6. Vorhersagen und Tests der Quantenelektrodynamik

6.1 Ein Elektron in einem elektrischen Feld

6.2 Der Prozess $e^- \mu^- \rightarrow e^- \mu^-$ -Berechnung eines Feynman-Diagrams-

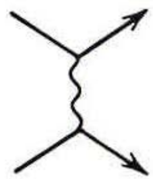
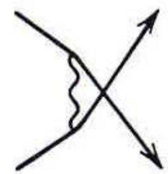
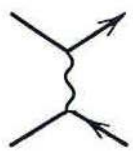
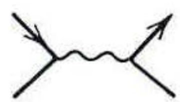
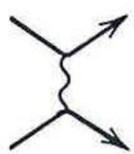
6.3 Die Feynman-Regeln der QED

6.4 Wichtige Streuprozesse der QED

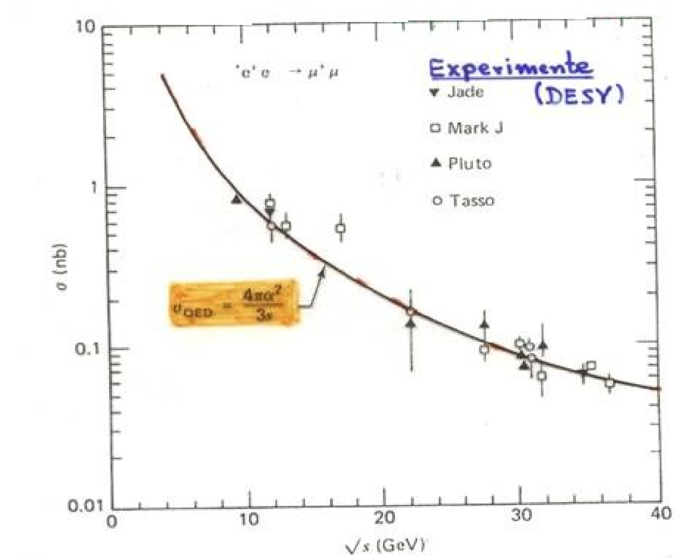
6.5 Experimentelle Tests der QED bei hohen Energien

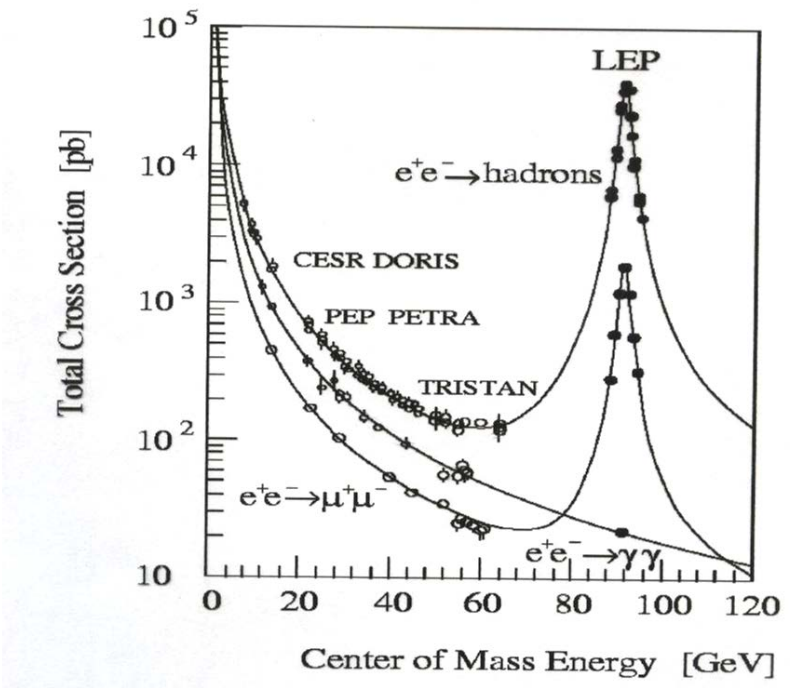
6.6 Experimentelle Tests bei niedrigen Energien, (g-2)-Experimente

Leading Order Contributions to Representative QED Processes

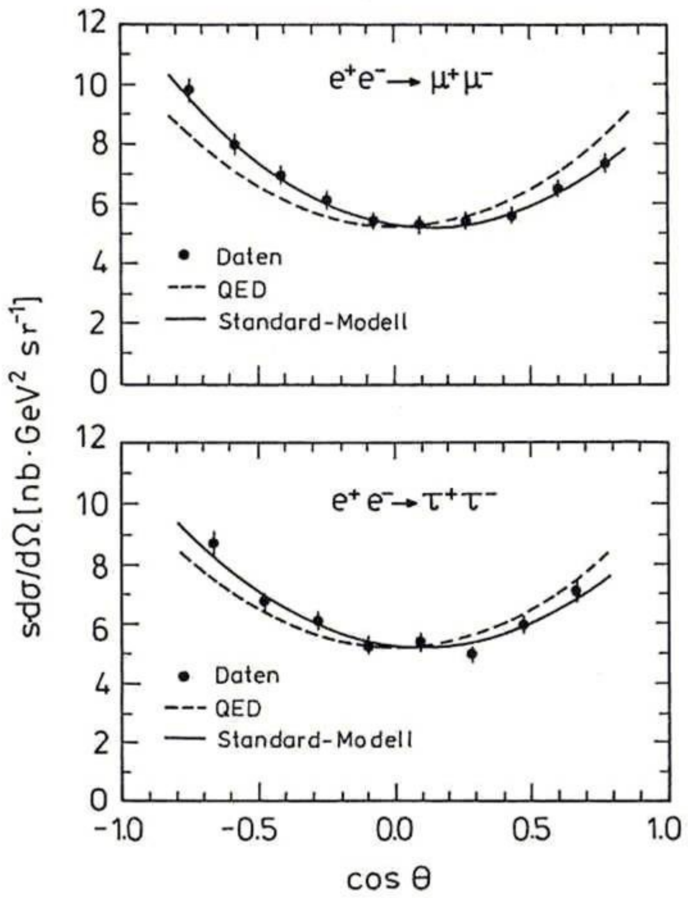
	Feynman Diagrams		$\overline{\vert\mathcal{M}\vert^2}/2e^4$		
	Forward peak	Backward peak	Forward	Interference	Backward
Møller scattering $e^-e^-\to e^-e^-$			$\frac{s^2+u^2}{t^2}$	$+\ \frac{2s^2}{tu}$	$+\ \frac{s^2+t^2}{u^2}$
			($u \leftrightarrow t$ symmetric)		
(Crossing $s \leftrightarrow u$)					
	Forward	"Time-like"	Forward	Interference	Time-like
Bhabha scattering $e^-e^+\to e^-e^+$			$\frac{s^2+u^2}{t^2}$	$+\ \frac{2u^2}{ts}$	$+\ \frac{u^2+t^2}{s^2}$
$e^-\mu^-\to e^-\mu^-$			$\frac{s^2+u^2}{t^2}$		
(Crossing $s \leftrightarrow t$) $e^-e^+\to\mu^-\mu^+$					$\frac{u^2+t^2}{s^2}$

$e^+e^- \rightarrow \mu^+ \mu^-$ Wirkungsquerschnitt
-Energieabhängigkeit-



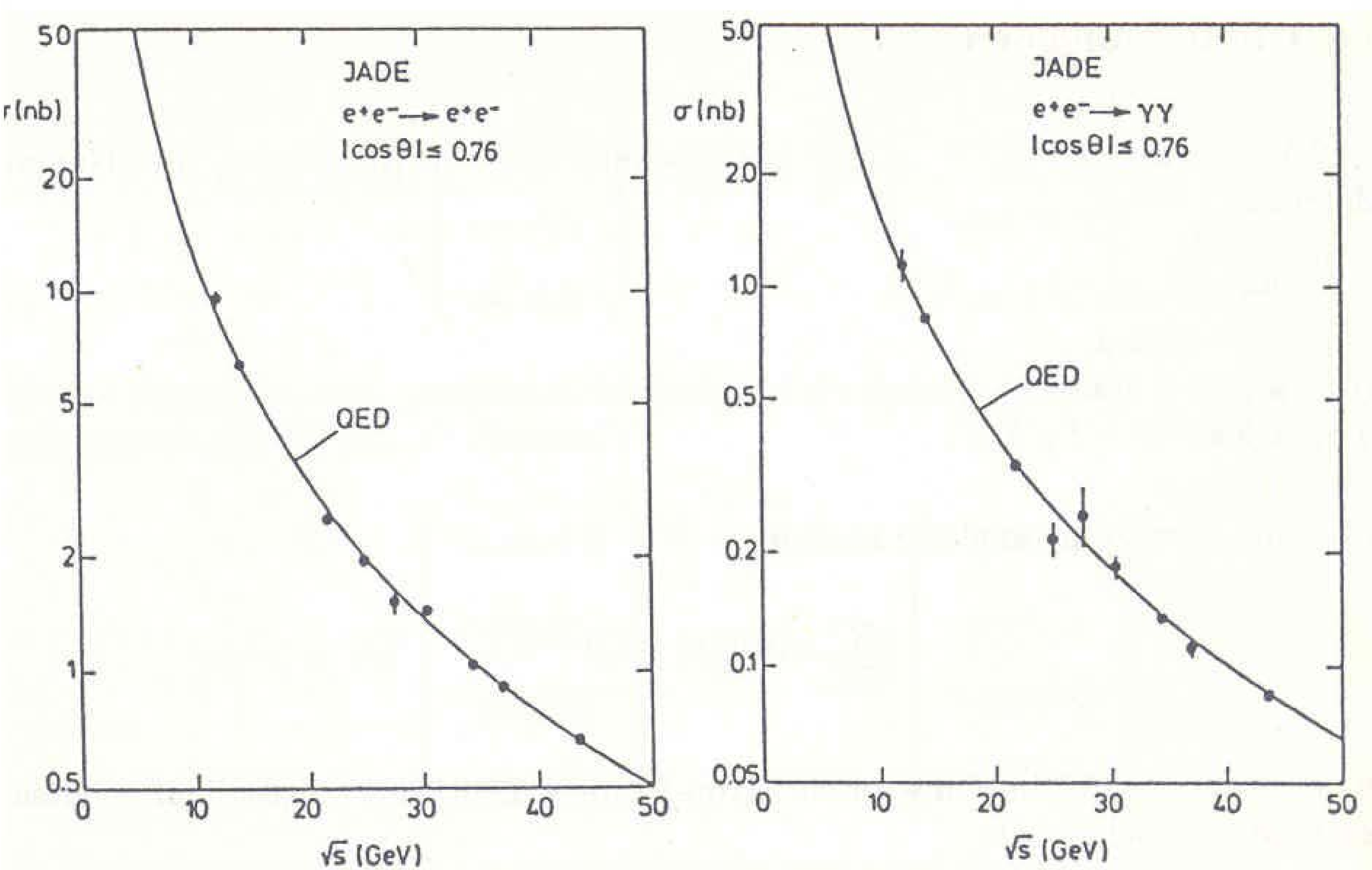


Winkelverteilungen für die Prozesse $e^+e^- \rightarrow \mu^+\mu^-$ und $e^+e^- \rightarrow \tau^+\tau^-$

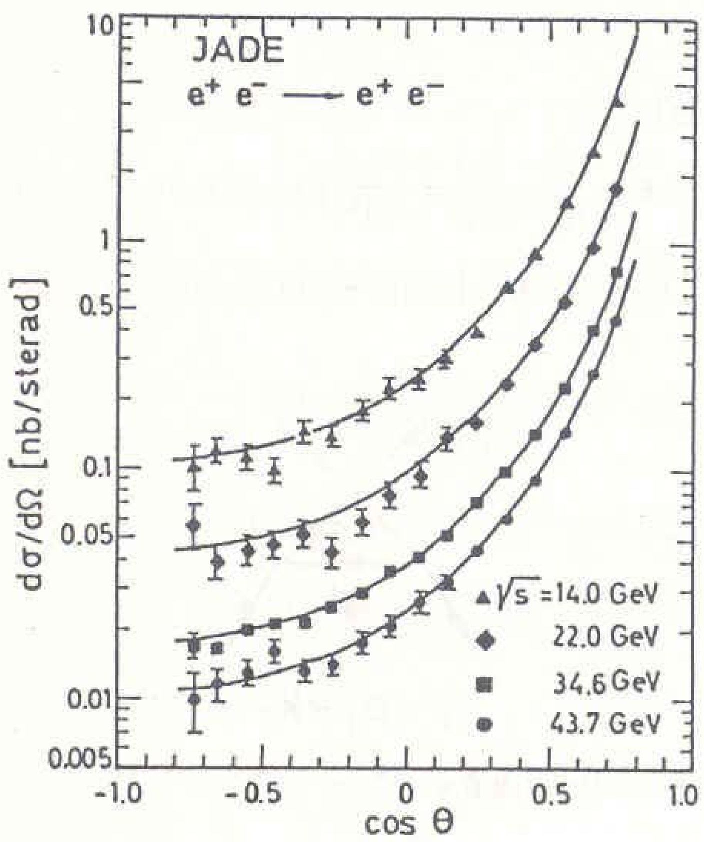


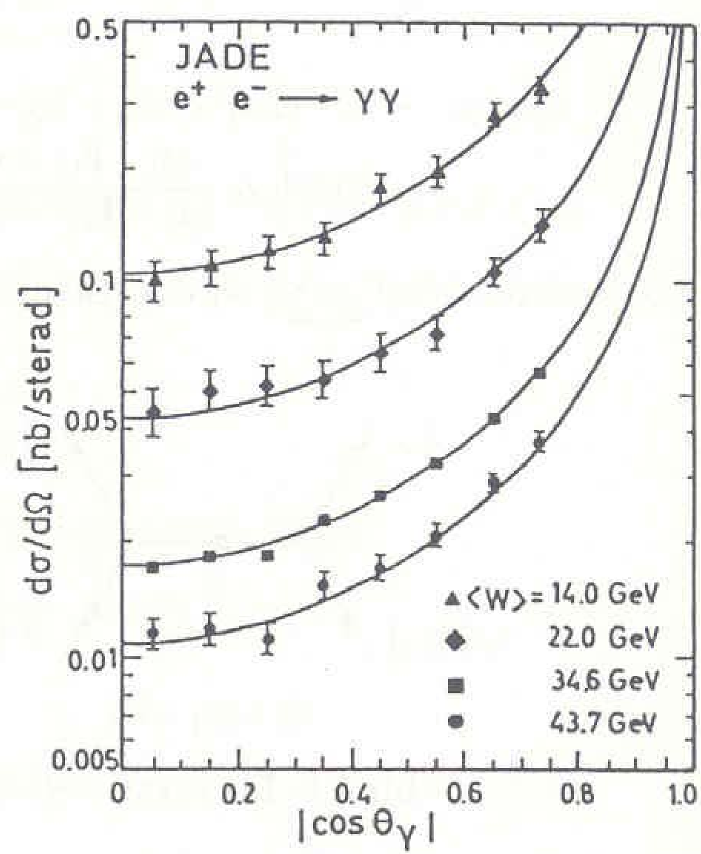
Die differentiellen Wirkungsquerschnitte für Myon- und Tau-Paar-Erzeugung bei einer Schwerpunktsenergie von 35 GeV (JADE 1990). Die QED-Vorhersagen gemäß (5.35) sind als gestrichelte Kurven eingezeichnet; sie sind symmetrisch zu 90^0. Die durchgezogene Kurve berücksichtigt die Interferenz zwischen dem γ- und dem Z^0-Graphen.

Energieabhängigkeit des totalen Wirkungsquerschnitts für die Prozesse $e^+e^- \rightarrow e^+e^-$ und $e^+e^- \rightarrow \gamma\gamma$

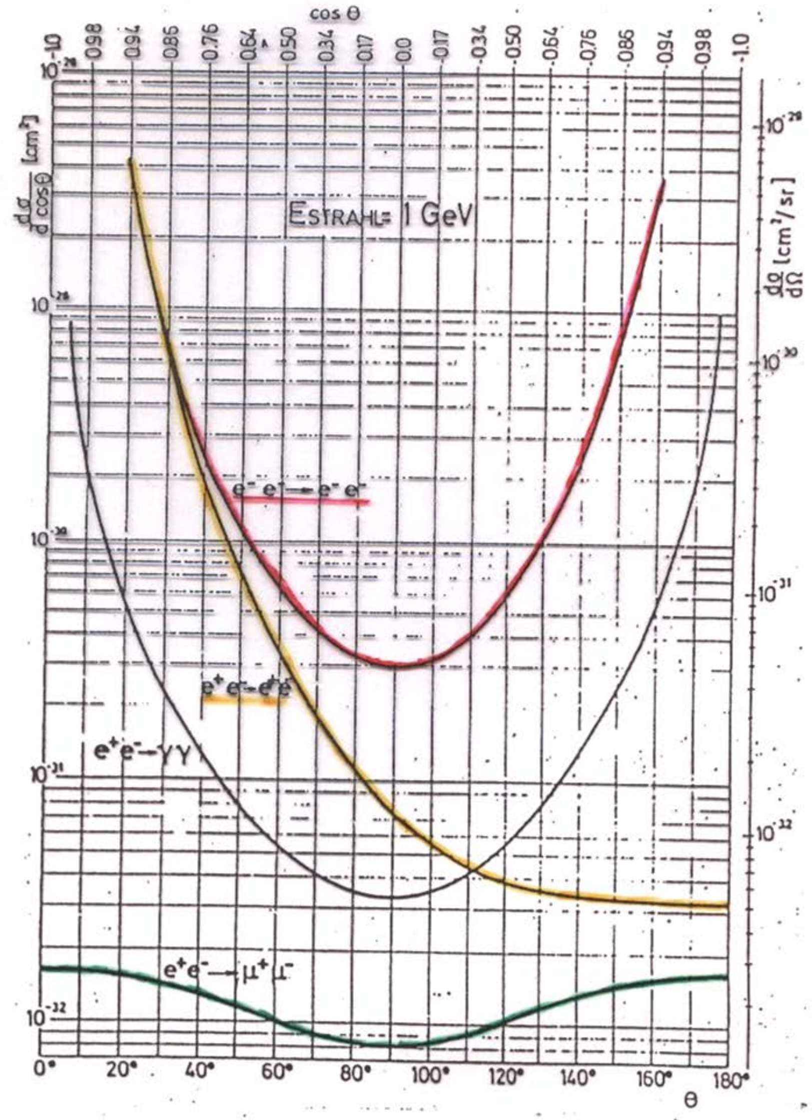


Winkelverteilungen für die Prozesse $e^+e^- \rightarrow e^+e^-$ und $e^+e^- \rightarrow \gamma\gamma$ im Vergleich mit QED-Vorhersagen





Zusammenfassung: Winkelverteilungen von QED-Prozessen



Myon (g-2)-Experimente

CERN (1970), Brookhaven (2004)

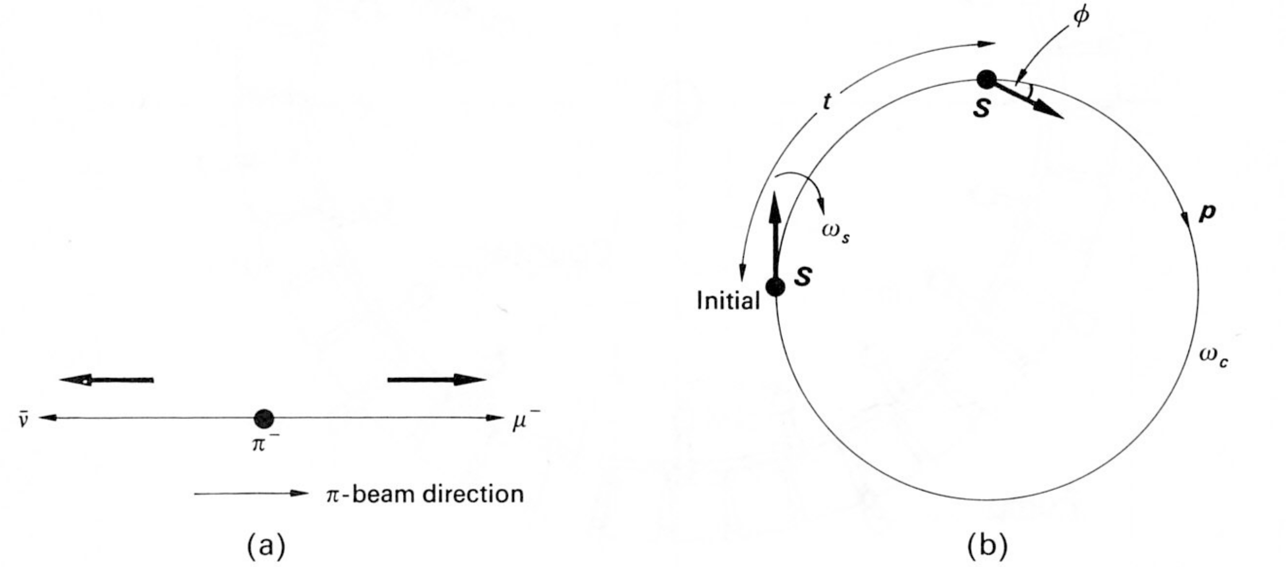


Fig. 8.5 (a) Spin polarization sense of muon emitted in the "forward" direction in π-decay in flight. (b) For a particle of $g \neq 2$ in a uniform magnetic field, the spin vector **s**, initially aligned with the momentum **p**, will "lead" by a phase angle ϕ at later times.

Myon (g-2)-Experimente

CERN (1970), Brookhaven (2004)

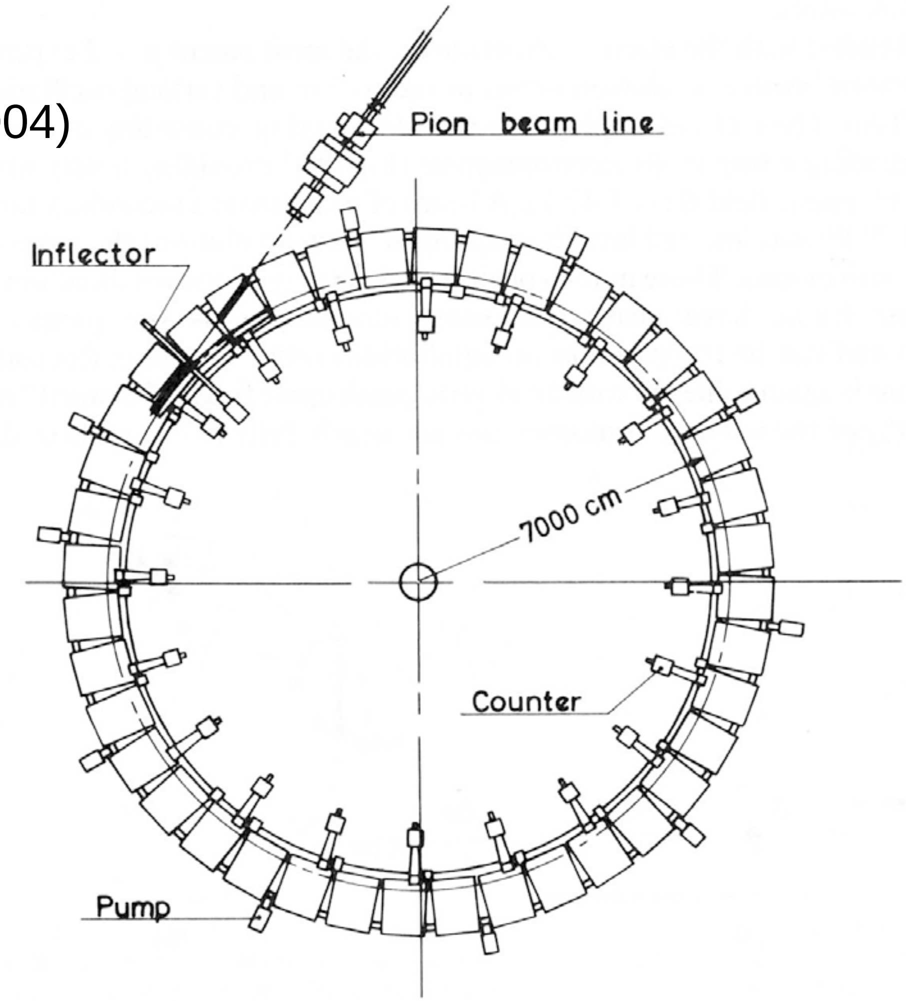
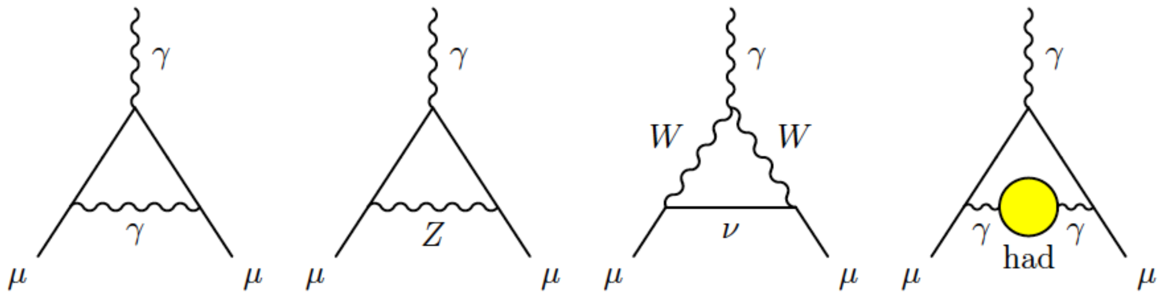


Fig. 8.4 Muon storage ring used in the last and most precise measurement of the $g-2$ value of the muon at the CERN laboratory (after Bailey *et al.* 1977).

Berechnung der Korrekturen höherer Ordnung im Standardmodell:



$$a_\mu^{\mathrm{QED}} = \frac{\alpha}{2\pi} + 0.765857410(27)\left(\frac{\alpha}{\pi}\right)^2 + 24.05050964(43)\left(\frac{\alpha}{\pi}\right)^3 + 130.8055(80)\left(\frac{\alpha}{\pi}\right)^4 + 663(20)\left(\frac{\alpha}{\pi}\right)^5 + \cdots \qquad (5)$$

QED-Anteile (Photon-Korrekturen, Lepton-Beiträge der Vakuumpolarisation) bis zur vierten Ordnung (α^4) komplett gerechnet, die führenden Terme der 5. Ordnung abgeschätzt (Ref: Particle Data, 2012)

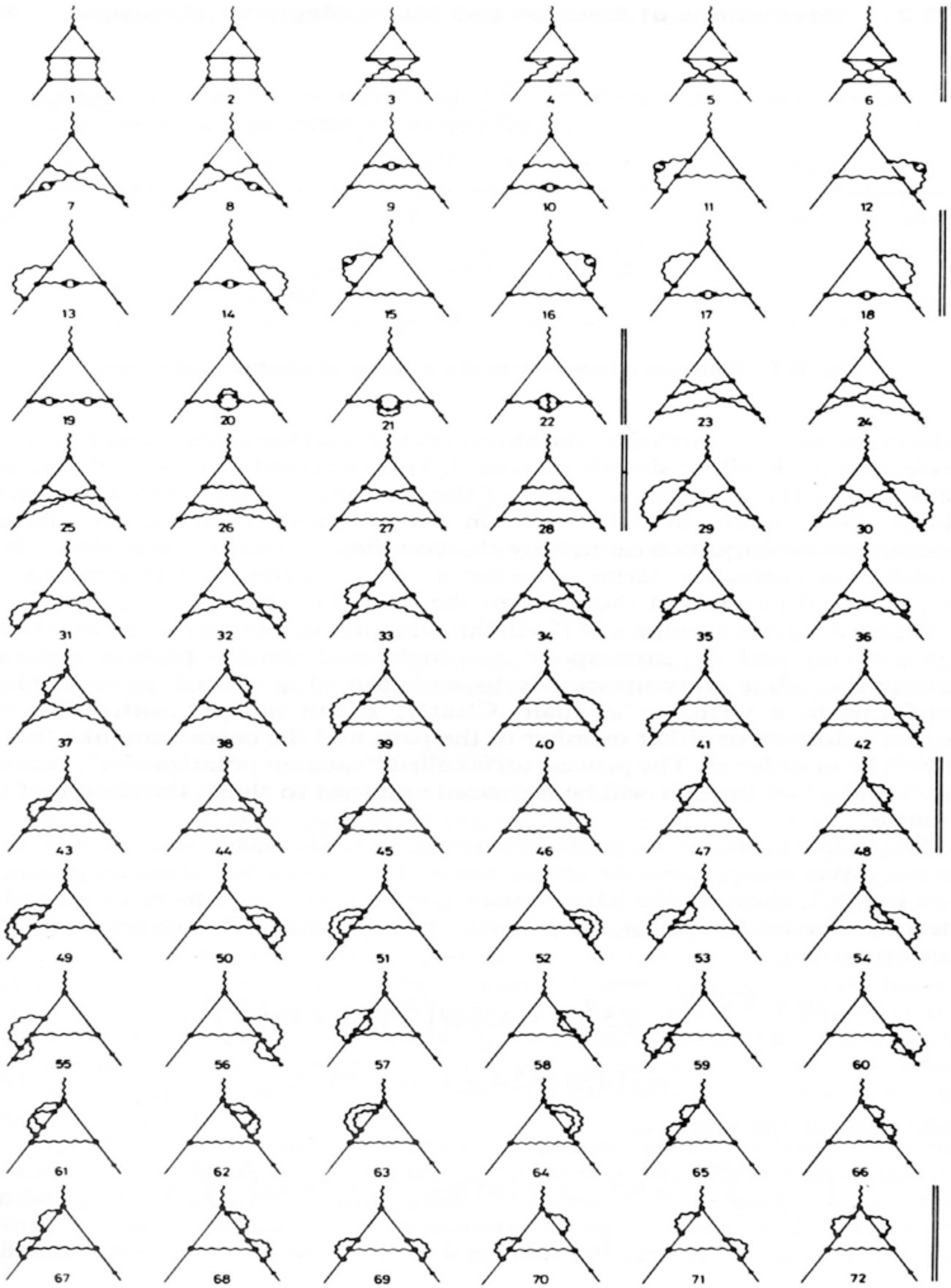


Fig. 8.2 The Feynman graphs which have to be evaluated in computing the α^3 corrections to the lepton magnetic moments (after Lautrup *et al.* 1972).

Myon-Speicherring am Brookhaven National Lab (BNL), Long Island, Upton New York

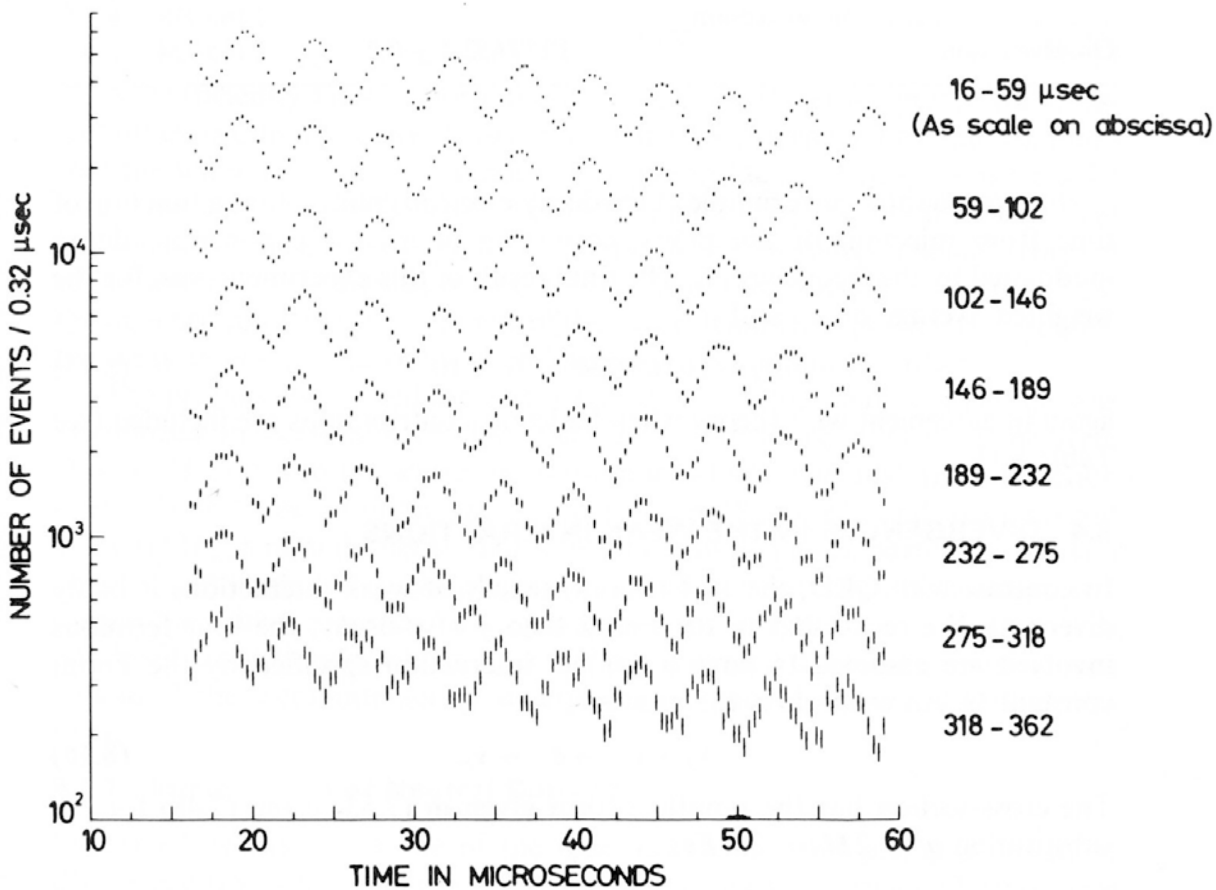
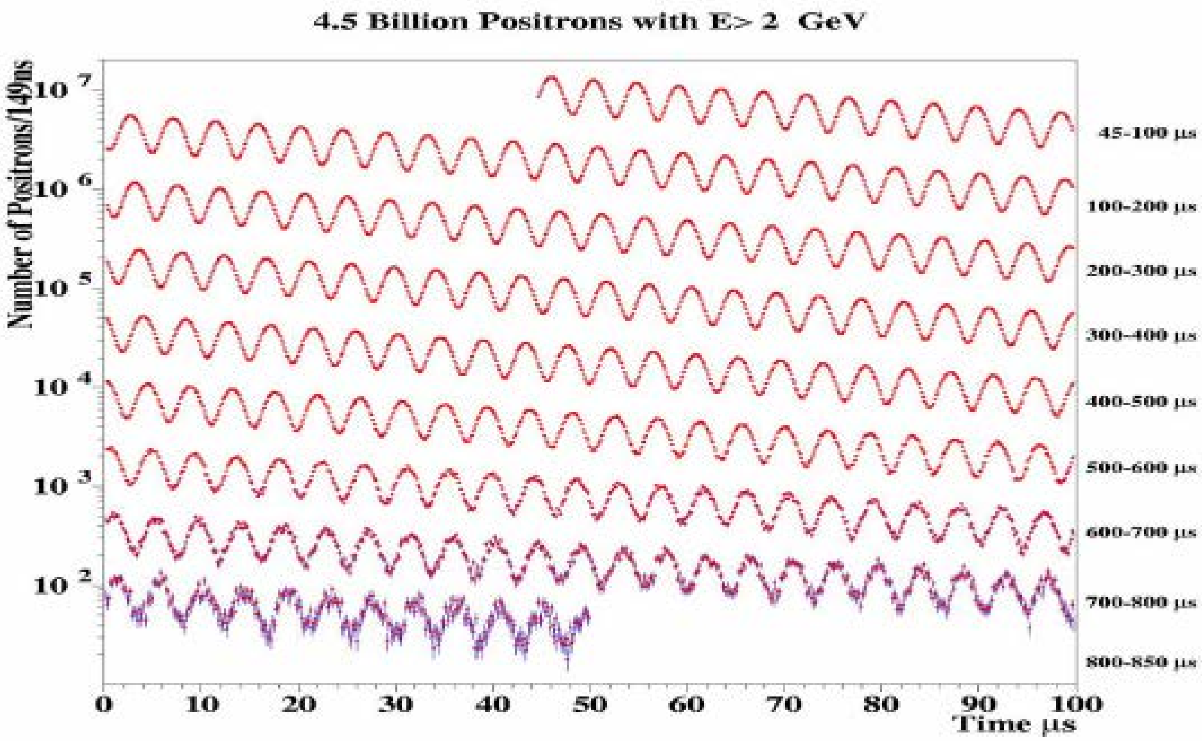


Fig. 8.6 Time dependence of the electron counting rate from the decay of muons in the CERN $g-2$ experiment. The general exponential decrease corresponds to the loss of muons by radioactive decay, with a mean lifetime dilated by the relativistic γ-factor of 30. (It is of interest to remark that this experiment provides the most precise (0.1% accuracy) check of Einstein's time-dilation formula. The overall decrease in count rate with time is modulated by the $g-2$ frequency $\omega_s - \omega_c$.

Man beobachtet die Zahl

$$N_{\text{ideal}}(t) = N_0 \exp\left(-\frac{t}{\gamma\tau_\mu}\right)\left[1 - A\cos(\omega_a t + \phi)\right]$$

der Zerfalls-e mit der Asymmetrie A:



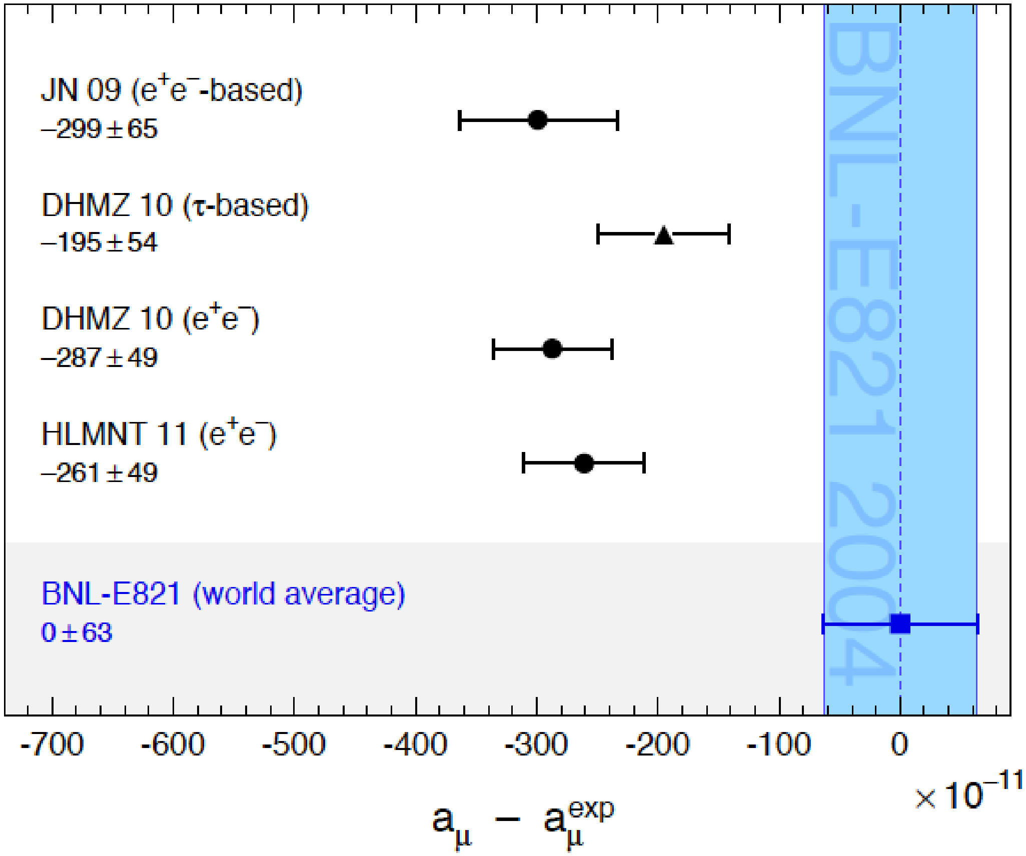


Figure 2: Compilation of recently published results for a_μ (in units of 10^{-11}), subtracted by the central value of the experimental average (3). The shaded band indicates the experimental error. The SM predictions are taken from: JN [4], DHMZ [15], and HMNT [19].

(aus Particle Data (2012))