Quark flavour		✓	✓	×
Isospin	I	✓	×	×
Parity	P	✓	✓	×
Charge Conjugtion	C	✓	✓	×
Time reversal	T	✓	✓	×
Matter-Antimatter	CP	✓	✓	×
Quantum Field Theory	CPT	✓	✓	✓

✓	conserved
×	Not *necessarily* conserved

Intrinsic Parity

- All particles have intrinsic parity quantum number
- By convention, fundamental fermions (quarks, leptons) have P=+1 (even)
- Fundamental anti-fermions have P=-1 (odd), follows from above
- Parity is multiplicative
  - E.g. pion has P=-1 as $P(q)P(\overline{q})=1x-1$
  - Further examples (table)

Particle		Parity	J^P
Quark	q	+1	$\frac{1}{2}^+$
Anti-quark	$\overline{q}$	-1	$\frac{1}{2}^-$
Pion	$q\overline{q}$	-1	0^-
Rho	$q\overline{q}$	-1	1^-
Proton	qqq	+1	$\frac{1}{2}^+$
antiproton	$\overline{q}\overline{q}\overline{q}$	-1	$\frac{1}{2}^-$
Photon	$(\gamma \rightarrow e^+e^-)$	-1	1^-

- Orbital angular momentum, L
  - contributes additional factor $(-1)^L$
- Parity of meson is $P = -(-1)^L$

P and T transformations

Observable	Parity transform	Time, T, transform
Position, **r**	-**r** (polar vector)	**r**
Momentum, **p**	-p	-p
Spin, σ	σ	–σ
Longitudinal polarisation, σ.**p**	-σ.p	σ.p
Electric field, **E**	-**E**	**E**
Magnetic field, **B**	**B**	-**B**
Magnetic dipole moment, σ.**B**	σ.**B**	σ.**B**
Electric dipole moment, σ.**E**	-σ.**E**	-σ.**E**