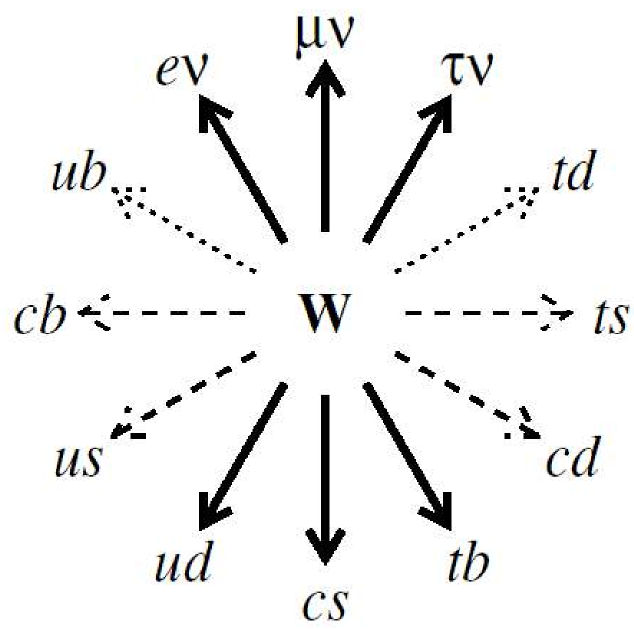
3. Physik des W-Bosons

Kopplungen an linkshändige Dubletts



3.1 Entdeckung des W-Bosons

1983 W, Z Entdeckung am Cern SPS $p\bar{p}$ collider (2×270 GeV) UA1, UA2

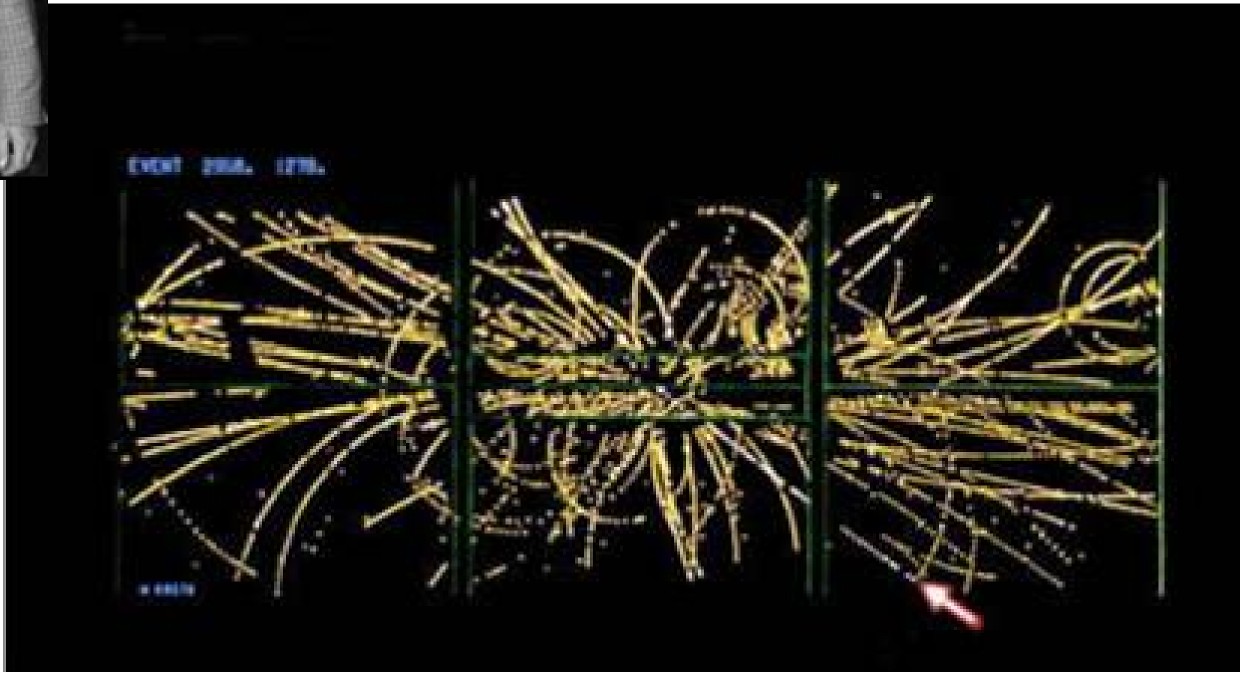
Rubbia & van der Meer Nobelpreis 1984

$$p\bar{p} \rightarrow W^{\pm} + X$$

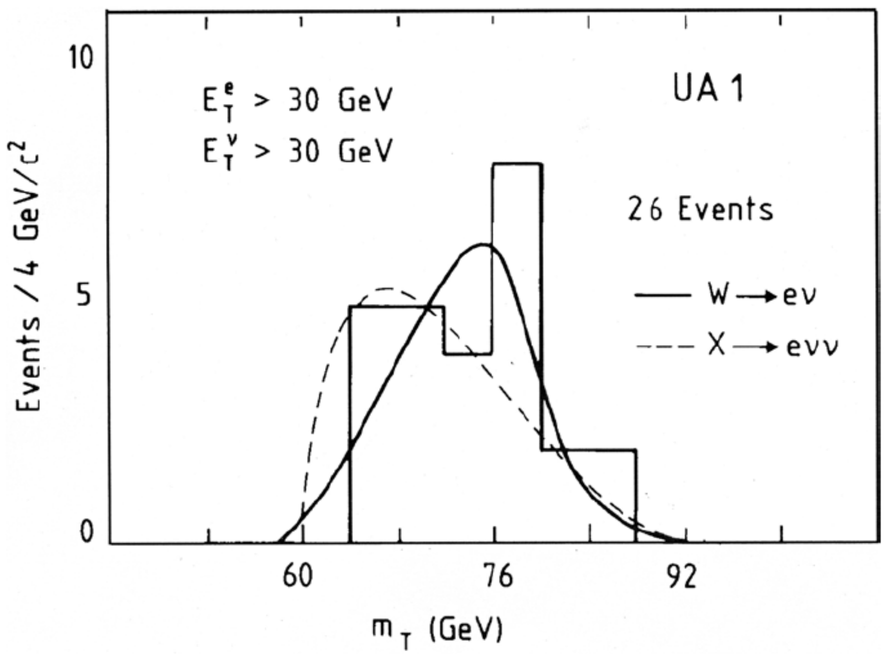
$$\downarrow$$

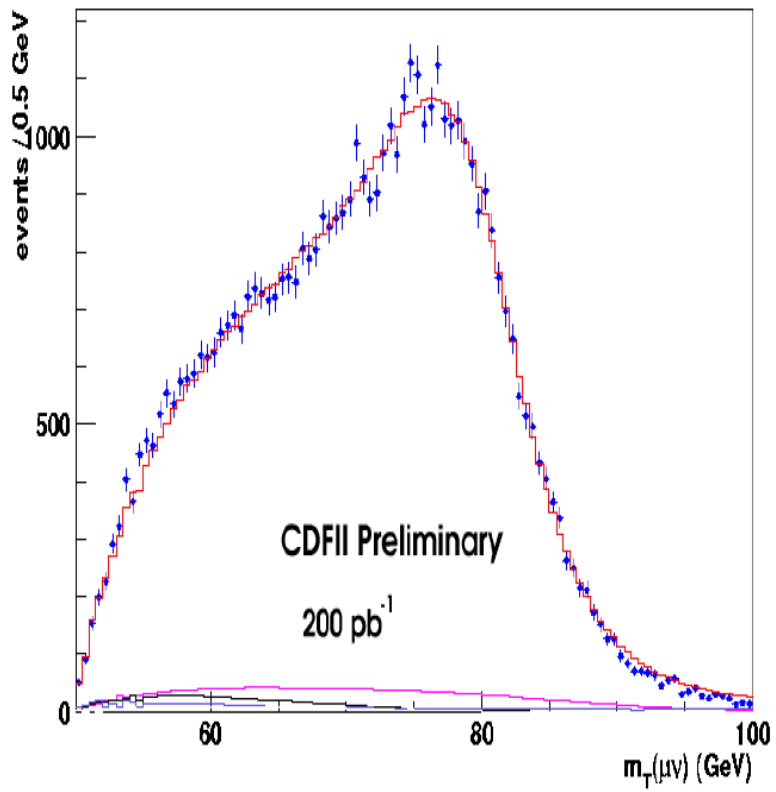
$$W^{+} \rightarrow e^{+}\nu_{e}$$

$$W^{+} \rightarrow \mu^{+}\nu_{e}$$

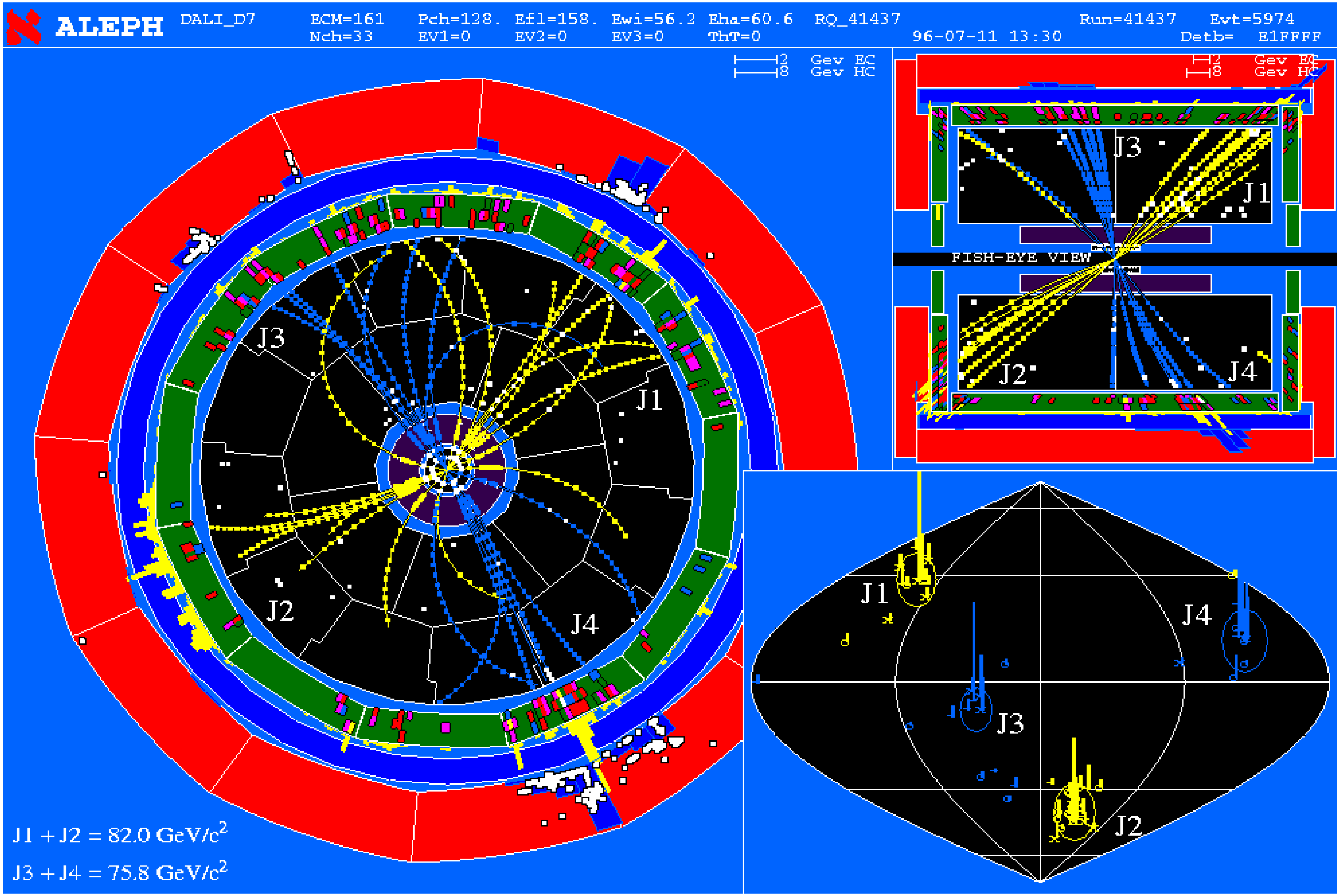


W-Massenbestimmung

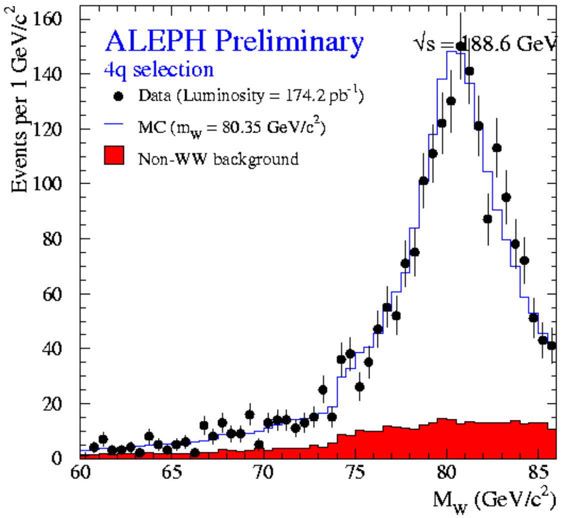




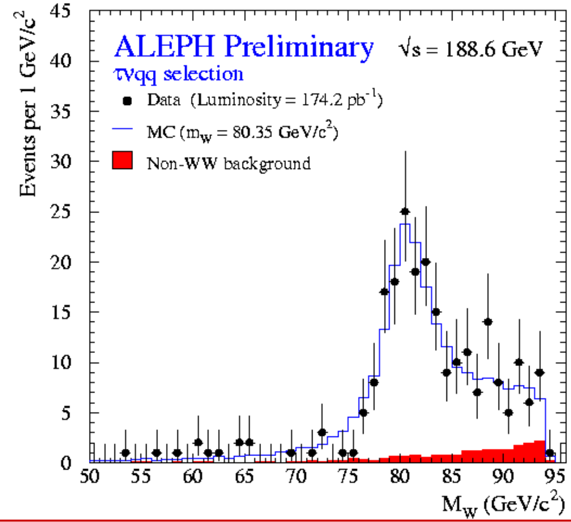
LEP200: $e^+e^- \to W^+W^- \to$ 4 Fermionen



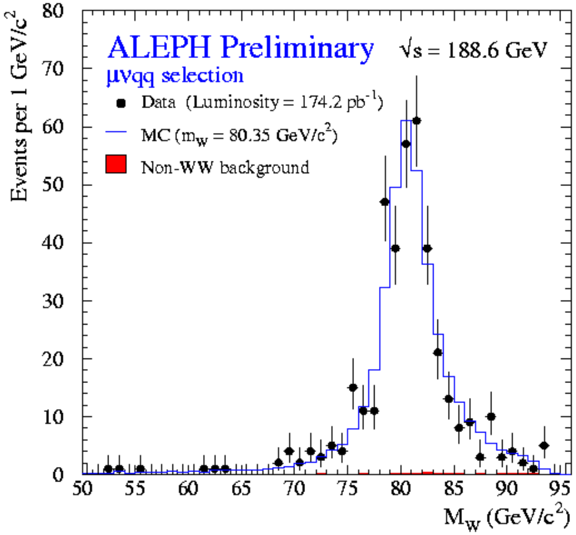
W-Massenbestimmung bei LEP



$e^+e^- \rightarrow W^+W^- \rightarrow 4f$

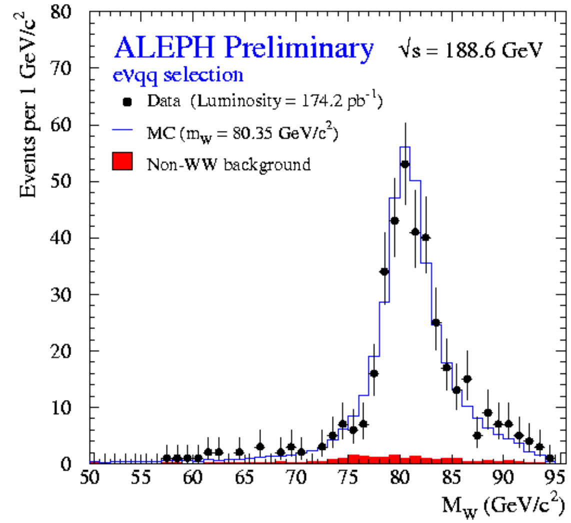


$M_W = 80.411 \pm 0.064(\text{stat.}) \pm 0.037(\text{syst.}) \pm 0.022(\text{BE-CR}) \pm 0.018(\text{LEP})$ GeV/c2



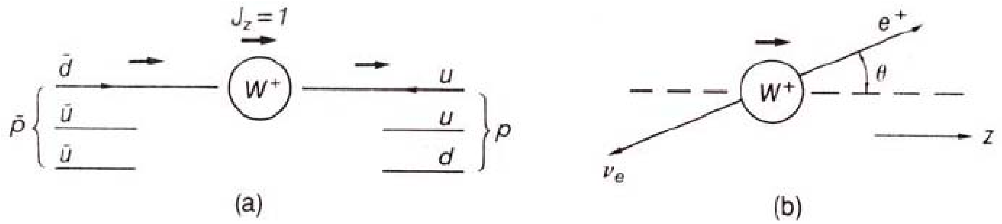
PDG 2004:

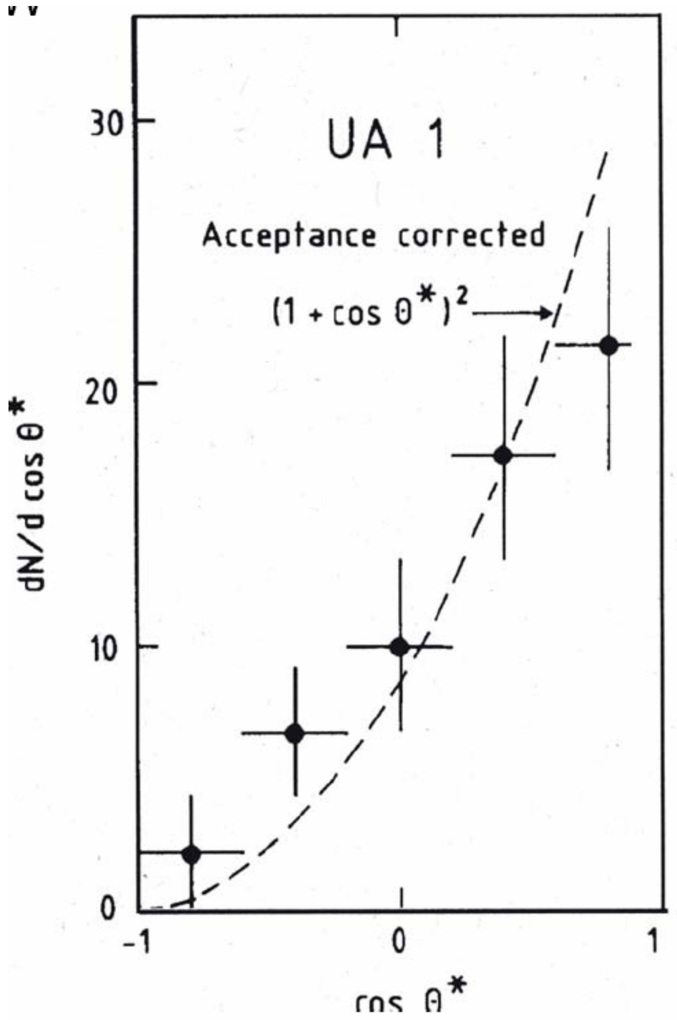
$M_W = 80.425 \pm 0.038$



Spin des W-Boson

Messung des Zerfallswinkels
im Ruhesystem des W





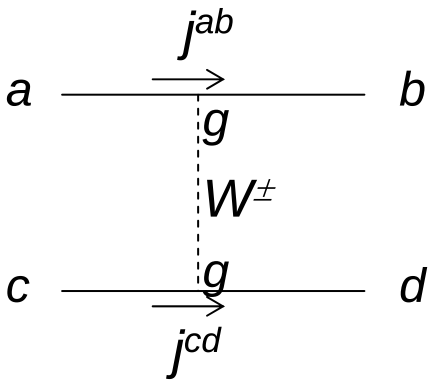
Drehung der Quantisiernungsachse
=> $(1+\cos\theta^*)^2$

Studenten-Praktika

Die Arbeitsgruppe "Experimentelle Elementarteilchenphysik I" bietet in den Semesterferien Studenten-Praktika zu Themen der (Astro-)Teilchenphysik an. Dieses Angebot richtet sich an Studenten, die einen genaueren Eindruck vom Wahlpflichtfach "Teilchenphysik" und von möglichen Diplomarbeiten erhalten wollen. Bitte vereinbaren Sie einen Termin mit den Betreuern, wenn Sie Näheres erfahren möchten. (Poster (PDF))

http://www-eep.physik.hu-berlin.de/pract.html

3.2 Geladene Ströme



Universelle V-A-Struktur der W-Kopplung an Ströme

$$\boldsymbol{j}_\mu^{ab} = \overline{\psi}_b \, \gamma_\mu (1 - \gamma_5) \, \psi_a = \overline{\psi}_b \, (1 + \gamma_5) \, \gamma_\mu \, \psi_a$$

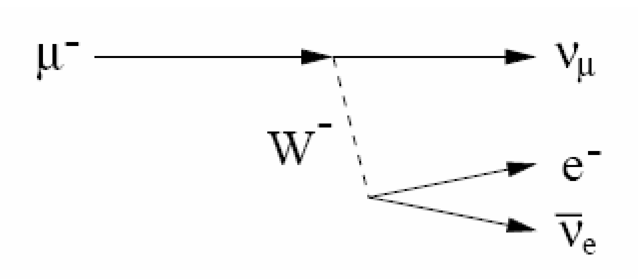
$\begin{pmatrix} a \\ b \end{pmatrix}$ SU(2)-Dubletts; Leptonen oder Quarks mit gleicher “schwacher Ladung” g

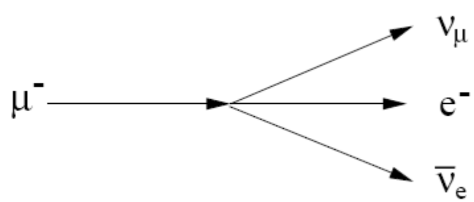
$$\boldsymbol{L} = \frac{g^2}{Q^2 + M_W^2} \, \boldsymbol{j}_\mu^{ab} \cdot \boldsymbol{j}^{cd\mu}$$

	$\begin{pmatrix} a \\ b \end{pmatrix}$	$\begin{pmatrix} c \\ d \end{pmatrix}$
leptonisch	lept.	lept.
hadronisch	had.	had.
semi-leptonisch	lept.	had.

3.3 μ-Zerfall

$$\mu^- \to e^- \nu_\mu \bar{\nu}_e$$





$Q^2 \to 0$

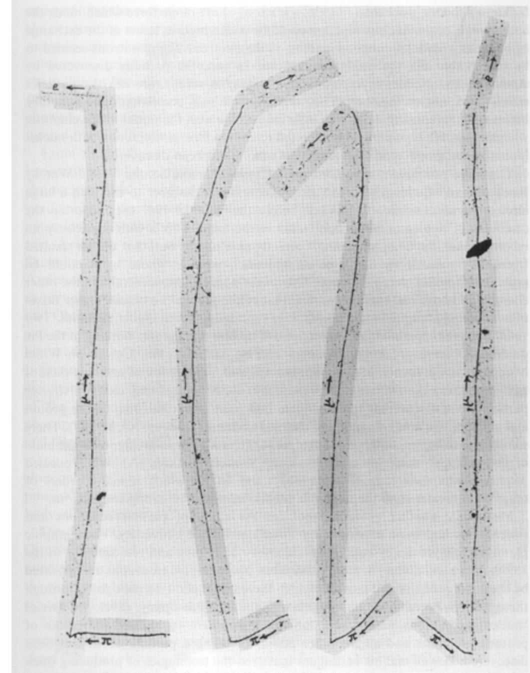
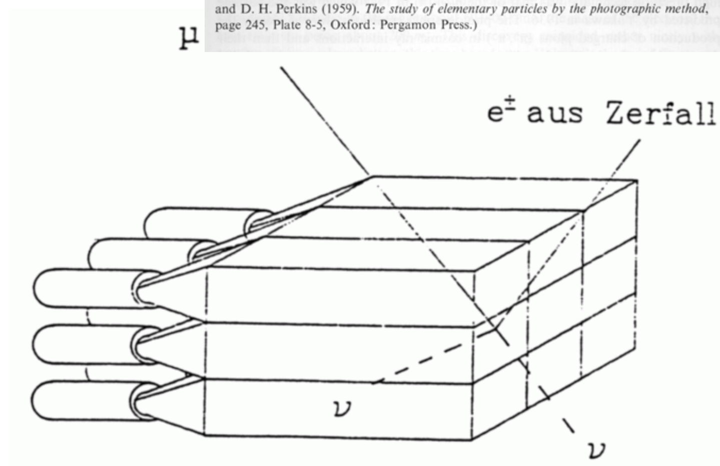


Figure 1.6. Four examples of the decay of a pion into a muon, followed by the subsequent decay of the muon into an electron. These processes were discovered by Powell and his collaborators using nuclear emulsions. (From C. F. Powell, P. H. Fowler and D. H. Perkins (1959). *The study of elementary particles by the photographic method*, page 245, Plate 8-5, Oxford: Pergamon Press.)

$$M_{fi} = \frac{G_F}{\sqrt{2}} \left[\bar{u}_{e^-} \gamma^\nu (1-\gamma_5)\, u_{\nu_e}\right] \left[\bar{u}_{\nu_\mu} \gamma_\nu (1-\gamma_5)\, u_\mu\right]$$

$$\Gamma_\mu = \frac{G_F^2 m_\mu^5}{192\,\pi^3}$$

$\tau = 2.2\,\mu s \quad \Rightarrow \quad G_F = 1.166\ 10^{-5}\ \mathrm{GeV}^{-2}$



Zerfallsbreiten, Phasenraum, …

siehe Skript zu StruMa c

http://www-zeuthen.desy.de/%7Ekolanosk/struma0304/title.html

$$d\Gamma(i \rightarrow f) = \frac{1}{2m} \left|M_{fi}\right|^2 dLips(s,\, p_{f1},\, \ldots,\, p_{fn})$$

$$\overline{\left|M_{fi}\right|^2} = \frac{1}{n_i} \sum_{i=1}^{n_i} \left|M_{fi}\right|^2$$

$$\sum_{f=1}^{n_f} \left|M_{fi}\right|^2 = (2s_1+1)(2s_2+1)\left|M_{fi}\right|^2$$

$$dLips(s,\, p_{f1},\, \ldots,\, p_{fn}) = (2\pi)^4\, \delta^4(p_{f1} + \ldots + p_{fn} - p_{i1} - p_{i2}) \prod_{j=1}^{n} \frac{d^3\vec{p}_{fj}}{(2\pi)^3\, 2E_j}$$

Universalität der τ-Kopplungen

$$\tau_\tau = \tau_\mu \left(\frac{g_\mu}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 \mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \frac{f(m_e^2/m_\mu^2)\, r_{RC}^\mu}{f(m_e^2/m_\tau^2)\, r_{RC}^\tau}$$

$$\tau_\tau = \tau_\mu \left(\frac{g_e}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 \mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) \frac{f(m_e^2/m_\mu^2)\, r_{RC}^\mu}{f(m_\mu^2/m_\tau^2)\, r_{RC}^\tau}$$

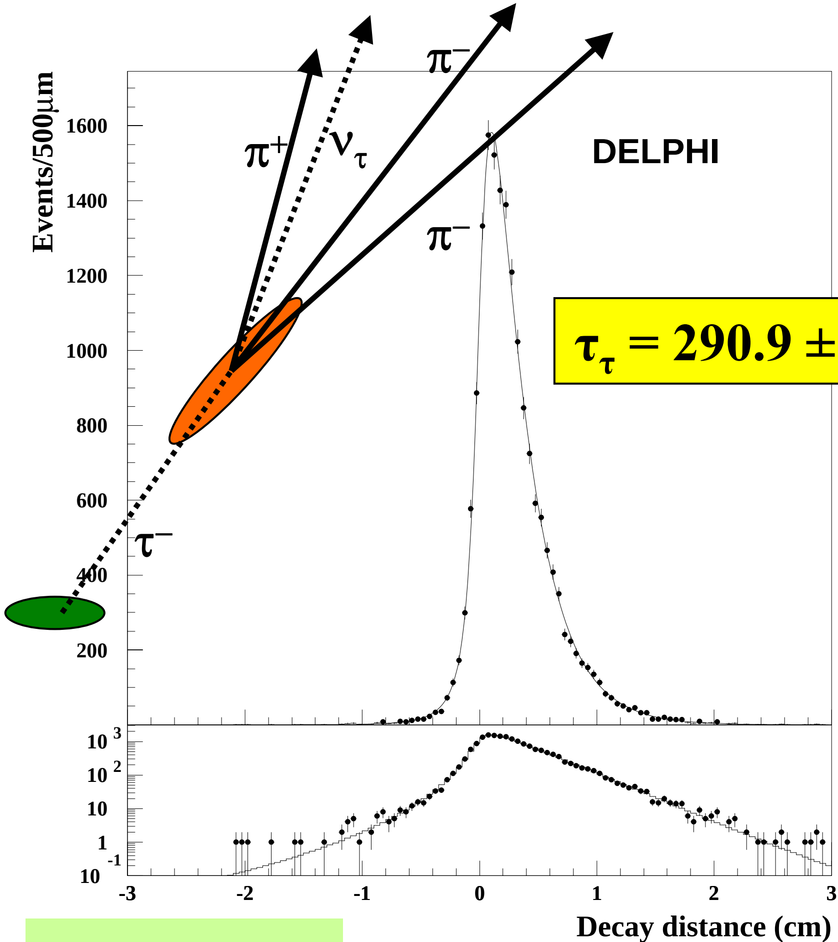
where

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x \ln x$$ (phase space ratios)

⇒ Messe
- Masse m_τ
- Lebensdauer τ_τ
- Verzweigungsverhältnis $B(\tau \to l\nu\nu)$

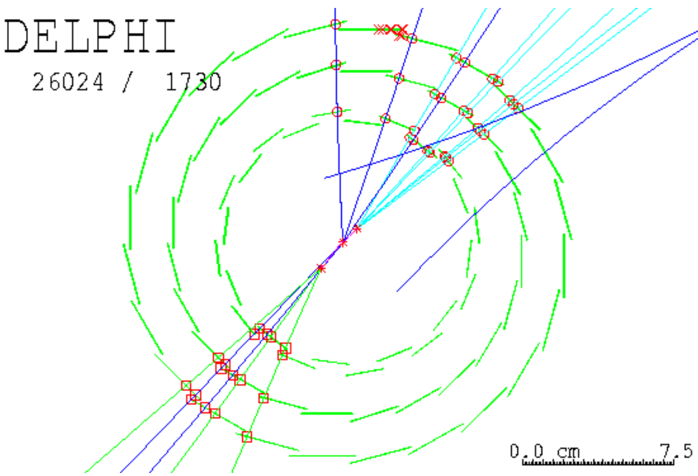
τ-Lebensdauer

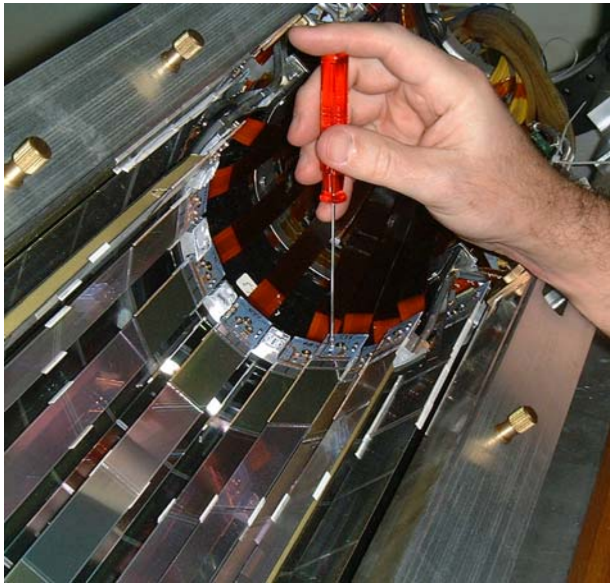
Beispiel: DELPHI



$\tau_\tau = 290.9 \pm 1.4 \pm 1.0$ fs

$l_\tau = \gamma \beta c \tau_\tau$





Lepton-Universalität

Charged current universality: tau decays

$$\tau_\tau = \tau_\mu \left(\frac{g_\mu}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 \mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \frac{f(m_e^2/m_\mu^2) r_{RC}^\mu}{f(m_e^2/m_\tau^2) r_{RC}^\tau}$$

$$\tau_\tau = \tau_\mu \left(\frac{g_e}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 \mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) \frac{f(m_e^2/m_\mu^2) r_{RC}^\mu}{f(m_\mu^2/m_\tau^2) r_{RC}^\tau}$$

where

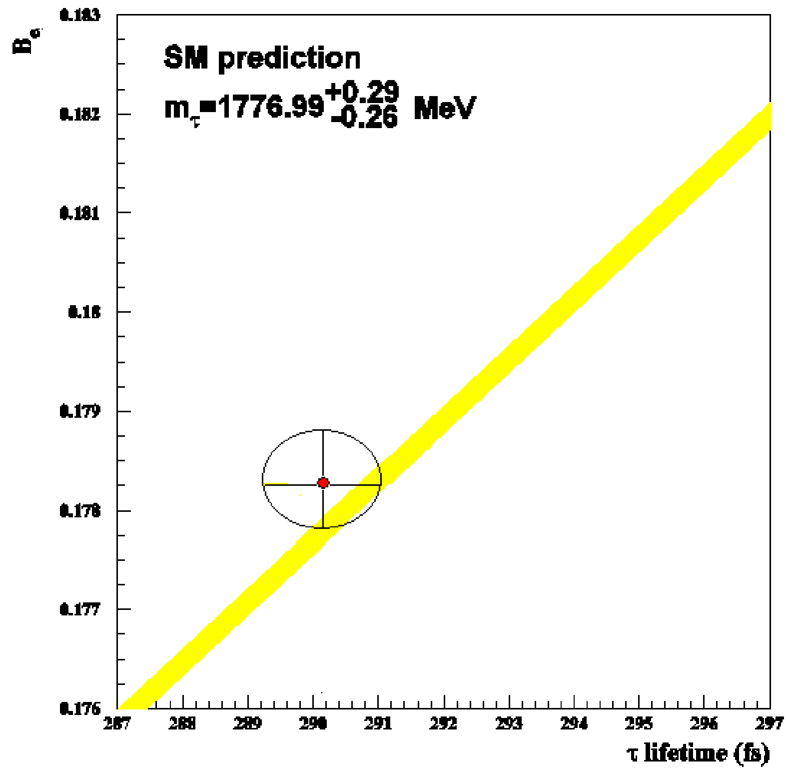
$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x \ln x$$ (phase space ratios)

BR($\tau \to e\nu\nu$)= (17.824 ± 0.052)% [0.29%]
BR($\tau \to \mu\nu\nu$)= (17.331 ± 0.048)% [0.28%]

e-μ univ:BR($\tau \to e\nu\nu$)= (17.821 ± 0.036)% [0.20%]

τ_τ= **290.15 ± 0.77 fs [0.27%]**

g_μ/g_e=0.9999 ± 0.0020
g_μ/g_τ=0.9982 ± 0.0021



Entwicklung der τ- Universalität

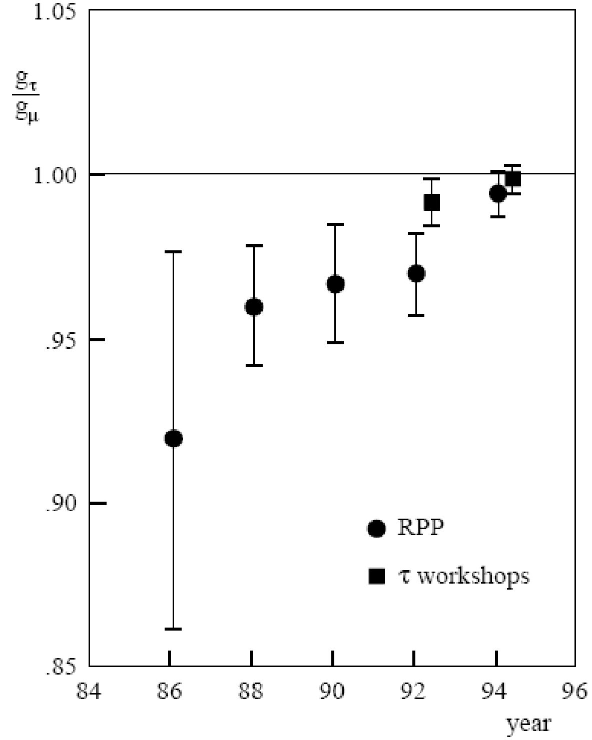


Fig. 19. *History of the test of $\tau - \mu$ universality.*

$$\left(\frac{g_\mu}{g_e}\right)_T = 1.0008 \pm 0.0028.$$

$$\left(\frac{g_\tau}{g_\mu}\right)_T = 1.0003 \pm 0.0029,$$

Lorentz-Struktur der W-Kopplungen

"allgemeinstes ableitunsfreies, lorentz-inv., lokales ME":

$$\mathcal{M} = 4\frac{G_0}{\sqrt{2}} \sum_{\substack{\gamma=\mathrm{S,V,T} \\ \epsilon,\omega=\mathrm{R,L}}} g^{\gamma}_{\epsilon\omega} \left\langle \overline{\ell}_\epsilon \middle| \Gamma^\gamma \middle| \nu_\ell \right\rangle \left\langle \overline{\nu}_\tau \middle| \Gamma_\gamma \middle| \tau_\omega \right\rangle .$$

$$\Gamma^{\mathrm{S}} = 1, \qquad \Gamma^{\mathrm{V}} = \gamma^\mu, \qquad \Gamma^{\mathrm{T}} = \frac{1}{\sqrt{2}}\,\sigma^{\mu\nu} \equiv \frac{i}{2\sqrt{2}}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu).$$

τ-Michel-Parameter

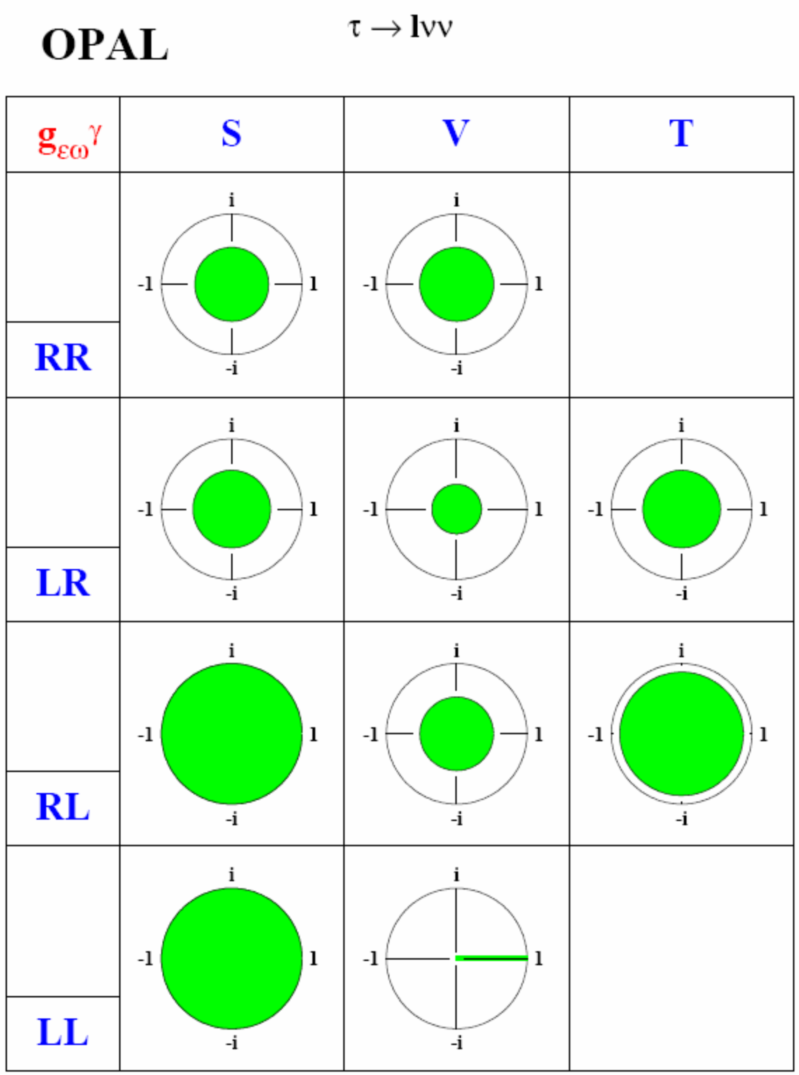


Figure 7: *90 % confidence limits on the normalized coupling constants $g^{\gamma}_{\varepsilon\omega}/g^{\gamma}_{\max}$ (with $g^{S}_{\max}=2$, $g^{V}_{\max}=1$ and $g^{T}_{\max}=\frac{1}{\sqrt{3}}$) under assumption of e-μ universality. The Standard Model coupling g^{V}_{LL} which is not constrained is chosen to be real and positive.*

Impulsspektrum:

$$\frac{d^2\Gamma_{\tau\to\ell\nu_\ell\nu_\tau}}{d\Omega\, dx^*} = \frac{G_0^2 m_\tau^5}{192\pi^4}\, x^{*2} \left\{ 3(1-x^*) + \rho_\ell\left(\frac{8}{3}x^* - 2\right) + 6\,\eta_\ell \frac{m_\ell}{m_\tau}\frac{(1-x^*)}{x^*} - P_\tau\, \xi_\ell \cos\theta^* \left[(1-x^*) + \delta_\ell\left(\frac{8}{3}x^* - 2\right)\right]\right\}.$$

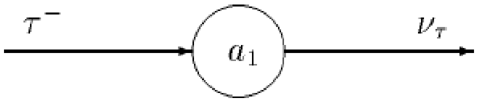
$$x^* = \frac{E_\ell{}^*}{E_\ell^{\max}}$$

Michel-Parameter:

$$\begin{aligned}
\rho &= \frac{3}{4}|g^V_{LL}|^2 + \frac{3}{4}|g^V_{RR}|^2 + \frac{3}{16}|g^S_{LL}|^2 + \frac{3}{16}|g^S_{LR}|^2 + \frac{3}{16}|g^S_{RL}|^2 + \frac{3}{16}|g^S_{RR}|^2 \\
&\quad + \frac{3}{4}|g^T_{LR}|^2 + \frac{3}{4}|g^T_{RL}|^2 - \frac{3}{4}\mathrm{Re}(g^S_{LR} g^{T*}_{LR}) - \frac{3}{4}\mathrm{Re}(g^S_{RL} g^{T*}_{RL}), \\
\xi &= |g^V_{LL}|^2 + 3|g^V_{LR}|^2 - 3|g^V_{RL}|^2 - |g^V_{RR}|^2 + 5|g^T_{LR}|^2 - 5|g^T_{RL}|^2 \\
&\quad + \frac{1}{4}|g^S_{LL}|^2 - \frac{1}{4}|g^S_{LR}|^2 + \frac{1}{4}|g^S_{RL}|^2 - \frac{1}{4}|g^S_{RR}|^2 + 4\mathrm{Re}(g^S_{LR} g^{T*}_{LR}) - 4\mathrm{Re}(g^S_{RL} g^{T*}_{RL}), \\
\xi\delta &= \frac{3}{4}|g^V_{LL}|^2 - \frac{3}{4}|g^V_{RR}|^2 + \frac{3}{16}|g^S_{LL}|^2 - \frac{3}{16}|g^S_{LR}|^2 + \frac{3}{16}|g^S_{RL}|^2 - \frac{3}{16}|g^S_{RR}|^2 \\
&\quad - \frac{3}{4}|g^T_{LR}|^2 + \frac{3}{4}|g^T_{RL}|^2 + \frac{3}{4}\mathrm{Re}(g^S_{LR} g^{T*}_{LR}) - \frac{3}{4}\mathrm{Re}(g^S_{RL} g^{T*}_{RL}), \\
\eta &= \frac{1}{2}\mathrm{Re}\left[g^V_{LL} g^{S*}_{RR} + g^V_{RR} g^{S*}_{LL} + g^V_{RL}(g^{S*}_{LR} + 6 g^{T*}_{LR}) + g^V_{LR}(g^{S*}_{RL} + 6 g^{T*}_{RL})\right].
\end{aligned}$$

τ-Neutrino-Helizität

$$\tau^- \rightarrow a_1^- \nu_\tau \rightarrow \rho^0 \pi^- \nu_\tau \rightarrow \pi^+ \pi^- \pi^- \nu_\tau$$



$J_z(\tau^-)$	$J_z(a_1)$	$J_z(\nu_\tau)$
$-\frac{1}{2}$	0	$-\frac{1}{2}$
$+\frac{1}{2}$	$+1$	$-\frac{1}{2}$

Possible spin configurations in the decay (4.28) if the ν_τ is left-handed (a_1^- rest system)

A parity violating observable is the expectation value of the pseudoscalar

$$\hat{p}_\tau \, \hat{n}_{3\pi} \cdot sign(s_1 - s_2).$$

$$\gamma_{AV} = \frac{2g_A g_V}{g_A^2 + g_V^2} = 1.25 \pm 0.23 \begin{array}{l} +0.15 \\ -0.18 \end{array}$$

H.Albrecht et al. [ARGUS Collaboration],
``Determination Of The Tau-Neutrino Helicity,''
Phys. Lett.B 250 (1990) 164;

H. Thurn and H. Kolanoski,
``A Test of the Lorentz Structure of Semi-Hadronic Tau Decays'',
Z. Phys. C60 (1993) 277.