Examples for precision tests of QED

The effects of QED on the magnetic moment of the electron/muon and the energy levels of hydrogen, i.e. the interactions of the electron(muon) with quantum fluctuations of the electromagnetic field (virtual photons), have been measured with impressive precision (computed up to 5 loops):

Anomalous magnetic moment:

$a_i = \frac{g_i - 2}{2}$:	$i = e$	$i = \mu$
experiment	0.0011596521884(43)	0.001165920230(1510)
theory (only QED)	0.0011596521577(230)	0.001165847057(29)
theory (SM)	0.0011596521594(230)	0.001165915970(670)

a_e: $\alpha(0)$ taken from quantum Hall effect, a_μ: $\alpha(0)$ extracted from a_e

from A.Czarnecki, W.Marciano, hep-ph/0102122

Limit on electron/muon radius: $r_{e,\mu} < 10^{-3}$ fm

1S Lamb shift from measurement of transition frequencies in hydrogen: experiment: $\Delta E(1S) = 8172837(22)$ kHz theory: $\Delta E(1S) = 8172819(68)$ kHz with proton charge radius: $r_p = 0.877(24)$ fm. T.van Ritbergen,K.Melnikov, hep-ph/9911277

1948:

The 350 MeV Berkley synchro-cyclotron produces the first “artificial” pions: Lattes and Gardener observe charged pions produced by 380 MeV alpha particles by means of photographic plates ($^4_2He \to \pi^+ + X$).

1950:

At the Berkley synchro-cyclotron Bjorkland et al. discover the neutral pion, $\pi^0 \to \gamma\gamma$.

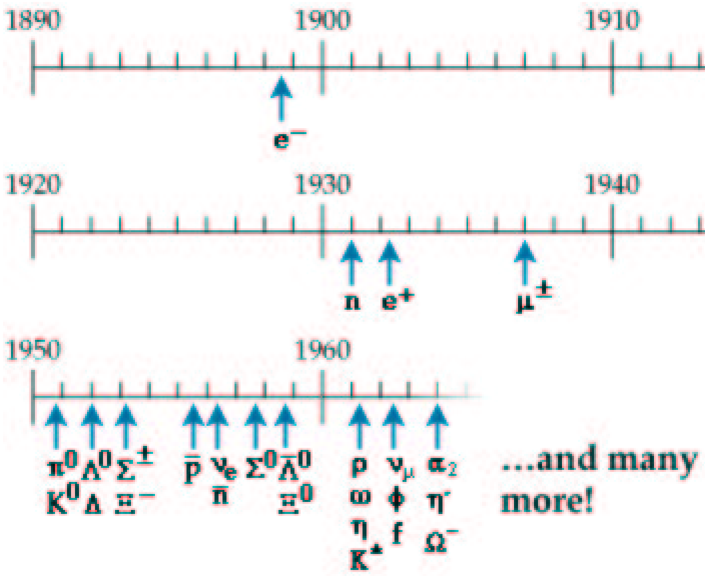
1952:

Glaser invents the bubble chamber: tracks of charged particles are made visible by a trail of bubbles in superheated liquid (e.g., hydrogen). It is the necessary tool to fully exploit the newly constructed particle accelerators.

The Brookhaven 3.3 GeV (reached in 1953) accelerator (Cosmotron) starts operation. For the first time protons were energized to 10^9 eV at man-made accelerators.

The beginning of a "particle explosion" - a proliferation of hadrons:

0060.gif (GIF Image, 465x288 pixels) http://ubpheno.physics.buffalo.edu/~dow/0060.gif



1953:

Reines and Cowan discover the anti-electron neutrino using a nuclear reactor as anti-neutrino source ($\bar{\nu}_e p \rightarrow n e^+$).

Gell-Mann and Nishijima introduce a new additive quantum number, "strangeness" (S), which is considered to be conserved in strong and electromagnetic interactions but sometimes violated in weak interactions:

- At accelerators K-mesons and Λ-hyperons are produced in reactions such as $\pi^- + p \to K^0 + \Lambda$ with cross sections of the order of 10^{-26}cm^2. Conclusion: K^0, Λ are produced via the strong interaction. Think of the cross section as the effective area of each target particle as seen by an incoming beam $\Rightarrow$ geometric cross section of hadrons: $\approx (10^{-13}\text{cm})^2$
- The observed decays of Λ-hyperons, $\Lambda \to p+\pi^-, n+\pi^0$, however, cannot be induced by the strong force, since the measured lifetime is too long ($\approx 10^{-10}$ sec).

When assigning a new quantum number, as follows:

	Q	I_3	B	S
p, n	+1,0	+1/2, -1/2	1	0
π^+, π^0, π^-	1,0,-1	1,0,-1	0	0
K^+, K^0	1,0	1/2,-1/2	0	1
Λ	0	0	1	-1

and when assuming that “strangeness” is not always conserved in weak interactions the puzzle can be solved:

S is conserved in the production process and thus can be induced by the strong force, while in the decay process S is violated and thus is only allowed when induced by the weak interaction. This explains the long lifetime $\tau_\Lambda \approx 10^{-10}$ sec.

1956/57:

The $\theta - \tau$-puzzle:

Lee and Yang postulate that parity (mirror symmetry) is violated in weak interactions.

$$\theta^+ \to \pi^+\pi^0 \text{with eigen parity } \eta = 1$$

$$\tau^+ \to \pi^+\pi^-\pi^+ \text{with eigen parity } \eta = -1$$

but $m_\theta = m_\tau$ and $\tau_\theta = \tau_\tau$. If θ and τ are the same particles then parity is violated in weak interactions. Then θ and τ are two decay channels of the same particle, which we call today the K^+ meson.

The experiment by Wu et al. (and Garwin et al.) establishes that nature distinguishes between left-handed and right-handed systems: The nuclear spins of ^{60}Co, $\vec{\sigma}$, were aligned by an external magnetic field. If parity is conserved in β-decay, $^{60}Co \to {}^{60}Ni^* + e^- + \bar{\nu}_e$, the electrons should be emitted as likely in the direction of the cobalt spin as in the opposite direction (100% polarized Co):

$$I(e^-) \propto 1 + \frac{|\vec{\sigma}||\vec{p}_e|}{E_e}\cos\theta \xrightarrow{P} 1 + \frac{|\vec{\sigma}||\vec{p}_e|}{E_e}\cos(\pi - \theta)$$

But Wu et al. observed that electrons prefer to be emitted in the direction opposite to that of the nuclear spin.